

MU-PAIR PRODUCTION BY 150 GeV/c HADRONS*

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We report the first results of a measurement of μ -pair production by 150 GeV/c protons and π^+ mesons. The experiment was performed in Fermilab's Muon Laboratory using hadrons from the N1 beam and the large acceptance Chicago cyclotron spectrometer.

At 150 GeV/c the 2-cm \times 2-cm positive beam consisted of a few percent muons and K^+ mesons, 23% π^+ mesons, and the rest protons. Two helium filled threshold Cerenkov counters situated in the incident beam were set just below the proton threshold and recorded as a tag with every trigger. Thus, pion induced μ -pairs were recorded simultaneously with the proton induced pairs and the ratio of the two cross sections is particularly insensitive to systematic effects.

As shown in Fig. 1, the beam was incident on a 5-cm-diameter, 10-cm-long beryllium target located 1.2 m upstream from a 2.2-m-thick movable steel hadron shield. Charged particles emerging from the hadron shield were momentum analyzed in the Chicago cyclotron spectrometer, which is described in detail elsewhere.¹ Briefly, the spectrometer consisted of eight 1-m-square MWPC planes to define track trajectories upstream of the magnet and 20 spark chamber planes to define the downstream trajectories. In addition,

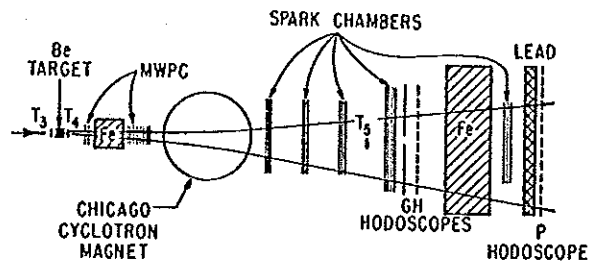


Fig. 1--Plan view of the detector.

signals from two 6-m-wide, 2-m-high hodoscope planes of horizontal and vertical scintillation counters (G and H of Fig. 1) were recorded as tags with the data to improve the time resolution of the downstream detector. The hodoscope planes were followed by 2.5 m of steel and lead for further muon identification and finally by a vertical hodoscope (P of Fig. 1) used for triggering.

The trigger logic required exactly one unaccompanied charged particle in the beam. A 3-counter beam telescope $T_1 \cdot T_2 \cdot T_3$ defined the incident trajectory and a pulse height requirement in T_3 ensured no more than a single particle in the beam. Large halo veto counters were used around the beam but in a position well shielded against backscatter from the target. Beam interactions in the target were selected by requiring at least 2 minimum ionizing particles in counter T_4 situated just downstream of the target. At least one count was required in the G hodoscope plane

shown in Fig. 1, and in the P-plane two non-adjacent counters were required to be struck. The P hodoscope was mounted flush against the downstream side of a 20-cm-thick lead wall to further reduce triggers from single μ 's accompanied by low energy electromagnetic showers. Finally, a 3-in-square counter T_5 was located downstream of the magnet and was used in anticoincidence to veto beam muons. This trigger gave a signal which was $\sim 70\%$ unaccompanied μ -pairs. Most of the remaining triggers were single muons which produced a shower in the downstream hadron filter and thereby hit two nonadjacent P counters.

Event reconstruction was straightforward since the MWPC's and spark chambers were in general well over 90% efficient, and since the probability that a μ -pair was accompanied by an extra track in the spectrometer was less than 5%. An effective mass was computed for the pair with no constraint on the z-coordinate of the μ -pair production point. A second calculation was made assuming the pair originated at the center of the target. These two calculations were required to agree to within 0.6 GeV. Monte Carlo studies showed this requirement had a negligible effect on the real signal from the target but was effective in removing pairs which originated elsewhere. The z-distribution for the vertex position of accepted events is shown in Fig. 2. There is no indication of events originating from any source other than the target.

