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UNIVERSITY OF VIRGINIA

EXPERIMENTAL AND THEORETICAL HIGH ENERGY PHYSICS

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By
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A. Introduction

In 1988 the Department of Physics of the University of Virginia made a strong commitment to form a high energy experimental physics group and to enhance the theoretical high energy effort. The University pledged several tenure and tenure track positions and considerable resources in the form of seed funding and an entire building to the formation of a strong, vigorous HEP group. Between October, 1988 and September 1990 five HEP faculty positions have been filled and the critical people are now in place. In addition, the beginnings of a technical infrastructure have been assembled with the addition of the first four support staff members. Finally, several graduate students joined the group to begin their PhD programs. The HEP group has grown to 12 PhD physicists, and 10 PhD graduate students as listed in Section B from a level of three theoretical faculty members and two graduate students in September, 1988.

As described in Section C, good progress has been made on providing facilities for the use of the HEP group. The first three phases of the preparation of the UVA High Energy Laboratory Building for the HEP group have been completed. The group has now moved into their renovated facility and the fourth and final phase of the work has been funded by the University. Plans have been developed and the Phase IV construction project will soon get underway. Using the resources committed to High Energy Experimental Physics by the University, the Commonwealth Center for Nuclear and High Energy Physics and the Institute for Nuclear and Particle Physics as well as state funds obtained through the Higher Education Equipment Trust (HEET), the HEP experimental group has begun to outfit this lab space. In particular, as described in section C.2, the experimental group has completed the installation of approximately 60 MIPS of dedicated computing and has begun to use this in the spring of 1990 in the analysis of the E705. Recently, we have begun the first processing of data from the E771 experiment. The theoretical group has also obtained a major boost to their computing capabilities with the addition of 80 MIPS of IBM workstations. Finally, a VAX 3200 test station and a data acquisition system have been added recently to the experimental group's VAX cluster. A priority during the upcoming year is the continuing upgrading of the computing facilities to match the increasing load of both theoretical and experimental computing. In addition to the continuing buildup of the UVA HEP dedicated computing facilities, the outfitting of the electronics laboratories and the development of electronics design capabilities will continue as described in section C.3.

The three major research activities of the UVA experimental HEP group in the past year have been all in the area of heavy flavor physics. These major efforts are the continuing analysis of E705, the execution of the test/startup run of E771 and the development of the Super Fixed Target Beauty Facility (SFT) at the SSC.

First, the UVA experimental group has continued to be involved in the analysis of Experiment E705 during the last year along with other members of the E705 collaboration (Athens, Duke, Fermilab, Prairie View A&M, McGill, Northwestern, Shandong). The direct photon data represent the highest statistics ever available for comparison of π^+ and π^- production of direct photons because of the large π^+ data sample accumulated. Likewise the charmonium data represents the largest data sample in existence for study of the hadroproduction of heavy quarkonium by gluon fusion. Between December, 1989 and March

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1990, the 7500 tapes written in the 1987-88 run of E705 were put through a first pass on the Fermilab ACP system. Over 200 million events were passed through the E705 event reconstruction programs. The processing of these tapes, containing data on the production of $3P_J$ charmonium states (detected via their $\Psi \chi$ decay modes) and high p_t direct photons by 300 GeV/c π^+, π^- , protons and antiprotons on a Li target, was made possible by the availability of computing time on the Fermilab ACP system which was finally scheduled in the December-March period. Due to the limited capacity of the Fermilab ACP system, shared among many fixed target experiments and CDF, the computer time for the massive number crunching required for E705 only came available in the past year. In addition, a second pass through the dimuon data was completed this summer and work is now beginning on several papers. The first pass output of the E705 and preliminary results obtained thus far are discussed in Section D.1

The major effort of the entire UVA experimental group, for the next several years, is experiment E771, a collaboration of Athens, Berkeley, Brown, UCLA, Duke, Fermilab, Houston, Indiana, Lecce, McGill, MIT, Nanjing, Northwestern, Pavia, Prairie View, Penn, South Alabama, Shandong and Virginia. The Institute for Nuclear Physics at Dubna along with several other Soviet and eastern European institutions has indicated a strong desire for participation in E771 (and the Super Fixed Target B Physics Facility at the SSC) and negotiations are underway to initiate this collaboration. The objectives of this experiment (detailed in Appendix IV) are to accumulate large numbers of B decays by triggering on single high p_t muons and multimuons states of high mass. The dimuon triggers will include $B \rightarrow J/\Psi \rightarrow \mu\mu$ decays, which provide an unambiguous signature since no other known phenomenon will produce a J/Ψ at a secondary vertex. The single muon trigger will allow the accumulation of a very large sample of B's on tape. The B's in events recorded with the single muon trigger are tagged by the charge of the muon as particle or antiparticle. A discussion of the expected yields of B's obtained by means of the single and dimuon trigger is given in Appendix IV.

E771 has begun operation, completing a setup/test run between April, 1990 and the end of August, 1990. The achievements of the test run are detailed in Section D.2.2. The objectives of the second half of the E771 run are discussed in Sections D.2.1. While the lack of electronics hampered the test run, a large amount of information was obtained which will provide a framework for preparations for the second half of the run presently scheduled to start at the end of December, 1990 and run through the late spring of 1991. The UVA experimental group is requesting funds for this run, including equipment funds to complete the construction of amplifier cards for the E771 pad chambers. This project forms the bulk of the equipment request for the next contract year. In addition, the UVA group will continue to be responsible for the second level muon trigger and the electromagnetic detector for E771. Finally, the UVA group appears to be forced by circumstances to take on the task of providing new amplifier cards to replace the no longer available MVL100 drift chambers amplifiers which are failing at a steady rate.

The third activity of the UVA HEP experimental group during the last year has been the beginning of a program of beauty physics at the SSC. Various members of the UVA group had been involved for many years in an effort to ascertain the best method of pursuing B physics after E771 (including consideration of e^+e^- options). During the last year, this activity resulted in the organization by the UVA group of a large international collaboration and the

preparation and submission of an Expression of Interest (EOI-14) to construct a Super Fixed Target 20 TeV B Physics Facility (the SFT) at the SSC. The 20 TeV fixed target option offers unique opportunities to study time distributions of B decays and has the potential of fully reconstructing large numbers of B decays in which the B itself is directly observable. The reception of this idea by the SSC management and the SSC Program Committee has been very positive. In their general recommendations arrived at in their 1990 Snowmass meeting and in subsequent communications with us (see Appendix II and III), the SSC PAC and the SSC management have clearly indicated that B physics should be a part of the initial program of the SSC and, furthermore, that the fixed target experiment with an external 20 TeV beam was the most promising of the options presented to them (in comparison with either an internal target option or a collider detector specializing in B physics). Assuming continued success in this endeavor, the 20 TeV Fixed Target Facility will form the basis of a considerable portion of the activity of the group for the next decade.

Finally, a number of minor activities of the UVa experimental group from prior commitments of the UVa group members are still underway. Several recent publications have resulted from this work (see Section D.4). These activities form a minor portion of the total effort of the group. Analysis of data from the UA6 experiment at CERN and final run of this experiment are in progress and constitute a small portion of the activity of a member of the UVa group (Dukes). In the same spirit, the continuing analysis of quark gluon plasma search experiment at Fermilab (E735) is a prior commitment of one of the UVa experimental group member (Nelson). Finally, two UVa group members (Conetti and Cox) have been involved in the preparation of the final publication of the dimuon experiment, Fermilab E537, during the last year.

The UVA theoretical group since the submission of the last contract renewal request in August, 1989 has continued their research, both phenomenological and theoretical, in electroweak interactions; in symmetry and symmetry breaking, including fundamental symmetries and family symmetries; in models for quantum chromodynamics at long distances. Furthermore, with the addition of H. Thacker who arrived in the fall of 1989, a new program was begun in lattice gauge calculations of QCD; and in exactly solvable models in statistical physics. The arrival of most of the members of the UVa experimental faculty in the fall and late winter of 1989-90 has stimulated the theoretical group to undertake work in areas relevant to the experimental groups's program. Finally, a new post doctoral fellow Joseph Minahan has recently joined the group and will add his efforts in the area of electroweak interactions in the study of the mass heirarcy of the quarks and leptons.

The proposed research effort of the UVa theoretical group is described in detail in Section E of this proposal. The group is asking for support for an additional postdoctoral fellow beginning in September 1991, as well as support for three graduate students. The post doctoral fellow would add to the efforts already underway in the lattice gauge efforts on B physics and add to the efforts of the experimental group in the general area of weak decays.

We request \$925 K in operating funds and \$105 K in equipment funds for the funding period from Feb 1, 1991 to Feb 1, 1992 for the UVa experimental group to carry out our program outlined above and detailed in this document. The UVa theoretical group requests \$278 K in operating funding to carry out their proposed activities.

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B. UVa High Energy Physics Group Personnel

B.1 Present UVa HEP Group Personnel

Following the inception of the UVa HEP group in the fall of 1988, the UVa HEP effort has undergone rapid growth to accommodate the present program of B physics at Fermilab and in preparation for an anticipated program at the Superconducting Super Collider. At present, the HEP group presently includes 22 physicists (12 PhD's and 10 graduate students) as listed below:

Faculty

S. Conetti: Professor of Physics (Exp)
B. Cox: Professor of Physics (Exp)
C. Dukes: Assistant Professor of Physics (Exp)
P. Fishbane: Professor of Physics (Theoretical)
P.Q. Hung : Associate Professor (Theoretical)
P. Kabir: Professor of Physics (Theoretical)
K. Nelson: Assistant Professor of Physics (Exp)
H. Thacker: Professor of Physics (Theoretical)

Senior Scientist

M. Arenton (Exp)

Engineering Physicist

M. Recagni(Exp)

Research Associates

A. McManus (Exp)
J. Minahan (Theoretical)

Administrative Assistant

D. Bunyard

Senior Technician

J. Segal(Exp)

Graduate Students:

P. Hanlet (Exp)
E. Larson (Exp)
S. Rakete (Exp)
S. Ramachandran (Exp)
C. Rivers (Exp)
J.G. Sun (Exp)
M. Timmins (Exp)
T.J. Liu (Theoretical)
R. McCoy (Theoretical)
D. Singleton (Theoretical)

B.2 Proposed New UVa HEP Group Personnel

The experimental HEP group proposes to add in the next year more students, two more research associates, a programmer who will manage the computing facility at UVa and a junior technician. The increase in the numbers of students reflects the growing interest in HEP which is taking place at UVa and is filtering down to the student level, as demonstrated by better and better student applications. The request for additional research associates reflects the urgent need to bring personnel of such a level into E771. During the past year, it was quite obvious that experienced individuals were needed in residence at Fermilab. During the period August, 1989 to August, 1990, this need was partially filled by UVa faculty who were excused from their teaching. This period of grace is over and now research associates are needed to fill the void.

Finally, there is a growing need in the HEP group for a technical infrastructure as the group turns to its more complex technical responsibilities. This infrastructure is required to aid the experimental group in preparations for their experiments and to help with the HEP computing facility in the analysis of the data. The UVa experimental HEP group proposes to add a computer programmer and a mechanical technician to help with the UVa construction and data acquisition projects at Fermilab and at UVa. The computer programmer would also enhance the data analysis capabilities of the UVa experimental group by taking responsibility for the UVa computing facilities and the organization of the massive flow of data through that system. This individual would also aid the theoretical group in mounting their lattice gauge efforts.

In the next year, the theoretical group would like to add a second research associate, preferably one with an interest in the area of weak decays to add to the efforts of both the UVa experimental group and the lattice gauge efforts.

Finally, plans are being developed that may, in the near future, allow for the addition of faculty at the University. The advent of the SSC program has generated opportunities for faculty positions at UVa. The possibility of two experimental HEP joint appointments between Oak Ridge National Laboratory and the University of Virginia has been seriously discussed. In addition, the possibility of another senior theoretical HEP faculty member for the CC/INPP is still under discussion and may become a reality in the near future.

C. Status of the UVa HEP Group Facilities

Since the submission of the last contract renewal request in August of 1989, the UVa group has made great strides in the development of their facilities and capabilities for building hardware and doing analysis at the University. These accomplishments are described below.

C.1 UVa High Energy Physics Building Renovation

At the time of the formation of the UVa experimental HEP group, the University of Virginia designated an existing building containing 7500 sq. ft of office and laboratory space for the housing of HEP group. Significant progress was made in the renovation of this building in the first year (October, 1988 to August, 1989) to make it suitable for occupation by the UVa HEP group. This work which was designated as Phase I and II of the project included a complete rework of the roof and the 70% of the interior of the existing building. A computer room was prepared to house the dedicated VAX cluster. This required increasing the HVAC capability of the building to handle the extra heat load. A Mechanical Shop area was completed and the various other office and lab spaces were renovated. This included an electronics laboratory that will be used for electronics design and development work by the HEP group. Renovation funds of the order of \$190 K were spent in the 1988-89 refurbishing of this building from various sources including the Office of the Associate Provost for Research at the University of Virginia, the Department of Physics and the Commonwealth Center/Institute.

