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**Progress Report  
and  
Proposal  
for  
TASK B  
High Energy Physics Studies**

February 1, 1992 - January 31, 1995

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August 1991

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**Appendix B:** "A Precision Measurement of the Branching Ratio  $K^+ \rightarrow \pi^+ \pi^0$  /  $K^+ \rightarrow \mu^+ \nu_\mu$ ", T. Usher, et al.

**Appendix C:** "Precision Measurements of Charmonium States Formed in  $\bar{p}p$  Annihilation", T. A. Armstrong, et al.

**Appendix D:** "Study of the  $\chi_1$  and  $\chi_2$  Charmonium States Formed in  $\bar{p}p$  Annihilation", T. A. Armstrong, et al.

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## 1 Introduction

Task B is involved in a unified program investigating charmed quark physics in two different, yet related accelerator experiments. The first of these is Fermilab Experiment E760, a high resolution study of the formation of charmonium states in proton-antiproton interactions. E760, which is actively running at the present time, has already produced results adding significantly to knowledge of the properties of several charmonium states, and is engaged in an important search for new states which cannot be formed in electron-positron collisions. Several papers reporting results obtained during the 1990 Fixed Target running period at Fermilab have recently been completed.

The second experiment, which the Task B Group has joined during the past year, is an intensive study of charmonium and charmed mesons using electron-positron collisions in the BEijing Spectrometer (BES) at the Beijing Electron Positron Collider (BEPC). This is a collaboration between several universities in the United States, SLAC and the Institute of High Energy Physics in Beijing. The collaboration was officially formed with a Memorandum of Understanding among BES Collaborators in December, 1990.

Work on one of the group's previous projects, a search for baryonium states in proton-antinucleon interactions at the Low Energy Antiproton Ring (LEAR) at CERN, was completed during the past contract year, and final papers reporting results have been submitted for publication.

The entire Task B Group is participating in the E760 project at Fermilab. This group consists of Professors Jonas Schultz and Mark Mandelkern; Post Graduate Researchers Michael Weber and George Zioulas, and graduate students Dan Broemmelsiek, James Fast, Keith Gollwitzer, Jose Marques, and Andrew Smith. The post doctorals and graduate students have been in continuous residence at Fermilab, and at the present time are all actively involved in the running of the experiment and analysis of data. Although the UCI group's primary responsibility has been the design, construction, calibration, installation and operation of the lead glass Central Calorimeter, which is the principal component of the detector, the group has participated significantly in all facets of the preparation, installation and running of the experiment. These activities have included work on the development of the data acquisition system, trigger design, software development and code management, participation in beam deceleration and beam operation during running, and data analysis on a variety of channels.

A subset of the Task B Group is participating in the BES project, of which Professor Andrew Lankford of UCI is also a member. In addition, Jonas Schultz participates with other UCI high energy physicists as a member of the IMB and GRANDE Collaborations.

TASK B PERSONNEL:

Jonas Schultz	Professor
Mark Mandelkern	Professor
Michael Weber	Post Graduate Research
George Zioulas	Post Graduate Research
Dan Broemmelsiek	Graduate Student
James Fast	Graduate Student
Keith Gollwitzer	Graduate Student
Jose Marques	Graduate Student
Andrew Smith	Graduate Student

## 2 Final Results from the Concluded LEAR Experiment, PS183

PS183 was a LEAR experiment which completed its data taking in 1986. It consisted of a search for monochromatic charged mesons and gammas from antiproton annihilations at rest in hydrogen and deuterium. The final two publications from this experiment were completed during the past year and submitted for publication. These papers are:

1. N. Graf, et al., "A Search for Narrow States in the Inclusive Gamma Ray Spectra Resulting from Antiproton Annihilations at Rest in Liquid Hydrogen and Deuterium" (accepted for publication in Physical Review).
2. T. Usher, et al., "A Precision Measurement of the Branching Ratio  $K^+ \rightarrow \pi^+ \pi^0 / K^+ \rightarrow \mu^+ \nu_\mu$ " (submitted for publication in Physical Review).

Graf and Usher were UCI graduate students and the papers represent work done at UCI. They are now staff members at Fermilab and SLAC, working on D0 and SLD, respectively.

## 3 An Overview of Fermilab Experiment E760

Fermilab Experiment E760 took data in 1990 and is now taking data in the 1991 Fixed Target period. We expect to operate E760 during the next Fixed Target cycle at Fermilab (1994) since a great deal of important and achievable physics will remain to be done after the current run is completed.

### 3.1 E760 Physics

E760 studies antiproton-proton interactions in the Antiproton Source. The beam is the internal beam in the Cooling Ring which is extremely well defined in momentum (1 Mev/c). The target is a gas jet of molecular hydrogen of  $10^{14}/\text{cm}^2$ . The E760 collaboration has learned to decelerate the beam to precise momenta corresponding to the formation energies of the  $J/\psi$ ,  $\psi$  and other known and predicted charmonium states. (Substantial instrumentation

was added for this purpose). A detector has been constructed for the observation of the charged and neutral decay modes of charmonium states. It is capable of rejecting backgrounds to a degree that cross sections as small as 10 pb can be observed for selected channels.

The important physics which E760 is doing includes:

1. Direct precision measurements of the masses and widths of known charmonia, including the three  $\chi$  states, the  $\eta_c$ , and the  $J/\psi$  and  $\psi'$ .
2. Search for predicted charmonia such as  $^1P_1$ ,  $\eta_c$ , singlet and triplet D states.
3. Dynamical tests of the quantum mechanics of charmonia, including branching ratios for the various  $\chi$  decays (2 gamma, radiative, gluonic, etc.)
4. Specific QCD tests, such as the angular distribution of  $\chi_2$  radiative decay.
5. Searches for exotic states, such as  $D\bar{D}$  and  $J/\psi\pi$  molecules, light quark exotics in pionic annihilations. As byproducts of the main thrust of the experiment, we are measuring the antiproton elastic differential cross section in the Coulomb and interference regions, cross sections for various annihilation reactions, the proton magnetic form factor in the time-like region, etc..

### 3.2 UCI Contribution

The UCI group has been part of E760 since its beginning. We played the major role in the design of the central lead glass calorimeter, in R&D and prototyping, in testing lead glasses and phototubes. We constructed the calibration and monitoring system, and UCI personnel did most of the actual assembly of the calorimeter. In addition, the UCI group has been involved in all aspects of the experiment. We provide below a detailed summary of the status of various projects being pursued by UCI staff, which includes work on the data acquisition, development of anti-pileup algorithms, analysis of charged and neutral channels, development of the experiment Monte Carlo, determination of the calorimeter linearity, etc. Four of the UCI graduate students will write PhD theses based on E760.

### 3.3 1990 Running

E760 began to operate early in 1990. The group learned how to decelerate from 8.9 GeV/c, the momentum at which antiprotons are accumulated, to momenta above 5.23 GeV/c, the transition momentum for the machine. However, only small stacks could be brought through transition and down to the  $J/\psi$  operating point. Nevertheless, the very large cross section at the  $J/\psi$  permitted us to run there for calibration purposes. We also calibrated at the  $\psi'$ . A "double scan" technique was developed to measure precisely the quantity  $\eta$ , which relates relative changes in frequency and momentum, yielding a determination of the beam width from the well measured frequency spectrum. This knowledge of the beam width allows us to deconvolute the beam width and directly measure the widths of narrow states (for example, states as narrow as the  $J/\psi$ , about

70 keV). We scanned through the  $\chi_1$  and  $\chi_2$ , and made precision measurements of the widths of these states, giving results significantly narrower than previous measurements). We began a scan of the  $^1P_1$ , starting at the center of gravity of the three  $\chi$  states, and are presently analyzing this data, searching for a signal at the  $<50$  pb level. (Some evidence of the existence of the  $^1P_1$  at the  $\chi$  center-of-gravity was obtained by the R704 experiment at CERN, and there are indications in the current data as well.) We took various "background" points, which will also be used for the study of scattering and annihilation reactions, and to measure, in particular, the proton magnetic form factor. Table 1 gives the integrated luminosities obtained at various energies during the 1990 run.

Table 1  
1990 Run

Resonance Studied	Pbeam (MeV/c)	Integrated Luminosity (nb <sup>-1</sup> )
J/ $\psi$	4063	360
$\psi$	6232	1470
$\chi_1$	5550	1030
$\chi_2$	5724	1160
$^1P_1$ search	5605	1250
Background	5660	420
Background	6110	185

### 3.4 Publications Describing the Detector and Results from 1990 Data

We have prepared three journal articles based on the 1990 data and several others describing the E760 experiment. A letter reports our precision measurements of the masses and widths of the  $\chi_1$  and  $\chi_2$  and of the width of the  $\psi$ . Two full length articles describe the details of these measurements including the "double scan" method developed by E760. Nuclear Instruments and Methods articles were co-authored by the UCI group on the Central Calorimeter and the  $4\pi$  geometry Cerenkov Counter.

E760 papers co-authored by the UCI Group submitted or published within the past year:

1. "The E760 Lead-Glass Central Calorimeter: Design and Initial Test Results", L. Bartoszek, et al., Nucl. Instr. and Meth. A301, 47 (1991).
2. "Study of the  $\chi_1$  and  $\chi_2$  Charmonium States Formed in  $\bar{p}p$  Annihilations", T. A. Armstrong, et al., to be submitted to Nucl. Phys. B.
3. "Charmonium Spectroscopy in the Fermilab  $\bar{p}$  Accumulator Ring", T. A. Armstrong, et al., to be submitted to Phys. Rev. D.
4. "Precision Measurements of Charmonium States formed in  $\bar{p}p$  Annihilations", T.A. Armstrong, et al., to be submitted to Phys. Rev. Lett.

5. "A Large Acceptance Threshold Cherenkov Counter for Experiment E760 at Fermilab", C. Biino, et al., to be submitted to Nucl. Instr. and Meth. A.

