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PROPOSAL TO STUDY $\bar{p}N$ INTERACTIONS IN THE P-WEST HIGH INTENSITY LABORATORY

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Proposal To Study $\bar{p}p$ Interactions

In The P-West High Intensity Laboratory

ABSTRACT

We propose to study the reactions:

$\bar{p}N \rightarrow$ neutral vee (Λ or K^o) + x

$\bar{p}N \rightarrow x^o + y^o + x$ (x^o and y^o are γ, π^o, η, ω)

$\bar{p}N \rightarrow e^+ e^- + x$

at a set of energies which will depend on the technique used to produce the $\bar{p}$ beam. In the case of each reaction, we will analyze as complicated an accompanying neutral and charged topology as possible with the proposed two magnet forward spectrometer. If the technique of using the antiprotons from the $\bar{\Lambda}^o$ decays in the 0^o neutral beam at the High Intensity Laboratory is used, then 100 GeV/c^2 and 200 GeV/c^2 $\bar{p}$ runs are proposed. If an accelerated antiproton beam is available from the accelerator then 300 GeV/c^2 and 400 GeV/c^2 data taking is proposed. The study of these antiproton interactions should be quite complementary to any colliding beam experimentation because of the luminosity advantage of a fixed target experiment.

INTRODUCTION

For some time it has been expected that a very exciting set of experiments could be performed with antiprotons. When compared with proton-proton experiments done at similar energies, such experiments should yield evidence for the quark structure of the nucleon and show marked effects arising from this structure. The probability of quark-antiquark interactions because of the presence of valence antiquarks in the antiproton structure should be much enhanced and the average center of mass energy of the quark-antiquark system is much greater than that of the quark-antiquark systems in pp collisions. This should lead to greater accessibility of high mass states. In addition, the presence of an antibaryon in the initial state should lead to enhanced charmed antibaryon production.

Because of these reasons, we are proposing to set up a forward spectrometer in the P-West High Intensity Laboratory[1] in the Proton Area to study $\bar{p}N$ interactions in a fixed target experiment. The general geography of this area is shown in Figure 1. The interactions that we propose to study would allow us to search for new particle production at high M^2/S and to gather additional information about the nucleon structure. We propose to use the High Intensity Laboratory because of the unique capability of generating a moderately clean, high intensity $\bar{p}$ beam. Even if an accelerated antiproton beam is available from the main ring, this would still be the selected site because of the limited percentage of machine time that would be available for antiproton acceleration in the main ring. In this location, lower energy $\bar{p}$ experimentation could still be carried out during the times when protons were being accelerated in the main ring.

The forward spectrometer that we propose would consist initially of two modified BM109s, a liquid argon shower detector capable of giving position and energy of photons and electrons with good resolution, and a proportional and drift chamber arrangement for measurement of the charged particles. With this two-magnet configuration, we would begin to study the mass spectra of all dileptons and diphotons (with good neutral and charged meson rejection) up to 6 GeV/c^2. In addition, with the planned neutral vee trigger and the relatively large aperture spectrometer, we would be able to isolate a data sample with strangeness in the final state and analyze relatively complicated topologies in which charmed baryon production had been enhanced.

The construction of the High Intensity Laboratory is proceeding rapidly and experiments requiring large spectrometer magnets are approved for this area. We believe that we can begin to do reasonable physics with a relatively modest set of spectrometer magnets which may, in fact, suffice for the first stage of other experiments.[2] Our interest will require (as explained in the body of the Proposal) large aperture. The two-magnet scheme is a compromise solution to the problem of extending acceptance of the spectrometer to cover as much of the charged particle phase space as possible. We think that a 200 GeV beam transport will exist and a suitable analysis magnet configuration can be achieved within 1-1/2 years. From the time that this occurs until an accelerated antiproton beam is available, this will be a unique spot to do high energy, high intensity $\bar{p}$ physics. If the accelerated beam becomes available, this spectrometer would be ready to extend the measurements quickly to higher energies.

Finally, even if a colliding proton-antiproton ring can eventually be achieved, fixed target experiments have been shown to be extremely fruitful. (Witness the comparison of the ISR and the Proton Area physics programs.) For some of the final states which we wish to study, the large laboratory energy of the outgoing particles is a positive asset to particle identification and energy determination and the luminosities of the fixed target experiments are superior to the contemplated proton-antiproton ring.

ANTIPROTON BEAM

Two quite independent approaches to obtaining a clean antiproton flux have been considered by us. The first of these is the technique[3] of using the neutral beam capability of the High Intensity Laboratory transport to produce a $\bar{\Lambda}^o$ flux. The schematic layout of the neutral beam channel and the charged transport of the High Intensity Laboratory beam is shown in Figure 2. The antiprotons from the decay $\bar{\Lambda}^o \rightarrow \bar{p}\pi$ are collected in a 10% momentum region by the high efficiency, large aperture beam and transported to the Experimental Hall. This technique for producing a secondary antiproton beam is much cleaner than any technique which uses the antiprotons directly produced at the target. In Figure 3, we show the expected fluxes of $\bar{p}$s along with π^- backgrounds arising from $K_S^o \rightarrow \pi^+ \pi^-$ and $\Lambda^o \rightarrow p\pi^-$. (We have used the Λ^o and K_S^o zero degree yield curves[4] as measured by E-8 in this calculation.) Even at 200 GeV, the $\bar{p}/\pi^-$ ratio attained in this scheme is 1/1, in contrast to the expected direct production ratios of $\bar{p}/\pi^-$ at small angles ($\leq$ 7 mrad) of 1/20. Additional backgrounds due to scraping of the neutral beam are not estimated but are not expected to be serious. Operation of this technique with 10^{13} protons should yield 2×10^6 $\bar{p}$ at 200 GeV/c. With the present 400 GeV accelerator it should be possible to produce 300 GeV/c antiproton beam if the rising backgrounds indicated by Figure 3 can be tolerated. As shown in Figure 4, we propose to separate the residual π^- background from the antiproton flux up to 400 GeV/c by use of an 80-foot differential Cerenkov counter just upstream of the experimental target. Assuming that the spill structure of the machine continues to be the same as experienced in the past[5], we believe that this Cerenkov counter can operate with a total π^- and $\bar{p}$ flux up to and perhaps exceeding 10^7 particles/second. We expect no K^- in this beam apart from a very small percentage produced by slit scattering.

The second approach which we have considered for obtaining a clean antiproton beam holds the most promise and is the most powerful method both from a flux and energy standpoint for a given energy of the machine. This method utilizes the possibility of accelerating antiprotons in the main machine. According to the Harvard-Wisconsin proponents of antiproton cooling and storage[6], 4×10^7 cooled $\bar{p}$/main ring pulse is possible. This flux would be a factor of 20 above the maximum flux that would be available in the $\bar{\Lambda}^o$ beam if this cooled $\bar{p}$ beam was not stacked in the storage ring but injected into the main ring, accelerated to the maximum machine energy and extracted to the Proton Area. (We assume that the cycle time for such a process would not be appreciably greater than the standard cycle time for the acceleration of protons to 400 GeV/c.) An additional advantage of this method of achieving an antiproton beam is that all the 'traditional' proton target stations in the Proton Area would technically be available for the site of the spectrometer. In particular, the upstream area in P-West would be available if the planned extension[7] of the PW1 pit is realized. The EE4 area which utilizes the broad band photon beam would also be a possibility if the photoproduction program in P-East were to permit. (The P-Center Area is a possibility but technically is somewhat harder because of the construction of the target point for the Hyperon Area.) The marked disadvantages of this second approach are that it certainly will require a much longer time to realize since the antiproton work is just getting under way; and that even after it becomes an established fact, the percentage of time in which acceleration of antiprotons for extraction to the external areas would be possible would even optimistically probably be less than 15%. Finally, the $\bar{\Lambda}^o$ antiproton beam will have enough π^- that a useful comparison of $\pi^-/\bar{p}$ interactions can be done at the same time as the antiproton experimentation is proceeding.

In view of the above consideration, our preferred site for the antiproton experiment remains the High Intensity Laboratory. This site gives the option of utilizing immediately this unique $\bar{\Lambda}^o \rightarrow \bar{p}$ beam and keeps the option open of using an accelerated antiproton beam if it becomes available.

LUMINOSITIES

Assuming that antiprotons are available on a 15-second cycle and assuming a segmented .5 interaction length Be target (approximately .5 radiation length) the effective luminosity will be:

$N = 2.2 \times 10^{-3}$ events/sec/nbarn for $\bar{\Lambda}^{o}$ beam

$N = 4.4 \times 10^{-2}$ events/sec/nbarn for an accelerated antiproton beam

In comparison, the luminosity for the proposed storage ring scheme of Reference 6 is:

$$N = 10^{-4} \text{ events/sec/nbarn}$$

for the coasting-colliding period. Therefore, as is the usual case, the fixed target and the colliding beam programs emphasize a different type of physics. The search for low cross section effects of moderate masses is best pursued in the fixed target environment, while the search experiments for high mass objects produced with 'reasonable' cross sections clearly belong in the colliding beam realm. (This remark ignores, of course, relative acceptances of feasible experimental setups.)

PHYSICS CONSIDERATIONS

The motivation for this experiment has been provided partially by previous experiments performed with intense[7,8,9] proton and neutron beams in the Proton Area and partially by theoretical considerations concerning the quark structure of nucleons and antinucleons and the effect of this structure on reaction rates.[10,11,12] We have selected three reactions which will allow us to:

1. Search for new charmed resonance production with hope of better signal-to-noise ratio because of either the enhanced probability of quark-antiquark annihilation or the presence of the antibaryon in the initial state. We also expect because of the valence nature of the antiquarks in the antiproton to have a much enhanced probability of producing high mass states.

2. Investigate the point-like structure inside the nucleon via the Drell Yan mechanism by observation of the lepton pair production as a function of M^2/S.

We chose to concentrate at least initially on the reactions:

1. $\bar{p}N \rightarrow$ neutral vee (Λ or K^o) + x
2. $\bar{p}N \rightarrow x^o + y^o + x$ (x^o, y^o are γ, π^o, η, ω)
3. $\bar{p}N \rightarrow e^+ e^- + x$

The purpose of studying Reaction 1 is to isolate the case of a relatively complicated final state with strangeness. In the GIM charm[7] scheme, almost all of the Cabibbo favored weak transitions of the charmed baryons generate K^o, Λ, Σ^o, Ξ^o, Ξ^-, Ω^- and/or their decay components. Compared with proton-proton experiments, we expect an enhancement of the production rates at high mass for a given final state because of the expected average momentum of the valence antiquark vs. the expected average momentum of a sea antiquark.

The desire to study Reaction 2 in this experiment is also motivated by expected enhancement of quark-antiquark annihilation process[11,12] in antiproton-proton interactions because of the expected antiquark structure of the antiproton. The combination of this expected enhancement plus the large solid angle nature of the forward spectrometer used in this experiment will serve to minimize the π^o background in the search for a two photon continuum or two photon resonance production and decay (η_c).

Finally, we also chose to emphasize a measurement of dilepton production since the comparison of the antiproton-proton production rate of dileptons with the dilepton rate as measured in proton-proton collisions[8] will give us additional information about whether our ideas about quark-antiquark annihilation are correct. C. Quigg[12] has calculated the expected increase in dilepton production in $\bar{p}p$ collisions as a function of M^2/S. This ratio is shown in Figure 5.

The expected data rates of interesting final states for Reaction 1 are difficult to estimate since there has been no measurement of a hadronic cross section for charmed baryon production. However, assuming that the cross section of interacting states would not be very different from the reported photoproduction[10] of $\Lambda_c \to \Lambda\pi\pi\pi$ in the broad band beam in P-East with a cross section times branching ratio in the 1 - 10 nbarn[16] range and using a reasonable acceptance of 30% for the proposed spectrometer, we could achieve greater than 150 events per day with the $\bar{\Lambda}^o$ beam operating at 2 x 10^6 $\bar{p}$/pulse at 200 GeV/c. For the dilepton production rate, we estimate that greater than 700 ψ^-/J can be accumulated per day if the rate in $\bar{p}N$ collisions is no greater than that reported in pp collisions[8]. Both of these rates are respectable and represent reasonable sensitivity. Moreover, the interesting two photon structure reported in Experiment 95[9] lies in the 50 nbarn range. This is completely within the sensitivity of this experiment. More detailed Monte Carlo calculations of the acceptance of the apparatus for various final states is under way.

EXPERIMENTAL APPARATUS

The general plan view of the apparatus is shown in Figure 6 and the overall seating of the experiment in the High Intensity Laboratory experimental hall is shown in Figure 4. Table I enumerates the various components of the spectrometer and gives their pertinent parameters. As shown, the heart of this spectrometer is the two magnet system concept. As noted in the discussion[17] of the proposed two magnet system for the Tagged Photon Laboratory system, there are many intriguing advantages to such a system. We also point out that the forward spectrometer[18] which is currently operating in the broad band photon beam also incorporates a two magnet system. The most fundamental of all the advantages of such a system for the physics which we propose to do is the effective increase in solid angle of the spectrometer that comes from separating the magnetic analysis into a high momentum system and a low momentum system. However, we point out that while a two magnet system is highly desirable we feel that we can begin to do exciting new physics with just one magnet.

A. Magnets

We calculate that an adequate two magnet set would consist of two modified BM109 magnets similar to the BM109 operated in the EE4 enclosure in the Proton Area currently. Each magnet would be opened up to a vertical gap of 20". With the horizontal aperture of 24" and the 71" length, the forward 70 mrad cone of neutral flux could be accepted for the neutral vee trigger. For configurations of the apparatus in which we are not triggering on the Λ^o or K^o, we would be able to increase this acceptance to 90 mrad. We would operate these magnets at a maximum of 15 kg for the central field (27 kg meters each). The power required for this type of operation is .5 megawatts per magnet[19]. This is well within the planned power available for an experiment at the High Intensity Laboratory experimental hall. The low conductivity cooling which would be needed is approximately 44 gpm with a 130 psi pressure drop and a ΔT of $83^{o}F$ across each magnet[19]. This capability is available from the upstream LCW system in the High Intensity Laboratory.

In some sense, the availability of magnets will dictate the final configuration used in this spectrometer. The SCM 105 analysis magnets used at Argonne National Laboratory would certainly be marginally acceptable and could be opened up to 20" gap with the same degree of ease (or difficulty) that is required to open up the BM109 magnets. We feel that for our experiment, the extra $\int B.dl$ that would be available in superconducting magnets with these apertures, while nice, would in no way be required to do reasonable physics. The large conventional magnet proposed by J. Peoples[20], while somewhat restricting in vertical aperture, would be acceptable as one of the magnets. The message which we wish to impart is that two conventional magnets with 20" x 24" apertures providing moderate $\int B.dl$ will suffice at least for the first round of $\bar{p}$ experimentation.

Finally, we propose to mount all elements of this spectrometer system, including these magnets, on rails such that longitudinal spacings may be changed at will for the various configurations of the experiment. At the present time, the preferred configuration is shown in Figure 6.

B. Wire Chambers

As shown in Figure 6, we propose to install 33 wire chamber planes. Table II enumerates the varieties and types of chambers desired. As indicated, the size of this spectrometer will require approximately 9000 wires of proportional chamber and 1000 wires of drift chamber.

While this is a large number of wires, it is consistent with the size of the spectrometer and in line with our previous experience[21]. The attempt has been made in this configuration to build a system capable of operating at the highest possible rates. Our experience has been that total rates of 5 MC per square foot of PWC plane are acceptable. Better than 50 nsec time resolution can be attained by the chambers themselves and we propose to use a system combining a parallel transfer of all wire signals via ribbon cable to the counting room and the latching one shot delay electronics, of the type designed by T. Nanamaker[26]. Each set of latches would be strobed out in parallel with every other chamber set, allowing up to 64 wires per chamber set to participate in an event and allowing the readout time of 8000 wires to be less than 2 msec. The dead time per wire can be minimized with this one-shot system to 100 nsec/wire. Presently we have on hand sufficient electronics of this type for 4000 wires. While considerable modification must be done to these electronics to configure it as outlined above, it still represents a considerable resource that can be committed toward the needs of this experiment.

C. Shower Detector

The need for good spatial resolution on the shower, as well as the desire for longitudinal shower development information, has dictated the choice of a liquid argon calorimeter for our shower detection system. Some of us have had considerable experience with the operation of lead glass arrays in previous experiments[22]. The superior speed of a lead glass phototybe arrangement ($\sim$ 40 nsec) has been weighed against the difficulties which we and other groups have experienced in maintaining gain stability for long periods of time and the moderate resolving power for closely spaced photons from π^os. We feel that the enhanced resolving power which is available from a liquid argon calorimeter plus the detailed information on the longitudinal development of the shower is critical, especially for Reaction 2 in which identification of high energy π^os is paramount. We propose a liquid argon calorimeter with the characteristics listed in Table III and schematically shown in Figure 7. In specifying this calorimeter we have relied almost entirely on the sources listed in References 24, 25 and 27.

A device this complicated must be designed very carefully and we are only beginning to work on this item. However, from the work of other people we believe that the device outlined in Table III is possible. In particular, we believe that a 100 - 150 nsec response time per strip can be attained by this device. This, coupled with the shower profile measured in E-95, leads us to believe that we compare reasonably well in rate taking ability with comparable lead glass arrays made up of 2-1/2" x 2-1/2" blocks. This stems from the .4 radiation length half width of the shower. We effectively have a factor of ≥ 2 density medium in the liquid argon array because of the lead plate arrangement and this leads to better spatial containment of a given distribution of showers in a given time interval. This effect should compensate somewhat for both the projection nature of the liquid argon shower detector and the slower response time of the strips.

D. Neutral Vee Triggers

We have two regions in which a neutral vee trigger may be constructed. First, immediately downstream of the target we allow a 2-meter drift space for a decay region. The vee trigger is constructed by counting particles into and out of the decay region with a fast counter hodoscope and appropriate logic. We would require the summed pulse height from the exit hodoscope plane to be greater by twice minimum ionizing than that from the entrance hodoscope plane. The major difficulty with operating such a trigger is the abundant lower energy heavily ionizing emissions from the target. For this reason, we have inserted the Be target for the antiproton beam inside a sweeping magnet (for example, one of the E-95 analysis magnets). We believe that any residual junk from the target will only cause an unbiased loss of real triggers and will not contribute to the trigger rate. Rate calculations indicate that the front hodoscope plane will have no trouble surviving if 5 kg meters of field is available in the small sweeping magnet.

In order to minimize bias against loss of higher energy vees which do not decay, we propose to extend this technique to the front face of the second BM109 by inserting two more hodoscope planes, one at the exit of the first magnet and one at the entrance of the second BM109. The analog comparison of pulse height, if done between these planes, should allow us to trigger on Λ^0s in the momentum ranges 6 GeV/c < p < 36 GeV/c and 70 GeV/c < p < 100 GeV/c.

SHOWER TRIGGER

For study of diphoton and dielectron states a shower trigger is planned using the total energy deposits in the east and west liquid argon calorimeter. A similar technique was used in Experiment 95 to trigger on high mass states producing two (or more) high energy electromagnetic showers. In order to implement such a procedure here, summation circuitry must be available for the collection strips in order to reconstruct the total energies of the east and west strips. Because the longitudinal and transverse grouping of the strips is not yet determined, no explicit circuitry has been considered.

RESOLUTIONS

The wire chamber magnet combination outlined above should allow a momentum resolution for 'slow' particles of $\frac{\delta p}{p} \sim 3.0 \times 10^{-4}p$. For the 'fast' particles which pass through both magnets, the resolution is approximately $\frac{\delta p}{\rho} \sim 1.5 \times 10^{-4}p$. This kind of momentum resolution, when coupled with the angular resolution of the front chambers, gives a reasonable mass resolution for the system. In particular, at the ψ/J mass, the resolution in invariant mass should be approximately $\pm$ 25 MeV/c^2. This is due mainly to momentum resolution.

The neutral mass resolution for this system is calculated assuming that shower positions of photons in the argon calorimeter can be determined to $\sigma \sim .1$" using transverse shower fitting techniques which we have developed in previous experiments[22]. This spatial resolution should lead to systems with the photon separated by less than .5". For diphoton masses of 4 GeV/c^2, we should be able to achieve resolutions of $\pm$ 50 MeV/c^2.

For these relatively large opening angle photons, the resolution is due mainly to energy resolution. At the π^o mass, because of the enhanced spacial resolution of this detector over the comparable lead glass array, we expect better than $\pm$ 10 MeV/c^2 resolution.

PARTICLE IDENTIFICATION

Two pressing particle identification problems face us in studying Reactions 2 and 3. In Reaction 3, it is necessary to separate electrons from hadrons. With the spectrometer as designed, the approaches to electron-hadron separation that can be used are:

1. Longitudinal shower development.
2. Transverse shower development.
3. E/p.

From previous experience we believe that the cumulative effect of these three things will be of the order of $10^4/1$ hadron rejection for each charged track. This should be more than adequate to isolate an $e^+ e^-$ sample in the study of Reaction 3.

In Reaction 2, in order to isolate a diphoton signal, good rejection of coalescing π^os is necessary. Our previous experience with a 'coarse grained' lead glass array of 2.5" x 2.5" block size (2.5 rl x 2.5 rl) indicates that 2 showers become indistinguishable when the two photons approach 3" - 4" separation. This separation is, of course, equivalent to a given energy π^o. With a liquid argon calorimeter such as we are proposing, we can hope to distinguish two showers down to 1" separations. This is equivalent to a 160 GeV/c π^o for the configuration of the spectrometer shower shown in Figure 6. For 200 GeV $\bar{p}$ interactions, this will be more than adequate suppression of π^os. For higher energy, the liquid argon calorimeter is simply moved further away.

CONCLUSIONS

We believe that this experiment is one that is begging to be done. The enormous effort that will be invested in producing an antiproton-proton colliding beam facility bespeaks the interest in $\bar{p}N$ collisions. If the interesting physics turns out to be in the moderate mass, lower cross section regime, than a fixed target $\bar{p}N$ experiment such as we propose will be quite competitive using the $\bar{\Lambda}^0 \to \bar{p}$ beam and even more competitive using an accelerated antiproton beam. Currently, no experiment using a forward spectrometer has been proposed to study antiproton interactions in a fixed target experiment. We would argue that it would be extremely useful to do this experiment in order to gain physics knowledge about $\bar{p}N$ interactions <u>before</u> a colliding beams facility is completely designed. Only the two arm 90° CMS spectrometer of Experiment 302[23] proposes to study $\bar{p}$ interactions and only from the standpoint of investigating possible deviations from charge symmetry in the $\bar{p}$ interactions. There is a definite need for a more complicated spectrometer to study more complicated topologies.

COSTS

We present rough estimates for the equipment costs entailed by this experiment.

		COST	WHO
1.	Magnets BM109 (2)*	300K	Proton Department
2.	Wire Chambers	150K	Physics Department
3.	Liquid Argon Calorimeter	150K	Physics Department
4.	Power Supplies - 500 KW (2)**	40K	Proton Department
5.	PREP Equipment	250K	Research Services
6.	Computer PDP - 11/45	80K	Computing Department
7.	Cerenkov Counter (Beam)	20K	Proton Department
8.	Incremental LCW	20K	Proton Department
9.	Counter Hodoscopes	30K	Physics Department
10.	Cabling	30K	Proton Department

These present, at the present, only very rough and very preliminary costs.

PERSONNEL

As indicated on the title page of the Proposal, we expect to have a major Fermilab participation in this experiment with eight staff members and two research associates. The University of Athens will contribute one staff member and one research associate. We are carrying on discussions with a number of individuals at various other universities who are interested in participating in this experiment.

*This is the total cost of two BM109s bought from scratch. The expectation is that BM109s will be available for modifications.

**It is expected that these power supplies will be available out of old equipment.

RUNNING TIME

We feel that we will need at least 300 hours of tuning and calibration to establish the antiproton beam and to make the apparatus function. Beyond this point, we would propose an initial run of 600 hours ($\sim$ 2 months) to take preliminary data. After a suitable period ($\sim$ 6 months) we would ask to return for a run of 800 hours to complete data taking on the three reactions.

REFERENCES

1. B. Cox et. al., P-West High Intensity Secondary Beam Area Design Report, Fermilab (1977).

2. Fermilab Proposal No. 192.

3. We find that a similar technique has been employed in the hadron beam to the 30" chambers in the Neutrino Area at Fermilab. See for example, W. W. Neale, Enriched Particle Beams at the Bubble Chambers at Fermi National Accelerator Laboratory, FN-259, 2200.

4. L. Pondrom, T. Devlin, Private communication.

5. We have found in Experiment 95 that spill non-uniformity causes a factor of two increase in two body accidentals when averaged over long periods of time.

6. D. Cline et. al., Collecting Antiproton in the Fermilab Booster and Very High Energy Proton-Antiproton Interactions, TM-689 2000.000.

7. B. Cox - Private communication.

8. Experiment 288 Papers.

9. Experiment 95 Papers.

10. Experiment 87 Papers.

11. Sidney Drell and Tung-Mou Yan, Massive Lepton Pair Production at High Energies, Physical Review Letters, 25, 5 (1970).

12. C. Quigg - Private communication.

13. E. Paschos, unpublished.

14. S. L. Glashaw, J. Iliopoulos, and L. Miani, Weak Interactions with Lepton-Hadron Symmetry, Physical Review Letters, 2, 7 (1970).

15. Mary K. Gaillard, Benjamin W. Lee, and Jonathon L. Rusner, Search for Charm, Fermilab-Pub-74/86 -THY, (1974).

16. John Peoples - Private communication.

17. Fermilab Proposal No. 516.

18. Fermilab Proposal No. 401/458.

19. A. T. Visser - Private communication.

20. J. Peoples Memo to B. Cox Dated January 27, 1977.

21. For example, with a relatively limited aperture, Experiment 95 operated a 4000 wire PWC system in a high rate enviroment. Experiment 288 and Experiment 87 have had comparable experiences.

22. Design and Performance of High Rate Photon Detector, (to be published by E-95).

23. Fermilab Proposal No. 302.

24. F. Lobkowicz, Argon Counter Shower Detector for Experiment 272, Internal Technical Notes.

25. D. Hitlin, et, al., Internal Technical Notes - Mark II, Private Communications.

26. T. Nanamaker, Universal Wire Detector Camac Scanning System.

27. Private conversation with Bill Willis.

TABLE I

Antiproton Spectrometer Components

Target	5 segments - .5cm decimeter - 2.5cm spaced by 25cm Be - .5cm x .5cm
Sweeping Magnet	6" x 6" x 40" - 11kg meters field
Proportional Wire Chambers	24 planes - 5 sets of X,Y,U,V,X Total Wires 8625. One and two mm spacing. See Table II
Drift Chambers	8 planes - 4 sets of X,Y,U,V Total Wires 1020 1 cm spacing. See Table II
Analysis Magnets	Modified BM109s or equivalent Total $\int B'dl$ per magnet = 27kg meters Length 2.05 meters per magnet
Liquid Argon Shower Detector	Two independent identical modules Size - 1 meter x 1.5 meters x 25 rl. See Table III

TABLE II

Wire Chambers Specification

Group	Type	Position	Wire Spacing	Size	Total Wires
Set 1	X,Y,U,V - PWC		1mm	6" x 6"	610
Set 2	X,Y,U,V,X - PWC		2mm	24" x 24"	1505
Set 3	X,Y,U,V,X - PWC		2mm	24" x 24"	1505
Set 4	X,Y,U,V,X - PWC		2mm	60" x 24"	3500
Set 5	X,Y,U,V,X - PWC		2mm	24" x 24"	1505
				Total	8625
Set 6 East	X,Y,U,V - Drift		1cm	60" x 24"	510
Set 6 West	X,Y,U,V - Drift		1cm	60" x 24"	510
					1020

Table III

Preliminary Argon Shower Detector Specification

Component	Number	Thickness	Width	Height
Pb Plates	150	1 mm	1.5 m	1 meter
Liquid Argon gaps	150	4 mm	1.5 m	1 meter
Collection Planes	150	1 mm (G-10 backing)	1.5 m	1 meter
Collection Strips	250/plane	--	2.5 mm	1 meter

Total Weight Pb	= 6 tons
Total Volume Argon	= 700 liters
Total Length	= 70 cm
Total Number of Radiation Lengths	= 25
Total Number of Collection Strips	= 80000

The preferred electronics scheme at this time is strip board connection between the ion collection strips and the amplifiers which sit in the 300°K enviroment outside the shower detection package. Any intermediate sample and hold storage device must be designed to 'snapshot' the analogue signals from each strip or strip group (depending on the longitudinal plane). Parts of this large analogue storage device are then serially digitized by suitable 11 bit A/Ds if a signal is present. The total time of digitization must be less than 2 m seconds. We are discussing the design of such a device with LeCroy.

Since both transverse and longitudinal shower information and good two photon resolving power is desired from this device we must keep individual strip information in the first 7 radiation lengths of planes. Beyond this point transverse and longitudual grouping of strips can begin. The details of this grouping are presently being worked on, therefore, the exact scope of the electronics is not yet known.

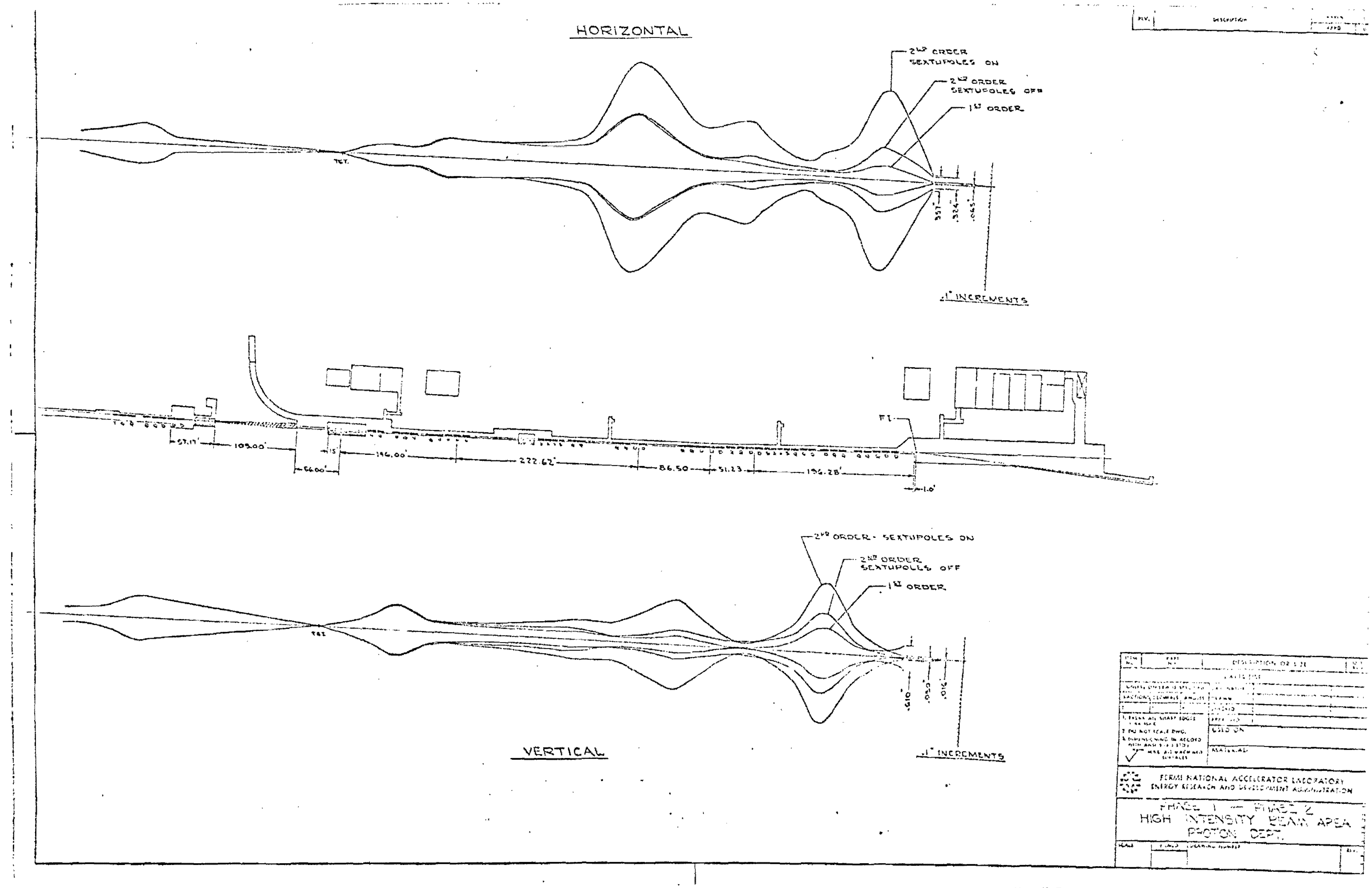

HORIZONTAL
2ND ORDER SEXTUPOLES ON
2ND ORDER SEXTUPOLES OFF
1ST ORDER
TGT.
.1" INCREMENTS
57.17'
105.00'
64.00'
146.00'
222.62'
86.50
51.23
196.28'
1.0'
2ND ORDER - SEXTUPOLES ON
2ND ORDER SEXTUPOLES OFF
1ST ORDER
TGT
VERTICAL
.1" INCREMENTS
FERMI NATIONAL ACCELERATOR LABORATORY
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
HIGH INTENSITY BEAM AREA
PROTON DEPT.

