Observation of Σ_b and Σ_b^* Baryons at CDF

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Σ_b Motivation

- Λ_b only established *b* baryon
- Enough statistics at Tevatron to probe other heavy baryons
- Next accessible baryons:

$= 3/2^+ (\Sigma_b^*)$

Σ_b: $\{qq\}b$; $J^P = S_Q + s_{qq}$

$= 1/2^+ (\Sigma_b)$

$\Sigma_b^{(*)+} = uub$

$\Sigma_b^{(*)-} = ddb$

$\Sigma_b^{(*)0} = udb$

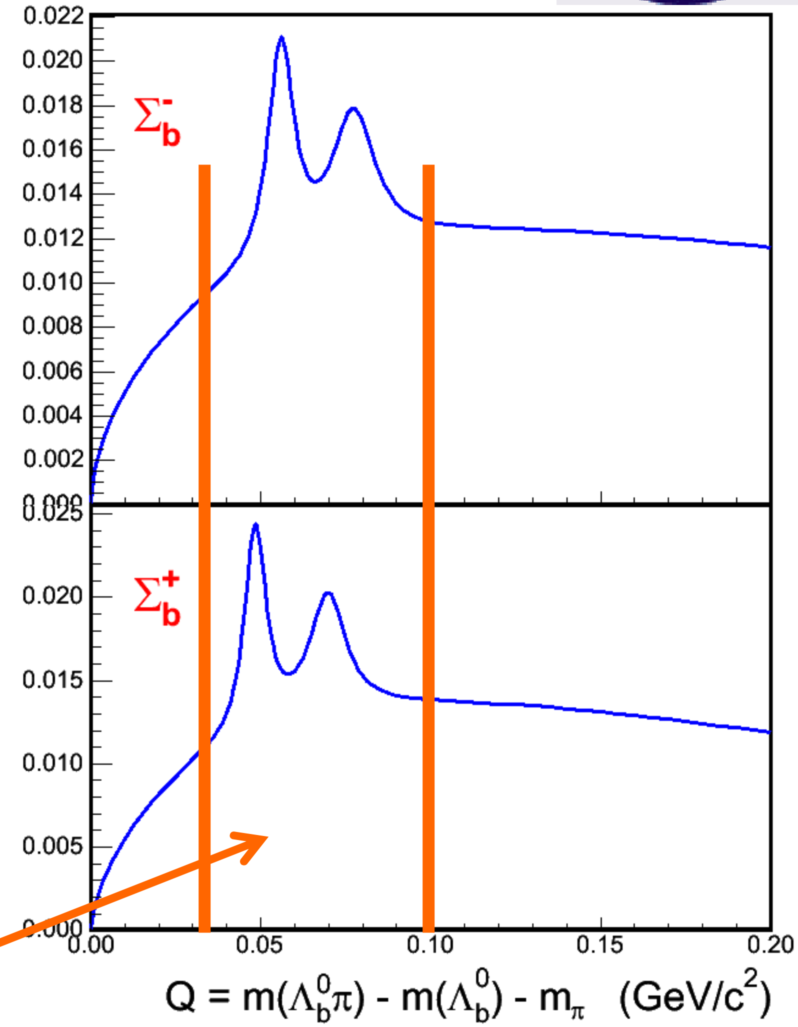
Can't see π^0

- $\Sigma_b^{\pm}$ decays to $\Lambda_b \pi^{\pm}$ via p-wave
- Baryon spectroscopy tests HQET, Lattice QCD, potential quark models…
- Discovering new particles always exciting!

