Properties of B^{**} and B_c Mesons

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(D0 Collaboration)

- Introduction
- B^{**} Analysis
- B_c Analysis
- Summary

Introduction

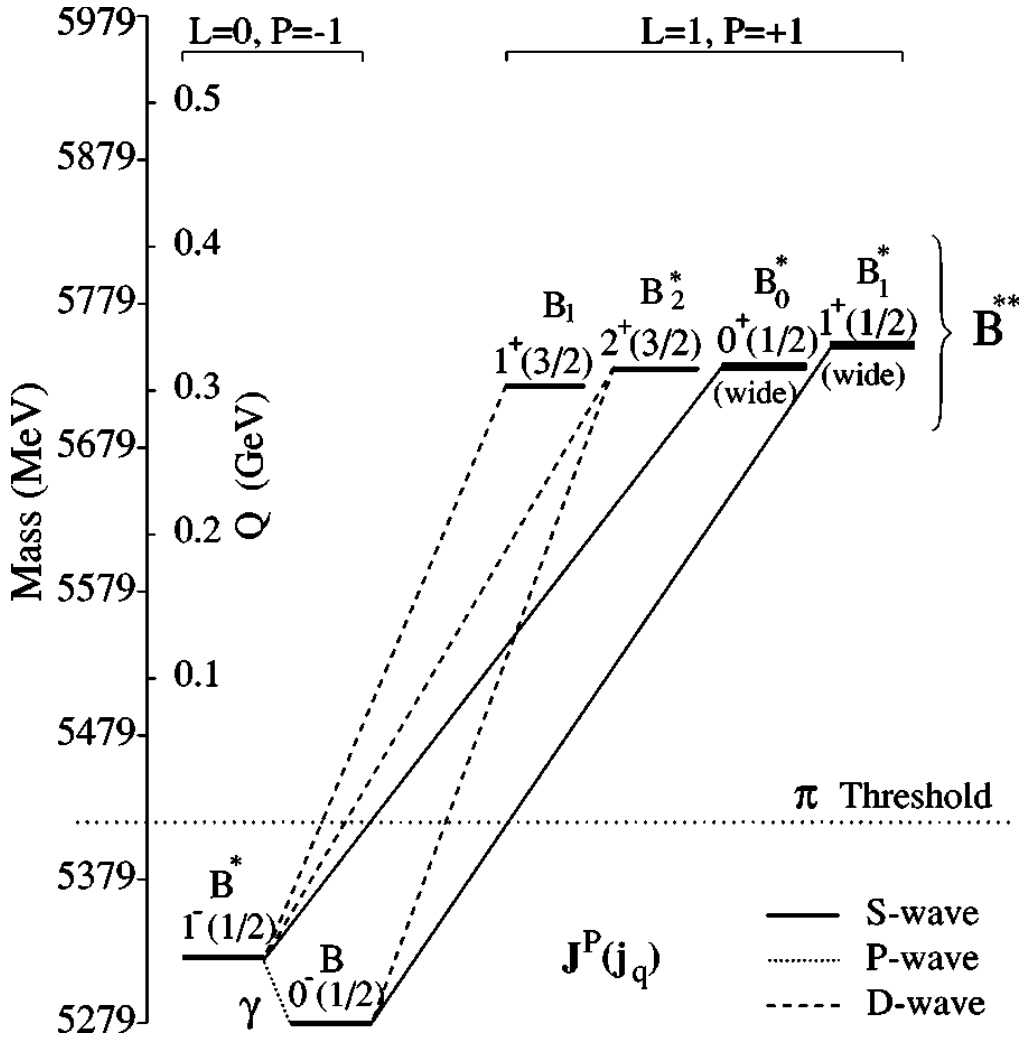
- B^{**} and B_c provide means for understanding heavy quark spectroscopy.
  - Useful test of quark models.
  - B^{**} is closest QCD analogue of hydrogen system.
- In HQET, b quark decouples from light degrees of freedom.
  - B mesons labeled by $\mathbf{j_q}$ of the light quark.
  - $\mathbf{j_q} = \mathbf{L} + \mathbf{s_q}$: Total angular momentum of light quark.
  - $\mathbf{J} = \mathbf{j_q} + \mathbf{s_Q}$: Total angular momentum of system.

B Meson Spectroscopy

- $L = 0$ states are the familiar B and B^* mesons.
- $L = 1$ states collectively called B^{**}.
  - $j_q = \frac{1}{2} \quad J = 0, 1 \rightarrow B_0^*, B_1^*$
  - $j_q = \frac{3}{2} \quad J = 1, 2 \rightarrow B_1, B_2^*$
- States within each doublet degenerate in mass.
  - Degeneracy broken because m_b is not infinite.

