Λ_b lifetime at DØ/Tevatron

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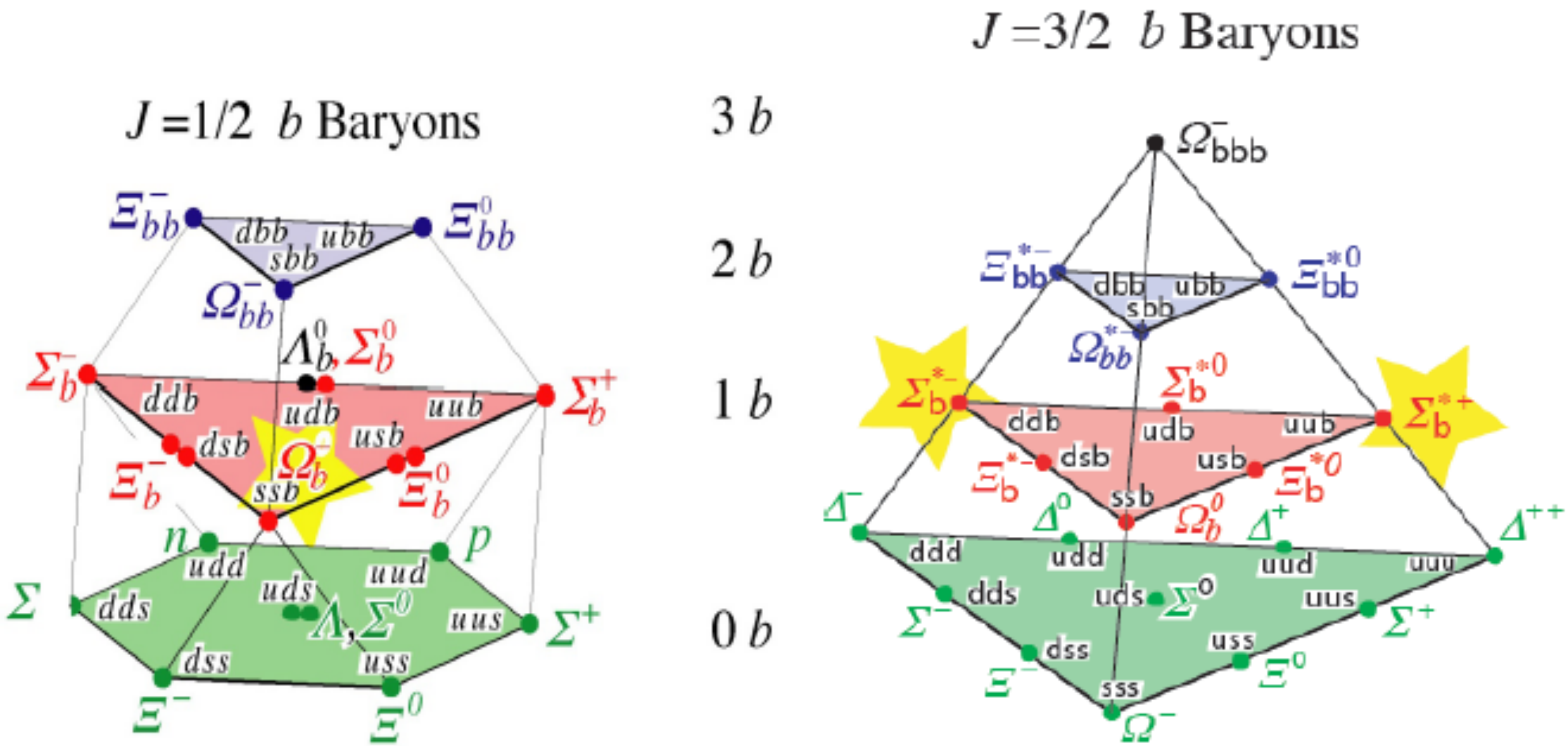
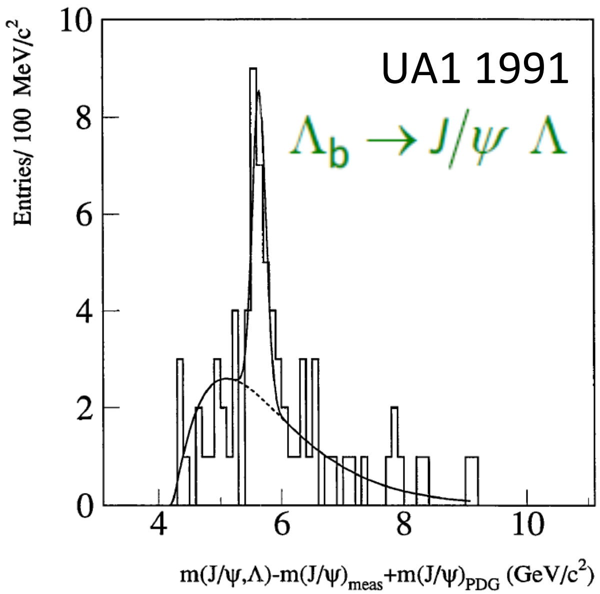
A total of 15 b baryons are predicted
(counting quark content only)

charmless b baryon (10 in total) multiplet



b baryons at hadron colliders

- Unique to hadron colliders (not produced in B factories)
- Produced copiously at the Tevatron
- At start of Run2 (2002): only Λ_b was established (~20 events)



J=1/2, 1 *b*

ground states

Λ_b(bud)

Σ_b^0(bud)

Σ_b^+(buu)

Σ_b^-(bdd)

Ξ_b^0(bus)

Ξ_b^-(bds)

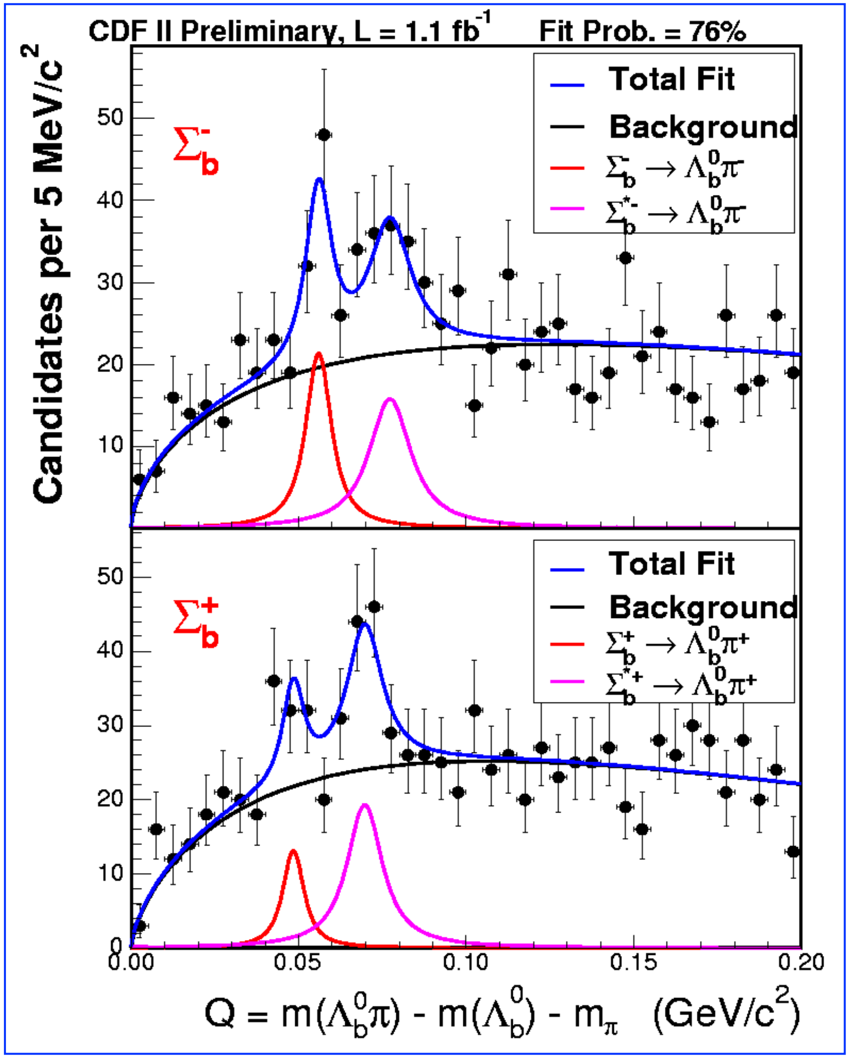
Ω_b^-(bss)

