RECENT RESULTS ON THE B_c MESON

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Abstract

The pseudoscalar B_c is the lowest mass bound state of the $c\bar{b}$ and the charge conjugate. It is the last such meson to be discovered. Both the CDF and D0 collaborations have reported recent results on the mass and lifetime of this elusive state.

1 Introduction

The B_c is the lowest mass bound state of $c\bar{b}$ or $b\bar{c}$. It is expected to be a pseudoscalar meson, the last such meson predicted by the Standard Model. The B_c is unique in that either one of its quarks can decay, leaving the other as a spectator. One decay path is $\bar{b} \to \bar{c}W^+$, often leading to final states containing a J/ψ. Although these modes do not have the largest branching ratios, they have proven to be the easiest to observe due to the clean J/ψ tag. If the c quark decays, leaving the b as a spectator, the final states often contain B_s mesons. These decay modes have yet to be observed.

There are many predictions for the mass and lifetime of the B_c. Heavy quark effective potentials predict the mass to be between 6.2 and 6.3 GeV/c^2. [1] Since the B_c lies between the well-measured $b\bar{b}$ and the $c\bar{c}$ states, it would be surprising if it's mass were very different from the predictions. Expectations for the B_c lifetime are more variable, with predictions ranging from 0.4 to 1.4 ps, so that a measurement of the B_c lifetime will discriminate between the different models. The B_c is expected to have a rich spectroscopy of narrow excited states, which, if observable, would also constrain the heavy quark potential.

The first observation of B_c came from CDF in Run I. They observed B_c in the semileptonic decay modes $B_c \to J/\psi\mu\nu$ and $B_c \to J/\psi e\nu$. This result has been published for some time.[2] There are two new results from Run II, which are reported here. D0 has made an observation of the B_c in the semileptonic mode $B_c \to J/\psi\mu X$ [3], and CDF has evidence for the exclusive final state $B_c \to J/\psi\pi$ [4]. Both of these results are preliminary.

2 D0 Observation of $B_c \to J/\psi\mu X$

The D0 result is based on 260 pb^{-1} of data. The analysis proceeds by reconstructing a good J/ψ from a dimuon data sample. A good 3-D vertex is required, and a J/ψ mass constraint is applied. Then events are selected in which a third muon track can be associated with the J/ψ vertex. A background control sample is defined in the same way, except that the third track is required to not be tagged as a muon. Since there is a missing neutrino in the final state, it is not possible to calculate the true proper time. A "pseudo-proper time" is calculated event-by-event, and this distribution is corrected on average based on Monte Carlo simulations.

Backgrounds arise from prompt J/ψs which accidently vertex with a third muon, and also from real heavy flavor decays which pick up a third muon. These background samples are treated separately in the analysis, since they will not have the same distributions in mass or proper time. The prompt background sample is obtained by taking events with negative pseudo-proper time (which arise from resolution effects) and reflecting the distribution about $t = 0$. This sample is then subtracted from the full background sample to obtain the heavy flavor background sample.

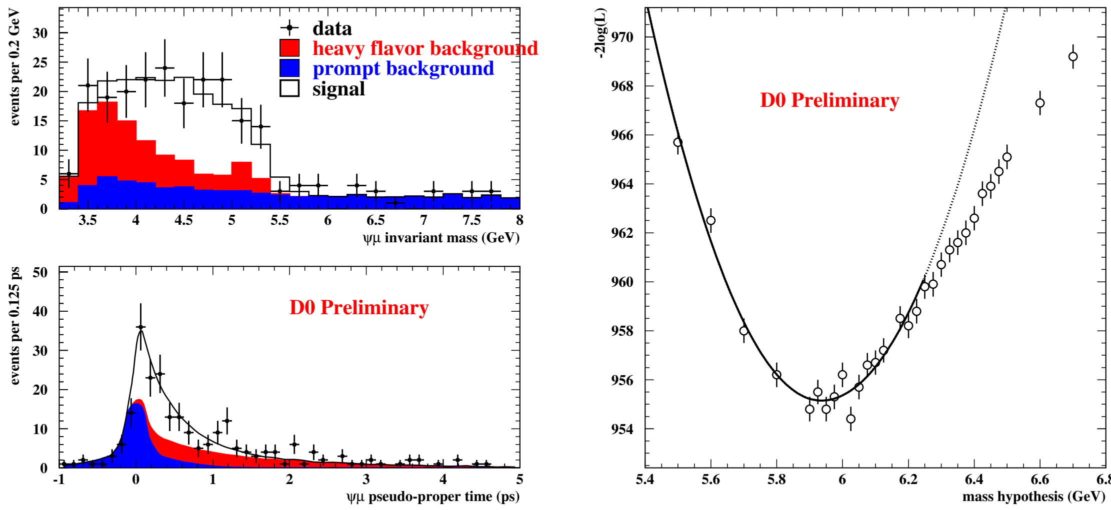

Figure 1: Results of the likelihood fit for $M_{\psi\mu}$ and pseudoproper time. The left plot shows the data and the fit results for the expected backgrounds and signal contributions. The right plot is an example log likelihood function vs. the B_c mass hypothesis.

