B Baryons at CDF

Beauty 2009

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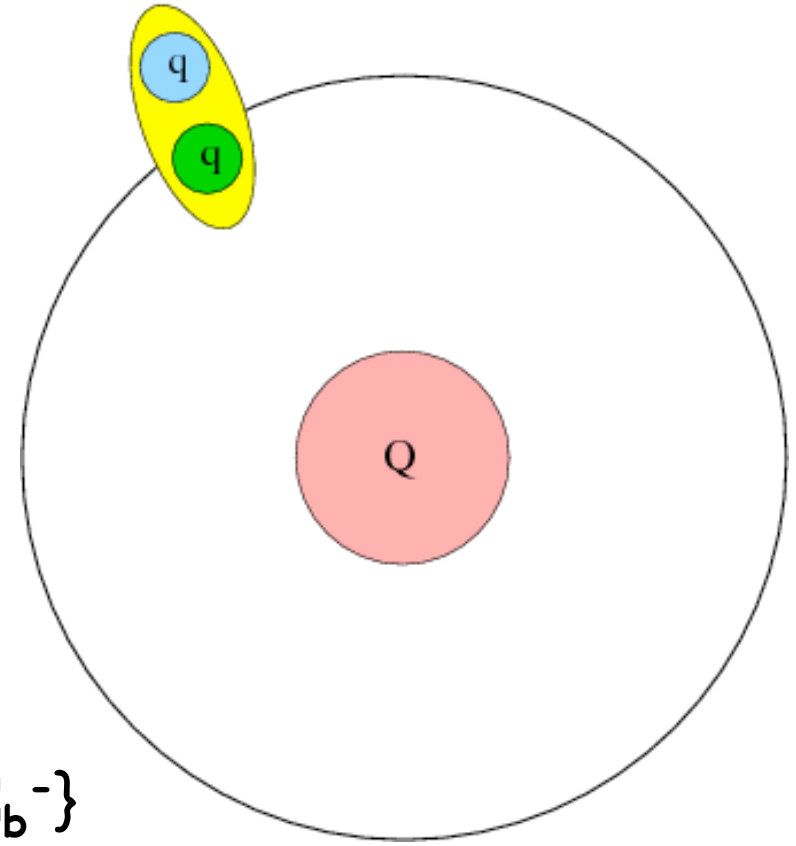
Bottom Baryons (I)

- b-baryons are nice laboratory to understand non-perturbative QCD and potential models

  - heavy b-quark → sizeable simplification in theoretical description
  - basic model: light diquark system qq surrounding the heavy b-quark „nucleus" Q
  - coupling similar as in hydrogen/helium atom



- Ground states (L=0)

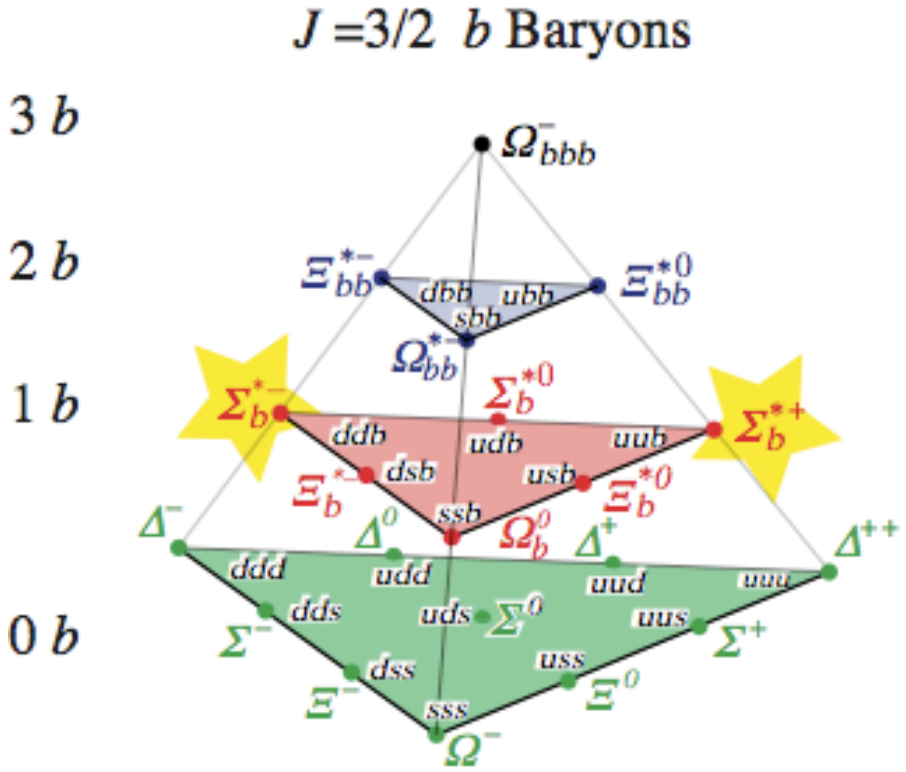
$J_{qq} = S_{qq} = 0 \rightarrow J = J_{qq} + S_Q = 1/2 \quad \{\Lambda_b^0, \Xi_b^-\}$

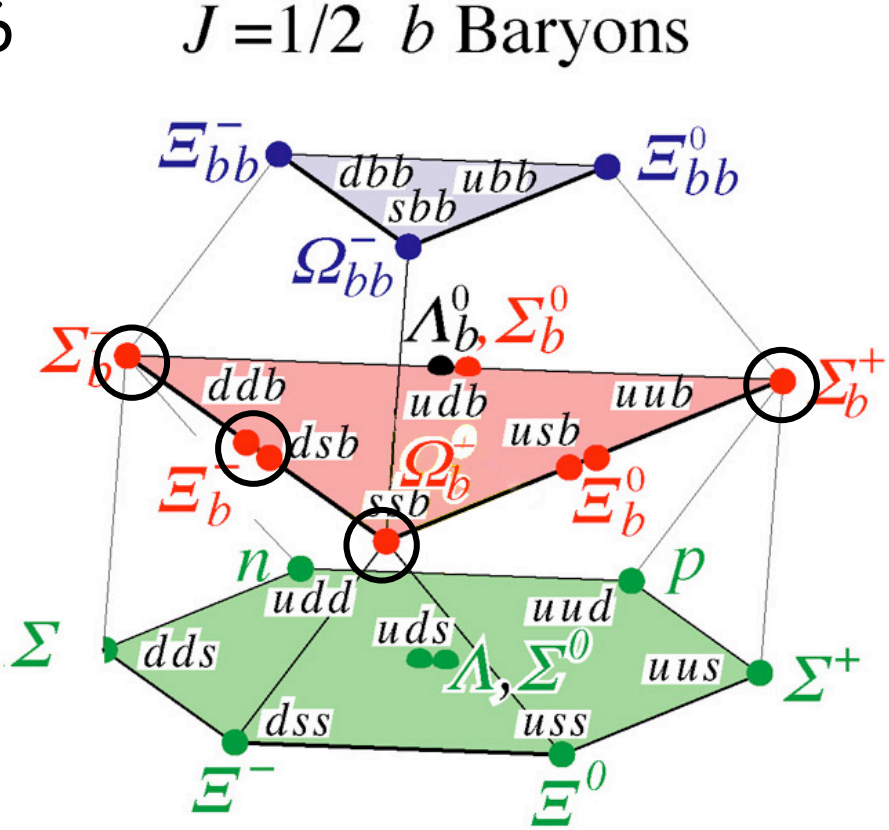
$J_{qq} = S_{qq} = 1 \rightarrow J = J_{qq} + S_Q = 1/2 \quad \{\Sigma_b, \Xi_b', \Omega_b\}$

$\rightarrow J = J_{qq} + S_Q = 3/2 \quad \{\Sigma_b^*, \Xi_b^*, \Omega_b^*\}$

Bottom Baryons (II)

- Our knowledge of b-baryons greatly expanded in the last ~2 years
- This is totally a Tevatron field
  - $\Sigma_b^{(*)+}$ and $\Sigma_b^{(*)-}$ observed in 2006
  - Ξ_b^- observed by in 2007
  - Ω_b^- observed in 2008





