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Scientific Statements of the Group Members

(a) R. D. Field

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

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

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

The invariant mass of the jet-pair is used only in the selection of events, the Higgs mass is reconstructed from the momentum of the jet-pair with \( M_{jj} \) set equal to \( M_z \). We were to obtain an overall signal to background enhancement of around 10 with the standard Higgs boson cuts. The neural network provides an additional enhancement of 4-5 beyond what can be achieved with the standard data cuts resulting in an overall enhancement of about 50. Our method works even with a large number of interactions per beam crossing which shows that some jet physics can be done even in the large pile-up environment of the LHC.
We are currently writing a paper entitled “Optimizing the Top Signal to Background Ratio at Hadron Colliders” (R. D. Field, Y. Kanev, M. Tayebnejad) in which we investigate the event signature of the $t\bar{t}b\bar{b}q\bar{q}$ decay mode of top-pair production in proton-antiproton collisions at 1.8 TeV. Neural networks and Fisher discriminates are used in conjunction with modified Fox-Wolfram “shape” variables to help distinguish the top-pair signal from the $W+$jets and $b\bar{b}+$jets background. Instead of requiring at least four jets in the event, we find that it is faster and better to simply cut on the number of calorimeter cells with transverse energy greater than some minimum. Our analysis of top-pair production can be summarized by the following selections and cuts:

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

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

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

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

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

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

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

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

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

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

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

(c) Z. Qiu

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

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

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

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

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

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

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

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

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

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

In particular, I am interested in understanding the (2,0) compactification beyond fermionic construction. I would like to find a general procedure to find and classify such compactifications. There are two more practical questions I would like to address in this direction. Is there realistic GUT compactification with high level Kac-Moody algebra? More generally, can one find realistic string compactifications?
Over the last five years, the thrust of my research has been to link fermion masses and hierarchies to fundamental theory. Lately, however, I have been studying the space of invariants which occur in $N = 1$ supersymmetric theories. Also I have joined the CMS collaboration.

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

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

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

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

\[ \frac{m_b}{m_\tau} = \lambda \tan^2 \theta_W - 5/3, \]

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

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

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

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

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

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

(e) P. Sikivie

A few years ago, J. Ipser and I pointed out that the spectrum of cold dark matter particles on Earth should be expected to have peaks in velocity space associated with dark matter particles falling onto the galaxy for the first time and with particles which have fallen in and out of the galaxy only a small number of times in the past. I. Tkachev, Y. Wang and I then wrote a paper, published last fall in Phys. Rev. Lett., which gives estimates of the average sizes and the velocity magnitudes of the peaks based upon the secondary infall model of galactic halo formation. We generalized this model to include, in a tractable way, the effect of angular momentum of the dark matter particles. Our model establishes a relationship between the core radius of the galactic halo and the amount of angular momentum which the dark matter particles carry. Our results are relevant to the dark matter axion search presently taking data at LLNL. Indeed, this experiment's sensitivity is increased by looking for narrow peaks provided there is one peak with energy spread $\delta E < 10^{-11} m_a$, where $m_a$ is the axion mass, and with fraction of the local halo density larger than about 1%. The LLNL experiment does have a high resolution data analysis stream to search for such narrow peaks. I am presently working on a long paper in collaboration with I. Tkachev and Y. Wang which gives the details of our analysis.
A few months ago, J. Ipser pointed out to me that recent Hubble Space Telescope observations of nearby elliptical galaxies show that their luminosity profiles have cusps at the galactic center which are reminiscent of the cusps that exist in the halo distribution of the model that I. Tkachev, Y. Wang and I developed. It turns out that they are in fact remarkably similar. To make sense of this one would argue that the stars in elliptical galaxies are distributed in the same way as dark matter in a galactic halo because they move in the same dissipationless way. This hypothesis is plausible in view of the fact that elliptical galaxies contain mostly old stars and very little gas compared to spiral galaxies. J. Ipser and I intend to look at this more closely and see whether other observations disagree with, or possibly confirm, this interpretation.

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

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

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

(f) C. B. Thorn

For quite a few years my research has been devoted to two broad areas of particle theory: the dynamics of strong interactions and string theory. Although these two areas were once closely linked (when I started my research, string theory was developed as a theory of strong interactions), they have by now gone down very separate roads. QCD has supplanted string theory as the “fundamental” theory of strong interactions, and string
theory is now the leading candidate theory to unify quantum gravity with the rest of physics. No longer is string a model of hadronic matter; it is now a promising model for the substructure of quarks, leptons, vector bosons and the graviton. The energy scale at which this substructure should be revealed, $M_{\text{string}} = \sqrt{\hbar c^2}$, is very likely to be well beyond the reach of earthbound accelerators, perhaps as large as the Planck mass.

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

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

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

Our string bit program is progressing, but there remain many issues to address:
1. It is most urgent to try to surmount the obstacles Bergman and I encountered with
fully supersymmetric string interactions in the realistic case of 3+1 dimensional superstring (or higher dimensions if extra ones are compactified). A completely successful supersymmetric string bit model would be a tremendous improvement over previous fundamental formulations of string theory. A truly nonperturbative formulation of superstring theory would have important implications for quantum gravity.

