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DIRECT ELECTRON PAIR PRODUCTION IN $\pi^{\pm}p$ INTERACTIONS AT 18 GeV/c*

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Abstract

Using the SLAC Hybrid Facility 1-m bubble chamber fitted with tantalum plates, a measurement was made of direct unexplained e^+e^- pair production in 18 GeV/c $\pi^{\pm}p$ interactions. Limits are set in π^+p processes. In π^-p a signal is observed which cannot be caused by η, ω or ρ decay, and for masses $> m_{\pi^0}$, $e^{\pm}/\pi^{\pm} = (0.87 \pm 0.25) \times 10^{-4}$. Some properties of the events are discussed.

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This report is based on data taken with the SLAC 1-m Bubble Chamber Hybrid Facility in an investigation of direct e^+ or e^- production in 18 GeV $\pi^+ p$ and $\pi^- p$ interactions. At similar energies, and also at the I.S.R., experiments using single particle spectrometers[1] have shown a low p_T enhancement of hadronically produced e^+ and e^- which is not yet understood.[2] (In the text, "electron" will refer to e^+ or e^-). An earlier result from this experiment[3] has indicated that unpaired electron production is not significant. Here we report measurements on pair production.

The bubble chamber was equipped with three tantalum plates, each 1.0 r.l. thick. Approximately 90% of electrons could be identified by spiralling, ionization (for momenta $\lesssim$ 200 MeV/c), Bremsstrahlung, etc. in the hydrogen, or by showers in the plates, while hadrons were misidentified as electrons[3] at a level $< 10^{-4}$. Backgrounds for events where both tracks are identified are consequently negligible. The remaining 10% of electrons have momentum $\gtrsim$ 200 MeV/c and miss the plates, and so require a momentum-dependent geometrical acceptance correction to the observations.

The technique contrasts with Ref. 1 in affording limited statistics but strong systematic advantages. Almost all charged tracks (and $\sim$ 80% of γ rays) are detected in the bubble chamber, including electrons from asymmetric pairs with momentum > 1 MeV/c. Possible backgrounds from δ rays or Compton scattering near the vertex are removed by requiring charge balance in the interaction.

Identification decisions were made by physicists after candidate events were found by scanners. The scanning efficiency for identifiable electron events was (94 ± 1) % after 66% of the film was scanned twice and 7% three times. Normalization was established by scanning random rolls for the number of pions produced in fiducial volume interactions. The data correspond to 4.2×10^5 inelastically produced $\pi^\pm$ from $\pi^+ p$ and 5.2×10^5 from $\pi^- p$

interactions. This count has been used to estimate e^+e^- pair production from known processes, and e/π production ratios after scanning and acceptance corrections.

Events with electrons fell into two categories; Cat. I: both tracks identified as electrons (3782 events); Cat II: one track identified, but accompanied by unidentifiable tracks of opposite charge (893 events). A few cases with only one possible "electron" were treated elsewhere.[3] Where two pairs occurred in an event the combinations with highest pair masses were rejected. There were 133 unmeasurable pairs, mostly because of momenta < 3 MeV/c. The background of photons converting near the primary vertex and taken to be Dalitz pairs was estimated at 214 ± 58 events.

Monte Carlo studies have been made on the identification acceptance and measurement resolution. Correlated $p_{\parallel}$, p_T distributions of inclusive pion production[4] lead to good agreement with the observed Dalitz pair spectra in pair mass, lab. momentum, p_T, etc. The ratio between populations of Cat. II and Cat. I is 0.236 ± 0.01: the simulation gives 0.234 ± 0.007. Using the known inclusive cross sections for $\pi^{\pm}$ and π^o,[4] for ρ^o, ω^o and η,[5] branching ratios,[6,7] and normalizing to the measured $\pi^{\pm}$ production, 4606 ± 393 pairs are expected in Cat. I and II, including the γ background. We observe 4675.

