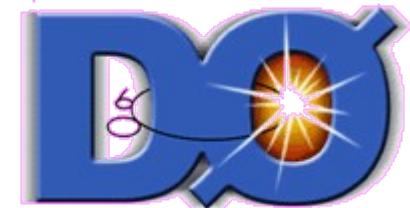


# Recent Results on B Spectroscopy at the Tevatron

DIS

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Martin Heck  
KIT, Universität Karlsruhe (TH)



on behalf of the CDF and D0 collaborations

# Properties of the Tevatron for B Physics

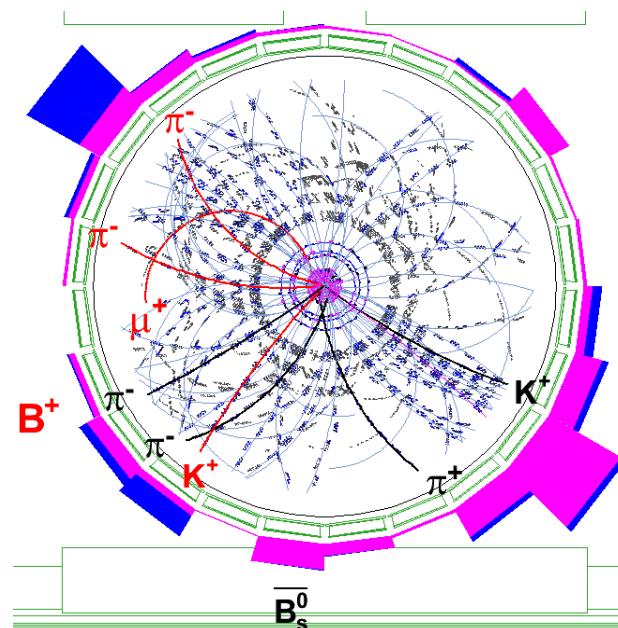
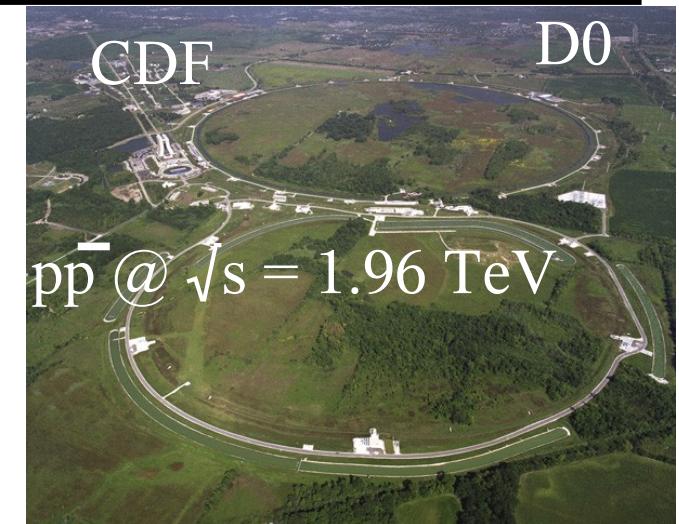
+ huge  $b\bar{b}$  Xsection ( $\sim 50 \mu b$ )

$\sim 10^{11}$  pairs produced)

+ production of all B hadron species

-  $\sim 10^3$  times larger inelastic Xsection

- background  
tracks from  
fragmentation



- broad  $\eta$  distribution:
  - low  $p_t$
  - low acceptance

# Properties for B Physics (cont.)

- Triggers select online useful events, most important triggers for B physics are

→ di-muon trigger

( $J/\psi \rightarrow \mu\mu$ )

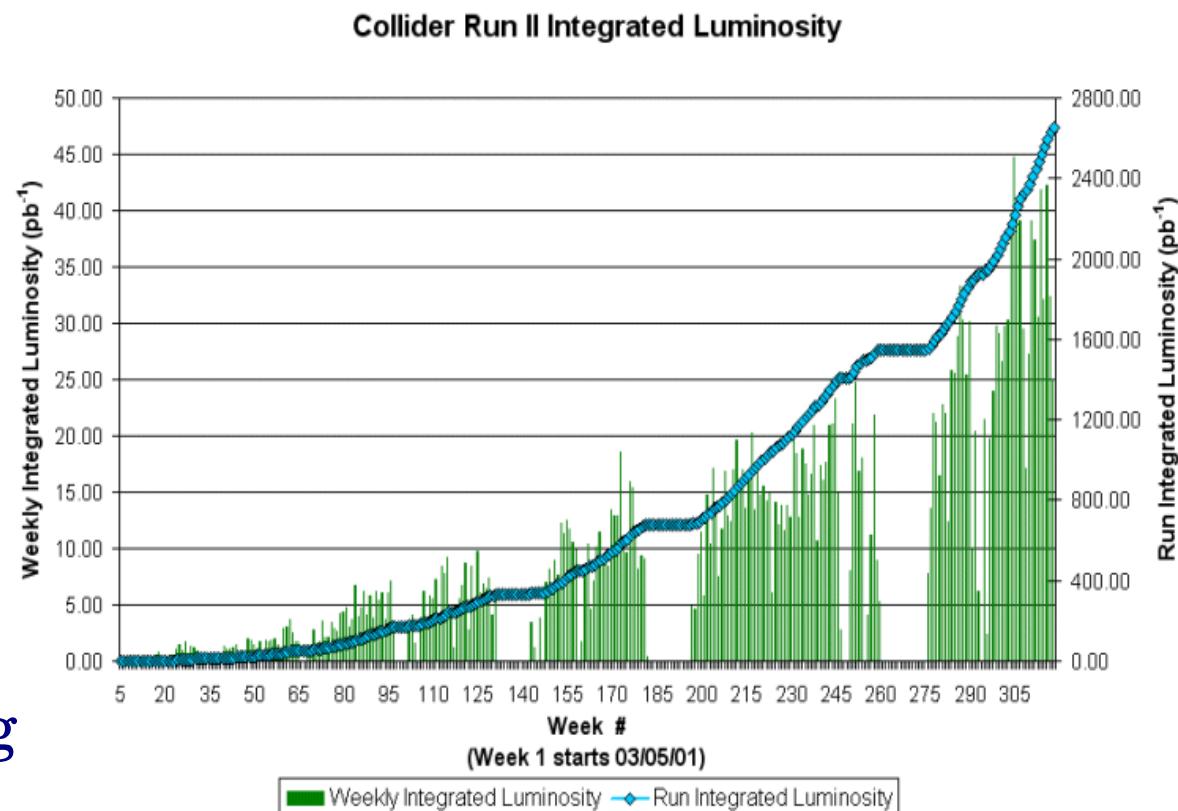
→ Silicon Vertex Trigger

(2 charged tracks with

min.  $\sim 1.5$  GeV  $p_t$ , forming

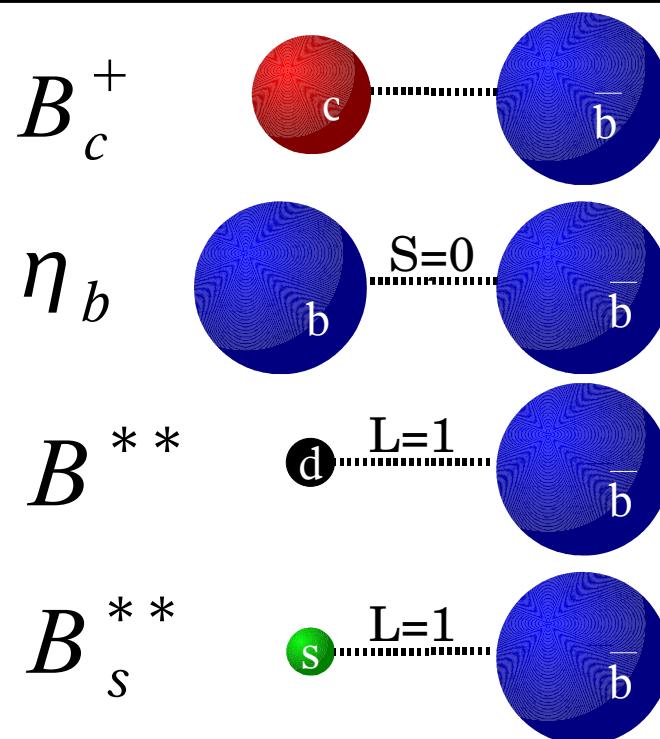
a secondary vertex)

