

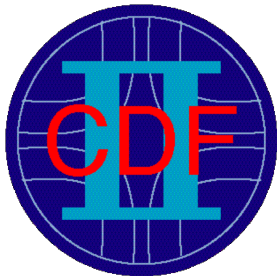
Measurement of B Baryon Properties at CDF

Patrick T. Lukens

Fermilab

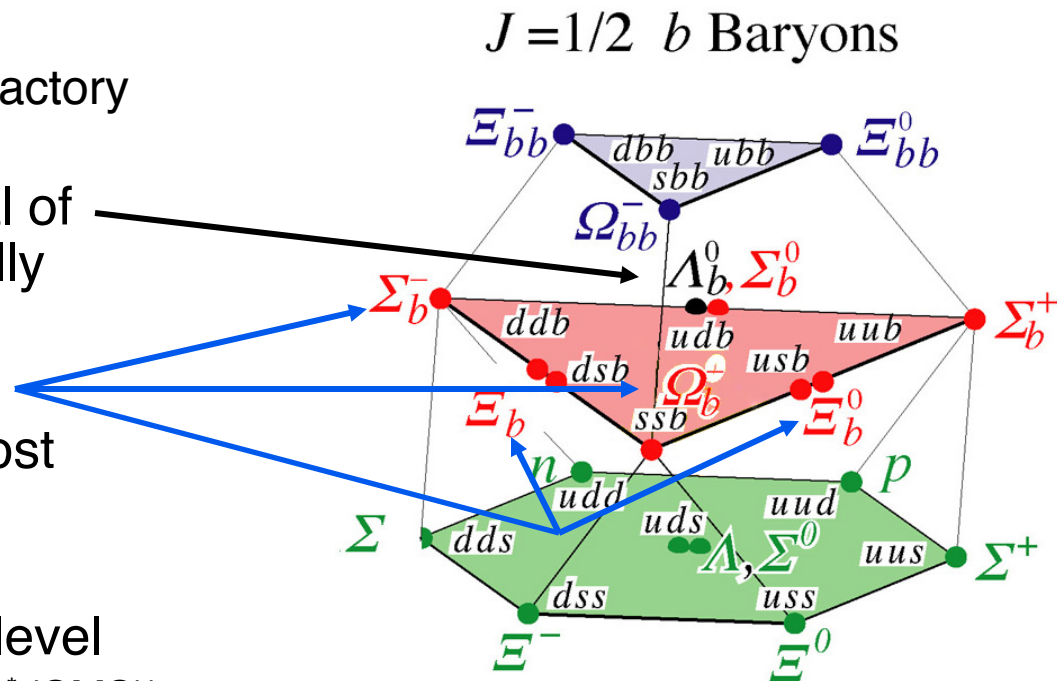
For the CDF Collaboration

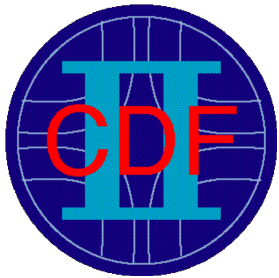
August 2013



b -Baryons

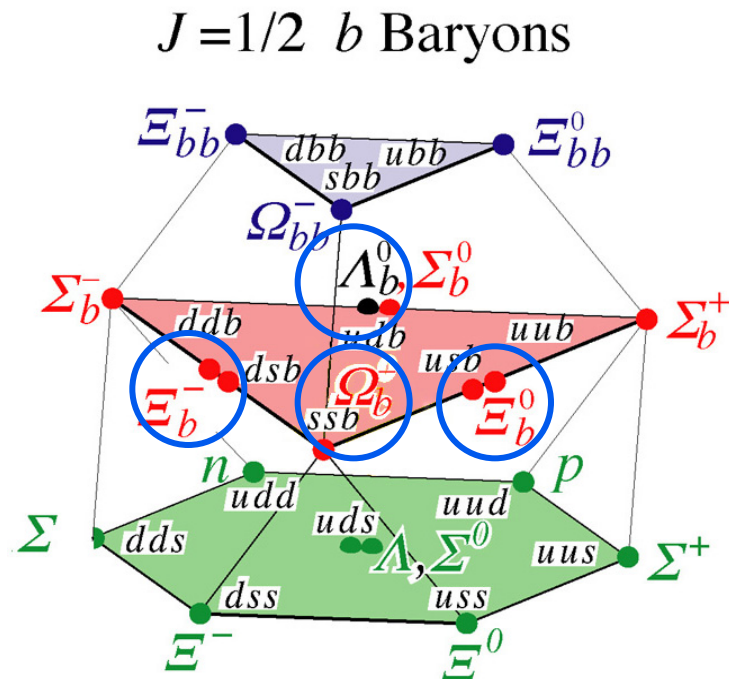
- The study of b -baryons is hadron collider job.
 - Masses are above the B factory reach
- Prior to 2000 a small signal of $\Lambda_b \rightarrow J/\psi \Lambda$ was the only fully reconstructed observation.
- The 2001-11 Tevatron run provided observation of most ground states with one b .
- The LHC operation is now opening the field to a new level
 - Excited states (Λ_b^* (LHCb), Ξ_b^* (CMS))
 - Greater precision (LHCb)

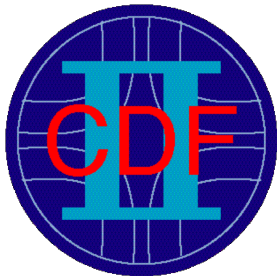




b -Baryons

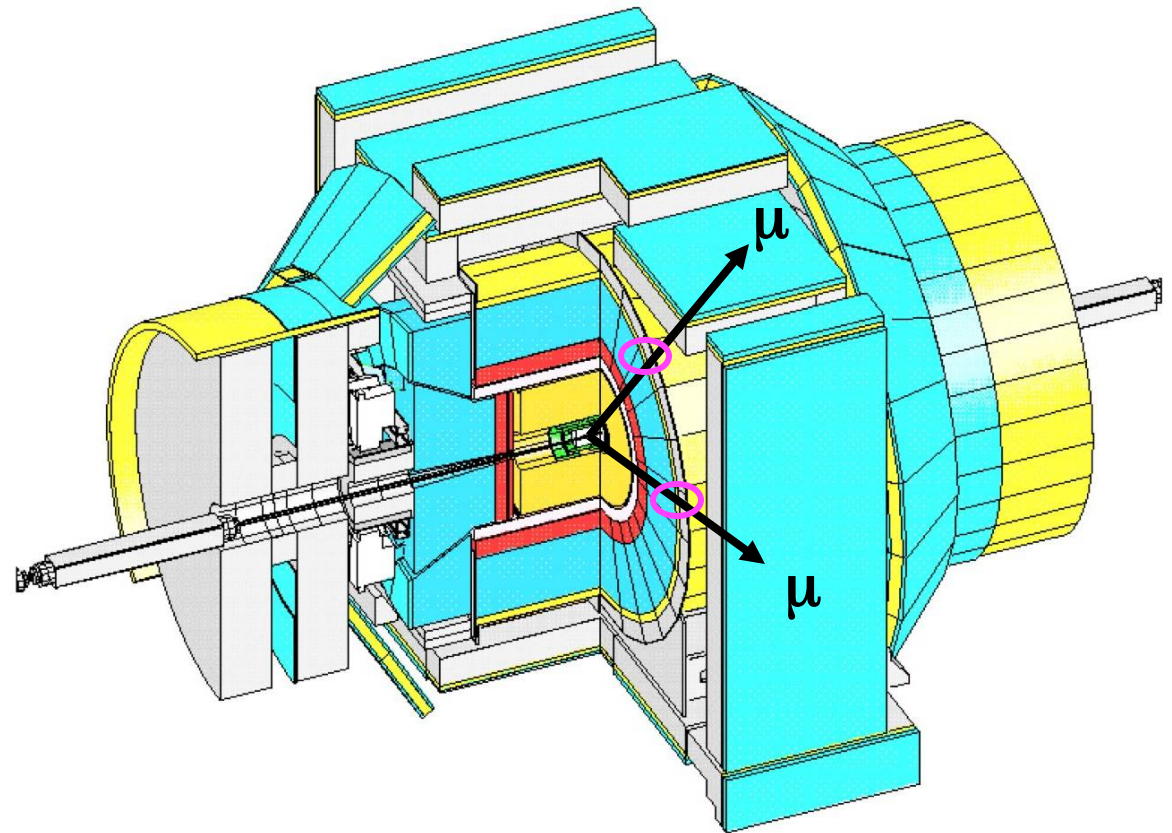
- This report provides an update on the mass and mean life properties of several weakly-decaying b baryons.
- The measurements use the full Run II CDF data set
 - 9.6 fb^{-1} – the full 2001-11 operation
- B mesons are measured as well, to establish the systematic uncertainties.

