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E610 Proposal Update

# CHI MESON PRODUCTION BY HADRONS

submitted by

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## ABSTRACT

We propose to continue our studies of hadronic chi meson production in the Chicago Cyclotron Magnet Spectrometer. In an initial test and data run in Spring 1980, a sample of approximately 2500 $\pi^-$ induced $J/\Psi$ mesons was acquired. From this sample hundreds of chi mesons will be obtained by combining gamma rays in a large lead glass array with the $J/\Psi$'s and calculating the effective masses. We wish to extend the physics usefulness of this existing event sample by repeating the same experiment with protons incident. In particular we propose to run with the dichromatic target train during the Fall 1981 experimental period. With $1 \times 10^{11}$ protons incident on the dichromatic train at 400 GeV and a 15-week running period, we could generate a sample of 8,200 proton induced $J/\Psi$ mesons. This should yield about 2100 chi mesons for comparison with our $\pi^-$ induced sample. The experiment could be done parasitically with the planned neutrino program.

## Introduction and Motivation

The hadronic production of chi mesons by pions and protons will reveal properties of these states that cannot be learned from the study of decay systematics in $e^+e^-$ experiments. In particular, it has been postulated by Carlson and Suaya[1] and by Ellis, Einhorn and Quigg[2] that the appropriate production mechanism is via the fusion of two gluons in a pair of colliding hadrons. This gluon mechanism is to be distinguished from the situation for $\Psi$ family mesons, which require three gluons or some electromagnetic process such as Drell-Yan to be produced.

The statements noted above can be understood by studying the systematics of Figure 1 in which the lower lying charmonium states are shown together with their measured(or assumed) quantum number assignments.[3] Note particularly that the three chi states with positive parity and charge conjugation $0^{++}$, $1^{++}$ and $2^{++}$ all have the same quantum numbers as a bound gluon pair, while the $1^{--}$ psi family states do not.

Combining the formation quantum number restrictions with the observed fact that chi states decay via single photon emission into $J/\Psi$ mesons with appreciable branching ratios,[4] we can understand the experimental fact that $J/\Psi(3097)$ occurs much more copiously than $\Psi'(3685)$ in strong interactions.[5] The $J/\Psi$'s come from one photon decay of chi states produced by gluon fusion. $\Psi'$ cannot come from higher lying chi analog states because such states are unbound and lie above the nearby threshold for open charm production. What can't be inferred from a comparison of $J/\Psi$ and $\Psi'$ alone are the actual chi states which contribute and in what proportions. We propose to continue our study of this and associated questions.[6]

A study of hadronic chi production including the Feynman X dependence and beam particle dependence can give information on the proposed gluon fusion mechanism plus information on the gluon structure function of the beam particle. It is also an opportunity to look for expected but so far unobserved hadrons which decay into J/Ψ through emission of photons, pions or etas. Two examples of such states are shown in Figure 1, namely $\eta_c'$ which should be connected via an M1 gamma transition to J/Ψ and the mysterious $1^{+-}$ state which is the spin singlet analog of the three known chi states of positive parity and charge conjugation.[3]

Finally, of course, we will keep our eyes open for totally new states which are unexpected in any of the conventional models. In principal, any heavy state which has an appreciable branching rate into J/Ψ is a candidate.

Apparatus, Rates and Yields

Since this proposal is a continuation of a previous effort, we will make this section brief, emphasizing changes in the apparatus. As before, we use the Chicago Cyclotron Spectrometer shown as Figure 2. It has now been outfitted with superconducting magnet coils to conserve power. The new coils were designed as a straight replacement for the old copper ones in terms of amp turns, hence the field magnitude will be the same and only small changes in the fringe field shape will occur.

The trigger for the experiment is :

$$T = CB \cdot I \cdot 2\mu$$

where,

T = event trigger

CB = "Clean Beam", a well defined incident beam particle

I = "Interaction" a set of thin counters before and after the Be target that signal an inelastic interaction there

$2\mu$ = two muon hits in opposite quadrants of the muon hodoscopes

In our preceding run, the value of T was 29 x $10^{-6}$ per live beam particle. Upon analyzing the data, we found that about half the triggers contained at least one "muon" hit that was significantly out of time relative to its nominal $\beta = 1$ trajectory. We ascribe these triggers to slow neutrons which can travel through the hadron absorber and cause accidental triggers. We will eliminate this source of triggers by adding another muon hodoscope behind the first and placing it in coincidence, thus eliminating the neutron rate. We expect this trick to lower T by a factor of 2 to make it 15 x $10^{-6}$ in the new run.

The live time fraction is determined by the event readin time to the computer and by the raw beam intensity. In our last run, the average readin time was measured to be 7 milliseconds per trigger. We propose to run at a raw beam intensity $R_o$ of 6 x $10^6$ $sec^{-1}$, hence:

$$f_{live} = \frac{1}{1 + \tau_{dead} R_o T}$$

$$f_{live} = \frac{1}{1 + (7 \times 10^{-3})(6 \times 10^6)(15 \times 10^{-6})}$$

$$f_{live} = 0.61$$

and, for the observed event trigger rate $E_{obs}$ we get:

$$E_{obs} = R_o f_{live} T$$

$$E_{obs} = (6 \times 10^6)(0.61)(15 \times 10^{-6})$$

$$E_{obs} = 55 \text{ event triggers/burst.}$$

We propose to run 15 weeks at this rate and with 30,000 good cycles per week. We thus generate an event sample of:

$$N_{trig} = E_{obs} N_{spills}$$

$$N_{trig} = (55)(15)(30{,}000)$$

$$N_{trig} = 24 \times 10^6 \text{ triggers}$$

$$(N_{trig} = 825 \text{ tapes at 6250 bpi.})$$

This sample is about three times the size of our first run in which we obtained approximately 240 data tapes.