Not yet observed

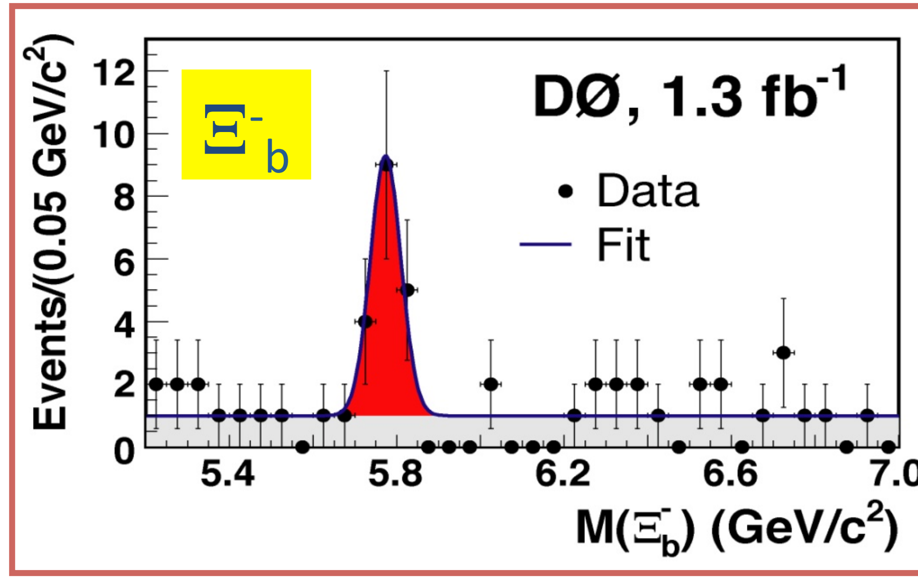
- Since 2007: 5 new *ground state* b baryons observed by CDF/DØ
- Interesting mass & lifetime predictions, using different models
- However, very challenging analysis required

New Ground States, J =1/2 1*b*

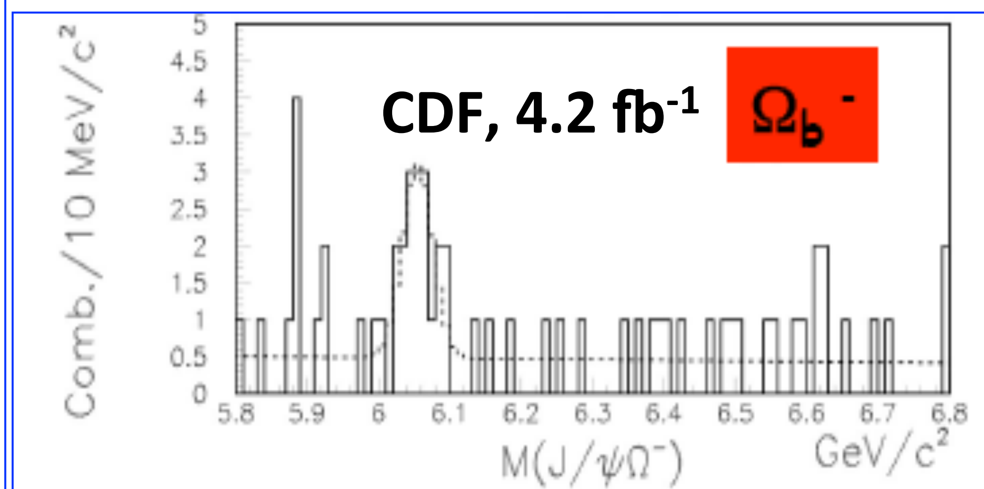
CDF 2007 $\Sigma_b^{\pm} \to \Lambda_b \pi^{\pm} \to \left(\Lambda_c^{+}\pi^{-}\right)\pi^{\pm}$



DØ 2007 $\Xi^-_b \to J/\psi + \Xi^-$



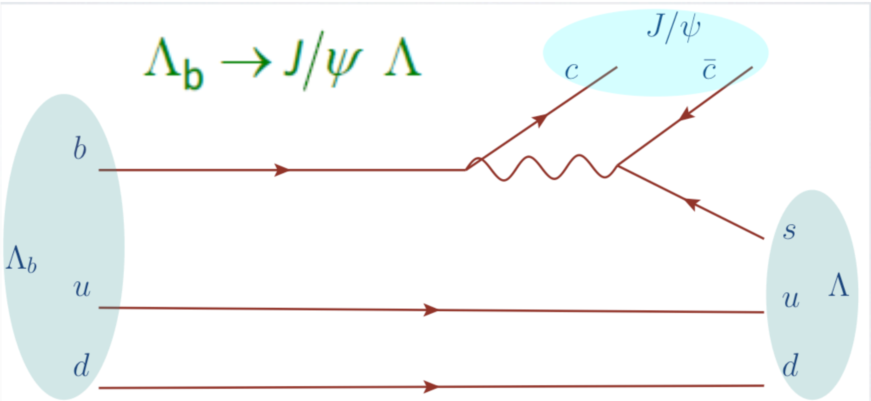
CDF 2009 $\Omega^-_b \to J/\psi + \Omega^-$

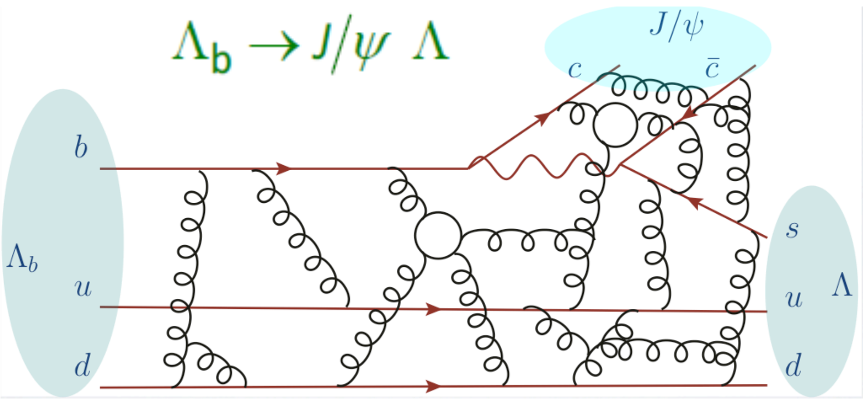


b hadron lifetimes

In the simple quark spectator model, the b quark decays independently of the other quarks