FIGURE 1

FIGURE 2

SCHEMATIC $\bar{\Lambda}^{o} \rightarrow \bar{p}\ \pi^{+}$
ANTIPROTON BEAM

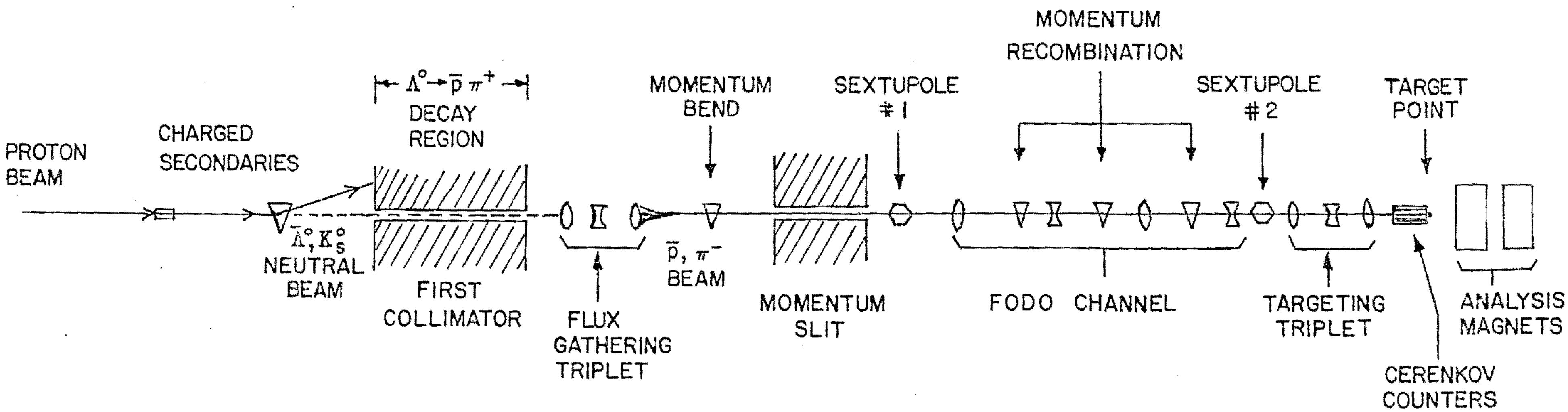
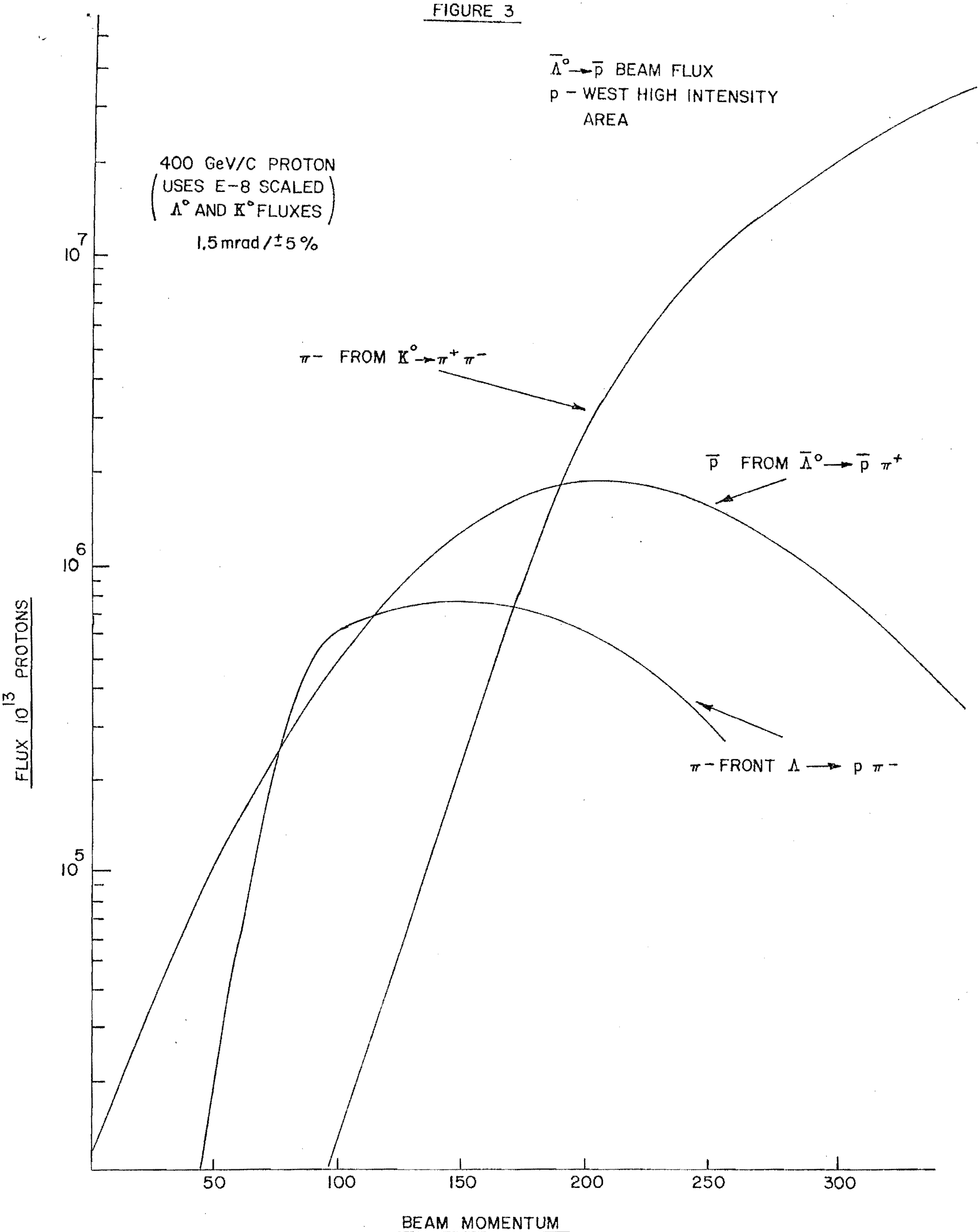


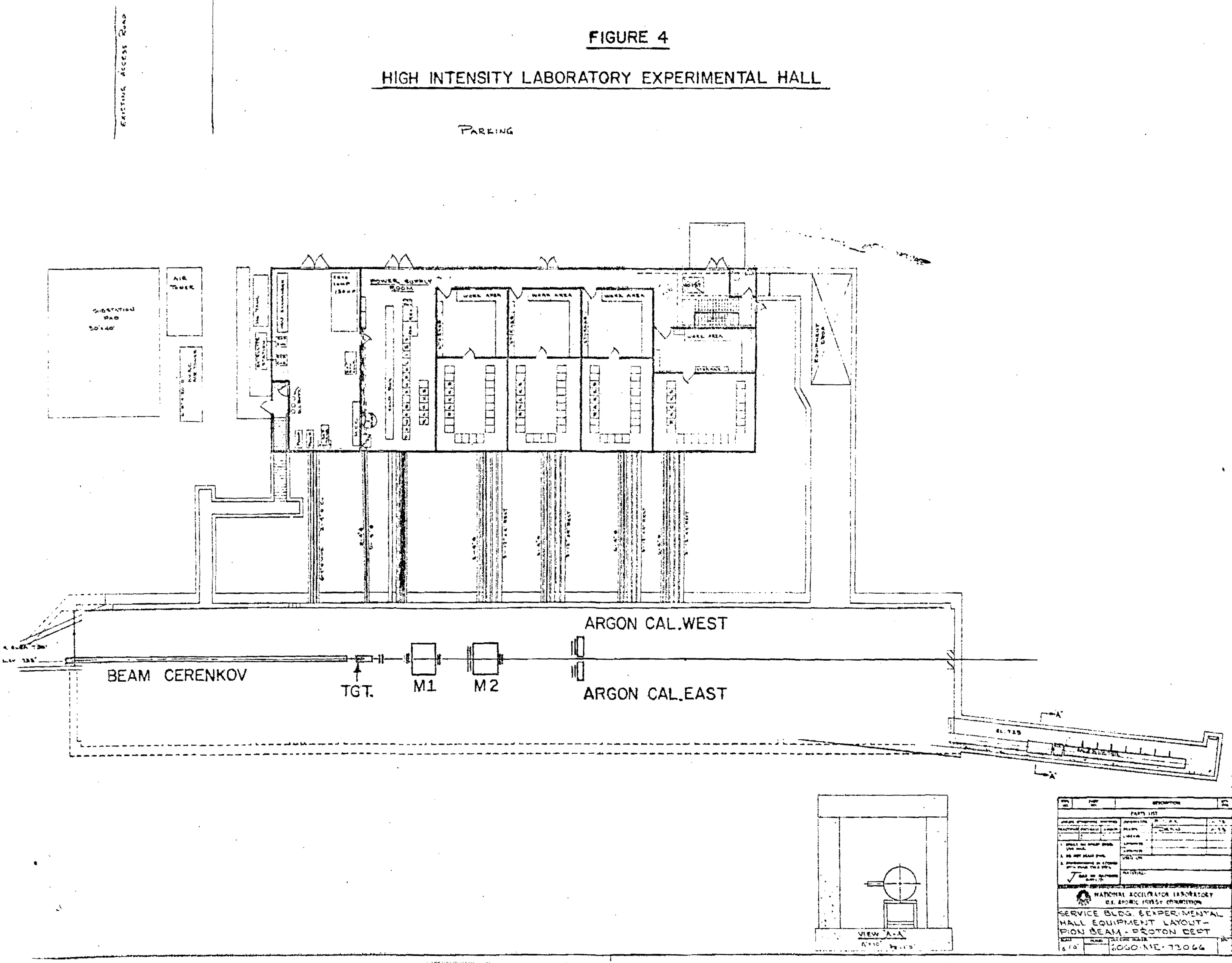
FIGURE 3

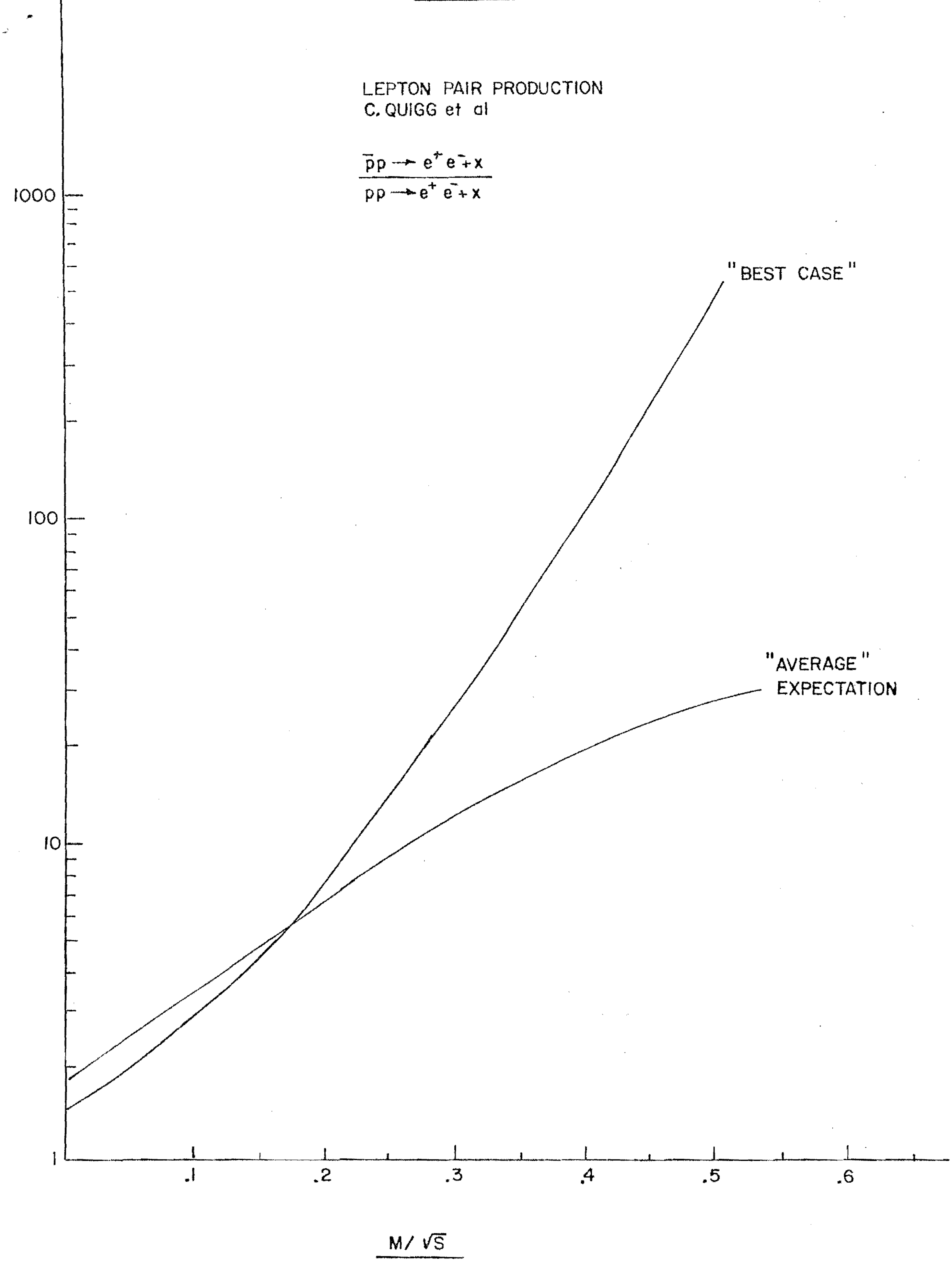


$\bar{\Lambda}^{\circ} \to \bar{p}$ BEAM FLUX
p – WEST HIGH INTENSITY AREA
400 GeV/C PROTON
(USES E-8 SCALED Λ° AND K° FLUXES)
1.5 mrad / ± 5 %
π^- FROM $K^{\circ} \to \pi^+ \pi^-$
$\bar{p}$ FROM $\bar{\Lambda}^{\circ} \to \bar{p}\,\pi^+$
π^- FRONT $\Lambda \to p\,\pi^-$
10^7
10^6
10^5
FLUX 10^{13} PROTONS
50
100
150
200
250
300
BEAM MOMENTUM

FIGURE 4

HIGH INTENSITY LABORATORY EXPERIMENTAL HALL

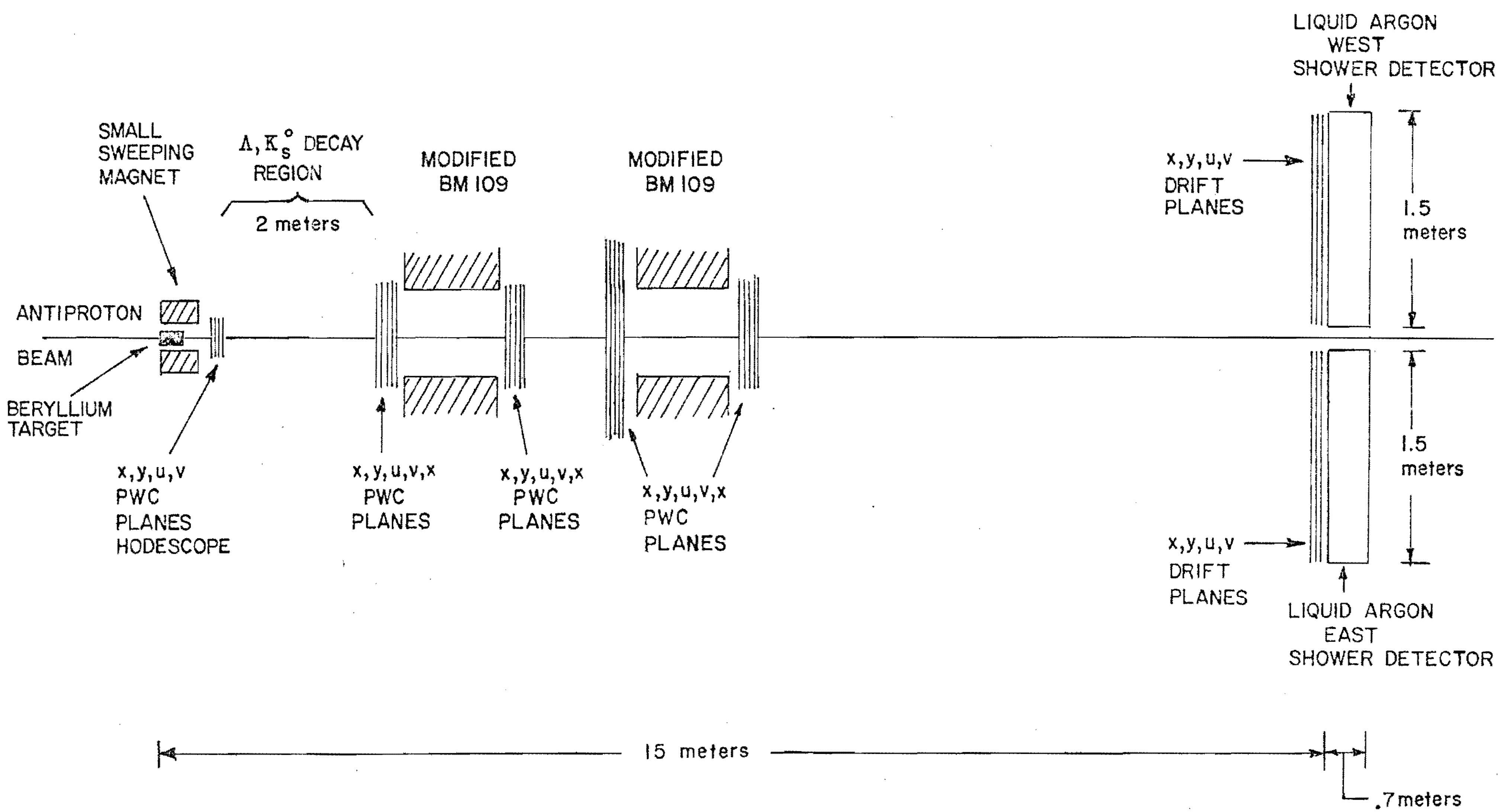




LEPTON PAIR PRODUCTION
C. QUIGG et al
$\frac{\bar{p}p \rightarrow e^+e^- + x}{pp \rightarrow e^+e^- + x}$
1000
100
10
1
"BEST CASE"
"AVERAGE" EXPECTATION
.1
.2
.3
.4
.5
.6
M/ √S

ANTIPROTON EXPERIMENT LAYOUT

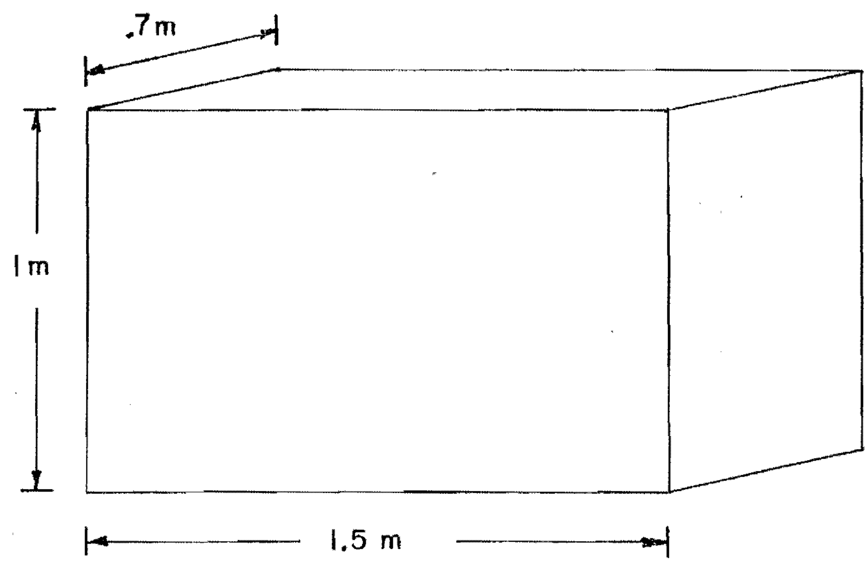
FIGURE 6



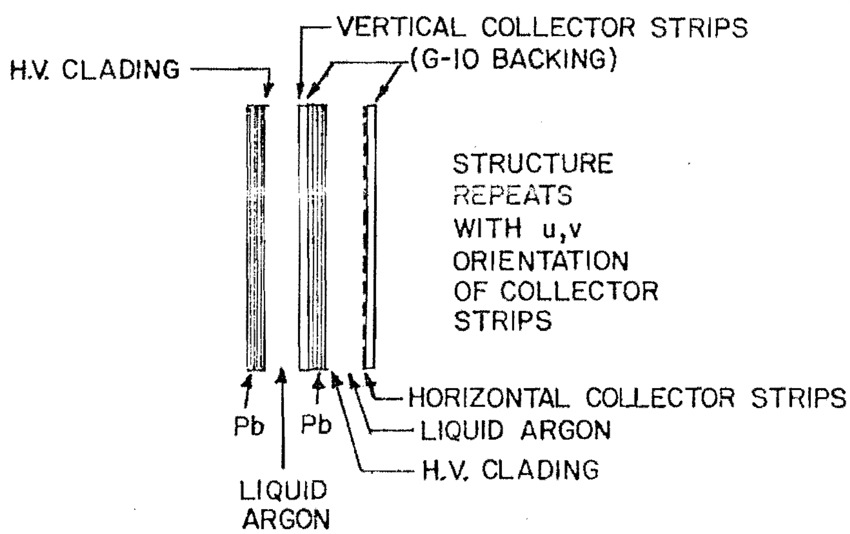
LIQUID ARGON SHOWER DETECTOR

FIGURE 7

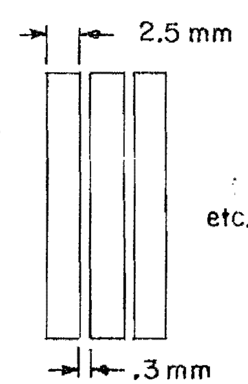
OVERALL DIMENSIONS



TYPICAL TRANSVERSE SECTION



TYPICAL COLLECTOR PLATE SURFACE



Addendum to P-537

FERMI NATIONAL ACCELERATOR LABORATORY

RECEIVED
NOV 3 1977
DIRECTORS OFFICE
FERMILAB

October 31, 1977

E. L. GOLDWASSER
Director's Office

Dear Ned:

The purpose of this letter and the enclosures is to respond to the Program Advisory Committee's request for estimates of the acceptances of the proposed spectrometer and the expected backgrounds. Enclosure I seeks to answer these questions for the following specific physics objectives.

I. Dimuon Continuum and Resonance Production by $\bar{p}$ and $\pi^{\pm}$ - Shielded Spectrometer Configuration

II. Hidden Charm Factory (Charmonium Production and Detection) - Open Spectrometer Configuration

III. Multi Photon Physics - Open Spectrometer Configuration

In addition to these specific pieces of physics we also indicate other intriguing possibilities for experimentation which we are investigating. Finally, we emphasize there is great excitement in this kind of experimentation which lies not in what we know about or can calculate today, but from the surprises which may appear when we begin to experiment with the antiquarks in the high intensity antiproton and pion beams.

We would also like to report on the activities of P-537. Since the Summer PAC Meeting we have proceeded to develop a design for our liquid argon module and have put together a small prototype system which we are scheduled to begin testing in P-West November 3rd. We are in the process of developing amplifiers and other associated electronics for the shower detector and we will test some of these devices during this test run. We have also initiated the design of a PWC and drift chamber system. We have at the request of the Laboratory prepared a 'proto-agreement' which details personnel, schedules, and costs for this experiment. Our spectrometer design has been hardened and defined by these activities and the many Monte Carolo studies which we have made. Most importantly, a scheme has been conceived whereby 200 GeV $\bar{p}$ and $\pi^{\pm}$ beams of high intensity can be achieved by early in June, 1978. We have included this scheme with this letter as Enclosure II. We feel that the possibility of this beam lends immediacy to our request to receive approval of P-537 at this time. In Enclosure III we have included a schedule which attempts to define major items in P-537 and when they might be ready. This schedule is interwoven with the schedule for turn-on of the High Intensity Laboratory.

We are asking for an initial run of 14 weeks to study dimuon production by $\pi^{\pm}$ and antiproton. We feel that we can begin this work with one magnet of the size listed in the 'proto-agreement'. We would like 10^{13} p/pulse for part of the antiproton running and several x 10^{12} p/pulse for the $\pi^{\pm}$ running. This data taking period would include a 100 hour period as soon as beam is turned on in which we would do tuning and measure the flux of the $\pi^{\pm}$ and $\bar{p}$ beams in order to sharpen our time estimates. Beyond this inital run, we foresee three additional runs of lengths from 10 - 14 weeks in which we try to address the physics questions of I, II and III. Of course our goals may be modified by physics discoveries that our group or other groups may make.

Finally, we would reiterate that we hope for an approval at this time. We are anxious to get on the air as early as possible and we feel that our physics goals and capabilities would give us an expectation of a high priority.

Sincerely,

Brad

Brad Cox

BC:al

cc: <u>University of Athens</u>

P. Kostarkis
C. Kourkoumelis
P. Mouzourekis
L. Resvanis

<u>Fermilab</u>

R. M. Baltrusaitis
M. Binkley
B. Cox
C. Hojvat
R. Kephart
T. Kondo
P. Mazur
T. Murphy
F. Turkot
W. Yang

<u>University of Michigan</u>

C. Akerlof
R. Fabrizio
P. Krashour
D. Nitz
R. Thun

ENCLOSURE I

I. DIMUON PRODUCTION BY $\bar{p}$ AND $\pi^{\pm}$ - Shielded Spectrometer Configuration

1. General Comments and Physics Goals

The first run of Experiment 537 will measure the production of dimuons by $\bar{p}$ and $\pi^{\pm}$. We have performed Monte Carlo calculations of the acceptance for the dimuon system at a variety of beam energies. Examples of these acceptances for the spectrometer of Figure 1 are shown in Figure 2. With good resolution ($\sigma_{M_{\mu^+\mu^-}} \lesssim 2\%$) the mass spectra for the various reactions can be measured out to limits indicated by Tables II.a and II.b. The questions and objectives which we will address in the first run of Experiment 537 with the shielded geometry will be:

a. What are the relative rates of $\bar{p}$ and $\pi^{\pm}$ production of the dimuon continuum between the ψ and the Υ? Is this process initiated by a simple Drell Yan type mechanism? The measurement of the absolute rate of $\bar{p}$ production of the dimuon spectrum should provide a fundamental test of our understanding of $\bar{q}q$ interactions. Is there a factor of three supression in this crossection due colored quarks?

b. What are the relative rates of ψ and ψ' production by $\bar{p}$ and $\pi^{\pm}$? Is gluon fusion, quark fusion, or a simple Drell Yan intermediate photon mechanism leading to the production of resonances?

c. What are the absolute rates of Υ and Υ' production by $\pi^{\pm}$? Do both these objects have the same nature?

d. What is the detailed dynamics of ψ, ψ', Υ, and Υ' production in x, y, and $p_{\perp}$? (Range of measurement includes x = 0, y = 0.) What are the detailed angular distributions of the resonance decays?

e. What is the energy dependence of the production cross sections? Does the continuum production scale as $M^3 \frac{d\sigma}{dydM}$? Does the energy dependence of the cross section for ψ, ψ' production for antiprotons and $\pi^{\pm}$ match the expectations of gluon fusion?

In general, the answering of these questions will allow us to judge whether the Drell Yan mechanism is the dominant mechanism for producing dimuon continuum and whether the presence of valence antiquarks in the antiproton and pions lead to a dramatic increase in the dilepton cross section. The comparison of relative resonance production rates will allow us to shed light on the production mechanisms for ψ, ψ', Υ and Υ' production. The unexpected enhancements of this resonance production depend sensitively on whether gluon or quark-antiquark annihilation is initiating the process. In fact, we are testing with this data the larger question of whether the constituent interactions are occurring or whether collective interactions such as the multiperipheral model still dominate.

2. Beams

We plan to use the various $\bar{p}$ and $\pi^{\pm}$ beams listed in Table I for the shielded spectrometer dimuon experiment. For runs in the energy range of 100 - 150 GeV we plan to use the $\bar{\Lambda}^0 \rightarrow \bar{p}$ beam. For higher energies we plan to use a direct antiproton beam where the intensity is limited by the requirement that the beam Cerenkov counter tag antiprotons and that the number of interactions per bucket average approximately one. The $\pi^{\pm}$ beams listed in Table I do not put extreme requirements on intensities of incident protons. The 100 and 200 GeV beams as outlined in Enclosure II will be ready with full intensity at turn-on of the High Intensity Laboratory this coming summer. 300 GeV capability should follow shortly after that time. The usable intensity of π's is set by calculations of punch through of the Be/Cu shield. We estimate approximately 1 - 2 x 10^8 particles penetrating the 14 absorption lengths of the shield using the data of Barish et al[1] and the shower calculation of Van Ginneken and Awschalom[2]. This flux is relatively low energy and isotropically distributed outside the deadened forward 10 mrad core. Experience of the proponents of this experiment indicate that this is a bearable rate for PWC planes. It should lead to less than one extra track/trigger.

3. Sensitivity

The event rates for the shielded forward spectrometer (shown in Figure 1) using the beams of Table I and calculated dimuon acceptances similar to those of Figure 2 are given in Tables II.a and II.b for resonance and dimuon continuum production for a five week run. We have used theoretical expectations for the enhancement of $\bar{p}$ continuum production of dimuons relative to p production as given by C. Quigg[3]. The predicted enhancements of the $\bar{p}$ reaction (up to 3 orders of magnitude) have been applied to the scaled data $\bar{p}N \rightarrow \mu^+ \mu^- + x$ of Hom et al[4]. We point out that the enhancement of antiproton relative to proton production was calculated with the sea quark distribution $(1 - x)^7$ of Feynman and Field[5]. In fact, the measurement of Hom et al appears to fall steeper than this ($\sim (1 - x)^9$ or greater) which argues for a larger enhancement of the $\bar{p}$ reaction than we have used. The $\pi^{\pm}$ production rates for continuum dimuons have been taken from Donnachie and Landshoff[6] since no data exists for production of dimuon pairs above the ψ' at this time. Both the CERN Ω experiment[7,8] and Anderson et al[9,10,11] have essentially no data above the ψ'. In all the continuum calculations the assumption has been made that $M^3 \frac{d\sigma}{dM} \sim f\,(\tau = \frac{M^2}{s})$ and scales with energy.

The resonance production cross sections at various energies for ψ, ψ', Υ, Υ' have been extrapolated from the existing pN

100 GeV $\bar{p}$	-	2 weeks	
200 GeV $\bar{p}$	-	4 weeks	
100 GeV π^-	-	2 weeks	
200 GeV π^+	-	5 weeks	
200 GeV π^-	-	1 week	
		14 weeks	= 1400 hours

This should allow us to accomplish at least a start on the physics goals of Section I. We would contemplate a second run of roughly the same duration at a later time.

II. HIDDEN CHARM FACTORY - Production and Detection of Charmonium and Higher χ States - Open Spectrometer

1. General Remarks and Physics Goals

The second run of the apparatus should be devoted to searches for and measurements of the reported hidden charm χ states intermediate in mass between the ψ and ψ' in the charmonium spectrum and to searches for higher lying χ states. As seen in Table IV, the various χ states[15] each participate in decay strings which start with the ψ' (or perhaps some higher state which does not decay into $e^+ e^-$) and end up in the ψ which decays into $e^+ e^-$. With our liquid argon detector we plan to trigger an $e^+ e^-$ and look for accompanying photons. There is a minimum rate of production of intermediate χ's, which Table IV shows, which is given by the decays of the ψ'. We use the production rates of ψ' given in Table III to calculate this minimum number. However, if current theoretical expectations are correct, process 3.c or 3.d of Figure 3 will be the dominating ψ production mechanism. In this case, practically every ψ will have come to first order from a χ. This leads to a much larger rate of χ which we can estimate, assuming (without any evidence or justification) that all χ's are produced with equal crossections in hadronic interactions. These rates are also shown in Table III. It is worth pointing out that this direct production of χ states is exactly where hadronic reactions are supposed to exceed and better $e^+ e^-$ reactions. The incredible sensitivity afforded by the $\psi \to e^+ e^-$ signature eliminates the high hadronic backgrounds and allows us to tag on likely candidates for χ events and therefore to construct this hidden charm factory. Detection of and measurement of this direct intermediate χ production is therefore a prime objective.

In addition to the search for the production of χ states the observation of these states should lead to a much better determination of their quantum numbers. Branching ratios data of Hom et al, the $\pi^{\pm}$ N data of Anderson et al, and the $\bar{p}N$ of Corden et al and from predictions of the referenced theoretical papers. The constituent interaction model predictions arise from at least the four diagrams[12] shown in Figure 3. These calculations would argue that a difference of less than a factor of two in pN and $\bar{p}N$ or $\pi^{\pm}N$ production at high energies of these resonances since the dominant diagram is the gluon fusion mechanism of 3.c. However, these production mechanisms for resonances are a strong function of energy and in fact for antiprotons the quark annihilation model dominates at low energy and would lead to a large enhancement of $\bar{p}$ production[13] relative to p production. The existing data shows a factor 6 difference at 39.5 GeV between $\bar{p}N \to \psi + x$ and $pN \to \psi + x$ and essentially equal cross sections for $\pi^{\pm}N \to \psi$ with approximately a factor of two difference between the pN and $\pi^{\pm}$ reactions at 225 GeV. The large difference in $\bar{p}N$ and pN is, as we mentioned, supposedly due to the different turn-on rate of process 3.b and 3.c. No convincing data exists at higher energies or for ψ' and Υ. We propose to increase the amount of information by measurement of $\bar{p}N \to \psi, \psi'$, and $\pi^{\pm} p \to \psi, \psi', \Upsilon, \Upsilon'$ at various energies. (See Section I.b.) Our resolution of order $\sigma \sim 2\%$ with the variable Be/Cu shield should be adequate to resolve the Υ, Υ'.

