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PRODUCTION OF HIGH-MASS MUON PAIRS IN π^-Be COLLISIONS AT 150 AND 175 GeV/c

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ABSTRACT

We present production and decay characteristics of 500 high-mass, high-resolution $\mu^+\mu^-$ pairs produced in π^-Be collisions at 150 and 175 GeV/c. Our data do not agree with a simple Drell-Yan production mechanism, but indicate that higher-order QCD corrections must be included.

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The production of high-mass $\mu^+\mu^-$ pairs in hadron-hadron collisions is expected to occur by quark-antiquark annihilation into a time-like virtual photon. The simple Drell-Yan model[1)] for this process ignores higher order QCD effects, such as gluon emission from a quark. We have observed 500 muon-pair events in π^-Be interactions at 150 GeV/c and 175 GeV/c at the CERN Super Proton Synchrotron (SPS). Part of our 150 GeV/c data has already been presented[2)]. Our data exhibit many general characteristics of the Drell-Yan model. We show new evidence which strongly suggests that higher order QCD effects are present in the production process.

Our apparatus consists of a Be target, a large-aperture magnetic spectrometer followed by a multi-celled Čerenkov counter, and a 2380 g/cm^2 iron muon filter. Eleven multiwire proportional chambers with a total of 40,000 wires, inside the magnet and upstream and downstream of the Čerenkov counter, measured charged hadron and lepton trajectories. Various scintillation counters and hodoscopes were used to trigger on high-mass $\mu^+\mu^-$ pairs. Details of our equipment and trigger scheme have been presented elsewhere[3)]. The J/ψ and ψ' mass peaks[3)] verify our excellent mass resolution of $\sigma_M/M = 0.015$.

Figure 1 shows our $\mu^+\mu^-$ mass spectra, in the form $M^3 d\sigma/dM$ versus $\tau = M^2/s$, for 150 and 175 GeV/c. The data have been corrected for the acceptance of our apparatus. Background can come from uncorrelated (non-prompt) muons, such as when one or both muons originate from a hadron decay and/or from the beam halo. This was studied by triggering our apparatus on like-sign muons. The like-sign muon data were enhanced by taking like-sign muons from different events in this data sample. We found that our lowest mass data points (the mass interval from 3.8-4.3 GeV/c^2) had a background of 17%. For each mass interval the background subtraction was less than the statistical error. The data were normalized by comparing the yield with the ψ yield[4)]. We estimate our overall normalization error to be ±20%. Also shown in Fig. 1 are data from other experiments on $\mu^+\mu^-$ production by π^- mesons, at 225 GeV/c [5)] and at 200 and 280 GeV/c [6)].

The Drell-Yan mechanism predicts that $M^3d\sigma/dM$ should scale in the variable M^2/s. This is also true if first-order QCD corrections are included[7]. Figure 1 shows that the 150, 175, 200, and 280 GeV/c data do scale. The 225 GeV/c data do not[8].

In Fig. 2 we show x_F and p_T distributions and decay angular distributions in the Gottfried-Jackson frame. We have combined our data at 150 GeV/c (60% of sample) and at 175 GeV/c (40% of sample). The smooth curves are fits to the data. For the x_F distribution (Fig. 2a) we fit to the form

$$\frac{d\sigma}{dx_F} = A\left\{1 - |x_F - B|\right\}^C .$$

We find A = 0.43 ± 0.03 nb, B = 0.14 ± 0.02, and C = 2.1 ± 0.3; the χ^2 was 4 for 8 degrees of freedom. The non-zero value of B suggests that quarks in the pion have greater average momentum than those in the nucleon. When the quarks annihilate, $x_F = x_1 - x_2$, where x_1 and x_2 are the pion and nucleon quark momentum fractions. $\langle x_1\rangle - \langle x_2\rangle$ is expected to be about 0.11 for valence quarks[9], while we find $\langle x_F\rangle =$ $= B = 0.14 \pm 0.02$. The p_T distribution (Fig. 2b) is fitted to

$$\frac{1}{p_T}\frac{d\sigma}{dp_T} = D\left\{1 + \left(\frac{p_T}{E}\right)^2\right\}^F ,$$