We can estimate the yield of J/Ψ mesons and the subsequent chi yield in the following way:

$$N_X = N_P t_{Be} \sigma_{Be}(inel) B_{\mu\mu} \left(\frac{\sigma_{Be}(J/\Psi)}{\sigma_{Be}(inel)}\right) F_{X/\Psi} \varepsilon_{\mu\mu}(J/\Psi) \varepsilon_\gamma(x),$$

where

$N_X$ = number of chi mesons detected

$N_p$ = total live time beam protons on target

$t_{Be}$ = target thickness

$\sigma_{Be}(J/\Psi)$ = J/Ψ production cross section on Be by protons($x > o$)

$\sigma_{Be}(inel)$ = inelastic p Be cross section

$B_{\mu\mu}$ = J/Ψ branching fraction into $\mu^+\mu^-$

$\varepsilon_{\mu\mu}(J/\Psi)$ = acceptance of the apparatus for $J/\Psi \rightarrow \mu^+\mu^-$ for positive Feynman X

$\varepsilon_\gamma(X)$ = acceptance of the chi decay photon for reconstructed $\mu^+\mu^-$ J/Ψ mesons in the Pb glass calorimeter

$F_{X/\Psi}$ = fraction of J/Ψ which comes from χ mesons

we choose,

$$t_{Be}\ \sigma_{Be(inel)} = 0.13 \quad (5\ \text{cm Be}).$$

$$N_P = N_{P_o}\, f_{live}$$

$$N_P = (6 \times 10^6)(15)(30{,}000)(0.61)$$

$$N_P = 1.6 \times 10^{12}\ \text{live protons incident}$$

and note that,

$$B_{\mu\mu} = 0.07$$

$$\varepsilon_{\mu\mu}(J/\Psi) = 0.16\ ,\ (x > o)$$

$$\varepsilon_\gamma(x) = 0.51\ ,\ (\text{assuming } J/\Psi \text{ accepted})$$

$$F_{X/\Psi} = 0.5\ ,\ (\text{see Reference 5})$$

For the production cross section of J/Ψ by protons, we scale the results of Fermilab Experiment 444 as reported by Anderson, et al [7] and scale the production from 225 GeV to 270 GeV by using the s dependence reported by M.Banner at Tokyo[8]:

$$B_{\mu\mu}\sigma_C(J/\Psi) = B_{\mu\mu}\sigma_{Be}\ (225\ \text{GeV})\left(\frac{\sigma\ (270)}{\sigma\ (225)}\right)$$

$$B_{\mu\mu}\sigma_C(J/\Psi) = (53\ \text{nb})(1.2)$$

$$B_{\mu\mu}\sigma_C(J/\Psi) = 64\ \text{nb/Carbon nucleus}$$

and,

$$\sigma_C(\text{inel}) = 258 \text{ mb/Carbon nucleus}$$

so that;

$$\frac{B_{\mu\mu}\sigma_{Be}(J/\Psi)}{\sigma_{Be}(\text{inel})} \simeq \frac{B_{\mu\mu}\sigma_C(J/\Psi)}{\sigma_C(\text{inel})}$$

$$\frac{B_{\mu\mu}\sigma_{Be}(J/\Psi)}{\sigma_{Be}(\text{inel})} = \left(\frac{64 \text{ nb}}{258 \text{ mb}}\right)$$

$$\frac{B_{\mu\mu}\sigma Be(J/\Psi)}{\sigma_{Be}(\text{inel})} = 2.5 \times 10^{-7}$$

Combining all the numbers, we get:

$$N_X = N_P \, t_{Be} \, \sigma_{Be}(\text{inel}) \left(\frac{B_{\mu\mu}\sigma_{Be}(J/\Psi)}{\sigma_{Be}(\text{inel})}\right) F_{X/\Psi} \, \varepsilon_{\mu\mu}(J/\Psi)\varepsilon_\gamma(X)$$

$$N_X = (1.6 \times 10^{12})(.13)(2.5 \times 10^{-7})(0.5)(.16)(0.51)$$

$$N_X = 2100 \text{ detected chis/experiment.}$$

The relative numbers of $0^{++}$, $1^{++}$ and $2^{++}$ states produced is the main interest of the experiment, along with the Feynman X dependence which leads indirectly to the gluon structure function. The ratio of $0^{++}$ to $2^{++}$ production is governed by simple arguments in the gluon fusion model[1]; the $1^{++}$ production mechanism is much less clear but has been estimated by Quigg to be of order unity relative to the other two states.[3] Hence,

| State | $0^{++}$ : | $1^{++}$ : | $2^{++}$ |
|---|---|---|---|
| $\Gamma(\chi \to \text{hadrons})$ | 15 | 0(1) | 4 |

Combining the hadronic decay widths with the $(2J + 1)$ statistical density of states and kinematic mass weighting factors, we predict the observed ratios of $\chi_i \to J/\Psi + \gamma$ to be:

| State | $0^{++}$ | : $1^{++}$ | : $2^{++}$ |
|---|---|---|---|
| Observed ratios | 1 | ∿2 | 5 |
| Observed events | 270 | ∿530 | 1300 |

The background under the chi peaks comes mainly from $\pi^0$ decays in which one gamma is lost and the other assumed to be associated with the J/Ψ. We have studied this background using events from E154, an old 30-inch bubble chamber run. We choose $N(\pi_0, x) = \frac{1}{2}(N(\pi^+, x) + N(\pi^-, x))$ together with the appropriate decay kinematics for $\pi^0$ and the measured $\pi^+$, $\pi^-$ spectra to generate a gamma spectrum for combination with the J/Ψ's. In Figure 3 we compare this calculated background with the results of our previous experiment.[6] Also shown is a background fit from combining photons in the data with J/Ψ's from a different event. The fits are equally good within statistics.

