Limit on Bottom-Meson Pair Production in π^--Nucleus Interactions at 225 GeV/c

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In an experiment to measure multimuon final states in interactions of 225-GeV/c π^- with nuclear targets we have observed 65 900 $J/\psi \to \mu^+\mu^-$ decays, of which 487 are accompanied by a third muon. We have used this sample to search for production of bottom-meson pairs, followed by the decays $B \to J/\psi + X$, $\overline{B} \to \mu + X$. We find, supposing linear A dependence, that $\sigma(B\overline{B}) < 8$ nb/nucleon with 90% confidence. This limit is in contradiction with a recent report that $\sigma(B\overline{B}) \approx 200$ nb/nucleon.

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A recent conference report presents an enhancement at 5.3-GeV/c^2 mass in the $(J/\psi)K\pi$ system produced in 150-GeV/c π^--Be interactions.[1] An estimate is given that the cross section times branching fraction for $B \to (J/\psi)K\pi$, where B is a bottom meson, is about 2 nb/nucleon assuming linear dependence on target atomic number. Following a model of Fritzsch,[2] the branching fraction $R(B \to (J/\psi)K\pi)$ is taken to be 0.01, which leads to a cross section for $B\overline{B}$ meson pairs of $\sigma(B\overline{B}) \sim 200$ nb. This includes both B^+B^- and $B^0\overline{B}^0$ combinations. Another experiment[3] has set a limit, based on an analysis of multimuon final states, that $\sigma(B\overline{B}) \lesssim 50$ nb in p-Fe interactions at 400 GeV/c. Because of the difference in beam-particle type it is unclear whether the 50-nb limit is in contradiction to the 200-nb cross-section report.[4] In this Letter we present a more direct comparison with Ref. 1 by searching for B meson pairs produced in π^--nucleus interactions at 225 GeV/c according to the process

$$\begin{array}{l}\pi^- N \to B\overline{B} + X \\ \quad\quad \overline{B} \to \mu + X \\ \quad\quad B \to J/\psi + X \\ \quad\quad\quad J/\psi \to \mu^+\mu^- . \end{array} \tag{1}$$

The analysis given below is model dependent, but the key assumption, $R(B \to J/\psi + X) = 0.03$, comes from the same model[2] as used in the interpretation of Ref. 1. Then, so long as $R(B \to (J/\psi)K\pi)/R(B \to J/\psi + X) \sim \frac{1}{3}$, we achieve a comparison which is reasonably model independent, and conclude that $\sigma(B\overline{B})$ for 225-GeV/c π^- is more than 20 times lower than the value reported in Ref. 1 for 150-GeV/c π^- beams.

We have reported elsewhere on the details of the apparatus, data analysis, and general features of the data of our experiment.[5,6] For the present analysis we examine the 65 900 events containing a $J/\psi \to \mu^+\mu^-$ decay produced by a 225-GeV/c π^- beam on C, Cu, and W targets and find 487 containing a third muon. These extra muons can be completely explained by decays of π and K mesons, and can be used to derive limits on charmed-meson production in association with a J/ψ.[7]

We consider now the possibility that the $J/\psi + \mu$ events arise from bottom-meson pair production in the Reaction (1). In the decay $B \to \mu + X$, the muon may be either a primary decay product, as in $B \to D\mu\nu$, or a secondary product, as in

$$\begin{array}{l} B \to D + X \\ \quad\quad D \to K\,(K^*)\ \mu\nu . \end{array}$$

These processes lead to a third muon which is not from J/ψ decay and which has a much broader transverse-momentum distribution than muons from π or K decay. The transverse momentum spectrum of the 487 third muons is shown as the histogram in Fig. 1, and details of the high-momentum tail are presented in Table I. The largest-transverse-momentum third muon had p_T

TABLE I. Analysis of events containing a $J/\psi \to \mu^+\mu^-$ decay and a third muon.