with D = 0.49 ± 0.05 nb/(GeV/c)^2, E = 1.7 ± 0.5 GeV/c, and F = −3.2 ± 1.3. $\chi^2 = 9$ for 10 degrees of freedom. $\langle p_T\rangle = 1.04$ GeV/c. The simple Drell-Yan model cannot explain[10] this large $\langle p_T\rangle$. In Fig. 2c we show a fit to

$$\frac{d\sigma}{d\cos\theta_{GJ}} = G(1 + \lambda\cos^2\theta_{GJ}) ,$$

where θ_{GJ} is the Gottfried-Jackson angle. We find G = 0.25 ± 0.02 nb, $\lambda = 0.52 \pm$ ± 0.46, and $\chi^2 = 4$ for 6 degrees of freedom. The Drell-Yan prediction is $\lambda = 1$, and QCD corrections[10] tend to reduce λ.

The Drell-Yan cross section with colored quarks is

$$\frac{d^2\sigma}{dMdx_F} = \frac{8\pi\alpha^2}{9M^3}\,(x_F^2 + 4M^2/s)^{-1/2}\, f^{\pi}(x_1)g^N(x_2) ,$$

where $f^{\pi}(x_1) = x_1\bar{u}^{\pi}(x_1)$ and $g^N(x_2) = (4/9)x_2u^N(x_2) + (1/9)x_2\bar{d}^n(x_2)$. Here, $\bar{u}^{\pi}(x_1)$ is the distribution function of $\bar{u}$ quarks in the π^- and $u^N(x_2)$ and $\bar{d}^N(x_2)$ are the nucleon u and $\bar{d}$ quark distribution functions, respectively. The nucleon structure $g^N(x_2)$ can be deduced with lepton probes. We use the nucleon structure function from the analysis of Buras and Gaemers[11)], and derive $f^{\pi}(x_1)$ from our data.

We determine $f^{\pi}(x_1)$ by fitting our data in x_F-M space in the region $-0.1 \leq$ $\leq x_F \leq 0.8$ and $3.8 \leq M \leq 7.8$ GeV/c^2. Our mass resolution allows us to fit down to 3.8 GeV/c^2 and still avoid contamination from the ψ'. The results to the fit[12)] are shown in Fig. 3. The smooth curve is a fit to the form $f^{\pi}(x_1) = a\sqrt{x_1}(1 - x_1)^b$. We find $a = 2.43 \pm 0.30$ and $b = 1.57 \pm 0.18$, with $\chi^2 = 77$ for 53 degrees of freedom. The data points in Fig. 3 arise from a fit in which $f^{\pi}(x_1)$ is allowed to assume different values in each 0.1 bin in x_1. These data points show that the kinematic domain of our experiment is such that we are not sensitive to the region $x_1 \lesssim 0.2$. Thus, we are not probing the pion sea quark distribution. Also shown on Fig. 3 (dashed curve) is the result from a similar analysis done on data from π^-N interactions at 225 GeV/c [13)]. The dotted line in Fig. 3 is the function $g^N(x_2)$, which we used for x_2 in the range 0.05 to 0.42.

Our pion structure function implies that approximately 40-50% of the π^- momentum comes from the $\bar{u}$ valence quark. Also, $\int_0^1 \left[f^{\pi}(x_1)/x_1\right] dx_1 = 2.8$. These values are both about 2.5 times higher than expected[9)]. Thus, in contrast with the 225 GeV/c results[13)], our data are in disagreement with the simple Drell-Yan model. The data at 200 and 280 GeV/c also give cross sections[6)] which correspond to large values of $f^{\pi}(x)$. If the quarks were colorless, our $f^{\pi}(x_1)$ would be reduced by a factor of three. However, if higher-order effects[10,14)] can increase the cross section by 100%, it seems more natural to attribute our result to QCD corrections to the Drell-Yan mechanism.

REFERENCES AND FOOTNOTES

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2) M.A. Abolins et al., Saclay preprint D.Ph.P.E. 78-05, Communication at the 19th Int. Conf. on High-Energy Physics, Tokyo, August 1978.

3) M. Abolins et al., Phys. Lett. 82B, 145 (1979).