Checks have been made that measurement systematics on these events do not mask the signal of interest, ∿ 50 events for e/π ∿ 10^{-4}, which may be sought where the π^o contribution is small, e.g., $m_{ee} \gtrsim m_{\pi^o}$. From the quality of fit of measurements to hypothetical trajectories, the reconstruction program estimated uncertainties in momentum and angle, and in invariant mass of each pair. (This procedure for uncertainties has been checked at fixed mass values with measurements of γ conversions in the hydrogen and K^o and Λ decays.) The mass uncertainties of pairs outside the low mass Dalitz pair peak agree

with the distributions expected and are not anomalously large, indicating that there is no significant contamination of higher masses by poorly measured low mass events. From the γ, K and Λ measurements the average mass uncertainty was σ_m = 7 MeV/c^2. In Fig. 1 is shown the mass spectrum for Cat. I events and simulations with and without resolution functions. A broad range of (non-Gaussian) resolution parameters is satisfactory above $\sim$ 20 MeV/c^2 and does not change the conclusions of the experiment.

The inclusive cross sections used for ρ, ω and η simulations are 4.9 ± 0.22, 4.15 ± 1.0 and 1.55 ± 0.55 mb respectively. The last two are scaled from semi-inclusive measurements by comparison with ρ production[5], but are consistent with quark model expectations for the production ratios.[8] To be conservative, we have arbitrarily increased the reported errors on σ_ω by X2 and on σ_η by X3. An inclusive result, $\sigma_\eta \lesssim 1$ mb has also recently been reported.[9] The distributions of these mesons are taken to follow those of the ρ in $p_{\parallel}$ and p_T,[5] since there is rather strong evidence for a universality in this respect, but wide variations do not affect the conclusions of this work.

In Fig. 2 are shown the mass distributions above 130 MeV/c^2 for Cat. I events, with π^+p and π^-p treated separately. Not plotted are 3 events in the ρ-ω mass region where 3.6 are expected, and an event in π^-p at 1420 MeV/c^2. There is an unexplained excess of π^-p, but not of π^+p, events

In the π^-p data, neither the 1420 MeV/c^2 event nor 3 events (where 0.15 are expected) between 420 and 600 MeV/c^2 could be explained by unexpectedly large ρ, ω or η contributions. For $m_\pi < m_{ee} < 600$ MeV/c^2 the <u>excess</u> is 16.1 ± 4.7 events, or $e^\pm/\pi^\pm = (0.87 \pm 0.25) \times 10^{-4}$, and is consistent with a parameterization exp $(-m_{ee}/M)$, M = 195 ± 80. In this mass range M = 100 for the η and ω contribution. In the lower mass interval $m_\pi/2$ to m_π the excess

is 7.0 ± 9.2 events.

Fig. 3 shows the electron p_T distribution. It contrasts with results of Ref. 1, which gave e^+/π^- for $p_T > 500$ MeV/c in π^+p and pp interactions at 15 GeV/c. In π^+p, our data require $e^\pm/\pi^\pm < 2.5 \times 10^{-5}$ (90% C.L.) for $m_{ee} > 100$ MeV/c^2. For tracks with $p_T > 500$ MeV/c and $m_{ee} > 100$ MeV/c^2, we have $e^\pm/\pi^\pm < 3 \times 10^{-5}$ (π^-p) and $< 1 \times 10^{-5}$ (π^+p) at 90% C.L.

Cat. II events (one track identified, with unidentified opposite charge tracks) have an additional background, evaluated in conjunction with Ref. 3, caused by pions interacting in the plates and simulating electrons at a rate of $\sim 0.5 \times 10^{-4}$. Allowing for this there is excellent agreement in both π^+p and π^-p between data in Cat. I and Cat. II. In particular, in π^-p for $m_\pi < m_{ee} < 600$, the 14 events observed correspond to 14.6 ± 3.3 scaled from Cat. I. The excess over "known" processes is 5.2 ± 4.7 events.

