Observation of orbitally excited (L=1) B mesons in $B \to J/\psi\ K$ decays

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Abstract

An observation of orbitally excited B mesons in $B \to J/\psi$ K decays is made in a 220 pb^{-1} sample from the CDF experiment at the Fermilab Tevatron. A straightforward sample selection is described to reconstruct the decay chain

$$B^{**} \to B^+\pi^-(B^+ \to J/\psi K^+, J/\psi \to \mu^+\mu^-)$$

Preliminary results are consistent with the predictions of Heavy Quark Effective Theories. A plan for continued observations is outlined.

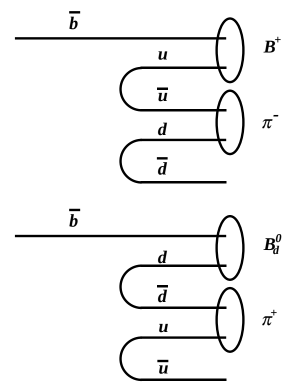

Figure 1: Same Side Tagging pion production.

1 Motivation for B^{**}

The search for the B^{**}, as the lowest energy orbitally excited B mesons have been collectively labelled, has two primary motivating factors - testing Heavy Quark Effective Theories and flavor tagging B^0 using Same Side Tagging.

1.1 Heavy Quark Effective Theory (HQET)

The basis for all HQET is Heavy Quark Symmetry. In mesons containing heavy quarks, the heavy quark mass can be approximated as infinite. This symmetry simplifies QCD calculations for the meson. HQET explained the unexpectedly narrow D^{**} states, and those results have been extrapolated for predictions of the B^{**} states [5]. Since the B^{**} is made up of one heavy and one light quark, it is also possible to use dynamical models of the light quark to achieve more accurate predictions.

Observation of the B^{**} tests the predictions of these various theories and determines which best fits the data. This will allow better predictions of all heavy-light quark bound states. It will also provide more information on the nature of the heavy-light quark interactions, thus helping to constrain the CKM matrix elements connecting these heavy and light quarks.

1.2 Same Side Tagging (SST)

SST is the search for pions produced along with B mesons. The pions will be charge-correlated with the accompanying B meson, making it possible to tag the flavor of the B meson at production. Flavor tagging is used to measure B^0 mixing. These correlated pions come from two different sources: the decay of B^{**} excited states,

	J	J_q	Mass (GeV/c^2)			Width
			EHQ [1]	non-rel [2]	EGF [3]	MeV
B_0^*	0	$\frac{1}{2}$	5.650	5.870	5.738	100
B_1^*	1	$\frac{1}{2}$	5.650	5.875	5.757	100
B_1^*	1	$\frac{3}{2}$	5.759	5.700	5.719	20
B_2^*	2	$\frac{3}{2}$	5.771	5.715	5.733	24

Table 1: Table reproduced from [4].

and fragmentation of the b-quark. The B^* is not massive enough to decay to a $B+\pi$, so it cannot be used for SST. The rate of B mesons from B^{**} decay was shown by all four LEP experiments to be $\approx 30\%$. Thus the B^{**} datasets will also be useful for SST studies.

2 B^{**} Theory

The neutral B mesons are made up of $\bar{b}d$ quarks. There are two ground states for $\bar{b}d$ - one with quark spins aligned anti-parallel (B^0), and the other, which has a higher mass, with spins parallel (B^{*0}).

Excited states of the B^0 come from excitations of the light quark's wavefunction. The first orbitally excited states (L=1) are lower in energy than the first radially excited states. Thus the four L=1 states have been classified as the B^{**}. In Table 1, the states have been classified by their values of $\mathbf{J} = \mathbf{J_q} \oplus \mathbf{S_Q}$. $\mathbf{J_q}$ is the toal angular momentum of the light quark and $\mathbf{S_Q}$ is the spin of the heavy quark. Theoretical predictions on the masses of the four B^{**} resonances vary, and the best estimate for the widths comes from scaling down the measured narrow state D^{**} widths. The widths should scale as $\frac{1}{m_Q}$, where m_Q is the mass of heavy quark.

The three mass columns in Table 1 are the masses calculated using Effective Heavy Quark (EHQ) theory, a non-relativistic valence quark theory, and a fully relativisitic valence quark (EGF) theory. As shown in Fig. 2, in all three of these theoretical predictions the two narrow peaks are located near each other, causing them to merge into one narrow peak. Naturally the two wide peaks also merge into one wide peak underlying the narrow peak.

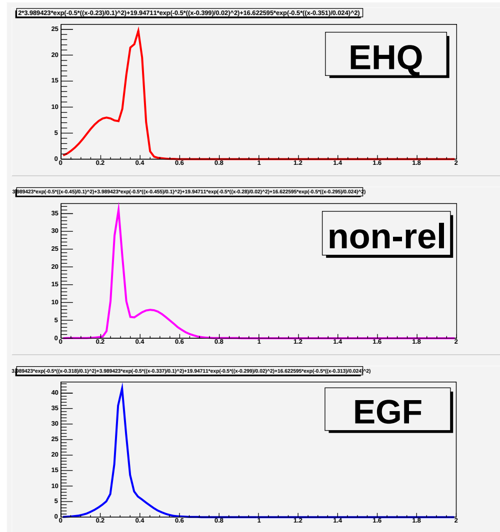

Figure 2: Theoretical mass predictions. Horizontal axis is Q = m(B^{**}) - m(B) - m(π).

