Observation of the Ω_b^- at CDF
[or, story of a doubly-strange baryon]

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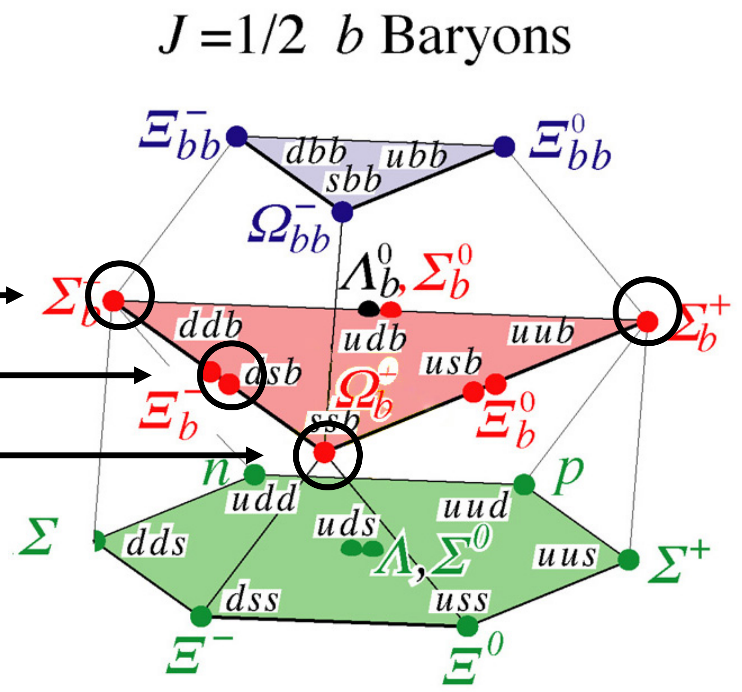
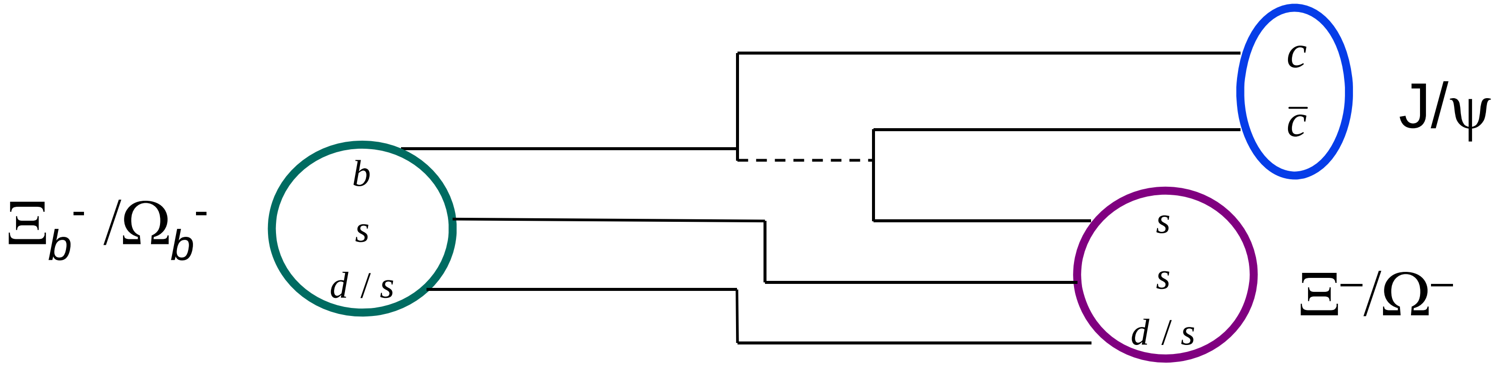
Bottom Baryon Ground States

- Our knowledge of *b*-baryons has greately expanded in the last ~2 years
- This is totally a Tevatron field
  - $\Sigma_b^{(*)+}$ and $\Sigma_b^{(*)-}$ observed by CDF in 2007
  - Ξ_b^-, observed by D0, CDF 2007
  - Ω_b^- , observed by D0 in 2008
- This talk is the CDF report on Ω_b [arXiv:0905.3123]
- The CDF analysis of Ω_b is actually a comprehensive analysis of the properties of weakly-decaying *b*-baryons Ξ_b^- , Ω_b^- ,(Λ_b)
- Similar, fully reconstructed J/ψ modes: convenient way to cross check.



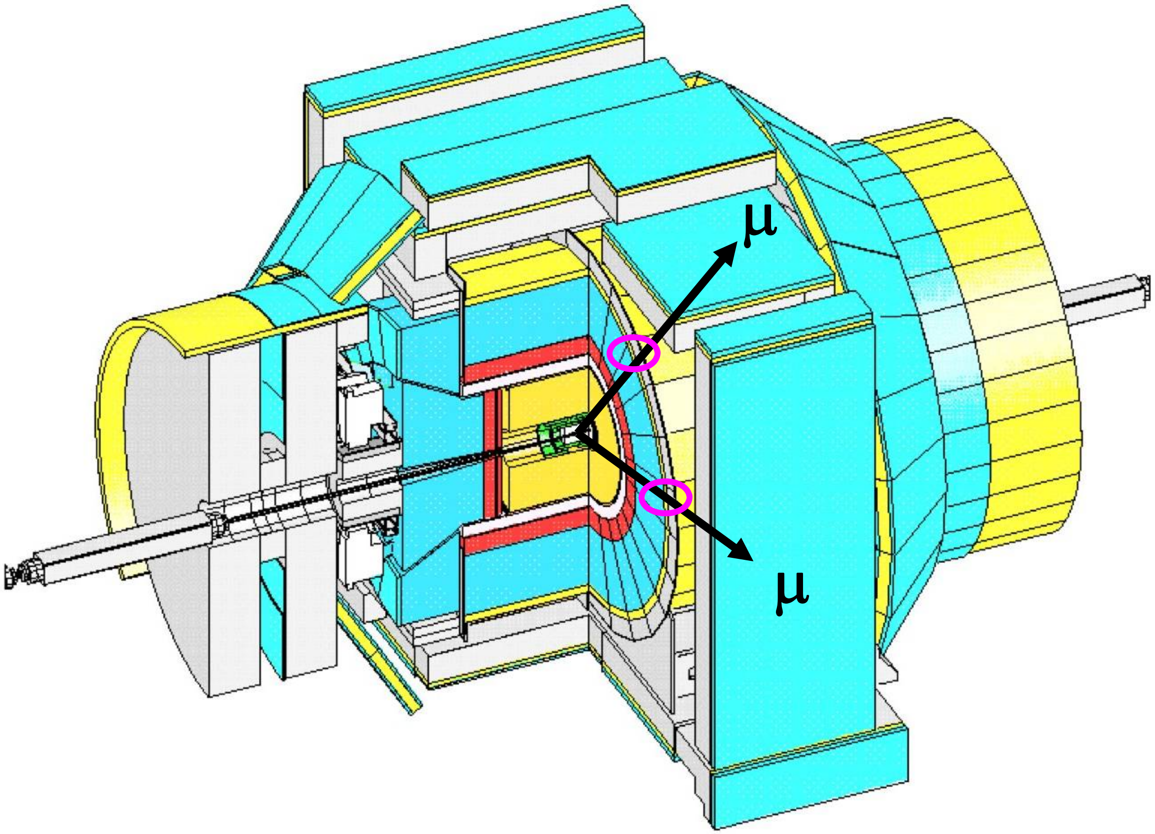
Decay Modes



- 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
- This data set contains many *b*-meson candidates
- Therefore, the mesons are used throughout, to cross check the measurements.