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

Σ_b Search Methodology

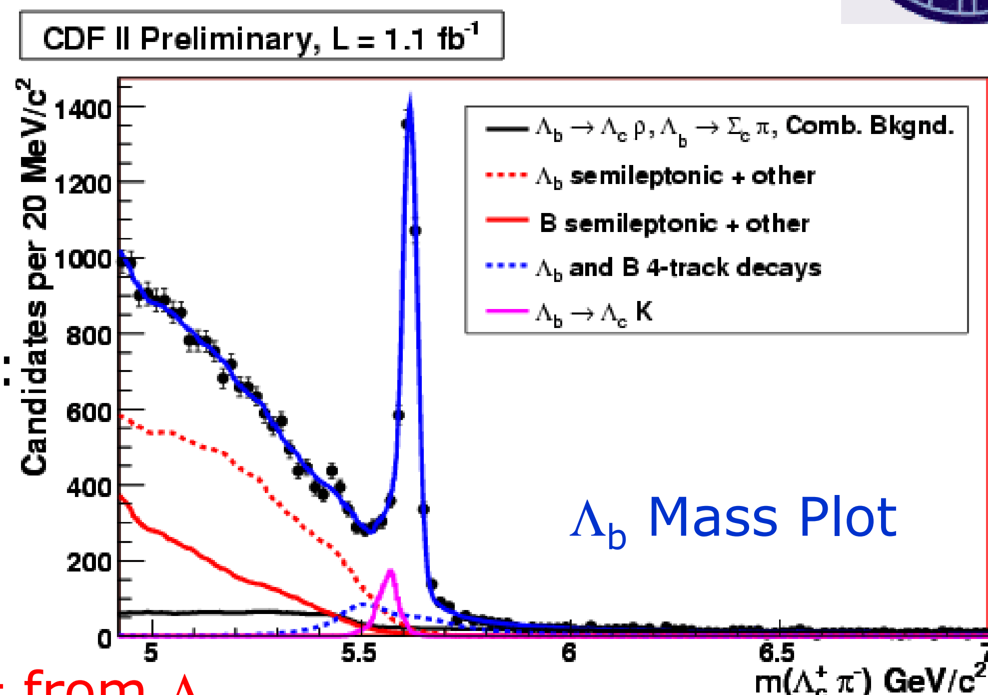
- Σ_b decays strongly at primary vertex → combine Λ_b candidate with good-quality prompt track to make Σ_b candidate
- Separate Σ_b^- and Σ_b^+:
  - $\Sigma_b^{(*)-} \to \Lambda_b^0 \pi^- \to \Lambda_c^+ \pi^- \pi^-$ (+ c.c.)
  - $\Sigma_b^{(*)+} \to \Lambda_b^0 \pi^+ \to \Lambda_c^+ \pi^- \pi^+$ (+ c.c.)
- Search for resonances in mass difference $Q = m(\Lambda_b \pi) - m(\Lambda_b) - m_\pi$
- Unbiased Σ_b selection
  - Optimize Σ_b cuts without looking in Σ_b signal region of: $30 < Q < 100$ MeV/c^2

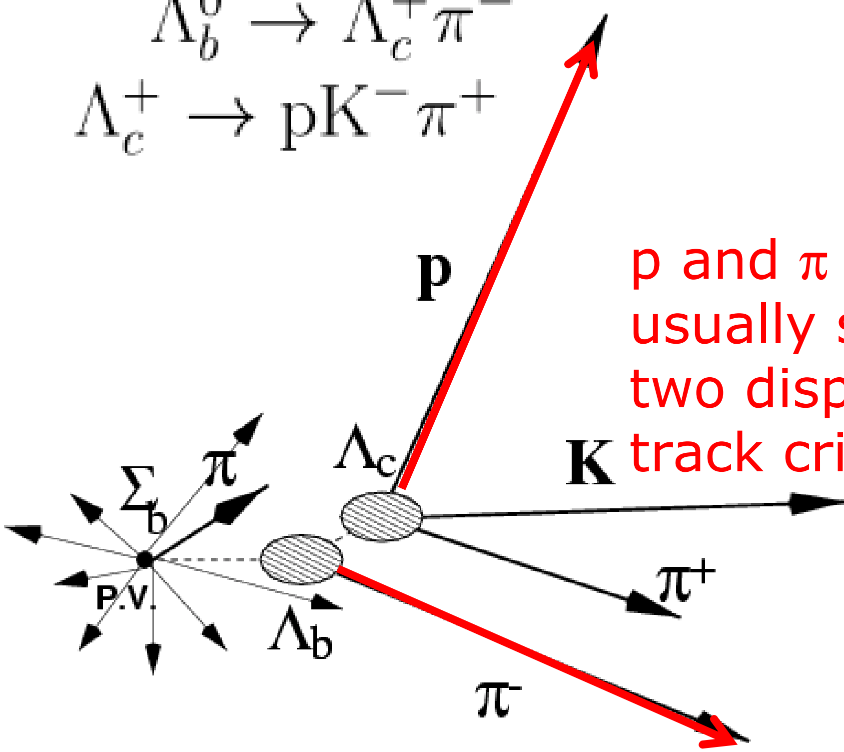


Reconstructing $\Sigma_b \to \Lambda_b \pi$

- With ~1.1 fb^{-1}, world's largest sample of Λ_b: ~3000
- Use CDF's two displaced track trigger to reconstruct:

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



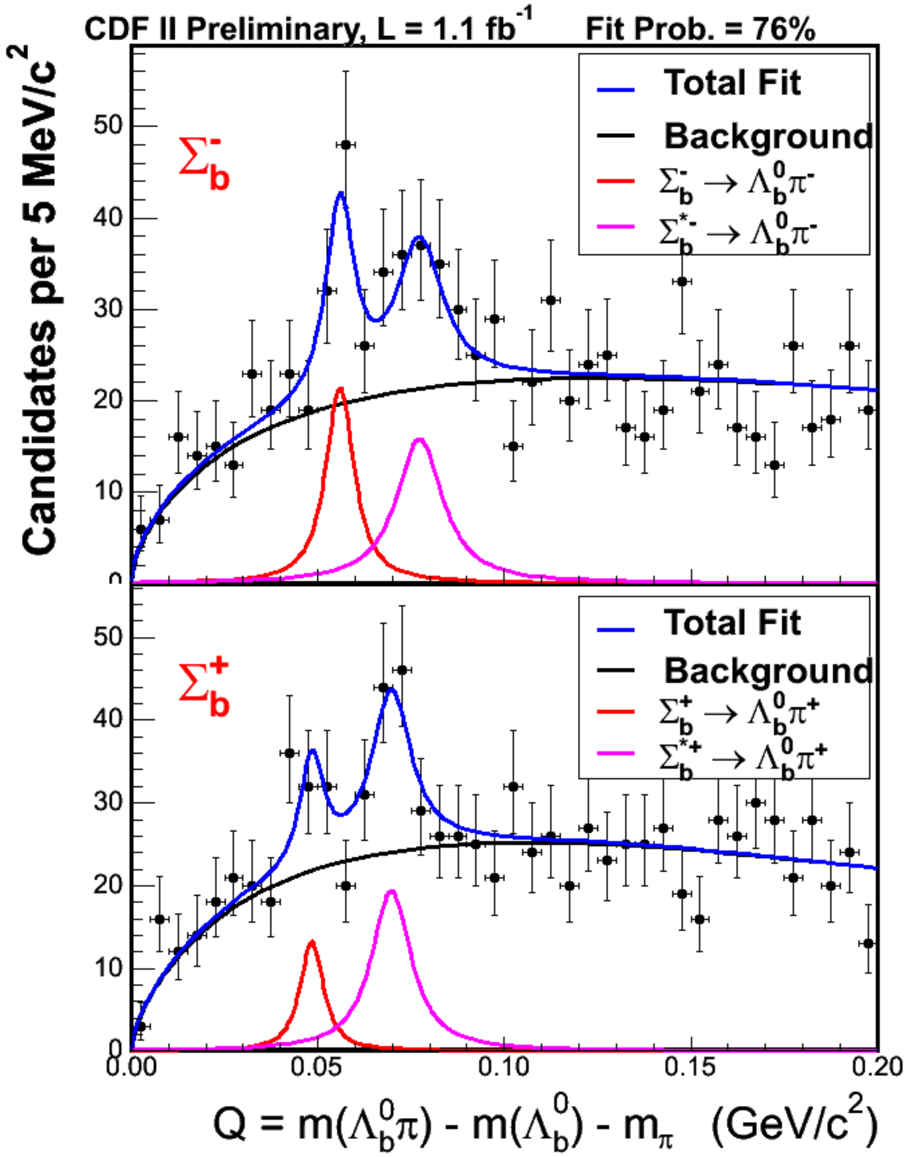


p and π from Λ_b usually satisfy two displaced track criteria

- Events in the Λ_b signal region contribute to Σ_b backgrounds
- Fix Σ_b backgrounds from data and Monte Carlo

Σ_b Observation

- Fit signal with unbinned likelihood fit
  - Background fixed
  - Peaks fit with Breit-Wigner convoluted with detector resolution
  - Common parameter $m(\Sigma_b{}^*) - m(\Sigma_b)$
- Observe signals consistent with lowest lying charged $\Sigma_b{}^{(*)}$ states
- "Null" hypothesis excluded at high confidence level ($> 5\sigma$)



