B spectroscopy at the Dzero experiment

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On behalf of the D0 collaboration

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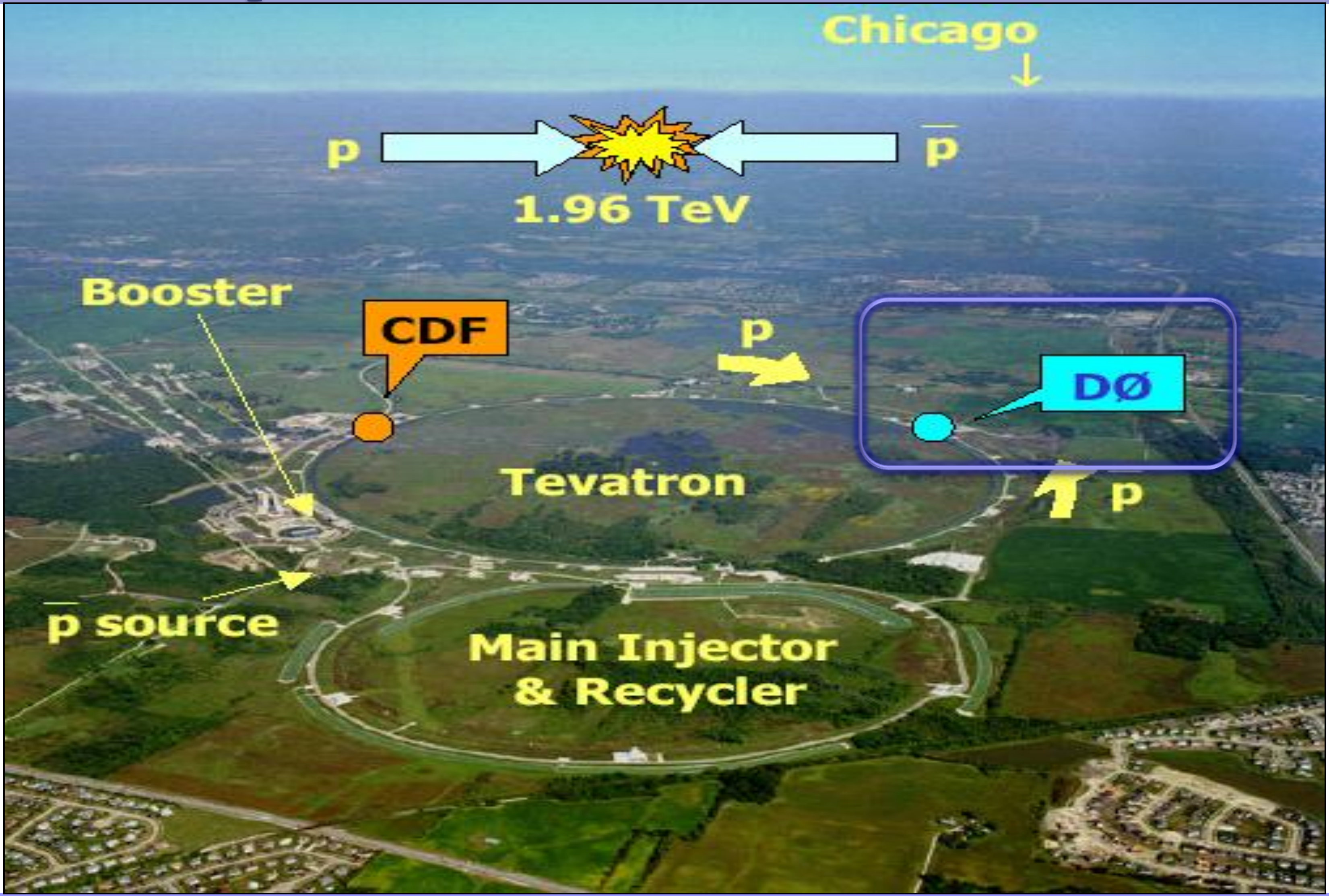
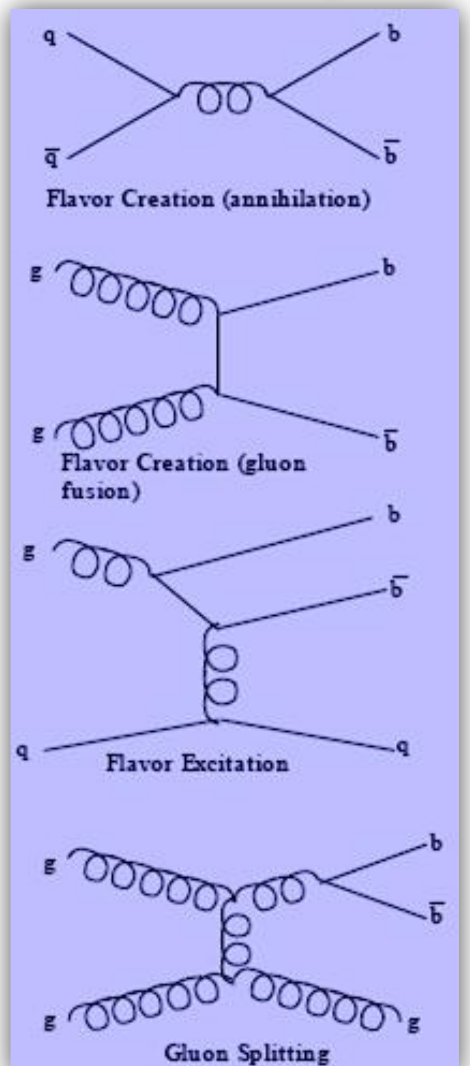
Outline:

- **DØ detector**
- **B Physics @ Tevatron**
- **B_c mass measurement**
- **Excited Bs mesons**
- **Ξ_b and Ω_b observations**
- **Summary**

D0 experiment at the Tevatron



Heavy flavor physics at Tevatron

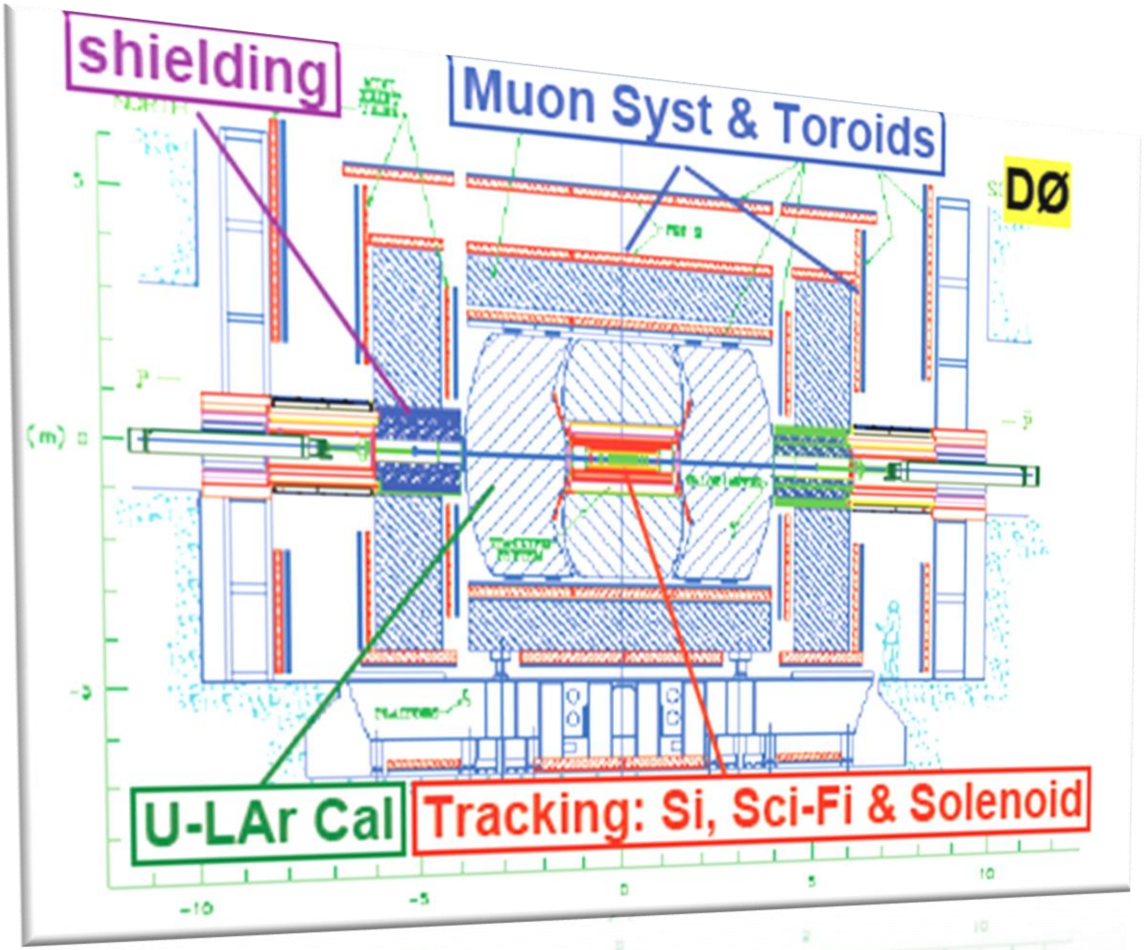


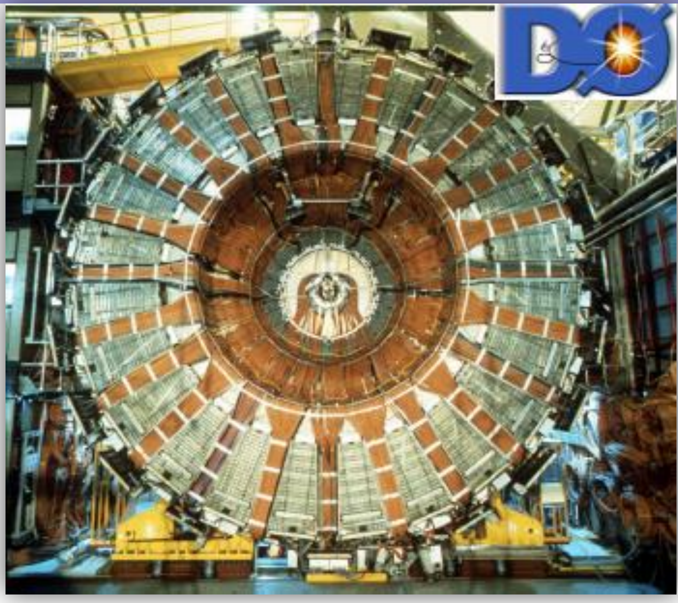
- Tevatron is an excellent place for flavor physics:
  - ✓ b production cross section is x1000 than $e^+ e^-$ B factories
  - ✓ All *b* and *c* hadron species are produced:
    - $B^+, B^0, B_s, B_c, \Lambda^0_b, \Xi_b, \Omega_b, \ldots$
    - $D^+, D^0, D_s, \Lambda_c, \chi_c, \Xi_c$, X(3872), etc.
- However:
  - Inelastic (QCD) background is x1000 higher than the b cross section.
  - Needs smart selection starting from triggers