In the past year (August, 1989 to August, 1990), Phase III of the renovation project has been completed at a cost of \$150 K provided by the Provost of the University. Phase III included the preparation of a 2500 sq ft Assembly/Detector Test area and the construction of a clean room.

In addition, the plans for a Phase IV were completed in the last year and additional funding (\$330K) has been allocated by the Provost to complete this work. This phase includes the addition of clean power in several areas for the electronics facility planned for the HEP building and the addition of a considerable amount of laboratory and office space, bringing the available work and office area of the HEP Building to 10,000 sq ft. The present schedule indicates completion of this work by the early summer of 1991, in time for the return of UVa personnel from Fermilab following the completion of the second half of the 1990-91 fixed target run. The plan view of the UVa HEP Building, including the features planned for Phase IV, are shown in Fig. 1.

C.2 Status of UVA HEP Dedicated Computing System

In the first year of its existence, the UVA HEP group, using state and private funding, procured the equipment to implement a 60 MIPS cluster of VAX 3600, 3100 and 3200 series machines.

The equipment that has been procured, installed and operated for E705 and now E771 analysis consists of a VAX 3600 with 2.4 gigabytes of disk capacity, and 32 Mbytes of memory serving a cluster of workstations consisting of three VAX Station 3100's, three DEC

Station 3100's and a VAX Station 3200. The system also includes two 6250 BPI magnetic tapes, five Summus Exabyte 8 mm tape and an ethernet link, plus modems for telephone links and servers for the various terminals distributed in the HEP building. A dedicated 19.4 Kbaud line connects this cluster to Fermilab. The DEC 3200 handles a test Data Acquisition station which will serve the Assembly/Detector Testing and electronics areas. Each work station has 300 Mbytes of disk and an Exabyte tapes. Our future plans are to add more memory and disk capacity to each workstation to enhance their ability to crunch data. In concert with the theoretica group we are also examining the possibility of a large multiprocessor device such as the Silicon Graphics. Finally, the auxiliary computing and terminal equipment accumulated thus far by the experimental group includes six MacIntosh PC's (MACII, SE's and SE30's) as well as several graphics terminals. CAD/CAM software has been procured for the MAC to provide the initial board layout capability for electronics design. Software licensing to be responsive to and coordinate with the Fermilab choices of graphics will be a priority (and an expense) this year as we bring the UVa system into full operation on the E705 and F771 analyses and on various Monte Carlo projects.

The use of this system for the analysis of E705 data is well under way and in the past year the system has been used extensively for this purpose. Indeed, the remainder of the Pass II direct photon analysis will be done on the UVa cluster and will be a major number crunching effort until the end of 1990. The analysis of E771 is underway with the beginning of the processing of the 100 Exabyte tapes taken in August, 1990 during the last month of the E771 test run.

In addition, according to our plans, components of this system were transported to Fermilab and used in the just completed test run of E771. During the past year, one of the UVA VAX3100 work station and one of the DEC3100's, along with various terminals were used in the E771 cluster at Fermilab. The original choice of a distributed network of VAX stations was made to allow this flexibility and maximum use was made of it during the last year.

In the coming year the UVA HEP experimental and theoretical groups seek to enhance the computing power of the cluster by the addition of very powerful workstation such as a Silicon Graphics machine. In addition, the UVA HEP group plans to extend the local area ethernet of the HEP building to the J.W Beams Laboratory Building to allow the addition of the UVA High Energy Theory group IBM320 work stations to the HEP cluster, making these workstations accessible to the entire group.

C.3 UVa HEP Electronics Facilities

One of the oft stated objectives of the UVa HEP group is to develop a capability for electronics design and construction. Indeed, the selection of faculty and personnel to date has been made with an eye to selection of individuals with the ability and inclination to develop this capability. In the process of building up the HEP group, we have also begun the procurement of the equipment and the preparation of the laboratory space that will give us these capabilities.

As mentioned above, the integration of clean power into the electrical distribution of the HEP building has been an integral part of the plan of development of the building. In

addition, cable conduits have been built into the HEP building to allow operation of electronic test stands connected to the VAX 3200 (and hence to the VAX cluster). Finally, the appropriate AC power has been introduced at several points to allow CAMAC and FASTBUS crate operation in the various work areas.

A modest amount of test electronics has been procured (mostly with university and state funding) to begin detector testing and electronic development. Among the items that have been obtained are a variety of fast electronics (discriminators, adc's, tdc's, QVT, digital and analog scopes, and CAMAC hardware). Some of this equipment has already been employed very fruitfully in E771 at Fermilab. It represents the very modest beginning of the outfitting of a complete electronics laboratory.

The most important step taken in the last year is the identification of an physicist with the right talents to take charge of this electronics effort. Matteo Recagni (see Appendix I.A) has joined the UVa group and will have as one of his main tasks, following the completion of the silicon electronics and pad chamber electronics projects at Fermilab, the management of this electronics effort. While his academic training is as a PhD high energy physicist, his inclinations are toward design of fast electronics. His performance as an important part of the Fermilab silicon electronics development project at Fermilab was the pivotal factor in the choice of Recagni to fill this important role in the infrastructure that we seek to build at UVa. While a Northwestern research associate, he became the essential man from the E771 experiment in the development of this system and his help was again and again solicited by Fermilab to tackle tough aspects of this effort. When his term at Northwestern was completed, both the opportunity and the necessity of preserving his efforts for the experiment led to his joining UVa.

The major objective of the coming year is the continued outfitting of the electronics laboratory and the expansion of the lab space devoted to this effort as we proceed to fulfill our commitments to E771.

University of Virginia High Energy Physics Laboratory

Upper Level

Lower Level

Fig. 1

D. UVA HEP Experimental Group Research Activities

As stated in the introduction, a major objective of the UVA experimental group in the coming year is the completion and preparation of publications for Experiment E705. A second major project is the examination of the E771 test data taken in the April, 1990 to August, 1990 test run just completed and participating in the second half of the Fermilab 1990-91 fixed target run. The longer term objective is the continuing development of the ideas and the design of the Super Fixed Target Beauty Facility for the SSC. The major activity in this area not directly related to E771 (which is very similar in geometry and technology to the SFT and forms the test bed for many of the ideas inherent to the SFT) will be the continuing development with the SSC accelerator group of the crystal channeling extraction system.

D.1 Objectives and Status of Fermilab Exp E705:

A Study of Charmonium and Direct Photon Production

The primary physics goal of E-705 is to determine the mechanisms responsible for the production of bound pairs of heavy quarks in hadron collisions. E705 has taken data on the production of the $^3P_J(\chi)$ states of the charmonium system in 300 GeV/c $\pi^\pm\text{Li}$ and $p^\pm\text{Li}$ interactions where the P states are detected by their decays into $\Psi\gamma$. This experiment is attempting to resolve the individual χ states. For each resolved χ state, the total forward production cross section, and the differential cross sections as functions of Feynman x , p_T , and center of mass decay angle of the χ can be measured. Given these distributions, the production mechanisms for charmonium production can be determined. Using the knowledge of the production mechanisms, gluon structure functions of the hadrons can then be extracted in an unbiased, independent way.

A second major physics objective of E-705 is the study of high transverse momentum direct photons. Since the cross sections for direct photon production have been calculated in QCD through second order, direct photons are one of the best places to determine the gluon structure functions of hadrons. Therefore, the two objectives of E705 complement each other in this respect; both should allow different but complementary determinations of the gluon structure functions of protons and pions in the same experimental setup.

D.1.1 Status of the E705 Charmonium Analysis

During the last year, the major data reduction of the E705 data was accomplished. At this point last year, the E705 effort awaited the scheduling of large amounts of time on the full sized Fermilab ACP system to complete the Pass I processing of 200,000,000 direct photon, dimuon and diphoton triggers from over 6300 data tapes written in the 1987-88 Fermilab fixed target run. This processing was finally completed when substantial ACP time was allocated to E705 in the December, 1989 - March, 1990 period. Approximately 2000 Pass I output tapes for the dimuon and direct photon trigger samples were produced in this pass. During that same period approximately 20% of the E705 direct photon data was processed through a Pass II to provide a moderately high statistics sample of high p_T photons

to examine for further development of the code. In addition, after examination of the Pass I dimuon output, a second pass through the one thousand Pass I dimuon output tapes was begun in May and was completed in July. At the present time, we are planning to complete direct photon Pass II this fall at UVa.

In addition to Pass I and Pass II processing, 1200 tapes of electron calibration and special condition running were processed. Among the things extracted from these tapes in the last year, were detailed calibration constants for the 8 months of of the 1987-88 run produced from five separate electron calibrations (done at 6,10, and 30 GeV/c). This massive effort was completed in August, 1990.

The final large run of data done during the past year was a set of five "100 raw data tape" runs in which all tracks were reconstructed (in distinction to normal dimuon trigger processing in which only muon candidate tracks are reconstructed). The purpose of these runs was several fold. First, electron samples can be extracted from the fully reconstructed events to give a separate, independent check on the performance of the E705 electromagnetic detector. Second, efficiencies of the individual detector elements can be studied systematically both for charged track and photon reconstruction. Finally, hadron backgrounds in the electromagnetic detector can be studied with high statistics. These runs have been completed and we are in the process of obtaining final efficiencies and determining backgrounds as a prerequisite to obtaining final cross sections.

Over 30,000 J/Ψ s have been extracted to date from the Pass II program. Fig. 2 shows the composite dimuon mass spectrum achieved to date. As can be seen, there is a very clean J/Ψ and Ψ' signal with a mass resolution of 60 MeV/c².

Figure 2

We have extracted J/Ψ and Ψ' from each of the data samples taken with the different beams as shown in Fig. 3.a,b,c,d.

Figure 3

From 10% of the data on J/Ψ and Ψ' production, a few preliminary results have been extracted. The preliminary cross sections for $\pi^\pm$ and $p^\pm$ Li $\rightarrow J/\Psi$ at 300 GeV/c extracted from this data are given in Table I along with the ratio of $B \cdot \sigma_{\Psi'}/B \cdot \sigma_{\Psi}$.

Table I

Beam	$B \cdot \sigma_{\Psi}$ (nb/nucleon)	$B \cdot \sigma_{\Psi'}/B \cdot \sigma_{\Psi}$
π^+	51 ± 11	0.025 ± 0.013
π^-	46 ± 10	0.045 ± 0.011
$\underline{p}$	40 ± 8	0.01 ± 0.01
$\overline{p}$	35 ± 19	--

Scaling these cross section using the Lyons energy scaling law for J/Ψ production and an A dependence of $A^{0.93}$, we can compare the cross sections for J/Ψ production to other measurements (including our 125 GeV/c, E537 results) at other energies for the four beam types. We show the results in Fig. 4 below.

Figure 4

In Fig. 5 we compare the ratios of Ψ' to Ψ with the results of previous experiments.

Figure 5

The differential cross sections $d\sigma/dp_T$ and $d\sigma/dx_F$ for J/ψ production for the $\pi^\pm$ and proton beams have been extracted from this 10% sample of the data. The comparison of our data to the data of NA3 is shown in Fig. 6 and 7 for these differential spectra. At the present time we plan to complete the analysis of the J/ψ and ψ' production and to publish the results in the near future. This will most likely be the first publication of E705 physics results.

Figure 6

a) $\pi^+ + N \rightarrow J/\psi + X$
 $\downarrow$
 $\mu^+\mu^-$

b) $\pi^- + N \rightarrow J/\psi + X$
 $\downarrow$
 $\mu^+\mu^-$

c) $p + N \rightarrow J/\psi + X$
 $\downarrow$
 $\mu^+\mu^-$

Figure 7

The process of extracting the best charmonium signals from this J/ψ data sample is still underway, with improvements to our calibrations constants and correction to the data obtained from this past summer's work still being folded into the analysis of the entire J/ψ data sample. However, at this point, chi signal are seen in the E705 data in the $\psi\gamma$ mass spectrum extracted from a portion of our data (as shown in figure 8 for the $\pi^\pm$ beam data. The solid line is our simulation of the background using photons from one event with J/ψ 's from another event. We are in the process of final adjustments to the photon reconstruction code to produce the optimum resolutions and are beginning the detailed studies of the photon pattern recognition process and reconstruction efficiencies which must be obtained to produce the charmonium hadroproduction cross sections. As soon as these are completed, the entire J/ψ data sample will be analyzed with the final code to extract the charmonium production cross sections for the various beam types and insure the apparent structure that is visible in Figure 8 persists with higher statistics.

Figure 8

D.1.2 Status of the E705 Direct Photon Analysis

In parallel with the analysis of the dimuon triggers, we have proceeded to analyze the high p_t photon triggers to extract the high p_t π^0, η and direct photon cross sections. We show in Fig. 9 the high p_t $\gamma\gamma$ mass spectrum for pairs with $p_t > 3.5$ GeV/c from 300 GeV/c $\pi^\pm$ $\bar{L}$ interactions from a small amount of our positive and negative beam data.