3 Candidate Selection

The analysis was performed on 220 pb^{-1} of data from the Run II Collider Detector at Fermilab (CDF) collected between March 2001 and Sept. 2003. The original $J/\psi \to \mu^+\mu^-$ data was stored in CDF datasets jbot0h, jpmm08, and jpmm09. In Dec. 2003 this J/ψ data was retracked and stored as CDF dataset xpmm0c. This retracking achieved better mass and L_{xy} resolution. Our baseline analysis plot (Fig. 3) came from xpmm0c data with the J/ψ mass constrained to its PDG value, using the event selection cuts listed in Table 2.

4 Preliminary Results

The preliminary result for the B^{**} mass from this search is plotted in Fig. 3. In this figure, the black line indicates events which produced the right sign; the charge of the B^{**}, Q(B^{**}), was 0. The red line indicates events which found a B^{**} with the wrong sign, Q(B^{**}) = ± 2. This occurs when the kaons and pions found are a result of fragmentation surrounding the production of a b-quark going directly to a B meson, rather than a B^{**} decay. Thus the

Particle	Cut	Cut Value	Units
Track Quality	Si Hits $(r-\phi)$	>3	
	COT axial hits	>20	
	COT stereo hits	>16	
	p_T	>0.5	GeV/c
$\mu^{\pm}$	opposite charge		
	p_T	>1.5	GeV/c
J/ψ	$\lvert m(J/\psi)-3.095\rvert$	<0.04	GeV/c^2
K	p_T	>2.0	GeV/c
B	$\lvert m(B)-5.28\rvert$	<0.04	GeV/c^2
	p_T	>6.5	GeV/c
	L_{xy}	>100	μm
	$L_{xy}/\sigma_{L_{xy}}$	>7	
π	p_T	>0.6	GeV/c
	$\lvert d_0/\sigma_{d_0}\rvert$	<3	
B^{**}	$m(B^{**})$	>5.2	GeV/c^2
	$m(B^{**})$	<7.2	GeV/c^2
	p_T	>6.0	GeV/c

Table 2: Baseline analysis cuts. B reconstruction based on [6].

wrong sign plot contains only fragmentation events and should have the same shape as the fragmentation background in the right sign plot [4]. This plot also uses the same horizontal axis as the theoretical prediction plots in Fig. 2. Comparing Figs. 2 and 3, there is a definite excess of events in the right sign plot in the signal region for the B^{**}. Also, the position of the narrow peak is more consistent with the predictions of the valence quark theories. If the fragmentation is described accurately by the wrong sign peak, this looks like a narrow peak sitting directly on top of a wider peak above background. This would be consistent with the EGF theory.

5 Analysis Plan

The next step is to generate a realistic Monte Carlo (MC) simulation of this decay. With this MC sample we will use RooFit to fit shapes for the B^{**} mass peaks, which will then be floated in the fit on data. Additionally, realistic MC will predict the expected background signal around the mass peaks, allowing us to judge our ability to see the wide peaks above the background.

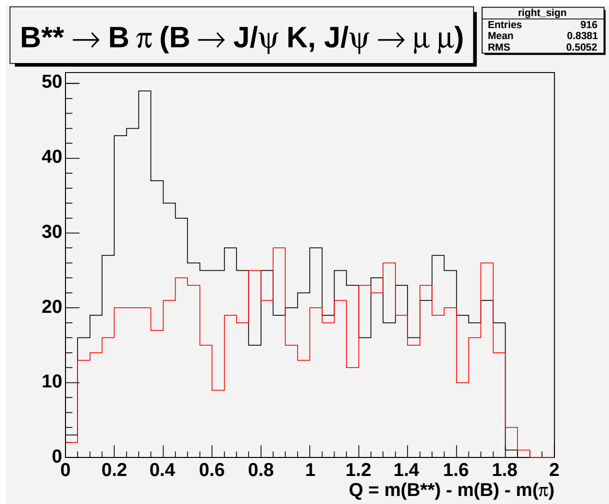

Figure 3: Right sign vs. wrong sign plot.

Comparing pure MC signal to a background data sample also makes it possible to choose cuts which optimize the signal/background ratio. The current baseline analysis cuts are based on previously optimized cuts [6], but have not been optimized specific to this analysis. Once these MC studies have been performed, we will run over data again with the optimized cuts.

We can also boost the statistics on the B^{**} by pursuing other B decay modes. There are many hadronic decay modes with higher statistics than the $J/\psi\, K$ modes; one which we have already begun investigating is

$$B^{**} \to B^+\pi^-(B^+ \to D^0\pi^+, D^0 \to K^+\pi^-)$$

Higher statistics will improve the quality of the fit and give conclusive final results.

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