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Measurement of D^* Production by Pions on Nucleons at $\sqrt{s}$ = 19 GeV

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ABSTRACT

We report results of an experiment to measure the cross section for the reaction $\pi^- + N \rightarrow D^{*\pm} + X$ at 200 GeV/c. We observe a 2.7 standard deviation signal corresponding to a D^* production cross section $d\sigma/dy = 1.0 \pm 0.4\ \mu b$ at $y = 0$.

We report here the results of a search for the reaction

$$\pi^- + N \rightarrow D^{*\pm} + X,\ D^{*\pm} \rightarrow \pi^\pm + D^\circ(\bar{D}^\circ),\ D^\circ(\bar{D}^\circ) \rightarrow K^\mp + \pi^\pm$$

at a beam momentum of 200 GeV/c. A number of experiments have indirectly measured the cross section for charmed mesons in hadronic interactions.[1] Previous experiments trying to observe directly the mass peak from the charmed meson have not been sensitive enough to see this level of cross section.[2] This experiment required the pion from the D^* decay in coincidence with a $K\pi$ system at the D° mass to suppress the non-charmed background, a technique first used in an experiment at charm threshold.[3] Since the branching ratio for $D^{*+} \rightarrow \pi^+ + D^\circ$ is 60%, much of the D° signal comes from this decay. The Q-value for the D^{*+} decay is measured to be 5.7 ± 0.5 MeV.[4] For this low Q-value the pion is almost at rest in the D° center of mass, so that only pions in a small region of phase space contribute to the background. Recently a photoproduction experiment has used this technique to observe a very clean charm signal.[5]

The experiment was performed at the Fermi National Accelerator Laboratory, using the high intensity pion beam in the P-West area. The apparatus, shown in Figure 1, consisted of a double-arm spectrometer to observe the D° decay products. Cherenkov counters provided π-K separation from 5 to 18 GeV and K-p separation above 11 GeV/c. The associated pion from the D^* decay is directed along the beam line with momentum between 1.0 and 2.5 GeV/c. This pion was bent in the vertical plane by a large aperture magnet near the target into two additional arms with drift chambers to reconstruct the angle and momentum of the pion. These arms, shown in Figure 2, accepted almost all pions associated with D°'s accepted by the double-arm spectrometer. The momentum resolution $\delta p/p$ was about 1% in all arms. The resolution in $K\pi$ mass at the mass of the D° was ± 14 MeV, and in Q-value it was ± 0.6 MeV on the average.

The trigger required an opposite sign pair in the double-arm spectrometer, each with momentum greater than 5 GeV/c, accompanied by a pion with momentum 1.0 - 2.5 GeV/c and angle less than 50 mrad. The trigger also required that one and only one arm have a signal in the threshold Cherenkov counter located in the magnet, which had a pion threshold of 5 GeV/c. The sign of the track which fired the pion counter was required to be the same as that of the pion in the low momentum arm, as required for a $K^\pm \pi^\mp \pi^\mp$ state. At a beam intensity of 8×10^7 pions per spill on a 1.8 g/cm^2 Be target we recorded 50 triggers per spill. The total integrated pion flux on target was 1×10^{13}. A Monte Carlo using a production cross section of the form $Ed^3\sigma/dp^3 = A\,(1-x)^3\,e^{-1.1\,p_T^2}$ gives a geometric acceptance of 3.4×10^{-4}. Including the trigger and analysis efficiencies the sensitivity is 0.57 events/μb of cross section times branching ratio. Including the known branching ratios[5] the sensitivity for total D^* production is 8.5 events/μb. The sensitivity in $d\sigma/dy$ at $y = 0$ is 27 events/μb, which is independent of the production model used.

To be assured that the apparatus and analysis programs were functioning properly, we recorded two calibration reactions simultaneously with the D^* candidates. A convenient mass calibration for the double-arm spectrometer was provided by $\psi \to \mu^+\mu^-$ events. The ψ signal, shown in Figure 3, has a mass resolution consistent with that calculated. The number of events in the peak and the well-measured ψ cross section provides an independent sensitivity check. We also observe a large number of $\Lambda^\circ \to p + \pi^-$ decays, with the proton in a fast arm and the pion in a slow arm. The momentum regions covered by the Λ° decays match that populated by D^* decays. The Λ° mass peak, shown in Figure 4, checks the operation of the slow arms, as well as the ability to merge the two types of arms.