The CDF II Detector

Drift chamber in 1.4 T B field

Excellent vertex & mass resolution

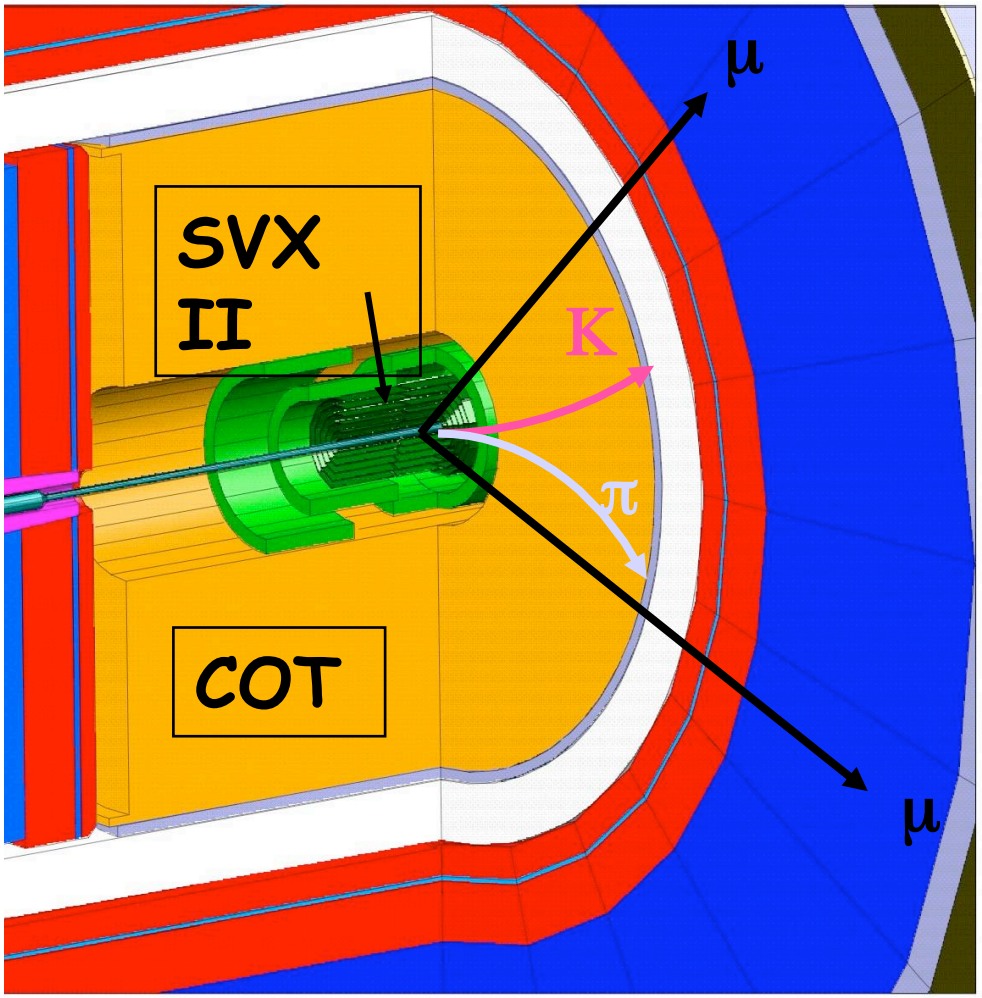
Silicon VerteX detector

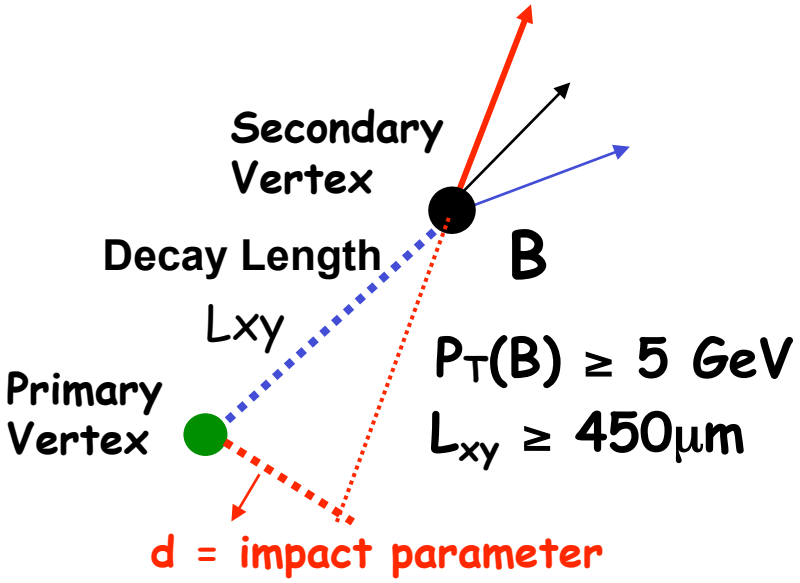
I.P. resolution: 35 μm @2GeV/c

Muon coverage $|\eta| < 1$

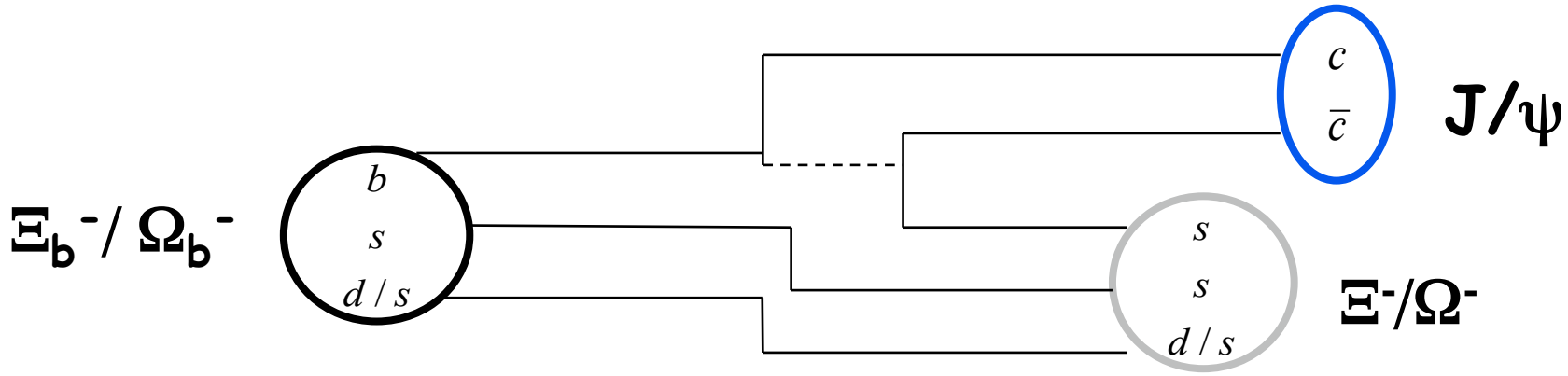
DiMuon Trigger

Displaced Vertex Trigger





Ξ_b^-/Ω_b^- Decay Modes



- We search for the Ξ_b^- and Ω_b^- through the processes
  - $\Xi_b^- \to J/\psi\, \Xi^-$, $J/\psi \to \mu^+\mu^-$, $\Xi^- \to \Lambda\pi^-$
  - $\Omega_b^- \to J/\psi\, \Omega^-$, $J/\psi \to \mu^+\mu^-$, $\Omega^- \to \Lambda K^-$

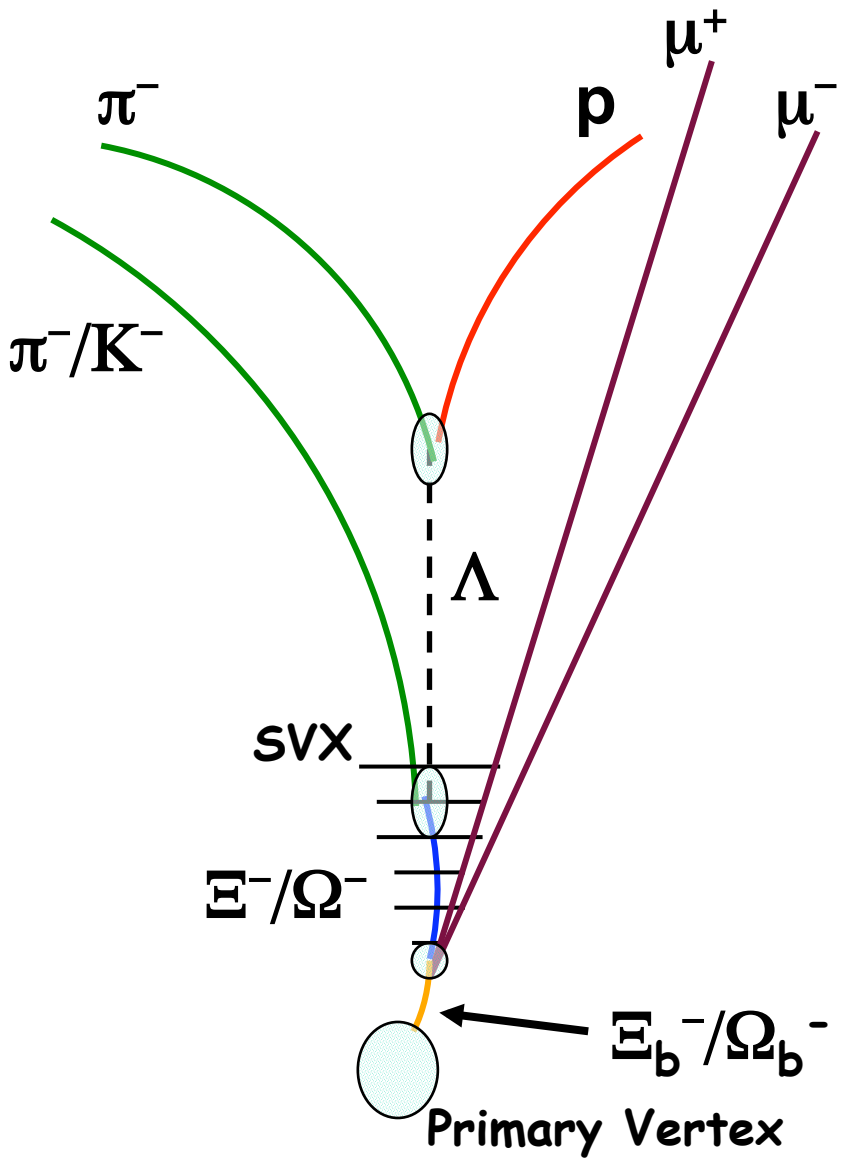
- The data set is from di-muon trigger
  - $J/\psi \to \mu^+\mu^-$ in the final state
- The data set contains many b-meson candidates (useful crosscheck)

Ξ_b^-/Ω_b^- Reconstruction (I)

5-track, 3-vertex fit

- $\mu^+\mu^-$ constrained to J/ψ mass
- Hadron trajectories constrained to appropriate topologies
- Reconstructed Ξ^-/Ω^- constrained to originate from the $\mu^+\mu^-$ intersection

The long life of the Ξ^- and Ω^- opens the possibility of seeing the hits left in the Silicon detector (more on this later)



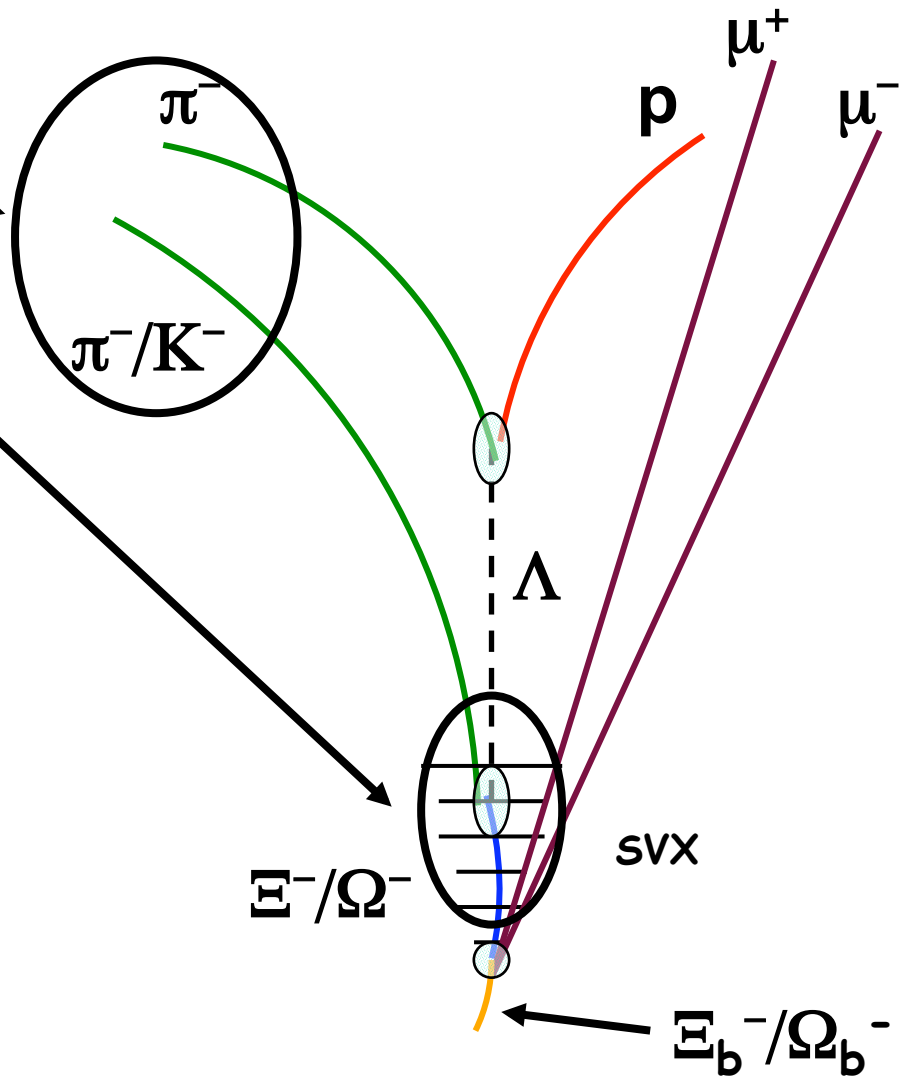
Ξ_b^-/Ω_b^- Reconstruction (I)

Selection may be satisfied by

- Like sign pairs (p may form a Λ with either)
- Both Λ – track intersections

Ambiguities resolved by

- Track information in the longitudinal (along beamline) view
- Fully constrained 5-track fit
  - Helix constraint avoids "wrong" intersection