→ The lifetimes of all b hadrons are expected to be equal

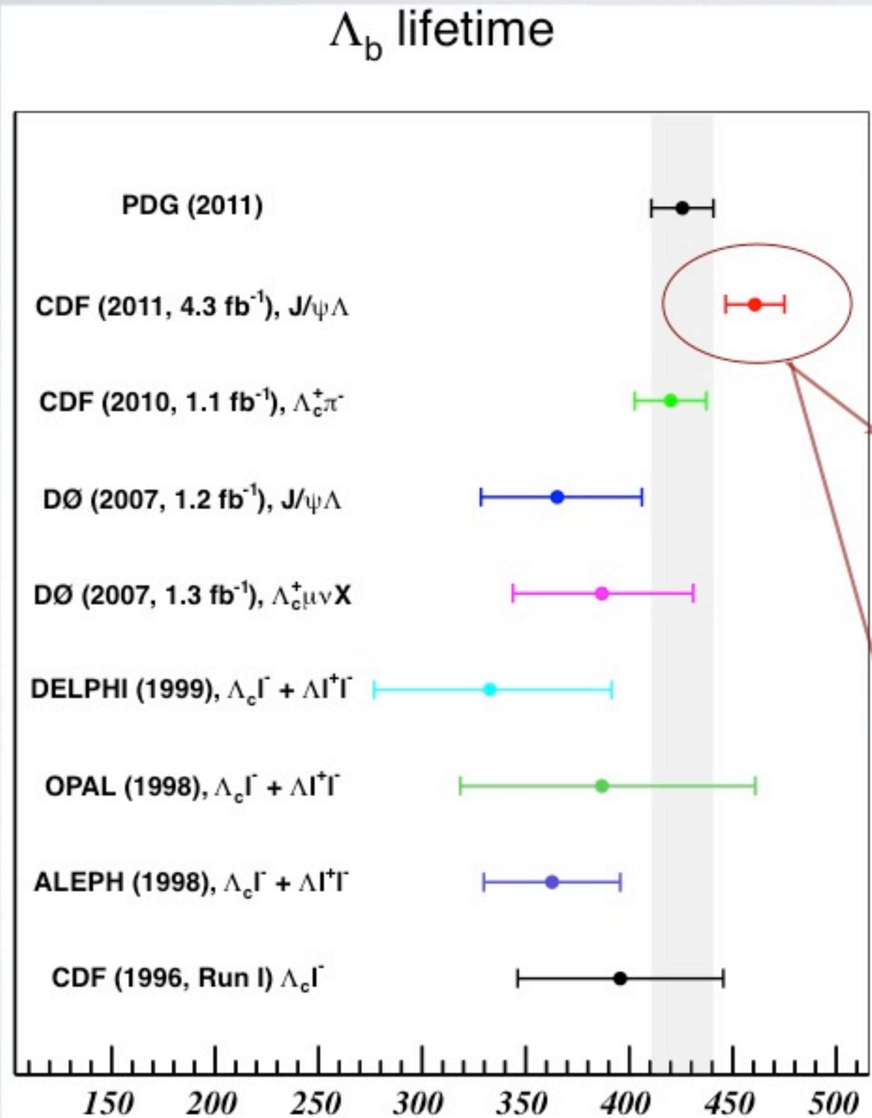




Simplicity of the weak interactions overshadowed by the complexity of strong interactions!

→ Measurements of b hadron lifetimes provide window into the importance of non-spectator contributions to b hadron decays

Experimental Status



μm

- Measurements by DØ and CDF in $\Lambda_b \to J/\psi\Lambda$:

$$\text{DØ (2005):} \quad c\tau_{\Lambda_b} = 366.0\,^{+65.2}_{-53.6}(\text{stat}) \pm 12.9(\text{syst})\ \mu m$$

$$\text{DØ (2007):} \quad c\tau_{\Lambda_b} = 365.1\,^{+39.1}_{-34.7}(\text{stat}) \pm 12.7(\text{syst})\ \mu m$$

$$\text{CDF (2007):} \quad c\tau_{\Lambda_b} = 477.6\,^{+25.0}_{-23.4}(\text{stat}) \pm 9.9(\text{syst})\ \mu m$$

$$\text{CDF (2011):} \quad c\tau_{\Lambda_b} = 460.8 \pm 13.5(\text{stat}) \pm 4.2(\text{syst})\ \mu m$$

- Long standing discrepancy between these measurements.

- The CDF (2011) measurements of $\tau(\Lambda_b)$ and $\tau(\Lambda_b)/\tau(B^0)$ are more than **2σ** higher than the W.A. (PDG < 2011).

Theoretical Status

- Precise predictions of *b*-hadron lifetimes are difficult to calculate. Ratios are predicted with fairly high accuracy by heavy quark effective theory (HQET). Up to $\mathcal{O}(1/m_b^4)$,

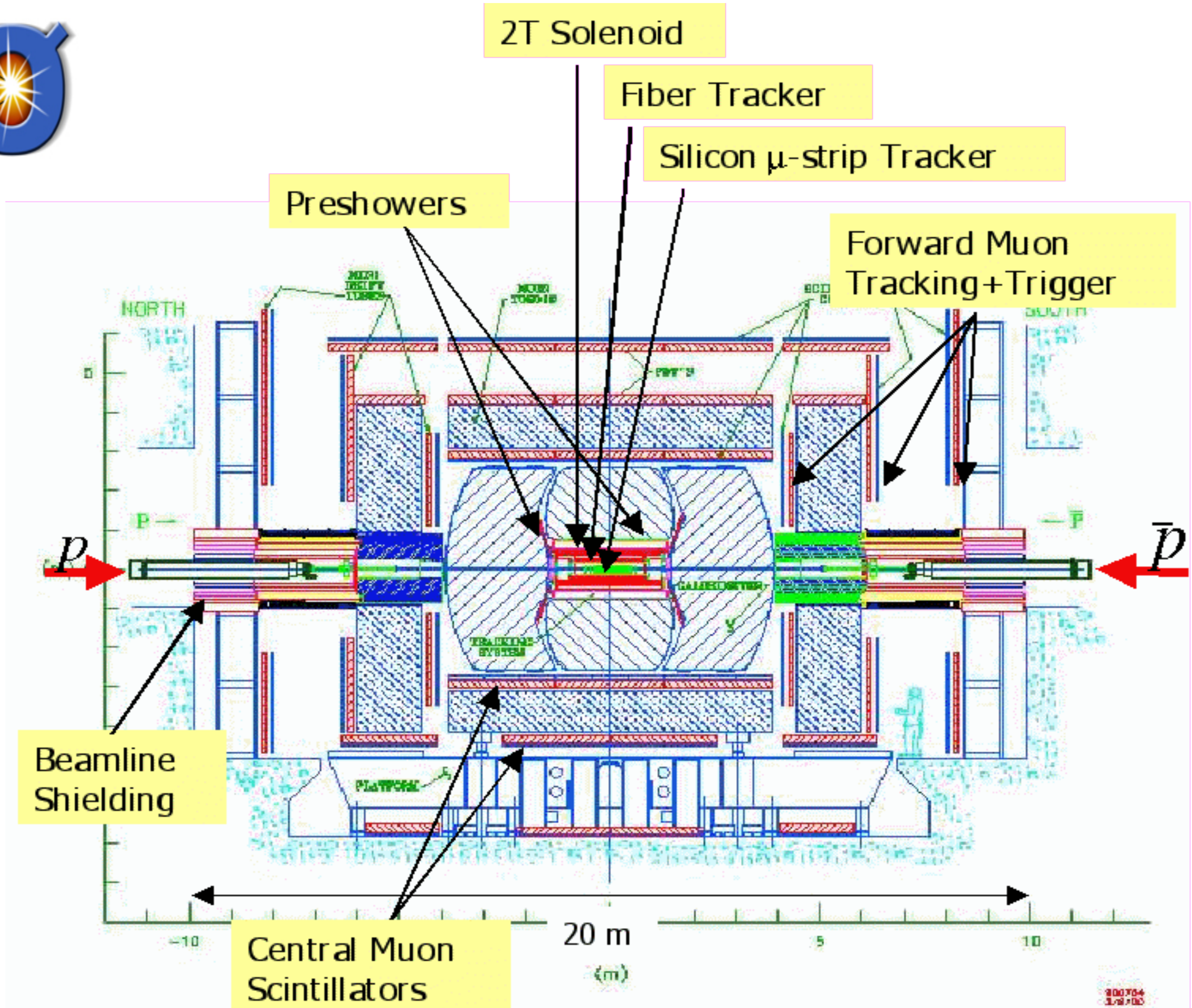
$$\left.\frac{\tau_{\Lambda_b}}{\tau_{B_d}}\right|_{NLO} = 0.88 \pm 0.05$$

