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IN PROTON-NUCLEUS COLLISIONS AT 400 GeV/c

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ABSTRACT

We present final results of a sensitive search for new particles in $\pi^{\pm}K^{\mp}$ effective mass spectra observed in proton-nucleus collisions at 400 GeV/c. We establish a limit for $D^{o}(1.865)$ production $B_{\pi^+K^-}\, d\sigma/dy < 360$ nb/nucleon at $y_{cm} \simeq -0.4$. For $\bar{D}^{o} \rightarrow \pi^{-}K^{+}$ the limit is 290 nb/nucleon.

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We have conducted a general search for two-hadron decays of new, narrow-width particles produced near 90° in the center-of-mass system of proton-nucleon collisions. Our efforts have concentrated, in particular, on the search for $D^{0}(1.865) \rightarrow \pi K$, the particle observed in $e^{+}e^{-}$ collisions[1] and presumably the carrier of the new quantum number associated with the J/ψ family of particles. Early results from our experiment and a description of the apparatus have been presented elsewhere.[2,3] In this paper we give the final results of our search for new particles in $\pi^{+}K^{-}$ and $\pi^{-}K^{+}$ mass spectra and give new limits on D^{0} and $\bar{D}^{0}$ production.

Pion-kaon pairs with an effective mass in the region from 1.5 to 4.0 GeV/c^2 were detected with a symmetric two-arm spectrometer whose configuration for most of the data is shown in Fig. 1. Briefly, each arm consisted of a magnet, 16 drift chamber planes, 3 Cerenkov counters, various scintillator trigger counters, and a muon identifier. The spectrometer arms were each placed at 100 mr to the Fermilab 400 GeV/c diffractive proton beam[4] and subtended a c.m. solid angle of about 0.2 steradian. Typical beam intensities were 10^8 per pulse. Various targets of polyethylene, beryllium and lead containing ten percent of a nuclear collision length were used during the measurements. The targets were segmented to reduce accidental pairs and multiple scattering. Table I summarizes the different experimental configurations and the respective number of πK pairs obtained in the final data.

The resolution, mass scale and sensitivity of the experiment were checked by detecting the J/ψ (3.1) particle in its $\mu^+\mu^-$ decay mode contemporaneously with the πK measurements. Figure 2 shows our final $\mu^+\mu^-$ spectrum with a clear, narrow peak at 3.110 GeV/c^2. The error of the measured J/ψ mass is estimated to be ±8 MeV and results primarily from systematic uncertainties in the spectrometer survey and magnetic field calibration.[5] The observed width is 25 ± 3 MeV (FWHM) and represents an empirical measurement of the mass resolution since the natural width of the J/ψ is negligible in comparison. Calculating the geometric acceptance with a Monte Carlo program and assuming a linear A-dependence, we obtain $B_{\mu\mu} d\sigma/dy = 4.7 \pm 1.0$ nb/nucleon for J/ψ production[6] at $y_{cm} \simeq -0.4$. Here, y symbolizes the rapidity of the J/ψ and $B_{\mu\mu}$ its branching ratio to muons.

We now turn to the measurements of the πK mass spectra. Figure 3 shows all πK data for π^-K^+, π^+K^- and their sum. These effective mass spectra are not corrected for the acceptance of the apparatus and are given in 10 MeV bins. The acceptance for the πK pairs peaks at $y_{cm} \simeq -0.4$ and low transverse momentum ($p_\perp \lesssim 1$ GeV/c). The region around 1.87 GeV/c^2 is shown more clearly in Fig. 4. If the D^0 were produced with sufficient cross-section to be observable above background it would appear near 1.865 GeV/c^2 as a peak with a width of about 17 MeV (FWHM) equal to the mass resolution. We have made fits to the data for each mass bin with a second-order polynomial covering 200 MeV regions centered on and excluding the bin of interest. The deviation of each data point from its associated fit is shown in Fig. 5.

We find no significant evidence of an observable, narrow πK signal near the D^o mass. The other parts of the mass region from 1.5 to 4.0 GeV/c^2 also do not show any statistically significant (> 4σ) deviations.

