Fermi National Accelerator Laboratory

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CDF

A Limit on $\sigma \cdot BR(B^{\pm}_{c} \rightarrow J/\psi+\pi^{\pm})/\sigma \cdot BR(B^{\pm}_{u} \rightarrow J/\psi+K^{\pm})$ in $\sqrt{s} = 1.8$ TeV Proton-Antiproton Collisions

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Abstract

We report on the results of a search for the B_c ($b\bar{c}$) meson in the decay $B_c^{\pm} \to J/\psi + \pi^{\pm}$. This search is guided by a control sample of decays of B_u mesons to $J/\psi + K$ and uses $\simeq$ 75pb^{-1} of data collected at the Collider Detector Facility (CDF) at Fermilab. The lifetime of the B_c meson is unknown, so the 95% confidence level limit on $\sigma \cdot \mathrm{BR}(B_c \to \psi + \pi)/\sigma \cdot \mathrm{BR}(B_u \to \psi + K)$ is obtained as a function of the B_c lifetime.

Introduction

The B_c is the bound state of the bottom and charm quarks and is predicted by the standard model. This particle can be found by using the fact that a large fraction of its decays ($\simeq 20\%$) are to J/ψ final states. The mass of the B_c is predicted to be $6.256 \pm .020$ GeV/c^2 with a lifetime of $\tau = 1.35 \pm .15$ ps.[1] Other theorists report smaller values for the lifetime, in the range of 0.5–0.7 ps.[2] Production estimates using perturbative QCD for the b quark fragmentation to B_c exist and predict production of B_c relative to other b mesons at $\approx 10^{-3}$ for $P_T > 10$ GeV/c.[3]

Search Method

The data sample used is 75pb^{-1} collected in two separate runs of the Fermilab Tevatron. The data sample is based on a dimuon trigger with muon pair invariant mass consistent with the J/ψ mass. The CDF detector is described elsewhere [5] and is defined on a coordinate system with the x–y plane perpendicular to the beam where the proton beam direction is the positive z axis.

The CDF dimuon trigger is staged. Level 1 requires two muon stubs in the muon chambers with $|\eta| < 0.6$ for the first 19pb^{-1}. The trigger coverage is extended to $|\eta| < 1.0$ for the remaining 54pb^{-1}. At level 2 at least one muon segment is required to match a central track found by the track processor. Levels 1 and 2 are hardware triggers. Within this data sample are the exclusive decays of B_c to $J/\psi + \pi$ and B_u to $J/\psi + K$.

The data is further processed to look for $J/\psi + K^{\pm}$, ($\pi^{\pm}$) events. The three tracks are constrained to come from the same vertex and the invariant mass of the two muons is constrained to the world average J/ψ mass. Since this is a fully reconstructed event, the momentum sum of the tracks is constrained to be parallel to the vector from the run-averaged beam position in the x–y plane to the 3-track vertex. At least one of the muon tracks and the third track are required to have hits in the silicon vertex detector (SVX) [6] and a fit with χ^2 probability greater than 5% is required of the resulting 3-track vertex. Transverse momentum cuts of 2 GeV/c are placed on the muons to get above the trigger thresholds and on the third track to reduce background from combinatorics. The P_T of the 3-track combination is required to be greater than 6.0 GeV/c. Since there is no particle identification, processing is done twice on the third track, once assuming a pion mass and then a kaon mass.

For the $J/\psi + K^{\pm}$ sample, a cut of $c\tau > 85\mu$m is imposed to remove the prompt background. Figure 1 shows the resulting three track invariant mass distribution with a clear signal from the $B^{\pm}$ mesons. This distribution is fit to a gaussian signal and a linear background in the range from 5.15 to 5.8 GeV/c^2. $N_{Bu} = 289 \pm 19$ $B^{\pm}$ events are obtained.

For the B_c search, the same cuts are used as for the $J/\psi + K$ sample. Shown in

Table 1: This is a table showing the $c\tau$ cut used, the chosen B_c lifetime, the relative efficiency of the cuts (R_ϵ), the largest number of data events in 4 consecutive bins from 6.1 to 6.4 GeV/c^2 (N_{tot}), and the fit to the data for the expected number of background events in those 4 bins ($\overline{N_{Bkg}}$).

