Properties of weakly-decaying bottom baryons, Ξ_b^- and Ω_b^-, at CDF

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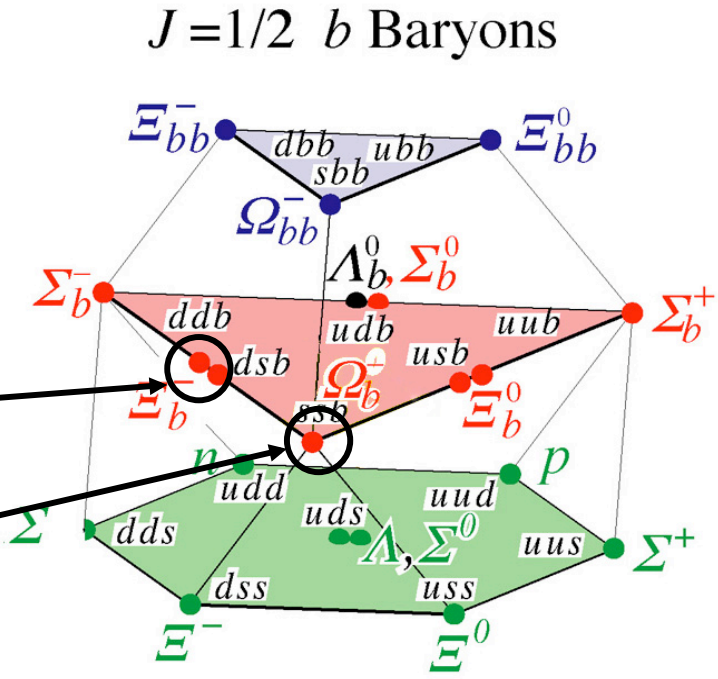
Baryon Ground States

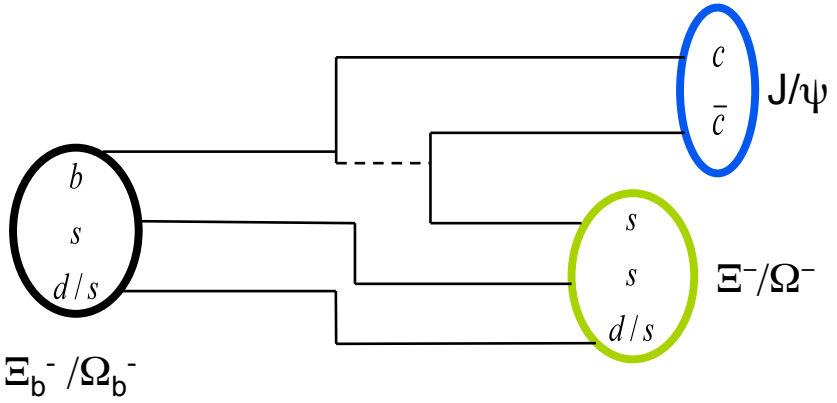
- We present measurements of *b*-baryon property from fully reconstructed states
- Properties of two of the most recently observed *b*-baryons
  - Ξ_b^-, observed in 2007
    - D0: 15, CDF: 18
  - Ω_b^-, observed by DØ in 2008
    - D0: 18
- Only available lifetime measurements of Ξ_b^- are semileptonic (LEP)



- Details of the analysis in: arXiv:0905.3123

B Baryon Searches

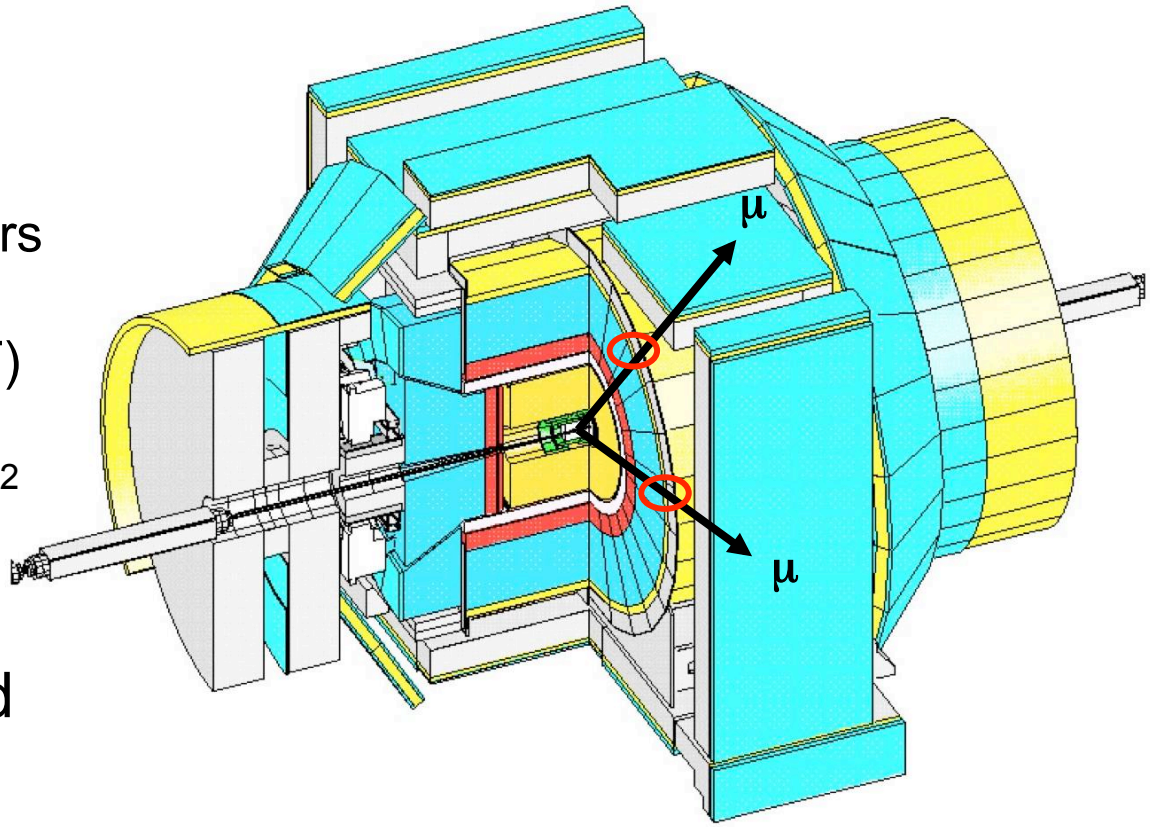
- The data set is collected using CDF's di-muon trigger
  - $J/\psi \rightarrow \mu^+\mu^-$ in the final state
- Ξ_b^- and Ω_b^- are searched via:
  - $\Xi_b^- \rightarrow J/\psi\ \Xi^-$, $J/\psi \rightarrow \mu^+\mu^-$, $\Xi^- \rightarrow \Lambda\pi^-$
  - $\Omega_b^- \rightarrow J/\psi\ \Omega^-$, $J/\psi \rightarrow \mu^+\mu^-$, $\Omega^- \rightarrow \Lambda K^-$
- Data set rich with all *b*-meson species
- B^0 and Λ_b decay modes are used as references:
  - $B^0 \rightarrow J/\psi\ K^{*0}$, $J/\psi \rightarrow \mu^+\mu^-$, $K^{*0} \rightarrow K^+\pi^-$
  - $B^0 \rightarrow J/\psi\ K_s^0$, $J/\psi \rightarrow \mu^+\mu^-$, $K_S^0 \rightarrow \pi^+\pi^-$
  - $\Lambda_b \rightarrow J/\psi\ \Lambda$, $J/\psi \rightarrow \mu^+\mu^-$, $\Lambda \rightarrow p\pi^-$