From these data we have calculated limits on the cross-section for producing new particles decaying to πK. This calculation includes the effects of geometric acceptance, pion and kaon decay (~20%), kaon identification efficiencies (~80%), tracking efficiencies (~85% per track) and mass resolution. For the geometric acceptance calculation we used the same Monte Carlo techniques as for the J/ψ analysis and assumed a transverse momentum distribution for the πK pairs of $d^2\sigma/dp_\perp^2 dy \sim e^{1.6 p_\perp}$. The mass resolution was obtained from the observed J/ψ width by scaling appropriately to other masses. The limits on $B_{\pi K}$ $d\sigma/dy$ at $y_{cm} = -0.4$ corresponding to narrow peaks with a statistical significance of four-standard deviations are given in Fig. 6. We have also fitted the data in the region of the $D^o(1.865)$ with the sum of a polynomial background and a Gaussian-shaped curve whose width is equal to our mass resolution. The amplitude variance of this Gaussian curve yields 95% confidence level limits of $B_{\pi K}$ $d\sigma/dy$ < 360 nb/nucleon for $D^o \rightarrow \pi^+K^-$ and < 290 nb/nucleon for $\bar{D}^o \rightarrow \pi^-K^+$ at $y_{cm} = -0.4$. For the combined spectra we find an upper limit (95% C.L.) of 500 nb.

These limits are a factor of 60 greater than the observed $J/\psi(3.1)$ cross-section in the $\mu^+\mu^-$ spectrum. We note that our summed πK spectrum contains nearly 10^4 events per 10 MeV bin in the D^o region corresponding to one percent fluctuations in the background. Our resulting sensitivity at 1.865 GeV/c^2 is an order of magnitude better than in other πK measurements at very high energy.[8] It would obviously not be easy to make significant improvements on this kind of measurement. We therefore feel that the observation of the D^0 in hadronic collisions, if at all possible, will require a scheme that focusses on some unique feature of D^0 production such as slow pions from $D^* \to \pi D$ decay[9] or prompt leptons from associated $\bar{D}^0$ decay.

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REFERENCES

[1] G. Goldhaber, et al., Phys. Rev. Lett. 37, 255 (1976).

[2] D. Bintinger, et al., Phys. Rev. Lett. 37, 732 (1976).

[3] R. Thun, et al., Nucl. Inst. Meth. 138, 437 (1976).

[4] As indicated in Table I some data were obtained at 200 GeV/c.

[5] The spectrometer magnets were calibrated with clean $K^0 \to \pi^+\pi^-$ signals observed in each arm.

[6] For other similar measurements of J/ψ production at 400 GeV/c see: H. D. Snyder, et al., Phys. Rev. Lett. 36, 1415 (1976); B. C. Brown, et al., Fermilab-77/54-EXP, 7100.288.

[7] The magnitude of these effects as well as the experimental dead times differed for the J/ψ and πK measurements. Direct statistical comparisons of the J/ψ and πK raw data are thus misleading in deducing ratios of cross-sections.

[8] M. G. Albrow, et al., Nucl. Phys. B114, 365 (1976).
J. C. Alder, et al., Phys. Letters 66B, 401 (1977).

[9] This has been proposed by V. Fitch and collaborators.

TABLE I

OUTLINE OF EXPERIMENTAL CONFIGURATIONS

Beam Momentum GeV/c	Target	Spectrometer Field-Integral (Tesla-Meter)	Number of πK Events
400	CH_2	32.9	76,300
400	Be	32.9	29,800
	Be	16.7	12,400
	Be	23.7	474,400
400	Pb	32.9	50,600
	Pb	16.7	18,200
200	Be	23.7	114,500

FIGURE CAPTIONS

Fig. 1: The spectrometer as seen from above. Symbols are defined as follows: DC1-DC5 drift chamber modules; C1-C3 Cerenkov counters; F, A, E, B, scintillation trigger counters; and G1-G3, MU1, MU2 scintillation muon counters.