B spectroscopy status

- Mesons:
  - B^+, B^0, B_s, B_c^+ (established)
  - B* (established),
  - **B**(CDF & DØ)**
  - **B_s** (CDF & DØ)**
- Baryons
  - Λ_b (established)
  - **Σ_b^+, and Σ_b^{*+}(CDF)**
  - **Ξ_b^-**, Ω_b^- (DØ &CDF)

DØ detector



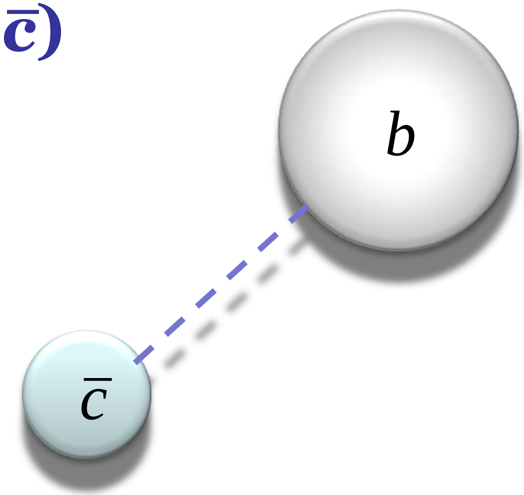


Important:

- Triggering
- Muons
- Tracking/vertexing

B_c meson

Bound state of two heavy quarks: $(b\bar{c})$



- Good lab for potential models
- B_c is the only meson with two heavy flavors
- Only weak decays possible

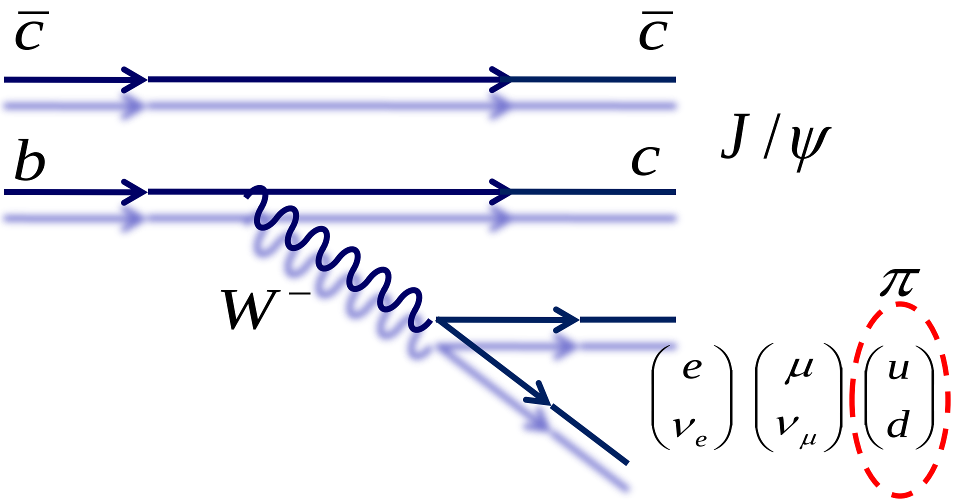
Experimental status:

- Discovered in Run I of the Tevatron in semileptonic decays
- With higher statistics in Run II of the Tevatron:
  - ✓ More precise lifetime measurement (D0 & CDF)
  - ✓ Observation on fully reconstructed decays: mass measurement

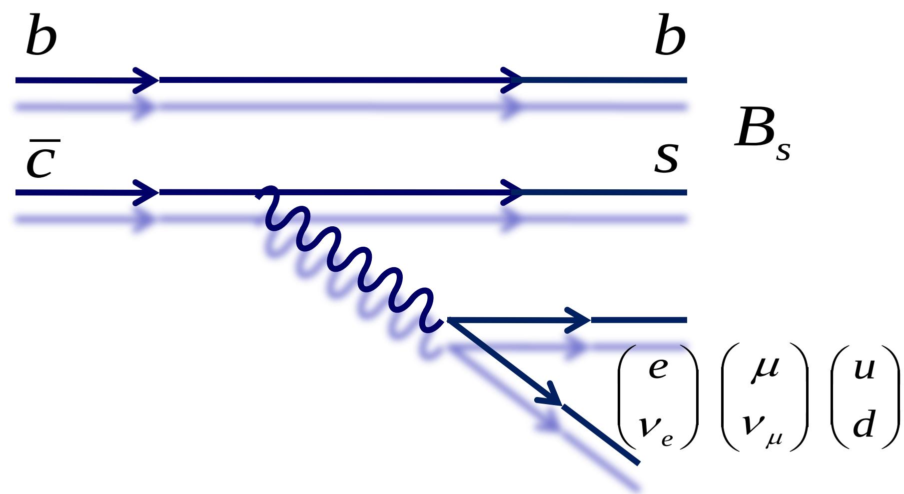
Challenge:

- B^+:B^0:B_s:b baryons ≈ 40:38:10:10, **B_c~0.5%**
- c-like lifetime observed : τ~ 0:45 ps

B_c meson decays



c as spectator (D0 measurement)

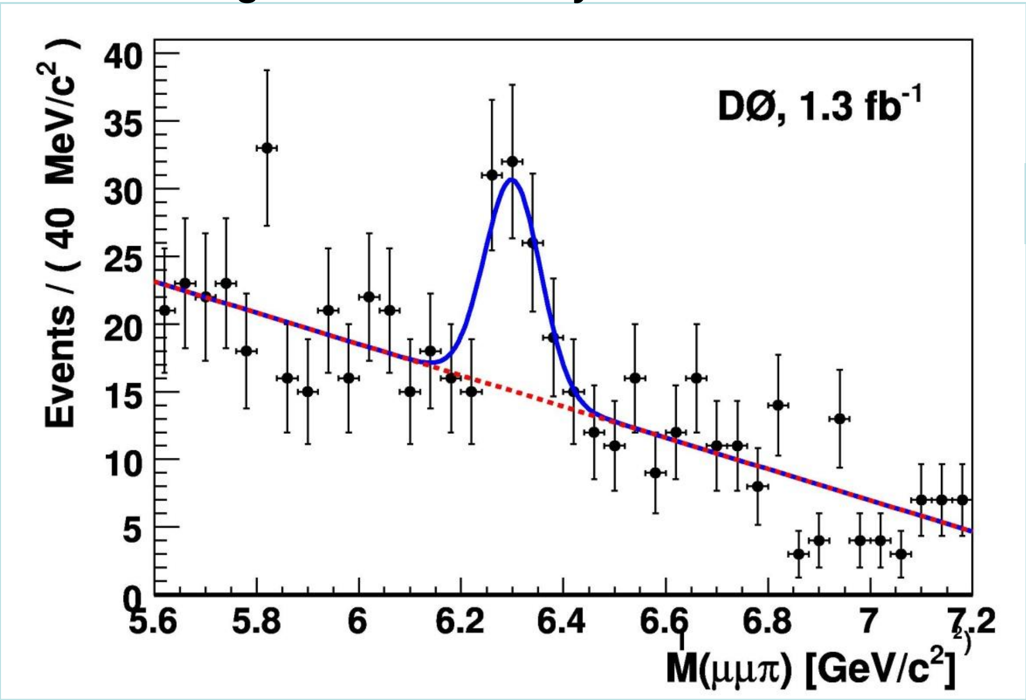


b as spectator (not yet observed)

- A J/ψ in the final state has huge advantage for triggering
- Semileptonic decays are not fully reconstructed
  - Mass extracted with large uncertainty
  - ✓ Higher statistics favors lifetime measurements

B_c mass measurement at D0

- ✓ Exclusive reconstruction in $B_c^+ \to J/\psi\pi^+$
- ✓ Optimization in $B+ \to J/\psi K+$ and $B_c^+ \to J/\psi\pi^+$ Monte Carlo
- ✓ Data of 1.3 fb^{-1} integrated luminosity

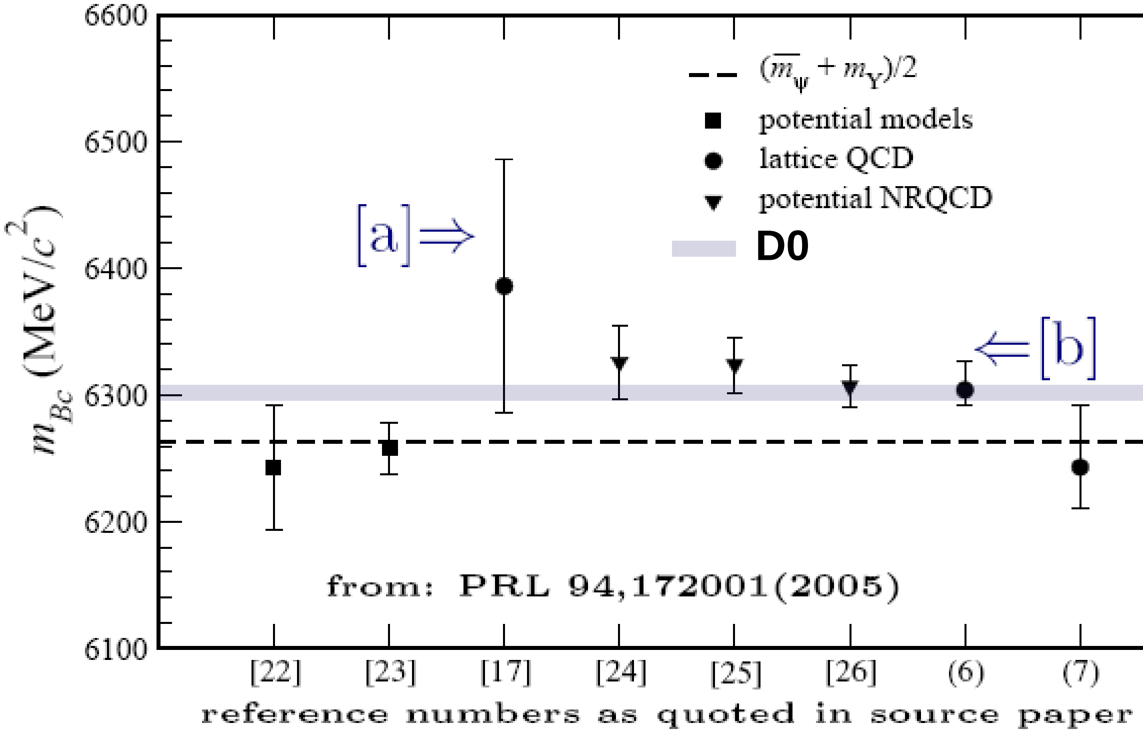


Signal significance > 5 σ

PRL 101, 012001 (2008)

$$M(B_c) = 6300 \pm 14\,(\text{stat}) \pm 5\,(\text{syst})\,\text{MeV/c}^2$$

B_c mass predictions



Lattice QCD:

- [a] Omitting sea quarks, (quenched approx.)
- [b] Add 2+1 sea flavors, u,d as light as possible, and strangeness mass

Our measurement is very consistent with predictions

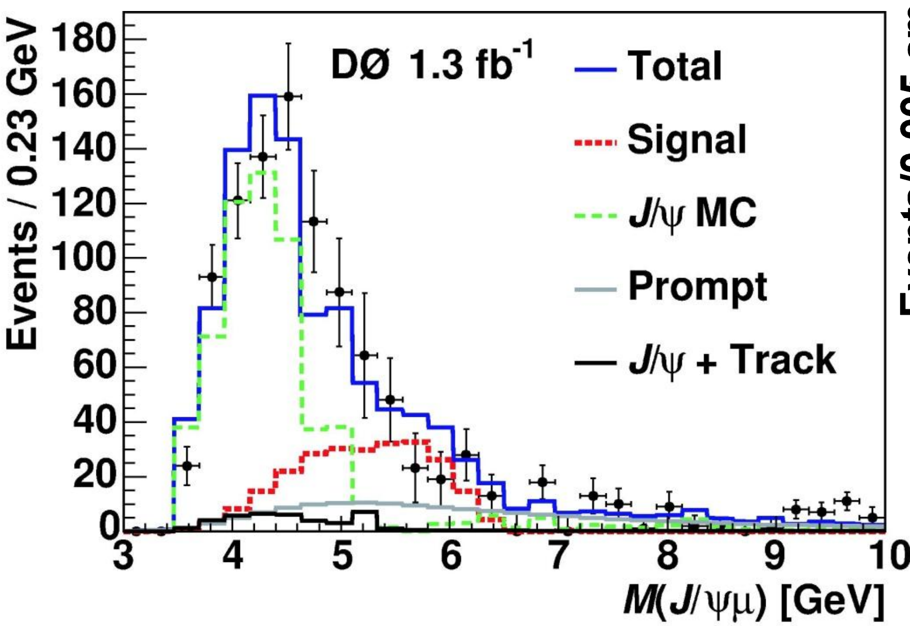
[a] PLB 453, 289 (1999)

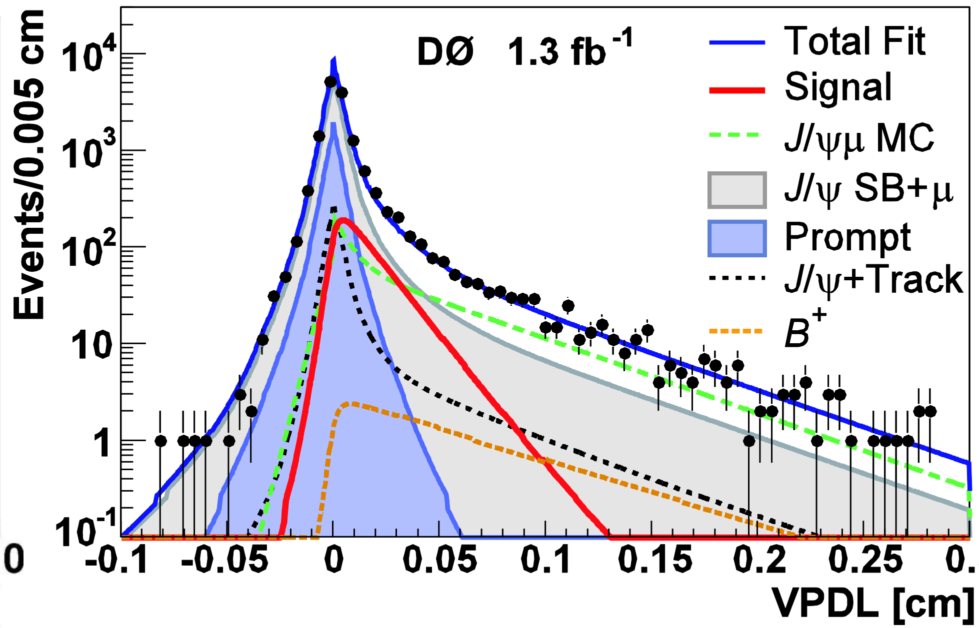
$$M(B_c) = 6386 \pm 9 \pm 15 \pm 98 \text{ MeV/c}^2$$

[b] PRL 94, 172001 (2005)

$$M(B_c) = 6304 \pm 4 \pm 11 ^{+18}_{-0} \text{ MeV/c}^2$$

B_c meson lifetime





- In addition we have measured the B_c lifetime in semileptonic decays to be:

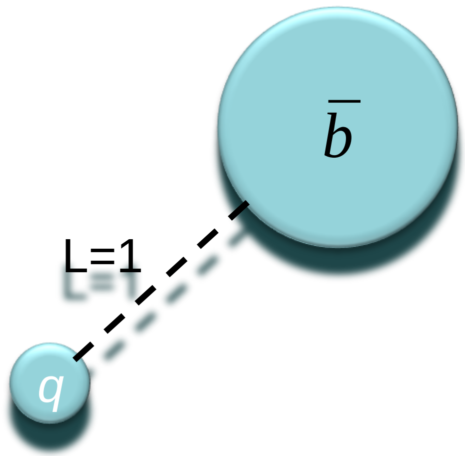
$$\tau(B_c) = 0.448^{+0.038}_{-0.036}\,(\text{stat}) \pm 0.032\,(\text{syst})\,\text{ps}$$

PRL 102, 092001 (2009)

Excited (L=1) B_s mesons

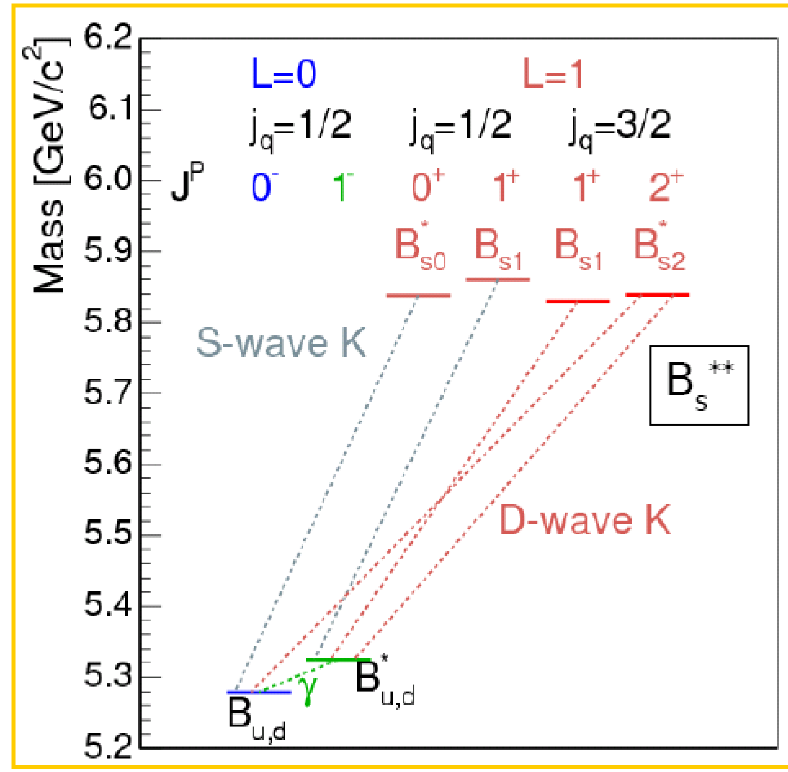
HQET:

Spin of quarks decouple



$j_q = 1 \oplus 1/2$ → 1/2, 3/2

$J = 1/2 \oplus j_q$ → $1/2 \oplus 1/2$ → 1^+, 0^+; $1/2 \oplus 3/2$ → 2^+, 1^+

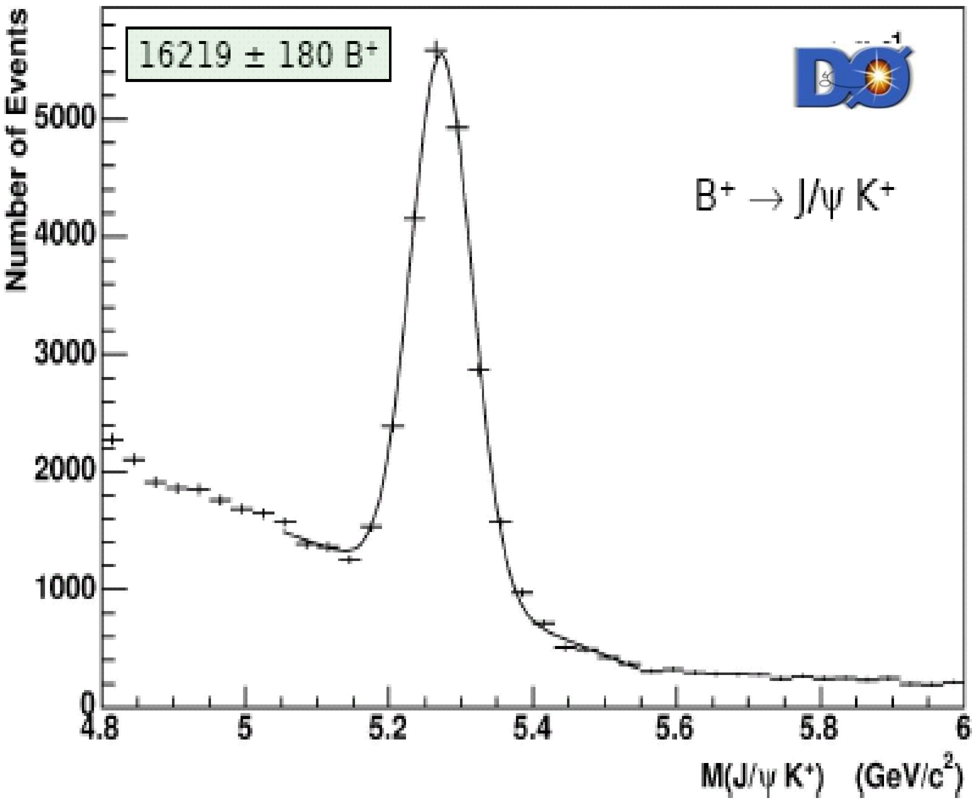


j_q=1/2 are wide states, we cannot observe them

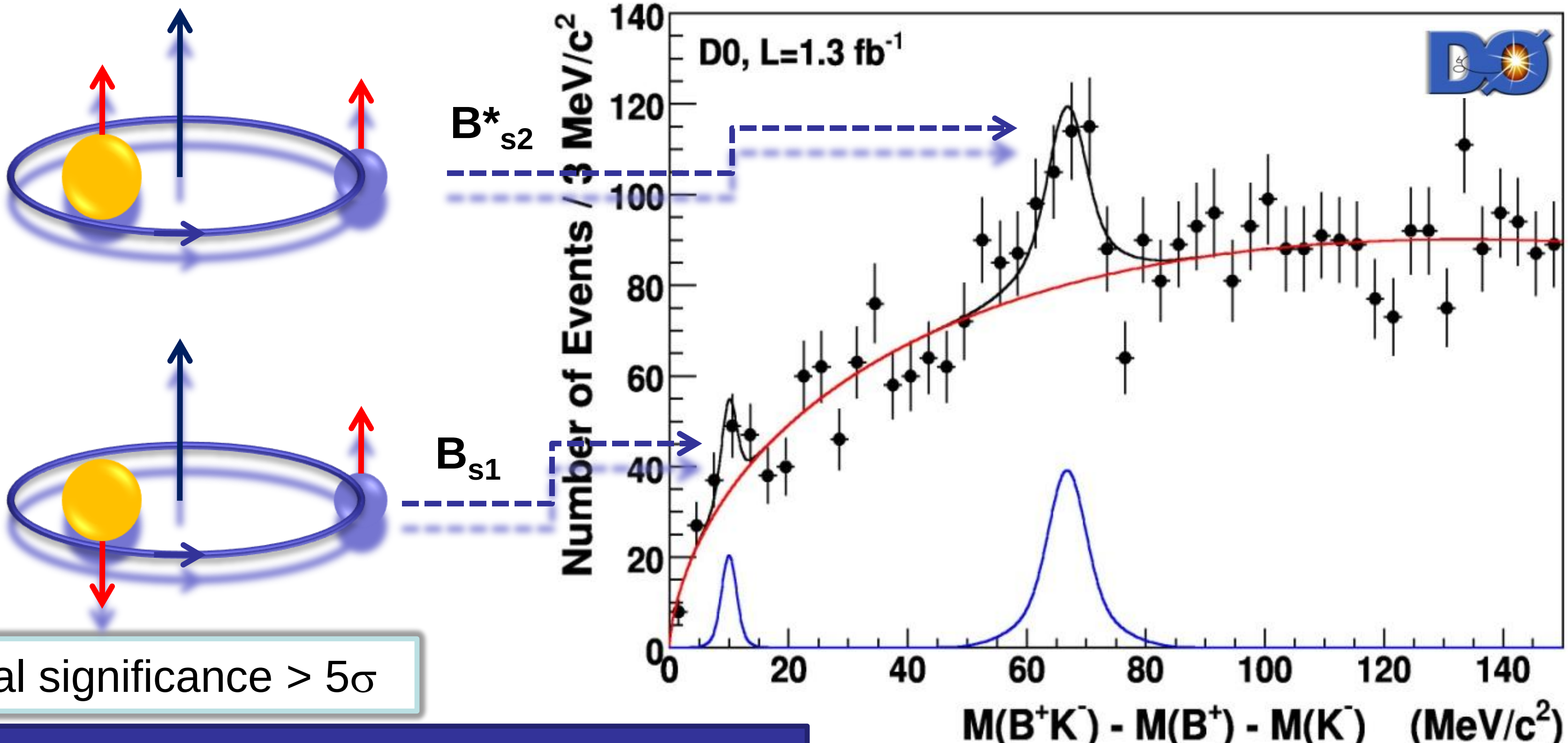
j_q=3/2 are narrow states (we can look for them)

Search for narrow B_s^{**} mesons

- Idea:
  - ✓ $B_s^{**} \to B^{(*)+}K^-$,
  - ✓ $B^{*+} \to B^+\gamma$ (γ undetected)
  - ✓ $B^+ \to J/\psi K^+$
  - ✓ Due to the undetected γ, we expect a Shift of possible B_{s2}^*, B_{s1} peaks by $\Delta M(B^{*+} - B^+) =$ 45.78 MeV/c² (see PDG)



Excited (L=1) B_s mesons



B^*_{s2} signal significance > 5σ

First direct observation of B_{s2}^*

$M(B_{s2}^*) = 5839.6 \pm 1.1(stat) \pm 0.7\ (syst)\ GeV/c^2$

$$\frac{Br(b \to B^*_{s2} \to B^+K^-)}{Br(b \to B^+)} = (1.15 \pm 0.23\,(stat) \pm 0.13\,(syst))\,\%$$

PRL 100, 082002 (2008)

When Tevatron Run II begun:

Notation	Quark content	J^P	SU(3)	(I,I_3)	S	Mass
Λ_b^0	**b[ud]**	**$1/2^+$**	**3***	**(0,0)**	**0**	**5619.7±1.2±1.2 MeV**
Ξ_b^0	b[su]	$1/2^+$	3*	(1/2,1/2)	-1	5.80 GeV
Ξ_b^-	b[sd]	$1/2^+$	3*	(1/2,-1/2)	-1	5.80 GeV
Σ_b^+	buu	$1/2^+$	6	(1,1)	0	5.82 GeV
Σ_b^0	b{ud}	$1/2^+$	6	(1,0)	0	5.82 GeV
Σ_b^-	bdd	$1/2^+$	6	(1,-1)	0	5.82 GeV
$\Xi_b^{0\prime}$	b{su}	$1/2^+$	6	(1/2,1/2)	-1	5.94 GeV
$\Xi_b^{-\prime}$	b{sd}	$1/2^+$	6	(1/2,-1/2)	-1	5.94 GeV
Ω_b^-	bss	$1/2^+$	6	(0,0)	-2	6.04 GeV
Σ_b^{*+}	buu	$3/2^+$	6	(1,1)	0	5.84 GeV
Σ_b^{*0}	bud	$3/2^+$	6	(1,0)	0	5.84 GeV
Σ_b^{*-}	bdd	$3/2^+$	6	(1,-1)	0	5.84 GeV
Ξ_b^{*0}	bus	$3/2^+$	6	(1/2,1/2)	-1	5.94 GeV
Ξ_b^{*-}	bds	$3/2^+$	6	(1/2,-1/2)	-1	5.94 GeV
Ω_b^{*-}	bss	$3/2^+$	6	(0,0)	-2	6.06 GeV