- This analysis uses 4.2 fb^{-1} data.
- Similar selection and techniques are used for all reconstructed species.

Tracks in the CDF II Detector

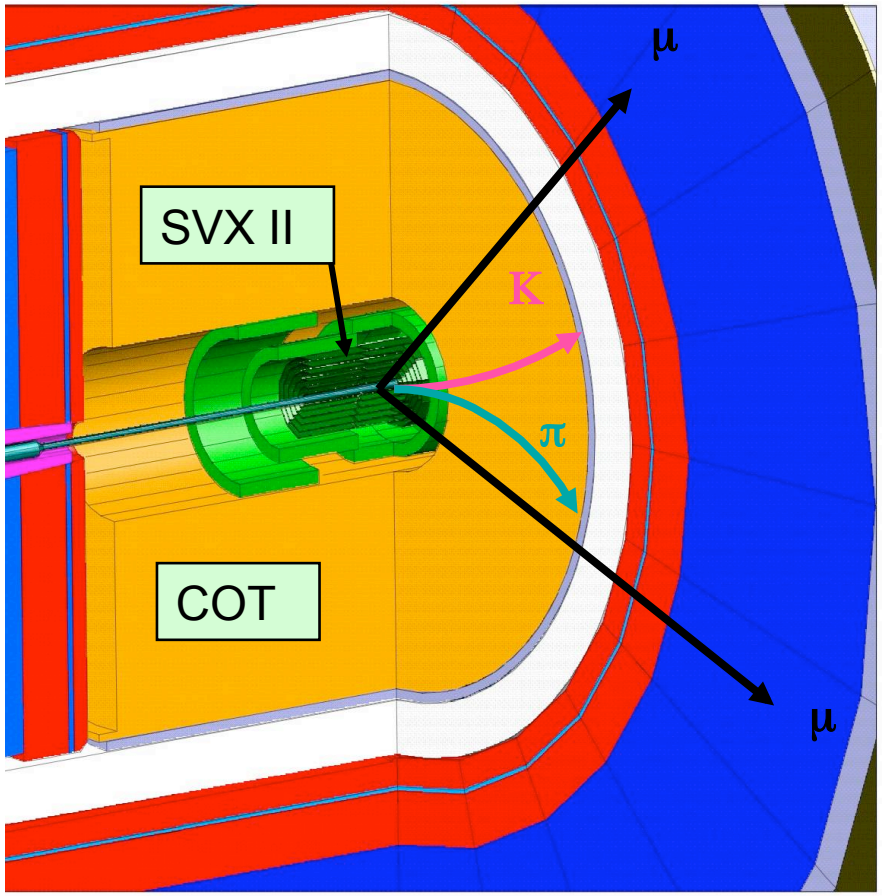
- The di-muon trigger requires
  - tracks in muon chambers
  - tracks in the central tracking chamber (COT) (p_T>1.5 GeV)
  - 2.7<M($\mu^+\mu^-$)<4.0 GeV/c^2



- The trigger is unbiased with respect to decay time for *b*-hadrons

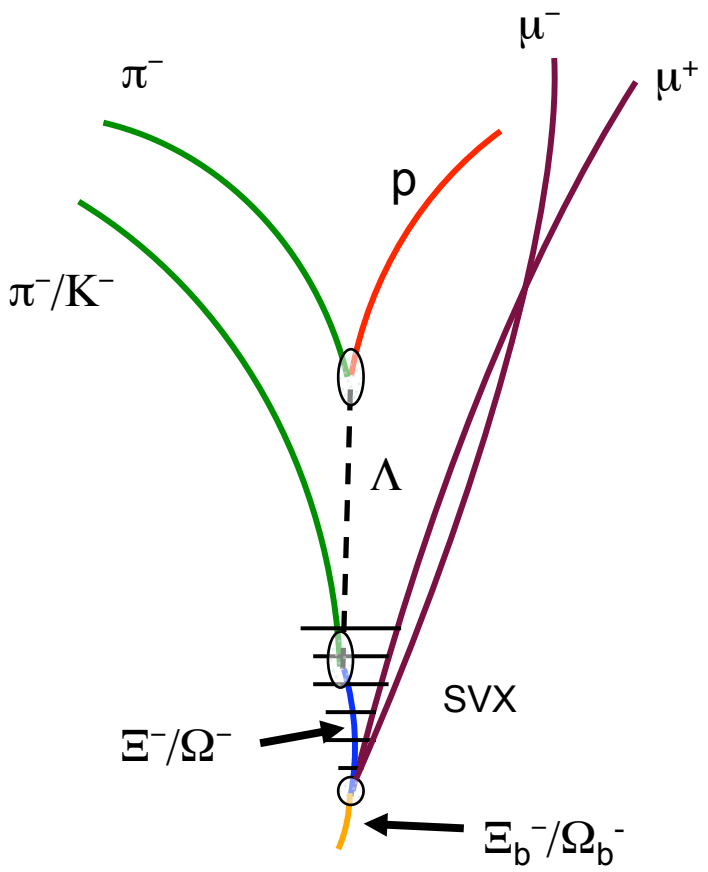
Tracks in the CDF II Detector

- In triggered events studied decays are fully reconstructed / analyzed.
- Track reconstruction identifies all tracks with p_T>0.4 GeV/*c*
- Three SVX II measurements are required for muon tracks.
  - Not used for p/K/π tracks



