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ELEMENTARY PARTICLE PHYSICS AT THE UNIVERSITY OF FLORIDA

Annual Progress Report
DOE GRANT DE-FG05-86ER40272

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University of Florida
Gainesville, Florida 32611

December 1, 1995

Task A: Theoretical Elementary Particle Physics
R. Field, P. Ramond, P. Sikivie, C. Thorn
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Grant Coordinator: *R. D. Field*

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

Annual Progress Report
TASK A

Theoretical Elementary Particle Research at the University of Florida

Principal Investigators:
Richard D. Field
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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 four 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, 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 has benefited substantially from the creation of the Institute for Fundamental Theory (IFT) at the University of Florida. The IFT is an interdisciplinary center involving high energy theory, condensed matter theory, cosmology-astrophysics, and mathematics and receives operating funds from the University of Florida.

The high energy theory group at the University of Florida was created in 1980 with the arrival of T. Curtright, R. D. Field, P. Ramond, and C. Thorn. The following year we were successful in acquiring a DOE grant. 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 group was allowed to increase by two junior faculty. 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 and to bring the size of the group to seven faculty.

This year Z. Qiu was promoted to Associate Professor, so at present our group consists of four Full Professors (R. D. Field, P. Ramond, C. Thorn, and P. Sikivie), two Associate Professor (R. Woodard, Z. Qiu), and one Assistant Professors (D. Kennedy). In addition, we have four postdoctoral research associates. Three are funded by the DoE and one is funded by the IFT. We have a good group of graduate students and have produced at least one Ph.D. in each of the last eight years.

The scientific activities of our group are rich and varied, ranging from theoretical theory all the way to numerical phenomenology. At one end of the spectrum, the baffling conceptual theoretical problem of formulating a consistent quantum theory of gravity is one aspect of the research conducted here. The extraordinarily rich superstring theory as the only known consistent theory of quantum gravity also provides a theoretical laboratory in which this difficult subject can be studied. Further, string theory offers new directions of study and links between hitherto unrelated fields of study. Some of these directions are explored in research conducted here.

This year on February 24-26 we hosted our third IFT workshop on "The Quantum Impurity Problem". The three day workshop attracted over 80 participants (theorists and experimenters) and was very successful.

II. PARTICLE THEORY PERSONNEL

(a) Faculty

The following is a list of the faculty members of the particle theory group and their status. Dallas Kennedy is the newest member of the group. Dallas received his Ph.D. from Stanford University under Bryan Lynn and was a Research Associate at Fermilab before joining the group. This year Zongan Qiu was 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. We have had as many as six concurrent postdoctoral positions. At one time two were funded by the Department of Physics, one by IFT and three by DoE. However, at present, the Department of Physics no longer provides for postdoctoral research associates and we have four positions (three supported by DoE and one supported by the IFT). 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
O. Bergman	**(IFT, 8/1/94-present)**	-
L. Chandar	**(8/1/95-present)**	-
C. Coriano	**(8/1/95-present)**	-
A. Faraggi	**(8/1/95-present)**	-

This year Paul Griffin accepted a position at Rockefeller University. In addition, K. Anagnostopoulos and M. Booth obtained Postdoctoral fellowships at John Hopkins and the Neils Bohr Institute, respectively. To replace these three Postoctoral positions we hired Lakshminarayan Chandar from Syracuse University, Claudio Coriano from Stony Brook, and Alon Faraggi from Texas A&M University.

In addition to postdoctoral research associates, we have had several long term visitors that have contributed significantly to our group. Jooyoo Hong visited our group for a year and has recently obtained a faculty position at Han-Yang University. Also M. Masip from the University of Granada, Spain and M. de Montigny from the University of Montreal, Canada have worked in our group. Masip and de Montigny came with their own fellowship money. This year Sang Hyeon Chang from Korea will visit the group for a year.

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-present)	Seoul National University

(c) Graduate Students

We have been successful in attracting good graduate students and in placing them in postdoctoral research positions. This year J. Rubio, J. Kim, and S. Mikaelian received their Ph.D. degree. Kim accepted a position at the Houston Advanced Research Center (HARC). Rubio and Mikaelian are looking for jobs. We feel that the training students in theoretical physics is an important part of our role. Each year we send students to summer programs such as TASI and SLAC. The following is a list of our current graduate students together with our former students and 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. 8/95
M. Tayebnejad	Field	Ph.D. expected in 1996
Y. Kanev	Field	Ph.D. expected in 1997
N. Irges	Ramond	Ph.D. expected in 1998
W.-L. Liu	Qiu	Ph.D. expected in 1997

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 IFT (and sometimes DSR) funds during the summer. In addition, whenever funds permit we would like to support students during the last stages 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 networks to distinguish between signal and background using a large number of 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.

We recently completed 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, submitted to Phys. Rev. D*). 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.

Since the completion of this paper, 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 with two "hidden layers". We have found that simpler networks with just one "hidden layer" are easier to train and perform as just as well on the types of problems that arise in collider phenomenology. We believe that by using these simpler networks and by increasing the number of input variables to include additional global information such as the number of forward jets in the event, *etc.* , we can improve on our previous analysis. We are also attempting to use neural networks to help identify top quark events at the Fermilab collider.

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 plan to attend the collaboration meeting in September. I hope that I can do some LHC collider phenomenology that will be of particular interest to the collaboration.

(b) D. Kennedy

In the past academic year, I completed my transition to working exclusively on particle and nuclear astrophysics, rooted in my past work in the solar neutrino problem, and ended my work in electroweak gauge theory and phenomenology. My earlier solar neutrino work had begun at U. Pennsylvania (Penn) with P. Langacker, S. Bludman, and N. Hata (now at Ohio State). This work concentrated on emphasizing the inadequacy of "reasonable" astrophysical solutions of the solar neutrino flux deficit and on combining solar model tests with tests of matter-enhanced (MSW) neutrino flavor oscillations, based on analysis of solar neutrino data. The work included my 1990 TASI lectures on solar neutrinos and a solar model/MSW data analysis code (SNEU) by myself and Hata. This research has since become a standard reference in the field and formed the basis for the expanded treatment by Hata, Langacker, and Bludman of combined neutrino and nuclear physics and solar structure. My own collaboration has branched off into related problems with Bludman and G. Bonvicini (CERN, now Wayne State U.), an experimentalist working on the HELLAZ experiment and solar neutrino/cosmic dark matter detection.

Bludman and I are in the draft stages of two interrelated projects concerning stellar and solar structure and evolution. Our interest in these problems grew out of the question of whether a simplified, alternative scheme was possible for Main Sequence stellar models, particularly with respect to their neutrino fluxes. Our method was to emphasize analytic treatment of stellar structure, considered as a combined problem of non-equilibrium thermodynamics and self-gravitation, and reformulate the structure and evolution problems in terms of mechanical and thermodynamic variational principles. The already-existing numerical treatments serve as theoretical calibrations and checks in our approach. Our work is yielding a new, compact formulation of stellar structure and evolution and, in parallel, a relatively simple analytic framework for the relation of neutrino fluxes to solar interior properties and solar model inputs. Bonvicini, Bludman, and myself are beginning a natural secondary project from these results, calibrating against the best available data and other Sun-like Main Sequence stars (as one would calibrate a laboratory source of neutrinos), the canonical solar model and neutrino flux predictions. This calibration is covering not only uncertainties the standard model inputs, but a general form for incorporating non-canonical structural features in the solar interior (rotation, magnetic fields, luminosity variations, other possibilities).

Before this collaboration is completed, I will probably complete some formal work in the non-equilibrium thermodynamics of relativistic particles and fields with G. C. Essex (U. Western Ontario), a specialist in radiation thermodynamics with whom I have had fruitful contacts.

I have two planned collaborations in the discussion stage to begin as soon as the stellar structure/neutrino projects are finished. The first is with G. Starkman (Case Western Reserve U.), concerning novel, inexpensive, and multi-purpose techniques for the detection of solar neutrinos and cosmic dark matter using atomic physics. The second is with P. Kumar (U. Florida) on relativistic many-body novelties and their application to astrophysics.

The Division of Particles and Fields (DPF) of the American Physical Society (APS) commissioned at the beginning of 1994 a study of American high-energy physics (Drell Panel). After attending the DPF workshop (Electroweak Symmetry Breaking) at U. California, Santa Barbara, February 1994, I researched and completed a review and summary of electroweak gauge theory and measurements. This work has been incorporated into the DPF proceedings and is now in publication as part of the final book form of the Drell Panel study. A short survey article I wrote at Fermilab (first version, March 1993) on ecological economics in the context of non-equilibrium complex systems has been submitted to the Santa Fe Institute for their new journal, *Complexity.*

I have placed my planned electroweak work, review articles on electroweak radiative corrections and precision measurements, and further work on broken technicolor (electroweak dynamical symmetry breaking), in hibernation for now. I hope to return to it within the next five years, as electroweak accelerator physics reaches further maturity.

Research Plans for 1994–97:

- Stellar and solar structure/evolution, relation to neutrinos
- Formal issues of non-equilibrium thermodynamics and gravity
- Relativistic many-body physics and astrophysics
- Novel detection methods for solar neutrinos and dark matter

(c) Z. Qiu

In recent papers, $I = 20$ 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 amplitude of the string theory has new contributions from "colored" Riemann surfaces, black and white in our 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.

There are many interesting questions one can consider following this idea. 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.

I also study the role of 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 "$c = 3D1$ barrier" is addressed. I also consider the quantization of the theory in critical dimensions in conformal gauge.

The main result of the paper 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 a much simple formulation of the problem in terms of matrix model. Works in this direction are 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 recently advances in these two subjects are based on the advance in the mathematical structure shared. The more familiar examples are the connections obetween 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. My would like to understand other type of non-local effect. One particular case is that two conformal field theories sharing a common boundary. The central object of interesting is an "interacting vertex" connecting two Hilbert spaces. The study of conformal interference also provides the mathematical tool needed in studying interactions of different types of strings.

