PRODUCTION OF MASSIVE DIMUONS IN PROTON-NUCLEON COLLISIONS AT FERMILAB

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ABSTRACT

We have studied the production of massive muon pairs ($7 \leq M_{\mu\mu} \leq 11$ GeV/c^2) in proton-nucleon collisions at Fermilab. It was found that a very large percentage of high $P_\perp$ direct muons is produced as a member of a high mass muon pair. The production cross section for muon pairs was also found to agree with predictions of the Drell-Yan model of quark-anti-quark annihilation.

The Chicago-Princeton collaboration[1] has measured the production cross section for the process $p + N \rightarrow \mu^+\mu^- + X$ at Fermilab in order to determine how often high $P_\perp$ direct muons are members of high mass muon pairs.

The apparatus is shown schematically in Fig. 1.

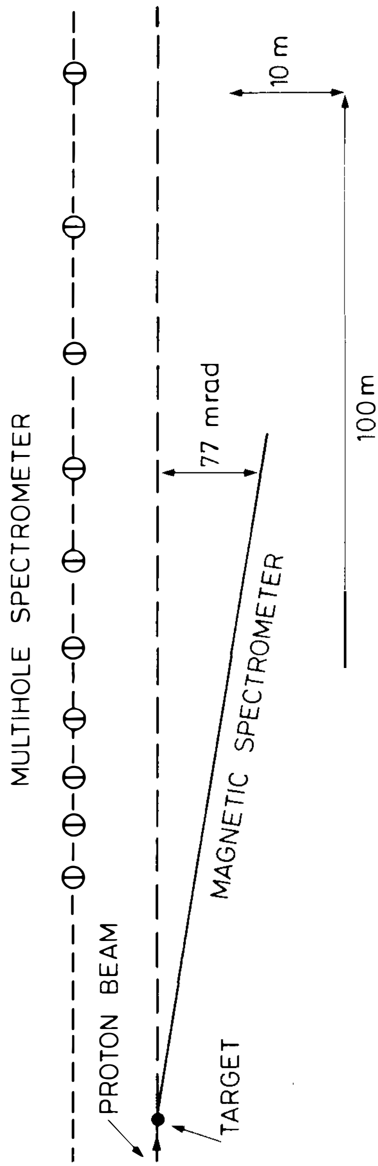

Fig. 1. Schematic diagram of the apparatus.

The magnetic spectrometer[2] detected particles produced near 90° in the proton-nucleon center of mass. With a hadron absorber inserted at the upstream end of the spectrometer, a detected μ was a direct μ ~70% of the time. In order to determine whether a direct μ was a member of a high mass pair, the multihole spectrometer (MHS) was built. It consisted of ten 3.7 m high x 1.2 m wide liquid scintillation counters inserted in 6 m deep holes in the ground. The counters were placed along a line parallel to, but at a distance of 6 meters from the incident proton beam line. The 6 m earth shield produced an approximately uniform transverse momentum cutoff of 3 GeV/c, below which no muon produced at the target could reach a multihole counter. The multihole detector covered a range in the center of mass of 60° - 126° in polar angle and -8° - 25° in azimuth. The mass acceptance of the apparatus was centered on twice the transverse momentum ($P_\perp^S$) of the direct muon detected in the magnetic spectrometer. Typical mass resolution was 2 GeV/c^2 FWHM at $M_{\mu\mu}$ = 10 GeV/c^2.

The multihole counters were interrogated each time a particle was detected in the magnetic spectrometer. The time of flight of the multihole count with respect to the trigger in the magnetic spectrometer was recorded. Figure 2 shows the results for a run with 400 GeV incident protons and with the magnetic spectrometer set to trigger on particles with transverse momentum of 4.5 GeV/c. The relative time of flight is plotted in units which reflect the Fermilab beam structure - 2 nsec wide RF bins separated by 19 nsec. RF bin number 4 was independently determined to be the coincidence bin. The $\mu\mu$ data (Fig. 2a) shows a clear signal above a flat accidental background. Figure 2b shows the time of flight spectrum for multihole muons in coincidence with a pion in the spectrometer. In this case there is no signal above the accidental background.