To improve statistics in the Q-value and $K\pi$ mass spectra, we combined D^{*+} and D^{*-} candidates. Fits to data away from the expected peak determined the smooth background forms. Figure 5 shows the Q-value spectrum for events with $K\pi$ mass between 1.835 and 1.875. A fit to the data using a Gaussian with $\sigma = 0.6$ MeV and a smooth background gave a peak of 60 ± 25 events with a central value of 5.8 ± 0.3 MeV. To make a similar plot for the $K\pi$ mass spectrum, we defined a variable $R = (Q - Q_o)/\delta Q$ where $Q_o = 5.7$ MeV and δQ is the error on Q for the particular event. A cut was applied on R rather than Q to take into account the variations of δQ from its average value of 0.6 MeV. Figure 6 shows a plot of $M_{K\pi}$ for events with $|R|<1.2$. A fit using a smooth background plus a Gaussian with $\sigma = 14$ MeV yielded a peak of 71 ± 24 events with mass 1851 ± 6 MeV. To use all of the information available we also made a joint fit to the two-dimensional spectrum, Q vs $M_{K\pi}$. These two variables were chosen because their errors are almost uncorrelated. The resulting peak contained 56 ± 21 events above background with $M_{K\pi} = 1851 \pm 9$ MeV and $Q = 5.9 \pm 0.3$ MeV. No other peak of comparable significance exists for any combination of $K\pi$ mass and Q-value. Converting 56 ± 21 events to a cross section gives

$$\sigma\,(D^*) = [\sigma(D^{*+}) + \sigma\,(D^{*-})]/2 = 3.3 \pm 1.2\ \mu b \text{ or}$$

$d\sigma/dy = 1.0 \pm 0.4\ \mu b$ at $y = 0$.

The total cross section depends on the y-dependence assumed, but the differential cross section is insensitive to it. Errors are statistical only, and do not include a systematic normalization error estimated to be ± 20%.

An analysis of the experiments listed in reference 1 yields a cross section of 25 ± 10 μb for D production with 400 GeV/c protons.[6] If one assumes that the cross section for 200 GeV/c pions is about the same as for 400 GeV/c protons, and that the ratio $D^{*+}/(D^{+} + D^{\circ})$ is .3 ± .05,[7] one expects 7.5 ± 3.0 μb for the D^{*} cross section (average of D^{*+} and D^{*-}). Our result of 3.3 ± 1.2 μb is consistent with this wide range, although it is at the lower end.

We wish to acknowledge the assistance of the Fermilab Staff, particularly that of the Proton Laboratory. We thank the staff of the Elementary Particles Laboratory at Princeton University and the support staff at Saclay for construction of most of the apparatus.

REFERENCES

1. K. W. Brown et al., Phys. Rev. Lett. 43, 410 (1974); J. L. Ritchie et al., Phys. Rev. Lett. 44, 230 (1980); A. Chilingarov et al., Phys. Lett. 83B, 136 (1979); J. Sandweiss et al., Phys. Rev. Lett. 44, 1104 (1980).

2. W. R. Ditzler et al., Phys. Lett. 71B (1977) 451. A D^+ peak is reported by D. Drijard et al., Phys. Lett. 81B (1979). The cross section measured, assuming less than 15% of the $D^+ \to K^- \pi^+\pi^+$ decay goes through $\bar{K}^*$ (890), is $d\sigma/dy$ = 200 μb, which is much larger than the cross sections from experiments of reference 1.

3. R. Cester et al., Phys. Rev. Lett. 40, 141 (1978).

4. G. J. Feldman et al., Phys. Rev. Lett. 38, 1313 (1977).

5. P. Avery et al., Phys. Rev. Lett. 44, 1309 (1980).

6. The prompt lepton experiments are sensitive to the D production cross section. Here a semileptonic branching ratio of 7.5% is assumed for D's. See M. S. Witherell, Talk at Experimental Meson Spectroscopy Conference, Upton, N. Y. (proceedings to be published) for more detail.

