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PHOTOPRODUCTION OF HIGH MASS TWO-BODY FINAL STATES

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I. INTRODUCTION

We propose to extend the photoproduction studies begun in Experiment E-87 by:

(1) measuring the energy dependence of $(d\sigma/dt)_{t=t_{min}}$ for $\psi(3.1)$ + nucleon $\rightarrow$ $\psi(3.1)$ + nucleon.

(2) measuring the $\psi'(3.7)$ - nucleon cross-section,

(3) investigating the mass spectrum of photoproduced e^+e^-, $\mu^+\mu^-$, K^+K^-, $p\,\bar{p}$, μe, etc. pairs in the interval $3.0 \leq M_{+-} \leq 7.0$ GeV.

The physics justification for pursuing each of these topics is straight-forward. For example, now that the $\psi(3.1)$ - nucleon cross-section has been measured, it is important to conduct a similar determination of the $\psi'(3.7)$ - nucleon total cross-section. A photoproduction experiment at Fermilab energies is perhaps the <u>only</u> way to obtain such a measurement. In addition, the measurement of the photon-induced, two-particle mass spectrum, both resonant and non-resonant, strikes us as a very natural use for the broad band beam. For a 6.0 GeV pair mass we expect to be sensitive to a cross-section X branching ratio of 1.0 nanobarns.

We plan to measure each of the topics mentioned above simultaneously, using the basic spectrometer and particle identification system of Experiment E-87, supplemented by:

(1) an additional bending magnet.

(2) one or more Cerenkov counters.

(3) an improved electron/photon identifier.

Although the additional equipment we propose is modest, it provides several improvements in the parameters of the E-87 spectrometer for two body final states:

(1) the mass resolution is approximately twice as good (82 MeV vs. 145 MeV FWHM).

(2) the attainable cross-section X branching ratio sensitivity should be ten times smaller.

(3) the region of non-zero acceptance spans a larger range of incident photon energies.

II. DETECTOR LAYOUT

The arrangement of the experimental apparatus is shown in Fig. 1. The major set of detectors consists of the spectrometer and particle identification system used in Experiment E-87, together with some small additions suggested in a companion proposal. The two new pieces of apparatus which would be required to conduct the measurements described here, and which are unique to this proposal, are the additional upstream magnet (M1) and the Cerenkov counter (c) indicated in the figure. The target (3.0" Be) would be located at the entrance to M1.

The additional magnet, M1, performs two functions: it sweeps out zero degree electron-positron pairs with a momentum less than 25 GeV/c and it focuses approximately 25% of the pairs arising from the decay of a massive parent. In Experiment E-87 one limitation in the maximum flux of beam particles was dictated by the rate of zero-degree electron-positron pairs which the first few proportional chambers could tolerate without being desensitized in the region around the beam. The new magnet M1 would sweep the low energy pairs outside the aperture of the spectrometer and remove this rate limitation, thereby allowing us to make use of an order of magnitude higher flux.

The Cerenkov counter shown in Fig. 1 would identify pions which are not removed by the upstream magnet M1. The thresholds for pions, kaons, and protons would be 14,50,and 95 GeV respectively. The various ways in which the Cerenkov counter would be used in the trigger logic are

discussed in Section IV.

III. DETECTION RATES AND SENSITIVITY

In estimating the sensitivity of the detector arrangement shown in Fig. 1 no attempt has been made as yet to optimize the layout. Consequently, the data presented here are minimal event rates. For the purpose of illustrating the sensitivity of the experiment we present results on the specific reaction

$$\gamma + Be \rightarrow X^{\circ} + \ldots\ldots$$
$$\hookrightarrow \mu^{+}\mu^{-}$$

but we point out that many other two body final states would be detected simultaneously ($e^{+}e^{-}$, $p\,\bar{p}$, μe, etc.). In Fig. 2 we indicate the detected dimuon event rate, for various mass parent particles, if the product of the photoproduction cross-section (σ) and the branching ratio into two muons (B) is 20 nanobarns/nucleus, i.e., if σB for heavier particles were identical to the measured result for the $\psi(3.1)$. The data in Fig. 2 assumes an extracted beam flux of 5×10^{12} protons per pulse, a 3.0" beryllium target and a decay angular distribution of $1 + \cos^{2}\theta$. Using this data the detected number of events in the dimuon channel alone for a 300 hour run would be 1200 events if the mass of the parent particle were 5.0 GeV and 250 events if the parent mass were 7.0 GeV. These high event rates, coupled with the ability to detect most other two body final states, illustrates that the experiment has good sensitivity for detection of heavy particles with masses up to at least 7.0 GeV. The rate estimates given here are based upon a main ring energy of 300 GeV. If the accelerator runs at 400 GeV at the time this data is collected these rates would increase by a factor of $1.5 \rightarrow 2.0$ in the mass range $3.0 \rightarrow 5.0$ GeV.