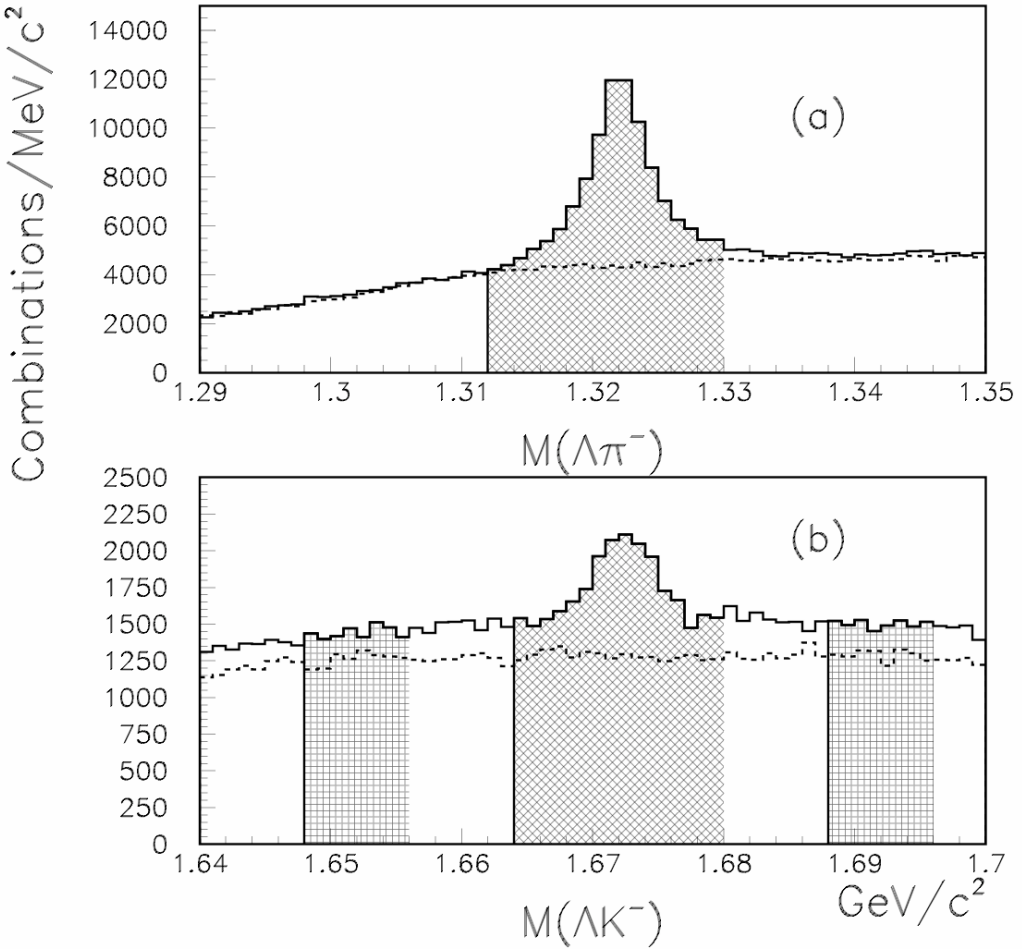
Ξ_b^-/Ω_b^- Reconstruction

- The Ξ_b^-/Ω_b^- have complex decay topology:
  - 5 tracks, 3 vertices
- Final state fit involves:
  - topology constraints
  - Λ, Ξ^-/Ω^-, and J/ψ mass constraints
- Long flight of the Ξ^- and Ω^- enable usage of silicon detector hits on the 6th track.
  - Impact parameter resolution improvement