Next, we apply this method to the proposed E610' sample. The result is shown for the expected sample in Figure 4. The mass resolution shown depends upon the(measured) momentum resolution for the J/Ψ and the energy and position resolution in the lead glass array:

$$\Delta M_X \approx \frac{(M_X{}^2 - M_\Psi^2)}{2M_X}\left[\left(\frac{\Delta P_\Psi}{P_\Psi}\right)^2 + \left(\frac{\Delta E_\gamma}{E_\gamma}\right)^2 + 4\left(\frac{\Delta\theta}{\theta}\right)^2\right]^{\frac{1}{2}}$$

$$\Delta M_X \approx 13 \text{ MeV.}$$

Note that separating $\chi(3551)$ from $\chi(3507)$ will involve parametrization with Gaussian resolution curves and maximum likelihood methods since it is unlikely that two states will be seen as separate peaks.

Schedule, Logistics and Progress on E610

In view of the limited opportunities for further 400 GeV running, we will explore various ways of maximizing our compatibility with neutrino running. We are compatible with secondary beams produced by the dichromatic, triplet and horn target trains. In certain circumstances with dichromatic and triplet trains,(basically secondary beam energies that differ by no more than 25%) we will be able to share the spill directly in a slow/fast spill mode with slow spill going to the Muon Lab and fast spill going to the neutrino experiments. Under these conditions, the magnets on the train would be ramped to different values at the end of slow spill in preparation for the 1.5 ms fast spill pulse.

During periods of mutual train compatibility, E610' would use parasitic slow spill of either charge sign and any energy for checkout, calibration and test purposes. We expect to have primary control over the train for enough of the running period of 22 weeks to complete the needed 15 weeks of prime data accumulation requested.

During the positive data running, the proton demands for E610' will be essentially parasitic, since our desired secondary flux levels of $6 \times 10^6$/sec will require only about $1 \times 10^{11}$ protons per pulse incident. It should also be noted that we can do an interesting investigation of the energy dependence of chi production by $\pi^-$ with only modest proton demands($2 \times 10^{12}$ protons/pulse) to complement our earlier work. Details of this possibility are shown in Appendix A.

The Chicago Cyclotron Magnet now has a set of superconducting coils. In order to install them, it was necessary to remove about one half of the E610 apparatus. Since it will require a number of months to restore the missing parts, and since other parts of the spectrometer will require upgrade and repair, we are anxious to be approved for this run at the earliest possible time, hopefully in Spring 1981.

Meanwhile, we are proceeding with the analysis of E610 data. As evidence of progress, we show in Figure 5 the early $J/\Psi$ spectrum from about one third of our data sample and in Figure 6 a diphoton mass spectrum indicating via the reconstructed $\pi^0$ peak that the lead glass energy calibration and resolution are about as expected. We do not present the $J/\Psi$-photon effective mass plot at this time since we do not want to circulate results until we understand better our reconstruction systematics, efficiencies and resolutions.

We close with a summary of our requests in Table 1.

Table 1

Summary of E610' Requests

| | |
|---|---|
| Beam Rate: | $6 \times 10^6$/pulse at 270 GeV positives with 1 second spill |
| Total Beam: | $2.7 \times 10^{12}$ (15 weeks at 30K pulses/week) |
| Chi Yield: | 2100 chi mesons from 8200 $J/\Psi$ mesons |
| Test Time: | Parasitic beam during antineutrino running |

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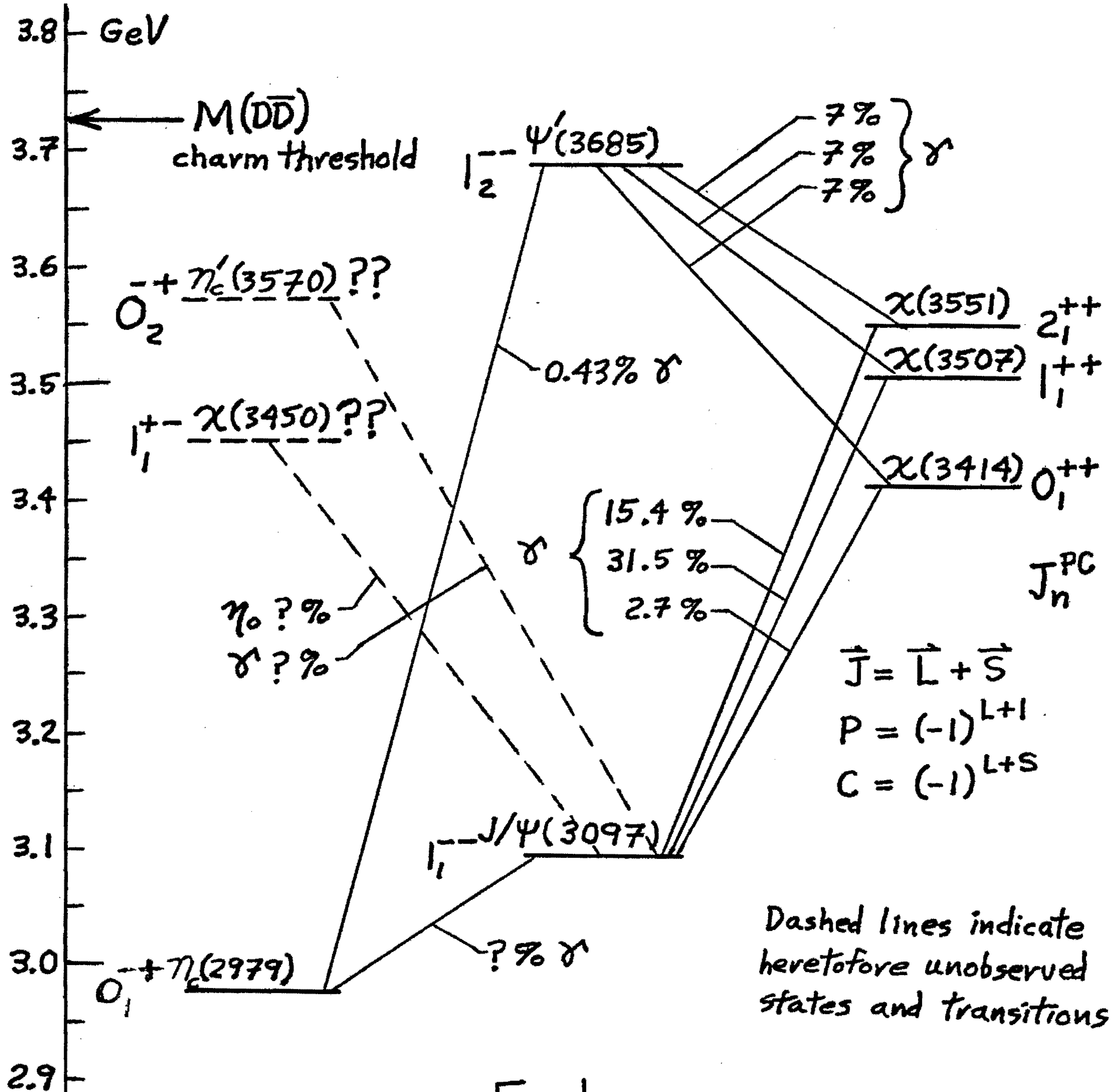



