

**Final Report
on Heavy Quark Studies
by the Prairie View High Energy Physics Group and
Research in Theoretical High Energy Physics**

to

Department of Energy

for

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Chapter 1

Report on E771 Progress

History

The HEP group at Prairie View has been involved with experiment E771 at Fermilab since its inception. Prior to the run, group members did a number of Monte Carlo studies of the E771 triggers, designed and programmed a large part of the E771 data acquisition system, and acquired and installed the Fastbus readout system for the PWC Central Chambers. During the run, our major responsibility was the smooth operation of the data acquisition system. Since the run ended, we have been involved in the offline data analysis of the dimuon trigger data. We also wrote a section of Proposal P867 at Fermilab, a continuation of the E771 study of B mesons. Our part of the proposal was a redesign of the data acquisition system to improve its efficiency in dealing with the high multiplicity events typical of E771. Our work on P867 was discontinued when the Program Advisory Committee at Fermilab recommended against the proposal, and our work on E771 is now winding down.

Off-line Data Analysis

Prairie View did the standard first pass analysis of 198 tapes from the E771 run; this amounts to about 12% of the total number of tapes written with the final 1A-1B trigger configuration. Each tape contains about 150,000 events, with each event using about 1 second of HP750 CPU time for analysis. Thus, a typical tape required about 40 hours on an HP750 to undergo the first pass analysis and have the output partitioned and written to tape. This analysis work on the 1A-1B trigger events was completed in 1993.

With the rejection of proposal P867, it was clear that there would be no more fixed target B physics done at Fermilab. The collaboration then decided to try to extract as much charm physics as possible from the data that was collected in the E771 run. To do this, a second "first pass" over the raw data was done which placed less stringent limits on the momenta of the decay muons. This not only resulted in a larger sample of charm

than the standard first pass, it also provided a larger event base for studying flavor-changing neutral currents. This was a very time-consuming pass, and the work was partitioned to three computer farms: one at Fermilab, another at the University of Virginia, and the third at Prairie View. We did about 15% of the work on this pass, which was completed late in 1994. At Prairie View, this work also included analyzing events which were written early in the E771 run, before the activation of the final 1A-1B trigger.

Throughout the analysis phase of E771, we investigated the use of object-oriented languages, predominantly C++, for physics analysis. The motivation for this work was the difficulty we experienced in porting FORTRAN-77 code originally written on a VAX VMS machine to Unix workstations. In addition to rewriting all of the I/O routines for our machines, which was expected, we also found many decoding routines which were not portable. Even when porting code from an HP750 to its close relative, the Apollo DN10000, several days of effort were required to flush out features which were tolerated by both VAX VMS and HP Unix, but not by Apollo Unix. Nearly all of these problems could have been avoided by using a strongly typed language like C++. It was also noticeable that the lack of bitwise operations in FORTRAN-77 made the portable code (using CERNLIB bit manipulation) significantly slower than it would be using a language which has built-in bitwise operations and standard hexadecimal notation. As part of our effort for P867, we rewrote a number of data acquisition and decoding routines in C++. One of our collaborators, Shigeki Misawa of Berkeley, has rewritten the entire E771 tracking package in C++ [Fermilab Pub 93/079 and Proceedings of the Computing in High Energy Physics '94 Conference, San Francisco, LBL-35822/CONF-940492/UC-405, 279 (1994)]. Both sets of code are notably simpler and shorter than their FORTRAN-77 counterparts. This work has carried over naturally to our simulation work on *BABAR*, which uses C++ heavily, and which has uncovered completely new portability problems.

Results

A number of papers have been prepared and submitted from E771 in 1995 and 1996. The Prairie View group wrote the data acquisition section of a report on the E771 spectrometer, which was recently published in Nuclear Instruments and Methods [T. Alexopoulos, *et al.*, NIM A376, 375 (1996)]. Another paper, giving an upper limit a factor of ten better than previously found for the flavor-changing neutral current decay $D^0 \rightarrow \mu^+ \mu^-$, will appear in Physical Review Letters. Most of this work was done at the University of Houston, with contributions from Prairie View and Fermilab personnel. A third paper, on differential cross sections of J/ψ and ψ' , has been submitted to Physical Review Letters. An earlier study on J/ψ , ψ' , and Υ production has been published in Physics Letters B [T. Alexopoulos, *et al.*, Phys. Lett. B 374, 271 (1996)].

