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Search for $B_c^{\pm} \to J/\psi\pi^{\pm}$ and the B Rare Decays $B_d^0 \to \mu^+ \mu^-$ and $B_s^0 \to \mu^+ \mu^-$ at CDF

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We present a search for the $B_c^{\pm}$ meson in the decay $B_c^{\pm} \rightarrow J/\psi\pi^{\pm}$. We measure the limit of $\sigma(B_c^{\pm})\cdot BR(B_c^{\pm} \rightarrow J/\psi\pi^{\pm})/\sigma(B_u^{\pm})\cdot BR(B_u^{\pm} \rightarrow J/\psi K^{\pm})$ as a function of the $B_c^{\pm}$ lifetime, using $\approx 110pb^{-1}$ of data collected at the Collider Detector at Fermilab (CDF). We present also a search for the rare decays $B_d^0 \rightarrow \mu^+\mu^-$ and $B_s^0 \rightarrow \mu^+\mu^-$, setting an upper limit on their respective branching ratios.

1 Search for $B_c^{\pm} \rightarrow J/\psi\pi^{\pm}$

The $B_c^{\pm}$ meson, the bound state of the bottom and the charm quarks, is expected to have a mass of $6.256 \pm 0.020\ GeV/c^2$ [1]. It's lifetime is predicted in the range of 0.4 – 1.35 ps [1].

A data sample of $\approx 110pb^{-1}$ collected at the Collider Detector at Fermilab (CDF) is used [2]. The Central Tracking Chamber (CTC) and Silicon Vertex Detector (SVX) provide momentum and vertex measurement. For the muons, the muon chambers were used as well.

The invariant mass of two oppositely charged muons, obtained from a vertex-constrained fit, is required to be within 3σ of the J/ψ world average mass. The χ^2 probability of the fit is required to be greater than 1%. A third track is then added. As CDF does not have particle identification in this momentum range, these tracks are processed twice, first as kaons, then as pions. The χ^2 probability of the vertex-constrained fit of the three tracks is required to be greater than 5%, and the p_T is required greater than $6.0\ GeV/c$

For the $J/\psi K^{\pm}$ sample, a cut on the kaon p_T is done at $1.5\ GeV/c$, as well as a cut on $c\tau$ at $150\mu m$. A fit of a gaussian signal and a linear background on the resulting mass distribution (Fig. 1, left) yields 353 ± 20 $B_u^{\pm}$ events.

For the $J/\psi\pi^{\pm}$ sample, a cut on the pion p_T is done at $2.5\ GeV/c$. Since the $B_c^{\pm}$ lifetime is unknown, four different cuts were used ($c\tau > 150, 100, 85, 60\mu m$) depending on the assumed lifetime. The invariant mass distribution for $c\tau > 150\mu m$ is shown in Figure 1. The search region is $\pm 150 MeV/c^2$ around the expected mass of $6.256\ GeV/c^2$. The candidates are taken in the four highest consecutive $20 MeV/c^2$-wide bins in that region, and the rest of the distribution is used to estimate the number of background events in these bins (Table 1).

To determine the relative efficiency ($\epsilon_{rel} = \epsilon(B_u)/\epsilon(B_c)$) a Monte Carlo event generator with detector simulation was used. A factor to account for the

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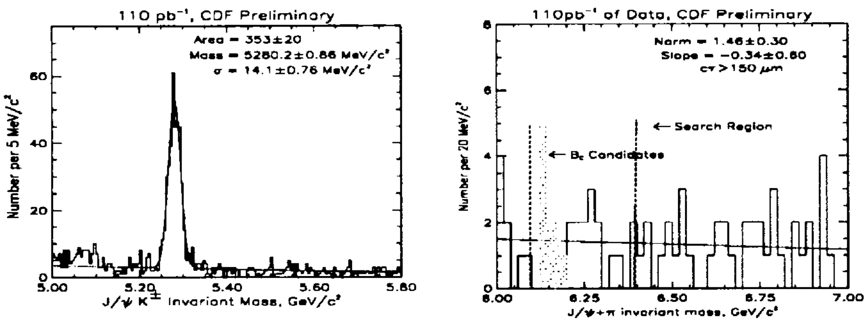

Figure 1: Invariant mass distribution of $J/\psi K^{\pm}$ events (left) and $J/\psi\pi^{\pm}$ events with $c\tau >$ $150\mu m$ (right).

decay-in-flight of kaons relative to pions inside the CTC is also included. The main sources of systematic uncertainties on (ϵ_{rel}) are the B production, decay kinematics and trigger simulation (4%) and the lifetimes and $c\tau$ cuts (3%).

