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NAL PROPOSAL NO. 443

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A PROPOSAL FOR CONTINUED STUDIES OF HADRON INDUCED μ-PAIRS IN A LARGE ACCEPTANCE SPECTROMETER

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Abstract

We propose to continue our studies of hadron induced μ-pairs using hydrogen and deuterium targets and an incident positive and negative beam an order of magnitude more intense than has been normally available to us in E-331.

We propose to complete the study of hadron induced μ-pairs as set out in our original proposal.[1] For reasons of scheduling and to minimize interference with E-98, the running of E-331 has been restricted to nuclear targets and a positive beam almost an order to magnitude less intense than the spectrometer can handle. We wish to extend our studies to hydrogen and deuterium targets and to use a higher quality hadron beam into the Chicago Cyclotron Spectrometer.

The physics goals of the experiment remain the same; namely, to study the hadron production of μ-pairs in a large acceptance detector with a minimum of detection biases. We will study the μ-pair production cross section as a function of x_F, P_T and $M_{\mu\mu}$ for incident pions, protons, and kaons. We will also measure the decay angular distribution of the μ-pair state.

Of special interest are the continuum μ-pair characteristics. We are in a unique position to study the continuum production by protons, as well as pions of both charges, interacting with free nucleons. These data will provide important constraints to any parton model of the hadrons.

Results to Date

Experiment E-331 is scheduled for its second and final data-taking run this fall. Results from our June run have already been presented for $M_{\mu\mu} >$ 2 GeV (copy attached). We are presently preparing a publication of these results. The total E-331 data sample will provide the following results for π^+ and proton collisions with nuclear targets at 2 incident beam energies:

(1) a measurement of inclusive vector meson production (ρ-ω,ϕ,J).

(2) a measurement of the μ-pair continuum for $1 < M_{\mu\mu} < 4$ GeV.

(3) a search for high mass states ($M_{\mu\mu} > 4$ GeV) with a sensitivity of $B\sigma \sim 10^{-35}$ cm^2.

(4) a measurement of the A dependence of vector meson and continuum production using targets of 3 atomic weights.

Results from Proposed Running

We believe it is possible to produce a good quality hadron beam of 10^7/pulse using only a small fraction of the accelerated protons. The implementation of such a beam is discussed below. The improved phase space of the beam would allow the 3 beam Cerenkov counters to identify kaons as well as pions and nucleons. The kaon separation has been impossible to date because of the large phase space of the present N1 beam.

The added flux in the beam would facilitate the use of the low density hydrogen and deuterium targets. For reasons of hadron decay background, we are limited to a target length of $\sim$1m, which gives $\sim$10% probability for an inelastic interaction in the hydrogen target. Our present data have been taken with a target of $\sim$20% interaction probability. Additional flux will also give higher statistics results on J and $\psi'(3.7)$ production as well as the high mass continuum. One can expect more than a factor of 5 gain in cross section sensitivity for equivalent running time.

Interesting parton model tests of μ-pair production can be made using nuclear targets and we hope to do such a study at the end of our run this fall.[2] $[\sigma(\pi^+ C \to \mu^+\mu^- + \cdots)$ vs $\sigma(\pi^- C \to \mu^+\mu^- + \cdots)]$ If the model still appears relevant after these studies, this experiment can be used to map out the parton x-distribution functions for the interacting particles. The use of a hydrogen target would free the data from any uncertainties associated with a nuclear target.

Finally, the hydrogen and deuterium studies will represent a definitive measurement of inclusive ρ and J production from free nucleons. They form a natural completion of the A dependence studies begun in E-331.

Technical Details

(a) High Rates

We are proposing to use a beam flux of 10^7/pulse. We have already operated the spectrometer and trigger at beam rates of 3×10^6/pulse for periods of one shift with no loss in performance, so that the extrapolation to 10^7 is less than a factor of 4. One should bear in mind that our final 54-counter hodoscope plane is protected from the incident beam by 4.7 m of steel and by a magnetic field of 35 kg-m. Moreover, we demand a 2 counter coincidence within this plane. We discuss below the effect of the higher beam flux on our upstream proportional chambers and on the trigger rate/data acquisition system.

The most rate sensitive detector elements are the MWPC's located between the target and the upstream hadron shield. With a 1-m-long target, they serve two functions. They locate the beam interaction point in the target, and they determine the initial muon directions before the multiple scattering in the shield.

For this experiment, the data taking divides itself naturally into two categories. For low mass μ-pairs ($M_{\mu\mu} < 1.5$ GeV) the upstream chambers are important to achieve good mass resolution and to distinguish μ-pairs originating in the target from pairs produced in the shield. In this mass region, however, the production cross section is large.[3] For its study, we plan to run with a beam flux of a few $\times 10^6$/pulse, and a minimum bias trigger so that the data acquisition system is saturated at ∿25 events/pulse. At this incident beam flux, the upstream chambers should perform nicely. Even for this data, however, the improved N1 beam is important to obtain sufficient intensity with negative particles.

