Studies of Orbitally Excited $D_{(s)}^{**}$ and B^{**} Mesons at CDF and DØ

- Motivation
- TeVatron Detectors
- Results
- Conclusions
- Future Research

Jennifer Pursley
The Johns Hopkins University
on behalf of the CDF and DØ Collaborations

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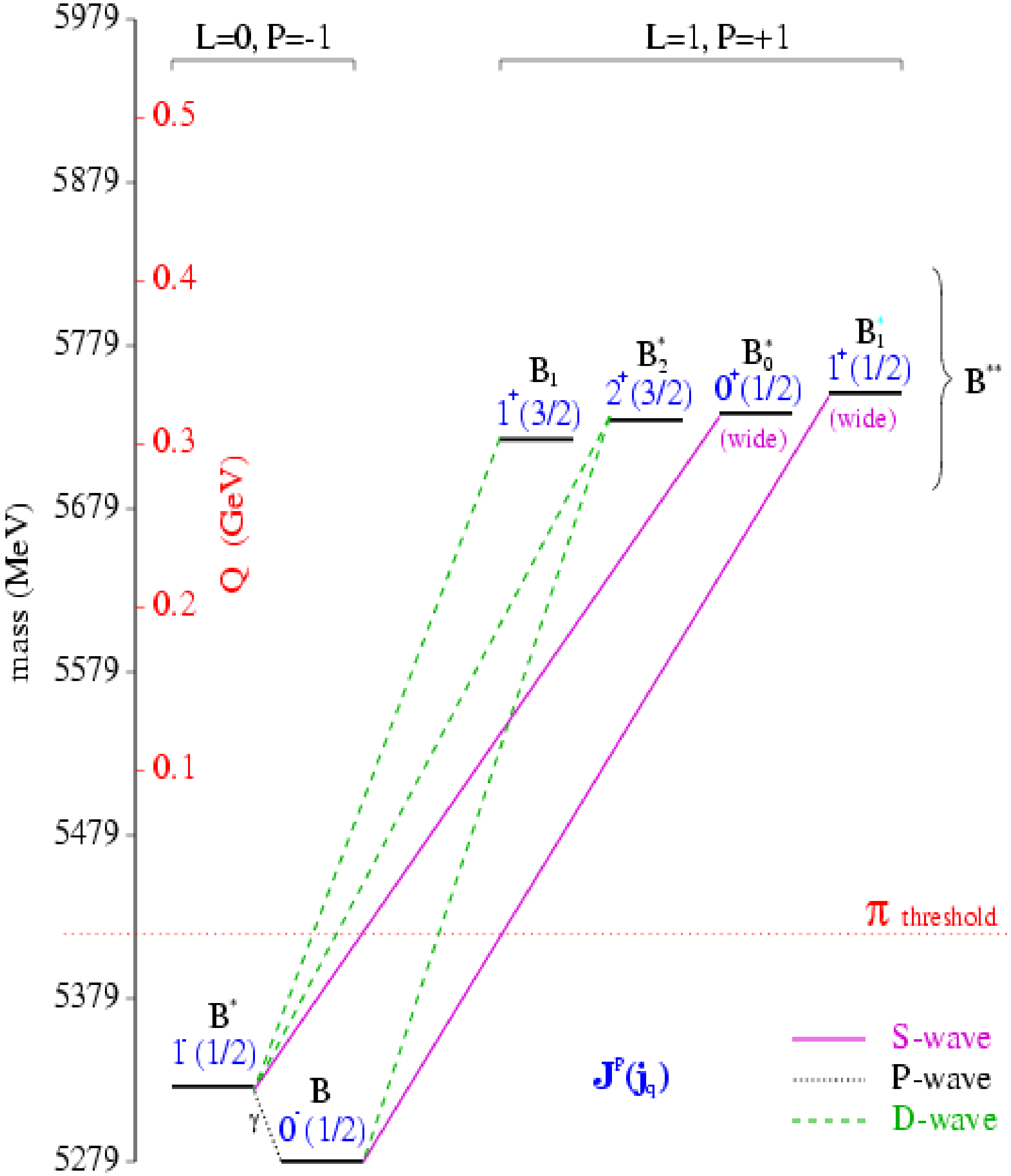
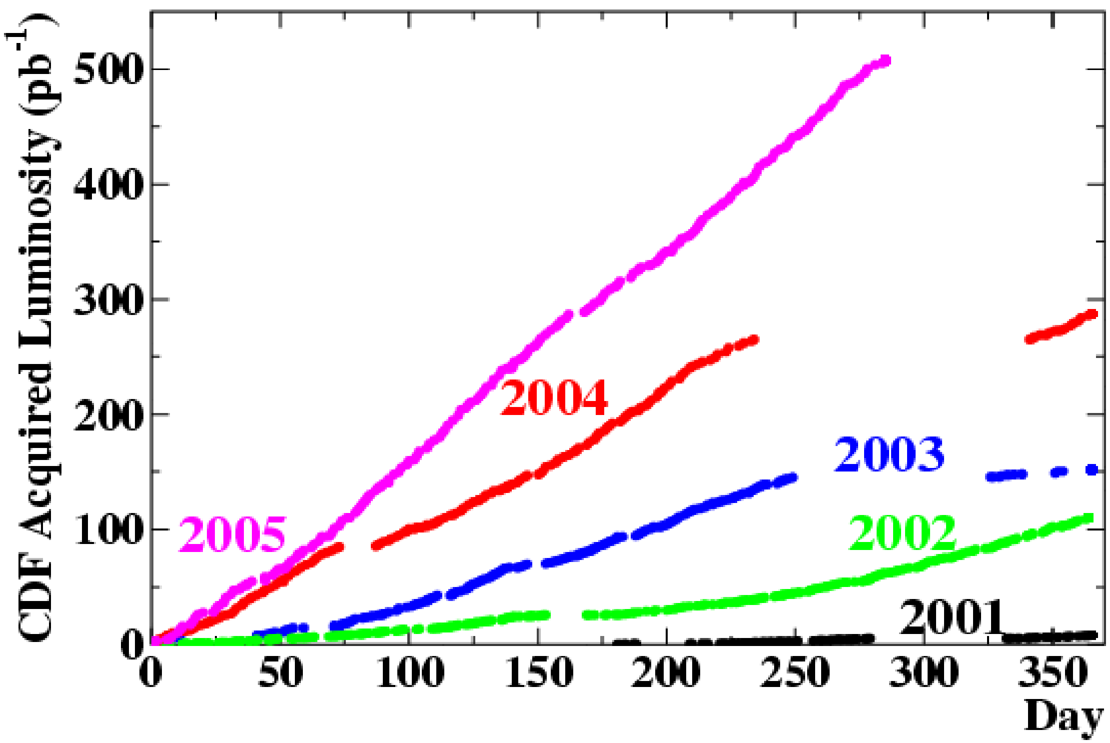
Motivation: HQET

