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ELEMENTARY PARTICLE PHYSICS AT THE UNIVERSITY OF FLORIDA

Annual Progress Report
DOE GRANT DE-FG05-86ER40272

University of Florida
Gainesville, Florida 32611

December 1, 1996

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TASK A

RESEARCH IN THEORETICAL ELEMENTARY PARTICLE PHYSICS

AT THE UNIVERSITY OF FLORIDA

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Principal Investigators:
Richard D. Field
Pierre M. Ramond
Pierre Sikivie
Charles B. Thorn

Grant Spokesperson: R. D. Field

DISCLAIMER

Annual Progress Report
TASK A

Theoretical Elementary Particle Research at the
University of Florida

Principal Investigators:
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ABSTRACT

This is the annual progress report of the theoretical particle theory group at the University of Florida under DoE Grant DE-FG05-86ER40272. At present our group consists of four Full Professors (*Field, Ramond, Thorn, Sikivie*), two Associate Professors (*Qiu, Woodard*), and one Assistant Professor (*Kennedy*). In addition, we have four postdoctoral research associates and three graduate students. The research of our group covers a broad range of topics in theoretical high energy physics including both theory and phenomenology. Included in this report is a summary of the last several years and an outline of our current research program.

OUTLINE

I. INTRODUCTION

This progress report on theoretical elementary particle physics is presented by the Particle Theory Group at the University of Florida. The particle theory group is also a component of the Institute for Fundamental Theory (IFT) at the University of Florida. The IFT is an interdisciplinary center comprising the disciplines of high energy theory, condensed matter theory, cosmology-astrophysics, and mathematics, and it receives operating funds from the University of Florida.

Our group was formed at the University of Florida in 1980 when T. Curtright, R. D. Field, P. Ramond, and C. Thorn accepted faculty positions in the Physics Department. The following year we were awarded a DoE grant, and have benefited from DoE funding every year since then. We were joined in 1981 by P. Sikivie. At that time the group had two postdoctoral associates, one funded by DoE and the other by the Department of Physics. In 1987, in response to the formation of the IFT, the University created two new junior faculty lines in particle theory. These positions were filled by Z. Qiu in 1988 and R. Woodard in 1989. T. Curtright left the group in 1986 to join the faculty at the University of Miami. In 1993 we hired Dallas Kennedy from Fermilab to fill Curtright's position, bringing the size of our group to seven faculty members.

At present our group consists of four Full Professors (R. D. Field, P. Ramond, C. Thorn, and P. Sikivie), two Associate Professors (R. Woodard, Z. Qiu), and one Assistant Professor (D. Kennedy). This year, we have four postdoctoral research associates, three funded by the DoE and one funded by the IFT. Also, we have a good group of graduate students and have produced at least one Ph.D. in each of the last nine years.

The scientific activities of our group are rich and varied, ranging from string theory and physics near the Planck scale to phenomenology and collaborations with experimenters. At one end of this spectrum is research on the baffling conceptual problem of formulating a consistent quantum theory of gravity. The extraordinarily rich superstring theory, the only known consistent theory of quantum gravity, provides a theoretical laboratory in which this difficult subject can be studied. Superstring theory also provides guidance for the construction of extensions of the standard model of particle physics. Of particular interest is the possibility that relations between the fermion masses and/or the weak mixing angles may be extracted and the possibility that physics just beyond the electroweak scale may reveal itself to be supersymmetric. Some of our work is committed to the task of devising tests by which signals of such new physics may be discovered at particle accelerators, in particular how to look for the anticipated Higgs boson of the standard model and for superpartners of the known particles. This can only be successful if the new physics signatures can be distinguished from the ever-present standard model background. It is crucial to know which series of cuts have to be made to minimize the background and expose the new phenomena we all hope will emerge at the new accelerators. This computer intensive study is conducted in contact with experimentalists. It has become increasingly recognized, however, that new physics may also be revealed by phenomena in the sky. For example, the deficit of solar neutrinos may be a signal that neutrinos have mass. If the strong CP problem of the standard model is solved by the existence of axions, the best way to look for such particles may be as a constituent of the dark matter in our galactic halo. The vanishing of the cosmological constant, an observed fact which deeply tests our understanding of our universe, is another example of the sort of problem which whets our research appetite. We are committed to developing whatever tools and techniques help us increase our knowledge of particle physics. We feel that our group's activities correctly reflect many of the modern trends in our field.

When the particle group was first formed, there was no high energy experimental program at the University of Florida. Since the formation of the theory group, we have worked to build up an experimental group. We would like to have a good balance in the department between theory and experiment. Until recently the balance has been skewed toward theory, since it is somewhat easier to build a theory group than an experimental group. We are very pleased that last Fall G. Mitselmakher accepted a position here and is now in the process of building a new experimental hadron collider group at the University of Florida. This has motivated R. Field and P. Ramond to join the CMS Collaboration and to work on some of the theoretical and phenomenological aspects of physics at the LHC.

The IFT sponsors a workshop every other year, with the subject rotating among the component disciplines. The first three workshops were on "Dark Matter" (Astrophysics), "Yukawa Couplings and the Origin of Mass" (Particle Theory), and "The Quantum Impurity Problem" (Condensed Matter Theory). For next year (1997) the fourth IFT workshop is planned to focus on the mathematical physics topic "Moduli Spaces in Geometry and Physics."

II. PARTICLE THEORY PERSONNEL

(a) Faculty

The following is a list of the current faculty members of the particle theory group. Zongan Qiu and Richard Woodard were hired as Assistant Professors in 1989. Since then they have both been promoted to Associate Professor with tenure.

Name	*Position*
R. D. Field	**Professor (9/1/80-present)**
D. Kennedy	**Assistant Professor (9/1/93-present)**
Z. Qiu	Assistant Professor (9/1/89-9/1/95) **Associate Professor (9/1/95-present)**
P. Ramond	**Professor (9/1/80-present)**
P. Sikivie	Assistant Professor (9/1/81-9/1/84) Associate Professor (9/1/85-8/31/88) **Professor (9/1/88-present)**
C. Thorn	**Professor (9/1/80-present)**
R. Woodard	Assistant Professor (9/1/89-8/1/94) **Associate Professor (8/1/94-present)**

(b) Postdoctoral Fellows and Long Term Visitors

We have been fortunate to have had excellent postdoctoral research associates over the years. At one time, DoE postdoctoral support was matched by the Physics Department. However, the Physics Department no longer provides these funds and we support our postdocs from our DoE grant and sometimes from IFT funds. IFT now supports two postdoctoral research associates to be shared among the four IFT disciplines. This means that some years we get IFT postdoc funds and some years we do not. As the following table shows, most of our postdocs have obtained good jobs upon leaving our group.

Particle Theory Postdoctoral Fellows

Name	*Length of Stay*	*Position after UF*
E. Braaten	(9/1/81-8/31/83)	Northwestern University
M. Chase	(9/1/81-8/31/83)	CERN
M. Sato	(9/1/82-5/1/83)	Japan
F. del Aguila	(9/1/82-8/31/84)	University of Granada
M. Doria	(9/1/83-8/30/85)	Los Alamos
R. Holman	(7/1/83-6/30/85)	Fermilab
V. Rodgers	(9/1/85-8/30/87)	Stony Brook
J. McCabe	(9/1/85-8/30/87)	LAPP
P. Oh	(9/1/86-7/31/87)	Korea
D. Harari	(9/1/86-8/31/89)	Buenos Aires, Argentina
J. Minahan	(9/1/87-8/31/90)	University of Virginia
D. Zoller	(9/1/87-8/31/90)	University of Cincinnati
S. Yost	(9/1/87-8/31/91)	University of Tennessee
A. Polychronakos	(IFT,9/1/87-8/31/90)	Columbia University
C. Preitschopf	(9/1/88-9/30/91)	Göteburg, Sweden
M. Awada	(10/1/89-8/31/91	University of Cincinnati
S. Martin	(9/1/90-8/31/92)	Northeastern University
S. Rey	(9/1/90-7/31/91)	Korea
S. Sin	(IFT,9/1/90-8/15/92)	Han-Yang University
Y. Wang	(9/1/91-8/1/93)	Fermilab
M. McGuigan	(9/1/91-8/1/94)	Physical Review
P. Griffin	(10/20/91-1/1/95)	Rockefeller University
K. Anagnostopoulos	(8/1/93-8/1/95)	Neils Bohr Institute
M. Booth	(8/1/93-8/1/95)	John Hopkins
L. Chandar	(8/1/95-2/1/97)	Tata Institute
O. Bergman	**(IFT, 8/1/94-9/1/96)**	**Brandeis**
C. Coriano	**(8/1/95-present)**	-
A. Faraggi	**(8/1/95-present)**	-
S. H. Chang	**(to begin 9/1/96)**	-
J. Elwood	**(to begin 9/1/96)**	-

In addition to postdoctoral research associates, we have had several long term visitors that have contributed significantly to our group. S. H. Chang from Seoul National University first joined the group for a year on a KOSEF fellowship and will continue as a postdoc in the Fall. Vincent Rodgers from University of Iowa is scheduled to visit us this Fall.

Particle Theory Long Term Visitors

Name	*Length of Stay*	*Institution*
J. Hong	(3/1/91-8/31/92)	Han-Yang University
M. de Montigny	(9/1/92-9/1/93)	University of Montreal
M. Masip	(9/1/91-9/1/94)	University of Granada
S. H. Chang	(9/1/95-9/1/96)	Seoul National University
D. K. Hong	(1/1/96-3/1/96)	Pusan University
V. Rodgers	(9/1/96-12/31/96)	University of Iowa

(c) Graduate Students

We have had, over the years, some success in attracting good graduate students and in placing them in postdoctoral research positions. Last year, J. Rubio and J. Kim received their Ph.D. degree and last month S. Mikaelian graduated. Kim has accepted a postdoctoral position at the Houston Advanced Research Center (HARC) and Rubio went into industry. Mikaelian is currently looking for a position. We send students to summer programs such as TASI and SLAC. The following is a list of our current and former students together with their position after graduating.

Particle Theory Graduate Students

Name	*Advisor*	*Position after UF*
M. Ruiz-Altaba	Ramond	Ph.D. 9/1/87, University of Geneve
D. Hong	Ramond	Ph.D. 9/1/88, Korea
R. Viswanathan	Ramond	Ph.D. 9/1/89, ICTP in Trieste, Italy
M. Chu	Thorn	Ph.D. 4/1/90, DAMPT in Cambridge, U.K.
C. Hagmann	Sikivie	Ph.D. 8/3/90, UC Berkeley
T. McCarty	Ramond	Ph.D. 8/3/90, industry
G. Kleppe	Ramond	Ph.D. 8/91, V.P.I.
B. Wright	Ramond	Ph.D. 8/92, University of Wisconsin
E. Piard	Ramond	Ph.D. 8/93, University of Virginia
B. Keszthelyi	Ramond	Ph.D. 8/93
H. Arason	Ramond	Ph.D. 8/93, teaching in Iceland
D. Castaño	Ramond	Ph.D. 8/93, M.I.T.
S. Carbon	Thorn	Ph.D. 8/93, industry
J. Rubio	Woodard	Ph.D. 12/94
J. Kim	Sikivie	Ph.D. 8/95, HARC
S. Mikaelian	Thorn	Ph.D. 5/96
M. Tayebnejad	Field	Ph.D. expected in 1996
Y. Kanev	Field	Ph.D. expected in 1997
N. Irges	Ramond	Ph.D. expected in 1998

Under our present funding profile, graduate students are supported by the department with teaching assistantships (TA) during the Academic Year. We support the students with DoE (and sometimes by IFT and DSR) funds during the summer. In addition, whenever funds permit, we support students during the last year of their Ph.D. research.

III. Scientific Statements of the Group Members

(a) R. D. Field

Over the last year my graduate students and I have been studying neural networks and other processing techniques as *tools* for high energy collider phenomenology. The great challenge at hadron colliders is to disentangle any new physics that may be present from the "ordinary" QCD background. Hadron collider events can be very complicated and quite often one has the situation where the signal is hiding beneath the background. In addition, there are many variables that describe a high energy collider event and it is not always obvious which variables best isolate the signal or precisely what data selection (or cuts) optimally enhance the signal over the background. Here neural networks are an excellent tool since they are ideal for separating patterns into categories (*e.g.*, signal and background). We are able to "train" a network to distinguish between signal and background using many variables to describe each event. The network computes a single variable that ranges from zero to one. When the training is successful the network will output a number near one for a signal event and near zero for a background event and a single cut can be made on the network output which will enhance the signal over the background.

In March, we published our first paper entitled "Using Neural Networks to Enhance the Higgs Boson Signal at Hadron Colliders" (*R. D. Field, Y. Kanev, M. Tayebnejad, and P. A. Griffin, Phys. Rev. D53, 2296 (1996)*). We demonstrated that neural networks are a useful tool in Higgs boson phenomenology. Using observables that measure how transverse energy and mass, respectively, are distributed around the away-side jet-jet system, neural networks can help to distinguish the two jet system originating from the $q\bar{q}$ decay of a color singlet Z boson from a random jet-pair coming from the "ordinary" QCD gluon bremsstrahlung of colored quarks and gluons. We used the neural network in conjunction with the standard Higgs boson cuts to provide additional signal to background enhancements. Our procedure can be summarized by the following series of selections and cuts:

- Lepton pair trigger.
- Jet-pair selection.
- Jet-jet profile cuts.
- Jet-jet invariant mass cuts.
- Neural network cut-off.

The invariant mass of the jet-pair is used *only* in the selection of events, the Higgs mass is reconstructed from the momentum of the jet-pair with M_{jj} set equal to M_z. We were to obtain an overall signal to background enhancement of around 10 with the standard Higgs boson cuts. The neural network provides an additional enhancement of 4-5 beyond what can be achieved with the standard data cuts resulting in an overall enhancement of about 50. Our method works even with a large number of interactions per beam crossing which shows that some jet physics can be done even in the large pile-up environment of the LHC.

We are currently writing a paper entitled "Optimizing the Top Signal to Background Ratio at Hadron Colliders" (*R. D. Field, Y. Kanev, M. Tayebnejad*) in which we investigate the event signature of the $\ell\nu b\bar{b}q\bar{q}$ decay mode of top-pair production in proton-antiproton collisions at 1.8 TeV. Neural networks and Fisher discriminates are used in conjunction with modified Fox-Wolfram "shape" variables to help distinguish the top-pair signal from the W+jets and $b\bar{b}$+jets background. Instead of requiring at least four jets in the event, we find that it is faster and better to simply cut on the number of calorimeter cells with transverse energy greater than some minimum. Our analysis of top-pair production can be summarized by the following selections and cuts:

- Lepton plus missing transverse energy trigger.
- Calorimeter cell cuts.
- Modified Fox-Wolfram shape parameters applied to the jets.
- Fisher discriminate or neural network cut-off.

To characterize the "shape" or topology of the outgoing jets in the event we define the following modified Fox-Wolfram moments,

$$\hat{H}_\ell = \left(\frac{4\pi}{2\ell+1}\right)\sum_{-\ell}^{+\ell}\left|\sum_{i}^{jets} Y_\ell^m(\Omega_i)\frac{E_T^i}{E_T(\text{sum})}\right|^2,$$

where Y_ℓ^m are the spherical harmonics and the inner sum is over all the jets in the event with transverse energy, E_T^i, greater than 15 GeV and $\Omega_i = (\theta_i, \phi_i)$ the angular location jet. Here, $E_T(sum)$ is the sum of the transverse energy of all the jets that are included in the sum. These moments lie in the range $0 \le \hat{H}_\ell \le 1$ and by definition $\hat{H}_0 = 1$. We use six of these moments as inputs to a neural network or Fisher discriminate. By combining the cell cuts with the event shape information we are able to obtain a signal to background ratio of around 9 while keeping 30% of the signal. This corresponds to a signal to background enhancement of around 370.

We have been working on developing neural networks that are more suited for collider phenomenology. The networks we used in our first paper were complicated networks with two "hidden layers". We have found that simpler networks with just one "hidden layer" are easier to train and perform just as well on many of the types of problems that arise in collider phenomenology. We used a simpler one layer net in our top quark analysis. Next we plan to study the signatures of supersymmetry at Fermilab and the LHC. We believe that we can improve the signal to background ratios for a variety of supersymmetric signals using the techniques that we have developed.

Recently, I have been working with two of our Postdocs (Claudio Coriano and S. Chang) and an Argonne National Laboratory Postdoc (L. Gordon) on a QCD perturbative calculation. We are calculating the order α_s^2 contributions to polarized Drell-Yan. We have completed the (*non-singlet*) calculation (actually we have finished all the order α_s^2 terms for the initial states $q\bar{q}$ and qq). We are currently writing a paper containing our results ("Polarized and Unpolarized Drell-Yan in NLO QCD: The Quark Contributions", S. Chang, C. Coriano, R. D. Field, and L. Gordon)

We calculate the spin dependence of the cross section by using the helicity projectors, $P_{\pm} = \frac{1}{2}(1 \pm \gamma_5)$, which project out the helicity states of an initial state quark and antiquark, respectively, as follows:

$$u(p_1, h_1) = \frac{1}{2}(1 + h_1\gamma_5)u(p),$$
$$\bar{v}(p_2, h_2) = \frac{1}{2}\bar{v}(p_2)(1 - h_2\gamma_5),$$

where $h_1 = \pm 1$ corresponds to quark helicity $\pm\frac{1}{2}$, and $h_2 = \pm 1$ corresponds to antiquark helicity $\mp\frac{1}{2}$. The lowest order (*non-singlet*) contributions to the large transverse momemtum production of virtual photons with invariant mass $q^2 = Q^2$ arise from the two, $q + \bar{q} \to \gamma^* + g$, "Born" amplitudes. The sum of the two Born amplitudes sqared is

$$\begin{aligned}|M_B(h_1, h_2)|^2 =& |M_B(h)|^2 \\ =& e_f^2 g^2 g_s^2 \frac{C_F}{N_c} \frac{2}{tu} \Big[(1-\epsilon)\left(2Q^2 s + (1-\epsilon)(t^2+u^2) - 2\epsilon tu\right) \\ & + h(1+\epsilon)\left(2Q^2 s + (1+\epsilon)(t^2+u^2) + 2\epsilon tu\right) + 4h\epsilon tu\Big],\end{aligned}$$

and depends only on the product $h = h_1 h_2$.

To any order in perturbation theory,

$$|M(h_1, h_2)|^2 = |M(h)|^2 = |\bar{M}|^2 - h\Delta|M|^2,$$

where $h = h_1 h_2$ and where

$$|\bar{M}|^2 = \tfrac{1}{4}|\sum_{h_1,h_2} M(h_1, h_2)|^2 = \tfrac{1}{4}\sum_{h_1,h_2} |M(h_1, h_2)|^2,$$

is the spin averaged (*unpolorized*) amplitude squared and

$$\Delta|M|^2 = \tfrac{1}{2}\left(|M_{++}|^2 - |M_{+-}|^2\right).$$

Furthermore,

$$|M_{--}|^2 = |M_{++}|^2,$$
$$|M_{-+}|^2 = |M_{+-}|^2,$$

and

$$|M_{++}|^2 = |\bar{M}|^2 + \Delta|M|^2.$$

The spin averaged (*unpolorized*) amplitude squared is determined from $|M(h)|^2$ by setting $h = 0$ and $-\Delta|M|^2$ is the coefficient of h. For the Born term, this results in

$$|\bar{M}|^2 = e_f^2 g^2 g_s^2 \frac{C_F}{N_c} \frac{2}{tu}\left[(1-\epsilon)\left(2Q^2 s + (1-\epsilon)(t^2+u^2) - 2\epsilon tu\right)\right],$$

and

$$\Delta|M|^2 = -e_f^2 g^2 g_s^2 \frac{C_F}{N_c} \frac{2}{tu} \left[(1+\epsilon) \left(2Q^2 s + (1+\epsilon)(t^2+u^2) + 2\epsilon tu \right) + 4\epsilon tu \right].$$

Adding these two terms yields

$$|M_{++}|^2 = -e_f^2 g^2 g_s^2 \left(\frac{C_F}{N_c} \right) \frac{2\epsilon}{tu} \left(Q^4 - Q^2 s + s^2 \right),$$

which is proportional to ϵ and vanishes in the limit $\epsilon \to 0$. Since at the Born level there are no $\frac{1}{\epsilon}$ singularities that might combine with this term to yield a finite contribution in the limit $\epsilon \to 0$,

$$|M_{++}|^2 = 0 \text{ and } \Delta|M|^2 = -|\bar{M}|^2.$$

However, this relationship ceases to be true at the next order.

In $N = 4 - 2\epsilon$ dimensions the differential cross section is related to the $2 \to 2$ invariant amplitude according to

$$s\frac{d\sigma}{dt}(s,t,Q^2,h) = \frac{1}{16\pi s} \left(\frac{4\pi s}{tu} \right)^\epsilon \frac{1}{\Gamma(1-\epsilon)} |M(h)|^2,$$

which can be written as

$$s\frac{d\sigma}{dt}(s,t,Q^2,h) = s\frac{d\bar{\sigma}}{dt}(s,t,Q^2) - h\; s\frac{d\sigma_{LL}}{dt}(s,t,Q^2),$$

where $sd\bar{\sigma}/dt$ is the unpolarized cross section and

$$s\frac{d\sigma_{LL}}{dt} = \frac{1}{2} \left(s\frac{d\sigma_{++}}{dt} - s\frac{d\sigma_{+-}}{dt} \right).$$

Substituting in the Born contribution yields

$$s\frac{d\bar{\sigma}}{dt}(s,t,Q^2) = e_f^2 K_2 \frac{\alpha_s}{s} T_B(Q^2,u,t),$$

where

$$\begin{aligned} T_B(Q^2,u,t) =& \frac{2}{tu} \left[(1-\epsilon) \left(2Q^2 s + (1-\epsilon)(t^2+u^2) - 2\epsilon tu \right) \right] \\ =& 2(1-\epsilon) \left[(1-\epsilon) \left(\frac{u}{t} + \frac{t}{u} \right) + \frac{2Q^2(Q^2-u-t)}{ut} - 2\epsilon \right]. \end{aligned}$$

and

$$K_2 = \pi\alpha \frac{C_F}{N_c} \frac{1}{\Gamma(1-\epsilon)} \left(\frac{4\pi\mu^2}{Q^2} \right)^\epsilon \left(\frac{sQ^2}{tu} \right)^\epsilon,$$

where we have rescaled, $\alpha_s \to \alpha_s(\mu^2)^\epsilon$, so that it remains dimensionless in $N = 4 - 2\epsilon$ dimensions. Furthermore,

$$s\frac{d\sigma_{LL}}{dt}(s,t,Q^2) = e_f^2 K_2 \frac{\alpha_s}{s} \Delta T(Q^2,u,t),$$

where

$$\Delta T(Q^2,u,t) = \frac{-2}{tu}\left[(1+\epsilon)\left(2Q^2 s + (1+\epsilon)(t^2+u^2) + 2\epsilon tu\right) + 4\epsilon tu\right]$$
$$= -2(1+\epsilon)\left[(1+\epsilon)\left(\frac{u}{t}+\frac{t}{u}\right) + \frac{2Q^2(Q^2-u-t)}{ut}\right] - \epsilon(3+\epsilon).$$

To order α_s^2 the $2 \to 3$ differential cross section also has the form,

$$s\frac{d\sigma}{dtdu}(s,t,u,Q^2,h) = s\frac{d\bar{\sigma}}{dtdu}(s,t,u,Q^2) - h\, s\frac{d\sigma_{LL}}{dtdu}(s,t,u,Q^2),$$

where the first term is the unpolarized cross section and the second is the spin asymmetry. We have verified that the unpolarized result which we get by setting $h = 0$ agrees with previous unpolarized calculation of R.K. Ellis, G. Martinelli, and R. Petronzio, Nucl. Phys. B211, 106 (1983).

To predict the spin asymmetry, A_{LL}, in say proton-proton collisions, one must convolute the spin dependent parton level calculation with the polarized structure functions. To make a meaningful prediction one must use structure functions and cross sections calculated to next-to-leading order. Currently, A_{LL} is estimated using the leading order result ($\Delta|M|^2 = -|\bar{M}|^2$), together with the leading order polarized structure functions. However, the leading order polarized structure functions are ambiguous and the prediction is not reliable. After we have completed our first paper (*non-singlet case*) we plan to do the (*singlet*) case and then combine our results with the second order polarized structure functions to do a complete job on the phenomenology of the production of large transverse momentum muon pairs with polarized beams.

I am very excited about the hiring of Gena Mitselmakher in the Department of Physics here at the University of Florida. In the hope of helping his effort to build a collider group at Florida, I have joined the CMS Collaboration and I attended the collaboration meeting in Lake Tahoe last September. I hope that I can do some LHC collider phenomenology that will be of particular interest to the collaboration.

(b) D. Kennedy

I have worked this year on several exciting collaborations applying high-energy physics to problems related to astrophysics. In addition, an old collaboration concerning electroweak gauge theory has developed some interesting results.

For the past three years, I have provided ideas and friendly criticism for a new mechanism of generating gauge boson masses developed by a collaborator in Australia (A. Nicholson). We are completing a joint paper outlining the basic idea at the moment and will explore the issue further. The mechanism involves spontaneous breakdown of chiral symmetry with fermions; in a chiral gauge theory (such as the electroweak standard model), this automatically breaks the gauge symmetry and generates gauge boson mass. The mechanism is apparently related to that of the 2-dimensional Schwinger model, but ours is in four dimensions and perturbative. Unlike the top condensate models, it involves no non-standard interactions and, to my knowledge, has never been tried before.

During a previous postdoctoral position at Fermilab, I provided theoretical guidance for a new group then forming (1991-92) to accumulate antiprotons in a storage ring and place limits on the antiproton lifetime. This experimental effort (the APEX experiment) has now started, and I have been working with one of APEX's leaders (S. Geer) on the other method for placing limits on antiproton lifetimes, by measuring their flux in cosmic rays. Assuming that the antiprotons are secondaries produced by protons hitting nuclei in the Galaxy (an assumption that can be checked by measuring the cosmic antiproton spectrum at low energies), the "storage ring" lifetime of galactic cosmic rays (known from measurement of unstable nuclei fluxes) places an order-of-magnitude limit on the antiproton lifetime against intrinsic decay; the limit can be further refined by examining the measured spectral shape of the antiproton flux. Determining the antiproton spectral shape requires correcting for the flux modulation by the solar wind and magnetic field. Geer and I think that the data are now good enough to make this worthwhile, and the situation will become much better in the next five years or so: more balloon experiments and possibly an orbital antimatter search will improve the available data dramatically.

