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FIRST EVIDENCE FOR UPSILON PRODUCTION BY PIONS

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ABSTRACT

We have measured the production of massive muon pairs in hadronic collisions at the CERN Super Proton Synchrotron (SPS). A clear signal of production of the Υ resonance by π^+ of 200 GeV/c and π^- of 200 and 280 GeV/c on a platinum target is observed.

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We have performed an experiment at the CERN SPS to measure the production of muon pairs in hadron-hadron collisions. The experimental layout is shown in fig. 1(a). A detailed description of the apparatus will be given elsewhere [1].

The incident beam is an unseparated secondary beam produced by 400 GeV protons on a 50 cm Be target. Particle identification was done by two differential Cerenkov counters (CEDAR) [2] for $K^{\pm}$ and $\bar{p}$, and by two threshold Cerenkov counters for π^{+}. Beam intensities used in the experiment were in the range from 10^7 to 3×10^7 particles/pulse. At 200 GeV/c the fraction of π^{-} in the negative beam was about 96%. The fraction of π^{+} and K^{+} in the positive beam after filtering by a 2 m long CH_2 absorber, was 36% and 4.6% respectively.

Platinum targets, 6 cm in length for the 200 GeV runs and 11 cm for the 280 GeV run, were used. The target was placed 40 cm upstream of a dump consisting of a 1.5 m long block of stainless steel with a heavy (tungsten-uranium) conical plug of ± 30 mrad aperture inserted in the centre.

The large acceptance magnetic spectrometer consists of:

i) a superconducting dipole magnet with a vertical field ($\int B\, d\ell = 4.0$ Tm) in a cylindrically shaped air gap of 1.6 m diameter [3];

ii) a set of six multiwire proportional chambers (31 planes with a total of about 26 000 wires) ranging in size from $0.6 \times 0.6\ m^2$ to $4.2 \times 4.0\ m^2$;

iii) a muon filter composed of 12 cm of lead and 1.8 m of iron, placed in front of the last triggering hodoscope T3;

iv) a trigger system composed of two symmetric telescopes of counters and chambers placed above and below the beam axis.

A two-level trigger was used to minimize the electronics dead-time due to the high particle flux in the chambers. The trigger elements are shown in fig. 1(b).

A "pretrigger" is provided by three planes of counter hodoscopes:

i) T1 placed at the end face of the beam dump consisting of 12 counters;

ii) T2 which is subdivided into 42 horizontal strips;

iii) T3 situated behind the iron wall, made of 22 horizontal strips.

The last two hodoscopes cover vertical angles from ± 6 mrad up to ± 165 mrad. The pretrigger which requires at least two particles in the coincidence T2, T3 and at least one particle in T1, provides a fast strobe for the proportional chambers PC1, PC2, M1 and M2. The pretrigger signal is vetoed by a ∿ 1 m^2 halo counter placed upstream of the target.

The trigger acts on the vertical component p_T^v of the transverse momentum of the muons. The p_T^v selection is achieved by two planes of cathode read-out chambers M1 and M2, covering vertical angles from ± 30 mrad up to ± 165 mrad and an over-all azimuthal acceptance of 2/3. The cathodes are printed in 18 separate horizontal bands, each subdivided into 64 cells corresponding to equal intervals of the tangent of the azimuthal angle. The correlation between cells of a given band provides a cut-off in the magnetic deflection angle and thus in p_T^v, which in turn, defines a rough lower cut on the muon pair effective mass. The trigger conditions in the course of the experiment were either $p_T^v > 0.7$ GeV/c for both muons, or $p_T^v > 1$ GeV/c for one muon, without a cut on the other muon. The over-all acceptance of the apparatus at 200 GeV/c, as determined by the geometry of the detectors and by the p_T^v cut is shown in fig. 2 as a function of the dimuon mass.

Pattern recognition of both muons is performed in the spectrometer chambers with an over-all efficiency of 94 ± 2%, measured from visual scanning of a sample of reconstructed events. Vertex reconstruction is done taking into account multiple scattering in the hadron absorber and beam constraint at the target. For dimuon events with a mass above 4 GeV/c^2, the distribution of reconstructed vertex position shows a clean separation between interactions in the platinum target and in the beam dump.