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

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

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

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

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

(g) R. Woodard

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

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

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

1. It operates in the far infrared where general relativity can be used reliably as a quantum theory of gravitation;
2. It introduces no new light quanta which would embarrass low energy phenomenology;
It has the potential to make unique predictions because gravity is the only phenomenologically viable theory which possesses the essential feature of massless quanta (so interactions superpose coherently) whose self-interactions are not conformally invariant (so their effect grows like the enormous invariant volume of the past light cone); and

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

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

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

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

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

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

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

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

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

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

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

3. Sum the 2-loop tadpole terms by re-doing our 2-loop result for arbitrary scale factor, and then solving the classical field equations with this as the source.
We have pushed (1) far enough to identify the following candidate effective field equations:

\[ R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = -\frac{1}{2} \Lambda g_{\mu\nu} + 8\pi G T_{\mu\nu} \]

where the effective stress tensor has the form:

\[ T_{\mu\nu} = g_{\mu\nu} T[g] - \nabla_\mu \nabla_\nu - V_{\nu,\mu} \]

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

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

(h) O. Bergman

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

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

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


(i) S. H. Chang

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

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

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

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

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

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

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


(j) Claudio Coriano

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

In QCD I have been studying both resummation effects at small-x from the point of view of t-channel unitarity (with A. White), and radiative corrections to spin physics (with L. Gordon). Spin phenomena are currently of great interest and a lot of work remains to be done in order to clarify the issue related to the spin content of the nucleons. We have studied double photon production to order $\alpha_s^3$ and we are currently studying polarized Drell Yan (with Chang and Gordon) to order $\alpha_s^4$. The measurement of this cross section at RHIC will be of crucial importance for the resolution of many unsolved puzzles in spin physics.

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

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

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

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

Research Papers:


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

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

Under the second topic I continued a previous study of the calculation of the fermion masses in a class of superstring derived models. In a previous letter I calculated the masses of the top and bottom quarks and of the tau lepton. In ref. [2] I discussed in detail the calculation of the fermion masses in the superstring models. I investigated the minimization of the Higgs potential and showed that the predicted fermion masses can be in agreement with the minimization of the one–loop effective Higgs potential. Currently, (in collaboration with Claudio Coriano) we are pursuing the calculation of the second generation of fermions. This involves calculation of higher order of string correlators and we are developing the techniques which are needed to evaluate these correlators.
Under the third topic (in collaboration with Sanghyeon Chang and Claudio Coriano) we have started an investigation of cosmological implications of superstring models. Motivated from the suggestion that additional colored matter may be the only way to resolve the string gauge coupling unification problem, we investigated the possibility that the same colored states may resolve the dark matter problem. In ref. [3] we suggested that this colored matter can be stable and evade all current experimental limits. In ref. [4] we expanded on our earlier suggestion and proposed that string models in general predict the existence of additional stable matter. This arises because in string models the gauge symmetries are broken by using Wilson lines. Wilson line breaking results in matter states that do not respect the symmetry of the original unbroken symmetry. This results in possible conservation laws that forbid the decay of the additional matter states into the lighter standard model states. We investigated the exotic massless states that appear in the free fermionic models. We proposed that the exotic matter states are good dark matter candidates and studied how previous constraints that were imposed, for example on fractionally charged states, may be modified in the string models. We believe that the existence of such exotic stable matter is generic in superstring models and may eventually lead to the verification or dismissal of superstring models of particle physics.

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

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

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

References:


ACTIVITIES OF THE PARTICLE THEORY GROUP (since 1993)

A. Lectures and Seminars

Field

URA Fermilab Review, February 5-6, 1993
High Energy Physics Seminar presented at the SSCL, Dallas, TX, June 7, 1993
Seminar on Neural Networks presented at the Institute for Fundamental Theory, University of Florida, May 24, 1994
Lecture on Quarks and Leptons presented at the Physical Chemistry Seminar, University of Florida, September 6, 1994
Seminar on Neural Networks presented at the CMS meeting, Lake Tahoe, California, September 25-29, 1995.
High Energy Physics Seminar presented at the University of California at Riverside, April 10, 1996.

Kennedy


Qiu

Seminar, University of Florida, January 1993
Theoretical Physics Seminar, Cornell University, May 1994
Colloquium, University of Florida, September 1994
Talk at String 95, USC, Los Angeles, CA, March 1995
Three Lectures at CCAST, Beijing, China, August 1995

Ramond

Invited Lecturer, Coral Gables Conference, Miami, Jan. 1993
Invited Lecturer, HARC, Houston, TX, April 1993
Seminar, Johns Hopkins University, Baltimore, MD, April 1993
Colloquium, University of Chicago, May 1993
Seminar, Southern Methodist University, Dallas, TX, May 1993
Colloquium, SSCL, Dallas, TX, June 1993
Invited Lecturer, Electroweak Workshop, Gran Sasso, Italy, Sept. 1993
Seminar, Ecole Normale, Paris, Sept. 1993
Invited Speaker, Recontres de Moriond, France, March 1994
Seminar, College of William and Mary, Williamsburg, VA, April 1994
Invited Lecturer, TASI, Boulder, CO, June 1994
Invited speaker, First Gürsey Symposium, Istanbul, Turkey, June 5-8, 1994
Invited speaker, O. Klein 100 Symposium, Stockholm, Sweden, September 17-28, 1994
Invited lecturer, Laboratoire de l'Accélérateur Linéaire, Orsay, France, September 1994
Invited speaker, Fermilab Workshop on Yukawa Couplings, Batavia, Illinois, October 13-16, 1994
Invited seminar, Florida State University, Tallahassee, Florida, October 28, 1994
Invited speaker at Conference on Unified Symmetry in the Large and in the Small, Coral Gables, Florida, February 2-5, 1995
Colloquium speaker, SUNY at Stony Brook, Stony Brook, New York, April 29 - May 3, 1995
Invited speaker CAM-95 Conference, Québec, Canada, June 14-18, 1995
Invited speaker at ITP workshop, Santa Barbara, October 1995
Invited speaker at supersymmetry workshop, Tallahassee, Fl, Nov 1995
Invited speaker at Kikkawa Symposium, December 1995, Osaka, Japan
Colloquium, Duke University, January 1996
Seminar speaker, Berkeley, March 1996.