Figure 9

The π^0 and η can be observed. From this amount of data, we determine that the average ratio of η to π^0 production at $p_t > 3.5$ GeV/c in 300 GeV/c p and $\pi^\pm$ interactions with $\bar{L}$ is

$$\eta/\pi^0 = 0.47 \pm 0.08$$

We have also extracted the differential cross sections $(1/p_t) d\sigma/dp_t$ and $d\sigma/dx_f$ for pizero production from our $\pi^\pm$ and proton data. In Fig. 10 we also show the differential cross sections for $\pi^-N \rightarrow \pi^0 + x$ compared to a parameterization of the WA70 data for the same reaction.

Figure 10

These data shown in Fig. 10 represent 25% of that accumulated in the E705 experiment. Empirical fits to the x_F spectrum extracted from the data yield the parametrization of our data

$$E d^3\sigma/dp^3 = (1-x_F)^{3.8} p_t \bar{A}^{9.6}$$

Production of π^0 's by the proton and π^+ beams has also been studied in 25% of our data. In Fig. 11 we show our preliminary π^0 high p_t cross sections for these data and compare them with a parameterization of the NA3 and WA70 experiments extrapolated to high p_t . As we can see the parameterization of π^0 production as observed by NA3 agrees quite well with our data while the WA70 data remains a bit low in absolute value and is slightly different in shape.

Figure 11

Finally, we have begun the extraction of the direct photon signals from approximately 25% of our high p_T photon triggers that have been processed thus far through Pass 2. Figure 12 shows, for the π^-N data, the differential cross section and the ratio of direct photon to pizero production versus p_T . The Duke - Owens Structure function Set 1 seems at this preliminary stage of analysis to be favored over the harder gluon structure function represented by Duke - Owens Set II.

Figure 12

The plan for the fall is to process the remainder of the high p_T photon and pizero/eta production data through Pass II at UVa and to complete the determination of the efficiencies and backgrounds necessary for the extraction of the final high p_T photon cross sections. In parallel with this effort, the various papers describing this data will be prepared starting with the description of the pizero and eta measurements for the four beam types, followed by papers describing the measurements and comparisons of the direct photon cross section for the various beam types.

D.2 Objectives and Status of Fermilab Exp E771: The Production and Decay of B Hadrons Into Muons

E771 is a Fermilab experiment to detect and measure the production and decay of B's via the $J/\psi \rightarrow \mu\mu$ and $B \rightarrow \text{semimuonic}$ decays. The B's are produced using the extracted proton beam from the Fermilab accelerator (800 GeV/c). The number of B decays which can be produced is large compared to the number of B decays produced to date in e^+e^- experiments. Our eventual goal in E771 is to achieve $> 5 \times 10^6$ seconds of operation at $> 10^7$ interactions per second resulting in an approximately 10^{14} total interactions and approximately 10^8 $B\bar{B}$ pairs produced in the experiment. The expectations of such a run (which are justified in some detail in Appendix IV) are that approximately 5000 $B \rightarrow J/\psi$ decays and 1,000,000 $B \rightarrow \mu + x$ events will survive the trigger and offline analysis and are candidates for complete reconstruction. The UVA group is, at present, providing the leadership of this experiment and is involved in all of its aspects.

D.2.1 Objectives of the E771 Test Run (Dec., 90 - May, 91)

Starting in April, 1990 of the past year, we began work on E771, running until August 27th. The achievements of that run are given in Section D.2.2 below. In the second half of the 1990-91 Fermilab fixed target run (scheduled at this point to resume at the end of December barring Gramm-Rudman sequestration problems), we plan to continue the setup of the experiment with the objective of taking some serious data in the latter part of the spring with a partially instrumented silicon detector and a working trigger and pad chamber system. This will allow us to trigger on and reconstruct muon events with good efficiency. Depending on the total amount of silicon data installed at that time, we will attempt the reconstruction of secondary vertices. The UVA group has several major responsibilities for the second half of the 1990-91 run which are detailed below.

At present, we are aiming to have 5-7 planes (of the 24 planes forming the full silicon system) instrumented shortly after the start of the upcoming run, with additional planes instrumented as the silicon electronics becomes available. The UVA group (A. McManus) will play the lead role in the task force set up to accomplish this.

Another major project to be accomplished before significant data taking can take place is the completion of the pad chambers and their attendant electronics. At present, the UVA group will take on a portion of this work, asking for funding to complete the amplifier cards as described in Section D.2.3.a. K. Nelson (UVA) will manage this enterprise, setting up to produce 8600 channels of amplifiers for the Northwestern/Fermilab pad chambers using the Berkeley design and the ASIC chips presently being fabricated by Tektronix.

The continuing work on the muon trigger is a critical item. We hope to have the IA and IB triggers fully implemented by the end of the 1990-91 fixed target run and, significant tests made on the second level trigger. The prerequisite for these activities is the installation of the readout system for the pad chambers. This will be the second objective of the McManus task force. S. Conetti (UVA) will coordinate with the Penn group and the Lecce/Pavia groups the continuing construction of the various components of this trigger. M. Recagni will supply part of the engineering required for the trigger and the readout system.

Finally, the restoration and the upgrade of the E771 EM detector are the responsibility of C. Dukes (UVa). Work was begun on this device as reported below but more work is required during the fall. The expectation is that the restoration work will be finished before the first run of E771 resumes. The upgrade work will continue with the goal of being ready for the second run of E771 in 1992-93.

D.2.2 Achievements of the E771 Test Run (April, 90 - August, 90)

The accomplishments of the test run just concluded in August, 1990 were very significant. A large amount of work was done restoring the previously existing pieces of the E705 to working condition and taking test data with the spectrometer. We detail below the milestones that were passed.

The new 800 GeV/c low intensity extracted proton beam was commissioned. We operated this beam in several modes and at several different intensities. The muon and hadron halos of the proton beam were minimal and the cleanliness of the beam was very good. Our expectations for the quality of the beam were met.

The revivification of most of the old equipment from the E705 spectrometer was completed. This includes the CPX,Y counter hodoscopes, the beam counters, the veto counters, the PWC and drift chambers and the muon counters plus their associated electronics (in total several hundred counters and nearly ten thousand chamber wires). Due to the efforts of the E771 university groups this equipment has been restored to its best condition ever.

Another major accomplishment was the installation and operation of a new Data Acquisition system and the conversion of the real time experiment monitoring to VAXONLINE. While additional channels must be added to the DA, all equipment necessary for this task is in hand and the proof of functioning of the system has been accomplished in the first half of the run. It is expected that the DA will be completed before the run resumes in January.

Several very significant milestones were passed in the development of the silicon readout system. The basic "one of a kind" test of the silicon readout system was completed during the summer by the 14th floor electrical engineering group responsible for the project in concert with members of the E771 experiment. In addition to this system test, installation and readout of a portion (a few hundred channels) of four planes of silicon detector was accomplished by the E771 experimenters. These tests proved the proper functioning of the most delicate parts of the silicon readout system (the amplifier and postamp/comparators) and have allowed us to observe tracks and determine efficiencies of the silicon planes. As stated above, the goal for the next run is to get as many silicon channels instrumented as allowed by the Fermilab electronics production schedule.

While the silicon electronics work buttressed our confidence that the silicon and pad chamber readout would function properly, another critical step was taken with the installation and testing of the first pad chamber (CC1) in the experiment. Signals from this chamber were observed and the chamber was quiet and well behaved in our beam tests. Work will proceed on these chambers during the fall with the priority set on having the

first four of these chambers in place in the experiment some time shortly after the first of the year. The objective for the second half of the run is the completion and installation of all of these chambers.

The installation and observation of signals from all three planes of the RPC muon chambers were accomplished by the Lecce and Pavia groups during this test run. The instrumentation of one quadrant of each chamber was completed. Signals were observed and rates were measured from triple coincidences of the appropriate pads in the three planes. While work remains to be done on these chambers to make their operation smooth, a major portion of the installation is complete. The objective is to have all channels instrumented before the beginning of the year and to have the 1A muon trigger implemented and ready for use.

The preparation and testing of the scintillator version of the 1A trigger was accomplished. This was completed and the measured rates were quite reassuring (the 2 quadrant dimuon trigger rate was less than 1×10^{-3} of the interactions, in line with expectations).

The E771 electromagnetic detector was recabled and voltages reset. Studies were begun and online software preparation started. The LGC/GTH active converter was turned on again and a newer, faster readout system based on the LeCroy 1885 ADC's was installed and read out with FASTBUS smart crate controllers.

The preparation and testing of a portion of the 1B p_t trigger was accomplished. The Penn group prepared mini-CC chambers, installed them and measured trigger rates and p_t trigger resolution. The objective is to complete the coverage of the solid angle by the 1B trigger during the spring run.

Beam region chambers, PCB1,3,4 were installed and partially instrumented for test run. The amplifier electronics were sufficient to allow operation of the chambers at minimum high voltage close to the noise threshold of 18K electrons, thereby minimizing stress on these chambers which cover the highest rate region of the spectrometer. With 3 PCB's and 4 silicon planes instrumented in the beam region we were able to take data at several silicon thresholds and the efficiencies of the chambers and the silicon planes can be determined from this data at a variety of running conditions.

Finally, we wrote over a hundred exabyte tapes containing $1-2 \times 10^7$ dimuon quadrant triggers as well as a multitude of test runs. A good J/ψ signal should be seen in this data.

D.2.3 UVA E771 Hardware Responsibilities

The UVA HEP group has had from the beginning hardware responsibilities in the area of the second level trigger and the upgrade of the electromagnetic detector. Those projects are proceeding as reported below at a reasonable pace. In addition, in the first test run of the E771 experiment, the group had to take additional responsibilities for several items including providing technician, engineering and physicist help to Fermilab in several areas of the silicon electronics project.

We now find that we must undertake other tasks. The failure of the NSF to provide Berkeley with funding for the completion of the amplifier boards means that we must help on that project. In addition, we must help on the first level trigger project

D.2.3.a Pad Chamber Readout Project

One of the UVA physicists, K. Nelson, had already been very much involved in the on-going design of the amplifier boards for the pad chambers. In the next few months using the Berkeley board design and the ASIC chips already in the process of fabrication he will undertake the production of an adequate number of boards to instrument the pad PWC's. (8700 channels - see section D.2.3.b below). At the present time, 58K has been expended on this project to fabricate the ASIC chips. In addition, funds will be needed to finish the readout channels for these amplifier cards. The UVA contribution to the board fabrications, discrete components and the board stuffing for the pad chamber readout is estimated to cost approximately \$55K in preparation for the upcoming spring, 1991 E771 run.

D.2.3.b Second Level Muon Trigger Upgrade

The four sets of new PWC pad chambers in the rear of the E771 spectrometer magnet together with the three layers of muon RPC chambers provide the input for the E771 trigger scheme. The pad structure is projective in the non bend (vertical) dimension from chamber plane to chamber plane. Each of the chamber stations which are projective in the y (non bend plane) direction contain two sets of x anode wire (8 mm wire spacing) planes and two sets of y strips (4 and 8 mm widths) in addition to two planes of pads. The two sets will be or'ed together to increase the efficiency of detection of the track in a given chamber station. There will be approximately 2048 wires, 1408 strips and 5280 pads instrumented in the first run. Due to financial constraints, only the pads from two planes of the pad chamber system will be instrumented for this run.

These chambers will feed a three level muon trigger processor. The UVA group will be involved in all stages of this project. The first level muon trigger provided by Penn will be fed directly from the PWC pad discriminators and will form, using Programmable Array Logic technology, the set of coincidences of the form

$$C_k = \sum_j (\text{Pad Chamber 1})_j * (\text{Pad Chamber 4})_k * \sum_j (\text{Muon Chamber Pads})_j * \sum_i \text{CH}_i$$

A signal from a particular pad in chamber 4 is required to be in coincidence with a signal the pads in a region of pad chamber 1, a set of scintillation hodoscope elements ($\sum \text{CH}_i$) and a signal from one of the pads in a specific region of the muon chambers in the steel. A set of approximately 5×10^4 coincidences is adequate to detect all muons passing through the spectrometer with a P_t greater than the chosen threshold. We are designing the pad configuration of the system for a minimum p_t of 0.8 GeV/c and a resolution of approximately 80 MeV/c averaged over all trajectories. The UVA group will require \$60K for this effort.

The second level of trigger for the E771 spectrometer which will be provided by UVA and Pavia in collaboration with Pisa will use the wires and pads and do true track finding, determining momentum and angles of the tracks produced in the event. This level of the muon trigger will be implemented by using associative memories which will be programmed

with all the possible track trajectories with a p_t of at least 0.4 GeV/c and within the acceptance of the spectrometer. The number of trajectories is finite and well within the capabilities of the technology. According to our Monte Carlo studies, we expect that the number of coincidences required for a track definition with a p_t cut of approximately 0.4 - 0.5 GeV/c is of the order of 100,000. With the second level of the trigger, not only will the muons be found but all tracks in the event will be available at the second level. This will allow the imposition of an additional trigger cut, the requirement of several intermediate p_t tracks in the event. The speed of this level of the trigger is dictated by the amount of time it takes to load the data (hits) from each chamber into the associative memories and will be less than a few microseconds. The UVA group will develop the electronics for this level of the trigger.