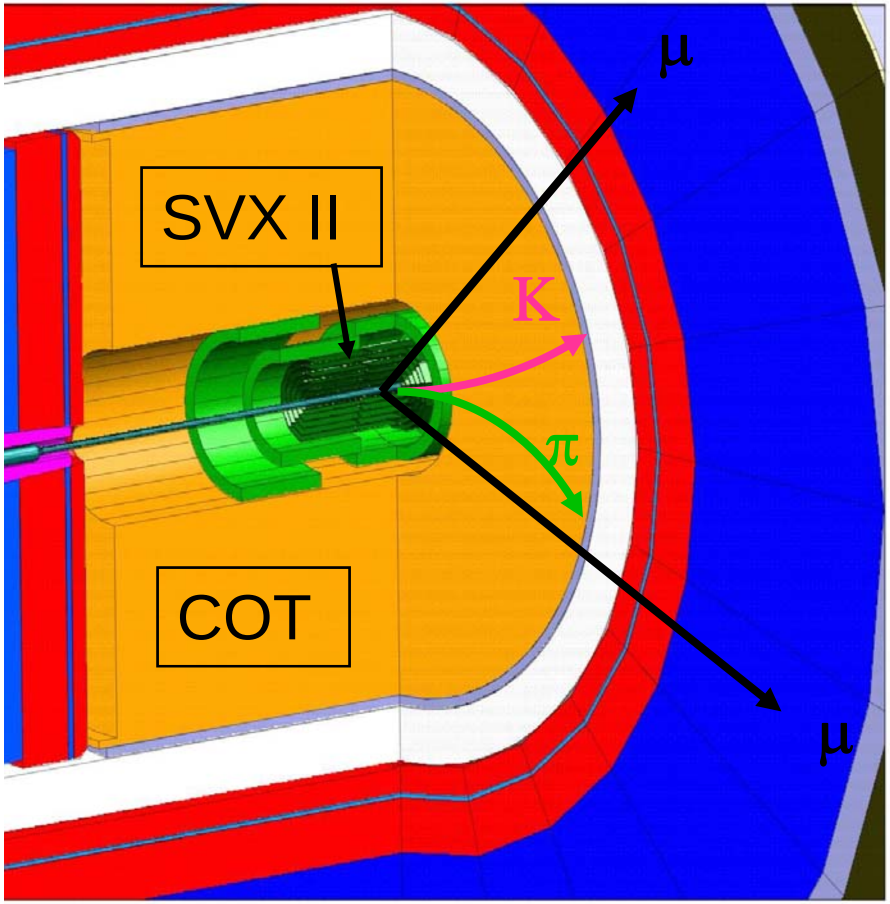
The CDF II Detector

- The data used in this analysis was collected with the CDF II Detector.
  - This analysis uses data from 4.2 fb^{-1}.
- The 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
- Unbiased with respect to decay time for *b*-hadrons



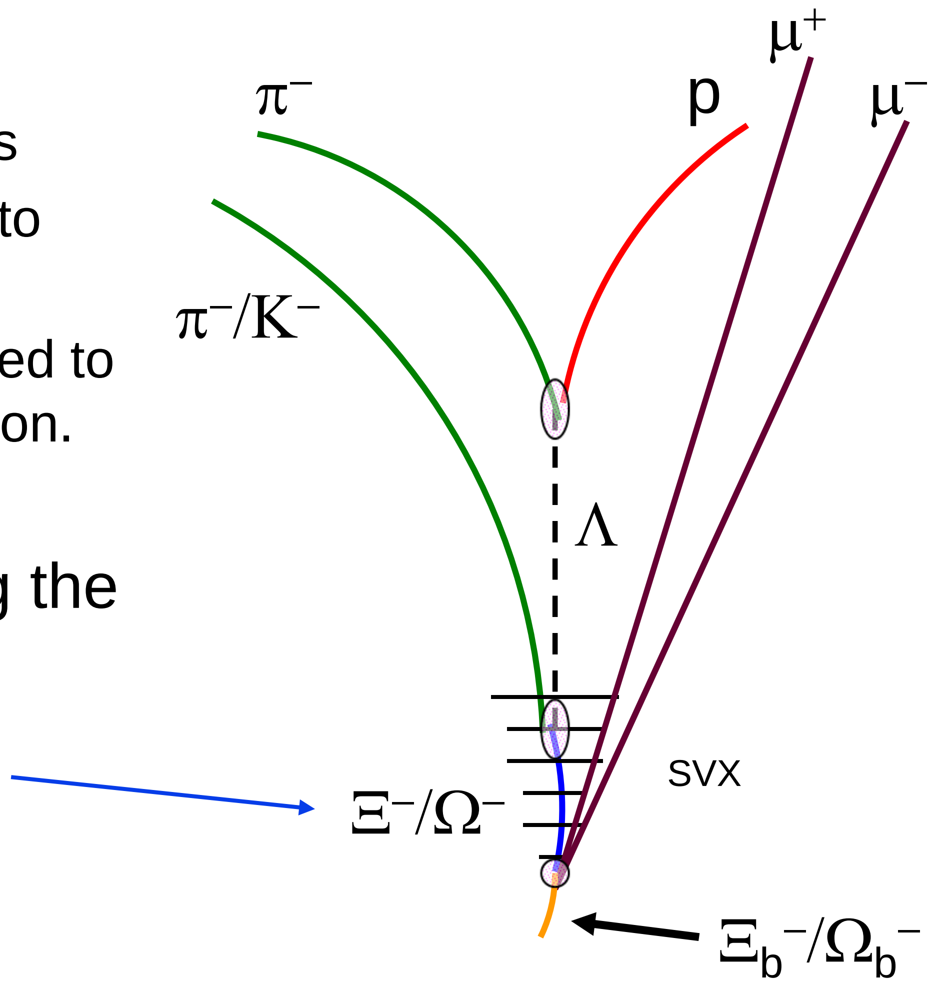
The CDF II Detector

- Events that satisfy the trigger are fully 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



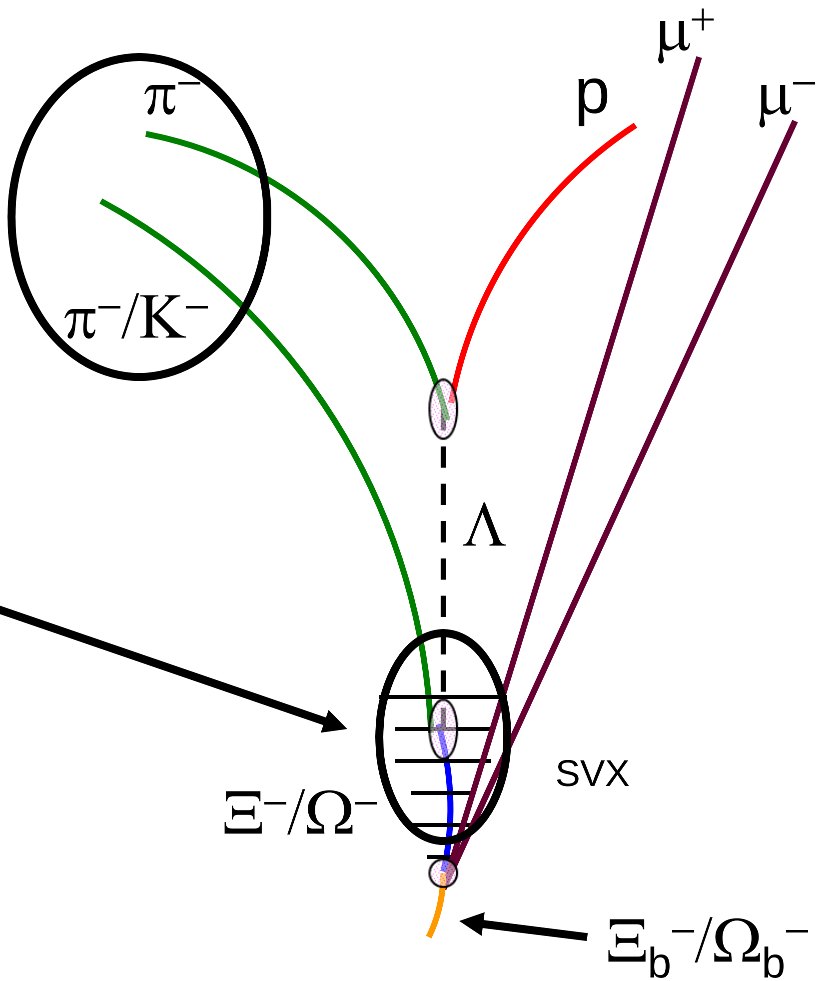
Ξ_b^-/Ω_b^- Reconstruction

- 5-track, 3-vertex fit
  - $\mu^+\mu^-$ are 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)