The data of Fig. 2 also indicates that in a 300 hour running period

we would detect 4500 $\psi(3.1) \rightarrow \mu^+\mu^-$ decays and a comparable number of $\psi(3.1) \rightarrow e^+e^-$ decays. These high statistics for the $\psi(3.1)$ will allow us to ask detailed questions about the photoproduction dynamics; in particular, we will be able to measure the energy dependence of the photoproduction cross-section in the interval of photon energies from 40 - 200 GeV. It will be of interest to extract $(d\sigma/dt)_{t=t_{min}}$ for $\psi(3.1)$ photoproduction, with good statistics, in this energy range and compare the result with the SLAC data at 20 GeV.

In Fig. 3 we show the number of $\psi(3.1) \rightarrow \mu^+\mu^-$ events accepted as a function of photon energy. We note that the energy dependence of our acceptance is rather flat and extends down to photon energies as low as 40 GeV. The mass resolution of the spectrometer in the region of the 3.1 resonance is also shown in Fig. 3.

The event rates illustrated in Fig. 2 also indicate that we should be able to extract the $\psi'(3.7)$ - nucleon total cross section if it is comparable to the $\psi(3.1)$ - nucleon total cross section. In particular, if we assume these cross-sections are equal, and use the SPEAR data on the $\psi'(3.7)$ leptonic width and branching ratio into $\mu^+\mu^-$, along with the curve in Fig. 2, we would expect to detect 150 $\psi'(3.7) \rightarrow \mu^+\mu^-$ events in a 300 hour running period.

IV. TRIGGER MODES AND BACKGROUNDS

The detector layout shown in Fig. 1 will allow us to clearly identify and select the high energy forward going events of interest. Fast ouptuts from 15 proportional wire planes will be used to select events with two charged particles in the final state. The prompt outputs from the muon identifier and the electron calorimeter, set at a threshold of approximately 30 GeV will be used as in E-87 to tag electrons and muons, while the energy of the forward going hadrons will be measured in the hadron calorimeter.

One function of the Cerenkov counter is to suppress forward going hadronic pairs arising, for example, from photoproduced rho mesons. We estimate that with an extracted beam flux of 5×10^{12} protons per pulse that approximately 100 $\rho \rightarrow \pi^+\pi^-$ pairs per pulse will be accepted by the spectrometer. Although the detectors and electronics are quite capable of handling this high rate, we do not plan to collect this data. The Cerenkov counter will serve to reduce the number of accepted pion pairs by approximately two orders of magnitude. Thus the data collection rates and the number of events analyzed off-line should be comfortable.

In addition the Cerenkov counter will allow us to separate pions and protons up to energies of 90 GeV and pions and kaons up to energies of 60 GeV with approximately 60% or better efficiency. We are currently investigating the possibility of a second Cerenkov counter to achieve a more complete identification of kaons and protons. We note, however, that the ability to recognize the signature of a two-body decay arising from a narrow resonant parent is obtained from the particle momenta measured by the spectrometer. The Cerenkov counter would serve to classify the two-body final state into the appropriate channel.

V. REQUESTS FROM FERMILAB AND TIMETABLE

The only piece of equipment which we would need to request of Fermilab in order to perform the experiment described here is the additional bending magnet, referred to as M1 in Fig. 1. The calculations we have performed indicate that a magnet with an aperture of 24" x 8" and an $\int \vec{B} \cdot \vec{dl} = 120$ kilogauss-ft would be adequate. These are exactly the aperture and field strength of a standard BM-109.

We should point out, however, that we are asking for twice as much beam as has been possible to transport down the proton beam line in

the past. This limitation has been due to the interaction of the proton beam halo with magnets upstream of the target box. We are assuming the forthcoming replacement of these magnets by ones with larger apertures will allow this extra intensity to be attained. We are further assuming that these planned Proton Lab improvements will also reduce the ambient muon fluxes in our apparatus from the upstream sources. If this reduction is not sufficient, we will need to request additional shielding in EE4.