Sikivie

Invited talk at the Coral Gables Conferences on Unification in the Large and the Small, Miami, FL, Jan. 26, 1993
Particle Theory Seminar at the Univ. of Pennsylvania, Philadelphia, PA, April 12, 1993
Particle Theory Seminar at CERN, June 10, 1993
Invited talk at the Workshop “The Dark Side of the Universe”, Rome, June 23-26, 1993
Particle Theory Seminar at the University of Geneva, July 1993
Invited talk at the 17th John Hopkins Workshop, Budapest, July 30-Aug. 1, 1993
Triangle Nuclear Theory Colloquium, Duke University, October 5, 1993
Invited talk at the Annual Meeting of the South Eastern Section of the APS, Columbia, S.C., Nov. 4-6, 1993
Invited talk at the Coral Gables Conference, Coral Gables, Jan. 27-30, 1994
Particle Theory seminar at ITP, UC Santa Barbara, May 1994
Particle Theory seminar at UCLA, June 1994
Invited talk at the Workshop on “Topological Defects in Cosmology” at the I. Newton Institute, Cambridge, England, Nov. 16-17, 1994

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

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


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


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


Physics Department Colloquium at Yale University, May 12, 1995

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

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

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

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

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

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

Thorn

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

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

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

Theoretical Physics Seminar presented at Rutgers University, May 1994

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

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

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

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

Woodard

Seminar, University of Crete, June 21, 1993

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

Seminar, University of Michigan, Jan. 6, 1994

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

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

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

Invited talk, Workshop on Quantum Infrared Physics (Paris, France), June 10, 1994
Seminar, University of Florida, September 6, 1994.

B. Travel

Field
URA Fermilab Review, February 5-6, 1993
SSC Laboratory, Dallas, TX, June 6-8, 1993
Participated in the Workshop on Yukawa Couplings, Institute for Fundamental Theory, University of Florida, February 11-13, 1994
Participated in the 10th Topical Workshop on Proton-Antiproton Collider Physics, Fermilab, May 9-13, 1995
Attended the CMS meeting, Lake Tahoe, California, September 25-29, 1995.
Participated in the mini-workshop on Supersymmetry at Wakulla Springs, Florida, November 11-12, 1996
Visited the University of California at Riverside, April 10, 1996.

Kennedy
Univ. of California, SB, Weak Interactions 94 Workshop
Snowmass Workshop on Nuclear and Particle Astrophysics and Cosmology in the Next Millenium, 6/29-7/14/94
University of Pennsylvania, collaboration with S. Bludman, 5/29-6/2/95
Aspen Center for Physics, summer physics program, 6/26-7/14/95
Institute for Nuclear Theory, University of Washington, Physics Beyond the Standard Model at Low and Intermediate Energies, workshop, 7/17-8/4/95
University of Pennsylvania, collaboration with S. Bludman 5/27-6/3/96
Telluride Summer Research Center, summer research program, 7/14-8/2/96

Qiu
PASCOS, Syracuse University May 1994
Cornell University, Ithaca, NY, May 1994
PASCOS, Syracuse University May 1994
Cornell University, Ithaca, NY, May 1994
String 95, USC, Los Angeles, CA, March 1995
95 Shantou Conference: Looking to the 21st Century, Shantou, China, August 1995
The 17th international Symposium on Lepton and Photon, Beijing, China, August 1995
CCAST, China Center of Advanced Science and Technology, Beijing, China, August 1995.
Ramond

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

Sikivie

Coral Gables Conference, Miami, Jan. 24-27, 1993
Univ. of Pennsylvania, April 2, 1993
CERN, June and July, 1993
Rome, Italy, June 23-26, 1993
Budapest, Hungary, July 30-Aug. 1, 1993
Duke University, October 5, 1993
Columbia, S.C., Nov. 4-6, 1993
Coral Gables, FL, Jan. 27-30, 1994
LBL, Feb. 21-24, 1994
ITP, UC, Santa Barbara, CA, May and June, 1994
UCLA, June 10, 1994
Stockholm, Sweden, Sept. 23-25, 1994
Orsay, France, Nov. 22, 1994
Brussels, Belgium, Nov. 25, 1994
Bariloche, Argentina, Jan. 13-19, 1995
Villars-sur-Ollon, Switzerland, Jan. 21-28, 1995
New Haven, Conn., May 12, 1995
Axion collaboration meeting at Lawrence Livermore National Laboratory, Livermore, CA, May 25-27, 1995
Aspen Center for Physics, June 5-25, 1995
Madison, Wisconsin, October 20, 1995
Santa Monica, Feb 14-16, 1996
Axion collaboration meeting at Lawrence Berkeley Laboratory, Feb 17-18, 1996
Baltimore, Maryland, Feb 29 - March 1, 1996
Indianapolis, IN, May 2-5, 1996

**Thorn**
Coral Gables Conference, Miami, Jan. 24-27, 1993
Workshop at the Institute for Theoretical Physics in Santa Barbara, June 1993
University of Miami, January 1994
Rutgers University, May 1994
Aspen, Colorado, July 1994
Fermilab Summer Visitors Program, July-August 1994
Small x Workshop, Fermilab, September 1994
Aspen Center for Physics, Aspen CO, 17 July - 13 August, 1995
Telluride Summer Research Center, Telluride CO, 14-15 August, 1995

