B Baryon Spectroscopy

Lattice QCD Meets Experiment

Workshop

Dec. 11, 2007

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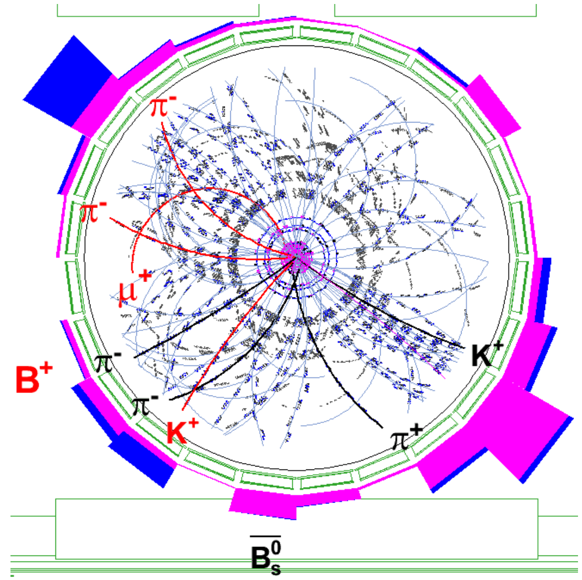
on behalf of the CDF and D0 collaborations

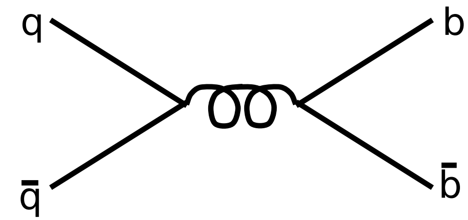
B baryon production at the Tevatron

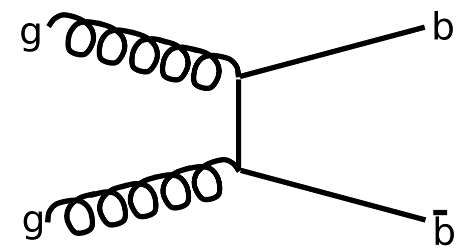
At present Tevatron is the only place to study B baryons:

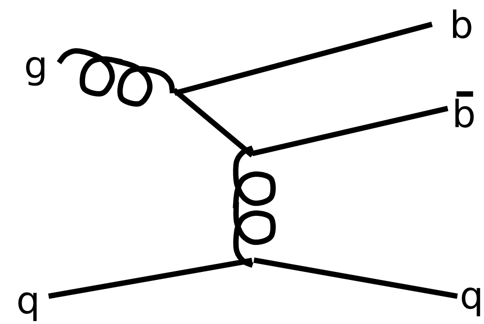
➔ Production of all B hadron species in fragmentation

➔ Huge $b\bar{b}$ cross section









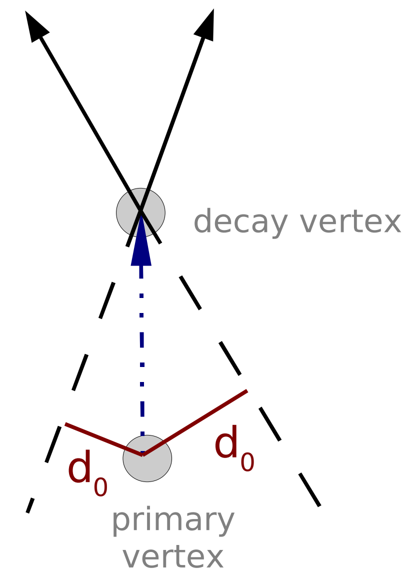
but

- $\sim 10^3$ times larger inelastic cross section
  $\rightarrow$ Trigger
- Soft p_T spectrum, limited η acceptance
  $\rightarrow$ Low efficiency
- Background tracks from fragmentation
  $\rightarrow$ High combinatorial background

B baryon detection

Trigger

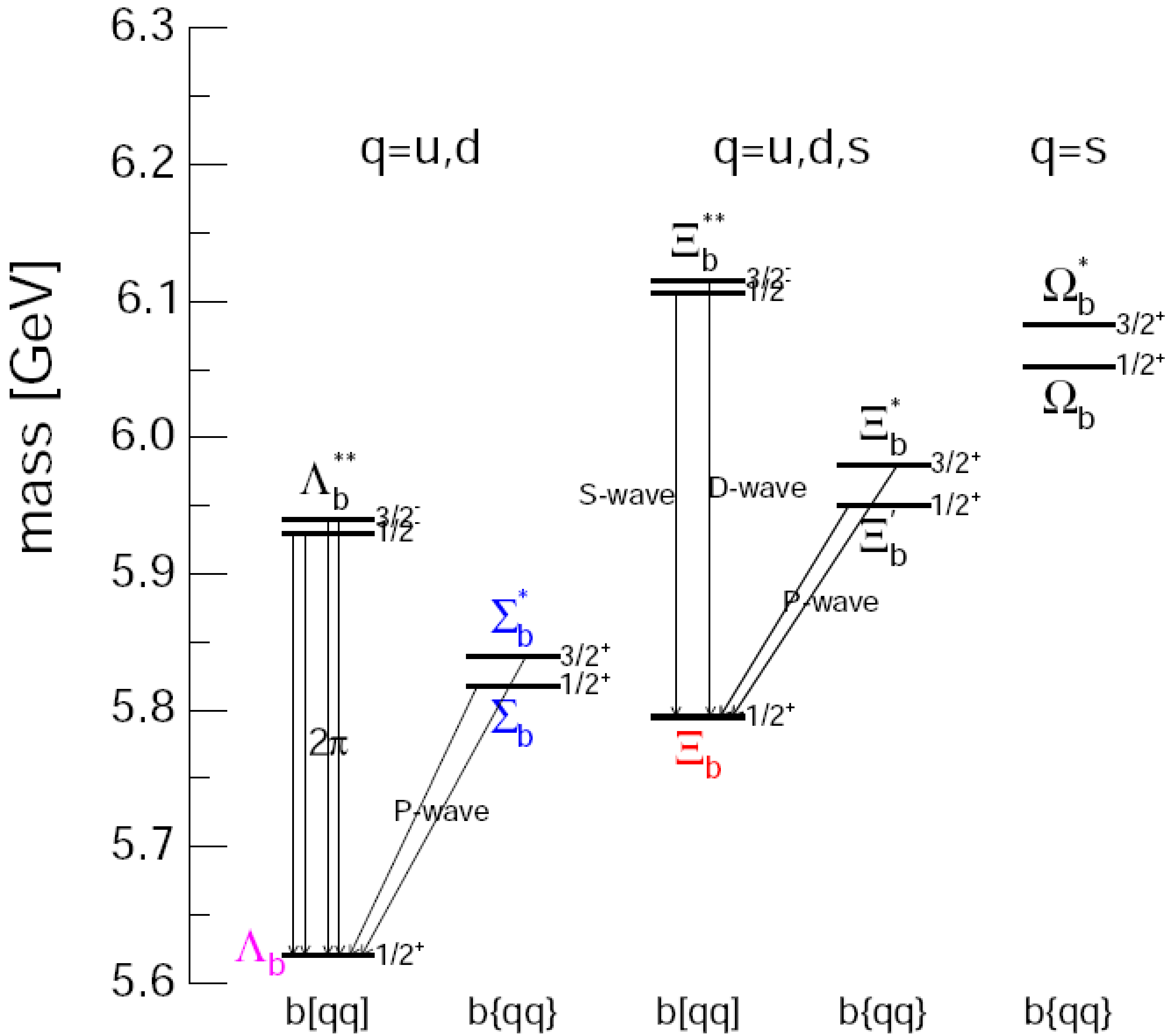
- Single muon (D0) $\rightarrow$ semileptonic decays
- Dimuon (CDF+D0) $\rightarrow$ decays to (J/)ψ X
- Displaced tracks (CDF) $\rightarrow$ hadronic and semileptonic decays

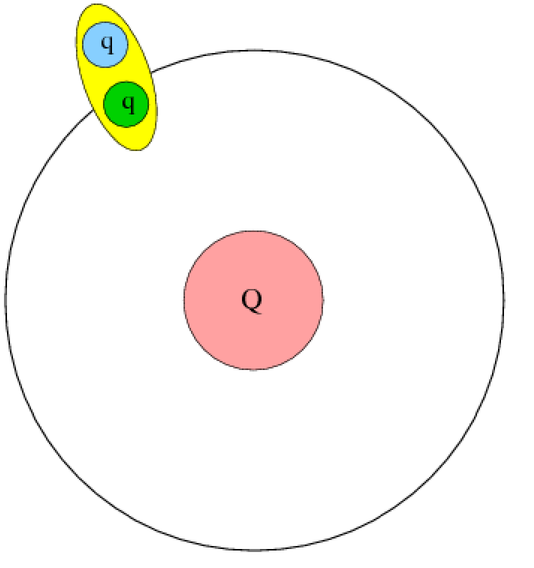


Reconstruction

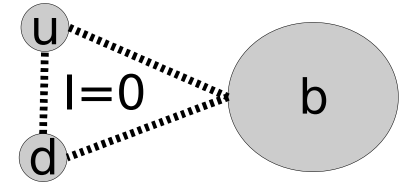
- Good charged particle and secondary vertex reconstruction in tracker
- PID in muon chambers, dE/dx, ToF
- Photon reconstruction only via conversion (at low p_T)
- No neutron and neutrino reconstruction (at low p_T)

B baryon spectrum





Λ_b Lifetime



(Mass: $m(\Lambda_b) = 5619.7 \pm 1.2 \pm 1.2$ MeV) PRL **96**, 202001 (2006)

- Spectator model: $\tau(\Lambda_b) = \tau(B^0)$
- Prediction: $\tau(\Lambda_b) / \tau(B^0) = 0.88 \pm 0.05$ Tarantino, Eur.Phys.J. **C33** (2004)