All other additions to the apparatus will be provided by the experimenters. We estimate these detectors could be completed, installed and ready to accept beam in six (6) months time.

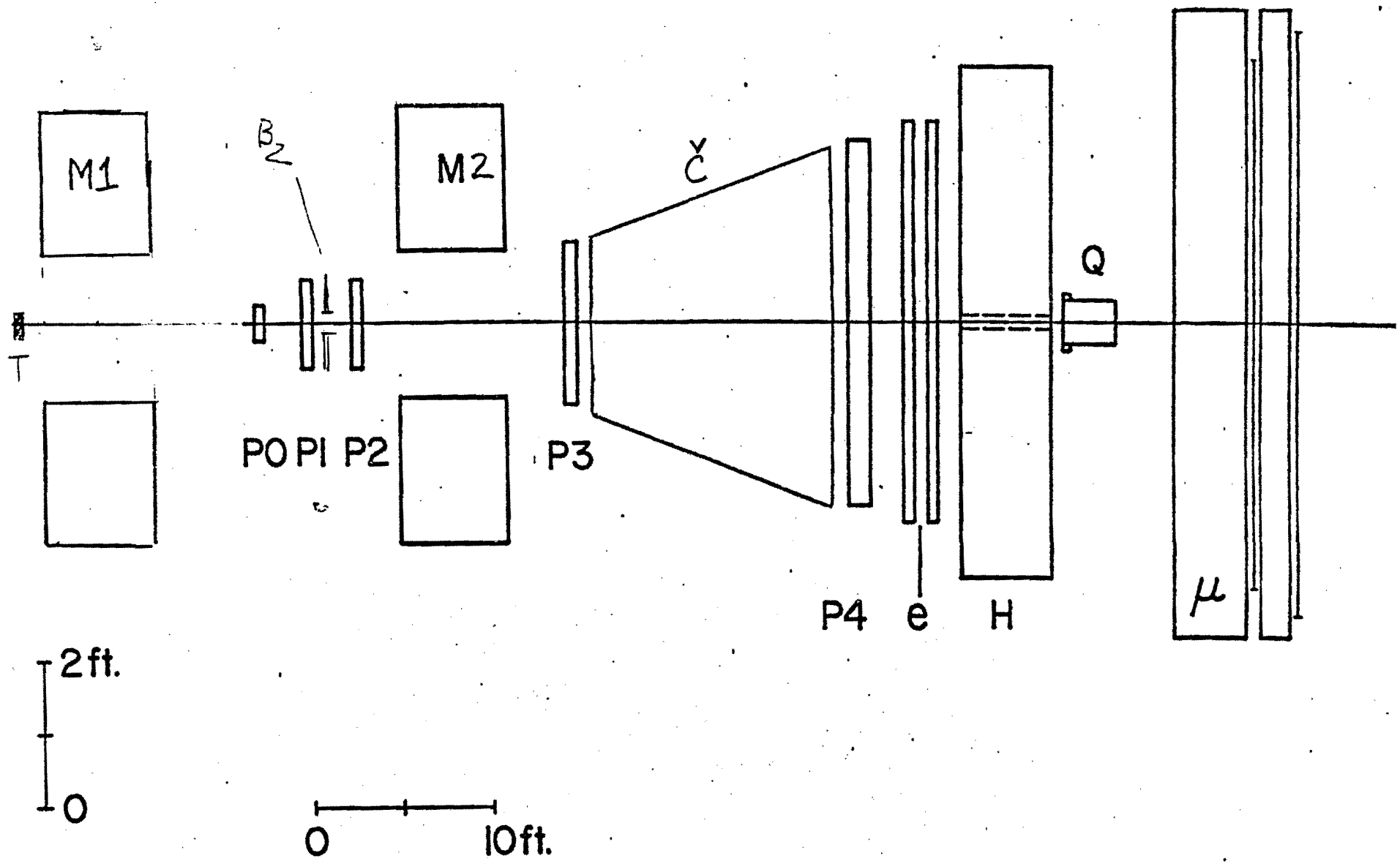