7. If one assumes that relative direct production of D^* and D follows 2J+1 weighting, the ratio is .35. If an equal amount of D^* and D° is directly produced, the ratio after decay is .25.

FIGURE CAPTIONS

Figure 1 Plan View of the Apparatus

Figure 2 Elevation View of the arms which detect the low momentum pion

Figure 3 The $\mu^+\mu^-$ and $\mu^\pm\mu^\pm$ mass spectra in the region of the ψ.

Figure 4 The $p\pi^-$ and $\bar{p}\pi^+$ mass spectra for events which decay downstream of the target.

Figure 5 The Q-value spectrum for events with $1.835 < M_{K\pi} < 1.875$ - $Q = M_{K\pi\pi} - M_{K\pi} - M_\pi$. The background shape is determined by fitting events with $K\pi$ mass outside the D^o region. Parameters resulting from fit are shown in the text.

Figure 6 The $K\pi$ mass spectrum for events with $|R|<1.2$. R is defined in the text. The background shape is determined by fitting events with Q-value away from D^* region. Parameters resulting from fit are shown in the text.

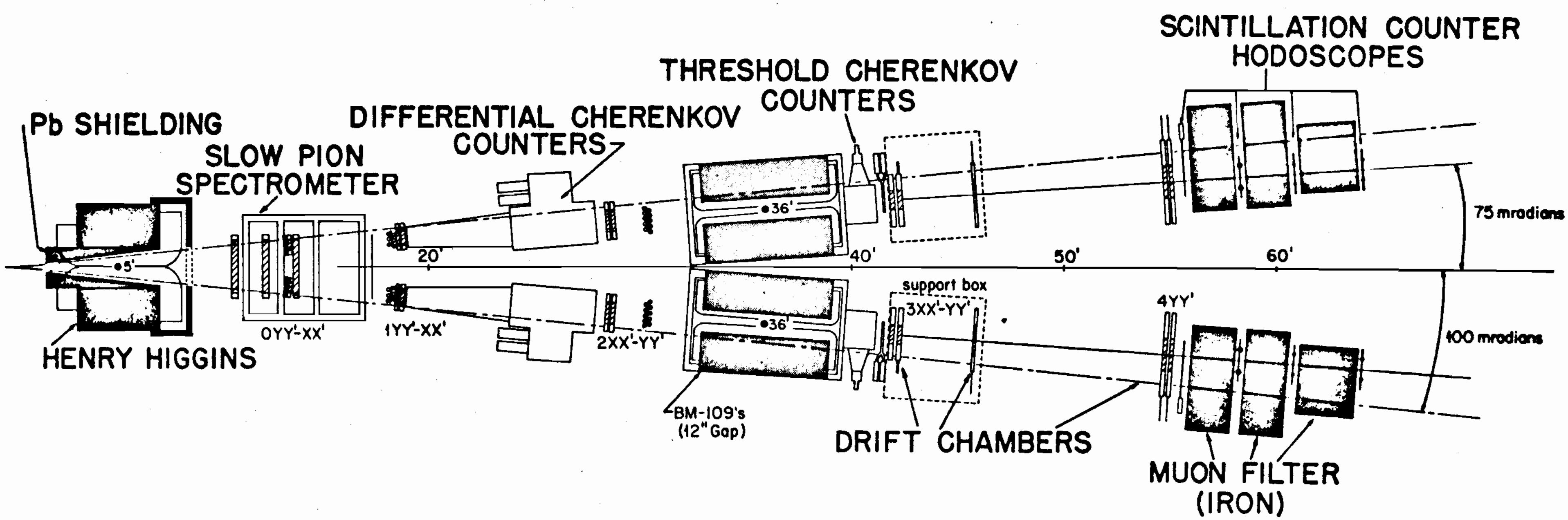
SCINTILLATION COUNTER HODOSCOPES
THRESHOLD CHERENKOV COUNTERS
DIFFERENTIAL CHERENKOV COUNTERS
Pb SHIELDING
SLOW PION SPECTROMETER
HENRY HIGGINS
5'
0YY'-XX'
1YY'-XX'
20'
2XX'-YY'
36'
36'
40'
support box
3XX'-YY'
50'
4YY'
60'
75 mradians
100 mradians
BM-109's (12" Gap)
DRIFT CHAMBERS
MUON FILTER (IRON)