To study the higher mass region with the full beam of 10^7/pulse, we will deaden the central 1 cm x 1 cm of the upstream chambers[4]. In this condition they will count at the rate of the interacting beam, a factor of 10 less than the incident flux. Few muons from the higher mass μ-pairs are lost in the central dead region. Even if lost, we still detect the wide angle hadrons from the beam interaction and they will be used to determine the interaction point in the target. The mass resolution as shown in the attached preprint is 130 MeV at 3 GeV when the interaction point is known to ±5 cm and only information from the downstream spectrometer is used in the mass calculation. We emphasize however that the upstream detectors would still be useful for the bulk of the high mass events.

Next consider the effect of the high beam flux on the trigger and data acquisition system. In our last run the trigger rate was 8 events/10^6 incident particles. For the 1m hydrogen target, we would expect ∿4 events/10^6. The system can be operated with a dead time of 15 msec. To trigger selectively on higher masses, we are adding this fall an additional hodoscope at the downstream face of the front hadron shield. This hodoscope can be used to impose an opening angle requirement on the pairs and thus suppress low mass triggers. Using our present data to test the hodoscope's effectiveness, we find that it reduces the trigger rate by a factor of 5 but leaves the region $M_{\mu\mu} > 2$ GeV untouched. To summarize, we expect to trigger on 8 high mass events/10^7 particles incident on a 1m hydrogen target.

(b) The Beam

During neutrino running, the present N1 hadron beam is derived from the horn target. The beam passes through the horn at a small grazing angle traversing ∿1 ft. of aluminum. During antineutrino operation when the hadron plug is installed downstream of the horn target, the N1 beam is derived from a target in the bypass beam to the bubble chamber. In both configurations the first quadrupoles are ∿1100 ft. downstream of the target. We urge that both the targeting and solid angle of the beam be improved.

The optimum solution would be a third split of the proton beam into Neuhall and the targeting of this third beam in enclosure 100 using the same techniques as in the Proton Lab. Because of the greatly increased solid angle, the number of protons on target would be relatively modest.

A second solution would use a special neutrino decay pipe triplet recently suggested in a note by Skuja and Stefanski[5] as a way of providing compatible running for the muon and neutrino experiments. The disadvantages here are that there could be no running during periods of antineutrino operation and the 400-m-long hadron decay path would introduce an unwanted muon component in the hadron beam.

We plan to actively pursue these solutions and others with the Neutrino Lab personnel.

Conclusions

The μ-pair studies embarked on in E-331 are already yielding interesting results. They fall short of the full potential of the detector and accelerator primarily because of the low quality beam presently available. We urge upgrading of the beam and further running of our experiment with hydrogen and deuterium targets, as set out in our original proposal.

References

1. The scope of the experiment is set out in detail in proposal number 308. This number was changed to 331 when the use of the Chicago cyclotron spectrometer was considered.
2. A Special Request for High Priority Running to Study High Mass Muon Pairs, K. J. Anderson *et al.*, a Fermilab proposal submitted September 1975.
3. We observe $\sim$ 45K events in the interval $0.5 < M_{\mu\mu} < 1.5$ GeV for $\sim$100 J events.
4. A small region of the chambers can be deadened by painting the anode wires in this region with Glyptol and thus removing the possibility of gas amplification. The Glyptol can be removed later with alcohol.
5. A. Skuja and R. Stefanski, Fermilab internal memo to J. Peoples (9/12/75).

EFI 75-55

MU-PAIR PRODUCTION BY 150 GeV/c HADRONS*

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We report the first results of a measurement of μ-pair production by 150 GeV/c protons and π^+ mesons. The experiment was performed in Fermilab's Muon Laboratory using hadrons from the N1 beam and the large acceptance Chicago cyclotron spectrometer.

At 150 GeV/c the 2-cm x 2-cm positive beam consisted of a few percent muons and K^+ mesons, 23% π^+ mesons, and the rest protons. Two helium filled threshold Čerenkov counters situated in the incident beam were set just below the proton threshold and recorded as a tag with every trigger. Thus, pion induced μ-pairs were recorded simultaneously with the proton induced pairs and the ratio of the two cross sections is particularly insensitive to systematic effects.

As shown in Fig. 1, the beam was incident on a 5-cm-diameter, 10-cm-long beryllium target located 1.2 m upstream from a 2.2-m-thick movable steel hadron shield. Charged particles emerging from the hadron shield were momentum analyzed in the Chicago cyclotron spectrometer, which is described in detail elsewhere.[1] Briefly, the spectrometer consisted of eight 1-m-square MWPC planes to define track trajectories upstream of the magnet and 20 spark chamber planes to define the downstream trajectories. In addition, signals from two 6-m-wide, 2-m-high hodoscope planes of horizontal and vertical scintillation counters (G and H of Fig. 1) were recorded as tags with the data to improve the time resolution of the downstream detector. These hodoscope planes were followed by 2.5 m of steel and lead for further muon identification and finally by a vertical hodoscope (P of Fig. 1) used for triggering.

The trigger logic required exactly one unaccompanied charged particle in the beam. A 3-counter beam telescope $T_1 \cdot T_2 \cdot T_3$ defined the incident trajectory and a pulse height requirement in T_3 ensured no more than a single particle in the beam. Large halo veto counters were used around the beam but in a position well shielded against backscatter from the target. Beam interactions in the target were selected by requiring at least 2 minimum ionizing particles in counter T_4 situated just downstream of the target. At least one count was required in the G hodoscope plane shown in Fig. 1, and in the P-plane two non-adjacent counters were required to be struck. The P hodoscope was mounted flush against the downstream side of a 20-cm-thick lead wall to further reduce triggers from single μ's accompanied by low energy electromagnetic showers. Finally, a 3-in-square counter T_5 was located downstream of the magnet and was used in anticoincidence to veto beam muons. This trigger gave a signal which was $\sim$70% unaccompanied μ-pairs. Most of the remaining triggers were single muons which produced a shower in the downstream hadron filter and thereby hit two nonadjacent P counters.