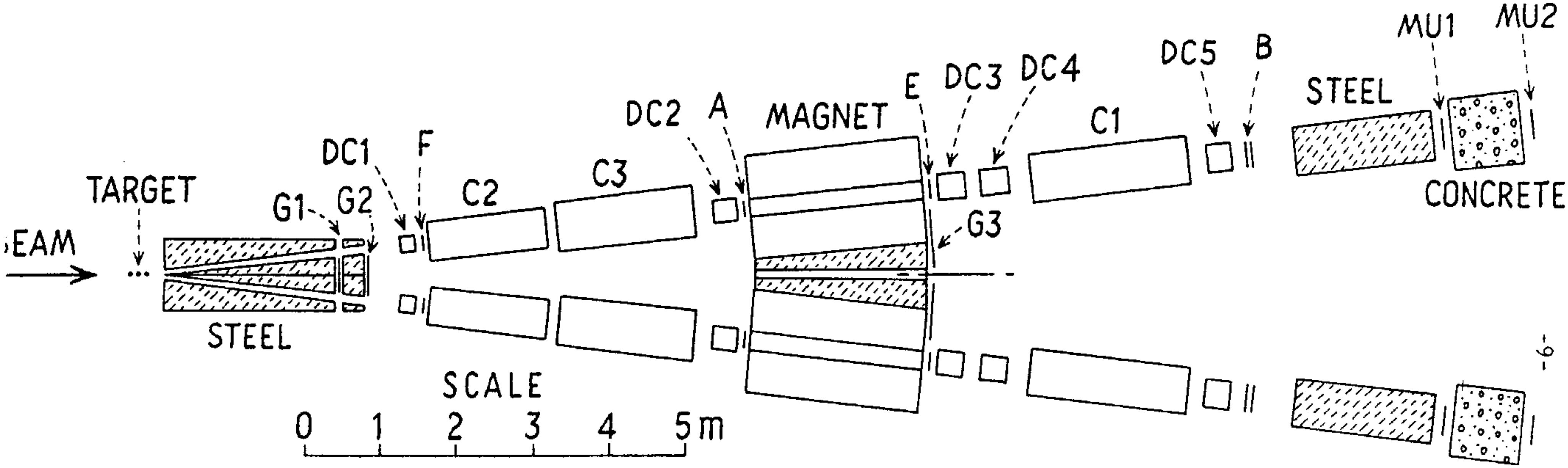
Fig. 2: Mass spectrum for $\mu^+\mu^-$ pairs. A clear $J/\psi(3.1)$ signal is observed.

Fig. 3: Effective mass spectra for π^+K^-, π^-K^+ and their sum.

Fig. 4: The πK mass spectra in the region of the $D^o(1.865)$.

Fig. 5: Results from fitting the πK mass spectra with a series of second-order polynomials (see text). No deviations above the 4σ level are observed.

Fig. 6: Sensitivity of the πK measurements to the production of new, narrow particles. The sensitivity is expressed in terms of the cross-section corresponding to a 4σ peak with a width given by the mass resolution.



