B Baryon Production and Decays and B Hadron Lifetimes

FPCP 2010

8th Flavour Physics and CP Violation 2010

May 25 – May 29, 2010

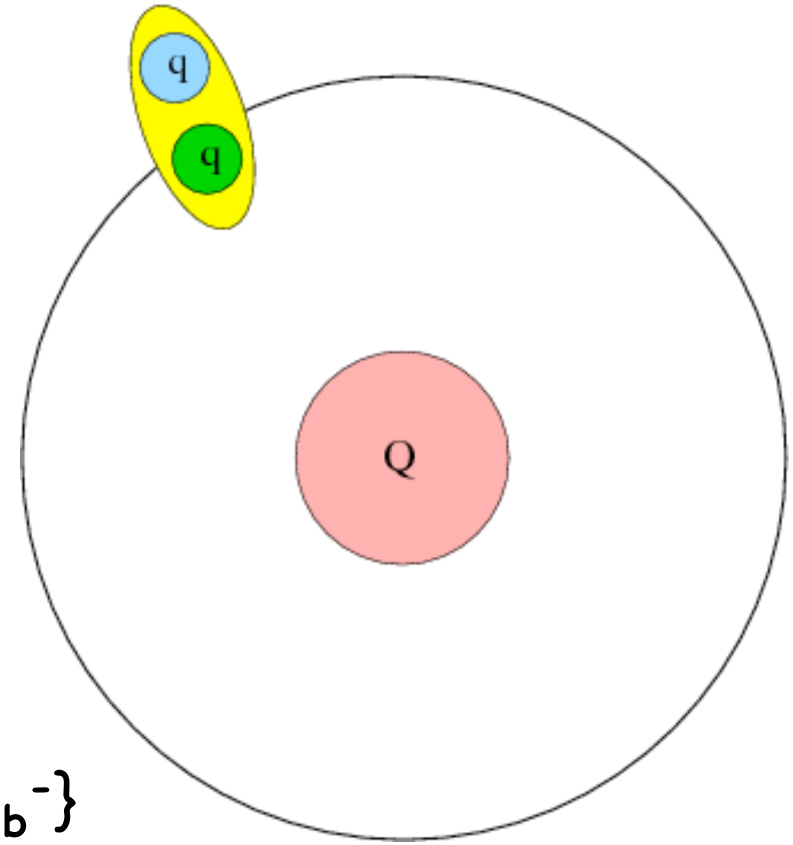
Simone Donati, for the CDF and D0 Collaborations

University and INFN Pisa

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)

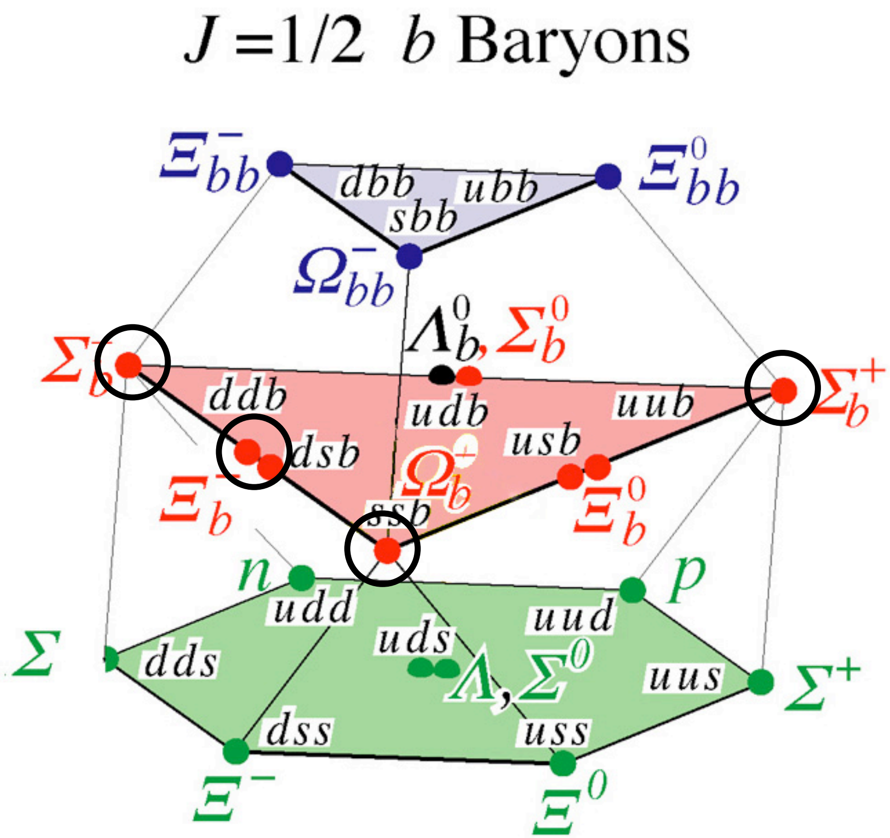
$J_{qq} = S_{qq} = 0 \rightarrow J = J_{qq} + S_Q = 1/2 \quad \{\Lambda^0_b, \Xi_b^-\}$

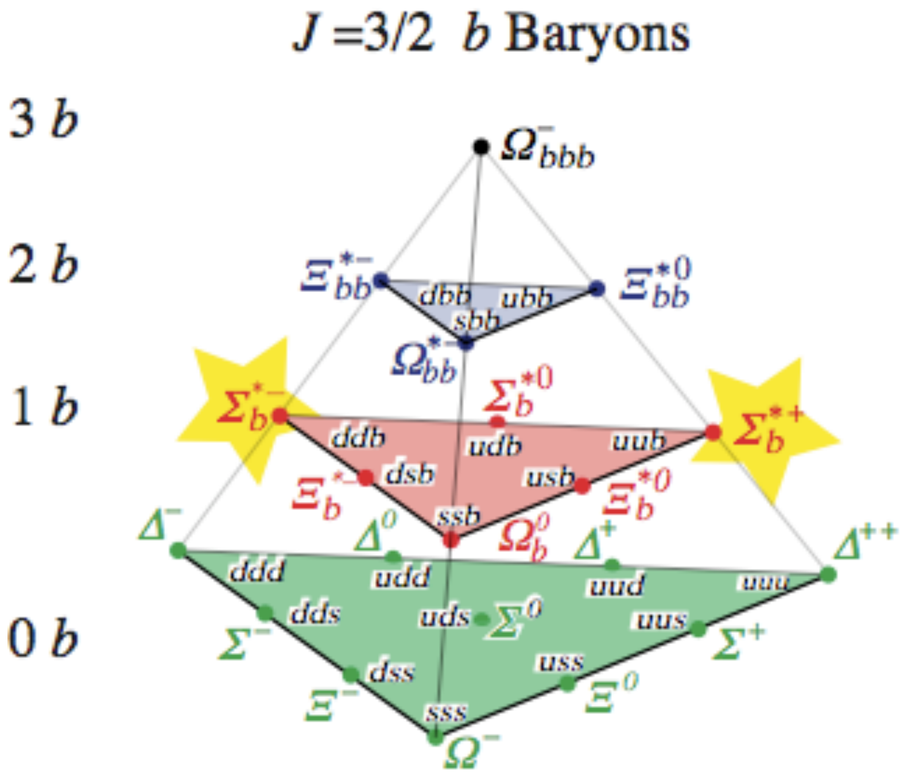
$J_{qq} = S_{qq} = 1 \rightarrow J = J_{qq} + S_Q = 1/2 \quad \{\Sigma_b, \Xi_b', \Omega_b\}$

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

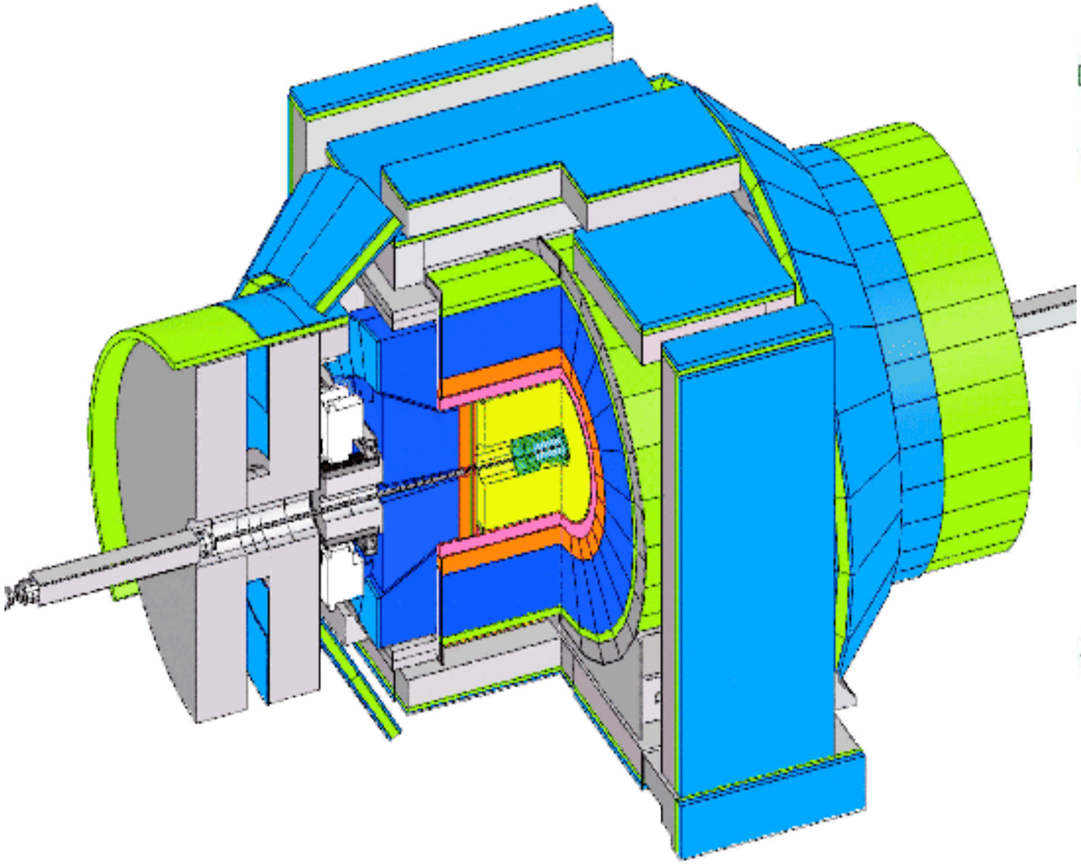
Bottom Baryons (II)

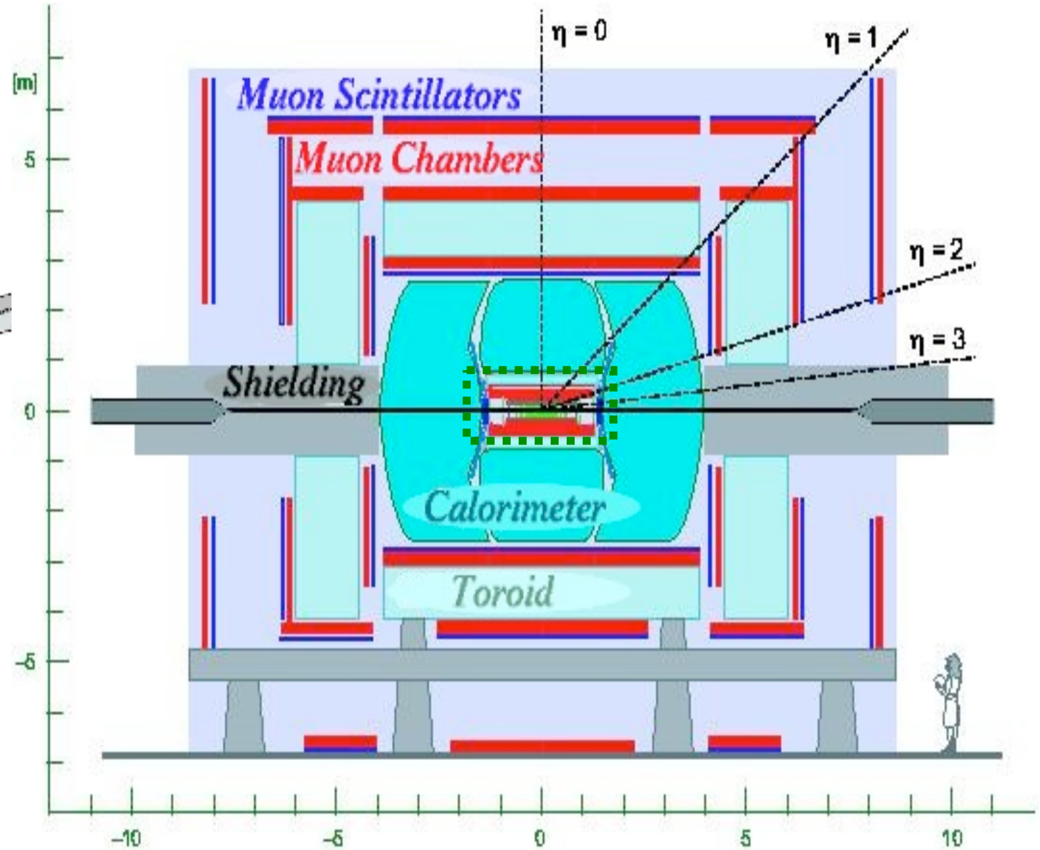
- This is totally a Tevatron field (b baryons copiously produced)
  - $\Sigma_b^{(*)+}$ and $\Sigma_b^{(*)-}$ observed in 2006
  - Ξ_b^- observed by in 2007
  - Ω_b^- observed in 2008
  - Several analyses involving Λ^0_b





CDF and D0 Detectors





Drift Chamber/Silicon detector
(R~1.4 m, 1.4 T B Field)
Excellent vertex/mass resolution
Displaced vertex Trigger
Tracker/Muon acceptance: $|\eta|<1$

Fiber Tracker/Silicon detector
(R~0.5 m, 2.0 T B Field)
Tracker/Muon acceptance: $|\eta|<2$

Ξ_b^-/Ω_b^- Reconstruction

Search for Ξ_b^- and Ω_b^- in the decays

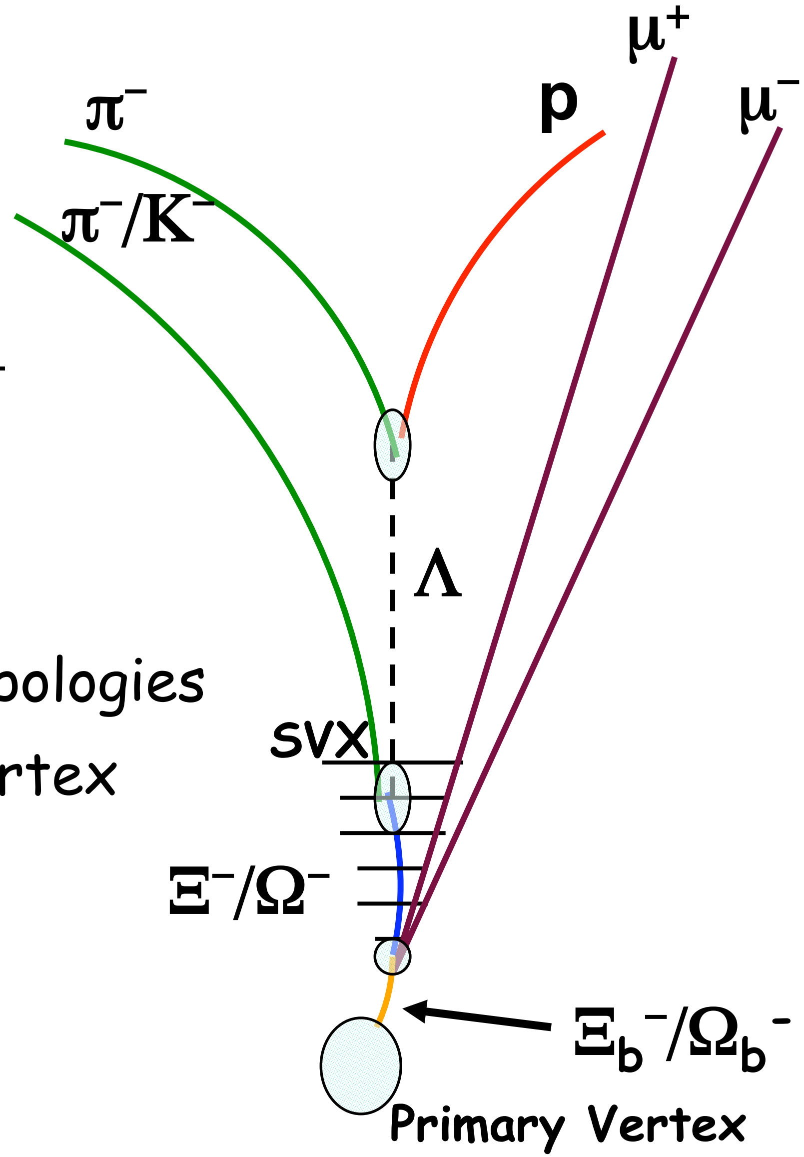
$\Xi_b^- \rightarrow J/\psi\ \Xi^-$, $J/\psi \rightarrow \mu^+\mu^-$, $\Xi^- \rightarrow \Lambda\pi^-$

$\Omega_b^- \rightarrow J/\psi\ \Omega^-$, $J/\psi \rightarrow \mu^+\mu^-$, $\Omega^- \rightarrow \Lambda K^-$