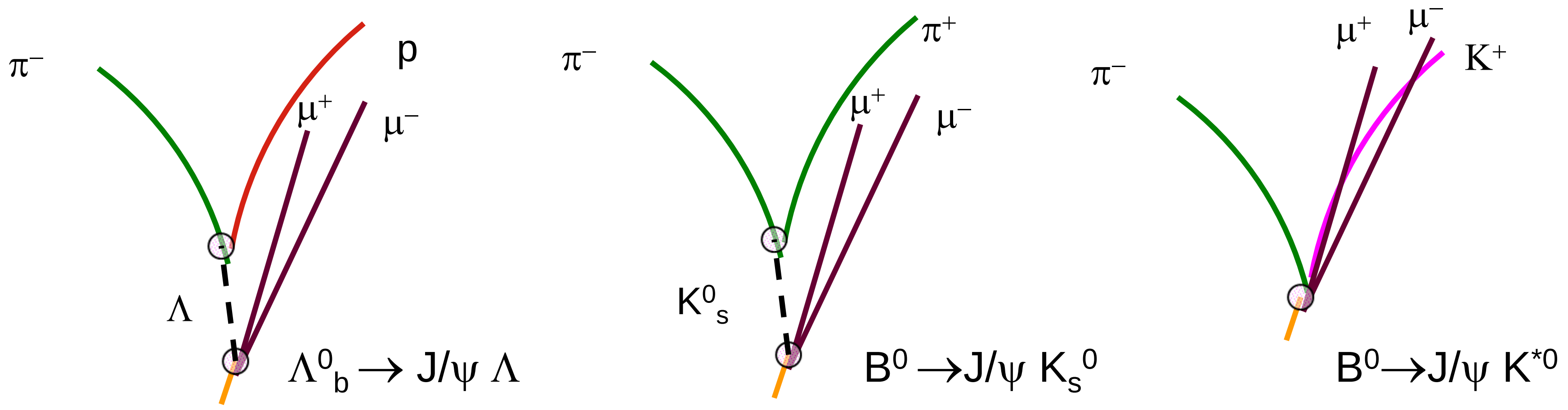


Ξ_b^-/Ω_b^- Reconstruction

- The third hadron track allows some occasional ambiguity
- Selection criteria may be satisfied by
  - Like sign pairs
    - p may form a Λ candidate with either
  - Both Λ – track intersections
- These are resolved by
  - Track measurements in the longitudinal (along beamline) view
  - Fully constrained 5-track fit
    - Helix constraint avoids “wrong” intersection



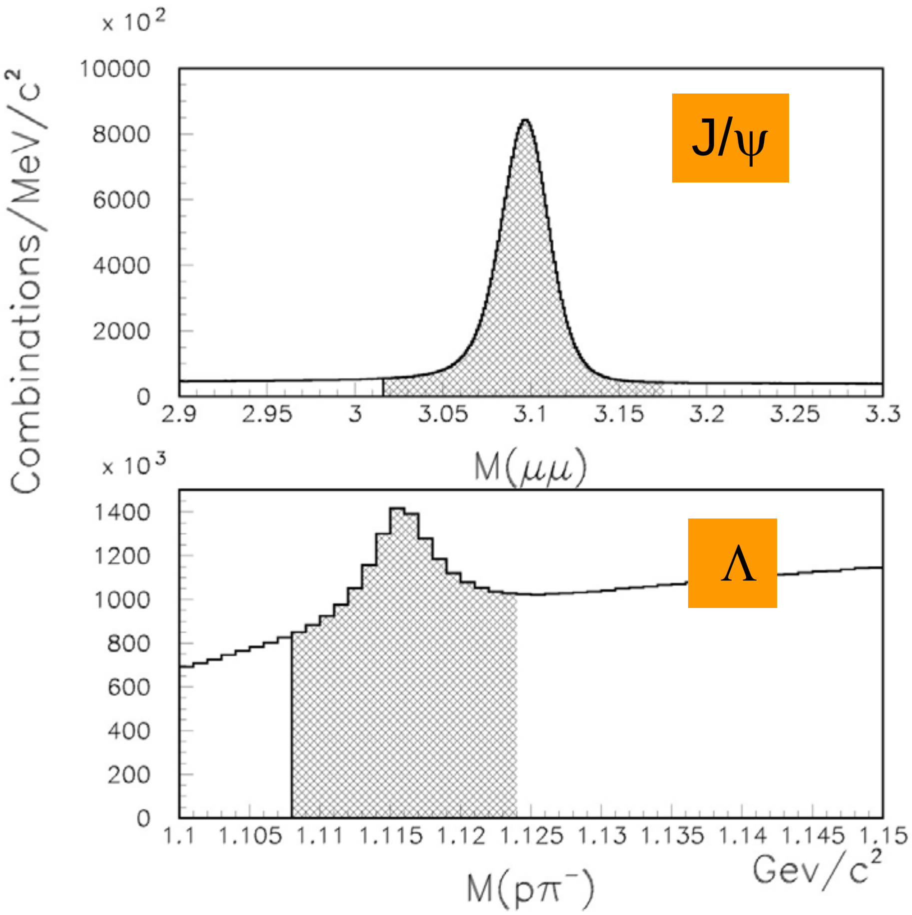
Control samples



- Measurements of B^0 properties provide a cross check.
  - Also the Λ_b^0, the most plentiful *b*-baryon
- Reconstruction is very similar for these.

J/ψ and Λ Samples

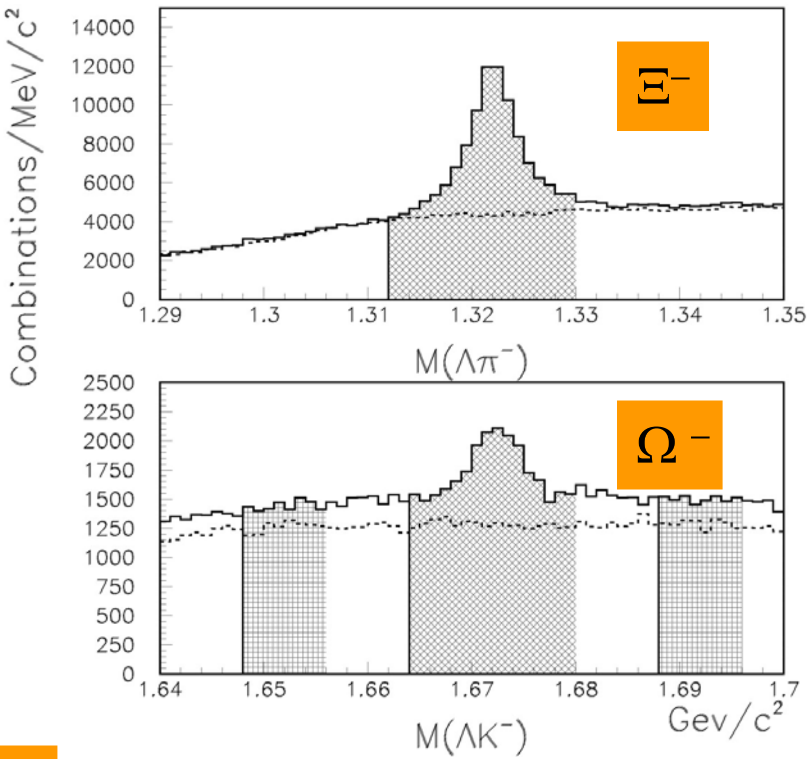
- The analysis is based on data collected from 4.2 fb^{-1} of collisions.
  - 29 M J/ψ
- For Λ in the J/ψ sample,
  - Require decay position > 1 cm transverse from the collision.
  - p_T > 2.0 GeV/c
  - 3.6 M Λ
- Shaded areas define the mass ranges used for *b*-hadron selection.