4) We measured the J/ψ cross section per nucleon to be 95 nb at 150 GeV/c. From this and J/ψ yields from other experiments, we deduced a total cross section of 110 nb per nucleon for J/ψ production at 175 GeV/c. Cross sections per nucleon were determined by assuming that the quarks and gluons in the nucleus act incoherently. Therefore, we divided the ^{9}Be cross sections by nine.

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6) J. Badier et al., Paper contributed to the EPS Int. Conf. on High-Energy Physics, Geneva, 1979, preprints CERN/EP 79-67 and 79-68.

7) C.T. Sachrajda, Phys. Lett. 73B, 185 (1978).

8) The A-dependence used by Anderson et al.[5] to get cross-sections per nucleon was A^α, with $\alpha = 1.12 \pm 0.05$. This rather large value of α may be partly responsible for the apparent lack of scaling of the 225 GeV/c data.

9) R.D. Field and R.P. Feynman, Phys. Rev. D 15, 2590 (1977).

10) E. Berger, SLAC-PUB-2314 (1979).

11) A.J. Buras and K.J.F. Gaemers, Nucl. Phys. B132, 249 (1978). Averaging over the neutrons and protons in our ^{9}Be target we find

$$g^N(x) = 0.877\, x^{0.594}(1-x)^{3.08} - 0.455\, x^{0.706}(1-x)^{3.84} + $$
$$+ 0.567\, x^{0.706}(1-x)^{3.84} + 0.201\,(1-x)^{14.4} .$$

The first two terms arise from proton valence u quarks, the third term from neutron valence u quarks, and the fourth term from u and $\bar{d}$ sea quarks. We used a fixed Q^2 of $(4.65\ \mathrm{GeV})^2$.

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14) G. Altarelli, R. Ellis and G. Martinelli, MIT Report CTP No. 776 (1979), submitted to Nucl. Phys. B;

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Figure captions

Fig. 1 : $M^3 d\sigma/dM$ is plotted against the scaling variable $\tau = M^2/s$. The 225 GeV/c data are from Ref. 5; the 200 and 280 GeV/c data are from Ref. 6. Data points labelled Υ come from the region of the upsilon.

Fig. 2 : a) $d\sigma/dx_F$ versus x_F.

b) $(1/p_T)(d\sigma/dp_T)$ versus p_T.

c) $d\sigma/d \cos \theta_{GJ}$ versus $\cos \theta_{GJ}$; θ_{GJ} is the Gottfried-Jackson angle.

For all parts of Fig. 2, the smooth curves are fits to the data and are described in the text.

Fig. 3 : The smooth curve and data points represent fits to the pion structure function using our data. The dashed curve is from a similar analysis at 225 GeV/c (see Ref. 13). The dotted curve is the proton structure function $g^N(x)$.

