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## ABSTRACT

We have searched for charmed particles produced hadronically in coincidence with the J particle, by looking for muons from the leptonic or semileptonic decays of the charmed particles. In a sample of 2500 J's, we see no muons above the level expected from $\pi$ and k decay.

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Shortly after the original discovery of the J particle,[1] it was shown that the cross section for hadronic production of the J increased by more than two orders of magnitude between AGS and Fermilab energies.[2] One possible explanation of this increase is that the major mechanism for J production by hadrons is the OZI (Okubo-Zweig-Iizuka) rule[3] allowed reaction:

$$N + N \rightarrow J C\bar{C} + \ldots \qquad (1)$$

where C and $\bar{C}$ are hadrons containing charmed quarks. Since the threshold for this process is above the energy of the AGS, only OZI-forbidden production is possible there, and so the cross section is suppressed. Possible support for this mechanism comes from recent observations of an excess of K's in hadronic production of the $\phi$ meson.[4]

We have tested this hypothesis by searching for the leptonic or semi-leptonic decays of charmed particles produced in association with a J particle as in reaction (2). The J was produced in neutron-nuclear collisions at Fermilab (average neutron energy about 300 GeV), and detected through its dimuon decay mode. T is the nuclear target: Be, Al, Cu, or Pb:

$$n + T \rightarrow \underset{\hookrightarrow \mu^+\mu^-}{J} + \underset{\hookrightarrow \mu^\pm + \ldots}{M^\pm} + M^\mp + X \qquad (2)$$

An additional source of trimuons is the pair production of J's, as in reaction (3):

$$n + T \to J(\to \mu^+\mu^-) + J(\to \mu^+\mu^-) + X \quad (3)$$

The most important source of trimuon background is due to the decay of one of the pions or kaons which are produced in association with the J, as in reaction (4).

$$n + T \to J(\to \mu^+\mu^-) + \pi^{\pm}(K^{\pm})(\to \mu^{\pm} + \nu) + X \quad (4)$$

Reaction 2) and 4) can be distinguished by comparing the simultaneous production of trimuons from targets which have different decay lengths for the $\pi$ and K and by comparing the rate of trimuon production at the J mass with the rate at the $\rho$ mass.

Dimuons were produced either in a target which was 75 cm upstream of a 75 cm Be absorber, followed by a steel dump of 1300 gram/cm$^2$ or in the tungsten core of the Be absorber. The three muon yield from the first target should be dominated by pion decay, while in the second pion decay will be suppressed relative to the first by a factor of seven. Descriptions of the apparatus, the mass calculation, and the methods of analysis were given in Ref. 5 and 6.

The sample of events was obtained as follows: The mass of the lepton pair, $M_V$, was calculated from the momenta of the tracks emerging from the absorber after correcting for energy loss in the dump. A second mass calculation, $M_C$, was made assuming that the lepton pair was produced in the target. If

$|M_c - M_v| < .32$ GeV/c$^2$ and if $M_c < 1.4$ GeV/c$^2$ or if $|M_c - M_v| < .48$ GeV/c$^2$ and if $M_c > 1.4$ GeV/c$^2$, then the event was assumed to come from the target. If an event did not satisfy these conditions it became a candidate for an event which was produced in the W core. The mass, $M_c'$ was recalculated assuming that the event came from a point 5 cm downstream of the beginning of the W core. In addition if the event satisfied the hypothesis that it came from the core, the target counter T must have no count. The mass distribution of events from the core is shown in Fig. 1b while the events from the target are shown in Fig. 1a. Although events from the core have poorer resolution, a clear J signal can be seen.

If the event had a third muon which was consistent with a common production vertex for all three muons, the event was a candidate for reactions (2) or (3). Each muon track was required to satisfy all of the cuts defined in Ref. 5.
The production vertex was assumed in this analysis to have been either in the plane perpendicular to the beam which passed through the center of the target or the plane 5 cm downstream from the beginning of the W core. The muon tracks were projected back to the interaction plane. The interaction point was the point halfway between the tracks of the two muons from the J(or $\rho$) decay. The third muon had to intersect the interaction plane at a distance from the interaction point which was no more than 2.5 times the expected multiple scattering if it were to be considered as coming from a common production vertex.

