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DIMUON PRODUCTION BY 150 GeV/c π^+ AND PROTONS WITH A LARGE-ACCEPTANCE DETECTOR*

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ABSTRACT

We have measured the cross section for $\mu^+\mu^-$ production in the reactions $(\pi^+,p) + Be \to \mu^+\mu^- +$ Anything at an incident momentum of 150 GeV/c. This report covers the pairs with masses above 2 GeV, in which region the signal is dominated by production of the J(3.1). No events with dimuon mass > 4.1 GeV were seen, although the experiment is sensitive up to $\gtrsim$ 12 GeV. Below the J peak, dimuons are produced ~6 times more copiously by π^+ than by protons in the mass range 2.0–2.6 GeV.

This report presents the first results[1] of a comprehensive study of dimuon production now under way at Fermilab, in which we shall measure the reactions $(\pi, p, K) + A \to \mu\mu + X$ (we are also sensitive to events with > 2 muons). In a recently completed test run with a 150 GeV/c positive beam, we have accumulated 400,000 events from the processes $\pi^+ + Be \to \mu\mu + X$ and $p + Be \to \mu\mu + X$, and have analyzed those with $\mu\mu$ pairs of masses > 2 GeV. The lower mass pairs and > 2 μ events will be reported shortly.

The detector is shown in Figure 1. The 2cm × 2cm wide beam, composed mainly of protons and pions in the ratio ≈3.3/1, strikes a 10cm-thick Be target, with a typical total flux of ~5×10^5 particles/burst. Two Cerenkov counters set just below the proton threshold separate mesons from protons (kaon and muon components were only ≈1%). Then, 1.2 meters downstream from the target, a 2.2-meter thick block of iron absorbs hadrons before they decay, allowing only muons to pass through into a large cylindrical magnet with a 2.1 meter radius and 1.2 meter gap height. Downstream from the magnet, the muons must penetrate an additional 2.5 meters of iron, after which they are detected by a large scintillation-counter hodoscope (shown as P, in Figure 1.) The trigger requirements are as follows:

1) one and only one beam particle and no "halo" particles within a time interval of 100 nsec. 2) $\geq$ 2 particles leaving the

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target 3) $\geq$ 1 particle in the G hodoscope 4) $\geq$ 2 muons in the P hodoscope. To reject single μ's accompanied by low-energy electromagnetic showers, the P hodoscope was mounted flush against the downstream side of a 20cm-thick Pb wall. Additional rejection was accomplished by requiring the muon pulses to be in non-adjacent counters. 5) No count in T_5, a 3" square counter to veto beam muons.

Approximately 70% of the triggers were clearly identifiable muon pairs. The rest, mainly single μ's with wide-angle showers, posed no problem for the analysis. The trigger rate was ~$8/10^6$ beam particles.

The particle trajectories were measured upstream of the magnet by 8 planes of MWPC, 1×1 m^2 in size and 1.5 mm wire-spacing, and downstream of the magnet by 20 planes of wire spark chambers ranging in size from 2×4 m^2 to 2×6 m^2. This large number of detectors gives more than adequate redundancy to eliminate spurious sparks and avoid biases from chamber inefficiencies. The resolution[2] of the system at $M_{\mu\mu} \sim 3$ GeV is $\langle \Delta M \rangle_{rms} \approx 130$ MeV. The spectrometer has substantial efficiency, calculated by Monte Carlo techniques, over a wide range of "phase space": $0.05 < x_F \equiv p^{CM}/p^{CM}_{MAX} \leq 1$ $0.5 < M_{\mu\mu} \lesssim 12$ GeV; and $0 < p_\perp \lesssim 4$ GeV/c.