5-track, 3-vertex kinematic fit

- $\mu^+\mu^-$ constrained to J/ψ mass
- Trajectories constrained to appropriate topologies
- Reconstructed Ξ^-/Ω^- constrained to $\mu^+\mu^-$ vertex

Long life of the Ξ^- and Ω^- leaves hits in the silicon detector (unique to baryons)



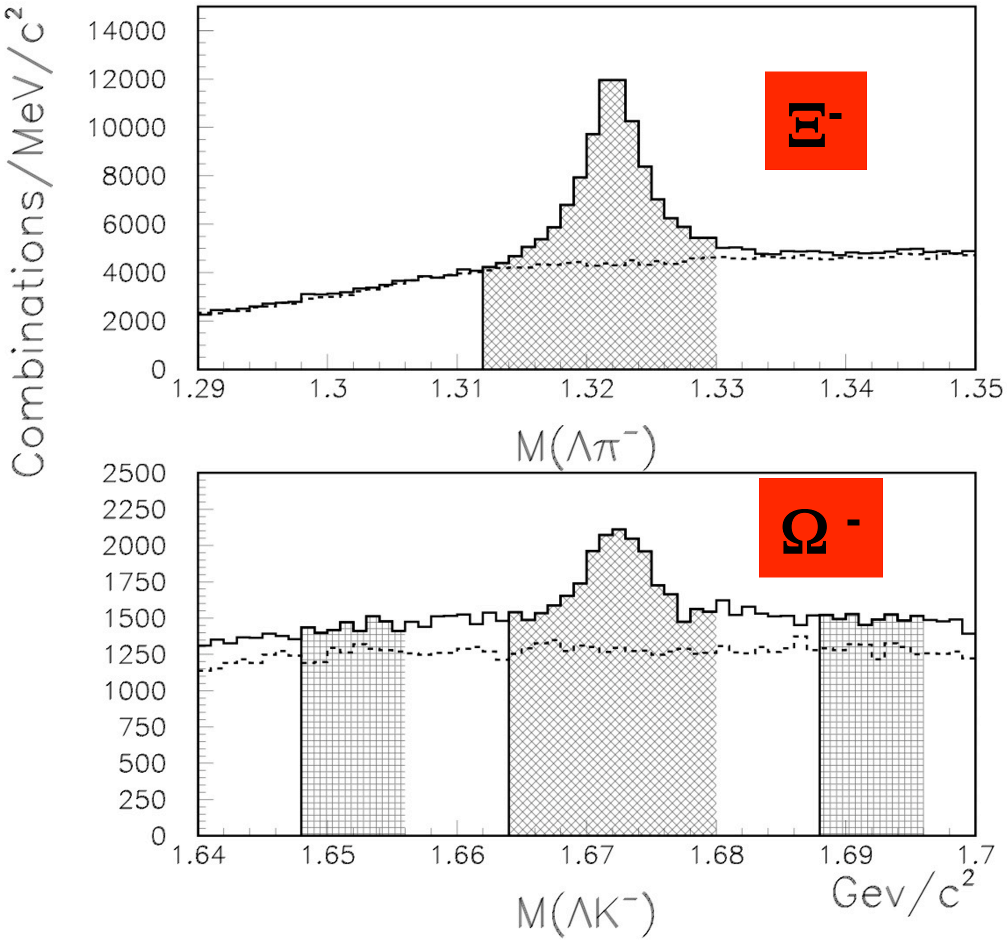
Inclusive Ξ^-/Ω^- Samples

Base sample is given by

- $1.1077 < M(p\pi) < 1.1237$
- $P_T(\Xi/\Omega) > 2.0$
- 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:

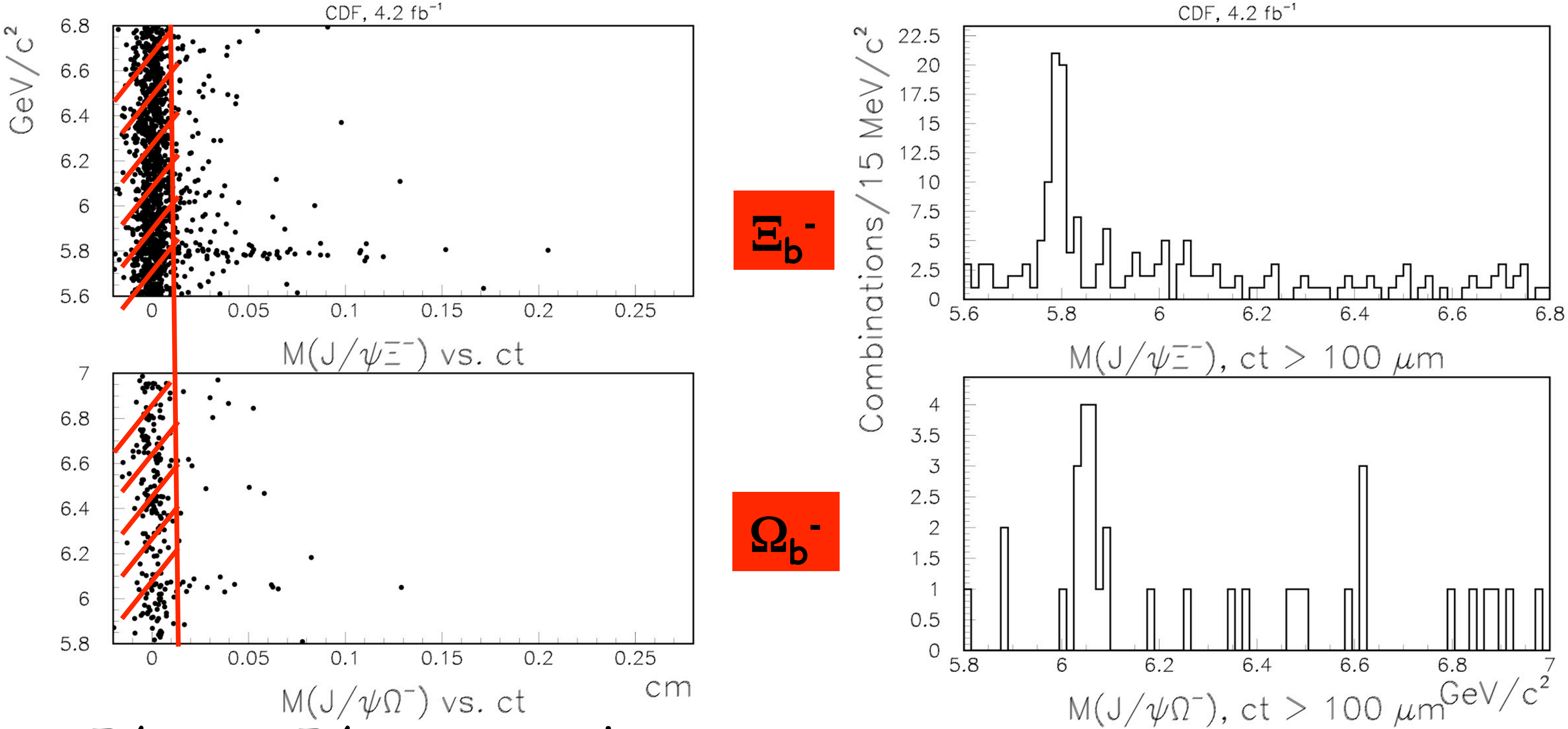
- Ξ^- : 41,000
- Ω^-: 3,500



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

Shaded are selection and SB region

Ξ_b^-/Ω_b^- reconstructed signals



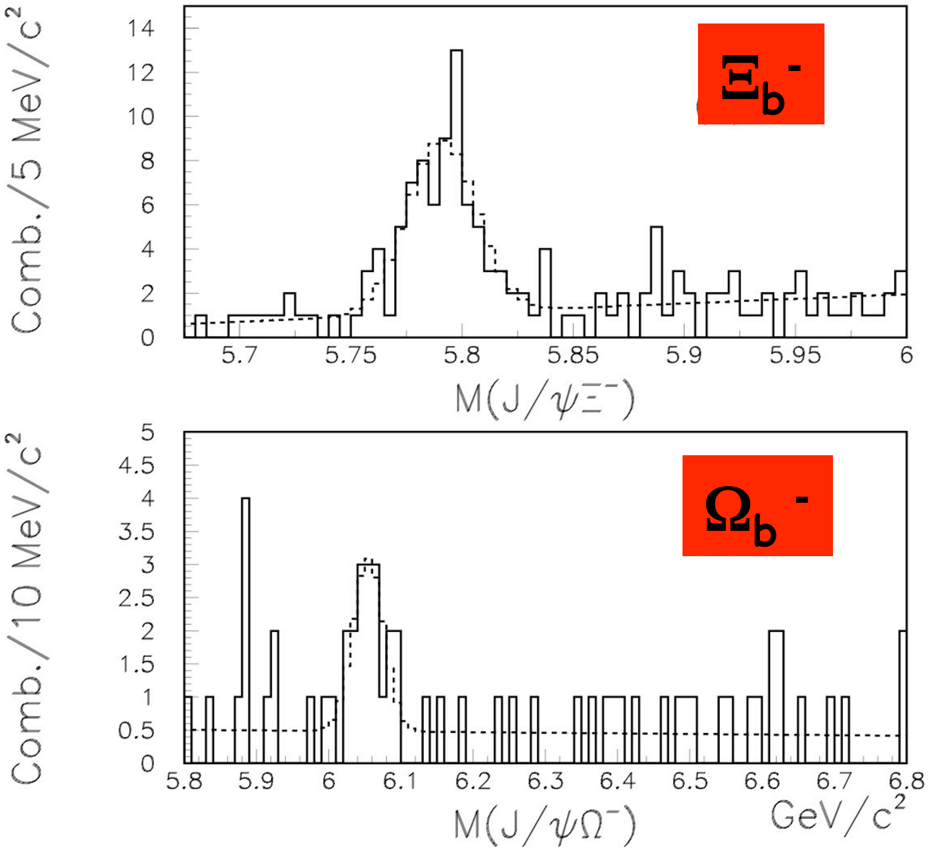
$J/\psi\Xi^-$, $J/\psi\ \Omega^-$ samples

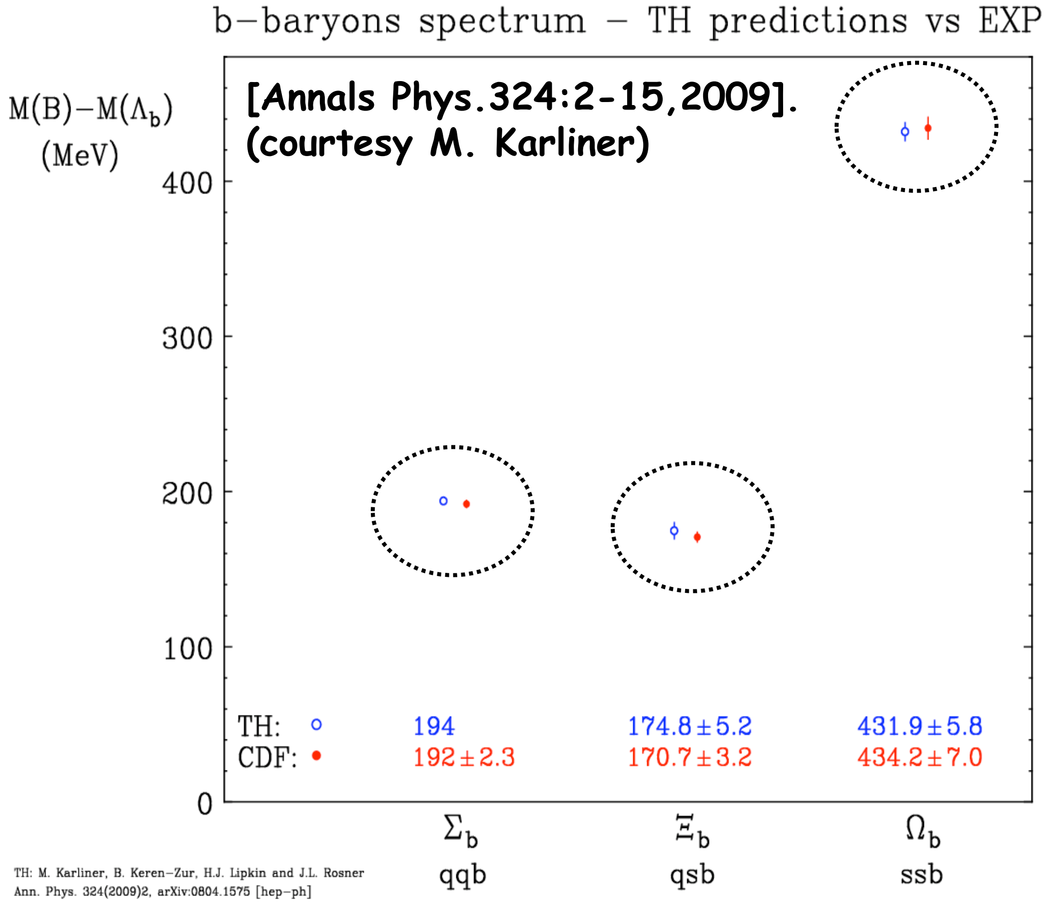
Obvious Ξ_b^- signal when **ct** > 100 μm