Since the background from "known" sources is only ∿ 25% of the 21 π^-p Cat. I events with $m_\pi < m_{ee} < 600$, (but ∿ 65% of Cat. II events) we have examined some of their properties. The distribution of charged hadron multiplicities is similar to that of 18 GeV/c πp interactions in general. The distribution of charge transferred to the backward hemisphere follows the "universal curve",[10] with a mean value of -0.89 ± 0.2. The angular distribution of the electron about the direction of the massive virtual "photon" resembles that of photon interactions, $(1 + a \cos^2 \theta)$, with $a = 1.4^{+\ 3.4}_{-\ 0.4}$. The pairs are clustered near X_F ($= p_{||}^{CM}/p_{Max}^{CM}$) = 0. Only two pairs exceed $X_F = 0.25$.

Finally, in Fig. 4 is given the multiplicity distribution of observed γ-conversions accompanying these events. The probability of detecting a γ ray is ∿ 80% which badly distorts the distribution at high γ multiplicities. As a comparison we indicate the distribution obtained by scanning interactions

without e^+e^- pairs, and (Fig. 4b) from events with low mass Dalitz pairs. The differences suggest that the excess high mass pairs occur in interactions with an even number of free γ rays, unlike π^o or η Dalitz pairs.

In summary, there is evidence of direct, unexplained, production of e^+e^- pairs in π^-p interactions, with a broad mass spectrum and a steep p_T dependence. The data from π^+p indicate a smaller effect, if any, and neither set is consistent with the p_T distribution reported in Ref. 1 for π^+p and pp interactions.

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References

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Figure Captions

1. Mass distribution of e^+e^- pairs from π^+p and π^-p, both electrons identified. The dots represent the simulation, and dashes the simulation without the effects of resolution.

2. Observed (lines) and expected (dots) events at higher masses: a. π^+p; b. π^-p.

3. Electron transverse momentum distributions for π^-p events with $135 < m_{ee} < 600$ MeV/c^2: a. Tracks in excess of expectations; b. The corresponding $e^\pm/\pi^\pm$ ratio, with the excess from Ref. 1 (dashes).

4. Gamma ray multiplicity distributions: a. Events in π^-p with $135 < m_{ee} < 600$ MeV/c^2 and (dots) events with no associated e^+e^- pair plotted at 1/5 scale; b. Events with an associated low mass Dalitz pair.