**Woodard**
University of Crete, 5/16/92-7/15/92
Brandeis University, 9/24/92
Brown University, 9/25/92-9/29/92
University of Texas at Austin, Nov. 14-17, 1992
Inst. for Theor. Phys./UCSB, Dec. 2-7, 1992
University of Crete, 5/22/93-7/3/93
Inst. for Theoretical Physics, July 14-21, 1993
University of Michigan, 1/6/94-1/8/94
Coral Gables Conference on Unified Symmetry in the Small and in the Large, 1/28/94-1/30/94
Univ. of Texas at Austin, 4/20/94-4/23/94
University of Crete, 5/10/94-6/4/94
Workshop on Quantum Infrared Physics (Paris, France), 6/6/94-6/10/94
University of Crete, 6/12/94-7/15/94
Brown University, 10/13/94-10/16/94
University of Crete, 5/26/95-7/26/95
Ecole Polytechnique (Paris, France) 5/8/96-6/8/96
University of Crete, June-July, 1996
CERN (Geneva, Switzerland) August, 1996

C. Seminar Speakers (since 1993)

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
<th>Dates</th>
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<tbody>
<tr>
<td>Dr. M. Awada</td>
<td>University of Cincinnati</td>
<td>1/4/93</td>
</tr>
<tr>
<td>Prof. D. Harari</td>
<td>IAFE, Argentina</td>
<td>1/6/93</td>
</tr>
<tr>
<td>Prof. N. Tsamis</td>
<td>Greece</td>
<td>1/8/93</td>
</tr>
<tr>
<td>Prof. T. Kephart</td>
<td>Vanderbilt University</td>
<td>1/23/93</td>
</tr>
<tr>
<td>Prof. R. Brandenberger</td>
<td>Brown University</td>
<td>1/27/93</td>
</tr>
<tr>
<td>Prof. P. Fishbane</td>
<td>University of Virginia</td>
<td>2/9/92</td>
</tr>
<tr>
<td>Prof. A. Linde</td>
<td>Stanford University</td>
<td>2/23/93</td>
</tr>
<tr>
<td>Dr. C. Preitschopf</td>
<td>Goteborg, Sweden</td>
<td>3/1/93</td>
</tr>
<tr>
<td>Dr. I. Kogan</td>
<td>Princeton University</td>
<td>3/1/93</td>
</tr>
<tr>
<td>Prof. R. Renken</td>
<td>University of Central Florida</td>
<td>3/5/93</td>
</tr>
<tr>
<td>Dr. D. Kennedy</td>
<td>Fermilab</td>
<td>3/10/93</td>
</tr>
<tr>
<td>Prof. S. Meshkov</td>
<td>SSCL</td>
<td>3/11/93</td>
</tr>
<tr>
<td>Dr. L. Thorlacius</td>
<td>Stanford University</td>
<td>3/14/93</td>
</tr>
<tr>
<td>Prof. E. Verlinde</td>
<td>Princeton University</td>
<td>3/16/93</td>
</tr>
<tr>
<td>Prof. M. Cvetic</td>
<td>University of Pennsylvania</td>
<td>3/19/93</td>
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Of these speakers, M. Wise, L. Susskind, G. ’t Hooft, H. Nielsen, and N. Seiberg, visited us for several days through the IFT distinguished visitor program. They each gave a particle theory seminar as part of a three lecture series.
Task B
1 Introduction

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

1.1 New Physics Building

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

2 The CLEO Experiment and CLEO III Upgrade

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

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

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

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

3 Physics Analysis

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

3.1 CLEO PUBLICATIONS

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

1. Lepton Asymmetry Measurements in $\bar{B} \to D^* l^- \bar{\nu}_l$ and Implications for $V - A$ and the Form Factors

2. Tau Decays with One Charged Particle plus Multiple $\pi^0$'s

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

4. Measurement of the $\tau$-Lepton Mass

5. Limit on the Tau Neutrino Mass

6. Evidence for Penguin-Diagram Decays: First Observation of $B \to K^*(892)\gamma$

7. Measurement of the Ratio $B(D^+ \to \pi^0 l^+\nu)/B(D^+ \to \bar{K}^0 l^+\nu)$

8. Two Measurements of $B^0\bar{B}^0$ Mixing

9. Measurement of the Decay $\tau^- \to \pi^- \pi^+ \pi^- 2\pi^0 \nu_{\tau}$

10. Measurement of the $D \to \pi \pi$ Branching Fractions
11. Study of the Decays $\Lambda_c^+ \rightarrow \Xi^0 K^+, \Lambda_c^+ \rightarrow \Sigma^+ K^+ K^-$ and $\Lambda_c^+ \rightarrow \Xi^- K^+ \pi^+$

12. Study of $D^0$ decays into $\bar{K}^0$ and $\bar{K}^{*0}$

13. Measurement of the Absolute Branching Fraction for $D^0 \rightarrow K^- \pi^+$

14. Measurement of Exclusive $\Lambda_c$ Decays with a $\Sigma^+$ in the Final State

15. Observation of the Charmed Baryon $\Sigma_c^+$ and Measurement of the Isospin Mass
    Splittings of the $\Sigma_c$

16. Measurements of Exclusive Semileptonic Decays of $D$ Mesons

17. Observation of $B^0$ Decay to Two Charmless Mesons

18. Measurement of Charmless Semileptonic Decays of $B$ Mesons

19. Search for Exclusive $b \rightarrow u$ Transitions in Hadronic Decays of $B$ Mesons Involving
    $D_s^+$ and $D_s^{*+}$ Mesons

