Studies of B States at the Tevatron

Les Rencontres de Physique
de la Vallée d'Aoste

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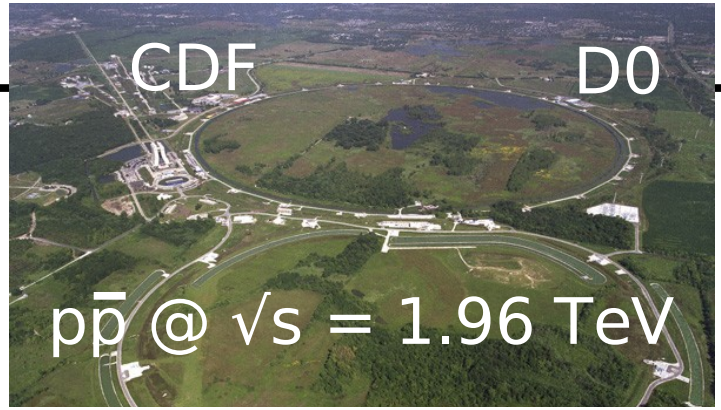
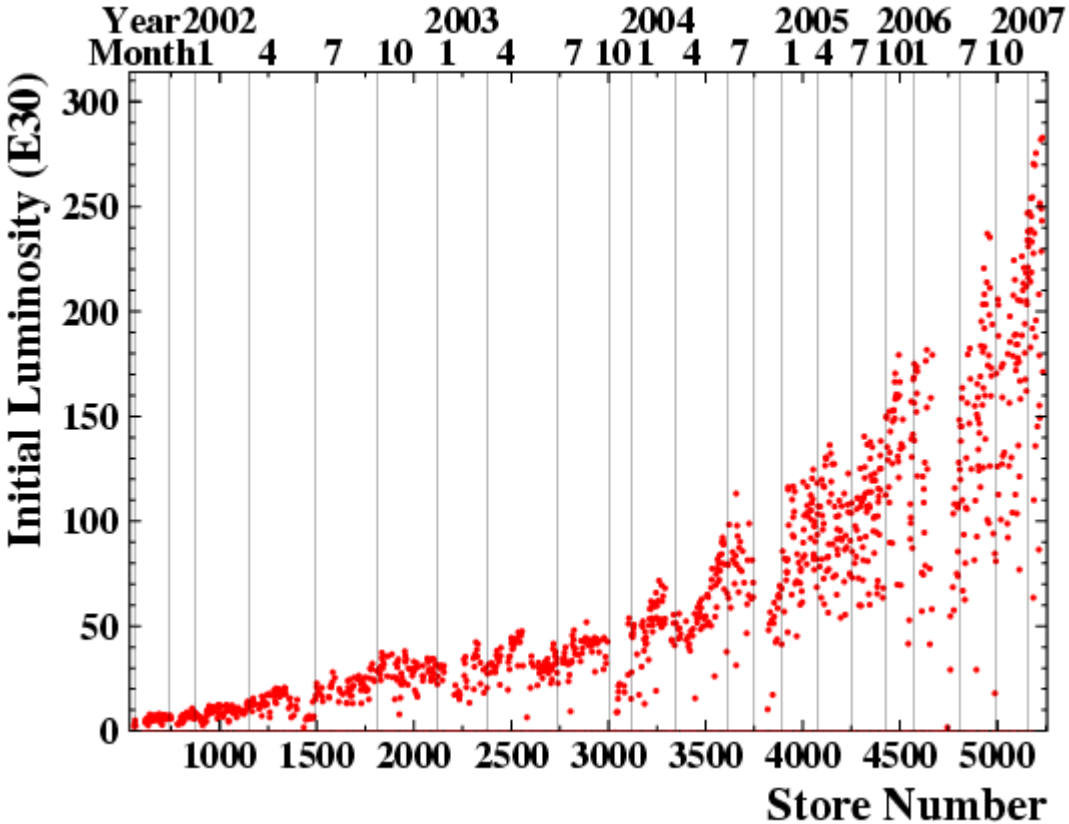
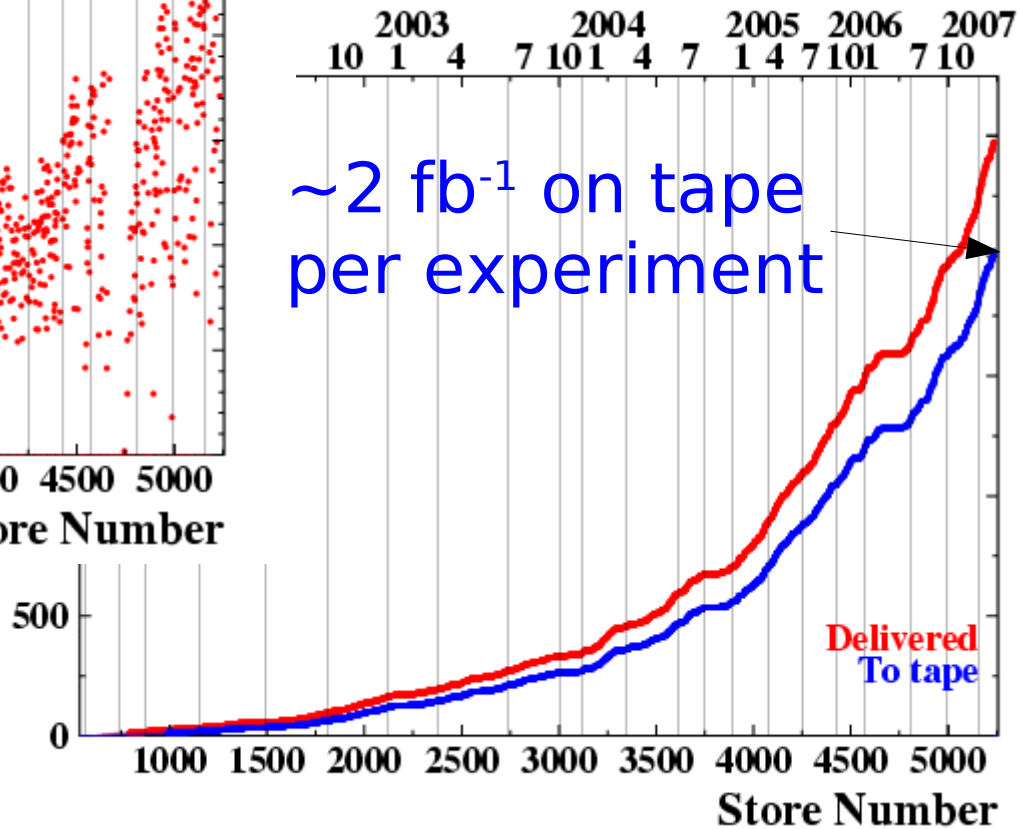
on behalf of the CDF and D0 collaborations

