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MASTER

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PRODUCTION OF LIKE SIGN DIMUON EVENTS BY NEUTRINOS*

by

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Abstract

A sample of 46 $\mu^-\mu^-$ events has been obtained in studying high energy neutrino interactions at Fermilab. The analysis of these data yields a prompt rate, $N^{\text{prompt}}(\mu^-\mu^-)/N^{\text{prompt}}(\mu^-\mu^+)$, of 0.12 ± 0.05 for $P_\mu > 10$ GeV/c. The $\mu^-\mu^-$ events are predominantly of hadronic origin.

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I. Introduction

The observation of dimuon events in high energy neutrino interactions was one of the first indications of the production of particles with a new quantum number.[1] Opposite sign dimuons are now known to arise predominantly, if not completely, from the production of charmed particles and subsequent semileptonic decay. The origin of same sign dimuon events ($\mu^-\mu^-$ or $\mu^+\mu^+$) however is not clear. The observed rate for such events is small and therefore decay in flight of pions and kaons produced in ordinary charged current interactions is an important background. We present here an analysis of 46 $\mu^-\mu^-$ events observed in high energy neutrino interactions at FNAL.

II. Beams and Detector

The different beams and detector used in the experiment are described in greater detail in another contribution to this conference[2] and in ref. 3. Two features of the detector are particularly important. One, the neutrino interactions occur in three targets of different hadron absorption lengths (see Table 1). Second, the 7.3 m diameter toroids in the muon spectrometer provide a very large acceptance that is independent of the sign of the muon.

III. Data Sample

The QT I and BTSSν runs described in ref. 2, yielded 199 $\mu^+\mu^-$ events and 46 $\mu^-\mu^-$ events. A sample of events from the QT II run has been analyzed and preliminary results for events with all momenta > 20 GeV/c will be presented.

IV. Is There a Prompt Signal?

The relative rates for $R(\mu^-\mu^-)/R(\mu^-)$ are difficult to determine because of acceptance and trigger differences. The ratio $N(\mu^-\mu^-)/N(\mu^-\mu^+)$, however, does not have these problems, i.e. triggers and geometrical acceptance are the same.

The observed numbers of events from each target are presented in Table 1. A cut of $P_\mu > 5$ GeV/c (10 GeV/c) reduces the number of $\mu^-\mu^-$ events to 38 (18). The ratio $N^{obs}(\mu^-\mu^-)/N^{obs}(\mu^-\mu^+)$ is shown in Fig. 1a and 1b for a 5 GeV/c and 10 GeV/c momentum cut, respectively. This ratio may be written as

$$N^{obs}(\mu^-\mu^-)/N^{obs}(\mu^-\mu^+) = \left[N^{prompt}(\mu^-\mu^-) + N^{decay}(\mu^-\mu^-)\right] \Big/ \left[N^{prompt}(\mu^-\mu^+) + N^{decay}(\mu^-\mu^+)\right]$$

The quantity $N^{decay}(\mu^-\mu^+)$ has been calculated by a Monte Carlo program which uses the known distributions of pions and kaons produced by neutrinos and which accounts for the reinteraction of the primary π's and K's.[4] For $P_\mu > 10$ GeV/c, the fraction of $\mu^-\mu^+$ from decay is 6-22%, depending upon the target (labelled $N^{decay}(\mu^-\mu^+)$ in Table 1). After this subtraction, the ratio $N^{obs}(\mu^-\mu^-)/N^{prompt}(\mu^-\mu^+)$ should depend linearly on hadronic absorption length (λ) and a finite intercept at $\lambda = 0$ would indicate a prompt source. This ratio is shown in Figs. 1c and 1d and the data are well described by linear fits.

Clearly for the 5 GeV/c cut data, a significant fraction of the observed $\mu^-\mu^-$ signal arises from π and K decay. The intercepts, however, are finite at $\lambda = 0$ for both the 5 GeV/c (0.09 ± 0.09) and 10 GeV/c (0.15 ± 0.10) cut data. Also, the fitted slopes are in reasonable agreement with the values obtained from the Monte Carlo calculation for $N^{decay}(\mu^-\mu^-)$. In particular, for the 5 GeV/c cut, the fitted slope value is $3.0 \pm 1.3 \times 10^{-3}$ cm^{-1} and the predicted value is $4.0 \pm 1.0 \times 10^{-3}$ cm^{-1}. One may then use the Monte Carlo values for $N^{decay}(\mu^-\mu^-)$ to obtain $N^{prompt}(\mu^-\mu^-)$.

Averaging over all three targets, we obtain $N^{prompt}(\mu^-\mu^-)/N^{prompt}(\mu^-\mu^+) = 0.06 \pm 0.05$ for the 5 GeV/c cut and 0.12 ± 0.05 for the

10 GeV/c cut. This indicates that a prompt signal may exist. It is somewhat more statistically powerful to observe that we see, for $P_\mu > 10$ GeV/c, 18 events and expect only 7.5 ± 1.9 events.