A second project begun in the last year started with P. Kumar (U. Florida) is based on applying the relativistic electron theory (Dirac equation in an external field) to the electrons near the surface of neutron stars. For the very strong magnetic fields near the neutron star poles (greater than 10^{12} gauss), we expect the magnetic field to influence strongly the electrons' energy states, producing something like a relativistic quantum Hall effect, albeit on a 2-dimensional spherical surface. I am in progress on examining this system in an idealized case with J. Gelb (U. Texas, Arlington) and a student here (K. S. Gopinath). Further issues to be considered will be the many-body states, fractional quantum Hall effect (if any), and related strong-field relativistic electrodynamics. These effects provide an interesting complement to the already-established conjectures concerning neutron star superfluidity and superconductivity.

My long-term collaboration with S. Bludman, G. Bonvicini, and G. C. Essex on nonequilibrium thermodynamics applied to solar neutrinos, stars and relativistic quanta is continuing. Bludman and I have completed a study applying simplified symmetries to solar structure, solar neutrino emission, and helioseismology (sunquakes). Our major line of research is in the application of integral, variational principles to stellar structure and neutrino emission and continues, although slowly. Our main result here is the combination of mechanical and thermal variational principles to stellar structure and the discovery of a general symmetry encompassing a class of standard (Main Sequence) stars. The other two research topics in this area remaining to be explored are: non-equilibrium thermodynamics of neutrinos (with G. C. Essex, U. Western Ontario) and precise calibration of the Sun and solar neutrino emissions with other, nearby, and similar stars.

(c) Z. Qiu

In recent work, I consider a string theory with two types of strings with geometric interaction. I show that the theory contains strings with constant Dirichlet boundary condition and those strings are glued together by 2-d topological gravity with macroscopic boundaries. A light-cone string field theory is given and the theory has interactions to all orders. This is a string theory that incorporates non-critical $d \leq 1$ strings into critical bosonic string theory. In the first quantized language, the amplitudes of the string theory has new contributions from "colored" Riemann surfaces, black and white in this case, which come from interactions between two types of strings. The white region represents ordinary bosonic string with suitable boundary condition and the black region the non-critical strings. Therefore in the calculation of amplitudes in the theory one not only has to sum over all surfaces but also has to sum over the coloration and all possible black strings as well.

The recent advances in understanding the non-perturbative structure of string theory in the context of duality give a further reason, at least in the case of superstring theory, why such singular string configurations become important in string theory. In addition to the point-like object, there are higher dimensional singular string configurations, the so called D-branes, which play a crucial role in the duality of string theory. The above totally different lines of reasoning lead to similar conclusion, it is therefore worthwhile to understand the connection between these complete different approaches.

There are many interesting questions in this new area of research. How to determine the exact mass spectrum of the modified bosonic string theory? The covariant formulation of the theory is another interesting problem in its own right. What is the dual formulation of the theory? Is it still a string theory in the dual formulation? These are just some of the questions I would like to study in the near future.

I also study the role of the interacting sector in string theory with $d > 1$. I consider the non-critical string theory in dimensions $1 < d < 25$ and study the scaling behavior of the partition function. The "string susceptibility" is calculated. The comparison with $d \leq 1$ non-critical string theory is made and the interpretation of the so-called "$c = 1$ barrier" is addressed. I also consider the quantization of the theory in critical dimensions in conformal gauge.

The main result is that I give a procedure to find the new fixed point of non-critical string theory of $d > 1$. The scaling properties of the new string theory is discussed. It is this new "fixed point" that gives a non-trivial d dimensional non-critical string theory. A new scaling relation is derived and its solution gives the "string susceptibility" of the new fixed point.

It is obvious that the above prescription hints at a much simpler formulation of the problem in terms of matrix model. Work in this direction is in progress. My work also provides a "stringy" way to deform one non-critical string theory to other. It could help us to understand better the space of all string theories.

There are close connections between the study of string theory and that of two dimensional conformal field theory. The two-dimensional conformal field theory is a very powerful tool in studying the properties of physical systems where the relevant degrees of freedom exhibit local scale invariance. The familiar examples are the two-dimensional critical phenomena and the properties of strong coupling fixed point of Kondo impurity system.

In fact, many recent advances in these two subjects are based on the progress in the mathematical structure shared. The more familiar examples are the connections between closed string theory and the bulk conformal field theory, open string theory and boundary critical phenomena, non-ghost theorem in string theory and the question of unitarity in conformal field theory, superstring and superconformal field theory, modular invariance as consistent condition of string theory and its role to determine the spectrum of conformal field theory.

The other subject of interest is the non-local effect in conformal field theory. These include the boundary conformal field theory which has been explored extensively in the last few years. I would like to understand other types of non-local effects. One particular case is that of two conformal field theories sharing a common boundary. The central object of interest is an "interacting vertex" connecting two Hilbert spaces. The study of conformal invariance also provides the mathematical tool needed in studying interactions of different types of strings.

I am also looking again at the problem of string compactification. The hope of many researchers that some non-perturbative string effect will resolve the gap between string theory and standard model has not been realized. So it may be a good time to approach this problem in a different way by first understanding the space of all compactifications. Then look for the restrictions imposed by known physics. The hope is that research in this direction may offer hints about how particular compactifications are favored. Furthermore any better understanding of the physics beyond the standard model will offer more restrictions. Similarly, the structure of the space of all compactifications might also give some guidance to physics beyond standard model.

In particular, I am interested in understanding the $(2,0)$ compactification beyond fermionic construction. I would like to find a general procedure to find and classify such compactifications. There are two more practical questions I would like to address in this direction. Is there realistic GUT compactification with high level Kac-Moody algebra? More generally, can one find realistic string compactifications?

(d) P. Ramond

Over the last five years, the thrust of my research has been to link fermion masses and hierarchies to fundamental theory. Lately, however, I have been studying the space of invariants which occur in $N = 1$ supersymmetric theories. Also I have joined the CMS collaboration.

1-) Most theorists agree that the standard model is to be viewed as an effective low energy theory of some more fundamental theory, yet to be determined. The most important question is the value of the cut-off. In a series of works from 1992 on, we have shown that the complexity of the Yukawa sector simplifies in the presence of low energy supersymmetry, albeit at a large cut-off, far removed from experimental energies. The perturbative use of the renormalization group obtains all the way to the cut-off as well. The next question is to learn how to "read" the (extrapolated to the cut-off) data, in a way that adds insight to the nature of the fundamental theory that underlies the standard model.

One expects the physics beyond the cut-off to be suppressed by inverse powers of the cut-off, making it very hard to detect. It is therefore important to focus on phenomena which are scale-independent. Anomalies of local symmetries escape this scale dependence. Although they are generated by massless fermions, they must be cancelled in the ultraviolet. In effective field theories, such cancellation appears as higher-dimension operators at the cut-off. In four-dimensions, a well-known example is the Green-Schwarz mechanism of anomaly cancellations, which comes about through a dimension-five axion-like coupling.

Thus I have been studying the possibility of an anomalous symmetry in the standard model. On the face of it, this would not seem to be a fruitful idea for it is well known that none of the symmetries of the standard model are anomalous. In fact the hypercharge anomaly cancels between leptons and quarks, requiring quarks to have fractional charges. More amazingly, the mixed gravitational anomaly of the hypercharge current vanishes as well, as if the model "knows" gravity, a hint of further unification.

If there is an anomalous symmetry of the standard model, it must belong to a symmetry broken between the large cut-off and experimental energies. Assuming it is carried by the known chiral fermions, it must be hidden in the riddle of the Yukawa sector, with its strong hierarchical structure among the fermion masses, and its small mixing angles. While many symmetries have been proposed as explanation, it is an open question of how to implement them. Since 1993, I have been pursuing the idea that the hierarchy suggests the existence of at least one extra phase symmetry in the standard model. The idea is that the hierarchy can be obtained by higher dimension operators, in the manner suggested by Froggatt and Nielsen. The greater the dimension of the operator, the smaller its effective coupling. I have suggested that the dimensions of the operators in the Yukawa sector are set by a symmetry. If true, this hypothesis can be tested in several ways. With P. Binétruy, I have shown that this hypothesis yields numerous predictions, all in agreement with experiment. We first showed that the data on mass hierarchies requires this symmetry to be anomalous. We then proposed that the anomaly be cancelled in the way suggested by Green and Schwarz. As emphasized by Ibáñez, this mechanism relates the Weinberg angle to the mixed anomaly coefficients. In string theories, it is automatically broken by loop effects below the cut-off. The most striking outcome from this picture is the formula

$$\frac{m_b}{m_\tau} = \lambda^{\tan^2\theta_w - 5/3} ,$$

where λ is a small expansion parameter. This relation, extrapolated to the cut-off, yields the physically favored "canonical" value of the weak mixing angle without any grand-unification. It is an example of using physics at the Planck scale to derive relations among physical observables!

While very encouraging, this does not yet mean that we have understood the detailed structure of the hierarchies. So over the last year, we have examined various aspects of this hypothesis, showing in a series of models, how to generalize our work to derive neutrino mass hierarchies and mixing. We also showed, using anomaly arguments alone, that not all dimension-four Yukawa couplings can appear at tree level, implying that some masses will be suppressed relative to others, as well as mixing among the quarks of different families.

At present, we have been trying to understand how to relate the details of the observed mixings and mass ratios to the structure of the theory. To achieve this, we need to consider models with more than one $U(1)$ symmetry, only one being anomalous. The study of such models is being pursued with my student N. Irges, here in Florida, and also with my overseas collaborators, P. Binétruy and his student S. Lavignac (Binétruy and I were awarded an NSF-CNRS travel grant to continue our collaboration). There are several directions we wish to explore. So far our approach has been shown to be consistent with the data, but it would be much more interesting if it were predictive. Since we are assuming low energy supersymmetry, we wish to explore what implications our picture has on the spectrum of supersymmetric partners, incorporating the stringent constraints of flavor changing interactions. For the time being, we are only learning how to relate observables to the value of these extra hypercharges.

2-) Last summer in Aspen, I started collaborating with Steve Giddings and Ann Nelson, to search for the Seiberg dual of F_4, E_6 and E_7 theories. None of the resulting work has been published since we have only met with partial success, finding only that E_6 is self-dual for six flavors, and that the global anomalies satisfy extra constraints for theories with no superpotentials and their duals. In the hope of understanding the origin of Seiberg duality, I have written an extensive catalog of theories and their duals, which remain unpublished, since I did not find their general structure. In this process, I have been studying the orbit space of representations of Lie groups. This interesting space, spanned by the invariants set of invariants (minimal integrity set), is a compact space, each region corresponding to an unbroken subgroup of the Lie group. The greater the symmetry, the smaller the manifold. For example a cusp is a point of maximal symmetry, while its inside region corresponds to minimal symmetry. It has been known for sometime, notably by L. Michel, and J. S. Kim, that different representations of different groups can have the same orbit space. In the hope this might throw light on the origin of Seiberg duality, I have been studying ways to characterize orbit spaces. One interesting result has emerged. For instance, the orbit space of a $N = 1$ supersymmetric local theory of n_f chiral fields transforming as the vector representation of the gauge group $SO(n_c)$, contains bosonic and fermionic invariants, as shown by Seiberg and Intriligator. I have found that these invariants form a representation of a sort of superalgebra, and that Seiberg duality seems to be connected to a conjugation of this algebra. This algebra contains anticommutators that are quadratic in the generators, suggesting novel algebraic structures. I plan to further study these superalgebras with two of our postdocs S. Chang, and C. Corianò, and with a spanish visitor from Granada, M. Masip.

3-) Recently, the University of Florida has made a major effort towards high energy experimental physics, hiring a group to play a major role in the muon detection part of CMS. I am quite excited by their presence, and have joined the CMS collaboration. With the help of an internal grant from the University of Florida, I have started work on improving computer visualization techniques for use at the LHC. Specifically, in collaboration with Rick Field and graduate students a long term project to make Feynman diagrams more accessible on Unix machines. The idea is to make available fast visualization of diagrams, especially for supersymmetric particles. While most of the software already exists, I view our role as one of integrating the already existing resources to make available to the collaboration convenient visualization of events detected at CMS. Another part of the project is to develop 3-d tools for visualizing events, with the ability of replacing particles by their associated showers, etc... . This is the beginning of a project which I plan to continue over the next five years mostly during the summer.

4-) I have accepted the presidency of the Aspen Center for Physics for the next three years. As a result, I have not finished the (*almost ready*) book I have been writing for the last four years on physics at and beyond the standard model. Another reason is that the subject of dynamical supersymmetry breaking has seen tremendous advances, and I am finding it difficult to find a stopping point in that chapter!

(e) P. Sikivie

A few years ago, J. Ipser and I pointed out that the spectrum of cold dark matter particles on Earth should be expected to have peaks in velocity space associated with dark matter particles falling onto the galaxy for the first time and with particles which have fallen in and out of the galaxy only a small number of times in the past. I. Tkachev, Y. Wang and I then wrote a paper, published last fall in Phys. Rev. Lett., which gives estimates of the average sizes and the velocity magnitudes of the peaks based upon the secondary infall model of galactic halo formation. We generalized this model to include, in a tractable way, the effect of angular momentum of the dark matter particles. Our model establishes a relationship between the core radius of the galactic halo and the amount of angular momentum which the dark matter particles carry. Our results are relevant to the dark matter axion search presently taking data at LLNL. Indeed, this experiment's sensitivity is increased by looking for narrow peaks provided there is one peak with energy spread $\delta E < 10^{-11} m_a$, where m_a is the axion mass, and with fraction of the local halo density larger than about 1%. The LLNL experiment does have a high resolution data analysis stream to search for such narrow peaks. I am presently working on a long paper in collaboration with I. Tkachev and Y. Wang which gives the details of our analysis.

A few months ago, J. Ipser pointed out to me that recent Hubble Space Telescope observations of nearby elliptical galaxies show that their luminosity profiles have cusps at the galactic center which are reminiscent of the cusps that exist in the halo distribution of the model that I. Tkachev, Y. Wang and I developed. It turns out that they are in fact remarkably similar. To make sense of this one would argue that the stars in elliptical galaxies are distributed in the same way as dark matter in a galactic halo because they move in the same dissipationless way. This hypothesis is plausible in view of the fact that elliptical galaxies contain mostly old stars and very little gas compared to spiral galaxies. J. Ipser and I intend to look at this more closely and see whether other observations disagree with, or possibly confirm, this interpretation.

The LLNL experiment, if it finds a signal, will be able to measure the energy spectrum of dark matter axions with very high precision and resolution. It is possible that some information about events in the very early universe may be inferred from this spectrum. This could be the case in particular if some of the velocity peaks still have their primordial widths associated with the inhomogeneity of the axion field at the QCD phase trasnsition, when the dark matter axions are produced by vacuum misalignment, axion string decay and axion domain wall decay. Claudio Coriano and Sangheon Chang, who are post-docs in our theory group, and I intend to reanalyze these production mechanisms with particular regard to the velocity dispersion of the axions produced in each. Already, we have found some qualitatively new things to say about the axions from domain wall decay. These findings, if they hold up, would impact the discussion of the inhomogeneities associated with axion mini-clusters whose existence was pointed out by C. Hogan and M. Rees, and by R. Kolb and I. Tkachev.

A few months ago, thanks to a comment of David Micha who is a faculty member in the Quantum Theory Project here, I have come to realize that the methods Eric D'Hoker, Youli Kanev and I developed to derive the Casimir force between beads attached to strings and membranes can also be applied to the calculation of the Van der Waals force between two polarizable atoms. We should be able not only to reproduce the famous result of Casimir and Polder on the size of this force but also derive the higher order corrections to it in an expansion in powers of the polarizabilities involved. I intend to look at this in collaboration with Eric D'Hoker and also possibly David Micha.

Other research topics that I am interested in working on are schemes to extend the axion mass range (presently $1.3 < m_a < 13\mu\text{eV}$) of the LLNL experiment to both lower and higher axion masses, and the nature and origin of the highest energy ($E \sim 10^{10}$ GeV) cosmic rays. I also intend to continue work on the review paper on axion physics that I have worked on off and on for the past ten years.

(f) C. B. Thorn

For quite a few years my research has been devoted to two broad areas of particle theory: the dynamics of strong interactions and string theory. Although these two areas were once closely linked (when I started my research, string theory was developed as a theory of strong interactions), they have by now gone down very separate roads. QCD has supplanted string theory as the "fundamental" theory of strong interactions, and string theory is now the leading candidate theory to unify quantum gravity with the rest of physics. No longer is string a model of hadronic matter: it is now a promising model for the substructure of quarks, leptons, vector bosons and the graviton. The energy scale at which this substructure should be revealed, $M_{\text{string}} = \sqrt{\hbar c T_0}$, is very likely to be well beyond the reach of earthbound accelerators, perhaps as large as the Planck mass.

Since both of the research areas mentioned above still have many fundamental unresolved issues, and since I have been able to contribute significantly to both, I plan to continue working in both areas in the future, not necesaarily simultaneously. Currently and for the past two years my focus has been on trying to develop a viable model of superstring as a composite of "string bits," a concept I proposed nearly 20 years ago. This effort is motivated by the desire to bring string theory into the framework of quantum field theory (albeit an unconventional one), and also by the feeling that the alternative, string field theory, is overly cumbersome and perhaps not even internally consistent. The model is a Galilei invariant (not Lorentz invariant!) field theory of particles (String Bits) moving in $D-2$ space + 1 time dimensions, where D is the dimension of space-time. Such models show that the rich structure of string can arise from a theory with vastly fewer degrees of freedom than quantum field theory in D space-time dimensions.

During AYs (94 - 96), I worked with Oren Bergman, one of our post-docs, to extend my string bit ideas to superstring. We have completed three papers devoted to this project. One addresses the general problem of supersymmetrizing the Galilei group. The second applies these methods to build a string bit model for superstring. That paper goes some distance toward the ultimate goal, reproducing the correct physics of free (noninteracting) superstring. But there remain problems in guaranteeing the full needed supersymmetry in the presence of string interactions. The third and most recent paper discusses a "toy" model for 2+1 dimensional superstring which maintains the required supersymmetry at the interacting level. This is important, because it shows that our difficulties in realistic dimensions are technical obstacles; they are not insurmountable in principle. Also important is the fact that this model can be constructed to satisfy the clustering property needed to have well defined scattering of macroscopic pieces of string rather than just microscopic scattering of string bits. The issue here was similar to the problem one would confront in QCD if the confinement mechanism did not completely screen out all long range interactions between quarks in spatially separated hadrons. The fact that our toy model evades this difficulty is very significant.

A provocative proposal by 't Hooft is that a resolution of the information loss paradox, associated with black holes emitting Hawking radiation, requires a drastic reduction in the number of fundamental degrees of freedom at the Planck scale. Indeed, 't Hooft has suggested that the world must be a hologram, *i.e.* one spatial dimension is a profound illusion. Our string bit model, which induces quantum gravity, has precisely this characteristic. This encourages us to hope that string bit models may ease the information loss problem (loss of quantum coherence), thus resolving a longstanding clash between quantum mechanics and general relativity.

Our string bit program is progressing, but there remain many issues to address:

1. It is most urgent to try to surmount the obstacles Bergman and I encountered with

fully supersymmetric string interactions in the realistic case of 3+1 dimensional superstring (or higher dimensions if extra ones are compactified). A completely successful supersymmetric string bit model would be a tremendous improvement over previous fundamental formulations of string theory. A truly nonperturbative formulation of superstring theory would have important implications for quantum gravity.

2. A striking feature of all string theories is the ubiquitous presence (at least at weak coupling) of both a massless helicity 2 particle, the graviton, and a massless helicity 0 particle, the "dilaton." The graviton is the major miracle of string theory and is something we want to retain. But the massless dilaton is problematic. We should try to understand the physics in string bit models underlying the appearance of these massless states. Then we might understand how nonperturbative dynamics could give a mass to the dilaton without spoiling the gravitational properties of the model.

3. In the past year there has been an explosion in the discovery of deep relationships between superficially different string theories. There are many "dualities" linking one theory to another. A major challenge is to understand these relationships in the context of our string bit models.

My most recent research activity on strong interaction dynamics (QCD) was in the years 1992 - 1994. It was focussed on a "stringy" side of QCD, Regge trajectories and 't Hooft's $1/N_c$ expansion. While it is undoubtedly true that $N_c \to \infty$ leads to some kind of string theory (assuming quark confinement), this "QCD string" is quite different from fundamental string. For one thing, QCD string must be compatible with asymptotic freedom and contain hard point like structures. For another, QCD has a global Poincaré invariance. and hence could never produce a massless graviton in a consistent approximation. Some years ago M. McGuigan and I showed that the Regge trajectories predicted by large N_c QCD (a limiting theory describing free mesons) must be nonlinear – unlike the exactly linear Regge trajectories in free string theory. We obtained the prediction that the ρ trajectory $\alpha(t)$ (more generally any quark-antiquark leading trajectory) should approach zero from above as $t \to -\infty$. Since existing measurements of the ρ trajectory (based on fits with $s < (20\text{GeV})^2$) indicate that it crosses zero at $t \sim$ -.5$(\text{GeV})^2$ and decreases further to around $-.7$ for $t \sim$-7 $(\text{GeV})^2$, this raises questions about how our QCD predictions square with the real world. However, even in this old data there was some indication in the fits that s was not large enough to isolate the true leading trajectory.

Mikaelian, a graduate student, studied the trends of existing data to estimate when asymptopia should set in. He fit the data to a superposition of a hard parton QCD term (behaving as s^0) consistent with our trajectories and a term behaving as a negative power of s to parametrize the soft hadronic part of the process. He found that a relative normalization of 1 : 20 roughly accounts for residual s dependence found in the measured ρ trajectory. If this interpretation is correct, at extremely high s, say 4000GeV^2, the QCD term ought to stand out clearly. Later, Brodsky, Tang and I directly estimated the normalization of the contribution of the "hard QCD reggeon" calculated by McGuigan and me to some purely hadronic inclusive processes. Interestingly, the calculation predicted a sufficiently small contribution that the low measured value of the ρ trajectory is consistent with a "hard ρ trajectory" above zero: much higher energies are needed to expose the true ρ trajectory.

In the next few years I expect my research efforts on QCD to consider possibilities for using existing accelerators to get a better handle on Regge trajectories in the regime predictable by perturbative QCD. The Tevatron is clearly a relevant machine, but another exciting possibility is the use of HERA for the study of Regge trajectories. This can be done because at ZEUS they are involved in studying the fragmentation of the proton as well as structure functions. There is a definite possibility that study of inclusive charge exchange from the proton will allow the extraction of the rho trajectory in a new kinematic domain. Estimates of cross sections along the lines followed by Brodsky, Tang and me, discussed above, should be helpful in assessing the viability of such experiments, both at HERA and the Tevatron.

(g) R. Woodard

My basic interest is quantum gravity in the larger context of Lagrangian field theory and particle physics. I am engaged in a long-term collaboration on the implications of quantum gravity for the problem of the cosmological constant with Dr. Nicholas Tsamis of the University of Crete. He comes here for a month during the winter and I go there for about two months every summer. Our travel has previously been supported by NATO (CRG-910627) and is now supported by NSF (grant 94092715) and the EEC (grant 933582). I plan to spend the Spring semester of 1997 on sabbatical at the Ecole Polytechnique in Paris, where Dr. Tsamis will also be visiting.

The cosmological constant is an apparently free parameter in Einstein's theory of gravitation. The associated "problem" is that classical gravitation causes the universe either to expand exponentially or else to rapidly collapse if this parameter is not at least 10^{120} times smaller than its natural value. The problem is especially vexing because observations of the present large scale structure indicate that the very early universe underwent a period of rapid expansion known as "inflation." One consequence is that the effective cosmological constant must once have been at least 34 orders of magnitude larger than the current bound; the usual assumption of inflationary cosmology is that the excess was actually more than 100 orders of magnitude. There is no larger hierarchy problem in physics. Further, the transition from inflation to the current epoch of slower expansion critically affects the observed density, makeup, and distribution of matter.

Dr. Tsamis and I believe that the bare cosmological constant is not unnaturally small. Inflation commences in our scheme for no other reason than that the temperature of the very early universe eventually falls below the critical value at which the natural amount of vacuum energy begins to dominate the stress tensor. Inflation stops in our scheme because the causal and coherent superposition of quantum gravitational interactions throughout the past light cone generates an ever-growing, negative vacuum energy. This is an attractive scenario because:

(1) It operates in the far infrared where general relativity can be used reliably as a quantum theory of gravitation;

(2) It introduces no new light quanta which would embarrass low energy phenomenology;

(3) It has the potential to make unique predictions because gravity is the only phenomenologically viable theory which possesses the essential feature of massless quanta (so interactions superpose coherently) whose self-interactions are not conformally invariant (so their effect grows like the enormous invariant volume of the past light cone); and

(4) The weakness of gravitational interactions makes the process slow enough to account for a long period of inflation without unnatural fine tuning.

We have recently completed a calculation which establishes the validity of our scenario for at least as long as perturbation theory remains reliable. The quantity we computed is the expectation value of the invariant element, starting from a homogeneous and isotropic, locally de Sitter, free vacuum on the manifold $T^3 \times R$:

$$\Big\langle \Omega \Big| \, g_{\mu\nu}(t, \vec{x}) \; dx^\mu dx^\nu \, \Big| \Omega \Big\rangle = -dt^2 + \mathrm{a}^2(t) \; d\vec{x} \cdot d\vec{x}$$

The rate of spacetime expansion is measured using the coordinate invariant effective Hubble constant:

$$H_{\text{eff}}(t) \equiv \frac{1}{\mathrm{a}(t)} \frac{d\mathrm{a}(t)}{dt}$$

One loop tadpoles make no contribution because they are ultra-local whereas infrared effects derive from the causal and coherent superposition of interactions throughout the past lightcone. The first secular effect comes from two loops:

$$H_{\text{eff}}(t) = H \left\{ 1 - \left(\frac{\kappa H}{4\pi} \right)^4 \left[\tfrac{43}{4} (Ht)^2 + \mathcal{O}(Ht) \right] - \mathcal{O}(\kappa^6) \right\}$$

where $H \equiv \sqrt{\frac{1}{3}\Lambda}$ is the Hubble constant at the onset of inflation and $\kappa^2 \equiv 16\pi G$ is the usual loop counting parameter of perturbative quantum gravity. We have also been able to show that the ℓ loop contribution to the bracketed term can be no stronger than $-\#(\kappa H)^{2\ell}(Ht)^\ell$. The minus sign derives from gravity's attractiveness, and is seen by using Feynman's tree theorem to represent the response to quantum loops as the classical response to an ensemble of gravitons. We have also used the tree theorem to establish that the dominant effect comes from gravitons whose physical wavelengths are approaching the Hubble radius.