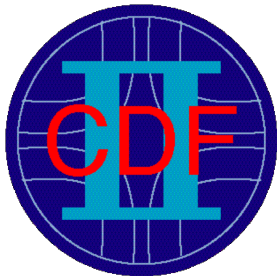




The CDF II Detector

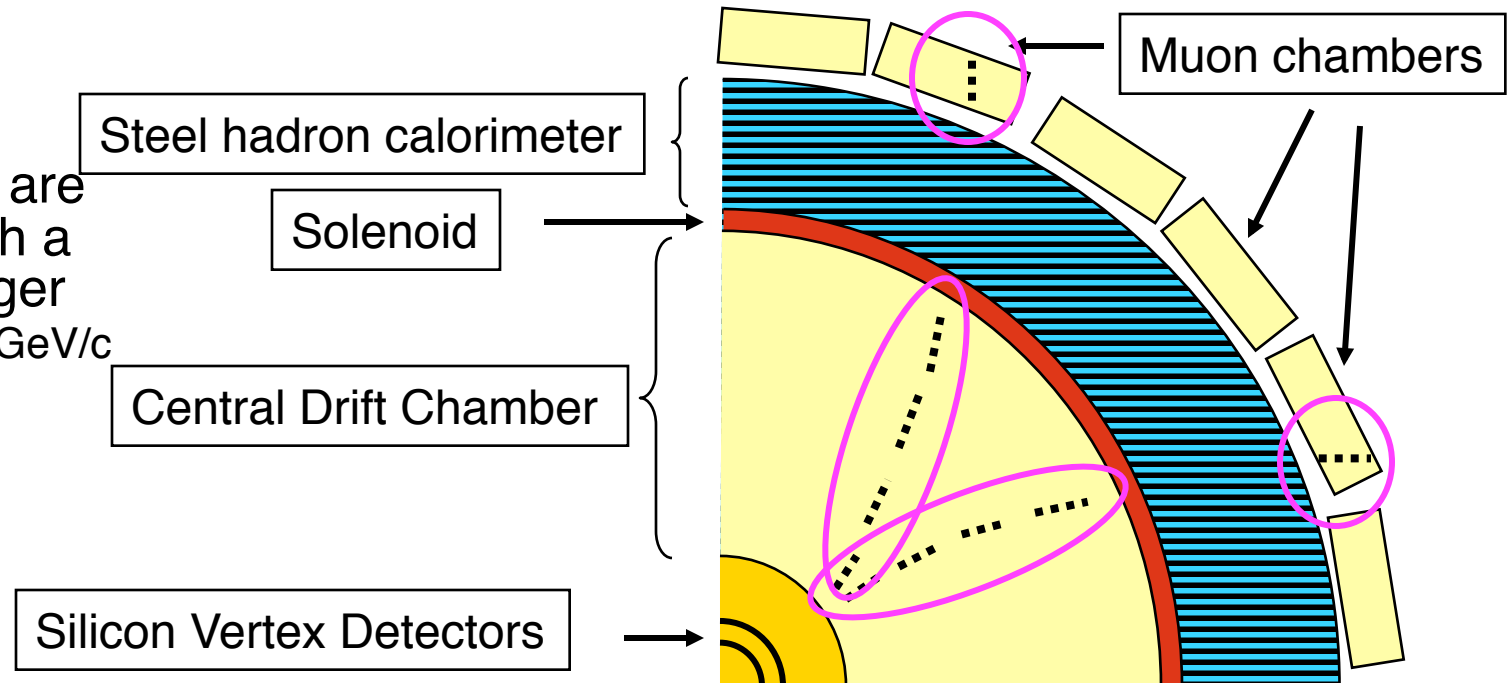
- The data used in this analysis was collected with the CDF II Detector.
- Two triggers are used
 - $\mu^+\mu^-$ trigger selects J/ψ
 - Unbiased with respect to decay time for b -hadrons
 - Displaced track trigger selects B decays
 - Biased for long decay time



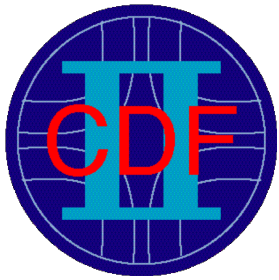


Collecting b Baryons with a J/ψ Final State

- $J/\psi \rightarrow \mu^+\mu^-$ are collected with a 2-muon trigger
 - $p_T(\mu) > 1.5 \text{ GeV}/c$

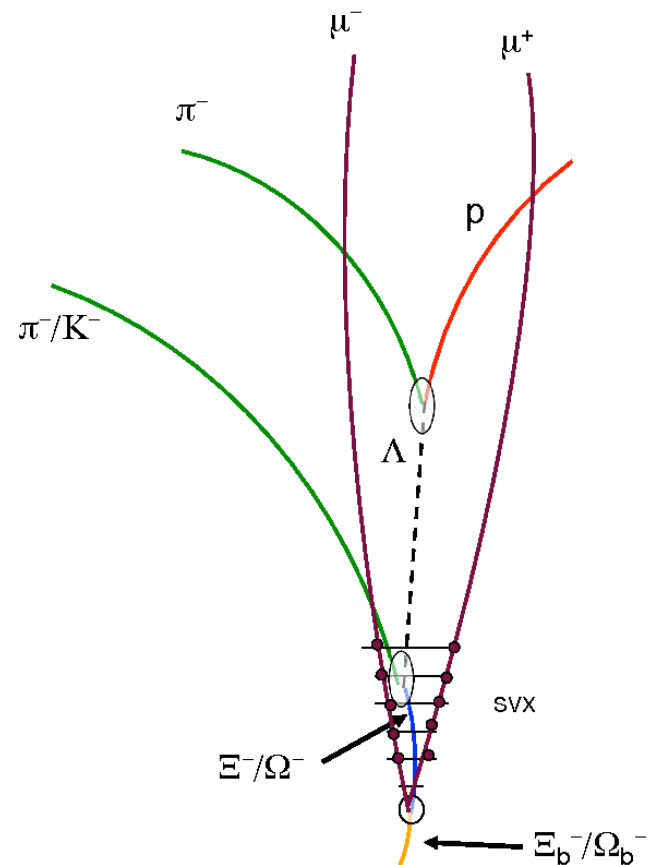


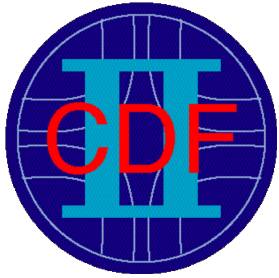
- This trigger matches central tracker and muon chamber tracks.
- A successful match will trigger acceptance of the event.



