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RESEARCH IN ELEMENTARY PARTICLE PHYSICS AT THE UNIVERSITY OF FLORIDA

DOE/ER/40272--91

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ANNUAL PROGRESS REPORT
DOE GRANT FG05-86-ER40272

University of Florida
Gainesville, Florida 32611

November 1, 1989

Task A: Theoretical Elementary Particle Physics
Task B: Experimental High Energy Physics
Task C: Axion Search
Task S: Computer Requisition

ABSTRACT

This is a progress report on the Elementary Particle Physics program at the University of Florida. The program has four tasks covering a broad range of topics in theoretical and experimental high energy physics. The research accomplished within the program has increased mankinds understanding of elemenary particle physics.

Grant Coordinator: R. D. Field

ANNUAL PROGRESS REPORT

Task A:

Theoretical Elementary Particle Research at the University of Florida

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

ABSTRACT

This is a progress report of the Theoretical Particle Theory group (Task A) at the University of Florida under DOE grant (FG05-86-ER40272). At present our Theoretical Particle Physics group consists of four Full Professors (Field, Ramond, Thorn, Sikivie) and two Assistant Professors (Qiu, Woodard). Furthermore, we have recently formed an Institute for Fundamental Theory (IFT) at the University of Florida. It is dedicated to the pursuit of fundamental research in an interdisciplinary environment. The research of our group covers a broad range of topics in theoretical high energy physics and has balance between theory and phenomenology.

OUTLINE

I. INTRODUCTION

This progress report on theoretical elementary particle physics is presented by the Particle Theory Group at the University of Florida. During the past years we have firmly established our group through solid research contributions in theoretical physics, and we expect to continue this tradiation in the years ahead.

At present our group consists of R. D. Field (Professor), P. Ramond (Professor), C. Thorn (Professor), P. Sikivie (Professor), Z. Qiu (Assistant Professor) and R. Woodard (Assistant Professor). Dr. Woodard is a newly hired Assistant Professor from Brown University. In addition, we have six post-doctoral research associates, ten graduate students, and we maintain a very active seminar and visitors program. Next year we plan to increase the size of our group by hiring another new assistant professor in theoretical particle physics.

An Institute for Fundamental Theory (IFT) has recently been created at the University of Florida. Its purpose is to provide an environment for the pursuit of interdisciplinary researches in the various fundamental areas of physics and mathematics such as: high energy theory, condensed matter theory, gravitation, theoretical astrophysics, differential geometry, finite group theory, symplectic geometry. The primary aim of the Institute is to provide the best intellectual habitat for young theoretical physicists and mathematicians. The best young minds demand such an interdisciplinary environment, reflecting the confluence of mathematics, high energy theory, condensed matter theory, cosmology and general relativity. By providing an atmosphere where scientists with these various skills are within easy collaborative distance of one another, the IFT is the ideal vehicle to attract the best young theorists in the world.

Seed money for the Institute has been provided for three years by the University of Florida on an initiative from P. Ramond. Funds from the University of Florida will help support postdoctoral associates, visitors, and graduate students. The detailed dollar amounts are listed in Section VII. There is at present no institute in the Southeast that incorporates the interdisciplinary fields in the manner we are proposing for the Institute for Fundamental Theory at the University of Florida. We intend the balance and scope of IFT to be comparable to or greater than that found at existing interdisciplinary Institutes such as the Institute for Theoretical Physics at the University of California, Santa Barbara, the Institute for Advanced Study at Princeton, and the joint particle-physics/astrophysics group at the Fermi National Laboratory near Chicago.

We have been unable to obtain funding for the IFT as an entity. We have not found an appropriate agency that is capable of funding an interdisciplinary center such as IFT. However, we hope that the improved environment and funds provided by IFT will allow each of the participating disciplines to increase their own individual grants. If the increased outside funding of the individual participating disciplines can be documented, then we feel that we will continue to receive University support for the Institute.

Our group has been very productive resulting in publications covering a broad range of topics in theoretical particle physics. In addition, members of the group have traveled and given important lectures at national and international physics conferences. Within the last several years two members of our group have received Guggenheim Fellowships (P. Ramond 1985-86, C. Thorn 1986-87). The research accomplished by the group in such areas as string field theory, quantum chromodynamics, grand unified theories, covariant string quantization, and high energy phenomenology has increased the understanding of elementary particle physics.

We feel that we have established an excellent group in theoretical particle physics at the University of Florida and that IFT should further improve the research and teaching environment. Our research covers a broad range of subjects within particle theory and has a good balance between pure theory and phenomenology. We are determined to actively participate in the further development of elementary particle physics. The funds we are requesting from DOE will enable us to accomplish this goal.

II. INSTITUTE FOR FUNDAMENTAL THEORY

The ultimate aim of the IFT is to provide the right intellectual environment for attracting the brighest among young mathematicians and theoretical physicists. We believe that in the years to come these will tend to thrive in an interdisciplinary environment where close interaction exists between mathematicians and physicists. There are several reasons for this belief.

First of all in Physics there has been in the past ten years a dramatic confluence between hitherto independent discipline: namely, cosmology - astrophysics, particle physics, and condensed matter physics.

The marriage between cosmology and high energy theory (HEP) is well documented, and needs no elaboration here. So far the links between HET and condensed matter theory (CMT) have occurred along the lines of quantum statistical mechanics, quantum field theory, critical phenomena, and there has also been dramatic overlap between CMT and cosmology via the study of the kinetics of phase transition. In our view the overlap between CMT and HET will increase still more along the lines of deriving specific mechanisms of symmetry breaking. In particular it is hoped that the techniques for symmetry breaking in string theory might prove useful to the solution of CMT problems. In addition with the advent of string theory there is a need for a rapport between gravitation and HET, in order to arrive at a geometrical formulation of string gravity.

Just as there has been a tightening of the bonds between different areas of theoretical physics due to the universality of the methods used, their mathematical origins have motivated a historic rapprochement with pure mathematics. Thus the rationales for the IFT.

Recently the advent of superstring theory as a leading candidate for unifying all fundamental interactions has underlined the use for setting up a natural habitat for both mathematicians and physicists. In fact over the last decade it can be demonstrated that advances in the understanding of strings has motivated new breakthroughs in pure mathematics and vice-versa.

Preliminary indications show that the formulation of string theories as field theories has a strong overlap with many areas of pure mathematics such as noncommutative geometry, moduli spaces, loop space, infinite dimensional Kahler manifolds, ... The determination of the ground state of string theories (hopefully our world) borrows heavily from differential geometry and finite group theory. In an apparently unrelated subject, there are hints that loop spaces themselves are connected to moduli spaces and to soliton equations.

At present, the following University of Florida Department and faculty will participate in the Institute:

Department of Physics:
- P. Ramond (Professor, Particle Theory)
- C. Thorn (Professor, Particle Theory)
- R. Field (Professor, Particle Theory)
- P. Sikivie (Professor, Particle Theory)

Z. Qiu (Assistant Professor, Particle Theory)
R. Woodard (Assistant Professor, Particle Theory)
J. Ipser (Professor, Theoretical Astrophysics)
R. Buchler (Professor, Theoretical Astrophysics)
S. Detweiler (Professor, Theoretical Astrophysics)
J. Fry (Assistant Professor, Theoretical Astrophysics)
P. Kumar (Associate Professor, Condensed Matter)
P. Hirschfeld (Assistant Professor, Condensed Matter)
C. Stanton (Assistant Professor, Condensed Matter)
J. Dufty (Professor, Condensed Matter)
K. Muttalib (Assistant Professor, Condensed Matter)
D. Levine (Assistant Professor, Condensed Matter)

Department of Mathematics:
G. Emch (Professor & Chairman, Mathematical Physics)
J. Glover (Associate Professor, Markov Processes & Stochastic Integrals)
C. Stark (Assistant Professor, Geometry & Topology of Manifolds)
L. Block (Professor, Dynamical Systems & Chaotic Dynamics)
P. Ehrlich
A. Fathi
D. Groisser
J. Klauder
P. Robertson
S. Summers
L. Flaminio

We expect participation in the Institute to grow over the next several years as the Department of Physics plans to hire new faculty in the area of High Energy Theory, Theoretical Astrophysics, and Condensed Matter Theory. Furthermore, the Department of Mathematics intends to hire new faculty with the aim of building a strong Mathematical Physics group. In addition, University of Florida faculty participation may increase as other researchers in physics, astrophysics, astronomy, and mathematics are attracted the Institute.

III. PARTICLE THEORY PERSONNEL (last several years)

Name	Position	Time Contributed to this Project
R. D. Field	Professor	20% Academic, 100% Summer
P. Ramond	Professor	20% Academic, 100% Summer
C. Thorn	Professor	20% Academic, 100% Summer
P. Sikivie	Assistant Professor (9/1/82-9/1/84)	20% Academic, 100% Summer
	Associate Professor (9/1/85-8/31/88)	20% Academic, 100% Summer
	Professor (9/1/88-present)	20% Academic, 100% Summer
T. Curtright	Assistant Professor (8/1/84-9/1/85)	20% Academic, 100% Summer
	Associate Professor (9/1/85-8/31/89)	20% Academic, 100% Summer
Z. Qui	Assistant Professor (9/1/89-present)	20% Academic, 100% Summer
R. Woodard	Assistant Professor (9/1/89-present)	20% Academic, 100% Summer
M. Awada	Post-Doc (10/1/89-present)	100%
D. Harari	Post-Doc (9/1/86-8/31/89)	100%
S. Yost	Post-Doc (9/1/87-present)	100%
J. Minahan	Post-Doc (9/1/87-present)	100%
D. Zoller	Post-Doc (9/1/87-present)	100%
A. Polychronakas	Post-Doc (9/1/87-present)	100%
C. Preitschopf	Post-Doc (9/1/88-present)	100%
M. Bowick	Graduate Student (Ph.D. 9/1/83, now at MIT)	100%

M. Ruiz-Altaba	Graduate Student (Ph.D. 9/1/87, now at CERN)	100%
T. McCarty	Graduate Student (Ph.D. 3/1/89)	100%
D. Hong	Graduate Student (Ph.D. 9/1/88)	100%
G. Kleppe	Graduate Student (Summer 1986-1989)	100%
R. Viswanathan	Graduate Student (Ph.D. 9/1/89)	100%
M. Chu	Graduate Student (Full time)	100%
E. Piard	Graduate Student (Summer 1987-1989)	100%
B. Keszthelyi	Graduate Student (Summer 1988-1989)	100%
G. Tulsian	Graduate Student (Summer 1988-1989)	50%
B. Wright	Graduate Student (Summer 1988-1989)	50%
Y. Dixon	Staff Assistant	100%

IV. ACTIVITIES OF THE PARTICLE THEORY GROUP (last several years)

A. Lectures and Seminars

Curtright

Seminar at Columbia University, Department of Physics, Feb. 2, 1987.
Seminar at Yale University, Department of Physics, Feb. 10, 1987.
Invited guest of the Physics Department, University of Miami, April 1987.
Seminar at LAPP, Annecy-le-Vieux, France, July 7, 1987.
Invited participant in the Summer Workshop in High Energy Physics and Cosmology, ICTP, Trieste, Italy, July 17-31, 1987.
Invited speaker at the XXth Summer Institute on Theoretical Physics, Ecole Normale Superieure, Paris, France, Aug. 9-12, 1987.
Invited lecturer at Universitat Autonoma de Barcelona, Departament de Fisica Teorica, Barcelona, Spain, Aug. 24-Sept. 4, 1987.
Invited speaker at Perspectives on String Theory, the Niels Bohr Institute, Copenhagen, Denmark, Oct. 12-16, 1987.

Field

Colliquium presented at Universitat Autonoma de Barcelona, Barcelona, Spain, Dec. 15, 1987.

Invited talk presented at the QCD Conference, ITP, Santa Barbara, California, Jan. 18-22, 1988.
Invited talk presented at the "Higher Twist Workshop", College de France, Paris, france, Sept. 21-23, 1988.

Invited talk presented at the Workshop on Collider Phenomenology, Argonne National Lab, June 2-3, 1989.

Ramond

Invited Lecturer, Rutherford Christmas Meeting, Dec. 1987.
Seminar, BU, April 1987.
Colloquium and Seminar, Univ. of Maryland, May 1987.
Invited Lecturer, TASI, Santa Fe, N. M., July 1987.

Colloquium, Penn State, September 1988.

Sikivie

Three short talks at the VIIth Rencontre de Moriond on New and Exotic Phenomena, Les Arcs, France, Jan. 1987.
Particle Physics talk at Cornell, March 1987.
Invited talk at the Spring Meeting of the American Physical Society, Washington, DC, April 1987.
Parallel session talk at the International Europhysics Conference on High Energy Physics, Uppsala, Sweden, June 1987.
Particle Physics Seminar at Carnegie-Mellon University, Nov. 1987.
Physics Department Colloquium at the University of Tennessee, Knoxville, Dec. 1987.

Theory Summary talk at the Ninth Workshop on Grand Unification, Aix-les-Bains, France, April 1988.
Particle Theory Seminar at CERN, May 1988.