Summary

- First observation of resonant $\Lambda_b\pi$ states!
  - Consistent with lowest lying charged Σ_b states
  - Very good agreement with theoretical predictions
  - Measure Σ_b^- and Σ_b^+ Q values, average $m(\Sigma_b^*) - m(\Sigma_b)$
  - Using $m(\Lambda_b) = 5619.7 \pm 1.2$ (stat) ± 1.2 (syst) MeV/c^2, absolute Σ_b masses:

$$m(\Sigma_b^-) = 5815.2 \pm 1.0\,(\mathrm{stat}) \pm 1.7\,(\mathrm{syst})\ \mathrm{MeV/c^2}$$

$$m(\Sigma_b^+) = 5807.7^{+2.0}_{-2.3}\,(\mathrm{stat}) \pm 1.7\,(\mathrm{syst})\ \mathrm{MeV/c^2}$$

$$m(\Sigma_b^{*-}) = 5836.5^{+2.1}_{-1.9}\,(\mathrm{stat}) \pm 1.7\,(\mathrm{syst})\ \mathrm{MeV/c^2}$$

$$m(\Sigma_b^{*+}) = 5829.0^{+1.6}_{-1.8}\,(\mathrm{stat}) \pm 1.7\,(\mathrm{syst})\ \mathrm{MeV/c^2}$$

Backup Slides

Σ_b Full Results

$$m(\Sigma_b^-) - m(\Lambda_b^0) - m(\pi) = 55.9 \pm 1.0\ (\text{stat}) \pm 0.1\ (\text{syst})\ \text{MeV}/c^2$$

$$m(\Sigma_b^+) - m(\Lambda_b^0) - m(\pi) = 48.4^{+2.0}_{-2.3}\ (\text{stat}) \pm 0.1\ (\text{syst})\ \text{MeV}/c^2$$

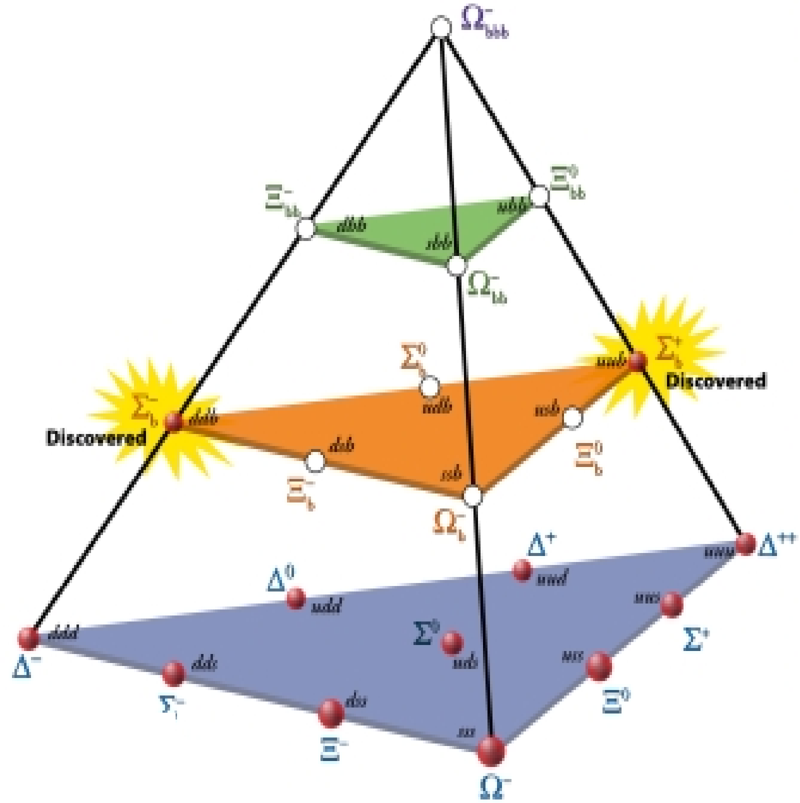
$$m(\Sigma_b^{*-}) - m(\Sigma_b^-) = m(\Sigma_b^{*+}) - m(\Sigma_b^+) = 21.3^{+2.0}_{-1.9}\ (\text{stat})\ ^{+0.4}_{-0.2}\ (\text{syst})\ \text{MeV}/c^2$$