⇒ $c\tau(\Lambda_b) \approx$ 378 - 423 μm

while the W.A. is $\tau_{\Lambda_b}/\tau_{B_d} = 1.00 \pm 0.06$

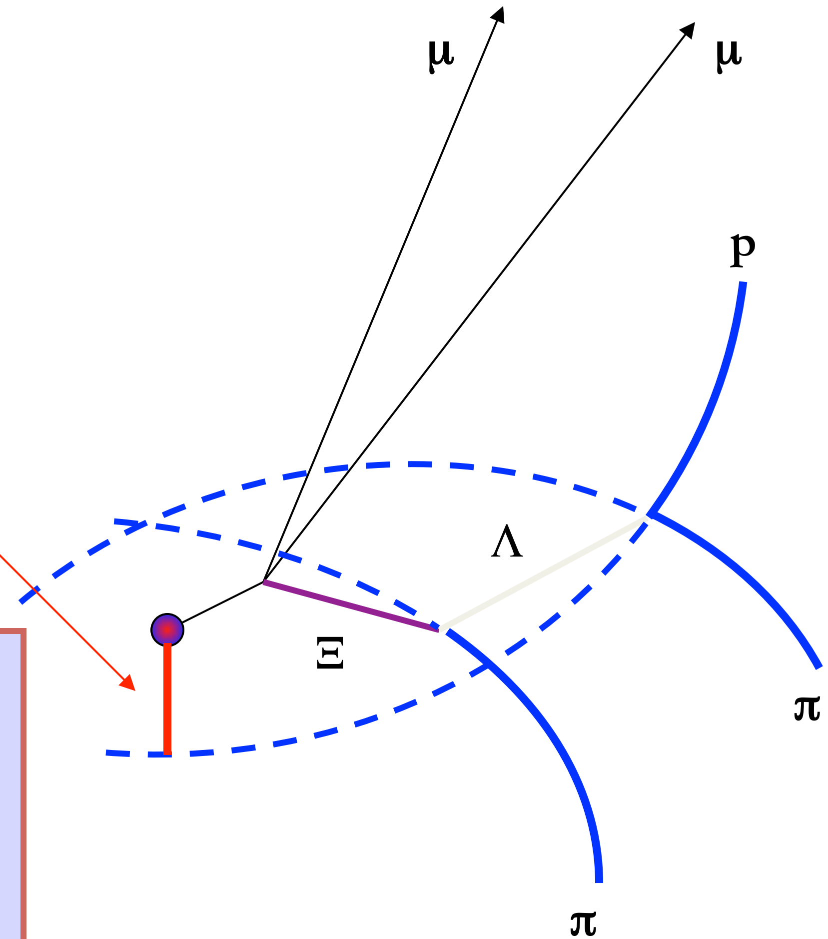
(CDF = $1.020 \pm 0.030 \pm 0.008$ and DØ = $0.811^{+0.096}_{-0.087} \pm 0.034$).

CDF measurement in the **J/ψ Λ** final state **contradicts** the expected hierarchy **$\tau(\Lambda_b) < \tau(B^0)$**


2T Solenoid
Fiber Tracker
Silicon μ-strip Tracker
Preshowers
Forward Muon Tracking+Trigger
NORTH
p
$\bar{p}$
Beamline Shielding
Central Muon Scintillators
20 m
-10
5
10
(m)

b baryon search: data reprocessing – *extended* tracking

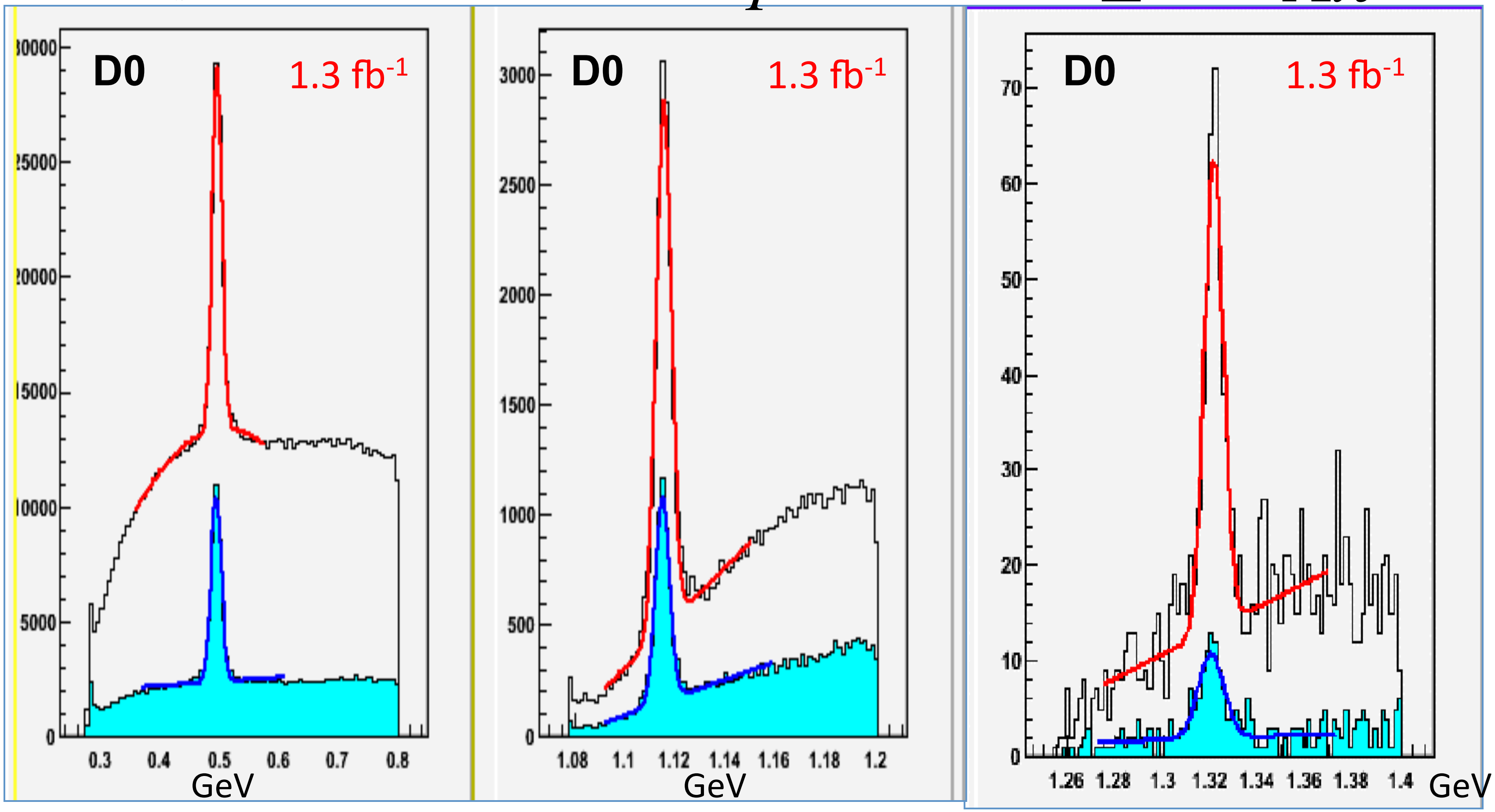
When tracks are reconstructed, a maximum *impact parameter* is required to increase the reconstruction speed and lower the rate of fake tracks.