Event reconstruction was straightforward since the MWPC's and spark chambers were in general well over 90% efficient, and since the probability that a μ-pair was accompanied by an extra track in the spectrometer was less than 5%. An effective mass was computed for the pair with no constraint on the z-coordinate of the μ-pair production point. A second calculation was made assuming the pair originated at the center of the target. These two calculations were required to agree to within 0.6 GeV. Monte Carlo studies showed this requirement had a negligible effect on the real signal from the target but was effective in removing pairs which originated elsewhere. The z-distribution for the vertex position of accepted events is shown in Fig. 2. There is no indication of events originating from any source other than the target.

The effective mass for these events is shown in Fig. 3. A clear J signal is seen at 3.1 GeV, and no events are observed above 4.1 GeV. The line shape is primarily determined by multiple scattering in the shield and is nearly Gaussian with $\sigma \sim 130$ MeV. The fraction of J events falling below 2.6 GeV is less than 2% as determined by a careful Monte Carlo study, which included the correlation between lateral and angular scattering in the shield, fluctuations in ionization energy loss, and fluctuations in energy loss through radiative processes. Background from two hadrons decaying to muons is negligible since we only observe a single event with both muons of the same charge and $M_{\mu\mu} > 2$ GeV.

The mass spectra for p-induced and π-induced pairs are shown separately in Fig. 4. If we define as J candidates all events in the interval $2.6 < m_{\mu\mu} < 3.5$, we observe 39 J candidates for incident pions and 46 candidates for incident protons. In the region $2.0 < M_{\mu\mu} < 2.6$, there are 11 and 6 events for incident pions and protons respectively. These events are observed with an effective beam composition of 3.3 protons for every pion.

The observed P_T distribution for the J candidates is shown in Fig. 5 for proton and pion events separately. The data show a mean P_T of 0.9 GeV/c. The variation in detector acceptance as a function of P_T is small, falling 20% between $P_T = 0$ and $P_T = 2$ GeV/c.

The distributions in Feynman X are given in Fig. 6 for protons and pions. In these figures, the relative pion to proton flux has been accounted for as has the variation in acceptance with X. The acceptance calculation is straightforward. The only model dependent aspect is the shape of the decay angular distribution of the μ-pair in its rest frame. We will assume no net polarization for the μ-pair state and hence that the angular distribution described above is flat in $\cos\theta^*$. The assumption of a $1 + \cos^2\theta^*$ distribution leads to a decrease in the integrated acceptance and would increase the cross sections quoted below by about 30%. The shape of the acceptance as a function of X and P_T is little affected by these assumptions.

These data lead to a cross section ratio of

$$\frac{\sigma(p + Be \rightarrow J + \cdots)}{\sigma(\pi^+ + Be \rightarrow J + \cdots)} = 0.61 \pm 0.27 \qquad X_F > 0.05$$

And for a larger value of X_F

$$\frac{\sigma(p + Be \rightarrow J + \cdots)}{\sigma(\pi + Be \rightarrow J + \cdots)} = 0.17 \pm 0.09 \qquad X_F > 0.45$$

For the mass region below the J peak, namely, $2.0 < M_{\mu\mu} < 2.6$ GeV, we obtain

$$\frac{\sigma(p + Be \rightarrow \mu^+\mu^- + \cdots)}{\sigma(\pi + Be \rightarrow \mu^+\mu^- + \cdots)} = 0.17 \pm 0.12 \qquad X_F > 0.05$$

In terms of absolute cross sections, we measure

$$B\sigma(p + Be \rightarrow J + \cdots) = 28 \pm 14 \text{ nb/Be nucleus} \qquad X_F > 0.05$$

$$B\sigma(\pi + Be \rightarrow J + \cdots) = 46 \pm 20 \text{ nb/Be nucleus}$$

Where B is the branching ratio of $J \rightarrow \mu^+\mu^-$.[2]

Dividing by A to estimate the cross section per nucleon[3] yields

$$B\sigma(p + N \rightarrow J + \cdots) = 3.1 \pm 1.6 \text{ nb/nucleon} \qquad X_F > 0.05$$

$$B\sigma(\pi + N \rightarrow J + \cdots) = 5.1 \pm 2.2 \text{ nb/nucleon}$$

Since no events are observed for masses greater than 4.1 GeV, we set a 90% confidence limit on the cross section in the interval $4 < M_{\mu\mu} < 10$ GeV and $0.4 < X_F < 0.6$ of:

$$\sigma(p + N \rightarrow \mu^+\mu^- + \cdots) < 2 \times 10^{-33}\ \mathrm{cm}^2/\mathrm{nucleus}$$

and

$$\sigma(\pi + N \rightarrow \mu^+\mu^- + \cdots) < 6.5 \times 10^{-33}\ \mathrm{cm}^2/\mathrm{nucleus}.$$

The results for hadron production of J's are in reasonable agreement with published measurements at slightly different energies,[4] although the data reported here extend down to lower values of X_F.