4. Background

Since in all phases of this experiment the interaction rate/bucket is low, the major background of dimuons comes from the coincident decay of two hadrons from a high mass hadron pair. Using the approximation that the shielded configuration of the spectrometer of Figure 1 has the equivalent of 10 inches of decay path, we calculate using the dihadron data of E-494[14], a signal to noise ratio at 400 GeV for $pN \to (\mu\mu) + x / pN \to (\mu\mu)_{decay} + x$ of approximately 200/1 at $M_{\mu^+\mu^-} = 4$ GeV. We estimate that at 8 GeV/c^2 we should have signal to noise of $2 \times 10^4/1$ in this configuration. Taking into consideration the lower energy of our 100 GeV running we estimate a worst case signal to noise of > 10/1 at 4 GeV and 1000/1 at 8 GeV. Estimates of the background in the two-arm experiments such as E-288 and E-357 arrived at in this way have in general been low by a factor of 10 due in large part to the accidental $(\pi \to \mu)$ $(\pi \to \mu)$ coincidences at low dimuon mass. We reiterate that we do not have this source in the wide aperture forward spectrometer.

5. Running Time For Dimuon Experiment

The rates exhibited in Tables II.a and b lead to an initial request for fourteen weeks of dimuon running to be distributed as follows:

can also be determined from the subset which appear as daughters. Even if no direct χ production exists, sufficient statistics will exist from the decays of the known ψ' production for this test.

2. Beams

In the open geometry we will take $\sim$ two order of magnitude less beam than in the shielded configuration. We will be restricted to the $\bar{\Lambda}^{o} \rightarrow \bar{p}$ beam and to the $\pi^{\pm}$ intensities of Table I.b, or lower initially. The calculated rates of particles arising from the interactions is bearable from a total PWC rate and a worst case single wire and 5 cm strip liquid argon rate. We have use the 30" Bubble Chamber data of Experiment 311 ($\bar{p}p$ at 100 GeV) to estimate the charged particle distributions at various planes. The neutral particle densities were assumed to be comparable. The forward 10 mrad cone of the detector is once again assumed to be deadened. The worst case liquid argon 5 cm strip is less than 2 $\times 10^{6}$ neutrals/pulse from our studies.

3. Sensitivity and Background

As mentioned, the event rates for known χ's are given in Table IV.a, with maximum and minimum rates determined by the non-existence or maximal existence of direct χ production. The truth probably lies somewhere between these two limits. We will determine this. An intriguing possibility is that ψ or ψ''s also result from small but finite branching ratios of χ's with mass above the ψ', i.e., above charm threshold.

We estimate the $e^{+}e^{-}$ backgrounds in the final analyzed data from misidentified $\pi^{+}\pi^{-}$ events to be $< 2 \times 10^{-7}$ of the $\pi^{+}\pi^{-}$ continuum. We estimate that this is achievable by our shower detector which has a fourfold longitudinal segmentation and good transverse shower development sampling. While it does not seem to be required from total trigger rate calculations (< 500 '$e^{+}e^{-}$'/spill) we plan to incorporate some supply longitudinal shower development criterion in the trigger. At masses of 4 GeV this rejection leads to approximately 100/1 signal to noise and increases rapidly with mass because of the steeper fall of the dihadron mass spectrum. Dalitz pair conversions which lead to a real background of $e^{+}e^{-}$ have been estimated and are about an order of magnitude lower than the false $e^{+}e^{-}$ arising from misidentified hadron pairs.

Once true $e^{+}e^{-}$ candidates have been isolated our sensitivity to these rare decays will be limited by backgrounds which would be of the form $m\pi^{o} + \psi$ or $m\eta^{o} + \psi$ production where one photon is missed. At this point there is insufficient data published to make an estimate of this flat background. From 93 event topologies of ψ + other particles, published by C.Kourkoumelis[16], it can be stated that in the limited solid angle of the Willis experiment, seven events had one extra 'photon' (sensitivity to π^{0}'s being limited), six with one extra photon plus one extra hadron, and six events with one or two extra photons plus other charged tracks. Three of the two-photon events are consistent with the η^0 mass and two of these events are consistent with the decay $\psi' \to \eta^0 \psi$. No π^0 candidates were observed though some portion of the single γ's could be π^0's. We then would estimate that at maximum $\sim$ 19 events could be π^0's or η^0 and at minimum there are at least three η^0 events. If we take into account the better efficiency of our laboratory experiment for identifying π^0's and η^0, we would estimate that the $\gamma\,\psi$ spurious background would be less than 1% of the ψ decays and would be spread uniformly in $\gamma\,\psi$ mass. We should then have signal/noise rates for the minimum known χ signals of from 10/1 to 100/1, depending on the χ state. This is using our calculated Monte Carlo resolution (σ) of 2% for the χ masses.

4. Running Time

Table IV.a guides the selection of running time. We request a tuneup and calibration time of 200 hours for the liquid argon system. Then, guided by a desire to first detect and then analyze χ decays and then to study the χ production, we request twelve weeks of running time.

2 weeks	-	Tuneup
7 weeks	-	Search for $\pi\bar{p}$ production of χ states at 100/200/300 GeV
5 weeks	-	Measurement of $\bar{p}$ production at 100 GeV
14 weeks		

At this time we would like to state that although the major motivation of this work is apparently somewhat independent of the availabiliby of the antiquarks in the various beams which we intend to use, there is motivation because of the possibility of the existence of process 3.d. The direct hadronic production of χ's will give us new information on the validity of the constituent interaction picture and the existence of the process 3.d.

III. MULTI PHOTON PHYSICS - Open Spectrometer

1. General Remarks

The objective of this measurement is twofold. The level of continuum diphoton production from $\bar{q}q \to \gamma\gamma$ is predicted[17] to be of the same level of cross section as Drell Yan production of dileptons. However, in addition to the production of p wave states, other angular momentum states such as s and d wave diphoton states can be produced in this process. Observation of a true 'direct' diphoton continuum such as this would be an additional boost to the constituent interaction model of high energy interactions. In addition, the two photon spectrum, if the diphotons from $\pi^o\pi^o$, $\eta^o\eta^o$ can be eliminated, may contain resonance diphoton states. As an example of this we cite the reported chain ψ (3.1) $\rightarrow \gamma\ \chi$ (2.8) $\rightarrow \gamma\gamma\gamma$. This is at this time very poorly established and the observation of this chain, while difficult, provides additional motivation for this work. Other surprises may appear in the various multiphoton mass spectra. As well as the difficulty of eliminating the photon combinations from the neutral mesons, there is an additional difficulty of constructing a selective trigger which will sort through the neutral flux. The ultimate limitations may turn out to be data acquisition rate (we are aiming at 500 triggers/second for uniform spill) on resonance searches at low mass.

2. Beams

In spite of the intensity of the neutral flux we feel that we can still construct two and three or more photon triggers which will allow us to use the open spectrometer configuration beam fluxes which are shown in Table III.

3. Sensitivity and Background

As shown in Table V.a, the diphoton background arising from hadronic interactions without π^o and η^o rejection becomes comparable to $\bar{q}q \rightarrow \gamma\gamma$ in the 6 - 7 GeV range. This is what we can expect a relatively crude trigger to produce. (Total energy plus a minimum photon separation requirement.) If we are unable to refine our trigger beyond this level we will probably suffer a factor of 2 - 4 loss in event rate in the 2 - 3 GeV bin. If we are able to recover the factor of 2 - 4 then we can take the requisite data in the 2 - 3 GeV bin in five weeks for the following quoted sensitivities for η_c. Above 3 GeV we can achieve the sensitivity regardless of trigger rate since in this mass region we are limited by the response times of the apparatus. We are in the process of investigating various triggers with our Monte Carlo calculations. These same Monte Carlo calculations give us the off line rejection of π^o and η^o which have both photons in the solid angle of the apparatus and lead to suppression rates listed in Table VI. Application of these factors to the data gives us 1/1 signal ($\bar{q}q \rightarrow \gamma\gamma$) to hadronic diphoton rate at $\sim$ 3 GeV. Beyond that point the dihadron induced mass spectra falls off rapidly and observation of direct diphoton continuum should be clean. We would seek to compare $\pi^{\pm}$, $\bar{p}$ induced diphoton spectra to confirm the direct nature of the diphoton continuum.

For resonance detection we have taken as a worst case ψ (3.1) $\rightarrow \gamma\chi$ (2.8) $\rightarrow \gamma\gamma\gamma$. While it is doubtful that this object has actually been observed at this point in time, the reported branching ratios[15] are so small that(as shown in Table V.b) very few χ (2.8)'s ($\sim$ 3000) are produced via

ψ (3.1) decay in five weeks. In addition, it lies in the lowest mass bin where the hadronic backgrounds are the worst. With requisite number of events accumulated in the bin and π^0 and η^0 rejection applied off line, the signal to noise ($\eta_c \rightarrow \gamma\gamma$/hadronic background $\rightarrow \gamma\gamma$) in the diphoton spectrum would be 1/100 for ψ (3.1) $\rightarrow \gamma\chi$ (2.8) $\rightarrow \gamma\gamma\gamma$. However, if we ask that there be three photons and that their mass combination lie in the ψ region, we estimate that we achieve approximately a factor of 10^5 rejection in noise with a loss of three in signal (3γ resolutions are of the order of $\sigma \sim 1.5\%$). This makes the observation of χ (2.8) difficult but possible if only χ (2.8) produced by ψ (3.1) is present. If direct χ production is present, then we should be able to directly observe the χ (2.8) in the two photon spectrum if χ(2.8) is as copious as ψ3.1) production.

4. Running Time

Once again in this run we request a mixture of $\pi^{\pm}$ and $\bar{p}$.

3 weeks	-	$\pi^- N$	-	200 or 300 GeV		Continuum Measurement
7 weeks	-	$\pi^+ N$	-	200 or 300 GeV		Resonance Search
3 weeks	-	$\bar{p}N$	-	100 GeV		Continuum Measurement

IV. OTHER TOPICS

We feel as though the three areas which we discussed are extremely rich in possibilities. However, we may have many, many more areas which intrigue us and we either have not investigated fully, or we have left out of the detailed discussion for sake of brevity. There is, for example, the matter of existence or non-existence of the direct photon production.[18,19,20] We are eminently suited with our antiquarks and large aperture spectrometer to pin this down. We also have an extremely rich field of investigation which requires only that we look at the hadronic particles associated with continuum dielectrons. Since the Drell Yan mechanism picks a valence antiquark out of incident $\bar{p}$, we know the initial composition of the forward jet from the remanents of the $\bar{p}$'s. Theoretical predictions[21] have been made about the expected charged pion structure for this jet, In general, large X hadronic production for which we have almost ideal acceptance is being examined theoretically[22] in the same way high p processes have been examined to see what they can tell us about the quark structure of the nucleon, antinucleon, and mesons. We will by nature of the apparatus study this region.

The list of additional subjects for experimentation for which there are theoretical expectations or predictions is far more extensive than that listed above. However, since we are entering an essentially unexplored area of experimentation with valence quark interactions there are probably completely unexpected phenomena and effects which we must cope with. We are attempting to keep a flexible spectrometer and an ability for many triggers in order to respond to other possibilities and to conduct sensitive searches. We plan to investigate the high p_t region by using a missing forward energy trigger. A relatively small and simple iron scintillator calorimeter a a zero degrees will furnish an anticoincidence signal for 'normal' collisions where most of the energy remains within a small forward cone. We expect $\sim$ 10% resolution at 75 GeV from this device. With it in anticoincidence selecting erergy dumps of less than 1/2 beam energy we will be able to trigger at the 10μ barn level in the $\bar{p}$ interactions yielding an event rate of less than 100 events/spill. Triggering on multiple vee (K^o or Λ^o) events via our change of multiplicity trigger in coincidence with our missing forward energy trigger should isolate hard quark interactions in which quantum number flow can be studied. Additional criteria can be imposed on this trigger such as requirements for additional muons. The resulting events would be prime candidates for charmed baryon search.

As a last category of physics that we have not referred to are the more 'standard' varieties of physics that can be done with these beams and this apparatus with its acceptance. As a benchmark of sensitivity we will quote what we could expect to do on the simplest experiment of this generic type, elastic scattering. With out H_2 target we expect to achieve an integrated luminosity of 5×10^5 events/microbarn for a 3 week run. This will permit measurements out to $-t = 8\ GeV^2$. With this apparatus one can easily compare the magnitude and slope of the $\bar{p}p$ and pp corssections in a region far beyond the diffractive peak. From the data of Cronin et al., it appears that the background due to multiparticles final states will not be severe at the larger momentum transfers. For momentum transfers near the dip region at $-t = 1.5\ GeV^2$ the problem is more serious but experiences of other experiments [23] show that this region is accessible. This antiproton measurement is just one of a large category which could be performed and are absolutely unique in this setup.

In conclusion, we feel strongly that the flexibility of this forward spectrometer and the beams and capabilities of the High Intensity Laboratory put us in a unique position to make very significant well determined measurements, to conduct searches for new phenomena, and to respond to new directions that physics may take during the lifetime of this facility. No where else does this combination of capabilities exist.

TABLE Ia

EXPECTED BEAM INTENSITIES

SHIELDED SPECTROMETER

PARTICLE	100 GeV	200 GeV	300 GeV
$\bar{p}$	$2\times10^{6}/10^{13}p$	$10^{6}/5\times10^{7}\pi^{-}/\text{few }\times10^{11}p^{*}$	$10^{6}/5\times10^{7}\pi^{-}/10^{12}p$
π^{+}	$\leq 5\times10^{8}/10^{12}p$	$\leq 5\times10^{8}/10^{12}p$	$\leq 5\times10^{8}/2\times10^{12}$
π^{-}	$\leq 5\times10^{8}/1.5\times10^{13}p$	$\leq 5\times10^{8}/3\times10^{12}p$	$\leq 5\times10^{8}/5\times10^{12}$

TABLE Ib

EXPECTED BEAM INTENSITIES

OPEN SPECTROMETER

PARTICLE	100 GeV	200 GeV	300 GeV
$\bar{p}$	$2\times10^{6}/10^{13}p$	$3\times10^{5}/10^{13}p$	$2\times10^{4}/10^{13}p$
π^{+}	$\sim10^{7}/10^{11}p$	$\sim10^{7}/10^{11}p$	$\sim10^{7}/10^{11}p$
π^{-}	$\sim10^{7}/10^{11}p$	$\sim10^{7}/10^{11}p$	$\sim10^{7}/10^{11}/p$

TABLE IIa

EXPECTED CONTINUUM DIMUON RATES (5 weeks) EVENTS/GeV

MASS $\mu^+\mu^-$ GeV/c^2	100 GeV $\sqrt{\tau}$	100 GeV $\bar{p}$	100 GeV π^+p	100 GeV π^-p	200 GeV $\sqrt{\tau}$	200 GeV $\bar{p}$	200 GeV π^+p	200 GeV π^-p	300 GeV $\sqrt{\tau}$	300 GeV $\bar{p}$	300 GeV π^+p	300 GeV π^-p
1- 2	.109	7.5×10^{6}			.077	7.6×10^{7}			.063	7×10^{7}		
2- 3	.182	7.4×10^{4}			.129	1.4×10^{5}			.105	2.3×10^{6}		
3- 4	.255	8.2×10^{3}	2.2×10^{6}	7.7×10^{6}	.180	4.0×10^{4}	2.5×10^{6}	9.0×10^{6}	.147	6.4×10^{4}	4.5×10^{6}	9×10^{6}
4- 5	.328	1.9×10^{3}	5.6×10^{5}	2.9×10^{6}	.232	1.1×10^{4}	8.4×10^{5}	5.5×10^{6}	.189	1.9×10^{4}	1.1×10^{6}	4.5×10^{6}
5- 6	.400	5.2×10^{2}	2.0×10^{5}	7.0×10^{5}	.283	2.6×10^{3}	4.5×10^{5}	1.5×10^{6}	.231	2.3×10^{3}	4.5×10^{5}	3.0×10^{6}
6- 7	.472	2.3×10^{2}	4.2×10^{4}	3.0×10^{5}	.335	1.2×10^{3}	1.7×10^{5}	9.1×10^{5}	.273	1.4×10^{3}	3.0×10^{5}	6.0×10^{5}
7- 8	.545	5.8×10^{1}	1.6×10^{4}	1.1×10^{5}	.336	3.8×10^{2}	7.0×10^{4}	3.5×10^{5}	.315	6.9×10^{2}	1.1×10^{5}	3.8×10^{5}
8- 9	.607	1.0×10^{1}	5.6×10^{3}	3.7×10^{4}	.438	2.5×10^{2}	2.7×10^{4}	1.4×10^{5}	.357	3.1×10^{2}	6×10^{4}	1.5×10^{5}
9-10	.690		1.5×10^{3}	1.9×10^{4}	.489	1.1×10^{2}	1.3×10^{4}	9.1×10^{4}	.389	1.8×10^{2}	4×10^{4}	8.3×10^{4}
10-11	.763		3.6×10^{2}	3.3×10^{3}	.541	$.8\times10^{2}$	5.6×10^{3}	6.6×10^{4}	.441	1.1×10^{2}	1.3×10^{4}	5.3×10^{4}
11-12	.835		1.3×10^{2}	1.3×10^{3}	.592		2.2×10^{3}	3.9×10^{3}	.483	8×10^{1}	6×10^{3}	3.0×10^{4}
12-13	.908		3×10^{1}	4.1×10^{2}	.644		1.1×10^{3}	9.8×10^{3}	.525	3×10^{1}	4×10^{3}	1.5×10^{4}
13-14	.980			7×10^{1}	.695		5.1×10^{2}	6.4×10^{3}	.567		2×10^{3}	7.5×10^{3}
14-15					.747		2.5×10^{2}	1.9×10^{3}	.609		1×10^{3}	5.0×10^{3}
15-16					.798		8.4×10^{1}	9.1×10^{2}	.651		5×10^{2}	3.5×10^{3}
16-17					.850		4.1×10^{1}	4.1×10^{2}	.693		2.5×10^{2}	1.0×10^{3}
17-18					.901			$\sim10^{2}$	.735		1.3×10^{2}	5×10^{2}
18-19					.953			$\sim5\times10^{1}$	.777		6×10^{1}	3×10^{2}
19-20					1.00			$\sim10^{1}$	.819		4×10^{1}	1.5×10^{2}

TABLE IIb

EXPECTED RESONANCE DIMUON RATES (5 weeks)

SHIELDED SPECTROMETER

RESONANCE	100 GeV $\bar{p}$	200 GeV $\bar{p}$	300 GeV $\bar{p}$	100 GeV $\pi^{\pm}$	200 GeV $\pi^{\pm}$	300 GeV $\pi^{\pm}$
$\psi \rightarrow \mu^+\mu^-$	3.3×10^4	7×10^4	8×10^4	1.3×10^7	4.5×10^7	7.8×10^7
$\psi' \rightarrow \mu^+\mu^-$	600	900	1400	4.7×10^5	$\sim1.6\times10^6$	2.6×10^6
$T \rightarrow \mu^+\mu^-$	<1	~ 2	~ 5	~ 250	~ 500	~ 900
$T \rightarrow \mu^+\mu^-$	$<<1$	< 1	1	~ 40	~ 80	~ 150

TABLE III

EXPECTED RESONANCE

PRODUCTION RATES

OPEN SPECTROMETER

RESONANCE	100 GeV $\bar{p}$	200 GeV $\bar{p}$	100 GeV $\pi^{\pm}$	200 GeV $\pi^{\pm}$	300 GeV $\pi^{\pm}$	370 GeV $\pi^{\pm}$
$\psi \to e^+e^-$	3.3×10^4	$\sim2\times10^4$	2.6×10^5	9×10^5	1.6×10^6	2.6×10^6
$\psi' \to e^+e^-$	600	$\sim$300	$\sim$9500	32000	52000	9.2×10^4
$\psi \to e^+e^-$	<1	$\sim$ 1	$\sim$ 5	$\sim$ 10	$\sim$ 20	$\sim$ 35
$\Upsilon' \to e^+e^-$	<<1	<<1	$\sim$ 1	$\sim$ 2	$\sim$ 3	$\sim$ 5

TABLE IV

CHARMONIUM DECAY

SEQUENCES AND χ RATES

$e^+e^+\gamma\gamma$ or $e^+e^-\gamma$ SIGNATURE

DECAY SEQUENCE	Ratio $\frac{\psi' \to \gamma\gamma e^+e^-}{\psi' \to e^+e^-}$	Rate of $e^+e^-\gamma$ or $e^+e^-\gamma\gamma$ from χ's: 5 Week Rate No Direct χ Prod.	Rate of $e^+e^-\gamma$ or $e^+e^-\gamma\gamma$ from χ's: 5 Week Rate* Direct χ Prod.
$\psi' \xrightarrow{7\%} \gamma\chi(3552) \xrightarrow{14\%} \gamma\gamma\psi(3.1) \xrightarrow{7.3\%} \gamma\gamma e^+e^-$	$\sim$ 8%	$\sim$ 2600 (50)	$1.5\text{x}10^5$ (3000)
$\psi' \xrightarrow{7\%} \gamma\chi(3508) \xrightarrow{35\%} \gamma\gamma\psi(3.1) \xrightarrow{7.3\%} \gamma\gamma e^+e^-$	$\sim$20%	$\sim$ 6400 (120)	$3.7\text{x}10^5$ (7600)
$\psi' \xrightarrow{7\%} \gamma\chi(3415) \xrightarrow{3\%} \gamma\gamma\psi(3.1) \xrightarrow{7.3\%} \gamma\gamma e^+e^-$	$\sim$ 4.6%	$\sim$ 1500 (30)	$3.2\text{x}10^4$ (650)
$\psi' \xrightarrow{<3\%} \gamma\chi(3454) \xrightarrow{100\%?} \gamma\gamma\psi(3.1) \xrightarrow{7.3\%} \gamma\gamma e^+e^-$	$\sim$24%	$\sim$ 7700 (150)	$1.1\text{x}10^6$ (22000)
		200 GeV $\pi^\pm$ (100 GeV $\bar{p}$)	

* The assumption needed to generate these rates are that all χ's are made with equal crossection and essentially all ψ's are decay products of χ's.

TABLE Va

EVENT RATES di γ

CONTINUUM 5 WEEK RUN

PER GeV/c^2

	$\bar{p}N \to \gamma\gamma+X$ 100 GeV		$\pi^{\pm}p \to \gamma\gamma + X$	$\pi^- p$ 300	$\pi^+ p$ 300	πp - 300 GeV	
$M\gamma\gamma$ GeV/c^2	Dihadron Induced Background	$q\bar{q} \to \gamma\gamma$	Dihadron* Induced 500 Background	$q\bar{q} \to \gamma\gamma^+$	$q\bar{q} \to \gamma\gamma^+$	Dihadron Without Aperture	Background With Aperture Cut
2- 3		7.4×10^4	5.3×10^8	2.1×10^5	1.1×10^5	4.2×10^6	2.3×10^6
3- 4		8.2×10^3	2.3×10^7	9.8×10^4	4.5×10^4	• 2.7×10^5	5.8×10^4
4- 5		1.9×10^3	1.1×10^6	4.5×10^4	1.1×10^3	3.7×10^3	1.6×10^3
5- 6		5.2×10^2	9.0×10^4	3.0×10^4	4.5×10^3	2.0×10^2	7.5×10^1
6- 7		2.3×10^2	1.5×10^4	9.2×10^3	3.0×10^3	2.3×10^1	7.1×10^0
7- 8		5.8×10^1	5.5×10^3	1.0×10^3	1.1×10^3	5.5×10^1	1.5×10^0
8- 9		1.0×10^1	6.6×10^2	3.8×10^3	6.0×10^2	-	-
9-10		-	3.0×10^1	1.5×10^3	3.8×10^2	-	-
10-11		-	1.3×10^0	8.3×10^2	1.5×10^2	-	-
11-12		-	< 1	5.3×10^2	7.1×10^1	-	-
12-13			<< 1	3.0×10^2	4.1×10^1	-	-
						Acceptance true$\gamma\gamma$-45%	Acceptance true$\gamma\gamma$-25%

• Denotes crossover points of various di hadron $\to \gamma\gamma$ backgrounds with 'direct diphoton' physics process $q\bar{q} \to \gamma\gamma$.

* Assumption: The measured values of E-95 can be extrapolated to higher masses by $e^{-3.1M}$ rule. Also we assume that 400 GeV pp hadronic background is an upper limit for 300 GeV $\pi^{\pm}$ N induced hadronic background.

\+ Assumption: $q\bar{q} \to \mu^+\mu^-$ from $\pi^{\pm}p$ can be taken from Donnachie and Landshoff's prediction of μ pair Drell-Yan. The preferred ratio of $(\pi N \to \gamma\gamma + X)/(\pi^- N \to \mu\mu + X)$ is calculated to be ~ 1 from the predictions of Paschos.

TABLE Vb

EVENT RATES $\chi(2.8)$

RESONANCE 5 WEEK RUN

		$\pi^{\pm}$ p induced 300 GeV		$\bar{p}p$ induced 100 GeV	
Decay Chain	Ratio $\frac{\psi \to \gamma\gamma\gamma}{\psi \to e^+e^-}$	5 week rate No Direct χ Prod.	5 week rate Direct $\chi = \psi$ Prod.	5 week rate No Direct χ's	5 week rate Direct $\chi = \Psi$ Prod.
$\psi(3.1) \xrightarrow{1.7\%} \gamma\chi(2.8) \xrightarrow{7\times10^{-3}} \gamma\gamma\gamma$	1.8×10^{-3}	2.9×10^{3}	1.5×10^{5}	60	3.2×10^{3}

Limit on χ (2.8) $\to \gamma\gamma$ production is $\sim$ 150 nb from E-95 at this moment.

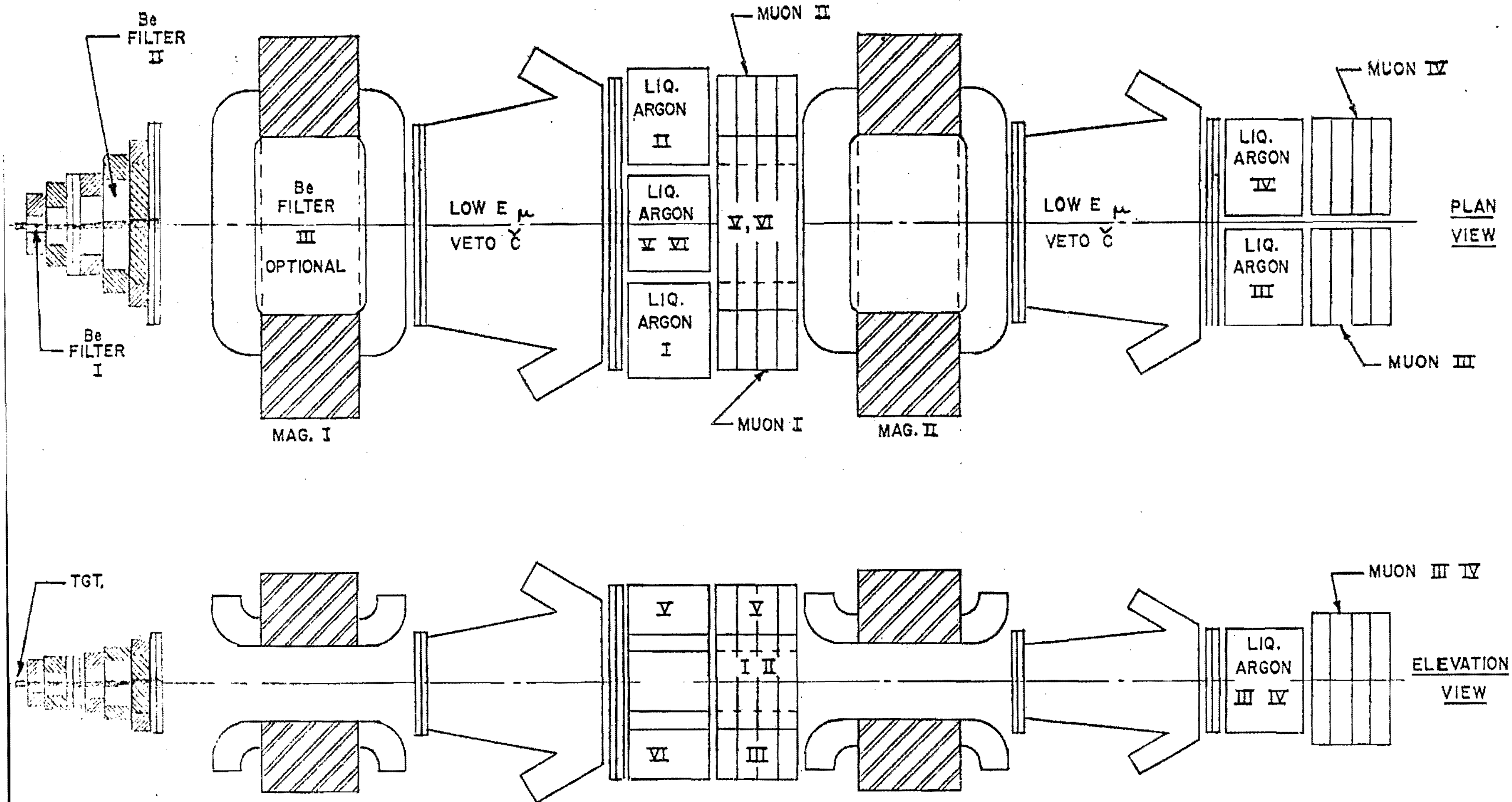
TABLE VI

SUPPRESSION FACTORS

DI PHOTON BACKGROUNDS

$M_{\gamma\gamma}$ (GeV/c^2)	Suppression Factor-Di Hadron Background No Aperture Cut	Suppression Factor-Di Hadron Background Aperture Cut
2- 3	125	230
3- 1	200	400
4- 5	300	700
5- 6	450	1200
6- 7	670	2100
7- 8	1000	3600
8- 9	1500	6200
9-10	2200	11000
10-11	3300	19000
11-12	5000	32000
12-13	7300	56000

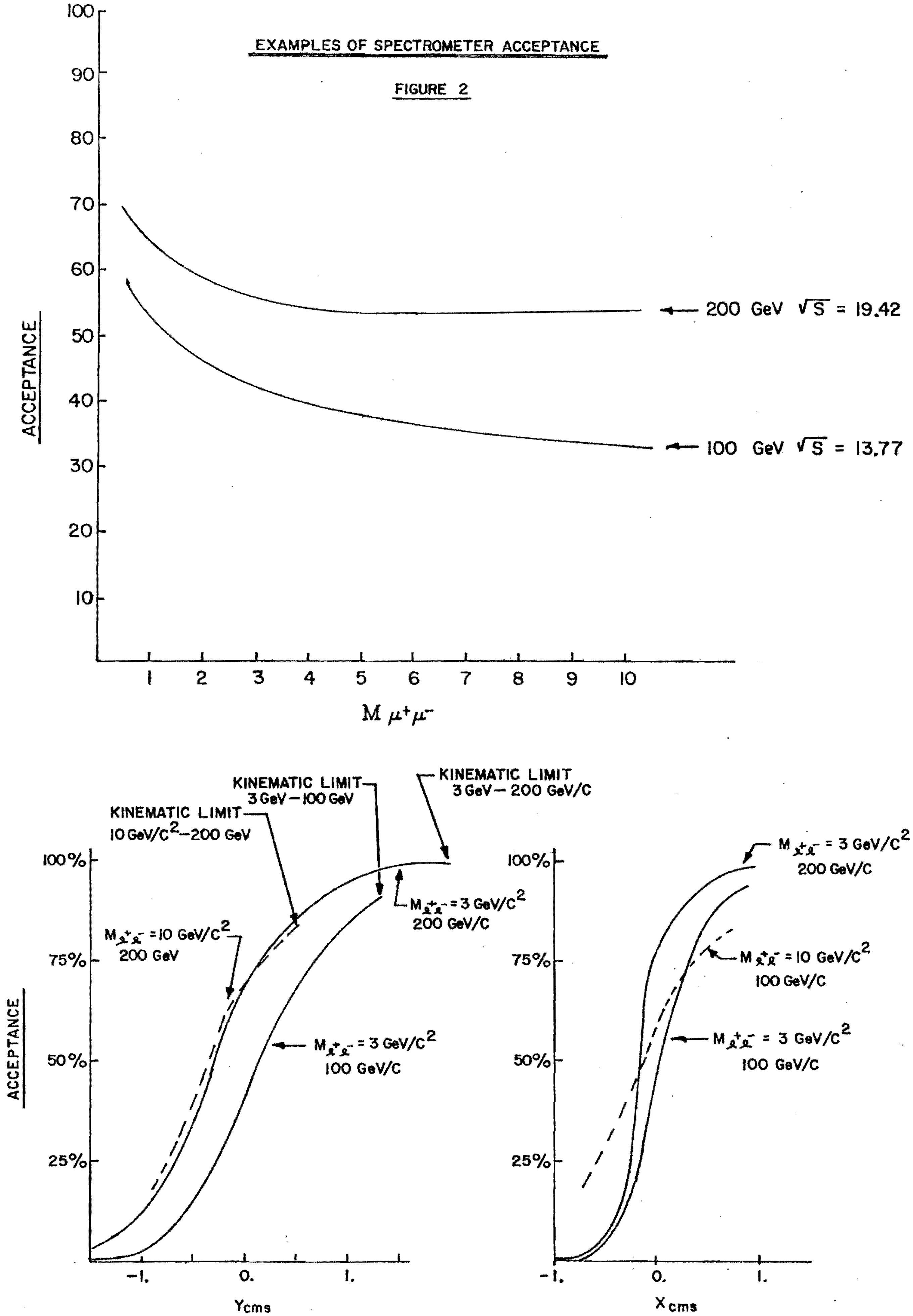
Based Monte Carlo calculations using E-494 hadronic production of di hadrons data and fitting exponentials to resulting di photon mass spectra.