B^{**} Spectroscopy

- $j_q = \frac{1}{2}$ decays via S-wave.
  - Expected to be broad.
- $j_q = \frac{3}{2}$ decays via D-wave.
  - Expected to be narrow.
  - $B_1 \to B\pi$
  - $B_2^* \to B\pi, B^*\pi$
- Theory
  - $M(B_1) \sim 5700 - 5755$
  - $M(B_2^*) \sim 5715 - 5767$
  - $\Gamma_{1,2} \sim 20$ MeV/c^2

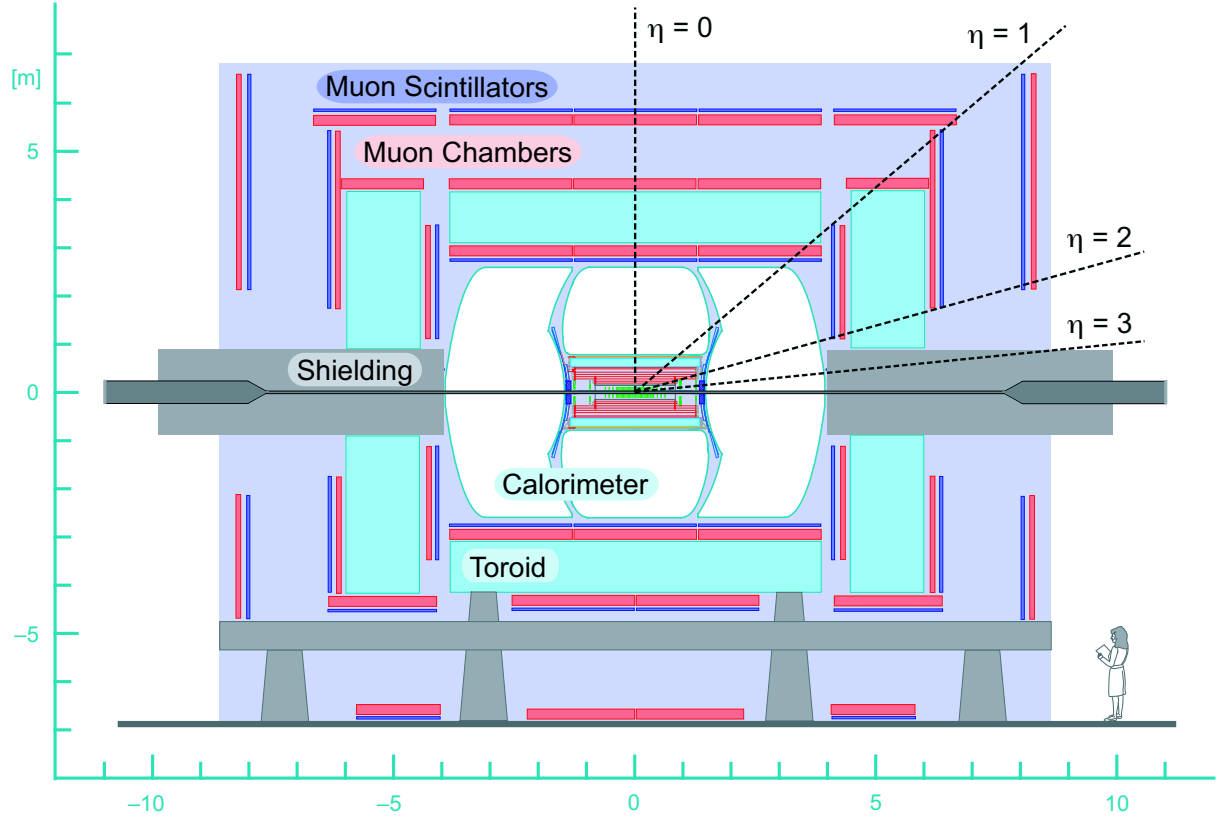


Previous B^{**} Results

Experiment	Reconstruction	B_j mass (MeV/c^2)	B_j Width
ALEPH	exclusive	5695 ± 18	53 ± 16
CDF	$(\mu D) + \pi$	5710 ± 10	NA
DELPHI	inclusive $B + \pi$	5732 ± 21	145 ± 28
OPAL	inclusive $B + \pi$	5681 ± 11	116 ± 24

- None of these experiments resolved four states.
  - Either inclusive or statistics limited.
  - Measured widths probably includes many states.
- PDG average mass: 5698 ± 8 MeV/c^2.