Inclusive Ξ^-/Ω^- Sample

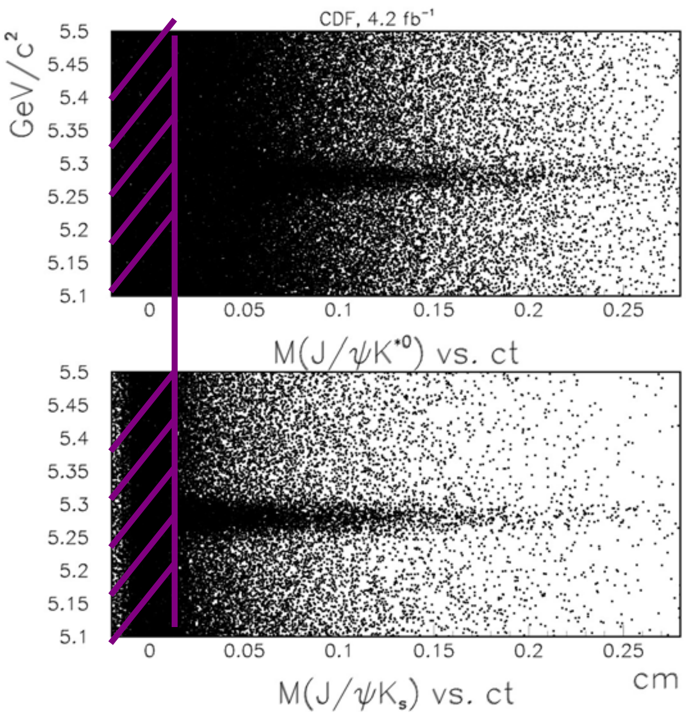
- The base sample is given by
  - $1.1077 < M(\pi p) < 1.1237$
  - $P_T(\Xi/\Omega) > 2.0$
  - Flight$(\Lambda/\Xi^-/\Omega^-)$ > 1 cm
  - Impact(Ξ^-/Ω^-) < 3σ
  - $P(\chi^2) > 10^{-4}$
  - $P(\chi^2)_{used} > P(\chi^2)_{swapped}$
  - Veto $1.311 < M(\Lambda\pi) < 1.331$ for ΛK sample (Ξ^- reflection)
- Yields in the J/ψ sample:
  - **Ξ^-: 41,000**
  - **Ω^-: 3,500**

Large samples !
Compare D0:
~1150 Ξ^- ~150 Ω^-



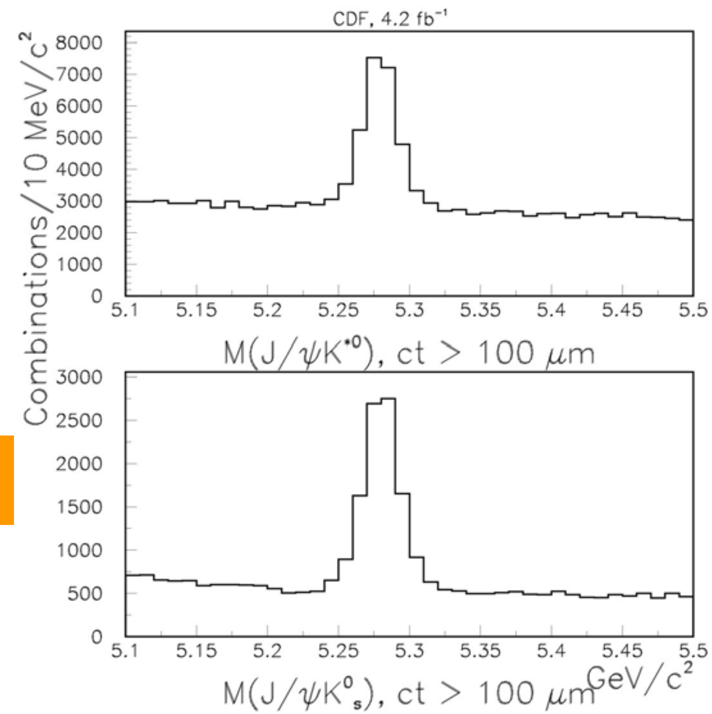
- Dashed histograms are $\Lambda\pi^+/K^+$
- Shaded are selection and sideband regions

b-meson signals



$B^0 \to J/\psi K^*$

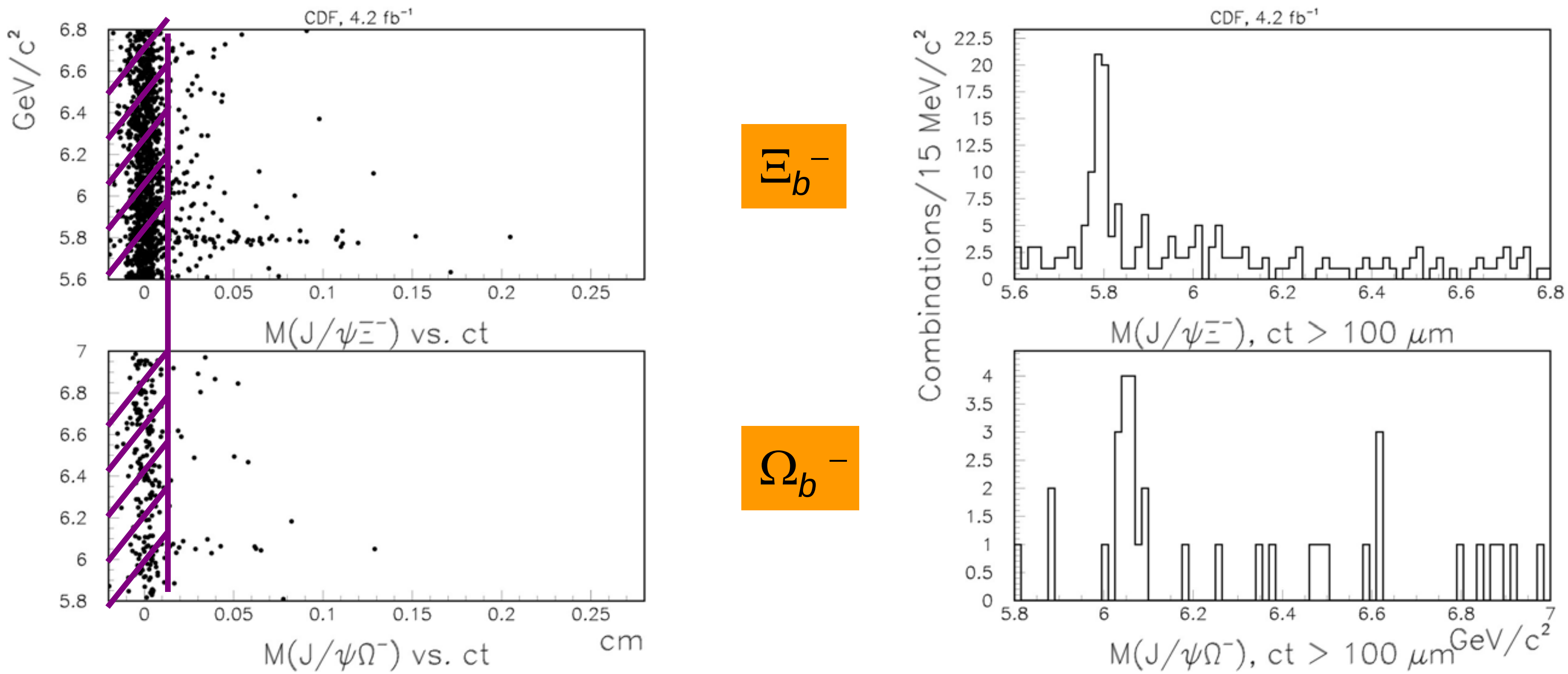
$B^0 \to J/\psi K_s$



- B hadron signals are distinctive
  - Precisely measured mass
  - Characteristic lifetime
  - *ct* > 100 μm removes most prompt background