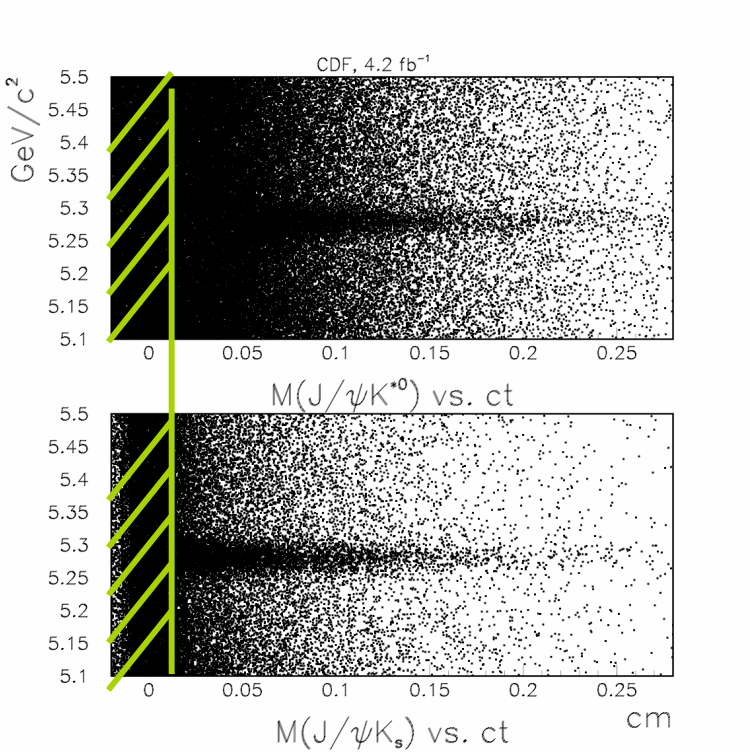


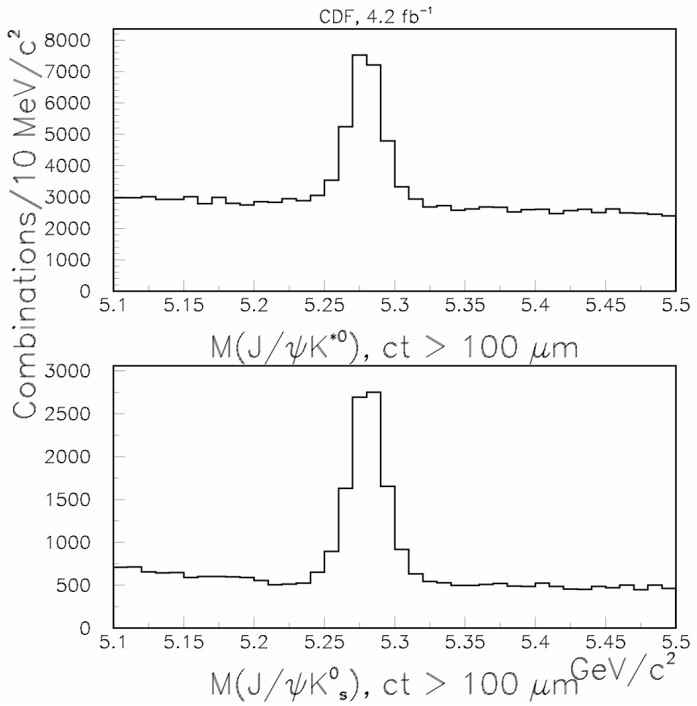
Inclusive Ξ^- / Ω^- Sample

- Yields in the full sample
  - J/ψ: 2.9×10^7
  - Λ: 3.6×10^6
  - Ξ^- : 41,000
  - Ω^-: 3,500
- Dashed histograms are $\Lambda\pi^+$ / ΛK^+ (wrong-sign decays)
- Shaded are selection and sideband regions



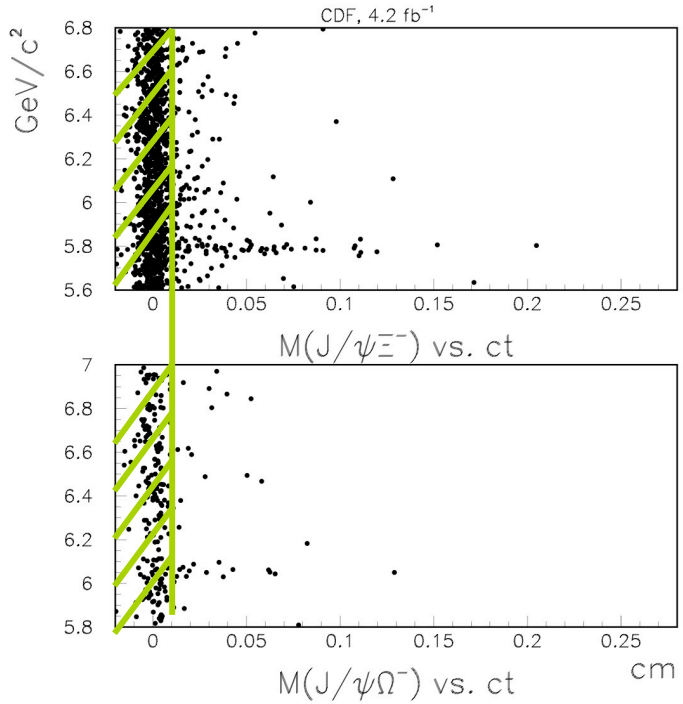
b-Meson Signals

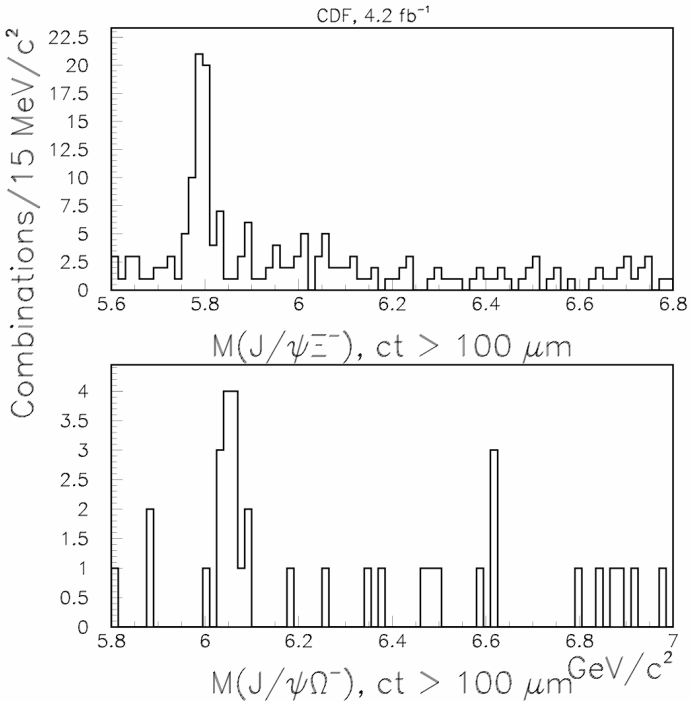




- Decay time selects B hadron signals from the prompt background
  - *ct* > 100 μm requirement removes most prompt background

b-Baryon Signals

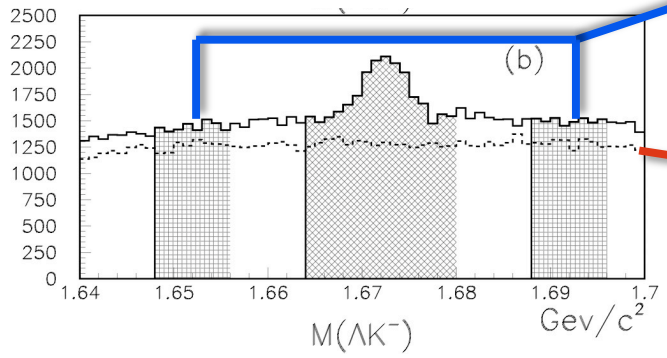




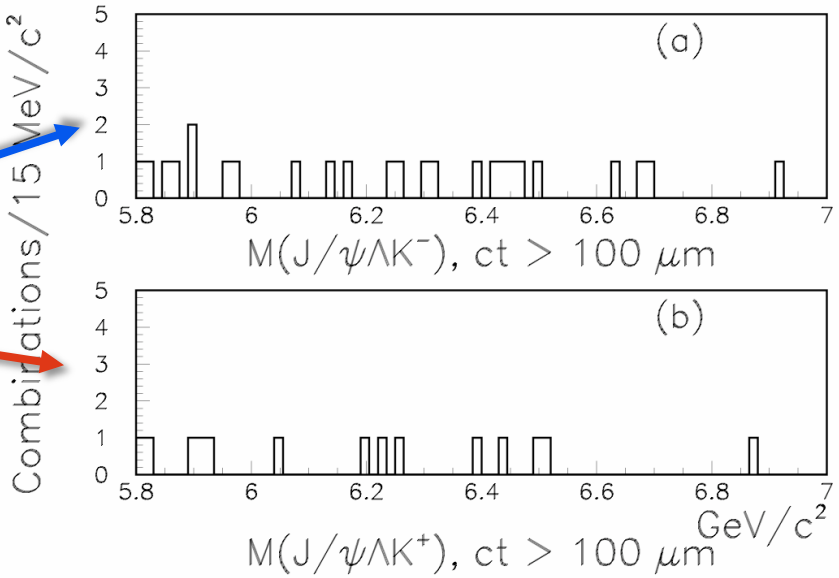
- J/ψ Ξ^- and J/ψ Ω^- samples
  - $p_T(B) > 6$ GeV/c
  - $p_T(\Xi^-/\ \Omega^-) > 2$ GeV/c
  - Good fit with J/ψ mass constraint
- Obvious Ξ_b^- signal when *ct* > 100 μm
- Cluster in the J/ψ Ω^- around 6.05 GeV/c^2 – test its significance