I am also look again at the problem of string compactification, together with H. Tye of Cornell University. 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 the research in this direction may offer hint about how a particular compactification or compactifications are favored. Furthermore any better understanding of the physics beyond standard model will offer more restrictions and similarly the structure of the space of all compactifications might also give some guidance to physics beyond standard model.

(d) P. Ramond

Recent Activities This year my research activities have centered on the connection between theories coming from superstrings and phenomenology. Regarding the low energy theory as an effective theory coming from perhaps superstrings, Pierre Binétruy and I have been able to relate certain aspects of the quark and lepton masses to the existence of an anomalous $U(1)$ symmetry. What cancels its anomalies? Superstring theories generically predict the existence of an anomalous $U(1)$ symmetry, broken a few orders of magnitude below the string unification scale. Its anomalies are cancelled via the Green-Schwarz mechanism. This enables us to relate the Weinberg angle to the order of magnitude of the ratio of quark to lepton masses. Amazingly we find that the known values of these masses, when extrapolated with supersymmetry to a few orders of magnitude below Planck scale, actually give the correct value of the Weinberg angle. Binétruy and I wrote a physics letter describing these results. We are now preparing a longer paper on the same subject, where the analysis has been extended to neutrino masses and mixing angles. Over the spring and the summer, I have been working on extending the Seiberg duality to exceptional groups. I am collaborating now on this work with S. Giddings at Santa Barbara, and Ann Nelson at Seattle. I have also been finishing my book on the standard model and beyond, with an anticipated completion date by this Christmas (late by one year!).

I have one student, N. Irges, who is working with me on extending our analysis of the anomalous $U(1)$ to include other symmetries.

(e) P. Sikivie

In March '95, the paper "Casimir Forces Between Beads on Strings and Membranes" by Eric d'Hoker (UCLA), Youli Kanev (Univ. of Florida) and myself appeared in Phys. Lett.B. In this paper, we develop a general formalism to calculate the force between beads attached to a flat membrane due to the quantum fluctuations of the membrane. We derive the interaction potential between the beads as a function of the dimension d of the membrane, its energy density, tension, stiffness and temperature. We find that the induced interaction turns off when d exceeds a certain critical dimension. The potential is attractive in all cases where it is non-zero. At finite temperature, it falls off exponentially at large distances.

In April '95, I. Tkachev and Y. Wang, both of whom are post-docs in the astrophysics group at Fermilab, and I finished our preprint "The Velocity Peaks in the Cold Dark Matter Spectrum on Earth". J. Ipser and I pointed out a few years ago that the spectrum of cold dark matter particles on Earth is expected to have peaks in velocity space. The new paper with Tkachev and Wang is the first to provide reliable estimates of the sizes and locations of the peaks as a function of cosmological parameters such as the age of the universe, the amount of angular momentum in our galactic halo and the index which characterizes the spectrum of primordial density perturbations. Our main tool is the secondary infall model of galactic halo formation which we have generalized to include angular momentum of the dark matter particles. Our model establishes a relationship between the core radius of a galactic halo and the amount of angular momentum the dark matter particles carry. Our results are relevant to the dark matter axion search at LLNL. Indeed, the signal to noise ratio of that search is increased by a factor 180 f_1 by looking for narrow peaks, where f_1 is the fraction of the local axion density in the largest of the peaks with width $\Delta E < 10^{-11}\ m_a$ where m_a is the axion mass. We find that f_1 is typically as large as 4%, implying that the signal to noise ratio of the experiment is increased by a factor 7 by looking for narrow peaks. We intend to write a longer paper describing our model in detail and comparing it against the available observational data on the distribution of dark matter in galactic halos.

I wrote a short review article on the sources and distribution of dark matter. It will be published in the proceedings of the conference on "Recent trends in Astroparticle Physics" that I attended in Stockholm last October. I also wrote an introduction to axion physics which is intended for a wide readership. It is entitled "The pooltable analogy to axion physics" and will be published in the proceedings of the Moriond Workshop which I attended last January. I intend to resume work on a review of axions. I have worked on this review intermittently for the past ten years. I would like to finish it this year.

In spring '94, my student, Jaewan Kim, and I wrote a paper in which we derive the response of a wiggle on a string to adiabatic stretching of the string for both longitudinal and transverse wiggles and for arbitrary equation of state, i.e. for arbitrary relation between the tension τ and the energy per unit length ϵ of the string. The Nambu-Goto string correponds to the particular case $\epsilon = \tau$. Our analysis completes the program Jooyoo Hong, Jaewan Kim and I started two years ago to drive the renormalization of string parameters which results from averaging out small scale wiggles on a string. Our main motivation has been to try and improve our understanding of cosmic gauge strings but the formalism we have developed is quite general and may have applications in other areas. Jaewan graduated this summer and found a post-doctoral position at the Houston Advanced Research Institute.

(f) C. B. Thorn

The hope is often expressed that string theory might be a useful tool for describing quark confinement in QCD. While it is undoubtedly true that 't Hooft's $1/N_c$ expansion of QCD leads to some kind of a string theory (assuming quark confinement), this "QCD string" is quite a different object than the subcritical string obtained from dual models.

For one thing, the QCD string must be compatible with asymptotic freedom and contain hard point like structures. For another, QCD is not generally covariant and hence could never produce a graviton in a consistent approximation. In 1992 M. McGuigan and I showed that the Regge trajectories predicted by large N_c QCD must be nonlinear – in sharp contrast to the exact linearity of Regge trajectories in zero coupling string theory. We did this by calculating the large t behavior of quark-antiquark Regge trajectories in large N_c QCD. Because we work at large t, perturbation theory is expected to be reliable. We published this work in a 1992 Physical Review Letter. A striking implication of these results is the prediction that the ρ trajectory should approach zero from above as $t \to -\infty$. Since existing measurements of the ρ trajectory indicate that it crosses zero at $t \sim -.5(\mathrm{GeV})^2$ and decreases further to around $-.7$ for $t \sim -7$ $(\mathrm{GeV})^2$, this raises questions about how the QCD predictions square with the real world. There is persistent evidence that the measured value of $\alpha_\rho(t)$ increases when it is extracted from higher energy data.

In Fall 1992 a graduate student Mikaelian and I studied the trends of existing data in order to estimate when asymptopia should set in and to decide whether future experiments might be able to resolve the discrepancy. We fit the data to a superposition

$$\mathcal{M} = \beta_1(t)s^0 + \beta_2(t)s^{\alpha}(t)$$

where the first term is a crude representation of the hard parton QCD prediction and the second term serves to parametrize the soft hadronic part of the process. We found that a value of $\beta_2/\beta_1 \sim 20$ gives a rough acount of the energy dependence found in the measured ρ trajectory. For extremely high s, say $4000\mathrm{GeV}^2$ the QCD term should stand out clearly. I presented these results to a conference at Coral Gables in January 1993. Mikaelian is currently seeking more understanding of the apparent suppression of hard components in Regge scattering in the context of a simple potential model that mimics the scaling violations of QCD. This work will form a substantial part of his doctoral dissertation.

In late 1993, Brodsky, Tang and I published a Physics Letter, in which we 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 relatively small contribution, so that the low measured value of the rho trajectory is consistent with a "hard rho trajectory" above zero: much higher energies are needed to expose the true rho trajectory.

For the past five years, I have been developing the idea that relativistic strings are composites of point-like objects I call String Bits. This project is motivated by the desire to bring string theory into the framework of ordinary quantum field theory, and also by the feeling that the apparatus of string field theory is overly cumbersome and perhaps not even internally consistent. In the early 90's I reworked an earlier "wee parton" model of composite strings into an explicit Galilei invariant (not Lorentz invariant!) field theory of particles (String Bits) moving in $D-2$ space + 1 time dimensions. This possiblility shows that one can get the rich structure of string theory from a theory with vastly fewer degrees of freedom than quantum field theory in D space-time dimensions. These ideas appeared in the proceedings as an invited talk to the Sakharov Conference in Moscow (May 1991). I recently (1994) posted an updated version of this talk to the hep-th bulletin board.

In 1993 Steve Carbon, then a graduate student, and I carried out a systematic study of the short distance structure of string theory via high momentum transfer scattering amplitudes. In particular we made a detailed exploration of the role "sister Regge trajectories" play at high momentum transfer. This study is a major component in the research of my student Carbon who received his Ph. D. in May 1993. A joint article by Carbon and me on the interpretation of sister trajectories in terms of string configurations has recently appeared as a rapid communication in Physical Review D. (1994).

In May and June 1993 I participated in a workshop on strings and black holes at the ITP in Santa Barbara. There I became intrigued by recent advances in understanding the information loss problem associated with Hawking radiation from black holes. One indication from recent work of 't Hooft and Susskind is that a resolution of the information loss paradox probably involves a profound reduction in degrees of freedom at the Planck scale. Since this is also a prominent feature of the reformulation of string theory I am pursuing, my enthusiasm for further work in this direction has substantially increased. I recently completed a long paper exploring the micro/macro connection between string bits and strings in my model. This work has been published in Physical Review D. (1995).

During the past academic year (94-95), I have worked with Oren Bergman, one of our post-docs, to extend my string bit ideas to the superstring. As I mentioned earlier, the string bit model is formulated as a Galilei invariant theory in one less dimension than string apparently experiences. Thus the first task is to extend the Galilei group to a "super" Galilei group. Such extensions had already been treated in the literature, but not in the context of string theory. We have recently completed two papers devoted to this project. One addresses the general problem of supersymmetrizing the Galilei group, and 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 at the level of interacting string.