Fig 1

Conventional Charmonium Spectrum

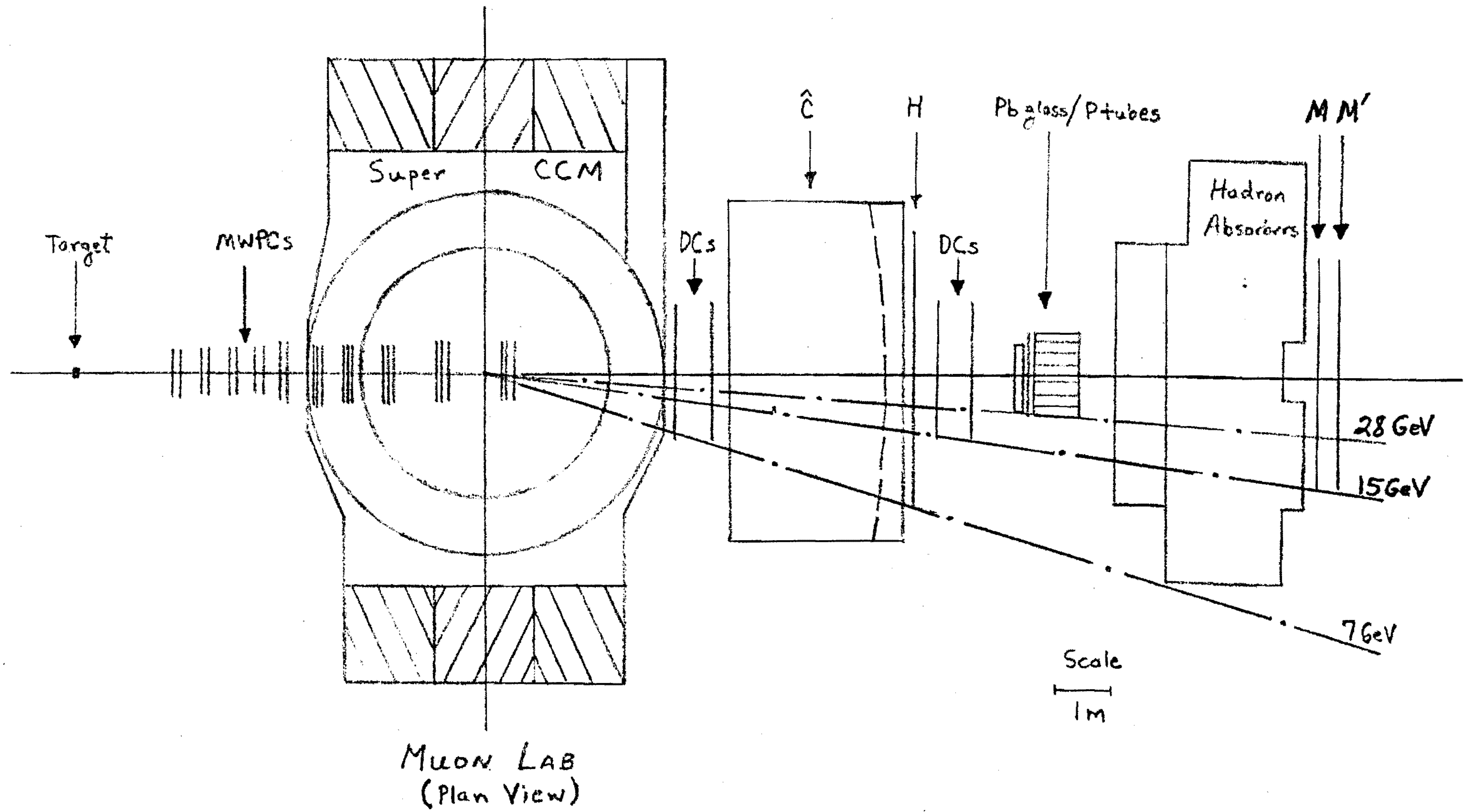