- $p_T(B^0)$ > 6 GeV/c
- $p_T(K)$ > 2 GeV/c

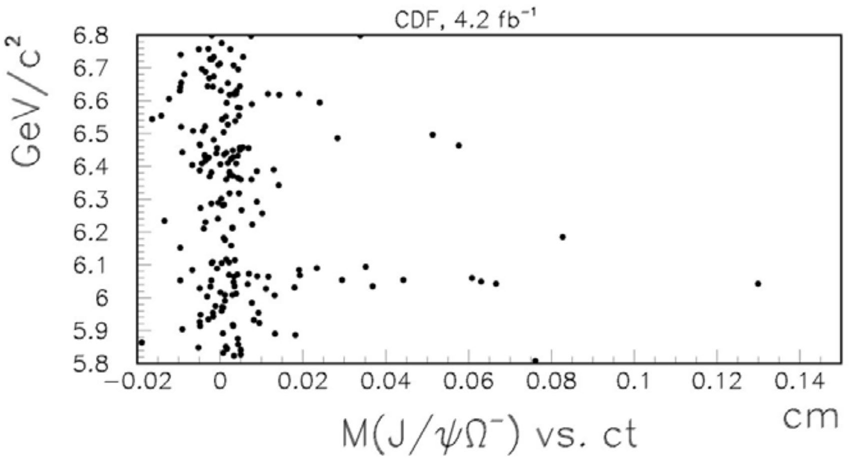
b-baryon signals



- J/ψΞ⁻ , J/ψ Ω⁻ samples
  - Obvious Ξ_b^- signal when *ct* > 100 μm
  - Cluster in the J/ψ Ω⁻ around 6.05 GeV/c² – test its significance

Ω_b^- Significance – Mass/Decay Time Distribution Test

- 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



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    - Exponential(τ_0) for signal
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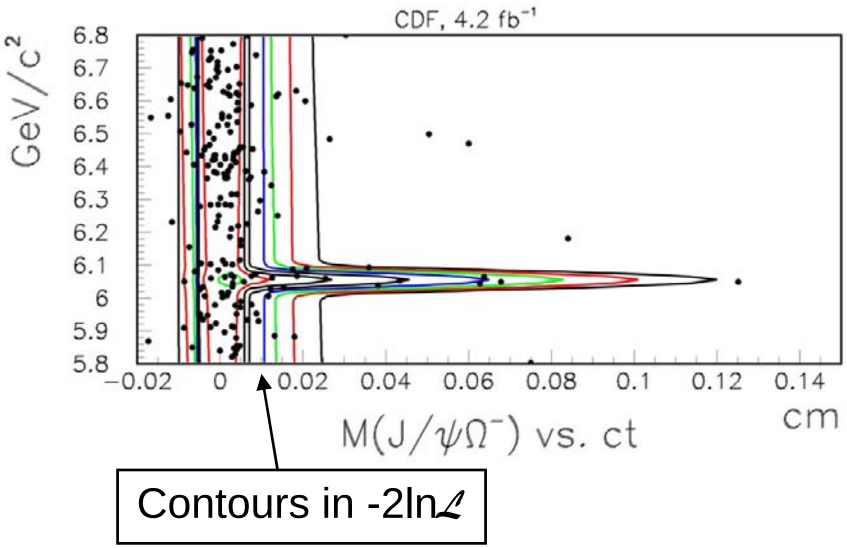
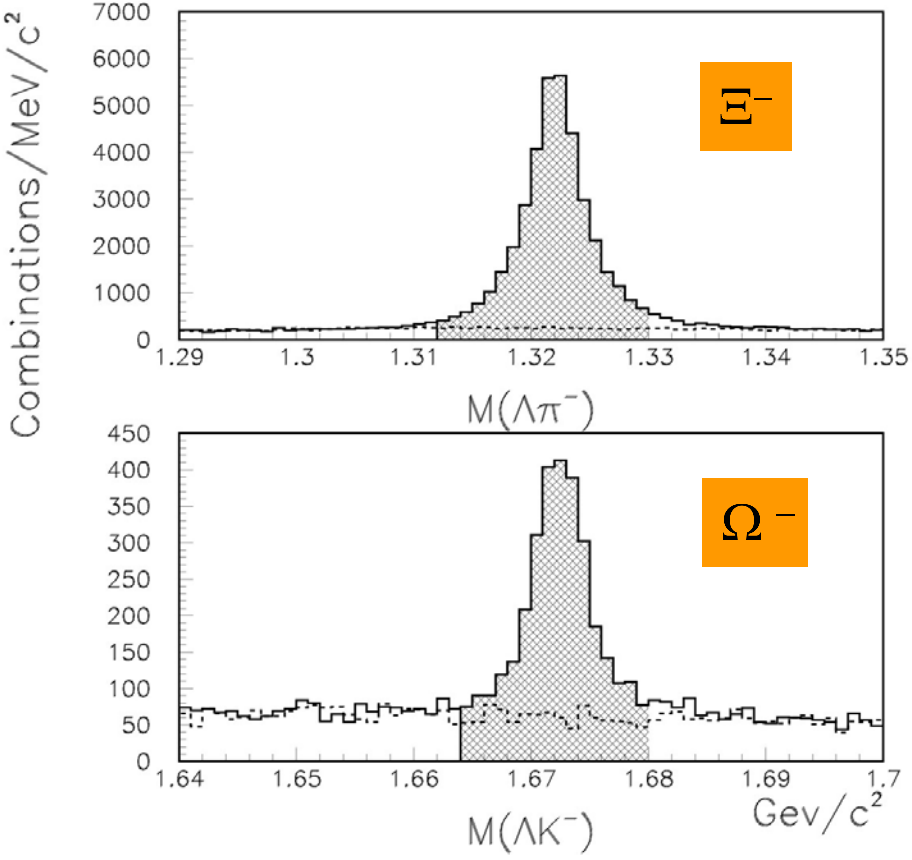
    - Delta function for prompt background
  - Fit freely, and with the null hypothesis
  - $\Delta 2\ln\mathcal{L} = 37.3$



- Interpreted as $P(\chi^2)$ with 3 d.o.f. = $4.0\ 10^{-8}$
  $\Rightarrow$ **5.5σ**
- Prudent evaluation, accounts for “look-elsewhere” effect

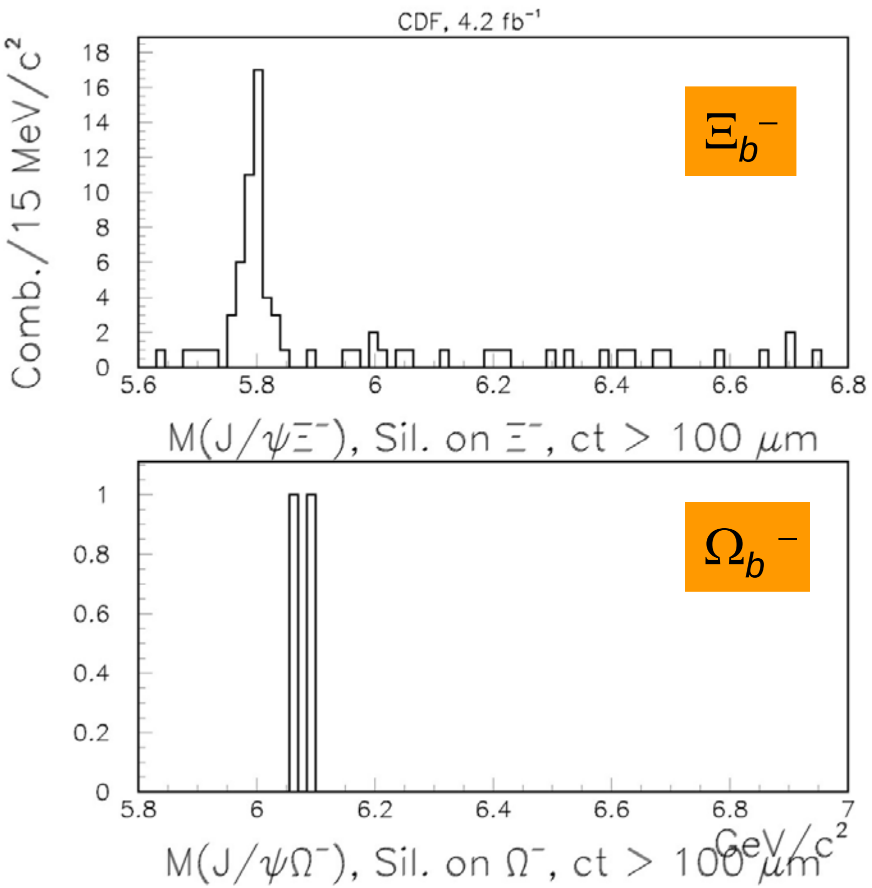
Cross-check 1: require Ξ^-/Ω^- hits in the detector

- Inclusive $\Lambda\pi$ and ΛK with previous selection and silicon hit on the Ξ^-/Ω^- track
- Shaded areas are our mass selection ranges.
  - Shorter lifetime of the Ω^- (1" vs. 2") implies lower efficiency
  - Many decay before reaching the silicon detector.