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

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

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

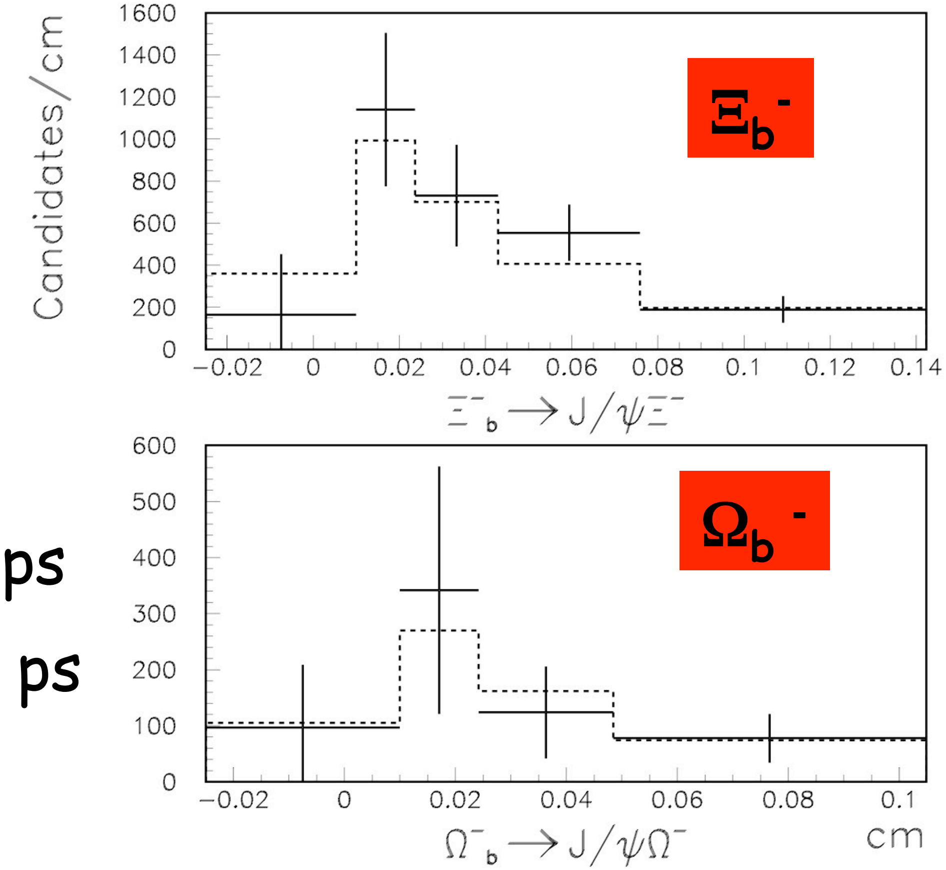
Systematic uncertainty

- 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

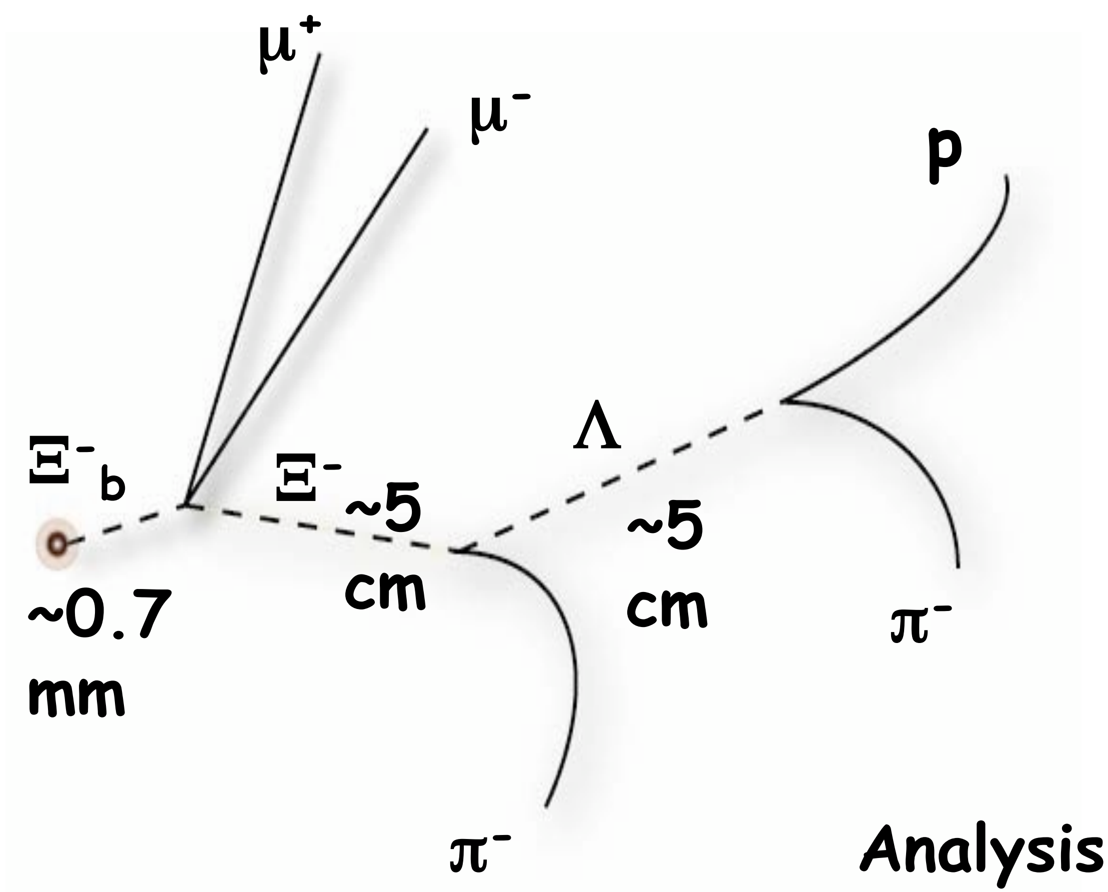
Systematic uncertainty

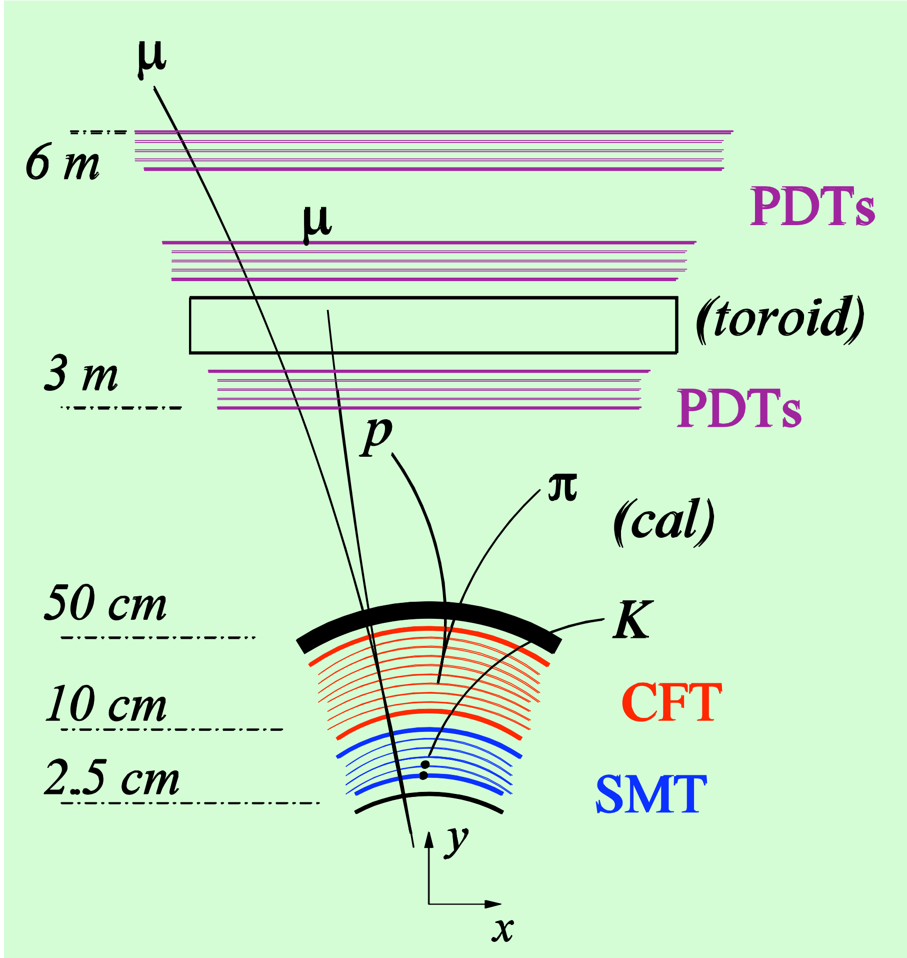
2 μm from σ^{ct} treatment
5 μm from binning

PRD 80, 072003 (2009)

Ξ^-_b Observation (I)

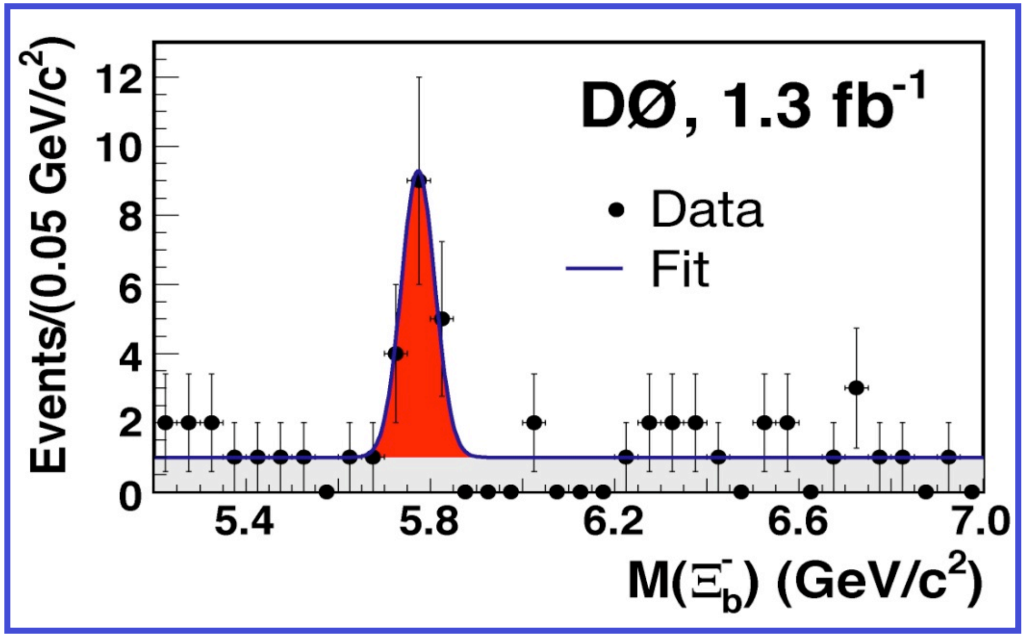
$\Xi^-_b \rightarrow J/\psi + \Xi^-$





Analysis required data reprocessing to increase reconstruction efficiency on large impact parameter tracks

Ξ_b^- Observation (II)



Number of events: 15.2 ± 4.4

Mass: 5.774 ± 0.011(stat) GeV

Width: 0.037 ± 0.008 GeV

We also measured:

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

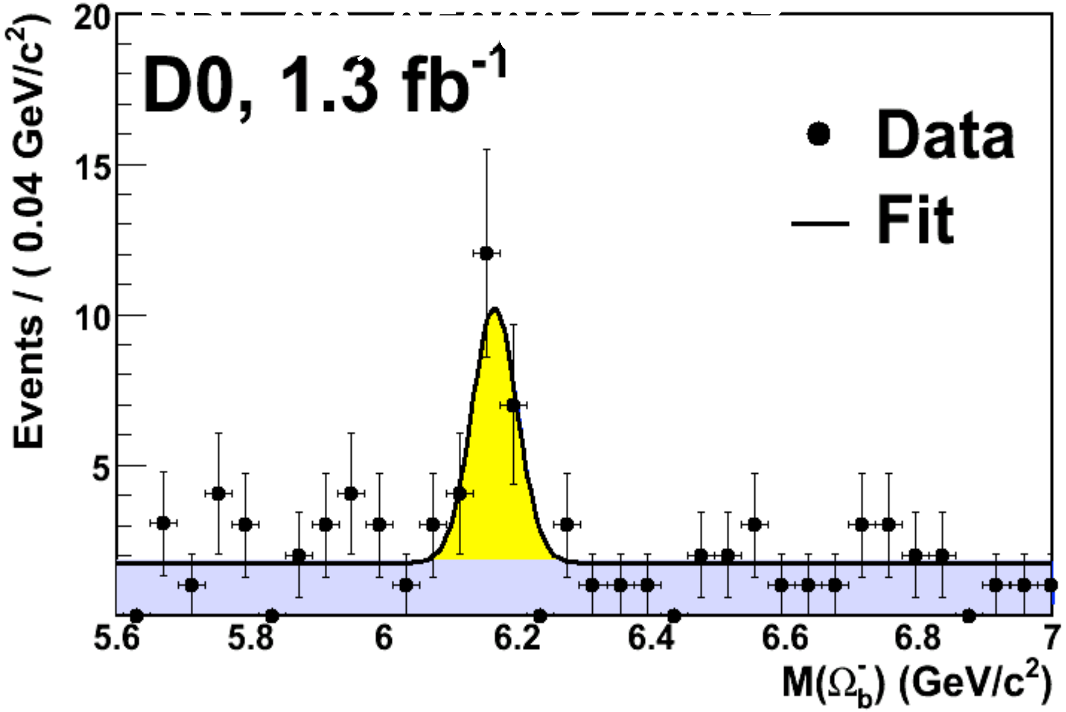
$$R = 0.28 \pm 0.09\,(\text{stat})\ {}^{+0.09}_{-0.08}\,(\text{syst})$$

Signal Significance:

$$\sqrt{-2\Delta \ln L} = \sqrt{-2\ln\left(\frac{L_B}{L_{S+B}}\right)} = 5.5\sigma$$

PRL 99, 052001 (2007)

Ω^-_b mass measurement



Fit:

- Unbinned extended log-likelihood fit
- Gaussian signal, flat background
- Number of background/signal events are floating parameters

Two likelihood fits are performed:

- Signal + background hypothesis (L_{s+B})
- Only background hypothesis (L_B)

We evaluate the significance:

$$\sqrt{-2\Delta \ln L} = \sqrt{-2\ln\left(\frac{L_B}{L_{S+B}}\right)}$$

Significance of the observed signal: 5.4σ

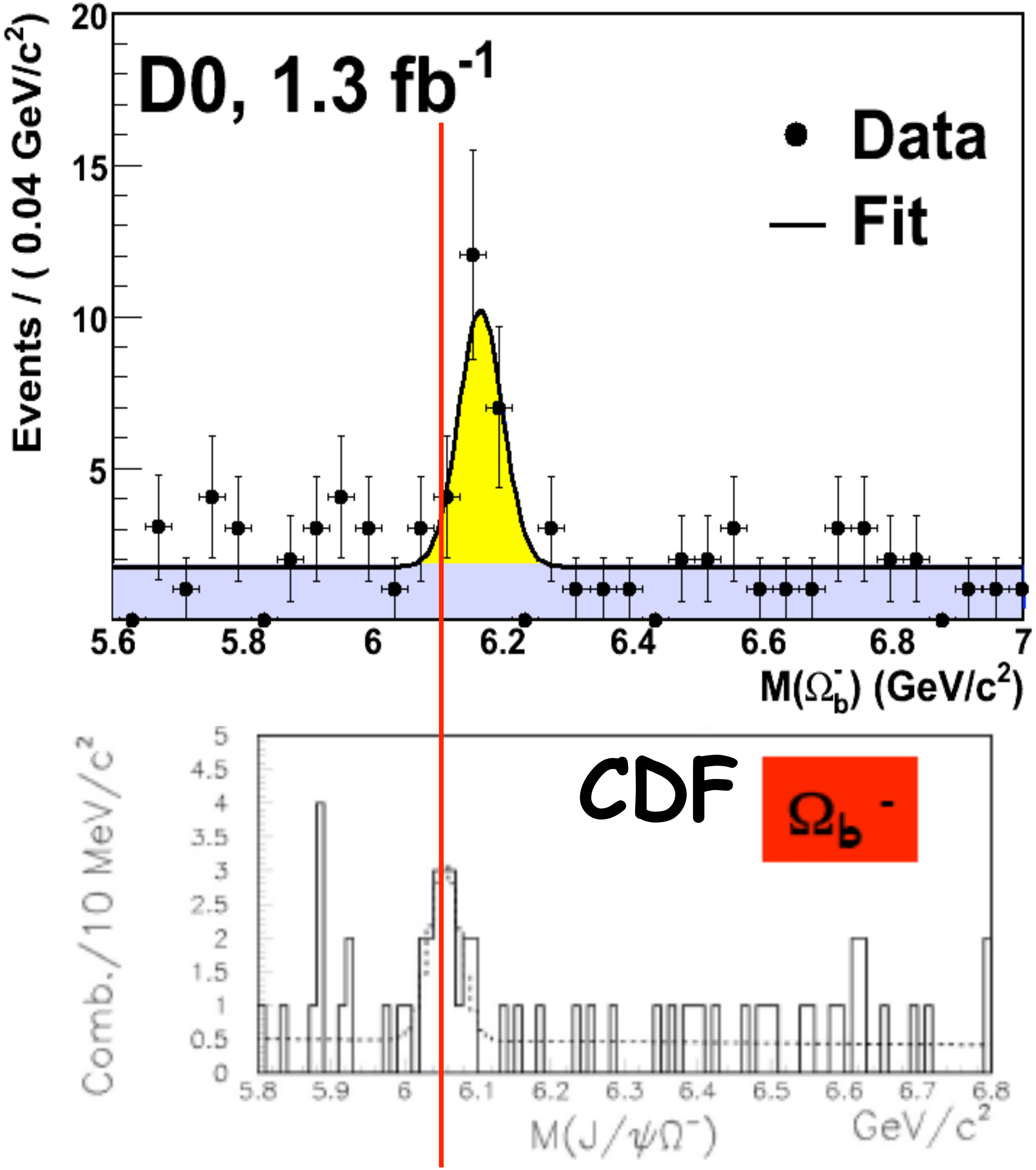
Number of signal events: 17.8 ± 4.9

Mean of the Gaussian: 6.165 ± 0.010(stat) ± 0.013 (syst) GeV

Width of the Gaussian fixed (MC): 0.034 GeV

PRL 101, 232002 (2008)

D0 Mass: 6.165 ± 0.010(stat) ± 0.013(syst) GeV/c^2



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

$\Delta M = |M_{D0} - M_{CDF}| \sim 6\sigma$

- D0 Λ_b & Ξ_b masses ~ PDG values
- D0 recon. Ω_b mass in MC ~ input
- ΔM ~ 10 xD0 Ω_b mass syst.