The uncorrected mass spectra for all $\mu^+\mu^-$ pairs with $M > 2$ GeV are shown in Figure 2. No events were seen above 4.1 GeV, although we have an efficiency of > 10% for masses well above 10 GeV. (It should be remembered in considering these raw spectra that the proton beam was 3.3 times as intense as the pion beam). The reconstructed vertex of each event was clearly resolved to come from the target, and not from the Fe absorber. Only one like-charge ($\mu^+\mu^+$ or $\mu^-\mu^-$) event was observed during the entire exposure. For the events in the prominent J(3.1) peak, which we define as $2.6 < M < 3.5$ GeV, the data are plotted in Figure 3 as a function of x_F, after having been corrected for the spectrometer efficiency. One sees that the π^+- and p-induced cross sections are equal to within our precision at the lowest values of x_F, but that the π^+ cross section falls much more slowly as x_F increases[3]. The data are also shown in Figure 4 as a function of $p_\perp$.

Quantitatively, our results are as follows:

I. Comparison of π^+ and p-Induced Dimuons

A. J Production ($2.6 < M < 3.5$ GeV)

$$\frac{\sigma(p + Be \rightarrow J + X)}{\sigma(\pi^+ + Be \rightarrow J + X)} = 0.61 \pm .27 \qquad (x_F > .05)$$

$$= 0.17 \pm .09 \qquad (x_F > .45)$$

B. Production of Continuum Dimuons ($2.0 < M < 2.6$ GeV)

$$\frac{\sigma(p + Be \rightarrow \mu^+\mu^- + X)}{\sigma(\pi^+ + Be \rightarrow \mu^+\mu^- + X)} = .17 \pm .12 \quad (x_F > .05)$$

II. Absolute Cross-Sections and Confidence Limits

A. J Production ($2.6 < M < 3.5$ GeV), ($x_F > .05$)

$$\sigma(p + Be \rightarrow \underset{\hookrightarrow \mu\mu}{J} + X) = (28\pm14) \times 10^{-33}\ cm^2/\text{nucleus}$$

$$\sigma(\pi^+ + Be \rightarrow \underset{\hookrightarrow \mu\mu}{J} + X) = (46\pm20) \times 10^{-33}\ cm^2/\text{nucleus}$$

B. Continuum ($2.0 < M < 2.6$ GeV)

$$\sigma(p + Be \rightarrow \mu^+\mu^- + X) \sim 1.5 \times 10^{-33}\ cm^2/\text{nucleus}$$

$$\sigma(\pi^+ + Be \rightarrow \mu^+\mu^- + X) \sim 10 \times 10^{-33}\ cm^2/\text{nucleus}$$

C. Like-Charged Dimuons ($2 < M < 4$ GeV), ($x_F > .2$)
If we neglect the one event we found (at $M = 2.4$ GeV), we have

$$\sigma(p + Be \rightarrow \mu^+\mu^+ \text{ or } \mu^-\mu^- + X) \lesssim 8\times10^{-34}\ cm^2/\text{nucleus}$$

$$\sigma(\pi^+ + Be \rightarrow \mu^+\mu^+ \text{ or } \mu^-\mu^- + X) \leq 3\times10^{-33}\ cm^2/\text{nucleus}$$

(90% conf.)

D. Higher-Mass Dimuons - We see none. To quote a limit, we restrict ourselves to the range $0.4 \leq x_F \leq 0.6$, and $5 \leq M_{\mu\mu} < 10$ GeV, where the acceptance is large. We find:

$$\sigma(p + Be \rightarrow \mu\mu + X) < 2 \times 10^{-33}\ cm^2/\text{nucleus}$$

$$\sigma(\pi^+ + Be \rightarrow \mu\mu + X) < 6.5 \times 10^{-33}\ cm^2/\text{nucleus}$$

(90% conf.)

E. $\psi(3.7)$ - There are 3 events in the mass spectrum of p-induced events in the region of $\psi(3.7)$. We clearly need more data to study this.

In concluding, the authors wish to acknowledge the assistance of the staff of Fermilab, and especially the members of the Chicago, Harvard, Oxford, Illinois muon-scattering group, whose spectrometer we have used in a modified form for this work.