But for particles like the Λ_b , Ξ_b^- or Ω_b this requirement could result in missing the π and proton tracks from the Λ decay

Increase of reconstruction efficiency

$K_S^0 \to \pi^+\pi^-$ $\Lambda \to p\pi^-$ $\Xi^- \to \Lambda\pi^-$



Opening up the IP cut: (Before) (After)

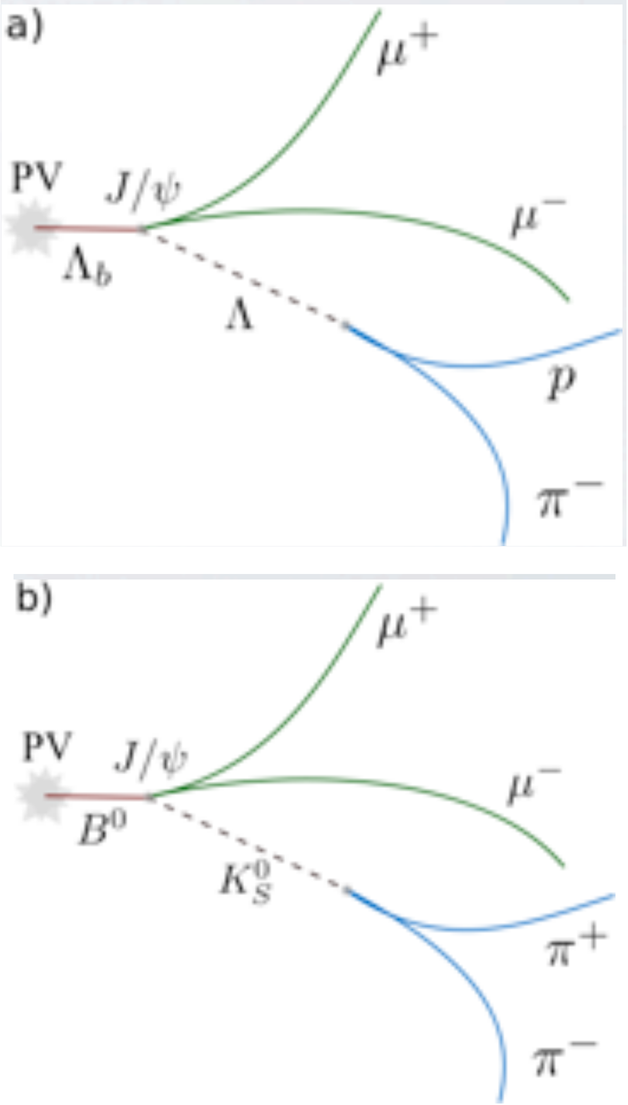
Reconstruction of Λ_b & B^0 decays

Analysis strategy:

- Exploit the very similar event topologies of these decays
- Utilize the very precisely known W.A. B^0 lifetime
  - to cross-check the event selection and analysis method used for the Λ_b lifetime measurement

Event selection:

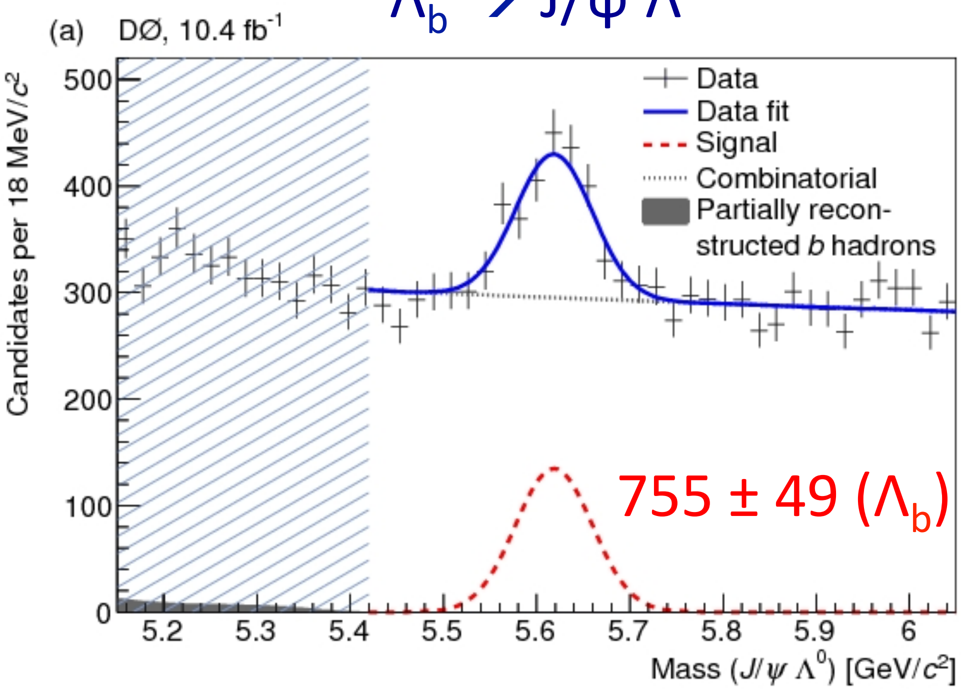
- 2 oppositely charged muons forming a good vertex (J/ψ)
- 2 tracks with significant IP forming a good vertex (Λ, K^0_S)
  - **P**(Λ) points back with 1^0 to the J/ψ vertex (suppress background from heavier b baryons to Λ_b)
- Fit to a common vertex for the Λ (K^0_S) and 2 muon tracks, constrained to the mass of the J/ψ
  - The trajectories of the decay products are readjusted
- The primary vertex is recalculated to exclude muon tracks
- Several optimization cuts to maximize $S / \sqrt{(S + B)}$
  - Λ decay length > 0.3 cm, significance > 3.5
  - $\mathbf{P_T}$ (J/ψ) > 4.5 GeV, etc
  - Λ_b isolation