In the next few years I expect my research efforts to involve:

1. Continued efforts to build a truly nonperturbative formulation of superstring theory. Progress here could of course have important implications for quantum gravity and, in particular, the black hole information loss problem. It is most urgent to try to surmount the obstacles Bergman and I encountered with fully supersymmetric string interactions. A completely successful supersymmetric string bit model would be a tremendous improvement over previous fundamental formulations of string theory.
2. Consideration of 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 I am also getting excited about 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.

3. Continued efforts toward a bootstrap approach to solving large N_c QCD. I am not currently pursuing this project, since developing a string bit model for superstring and the phenomenology of measuring Regge trajectories at the Tevatron and HERA are higher priorities for me.

(g) R. Woodard

My basic interest is quantum gravity in the larger context of Lagrangian field theory and particle physics. For most of the past year I have worked in collaboration with Professor Nicholas Tsamis of the University of Crete on the implications of quantum gravity for the problem of the cosmological constant. This problem is that Einstein's theory of gravity has an apparently free parameter called the "cosmological constant" whose current value must be fine tuned to one part in 10^{120} in order to prevent the radius of the universe from either shrinking to near zero or else expanding exponentially. The problem is especially vexing because direct 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.

For the past four years Nick and I have been pursuing the idea that quantum gravity might mediate the transition from inflation because gravitons are unique among the known massless particles in possessing a coupling of dimension three and in violating conformal invariance. We call this theory, "quantum cosmological gravity," or QCG, in order to distinguish it from the conventional theory with zero cosmological constant. Our initial work produced the first correct perturbative formulation of QCG. We have used the formalism to establish the following facts:

(1) Although QCG is not perturbatively renormalizable, it can still be used reliably as a quantum theory in the far infrared;

(2) QCG corrections to the large scale structure of an inflating universe become strong at late times;

(3) QCG dominates the large scale structure of an inflating universe with respect to any matter theory whose current phenomenological viability does not require fine tuning;

(4) If one assumes that the natural vacuum of inflation suffers only perturbatively small corrections then asymptotic graviton scattering amplitudes are infrared divergent even at tree order;

(5) Causal time evolution from an initially inflating universe results in QCG corrections which act to slow inflation by an amount that becomes non-perturbatively large at late times.

Point (5) is based on a calculation we did in the summer of 1994 but did not have time to check thoroughly then. Starting from a homogeneous and isotropic free vacuum on $T^3 \times R$, we follow the evolution of the expectation value of the invariant element in co-moving coordinates:

$$\Big\langle 0 \Big| g_{\mu\nu}(t,\vec{x})\, dx^\mu dx^\nu \Big| 0 \Big\rangle = -dt^2 + a^2(t)\, d\vec{x} \cdot d\vec{x}$$

From this we define the (generally coordinate invariant) effective Hubble constant as:

$$H_{\rm eff}(t) \equiv \frac{d\ln(a)}{dt}$$

Our initial result for $H_{\rm eff}(t)$ contained an error in the loop integrations; a special class of denominators was given double strength. Fortunately, we discovered the error before submitting a paper for publication. Unfortunately, correcting the error resulted in the complete cancellation of the leading order, $(Ht)^3$ terms. We have spent most of this year understanding why the cancellation must occur, obtaining the non-zero result from the order $(Ht)^2$ terms, and subjecting the revised calculation to every check we could imagine. The revised result is:

$$H_{\rm eff}(t) = H\left\{1 - \left(\frac{\kappa H}{2\pi}\right)^4 \left[\tfrac{605}{36}(Ht)^2 + \text{subdominant}\right] + O\left(\kappa^6 H^6\right)\right\}$$

Here $H \equiv \sqrt{\frac{1}{3}\Lambda}$ is the classical Hubble constant and $\kappa^2 \equiv 16\pi G$ is the usual loop counting parameter of quantum gravity. The usual caveat should be given: this is only the second two loop calculation ever done in quantum gravity, and it is the first one for which the ultraviolet finite part was obtained. Though I will not be completely happy until the revised result has been independently confirmed, we did make the following checks:

(1) The loop integrations were performed in two completely different ways.

(2) Hand calculations were made of the contribution from individual vertices, and this was checked against the computer generated result for the same combination of vertices.

(3) The sign of the contribution to $H_{\rm eff}(t)$ from each diagram was checked and shown to agree with theory. The coefficient of $(Ht)^2$ can be broken down as follows:

$$\tfrac{605}{36} = \tfrac{8273}{108} - \tfrac{1271}{27} - \tfrac{20}{3} - \tfrac{109}{18}$$

The first term arises from the diagram with three graviton 3-point vertices. It is positive because 3-point interactions lower the vacuum energy. The second and third terms arise from diagrams with two and three ghost-graviton vertices. They are negative because ghosts subtract unphysical degrees of freedom from the positive, pure graviton loops. The final term comes from a diagram where the external graviton connects to a 4-graviton vertex. It is negative because the 4-point interaction tends to stabilize the energy.

(4) The one loop graviton self-energy — which is a component of the two loop tadpole — obeys the Ward identity.

(5) The flat space limit of the one loop graviton self-energy agrees with the flat space result obtained by Capper (J. Phys. **A13** (1980) 199.) in the same gauge.

(6) The gauge independence of $H_{\text{eff}}(t)$ was checked by explicit calculation.

(7) The appearance of non-zero $(Ht)^2$ terms at this order in perturbation theory was shown to be a consequence of dimensional analysis and the ultraviolet divergence structure predicted for QCG by Deser and van Nieuwenhuizen (Phys. Rev. **D10** (1974) 401).

We also came up with a simple physical argument for why the induced stress-energy obeys the equation of state for negative vacuum energy, to leading order. My plans for the coming year are to carefully document the result and then move on to the problem of developing a non-perturbative model for the effect.

(h) O. Bergman

During the past year I have studied two different approaches to the problem of formulating a fundamental theory of strings. The first, string field theory, was studied in collaboration with B. Zwiebach (MIT), and the second, string-bit models, in collaboration with C. Thorn (Florida).

B. Zwiebach and I proved a theorem in closed string field theory, long believed to hold for on-shell string scattering amplitudes [1]. Our work extends the result for off-shell processes, and in fact shows that it is a consequence of a particular symmetry of the string field action. The theorem relates the closed string coupling constant to a particular state of the string excitation, namely the dilaton. The theorem was proven as an extension of background independence of string field theory, and is a hint that the space of closed string backgrounds is not quite equivalent to the space of conformal field theories. This may have implications to a manifestly background independent formulation of string theory. More work is required to determine what these implications are.

String-bit models are an attempt to reformulate string theory as a matrix field theory of particles called string-bits. C. Thorn and I have managed to extend the picture of the free string as a composite of small string-bits to incorporate the supersymmetry of the type IIB superstring [2]. Our superstring bit model requires more work in order to understand the emergence of string-string interactions. We would also like to study the implications of superstring bit models on black hole physics, and whether the compositeness of strings can account for the entropy of a black hole.

As an off-shoot of superstring bit models, C. Thorn and I have also studied other Super-Galilei invariant field theories [3]. These are generalizations of previously studied non-relativistic supersymmetric theories. For matrix valued fields, which are relevant for string-bit models, we find a rather severe restriction on the form of the theory: It is exactly conformally invariant. Consequently it is inadequate to describe strings. This raises the question of whether one can retain enough supersymmetry in a good string-bit model. We expect to answer this question in the coming year.

References:

[1] The Dilaton Theorem and Closed String Backgrounds, O. Bergman and B. Zwiebach, Nuc. Phys. B 441 (1995).

[2] String Bit Models for Superstring, O. Bergman and C. Thorn, to appear in Phys. Rev. D, hep-th 9506125.

[3] Super-Galilei Invariant Field Theories in 2+1 Dimensions, O. Bergman and C. Thorn, hep-th 9507007.

(i) L. Chandar

My current area of research is in the application of edge states in the understanding of two very different problems: (a) Quantum Hall Effect; (b) Black hole Physics.

In the former, we have shown [1] how one can obtain a hierarchy of the observed fractional conductivities by means of certain duality transformations of the theory describing the edge currents. We have also discussed corresponding sequences of the bulk Chern-Simons models and an analogous "duality" for the Chern-Simons theory in a subsequent work [2]. I am also currently investigating the problem of tunneling between multi-layered Hall samples where the tunneling is via the edge states.

As regards the application to black hole physics, we have studied the appearance of similar edge states in Einstein gravity [3] when the region corresponding to the interior of the black hole is excised from the manifold. Our aim is to understand the black hole entropy in terms of a "lack of knowledge" of these edge degrees of freedom. More specifically, in our approach, we identify (at least a part of) the black hole entropy with the entanglement entropy that arises when we trace out the edge states. It is therefore of significant interest that in a model calculation that we carried out in a 2+1 dimensional setting [4], this entropy does obey an area law. The generalization of this result to 3+1 dimensions is one of the problems that I am currently looking into.

References:

[1] Duality and the Fractional Quantum Hall Effect, A.P. Balachandran, L. Chandar and B. Sathiapalan, Nucl. Phys. B443 465 (1995).

[2] Chern-Simons Duality and Hall Effect, A.P. Balachandran, L. Chandar and B. Sathiapalan PSU/TH/156, SU-4240-598, UFIFT-HEP-95-16.

[3] Gravitational Edge States and Black Hole Physics, A.P. Balachandran, L. Chandar and A. Momen, SU-4240-590, gr-qc/9412019 (1994).

[4] Role of Edge States in Entanglement Entropy, A.P. Balachandran, L. Chandar and A. Momen (in preparation).

(j) A. Faraggi

During the academic year 1994/5 I worked mainly on three topics. The first is the analysis of the vacuum structure of N=2 supersymmetric SU(N) gauge theories (in collaboration with Philip Argyres). The second is on the problem of gauge coupling unification in superstring theory. The third is on fermion masses in superstring derived models.