In figs. 2 and 3 we show the $\mu^+\mu^-$ mass spectra for π^+ and π^- at 200 GeV/c, and for π^- at 280 GeV/c. A clear signal around 9.5 GeV/c^2 is seen in the π^+ induced mass spectrum. This is the first evidence for production of the Τ state [4] in pion induced reactions. The signals are less prominent in the π^- induced spectra as a consequence of the higher level of the Drell-Yan dimuon continuum. It can be seen from fig. 2 that the background of like-charge muon pairs, produced essentially by π and K decays, is extremely low and disappears above 4 GeV/c^2.

The acceptance for the Τ was calculated assuming, as for the J/ψ [5], an isotropic decay distribution in the Τ rest frame. For the Drell-Yan continuum we have taken a $(1 + \cos^2 \theta)$ dependence in the Gottfried-Jackson frame, which is consistent with our data [6].

The dimuon mass spectra of figs. 2 and 3 have been fitted to a sum of an exponentially falling continuum, and three Gaussian distributions representing the known Τ states. The calculated mass acceptance has been folded into the fit. The widths of the three Τ states, which are not resolved in this experiment, have been fixed equal to the experimental mass resolutions. They were evaluated by a Monte-Carlo calculation and found to be σ = 4.5% at 200 GeV/c and σ = 5.0% at 280 GeV/c. At the Τ mass the resolution is dominated by the measurement error on the muon momenta. The masses of the Τ states were fixed at their known values [7,8].

Four parameters were left free in the fit:

i) the ratio α of the sum of the three Τ states to the Drell-Yan continuum at 9.46 GeV/c^2;

ii) the relative abundances of the Τ' and Τ'' states with respect to the Τ; these quantities were found to be consistent with the values obtained in proton induced reactions [8];

iii) the slope parameter b of the exponential exp(-bM) which describes the continuum.

The fitted values of the parameters α and b are given, together with the total number of events corresponding to the production of all three Υ states in table 1.

In table 2 the quantity $B\sigma$ (production cross section times the branching ratio into muon pairs) measured in this experiment for the Υ family is given together with the ratio of Υ to J/ψ, obtained at the same energies [5]. The cross section per nucleon was evaluated assuming a linear A dependence.

The x-distribution for events in the mass range from 8.5 up to 11 GeV/c^2 for incident π^+ at 200 GeV/c is shown in fig. 4, where $x = 2\, p_L^*/\sqrt{s}$, p_L^* being the longitudinal momentum of the dimuon in the c.m.s.. About 2/3 of the events in this mass interval correspond to production of the Υ resonances. The mean value of x is found to be ~ 0.2.

For the above sample of events, the decay angular distribution in the Gottfried-Jackson frame was fitted to the expression $1 + \lambda \cos^2 \theta$. The best fitted value of the parameter λ was 0.12 ± 0.77 with a $\chi^2 = 1.5$ for 6 degrees of freedom.

We have also made an estimate of the Υ production by K^+ and protons. The K^+ and p mass spectra were fitted with the same procedure used to extract the Υ cross section for incident pions. A small excess of events at M = 9.5 GeV/c^2 was then found, which leads to the figures given in table 3 for the cross section ratios K^+/π^+ and p/π^+. The corresponding proton cross section can be estimated to be $B\, d\sigma/dy = (3.8 \pm 3.2) \times 10^{-38}$ cm^2/nucleon, assuming a flat y distribution. The results of a model calculation based on the light-quark fusion mechanism, using the structure functions which were obtained from the Drell-Yan analysis of our dimuon data [9], are also indicated in table 3. The experimental results are consistent with these predictions. We note that a pure gluon fusion mechanism would give about the same cross section for Υ production by K^+ and by π^+, which is not favoured by the data.

Our results for pions and protons are compared in fig. 5 with previous measurements on proton-platinum collisions at FNAL [10] and on proton-proton collisions at the ISR [11,12,13]. The energy dependence of Υ production as well as the ratio of the cross sections for incident pions and protons at a given value of $M/\sqrt{s}$, agree qualitatively with current models using either light-quark fusion or a combination of light-quark fusion and gluon-gluon fusion mechanism [14].

In conclusion, we have shown that pions are much more effective than protons in producing the Υ states. At 200 GeV/c ($M/\sqrt{s} = 0.49$), the pion to proton ratio of the Υ cross sections is of the order of 30. The Υ cross section is about the same for π^+ and π^-. For incident π^- the ratio of the Υ peak to the continuum is about one, while for π^+ it is about four. The ratio of the $B\sigma$ values of Υ to J/ψ is of the order of $2 \cdot 10^{-4}$ for incident pions.