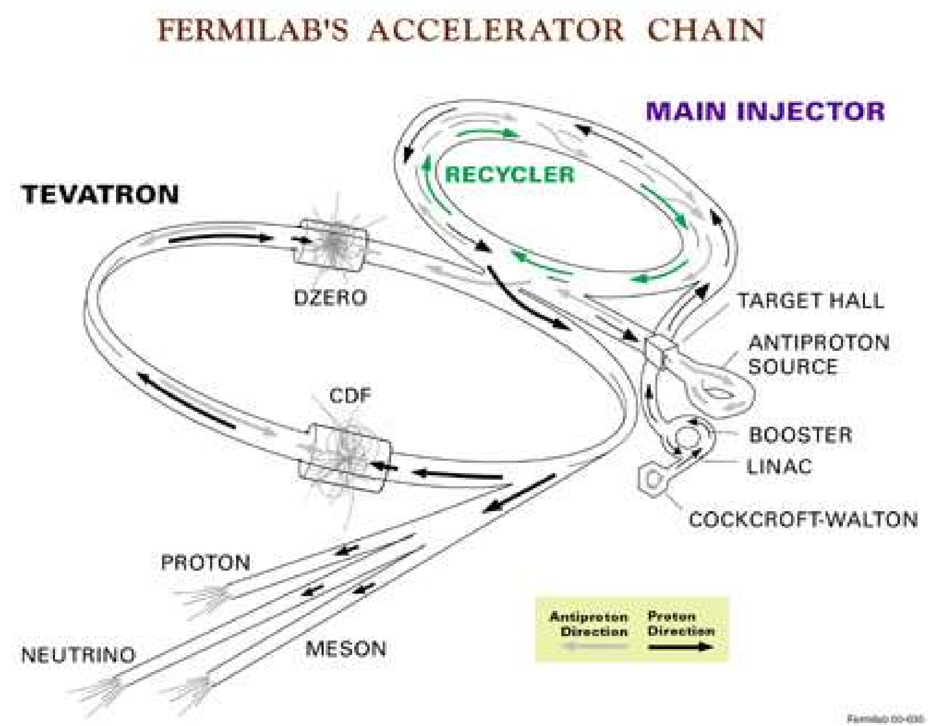


- Heavy-light bound state
- Heavy Quark Effective Theory
  - treat $m_{c(b)} \rightarrow \infty$ ($\gg \Lambda_{QCD}$)
  - precise predictions for mass, width, decay branching fractions
- $D_{(s)}^{**}$, B^{**} = first radial excitation of light quark (L = 1 states)
- Spectroscopy of these states not well studied
- Heavy excited states produced abundantly at TeVatron

TeVatron Performance

- $\sqrt{s}$ = 1.96 TeV $p\bar{p}$ collider
  - Performance consistently improving
  - World Record initial luminosity at a hadron collider 1.42×10^{32} $sec^{-1}cm^{-2}$ (Oct 4, 2005)
  - Expect 4 - 8 fb^{-1} by 2009