### 3.5 1991 Run Plan

During the current run, E760 plans to study resonances which decay to all-neutral final states containing two or more photons. The run plan is as follows:

1. Perform a double scan at the  $J/\psi$  and  $\psi'$  to calibrate the accelerator energy and measure the  $J/\psi$  width. Calibrate the calorimeter using  $J/\psi$  events.
2. Take data at the  $\chi_2$  peak to measure the angular distribution of the radiative decay and discover the 2 gamma decay. About  $6 \text{ pb}^{-1}$  of total integrated luminosity will be taken at the  $\chi_2$ .
3. Scan for the  $^1P_1$ , using a 5 point scan near the  $\chi$  center-of-gravity, with about  $1.5 \text{ pb}^{-1}$  of integrated luminosity at each point.
4. Scan for the  $\eta'_c$ , with about  $3 \text{ pb}^{-1}$ , to confirm its existence and measure the width.
5. Measure the  $\eta_c$  width.
6. Take data with relatively small integrated luminosity in the mass range where one might expect molecular or D states.
7. Measure the mass and width of the  $\chi_0$ ; find its 2 gamma decay.

As noted above, we do not expect to finish this program in 1991, and expect to continue during the next Fixed Target running period.

A more detailed description of the experiment and discussion of various aspects of analysis of the 1990 data and of work done on the detector in preparation for the 1991 run is presented in the following two sections. This discussion focusses, in particular, on work done by UCI members of the collaboration and efforts in which UCI has played a central role.

## 4 Analysis of the 1990 Data

### 4.1 Analysis of the $\chi$ States (J. Marques)

Fermilab experiment E760 is studying the charmonium resonances produced in proton-antiproton collisions. The experiment is located in one of the low dispersion regions of the Fermilab  $\bar{p}$  source, and uses a molecular hydrogen gas jet as a target. The coasting  $\bar{p}$  beam intersects the gas jet and produces  $p\bar{p}$  annihilations into mostly nonresonant hadronic channels. The total cross section for  $p\bar{p}$  interactions is about 70 mb while the formation cross section for the  $\chi_1$  is about 130 nb and for the  $\chi_2$  is about 240 nb. The E760 detector (Figure 1) has been designed to pick out the electromagnetic final states of charmonium decays from the large hadronic background by using a threshold

Cherenkov counter[1], for identifying electrons and a lead glass calorimeter[2]. For the  $\chi$  states the following reactions were examined:

$$p\bar{p} \rightarrow \chi_{1,2} \rightarrow J/\psi + \gamma \rightarrow e^+ + e^- + \gamma$$

During the 1990 run, E760 was able to scan both the  $\chi_1$  and  $\chi_2$  resonances several times. The scanning procedure was to take data points of roughly equal integrated luminosity at seven different energies. This type of scan yields about half the number of events one would expect from sitting at the resonance peak. Since the momentum bite of the  $\bar{p}$  beam is small (roughly 300 KeV in the center of mass) compared to the resonance width, the scans resulted in excitation curves (Figure 2) from which the resonance parameters could be extracted. The table below summarizes the  $\chi$  data taken during 1990:

**Table 2**  
 $\chi$  Scans

State	Integrated Luminosity	Number of Events
$\chi_1$	1030 nb <sup>-1</sup>	513
$\chi_2$	1160 nb <sup>-1</sup>	585

The events that are used in the analysis are easily selected by conducting a kinematic fit to the three body final state and requiring identification of at least one of the electrons. The invariant mass of the electron-positron pair is plotted in Figure 3. The background cross section was determined by conducting the same analysis on points far from the resonance. The trigger and reconstruction efficiencies have been studied by using a background-free sample of about 4000  $J/\psi$  events. The trigger efficiency has been found to be greater than 99% while the reconstruction efficiency is around 86%.

The resonance parameters are extracted by assuming that the observed excitation curve is a convolution of a Breit-Wigner line shape with a Gaussian beam energy resolution. The fit to the data is done by applying the Maximum Likelihood method where the resonance mass, resonance width, and the product of the partial widths are all outputs of the fit. The results of the analysis are summarized below[3]:

**Table 3**  
Results of  $\chi$  Resonance Parameter Fits

State	Mass (MeV/c <sup>2</sup> )	Width (KeV)
$\chi_1$ (E760)	3510.53 $\pm$ 0.04 $\pm$ 0.12	880 $\pm$ 110 $\pm$ 80
$\chi_1$ (Particle data book)	3510.6 $\pm$ 0.5	< 1300
$\chi_2$ (E760)	3556.15 $\pm$ 0.07 $\pm$ 0.12	1980 $\pm$ 170 $\pm$ 70
$\chi_2$ (Particle data book)	3556.3 $\pm$ 0.4	2600+1200/-900

These results provide, then, a first measurement of the width of the  $\chi_1$ , and significant improvements on the width of the  $\chi_2$  and the masses of both states.

During the 1991 run we hope to collect an additional 3-4 pb<sup>-1</sup> of luminosity at the peak of the  $\chi_2$ . This will enable us to make a measurement of the  $\chi_2$  angular distributions as well as look for the 2 gamma decay of the  $\chi_2$ .

## 4.2 Analysis of All-Neutral Decays of Charmonium (J. Fast)

Experiment E760 was designed to detect the electromagnetic decays of charmonium into final states containing an  $e^+e^-$  pair (inclusive  $J/\psi$ ) or into final states of 2 and 3 photons. The all-neutral final states rely entirely on the performance of the central lead glass calorimeter. Since we are producing charmonium through  $p\bar{p}$  annihilation we are faced with an enormous hadronic background, much of which is all-neutral (approximately 8 mb). The primary all-neutral final states we are looking for are:

$$p\bar{p} \rightarrow \text{Resonance} \rightarrow 2\gamma \quad (\eta_c, \eta_c', \chi_2)$$

$$p\bar{p} \rightarrow \text{Resonance} \rightarrow \eta_c + \gamma \rightarrow 3\gamma \quad ({}^1P_1)$$

The cross sections for these processes range from a few pb to a few hundred pb, or a factor of 1 million smaller than the all-neutral rate.

In order to distinguish charmonium decays from non-resonant background, one needs very good calorimetry to constrain the event topology. The most difficult background that we face is that from  $p\bar{p} \rightarrow 2\pi^0$ . The majority of the  $2\pi^0$  events are easily rejected by multiplicity cuts since we are looking for a two body final state. There are still two scenarios which cause difficulties and which motivated the original design of the calorimeter. First there is symmetric  $\pi^0$  decay, in which the photons from the  $\pi^0$  are very close together. This determined the granularity of the calorimeter. Second there is the asymmetric decay, in which one photon carries the majority of the energy and momentum of the  $\pi^0$ . In order to reject these one needs a low energy threshold for detection of the soft gamma. In this case one also has to worry about spurious energy from out-of-time events in the calorimeter faking low energy gammas.

In our first data taking period (1990), scans were done of the  $J/\psi$  (for calibration of the detector and  $\bar{p}$  source), the  $\psi'$ , the  $\chi_1$ , the  $\chi_2$ , and 3 points at the  $\chi$  center of gravity ( ${}^1P_1$  search). Analyses of these data show that the calorimeter is performing extremely well. Our measured position resolution is 7mrad in  $\theta$  and 9mrad in  $\phi$ , or about 9mm at the face of the lead glass blocks. The energy resolution is found to be  $8\%/\sqrt{E}$  and has room for improvement with better calibration data (to be taken at the beginning of the 1991 running). The low energy threshold is 50 MeV and could be lowered if we can improve the technique for rejecting out-of-time energy deposits in the calorimeter. From the data taken thusfar, the background for the 2 gamma final states of the  $\eta_c$  and  $\chi_2$  has been determined to be 10-20 pb with an analysis efficiency of 67% and an acceptance of 0.5. In addition, the preliminary analysis of the  $\chi_2$  data shows a small possible signal (see Figure 4) of  $5.0 \pm 4.9$  pb. The present result places an upper limit of 85 eV (95% CL) on the partial width ( $\chi_2 \rightarrow 2\gamma$ ). For comparison, CLEO recently reported an upper limit of 100 eV for this width, determined from studying  $2\gamma$  physics. An additional  $3.5 \text{ pb}^{-1}$  of data at the peak of the  $\chi_2$  are needed to establish this signal at a 3-4 standard deviation level. This data is to be taken early in our 1991 running. It is hoped that the rejection efficiency will improve with a better calibration in the upcoming run.

One of the main objectives of the experiment is the discovery of the singlet P-state of charmonium ( ${}^1P_1$ ). The decay of the  ${}^1P_1$  is expected to be dominated

by the radiative transition to the  $\eta_c$ . Thus the decay  ${}^1P_1 \rightarrow \eta_c + \gamma \rightarrow 3\gamma$  is one of the primary channels at which we are looking. As mentioned above, data has been taken at three points near the  $\chi$  center of gravity: 3524.4, 3524.8, 3525.4 MeV. 300-500 nb<sup>-1</sup> of data were collected at each of these points. In addition 400-700 nb<sup>-1</sup> of data were taken at both the  $\chi_1$  and  $\chi_2$  providing background points on either side of the region of interest. The  $\chi_1$  and  $\chi_2$  radiative decays to the  $J/\psi$  also provide a background-free sample of events that are topologically identical to the  ${}^1P_1$  decay, allowing the efficiency of various analyses to be tested. The background to the 3 gamma channel is found to be  $9 \pm 3$  pb with an analysis efficiency of 37% and acceptance of 0.6. Preliminary results of the 3 gamma analysis are shown in Figure 5. A  $20 \pm 10$  pb signal is seen at 3524.4 MeV. These results are very encouraging, but need to be confirmed.

In conclusion, the lead glass calorimeter is performing exceptionally well. There is room for improvement in energy resolution and pile-up issues. Work is presently underway to this end (as described in Section V below.) Preliminary analyses indicate that we are able to reduce our backgrounds to acceptable levels (5-20 pb) with good efficiencies. Indications of signals in the  $\chi_2 \rightarrow 2\gamma$  and  ${}^1P_1 \rightarrow 3\gamma$  channels are promising, and confirmation of these is of highest priority in the 1991 run. In addition, confirmation of the existence of the  $\eta_c$  through the channel  $\eta_c \rightarrow 2\gamma$  is one of the objectives of this running period.