The third muon must have gone through the complete muon identifier and each muon counter which the track penetrated must have had a hit. This requirement caused the momentum of the third muon to be 5 GeV/c or greater.

The results of this analysis are shown in Table I. On the assumption that more than 90% of the 3$\mu$ events which emerged from the target were a result of $\pi$ or K decay, we can predict the number of 3$\mu$ events expected from decay in the dump. The results are also given in Table I. In particular, at the J mass we observed two trimuon events from the dump, whereas we expect one event from decays. Table I also shows the average momentum and the average transverse momentum squared of the observed third muons. These values are quite consistent with what would be expected from pion and kaon decays. The models discussed below predict that $< p > = 34$ GeV/c and $< p_\perp^2 > = .37$ GeV/c$^2$ for a third muon from the decay of a new particle.

This lack of trimuon production above the level expected from decays contradicts the joint hypothesis that the factor of 100 rise in J production from 30 GeV to 300 GeV is due to production of J in association with C and $\bar{C}$ pair and that the branching ratio of C($\bar{C}$) into $\mu^+\nu$ ($\mu^-\nu$) + hadrons is 10% or more. In order to arrive at a quantitative measure of our sensitivity to this process we assumed the following model for the production of the C $\bar{C}$ pair in association with a J: The J was picked with rapidity y distributed according to $d\sigma/dy \, \alpha (1-x)^{5.2}$ (See Ref. 6). The C was picked to be within ±3 units of rapidity of the J according to the distribution $e^{-2|Y_C - Y_J|}$. The antiparticle of the C was assumed to be produced according to the same distribution law, except that $Y_J$ was between $Y_C$ and $Y_{\bar{C}}$. The transverse momenta of the C and J were picked independently according to $e^{-2p_\perp}$ and $e^{-1.6p_\perp}$ respectively.[6] The transverse momenta of the $\bar{C}$ was picked to balance the transverse momentum. Finally the sum of Feynman $x_F$ for the three particles in the center of mass had to be less than 0.7. The expected yield of J's in our apparatus from this model is shown in Fig. 2 in comparison with our data for J production. The figure shows that even with the cutoff at $\Sigma x_F = 0.7$, there is substantial $JC\bar{C}$ production with $x_F$ of the J greater than 0.3, where we observe J production.

Two choices were made for a model for the decay of a C. In the first case we assumed that the relevant decay mode was

$$C^\pm \rightarrow K^0 \mu^\pm \nu \tag{5}$$

Furthermore we assumed that the distribution of momenta in the C center of mass went according to three body phase space. The angle of the $\mu$ was picked at random in the rest system of the C. The second choice was to assume that the decay went according to:

$$C^\pm \rightarrow K^\mp \pi^\pm \mu^\pm \nu \tag{6}$$

The mass of the $K\pi$ was taken to be 1.0 GeV. The distribution of the momenta of the $\mu$, $\nu$, and the $K\pi$ system was made according to three body phase space.

The efficiency for our detector to detect the muon from the C decay is 45% for the decay mode of (5) and is 43% for the decay mode of (6) when the $K\pi$ mass is 1 GeV/$c^2$. Purely leptonic two-body decays give even higher acceptance for the third muon. We assumed that the C mass was 2.0 GeV. The calculation was repeated for $M_C$ masses of 2.5 GeV/$c^2$ and 3.0 GeV/$c^2$, and detection efficiency for the third muon was always at least 40%. Assuming the observed two events out of 1915 represent direct trimuons, we take 5 events as the 90% confidence level upper limit. Including the acceptance, this becomes 12 events out of 1915, and so we can set a 90% C.L. upper limit for production times branching ratio which is effectively independent of the mass and decay mode of the charmed particle of

