LIMITS ON B MESON PRODUCTION AND EVIDENCE FOR LONGITUDINAL VIRTUAL PHOTON POLARIZATION IN MUON PAIR PRODUCTION BY PIONS

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ABSTRACT

From a sample of three muon events produced in π^-N interactions at 225 GeV/c, limits are set on the production of a heavy meson (B) containing a b-quark. The production of $B\overline{B}$ pairs would lead to a three muon signal through the decays $B \to J/\psi$ and $\overline{B} \to \mu + X$. Using theoretically predicted branching ratios, a 90% confidence limit of $\sigma(B\overline{B}) < 8$ nb/nucleon is found. Evidence of longitudinal virtual photon polarization in high mass ($M_{\mu\mu} > 4$ GeV/c^2) muon pair data near $x_F = 1$ is reviewed. The data are consistent with the model calculations of Berger and Brodsky using higher twist QCD terms.

I. INTRODUCTION

There are two results I wish to describe from the work of the Chicago-Illinois-Princeton (sometimes CP-II) collaboration. The group has performed a series of experiments using the Chicago Cyclotron Magnet Spectrometer at Fermilab investigating μ-pair production. The large acceptance of the apparatus and the use of proton, π^+, and π^- beams have allowed us to make a systematic study of the characteristics of μ-pair production over a broad range of the kinematic variables. The data I will discuss are at a beam momentum of 225 GeV/c.

Because of the broad acceptance of the apparatus, we have good sensitivity to events with more than two muons in the final state (multimuon events). A recent conference report of an enhancement in $J/\psi K\pi$ in 150 GeV/c π^-Be interactions which was presented as possible evidence of B (bottom meson) production, has motivated us to make a study of our multimuon data for evidence of B production. I will present the results of this study.

The second topic I will discuss is the observation of longitudinal virtual photon polarization near x_F=1 in our high mass ($M_{\mu\mu}$>4 GeV/c^2)π^-N data and the interpretation of the data resulting from higher twist QCD terms.

II. LIMIT ON B MESON PAIR PRODUCTION

At the recent Lepton-Photon Conference at Fermilab, the Goliath group presented data showing a 4σ narrow state in $J/\psi K\pi$ at 5.3 GeV/c^2 in π^-Be interactions at 150 GeV/c.[1)] The state appeared to be an attractive candidate for B meson production (a meson containing a b-quark). Assuming a linear atomic number dependence and a 1% branching ratio to the $J/\psi K\pi$ channel[2)] resulted in a cross section estimate of 200 nb/nucleon for $B\overline{B}$ production (both neutral and charged states). Another experiment has set a limit, based on the analysis of multimuon final states, that $\sigma(B\overline{B}) \lesssim$ 50 nb/nucleon in pFe interactions at 400 GeV/c.[3)]

Analysis of our data offered the possibility of a more direct comparison with Ref. 1. The sensitivity of the experiment (~66,000 J/ψ events) allow us to set a limit on B production more than twenty times lower than the reported value in Ref. 1 in π^-N interactions at 225 GeV/c.

The apparatus, data analysis, and general features of the data have been discussed in the literature.[4)] The multimuon data sample contains 487 J/ψ events accompanied by a third muon. These events are adequately described by the hypothesis that the extra muon originates from the decay of a π or K meson produced in the interaction. A detailed study of this process has been made in deriving limits on charm meson production associated with the J/ψ.[5)]

Three muon events could result from the process;

$$\pi^- N \to B\bar{B}X$$
$$B \to \mu X$$
$$\bar{B} \to J/\psi X$$
$$J/\psi \to \mu^+\mu^-$$

where the third muon can come from the primary B decay, for example $B \to D\nu\mu$ or from a secondary product as in $B \to DX$, $D \to K(K^*)\mu\nu$. The third muon from these processes would have a much broader transverse momentum spectrum than that from π and K decay. Figure 1 shows the observed transverse momentum distribution of third muons. The dashed curve is the spectrum one would expect if all events originated from $B\bar{B}$ production. The expected

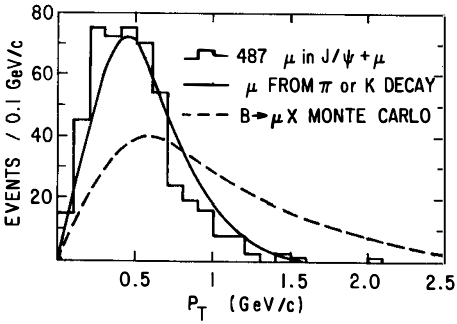


Fig. 1. The transverse momentum of third muons in the 487 observed events containing a $J/\psi \to \mu^+\mu^-$ is shown in the histogram. Normalized to this data sample are the expected spectra from π and K decay (solid curve) and the Monte Carlo spectra for $B \to \mu + X$ events (dashed curve).

distribution of π and K decay muons can be obtained from our large sample of low mass like-sign muon pairs (solid curve). This estimate assumes no correlation of the π and K production with the J/ψ which could result in some small modification of this shape. Nevertheless, both in shape and size, we find that this decay background adequately accounts for the observed third muon data sample.