Our current effort is to develop a model that can be extended past the time $t \sim (\kappa H)^{-2} H^{-1}$ at which perturbation theory breaks down. We are pursuing three approaches:

(1) Identify principles which constrain the dominant terms in the effective field equations enough that they can be guessed;

(2) Use the tree theorem to identify an infrared truncation of the propagators and vertices which captures the dominant effect, and then attempt to sum the series of all corrections when this truncation is made; and

(3) Sum the 2-loop tadpole terms by re-doing our 2-loop result for arbitrary scale factor, and then solving the classical field equations with this as the source.

We have pushed (1) far enough to identify the following candidate effective field equations:

$$R_{\mu\nu} - \tfrac{1}{2} g_{\mu\nu} R = -\tfrac{1}{2} \Lambda g_{\mu\nu} + 8\pi G T_{\mu\nu}$$

where the effective stress tensor has the form:

$$T_{\mu\nu} = g_{\mu\nu} T[g] - V_{\mu;\nu} - V_{\nu;\mu}$$

$$T[g] = \tfrac{43}{36} \left(\frac{G}{8\pi} \right)^2 R \left(R \frac{1}{\Box} R \right)^2$$

(The vector V_μ is chosen to enforce conservation, $T_{\mu\nu}{}^{;\nu} = 0$.) Although this model is probably not unique, it does reproduce the perturbative result and has some desirable features besides. Note that it is protected from permanently decaying to negative R by its oddness in the Ricci scalar. The tendency as R approaches zero seems to be for the effective stress tensor to provide a restoring force, which would generate the sort of oscillations conducive to a substantial reheating. Of course one would need at this stage to include the drag imposed by the leakage of energy into the matter sector. Note also that the model seems to show complete relaxation since the term $R\Box^{-1}R$ would grow without bound if the Ricci scalar where to approach any value other than zero at late times. We propose to numerically integrate the ordinary differential-integral equation which results for the scale factor $a(t)$. We will then compute the spectrum of density fluctuations, the reheating temperature, and the asymptotic value of the deceleration parameter for late times.

(h) O. Bergman

During the academic year 1995/96 I continued to study supersymmetric string-bit models, but I have also begun investigating string duality and its implication on the possible reformulation of string theory in terms of string bits.

String-bits are particles transforming in the adjoint representation of a "color" group $SU(N_c)$, and obeying non-relativistic dynamics. String-bit models allow for the formation of long closed chains of string-bits, whose low energy properties approximate those of relativistic strings in the light-cone gauge. As such, these models are candidates for a fundamental reformulation of string theory, in which the string, Lorentz invariance, and the longitudinal dimension appear as effective low-energy features. Last year C. Thorn and I have constructed supersymmetric string-bit models for the type IIB superstring theory in various dimensions [1]. This year we concentrated on the $D = 3$ model, and proved a restricted form of Universality with regards to the microscopic bit interactions [2]. This allowed us to localize the bit interaction and thus avoid the catastrophe of strong interactions between well separated chains. We would like to the same for the more realistic $D = 4$ and $D = 10$ models.

String duality has attracted much attention this past year, because it strongly suggests that the current formulation of string theory is incomplete. A proper formulation should account for the dualities between different string theories, and should include other extended structures such as membranes. I have been considering the possibility that this formulation might be a bit theory, and have accumulated some evidence for this [3]. The evidence consists of the curious high-temperature behavior of strings, the possibility of a new energy scale, and the emergence of other extended objects (p-branes) as necessary ingredients in string dualities. The underlying bit theory is a generalization of string-bit models that can accommodate not only strings, but also other extended objects.

[1] String-Bit Models for Superstring, O. Bergman and C.B. Thorn, Phys. Rev. **D52** (1995) 5980.

[2] Universality and Clustering in 1+1 Dimensional Superstring-Bit Models,, O. Bergman and C.B. Thorn, Phys. Rev. Lett. **76** (1996) 2214.

[3] Evidence for String Substructure, O. Bergman, work in progress.

(i) S. H. Chang

My major field is high energy particle physics phenomenology. My main topics of research have been weak interaction, CP violation, axion model and cosmology.

After I moved to the Institute for Fundamental Theory, I have written a paper with Dr. H. B. Kim on the supersymmetric axion dark matter, "A dark matter solution from ...". We have found that in the supersymmetric extensions of the axion model, there is a new type of axion dark matter. This new model is a model of axion cold dark matter with relativistic axions. We have a few interesting predictions: (1) the structure formation is governed by one light degree of freedom.; (2) the Hubble constant could be larger than 50km$\text{Mpc}^{-1}\text{sec}^{-1}$, in the flat $\Omega_{CDM} = 1$ universe. This paper will be published in Physical Review Letters.

Recently, Dr. C. Coriano, Dr. A. Faraggi and I, are working on the strongly interacting cold dark matter candidate from string unification models. In our papers ("New dark matter candidates motivated..", "Stable Superstring Relics"), we have found that there are a few mass windows of dark matter. In these windows, the stable heavy down-like quark, which is predicted by one class of string string unification models could be the dark matter of our universe.

I am currently working on the two jet events from the CDF experiment using the ISAJET program with Prof. R. Field and Dr. Coriano. Dr. Coriano and I have also started to calculate the cross section for polarized Drell-Yan to the second order and we expect we will have a new results in a few months.

We have started work on the phenomenology of the MSSM with a particular attention to the detection of the supersymmetric Higgs boson. We hope we can figure out whether the MSSM can be tested by the future detector like LHC.

Dr. Coriano, Prof. Sikivie and I are working on the decay of axionic domain wall in early universe.

Dr. Masip, Prof. Ramond and I are currently studying the duality between two different gauge groups by analyzing there structure of orbit space.

References:

[1] S. Chang and H. B. Kim, "A dark matter solution from the supersymmetric àxion model" UFIFT-HEP-96-8, (*to appear in Phys. Rev. Letters*).

[2] S. Chang, C. Coriano and A. E. Faraggi, "New dark matter candidates motivated from superstring derived unification" UFIFT-HEP-96-9, (*submitted to Phys. Rev. Letters*).

[3] S. Chang, C. Coriano and A. E. Faraggi, "Stable superstring relics" UFIFT-HEP-96-12, (*submitted to Nucl. Phys. B*).

(j) Claudio Corianò

The research activity I have pursued since I moved to the Institute for Fundamental Theory (September 1995) has been focussed on various aspects of QCD and on the application of particle physics to cosmology.

In QCD I have been studying both resummation effects at small-x from the point of view of t-channel unitarity (with A. White), and radiative corrections to spin physics (with L. Gordon). Spin phenomena are currently of great interest and a lot of work remains to be done in order to clarify the issue related to the spin content of the nucleons. We have studied double photon production to order α_s and we are currently studying polarized Drell Yan (with Chang and Gordon) to order α_s. The measurement of this cross section at RHIC will be of crucial importance for the resolution of many unsolved puzzles in spin physics.

Together with Dr. Chang and Prof. Field we are studying susy effects in QCD and in the Minimal Supersymmetric Standard.

Dr. Chang, Dr. Faraggi and I have been studying the cosmological implications of string models at low energy and found that these models predict the existence of new stable particles which might contribute to the dark matter content of the universe.

Dr. Faraggi and I have started to analize the string corrections to the Yukawa couplings of these low energy effective string models. This calculation is of considerable phenomenological interest.

Dr. Chang, Prof. Sikivie and I are currently investigating the role of the decay of axionic string domain walls in the early universe.

Research Papers:

[1] S. Chang, C. Corianò and A. E. Faraggi, "Stable Superstring Relics", IASSNS-HEP-96-44 UFIFT-HEP-96-12, *submitted to Nucl. Phys. B.*

[2] S. Chang, C. Corianò and A. E. Faraggi, "New dark matter candidates motivated from superstring derived unification", *submitted to PRL.*

[3] C. Corianò and L. E. Gordon, "Polarized Double Prompt photon production in QCD to order α_s", UFIFT-HEP-96-6, *to appear in Phys. Rev D.*

[4] C. Corianò and L. E. Gordon, "Polarized and unpolarized double prompt photon production in next to leading order QCD", IFT-UFL-95-28, *to appear in Nucl. Phys. B.*

[5] C. Corianò and A.R. White, "Unitarity Derivation of Conformally Symmetric QCD High Energy Kernels", lectures given at the XXXV Cracow School, Poland June 4-14, 1995 Acta Phys. Pol. **B 226**, 2005 (1996).

[6] C. Corianò and A.R. White, "Small-x evolution and Higher Order Corrections in QCD", VII International Conference on Elastic and Diffractive Scattering, Ecole Polytechnique, Blois, France June 20-24, 1995.

[7] C. Corianò, R. Parwani and A.R. White, "The scale invariant $O(g^4) kernel$ at non zero momentum transfer", ANL-HEP-PR-95-53, *to appear in Nucl. Phys. B.*

[8] C. Corianò and A.R. White, "Gauge theory high energy expansions from J-plane unitarity", ANL-HEP-PR-95-19, *to appear in Nucl. Phys. B.*

(k) A. Faraggi

During the academic year 1995/6 I worked mainly on several topics. The first is on the problem of gauge coupling unification in superstring theory. The second is on fermion masses in superstring derived models. The third is on cosmological implications of realistic superstring models. The fourth is on potential new gauge bosons from superstring models. I have also investigated the construction of higher level string models and started to study the subject of noncommutative geometry.

In the first work we [1] investigated the issue of the renormalization of the weak hypercharge in superstring models. A well known problem in superstring unification is the mismatch between the string predicted unification scale and the unification scale that is predicted by the minimal supersymmetric standard model. It has been suggested that different normalization of the weak hypercharge, from the one that is traditionally obtained in Grand Unified Theories (GUTs), may resolve the problem. In ref. [1] (in collaboration with Keith Dienes and John March–Russell) we analyzed the possible weak hypercharge normalizations that may appear in superstring models. We argued that the normalization of the weak hypercharge is quite restrictive and in fact in most string constructions does not admit the values that are needed to solve the string gauge coupling unification problem. We also studied the effect of changing the Kac–Moody levels of the $SU(3)$ and $SU(2)$ gauge groups and searched for the possible values that may be in agreement with the string unification predicted scale. Our conclusions reinforces our previous suggestion that the only possible resolution of the string gauge coupling unification problem is the existence of additional matter states beyond the minimal supersymmetric standard model.

Under the second topic I continued a previous study of the calculation of the fermion masses in a class of superstring derived models. In a previous letter I calculated the masses of the top and bottom quarks and of the tau lepton. In ref. [2] I discussed in detail the calculation of the fermion masses in the superstring models. I investigated the minimization of the Higgs potential and showed that the predicted fermion masses can be in agreement with the minimization of the one–loop effective Higgs potential. Currently, (in collaboration with Claudio Coriano) we are pursuing the calculation of the second generation of fermions. This involves calculation of higher order of string correlators and we are developing the techniques which are needed to evaluate these correlators.

Under the third topic (in collaboration with Sanghyeon Chang and Claudio Coriano) we have started an investigation of cosmological implications of superstring models. Motivated from the suggestion that additional colored matter may be the only way to resolve the string gauge coupling unification problem, we investigated the possibility that the same colored states may resolve the dark matter problem. In ref. [3] we suggested that this colored matter can be stable and evade all current experimental limits. In ref. [4] we expanded on our earlier suggestion and proposed that string models in general predict the existence of additional stable matter. This arises because in string models the gauge symmetries are broken by using Wilson lines. Wilson line breaking results in matter states that do not respect the symmetry of the original unbroken symmetry. This results in possible conservation laws that forbid the decay of the additional matter states into the lighter standard model states. We investigated the exotic massless states that appear in the free fermionic models. We proposed that the exotic matter states are good dark matter candidates and studied how previous constraints that were imposed, for example on fractionally charged states, may be modified in the string models. We believe that the existence of such exotic stable matter is generic in superstring models and may eventually lead to the verification or dismissal of superstring models of particle physics.

Under the next topic (with Manuel Masip) we showed how string models produce a leptophobic Z' gauge boson. Recently it was suggested in the literature that there is experimental evidence for such a leptophobic heavy gauge bosons. We showed that there are string models in which the $B - L$ gauge boson combines with the horizontal flavor symmetries to produce a universally leptophobic $U(1)$ symmetry. We are currently investigating whether the leptophobic $U(1)$ can be broken at low energies.

In addition to the topics above I also studied during the last year the problem of constructing higher level string models. I have mainly focused on studying how the higher level symmetries are realized in superstring models. Finally, I devoted some of my time to the study of duality symmetries in string theory and to noncommutative geometry. I believe that string theory arises as an effective theory due to noncommutative geometry and the duality symmetries that have been revealed in the last few years will be manifest in a noncommutative geometric formulation of string theory. I plan to pursue this hypothesis in the coming years.

In the coming year I plan to continue my efforts to bring string theory as close as possible to reality as well as trying to extract some general properties of superstring models that may be accessible to experiments.

References:

[1] String unification, higher–level gauge symmetries and exotic hypercharge normalizations, K. R. Dienes, A. E. Faraggi and J. March–Russell, Nucl. Phys. **B467** (1996) 44.

[2] Calculating fermion masses in superstring derived standard–like models, A. E. Faraggi, IASSNS–HEP–95/60, UFIFT-HEP-95-24, submitted to Nucl. Phys **B**.

[3] New dark matter candidates motivated from superstring derived unification, S.H. Chang, C. Coriano and A.E. Faraggi, UFIFT-HEP-96-9, submitted to Phys. Rev. Lett.

[4] Stable superstring relics, S.H. Chang, C. Coriano and A.E. Faraggi, UFIFT-HEP-96-12, paper in preparation.

[5] Leptophobic Z' from realistic superstring derived models, A.E. Faraggi, UFIFT-HEP-96-11, submitted to phys. Lett. B.

IV. ACTIVITIES OF THE PARTICLE THEORY GROUP (*since 1993*)

A. Lectures and Seminars

Field

URA Fermilab Review, February 5-6, 1993

High Energy Physics Seminar presented at the SSCL, Dallas, TX, June 7, 1993

High Energy Physics Seminar presented at the Institute for Fundamental Theory, University of Florida, Junuary 25, 1994

Seminar on Neural Networks presented at the Institute for Fundamental Theory, University of Florida, May 24, 1994

Lecture on Quarks and Leptons presented at the Physical Chemistry Seminar, University of Florida, September 6, 1994

High Energy Physics Seminar entitled "Neural Networks as a Tool for High Energy Phenomenology" presented at the Institute for Fundamental Theory, University of Florida, October 4, 1994

Seminar on Neural Networks presented at the CMS meeting, Lake Tahoe, California, September 25-29, 1995.

High Energy Physics Seminar presented at Florida State University, Tallahassee, Florida, October 17, 1995.

High Energy Physics Seminar presented at the Institute for Fundamental Theory, University of Florida, October 24, 1995.

Physics Colloquium presented at University of Florida, Gainesville, Florida, March 7, 1996.

High Energy Physics Seminar presented at the University of California at Riverside, April 10, 1996.

Kennedy

Seminar, University of Florida, September 1994: Report on Glasgow Conference.

Seminar, University of Florida, September 1994: Solar Neutrinos.

Seminar, University of Washington, August 1995: Solar/Stellar Structure, Evolution, Neutrino Fluxes.

Seminar, University of Florida, September 1995: Solar/Stellar Structure, Evolution, Neutrino Fluxes.

Qiu

Seminar, University of Florida, January 1993

Theoretical Physics Seminar, Cornell University, May 1994

Colloquium, University of Florida, September 1994

Talk at String 95, USC, Los Angeles, CA, March 1995

Three Lectures at CCAST, Beijing, China, August 1995

Ramond

Invited Lecturer, Coral Gables Conference, Miami, Jan. 1993

Invited Lecturer, HARC, Houston, TX, April 1993

Seminar, Johns Hopkins University, Baltimore, MD, April 1993

Colloquium, University of Chicago, May 1993

Seminar, Southern Methodist University, Dallas, TX, May 1993

Colloquium, SSCL, Dallas, TX, June 1993

Invited Lecturer, Electroweak Workshop, Gran Sasso, Italy, Sept. 1993

Seminar, Ecole Normale, Paris, Sept. 1993

Invited Speaker, Recontres de Moriond, France, March 1994

Seminar, College of William and Mary, Williamsburg, VA, April 1994

Invited Lecturer, TASI, Boulder, CO, June 1994

Invited speaker, First Gürsey Symposium, Istanbul, Turkey, June 5-8, 1994

Invited speaker, O. Klein 100 Symposium, Stockholm, Sweden, September 17-28, 1994

Invited lecturer, Laboratoire de l'Accélérateur Linéaire, Orsay, France, September 1994

Invited speaker, Fermilab Workshop on Yukawa Couplings, Batavia, Illinois, October 13-16, 1994

Invited seminar, Florida State University, Tallahassee, Florida, October 28, 1994

Invited speaker at Conference on Unified Symmetry in the Large and in the Small, Coral Gables, Florida, February 2-5, 1995

Colloquium speaker, SUNY at Stony Brook, Stony Brook, New York, April 29 - May 3, 1995

Invited speaker at SUSY95 International Workshop on Supersymmetry and Unification of Fundamental Interactions, Paris, France, May 14-27, 1995

Invited speaker CAM-95 Conference, Québec, Canada, June 14-18, 1995

Invited speaker at ITP workshop, Santa Barbara, October 1995

Invited speaker at supersymmetry workshop, Tallahassee, Fl, Nov 1995

Invited speaker at Kikkawa Symposium, December 1995, Osaka, Japan

Colloquium, Duke University, January 1996

Seminar speaker, Berkeley, March 1996.

Sikivie

Invited talk at the Coral Gables Conferences on Unification in the Large and the Small, Miami, FL, Jan. 26, 1993

Particle Theory Seminar at the Univ. of Pennsylvania, Philadelphia, PA, April 12, 1993

Particle Theory Seminar at CERN, June 10, 1993

Invited talk at the Workshop "The Dark Side of the Universe", Rome, June 23-26, 1993

Particle Theory Seminar at the University of Geneva, July 1993

Invited talk at the 17th John Hopkins Workshop, Budapest, July 30-Aug. 1, 1993

Triangle Nuclear Theory Colloquium, Duke University, October 5, 1993

Invited talk at the Annual Meeting of the South Eastern Section of the APS, Columbia, S.C., Nov. 4-6, 1993

Invited talk at the Coral Gables Conference, Coral Gables, Jan. 27-30, 1994

Invited Plenary Session talk at the Workshop on "Strategies for the Detection of Dark Matter Particles, LBL, Feb. 21-24, 1994

Particle Theory seminar at ITP, UC Santa Barbara, May 1994

Particle Theory seminar at UCLA, June 1994

Invited talk at the Conference "Trends in Astroparticle Physics" in Stockholm, Sweden, Sept. 22-25, 1994

Invited talk at the Workshop on "Topological Defects in Cosmology" at the I. Newton Institute, Cambridge, England, Nov. 16-17, 1994

Particle Theory Seminar at Orsay, France, on Nov. 22, 1994

Particle Theory Seminar at the Université Libre of Brussels, Belgium, Nov. 25, 1994

Particle Theory Seminar at Oxford University, Oxford, England, Dec. 2, 1994

Cosmology seminar at the I. Newton Institute, Cambridge, England, Dec. 8, 1994

Particle Theory Seminar at Imperial College, London, England, Dec. 13, 1994

Four lectures at VIth Argentine Symposium of Theoretical Physics on Particles and Fields, Bariloche, Argentina, Jan. 9-20, 1995

Invited talk at XXXth Rencontres de Moriond, "Dark Matter in Cosmology. Clocks and Tests of Fundamental Laws", Villars-sur-Ollon, Suisse, Jan. 21-28, 1995

Physics Department Colloquium at Yale University, May 12, 1995

Talk at the workshop on "Dense Stellar Systems" at the Aspen Center for Physics, Aspen, Colorado, June 16, 1995

Physics Department Colloquium at the University of Wisconsin, Madison, October 20, 1995

Invited talk at the DM96 Workshop on "Sources and Detection of Dark Matter in the Universe", Santa Monica, CA, Feb. 14-16, 1996

Physics Department Colloquium at Johns Hopkins University, February 29, 1996

Particle Theory Seminar at Johns Hopkins University, March 1, 1996

Invited talk at the APS/AAPT Meeting in Indianapolis, May 2-5, 1996

Thorn

Invited talk at the Coral Gables Conferences on Unification in the Large and the Small, Miami, FL, Jan. 26, 1993

Theoretical Physics Seminar presented at SLAC and UC, Santa Barbara, June 1993

Theoretical Physics Seminar presented at Univ. of Miami, Jan. 1994

Theoretical Physics Seminar presented at Rutgers University, May 1994

Theoretical Physics Seminar presented at Aspen Center for Physics, July 1994

Theoretical Physics Seminar presented at Argonne National Lab., August 1994

Theoretical Physics Seminar presented at Aspen Center for Physics, July 1995

Invited talk to the Fifth Workshop on Light-Cone QCD at the Telluride Summer Research Center in Telluride, Colorado, 14-26 August 1995

Woodard

Seminar, University of Crete, June 21, 1993

Seminar, Inst. for Theoretical Physics (Santa Barbara, CA), July 16, 1993

Seminar, Univesity of Michigan, Jan. 6, 1994

Invited talk, Coral Gables Conference on Unified Symmetry in the Small and in the Large, Jan. 28, 1994

Colloquium, Univ. of Texas at Austin, April 20, 1994

Seminar, Univ. of Texas at Austin, April 21, 1994

Invited talk, Workshop on Quantum Infrared Physics (Paris, France), June 10, 1994

Seminar, University of Florida, September 6, 1994.

Seminar, Brown University, October 13, 1994

Invited Talk, Coral Gables Conference, Jan. 27, 1996

B. Travel

Field

URA Fermilab Review, February 5-6, 1993

SSC Laboratory, Dallas, TX, June 6-8, 1993

Participated in the Workshop on Yukuwa Couplings, Institute for Fundamental Theory, University of Florida, February 11-13, 1994

Participated in the 10^{th} Topical Workshop on Proton-Antiproton Collider Physics, Fermilab, May 9-13, 1995

Attended the CMS meeting, Lake Tahoe, California, September 25-29, 1995.

Participated in the mini-workshop on Sypersymmetry at Wakulla Springs, Florida, November 11- 12, 1996

Participated in the workshop on "High Energy Physics at the LHC", Fermilab,March 28-30, 1996.

Visited the University of California at Riverside, April 10, 1996

Kennedy

Univ. of California, SB, Weak Interactions 94 Workshop

Snowmass Workshop on Nuclear and Particle Astrophysics and Cosmology in the Next Millenium, 6/29-7/14/94

International Conference on High Energy Physics 1994, Glasgow, Scotland, 7/20-28/94

University of Pennsylvania, collaboration with S. Bludman, 5/29-6/2/95

Aspen Center for Physics, summer physics program, 6/26-7/14/95

Institute for Nuclear Theory, University of Washington, Physics Beyond the Standard Model at Low and Intermediate Energies, workshop, 7/17-8/4/95

University of Pennsylvania, collaboration with S. Bludman 5/27-6/3/96

Telluride Summer Research Center, summer research program, 7/14-8/2/96

Qiu

PASCOS, Syracuse University May 1994

Cornell University, Ithaca, NY, May 1994

PASCOS, Syracuse University May 1994

Cornell University, Ithaca, NY, May 1994

String 95, USC, Los Angles, CA, March 1995

95 Shantou Conference: Looking to the 21st Century, Shantou, China, August 1995

The 17th international Symposium on Lepton and Photon, Beijing, China, August 1995

CCAST, China Center of Advanced Science and Technology, Beijing, China, August 1995

Ramond

Coral Gables Conference, Jan. 1993
HARC, Houston, TX, April 1993
HEPAP travel, April, 1993
Johns Hopkins University, April 1993
University of Chicago, May 1993
Southern Methodist University, May 1993
SSCC, Dallas, TX, May-June 1993
Sasso, Italy, September 1993
Ecole Normale, Paris, Sept. 1993
Recontres de Moriond, France, March 1994
University of Virginia, April 1994
College of William and Mary, April 1994
TASI, Boulder, CO, June, 1994
Aspen Center for Physics, July 1994
Istanbul, Turkey, June 1994
Paris, France, June 1994
Stockholm, Sweden, September 1994
Laboratoire de l'Accélérateur Linéaire, Orsay, France, September 1994
Fermilab, Batavia, Illinois, October 1994
Florida State University, October 1994
University of Miami, Coral Gables, Florida, February 1995
University of Paris, Paris, France, March 1995
SUNY at Stony Brook, New York, April 1995
Paris, France, SUSY95, May 1995
Aspen Center for Physics, July 1995
UC Berkeley, October 1995
ITP, Santa Barbara, October 1995
Osaka Japan, December 1995
Durham, North Carolina, January 1996
UC Berkeley, March 1996

Sikivie

Coral Gables Conference, Miami, Jan. 24-27, 1993
Univ. of Pennsylvania, April 2, 1993
CERN, June and July, 1993
Rome, Italy, June 23-26, 1993
Budapest, Hungary, July 30-Aug. 1, 1993
Duke University, October 5, 1993
Columbia, S.C., Nov. 4-6, 1993

Coral Gables, FL, Jan. 27-30, 1994

LBL, Feb. 21-24, 1994

ITP, UC, Santa Barbara, CA, May and June, 1994

UCLA, June 10, 1994

Stockholm, Sweden, Sept. 23-25, 1994

Isaac Newton Institute, Cambridge, England, Nov. 14 - Dec. 16, 1994

Orsay, France, Nov. 22, 1994

Brussels, Belgium, Nov. 25, 1994

Oxford, England, Dec. 2, 1994

Imperial College, London, England, Dec. 13, 1994

Bariloche, Argentina, Jan. 13-19, 1995

Villars-sur-Ollon, Switzerland, Jan. 21-28, 1995

New Haven, Conn., May 12, 1995

Axion collaboration meeting at Lawrence Livermore National Laboratory, Livermore, CA, May 25-27, 1995