FIGURE 1

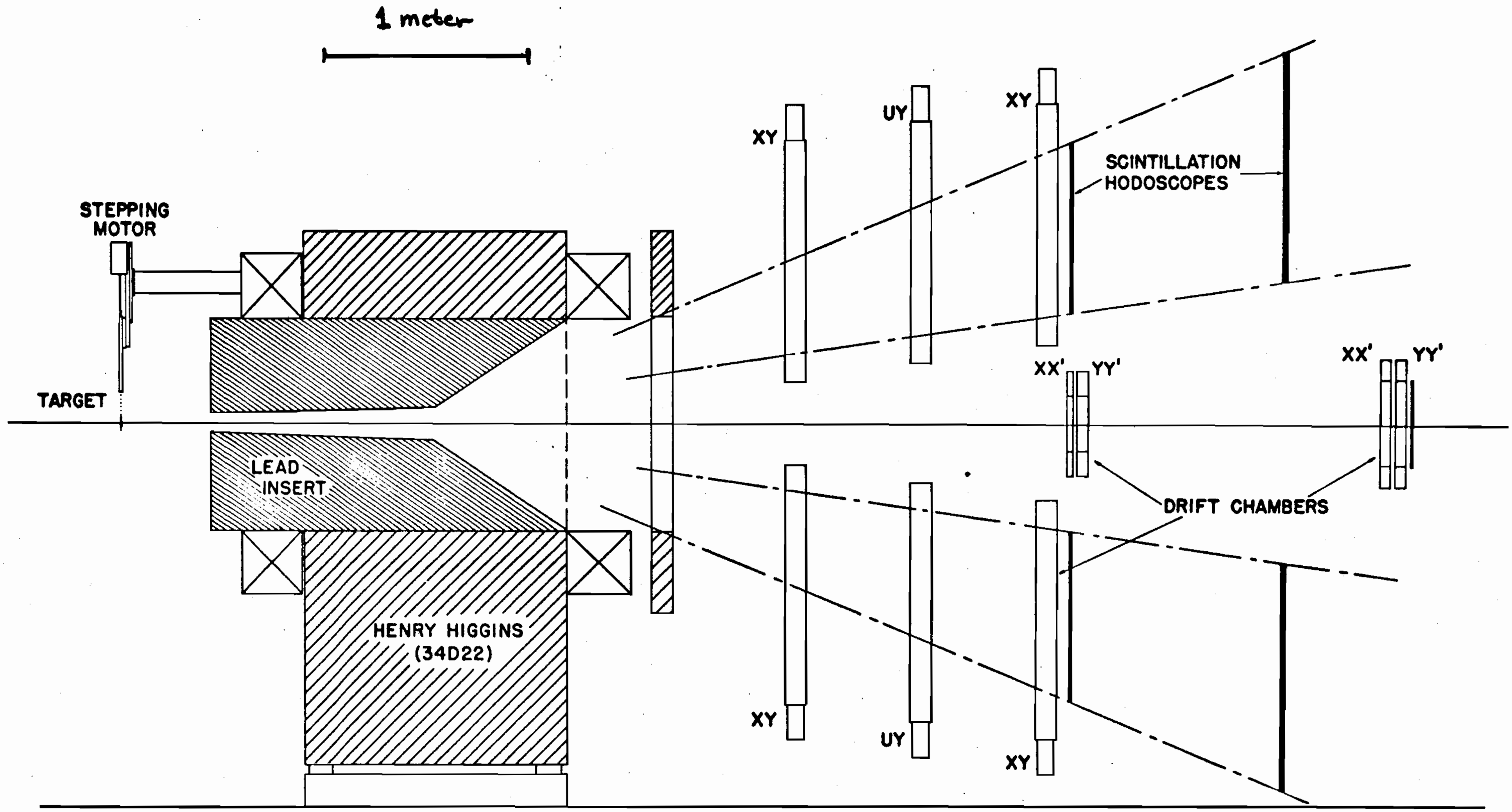
1 meter
STEPPING MOTOR
TARGET
LEAD INSERT
HENRY HIGGINS (34D22)
XY
UY
XY
SCINTILLATION HODOSCOPES
XX'
YY'
XX'
YY'
DRIFT CHAMBERS
XY
UY
XY