The design for the second level trigger is centered around the concept of "content addressable" or "associative" memories. The working principle of such devices is the reciprocal of regular memories: rather than providing the contents of a memory location, when presented with its address, the associative memory, when presented with a datum as an input, will provide the address, if any, at which the datum is stored. Associative memory arrays, which now can be produced at moderate cost using ASIC (Application Specific Large Scale Integrated Circuits) technology, lend themselves ideally to fast pattern recognition. In particular, for the purpose of track finding in a system of wire (or pad) chambers, a memory array, pre-loaded with all and only the hit combinations corresponding to acceptable tracks (a very small subset of all the possible combinations of the chamber elements) can be quickly interrogated to provide the list of the good tracks derivable from the set of chamber hits in each particular event. In its first application for a particle physics experiment, associative memory chips containing 8 64-bit "patterns" per chip were developed, for the Fenice experiment at Frascati. A higher density chip, expected to contain up to 100 patterns/chip, for a projected price of around \$0.50/pattern, is feasible for an estimated cost of about \$50K for the chips for the second level.

At the present time this chip development and prototyping is going smoothly and we do not foresee a significant request this year for further funding for this project.

D.2.3.c Electromagnetic Detector Upgrade

The second UVA project is the upgrade of the central region of the electromagnetic detector to accommodate the higher energy and accompanying higher density of photon showers expected in 800 GeV/c interactions. The upgrade involves the replacement of approximately the central $1.0 \times 1.0 \text{ m}^2$ of the 6 m^2 electromagnetic detector around the beam hole with a denser detector of the spaghetti calorimeter design. This new section would consist of a lead-scintillating fiber matrix (where the scintillating fibers would be embedded in the lead). The fibers will be oriented in the beam direction. The segmentation of this detector would be determined by the size of a module, approximately 3.25 cm^2 (as compared to the 7.5 cm^2 glass counters that are being replaced). Showers would have a Moliere radius of approximately 8 mm in comparison to the few cm radius typical of the glass, thereby greatly reducing the overlap problem at the higher energies of E771.

The number of modules of this size required for this spaghetti calorimeter is approximately 900. The readout will be accomplished with 1.125 inch diameter

phototubes. The total cost of the electromagnetic detector upgrade will be approximately \$202 K. We will not seek additional funding for this project until the ongoing prototyping and testing is completed.

D.2.4 UVA Software Responsibilities

The UVA group will take responsibility for several areas of the software. The tracking program will be developed by B. Cox, M. Arnton and UVA students and visiting scientists. C. Dukes and UVA students will participate in the updates of the code for the EM detector to take into account the upgrades of that device. S. Conetti will coordinate the development of the trigger and detector simulations.

D.3. SSC 20 TeV Beauty Physics Facility (SFT)

The debate about the future best way to do B physics is well documented in a number of workshops and proceedings. See for example the various Snowmass proceedings, the proceedings of the Stanford B Meson Factory Workshop, the Stanford International Heavy Flavors Symposium, the Erice meetings of 1987 and 1988 which are cited in the references. The members of the UVA group have participated in and led many of these studies. The result of these deliberations and studies has been the decision by the UVA group to pursue the design of a system for non-destructively extracting 20 TeV beams from the SSC using crystal channeling. The non destructive "peeling" of a low intensity beam would allow simultaneous operation with the collider experiments. The 100% duty factor 20 TeV proton beam would be ideal for a fixed target B experiment in which the cross section is 2-10 microbarns and the decay lengths of the B mesons are fractions of a meter, making possible the direct observation of the B itself. This technique holds promise as the easiest, cleanest and most economical way to achieve the large numbers of reconstructed B's necessary for serious studies of CP violation.

In the past year, those of us at UVA have held a set of meetings of interested parties. A major workshop was held in November, 1989 to discuss the fixed target option. Several other smaller meetings were held subsequently, which resulted in the submission on May 25 of this year of a Expression of Interest for a 20 TeV Super Fixed Target Beauty Facility at the SSC (see Appendix V). Thirty six institutions were signatories to this EOI (#14). The EOI was presented at the June 7,8 meeting of the SSC PAC in Dallas and was carefully reviewed by an SSC Laboratory assigned "reading group". The reception by the PAC and the reading group was very positive and resulted in the general recommendations of the SSC program committee and the subsequent letter from Roy Schwitters (see Appendix III) following the July, 1990 Snowmass meeting.

In the next year, we will continue to develop the SFT proposal. The highest priority will be to consolidate the ideas for the extraction system and perhaps to engage in a test at Fermilab to provide more information if necessary. A second area of activity will be to simply proceed with E771 which has many of the attributes of the SFT spectrometer. A third area of activity will be to begin the R&D for such long lead time items as the RICH counter (which has been proposed as an addition to the E771 detector in any case) and the development of silicon detectors of appropriate cost and performance.

E. UVA HEP Theoretical Group Research Activities

E.1 Current and Proposed Research - P.M. Fishbane

E.1.1 Proposed Research (Feb.1991 - Feb.1992)

E.1.1.1 Family symmetry and the fermion mass matrix (collaborators: P.Q. Hung, University of Virginia; P. Kaus, University of California, Riverside; S. Gasiorowicz, University of Minnesota).

One of the most important unanswered questions in the Standard Model concerns the origin of Fermion masses in a three family structure. There are thus far only a few realistic dynamical models which account at some level for additional features of electroweak interactions, including the mixing matrix describing the interaction structure and, possible, the nature of CP violation. I will discuss here two different approaches to these questions.

E.1.1.1.A. Broken Chiral Symmetry and the Higgs Mechanism

A certain class of mass matrices¹ in which the strength of the entries occurs in powers of a parameter λ gives a phenomenologically acceptable description of physical fermion masses and observed mixing phenomena. P.Q. Hung and I have developed a class of dynamical models which lead to quark² and lepton³ mass matrices of this type. In these models, family symmetry is associated with a chiral gauge symmetric, and is broken by the Higgs mechanism. The horizontal gauge group is left-right symmetric, $G_H = SU(2)_{HL} \times SU(2)_{HL}$, and the electroweak gauge group G_W is preferentially $SU(2)_L \times SU(2)_R \times A(1)_Y$. The preference for G_W is based both on phenomenology and on the possibilities for the construction of the Higgs sector of these models.

The chiral nature of the family group leads to a hierarchical family mass structure based on the perturbation around some tree-level driving terms for those masses. By choosing a triplet structure of fermions for each $SU(2)_H$ we avoid anomalies and come naturally to the three family structure. The Higgs sector breaks down G_H through non-zero vev's in both components of the doublet Higgs fields. The latter differs from the electroweak Higgs sector because there is no exact symmetry such as charge conservation to restrict the vev of the Higgs to the electrically neutral sector. This in turn leads to mixing between G_H and the G_W gauge bosons, a crucial factor in the calculation of the mass matrix. Earlier work⁴ provides an existing framework for the construction of the necessary vacuum structure.

There is an interesting question which we want to answer concerning the two Higgs structure, which occurs not only in this model but in all models which account for the family structure through a spontaneously broken gauge symmetry. At least one family of fermions gains their masses through the usual Standard Model Higgs mechanism in this picture, and in order that the Higgs mechanism which breaks the family symmetry not give unwanted masses to the fermions, the quantum numbers of this second Higgs particle must be such that fermions do not couple to it. However, both Higgs particles contribute to the masses of gauge bosons. The multiple Higgs structure must accommodate both requirements

in a gauge invariant way when the fermions interact with the gauge bosons and with the Goldstone bosons which the broken symmetry leads to. Hung and I have seen how this occurs and are presently in the process of preparing a paper on the subject.

The second problem which deserves attention is more numerical. Even without invoking the gauge structure of the theory in a fundamental way, the model in which broken chiral symmetry leads to a mass matrix provides an effective Lagrangian for the calculation of the mass matrix and low energy family-mixing processes. This approach avoids the Higgs structure of the theory entirely and provides a set of numerical tests which can at least be carried out through the Monte Carlo calculations of up to two loop graphs. These calculations will allow us to see if realistic mass matrices can be reproduced in this picture. Earlier, we had seen that our broken chiral symmetry picture is consistent with the data on masses¹⁻³. Now we want to carry through numerical fits, as opposed to merely order of magnitude calculations, for the mass matrix itself for a range of couplings and masses. In addition, we want to go further on family mixing processes. We had earlier shown that the decay $\mu \rightarrow e \chi$ puts a strong constraint on couplings as well as on the masses of both the horizontal gauge boson and the right-handed Z boson. We will want to demonstrate what analogous constraints the absence of flavor-changing neutral currents puts on couplings. This work, which was part of last year's proposal, is well underway.

In going beyond the effective Lagrangian approach, more work on the Higgs sector is required. This sector is sufficiently large to include phases which can lead to CP violation. In addition, when we choose the left-right symmetric version of G_W , the family hierarchy parameter sets limits in which the masses of the Higgs bosons approach the unitarity limit of a strongly coupled Higgs system⁵. Investigation of such a strongly coupled Higgs system appears worthwhile.

E.1.1.1.B. Pure Phase Mass Matrix

Branco *et al.*⁶ have proposed that a mass matrix composed of pure phases with the same strength can satisfy what is known about the physical fermion masses as well as the KM matrix. P. Kaus, S. Gasiorowicz, and I have begun to look again at this proposal, which is intriguing because it is so close to the physical situation, in which one dominant mass (top, bottom, or tau) much larger than the others in its family translates in a different basis into a mass matrix with equal entries. The pure phase matrix then becomes a new way to modify the leading order situation. The possibility that a larger Higgs strongly-coupled Higgs sector can lead to phases becomes much more interesting as a way dynamically to realize the pure phase form.

E.1.1.2. Quark degrees of freedom in threshold annihilation of nucleons (collaborator: C. Dover, Brookhaven National Laboratory).

Nucleon-antinucleon annihilation at threshold into a few mesons, which presents opportunities for testing the role of the fundamental dynamical parameters of QCD, has been of interest to us for some time⁷. Current and future data from LEAR includes invaluable restrictions on the quantum numbers of the initial state. One interesting set of processes involves strange quarks, through the presence of mesons states with (K mesons and their excitations) and without (f' or ϕ for example). Here the topology and the dynamics

associated with the quark degrees of freedom enter in new ways. Three body final states such as $K\bar{K}M$, where M is another vector or pseudoscalar meson, are a particularly interesting set of reactions, both because they make for interesting tests of dynamical models and because substantial data is or will be available.

References for proposed research:

1. P.M. Fishbane and P.Q. Hung, Phys. Rev D36, 197 (1987).
2. P.M. Fishbane and P.Q. Hung, "A Dynamical Model of Quark Masses and Mixing Angles," to be published.
3. P.M. Fishbane and P.Q. Hung, Zeit. f. Phys. C38, 649 (1988).
4. R.N. Mohapatra and G. Senjanovic, Phys. Rev. D23, 165 (1981).
5. P.Q. Hung and H.B. Thacker, Phys. Rev. D31, 2866 (1985).
6. G.C. Branco, J.I. Silva-Marcos, and M.N. Rebelo, Phys. Lett. B237, 446 (1990).
7. C.B. Dover, P.M. Fishbane, and S. Furui, Phys. Rev. Lett. 57, 1538 (1986).

E.1.2 Completed Research (August, 1989 to August, 1990)

E.1.2.1 Quark degrees of freedom in threshold annihilation of nucleons (collaborator: C. Dover, Brookhaven National Laboratory).

The threshold annihilation of nucleons into mesons is a unique laboratory for testing the role of quark degrees of freedom in low energy processes, as well as for the study of low-lying states of QCD. Recent work had raised the possibility that the quark structure of the nucleon was more complicated than previously envisioned, and particularly that there was a significant admixture of $\bar{s}s$ content¹. This admixture is then used to explain a breakdown of the OZI rule, as for example in the ratio $\sigma(N + \bar{N} \rightarrow \phi + X)$ to $\sigma(N + \bar{N} \rightarrow \omega + X)$. We have questioned this interpretation² in connection with observed enhancements of OZI rule violations as a function both of final state and initial state quantum numbers induced by $N\bar{N}$ coupling to $Q^2\bar{Q}^2$ resonances as opposed to those induced by a sizable $\bar{s}s$ component in the nucleon. We argue that four-quark intermediate state resonances containing a sizable $\bar{s}s$ admixture produce selective enhancements in particular $N\bar{N}$ annihilation channels with ϕ mesons, in agreement with the observations, whereas a simple admixture of $\bar{s}s$ in the nucleon cannot.