### 4.3 Search for the ${}^1P_1$ State (K. Gollwitzer)

The singlet P state,  ${}^1P_1$ , has not been definitively seen in the charmonium spectrum. The  ${}^1P_1$  mass is expected to be near the spin weighted center of gravity of the masses of the three  $\chi$  states. Determination of the  ${}^1P_1$  mass will provide important information about the short range quark-antiquark potential, in particular the hyperfine spin-spin potential. In the Fermi-Breit Approximation to the quark-antiquark potential, the hyperfine interaction vanishes identically in P states. In the so-called Generalized Fermi-Breit Approximation, in which the fundamental potential is modified from the canonical  $1/r$  form expected from single gluon exchange, the hyperfine interaction is non-vanishing, but is expected to be attractive in the singlet spin state and repulsive in the triplet state, just as is observed in the S states of charmonium. Such a hyperfine interaction would yield a  ${}^1P_1$  mass below the  $\chi$  center of gravity. On the other hand, in several potential models employing perturbative QCD corrections to order  $\alpha_s^2$ , the predicted  ${}^1P_1$  mass turns out to be above the  $\chi$  center of gravity. In all cases the mass separation is predicted to be less than or about 4 MeV. Hence a determination of this mass difference offers a crucial test of the various theoretical approaches (Generalized Fermi-Breit vs QCD correction formalisms) to the quark-antiquark potential[4].

The width of the  ${}^1P_1$  is expected to be narrow,  $< 1$  MeV, and the expected cross section ( $p\bar{p} \rightarrow {}^1P_1 \rightarrow \text{all}$ ) could possibly be 100 nb. The radiative decay to  $\eta_c$  is expected to be the dominant decay channel, while decay channels which include a  $J/\psi$  are also expected.

The E760 central calorimeter was designed to detect inclusive  $J/\psi$  and two and three body final states of electromagnetic particles. We are searching for the hadronic decay to  $J/\psi$  inclusive and the radiative decay to  $\eta_c\gamma$ . The  ${}^1P_1$

inclusive  $J/\psi$  trigger is the same as the inclusive  $J/\psi$  trigger for the  $\chi$  states and the  $\psi$ . The expected large radiative decay rate suggests that looking for this decay mode may result in a larger number of events. Rates for detectable final states from the radiative decay to  $\eta_c$  are dependent upon the  $\eta_c$  branching ratios to these electromagnetic states. Perhaps the simplest to identify is  $\eta_c \rightarrow \gamma\gamma$ . However, this branching ratio is only  $6 \times 10^{-4}$ . Other decay channels that have been investigated are  $\eta_c \rightarrow \eta\pi\pi$  and  $\eta_c \rightarrow \phi\phi$ . The all-neutral  $\eta\pi\pi$  mode would eventually result in six gammas in addition to the radiative gamma; the charged version would involve three gammas and two charged pions. The effective cross section for the neutral and charged versions of radiative gamma  $\eta\pi\pi$  is 10 to 25 times greater than the three gamma final state ( $\sim 10$  pb). The  $\phi\phi$  channel would decay to four charged kaons and has an expected effective cross section comparable to the three gamma final state.

As stated before, the  $J/\psi$  inclusive channel trigger is the same as for the other charmonium states. The two neutral channels are triggered by using a total central calorimeter energy trigger; the ACP system is then used to quickly analyze the calorimeter signals. The ACP system passes along events in which an invariant mass of two clusters in the calorimeter is greater than 2 GeV as well as events which have 90% of the expected lab energy. The  $\gamma\eta\pi^+\pi^-$  hardware trigger rate is too large to be used in parallel with other triggers. The same is true for the  $\phi\phi$  channel.

With regard to analysis, looking for the  $J/\psi$  inclusive channel is like the analyses of other charmonium states. Analysis of the radiative decay to  $\eta_c$  and subsequent  $\eta_c$  decay to gamma gamma is the same as doing a "calorimeter only" analysis of the radiative  $\chi$  decays. The backgrounds to the above two channels are small since there are few processes which have the same topology, which includes a high invariant mass ( $J/\psi$  or  $\eta_c$ ) of two of the clusters. The  $\gamma\eta\pi^0\pi^0$  channel has a great amount of background since  $p\bar{p}$  annihilations to  $\eta\pi^0\pi^0\pi^0$  can be confused with the  $^1P_1$  signal when one  $\pi^0$  decays asymmetrically and a photon escapes detection (due to energy threshold or acceptance), while a high energy photon is mistaken for the radiative gamma. Annihilation to 4 neutral pions can also imitate the  $^1P_1$ . The  $\phi\phi$  to four kaons has a large hadronic background that can satisfy the initial analysis.

During the 1990 data run, the above channels were investigated while searching for the  $^1P_1$ . Three points near the chi center of gravity were taken; 300-500  $\text{nb}^{-1}$  of data were taken at energies of 3524.4, 3524.8 and 3525.4 MeV. A possible signal has been noticed at the first of these points using the three gamma final state. The three points could be considered as background measurements for the inclusive  $J/\psi$ , three gamma and seven gamma final states. In addition, the resonance scans of the other charmonium states provide more background measurements for the two neutral final states. The  $\gamma\eta\pi^+\pi^-$  and the  $\phi\phi$  channels had special triggers which were run separately to measure the background. The expected signal to (measured) background ratios for the inclusive  $J/\psi$  and three gamma channels are 3/1. The neutral and charged  $\gamma\eta\pi\pi$  channel S/B ratios are 1/20 and 1/10, respectively. The  $\phi\phi$  channel S/B ratio is less than 1/100.

Progress continues in the analysis effort to increase the S/B ratio for the different decay channels. The inclusive  $J/\psi$  and three gamma channels are

being used for the  $^1P_1$  search while the others will be used to confirm any signal. The seven gamma final state is the best confirmation channel since data for this channel are taken in parallel with the search channels. The other two confirmation channels require special data runs and may or may not be pursued due to the fullness of the E760 physics program. The 1991 data run will resume the 1990 search for the  $^1P_1$  starting with the lowest energy point taken, where a possible signal was seen, and continue with lower energy points.

#### 4.4 Measurement of the Proton Magnetic Form Factor in the Time-like Region (M. Weber)

The proton magnetic form factor in the time-like region can be measured from the electromagnetic annihilation process  $\bar{p}p \rightarrow e^+e^-$ . Excluding CERN Experiment R704 and E760, the only existing measurements of the form factor in the time-like region were obtained for values of  $Q^2 < 5.7$  (GeV/c) $^2$  [5]. In 1985, R704 published upper limits at  $Q^2$  values of 8.9 (GeV/c) $^2$  and 12.5 (GeV/c) $^2$  [6]. During the 1990 E760 data run, we collected data at background (off resonance) points corresponding to  $Q^2 = 12.4$  (GeV/c) $^2$ . For a total integrated luminosity of 1.4 pb $^{-1}$ , we have detected four events (preliminary) which can be identified with the above annihilation process to  $e^+e^-$ . Assuming  $|G_M|$  dominance as predicted by perturbative QCD, this implies the following new (preliminary) results:

$$|G_M| = 0.034 \pm 0.009 \quad \sigma_T(\bar{p}p \rightarrow e^+e^-) = 9.7 \pm 4.8 \text{ pb.}$$

This value of  $|G_M|$  is consistent with extrapolation from previous measurements using the QCD prediction that  $|G_M|$  is inversely proportional to  $Q^4$ .

Presently, members of the UCI group are re-analyzing this data, paying particular attention to the methods used to select events with two central calorimeter clusters in the final state. This analysis incorporates, among other things, new information on the timing of the clusters. It has been shown that some three and four cluster events (according to the offline analysis code) are actually two cluster events with the remaining clusters belonging to a different event. Thus, the event sample may be increased. Other cuts used to select  $e^+e^-$  final states are also being carefully scrutinized, as well as backgrounds which mimic the annihilation process.

For the 1991 E760 data run, we will continue to collect data off resonance near  $Q^2 = 12.4$  (GeV/c) $^2$  using the inclusive  $e^+e^-$  trigger. We hope to obtain an integrated luminosity of between 1.4 pb $^{-1}$  and 2.3 pb $^{-1}$ , which will provide a measurement with a three to four standard deviation statistical significance. We will also take data at another energy, that of the  $\eta_c$ . We require an integrated luminosity of between 1.4 pb $^{-1}$  and 2.3 pb $^{-1}$  for a measurement with the same statistical significance as above.

## 5 Developments and Improvements in E760 for 1991 Run

### 5.1 The Trigger (G. Zioulas)

The absolute and effective cross sections that E760 is trying to measure during this run are very small (from several pb to a few hundred pb) relative to the total  $\bar{p}p$  cross section (about 70 mb). The interaction rate is 700 kHz at the maximum luminosity rate expected by the experiment ( $10^{31} \text{ cm}^{-2}\text{s}^{-1}$ ). Consequently, in order to avoid excessive deadtime in the data acquisition, E760 needs a fast trigger with good efficiency and large rejection factor. Such a trigger was designed and implemented in the last run of the experiment and was upgraded for the 1991 run, in order to accommodate the higher interaction rates that the experiment plans to take.

The trigger takes advantage of the fact that the light products of the decays of charmonium states (electrons for  $J/\psi$  and  $\psi'$ , or photons for  $\chi_2$ ,  $\eta_c$  and  $\eta'_c$ ) are produced almost back-to-back in the center of mass of the interaction, resulting in two showers in opposite azimuthal angles of the calorimeter.