Aspen Center for Physics, June 5-25, 1995

Madison, Wisconsin, October 20, 1995

Santa Monica, Feb 14-16, 1996

Axion collaboration meeting at Lawrence Berkeley Laboratory, Feb 17-18, 1996

Baltimore, Maryland, Feb 29 - March 1, 1996

Indianapolis, IN, May 2-5, 1996

Thorn

Coral Gables Conference, Miami, Jan. 24-27, 1993

Workshop at the Institute for Theoretical Physics in Santa Barbara, June 1993

University of Miami, January 1994

Rutgers University, May 1994

Aspen, Colorado, July 1994

Fermilab Summer Visitors Program, July-August 1994

Small x Workshop, Fermilab, September 1994

Aspen Center for Physics, Aspen CO, 17 July - 13 August, 1995

Telluride Summer Research Center, Telluride CO, 14-15 August, 1995

Woodard

University of Crete, 5/16/92-7/15/92

Brandeis University, 9/24/92

Brown University, 9/25/92-9/29/92

University of Texas at Austin, Nov. 14-17, 1992

Inst. for Theor. Phys./UCSB, Dec. 2-7, 1992

University of Crete, 5/22/93-7/3/93

Inst. for Theoretical Physics, July 14-21, 1993

University of Michigan, 1/6/94-1/8/94

Coral Gables Conference on Unified Symmetry in the Small and in the Large, 1/28/94-1/30/94

Univ. of Texas at Austin, 4/20/94-4/23/94

University of Crete, 5/10/94-6/4/94

Workshop on Quantum Infrared Physics (Paris, France), 6/6/94-6/10/94

University of Crete, 6/12/94-7/15/94

Brown University, 10/13/94-10/16/94

University of Crete, 5/26/95-7/26/95

Ecole Polytechnique (Paris, France) 5/8/96-6/8/96

University of Crete, June–July, 1996

CERN (Geneva, Switzerland) August, 1996

C. Seminar Speakers (*since 1993*)

Name	*Institution*	*Dates*
Dr. M. Awada	University of Cincinnati	1/4/93
Prof. D. Harari	IAFE, Argentina	1/6/93
Prof. N. Tsamis	Greece	1/8/93
Prof. T. Kephart	Vanderbilt University	1/23/93
Prof. R. Brandenberger	Brown University	1/27/93
Prof. P. Fishbane	University of Virginia	2/9/92
Prof. A. Linde	Stanford University	2/23/93
Dr. C. Preitschopf	Goteborg, Sweden	3/1/93
Dr. I. Kogan	Princeton University	3/1/93
Prof. R. Renken	University of Central Florida	3/5/93
Dr. D. Kennedy	Fermilab	3/10/93
Prof. S. Meshkov	SSCL	3/11/93
Dr. L. Thorlacius	Stanford University	3/14/93
Prof. E. Verlinde	Princeton University	3/16/93
Prof. M. Cvetic	University of Pennsylvania	3/19/93
Dr. G. Starkman	University of Toronto	3/24/93
Prof. B. Greene	Cornell University	3/25/93
Dr. G. Valencia	Fermilab	3/27/93
Dr. M. Savage	University of California	4/4/93
Prof. Z. Berezhiani	University of Ferrara	4/22/93
Prof. L. Baulieu	Paris, France	6/14/93
Dr. S. Martin	Northeastern University	6/21/93
Dr. B. Grinstein	SSCL	8/31/93
Prof. V. Nair	CUNY and Columbia Univ.	9/10/93
Prof. H. Baer	Florida State Univ.	9/21/93
Prof. S. Barr	Bartol Resch. Inst.	9/28/93
Prof. S. Carlip	Univ. of California, Davis	10/8/93
Prof. B. Zwiebach	MIT	10/15/93
Prof. C. Taylor	CWRU	10/22/93
Prof. R. Holman	Carnegie-Mellon Univ.	10/26/93
Dr. S. Mukhanov	Inst. for Nucl. Resch., Moscow	10/29/93
Dr. J. Dixon	Texas A&M Univ.	11/2/93

Prof. L. Mezincescu	University of Miami	11/12/93
Prof. T. Jacobson	University of Maryland	12/3/93
Dr. M. Bailey	Purdue University	12/10/93
Prof. M. Srednicki	Univ. of California, SB	1/14/94
Prof. H. Tye	Cornell University	1/21/94
Dr. M. Li	Brown University	1/28/94
Prof. L. Susskind	Stanford University	2/1/94
Dr. B. Urosevic	Brown University	2/4/94
Prof. K. Johnson	MIT	2/8/94
Prof. H. Nielsen	Niels Bohr Institute	2/15/94
Dr. C. Eifhimiou	Cornell University	2/18/94
Prof. A. Shapere	Cornell University	2/25/94
Prof. A. Kostelecky	University of Indiana	3/4/94
Dr. V. Koulovassilopoulos	Boston University	3/18/94
Prof. G. 't Hooft	University of Utrecht	3/25/94
Dr. I. Tkachev	Fermilab	3/27/94
Dr. W. Stöffl	Lawrence Livermore Nat. Lab.	4/1/94
Prof. A. Zhitnitsky	Southern Methodist Univ.	4/7/94
Dr. G. Gilbert	University of Maryland	4/14/94
Dr. M. Awada	University of Cincinnati	4/11/94
Dr. S. Martin	University of Michigan	8/20/94
Prof. L. Rozansky	University of Miami	8/30/95
Prof. K. Intriligator	Rutgers University	9/9/94
Prof. R. Perry	Ohio State University	9/24/94
Prof. E. Carlson	Harvard University	10/13/94
Dr. G. Kleppe	University of Alabama	10/17/94
Prof. A. Shapere	University of Kentucky	10/27/94
Prof. M. Sher	William and Mary	11/11/94
Prof. M. Wise	CALTECH	11/14/94
Prof. L. Krauss	Case Western University	11/21/94
Dr. M. Awada	University of Cincinnati	11/27/94
Prof. G. Raffelt	Munchen, Germany	1/5/95
Dr. J. Lykken	Fermilab	1/12/95
Dr. D. Castaño	M.I.T.	1/19/95
Prof. J. Patera	University of Montreal	3/2/95
Prof. R. Nepomechie	University of Miami	3/17/95
Prof. H. Baer	Florida State University	3/31/95
Prof. E. D'Hoker	University of California	5/7/95
Prof. A. Roslyi	University of Minnesota	5/15/95
Dr. C. Preitschopf	Berlin, Germany	9/13/95
Prof. O. Alvarez	University of Miami	10/23/95
Dr. C. Kolda	Inst. for Advanced Study	11/9/95
Dr. D. Castaño	Florida State University	11/21/95
Prof. M. Voloshin	University of Minneapolis	12/7/95
Prof. D. Hong	University of Pusan	12/20/95
Prof. J. Ellis	Geneve, Switzerland	1/5/96
Dr. N. Tsamis	Ecole Polytechnique, Paris	1/19/96
Prof. S. Coleman	Harvard University	1/11/96
Prof. R. Jackiw	MIT	1/12/96
Dr. A. Nieto	Ohio State University	1/27/96
Prof. M. Turner	University of Chicago	1/24/96

Dr. K. Dienes	Princeton University	1/25/96
Prof. J. Patera	University of Montreal	2/18/96
Prof. K. Lee	SUNY, N.Y.	2/21/96
Dr. A. White	Argonne Nat. Lab.	3/6/96
Prof. L. Thorlacius	Princeton University	3/14/96
Prof. N. Seiberg	Rutgers University	3/17/96
Dr. M. Awada	University of Cincinnati	3/25/96
Prof. T. Weiler	University of Tennessee	4/13/96
Dr. C. Zachos	Argonne Nat. Lab.	4/18/96
Dr. P. Watts	University of Miami	4/23/96

Of these speakers, M. Wise, L. Susskind, G. 't Hooft, H. Nielsen, and N. Seiberg, visited us for several days through the IFT distinguished visitor program. They each gave a particle theory seminar as part of a three lecture series.

Appendix A. GROUP PUBLICATIONS (*since 1993*)

1. Mass and Mixing Angle Patterns in the Standard Model and Its Minimal Supersymmetric Extension, *H. Arason, E. Castaño, E. Piard* and *P. Ramond*, UFIFT-HEP-92-8, Phys. Rev. **D47**, 322 (1993).
2. Late Time Cosmological Phase Transition and Galactic Halo as 4Bose-Liquid, *S. Sin*, UFIFT-HEP-92-11, Phys. Rev. **D50**, 3655 (1994).
3. The Structure of Perturbative Quantum Gravity on a de Sitter Background, N. C. Tsamis and *R. P. Woodard*, UFIFT-HEP-92-14, Commun. Math. Phys. **162**, 217-248 (1994).
4. Enforcing the Wheeler-DeWitt Constraint the Easy Way, *R. P. Woodard*, UFIFT-HEP-92-16, Class. and Quantum Grav. **10**, 483-496 (1993).
5. Classical Fluids of Negative Heat Capacity, P. T. Landsberg and *R. P. Woodard*, UFIFT-HEP-92-18, J. Stat. Phys. **73**. 361-378 (1993).
6. Staggered Fermions and Chiral Symmetry Breaking in Transverse Lattice Regulated QED, *P. Griffin*, UFIFT-HEP-92-19, Phys. Rev. **D47**, 3530 (1993).
7. Relaxing the Cosmological Constant, *R. Woodard* and N. Tsamis, UFIFT-HEP-92-23, Phys. Lett. **B301**, 483-496 (1993).
8. Strong Infrared Effects in Quantum Gravity, *R. P. Woodard* and N. C. Tsamis, UFIFT-HEP-92-24, Ann. of Phys. **238**, 1-82 (1995).
9. Point-Like Interactions in String Theory Induced by 2-D Toplogical Gravity, UFIFT-HEP-92-26, Phys. Lett. **B306** 261 (1993).
10. Long Range Forces From Two Neutrino Exchange, *P. Sikivie* and S. Hsu, UFIFT-HEP-92-28, Phys. Rev. **D49**, 4951-4953 (1994).
11. Casimir Forces Between Beads on Strings, E. D'Hoker and *P. Sikivie*, UFIFT-HEP-92-33, Phys. Rev. Lett. **71**, 1136 (1993).
12. Axion Dection in the 10^{-4} eV Mass Range, *P. Sikivie, D. B. Tanner* and *Y. Wang*, UFIFT-HEP-93-2, Phys. Rev. **D50**, 4744 (1994).
13. Enchancing the Heavy Higgs Signal with Jet-Jet Profile Cuts, *R. Field* and *P. Griffin*, UFIFT-HEP-93-3, Phys. Rev. **D48**, 3167 (1993).
14. SDC Solenoidal Detector Notes: Enchancing the Heavy Higgs Signal, *R. Field* and *P. Griffin*, UFIFT-HEP-93-4, SDC-93-459 (1993).
15. Baryogenesis in a Supersymmetric Model with Z_3 matter parity, *M. Masip* and *Y. Wang*, UFIFT-HEP-93-5, Phys. Rev. **D48**, 1555-1559 (1993).
16. Stitching the Yukawa Quilt, *P. Ramond*, R. Roberts and G. Ross, UFIFT-HEP-93-6, Nucl. Phys. **B406**, 19 (1993).
17. The de Sitter-Invariant Differential Equations and Their Contraction to Poincare and Galilei, *M. de Montigny*, UFIFT-HEP-93-10, Nuovo Cim. **108B**, 1171-1180 (1993).
18. Discrete Gauge Symmetries in Supersymmetric Grand Unified Models, *M. Masip* and *M. de Montigny*, UFIFT-HEP-93-11, Phys. Rev. **D49**, 3734-3740 (1994).
19. Sparticle Spectrum Constraints, *S. Martin* and *P. Ramond*, UFIFT- HEP-93-16, Phys Rev. **D48**, 5365 (1993).
20. The Physical Basis for Infrared Divergences in Inflationary Quantum Gravity, *N. C. Tsamis* and *R. P. Woodard*, UFIFT-HEP-93-17, Class. Quantum Grav. **11**, 2969-2989, 1993.
21. Renormalization II, *D. Castano, E. Piard,* and *P. Ramond*, UFIFT-HEP-93-18, Phys. Rev. **D49**, 4882 (1994).
22. Comments on the Neutrino Fraction in Our Galactic Halo, *P. Sikivie* and *J. Ellis*, UFIFT-HEP-93-19, Phys. Lett. **B321**, 390-393 (1994).

23. Reduced Hamiltonians in General, *J. A. Rubio* and *R. P. Woodard*, UFIFT-HEP-93-20, Class. Quantum Grav. **11**, 2225-2251 (1994); Reduced Hamiltonians for Gravity, Class. Quantum Grav. **11**, 2253-2281 (1994).

24. The Reggeon Trajectory in Exclusive and Inclusive Large Momentum Transfer Reactions, *C. B. Thorn, S. J. Brodsky* and *W. K. Tang*, UFIFT-HEP-93-21, Phys. Lett. **B318**, 203 (1994).

25. Scaling of $1 < d < 25$ Dimensional No-Critical String Theory, *Z. Qiu*, UFIFT-HEP-93-22, Phys. Lett. **B321**, 49 (1994).

26. Enhancing the Heavy Higgs $\rightarrow WW$ Signal at Hadron-Hadron Colliders, *P. Griffin* and *R. Field*, UFIFT-HEP-93-23, Phys. Rev. **D50**, 302 (1994).

27. Determination of V_{ts} from $D \rightarrow K * e\nu$ and $B \rightarrow K * \gamma$ Data Via Heavy Quark Symmetry and Perturbative QCD, *P. Griffin, M. McGuigan,* and *M. Masip*, UFIFT-HEP-93-25, Phys. Rev. **D50**, 5751 (1994).

28. Interpretation of High Energy String Scattering in Terms of String Configurations, *S. Carbon* and *C. B. Thorn*, UFIFT-HEP-94-2, Phys. Rev. **D49**, R6264 (1994).

29. Stretching Wiggly Strings, *J. W. Kim* and *P. Sikivie*, UFIFT-HEP-94-4, Phys. Rev. **D50**, 7410 (1994).

30. Non-Local Effect in 2-d Conformal Field Theory, *Z. Qiu*, UFIFT-HEP-94-5, unpublished.

31. Finite Black Hole Entropy and String Theory, *M. McGuigan*, UFIFT-HEP-94-7, Phys. Rev. **D50**, 5225 (1994).

32. Calculating the Rest Tension for a Polymer of String Bits, *C. B. Thorn*, UFIFT-HEP-94-8, Phys. Rev. **D51** (1995) 647.

33. Quenched Chiral Perturbation Theory for Heavy-Light Mesons, *M. Booth*, UFIFT-HEP-94-9, Phys. Rev. **D51**, 2338 (1995).

34. Quenched Chiral Corrects to Heavy Meson Masses and Decay Constants at order 1/M, *M. Booth*, UFIFT-HEP-94-10 *submitted to Phys. Rev. D.*

35. Quantum Gravity Slows Down Inflation, *R. Woodard and N. Tsamis*, UFIFT-HEP-94-12, (*unpublished*).

36. The Dilaton Theorem and Closed Strings Backgrounds, *O. Bergman and B. Zwiebach*, UFIFT-HEP-94-14, Nucl. Phys. **B441**, 76-118 (1995).

37. Electroweak Flavor-Conserving Gauge Processes: Virtual Effects, contribution to the APS/DPF Drell Panel Study of American High-energy Physics...-94-16, APS/DPF '94 Albuquerque Meeting; in *R. Cahn, et al, eds., Division of Particle and Fields Working Groups Reports*, World Scientific (1995), *D. Kennedy*, UFIFT-HEP-94-16.

38. Casimir Forces Between Beads on Strings and Membranes, *P. Sikivie, E. D'Hoker and Y. Kanev*, UFIFT-HEP-94-17, Phys. Lett. **B347** (1995) 56-62.

39. Yukawa Textures and Anomalies, *P. Ramond and P. Binetruy*, UFIFT-HEP-94-19, Phys. Lett. **B350**, 49 (1995).

40. Raising the Unification Scale in Supersymmetry, *P. Ramond and S. Martin*, UFIFT-HEP-95-1, Phys. Rev. **D51**, 6515 (1995).

41. Discrete Anomaly and Dynamical Mass in $2+1$ Dimensional $U(1)_V xU(1)_A$ model, *D. K. Hong*, UFIFT-HEP-95-3.

42. The Velocity Peaks in the Cold Dark Matter Spectrum on Earth, *P. Sikivie, I. I. Tkachev and Y. Wang*, UFIFT-HEP-95-6, Phys. Rev. Letters **75**, 2911 (1995).

43. String Bit Models for Superstring, *O. Bergman and C. B. Thorn*, UFIFT-HEP-95-8, Phys. Rev. **D52** (1995) 5980.

44. Solar Core Homology, Solar Neutrinos and Helioseismology, *S. Bludman and D. Kennedy*, UFIFT-HEP-95-13, NSF-ITP-95-72, DOE/ER/40561-215-INT95-17-03 (*to appear in Astrophysical Journal*).

45. Using Neural Networks to Enhance the Higgs Boson Signal at Hadron Colliders, *R. Field, Y. Kanev and M. Tayebnejad*, UFIFT-HEP-95-11, Phys. Rev. **D53** 2296 (1996).
46. Super-Galilei Invariant Field Theories in 2 + 1 Dimensions, *C. B. Thorn and O. Bergman*, UFIFT-HEP-95-12, Phys. Rev. **D52** (1995) 5997.
47. Quantum Gravity Slows Inflation, *R. Woodard and N. Tsamis*, UFIFT-HEP-95-17, February 1996, (*accepted for publication in Nuclear Physics B*).
48. Polarized and Unpolarized Double Prompt Photon Production in Next to Leading Order QCD, *C. Coriano* and *L. E. Gordon*, UFIFT-HEP-95-28, (*to appear in Nucl. Phys. B*).
49. Universality and Clustering in (1+1)-Dimensional Superstring Bit Models, *O. Bergman* and *C. B. Thorn*, UFIFT-HEP-95-31, Phys. Rev. Lett. **76** (1996) 2214.
50. Yukawa Textures with an Anomalous Horizontal Abelian Symmtetry, *P. Binetruy, S. Lavignac* and *P. Ramond*, UFIFT-HEP-96-1, (*to appear in Nuclear Physics B*).
51. Oscillons in a Hot Heat Bath, *M. Gleiser* and *R. Haas*, UFIFT-HEP-96-2, (*to appear in Physical Review D*).
52. RG Analysis of Magnetic Catalysis in Dynamical Symmetry Breaking, *D. K. Hong, S. J. Sin* and *Y. Kim*, UFIFT-HEP-96-3.
53. One Loop Graviton Self-Energy In A Locally De Sitter Background, *N. C. Tsamis* and *R. P. Woodard*, UFIFT-HEP-96-4, February 1996, (*accepted for publication in Physical Review D15*).
54. The Quantum Gravitational Back-Reaction On Inflation, *N. C. Tsamis* and *R. P. Woodard*, UFIFT-HEP-96-5, February 1996, (*accepted for publication in Annals of Physics*).
55. Polarized Double Photon Production in QCD to Order α_s, *C. Coriano* and *L. E. Gordon*, UFIFT-HEP-96-6, (*to appear in Phys. Rev. D*).
56. A Dark Matter Solution from the Supersymmetric Axion Model, *S. Chang* and *H. B. Kim*, UFIFT-HEP-96-8, (*to appear in Phys. Rev. Letters*).
57. New Dark Matter Candidates Motivated from Superstring Derived Unification, *S. Chang, C. Coriano* and *A. Faraggi*, UFIFT-HEP-96-9, (*submitted to Phys. Rev. Letters*).
58. Leptophobic Z' from Superstring Derived Models, *A. Faraggi* and *M. Masip*, UFIFT-HEP-96-11, (*submitted to Phys. Lett. B*).
59. Stable Superstring Relics, *S. Chang, C. Coriano*, and *A. Faraggi*, UFIFT-HEP-96-12, (*submitted to Nucl. Phys. B*).

B. Conference Reports

1. Symmetric Textures, *P. Ramond* Invited talk at Global Foundation Conference, Coral Gales, Florida, Jan. 1993, UFIFT-HEP-93-7, *to appear in the proceedings.*
2. Regge Trajectories in QCD, *C. B. Thorn*, Invited talk at Global Foundation Conference on Symmetries in the large and in the small, Coral Gables, Florida, January 1993, UFIFT-HEP-93-12, *to appear in the proceedings.*
3. Renormalization Group Study of the Minimal Supersymmetric Standard Model: No Scale Models, *P. Ramond*, Invited talk at workshop "Recent Advance in the Superworld", Houston Advanced Research Center, the Woodlands, TX, April 1993, UFIFT-HEP-93-13, *to appear in the proceedings.*
4. Dark Matter Axions '93, *P. Sikivie*, Invited talk at the 17th John Hopkins Workshop on Current Problems in Particle Theory, Budapest, Hungary, July 30-August 1, 1993 and at the Workshop "The Dark Side of the Universe", Rome, Italy, June 23-25, 1993; UFIFT-HEP-93-26, *to appear in the proceedings.*
5. Results from Quantum Cosmological Gravity, *R. P. Woodard*, UFIFT-HEP-94-6, Invited talk at the International Symposium on Unified Symmetry in the Small and in the Large, Coral Gables, Florida, January 1994, *to appear in the proceedings.*

6. Introductory Lectures on Low Energy Supersymmetry, *P. Ramond*, UFIFT-HEP-94-20.
7. Scale Ratios in the Standard Model, *P. Ramond*, UFIFT-HEP-94-21. Invited lecture at the 1994 Moriond Conference, Meribel, March 1994.
8. A Quantum Gravitational Mechanism for Existing Inflation, *R. P. Woodard*, UFIFT-HEP-94-11, invited talk at the Workshop on Quantum Infrared Physics, Paris, France, June 1994, ed. H. M. Fried and B. Müller (World Scientific, Singapore, 1995), pp. 450-459.
9. Superstrings: The View from Below, *P. Ramond*, UFIFT-HEP-94-22. Invited talk at the First Gürsey Symposium, Istanbul, Turkey, June 5-8, 1994.
10. Partons and Black Holes, *L. Susskind and P. Griffin*, UFIFT-HEP-94-13. Lectures given by L. S. at the "Theory of Hadrons and Light-Front QCD" workshop in Zakopone, Poland, August 1994.
11. Light Front Hamiltonian for Transverse Lattice QCD, *P. Griffin*, UFIFT-HEP-94-15. Based on a lecture given at the "Theory of Hadrons and Light-Front QCD" workshop in Zakopane, Poland, August 1994.
12. Probing for the Roots of the Standard Model, *P. Ramond*, UFIFT-HEP-95-2. Lecture delivered at the Oskar Klein Contenary Symposium, September 17-28, 1994.
13. Sources and Distributions of Dark Matter, *P. Sikivie*, UFIFT-HEP-95-5. To appear in the Proceedings of the Conference "Trends in Astroparticle Physics", Stockholm, Sweden, Sept. 22-25, 1994, Nucl. Phys. B. Proc. Supplements **43**, 90 (1995).
14. Consequences of an Abelian Family Symmetry, *P. Ramond*, UFIFT-HEP-95-7. Invited speaker at the CAM-95 Conference, Quebec, Canada, June 14-18, 1995.
15. Light Cone Formulation of String Theory, *C. B. Thorn*, invited talk at the 5th Workshop on Light Cone QCD, Telluride, CO, August 14, 1995.
16. The Pooltable Analogy to Axion Physics, *P. Sikivie*, UFIFT-HEP-95-9. To be published in the Proceedings of the XXXth Rencontres de Moriond "Dark Matter in Cosmology" and "Clocks and Tests of Fundamental Laws", Villars-sur-Ollon, Switzerland, Sept. 21-28, 1995.
17. Mass Hierarchies from Anomalies: A Peek Behind the Planck Curtain, *P. Ramond*, UFIFT-HEP-96-10, (*to appear in the proceedings of K. Kikkowa's* 60th *birthday symposium*).

Research in Experimental High Energy Physics

Task B

1 Introduction

UF Task B has been funded continuously by the DoE since 1986. Formerly it included work on the D0 experiment at Fermilab which is no longer a part of the UF program. With the addition of Prof. Guenakh Mitselmakher, Dr. Jacobo Konigsberg and one more Assistant Professor to the faculty, we now have a new Task to incorporate their work at Fermilab and Cern. We intend Task B to continue to cover the major research of Paul Avery and John Yelton, which is presently directed towards the CLEO detector with some effort going to B physics at Fermilab.

1.1 New Physics Building

The New Physics Building is presently being built. The official ground-breaking occured in December 1995. The building plan includes a high bay area for High Energy Physics research, and a considerable number of laboratory module space for High Energy Physics. There are 7 faculty offices reserved for HEE, as well as post-doc, student, and staff space. There is also a purpose built computer room for the Department. The construction time is approximately 18 months, and the target for moving the offices is Fall 1997, though maybe early 1998 is more realistic.

2 The CLEO Experiment and CLEO III Upgrade

The CLEO collaboration now consists of around 200 physicists from 24 institutions (Purdue, Rochester, SMU, Vanderbilt, VPI, CalTech, UCSB, Colorado, Cornell, Florida, Harvard, Hawaii, Illinois, Carleton, McGill, Ithaca College, Kansas, Minnesota, SUNY Albany, Ohio State, SLAC and Oklahoma. In the last few years CLEO has grown from a mostly NSF funded collaboration based in the North-East of the U.S. to an NSF and DoE funded collaboration spread over much of North America. Florida has been a member since September, 1985.

The present detector configuration is known as CLEO 2.5. The installation of a silicone vertex detector has now been completed. This will allow the tagging of charmed particles. The detector is now at Cornell and is being placed inside the detector. A further, even more major upgrade (including a new drift chamber and particle identification system) will be known as CLEO III. The human resources have been strained to the limit as there is much work in keeping the software constants optimized for CLEO II data, extracting the physics form the large data sample already available, installing the hardware and software for the silicone vertex detector, and designing and developing the CLEO III detector. Of course, we are still regularly taking data-taking shifts.

In keeping with its previous tradition, Florida will contribute software expertise to CLEO III, particularly in the areas of (1) event display and visualization, (2) secondary vertexing and (3) kinematic fitting. Visualization has become a growth market in the computer industry in recent years, but HEP experimental groups have only recently been exploring its full potential. The current CLEO event display program is fairly weak and doesn't provide the kind of information needed to debug analyses and understand what is happening within an event. We believe that a strong commitemnt by a group using the latest tools in the computing industry is needed to make event and data visualization a useful tool for data analysis and software debugging and not just a way to generate pretty pictures.

Our group has already been involved with secondary vertexing (Yelton) and kinematic fitting (Avery). Now that the silicon detector has been installed and the Kalman filter is used in track fits (generating believable error matrices), vertexing and kinematic fitting will play a much more important role in ordinary data analysis. We are committing ourselves to supply CLEO with much improved versions of the current software packages.

3 Physics Analysis

The collaboration as a whole continues to have an outstanding output of paper.

