FERMILAB-Proposal-0471

PROPOSAL TO INVESTIGATE THE NATURE OF ψ PRODUCTION BY PIONS AND PROTONS

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January 19, 1976

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FNAL Ext 3917

30 pgs.

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SUMMARY

We propose an experiment that investigates the properties of particles produced in association with the ψ(3.1) and ψ'(3.7). The physics objectives include a search for heavy parent particles which decay into the ψ and multiparticle resonances produced along with the ψ. The latter possibility includes both a search for particles which may be "charmed" (in which case two should be produced along with the ψ) as well as a search for true associated production, which may occur if the ψ itself has a new quantum number.

The experiment investigates both pion and proton initiated ψ production processes. The differences observed in inclusive ψ production by pions and by protons are an indication that the production mechanisms may depend on the nature of the incident particle. For example, processes requiring anti-quarks would be more likely to be initiated by pions than by protons. Therefore, it is necessary that beams of both particles be used to search for new particles associated with the ψ.

The apparatus is a good resolution, large acceptance spectrometer followed by an iron muon filter. The spectrometer will be triggered by muon pairs originating from ψ and ψ' decay and other processes, and will be used to obtain the effective mass distributions of the charged particles produced in coincidence with the ψ and ψ'. A large acceptance spectrometer is crucial since both the ψ and decay products of resonances produced along with it must be detected simultaneously. To achieve a large multiparticle acceptance with a magnet of conventional size, the thin target (1/2" beryllium) is placed inside a BM109 magnet and the particle trajectories are measured only after magnetic deflection. The resulting mass resolution for a centrally produced ψ is 140 MeV (FWHM), which is more than sufficient to separate the ψ from the muon pairs due to pion decay. At 400 GeV, the acceptance for a two body decay of a particle produced at rest in the C.M.S. is about 35%.

We propose to make the measurement in the M2 line using pion and proton beams at an intensity of 10^7/pulse. We will require about two hundred hours of set up time and 1200 hours of data collection time, split evenly between pion and proton beams. The expected yield of at least 5,000 proton induced ψ events and at least 10,000 pion induced ψ events is sufficient to investigate phenomena which contribute as little as a few tenths of a percent to inclusive ψ production.

This experiment is similar in purpose to E-400 but differs in two crucial respects. First, although both experiments search for new particles produced along with the ψ, this experiment has a much larger acceptance because the apparatus subtends about five times more solid angle in the lab. Thus, not only does it have a greater sensitivity to rare processes but it can also detect particles in kinematic regions inaccessible to E-400. Second, the pion initiated events collected in this experiment cannot be obtained by E-400. Consequently, the two experiments are in fact complementary.

I. INTRODUCTION

We propose an experiment to search for new particles produced by pions and protons in association with the $\psi(3.1)$ and $\psi'(3.7)$ mesons. The apparatus consists of an effective mass spectrometer with a large aperture and good resolution that is placed before an iron muon filter. The normal trigger for the system is two or more muons. The spectrometer is used to obtain effective mass distributions of particles produced and detected in coincidence with the ψ and the ψ'.

II. PHYSICS

The study of the processes by which a particle is produced can in some cases be as useful for understanding the nature of the particle as an investigation of its decay processes. The suppression of the ψ production cross section, like the suppression of its decay, requires the existence of a new phenomenon in high energy physics. Many models of ψ production suggest that the phenomenon may manifest itself in new particles. Consequently, an investigation of the process of inclusive ψ production may lead to the discovery of new particles. From a purely phenomenological point of view, a search for new particles produced in association with the ψ appears potentially very fruitful.

The primary objective of this experiment is to conduct such a search for new particles produced in association with the ψ. The experimentally established differences in inclusive ψ production[1, 2] by pions and by protons first observed by some of us are an indication that differing processes may be at work for the two beams. If antiquarks play an important role in new particle production, pions offer the advantage of having core antiquarks at large X, while protons have only sea antiquarks, which are at a smaller X. It is also possible that different particles are associated with the ψ when it is produced by a pion than when it is produced by a proton. Therefore, it is essential that both pion and proton beams be used in this search for new particles.

In designing the experiment we chose not to be governed by any one of the current theoretical models of ψ structure. However, we believe that the experiment is sensitive to and capable of distinguishing among the following broad categories:

1. The ψ mesons are produced in association with charmed particles.[3] The charmonium model of ψ structure has been at least partially vindicated by the recent observation of radiative transitions from the ψ and ψ' to other states. This model, together with Zweig's rule, suggests that two charmed particles may accompany each ψ (See Fig. 1). The charmed particles would be identified by narrow peaks in the effective mass spectra of final state charged particles produced with the ψ. (Preliminary results[4] of E-366 may indicate that the mechanism described here does not dominate ψ production[5], but is probably large enough to be within the detection capability of our experiment.)

If new narrow resonant states are observed, the theoretical relationship between them and the ψ will be experimentally confirmed. Experiments searching only for narrow resonances are incapable of making this connection.

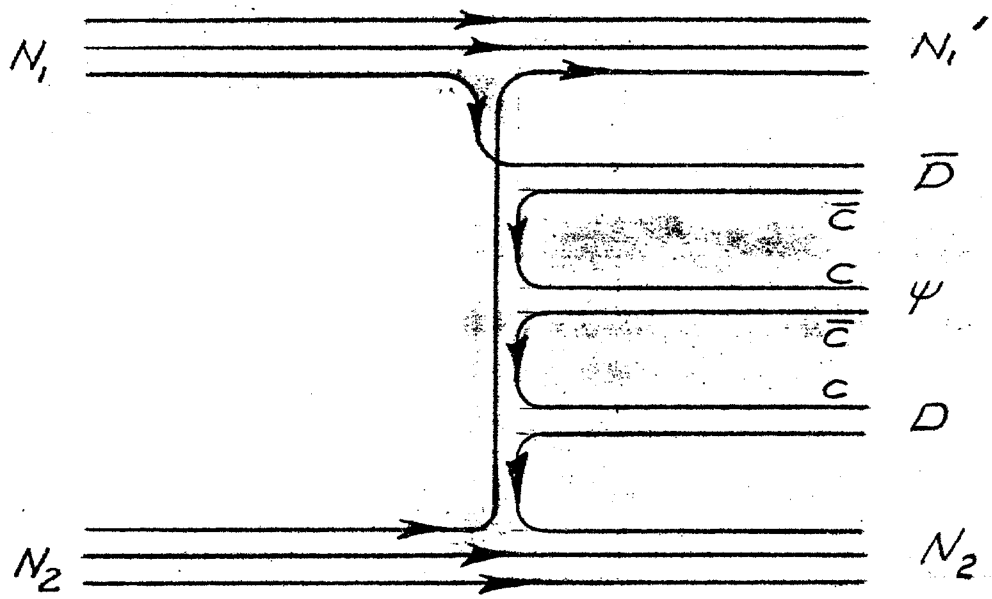
2. The ψ and the ψ' are decay products of higher mass parent particles. Effective mass spectra of the ψ and its associated particles should have one or more peaks if this conjecture is correct. The large branching ratio of the ψ' into the ψ suggests that other parents may be likely. The fact that the X dependence of the inclusive ψ production cross section is considerably flatter in the central region than that of the inclusive pion cross section may also suggest high mass parents. Note that a high mass charmed particle can decay strongly into a ψ and a lower mass charmed particle without violating Zweig's rule.