The trigger uses the signals from the 1280 lead glass blocks of the central calorimeter. The blocks are arranged in cylindrical geometry, with 20 rings spanning the range of polar angle and 64 identical "wedges" covering the full azimuthal range of 360 degrees. For purposes of the trigger logic, the wedges are combined into 8 "super-wedges", each consisting of 9 adjacent wedges (with an overlap of one wedge at each end where adjacent super-wedges meet). Signals from the 9 blocks of every super-wedge contained in each ring are summed in the Level I summing modules and the resulting 160 analog output signals are sent to the Level II summers. There, the signals are split off, and a part of them is sent directly to discriminators while the other part is sent to a summation circuit. The thresholds of the discriminators for these signals correspond to 80 MeV of deposited energy in a super-wedge and their outputs are ORed together to form a minimum bias trigger. The summation circuit groups and adds the corresponding super-wedge signals of five adjacent rings (a "super-ring"), forming 40 "super-clusters", each covering a region of  $5 \times 9$  blocks. (Again, one ring is common between two adjacent super-rings, and the 20 rings are grouped into 5 super-rings). The purpose of this is to take care of the transverse spread of the electromagnetic showers and to reduce the number of channels in the trigger. The 40 signals are first sent to the "integrator" modules where the total charge of each pulse is converted to an output voltage, and then to discriminators. The thresholds of these discriminators are set according to the minimum energy expected in the corresponding super-ring from the kinematics of the decay. The digital signals of the 5 super-rings in a given super-wedge are ORed together forming 8 signals, each corresponding to an azimuthal octant of the calorimeter. A memory lookup unit (MLU) is then used to perform pattern recognition, looking for back-to-back octants with energy deposition above a threshold.

The trigger efficiency was tested by comparing data taken at the  $J/\psi$  resonance with the previously described trigger and another trigger not requiring a signal from the calorimeter. This trigger required signals to be in opposite sides of the hodoscopes and Cerenkov counter, consistent with  $J/\psi$  decay to  $e^+e^-$ .

The comparison between the two triggers showed that the calorimeter trigger was more than 99% efficient. The minimum bias trigger rate was about 800 kHz at about  $10^{31}$  cm<sup>-2</sup>sec<sup>-1</sup> luminosity. A neutral trigger was defined as a calorimeter trigger vetoed by the hodoscopes in order to accept events with no charged particles in the final state. The rate of this trigger, at the maximum luminosity, was about 50 Hz at the J/ψ resonance and about 450 Hz at the χ<sub>2</sub>. The difference was due to looser criteria for inclusive decays (like χ<sub>2</sub> → J/ψ + γ, or <sup>1</sup>P<sub>1</sub> → η<sub>c</sub> + γ), where the condition of one octant being in coincidence with any one of the opposite 3 octants was applied. These trigger rates produce no deadtime problem.

## 5.2 Data Acquisition and Upgrades for 1991 Running (D. Broemmelsiek)

All digital and analog electronics for the acquisition of data from the detectors comprising E760 reside in thirteen CAMAC crates. Each CAMAC dataway is arbitrated by a FNAL Smart Crate Controller (SCC). These SCCs allow the acquisition of data to be defined on an event type basis. The data acquired by the SCC are then passed to a data buffer residing in what is known as an ACP (Advanced Computing Project). An ACP is a VME crate containing a VAX/VME interface module, microprocessors, and data buffers. The microprocessors are programmed to perform first order calculations on the incoming events, subsequently putting each event into one or more predetermined physics categories. All useful data are then transmitted to a MicroVAX II which moves the data to 8mm magnetic tape for storage and to other computers for monitoring.

Event triggering is done primarily in a Memory Lookup Unit. Matrices are programmed into the MLU which define interesting topologies in the E760 detectors. The MLU is strobed by a lead glass calorimeter detector OR which has an enforced deadtime of 45 ns. This is the time required for the MLU to make a trigger determination. Therefore a trigger determination can be performed at a rate of 22 MHz. Once an event has been identified, the SCCs are informed of event type and all necessary gates are passed to the detector electronics.

The three basic event types are clocked, charged, and neutral. Clocked events are beam energy, luminosity, and detector scalars. These events come at intervals of 3 minutes, 5 minutes, and 3 seconds respectively and do not contribute significantly to event readout deadtime. Charged events have 700 microsecond event readout while neutral events have 100 microsecond event readout. These times imply that the number of true events lost for every kHz in rate is  $q_1 \times .7 + q_2 \times .1$  where  $q_1$  and  $q_2$  are the relative prescale factors for charged and neutral events respectively. Since the data are buffered into the ACP, the actual maximum rate before significant losses occur is dominated by the ACP. This rate is approximately 2 kHz and is critically dependent on the number of bytes per event.

Another rate limitation is the maximum transfer rate to 8mm tape. Currently, E760 averages approximately 87 events/sec written to tape. This is adequate for nearly all the channels of interest.

In preparation for the FNAL Fixed Target run of 1991, several modifications

and additions to the data acquisition system were made. The most significant in terms of physics capability was the expansion of the ACP from 20 to 27 microprocessors. This allows for either an increase in overall hardware rate or more types of interesting physics flagged by the ACP. Charged trigger logic and neutral trigger logic are now done concurrently instead of sequentially. This was implemented to make better use of the calorimeter delay cables and to have the calorimeter OR as the event strobe. The neutral event readout was modified to include the hodoscopes and the Cerenkov counter, increasing the neutral event readout time by less than 10% and at the same time adding essential information.

A program to monitor the clocked events was developed and implemented. This provides monitoring of hardware rates and critical quantities such as beam current, orbit length, gas jet pressures, etc.

### 5.3 Solution of the Pile-up Problem (K. Gollwitzer)

With every triggered event there exists the possibility that signals from another interaction close in time will also be recorded. A procedure has been developed to identify the extra signals in the central electromagnetic calorimeter. The calorimeter signals are charge integrated for 150 ns. Secondary event signals can occur within this 150 ns gated time window and up to 600 ns before the triggered interaction. The reason that signals from interactions occurring 600 ns before the trigger must be considered is that the calorimeter signals have long tails in which a significant amount of charge can be found 500 ns after the arrival. The extra signals can appear as extra particles in the final state. This condition is called "pile-up," and its severity is proportional to the instantaneous luminosity.

E760 does not have 1280 TDCs or latch units, which would allow one to be used with each central calorimeter counter. The procedure for identification of signals caused by pile-up (out-time) as well as the signals from the trigger interaction (in-time) uses the Level I and Level II Summer signals[8]. Briefly, there are 160 latch coincidence units corresponding to a Level I sum signal of 9 consecutive counters within the same ring (same  $\theta$ ) and 40 sets of 2 charge integrating ADCs corresponding to a Level II sum signal of 5 Level I sum signals within the same azimuthal octant of ( $5 \times 9$  grid of counters). The 2 ADCs of each set are gated independently, the same 150 ns gate as the central calorimeter counters and a gate shifted to earlier in time. During the first half of the 1990 data run, the two ADCs integrated charge for overlapping time windows; in the second half of the run, the time windows were non-overlapping and consecutive in time. Overlapping time windows will be used for the 1991 data run.

The Level I sum coincidence units, or pattern units, had an effective threshold of 80 MeV. However, an energy deposit is generally shared by some counters which can participate in different sums. The threshold for an incident particle was essentially 120 MeV for a pattern unit to have a signal. The E760 central calorimeter was designed to be able to detect 50 MeV photons. This detection level is necessary to identify low energy photons from asymmetric  $\pi^0$  decays, the major source of background for two gamma final states. It is also necessary to ascertain if the low energy signal is from the triggered interaction.

If the pattern units are not capable of making a determination of whether a

signal is in-time or out-time, the Level II sum signals are used. A ratio of the two ADCs values is calculated. There is an acceptable range of ratios which will determine a signal to be in-time; outside the range, the signal is out-time. There are however cases when the two signals participate within the same Level II sum, making it not possible to determine the time status of the signals.

This procedure has been used successfully. If the  $\chi_1$  or  $\chi_2$  analysis of the final three body state ( $\chi \rightarrow J/\psi\gamma$ ,  $J/\psi \rightarrow e^+e^-$ ) includes a cut on the number of signals, instead of the inclusive  $J/\psi$  final state analysis, the additional identification of the out-time signals increases the number of events in the chi sample by 8%. Another significant result has been in the  $^1P_1$  search using the three gamma final state ( $^1P_1 \rightarrow \eta_c\gamma$ ,  $\eta_c \rightarrow \gamma\gamma$ ). Before applying the procedure, there were 16 events which satisfied the analysis from the three  $^1P_1$  search points as well as from the  $\chi$  and  $\psi'$  data points (a total integrated luminosity of  $3.5 \text{ pb}^{-1}$ .) When the procedure is performed, only 4 events pass all cuts, and these events are all from  $700 \text{ nb}^{-1}$  of data from two of the  $^1P_1$  search points.

For the 1991 data run, work is progressing in lowering the threshold of the Level I pattern units to a detection threshold of 50 MeV. This will decrease the pile-up signals which can contaminate central calorimeter identification of final states. This is more important for the 1991 run, since it is planned to take data with a greater instantaneous luminosity than during the 1990 data run.

#### 5.4 Calibration and Linearity of the Central Calorimeter (A. Smith)

Since the bulk of the physics program in the 1991 E760 run is dedicated to the study of charmonium decay to all-neutral channels, the role of the central calorimeter becomes even more important than before. Understanding the statistical and systematic errors in calibration, specifically the effects of non-linearity in the central calorimeter, is vital to the reduction of background. During the 1990 run, the calorimeter was calibrated to  $8\%/\sqrt{E}$ , and during the upcoming run we hope to do better.