BEAM
TARGET
STEEL
G1
G2
DC1
F
C2
C3
DC2
A
MAGNET
E
DC3
DC4
G3
C1
DC5
B
STEEL
MU1
MU2
CONCRETE
SCALE
0
1
2
3
4
5m

Figure 1

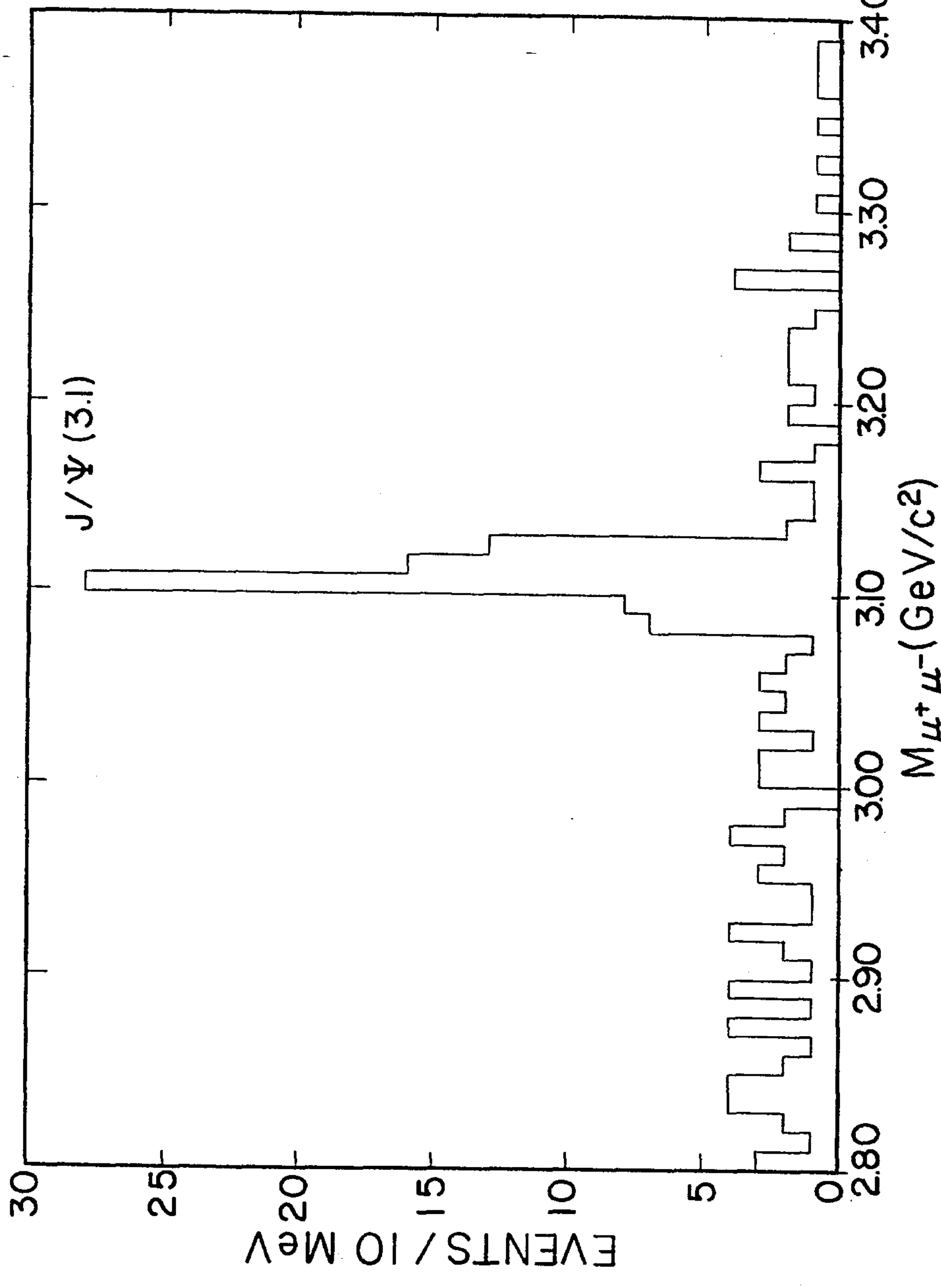

J/Ψ (3.1)
EVENTS / 10 MeV
0
5
10
15
20
25
30
2.80
2.90
3.00
3.10
3.20
3.30
3.40
$M_{\mu^+\mu^-}$ (GeV/c²)