- Detectors more than 80% of the time working

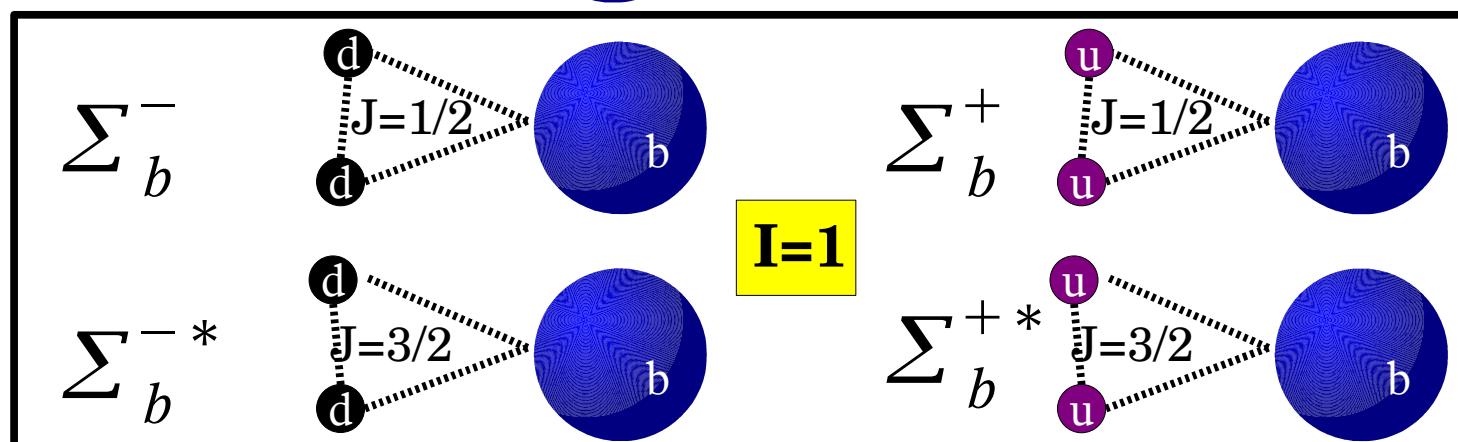


# $B$ states covered in this talk

Mesons:

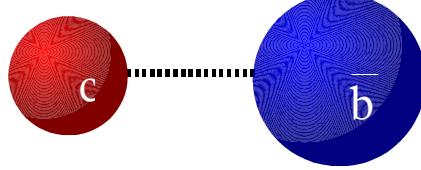


Baryon:



$B_c^+$ 

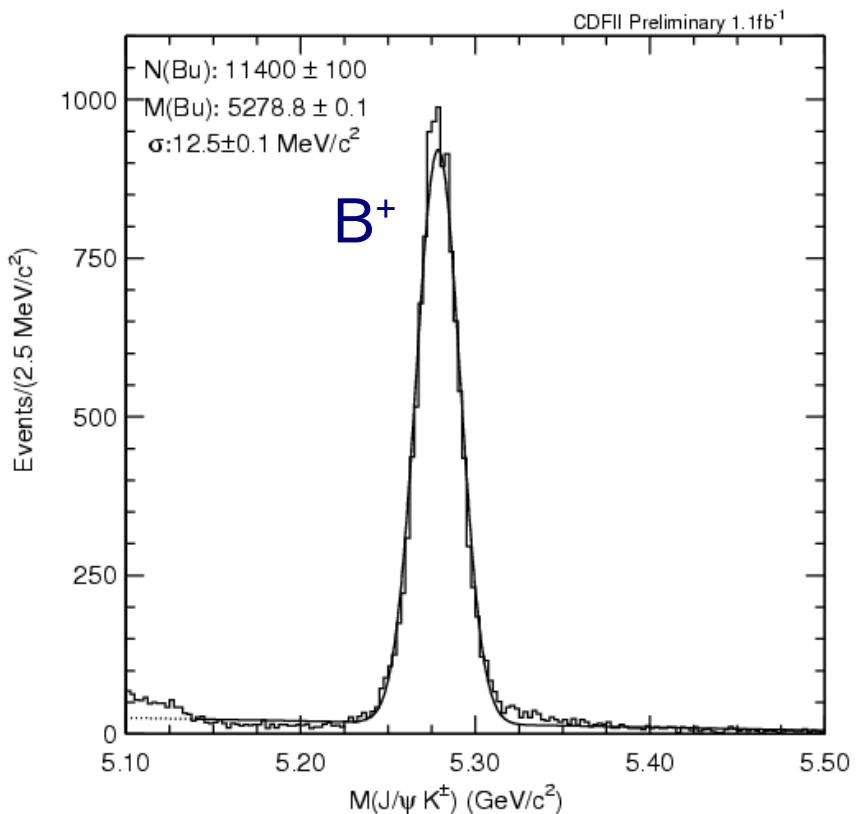
# First direct Observation



- Low production rate:  
 $f(b \rightarrow B_c) \sim 0.05\%$
- Weak interaction decay, e.g.
  - $J/\psi \mu/e X$ 
    - observation + lifetime,  
lepton easy to find,  
but  $\nu$  missing  
=> unprecise mass  
measurement
  - $J/\psi \pi^+$  (exclusive!)