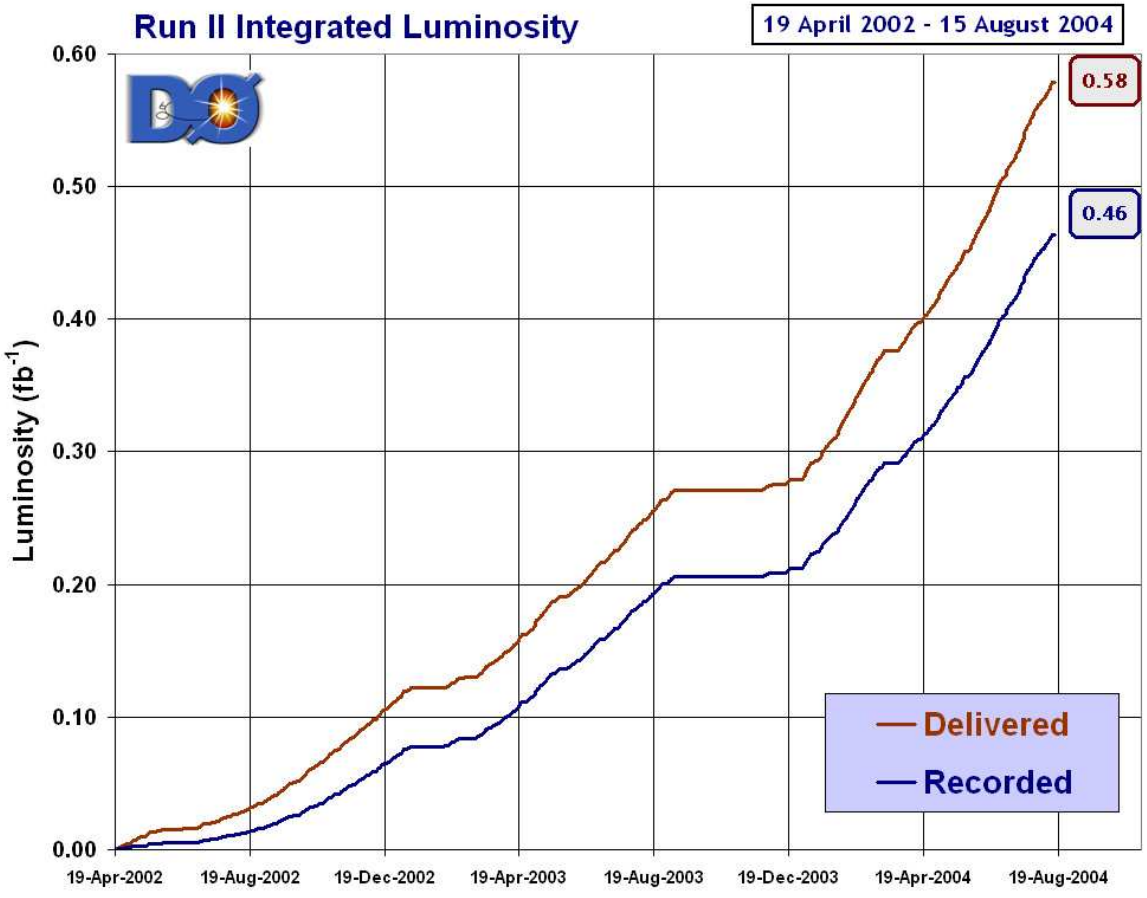
D0 Detector



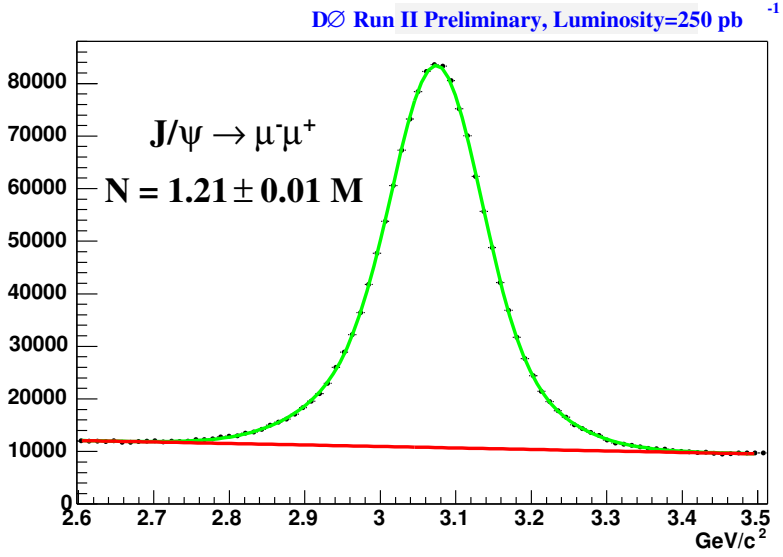
- Muon coverage out to $|\eta| < 2.0$
- Tracking with silicon vertex detector.
- 2.0T Magnetic field.

Data Set

- B^{**} analysis: 350 pb-1
- B_c analysis: 210 pb-1



B^{**} Event Selection



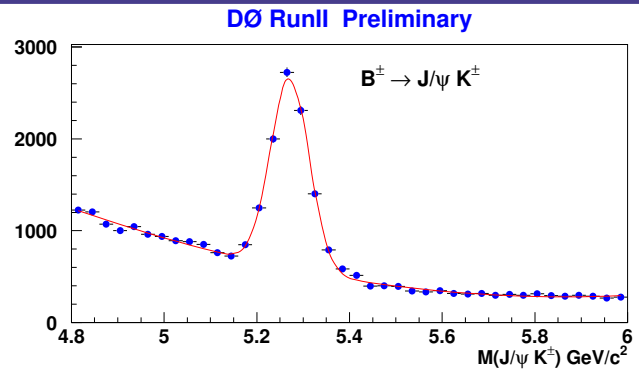
- Two oppositely charged muons ($2.8 < m < 3.35$ GeV/c^2).
- Constrain to J/ψ mass.
- Require additional particles to form B meson.
  - $K^{\pm}$, K^{*0}, K_s.
- Require large B decay length significance (L/σ_L).
- Require B momentum along direction from primary to decay vertex.

Reconstructed B Masses

$B^{\pm} \rightarrow J/\psi K^{\pm}$

$\hookrightarrow \mu^+\mu^-$

7217 ± 127 events.