In conclusion we wish to give special thanks to the members of the Chicago, Harvard, Illinois, Oxford muon-scattering group whose spectrometer was used in modified form for this work. We also acknowledge the help of the Fermilab Neutrino Laboratory staff and the technical support groups at our institutions headed by R. Armstrong and T. Nunamaker at Chicago and by K. Wright at Princeton.

[*] Work supported by the National Science Foundation and the Energy Research and Development Agency.

[+] Enrico Fermi Postdoctoral Fellow.

References

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3. The parton model leads to a linear A dependence in the nuclear cross section--S. Brodsky, private communication. In addition, more general considerations also lead to a linear A dependence--P. M. Fishband and J. S. Trefil, Shadowing in Inclusive Reactions on Composite Systems and Large $P_\perp$ Inclusive Reactions in Nuclei, University of Virginia preprint.
4. B. Knapp *et al.*, Phys. Rev. Lett. 34, 1044 (1975).
   G. Blanar *et al.*, Phys. Rev. Lett. 35, 346 (1975).

Figure Captions

Figure 1 - Plan view of the detector.

Figure 2 - z-distribution for vertex position of accepted μ-pairs.

Figure 3 - Mass distribution for all μ-pairs.

Figure 4 - Mass distribution for pion and proton induced pairs shown separately.

Figure 5 - Uncorrected pairs P_T spectra.

Figure 6 - Feynman X distribution for protons and pion induced μ-pairs.