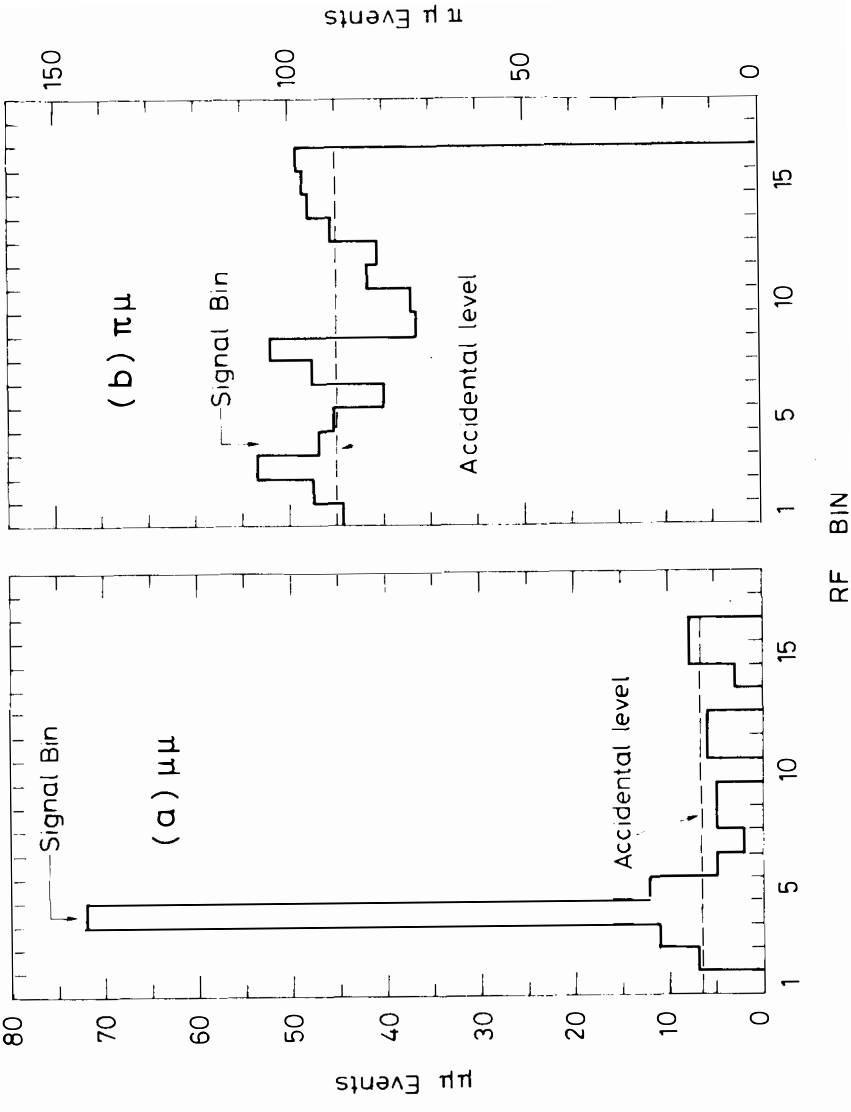

Fig. 2. Time distributions of MHS counts with respect to (a) a muon trigger, and (b) a pion trigger in the magnetic spectrometer (set at $P_{\perp}^{S}$ = 4.5 GeV/c). Time intervals are plotted in units of an RF period of the Fermilab accelerator (18.9 nsec).

This $\pi\mu$ data, taken simultaneously with the $\mu\mu$ data, shows conclusively that the $\mu\mu$ signal is real.

TABLE I

$P_\perp^S$	$<M_{\mu\mu}>$	Dimuon Yield	Yield per 10^{12} Protons	$\mu\mu/\mu$ Observed
3.75 GeV/c	7.6 GeV/c^2	55 ± 11	117 ± 20	(0.6 ± 0.1)%
4.50	8.7	152 ± 15	70 ± 7	(3.2 ± 0.3)%
5.25	9.9	34 ± 6	35 ± 6	(9.9 ± 1.7)%
6.00	11.0	13 ± 4	5.3 ±2	(12 ± 3.7)%

The raw results at 400 GeV incident beam energy are presented in Table I. The fraction of direct muons which was accompanied by a muon in the multihole detector increases with increasing $P_\perp^S$. At $P_\perp^S$ = 5.25 GeV/c, for example, the fraction was ~10%. In order to deduce the total fraction of direct muons which was produced as a member of a high mass pair, one must correct for the acceptance of the MHS. If the parent of the muon pair had limited transverse momentum (≲300 MeV/c) with respect to the incident proton direction, then the muon detected in the MHS would lie in the production plane, defined by the incident beam line and the magnetic spectrometer. The MHS detection efficiency for the second muon would then be quite high. If, on the other hand, the muon pair had large transverse momentum with respect to the incident beam, then the coplanarity condition would not be satisfied resulting in a significantly lower MHS detection efficiency. Figure 3 shows the vertical distribution of counts in the multihole counters along with the expected distribution for limited dimuon transverse momentum. From the vertical distribution it was determined that the mean transverse momentum of the dimuon parent is $<P_\perp> \simeq 1.2$ GeV/c.