3.1 CLEO PUBLICATIONS

In the 36 months since our last renewel, the following papers have been published.

1. Lepton Asymmetry Measurements in $\bar{B} \to D^* l^- \bar{\nu}_l$ and Implications for $V - A$ and the Form Factors
   S. Sanghera *et al.*, Physical Review D **47**, 791 (1993)

2. Tau Decays with One Charged Particle plus Multiple π^0's
   M. Procario *et al.*, Physical Review Letters **70**, 1207 (1993)

3. Search for Exclusive $b \to u$ Semileptonic Decays of B Mesons
   A. Bean *et al.*, Physical Review Letters **70**, 2681 (1993)

4. Measurement of the τ-Lepton Mass
   R. Balest *et al.*, Physical Review D **47**, R3671 (1993)

5. Limit on the Tau Neutrino Mass
   D. Cinabro *et al.*, Physical Review Letters **70**, 3700 (1993)

6. Evidence for Penguin-Diagram Decays: First Observation of $B \to K^*(892)\gamma$
   R. Ammar *et al.*, Physical Review Letters **71**, 674 (1993)

7. Measurement of the Ratio $\mathcal{B}(D^+ \to \pi^0 \ell^+ \nu)/\mathcal{B}(D^+ \to \bar{K}^0 \ell^+ \nu)$
   M.S. Alam *et al.*, Physical Review Letters **71**, 1311 (1993)

8. Two Measurements of $B^0 \bar{B}^0$ Mixing
   J. Bartelt *et al.*, Physical Review Letters **71**, 1680 (1993)

9. Measurement of the Decay $\tau^- \to \pi^- \pi^+ \pi^- 2\pi^0 \nu_\tau$
   D. Bortoletto *et al.*, Physical Review Letters **71**, 1791 (1993)

10. Measurement of the $D \to \pi\pi$ Branching Fractions
    M. Selen *et al.*, Physical Review Letters **71**, 1973 (1993)

11. Study of the Decays $\Lambda_c^+ \to \Xi^0 K^+, \Lambda_c^+ \to \Sigma^+ K^+ K^-$ and $\Lambda_c^+ \to \Xi^- K^+ \pi^+$
P. Avery *et al.*, Physical Review Letters **71**, 2391 (1993)

12. Study of D^0 decays into $\bar{K}^0$ and $\bar{K}^{*0}$
M. Procario *et al.*, Physical Review D **48**, 4007 (1993)

13. Measurement of the Absolute Branching Fraction for $D^0 \to K^-\pi^+$
D.S. Akerib *et al.*, Physical Review Letters **71**, 3070 (1993)

14. Measurement of Exclusive Λ_c Decays with a Σ^+ in the Final State
Y. Kubota *et al.*, Physical Review Letters **71**, 3255 (1993)

15. Observation of the Charmed Baryon Σ_c^+ and Measurement of the Isospin Mass Splittings of the Σ_c
G. Crawford *et al.*, Physical Review Letters **71**, 3259 (1993)

16. Measurements of Exclusive Semileptonic Decays of D Mesons
A. Bean *et al.*, Physics Letters B **317**, 647 (1993)

17. Observation of B^0 Decay to Two Charmless Mesons
M. Battle *et al.*, Physical Review Letters **71**, 3922 (1993)

18. Measurement of Charmless Semileptonic Decays of B Mesons
J. Bartelt *et al.*, Physical Review Letters **71**, 4111 (1993)

19. Search for Exclusive $b \to u$ Transitions in Hadronic Decays of B Mesons Involving D_s^+ and D_s^{*+} Mesons
J.P. Alexander *et al.*, Physics Letters B **319**, 365 (1993)

20. Analysis of Hadronic Transitions in $\Upsilon(3S)$ Decays
F. Butler *et al.*, Physical Review D **49**, 40 (1994)

21. Study of the Decay $\Lambda_c^+ \to \Lambda \ell^+ \nu_\ell$
T. Bergfeld *et al.*, Physics Letters B **323**, 219 (1994)

22. Observation of $D^0 \to K^+\pi^-$
D. Cinabro *et al.*, Physical Review Letters **72**, 1406 (1994)

23. Observation of a New Charmed Strange Meson
Y. Kubota *et al.*, Physical Review Letters **72**, 1972 (1994)

24. Measurement of the Branching Fraction for $D^+ \to K^-\pi^+\pi^+$
R. Balest *et al.*, Physical Review Letters **72**, 2328 (1994)

25. A Measurement of $\mathcal{B}(D_s^+ \to \phi \ell^+ \nu_\ell)/\mathcal{B}(D_s^+ \to \phi\pi^+)$
F. Butler *et al.*, Physics Letters B **324**, 255 (1994)

26. Observation of Λ_c^+ Decays to $\Lambda\pi^+\pi^0$, $\Sigma^0\pi^+$, $\Sigma^0\pi^+\pi^0$, and $\Sigma^0\pi^-\pi^+\pi^+$
P. Avery *et al.*, Physics Letters B **325**, 257 (1994)

27. First Measurement of $\Gamma(D_s^+ \to \mu^+\nu)/\Gamma(D_s^+ \to \phi\pi^+)$
D. Acosta *et al.*, Physical Review D **49**, 5690 (1994)

28. Search for B^0 Decays to Two Charged Leptons
R. Ammar *et al.*, Physical Review D **49**, 5701 (1994)

29. A Measurement of the Branching Fraction $\mathcal{B}(\tau^- \to h^-\pi^0\nu_\tau)$
M. Artuso *et al.*, Physical Review Letters **72**, 3762 (1994)

30. Production and Decay of $D_1(2420)^0$ and $D_2^*(2460)^0$
P. Avery *et al.*, Physics Letters B **331**, 236 (1994)
Erratum Physics Letters B **342**, 453 (1995)

31. Exclusive Hadronic B Decays to Charm and Charmonium Final States
M.S. Alam *et al.*, Physical Review D **50**, 43 (1994)

32. Precision Measurement of the $D_s^{*+} - D_s^+$ Mass Difference
D.N. Brown *et al.*, Physical Review D **50**, 1884 (1994)

33. Two-Photon Production of Charged Pion and Kaon Pairs
J. Dominick *et al.*, Physical Review D **50**, 3027 (1994)

34. Measurement of Two-Photon Production of the χ_{c2}
J. Dominick *et al.*, Physical Review D **50**, 4265 (1994)

35. Measurement of the Cross-Section for $\gamma\gamma \to p\bar{p}$
M. Artuso *et al.*, Physical Review D **50**, 5484 (1994)

36. Luminosity Measurement with the CLEO II Detector
G. Crawford *et al.*, Nuclear Instruments and Methods A **345**, 429 (1994)

37. Study of the Five-Charged-Pion Decay of the τ Lepton
D. Gibaut *et al.*, Physical Review Letters **73**, 934 (1994)

38. Measurement of Cabibbo-suppressed Decays of the τ Lepton
M. Battle *et al.*, Physical Review Letters **73**, 1079 (1994)

39. Observation of Inclusive B Decays to the Charmed Baryons Σ_c^{++} and Σ_c^0
M. Procario *et al.*, Physical Review Letters **73**, 1472 (1994)

40. Search for Neutrinoless Decays of the Tau Lepton
J. Bartelt *et al.*, Physical Review Letters **73**, 1890 (1994)

41. Semileptonic Branching Fractions of Charged and Neutral B Mesons
M. Athanas *et al.*, Physical Review Letters **73**, 3503 (1994)

42. Measurement of the Ratios of Form Factors in the Decay $D_s^+ \to \phi e^+\nu_e$
P. Avery *et al.*, Physics Letters B **337**, 405 (1994)

43. Measurement of the Branching Fraction for $\Upsilon(1S) \rightarrow \tau^+\tau^-$
D. Cinabro *et al.*, Physics Letters B **340**, 129 (1994)

44. Observation of $D_1(2420)^+$ and $D_2^*(2460)^+$
T. Bergfeld *et al.*, Physics Letters B **340**, 194 (1994)

45. Observation of $B \rightarrow \psi\pi$ Decays
J.P. Alexander *et al.*, Physics Letters B **341**, 435 (1995)
Erratum Physics Letters B **347**, 469 (1995)

46. Measurement of the $\bar{B} \rightarrow D^*\ell\bar{\nu}$ Branching Fractions and $|V_{cb}|$
B. Barish *et al.*, Physical Review D **51**, 1014 (1995)

47. $\Upsilon(1S) \rightarrow \gamma$ + Non-interacting Particles
R. Balest *et al.*, Physical Review D **51**, 2035 (1995)

48. First Measurement of the Rate for the Inclusive Radiative Penguin Decay $b \rightarrow s\gamma$
M.S. Alam *et al.*, Physical Review Letters **74**, 2885 (1995)

49. First Observation of $\Xi_c^+ \rightarrow \Xi^0 e^+\nu_e$ and an Estimate of the Ξ_c^+/Ξ_c^0 Lifetime Ratio
J.P. Alexander *et al.*, Physical Review Letters **74**, 3113 (1995)
Erratum Physical Review Letters **75**, 4155 (1995)

50. Observation of Excited Charmed Baryon States Decaying to $\Lambda_c^+\pi^+\pi^-$
K.W. Edwards *et al.*, Physical Review Letters **74**, 3331 (1995)

51. New Decay Modes of the Λ_c^+ Charmed Baryon
R. Ammar *et al.*, Physical Review Letters **74**, 3534 (1995)

52. Form Factor Ratio Measurement in $\Lambda_c^+ \rightarrow \Lambda e^+\nu_e$
G. Crawford *et al.*, Physical Review Letters **75**, 624 (1995)

53. A Search for $B \rightarrow \ell\bar{\nu}_\ell$
M. Artuso *et al.*, Physical Review Letters **75**, 785 (1995)

54. Observation of the Isospin-Violating Decay $D_s^{*+} \rightarrow D_s^+\pi^0$
J. Gronberg *et al.*, Physical Review Letters **75**, 3232 (1995)

55. Measurement of the $D_S^+ \rightarrow \eta\ell^+\nu$ and $D_S^+ \rightarrow \eta'\ell^+\nu$ Branching Ratios
G. Brandenburg *et al.*, Physical Review Letters **75**, 3804 (1995)

56. Measurements of the Decays $\tau^- \rightarrow h^-h^+h^-\nu_\tau$ and $\tau^- \rightarrow h^-h^+h^-\pi^0\nu_\tau$
R. Balest *et al.*, Physical Review Letters **75**, 3809 (1995)

57. Observation of a Narrow State Decaying into $\Xi_c^+\pi^-$
P. Avery *et al.*, Physical Review Letters **75**, 4364 (1995)

58. Measurement of the Decay Asymmetry Parameters in $\Lambda_c^+ \rightarrow \Lambda\pi^+$ and $\Lambda_c^+ \rightarrow \Sigma^+\pi^0$
M. Bishai *et al.*, Physics Letters B **350**, 256 (1995)

59. Measurement of α_s from τ Decays
T. Coan *et al.*, Physics Letters B **356**, 580 (1995)

60. Measurement of the Ratio of Branching Fractions $\mathcal{B}(D^0 \to \pi^- e^+ \nu_e)/\mathcal{B}(D^0 \to K^- e^+ \nu_e)$
F. Butler *et al.*, Physical Review D **52**, 2656 (1995)

61. Inclusive Decays of B Mesons to Charmonium
R. Balest *et al.*, Physical Review D **52**, 2661 (1995)

62. Search for CP Violation in D^0 Decay
J. Bartelt *et al.*, Physical Review D **52**, 4860 (1995)

63. Measurement of the B Semileptonic Branching Fraction with Lepton Tags
B. Barish *et al.*, Physical Review Letters **76**, 1570 (1996)

64. Tau Decays into Three Charged Leptons and Two Neutrinos
M.S. Alam *et al.*, Physical Review Letters **76**, 2637 (1996)

65. Limits on Flavor Changing Neutral Currents in D^0 Meson Decays
A. Freyberger *et al.*, Physical Review Letters **76**, 3065 (1996)

66. Measurement of the Form Factors for $\bar{B}^0 \to D^{*+} \ell^- \bar{\nu}$
J.E. Duboscq *et al.*, Physical Review Letters **76**, 3898 (1996)

67. First Observation of the Decay $\tau^- \to K^- \eta \nu_\tau$
J. Bartelt *et al.*, Physical Review Letters **76**, 4119 (1996)

68. Observation of the Ξ_c^+ Charmed Baryon Decays to $\Sigma^+ K^- \pi^+$, $\Sigma^+ \bar{K}^{*0}$, and $\Lambda K^- \pi^+ \pi^+$
T. Bergfeld *et al.*, Physics Letters B **365**, 431 (1996)

69. Study of $B \to \psi \rho$
M. Bishai *et al.*, Physics Letters B **369**, 186 (1996)

70. Observation of New Decay Modes of the Charmed-Strange Baryon Ξ_c^+
K.W. Edwards *et al.*, Physics Letters B **373**, 261 (1996)

71. A Measurement of $\mathcal{B}(D^0 \to K^- \pi^+ \pi^0)/\mathcal{B}(D^0 \to K^- \pi^+)$
B. Barish *et al.*, Physics Letters B **373**, 334 (1996)

72. Observation of the Cabibbo Suppressed Charmed Baryon Decay $\Lambda_c^+ \to p\phi$
J.P. Alexander *et al.*, Physical Review D **53**, R1013 (1996)

73. Search for Exclusive Charmless Hadronic B Decays
D.M. Asner *et al.*, Physical Review D **53**, 1039 (1996)

74. Measurements of $B \to D_s^+ X$ Decays
D. Gibaut *et al.*, Physical Review D **53**, 4734 (1996)

3.2 Preprints

In addition the following have been released as preprints and are likely to be published soon.

1. A study of Jet Production Rates in the Four Flavor Continuum and a Test of QCD
   L. Gibbons *et al.*, CLNS 95/1323, CLEO 95–2
   (submitted to Physical Review D)

2. The Inclusive Decay $B \to \eta X$
   Y. Kubota *et al.*, CLNS 95/1327, CLEO 95–4
   (submitted to Physical Review D)

3. Measurement of the Inclusive Semi-electronic D^0 Branching Fraction
   Y. Kubota *et al.*, CLNS 95/1363, CLEO 95–18
   (submitted to Physical Review D)

4. Measurement of the Branching Fraction for $D_s^- \to \phi\pi^-$
   M. Artuso *et al.*, CLNS 95/1387, CLEO 95–23
   (submitted to Physics Letters B)

5. Analysis of $D^0 \to K\bar{K}X$ Decays
   D.M. Asner *et al.*, CLNS 96/1390, CLEO 96–2
   (submitted to Physical Review D)

6. Decays of Tau Leptons to Final States Containing K_S^0 Mesons
   T.E. Coan *et al.*, CLNS 96/1391, CLEO 96–3
   (submitted to Physical Review D)

7. Observation of an Excited Charmed Baryon Decaying into $\Xi_c^0\pi^+$
   L. Gibbons *et al.*, CLNS 96/1394, CLEO 96–4
   (submitted to Physical Review Letters)

8. Study of Flavor-Tagged Baryon Production in B Decay
   R. Ammar *et al.*, CLNS 96/1401, CLEO 96–7
   (submitted to Physical Review Letters)

3.3 Florida Publications

It is clear that as members of the CLEO collaboration the Florida personel have their names on a large number of publications, regardless of whether they, themselves, have performed the analysis. However Florida has made a contribution to the physics analysis of CLEO data out of all porportion to its size. The following papers published in the last few years were based on work done by the UF group. In most cases the analysis work for these papers was performed entirely by members of the the UF group. In some cases a member of the group contributed a part of the paper.

1. Limits on B rare Decays
   P. Avery *et al.*, Physics Letters B **183**, 429 (1987)

2. Production of η and ω mesons in τ decays
P. Baringer *et al.*, Physical Review Letters **59**, 1993 (1987)

3. Search for the Charmless Decays, $B \rightarrow p\overline{p}\pi$ and $p\overline{p}\pi\pi$
C. Bebek *et al.*, Physical Review Letters **62**, 863 (1989)

4. Σ_c^{++} and Σ_c^0 Production in e^+e^- Annihilation
T. Bowcock *et al.*, Physical Review Letters **62**, 1240 (1989)

5. A Search for Exclusive Penguin Decays in B Mesons.
P. Avery *et al.*, Physics Letters B **233**, 470 (1989)

6. Observation of the Charmed, Strange Baryon Ξ_c^0
P. Avery *et al.*, Physical Review Letters **65**, 1184 (1989)

7. Measurement of the Isospin Splitting $\Xi_c^+ - \Xi_c^0$
M.S.Alam *et al.*, Physics Letters B **226**, 401 (1989)

8. Study of D Decays into $K\overline{K}$ and $\pi\pi$
J. Alexander *et al.*, Physical Review Letters **65**, 1184 (1990)

9. Study of K^* Production in τ Decays
M. Goldberg *et al.*, Physics Letters B **223**, 1 (1990)

10. The Decay $D^0 \rightarrow K^0\overline{K^0}$
J. Alexander *et al.*, Physical Review Letters **65**, 1184 (1990)

11. Radiative $\Upsilon(1S)$ Decays
R. Fulton *et al.*, Physical Review D **41**, 1401 (1990)

12. The Study of D^0 Decays into Final States including a π^0 or an η^0
K. Kinoshita *et al.*, Physical Review D **43**, 3383 (1991)

13. Unusual Decays of D Mesons
R. Ammar *et al.*, Physical Review D **44**, 3383 (1991)

14. Λ_c^+ Production in e^+e^- Annihilation at E=10 GeV
P. Avery *et al.*, Physical Review D **43**, 3591 (1991)

15. Observation of the Decay $\Xi_c^0 \rightarrow \Omega^- K^+$
S.Henderson *et al.*, Physics Letters B **283**, 161 (1992)

16. Observation of Excited Charmed Baryon States Decaying to $\Lambda_c^+\pi^+\pi^-$
K.W. Edwards *et al.*, Physical Review Letters **74**, 3331 (1995)

17. Study of the Decays $\Lambda_c^+ \rightarrow \Xi^0 K^+, \Lambda_c^+ \rightarrow \Sigma^+ K^+ K^-$ and $\Lambda_c^+ \rightarrow \Xi^- K^+ \pi^+$
P. Avery *et al.*, Physical Review Letters **71**, 2391 (1993)

18. Measurement of the Absolute Branching Fraction for $D^0 \rightarrow K^-\pi^+$
D.S. Akerib *et al.*, Physical Review Letters **71**, 3070 (1993)

19. Measurements of Exclusive Semileptonic Decays of D Mesons
A. Bean *et al.*, Physics Letters B **317**, 647 (1993)

20. Search for Exclusive $b \to u$ Transitions in Hadronic Decays of B Mesons Involving D_s^+ and D_s^{*+} Mesons
J.P. Alexander *et al.*, Physics Letters B **319**, 365 (1993)

21. Measurement of the Branching Fraction for $D^+ \to K^-\pi^+\pi^+$
R. Balest *et al.*, Physical Review Letters **72**, 2328 (1994)

22. Observation of a Narrow State Decaying into $\Xi_c^+\pi^-$
P. Avery *et al.*, Physical Review Letters **75**, 4364 (1995)

23. Measurement of the Decay Asymmetry Parameters in $\Lambda_c^+ \to \Lambda\pi^+$ and $\Lambda_c^+ \to \Sigma^+\pi^0$
M. Bishai *et al.*, Physics Letters B **350**, 256 (1995)

24. Measurement of the Inclusive Semi-electronic D^0 Branching Fraction
Y. Kubota *et al.*, CLNS 95/1363, CLEO 95–18
(submitted to Physical Review D) (accepted for publication)

25. Observation of an Excited Charmed Baryon Decaying into $\Xi_c^0\pi^+$
L. Gibbons *et al.*, CLNS 96/1394, CLEO 96–4
(submitted to Physical Review Letters) (accepted for publication)

26. Exclusive Hadronic B Decays to Charm and Charmonium Final States
M.S. Alam *et al.*, Physical Review D **50**, 43 (1994)

27. Measurement of the $\bar{B} \to D^*\ell\bar{\nu}$ Branching Fractions and $|V_{cb}|$
B. Barish *et al.*, Physical Review D **51**, 1014 (1995)

28. A Measurement of $\mathcal{B}(D^0 \to K^-\pi^+\pi^0)/\mathcal{B}(D^0 \to K^-\pi^+)$
B. Barish *et al.*, Physics Letters B **373**, 334 (1996)

29. Search for Exclusive Charmless Hadronic B Decays
D.M. Asner *et al.*, Physical Review D **53**, 1039 (1996)

4 Florida Personel

4.1 Faculty

4.1.1 Paul Avery

Paul Avery (Professor) was promoted to Full Professor in Summer, 1995. He has been working on with Jorge Rodriguez on two-body color suppressed B decays of the type $B^0 \to D^{(*)}X^0$, with X^0 being a π^0, η, η', ω or ρ^0. The results of this analysis, and accurate measurements of the normalization modes ($B^- \to D^{(*)0}X^-$ and $\overline{B}^0 \to D^{(*)+}X^-$, with $X^- = \pi^-$ or ρ^-) were published in the "big B" paper in 1994. We recently extended the analysis to cover twice the previous data sample; the main results have just appreared in Jorge's thesis in August, 1995. The main improvement, besides the increased accuracy and sensitivity due to larger statistics, has been the improved understanding of the background shape which has allowed us to reduce the systematic errors in the normalization modes. We also analyzed an even larger data sample with the aim of seeing the color suppressed modes described above. A small signal has appeared in $\overline{B}^0 \rightarrow D^0\pi^0$, in the $D^0 \rightarrow K^-\pi^+$ submode, but doesn't appear consistently in the other channels.

Avery and Rodriguez are repeating this analysis this summer with a much larger data sample. Unfortunately, the improved tracking from the new recompress will not be available for this analysis. Avery will be organizing the effort to publish updated results on all the exclusive B results using the much larger data sample. This effort will use the improved tracking from the new recompress which will be available in early 1997.

Avery has a number of software responsibilities in CLEO:

1. Developing (with Chris Jones) a completely new event display for CLEO II and CLEO III. The design is very modular and will allow other types of detectors and event types to be added later, e.g., ISAJET, PYTHIA and detectors based on MCFAST (described below).

2. Developing (with Chris Jones) a new analysis framework for CLEO III. This is beingh done in association with Minnesota.

3. Developing, as one of the principals in Nile, distributed computing software for HEP. Florida wrote most of the FastTrack system (Michael Athanas) and has primary responsibility for the Data Model (Karp Jeong).

4. Writing (with Martin Lohner) new kinematic fitting software for CLEO II.5. His software is currently being used in CLEO II, but updates are necessary to account for scattering in silicon and to convert the entire system to C++ in anticipation of CLEO III.

Avery is also involved as a PI in the BTEV collaboration, a group of physicists from Florida, Fermilab, Syracuse, Penn and Carnegie Mellon who are interested in pursuing a hadronic B program at Fermilab, preferably through the development of a new interaction region. Avery's principal contribution to BTEV is the MCFAST Monte Carlo program, developed with the Fermilab B Simulation Group which he headed in 1993–94. MCFAST is a fast simulation program offering advanced features such as particle tracing through complicated geometries (including multiple magnets), Kalman filter tracking, multiple collisions and accurate hadronic shower modeling. The Fermilab simulation group is expecting to make MCFAST available for the 1996 Snowmass workshop. A large number of simulations, especially backgrounds, will be generated at Fermilab and Florida to make comparisons between detectors with respect to B physics, principally CP violation capabilities.

Now that the C0 intersection region might be developed for trigger studies and proof-of-concept runs, there is a renewed effort to provide computer simulations for physics and detector studies. An EOI was submitted May 31, 1996, and is being followed up by physics and detector studies. The simulation group (located in the Fermilab Computing Division) is now officially sanctioned by Fermilab in the sense that it will provide the tools (principally

MCFAST and supporting software) used by the collider groups to develop detectors and study physics in the next era of running at Fermilab, including top quark physics. A new research scientist position has been filled there to support this effort. Florida has recently hired a new postdoc (Martin Lohner) who will spend up to 1/3 of his time developing MCFAST and running BTEV and CMS simulations.

Avery has been investing more of his time in CMS, and is now a member of the US Computing group. He will concentrate on tracking in the forward region and These new activities will certainly put additional strains on our computing resources, particularly because of the large number of CMSIM (CMS GEANT package) simulations which will have to be run. As MCFAST becomes adapted for CMS, a large number of simulations will need to be run as well, particularly to study track reconstruction and physics results.

4.1.2 John Yelton

John Yelton (Associate Professor) has continued to play a leading role in charmed baryons analysis in CLEO. In the last few years, CLEO has produced a large fraction of the definitive charmed baryon results; finding many new states and measuring many branching fractions and other decay parameters. Since he joined CLEO in early 1988, John Yelton has led the analysis of the discovery of a total of 4 new charmed baryon states (plus 2 more that have not yet been officially released by the CLEO collaboration). In 1988 he led the analysis for the discovery of the Ξ_c^0. This observation has since been confirmed by several other collaborations. He was also responsible for the first definitive observation of W-exchange decays of charmed baryons ($\Xi_c^0 \to \Omega K^+$), and also new decay modes of the D^+ and D^0. He also made important contributions to the papers on the confirmation of the Σ_c^{++} and Σ_c^0, and on the paper on new decay modes of the Λ_c^+.

More recently, he led the analysis on the discovery of the $\Lambda_c^{*+}(2593)$. ARGUS previously had shown that there was a peak in $\Lambda_c^+\pi^+\pi^- - \Lambda_c^+$ mass difference plots, although they could not determine exactly what state it was. The CLEO analysis showed not only this peak, but a second just above threshold. Whereas the upper state does not appear to go via an intermediate Σ_c, the lower state does. After much study, the two states are now rather reliably identified as a pair of $L = 1$ Λ_c^+ states with total spin 1/2 and 3/2. A preliminary analysis of this particle was first shown in 1993; after much further work (including limits for single π and γ transitions from this state) it was published by PRL in 1995. The main features of this analysis have been confirmed by the E-687 collaboration. They agree with the CLEO finding on the resonant substructure of the upper state, thus also disagreeing with Argus.