Where we expect nothing…

- For the same candidate selection, except for in the Ω^- (ΛK^-) mass sidebands and wrong-sign combinations:



Sidebands



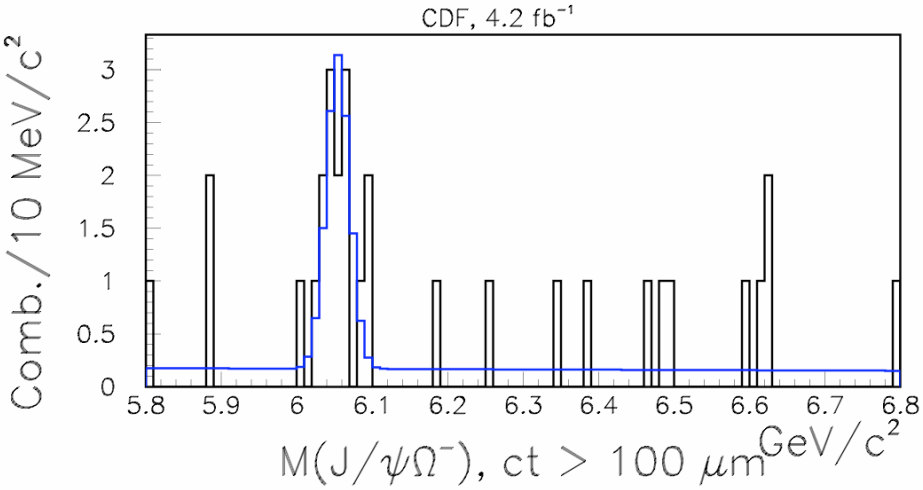
Wrong-sign candidates

- Neither shows any features anywhere

Ω_b^- Significance: Mass Distribution Test

- Two tests are used to determine the significance of the candidate signal in the $J/\psi\Omega^-$ sample.
- First, ratio of likelihoods of the mass distribution with ct > 100 μm
  - P.D.F is Gaussian signal and a flat background.
  - Fit freely, and with the null hypothesis

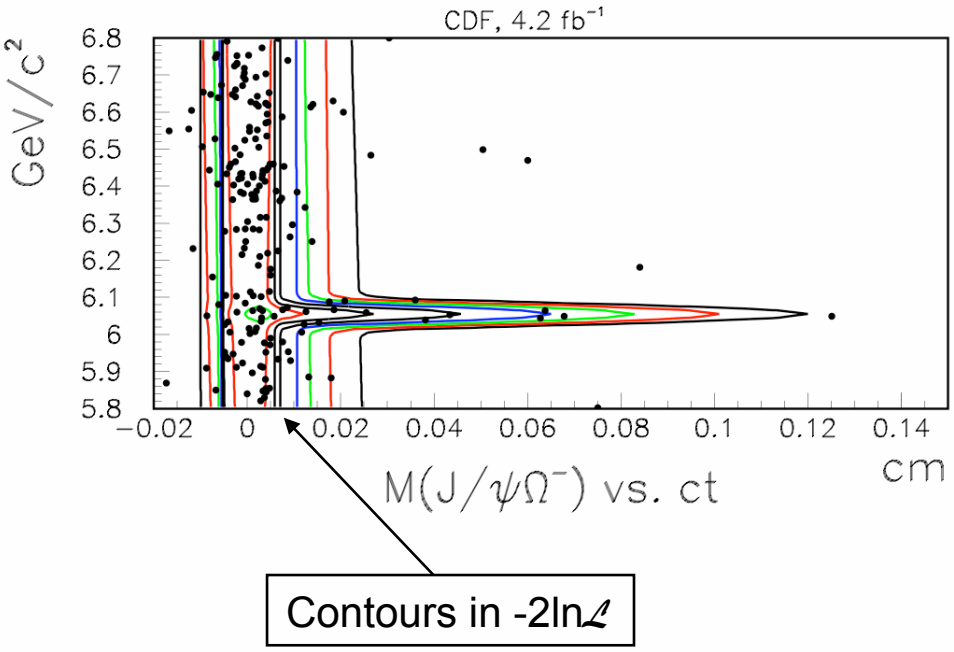
$\Delta 2\ln\mathcal{L} = 27.9$



- Interpreted as $P(\chi^2)$ with 2 d.o.f., = 8.7×10^{-7} ➔ 4.9σ
  - Confirmed by simulation
    - Similar prob. For random background
    - ± 200 MeV/c^2 search range

Ω_b^- Significance: Mass/Decay Time Distribution Test

- Second method: ratio of likelihoods of the mass-decay time distribution.
  - P.D.F in mass is Gaussian signal and a flat background.
  - P.D.F. in time is resolution smeared
    - Exponential(τ_0) for signal
    - Exponential(τ_b) for b-background
    - Delta function for prompt background
  - Fit freely, and with the null hypothesis