Some of the properties of the $\mu^-\mu^-$ events are shown in Figs. 3a, 4a, 5a, 6a and 7a. Similar distributions for the ν induced $\mu^-\mu^+$ events are shown in Figs.3b, 4b,5b, 6b and 7b for comparison. One observes that there is no striking difference between the properties of $\mu^-\mu^+$ and $\mu^-\mu^-$ events. The $\Delta\varphi$ distribution (Fig.3a) suggests that the $\mu^-\mu^-$ events are predominantly of hadronic origin. The visible energy distribution (Fig.4) indicates a production energy dependence similar to charm production. Of course the substantial background from decay is included in the plots which would dilute any energy dependence dissimilar from charm.

There are at least two conventional origins for $\mu^-\mu^-$ events. First, the same processes which yield trimuon events ($\mu^-\mu^-\mu^+$) may also result in $\mu^-\mu^-$ events if the μ^+ is lost as a result of detection inefficiency. Second, the production of charm-anticharm pairs and subsequent decay could also result in same sign dimuons. It is presently believed that the majority of trimuon events ($\geqslant 80\%$) come from radiative or direct muon pair production.[2] If these virtual photon processes were entirely responsible for the prompt $\mu^-\mu^-$ signal, one would expect $R(\mu^-\mu^-)/R(\mu^-\mu^-\mu^+) < 1$, particularly for $E_\nu > 100$ GeV where the trimuon acceptance is good. At present, the data do not support this hypothesis as $R(\mu^-\mu^-)$ is ~ 6 times the trimuon rate. Current theoretical estimates for the production of charm-anticharm predict rates lower than the measured value.[5] It is unlikely that the majority of the prompt $\mu^-\mu^-$ events come from the production of hadronic flavors beyond charm. We do not observe a rate increase as E_ν increases as one would anticipate for heavy new quark production. Also the $P_\perp$ (out of the ν- μ plane) distribution shown in Fig. 7 is consistent with the decay of particles with mass $\leq$ charm.

V. Preliminary Results from QT II

At present we have analyzed a small fraction of the dimuon data obtained during the QT II run. In particular we have selected events in which both muons traverse the entire spectrometer. This yields a sample containing 12 $\mu^-\mu^-$ events with $P_\mu > 20$ GeV/c. Since this sample is not free of acceptance biases as was the earlier, we have attempted to correct for the relative acceptance of $\mu^-\mu^-/\mu^-\mu^+$ by using a charm-like model, i.e. assume $\mu^-\mu^-$ has the same kinematical characteristics as $\mu^-\mu^+$ from charm. With this assumption, we obtain an $N^{\text{prompt}}(\mu^-\mu^-)/N^{\text{prompt}}(\mu^-\mu^+)$ of 0.10 ± 0.05, in agreement with our earlier conclusion. Stated another way, we see 12 events and expect only 3.5 from π or K decay.

VI. Conclusion

We have presented evidence for the production of prompt $\mu^-\mu^-$ events by neutrinos at a rate $10 \pm 5\%$ of the prompt $\mu^-\mu^+$ rate. Using our measured opposite sign production rate would yield $R(\mu^-\mu^-)/R(\mu^-) = 4 \pm 2 \times 10^{-4}$ for all E_ν and $6.5 \pm 3.5 \times 10^{-4}$ for $E_\nu > 100$ GeV.[6] The observed $\mu^-\mu^-$ events are predominantly of hadronic origin. New heavy quarks or heavy leptons do not appear to be a significant source of the events. Further data are needed to determine what fraction of the $\mu^-\mu^-$ signal arises from charm-anticharm and radiative process.

The data presented here were obtained by members of the E-310 collaboration from Fermilab, Harvard, Ohio State, Pennsylvania, Rutgers and Wisconsin. The members are: A Benvenuti, F. Bobisut, D. Cline, P. Cooper, S. M. Heagy, R. Imlay, T. Y. Ling, A. K. Mann, S. Mori, D. D. Reeder, J. Rich, R. Stefanski, and D. R. Winn.

References and Footnotes

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1. A. Benvenuti et al, Phys. Rev. Lett. 34, 419 (1975); A. Benvenuti et al, Phys. Rev. Lett. 35, 1199 (1975); ibid 35, 1203 (1975).
2. Trimuon Production by Neutrinos, M.G.D. Gilchriese submitted to this conference.
3. A. Benvenuti et al, Phys. Rev. Lett. 40, 432 (1977).
4. The decay calculation has an estimated error of ± 25% and is described in greater detail in an E-310 internal memo, Muons from π and K Decay, by R. Imlay.
5. H. Goldberg, Phys. Rev. Lett. 39, 1598 (1977); B. L. Young, T. F. Walsh and T. C. Yang, Phys. Lett. 74B, 111 (1978).
6. The $\mu^-\mu^+$ rates may be found in A. Benvenuti et al preprint COO-1545-233, to be published.