E 537 EQUIPMENT LAYOUT *

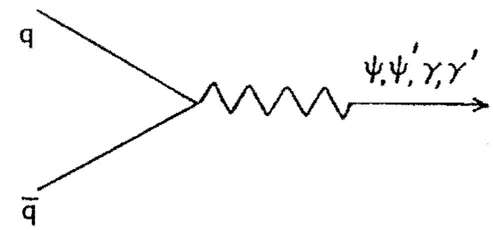
FIGURE 1

*Shielded Spectrometer Configuration
Open Spectrometer Configuration without
Shield Incorporates a 2 Meter D_2 Target.



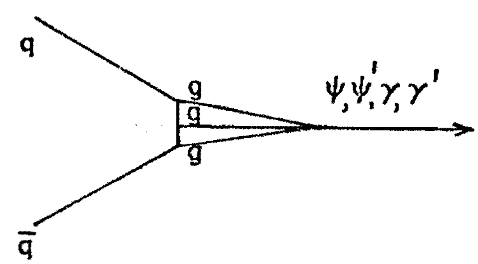
EXAMPLES OF SPECTROMETER ACCEPTANCE
FIGURE 2
ACCEPTANCE
100
90
80
70
60
50
40
30
20
10
1 2 3 4 5 6 7 8 9 10
M $\mu^+\mu^-$
200 GeV $\sqrt{S}$ = 19.42
100 GeV $\sqrt{S}$ = 13.77
KINEMATIC LIMIT 3 GeV — 100 GeV
KINEMATIC LIMIT 3 GeV — 200 GeV/C
KINEMATIC LIMIT 10 GeV/C^2 — 200 GeV
ACCEPTANCE
100%
75%
50%
25%
$M_{\ell^+\ell^-}$ = 10 GeV/C^2 200 GeV
$M_{\ell^+\ell^-}$ = 3 GeV/C^2 200 GeV/C
$M_{\ell^+\ell^-}$ = 3 GeV/C^2 100 GeV/C
−1. 0. 1.
Ycms
$M_{\ell^+\ell^-}$ = 3 GeV/C^2 200 GeV/C
$M_{\ell^+\ell^-}$ = 10 GeV/C^2 100 GeV/C
$M_{\ell^+\ell^-}$ = 3 GeV/C^2 100 GeV/C
−1. 0. 1.
Xcms

(a)



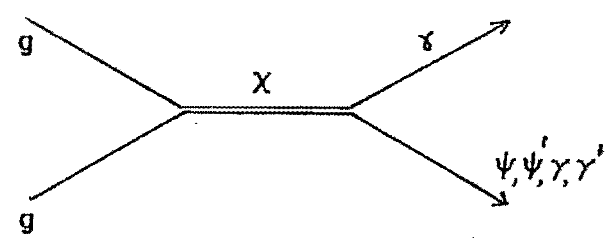
DRELL–YAN

(b)



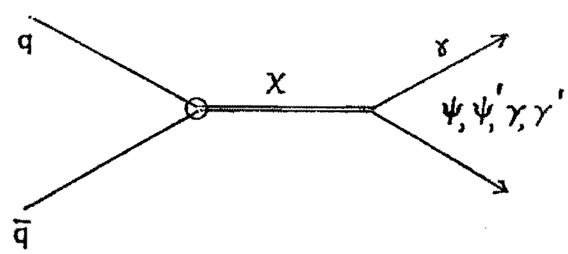
QUARK FUSION

(c)



GLUON FUSION
INTERMEDIATE χ

(d)



QUARK FUSION
INTERMEDIATE χ

DIAGRAMS (a), (b) AND (d) ARE AIDED BY THE PRESENSE OF VALENCE ANTIQUARKS

FIGURE 3

REFERENCES

1. B. C. Barish et al., Calibration of a Sampling Total Absorption Detector Designed for Neutrino Experiments, Nucl. Instrum. Methods 130, 49 (1975).

2. A. Van Ginneken, High Energy Particle Interaction in Large Targets, Fermilab Publication.

3. C. Quigg, Production and Detection of Intermediate Vector Bosons and Heavy Leptons in pp and $\bar{p}p$ Collisions, Rev. Mod. Phys. 49, No. 2, April 1977.

4. D. Hom et al., Observation of a Dimuon Resonance at 9.5 GeV in 400 GeV Proton Nucleus Collisions, Fermilab-Pub-77/58-EXP 7100.288. - Also private communications.

5. R. D. Field and R. P. Feynman, 1976 Caltech Report, CALT-68-565 (unpublished).

6. A. Donnachie and P. V. Landshoff, Production of Lepton Pairs, J/ψ, and Charm with Hadron Beams, Nucl. Phys. B112, 233 (1976).

7. M. J. Carden et al., Experimental Comparison of J/ψ Production by $\pi^{\pm}$, $K^{\pm}$, p, and $\bar{p}$ Beams at 39.5 GeV/c, Phys. Lett. 68B, No. 1, 96.

8. M. J. Carden et al., Massive Muon Pair Production at 39.5 GeV/c by $\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$ on Copper, CERN Preprint, unpublished.

9. K. J. Anderson et al., Production of J(3.1) and ψ'(3.7) by 225 GeV π^+, π^-, and Protons, XVIII International Conference, Tbilisi, USSR, 1976.

10. K. J. Anderson et al., Production at Continuum Muon Pairs at 225 GeV by Pions and Protons, XVIII International Conference, Tbilisi, USSR, 1976.

11. K. J. Anderson et al., Inclusive μ Pair Production at 150 GeV by π^+ Mesons and Protons, XVIII International Conference, Tbilisi, USSR, 1976.

12. H. J. Teper, ψ/J Production in Hadronic Collisions: A Critical Review of Models, Invited Contribution to the 12th Rencontre de Moriond, Flaine, March 1977.

13. Y. Kazama (unpublished). - Also see T. Hagiwara et al., The Newly Found Resonance Υ(9.5) and the Charge of the Heavy Quark.

14. R. D. Kephart et al., A Measurement of the Dihadron Mass Continuum in Proton-Be Collisions and a Search for Narrow Resonances, Fermilab-Pub-77/83-EXP 7100.494.

15. G. Feldman, Recent Results in Charmonium Spectroscopy, Vth International Conference on Experimental Meson Spectroscopy, Northeastern University, April 29-30, 1977.

16. C. Kourkoumelis, A Study of the J/ψ Production in Proton-Proton Collisions at the CERN ISR, Using Liquid Argon Calorimeters and Lithium/Xenon Transition Radiation Detectors, Thesis, CERN 77-06, Experimental Physics Division, March 29, 1977.

17. E. A. Paschos, Massive Gamma Pair Production in Hadron-Hadron Collisions, Preprint.

18. G. R. Farrar and S. Frautschi, Copious Direct Photon Production: A Possible Resolution of the Prompt-Lepton Puzzle, Phys. Rev. Lett. 36, No. 17 (1976).

19. G. R. Farrar, Experimental Means for Distinguishing Models of Large $p_{\perp}$ Inclusive Scattering, CALT-68-576.

20. P. Darriulat et al., Large Transverse Momentum Photons from High Energy Proton-Proton Collisions, CERN Preprint.

21. T. A. De Grand and H. I. Miettinen, Hadronic Production with a Drell-Yan Trigger, unpublished.

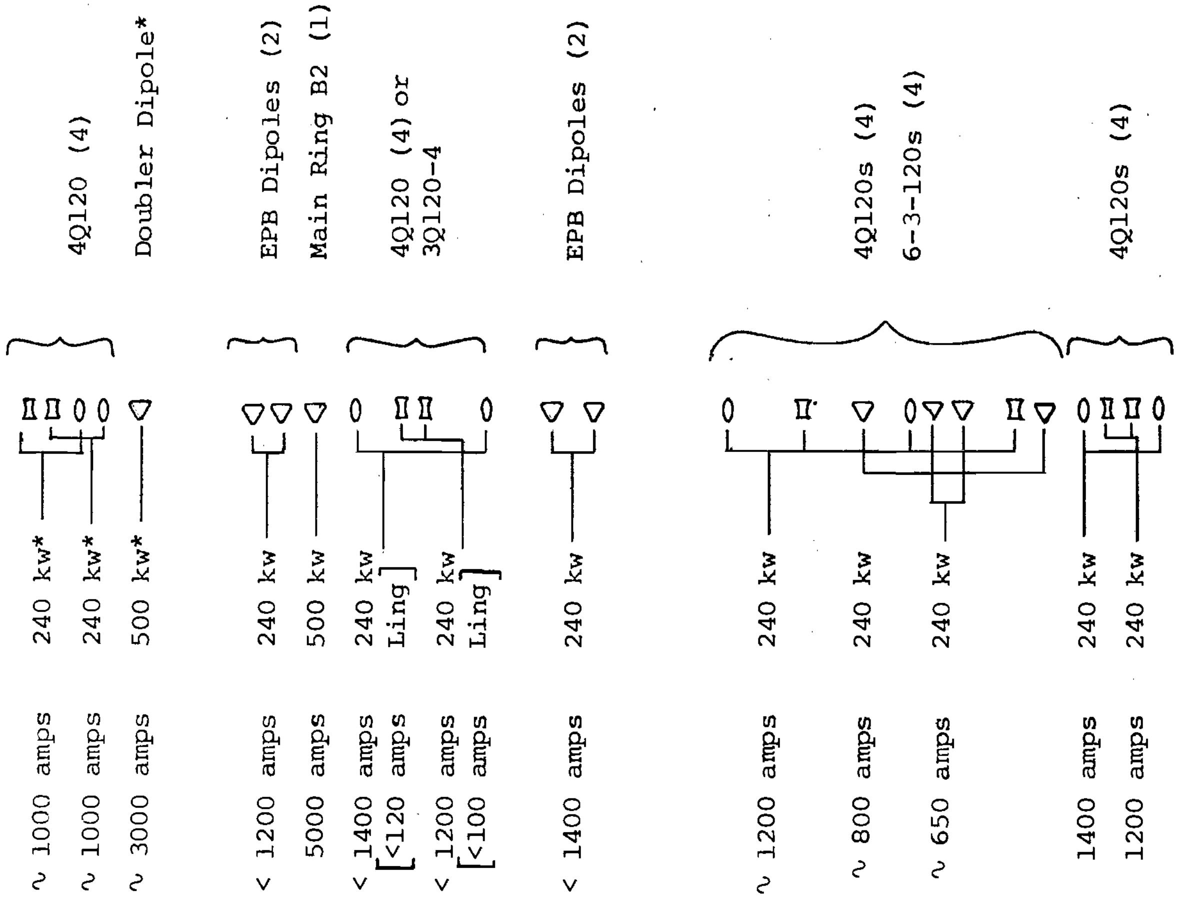
22. S. Brodsky and J. Gunion, Hadronic Fragmentation as a Probe of the Underlying Dynamics of Hadron Collisions, UCD-77-9, SLAC-PUB-1939, May 1977.

23. Fermilab Experiment 7 achieved this measurement at low t with a similar spectrometer and technique.

SCHEMATIC BEAM LINE - [200 GeV Conventional - Superconducting Mixture]

Configuration I

Enclosure II



Totals for PS (Not Installed)	
240 kw	- 7 or 9 or 5
Lings	- 2 or 0 or 2
500 kw	- 1 or 1 or 3

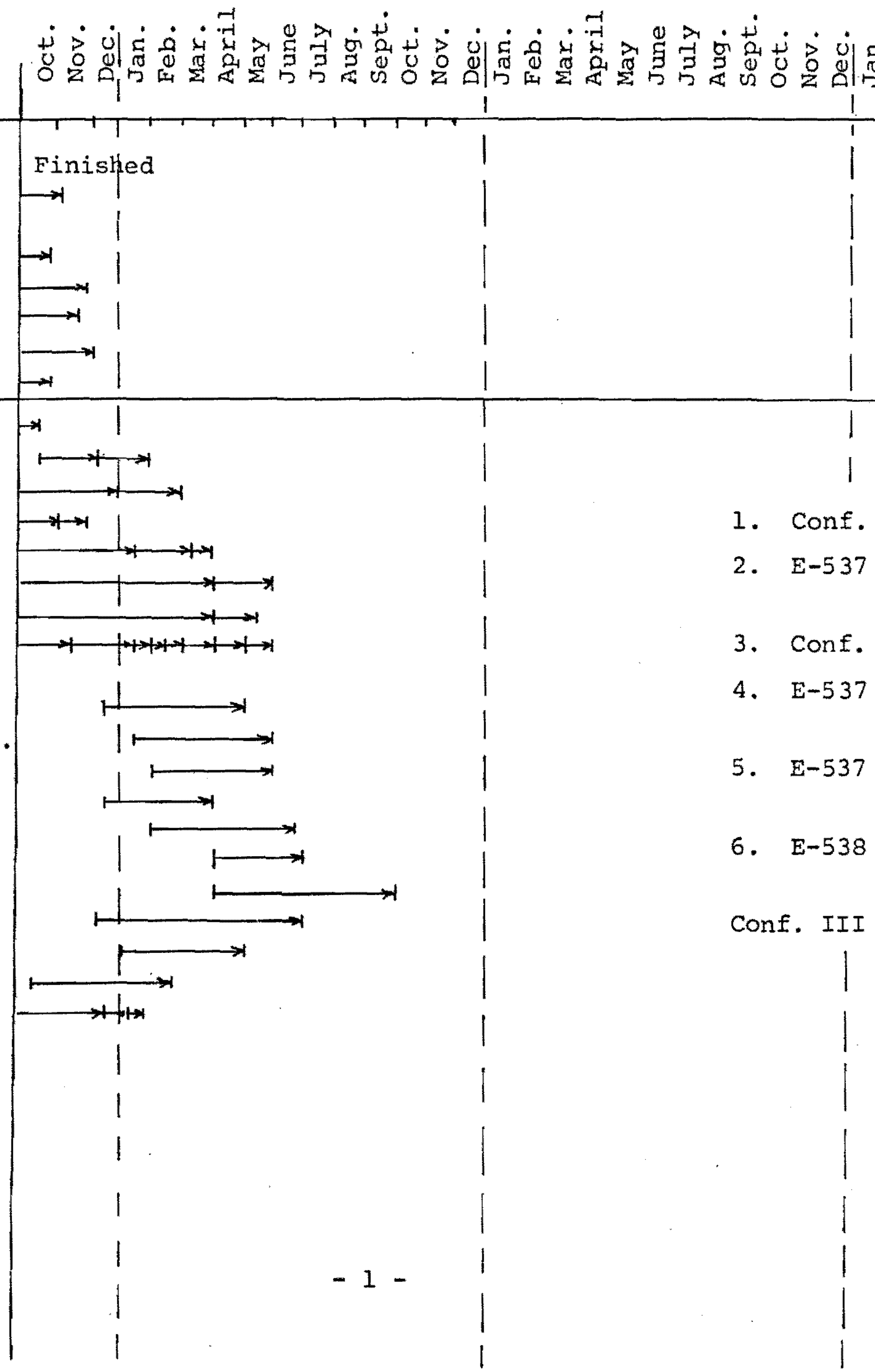
Totals for Magnets (Not Installed)	
4Q120s	- 8 or 12
3Q120s	- 8 or 0
6-3-120s	- 4
3D120s	- 4

*Already installed

SCHEDULE - HIGH INTENSITY LABORATORY - P-537 *Items Indicate Hoped For Dates Particular to P-537 B. Cox Oct. 1977

Enclosure III

GROUP	ACTIVITY
Architectural Services	Civil Phase I
	Elec Phase I
	Mech Phase I
	Civil Phase II
	Elec Phase II
	Mech Phase II
	Roadwork
	Rework Exp Floor
Proton Mechanical (and Site)	Steel Floor
	Mom Slit Steel
	Target Box
	Prod. Target
	Collimator/Dump
	Transporter
	Mom Slit
	Mag Stands
	Spoilers
	*Rail System
	*Solid Target Assy.
	*Al Mag I Stand
	*Chamber Stand
	*μSteel + Stand
	*L.A. Stands
	*Be Filter
	Beam Cerenkov
	Vacuum System
	Safety Collimator
	B-2 Magnet

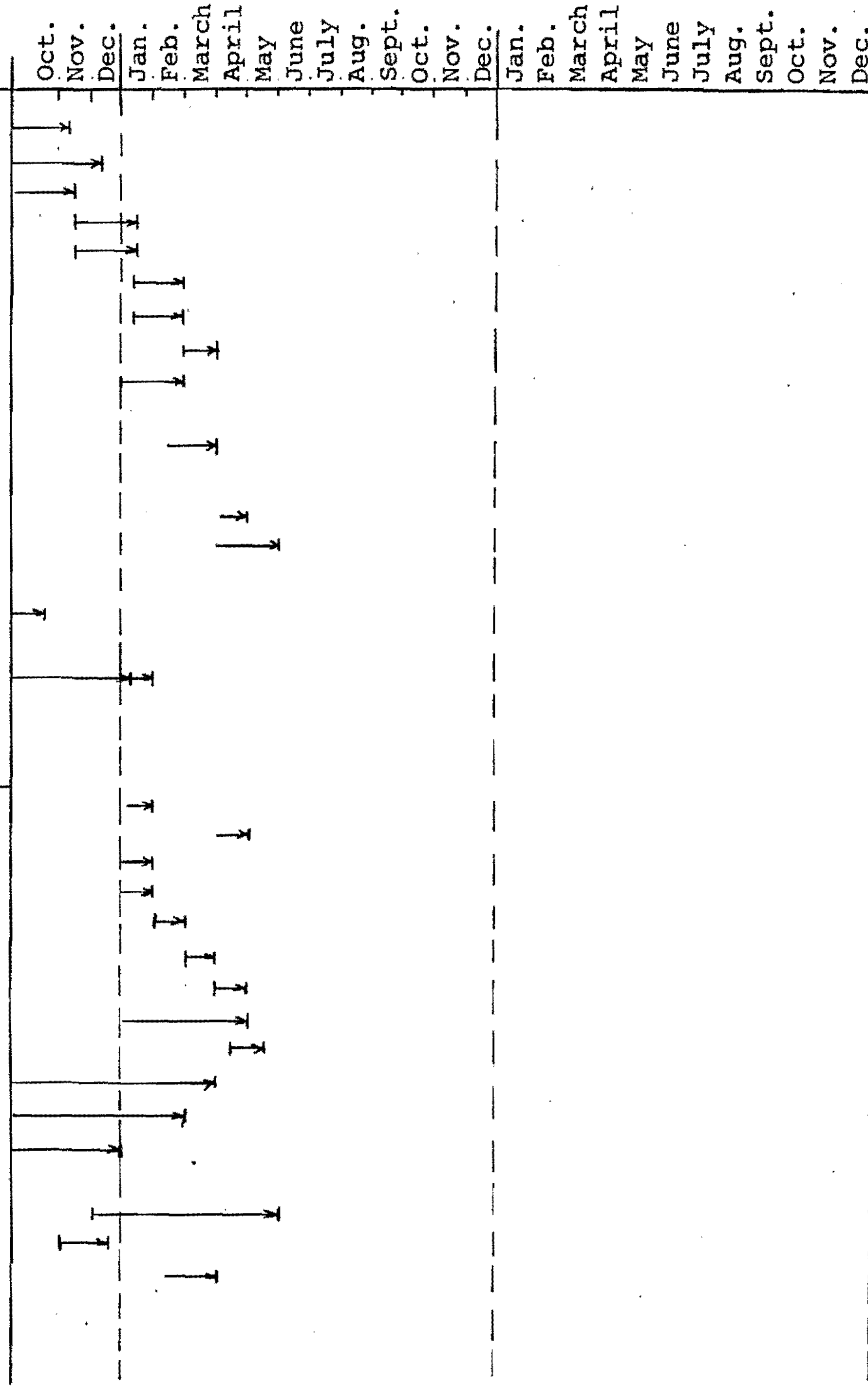


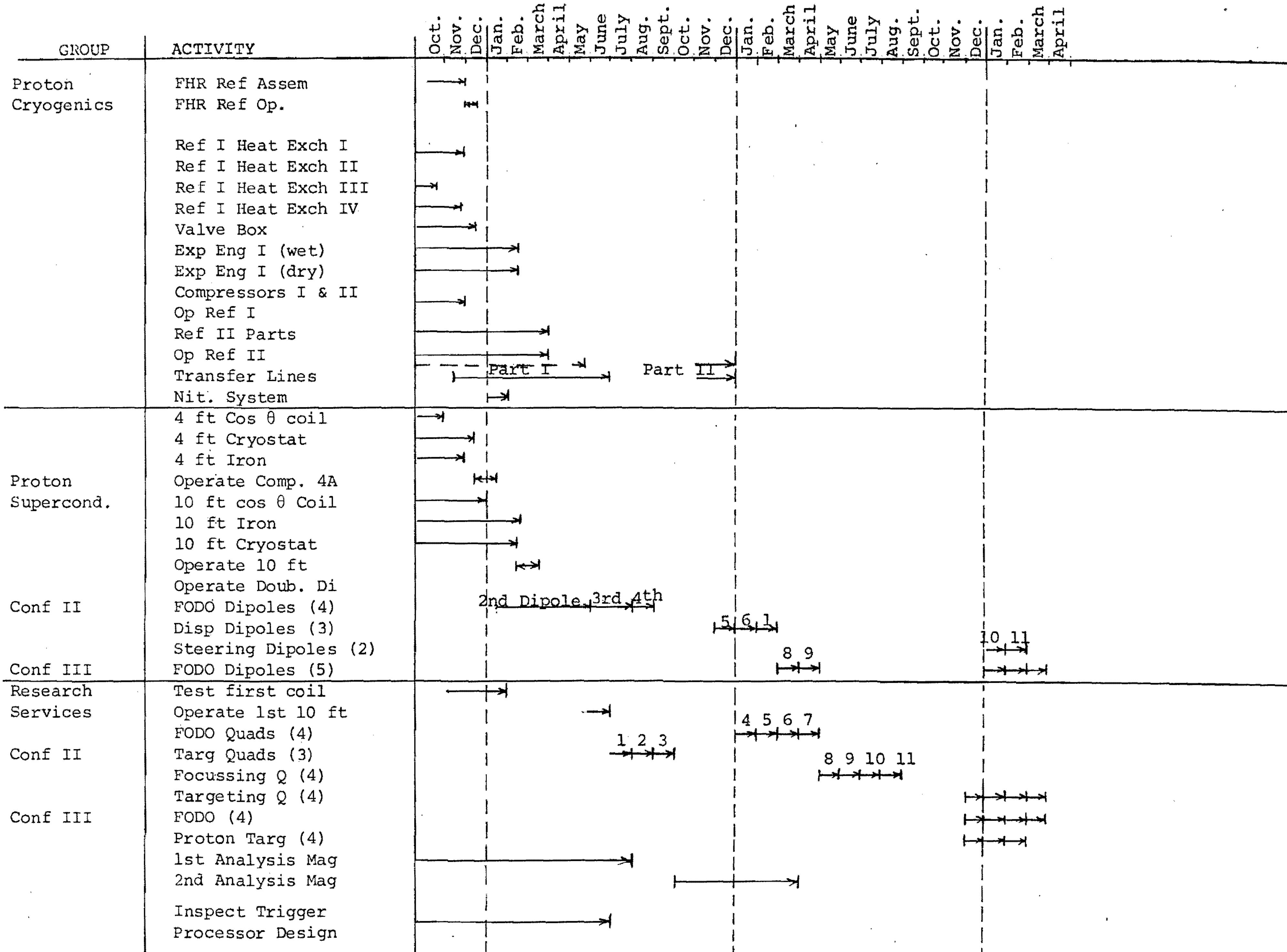
MAJOR GOALS & DATES

1. Conf. I 200 GeV Beam - June 78
2. E-537 First Data - July, Aug., Sept. 78
3. Conf. II 400 GeV Beam- March 1, 79
4. E-537 Second Run - April, May June 79
5. E-537 Third Run - Oct., Nov., Dec. 79
6. E-538 Fourth Run - April, May, June 80

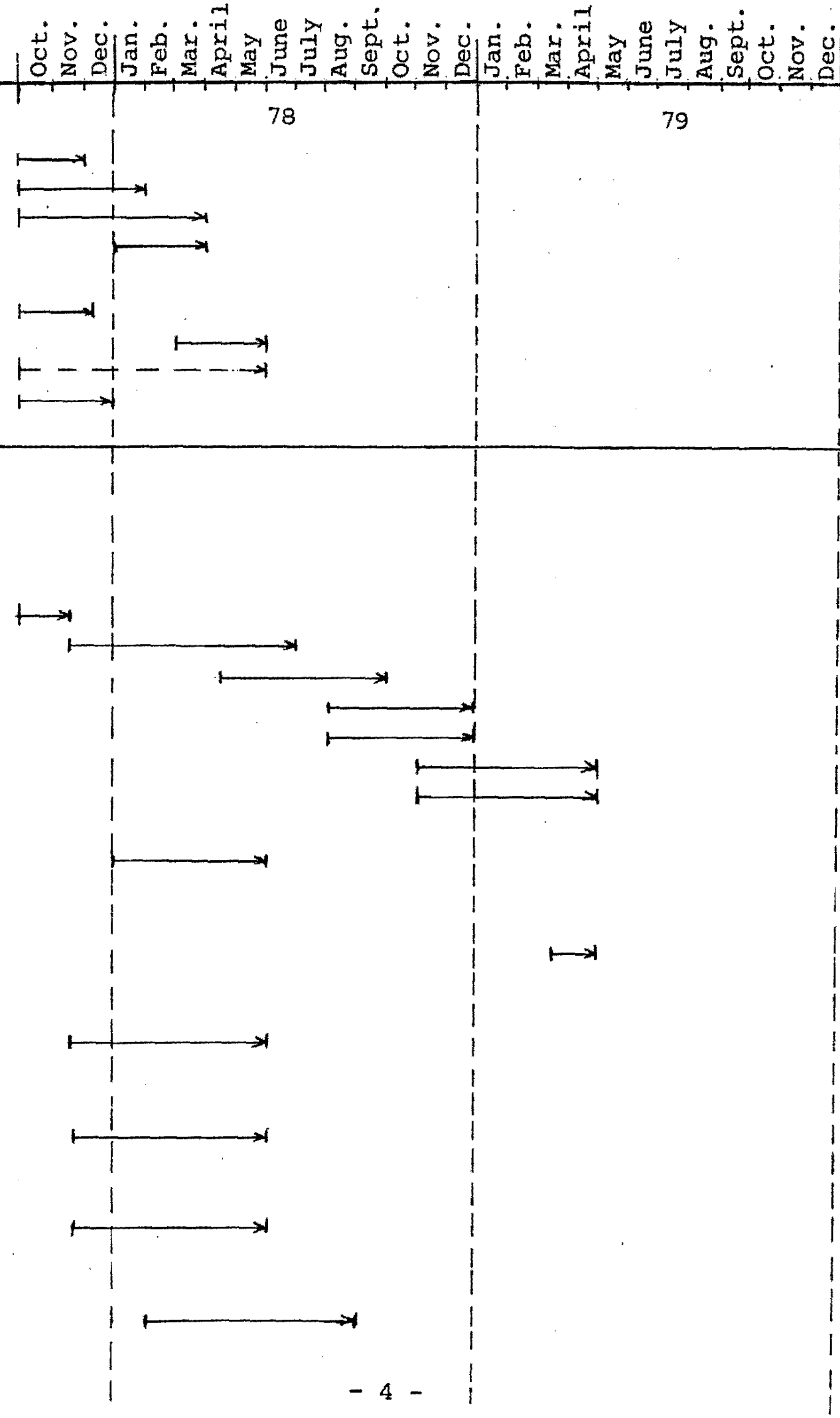
Conf. III 1000 GeV Beam - March 1, 80

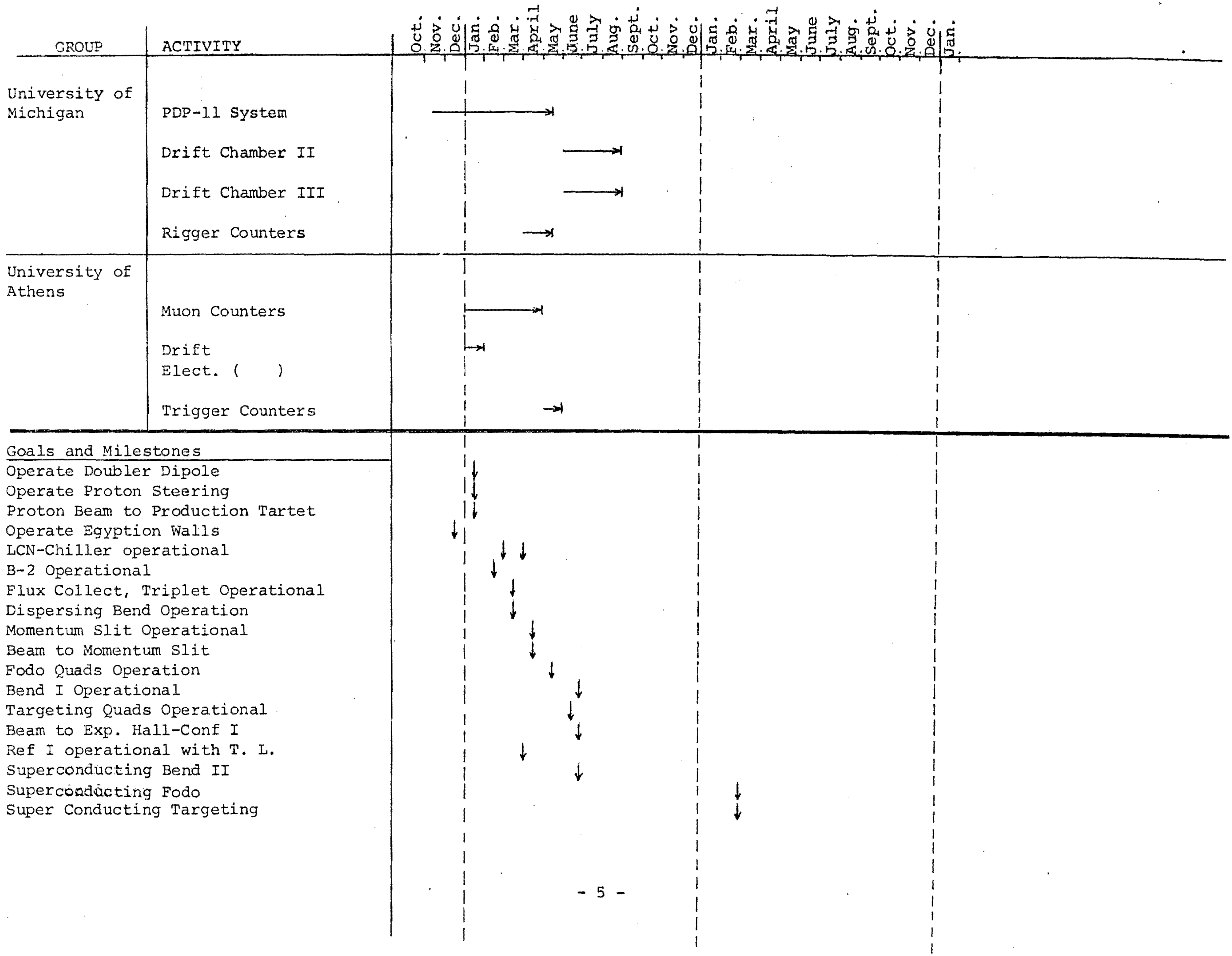
GROUP	ACTIVITY
Electrical	Doubler PS
(and Site)	B-2 PS (500 kw)
	Prot-Tag PS (240 kw)
Conf. I	Triplet PS (240 kw)
	Disp Bend PS (240 kw)
	FODO PS (240 kw)
	Bend II PS (240 kw)
	Targeting Quads (240)
	Trim PS
	Low Imp PS
Conf. II	Low Imp PS
	1st Anal Mag PS
	2nd Anal Mag MS
	Controls Cable
	Watercooled Bus
Site	B-2 Inst
Support	Proton Targ. Inst.
	Triplet Inst.
Conf. I	Disp. Bend Inst.
	FODO Inst.
	Bend II Inst.
	Targeting Quad Inst.
	Trims Inst.
	Collimator Inst.
	LCW System
	Chiller System
	LCW Piping
	Interlock System
	Vacuum System
	Mom. Slit Steel
	Mom Slit




GROUP
ACTIVITY
Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept. Oct. Nov. Dec. Jan. Feb. March April
Proton Cryogenics
FHR Ref Assem
FHR Ref Op.
Ref I Heat Exch I
Ref I Heat Exch II
Ref I Heat Exch III
Ref I Heat Exch IV
Valve Box
Exp Eng I (wet)
Exp Eng I (dry)
Compressors I & II
Op Ref I
Ref II Parts
Op Ref II
Transfer Lines
Part I
Part II
Nit. System
4 ft Cos θ coil
4 ft Cryostat
4 ft Iron
Proton Supercond.
Operate Comp. 4A
10 ft cos θ Coil
10 ft Iron
10 ft Cryostat
Operate 10 ft
Operate Doub. Di
Conf II
FODO Dipoles (4)
2nd Dipole 3rd 4th
Disp Dipoles (3)
5 6 1
Steering Dipoles (2)
10 11
8 9
Conf III
FODO Dipoles (5)
Research Services
Test first coil
Operate 1st 10 ft
FODO Quads (4)
4 5 6 7
1 2 3
Conf II
Targ Quads (3)
8 9 10 11
Focussing Q (4)
Targeting Q (4)
Conf III
FODO (4)
Proton Targ (4)
1st Analysis Mag
2nd Analysis Mag
Inspect Trigger Processor Design