In the first work we [1] extended the analysis of Seiberg and Witten for N=2 super Yang-Mills with SU(2) gauge group to N=2 super Yang-Mills with SU(N) gauge group. The exact nonperturbative solution that describes the moduli space of the vacua and the spectrum of physical states was identified with the moduli space of a special set of genus n-1 hyperelliptic Riemann surfaces.

Under the second topic I pursued several research projects, related to the superstring models that he constructed. These models are constructed in the free fermionic formulation and are the most realistic superstring models constructed to date. Several general properties of this class of string models suggest that the true string vacuum may indeed lie in their vicinity. However, free fermionic models in particular, and string theory in general, predict that gauge couplings are unified at the string scale, while the unification of gauge couplings within the minimal supersymmetric standard model occurs at a scale which is smaller by a factor of twenty. The problem of gauge coupling unification is one of the major problems confronting string model building. I investigated (in collaboration with Keith Dienes) [2] the problem of gauge coupling unification in realistic free fermionic string models. First, we developed a systematic procedure for evaluating the one-loop heavy string threshold corrections in free-fermionic string models, and explicitly evaluated these corrections for each of the realistic models. The string threshold corrections were found to be small, and general arguments explaining why such threshold corrections are suppressed in string theory were given. The effect of non-standard hypercharge normalizations, light SUSY thresholds, and intermediate-scale gauge structure, were studied as well. Finally, the effect of additional color triplets and electroweak doublets beyond the MSSM, was investigated. The conclusion is that among those effects only intermediate matter thresholds can resolve the disagreement with the low energy data. It was shown that string models, in general, predict the existence of the needed spectrum and that if the additional states exist at the appropriate thresholds, then the gauge couplings will indeed unify at the string scale.

The third topic is investigation of the effect of the intermediate matter thresholds on the top quark mass prediction. I predicted the top quark mass to be in the range 175-180 GeV several years prior to its experimental confirmation by the CDF/D0 collaborations. Following the confirmation by the CDF/D0 collaborations I revisited this analysis and included the effect of the intermediate matter thresholds that are required for string gauge coupling unification. I showed that the measured gauge couplings as well as the top bottom and tau lepton masses, can all be consistent with the superstring derived standard-like models that I constructed [4].

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] The vacuum structure and spectrum of N=2 supersymmetric SU(N) gauge theory, P. C. Argyres and A. E. Faraggi, Phys. Rev. Lett 74 (1995) 3931.

[2] GAUGE COUPLING UNIFICATION IN REALISTIC FREE FERMIONIC STRING MODELS, K. R. Dienes and A. E. Faraggi, IASSNS-HEP-94-113, submitted

to Nucl. Phys. B.

[3] MAKING ENDS MEET: STRING UNIFICATION AND LOW-ENERGY DATA, K. R. Dienes and A. E. Faraggi, IASSNS-HEP-95-24, to appear in Phys. Rev. Lett.

[4] TOP QUARK MASS PREDICTION IN SUPERSTRING DERIVED STANDARD-LIKE MODELS, A. E. Faraggi, IASSNS-HEP-95-53, submitted to Phys. Rev. Lett.

[5] CALCULATING FERMION MASSES IN SUPERSTRING DERIVED MODELS, A. E. Faraggi, IASSNS-HEP-95-60, to appear.

IV. ACTIVITIES OF THE PARTICLE THEORY GROUP (*since 1992*)

A. Lectures and Seminars

Field

URA Fermilab Review, Jan 17-18, 1992

Physics Colloquium presented at the University of Florida, Feb. 6, 1992

High Energy Physics Seminar presented at the Institute for Fundamental Theory, University of Florida, Nov. 6, 1992

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

Kennedy

Seminar, University of Florida, October 1993

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.

Qiu

Theoretical Physics Seminar, Cornell University, August 1992

Seminar, University of Florida, September 1992

Colloquium, University of Florida, October 8, 1992

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 Angles, CA, March 1995

Three Lectures at CCAST, Beijing, China, August 1995

Ramond

Seminar, Princeton University, May 1992

Colloquium, SSC, June 1992

Public Lecture, Aspen, Co, July 1992

Invited Lecturer, Erice, Italy, Sept 1992. Title: Neutrinos in Particle Physics

Seminar, Ecole Normale Supérieure, Paris, Sept 1992

Invited Lecturer, Yale Workshop, Oct 1992

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, University of Virgina, Richmond, VA, April 1994

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

Invited Speaker, 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 speaker, Florida State University, Tallahassee, Florida, October 28, 1994

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, Quebec, Canada, June 14-18, 1995

Sikivie

Invited talk at the IFT Workshop on Dark Matter, Gainesville, FL, Feb. 14-16, 1992

Invited talk at the ITP Workshop on Cosmological Phase Transitions, Santa Barbara, CA, April 2-4, 1992

Particle Physics Seminar at UCLA, May 8, 1992

Colloquium at the Institute for Theoretical Physics, Santa Barbara, CA, May 13, 1992

Particle Physics Seminar at Caltech, May 25, 1992

Seminar at ITP, Santa Barbara, CA, June 17, 1992

Colloquium at the FSU Physics Department, Tallahassee, FL, Oct. 8, 1992

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 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

Thorn

Theoretical Physics Seminar, Univ. of North Carolina, Chapel Hill, NC, March 1992

Theoretical Physics Seminar, Institute for Advanced Study, Princeton, NJ, June 1992

Theoretical Physics Seminar, Johns Hopkins University, Baltimore, MD, July 1992

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 Florida, March 31, 1992

Seminar, University of Florida, April 7, 1992

Seminar, University of Crete, June 23, 1992

Invited Talk, Rome-Paris-Utrecht Triangular Conference, July 29, 1992

Seminar, University of Florida, Sept. 18, 1992

Seminar, Brandeis University, Sept. 24, 1992

Seminar, Brown University, Sept. 25, 1992

Seminar, University of Texas at Austin, Nov. 16, 1992

Seminar, Inst. for Theor. Physics/UCSB, Dec. 3-4, 1992

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

B. Travel

Field

URA Fermilab Review, Jan 17-18, 1992

Participated in the XXVI International Conference on High Energy Physics, SMU, Dallas, TX, August 6-12, 1992

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

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

Qiu

Cornell University, Ithaca, NY, August 1992

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

HEPAP travel and Witherell Subpanel member, 1992
Princeton University, May 1992
SSC, June 1992
Aspen Center for Physics, July 1992
Erice, Italy, Sept 1992
Ecole Normale, Paris, Sept 1992
Yale Workshop, Oct 1992

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

Sikivie

ITP, Santa Barbara, CA, April 2-4, 1992
ITP, Santa Barbara, CA, May and June, 1992
UCLA, May 8, 1992
Caltech, May 25, 1992
Aspen, July 6-26, 1992
FSU, Tallahassee, FL, Oct. 8, 1992
DPF92, Fermilab, Nov. 11-13, 1992
University of Maryland, Dec. 1-2, 1992

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

Thorn

Chapel Hill, NC, March 1992
IAS, Princeton, NJ, June 1992

Johns Hopkins University, Baltimore, MD, July 1992

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

C. Seminar Speakers (*since 1992*)

Name	*Institution*	*Dates*
Prof. A. Mueller	Columbia University	2/17/92
Prof. K. Bitar	Florida State University	10/16/92
Dr. S. Yost	University of Tennessee	10/12/92
Prof. E. Farhi	MIT	11/12/92
Prof. S. Hsu	Harvard University	11/18/92
Dr. G. Kleppe	Virginia Polytechnic Institute	11/21/92
Prof. F. Paige	SSC Laboratory	11/16/92
Prof. C. Stephens	University of Maryland	12/10/92
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	R. Regan Nat. Accel. Fac.	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. K. Kuchar	University of Utah	11/30/93
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
Prof. 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. 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

Appendix A. GROUP PUBLICATIONS (*since 1992*)

1. Symplectic Structure of Isospin Particles in Yang-Mills Fields, *P. Oh*, UFIFT-HEP-92-2, Mod. Phys. Lett. **A7**, 1923 (1992).
2. Mass and Mixing Angle Patterns in the Standard Model and Its Minimal Supersymmetric Extension, *P. Ramond*, contributed to John Klauder's 60th Birthday, UFIFT-HEP-92-4, *unpublished.*
3. Domain Wall Formation in Late-Time Phase Transitions, E. W. Kolb and *Y. Wang*, UFIFT-HEP-92-5, Phys. Rev. **D45**, 4421 (1992).
4. Cosmic Microwave Background Anisotropies From Plausible Double Inflation, *J. Fry* and *Y. Wang*, UFIFT-HEP-92-6, Phys. Rev. **D46**, 3318 (1992).
5. A Tumbling Top-Quark Condensate Model, *S. Martin*, UFIFT-HEP-92-7, Phys. Rev. **D46**, 2197 (1992).
6. 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).
7. Effects of a Nambu-Goldstone Boson on the Polarization of Radio Galaxies and the Cosmic Microwave Background, *D. Harari* and *P. Sikivie*, UFIFT-HEP-92-9, Phys. Lett.**B289**, 67-72 (1992).
8. Wiggly Relativistic Strings, *J. Hong, S. Kim* and *P. Sikivie*, UFIFT-HEP-92-10, Phys. Rev. Lett. **69**, 2611-2614 (1992).
9. Late Time Cosmological Phase Transition and Galactic Halo as Bose-Liquid, *S. Sin*, UFIFT-HEP-92-11, Phys. Rev. **D50**, 3655 (1994).
10. Quark-Antiquark Regge Trajectories in Large N_c QCD, *C. Thorn* and *M. McGuigan*, UFIFT-HEP-92-12, Phys. Rev. Lett. **69**, 1312 (1992).
11. Intermediate Scales of Symmetry Breaking in Calabi-Yau Models, *M. Masip*, UFIFT-HEP-92-13, Phys. Rev. **D46**, 3601 (1992).
12. 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).
13. Enforcing the Wheeler-DeWitt Constraint the Easy Way, *R. P. Woodard*, UFIFT-HEP-92-16, Class. and Quantum Grav. **10**, 483-496 (1993).
14. The Sine-Gordon Model and the Small K^+ Region of Light-Cone Perturbation Theory, *P. Griffin*, UFIFT-HEP-92-17, Phys. Rev. **D46**, 3538 (1992).
15. Classical Fluids of Negative Heat Capacity, P. T. Landsberg and *R. P. Woodard*, UFIFT-HEP-92-18, J. Stat. Phys. **73**. 361-378 (1993).
16. Staggered Fermions and Chiral Symmetry Breaking in Transverse Lattice Regulated QED, *P. Griffin*, UFIFT-HEP-92-19, Phys. Rev. **D47**, 3530 (1993).
17. Mode Analysis and Ward Identities for Perturbative Quantum Gravity in de Sitter Space, N. C. Tsamis and *R. P. Woodard*, UFIFT-HEP-92-20, Phys. Lett.**B292**, 269 (1992).