3. The ψ and the ψ' have a new quantum number and are produced in pairs or with completely new unexpected particles. Even if hadronic decay modes of the ψ rule out a new quantum number, unknown dynamical effects might enhance production of pairs of ψ's or production of other new particles along with the ψ. If new

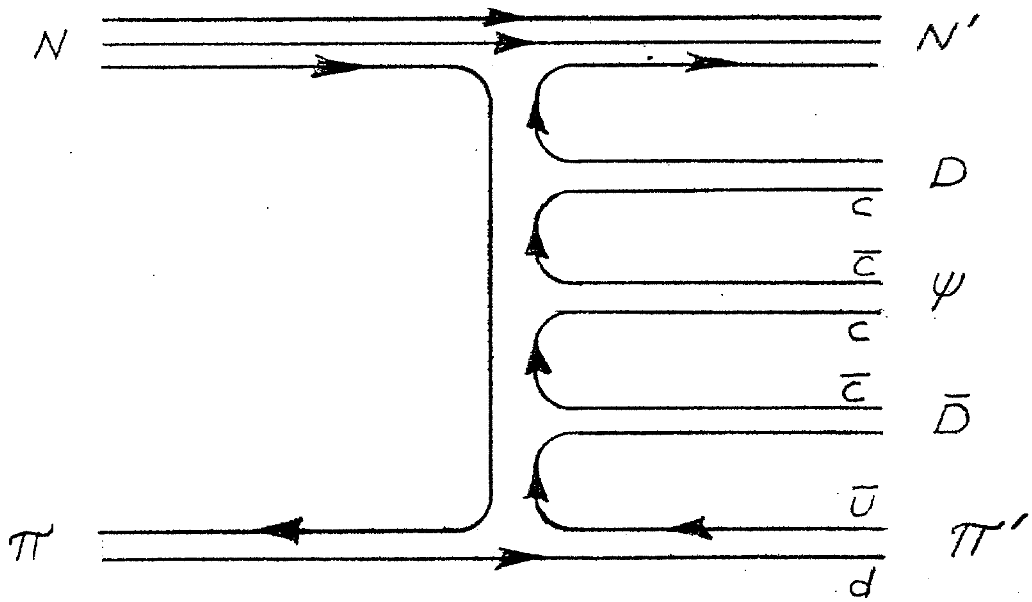
FIGURE 1

POSSIBLE QUARK DIAGRAMS FOR $\psi D\bar{D}$ PRODUCTION

$NN \to \psi D\bar{D}NN$



$\pi N \to \psi D\bar{D}\pi N$



particles are produced, peaks would be observed in the effective mass spectra of particles produced with the ψ.

4. The ψ mesons are produced "normally." In this case, no new resonances would be observed in the invariant mass spectra of the hadrons produced with the ψ. However, charged particle multiplicity and π-ψ rapidity correlations might yield some clue to the production mechanism, as would an anomalously large K_s^o yield.

If a narrow resonance is observed, it may be possible to determine the identity of the particles that result from the decay, even though we cannot use Cerenkov counters. In order to make this determination, we use the fact that if an incorrect mass assignment is made to a particle resulting from the decay of the resonance, the calculated effective mass will depend on the polar angle of the decay. If a kaon is misidentified as a pion, the variation in effective mass will be larger than our resolution, and may thus enable us to distinguish between the two particles.

Manifestations of new phenomena may occur in our data in more subtle ways than outlined above. Two interesting possibilities are the following:

1. The transverse or longitudinal momentum of charged particles does not balance properly. A larger imbalance at a dimuon invariant mass of the ψ than elsewhere would indicate a peculiarity in the unobserved neutrals. An explanation of the peculiarity could be the production and subsequent leptonic or semileptonic decay of a new object associated with the ψ. The additional momentum imbalance would then be due to neutrino production.

2. A third muon is observed more frequently at the dimuon invariant mass of the ψ than at other invariant masses. Mu-tridents might tag ψ's produced in association with charmed particles if one of the latter undergoes a leptonic or semileptonic decay. Narrow resonances observed with these events could probably be assumed to have weak decays.

We invoked the same model for both phenomena described above. If, in fact, a third muon does accompany the ψ, the model suggests that an excess transverse momentum imbalance should exist and that the average net transverse momentum vector should lie along that of the average transverse momentum of the third muon.

Although the primary goal of the experiment is to elucidate the nature of the ψ, other interesting data will be collected simultaneously. With these data we expect to explore the physics outlined below.

1. We will obtain normalized inclusive and semi-inclusive cross sections for all B particles, where B is η, ρ, ω, φ, $\psi(3.1)$, $\psi'(3.7)$, or any other particle which decays into two muons.

2. We will obtain X_F and $P_\perp$ distributions for all B particles.

3. B-π rapidity correlations will be studied.

4. Zweig's rule for φ production will be tested by looking for K_s^o's produced in association with the φ.

5. Bπ and B$\pi\pi$ mass spectra and partial waves will be extracted from the data. Inclusive cross sections for resonances such as the A2 will be obtained.

6. In the central region we will study interference effects among the various B mesons in the dimuon channel for inclusive and semi-inclusive reactions.

7. The dependence of the B production cross sections on atomic number will be studied. Hopefully, the large ranges of dimuon invariant mass, of $P_\perp$, and of X_F will provide sufficiently rich data to determine the physical origin of the unexpected A dependence observed in previous experiments. These data will also permit extrapolation to hydrogen cross sections.

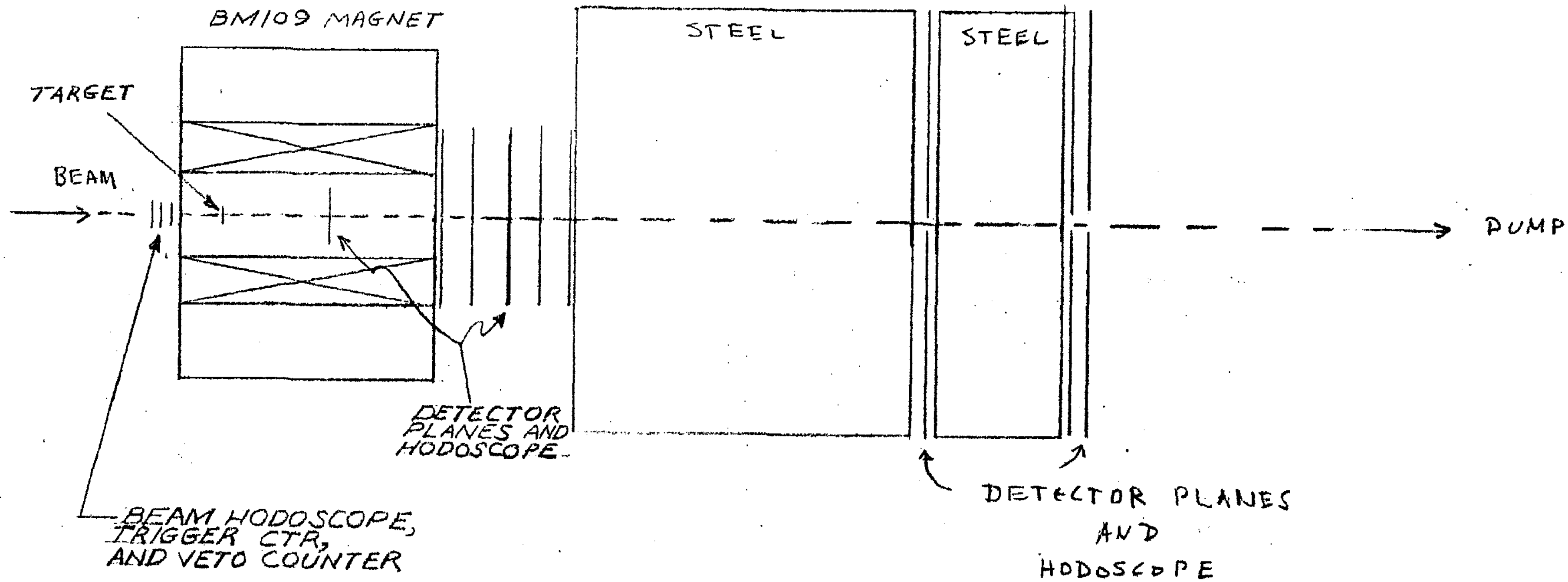
Using the same apparatus for both pion and proton beams has the obvious advantage of minimizing systematic errors in the comparison of data on pion- and proton-induced interactions.