The central calorimeter is calibrated using  $e^+e^-$  decays of the  $J/\psi$ . The electrons from the  $J/\psi$  can be tagged and tracked using the hodoscopes, tracking chambers, and Cherenkov detector to separate the signal from the hadronic background. These tagged electron showers are used to calibrate the central calorimeter in rings 1 to 14 of the 20 ring detector. The downstream 6 rings cannot be calibrated this way because when an electron or positron from a  $J/\psi$  decay hits these rings the accompanying particle escapes our detector and the event is not tagged. During the 1990 run, machine problems limited our luminosity at the energy of the  $J/\psi$ , so only about 3000 events were collected. In the upcoming 1991 run we hope to more than double this number. The forward rings are calibrated with  $\pi^0\pi^0 \rightarrow 4\gamma$  events. The cross section for this channel is large enough so that tens of thousands of these events have been collected. The events are tagged by their kinematics with an approximate calorimeter energy calibration and then the positions of the showers are used to predict the shower energy. The problem with this method is that, in general, the gammas from  $\pi^0$  decays have overlapping showers in the calorimeter, making it difficult to deconvolute the contribution of each showering gamma to the pulse

height in a given channel. In addition, the calorimeter's resolution in  $\theta$  and  $\phi$  is slightly inferior to that of the charged tracking, making energy reconstruction more inaccurate. However, the superior statistics allow the neutral calibration method to rival that of the  $J/\psi$  calibration.

The calibration of the calorimeter with electron showers from the decay of the  $J/\psi$  has the drawback that the angle between the beam axis and the electron track exactly determines the electron's energy. The result is that each block is illuminated by showers of only one energy, making it impossible to study nonlinearity with this channel. Study of exclusive two electron decays of the  $\psi$  introduce a second energy point about 40% higher in energy than the  $J/\psi$ . We have only collected about 200  $\psi$  exclusive decays to 2 electrons, but we can show that the calorimeter is linear to within 3% (ie. systematic errors due to nonlinear effects are below 3% in this energy regime) in the region between 1.5 and 5 GeV. Linearity in the low energy region is being studied through the kinematical reconstruction of  $\eta\eta \rightarrow 4\gamma$  events. In the case of the  $\eta$ , unlike the  $\pi^0$ , the separation is in general large enough so that the showers formed by the gammas from the decay of a single  $\eta$  do not overlap. Kinematical fitting is used to calculate the energy of each gamma from the positions of the showers in the calorimeter, and these are compared to the measured energies in the calorimeter. Initial indications confirm that the calorimeter is linear above 1 GeV to within 3%, but below 500 MeV the measured energy may be on average as much as 8% to 10% lower than the actual energy. Further work needs to be done with the event selection for this channel before we can introduce a software fix to the problem of nonlinearity in the low energy region. The reduction of systematic effects in the measurement of soft gammas (below 1 GeV) is important in the study of several physics channels, including the recoil gamma from  $^1P_1 \rightarrow \gamma\eta_c$  and any channel including  $\pi^0$ s or  $\eta$ s.

### 5.5 Monte Carlo Simulation and Shower Library (G. Zioulas)

The main background to electromagnetic decays of charmonium states that have photons as final products arises mostly from 2 or more  $\pi^0$ s exclusively produced. Due to their relatively high energy (about 3 GeV) the  $\pi^0$ 's decay to two photons of small opening angles. This results in two showers closely spaced in the calorimeter, which can be reconstructed as one due to the transverse development of the electromagnetic showers and the segmentation of the calorimeter. For example, 2  $\pi^0$ 's produced at the  $\chi_2$  energy can be reconstructed as two photons and add to the background of the decay channel  $\chi_2 \rightarrow 2\gamma$ . To study these cases, a Monte Carlo simulation of the detector was made using the GEANT software package. Events with 2  $\pi^0$ 's were generated with flat angular distributions, and the  $\pi^0$ 's were each made to decay to photons at the vertex of the interaction. The photons were then propagated through the detector and showers in the lead glass were generated using the EGS program. Distributions of kinematical variables simulated by the Monte Carlo were compared to the corresponding distributions measured in the data and were found to be in good agreement. However, the EGS Monte Carlo is very slow and it is almost impossible to accumulate enough statistics to study the effect of the overlap of the two showers.

To solve this problem, a shower library was produced using electromagnetic showers extracted from the data. Data with exclusively produced  $J/\psi$ 's were analyzed and the single electron showers were kept in a file, sorted according to their energy and position in the calorimeter. For each shower the energy,  $\theta$ ,  $\phi$  coordinates and the fraction of the energy deposited in each block of a 3x3 block grid, centered at the hit block, were saved. Due to the azimuthal symmetry of the calorimeter, the 64 wedges were folded to half wedge in order to minimize the number of the different cases and to increase the number of showers per case. The half wedge was divided into 5 strips and the 20 rings to 148 strips, creating cells of 10 mrad by 7 mrad in  $\phi$  and  $\theta$ , respectively. The showers that hit each of these cells were sorted in ascending energy. More showers, of energies lower than the energies of the  $J/\psi$  electrons, were added to the library by analyzing data with  $\eta$ 's. The opening angle of the photons of the  $\eta$  decays is 4 times larger than the corresponding angle of the  $\pi^0$ , making the extraction of isolated single photon showers more efficient.

During the 1991 run, the accumulation of more  $J/\psi$ 's and neutral events will increase the statistics in the shower library and the efficiency of the Monte Carlo program.

## 6 Proposed Calorimeter Upgrade for Future E760 Running

For the next Fixed Target running cycle at Fermilab, it will be important to upgrade the Central and Forward Calorimeter readout and calibration systems. The calorimeters themselves work very well and no design changes to the detectors are envisioned.

### 6.1 Readout

The E760 Calorimeters are read out to FERA ADC's. Certain groupings of channels are added by the "Summer Boxes" and discriminated to obtain patterns necessary for triggering. There are additional ADC's which digitize the summer outputs. These are used to reject events with extraneous ADC data caused by the long tails from pulses coming from interactions which are earlier than the event of interest. Unfortunately, at high luminosity we lose a significant number of events (1%/ma of stored beam) and pile-up induced background is still present, albeit at a low level. For the next Fixed Target cycle, we anticipate higher luminosities and expect to study lower cross section channels. These conditions will aggravate the problem caused by pile-up. The long pulse tails are caused mainly by the large amount of delay cable, (about 55 feet of RG174 plus 250 feet of RG58) between the phototube and the ADC. There are several possible cures. One is pulse shaping at the ADC, which would require shaping amplifiers on each channel. A second is TDC's on every channel. A resolution of several ns is sufficient and 5 or 6 bits is adequate. Commercial TDC's and the required discriminators are very costly and represent overkill. They also cause a large expansion of the CAMAC system and contribute significantly to readout time. A third alternative is CAMAC latches. These are packaged

densely, are much less costly than TDC's and do not increase the readout time. Discriminators are still required. We are leaning toward the last option. A rough cost estimate for this upgrade of the Central and Forward Calorimeters is \$200,000. If this cost is shared according to the same formula as the Central Calorimeter (20% per U.S. university group), UCI's share will be \$40,000.

## 6.2 Calibration and Monitoring System

The existing system, built by UCI, consists of a Xenon Flash Lamp which illuminates all of the lead glass counters via fiber optics. Monitor PMTs allow normalization of the lamp intensity. The light pulses are much longer than those due to Cerenkov light, which causes a significant error in the calibration. We intend to replace the Xenon lamp with a Nitrogen Laser which can produce narrow pulses of adequate intensity, which will cost about \$20,000.

## 7 The BES Experiment

A collaboration of American Institutions has been formed to upgrade and exploit the BES Detector at BEPC, the Beijing Electron Positron Collider. These include SLAC, UC Irvine, Caltech, the University of Washington and the University of Texas at Dallas. At UCI, the collaborators include Professors Andrew Lankford, Mark Mandelkern and Jonas Schultz, and Dr. George Zioulas. Andrew Smith will do his Ph.D. thesis research on this project. The UCI group intends to add an additional post doctoral physicist to the collaboration. The UCI group has a particular interest in charmonium physics and intends to lead the effort to upgrade the data acquisition capability of BES, which is crucial in view of the luminosity upgrades in progress.

### 7.1 The BEPC Machine

The machine is an electron positron collider designed to operate in the charmonium regime. The maximum energy is 2.8 GeV per beam, and the luminosity at the  $J/\psi$  is approximately four times that of SPEAR, or approximately  $2 \times 10^{30}$   $\text{cm}^{-2}\text{s}^{-1}$ . The machine is designed to be upgradeable from single bunch to multibunch operation. A low beta insertion at the interaction region is anticipated. It is expected that the luminosity will be increased by approximately one order of magnitude over the next several years.

### 7.2 The BES Detector

The BES is a solenoidal magnetic detector of nearly  $4\pi$  solid angle (Figure 6). It is roughly similar to the Mark 3 Detector at SPEAR. Its main components are a Vertex Wire Chamber, a Main Drift Chamber, a lead/self quenching limited streamer tube Barrel Shower Counter, a TOF Scintillation Detector System, a Proportional Chamber System outside of the magnet iron for muon detection, and two End Caps. The Vertex Chamber and the End Cap TOF and Shower Counters are read out but are not yet part of the event reconstruction. The performance of the operational systems is not yet comparable to similar systems

at Mark 3, however reasonable data has been taken (see below). The data acquisition system of BES is also based on that of Mark 3, in particular on sample and hold ADC's and TDC's which are read out by BADC modules in CAMAC, which are then read out serially into a Unibus VAX 785. This system is designed for the low luminosity operation of SPEAR and is already operating at approximately 20% dead time at BEPC. At the higher anticipated luminosities, not only would the deadtimes be prohibitive, but the reset time required by the front end electronics would not be available.

Several aspects of the BES Detector are worth noting in the consideration of upgrading the detector:

1. The Barrel Shower Counter has a worse resolution ( $22\%/\sqrt{E}$  compared to  $17\%/\sqrt{E}$  for Mark 3) because it utilizes streamer mode instead of proportional mode. The expense of retrofitting is about \$.5M (new amplifiers for each of 22000 channels) and the improvement in performance is probably not worth it. A more modest upgrade consists of adding readout channels such that the electromagnetic shower is more finely sampled near its origin, i.e. at small radii. We hope to find existing SLAC electronics which can be installed for this purpose.
2. The Vertex Chamber consists of 4 layers of cylindrical drift chamber. It is not capable of very precise vertex determination. An idea which we are considering is to install the Mark 3 Vertex Chamber at BES. Among its features are a Beryllium beam pipe which would be a major improvement over the 2 mm Al beam pipe now in place. Required are 640 channels of drift chamber TDC which will cost about \$75,000. This expenditure is well worth it.
3. The Main Drift Chamber has an insufficient number of independent high voltage channels, which causes unwanted coupling between adjacent layers. We hope to add about 60 channels by utilizing old SLAC equipment.
4. We plan to add modules obtained from SLAC to the data acquisition system to improve its performance somewhat. In particular we wish to add sufficient BADC so that there will be 1 per CAMAC crate of sample and holds. We hope to speed up the cycle time with which data words are transferred to the VAX from the BADC's from the present 8-10 microseconds/word to 3 microseconds/word. It should be possible to make the trigger more stringent. These improvements should allow us to run at higher luminosities so long as there are fewer than about 3 bunches in the ring. Full multibunch operation requires a new front end for the system, which is our long term goal. We plan to study the suitability of electronics designed for high luminosity hadron colliders for which large numbers of channels can be obtained at modest cost.