18. Some Simple Criteria for Gauged R-Parity, *S. Martin*, UFIFT-HEP-92-22, Phys. Rev. **D46**, 2769 (1992).

19. Relaxing the Cosmological Constant, *R. Woodard* and N. Tsamis, UFIFT-HEP-92-23, Phys. Lett. **B301**, 483-496 (1993).

20. Strong Infrared Effects in Quantum Gravity, *R. P. Woodard* and N. C. Tsamis, UFIFT-HEP-92-24, Ann. of Phys. **238**, 1-82 (1995).

21. Massive Neutrinos in a Calabi-Yau Model, *M. Masip*, UFIFT-HEP-92-27, Phys. Rev **D47**, 3071 (1992).

22. Point-Like Interactions in String Theory Induced by 2-D Toplogical Gravity, UFIFT-HEP-92-26, Phys. Lett. **B306** 261 (1993).

23. Long Range Forces From Two Neutrino Exchange, *P. Sikivie* and S. Hsu, UFIFT-HEP-92-28, Phys. Rev. **D49**, 4951-4953 (1994).

24. SDC Solenoidal Detector Notes: Forward Jets and Missing E_T, *R. D. Field*, UFIFT-HEP-92-30, SDC-92-355 (1992).

25. Continuing Between Closed and Open Strings, *C. B. Thorn* and M. B. Green, Nuclear Phys. **B367**, 462 (1991).

26. Contractions of Lie Groups applied to Differential Equations, *Marc de Montigny*, UFIFT-HEP-92-31.

27. Third Quantization and Black Holes, *M. McGuigan*, UFIFT-HEP-92-32, unpublished.

28. Casimir Forces Between Beads on Strings, E. D'Hoker and *P. Sikivie*, UFIFT-HEP-92-33, Phys. Rev. Lett. **71**, 1136 (1993).

29. 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).

30. Enchancing the Heavy Higgs Signal with Jet-Jet Profile Cuts, *R. Field* and *P. Griffin*, UFIFT-HEP-93-3, Phys. Rev. **D48**, 3167 (1993).

31. SDC Solenoidal Detector Notes: Enchancing the Heavy Higgs Signal, *R. Field* and *P. Griffin*, UFIFT-HEP-93-4, SDC-93-459 (1993).

32. 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).

33. Stitching the Yukawa Quilt, *P. Ramond*, R. Roberts and G. Ross, UFIFT-HEP-93-6, Nucl. Phys. **B406**, 19 (1993).

34. 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).

35. Discrete Gauge Symmetries in Supersymmetric Grand Unified Models, *M. Masip* and *M. de Montigny*, UFIFT-HEP-93-11, Phys. Rev. **D49**, 3734-3740 (1994).

36. Sister Trajectories and the Cerulus-Martin Bound, *S. Carbon*, UFIFT-HEP-93-15, unpublished.

37. Sparticle Spectrum Constraints, *S. Martin* and *P. Ramond*, UFIFT- HEP-93-16, Phys Rev. **D48**, 5365 (1993).

38. 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.

39. Renormalization II, *D. Castano, E. Piard,* and *P. Ramond*, UFIFT-HEP-93-18, Phys. Rev. **D49**, 4882 (1994).

40. Comments on the Neutrino Fraction in Our Galactic Halo, *P. Sikivie* and *J. Ellis*, UFIFT-HEP-93-19, Phys. Lett. **B321**, 390-393 (1994).

41. 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).

42. 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).

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

44. 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).

45. 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).

46. 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).

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

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

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

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

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

52. 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.*

53. Quantum Gravity Slows Down Inflation, *R. Woodard and N. Tsamis*, UFIFT-HEP-94-12.

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

55. 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.

56. Casmir 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.
57. Yukawa Textures and Anomalies, *P. Ramond and P. Binetruy*, UFIFT-HEP-94-19, Phys. Lett. **B350**, 49 (1995).
58. Raising the Unification Scale in Supersymmetry, *P. Ramond and S. Martin*, UFIFT-HEP-95-1, Phys. Rev. **D51**, 6515 (1995).
59. Discrete Anomaly and Dynamical Mass in 2 + 1 Dimensional $U(1)_V xU(1)_A$ model, *D. K. Hong*, UFIFT-HEP-95-3.
60. Variational Principles and Stellar Structure, *Dallas Kennedy and S. Bludman*, UFIFT-HEP-95-4, NSF-ITP-95-71 (*in preparation*).
61. The Velocity Peaks in the Cold Dark Matter Spectrum on Earth, *P. Sikivie, I. I. Tkachev and Y. Wang*, UFIFT-HEP-95-6.
62. String Bit Models for Superstring, *O. Bergman and C. B. Thorn*, UFIFT-HEP-95-8, to appear in Phys. Rev. D.
63. Solar Core Homology and Solar Neutrinos, *S. Bludman and D. Kennedy*, UFIFT-HEP-95-10, NSF-ITP-95-72, DOE/ER/40561-215-INT95-17-03 (*in preparation*).
64. Using Neural Networks to Enhance the Higgs Boson Signal at Hadron Colliders, *R. Field, Y. Kanev and M. Tayebnejad*, UFIFT-HEP-95-11, *submitted to Phys. Rev. D.*
65. Super-Galilei Invariant Field Theories in 2 + 1 Dimensions, *C. B. Thorn and O. Bergman*, UFIFT-HEP-95-12, *submitted to Phys. Rev. D.*
66. Variational Approximations for Stars, *D. Kennedy and S. Bludman*, UFIFT-HEP-95-13 (*in preparation*).
67. Calibrating the Standard Sun, *S. Bludman, D. Kennedy and G. Bonvicini*, UFIFT-HEP-95-14, DOE/ER/40561-261-INT95-17-04 (*in preparation*).

B. Conference Reports

68. Dark Matter Axions, *P. Sikivie*, lecture given at the Dark Matter Workshop, Univ. of Florida, Feb. 12-14, 1992, UFIFT-HEP-92-25, *to appear in the proceedings.*
69. Neutrinos as Fundamental Probes, *P. Ramond*, UFIFT-HEP-92-29, *to appear in the Proceedings of Daniel Challonge School.*
70. Symmetric Textures, *P. Ramond* Invited talk at Global Foundation Conference, Coral Gales, Florida, Jan. 1993, UFIFT-HEP-93-7, *to appear in the proceedings.*
71. 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.*
72. Renormalization Group Study of the Minimal Supesymmetric 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.*

73. 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.*

74. 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.*

75. Introductory Lectures on Low Energy Supersymmetry, *P. Ramond*, UFIFT-HEP-94-20.

76. Scale Ratios in the Standard Model, *P. Ramond*, UFIFT-HEP-94-21. Invited lecture at the 1994 Moriond Conference, Meribel, March 1994.

77. 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.

78. Superstrings: The View from Below, *P. Ramond*, UFIFT-HEP-94-22. Invited talk at the First Gürsey Symposium, Istanbul, Turkey, June 5-8, 1994.

79. 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.

80. 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.

81. 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.

82. 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, edited by L. Gergstrom, P. Carlson, P. O. Hulth and H. Snellman.

83. 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.

84. Light Cone Formulation of String Theory, *C. B. Thorn*, invited talk at the 5th Workshop on Light Cone QCD, Telluride, CO, August 14, 1995.

85. The Pooltable Analogy to Axion Physics, *P. Sikivie*, UFIFT-HEP-95-9. To be published in the Proceedings of the XXX^{th} Rencontres de Moriond "Dark Matter in Cosmology" and "Clocks and Tests of Fundamental Laws", Villars-sur-Ollon, Switzerland, Sept. 21-28, 1995.

Research in Experimental High Energy Physics

Task B

Principle Investigators: Paul Avery and John Yelton

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 to the faculty, we are proposing a new Task to incorporate him and the new non-teaching faculty member. 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

Funding for a brand new, purpose built, physics building is still in place. The site has been cleared of the former buildings and the official ground-breaking is scheduled for the Fall. 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.

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 II. There are two major upgrade efforts underway; firstly the installation of a silicone vertex detector which 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 has had another outstanding year of physics analysis.

3.1 CLEO PUBLICATIONS

In the 12 months since our last proposal, the following papers have been published.