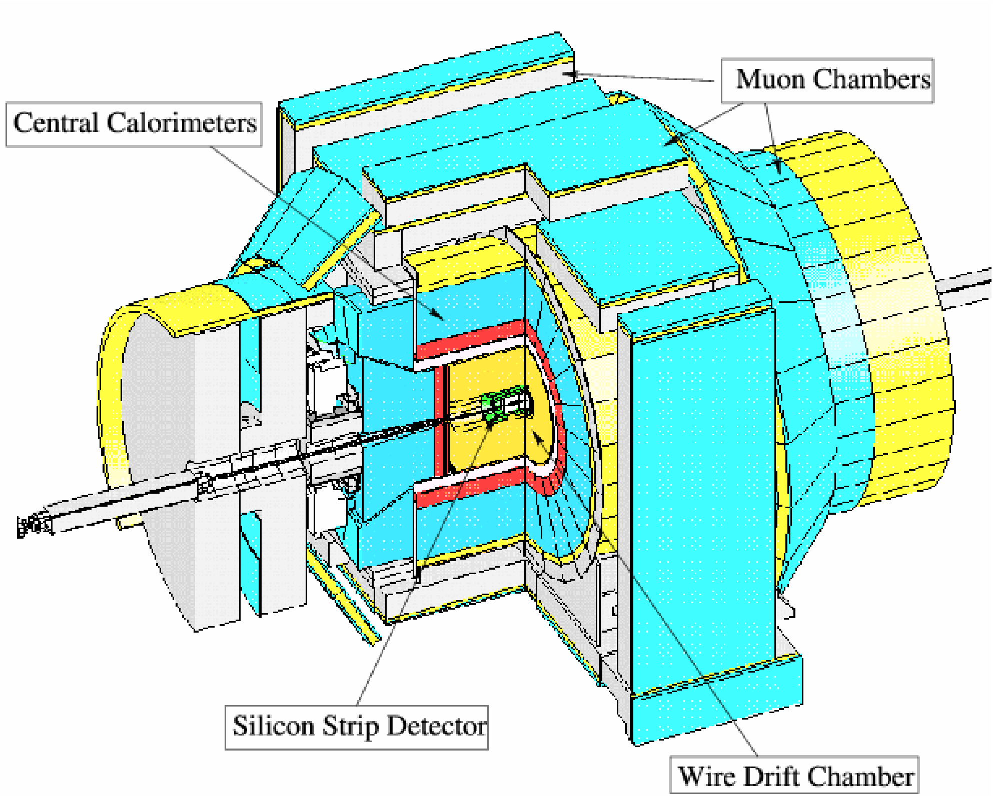


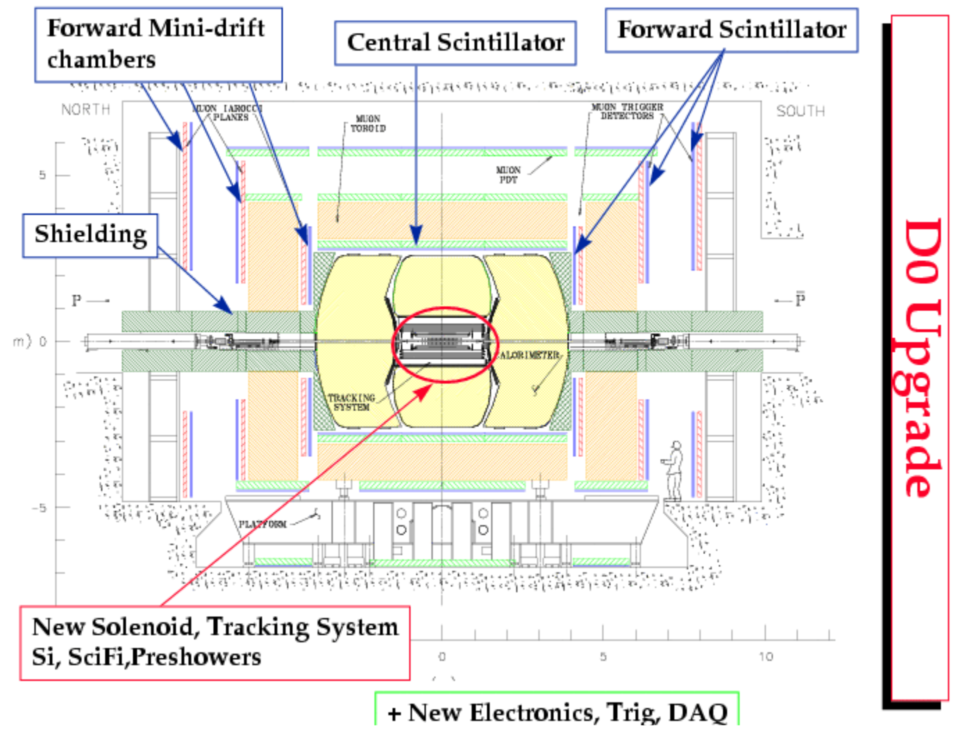


- Both experiments have ~ 1 fb^{-1} to tape
  - Results use 210 pb^{-1} (2003 shutdown) up to 490 pb^{-1} (2004 shutdown)
  - Results with new data out SOON

CDF and DØ Detectors

- CDF
  - Wire drift chamber
  - Silicon vertex trigger
- Triggered muon coverage |η| < 1.1