20. Analysis of Hadronic Transitions in $\Upsilon(3S)$ Decays

21. Study of the Decay $\Lambda_c^+ \rightarrow \Lambda \ell^+ \nu_\ell$

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

23. Observation of a New Charmed Strange Meson

24. Measurement of the Branching Fraction for $D^+ \rightarrow K^- \pi^+ \pi^+$

25. A Measurement of $B(D_s^+ \rightarrow \phi \ell^+ \nu_\ell)/B(D_s^+ \rightarrow \phi \pi^+)$

26. Observation of $\Lambda_c^+$ Decays to $\Lambda \pi^+ \pi^0, \Sigma^0 \pi^+, \Sigma^0 \pi^+ \pi^0,$ and $\Sigma^0 \pi^- \pi^+ \pi^+$
27. First Measurement of $\Gamma(D_s^+ \rightarrow \mu^+\nu)/\Gamma(D_s^+ \rightarrow \phi\pi^+)$

28. Search for $B^0$ Decays to Two Charged Leptons

29. A Measurement of the Branching Fraction $B(\tau^- \rightarrow h^0\pi^0\nu_\tau)$

30. Production and Decay of $D_1(2420)^0$ and $D_2^*(2460)^0$

31. Exclusive Hadronic $B$ Decays to Charm and Charmonium Final States

32. Precision Measurement of the $D_s^{*-} - D_s^{+}$ Mass Difference

33. Two-Photon Production of Charged Pion and Kaon Pairs

34. Measurement of Two-Photon Production of the $\chi_c^2$

35. Measurement of the Cross-Section for $\gamma\gamma \rightarrow p\bar{p}$

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

37. Study of the Five-Charged-Pion Decay of the $\tau$ Lepton

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

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

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

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

42. Measurement of the Ratios of Form Factors in the Decay $D_s^+ \rightarrow \phi e^+\nu_e$
43. Measurement of the Branching Fraction for $\Upsilon(1S) \rightarrow \tau^+\tau^-$

44. Observation of $D_1(2420)^+$ and $D_2^*(2460)^+$

45. Observation of $B \rightarrow \psi \pi$ Decays

46. Measurement of the $\bar{B} \rightarrow D^*\ell\nu$ Branching Fractions and $|V_{cb}|$

47. $\Upsilon(1S) \rightarrow \gamma +$ Non-interacting Particles

48. First Measurement of the Rate for the Inclusive Radiative Penguin Decay $b \rightarrow s\gamma$

49. First Observation of $\Xi_c^+ \rightarrow \Xi^0 e^+\nu_e$ and an Estimate of the $\Xi_c^+ / \Xi_c^0$ Lifetime Ratio

50. Observation of Excited Charmed Baryon States Decaying to $\Lambda_c^+\pi^+\pi^-$

51. New Decay Modes of the $\Lambda_c^+$ Charmed Baryon

52. Form Factor Ratio Measurement in $\Lambda_c^+ \rightarrow \Lambda e^+\nu_e$

53. A Search for $B \rightarrow \ell\nu\ell$

54. Observation of the Isospin-Violating Decay $D_s^* \rightarrow D_s^+\pi^0$

55. Measurement of the $D_S^+ \rightarrow \eta\ell^+\nu$ and $D_S^+ \rightarrow \eta'/\ell^+\nu$ Branching Ratios

56. Measurements of the Decays $\tau^- \rightarrow h^-h^+h^-\nu_\tau$ and $\tau^- \rightarrow h^-h^+h^-\pi^0\nu_\tau$

57. Observation of a Narrow State Decaying into $\Xi_c^+\pi^-$

58. Measurement of the Decay Asymmetry Parameters in $\Lambda_c^+ \rightarrow \Lambda\pi^+$ and $\Lambda_c^+ \rightarrow \Sigma^+\pi^0$
59. Measurement of $\alpha_s$ from $\tau$ Decays  

60. Measurement of the Ratio of Branching Fractions $\mathcal{B}(D^0 \rightarrow \pi^- e^+ \nu_e)/\mathcal{B}(D^0 \rightarrow K^- e^+ \nu_e)$  

61. Inclusive Decays of $B$ Mesons to Charmonium  

62. Search for CP Violation in $D^0$ Decay  

63. Measurement of the $B$ Semileptonic Branching Fraction with Lepton Tags  

64. Tau Decays into Three Charged Leptons and Two Neutrinos  

65. Limits on Flavor Changing Neutral Currents in $D^0$ Meson Decays  

66. Measurement of the Form Factors for $\bar{B}^0 \rightarrow D^{*+} \ell^- \bar{\nu}$  

67. First Observation of the Decay $\tau^- \rightarrow K^- \eta \nu_\tau$  

68. Observation of the $\Xi_c^+$ Charmed Baryon Decays to $\Sigma^+ K^- \pi^+$, $\Sigma^+ K^*0$, and $\Lambda K^- \pi^+ \pi^+$  