The Tevatron





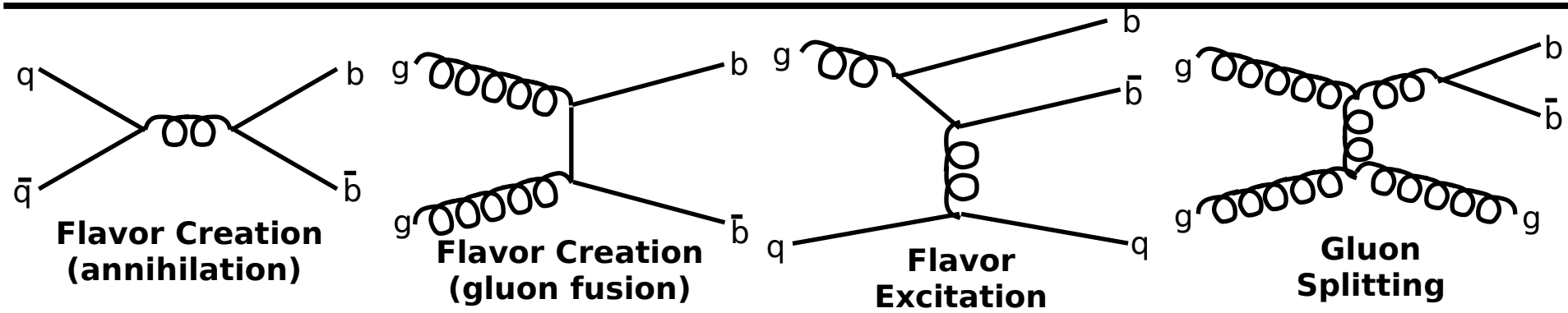


~2 fb^{-1} on tape per experiment

Record peak luminosities

→ very good performance

B states at the Tevatron



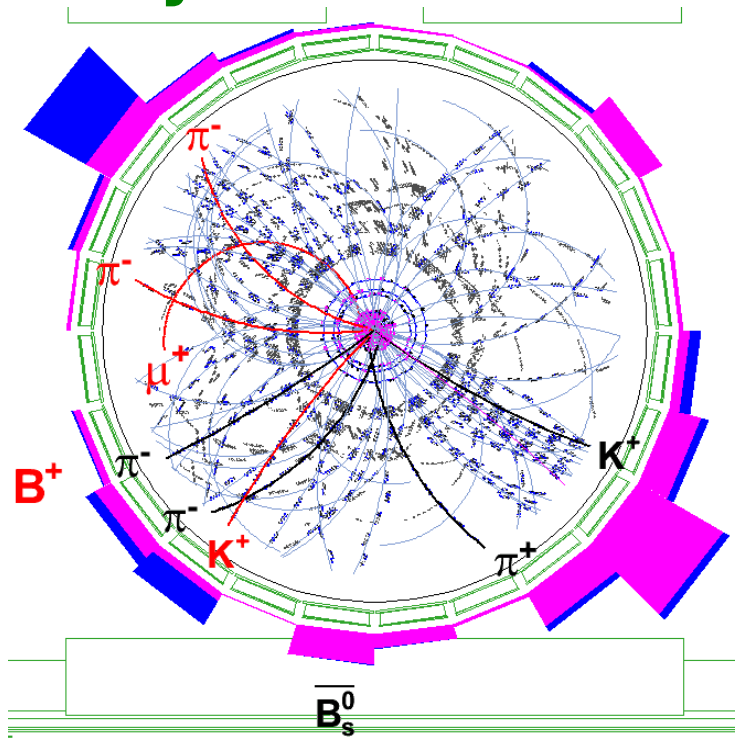
Tevatron is an excellent place to study B states:

➔ huge $b\bar{b}$ cross section

➔ production of all B hadron species

but

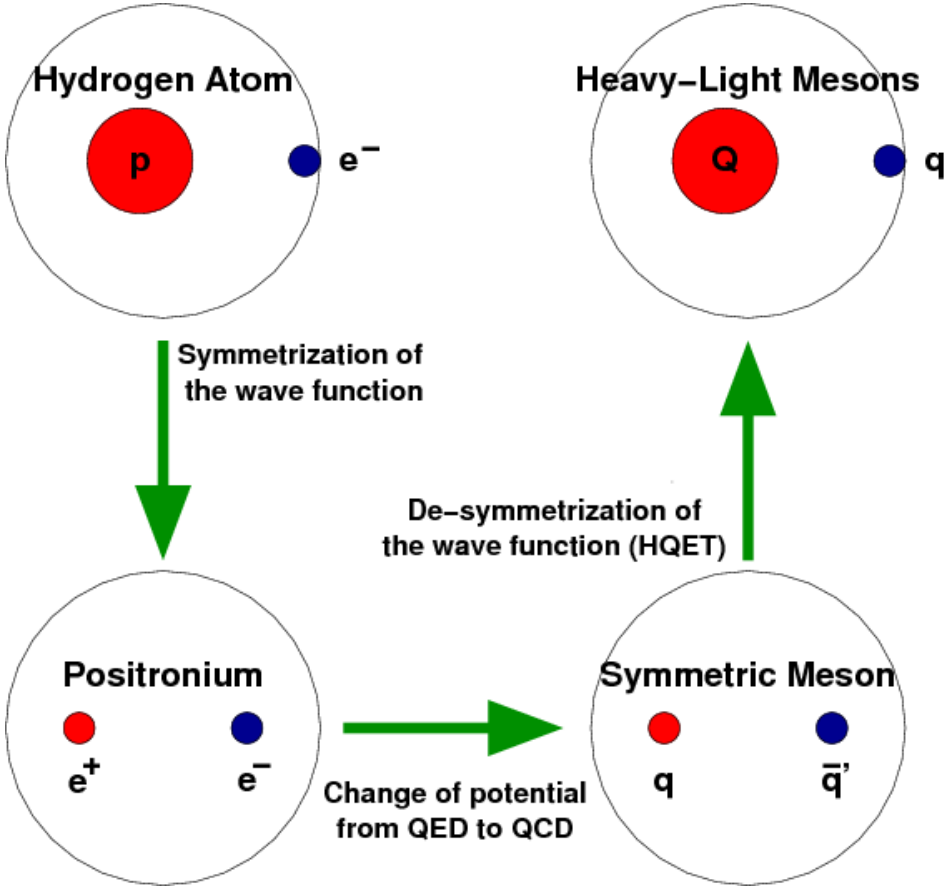
- ~10^3 times larger inelastic cross section
- soft $p_T(B)$ spectrum, limited η acceptance
- background tracks from frag.



Studies of B states

Study of B states = study of (non-perturbative) QCD

- Analogy: Heavy meson ↔ Hydrogen atom
  - Hydrogen spectroscopy ⇔ QED
  - B spectroscopy ⇔ QCD

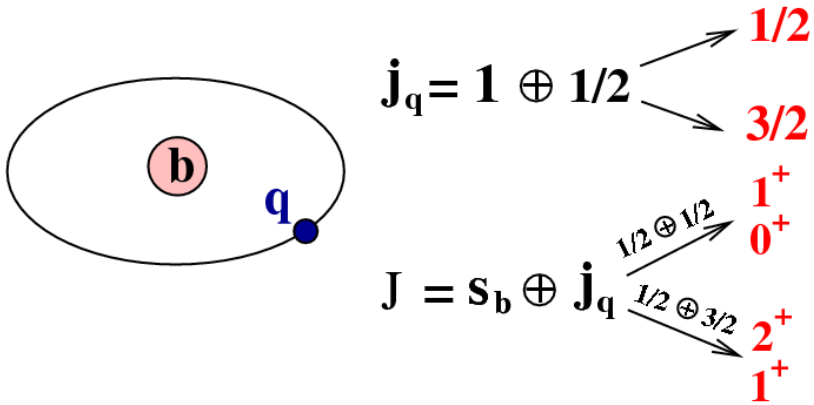


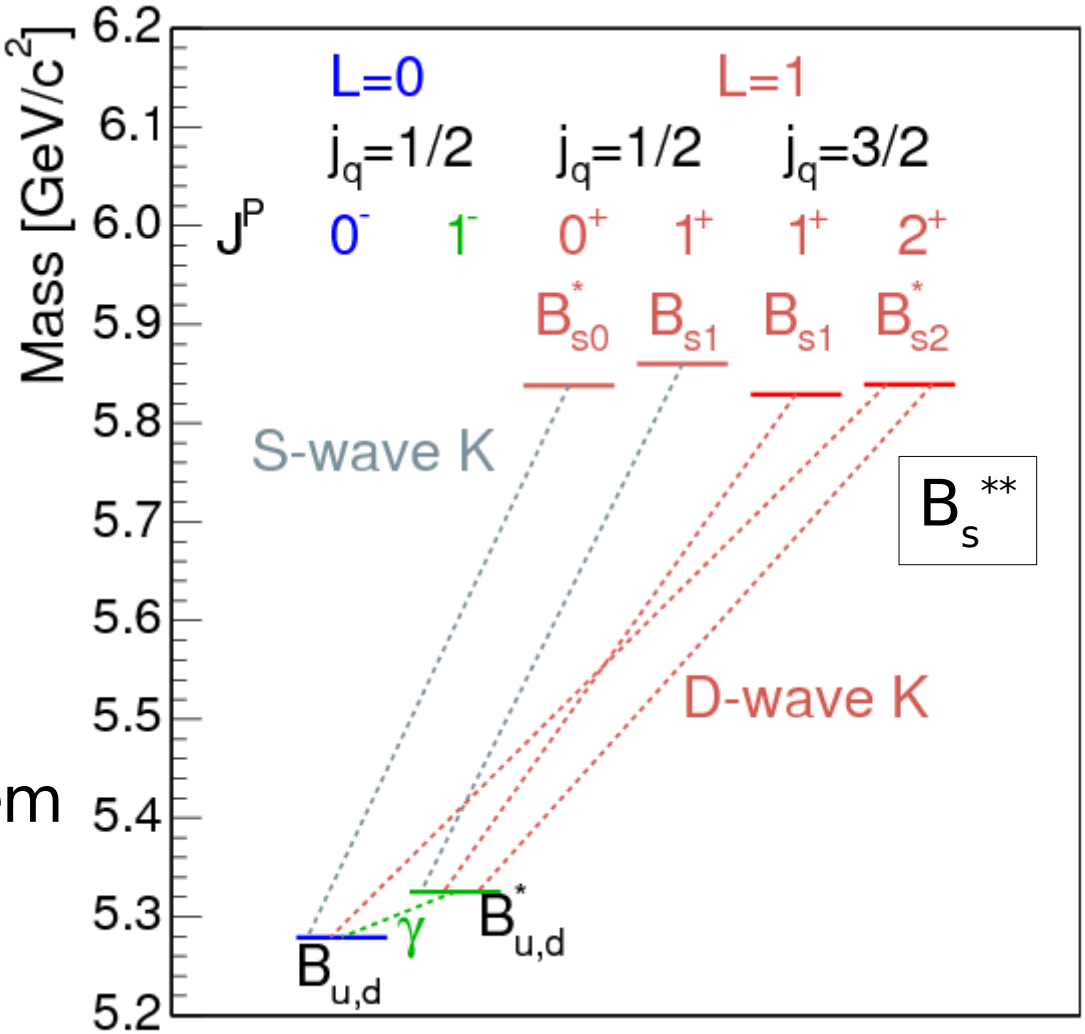
Heavy quark effective theory (HQET):