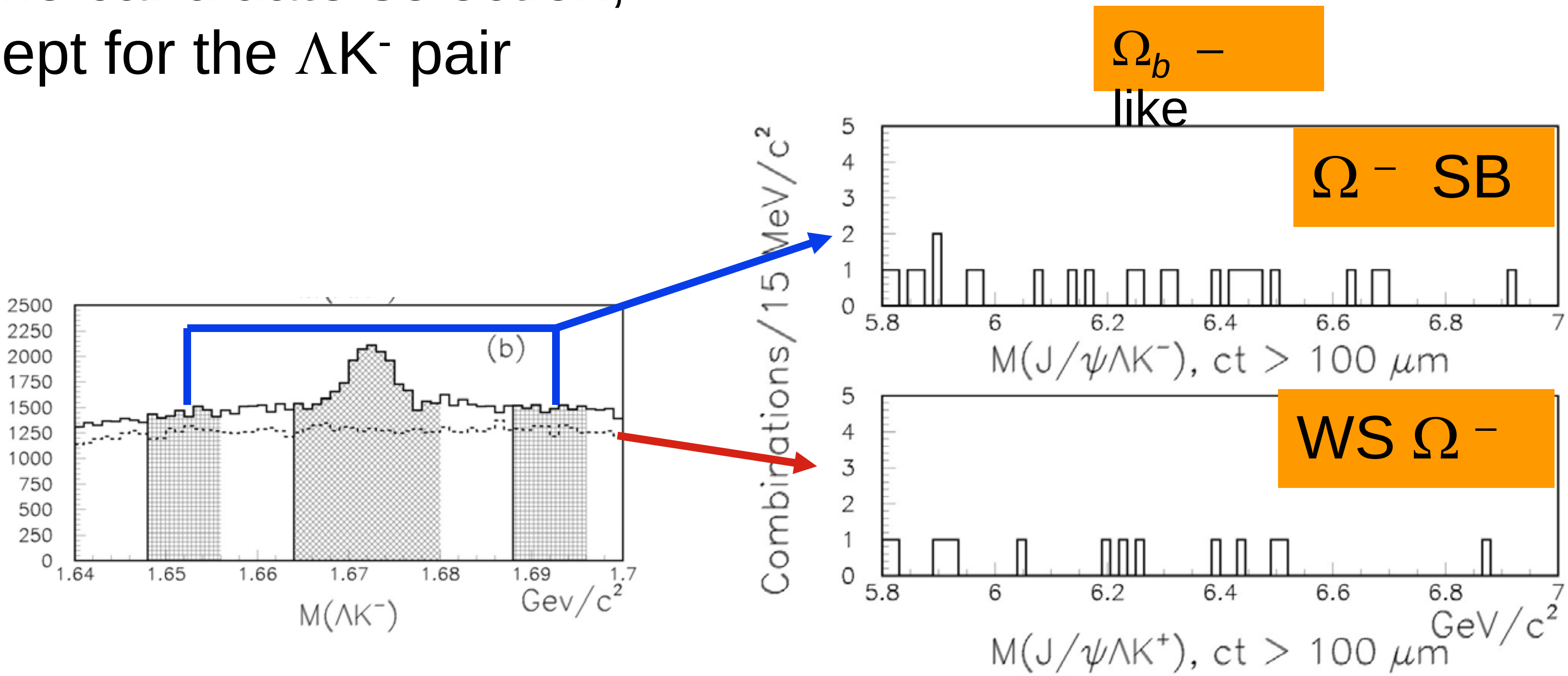
Cross-check 1: require Ξ^-/Ω^- hits in the detector

- Inclusive $\Lambda\pi$ and ΛK with previous selection and silicon hit on the Ξ^-/Ω^- track
- Obvious Ξ_b^- signal
- Just 2 Ω_b candidates (low acceptance), but mass consistent with the main selection



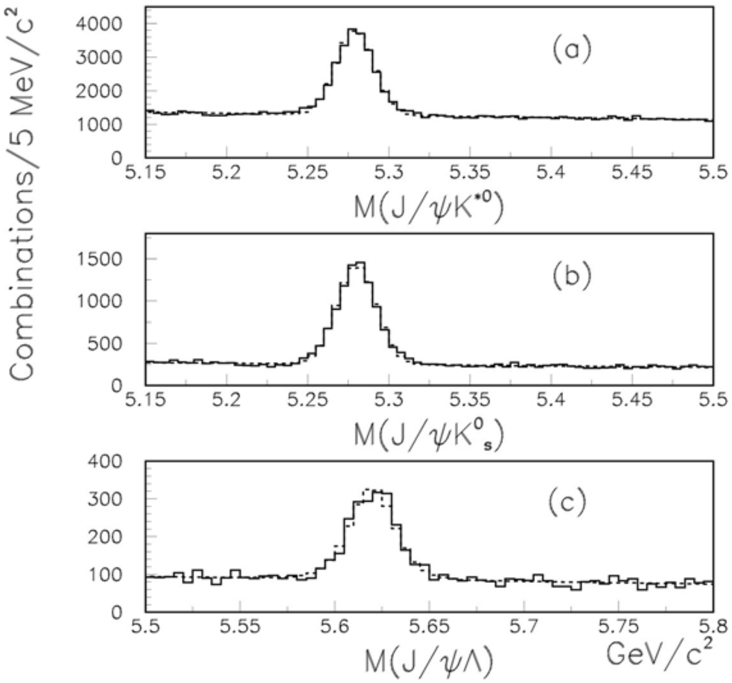
Cross-check 2
Sideband/Wrong-Sign selections

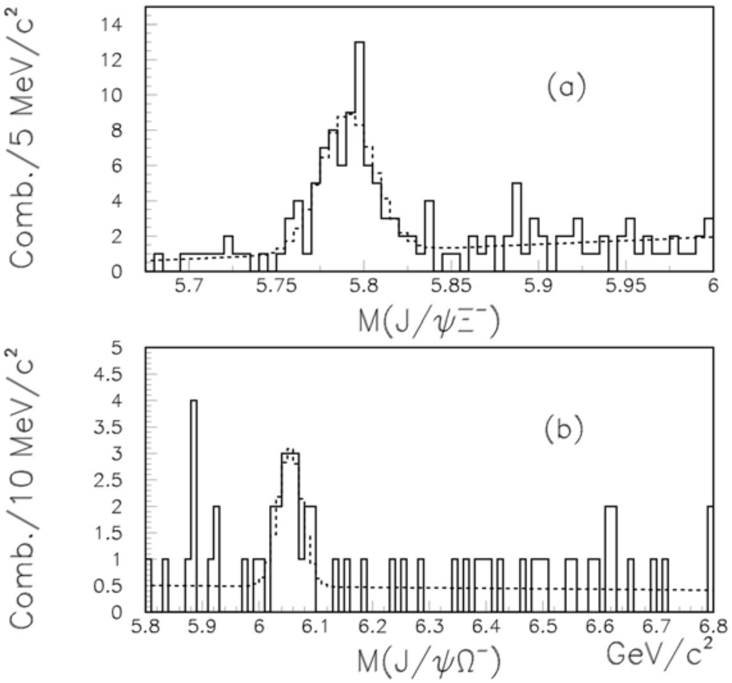
- Same candidate selection, except for the ΛK^- pair