### 7.3 1990/91 Running

The commissioning of BES was done at the  $J/\psi$ , and a total of 10 million  $J/\psi$  events were recorded. These are being used for calibration of the detector and also for the physics analysis of various channels, in particular multipion,

multikaon and radiative decays. A new measurement of the  $J/\psi$  width was made, a run at the  $\psi'$  yielding 150,000 events was performed, and a test run at low luminosity was done at a center of mass energy of 4.03 GeV to investigate the collider performance there. Analysis of the  $J/\psi$  data is in progress. The  $\Xi(2.2)$  is observed in several channels, and the  $\pi^+\pi^-\pi^0$  Dalitz plot is being fit with an amplitude analysis. First data from BES have been presented at the 1990 Singapore Conference.

#### 7.4 1991/92 Run Plans and Physics Goals

The BES detector is being repaired and upgraded prior to the Fall, 1991 run which should commence on October 4. The Main Drift Chamber is being repaired, and the trigger is being upgraded, including the addition of Mean Timers to the TOF system. The Fall run will end on January 25, 1992, and a Spring, 1992 run will start sometime in March or April.

The physics goals of BES include the following:

1.  $\psi$  physics, including study of radiative transitions to glueballs and to the  $\eta_c$  and  $\chi$  states, study of neutral decays of the  $J/\psi$ , study of  $\eta_c$  and  $\chi$  state hadronic decays.
2.  $\psi(3770)$  physics for study of the non-D  $\bar{D}$  branching modes, D physics, including CKM matrix elements, double Cabibbo-suppressed decay events,  $D^0 \bar{D}^0$  mixing, absolute branching ratios for D decay, including leptonic decay yielding a measurement of  $f_D$ .
3.  $D_s$  physics is one of the potentially richest areas for BES. Absolute branching ratios for very few modes have been observed. We will study hadronic and semileptonic modes and try to observe the purely leptonic mode for a measurement of  $f_{D_s}$ . An important issue here is where to run. Mark 3 ran at 4.14 GeV, well above threshold. It has been speculated that there is a peak in the cross section at 4.03 GeV, which would allow application of a beam energy constraint. The collaboration will take some data at 4.03 GeV to determine whether it is a good place to take data.
4.  $\tau$  Physics: Several important measurements are the mass, Michel parameter  $\rho$ , and observation of various rare decay modes. We intend to do a one month run at the  $\tau$  threshold regime this fall.
5. Charmed baryon production: There is little good data with charmed baryon events.

As noted above, we will shortly take some data at 4.03 GeV and above tau threshold. The remainder of the Fall, 1991 run will be devoted to  $\psi(3770)$  running to do D physics.  $D_s$  physics will be done in subsequent run periods, the energy to be determined by the results of the 4.03 GeV run.

#### 7.5 UCI Contribution

The UCI group is investigating the data acquisition upgrade required at BES. Our goal is to design a system upgrade at modest cost, but one which is suitable

for an anticipated ten year running cycle. We expect to exploit the technologies which are being developed for SSC data acquisition, which include low cost, densely packed electronics capable of much higher acquisition rates than those anticipated at BES. The UCI group anticipates beginning a data analysis program with the data which will come from the Fall, 1991 run. We have a particular interest in  $\psi(3770)$  decay, which is related to our FNAL charmonium studies.

## 8 REFERENCES

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## 9 FIGURE CAPTIONS

Fig. 1 The E760 Detector

Fig. 2 Excitation curves from scans of (a)  $\chi_1$  and (b)  $\chi_2$ . Full curve represents best fit to the data, and dashed curve shows a typical center of mass energy distribution for the beam.

Fig. 3 Invariant mass of the  $e^+e^-$  (a) after passing preliminary cuts and a cut on the electron quality, and (b) in the final  $\chi_2$  sample. The shaded area corresponds to events collected in a control region outside the resonance, normalized to equivalent luminosity.

Fig. 4 Measured 2 gamma cross section as a function of center of mass energy, showing a possible enhancement at the  $\chi_2$ .

Fig. 5 Measured 3 gamma cross section as a function of center of mass energy, showing a possible signal near the  $\chi$  center of gravity.

Fig. 6 The BES Detector

## 10 APPENDICES

*Processed Separately*

Appendix A: "A Search for Narrow States in the Inclusive Gamma Ray Spectra Resulting from Antiproton Annihilations at Rest in Liquid Hydrogen and Deuterium", N. Graf, et al.

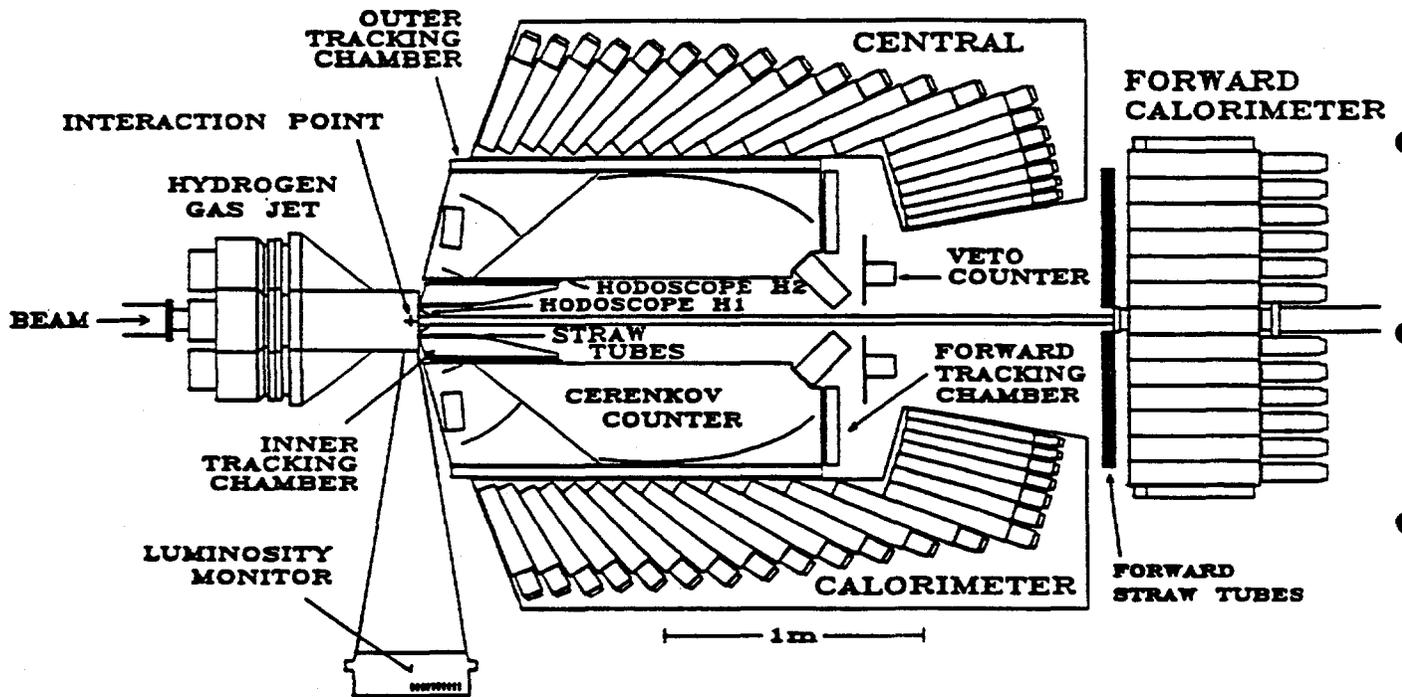
Appendix B: "A Precision Measurement of the Branching Ratio  $K^+ \rightarrow \pi^+ \pi^0$  /  $K^+ \rightarrow \mu^+ \nu_\mu$ ", T. Usher, et al.

Appendix C: "Precision Measurements of Charmonium States Formed in  $\bar{p}p$  Annihilation", T. A. Armstrong, et al.

Appendix D: "Study of the  $\chi_1$  and  $\chi_2$  Charmonium States Formed in  $\bar{p}p$  Annihilation", T. A. Armstrong, et al.