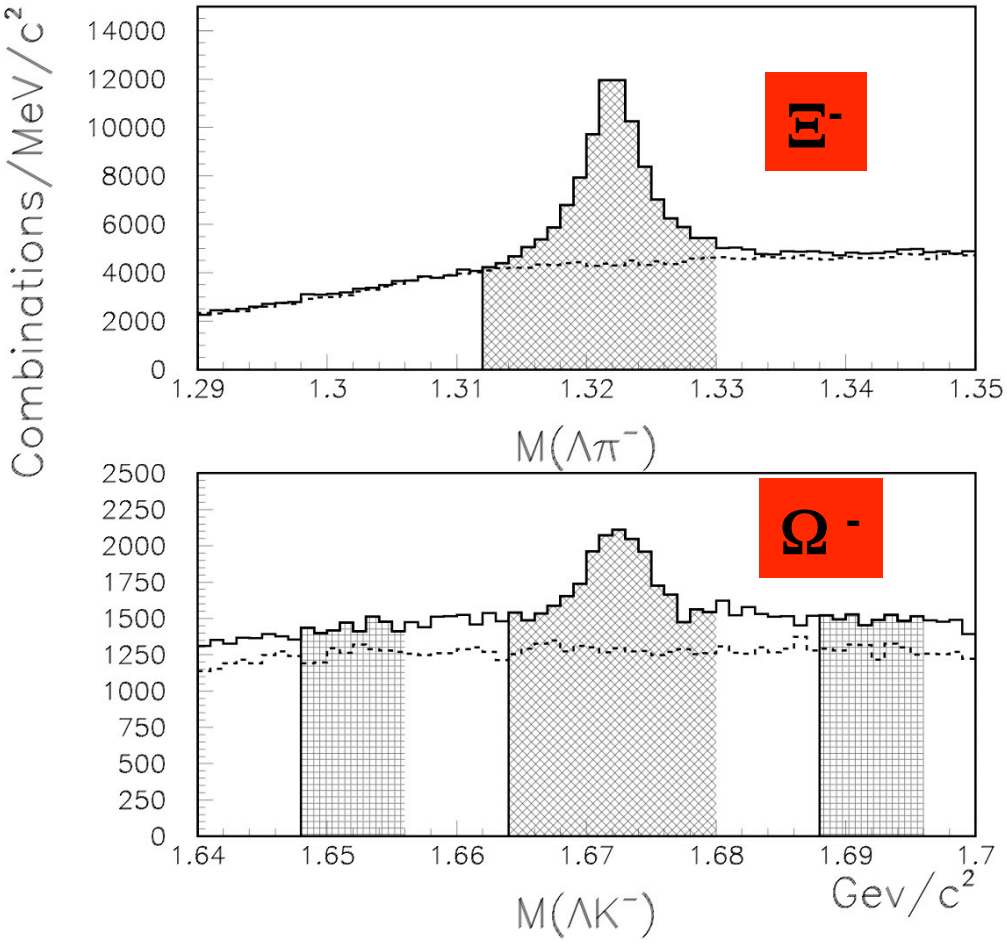
Inclusive Ξ^-/Ω^- Samples

The base sample is given by

- $1.1077 < M(p\pi) < 1.1237$
- $P_T(\Xi/\Omega) > 2.0$
- $\text{Flight}(\Lambda/\Xi^-/\Omega^-) > 1$ cm
- $\text{Impact}(\Xi^-/\Omega^-) < 3\sigma$
- $P(\chi^2) > 10^{-4}$
- $P(\chi^2)_{\text{used}} > P(\chi^2)_{\text{swapped}}$
- Veto $1.311 < M(\Lambda\pi) < 1.331$ for ΛK sample (Ξ^- reflection)

Yields in the J/ψ sample:

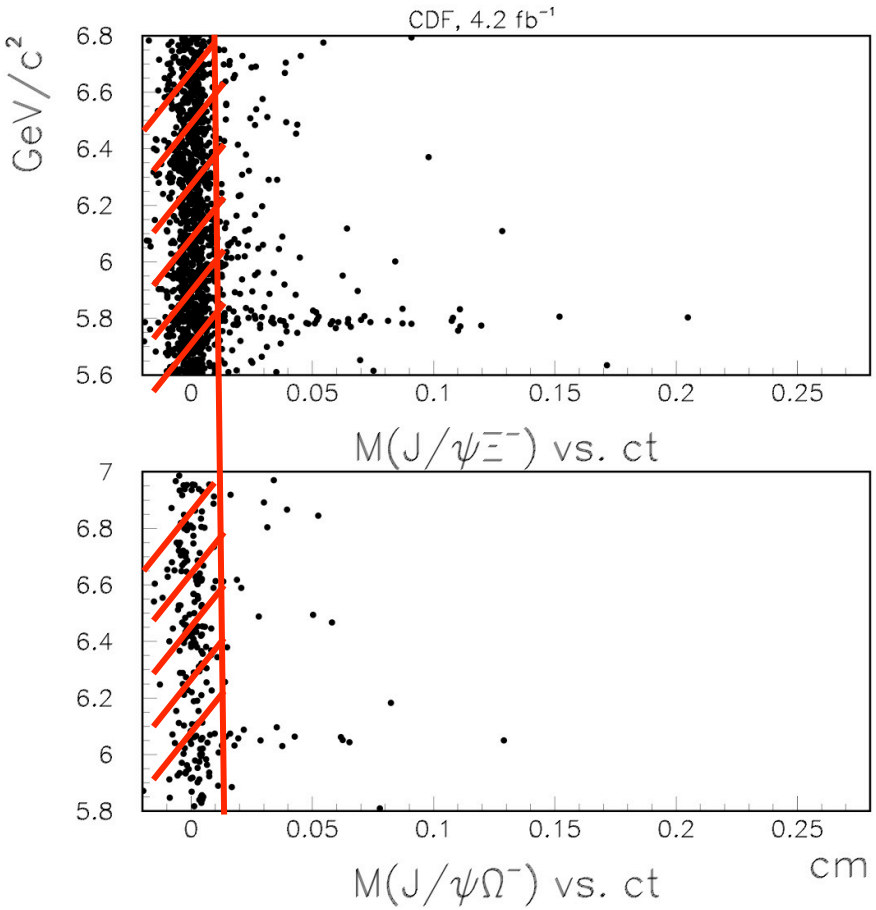
- Ξ^- : 41,000
- Ω^-: 3,500



Dashed histograms are WS $\Lambda\pi^+/K^+$

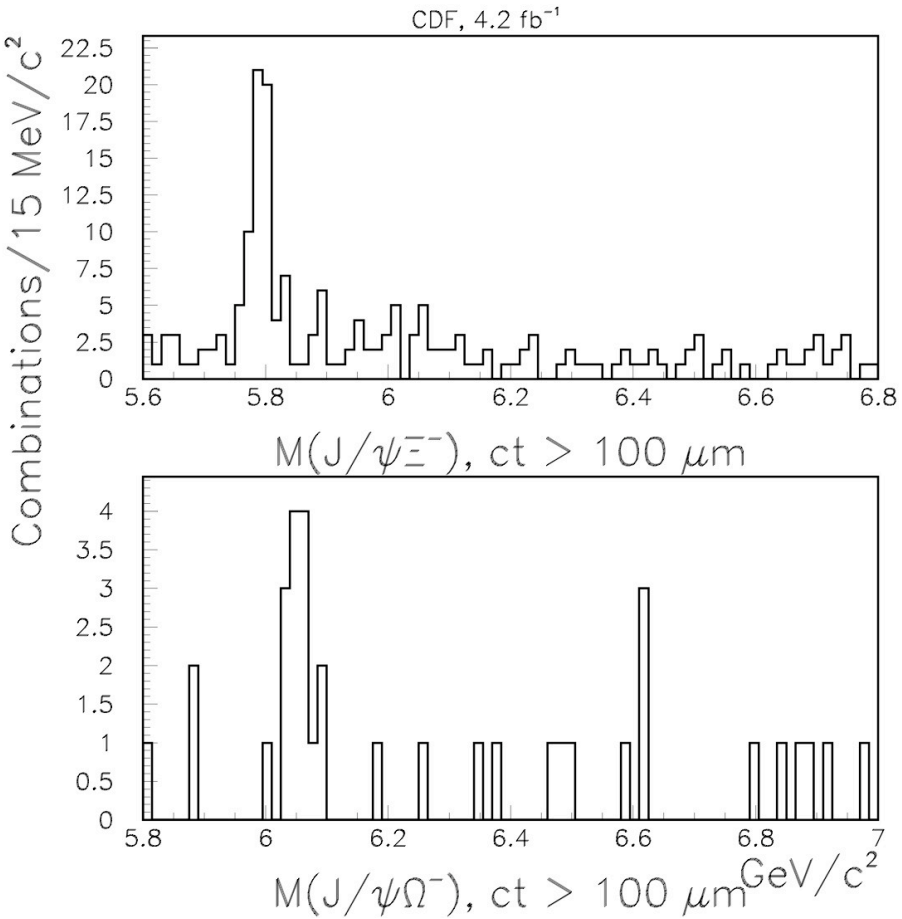
Shaded are selection and SB region

Ξ_b^-/Ω_b^- reconstructed signals



Ξ_b^-

Ω_b^-



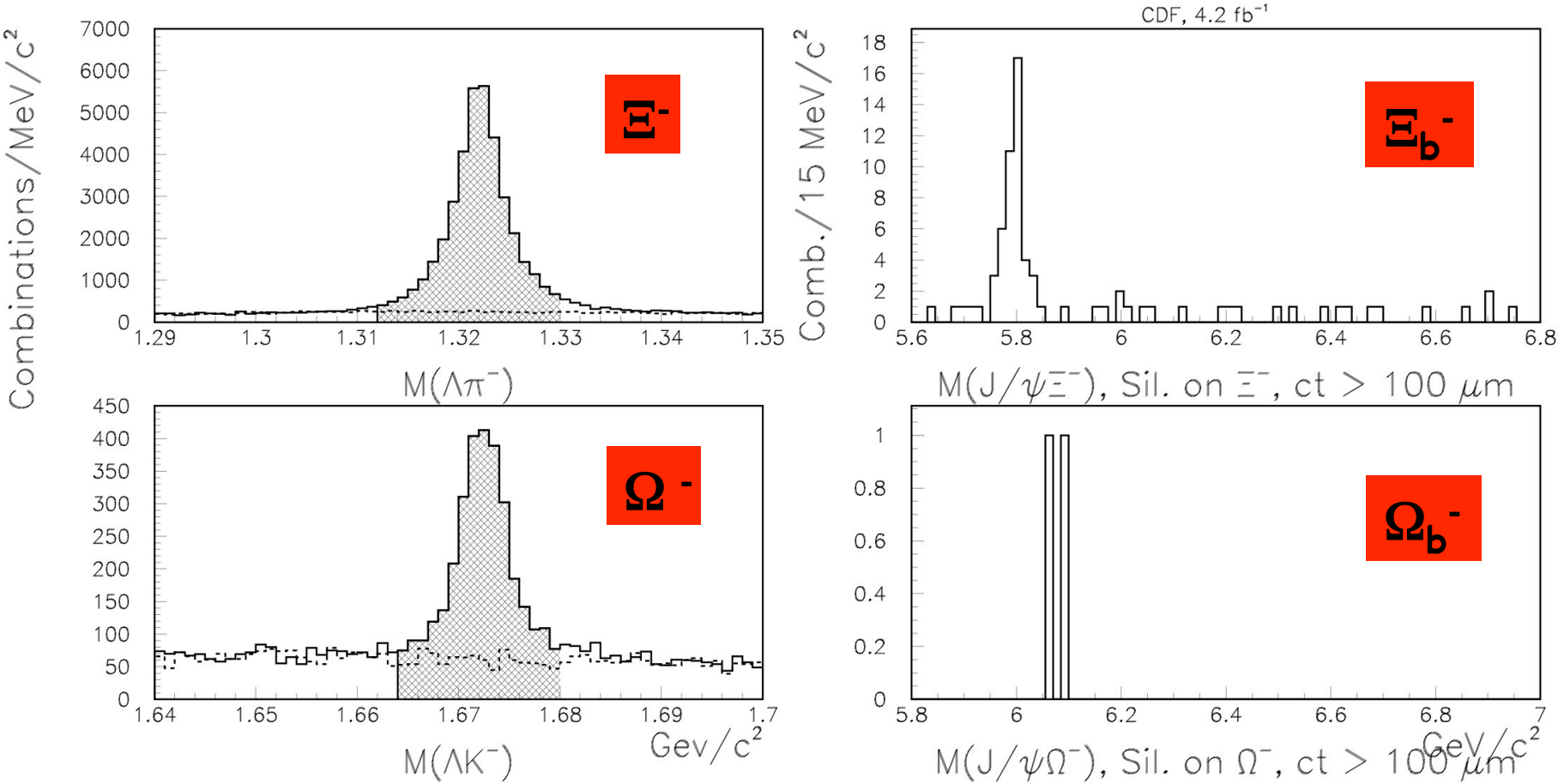
$J/\psi\Xi^-$, $J/\psi\ \Omega^-$ samples