A large number of conference papers and technical papers have been prepared by the collaboration. A not-always-up-to-date listing of these, along with a listing of graduate theses describing E771, can be found on E771's web page:
<http://fermi.clas.virginia.edu/~aal2q/e771/e771hp.html> .

Chapter 2

Report on BABAR Progress

Summary

The Prairie View A&M University High Energy Physics group joined the *BaBar* Collaboration at SLAC in September 1994. *BaBar* is the experiment and detector to be run in the PEP-II ring at SLAC as part of the Asymmetric *B* Factory project there to study *CP* violation and heavy flavor physics. The focus of our effort so far has been with the Muon/Neutral Hadron Detector/Instrumented Flux Return subgroup of the *BaBar* collaboration that will be designing, simulating, building, and testing the Instrumented Flux Return (IFR) and its Resistive Plate Chamber (RPC) muon detector. Within this *BaBar* muon detector subgroup, we are working closely with collaborators from Lawrence Livermore National Laboratory (LLNL), the INFN from Italy, and the University of Pennsylvania. Our immediate task on *BaBar* will be to run the muon simulation programs on our Hewlett-Packard (HP) workstations at Prairie View, use this data in the design optimization of the *BaBar* IFR, and work on plans for testing and installing the RPC detectors in the IFR.

Infrastructure

In the first year after joining *BaBar*, our group was heavily involved with porting the simulation program BBSIM and its supporting utilities to our HP9000/750 computers. This was a fairly complicated process, since the native HP C++ compiler is not used to compile BBSIM code. It was necessary to port the GNU C++ compiler, together with GNU gmake utilities, to compile the code. Additional software packages needed were SLAC's rCVS and Software Release Tools, both of which were added to our machines. BBSIM uses a large amount of disk space, so a SCSI disk was added to one of our HPs to accommodate it.

While the basic housekeeping of BBSIM at Prairie View has been completed, there are still updates and changes to the support utilities which need to be done periodically. A major change to the CVS utility was made after we joined the collaboration, and this

change went smoothly. Updates to GNU C++ have not always been so successful. Part of the rationale for using GNU C++ was to have a portable compiler for C++ code which would behave the same on all supported platforms. This has proven not to be the case with GNU C++, and it remains to be seen if the situation will improve with later releases of the compiler. The Prairie View group has investigated the native HP C++ compilers, but these have proven to be even more problematic with BBSIM. Nearly all of the collaboration's testing of HP GNU C++ has been done at Prairie View. HPs are also used at LLNL and Genova, both of which are involved with us in the IFR subgroup.

The collaboration initially intended to support FORTRAN-90, in addition to extended FORTRAN-77 and C++. Support for FORTRAN-90 has now been dropped, a decision which we supported wholeheartedly.

The current BBSIM program is essentially a GEANT 3.21 simulation, primarily using FORTRAN. Eventually, GEANT 3.21 is expected to be supplanted by the C++ based GEANT4. The Livermore group is closely involved with the design of the base GEANT4 utilities. These are not expected to be ready before the RPCs are built; consequently it will be necessary to most of the IFR simulation work with the tools available now. LLNL has done a significant amount of work to ensure that C++ code can be written to coexist with GEANT 3.21. The C++ muon code which we have written has been almost problem-free in this regard.

The *BaBar* collaboration intends to move to AFS in the near future. This will require all collaborators to have at least the AFS client software installed and running on their machines. We are currently investigating packages for our machines.

Student Participation

Our of our group's goals in the project is to provide an opportunity for our students to participate in the frontier of high energy physics research. In the past year, several of our students have participated in our group's research work at Prairie View, SLAC, and LLNL, in order to learn some of the basic concepts of particle physics and the methods of high energy physics research. During the summer of 1995, one of our students, George Aduo, had a chance to work at LLNL for ten weeks. He worked in the Physics and Space Science Section, learning how to run simulation programs. He also spent time in the LLNL RPC laboratory learning how high energy physicists conduct experimental research and build detectors for a large experiment like *BaBar*. In the summer of 1996, three students, Johnson Acheampong, Emmanuel Acheampong, and John Cooney, worked at the Prairie View campus, learning parts of the *BaBar* simulation software design.