from hep-ph/9406359

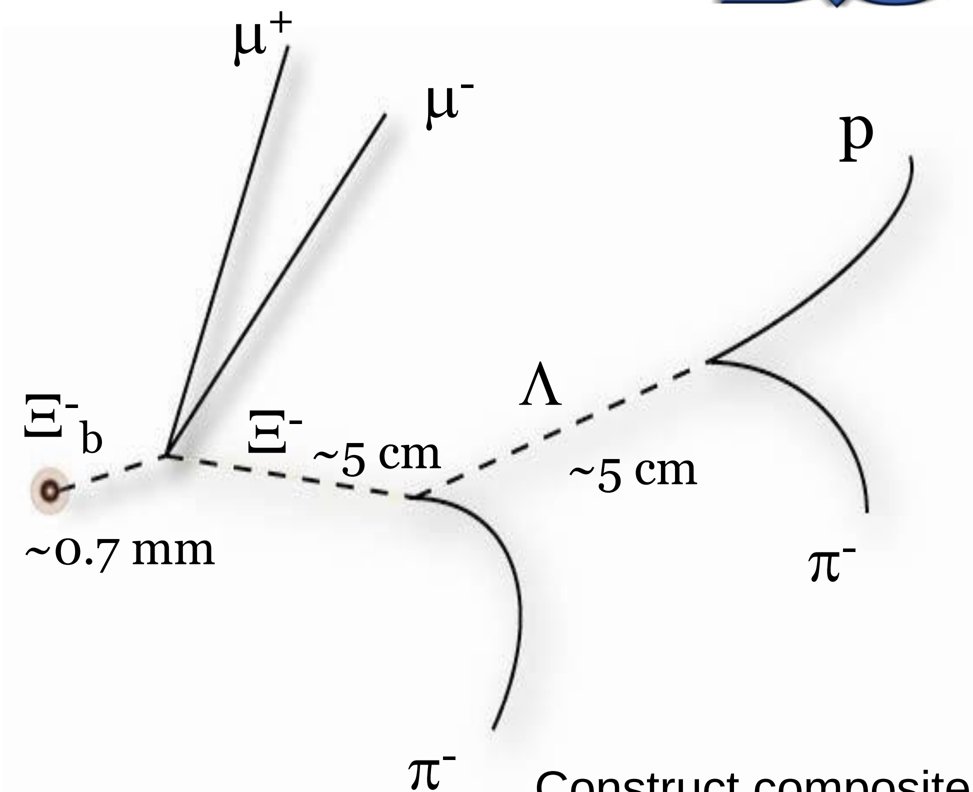
During Tevatron Run II

Notation	Quark content	J^P	SU(3)	(I,I_3)	S	Mass
Λ_b^0	b[ud]	$1/2^+$	3*	(0,0)	0	5620.2 ± 1.6 MeV
Ξ_b^0	b[su]	$1/2^+$	3*	(1/2,1/2)	-1	5.80 GeV
Ξ_b^-	b[sd]	$1/2^+$	3*	(1/2,-1/2)	-1	5792.4 ± 3.0 MeV
Σ_b^+	buu	$1/2^+$	6	(1,1)	0	5807.8 ± 2.7 MeV
Σ_b^0	b{ud}	$1/2^+$	6	(1,0)	0	5.82 GeV
Σ_b^-	bdd	$1/2^+$	6	(1,-1)	0	5815.2 ± 2.0 MeV
$\Xi_b^{0'}$	b{su}	$1/2^+$	6	(1/2,1/2)	-1	5.94 GeV
$\Xi_b^{-'}$	b{sd}	$1/2^+$	6	(1/2,-1/2)	-1	5.94 GeV
Ω_b^-	bss	$1/2^+$	6	(0,0)	-2	6.04 GeV
Σ_b^{*+}	buu	3/2+	6	(1,1)	0	5829.0 ± 3.4 MeV
Σ_b^{*0}	bud	$3/2^+$	6	(1,0)	0	5.84 GeV
Σ_b^{*-}	bdd	$3/2^+$	6	(1,-1)	0	5836.4 ± 2.8 MeV
Ξ_b^{*0}	bus	$3/2^+$	6	(1/2,1/2)	-1	5.94 GeV
Ξ_b^{*-}	bds	$3/2^+$	6	(1/2,-1/2)	-1	5.94 GeV
Ω_b^{*-}	bss	$3/2^+$	6	(0,0)	-2	6.06 GeV

Search for $\Xi_b^- \to J/\psi \Xi \to (\mu+\mu-)\Lambda\pi-$

Reconstruction procedure:

- ✓ Reconstruct $J/\psi \to \mu^+\mu^-$
- ✓ Reconstruct $\Lambda \to p\pi$
- ✓ Reconstruct $\Xi \to \Lambda + \pi$
- ✓ Combine $J/\psi + \Xi$
- ✓ Improve mass resolution by using an event-by-event mass difference correction
- ✓ **The optimization:**
  - ✓ **$\Lambda_b \to J/\psi\Lambda$ decays in data**
  - ✓ **$J/\psi + \Xi$(fake from $\Lambda(p\pi^-)\pi^+$)**
  - ✓ **Monte Carlo simulation of $\Xi_b^- \to J/\psi + \Xi^-$**



Construct composite particle from $\Lambda\pi$.

Ξ_b^- Search optimization

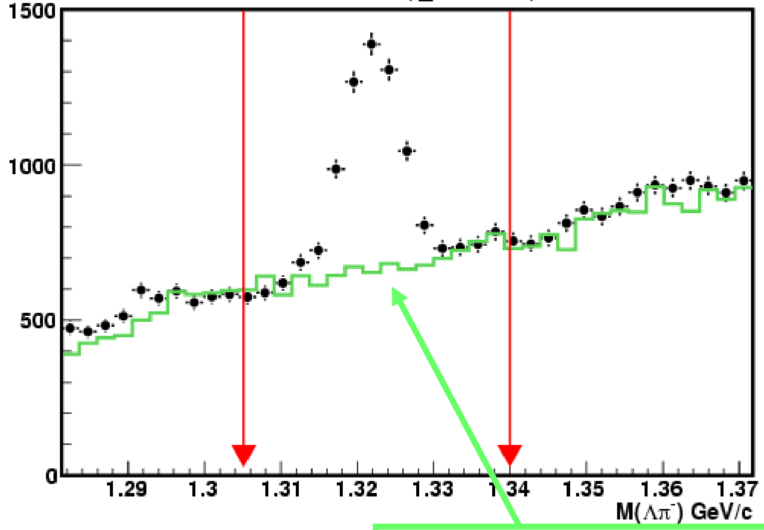
Final Ξ_b selection cuts:

- $\Lambda \to p\pi$ decays:
  - $p_T(p)>0.7$ GeV
  - $p_T(\pi)>0.3$ GeV
- $\Xi^- \to \Lambda\pi$ decays:
  - $p_T(\pi)>0.2$ GeV
  - Transverse decay length>0.5 cm
  - Collinearity>0.99
- Ξ^-_b particle:
  - Lifetime significance>2. (Lifetime divided by its error)

Based on:

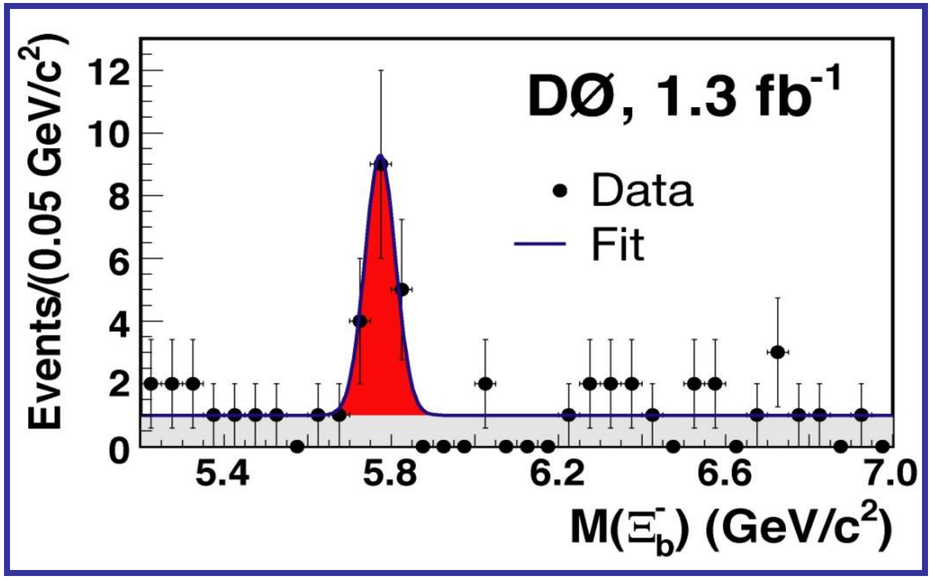
- $\Lambda_b \to J/\psi\Lambda$ decays in data
- $J/\psi + \Xi$(fake from $\Lambda(p\pi-)\pi+$)

$$\Xi^- \to \Lambda(p\pi^-)\pi^-$$



Background events from wrong-sign combinations ($\Lambda(p\pi^-)\ \pi^+$)

Ξ^-_b observation (DØ)



Number of events: 15.2 ± 4.4

Mass: 5.774 ± 0.011(stat) GeV

Width: 0.037 ± 0.008 GeV

Signal significance > 5 σ

- Fit:
  - Unbinned extended log-likelihood fit
  - Gaussian signal, flat background
  - Number of background/signal events are floating parameters

We also measured:

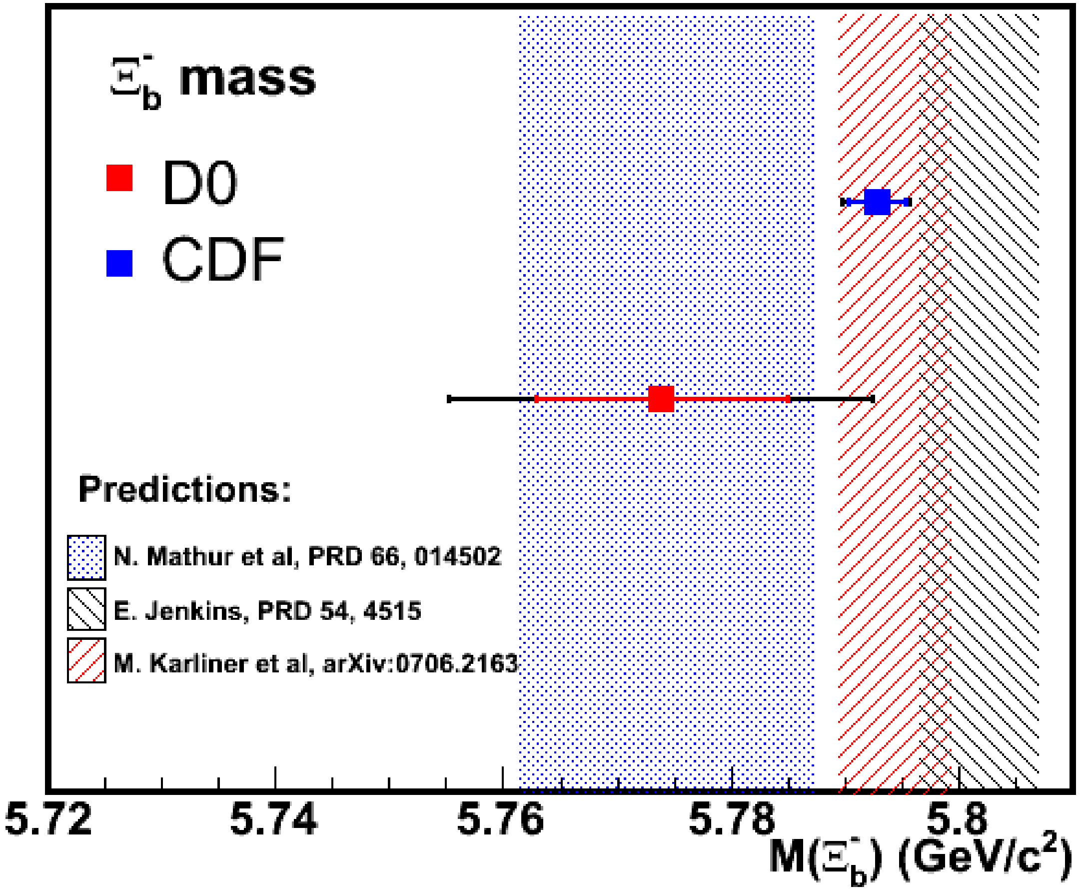
$$R = \frac{\sigma(\Xi_b^-)BR(\Xi_b^- \to J/\psi\,\Xi^-)}{\sigma(\Lambda_b)BR(\Lambda_b \to J/\psi\Lambda)}$$

$$R = 0.28 \pm 0.09\,(\text{stat})\,^{+0.09}_{-0.08}\,(\text{syst})$$

$$M(\Xi_b^-) = 5.774 \pm 0.011\,(\text{stat}) \pm 0.015\,(\text{syst})$$

PRL 99, 052001 (2007)