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

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

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

4. 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)

5. 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)

6. 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)

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

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

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

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

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

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

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

14. 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)

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

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

17. 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)

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

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

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

21. 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)

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

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

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

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

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

27. 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)

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

3.2 Preprints

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

1. Inclusive Decays of B Mesons to Charmonium
   R. Balest *et al.*, CLNS 94/1315, CLEO 94–26
   (submitted to Physical Review D)

2. 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)

3. Measurement of the Ratio of Branching Fractions $B(D^0 \to \pi^- e^+ \nu_e)/B(D^0 \to K^- e^+ \nu_e)$
   F. Butler *et al.*, CLNS 95/1324, CLEO 95–3
   (submitted to Physical Review D)

4. A Search for $B \to \ell \bar{\nu}_\ell$
   M. Artuso *et al.*, CLNS 95/1331, CLEO 95–5
   (submitted to Physical Review Letters)

5. Measurement of α_s from τ Decays
   T. Coan *et al.*, CLNS 95/1332, CLEO 95–6
   (submitted to Physical Review Letters)

6. Search for CP Violation in D^0 Decay
   J. Bartelt *et al.*, CLNS 95/1333, CLEO 95–7
   (submitted to Physical Review D)

7. Search for Exclusive Charmless hadronic B Decays
   D.M. Asner *et al.*, CLNS 95/1338, CLEO 95–8
   (submitted to Physical Review D)

8. Observation of the Cabibbo Suppressed Charmed Baryon Decay $\Lambda_c^+ \to p\phi$
   J.P. Alexander *et al.*, CLNS 95/1343, CLEO 95–9
   (submitted to Physical Review Letters)

9. Observation of the Isospin-Violating Decay $D_s^{*+} \to D_s^+ \pi^0$
   J. Gronberg *et al.*, CLNS 95/1346, CLEO 95–10
   (submitted to Physical Review Letters)

10. 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.*, CLNS 95/1349, CLEO 95–12
    (submitted to Physical Review Letters)

11. Measurements of the Ratios $\mathcal{B}(D_S^+ \to \eta \ell^+ \nu)/\mathcal{B}(D_S^+ \to \phi \ell^+ \nu)$ and
    $\mathcal{B}(D_S^+ \to \eta' \ell^+ \nu)/\mathcal{B}(D_S^+ \to \phi \ell^+ \nu)$
    G. Brandenburg *et al.*, CLNS 95/1351, CLEO 95–13
    (submitted to Physical Review Letters)

12. Observation of a Narrow State Decaying into $\Xi_c^+\pi^-$
P. Avery *et al.*, CLNS 95/1352, CLEO 95–14
(submitted to Physical Review Letters)

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 last year. We recently extended the analysis to cover twice the previous data sample; the main results have just appreared in Jorge's thesis. The main improvements, 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 $\overline{B}^0 \to D^0\pi^0$, in the $D^0 \to K^-\pi^+$ submode, but doesn't appear consistently in the other channels. 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 started this Fall.

Avery is also working, with Karen Lingel, on the Cabibbo suppressed decays $\overline{B}^0 \to D^{*+}D^{*-}$, which is interesting because it is one of the signature decays expected to be used in measurements of CP violation. The decay is expected to occur at the 0.1% level, which is just barely within limits of detectability of the new data sample (3 events expected). Since the detection efficiency depends on the square of the D branching fractions, our analysis depends heavily on being able to combine the results of three D^0 decay modes. Naturally, backgrounds are a problem, particularly in the $D^0 \to K^-\pi^+\pi^0, K^-\pi^+\pi^+\pi^-$ submodes. We are trying to use a vertex fitting algorithm to narrow the $D^{*+} - D^0$ mass peak since it appears twice in the decay. We expect to have a result by the middle of the Fall.

Avery has also maintained his involvement in the Fermilab B program through his work with the Fermilab B Simulation Group, which he headed in 1993–94. He spent two weeks in the summer of 1995 at Fermilab working with the group. As a result, Mcfast now supports combinations of central and forward geometries in a very general way, and still require less than 1 second per event for a typical hadronic event. The Lab director, John Peoples, has announced that the Simulation Group will be officially supported for all Fermilab simulations, particularly for the high p_T physics studies which are being undertaken for Run III. It is expected that the Group will be supplying the software and support for studies at Snowmass 1996. A new position at the Scientist level is now being advertised and it is possible that a new opening might be made available later this Winter.

The great importance of event display and visualization tools for studying simulations became obvious during Avery's visits to Fermilab. Many mistakes made in tracking and tracing tracks through the detector could not have been discovered without the visual display developed by Amber Boehnlein of Fermilab. The Fermilab Workshop on Visualization in HEP, attended by a number of experts around the world (Bjorken gave the opening speech), demonstrated quite conclusively the importance of event display and data visualization for rapid debugging and physics studies. As a result, we intend to buy some visualization software and graphics accelerator cards for the DEC Alphas and begin work on improving the event display for Mcfast, CLEO II and CLEO III.

4.1.2 John Yelton

John Yelton (Associate Professor) performed the analysis and wrote the first draft of the publication containing evidence of a new particle, an excited Λ_c^+. 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. This 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.

Following this he worked on searches for $J = \frac{3}{2}$ charmed baryons, i.e. radial 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 a signal for decay $\Xi_c^{*0} \to \Xi_c^+\pi^-$ 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 circulated as a CLEO preprint, and has been sent to PRL where it is now in the hands of the referees.

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. A draft of a paper has been written and is undergoing the editing process by the CLEO collaboration. On the present timetable, the paper will be voted on by the collaboration at the October group meeting, and will be sent for publication at the end of October. 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.

4.2 Post-Doctoral Research Associates

4.2.1 Song Yang

Song Yang has played a major role in the discovery and identification of the Ξ_c^* states described above. He has also led searchs 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 $\Xi_{c'}$ 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 wither by them or by Song's search. However it is clear that these states should be visible in CLEO II eventually. He has continued to work on 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 more than 10,000,000 events in the last 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 is working on a partial reconstruction technique to analyze $B \to D_s D$ decays, and has written, 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.

4.2.2 Karen Lingel

Karen Lingel has been the post-doc in residence at Cornell for the last year. 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 has recently submitted a paper to Phys. Rev. D (see above) with results of 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 is presently working on searches for $B \to D^{*+}D^{*-}$, $B \to l^+l^-$ and $B \to K^*K$. She is chair of the "Rare B Physics Group" and the "Rare Electromagnetic Group". She is a working member of the Tracking Group, with a recent 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 is also CERN librarian for CLEO, and thus responsible for the installation and maintenance of the CERN software relevent documentation.

Karen has just resigned from UF to take up a position at SLAC. We are reviewing applications for her successor at this moment.

4.2.3 Arne Freyberger

Arne Freyberger resigned from the collaboration last year but has remained loosely connected to the collaboration. He has just finished the last work he was involved in when employed by UF, that of the measurement of the inclusive $D^0 \to Xe^+\nu$. A draft of a paper for submission to Phys. Rev. D. is being circulated around the collaboration.

We are happy to be able to say all 5 of the post-docs that have been employed by the UF CLEO group are still working in the field. Ransom Stephens is Assistant Professor at UT Arlington, Arne Freyberger is a staff member at SLAC, 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.

4.3 Students

4.3.1 Jorge Rodriguez

Jorge Rodriguez has completed his writing his thesis, entitle "Exclusive Two Body Decays of the Bottom Meson" has been examined and he was awarded his PhD in August 1995. His analysis is detailed in the section on Paul Avery 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.

4.3.2 Craig Prescott

Craig Prescott has now been author on CLEO publications for one year. His main contribution has been optimizing the code for Ξ^0, Ξ^- and Ω^- hyperons. This has been used for his own analysis of Ω_c searches, the Ξ_c^* analyses described above, and also has been passed to 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. Craig is now in charge of remaking the "vee-finder", used to find secondary vertices by all of the collaboration, for the recompression of all the CLEO II data. The plan is to refind and fit all tracks in the existing data set with a new "Kalman Filter" program that takes into account the energy loss in the fitting process. This should yield better vees, and certainly the old vee-finder needs changes as each charged tracks now has multiple fits according to its identity. This is an opportunity to make the vee-finder better (i.e. reject more background and improve the mass resoultion without impairing the efficiency). We need to supply this software to CLEO in the next few months.

4.3.3 Jiu Zheng

Jiu Zheng is now beginning his third year in graduate school, has now participated in CLEO meetings, and will take data taking shifts after the beginning of new running in the Fall. 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 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. We hope to publish this analysis within a year, and then he will move on to a thesis topic.

4.3.4 Fadi Zeini

Fadi Zeini has been working with Paul Avery to remove the systematic position and angle dependence caused by energy loss in the walls between the tracking detectors. Although an earlier version of this correction (written by Avery) has been in use for several years, an updated algorithm is needed for low momentum tracks, particularly pions from D^{*+} and charmed baryon decays. Removing this strong bias will permit kinematic fitting to work more accurately and improve mass resolutions for certain cascade decays.

Task C

AXION SEARCH EXPERIMENT

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Abstract

The UF Axion Search Project is participating in the operation of a large-scale axion detector at Lawrence Livermore National Laboratory. UF is taking responsibility for the assembly, programming, and installation of the high-resolution spectrometer for this experiment. We also plan to take shifts during the operation of the detector in FY96.

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A. Introduction

This document is a request for continuation of funding for the Florida axion search group during 1996-7. Our main task will be to contribute to the large-scale axion search experiment that has been built at Lawrence Livermore National Laboratory (LLNL). This detector, which improves the sensitivity over first-generation detectors by at least a factor of 50, will take data during FY96.

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 only plausible remaining mass window for axions is 1-1000 μeV. At the low mass end of this window axions have the appropriate properties to constitute the dark matter of the universe.[1] These axions may be stimulated to convert into monochromatic microwave photons in a high Q cavity threaded by a large magnetic field. Two groups, our collaboration and one in Japan, are now undertaking such an experiment. The LLNL detector consists of a large volume superconducting magnet, a physics package consisting of up to 16 tunable RF cavities, and HEMT microwave amplifiers. This detector can search for axions in a 1-12 μeV window with sufficient sensitivity to detect all but the most weakly coupled axions. The Japanese detector[2] has a smaller volume magnet, a single RF cavity physics package, and Rydberg atom microwave detection. It searches a much narrower range of axion mass, but at a sensitivity adequate to detect even the most weakly coupled axions.