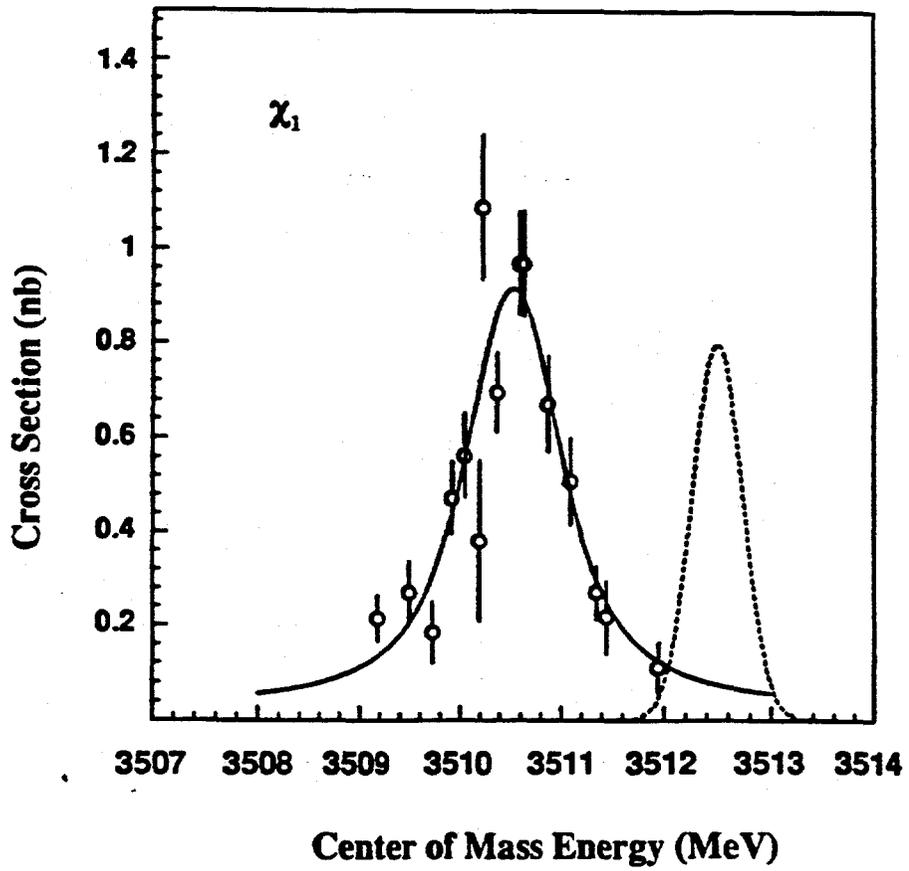
Appendix E: "Charmonium Spectroscopy in the Fermilab  $\bar{p}$  Accumulator Ring," T.A. Armstrong, et al. (preprint draft)

*preprint removed*



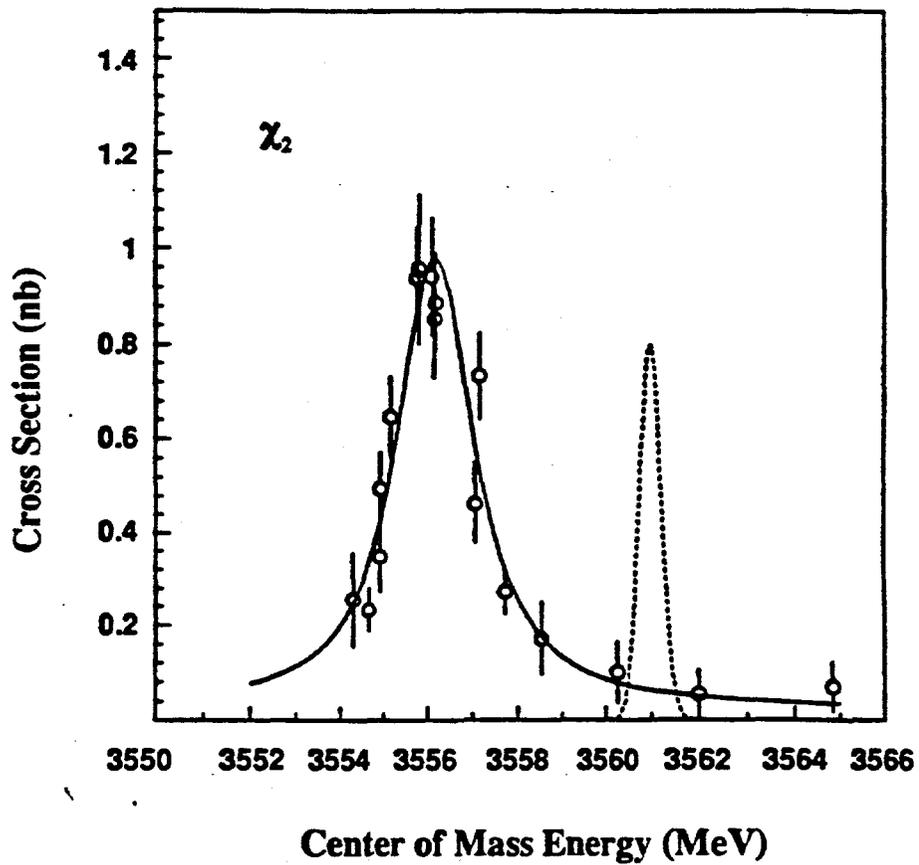
**Fig. 1: E760 equipment layout.**

Fig. 1



The excitation curve observed for the  $\chi_1$ .

Fig. 2(a)



The excitation curve observed for the  $\chi_2$ .

Fig. 2(b)

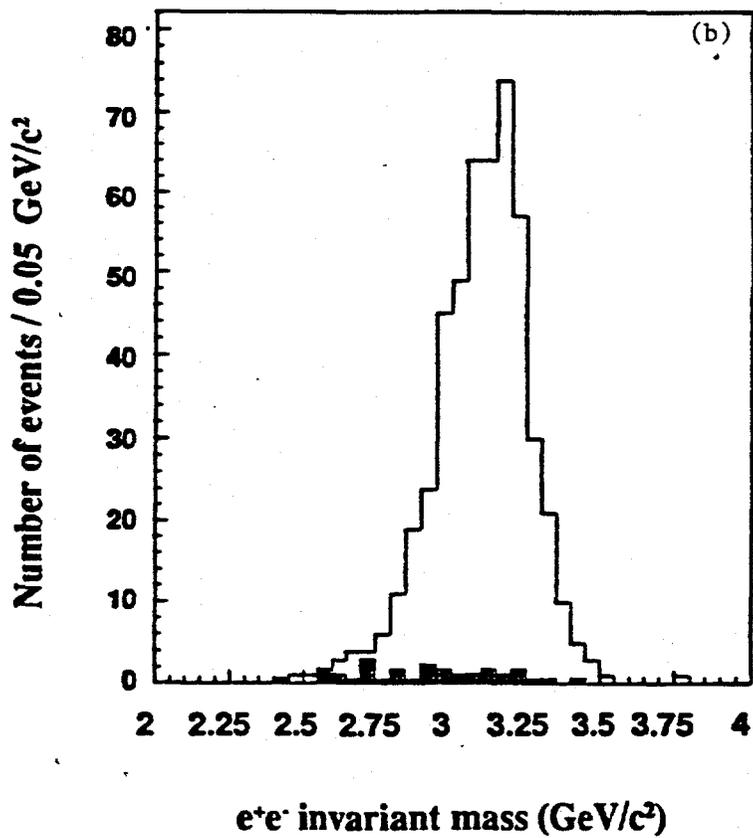
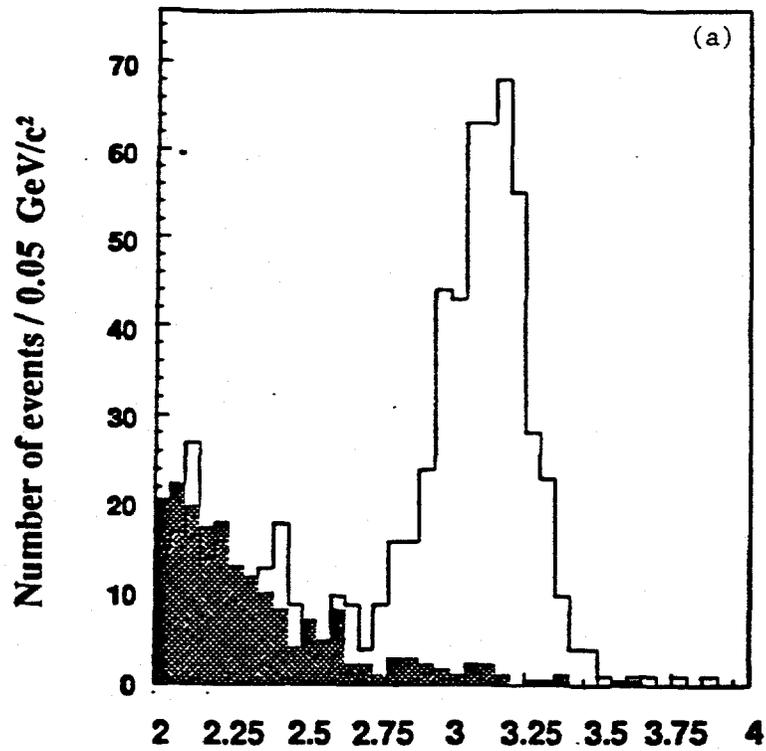