Particle Theory Seminar at the Ecole Normale Superieure, Paris, May 1988.
Particle Theory Seminar at the Ecole Polytechnique, Saclay, France, May 1988.
A long talk (2 hours, reviewing axion physics) and a short talk (20 minutes, on cosmic global strings) at the Aspen Center for Physics, June 1988.
Particle Theory Seminar at SLAC, July 1988.
Particle Theory Seminar at the Institute for Advanced Study, Princeton, Oct. 1988.
The Joint BU-Harvard-MIT Theory Seminar at Boston University, Oct. 1988.
Particle Theory Seminar at the University of Rochester, Oct. 1988.
Two lectures at the III^{d} Nishinomiya-Yukawa Symposium on Dark Matter, Nishinomiya, Japan, Nov. 1988.
Particle Theory Seminar at Kyoto University, Kyoto, Japan, Nov. 1988.
Particle Theory Seminar at Tohoku University, Sendai, Japan, Nov. 1988.
Particle Theory Seminar at the Institute for Cosmic Ray Physics, Tokyo Univeristy, Tokyo, Japan, Nov. 1988.
Participated in a panel discussion on cosmic axion detection at the Berkeley Workshop on Particle Astrophysics, Dec. 1988.

Astrophysics Seminar at Fermilab, Feb. 1989.
Physics Department Colloquium at Univ. of Alabama, Tuscaloosa, March 1989.
Particle Physics Seminar at LBL, March 1989.
Invited talk at the Cosmic Axion Workshop at BNL, April 1989.
Invited talk at the Symposium on Quantum Fluids and Solids, QFS 1989 Gainesville, April 1989.
Invited talk at 1st Workshop on Particle Astrophysics, San Miniato, Italy, May 1989.
Particle Theory Seminar at the University of Pisa, Italy, May 1989.
Invited talk at the Conference on CP Violation in Particle Physics and Astrophysics, Blois, France, May 1989.

Thorn

Theoretical Physics Seminar, Rockefeller Univ., Jan. 1987.
Theoretical Physics Seminar, Inst. for Adv. Study, May 1987.
Theoretical Physics Seminar, Fermilab, May 1987.
University of Chicago, May 1987.
Invited lectures, String Workshop, Copenhagen, Denmark, Oct. 1987.

Invited lectures, Trieste Spring School, Trieste, Italy, April 1988.
Invited lectures, Maryland: Strings 88, May 1988.
Aspen Center for Physics, August 1988.

Theoretical Physics Seminar, Cornell, May, 1989.
Theoretical Physics Seminar, Univ. of California, Berkley, July 1989.

B. Travel

Curtright

Columbia University, February 1987.
Yale University, February 1987.

University of Miami, April 1987.
LAPP, Annecy-le-Vieux, France, July 1987.
ICTP, Trieste, Italy, July 1987.
Ecole Normale Superieure, Paris, France, August 1987.
Universitat Autonoma de Barcelona, Spain, Aug.-Sept. 1987.
Niels Bohr Institute, Copenhagen, Denmark, Oct. 1987.

Field

Fermilab PAC Meeting, April 3-4, 1987.
Fermilab PAC Meeting, June 13-20, 1987.
Aspen Center for Physics, June 22-July 12, 1987.
Universitat Autonoma de Barcelona, Barcelona, Spain, Dec. 14-16, 1987

ITP QCD Workshop, Jan.-June, 1988.
Fermilab PAC Meeting, April 7-8, 1988.
Fermilab PAC Meeting, Aspen, CO, June 18-27, 1988.
Snowmass Workshop, June 27-July 15, 1988.
College de France, Paris, France, Sept. 21-23, 1988.
Fermilab PAC Meeting, Oct. 20-21, 1988.

Dedication of the Feynman Computer Center, Fermilab, Dec. 1-2, 1989.
Fermilab PAC Meeting, Jan. 27-28, 1989.
Fermilab PAC Meeting, April 28-29, 1989.
Workshop on Collider Phenomenology, Argonne Nat. Lab., June 2-3, 1989.
Conference on Supercollider Physics and Experiments, Dallas,
October 1-4, 1989.
DPF Executive Committee, Dallas, Oct. 4, 1989.

Ramond

Washington, D.C., Jan. 1987.
Washington, D.C., March 1987.
Boston, Mass., April 1987.
College Park, Univ. of Maryland, May 1987.
Santa Fe, New Mexico, July 1987.
Aspen, Colorado, July 1987.
SLAC, September 1987.

Penn State, September 1988

Caltech - M. Gell Mann's Festschrift, January 1989.
Hepap Subcommittee, Hilton Head, S.C., January 1989.
Aspen Center for Physics, June-July, 1989.
Tuscaloosa, String Meeting, November 1989.

Sikivie

Les Arcs, France, January 1987.
Cornell, March 1987.
Washington, D.C., April 1987.
Uppsala, Sweden, June 1987.
Carnegie-Mellon University, Nov. 1987
University of Tennessee, Knoxville, Dec. 1987

Ninth Workshop on Grand Unification, Aix-les-Bains, France, April 1988.
CERN, May 1988

Ecole Normale Superieure, Paris, May 1988.
Ecole Polytechnique, Saclay, France, May 1988.
Aspen, Colorado, June 1988.
SLAC, July 1988.
The National Radio-Astronomy Observatory, Soccorro, New Mexico, July 1988
The Institute for Advanced Study, Princeton, Oct. 1988.
Boston University, Oct. 1988.
University of Rochester, Oct. 1988.
Nishinomiya, Japan, Nov. 1988.
Kyoto University, Kyoto, Japan, Nov. 1988.
Tohoku University, Sendai, Japan, Nov. 1988.
Institute for Cosmic Ray Physics, Tokyo Univ., Tokyo, Japan, Nov. 1988.
University of California, Berkeley, Dec. 1988.

Fermilab, Feb. 1989
Univ. of Alabama, Tuscaloosa, Feb. 1989.
Lawrence Berkeley Laboratory, March 1989.
Brookhaven National Laboratory, April 1989.
San Miniato, Italy, May 1989.
Pisa, Italy, May 1989.
Blois, France, May 1989.
Aspen Center for Physics, Aug. 1989.

Thorn

Rockefeller University, June 1987.
Fermilab, May 1987.
University of Chicago, May 1987.
Institute for Advanced Study, May 1987.
Copenhagen, Denmark, Oct. 1987.

Trieste, Italy, April 1988.
University of Maryland, May 1988.
Aspen Center for Physics, August 1988.

Cornell University, May 1989
SLAC, July 1989

C. Seminar Speakers and Visitors (last six years)

A. Irving (Fla. State)
J. Schwarz (Caltech)
J. Patera (Montreal)
L. Alvarez-Gaume (Harvard)
D. Friedan (Univ. of Chicago)
D. Reiss (Univ. of Washington)
J. Walker (Fermilab)
M. Wise (Harvard)
J. Ward (UC-Irvine)
D. Freedman (MIT)
M. Bander (Univ. of Calif.)
A. Ali (DESY)
B. Zwiebach (Caltech)
P. Steinhardt (Univ. of PA)
L. Brink (Goteborg)
A. White (Argonne)
R. Gastmans (Belgium)
B. Wybourne (New Zealand)
A. Terrano (Columbia)
R. Barbieri (Pisa)
M. Derrick (SLAC)
G. Ross (Oxford)
H. Green (Australia)
W. Walker (Duke)
D. Preston (Calif. State Univ.)
P. Goddard (Univ. of Virginia)
S. Mandelstam (Univ. of Calif.)
H. Pagels (Rockefeller Univ.)

S. Gates (CALTECH)
E. Berger (Argonne)
L. Abbott (Brandeis)
D. Olive (Univ. of Virginia)
W. Celmaster (Northeastern Univ.)
S. Rajeev (Syracuse Univ.)
C. Buchanan (UCLA)
S. Raby (Los Alamos-Michigan)
H. Montgomery (CERN)
G. Domokos (John Hopkins)
J. Ellis (SLAC)
Q. Shafi (NASA)
L. McLerran (Univ. of Washington)
M. Doria (Yale)
P. Landshoff (Oxford)
O. Fackler (Lawrence Livermore)
C. Callan (Princeton)
H. Gordon (Brookhaven)
S. Shenker (Univ. of Chicago)
H. Georgi (Harvard)
P. Van Nieuwenhuizen (SUNY)
M. Gaillard (Berkeley)
E. Corrigan (England)
M. Feigenbaum (New York)
M. Bowick (Yale)
E. Witten (Princeton)
M. Dine (Princeton)
S. Reucroft (CERN)
H. Weisberg (SUNY)
M. Atiya (Columbia)
J. McCabe (Ohio State)
E. Farhi (Boston)
C. Hill (Batavia)
T. Kephart (West Lafayette, IN)
C. Zachos (ANL)
K. Choi (Pittsburgh, PA)
M. Jensen (Chicago)
T. Matsuki (Baton Rouge, LA)
R. Slansky (Albuquerque, NM)
M. Feigenbaum (Ithaca, NY)
G. Ghandour (Kuwait)
Y. Hosotani
A. Dragt
B. Ovrut (Pennsylvania)
S. Meshkov (Washington, D.C.)
C. Nappi (Princeton)
S. Giddings (Princeton)
D. Olive (Princeton)
A. Sanda (New York)
R. Rohm (CALTECH)
H. Sonoda (Cambridge, MA)

A. Sanda (Rockefeller Univ.)
J. Gervais (LPTENS)
M. Sher (Univ. of CA)
P. Fishbane (Univ. of Virginia)
S. Deser (Brandeis)
F. Taylor (Fermilab)
G. Farrar (Rutgers)
R. Rau (BNL)
L. Clavelli (Argonne)
S. Shankar (Yale)
H. Haber (Univ. of CA)
R. Coquereaux (CERN)
R. Holman (NASA)
K. Foley (BNL)
J. Polchinski (Harvard)
V. Nair (Inst. for Adv. Study)
S. Das (Fermi)
H. Lipkin (Fermi)
L. Baulieu (Rockefeller Univ.)
M. Gronau (NY)
E. Braaten (Argonne)
G. Black (Kentucky)
M. Shaevitz (Columbia)
Y. Nambu (Chicago)
H. Gordon (BNL)
T. Appelquist (Yale)
E. Alvarez (Madrid, Spain)
R. Johnson (BNL)
A. Vilenkin (Mass.)
M. Cvetic (Univ. of Maryland)
J. Harvey (Princeton)
H. Hamber (Princeton)
G. Coughlan (London)
W. Bardeen (Chicago)
L. Parker (Milwaukee)
L. Mezincescu (Austin, TX)
R. Rohm (Princeton)
V. Kaplunovsky (Princeton)
E. Martinec (Princeton)
A. Mendez (Spain)
R. Frampton (North Carolina)
D. Zanon
E. Kolb (Fermilab)
E. Eichten (Chicago)
K. Ellis (Chicago)
A. Mueller (New York)
A. Hasenfratz (Florida State)
L. Abbott (Boston)
A. Kent (Princeton)
K. Pilch (MIT)
P. Soholsky (Salt Lake City, UT)

V. GROUP PUBLICATIONS (last several years)

1. Effective Generating Functions for Quantum Canonical Transformations, G. I. Ghandour, UFTP-86-15, Phys. Rev. D35, 1289-1295 (1987)
2. A Classification of 2-Dimensional Conformal Supergravity Theories with Finite-Dimensional Algebras, J. McCabe and B. Velikson, UFTP-86-16.
3. Jets Produced in Association with W and Z Bosons, R. D. Field and T. Gottschalk, UFTP-86-19, Phys. Rev. D35, 875 (1987).
4. Unconstrained Gauge Invariant Field Theory of Free Closed Strings, P. Ramond and V. G. J. Rodgers, UFTP-86-21, submitted to Phys. Lett.
5. The Explicit Gauge Invariance of the Free Ramond String and Closed String Theories, P. Ramond, V. G. J. Rodgers and R. R. Viswanathan, UFTP-86-22, Nuclear Physics B293, 293-316 (1987).
6. Q-Balls for the ^{3}He AB-Transition, D. K. Hong, UFTP-86-25, submitted to Phys. Rev. Lett.
7. Curvature of Super Diff$(S^1)/S^1$, P. Oh and P. Ramond, UFTP-87-9, Phys. Lett. B195, 130-134 (1987).
8. The Superstring, DiffS^1/S^1 and Holomorphic Geometry, P. Ramond, D. Harari, D. K. Hong and V. G. J. Rodgers, UFTP-87-10, submitted to Nuclear Physics B (1987).
9. On the Evolution of Global Strings in the Early Universe, P. Sikivie and D. Harari, UFTP-87-4, Phys. Lett. B195, 361-365 (1987).
10. Coset Representation of Closed Loop Space in String Field Theory,, P. Oh, UFTP-87-12, Phys. Lett. B196, 336-338 (1987).
11. Estimates of the Density of Dark Matter Near the Center of the Galaxy, P. Sikivie and J. R. Ipser, UFTP-87-5, Phys. Rev. D38, 3695 (1987).
12. A Detailed Study of the Physical State Conditions in Covariantly Quantized String Theories, C. Thorn, Nuclear Physics B286, 61 (1987).
13. BRST Invariant Transitions Between Closed and Open Strings, C. Thorn and J. A. Shapiro, UFTP-87-14, Phys. Rev. D36, 432-464 (1987).
14. The Nonplanar One-Loop Amplitude in Witten's String Field Theory, C. Thorn, D. Z. Freedman, S. B. Giddings and J. A. Shapiro, UFTP-87-15 (1987), to appear in Nuclear Phys. B.
15. Perturbation Theory for Quantized String Fields, C. Thorn, UFTP-87-16, Nuclear Physics B287, 61-92 (1987).
16. A Detailed Study of the Physical State Conditions in Covariantly Quantized String Theories, C. Thorn, UFTP-87-17, Nuclear Physics B286, 61-77 (1987).

17. Closed String-Open String Transitions and Witten's String Field Theory, C. Thorn and J. A. Shapiro, UFTP-87-18, Phys. Lett. B194, 43-48 (1987).

18. The $Z' \to WW \to \ell + \nu + \text{jet} + \text{jet}$ Signal at Hadron Colliders, F. del Aguila, Ll. Ametller, R. D. Field and Ll. Garrido, UFTP-87-13, Phys. Lett. B201, 375 (1988).