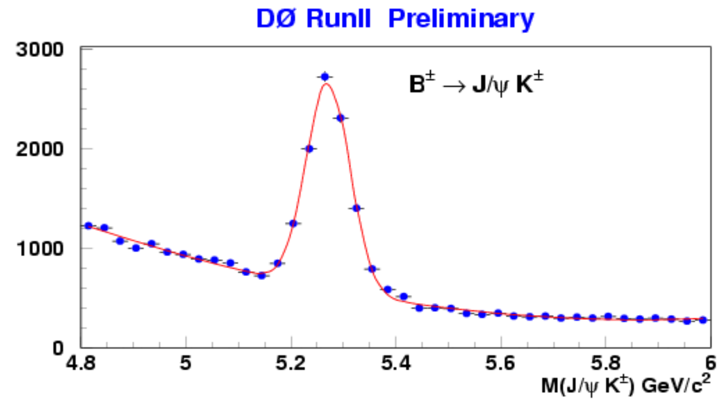


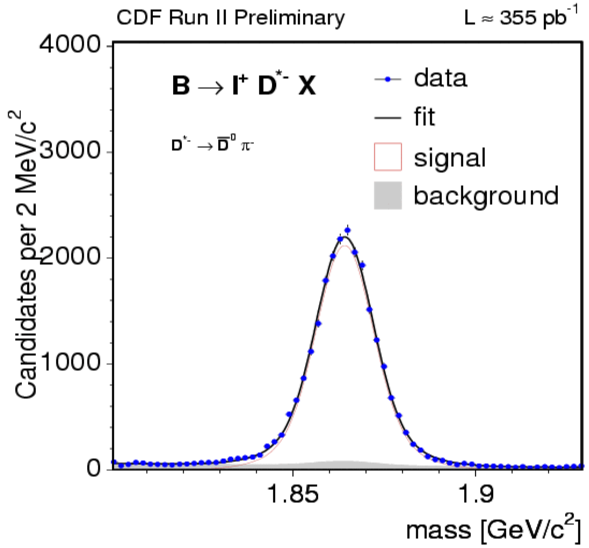


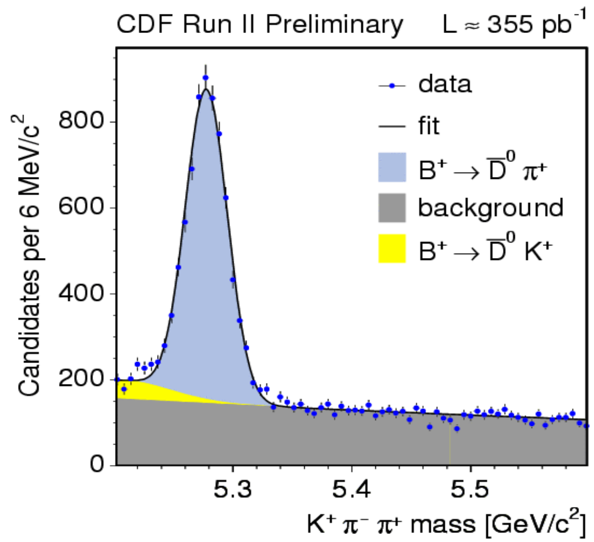
- DØ
  - Scintillating fiber tracker and silicon
  - Trigger tracking to |η| < 2
- Triggered muon coverage |η| < 2

Data Samples

- J/ψ samples:
  - Exclusive $B \to J/\psi\ K$ modes
  - Dimuon trigger
- Semileptonic $B \to D \ell \nu X$ samples:
  - DØ has larger muon acceptance
  - CDF lowers lepton trigger p_T by requiring additional displaced track
- Fully hadronic samples (CDF only):
  - Secondary vertex trigger
  - Fully reconstructed B events



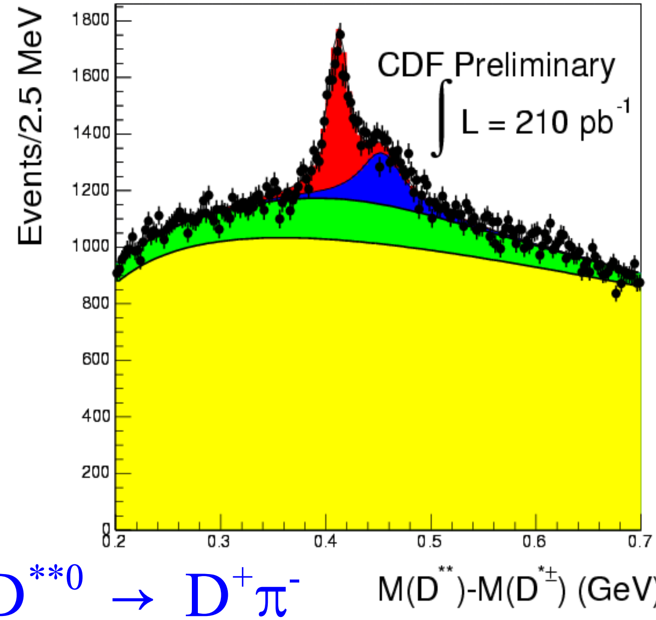




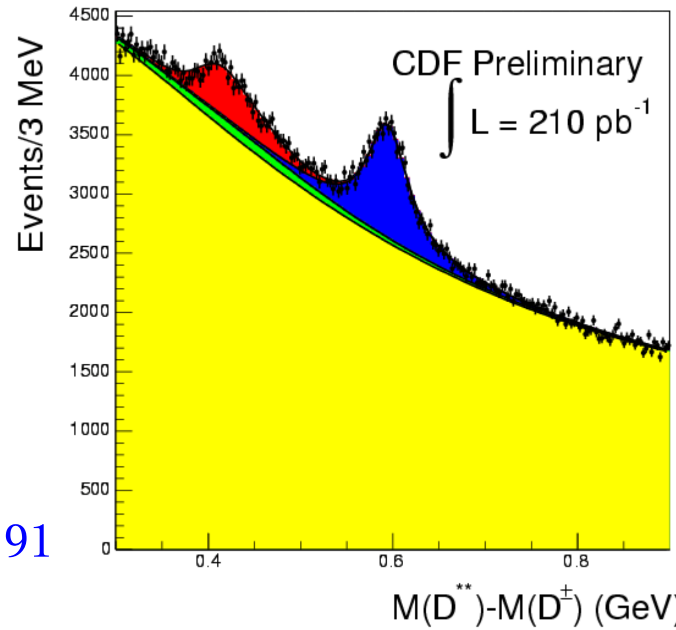
D^{**} narrow states: D_1^0 and D_2^{*0}