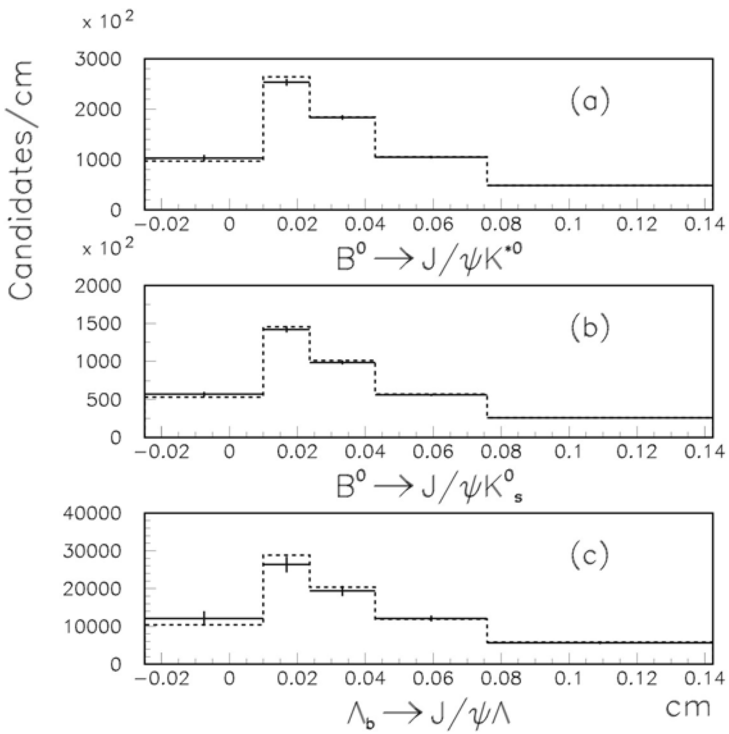
Mass and Lifetime Measurements

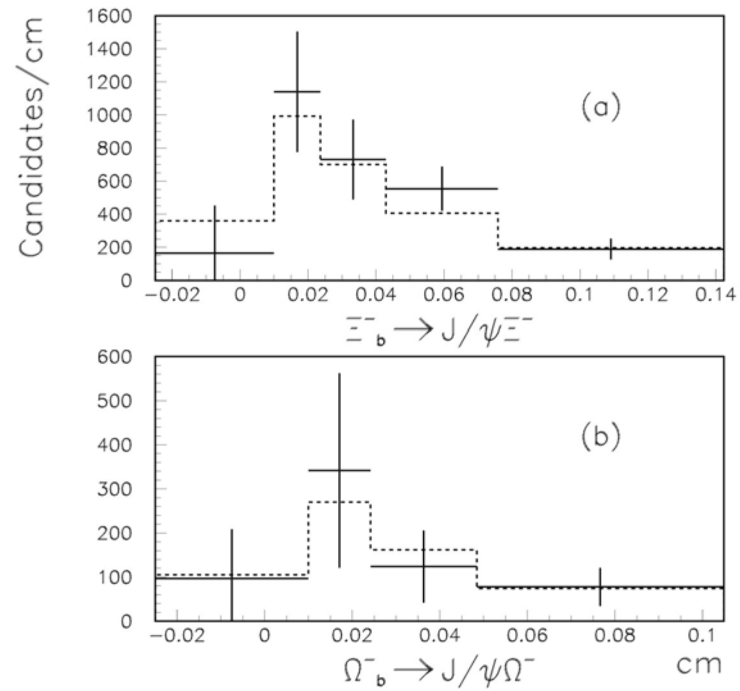
- Masses and lifetimes calculated for 5 final states
  - 3 are references (B^0 in K^{*0} and $K_s{}^0$ final states and $\Lambda_b{}^0$)
  - 2 are results ($\Xi_b{}^-$, $\Omega_b{}^-$)





Lifetime Measurements, Data and Fits





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

Mass and Lifetime Results

	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: $B^0(K^{*0})$, $B^0(K^0_s)$, Λ_b

Results: Ξ_b, Ω_b

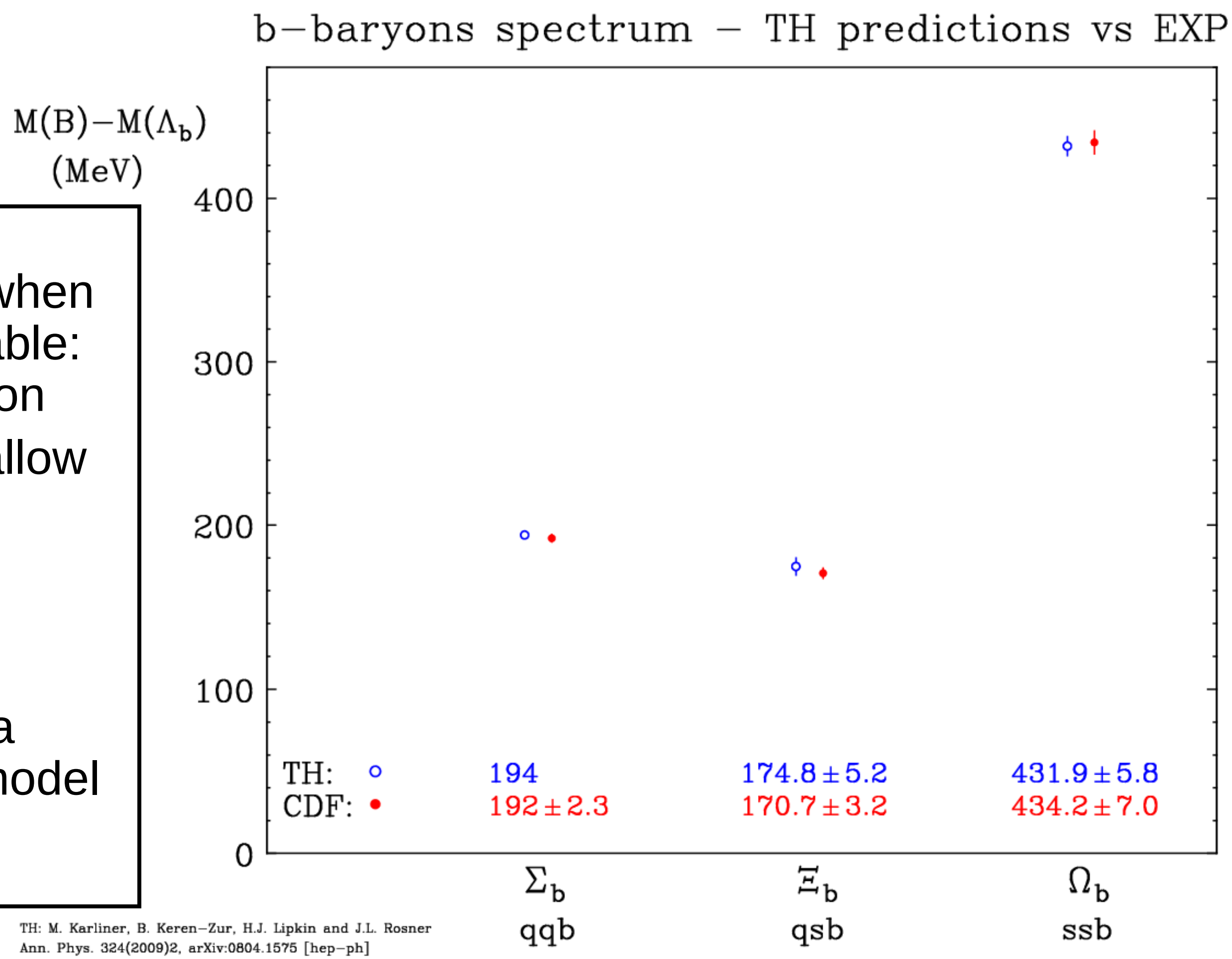
- Systematic uncertainty on mass – 0.8 (Ξ_b^-) and 0.9(Ω_b^-) MeV/c^2
  - 0.55 MeV from $B^0(K_s)$ error – scale by 80% for kinetic energy in the decay
  - 0.5 MeV from Λ_b resolution treatment (considered largest possible)
  - 0.3 MeV from Ω^- mass
- Systematic uncertainty on lifetime – 1.3% overall
  - 2 μm from σ^{ct} treatment – range is 15-40 μm in B^0
  - 5 μm from binning

Results

- Masses:
  - Ξ_b^- : 5790.9 ± 2.6(stat.) ± 0.9(syst.) MeV/c^2
    - 2.0 MeV/c^2 shift from 1.9 fb^{-1} measurement [PRL 99,052002(2007)]
  - Ω_b^- : 6054.4 ± 6.8(stat.) ± 0.9(syst.) MeV/c^2
- Lifetimes:
  - Ξ_b^- : $1.56^{+0.27}_{-0.25}$(stat.) ± 0.02(syst.) ps
    - First in a fully reconstructed state.
  - Ω_b^- : $1.13^{+0.53}_{-0.40}$(stat.) ± 0.02(syst.) ps
    - First ever