Figure 2

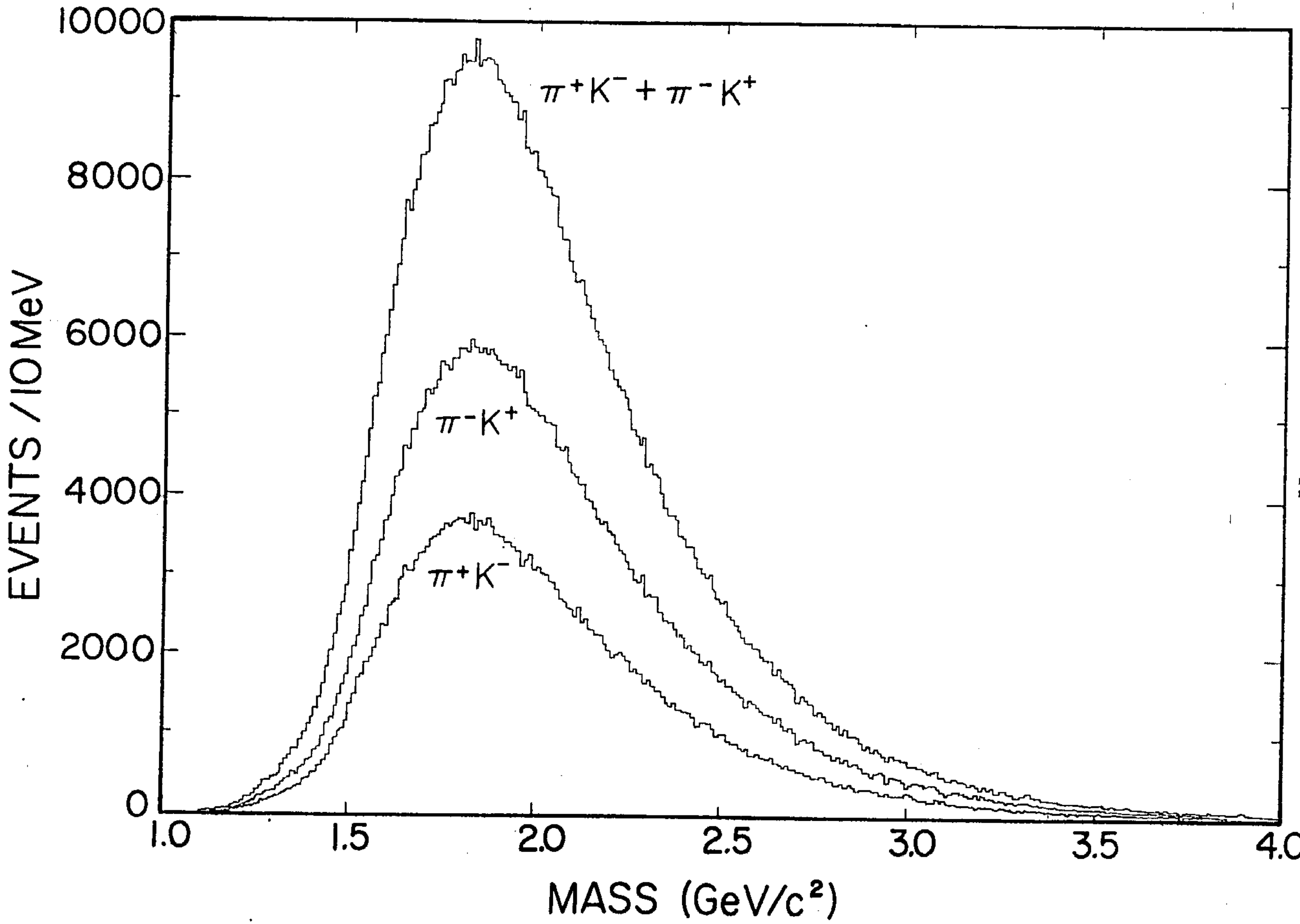