- CDF: 210 pb^{-1}
  - Two channels, $D^0 \to K^+\pi^-$ and $D^+ \to K^-\pi^+\pi^+$
    - $D^{**0} \to D^{*+}\pi^-$, $D^{*+} \to \pi^+ D^0$
    - $D^{**0} \to D^+\pi^-$ (also feed-down from $D^{*+} \to \pi^0 D^+$)
- Fit mass difference $M(D^{**0})$ - $M(D^{(*)+})$
- Best measurement!
  - **$M(D_1^0) = 2421.7 \pm 0.7 \pm 0.6$ MeV/c^2 (seen at Belle, $M(D_1^0) = 2427 \pm 26 \pm 25$ MeV/c^2)**
  - **$\Gamma(D_1^0) = 20.0 \pm 1.7 \pm 1.3$ MeV/c^2**
  - **$M(D_2^{*0}) = 2463.3 \pm 0.6 \pm 0.8$ MeV/c^2 (PDG average $M(D_2^{*0}) = 2461.1 \pm 1.6$ MeV/c^2)**
  - **$\Gamma(D_2^{*0}) = 49.2 \pm 2.3 \pm 1.3$ MeV/c^2**

$D^{**0} \to D^{*+}\pi^-$



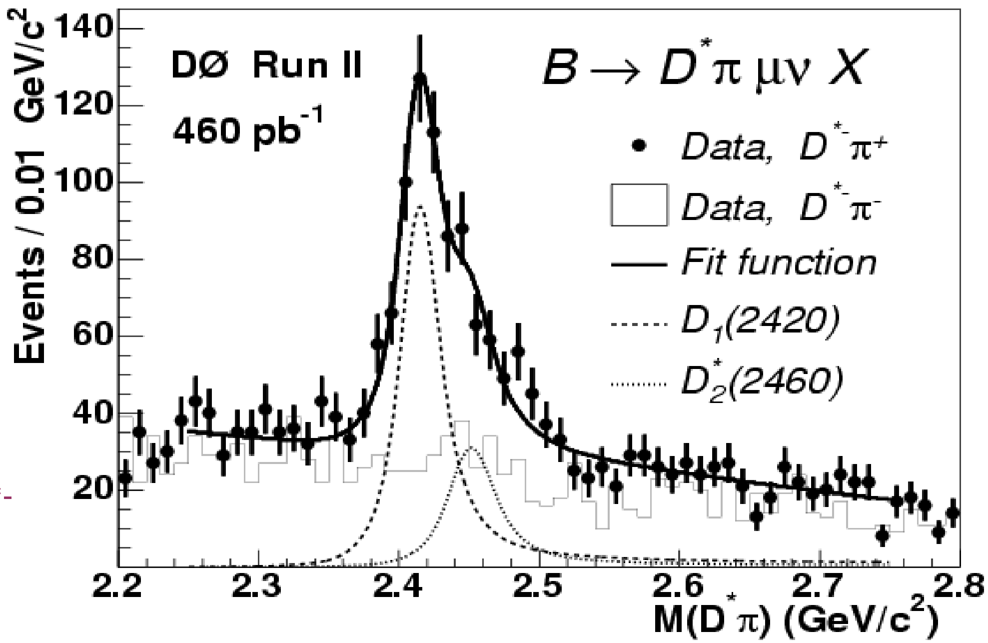
$D^{**0} \to D^+\pi^-$



CDF public note 7191

D^{**} narrow states cont.

- DØ: 460 pb^{-1}
- Semileptonic
  - $B \rightarrow D_1^0 \mu^+ \nu_\mu X$ and $B \rightarrow D_2^{*0} \mu^+ \nu_\mu X$
  - $B \rightarrow D^{*-} \pi^+ \mu^+ \nu_\mu X$:
    - find $\mu^+ D^0$
    - add soft track of opp. charge to D^0 for D^{*-}
    - Add π^+ to D^{*-} to reconstruct D^{**} decay



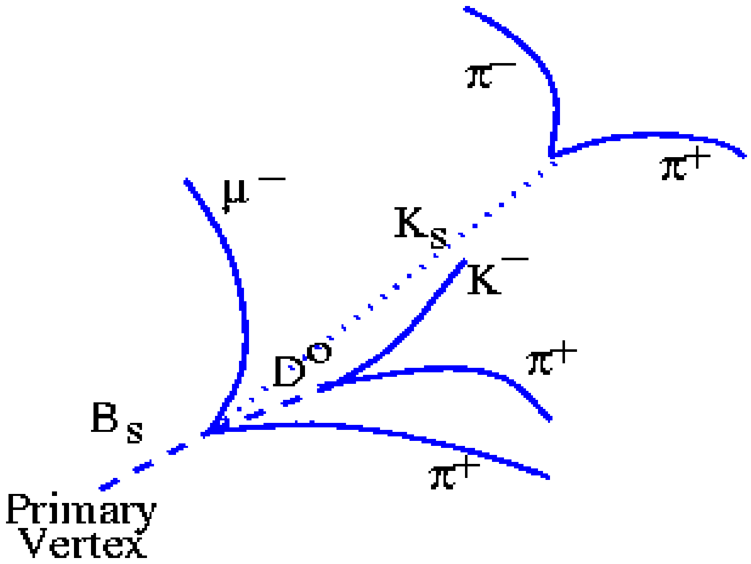
- Normalization to $ß(\bar{b} \rightarrow D^{*-} \ell^+ \nu X) = (2.75 \pm 0.19)\%$ (PDG avg.)
- Order of magnitude better than previous results!
  - $ß(\bar{b} \rightarrow B) \bullet ß(B \rightarrow (\bar{D}_1^0, \bar{D}_2^{*0}) \mu^+ \nu_\mu X) \bullet ß((\bar{D}_1^0, \bar{D}_2^{*0}) \rightarrow D^{*-} \pi^+) = (0.122 \pm 0.007 \pm 0.015)\%$
  - $ß(\bar{b} \rightarrow B) \bullet ß(B \rightarrow \bar{D}_1^0 \mu^+ \nu_\mu X) \bullet ß(\bar{D}_1^0 \rightarrow D^{*-} \pi^+) = (0.087 \pm 0.007 \pm 0.015)\%$
  - $ß(\bar{b} \rightarrow B) \bullet ß(B \rightarrow \bar{D}_2^{*0} \mu^+ \nu_\mu X) \bullet ß(\bar{D}_2^{*0} \rightarrow D^{*-} \pi^+) = (0.035 \pm 0.007 \pm 0.008)\%$
  - $$\frac{ß(B \rightarrow \bar{D}_2^{*0} \mu^+ \nu_\mu X) \bullet ß(\bar{D}_2^{*0} \rightarrow D^{*-} \pi^+)}{ß(B \rightarrow \bar{D}_1^0 \mu^+ \nu_\mu X) \bullet ß(\bar{D}_1^0 \rightarrow D^{*-} \pi^+)} = 0.39 + 0.09 + 0.12$$