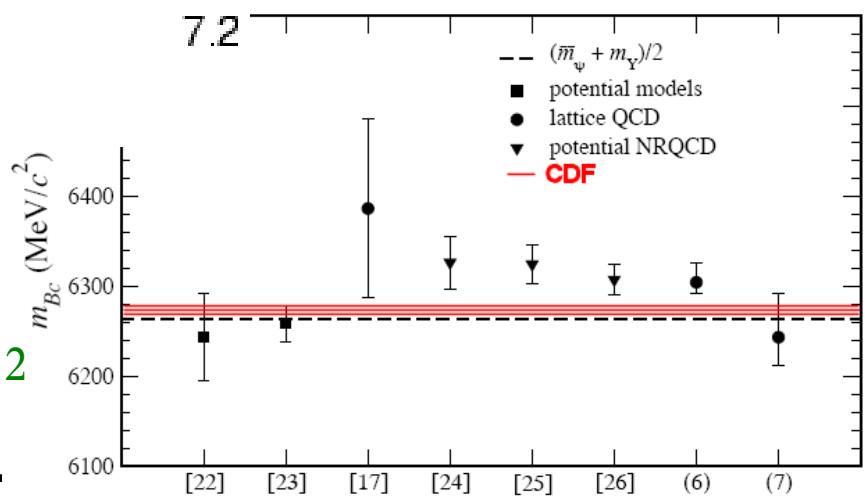
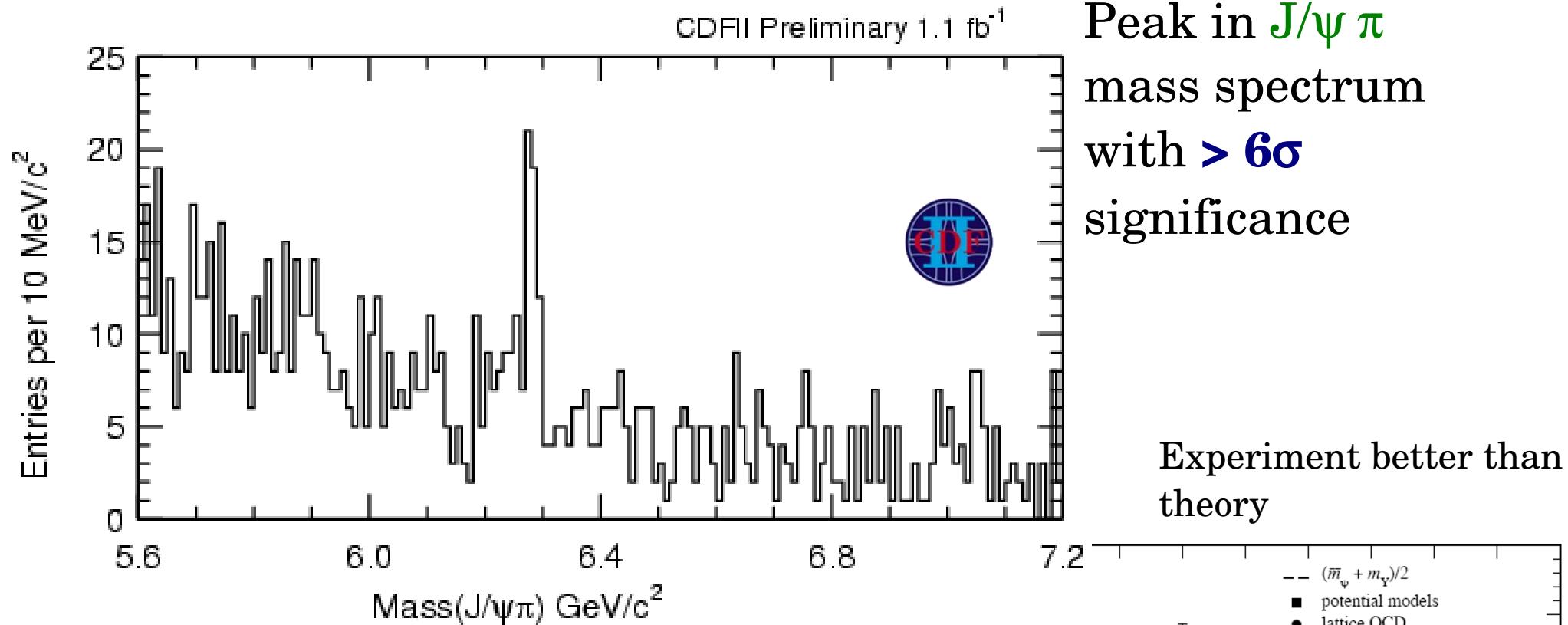
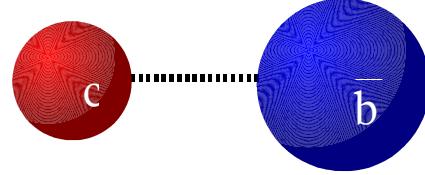