19. Vacuum Decoy in Curved Background, L. Abbott, D. Harari and Q-H. Park, Classical and Quantum Gravity (in press).

20. Q-balls in Superfluid ^{3}He, D. K. Hong, UFTP-87-20.

21. The Gravitational Field of a Global String, D. Harari and P. Sikivie, UFTP-87-22, Phys. Rev. D37, (1988) 3438-3440.

22. The Conformal Factor and DiffS^1/S^1, D. Hong, UFTP-88-1.

23. A Reparametrization-Invariant Approach to String Field Theory, G. Kleppe, P. Ramond and R. Viswanathan, UFTP-88-2, Phys. Lett. B206, 466 (1988).

24. Evidence for a Nambu-Goldstone Boson, P. Sikivie, UFTP-88-4.

25. Non-Relativistic Bosonization and Fractional Statistics, A. Polychronakos, UFTP-88-5.

26. Gravitational Time Delay Due to a Spinning String, D. Harari and A. Polychronakos, UFTP-88-6.

27. NWOGU Theory Summary, P. Sikivie, UFTP-88-8.

28. A Reparametrization-Invariant Approach to Superstring Field Theory, G. Kleppe, P. Ramond and R. Viswanthan, UFTP-88-9, to be published in Nuclear Physics B.

29. Bosonized Superstring Boundary States and Partition Functions, S. Yost, UFTP-88-11.

30. String Field Theory, C. B. Thorn, UFTP-88-12, to be published in Physics Reports.

31. Searching for the $Z' \to WW \to \ell\nu + \text{jet} + \text{jet}$ Signal at Hadron Colliders, R. D. Field, UFTP-88-13, submitted to Physics Letters.

32. Lattice Strings, C. B. Thorn, UFTP-88-16.

33. Calculation of the one-loop graviton mass-shift in bosonic string theory, J. Minahan, UFTP-89-2.

34. Cavity design for a cosmic axion detector, P. Sikivie, C. Hagmann, N. Sullivan, D. Tanner, S.-I. Cho, UFTP-89-4.

35. Algebra of Reparametrization-Invariant and Normal Ordered Operators in Open String Field Theory, P. Ramond, UFTP-89-5.

36. Albelian Chern-Simons Theories in 2+1 Dimensions, A. Polychronakos, UFTP-89-7.

37. Alternative Ghost Structures for Superstring Field Theory, G. Kleppe and R. Viswanathan, UFTP-89-8.

38. Abelian Chern-Simons Theories and Conformal Blocks, A. Polychronakos, UFTP-89-9.

39. Solar and Cosmic Axion Hunting, P. Sikivie, UFTP-89-10.

40. Massive Condensates and Scaling In String Field Theory, D. Zoller, UFTP-89-11.

41. Algebra of Reparametrization-Invariant Operators in Open String Field Theory, G. Kleppe, P. Ramond and R. Viswanathan, UFTP-89-12.

42. A New Non-Grassmannian Pseudo-Classical Action for Spin-1/2 Particles, R. Warner, UFTP-89-13.

43. Gravitational Particle Production by Cosmic Strings, J. Garriga, E. Verdaguer, D. Harari, UFTP-89-14.

44. Stueckelberg Revisited, J. Minahan, UFTP-89-15.

45. A Comment on Anomaly Cancellation in the Standard Model, J. Minahan, P. Ramond and R. Warner, UFTP-89-16.

46. The Strong CP Problem and the Axion, P. Sikivie, UFTP-89-17.

47. A Global String with an Event Horizon, A. Polychronakos and D. Harari, UFTP-89-18.

48. Superstring Field Theory, C. Preitschopf, S. Yost and C. Thorn, UFTP-89-19.

49. The Orientation of the QCD Vacuum, P. Sikivie and C. Thorn, UFTP-89-20.

50. Open-Closed Transition for the NSR Spinning Strings, M. Chu, UFTP-89-21.

B. Conference Reports

51. The Early Years of String Theory: The Dual Resonance Model, P. Ramond, UFTP-87-19, lectures given at the '87 TASI held at St. Johns College, Santa Fe, New Mexico, July 1987.

52. Lectures on String Theory, C. B. Thorn (Three lectures presented at the Spring School on Superstrings, held at the ICTP, Trieste, Italy, April 1988.

53. Lattice Strings, C. B. Thorn (lecture at the workshop Strings '88), University of Maryland, May 1988.

F. Scientific Progress Reports of the Group Members

a. R. D. Field

My research interests involve the extraction of measurable predictions from the theory of Quantum Chromodynamics (QCD). QCD is a precise and complete theory of quarks and gluons which purports to be an ultimate explanation of all strong interaction experiments at all energies, high and low. There are many reasons to hope and expect it to be right. The question is, is it indeed right? Mathematical complexity has, so far, prevented quantitatively testing its correctness. The primary obstruction is the fact that the fundamental quarks and gluons of QCD apparently cannot be isolated as free particles, but are always confined within hadrons by strong forces not amenable to treatment by perturbative methods. Nevertheless, because QCD is an asymptotically free theory, interaction forces become weak at small distances (large energies) and calculations using perturbation theory and Feynman diagrams are possible. Unfortunately, most processes involve both low and high energy aspects, and ways of separating the low energy pieces, which are not calculable by perturbative methods, from the high energy perturbative parts, are just becoming understood. The nonperturbative (low energy) pieces are parameterized, taken from data, or a model is built to describe the regime. However, "true tests of perturbative QCD" often turn out merely as tests of the authors' cleverness in parameterizing the nonperturbative uncalculable part of the problem and not as actual tests of QCD. Great care must be taken in examining the sensitivity of predictions to the uncalculable parts of the problem.

During the year I would like to continue to investigate perturbative applications of the QCD theory of quarks and gluons with the aim of guiding and predicting experiments. Not until precise predictions are made can deviations from the theory be observed and it is such deviations that lead to the discovery of new phenomena. Over the past several years I have been studying Monte Carlo techniques for simulating on a computer what hadron-hadron collisions events are like at high energy. At present QCD Monte Carlo models are quite crude. They contain a little QCD perturbation theory and a lot of phenomenology. I would like to spend some time in an attempt to improve the accuracy of QCD Monte Carlo models for hadron-hadron collisions or at least understand better the limitations of the models. I have done detailed comparisons with data on proton-antiproton collisions at the CERN CM energy of 540 GeV and the models agree reasonably well with experiment. In addition, I have investigated the jets produced in association with W and Z bosons. I plan to make a comprehensive series of predictions of the event topologies at the Fermilab CM energy of 2,000 GeV. Within the next year or two the CDF group will take data at this new facility which is now the highest energy hadron-hadron collider in the world. Predictions made before the data are available are usually considerably more significant than those made afterward.

The United States has decided to construct a "Superconducting Super Collider" (SSC) which will allow scientists to examine hadron-hadron collisions at much higher energies than previously conceived (40,000 GeV). At these energies many new phenomena are sure to occur. However, the experimental observation of the new phenomena depends crucially on our understanding the events expected from QCD. QCD multijet events will be the "background" for the

the easier it will be to pick out the new physics. Recently, I have begun to simulate events at SSC energies and to analyze these events as one would in a real experiment. I have learned that although quark and gluon "jet spectroscopy" is an attractive idea, experimentally it is more difficult than one first thought. I have tried to reconstruct the invariant mass of fictitious heavy W and Z bosons from their jet-jet decay mode and it is not easy. In addition, I have attempted to reconstruct events in which a heavy Higgs particle decays into a W+W- pair with each W subsequently decaying into pair of leptons or into a quark and antiquark jet. Also, I am examining the feasibility of detecting a new heavy Z' boson via its decay into a lepton, neutrino and two jets (i.e. $Z' \to \ell + \nu + \text{jet} + \text{jet}$). Much more work needs to be done and I believe that I can contribute significantly in this area.

I plan to continue to work to improve the hadron-hadron Monte Carlo approach and to study the event structure predicted at the SSC. It is very important for the experimenters who are designing detectors to have some idea of what to expect. I participated in the 1984 Snowmass Summer Study, the 1985 Oregon Workshop, and the 1986 Snowmass Summer Study, and I plan to continue to be involved with SSC physics.

b. Z. Qiu

I have been working on string theory and two dimensional conformal field theory for the last few years. My interest in string theory arises from the fact that it is the only known theory which (apparently) consistently incorporates both quantum mechanics and general relativity. On the other hand, two dimensional conformal field theory is not only a powerful tool, in both practical calculations and general formulation, in studying string theory but also in its own right describes two dimensional critical phenomena.

One of the crucial questions in string theory is how nature selects one particular vaccum, our world, out of millions of solutions of string equation of motion. String field theory seems to be one promising way to study this nonpertubative aspect of string theory. Unfortunately the present formulation of string field theory cannot even describe all the solutions of string equation of motion. In a recent work, Tye and I proposed a configuration space for string field theory. It is essentially the space of all conformal field theories, both unitary and non-unitary, of central charge c=26 (15 for superstring). The configuration space includes all the solutions of string equation of motion. Moreover our proposal also suggests a much larger symmetry underlying string theory. I intend to continue our work in this direction. We are now in the process of finding the kinetic term of string field theory in our formulism. We will next study the geometric structure of this configuration space. Hopefully, it will lead us to the completion of string field theory action. I also intend to attempt to apply these ideas towards a calculation of non-perturbative quantum effects while working on the formal aspect of string field theory.

At the same time I would like to continue my research in understanding the space of conformal field theories. My objective is the classification of conformal field theories. It will also enable one to identify all universal classes in two dimensional phase transitions. The approach I am currently interested is bosonization. In this approach one has an universal description for conformal field theories which now have to be constructed through many different methods. We have been able to find bosonic realizations of most known conformal field theories. The next step is to extract the central idea and formulates bosonization in general. I also intend to investigate the relationship between conformal field theory and other area of research. These include itegrable model, 2+1 dimensional quantum field theory, quantum field theory of anyon and its application in high temperature superconductivity.

c. P. Ramond

(a) Students

In the spring of 1989, I graduated my third Florida Ph.D. student, R. Raju Viswanathan who is now a Postdoc at ICTP, Trieste. At the moment I am advising G. Kleppe, B. Wright, B. Keszethelyi, E. Piard, D. Castano and A. Arason. Of these G. Kleppe is expected to get his Ph.D. in spring 90.

(b) Projects

This last year, I followed my research into the meaning string field theory. In a series of publications with G. Kleppe and R. Raju Viswanathan I pursued the question of reparameterization invariance as the central ingredient. We found a promising new set of reparameterization invariant operators, including a symmetric second rank tensor, with the BRST as its trace, but its algebra had operator anomalies. The anomaly free sector contained no more than the usual BRST theory. After a similar lack of progress in formulating a closed string field theory, because of the upcoming data at SLAC and LEP, and of the relative ignorance of students in phenomenological matters, I decided to concentrate on answering questions of more immediate interest -- such as what lies directly beyond the Standard Model. I am presently teaching a course on that subject. As a by product I found that anomaly cancellation was enough to ensure the correct charge quantization, which came as a surprise in view of the standard explanation which demands grand unification. This work was done with a postdoc J. Minahan and an Australian IFT visitor R. Warner. Presently I am investigating the question of six quark condensates and, should they exist, their role in generating neutrino masses.

With students E. Piard, B. Keszethelyi and B. Wright we are looking at various 2+1 dimensional theories -- notably Weyl theory which contains Chern-Simon terms for both gravity and a vector field, together with no trivial torsion dependent local interaction terms. I am also interested in understanding functional determinants with non-standard exponents and in generalizing Bogolynbov transformations to oscillators that generate quantum groups.

d. P. Sikivie

Some fraction of my time is spent worrying about the Florida cosmic axion detector and issues related to it. At present, the detector is built and taking data. This work is the result of a collaboration between C. Hagmann, N. Sullivan, D. Tanner and myself. We should be able to publish a limit on the local axion density in a few months. We expect that it will be a factor two or three more severe than that which was obtained the Rochester-Brookhaven-Fermilab collaboration. The present sensitivity is about a factor 300 short of the sensitivity required to detect galactic halo axions. With an eye towards the construction of a larger detector, we have carried out computer simulations which optimize the cavity design to obtain the highest possible cosmic axion search rate for a given magnet size. We have written up our results in a paper entitled "Cavity Design for a Cosmic Axion Detector" submitted to the journal Reviews of Scientific Instruments.

Another fraction of my time is spent writing up lectures or conference talks, usually on axions. During the last year I wrote "Solar and Cosmic Axion Hunting" for the Proceedings of the III^{d} Yukawa-Nishinomiya Symposium (held in Nishinomiya, Japan, in November 1988) and "The Strong CP Problem and the Axion" for the Proceedings of the Conference on CP Violation in Particle Physics and Astrophysics (in Blois, France, June 1989). Writing up talks is tedious and often repetitive. However, it does force one to keep up to date and to continue to clarify the foundations and issues in one's field of interest.

One such issue, which arose in discussions of the strong CP question within the framework of wormhole physics, is what are the implications of "$\bar{\theta}=\pi$". It appears that there is some confusion in the literature, as manifested in such phrases as: "$\bar{\theta}=\pi$ implies poor current algebra relations among the pseudo-scalar masses". C. Thorn and I have considered this issue in some detail and have written a short paper on that subject: "The Orientation of the QCD Vacuum" submitted to Phys. Lett. B. Our main point is that when P and CP symmetry is imposed on the order parameter describing chiral symmetry breaking in massless QCD, there are two physically distinct orientations of that order parameter. We may label them: $\gamma = 0$ and $\gamma = \pi$. The condition under which good (poor) pseudo-scalar mass relations are obtained is $\gamma + \bar{\theta} = \pi$ ($\gamma + \bar{\theta} = 0$), instead of $\bar{\theta} = 0$ ($\bar{\theta} = \pi$) as in usually stated. However, using a theorem of Vafa and Witten, one can show that, in the case of three light flavors, $\gamma = \pi$. So it turns out that the usual assertion is not in error after all, but it does require the additional theoretical input provided by the Vafa-Witten theorem.