Obvious Ξ_b^- signal when **ct** > 100 μm

Cluster in the $J/\psi\ \Omega^-$ around 6.05 GeV/c^2

Test of Ω_b^- significance finds 5.5σ (with no ct cut)

Require Ξ^-/Ω^- hits in SVX



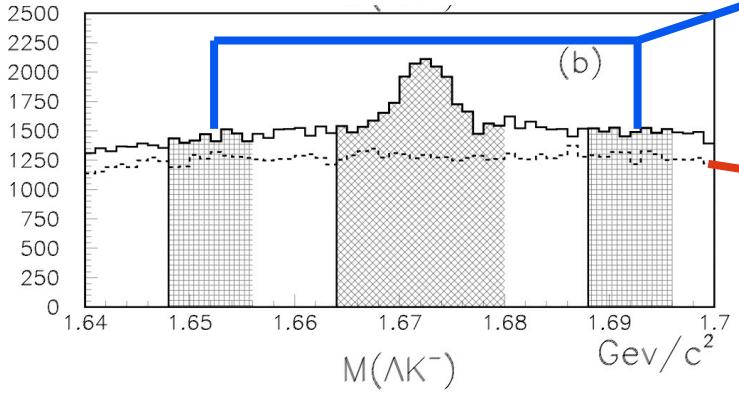
Inclusive $\Lambda\pi$ and ΛK with previous selection and additional request of silicon hits on the Ξ^-/Ω^- track

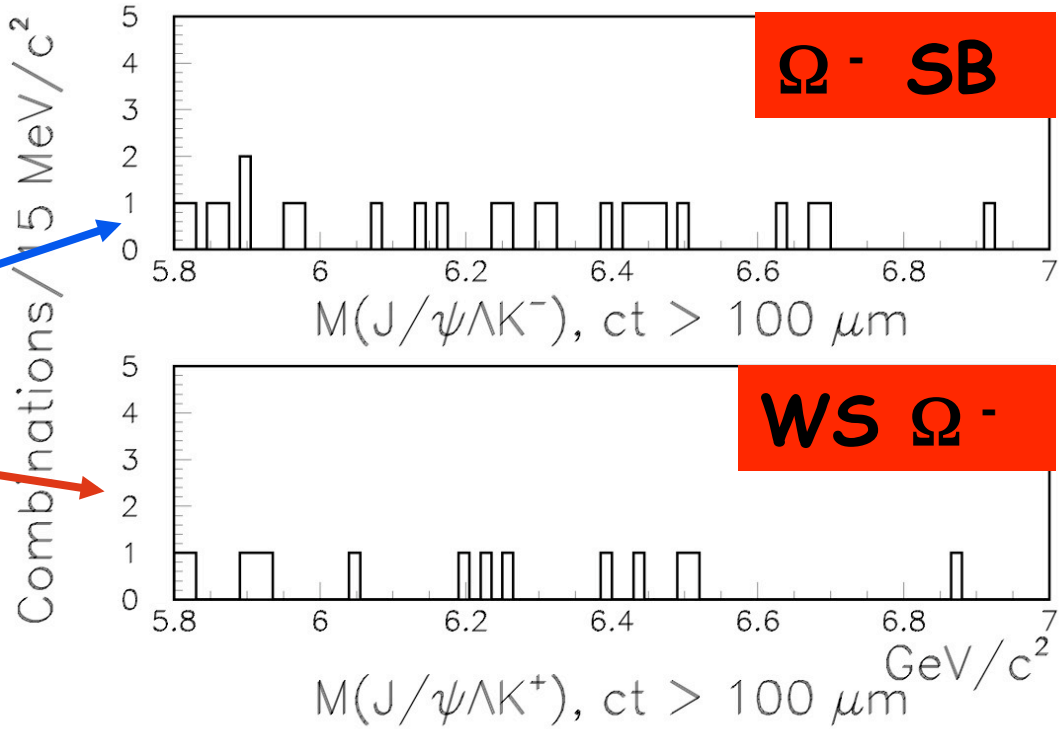
Obvious Ξ_b^- signal

Just 2 Ω_b candidates (due to lower Ω^- lifetime) but mass consistent with the main selection

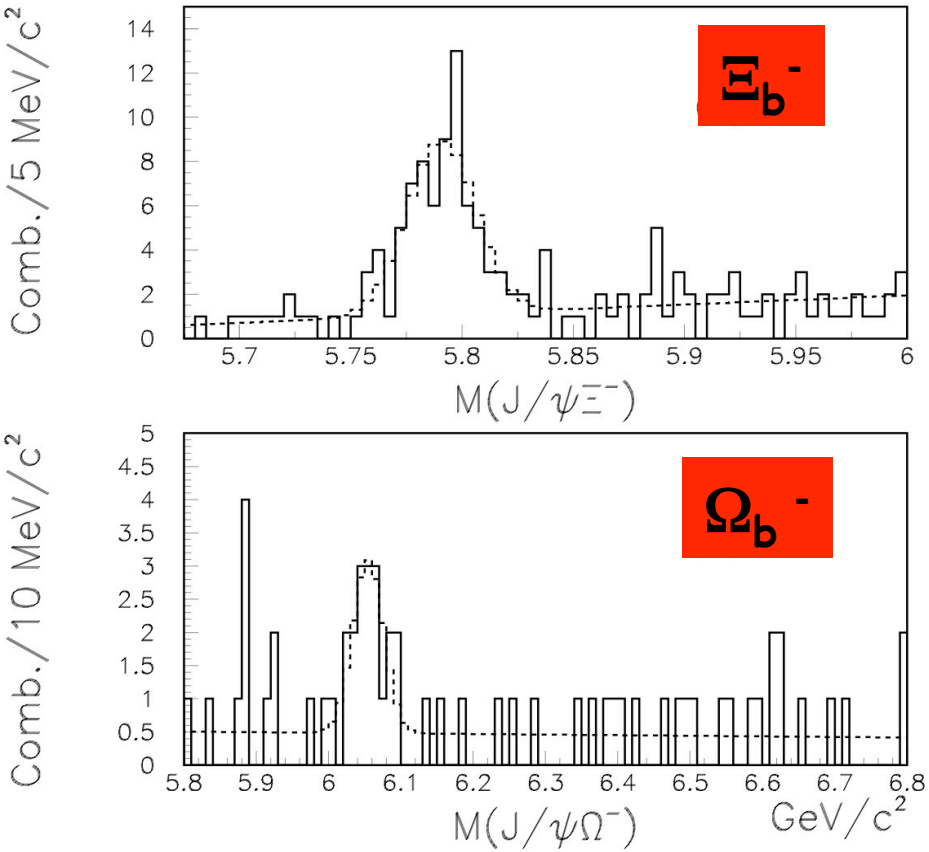
Sideband/Wrong-Sign selections

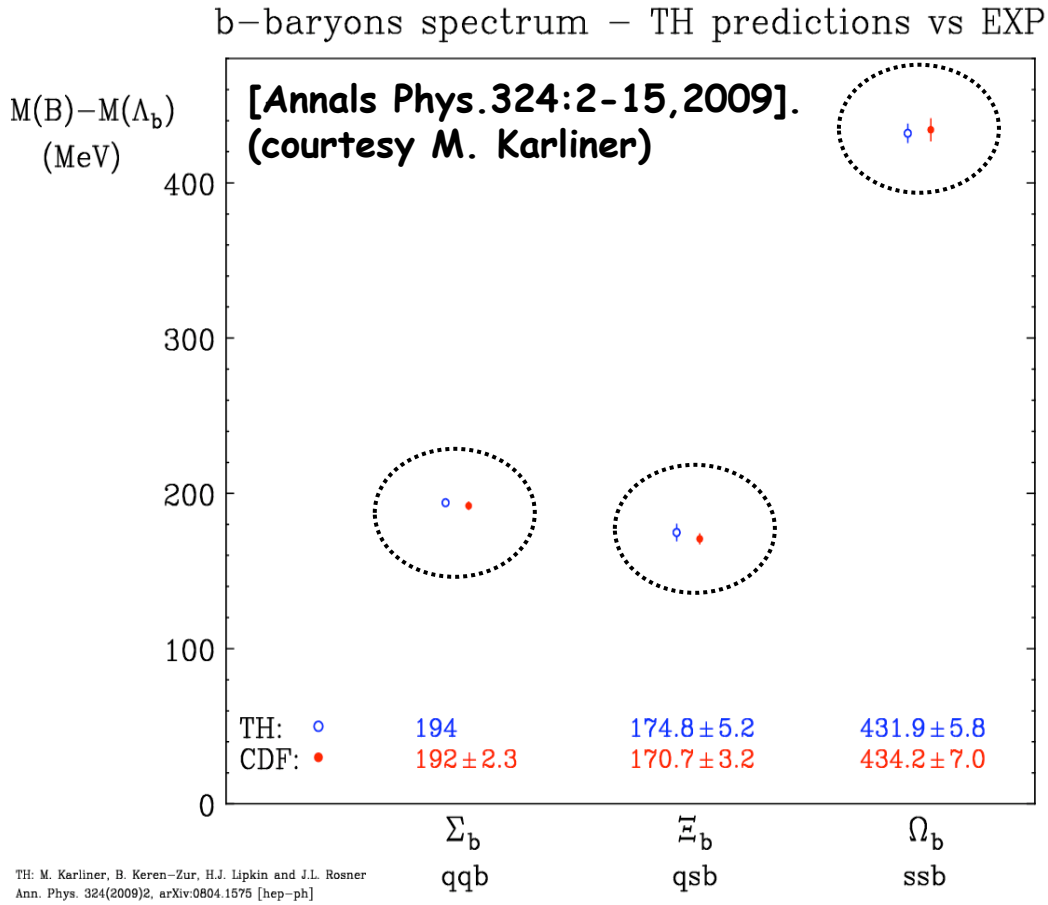
Same candidate selection, except for the ΛK^- pair