BBSIM at Prairie View

The work on simulating the IFR component of the *BaBar* detector has a very high priority within the collaboration, since the IFR will be the first part of the detector built. It is scheduled to be ready by June of 1997, about a year before other components come on line. During the wait for other detector components, the IFR is expected to be tested with cosmic ray muon triggers.

The work we have been doing in the past few months has been to make a more realistic model of the IFR in BBSIM. When the TDR was published, the performance of the IFR for muon identification, π/μ separation, and K_L^0 detection was estimated, based on a rather simplistic view of both the IFR steel plates and the RPC configuration. Both were taken to be monolithic, with no gaps, and each RPC was represented as a gas gap between graphite plates. It was also assumed that each RPC plane would have a two-dimensional strip readout. A number of simulation changes have been incorporated since then, and a number of hardware design changes have also been necessary.

The first simulation change made by the Prairie View group was to replace the simple RPC plane setup with a more accurate RPC model comprising bakelite, aluminum, and PVC planes. This work has been completed and incorporated into current BBSIM releases. The second change, being done at Prairie View and Livermore, is to break up the monolithic steel and RPC polygons into real world planes, with gaps and supports included. Doug Wright at Livermore is currently incorporating the latest steel designs into the simulation; we have just completed the work on the RPC modules. Whenever the steel design is refined, a new magnetic field map is required. So far, two iterations of the field map have been done, with the latest coming from Luca Lista (Napoli).

When the TDR was published, we believed that we would be able to put two-dimensional RPC strip readouts on every RPC plane. It now appears that this cannot be done, due to funding constraints in Italy. It is likely that about 50 each strip (which is planned), it is possible to convert the output of a one-dimensional readout to a quasi-two-dimensional readout, but there will be some loss of efficiency. Coding of the reconstruction software, which will take this problem into consideration, has begun in Genova and Napoli. The RPC modules themselves, which were assumed to be limited to a length of one meter, have been redesigned with a maximum length of two meters. This will decrease the number of clearance gaps in the barrel.

In the immediate future, the Prairie View group plans to continue working primarily on IFR software. Our next project is to code some validation histograms of raw and reconstruction variables. Initially, these routines will be attached to the BBSIM program to provide a quick check that the simulation is functioning correctly as various parameters are modified. The routines should be written in such a way that they can also provide online monitoring capability.

We also need to do another pass of our π/μ separation study with the new BBSIM program, and see if the separation can be improved with new muon reconstruction parameters.

Muon and Neutral Hadron Detector

The following is a brief description of the Muon and Neutral Hadron Detector of *BaBar* (re: *BaBar* Technical Design Report, SLAC-R-95-457, March 1995).

The iron structure that constitutes the return yoke for the magnetic field is fully instrumented in order to provide muon identification and K_L^0 detection. The Instrumented Flux Return (IFR) consists of a barrel, enclosing the superconducting coil, and two endcaps, and is subdivided into slabs with active detectors inserted into the intervening gaps. The total steel thickness required to contain the magnetic flux from the solenoid coil is about 60 cm; this is a good match to the absorber thickness required for a muon filter. Particles reaching the iron will have passed through the inner detectors and the coil (a total of 0.9 interaction lengths); to emerge from the iron and strike the outermost chamber they must pass through an additional 3.6 interaction lengths. This is enough material to reduce the pion punch-through misidentification probability to the percent level in the momentum range between 1 and 3 GeV/c, comparable to the probability for hadron decay to muons.

Since the measurement of CP -violating asymmetries and the experimental program at PEP-II in general are based on exclusive-state reconstruction, the measurement of the hadron energy deposition is not of primary importance; the IFR is not used as a calorimeter for total energy measurement, but as a neutral hadron (primarily K_L^0) and muon identifier. Thus, a strip type detector with digital readout is envisioned; strips can run along the x or z direction in the barrel and in the x or y direction in the endcaps. Bi-directional information is possible, either by using strips in both directions or by measuring the difference in arrival time of signals at the ends of the detector.