We are very grateful to the members of the SPS operating crew and the Experimental Areas group. In particular we acknowledge the skilful and dedicated collaboration of Mr. N. Doble for providing full operation of the beam line. We finally would like to express our deep gratitude to the engineering and technical staff of our collaboration for the outstanding contribution in the design, construction and operation of our apparatus.

REFERENCES

[1] General description of CERN NA3 Spectrometer (to be published).

[2] C. Bovet et al., IEEE Trans. Nucl. Sci. NS/25 (1978) 572.

[3] M. Morpurgo, A large superconducting dipole cooled by forced circulation of two phase helium, Cryogenics 19 (1979) 411.

[4] S.W. Herb et al., Phys. Rev. Lett. 39 (1977) 252.

[5] J. Badier et al., Dimuon resonance production from 200 and 280 GeV/c tagged hadron beam, EPS Int. Conf. on High Energy Physics, Geneva, 1979.

[6] J. Badier et al., Muon pair production at masses above 4 GeV/c^2 (Drell-Yan continuum) by $\pi^{\pm}$, $K^{\pm}$, $\bar{p}$ and p of 200 GeV/c and by π^- of 280 GeV/c on platinum and hydrogen targets, EPS Int. Conf. on High Energy Physics, Geneva, 1979.

[7] J.K. Bienlein et al., Phys. Lett. 78B (1978) 360.
C.W. Darden et al., Phys. Lett. 78B (1978) 364.

[8] K. Ueno et al., Phys. Rev. Lett. 42 (1979) 486.

[9] J. Badier et al., Experimental determination of the pion and nucleon structure functions by measuring high-mass muon pairs produced by pions of 200 and 280 GeV/c on a platinum target, EPS Int. Conf. on High Energy Physics, Geneva, 1979.

[10] J.K. Yoh et al., Phys. Rev. Lett. 41 (1978) 684.

[11] I. Mannelli, Electron pairs production at the ISR, Proc. of the 19th Int. Conf. on High Energy Physics, Tokyo, 1978, (Physical Society of Japan, Tokyo, 1979), p. 189.

[12] A.L.S. Angelis et al., A measurement of the production of massive e^+e^- pairs in p-p collisions at $\sqrt{s}$ = 63 GeV, presented at the EPS Int. Conf. on High-Energy Physics, Geneva, 1979.

[13] D. Antreasyan et al., Dimuon spectra from 62 GeV proton collisions, presented at the EPS Int. Conf. on High-Energy Physics, Geneva, 1979.

[14] J.F. Owens and E. Reya, Phys. Rev. D17 (1978) 3003.

TABLE 1

Fitted parameters of the mass spectra of figs. 2 and 3 obtained on a platinum target

Incident particle	π^+ 200 GeV/c	π^- 200 GeV/c	π^- 280 GeV/c
b $(GeV/c^2)^{-1}$	1.055 ± 0.029	0.909 ± 0.016	0.814 ± 0.015
α (GeV/c^2)	4.2 ± 1.0	0.87 ± 0.26	0.70 ± 0.22
$N_{\Upsilon} + N_{\Upsilon'} + N_{\Upsilon''}$	53 ± 12	55 ± 15	66 ± 20

TABLE 2

Bσ values for Υ production and for the ratio of Υ to J/ψ production for different incident particles on a platinum target (systematic errors included)

Particle	π^+ 200 GeV/c	π^- 200 GeV/c	π^- 280 GeV/c
$\frac{B\sigma(\Upsilon + \Upsilon' + \Upsilon'')}{B\sigma(J/\psi)}$	$(2.4 \pm 0.6) \times 10^{-4}$	$(1.9 \pm 0.5) \times 10^{-4}$	$(2.2 \pm 0.7) \times 10^{-4}$
$B\sigma(\Upsilon + \Upsilon' + \Upsilon'')$ (pb/nucleon)	1.9 ± 0.6	1.5 ± 0.5	2.4 ± 0.9
$B\left[\frac{d\sigma}{dy}\right]_{y \approx 0.2}(\Upsilon+\Upsilon'+\Upsilon'')$ (pb/nucleon)	2.7 ± 0.9	2.1 ± 0.7	3.4 ± 1.3