Reconstruction in the J/ψ Sample

- For all states, require
 - $P_T > 6 \text{ GeV}/c$
 - $P_T(\text{hadron}) > 2 \text{ GeV}/c$
 - $P_T(\text{all tracks}) > 0.4 \text{ GeV}/c$
 - $P(\chi^2) > 10^{-4}$ for charmonium mass, vertex fit
 - $ct > 100 \mu\text{m}$
- Silicon is required on the muon tracks
 - Provides vertex resolution
 - Not used on any other tracks

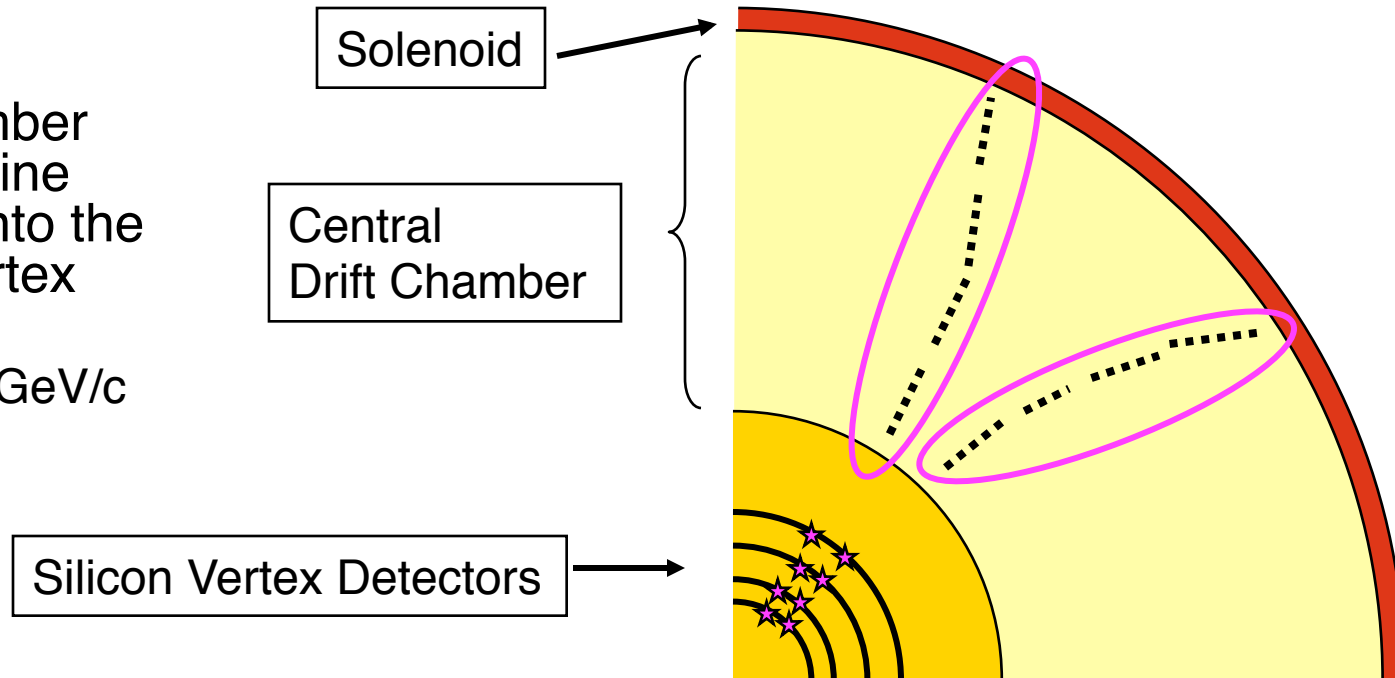




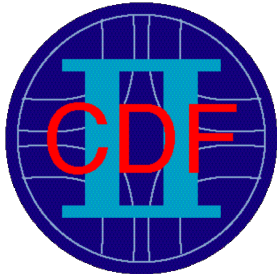
CDF Two-Track Trigger

- Drift chamber tracks define “roads” into the silicon vertex detector.

➤ $p_T > 2 \text{ GeV}/c$

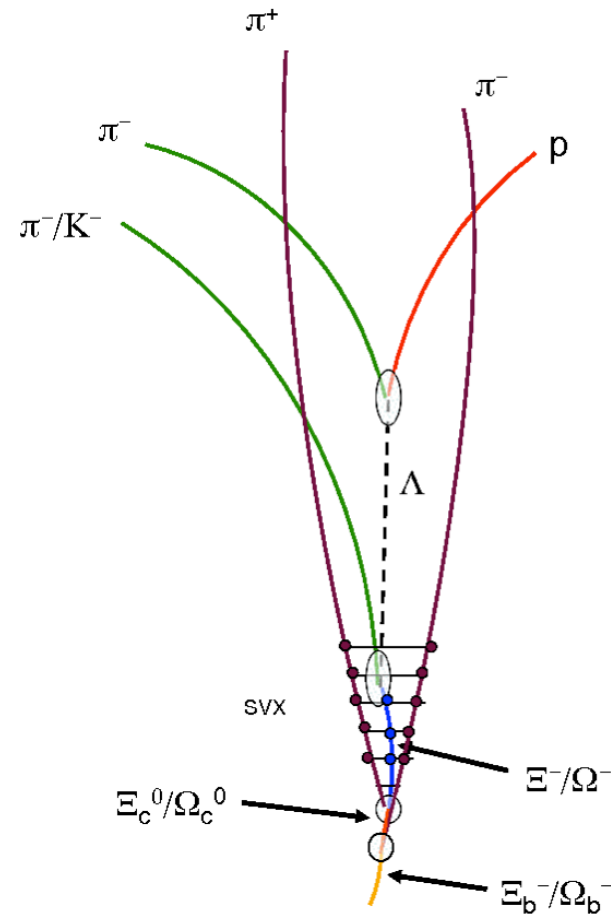


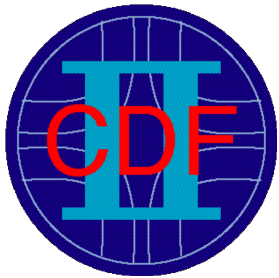
- Data that match prescribed patterns in the silicon triggers acceptance of the event.
 - $100 \mu\text{m} < |d| < 1 \text{ mm}$
- Provides purely hadronic final states - biased to heavy flavor
 - Flight from the beam $> 200 \mu\text{m}$