FIGURE 1

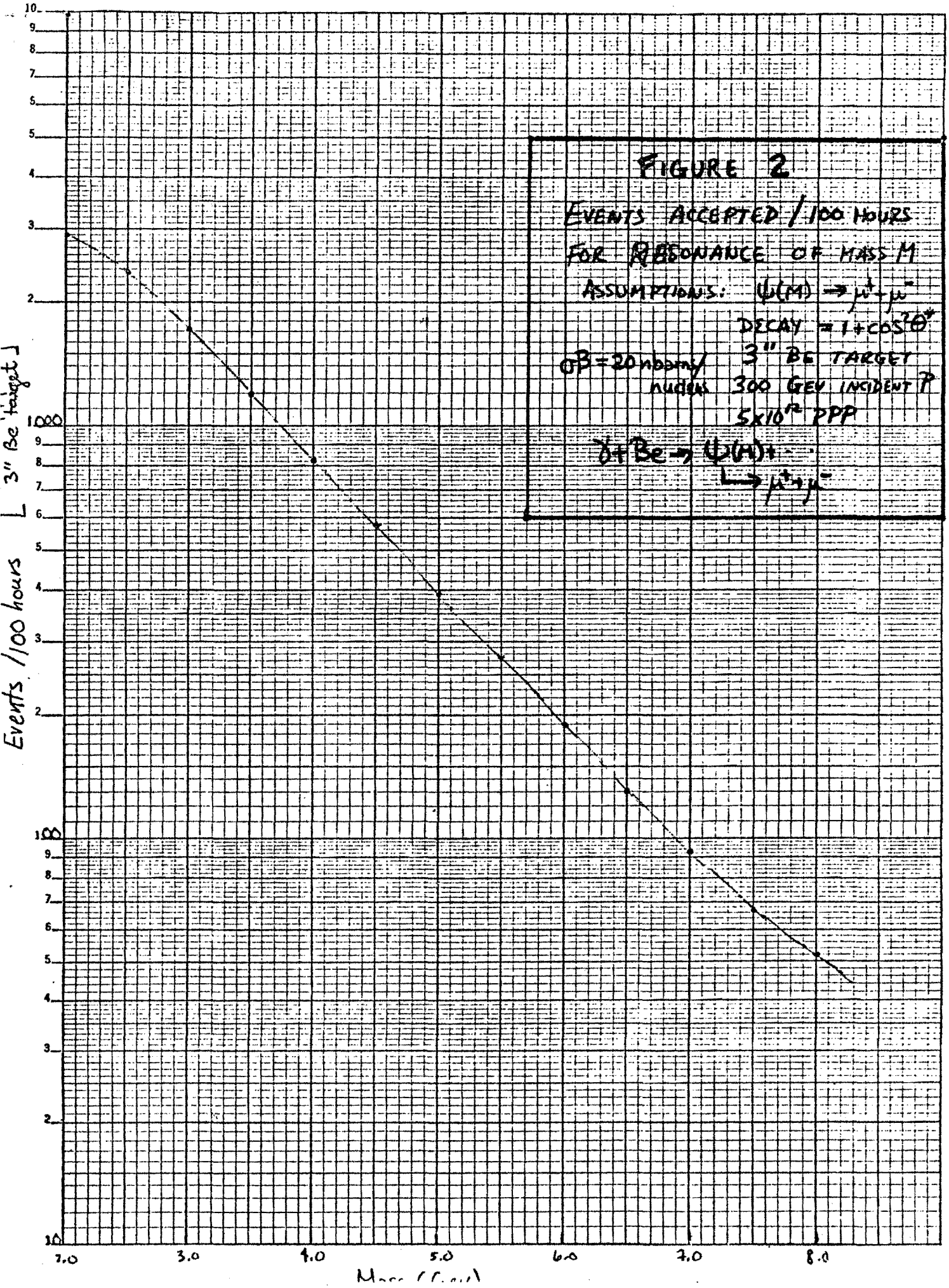
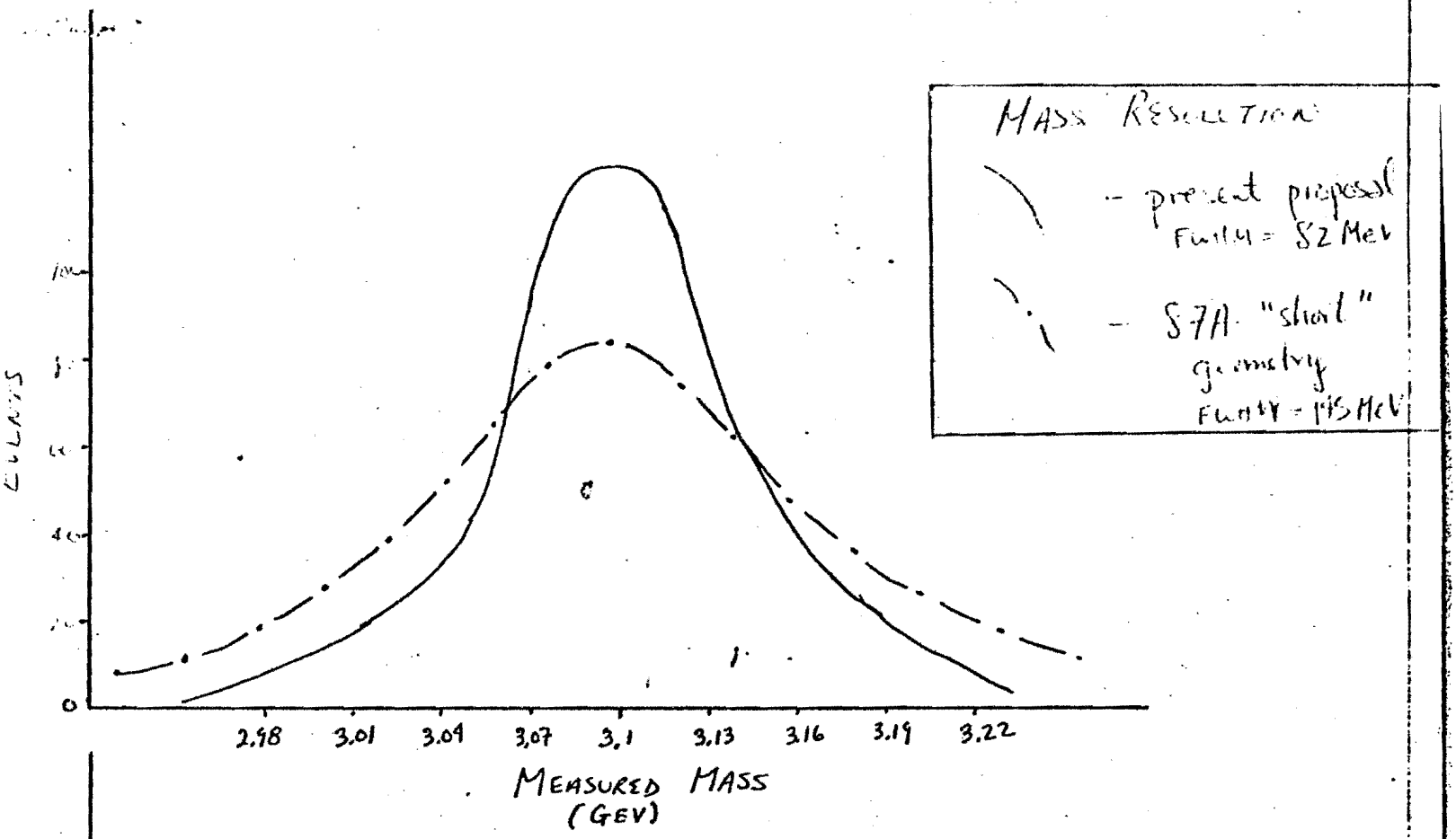