- In the limit $m_b \to \infty$: light quark in static QCD field of b quark

Orbitally excited (L=1) B mesons (B^{**}, B_J)

HQET:
spins of quarks decouple





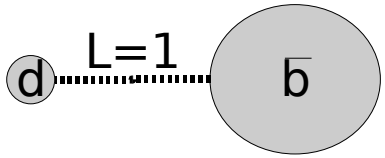
- j_q =1/2 states are broad

→ don't expect to observe them

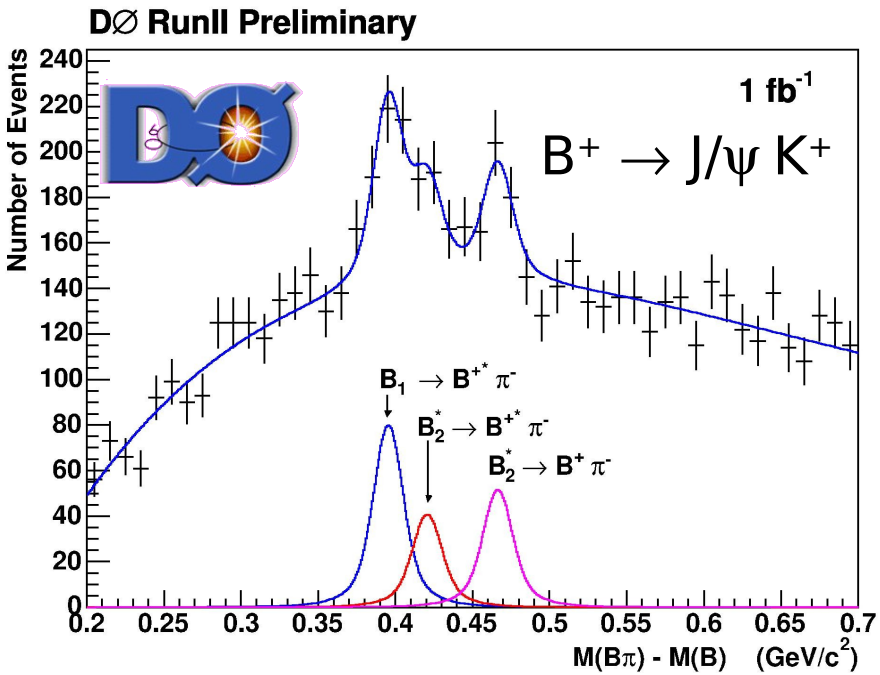
- j_q= 3/2 states are narrow

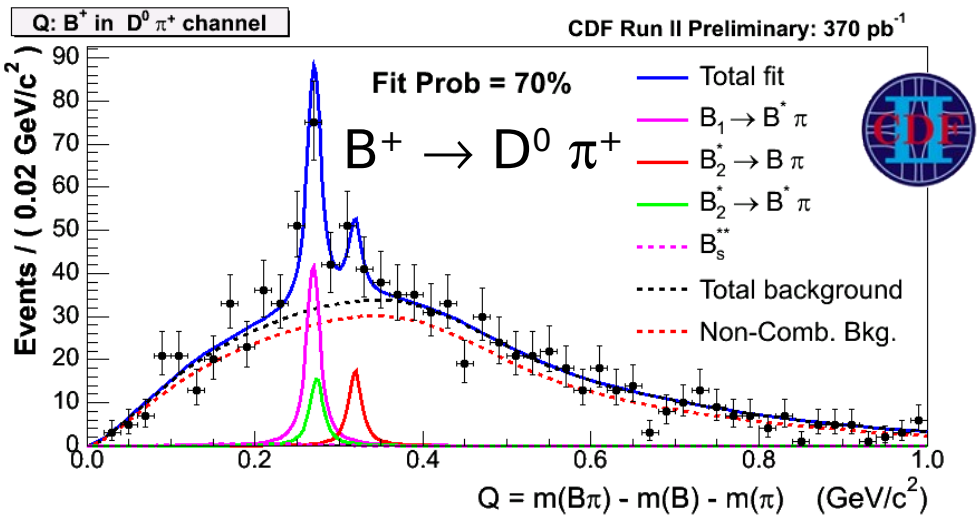
→ expect 3 peaks

B^{**}



$B^{**} \to B^{(*)+} \pi^-$, $B^{*+} \to B^+ \gamma$ (γ undetected)



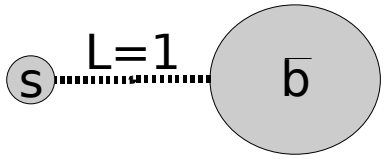


($B^+ \to J/\psi K^+$ not shown)

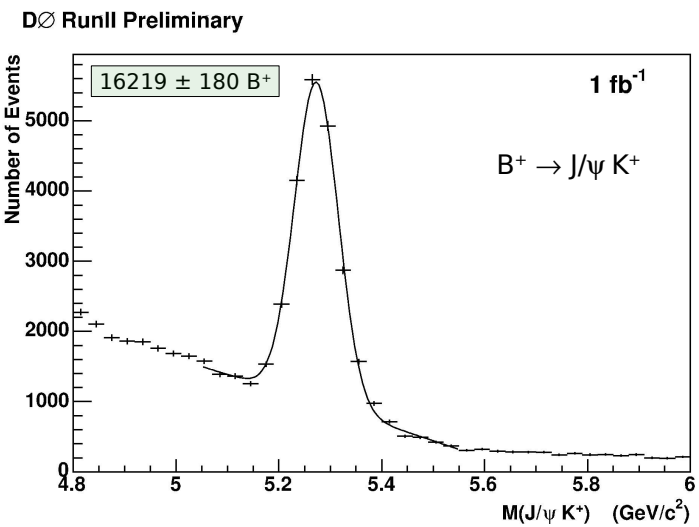
	D0 (1 fb^{-1})	CDF (370 pb^{-1})
$m(B_1)$ [MeV/c^2]	5720.8 ± 2.5 ± 1.1	5734 ± 3 ± 2
$m(B_2^*)-m(B_1)$ [MeV/c^2]	25.2 ± 3.0 ± 1.1	4 ± 6 ± 2

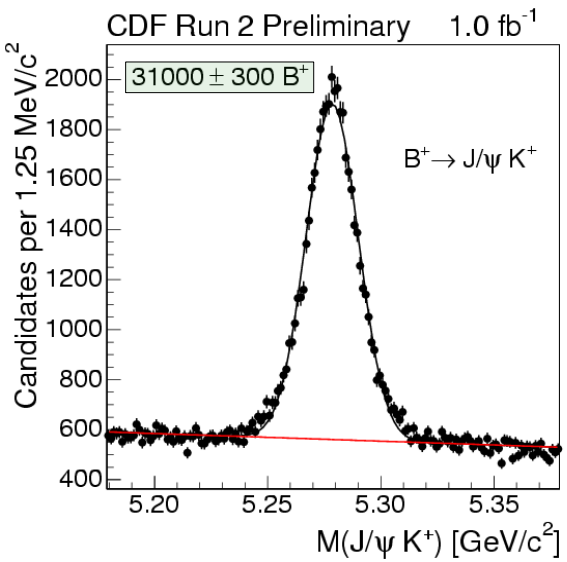
Update to 1 fb^{-1} coming soon

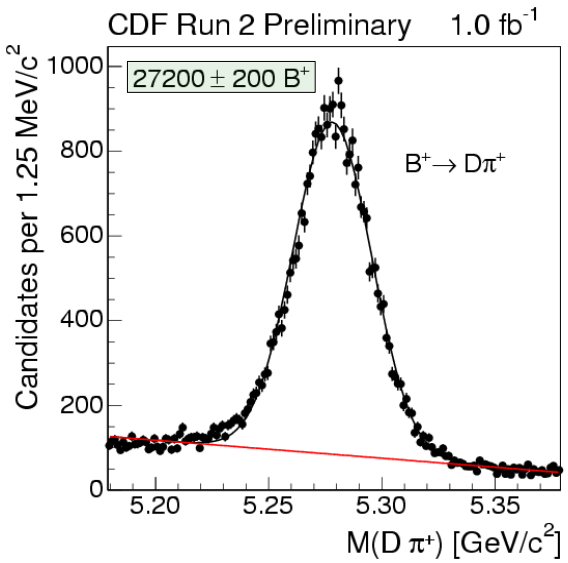
B_s^{**}



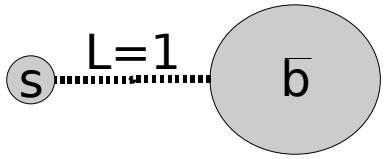
- Decay $B_s^{**} \to B_s\,\pi$ not allowed by isospin conservation
- Reconstruct $B_s^{**} \to B^{(*)+}\,K^-$, $B^{*+} \to B^+\,\gamma$ (γ undetected)
  $B^+ \to J/\psi\,K^+$ (D0, CDF), $B^+ \to D^0\,\pi^+$ (CDF)