CDF Preliminary				
$c\tau$ cut	B_c lifetime	$R_\epsilon \equiv \frac{\epsilon(B_u)}{\epsilon(B_c)}$ (stat+sys)	N_{tot}	$\overline{N_{Bkg}}$ (stat)
60 μm	0.17 ps	2.02 ± 0.13	43	40.6 ± 2.2
85 μm	0.33 ps	1.71 ± 0.09	31	21.6 ± 1.7
100 μm	0.5 ps	1.49 ± 0.07	25	15.8 ± 1.4
100 μm	0.8 ps	1.21 ± 0.06	25	15.8 ± 1.4
100 μm	1.0 ps	1.12 ± 0.05	25	15.8 ± 1.4
100 μm	1.3 ps	1.03 ± 0.05	25	15.8 ± 1.4
100 μm	1.6 ps	0.99 ± 0.045	25	15.8 ± 1.4

Figure 2 is the invariant mass distribution with the same cuts as Figure 1. Since the B_c is made of two heavy quarks, there is some confidence that the predictions of the mass are correct, consequently we restrict our search region to ± 150 MeV/c^2 around the nominal mass of 6.256 GeV/c^2.

Because the B_c lifetime is chosen to be variable, the cut on proper decay length is varied to optimize its effectiveness based on different lifetimes. Three different cuts on $c\tau$ are used depending on the assumed B_c lifetime. The $c\tau$ cuts used are shown in Table 1.

To determine the bin size in Figure 2, a Monte Carlo of B_u and B_c decays was run through a detector simulation. The ratio of the widths of the mass peaks obtained was used to scale the observed width of the B_u mass to the estimated B_c mass. The bin size of 16 MeV/c^2 in Figure 2 is equal to that estimate. The four largest consecutive bins in Figure 2 are defined as containing the B_c signal candidates (N_{tot}) for the purpose of calculating the limit. The remaining events are used to fix the level of background and are fit to a straight line with the four 'signal' bins excluded. From the fit the average background under the signal ($\overline{N_{bkg}}$) is obtained. These quantities are also shown in Table 1 for the different $c\tau$ cuts.

Determination of the relative efficiency R_ϵ

If one were to see a B_c signal, determination of the relative rate to B_u would proceed by the following equation:

$$\frac{\sigma \cdot \mathrm{BR}(B_c)}{\sigma \cdot \mathrm{BR}(B_u)} = \frac{N_{\psi+\pi}}{N_{\psi+K}} \cdot R_\epsilon$$

where $R_\epsilon \equiv \epsilon_{Bu}/\epsilon_{Bc}$. The experimental advantage of comparing the $J/\psi + \pi$ decay to the $J/\psi + K$ is clear. The tracking efficiencies for muons and for tracks will cancel in the ratio as will the integrated luminosity. Efficiencies of the muon chambers given a track in the fiducial volume, will also cancel because both samples come from the same trigger.

To determine the relative efficiency the B_c lifetime is first set equal to the B_u lifetime. A Monte Carlo and detector simulation is run for both types of mesons where the input spectrum, the b fragmentation to B_u, and the trigger simulation are varied in shape. This causes a systematic error of 4% on the relative efficiency. The value of R_ϵ obtained is shown in Table 1. The fragmentation of $b \rightarrow B_c$ uses the perturbative QCD calculation in [4] and is not included in the systematic uncertainties associated with R_ϵ.

R_ϵ must be corrected for the assumed lifetimes of the B_c. The data from 5.5 to 6.0 GeV/c^2 is used to characterize the $c\tau$ distribution of zero lifetime background and is fit to a parameterization. The parameterization is then used to smear an ideal $c\tau$ distribution for an arbitrary B_c lifetime. The same function is used to smear the lifetime distribution of B_u. The ratio of the areas under the two functions, with the correct $c\tau$ cuts and normalization, is used to adjust R_ϵ for an arbitrary B_c lifetime. This contributes a 5% systematic uncertainty in R_ϵ for short-lived B_c's, but falls to 0.2% when the lifetimes are equal.

The Limit

Calculation of the 95% confidence level limit uses the method described by [7]. This method assumes Poisson statistics for the signal and background and accounts for the uncertainty in $\overline{N_{bkg}}$, the uncertainties in the estimate of R_ϵ, and the statistical uncertainty in the number of $J/\psi + K^\pm$ obtained. The number of $J/\psi + K^\pm$ that are lost due to the decay-in-flight of kaons relative to pions have not been included in this calculation. Such a correction would lower the limit. The 95% C.L. limit on $\sigma\cdot$BR for $B_c^\pm \rightarrow J/\psi + \pi^\pm$ versus $B_u^\pm \rightarrow J/\psi + K^\pm$ as a function of the B_c lifetime is shown in Figure 3. Also shown is an estimate of the theoretical production ratio where it is assumed that B_c mesons are produced 1000 times less often than the other B mesons and that $\Gamma(B_c^\pm \rightarrow J/\psi + \pi^\pm) = 3.4 \times 10^9\text{s}^{-1}$. [8]

References

[1] C. Quigg, B_c, FERMILAB-Conf-93/265-T.