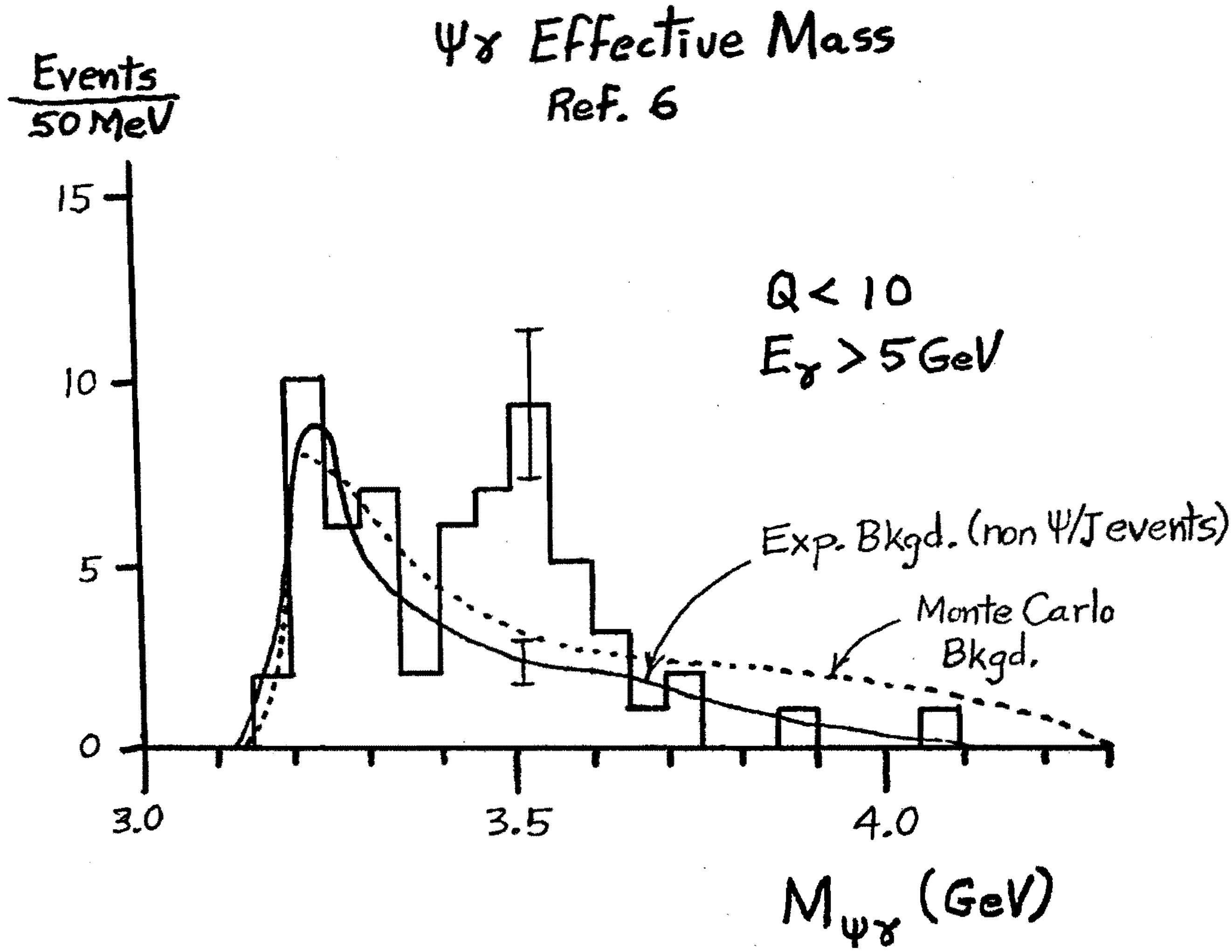
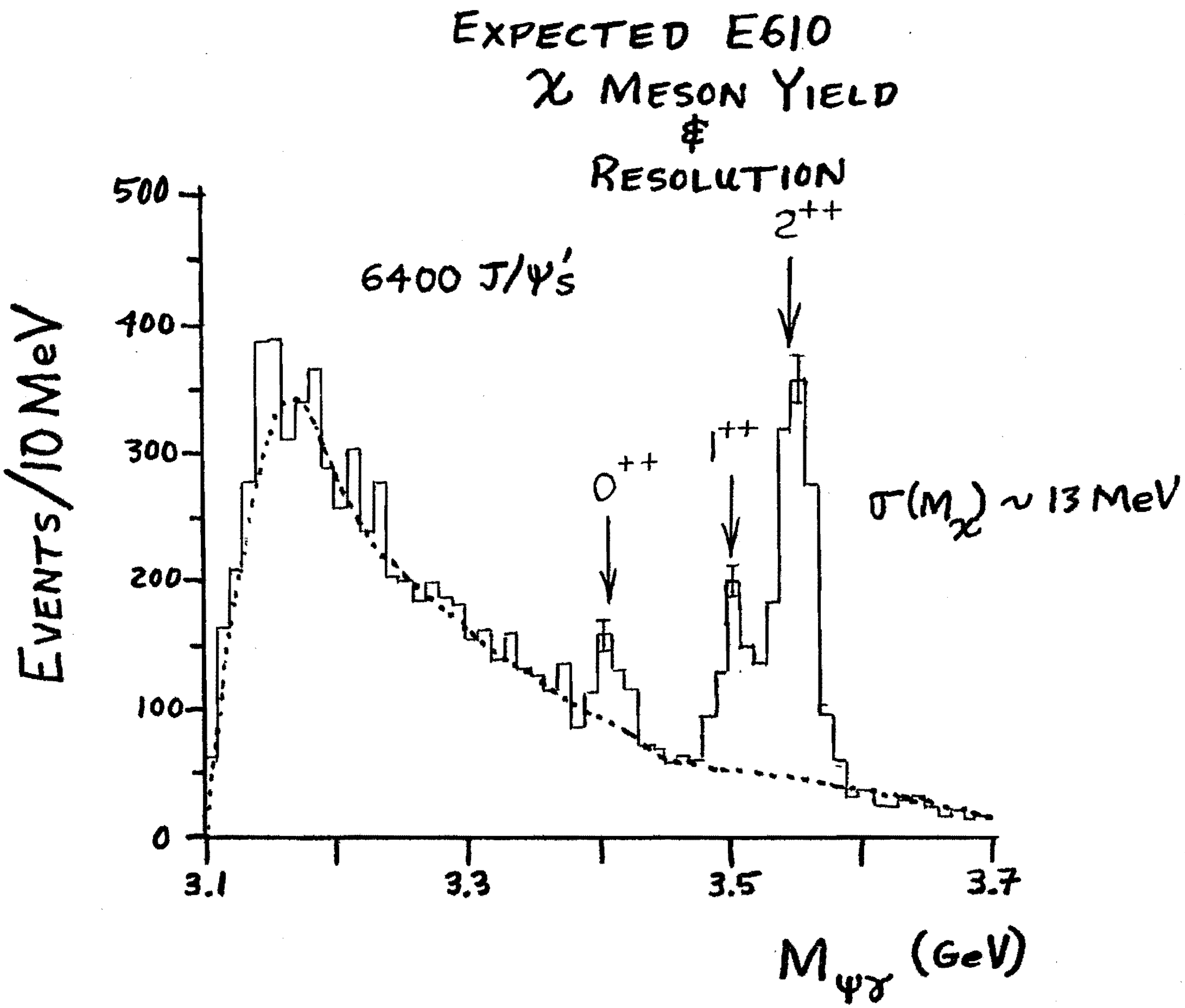