$$N(\Sigma_b^-) = 60^{+15}_{-14}\ (\text{stat})\ ^{+8}_{-4}\ (\text{syst})$$

$$N(\Sigma_b^+) = 29 \pm 12\ (\text{stat})\ ^{+5}_{-3}\ (\text{syst})$$

$$N(\Sigma_b^{*-}) = 74^{+18}_{-17}\ (\text{stat})\ ^{+16}_{-5}\ (\text{syst})$$

$$N(\Sigma_b^{*+}) = 74^{+17}_{-16}\ (\text{stat})\ ^{+10}_{-6}\ (\text{syst})$$



Strength of Σ_b hypothesis

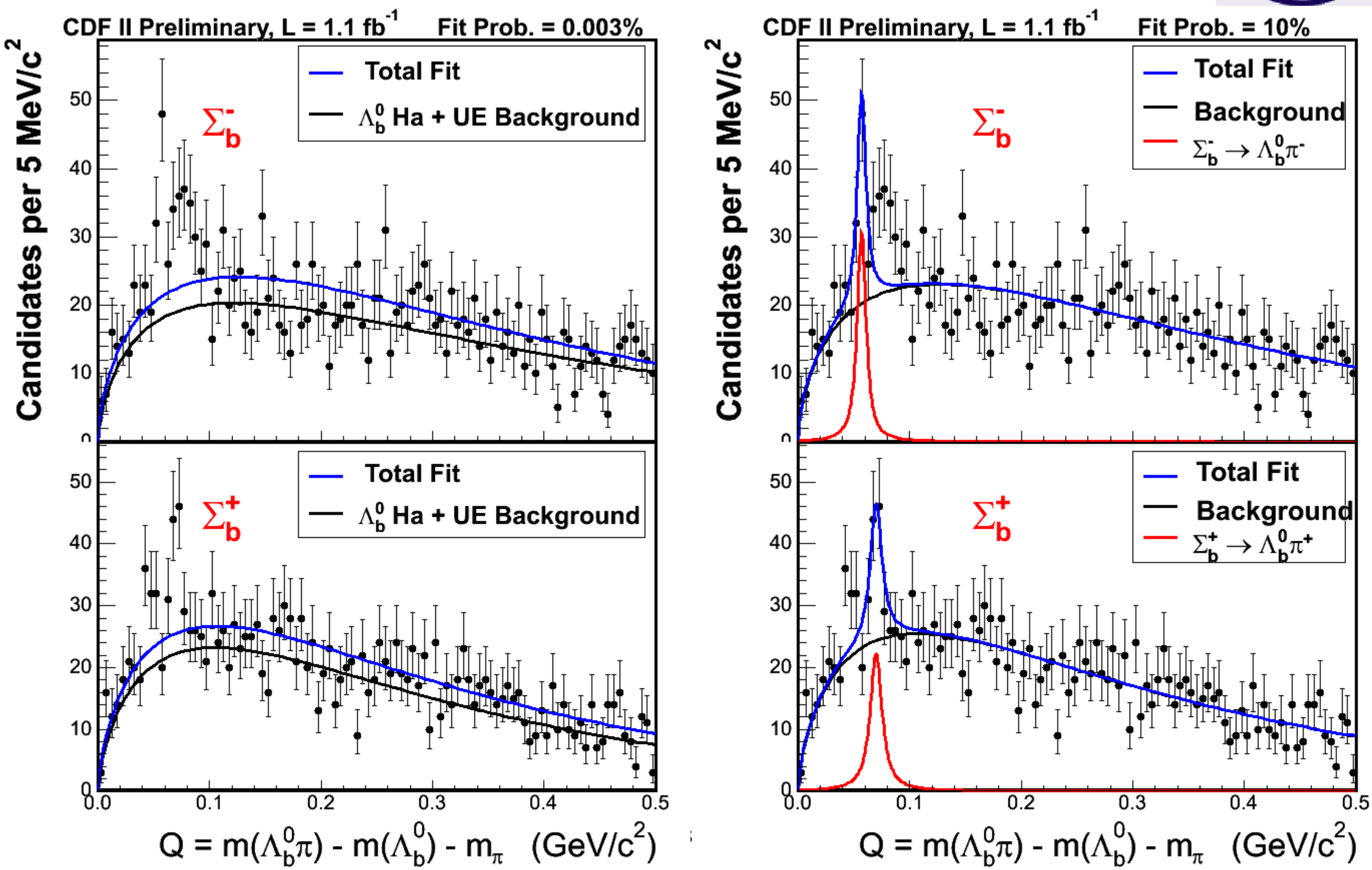
- Evaluate Likelihood Ratio:

$$LR = \frac{L_{\text{no peak fit}}}{L_{\text{four peak fit}}}$$

- Evaluated LR for systematic variations of the fit model and pick the worst scenario!
- "Null" hypothesis excluded at high confidence level