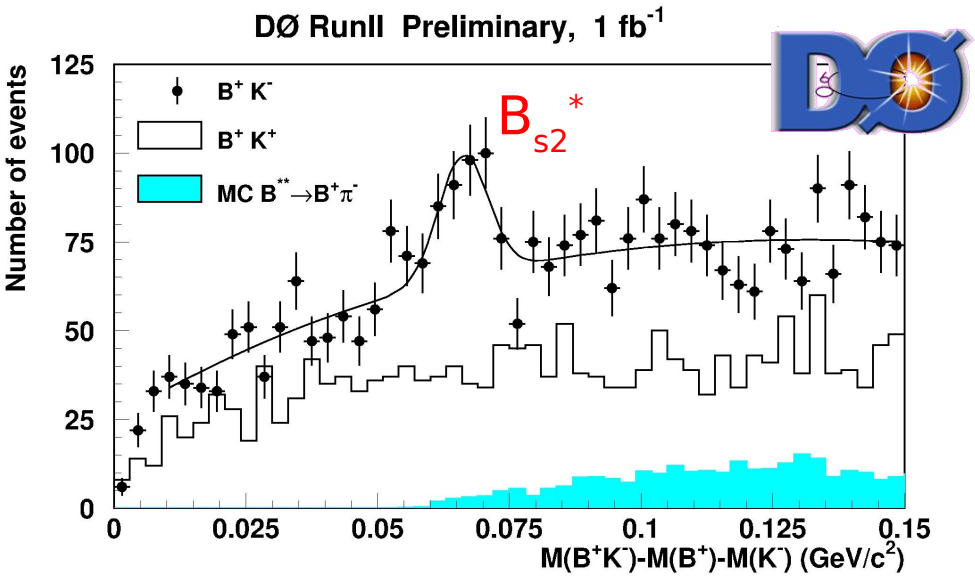




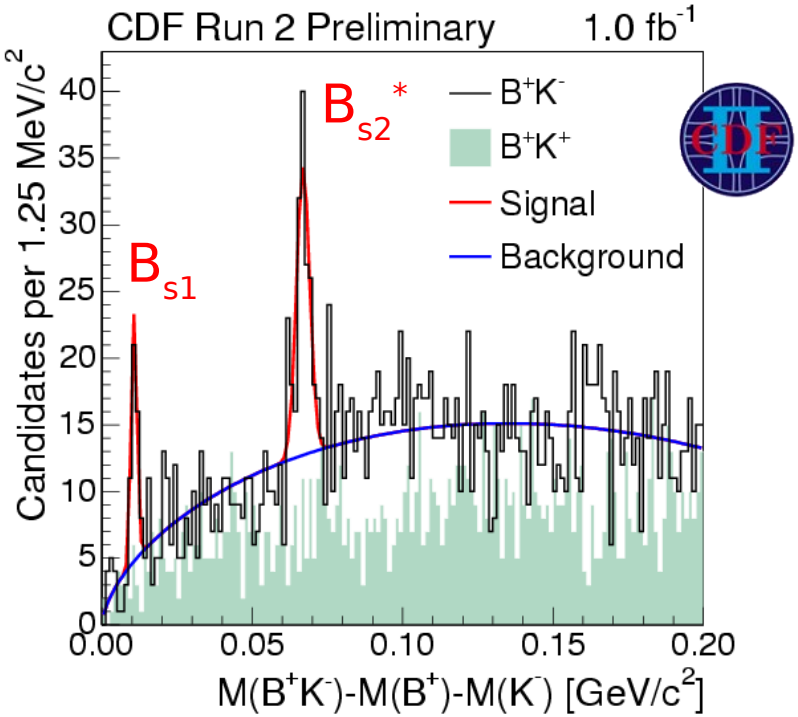
B_s^{**}



First direct observation of B_{s2}^*

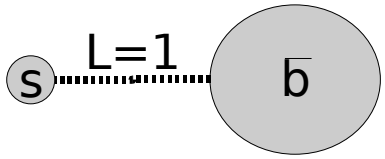


First observation of B_{s1}

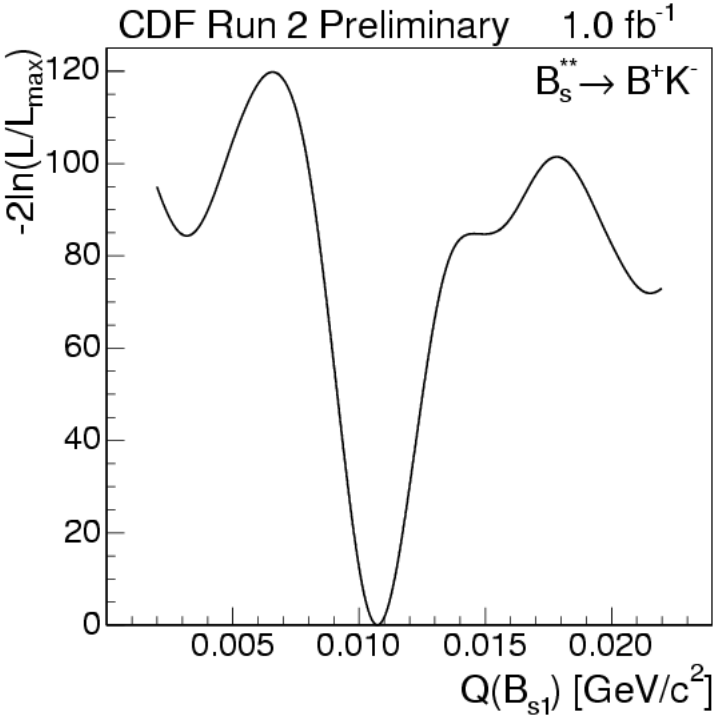


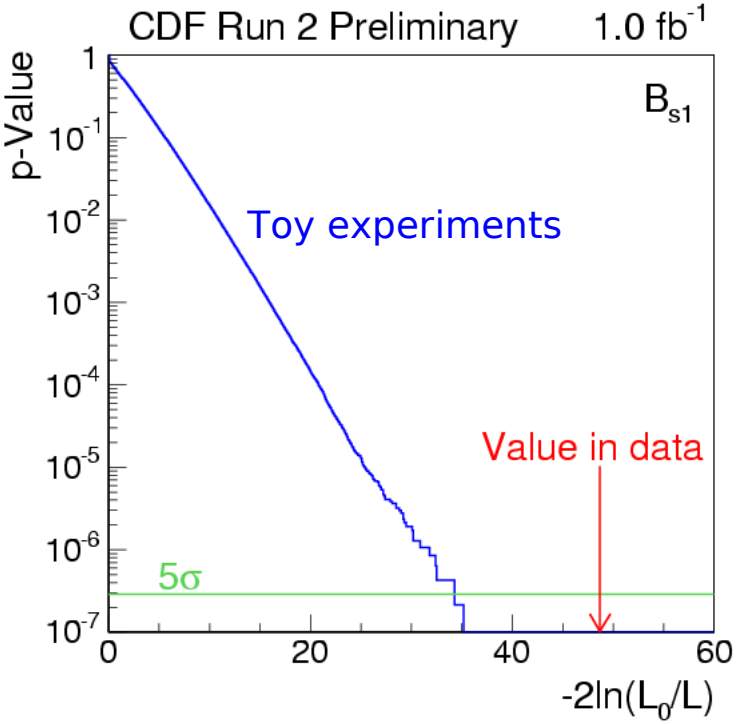
$m(B_{s2}^*)$ [MeV/c^2]	5839.1 ± 1.4 ± 1.5	D0
	5839.64 ± 0.30 ± 0.14 ± 0.5 (PDG)	CDF
$m(B_{s1})$ [MeV/c^2]	5829.41 ± 0.21 ± 0.14 ± 0.6 (PDG)	CDF

B_{s1} Significance

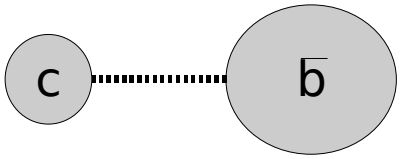


- $N(B_{s1}) = 36.4 \pm 9.0$
- $-2 \ln L_0/L \approx \chi^2 \rightarrow$ significance = 6.3 σ
- Toy experiments: p-value < 2×10^{-7} (5σ)