Reconstruction in the Hadronic Trigger Sample

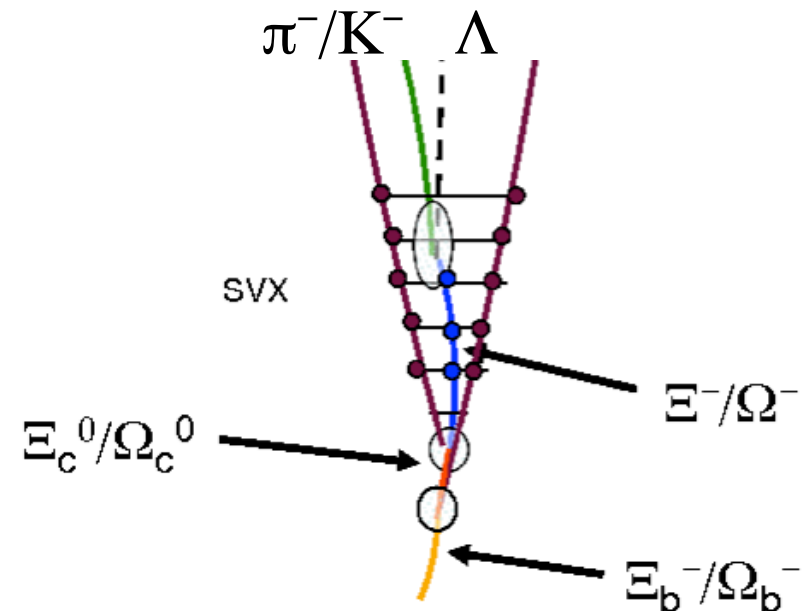
- For all states, require
 - 2 trigger tracks
 - $P_T(\Xi_c/\Omega_c) > 4 \text{ GeV}/c$
 - $P_T(\text{all tracks}) > 0.4 \text{ GeV}/c$
 - $P(\chi^2) > 10^{-4}$ for full mass, vertex fit
 - $ct > 100 \mu\text{m}$, $|dl| < 100 \mu\text{m}$
- Silicon is required on the trigger tracks.
- Decay products of the $\Lambda/\Xi^-/\Omega^-$ are found in the drift chamber.



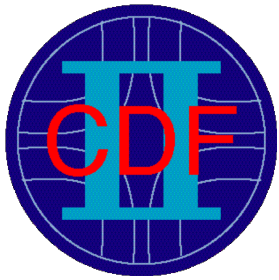


Hyperon Tracks

- The final state fit provides a decay point and momentum measurement of Ξ^-/Ω^- .
- This defines a helix, used as a search road for silicon hits.

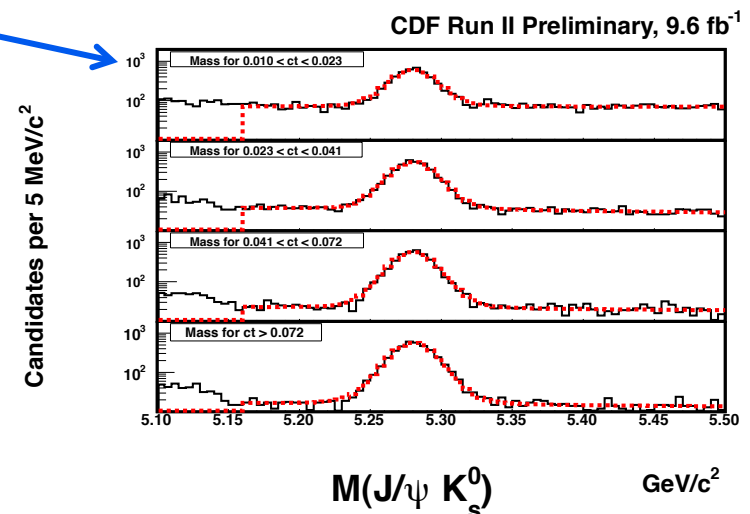
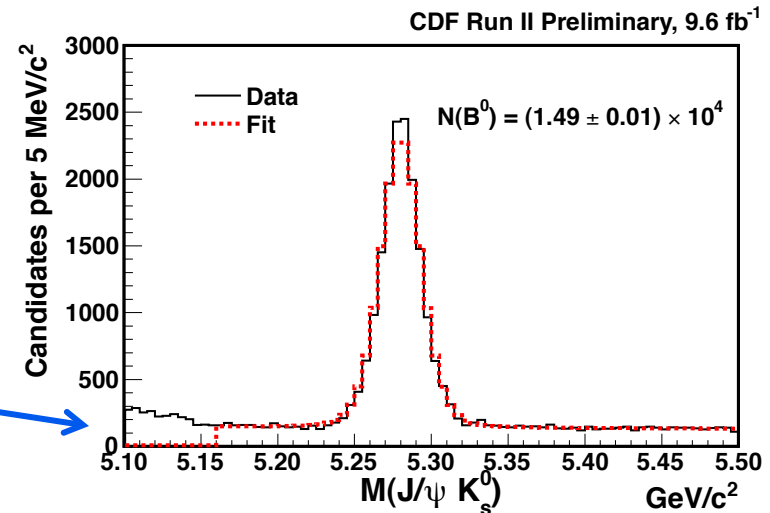


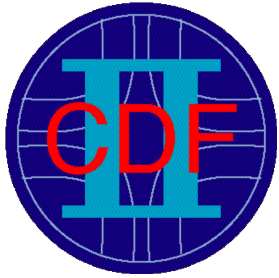
- The resulting Ξ^-/Ω^- track precision allows resolution of the charm vertex.



Mass, Mean Life Measurements

- Mass and mean life measurements use an unbinned likelihood fit to the mass distributions
 - Full sample provides a mass measurement
 - Sample binned in decay time for a mean life measurement.
 - Fit is insensitive to background “lifetime”, resolution terms.
- Reference measurements are made for B^+ and B^0 .

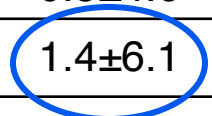


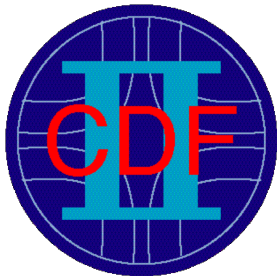


B Meson Properties

Process	Data	Mass(MeV/c ²)		Mean Life(μm)	
		Measured	δm	Measured	δcτ
B ⁺ →J/ψK ⁺	All	5278.57±0.05	0.7±0.2	487.2±1.9	-4.8±3.1
	Not Published	5278.57±0.08	0.7±0.2	489.3±2.7	-2.7±3.6
B ⁰ →J/ψK ^{0*}	All	5279.04±0.11	0.5±0.2	458.8±3.3	3.4±3.9
	Not Published	5278.96±0.15	0.6±0.2	459.0±4.6	3.6±5.1
B ⁰ →J/ψK ^{0_s}	All	5280.02±0.12	-0.4±0.2	454.9±4.1	0.5±4.6
	Not Published	5280.10±0.18	-0.5±0.2	456.8±5.7	1.4±6.1