TABLE 3

Cross section ratios for Υ production at 200 GeV/c. The π^-/π^+ ratio is for a platinum target, while the K^+/π^+ and p/π^+ ratios include events from the platinum target and the dump

	Experiment	Model
$\frac{\sigma(K^+)}{\sigma(\pi^+)}$	0.34 ± 0.23	0.10
$\frac{\sigma(p)}{\sigma(\pi^+)}$	0.03 ± 0.02	0.05
$\frac{\sigma(\pi^-)}{\sigma(\pi^+)}$	0.76 ± 0.29	0.83

FIGURE CAPTIONS

Fig. 1 (a) General layout of the NA3 spectrometer for the study of dimuon production in hadronic collisions. T1, T2, T3: counter hodoscopes; M1, M2: trigger chambers; PC1-6: proportional chambers.

(b) Sketch of the trigger system. The azimuthal subdivision of M1 and M2 (64 cells) is much finer than indicated.

Fig. 2 Dimuon mass spectrum for incident π^+ on a platinum target at 200 GeV/c. In the insert, the acceptance of the spectrometer as a function of the dimuon mass is shown.

Fig. 3 Dimuon mass spectra in the Υ region. The curves represent the results of the fits as described in the text.

(a) Incident π^- at 200 GeV/c.

(b) Incident π^- at 280 GeV/c.

Fig. 4 x-distribution of the events in the mass interval $8.5 < M < 11$ GeV/c^2 for π^+ at 200 GeV/c. The kinematical limit is also indicated.

Fig. 5 Differential cross section B $d\sigma/dy$ for production of the three Υ states plotted as a function of $M/\sqrt{s}$ for incident protons and pions. The FNAL proton data at 300 and 200 GeV are for $y \simeq 0.2$ and $y \simeq 0.4$, respectively. The pion data of this experiment are for $y \simeq 0.2$. Other data are for $y \simeq 0$. The line exp $(-18\ M/\sqrt{s})$ represents an eye fit to the proton data.