III. APPARATUS

The distinguishing feature of the apparatus (Fig. 2) is that the target is

FIGURE 2

PLAN VIEW OF APPARATUS



SCALE: 1/4" = 1'

located just inside the upstream end of the magnet. The characteristics of this geometry are as follows:

1. Particle trajectories are measured during and after magnetic deflection. The slopes and intercepts of the trajectories after deflection and the coordinates of the event vertex are alone sufficient to determine production angles and momenta Using a magnet of conventional size, a much larger acceptance is possible than if trajectories are measured before deflection, as is the case in a standard forward spectrometer.

2. The forward cone of particles produced in the high-energy interaction is spread out, which reduces the hit rate and density on the detectors. Delta-rays and target fragmentation particles are swept out.

3. The distance between the target and the hadron absorber is minimized, which in turn minimizes the probability of in-flight pion decay.

The components of the apparatus, in the order in which the beam passes through them, are as follows:

1. A beam-measuring hodoscope, a trigger-counter, and a hole veto counter.

2. A standard BM 109 magnet.

3. A 1/2-inch thick beryllium target inside the BM 109.

4. A 1-mm sense wire spacing MWPC at the magnet bend plane. The chamber will have three planes: one with vertical wires, one with wires at -60° to the vertical, and one with wires at $+60^{\circ}$ to the vertical.

5. Four MWPC's behind the magnet having planes with the same wire orientation as above, but with 1.5-mm sense wire spacing.

6. Scintillation counter hodoscope elements.

7. Eight feet of steel with a hole for the beam.

8. Drift or proportional chambers.

9. Three feet of steel with a hole for the beam.

10. Scintillation counter hodoscope elements.

11. Drift or proportional chambers.

The spectrometer has a momentum resolution, $\frac{dp}{p}$, of about .0024 P FWHM, where P is the momentum of the particle in GeV/c. The mass resolution, $\frac{dm}{m}$, for a symmetric two-body decay is about .001 $P(1 + 1/m^2)^{1/2}$ FWHM, where P is the lab momentum in GeV/c of the particle decaying, and m is its mass in GeV/c^2. For a $\psi(3.1)$ produced by a 400 GeV beam at X=0, the mass resolution is about 0.14 GeV/c^2 FWHM.

Since the expected pion beam energy is 250 to 300 GeV, the target will be moved farther downstream for most of the pion beam running in order to maintain a large multibody acceptance in the central region. Consequently, the momentum resolution will suffer. However, the mass resolution for the particles of interest will deteriorate only slightly because the smaller particle momenta almost compensate for the poorer momentum resolution.

We intend to use a beam intensity of 10^7 particles per second. To avoid *ambiguities in the origin of the interaction, we could reject events that have* more than one particle per R. F. bucket, thus reducing the usable intensity by 20%. An alternative method of rejecting these ambiguities is to use x, y, and u hodoscope planes to define the beam position. The vertical projection of the spectrometer tracks would locate the y-coordinate of the event origin. The x-coordinate could then be found by matching hits in the three beam hodoscope planes. This method rejects no beam and, in principle, allows one to use a more intense beam. A third alternative is to add a quadrupole magnet to the beam line. The focus at the target would be large vertically and sufficiently narrow horizontally to eliminate the need for a beam hodoscope. If we chose this alternative, we could use a beam intensity approaching 10^8 per pulse.

If the inclusive pion production cross section is the same for events in which a ψ is detected as it is for ordinary events, we expect an average of four pion tracks in addition to the two muon tracks. The detector planes in and behind the absorber will be used to make a crude off-line mass cut and will select the muon tracks in the chambers behind the magnet. The latter chambers will be used to sort out the remaining tracks. Finally, the chamber in the magnet will be used with the chambers behind the magnet to calculate production angles and momenta.

The normal trigger for the apparatus will be two or more muons detected behind the eleven-foot thick iron absorber. Hodoscopes before and after the absorber will aid in tracking, define muons, and, if necessary, reduce the trigger rate.

IV. RATES

Using the data of reference 2 and assuming a beam of 10^7 protons per 1 second pulse with 350 pulses per hour, we calculate a proton-initiated yield of 16 $\psi(3.1)$ per hour for $X_F > .05$. Our average acceptance is greater than .5, so we expect at least eight ψ events per hour of beam. The pion-initiated event rate will be about twice as great because the cross section is larger and because the mean X_F of the ψ's is larger.

The measured cross section for $pBe \rightarrow \psi(3.1)X$ is about two orders of magnitude larger at 150 GeV [2] than at 30 GeV.[6] Therefore, the cross section at 400 GeV, which is the proton beam energy that we expect to use, is probably significantly larger than at 150 GeV. Since we have used the measured values at 150 GeV in our calculations, we have probably underestimated our yield by a substantial factor.

Our .5-inch beryllium target is 3.5% of an absorption length. Thus, we expect 3.5×10^5 observed interactions per second for a beam of 10^7 per pulse. The proposed apparatus should operate without difficulty at these background rates.

The thin target is used primarily because its length affects the resolution. Another important reason is that it reduces the problem of secondary target interactions of hadrons produced in an event. (For example, in a two-inch beryllium target, there is an 8% average probability that a hadron produced in the target will interact again. For multiparticle events, this could be a significant problem.)

Using a Monte Carlo program, we have calculated that, without mass selection, our trigger rate due to pion decay would be about 100 per pulse.

V. ACCEPTANCE

The calculation of the N-body acceptance of the apparatus for $2 \leqq N \leqq 5$ used two simplifying assumptions: The first was that the angular and momentum distributions of the decay products are given by pure phase space. The second was that the parent particle is produced at $P_{\perp}=0$. The latter assumption is safe since the acceptance is large for $P_{\perp}=0$, and for high-mass objects the transverse momentum of the parent is small compared with that of the daughters. The results of these calculations are given in Figures 3a - 3e.

A further requirement not included in the calculations is that the region of the chambers through which the beam passes must be deactivated. A one-inch deactivated square in the chambers behind the magnet cuts the expected yield of *ψ(3.1)'s by less than a factor of two. Since we expect to use a deactivated area* smaller than $1/4(\text{inch})^2$, the resulting reduction in yield is negligible.