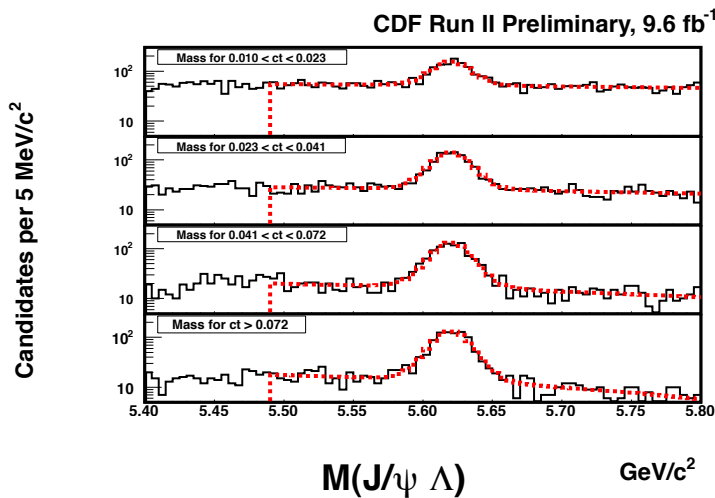
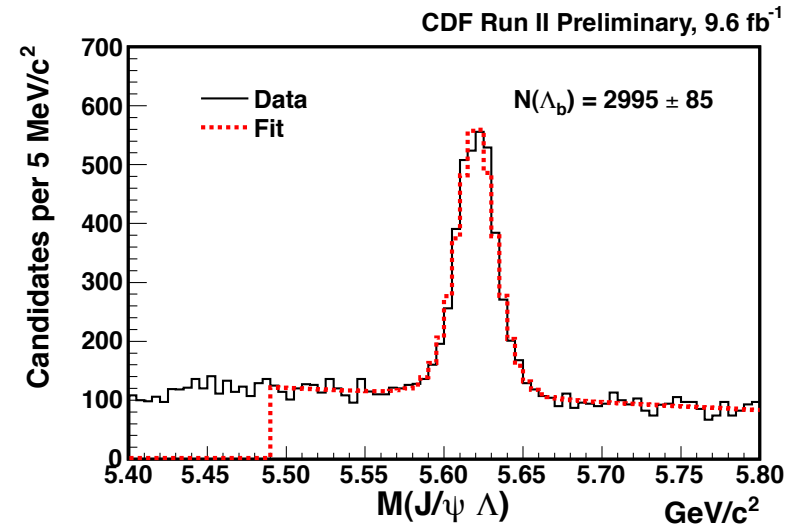
- B mesons establish our lifetime accuracy
 - Fully reconstructed B, two μ tracks for vertex
 - Differences are with respect to the PDG
 - Most conservative unpublished comparison
 - No worse than 6/455



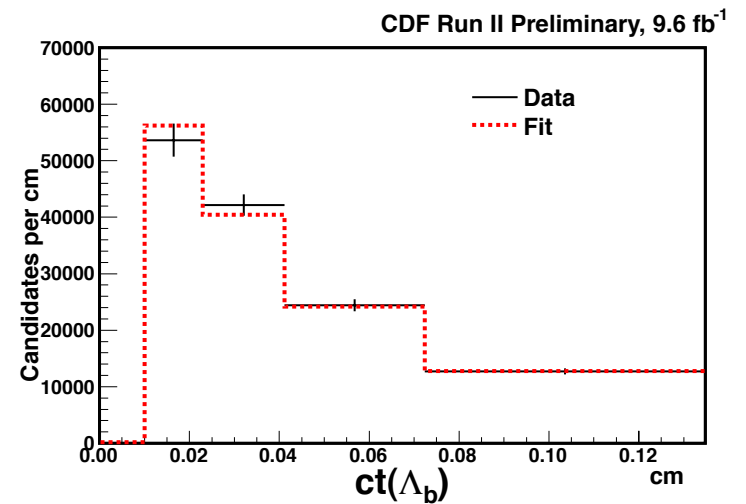


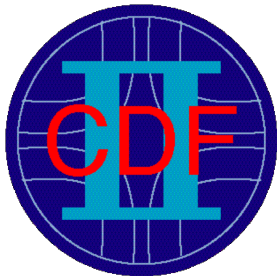
Λ_b Sample

- $\Lambda_b \rightarrow J/\psi \Lambda$ selection differs from the K_S only in track mass assignments and two-track mass range.



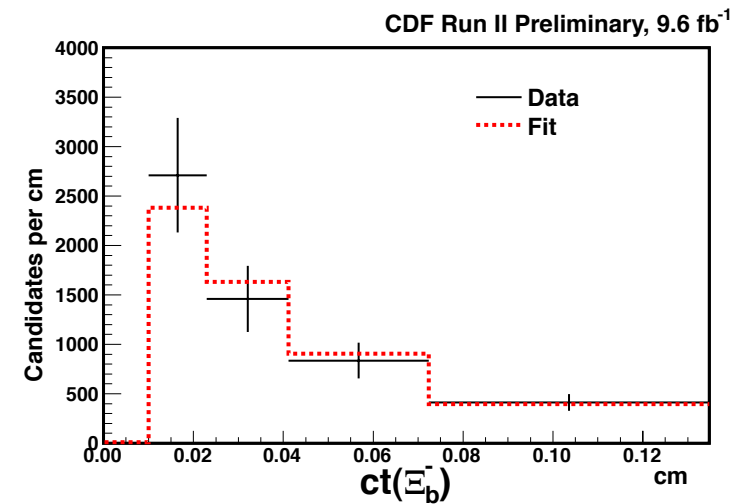
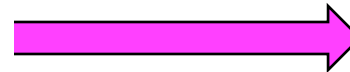
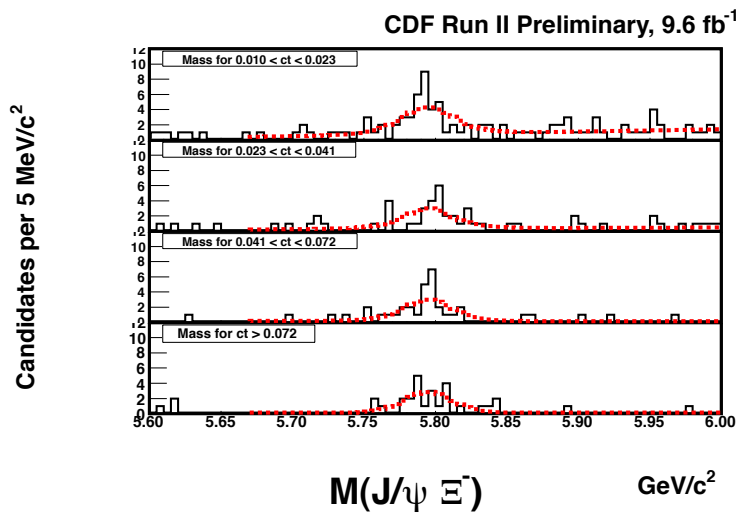
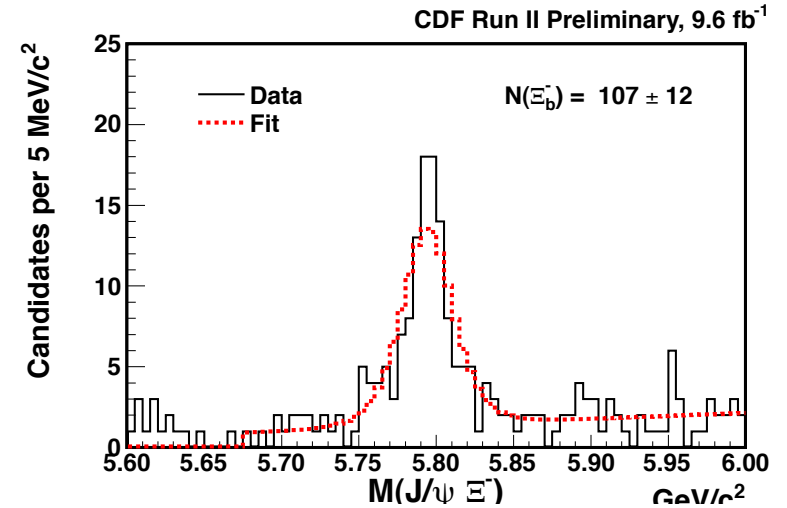
Mean life is fit to the distribution of yields in each time range