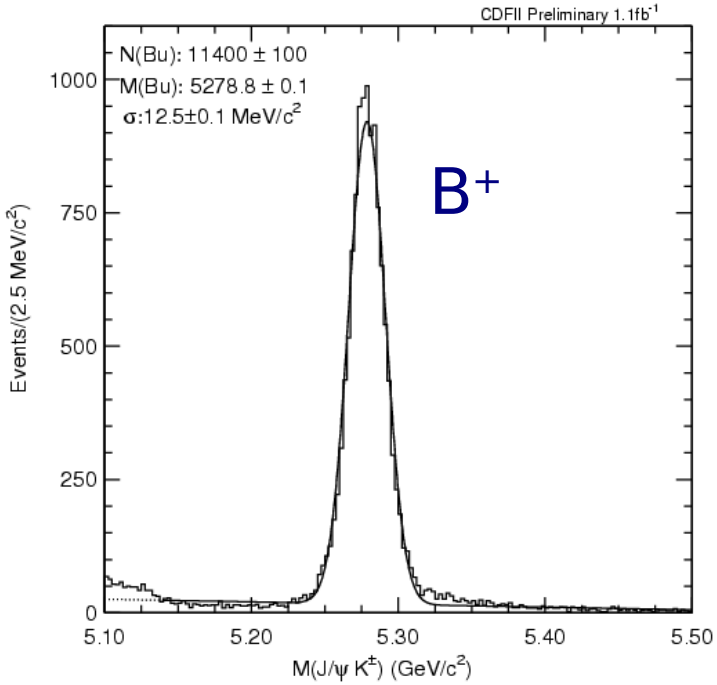
B_c



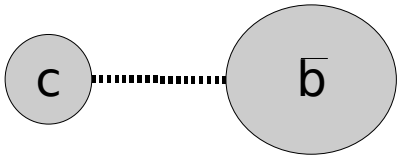
- Two distinct heavy quarks, weak decay
- Experimentally challenging because of low production rate $f(b \to B_c) \sim 0.05$ %
- Observed and lifetime measured by D0 and CDF in $B_c \to J/\psi\ \mu/e\ X$

CDF:

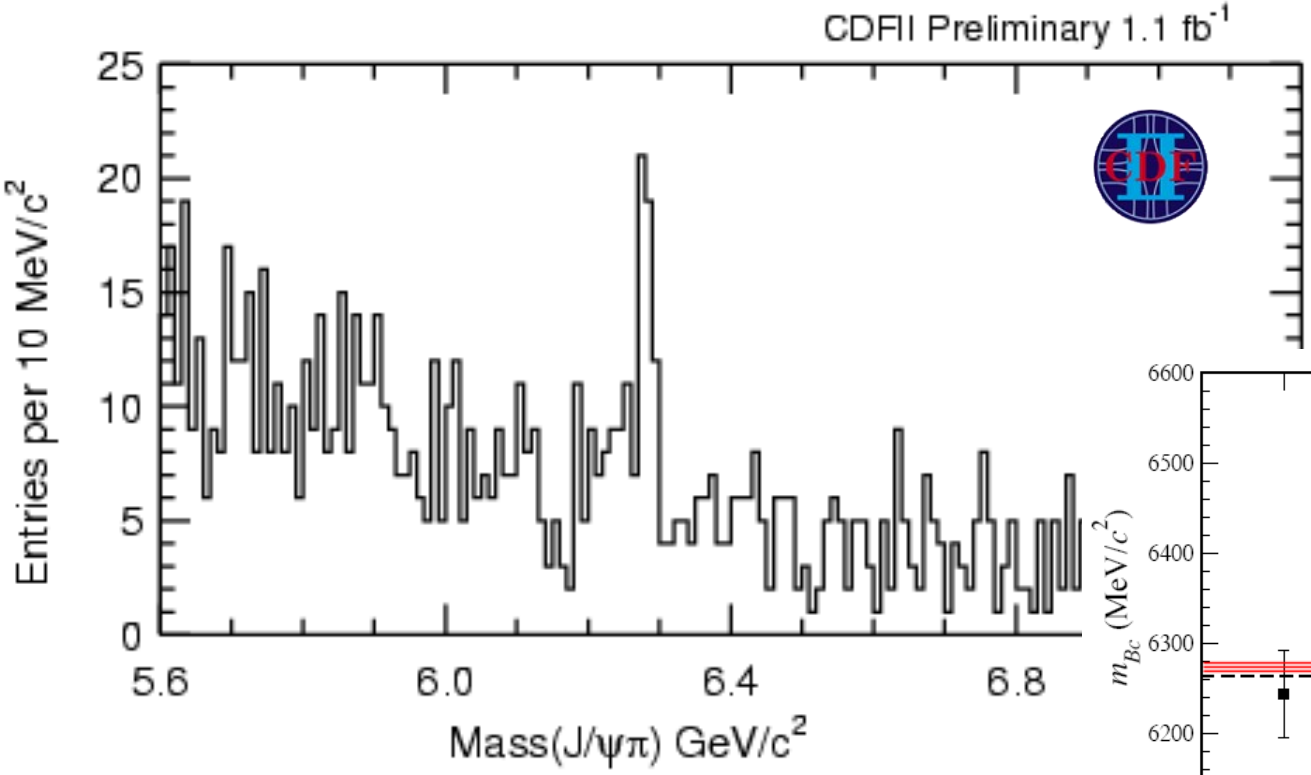
- Exclusive reconstruction $B_c^+ \to J/\psi\ \pi^+$ allows for precise mass measurement
- Optimize selection cuts on $B^+ \to J/\psi\ K^+$



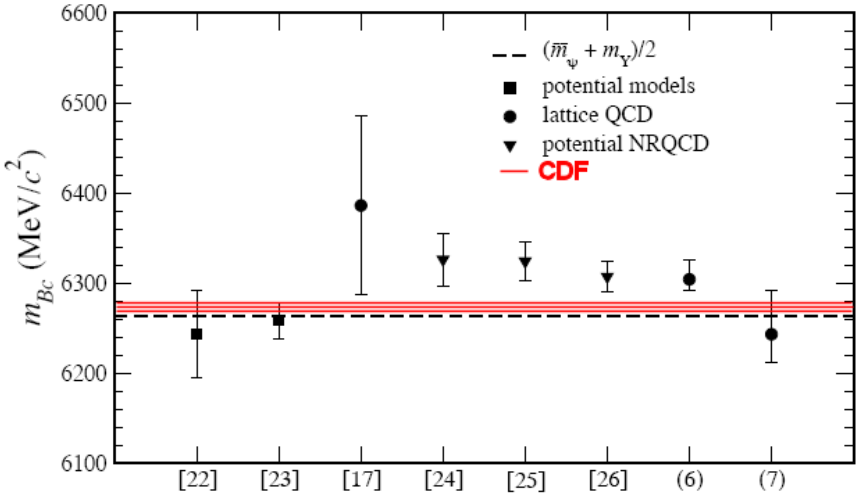
B_c



Peak in $J/\psi\,\pi$ mass spectrum with > 6σ significance



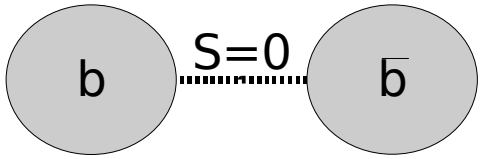
Result challenges potential models, lattice QCD and NRCQD



Unbinned fit:

$m(B_c) = 6276.5 \pm 4.0 \pm 2.7$ MeV/c^2

η_b

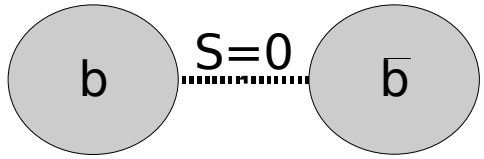


- $b\bar{b}$ vector meson Υ well studied,
  but pseudo-scalar $b\bar{b}$ state η_b not observed yet

➔ Search for $\eta_b \rightarrow J/\psi\ J/\psi$

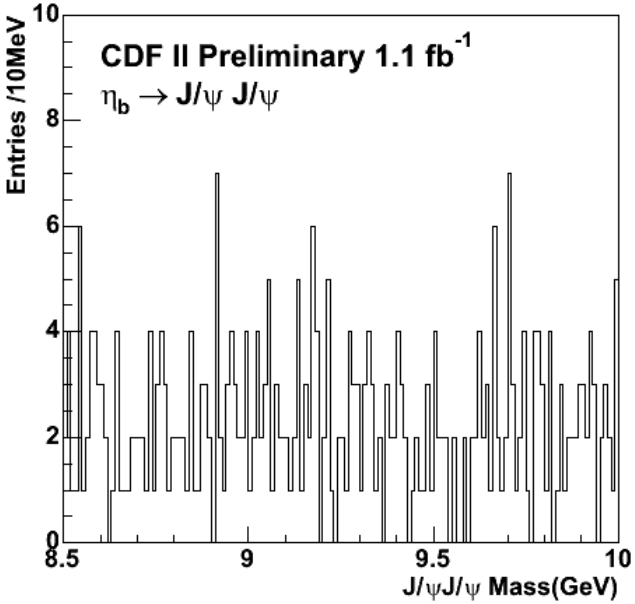
- Predictions:
  - $BR(\eta_b \rightarrow J/\psi\ J/\psi) = 7 \times 10^{-4\pm1}$
    $\Rightarrow$ 0.2 – 20 visible events per fb^{-1}
  - $m(\Upsilon(1S)) - m(\eta_b) = 30 – 160\ MeV/c^2$
  - $\Gamma(\eta_b) < \Gamma(\eta_c) = 25.5 \pm 3.4$ MeV