The expected third muon transverse momentum distribution for $B\bar{B}$ events shown in Fig. 1 was obtained from a Monte Carlo calculation. In this calculation an 11 GeV/c^2 parent of the $B\bar{B}$ pair was generated according to;

$$\frac{d\sigma}{dx\,dp_T} \sim (1-|x|)^{\alpha} p_T e^{-\beta p_T}$$

where $x=2\,p_L/\sqrt{s}$ has a maximum of $1-(11)^2/s$, and s = center of mass energy squared. The 11 GeV/c^2 parent was selected to simulate a distribution peaked near $B\bar{B}$ mass threshold which one would expect for such a process. For the parameters α and β, we select values characteristic of this mass range observed for high mass muon pairs, $\alpha=0$ and $\beta=1.67$.[6)] This results in a $B\bar{B}$ parent state with $\langle p_T \rangle=1.2$ GeV/c. The B meson mass values were set at 5.3 GeV/c^2. For the decay $B\to J/\psi+X$, we take $m_X=1.1$ GeV/c^2.[7)] For the leptonic decay $B\to\mu+X$, we take the muon energy spectrum in the B rest frame from a calculation of Ali[8)] which includes both primary and secondary decays. The acceptance for the third muon from B decay is relatively insensitive to the details of the Monte Carlo since the primary source of transverse momentum is the large mass of the B state. Each of the following changes resulted in a less than 5% relative change in the acceptance; a 12 GeV/c^2 parent mass, $\alpha=1$, $\beta=2.67$, or a 1.8 GeV/c^2 recoil mass in $B\to J/\mu+X$. A 10% increase in average muon energy in the decay $B\to\mu+X$ would cause a 20% increase in the high p_T acceptance.

The 90% confidence level upper limits for $B\bar{B}$ meson production given in Table I assume a linear atomic number dependence, $BR(J/\psi\to\mu^+\mu^-) = 0.07$, $BR(B\to J/\psi+X) = 0.03$[2,9)] and $BR(B\to\mu+X) = 0.18$.[2)] Both the B and $\bar{B}$ are assumed to contribute with equal branching ratios to the J/ψ and third muon signals.

TABLE I

P_T min of 3rd μ	No. of Events	Calculated Background From π, K Decay	Monte Carlo Acceptance	$2\,\sigma(B\bar{B})$ $BR(B\to J/\psi X)$ $BR(\bar{B}\to \mu X)$	$\sigma(B\bar{B})$ (90% Conf.)
1.4 GeV/c	4	2	.0161	<124 pb/nucleon	<11nb/nucleon
1.5	2	1	.0135	< 97	< 9
1.6	1	0.5	.0113	< 81	< 7.5

Our best limit for $B\bar{B}$ production is with p_T>1.6 GeV/c (one event observed) and is $\sigma(B\bar{B}) \lesssim 7.5$ nb/nucleon. It is interesting to compare this limit and the Υ cross section measured in 200 GeV/c π^-N interaction[10) with similar numbers for the charm quark states. We find $\sigma(B\bar{B})/\sigma(\Upsilon) \lesssim 75$ and $\sigma(C\bar{C})/\sigma(J/\psi)$>100.[11) The numbers are comparable although one might conclude that a 3% branching ratio for $B\to J/\psi+X$ is slightly optimistic. A smaller branching ratio would weaken our limit. It would not remove the discrepancy with the observation in Ref. 1 since the branching ratio to J/ψ is used there also.