One problem with the interpretation of the data is that it involves quantities proportional to the square of any $\bar{s}s$ component of the nucleon. We found³ a set of first order tests of the strange quark content of the nucleon. The relative cross sections for the reaction processes $\eta p, \eta' p \rightarrow \eta p, \eta' p, K^+ \Lambda$ and $\pi^+ p \rightarrow \eta n, \eta' n$, induced by pseudoscalar mesons on a nucleon target, provide a sensitive test for the presence of an $\bar{s}s$ component in the nucleon's wave function. This follows because η and η' contain both strange and nonstrange components, and interference effects between them can be important in the reaction amplitudes.

E.1.2.2. Dynamics of confinement.

In earlier work on this subject, we have been interested in the energies, both classical⁴ and quantum mechanical⁵, of states of a "dielectric vacuum" model of QCD, in

which the QCD vacuum is a dielectric with $\epsilon = 0$, while $\epsilon = 1$ in regions where sources produce sufficiently strong fields. For example, a quark-antiquark bound state forms a classically stable bubble in the vacuum, and zero-point quantum mechanical energies (Casimir forces) appear in the cavity. We have previously calculated zero-point energies down to the Coulomb-like terms. These terms are equivalent to the Luscher terms of the hadronic string energy.

The quark-containing states are static configurations. One question of interest in this picture concerns the possibility of glueball (quark-free) states. It had been thought that a state of pure glue should have at least one topological hole in it. What was not known is whether even the simplest toroidal topology can support the dielectric vacuum boundary conditions. An attempt⁶ to investigate this question was made by Robson, but he was forced for technical reasons to replace the dielectric boundary condition with an entirely different criterion. We have re-investigated⁷ this question and have been able to show that static glueballs can be formed in the context of the dielectric vacuum model of QCD only if regions with dielectric constants of both signs are allowed. These states have zero energy. The toroidal topology is unnecessary. In a spheroidal-ellipsoidal topology, only a sphere surrounded by a spherical shell is allowed, with the relative thickness of the shell as well as the allowed values of the dielectric constant determined. The radius of the cavity in these solutions is only fixed by some new condition extrinsic to the model. One possibility is the quantization of induced charge. Even then, the fact that these are zero energy solutions means that they are by themselves of no physical interest. Since the solutions represent cavities in the QCD vacuum, zero point fluctuations of quantum fields would change the energy. We have not ruled out the possibility of other topologies, but if there are any, they will also have zero total energy as long as the region of normal vacuum is finite.

References for Work Accomplished

1. See, for example, J. Ellis et al., Phys. Lett. B 198 393 (1987), or A.E. Nelson, Phys. Lett. B 221 60 (1989).
2. P.M. Fishbane and C. Dover, Phys. Rev. Lett. 62, 2917 (1989).
3. P.M. Fishbane and C. Dover, Phys. Rev. Lett. 64, 3115 (1990).
4. P.M. Fishbane, S. Gasiorowicz, and P. Kaus, Phys. Rev. D36, 251 (1987).
5. P.M. Fishbane, S. Gasiorowicz, and P. Kaus, Phys. Rev. D37, 2623 (1988).
6. D. Robson, Zeit. f. Physik C3, 199 (1980).
7. P.M. Fishbane, S. Gasiorowicz, and P. Kaus (University of Virginia preprint).

E.2 Current and Proposed Research - P.K. Kabir

E.2.1 Proposed Research/Work in Progress

1. The improved accuracy expected from the CPLEAR experiment for the difference between η^{+-} and η^{00} , of vital interest for the origin of CP - nonconservation, will be continued at CERN. Extraction of further information on CP - nonconservation from the wealth of data expected to be accumulated, will be attempted.
2. The long-term program of studying the BCS theory of superconductivity, with a view of securing a better understanding of the Higgs mechanism, is continuing.

F.2.2 Current Research

1. The work on angular correlations in three-particle decays of quarkonium systems was finally written up and published by Dr. S. Banerjee¹. I may write a synthesized overview of two and multiparticle decays, if time permits.
2. At the UCLA workshop on "TCP etc. tests at a Phi Factory", held in April 1990, I presented² an analysis of the conclusions to be drawn from precise measurements of the phase-difference between the CP-nonconservation parameters η^{+-} and η^{00} .

References:

1. S. Banerjee, Phys. Rev. D41, xxx (1989).
2. P.K. Kabir, Proc. of UCLA Workshop on "TCP Tests at Phi Factory", to be published.

E.3 Current and Proposed Research - P.Q. Hung

P.Q. Hung's past (1989-1990) and ongoing research deals with the study of "family" gauge symmetry and a mechanism for generating quark and lepton masses, as well as the physics of super heavy fermions.

The work on "family" gauge symmetry was performed in collaboration with Paul Fishbane. It is an attempt to understand the hierarchy of quark and lepton masses by invoking a new kind of gauge symmetry which connects fermions of different "families" (at the present time, there seems to be only three families). This work is still in progress, with various aspects being written up along the way.

The work on mass generation for quarks and leptons has just been completed. In the model that Hung has proposed, there exists a fourth family of heavy quarks and leptons which serve as seeds for generating masses of the first three families. The masses of the top quark and the fourth family down quark are predicted to be correlated and may be accessible to hadron colliders.

Issues concerning possible new physics connected with these heavy fermions are explored in two papers with two different collaborators: V. Soni from the University of New Delhi; and, S. Nussinov from Tel Aviv University.

References:

1. "On Chiral Gauge Theories with Multiple Higgs Scalars" Paul Fishbane and Pham Q. Hung.
2. "From Preons to Quarks and Leptons: A Dynamical Model of Fermion Masses" P.Q. Hung.
3. "Lepto-Quark Bound States by Strong Yukawa Interactions" P.Q. Hung and V. Soni.
4. "Can Superheavy Fermions Carry the Standard Model Quantum Numbers?" P.Q. Hung and S. Nussinov.

F.3 Current and Proposed Research - H.B. Thacker

H.B. Thacker is pursuing a program of research which focuses on a number of topics in particle physics and quantum field theory. The two main subjects which have been worked on are: (1) Lattice Gauge Theory calculations of Standard Model amplitudes; and (2) Investigation of the Algebraic and Geometrical Structure of Two-Dimensional Integrable Field Theories and Lattice Statistical Mechanical Models.

He has continued to collaborate with members of the Fermilab Theory Group on the ACPMAPS project¹. This project began several years ago while he was working at Fermilab. The ACPMAPS is a large scale parallel supercomputer consisting of 256 nodes with a total peak processing power of 3 to 5 gigaflops. The machine is programmable in a high level language (C) with the parallelism handled by the CANOPY software system. Several sets of QCD lattices have been generated at values of the gauge coupling $\beta = 5.7$ and 5.9 . These data sets include the Monte Carlo generated gauge lattices as well as quark propagators. These lattices are being used to study a variety of QCD properties, including hadron masses, wave functions, and electroweak matrix elements. In collaboration with E. Eichten and G. Hockney, Thacker has been particularly concentrating on the study of B-meson physics, using the lattice to calculate the QCD matrix elements relevant to B decays². These studies exploit the technique suggested by Eichten and Feinberg for introducing heavy quarks on the lattice. The quantity Eichten, Feinberg and Thacker have studied in the most detail so far is the pseudoscalar B-meson decay constant f_B . Our preliminary value for f_B at $\beta = 5.7$ is substantially larger than naive expectations based on nonrelativistic quark model arguments. They are currently investigating this result in more detail by studying the B-meson wave function directly on the lattice³. Other calculations such as B-B^{*} mixing matrix elements and semileptonic B decay amplitudes, as well as calculation of the masses, wave functions, and matrix elements of light hadrons, are also underway.

In the area of integrable quantum field theories, Thacker is continuing his research into the intriguing relationship between integrable systems and infinite dimensional Lie algebras. These developments appear to be leading to a unification of the geometrical and algebraic structures underlying integrable quantum systems and conformal field theory. This subject is deeply related to the properties of the corner transfer matrix introduced by R.J. Baxter. He has found that, for a variety of integrable lattice models, the eigenstates of the corner transfer matrix form representations of a Virasoro algebra. This follows from the algebraic properties of the CTM and the way in which it intertwines with the quantum inverse scattering operators. Geometrically, the Virasoro algebra generates diffeomorphisms of momentum space associated with the introduction of the elliptic function (spectral) parameters. These results promise to give deeper insight into the structure of the Bethe ansatz wave functions and their role as the "spherical harmonics" of the lattice Virasoro algebra.

References:

1. M. Fischler, et al., Nucl. Phys. B (Proc. Suppl.).
2. E. Eichten, G. Hockney, and H.B. Thacker, Fermilab Preprint, FERMILAB-CONF-89/211-T (1989), (Nucl. Phys. B., to be published).
3. E. Eichten, Nucl. Phys. B (Proc. Suppl.) 4, 170 (1988).

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Director's office

July 31, 1990

Professor Brad Cox
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University of Virginia
McCormick Road
Charlottesville, VA 22901

Dear Brad:

Thank you for your response to the questions posed by the Program Advisory Committee about your Expression of Interest in an experiment at the SSC (EOI-14 - "Super Fixed Target Beauty Facility"). The PAC met for a week (July 14-20) at Snowmass and discussed all the EOIs and the associated responses.

The Committee recognized that B physics is an important and promising area of elementary particle physics research, especially in the study of CP violation and other rare phenomena which may give us an insight into physics that lies beyond the Standard Model. The PAC also felt that the SSC has some special capabilities for B physics. In its report it stated that "Given the strong interest of the physics community, it would be desirable to incorporate B physics into the initial SSC program. We note, however, that considerable evolution of the field may occur over the next few years. The cost and technical risk associated with a collider detector for B physics make it premature to encourage such a proposal at this time; it may be more appropriate a few years from now. For the initial SSC program a fixed-target experiment may prove a better choice."

With respect to your particular EOI, the Committee felt that an external target experiment had some important advantages over an internal target approach if extraction of an external beam is shown to be feasible without impairing the operation of the collider. There are serious concerns here, and the Committee recommended that tests on the viability of the proposed crystal extraction scheme deserve a high priority within this context. In particular, a test at Fermilab in a realistic environment was deemed as one appropriate course of action that would hopefully give us some hard evidence on the likelihood of the extraction technique working at the SSC.

While the number of produced B's is acknowledged to be at least competitive with the sample at other electron-positron and hadron colliders likely to be operating at the time of turn-on of the SSC, the PAC found that the reconstruction efficiency assumed in the EOI for seeing the B and the $\bar{B}$ was far beyond the state-of-the-art with a "live" target. A high efficiency will indeed be necessary to be fully competitive with proposed electron-positron projects. Consequently, the PAC will follow closely the physics results and the progress that is made in reconstruction/tagging efficiencies in on-going experiments, including your own.

The PAC recommended that we now focus on proposals for two large detectors to be ready to address the high p_T physics at turn-on. Somewhat later, we will consider other proposals, although we do intend to reserve substantial funds for pursuing these other physics objectives. In any case, there is a period of several years before such proposals would be submitted, giving us time both for some serious work on the feasibility of an extracted beam and for thinking more deeply about the wide class of physics questions that could be addressed in fixed target experiments at the SSC.

Sincerely,

Roy F. Schwitters/jr
Roy F. Schwitters

RFS/ap

cc: N. Baggett
F. Gilman

Beauty Physics in E771 Using Single and Dimuon Triggers

I. Introduction

For some time lepton triggers have been understood¹ to be a potentially important means of rejecting ordinary interactions and selecting $B\bar{B}$ events in hadronic interactions. The primary objective of Fermilab experiment E771² is the measurement of beauty production and decay as detected using the muons from $B \rightarrow J/\psi \rightarrow \mu\mu$ decays of the various species of B mesons and hadrons. A second important objective of E771 is the accumulation of additional "tagged" B events by triggering on the single muons from $B \rightarrow \mu + x$ semileptonic decays. This note describes the means by which single and dimuon triggers are implemented in E771 and the expectations for obtaining B events from both sources.

In preparing a dimuon trigger system for E771, it was found that a very fast, economical and efficient way of selecting high mass dimuons was to require two muons as defined by the E771 muon detector and to further require that at least one of the muons have a large p_T . Therefore, the E771 trigger, which is designed along these lines, contains a single muon trigger as a natural component. This single muon trigger is a part of Level I and is capable of operating at rates greater than 10^7 interactions per second. So both single and dimuon triggers are available to E771 without additional electronics, and both types of B decay modes can be used to accumulate B data.

The $B \rightarrow J/\psi \rightarrow \mu\mu$ and the $B \rightarrow \mu + x$ decay modes offer different opportunities to the experimentalist. The $B \rightarrow J/\psi \rightarrow \mu\mu$ events are relatively rare but very distinctive. The dimuons from $B \rightarrow J/\psi \rightarrow \mu\mu$ decays are one of the most striking manifestation of beauty production in hadronic interactions and serve as the most powerful method to separate the beauty events from the rest of the total cross section in the offline data analysis. The trigger strategy that E771 has adopted takes advantage of the special attributes of the $B \rightarrow J/\psi \rightarrow \mu\mu$ decays to produce a trigger with a large online rejection of backgrounds due to decays of π 's, K's and charm, yielding an extremely low ratio of triggers to interactions.