Equally important as the N-body acceptance for a single parent is the acceptance for two or more resonances associated with the ψ. In order to calculate this acceptance, one needs a model of the production dynamics to relate the kinematic variables of the parents. The production of $\psi D\bar{D}$ is considered as an example. The results would be similar if the ψ itself had a new quantum number and were produced only in association with other particles. Consider Figure 1, which schematically represents the $\psi D\bar{D}$ production mechanism prescribed by Zweig's rule in the multiperipheral model, if the ψ is composed of a pair of charmed quarks and the D's are charmed mesons, as yet undiscovered. The model orders the particles so that the rapidity of the ψ lies between that of the D and that of the $\bar{D}$. Current theoretical conjecture[7] suggests that the rapidity correlations between these three particles are sufficiently short-range that all three should have almost the same rapidity.

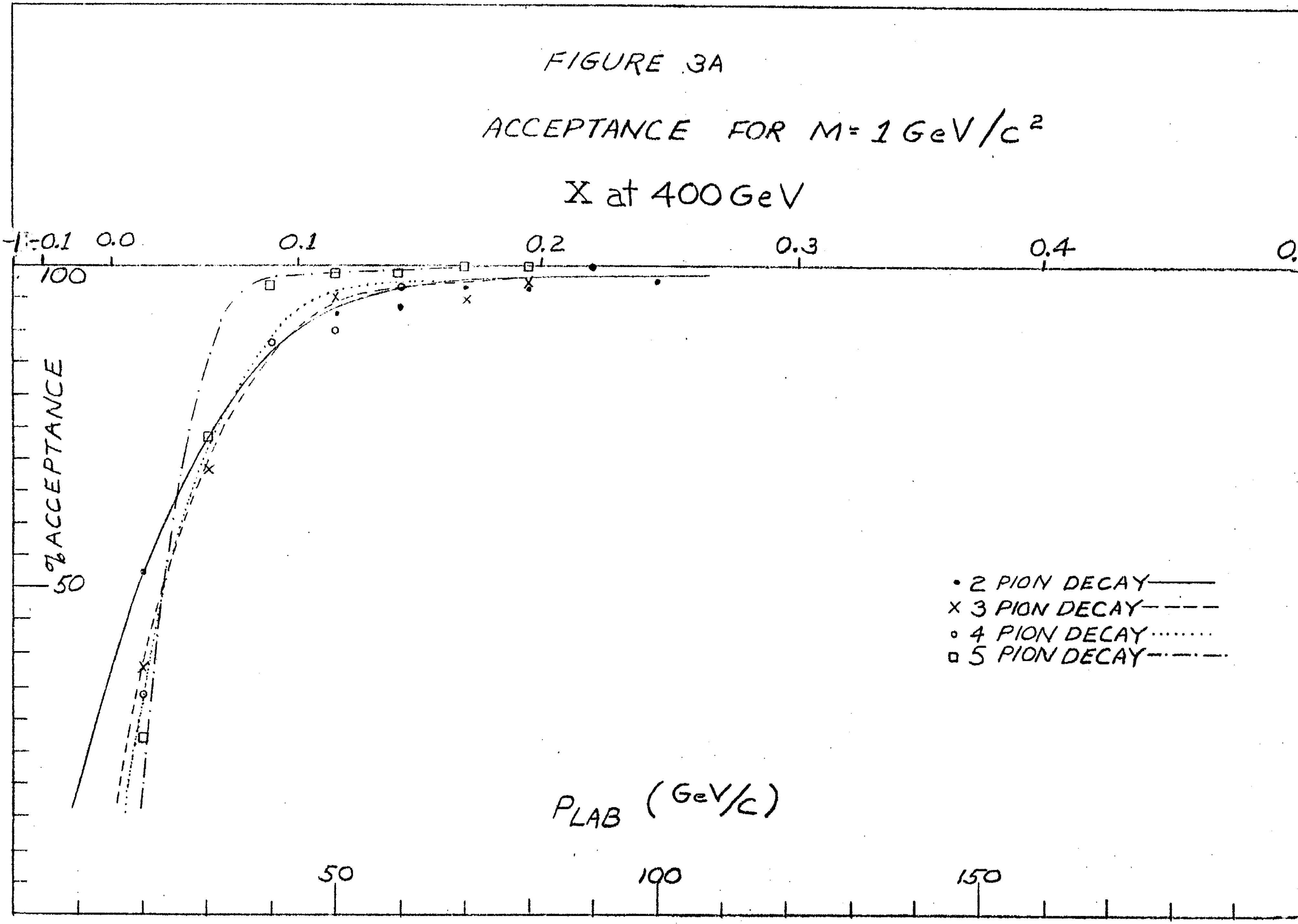


FIGURE 3A
ACCEPTANCE FOR M = 1 GeV/c²
X at 400 GeV
-.1 -0.1 0.0 0.1 0.2 0.3 0.4 0.5
100
50
% ACCEPTANCE
• 2 PION DECAY
× 3 PION DECAY
∘ 4 PION DECAY
□ 5 PION DECAY
P_LAB (GeV/c)
50
100
150