REFERENCES

1. Because of space limitations, no attempt is made at referencing previous work on dimuon production. See B. Knapp et al., Phys. Rev. Lett. 34, 1044 (1975) for other references.
2. In our final results, we shall use information from additional MWPC's between the target and the Fe absorber to improve the resolution.
3. This feature is insensitive to the polarization of the J. Our absolute cross-sections were calculated for unpolarized J's; if the polarization were $1+\cos^2\theta_{CM}$ instead, the cross-sections would be 35% higher than those quoted here.

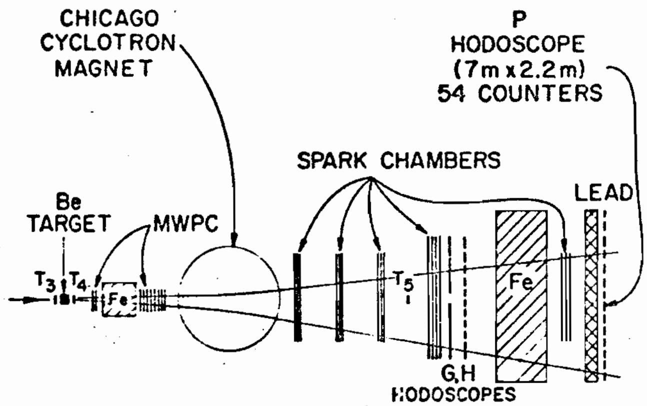

Fig. 1 The Apparatus

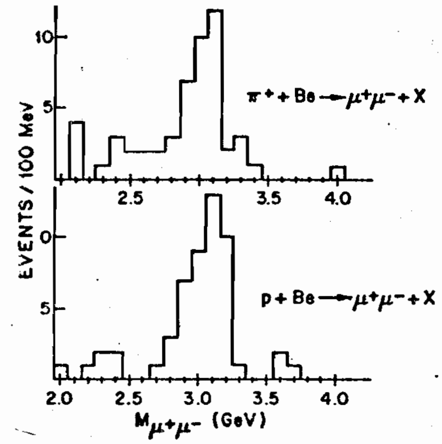

Fig. 2 Uncorrected Mass Spectra

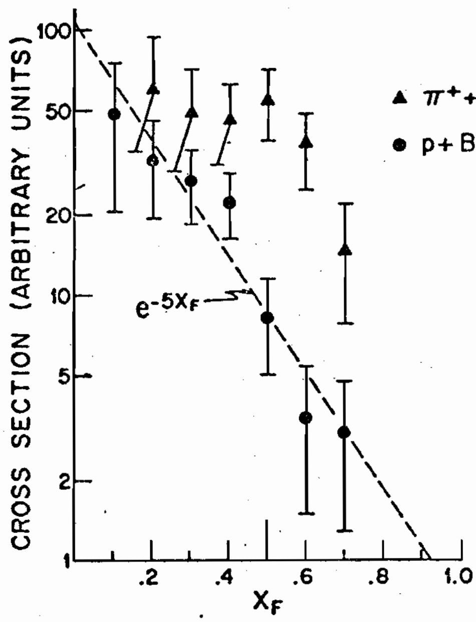

Fig. 3 Relative cross-sections for J production.

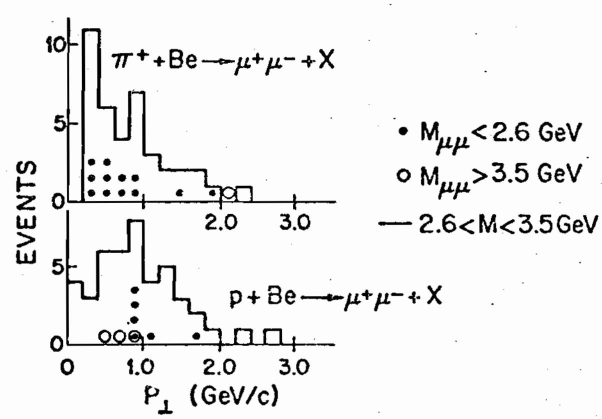

Fig. 4 $p_\perp$ distributions. The acceptance is uniform in $p_\perp$ within 20 percent.