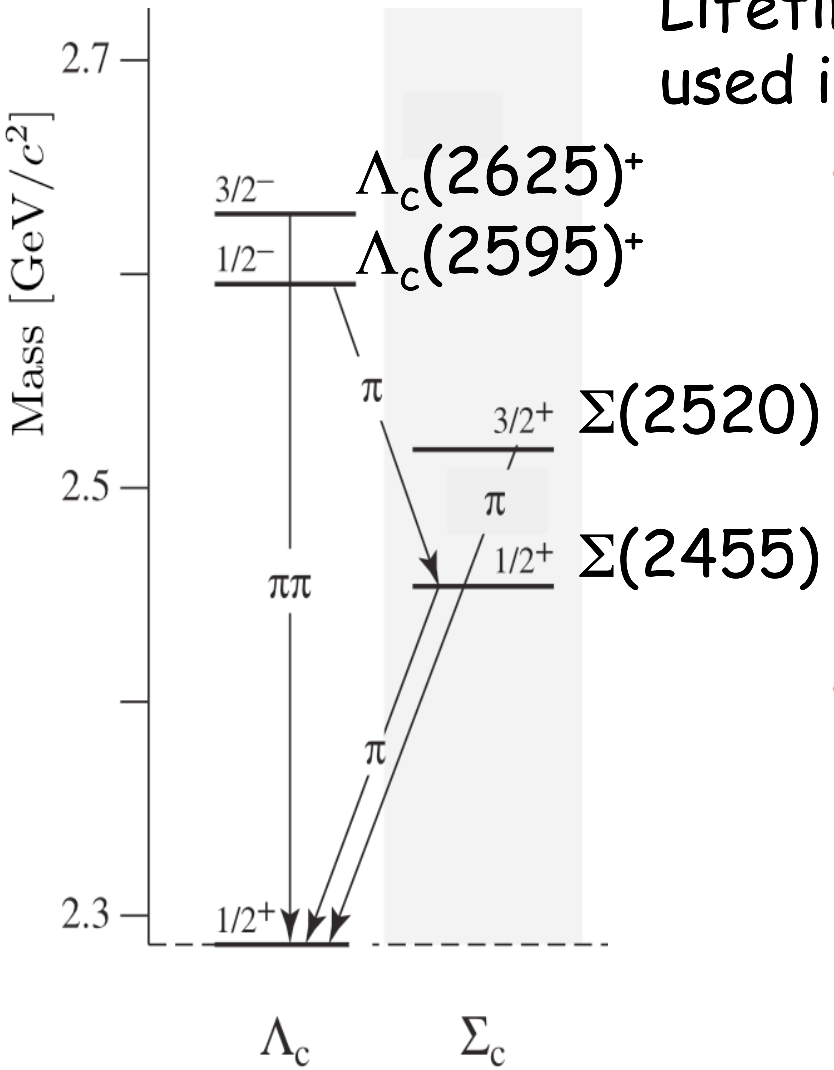
- Uncertainties on theoretical predictions for m(Ω_b)~50-100 MeV (HQET, Feynman-Hellmann, Non-relativistic lattice QCD)
- D0 Ω_b mass ~ 1.5-2.0 σ > theory

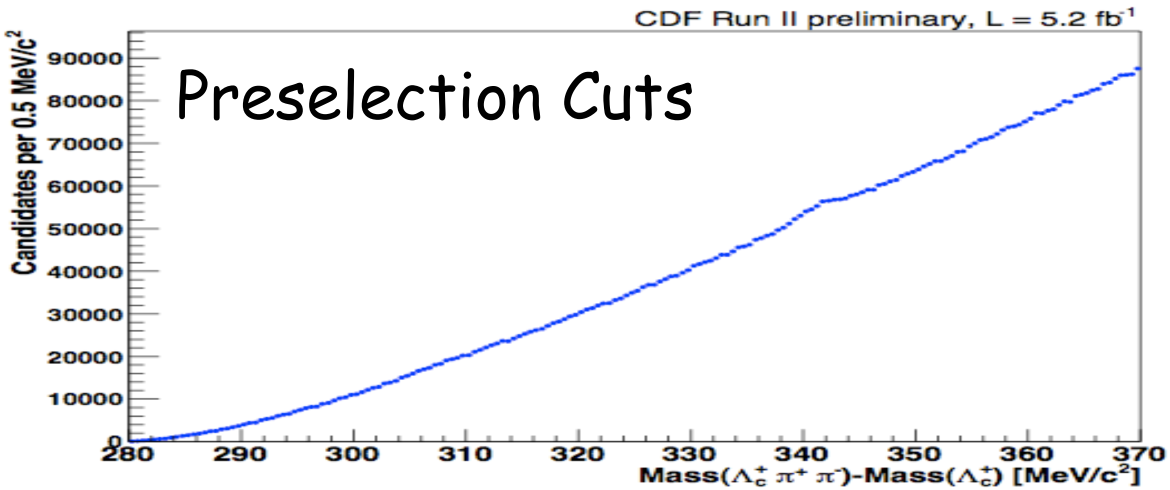
- D0 analysis based on Run 2a detector (no SMT layer-0), same sample used for Ξ_b discovery
- New analysis with 5x data is underway but it requires data reprocessing to open IP cut.

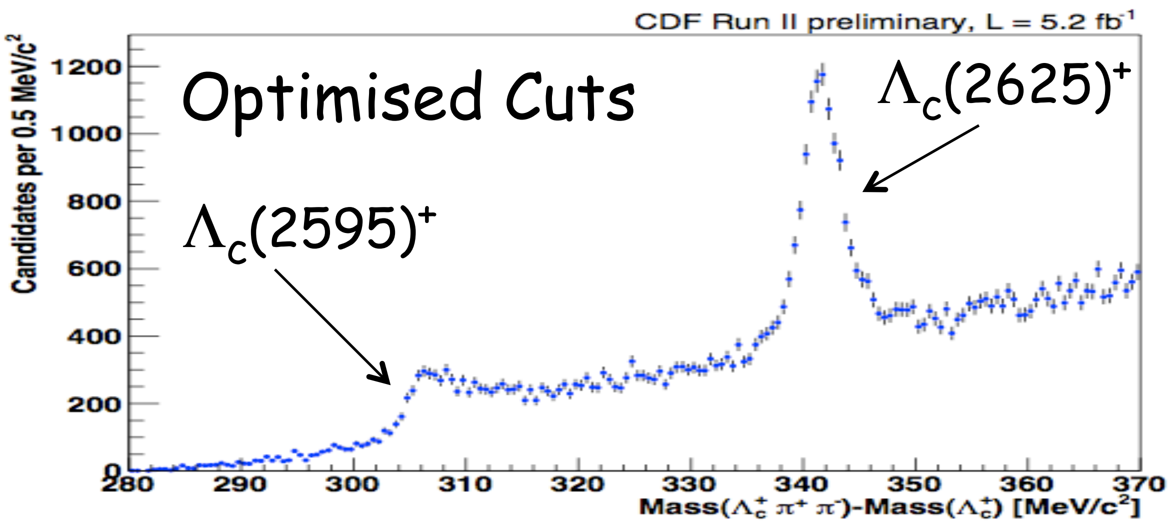
Charm baryon spectroscopy

Reconstruct $\Sigma_c^{0/++} \to \Lambda_c^+ \pi^-/\pi^+$ and $\Lambda_c^{*+} \to \Lambda_c^+ \pi^-\pi^+$ ($\Lambda_c^+ \to pK\pi$) in the hadronic sample

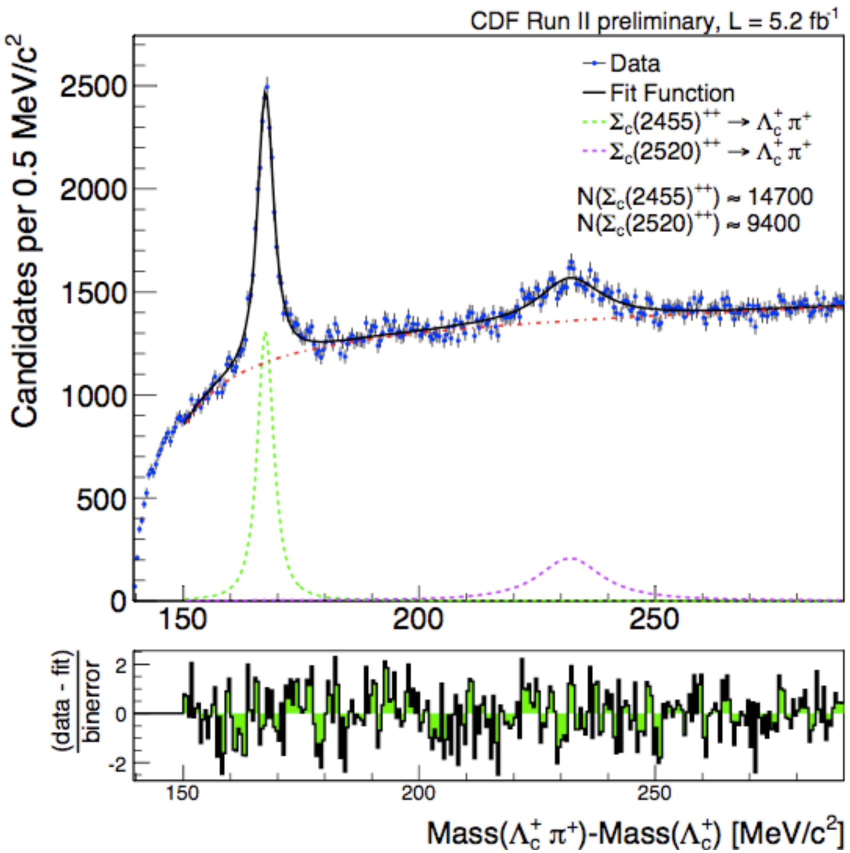
Lifetime, vertex fit, PID, Dalitz structure used in a neural network to extract signal

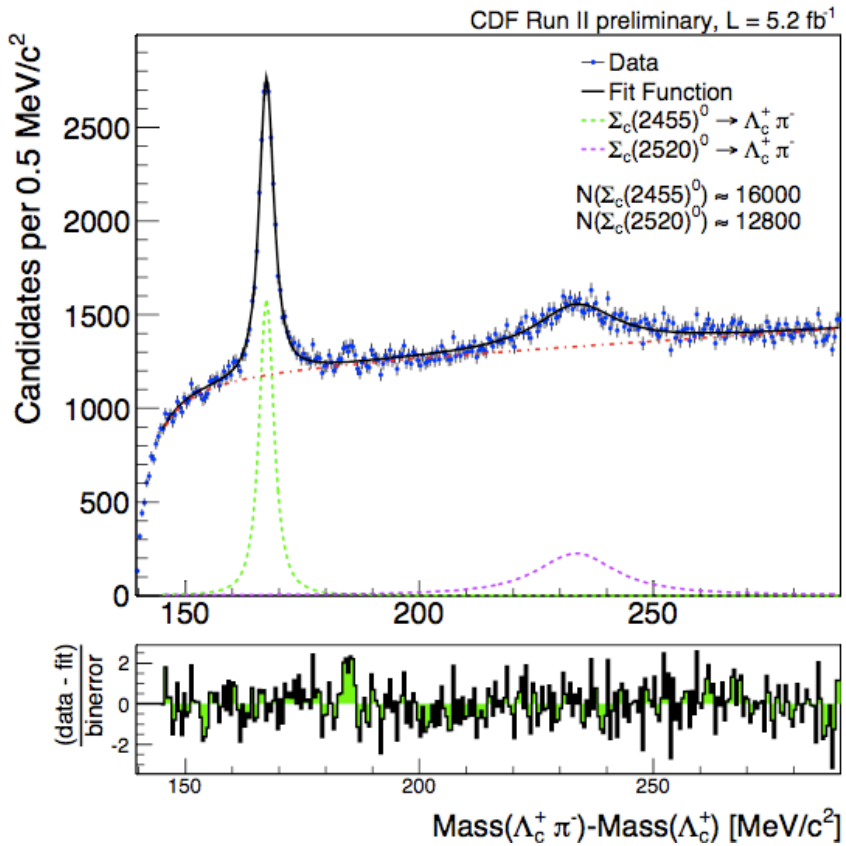






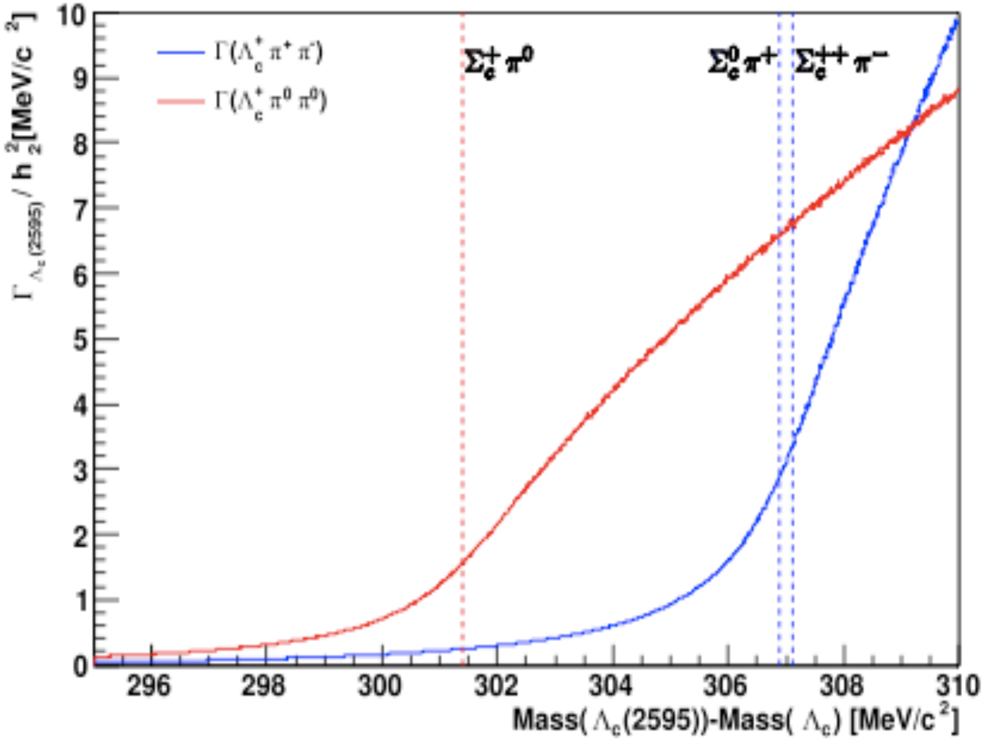
$\Sigma_c(2455)^{0,++}$ and $\Sigma_c(2520)^{0,++}$ Fits

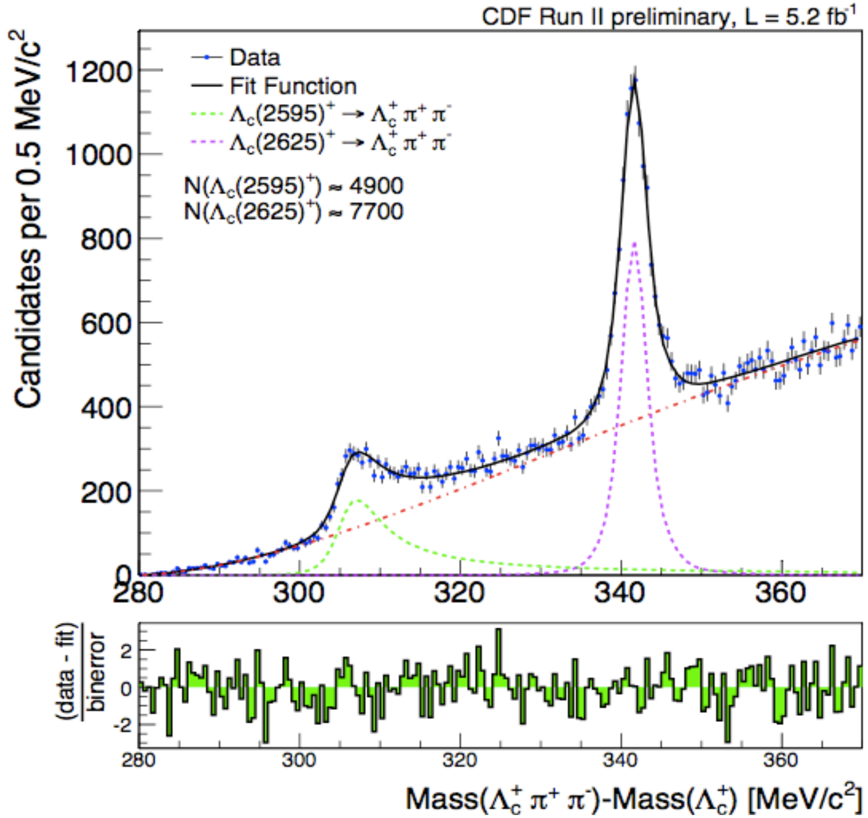




- Use a binned Maximum Likelihood technique
- Signals modeled with convolution of Breit Wigner and detector resolution (from Monte Carlo)
- Phenomenological background functions

$\Lambda_c(2595)^+$ and $\Lambda_c(2625)^+$ Fits





- Use Breit Wigner with mass dependent width to model $\Lambda_c(2595)^+ \rightarrow \Sigma_c(2455)^{0/++}\pi^{+/-}$ kinematic threshold
- Same procedure as in Phys.Rev.D67:074033 (2003)

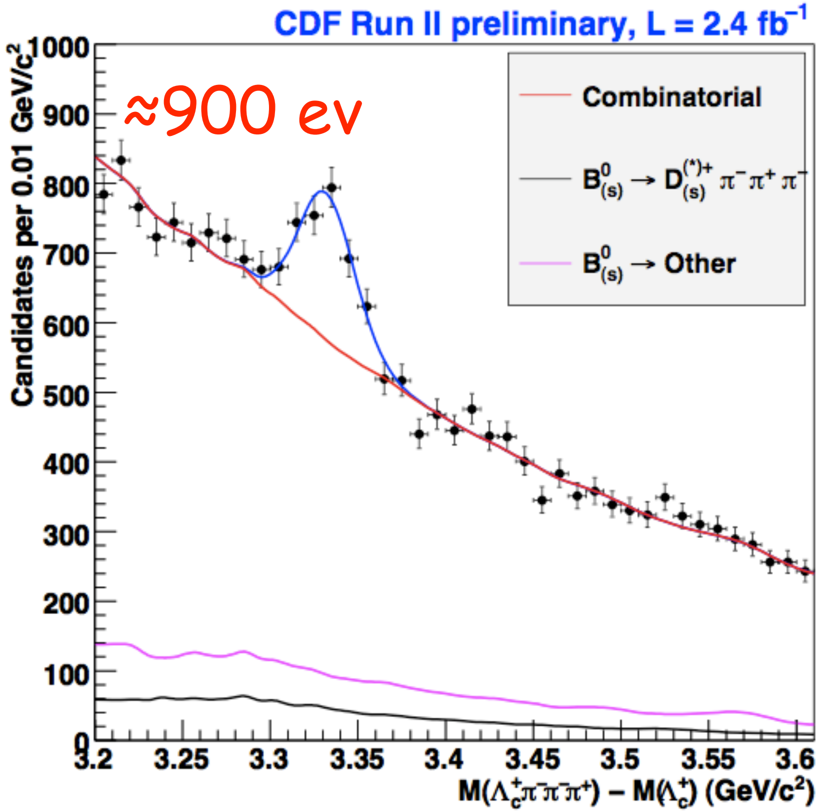
(tested with CLEO samples of ≈110 $\Lambda_c(2595)^+$ and ≈250 $\Lambda_c(2625)^+$ finds $\Lambda_c(2595)^+$ mass ≈3 MeV/c^2 lower than previous measurements)