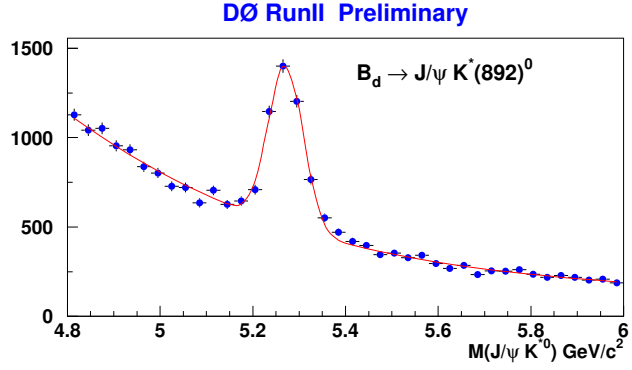


$B_d \rightarrow J/\psi K^{*0}$

$\hookrightarrow K^+\pi^-$

$\hookrightarrow \mu^+\mu^-$

2826 ± 93 events.

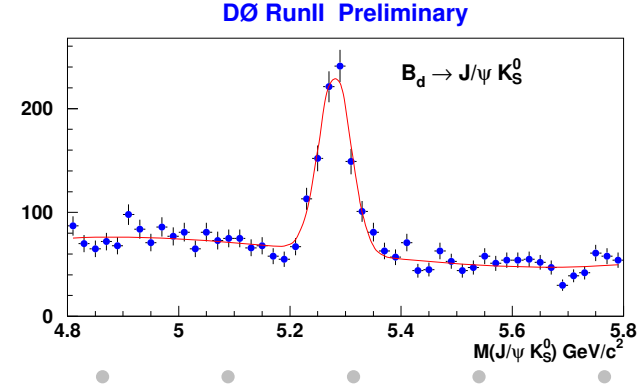


$B_d \rightarrow J/\psi K_s$

$\hookrightarrow \pi^+\pi^-$

$\hookrightarrow \mu^+\mu^-$

624 ± 41 events.

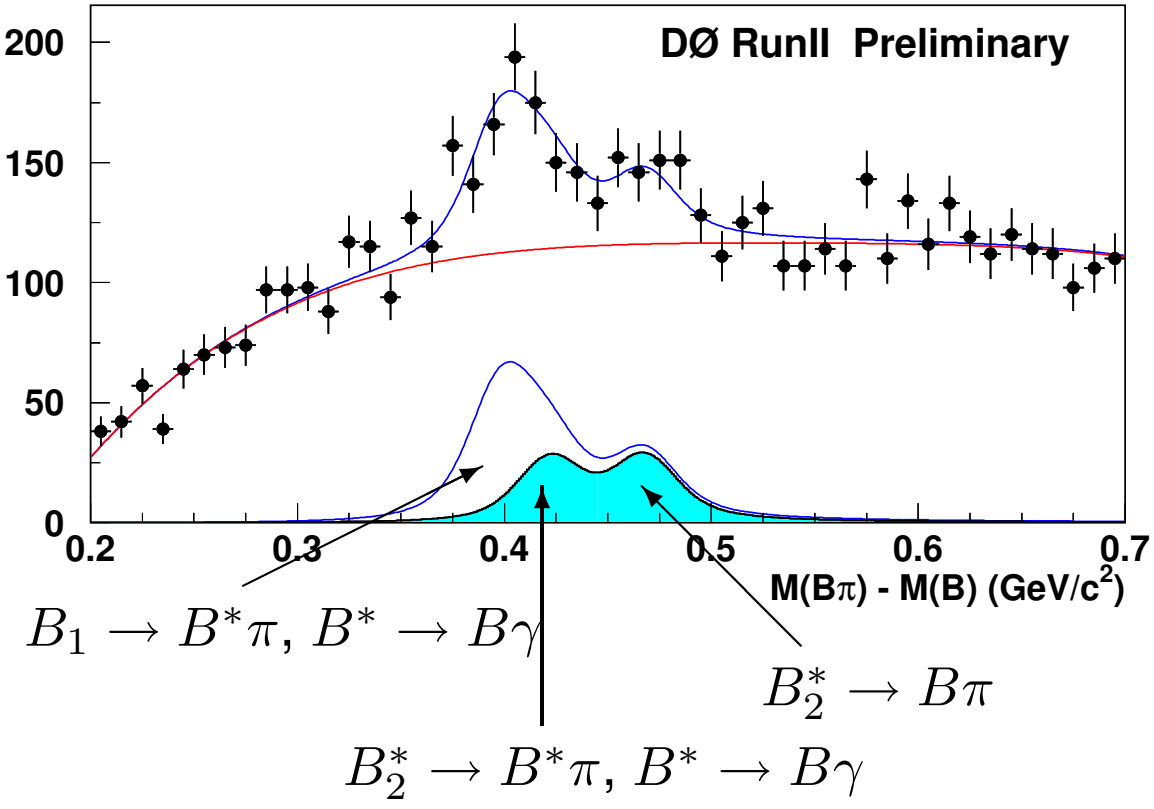


B^{**} Reconstruction

- Select B^+ and B_d^0 candidates.
- Combine with $\pi^\pm$ candidate from primary vertex.
- Plot $M(B\pi) - M(B)$.
  - Mass difference improves resolution.
- Expect three peaks.
  - $B_1 \to B^*\pi$ ($B_1 \to B\pi$ forbidden by J, P cons).
  - $B_2^* \to B^*\pi$
  - $B_2^* \to B\pi$
- Ignore γ from B^* decays.
  - Shifts mass difference by 46 MeV/c^2.
- Cannot distinguish wide $j_q = \frac{1}{2}$ states from bkg.