Figure 1 shows the result of a combined likelihood fit for the B_c mass and lifetime. The left plot shows the distributions in $M_{\psi\mu}$, the invariant mass of the $J/\psi\mu$ system, and the pseudo-proper time. Three contributions to the full data sample are shown: the prompt background, heavy flavor background, and B_c signal. The right plot shows an example of the log likelihood function vs. the B_c mass hypothesis, for an assumed lifetime value of 0.45 ps. The fitting procedure gives 95 $\pm 12(stat) \pm 11(sys)$ signal events. This result is currently the most statistically significant observation of the B_c. The best fit value for the mass is $5.95^{+0.14}_{-0.13}(stat) \pm 0.34(sys)$. The best fit value for the lifetime is $0.45^{+0.12}_{-0.10}(stat) \pm 0.12(sys)$. The mass and lifetime are uncorrelated in the fit.

3 CDF Evidence for $B_c \to J/\psi\pi$

CDF has recently observed evidence for the B_c in the exclusive final state $B_c \to J/\psi\pi$. The analysis uses a 360 pb^{-1} sample of data with $J/\psi \to \mu\mu$ identified at the L3 trigger. A mass constraint is applied to the muons forming the J/ψ, and a third track, assumed to be a π, is required to form a good 3D vertex with the J/ψ. The prominent decay $B^+ \to J/\psi K^+$ is used as the reference mode to validate the Monte Carlo simulations and check the various cuts. The left plot in figure 2 shows the $B^+ \to J/\psi K^+$ mass distribution, demonstrating the low level of background in this reference mode. The right plot of figure 2 shows the $M_{J/\psi\pi}$ mass distribution in the mass region used for the B_c search.

A blind analysis was performed in the following way. A significance function was defined as $\Sigma = \frac{S}{1.5+\sqrt{B}}$ where S represents the number of signal events within $\pm 2\sigma$ of the assumed mass, with σ determined from Monte Carlo. B is the number of background events in the same mass region, with the background taken to be linear. In searching for the B_c signal, a likelihood fit was done in bins of $M_{J/\psi\pi}$ 10 MeV/c^2 wide.

Before the $M_{J/\psi\pi}$ distribution in the data was revealed, a Monte Carlo study was performed using 1000 Monte Carlo samples which consisted of only background. In these sam-

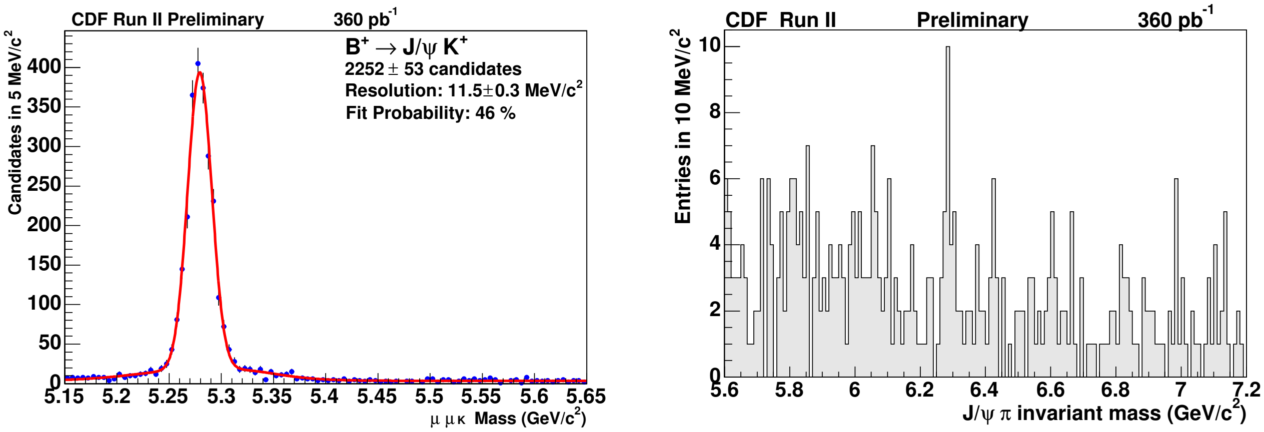

Figure 2: The left plot shows the $M_{J/\psi K^+}$ distribution from $B^+ \to J/\psi K^+$ reference mode. The right plot shows the $M_{J/\psi\pi}$ distribution in the search region.

ples, the background consisted of two components: a combinatorical part, which was taken to be linear, and a contribution from various partically reconstructed B_c decays, taken from Monte Carlo. These samples were then fit for the B_c signal plus background, and the significance function Σ was calculated in all mass bins from 5.7 to 7.2 GeV/c^2. Occasionally, due to statistical fluctuations, the value of Σ could be large. In these 1000 samples, over all mass values, the maximum value of Σ that occurred was 3.5. Therefore, this value of Σ was taken as the minimum required to claim statistically signficant evidence for $B_c \to J/\psi\pi$.