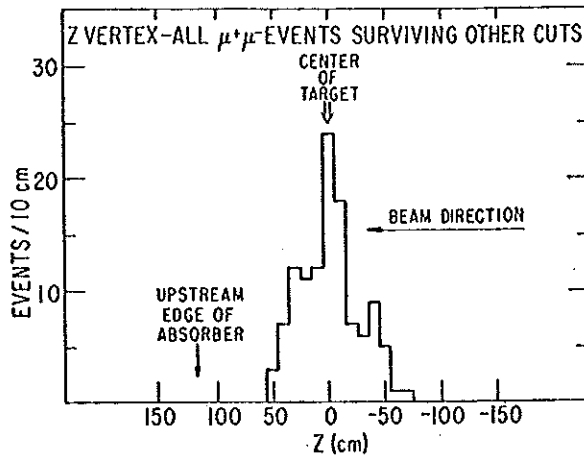


Fig. 2--z-distribution for vertex position of accepted μ -pairs.

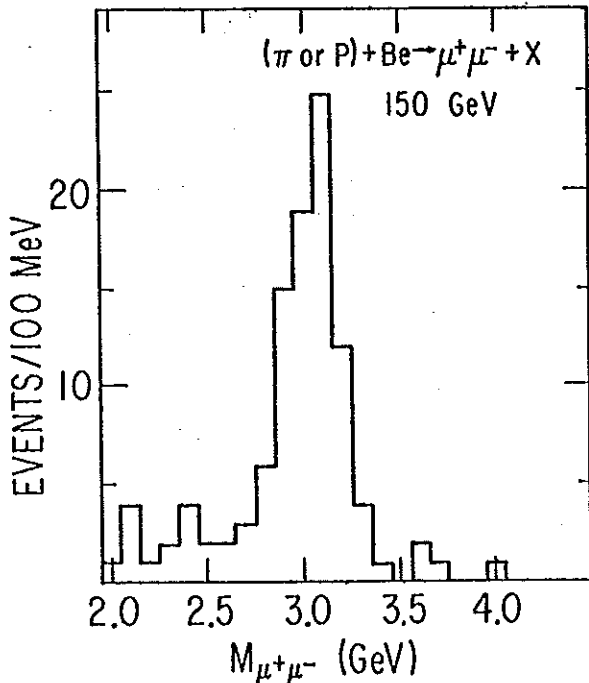


Fig. 3--Mass distribution for all μ -pairs.

The effective mass for these events is shown in Fig. 3. A clear J signal is seen at 3.1 GeV, and no events are observed above 4.1 GeV. The line shape is primarily determined by multiple scattering in the shield and is nearly Gaussian with $\sigma \sim 130$ MeV. The fraction of J events falling below 2.6 GeV is less than 2% as determined by a careful Monte Carlo study, which included the correlation between lateral and angular scattering in the shield, fluctuations in ionization energy loss, and fluctuations in energy loss through radiative processes. Background from two hadrons decaying to muons is negligible since we only observe a single event with both muons of the same charge and $M_{\mu\mu} > 2$ GeV.