Ξ_b^-/Ω_b^- Mass Measurements





$m(\Xi_b^-)$: 5790.9 ± 2.6(stat.) ± 0.8(syst.) MeV/c^2

$m(\Omega_b^-)$: 6054.4 ± 6.8(stat.) ± 0.9(syst.) MeV/c^2

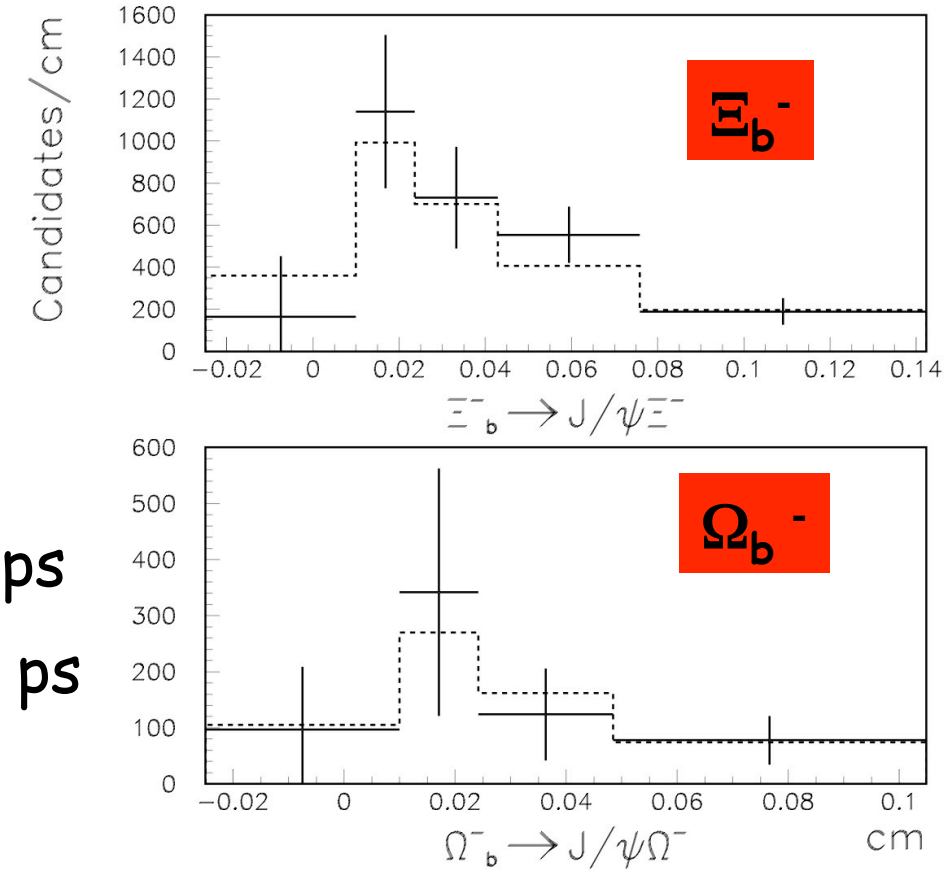
Systematic uncertainty

- **0.55 MeV from $B^0(K_s)$ error scale by 80% for kinetic energy in the decay**
- **0.5 MeV from Λ_b resolution treatment (considered largest possible)**
- **0.3 MeV from Ω^- mass**

Ξ_b^-/Ω_b^- Lifetime Measurements

Binned lifetime fit distributions

- Each bin comes from an independent fit to the mass distribution
- Dashed lines are fit projections



$\tau(\Xi_b^-)$: $1.56^{+0.27}_{-0.25}$(stat) ± 0.02(syst) ps

$\tau\,(\Omega_b^-)$: $1.13^{+0.53}_{-0.40}$(stat) ± 0.02(syst) ps

Systematic uncertainty

2 μm from σ^{ct} treatment

5 μm from binning

Ξ_b^-/Ω_b^- Production Rate Measurements

We measure ratios of cross section times BR with respect to the Λ^0_b, only **b**-baryon with a large sample

Issues:

Experiment's acceptance is p_T dependent

Cross section is p_T dependent

Unknown - assume Λ^0_b distribution

Limited data sample requires integration over p

Combine acceptance with yields

Λ^0_b : 1812 ± 61 candidates

Ξ_b^- : 66^{+14}_{-9} candidates

Ω_b^- : 16^{+6}_{-4} candidates

$$\frac{\sigma B(\Xi_b^- \to J/\psi \Xi^-)}{\sigma B(\Lambda_b \to J/\psi \Lambda)} = 0.167^{+0.037}_{-0.025} \pm 0.012$$

$$\frac{\sigma B(\Omega_b^- \to J/\psi \Omega^-)}{\sigma B(\Lambda_b \to J/\psi \Lambda)} = 0.045^{+0.017}_{-0.012} \pm 0.004$$

arXiv:0905.3123

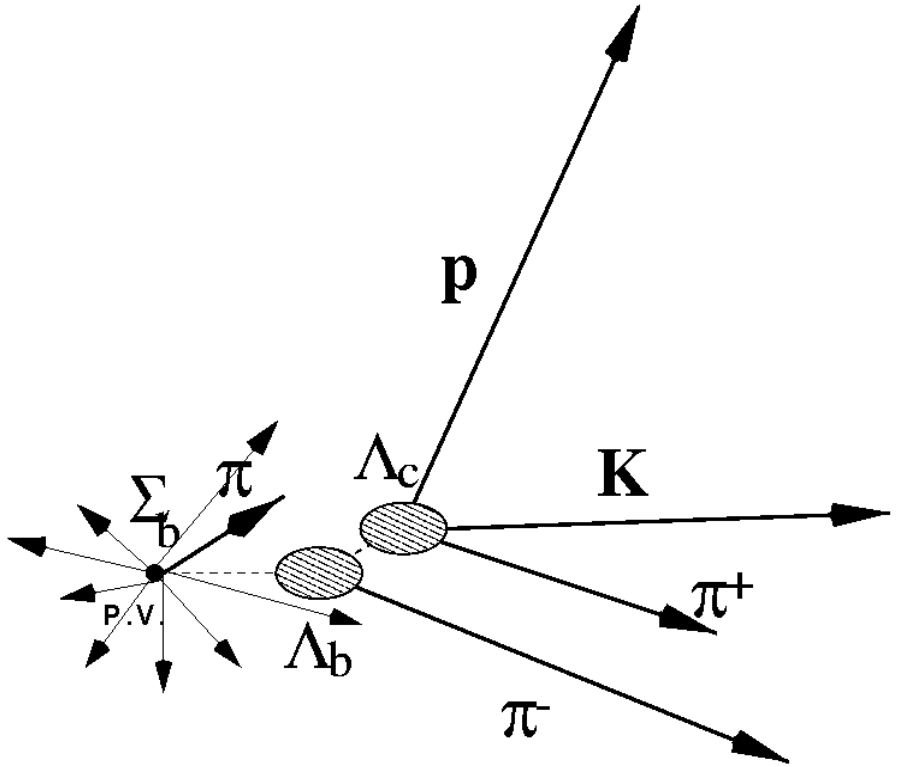
Search for $\Sigma_b^{\pm(*)}$

Decay chain

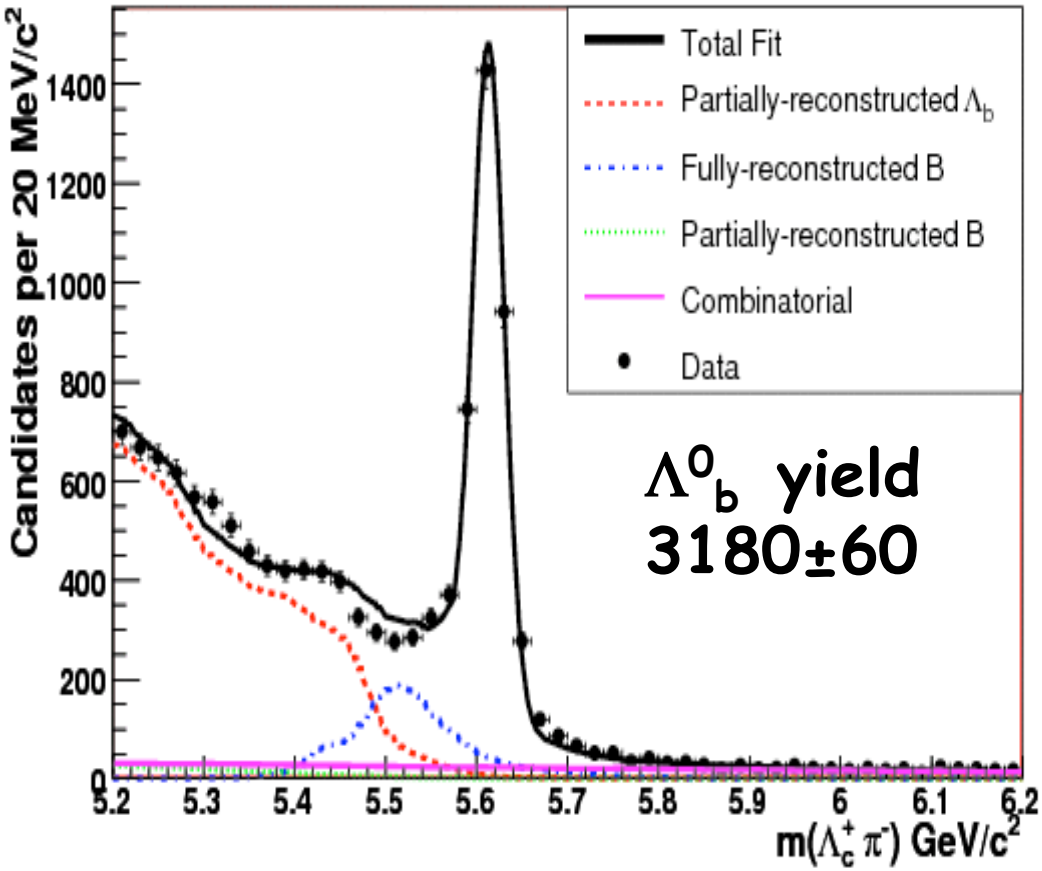
$\Sigma_b^{-(*)} \rightarrow \Lambda_b^0 \pi^-$

$\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-$

$\Lambda_c^+ \rightarrow p\, K^-\, \pi^+$



PRL 99, 202001 (2007)



Contributions in Λ^0_b mass window

86.4 % of Λ^0_b (all decays)

9.3 % of B-meson (all decays)