- \* Optimize selection cuts  
on  $B^+ \rightarrow J/\psi K^+$



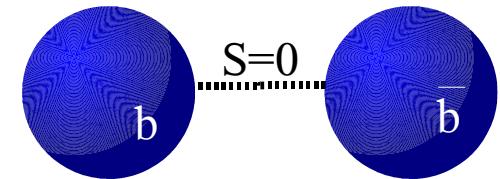
$B_c^+$ 

# Observation (cont.)

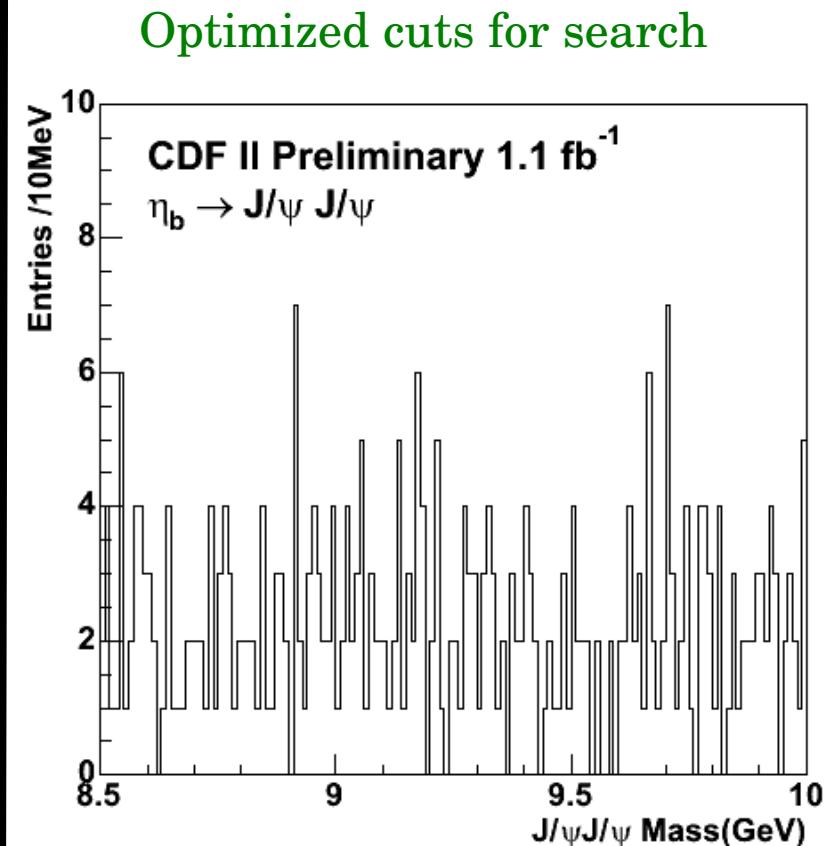


$\eta_b$

# Search



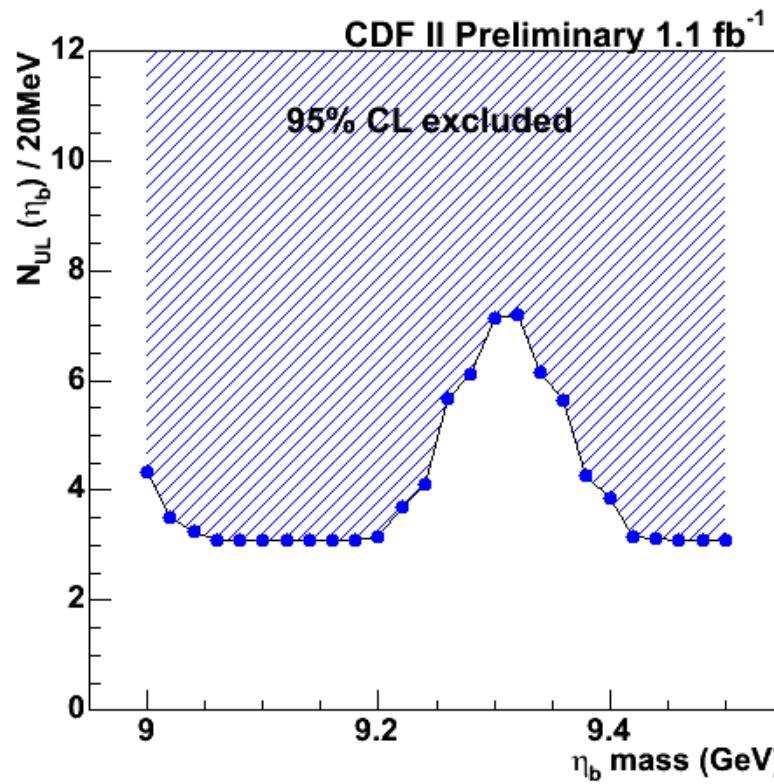
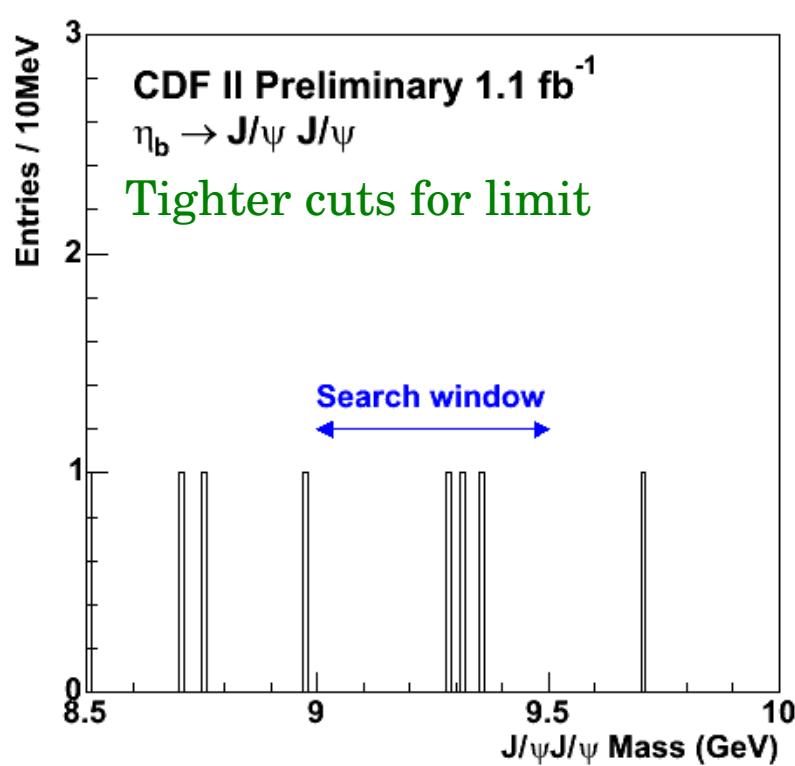
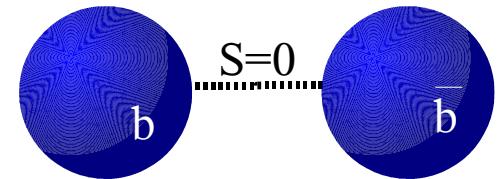
- pseudo-scalar  $b\bar{b}$  state  $\eta_b$   
not observed yet,  
LAST undiscovered  
ground state meson
- Predictions:
  - $BR(\eta_b \rightarrow J/\psi J/\psi) = 7 \times 10^{-4 \pm 1}$   
 $\Rightarrow 0.2 - 20$  visible events per  $fb^{-1}$
  - $m(Y(1S)) - m(\eta_b) = 30 - 160$  MeV/c<sup>2</sup>
  - $\Gamma(\eta_b) < \Gamma(\eta_c) = 25.5 \pm 3.4$  MeV
- Search for  $\eta_b \rightarrow J/\psi J/\psi$



No evident resonance  
==> make a limit

$\eta_b$

# Search (cont.)



$$\frac{\sigma(p\bar{p} \rightarrow \eta_b X; |\eta(\eta_b)| < 0.6, P_T(\eta_b) > 3.0 \text{ GeV}) \times Br(\eta_b \rightarrow J/\psi J/\psi)}{\sigma(p\bar{p} \rightarrow H_b \rightarrow J/\psi X; |\eta(J/\psi)| < 0.6, P_T(J/\psi) > 3.0 \text{ GeV})} < 5.0 \times 10^{-3} \text{ (95\%)}$$

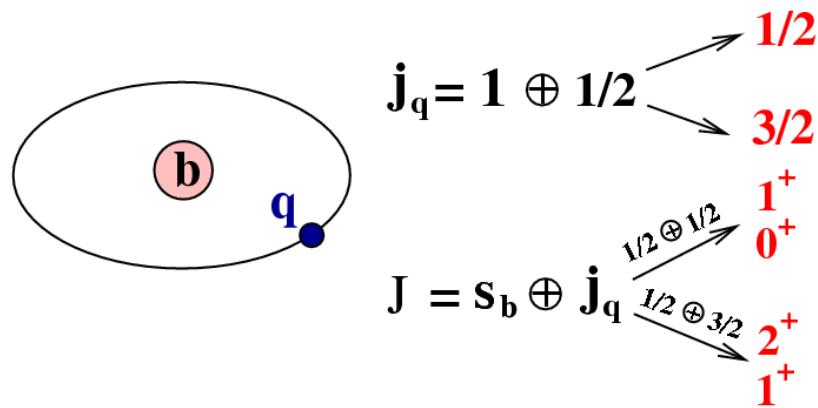
combined with  
other results

$$\sigma(p\bar{p} \rightarrow \eta_b X; \eta, p_t \text{ cuts}) \times Br(\eta_b \rightarrow J/\psi J/\psi) \times [Br(J/\psi \rightarrow \mu\mu)]^2 < 2.6 \text{ pb (95\%)}$$

# Orbitally excited ( $L=1$ ) $B_{(s)}$ Mesons ( $B_{(s)}^{**}$ )

HQET ( $m_b \rightarrow \infty$ ):