Following this, he worked on searches for $J = \frac{3}{2}$ charmed baryons, i.e. "spin excitations" of the ground states. There should be 6 such particles, 2 Ξ_c^*'s, 3 Σ_c^*'s and 1 Ω_c^*. So far in the literature there is only one extremely weak signal in a Σ_c^{*++} that is not believed by most impartial judges. This search has born fruit firstly in the discovery of the neutral excited charmed-strange baryon, the Ξ_c^{*0}, found decaying $\to \Xi_c^+\pi^-$ with a mass difference of around 178 MeV. The analysis first required optimized hyperon finding code (supplied by Craig Prescott, see below), and then several Ξ_c^+ channels were optimized for high efficiency, and low background. John Yelton led this analysis effort, with Song Yang performing the checks necessary before claiming a new particle, and generating all necessary the Monte-Carlo. This analysis has now been published.

Clearly, the Ξ_c^{*0} should have an isospin partner that should not be any more difficult to see. First analysis of the decay $\Xi_c^{*+} \to \Xi_c^0 \pi^+$ showed a small signal, but not sufficient to claim a signal for a new particle. However further optimizations of code and added data has led to a signal has now improved. This second discovery was first presented publicly in December 1995, and the subsequent paper has now been accepted for publication in PRL. The same team as above was responsible for this analysis.

The last analysis he has been personally responsible for is searching for the Σ_c^* states. At first sight it is surprising that these have not been seen when the charmed, strange versions of these baryons have been seen. However, unlike the Ξ_c^* states, phase space considerations lead these states to be wide. Furthermore, there is a background which is not easily parameterized by a polynomial, ironically because of the pair of Λ_c^*'s described above. There is now good evidence for both the Σ_c^{*++} and Σ_c^{*0}. This analysis has been presented to our collaborators, but has not yet been cleared for public announcement.

John Yelton has also been responsible for CLEO service software. One notable contribution is the technique for isolating secondary vertices that include π^0's. This has been used for several analyses that include Ξ^+ and Ξ^0 decays, as well as those performed by the Florida group and listed above.

It is clear that the charmed baryon sector is still a fruitful field of research for several years to come. Although there are other experiments competing with CLEO, none has all the capabilities of CLEO to find and study these states. In the next few years CLEO expects to publish definitive signals in Σ_c^{++}, Σ_c^{*0}, $\Xi_c'^{+}$ and $\Xi_c'^{0}$. John Yelton is either in charge of these searches or acts as the internal committee chair to review the analysis of these searches. There are also possibilities to find Σ_c^{*+} and Ω_c^* states, but these are less certain.

John Yelton is also planning to supervise Craig Prescott and Jiu Zheng on theses that will include a systematic study of one and two pion transitions into Λ_c^+ and Ξ_c states. This will include measurements of their alignment, the width of the resonant states, their production cross-sections and their fragmentation properties.

4.2 Post-Doctoral Research Associates - Current

4.2.1 Christopher Jones

Chris Jones is a recent graduate from Cornell University who has joined us as a post-doc starting April 1996. His thesis entitled "Measurement of Exclusive Electromagnetic Penguin Decays of the B Meson" appeared in April 1996. He is presently extending this work to write a definitive paper on this subject with the full CLEO 2.5 data sample. He and Avery are working together in developing a new event display for CLEO II.5 and CLEO III.

4.2.2 Martin Lohner

Martin has just received his PhD from University of Colorado, with a thesis on τ decays in CLEO. He will join our group as post-doc in residence at Cornell starting July 1st. He intends to move away from τ physics towards B physics. He will be our resident expert in shift running. He and Avery plan to work on CLEO II kinematic fitting and the MCFAST effort at Fermilab.

4.3 Post-Doctoral Research Associates - Previous

We have a good record of placing our previous employees in the field. Ransom Stephens is now an Assistant Professor at UT Arlington where he works with the $D0$ Collaboration, Arne Freyberger is a staff member at CEBAF, Karen Lingel is employed by SLAC, Lynn Garren is now working in the Fermilab computer group and a member of the E-687 collaboration, and David Besson is a very active Assistant Professor at the University of Kansas. Song Yang is our first post-doc to leave the field; he did not attempt to find another position in physics.

Here we review our post-doctoral research associates who have been employed for some part of the last three years.

4.3.1 Song Yang 1994-1996

Song Yang has played a major role in the discovery and identification of the Ξ_c^* states described above. He has also led searches for decays of these states via π^0 transitions, which should also be present but at a lower rate than $\pi^\pm$ transitions. He has also unsuccessfully searched for Ξ_c' states that decay into $\Xi_c\gamma$. A signal for one of these states, which are the charmed,strange analogues of the Σ_c states, has been claimed by the WA-89 group at CERN but the claim has not been confirmed either by them or by Song's search. However it is clear that these states should be visible in CLEO II eventually.

He also revamped the method of evaluating the energy-loss (dE/dx) in the drift chamber which has led to increase in the resolution for particle identification which will be fully operational in the new "recompress" of the CLEO data.

Song has led the effort to use the Florida Alpha farm to generate general purpose data simulation for the entire collaboration. This has led to the generation of up to 10,000,000 events per year. Most of these are "generic" Monte-Carlo designed to be of use for the whole collaboration. Other, specific topology events are generated at the behest of individual CLEO collaborators in order to complete their analysis.

Song also wrote, for CLEO general use, interface programs to ease the use of the kinematic fitting routines written by Paul Avery which are used in total or in part by all members of CLEO. Song left the collaboration in early 1996 to take a position in Walnut Creek, California, where he will use his simulation and programming expertise to model financial markets.

4.3.2 Karen Lingel 1994-95

Karen Lingel was the post-doc in residence at Cornell from Summer 1994 to September 1995. After her work on the observation of the charmless B decays ($B \to \pi\pi$ and $B \to K\pi$) published in 1993, she has expanded the analysis to include channels with K^* and ρ's. These are decays that arise from $b \to u$ or $b \to s\gamma$ penguin processes. She has been the organizer of the Rare B Hadronic working group for the last 4 years. This group provided the results of the paper published by Phys. Rev. D (number 28 of Florida papers above), this included 25 different modes of rare hadronic decays, of which she herself was responsible for 11. The limits in the paper are improvements of approximately an order of magnitude over previous measurements, and are pushing the theoretical predictions.

Karen was also chair of the "Rare B Physics Group" and the "Rare Electromagnetic Group". She was a working member of the Tracking Group, with a notable contribution being the understanding of the wire-to-wire time-zero calibaration as a function of per-amp channel and the time variations of these calibrations. She was a member of the tracking Systematic Committee, which was responsible for collecting all information known about tracking efficiencies, systematic uncertainties and Monte-Carlo simulation. Karen was also CERN librarian for CLEO, and thus responsible for the installation and maintenance of the CERN software relevent documentation.

Karen left the group, but not the Collaboration, in 1995 to take a position at SLAC.

4.3.3 Arne Freyberger 1990-93

Arne Freyberger was the post-doc in residence at Cornell until Summer 1993. He was very active in data analysis, and in software service to the Collaboration. He was for one year the CLEO librarian, collecting together all additions and corrections for CLEO libraries and installing them. His performance in this job won praise from many sources not onlt for his conscientiousness but in his development of the system that helped future librarians. His analysis included precision measurements of the $D^0 \to K^-\pi^+$ branching fraction, precision measurement of the $D^+ \to K^-\pi^+\pi^+$ branching fraction, measurement of $B \to D^* l\nu$ and extraction of V_{cb} performed in collaboration with Xu Fu, and Oklahoma graduate student, and also the analysis of $D^0 \to Xe\nu$ which has jsut been accepted by Physical Review D. He was secretary of the charm semi-leptonic group, and in the months before he left he was responsible for organizing all CLEO internal talks at Cornell. He was elected analysis coordinator for CLEO for the 1994-95 year, but left before being able to take office. Since his departure, he has continued to be loosely connected with the collaboration and still contributes ideas and criticisms of analyses.

4.3.4 Ransom Stephens 1992-93

Ransom Stephens was a post-doc on CLEO based at Florida until September 1993. He was instrumental in the setting up of the Monte-Carlo generation system in Florida. His maon analysis topic was the search for $b \to u$ transitions using $B \to D_s X$ and D^*. The analysis also involved measurement of the normalization modes. This analysis was published soon after his departure for UT Arlington.

4.4 Students - Current

4.4.1 Craig Prescott

Craig Prescott has now been author on CLEO publications for two year. His main contribution has been optimizing the code for Ξ^0, Ξ^- and Ω^- hyperons. The analysis of hyperons is rather sophisticated as it involves finding a primary event vertex, a Ξ or Ω vertex and a Λ vertex. In the case of Ξ^0 the second of these is inferred rather than measured, but measuring the impact parameters of the Λ momentum vector as well as the direction of the π^0, by method first invented by John Yelton. These techniques have been used for Craig's own particle searches, the Ξ_c^* analyses described above, and also by many other collaborators for use in their analyses. For instance, the much improved signal:background achieved by his code, led to an improved analysis of the searches for $\Omega l\nu$ by the Purdue group - unfortunately this did not lead to a signal which CLEO are prepared to show the world. He has been in charge of searches for the charmed, doubly strange baryon, the Ω_c. Although other groups have now seen this particle (notably WA-89), it does not seem to be produced in measurable numbers in e^+e^- annihilation at CESR energies. CLEO has shown in a summer conference paper in 1993 limits on Ω_c production that disagreed with the ARGUS signal (this analysis done by John Yelton), Craig has extended this search to more decay modes, more data and a refined analysis.

Craig is now in charge of remaking the basic "vee-finder", used to find secondary vertices by all of the collaboration, for the recompression of all the CLEO II data. The entire data set taken with CLEO II is presently being "re-pass2'ed", that is all tracks are being refound and refit. The new track fitter enploys the "Kalman Filter" program that takes into account the energy loss in the fitting process. This program yields more vees with better resolution. Craig has finished rewriting the vee-finder to take into account the improvements of the Kalman filter. This includes swimming the tracks through the detector making energy-loss adjustments between the primary and secondary vertices. Craig is now resident at Cornell, and has now taken over as CLEO librarian (see Arne Freyberger above). It is unusual for a graduate student to be given a job as responsible as this, but he has already shown his aptitude for the task.

4.4.2 Jiu Zheng

Jiu Zheng is now ending his third year in graduate school, and is a fully fledged mamber of the CLEO collaboration. His major research topic has been on repeating the analysis done by John Yelton on Λ_c^+ decays into $pK^-\pi^+\pi^0$ and $p\overline{K^0}\pi^0$ which was announced in conferences but never published two years ago. He has added much data, optimized cuts, and studied systematic uncertainties. He has also added a new decay mode, $p\overline{K^0}\pi^0\pi^0$ which has not previously been seen by anyone. This analysis is presently being reviewd by a CLEO committee with a view to publication soon.

4.4.3 Antonio Rubiera

One new student has just joined the group. Antonio Rubiera has a background in Electrical Engineering from Cornell University. He has started studying the signature of anti-neutrons in the CsI crystals - it is possible that this could lead to a fruitful line of research including study of the D_s^+ annihilation diagram decays and new decays of charmed baryons. He intends to become an official member of the colalboration after passing the Department written qualifying exams.

4.5 Students - Previous

4.5.1 Jorge Rodriguez

Jorge Rodriguez graduate with a thesis, entitled "Exclusive Two Body Decays of the Bottom Meson" and he was awarded his PhD in August 1995. His analysis is detailed in the section on Paul Avery above, and was a coninuation of his major contribution to the very large CLEO paper published in 1994 (Number 26 of Florida papers, above). Jorge has accepted a position as a post-doc with the University of Hawaii, where he can continue his work on CLEO as well as writing software for the BELLE collaboration. He has continued to collaborate with Paul Avery on extension to the analysis.

ANNUAL REPORT TO THE DEPARTMENT OF ENERGY

Task C:

SECOND-GENERATION DARK-MATTER AXION SEARCH

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Abstract

This research project is a collaboration with the axion search experiment at Lawrence Livermore National Laboratory. The axion is a particle that affects two important issues in particle physics and astrophysics: the origin of CP symmetry in the strong interactions, and the composition of the dark-matter of the universe. First predicted in 1978, present laboratory, astrophysical, and cosmological constraints suggest axions have a mass in the 1 μeV–1 meV range. Axions are especially significant as dark matter if their mass is in the range 1–10 μeV. These dark matter axions may be detected by their coupling to photons through the $\mathbf{E} \cdot \mathbf{B}$ interaction in a tunable high-Q microwave cavity permeated by a strong external magnetic field. The present experiment is the first cavity experiment with the sensitivity to possibly observe cosmic axions. It has recently begun taking data and will operate for the next several years. The University of Florida plans to contribute to the operation of this detector and to the design and prototyping of cavities for the experiment.

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I. INTRODUCTION

This document is the annual report for the University of Florida part of an ongoing axion search experiment. The discovery of the axion, or placing strong limits on its existence, would have profound implications for two of the most important problems in contemporary physics: (i) the origin of CP symmetry in the strong interactions of particle physics, and (ii) the composition of the dark matter that makes up approximately 90% of the mass of the universe.

The existence of the axion is well motivated from a particle physics point of view because it would explain why the strong interactions conserve parity P and the product CP of charge conjugation with parity. The experiment searches for axions as a component of the dark-matter halo of our galaxy. There are a number of observations which imply the existence of large halos of nonluminous matter surrounding galaxies. The composition of this dark matter is a mystery whose solution is one of the most exciting challenges confronting science today. It seems probable from the success of models of nucleosynthesis in explaining the abundance of light isotopes, and of cosmological inflation in explaining the flatness and homogeneity of the present universe that much of the dark matter is non-baryonic. The leading non-baryonic candidates are finite-mass neutrinos, weakly interacting massive particles, and axions. Among these, the axion is special in the sense that a laboratory experiment can be carried out with current technology that can definitely detect the particle at the expected level of abundance. The only plausible remaining mass window for these axions is 1-1000 μeV. At the low end of this this window axions have the appropriate mass to exactly close the universe.[1]

The hypothesis that the halo of our galaxy is made of axions can be tested experimentally. Axions may be stimulated to convert into monochromatic microwave photons in a high Q cavity threaded by a large magnetic field.[2] The present report is for the DOE-supported, University of Florida participation in a "second-generation" axion search experiment that presently is taking data at Lawrence Livermore National Laboratory (LLNL). This axion detector has improved the sensitivity over first-generation detectors by at least a factor of 50. The detector consists of a large superconducting magnet containing one or more microwave cavities; axions which overlap the high-field region will be stimulated to decay into microwave photons when the resonant frequency of the cavity equals the mass of the axion. Over the next few years, the detector will tune over the 1.3–13 μeV axion mass range; its sensitivity will make it the *first* dark matter detector with enough sensitivity actually to detect a signal given the constraints on dark matter density set by astrophysical and cosmological considerations.

A. Background about the Axion

The axion is a hypothetical particle whose existence would insure that the strong interactions conserve P and CP in spite of the fact that other interactions violate those symmetries.[3] Indeed, the action density of the standard model of elementary particles contains in general a term:

$$L_\theta = \frac{\theta g_s^2}{32\pi^2} G^a_{\mu\nu} \tilde{G}^{a\,\mu\nu} \tag{1}$$

where $G^a_{\mu\nu}$ is the gluonic field strength, $\tilde{G}^a_{\mu\nu}$ is the dual of $G^a_{\mu\nu}$, and g_s is the QCD gauge coupling. If $\theta \neq 0$, non-perturbative QCD effects induce violations of P and CP in the strong interactions. No such violation has been observed. In particular, the upper limit on the neutron electric dipole moment requires $\theta < 10^{-9}$. But there is no reason in the standard model for the parameter θ to be small. This shortcoming has been called the "strong CP problem".

Peccei and Quinn modified the standard model in such a way that the parameter θ in Eq. 1 gets replaced by $\frac{a(x)}{f_a}$ where $a(x)$ is a dynamical pseudo-scalar field whose quantum is called the axion ; f_a is a quantity with dimension of energy called the axion decay constant. By construction, the vacuum expectation value of $a(x)$ is indifferent except for those non-perturbative effects that make QCD depend upon θ. The latter produce an effective potential $V(\theta) = V\left(\frac{a(x)}{f_a}\right)$ whose minimum is at $\theta = 0$. Thus by postulating an axion, θ is allowed to relax to zero dynamically and the strong CP problem is solved.

The properties of the axion can be derived using the methods of current algebra. The axion mass is related to f_a by:

$$m_a \simeq 0.6\text{eV}\frac{10^7\text{GeV}}{f_a}. \tag{2}$$

All the axion couplings are inversely proportional to f_a. Thus, a very light axion is also very weakly coupled.[4] A priori, the value of f_a, and hence that of m_a, is arbitrary. However, astrophysical considerations[5] and searches for the axion in high-energy and nuclear physics experiments[6] rule out $m_a > 10^{-3}$ eV. On the other hand, cosmology places *a lower limit* on m_a of order 10^{-6} eV by requiring that axions do not overclose the universe.[7]

Indeed, for small masses, axion production in the early universe is dominated by a novel mechanism. The point is that the non-perturbative QCD effects that produce the effective potential $V\left(\frac{a(x)}{f_a}\right)$ are strongly suppressed at temperatures high compared to Λ_{QCD}. At these high temperatures, $\langle a(x)\rangle$ has arbitrary value. At $T \simeq 1$ GeV, the potential V turns on and the axion field starts to oscillate about its CP conserving minimum. These oscillations do not dissipate in other forms of energy because, in the relevant mass range, the axion is too weakly coupled for that to happen. The oscillations of the axion field may be described as a fluid of axions. The typical momentum of these axions is the inverse of the correlation length of the axion field at $T \simeq 1$ GeV. Since that correlation length is of order the horizon then, we have $p_a \sim \frac{1}{t_{1\text{GeV}}} \sim \frac{1}{10^{-6}\text{sec}} \sim 10^{-9}$ eV. Thus, the axion fluid is very cold compared to the ambient temperature. Its contribution to the present cosmological energy density is found to be of order

$$\Omega_a h^2 \simeq 0.3 \left(\frac{10^{-6}\mathrm{eV}}{m_a}\right)^{\frac{7}{6}} \left(\frac{200\mathrm{MeV}}{\Lambda_{\mathrm{QCD}}}\right)^{\frac{3}{4}} . \tag{3}$$

Several sources of uncertainty affect the relationship between $\Omega_a h^2$ and m_a, amongst which are the nature of the QCD phase transition and the contribution to $\Omega_a h^2$ from cosmic axion strings.[8,9] Also, if inflation occurs and the post-inflation reheating temperature is less than f_a, then the axion field gets homogenized and there may be an accidental suppression of $\Omega_a h^2$ because the axion field happens to lie everywhere close to the CP conserving minimum of V. From the point of view of large scale structure formation, axions are cold dark matter since they are non-relativistic from the moment of their production during the QCD phase transition, as was emphasized above.

B. The cavity detector of halo axions

The hypothesis that the halo of our galaxy is made of axions can be tested experimentally by looking for the resonant conversion of galactic halo axions to photons in a laboratory magnetic field. To this effect, a tunable high Q cryogenic cavity is placed in the bore of a superconducting solenoid, and the frequency of its lowest TM mode is slowly changed until excess power is detected in that mode from resonant axion photon conversion.[2] The excess power is

$$\begin{aligned} P = & 2.3 \cdot 10^{-26}\mathrm{Watt} \left(\frac{V}{200\ell}\right) \left(\frac{B_0}{8\mathrm{Tesla}}\right)^2 C_{nl} \left(\frac{g_\gamma}{0.97}\right)^2 \cdot \\ & \left(\frac{\rho_a}{0.5 \cdot 10^{24}\mathrm{g/cm}^3}\right) \left(\frac{m_a}{2\pi\mathrm{GHz}}\right) \min(Q_{\mathrm{L}}, Q_{\mathrm{a}}) \end{aligned} \tag{4}$$

where V is the volume of the cavity, B_0 is the effective magnetic field strength, C is a mode-dependent form factor of order 0.5, ρ_a the density of galactic halo axions at the earth, m_a is the axion mass, Q_L is the loaded quality factor of the cavity and $Q_a \sim 10^6$ is the "quality factor" of the galactic halo axions, *i.e.*, the ratio of their energy to their energy spread. Finally, g_γ is the coupling strength of the axion to two photons. The value $g_\gamma \sim 0.36$ is predicted by the Dine-Fischler-Srednicki-Zhitnitskii (DFSZ) model. More generally, $g_\gamma \sim 0.36$ follows from grand unification of the strong and electroweak interactions. In all other models that have been put forth, the magnitude of g_γ is predicted to be larger than 0.36 *e.g.*, $g_\gamma = -0.97$ in the model of Kim-Shifman-Vainshtein-Zakharov (KSVZ).

One does not know the value of the axion mass, which determines the resonant frequency $f = m_a c^2/h$ but it is known that axions with mass near 4μeV provide the critical energy density for closing the universe. The search rate appropriate for a given signal/noise ratio (s/n) is given by the formula:

$$\frac{df}{dt} = \frac{73\text{GHz}}{\text{year}} \left(\frac{4}{\text{s/n}}\right)^2 \left(\frac{V}{200\ell}\right)^2 \left(\frac{B_0}{8\text{Tesla}}\right)^4 C^2 \left(\frac{g_\gamma}{0.97}\right)^4 \cdot \frac{\rho_a}{0.5 \cdot 10^{-24}\text{g/cm}^3} \left(\frac{5K}{T_n}\right)^2 \left(\frac{f}{1\text{GHz}}\right)^2 \left(\frac{Q_L}{Q_a}\right) \tag{5}$$

where T_n is the total nose (cavity plus electronic) of the microwave detector.

Pilot experiments have been carried out using relatively small volume magnets at Brookhaven National Laboratory and at the University of Florida. These experiments had $B_0^2 V$ values of 0.36 and 0.45 $T^2 m^3$, respectively. Figure 1 shows the regions in the $(\text{coupling})^2$ versus mass plane that have been eliminated by these searches, compared with the predictions of theoretical models. The pilot experiments have demonstrated the principle of cosmic axion detection and have shown that reasonable sensitivity can be achieved over a wide range of frequencies. However, much larger systems are needed to provide meaningful tests of the theoretically favored models.

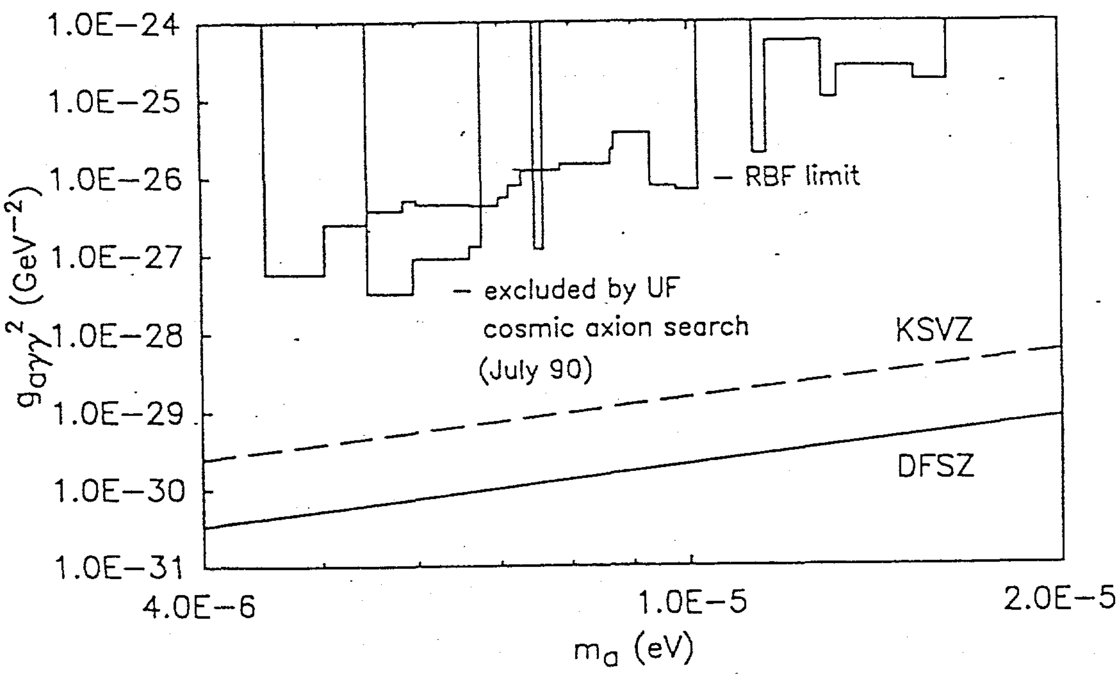

Fig. 1. The exclusion regions in the axion mass vs. axion-photon coupling constant plane obtained by the Rochester-Brookhaven-Fermilab (RBF) and the University of Florida (UF) pilot experiments. Also shown are the axion-photon coupling strengths expected in a range (DFSZ and KSVZ) of axion models. The area extending into the KSVZ sensitivity is the expected search region of the present experiment.

C. The phase-space structure of cold dark matter halos

If a signal is found in the cavity detector of galactic halo axions, it will be possible to measure the energy spectrum with great precision and resolution because all the time that was previously used in searching for the signal can now be used to accumulate data. Hence there is good motivation to ask what can be learned about our galaxy from analyzing such a signal.

In many past discussions of dark matter detection on earth, it has been assumed that the dark matter particles have an isothermal distribution. Thermalization has been argued to be the result of a period of "violent relaxation"[10] following the collapse of the protogalaxy. If it is strictly true that the velocity distribution of dark matter particles is isothermal, which seems to be a strong assumption, then the only information that can be gained from its observation is the corresponding virial velocity and our own velocity relative to its standard of rest. If, on the other hand, the thermalization is incomplete, a signal in a dark matter detector may yield additional information.

Sikivie and Ipser have discussed[11] the extent to which the phase-space distribution of cold dark matter particles is thermalized in a galactic halo and concluded that there are substantial deviations from a thermal distribution in that the highest energy particles have discrete values of velocity. There is one velocity peak on earth due to dark matter particles falling onto the galaxy for the first time, one peak due to particles falling out of the galaxy for the first time, one peak due to particles falling into the galaxy for the second time, etc. The peaks due to particles that have fallen in and out of the galaxy a large number of times in the past are washed out because of scattering in the gravitational wells of stars, globular clusters and large molecular clouds. But the peaks due to particles which have fallen in and out of the galaxy only a small number of times in the past are not washed out.

If the fraction of the local dark matter density which is in these velocity peaks is sufficiently large, a direct dark matter search, such as the LLNL experiment, may be made more sensitive by having it look specifically for velocity peaks. I. Tkachev, Y. Wang and I have been studying galactic halo formation with the purpose of obtaining estimates of the sizes and locations of the velocity peaks.[12] To this end, we have generalized the secondary infall model of galactic halo formation to include angular momentum of the dark matter particles. This new model is still spherically symmetric and it has self-similar solutions. We find that the typical fraction of the local cold dark matter density in any one of the highest energy velocity peaks is several percent. A forthcoming paper will give estimates of the highest energy peaks as a function of the amount of angular momentum and other model parameters.