4.3 % combinatorial

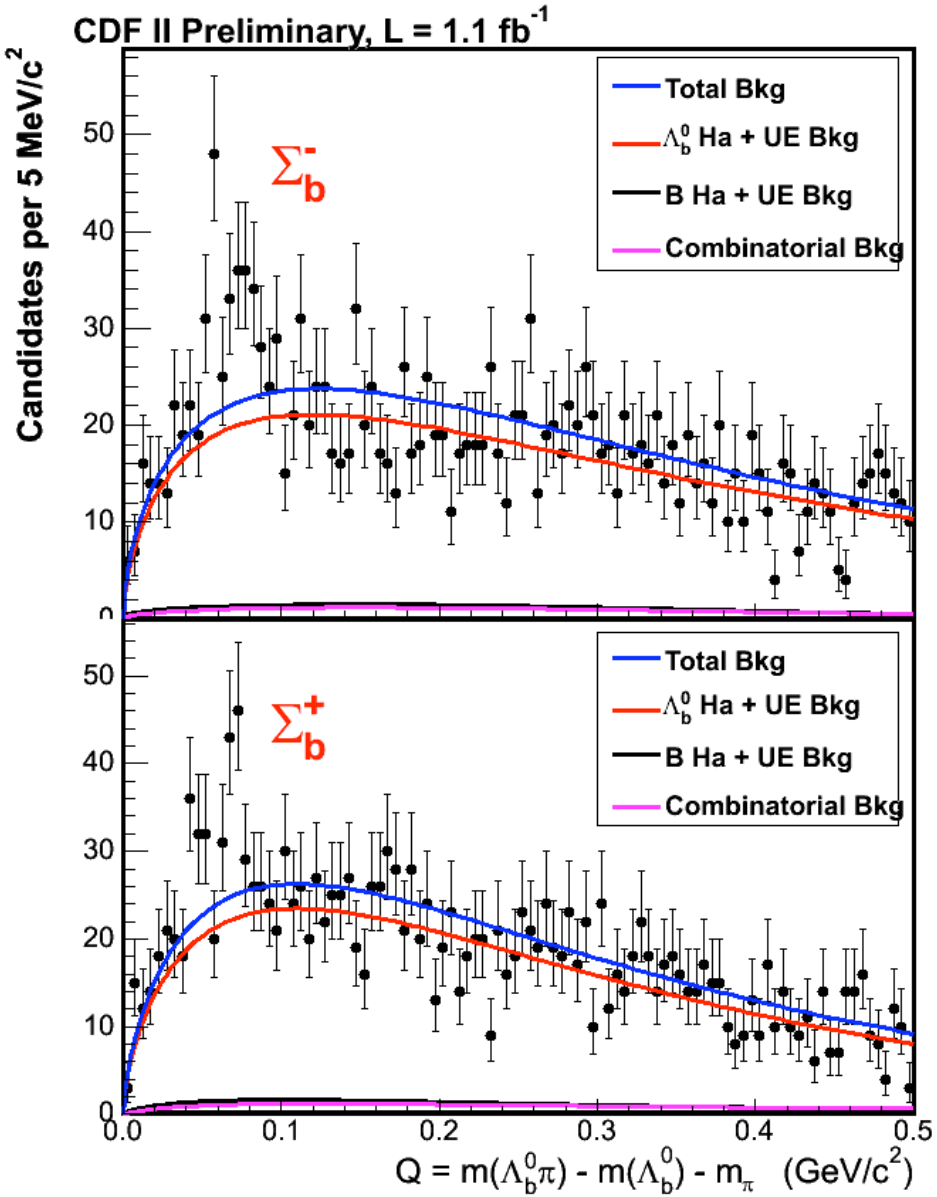
$\Sigma_b^{\pm(*)}$ Event Selection

Search for resonances in
$Q = m(\Lambda_b\,\pi) - m(\Lambda_b) - m(\pi)$

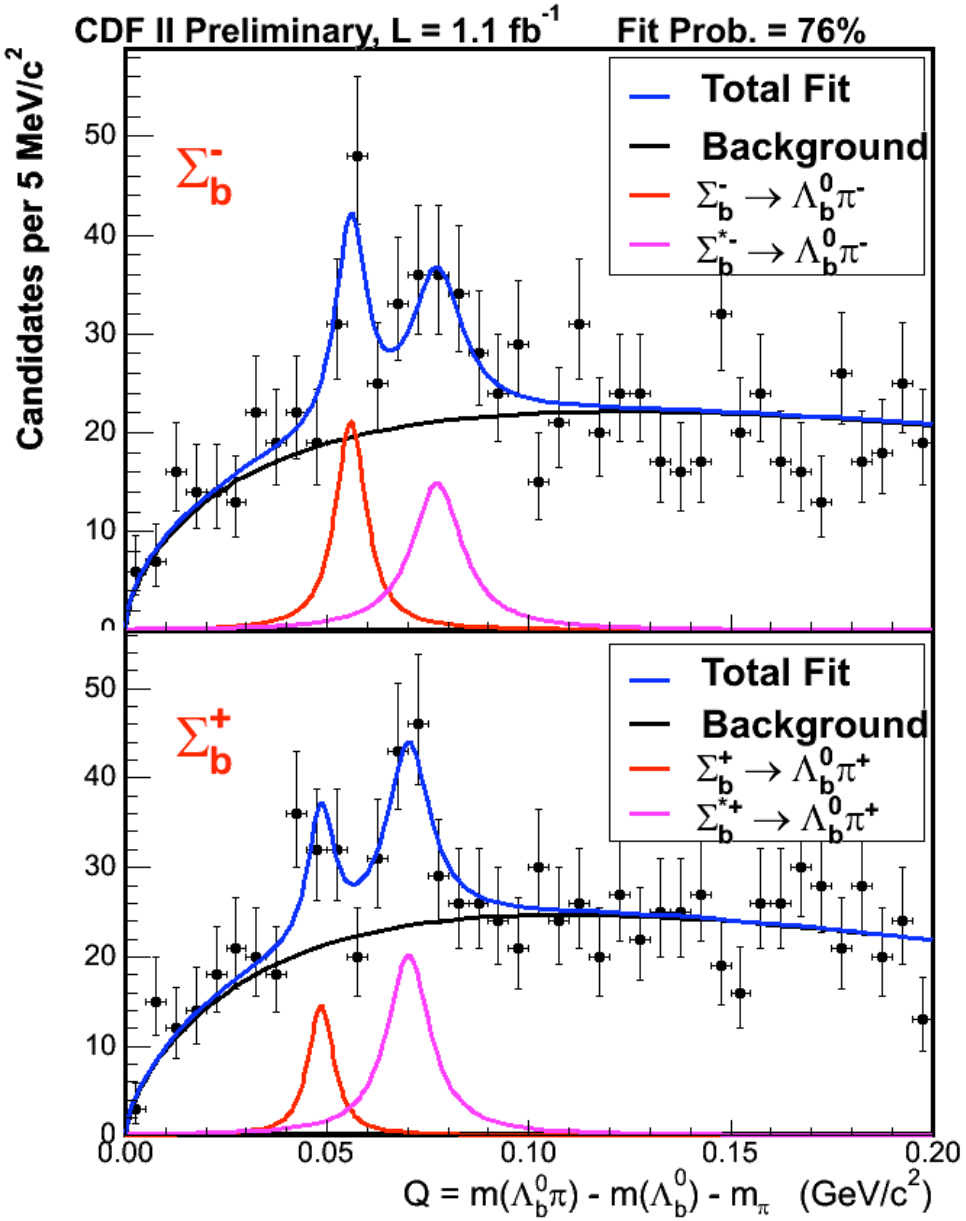
Exclude $0.03 < Q < 0.10$ GeV region from signal selection procedure (blinding)

Optimize selection based on
- MC simulation for Σ signal
- Sidebands from data

Fix background contributions at $m(\Lambda^0_b)$ fit



Observation of $\Sigma_b^{\pm(*)}$



Observed four signals with significance

- >5.2σ (4 peaks vs. only BG)
- each peak >3σ (except Σ^+_b)

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

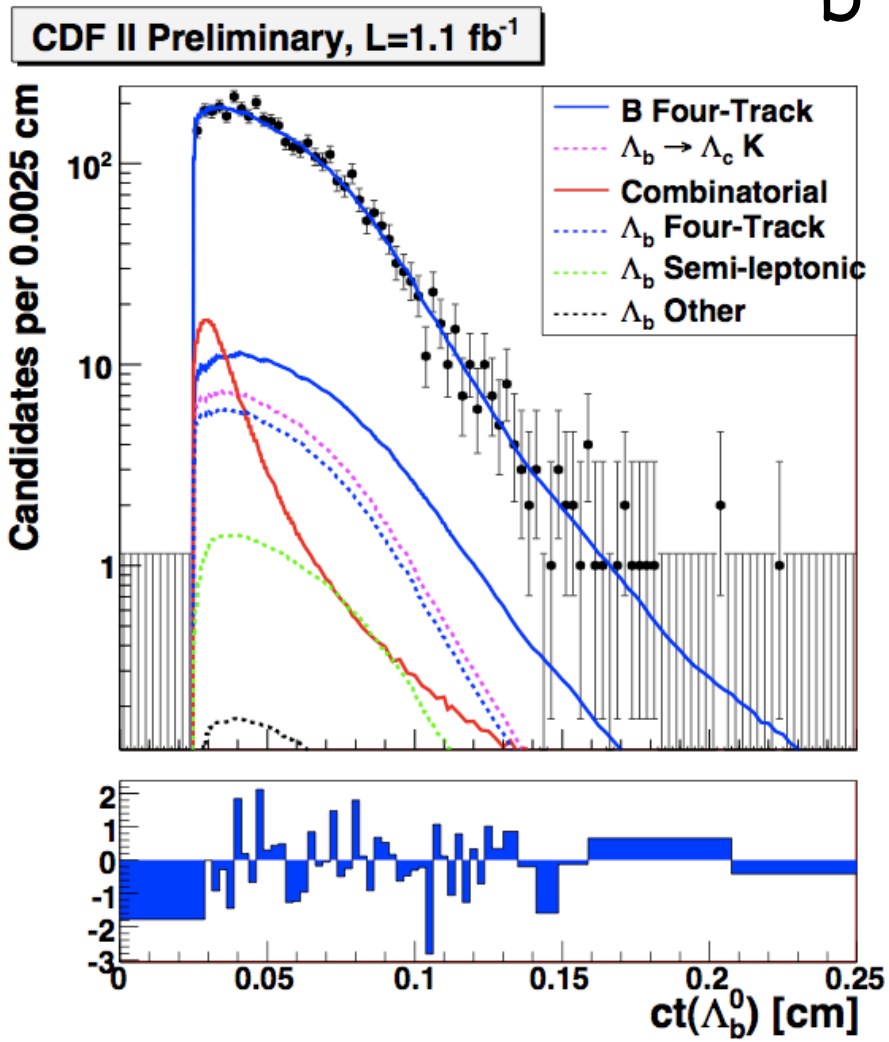
$m(\Sigma_b^-) = 5816^{+1.0}_{-1.0} \pm 1.7$ MeV