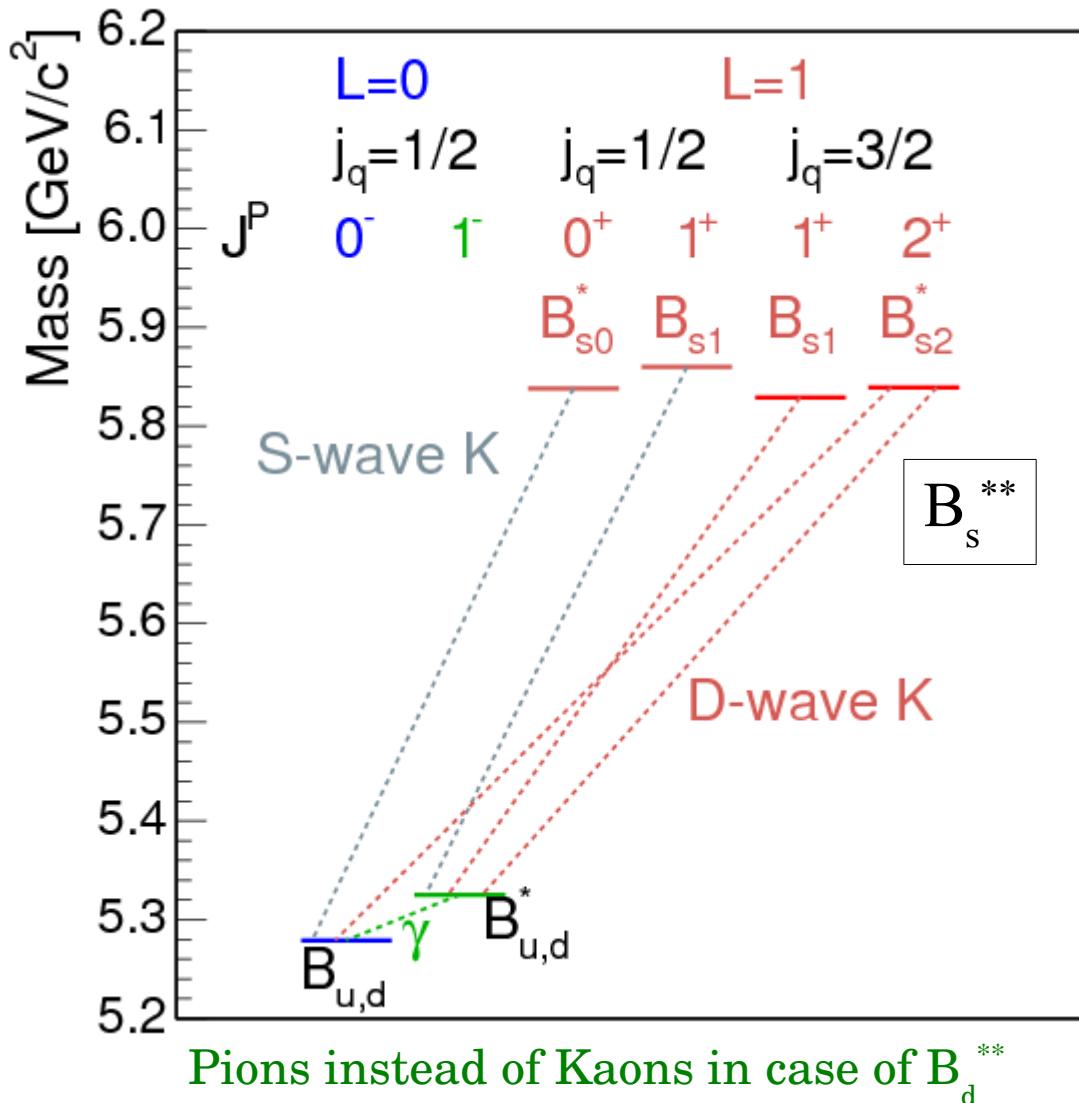
spins of quarks decouple



- $j_q = 1/2$  states are broad  
→ don't expect to observe them

- According to HQET spin of b-quark is decoupled  
=> D-wave needed for Spin-Parity conservation ( $B_{(s)1}(3/2)$ )  
→  $j_q = 3/2$  states are narrow

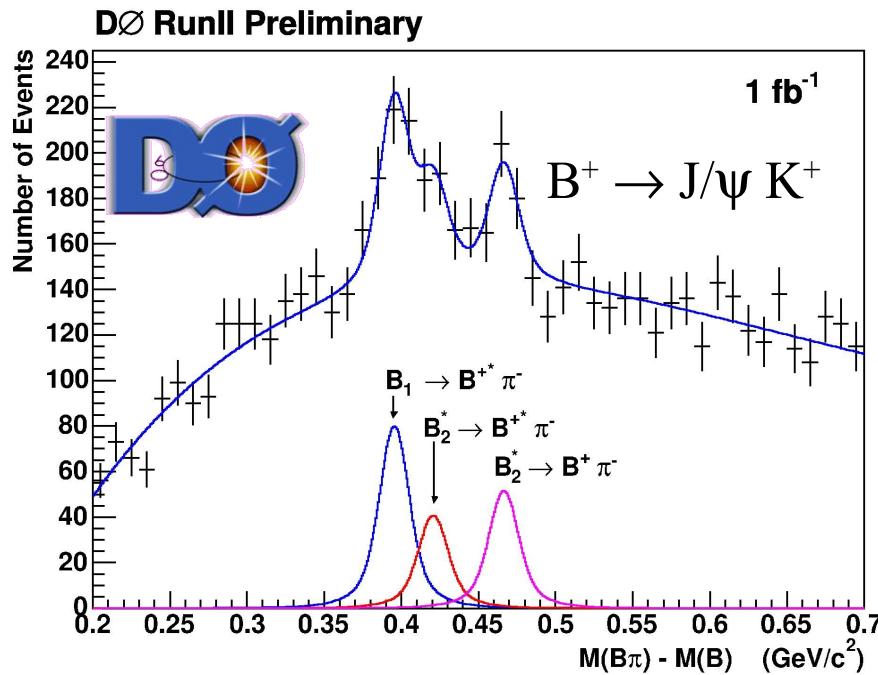
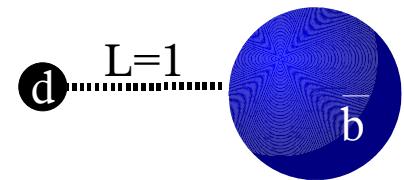
# Orbitally excited ( $L=1$ ) B Mesons ( $B^{**}$ , $B_J$ )



- $B_d^{**}$  decays to  $B^{(*)}\pi$
  - $B_s^{**}$  decays to  $B^{(*)}K$ ,  
 $B_s^{(*)}\pi$  forbidden by isospin
- expect 3 peaks
- $$B_{(s)1} \rightarrow B_{u,d}^* \pi^{(-)} (K^{-})$$
- $$B_{(s)2}^* \rightarrow B_{u,d}^* \pi^{(-)} (K^{-})$$
- $$B_{(s)2}^* \rightarrow B_{u,d} \pi^{(-)} (K^{-})$$

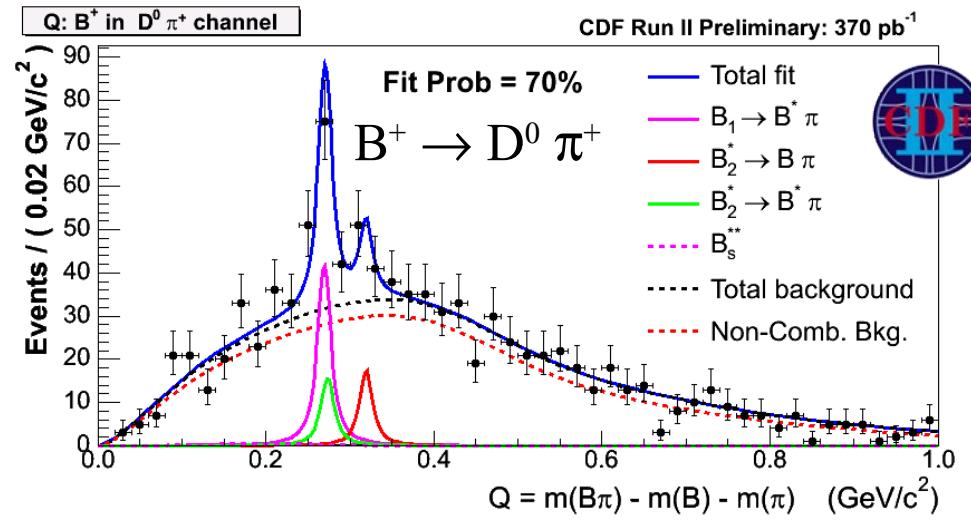
$B^{**}$

# First direct Observation



*use of Likelihood ratios*

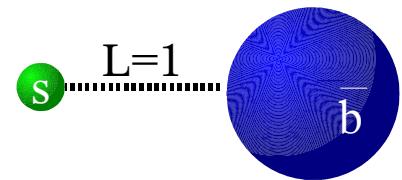
$B^{**} \rightarrow B^{(*)+} \pi^-$ ,  $B^{*+} \rightarrow B^+ \gamma$  ( $\gamma$  undetected)