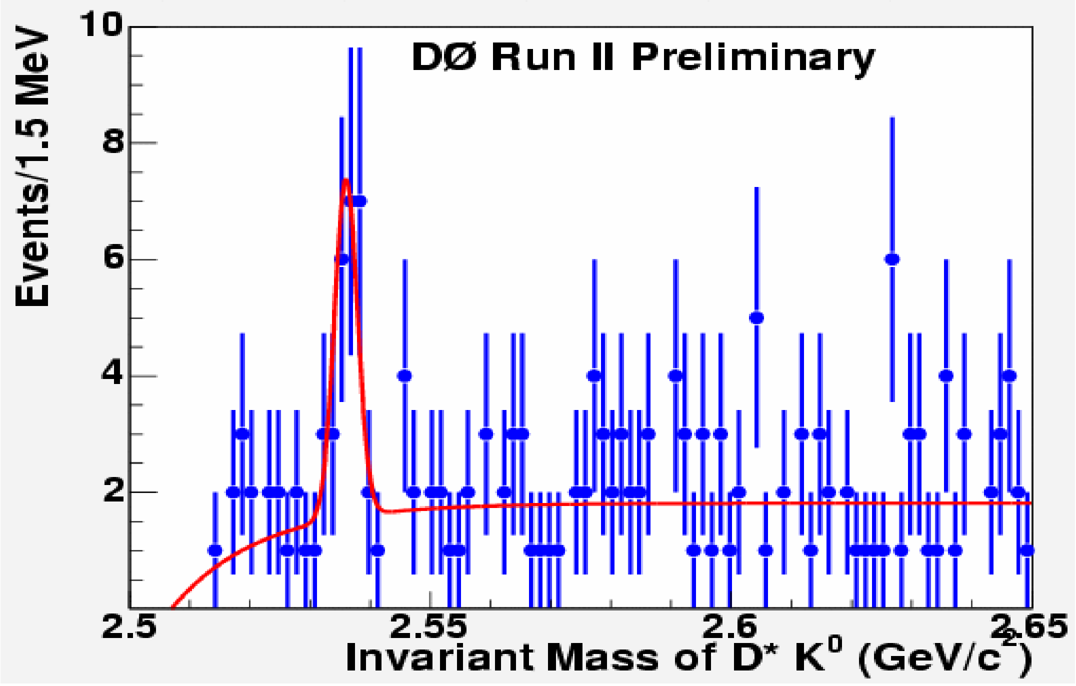
DØ PRL 95 171803 (2005)

First Evidence of $B_s \to D_{s1}^{+}\mu\nu X$

- DØ: 485 pb^{-1}
- Complex 6 track final state:

$B_s^0 \to D_{s1}^+(2536)\mu^-\nu_\mu X$
→ $D^{*+}K_s^0$
→ $\pi^+\pi^-$
→ $D^0\pi^+$
→ $K^-\pi^+$