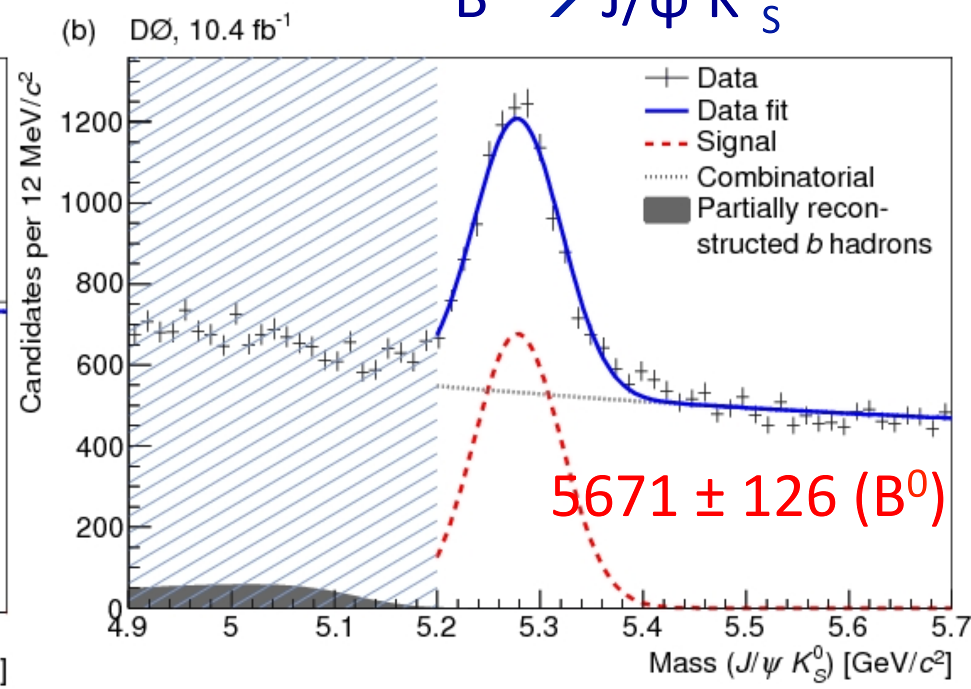
Λ_b signal & B^0 reference samples

... after removal of partially reconstructed *b* hadrons

$\Lambda_b \rightarrow J/\psi\ \Lambda$



$B^0 \rightarrow J/\psi\ K^0_S$



Main backgrounds: COMBINATORIAL and PARTIALLY RECONSTRUCTED *b* HADRON DECAYS

PROMPT: J/ψ from PV (~70% of total background)
NON-PROMPT: J/ψ from *b* hadron decays

Lifetime fits

We defined proper decay length (PDL) as:

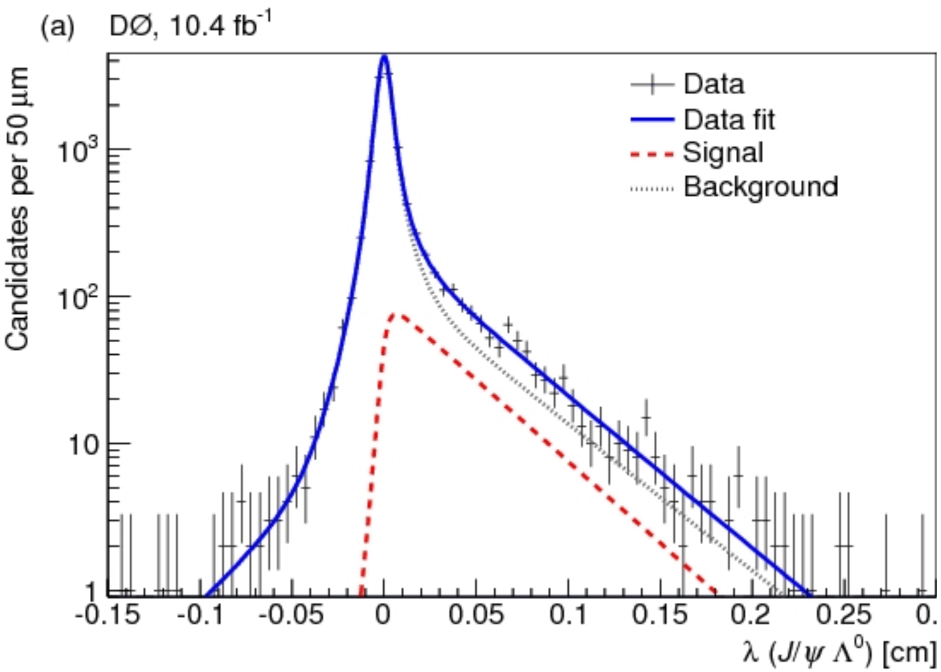
$$\lambda = \frac{(\vec{x}_B - \vec{x}_{PV}) \cdot \vec{p}_T}{p_T} \frac{cM_B}{p_T}$$

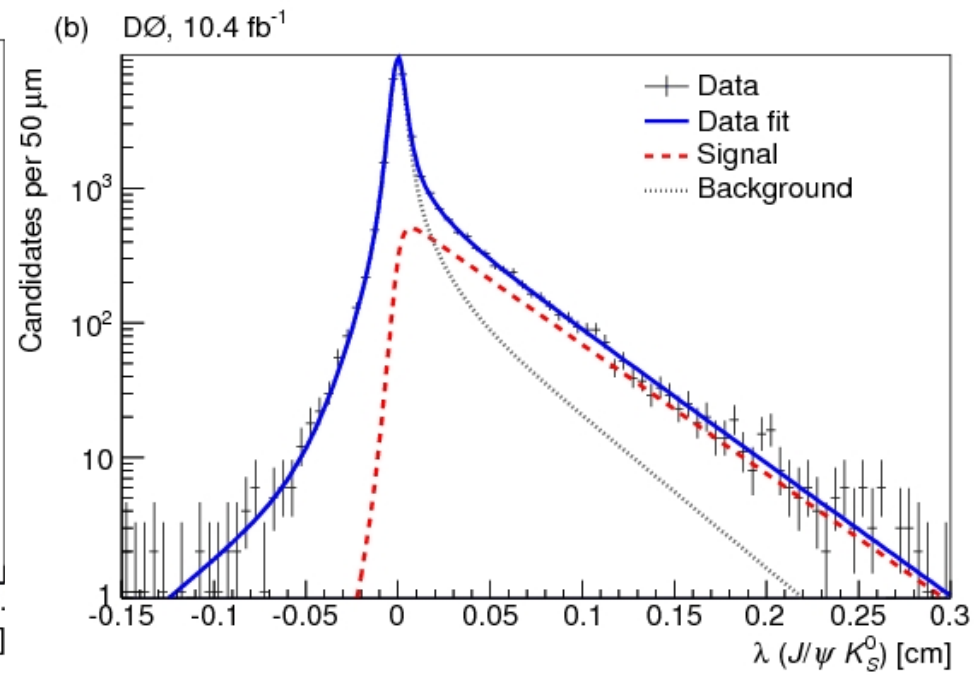
Boost

The Λ_b lifetime is extracted from a simultaneous unbinned maximum likelihood fit to M, λ and σ (PDL uncertainty) distributions:

$$\mathcal{L} = \prod_j \left[f_s \mathcal{F}_s(m_j, \lambda_j, \sigma_j^\lambda) + (1 - f_s) \mathcal{F}_b(m_j, \lambda_j, \sigma_j^\lambda) \right]$$

There are 19 parameters in this fit.





$c\tau(\Lambda_b) = 390.7 \pm 22.4\ \mu m$

$c\tau(B^0) = 452.2 \pm 7.6\ \mu m$

Systematic Uncertainties

Source	Λ_b (μm)	B_d (μm)	Ratio
Mass model	2.2	6.4	0.008
Proper decay length model	7.8	3.7	0.024
Proper decay length uncertainty	2.5	8.9	0.020
Partially reconstructed b hadrons	2.7	1.3	0.008
$B_s \to J/\psi K_S$	–	0.4	0.001
Alignment	5.4	5.4	0.002
Total	10.4	12.9	0.033

1% of B^0 ⟷ ($B_s \to J/\psi K_S$)

Changed *b*-hadron mass threshold ← (Partially reconstructed b hadrons)

Mass model

- Double-Gaussian for signal.
- Exponential decay for non-prompt component.
- Second order polynomial for non-prompt component.

λ model

- Double-Gaussian for resolution function.
- Non-prompt exponentials convoluted with the resolution.
- Only one negative exponential.
- Only one positive exponential.

σ model

- Extracted from data by bkg. subtraction.
- Used σ distributions from MC generated with different input lifetimes.