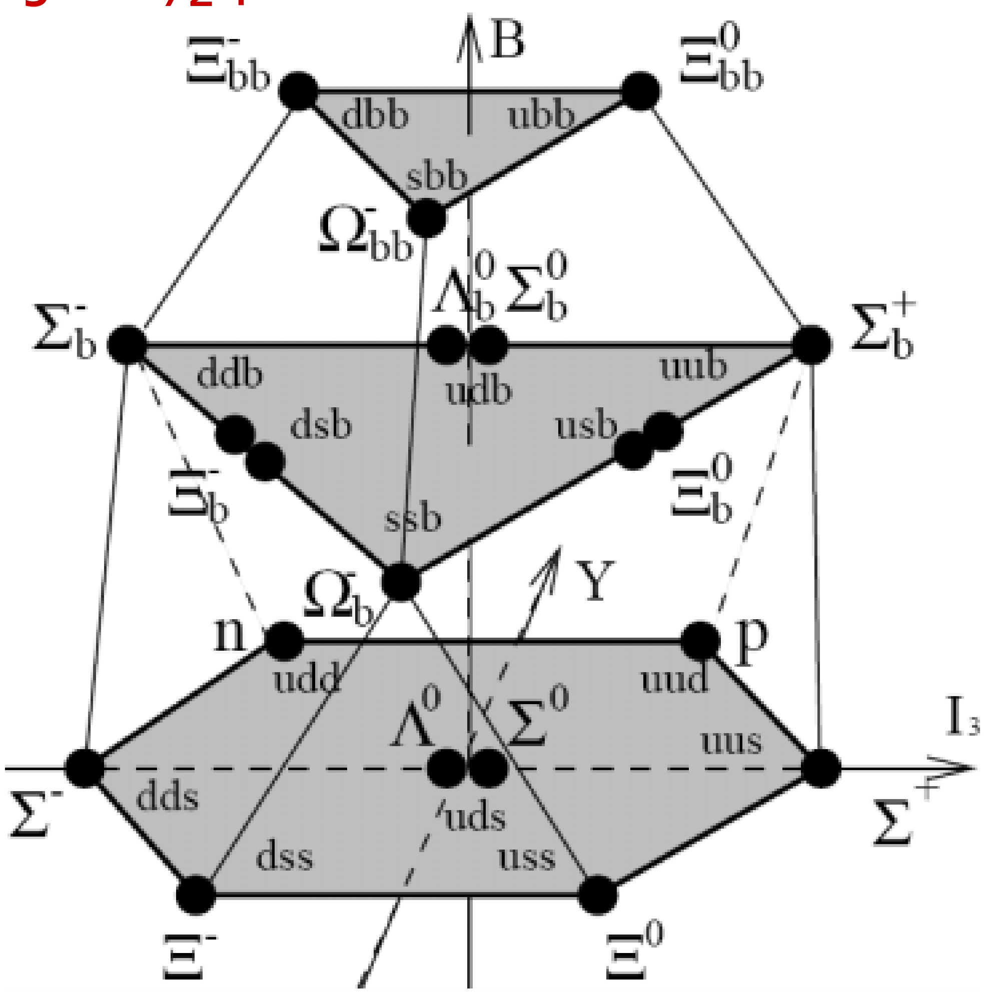
Hypothesis	$\Delta(-\ln L)$	1/LR
"NULL" vs. "4 Peak"	**44.7**	**2.6e19**
"2 Peak" vs. "4 Peak"	**14.3**	**1.6e6**
No Σ_b^- Peak	**10.4**	**3.3e4**
No Σ_b^+ Peak	**1.1**	**3**
No Σ_b^{*-} Peak	**10.1**	**2.4e4**
No Σ_b^{*+} Peak	**9.8**	**1.8e4**