69. Study of $B \rightarrow \psi p$  

70. Observation of New Decay Modes of the Charmed-Strange Baryon $\Xi_c^+$  

71. A Measurement of $\mathcal{B}(D^0 \rightarrow K^- \pi^+ \pi^0)/\mathcal{B}(D^0 \rightarrow K^- \pi^+)$  

72. Observation of the Cabibbo Suppressed Charmed Baryon Decay $\Lambda_c^+ \rightarrow p \phi$  

73. Search for Exclusive Charmless Hadronic $B$ Decays  

74. Measurements of $B \rightarrow D^+_s X$ Decays  
3.2 Preprints

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

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

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

   Y. Kubota et al., CLNS 95/1363, CLEO 95–18
   (submitted to Physical Review D)

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

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

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

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

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

3.3 Florida Publications

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

1. Limits on B rare Decays
2. Production of $\eta$ and $\omega$ mesons in $\tau$ decays

3. Search for the Charmless Decays, $B \rightarrow \pi\pi\pi$ and $p\bar{p}\pi\pi$

4. $\Sigma^+_c$ and $\Sigma^0_c$ Production in $e^+e^-$ Annihilation


6. Observation of the Charmed, Strange Baryon $\Xi^0_c$

7. Measurement of the Isospin Splitting $\Xi^+_c - \Xi^0_c$

8. Study of D Decays into $K\bar{K}$ and $\pi\pi$  

9. Study of $K^*$ Production in $\tau$ Decays

10. The Decay $D^0 \rightarrow K^0\bar{K}^0$

11. Radiative $\Upsilon(1S)$ Decays

12. The Study of $D^0$ Decays into Final States including a $\pi^0$ or an $\eta^0$

13. Unusual Decays of D Mesons

14. $\Lambda^+_c$ Production in $e^+e^-$ Annihilation at $E=10$ GeV

15. Observation of the Decay $\Xi^0_c \rightarrow \Omega^- K^+$

16. Observation of Excited Charmed Baryon States Decaying to $\Lambda^+_c\pi^+\pi^-$

17. Study of the Decays $\Lambda^+_c \rightarrow \Xi^0 K^+$, $\Lambda^+_c \rightarrow \Sigma^+ K^+ K^-$ and $\Lambda^+_c \rightarrow \Xi^- K^+\pi^+$

18. Measurement of the Absolute Branching Fraction for $D^0 \rightarrow K^-\pi^+$
19. Measurements of Exclusive Semileptonic Decays of $D$ Mesons

20. Search for Exclusive $b \rightarrow u$ Transitions in Hadronic Decays of $B$ Mesons Involving $D_s^+$ and $D_s^{++}$ Mesons

21. Measurement of the Branching Fraction for $D^+ \rightarrow K^- \pi^+ \pi^+$

22. Observation of a Narrow State Decaying into $\Xi_c^+ \pi^-$

23. Measurement of the Decay Asymmetry Parameters in $\Lambda_c^+ \rightarrow \Lambda \pi^+$ and $\Lambda_c^+ \rightarrow \Sigma^+ \pi^0$

Y. Kubota et al., CLNS 95/1363, CLEO 95–18
(submitted to Physical Review D) (accepted for publication)

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

26. Exclusive Hadronic $B$ Decays to Charm and Charmonium Final States

27. Measurement of the $\bar{B} \rightarrow D^* \ell \nu$ Branching Fractions and $|V_{cb}|$

28. A Measurement of $B(D^0 \rightarrow K^- \pi^+ \pi^0)/B(D^0 \rightarrow K^- \pi^+)$

29. Search for Exclusive Charmless Hadronic $B$ Decays

4 Florida Personel

4.1 Faculty

4.1.1 Paul Avery

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

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

Avery has a number of software responsibilities in CLEO:

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

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

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

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

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

Now that the C0 intersection region might be developed for trigger studies and proof-
of-concept runs, there is a renewed effort to provide computer simulations for physics and
detector studies. An EOI was submitted May 31, 1996, and is being followed up by physics
and detector studies. The simulation group (located in the Fermilab Computing Division) is
now officially sanctioned by Fermilab in the sense that it will provide the tools (principally
MCFAST and supporting software) used by the collider groups to develop detectors and study physics in the next era of running at Fermilab, including top quark physics. A new research scientist position has been filled there to support this effort. Florida has recently hired a new postdoc (Martin Lohner) who will spend up to 1/3 of his time developing MCFAST and running BTEV and CMS simulations.

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

4.1.2 John Yelton

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

More recently, he led the analysis on the discovery of the $\Lambda_c^{++}(2593)$. ARGUS previously had shown that there was a peak in $\Lambda_c^+\pi^+\pi^- - \Lambda_c^+\pi^0$ mass difference plots, although they could not determine exactly what state it was. The CLEO analysis showed not only this peak, but a second just above threshold. Whereas the upper state does not appear to go via an intermediate $\Sigma_c$, the lower state does. After much study, the two states are now rather reliably identified as a pair of $L = 1$ $\Lambda_c^+$ states with total spin 1/2 and 3/2. A preliminary analysis of this particle was first shown in 1993; after much further work (including limits for single $\pi$ and $\gamma$ transitions from this state) it was published by PRL in 1995. The main features of this analysis have been confirmed by the E-687 collaboration. They agree with the CLEO finding on the resonant substructure of the upper state, thus also disagreeing with Argus.

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

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

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

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

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

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

4.2 Post-Doctoral Research Associates - Current

4.2.1 Christopher Jones

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

4.2.2 Martin Lohner

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

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

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

4.3.1  Song Yang 1994-1996

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

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

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

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

4.3.2  Karen Lingel 1994-95

Karen Lingel was the post-doc in residence at Cornell from Summer 1994 to September 1995. After her work on the observation of the charmless $B$ decays ($B \rightarrow \pi\pi$ and $B \rightarrow K\pi$) published in 1993, she has expanded the analysis to include channels with $K^*$ and $\rho$'s. These are decays that arise from $b \rightarrow u$ or $b \rightarrow s\gamma$ penguin processes. She has been the organizer of the Rare $B$ Hadronic working group for the last 4 years. This group provided the results of the paper published by Phys. Rev. D (number 28 of Florida papers above), this included 25 different modes of rare hadronic decays, of which she herself was responsible for 11. The limits in the paper are improvements of approximately an order of magnitude over previous measurements, and are pushing the theoretical predictions.
Karen was also chair of the “Rare B Physics Group” and the “Rare Electromagnetic Group”. She was a working member of the Tracking Group, with a notable contribution being the understanding of the wire-to-wire time-zero calibration as a function of per-amp channel and the time variations of these calibrations. She was a member of the tracking Systematic Committee, which was responsible for collecting all information known about tracking efficiencies, systematic uncertainties and Monte-Carlo simulation. Karen was also CERN librarian for CLEO, and thus responsible for the installation and maintenance of the CERN software relevant documentation.