Lifetime Results

- Using full DØ Run2 dataset (10.4 fb^{-1}), measured the Λ_b lifetime in the exclusive decay mode $J/\psi\ \Lambda$

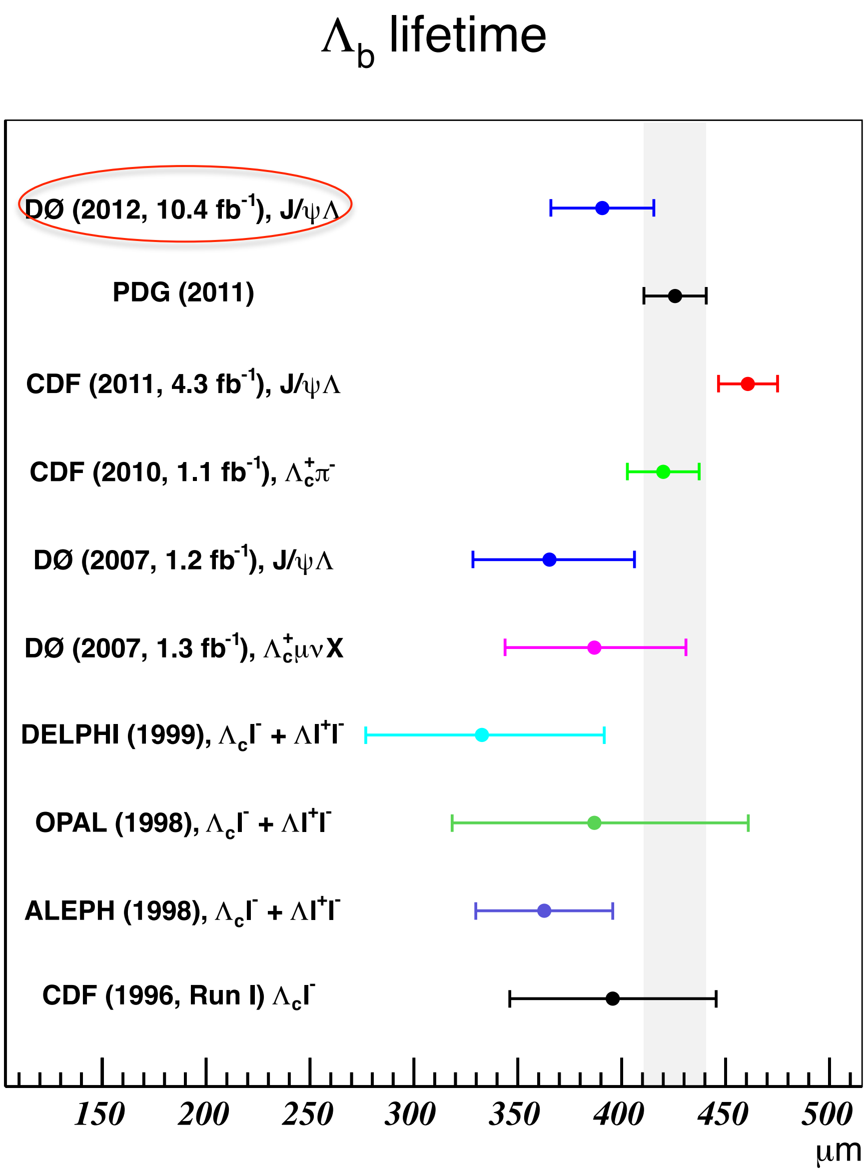
$\tau(\Lambda_b)$ = 1.303 ± 0.075 (stat) ± 0.035 (sys) ps

Consistent with previous DØ measurements and the PDG World Average (2011)
1.425 ± 0.032 ps

- Method was thoroughly tested in $B^0 \rightarrow J/\psi\ K^0_S$ decays

$\tau(B^0)$ = 1.508 ± 0.025 (stat) ± 0.043 (sys) ps

in very good agreement with the WA value
1.519 ± 0.007 ps



Λ_b / B^0 lifetime ratio

- These measurements can be used to calculate the ratio of lifetimes (with many systematic uncertainties reduced):

$\tau(\Lambda_b)/\tau(B^0) = 0.864 \pm 0.052\ (\text{stat}) \pm 0.033\ (\text{sys})$

- Theoretical predictions are in excellent agreement with our measurement

$$\left.\frac{\tau_{\Lambda_b}}{\tau_{B_d}}\right|_{NLO} = 0.88 \pm 0.05$$

and it is consistent with the W.A.,

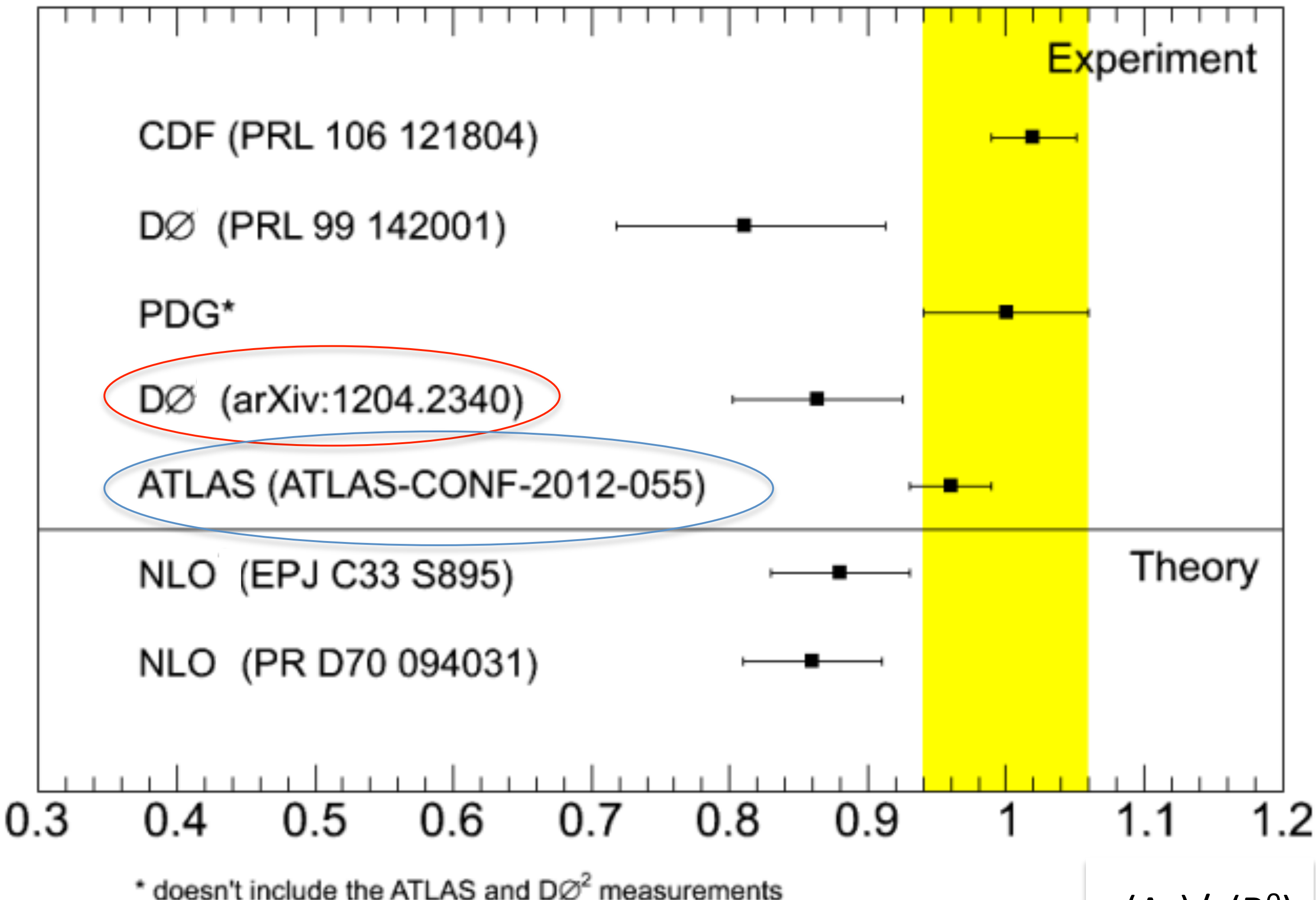
$$\frac{\tau_{\Lambda_b}}{\tau_{B_d}} = 1.00 \pm 0.06 \qquad \text{(W.A.)}$$