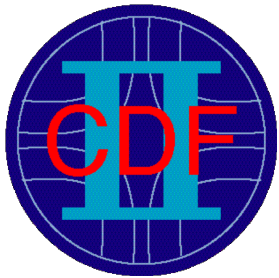




Ξ_b^- Sample

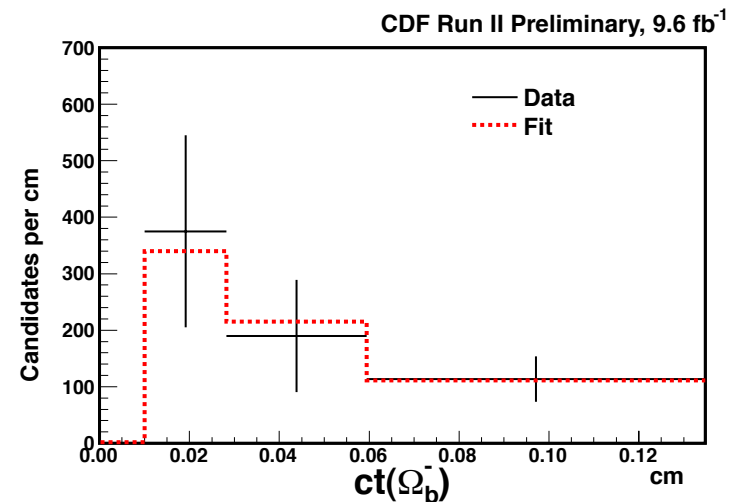
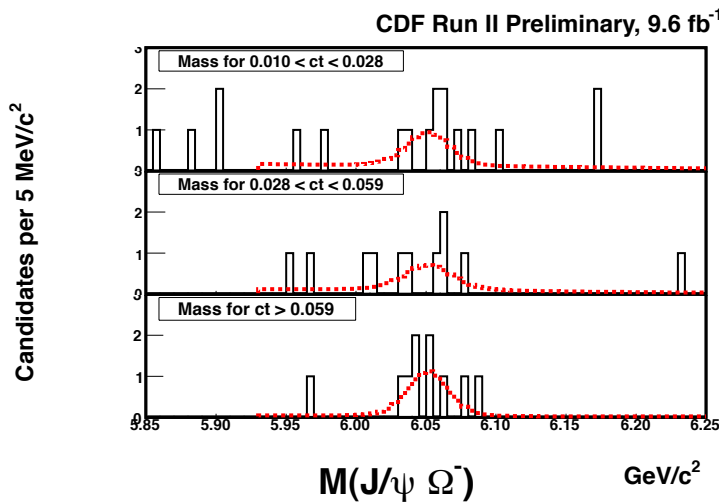
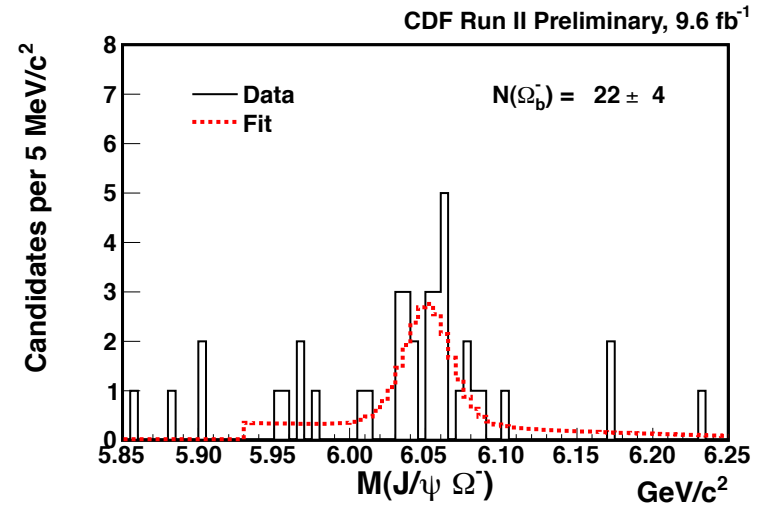
- $\Xi_b^- \rightarrow J/\psi \Xi^-, \Xi^- \rightarrow \Lambda \pi^-$
 reconstruction simply adds a
 third hadron track.

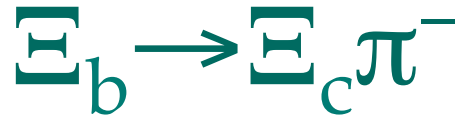
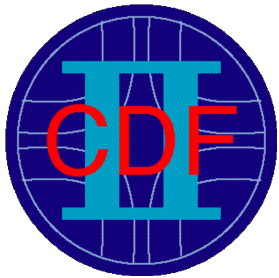




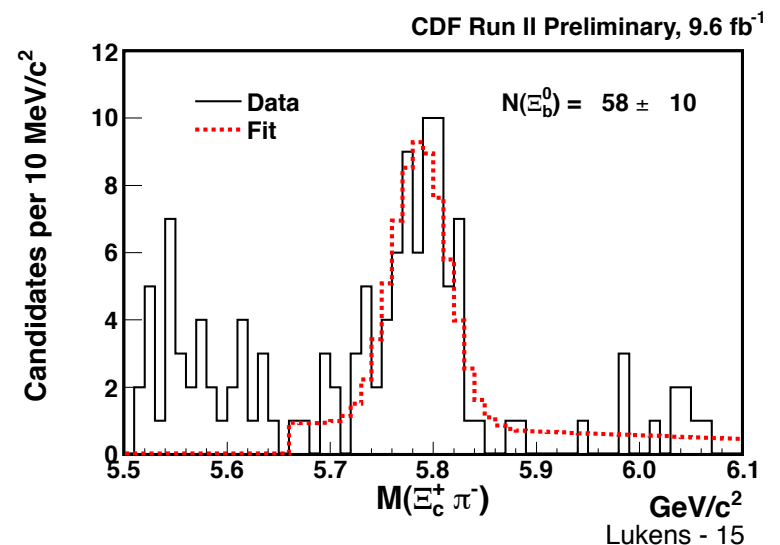
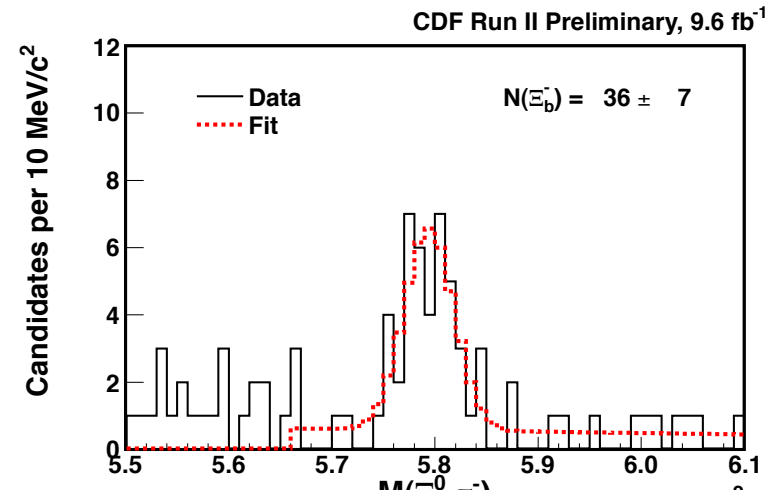
Ω_b^- Sample