Solid angle coverage is complete down to the region occupied by beamline components. The precise shape of the end cap yoke in the region near the beam line is not yet defined; it is possible that muon identification could be extended to angles below 300 mrad. This would not affect the cost since the number of readout channels would not change significantly, but could allow an increase in B tagging efficiency and make the IFR more hermetic. Maximum solid angle coverage for hadrons is important, for example, in the measurement of the branching ratio of $B \rightarrow \tau\nu_\tau$. A detailed Monte Carlo is needed to evaluate the background, and in general to verify the benefits of the IFR covering a larger solid angle than the rest of the detector.

The IFR could also allow us to veto cosmic rays at the trigger level by determining the direction (inward or outward) of a track. This could be done by adding a small number of TDCs (one per chamber in a few layers) to measure the time of the first hit in the chambers. Cosmic rays could be well separated from events originating at the interaction point, even with a modest time resolution (in the range of a few nanoseconds).

Design Considerations

The physics objectives driving the performance required of the IFR detector are: B (and D) tagging with muons, study of semimuonic decays, reconstruction of $J/\psi \rightarrow \mu^+ \mu^-$, and K_L^0 identification in the B decay products. To reach these goals, the IFR should deliver μ - τ separation from ≈ 4 GeV/ c down to as far below 1 GeV/ c as possible (muons from the charm quark cascade peak at ≈ 500 MeV/ c), with high efficiency and little misidentification; and K_L^0 identification, with directional information, in the energy range of 1–3 GeV. The light quark (uds) contribution is almost entirely from pion and kaon decay.

The total detector surface and the number of readout channels are the key factors in the cost estimate of the subsystem. Detailed Monte Carlo simulation studies of the full detector with single particle and $\nu(4S)$ event inputs have begun to address the issues of IFR design. The hadronic shower Monte Carlos in most common use are known not to simulate low momentum particles correctly; different generators use different cross sections and models. This difficulty is compounded by the fact that there is little data against which to test the simulations.

The optimization process will proceed as more work is performed in preparation for the Technical Design Report. The main points on which activity will be focused on are the iron segmentation, both in the barrel and in the two endcaps, the design of the active detector components, and the effect of the solenoid coil thickness.

The impact of detector inefficiencies (mostly due to inactive areas) on performance will be investigated, as well as the merits of using double layers. The number of readout channels, determined by the size of the strips and the number of layers to be equipped with bi-dimensional readout, must also be optimized. The possible benefit of inserting an additional detector layer between the CsI calorimeter and the coil is being investigated. The energy asymmetry of PEP-II leads to a momentum distribution that is function of polar angle; the design of the endcap detector system should reflect this, to the degree permitted by magnetic considerations, in order to be cost effective without compromising performance.

The optimization process has begun with a detailed study of muon identification efficiency *vs.* hadron contamination, as a function of momentum and angle of incidence; B tagging efficiency, in particular for benchmark channels; and K_L^0 identification and angular resolution in $B^0 \bar{B}^0$ events.

Muon Identification

Since the interaction region is enclosed by the CsI calorimeter and magnet solenoid, muons with momenta below 400 MeV/ c do not reach the IFR. Those muons that do reach the IFR must be distinguished from backgrounds resulting from primary charged hadrons (most pions) and secondaries from hadronic showers and decays.

Considering their mass difference and ignoring hadronic interactions, pions and muons

differ in their most probable penetration depth (range) in iron by approximately 2-3 cm for momenta below 1 GeV/c. This effect is overshadowed by the high pion-nuclear interaction cross-section. Muons with momenta greater than 1.5 GeV/c completely penetrate the IFR iron.

To exploit the range difference between pions and muons for pion rejection, the momentum of the charged particle must be measured. Furthermore, the charge of the muon must be determined for B^0 tagging. The central tracking chamber provides this information; its geometrical acceptance is less than that of the flux return, thereby restricting the solid angle for muon identification.

Depending on how much loss of muon efficiency one can tolerate, a range cut reduces the pion misidentification probability to a few percent. Monte Carlo studies have indicated that reducing the iron plate thickness to 2.5 cm from 0.5 cm did not significantly improve the pion rejection. Pion background can be further reduced by requiring a high degree of continuity in the pattern of hits in the IFR. Muons tend to give a hit in every layer they go through; pions initiate hadronic showers that can 'skip' detection layers.