Mass Difference

First observation of separate states.



$N(B^{**}) = 536 \pm 114,\ \sim 7\sigma$ significance.

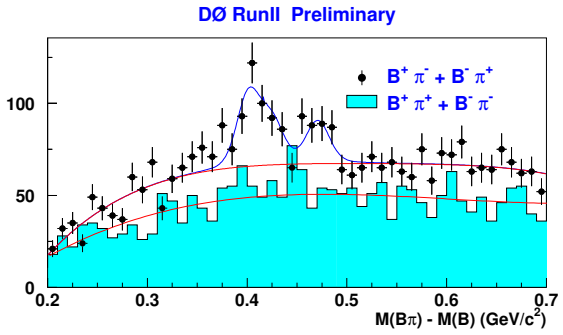
Signal Fit

$$
\begin{aligned}
N_{sig} = \quad & N\Big(f_1 \times G(\Delta_1, \Gamma_1) && B_1 \to B^*\pi \quad (273 \pm 59) \\
+ \quad & (1 - f_1)\{ f_2 \times G(\Delta_2, \Gamma_2) && B_2^* \to B^*\pi \quad (131 \pm 30) \\
+ \quad & (1 - f_2) G(\Delta_2, \Gamma_2)\} \Big) && B_2^* \to B\pi
\end{aligned}
$$

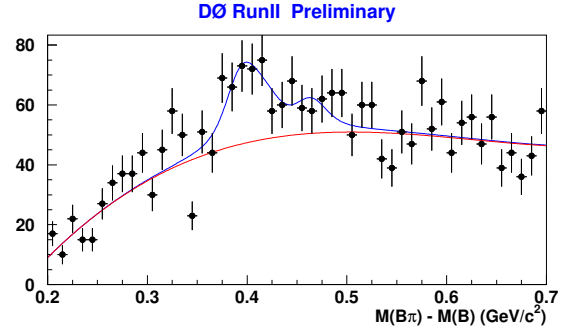
- N: Number of B^{**} candidates.
- f_1, f_2: B_1 fraction of total, BF($B_2^* \to B^*\pi$).
- G: Breit-Wigner convoluted with a gaussian.
- $\Gamma_{1,2}$, $\Delta_{1,2}$: $B_{1,2}$ width and mass difference.
- Theory: $\Gamma_1 = \Gamma_2$ and $f_2 = 0.5$.
- MC: ΔM resolution = 10.3 MeV/c^2.

Consistency Checks

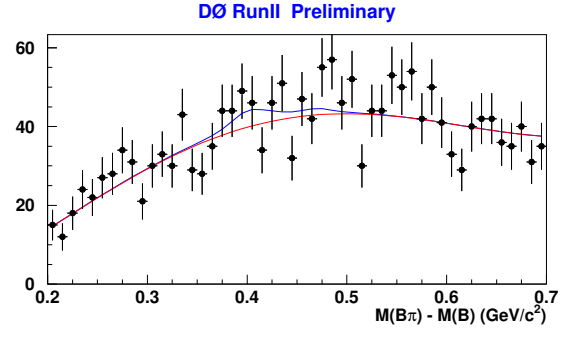
Signal is evident for $B^{\pm}$ decays.



Signal is evident for B_d^0 decays.



$N = 32 \pm 36$ for events where pion is inconsistent with primary vertex.



Systematic Errors

Preliminary

Source	$M(B_1)$ (MeV/c^2)	$M(B_2^*) - M(B_1)$ (MeV/c^2)	$\Gamma_{1,2}$ (MeV/c^2)	f_1
Background shape	2	2.2	4.5	0.03
$B_2^* \to B^*\pi$ rate (0.0-0.7)	6	3.1	6.2	0.21
Float Γ_2	0	0.5	1.4	0.02
Mass resolution	2	0.6	7.1	0.03
Momentum scale	1	0.1	0.0	0.00
Total	6.7	3.9	9.3	0.21

B^{**} Results

Preliminary

First observation of B_1 and B_2^* separation.

- $M(B_1) = 5724 \pm 4 \pm 7$ MeV/c^2.
- $M(B_2^*) - M(B_1) = 23.6 \pm 7.7 \pm 3.9$ MeV/c^2.
- $\Gamma_1 = \Gamma_2 = 23 \pm 12 \pm 9$ MeV/c^2.
- $f_1 = 0.51 \pm 0.11 \pm 0.21$.

First errors are statistical and second errors are systematic.