In addition, the dimuons act as a starting point for the offline analysis, reducing the amount of reconstruction that must be performed on each recorded event before full reconstruction is attempted. The E771 analysis strategy takes advantage of the special features of the $B \rightarrow J/\psi \rightarrow \mu\mu$ decays to produce a very economical offline analysis process. Finally, the $B \rightarrow J/\psi$ signature is distinctive enough to permit excellent offline rejection of backgrounds. The observation of a J/ψ from a secondary vertex unambiguously insures that an event contains a $B\bar{B}$ pair, rejecting almost all potential backgrounds. Because of the potential for achieving low backgrounds to the $B \rightarrow J/\psi \rightarrow \mu\mu$ modes, we have adopted a strategy of collecting every $B \rightarrow J/\psi \rightarrow \mu\mu$ event possible, operating with relatively loose constraints on the dimuon triggers to insure the largest possible acceptance of dimuons in the J/ψ mass region.

The $B \rightarrow \mu + x$ semimuonic decays offer different challenges and opportunities. However, two features of the $B \rightarrow \mu + x$ semileptonic decays are very different from the $B \rightarrow J/\psi$ modes and are very important. First, the charge of the muon "tags" the decaying B so that some knowledge is gained about its particle or antiparticle nature. This is potentially important for both mixing and, ultimately, for CP studies. In addition and most importantly, the $B \rightarrow \mu + x$ decays are far more copious than the $B \rightarrow J/\psi \rightarrow \mu\mu$ decays. In events containing a $B\bar{B}$ pair, semimuonic decay will produce a muon approximately 23% of the time and approximately 85% of these muons will have a $p_T > 0.8$ GeV/c. Muons with p_T this large are quite unusual. Semileptonic decays of pions, kaons and charm produce muons with this magnitude of p_T in less than 3×10^{-4} of all 800 GeV/c interactions. Therefore, high p_T muons provide a distinctive signal on which to trigger. Because of the large branching ratio and the resulting large number of $B \rightarrow \mu + x$ decays, the single muon trigger strategy produces a very large enrichment factor (ratio of $B\bar{B}$ events to other logged events) of the data written to tape.

Finally, because there are more B semimuonic decays, more losses can be tolerated in the trigger and analysis schemes. This is quite important in a new experimental situation where the cross sections, branching ratios and efficiencies of the experiment are unknown. However, the techniques for offline rejection of backgrounds to the B semimuonic decay

modes is not as simple as the rejection of backgrounds in the case of the $B \rightarrow J/\psi$ modes, since the constraint of a J/ψ from a secondary vertex is not present. The relationship of the single and dimuon triggers and the data samples obtained with each type of trigger are discussed below.

II. E771 Trigger Scheme

The E771 trigger, as presently being prepared, depends on the detection of unusual muons at Level I (presence of one or more 6 GeV/c muons in the event, at least one of which has a high p_t), unusual global event characteristics at Level II (detection of several moderate p_t hadrons in the event), and detection of secondary vertices at Level III (algorithm for calculating the probability that the event contains a secondary vertex). The scheme is flexible enough to allow a change of criteria at the various levels if experience indicates that other criteria for rejecting the decay backgrounds are more effective.

Level I is composed of two separate parts, Level IA and Level IB, which operate independently and in parallel. Level IA, developed by Lecce, Pavia and the University of Virginia requires the detection of one or more muons as defined by the triple coincidence of an aligned set of pads in the projective pad geometry of the three layers of Resistive Pad Chambers (RPC), embedded in the steel of the E771 muon detector (See Figure 1). The minimum energy required of a muon to penetrate the E771 muon detector steel and produce a signal in the RPC's is 10 GeV in the central part of the acceptance and 6 GeV at wider angles. The RPC chambers have excellent time resolution (<0.5 ns) and rate characteristics that make them adequate even in the hottest area of the E771 muon chamber at rates greater than 10^7 interactions per second.

The Level IB trigger³, developed by University of Pennsylvania in collaboration with Lecce, Pavia and UVa, requires at least one muons with a p_t above a minimum threshold. The Level IB trigger is based on the idea that the high p_t muon passes through the spectrometer magnet with only limited deflection and these trajectories can be defined for both inbending muons and outbending muons by coincidences between a limited number of pads in the two

dimensional pad structure of the new tracking chambers of the E771 spectrometer. Figure 2 shows (in plan view) some sample trajectories. The Level IB trigger for high p_t muons is formed from the OR of a large number of four fold coincidence between particular sets of pads in the CC1, CC4 pad chambers and in the RPC layer 1, and particular scintillation counters in the CPX scintillation hodoscope. While there are several million possible coincidences between these detector elements, only coincidences that can be caused by an inbending or outbending muon of p_t greater than a preselected threshold are allowed to generate a Level IB trigger. Both the Level IA and IB triggers are implemented using Programmable Logic Gate Arrays. They are both pipelined, requiring a few hundred nanoseconds to accomplish and are capable of operating at rates greater than 10^7 interactions per second. Both Level IA and Level IB are required before higher levels of trigger are interrogated.

Level II (which will not be implemented for the 1990-91 run of E771) will perform complete online tracking in a few microseconds. The implementation of this trigger will be done with associative or content addressable memories presently being developed by INFN. The application of this technology to E771 Level II will be accomplished through a joint effort of Lecce and UVa. This level of trigger will increase the rejection of the total cross section by imposing the requirement that several tracks with intermediate p_t be present in the event, thereby increasing the probability that the selected events contain high mass Σ hadrons. Several existing Monte Carlo studies assure us that large rejection factors can be achieved by this sort of criterion. In addition, this sort of online tracking can be applied to the silicon microstrip detector to detect secondary vertices. Once again, existing Monte Carlo studies assure us that large reduction factors in trigger rate can be achieved by the application of this technique to the problem of detecting secondary vertices in an event. These extra rejection factors by Level II online tracking should permit us to increase the rate capability of the E771 experiment toward our ultimate goal of logging all single and dimuon triggers at rates greater than 10^7 interactions per second.

Level III of the E771 trigger system is constructed from several VME based ACP I or II microprocessor modules. We have developed a fast filter program which uses the E771

silicon vertex detector data to search for evidence of secondary vertices. Using relatively simple coding, the filter can, in less than 30 ms, calculate the probability that an event contains a secondary vertex. This detection of a secondary vertex is completely independent of the single and dimuon requirements imposed on the events and, therefore, permits a cut completely orthogonal to the muon criteria.

The effectiveness of this secondary vertex detection algorithm has been extensively studied by a Monte Carlo containing random noise, multiple scattering, gamma conversions, delta ray production and secondary interactions. Rejection factors (shown in figure 3) can range from a few to several tens depending on the efficiency for retaining the beauty signal that is desired. At present we are opting for good efficiency (greater than 90%) and relatively modest rejection factors (approximately 3). No attempt is presently made at any trigger level to require online that the single or double muon be produced at a secondary vertex.

Events passing the software filter are logged by six Exabyte tape units coupled directly to the VME/ACP system. The slowest device in the E771 DA system is presently the 4290 CAMAC TDC's which require 400 μ seconds for digitization and readout. Setting the limit on the desirable dead time of the experiment DA to be 25%, results in a limit of 600 events per second of spill, 450 of which can be recorded. Therefore, the overall data recording capacity of the E771 system is presently sized to handle 450 events per second of spill (approximately 125 Mbytes per spill assuming 23 seconds of spill and an E771 event size of 12 Kbytes). Assuming the spill cycle to be 23 seconds of spill out of every 56 seconds of calendar time (similar to the slow spill cycle during the last Fermilab fixed target run), approximately 60% of the data accumulated during the spill will be stored and written to tape in the 33 seconds interspill interval. The remaining 40% will be written to tape during the spill. The storage capacity required of the VME/ACP system for this task is approximately 75 Mbytes and resides in the "Baumbaugh" buffers of the front end of the E771 VME/ACP system. The present plans for the E771 DA are to use Exabyte tapes for data logging. A reasonable assumption for the present generation of tape units is a writing speed of 200 Kbytes per second in the E771 environment. Since 125 Mbytes must be logged every

56 seconds and each tape unit can write 11 Mbytes per 55 seconds of operation, approximately 11 Exabyte tape units are required if no filtering is done at Level III. If the Level III filter performs as advertised, only 6 Exabyte tapes will be required to provide the necessary data logging capability .

III. Expected Performance of the E771 Trigger System

Since we will only have Levels IA, IB and III operational during the first run of E771, we will concentrate on their expected performance for single and dimuons. The vast majority of the raw muon trigger rate is due to the decays of charged pions and kaons. Only at the higher levels of the trigger, can the presence of charm decays in the data can be detected. Using measurements made during E705 and a variety of Monte Carlo's containing π, K and charm semimuonic decays, we have estimated the trigger rates at each level of the trigger. These trigger rates per interactions are shown in Table I below:

Table I Expected Trigger Rates per Interaction		
Trigger Level	DiMuon Trigger Rates	Single Muon Trigger Rates
IA	$O(10^{-3})$	4×10^{-2}
IB	2×10^{-1}	$2.5 \times 10^{-2} *$
IA*IB	$O(2 \times 10^{-4})$	10^{-3}
III	.3	.3
IA*IB*III	$O(10^{-4})$	3×10^{-4}

* Achieved by exclusion of outbenders with poor p_t resolution

At an interaction rate of 2×10^6 /second (planned operating point for the 1990-91 E771 run), we expect 400 dimuon and 1000 single muon triggers per second of spill to be present entering Level III. This dimuon trigger rate could conceivably be greater if contributions due to clutter in the RPC's from the 800-900 GeV beam dump or from the beam halos are greater than expected. The total trigger rate of 1400 per second clearly exceeds the present capabilities of the E771 (600 events per second of spill with a dead time of 25%). In fact, the dimuon trigger rate is close to the saturation of the capacity of the data acquisition system. This is not surprising since our trigger system and DA were configured for the expected dimuon rates at 2×10^6 interactions per second.

Giving priority to accepting the 400 dimuon triggers per spill second generated at 2×10^6 interactions per second, we presently anticipate the need to reduce the single muon trigger rate to 200 per second. Unless we operate at less than 2×10^6 interactions per second, we will be able to take a larger fraction of the single muon triggers only if we find ways to improve our single and dimuon triggers or increase our data logging capability. The fraction of single muon triggers that we will be able to record will obviously depend on all these factors and will be uncertain until some experimental experience is gained. However, given that we expect to be able to accept only a fraction of the single muon events at present, we plan to make that fraction of the single muon triggers as rich as possible in B events by concentrating on regions of our acceptance and types of muons where the signal to background at the trigger level is optimal.

The large single muon trigger rate will be tailored to fit into the residual data acquisition capability in the following ways:

1. By accepting only inbending single muons whose p_t is determined with better resolution than comparable outbenders
2. By limiting the acceptance of the single muon trigger to regions which are relatively rich in B events but where background muons from π and K decay

are smaller (large angle regions).

3. By prescaling the single muon rate to fit the residual data acquisition capacity.

Option 3 is a last resort if we cannot find more discriminating ways to eliminate trigger rate. While we will lose signal using options 1 and 2, our recorded triggers will be richer in B decays. Since the $B \rightarrow \mu$ decays are so copious, we will, for the present, adopt a strategy of being selective about the acceptance and type of single muon events to collect only that portion of the signal where the backgrounds are small and muon p_t resolutions are good. From our Monte Carlo's, we estimate that reducing the solid angle coverage of the single muon triggers to the most favorable 20% to 25%, the trigger rate would be reduced by a factor of 5 while the signal would be reduced by a factor of 3. We also plan to to exclude outbending muons whose p_t resolution is poor from the trigger for the time being.

Taking into account, the 25% dead time of the DA at our nominal operating point of 2×10^6 interactions per second we will, therefore, be able to process 300 dimuon triggers and 150 single muon triggers per second of spill. Assuming that the Level III filter performs as expected (suppression of the single and dimuon trigger rates by a factor of 3 with 90% efficiency for accepting $B \rightarrow J/\psi \rightarrow \mu\mu$ and $B \rightarrow \mu+x$), we will log one third of these triggers on tape, leading to a rate of 100 dimuon and 50 single muons triggers per second of spill written to tape.

IV. Estimated Acceptances/Efficiencies of Single and Dimuon Trigger and Offline Analysis

The yields of B decays depend on the geometric acceptances and on the efficiencies of the various elements of the E771 spectrometer and the way they enter into both the trigger and in the offline reconstruction sequence. In addition, the effective cuts required to improve the signal to noise produces some loss of signal as well as a diminution of background. In Table II below, the cumulative effect of the all the acceptances, efficiencies and cuts on the muons from $B \rightarrow J/\psi \rightarrow \mu\mu$ and $B \rightarrow \mu+x$ decays have been estimated using Monte Carlo's, test

beam data for various detectors and the experiences of E705.