Improving our understanding of hadron dynamics

- Accurate comparison to predictions are possible when several data points available: Ω_b a very welcome addition
- Resolutions are such to allow significant progress in discriminating between models.
- Here is an example of comparison of CDF with a color hyperfine-splitting model [Annals Phys.324:2-15,2009]. *(courtesy M. Karliner)*



Production Rate Measurements

- We have access to the product of cross section times BR.
  - We measure ratios with respect to the Λ_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_b distribution (no systematics)
  - Limited data sample requires integration over p
- Combine acceptance with yields:
  - Λ_b^0: 1812 ± 61
  - Ξ_b^- : 66^{+14}_{-9}
  - Ω_b^- : 16^{+6}_{-4}

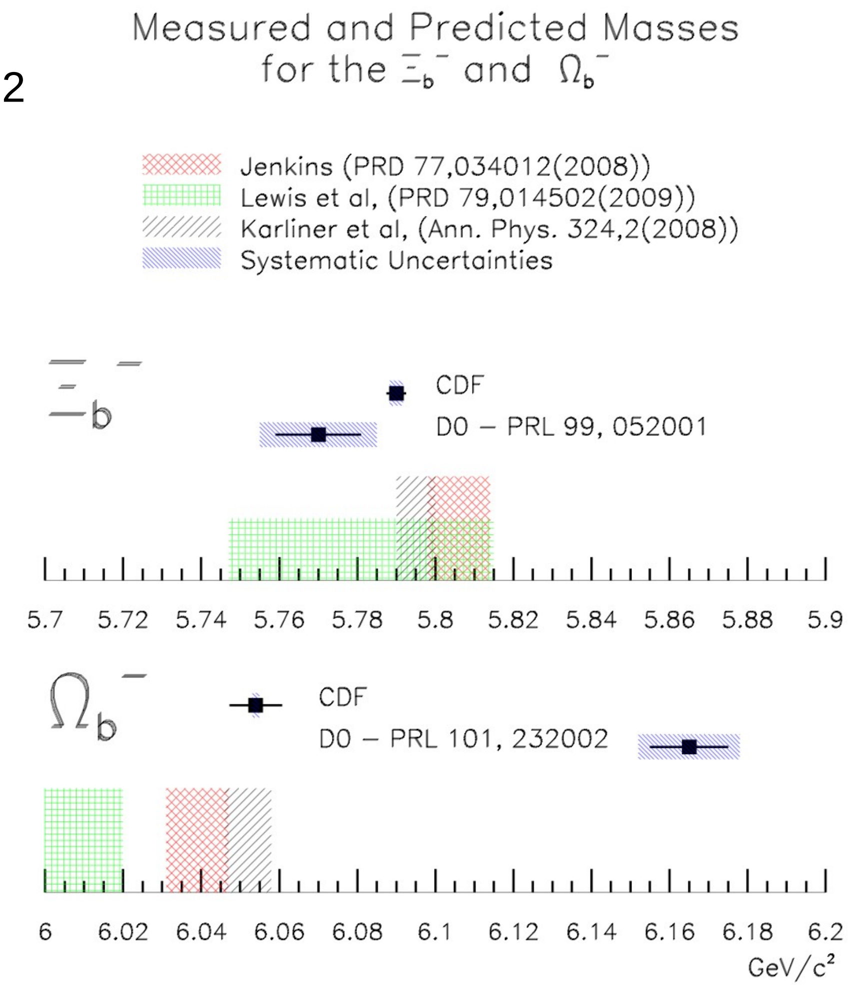
Results:

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

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

Are we seeing the same Ω_b as D0?

- We find:
  $M(\Omega_b^-) = 6054.4 \pm 6.8 \pm 0.9\ \mathrm{MeV}/c^2$
- D0 finds [PRL **101**, 232002(2008)]:
  $M(\Omega_b^-) = 6165 \pm 10 \pm 13\ \mathrm{MeV}/c^2$
- $M(\Omega_b)_{D0} - M(\Omega_b)_{CDF} =$
  $111 \pm 12 \pm 14\ \mathrm{MeV}/c^2$
  - Significant disagreement (6-sigma)
- Agreement on Ξ_b^-
  - Does not look like a scale problem



What about rates ?

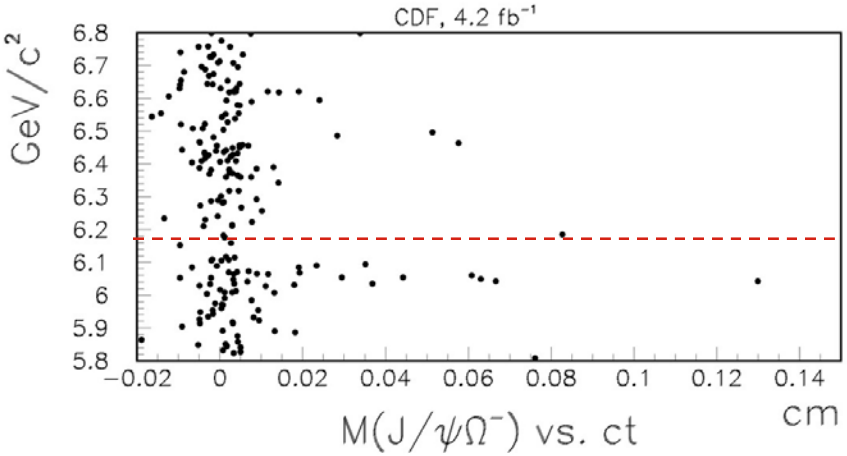
D0

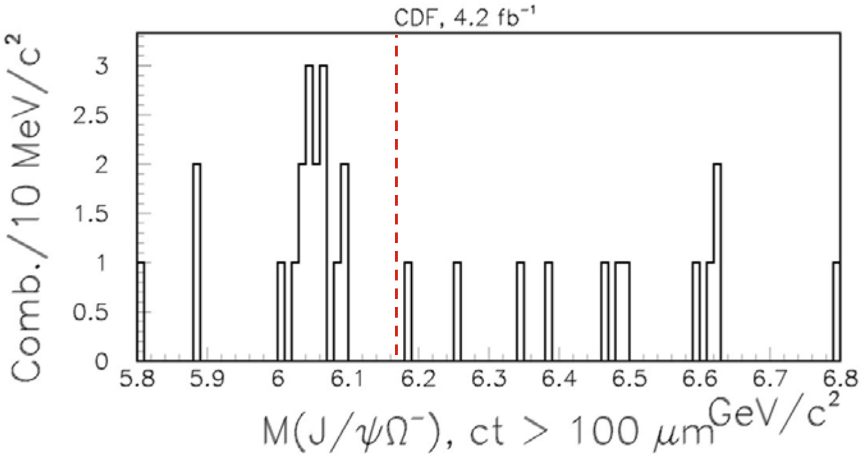
$$\frac{f(b\to\Omega_b^-)B(\Omega_b^-\to J/\psi\Omega^-)}{f(b\to\Xi_b^-)B(\Xi_b^-\to J/\psi\Xi^-)} = 0.80\pm0.32^{+0.14}_{-0.22}$$

CDF

$$\frac{\sigma B(\Omega_b^-\to J/\psi\Omega^-)}{\sigma B(\Xi_b^-\to J/\psi\Xi^-)} = 0.27\pm0.12\pm0.01$$

- Not very useful: the D0 number is less than 3 sigma from zero, although significance > 5 sigma (non-gaussian uncertainty is misleading)
- A D0 measurement relative to Λ_b would be helpful
- Scaling the yields, we were expecting to see ~50 events in our plots





Conclusions

- CDF started out in a search for D0's Ω_b,
but eventually found its own.
- It's always good to have several experiments
do the same measurement.
- Both results look convincing: solution of the "doubly-strange" baryon puzzle can only come from more measurements:
  - CDF – other channels?
  - D0 has more data on tape: analyzed 1.3 fb-1
  - Tevatron will soon double the current sample
- These measurements are useful: can be compared with theory predictions of similar precision to improve our understanding.