B_c Mesons

- Last of ground state mesons to be observed.
- Good test of quark models.
- Theory
  - $M(B_c) \sim 6.4$ GeV/c^2
  - Lifetime 0.3-0.5 ps
- Only previous result: CDF Run I
  - $20.4^{+6.2}_{-5.5}$ events.
  - $M(B_c) = 6.40 \pm 0.39 \pm 0.13$ GeV/c^2.
  - $\tau(B_c) = 0.46^{+0.18}_{-0.16} \pm 0.03$ ps

B_c Event Reconstruction

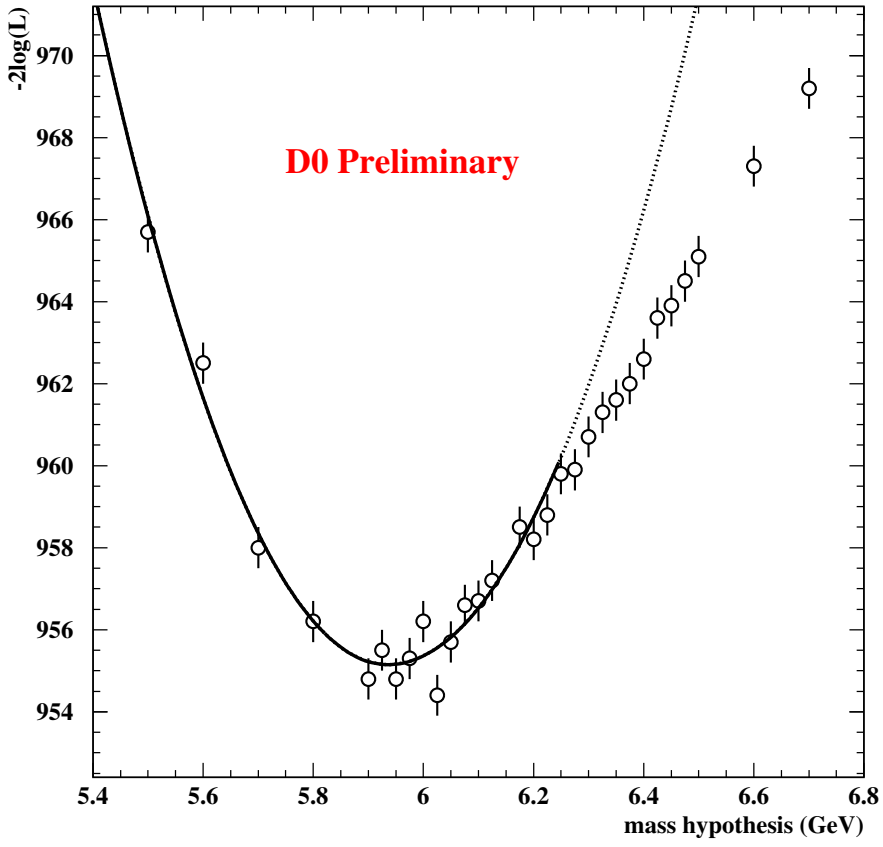
- $B_c^{\pm} \rightarrow J/\psi \mu^{\pm} \nu$

  $J/\psi \rightarrow \mu^+ \mu^-$

- Require $M(\mu^+\mu^-)$ within 0.25 GeV/c^2 of J/ψ.
  - Constrain mass to J/ψ.
- Combine with extra high-quality μ in event.
- Backgrounds estimated with J/ψ + non-μ track.

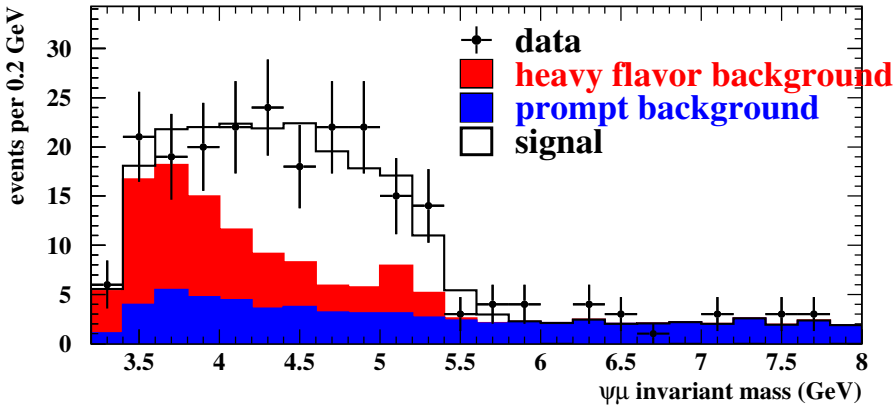
B_c Fit

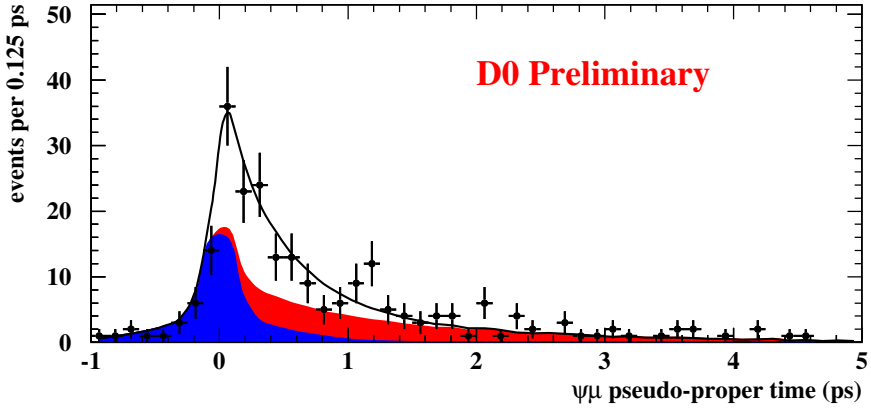
- B_c signal is extracted from a simultaneous unbinned likelihood fit to $J/\psi\mu$ mass and $J/\psi\mu$ proper time.
- Performed for a variety of mass hypotheses.