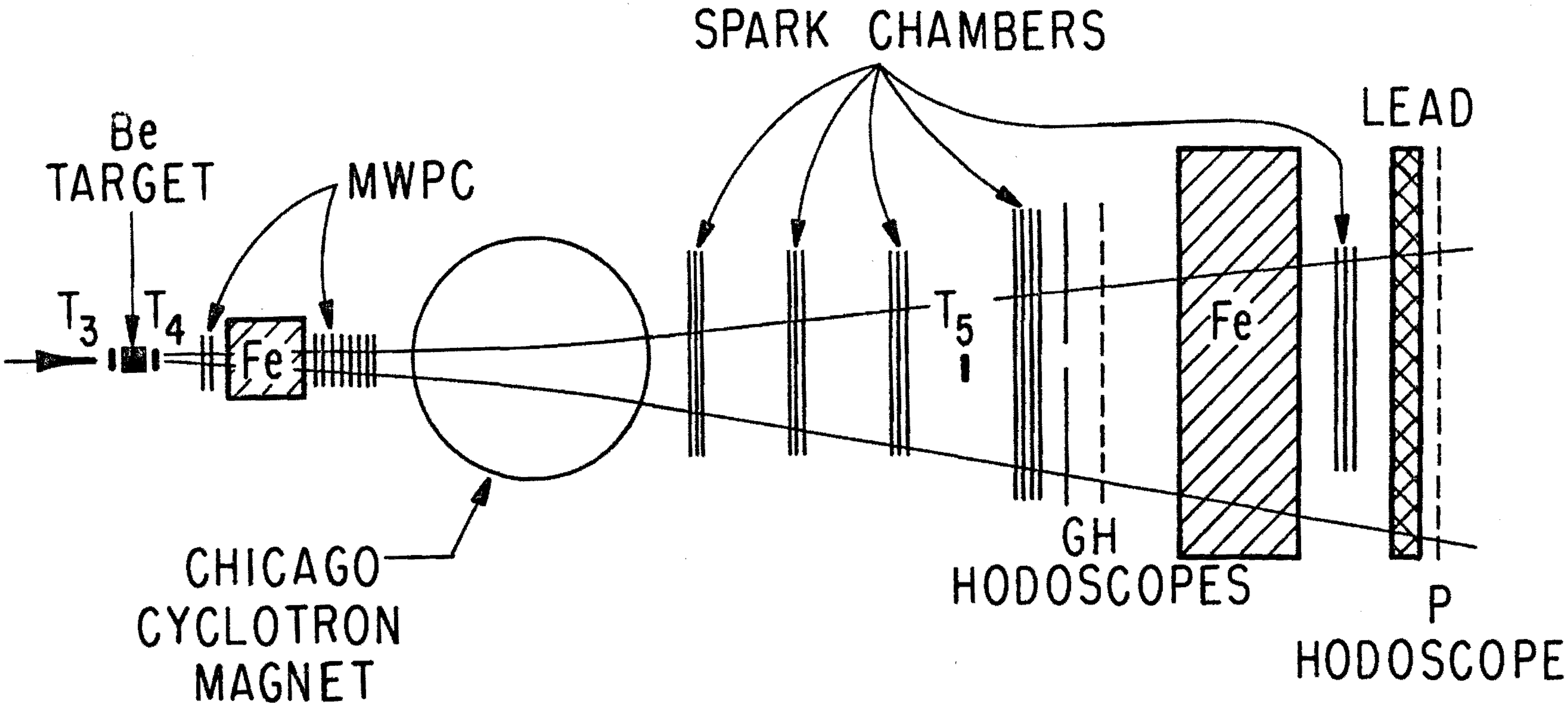

SPARK CHAMBERS
LEAD
Be
TARGET
MWPC
T_3
T_4
Fe
T_5
Fe
GH
HODOSCOPES
CHICAGO
CYCLOTRON
MAGNET
P
HODOSCOPE

Figure 1

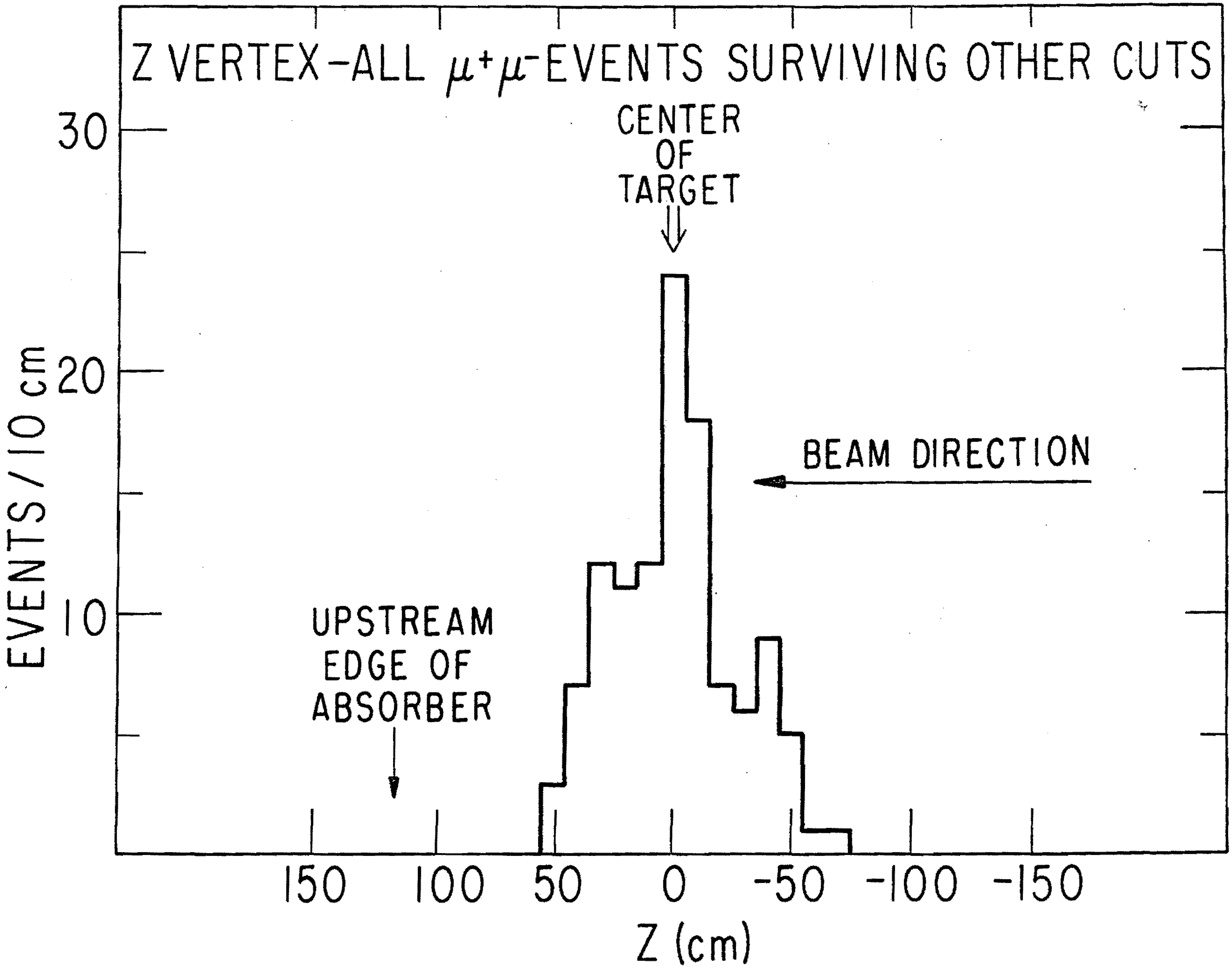

Z VERTEX-ALL $\mu^+\mu^-$ EVENTS SURVIVING OTHER CUTS
CENTER OF TARGET
BEAM DIRECTION
UPSTREAM EDGE OF ABSORBER
EVENTS / 10 cm
30
20
10
150
100
50
0
-50
-100
-150
Z (cm)