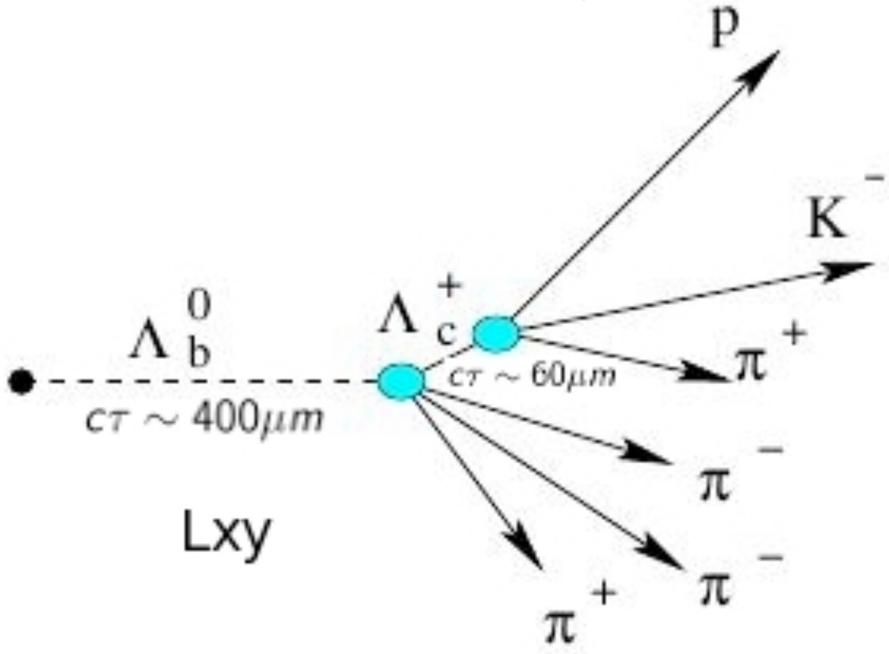
Resonances in $\Lambda^0_b \rightarrow \Lambda^+_c 3\pi$

Observed resonant semileptonic decays

$\Lambda^0_b \rightarrow \Lambda_c(2595)^+ \mu^- \nu$
$\Lambda^0_b \rightarrow \Lambda_c(2625)^+ \mu^- \nu$
$\Lambda^0_b \rightarrow \Sigma_c(2455)^0 \pi^+ \mu^- \nu$
$\Lambda^0_b \rightarrow \Sigma_c(2455)^{++} \pi^- \mu^- \nu$
PRD 79, 032001 (2009)

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

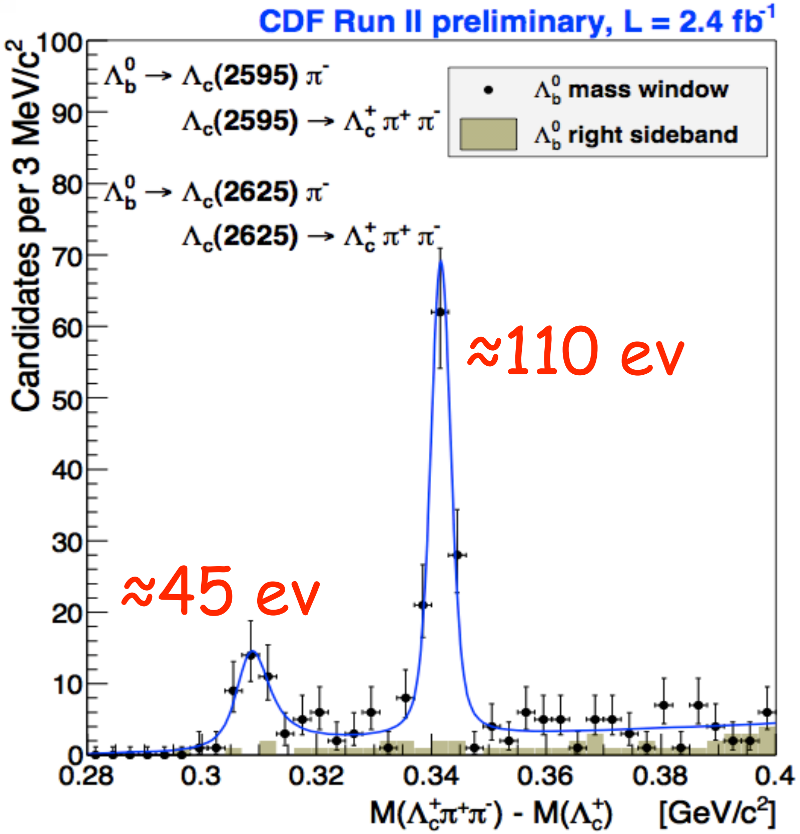


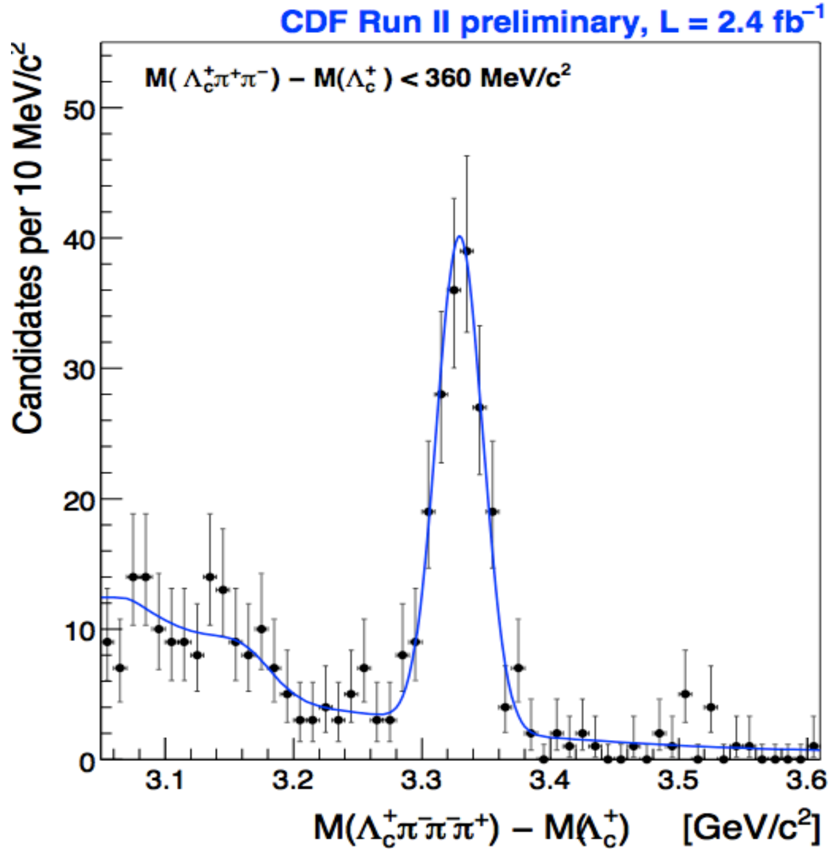


$\Lambda^0_b \rightarrow \Lambda^+_c\, 3\pi$ Selection

$p_T(\Lambda^0_b) > 9$ GeV/c
$Lxy(\Lambda^0_b) > 200$ um
$Lxy(\Lambda^0_b)/\sigma Lxy(\Lambda^0_b) > 16$
$|d0(\Lambda^0_b)| < 70$ um
$\Delta R(3\pi) < 1.2$

$\Lambda^0_b \to \Lambda_c(2595)^+\pi^-$ and $\Lambda^0_b \to \Lambda_c(2625)^+\pi^-$



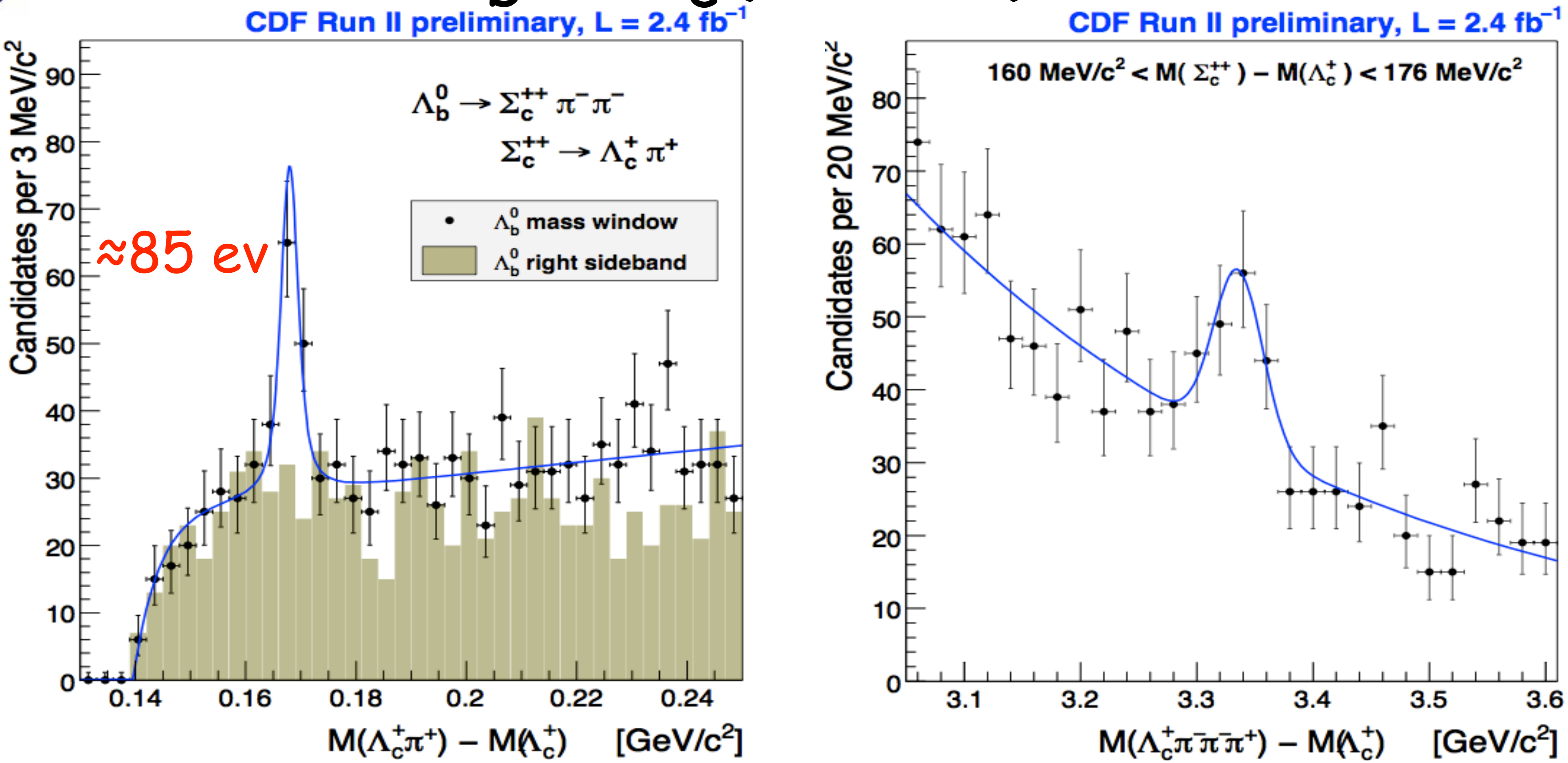


$$\frac{BR(\Lambda^0_b \to \Lambda_c(2595)^+ \pi^- \to \Lambda^+_c \pi^-\pi^+\pi^-)}{BR(\Lambda^0_b \to \Lambda^+_c \pi^-\pi^+\pi^- (\text{all}))} = (2.5 \pm 0.6 \pm 0.5) \times 10^{-2}$$

$$\frac{BR(\Lambda^0_b \to \Lambda_c(2625)^+ \pi^- \to \Lambda^+_c \pi^-\pi^+\pi^-)}{BR(\Lambda^0_b \to \Lambda^+_c \pi^-\pi^+\pi^- (\text{all}))} = (6.2 \pm 1.0 \pm 1.0) \times 10^{-2}$$

Main systematics due to unknown baryon polarisation and averaging efficiency of unresolved $\Lambda^0_b \to \Lambda^+_c \rho^0\pi^-$ and $\Lambda^0_b \to \Lambda^+_c \pi^-\pi^+\pi^-(\text{nr})$ modes

$\Lambda^0_b \to \Sigma_c(2455)^{++}\pi^-\pi^-$

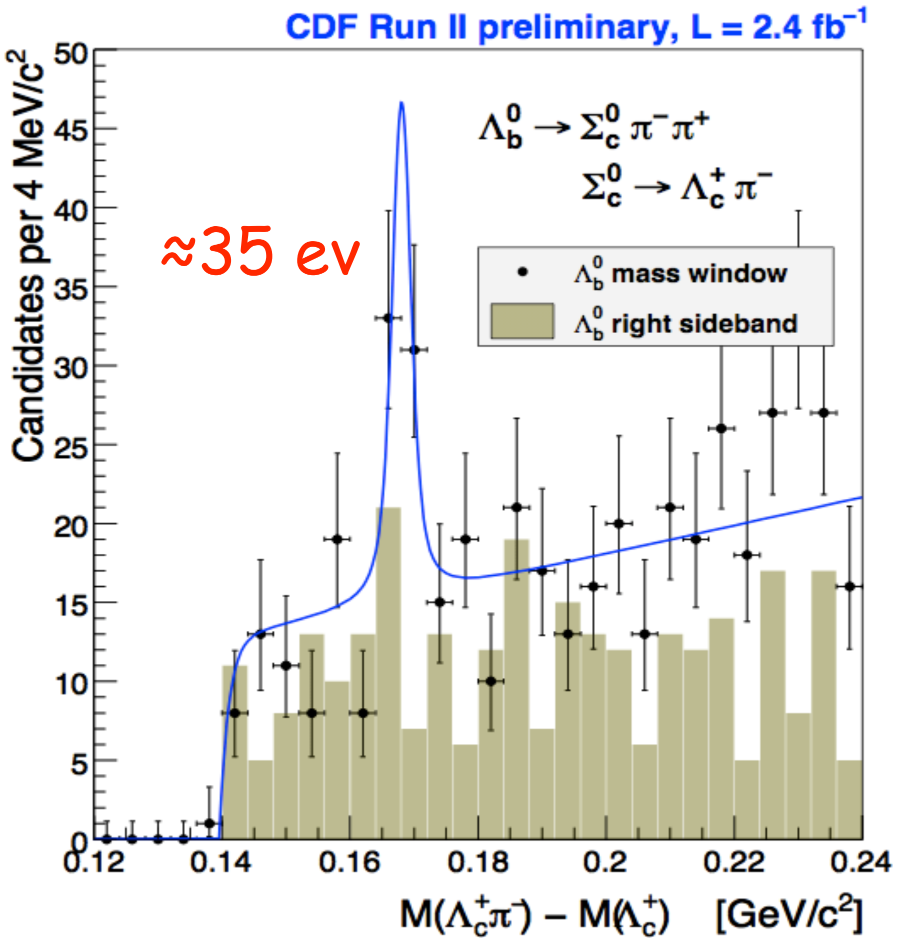


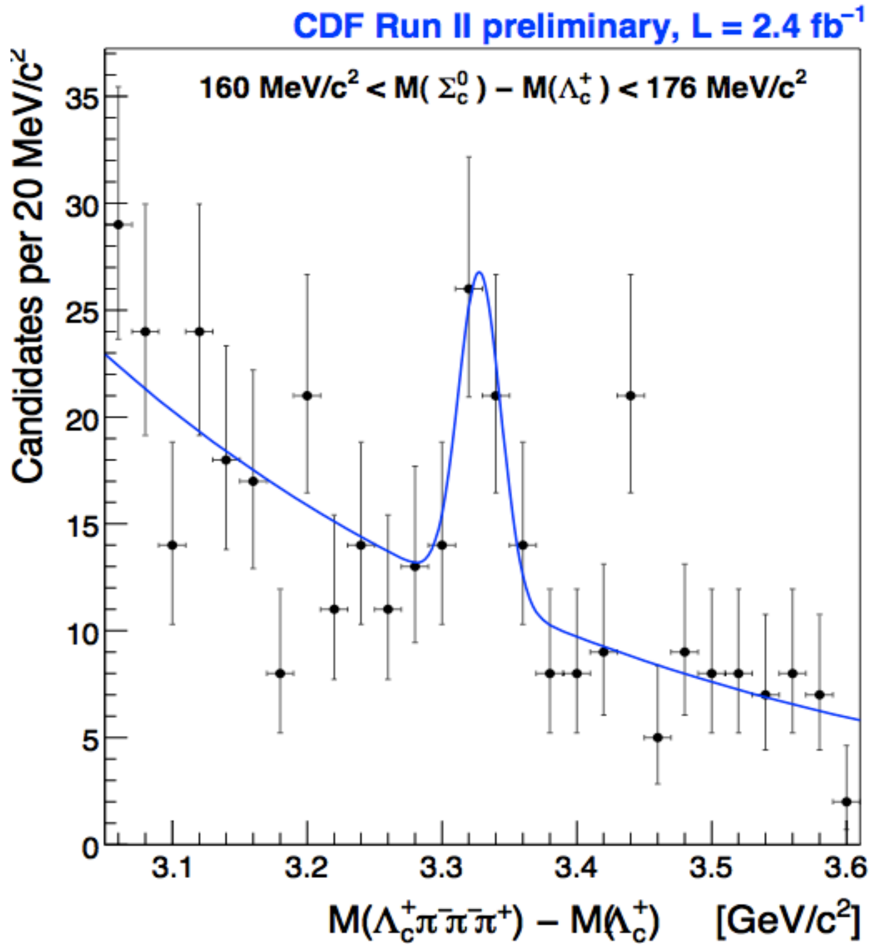
$$\frac{BR(\Lambda^0_b \to \Sigma_c(2455)^{++}\pi^-\pi^- \to \Lambda^+_c\,\pi^-\pi^+\pi^-)}{BR(\Lambda^0_b \to \Lambda^+_c\,\pi^-\pi^+\pi^-\,(\text{all}))} = (5.2 \pm 1.1 \pm 0.8) \times 10^{-2}$$