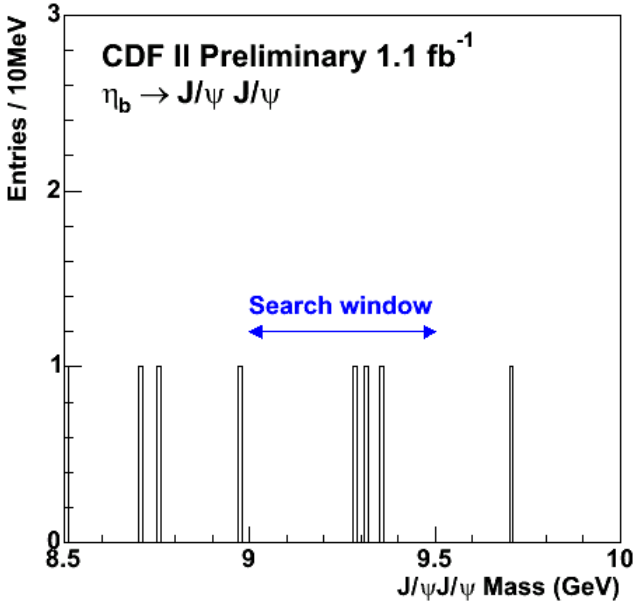
η_b

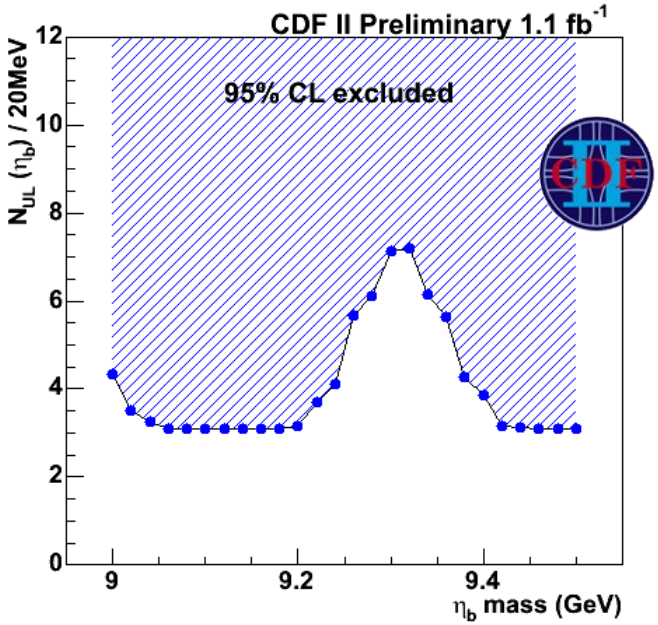


Optimized cuts for search

Tighter cuts for limit





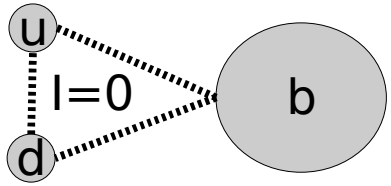


95% CL limit for $|y| < 0.6$, $p_T > 3.0$ GeV/c^2:

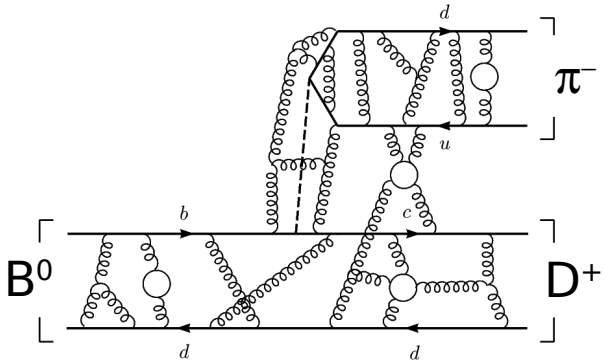
$$\sigma(p\bar{p} \to \eta_b X) \cdot BR(\eta_b \to J/\psi\ J/\psi) / \sigma(p\bar{p} \to b \to J/\psi\ X) < 5.0 \times 10^{-3}$$

$$\sigma(p\bar{p} \to \eta_b X) \cdot BR(\eta_b \to J/\psi\ J/\psi) \cdot BR(J/\psi \to \mu\mu)^2 < 2.6\ \text{pb}$$

Λ_b Lifetime



- Lightest b baryon, isospin singlet
- Spectator model: $\tau(\Lambda_b) = \tau(B^0)$
- NLO QCD: $\tau(\Lambda_b) / \tau(B^0) = 0.86 \pm 0.05$



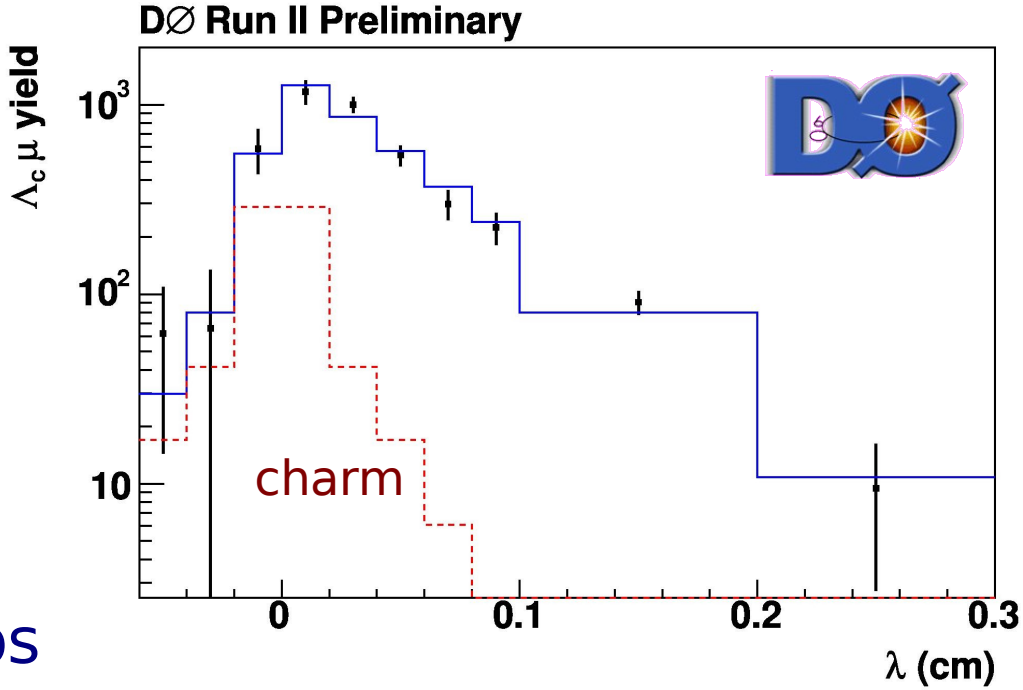
Semileptonic decay:

$\Lambda_b^0 \rightarrow \Lambda_c^+ \mu^- \bar{\nu}_\mu X$,

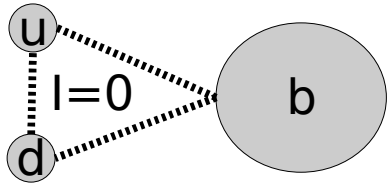
$\Lambda_c^+ \rightarrow K^0_S p$

- High statistics
- Correction for missing momentum (k-factor)

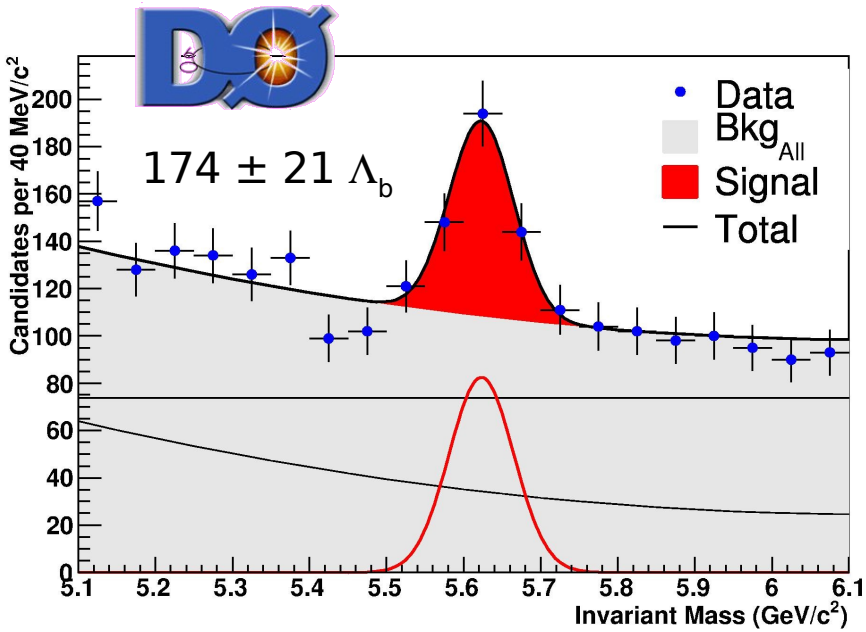
$\tau(\Lambda_b) = 1.28\ ^{+0.12}_{-0.11} \pm 0.09$ ps