Figure 2

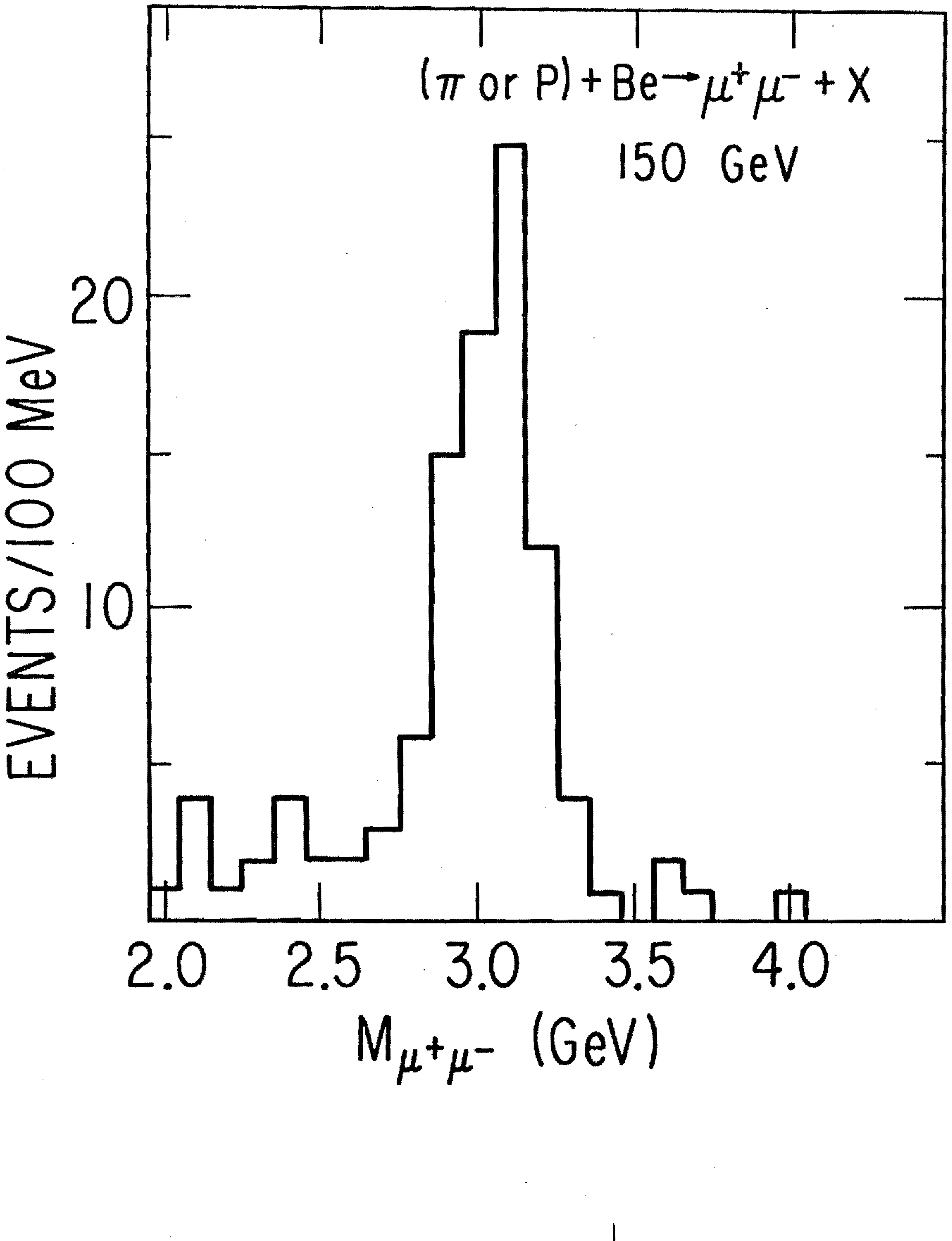


Figure 3

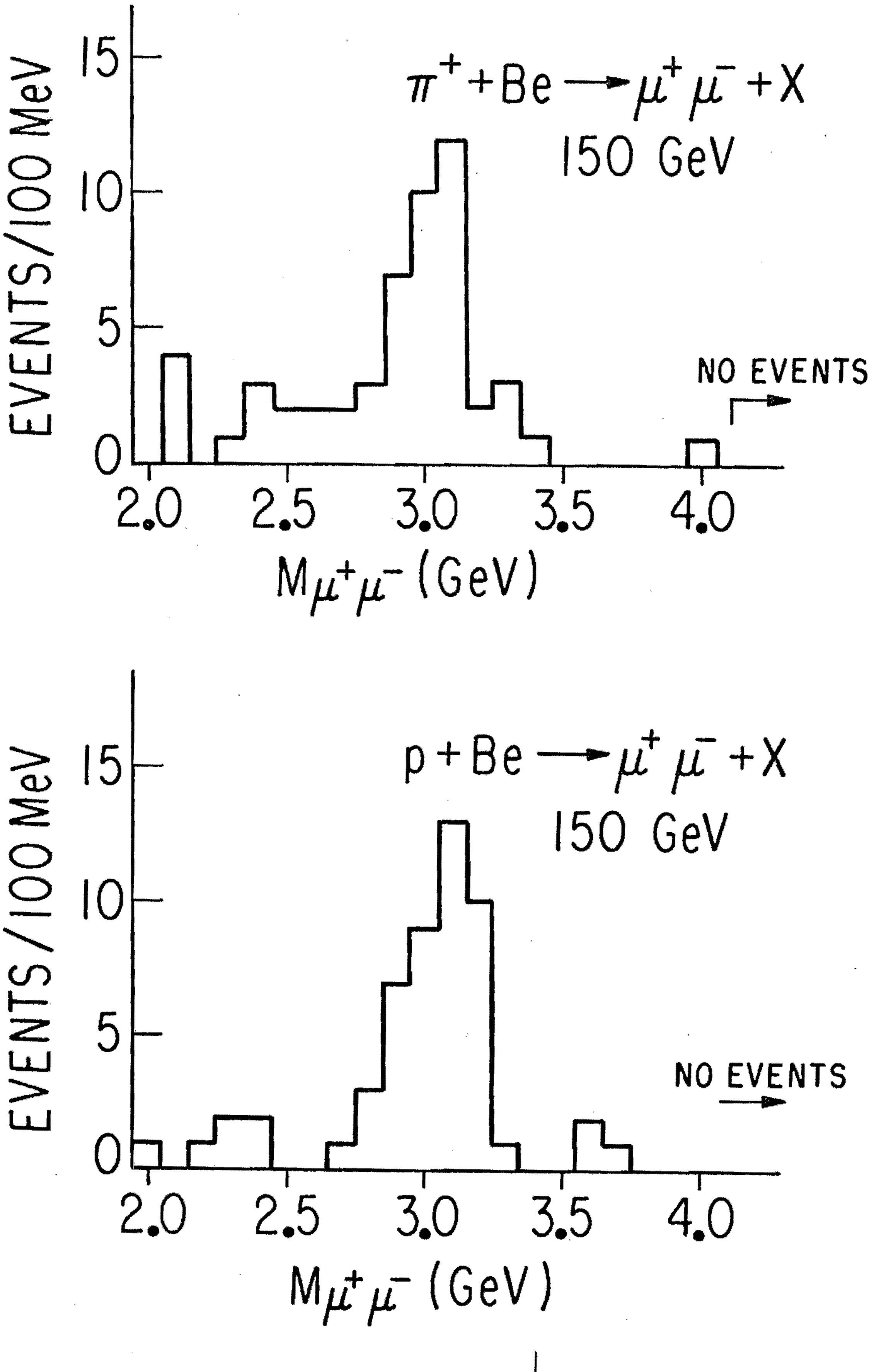
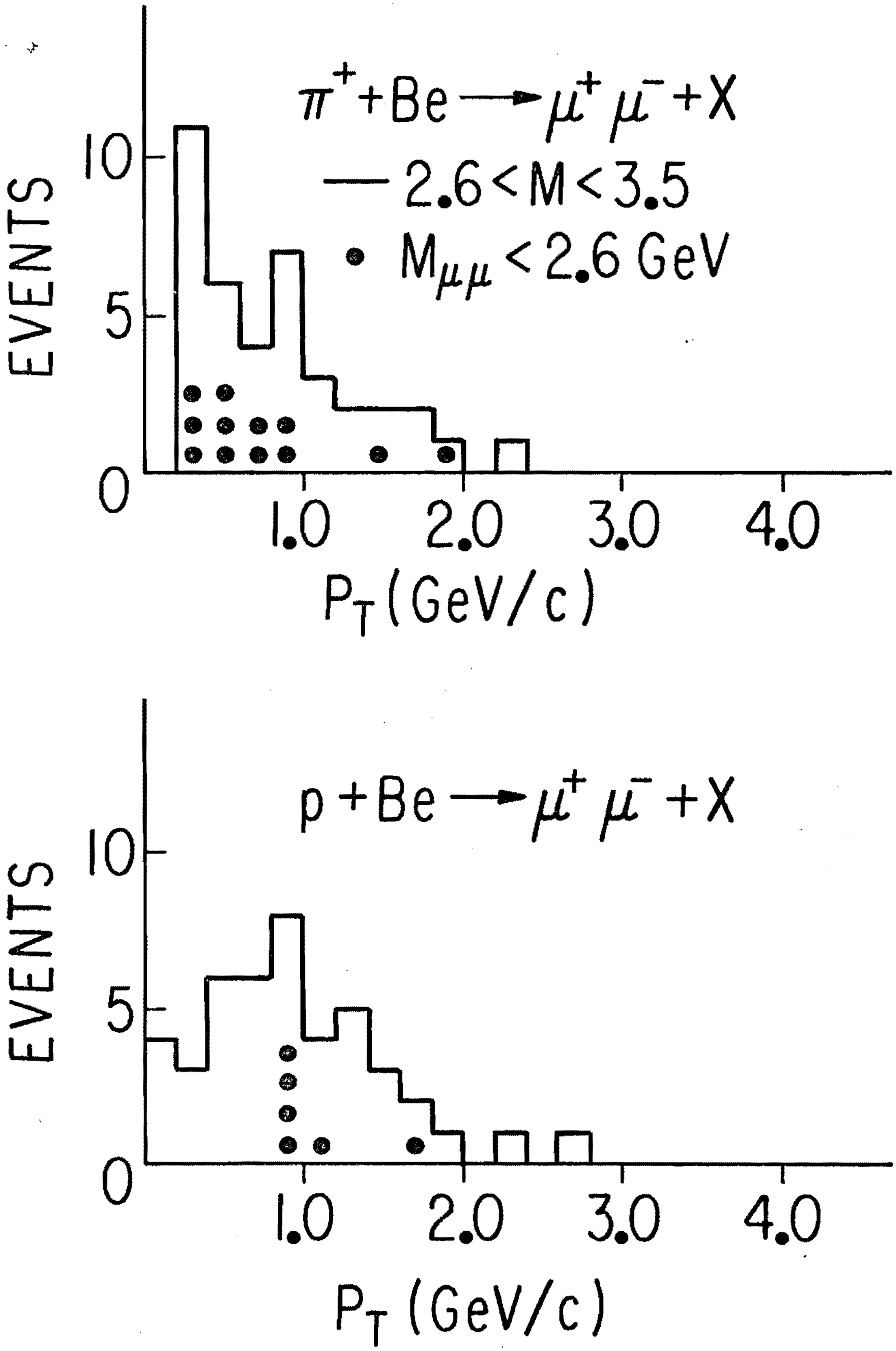
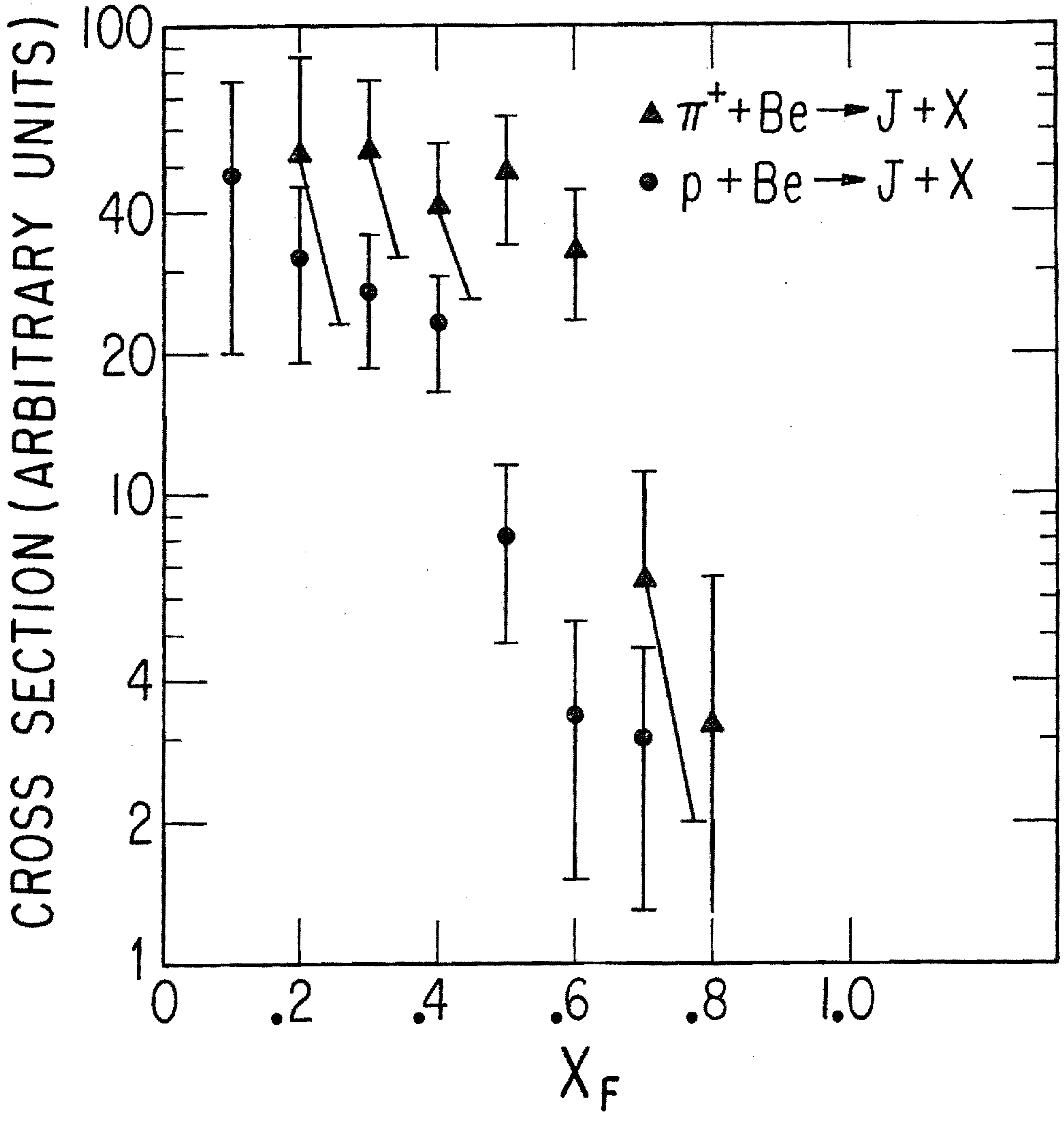

$\pi^+ + Be \rightarrow \mu^+\mu^- + X$
150 GeV
EVENTS/100 MeV
15
10
5
0
NO EVENTS
2.0
2.5
3.0
3.5
4.0
$M_{\mu^+\mu^-}$ (GeV)
$p + Be \rightarrow \mu^+\mu^- + X$
150 GeV
EVENTS/100 MeV
15
10
5
0
NO EVENTS
2.0
2.5
3.0
3.5
4.0
$M_{\mu^+\mu^-}$ (GeV)

Figure 4



$\pi^+ + Be \rightarrow \mu^+ \mu^- + X$
— 2.6 < M < 3.5
● $M_{\mu\mu}$ < 2.6 GeV
EVENTS
0
5
10
1.0
2.0
3.0
4.0
P_T (GeV/c)
$p + Be \rightarrow \mu^+ \mu^- + X$
EVENTS
0
5
10
1.0
2.0
3.0
4.0
P_T (GeV/c)

Figure 5



CROSS SECTION (ARBITRARY UNITS)
100
40
20
10
4
2
1
0
.2
.4
.6
.8
1.0
X_F
▲ $\pi^+ + Be \rightarrow J + X$
● $p + Be \rightarrow J + X$

Figure 6