The research topic on which I spend most of my time, however, is the observational implications of the existence of a massless Nambu-Goldstone boson and of global cosmic strings. I think this is very exciting stuff. A few years ago, D. Harari and I conjectured that the dynamical behaviour of global strings is very different from that of gauge strings. Specifically, we conjectured that an initially bent global string would release its energy at once, in one or two oscillation times, and that the energy spectrum of radiated Nambu-Goldstone boson is proportional to 1/k (equal amounts of energy in equal log k intervals). During the past year, C. Hagmann and I have carried out computer simulations of the decay of a global string. They support the above conjecture. C. Hagmann and I plan to write up these results before too long. If global cosmic strings exist, they would produce a cosmological flux of Nambu-Goldstone bosons, with a 1/k spectrum. Some of the N-G bosons will convert to photons — with energies ranging from the radio part of the spectrum all the way up to the grand unification scale ($\sim 10^{14}$ GeV) — in the magnetic fields of galactic halos and of clusters of galaxies. I believe that evidence that this phenomenon actually occurs can be found in a number of astrophysical observations including the polarization maps and x-ray luminosity of radio-jets, high energy-cosmic rays and the phenomenology of quasars.

e. C. B. Thorn

Last year (1988-89), I devoted a significant amount of time in the Fall semester completing a major review article on string field theory for Physics Reports. This article appeared in April, 1989. My research activities were divided between development of superstring field theory and the search for an alternative fundamental formulation of string theory. As it turned out more time was spent on the former problem, because Scott Yost, Christian Preitschopf, and I achieved a mini breakthrough which enabled us to begin to surmount an obstacle which had stalled research for over a year. There is still much work to do in following up on our discovery, and I expect this work will continue well into next year (1989-90).

My search for an alternative formulation of string theory centered on trying to revisit an attempt of mine to get a handle on planar QCD (i.e. the limit $N_c \to \infty$) by summing fishnet (large planar) diagrams. However, there was no justification in the case of QCD that these fishnet diagrams should dominate. Since the result of summing them was a string theory, including the graviton, the absence of general covariance in QCD proves that they can't dominate. However, if instead of QCD one starts with a generally covariant quantum field theory, it is not impossible that some kind of fishnet approximation is viable. This work has been temporarily put on hold while I am completing work on superstring field theory, but I hope to return to it in the coming year.

Finally, as new data start coming in from SLC, Fermilab, and LEP, I find myself thinking more about issues surrounding the standard model. This past summer (1989) Pierre Sikivie and I had a new look at questions concerning the QCD θ parameter, in particular the phenomenological differences between the two CP conserving values, $\theta = 0$ and $\theta = \pi$. Although this yielded no new results, we think our study dispelled some confusion in the literature. I hope to continue an active interest in such issues in the coming years.

f. R. Woodard

My basic interest is quantum gravity in the larger context of Lagrangian field theory and particle physics. Since 1985 I have been working on string theory with short breaks devoted to conventional quantum gravity. Because I intend to continue this dual effort the immediate future I will include one paragraph summarizing my string program and another on conventional quantum gravity.

My interests in string theory are its consistency and what it tells us beyond the weak field limit. Since neither issue is perturbative I have been led to invariant string field theory. A number of papers have emerged from this work. Current work includes a proposal for invariant closed string field theory and a classification scheme for the general solution to the cubic action field equations.

I began my career working in conventional quantum gravity and am still intensely interested in it, though I have dawdled about publishing early work. My thesis, "Invariant Formulation of and Radiative Corrections in Quantum Gravity", reformulated the theory around a set of invariant Green's functions. I have written papers debunking conformal scalar-metric theory and unregulated studies of the factor ordering problem. Current work concerns infrared problems with Coleman's "Big Fix" scenario.

g. D. Harari

During the past year I evaluated effects in the time-dependent gravitational field of cosmic strings. This work was done in collaboration with J. Garriga and E. Verdaguer, at the Universidad Autonoma de Barcelona. Quantum pair production during the formation of the string network was previously estimated by L. Parker. We found that loops of cosmic string, that keep forming and oscillating after the string network formation, have a more significant effect, although still not large enough to have relevant consequences in cosmology.

With A. Polychronakos we analysed the exact solutions to Einstein equations around a global cosmic string. About two years ago, we found (in collaboration with P. Sikivie) its gravitational effects in the linear approximation to general relativity. Since then, other authors have found the exact solution to Einstein eqs. for this system. The metric becomes singular at a finite distance from the string core. Now we studied the dependence on the equation of state for the core, finding that there exist solutions which are non-singular. They have instead a horizon at a finite proper distance from the core, such that observers beyond the horizon are bound to move away from the string. Thermal effects in a quantum field theory due to the presence of this horizon were also analysed.

This coming year I will be working at the Institute for Astronomy and Space Physics in Buenos Aires, Argentina, with a research position with the Argentina Research Council.

h. J. Minahan

This is my third year as a post-doc at the University of Florida. My latest research has been in collaboration with Roland Warner of the University of Melbourne on a generalization of the Stueckelberg formulation for massive gauge fields. It turns out that these fields can obtain a mass in a gauge invariant way by adding a topological term to the action. A paper has been submitted to Physical Review Letters on this subject.

I have also done some research with P. Ramond and R. Warner on constraints on charge quantization enforced by anomaly cancellation. We have found that anomaly cancellation in the standard model with the electroweak gauge group $SU(2)_L xU(1)$ quantizes the U(1) charges. The minimal Higgs breaking mechanism then gives the correct electric charges for the matter fields. Technicolor theories, since they have added gauge groups lose these quantization conditions. This work has been summarized in a paper submitted to Physical Review D.

In the future, I would like to address some issues in high T_c superconductors and their relation to Chern-Simons theories and fractional statistics. It is possible that properties of these theories might mimic some of their phenomena. Another problem I would like to consider is string theory propagation on SU(1,1) group manifolds.

i. A. Polychronakos

My research in the last year has concentrated on topological field theories, cosmic strings and, recently, quantum groups.

Topological field theories have emerged recently and, apart from their interest as mathematical objects, have provided tools and ideas towards the understanding of such issues as fractional statistics excitations in planar systems, fractional quantum Hall effect and high temperature superconductivity. My own contribution to the subject was to provide a simple understanding of the fact that such theories have finitely many states, to calculate the Hilbert space of these theories and to demonstrate their connection with two-dimensional conformal field theories.

On cosmic strings my work was to show, in collaboration with D. Harari, that spacetime around a global string need not have a singularity, as thought earlier, but it can, instead have a horizon at a finite distance from the core.

Finally, on quantum groups I am trying to reproduce their structure by appropriately deforming the corresponding classical groups, especially in the interesting and, as yet, unknown quantum versions of the Virasoro and Kac-Moody algebras.

My research plans for the immediate future are aimed at related issues, namely, the relevance of fractional statistics to superconductivity and the quantum Hall effect and the connection of quantum groups with the quantization of systems realizing the corresponding classical symmetry.

j. S. Yost

I am a postdoctoral associate in my third year at the University of Florida. My most recent work has concerned superstring field theory. I have been collaborating with Prof. C. Thorn and another Florida postdoc, C. Preitschopf, on a new formulation of superstring field theory, following the Chern-Simons approach introduced by E. Witten. This work is summarized in the present UFIFT-HEP-89-19, "Superstring Field Theory". Our formulation avoids the problem of infinite contact interactions which plagued earlier formulations.

In the course of this work, we discovered the advantages of working in a non-traditional gauge for string field theory, one which formally eliminates the cubic interaction of the Chern-Simons action. The existence of such a gauge is of interest for both bosonic and superstring field theory, and it is especially useful for simplifying superstring perturbation theory. Although the new gauge formally linearizes the theory, scattering is not eliminated because the gauge choice is somewhat singular. The existence of a linearizing gauge is a feature shared by ordinary Chern-Simons field theory, and it would be interesting to find ways to exploit this analogy.

I am also interested in a number of other aspects of superstring theory. Earlier, I have worked on the question of how string theory differs from conformal field theory, which is essentially the classical limit obtained by ignoring string loop effects. The string loop corrections to conformal invariance have not yet been understood in a systematic manner, and I will probably return to this question in future work. The foundations of string theory are still only beginning to be explored, so it is difficult to predict which approaches will be most fruitful. I feel that it is important to keep an open mind toward all possibilities, since string theory has the potential to revolutionize our understanding of the structure and origin of the universe.

k. D. Zoller

The finiteness of the cosmological constant and modular invariance are presently understood only at the level of first quantized string theory (i.e., in perturbation theory). I am trying to understand these issues at the level of string field theory. In light cone string field theory the cosmological constant is an integral over $\vec{p}$ and p^+. Rough calculations indicate that $\vec{p}$ integral is exponentially suppressed and I do not yet understand the p^+ integral. The modular transformation which requires a self dual lattice appears to be connected with the reality condition on the string field. I am also investigating global gravitational anomalies for the spacetime $S^3 x R$. Their existence has been reduced to the topological question of whether there are non-contractible closed loops in the set of spatial local SO(3) rotations.

VII. UNIVERSITY AND DEPARTMENT SUPPORT FOR PARTICLE THEORY AND IFT

1. Particle Theory Support from the Physics Department:

Subject to the availability of state funds the Department of Physics will provide $22,000 per year in expense money to be used for travel and visitors and for the operation of the group (xeroxing, phones, mailing, etc.). In addition, the Department will provide matching funds for two post-doctoral associates. Over the next few years we expect the Department of Physics to provide the following:

	1990-91	1991-92 (Estimated)
Post-Docs	$47,000	$47,000
Travel and Visitors	$13,000	$13,000
Operating Expense	$ 9,000	$ 9,000

2. Support for IFT from the University of Florida:

The University of Florida has committed the following funds to the Institute (AA = Academic Affairs, GS = Graduate School, and DSR = Department of Sponsored Research):

	1987-88	1988-89	1989-90	Source
Post-docs	$30,000	$60,000	$90,000	(AA)
Visitors	$15,000	$30,000	$60,000	(GS)
Graduate Students	$15,000	$30,000	$30,000	(DSR)

The funding for Post Doctoral positions and visitors is committed by the University as long as the IFT is in operation. The funding for graduate students will end after three years. In addition, the University will provide a one time sum of $10,000 for conferences.

II. Summary of Experimental Particle Physics at the University of Florida at Gainesville

In the past year, several important milestones and physics results have been achieved from our research at Fermilab and Cornell. The neutrino program presented results at an International Conference in the summer of 1989 after having completed its final run in February 1988. The DO collaboration to study pp collisions at 2 TeV at Fermilab is now firmly committed to a first run in 1991. The CLEO program to upgrade the detector is now complete and we are playing a substantial role in that effort. Hence, our focus is on colliding beam physics at TeV I and CESR.

There has been continued development of the required infrastructure at UF to successfully conduct this work. In addition, there has been continued personnel growth. In addition, we have initiated a search for a new faculty person to join the group in the fall of 1990. Personnel and their areas of research have been/are/will be:

TASK B

(1) Fermi Program

Professor:	James K. Walker
Research Scientist:	Andrew White
Research Associates:	John Womersley, Zachary Wolf
Undergraduate student:	David Pettey

(2) Cornell Program

Assistants Professors:	Paul Avery, John Yelton
Research Associates:	David Besson, Lynn Garren

TASK D

(3) Detector Development at UF

Two groups have had extremely active programs:

Group 1

Professor:	James K. Walker
Asso. Research Scientist:	Julie P. Harmon
Research Associates:	Vladimir Feygelman Sophia Szafran
Graduate Student:	Tushar Jhaveri

Group 2

Research Scientist:	Stan Majewski
Research Associates:	Mohammed Jibaly Carl Zorn
Technician:	Margaret Bowen

TASK S

(4) Computer Development Program

Assistant Professor:	Paul Avery
Research Scientist:	Andrew White
Postdoctoral:	A search is currently being conducted.
Graduate Student:	Chandra Chegireddy
Undergraduate Student:	Greg Huey

Last year an important contribution by UF to the DO collaboration was to show that an intercryostat detector (ICD) eliminated the deleterious effects of the steel walls of the cryostats. We showed the necessity for a 768 element scintillation counter ICD for installation in DO in 1990. The design and prototyping is complete and construction will shortly begin in collaboration with Michigan and a group from the USSR. In addition, major contributions were made to test beam MWPC construction, a liquid argon module test facility, and a monitoring system for calorimeter modules. In terms of software, we have had substantial responsibilities for Monte Carlo development, reconstruction program development, simulated processed event production, test beam software and physics studies.

Our effort on the CLEO experiment at Cornell has achieved substantial physics results in the last year. The partially upgraded detector, CLEO 1.5, completed its first run for data in April 1988. Of the twelve papers announcing physics results since that time, our group has made major contributions to three and were involved significantly in two others. In one paper, the discovery was reported of the first and only observation of the charmed strange baryon. The analysis was performed entirely at Florida. We have also planned, built and debugged the UFMulti multiprocessing software package adopted by CLEO for date reduction and event simulation. Finally, our group has had responsibility for running and calibrating the CLEO shower counters during data collection and for maintaining the central detector calibration software.