TARGET	FIDUCIAL MASS (Tons)	ABS. LENGTH (cm)	$N^{obs}(\mu^-\mu^+)$		$N^{decay}(\mu^-\mu^+)$		$N^{obs}(\mu^-\mu^-)$		$N^{decay}(\mu^-\mu^-)$	
			$p_\mu>5$ GeV	$p_\mu>10$ GeV	$p_\mu>5$ GeV	$p_\mu>10$ GeV	$p_\mu>5$ GeV	$p_\mu>10$ GeV	$p_\mu>5$ GeV	$p_\mu>10$ GeV
IRON (FeT)	198	31	75	50	11.7	3.1	12	8	8.1	1.9
IRON CAL. (FeC)	42	61	42	23	11.1	2.3	10	4	7.8	1.8
LIQ. CAL. (LiqC)	36	120	56	32	23.5	6.9	16	6	16.3	3.8
TOTAL			173	105	46.3	12.3	38	18	32.2	7.5

TABLE 1. Fiducial masses, absorption lengths and numbers of observed dimuon events in the three targets. Also shown are the calculated numbers of dimuon events from pion and kaon decays.

Figure Captions

1. Ratios of like sign to opposite sign events before correcting $\mu^-\mu^+$ for decay (a) and (b) and after, (c) and (d).