Zero and Two Peak Fits

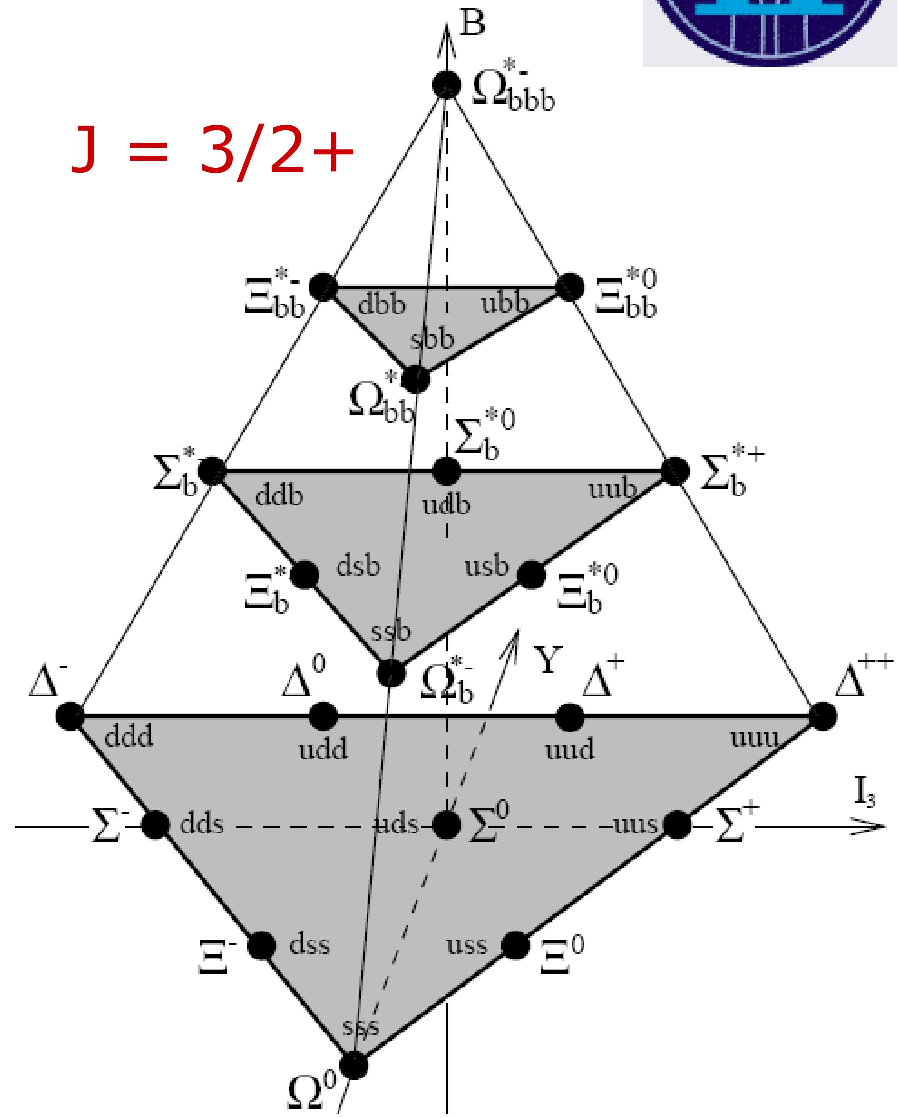


Baryon multiplets:

J = ½+



J = 3/2+



Σ_b Backgrounds

- Σ_b backgrounds:
  - Hadronization tracks around prompt Λ_b – Dominant!
  - *B* meson hadronization tracks
  - Combinatorial background
- Take background shapes from data or PYTHIA Monte Carlo, normalize using Λ_b sample comp.
- Backgrounds are fixed before looking in the Σ_b signal region

Background type		Sample	Contribution
Λ_b HA+UE		PYTHIA	dominant
Combinatorial		Upper Λ_b sideband $m(\Lambda_b) \in [5.8, 7.0]$	small
B mesons		data	small
B meson reflections	*π_Σ from B HA+UE*	Pythia	Dominant within B
	π_Σ from B decay (D^*, D^{**})	Inclusive BGen	negligible
	π_Σ from B^{**}	B0 Pythia	negligible