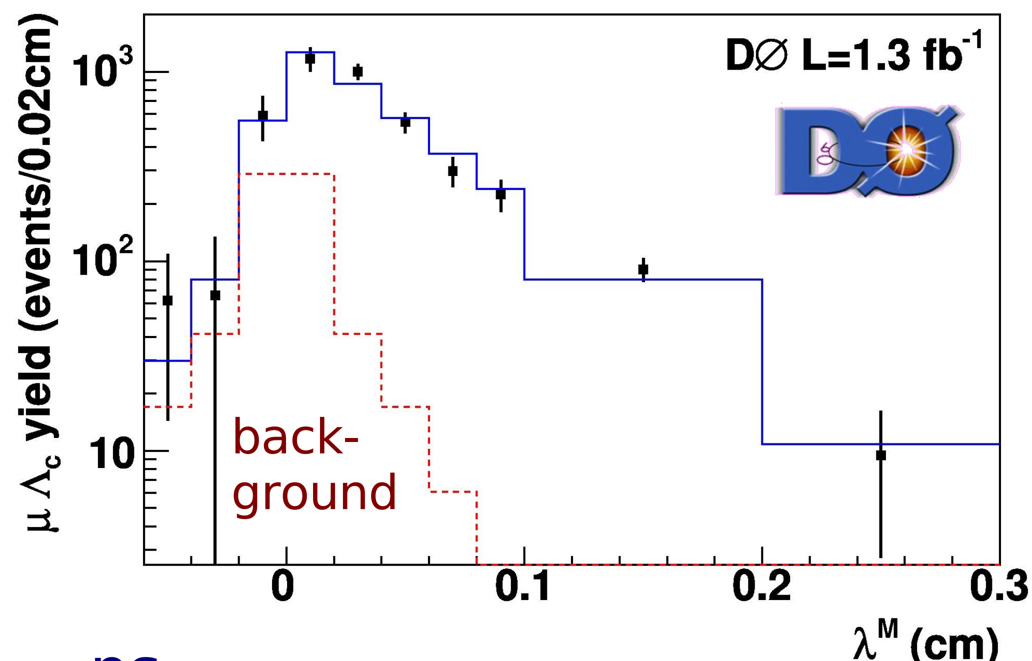
PRL **99**, 182001 (2007)

Semileptonic decay:

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

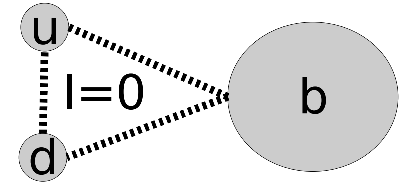
$\Lambda_c^+ \rightarrow K^0_S\, p$

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



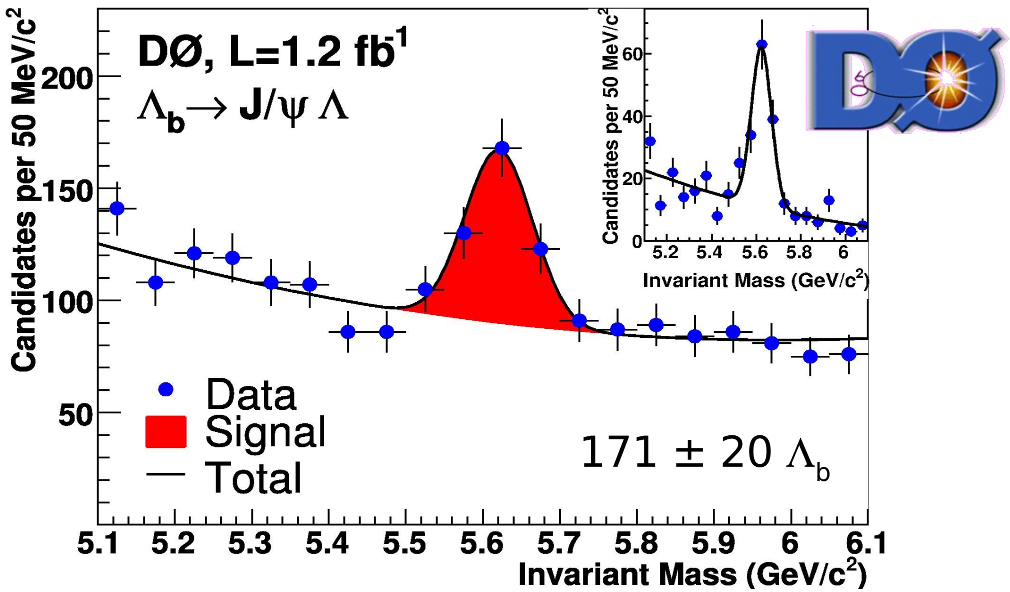
$\tau(\Lambda_b) = 1.290\ ^{+0.119}_{-0.110}\ ^{+0.087}_{-0.091}$ ps

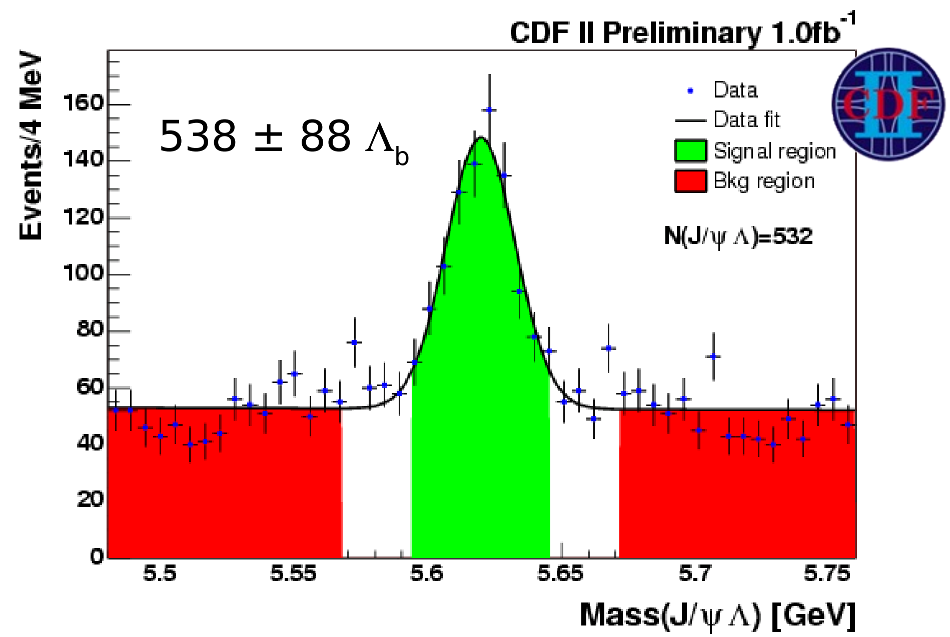
Λ_b Lifetime



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

PRL **99**, 142001 (2007)





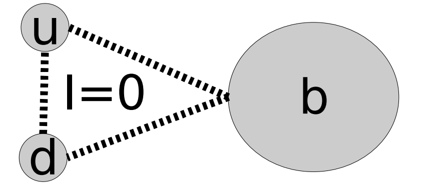
✔ Cross check: $B^0 \to J/\psi\ K^0_S$

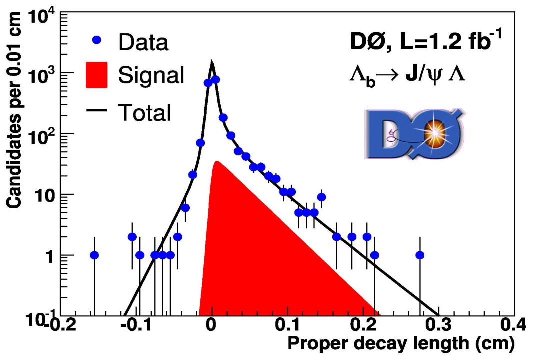
D0 : $\tau(B^0) = 1.501\ ^{+0.078}_{-0.074} \pm 0.050$ ps

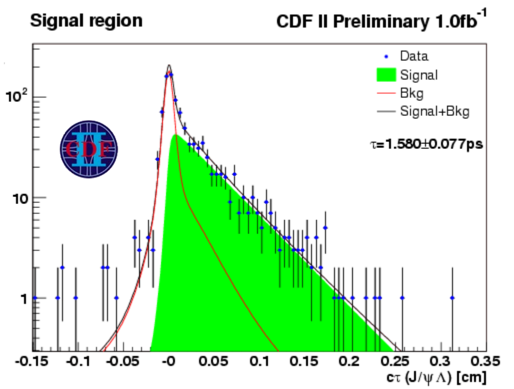
CDF : $\tau(B^0) = 1.551 \pm 0.019 \pm 0.011$ ps