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

4.3.3 Arne Freyberger 1990-93

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

4.3.4 Ransom Stephens 1992-93

Ransom Stephens was a post-doc on CLEO based at Florida until September 1993. He was instrumental in the setting up of the Monte-Carlo generation system in Florida. His main analysis topic was the search for \( b \to u \) transitions using \( B \to D_X \) and \( D^* \). The analysis also involved measurement of the normalization modes. This analysis was published soon after his departure for UT Arlington.
Task C
During the present grant period, we had responsibility for the design, assembly, and programming of the high-resolution spectrometer which looks for narrow peaks in the output of the cavity in the LLNL experiment. We successfully carried out this task. As was mentioned in the preceding section, velocity peaks are expected in the spectrum of dark matter axions on Earth and the sensitivity of the LLNL experiment may be increased by looking for such peaks.

Our proposed research for the next three years is detailed in this section. Briefly we propose first to contribute to data taking and operations of the second-generation experiment through having a student located on site, and second to take responsibility for the design and prototyping of the third cavity array for this experiment.

A. The Second Generation Experiment

We propose to maintain and extend our participation in the second-generation axion search, operated at the Lawrence Livermore National Laboratory, which is now taking data.

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

- To achieve a power sensitivity which is conservatively a factor of 50 improvement over the pilot experiments. This is to be achieved by a combination of scaling up in magnet volume, and incremental progress in the noise temperature of state-of-the-art microwave amplifiers.

- To search the mass range $1.3 \mu eV < m_a < 13 \mu eV$. At the high end of this range, the search will be achieved through filling the magnet volume with multiple cavities.

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

The magnet cryostat has a "cool bore" of 55 cm diameter, which allows the exchange of cavity arrays in the experimental volume while the magnet is cold. Equally important, the temperature of the cavity arrays is independent of that of the magnet. The experiment is operated at about 1.5 K, to match the noise temperatures of the best low-noise microwave amplifiers available today.
A second feature of the current experiment is that for the first time, arrays of multiple cavities will be used to expand the mass search range. Each cavity is separately tuned by moving dielectric or metallic rods within the cavity. The experiment will cover the range $1.3 \mu eV < m_\chi < 13 \mu eV$. To accomplish this, requires three separate cavity arrays with one, four and sixteen cylindrical cavities filling as much of the magnet bore as possible (Table 1).

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

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<td>FY97</td>
<td>FY98</td>
<td>FY98/9</td>
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</table>

In order that tuning rods may be changed in the cavity periodically, the cavity must be assemblable without breaks in wall conductivity at the joints. We developed a successful technique of plating stainless-steel cavities with copper, where the end-flanges are joined to the barrel section with knife-edge seals; the Q's achieved are close to theoretical maximum
in the anomalous skin-depth regime at 4K. We acieved $Q \sim 250,000$ for the cavity in Array I.

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

A block diagram of the detector is shown in Fig. 3. The signal from the cavity is amplified by a low noise microwave amplifier located in a small refrigerator box located just above the top flange of the cavity. Figure 4 shows the electronic noise temperature $T_n$ for the currently employed front-end cryogenic amplifier. This is a balanced, 30-db gain, 2-stage HEMT amplifier build by NRAO. Its nominal noise temperature is $\approx 4$ K for physical temperatures $< 15$ K. The HEMT amplifier $T_n$ will get even better as the axion search moves up into the GHz region.

A postamp provides 60 dB of gain, and the signal is then sent through 10 m of low-loss coax cable to the temperature-controlled electronics house. The total noise contribution after the HEMT amp, referenced to its input, is $< 0.1$ K. The receiver (Fig. 3) is very similar to the UF design. The first stage image-reject mixer converts the signal to an IF (10.7 MHz); this is amplified and shaped with a 30 KHz bandpass filter which rejects power outside the cavity bandwidth. The IF is mixed down to a center frequency of 25 Hz with a crystal filter bandwidth of 30 KHz. The near-audio signal is split into two data streams. One goes to a SRS real-time FFT analyzer, which accumulates the medium-resolution power spectrum (bin width $\sim 100$ Hz) that would see the virialized axion linewidth distributed over several
channels. We have measured the noise in our FFT power spectrum for the entire receiver, and it drops like $t^{-1/2}$ as it should for at least 1000 seconds, much longer than our runs will be. The second data stream feeds a narrow-bin FFT analyzer built from commercial board-level components and packaged into a PC chassis. The two main components are a 100 KHz ADC connected over a dedicated data bus to a fast DSP containing sufficient on-board memory to store and process over $10^6$ ADC samples\textsuperscript{14}. The result is a high-resolution FFT (0.1 Hz) that can search for fine-structure\textsuperscript{12,15} in the axion kinetic energy distribution with much greater sensitivity. The required specifications on local oscillator phase noise and stability of the ADC clocking electronics are comfortable. The assembly and C-programming of the DSP is well-dug, and the concurrent ADC and DSP routines have been successfully tested. Additionally, the digitized data for the entire experiment is streamed to 8 mm tape archive, in case it is ever conceived that some specialized filtering could improve the sensitivity of the search.

This experiment started taking data in 1995, and will run for three to four years. This second-generation experiment is the first to have sensitivity to a likely dark matter candidate with plausible couplings to matter and radiation. This sensitivity is illustrated by Fig. 5, which shows the sensitivity of our scan of the 2.7–3.0 $\mu$eV (660–720 MHz) region in Feb. 96. Data analysis is in progress\textsuperscript{16}.