FIGURE 3B

ACCEPTANCE FOR $M = 2 GeV/c^2$

X at 400 GeV

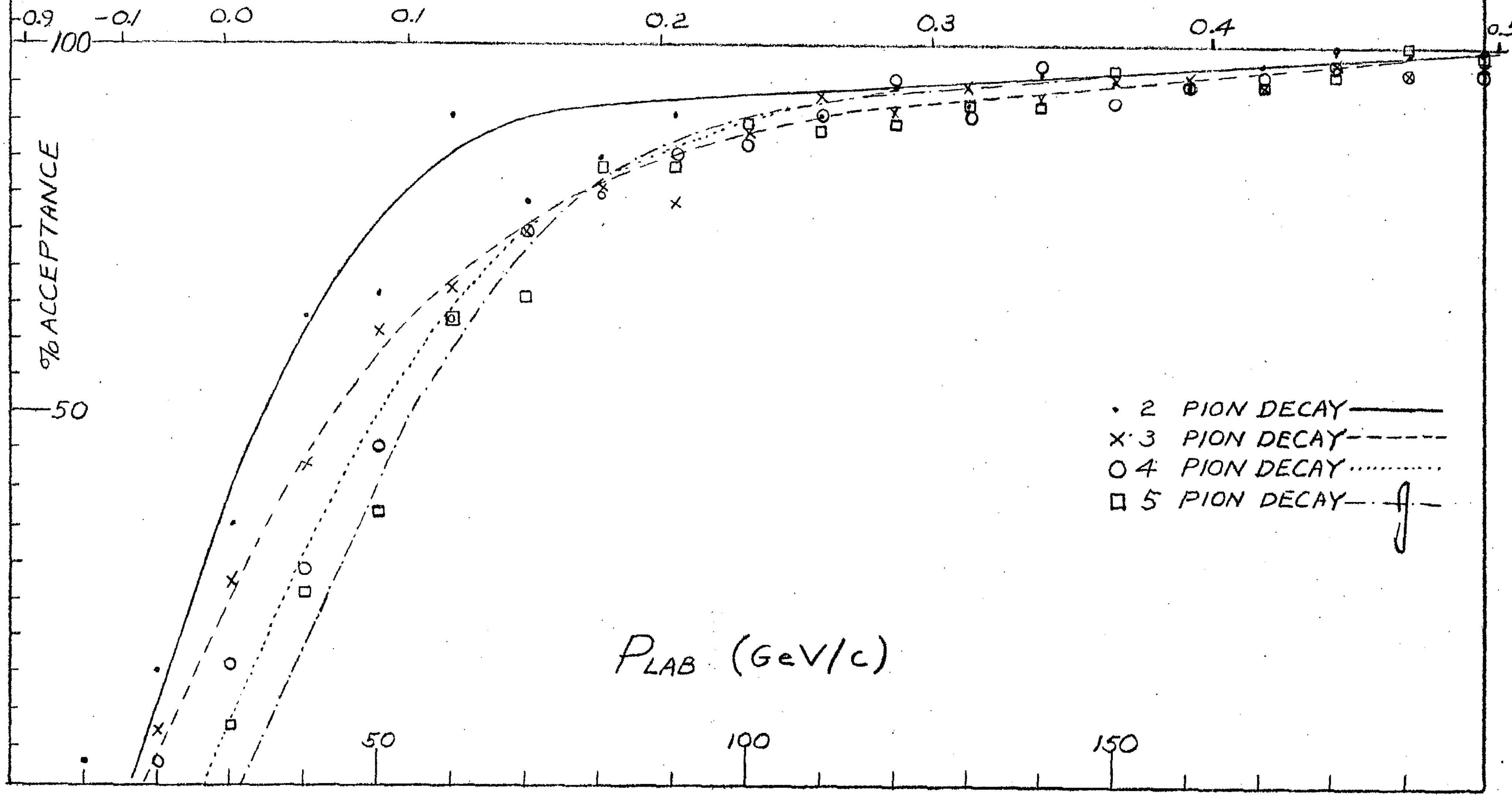
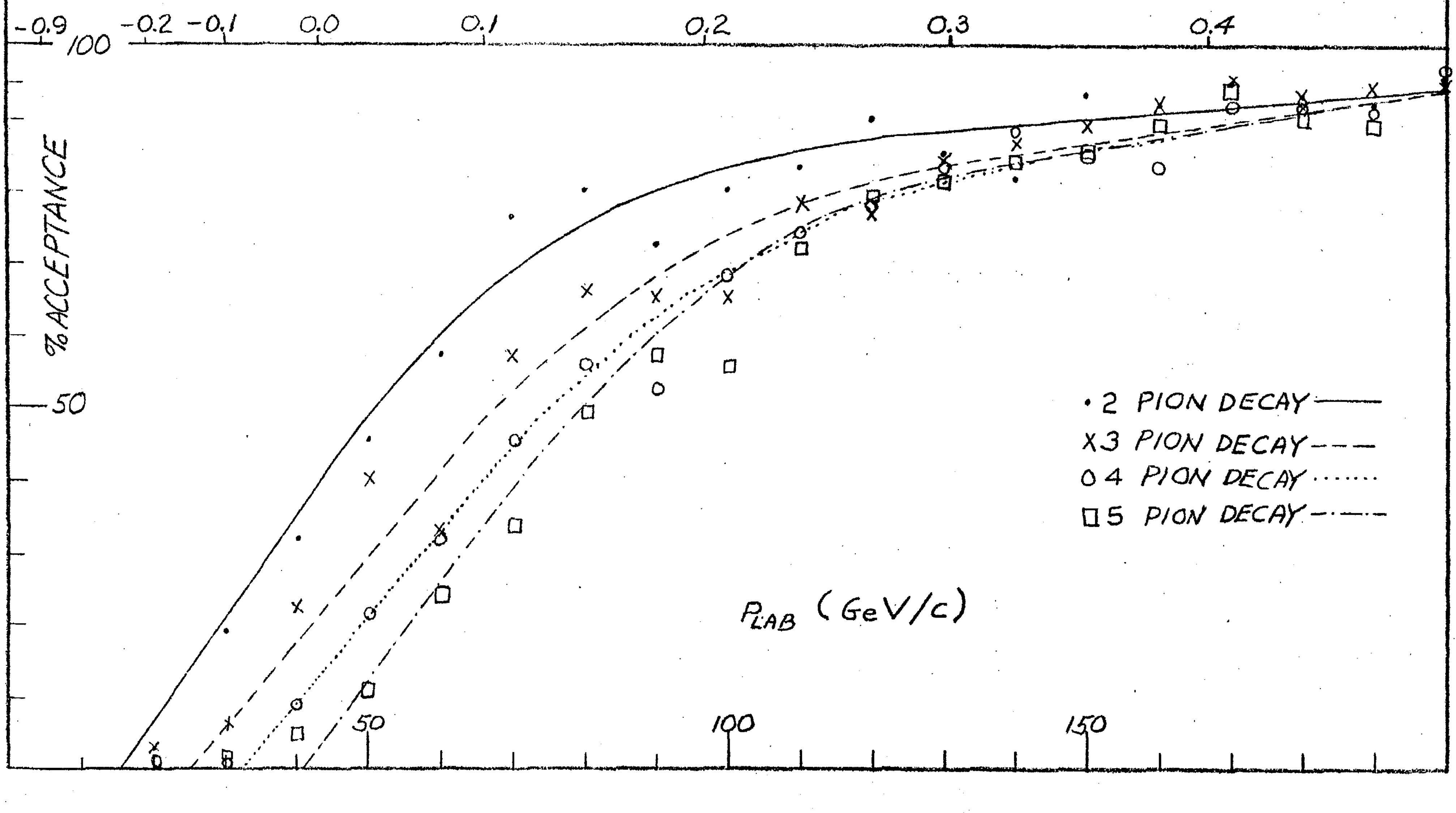