FIGURE 2

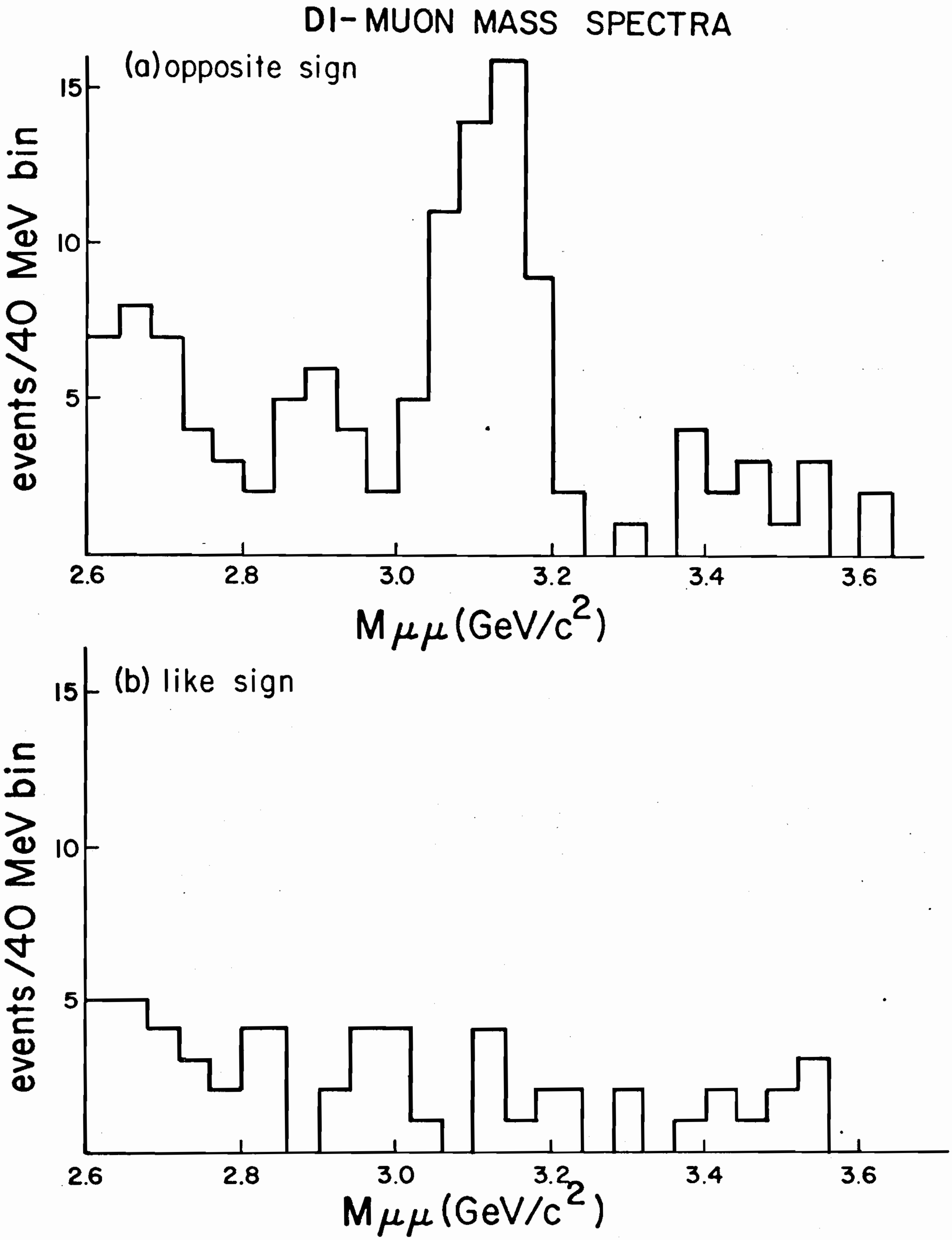
DI-MUON MASS SPECTRA
(a) opposite sign
events/40 MeV bin
15
10
5
2.6
2.8
3.0
3.2
3.4
3.6
Mμμ (GeV/c²)
(b) like sign
events/40 MeV bin
15
10
5
2.6
2.8
3.0
3.2
3.4
3.6
Mμμ (GeV/c²)