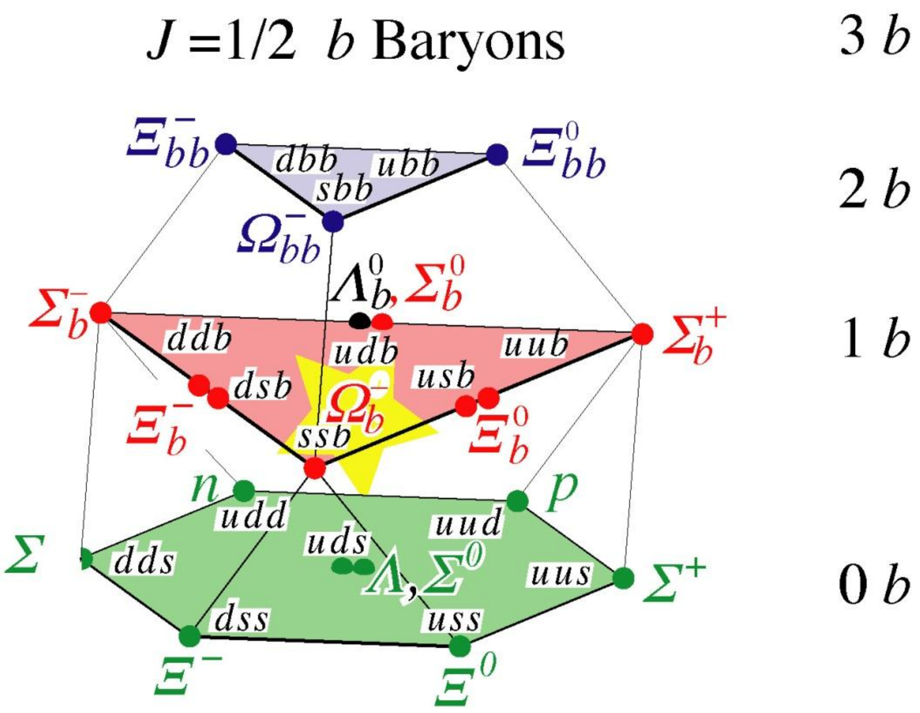
Comparison: Experiment/Theory



DØ PRL 99, 052001 (2007)

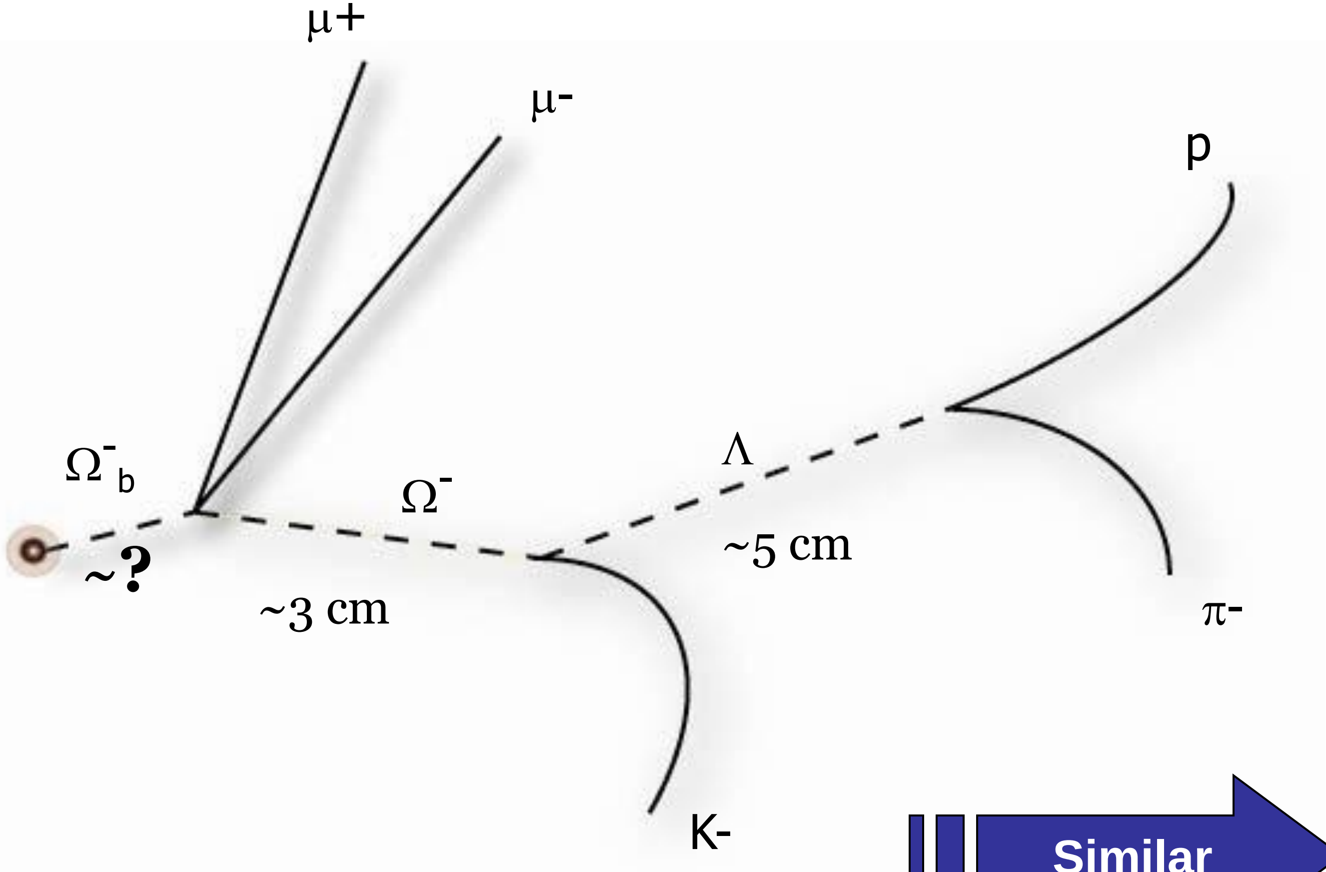
CDF PRL 99, 052002 (2007)

Search for the Ω^-_b(bss)

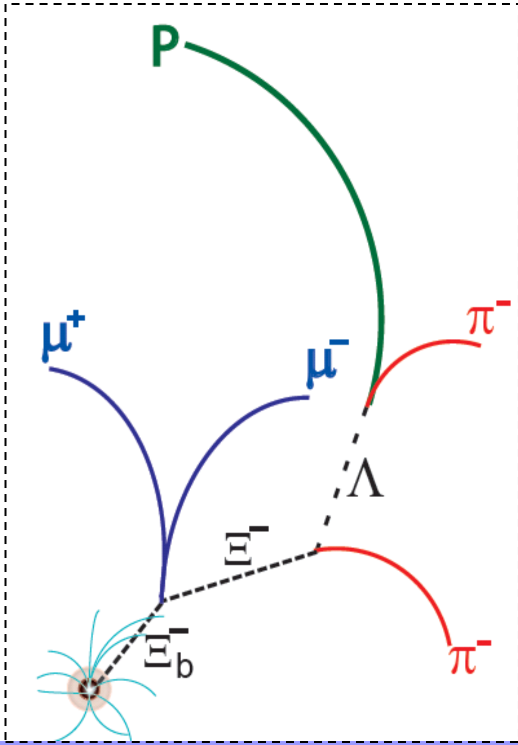


- *bss* quarks combination
- Mass is predicted to be 5.94 - 6.12 GeV
- $M(\Omega^-_b) > M(\Lambda_b)$
- Lifetime is predicted to be $0.83<\tau(\Omega^-_b)<1.67$ ps

How do we look for it?