FIGURE 3C

ACCEPTANCE FOR $M = 3 \text{GeV}/c^2$

X = 400 GeV



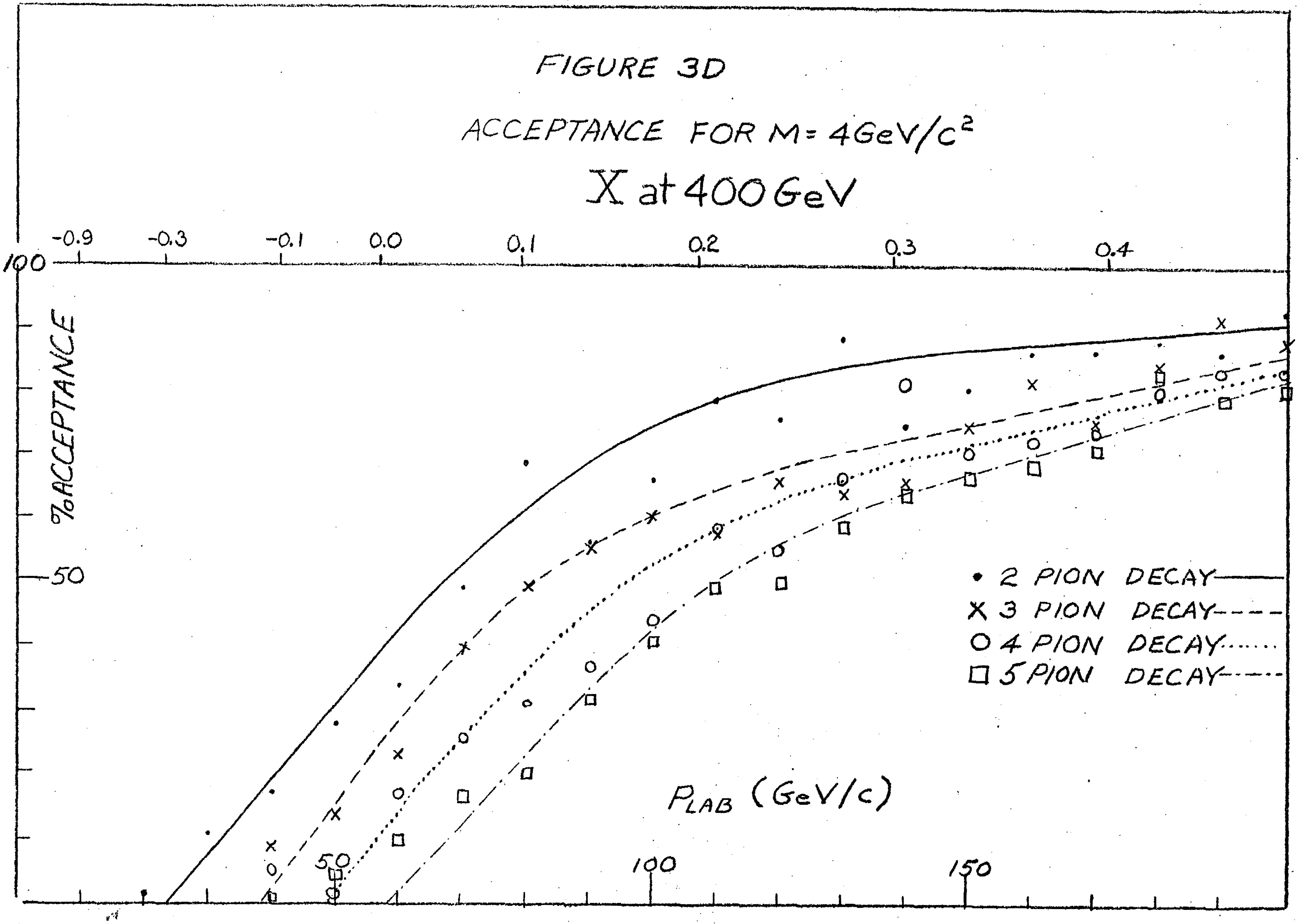
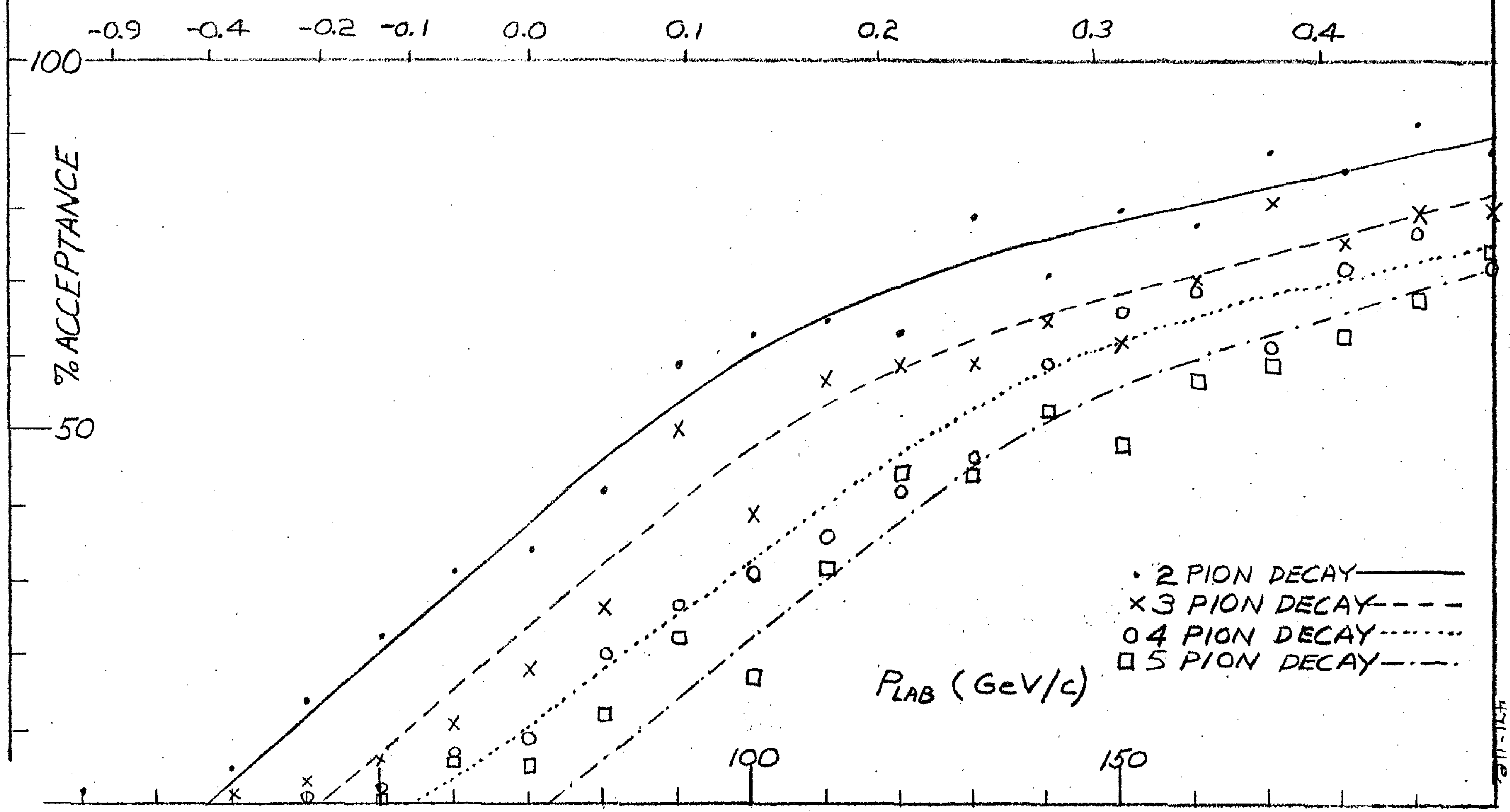


FIGURE 3D
ACCEPTANCE FOR M = 4GeV/c²
X at 400 GeV
-0.9
-0.3
-0.1
0.0
0.1
0.2
0.3
0.4
100
%ACCEPTANCE
50
• 2 PION DECAY
X 3 PION DECAY
O 4 PION DECAY
□ 5 PION DECAY
P_LAB (GeV/c)
50
100
150

FIGURE 3E

ACCEPTANCE FOR $M = 5\,GeV/c^2$

X at 400 GeV



Therefore, if one observes a $\psi(3.1)$ at $X_\psi=.4$ and if the D mass is 2 GeV/c^2, then the sum of $X_{\bar{D}}$, X_ψ, and X_D should equal approximately 1. One can conclude that $\psi(3.1)$'s observed at $X > .4$ are probably not produced via the mechanism of Figure 1, and the $\psi(3.1)$'s at $X > .6$ cannot be so produced. Since the cross section for both pion- and proton-induced inclusive $\psi(3.1)$ production is nearly the same at X=.4 as at X=0, one must conclude (1) that inclusive $\psi(3.1)$ production is not dominated by the mechanism of Figure 3 and (2) if this mechanism has any substantial effect, its contribution must be in the region closer to X=0.

To estimate the acceptance, we assume that the $\psi D\bar{D}$ inclusive production has the same X' dependence (where X' is the sum of $X_{\bar{D}}$, X_ψ, and X_D, and all particles are produced at the same rapidity) as that of $\psi(3.1)$ production[2]. We calculate that if a $\psi(3.1)$ is detected, the probability of detecting the D or the $\bar{D}$ is nearly 1 for charged particle decay modes.

VI. BACKGROUNDS

We have investigated three potentially serious sources of background.