GROUP	ACTIVITY
Proton Inst.	SC 700/701
	SC 702
	SC 703/704/705
	SC 706/707
	Egyption Walls
	Cryo Monitors
	Loss Monitors
	Temp Monitors
Physics Dept.	L. A. Design
	Module I + Elect.
	Module II + Elect.
	Module III + Elect.
	Module IV + Elect.
	Module V + Elect.
	Module VI + Elect.
	Drift Chamber I Elect. (1300)
	Drift Chamber Elect. (500)
	PWC I PWC ELECT. ( )
	PWC II PWC Elect. ( )
	PWC III PWC Elect. ( )
	Select Trigger Processor

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University of Athens
Muon Counters
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Trigger Counters
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Operate Proton Steering
Proton Beam to Production Tartet
Operate Egyption Walls
LCN-Chiller operational
B-2 Operational
Flux Collect, Triplet Operational
Dispersing Bend Operation
Momentum Slit Operational
Beam to Momentum Slit
Fodo Quads Operation
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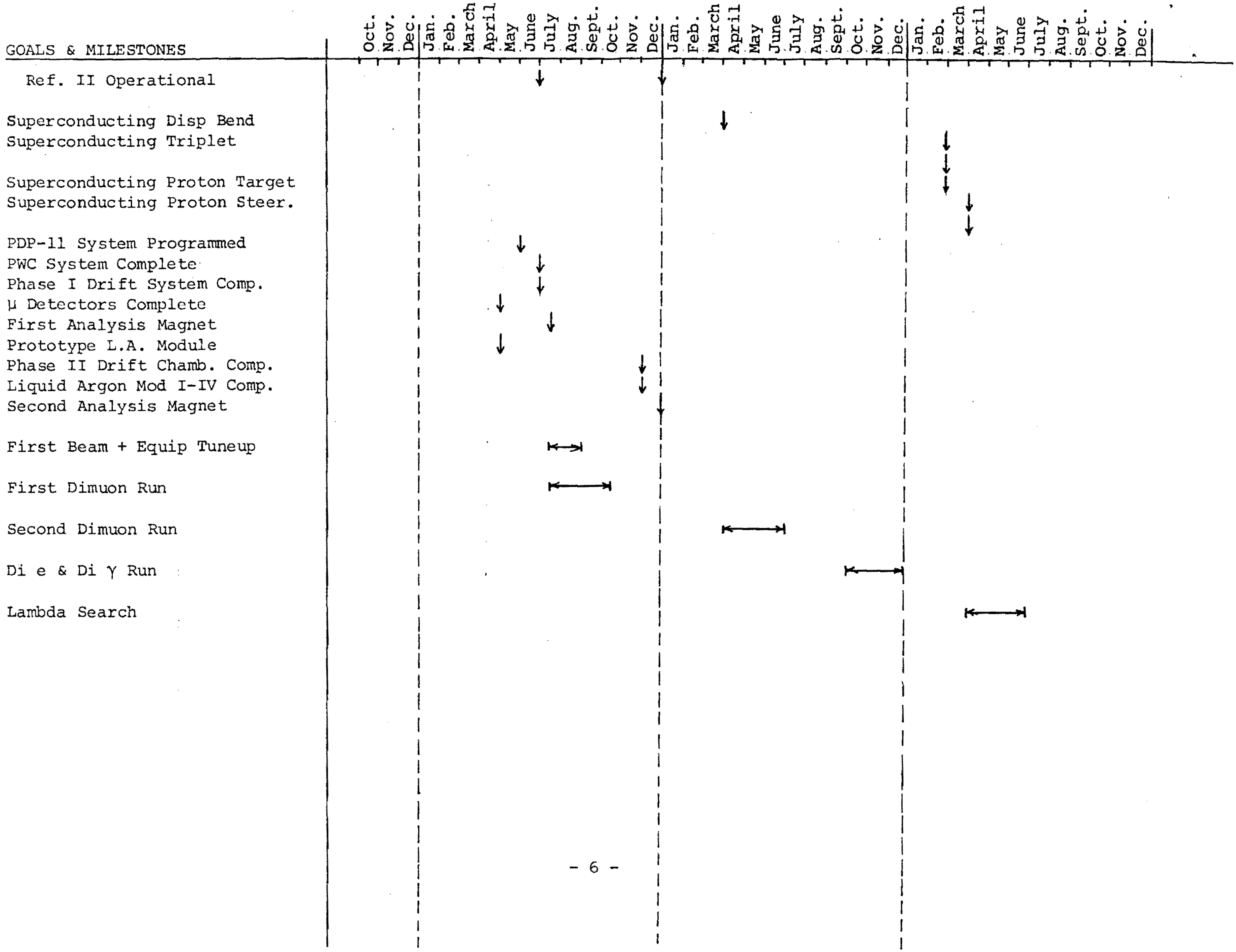
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Superconducting Triplet
Superconducting Proton Target
Superconducting Proton Steer.
PDP-11 System Programmed
PWC System Complete
Phase I Drift System Comp.
μ Detectors Complete
First Analysis Magnet
Prototype L.A. Module
Phase II Drift Chamb. Comp.
Liquid Argon Mod I-IV Comp.
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Addendum to P-537

FERMI NATIONAL ACCELERATOR LABORATORY

RECEIVED
NOV 3 1977
DIRECTORS OFFICE
FERMILAB

October 31, 1977

E. L. GOLDWASSER
Director's Office

Dear Ned:

The purpose of this letter and the enclosures is to respond to the Program Advisory Committee's request for estimates of the acceptances of the proposed spectrometer and the expected backgrounds. Enclosure I seeks to answer these questions for the following specific physics objectives.

I. Dimuon Continuum and Resonance Production by $\bar{p}$ and $\pi^{\pm}$ - Shielded Spectrometer Configuration

II. Hidden Charm Factory (Charmonium Production and Detection) - Open Spectrometer Configuration

III. Multi Photon Physics - Open Spectrometer Configuration

In addition to these specific pieces of physics we also indicate other intriguing possibilities for experimentation which we are investigating. Finally, we emphasize there is great excitement in this kind of experimentation which lies not in what we know about or can calculate today, but from the surprises which may appear when we begin to experiment with the antiquarks in the high intensity antiproton and pion beams.

We would also like to report on the activities of P-537. Since the Summer PAC Meeting we have proceeded to develop a design for our liquid argon module and have put together a small prototype system which we are scheduled to begin testing in P-West November 3rd. We are in the process of developing amplifiers and other associated electronics for the shower detector and we will test some of these devices during this test run. We have also initiated the design of a PWC and drift chamber system. We have at the request of the Laboratory prepared a 'proto-agreement' which details personnel, schedules, and costs for this experiment. Our spectrometer design has been hardened and defined by these activities and the many Monte Carolo studies which we have made. Most importantly, a scheme has been conceived whereby 200 GeV $\bar{p}$ and $\pi^{\pm}$ beams of high intensity can be achieved by early in June, 1978. We have included this scheme with this letter as Enclosure II. We feel that the possibility of this beam lends immediacy to our request to receive approval of P-537 at this time. In Enclosure III we have included a schedule which attempts to define major items in P-537 and when they might be ready. This schedule is interwoven with the schedule for turn-on of the High Intensity Laboratory.

We are asking for an initial run of 14 weeks to study dimuon production by $\pi^{\pm}$ and antiproton. We feel that we can begin this work with one magnet of the size listed in the 'proto-agreement'. We would like 10^{13} p/pulse for part of the antiproton running and several x 10^{12} p/pulse for the $\pi^{\pm}$ running. This data taking period would include a 100 hour period as soon as beam is turned on in which we would do tuning and measure the flux of the $\pi^{\pm}$ and $\bar{p}$ beams in order to sharpen our time estimates. Beyond this inital run, we foresee three additional runs of lengths from 10 - 14 weeks in which we try to address the physics questions of I, II and III. Of course our goals may be modified by physics discoveries that our group or other groups may make.

Finally, we would reiterate that we hope for an approval at this time. We are anxious to get on the air as early as possible and we feel that our physics goals and capabilities would give us an expectation of a high priority.

Sincerely,

Brad

Brad Cox

BC:al

cc: <u>University of Athens</u>

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C. Kourkoumelis	L. Resvanis

<u>Fermilab</u>

R. M. Baltrusaitis	T. Kondo
M. Binkley	P. Mazur
B. Cox	T. Murphy
C. Hojvat	F. Turkot
R. Kephart	W. Yang

<u>University of Michigan</u>

C. Akerlof	D. Nitz
R. Fabrizio	R. Thun
P. Krashour	

ENCLOSURE I

I. DIMUON PRODUCTION BY $\bar{p}$ AND $\pi^{\pm}$ - Shielded Spectrometer Configuration

1. General Comments and Physics Goals

The first run of Experiment 537 will measure the production of dimuons by $\bar{p}$ and $\pi^{\pm}$. We have performed Monte Carlo calculations of the acceptance for the dimuon system at a variety of beam energies. Examples of these acceptances for the spectrometer of Figure 1 are shown in Figure 2. With good resolution ($\sigma_{M_{\mu^+\mu^-}} \gtrsim 2\%$) the mass spectra for the various reactions can be measured out to limits indicated by Tables II.a and II.b. The questions and objectives which we will address in the first run of Experiment 537 with the shielded geometry will be:

a. What are the relative rates of $\bar{p}$ and $\pi^{\pm}$ production of the dimuon continuum between the ψ and the Υ? Is this process initiated by a simple Drell Yan type mechanism? The measurement of the absolute rate of $\bar{p}$ production of the dimuon spectrum should provide a fundamental test of our understanding of $q\bar{q}$ interactions. Is there a factor of three supression in this crossection due colored quarks?

b. What are the relative rates of ψ and ψ' production by $\bar{p}$ and $\pi^{\pm}$? Is gluon fusion, quark fusion, or a simple Drell Yan intermediate photon mechanism leading to the production of resonances?

c. What are the absolute rates of Υ and Υ' production by $\pi^{\pm}$? Do both these objects have the same nature?

d. What is the detailed dynamics of ψ, ψ', Υ, and Υ' production in x, y, and $p_{\perp}$? (Range of measurement includes x = 0, y = 0.) What are the detailed angular distributions of the resonance decays?

e. What is the energy dependence of the production cross sections? Does the continuum production scale as $M^3 \frac{d\sigma}{dydM}$? Does the energy dependence of the cross section for ψ, ψ' production for antiprotons and $\pi^{\pm}$ match the expectations of gluon fusion?

In general, the answering of these questions will allow us to judge whether the Drell Yan mechanism is the dominant mechanism for producing dimuon continuum and whether the presence of valence antiquarks in the antiproton and pions lead to a dramatic increase in the dilepton cross section. The comparison of relative resonance production rates will allow us to shed light on the production mechanisms for ψ, ψ', Υ and Υ' production. The unexpected enhancements of this resonance production depend sensitively on whether gluon or quark-antiquark annihilation is initiating the process. In fact, we are testing with this data the larger question of whether the constituent interactions are occurring or whether collective interactions such as the multiperipheral model still dominate.

2. Beams

We plan to use the various $\bar{p}$ and $\pi^{\pm}$ beams listed in Table I for the shielded spectrometer dimuon experiment. For runs in the energy range of 100 - 150 GeV we plan to use the $\bar{\Lambda}^0 \to \bar{p}$ beam. For higher energies we plan to use a direct antiproton beam where the intensity is limited by the requirement that the beam Cerenkov counter tag antiprotons and that the number of interactions per bucket average approximately one. The $\pi^{\pm}$ beams listed in Table I do not put extreme requirements on intensities of incident protons. The 100 and 200 GeV beams as outlined in Enclosure II will be ready with full intensity at turn-on of the High Intensity Laboratory this coming summer. 300 GeV capability should follow shortly after that time. The usable intensity of π's is set by calculations of punch through of the Be/Cu shield. We estimate approximately 1 - 2 x 10^8 particles penetrating the 14 absorption lengths of the shield using the data of Barish et al[1] and the shower calculation of Van Ginneken and Awschalom[2]. This flux is relatively low energy and isotropically distributed outside the deadened forward 10 mrad core. Experience of the proponents of this experiment indicate that this is a bearable rate for PWC planes. It should lead to less than one extra track/trigger.

3. Sensitivity

The event rates for the shielded forward spectrometer (shown in Figure 1) using the beams of Table I and calculated dimuon acceptances similar to those of Figure 2 are given in Tables II.a and II.b for resonance and dimuon continuum production for a five week run. We have used theoretical expectations for the enhancement of $\bar{p}$ continuum production of dimuons relative to p production as given by C. Quigg[3]. The predicted enhancements of the $\bar{p}$ reaction (up to 3 orders of magnitude) have been applied to the scaled data $pN \to \mu^+ \mu^- + x$ of Hom et al[4]. We point out that the enhancement of antiproton relative to proton production was calculated with the sea quark distribution $(1 - x)^7$ of Feynman and Field[5]. In fact, the measurement of Hom et al appears to fall steeper than this ($\sim (1 - x)^9$ or greater) which argues for a larger enhancement of the $\bar{p}$ reaction than we have used. The $\pi^{\pm}$ production rates for continuum dimuons have been taken from Donnachie and Landshoff[6] since no data exists for production of dimuon pairs above the ψ' at this time. Both the CERN Ω experiment[7,8] and Anderson et al[9,10,11] have essentially no data above the ψ'. In all the continuum calculations the assumption has been made that $M^3 \frac{d\sigma}{dM} \sim f\ (\tau = \frac{M^2}{s})$ and scales with energy.

The resonance production cross sections at various energies for ψ, ψ', Υ, Υ' have been extrapolated from the existing pN

100 GeV $\bar{p}$	-	2 weeks
200 GeV $\bar{p}$	-	4 weeks
100 GeV π^-	-	2 weeks
200 GeV π^+	-	5 weeks
200 GeV π^-	-	1 week
		14 weeks = 1400 hours

This should allow us to accomplish at least a start on the physics goals of Section I. We would contemplate a second run of roughly the same duration at a later time.

II. HIDDEN CHARM FACTORY - Production and Detection of Charmonium and Higher χ States - Open Spectrometer

1. General Remarks and Physics Goals

The second run of the apparatus should be devoted to searches for and measurements of the reported hidden charm χ states intermediate in mass between the ψ and ψ' in the charmonium spectrum and to searches for higher lying χ states. As seen in Table IV, the various χ states[15] each participate in decay strings which start with the ψ' (or perhaps some higher state which does not decay into $e^+ e^-$) and end up in the ψ which decays into $e^+ e^-$. With our liquid argon detector we plan to trigger an $e^+ e^-$ and look for accompanying photons. There is a minimum rate of production of intermediate χ's, which Table IV shows, which is given by the decays of the ψ'. We use the production rates of ψ' given in Table III to calculate this minimum number. However, if current theoretical expectations are correct, process 3.c or 3.d of Figure 3 will be the dominating ψ production mechanism. In this case, practically every ψ will have come to first order from a χ. This leads to a much larger rate of χ which we can estimate, assuming (without any evidence or justification) that all χ's are produced with equal crossections in hadronic interactions. These rates are also shown in Table III. It is worth pointing out that this direct production of χ states is exactly where hadronic reactions are supposed to exceed and better $e^+ e^-$ reactions. The incredible sensitivity afforded by the $\psi \to e^+ e^-$ signature eliminates the high hadronic backgrounds and allows us to tag on likely candidates for χ events and therefore to construct this hidden charm factory. Detection of and measurement of this direct intermediate χ production is therefore a prime objective.

In addition to the search for the production of χ states the observation of these states should lead to a much better determination of their quantum numbers. Branching ratios data of Hom et al, the $\pi^{\pm}$ N data of Anderson et al, and the $\bar{p}$N of Corden et al and from predictions of the referenced theoretical papers. The constituent interaction model predictions arise from at least the four diagrams[12] shown in Figure 3. These calculations would argue that a difference of less than a factor of two in pN and $\bar{p}$N or $\pi^{\pm}$N production at high energies of these resonances since the dominant diagram is the gluon fusion mechanism of 3.c. However, these production mechanisms for resonances are a strong function of energy and in fact for antiprotons the quark annihilation model dominates at low energy and would lead to a large enhancement of $\bar{p}$ production[13] relative to p production. The existing data shows a factor 6 difference at 39.5 GeV between $\bar{p}N \to \psi + x$ and $pN \to \psi + x$ and essentially equal cross sections for $\pi^{\pm}N \to \psi$ with approximately a factor of two difference between the pN and $\pi^{\pm}$ reactions at 225 GeV. The large difference in $\bar{p}$N and pN is, as we mentioned, supposedly due to the different turn-on rate of process 3.b and 3.c. No convincing data exists at higher energies or for ψ' and Υ. We propose to increase the amount of information by measurement of $\bar{p}N \to \psi, \psi'$, and $\pi^{\pm}\, p \to \psi, \psi', \Upsilon, \Upsilon'$ at various energies. (See Section I.b.) Our resolution of order $\sigma \sim 2\%$ with the variable Be/Cu shield should be adequate to resolve the Υ, Υ'.

4. Background

Since in all phases of this experiment the interaction rate/bucket is low, the major background of dimuons comes from the coincident decay of two hadrons from a high mass hadron pair. Using the approximation that the shielded configuration of the spectrometer of Figure 1 has the equivalent of 10 inches of decay path, we calculate using the dihadron data of E-494[14], a signal to noise ratio at 400 GeV for $pN \to (\mu\mu) + x / pN \to (\mu\mu)_{decay} + x$ of approximately 200/1 at $M_{\mu^+\mu} = 4$ GeV. We estimate that at 8 GeV/c^2 we should have signal to noise of $2 \times 10^4/1$ in this configuration. Taking into consideration the lower energy of our 100 GeV running we estimate a worst case signal to noise of > 10/1 at 4 GeV and 1000/1 at 8 GeV. Estimates of the background in the two-arm experiments such as E-288 and E-357 arrived at in this way have in general been low by a factor of 10 due in large part to the accidental $(\pi \to \mu)$ $(\pi \to \mu)$ coincidences at low dimuon mass. We reiterate that we do not have this source in the wide aperture forward spectrometer.

5. Running Time For Dimuon Experiment

The rates exhibited in Tables II.a and b lead to an initial request for fourteen weeks of dimuon running to be distributed as follows:

can also be determined from the subset which appear as daughters. Even if no direct χ production exists, sufficient statistics will exist from the decays of the known ψ' production for this test.

2. Beams

In the open geometry we will take $\sim$ two order of magnitude less beam than in the shielded configuration. We will be restricted to the $\Lambda^0 \rightarrow \bar{p}$ beam and to the $\pi^{\pm}$ intensities of Table I.b, or lower initially. The calculated rates of particles arising from the interactions is bearable from a total PWC rate and a worst case single wire and 5 cm strip liquid argon rate. We have use the 30" Bubble Chamber data of Experiment 311 ($p\bar{p}$ at 100 GeV) to estimate the charged particle distributions at various planes. The neutral particle densities were assumed to be comparable. The forward 10 mrad cone of the detector is once again assumed to be deadened. The worst case liquid argon 5 cm strip is less than 2×10^6 neutrals/pulse from our studies.

3. Sensitivity and Background

As mentioned, the event rates for known χ's are given in Table IV.a, with maximum and minimum rates determined by the non-existence or maximal existence of direct χ production. The truth probably lies somewhere between these two limits. We will determine this. An intriguing possibility is that ψ or ψ''s also result from small but finite branching ratios of χ's with mass above the ψ', i.e., above charm threshold.

We estimate the $e^+ e^-$ backgrounds in the final analyzed data from misidentified $\pi^+ \pi^-$ events to be $< 2 \times 10^{-7}$ of the $\pi^+ \pi^-$ continuum. We estimate that this is achievable by our shower detector which has a fourfold longitudinal segmentation and good transverse shower development sampling. While it does not seem to be required from total trigger rate calculations (< 500 '$e^+ e^-$'/spill) we plan to incorporate some supply longitudinal shower development criterion in the trigger. At masses of 4 GeV this rejection leads to approximately 100/1 signal to noise and increases rapidly with mass because of the steeper fall of the dihadron mass spectrum. Dalitz pair conversions which lead to a real background of $e^+ e^-$ have been estimated and are about an order of magnitude lower than the false $e^+ e^-$ arising from misidentified hadron pairs.

Once true $e^+ e^-$ candidates have been isolated our sensitivity to these rare decays will be limited by backgrounds which would be of the form $m\pi^0 + \psi$ or $m\eta^0 + \psi$ production where one photon is missed. At this point there is insufficient data published to make an estimate of this flat background. From 93 event topologies of ψ + other particles, published by C.Kourkoumelis[16], it can be stated that in the limited solid angle of the Willis experiment, seven events had one extra 'photon' (sensitivity to π^0's being limited), six with one extra photon plus one extra hadron, and six events with one or two extra photons plus other charged tracks. Three of the two-photon events are consistent with the η^0 mass and two of these events are consistent with the decay $\psi' \to \eta^0 \psi$. No π^0 candidates were observed though some portion of the single γ's could be π^0's. We then would estimate that at maximum $\sim$ 19 events could be π^0's or η^0 and at minimum there are at least three η^0 events. If we take into account the better efficiency of our laboratory experiment for identifying π^0's and η^0, we would estimate that the $\gamma\,\psi$ spurious background would be less than 1% of the ψ decays and would be spread uniformly in $\gamma\,\psi$ mass. We should then have signal/noise rates for the minimum known χ signals of from 10/1 to 100/1, depending on the χ state. This is using our calculated Monte Carlo resolution (σ) of 2% for the χ masses.

4. Running Time

Table IV.a guides the selection of running time. We request a tuneup and calibration time of 200 hours for the liquid argon system. Then, guided by a desire to first detect and then analyze χ decays and then to study the χ production, we request twelve weeks of running time.

2 weeks	-	Tuneup
7 weeks	-	Search for πp production of χ states at 100/200/300 GeV
5 weeks	-	Measurement of $\bar{p}$ production at 100 GeV
14 weeks		

At this time we would like to state that although the major motivation of this work is apparently somewhat independent of the availabiliby of the antiquarks in the various beams which we intend to use, there is motivation because of the possibility of the existence of process 3.d. The direct hadronic production of χ's will give us new information on the validity of the constituent interaction picture and the existence of the process 3.d.

III. MULTI PHOTON PHYSICS - Open Spectrometer

1. General Remarks

The objective of this measurement is twofold. The level of continuum diphoton production from $\bar{q}q \to \gamma\gamma$ is predicted[17] to be of the same level of cross section as Drell Yan production of dileptons. However, in addition to the production of p wave states, other angular momentum states such as s and d wave diphoton states can be produced in this process. Observation of a true 'direct' diphoton continuum such as this would be an additional boost to the constituent interaction model of high energy interactions. In addition, the two photon spectrum, if the diphotons from $\pi^0\pi^0$, $\eta^0\eta^0$ can be eliminated, may contain resonance diphoton states. As an example of this we cite the reported chain ψ (3.1) $\rightarrow \gamma$ χ (2.8) $\rightarrow \gamma\gamma\gamma$. This is at this time very poorly established and the observation of this chain, while difficult, provides additional motivation for this work. Other surprises may appear in the various multiphoton mass spectra. As well as the difficulty of eliminating the photon combinations from the neutral mesons, there is an additional difficulty of constructing a selective trigger which will sort through the neutral flux. The ultimate limitations may turn out to be data acquisition rate (we are aiming at 500 triggers/second for uniform spill) on resonance searches at low mass.

2. Beams

In spite of the intensity of the neutral flux we feel that we can still construct two and three or more photon triggers which will allow us to use the open spectrometer configuration beam fluxes which are shown in Table III.

3. Sensitivity and Background

As shown in Table V.a, the diphoton background arising from hadronic interactions without π^0 and η^0 rejection becomes comparable to $\bar{q}q \rightarrow \gamma\gamma$ in the 6 - 7 GeV range. This is what we can expect a relatively crude trigger to produce. (Total energy plus a minimum photon separation requirement.) If we are unable to refine our trigger beyond this level we will probably suffer a factor of 2 - 4 loss in event rate in the 2 - 3 GeV bin. If we are able to recover the factor of 2 - 4 then we can take the requisite data in the 2 - 3 GeV bin in five weeks for the following quoted sensitivities for η_c. Above 3 GeV we can achieve the sensitivity regardless of trigger rate since in this mass region we are limited by the response times of the apparatus. We are in the process of investigating various triggers with our Monte Carlo calculations. These same Monte Carlo calculations give us the off line rejection of π^0 and η^0 which have both photons in the solid angle of the apparatus and lead to suppression rates listed in Table VI. Application of these factors to the data gives us 1/1 signal ($\bar{q}q \rightarrow \gamma\gamma$) to hadronic diphoton rate at $\sim$ 3 GeV. Beyond that point the dihadron induced mass spectra falls off rapidly and observation of direct diphoton continuum should be clean. We would seek to compare $\pi^{\pm}$, $\bar{p}$ induced diphoton spectra to confirm the direct nature of the diphoton continuum.

For resonance detection we have taken as a worst case ψ (3.1) $\rightarrow \gamma\chi$ (2.8) $\rightarrow \gamma\gamma\gamma$. While it is doubtful that this object has actually been observed at this point in time, the reported branching ratios[15] are so small that(as shown in Table V.b) very few χ (2.8)'s ($\sim$ 3000) are produced via

ψ (3.1) decay in five weeks. In addition, it lies in the lowest mass bin where the hadronic backgrounds are the worst. With requisite number of events accumulated in the bin and π^0 and η^0 rejection applied off line, the signal to noise ($\eta_c \to \gamma\gamma$/hadronic background $\to \gamma\gamma$) in the diphoton spectrum would be 1/100 for ψ (3.1) $\to \gamma\chi$ (2.8) $\to \gamma\gamma\gamma$. However, if we ask that there be three photons and that their mass combination lie in the ψ region, we estimate that we achieve approximately a factor of 10^5 rejection in noise with a loss of three in signal (3γ resolutions are of the order of $\sigma \sim 1.5\%$). This makes the observation of χ (2.8) difficult but possible if only χ (2.8) produced by ψ (3.1) is present. If direct χ production is present, then we should be able to directly observe the χ (2.8) in the two photon spectrum if χ(2.8) is as copious as ψ3.1) production.

4. Running Time

Once again in this run we request a mixture of $\pi^\pm$ and $\bar{p}$.

3 weeks	-	π^-N	-	200 or 300 GeV	Continuum Measurement
7 weeks	-	π^+N	-	200 or 300 GeV	Resonance Search
3 weeks	-	$\bar{p}N$	-	100 GeV	Continuum Measurement

IV. OTHER TOPICS

We feel as though the three areas which we discussed are extremely rich in possibilities. However, we may have many, many more areas which intrigue us and we either have not investigated fully, or we have left out of the detailed discussion for sake of brevity. There is, for example, the matter of existence or non-existence of the direct photon production.[18,19,20] We are eminently suited with our antiquarks and large aperture spectrometer to pin this down. We also have an extremely rich field of investigation which requires only that we look at the hadronic particles associated with continuum dielectrons. Since the Drell Yan mechanism picks a valence antiquark out of incident $\bar{p}$, we know the initial composition of the forward jet from the remanents of the $\bar{p}$'s. Theoretical predictions[21] have been made about the expected charged pion structure for this jet, In general,large X hadronic production for which we have almost ideal acceptance is being examined theoretically[22] in the same way high p processes have been examined to see what they can tell us about the quark structure of the nucleon, antinucleon, and mesons. We will by nature of the apparatus study this region.

The list of additional subjects for experimentation for which there are theoretical expectations or predictions is far more extensive than that listed above. However, since we are entering an essentially unexplored area of experimentation with valence quark interactions there are probably completely unexpected phenomena and effects which we must cope with. We are attempting to keep a flexible spectrometer and an ability for many triggers in order to respond to other possibilities and to conduct sensitive searches. We plan to investigate the high p_t region by using a missing forward energy trigger. A relatively small and simple iron scintillator calorimeter a a zero degrees will furnish an anticoincidence signal for 'normal' collisions where most of the energy remains within a small forward cone. We expect $\sim$ 10% resolution at 75 GeV from this device. With it in anticoincidence selecting erergy dumps of less than 1/2 beam energy we will be able to trigger at the 10μ barn level in the $\bar{p}$ interactions yielding an event rate of less than 100 events/spill. Triggering on multiple vee (K^o or Λ^o) events via our change of multiplicity trigger in coincidence with our missing forward energy trigger should isolate hard quark interactions in which quantum number flow can be studied. Additional criteria can be imposed on this trigger such as requirements for additional muons. The resulting events would be prime candidates for charmed baryon search.

As a last category of physics that we have not referred to are the more 'standard' varieties of physics that can be done with these beams and this apparatus with its acceptance. As a benchmark of sensitivity we will quote what we could expect to do on the simplest experiment of this generic type, elastic scattering. With out H_2 target we expect to achieve an integrated luminosity of 5 x 10^5 events/microbarn for a 3 week run. This will permit measurements out to $-t = 8$ GeV^2. With this apparatus one can easily compare the magnitude and slope of the $\bar{p}p$ and pp corssections in a region far beyond the diffractive peak. From the data of Cronin et al., it appears that the background due to multiparticles final states will not be severe at the larger momentum transfers. For momentum transfers near the dip region at $-t = 1.5$ GeV^2 the problem is more serious but experiences of other experiments [23] show that this region is accessible. This antiproton measurement is just one of a large category which could be performed and are absolutely unique in this setup.

In conclusion, we feel strongly that the flexibility of this forward spectrometer and the beams and capabilities of the High Intensity Laboratory put us in a unique position to make very significant well determined measurements, to conduct searches for new phenomena, and to respond to new directions that physics may take during the lifetime of this facility. No where else does this combination of capabilities exist.