Main systematics due to unknown baryon polarisation, averaging efficiency of $\Lambda^0_b \to \Lambda^+_c\,\rho^0\pi^-$ and $\Lambda^0_b \to \Lambda^+_c\,\pi^-\pi^+\pi^-$(nr)

Limited contribution from Signal/Bck shapes, Cab supp modes, Trigger model, Λ^+_c res structure, $p_T(\Lambda^0_b)$, $\tau(\Lambda^0_b)$ and $\tau(\Lambda^+_c)$

$\Lambda^0_b \to \Sigma_c(2455)^0 \pi^+\pi^-$

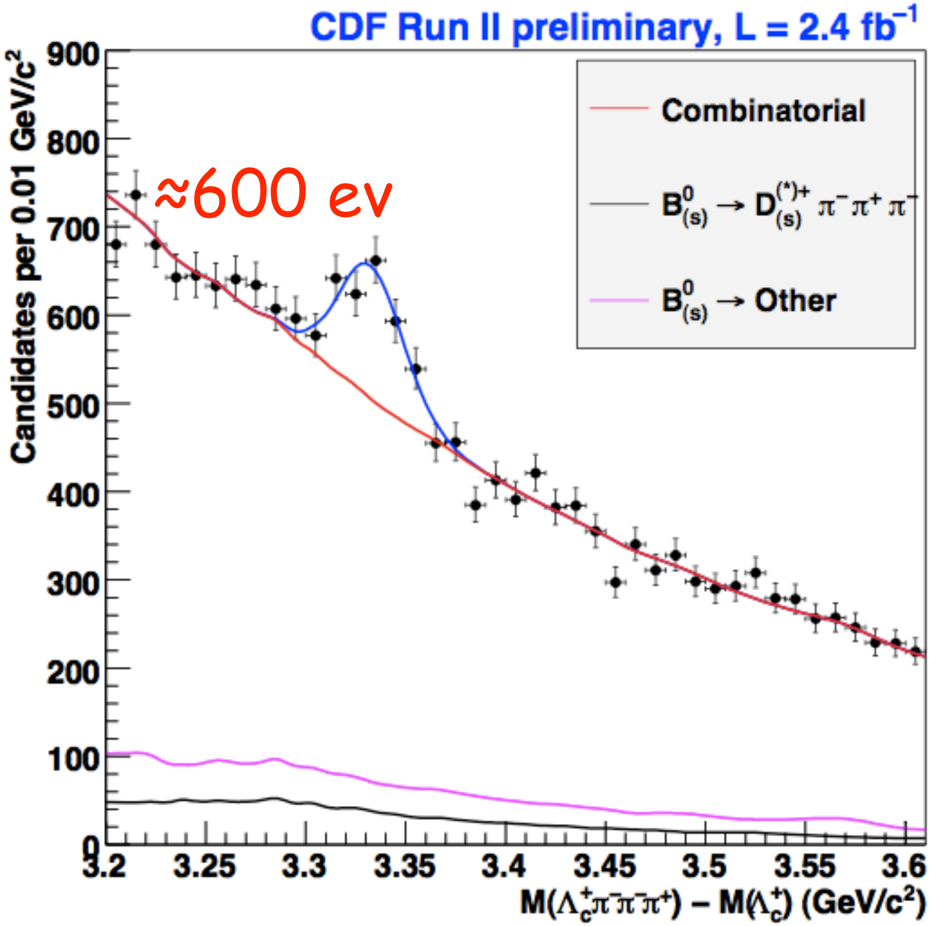




$$\frac{BR(\Lambda^0_b \to \Sigma_c(2455)^0 \pi^+\pi^- \to \Lambda^+_c \pi^-\pi^+\pi^-)}{BR(\Lambda^0_b \to \Lambda^+_c \pi^-\pi^+\pi^- (\text{all}))} = (8.9 \pm 2.1 \pm 1.2) \times 10^{-2}$$

$$\frac{BR(\Lambda^0_b \to \Sigma_c(2455)^{++} \pi^-\pi^- \to \Lambda^+_c \pi^-\pi^+\pi^-)}{BR(\Lambda^0_b \to \Sigma_c(2455)^0 \pi^+\pi^- \to \Lambda^+_c \pi^-\pi^+\pi^-)} = (58.1 \pm 16.9 \pm 9.1) \times 10^{-2}$$

$\Lambda^0_b \to \Lambda^+_c \rho^0 \pi^- + \Lambda^0_b \to \Lambda^+_c \pi^- \pi^+ \pi^-$ (nr)



We apply veto on all the resonant decay modes

We do not separate the two decay modes and we measure the sum of Branching Fractions

CDF-Public Note 10001

$$\frac{BR(\Lambda^0_b \to \Lambda^+_c \rho^0 \pi^- + \Lambda^+_c \pi^- \pi^+ \pi^- (nr) \to + \Lambda^+_c \pi^- \pi^+ \pi^-)}{BR(\Lambda^0_b \to \Lambda^+_c \pi^- \pi^+ \pi^- (all))} = (77.3 \pm 3.1 \pm 3.3) \times 10^{-2}$$

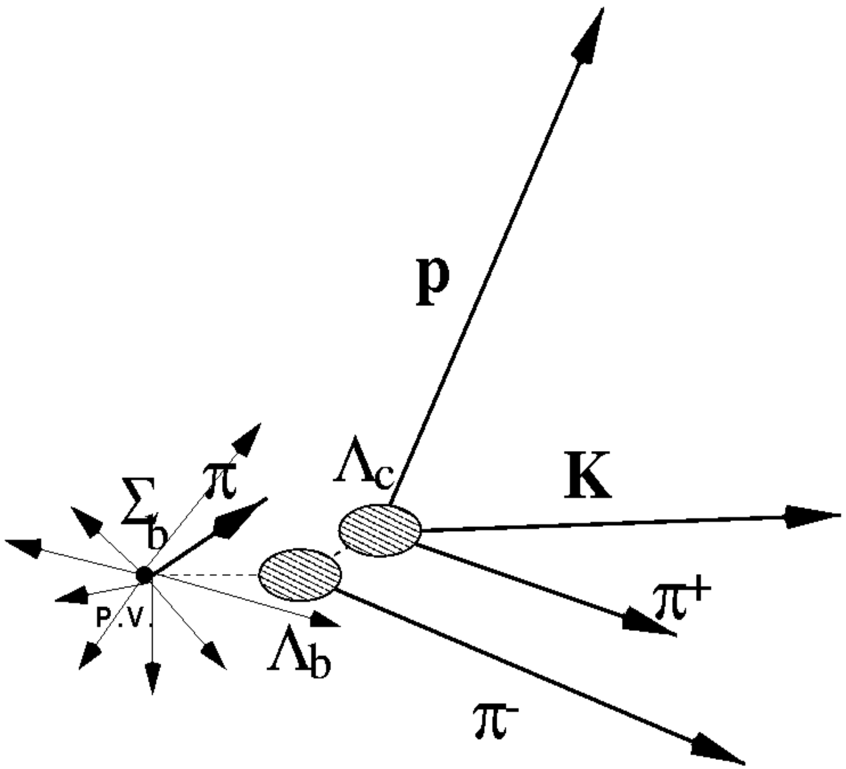
Updating $\Sigma_b^{\pm(*)}$ analysis to 5 fb^{-1} (I)

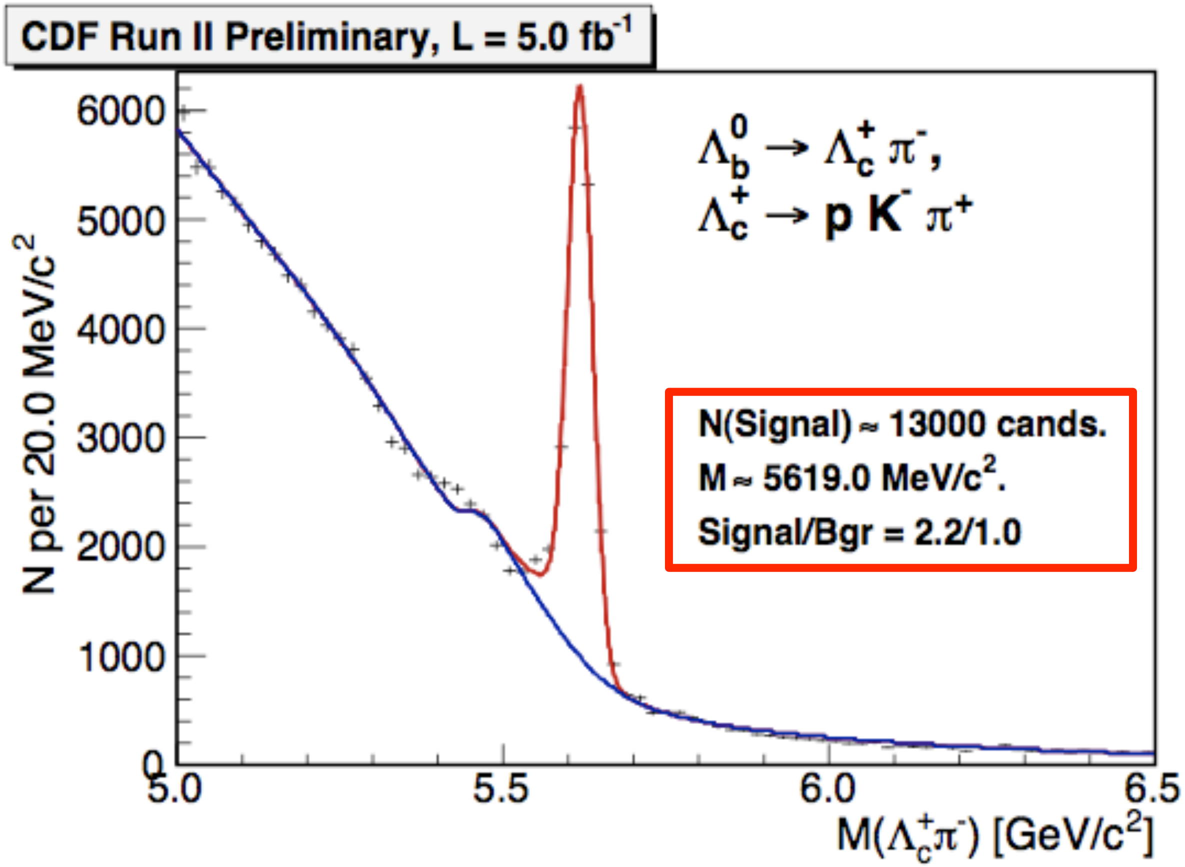
$\Sigma_b^{-(*)} \rightarrow \Lambda^0_b \pi^-$

$\Lambda^0_b \rightarrow \Lambda_c^+ \pi^-$

$\Lambda^+_c \rightarrow p K^- \pi^+$

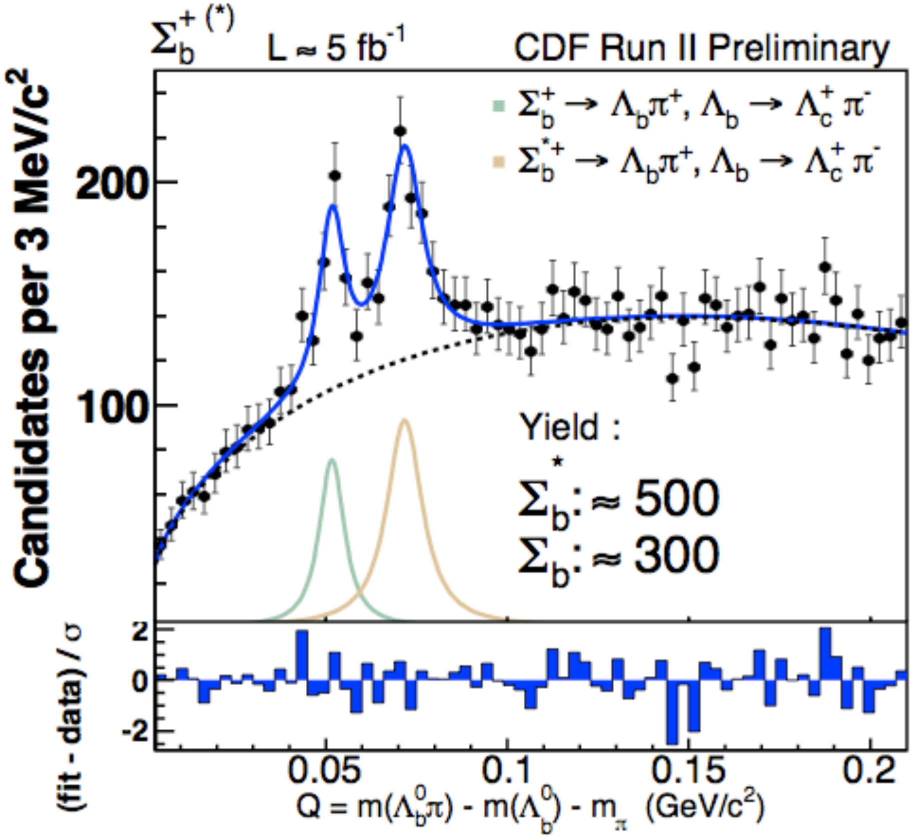
(Observation of Σ_b^+, Σ_b^-, Σ_b^{*+} and Σ_b^{*-} in 1.1 fb^{-1})
PRL 99, 202001 (2007)

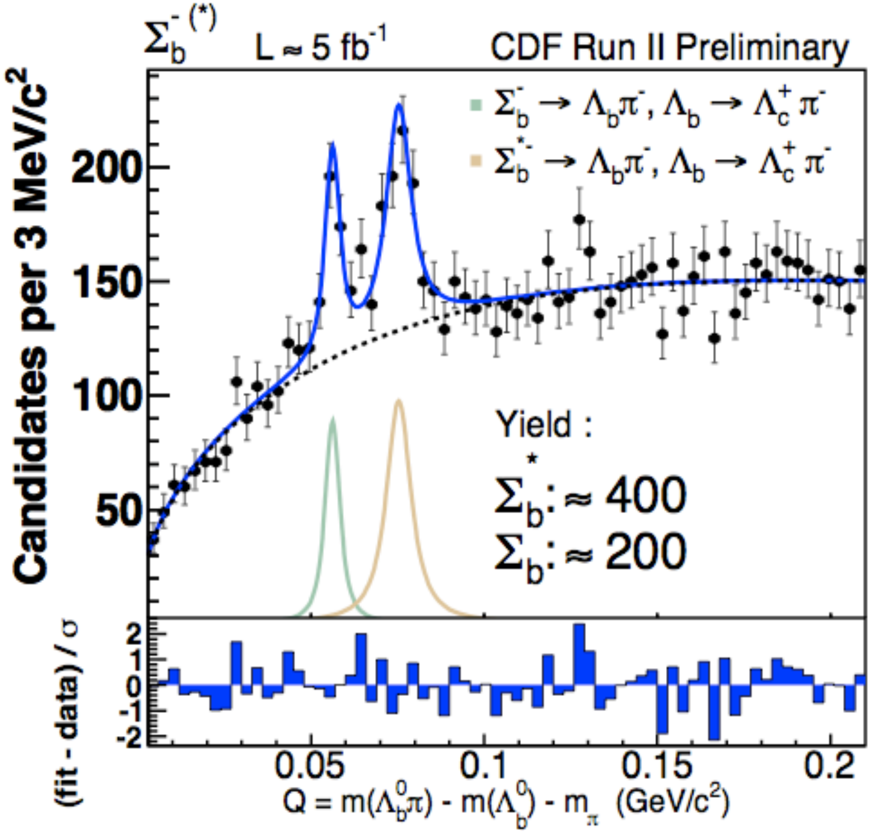




≈4x increase of Λ^0_b sample wrt published analysis

Updating $\Sigma_b^{\pm(*)}$ analysis to 5 fb^{-1}(II)





Analysis Goals

- Improve mass measurements
- Measure natural widths of $(3/2)^+$ and $(1/2)^+$ states and mass splittings with no theoretical constraints

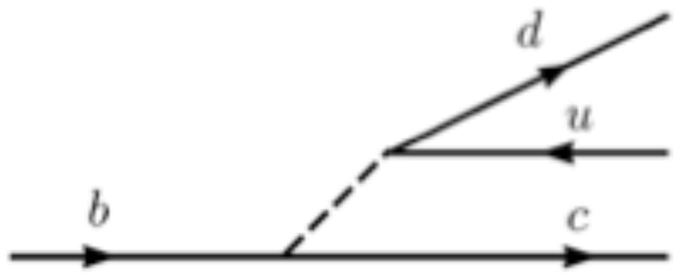
B Hadron Lifetimes

Spectator model: all B hadrons have the same lifetime

Difference due to light quark interactions

Expected Hierarchy:

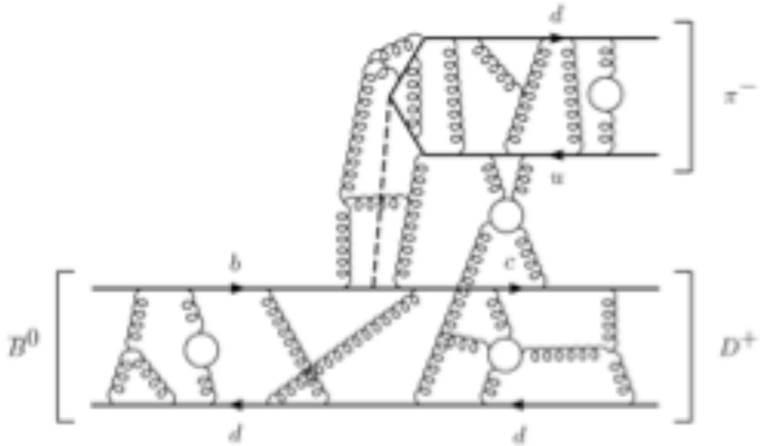
$\tau(B_u) > \tau(B_d) \sim \tau(B_s) > \tau(\Lambda_b) >> \tau(B_c)$



Ratio Predictions (HQE):

$\tau(B^+) = 1.063 \pm 0.027\ \tau(B_d)$

$\tau(\Lambda_b) = 0.88 \pm 0.05\ \tau(B_d)$



Lifetimes important for understanding the interactions of quarks inside hadrons

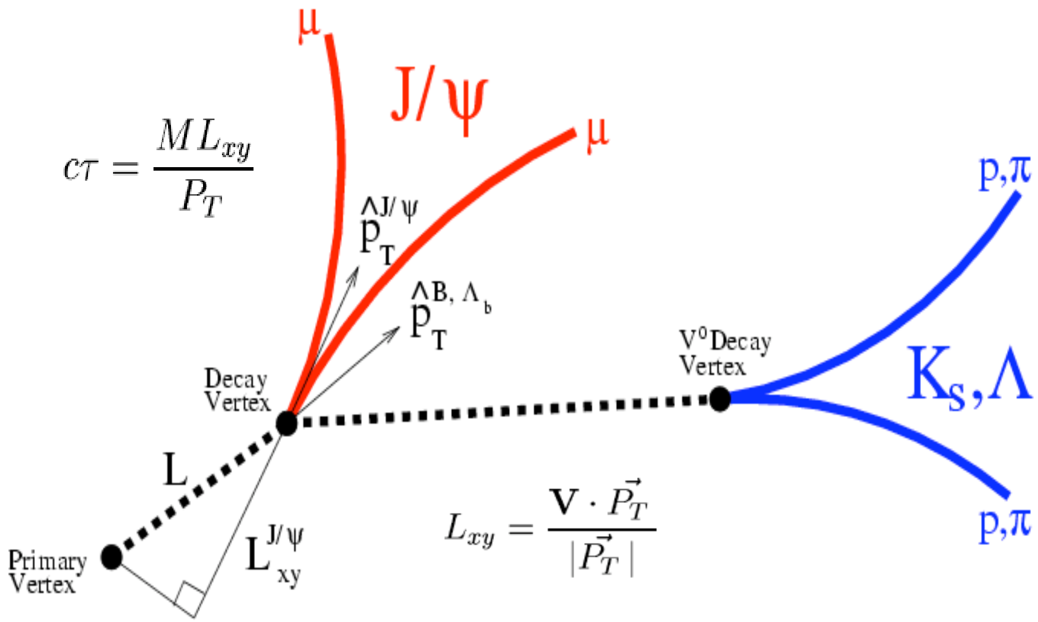
HQE is used to calculate Γ_{12} and semileptonic asymmetry

A.Lenz arXiv:0802.0977

Lifetimes in decays with J/Ψ

Yields in 4.3 fb^{-1}

$B^+ \rightarrow J/\Psi K^+$	45000 ± 230
$B^0 \rightarrow J/\Psi K^*$	16860 ±140
$B^0 \rightarrow J/\Psi K_s$	12070 ±120
$\Lambda_b \rightarrow J/\Psi \Lambda$	1710+50

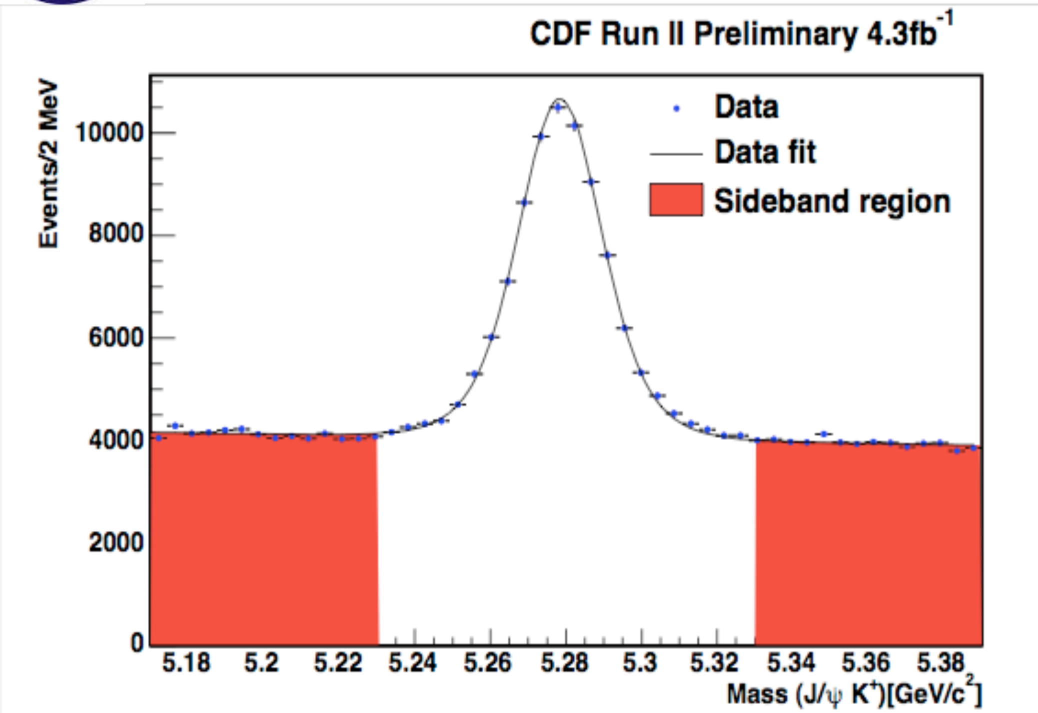


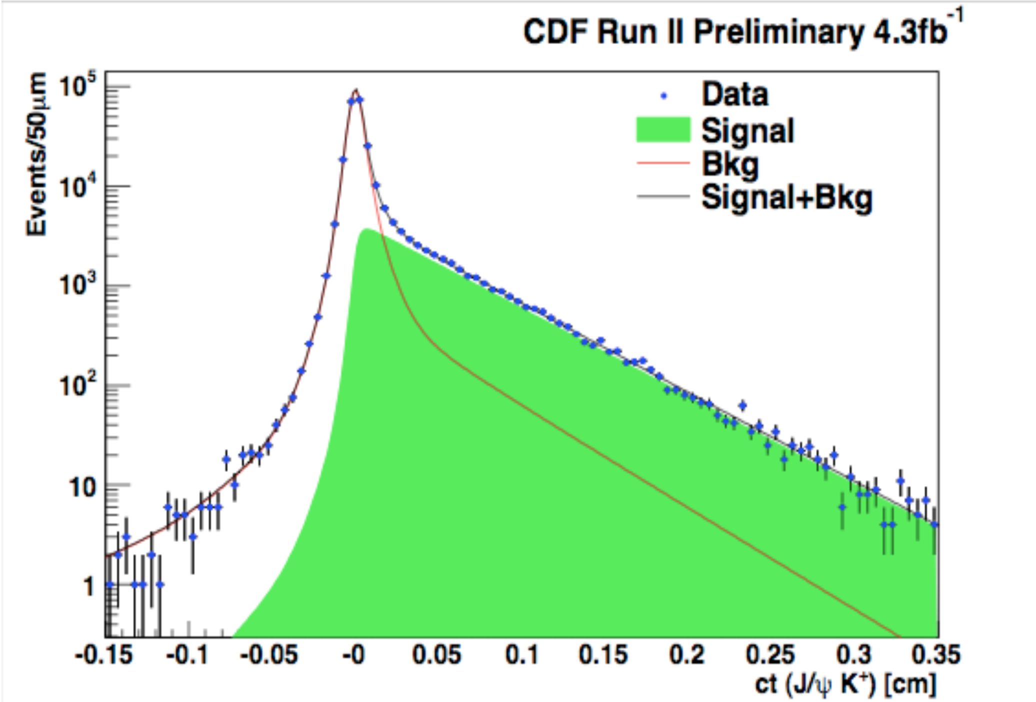
Use the J/ψ vertex to determine the Decay Vertex for all modes (makes detector resolution similar for all channels)

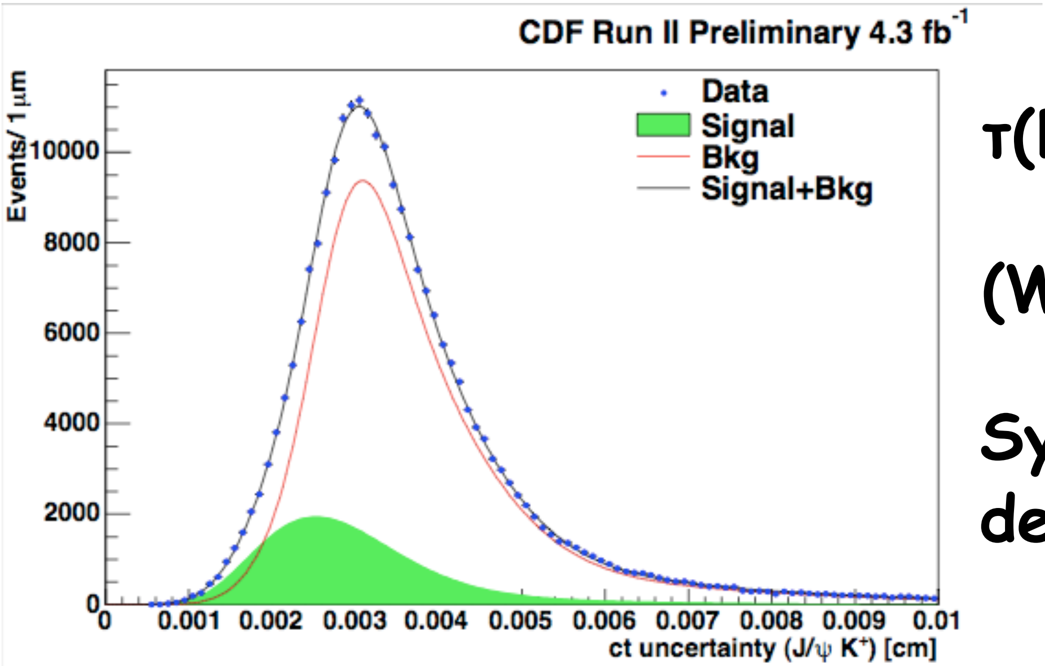
Use the J/ψ sample for further study

Lifetime extracted from an un-binned likelihood fit, simultaneously in mass, decay time and decay time error

B^+ Fit Projections





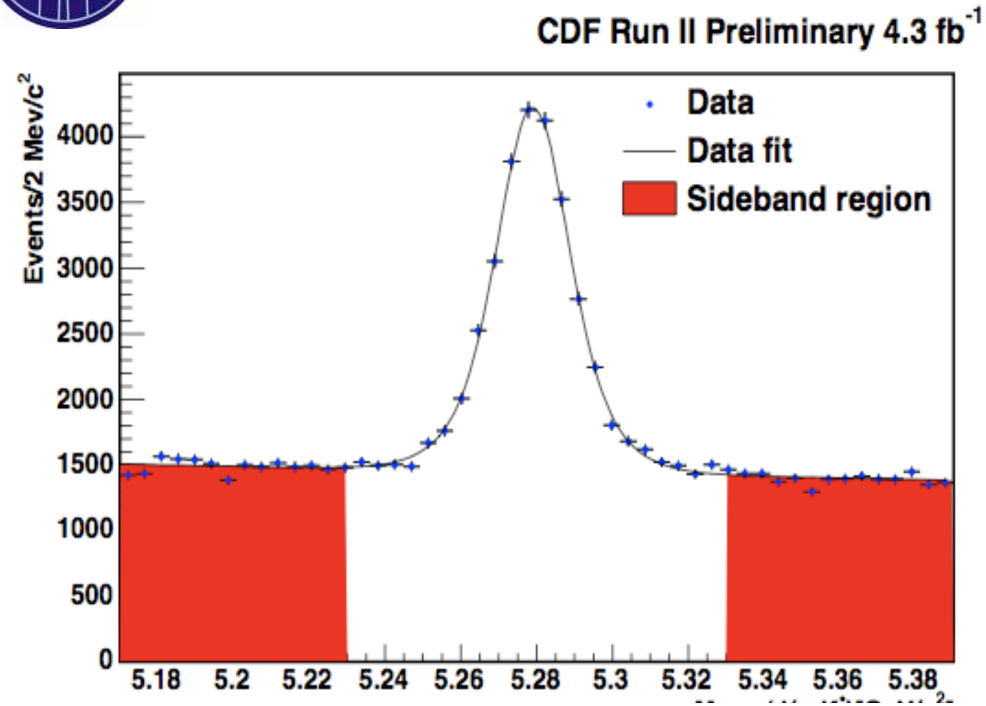


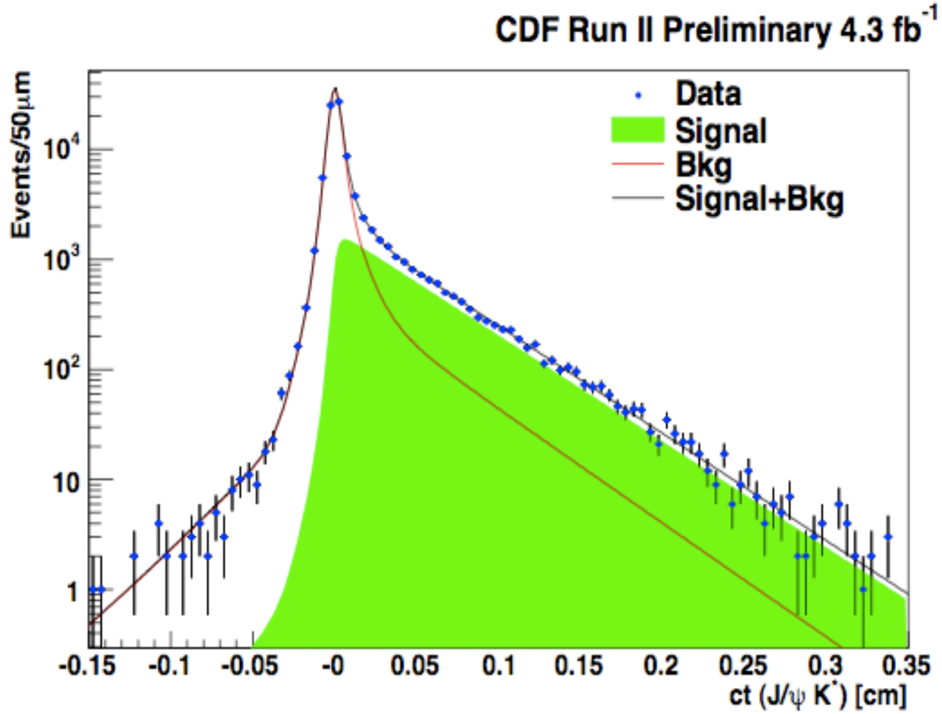
$\tau(B^+) = 1.639 \pm 0.009(\text{stat}) \pm 0.009\ (\text{syst})$ ps