Fig. 2 — E610′ Apparatus




162 ψ/J's
62 γ's

Fig 3



EXPECTED E610
χ MESON YIELD
&
RESOLUTION
6400 J/ψ's
2++
1++
0++
σ(Mχ) ~ 13 MeV
EVENTS/10 MeV
500
400
300
200
100
0
3.1
3.3
3.5
3.7
Mψγ (GeV)


Fig 4

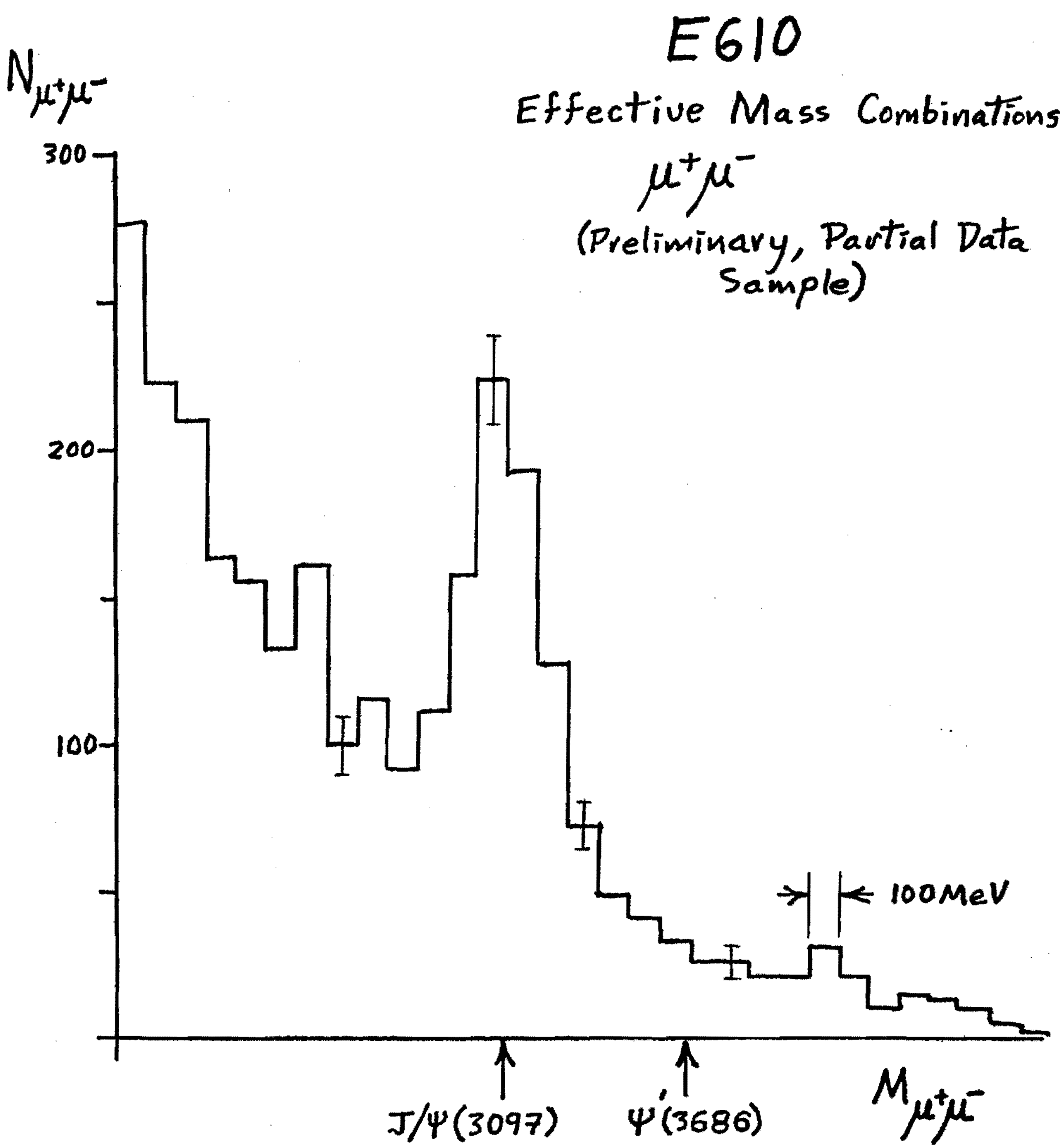
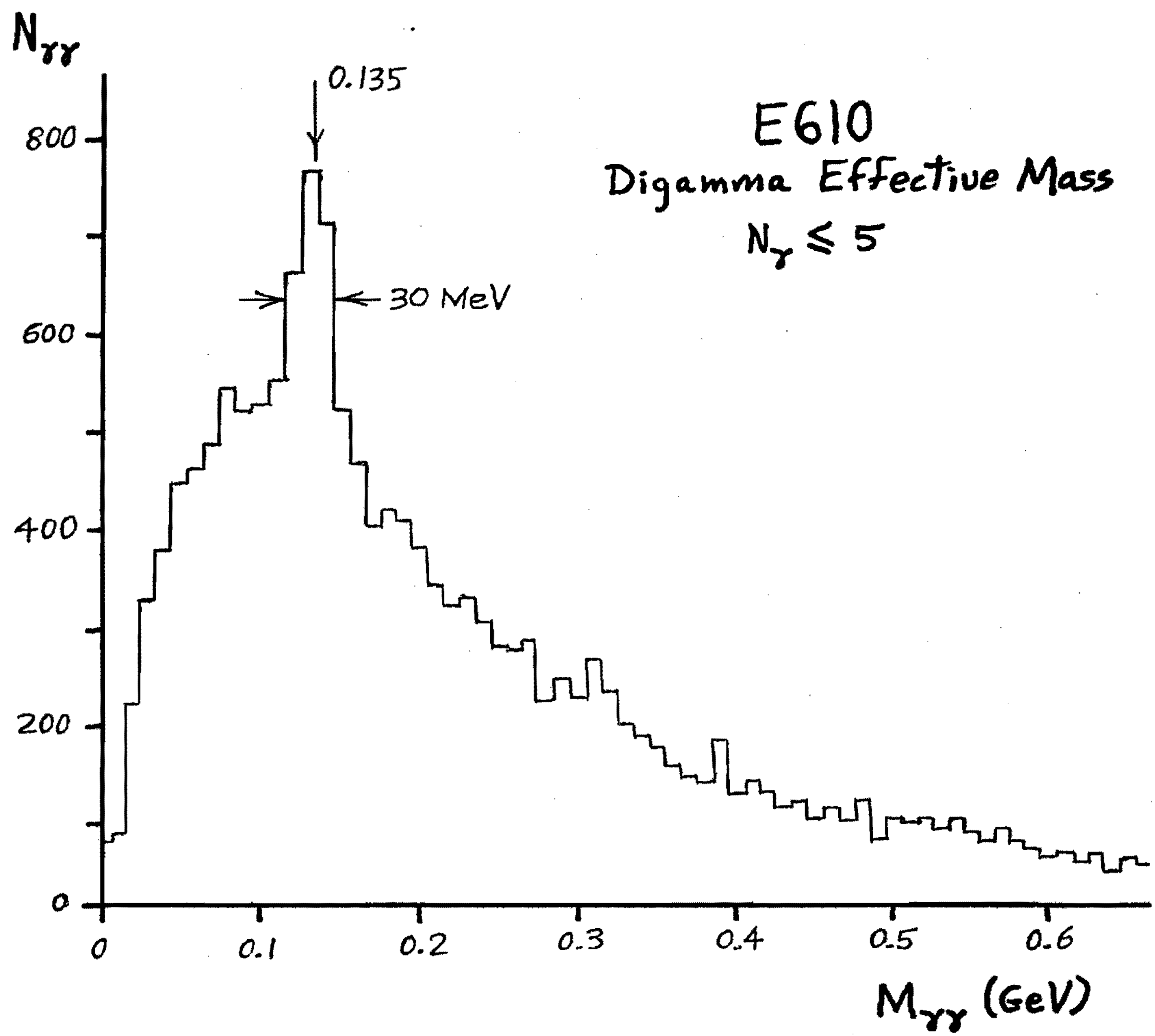

E610
Effective Mass Combinations
μ+μ-
(Preliminary, Partial Data Sample)
Nμ+μ-
300
200
100
100MeV
J/ψ(3097)
ψ'(3686)
Mμ+μ-

Fig 5



N_γγ
0.135
E610
Digamma Effective Mass
N_γ ≤ 5
800
600
400
200
0
30 MeV
0
0.1
0.2
0.3
0.4
0.5
0.6
M_γγ (GeV)


Fig 6

<u>Appendix A</u>

<u>Further Studies With a $\pi^-$ Beam in E610</u>

We have explored the possibility of using a $\pi^-$ beam from the dichromatic target train during part of the Fall 1981 experimental period. With $10^{12}$ protons incident on the dichromatic train at 400 GeV/c and a four-week running period, we could obtain a sample of 1700 $\pi^-$ induced J/$\Psi$ mesons at 150 GeV/c. This should yield 100-300 $\chi$ mesons and allow a study of $\chi$ production s-dependence between 150 GeV/c and 225 GeV/c. We aim to investigate the s-dependence of (1) the fraction($F_{\Psi\chi}$) of J/$\Psi$'s produced via an intermediate state and (2) the relative production of the $0^{++}$, $1^{++}$, $2^{++}$ $\chi$'s.