p_T^{min} (GeV/c) of third muon	No. of events	Calculated background from π, K decay	Monte Carlo acceptance	$2\sigma(B\bar{B}) \times R(B \to (J/\psi)X) \times R(\bar{B} \to \mu X)$ (pb/nucleon)	$\sigma(B\bar{B})$ (90% C.L.) (nb/nucleon)
1.4	4	2	0.0161	< 124	< 11
1.5	2	1	0.0135	< 97	< 9
1.6	1	0.5	0.0113	< 81	< 7.5

$= 2.0$ GeV/c. The spectrum for muons from π or K decay is obtained from our large sample of low-mass, like-sign muon pairs.[7] The result is shown as the solid curve in Fig. 1, normalized to 487 events, and the expected numbers of high-transverse-momentum muons are also listed in Table I. We note that the region above $p_T = 1.5$ GeV/c is free of background from π and K decay.

The acceptance of the apparatus for process (1) has been estimated by a Monte Carlo calculation which yields the spectrum of third muons shown as the dashed curve in Fig. 1, again normalized to 487 events. In the calculation an 11-GeV/c^2 parent of the $B\bar{B}$ pair is generated according to

$$d\sigma/dx\, dp_T \sim (1 - |x|)^\alpha p_T \exp(-\beta p_T),$$

where $x = 2p_L/\sqrt{s}$ has a maximum of $1 - (11)^2/s$, and s is the square of the center-of-mass energy. The use of an 11-GeV/c^2 parent is an hypothesis to simulate the proper kinematic correlation between the B and $\bar{B}$ meson. For the parameters we use $\alpha = 0$ and $\beta = 1.67$ based on our studies of high-mass muon pairs[6]; the choice of β corresponds to

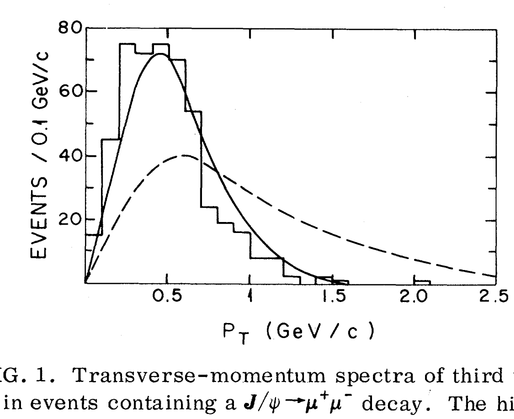

FIG. 1. Transverse-momentum spectra of third muons in events containing a $J/\psi \to \mu^+\mu^-$ decay. The histogram is of the 487 observed events. The solid curve is a measurement of the μ spectra from π or K decay described in the text. The dashed curve is a Monte Carlo simulation of the decay $B \to \mu X$. Both curves are normalized to 487 events.

$\langle p_T \rangle = 1.2$ GeV/c. The 11-GeV/c^2 parent then decays into two B mesons of mass 5.3 GeV/c^2 each. For the decay $B \to J/\psi + X$, we assume that the missing mass of X has a fixed value of 1.1 GeV/c^2.[4] For the 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 average decay-muon energy is 1.05 GeV in the B frame. The resulting acceptance estimates are given in Table I as a function of the third muon's transverse momentum in the laboratory. Note that the background from π and K decays decreases rapidly with transverse momentum, while the acceptance for B decays varies relatively slowly. This occurs because the average transverse momentum of the third muon from B decay is 950 MeV/c, about 2.5 times that of muons from π and K decays. A 10% increase in average muon energy in the decay of $B \to \mu + X$ would cause a relative increase of 20% in the high-p_T acceptance, and hence a 20% decrease in $\sigma(B\bar{B})$. Each of the following changes caused less than a 5% relative shift in acceptance: a 12-GeV/c^2 parent mass; $\alpha = 1$; $\beta = 2.67$; a 1.8-GeV/c^2 recoil mass in $B \to J/\psi + X$.