The Detector Development group has continued to develop its discovery of the extremely radiation resistant polysiloxane based plastic scintillator. The basic attributes of primary fluors which confer radiation stability are now understood. A study of secondary fluors has been made and one has been found with highly desirable characteristics. The combination of plastic, primary and secondary fluors has been tested up to 30 Megarads and has been shown to have a stable light output to within + 5%. This is more than a factor of 100 times more radiation resistant than the standard commercial scintillator. This major development in detector technology opens up new opportunities for both calorimetry and particle tracking at the SSC. In addition to further research on the basic material, we will now address the processing of the material into fibers and plates. A comparative study of commercially available scintillators and new formulations of dyes in conventional plastics has also been performed. Work on non-aging wire detectors based on dimethyl gas has been successfully completed this year with good results.

The VAX 6220 and 5 workstations which had been bought last year was augumented with eight 3200 nodes which could be used as a parallel processor. The UFMulti software environment was completed which permits the system to operate with a total analysis power equivalent to 60 VAX 780 (or 60 MIPS). This is the most powerful multiprocessor of any University high energy group in the country. This system has now been used by us for extensive analysis of CLEO data, simulation of the DO detector, and simulation of SSC physics. The Berkeley group of E. Wang and Gilchriese are beginning to use the system for simulation studies with the solenoid collaboration for SSC studies. We anticipate significant further use by other SSC groups as they become familiar with the facility.

Finally, we have made contributions to the development of SSC physics in the form of two sub-system proposals in October 1989.

A. Calorimetry

The detector group was supported by SSC funds through its generic R & D program to develop the concept of fiber tower calorimetry (FITCAL). This led to the October 1989 submission of a $5.4 million major sub-system proposal for FITCAL design and construction. This is a collaboration of several insitutions, including Oak Ridge National Laboratory, with UF as the lead institution. This calorimeter is designed to use the new super radiation resistant plastic scintillator developed by our group.

B. Computer Farms

We would like to extend our pioneering achievement of establishing a <u>user friendly</u> software environment for multiprocessing in a VAX based VMS environment to a RISC based

UNIX (ULTRIX) environment. A major sub-system proposal ($1.4 million) for a RISC based multi processor farm was therefore submitted to the SSC in October 1989. We expect to port the existing UFMulti software system to this new hardware within 2-3 months. This short time scale will be essential for the rapid final design and optimization of major detector sub-systems, and full SSC detector simulation.

General Remarks

As can be seen from the above discussion the group has had great productivity and in some cases has had major achievements in the last year. All of this activity has required more traveling costs than anticipated. We are most pleased that we have been authorized to search for a new faculty person to start in the fall of 1990. We intend to continue our activities in DO and CLEO for the next 5 to 10 years with a concomitant gradual increase in activity in SSC physics. Finally, a proposal for a Center of High Energy Experimental Physics at UF has been prepared, and is in the process of being submitted to the Physics Department for eventual approval by the Board of Regents.

III The D0 Experiment at Fermilab

III.1 Software and Physics Studies

(a) Monte Carlo Development

The D0 Monte Carlo program, D0GEANT, has undergone major revisions during the year. It was decided to rework the entire code to allow the detector parameters and geometrical constants to be held in external files (the SRCP or Static Run Control Parameter system). We have participated in the testing and debugging of this new system and have created a version of D0GEANT to run on the UF VAX "farm". We shall use the farm to generate a large fraction of the 10^5 events to be used as a test of the reconstruction and analysis software. Due to the redevelopment of D0GEANT we have postponed further Monte Carlo analysis of the ICD until very recently. We have, however, run a limited sample of jet events through the latest version of D0GEANT, which contains a detailed description of the ICD. The ICD analysis routines have been reworked and extended to allow for more flexible development and testing of correction algorithms.

We have taken responsibility for steering the development of the Monte Carlo simulations of calorimeter modules for the next test beam run. The primary objective of this work is to take advantage of the SRCP scheme to use the same description for both the test beam and full detector simulations. This will greatly ease the transfer of test beam results into a correct simulation of the full detector. This work involves the coordination of Monte carlo activities at LBL (ECEM module), and Fermilab (ECIH and the Monte Carlo framework). We have also led the discussion of simulation priorities and their coordination with test beam run priorities. A final contribution has been to develop the code for the generation of fake raw data from the test beam Monte Carlo program, as we have already done for the full D0GEANT.

(b) Reconstruction program

To facilitate the development of the many areas of the D0 event reconstruction software, a number of "particle algorithm groups" have been formed. One of us (A.White) is the co-leader of the Missing Et group. We have evolved a four level scheme for the MEt calculation. The first level evaluates a "raw" MEt from the calorimeter data alone. The second level applies the ICD and massless gap corrections. The third level takes into account reconstructed muons and the associated energy deposition in the calorimeter. The fourth level involves event specific corrections. The approach we have adopted is that the first three levels will be carried out routinely (with certain choices of algorithms allowed), while the fourth level will be the subject of progressive development and implementation as we gain experience handling the data. The first versions of the code for the first three levels have been written and tests have begun within the framework of the D0USER package.

(c) Supersymmetry studies

We have used the procedures developed for the SSC supersymmetry studies (see SSC section of this report) to examine the discovery potential of D0 in this area. Fig. 1 shows the result of high statistics QCD background and SUSY signal runs using the UF VAX farm. The line shape of the QCD background is established out to very large MEt. This work was carried out mainly at the Breckenridge Workshop on Physics at Fermilab in the 1990s. These procedures will form the Monte Carlo component of the D0 SUSY analysis when used in conjunction with the full D0GEANT. The same procedures will be used to provide physics benchmarks for SSC detectors, as discussed below.

(d) Test Beam Data Analysis

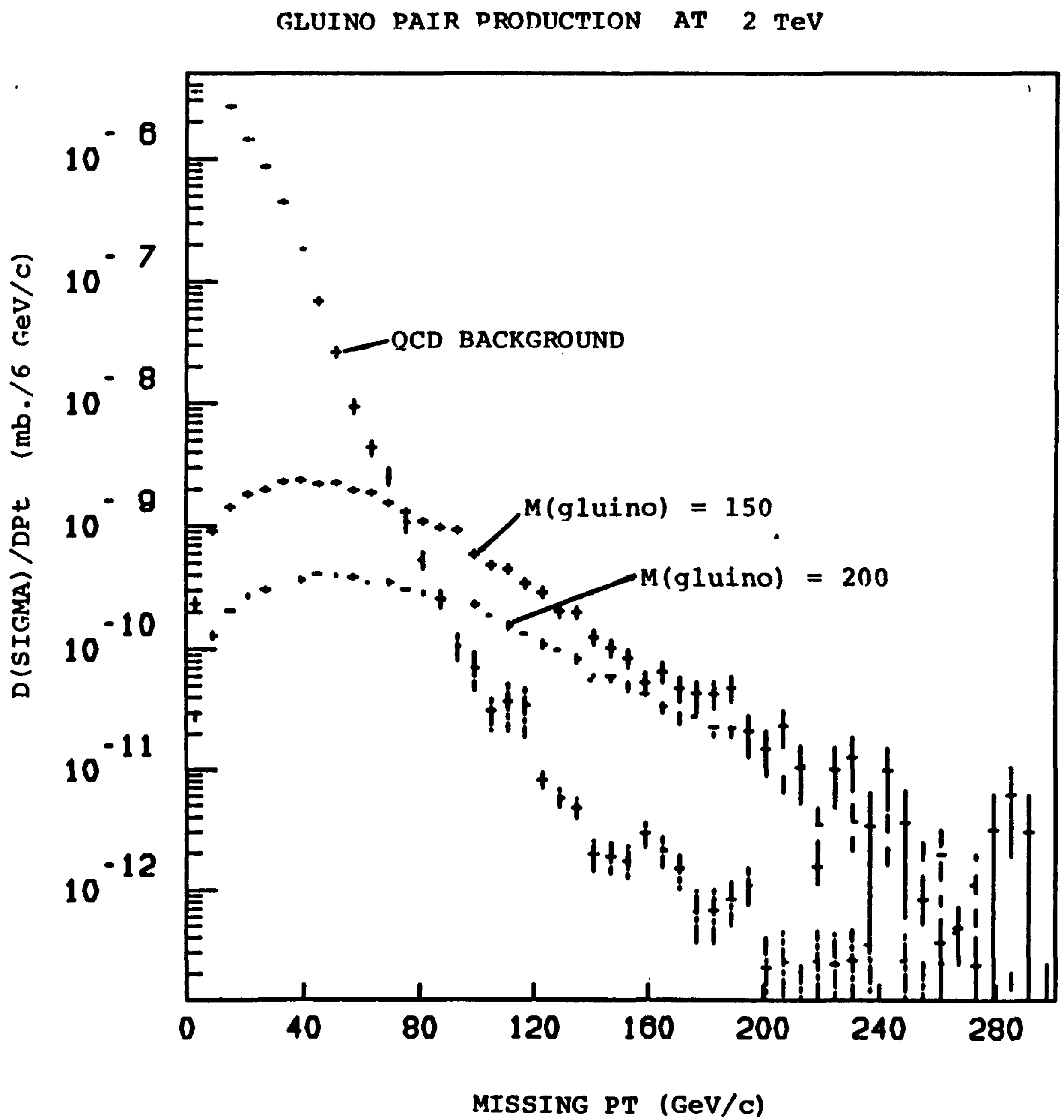
John Womersley was jointly responsible for much of the analysis of the data taken during the '87 test beam run at Fermilab. This work has now been published in Nuclear Instruments and Methods.

(e) Simulated Processed Event

Zachary Wolf wrote a series of routines for the D0Geant Monte Carlo which produce an output, the "simulated processed event", which is useful to those writing the D0 jet-finding algorithms. In the Monte Carlo a proton-antiproton interaction is simulated by ISAJET. The final state particles are tracked through a simulation of the D0 detector. The "simulated processed event" routines record the energy deposited in the calorimeters by each ISAJET jet. This information corresponds to an imperfect detector, but a perfect jet-finding algorithm. The results have proved useful to the persons writing the D0 jet-finding algorithms as they can compare their results to the results from a perfect algorithm.

(f) Test Beam PWC Software

Zachary Wolf has taken the responsibility of incorporating the data from our movable PWC (see item (2)(b) below) into the test beam analysis. Our PWC will very accurately give the position of the beam as it enters the cryostat. This information will be coupled with the position and orientation of the movable cryostat and information from the upstream PWCs to accurately determine the position and direction of the beam as it enters the calorimeter module under test.


GLUINO PAIR PRODUCTION AT 2 TeV
D(SIGMA)/DPt (mb./6 GeV/c)
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
QCD BACKGROUND
M(gluino) = 150
M(gluino) = 200
0
40
80
120
160
200
240
280
MISSING PT (GeV/c)

(g) Top Quark Mass Study

One of us (Zachary Wolf) did a study of how well D0 can measure the top quark mass once the top quark is found. The method studied involves reconstructing the top quark 4-momentum to find its mass. This can be done in $t\bar{t}$ events in which one t decays semileptonically and the other hadronically. The subtlety of the method is in reconstructing the neutrino 4-momentum. The neutrino's transverse momentum is determined from the event's missing transverse energy. The longitudinal momentum is found from a quadratic equation. The results of the study were presented at the Fermilab conference "Physics at Fermilab in the 1990's" recently held at Breckenridge, Colorado. The results and a brief description of the method will appear in the conference proceedings. These studies will be continued and will be detailed in a D0 note.

III.2 Hardware

(a) Intercryostat Detector

This year has seen many developments in the design of the ICD, culminating in a final design and a production schedule for next year. A simple design with 1-inch wide wavelength shifter bars on top of a scintillator tile was shown in cosmic ray tests to have +-20% non-uniformity of response across the area of the tile. While significantly less than the +-50% variation inherent in the correlations between the ICD signal and energy deposited in dead material, it was decided that an alternative design with +-5% variation was more acceptable at the expense of a slightly more complicated construction. This latter design uses multiple fibers or rods set in channels in the scintillator tile.

We have tried a number of combinations of single fibers, rods, and fiber bundles. Concerns over single fiber stressing and fiber-rod joints led us to settle on continuous fiber bundles as the final design. Each bundle will be made from a large number of 200 micron fibers and will sit in a 3x3 mm^2 channel in a tile. Tiles will have 3,4 or 5 bundles depending on their size. The bundles from a single tile are brought to a single larger bundle at the face of the phototube. This approach has given us a great deal of flexibility in the layout of components inside the ICD boxes. This is important since, predictably, we are now required to fit the ICD into a smaller space between the CC and EC cryostats than was originally foreseen. Specifically, we are now able to position the three phototubes for each box at the end of each box affording the maximum space - at the widest separation of the cryostats.

A full prototype based on the fiber bundle design was constructed at UF and tested at U. Michigan. Results were consistent with expectations for uniformity and signal level, and we feel confident to proceed to production of the final detector with this design. The fiber pre-forms will be made at Fermilab and sent to PolyOptical Inc. to be drawn into fibers which will then be assembled into bundles. The scintillator may be provided by the Serpukhov D0 group, in which case the mechanical assembly of the detector would be divided between UF and Serpukhov, with the final instrumentation and testing being carried out at U. Michigan.

(b) Test Beam PWC

We are nearing completion of a project for the upcoming D0 test beam run. We are providing a proportional wire chamber (PWC) mounted to a frame which is movable so as to cover the area of the test beam cryostat entrance window. The PWC will be used to get a very accurate measurement of the position and direction of the beam as it enters the calorimeter module under test. The PWC is a standard Fermilab Fenker PWC, the same as the others in the beam line. We purchased an X-Y translating table with 24 inch travel to move the PWC over the entire area of the cryostat entrance window. We mounted electronic scales to the table to accurately read out the PWC position to a computer. We built electronics to control the motion of the table and give a visual display of its position. The mounting of the PWC was carefully done so the wires were accurately aligned with the table's directions of travel. We are presently preparing the device for shipment to Fermilab for installation. Zachary Wolf was responsible for this project.