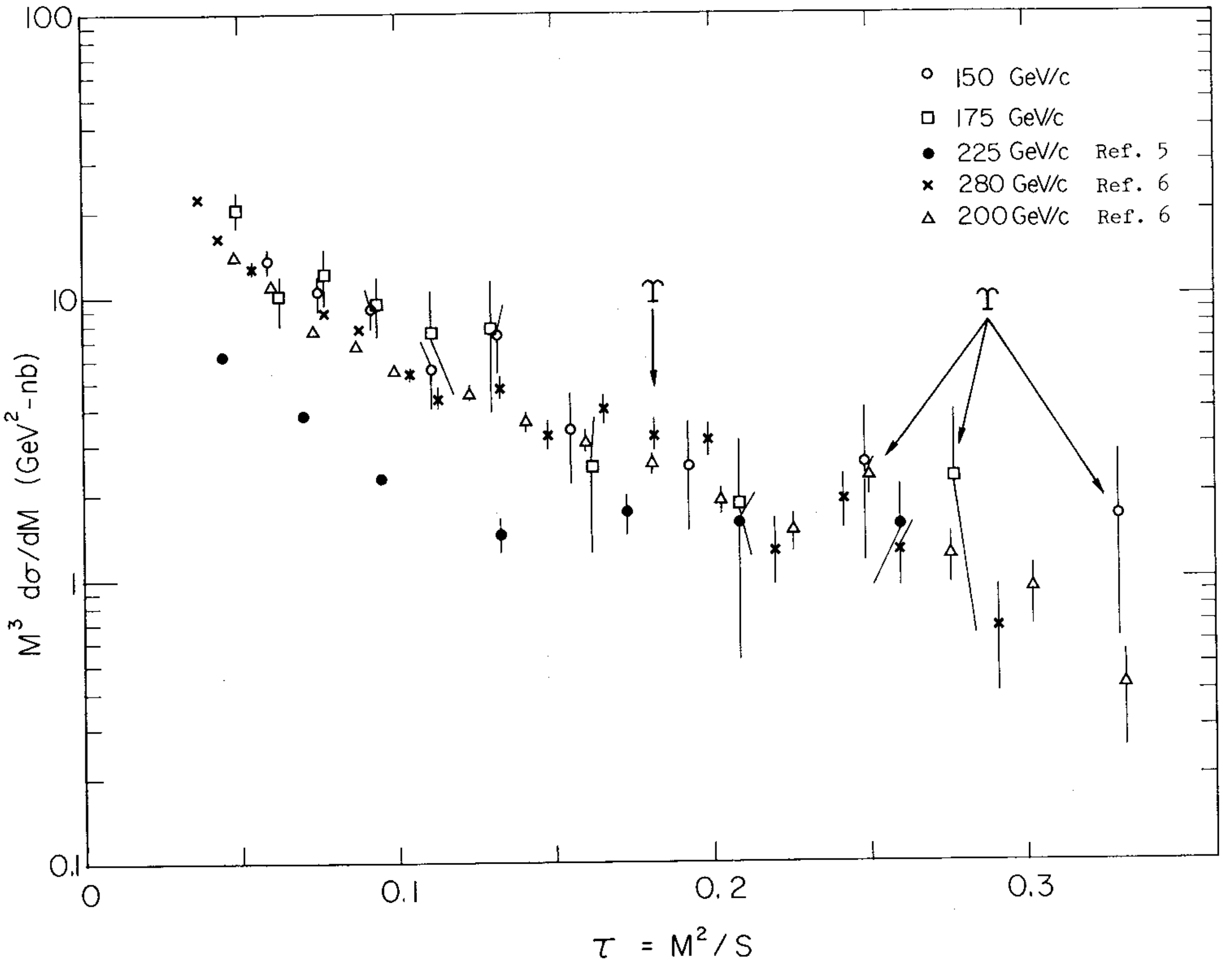
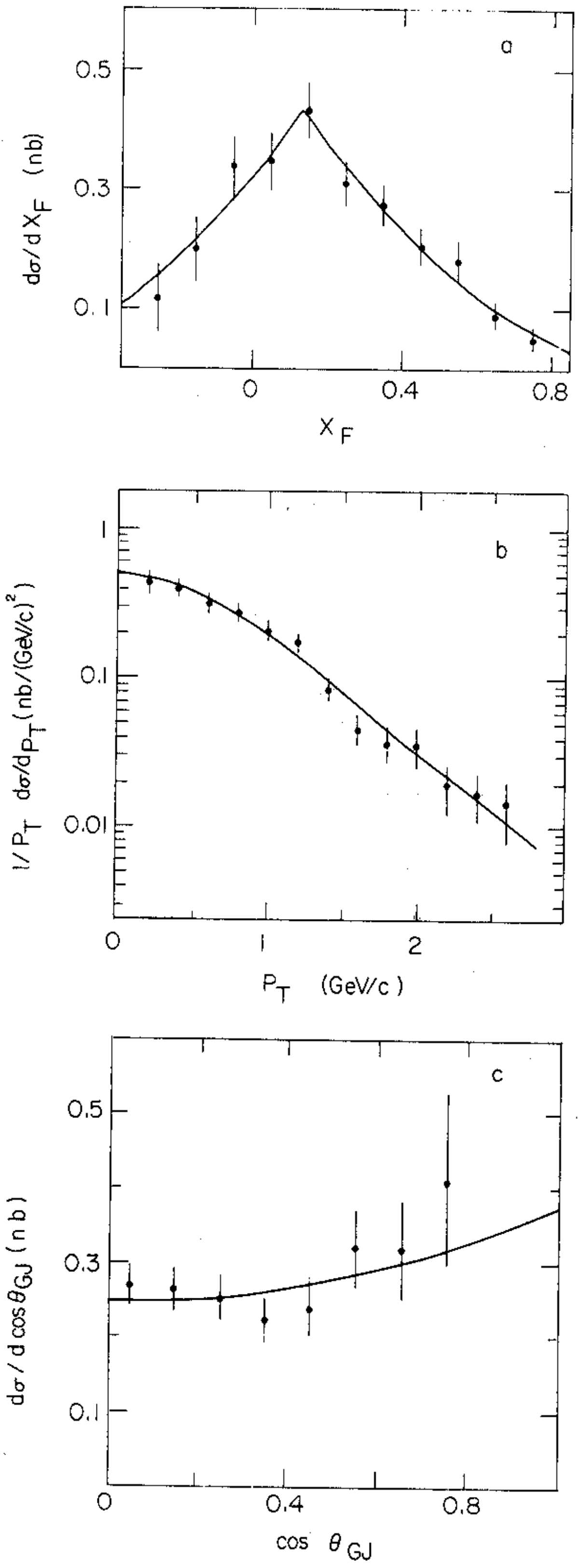