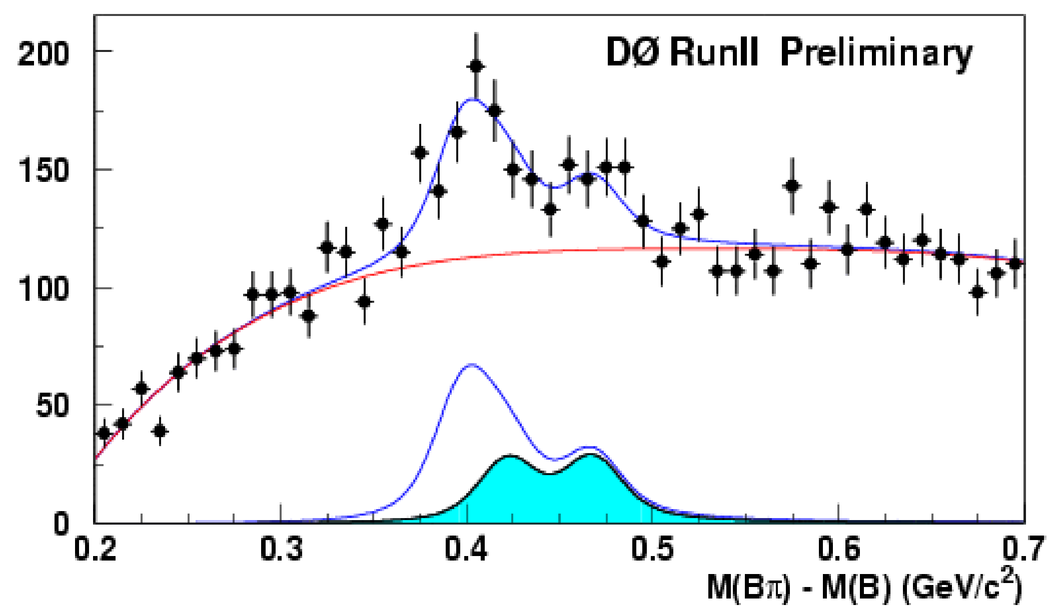


- > 3.0 sigma significance
- Ability to measure production and properties of D_{s1}^{+}
- Observe $D_{s2}^{*+}(2573)$ with more data?

DØ conf note 4727

B^{**} narrow states: B_1 and B_2^*

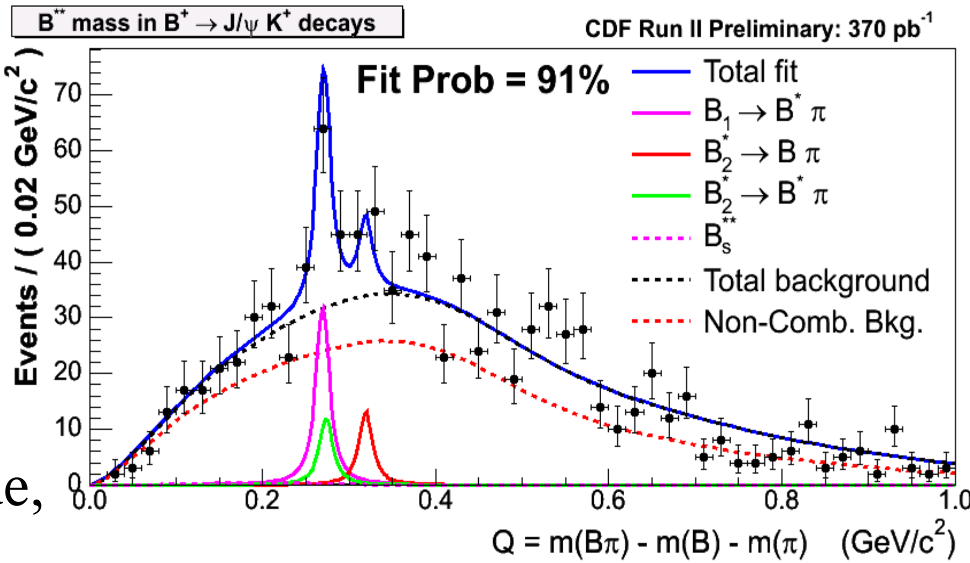
- DØ: 350 pb^{-1}
- Reconstruct $B^{**} \to B^{(*)}\pi^-$ in three decay modes:
  - $B^+ \to J/\psi\ K^+$ and $B^0 \to J/\psi\ K^{*0}$ and $B^0 \to J/\psi\ K_s$
- Add events from all three modes, fit mass difference $M(B\pi) - M(B)$
- Fix $\Gamma(B_1) = \Gamma(B_2^*)$ (theoretical expectation), allow width to float in fit
- Fix $\frac{\beta(B_2^* \to B\pi)}{\beta(B_2^* \to B^*\pi)} = 1.0$ (theoretical expectation)
- First observation of separate peaks at a hadron collider; only narrow width measurement!
  - **$M(B_1) = 5724 \pm 4 \pm 7$ MeV/c^2**
  - **$M(B_2^*) - M(B_1) = 23.6 \pm 7.7 \pm 3.9$ MeV/c^2**
  - **$\Gamma(B_1) = \Gamma(B_2^*) = 23 \pm 12 \pm 9$ MeV/c^2**

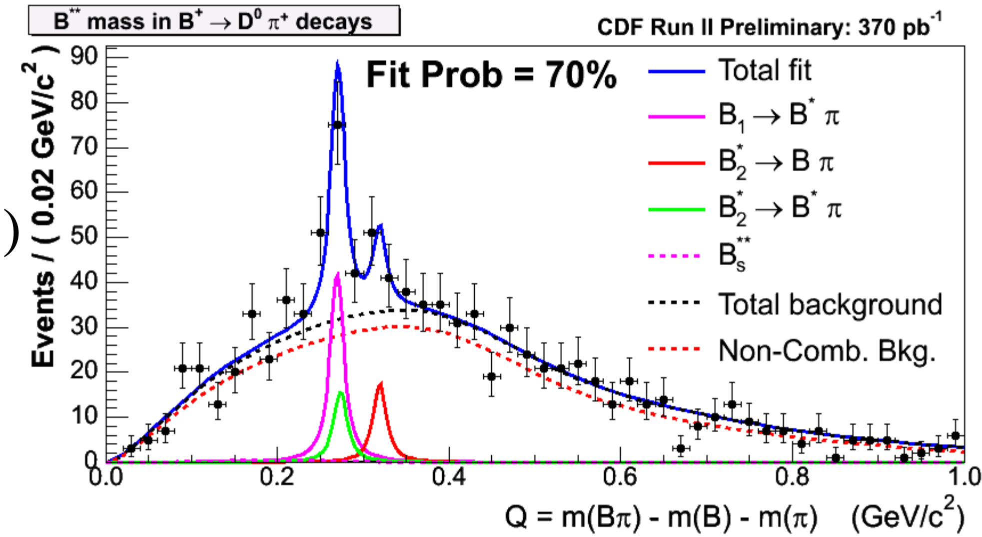


DØ conf note 4517

B^{**0} narrow states cont.