(c) EC Module test facility

John Womersley has worked on the setting up of a liquid argon vessel capable of containing a ECMH or ECOH module. This system allows the modules to be cold tested prior to installation in the EC cryostat. The high voltage system and readout electronics for the test facility have also been installed and a first version of the online program created to control data acquistion. First tests have been carried out on an ECMH module.

(d) Capacitance measuring system for calorimeter modules

The capacitance measuring system developed by John Womersley was moved to the area used for stacking the ECMH modules. This system is needed to verify the integrity of electrical connections before sealing modules in an EC cryostat. The comparison of capacitance measurments for signal channels with expectations can reveal the presence of a disconnection on even the smallest pad. The system has been enhanced by the addition of a check that compares any discrepancies against the capacitance of a single smallest pad in a tower. This replaces the fixed threshold used before and greatly speeds up the analysis of results.

III.3 General

We give below a summary of some notable occurences relating to our participation in D0 this year:

- One of our postdocs, John Womersley, left us in August to take a junior faculty position at Florida State University.

- A. White won an award of $9100 from the UF Division of Sponsored Research to support development work on the ICD.

- A.White was asked to give the D0 experiment status report at the Proton-Antiproton Workshop at Castiglione (Italy) in September.

III.4 Activities for Next Year

(1) Software

- The priority for our Monte carlo work at UF is the detailed checking of the ICD performance using the results from the high statistics D0GEANT runs now underway at UF.

- Within the context of the Missing Et particle algorithm group we shall optimize the algorithms for the correction of energy losses in the transition region. Through our leadership of this group we shall ensure that D0 has a working and tested set of reconstruction routines as a basis for physics studies in this important area.

- We shall continue to supply a large fraction of the Monte Carlo production effort using the UF VAX farm.

- We shall pursue the development of the Test Beam version of D0GEANT and the production of simulation results for comparison with the '90 Test Beam data.

- We shall be centrally involved in the planning for the analysis of D0 data. We have successfully tested the exchange of data with Fermilab on 8mm. cassettes using our new, ultra high density drives. We shall determine the most efficient way to process the large quantities of data expected from D0 using these tapes and large disk staging areas.

- With our newly developed system for SUSY calculations, we shall explore a number of scenarios in order to prepare ourselves for the arrival of real data. We would like to explore a number of combinations of the parameters defining a SUSY "theory" to be fully sensitive to the range of possible experimental signatures.

(2) Hardware

- Construction of the final ICD will begin early in 1990. This is somewhat later than was originally planned due to extended prototype work and movement of the D0 schedule and funding priorities. However, the first EC cryostat will now be available for ICD installation in January 1991, giving us sufficient time for the complete ICD construction.

- We shall shortly install the PWC system we have developed at UF on the head window of the new Test Beam cryostat. Once it is installed, we shall be responsible for its correct operation. We shall also develop a solution to providing the necessary beam position information at the side window of the cryostat for use with second test beam load later in 1990.

- We shall work on the preparation for a test of energy loss correction in the overlap region between central and end calorimeter modules in the second test beam load in 1990. For this we shall simulate the cryostat walls with steel plates in the argon. The ICD will be represented by a "massless gap" due to the difficulties of operating a scintillator system inside the cryostat.

IV The CLEO Experiment

IV.0 Introduction and History

The CLEO experiment resides at the south end of the Cornell Electron Storage Ring (CESR). The detector is used to study e^+e^- interactions at center of mass energies near 10 GeV. Much of our effort has focussed on the properties of the Υ family of resonances (a total of 6 have been discovered), particularly the $\Upsilon(4S)$ since it decays into mesons carrying a single b quark. In the spring of 1988 there was a large data set taken at the $\Upsilon(5s)$ which is expected to decay to B_s mesons. No unambiguous B_s has yet been found, but there is now evidence of its existence from studying the particle yields at the $\Upsilon(5s)$. The energy range is also well suited to studies of charmed mesons and baryons. This has become an increasingly fruitful area of the research for CLEO now that the SPEAR facility as SLAC has been closed down. The CLEO collaboration now comprises around 100 professional physicists and graduate students from 13 institutions (Cornell, Florida, Harvard, Kansas, Maryland, Minnesota, Ohio State, Oklahoma, Purdue, Rochester, SUNY-Albany, Syracuse, and Vanderbilt). Minnesota has joined in the last year. It is expected that the size of the collaboration will increase further in the next few years. Florida has been a member since September, 1985

CLEO has just completed a $36 million upgrade program funded by NSF. The 1987-88 data set was taken with a new tracking system (main drift chamber and vertex chamber), this configuration was known as "CLEO 1.5". Since then there have been further improvements in the inner detector together with a large "crystal calorimeter" which will dramatically improve the detection and measurement of neutral particles. The detector, in its new and improved form, is now known as "CLEO II". There has also been a major upgrade to CESR which increases the number of collisions to be detected by CLEO and therefore increases its sensitivity to rare events.

IV.1 Summary of Work at CLEO: Oct. 1989 - Oct. 1990

Hardware changes

The major upgrade from "CLEO 1.5" to "CLEO II" was performed between the end of data taking in April 1988 and the turn on of CESR in September 1989. A new superconducting magnet coil has been installed together with a new refrigeration system. There are 64 new time-of-flight counters built by the Harvard group. These fit inside the coil with a great increase of solid angle compared with the previous time-of-flight counters. The Syracuse group have constructed and installed a muon detection system of 2400 tubes.

After much discussion, a decision was made to manufacture a beam pipe of 3.5 cm radius. This decrease in radius compared with the CLEO-I beampipe (5.5 cm radius) decreases the effects of multiple scattering on the measurement of charged particle trajectories. The Ohio State group have manufactured a six layer straw inner vertex detector. The first measurement point is now at around 4.5 cm from the vertex. There is sufficient space between the beam-pipe and vertex chamber for a test of a silicon detector.

The highlight of the upgrade is the system of 7400 CsI crystals. These give good segmentation, resolution and solid angle for the detection of neutral particles and make many more decay modes of B mesons accessible.

There has been a major upgrade of CESR which it is hoped will improve the luminosity in the CLEO interaction area by a factor of 7. These improvements are, in order of importance to the luminosity increase; a) Increase in the number of bunches from 7 to 14. b) Removal of the low beta insertion in the north interaction region (CUSB) will help luminosity in the south region (CLEO) c) Realization of the beam-beam limit by installing new horizontal separators that will not spark. d) Improvements in optics control. e) Reduction in filling time. f) RF cavity and vacuum system improvements. It is too early to know how much of this planned luminosity increase will be realized in practice.

Physics Analysis at CLEO

When CLEO 1.5 stopped HEP running in April 1988. A total of 212 pb^{-1} of data had been taken at the $\Upsilon(4s)$ resonance, 102 pb^{-1} just below the $\Upsilon(4s)$ resonance, and 114 pb^{-1} at the $\Upsilon(5s)$. The data set at the $\Upsilon(5s)$ was twice as large as originally envisaged due to the good performance of CESR at that time. Data taking started using CLEO II in September 1989, but to date there has not been a significant luminosity taken.

Although many members of the collaboration were fully occupied with the hardware changes, the last year has been one of high output of publications using the CLEO 1.5 data. In all 12 publications have appeared in refereed journals (three in Physical Review D, five in Physical Review Letters and four in Physics Letters). In general the group are now submitting letters to Phys. Lett rather than PRL because of the speed with which the former acts.

The following papers were published during the year up to October 1989.

1. Investigation of the Total Charm Particle Cross-Section in Non-resonant e^+e^- Annihilation. T. Bowcock et al., Phys. Rev. D38, 2679.

2. Search for the Charmless Decays $B \to p\bar{p}\pi$ and $p\bar{p}\pi\pi$. We have not observed these modes. In 1988 the ARGUS experiement reported an observation of these modes, claiming it as evidence of $b \to u$ transitions. In this paper CLEO published stringent upper limits on their existence; ARGUS have not found the signal in their new data. Florida was involved in this analysis.

3. Inclusive ψ Production in Υ Decays. R.Fulton et al., Phys. Lett. B224, 445. This is the first observation of a $c\bar{c}$ bound state in Υ decays.

4. Observation of the Charmed Strange Baryon Ξ_c^0. P.Avery et al., PRL 62,863. This is the first, and so far only, observation (and mass measurement) of the baryon consisting of a csd quark combination. This analysis was performed by Florida.

5. B^0-$\bar{B}^0$ mixing at the $\Upsilon(4s)$. M.Artuso et al., PRL 62:2233. This mixing, measured by the observation of like-sign di-leptons, confirms the important 1987 result from the ARGUS experiment.

6. Measurement of the muonic Branching Fraction of $\Upsilon(1s)$ and $\Upsilon(3s)$. W. Chen et al., Phys. Rev. D39,3528. The Υ resonances have muonic decay channels that compete with 3 gluon decays. A measurement of these channels yield a value for the total width of the resonances.

7. A Search for $b \to u$ Transitions in Exclusive B meson Decays. PRL62:2436. Limits are placed on several exclusive channels where $b \to u$ transitions would be expected to manifest themselves. The lack of signals in these channels give important constraints on the elements of the K-M matrix.

8. Σ_c^{++} and Σ_c^0 Production in e^+e^- Annihilation. T. Bowcock et al., PRL 62,1240. This letter cleared up the controversy surrounding the mass of the $\Sigma_c{}^0$. Florida made a major contibution to this analysis.

9. A Search for Exclusive Penguin Decays in B mesons. P. Avery et al., Phys. Lett. B233,470. Several explicit decays in B mesons are searched for. Florida was involved in this analysis.

10. Search for Fractionally Charged Particles. T. Bowcock et al., Phys. Rev. D40, 263. Limits are placed on the production of quarks or similar fractionally charged objects.

11. Measurement of the Isospin Mass Splitting of the Ξ_c^0 and Ξ_c^+. M.S. Alam et al., Phys. Lett. 226:401. This follows up on the CLEO discovery of the Ξ_c^0. Evidence for the Ξ_c^+ has previously been published by two other experiments but their results are controversial and their mass measurements poor. One other experiment has presented good evidence for its existance but has not yet published their results. CLEO is the only experiment that has obseved both states and so can measure the mass splitting. Florida performed this analysis.

12. Measurement of D_s Decay Modes. W. Chen et al., Phys. Lett. 226,192. Several new decay modes of the D_s are presented.

The following papers were also submitted to the Lepton-Photon Conference at Stanford in August 1989. They are in the main available as preprints, or are awaiting publication.

1. On Semileptonic Branching Ratios of B^0 and B^- Mesons and $B\bar{B}$ mixing, J.Alexander et al. New measurements of the neutral B branching fraction together with the ratio of B branching fractions are combined with other measurements to yield best-fit values, and so reduce the uncertainty in $B\bar{B}$ mixing measurements.

2. Exclusive Semileptonic Decays of B Mesons into D Mesons. J.Alexander et al. New measurements are presented for $B^- \rightarrow D^{*0} l^- \nu$ and $B^- \rightarrow D^0 l^- \nu$.

3. A Measurement of the B^0 Semileptonic Branching Ratio. M.S.Alam et al. This is the measurement using partially constructed D^{*0} events.

4. B Decays to Charm: Exclusive Decays and Inclusive Rates. W. Chen et al. This is a summary of the B decay rates CLEO has mesaured, in particular the observation of double charm events such as $B \rightarrow D_s D^+$.

5. The Decay $D^0 \rightarrow K^0 \bar{K}^0$. D. Bortoletto et al. This is a measurement of an important Cabibbo suppressed decay of the D^0. Florida made a major contribution to this analysis.

6. Study of Rare D^0 Decays. P.Avery et al. Several new decay modes are observed and measured using the information from the neutral detector. Also new improved measurements of Cabibbo suppressed decays into 2π's or 2K's are presented. This analysis was performed by Florida.

7. P-Wave Charmed Mesons in e^+e^- Annihilation. T.Bowcock et al. Several "D^{**}" states are now observed and their cross-sections measured.

8. Study of the Decay Process $\Upsilon \rightarrow D^{*+} + X$. P. Avery et al. This is a search for D^{*+} Production analogous to the already observed Ψ production. None is found and stringent limits are placed. Florida performed this analysis.

9. Search for Neutinoless Decays of the τ Decays. R.Fulton et al. Such decays are not expected to exist, and limits placed upon them give important checks on the sequential nature of the τ-lepton.

10. Search for Neutral Higgs Boson in B-Meson Decay. Limits are placed which constrain the theory of Higgs production from B-mesons.

11. Radiative $\Upsilon(1s)$ Decays. R.Fulton et al. Modes of $\Upsilon(1s)$ decay with many π's and/or K's are measured. This paper has been released in a preprint (CLNS 89/939) and is awaiting publication. Florida performed this analysis.

There are several other analyses that are in an advanced state of preparation but not yet available in preprint form.

1. Λ_c^+ Production and Branching Ratios. This details all 6 decay modes of the Λ_c^+, including the $\Xi^- K^+ \pi^+$ mode that has not been seen by anybody else. These results have presented in conferences and may be read in their proceedings. Florida made a major contribution to this analysis.

2. τ Decays in K and K*. CLEO has a vast sample of τ events and is preparing a paper investigating the Cabbibo suppressed decays involving K's. This analysis is being performed by Florida.