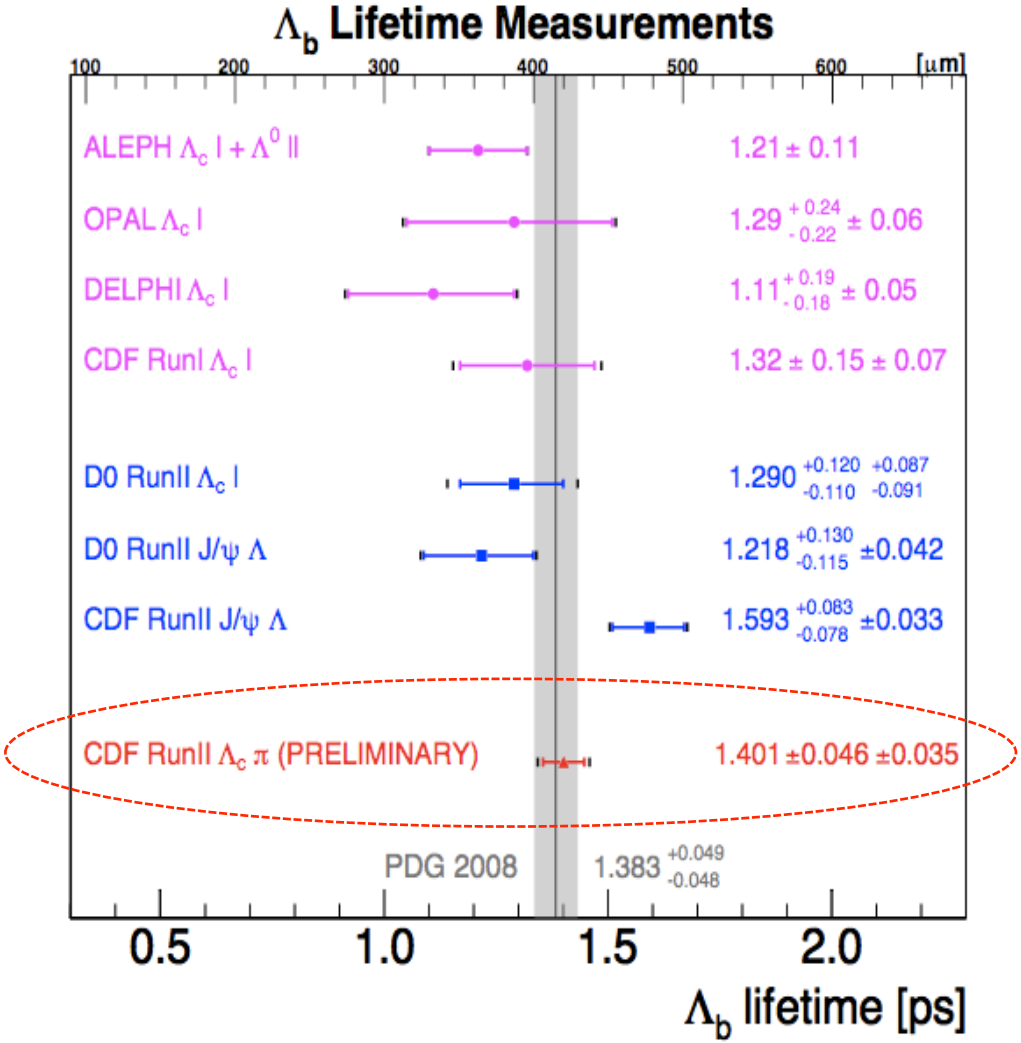
$m(\Sigma_b^{*+}) = 5829^{+1.6}_{-1.8} \pm 1.7$ MeV

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

PRL 99, 202001 (2007)

Λ^0_b lifetime





Use ≈3000 ev signal $\Lambda^0_b \rightarrow \Lambda^+_c \pi^-$ from the displaced vertex trigger

$c\tau(\Lambda^0) = 420.1 \pm 13.7(\text{stat}) \pm 10.6(\text{syst})\ \mu\text{m}$

Systematics dominated by MC model of trigger efficiency and decay

See Heather Gerberich's talk for details

Resonances in $\Lambda^0_b \to \Lambda^+_c 3\pi$ (I)

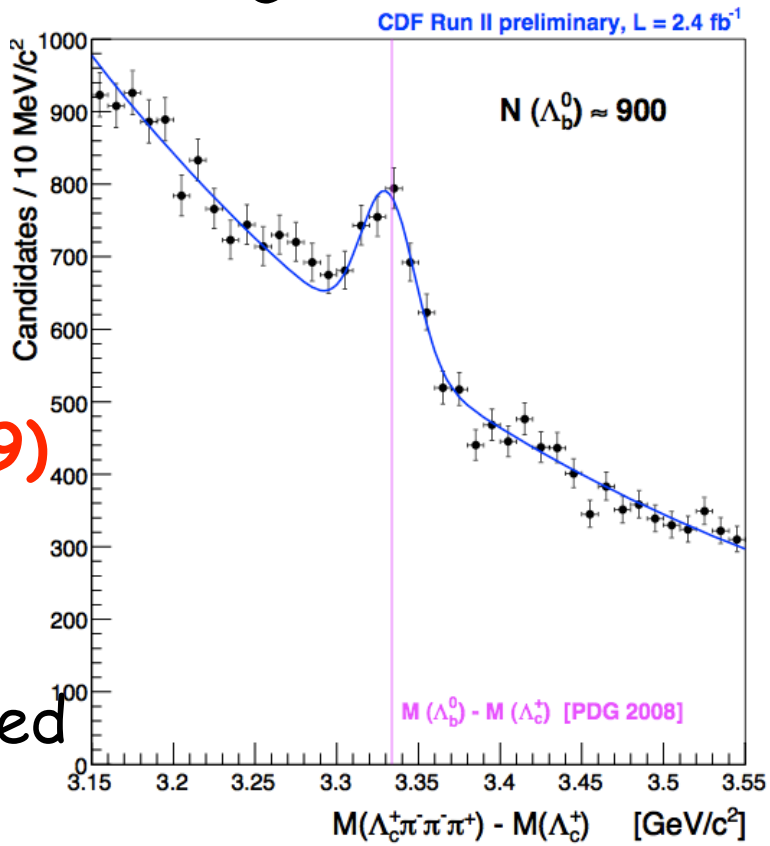
CDF observed resonant semileptonic decay modes and measured

$$\frac{BR(\Lambda^0_b \to \Lambda^+_c(2595)\mu^-\nu)}{BR(\Lambda^0_b \to \Lambda^+_c\mu^-\nu)}$$

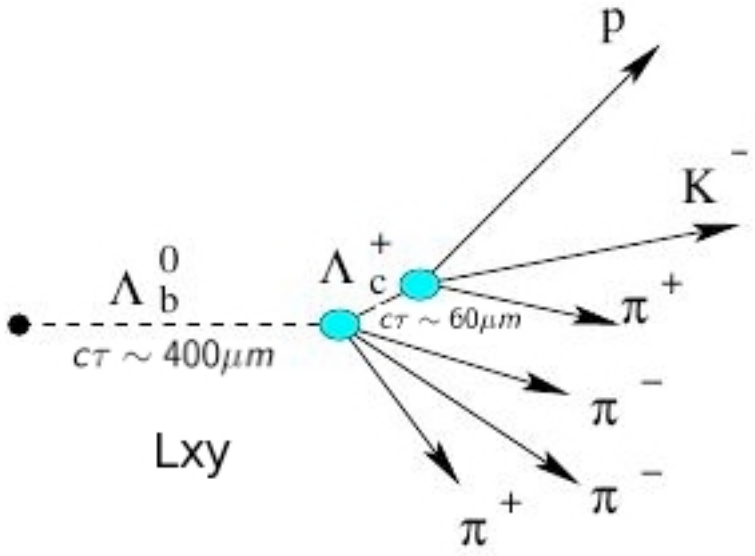
$$\frac{BR(\Lambda^0_b \to \Lambda^+_c(2625)\mu^-\nu)}{BR(\Lambda^0_b \to \Lambda^+_c\mu^-\nu)}$$

PRD 79, 032001 (2009)

$$\frac{BR(\Lambda^0_b \to \Sigma^0_c(2455)\pi^+\mu^-\nu)+BR(\Lambda^0_b \to \Sigma^{++}_c(2455)\pi^-\mu^-\nu)}{2x\ BR(\Lambda^0_b \to \Lambda^+_c\mu^-\nu)}$$

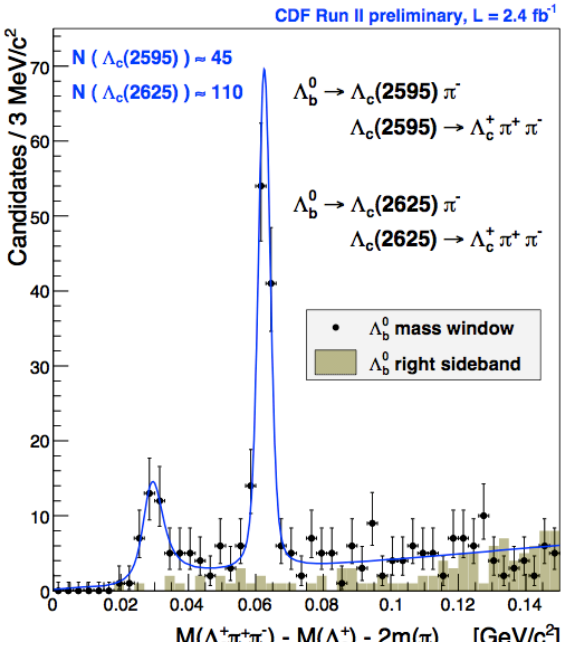


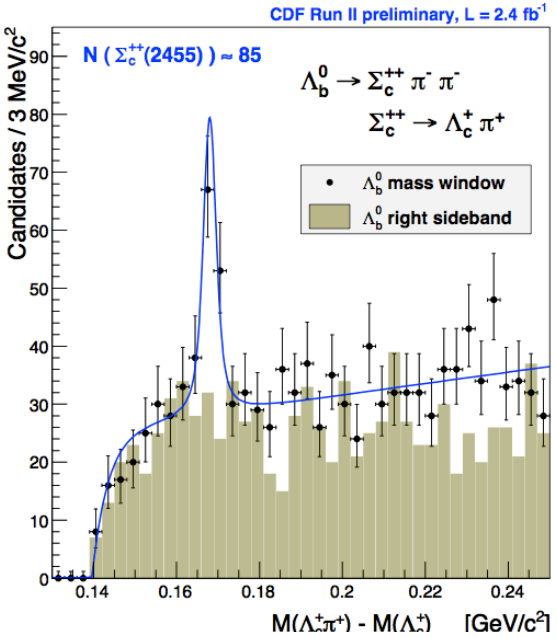
Similar resonant decay modes reconstructed in the $\Lambda^0_b \to \Lambda^+_c\pi^-\pi^+\pi^-$ decay

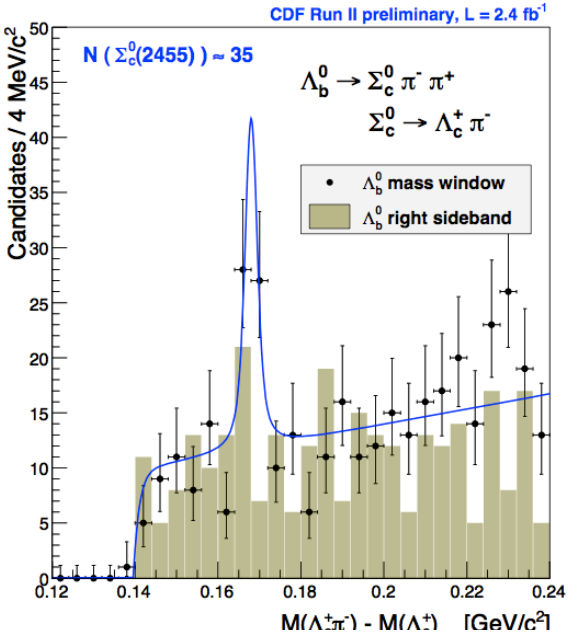


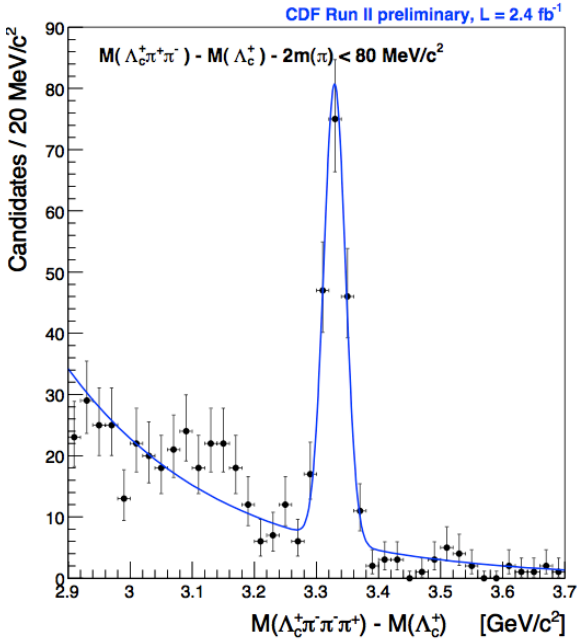
Λ^0_b decay mode	Rec. Yields
$\Lambda^0_b \to \Lambda^+_c\pi^-\pi^+\pi^-$	≈900
$\Lambda^0_b \to \Lambda^+_c(2595)\pi^-$	≈45
$\Lambda^0_b \to \Lambda^+_c(2625)\pi^-$	≈110
$\Lambda^0_b \to \Sigma^{++}_c\pi^-\pi^-$	≈85
$\Lambda^0_b \to \Sigma^0_c\pi^+\pi^-$	≈35