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

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

Update to  $1 \text{ fb}^{-1}$   
in progress



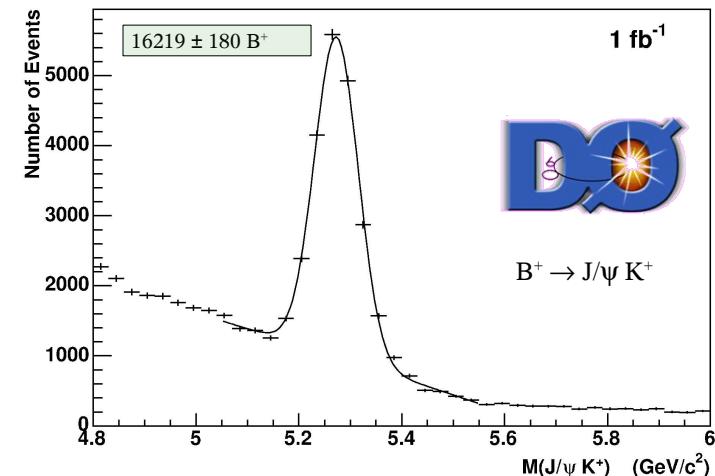
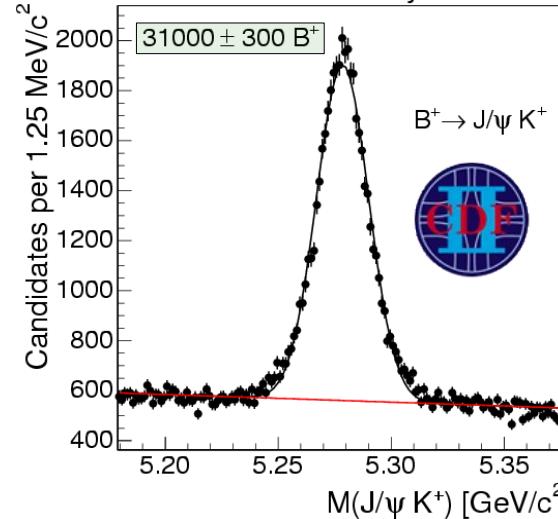
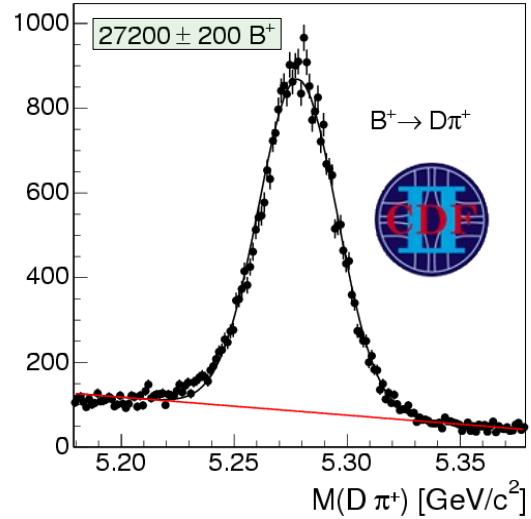
- Reconstruct  $B_s^{**} \rightarrow B^{(*)+} K^-$   
 $B^{*+} \rightarrow B^+ \gamma$  ( $\gamma$  undetected)
- $B^+ \rightarrow J/\psi K^+$  (D0, CDF)
- $B^+ \rightarrow D^0 \pi^+$  (CDF)

Use of multivariate analysis methods

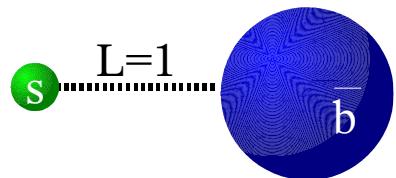
*Neural Network (CDF)*

*Likelihood Ratio (D0)*

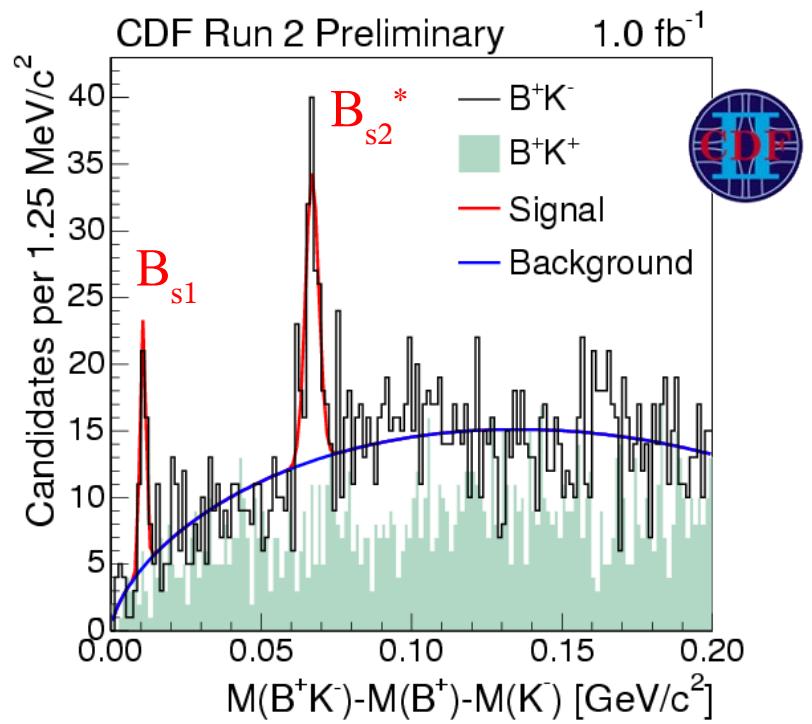
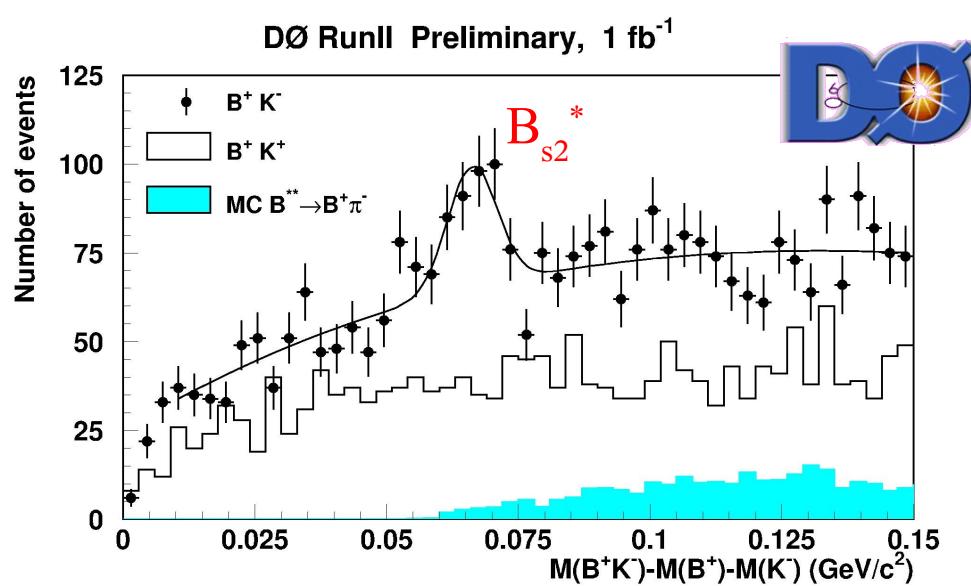
DØ RunII Preliminary

CDF Run 2 Preliminary 1.0  $\text{fb}^{-1}$ CDF Run 2 Preliminary 1.0  $\text{fb}^{-1}$ 

# *Observation (cont.)*



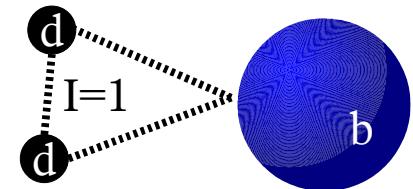
## First observation of $B_{s2}^*$ and $B_{s1}$