2. Scatter plot of the fast vs slow μ^-.

3. Azimuthal difference, $\Delta\varphi$; (a) $\mu^-\mu^-$ and (b) $\mu^-\mu^+$ events.

4. Visible energy distribution; (a) $\mu^-\mu^-$ and (b) $\mu^-\mu^+$ events.

5. X_{vis} distribution for; (a) $\mu^-\mu^-$ and (b) $\mu^-\mu^+$ events.

6. Y_{vis} distribution for; (a) $\mu^-\mu^-$ and (b) $\mu^-\mu^+$ events.

7. The transverse momentum out of the ν- μ scattering plane; (a) $\mu^-\mu^-$ and (b) $\mu^-\mu^+$ events.

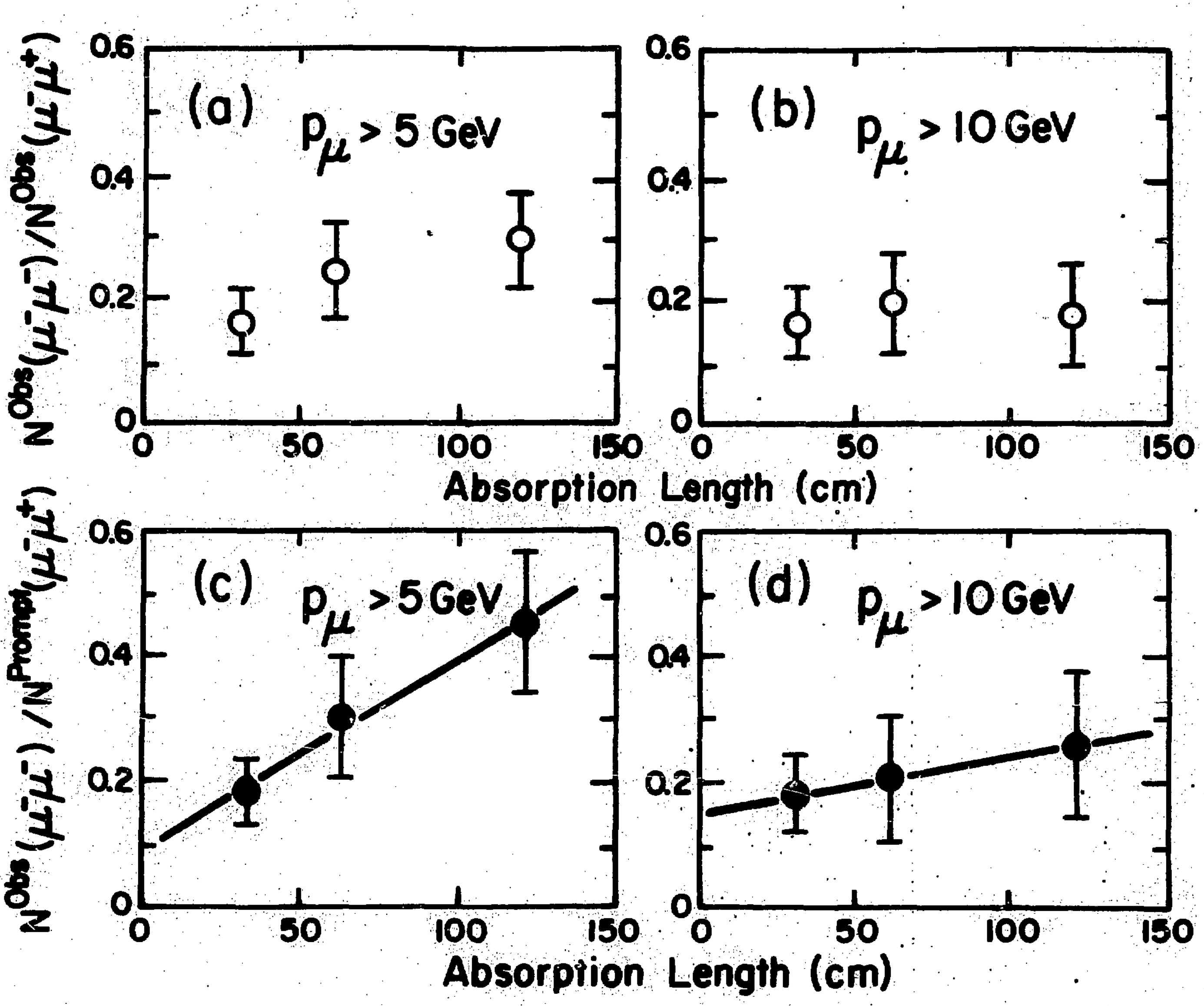
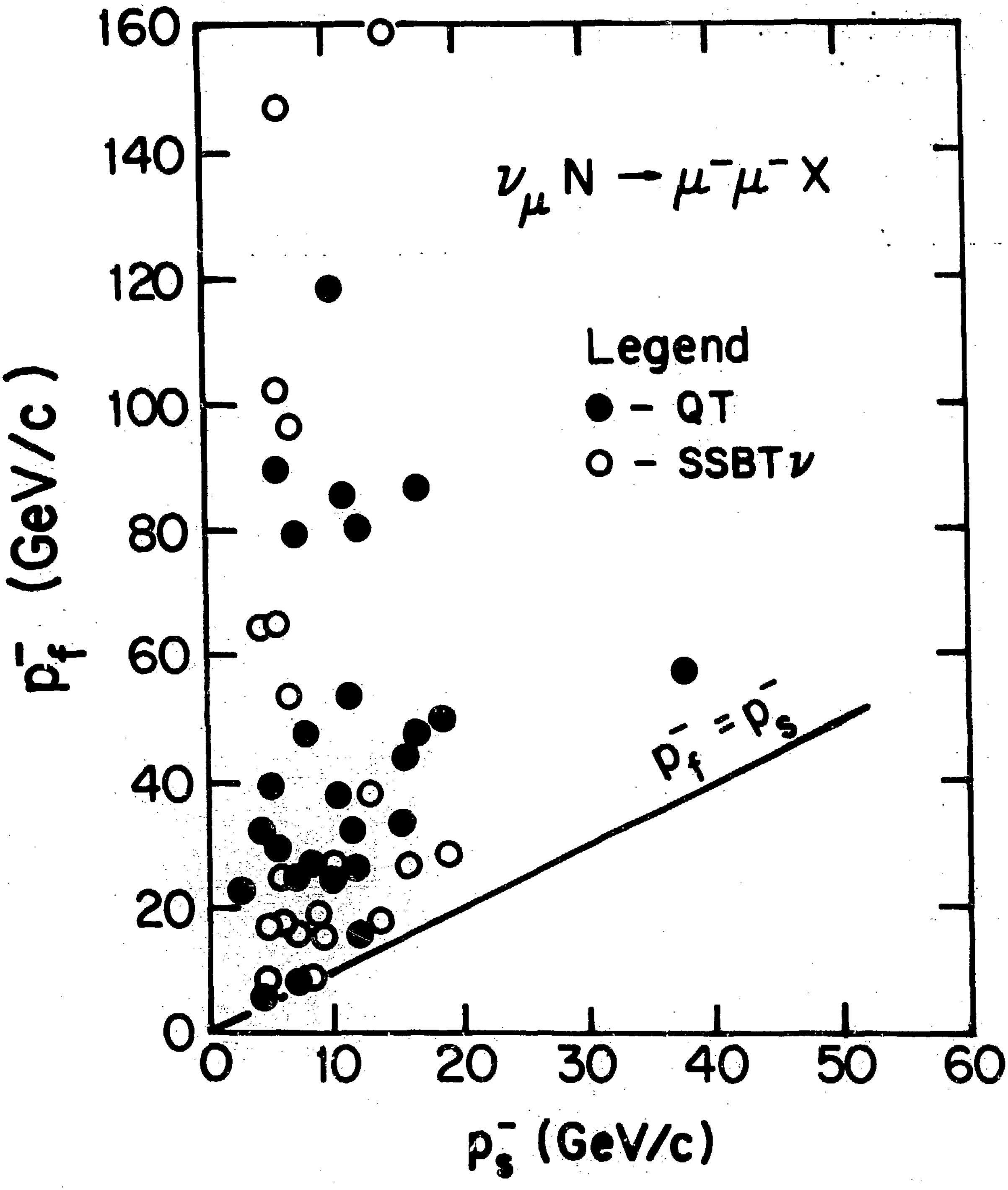

$N^{Obs}(\mu^-\mu^-)/N^{Obs}(\mu^-\mu^+)$
(a)
$p_\mu > 5$ GeV
(b)
$p_\mu > 10$ GeV
0.6
0.4
0.2
0
0
50
100
150
Absorption Length (cm)
$N^{Obs}(\mu^-\mu^-)/N^{Prompt}(\mu^-\mu^+)$
(c)
$p_\mu > 5$ GeV
(d)
$p_\mu > 10$ GeV
Absorption Length (cm)

Fig. 1



$\nu_\mu N \rightarrow \mu^- \mu^- X$
Legend
● - QT
○ - SSBTν
$p_f^- = p_s^-$
p_f^- (GeV/c)
p_s^- (GeV/c)
0
20
40
60
80
100
120
140
160
0
10
20
30
40
50
60