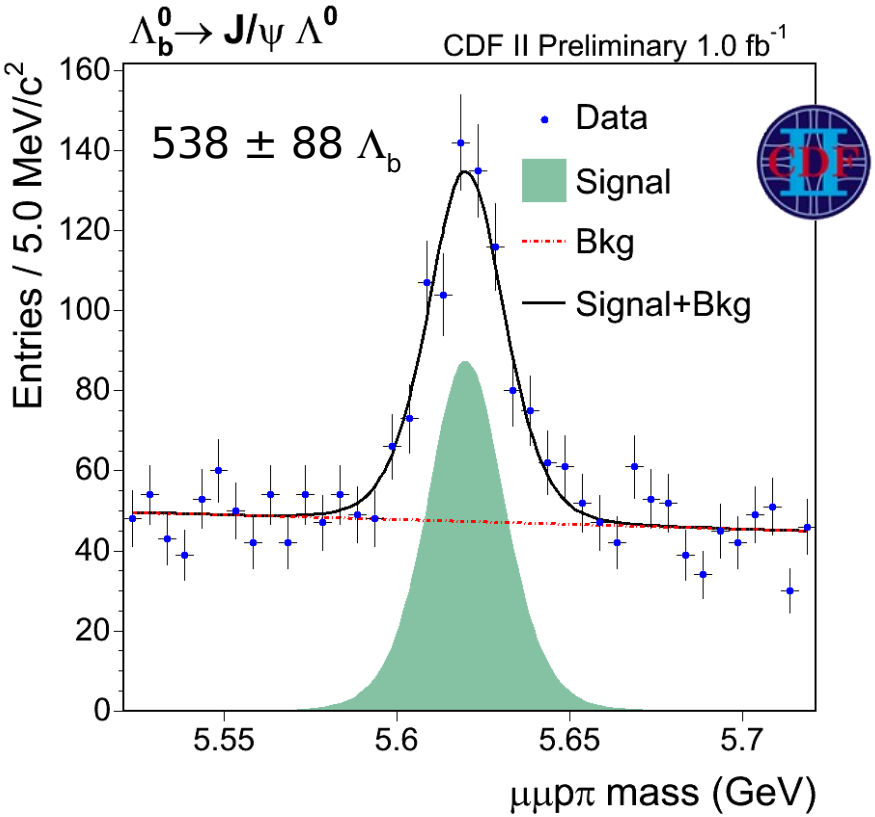


Λ_b Lifetime



Exclusive decay: $\Lambda_b^0 \rightarrow J/\psi\ \Lambda^0$





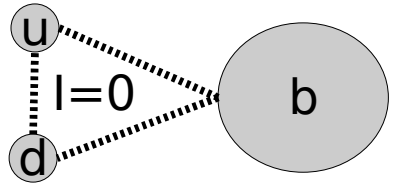
- ✔ Cross check: $B^0 \rightarrow J/\psi\ K^0_S$

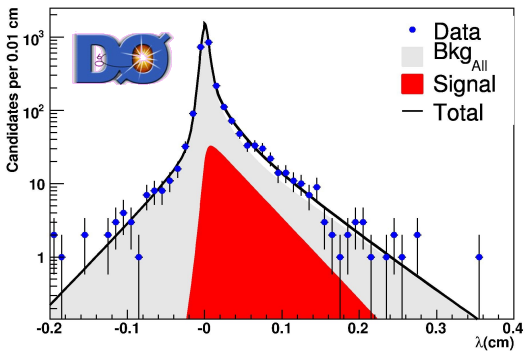
D0 : $\tau(B^0) = 1.492 \pm 0.075 \pm 0.047$ ps

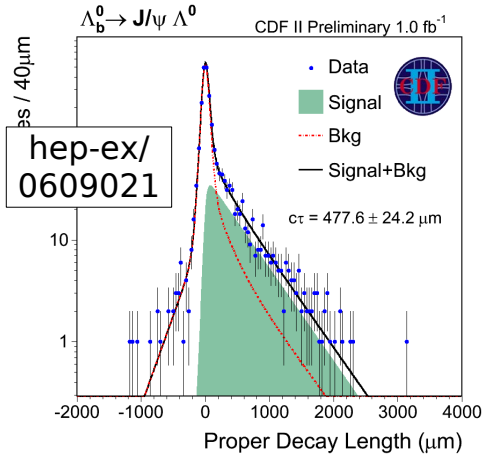
CDF : $\tau(B^0) = 1.524 \pm 0.030 \pm 0.016$ ps