II. RESEARCH

During the present grant period, we had responsibility for the design, assembly, and programming of the high-resolution spectrometer that presently is part of the experiment. Our research is detailed in this section. Briefly we contribute to data taking and operations of the second-generation experiment and are planning the design and prototyping of the third cavity array for this experiment.

A. The Second Generation Experiment

We participate in the second-generation axion search, operated at the Lawrence Livermore National Laboratory, which is now taking data.

In the following we give some details of the experiment. The spokespersons are Leslie J Rosenberg (MIT) and Karl van Bibber (LLNL). The capability of this experiment to either detect axions (with s/n of 4) or exclude them (at the 97.7% C.L.) extends into the KSVZ region of axion couplings as shown in Fig. 1. We summarize the key goals of the experiment as follows:

- To achieve a power sensitivity which is conservatively a factor of 50 improvement over the pilot experiments. This is to be achieved by a combination of scaling up in magnet volume, and incremental progress in the noise temperature of state-of-the-art microwave amplifiers.
- To search the mass range 1.3 μeV $< m_a <$ 13μeV. At the high end of this range, the search will be achieved through filling the magnet volume with multiple cavities.

A sketch of the experiment is shown in Fig. 2. The magnet was constructed by Wang NMR Inc (Livermore, CA). The coil has a length of 100 cm, a bore of 60 cm, and is wound of 100 km of NbTi conductor. The inductance is 540 H. It is bath cooled to 4.2K, and is energized through optimized vapor-cooled leads. It has been trained up to 7.9 T, but is used at 7.5 T. The coil alone weighs 6 tons while the entire magnet and cryostat weigh 11 tons; the cryostat is 3.6 m high. Liquid helium (LHe) consumption is ~2 l/hr.

The magnet cryostat has a "cool bore" of 55 cm diameter, which allows the exchange of cavity arrays *etc.* in the experimental volume while the magnet is cold. Equally important, the temperature of the cavity arrays is independent of that of the magnet. The experiment is operated at about 1.5 K, to match the noise temperatures of the best low-noise microwave amplifiers available today.

A second feature of the current experiment is that for the first time, arrays of multiple cavities will be used to expand the mass search range. Each cavity is separately tuned by moving dielectric or metallic rods within the cavity. The experiment will cover the range 1.3μeV $< m_a <$ 13μeV. To accomplish this, requires three separate cavity arrays with one, four and sixteen cylindrical cavities filling as much of the magnet bore as possible (Table 1).

In order that tuning rods may be changed in the cavity periodically, the cavity must be able to be assembled without breaks in wall conductivity at the joints. We developed a

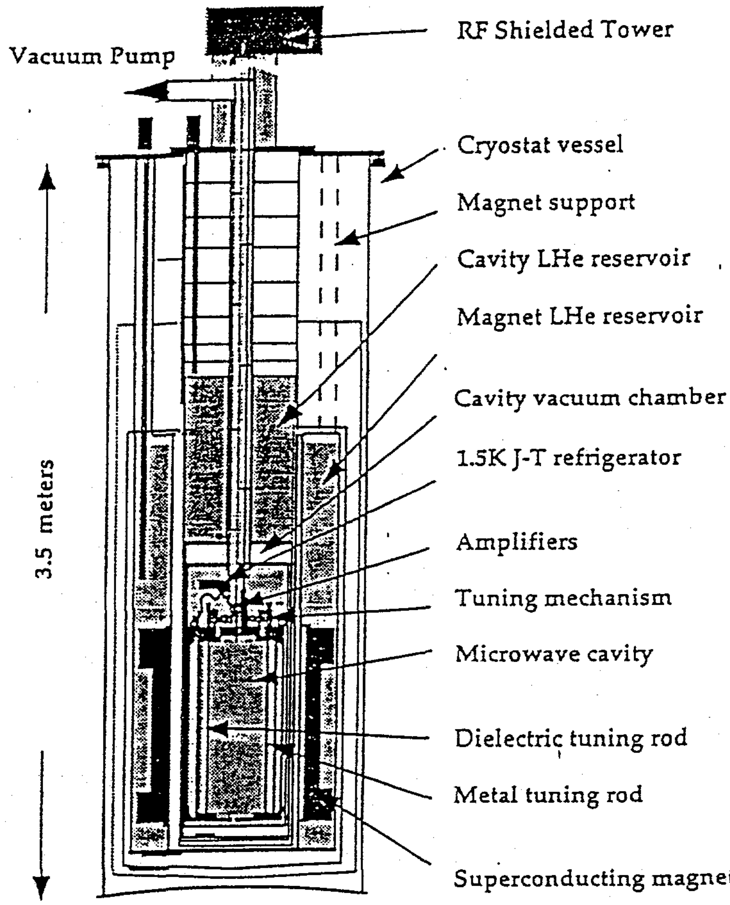

Fig. 2. Sketch of the axion search experiment.

Table 1. Cavity arrays. Status: D = Designed, F = Fabricated, I = Integrated.

Array	N	R [cm]	Freq. [MHz]	Mass [μeV]	Packing	D	F	I
I.	1	25.0	307–718	1.27–2.97	1.0	Y	Y	Y
II.	4	10.4	711–1666	2.94–6.89	0.69	Y	FY95/6	FY97
III.	16	5.7	1621–3142	6.70–13.0	0.82	FY97	FY98	FY98/9

successful technique of plating stainless-steel cavities with copper, where the end-flanges are joined to the barrel section with knife-edge seals; the Q's achieved are close to theoretical maximum in the anomalous skin-depth regime at 4K. (Q~250,000 for Cavity Array I.)

For the first single cavity, all mechanical motions are made by stepper motors (200 steps/turn) on top of the tower (300K) and transmitted to the cavity (1.5K) by rotary G-10 shafts. For the tuning mechanism, a gear reduction of 30,000 permits smooth and reproducible translation of the rods by ~100 nm, or frequency increments of 10^{-7}.

A block diagram of the detector is shown in Fig. 3. The signal from the cavity is amplified by a low noise microwave amplifier located in a small refrigerator box located just above the top flange of the cavity. Figure 4 shows the electronic noise temperature T_n

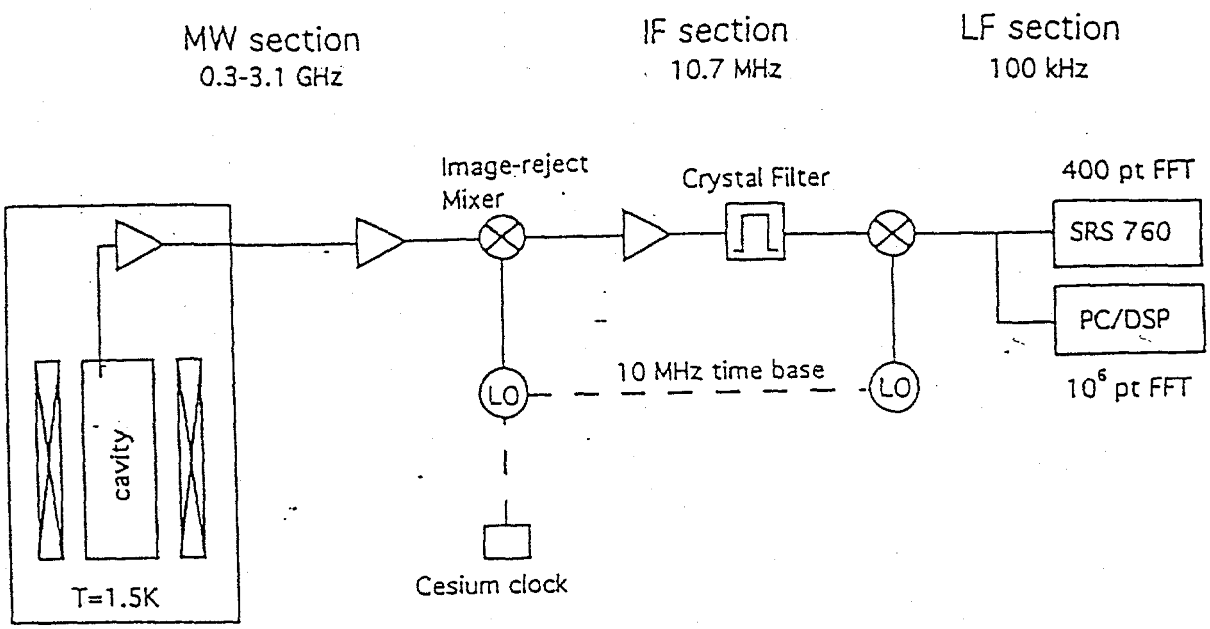

Fig. 3. Block diagram for the detector.

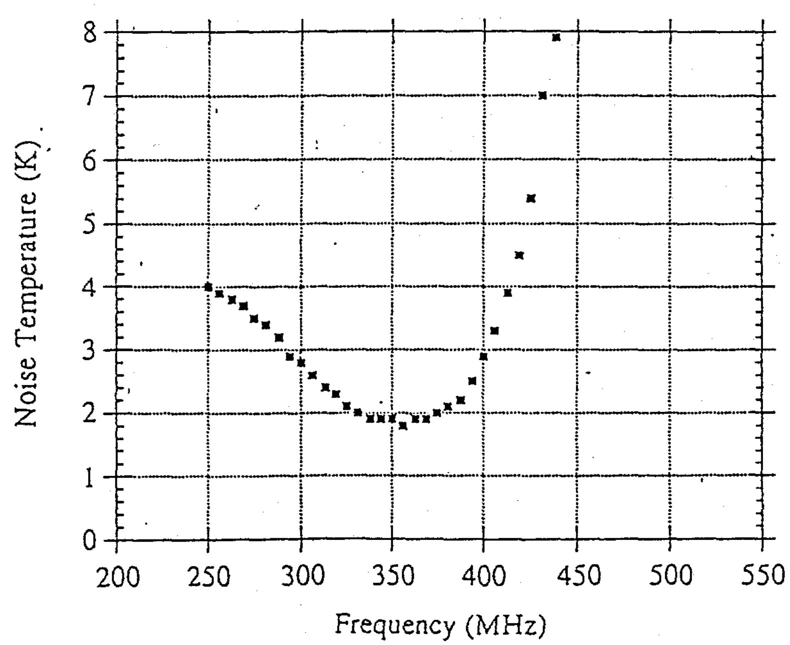

Fig. 4. Noise for NRAO HEMT amplifier

for the currently employed front-end cryogenic amplifier. This is a balanced, 30-db gain, 2-stage HEMT amplifier build by NRAO.[13] Its nominal noise temperature is ≈ 4 K for physical temperatures < 15 K. The HEMT amplifier T_n will get even better as the axion search moves up into the GHz region.

A postamp provides 60 dB of gain, and the signal is then sent through 10 m of low-loss coax cable to the temperature-controlled electronics house. The total noise contribution after the HEMT amp, referenced to its input, is < 0.1 K. The receiver (Fig. 3) is very similar to the UF design. The first stage image-reject mixer converts the signal to an IF (10.7 MHz); this is amplified and shaped with a 30 KHz bandpass filter which rejects power outside the cavity bandwidth. The IF is mixed down to a center frequency of 25 Hz with a crystal filter bandwidth of 30 KHz. The near-audio signal is split into two data streams. One goes to a SRS real-time FFT analyzer, which accumulates the medium-resolution power spectrum (bin width ~100 Hz) that would see the virialized axion linewidth distributed over several channels. We have measured the noise in our FFT power spectrum for the entire receiver, and it drops like $t^{-1/2}$ as it should for at least 1000 seconds, much longer than our runs will be. The second data stream feeds a narrow-bin FFT analyzer built from commercial board-level components and packaged into a PC chassis. The two main components are a 100 KHz ADC connected over a dedicated data bus to a fast DSP containing sufficient on-board memory to store and process over 10^6 ADC samples[14]. The result is a high-resolution FFT (0.1 Hz) that can search for the axion fine-structure[11,12] with much greater sensitivity. The required specifications on local oscillator phase noise and stability of the ADC clocking electronics are comfortable. The assembly and C-programming of the DSP is well-along, and the concurrent ADC and DSP routines have been successfully tested. Additionally, the digitized data for the entire experiment is streamed to 8 mm tape archive, in case it is ever conceived that some specialized filtering could improve the sensitivity of the search.

This experiment started taking data in 1995, and will run for three to four years. This second-generation experiment will be the first to have sensitivity to a likely dark matter candidate with plausible couplings to matter and radiation. This sensitivity is illustrated by Fig. 5, which shows result from a scan of 2.7–3.0 μeV (660–720 MHz). Data analysis is in progress.[15]

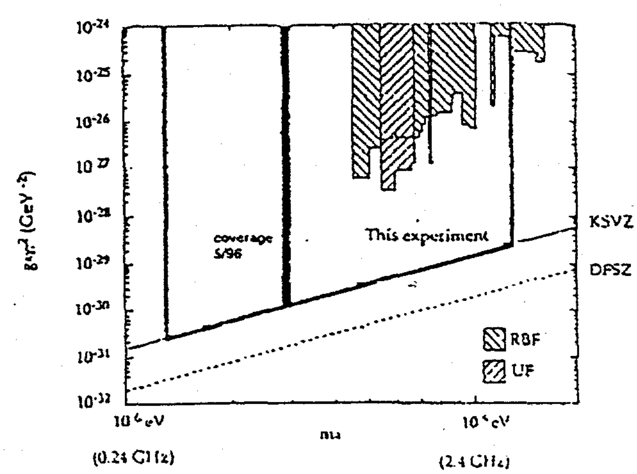

Fig. 5. Exclusion plot for galactic axions, assuming a halo density of $\rho_a = 300$ MeV/cm^3.

B. Multiple cavity arrays

We are planning to design the prototype for the cavities that will be used in cavity array III of this experiment. The design will be done in consultation with the group at Livermore that has designed the first and second arrays. The prototype cavity will be built at the University of Florida.

As seen in Table 1, there are three separate cavity arrays required to cover the mass range 1.3–13 μeV. The first array consists of a single large cavity (f = 460 MHz); it is part of the experiment already in operation. To go to higher frequencies (masses) requires smaller diameter cavities, but more of them to utilize the available magnetic volume and thus not sacrifice sensitivity. A schematic packing arrangement for the single and multiple cavity arrays is shown in Fig. 6.

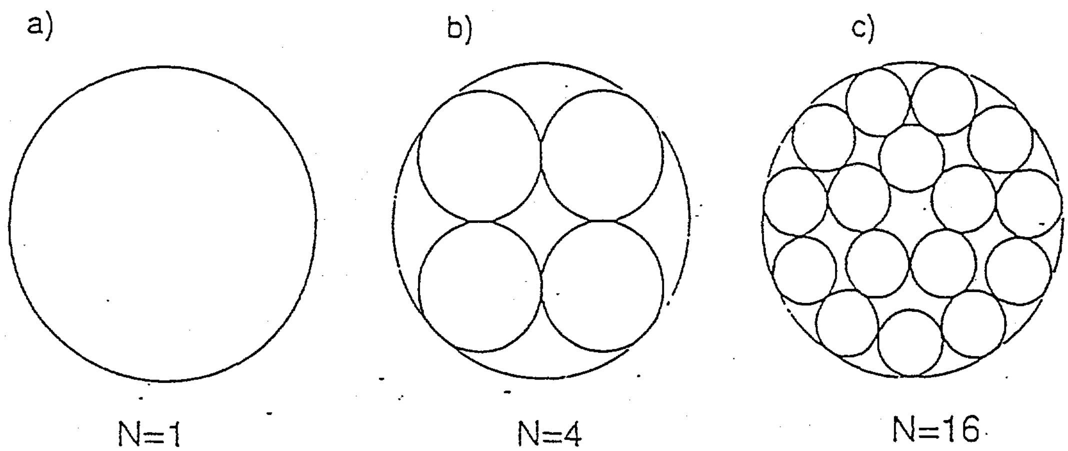

Fig. 6. The three cavity arrays with central frequencies of (a) 460; (b) 1110; (c) 2025 MHz.

Array II has been designed, and major components have been fabricated and ordered. Array III has not yet been designed. It is very appropriate that the University of Florida take responsibility for the design and prototyping of multiple cavity arrays. First, the concept for the microwave cavity experiment came from Florida, and it is ironic that they have no significant support for axion research. Second, this group carried out extensive conceptual studies, modeling and R&D on microwave cavities for the axion experiment (tuning schemes, mode crossings, mode localization, quality factor issues, tolerance criteria, materials, techniques for higher frequencies, etc.)[16]. Third, the original concept and two-cavity demonstration of power combining multiple cavities came from Hagmann's thesis work at Florida[17]. Last, the University of Florida will contribute the machine shop work for the fabrication of the cavity.

A brief discussion of how one power-combines cavities is in order. Power combiners/splitters with 2^n ports are most common, but arbitrary numbers are possible. When the input amplitudes to a 2-port device are $ae^{-i\omega t}$ and $be^{-i(\omega t+\phi)}$, the output is given by $(a + be^{-i\phi})e^{-i\omega t}/\sqrt{2}$; the output power is the sum of the input powers so long as the input signals are balanced and in phase, otherwise power is dissipated in the device. Because the axion conversion is coherent over the entire volume (the typical de Broglie wavelength—of order of 100 m—of galactic halo axions is much larger than the dimensions of the experiment) the signals from the cavities will be of equal amplitude and phase so long as one matches the length of the coaxial waveguide to the combiner. A simple analysis shows that there is no penalty in signal-to-noise s/n by power-combining multiple cavities, relative to a single cavity of larger volume. (One of the first follow-on experiments to discovery of the axion would be to measure the coherence length of the axion field by separating two such microwave cavities, and seeing where the combined power falls off by half.)

A demonstration of power-combining two cavities was carried out at the University of Florida[17]. The signal from a frequency synthesizer was divided by a power combiner/splitter, and sent to the weakly-coupled input port on two cavities, one of fixed frequency ω_0 and one of variable frequency ω. The signal from the two cavities' output couplers were combined through a similar device, and the total transmitted power measured as a function of the variable resonant frequency and coupling strength (Figure 7). The agreement between the calculated and measured values was exact within errors. Note the distinction between power-combining cavities where there is large isolation between input ports (> 30 db), and cross-coupling the cavities, which would have produced mode-mixing and splitting into symmetric and antisymmetric modes.

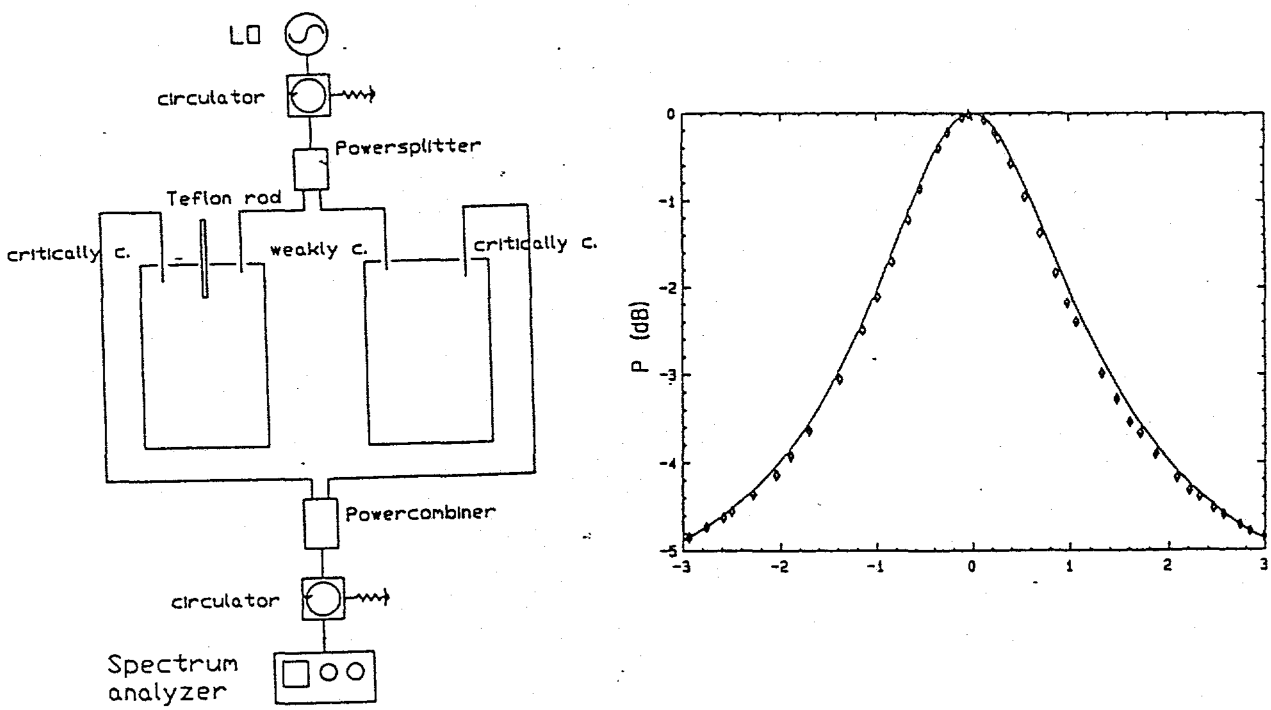

Figure 7. Test of power-combining two cavities. The solid line (right) is calculated behavior.

Our plan is to construct and test a single prototype cavity for array III during 1996-7. Then, 16 identical cavities would be prepared over the next year and a half for integration into the experiment. The funding for the construction of these cavities will be the subject of a separate proposal.

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Research in Theoretical and Elementary Particle Physics

Task G: Experimental Research in Collider Physics

Principal Investigator: Guenakh Mitselmakher
Co-principal Investigators: Paul Avery, Jacobo Konigsberg, Andrey Korytov

1 Introduction

In 1995 the University of Florida started a major expansion of the High Energy Experimental Physics group (HEE) with the goal of adding four new faculty level positions to the group in two years. This proposal covers the second year of operation of the new group and gives a projection of our research program for the next five years, when we expect our activities to be broader and well defined.

The expansion of the HEE group started in the Fall of 1995 when Guenakh Mitselmakher was hired from Fermilab as a Full Professor. A search was then performed for two junior faculty positions. The first being a Research Scientist/Scholar position which is supported for 9 months by the University on a faculty line at the same level as Assistant Professor but without the teaching duties. The second position is that of an Assistant Professor. The search has been successfully completed and Jacobo Konigsberg from Harvard University has accepted the position of Research Scientist and Andrey Korytov from MIT has accepted the position of Assistant Professor. They will join the group in August 1996.

The Physics Department at UF is committed to open one more junior faculty position for our group in 1997. We expect to start a search for a suitable candidate by the Fall of 1996. This will bring the total number of HEE faculty to six in 1997 (Paul Avery, John Yelton, Guenakh Mitselmakher, Jacobo Konigsberg, Andrey Korytov + 1 Assistant/Associate professor). In addition, Andrey Nomerotski, who will graduate from Padova University (Italy) in September, 1996 was recently hired as a post-doc and we expect to be able to hire another post-doc early in 1997. The group will be further strengthened in the Fall of 1996 when a Senior Technician or an Engineer will be hired (with 50% of his/her salary being provided by the University).

In 1995 the University of Florida began the construction of a new physics building in which, in addition to offices, machine and electronic shops, the HEE group has been allocated 6000 sq. ft. of laboratory space (including 2000 sq. ft. within a high bay area). This will allow us to undertake large hardware construction projects. The building will be completed in January 1998, and temporary lab space has been assigned to the group in the interim period.

The University of Florida as a whole, and the Physics Department particularly, strongly support this new experimental high energy physics program. The University has committed so far $600K as start up funds for the new group members and, in addition to that, some equipment funds will be available for the new laboratory. We are looking forward to a very exciting and productive physics research program.

2 Physics Program

The physics program for the new group is focused on hadron collider physics. G. Mitselmakher has been leading the CMS endcap muon project since 1994. A. Korytov is the coordinator of the endcap muon chamber effort for CMS and a member of the CDF collaboration and J. Konigsberg is a member of CDF where he has participated in various physics analyses (including being leader of one of the groups that discovered the top quark) and has been coordinator of the gas calorimetry group. Our group at the U. of Florida has recently been accepted as an official collaborating institution on CDF. We have been assigned the responsibility of determining the collider beam luminosity at CDF and we will also be an active participant in the design and operation of the muon detectors for the intermediate rapidity region. In addition we expect to continue our strong participation in the present and future physics analyses of the CDF data. G. Mitselmakher is also a member of the MINOS collaboration (a long-baseline neutrino search) at Fermilab. Below we discuss this program in more detail.

2.1 Compact Muon Solenoid Experiment at the LHC

P. Avery, R. Field, J. Konigsberg, A. Korytov, G. Mitselmakher, A. Nomerotski, P. Ramond, J. Yelton + Research Scientist + Post-doc + Grad. Students.

Since 1994 a large number of American groups (about 300 physicists) have joined the CMS experiment for the LHC collider at CERN, bringing with them valuable experience from the GEM, SDC, CDF and D0 experiments. Groups from the US are responsible for about 1/4 of CMS, including managerial and major construction responsibilities in three large subsystems: Endcap Muons (EMU), Hadron Calorimeter (HCal) and Trigger/Data Aquisition.

The University of Florida joined CMS in 1995. The group presently includes six experimentalists: P. Avery, J. Konigsberg, A. Korytov, G. Mitselmakher, A. Nomerotski, J. Yelton, and two theorists R. Field and P. Ramond.

Guenakh Mitselmakher leads the Endcap Muon Project, he was appointed by the CMS spokesman as the Project Manager and he is a member of the overall CMS management board. The expected US contribution is about M$40 out of the M$70 total cost for the EMU project (by US costing methods). The rest is expected to come from Russia, CERN, China and the CMS collaboration common fund. About 80 US physicists are currently involved in the Project, representing 14 universities, Fermilab and LLNL. The project encompasses the design and construction of the endcap muon chambers, chamber electronics, trigger and detector alignment, and also the design of endcap iron. The US group also participates in RPC development and bears the responsibility for the overall endcap integration. The CMS Endcap Muon group R&D proposal has been submitted to DOE (see attachment 1 to this document) and has been presented by G. Mitselmakher in the DOE review of ATLAS and

CMS in January 1996.

Andrey Korytov is the coordinator of the endcap muon chamber effort, which includes chamber R&D, design, chamber production, testing and commissioning. The Endcap Muon System consists of 600 6-layer Cathode Strip Chambers (CSCs) with a total count of more than 2 million wires. This exceeds by an order of magnitude the scale of the largest Multiwire Proportional Chamber systems. The chambers themselves, being $3.3 \times 1.5\ m^2$, are larger than the biggest CSCs ever built.