2. Florida's Activities at CLEO: Oct. 1988 - Oct. 1989

Florida has made a major contribution to the physics analysis as descibed in the first part of section 4. In addition, we completed or are working on the following activities to improve the CLEO detector.

1. The planning, building and debugging of the UFMulti multiprocessing software package. This is explained in detail in the task S summary. This system has already been used for much of the data analysis performed by Florida and detailed above. It has also been adopted by CLEO as the standard system for the collaboration and will be used for standard data reduction, Monte-Carlo event generation and DST analysis.

2. In the last years of CLEO 1.5 running, Florida has had responsibility for the running and calibration of the CLEO shower counters. This calibration is now used for the luminosity measurements used in all CLEO publications.

3. The calibration of the central detector. This now includes the new straw chamber along with the vertex detector and main drift chamber for which Florida has already had responsibility. Many changes are necessary as a result of the change in the magnet field strength, which is now a maximum of 1.5 T.

There will be a vast increase in the volume of data in the next few years. This is due to the increase in luminosity of the machine, and also the increase in complexity of the experiment. This data is presently stored on standard magnetic tapes, new versions of these tapes have to be sent from Cornell to Florida any time the data is reprocessed. We have purchased 2 Exabyte video tape systems with Summus controller, compatible with those used both at Cornell and FNAL. This enables us to store and transport data much more efficiently and help us take full advantage of our computer power.

V Other Activities

V.1 Fermilab BCD experiment

Paul Avery and John Yelton have joined about 20 institutions in signing a Letter of Intent to carry out an ambitious collider experiment at Fermilab (and possibly SSC) with the intent of observing CP violation in B decay. We regard the B Collider experiment as something we could naturally move to if we decide to leave CLEO in the next few years. Although our work with CLEO precludes us from taking on new major commitments at this time, we have agreed to carry out some Monte Carlo studies of B vertex reconstruction to see what levels of precision are needed for a microvertex detector to detect B branching fractions at the level of 10^{-7} or so. We are working with a B reconstruction subgroup on this topic. UF's contribution will be to develop constrained fitting software and use it on events generated by Fermilab. We will also have to generate some GEANT events on the multiprocessor at UF for other related studies. We have chosen the vertexing work precisely because it covers the same ground that we are covering for CLEO microvertex project described in the previous section. We will be carrying out a major fraction of the vertex studies on the UF computer system to take advantage of its multiprocessing capabilities.

As part of our involvement in this study, we will need to take occasional trips to attend meetings. This is documented in the budget discussion.

V.2 B-Factory Studies

There is no reason to believe that CLEO II will be the ultimate experiment to run at the CESR energy range. There are several efforts mounted around the country to propose a high luminosity "B-Factory" that will produce e^+e^- annihilations at around 100 times the CESR luminosity. The main physics drive of such a machine would be the investigation of CP violation effects in rare B-decays. In many ways Cornell is the natural site for a machine of this type to be built; the laboratory and accelerator physicists are already there, and the new machine could be a rebuilt CESR. Therefore it is not surprising that many of the CLEO collaboration are getting involved in aspects of its planning. Cornell has just submitted a proposal to upgrade CESR into a B factory.

Following a B-Factory workshop, Paul Avery has become the leader of a group that will do serious Monte-Carlo studies of B events with a view to defining the parameters of a suitable experiment to run at the planned luminosity. The UF CLEO personnel form the nucleus of the group, and are likely to spend a considerable amount of time on the project in the next year. We will need to expand our computer resources to handle this extra activity (as well as the BCD simulations).

Experimental Search for the Axion — Development Project

Task C of USDOE contract FG05-86ER-4072

P. Sikivie, N.S. Sullivan, and D.B. Tanner

Department of Physics
University of Florida
Gainesville, FL 32611

Progress Report for the period
November 1, 1988–October 30, 1989

The purpose of this report is to describe the progress we have made in the development of a galactic halo axion detector and to request support for the experiment, which is now running, during 1990. The aim of the project for the past year has been to construct a small-scale "pilot" detector and to operate that detector for an extended time. The success of the pilot experiment would demonstrate the feasibility of a full-scale apparatus for detecting galactic halo axions by their conversion to photons in a strong magnetic field. In addition, the operation of the pilot experiment in combination with simulation studies would determine the optimum design for a full-scale detector having the sensitivity required either to detect or to place meaningful limits on the density of axions ($m_a \sim 10^{-6}$–10^{-5} eV) in the halo of the Milky Way.

The project has been supported as task C of the DOE award to the particle physics group at the University of Florida and by matching awards from the University.

Results

1. Detector operation We have operated our small-scale detector for several months, scanning two frequency ranges using two different cavities and tuning arrangements. The first run took place in December 1988–January 1989 and covered 1.48–1.52 GHz. The second, with improved cavity and data acquisition, began in September 1989 and is continuing at present, with the frequency coverage planned to be 1.32–1.44 GHz.

2. Detector design The detector includes a 7 ℓ microwave cavity, 9.5 T superconducting magnet, and 3 K noise temperature microwave amplifier, all immersed in liquid Helium cooled using a "λ-tip" system to 2.2 K.

3. Data acquisition An automated data acquisition system using a high-speed analog-to-digital converter and signal-processing board has allowed continuous operation of the experiment with on-line spectral analysis. The compete system is shown in Fig. 1, below.

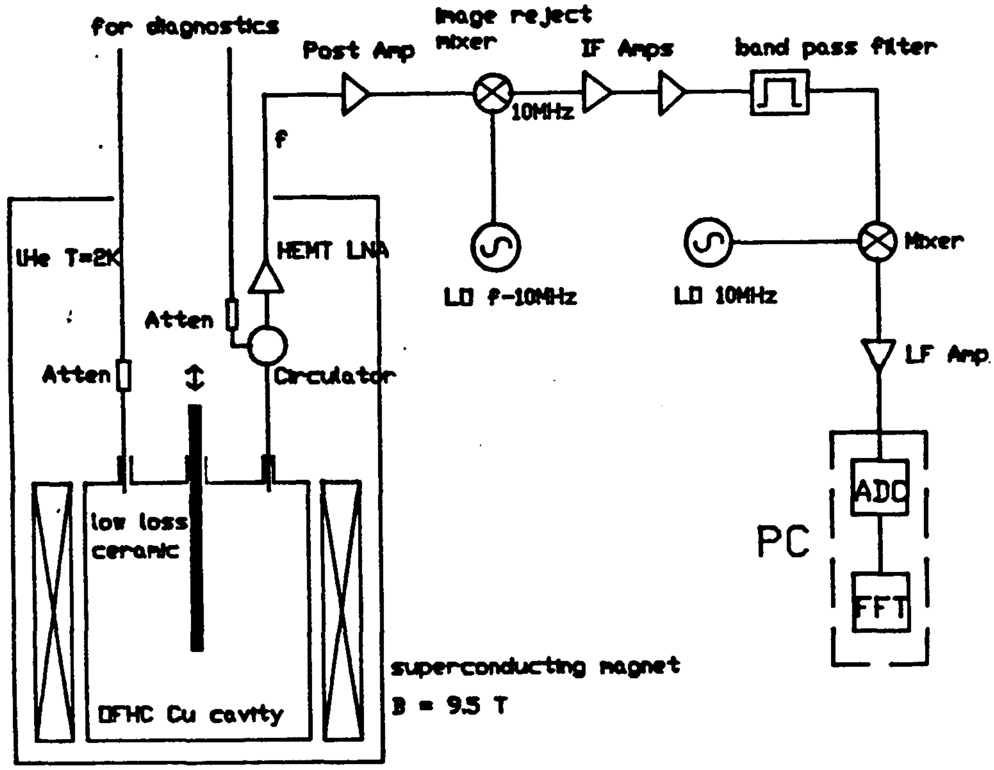


Fig. 1. Block diagram of the axion detector.

The microwave emission from the cavity is amplified and downconverted to an audio signal having a frequency spread equal to that of the cavity, ω_0/Q. This signal is sampled at 70 kHz by the a/d converter and then Fourier analyzed by a fast signal processing circuit. This circuit calculates the power spectrum emitted from the cavity every 0.9 ms. A large number (100,000) of these spectra are averaged at each setting of the cavity tuning rod. Fig. 2 shows one such spectrum, spanning 1.322956–1.322985 GHz with a resolution of 1.1 kHz. (1.1 kHz is the half-width of the expected axion signal, since galactic halo axions have velocities β of order 10^{-3} and hence energies

$$E_a = m_a + \frac{1}{2} m_a \beta^2$$

which have a spread of order10^{-6} above the axion mass.)

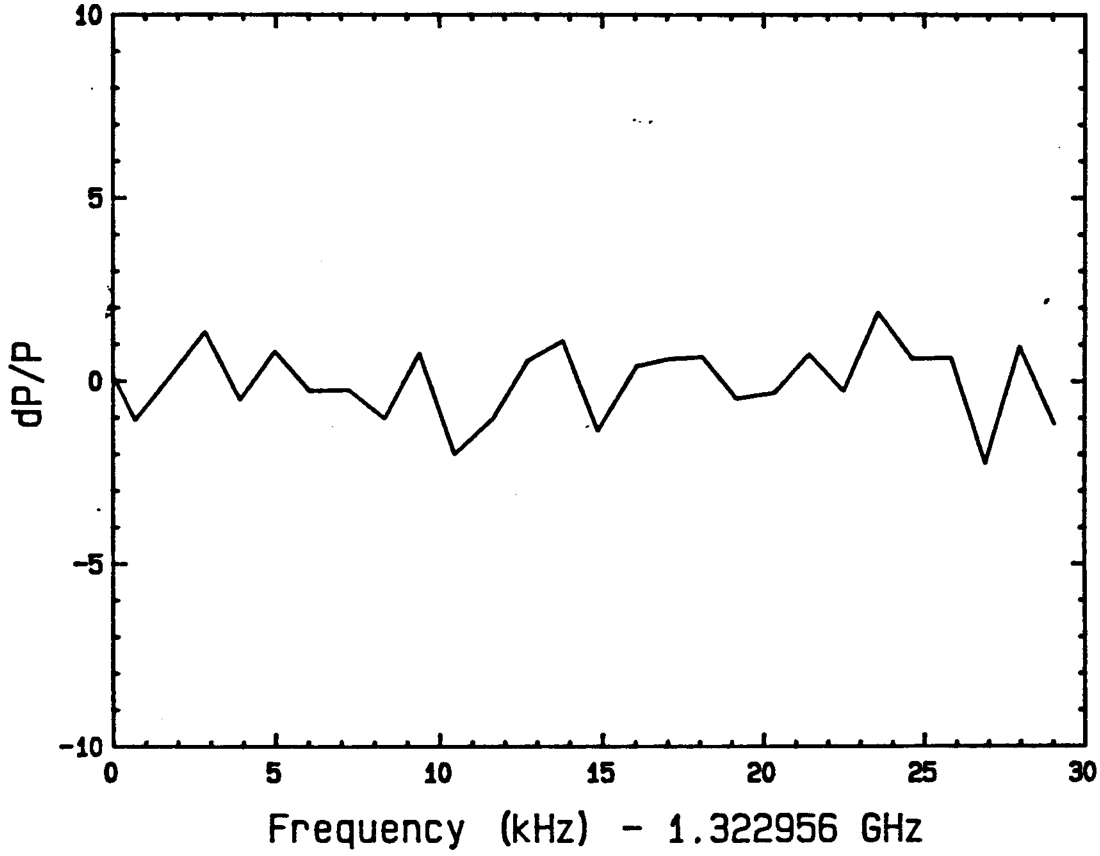


Fig. 2. Signal from the axion detector. The signal is plotted as $\Delta P/P$, the deviation from the average power expressed as a standard deviation, versus the frequency. The program looks for peaks which are 3σ above the background level.

4. Detector sensitivity The ultimate sensitivity of our current detector (on account of its relatively small volume) is approximately 1/420 of that required to observe the DFS

(Dine-Fischler-Srednicki) limit. This sensitivity is an improvement by a factor of 16 (or more—see below) over that obtained by the Rochester/BNL/Fermilab group, and it is important to continue the search over a wider frequency band.

5. Simulation studies Detailed simulations of cavity modes, described by a paper submitted to *Review of Scientific Instruments,* have revealed severe shortcomings in the tuning scheme used by us in our first run as well as by the Rochester/BNL/Fermilab group. This scheme tunes the resonance by the insertion of a dielectric rod on the axis of the cavity. The problem is that the longitudinal symmetry of the cavity is broken by such tuning, leading to localization of the resonance at one end of the cavity. This localization reduces the form factor C which describes the efficiency of axion–photon conversion in the cavity. The relevant parameter, C^2Q, is shown in Fig. 3 as a function of the depth of insertion of the rod. The lower curve is for a rod which gives a tuning range of 5% and severely degrades C^2Q; the middle and upper curves have a a smaller reduction in C^2Q but have tuning ranges of only 2% and 0.7% respectively.

To overcome the mode localization problem, our current design tunes the cavity by a sideways translation of a rod extending the entire length of the cavity. This sideways motion permits a relatively large frequency tuning range (~ 20%) with C^2Q remaining above 0.5 at all frequencies.

Papers and presentations

1. Papers

1. "Cavity Design For a Cosmic Axion Detector," C. Hagmann, P. Sikivie, N.S. Sullivan, and D.B. Tanner, in *Proceedings of the Storrs Meeting,* edited by K. Haller *et al.* (World Scientific, Singapore, 1989), pp. 249–251. (This paper was acknowledged as a preprint in our last progress report.)
2. "Solar and cosmic axion hunting," P. Sikivie, *Proceedings of the III Nishinomiya-Yukawa Symposium,* Springer-Verlag, in press.
3. "A cosmic axion detector," C. Hagmann, P. Sikivie, N.S. Sullivan, and D.B. Tanner, *Proceedings of the Symposium on Quantum Fluids and Solids—89* in press.