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

Λ_b Lifetime

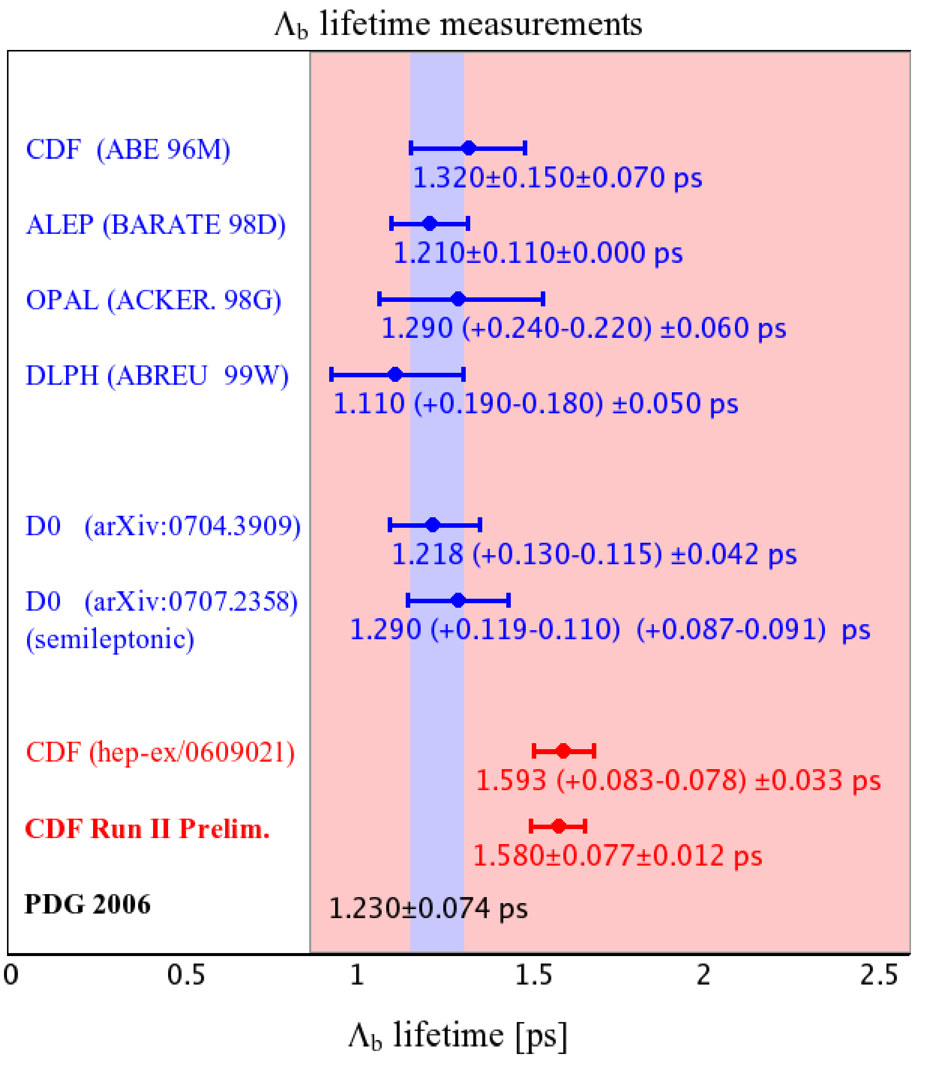




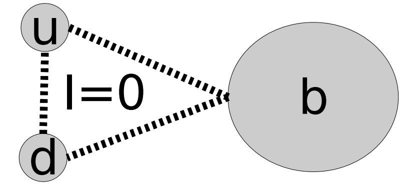


- D0 results consistent with world average
- CDF result ~3σ above world average
- D0 and CDF $\Lambda_b^0 \to J/\psi\ \Lambda^0$ results consistent at ~2σ

➔ Need more measurements



Fully hadronic Λ_b decays

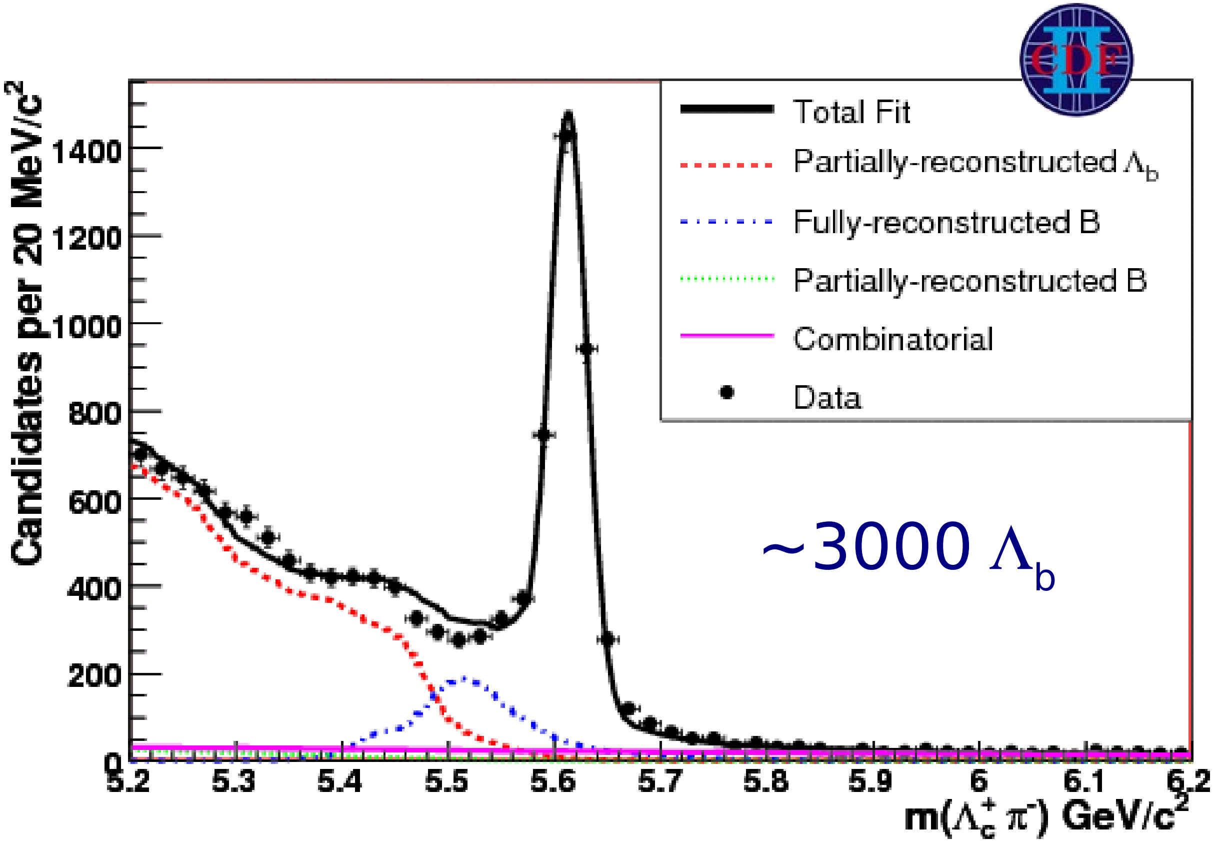


- Fully hadronic Λ_b decay

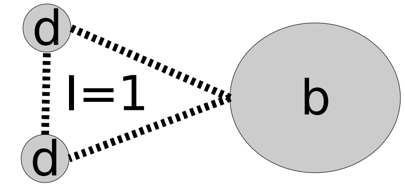
  $\Lambda_b^0 \to \Lambda_c^+ \pi^-$,

  $\Lambda_c^+ \to p K^- \pi^+$

  - Displaced track trigger
  - → Bias on lifetime
  - → Hadronic Λ_b sample so far only used for Σ_b search



Σ_b strategy



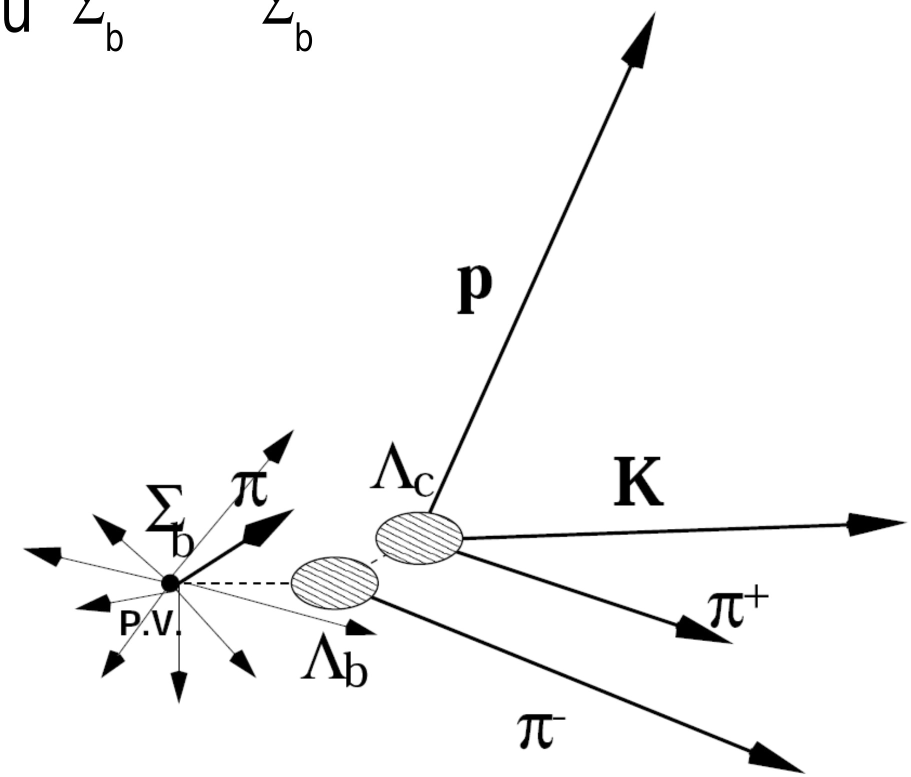
- Decay mode:
  $\Sigma_b^{(*)\pm} \rightarrow \Lambda_b^0 \pi^\pm$,
  $\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-$,
  $\Lambda_c^+ \rightarrow p K^- \pi^+$

		J=1/2	J=3/2	
I_3=-1	bdd	Σ_b^-	Σ_b^{*-}	
I_3=0	bdu	Σ_b^0	Σ_b^{*0}	(no π^0 reconstruction)
I_3=+1	buu	Σ_b^+	Σ_b^{*+}	

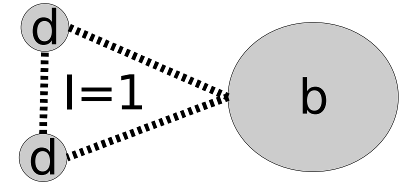
➔ Optimize Λ_b and Σ_b cuts

➔ Look at Q-value spectrum (better resolution than mass):
$Q = m(\Lambda_b\pi) - m(\Lambda_b) - m(\pi)$

➔ Σ_b background (Λ_b, B, comb.):
- Normalization from Λ_b fit
- Shape from PYTHIA



Σ_b result



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

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

- Unbinned fit:

$Q(\Sigma_b^+) = 48.5\ ^{+2.0}_{-2.2}\ ^{+0.2}_{-0.3}$ MeV/c²

$Q(\Sigma_b^-) = 55.9 \pm 1.0 \pm 0.2$ MeV/c²

$\Delta\Sigma_b^* = 21.2\ ^{+2.0}_{-1.9}\ ^{+0.4}_{-0.3}$ MeV/c²

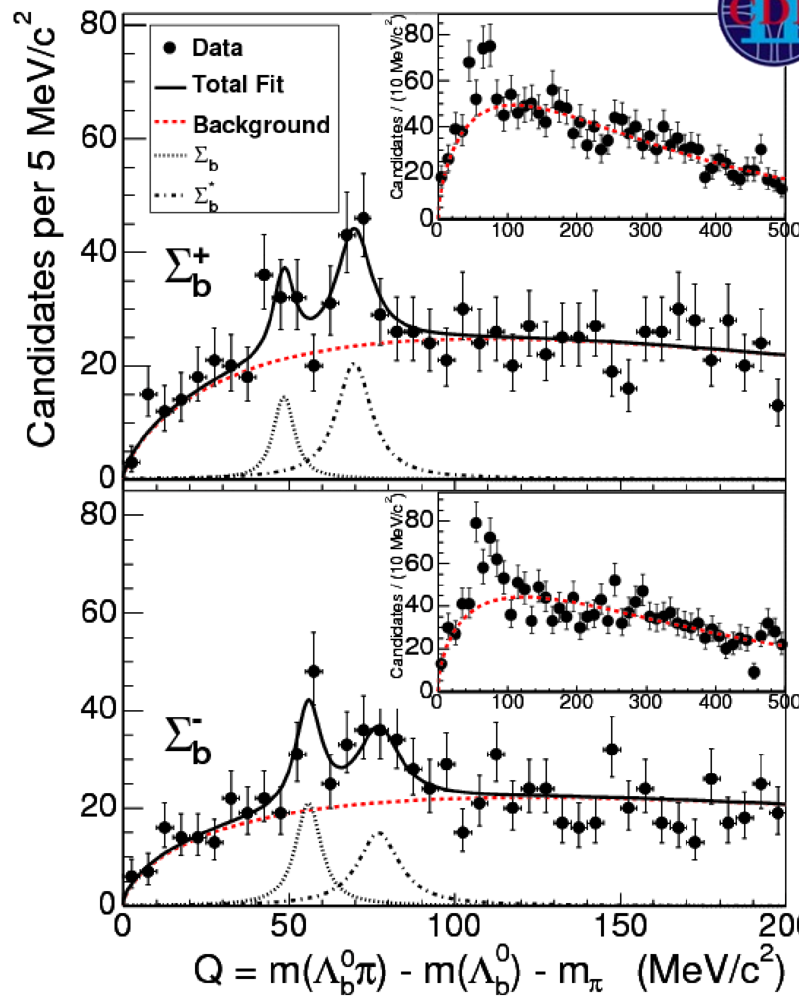
$m(\Sigma_b^+) = 5807.8\ ^{+2.0}_{-2.2} \pm 1.7$ MeV/c²

$m(\Sigma_b^-) = 5815.2 \pm 1.0 \pm 1.7$ MeV/c²

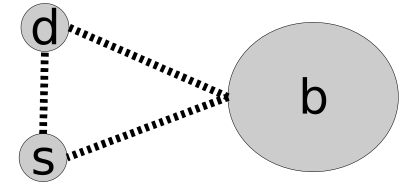
$m(\Sigma_b^{*+}) = 5829.0\ ^{+1.6}_{-1.8}\ ^{+1.7}_{-1.8}$ MeV/c²

$m(\Sigma_b^{*-}) = 5837 \pm 2.0\ ^{+1.8}_{-1.7}$ MeV/c²

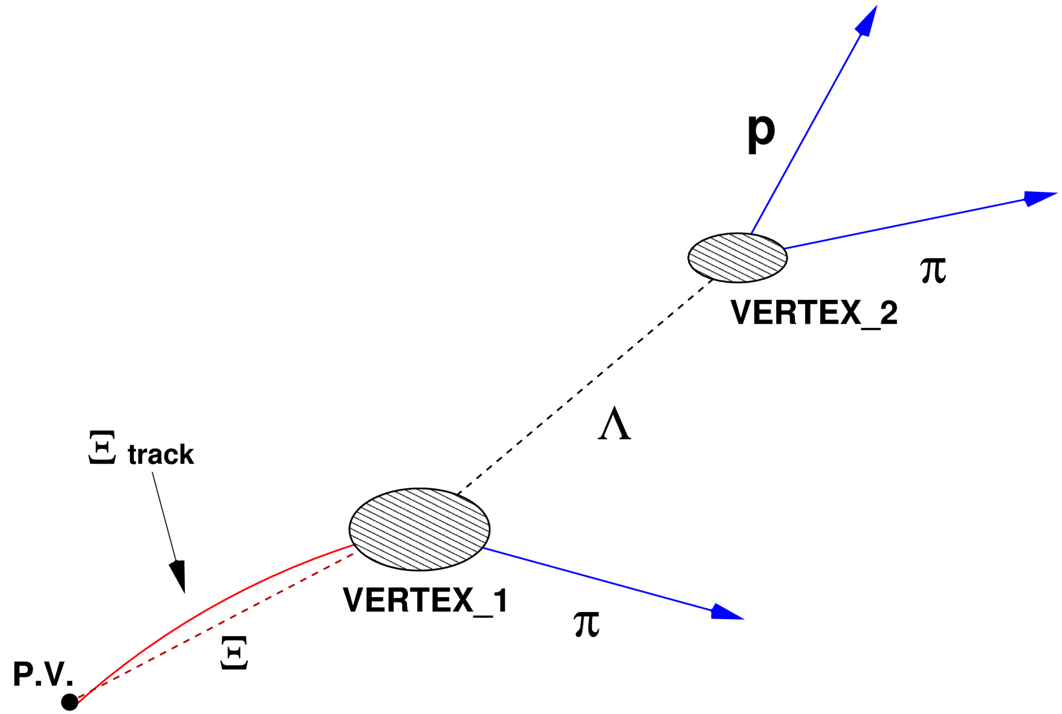
PRL **99**, 202001 (2007)



Search for Ξ_b

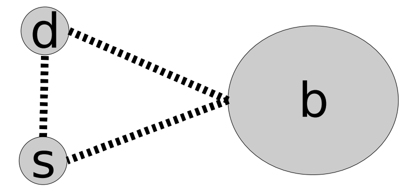


- Dimuon trigger,
  - $\Xi_b^- \rightarrow J/\psi\, \Xi^-$,
    $J/\psi \rightarrow \mu^+\mu^-$, $\Xi^- \rightarrow \Lambda^0 \pi^-$
- Displaced track trigger
  - $\Xi_b^- \rightarrow \Xi_c^0\, \pi^-$,
    $\Xi_c^0 \rightarrow \Xi^-\, \pi^+$, $\Xi^- \rightarrow \Lambda^0 \pi^-$
  - $\Xi_b^0 \rightarrow \Xi_c^+\, \pi^-$,
    $\Xi_c^+ \rightarrow \Xi^-\, \pi^+ \pi^+$, $\Xi^- \rightarrow \Lambda^0 \pi^-$
- Lepton trigger
  - $\Xi_b \rightarrow \Xi_c\, l^- X$



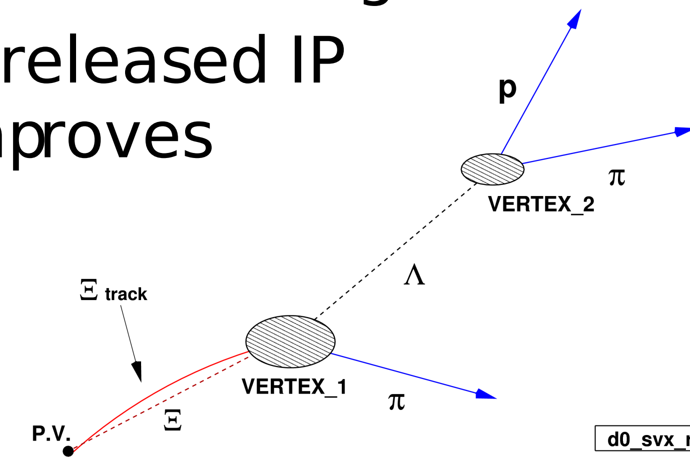
➔ Need Ξ^- reconstruction

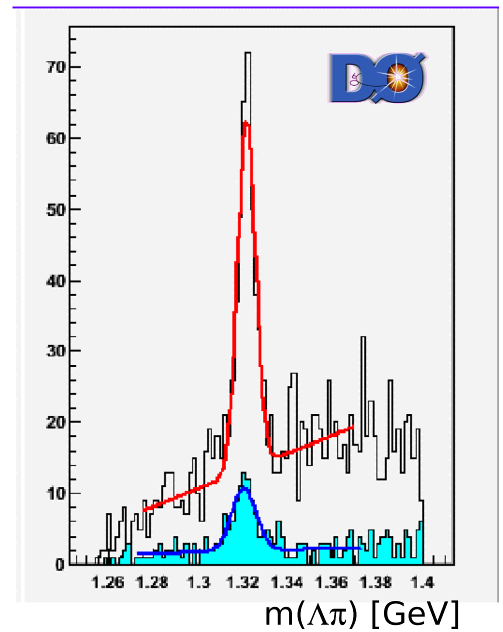
Ξ^- reconstruction



D0:

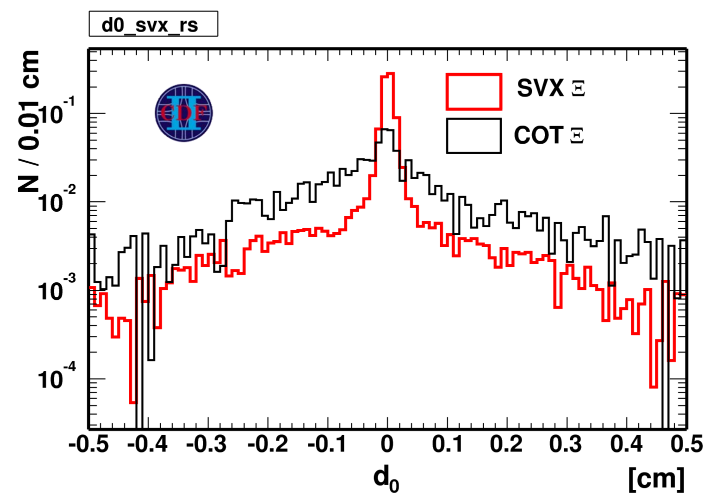
- Cut on impact parameter (IP) in default reconstruction removes Λ daughters
  - Reprocessing with released IP cut significantly improves efficiency



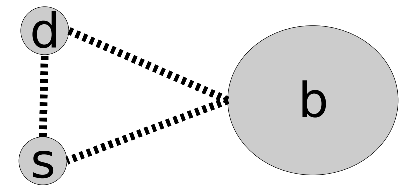


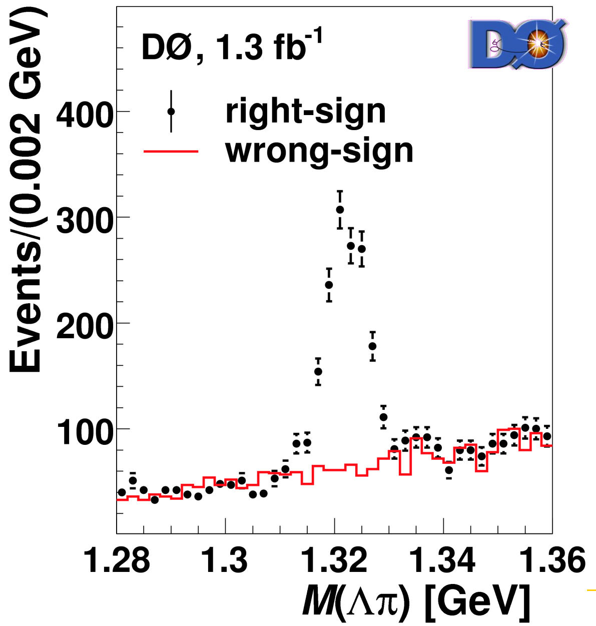
CDF:

- Hyperon tracking in the silicon detector
  - Improved IP resolution and signal to background ratio

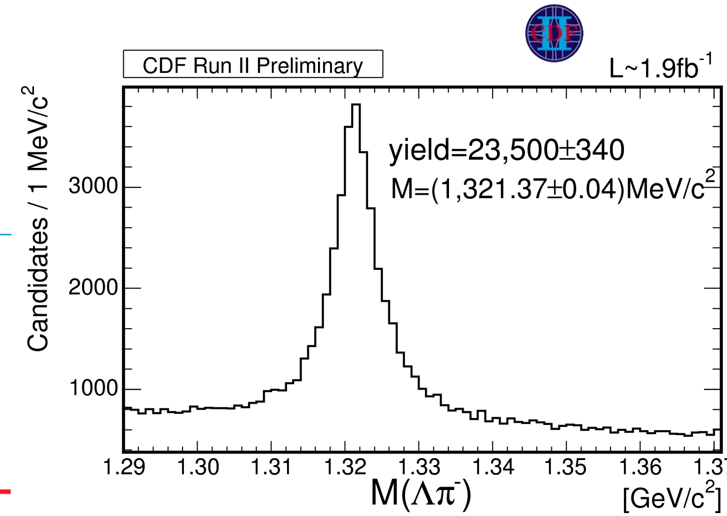


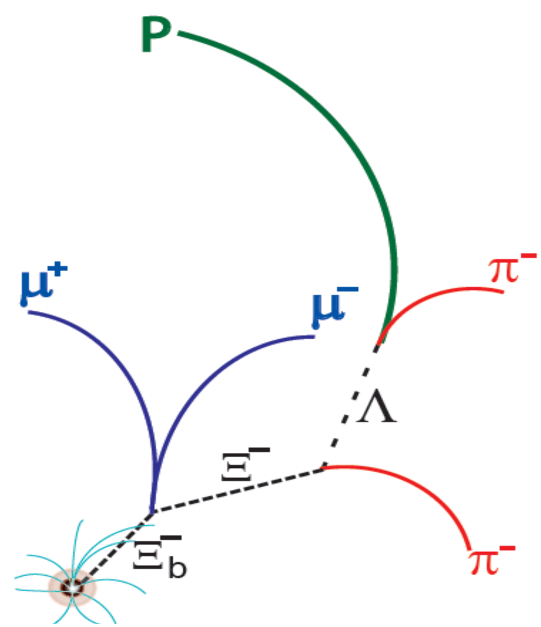
$\Xi_b^- \to J/\psi\ \Xi^-$

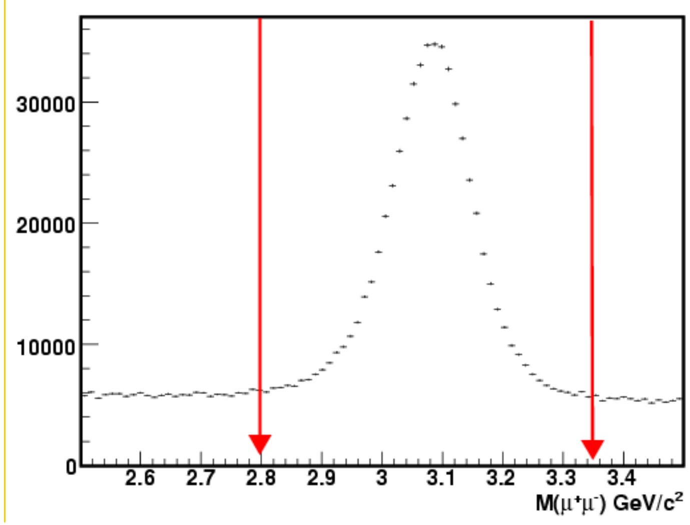


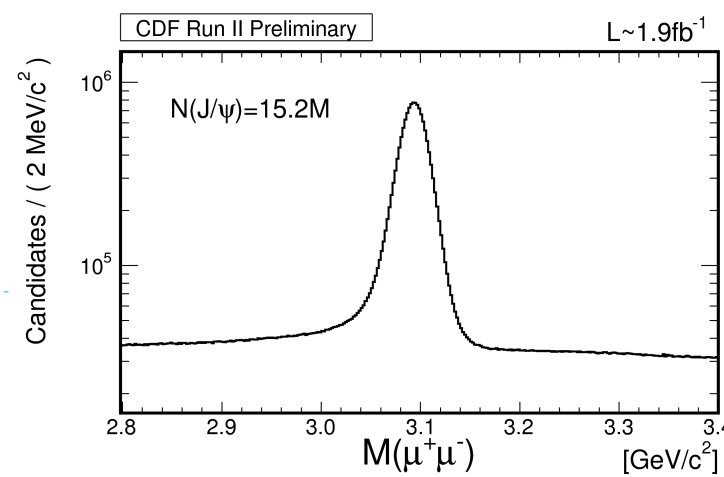


$$\Xi^- \to \Lambda^0 \pi^-$$



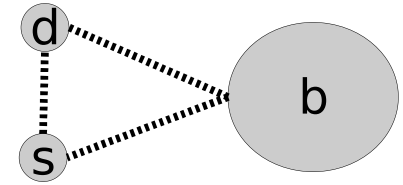






$$J/\psi \to \mu^+\mu^-$$

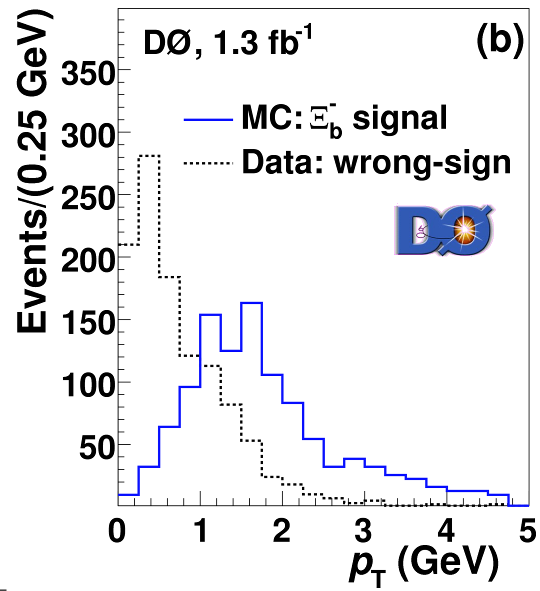
Ξ_b selection



- Cuts on kinematic and vertex fit quality variables

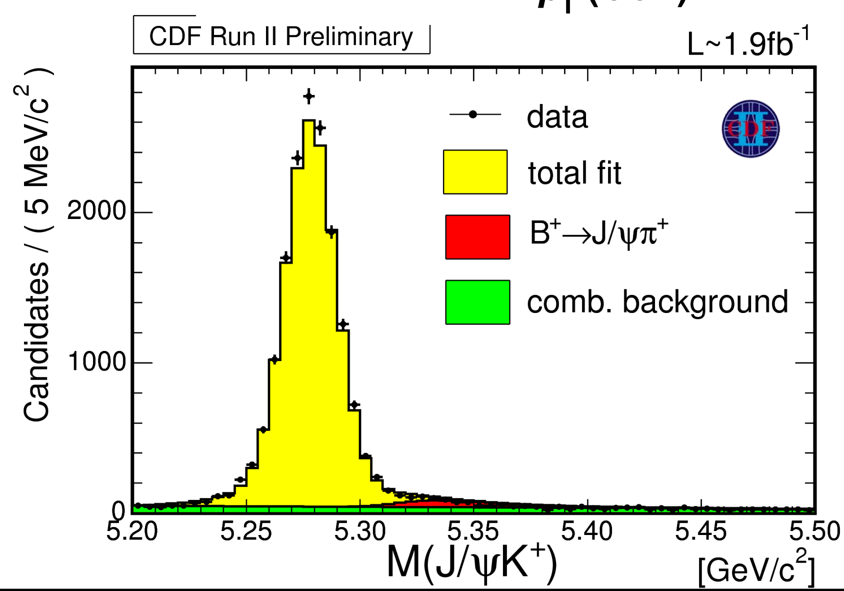
D0:

- Cut optimization on Λ_b data and Ξ_b signal MC plus wrong-sign and sideband data

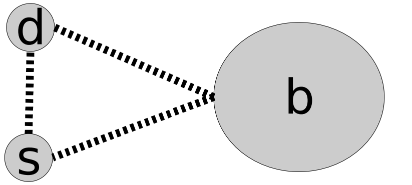


CDF:

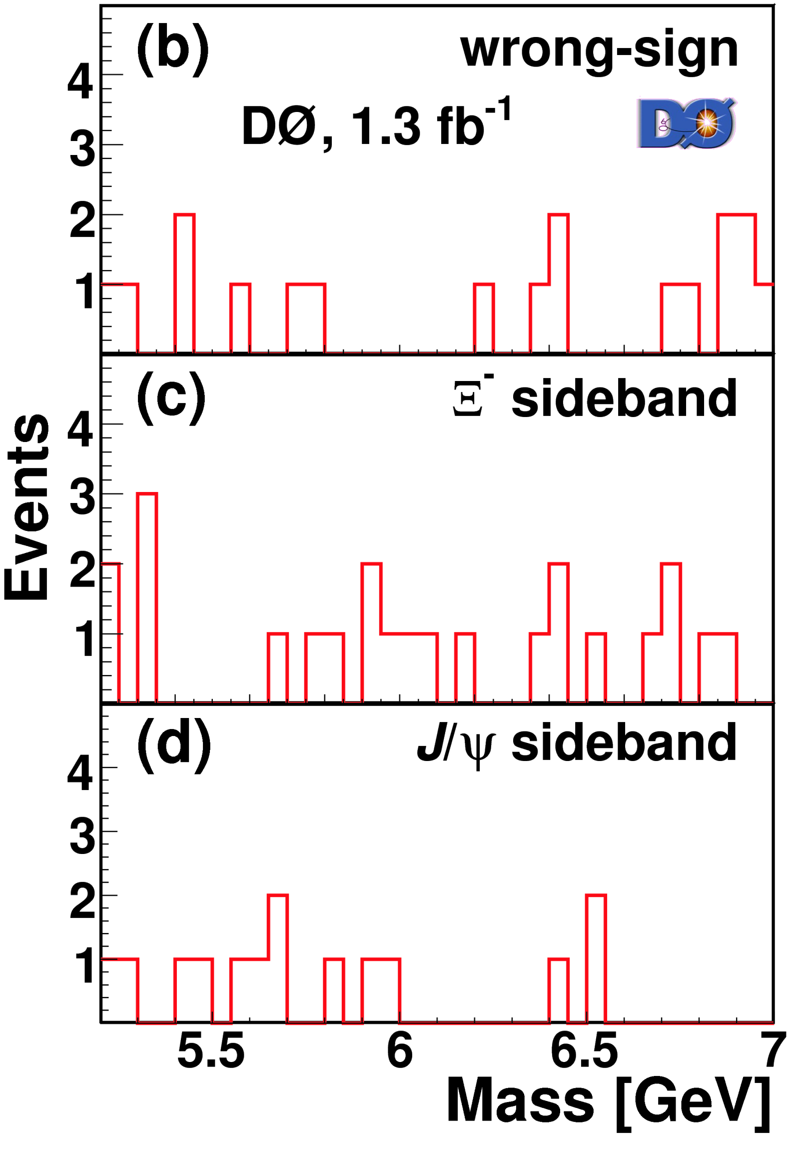
- Cut optimization on $B^+ \rightarrow J/\psi\, K^+$ data, $B/K \leftrightarrow \Xi_b/\Xi$



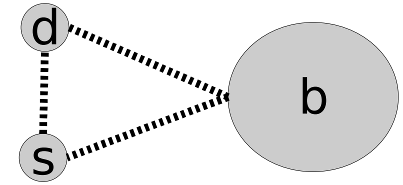
Ξ_b cross checks



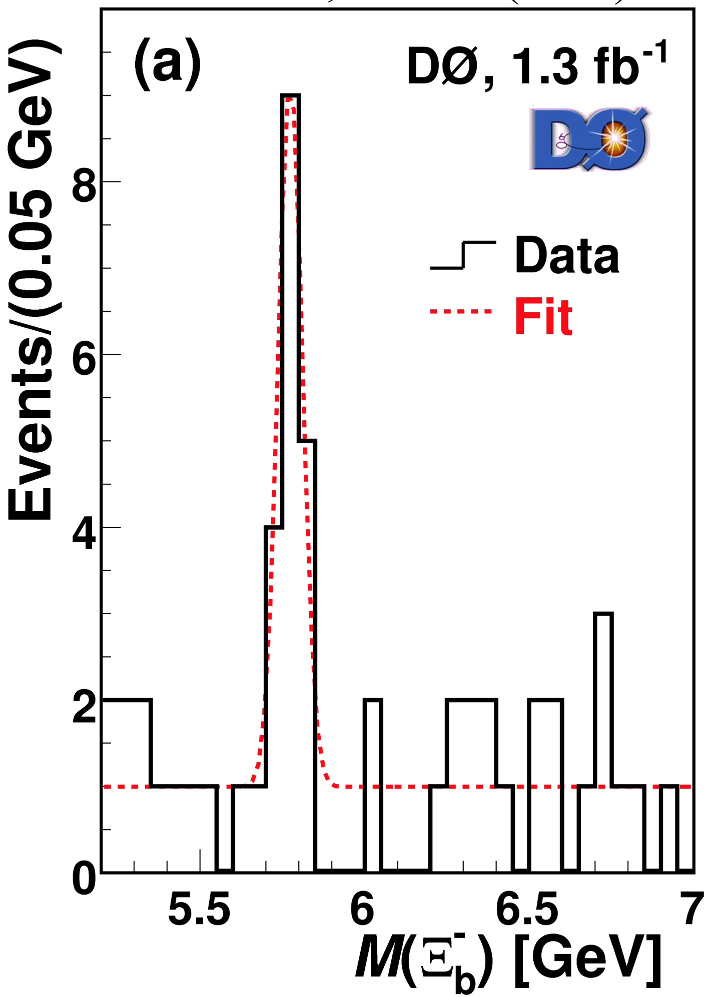
- ✔ Wrong-sign ($\Lambda^0\pi^+$)
- ✔ Ξ^- sideband
- ✔ J/ψ sideband
- ✔ Cut variations
- ✔ B hadron reflections



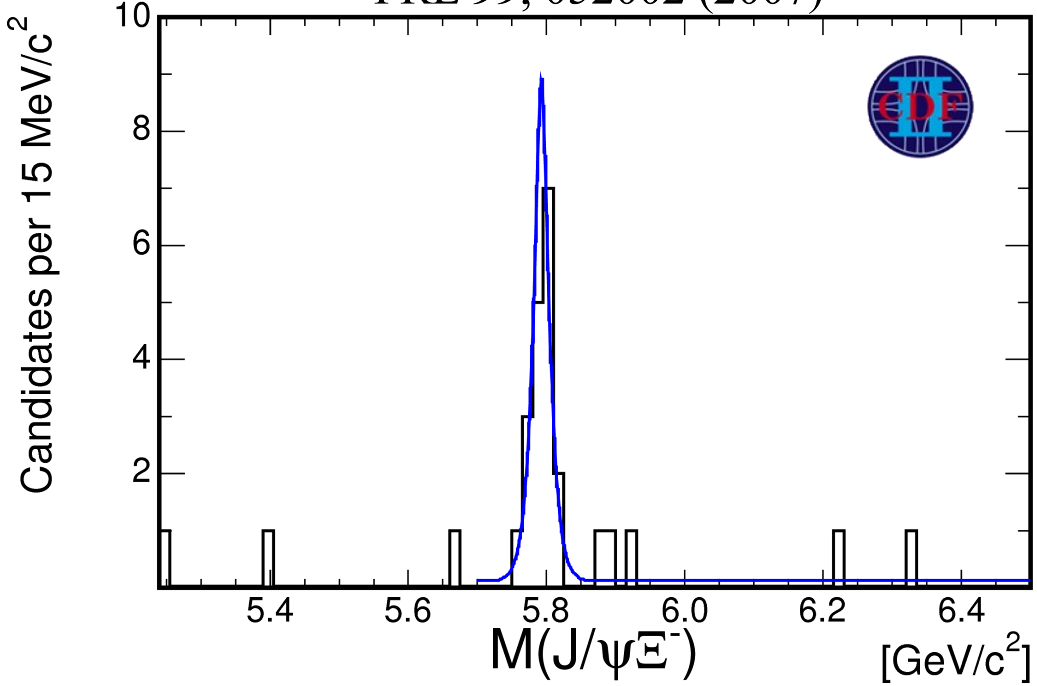
Ξ_b signal



PRL **99**, 052001 (2007)



PRL **99**, 052002 (2007)