- CDF: 370 pb^{-1}
- $B^{**0} \rightarrow B^{(*)+}\pi^-$ in two decay modes:
  - $B^+ \rightarrow J/\psi\, K^+$ and $B^+ \rightarrow D^0\pi^+$
- Fit $M(B\pi) - M(B) - M(\pi)$ simultaneously for both modes
- Low statistics → fix width to theoretical value, $\Gamma(B_2^{*0}) = 16 \pm 6$ MeV/c² (hep-ph/9507311)
  - Fix $\Gamma(B_1^0) = \Gamma(B_2^{*0})$
- Fix $\dfrac{\mathcal{B}(B_2^{*0} \rightarrow B\pi)}{\mathcal{B}(B_2^{*0} \rightarrow B^*\pi)} = 1.1 \pm 0.3$ (DELPHI 2004-025 CONF 700)
- Best measurement!
  - $M(B_1^0) = 5734 \pm 3 \pm 2$ MeV/c²
  - $M(B_2^{*0}) = 5738 \pm 5 \pm 1$ MeV/c²





CDF and DØ results agree within errors; differences look like statistical fluctuations

Conclusions

Exp	Comment	D_1^0 mass (MeV/c²)	D_1^0 width (MeV/c²)
BELLE	$B^- \to D^{*+}\pi^-\pi^-$	$2427 \pm 26 \pm 25$	$384^{+107}_{-75} \pm 74$
CDF	$p\bar{p}$ at 1.96 TeV	$2421.7 \pm 0.7 \pm 0.6$	$20.0 \pm 1.7 \pm 1.3$

Exp	Comment	D_2^{*0} mass (MeV/c²)	D_2^{*0} width (MeV/c²)
BELLE	$B^- \to D^+\pi^-\pi^-$	$2461.6 \pm 2.1 \pm 3.3$	$45.6 \pm 4.4 \pm 6.7$
CLEO2	$e^+e^- \to D^+\pi^-X$	$2465 \pm 3 \pm 3$	$28^{+8}_{-7} \pm 6$
E687	$\gamma Be \to D^+\pi^-X$	$2453 \pm 3 \pm 2$	$25 \pm 10 \pm 5$
CDF	$p\bar{p}$ at 1.96 TeV	$2463.3 \pm 0.6 \pm 0.8$	$49.2 \pm 2.3 \pm 1.3$

Exp	Comment	B_j^* mass (MeV/c²)	B_j^* width (MeV/c²)
CDF I	$p\bar{p}$ at 1.8 TeV	5710 ± 20	
DELPHI	$E_{cm}^{ee} = 88\text{-}94$ GeV	$5732 \pm 5 \pm 20$	145 ± 28
OPAL	$E_{cm}^{ee} = 88\text{-}94$ GeV	5681 ± 11	116 ± 24

Exp	Comment	B_1^0 mass (MeV/c²)	B_1^0 width (MeV/c²)
DELHPI	$e^+e^- \to Z$	5732 ± 20	
DØ	$p\bar{p}$ at 1.96 TeV	$5724 \pm 4 \pm 7$	$23 \pm 12 \pm 9$
CDF	$p\bar{p}$ at 1.96 TeV	$5734 \pm 3 \pm 2$	

Exp	Comment	B_2^{*0} mass (MeV/c²)
DELHPI	$e^+e^- \to Z$	5738 ± 14
CDF	$p\bar{p}$ at 1.96 TeV	$5738 \pm 5 \pm 1$

- Best D^{**} narrow mass and width measurements
- Best D^{**} narrow semi-leptonic branching ratio measurement
- First observation of $B_s \to D_{s1}^+\mu\nu X$
- Best measurement of B^{**} narrow masses
- Best (only!) measurement of B^{**} narrow width

Future Research

- Measurements are statistically limited
  - **More data being processed**
- Results are interesting and competitive
  - DØ semileptonic branching fractions order of magnitude better than previous measurements
  - CDF B^{**} mass measurement the best so far
- New analyses (*eg* B_s^{**} search) also underway
- **All test different models of HQET**

Stay tuned for more results from the TeVatron!

Backup Slides

Compare CDF/DØ B^{**} Result

- CDF: $M(B_2^*) - M(B_1) \sim 4$ MeV/c^2, DØ: $M(B_2^*) - M(B_1) \sim 24$ MeV/c^2
- Agrees within errors, but why the discrepancy?
  - Similar B decay channels ($B^+ \to J/\psi K^+$)
  - Tighter cuts for B^{**}pion in CDF: π in a cone around B, B isolation cut
  - Similar signal structure:
    - CDF non-rel. Breit-Wigner, DØ rel. Breit-Wigner
    - CDF width fixed, DØ width floats
    - $ß(B_2^* \to B\pi)/ß(B_2^* \to B^*\pi) = 1.1$ for CDF, 1.0 for DØ
  - Different background parameterizations
    - CDF: use B sidebands to separate combinatorial bkg
    - DØ: fit all bkg together
  - Evaluated same systematic errors (including one for bkg parameterization)
- Conclusion: statistical fluctuation, need more data