Because our vertex cut in the analysis is quite loose, we are not very sensitive to the unknown lifetime of the B meson. Only for lifetimes longer than 10^{-9} seconds is our limit appreciably altered (Fig. 2). This is shorter than present experimental limits of 5×10^{-8} seconds[12) but long compared to theoretical estimates which predict a B meson lifetime around 5×10^{-13} seconds.[13)

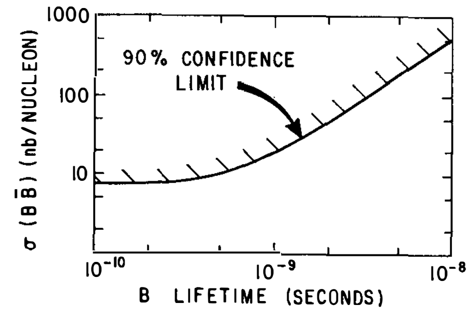


Fig. 2. Lifetime dependence of the $B\bar{B}$ production cross-section limit.

III. LONGITUDINAL VIRTUAL PHOTON

A good deal of the focus of the theoretical discussions at this conference has been on the question of QCD and the problem of identifying the relevant subprocesses in the data. The logarithmic Q^2 dependence of the "radiative" process cannot be distinguished from power law Q^2 dependent "higher twist terms" in currently available data. It is important therefore to look for kinematical regions where an identifiable subprocess is clearly dominant. Berger and Brodsky[14] have suggested that the large x_F region of high mass muon pairs produced by pion beams offers such a prospect. In their analysis, the diagrams shown in Fig. 3 dominate and lead to a pion structure function of the form;

$$f_\pi(x_1) \sim \underbrace{(1-x_1)^1}_{\text{TRANSVERSE}} + \frac{2\langle k_T^2\rangle}{9}\underbrace{\frac{(1-x_1)^\circ}{Q^2}}_{\text{LONGITUDINAL}}$$

where $\langle k_T^2\rangle$ is the mean square transverse momentum of the annihilating pion valence quark and x_1 is its momentum fraction. The two terms have the indicated associated virtual photon polarization. This explicit Q^2 dependence means that the pion structure is not scale invariant. While our current data are consistent with this prediction,[15] the data sample is not sufficient to clearly identify the expected $1/Q^2$ dependence near $x_1 \to 1$. The virtual photon polarization offers a strong test of the model. In Fig. 4 the variation of α with x_1 is shown where α parameterizes the polarization observed in the data:

$$\frac{d\sigma}{d\cos\theta} \sim 1+\alpha\cos\theta$$

where θ is the polar angle between the annihilating quark direction and the μ-pair direction in the pair center of mass system. A transverse virtual photon is characterized by $\alpha=1$ and $\alpha=-1$ for a longitudinal virtual photon. The data are consistent with the model and new data from the NA-3 experiment at CERN presented at this conference has confirmed the effect.[16]

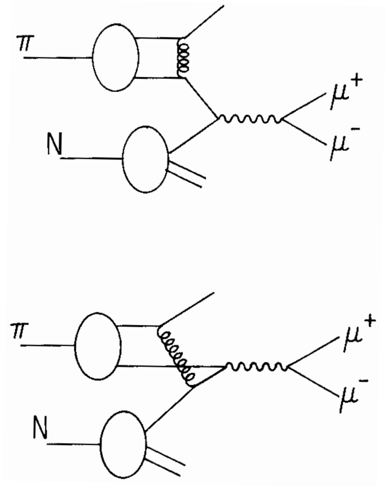
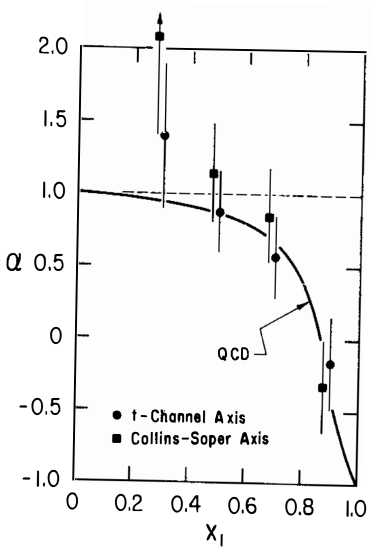


Fig. 3. Higher twist terms which dominate muon-pair production by pions near $x_F \to 1$ in the Berger-Brodsky model.

Fig. 4. The dependence on α and x_1 for pion produced muon-pair data with $M_{\mu\mu}>4$ GeV. The dashed curve is the expected result for the naive Drell-Yan model. The solid curve is the prediction of the Berger-Brodsky model.



Clearly more experimental and theoretical work needs to be done to unambiguously establish that higher twist effects are being observed. Our current experimental effort is being directed towards this goal. The rapid change in virtual photon polarization near $x_F=1$ makes the muon pair data fruitful areas for further enquiry.

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