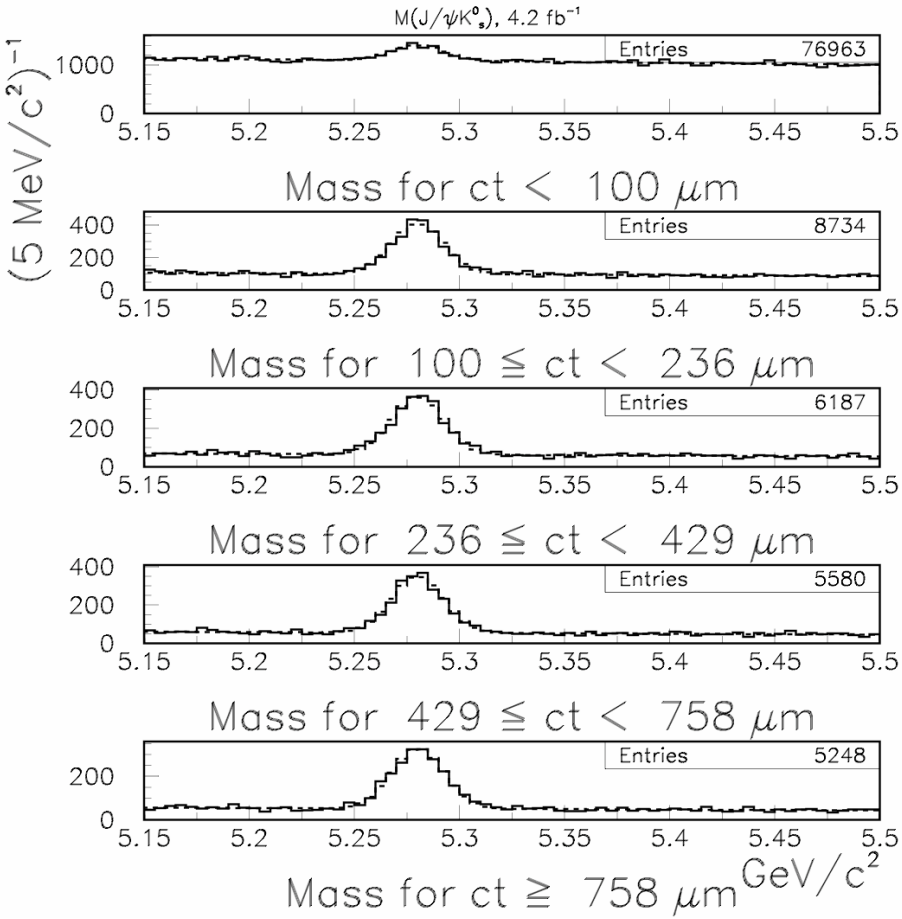
$\Delta 2\ln\mathcal{L} = 37.3$

Mass and Lifetime Measurements

- Masses and lifetimes are calculated for 5 final states
  - 3 are references (B^0 in K^{*0} and K_s^0 final states and Λ_b^0)
  - 2 are results (Ξ_b^-, Ω_b^-)
- Similar selection is used for all final states
  - Same J/ψ selection, $p_T(B) > 6.0$, $p_T(K/\Lambda/\Xi/\Omega) > 2.0$
  - Drop impact parameter requirements – various efficiency for this
  - Mass windows set for hadrons, full fit $P(\chi^2) > 10^{-4}$
- Unbinned mass fit applied to $ct > 100$ μm samples
  - Used in Ω_b^- significance evaluation
- Unbinned mass, binned lifetime fit applied to whole sample
  - Mass and lifetime extraction

A Binned Lifetime Calculation

- A binned lifetime fit makes us insensitive to the modeling of background in decay time
  - Demonstrated on the full $B^0 \rightarrow J/\psi K^0_S$ sample.
  - Bin boundaries are indicated.
    - ~20% area in each time range
  - Projections of the mass fits are overlaid on the data.
- Fit results:
  - Yield: 9424 ± 167
  - Mass: 5280.2 ± 0.2 MeV/c^2
    - PDG: 5279.53 ± 0.33 MeV/c^2
  - $c\tau_0$: 448 ± 7 μm
    - PDG: 459 ± 3 μm

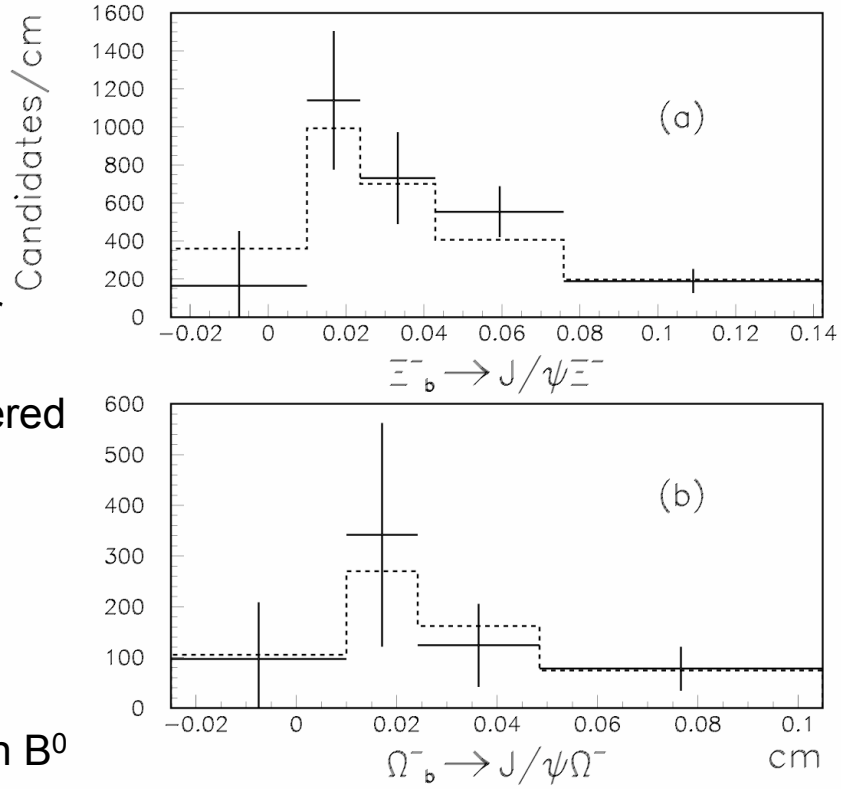


Mass and Lifetime Results

- 2.0 MeV/c^2 shift in Ξ_b^- from 1.9 fb^{-1} measurement - PRL 99,052002(2007)
- Systematic uncertainty on mass:

  0.8 (Ξ_b^-) and 0.9(Ω_b^-) MeV/c^2
  - 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
- Systematic uncertainty on lifetime:

  1.3% overall
  - 2 μm from σ^{ct} treatment – range is 15-40 μm in B^0
  - 5 μm from binning



	Mass (MeV)		Lifetime(μm)		
$B^0(K^{*0})$	5279.2 ± 0.2		453 ± 6		
$B^0(K^0_s)$	5280.2 ± 0.2		448 ± 7		
Λ_b	5620.3 ± 0.5		472 ± 17		
Ξ_b	5790.9 ± 2.6		468	$^{+82}_{-74}$	
Ω_b	6054.4 ± 6.8		340	$^{+160}_{-120}$	