B_c Signal

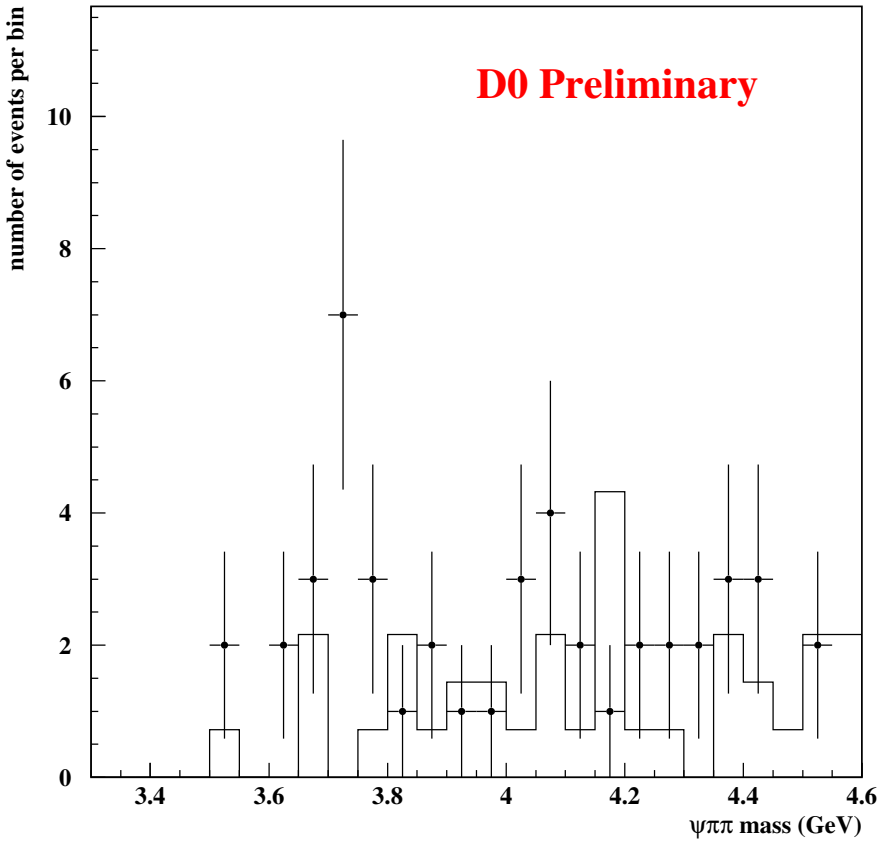
- Background probability density determined from $J/\psi+$ track events.
  - $T < 0 \rightarrow$ prompt bkg.
  - $T > 0, 2 \rightarrow$ heavy flavor bkg.
- Excess composed of:
  - $B_c \rightarrow J/\psi\mu\nu$
  - $B_c \rightarrow \psi(2S)\mu\nu$
  - $B_c \rightarrow J/\psi\mu\nu\pi^0$





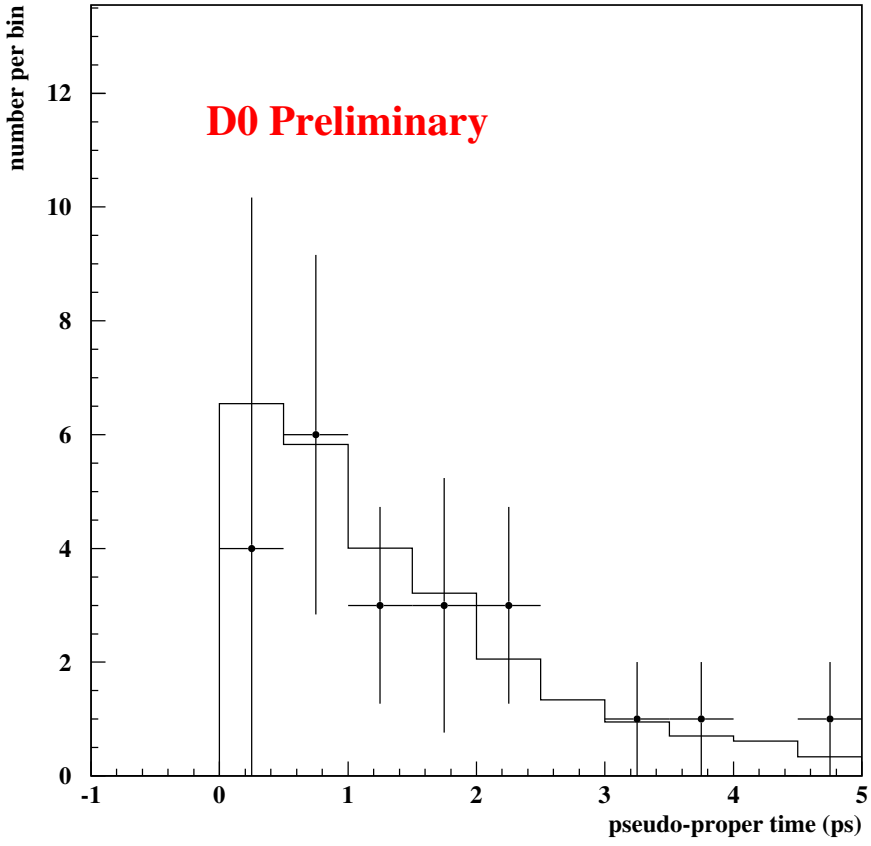
B_c Backgrounds

- Look for feeddown from $B_c^+ \to \psi(2S)\mu^+\nu$.
  - $\psi(2S) \to J/\psi X$.
- Observe fewer than 15 $\psi(2S)$ candidates.
- Use this to fix feeddown fraction at $(15 \pm 15)\%$.
- Use B_u and B_d decays as guide for non-resonant backgrounds $(15 \pm 15\%)$.