TABLE Ia

EXPECTED BEAM INTENSITIES

SHIELDED SPECTROMETER

PARTICLE	100 GeV	200 GeV	300 GeV
$\bar{p}$	$2\times10^{6}/10^{13}p$	$10^{6}/5\times10^{7}\pi^{-}/\text{few}\times10^{11}p^{*}$	$10^{6}/5\times10^{7}\pi^{-}/10^{12}p$
π^{+}	$\leq 5\times10^{8}/10^{12}p$	$\leq 5\times10^{8}/10^{12}p$	$\leq 5\times10^{8}/2\times10^{12}$
π^{-}	$\leq 5\times10^{8}/1.5\times10^{13}p$	$\leq 5\times10^{8}/3\times10^{12}p$	$\leq 5\times10^{8}/5\times10^{12}$

TABLE Ib

EXPECTED BEAM INTENSITIES

OPEN SPECTROMETER

PARTICLE	100 GeV	200 GeV	300 GeV
$\bar{p}$	$2\times10^{6}/10^{13}p$	$3\times10^{5}/10^{13}p$	$2\times10^{4}/10^{13}p$
π^{+}	$\sim10^{7}/10^{11}p$	$\sim10^{7}/10^{11}p$	$\sim10^{7}/10^{11}p$
π^{-}	$\sim10^{7}/10^{11}p$	$\sim10^{7}/10^{11}p$	$\sim10^{7}/10^{11}/p$

TABLE IIa

EXPECTED CONTINUUM DIMUON RATES (5 weeks) EVENTS/GeV

MASS $\mu^+\mu^-$ GeV/c^2	100 GeV $\sqrt{\tau}$	100 GeV $\bar{p}$	100 GeV π^+p	100 GeV π^-p	200 GeV $\sqrt{\tau}$	200 GeV $\bar{p}$	200 GeV π^+p	200 GeV π^-p	300 GeV $\sqrt{\tau}$	300 GeV $\bar{p}$	300 GeV π^+p	300 GeV π^-p
1- 2	.109	7.5×10^{6}			.077	7.6×10^{7}			.063	7×10^{7}		
2- 3	.182	7.4×10^{4}			.129	1.4×10^{5}			.105	2.3×10^{6}		
3- 4	.255	8.2×10^{3}	2.2×10^{6}	7.7×10^{6}	.180	4.0×10^{4}	2.5×10^{6}	9.0×10^{6}	.147	6.4×10^{4}	4.5×10^{6}	9×10^{6}
4- 5	.328	1.9×10^{3}	5.6×10^{5}	2.9×10^{6}	.232	1.1×10^{4}	8.4×10^{5}	5.5×10^{6}	.189	1.9×10^{4}	1.1×10^{6}	4.5×10^{6}
5- 6	.400	5.2×10^{2}	2.0×10^{5}	7.0×10^{5}	.283	2.6×10^{3}	4.5×10^{5}	1.5×10^{6}	.231	2.3×10^{3}	4.5×10^{5}	3.0×10^{6}
6- 7	.472	2.3×10^{2}	4.2×10^{4}	3.0×10^{5}	.335	1.2×10^{3}	1.7×10^{5}	9.1×10^{5}	.273	1.4×10^{3}	3.0×10^{5}	6.0×10^{5}
7- 8	.545	5.8×10^{1}	1.6×10^{4}	1.1×10^{5}	.336	3.8×10^{2}	7.0×10^{4}	3.5×10^{5}	.315	6.9×10^{2}	1.1×10^{5}	3.8×10^{5}
8- 9	.607	1.0×10^{1}	5.6×10^{3}	3.7×10^{4}	.438	2.5×10^{2}	2.7×10^{4}	1.4×10^{5}	.357	3.1×10^{2}	6×10^{4}	1.5×10^{5}
9-10	.690		1.5×10^{3}	1.9×10^{4}	.489	1.1×10^{2}	1.3×10^{4}	9.1×10^{4}	.389	1.8×10^{2}	4×10^{4}	8.3×10^{4}
10-11	.763		3.6×10^{2}	3.3×10^{3}	.541	$.8\times10^{2}$	5.6×10^{3}	6.6×10^{4}	.441	1.1×10^{2}	1.3×10^{4}	5.3×10^{4}
11-12	.835		1.3×10^{2}	1.3×10^{3}	.592		2.2×10^{3}	3.9×10^{3}	.483	8×10^{1}	6×10^{3}	3.0×10^{4}
12-13	.908		3×10^{1}	4.1×10^{2}	.644		1.1×10^{3}	9.8×10^{3}	.525	3×10^{1}	4×10^{3}	1.5×10^{4}
13-14	.980			7×10^{1}	.695		5.1×10^{2}	6.4×10^{3}	.567		2×10^{3}	7.5×10^{3}
14-15					.747		2.5×10^{2}	1.9×10^{3}	.609		1×10^{3}	5.0×10^{3}
15-16					.798		8.4×10^{1}	9.1×10^{2}	.651		5×10^{2}	3.5×10^{3}
16-17					.850		4.1×10^{1}	4.1×10^{2}	.693		2.5×10^{2}	1.0×10^{3}
17-18					.901			$\sim10^{2}$	.735		1.3×10^{2}	5×10^{2}
18-19					.953			$\sim5\times10^{1}$	.777		6×10^{1}	3×10^{2}
19-20					1.00			$\sim10^{1}$	.819		4×10^{1}	1.5×10^{2}

TABLE IIb

EXPECTED RESONANCE DIMUON RATES (5 weeks)

SHIELDED SPECTROMETER

RESONANCE	100 GeV $\bar{p}$	200 GeV $\bar{p}$	300 GeV $\bar{p}$	100 GeV $\pi^{\pm}$	200 GeV $\pi^{\pm}$	300 GeV $\pi^{\pm}$
$\psi \to \mu^+\mu^-$	3.3×10^4	7×10^4	8×10^4	1.3×10^7	4.5×10^7	7.8×10^7
$\psi' \to \mu^+\mu^-$	600	900	1400	4.7×10^5	$\sim1.6\times10^6$	2.6×10^6
$\Upsilon \to \mu^+\mu^-$	<1	~ 2	~ 5	~ 250	~ 500	~ 900
$\Upsilon \to \mu^+\mu^-$	$<<1$	< 1	1	~ 40	~ 80	~ 150

TABLE III

EXPECTED RESONANCE

PRODUCTION RATES

OPEN SPECTROMETER

RESONANCE	100 GeV $\bar{p}$	200 GeV $\bar{p}$	100 GeV $\pi^{\pm}$	200 GeV $\pi^{\pm}$	300 GeV $\pi^{\pm}$	370 GeV $\pi^{\pm}$
$\psi \rightarrow e^{+}e^{-}$	3.3×10^{4}	$\sim 2 \times 10^{4}$	2.6×10^{5}	9×10^{5}	1.6×10^{6}	2.6×10^{6}
$\psi' \rightarrow e^{+}e^{-}$	600	$\sim$300	$\sim$9500	32000	52000	9.2×10^{4}
$\psi \rightarrow e^{+}e^{-}$	<1	$\sim$ 1	$\sim$ 5	$\sim$ 10	$\sim$ 20	$\sim$ 35
$\Upsilon' \rightarrow e^{+}e^{-}$	<<1	<<1	$\sim$ 1	$\sim$ 2	$\sim$ 3	$\sim$ 5

TABLE IV

CHARMONIUM DECAY

SEQUENCES AND χ RATES

$e^+e^+\gamma\gamma$ or $e^+e^-\gamma$ SIGNATURE

DECAY SEQUENCE	Ratio $\frac{\psi' \to \gamma\gamma e^+e^-}{\psi' \to e^+e^-}$	Rate of $e^+e^-\gamma$ or $e^+e^-\gamma\gamma$ from χ's	
		5 Week Rate No Direct χ Prod.	5 Week Rate* Direct χ Prod.
$\psi' \xrightarrow{7\%} \gamma\chi(3552) \xrightarrow{14\%} \gamma\gamma\psi(3.1) \xrightarrow{7.3\%} \gamma\gamma e^+e^-$	$\sim$ 8%	$\sim$ 2600 (50)	$1.5\text{x}10^5$ (3000)
$\psi' \xrightarrow{7\%} \gamma\chi(3508) \xrightarrow{35\%} \gamma\gamma\psi(3.1) \xrightarrow{7.3\%} \gamma\gamma e^+e^-$	$\sim$20%	$\sim$ 6400 (120)	$3.7\text{x}10^5$ (7600)
$\psi' \xrightarrow{7\%} \gamma\chi(3415) \xrightarrow{3\%} \gamma\gamma\psi(3.1) \xrightarrow{7.3\%} \gamma\gamma e^+e^-$	$\sim$ 4.6%	$\sim$ 1500 (30)	$3.2\text{x}10^4$ (650)
$\psi' \xrightarrow{<3\%} \gamma\chi(3454) \xrightarrow{100\%?} \gamma\gamma\psi(3.1) \xrightarrow{7.3\%} \gamma\gamma e^+e^-$	$\sim$24%	$\sim$ 7700 (150)	$1.1\text{x}10^6$ (22000)
		200 GeV $\pi^\pm$ (100 GeV $\bar{p}$)	

* The assumption needed to generate these rates are that all χ's are made with equal crossection and essentially all ψ's are decay products of χ's.

TABLE Va

EVENT RATES di γ

CONTINUUM 5 WEEK RUN

PER GeV/c^2

	$\bar{p}N \to \gamma\gamma + X$ 100 GeV		$\pi^{\pm}p \to \gamma\gamma + X$	$\pi^- p$ 300	$\pi^+ p$ 300	πp - 300 GeV	
$M\gamma\gamma$ GeV/c^2	Dihadron Induced Background	$q\bar{q} \to \gamma\gamma$	Dihadron* Induced 500 Background	$q\bar{q} \to \gamma\gamma^+$	$q\bar{q} \to \gamma\gamma^+$	Dihadron Without Aperture	Background With Aperture Cut
2- 3		7.4×10^4	5.3×10^8	2.1×10^5	1.1×10^5	4.2×10^6	2.3×10^6
3- 4		8.2×10^3	2.3×10^7	9.8×10^4	4.5×10^4	• 2.7×10^5	5.8×10^4
4- 5		1.9×10^3	1.1×10^6	4.5×10^4	1.1×10^3	3.7×10^3	1.6×10^3
5- 6		5.2×10^2	9.0×10^4	3.0×10^4	4.5×10^3	2.0×10^2	7.5×10^1
6- 7		2.3×10^2	1.5×10^4	9.2×10^3	3.0×10^3	2.3×10^1	7.1×10^0
7- 8		5.8×10^1	5.5×10^3	1.0×10^3	1.1×10^3	5.5×10^1	1.5×10^0
8- 9		1.0×10^1	6.6×10^2	3.8×10^3	6.0×10^2	-	-
9-10		-	3.0×10^1	1.5×10^3	3.8×10^2	-	-
10-11		-	1.3×10^0	8.3×10^2	1.5×10^2	-	-
11-12		-	< 1	5.3×10^2	7.1×10^1	-	-
12-13		-	$<< 1$	3.0×10^2	4.1×10^1	-	-
						Acceptance true $\gamma\gamma$-45%	Acceptance true $\gamma\gamma$-25%

• Denotes crossover points of various di hadron $\to \gamma\gamma$ backgrounds with 'direct diphoton' physics process $q\bar{q} \to \gamma\gamma$.

* Assumption: The measured values of E-95 can be extrapolated to higher masses by $e^{-3.1M}$ rule. Also we assume that 400 GeV pp hadronic background is an upper limit for 300 GeV $\pi^{\pm}$ N induced hadronic background.

\+ Assumption: $\bar{q}q \to \mu^+\mu^-$ from $\pi^{\pm}p$ can be taken from Donnachie and Landshoff's prediction of μ pair Drell-Yan. The preferred ratio of $(\pi N \to \gamma\gamma + X)/(\pi^- N \to \mu\mu + X)$ is calculated to be ~ 1 from the predictions of Paschos.

TABLE Vb

EVENT RATES $\chi(2.8)$

RESONANCE 5 WEEK RUN

Decay Chain	Ratio $\frac{\psi \to \gamma\gamma\gamma}{\psi \to e^+e^-}$	$\pi^{\pm}p$ induced 300 GeV 5 week rate No Direct χ Prod.	$\pi^{\pm}p$ induced 300 GeV 5 week rate Direct $\chi = \psi$ Prod.	$\bar{p}p$ induced 100 GeV 5 week rate No Direct χ's	$\bar{p}p$ induced 100 GeV 5 week rate Direct $\chi = \Psi$ Prod.
$\psi(3.1) \xrightarrow{1.7\%} \gamma\chi(2.8) \xrightarrow{7\times10^{-3}} \gamma\gamma\gamma$	1.8×10^{-3}	2.9×10^{3}	1.5×10^{5}	60	3.2×10^{3}

Limit on χ (2.8) $\to \gamma\gamma$ production is $\sim$ 150 nb from E-95 at this moment.

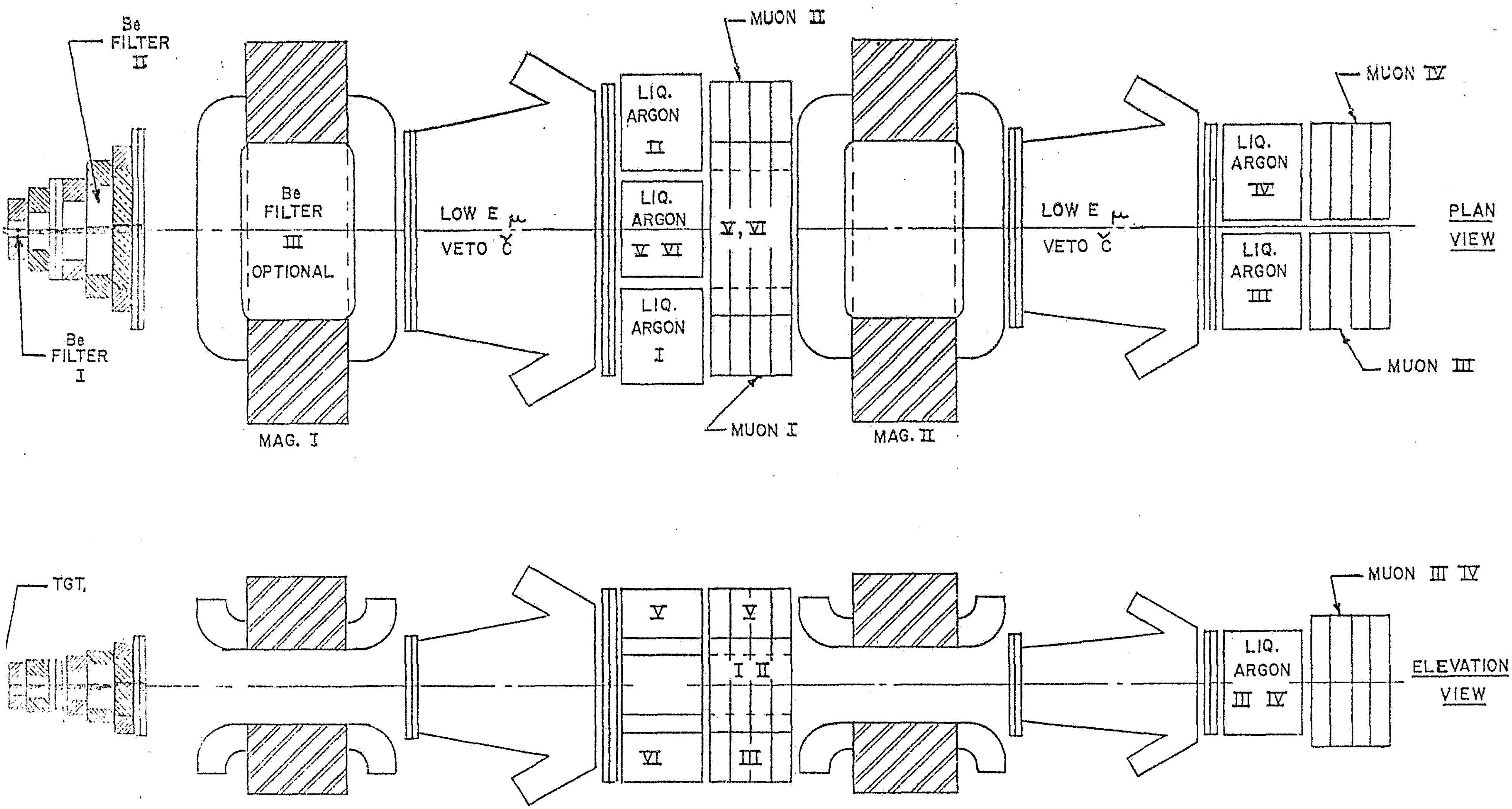
TABLE VI

SUPPRESSION FACTORS

DI PHOTON BACKGROUNDS

$M_{\gamma\gamma}$ (GeV/c^2)	Suppression Factor-Di Hadron Background No Aperture Cut	Suppression Factor-Di Hadron Background Aperture Cut
2- 3	125	230
3- 1	200	400
4- 5	300	700
5- 6	450	1200
6- 7	670	2100
7- 8	1000	3600
8- 9	1500	6200
9-10	2200	11000
10-11	3300	19000
11-12	5000	32000
12-13	7300	56000

Based Monte Carlo calculations using E-494 hadronic production of di hadrons data and fitting exponentials to resulting di photon mass spectra.



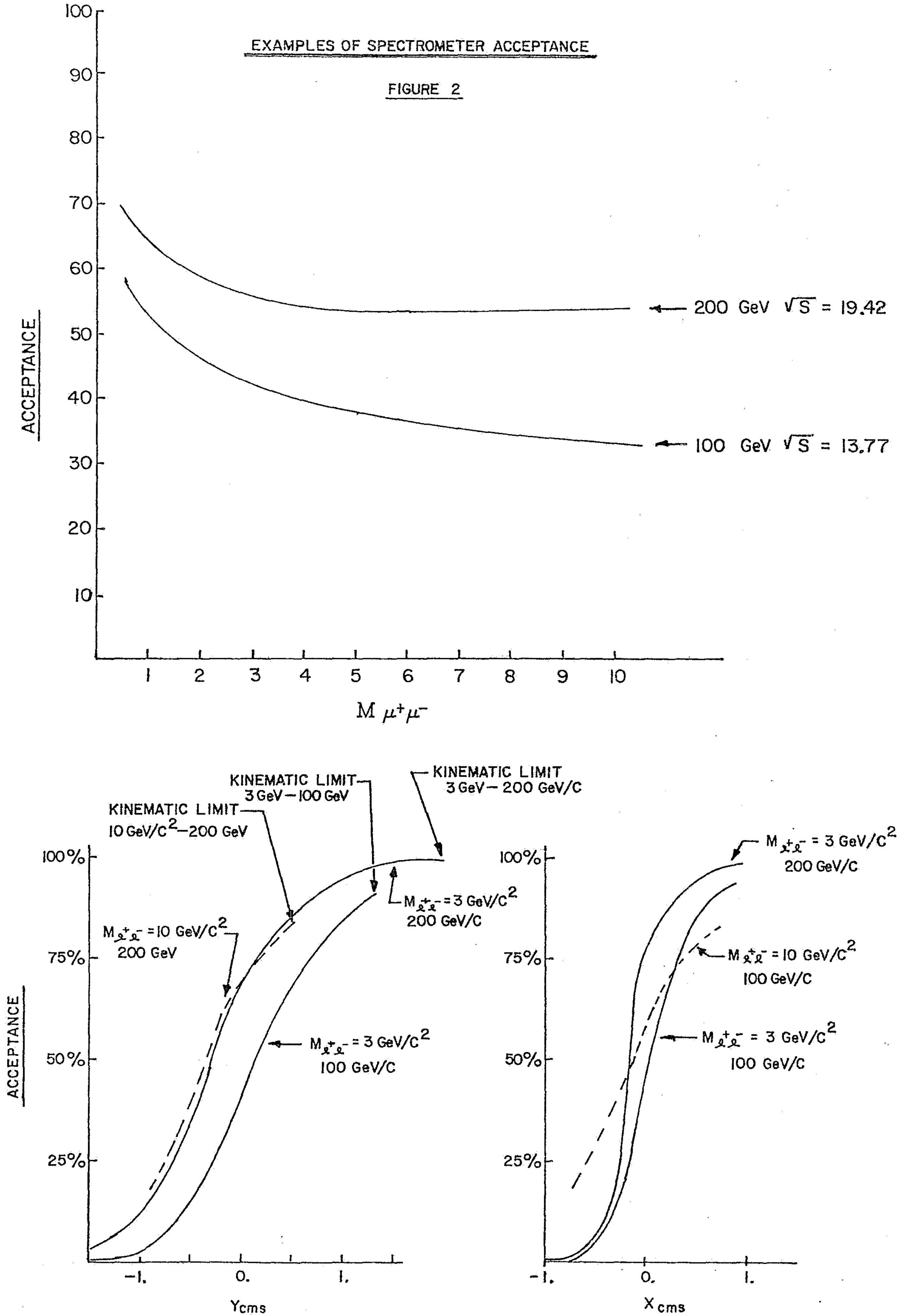
E 537 EQUIPMENT LAYOUT *

FIGURE 1

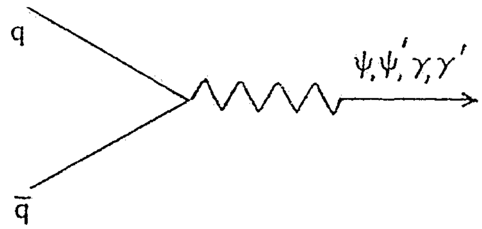
*Shielded Spectrometer Configuration
Open Spectrometer Configuration without Shield Incorporates a 2 Meter D_2 Target.

EXAMPLES OF SPECTROMETER ACCEPTANCE

FIGURE 2

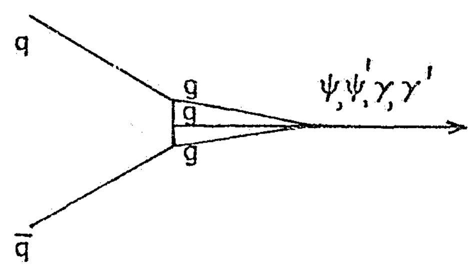


(a)



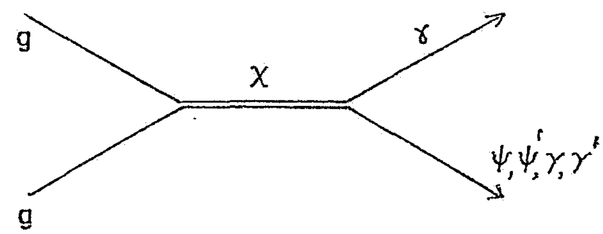
DRELL-YAN

(b)



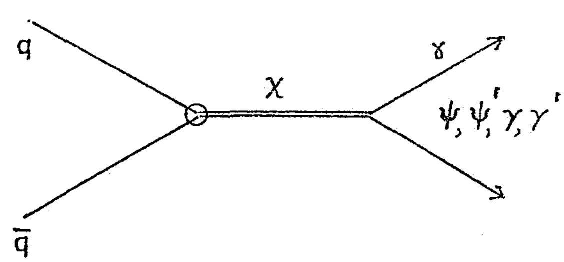
QUARK FUSION

(c)



GLUON FUSION
INTERMEDIATE χ

(d)



QUARK FUSION
INTERMEDIATE χ

DIAGRAMS (a), (b) AND (d) ARE AIDED BY THE PRESENSE OF VALENCE ANTIQUARKS

REFERENCES

1. B. C. Barish et al., Calibration of a Sampling Total Absorption Detector Designed for Neutrino Experiments, Nucl. Instrum. Methods 130, 49 (1975).

2. A. Van Ginneken, High Energy Particle Interaction in Large Targets, Fermilab Publication.

3. C. Quigg, Production and Detection of Intermediate Vector Bosons and Heavy Leptons in pp and $\bar{p}p$ Collisions, Rev. Mod. Phys. 49, No. 2, April 1977.

4. D. Hom et al., Observation of a Dimuon Resonance at 9.5 GeV in 400 GeV Proton Nucleus Collisions, Fermilab-Pub-77/58-EXP 7100.288. - Also private communications.

5. R. D. Field and R. P. Feynman, 1976 Caltech Report, CALT-68-565 (unpublished).

6. A. Donnachie and P. V. Landshoff, Production of Lepton Pairs, J/ψ, and Charm with Hadron Beams, Nucl. Phys. B112, 233 (1976).

7. M. J. Carden et al., Experimental Comparison of J/ψ Production by $\pi^{\pm}$, $K^{\pm}$, p, and $\bar{p}$ Beams at 39.5 GeV/c, Phys. Lett. 68B, No. 1, 96.

8. M. J. Carden et al., Massive Muon Pair Production at 39.5 GeV/c by $\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$ on Copper, CERN Preprint, unpublished.

9. K. J. Anderson et al., Production of J(3.1) and ψ'(3.7) by 225 GeV π^+, π^-, and Protons, XVIII International Conference, Tbilisi, USSR, 1976.

10. K. J. Anderson et al., Production at Continuum Muon Pairs at 225 GeV by Pions and Protons, XVIII International Conference, Tbilisi, USSR, 1976.

11. K. J. Anderson et al., Inclusive μ Pair Production at 150 GeV by π^+ Mesons and Protons, XVIII International Conference, Tbilisi, USSR, 1976.

12. H. J. Teper, ψ/J Production in Hadronic Collisions: A Critical Review of Models, Invited Contribution to the 12th Rencontre de Moriond, Flaine, March 1977.

13. Y. Kazama (unpublished). - Also see T. Hagiwara et al., The Newly Found Resonance $\Upsilon(9.5)$ and the Charge of the Heavy Quark.

14. R. D. Kephart et al., A Measurement of the Dihadron Mass Continuum in Proton-Be Collisions and a Search for Narrow Resonances, Fermilab-Pub-77/83-EXP 7100.494.

15. G. Feldman, Recent Results in Charmonium Spectroscopy, Vth International Conference on Experimental Meson Spectroscopy, Northeastern University, April 29-30, 1977.

16. C. Kourkoumelis, A Study of the J/ψ Production in Proton-Proton Collisions at the CERN ISR, Using Liquid Argon Calorimeters and Lithium/Xenon Transition Radiation Detectors, Thesis, CERN 77-06, Experimental Physics Division, March 29, 1977.

17. E. A. Paschos, Massive Gamma Pair Production in Hadron-Hadron Collisions, Preprint.

18. G. R. Farrar and S. Frautschi, Copious Direct Photon Production: A Possible Resolution of the Prompt-Lepton Puzzle, Phys. Rev. Lett. 36, No. 17 (1976).

19. G. R. Farrar, Experimental Means for Distinguishing Models of Large $p_\perp$ Inclusive Scattering, CALT-68-576.

20. P. Darriulat et al., Large Transverse Momentum Photons from High Energy Proton-Proton Collisions, CERN Preprint.

21. T. A. De Grand and H. I. Miettinen, Hadronic Production with a Drell-Yan Trigger, unpublished.

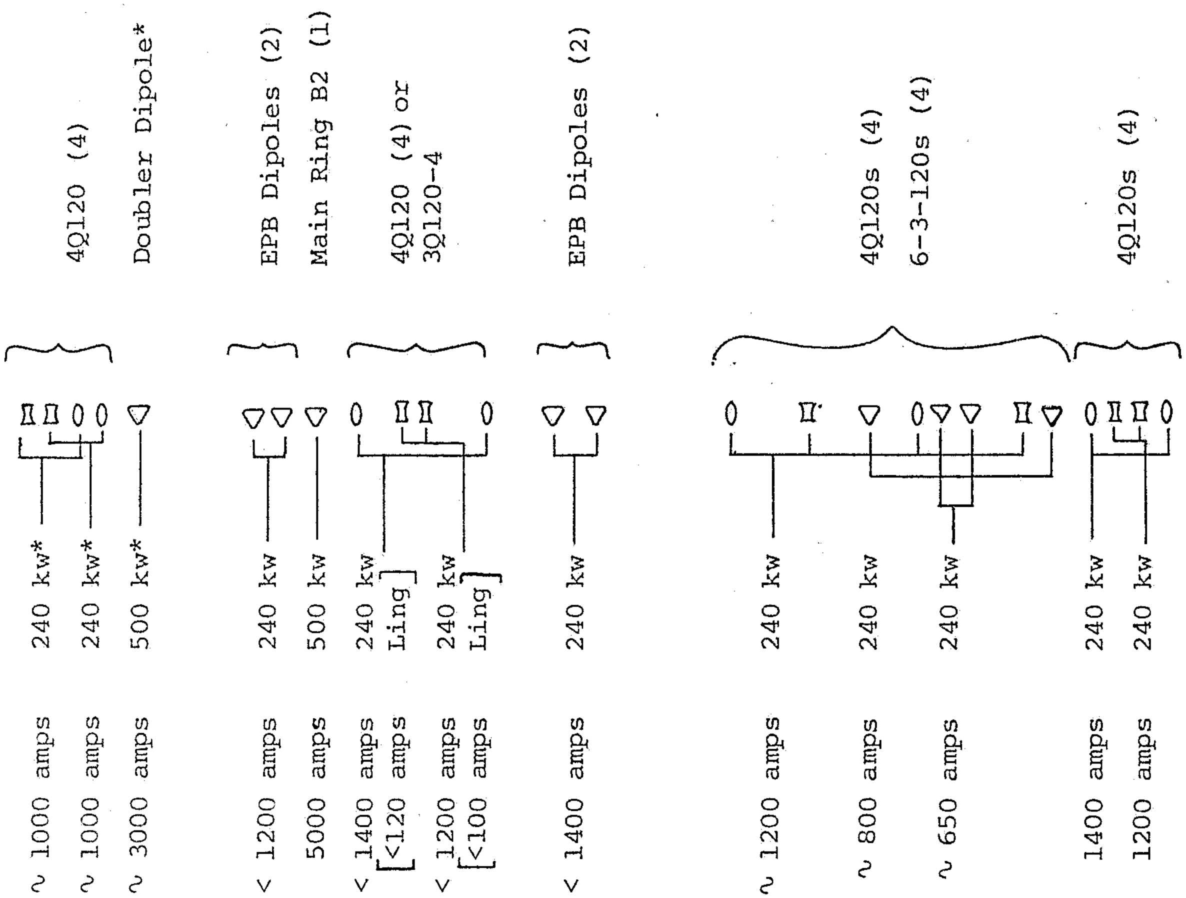
22. S. Brodsky and J. Gunion, Hadronic Fragmentation as a Probe of the Underlying Dynamics of Hadron Collisions, UCD-77-9, SLAC-PUB-1939, May 1977.

23. Fermilab Experiment 7 achieved this measurement at low t with a similar spectrometer and technique.

SCHEMATIC BEAM LINE - [200 GeV Conventional - Superconducting Mixture]

Configuration I

Enclosure II



Totals for PS (Not Installed)

240 kw - 7 or 9 or 5

Lings - 2 or 0 or 2

500 kw - 1 or 1 or 3

Totals for Magnets (Not Installed)

4Q120s - 8 or 12

3Q120s - 8 or 0

6-3-120s - 4

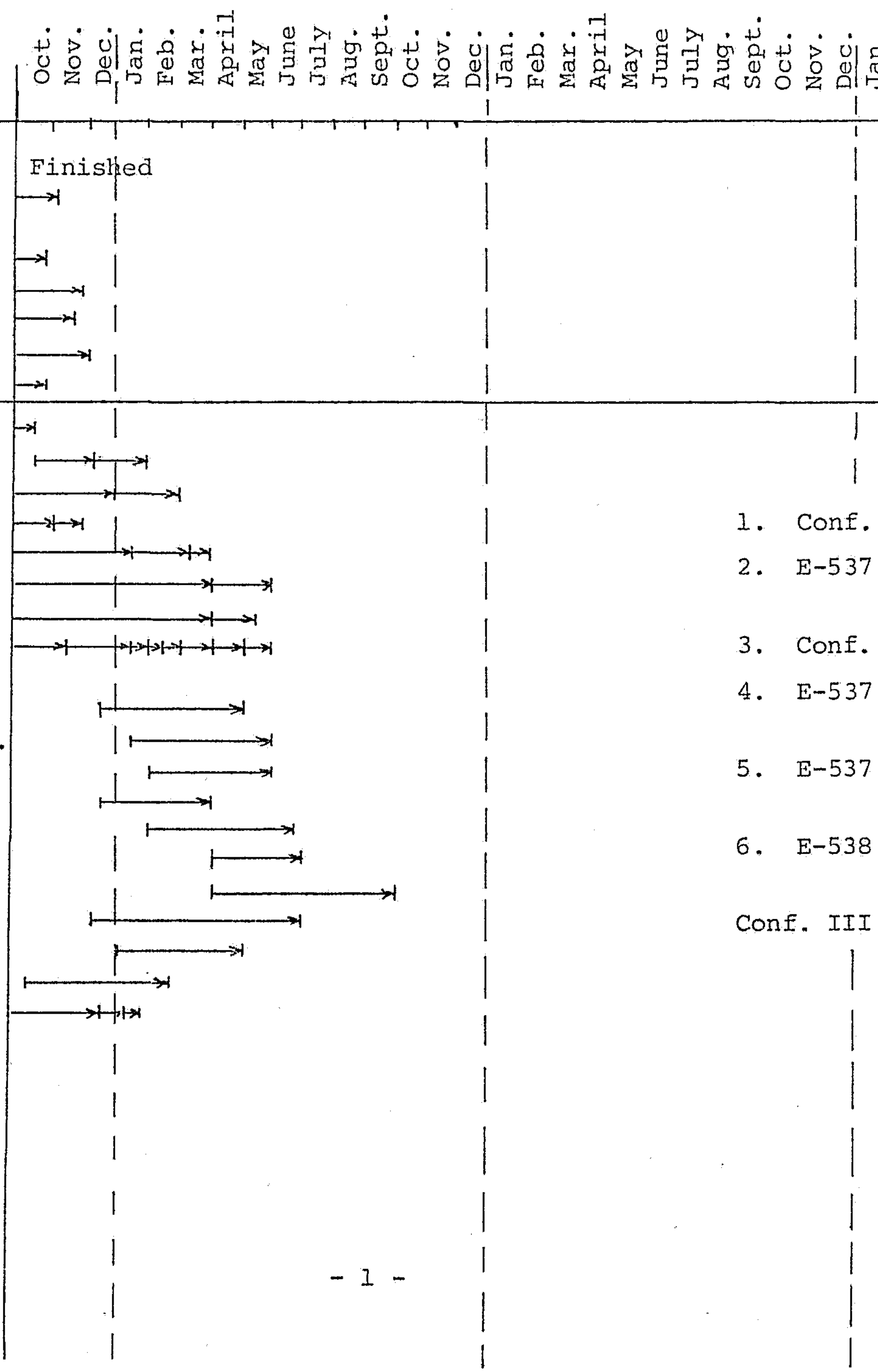
3D120s - 4

*Already installed

SCHEDULE - HIGH INTENSITY LABORATORY - P-537 *Items Indicate Hoped For Dates Particular to P-537 B. Cox Oct. 1977

Enclosure III

GROUP	ACTIVITY
Architectural Services	Civil Phase I
	Elec Phase I
	Mech Phase I
	Civil Phase II
	Elec Phase II
	Mech Phase II
	Roadwork
	Rework Exp Floor
Proton Mechanical (and Site)	Steel Floor
	Mom Slit Steel
	Target Box
	Prod. Target
	Collimator/Dump
	Transporter
	Mom Slit
	Mag Stands
	Spoilers
	*Rail System
	*Solid Target Assy.
	*Al Mag I Stand
	*Chamber Stand
	*μSteel + Stand
	*L.A. Stands
	*Be Filter
	Beam Cerenkov
	Vacuum System
	Safety Collimator
	B-2 Magnet