NA 3 SPECTROMETER

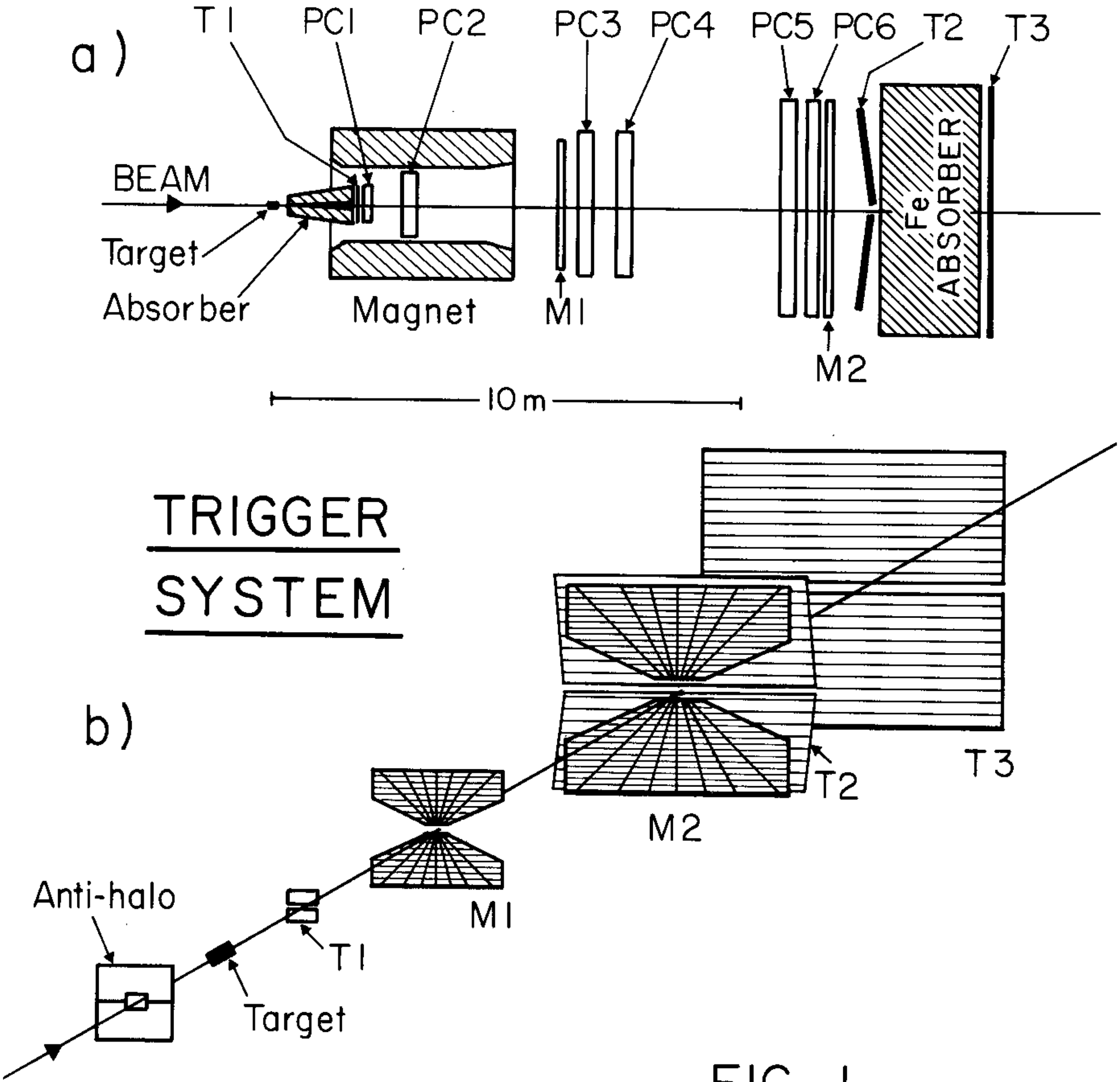

FIG. 1

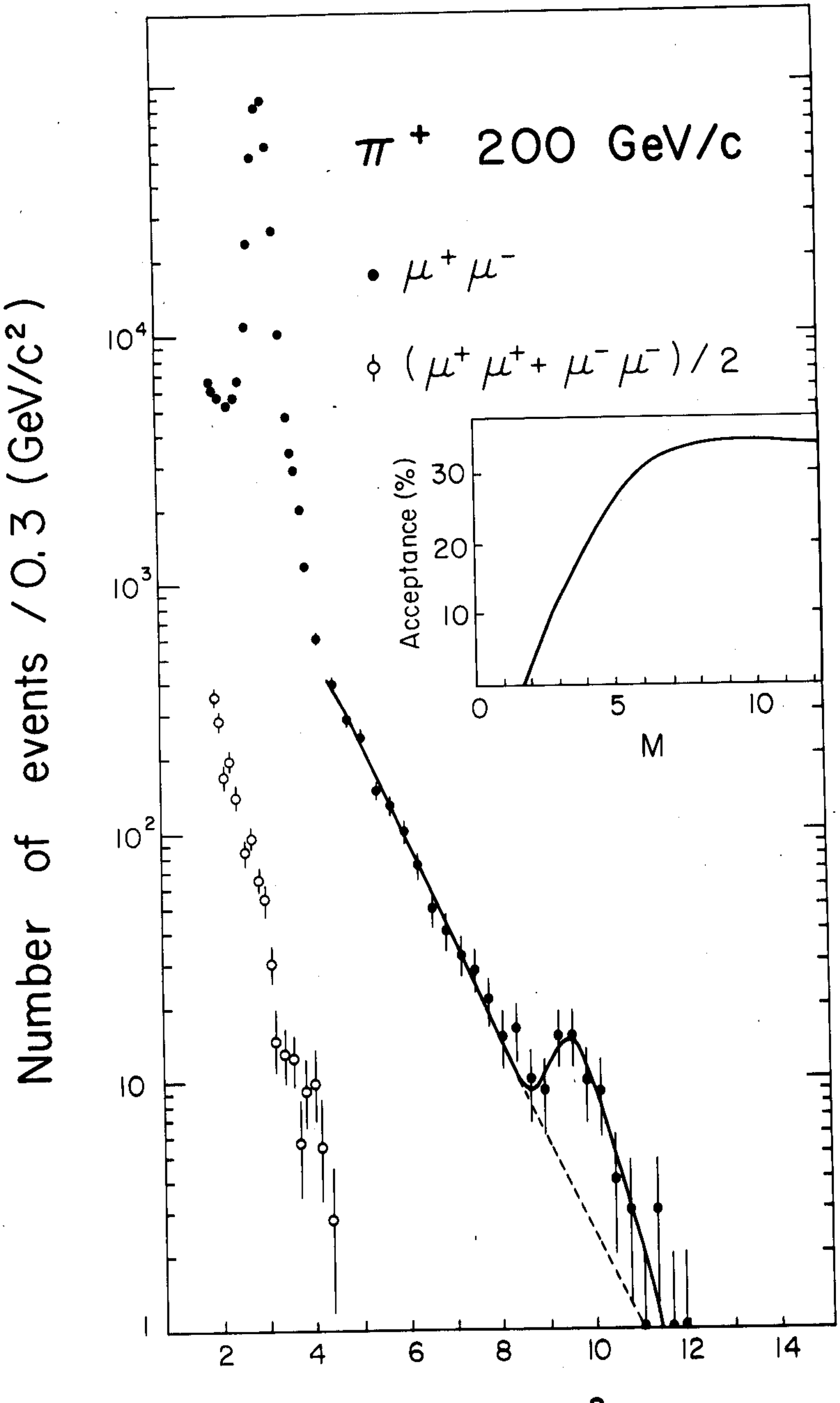
π⁺ 200 GeV/c
μ⁺μ⁻
(μ⁺μ⁺+ μ⁻μ⁻)/2
Number of events /0.3 (GeV/c²)
M (GeV/c²)
Acceptance (%)
M