FIGURE 3

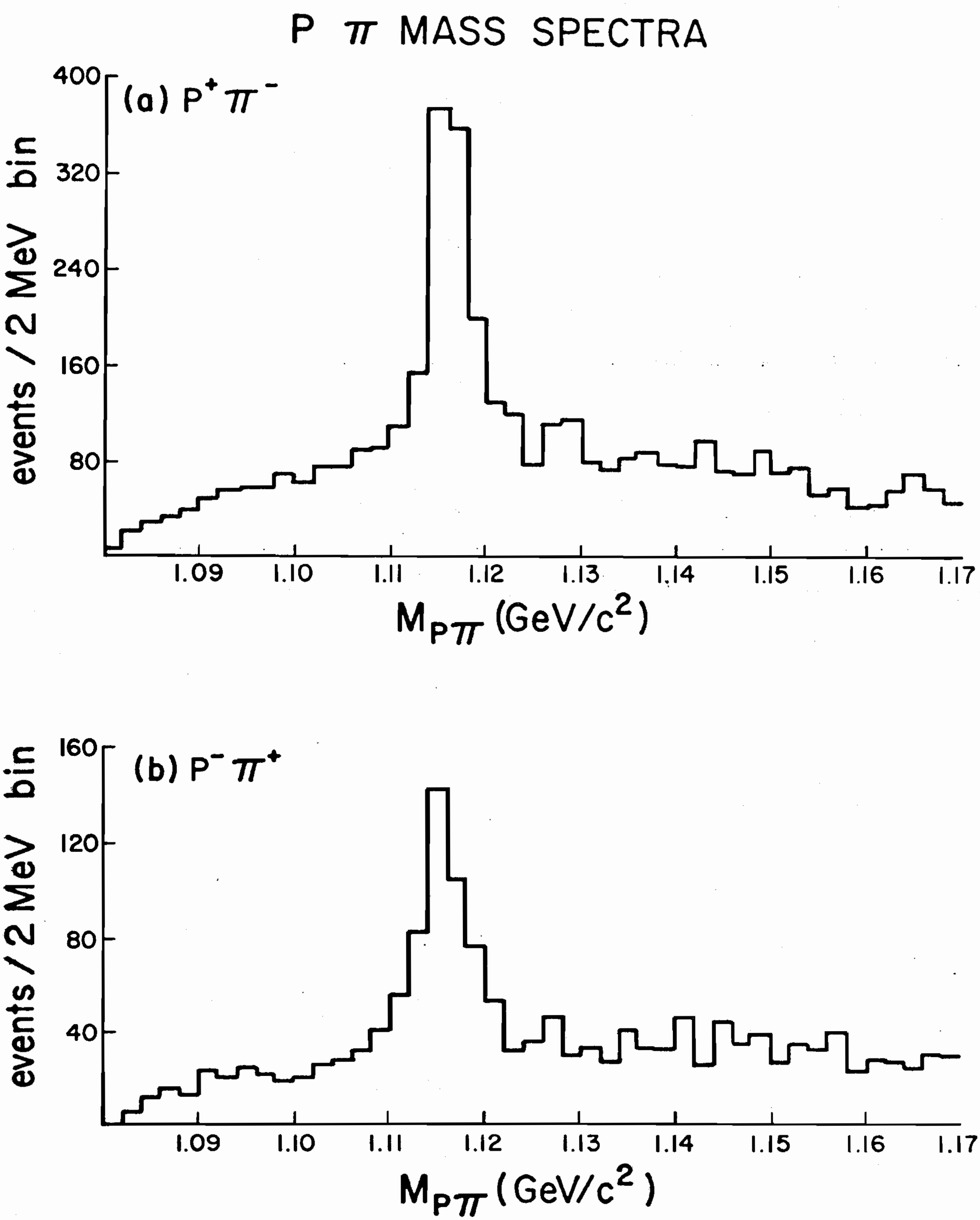
P π MASS SPECTRA
(a) P+ π−
events / 2 MeV bin
400
320
240
160
80
1.09
1.10
1.11
1.12
1.13
1.14
1.15
1.16
1.17
M_Pπ (GeV/c²)
(b) P− π+
events / 2 MeV bin
160
120
80
40
1.09
1.10
1.11
1.12
1.13
1.14
1.15
1.16
1.17
M_Pπ (GeV/c²)