This entire procedure was carried out before the $M_{J/\psi\pi}$ distribution in the data was revealed. After the requirement on Σ had been fixed, the same procedure was carried out on the actual data. Figure 3 shows the value of the significance function Σ in each mass bin for the data(left plot). The maximum value of Σ observed is 3.6, just above the predetermined cutoff of 3.5, at a mass value around 6.3 GeV/c^2. Figure 3 also shows an expanded view of the $M_{J/\psi\pi}$ distribution, showing the signal region and the fit to the B_c mass. The fit returns 18.9 $\pm$5.7 signal events and a mass of 6.2879 $\pm$0.0048$(stat) \pm 0.0011(sys)$ GeV/c^2. There is as yet no lifetime determination from this analysis.

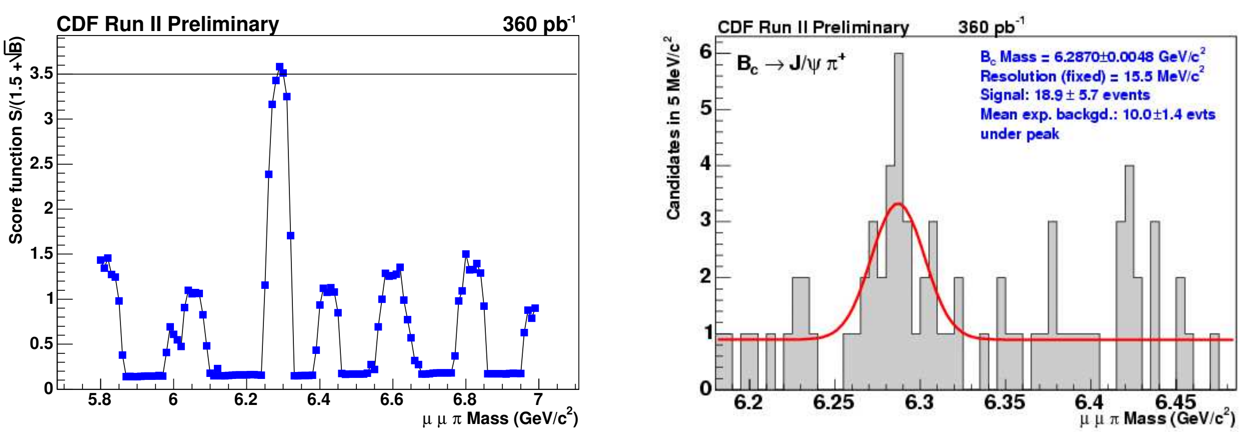

Figure 3: Significance function Σ calculated in mass bins for the data. The maximum value of Σ is 3.6, just above the predetermined cutoff of 3.5. The right plot shows an expanded view of the $M_{J/\psi\pi}$ distribution, showing the signal region and the result of an unbinned likelihood fit. The fit returns 18.9 $\pm$5.7 events and a mass of 6.2879 $\pm$ 0.0048 GeV/c^2.

	$\mathcal{L}$ (pb^{-1})	Signal Events	Mass (GeV/c^2)	Lifetime (ps)
CDF Run I ($B_c \to J/\psi l\nu$)	110	$20.4^{+6.2}_{-5.5}$	6.4 $\pm 0.39 \pm 0.13$ (published)	$0.46^{+0.18}_{-0.16} \pm 0.03$ (published)
D0 Run II ($B_c \to J/\psi\mu X$)	210	$95 \pm 12 \pm 11$	$5.95^{+0.14}_{-0.13} \pm 0.34$ (preliminary)	$0.45^{+0.12}_{-0.10} \pm 0.12$ (preliminary)
CDF Run II ($B_c \to J/\psi\pi$)	360	18.9 ± 5.7	$6.287 \pm 0.0048 \pm 0.0011$ (preliminary)	—

Table 1: Summary of experimental results for the B_c meson mass and lifetime. In all cases the first errors are statistical and the second are systematic.

4 Summary

Table I summarizes the observations of and evidence for the B_c meson. All results are in agreement with expectations from heavy quark potential models. Analysis is proceeding for both experiments. Much more data is already in hand and we can expect improved determinations of the B_c mass and lifetime soon.

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