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

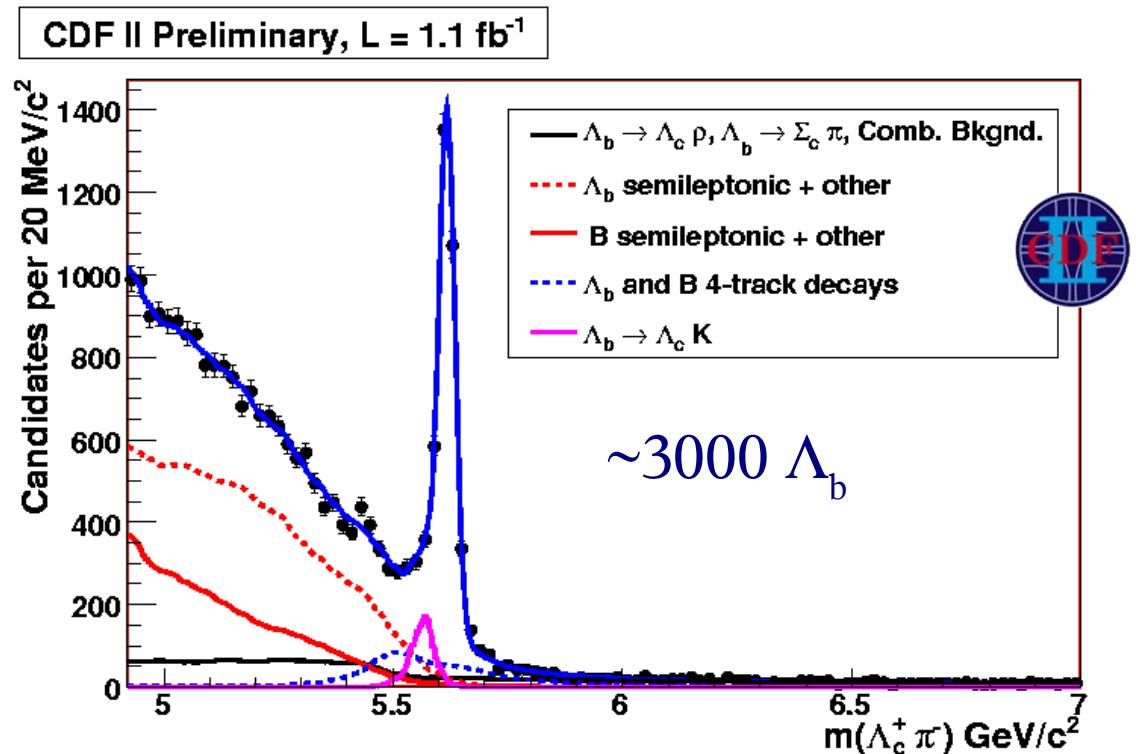
$\sum_b$ 

# Observation



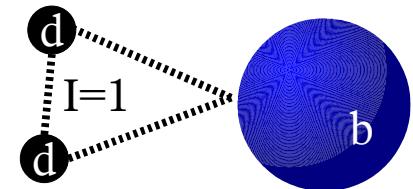
- $\Lambda_b$  only established  
b baryon
- $\Sigma_b^{(*)\pm} \rightarrow \Lambda_b^0 \pi^\pm$   
with  
 $\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-$ ,  
 $\Lambda_c^+ \rightarrow p K^- \pi^+$   
in a blind analysis

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



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

# Observation



- Four peaks in unblinded signal region
- Significance  $> 5\sigma$

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

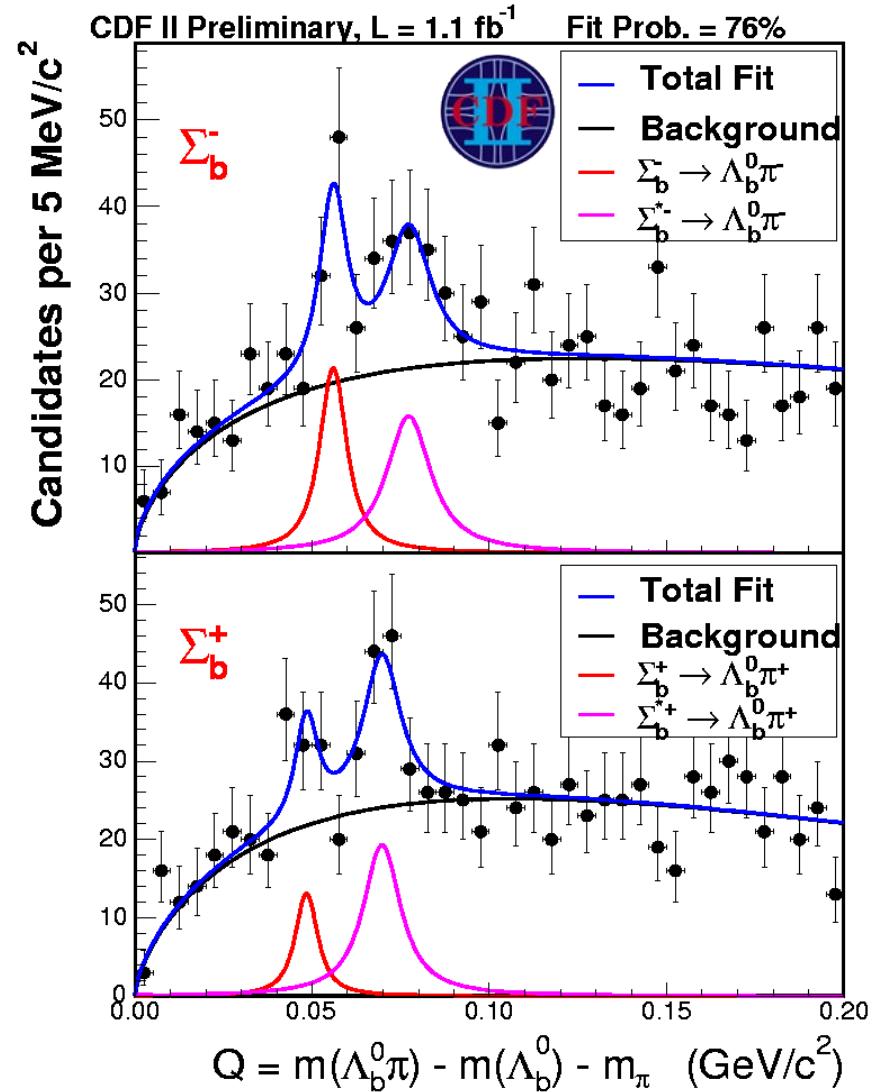
- Unbinned fit:

$$m(\Sigma_b^-) = 5816^{+1.0}_{-1.0} \pm 1.7 \text{ MeV}/c^2$$

$$m(\Sigma_b^+) = 5808^{+2.0}_{-2.3} \pm 1.7 \text{ MeV}/c^2$$

$$m(\Sigma_b^{*-}) = 5837^{+2.1}_{-1.9} \pm 1.7 \text{ MeV}/c^2$$

$$m(\Sigma_b^{*+}) = 5829^{+1.6}_{-1.8} \pm 1.7 \text{ MeV}/c^2$$



# Summary

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

- First direct observation of  $B_c$
- Most stringent limit on  $\eta_b$  production
- Most precise mass measurement of both  $B^{**}$  states
- First observation of  $B_{s2}^*$  and  $B_{s1}$
- First observation of  $\Sigma_b^+$ ,  $\Sigma_b^{++}$ ,  $\Sigma_b^-$ ,  $\Sigma_b^{-*}$

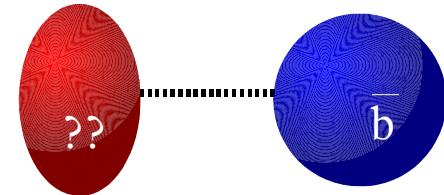
For more information see

[www-cdf.fnal.gov/physics/new/bottom/bottom.html](http://www-cdf.fnal.gov/physics/new/bottom/bottom.html)

[www-d0.fnal.gov/Run2Physics/WWW/results/b.htm](http://www-d0.fnal.gov/Run2Physics/WWW/results/b.htm)

Much more data expected to come

→ Improved precision, new discoveries?