150 GeV/c
175 GeV/c
225 GeV/c Ref. 5
280 GeV/c Ref. 6
200 GeV/c Ref. 6
Υ
Υ
$M^3\ d\sigma/dM$ (GeV^2-nb)
100
10
1
0.1
0
0.1
0.2
0.3
$\tau = M^2/S$

Fig. 1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0.3
0.1
dσ/dX_F (nb)
0
0.4
0.8
X_F
b
1
0.1
0.01
1/P_T dσ/dP_T (nb/(GeV/c)^2)
0
1
2
P_T (GeV/c)
c
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dσ/d cosθ_GJ (nb)
0
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0.8
cos θ_GJ

Fig. 2

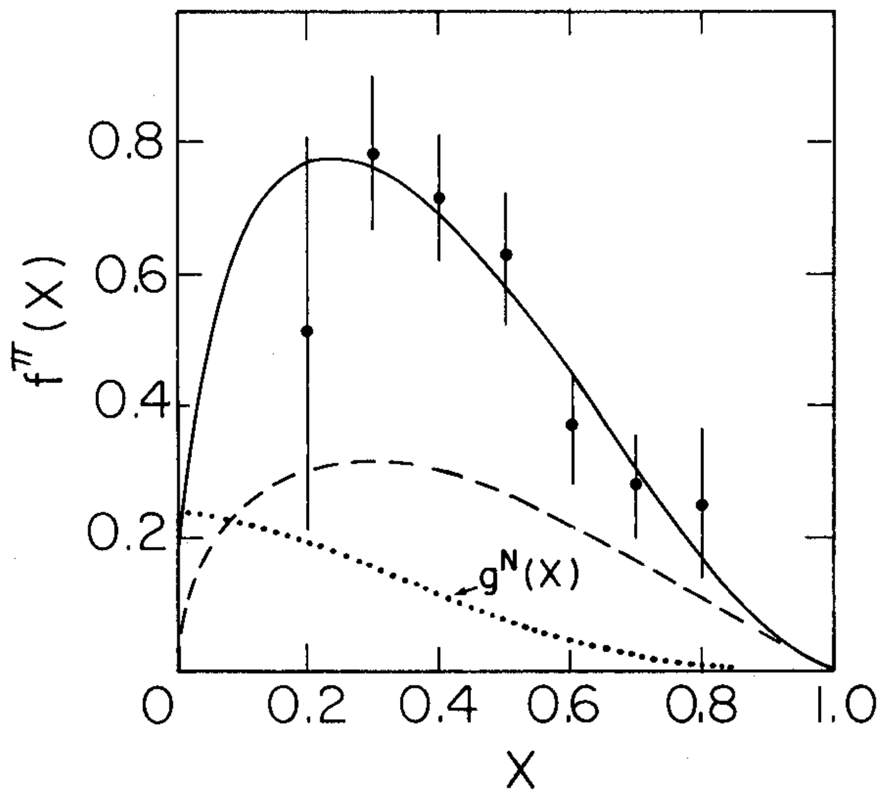

Fig. 3