Preliminary Monte Carlo studies indicate that muon identification can be done with high efficiency (above 90%) and low contamination (a few %) from 500 to 1000 MeV/c momentum, using a total thickness of 40 cm of iron divided into plates of approximately 2 cm. The remaining portion of the IFR could be divided into thicker plates with compromising performance. Monte Carlo studies are underway to optimize the choice of plate thickness and to verify the impact of segmentation on K_L^0 detection.

K_L^0 Detection

The granularity of the IFR detector is also driven by the need to identify the K_L^0 's produced in B decays. A sizable fraction of K_L^0 produced in $B^0\bar{B}^0$ interact in the CsI calorimeter. Preliminary Monte Carlo studies have shown that the fraction of all K_L^0 which reach the IFR varies according to the hadron simulation package used; the only experimental data available[1] seem to indicate the K_L^0 cross sections on nuclei are overestimated in the GHEISHA package and agree with those used in FLUKA. This is consistent with our findings and encourages us to use FLUKA for these studies.

Some preliminary results from a simulation employing FLUKA indicate that the probability of identifying a 2 GeV/c K_L^0 requiring at least 5 layers hit is about 70% for iron plates 1 cm thick, dropping to $\approx 50\%$ if the plates are 2 cm thick. Showers produced by photons of the same momentum in the CsI calorimeter do not penetrate past the first 1-2 cm of iron. Requiring no energy to be deposited in the CsI calorimeter (*i.e.* selecting those K_L^0 's that interact directly in the IFR) reduces the identification probability to 20-25%. The angular resolution is typically a few degrees, which is adequate for the kinematic cuts used to reconstruct $B^0 \rightarrow J/\psi K_L^0$ final states. A detector layer inserted before the coil may be of real benefit here and is being investigated.

The Active Detectors

The instrumentation of the flux return covers a surface of $\approx 4000 \text{ m}^2$, has a total of $\approx 50,000$ readout channels and is inserted into the gaps between the steel plates. Access for maintenance and/or repair will be very difficult at best. The main requirements for the detector technology are therefore the following: long term reliability, sturdiness, simplicity of construction and operation, and low cost of the raw materials and readout electronics.

A well-known technique that satisfies these requirements has been considered: Resistive Plate Chambers (RPCs). It is a gas detector in which a sizable pulse is induced on external electrodes by the charge produced by a particle ionizing the gas. In principle, RPCs have better time resolution and less dead space and the lack of wires make them less likely to have breakdowns compared to competing technologies.

Resistive Plate Chambers

Resistive Plate Chambers (RPCs) are large area, parallel plate detectors operated in DC mode. They are under consideration for the IFR because of their low cost, high efficiency, good timing, and simple electronics requirements. RPCs are constructed of two parallel plate electrodes (traditionally bakelite) of high electrical resistivity held apart by space buttons and filled with a mixture of argon, isobutane, and freon. With an electric field of 4 kV/mm between the electrodes, a charged particle crossing the gap will initiate a sparklike discharge between the electrodes which terminates when the electric field collapses, due to the resistance of the plates. The spark is of sufficient amplitude to induce large pulses on external striplines, which are then read out to determine the particles' position.

This technique has been proposed for muon detectors at future hadron collider experiments, because of the superior timing performance and suitability to detectors with very large surface area. This technique also looks attractive for *BaBar* because the assembly of wireless chambers is straightforward; they can be readily adapted to the endcap design, where the geometry is not longitudinal as in the barrel and the chambers will not have a rectangular shape. Another advantage of this technique is that the production process have already been adapted to industry and factories with the necessary tooling exist.

RPCs have been used successfully in the NADIR experiment at Grenoble, FENICE at Adone (Frascati), E771 at FNAL and WA92 at CERN, and in several cosmic ray detectors. A recent larger scale application of this technique is the trigger system for the L3 muon endcaps, consisting of 600 m^2 of double gap chambers. This design has an independent high voltage supply to each gap, resulting in more than 99% efficiency and providing a backup capability in case of failure. This feature seems particularly attractive for a system that is difficult to access, such as the IFR. Both sides of the high voltage plane are active gaps, with the readout strips in the middle. A two-dimensional scheme, with two planes of strips running in orthogonal directions, has also been proposed[2].