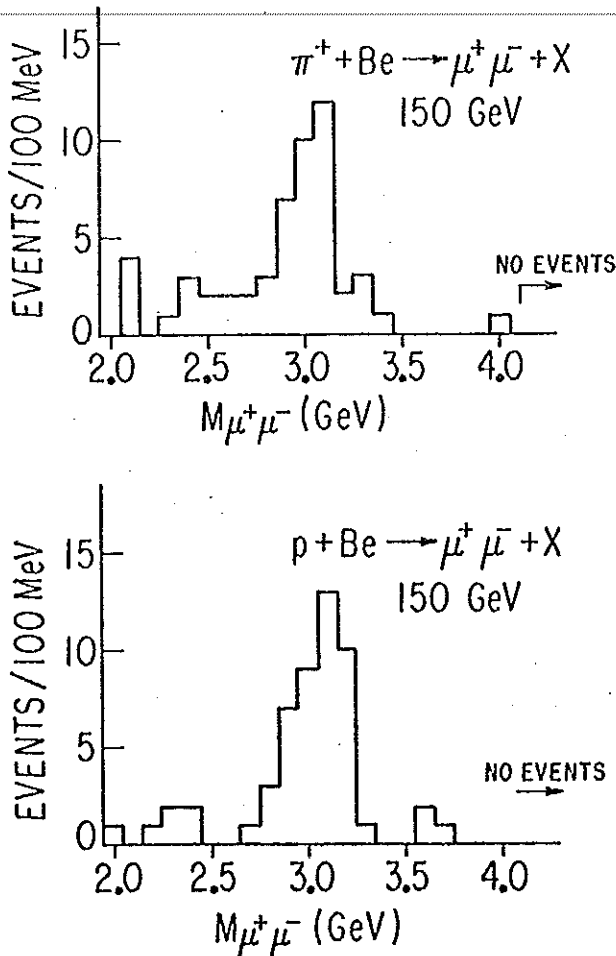


Fig. 4--Mass distribution for pion and proton induced pairs shown separately.

The distributions in Feynman X are given in Fig. 6 for protons and pions. In these figures, the relative pion to proton flux has been accounted for as has the variation in acceptance with X. The acceptance calculation is straightforward. The only model dependent aspect is the shape of the decay angular distribution of the μ -pair in its rest frame. We will assume no net polarization for the μ -pair state and hence that the angular distribution described above is flat in $\cos\theta^*$. The assumption of a $1 + \cos^2\theta^*$ distribution leads to a decrease in the integrated acceptance and would increase the cross sections quoted below by about 30%. The shape of the acceptance as a function of X and P_T is little affected by these assumptions.

The mass spectra for p-induced and π -induced pairs are shown separately in Fig. 4. If we define as J candidates all events in the interval $2.6 < m_{\mu\mu} < 3.5$, we observe 39 J candidates for incident pions and 46 candidates for incident protons. In the region $2.0 < m_{\mu\mu} < 2.6$, there are 11 and 6 events for incident pions and protons respectively. These events are observed with an effective beam composition of 3.3 protons for every pion.

The observed P_T distribution for the J candidates is shown in Fig. 5 for proton and pion events separately. The data show a mean P_T of 0.9 GeV/c. The variation in detector acceptance as a function of P_T is small, falling 20% between $P_T = 0$ and $P_T = 2$ GeV/c.

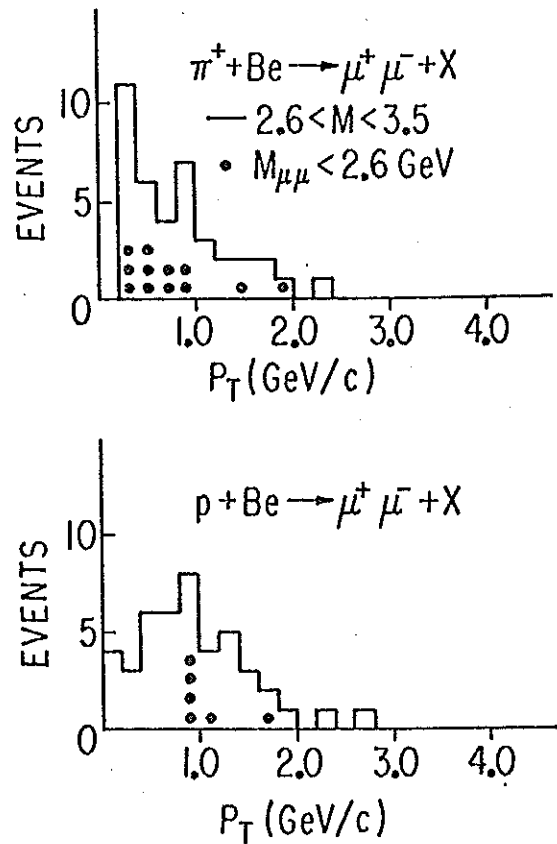


Fig. 5--Uncorrected pairs P_T spectra.