Fig. 2

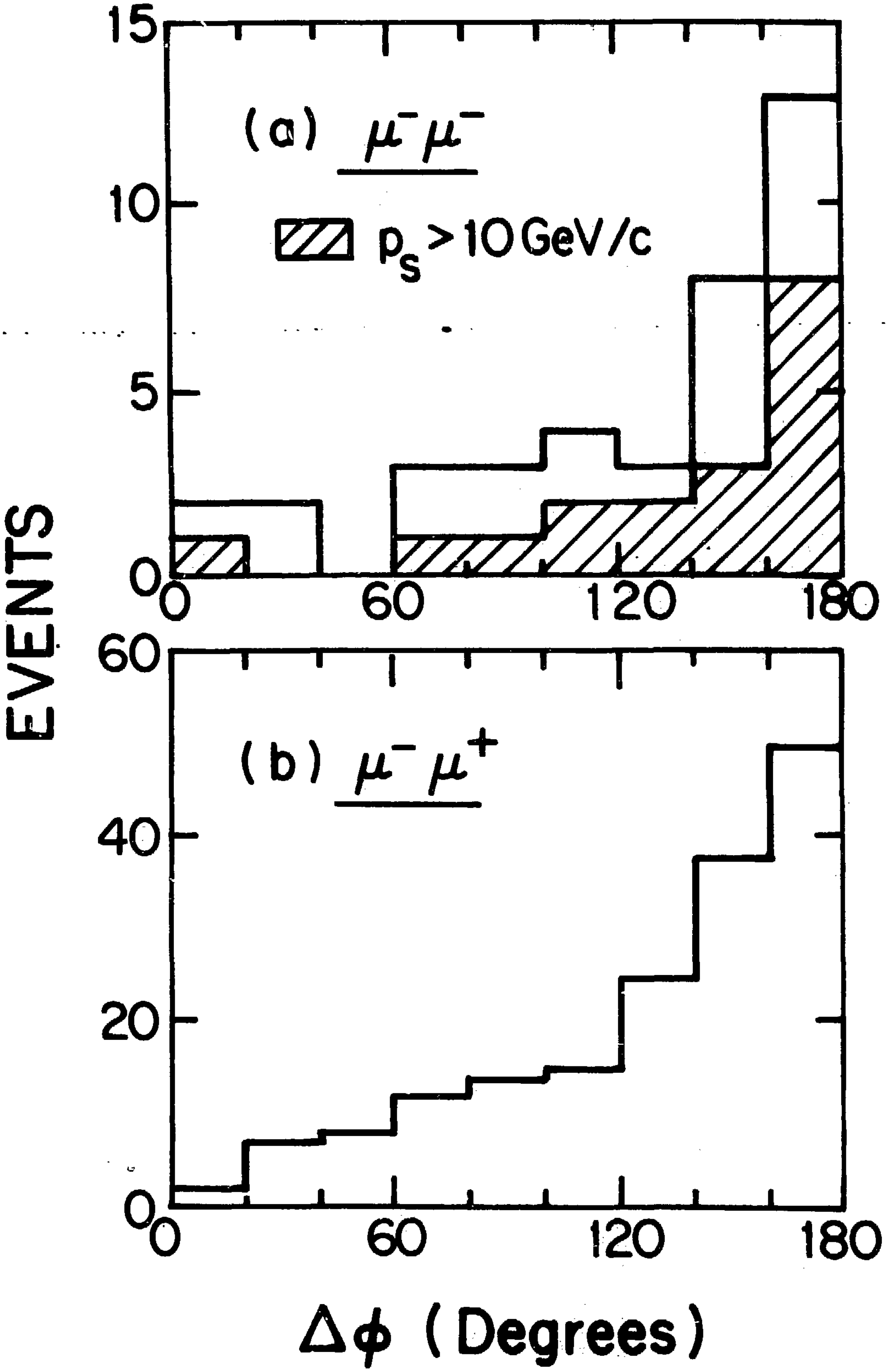
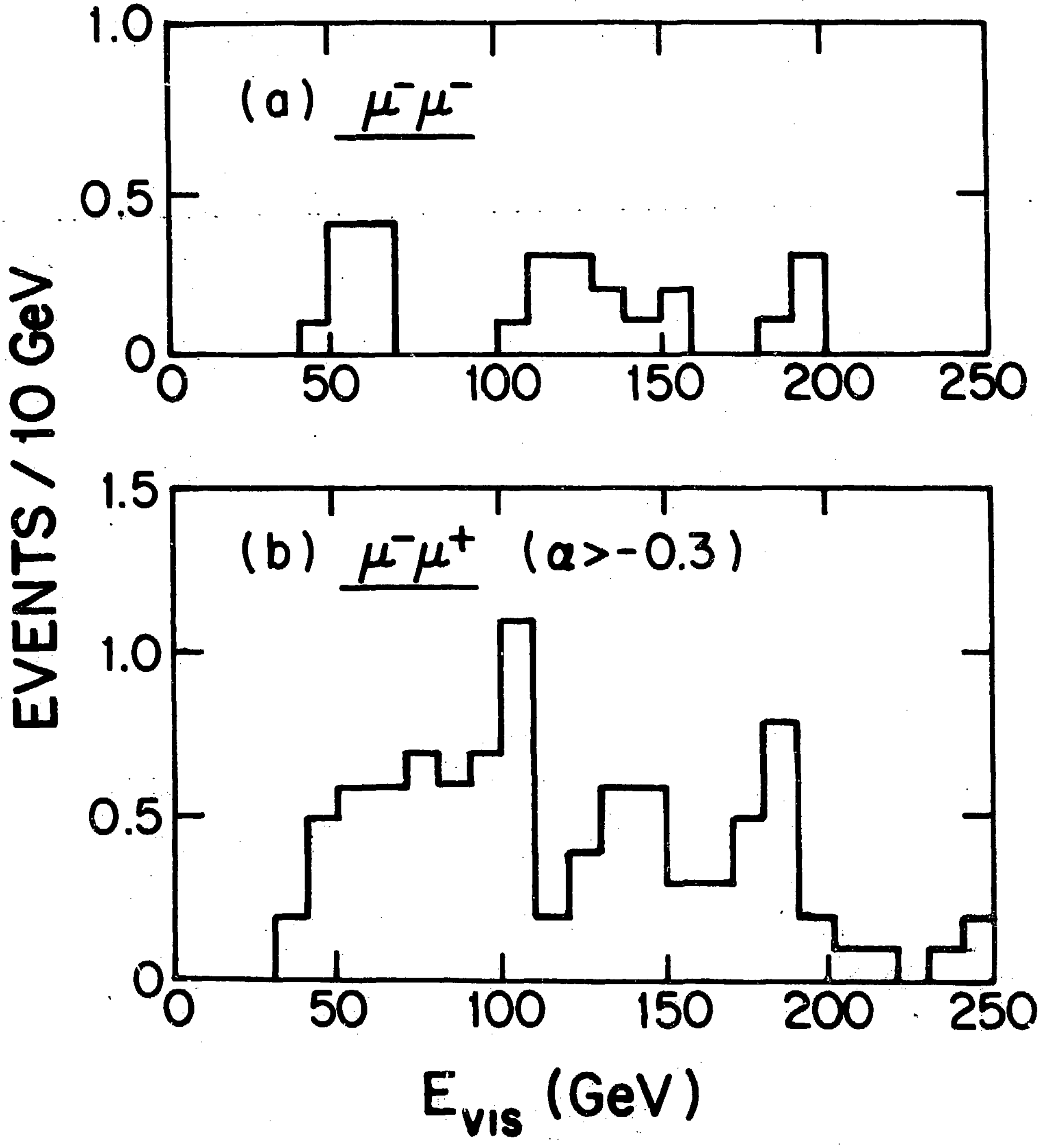