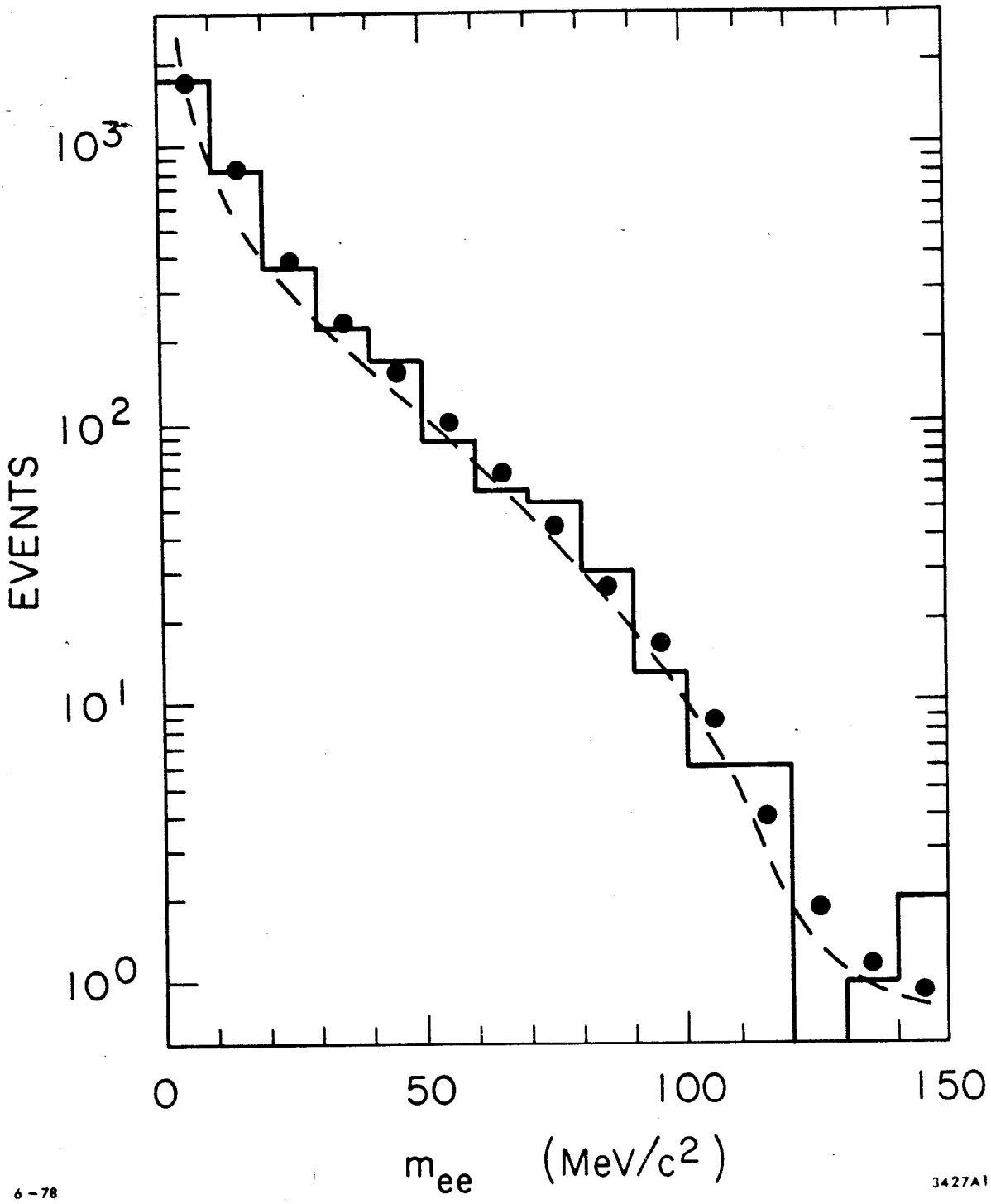

Fig. 1

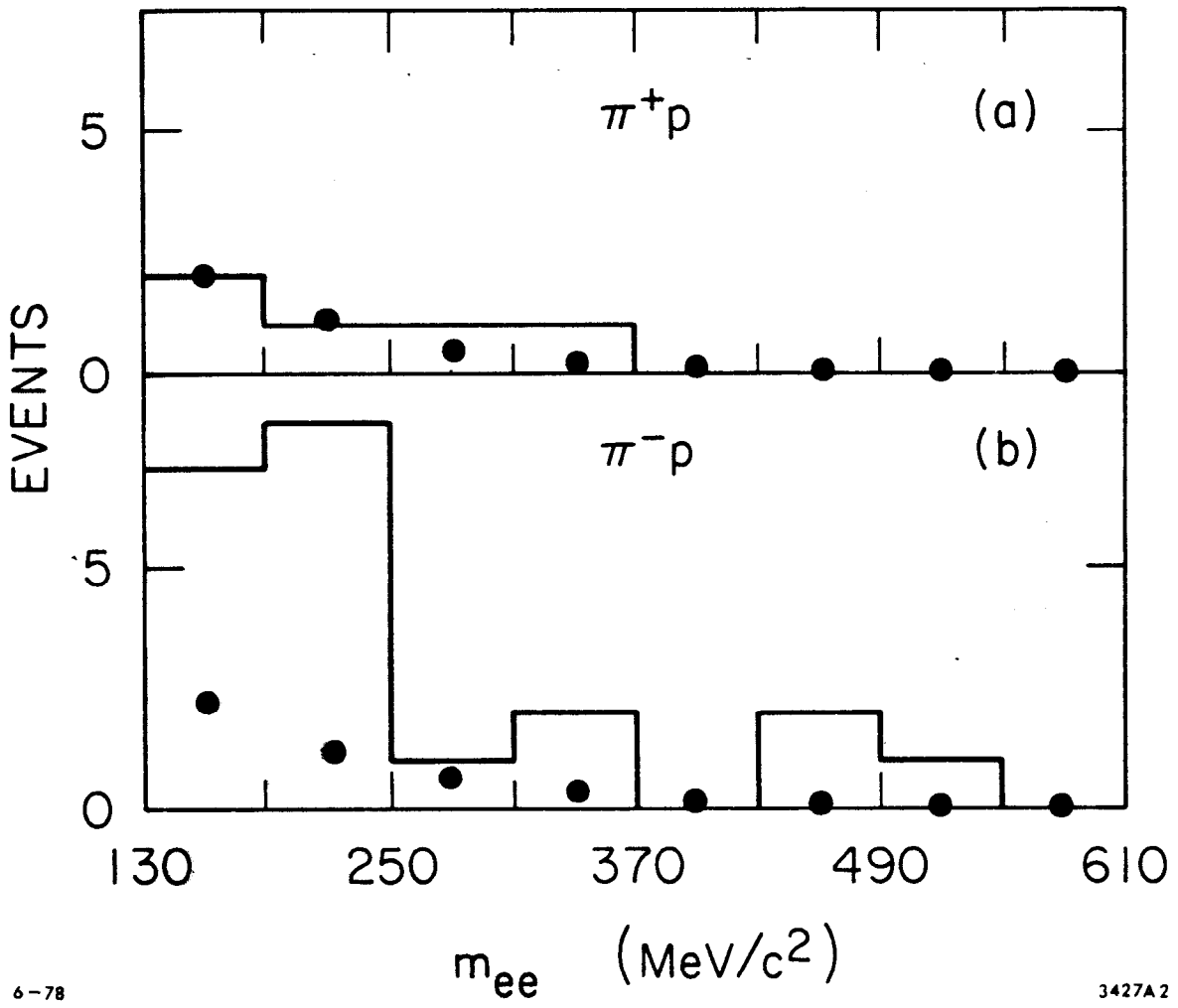
π^+p
(a)
5
0
EVENTS
π^-p
(b)
5
0
130
250
370
490
610
m_{ee} (MeV/c^2)
6-78
3427A2