Figure A-1 displays the available data on $F_{\Psi\chi}$ in $\pi^-N$ interactions. The four points at lower energy come from the WA-11 Collaboration[9] at CERN and the highest energy point is from Fermilab E369(Reference 6). In Figure A-1, $F_{\Psi\chi}$ appears to rise dramatically between 150 GeV/c and 225 GeV/c. Such an energy behavior runs counter to theoretical models of charmonium hadroproduction[1, 10] which predict a roughly constant $F_{\Psi\chi}$ as a function of s. We note that the apparent rise of $F_{\Psi\chi}$ depends primarily upon the two low energy results which were statistically limited (± 30% errors). A measurement at 150 GeV/c with better statistics and good mass resolution would clarify the situation. If $F_{\Psi\chi} = 0.35$ at 150 GeV/c, we expect to see 300 $\chi$'s, and if $F_{\Psi\chi} = 0.12$, we expect only about 100 $\chi$'s. In one scenario we confirm the WA-11 measurement with much smaller error bars and challenge the theoretical models. At the other extreme we show the WA-11 measurement to be in error and clear up a confusing experimental picture.

The available data on the relative production of the $0^{++}$, $1^{++}$, $2^{++}$ $\chi$'s come from WA-11 at 160 GeV/c (15-$1^{++}$ events seen) and at 191 GeV/c (100-$1^{++}$ events and 70-$2^{++}$ events seen). The relative proportions of these states as a function of s will indicate[1,11] whether gluon-gluon fusion or light quark-light antiquark fusion is the more important production mechanism. In $\pi^-$ N interactions both mechanisms should be present, but the gluon component is expected to grow by a factor of two while the light quark component remains roughly constant between 150 GeV/c and 225 GeV/c. Therefore, a measurement at 150 GeV/c with good statistics and good mass resolution helps to untangle the $\chi$ production mechanism in $\pi^-$ N interactions and complements our existing data at 225 GeV/c.

Appendix

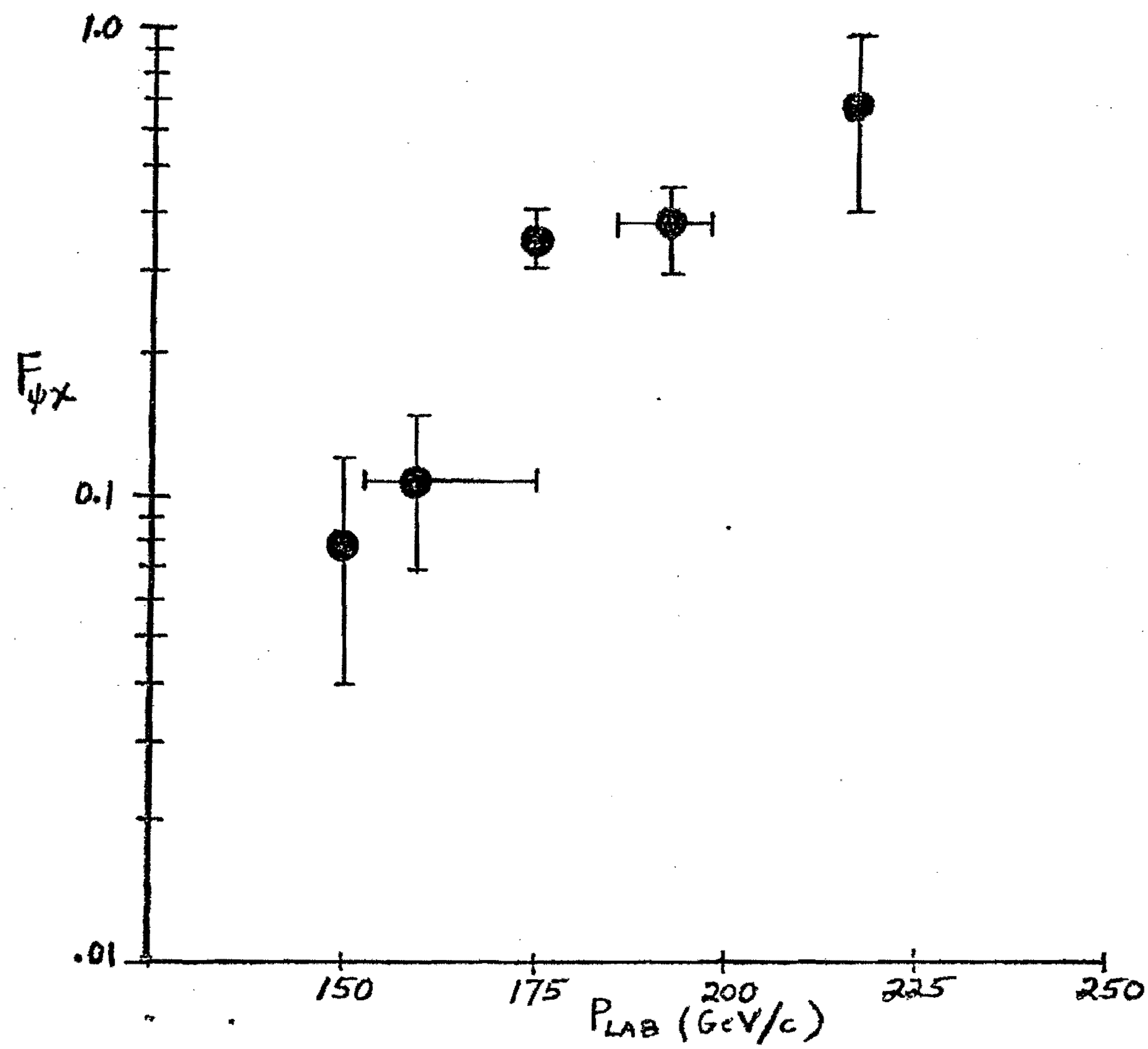



Figure A-1

The fraction ($F_{\psi\chi}$) of J/Ψ's produced via an intermediate χ state in $\pi^-$ N interactions. The errors are statistical only.