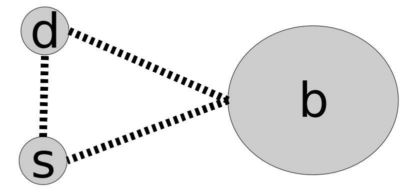


First direct observation

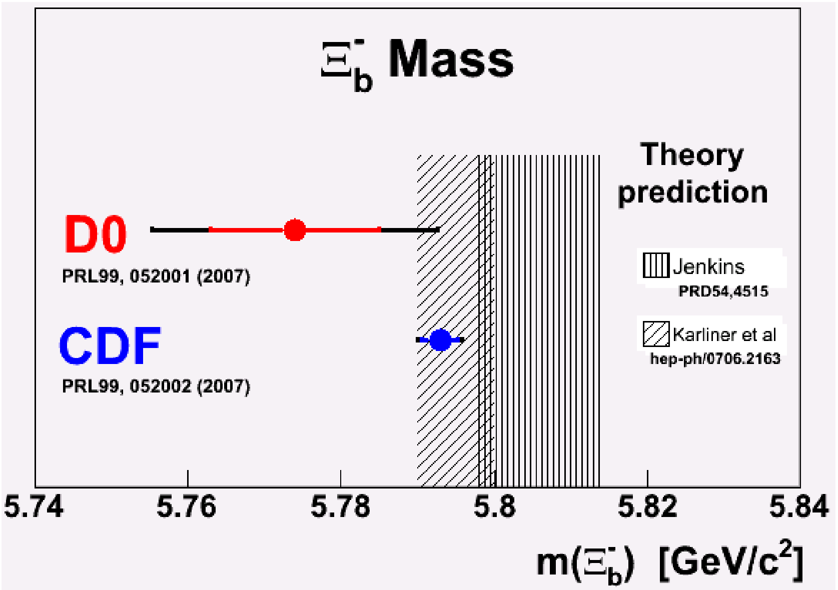
Significance
(prob. of background fluctuation):

- D0: 5.2σ, LH ratio: 5.5σ
  (>5.3σ with systematics)
- CDF: 7.7σ

Ξ_b mass measurement



Unbinned maximum likelihood fit

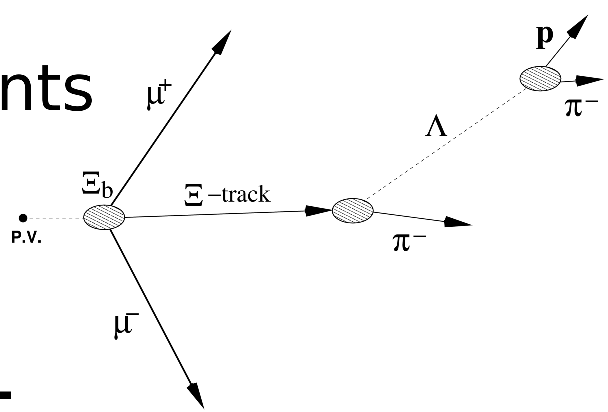


D0:

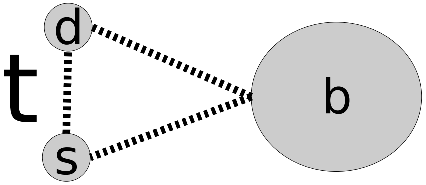
- Q-value technique:
  $m(J/\psi\ \Xi^-) - m(\mu^+\mu^-) - m(\Lambda\pi^-) + m_{PDG}(J/\psi) + m_{PDG}(\Xi^-)$
  - → $m(\Xi_b^-) = 5774 \pm 11 \pm 15$ MeV
- Dominant systematics: event selection

CDF:

- 5 track fit with vertex and mass constraints
  - → $m(\Xi_b^-) = 5792.9 \pm 2.5 \pm 1.7$ MeV
- Dominant systematics: fit model



Ξ_b production ratio measurement



Fraction of b $\rightarrow \Xi_b^-$ times BR, relative to Λ_b^0

- Similar selection for Λ_b^0 and Ξ_b^-
- Relative efficiency from MC
- Dominant systematics: MC modeling

$$\frac{f(b \rightarrow \Xi_b^-) BR(\Xi_b^- \rightarrow J/\psi \Xi^-)}{f(b \rightarrow \Lambda_b) BR(\Lambda_b \rightarrow J/\psi \Lambda)} = 0.28 \pm 0.09\,(\mathrm{stat}) \,{}^{+0.09}_{-0.08}\,(\mathrm{syst})$$

➔ Compare to f(b $\rightarrow$ B_s) / f(b $\rightarrow$ B^+) ≈ 1/4

Summary

Unique B baryon studies at the Tevatron:

- Precise Λ_b lifetime measurements
  Discrepancy between CDF and D0

- First observation of charged Σ_b

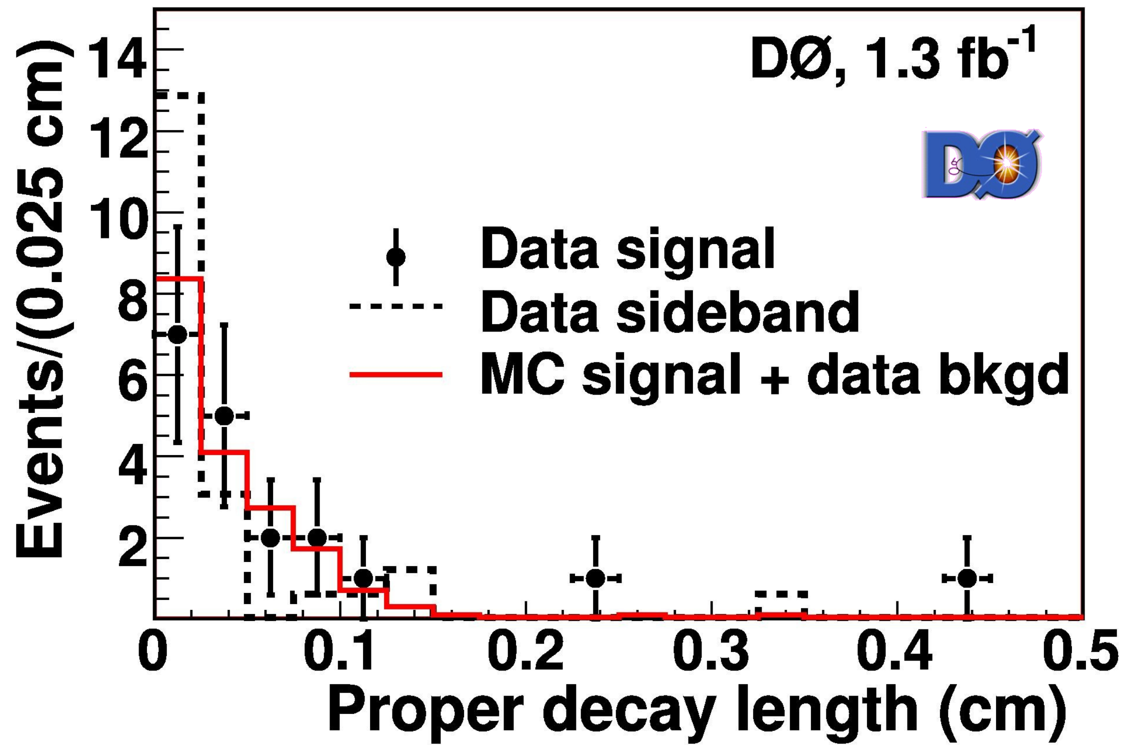
- First direct observation of Ξ_b^-
  Production ratio measurement

Experimental knowledge on B baryon sector increasing
➔ What comes next?

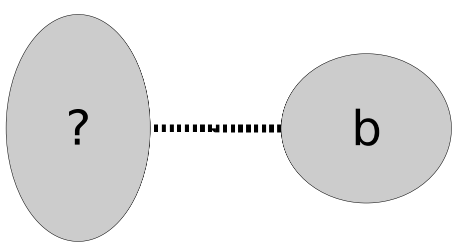
Outlook

Future measurement:

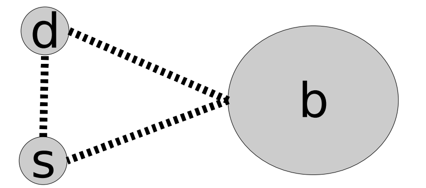
- Λ_b lifetime measurement in fully hadronic decays
- Width and production rate of Σ_b
- Lifetime of Ξ_b^-
- Search for Ξ_b^0
- Search for Ω_b