Fig. 3

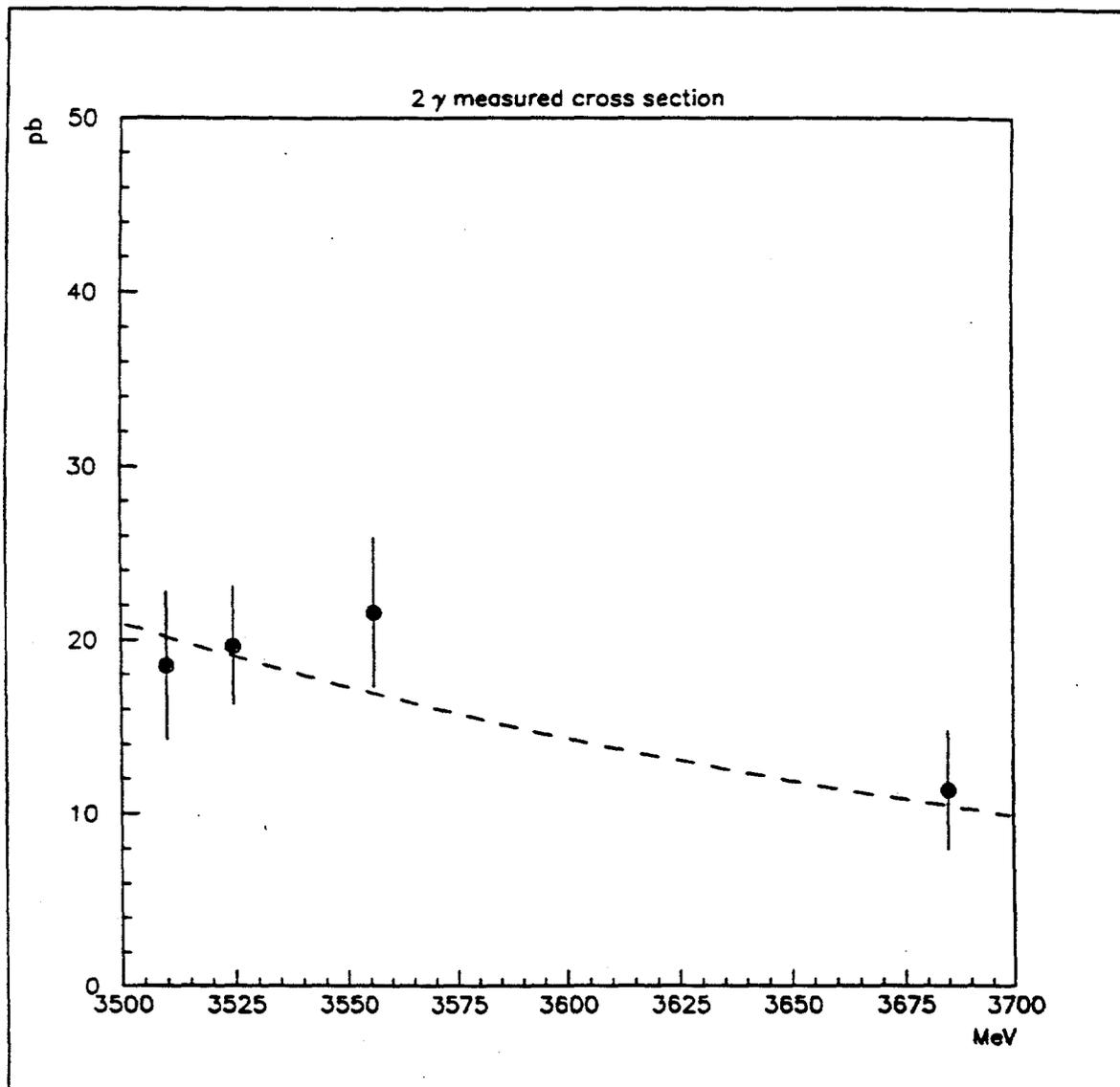


Fig. 4

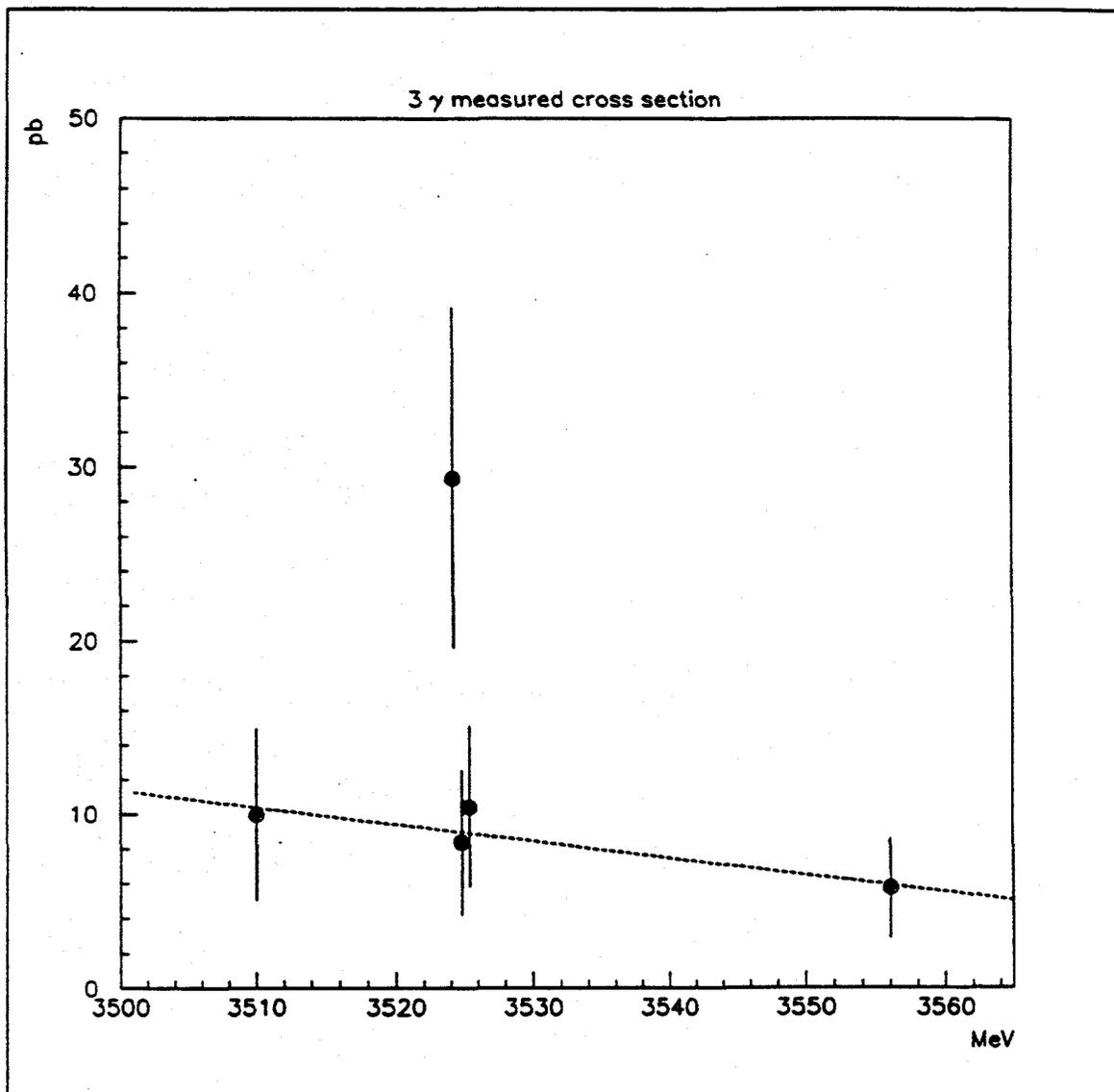
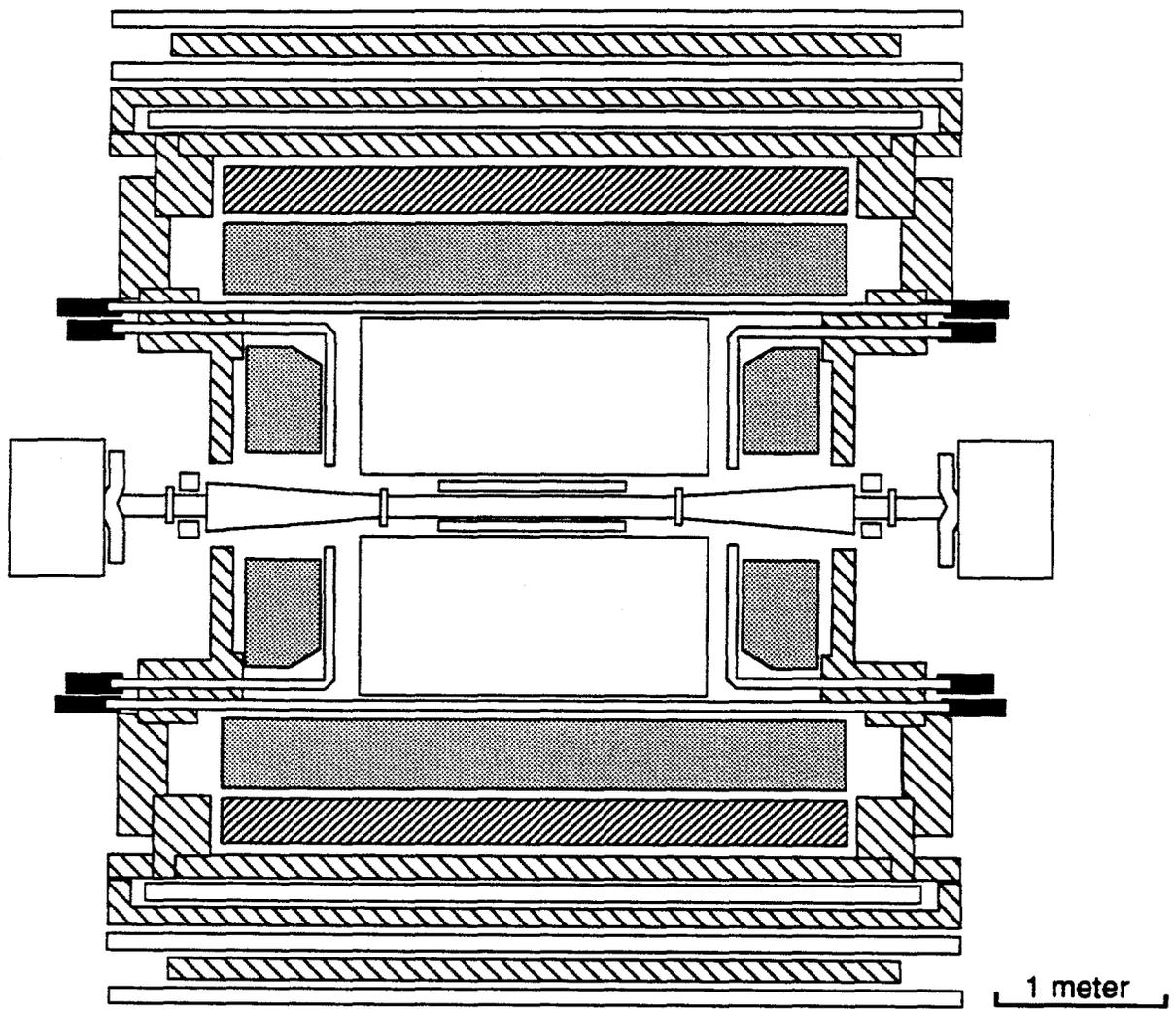


Fig. 5



# BES Detector

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Fig. 6