Several other large RPCs have been prototyped that utilize a doped ABS plastic sheet

as the resistive electrode. The doped ABS is manufactured and sold as a static dispersive packaging material for electronics components; it is manufactured with strict quality control on resistivity and produced in easy-to-handle plastic rolls. Like their traditional bakelite counterparts, the doped ABS RPCs exhibit high efficiency and time resolutions of 1 to 3 ns. The two resistive electrodes are made of sheets of 0.030" thick doped ABS plastic. They are held apart by 2 mm high plastic buttons. High voltage (8500 V) is applied to the top electrode through a 0.004" graphite sheet (Velostat) laminated directly to the ABS plastic and protected by a 0.005" mylar sheet. The bottom electrode is grounded through an array of copper readout strips deposited directly on the ABS plastic. A thicker spacer grid holds a 0.0007" thick sheet of Al foil at the proper distance to form the ground plane of a 50 Ω transmission line for propagating the induced pulses.

R&D activity in the coming months will focus on alternative gas mixtures, with emphasis on eliminating freon and reducing flammability, and on mass production techniques with stringent quality control.

Chapter 3

Report on Theoretical Physics Progress

Progress of the Theoretical Work of Dr. Dan-Di Wu

Dr. Dan-Di Wu has completed three theoretical papers in the past year:

Paper 1: CP symmetry and fermion masses in $SO(10)$ models. In collaboration with Dr. Yue Liang Wu at Ohio State University.

This work gives a more convenient representation of the $SO(10)$ gamma-matrices. It also finds the relation between the general two Higgs model and the minimal $SO(10)$ model.

Paper 2: The calculation of a high order QCD process— gg to $t\bar{t}gg$. In collaboration with Drs. Da-Hua Zhang, David Wagoner, and Dennis Judd.

This high order QCD process involves 159 Feynman diagrams. This is a very complicated calculation. We use the permutation symmetry to simplify the calculation. In addition, the color sum is neatly done by hand by the use of a smart algebra. We also invented methods to check the program so the mistakes can be located accurately and eliminated. The speed of the program is therefore quite fast.

This process will be an important background at the Large Hadron Collider at CERN, when they will try to find Higgs particles and other heavy particles.

Paper 3: An enigma with Majorana masses. In collaboration with Richard Arnowitt at Texas A&M University.

When there is more than one Weyl neutrino which has a Majorana mass, the mass matrix of the neutrinos is symmetric and in general complex. The question of simultaneous diagonalizability (SD) of the mass terms and kinetic terms is discussed in some detail. There does not seem to be any neat solution to realize SD. The possibility of allowing a small non-diagonal part for the mass terms, when the kinetic terms are diagonalized, is discussed by perturbation.

Copies of the first two papers are available on the Los Alamos National Laboratory Electronic Preprint System, together with the report to the Madison Workshop.

B physics discussion and work is also ongoing in this HEP group both for the preparation of the *BABAR* experiment and the search for potentially interesting theoretical subjects to study.

Academic Activities

Dr. Wu has reported the first result of his work to the HEP group at Texas A&M University and to the workshop held at University of Wisconsin, Madison. He also gave an invited talk at Southern University, Baton Rouge, Louisiana.

Dr. Wu has spent three weeks at the Institute of High Energy Physics in Beijing, China. While in China, he contributed three lectures at IHEP, Fudan University (in Shanghai), and Shanghai Normal University. These institutions covered part of his local expenses. He then spent three weeks during the summer of 1996 at Texas A&M University, College Station, Texas, to develop his ideas and conduct theoretical research. The third paper with Dr. Arnowitt is the result of this visit. His third paper was just completed in September 1996. Presentations on this paper are scheduled before the end of 1996.

Dr. Wu has attended two local APS meetings, the APS Southeastern Meeting at University of Florida, Tallahassee, where he made one presentation, and the APS Texas Section Meeting at Abilene Christian University, Abilene, where he made two presentations.

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- [2] Bacci *et al.*, Sezione di Roma dell'INFN Report 1024, 1993, (Submitted to *Nucl. Instrum. Meth.*).

Chapter 4

Publications

The following is a list of the latest publications from the Prairie View High Energy Physics group on this project.