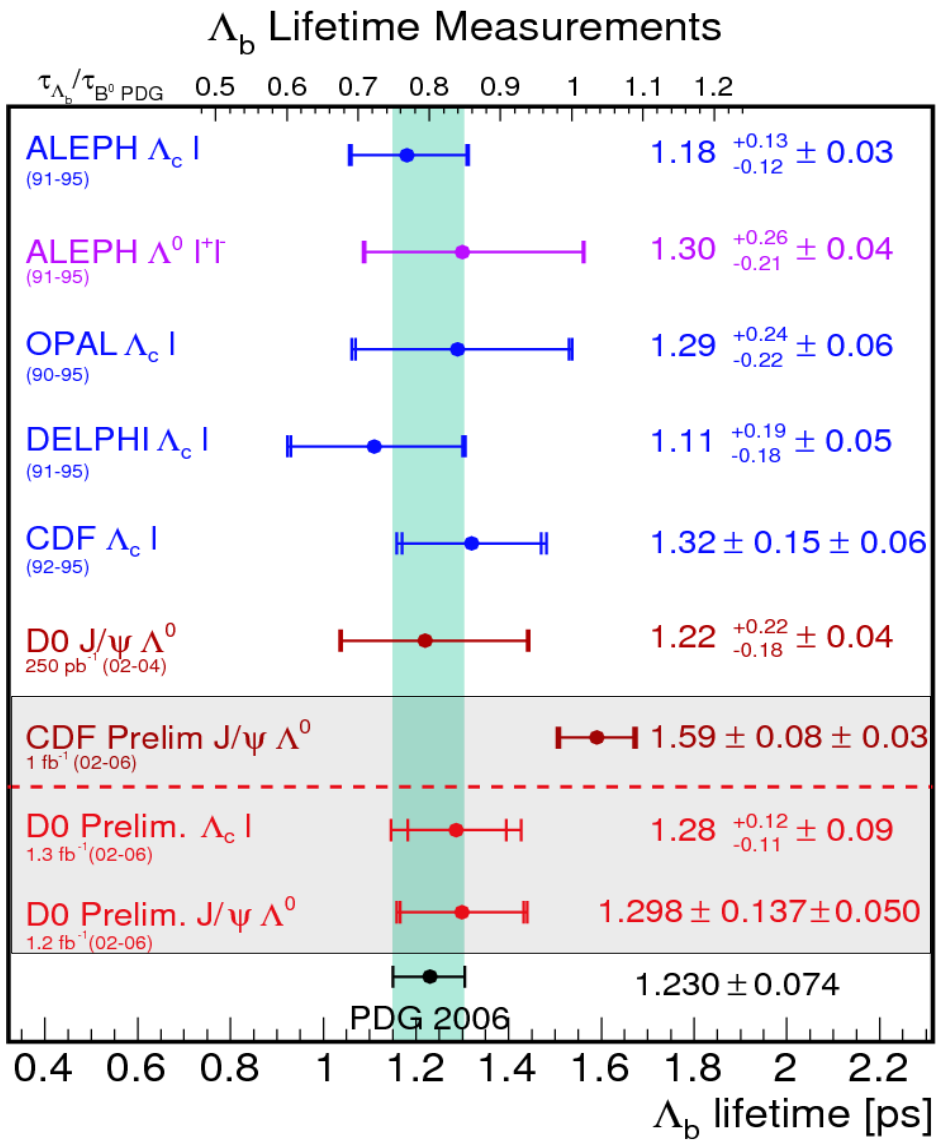
PDG : $\tau(B^0) = 1.530 \pm 0.009$ ps

Λ_b Lifetime





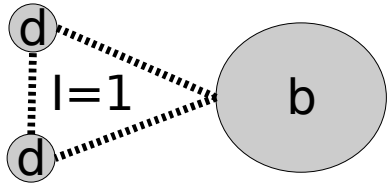




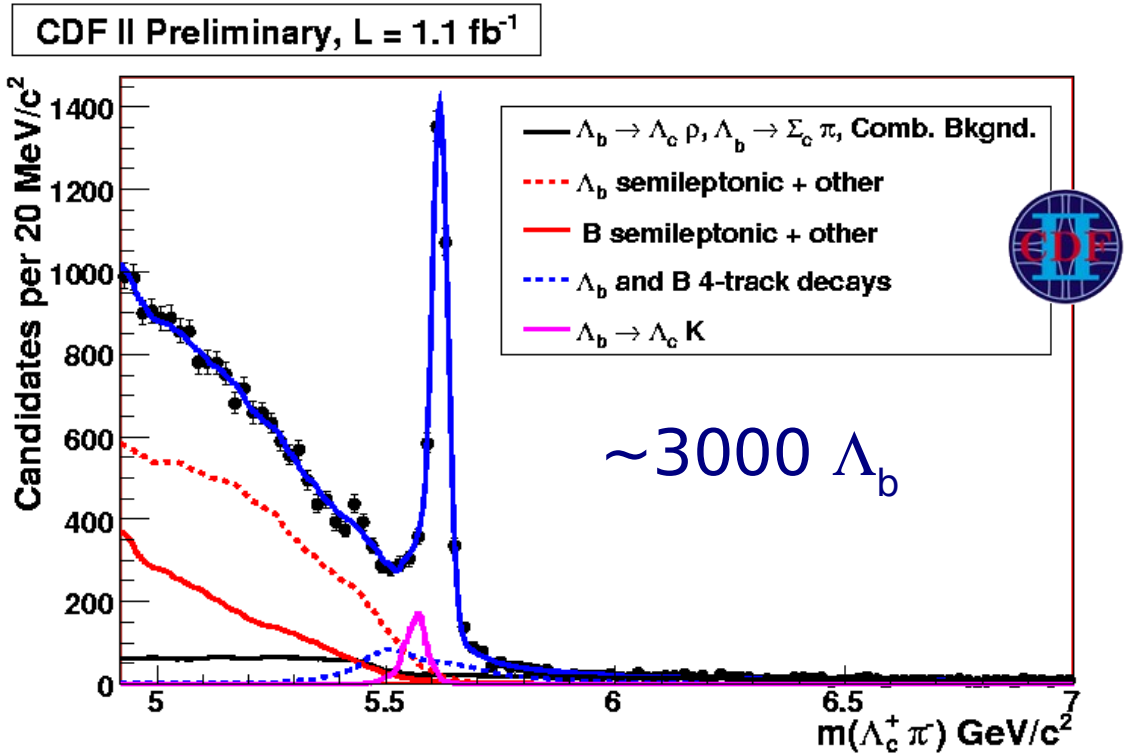
- D0 results consistent with world average
- CDF result 3.2σ above world average
- D0 and CDF $\Lambda_b^0 \to J/\psi\ \Lambda^0$ results consistent at 1.7σ

➔ Need more measurements

Σ_b



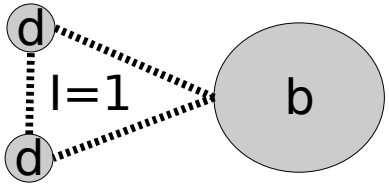
- Λ_b only established b baryon
- Use fully hadronic decay $\Lambda_b^0 \to \Lambda_c^+ \pi^-$, $\Lambda_c^+ \to p K^- \pi^+$ to search for $\Sigma_b^{(*)\pm} \to \Lambda_b^0 \pi^\pm$



		J=1/2	J=3/2
I_3=-1	bdd	Σ_b^-	Σ_b^{*-}
I_3=0	bdu	Σ_b^0	Σ_b^{*0}
I_3=+1	buu	Σ_b^+	Σ_b^{*+}

Σ_b property	Expected values (MeV/c^2)
$m(\Sigma_b)$ - $m(\Lambda_b^0)$	180 – 210
$m(\Sigma_b^*)$ - $m(\Sigma_b)$	10 – 40
$m(\Sigma_b^-)$ - $m(\Sigma_b^+)$	5 – 7
$\Gamma(\Sigma_b), \Gamma(\Sigma_b^*)$	~8, ~15

Σ_b



- Four peaks in unblinded signal region
- Significance > 5σ

➔ First observation of charged $\Sigma_b^{(*)}$ baryons

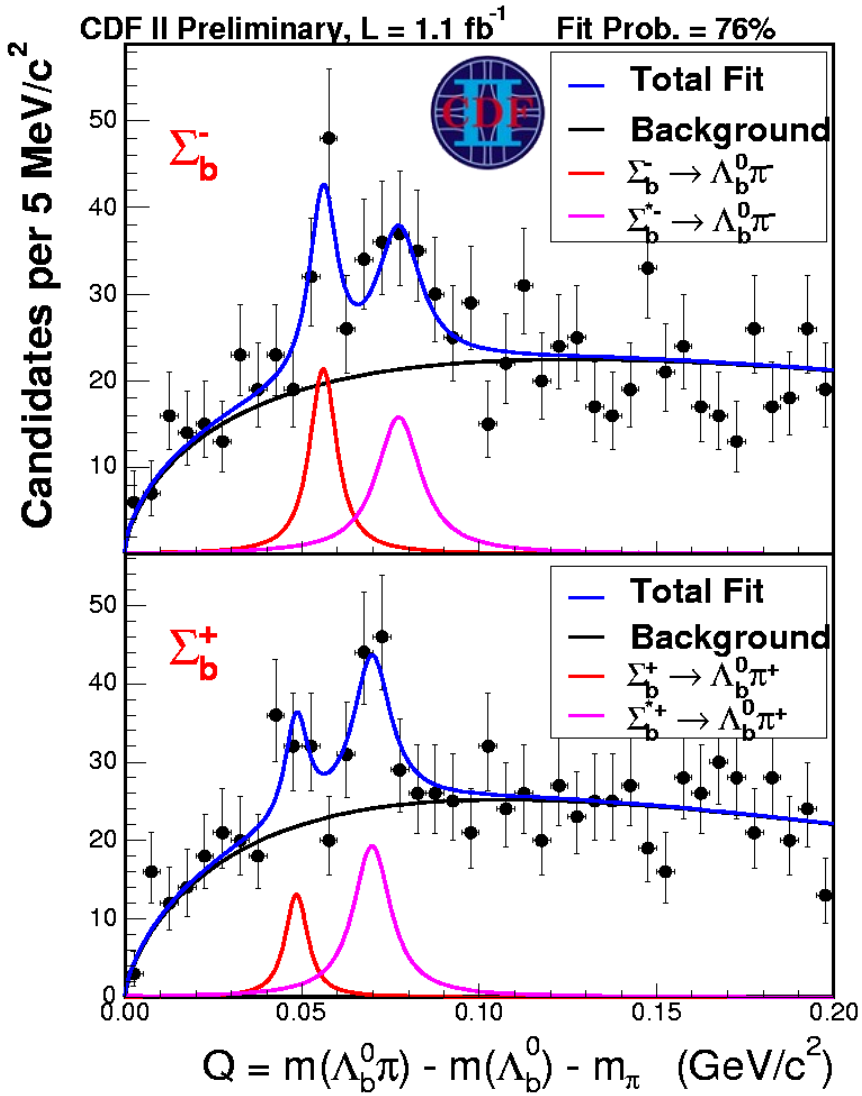
- Unbinned fit:

$m(\ _b^{-}) = 5816\ ^{+1.0}_{-1.0} \pm 1.7$ MeV/c²

$m(\ _b^{+}) = 5808\ ^{+2.0}_{-2.3} \pm 1.7$ MeV/c²

$m(\ _b^{*-}) = 5837\ ^{+2.1}_{-1.9} \pm 1.7$ MeV/c²

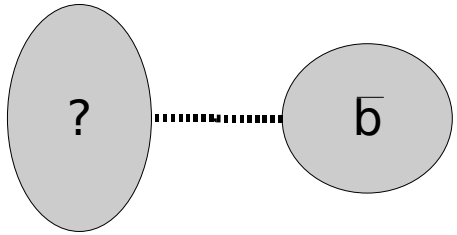
$m(\ _b^{*+}) = 5829\ ^{+1.6}_{-1.8} \pm 1.7$ MeV/c²



Summary

Broad spectrum of very competitive or even unique B state studies at the Tevatron:

- Most precise B^{**} mass measurements
- First direct observation of B_{s2}^{*} and B_{s1}
- Exclusive reconstruction and most precise mass measurement of B_c
- Most stringent limit on η_b production
- Partial and full reconstruction and precise lifetime measurements of Λ_b
- First observation of Σ_b



Much more data expected to come

➔ Improved precision, new discoveries?