FIGURE 4

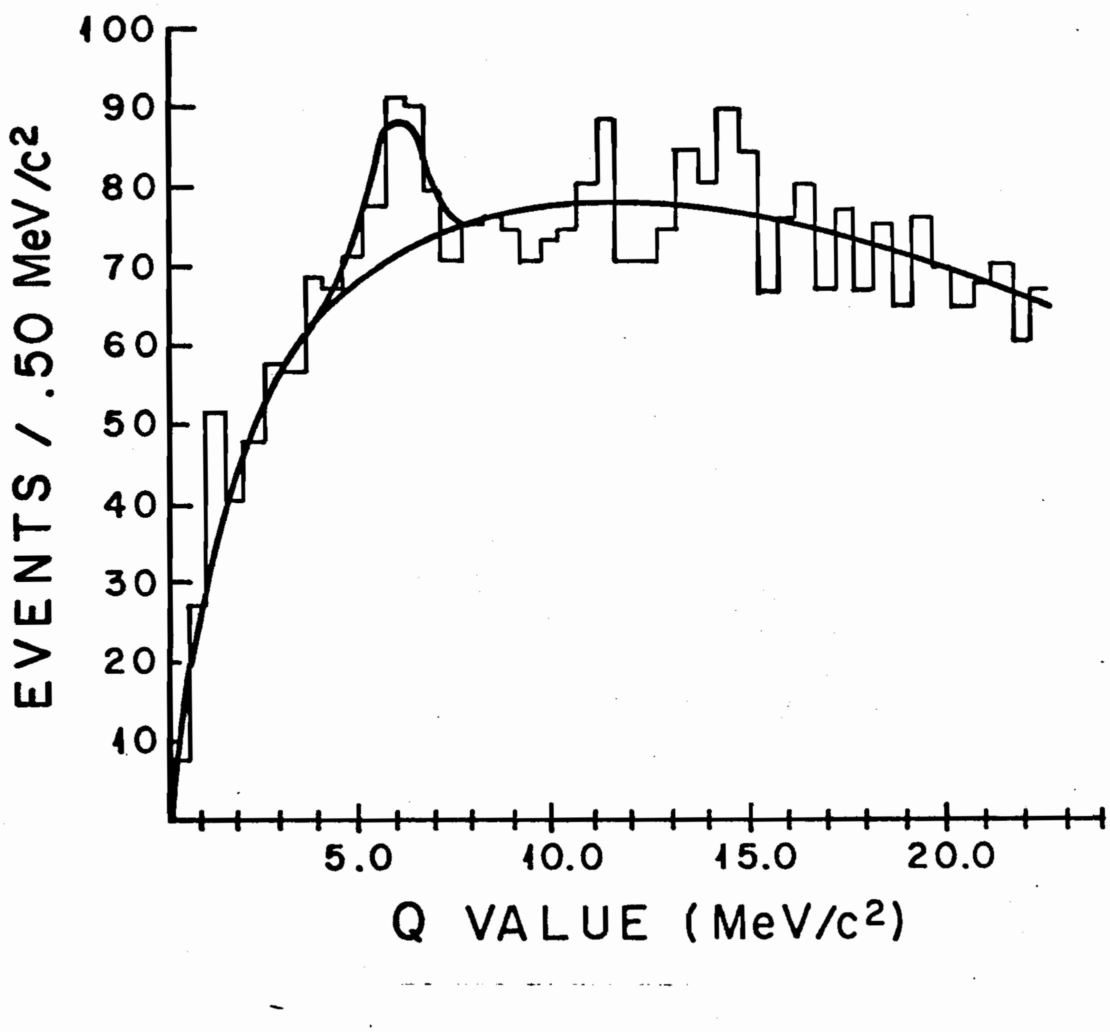
EVENTS / .50 MeV/c²
100
90
80
70
60
50
40
30
20
10
5.0
10.0
15.0
20.0
Q VALUE (MeV/c²)