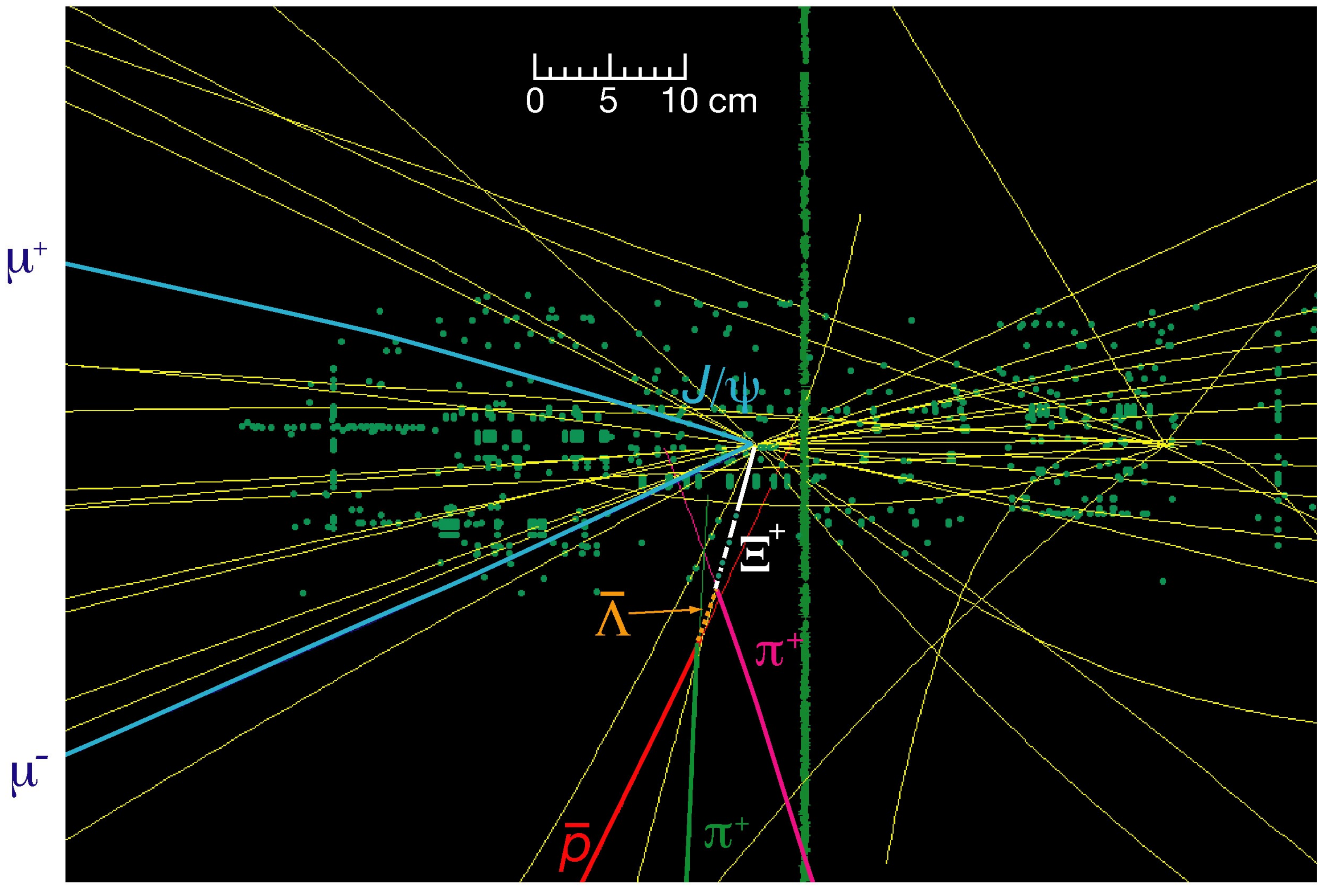


- New discoveries?



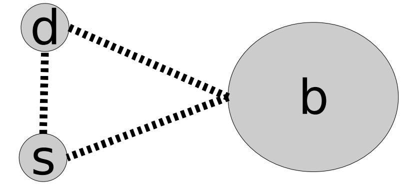
Bonus: Ξ_b event candidate

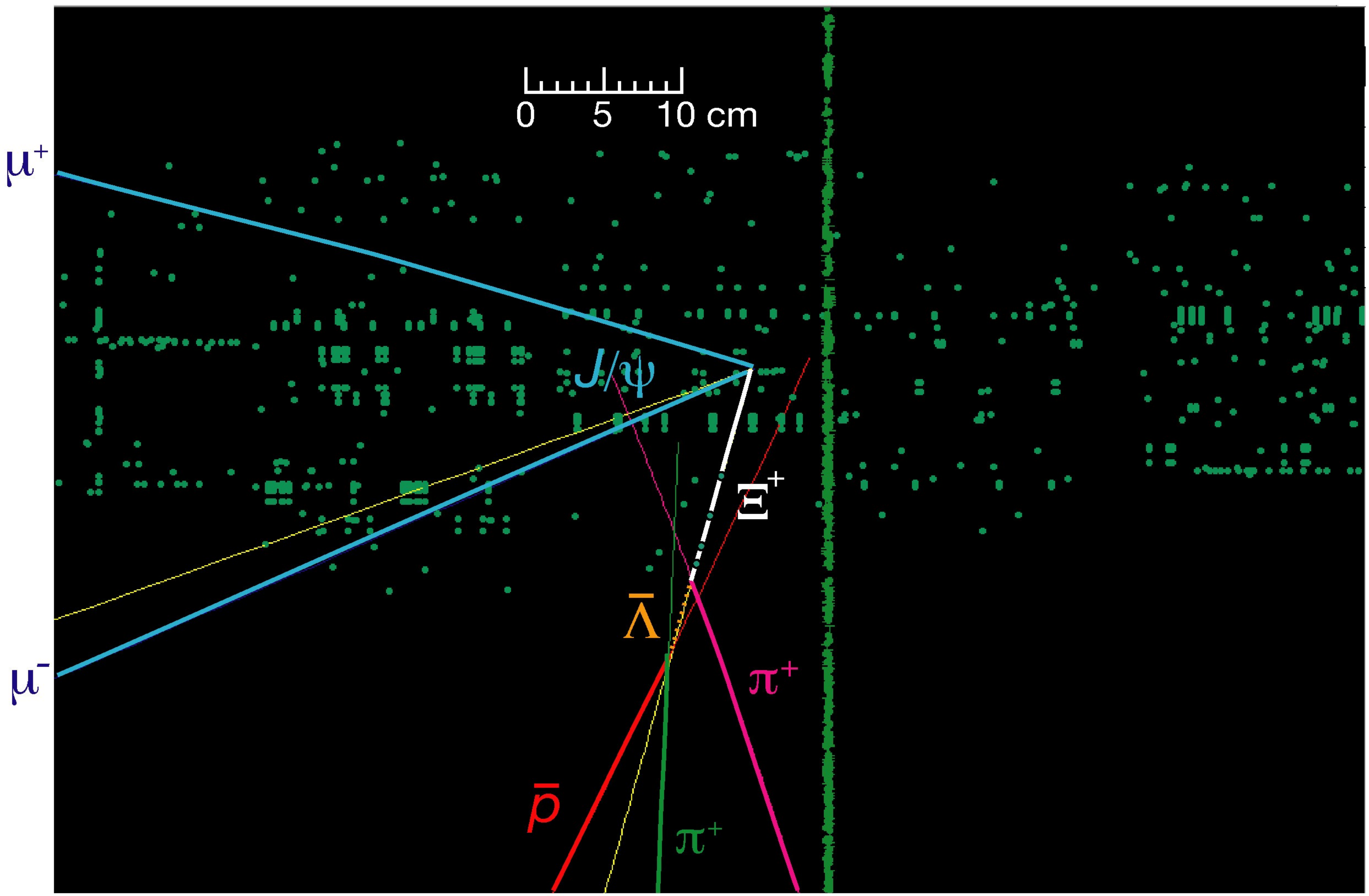




Run 179200, Event 55278820, $M(\Xi_b)$ = 5.788 GeV

Bonus: Ξ_b event candidate





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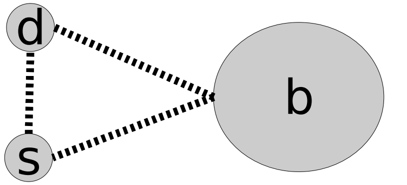
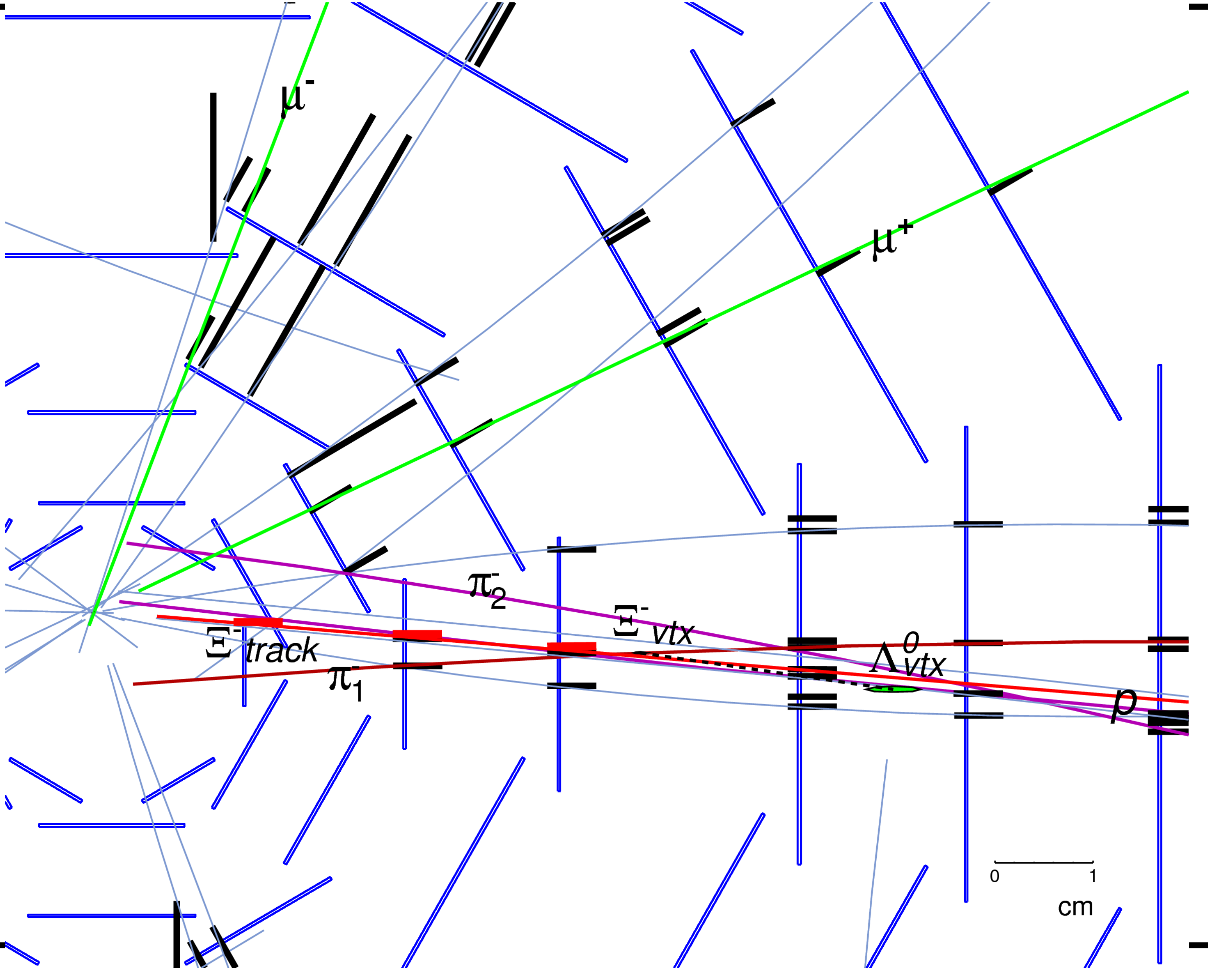
Bonus: Ξ_b event candidate





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