References

Results

Production Rate Measurements

- We have access to the product of cross section times branching fraction.
  - We will measure ratios, with respect to the Λ_b^0:
    - Only other *b*-baryon with a large sample

$$\frac{\sigma B(\Xi_b^- \to J/\psi \Xi^-)}{\sigma B(\Lambda_b \to J/\psi \Lambda)}$$

$$\frac{\sigma B(\Omega_b^- \to J/\psi \Omega^-)}{\sigma B(\Lambda_b \to J/\psi \Lambda)}$$

- The method:
  - Obtain acceptance vs. p_T from simulation
  - Cross section of Ξ_b^- and Ω_b^- is p_T dependent
    - Assume it has the same dependence as Λ_b^0
  - Use measured Λ_b^0 production to integrate Ξ_b^- and Ω_b^- acceptance over p_T (6-20 GeV/c).
    - No Ξ_b^- or Ω_b^- candidates above 20 GeV/c

Rate Results

	Acceptance (6-20 GeV) * 10^{-3}	Yield
Λ_b^0	31 ± 2	1812 ± 61
Ξ_b^-	6.7 ± 0.2	66^{+14}_{-9}
Ω_b^-	9 ± 0.3	16^{+6}_{-4}

- Total systematic uncertainty of 7% for Ξ_b^-, 9% for Ω_b^-
- Yields, acceptances, and known branching fractions are combined to give

$$\frac{\sigma B(\Xi_b^- \to J/\psi \Xi^-)}{\sigma B(\Lambda_b^0 \to J/\psi \Lambda)} = 0.167^{+0.037}_{-0.025}(stat.) \pm 0.012(syst.)$$

$$\frac{\sigma B(\Omega_b^- \to J/\psi \Omega^-)}{\sigma B(\Lambda_b^0 \to J/\psi \Lambda)} = 0.045^{+0.017}_{-0.012}(stat.) \pm 0.004(syst.)$$

Summary of Results

- CDF observes the process $\Omega_b^- \rightarrow J/\psi\ \Omega^-$
  - Simultaneous mass and decay time fit => 5.5σ significance.

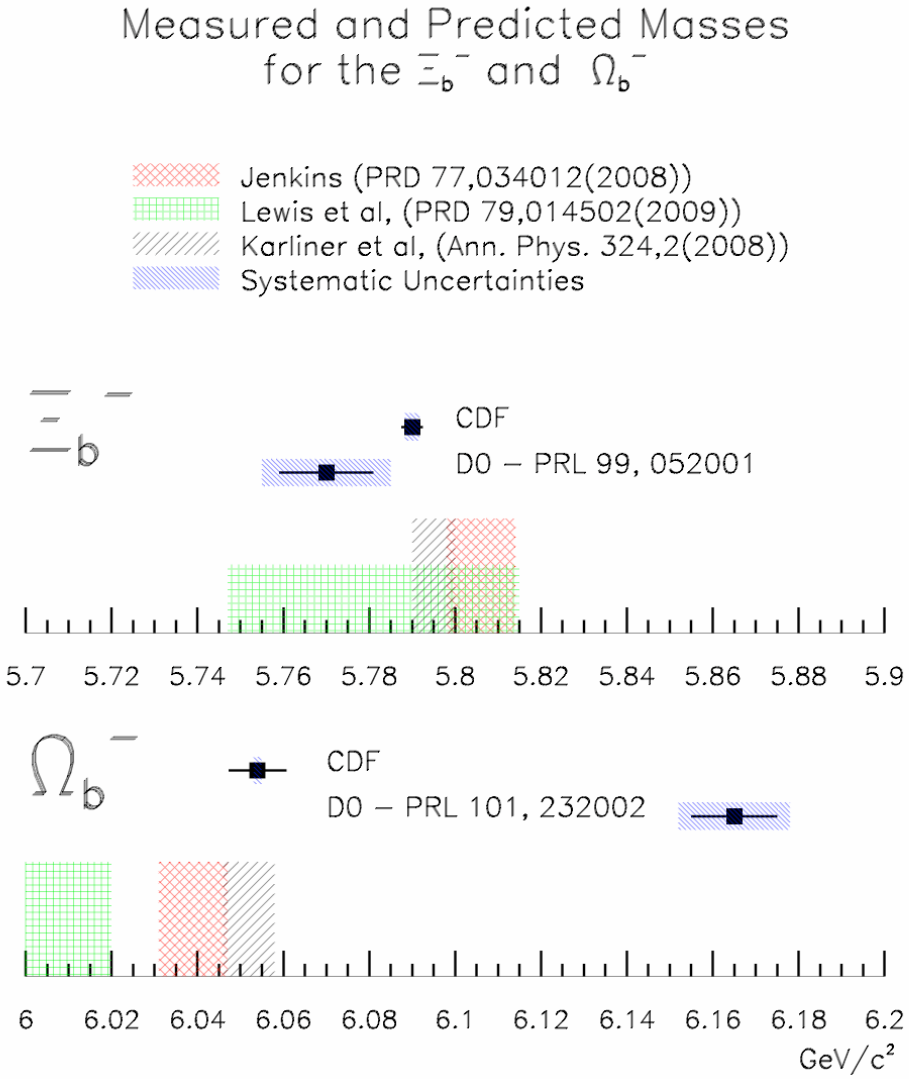
- Properties of both Ξ_b^- and Ω_b^- have been measured:

	Mass (MeV/c^2)					τ_0(ps)					$\sigma B/\sigma B(\Lambda_b^0)$				
Ξ_b^-	5790.9	±	2.6	±	0.9	1.56	$^{+0.27}_{-0.25}$		±	0.02	0.167	$^{+0.037}_{-0.025}$		±	0.012
Ω_b^-	6054.4	±	6.8	±	0.9	1.13	$^{+0.53}_{-0.40}$		±	0.02	0.045	$^{0.017}_{-0.012}$		±	0.004

- Masses – new level of precision
- Lifetimes – first Ω_b^-, first fully reconstructed Ξ_b^-

b-Baryon Masses Comparison

- CDF results are from this analysis
- They are at odds with the DØ results
  - Consistency with the Ξ_b^-
  - Inconsistency with the Ω_b^-
- Resolution of this puzzle can only come with more measurements
  - CDF – other channels?
  - DØ – more J/ψ sample?