$$\frac{2B_{C \to \mu + x} \cdot \sigma_{JC\bar{C}}}{\sigma_J} < .006 \; .$$

($\sigma_{JC\bar{C}}$ and $\sigma_J$ are the partial cross sections for $x_F$ of the J > 0.25). If the decay into muons occurs 10% of the time, then $\sigma_{JC\bar{C}}/\sigma_J$ is 3% or less.[8] Alternatively, if $\sigma_{JC\bar{C}} = \sigma_J$ (every J is produced with a $C\bar{C}$ pair), a 10% muonic branching ratio implies we would expect 160 trimuon events, compared to the observed two events.

The three muon result can also be used to set a limit on J pair production. In this instance we assumed that the two J's were produced independently with $(1-x)^{5.2}$ rapidity distributions. We again required the sum of

$x_F$ for the two particles to be less than 0.7. From this model, the probability of detecting a third muon from a J if the muons from the other J were detected was 15%. On this basis we can state that the pair production cross section for J's is less than 12% of the J cross section.

REFERENCES

[1]J. J. Aubert, et al., Phys. Rev. Lett. 33, 1404 (1974).

[2]B. Knapp, et al., Phys. Rev. Lett. 34, 1044 (1975).

[3]A. Okubo, Phys. Lett. 5, 165 (1963).

G. Zweig, CERN-TH 412 (1964).

T. K. Gaisser and F. Halzen, Phys. Rev. D11, 3157 (1975).

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

R. M. Barnett and D. Silverman, Phys. Rev. D12, 2037 (1975).

[4]R. A. Donald, et al., Phys. Lett. 61B, 210 (1976).
Previous experiments had failed to find evidence for Zweig's rule in ø production:
V. Blobel, et al., Phys. Lett. 59B, 88 (1975).

[5]M. Binkley, et al., Fermilab PUB-76/41, submitted to Phys. Rev. Letters.

[6]M. Binkley, et al., Fermilab PUB-76/42, submitted to Phys. Rev. Letters.

[7]This rapidity correlation is chosen in the spirit of multi-peripheral type models. Relaxing this assumption and producing the C and $\bar{C}$ completely uncorrelated from the J reduces the third muon acceptance by a factor of 2.

[8]This conclusion would be weakened if the mechanism for $JC\bar{C}$ production only yielded J's with $x_F$ near 0. However, the data on J production (e.g., Ref. 6) shows that there is no increase in J production near $x_F = 0$, and so only central production of $JC\bar{C}$ cannot explain the large rise in cross section.

TABLE I

OBSERVED YIELD OF TRIMUONS

| $\mu^+\mu^-$ Mass | | TARGET #2 $\mu$ | TARGET #3 $\mu$ | TARGET $\langle p \rangle$ 3rd $\mu$ | TARGET $\langle p_\perp^2 \rangle$ of 3rd $\mu$ | CORE #2 $\mu$ | CORE #3 $\mu$ | CORE $\langle p \rangle$ of 3rd $\mu$ | CORE $\langle p_\perp^2 \rangle$ of 3rd $\mu$ | Predicted #3 $\mu$ from core |
|---|---|---|---|---|---|---|---|---|---|---|
| .60 - .95 | ($\rho$) | 26443 | 91 | 29. | .17 | | | | | |
| 2.6 - 3.6 | (J) | 558 | 2 | 10. | .10 | 1915 | 2 | 15 | .30 | 1 |

# FIGURE CAPTIONS

Figure 1: Yield of dimuons from a) target b) core
Flux in high mass data represents 2.5 times flux in low mass data.