[2] P. Colangelo, *et. al.*, Z. Phys. C **57**, 43 (1993); S.S. Gershtein, *et. al.*, Int. J. Mod. Phys., **A6**, 2309 (1991).

[3] E. Braaten, K. Cheung, and T.C. Yuan, Phys. Rev. D **48**, R5049 (1993).

[4] K. Cheung and T.C. Yuan, NUHEP-TH-93-30.

[5] CDF Collaboration, F. Abe *et al.*, Nucl. Inst. Methods Phys. Res., Sect. A **271**, 387 (1988); F. Bedeschi *et al.*, Nucl. Inst. Methods Phys. Res., Sect. A **268**, 50 (1988); G. Ascoli *et al.*, Nucl. Inst. Methods Phys. Res., Sect. A **268**, 33 (1988).

[6] F. Bedeschi et al., FERMILAB-CONF-92/263-E.

[7] G. Zech, Nucl. Instr. Meth., A **277**:608 (1989); O. Helene, Nucl. Instr. Meth., **212**: 319 (1982).

[8] E. Eichten, private communications, 1995 and FERMILAB-PUB-95/255-T (in preparation).

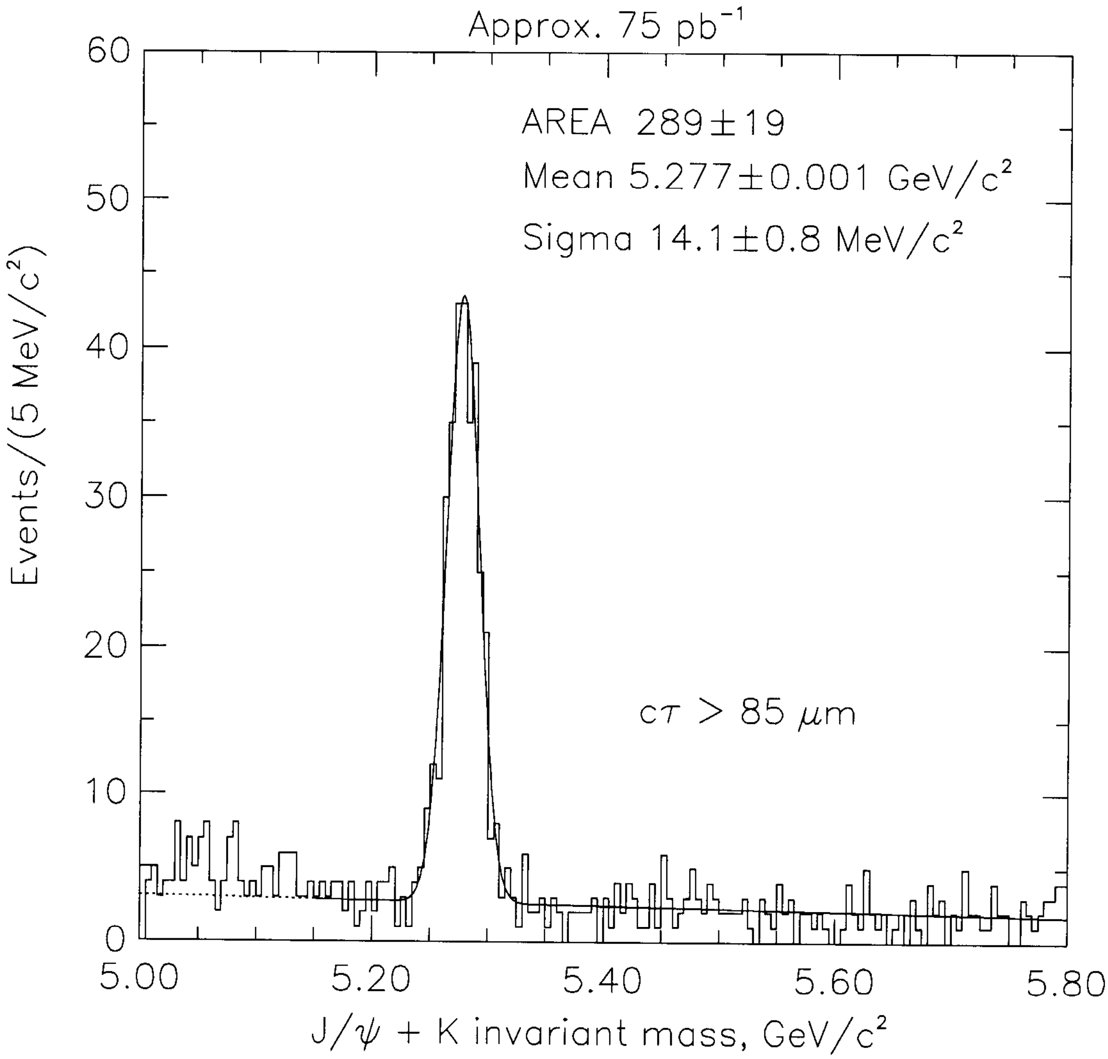

Figure 1: The figure shows the three-track invariant mass distribution where the third track is assumed to be a kaon. The fit is to a gaussian and a linear background with $N_{Bu} = 289 \pm 19$ in the $J/\psi + K^{\pm}$ peak.