15
10
5
0
(a) $\mu^-\mu^-$
▨ $p_s > 10$ GeV/c
0
60
120
180
EVENTS
60
40
20
0
(b) $\mu^-\mu^+$
0
60
120
180
Δφ (Degrees)

Fig. 3



EVENTS / 10 GeV
1.0
(a) $\mu^-\mu^-$
0.5
0
0
50
100
150
200
250
1.5
(b) $\mu^-\mu^+$ ($\alpha>-0.3$)
1.0
0.5
0
0
50
100
150
200
250
E_{VIS} (GeV)

Fig. 4

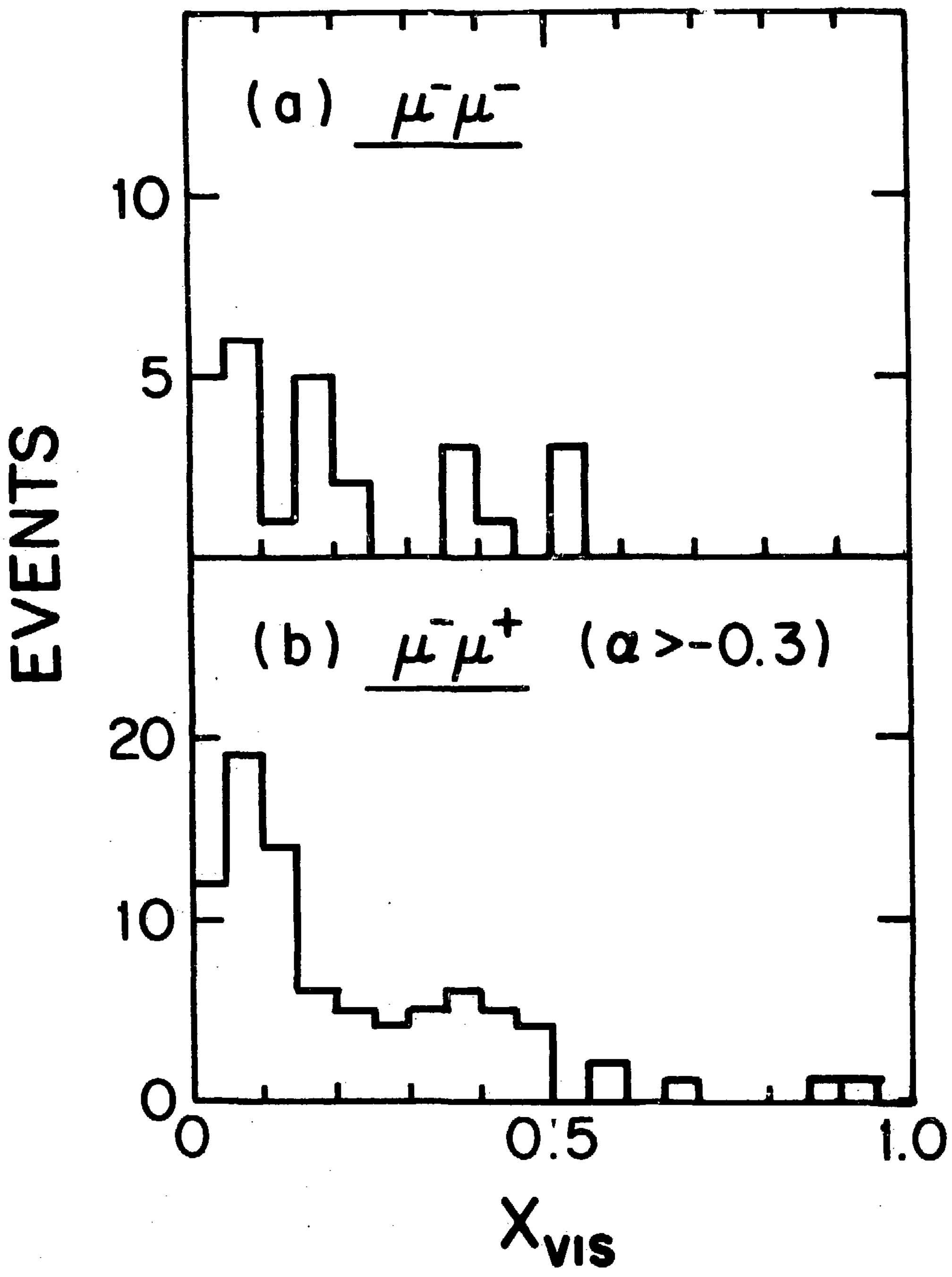


Fig. 5

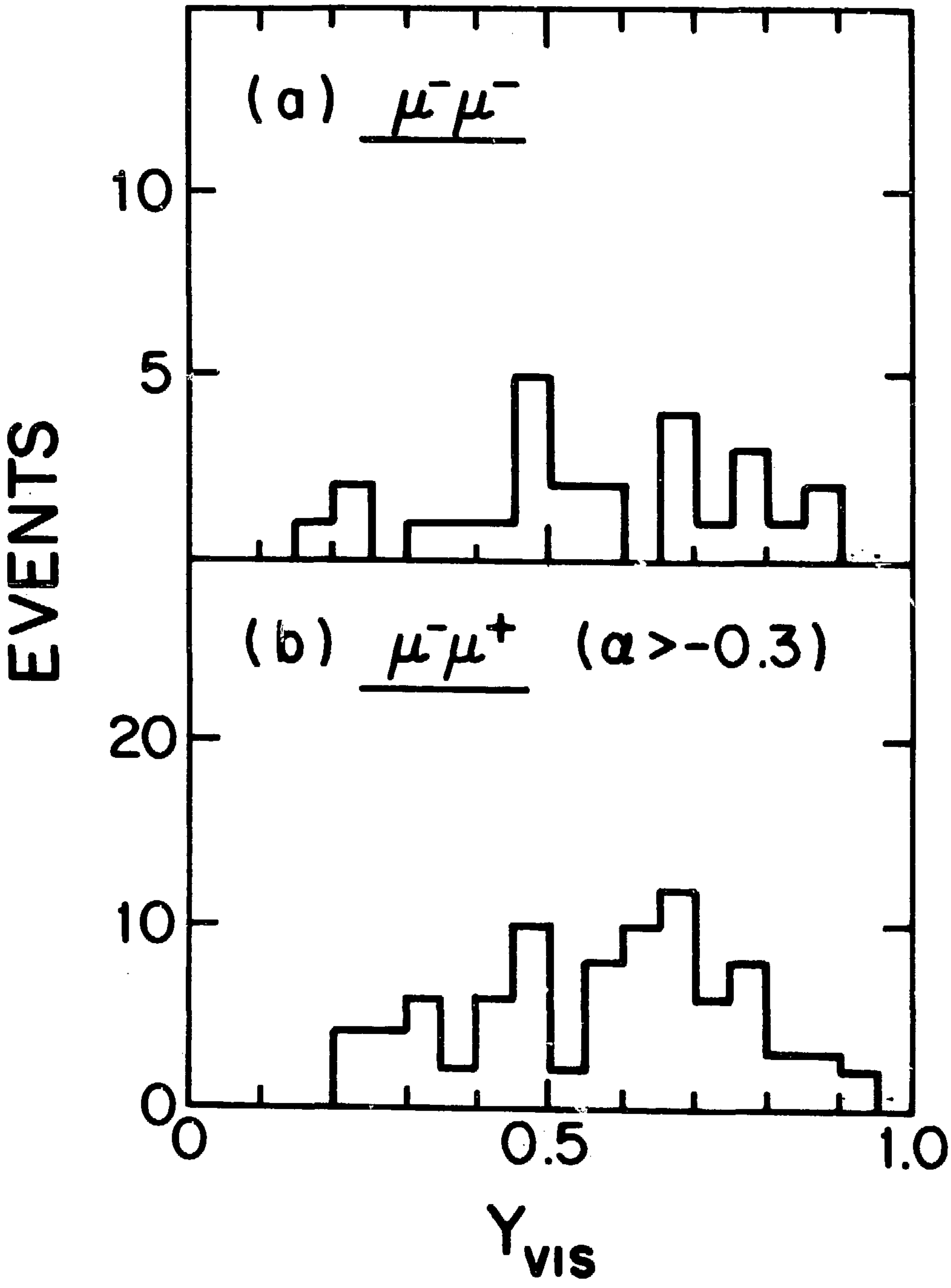


Fig. 6

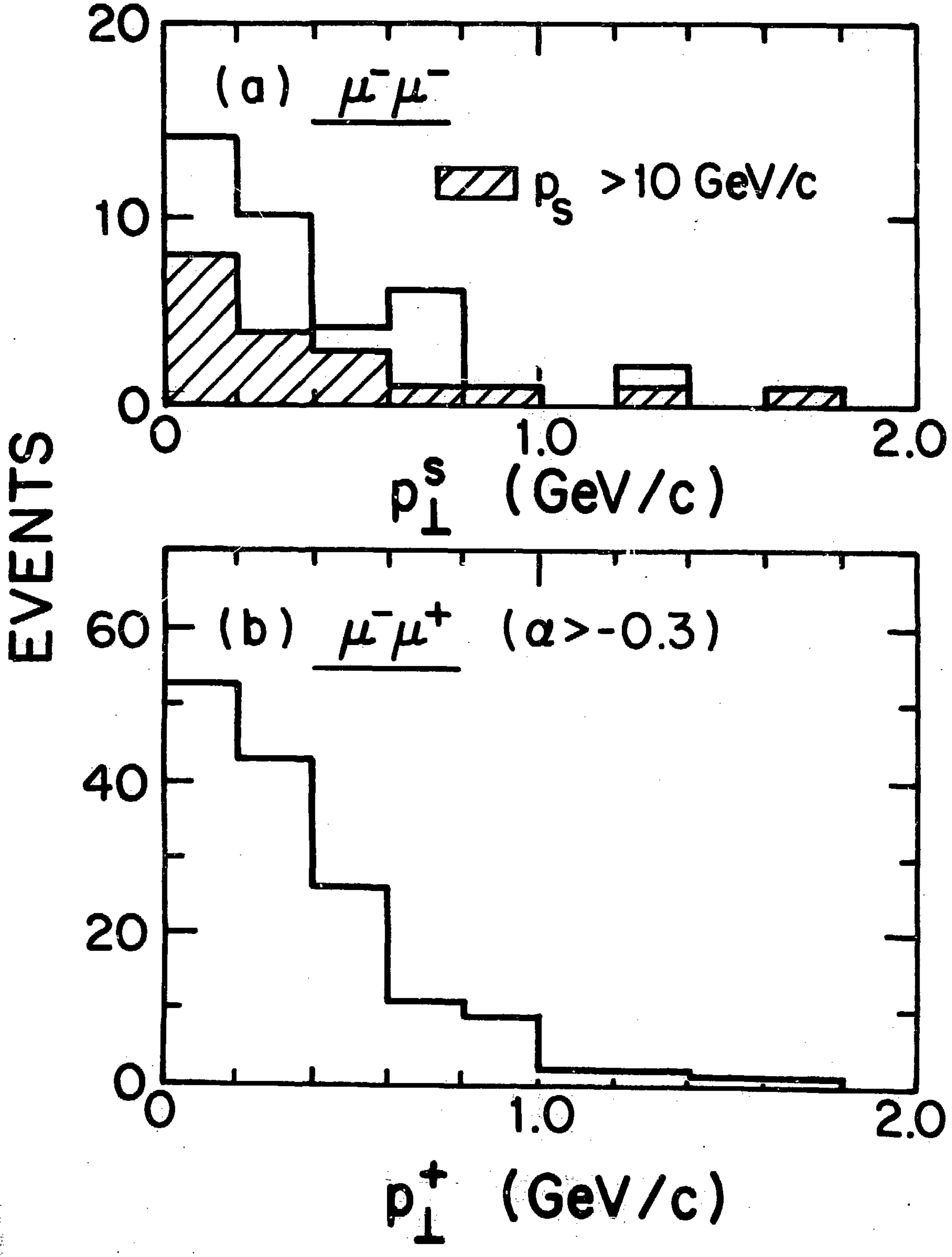

EVENTS
20
10
0
(a) $\mu^-\mu^-$
▨ p_s >10 GeV/c
0
1.0
2.0
$p_\perp^s$ (GeV/c)
60
40
20
0
(b) $\mu^-\mu^+$ (α>-0.3)
0
1.0
2.0
$p_\perp^+$ (GeV/c)

Fig. 7