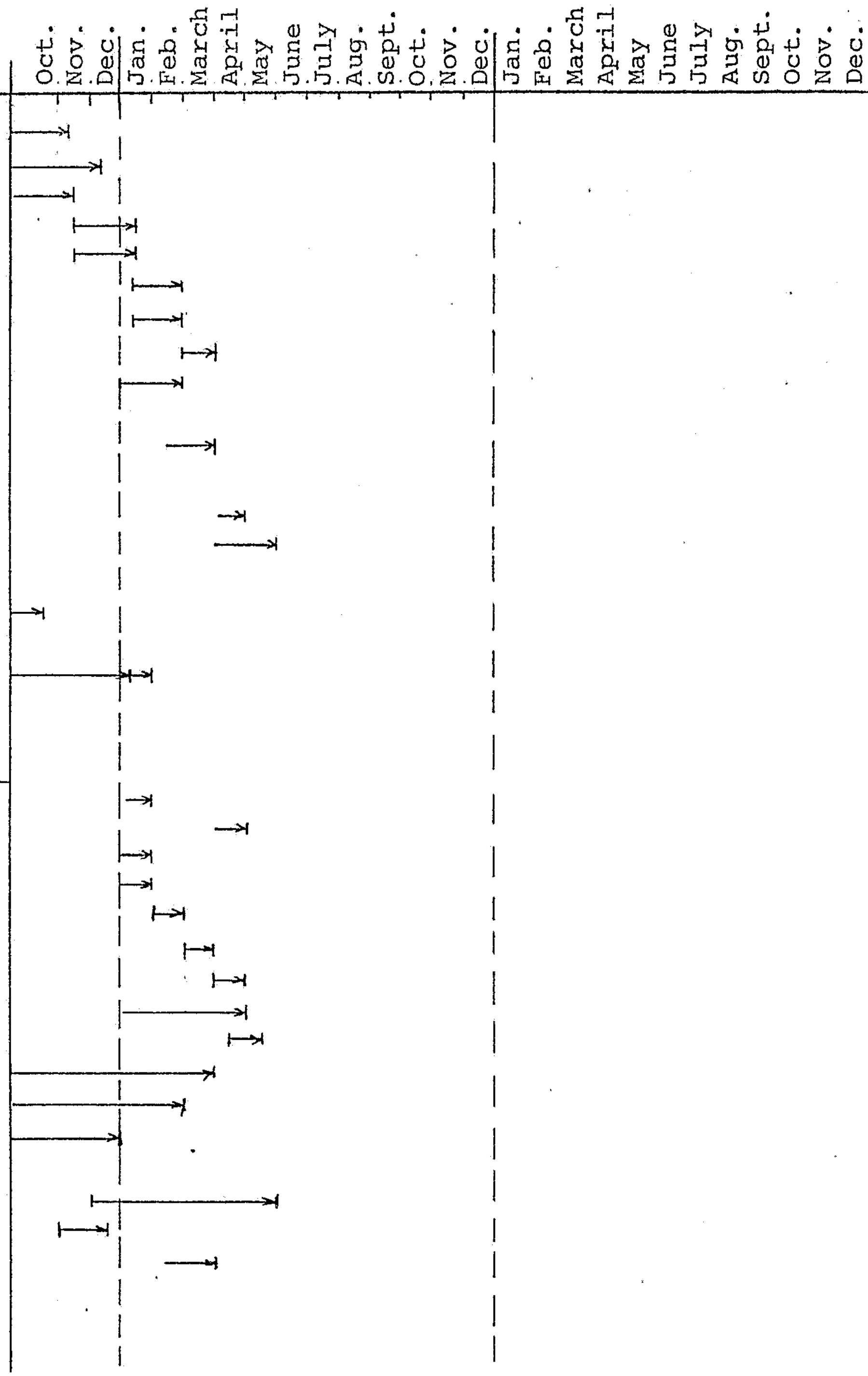


MAJOR GOALS & DATES

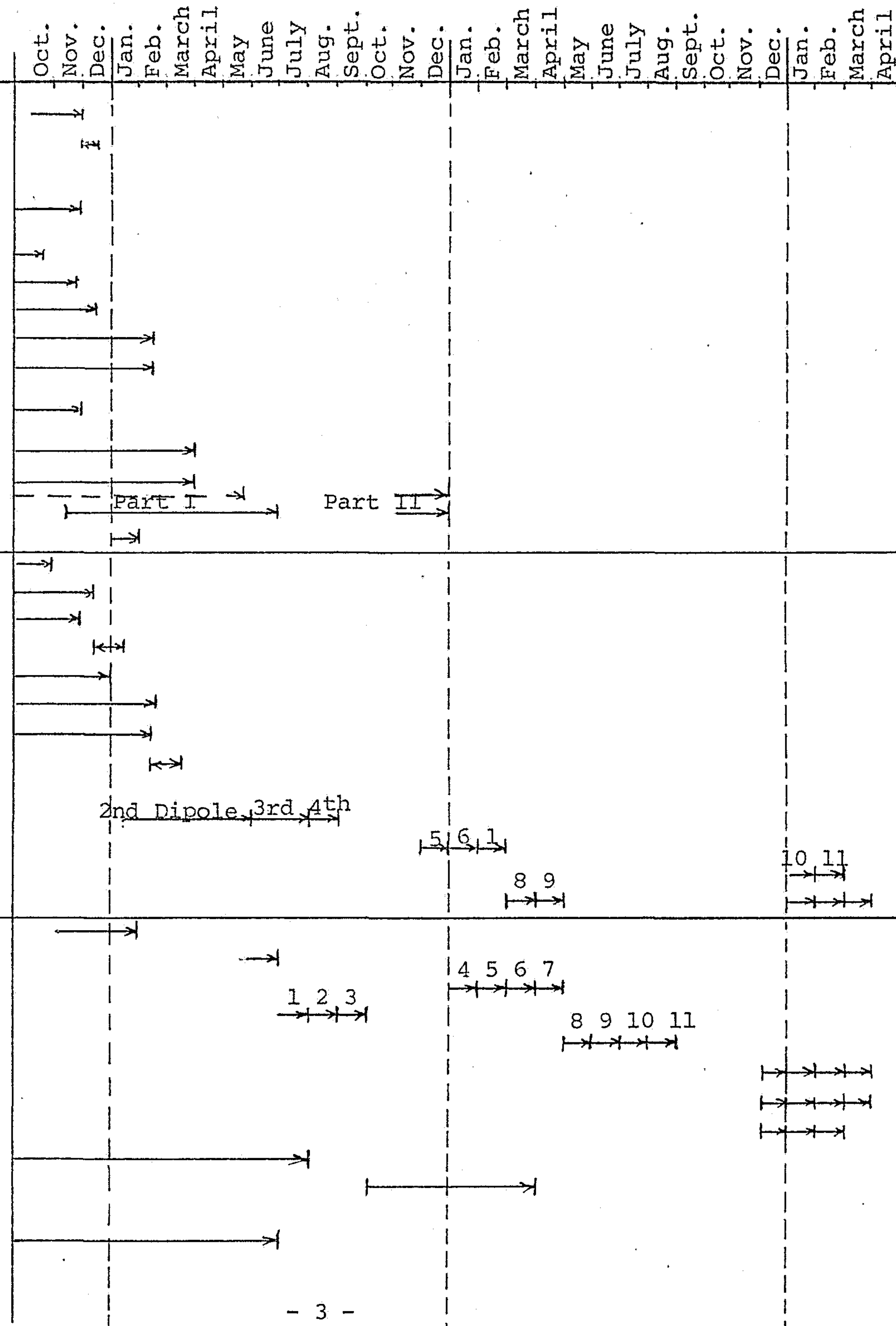
1. Conf. I 200 GeV Beam - June 78
2. E-537 First Data - July, Aug., Sept. 78
3. Conf. II 400 GeV Beam- March 1, 79
4. E-537 Second Run - April, May June 79
5. E-537 Third Run - Oct., Nov., Dec. 79
6. E-538 Fourth Run - April, May, June 80

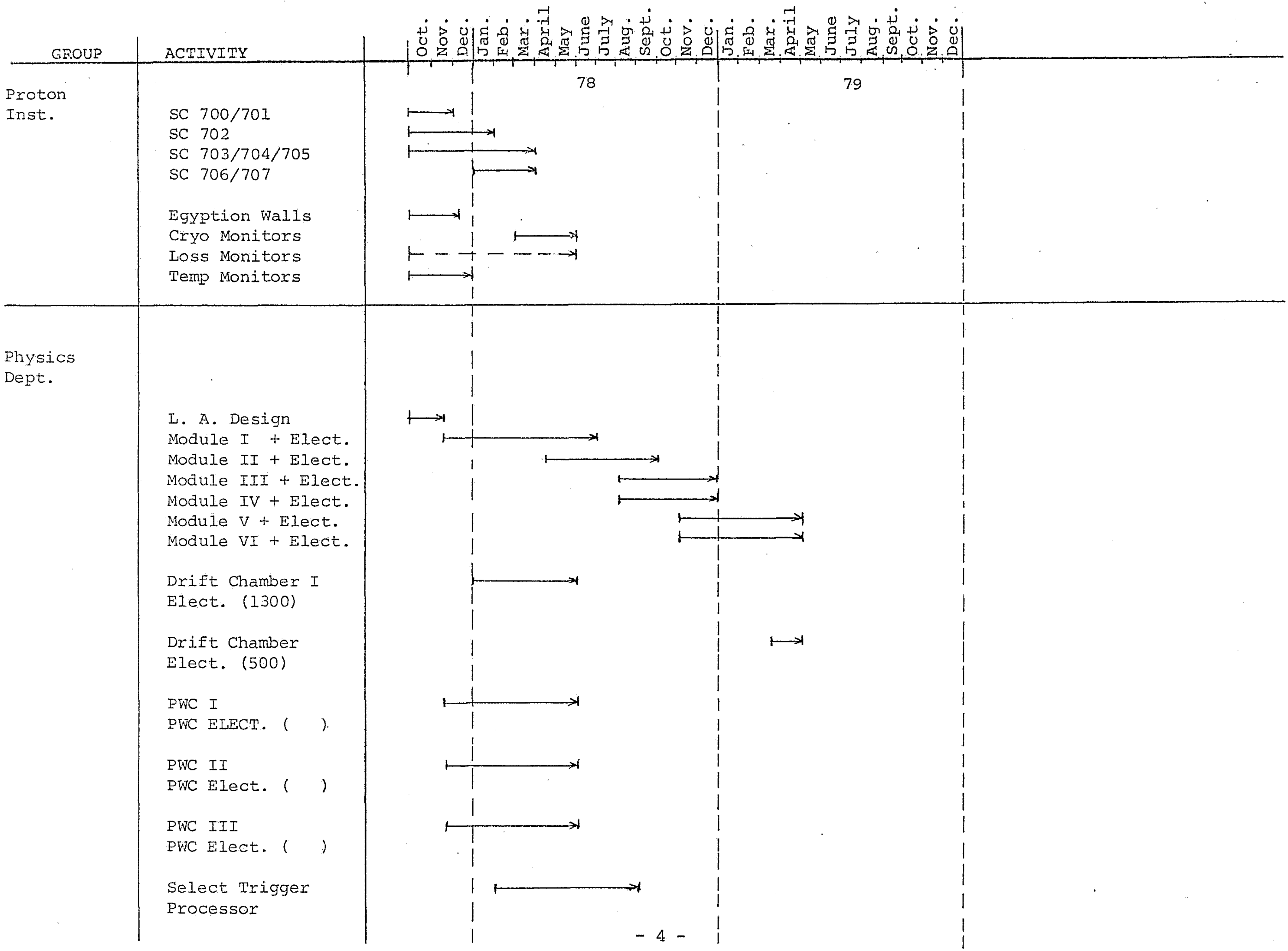
Conf. III 1000 GeV Beam - March 1, 80

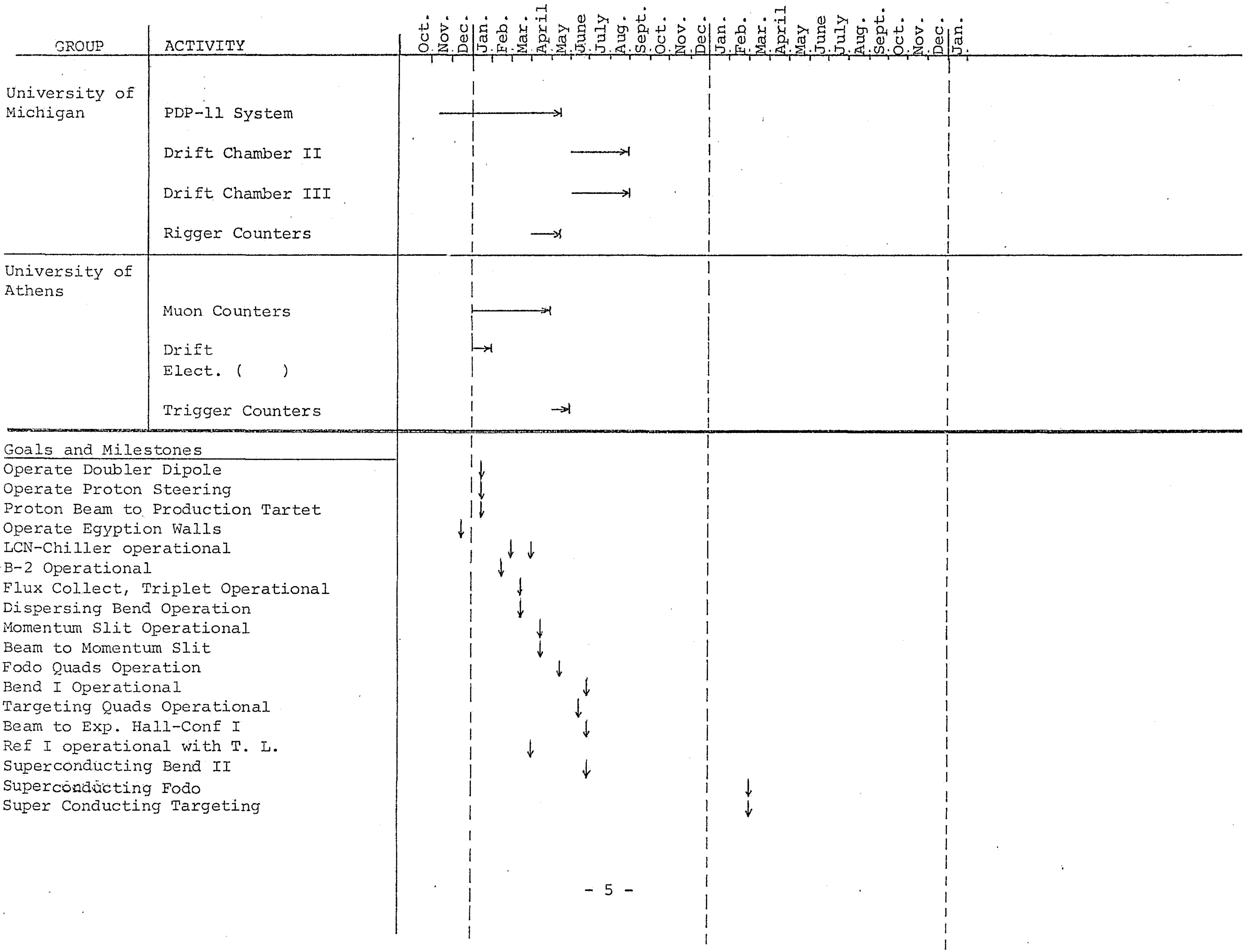
GROUP	ACTIVITY
Electrical (and Site)	Doubler PS
	B-2 PS (500 kw)
	Prot-Tag PS (240 kw)
Conf. I	Triplet PS (240 kw)
	Disp Bend PS (240 kw)
	FODO PS (240 kw)
	Bend II PS (240 kw)
	Targeting Quads (240)
	Trim PS
	Low Imp PS
Conf. II	Low Imp PS
	1st Anal Mag PS
	2nd Anal Mag MS
	Controls Cable
	Watercooled Bus
Site Support	B-2 Inst
	Proton Targ. Inst.
	Triplet Inst.
Conf. I	Disp. Bend Inst.
	FODO Inst.
	Bend II Inst.
	Targeting Quad Inst.
	Trims Inst.
	Collimator Inst.
	LCW System
	Chiller System
	LCW Piping
	Interlock System
	Vacuum System
	Mom. Slit Steel
	Mom Slit

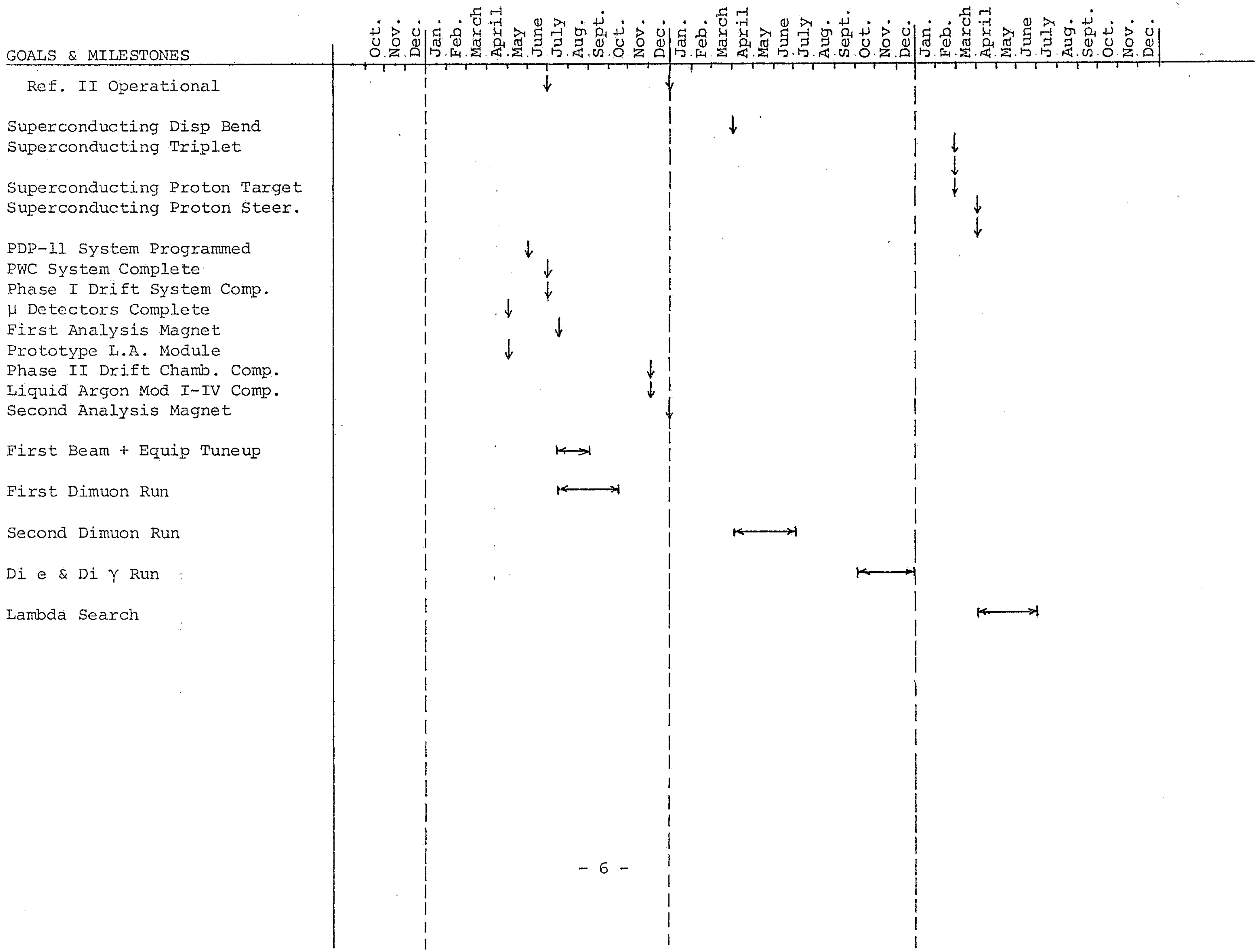


GROUP	ACTIVITY
Proton Cryogenics	FHR Ref Assem
	FHR Ref Op.
	Ref I Heat Exch I
	Ref I Heat Exch II
	Ref I Heat Exch III
	Ref I Heat Exch IV
	Valve Box
	Exp Eng I (wet)
	Exp Eng I (dry)
	Compressors I & II
	Op Ref I
	Ref II Parts
	Op Ref II
	Transfer Lines
	Nit. System
Proton Supercond.	4 ft Cos θ coil
	4 ft Cryostat
	4 ft Iron
	Operate Comp. 4A
	10 ft cos θ Coil
	10 ft Iron
	10 ft Cryostat
	Operate 10 ft
	Operate Doub. Di
Conf II	FODO Dipoles (4)
	Disp Dipoles (3)
	Steering Dipoles (2)
Conf III	FODO Dipoles (5)
Research Services	Test first coil
	Operate 1st 10 ft
	FODO Quads (4)
Conf II	Targ Quads (3)
	Focussing Q (4)
	Targeting Q (4)
Conf III	FODO (4)
	Proton Targ (4)
	1st Analysis Mag
	2nd Analysis Mag
	Inspect Trigger Processor Design




GROUP
ACTIVITY
Oct.
Nov.
Dec.
Jan.
Feb.
Mar.
April
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.
Jan.
Feb.
Mar.
April
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.
78
79
Proton Inst.
SC 700/701
SC 702
SC 703/704/705
SC 706/707
Egyption Walls
Cryo Monitors
Loss Monitors
Temp Monitors
Physics Dept.
L. A. Design
Module I + Elect.
Module II + Elect.
Module III + Elect.
Module IV + Elect.
Module V + Elect.
Module VI + Elect.
Drift Chamber I
Elect. (1300)
Drift Chamber
Elect. (500)
PWC I
PWC ELECT. ( )
PWC II
PWC Elect. ( )
PWC III
PWC Elect. ( )
Select Trigger
Processor


GROUP
ACTIVITY
Oct. Nov. Dec. Jan. Feb. Mar. April May June July Aug. Sept. Oct. Nov. Dec. Jan. Feb. Mar. April May June July Aug. Sept. Oct. Nov. Dec. Jan.
University of Michigan
PDP-11 System
Drift Chamber II
Drift Chamber III
Rigger Counters
University of Athens
Muon Counters
Drift Elect. ( )
Trigger Counters
Goals and Milestones
Operate Doubler Dipole
Operate Proton Steering
Proton Beam to Production Tartet
Operate Egyption Walls
LCN-Chiller operational
B-2 Operational
Flux Collect, Triplet Operational
Dispersing Bend Operation
Momentum Slit Operational
Beam to Momentum Slit
Fodo Quads Operation
Bend I Operational
Targeting Quads Operational
Beam to Exp. Hall-Conf I
Ref I operational with T. L.
Superconducting Bend II
Superconducting Fodo
Super Conducting Targeting


GOALS & MILESTONES
Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept. Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept. Oct. Nov. Dec.
Ref. II Operational
Superconducting Disp Bend
Superconducting Triplet
Superconducting Proton Target
Superconducting Proton Steer.
PDP-11 System Programmed
PWC System Complete
Phase I Drift System Comp.
μ Detectors Complete
First Analysis Magnet
Prototype L.A. Module
Phase II Drift Chamb. Comp.
Liquid Argon Mod I-IV Comp.
Second Analysis Magnet
First Beam + Equip Tuneup
First Dimuon Run
Second Dimuon Run
Di e & Di γ Run
Lambda Search

Fermilab Proposal No: 537

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PROPOSAL TO STUDY $\bar{p}N$ INTERACTIONS IN THE P-WEST HIGH INTENSITY LABORATORY

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ABSTRACT

The antiproton beam of the P-West High Intensity Laboratory represents a unique opportunity to study hadronic interactions with well defined antiquark distributions. As the initial measurement of a research program to study antiproton interactions, we propose to examine the following reactions:

1) $\bar{p}N \rightarrow \mu^+\mu^- + X$

2) $\bar{p}p \rightarrow e^+e^-$ + other measured particles (pions, photons, etc.)

The measurement of the first reaction will test the Drell-Yan hypothesis including the factor of three required by color. The study of the second reaction will allow an examination of the production mechanisms of the ψ and ψ'. In particular, direct formation of χ states which produce ψ via the $\gamma\psi$ decay mode will be measured. Correlations of ψ and ψ' with final state hadrons will be measured to search for other sources of ψ and ψ' production.

INTRODUCTION

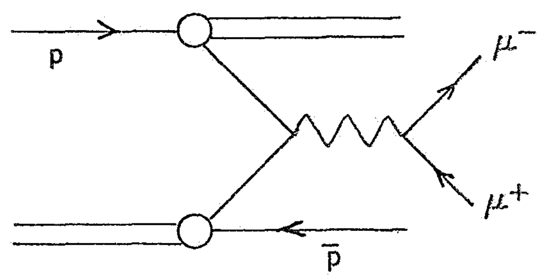
The remarkable discoveries of high mass, narrow width states from e^+e^- and proton-nucleus collisions have given an enormous boost to the idea of explaining strong interactions by constituent quark-quark interactions. However, as embodied in quantum chromodynamics, the various physical behaviors of confined colored quarks and gluons are difficult to isolate by any single experiment. Theory suggests that the observable consequences of the hadronic internal structure are rather subtle at best. Thus, it is appropriate to search for the simplest processes that can reveal the fundamental interactions between hadron constituents. Fortunately the deep inelastic electroproduction data have provided us with quantitative distributions of the valence quarks within the nucleon. By charge conjugation symmetry, these distributions must also describe the light antiquark constituents of antinucleons. Thus antiproton collisions are ideal for studying any process related to an initial quark-antiquark annihilation.

To pursue these goals we propose to construct a large aperture spectrometer in the new High Intensity Laboratory. This apparatus will use the available flux of antiprotons from the $\bar{\Lambda}^o$ beam to make a series of fundamental measurements of $\bar{p}N$ interactions. Two of these measurements are described in this document.

REACTION 1

$$\bar{p}N \rightarrow \mu^+\mu^- + X$$

The simplest manifestation of the internal quark structure of hadrons is found in the Drell-Yan process[1]



The dilepton final state has been intensively measured in proton-nucleon[2] and pion-nucleon[3] collisions and some qualitative features of the process have been confirmed. Unfortunately the uncertainty in the anti-quark distributions of protons and pions have made precise quantitative comparisons with theory rather hazardous. This situation is illustrated in Fig. 1 where the Drell-Yan cross section is plotted for pN and $\bar{p}$N interactions as a function of the dilepton effective mass. The envelopes encompass three different parameterizations[4] of the nucleon parton distribution functions. Two salient conclusions follow immediately: (1) the spread in predictions for proton interactions covers a factor of 3 at 5 GeV effective mass as compared with a range of $\simeq$ 25% for the antiprotons; (2) the antiproton cross sections are at least 10 times larger than the proton cross sections, reflecting the large enhancement from valance antiquarks. This means that the Drell-Yan formula can be rigorously compared with the $\bar{p}N$ data to a precision of $\pm15\%$. An experiment of this type will provide an unambiguous test of the statistical factor of 3 required by the "color" degree of freedom for quarks. If true, this would be a strong confirmation of current theoretical ideas. Additional features of the Drell-Yan continuum such as the expected $1 + \cos^2\theta$ distribution of the muons in the di-muon center of mass will be examined to test the electromagnetic nature of the Drell-Yan hypothesis.

A. Apparatus

The plan view of the apparatus for the dimuon experiment is shown in Fig. 2(a). The large aperture dipole required is shown as a 72" wide, 40" long, 32" high magnet of the type the Laboratory will probably order sometime this year. In order to extract the cross section for single nucleons both beryllium and copper targets will be used with lengths sufficient to interact inelastically 65% of the beam. 60" of Copper will be used as an initial hadron absorber immediately downstream of the target (8.4 metric tons). The muon trigger will be provided by a hodoscope array buried behind an iron absorber shield (132 metric tons). This will require a minimum momentum of 4.5 GeV for each muon to trigger a set of counters. A beam Cerenkov counter (not shown) will provide a signal to remove the π^- component of the beam. At the beam rates quoted below, this counter will operate at the 10 Mh level. We have investigated the response of the counter at this rate and have concluded that good phototube stability can be maintained. We expect to lose approximately 20% of the data from buckets containing more than one particle. This factor is included in the luminosity calculations for both open and closed geometry operation.

B. Beam and Luminosity

The expected flux of antiprotons from the $\bar{\Lambda}^o$ decay channel is given below for 10^{13} 400 GeV incident protons on the production target:

TABLE I

$P_{\bar{p}}$	$\bar{p}/10^{13}$ incident protons	$\bar{p}/\pi^-$
50	2.4×10^6	.02
100	1.0×10^7	.49
150	3.9×10^6	.11
200	1.0×10^6	.06

This table shows that the maximum $\bar{p}$ flux is obtained at 100 GeV/c. For the data taking phase of this measurement we expect the Laboratory to provide 5×10^{12} protons on the production target. Under these conditions, assuming a 750 hour exposure with a 12 second accelerator repetition rate, we can expect 7.4×10^{11} antiprotons to interact within the target described above. For a 500 hour exposure with Be and a 250 hour exposure with Cu we obtain an integrated luminosity of 3.2×10^{37} cm^{-2} taking thick target effects and loss of data due to pile up in the beam Cerenkov counter into account. For 100 GeV incident beam momentum we expect the following number of events within our detector:

TABLE II

$M_{\mu\mu}$	$\Delta\sigma$	Geometric Acceptance	Events/750 hours
$\psi(3100)$	$\simeq 1 \times 10^{-32}$	.34	100,000
$\psi(3700)$	$\simeq 2 \times 10^{-34}$	.34	2,100
DRELL-YAN CONTINUUM			
$3.0 \rightarrow 4.0$	2.7×10^{-34}	.34	2,900
$4.0 \rightarrow 5.0$	7.7×10^{-35}	.34	830
$5.0 \rightarrow 6.0$	2.3×10^{-35}	.33	240
$6.0 \rightarrow 8.0$	8.1×10^{-36}	.31	80
$8.0 \rightarrow 11.0$	4.6×10^{-37}	.30	5

These yields were obtained using the results of Hom et al.,[2] for the P_t dependence of the dimuon pair and the Drell-Yan predictions for the P_ℓ dependence.

The number of events obtained will provide sufficient statistics in the mass range above 4.0 GeV to test the Drell-Yan formula to 15% in several bins. We are requesting a total of 1000 hours of time for this measurement; 250 hours for tuning and equipment testing and 750 hours for data taking.

C. Aperture, Resolution, and Backgrounds

The geometric detection efficiency for dimuon pairs is shown in Fig. 3. This number is greater than 30% for the mass region of interest. The mass resolution, σ_M/M, is 4.0%, suitably averaged over the forward center-of-mass hemisphere. This is more than sufficient to keep the tails of the ψ and ψ' peaks from contaminating the higher mass continuum region. Furthermore the pion and kaon decay backgrounds will be negligible above 4 GeV. This can be checked experimentally by comparison of the $\mu^+\mu^-$ mass spectrum with the $\mu^+\mu^+$ and $\mu^-\mu^-$ mass spectra.[2] The background contribution from the higher mass charmonium states above $D\bar{D}$ threshold (such as $\psi(4100)$) is insignificant since these states decay almost entirely hadronically.[6]

D. Trigger Rate

From the Chicago-Princeton data[7] we estimate a total dimuon cross section in the neighborhood of 2 microbarns/nucleon in the forward hemisphere yielding a trigger rate of 50 events/spill. The low mass region of the spectrum can be discriminated against by demanding some minimal spatial separation of the muons in the trigger hodoscope so that 15 events/spill is a reasonable estimate. Since we will be able to record more than 300 events/spill,[8] the trigger rate will not provide a serious deadtime.

The muon halo surrounding the antiproton beam will not seriously affect the trigger rate. The absolute rate will be $10^6\mu/10^{12}$ incident protons with most of this flux coming from the target box and will be dispersed far from the beam line (~1 meter) at our apparatus. We expect approximately 20 triggers per pulse due to the accidental coincidence of a decay of a secondary kaon or pion and a halo muon.

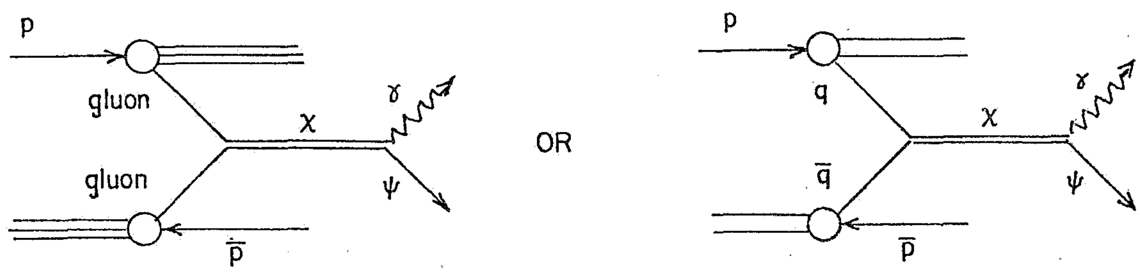
REACTION 2

$\bar{p}p \rightarrow e^+e^-$ + other measured particles (pions, photons, etc.)

The measurement of the correlations of final state photons and hadrons with the ψ and ψ' produced in antiproton interactions will allow a unique study of quark-antiquark and gluon-gluon mechanisms for hadronic production of these resonances and will allow a better understanding of the quantum numbers of the χ states.

1) <u>χ Search (Photons Associated with ψ Production)</u>

It is important to search for direct production in $\bar{p}p$ interaction of the χ states intermediate in mass to the ψ and ψ' which have been detected in the SPEAR experiments[10] and to search for other new objects of higher mass. Current theoretical expectation is that the dominant hadronic production mechanism for ψ production should be 'direct' production of a χ state[11] and the subsequent decay of that state into $\gamma\psi(3.1)$ as shown below:



If direct χ production is as dominant as expected theoretically and as copious as seems to have been observed experimentally[12] we will be able in this experiment to make a comparison of the antiproton and proton induced production of the various χ states to separate gluon and antiquark-quark production mechanisms. Both types of processes should be important in the antiproton reaction while in the pp interaction the quark-antiquark process should be suppressed because of the absence of valence antiquarks. In addition, once the presence of χ production is unambiguously established in antiproton interactions, a study of the angular distributions of the decay photons allows us not only to distinguish between gluon and quark-antiquark production of charmonium but also to test the spin-parity of the decaying χ state. Therefore information can be contributed to the spectroscopy of the χ states.[13] In particular, the spin-parity of the $\chi(3454)$ is uncertain since in e^+e^- interactions it has been observed only as a decay product of the ψ', suppressed because of small branching ratios.[14] Direct hadronic production of this state would yield ample data for a detailed spin-parity analysis. (See Table IV and Fig. 4).