Figure 2: Observed $p_{||}$ distribution of J's in our apparatus.
Solid line = data
Dotted line = prediction from model of OZI-allowed production

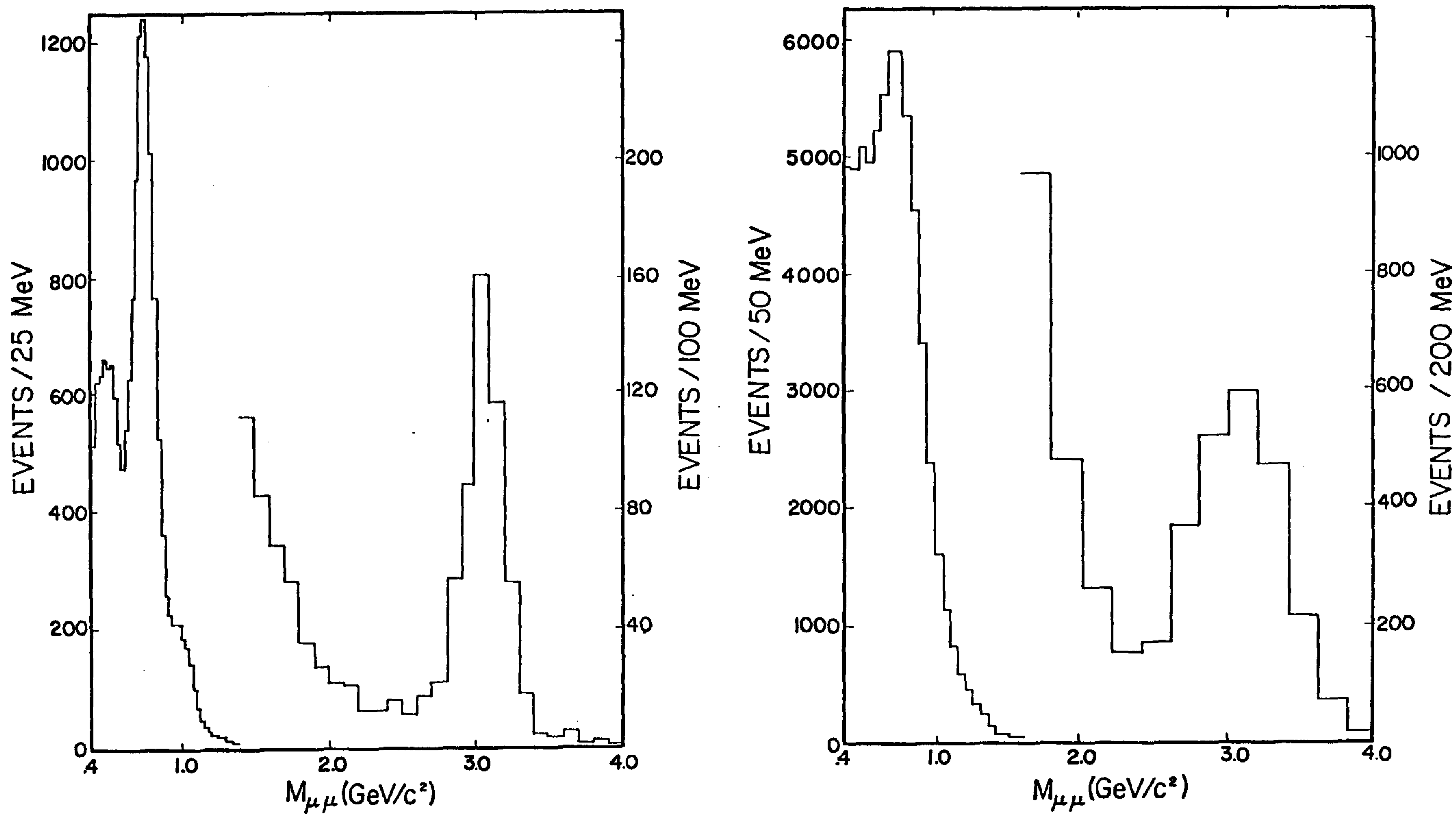
EVENTS / 25 MeV
EVENTS / 100 MeV
EVENTS / 50 MeV
EVENTS / 200 MeV
1200
1000
800
600
400
200
0
6000
5000
4000
3000
2000
1000
.4
1.0
2.0
3.0
4.0
$M_{\mu\mu}$ (GeV/c²)