The exposure of the experiment, uncorrected for acceptance, is 1.7×10^{-38} cm^2 event^{-1} nucleon.$^{-1}$

There are four J/ψ events containing a third μ with $p_T \geq 1.4$ GeV/c; if we simply attribute them to $B\bar{B}$ production we obtain the 90% confidence limits given in Table I. We emphasize that no background subtraction has been made. We have used $R(J/\psi \to \mu^+\mu^-) = 0.07$, and the assumption of linear A dependence. The further assumptions, that $R(B \to J/\psi + X) = 0.03$ (Refs. 2, 9-11) and $R(\bar{B} \to \mu + X) = 0.18$ (Ref. 8), and the fact that either the B or the $\bar{B}$ can decay to $J/\psi + X$, lead to the limits on $\sigma(B\bar{B})$ also given in Table I. The systematic uncertainty on all limits due to experimental effects is about 25%.

We can set another limit on $\sigma(B\bar{B})$ by searching for events containing two J/ψ particles. Briefly, we find none and obtain $\sigma(B\bar{B}) \cdot R^2(B \to J/\psi + X)$

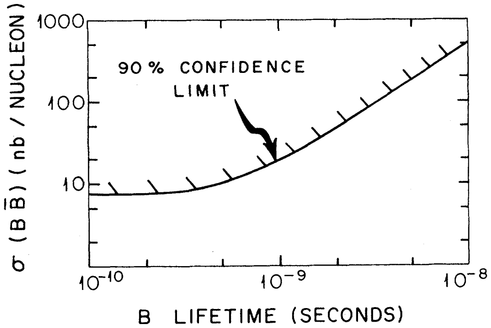

FIG. 2. The limit for $\sigma(B\bar{B})$ as a function of the as yet unknown lifetime of the B meson.

$\lesssim 200$ pb/nucleon at 90% confidence level. Then if $R(B\to J/\psi+X)=0.03$, we have $\sigma(B\bar{B})\lesssim 220$ nb/nucleon.

The most sensitive limit on $B\bar{B}$ production is that based on the p_T region above 1.6 GeV/c, where we have observed only a single event, even though a sizable fraction of $B\bar{B}$ events would have a muon in this region. We find $\sigma(B\bar{B})<7.5$ nb/nucleon, which implies that $\sigma(B\bar{B})/\sigma(\Upsilon)\lesssim 75$ since $\sigma(\Upsilon)\sim 100$ pb in 200-GeV/c π^-N interactions.[12] Such a small ratio is surprising given the reports[13] that $\sigma(C\bar{C})/\sigma(J/\psi)>100$ where C is a charmed meson. It may be that the estimate $R(B\to J/\psi+X)=0.03$ is somewhat optimistic, since it implies $c\bar{c}$ quarks produced in B-meson decay form a bound state quite often, while $c\bar{c}$ pairs produced in strong interactions break up 99% of the time. If instead $R(B\to J/\psi+X)\sim 0.003$, our limit would be $\sigma(B\bar{B})\lesssim 75$ nb, a weak limit; but then the result of Ref. 1 would be $\sigma(B\bar{B})\sim 2$ μb since now $R(B\to(J/\psi)K\pi)\sim 0.001$.

Finally, we note that our limit is not very sensitive to the unknown lifetime of the B meson. This is because the vertex cut in our analysis is quite loose; both the B and $\bar{B}$ must decay within 30 cm of the production vertex for an event to be reconstructed. The resulting dependence of the limit for $\sigma(B\bar{B})$ on the B lifetime is shown in Fig. 2. Only for lifetimes τ_B longer than 10^{-9} sec is our limit appreciably altered. This is shorter than the present experimental limit[14,15] that $\tau_B<5\times10^{-8}$ sec, but long compared to theoretical estimates[16] that $\tau_B\sim 5\times10^{-13}$ sec. In any case, the $\sigma(B\bar{B})$ of Ref. 1 would also be raised for long τ_B in a manner similar to that shown in Fig. 2.

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