As part of its contribution to the LLNL detector, the University of Florida is providing the computer and programming necessary to search for very narrow lines which may exist as substructure in the axion signal, representing the memory of the phase space distribution of the initial almost zero-temperature gas of axions.[3] Theoretically these lines may be monochromatic to 10^{-19} and our spectrometer will have a resolution of 10^{-10} (*i.e.*, 0.1–0.01 Hz resolution at a 1 GHz frequency). Significant improvements in signal to noise may be achieved even if only a few percent of the axions are in these narrow lines.

B. Axions as Dark Matter

Axions were postulated originally as a solution to the strong CP problem and it was recognized that they would be strong candidates for the dark matter. Current laboratory and cosmological observations constrain the mass of the axion to the 1-1000 μeV range. All masses larger than 10^{-3} eV have been ruled out either by previous searches, stellar evolution constraints or SN1987a. Axion masses smaller than approximately 10^{-6} eV require that there be the right kind of inflation after the Peccei-Quinn phase transition and that the initial vacuum misalignment angle happens to be small.

Axions in this mass range can be detected by their conversion into microwave photons in an electromagnetic cavity placed in a strong magnetic field. Single-cavity pilot experiments with small-scale detectors have shown that the method is feasible and that reasonable sensitivity can be reached with current technology.

With regard to studies of large scale structure and galaxy formation, the axion falls in the category called "cold dark matter," whereas the neutrino is an example of "hot dark matter." Generally speaking, studies of large scale structure and galaxy formation favor substantial amounts of cold dark matter over substantial amounts of hot dark matter, although this point is hardly settled. If the dark matter is a mixture of the two, it is the cold component that constitutes the galactic halos.

It has been shown that the axion signal may have structure in the form of narrow lines.[3] Recently, the positions and sizes of these lines have been calculated as a function of cosmological parameters such as the age of the universe, the amount of angular momentum carried by our galactic halo, and the index which characterizes the spectrum of primordial density perturbations.

C. The Second-generation Experiment

1. Technical overview

A large-scale axion search, located initially at the Lawrence Livermore National Laboratory, is about to start taking data. The spokespersons are Leslie J Rosenberg (MIT) and Karl van Bibber (LLNL). We summarize the key goals of the experiment as follows:

- To achieve a power sensitivity which is conservatively a factor of 40 improvement (and probably closer to a factor of 100) 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 $< m_a <$ 12.6 μeV. This is to be achieved through filling the magnet volume with multiple cavities.

The experiment utilizes a commercial magnet with a central field of ~7.5 T. The volume for the cavities has an inner diameter of 50 cm, and a length of 100 cm. Hence, $B_0^2 V = 12$ $T^2 m^3$, approximately 25 times larger than the $B_0^2 V$ values of the pilot experiments. The experimental volume is separated from the magnet cryostat by a cold-vacuum wall. It is possible to exchange cavity arrays, etc., in the experimental volume while the magnet is energized, and most importantly the temperature of the cavity arrays is independent of that of the magnet. Initially, the experiment will be operated at about 1.5 K, to match the noise temperatures of the best low-noise microwave amplifiers available today in the L- and S-bands (0.5 through 3 GHz), with noise temperatures (physical plus electronic) measured to be around 3 K.

The other innovation in the 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 1.3 μeV $< m_a <$ 12.6 μeV. It will start taking data in 1995, and run for approximately three years. This large-scale experiment will be the first to have sensitivity to a likely dark matter candidate with plausible couplings to matter and radiation.

2. The collaboration and division of labor

At the present time, the collaboration consists of the following institutions and personnel

- LLNL: C. Hagmann, W. Stöffl, K. van Bibber
- MIT: E. Daw (GS), L. Rosenberg
- UF: P. Sikivie, N. Sullivan, D. Tanner
- LBL: D. Moltz
- FNAL/Chicago: F. Nezrick, M. Turner
- INR: N. Golubev, L. Kravchuk

LLNL is responsible for the design and fabrication of the magnet; the design and fabrication of the physics package, including cavity array #1; siting the experiment and its operation. Livermore also provides overall coordination of the experiment; K. van Bibber is co-spokesman for the project.

MIT is responsible for most of the microwave electronics, including the HEMT amplifiers and the receiver. The host computer (Quadra 950) and some test equipment is provided by LLNL, along with the signal-processing board for the high-resolution electronics. L. Rosenberg is co-spokesman of the experiment.

LBL contributes to the cavity R&D and prototyping activities, and will undertake to do the development of the piezoelectric motors, both circular and linear, for the tuning of multi-cavity arrays. LBL contributes some machine shop work to the project.

FNAL has both expertise and hardware from the RBF pilot experiment and is conducting R&D on the frequency stability of "dry" cryogenic cavities, such as in the present design.

INR assists in cavity R&D, especially copper-plated stainless cavities.

UF contributes expertise and hardware from its pilot experiment and is developing the high-resolution spectrum analysis. UF provided the host computer (66 MHz pentium pc) and has written the FFT and control programs.

D. Planned Work During 96-97

1. High-resolution data acquisition

Because the interaction of axions with other matter is weak, and because the axions at the time of their creation are very cold, the halo axions are located in phase space on very thin sheets, and, hence, the axions have specific, well defined energies, determined by their history since the formation of the galaxy.[3] As mentioned above, the sensitivity of the experiment could be increased substantially by measuring the spectrum at high resolution, 0.1–0.01 Hz or a part in 10^{-10}. The high resolution spectrum analysis will be carried out in parallel with a spectrum analysis at a resolution of order 1 kHz appropriate to observe the spread of energy due to the motion of axions around the center of the galaxy.[4]

The improvement in signal to noise depends on the integration time τ of the experiment and the fraction p of the axion signal that is in these narrow peaks. Briefly, with integration time of 30 sec, a factor of ~5 gain is expected if 3% of the signal is in one narrow peak; a factor of ~9 if 5% is.

The boards for the high resolution spectrometer (BittWare) were purchased by our MIT collaborators. UF provided the host PC and is carrying out the integration and programming of the system, with delivery expected around 1 October 1995. The FFT program has been written, along with most of the host control program. The system at present can measure up to 10^6 data points and carry out a 10^6 point FFT spectrum analysis of the signal. The data acquisition requires 10 sec and the million-point FFT about 14 sec in the present implementation. This is comfortably shorter than the ~100 sec needed to conduct the low-resolution spectrum analysis, and we anticipate a modest improvement over these figures in the operational version.

2. Operations of the large-scale axion detector

The hardware for the large-scale detector is complete and has been cooled to Helium temperatures two times, with the magnet energized most recently in August 1995. The cavity has a better-than expected Q while the noise temperature is in the ~6K range. Very shortly the first operational run of the detector will begin. It will require about 1 year of running time to cover the full tuning range of the first cavity package. We plan to participate in this running through visits of both faculty and a graduate student to Livermore. We believe that for our participation in this next-generation experiment to be more than nominal, we must provide the collaboration with a graduate student to contribute to the operations of the detector. This is our highest priority for the next fiscal year.

References

1. Edward W. Kolb and Michael S. Turner, *The Early Universe*, Addison-Wesley, New York (1990).

2. S. Matsuki and K. Yamamoto, *Phys. Lett.* **B263** (1991) 523.

3. P. Sikivie and J. Ipser, *Phys. Lett.* B291 (1992) 288; P. Sikivie, I. Tkachev and Y. Wang, preprint UFIFT-HEP-95-6 (April 1995).

4. Galactic halo axions have have velocities β of order 10^{-3} and hence their energies $\epsilon_a = m_a + \frac{1}{2}m_a\beta^2$ have a spread of order 10^{-6} above the axion mass.

E. Papers and Presentations

The following lists the papers and presentations of the Task C group during the past year.

1. Papers

(Papers 5, 6, and 7 are also listed in Task A.)

1. "Axion detection in the 10^{-4} eV mass range," Pierre Sikivie, D.B. Tanner, and Yun Wang, *Phys. Rev. D* 50, 4744–4748 (1994).
2. "A next-generation cavity microwave experiment to search for dark-matter axions," K. van Bibber, W. Stöffl, P.L. Anthony, P. Sikivie, N.S. Sullivan, D.B. Tanner, V. Železný, N.A. Golubev, O.V. Kazachenko, L.V. Kravchuk, V. Kuzmin, G.V. Romanov, I.V. Sekachev, L.J. Rosenberg, C. Hagmann, D.M. Moltz, F. Nezrick, M.S. Turner, and F. Villa, in *The 1^{st} IFT Workshop: Dark Matter*, edited by R.D. Field, J. Fry, P. Ramond, and P. Sikivie (World Scientific, Singapore, 1994).
3. "Status of the large-scale dark-matter axion search," K. van Bibber, C. Hagmann, W. Stöffl, E. Daw, L. Rosenberg, P. Sikivie, N. Sullivan, D. Tanner, D. Moltz, R. Tighe, F. Nezrick, M. Turner, N. Golubev, and L. Kravchuk, in *Proceedings of the 1st International Symposium on Sources of Dark Matter in the Universe*, edited by D. Cline (World Scientific, Singapore, 1995), pp. 248-262.
4. "A second generation cosmic axion experiment," C. Hagmann, W. Stöffl, K. van Bibber, E. Daw, D. Kinion, L. Rosenberg, P. Sikivie, N. Sullivan, D. Tanner, D. Moltz, F. Nezrick, M. Turner, N. Golubev, and L. Kravchuk, UCRL-JC-120869, 1995, 6pp, 30^{th} Rencontres de Moriond: Perspectives in Particle Physics, Atomic Physics and Gravitation, Villars-sur-Ollon, Switzerland.
5. "The velocity peaks in the cold dark matter spectrum on Earth", P. Sikivie, I. Tkachev and Y. Wang, preprint UFIFT-HEP-95-6 (April 1995), *submitted to Phys. Rev. Letters.*
6. "Sources and distributions of dark matter", P. Sikivie, Nucl. Phys. B (Proc. Suppl.) 43 (1995) 90-99.
7. "The pooltable analogy to axion physics", P. Sikivie, preprint UFIFT-HEP-95-9, to be published in the Proceedings of the XXX^{th} Recontres de Moriond, "Dark Matter in Cosmology" and "Clocks and Tests of Fundamental Laws", Villars-sur-Ollon, Switzerland.