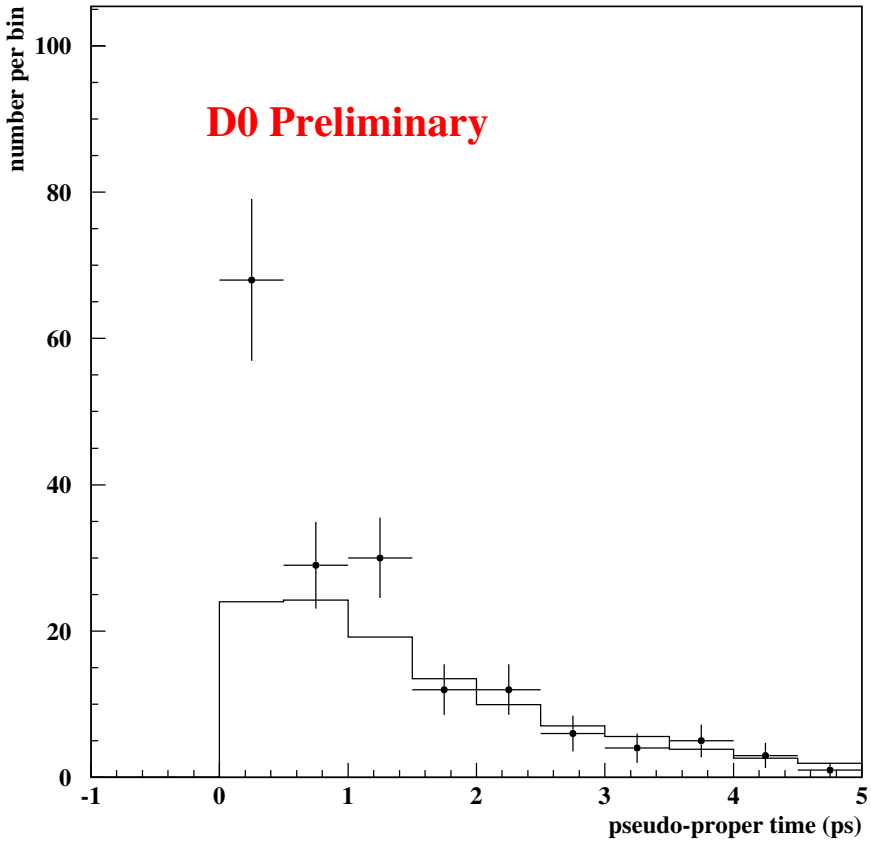
Check of Background Estimation

- Expect $B_c^+ \to \psi(2S)\mu^+X$, $\psi(2S) \to \mu^+\mu^-$ sample to be dominated by background.
  - $B_c^+ \to \psi(2S)\mu^+X \sim 5 - 100$ times smaller than $B_c^+ \to J/\psi\mu^+\nu$.
  - Compare J/ψ + track sample to $B_c^+ \to \psi(2S)\mu^+X$ sample.
  - Test of heavy flavor background.



B_c Consistency Checks

- Simple counting experiment.
  - Normalize background sample to events with $T > 2$.
  - See excess consistent with B_c signal.
- Fit w/o signal $\rightarrow$ Δ(log-likelihood) = 60 for 5 degrees of freedom.



Systematic Studies

Source	Mass (GeV/c^2)	Lifetime (ps)	# Signal
Limited background statistics	0.06	0.013	3.0
Fraction non-resonant $B_c^+ \to J/\psi\mu^+\pi^0\nu$	0.14	0.022	6.7
Feed-down fraction from $B_c^+ \to J/\psi(2S)\mu^+\nu$	0.08	0.017	5.4
MC signal modeling: phase space vs. ISGW	0.16	0.023	4.4
MC signal modeling: HQET vs. ISGW	0.06	0.007	1.8
B_c p_T spectrum	0.05	0.004	0.8
Momentum binning	0.14	0.062	0.4
Alignment and primary vertexing algorithm	0.08	0.085	3.1
Vertex algorithm selection criteria	0.06	0.028	–
Prompt/heavy relative bkgd fraction	0.15	0.036	–
Total systematic error	0.34	0.121	10.7

B_c Result

- Events: $95 \pm 12 \pm 11$.
- Mass: $5.95^{+0.14}_{-0.13} \pm 0.34$ GeV/c^2.
- Lifetime: $0.448^{+0.123}_{-0.096} \pm 0.121$ ps.

First errors are statistical and second errors are systematic.

Summary

- D0 has made new observations of B^{**} and B_c mesons.
- First time separation of B_1 and B_2^* is observed.
- New results on B_c with significantly more statistics.
- Expect new and interesting discoveries in B mesons from the Tevatron.