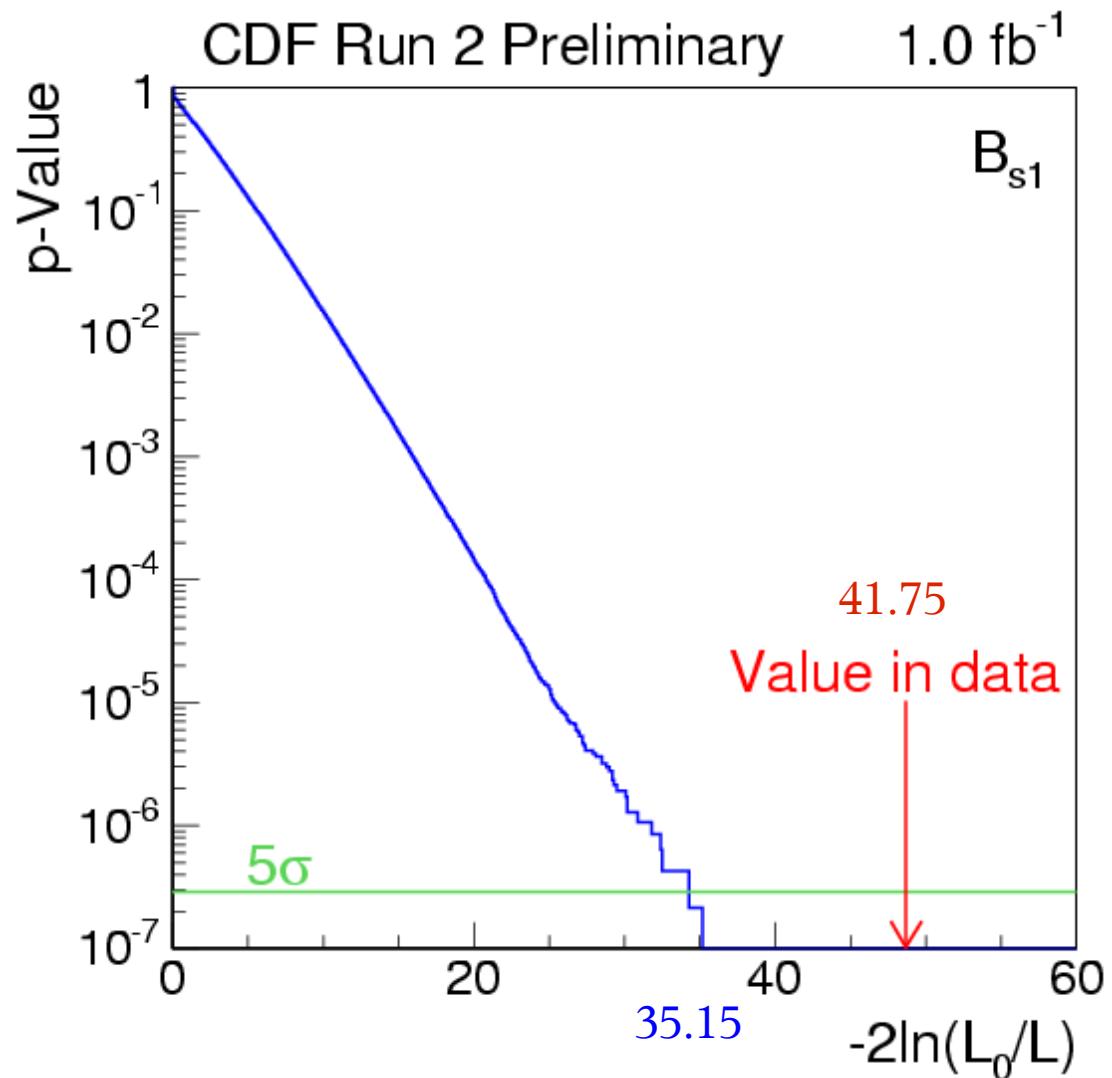


# Backup

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- $B_{s1}$  Significance
- $\Sigma_b$ 
  - Fit
  - single peak significance
  - Systematics

- Toy MC ensemble according to Background only ( $+B_{s2}^*$ ) fit
- Fitting with Gaussian between 0 and 50 MeV and without.  
==> Calculation of difference in Loglikelihood
- p-value: Integral over all Toy MCs with at least a given difference over all Toy MCs



# $\Sigma_b$ Fit

Parameter	Value	Errors (stat)
$Q(\Sigma_b^-)$ [MeV/c <sup>2</sup> ]	<b>55.9</b>	<b>-0.96, +0.99</b>
$Q(\Sigma_b^+)$ [MeV/c <sup>2</sup> ]	<b>48.4</b>	<b>-2.29, +2.02</b>
$N(\Sigma_b^-)$	<b>60</b>	<b>-13.8, +14.8</b>
$N(\Sigma_b^+)$	<b>29</b>	<b>-11.6, +12.4</b>
$N(\Sigma_b^{*-})$	<b>74</b>	<b>-17.4, 18.2</b>
$N(\Sigma_b^{*+})$	<b>74</b>	<b>-16.3, 17.2</b>
$Q(\Sigma_b^*) - Q(\Sigma_b)$ [MeV/c <sup>2</sup> ]	<b>21.3</b>	<b>-1.94, 2.03</b>

Width is fixed on prediction values

# $\Sigma_b$ Single peak significance

- for each peak a set of Toy MC generated and probability calculated that background gives a peak as observed
- 4 vs NULL > 5  $\sigma$
- all but  $\Sigma_b^+$  p over 3  $\sigma$  alone
- from all hypothesis 4 peak hypothesis by far the most preferred

Hypothesis	$\Delta(-\ln(\mathcal{L}))$	p-value	Signi. ( $\sigma$ )
“NULL”	42.9	$6.4 \times 10^{-8}$	5.3
“Two Peaks”	14.1	$9.4 \times 10^{-5}$	3.7
No $\Sigma_b^-$ peak	9.8	$4.0 \times 10^{-4}$	3.4
No $\Sigma_b^+$ peak	1.8	0.057	1.6
No $\Sigma_b^{*-}$ peak	9.1	$1.8 \times 10^{-4}$	3.6
No $\Sigma_b^{+*}$ peak	10.7	$3.3 \times 10^{-4}$	3.4

$$5\sigma \approx 2.87 \times 10^{-7} \text{ error probability}$$

# $\Sigma_b$ Systematics

<b>Parameter</b>	<i>Tracking</i>	$\Lambda_b Comp$	$\Lambda_b Norm$	$\Lambda_b Shape$	<i>reweight</i>	<i>Det. Res.</i>	$\Sigma_b width$	<i>Total</i>
$\Sigma_b^- Q$ [Mev/c <sup>2</sup> ]	0.06 -0.06	0.00 -0.03	0.00 -0.002	0.000 -0.011	0.04 -0.0004	0.0 -0.011	0.009 -0.005	0.07 -0.07
$\Sigma_b^+ Q$ [Mev/c <sup>2</sup> ]	0.06 -0.06	0.03 0.0	0.013 -0.013	0.013 0.0	0.0 -0.11	0.0 -0.014	0.01 -0.02	0.07 -0.13
$\Sigma_b^* - \Sigma_b^- Q$ [Mev/c <sup>2</sup> ]	0.06 -0.06	0.05 0.0	0.14 -0.13	0.04 0.00	0.32 0.0	0.02 0.0	0.07 -0.07	0.37 -0.16
$\Sigma_b^-$ events	0.0 0.0	0.7 0.0	2.2 -2.2	0.3 0.0	7.4 0.0	0.3 0.0	3.4 -3.4	8.5 -4.0
$\Sigma_b^+$ events	0.0 0.0	3.3 0.0	2.1 -2.1	1.2 0.0	2.3 -1.8	0.3 0.0	1.8 -2.0	5.0 -3.4
$\Sigma_b^{*-}$ events	0.0 0.0	0.4 0.0	4.8 -4.7	0.3 0.0	14.7 0.0	0.1 0.0	1.7 -1.7	15.6 -5.0
$\Sigma_b^{*+}$ events	0.0 0.0	7.3 0.0	4.8 -4.8	2.8 0.0	4.6 -2.9	0.2 0.0	0.8 -0.8	10.3 -5.7