The first is the background of two in-flight pion decays in the 2-muon invariant mass spectrum at the $\psi(3.1)$ mass. For the purposes of the calculation, we assumed all pions to be produced at X=0. From the $\frac{d\sigma}{dP_\perp^2}$ given in reference 8, we calculated the probability that two oppositely charged pions having a $p_\perp > 1$ GeV/c could decay between the target and the absorber. The yield of such events was found to be about 2% of the ψ yield. The off-line $p_\perp$ cut would reduce the ψ yield by about 30% but probably would not be needed.

The second is the expected background beneath a multipion resonance associated with the ψ. We assumed that the background would be due to uncorrelated pions and that the form of the inclusive pion cross section would not change when a ψ was produced. To generate the mass spectra, we used a Monte Carlo program, which calculated the effective mass of two or more pions generated with the inclusive spectrum

$$E \frac{d^3\sigma}{dp^3} \propto \begin{cases} e^{-6P_\perp} (1 - |X|)^4, & \text{for } P_\perp < .5 \text{ GeV/c} \\ (P_\perp^2 + .86)^{-4.5} (1 - |X|)^4, & \text{for } P_\perp > .5 \text{ GeV/c} \end{cases}$$

The two pion effective mass distribution thus obtained agreed well with 205 GeV bubble chamber data[9]. Large uncorrelated multipion effective masses are produced by large differences in the rapidity of the pions rather than by large transverse momenta. Therefore, we required the sum of the absolute values of the pion transverse momenta to be greater than two-thirds of the effective mass. The cut eliminated about 30% of the true resonances. For ten thousand events generated at 400 GeV, the background in all topologies was less than five events per mass resolution bin above a mass of 2 GeV/c^2 and below a decaying particle energy of 100 GeV. Consequently, any particle production mechanism which leads to the population of a resolution bin in any topology at the level of a few tenths of a percent per event should be clearly distinguishable from background. Thus, we expect the quality of our data to be dominated by statistics, rather than by resolution.

The third source of background has a purely instrumental origin. Using the Monte Carlo pion generation described above, we calculated the probability that a track other than one of the muons that triggered the apparatus would project to the hit at the back of the absorber. The average probability was less than 1% for ψ(3.1) production. The chambers in and behind the absorber will further reduce the background by enabling a cut on track slopes as well as intercepts.

VII. REQUESTS OF FERMILAB

We request 600 hours of proton beam at about 400 GeV and 10^7 per pulse, and 600 hours of negative pion beam at the highest energy at which an intensity of 10^7/pulse is possible. This amount of beam time would provide about 5,000 proton-induced ψ events and 10,000 pion-induced ψ events. The M2 line in the Meson Laboratory is probably the only appropriate beam line. An additional 200 hours of beam time would be required for testing and debugging; half of this time could be parasitic.

We also request the BM 109, the iron absorber, the necessary PREP and BISON electronics, and 100 hours of CDC 6600 CPU time for off-line data checks. If the McGill PDP-11 computer and associated peripherals are not still required for E-177, we will use them for this experiment; otherwise, we would request that Fermilab supply us with a computer suitable for data acquisition.

Of the items requested of Fermilab, we have estimated the cost of the PREP and BISON electronics only and find it to be about $100,000. We estimate the cost of the basic apparatus to our collaboration to be about $90,000. Electronics for the 13,000 wire proportional chamber system will cost about $65,000. The chambers will cost about $10,000; hodoscopes will cost about $15,000.

VIII. COMPARISON WITH E-400

Approved Fermilab experiment E-400 will attempt physics that is similar to that of this proposal; therefore, a comparison between it and this proposal is appropriate. As discussed below, the distinctive advantages of our experiment are its use of a pion beam in addition to a proton beam, and its superior sensitivity to new particle production in the central region.

The apparatus used in E-400 is a compressed version of the E-87 forward spectrometer which has detectors before and after the magnet. Consequently, this apparatus has better momentum resolution than that which we have proposed. However, the forward geometry of E-400 accepts only particles of higher momentum, and it therefore requires better momentum resolution to achieve a mass resolution which is comparable to that of this experiment in the region of good acceptance.

We consider that the most important difference between the apparatus of E-400 and that of this proposal is our larger acceptance. For our apparatus, the solid angle at the target subtended by the exit aperture of the magnet is .05 steradian. For E-400, the solid angle is .01 steradian. Consequently, in the $\mu^+\mu^-$ decay mode, the acceptance that E-400 has for $\psi(3.1)$ production at X=0 is only about 2%, while our acceptance is about 35%. If a new 2 GeV/c^2 particle were produced along with the ψ at X=0 and the particle subsequently decayed into three charged particles, our experiment would detect 25% of the new particles, and E-400 would detect none.

As we have explained in section V, we suspect that there may be important classes of ψ production processes that can occur only in the central region, and therefore require a large acceptance. The expected large mass of particles that may be associated with the ψ probably means that their two particle decay branching ratios will be only a few percent and that multihadron decay modes dominate.[10, 11] The detection and measurement of such decays also require a large acceptance.

Because both the ψ and the new particles must be detected simultaneously, the sensitivity to new particle production varies roughly as the square of the acceptance. Therefore, even though the number of $\psi(3.1)$ events collected in our experiment is comparable to that collected in E-400, we believe that large acceptance makes our experiment far more sensitive to new particle production in the region in which it may be most likely to occur. Because the data sample is small and because new processes may constitute only a small fraction of the total ψ rate, this good sensitivity is crucial.

Another advangage of our geometry is that the distance between the target and the hadron absorber is minimized. Since the distance is only a little more than 1/3 that of E-400, the dimuon background due to pion decay is reduced by about a factor of eight.

The experimentally observed differences between pion- and proton-initiated inclusive ψ production[1, 2] suggest that the processes responsible for ψ production may differ for the two beams. For example, the antiquark content of the pion may be crucial for certain classes of production processes. Another possibility is that, if ψ's can be produced with new particles by diffractive excitation of a beam particle, using a proton beam one might observe a leading charmed baryon, and using a pion beam observe a leading charmed meson. E-400 is well suited to the former type of reaction, but cannot observe the latter.

Even if the processes responsible for ψ production do not depend on the type of beam particle, the pion beam offers a possible advantage over the proton beam. Since pion-induced ψ's are produced at a larger mean X than proton-induced ψ's[1, 2], one would expect that particles produced in association with the ψ should also be produced at a larger mean X, and thus be easier to detect.

In conclusion, both the large acceptance of this experiment and its use of a pion beam independently justify it. Whether or not E-400 is successful in its search for new phenomena, our proposed experiment could make a valuable contribution because it probes regions of physics inaccessible to E-400.

References and Footnotes

1. G. J. Blanar, et al., Phys. Rev. Lett. 36, 346 (1975).

2. K. J. Anderson, et al., Mu-Pair Production by 150 GeV/c Hadrons. Paper presented at the 1975 International Symposium on Lepton and Photon Interactions at High Energy, Stanford University, 1975.

3. D. Sivers, Phys. Rev. D11, 3253 (1975).

4. R. Sidwell, Presentations of Preliminary Results of E-366 at Fermilab Joint Experimental-Theoretical Seminar, November 14, 1975. (The preliminary data indicate a possible 40 $\pm$ 20 nb $K^-\pi^+$ bump at 2.29 GeV/c^2.)