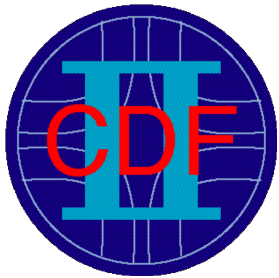
- $\Omega_b^- \rightarrow J/\psi \Omega^-, \Omega^- \rightarrow \Lambda K^-$
selection is very similar to the Ξ_b^- .
 - Reassign $\pi^- \rightarrow K^-$
 - $p_T(K^-) > 1 \text{ GeV}/c$





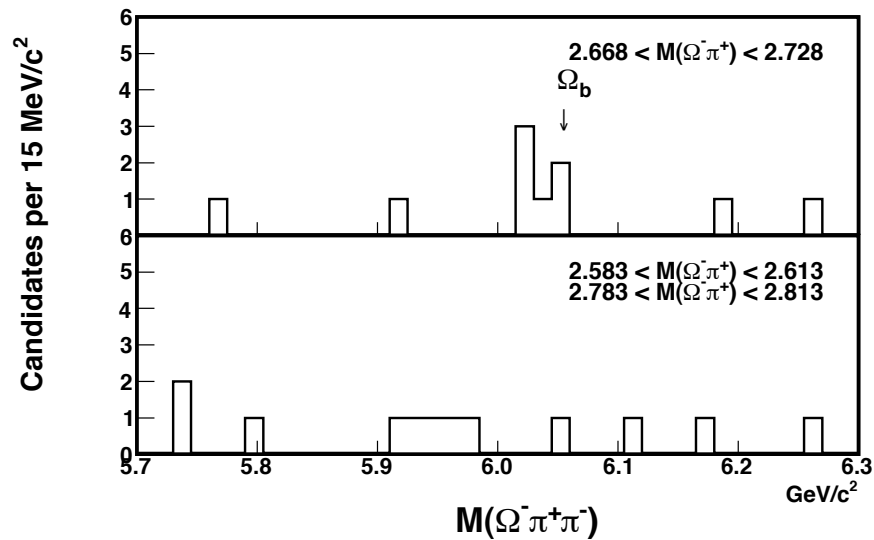
- In the track trigger, we reconstruct
 - ↘ $\Xi_b^{-/0} \rightarrow \Xi_c^{0/+} \pi^-$,
 - ↘ $\Xi_c^{0/+} \rightarrow \Xi^- \pi^+ (\pi^+)$,
 - ↘ $\Xi^- \rightarrow \Lambda \pi^-$,
 - ↘ $\Lambda \rightarrow p \pi^-$.
- The track trigger is biased in lifetime.
- Therefore, only masses will be extracted



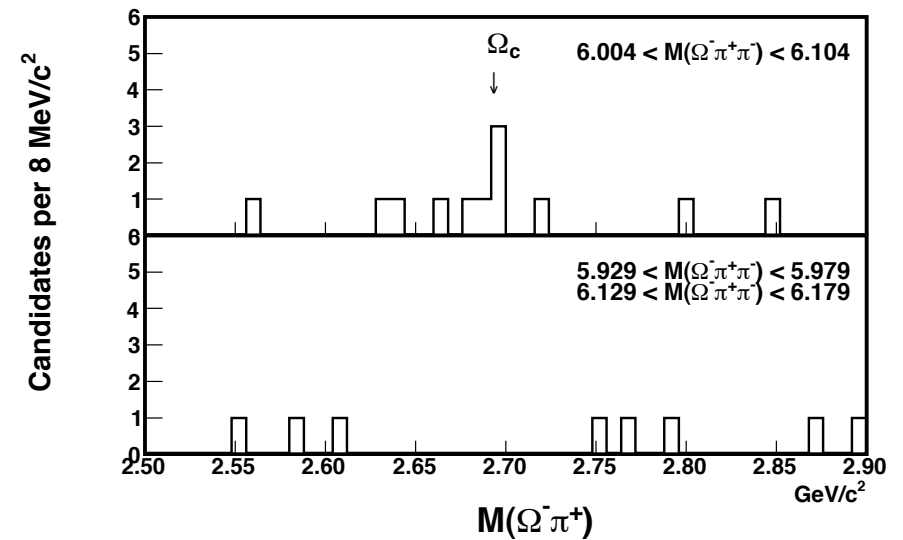


$\Omega^- \pi^+ \pi^-$ distribution

CDF Run II Preliminary, 9.6 fb⁻¹

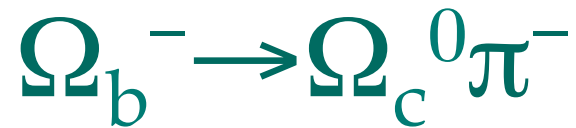
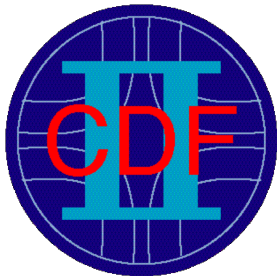


CDF Run II Preliminary, 9.6 fb⁻¹

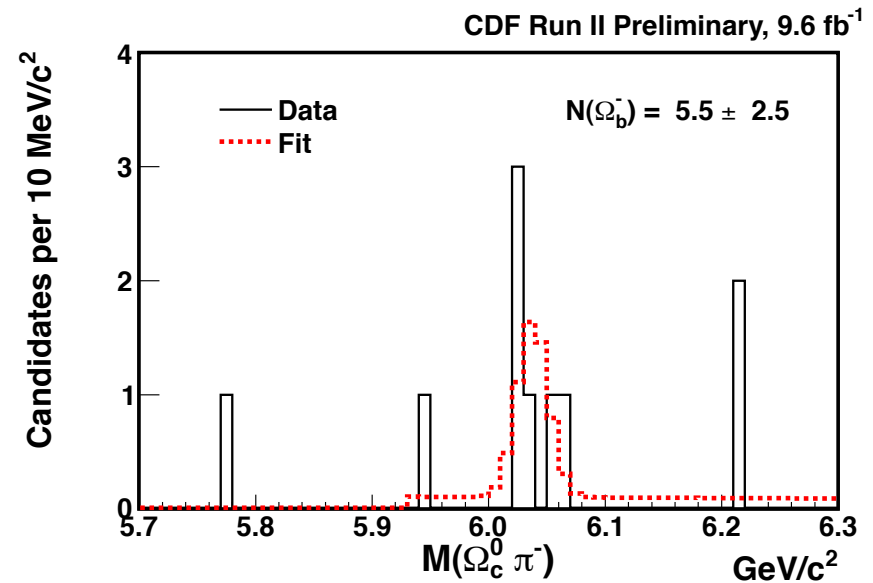


- The full data set allows the baryon search to extend into the $\Omega^- \pi^+ \pi^-$ system.