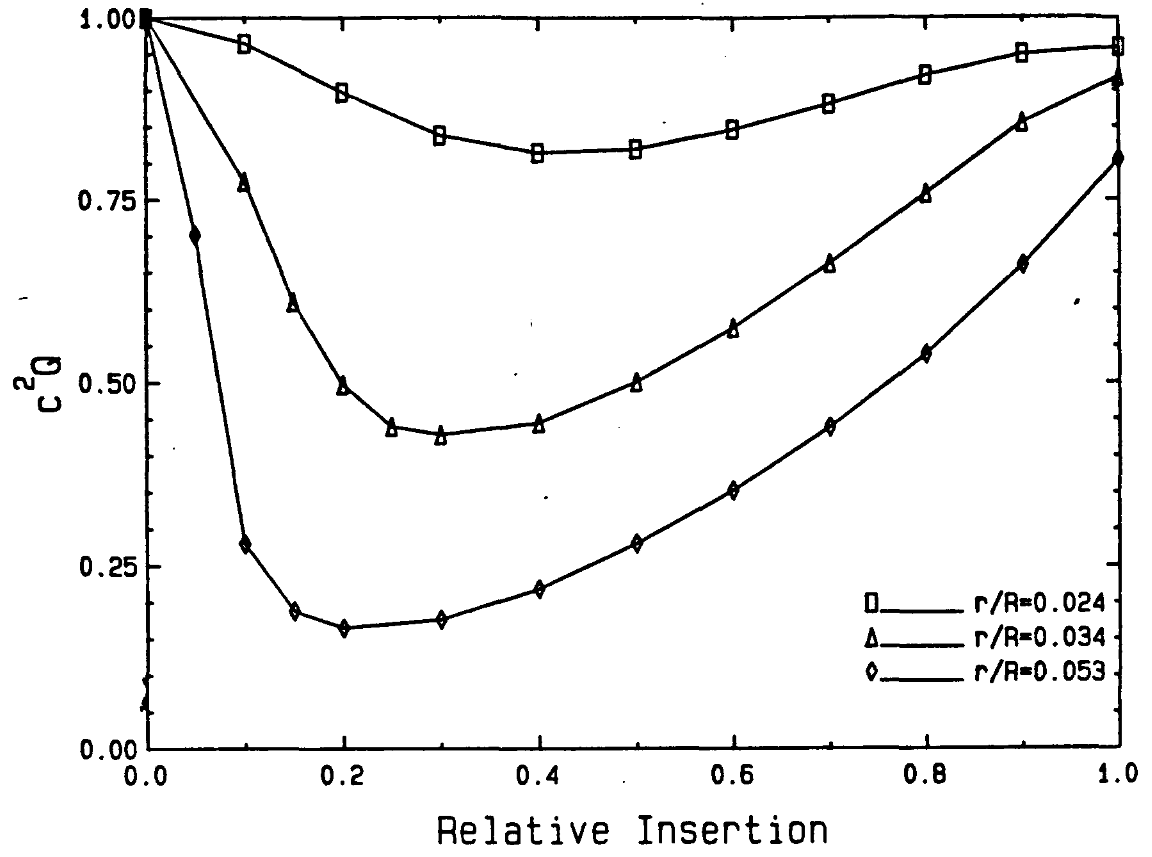


Fig. 3. Cavity form factor C^2Q versus depth of insertion of a dielectric rod ($\epsilon = 10$) on axis.

4. "Search for Dark Matter Axions," P. Sikivie, *Proceedings of the Symposium on Quantum Fluids and Solids—89* in press.
5. "Experience with the Florida cosmic axion detector," C. Hagmann, P. Sikivie, N.S. Sullivan, and D.B. Tanner, *Proceedings of the Brookhaven Workshop on Cosmic Axion Detection,*in press. (published by World Scientific)
6. "Cavity Design for a Cosmic Axion Detector," C. Hagmann, P. Sikivie, N. Sullivan, D.B. Tanner, and S.-I. Cho, *Rev. Sci. Instrum.* submitted.

2. Presentations

1. "Solar and cosmic axion hunting," P. Sikivie, two lectures at the *III Nishinomiya-Yukawa Symposium* (Nishinomiya, Japan, 9 and 10 November 1988). (Invited)
2. "Experience with the University of Florida Detector," C. Hagmann, P. Sikivie, N.S.

Sullivan, and D.B. Tanner, *Workshop on Cosmic Axions* (Brookhaven, 13 April 1989). (Invited)

3. "A cosmic axion detector," C. Hagmann, P. Sikivie, N.S. Sullivan, and D.B. Tanner, *Symposium on Quantum Fluids and Solids—1989* (Gainesville, 25 April 1989). (Poster)

4. "Search for Dark Matter Axions," P. Sikivie, *Symposium on Quantum Fluids and Solids—1989* (Gainesville, 25 April 1989). (Invited) (Note: A special session on Dark Matter Detectors was organized by the UF Low Temperature Group during the Quantum Fluids and Solids symposium.

Continuation of Current Experiment

It is important to continue the current experiment in order to obtain the best limits that can be placed on the axion density using current detectors. The Florida detector is more than an order of magnitude more sensitive than previous experiments. At present it is running continuously and essentially free of trouble, with a broad-band search covering ~5 Mhz/day. (Note that 5 Mhz is more than 4000 channels with our 1.1 kHz resolution.)

With continued support at a minimal level, the search can be continued to extend the total range searched to approximately 1.32–1.65 GHz. The budget required is indicated below.

Computer Acquisition for
Research in Theoretical and Experimental High Energy Physics

Task S

Principal Investigators:

Paul Avery and Andrew White
Physics Department
University of Florida
Gainesville, Florida 32611

Abstract

We present an update of the status of our computer acquisition. The Phase I system has been used for over a year for CLEO, D0 and SSC analysis and simulations. All of these codes use our new multiprocessing software system, UFMulti, to take advantage of the large amount of processing power available in the workstations. UFMulti has been installed at Cornell for use by CLEO and will be used on our system to generate the largest portion of the 10^5 event Monte Carlo sample planned by D0.

We are requesting funding for equipment to upgrade the processing power and I/O storage capacity to the Phase II level as discussed with DOE in 1988. The hardware includes new RISC workstation processors and disk drives. The request is $205,395 from DOE, with the rest coming from matching funds obtained from UF. This funding includes salary for an experienced programmer/physicist to further develop the UFMulti software, which will ensure its widespread utility and continuity in being upgraded for the high energy physics community. The funding also includes continued maintenance support.

I Previous Agreement with DOE

DOE agreed to provide $200,000 in capital costs for the purchase of a Phase I system of VAX 6220 file server, several workstations, about 6 Gbytes of disk and approximately 50 VAX equivalents of processing power in the form of workstations mounted in racks. The money was to be provided in the amounts of $50K, $75K and $75K during the 1988-91 fiscal years.

After we had sufficient experience with the Phase I system, DOE would consider a proposal by us to upgrade the system to "Phase II" level. The definition of Phase II was somewhat indeterminate, but the general capabilities were roughly 100 VAX equivalents of processing power in the multiprocessor and 15-20 Gbytes of disk.

II Components of the Current Computer System

The system presently consists of the following pieces:

VAX 6220 computer
5 VAX 3200 workstations (diskless)
8 VAX 3200 computing nodes (multiprocessor farm)
3 VAX 3100 workstations
1 DEC 3100 RISC workstation (300 MB disk)
2 RA82 disk drives
8 RA90 disk drives
2 KDB50 disk controllers
1 DMB32 interface for our telephone line
3 Ethernet controllers
1 TU81 tape drive

Power conditioning system (PCS)
Manuals, software and licenses

We maintain connections with our high energy physics colleagues through our leased telephone line to Fermilab, which is routed through Florida State University to reduce our leased line expenses.

The multiprocessor, consisting of 8 VAX 3200 workstations assembled in a rack, has a total computing capability of 25 MIPS (1 MIPS = 1 VAX 780 equivalent), less than the 50 planned for the Phase I system. We decided that it was more important initially to acquire an extra 5 Gbytes of disk so that the large CLEO and D0 data sets would fit on disk. This decision has proven to be prescient, since we are already straining the 11 Gbyte capacity we now have. During the day, the multiprocessing software UFMulti utilizes the 8 VAX 3200 computing nodes as a multiprocessing farm. At night, all the workstations are used for computing (about 55 MIPS total).

We have purchased a DEC 3100 RISC workstation (using special funds given to us by UF to enhance this project) to get experience with computing in a UNIX environment and to port the UFMulti software to UNIX. Before this purchase, we had borrowed a DEC 3100 from the DEC field office for 2 months and were successful in developing a good portion of UFMulti on that system.

III What has been accomplished with the System

During the past fiscal year we have managed to put a workstation on the desk of almost every faculty member and post-doc in the theoretical and experimental groups. The remaining individuals have terminals which communicate with the VAX 6220 file server.

We have developed a new multiprocessing software package called UFMulti which permits individual jobs to take advantage of the combined computing power of this large array of workstations. A talk summarizing this work was presented by one of us (PA) at the 1989 Oxford High Energy Physics Computing Conference (see the attached reprint). We have also submitted an article to Computers in Physics which will be published in the Features section in a forthcoming issue.

A large amount of analysis and simulation has been carried out on the UF multiprocessor using UFMulti and is described in the Task B proposal. The work includes

1. The CLEO Ξ_c^0 and Ξ_c^+ analyses (published in PRL)
2. The CLEO $\Upsilon \rightarrow D^{*+} + X$ analysis (presented at Photon-Lepton Conference; in preparation for publication)
3. Many samples of GEANT detector events for D0

4. 4×10^6 events generated for an SSC SUSY study in collaboration with Frank Paige of Brookhaven National Laboratory.

IV Current Status of UFMulti

The UFMulti software is installed at UF and Cornell on VAX/VMS machines and we will implement it on the Florida State University VAX cluster for the D0 group in November. The software was written by a small group consisting of the PI's on this proposal, 1 graduate student and 1 undergraduate student. We are also collaborating with several Cornell people to develop the software for a multiuser environment: Ray Helmke (Director of Computer services at the Laboratory of Nuclear Studies); Selden Ball (system manager at LNS) and Dave Kreinick (physicist at LNS in charge of online software).

In June, 1989 we submitted a supplemental request to DOE to fund 1/2 of a full time physicist/programmer to work on multiprocessing development. Our expanded activities in SSC and B factories have become very demanding in terms of time and have noticeably slowed our software development growth. Two major efforts are planned. The first will allow jobs to run on the DEC 3100 RISC workstations which use the ULTRIX operating system (a variant of UNIX). This step is necessary because Cornell is using these machines for its processing farm. It will also allow us to become familiar with UNIX. We are working very closely with Cornell on this problem because they are trying to port the CLEO software and the CERN packages to the DEC 3100's (most of this work is being done by Ray Ng of Purdue). Secondly, we are developing central intelligence for the system to better support multiple users. Although close attention has been paid to CPU and I/O load balancing within a single, multi-cpu job, the system is noticeably inefficient when several jobs are active simultaneously.

V Need for Upgraded CPU and Disk Capacity (Phase II)

The present Phase I system cannot handle the computing load that will be generated by our involvement in our experiments plus our new levels of activity with SSC, BCD and B factory groups. These activities were discussed in the Task B proposal and are summarized below.

1. UF is taking on a major fraction of the D0 GEANT simulation effort, in particular we will carry out 50% of the analysis needed to generate a shower sample of 10^5 events to study missing E_t backgrounds. Monte Carlo samples for the D0 test beam will also be generated by our group.

2. CLEO has just started taking data and we expect to use a large amount of computing in running the central detector calibration software, which provides CLEO with its excellent momentum resolution and for which the UF group is responsible.

3. We are collaborating with Frank Paige in a SUSY study to determine what experimental signatures are visible to a calorimetric detector such as D0. This study will involve the simulations of many SUSY events which will need to be tracked through the detector with GEANT. We have already generated 4 million physics events on the multiprocessor to establish the high E_t tail of the background out to several hundred GeV.

4. We are collaborating with a tracking subgroup of the BCD Fermilab group to determine the momentum and mass resolutions of several possible geometries. Events have already been generated by GEANT at Fermilab and we will reconstruct these events at UF to determine the resolutions.

5. UF is now in charge of an effort to study the effects of experimental designs on physics signatures at e^+e^- B factories. We have already begun this activity and it is already apparent that it will require major computing resources.

6. Because of our calorimeter work with FITCAL and other SSC related activities, we expect to be performing computer simulations of SSC events to test calorimeter designs. GEANT will be used in many of these simulations.

7. M.G.D. Gilchriese and E. Wang of Berkeley have begun developing a suite of codes that will generate events from several physics models for the purpose of providing benchmark events for SSC proposals. These codes will be run on the UF multiprocessor.

The above activities will require major computing resources far in excess of the 25 MIPS full time (and 55 MIPS part time) that we currently have available. We estimate that we will need an extra 100 MIPS of computing capacity and 10 Gbytes of disk storage to meet these needs. These numbers are consistent with what we estimated last year in our early Phase II projections.

It is clear that GEANT simulation studies of SSC experiments will require computing capacities measured in hundreds of MIPS and this kind of power can only reasonably be supplied through RISC processors. Accordingly, we submitted a proposal to SSC in Oct. 1989 for the purpose of developing a RISC based multiprocessing farm for use by institutions participating in the US Solenoidal proposal. If funded, this facility will only be used for SSC simulations and will be distinct from the multiprocessing farm that is needed to carry out the analyses listed above.

Conf paper cycled separately.