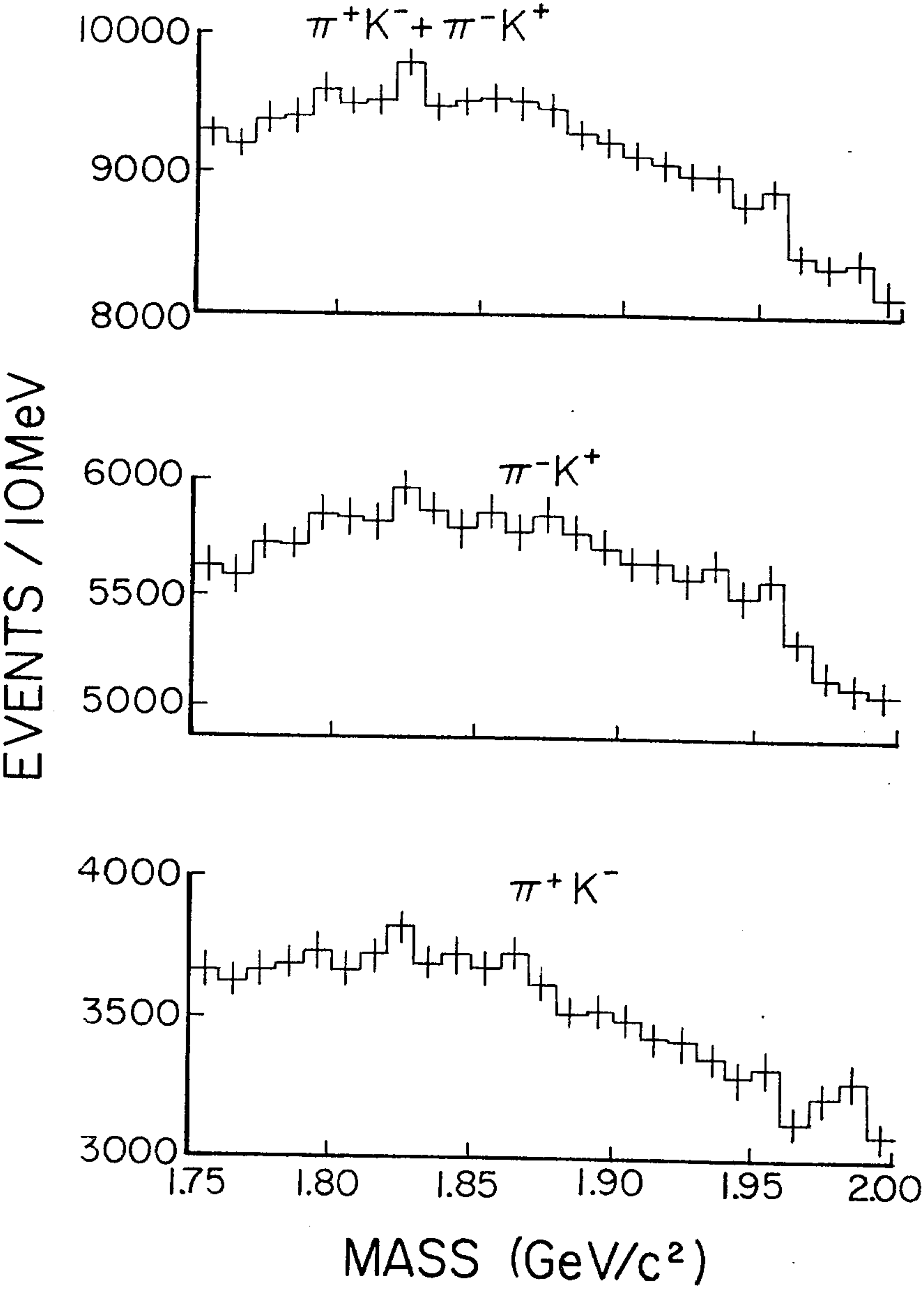