In order to evaluate the detection efficiency for dimuons, a model was assumed for the $P_\perp$ and x dependence of the dimuon production cross section:

$$E\frac{d\sigma}{dp^3} \propto e^{-1.6\,P_\perp}(1-|x|)^{4.3}.$$

The $P_\perp$ dependence reflects the $<P_\perp>$ determined from the data. The Feynman x

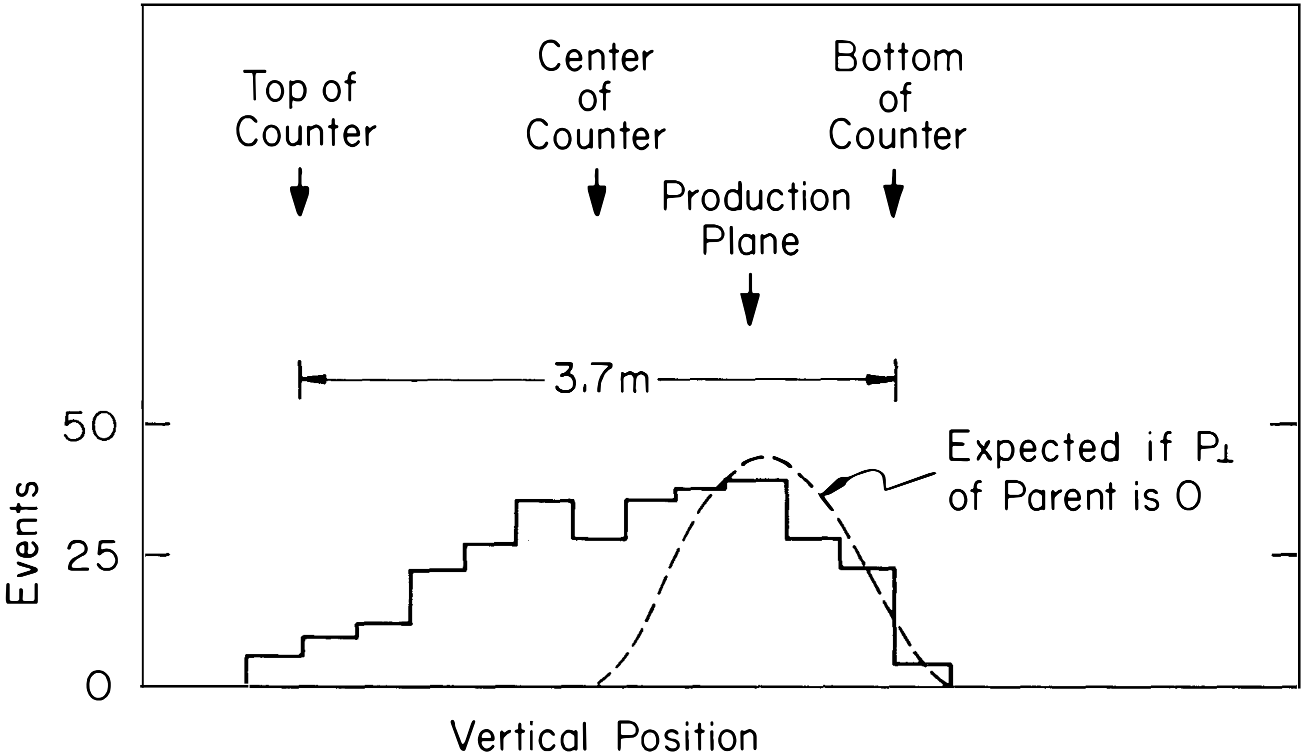

Fig. 3. Vertical distribution of counts in the MHS.