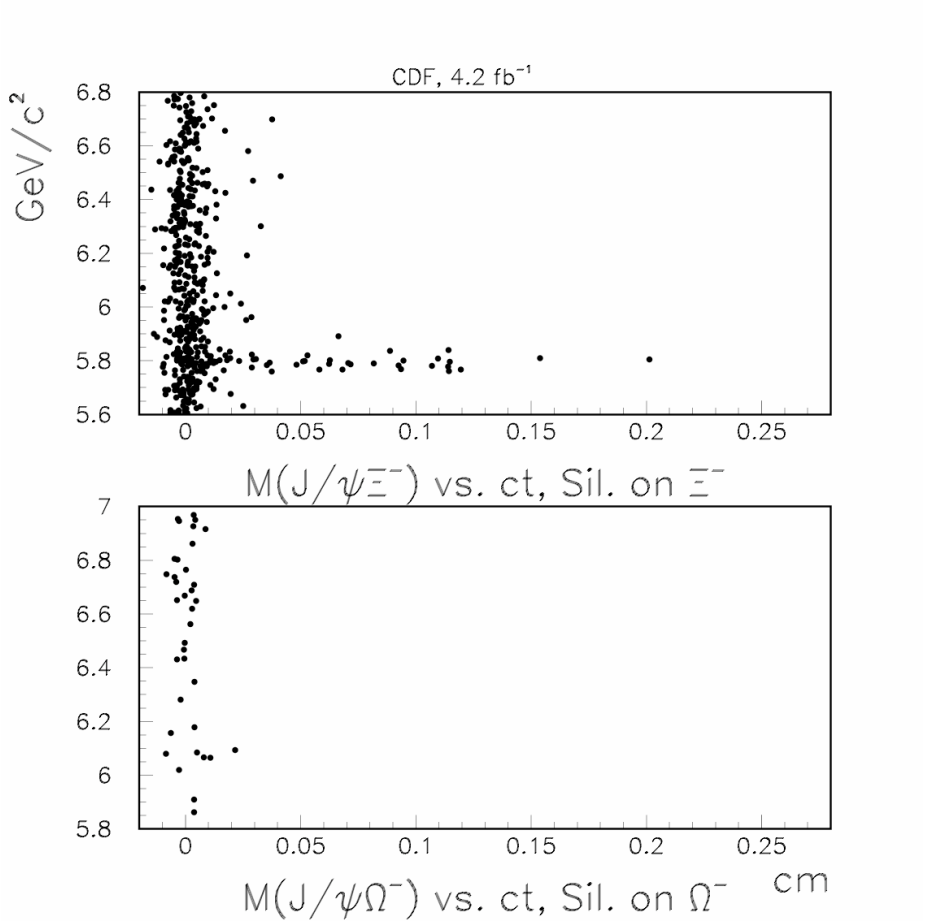


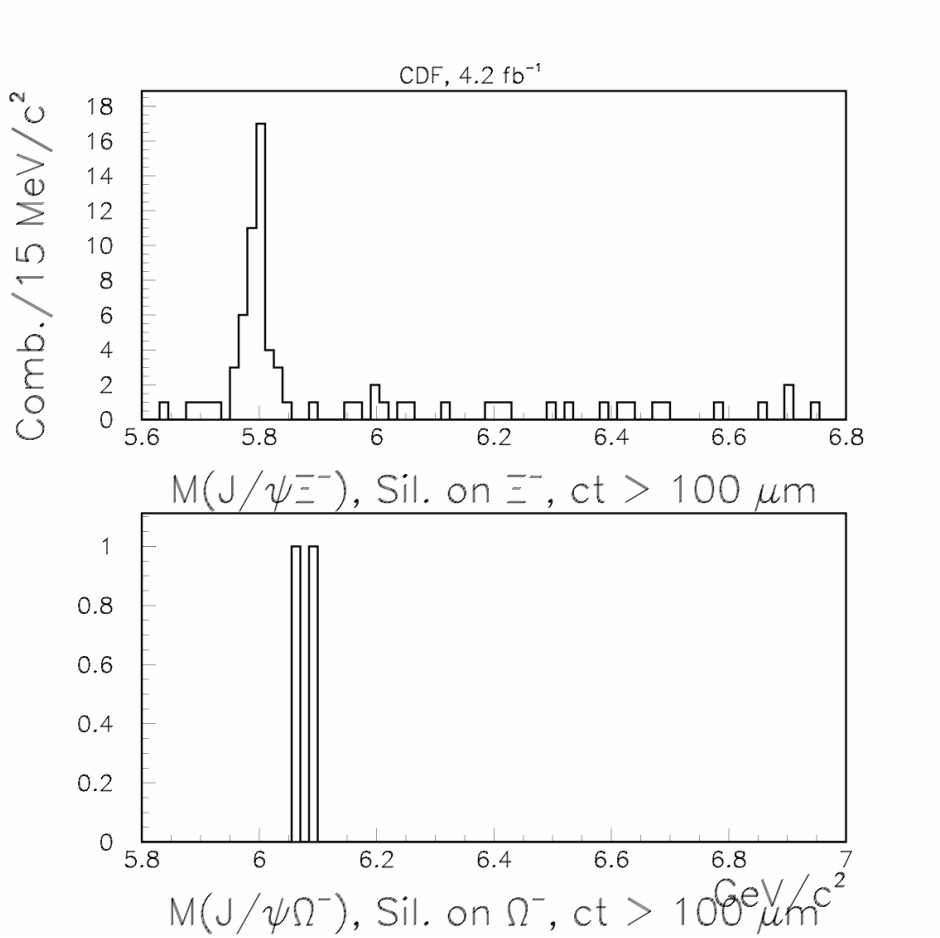
Conclusions

- CDF performs a "cut-based" selection on its J/ψ sample in 4.2 fb^{-1} to isolate B^0, Λ_b^0, Ξ_b^- and Ω_b^- samples.
- Mass, lifetime, and relative production rates are obtained for the Ξ_b^- and Ω_b^-.
  - Plentiful B^0 and Λ_b^0 serve as cross checks and motivate systematics.
- More measurements are necessary to shed light on the Ω_b^- mass puzzle.
- These strange *b*-baryons are simply additional members of a rich program of fully reconstructed *b*-hadrons obtained in the CDF J/ψ sample.

BACKUP SLIDES

Silicon on Ξ^-/ Ω^- Helices





- 34700 Ξ^- and 1900 Ω^- with silicon information
- Due to short lifetime of Ω^- many decay before reaching silicon (1.5 cm)