The geometric acceptances in Table II - line 1 are calculated using PYTHIA for a mixture of $B \rightarrow J/\psi \rightarrow \mu\mu$ modes. The semileptonic inclusive $B \rightarrow \mu + x$ are generated using the model for fragmentation and hadronization incorporated in PYTHIA. These muons are required to be in the acceptance of the spectrometer and to have sufficient energy to penetrate the various thicknesses of muon steel. As indicated, 40% of the $B \rightarrow J/\psi \rightarrow \mu\mu$ and 67% of the $B \rightarrow \mu + x$ semileptonic decays satisfy this basic requirement.

The efficiency of the Level I trigger for detecting these muons depends critically on the efficiencies of both the resistive plate counters (RPC's) embedded in the muon steel and the PWC pad chambers downstream of the E771 analysis magnet. The efficiencies for the RPC chambers have been determined as a function of rate by E771 in a beam test at CERN in the fall of 1988. The efficiency of the RPC's was found in these tests to be greater than 95% at $50 \mu\text{cm}^2/\text{second}$. This would be highest rate expected anywhere in the RPC's (specifically in the region of the RPC's near the beam when E771 operates at 10^7 interactions per second). For purposes of calculating the trigger efficiency, we have taken an overall RPC efficiency of 95% for the entire muon detector acceptance.

In the case of the PWC pad chambers we have anticipated the problem of vulnerability of the trigger to the efficiency of the chamber by constructing the chamber so that each pad signal is formed from the OR of two identical pads built into the structure of the chamber. Each has its separate gas volume and covers the same solid angle so that there are effectively two chances to pick up the muon tracks. In this way we expect to be able to obtain efficiencies that will be higher for both devices than 95% per plane, the number used in estimating the trigger efficiencies. Since the efficiencies for single and dimuons are high powers of the individual efficiencies (dimuon trigger efficiency = $\text{Eff}_{\text{RPC}}^6 \cdot \text{Eff}_{\text{CC}}^2$ and single muon trigger efficiency = $\text{Eff}_{\text{RPC}}^3 \cdot \text{Eff}_{\text{CC}}^2$), it is necessary to achieve this level of efficiency for the RPC and PWC pad chambers in order to have a suitably efficient trigger. Our estimates for Level I calculated in this way are shown in Table II-line 2.

The Level IB trigger has two different cuts that are applied to the muon tracks. The first cut, listed in Table II is the minimum p_t requirement. For the dimuon trigger this cut is set low ($p_t > 0.8$ GeV/c) in order to maximize acceptance of these relatively rare $B \rightarrow J/\psi \rightarrow \mu\mu$ events. The single muon p_t cut is set somewhat higher ($p_t > 1.0$ GeV/c). In addition, only a portion of the relatively poor p_t resolution outbenders are accepted in the single muon triggers. Taking into account all acceptances, detector efficiencies and Level IB cuts, the cumulative efficiency for the muon part of the trigger is estimated to be 25% for dimuons and 23% for single muons.

The Level III cuts have been exhaustively estimated as described above by an extensive Monte Carlo. The silicon vertex detector information is used to calculate, exploiting a simple algorithm⁴ which depends on a function of the impact parameters of all tracks in the event, a quantity related to the probability that the event has no secondary vertex. The distribution of this quantity is strikingly different for B events containing secondary vertices and events containing only a primary vertex. This quantity can be used to select events containing B's as shown in figure 3. We presently plan to set cuts so that >90% of the B's are retained.

In the case of the offline analysis, we have extrapolated from the E705 experience reconstructing muons, taking into account the improvements that we anticipate in E771. We have estimated the vertex cut efficiencies for single muons using the Monte Carlo's mentioned above which were used to test the algorithm for Level III secondary vertex detection. As mentioned above, these Monte Carlo's include random noise, multiple scattering, gamma conversions, delta ray production and secondary interactions. The offline reconstruction and vertex cuts outlined in the offline strategies discussed below will lead to efficiencies for the muon part of the event listed in Table II.

Finally, the overall cumulative efficiency for passing the muons from $B \rightarrow J/\psi \rightarrow \mu\mu$ and $B \rightarrow \mu + x$ through the trigger and analysis chain is approximately 9% for both channels. The efficiency for the rest of the decay products must be estimated on a mode by mode basis.

Table II
 $B \rightarrow J/\psi \rightarrow \mu\mu$ and $B \rightarrow \mu+x$
 Muon Acceptances and Efficiencies

	<u>$B \rightarrow J/\psi \rightarrow \mu\mu$</u>	<u>$B \rightarrow \mu+x$</u>
Geometric Acceptance for Muon Triggers	0.4	0.67
Level I Trigger efficiency due to detector efficiencies	0.66	0.77
Level IB P_T cut efficiency for muons	>0.95	0.67
Level IB muon outbender cut	<u>-</u>	<u>0.67</u>
Cumulative Level I trigger acceptance/efficiency	0.25	0.23
Level III Secondary Vertex Algorithm Efficiency*	0.9	0.9
Offline reconstruction efficiency for muons	0.8	0.9
Offline Vertex cut requirements for muons	<u>0.5</u>	<u>0.5</u>
Cumulative offline muon efficiency	0.4	0.45
Composite Acceptance/Efficiency for single or dimuons	0.09	0.09

*Level III does not involve muons

V. Comparison of the $B \rightarrow J/\psi \rightarrow \mu\mu$ and $B \rightarrow \mu+x$ Data Samples

Certain features of the two types of B data samples have already been mentioned earlier in this note. We estimate below the richness of the two different trigger samples in B

decays and the signal to background that we expect at each level of the trigger and off line analysis, using the expectation that $1/1.5 \times 10^6$ of all interactions will contain B's.

V.a B- $\rightarrow$ J/ Ψ - $\rightarrow\mu\mu$ Data Sample

Because of the cumulative branching ratios, the portion of the dimuon triggers due to actual B decays is relatively small. Given the 1.1% branching ratio for B- $\rightarrow$ J/ Ψ + anything and the 6.9% branching ratio for J/ Ψ - $\rightarrow\mu\mu$, only 1.5×10^{-3} of the BB events will be collected by the dimuon trigger strategy (taking into account that there are two B's in every event). Therefore, only one event out of every 10^9 interactions will have a B- $\rightarrow$ J/ Ψ - $\rightarrow\mu\mu$ decay.

However, the backgrounds to the B- $\rightarrow$ J/ Ψ - $\rightarrow\mu\mu$ events can be reduced more easily in the trigger and the offline analysis than the backgrounds to B- $\rightarrow\mu$ +x events, since the constraint of requiring J/ Ψ 's at secondary vertices is very powerful. The requirement for the dimuon to be a J/ Ψ , by itself, eliminates a large portion of the background decay dimuons. For 800 GeV/c p Si interactions the J/ Ψ production cross section is estimated to be approximately $11\mu\text{b}$ (using an A dependence of $A^{0.93}$). The $B\bar{B}$ beauty hadron production cross section in an 800 GeV/c p Si interactions is estimated to be approximately 280 nb assuming a linear A dependence of the beauty production cross sections and using the third order beauty hadroproduction cross section calculations of K. Ellis. Using a branching ratio for B- $\rightarrow$ J/ Ψ of 1.1 %, we estimate that $1/1800$ of the produced J/ Ψ 's are due to a $B\bar{B}$ event in which one or the other of the B's decayed via a J/ Ψ decay mode. Therefore, the first objective of the online trigger and the offline analysis will be to select events containing J/ Ψ - $\rightarrow\mu\mu$ decays. Taking into account that the direct J/ Ψ production is decreased by a factor of three by the vertex requirements of the Level III algorithm (as are the π , K decay backgrounds), we expect that $1/600$ J/ Ψ entering the online analysis stream will be due to a B decay. Approximately 90% of the B events survive Level III.

A second offline condition that can be applied after the J/ Ψ signal is obtained is to require that the muon pair from the J/ Ψ decay comes from a secondary vertex. The vertex

cuts necessary to impose this condition are estimated to lose approximately 50% of the signal but make a further dramatic improvement in the signal to background ratio (greater than a 1000 from our Monte Carlo). This improves the signal to background ratio to better than 1/1 for $B \rightarrow J/\psi$. Finally, detection of at least one additional track from the candidate secondary vertex will further reduce the probability that the event is a mismeasured J/ψ by a factor greater than 10, leading to signal to background ratio greater than 10/1. Since the invariant masses of the remaining background events are spread over a large kinematic range, there will be essentially no backgrounds to the reconstructed $B \rightarrow J/\psi$ mass spectra for specific exclusive final states.

V.b $B \rightarrow \mu + x$

In contrast to the small cumulative branching ratio for $B \rightarrow J/\psi \rightarrow \mu\mu$, approximately 23% of all BB events will produce at least one muon via the semileptonic decay modes and that muon will have a high p_t a large fraction of the time (67% for $p_t > 1.0$ GeV/c). This difference in branching ratios will allow a much greater number of $B \rightarrow \mu + x$ events to be produced for a given number of interactions as shown below in Table III.

The trigger strategy for obtaining the single muon trigger sample proceeds along lines similar to those of the dimuon triggers. In spite of the fact that the $B \rightarrow \mu$ decays are less distinctive than the $B \rightarrow J/\psi \rightarrow \mu\mu$ decays, the percentage of events passing trigger level I containing a $B \rightarrow \mu + x$ is still much greater than the fraction which contain $B \rightarrow J/\psi \rightarrow \mu\mu$ decays because of the large branching ratio for $B \rightarrow \mu + x$. An enrichment factor of one $B\bar{B}$ event for every 6000 triggers is obtained for the single muon trigger sample written to tape, as compared to 1/370,000 for dimuon triggers. Thus, as we shall see in Section VI, in our short 1990-91 run, we may be able to record as many as 15 K $B \rightarrow \mu + x$ events on tape.

The first step of $B \rightarrow \mu + x$ offline analysis increases the $B \rightarrow \mu + x$ enrichment factor to 1/1200 by sharpening the resolution of the p_t cut made on the completely reconstructed muon. The second step in the offline analysis for all single muon triggers is to require that the muon not come from the primary vertex. According to Monte Carlo studies, the

requirement of a 30 micron impact parameter for the muon in the E771 silicon microvertex detector improves the signal to background by a factor of approximately 10, producing an enrichment factor of 1/120 events while retaining approximately 50% of the signal. Finally, finding additional charged tracks which are part of the secondary vertex, will help to eliminate false secondary vertex single muon candidates due to mismeasured single muons. The detection of additional tracks from the secondary vertex reduces the backgrounds by a factor greater than ten leading to a signal to noise in the resulting data sample of greater than 1/12.

Several additional strategies can be employed to further isolate a sample of events containing B's before complete reconstruction is attempted. These strategies will depend on whether the objective is to reconstruct the semileptonic B decay (by means of a zero c fit) or to reconstruct the other B in the event (which can decay into any one of a number of different modes). In both cases, simple examination of the overall topology of the event may help determine if the event contains a $B\bar{B}$. For example, $B\bar{B}$ events can be further distinguished from the charm and other backgrounds by stratagems such as the observation of tertiary vertices. Another stratagem that is possible without complete reconstruction of the event is the determination that the invariant mass of a part of the secondary vertex decay products have mass greater than the charm mass. Depending on the mode, these sorts of strategies may help to select a sample of events with a higher probability for containing a $B\bar{B}$.

Since the final signal to background ratio will depend on the branching ratios, acceptances and efficiencies for sought after decays, as well as the rejections of the specific backgrounds to those decays, we do not attempt to define a global strategy because of the many, as yet unknown, parameters. However, if we can reach a signal to background of one $B\bar{B}$ event for every 10-20 background events, then, because of the wide range of masses of the reconstructed background secondary vertices, we will be able to search with good sensitivity for the presence of B mesons in various final states with very small backgrounds to the reconstructed B mass peaks.

Table III
Enrichment Factors at Various Levels

Level	DiMuon Trigger (signal = $B \rightarrow J/\Psi \rightarrow \mu\mu$)	Single Muon Trigger (signal = $B \rightarrow \mu + x$)
BB/ interaction	$1/1.5 \times 10^6$	$1/1.5 \times 10^6$
signal/interaction	$1/10^9$	$1/6.5 \times 10^6$
signal/ IA*IB trigger	$1/8 \times 10^5$	$1/2.8 \times 10^4$
signal/ tape event	$1/3.0 \times 10^5$	$1/6 \times 10^3$
Offline Step I Signal/background*	$1/6 \times 10^2$	$1/1.2 \times 10^3$
Offline Step II Signal/background	$>1/1$	$1/1.2 \times 10^2$
Offline Step III Signal/background	$>10/1$	$>1/12$

*Assumes a factor of three reduction of the directly produced J/Ψ due to Level III filtering versus a retention of 90% of the $B \rightarrow J/\Psi \rightarrow \mu\mu$ signal.