Fig. 2

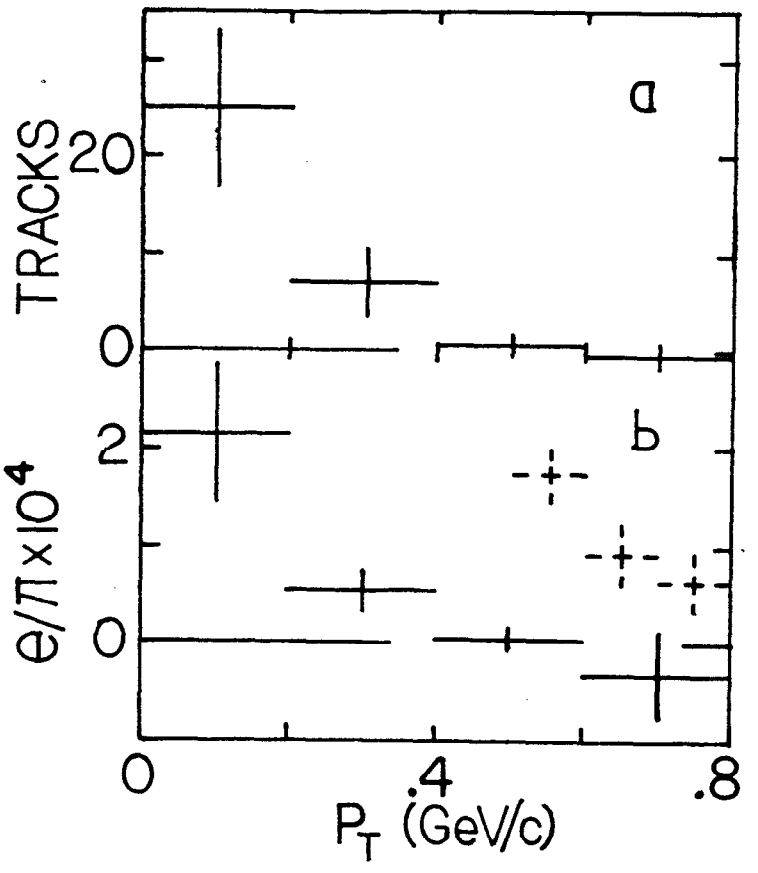

Fig. 3

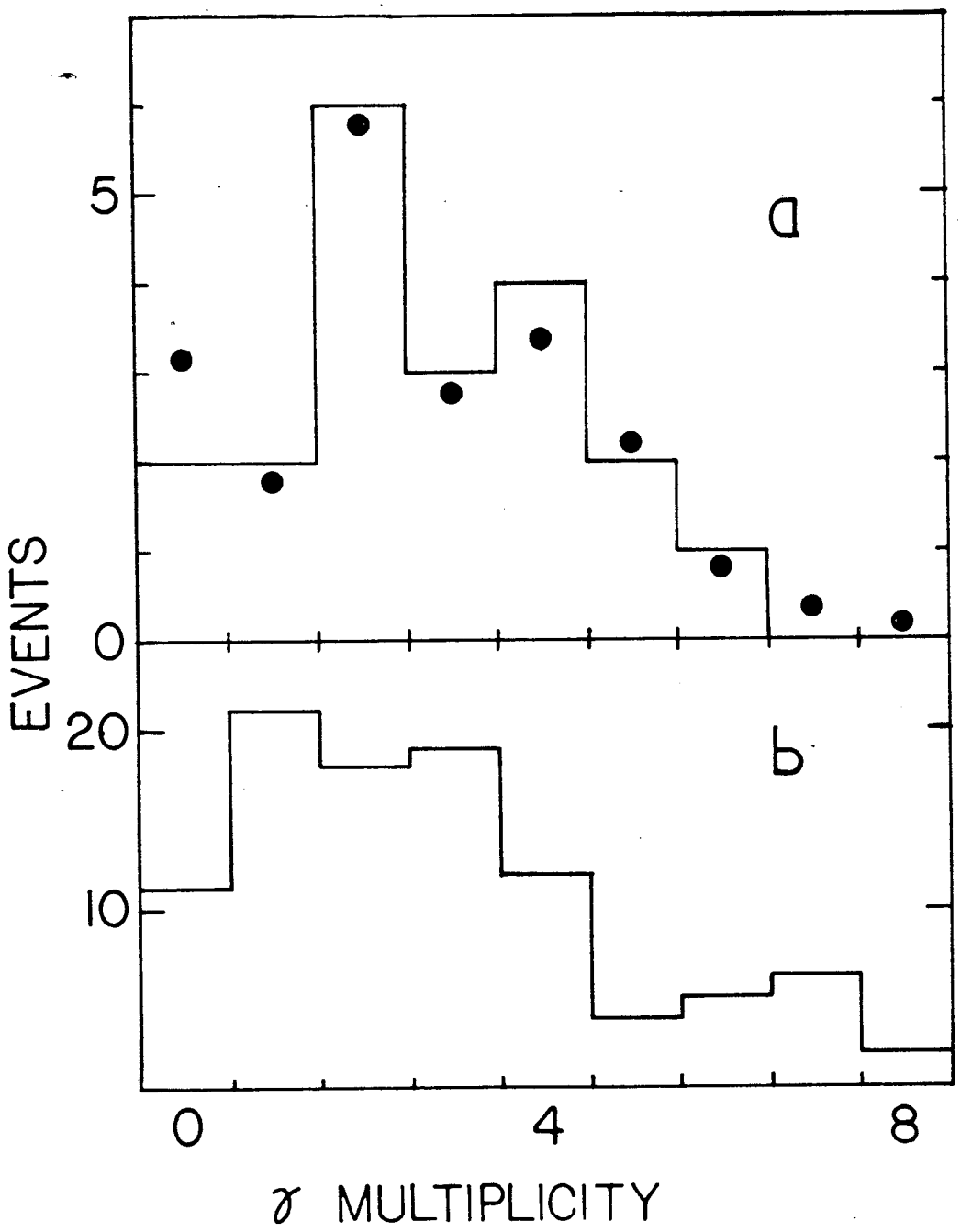

Fig. 4