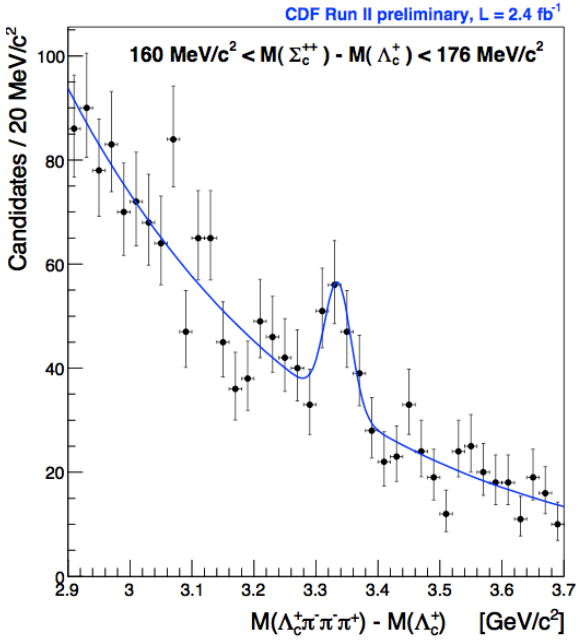
Resonances in $\Lambda^0_b \to \Lambda^+_c 3\pi$ (II)

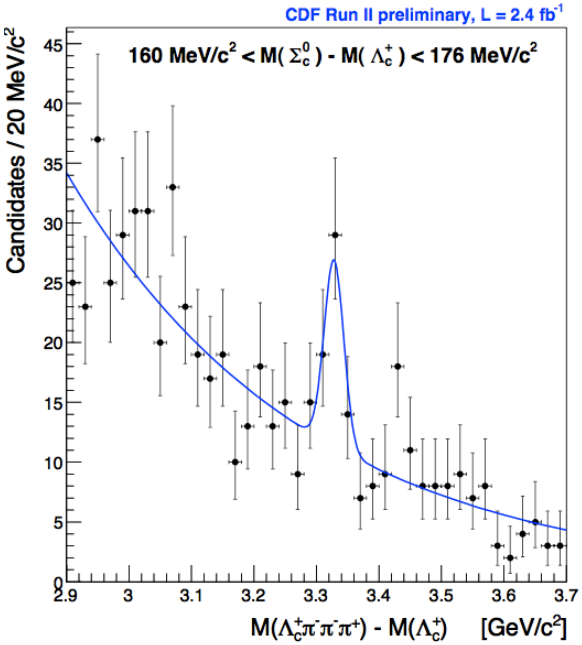




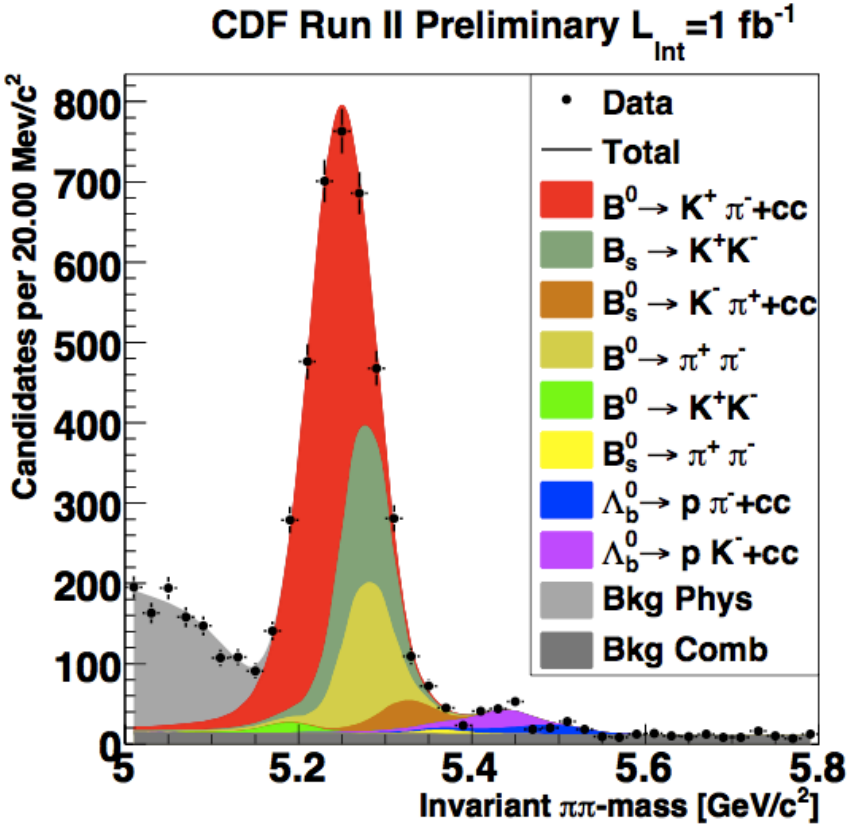


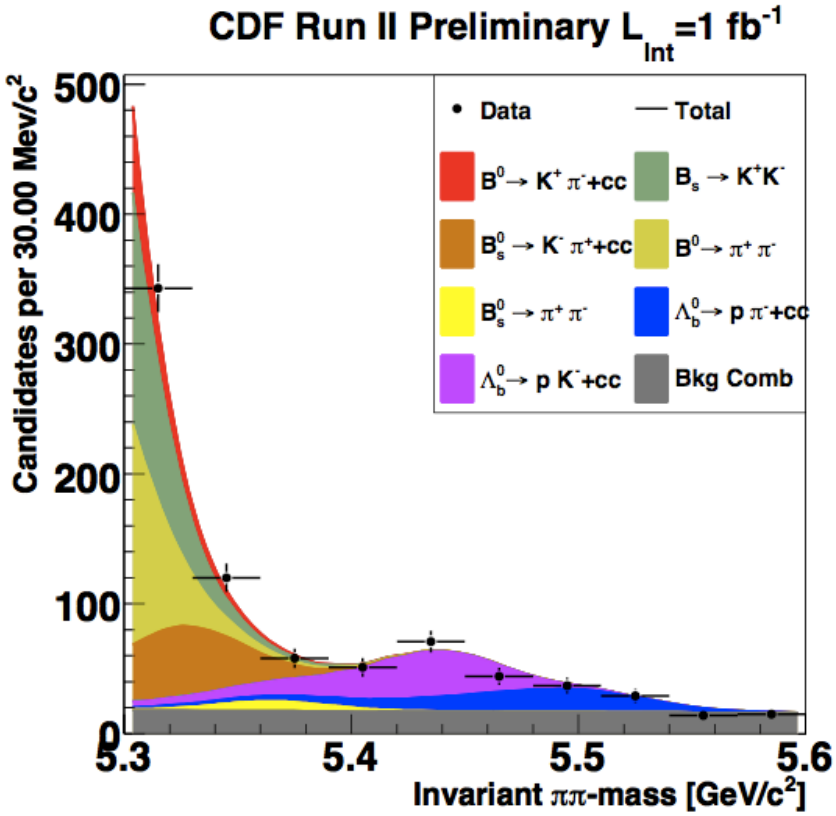






BR and A_{CP} in $\Lambda^0_b \to p\pi(K)$





First study of CP asymmetry in b-baryon decays (SM predicts DCPV ~10%)
Use large sample collected by two displaced track trigger along with B→hh

We take into account Lb pT spectrum (different from B), Lb polarization (modifies kinematics) and p/K nd p/π efficiencies

BR and A_{CP} in $\Lambda^0_b \to p\pi(K)$

$$A_{CP}(\Lambda_b^0 \to p\pi^-) = \frac{\mathcal{B}(\Lambda_b^0 \to p\pi^-) - \mathcal{B}(\overline{\Lambda}_b^0 \to \overline{p}\pi^+)}{\mathcal{B}(\Lambda_b^0 \to p\pi^-) + \mathcal{B}(\overline{\Lambda}_b^0 \to \overline{p}\pi^+)} = 0.03 \pm 0.17\ (stat.) \pm 0.05\ (syst.)$$

$$A_{CP}(\Lambda_b^0 \to pK^-) = \frac{\mathcal{B}(\Lambda_b^0 \to pK^-) - \mathcal{B}(\overline{\Lambda}_b^0 \to \overline{p}K^+)}{\mathcal{B}(\Lambda_b^0 \to pK^-) + \mathcal{B}(\overline{\Lambda}_b^0 \to \overline{p}K^+)} = 0.37 \pm 0.17\ (stat.) \pm 0.03\ (syst.)$$

$$\frac{\sigma(p\bar{p} \to \Lambda_b^0 X, p_T > 6\ \mathrm{GeV}/c)}{\sigma(p\bar{p} \to B^0 X, p_T > 6\ \mathrm{GeV}/c)} \frac{\mathcal{B}(\Lambda_b^0 \to p\pi^-)}{\mathcal{B}(B^0 \to K^+\pi^-)} = 0.0415 \pm 0.0074\ (stat.) \pm 0.0058\ (syst.)$$

$$\frac{\sigma(p\bar{p} \to \Lambda_b^0 X, p_T > 6\ \mathrm{GeV}/c)}{\sigma(p\bar{p} \to B^0 X, p_T > 6\ \mathrm{GeV}/c)} \frac{\mathcal{B}(\Lambda_b^0 \to pK^-)}{\mathcal{B}(B^0 \to K^+\pi^-)} = 0.0663 \pm 0.0089\ (stat.) \pm 0.0084\ (syst.)$$

PRL 103, 031801 (2009)

BRs are in agreement with SM predictions and exclude O(10-4) values indicated for R-parity violating Minimal Supersymmetric extensions of the Standard Model [PRD63,056006(2001)]

First DCPV measurements in b-baryon decays (statistical uncertainty dominates)

First hint of DCPV in b-baryon decays (very interesting to pursue with more data).

Conclusions

Tevatron is giving great contribution to increase our knowledge of b-baryons

Observation of the Ω_b^- and Ξ_b^-

- Measurement of Ω_b^- mass and lifetime
- Measurement of Ξ_b^- mass and lifetime

Observation of the $\Sigma_b^{\pm(*)}$

Improving measurements of Λ_b properties

- World best mass and lifetime
- Reconstruction of new decay modes
- BR/CP violation in $\Lambda_b \rightarrow p\pi(K)$