5. We arrive at the tentative conclusion that inclusive ψ production is not dominated by $\psi\bar{C}D$ production by making a few simplifying assumptions. (The lowest mass charmed meson is the D; C represents any other charmed particle.)

i. The suppression of charmed particle production is due to the difficulty of producing large masses and charmed quarks.

ii. If two pairs of charmed particles are produced, the pairs will not be correlated.

iii. The $K^-\pi^+$ enhancement in the E-366 data is due to associated charmed particle production.

iv. The $K^-\pi^+$ branching ratio of the D is 4%.[11]

v. The cross section for the region of X covered by E-366 is about 15% of the total.

From these assumptions, one concludes:

i. The $\psi\bar{C}D$ inclusive cross section equals the $D\bar{C}$ - $D\bar{C}$ cross section.

ii. The probability of production $D\bar{C}$ - $D\bar{C}$ in an interaction is the square of the probability of producting $D\bar{C}$. Using the data of references 2 and 4, we conclude that $\psi\bar{C}D$ could account for about a percent of inclusive ψ production in N-Be interactions. However, even an effect of the magnitude estimated above is within the detection capability of the experiment if the D frequently decays into one particular topology of charged particles. The subtleties of the production dynamics, which have been ignored in the estimate, and quantitative errors in the assumptions could easily increase or decrease the $\psi\bar{C}D$ rate by an order of magnitude or more.

6. J. J. Aubert, et al., Phys. Rev. Lett. 33, 1404 (1974).

7. C. Quigg, Private Communication.

8. T. Ferbel, Recent Results from Bubble Chamber Experiments at Fermilab, Lecture given at the 1974 SLAC Summer Institute on Particle Physics.

9. F. T. Dao, Recent Results on Inclusive Reaction, A. I. P. Conference Proceedings #23 (Particles and Fields) - C. F. Carlson, Editor, 1974.

10. H. Harari, Theoretical Implications of the New Particles, Rapporteur talk at the International Symposium on Lepton and Photon Interactions at High Energies, Stanford, California, 1975 - and Preprint WIS-75/40Ph.

11. J. Ellis, et al., CERN Preprint Ref. TH. 2030-CERN.

SUPPLEMENT TO P-471

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February 23, 1976

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FNAL Ext 3917

This supplement describes why and how we will (1) increase our data sample from about 15,000 to 60,000 $\psi(3.1)$'s and (2) add a lead-lucite sandwich γ-detector to the P-471 apparatus.

1. DATA RATE

We have become further convinced, in part by recent discoveries and in part by review of the currently available data on the ψ, that a large data sample is crucial to the success of any experiment designed to search for new physics or new particles associated with ψ-like objects. On the basis of the following considerations, we have decided to increase our data sample as much as possible.

A. The acceptance of any forward spectrometer is poorly matched to reactions which, as we have explained in the proposal, are expected to take place centrally.

B. New processes may constitute only a small fraction of inclusive ψ production.

C. New particles associated with the ψ may have decay processes similar to those of the ψ. Consequently, the experimental design must be prepared to deal with a large mean decay multiplicity and a small branching ratio into any particular topology. For example, the largest measured hadronic branching ratio of the ψ is 4% into $\pi^+\pi^+\pi^-\pi^-\pi^0$.

D. The addition of the γ detector to the P-471 apparatus permits the investigation of the radiative decays of parent states into the ψ. Since the $\psi'(3.7)$ inclusive hadronic cross-section is much smaller than the $\psi(3.1)$ cross-section, one might expect the cross section of other parent states to be similarly small.

E. New discoveries are reported almost daily. E-288 has data that indicate the possible existence of narrow dimuon states at 6 GeV/c^2 (Υ) and at 7.3 GeV/c^2. E-87 has results that hint at a new narrow state at 4.7 GeV/c^2, which is produced by photons but not by neutrons. We would expect to see about thirty Υ's and would look for the 4.7 GeV/c^2 bump with pions. In both cases, however, the emphasis would be on a search for other new particles associated with these states.

F. Some strong interaction models predict that new particles are more likely to accompany the ψ when it is produced at high $p_\perp$ than at low $p_\perp$. To adequately test these ideas, or to purify the data sample, the latter must be large enough to permit separation into different kinematic regions.

G. Finally, and most speculatively, we note that the total hadronic cross-section for inclusive ψ production is only about 10^4 times larger than the neutrino-nucleon cross-section. It is therefore conceivable that one observe a parity violating polarization in some kinematic regions of ψ production. Particles associated with the ψ in such a region might have a completely different character than those associated with a strongly produced ψ.

We expect to increase our data rate by about a factor of four and thus increase the data sample from 15,000 to 60,000 ψ's. To achieve this increase, we will use a 1"-thick beryllium target (instead of 1/2"-thick) and attempt to use a beam of 2 x 10^7 per pulse (instead of 10^7). With this increase, we would probably be forced to use a mass-selective trigger. Since most of the trigger rate is due to low-energy pion decay in-flight, most muons will be deflected by the magnet to large angles and consequently appear at a large lateral distance from the beam. For the trigger, we will require that one of the muons behind the hadron absorber be close to the beam. This scheme will eliminate little of the desired data.

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II. THE γ DETECTOR

We have decided to add a γ detector to our apparatus. There are three principle reasons why this additional capability is highly desirable:

A. Since one expects the mean decay multiplicity of objects associated with the ψ to be high, one must also expect that many if not most decay topologies will involve one or more π^0's.

B. Strong decays into pions always contain one or more π^0's if the parent is a G=-1, Q=0 or G=+1, Q=$\pm$1 state. Since the primary purpose of the experiment is to search for states associated with the ψ and because the ψ itself is a G=-1, Q=0 state, omission of a γ detector would seem unwise.

C. At least two states between the ψ and ψ' seem to decay radiatively into the ψ. With a γ detector, the spin-parity of these states can be studied, and new parent states can be searched for.

Our tentative γ detector design is two 16" x 24" lead-lucite sandwich counter assemblies placed to either side of the beam behind the spectrometer. Each assembly will contain eight shower sampling cells consisting of layers of .25" lead, eight horizontal 2"-wide lucite slats, .25" lead, and 12 vertical 2"-wide lucite slats. The eight slats in adjacent cells are viewed by one PMT. Thus, the detector will require forty PMT's; it will have a total of 192 bins, which after software reconstruction are distinct. Although the position of the photon will be determined by requiring it to convert in a 2 radiation length thick lead sheet in front of the last MWPC, the large number of detector bins is nonetheless important. For example, assume M charged hadrons and one π^0 are uniformly distributed on the γ detector. The probability, P, that the two γ's from the π^0 are in bins containing no hadrons is $P = (\frac{N-2}{N})^M \simeq 1 - \frac{2M}{N}$, where N is the number of detector bins. In fact, particles are not distributed uniformly on the γ detector; consequently P is reduced and, hence, a large number of detector bins is even more important.

Our expected energy resolution is $\frac{dE}{E} = .3\ E^{-\frac{1}{2}}$ FWHM, where E is the photon energy in GeV. The 2 γ mass resolution at the π^{0} mass is at its best (9 MeV FWHM) at about 20 GeV; the resolution is proportional to E for larger energies and proportional to $E^{-\frac{1}{2}}$ for smaller energies.

The mass resolution for the ψ-γ system is roughly 100 MeV FWHM for a centrally produced $\chi(3.5) \rightarrow \psi\gamma$, although cuts can be applied to the data to improve the resolution by a factor of two or more. In the central region, the $\psi\gamma$ mass resolution is dominated by the energy resolution of the γ-detector; the mass of the ψ is forced to its known value. Note that our resolution is sufficient to separate some of the states between the ψ and ψ' which decay radiatively into the ψ.