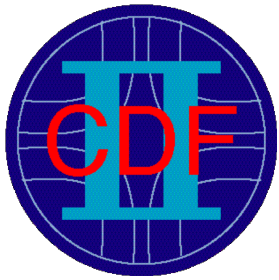
- In $\Omega^- \pi^+ \pi^-$ distribution
 - Ω_b^- candidates in Ω_c^0 range
 - Ω_c^0 candidates in Ω_b^- range



- Significance is tested by a $\Delta \log \mathcal{L}$ test
 - Assume a mass in the range 6046(LHCb) to 6054(CDF) MeV/c^2 .
- Simulation of uniform distribution gives $P=1-5 \times 10^{-4}$ for comparable $\Delta \log \mathcal{L}$
 - $3.3-3.6\sigma$



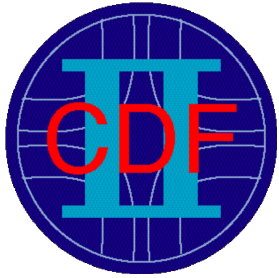
- Considered evidence for $\Omega_b^- \rightarrow \Omega_c^0 \pi^-$



Systematic Uncertainties on Mass

Effect	Uncertainty(MeV/c ²)								
	B ⁺	B ⁰		Λ_b	Ξ_b^-		Ξ_b^0	Ω_b^-	
		J/ ψ K ^{0*}	J/ ψ K ^{0_s}		J/ ψ Ξ^-	$\Xi_c^0\pi^-$		J/ ψ Ω^-	$\Omega_c^0\pi^-$
Ξ_c, Ω mass	–	–	–	–	–	0.8	0.6	0.29	1.7
Momentum scale	0.45	0.42	0.45	0.4	0.4	0.5	0.4	0.4	0.55
Uncertainty model	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	0.45	0.42	0.45	0.4	0.4	0.95	0.73	0.5	1.8

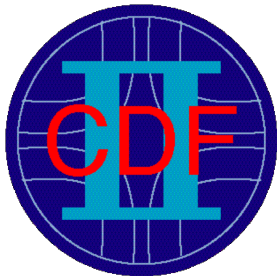
- Momentum scale from J/ ψ , $\psi(2S)$, Υ
- Uncertainty model from variations in the fit
- Total is quadrature sum.
- B measurements are consistent with PDG



Baryon Properties from $\mu\mu$ trigger

Process	Mass(MeV/c ²)	Mean Life(ps)
$\Lambda_b \rightarrow J/\psi \Lambda$	$5620.14 \pm 0.31(\text{stat}) \pm 0.40(\text{syst})$	$1.565 \pm 0.035(\text{stat}) \pm 0.020(\text{syst})$
$\Xi_b^- \rightarrow J/\psi \Xi^-$	$5794.1 \pm 2.0(\text{stat}) \pm 0.40(\text{syst})$	$1.36 \pm 0.15(\text{stat}) \pm 0.02(\text{syst})$
$\Omega_b^- \rightarrow J/\psi \Omega^-$	$6051.4 \pm 4.2(\text{stat}) \pm 0.50(\text{syst})$	$1.77^{+0.55}_{-0.41}(\text{stat}) \pm 0.020(\text{syst})$

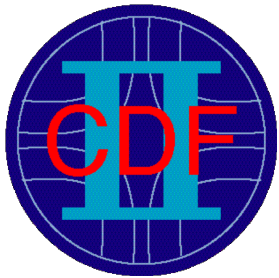
- Baryon properties were obtained for several variations of resolution and decay time binning.
- These supersede our previous results.



Baryon Properties from Hadronic Trigger

Process	Mass(MeV/c ²)
$\Xi_b^- \rightarrow \Xi_c^0 \pi^-$	$5796.5 \pm 4.7(\text{stat}) \pm 0.95(\text{syst})$
$\Xi_b^0 \rightarrow \Xi_c^+ \pi^-$	$5791.6 \pm 5.0(\text{stat}) \pm 0.73(\text{syst})$
$\Omega_b^- \rightarrow \Omega_c^0 \pi^-$	$6040 \pm 8(\text{stat}) \pm 2(\text{syst})$

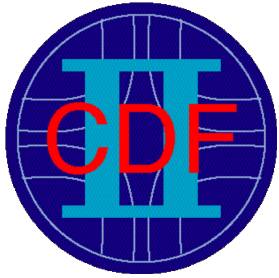
- Evidence for $\Omega_b^- \rightarrow \Omega_c^0 \pi^-$ is given at 3.3-3.6 σ level
- Observation of the Ξ_b^0 provides mass difference
 - $M(\Xi_b^-) - M(\Xi_b^0) = 2.5 \pm 5.4(\text{stat}) \pm 0.6(\text{syst}) \text{ MeV}/c^2$



Comparison to LHCb

Process		Mass(MeV/c ²)	Mean Life(ps)
$\Lambda_b \rightarrow J/\psi \Lambda$	CDF	$5620.14 \pm 0.31(\text{stat}) \pm 0.40(\text{syst})$	$1.565 \pm 0.035(\text{stat}) \pm 0.020(\text{syst})$
	LHCb	$5619.53 \pm 0.13(\text{stat}) \pm 0.45(\text{syst})$	$1.482 \pm 0.018(\text{stat}) \pm 0.012(\text{syst})$
$\Xi_b^- \rightarrow J/\psi \Xi^-$	CDF	$5794.1 \pm 2.0(\text{stat}) \pm 0.4(\text{syst})$	$1.36 \pm 0.15(\text{stat}) \pm 0.02(\text{syst})$
	LHCb	$5795.8 \pm 0.9(\text{stat}) \pm 0.4(\text{syst})$	–
$\Omega_b^- \rightarrow J/\psi \Omega^-$	CDF	$6051.4 \pm 4.2(\text{stat}) \pm 0.5(\text{syst})$	$1.77^{+0.55}_{-0.41}(\text{stat}) \pm 0.020(\text{syst})$
	LHCb	$6046.0 \pm 2.2(\text{stat}) \pm 0.5(\text{syst})$	–

- Only discrepancies of note are with the Λ_b
 - 2σ in mass
 - 2.5σ in mean life



Conclusions

- The full CDF data set allows measurements of several b-baryon properties.
- Masses and mean life from the dimuon trigger
 - Confirm our Ω_b^- observation paper
- Masses from the hadronic trigger.
 - Confirm our Ξ_b^0 – only observation to date
 - New evidence for the second observed final state of the Ω_b^-
- Where possible, comparisons are consistent with latest LHCb results.