VI. 1990-91 Run Estimated $B \rightarrow J/\Psi \rightarrow \mu\mu$ and $B \rightarrow \mu + x$ Yields

Given the present schedule for E771, we can, at best, expect approximately three months of data logging, beginning early in 1991. Assuming three months of operation (12 weeks at 100 hours per week with a 23 seconds of spill out of every 56 seconds of spill = 1.8×10^6 seconds of spill) at 2×10^6 interactions per second, the E771 spectrometer will sample 3.6×10^{12} 800 GeV/c p Si interactions. 2.4×10^6 $B\bar{B}$ events will be produced in that short period and 2.7×10^8 events will be recorded on tape. Table IV below summarizes the yield of $B \rightarrow J/\Psi$ and $B \rightarrow \mu + x$ at the major junctures of the data processing.

Table IV
Estimated B Yields, 1990-91 Run
(Est. 1.8×10^6 seconds of spill)

	<u>B $\rightarrow$ J/Ψ $\rightarrow$ $\mu\mu$</u>	<u>B $\rightarrow$ μ+x</u>
Signal Produced	3.6×10^3	5.5×10^5
Signal on Tape*	6.0×10^2	1.5×10^4
Signal surviving offline analysis*	2.6×10^2	6.8×10^3

*The offline analysis referred to is the first two steps which deal only with the muons from the B decay. The number for B $\rightarrow$ μ +x includes reducing the single muon triggers by a factor of 5 as discussed on page 8 to fit into the present DA capability of E771.

As shown in Table IV, the first short run of E771 can result in the accumulation of a few hundred B $\rightarrow$ J/ Ψ $\rightarrow$ $\mu\mu$ events on tape some of which can be totally reconstructed. Given the efficiencies/acceptances for the decay products other than the muon and the measured or expected branching ratios for various exclusive decay modes such as B $\rightarrow$ J/ Ψ K^0_S , we might expect to be able to reconstruct a few events in each of several exclusive mode. There would be almost no background to these events.

In addition, we can accumulate more than 15K B $\rightarrow$ μ +x decays to be written to tape in the short 1990-91 run even under the constraint of being very selective of the single muon triggers. Of the logged single muon triggers, 9 K will survive the muon part of the analysis sequence. This data should include appreciable numbers of events in several exclusive decay modes in which the decay products of the "other" B are in the acceptance of the spectrometer and can be totally reconstructed. An example of such decay modes are the B $\rightarrow$ D* decays some of which have mainly charged decay products and have reasonable acceptances and branching ratios.

VII. 1992-93 Run Estimated $B \rightarrow J/\psi \rightarrow \mu\mu$ and $B \rightarrow \mu + x$ Yields

The short run in 1990 should allow us to understand our triggers, tune our spectrometer and collect some data. However, we plan for operations at a much higher rate in the 1992 run, nominally operating at 10^7 interactions/second or greater. Our Level II trigger, presently under development, will allow us to accommodate these higher rates, to accumulate the bulk of both the single and dimuon triggers produced in the 1992-93 run. In addition, to be able to operate at the higher rates, some improvements must be made in the rate capability of certain components of our spectrometer (in particular the central region of the EM detector). Finally, we propose to add for the 1992 run a Cerenkov for K, π , and p identification to the spectrometer to allow complete reconstruction of B events with K's or proton decay products.

With these improvements and assuming the 1992 fixed target run is ten to eleven months long (the approximate total length of the 1990-91 run), operation at 10^7 interactions per second for eight months during that run will result in approximately 4.8×10^6 seconds of spill delivered to E771, resulting in 4.8×10^{13} interactions sampled by the spectrometer. If we can operate at 10^7 interactions per second in the 1992-93 run, 3.2×10^7 $B\bar{B}$'s will be produced and 7.2×10^8 events will be written on tape (assuming no increase in the E771 data acquisition system capabilities will be required, in addition to our trigger improvements, to accommodate the increased operating rate). Table V below shows the expected yields of $B \rightarrow J/\psi \rightarrow \mu\mu$ and $B \rightarrow \mu + x$ under these assumptions:

Table V

Estimated B Yields, 1992-93 Run

(Est. 4.8×10^6 seconds of beam)

	<u>$B \rightarrow J/\psi \rightarrow \mu\mu$</u>	<u>$B \rightarrow \mu + x$</u>
Signal Produced	4.8×10^4	7.4×10^5
Signal on Tape*	6.4×10^3	1.1×10^6
Signal surviving offline analysis*	2.6×10^3	5.0×10^5

*Assumes that no prescaling or strong selection of single muon triggers is necessary in 1992. Assumes that the E771 trigger system is improved to accommodate all the single and dimuon triggers at 10^7 interactions per spill second.

VIII. Computing Requirements of E771

Given the E771 capacity for logged on tape, we can estimate the requirements for offline computing for the fall, 1990 run of E771 and for the 1992 run assuming that the E771 data acquisition capability remains at 600 events per spill second during that period (450 events per spill second logged to tape). Based on this assumption, the expected accumulation of events on tape during those two runs is approximately 10^9 events, given our ability to filter at Level III to match the tape writing capabilities of six Exabyte units.

The E771 concentration on muon signatures for B events gives a focus to the offline analysis. Because of this considerably less computer time is needed per event than for experiments which must search globally for evidences of secondary vertices and do complete reconstruction to determine if a secondary vertex is due to a B decay. The muon based B analysis strategies allow structuring of the analysis programs to filter with successively more and more sophistication with the number of remaining events decreasing dramatically at each stage. For purposes of estimating the computing time required for the analysis, we have assumed a mixture of single and dimuon triggers with the 1990-91 data dominated by dimuon triggers and the 1992-93 data weighted toward single muons (presuming that we can find improvements of the triggers such that the logged events will tend toward the more natural split between single and dimuon triggers of 3 to 1.

Considering first the data we might hope to obtain in the 1990-91 run, we estimate first the computing requirements for $B \rightarrow J/\psi \rightarrow \mu\mu$ decays (1.8×10^8 triggers on tape). We will express the needs of the various analyses in units of VAX780 years. A year will be taken to be 10^7 seconds for purposes of these estimates (Computing duty factor of 1/3).

The stages in the dimuon offline data analysis process are:

1. The first step will be a fast filter program to determine if the dimuon has a mass greater than $2.5 \text{ GeV}/c^2$. This filter will select events containing J/ψ 's or determine if both muons have a p_t greater than $1.0 \text{ GeV}/c$ (to select events in which both B's have decayed semileptonically). Based on our E705 experience, such a filter program, computing a relatively crude dimuon mass, can reduce the data sample by a factor of 5 at a rate of 250 ms per event on a VAX780. The pad structure of the new E771 chamber set should allow us to achieve a larger rejection factor in less time per event. Using the E705 experience as an upper limit, the total computer time required to perform this first step for the 1990-91 data (assuming 2×10^8 dimuon triggers on tape) would be, approximately 5 VAX780 years, passing less than 4×10^7 events on to subsequent analysis steps.

2. The second step in the offline analysis of the dimuon will be a second pass, higher resolution, three dimensional reconstruction of the dimuons. This step is estimated to take considerably less than the 3 VAX780 seconds per event that required for an E705 event since the pad chambers in E771 should greatly speed up three dimensional track finding. In any case, using the E705 experience as an upper limit, we estimate approximately 10 VAX780 years to accomplish this step and a reduction of the data sample by a factor of 20, leaving 2 million dimuon candidate events for further analysis. Moreover only a few hundred thousand of these will be contained in the J/ψ mass region.

3. A third step in the analysis process will be a filter program which checks the muon tracks to determine if they come from secondary vertices. The program which uses the three dimensional high p_t muon track found in the spectrometer chambers in step 2, extrapolates the track back into the silicon vertex detector. In this way, the process of finding the muon track in the silicon vertex detector can be greatly speeded up since not all silicon hits need be involved in the silicon muon track finding process. The silicon muon track, found in this way, is checked to see if it comes from the primary vertex (defined at this stage as being the intersection of a target foil and a beam track as reconstructed from

the beam silicon tracker). This process, which should be relatively fast (estimated to be less than 500 ms per event or less than a VAX780 year), would filter the dimuon data by a factor much greater than 10, reducing the data sample to a few hundred thousand for the final analysis step.

4. The final stage in the process is an analysis of the remaining events in some detail to isolate and separate the final data sample of B decays. It is not unreasonable to imagine that the remaining process would be quite lengthy since we will have to completely reconstruct all tracks, including the electromagnetic signals. Since we have no experience to draw on, we will assume 30 VAX780 seconds per event as an initial estimate for this final step of extracting the B signals from these few hundred thousand events. This would result in less than a VAX 780 year to complete the process of extraction of the signal.

The single muon analysis scheme is similar to and is intermingled with the analysis stream for the dimuons.

1. The first step for single muons would be a part of the first step filter program for dimuons. There will be a relatively crude check of the high p_t trigger muon with better resolution than is possible with the online trigger. We estimate that a factor of 4-5 rejection will still be possible at this step for single muon triggers given that we will apply tighter cuts to the single muon sample. Assuming a data sample of 10^8 single muon triggers, approximately 2×10^7 events will pass on to later stages of analysis. Approximately 3 VAX780 years will be required for this step for the 1990-91 single muon data sample.

2. The second step in the analysis tree for single muons is also similar to that of the dimuon analysis. We plan to reconstruct the single muon completely and apply more restrictive quality criteria to it than have been applied in step 1 filter. However, because we do not have the constraint of the J/ψ mass, we will not realize as great a reduction factor from this step as we can obtain in the dimuon trigger data. We estimate a factor of three rejection of background in this step, leaving 7×10^6 events for the third level of the analysis. This step is estimated to require 6 VAX780 years for the single muon trigger

sample from the 1990-91 run.

3. The third step in the analysis process is similar to the third step in the analysis of the dimuons. However, this filter is much more important for the single muon trigger than for dimuon triggers since the second step of the single muon analysis is not as powerful as the second step of the dimuon analysis. This filter will require 1.5 VAX780 years for the 7×10^6 single muon triggers in the 1990-91 data, and should filter by a factor of 10, reducing the data sample to less than a million for the final analysis.

4. We anticipate that the extraction of the B signals from the single muon triggers that remain at this stage will be more difficult than the extraction of B's from the J/ψ sample. In addition we will have approximately 10 times as many events at this step to completely reconstruct. Therefore, we, rather arbitrarily, estimate that this step will require 60 VAX780 seconds per event, leading to 6 VAX years to accomplish this task for the 1990-91 data.

By summing the steps required for the analysis of single and dimuon triggers, we can see that, roughly speaking, we can expect a single trigger to take twice as long to analyze as a dimuon trigger on average, most of the difference coming in our assumptions about the relative weakness of step 2 in the single muon analysis process and the additional difficulties anticipated in the final step of the analysis in extracting the B's from the more background prone single muon triggers. However, the total computing power that needed for all the 1990-91 data is not excessive, totaling less than 40 VAX780 years.

The analysis streams would be approximately the same for the 1992-93 data but we would have many more events to analyze (7.2×10^9 compared to 3×10^8). We also might expect these events to be more dominated by the single muon triggers. Under this worst case scenario, we estimate less than 200 VAX780 node years will be required for the 1992-3 data sample.

In conclusion, while these crude estimates of the computing time required for E771

are the best that can be done at the moment given our lack of experience in the process of analyzing decays in a silicon vertex detector, they are probably not totally out of line with our eventual needs. We have not invoked the power of the new PWC pad chambers in estimating the times required for our level 2 filter and we are probably conservative in estimating the times required for the final step in extracting the B signals. The factors may balance the inexperience and the oversights that are surely present in our present thinking about the E771 analysis procedures.

Table V		
E771 Computing Requirements		
	1990	1992
Spill Seconds	1.8×10^6	4.8×10^6
Interactions produced	3.6×10^{12}	4.8×10^{13}
BB produced	2.4×10^6	3.2×10^7
Events logged to tape*	2.7×10^8	7.2×10^8
VAX780 node years to process	<40	<200

*Assumes that the trigger effectiveness can be improved by the time of the 1992 run to accommodate the increase in interactions/sec

IX. Summary

The ability to trigger on high p_T single muons is an intrinsic part of the E771 dimuon trigger. Having this capability will broaden the ability of E771 to study B decays, giving us an additional option in this, as yet, undeveloped area of experimentation. The single muon triggers are the most copious B signature that can be easily triggered on and produce the largest enrichment factor in the data logged to tape. Exercising this capability will allow us to write several hundred $B \rightarrow J/\psi \rightarrow \mu\mu$ and over 15 thousand $B \rightarrow \mu$ events onto tape in the 1990-91 run and may eventually lead to data samples of several thousand of $B \rightarrow J/\psi \rightarrow \mu\mu$

events and greater than one million $B \rightarrow \mu + x$ on tape in the 1992-93 run. The amount of computing time per single muon trigger required to analyze these events is probably within a factor of two of the time required for dimuon triggers. In any case, the total computing time required for the mixed trigger samples that we expect to accumulate is not excessive by the standards of several charm experiments due to the fact that we have the muons to guide our analysis process.

References

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HIGH INTENSITY LAB SPECTROMETER E771

Figure 2

REJECTION vs BEAUTY EFFICIENCY

Figure 3

(some appendices removed and cycled separately) -

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