These data lead to a cross section ratio of

$$\frac{\sigma(p+\text{Be} \rightarrow J+\dots)}{\sigma(\pi^+\text{Be} \rightarrow J+\dots)} = 0.61 \pm 0.27 \quad \chi_F > 0.05$$

And for a larger value of χ_F

$$\frac{\sigma(p+\text{Be} \rightarrow J+\dots)}{\sigma(\pi^+\text{Be} \rightarrow J+\dots)} = 0.17 \pm 0.09 \quad \chi_F > 0.45$$

For the mass region below the J peak, namely, $2.0 \leq m_{\mu\mu} \leq 2.6$ GeV, we obtain

$$\frac{\sigma(p+\text{Be} \rightarrow \mu^+\mu^-+\dots)}{\sigma(\pi^+\text{Be} \rightarrow \mu^+\mu^-+\dots)} = 0.17 \pm 0.12$$

$$\chi_F > 0.05$$

In terms of absolute cross sections, we measure

$$B\sigma(p+\text{Be} \rightarrow J+\dots) = 28 \pm 14 \text{ nb/Be nucleus} \quad \chi_F > 0.05$$

$$B\sigma(\pi^+\text{Be} \rightarrow J+\dots) = 46 \pm 20 \text{ nb/Be nucleus}$$

Where B is the branching ratio of $J \rightarrow \mu^+\mu^-$.²

Dividing by A to estimate the cross section per nucleon³ yields

$$B\sigma(p+N \rightarrow J+\dots) = 3.1 \pm 1.6 \text{ nb/nucleon} \quad \chi_F > 0.05$$

$$B\sigma(\pi^+N \rightarrow J+\dots) = 5.1 \pm 2.2 \text{ nb/nucleon}$$

Since no events are observed for masses greater than 4.1 GeV, we set a 90% confidence limit on the cross section in the interval $4 < M_{\mu\mu} < 10$ GeV and $0.4 < \chi_F < 0.6$ of:

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

and

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

The results for hadron production of J's are in reasonable agreement with published measurements at slightly different energies,⁴ although the data reported here extend down to lower values of χ_F .

In conclusion, we wish to give special thanks to the members of the Chicago, Harvard, Illinois, Oxford muon-scattering group whose spectrometer was used in modified form for this work. We also acknowledge the help of the Fermilab Neutrino Laboratory staff and the technical support groups at our institutions headed by R. Armstrong and T. Nunamaker at Chicago and by K. Wright at Princeton.

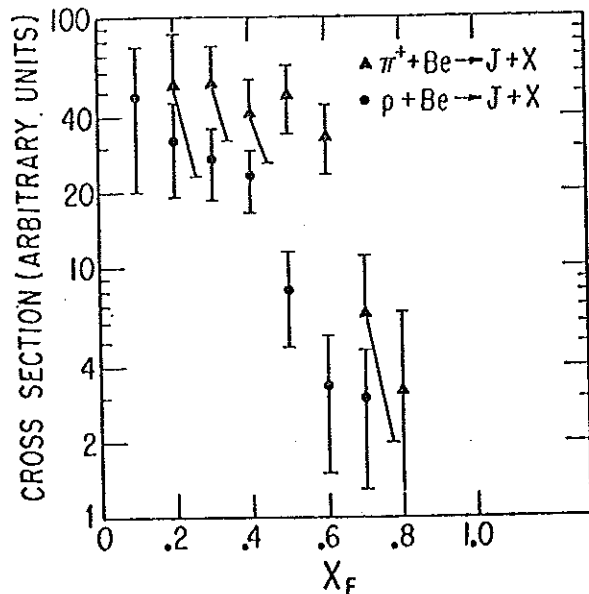


Fig. 6--Feynman X distribution for protons and pion induced μ -pairs.

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