Both G. Mitselmakher and A. Korytov have been in CMS since 1994. In addition to their managerial and coordinating roles, they both have made a number of critical personal contributions which had a strong impact on the overall system outline, chamber design, electronics design, trigger philosophy, and chamber alignment.

Jacobo Konigsberg, having been a member of the CDF collaboration for several years, has much experience in detailed physics analysis which involve muons.

Paul Avery has been investing more of his time in CMS, and is now a member of the US Computing group. He will concentrate on tracking in the forward region and these new activities will certainly put additional strains on our computing resources, particularly because of the large number of CMSIM (CMS GEANT package) simulations which will have to be run. As MCFAST becomes adapted for CMS, a large number of simulations will need to be run as well, particularly to study track reconstruction and physics results.

Rick Field and Pierre Ramond work on theoretical issues relevant to the highest priority LHC physics, such as Higgs and Supersymmetry. R. Field gave a presentation, "Catching the Higgs with Neural Networks", at the CMS week in Granlibakken, CA in September 1995.

2.1.1 Research Program

- Endcap Muon Project (EMU) Management *(G. Mitselmakher)*. It includes managing all aspects of the EMU project as well as playing an active role in defining the US CMS Project and in the development of CMS as a whole as a member of the CMS Management Board. G. Mitselmakher reports on the status of the endcap muon project at DoE reviews, CMS collaboration meetings and LHC reviews at CERN.

- Endcap Muon Chamber Group coordination *(A. Korytov)*. It includes directing all aspects of the Cathode Strip Chambers (CSC) R&D program. This implies coordinating the efforts of about thirty physicists and engineers from about ten US and foreign institutions towards a chamber design of adequate performance and high reliability. He is responsible for coordinating the building and testing of chamber prototypes in the US institutions and he is also responsible for keeping the comprehensive cost estimate of the CSC system up to date. He runs regular chamber group meetings and weekly video-conferences and reports on the project progress to external reviewers both in the US and at CERN.

- CSC R&D *(A. Korytov, G. Mitselmakher, J. Konigsberg, A. Nomerotski)*. A number of CSC prototypes have been already constructed and tested under our supervision and close technical involvement: a small CSC with rotating wires (Vienna International

Wire Chamber Conference 1995: NIM A367 (1995) 311), a T0 engineering prototype (summary in CMS Note 95-131), a P0 performance prototype and T1A/T1B engineering prototypes. A first full scale P1A engineering prototype has been constructed at the beginning of 1996 and is now being tested. As a result of these tests we have been able to evaluate and define the basic chamber parameters, find engineering solutions for their construction and obtain realistic cost estimates.

We will continue to lead this effort of chamber design optimization. By 1997 we expect to complete the major CMS milestone in CSC chamber prototyping: the construction of a 6-gap large scale ($3.3 \times 1.2\ m^2$) chamber (P1 prototype). We lead and are technically involved in this effort (design, construction, tests and analysis). In addition, we will make several mechanical, electrical and performance tests on smaller mockups and prototypes (tests of panel mechanical strength, studies of cross-talks, studies of edge effects on the first/last wires in a wire group, R&D on chamber performance in high rate and etc.). We are also involved in the upcoming beam tests of the P0-prime prototype at CERN.

Our group will continue to work on the tasks described above both at Fermilab and at the University of Florida where we are setting up a laboratory. This laboratory will grow in size and scope when moved to the new Physics building in early 1998, where we envision having substantial facilities for testing the chambers and conducting a broad range of detector studies.

- Final Assembly and Test Site for CMS Muon Chambers at UF *(A. Korytov, G. Mitselmakher, J. Konigsberg, A. Nomerotski + Research Scientist + Post-doc + Grad. Students).*

  We have proposed to the CMS collaboration for the University of Florida to become one of the major final assembly and performance testing sites for the muon endcap cathode strip chambers (CSC's). It is expected that a substantial fraction of the chambers produced in the U.S. will be equipped with electronics at Florida and tests of the full system will be performed. We anticipate to test several hundred large chamber planes with several hundred thousand wires and electronic channels. These operations are expected to begin in our new laboratory in 1998 and continue through 2002. This will require the involvement of all members of our group and in particular the need for a full time Research Scientist to oversee and coordinate this effort. We expect to fill this new position on FY99. The chambers will be then shipped from Florida directly to CERN and it will be our responsibility to install, commission and maintain them.

- Software development *(P. Avery, J. Yelton).* There are two efforts underway. First, we are bringing the MCFAST fast simulation program to CMS. MCFAST includes many advanced features such as tracing in forward and central geometries, inclusion of physics processes during particle tracing (decays in flight, multiple scattering, energy loss, bremsstrahlung, pair conversions), Kalman track fitting, accurate modeling of hadronic and electromagnetic showers and multiple interactions. It was originally developed by the Fermilab Simulation Group (which Avery headed in 1993-94) for the B physics program at Fermilab. MCFAST is a supported product at Fermilab and is beginning to be used by the CDF and D0 collider efforts. The second effort is focused on two tracking issues: (1) reconstructing the event interaction vertex, a very challenging task of the CMS Detector and (2) tracking reconstruction using a reformulation of a link tree algorithm in c^{++} by one of our colleagues. The tracking effort is important for improving the momentum resolution and therefore related to our efforts with the muon system.

- Physics at the LHC and beyond *(R. Field, P. Ramond).* The theoretical particle physics group at the University of Florida has been extensively involved in exploring the physics possibilities that the LHC has to offer. The expansion of the experimental group has been successful largely due to the interest and support of the theoretical physicists. The collaboration between the experimentalists and the theorists promises to be extremely fruitful especially in the area of searches for new physics, where the interpretation of unfamiliar signatures is essential.

2.2 The CDF Experiment at Fermilab

J. Konigsberg, A. Korytov, G. Mitselmakher, A. Nomerotski, A. Safonov + another post-doc + another graduate student

A very important goal in the immediate and intermediate future is for our group to participate actively and vigorously in one of the existing collider experiments at Fermilab. The group will gain invaluable experience in hadron collider experiments, will partake in the excellent physics coming out of these experiments, and will be well positioned to be a major contributor at all stages of CMS.

Recently, two new faculty members have been added to the group: Jacobo Konigsberg and Andrey Korytov. Both are presently members of the CDF collaboration. J. Konigsberg has been on CDF for the last 6 years with the Harvard group and A. Korytov for the last 2 years with the MIT group. In mid-July, 1996, our group requested to become an official collaborating institution on CDF. Our membership was officially approved by the CDF executive board in mid-August 1996.

Very recently, a graduate student, Alexei Safonof, has joined our group. We expect to add soon another graduate student to this program and would like to be able to hire another post-doc by the Spring of 1997. A group of this size will have the critical mass needed to make significant contributions and undertake the major responsibilities that we intent to undertake on CDF and which are described below.

While on CDF J. Konigsberg has led several physics analyses. He developed algorithms for tau/jet separation, did a search for non-standard model top decays via a charged higgs ($t \to H^+b$ with $H^+ \to \tau^+\nu$). J. Konigsberg was co-leader of the group that discovered the top quark in the dilepton channel. Recently he has made a measurement of the top mass in this channel and is working on measuring kinematical distributions related to top quark production. Jacobo has been a reviewer of CDF papers from the electroweak and B-groups and has represented the CDF collaboration at major conferences, including Moriond in 1995, DPF in 1994 and others. He also has significant experience in guiding and working together with graduate students towards their Ph.D. theses.

J. Konigsberg also participated in two test-beams calibrating the plug and forward Gas Calorimeters. He lead the analysis of the test-beam data which translated into energy scales, response maps, non-linearity corrections, faster trigger turn-on and the maintenance of constant gain throughout the run. He later became the coordinator of the CDF gas calorimetry group which included physicists and graduate students from various institutions. He was in particular responsible for the installation, operation and maintenance of the forward electromagnetic calorimeter.

After joining CDF in 1994, A. Korytov initiated a new QCD analysis with the goal to probe perturbative QCD at the limits of its applicability by studying such inherently soft processes as jet fragmentation. Andrey proved the feasibility of this analysis at CDF and obtained the first results, which he will be presenting at the QCD 96 Conference in Montpellier, France (4-12 July 1996). These results suggest that the domain of perturbative QCD may be expanded all the way down to the cut-off scale of the order of Λ_{QCD} despite the seemingly inevitable problems of collinear and soft divergencies and the necessity to deal with essential interference of multiple-order diagrams. As part of of his CDF duties Andrey has been sharing the responsibility for the control system whose function was to maintain a constant gas gain for all the CDF Gas Calorimeters.

A. Nomerotski has been a member of the DELPHI collaboration for the last few years. His accomplishments include major responsibility for the design and construction of the Silicon Micro-vertex detector. This detector has been recently installed and commissioned with very active participation by Nomerotski. Before coming to DELPHI, as an undergraduate, Nomerotski built the wire-tube detectors for the muon system of the MD2 collider experiment at Novosibirsk. He has also done an analysis which measures the V_{cb} constant by using B^+ decays. He presented his analysis at the EPS conference in Brussels in July 1995.

2.2.1 Research Program

- Detector Upgrades

The CDF experiment is undergoing very significant upgrades in all its detector sub-systems. There are many opportunities for contributing to these upgrades (to be completed by mid-1999), and for participating in the ensuing data-taking and data analysis period. In particular CDF plans substantial upgrades to the muon systems and our participation in the planning and installation of these upgrades, as well in their operation and maintenance will be of great mutual value for our group and for the experiment. Our discussions with the CDF management indicate that Jacobo Konigsberg might play an important role in the muon upgrade management which will also allow the UF group to become involved in specific projects within this upgrade. Presently (Dec-1996) we are discussing the exact details of Florida's participation in the CDF muon system upgrade, which we expect to be substantial. In all likelihood we will be responsible for the design, installation, calibration, operation, triggering and maintenance of a very large array of scintillating counters (864 units) used for muon triggering and identification in the intermediate rapidity region (between 1.0 and 1.5). The installation and calibration will be shared with another CDF institution but ultimately the detectors will be under the the sole responsibility of our group.

In addition we have been assigned by CDF to undertake the design, building and operation of a luminosity monitor device for the coming Run II. This device needs to operate at the highest expected Tevatron luminosities ($2 \times 10^{32}\ cm^{-2}s^{-1}$) and provide several essential functions both for the accelerator and for CDF. Our group will also be ultimately responsible for the actual luminosity measurements needed by CDF for the Run 2 physics analyses.

- Physics Analysis

In addition to our participation in the upgrades of the collider experiments at Fermilab we expect to engage actively in the completion of the analysis of the existing data from Run I, and in the analysis of the very rich physics data expected in the next collider Run II (1 to 2 fb^{-1} total integrated luminosity). This physics program that spans the interests of our group members includes: supersymmetry searches, where we expect to collaborate with UF theorists (Field and Ramond), more precise measurements and understanding of top quark physics (mass, production cross-section, kinematics, rare-decays etc.). We are also interested in searching for quark-compositness in the various spectra of jet events and in searching for associated production of the higgs (with W, Z bosons). We are also interested in further pursuing studies of jet fragmentation which have opened a new area in the QCD studies at CDF and branch into a number of sub-topics with possible applications in various other analyses. This range of topics is both interesting and exciting and will provide copious material for involvement of post-docs and for Ph.D. theses for graduate students.

In conclusion, the physics program that we've outlined for our group at CDF is very rich and consistent with the composition and goals of our group. The collective experience of J. Konigsberg and A. Korytov have already facilitated a quick startup in the collaboration and work is already in progress in all projects described above.

2.3 MINOS experiment at Fermilab

G. Mitselmakher

Guenakh Mitselmakher is a member of the MINOS long-baseline experiment at Fermilab. This experiment was recommended by the HEPAP subpanel and approved by Fermilab in 1995. Mitselmakher joined this experiment, before coming to Florida, as a member of the Fermilab team.

Mitselmakher has substantial experience in Iarocci detectors which is one of detector technologies considered by MINOS (Mitselmakher lead the group which built the DELPHI hadron calorimeter based on Iarocci detectors). This experience is very relevant for the MINOS detector studies and will help UF contribute to this program. Currently Mitselmakher is a member of the MINOS Technical Board, a member of the MINOS R&D committee and co-convener of Iarocci detector technology group. He is also the International Coordinator in MINOS, coordinating the R&D efforts of several Russian and Chinese groups participating in MINOS.

In 1997 G. Mitselmakher in collaboration with Fermilab, Argonne and Dubna will continue his R&D activity for MINOS. This activity initially will be based at Fermilab and will include modified Iarocci detectors and readout tests with radioactive source, Iarocci detectors based calorimeters beam tests in streamer and proportional mode, and participation in detector production factory design and optimization.

Computing Support for High Energy Physics

Task S

I Introduction

This computing proposal (Task S) is submitted separately but in support of the High Energy Experiment (CLEO, Fermilab, CMS) and Theory tasks. We have built a very strong computing base at Florida over the past 8 years. In fact, computing has been one of the main contributions to our experimental collaborations, involving not just computing capacity for running Monte Carlos and data reduction, but participation in many computing initiatives, industrial partnerships, computing committees and collaborations. These facts justify the submission of a separate computing proposal.

II History

Our computing system has undergone many changes. Before 1986, there was a VAX 750 purchased by the Theory group which was suitable for software development but did not permit data analysis because of the lack of a tape drive. After the arrival of the experimental group in 1984-1985, we were able to acquire in 1986 a single MicroVAX II (2 MB) with 1.4 Gbytes of disk and a tape for CLEO use. Money for this machine was provided by a $25K competitive award at UF based on our proposed work on distributed computing. The MicroVAX II allowed us to do software development for CLEO and D0 and permitted local data analysis using the large (for its time!) disk resources.

In 1988 or so we put together a package of $400K (50% UF and 50% DOE) to acquire a VAX 6220 with 10 Gbytes of disk, 6250 tape, 5 VAX 3100 desktop workstations and an 8 node VAX 3200 computing farm. We signed an External Research Proposal (ERP) with DEC which brought us contacts with DEC engineers and a 50% price reduction on all hardware components. The deal with DEC, UF and DOE was based on our distributed computing system UFMulti which we had just developed for Vax systems. This software allowed us to run single jobs on the whole computing farm, giving us access to more computing than what was available at Cornell. Andy White, who was at UF at the time, also ran a great deal of D0 and SSC simulations on the farm.

In 1990, we traded in the VAX 6220, 10 Gbytes disk, 6250 bpi tape and the 8 node Vax farm for 28 DECstation 5000s (16 MB), 17 of them networked with FDDI. This deal involved a second Research Proposal with DEC and cost us nothing for the DECstations since we negotiated a large price allowance for the VAX trade in. We then purchased two VAX-3100 servers to replace the expensive 6220 and a lot of disk, along with several 8mm tape drives. We also hired students to port UFMulti to Unix, a necessary move, since it was used for three years to distribute jobs across the DECstations.

In Fall, 1993, we purchased a system based around the new DEC Alpha processors using DOE and University funds. We were able to convince DEC to donate to UF the 26 DEC 5000–200 processors we traded in, making it possible to get $140K in funds from the University. (The processors, monitors, 25 GB of disk and most of our FDDI network were donated to UF to start up a new Unix laboratory for students). Since that time we have added X-Terminals, additional CPUs and disk, DLT tape drives, printers and videoconferencing equipment.

III Current System

Our system is based currently on Digital Equipment Corporation's Alpha processors running Digital Unix, and was purchased with a combination of State and DOE funds over several years. We chose DEC because we have been able to negotiate extremely favorable discounts for many years (some of these discounts resulted from 11th hour negotiation when we were on the verge of moving to other vendors). The system consists of the following pieces:

File servers

1	DEC 3000-500	General users
1	DEC 3000-600	HET server
1	DEC 250 4/266 (PCI)	HEE server
2	DEC 250 4/266 (PCI)	Nile servers
1	DEC 250 4/266 (PCI)	WinNT server
1	Gateway P90	WinNT server (WinDD)

Compute servers

10	DEC 300 5/333 (PCI)	
1	DEC 250 4/266 (PCI)	
8	DEC 3000-600	
3	DEC 3000-700	
12	DEC 3000-600	(Reconstruction farm at Cornell)

Desktop workstations

2	DEC 250 4/266 (PCI)	Graphics workstations
>30	Tektronix	X-Terminals
>10	PCs	

Disk & Tape

170 GB disk

4	DAT drives
3	DLT tape drives (10 GB)

Network

2	Asante 100 Mbit Ethernet hubs (24 ports total)
1	Plaintree 10 Mbit Ethernet switch (16 ports)
1	Asante 10-100 bridge
1	DEC 10 Mbit bridge
1	DEC 10 Mbit hub
13	Incoming modems (28.8 Kbit)
1	ISDN line (for videoconferencing)

Videoconferencing

1	PictureTel Venue 2000 (with audio option, document camera)
1	PictureTel Live 200p (for Cornell office)

Printers

1	HP 4si/MX
1	Tektronix Phaser 550 (color)
1	HP 1600 Deskjet
1	HP 1200 Deskjet
2	HP 660 Deskjet
1	HP 850 Deskjet
1	HP Laserjet 4M+

Notes on the current configuration

1. The system currently supports the high energy experimental and theoretical groups and our collaborators. Essentially every faculty member, postdoc and graduate student has an X-Terminal or equivalent on his/her desk.
2. We also provide accounts for a large number of graduate students finishing their theses and all physics undergraduates. Our support of these latter activities adds a negligible load to the system but provides goodwill within the department.
3. Our networking is based primarily on Fast Ethernet for servers which can support it (PCI based architectures such as the DEC 300 5/333 and DEC 250 4/266). Servers which cannot support Fast Ethernet are connected to the Plaintree Ethernet switch which provides a dedicated 1 MB/sec path to each machine.
4. All PCI based servers have fast/wide SCSI controllers to achieve high disk throughput.
5. We use software from Tektronix (WinDD) to run Windows on X-Terminals. Windows programs such as Word and Excel run on the P90 server but the Windows screen is rendered on the user's X-Terminal. This has turned out to be very cost-effective solution since one PC server can support several Windows users without requiring us to buy a PC for each of them.
6. The two graphics workstations have a high end graphics card for fast 3-D rendering. They are used to support our graphics leadership on CLEO III and CMS.

IV Future Computing Activities

Our acquisition of computing equipment has basically followed the growth in computing requirements in our experimental collaborations, particularly CLEO. However, our group is in a growth phase and we are now obligated to support new experimental endeavors at Fermilab and LHC. We hired a new senior experimenter (Gena Mitselmakher), Scientist (Jacobo Konigsberg) and postdoc (Andrei Numerotsky) and we have an offer out to fill an Assistant Professor position. We expect to fill another tenure track position by Fall, 1997. Thus the HEE group will have more than doubled over a two year period, putting additional pressure on our computing resources.

IV.1 CLEO

Our computing activities up till now have been dominated by CLEO, not only in analysis but in data reduction (Compress) and new iterations of data reduction (Recompress) when warranted by new tracking and particle ID algorithms. These demands are accelerating, driven largely by the high rate of data collection at CLEO, which in turn increases the computing resources needed by data analysis, GEANT Monte Carlo, Compress data reduction and Recompress of all data. Compress, Recompress and Monte Carlo require by far the most computing cycles, and are the areas in which Florida has contributed most heavily over the past several years.

Compress Data Reduction

Florida provides the computing resources to carry out the ongoing Compress data reduction, for 50 pb^{-1} per week which is expected to reach close to 100 pb^{-1} per week after the changes to CESR are implemented. A major change is that the silicon detector will need to be incorporated into the tracking, increasing the time needed to process a single event. However, this increase can be accommodated by the farm already in place. Other groups provide the software and manpower needed to run Compress.

Recompress

CLEO is poised now to redo Compress on the entire CLEO II data sample taken before silicon running, approximately 4.8 fb^{-1}, representing a data sample four times larger than the one Recompressed in 1993, which was a major computing effort by CLEO (Florida carried out 3/4 of that Recompress). Major changes are being incorporated (particularly Kalman filter tracking) and this effort is being given the highest computing priority within CLEO.

Recompress will be run on a DEC Alpha farm, with Florida providing more than half the total computing capacity. Although Recompress has been run every 2-3 years on the total accumulated data sample, we expect that this is the last time it will be run on pre-silicon data. Nevertheless, we expect Recompress to be run in the future to accommodate the inevitable improvements in tracking, particle ID and shower reconstruction. Thus it will demand an ever increasing share of resources.

Monte Carlo

Florida historically generated between 1/2 and 2/3 of the GEANT Monte Carlo events for CLEO, depending on the availability of the farm and the resources used at other institutions, particularly Minnesota. With the new Alpha system in place, we expect to generate between 10 – 15 million events per month for several months after the Recompress is complete, essentially all the Monte Carlo needed by CLEO.

Growth of CLEO Data

The first of several improvements to CESR has been installed which will provide a factor of approximately 2 increase in instantaneous luminosity this year. We expect a total factor of 5 increase by 1997 or so. CLEO currently has on tape about 4.8 fb^{-1}. By late 1997, before these improvements have all been made, we will have approximately 8–10 fb^{-1} of data collected. Thus computing and storage issues are paramount. To effectively carry out the tasks described above we will need to augment our computing resources over the next few years, as will Cornell.

IV.2 BTEV at Fermilab

The BTEV collaboration, begun in 1994, is interested in pursuing a hadronic *B* program at *Fermilab*. Florida's involvement (principally Paul Avery) has been mostly through the development of the MCFAST simulation effort, a fast simulation program offering advanced features such as particle tracing through complicated geometries (including multiple magnets), Kalman filter tracking, multiple collisions and accurate hadronic shower modeling. Now that the C0 intersection region might be developed for trigger studies and proof-of-concept runs, there is a renewed effort to provide computer simulations for physics and detector studies. An EOI was submitted May 31, 1996, and is being followed up by physics and detector studies.

The simulation group (located in the computing Division) is now officially sanctioned by Fermilab in the sense that it will provide the tools (principally MCFAST and supporting software) used by the collider groups to develop detectors and study physics in the next era of running at Fermilab, including top quark physics. A new research scientist position has been filled there to support this effort. The Florida group has recently hired a new postdoc (starting July 1) who will spend up to 1/3 of his time developing MCFAST and running BTEV and CMS simulations.

The Fermilab simulation group is expecting to provide the fast simulation tools for the LHC groups (ATLAS and CMS) at the 1996 Snowmass workshop. We expect that this effort will lead to a great deal of work over the coming year as proposed subdetector elements are added and simulated (only the CMS simulations will be generated in any quantity at Florida). In addition, a large number of simulations, especially backgrounds, will be generated at Fermilab and Florida to make comparisons between detectors with respect to *B* physics, principally CP violation capabilities.

IV.3 Fermilab (CDF/D0) and CMS

With Mitselmakher's arrival in Fall, 1996, Florida has now become a full member of the CMS (Compact Muon Solenoid) experiment at LHC. Mitselmakher is the Project Manager for the Forward Muon Spectrometer, one of six major subsystems of CMS. As mentioned above, two additional faculty level people and a postdoc will be in place by Fall, 1996. To maintain a connection with current experiments, the new Florida group is negotiating to join either CDF or D0 (Avery and Yelton will remain with CLEO). In addition, Avery, Yelton and Rick Field have joined CMS and have recently begun taking active roles.

These new activities will certainly put additional strains on our computing resources, particularly because of the large number of CMSIM (CMS GEANT package) simulations which will have to be run. As MCFAST becomes adapted for CMS, a large number of simulations will need to be run as well, particularly to study track reconstruction and physics results.

V The UFMulti and Nile Distributed Computing Projects

In 1989 we developed a distributed computing software system called UFMulti, which became the cornerstone of the UF analysis effort from 1989 to 1994. With UFMulti a single HEP analysis application could be distributed across a large set of Unix machines and run in parallel. Our development of UFMulti also helped generate funding for computer resources and enabled us to negotiate better discounts from computer vendors. The latter parts of this work were done in collaboration with Theodore Johnson of the Computer Information Science Department at Florida.

UFMulti was limited to running analysis jobs run in well understood environments. It was difficult to port to Cornell because of the large numbers of people using few computing cycles, which led to a zero-sum situation which could not be helped by distributed computing. However, our experience in that effort led to us to become co-PIs in an ambitious National Challenge computing effort called "Nile" to develop a powerful networked computer system which would have the ability to run jobs on computers spread across geographic distances. The institutions involved are Florida, Cornell, UT Austin and UCSD.

We received funding for Nile in July, 1994 from the NSF and we expect it to continue for a total of 5 years (we are just about to receive our year 3 funding). We are developing the software using ideas developed in UFMulti together with the highly fault–tolerant distributed software developed by the ISIS group at Cornell. We are also adopting database tools developed elsewhere and are designing paradigm for data analysis which is explicitly parallel. Since most of the money funds graduate students and postdocs working directly on distributed computing, Nile contributes only marginally to the processing capacity at UF (e.g., fast networking).

The hardware centerpiece of the proposal are the testbed systems, which consist of two farms located at Cornell and UF, each of which has its components linked together by fast networking hardware paid out of the grant. A prototype software system called FastTrack has just been made available for CLEO collaborators to run analysis jobs on the testbed systems. FastTrack is being used to gain front-line experience in running real analysis jobs (using data stored in the standard format) and will evolve into a more robust system which will use database storage (for faster and more direct data access) and take advantage of computers at multiple sites.

VI Other Computing Activities and Talks

Paul Avery has been involved in computing activities since his arrival at Florida in 1985. He served on three SSC computing committees and has reviewed computing activities at the D0 experiment, the BaBar experiment and CEBAF. He is a member of the High Energy Physics Network Research Committee (HEPNRC) and is a member of the US Computing Group of CMS. He has given a number of talks on computing, some of which are listed below.

1. "A New Approach to Distributed Computing in High Energy Physics", at the XXVI International Conference on High Energy Physics, Dallas, TX, August, 1992.
2. "Distributed HEP Computing with NetQueues", at the Meeting of the Division of Particles and Fields, Fermilab, Chicago, IL, Nov., 1992.
3. "The UFMulti Project", at the International Conference on Computing in High Energy Physics, San Francisco, CA, April, 1994.

4. "Use of Network Modeling Tools in the Nile System Design", presented at the International Conference on Computing in High Energy Physics, Rio De Janeiro, Brazil, Sep. 21, 1995.
5. "Summary of the Analysis Session", summary paper presented at the International Conference on Computing in High Energy Physics, Rio De Janeiro, Brazil, Sep. 21, 1995.