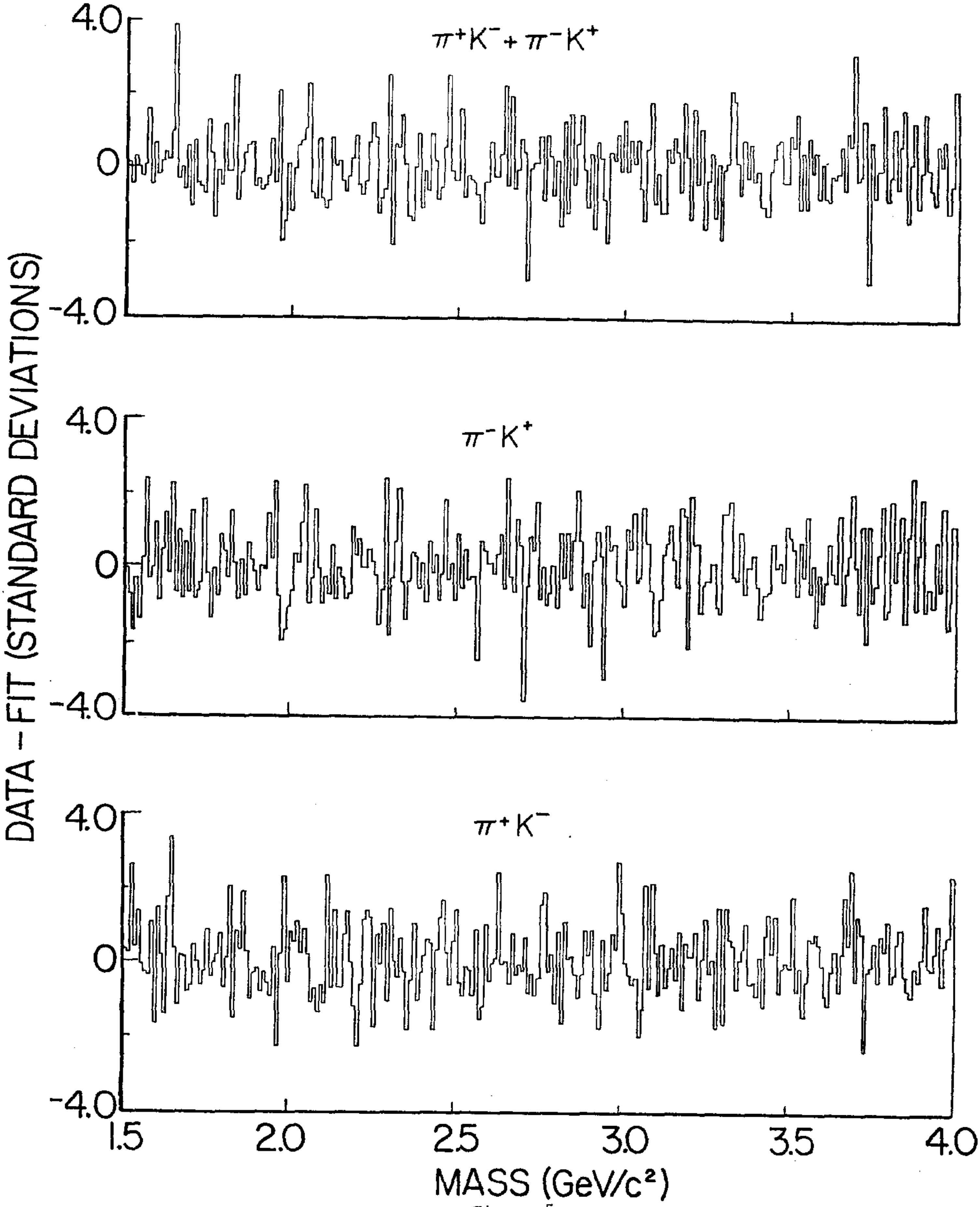