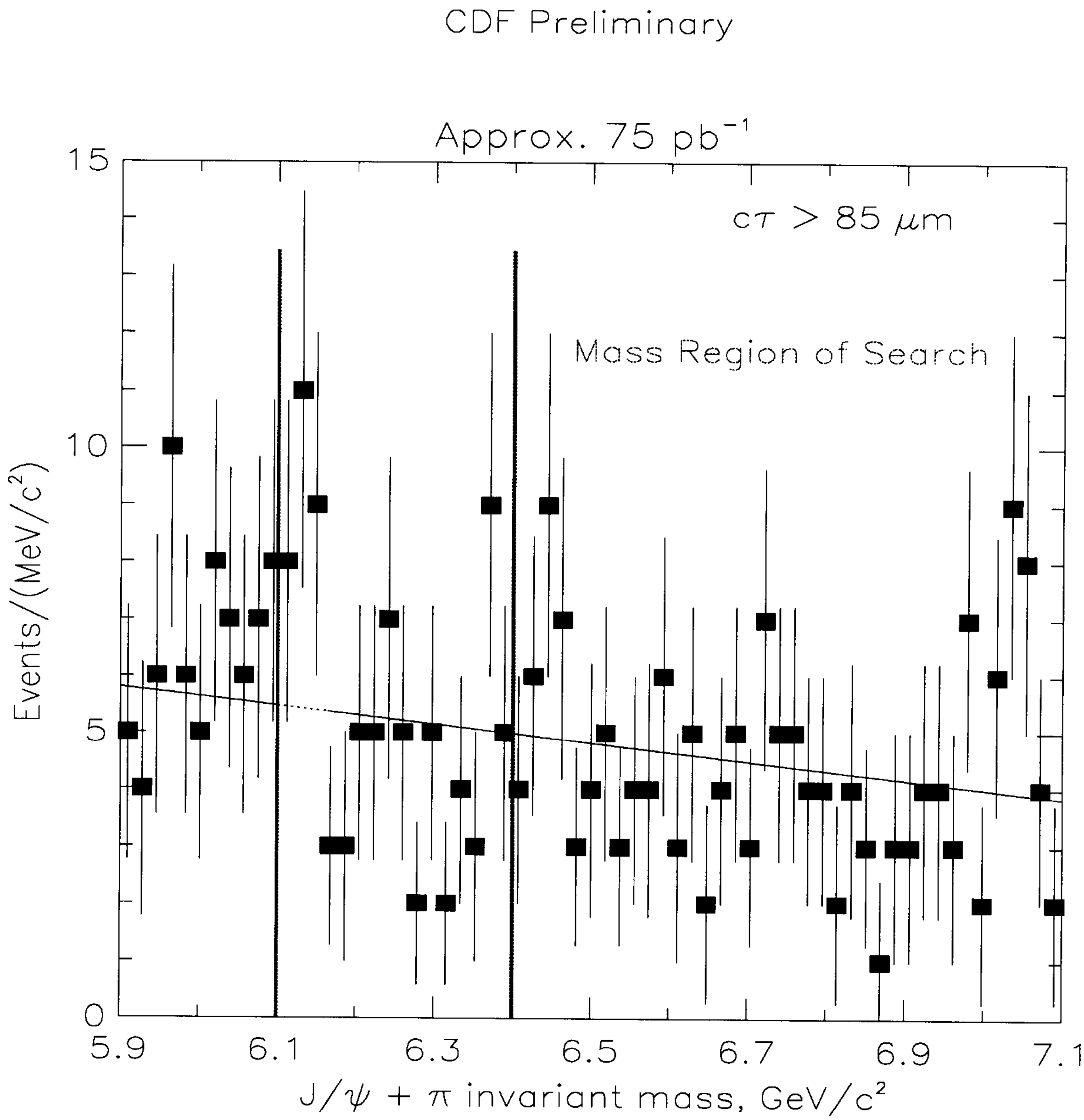

Figure 2: The three-track invariant mass region from 5.9 to 7.1 GeV/c^2 using the same cuts as Figure 1 but assuming the third track has a pion mass. The vertical lines encompass the search region for the B_c meson. The four highest bins in the search region are excluded from the fit (shown as a dotted line).

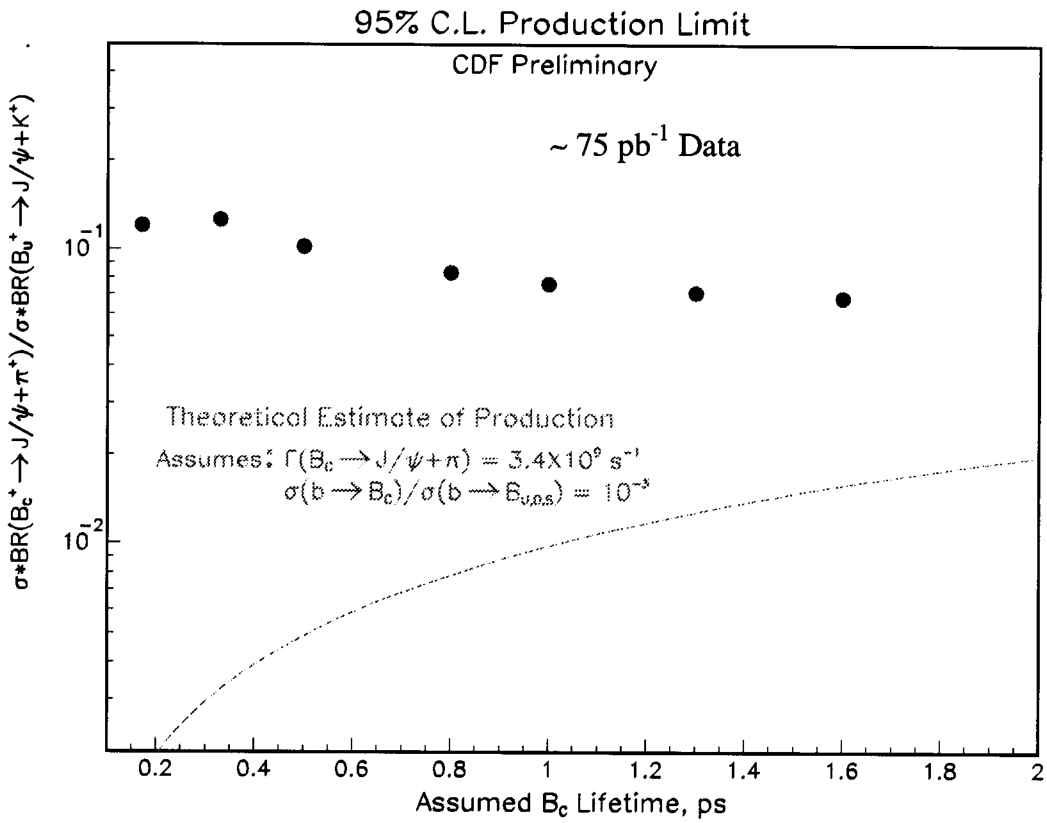

Figure 3: Shown as circular points is the 95% C.L. limit on the production of $J/\psi + \pi^+$ from B_c^+ relative to $J/\psi + K^+$ from B_u^+ as a function of the B_c lifetime. Also shown is a theoretical estimate of the relative production ratio based on the assumption that the B_c is produced 10^{-3} times less often than the other B mesons and that the partial width of the B_c decay to $J/\psi + \pi$ is $3.4 \times 10^9 \mathrm{s}^{-1}$.