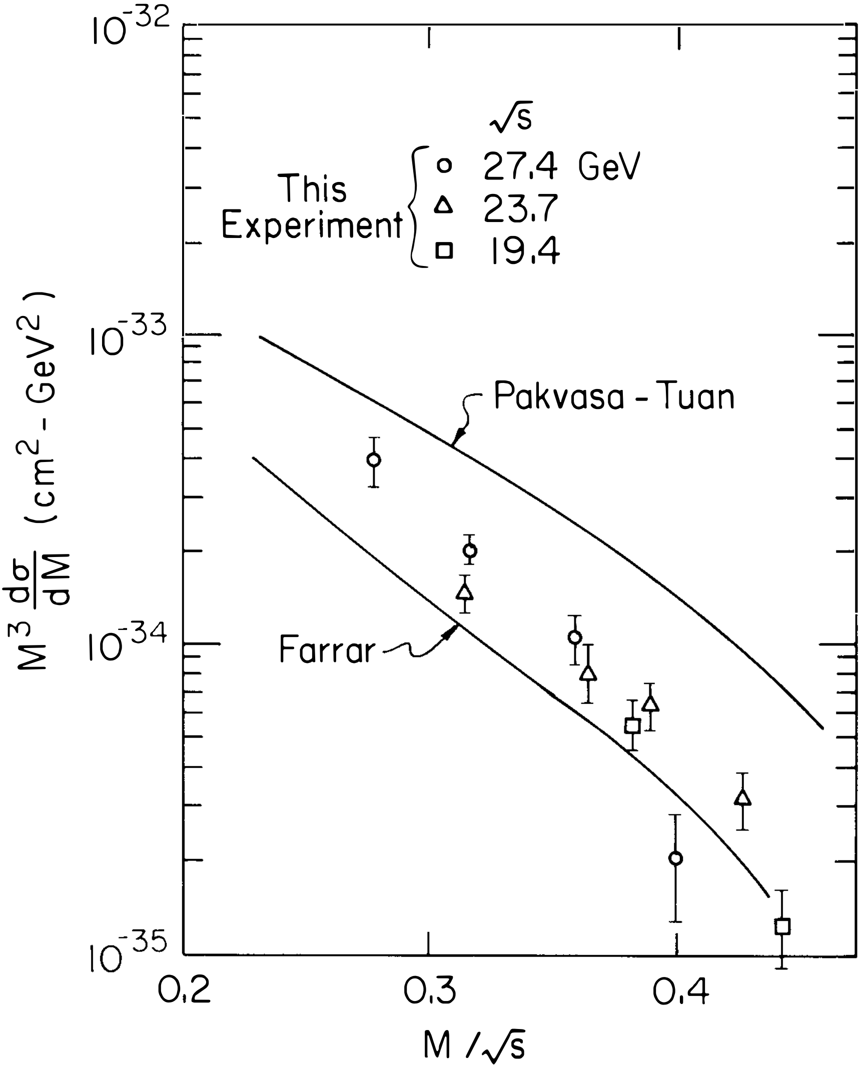

Fig. 4. Dimuon cross sections plotted to show scaling properties of the data. The results of two parton model calculations are also shown.

dependence is that measured in J/ψ production at Fermilab.[4] (The results presented here are insensitive to the form of the x dependence.) Using this parametrization, we find that, for a spectrometer transverse momentum of 5.25 GeV/c, 13% of dimuons would be detected in the MHS. Since (10 ± 2)% of the direct muons at $P_\perp^S = 5.25$ GeV/c are accompanied by an MHS count, we conclude that a very large fraction of high $P_\perp$ direct muons has high mass dimuon parentage.

The results of the experiment can be compared with predictions of the Drell-Yan model[3]: quark anti-quark annihilation into a virtual photon which materializes into the muon pair. One such prediction is the scaling behavior of the cross section $M_{\mu\mu}^3 \frac{d\sigma}{dM_{\mu\mu}} = f\left(\frac{M_{\mu\mu}}{\sqrt{s}}\right)$ where f depends only on the fraction of the center-of-mass energy carried off by the muon pair. The cross sections, evaluated by using the production model given above, are shown in Fig. 4. The scaling behavior, i.e., data at different center-of-mass energies lying on a universal curve, is observed. Results from Hom et al.[4] as well as from two parton model calculations[5,6] are also shown. The models differ in the assumed form of the anti-quark distribution in the nucleon. Agreement between data and the model is quite good.

The atomic number dependence of the dimuon invariant cross section has also been measured. We find $E \frac{d\sigma}{dp^3} \propto A^{1.05 \pm 0.10}$.

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