10000
8000
6000
4000
2000
0
EVENTS / 10 MeV
1.0
1.5
2.0
2.5
3.0
3.5
4.0
MASS (GeV/c²)
π⁺K⁻ + π⁻K⁺
π⁻K⁺
π⁺K⁻

Figure 3



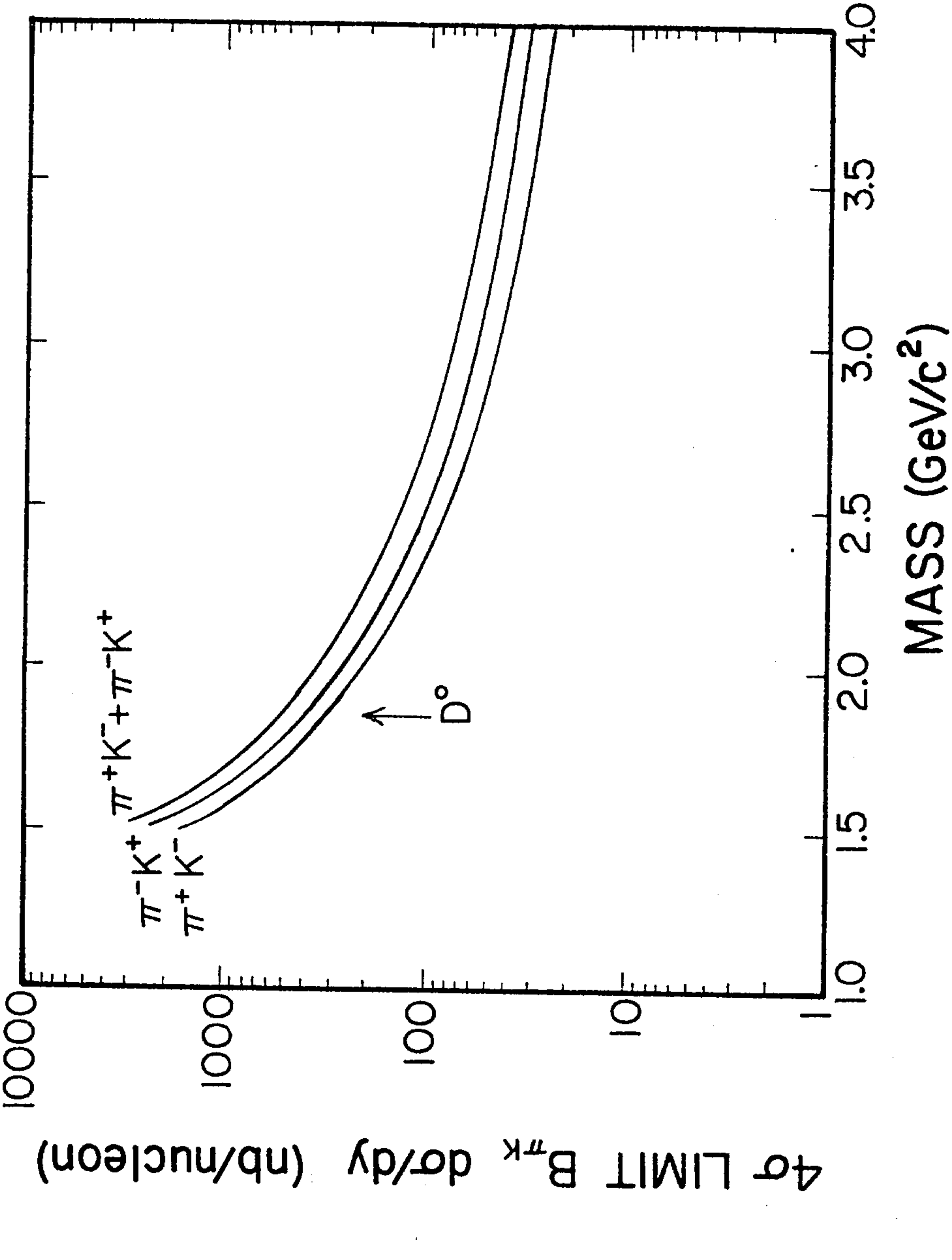
$\pi^+K^- + \pi^-K^+$
10000
9000
8000
π^-K^+
6000
5500
5000
π^+K^-
4000
3500
3000
1.75
1.80
1.85
1.90
1.95
2.00
EVENTS / 10MeV
MASS (GeV/c²)

Figure 4



DATA - FIT (STANDARD DEVIATIONS)
4.0
0
-4.0
$\pi^+K^- + \pi^-K^+$
π^-K^+
π^+K^-
1.5
2.0
2.5
3.0
3.5
4.0
MASS (GeV/c²)

Figure 5



4σ LIMIT B$_{\pi K}$ dσ/dy (nb/nucleon)
10000
1000
100
10
1
1.0
1.5
2.0
2.5
3.0
3.5
4.0
MASS (GeV/c^2)
π⁻K⁺
π⁺K⁻
π⁺K⁻+π⁻K⁺
D°

Figure 6