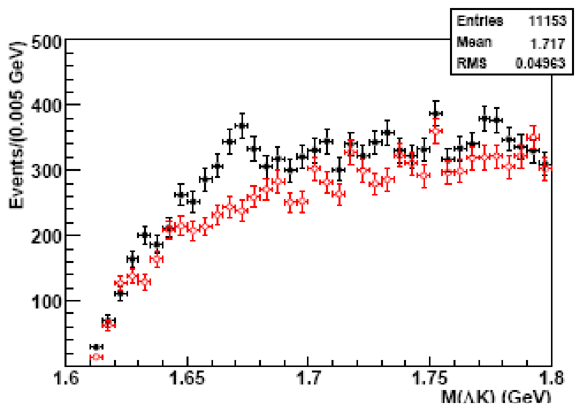
Similar

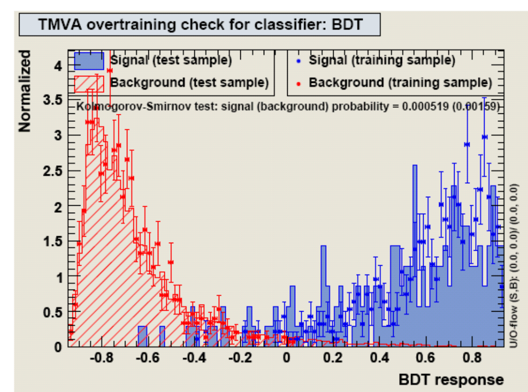


Analysis strategy

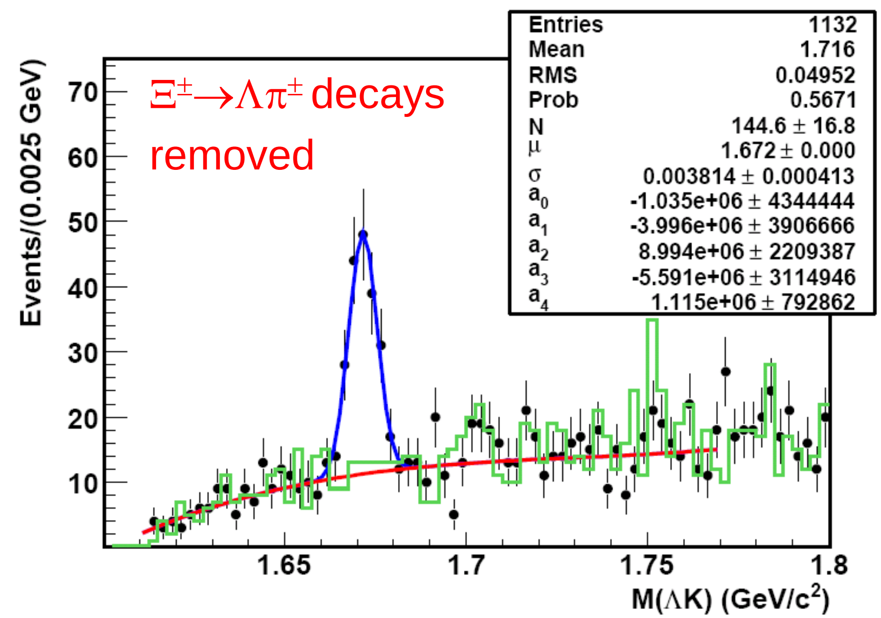
Select J/ψ candidates	Events are reprocessed to increase reconstruction efficiency of long-lived particles.
Select $\Lambda \to p\pi$	Yield is optimized by using proper decay length significance cuts.
Reconstruction of $\Omega \to \Lambda + K$	Optimize yield by using multivariate techniques
Combine $J/\psi + (\Lambda K^+)$	Keep blinded $J/\psi + \Omega$ combinations and optimize on $J/\psi + (\Lambda K^+)$
Event per event mass correction	Improve mass resolution from 80 MeV to 34 MeV
Fix selection criteria and then apply them to $J/\psi + \Omega$	Perform as many test as possible in different background samples

BDT to select $\Omega^- \to \Lambda K$ decays



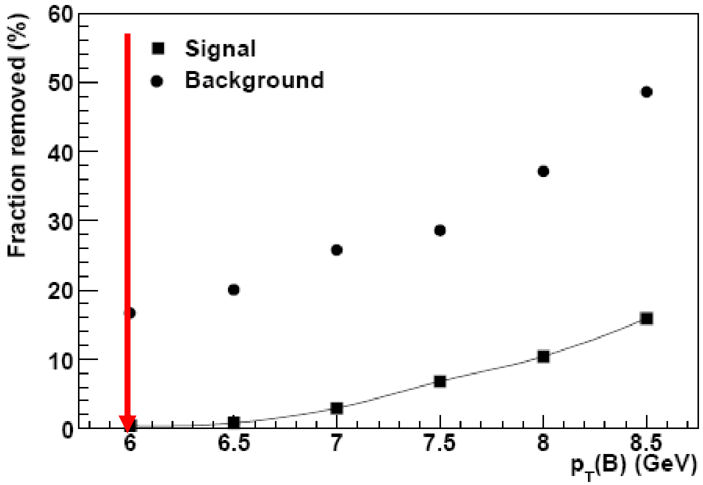


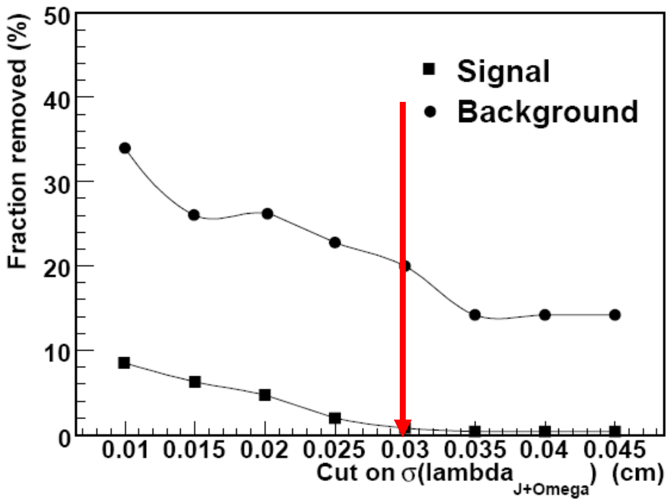
Variable description
Λ vertex χ^2
Λ collinearity
Λ lifetime significance
p track (from Λ) χ^2
p (from Λ) combined impact parameter significance
p track SMT hits
p track CFT hits
π track (from Λ) χ^2
π (from Λ) combined impact parameter significance
π track SMT hits
π track CFT hits
p (from Λ) p_T
π (from Λ) p_T
Λ transverse decay length
Error on Λ transverse decay length
Error on Ω^- transverse decay length
Ω^- transverse decay length
Ω^- collinearity
K^- (from Ω^-) p_T
K^- (from Ω^-) combined impact parameter significance



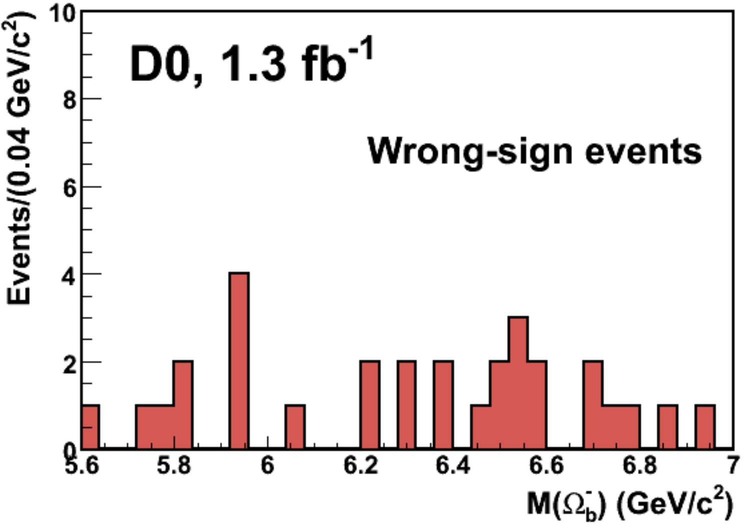
Final optimization

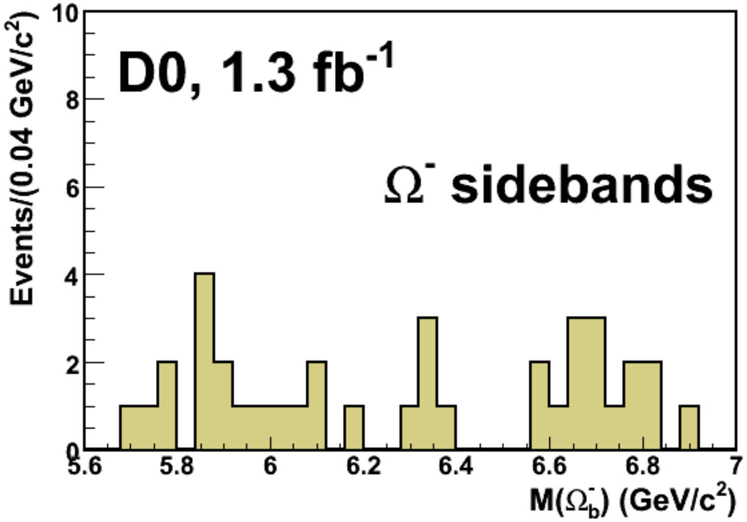
- We compare MC signal vs wrong-sign background events.

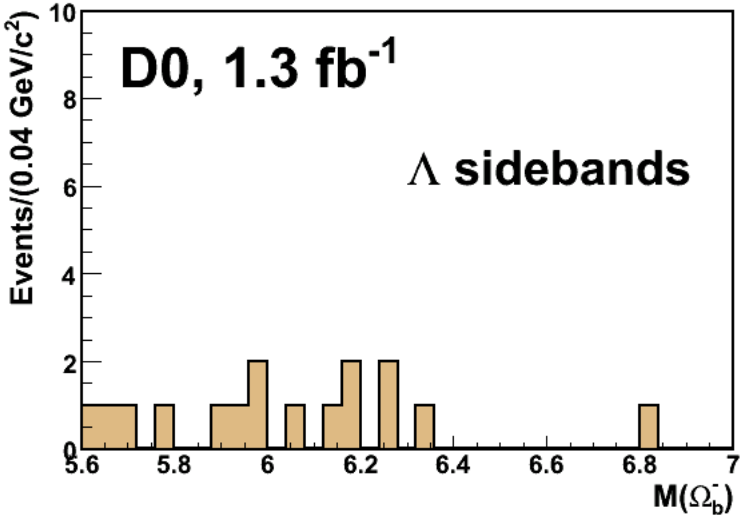




Nothing where nothing should be







We check also high statistics MC samples

$$\Lambda_b \to J/\psi\Lambda \to (\mu^+\mu^-)(p\pi^-)$$

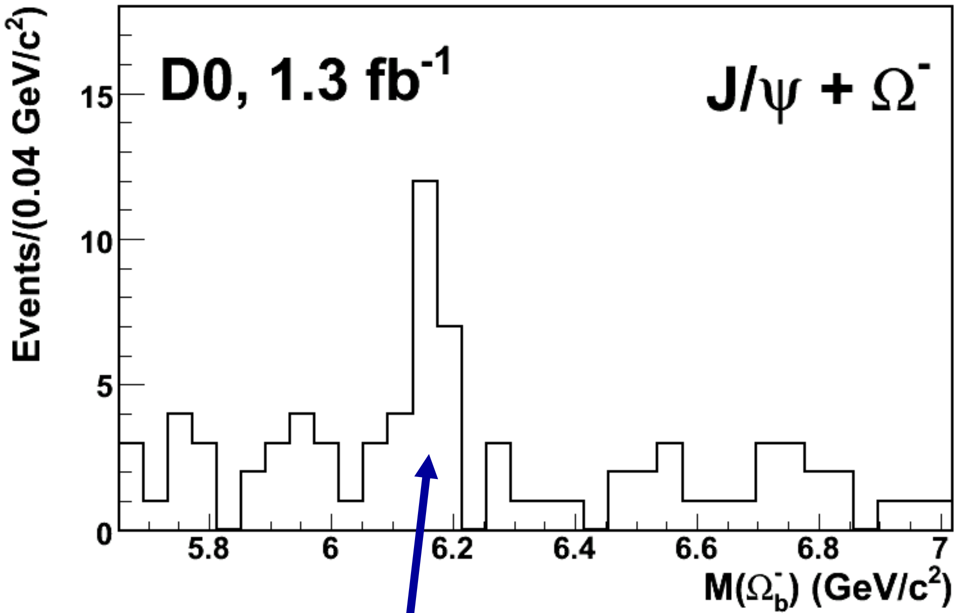
$$B^- \to J/\psi K^{*-} \to (\mu^+\mu^-)(K_S^0\pi^-) \to (\mu^+\mu^-)((\pi^+\pi^-)\pi^-)$$

$$\Xi_b^- \to J/\psi\Xi^- \to (\mu^+\mu^-)(\Lambda\pi^-) \to (\mu^+\mu^-)((p\pi^-)\pi^-)$$

No excess is observed in any control samples after selection criteria is applied to them.