1. T. Alexopoulos, *et al.*, "Search for the Flavor Changing Neutral Current Decay $D^0 \rightarrow \mu^+ \mu^-$ in 800 GeV Proton-Silicon Interactions", *Phys. Rev. Lett.* **77**, 2380 (1996).
2. T. Alexopoulos, *et al.*, "The Fermilab E771 Spectrometer: A Large Aperture Spectrometer to Study Charm and Beauty States as Detected by Decays into Muons", *Nucl. Instrum. Meth.* **A376**, 375 (1996).
3. D. Wu, "Small Elements in Fermion Mass Matrices and Anomalous Dipole Moments", *Phys. Lett. B* **374**, 100 (1996).
4. T. Alexopoulos, *et al.*, "Measurement of J/ψ , ψ' and Υ total cross-sections in 800 GeV/c proton-Silicon interactions", *Phys. Lett. B* **374**, 271 (1996).
5. S. Ramachandran, *et al.*, "Results on $B\bar{B}$ hadroproduction at $\sqrt{s} = 38.8$ GeV", Submitted to DPF96, the 9th Meeting of the Division of Particles and Fields of the American Physical Society, Minneapolis (1996).
6. K. Hagan, *et al.*, " χ Production in 800 GeV p -Si Interactions", Submitted to DPF96, the 9th Meeting of the Division of Particles and Fields of the American Physical Society, Minneapolis (1996).
7. T. Alexopoulos, *et al.*, " η production at $\sqrt{s} = 38.8$ GeV and the Branching Ratio $BR(\eta \rightarrow \mu^+ \mu^-)$ ", Submitted to DPF96, the 9th Meeting of the Division of Particles and Fields of the American Physical Society, Minneapolis (1996).
8. M. Arenton, *et al.*, "Charmonium Production with 300 GeV/c π^+ , π^- , p and \bar{p} Beams", *Int. Jour. Mod. Phys. A* (1996).
9. T. Alexopoulos, *et al.*, "Differential Cross Sections of J/ψ and ψ' in 800 GeV/c p -Si interactions", To be published in *Phys. Rev. D* (1996).

10. D. Wu and Y. Wu, "*CP* symmetry and fermion masses in $SO(10)$ models", Prairie View HEP Preprint, to be published in *Mod. Phys. Lett. A*, (1996).
11. D. Zhang, D. Wu, D. Wagoner, and D. Judd, "The calculation of a high order QCD process— gg to $t\bar{t}gg$ ", Prairie View HEP Preprint PVAMU-96-6, submitted to *Comm. Theoret. Phys.*, (1996).
12. D. Wu, "FCNC, *CP* violation, and impure Majorana neutrinos", Prairie View HEP Preprint HEP-3-96 (1996).
13. D. Wu and R. Arnowitt, "An enigma with Majorana masses", Prairie View HEP Preprint (1996).
14. D. Boutigny, *et al.*, "BaBar Technical Design Report", SLAC Report SLAC-R-95-457 (1995).
15. A. McManus, *et al.*, "A Search for New Charmonium States Decaying into J/ψ plus Charged Pions", *Proceedings of the 8th Meeting of the Division of Particles and Fields of the American Physical Society*, Albuquerque, World Scientific, 547 (1995).
16. G. H. Mo, *et al.*, "Search for the Flavor Changing Neutral Current Decay $D^0 \rightarrow \mu^+ \mu^-$ in 800 GeV/c Proton-Silicon Interactions", *Proceedings of the 8th Meeting of the Division of Particles and Fields of the American Physical Society*, Albuquerque, World Scientific, 956 (1995).
17. G. Corti, *et al.*, "High Mass Dimuon States Produced in 800 GeV/c pSi Interactions", *Proceedings of the 8th Meeting of the Division of Particles and Fields of the American Physical Society*, Albuquerque, World Scientific, 1272 (1995).
18. T. Alexopoulos, *et al.*, "Measurement of J/ψ , ψ' and Υ total Cross Sections in 800 GeV/c p -Si Interactions", FERMILAB-Pub-95/297-E, submitted to *Phys. Rev. Lett.*, (1995).
19. D. Wu, "*CP* Violation in $O(10)$ Models Which Is Tied to the Group Structure", PVHEP Preprint HEP-12-95 (1995).
20. D. Wu, "Mass hierarchy and the spectrum of scalars", PVHEP Preprint HEP-3-95, submitted to *Phys. Rev. Lett.*, (1995).
21. D. Wu, "Cascade Global Symmetry and Quark Mass Hierarchy", Submitted to International Workshop on Particle Theory and Phenomenology, Ames (1995).