FIG. 2

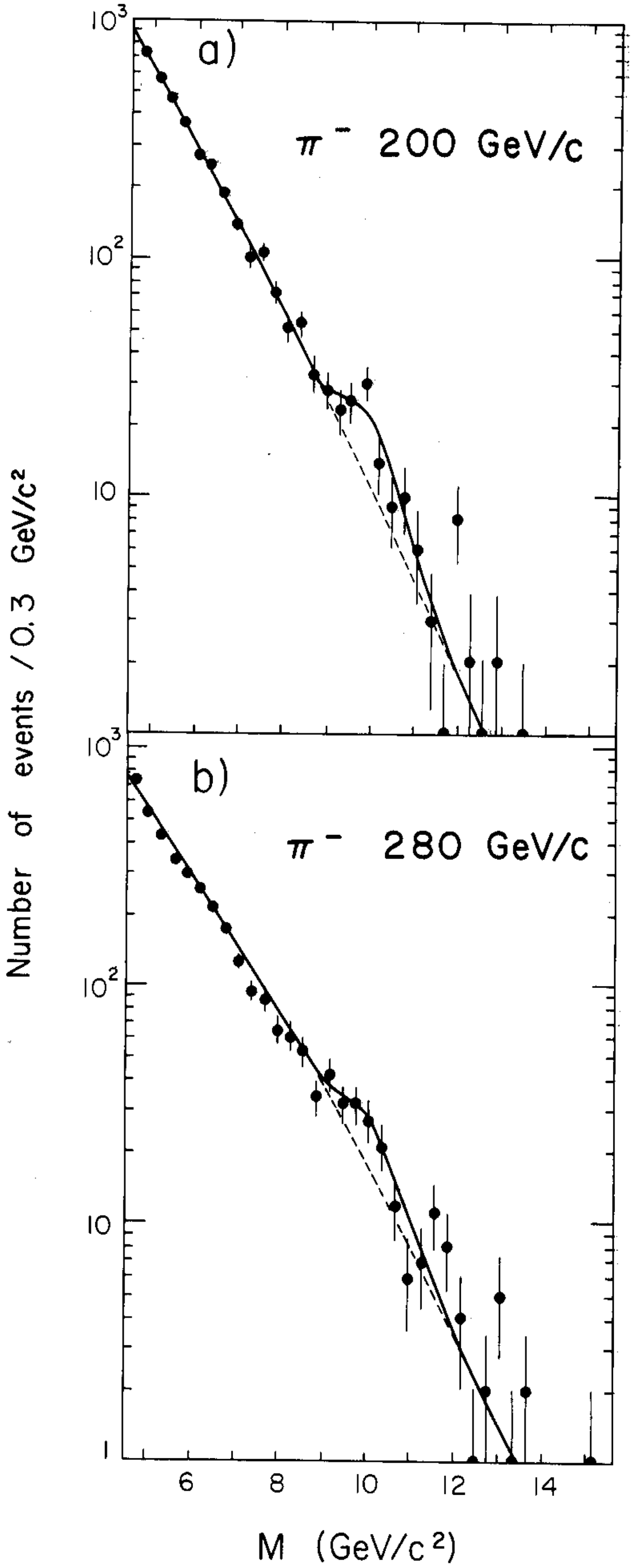

FIG.3

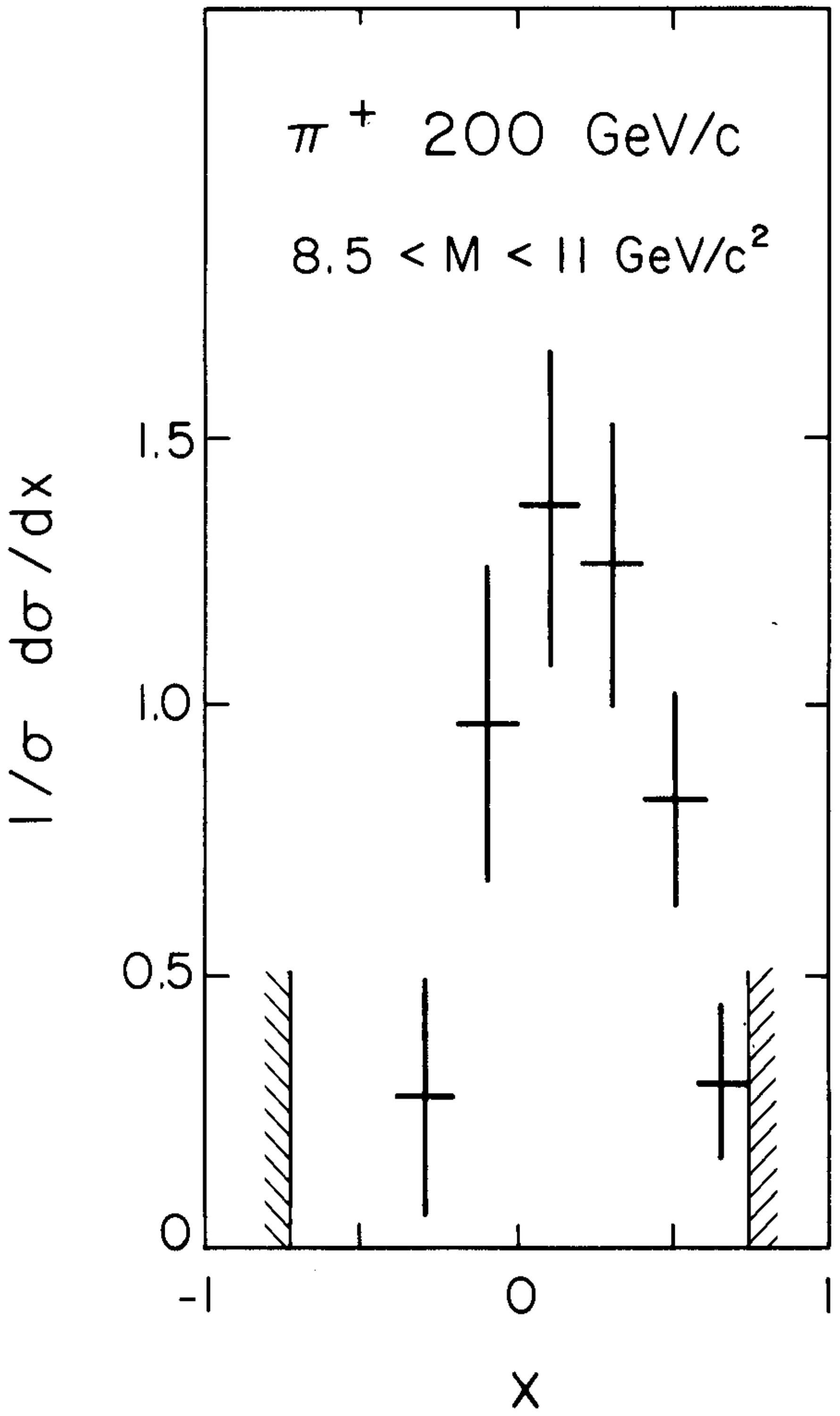

FIG. 4

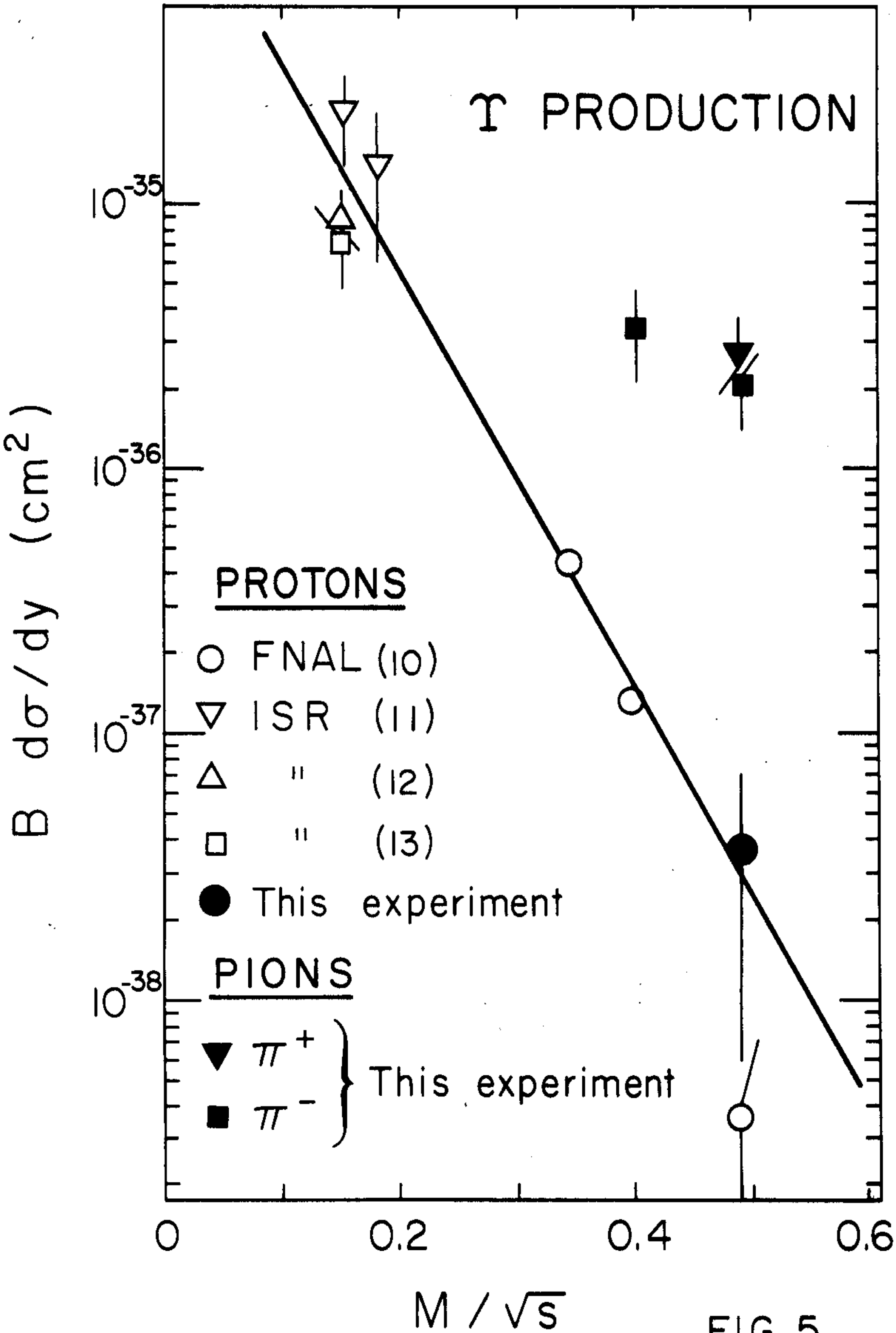
Υ PRODUCTION
B dσ/dy (cm²)
10⁻³⁵
10⁻³⁶
10⁻³⁷
10⁻³⁸
PROTONS
FNAL (10)
ISR (11)
" (12)
" (13)
This experiment
PIONS
π⁺
π⁻
This experiment
0
0.2
0.4
0.6
M / √s

FIG.5