FIGURE 2
EVENTS ACCEPTED / 100 HOURS
FOR RESONANCE OF MASS M
ASSUMPTIONS: ψ(M) → μ⁺+μ⁻
DECAY = 1+cos²θ*
σB = 20 nbarns/nucleus
3" BE TARGET
300 GEV INCIDENT P
5x10¹² PPP
γ+Be → ψ(M)+ ...
→ μ⁺+μ⁻
Events /100 hours [3" Be target]
1000
100
10
2.0
3.0
4.0
5.0
6.0
7.0
8.0


MASS RESOLUTION
- present proposal
FWHM = 82 MeV
- 87A "short" geometry
FWHM = 115 MeV
EVENTS
0
2.98
3.01
3.04
3.07
3.1
3.13
3.16
3.19
3.22
MEASURED MASS
(GEV)

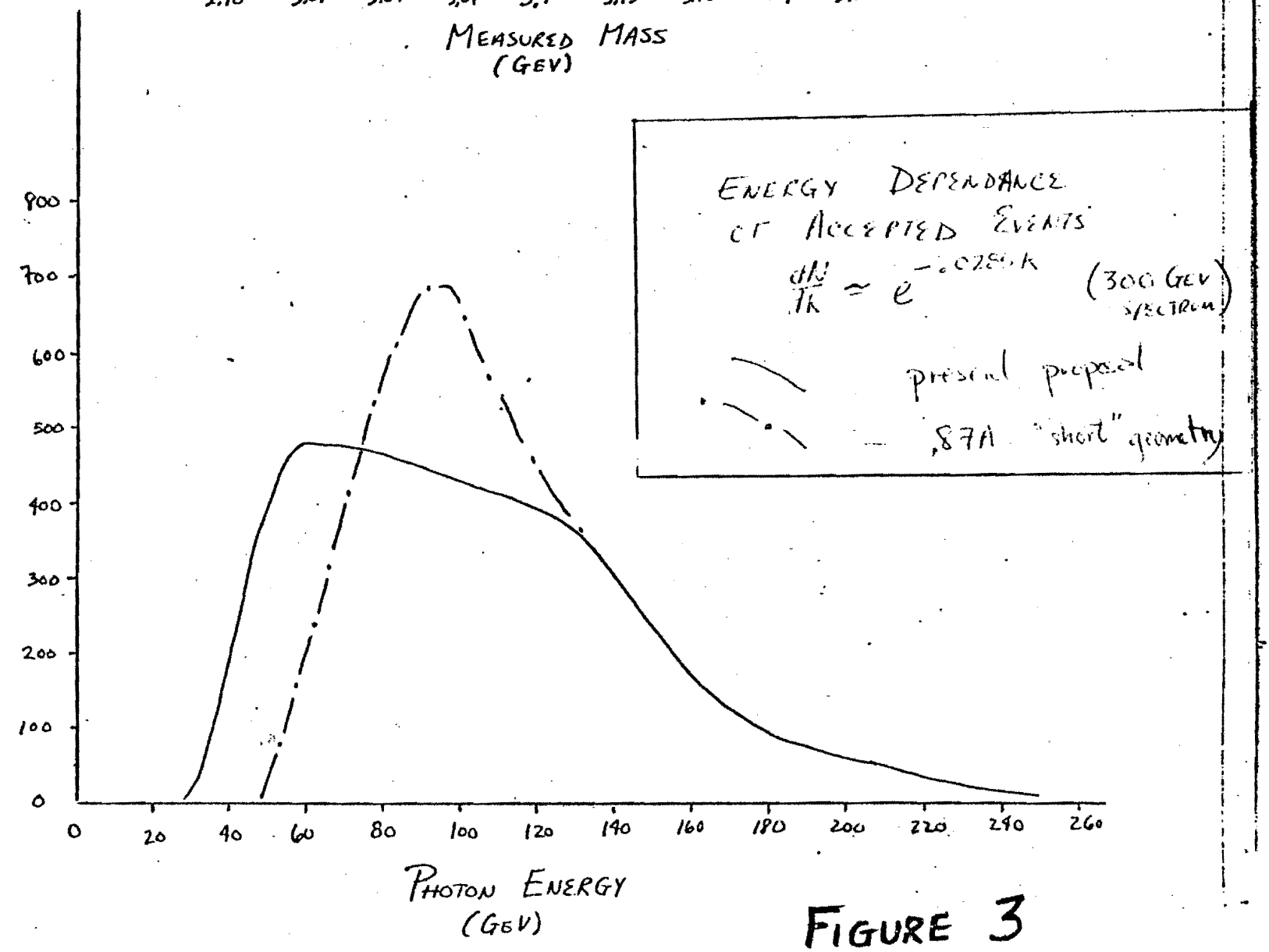

ENERGY DEPENDANCE
OF ACCEPTED EVENTS
$\frac{dN}{dk} \simeq e^{-.0280k}$
(300 GEV SPECTRUM)
present proposal
87A "short" geometry
0
100
200
300
400
500
600
700
800
0
20
40
60
80
100
120
140
160
180
200
220
240
260
PHOTON ENERGY
(GEV)

FIGURE 3