Table 1: For each assumed lifetime, the $c\tau$ cut used, the relative efficiency (ϵ_{rel}), the number of candidates in the four highest consecutive bins (N_{tot}), the number of background events expected in these four bins (N_{Bkg}) and the resulting 95 % CL upper limit is shown

Lifetime	$c\tau$ cut	ϵ_{rel}	N_{tot}	$N_{Bkg}(stat)$	95 % CL
0.17 ps	60 μm	2.50 ± 0.15	40	29.2 ± 2.6	0.15
0.33 ps	85 μm	2.10 ± 0.12	25	16.5 ± 2.1	0.10
0.5 ps	100 μm	1.84 ± 0.11	18	12.7 ± 1.7	0.070
0.8 ps	150 μm	1.80 ± 0.10	10	5.9 ± 1.2	0.053
1.0 ps	150 μm	1.61 ± 0.09	10	5.9 ± 1.2	0.046
1.3 ps	150 μm	1.43 ± 0.08	10	5.9 ± 1.2	0.042
1.55 ps	150 μm	1.35 ± 0.07	10	5.9 ± 1.2	0.040

The method[3] used to calculate the 95% confidence level limit of $\sigma(B_c^{\pm}) \cdot BR(B_c^{\pm} \to J/\psi\pi^{\pm})/\sigma(B_u^{\pm}) \cdot BR(B_u^{\pm} \to J/\psi K^{\pm})$ assumes Poisson distribution for the signal and background and accounts for the uncertainties in N_{Bkg}, ϵ_{rel} and the number of $J/\psi K^{\pm}$. This limit as a function of the assumed $B_c^{\pm}$ lifetime is given in Table 1.

2 Search for B rare decays $B_d^0 \to \mu^+\mu^-$ and $B_s^0 \to \mu^+\mu^-$

In the Standard Model of electroweak interactions, the decays $B^0 \to \mu^+\mu^-$ are forbidden at tree level. However they can proceed at very low rate through higher order diagrams. Current theory[4] predicts branching ratios of

$BR(B_d^0 \to \mu^+\mu^-) = (0.6 - 1.9) \cdot 10^{-10}$ and $BR(B_s^0 \to \mu^+\mu^-) < 5.0 \cdot 10^{-9}$ in the Standard Model. Observing higher branching ratios would indicate decays through processes which are extensions to the Standard Model. The previous CDF measurement[5] using $17.8\, pb^{-1}$ from Run IA obtained: $BR(B_d^0 \to \mu^+\mu^-) < 2.0 \cdot 10^{-6}$ and $BR(B_s^0 \to \mu^+\mu^-) < 6.8 \cdot 10^{-6}$ at 90% confidence level. We use here an additional $80.1 \pm 6.4\ pb^{-1}$ from Run IB and combine both data sets for the final result.

The invariant mass of the muon pair is derived from a vertex-constrained fit, requiring $\chi^2 < 12$. Both muons are required to have $p_T > 2\ GeV/c$. As a direct measurement is done here, we use the B meson cross-section measured at CDF to be $\sigma(B_d^0) = 3 \cdot \sigma(B_s^0) = 2.54 \pm 0.22 \pm 0.58 \mu b$ [6] for $p_T > 6$ GeV/c^2 and $|y(B)| < 1$. The muon pair is therefore required to have $p_T > 6\ GeV/c$.

The $c\tau$ was required to be $> 100\mu m$.

The isolation of the muon pair, defined as $I = \frac{p_T(\mu^+\mu^-)}{p_T(\mu^+\mu^-)+\sum p_T}$, was required > 0.7. The sum is the scalar sum of all tracks within a cone of $\Delta R < 1$ ($\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$) around the momentum vector of the dimuon pair.

The pointing angle, defined as the angle between the transverse momentum of the dimuon pair and the vector pointing from the primary to the secondary vertex, is required to be smaller than 0.2 rad.

The search region is the dimuon invariant mass regions $5.205 - 5.355\ GeV/c^2$ for the B_d^0 and $5.3 - 5.45\ GeV/c^2$ for the B_s^0. The estimated mass resolution is $\approx 35 MeV/c^2$. Mass windows of $\pm 75 MeV/c^2$ were similarly used in the Run IA analysis. The invariant mass distribution of the muon pairs passing all the cuts is shown in Figure 2. We are left with no candidate either in the B_d^0 or in the B_s^0 mass window.

The efficiency and acceptance is for Run IA 1.59 ± 0.19 % and for Run IB 2.29 ± 0.23 %.

Include all systematic uncertainties in our result, using the method described in[8], the combined Run IA-Run IB 90% and 95% confidence level upper limits are

$$BR(B_d^0 \to \mu^+\mu^-) < 2.6 \cdot 10^{-7}\ (90\% CL)$$

$$BR(B_s^0 \to \mu^+\mu^-) < 7.7 \cdot 10^{-7}\ (90\% CL)$$

$$BR(B_d^0 \to \mu^+\mu^-) < 3.4 \cdot 10^{-7}\ (95\% CL)$$

$$BR(B_s^0 \to \mu^+\mu^-) < 10.3 \cdot 10^{-7}\ (95\% CL)$$

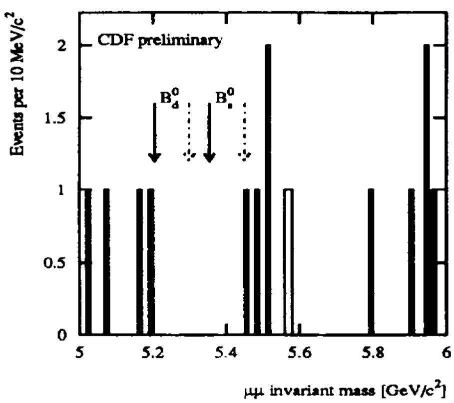

Figure 2: Invariant mass distribution of $\mu^+\mu^-$ events after all cuts.

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