2. Hadronic Final States Associated with ψ and ψ' Production

It is also important to study the correlations of final state hadrons in this data with the ψ and ψ'. The observation of these correlations will shed light on sources of ψ and ψ' production other than through χ production and decay. If the CERN measurement[12] is correct 57% of the ψ's are not associated with χ's and therefore must be produced by other mechanisms. Similarly the ψ' which has a level of production of approximately 14% of ψ production is not expected to have a production mechanism such as the $\chi \to \gamma\psi$ chain since all known states with mass higher than the ψ' are above charm threshold and can decay into charmed mesons. The simple comparison of the rates of ψ and ψ' production by protons and antiprotons will allow a determination of the relative importance of quark and gluon fusion production mechanisms but will not produce a detailed picture. Studies of the correlations of hadrons with the ψ and ψ' will allow a search for unexpected resonant sources of production. In the absence of such resonant sources the study of these correlations will yield information about continuum type mechanisms such as massive intermediate gluon formation[15] by quark or gluon fusion. While a precise theoretical description of such processes is not available these mechanisms should produce correlation between the hadrons and the ψ,ψ' states, and these correlations should be different in the proton and antiproton induced reactions.

A. Apparatus

The open geometry apparatus is shown in Fig. 2(b). The nuclear target used in the measurement of the dimuons is replaced by a 200 cm hydrogen target. The number of sets of drift chambers have been increased to 5 by the addition of a small chamber set 5 inches downstream of the target and by the addition of one set in front of the rear liquid argon modules. The beam Cerenkov counter remains the same as in the dimuon measurement. The major new component necessary for the di-electron measurement is the liquid argon detector system. These shower counters provide the basis for the di-electron trigger and for rejection of hadronic backgrounds. (See Section D). They provide energy ($\sigma \sim \frac{8\%}{\sqrt{E}}$)[16] and position ($\sigma$ < 2 m m) resolution for the final state photons. Both modules are approximately 2 meters by 2 meters by 24 radiation lengths. This liquid argon detector gives the spectrometer the unique capability of measuring the hadronic production of χ states with good resolution. (See Section C for magnitudes of all resolutions.)

A second analysis magnet has been very seriously considered for this experiment for the purpose of increasing the resolution on fast forward tracks while keeping the acceptance high for low momentum tracks. (See Appendix A). Our tentative conclusion is that the one magnet system shown in Fig. 2(b) is adequate for the specifically proposed 100 GeV measurements based on our present evaluation of achievable resolutions and rates. However, a second magnet would definitely improve the capabilities of the spectrometer and we plan to design all detectors with that eventuality in mind. At this time we specifically request that the possibility of a spectrometer upgrade by the addition of a second magnet during the course of E537 be recognized and left as topic for negotiation with the Laboratory management.

B. Beam and Luminosity

The $\bar{\Lambda}^{o} \rightarrow \bar{p}$ beam will also be used in the open geometry measurements of Reaction 2. 750 hours of data taking with 5 x 10^{12} on the production target and a 12 second cycle time yields 1.13 x 10^{12} antiprotons incident on our .22 interaction length H_2 target and a luminosity of 8 x 10^{36}. With the apparatus configuration shown in Fig. 3(b) we estimate from E311 bubble chamber data that the innermost liquid argon segments will operate at approximately .5 MC and should cause no serious problems. (A 4" x 4" hole has been left in the center of the liquid argon). With this luminosity we can expect the following di-electron resonance and continuum rates for the open geometry at 100 GeV:

TABLE III

$M_{e^+e^-}$	$\sigma.B$	Geometric Acceptance	Trigger Acceptance	Events 750 Hours
$\psi(3100) \to e^+e^-$	1×10^{-32}	.30	.72	17300
$\psi(3700) \to e^+e^-$	2×10^{-34}	.27	.80	350
$\psi(3700) \to \psi(3.1)\pi\pi$, $\psi(3.1) \to e^+e^-$	5.4×10^{-34}	.20	.70	600
Drell-Yan				
1.0 - 2.0	2.0×10^{-32}	.34	.24	13000
2.0 - 3.0	1.9×10^{-33}	.31	.65	3100
3.0 - 4.0	3.9×10^{-34}	.29	.80	720
4.0 - 5.0	1.0×10^{-34}	.25	.89	180
5.0 - 6.0	2.8×10^{-35}	.25	.91	51
6.0 - 7.0	7.5×10^{-36}	.24	.95	14
7.0 - 8.0	1.8×10^{-36}	.24	.97	3

The Drell-Yan cross sections for a proton target are obtained from calculations using the Field and Feynman quark distributions. (Table II gives the cross sections for an isospin averaged target.)

From the expected levels of ψ' production, the branching ratios for decays of the type

$$\chi \to \gamma\psi \\ \quad\quad \hookrightarrow e^+e^-$$

and the assumption that the production cross section of all χ's are equal, then a 'maximum' rate of χ production can be calculated if we assume that every ψ comes from a χ. (The preliminary result from the ISR indicates that as many as 43% of all $\psi(3.1)$ come from χ decay but that experiment cannot resolve individual χ states). These 'maximum' and minimum numbers of χ produced in a 750 hour data run are given in Table IV:

TABLE IV

	Ratio $\frac{\psi'\gamma\gamma e^+e^-}{\psi'\to e^+e^-}$	Expected Production of χ from ψ decay	Expected Direct Production of χ
$\psi'(3.7) \xrightarrow{7\%} \gamma\chi(3415)$ $\hookrightarrow$ 3% $\gamma\psi(3.1)$ $\hookrightarrow$ 7.3% e^+e^-	~1.7%	~ 6	~ 260
$\psi'(3.7) \xrightarrow{\leq 3\%} \gamma\chi(3454)$ $\hookrightarrow$ 100% $\gamma\psi(3.1)$ $\hookrightarrow$ 7.3% e^+e^-	~ 24%	~84	~8750
$\psi'(3.7) \xrightarrow{7\%} \gamma\chi(3508)$ $\hookrightarrow$ 26% $\gamma\psi(3.1)$ $\hookrightarrow$ 7.3% e^+e^-	~ 15%	~53	~2250
$\psi'(3.7) \xrightarrow{7\%} \gamma\chi(3552)$ $\hookrightarrow$ 12% $\gamma\psi(3.1)$ $\hookrightarrow$ 7.3% e^+e^-	~6.8%	~24	~1030
		$\gamma\gamma e^+e^-$ signature	γe^+e^- signature

If the direct production of χ states approaches the levels suggested by Table V then some of the requested 750 hours of data taking for the open geometry can be devoted to the comparison of χ production from protons with the beam tuned to 100 GeV positives. The π^+/proton ratio is approximately 1.5/1 at 100 GeV. This is somewhat better than the 2/1 ratio of π^-/antiproton at 100 GeV that we experience in the $\bar{p}$ beam and therefore a 250 hour segment might be devoted to study of the proton-proton reaction. We request 1000 hours for tune up and data taking in the open geometry configuration in order to accomplish these measurements.

C. Aperture and Resolution

In Fig. 3 the geometric efficiency and the overall efficiency including the trigger are shown for di-electron measurement (See Section D for a discussion of the trigger). The low mass di-electrons and backgrounds are suitably suppressed and the mass threshold is sharp enough to give good acceptance for true electron pairs. For the ψ and ψ' the overall acceptance is 22% and the acceptance for the χ decays into $\gamma\psi_{\rightarrow e^+e^-}$ is 15%. The $\psi(3.1)$, $\psi(3.7)$, and χ state acceptances have been calculated using the transverse momentum distributions observed by Hom et al.,[1] and Feynman and Field[4] quark longitudinal momentum distributions. The resolution of the di-electron states (either continuum or resonance) is a slowly varying function of mass. For the mass region in question $\sigma_{M_{e^+e^-}}$ ~1.5% for a one magnet system. Specifically $(\frac{\Delta M}{M})_{\psi(3.1)}$ ~40 MeV/C^2 for one magnet configuration at 100 GeV/c. (See Appendix A for the two magnet resolutions). The resolution of the χ states has been calculated constraining the mass of the e^+e^- system to 3.1 GeV/c^2. In this way a resolution $\sigma_{M_{e^+e^-}} \sim 13$ MeV/c^2 is achieved at 100 GeV/c with one magnet which is adequate to resolve the charmonium states. (See Fig. 4). For strictly exploratory searches in which the e^+e^- mass is not constrained the $e^+e^-\gamma$ mass resolution is 45 MeV/c^2 with one magnet.

D. Trigger[17] Rates, Backgrounds

The backgrounds for the di-electron trigger come from the several sources listed below:

1) Hadrons faking an $e^{\pm}$,

2) Hadron overlap with photons

3) Photon conversions producing e^+e^-.

In order to suppress false e^+e^- triggers arising from various combinations of these sources, a two level trigger will be used in the open spectrometer configuration. This trigger consists of:

Level I: Requires two or more electron candidates where an electron candidate satisfies the following requirements:

(1) Presence of a charged particle as determined by H1.H2 hodoscope coincidence (see Fig. 2(b)).

(2) Presence of greater than four times minimum pulse height in the S1.S2 hodoscope which is behind one radiation length of lead in front of the liquid argon detectors (see Fig. 2(b)).

(3) Presence of an energy dump greater than 3 GeV in the first 12 radiation lengths of liquid argon detectors in the region immediately behind the hodoscope coincidence.

Level II: Requires that the sum of the energy dumps of all electron like tracks be greater than a threshold energy which is dependent on the separation of the electron tracks.

Shower development data from E95[18] and the di-electron phase of E288[19] have been used to simulate Level I conditions 1 and 2 and 30" Bubble Chamber data from E311 ($\bar{p}p$ at 100 GeV) has been used to estimate effectiveness of Levels I and II. We find that 4×10^{-3} of the antiproton interactions will have at least two false electrons coming from various combinations of the three false electron sources and will pass the Level I trigger. (This corresponds to a rate of 10KC). The major contributor to this rate is a final state in which a slow conversion electron is in coincidence with one of the other two backgrounds. Almost all of these combinations are low mass and are eliminated by the Level II trigger. We estimate that less than 1% of the events passing Level I will pass the threshold of the Level II trigger. This corresponds to approximately 80 triggers/spill.

Adequate techniques exist to implement both Level I and Level II. Level I will be constructed from standard fast logic with a 2" hodoscope granularity. Level II requires the use of a set of programmable RAMS (such as those developed by E. Platner[20] at Brookhaven for hodoscope correlation) to determine the spatial separations of the electron candidates. Our studies show that a 5" granularity at this level is adequate and leads in the hodoscope arrangement of Fig. 2(b) to 32 possible track separations in the horizontal plane. Since $M^2_{e^+e^-} \sim p_+ p_- d^2$ where d is the separation of two candidates, the sum $p_+ + p_-$ must always be less than $2 \frac{d}{M_{e^+e^-}}$. Therefore for a given separation an energy cut on $p_+ + p_-$ is a reasonable approximation to a mass cut. The mass threshold generated by this trigger is shown in Fig. 3.

In the mass region above 2.5 GeV/c^2 we have used the di-hadron measurements of E357[21] and E494[22] and the di-π^o measurements of E95[23] to estimate our ability to reject high mass di-hadron states in the off-line analysis. The irreducible backgrounds in the high mass region from the three false electron backrounds are estimated to be less than 10% of the expected rate of Drell-Yan di-electron continuum.

Finally we have estimated the backgrounds that we expect to see at 100 GeV under the χ states by superimposing $\psi(3.1)$ final states on the E311 data. The resulting expected level and shape of the background mass spectrum is shown in Fig. 4. The χ spectra that are shown in the same figure are normalized assuming that 43% of the ψ states originated via χ decay and that the relative rates of χ production given in Table IV are observed. The off-line suppression of π^o and η^o photons has been included in the normalization of the backgrounds and the χ resolutions are those expected in the experiment using a 100

GeV beam. The general conclusions that can be drawn from these figures are: (1) The backgrounds arising from π^o or η photon combinations with a ψ are no problem. (2) The relative observed intensities of the χ's will be critical for clean separations. Closely spaced χ signals with relative strengths of 10/1 can be resolved.

REFERENCES

[1]Sidney D. Drell and Tang-Mow Yan, Phys. Rev. Lett. 25, 316 (1970).

[2]D. C. Hom et al., Phys. Rev. Lett. 36, 1236 (1976).

D. C. Hom et al., Phys. Rev. Lett. 37, 1374 (1976).

L. Kluberg et al., Phys. Rev. Lett. 37, 1451 (1976).

L. M. Lederman, and B. G. Pope, Phys. Lett. 66B, 486 (1977).

J. G. Branson et al., Phys. Rev. Lett. 38, 1334 (1977).

S. W. Herb et al., Phys. Rev. Lett. 39, 252.

W. R. Innes et al., Phys. Rev. Lett. 39, 1240.

[3]K. J. Anderson et al., Phys. Rev. Lett. 36, 237 (1976); Phys. Lett. 37, 799 (1976).

J. G. Brown et al., Phys. Rev. Lett. 38, 1334 (1977).

[4]R. D. Field and R. P. Feynman, Phys. Rev. D15, 2590 (1977).

Sandip Pakvasa, Dayanand Parashar, and S. F. Tuan, Phys. Rev. D10, 2124 (1974).

J. P. Gunion, Phys. Rev. D10, 242 (1974).

M. Duong-Van, Phys. Lett. 60B, 287 (1976).

[5]R. Thun et al., Nucl. Inst. and Meth. 138, 437 (1976).

[6]J. Siegrist et al., Phys. Rev. Lett. 36, 700 (1976).

[7]K. J. Anderson et al., Phys. Rev. Lett. 37, 799 (1976).

[8]W. R. Ditzler et al., Fermilab preprint 77/87 (to be published in Phys. Lett.).

[9]H. D. Snyder et al., Phys. Rev. Lett. 36, 1415 (1976).

J. G. Branson et al., Phys. Rev. Lett. 38, 1331 (1977).

[10]Feldman, Vth International Conference on experimental Meson Spectroscopy, April 29-30 (1977).

J. S. Whitaker et al., Phys. Rev. Lett. 37, 1596 (1976).

[11]B. L. Joffe, Phys. Rev. Lett. 39, 1589 (1977).

[12]J. H. Cabb et al., Study of Photons Produced Simultaneously with the J/ψ Particles at the CERN ISR, CERN Preprint, (Submitted to Physics Letters).

[13]J. D. Jackson, TH. 2351 - CERN.

[14]T. Trippe et al., Physics Letters, 68B, 1, (1977).

[15]H. Fritzsch, Physics Letters, 67B, 2, (1977). M. Teper, J/ψ Production in Hadronic Collisions, Invited contributions to the XII Recontre de Moriond, (1977).

[16]D. Hitlin et al., SLAC-Pub-1761, May (1976).

[17]We have investigated the possibility of using a dimuon trigger along with the dielectron trigger in this measurement. The level of background from dimuon decay which cannot be eliminated offline is considerably larger than the residual di-electron background and trigger rates appear high but we are continuing to consider the simultaneous use of this trigger.

[18]M. Goodman et al., Functioning of Double Arm-Pb Glass Spectrometer, (in preparation for submission to Nucl. Instrum. and Methods).

[19]J. A. Appel et al., Nucl. Instrum. and Methods, 127 (1975) 495-505, T. Yamanouchi, Private Communications.

[20]E. Platner, I.E.E.E. Transactions on Nuclear Science, Vol. N5-24, No. 1 (1977).

[21]E357, Private Communications.

[22]R. D. Kephart, et al., Fermilab-PUB-77/83 - EXP, Sept. (1977).

[23]E95, Private Communications.

APPENDIX A

We have investigated a two magnet spectrometer and have concluded that an appreciable improvement in charged particle mass resolution can be achieved beyond that obtained in a one magnet geometry. We list the two body mass resolutions (σ) at 100 and 200 GeV for the $\psi(3.1)$.

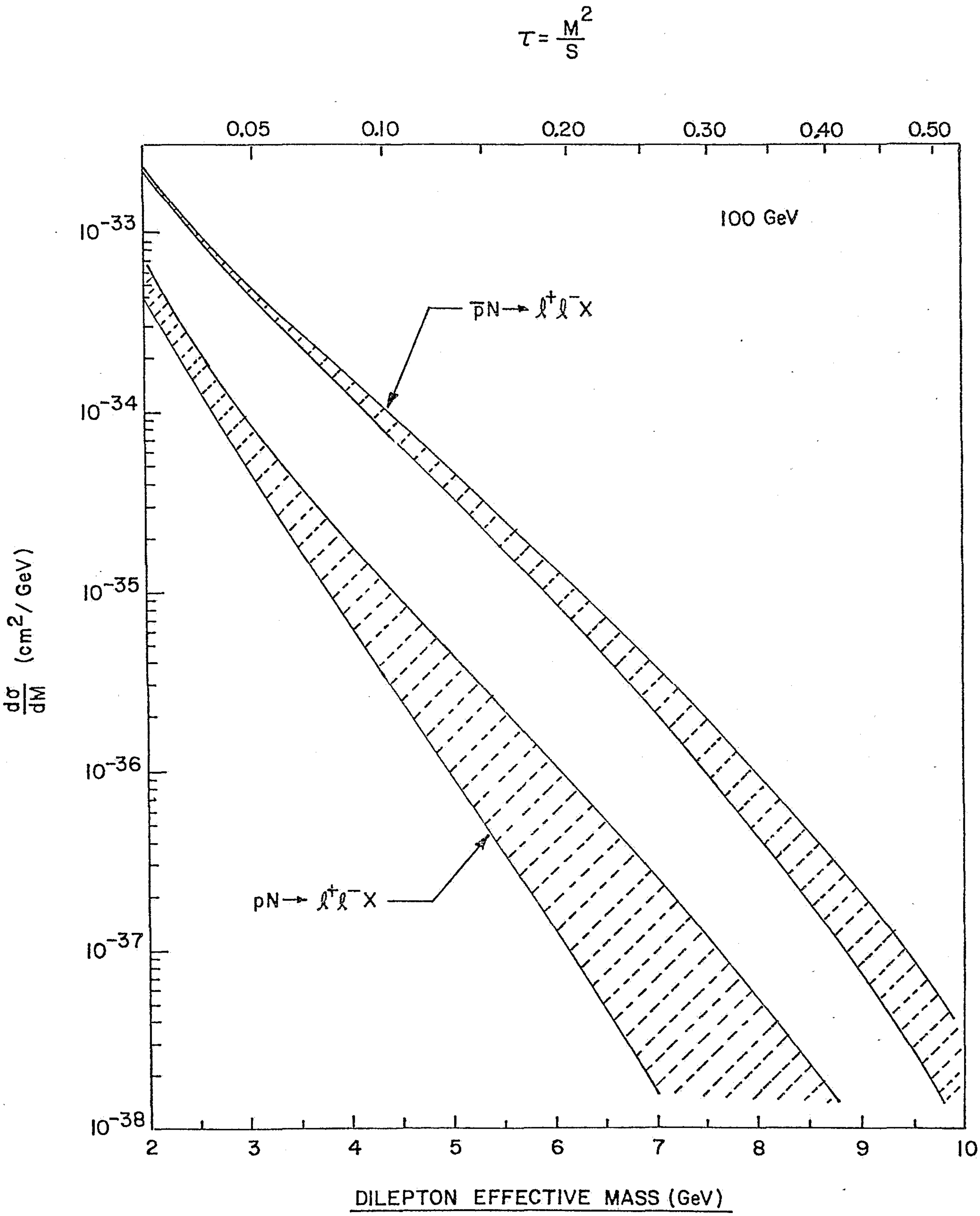
	100 GeV	200 GeV
1 magnet	36 MeV/c^2	48 GeV/c^2
2 magnet	26 MeV/c^2	34 GeV/c^2

A pertinent observation deduced from the table is that a 2 magnet system at 200 GeV has the same mass resolution as the one magnet system at 100 GeV. Both a geometry with the second magnet surrounding the target and a geometry with the second magnet added downstream of the first magnet gave comparable results.

APPENDIX B

We list a short summary of relevant numbers of hodoscope counters, drift chamber wires, and liquid argon channels for the one magnet spectrometer below:

Muon Hodoscope	120 Counters
S1·S2 Hodoscope	160 Counters
H1·H2 Hodoscope	320 Counters
Drift Chamber Wires	2200 Wires
Liquid Argon Channels	1600 Channels
Additional Scintillators	100 Counters



$\tau = \frac{M^2}{S}$
0.05
0.10
0.20
0.30
0.40
0.50
100 GeV
$\bar{p}N \rightarrow \ell^+\ell^- X$
$pN \rightarrow \ell^+\ell^- X$
10^{-33}
10^{-34}
10^{-35}
10^{-36}
10^{-37}
10^{-38}
$\frac{d\sigma}{dM}$ (cm^2/ GeV)
2
3
4
5
6
7
8
9
10
DILEPTON EFFECTIVE MASS (GeV)

FIGURE 1

FIGURE 2a

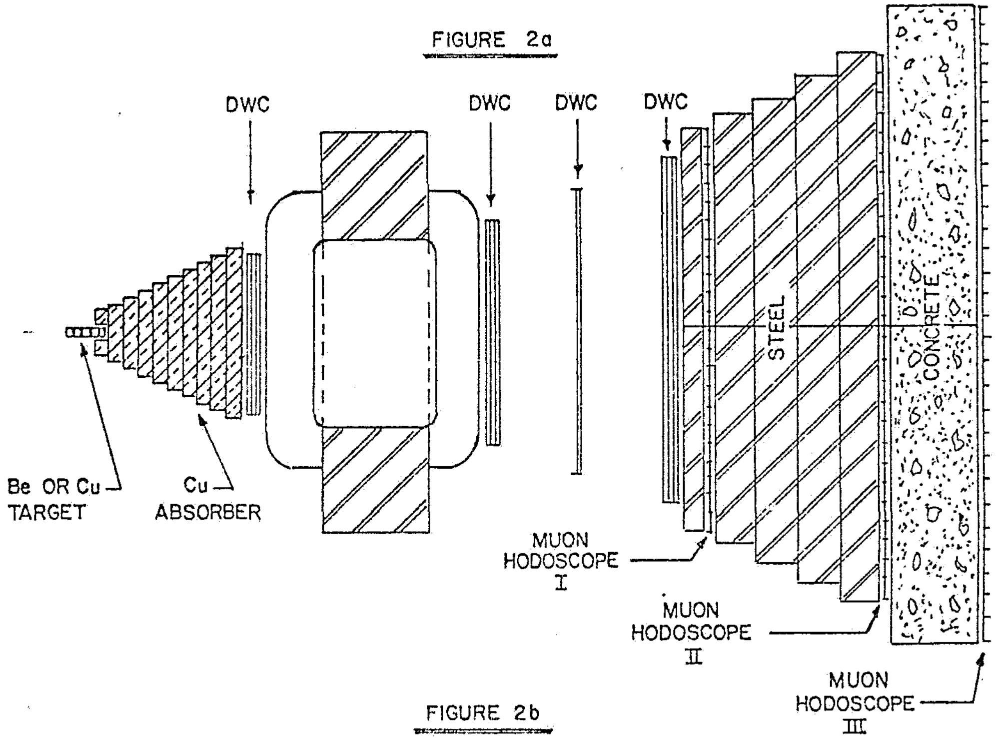
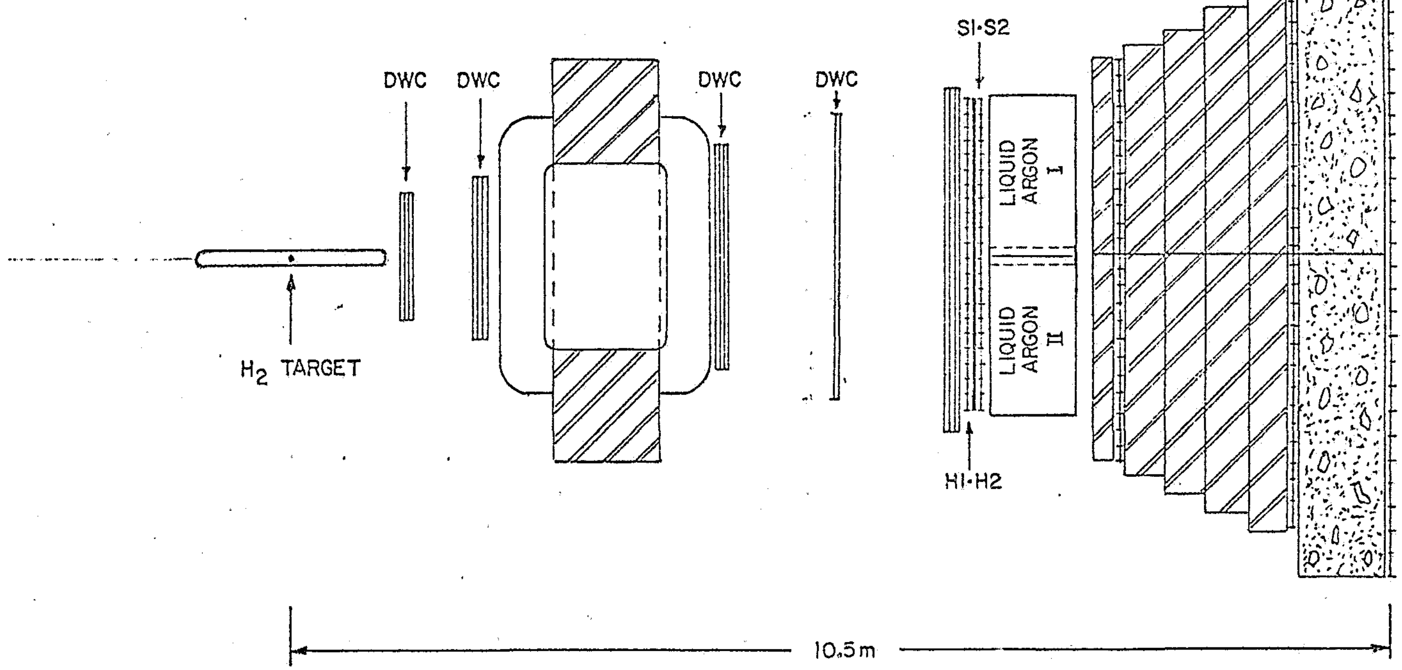
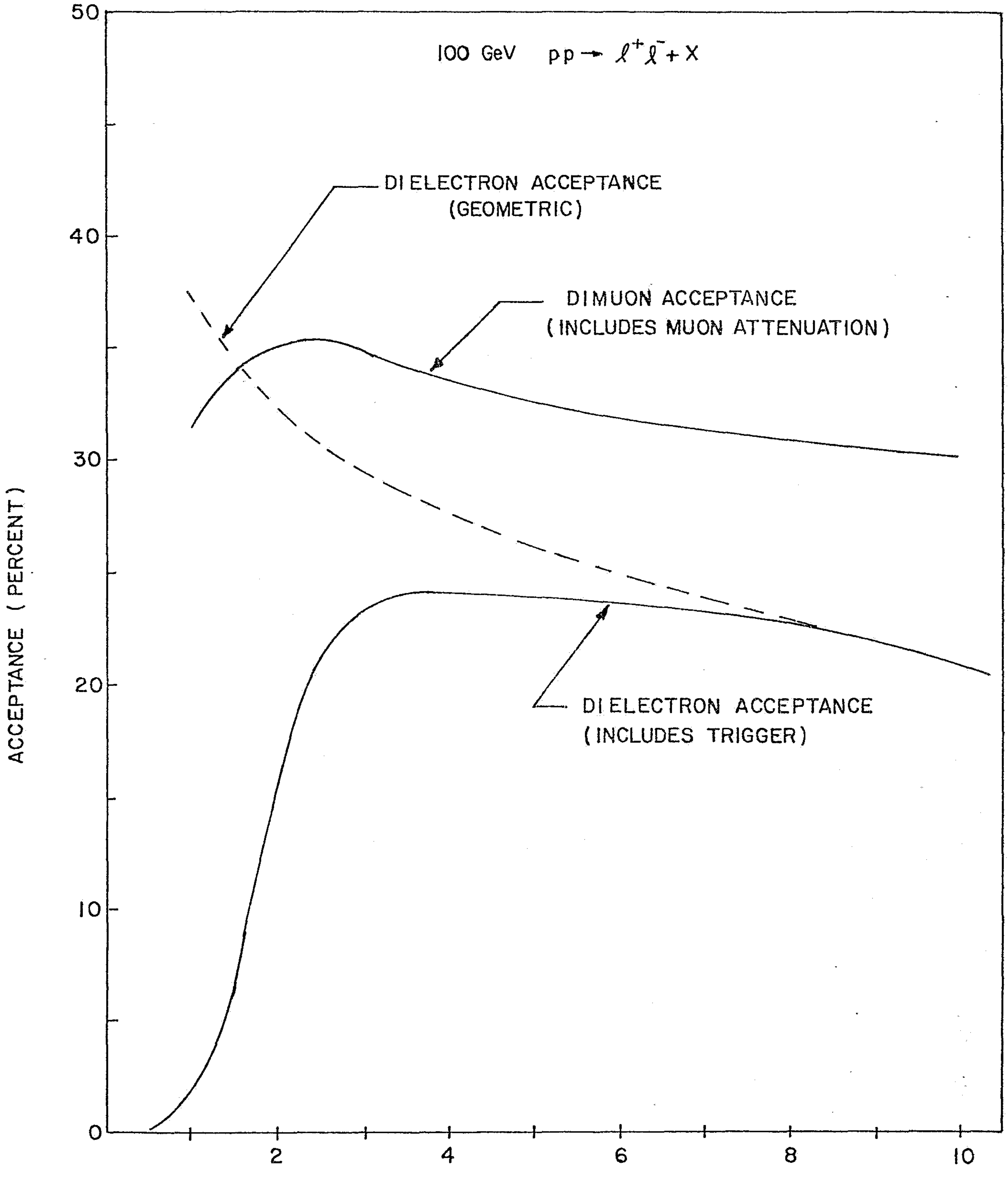


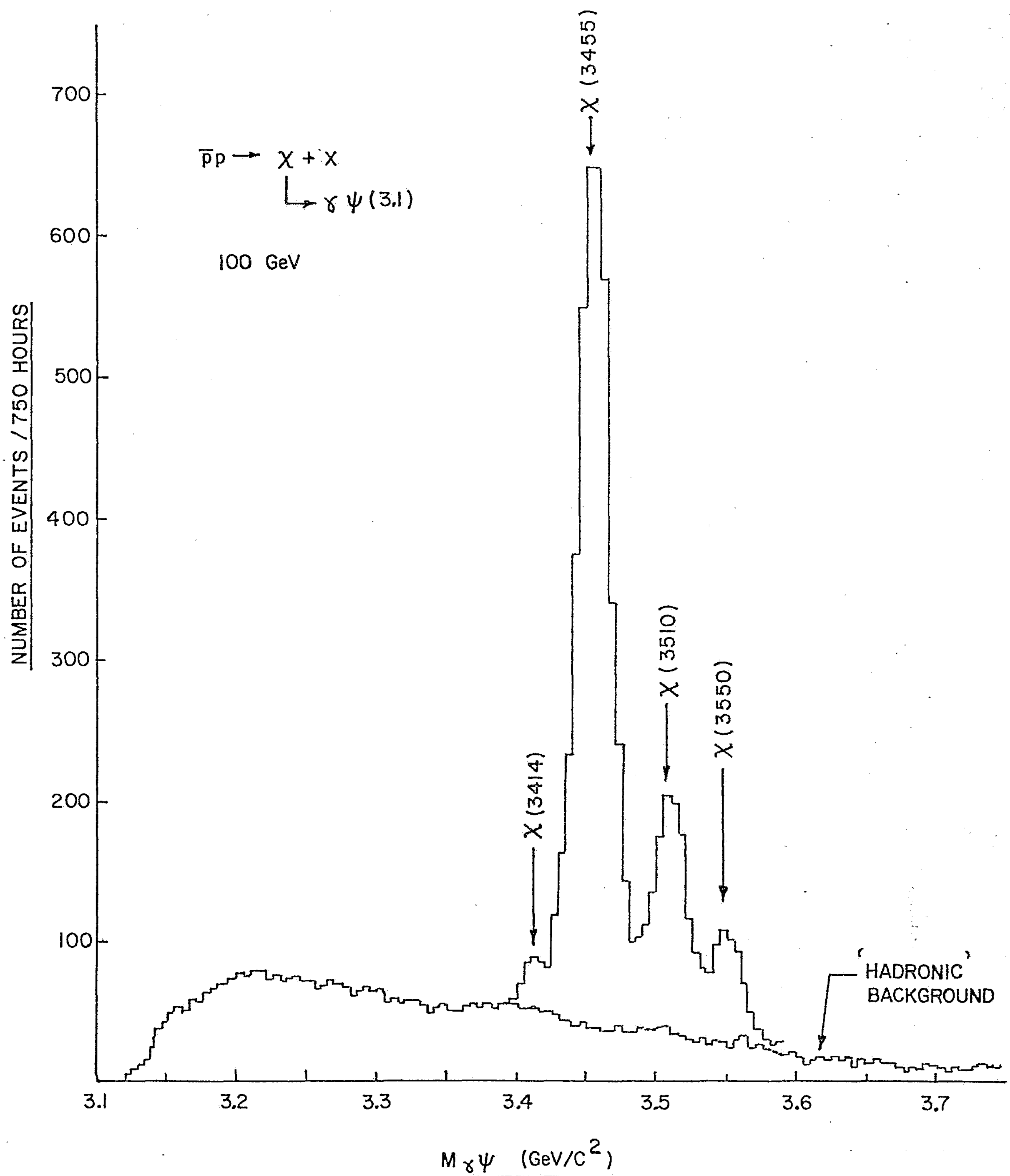
FIGURE 2b





SPECTROMETER ACCEPTANCE

FIGURE 3



NUMBER OF EVENTS / 750 HOURS
700
600
500
400
300
200
100
$\bar{p}p \rightarrow \chi + X$
$\gamma\,\psi(3.1)$
100 GeV
χ (3455)
χ (3510)
χ (3550)
χ (3414)
'HADRONIC' BACKGROUND
3.1
3.2
3.3
3.4
3.5
3.6
3.7
$M_{\gamma\psi}$ (GeV/C^2)

FIGURE 4