FIGURE 5

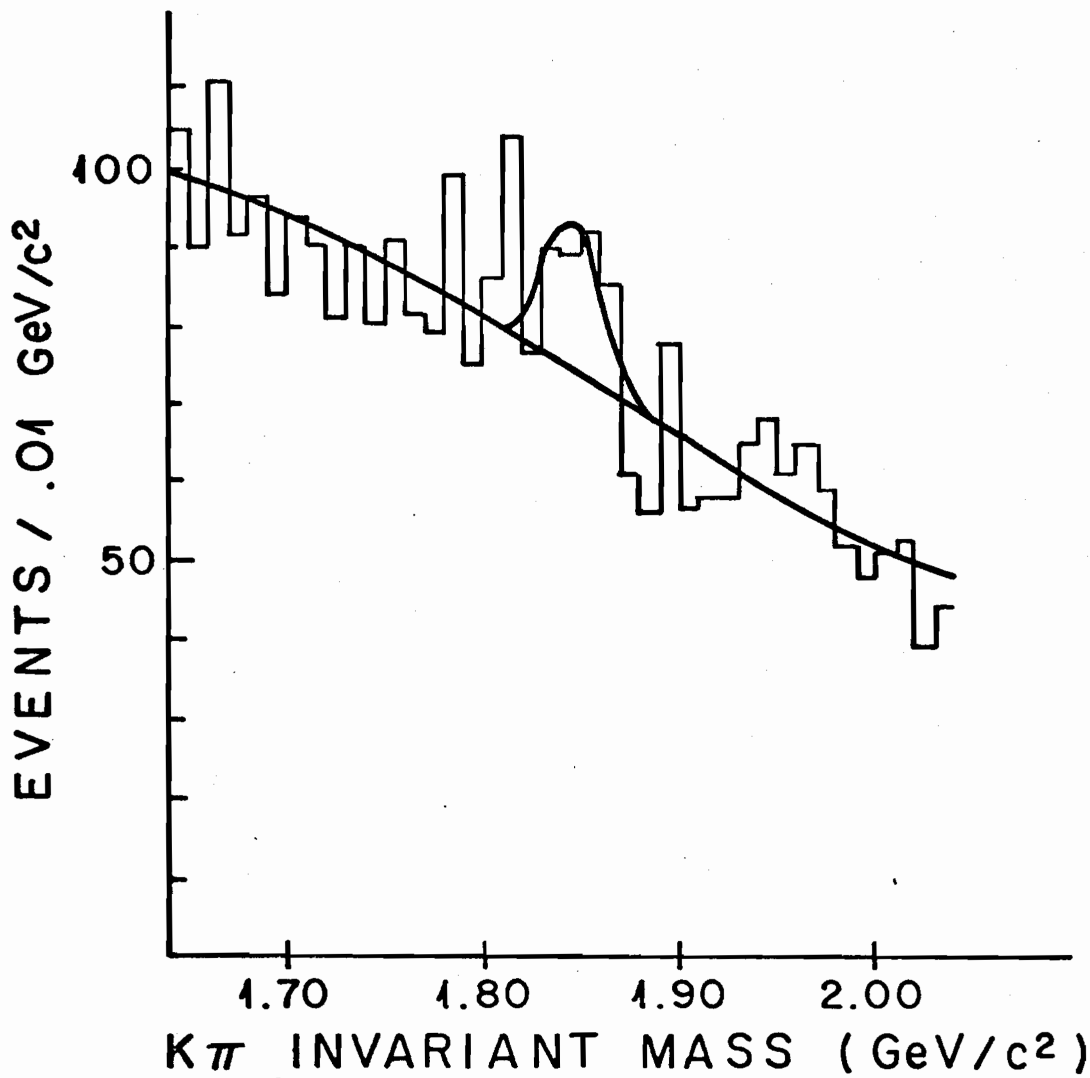
100
50
EVENTS / .01 GeV/c²
1.70
1.80
1.90
2.00
Kπ INVARIANT MASS (GeV/c²)

FIGURE 6