2. Presentations

(Also listed in Task A.)

1. P. Sikivie, Invited talk at the Conference "Trends in Astroparticle Physics" in Stockholm, Sweden, Sept. 22-25, 1994.
2. P. Sikivie, Particle Theory Seminar at Orsay, France, on Nov. 22, 1994.
3. P. Sikivie, Particle Theory Seminar at the Université Libre of Brussels, Belgium, Nov. 25, 1994.
4. P. Sikivie, Particle Theory Seminar at Oxford University, Oxford, England, Dec. 2, 1994.
5. P. Sikivie, Four lectures at VIth Argentine Symposium of Theoretical Physics on Particles and Fields, Bariloche, Argentina, Jan. 9-20, 1995.
6. P. Sikivie, Invited talk at XXX^{th} Reconcontres de Moriond, "Dark Matter in Cosmology. Clocks and Tests of Fundamental Laws", Villars-sur-Ollon, Suisse, Jan. 21-28, 1995.
7. P. Sikivie, Physics Department Colloquium at Yale University, May 12, 1995.

Computer Support for Research in Theoretical and Experimental High Energy Physics

Task S

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Abstract

We present a continuation of our three year proposal to DOE to upgrade and maintain the HEP computing facilities at the University of Florida. Our request is for equipment upgrades and continuation of support for students, system manager/programmer support and maintenance.

I Introduction

This computing proposal (Task S) is submitted separately but in support of the High Energy tasks (CLEO/Fermilab, Delphi/CMS and Theory). We have a very strong computing base at Florida and have been involved with many computing initiatives, both of which justify the submission of separate proposals.

Current system

We purchased a system based around the new DEC Alpha processors in Fall, 1993 using DOE and University funds. We chose DEC because we were able to negotiate an extremely good discount and we were able to convince them to donate the 26 DEC 5000–200 processors we traded in back to UF, which in turn made it possible to get funding from the University. (The processors, monitors, 25 GB of disk and most of our FDDI network were given to UF to start up a new Unix laboratory for students.) The system currently consists of the following pieces:

1 DEC 3000–500 AXP processor (160MB, 8GB) file server for general users
1 DEC 3000–600 AXP processor (160MB, 1GB) file server for HEE users
10 DEC 3000–600 AXP processors (64MB, 1GB disk) computing farm at UF
8 DEC 3000–600 AXP processors (64MB, 1GB disk) computing farm at Cornell
4 DEC 4/250 AXP (64 MB, 1GB disk, PCI bus) computing farm at UF
2 DEC 5000–25 desktop workstations (16MB) used at Cornell
17 X–Terminals
100GB of disk (90GB for data storage)
4 DAT drives
2 Exabyte drives (2 GB)
2 DLT tape drives (10 GB)
Several PCs

The system current supports the high energy experimental and theoretical groups and our collaborators. We also provide accounts for a large number of graduate students finishing their theses and physics undergraduates who need computing support. These latter activities are a negligible load on the system but provide goodwill within the department.

This past year we disconnected our dedicated 9600 baud line to Florida State University that had provided a DECnet path to Fermilab. The line had seen diminishing use compared with the T1 line to NSFnet maintained by the University. This year we moved all our software from the DECstations to the new DEC Alpha machines in order to simplify maintenance and upgrades.

This past year we purchased software from Tektronix (WinDD) to run Windows programs on X-Terminals. Windows programs such as Word and Excel run on a PC server but the Windows screen is rendered in X format on the X-Terminal. This has turned out to be very cost-effective solution since one or two PC servers can support a whole network of Windows users without requiring us to buy a PC for every desktop that needs it.

II Computing activities

Our acquisition of computing equipment has barely kept up with the demands we have placed on it. 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. Recompress and Monte Carlo require by far the most computing cycles, and are the areas in which Florida has contributed most heavily. We have committed ourselves to these activities over the next few years.

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}, of which 3.4 fb^{-1} has made its way through the PASS2 standard data reduction process. (The data processing delays are not computer driven; it turns out to be difficult to produce the needed tracking and *dE/dx* constants as fast as data are accumulated.) By late 1996, before these improvements have all been made, we will have approximately 10 fb^{-1} of data collected. Thus computing and storage issues are paramount. To effectively carry out the tasks described below we will need to augment our computing resources over the next few years, as will Cornell.

We have two other activities in addition to CLEO. We hired a new senior experimentalist (Gena Mitselmakher) who started in January, 1995, and we have searches open for a senior research scientist and a post-doc, to work on CMS and Delphi related activities, which we expect to fill by Spring, 1996. Over the next three or so years, we expect to fill three new junior faculty positions. Mitselmakher is setting up a CMS group at UF to support his role as Project Manager for the CMS Forward Muon Spectrometer. He is also founding a Delphi group at UF which will take part in data analysis initially.

We are still involved with hadron *B* physics at Fermilab (via Paul Avery), mostly through support of the MCFAST simulation effort there. The Simulation Group (which Avery headed 1993-94) 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 in the Simulation Group will be filled by Fermilab by Winter, 1995.

The simulation group is expecting to provide the fast simulation tools for the next Snowmass workshop in June, 1996. This will require a great deal of work over the coming year. Avery, who led the group till August, 1994, is continuing his involvement. A large number of simulations, especially backgrounds, will be generated on farms at Florida and Fermilab to make comparisons between detectors with respect to *B* physics, principally CP violation capabilities.

The following is a list of activities which require large computing support for the next few years.

1. Compress of incoming CLEO data

Florida provides the computing resources to carry out the ongoing Compress data reduction, for 50 pb^{-1} per week. The data rate is expected to reach 80–100 pb^{-1} per week after the changes to CESR are implemented and running conditions reach equilibrium. One major change is that the silicon detector will need to be incorporated into the tracking; this will probably increase the time to process a single event. Other groups within CLEO provide the personnel to run Compress and take care of tape handling and bookkeeping.

2. *Recompress of CLEO data*

CLEO is making a major effort this year to redo the standard data reduction ("recompress") for all the data taken by CLEO II since 1989, a total of 4.8 fb^{-1}. This data sample is more than four times as large as the one we re-analyzed in 1992. Major improvements in tracking and particle ID are being incorporated. As a result, this effort is being given the highest priority within CLEO. We expect that more than 200 DLT tapes will need to be processed to produc the output DSTs used for data analysis.

The Recompress will be run on three DEC Alpha subfarms, containing a total of 8 DEC 3000-600 AXP processors belonging to UF, 7 new DEC 4/250 processors purchased with Florida's Nile money (these will be stationed at Cornell) and several machines from other institutions. Four other Florida machines are being used by the Cornell Analysis Farm (CAF) to support the analysis load while the data is being recomressed (they will be returned to Florida at the end of the 4-5 month recompress period) when they will be used for Monte Carlo generation for the CLEO collaboration. The Monte Carlo effort will not be able to commence until three months after the start of recompress, because of the effort and resources needed for the latter, but we will have to generate approximately 30-60 million $B\overline{B}$ events

From experience we expect that Recompress will happen about every two to three, driven mostly by ongoing improvements in charged particle tracking, shower fitting and particle ID. At the current rate of data collection at CLEO (about 2 fb^{-1} per year), Recompress will demand an ever increasing share of computing and personnel resources.

3. *CLEO Monte Carlo and analysis*

Florida generates approximately 2/3 of the generic Monte Carlo sample used by all of CLEO. We generate about 3 million events per month on 14 DEC Alpha processors. With the much larger data samples that will be stored on disk, our physics analyses and GEANT Monte Carlo simulations will require more computing power and disk space. These include the processes we are studying now, such as partial B reconstruction, color suppressed B modes, charmed baryon processes and charm decays. CLEO members who are collaborating with us on these projects will also be pursuing related analyses and simulations on our system.

4. *Hadron B Monte Carlo*

We will be generating large amounts of signal and background Monte Carlo for studying hadron B physics.

5. *CMS Monte Carlo*

A Research Scientist and post-doc involved with Delphi/CMS will be using the MCFAST simulation program developed at Fermilab to do fast simulations of CMS and other LHC detectors for development purposes. Some Geant based simulations might also be required.

III The Nile distributed computing project

The UFMulti software system we developed at UF was the cornerstone of our computing effort from 1988 till the past year. With UFMulti a single HEP 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.

We are now collaborators in an ambitious "National Challenge" computing effort (called "Nile") to develop a powerful networked computer system which would have the ability to run jobs across geographic distances, utilizing ATM networks in the final phases of the effort. We received funding for Nile in July, 1994 from the NSF and we expect it to continue for a total of 5 years. The institutions are Florida, Cornell, UT Austin and UCSD. We will develop 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 (e.g., "Ptool") and a paradigm for data analysis which will be explicitly parallel.

The hardware centerpiece of the proposal is the testbed system, which consists of the two UF farms located at Cornell and UF, each of which will be linked together by networking hardware paid out of the grant. Since ATM hardware is expensive, we plan to use networking based on the much cheaper "fast ethernet" as an interim solution for the next two years or so, until the prices for ATM switches and interface cards become more reasonable. The testbed system will be used to analyze real CLEO data with software designed by this group. Most of the grant ($3M over a 5 year period) will be used to pay for personnel, with the rest going to network related equipment, software and some new CPUs for the testbed system.