B. Multiple cavity arrays

We propose to design and build the prototype for the cavities that will be used in cavity array III of this experiment. The design will be done in consultation with the group at Livermore that has designed the first and second arrays. The prototype cavity will be built at the University of Florida.
As seen in Table 1, there are three separate cavity arrays required to cover the mass range 1.3–13 μeV. The first array consists of a single large cavity \( f = 460 \) MHz; it is part of the experiment already in operation. To go to higher frequencies (masses) requires smaller diameter cavities, but more of them to utilize the available magnetic volume and thus not sacrifice sensitivity. A schematic packing arrangement for the single and multiple cavity arrays is shown in Fig. 6.

Array II has been designed, and major components have been fabricated and ordered. Array III has not yet been designed. It is very appropriate that our group take responsibility for the design and prototyping of multiple cavity arrays. Our group carried out extensive conceptual studies, modeling and R&D on microwave cavities for the axion experiment (tuning schemes, mode crossings, mode localization, quality factor issues, tolerance criteria, materials, techniques for higher frequencies, etc.)\(^\text{17}\). Also, the original concept and two-cavity demonstration of power combining multiple cavities came from Hagmann’s thesis work at Florida\(^\text{18}\). Finally, the University of Florida would contribute the machine shop...
work for the fabrication of the cavity.

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

![Diagram of power-combining two cavities.](image)

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

The signal from a frequency synthesizer was divided by a power combiner/splitter, and sent to the weakly-coupled input port on two cavities, one of fixed frequency $\omega_0$ and one of variable frequency $\omega$\textsuperscript{18}. The signal from the two cavities' output couplers were combined through a similar device, and the total transmitted power measured as a function of the variable resonant frequency and coupling strength (Figure 7). The agreement between the calculated and measured values was exact within errors. Note the distinction between
power-combining cavities where there is large isolation between input ports (> 30 db), and cross-coupling the cavities, which would have produced mode-mixing and splitting into symmetric and antisymmetric modes.

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


13. National Radio Astronomical Observatory, Charlottesville, VA 22903

14. Bitware Corp., 26 South Main St., Concord, NH 03301


Task S
I Introduction

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

II History

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

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

In 1990, we traded in the VAX 6220, 10 Gbytes disk, 6250 bpi tape and the 8 node Vax farm for 28 DECstation 5000s (16 MB), 17 of them networked with FDDI. This deal involved a second Research Proposal with DEC which brought us contacts with DEC engineers and a 50% price reduction on all hardware components. The deal with DEC, UF and DOE was based on our distributed computing system UFMulti which we had just developed for Vax systems. This software allowed us to run single jobs on the whole computing farm, giving us access to more computing than what was available at Cornell. Andy White, who was at UF at the time, also ran a great deal of DO and SSC simulations on the farm.

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

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

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</table>

#### Disk & Tape

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>170</td>
<td>GB disk</td>
</tr>
<tr>
<td>4</td>
<td>DAT drives</td>
</tr>
<tr>
<td>3</td>
<td>DLT tape drives (10 GB)</td>
</tr>
</tbody>
</table>

#### Network

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Asante 100 Mbit Ethernet hubs (24 ports total)</td>
</tr>
<tr>
<td>1</td>
<td>PlainTree 10 Mbit Ethernet switch (16 ports)</td>
</tr>
<tr>
<td>1</td>
<td>Asante 10-100 bridge</td>
</tr>
<tr>
<td>1</td>
<td>DEC 10 Mbit bridge</td>
</tr>
<tr>
<td>1</td>
<td>DEC 10 Mbit hub</td>
</tr>
<tr>
<td>13</td>
<td>Incoming modems (28.8 Kbit)</td>
</tr>
<tr>
<td>1</td>
<td>ISDN line (for videoconferencing)</td>
</tr>
</tbody>
</table>
Videoconferencing

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

Printers

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

Notes on the current configuration

1. The system currently supports the high energy experimental and theoretical groups and our collaborators. Essentially every faculty member, postdoc and graduate student has an X-Terminal or equivalent on his/her desk.

2. We also provide accounts for a large number of graduate students finishing their theses and all physics undergraduates. Our support of these latter activities adds a negligible load to the system but provides goodwill within the department.

3. Our networking is based primarily on Fast Ethernet for servers which can support it (PCI based architectures such as the DEC 300 5/333 and DEC 250 4/266). Servers which cannot support Fast Ethernet are connected to the Plaintree Ethernet switch which provides a dedicated 1 MB/sec path to each machine.

4. All PCI based servers have fast/wide SCSI controllers to achieve high disk throughput.

5. We use software from Tektronix (WinDD) to run Windows on X-Terminals. Windows programs such as Word and Excel run on the P90 server but the Windows screen is rendered on the user’s X-Terminal. This has turned out to be very cost-effective solution since one PC server can support several Windows users without requiring us to buy a PC for each of them.

6. The two graphics workstations have a high end graphics card for fast 3-D rendering. They are used to support our graphics leadership on CLEO III and CMS.
IV Future Computing Activities

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

IV.1 CLEO

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

Compress Data Reduction

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

Recompress

CLEO is poised now to redo Compress on the entire CLEO II data sample taken before silicon running, approximately 4.8 fb$^{-1}$, representing a data sample four times larger than the one Recompressed in 1992, which was a major computing effort by CLEO (Florida carried out 3/4 of that Recompress). Major changes are being incorporated (particularly Kalman filter tracking) and this effort is being given the highest computing priority within CLEO.

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

Monte Carlo

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

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

IV.2 BTEV at Fermilab

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

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

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

IV.3 Fermilab (CDF/D0) and CMS

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

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

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

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

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

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

VI Other Computing Activities and Talks

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