Fig. 1

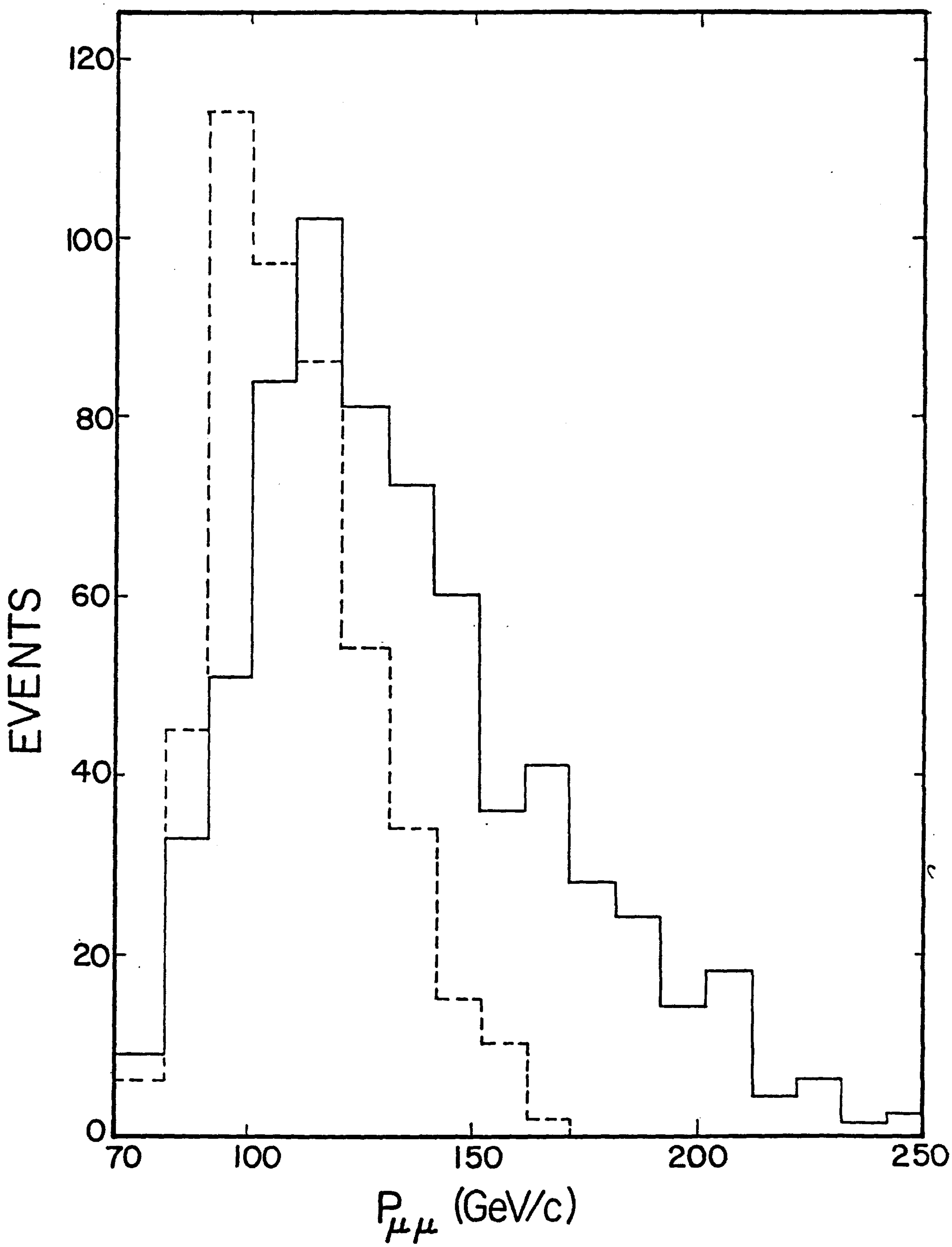


Fig. 2