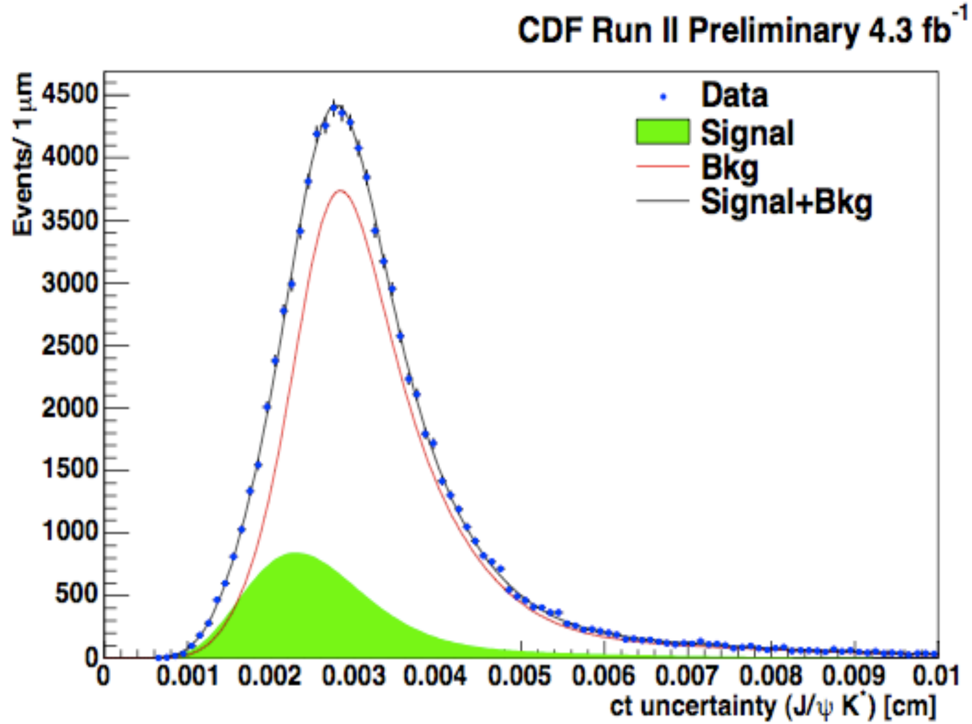
(World's best measurement)

Systematic error now limited by detector alignment (~2 μm)

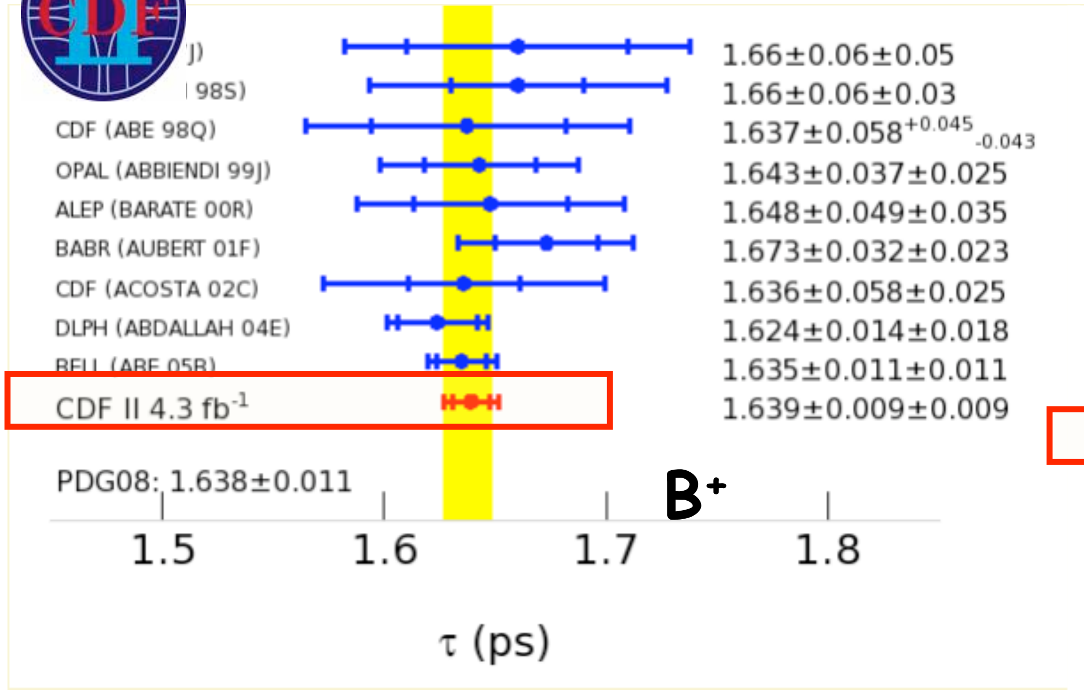
B^0 Fit Projections

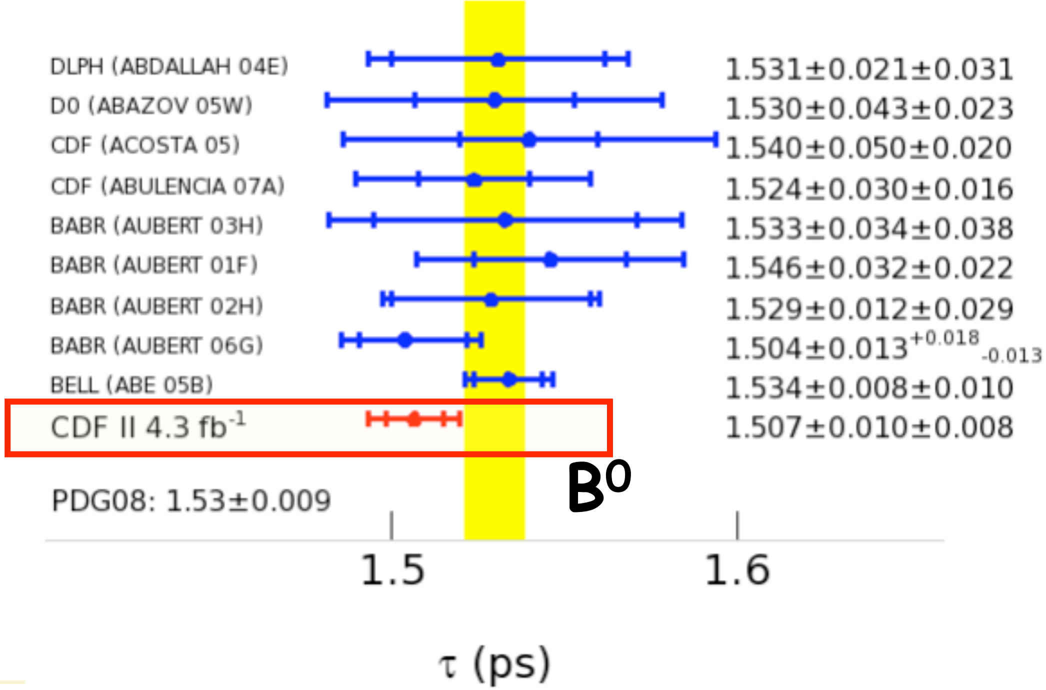


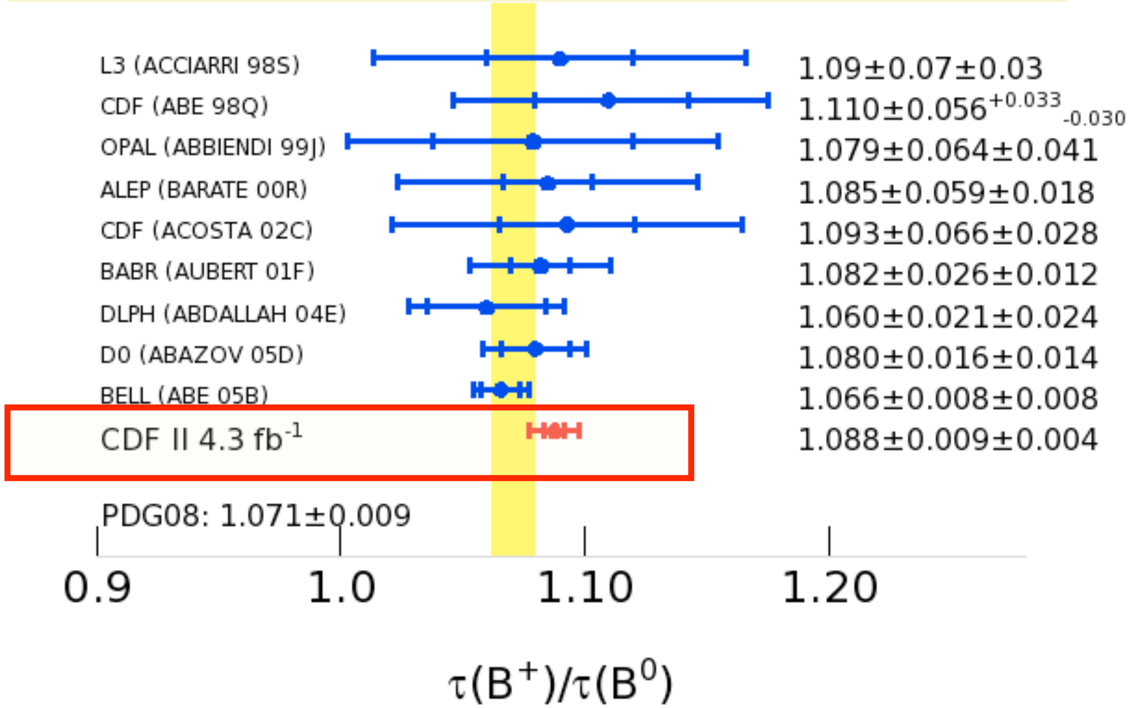




$\tau(B^0)$ = 1.507 ± 0.010(stat)
± 0.008 (syst) ps
(World's best measurement)







Results shown against PDG and other measurements

Most precise meas. of $\tau(B^+)/\tau(B^0)$

In agreement with theoretical prediction:

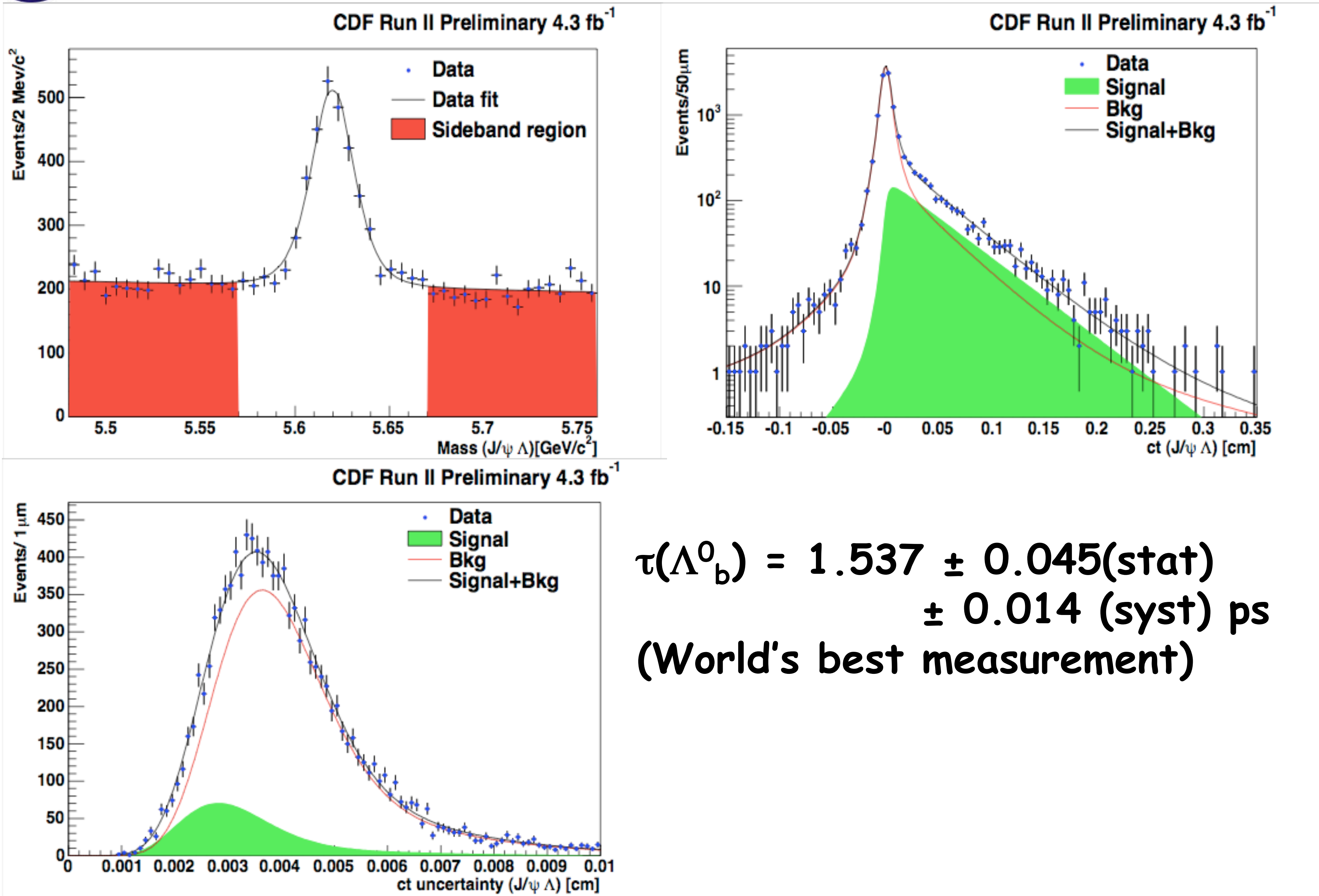
$\tau(B^+)/\tau(B^0) = (1.063 \pm 0.027)$ (theory)

$\tau(B^+)/\tau(B^0) = (1.088 \pm 0.009 \pm 0.004)$ (exp)

CDF-Public Note 10071

A.Lenz, arXiv:0802.0977

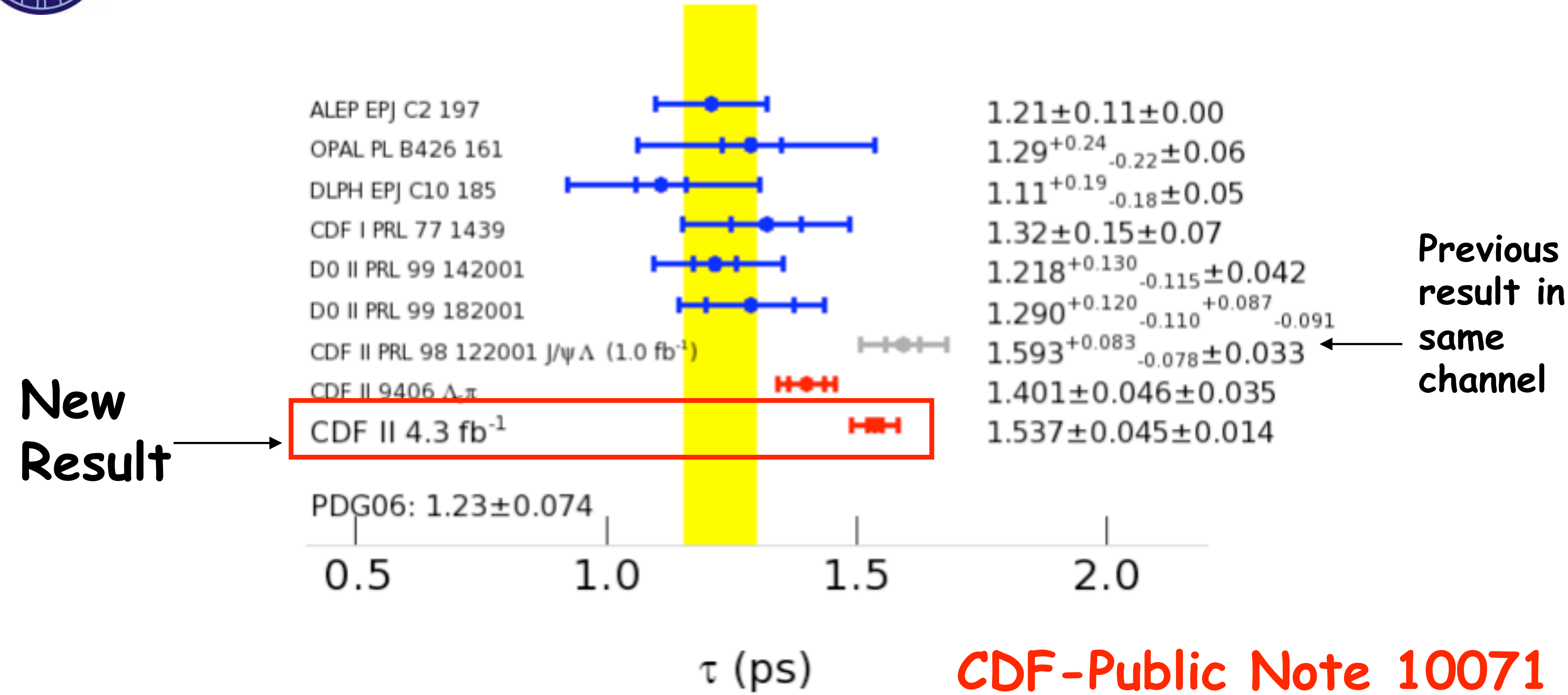
Λ^0_b Fit Projections



$\tau(\Lambda^0_b) = 1.537 \pm 0.045(\text{stat}) \pm 0.014\ (\text{syst})$ ps

(World's best measurement)

Λ_b Lifetime results



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Most precise Λ^0_b lifetime measurement

With 4.3 fb^{-1} the Λ^0_b lifetime remains higher than other measurements

Measured Ratio: $\tau(\Lambda^0_b)/\tau(B^0)$ =1.020±0.030(stat)±0.008(syst)

Theory: $\tau(\Lambda^0_b)/\tau(B^0)$ =0.88±0.05 (A.Lenz, arXiv:0802.0977)

Some theories favor higher ratio 0.9-1.0 (I.I Bigi, hep-ph/0001003)

Conclusions

Tevatron is giving great contribution to our knowledge of b-baryons
- Observation of the Ω_b^- and Ξ_b^-
- Observation of the $\Sigma_b^{\pm(*)}$
- Improving measurements of Λ_b properties (new decay modes)
- New CDF analysis provides world best b hadron lifetimes