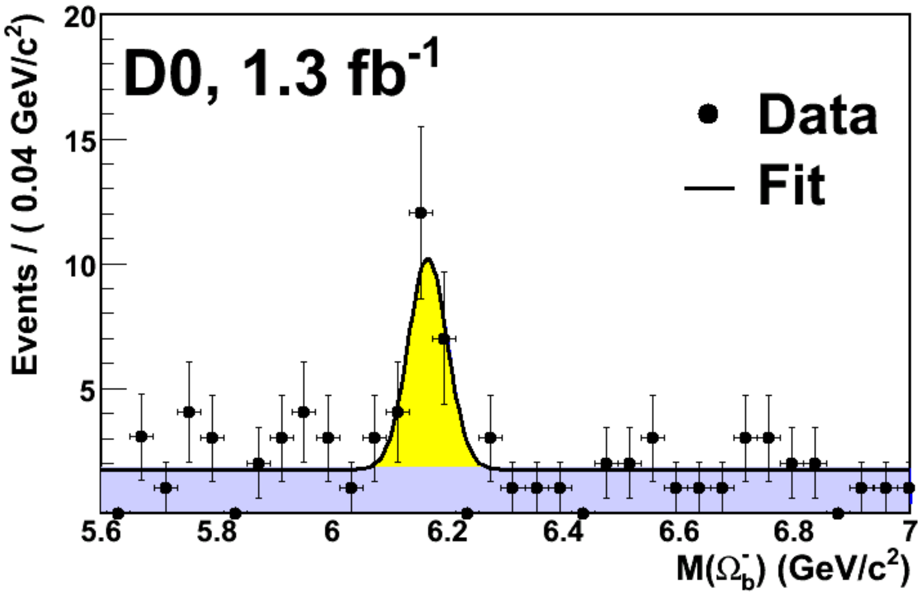
Looking at right-sign combinations

- After optimization:
  - σ_λ<0.03 cm
  - J/ψ and Ω in the same hemisphere
  - p_T(J/ψ+Ω)>6 GeV
- Mass window for the search: 5.6 - 7 GeV



Clear excess of events near 6.2 GeV

Ω_b^- mass measurement



- Fit:
  - Unbinned extended log-likelihood fit
  - Gaussian signal, flat background
  - Number of background/signal events are floating parameters

N= 17.8 ± 4.9 (stat) ± 0.8(syst)

Mass: 6.165 ± 0.010(stat) ± 0.013(syst) GeV

Width fixed (MC): 0.034 GeV

Signal significance > 5 σ

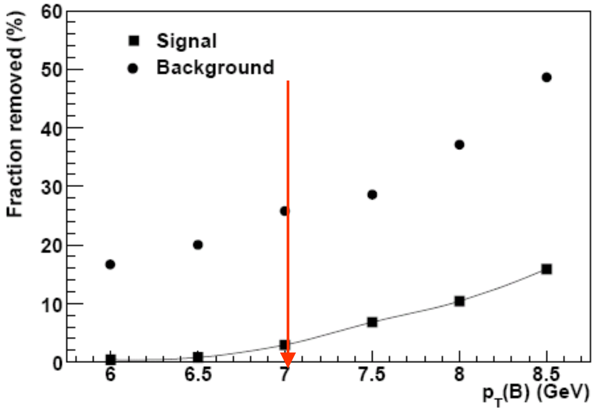
$$R = \frac{f(b \to \Omega_b^-) Br(\Omega_b^- \to J/\psi\ \Omega^-)}{f(b \to \Xi_b^-) Br(\Xi_b^- \to J/\psi\ \Xi^-)}$$

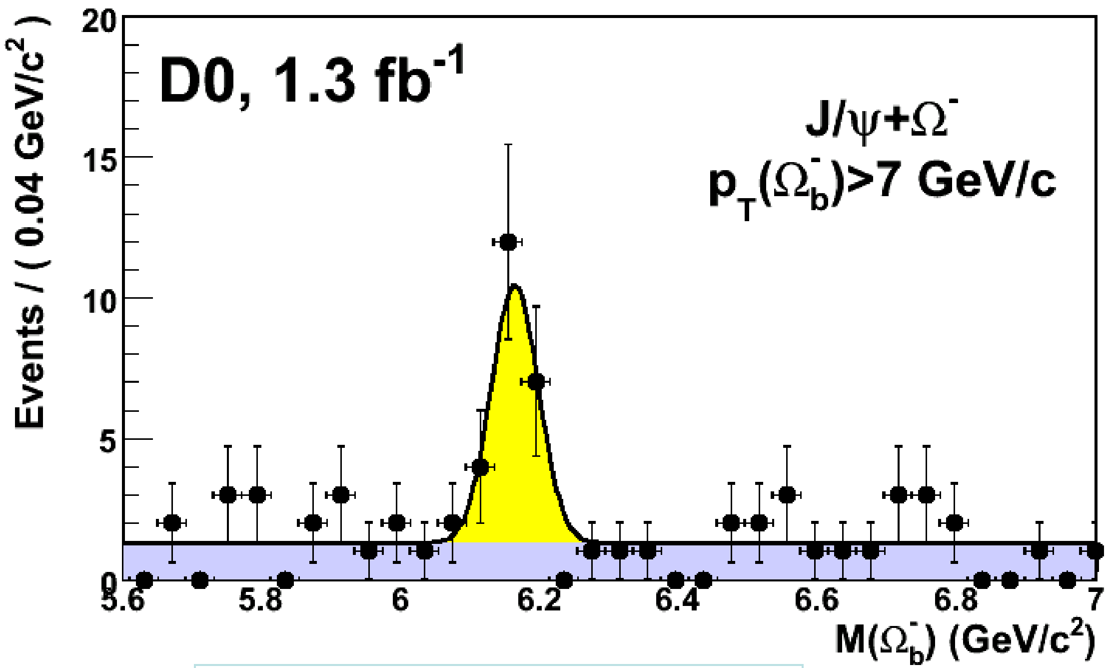
$$R = 0.80 \pm 0.32(stat)^{+0.14}_{-0.22}(syst)$$

PRL 101, 232002 (2008)

$$M(\Omega_b^-) = 6.165 \pm 0.010(\mathrm{stat}) \pm 0.013(\mathrm{syst})\ \mathrm{GeV}$$

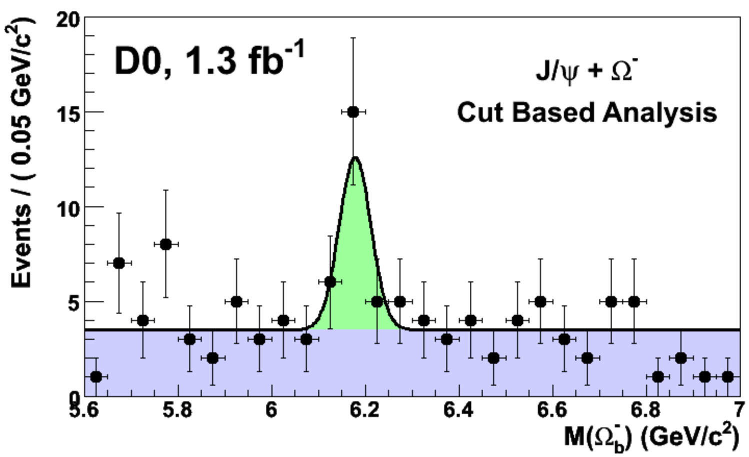
Consistency check: Increase $p_T(B)$





Signal significance > 6 σ

Cut Based Analysis (CBA)



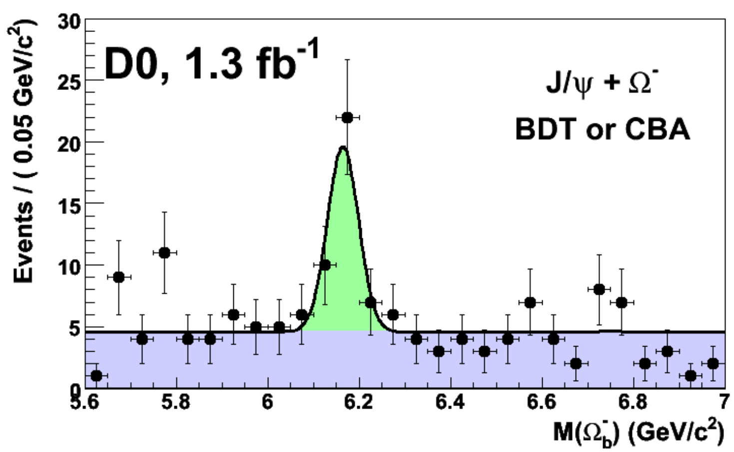
Variable	BDT	CBA
$p_T(\pi)$ (GeV)	>0.2 and input to BDT	>0.2
$p_T(p)$ (GeV)	>0.2 and input to BDT	>0.7
$p_T(K)$ (GeV)	input to BDT	>0.3
Ω^- collinearity	input to BDT	>0.99
Ω^- transverse decay length (cm)	input to BDT	>0.5
Proper decay length uncertainty (cm)	<0.3	<0.3

Number of signal events: 15.7 ± 5.3

Mean : 6.177 ± 0.015(stat) GeV

Width fixed (MC): 0.034 GeV

Signal significance ~4σ



- After remove duplicate events, we observe 25.5 ± 6.5 events.
- Significance > 5σ

Summary

Many unique results coming from D0:

- Direct observation of B_{s1} and B_{s2}^{*}
- Precise measurement of the B_c mass and lifetime.
- First observation of Ξ_b^- and Ω_b^- baryons
- Not shown here many more results ...

http://www-d0.fnal.gov/Run2Physics/WWW/results/b.htm