N.B. **New** HFAG value (including DØ result) = 0.930 ± 0.020

arXiv:1207.1158v1 (5 July 2012)

K.Toms (ATLAS) – this conference

Ratio of Λ_b and B_d lifetime



$\tau(\Lambda_b)/\tau(B^0)$

N.B. **New** HFAG value (including DØ result) = 0.930 ± 0.020

arXiv:1207.1158v1 (5 July 2012)

Backup slides

Fit models

Signal Model (physics motivated + resolution effects)

$$\mathcal{F}_s^j = \mathrm{Gauss}(m_j) \times [exp \otimes \mathcal{R}(\sigma_j)](\lambda_j) \times E_s(\sigma_j)$$

Event-by-event error gaussian resolution ($\mathcal{R}(\sigma_j)$)

From MC ($E_s(\sigma_j)$)

Background Model

(empirical, describes mass sidebands, divided in prompt and non-prompt **J/ψ** decays)

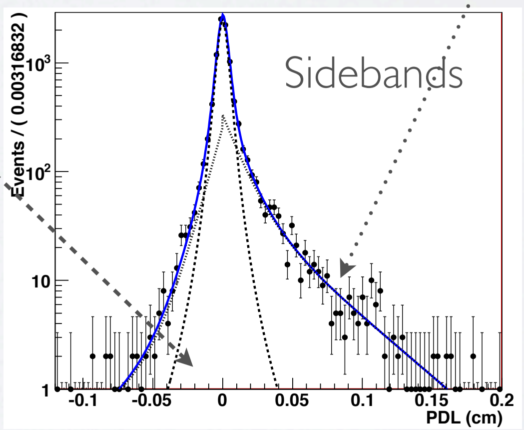
$$\mathcal{F}_b^j = [f_p M_p(M_j) T_p(\lambda_j, \sigma_j) + (1 - f_p) M_{np}(M_j) T_{np}(\lambda_j, \sigma_j)]\, E_b(\sigma_j)$$

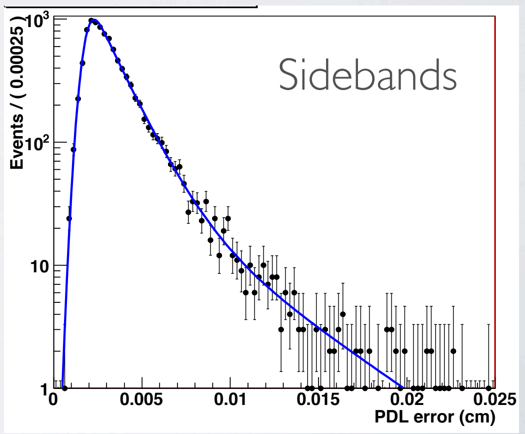
Constant (M_p)

$= \mathcal{R}$ (T_p)

exp (M_{np})

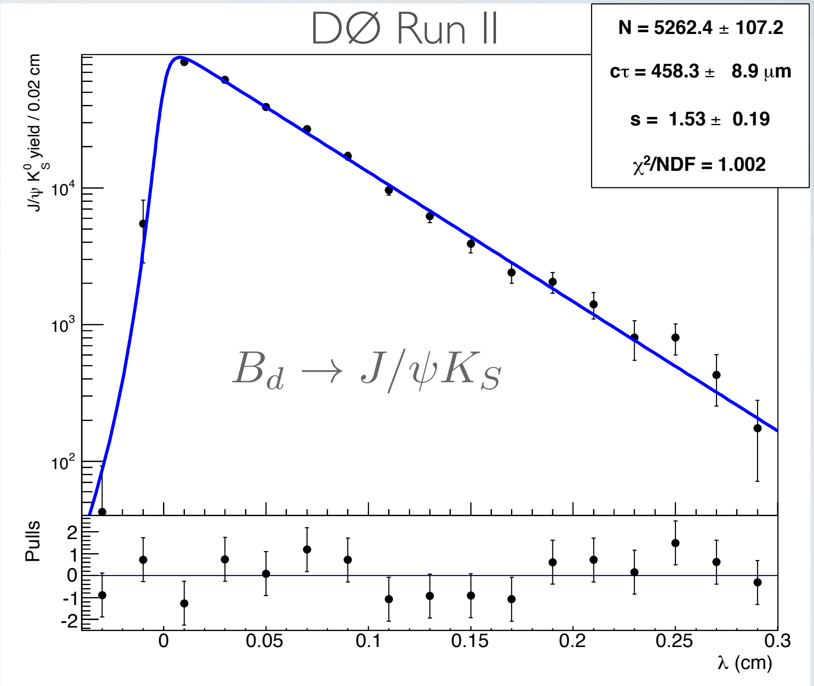
All signal and bkg parameters are allowed to float in the 3D likelihood fit





CONSISTENCY CHECKS

- Measured the **B_d and Λ_b lifetimes with an alternative method**, less dependent on background modeling, but statistically inferior:
  - Extract signal (mass fits) in bins of PDL. χ^2 fits return:
    $c\tau(B_d)$= 458.3 ± 8.9 (stat.) μm
    $c\tau(\Lambda_b)$= 391.4 ± 35.8 (stat.) μm
- Divided data in different **data taking epochs, η, number of SMT hits**: results are statistically consistent.



Epoch	$\tau_{\Lambda_b}(\mu m)$	$\tau_{B_d}(\mu m)$
Run IIa	346.1 ± 46.1 (stat)	480.4 ± 19.4 (stat)
Run IIb	416.8 ± 25.2 (stat)	456.6 ± 12.6 (stat) 451.6 ± 12.3 (stat)

CONSISTENCY CHECKS (2)

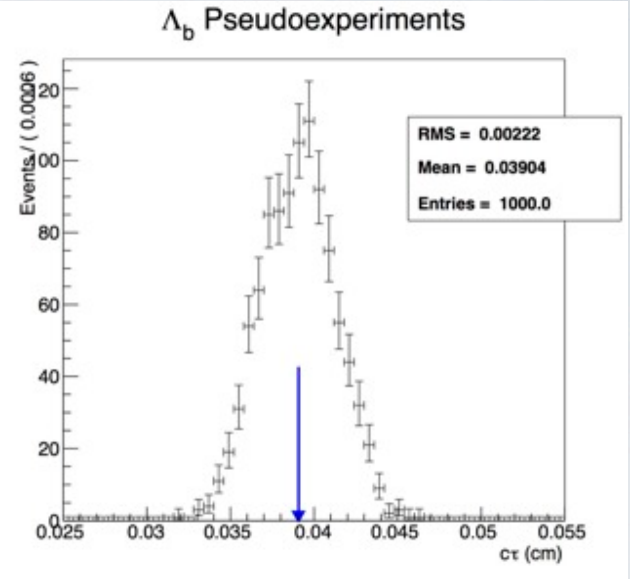
- **Our results remain stable** when:
  - All requirements in variables used in the optimization are removed one at a time.
  - Apply looser and tighter cuts to kinematic variables.
  - The high-end tail of the uncertainty distribution is removed.
  - Used the same selection criteria as in previous DØ lifetime measurements.

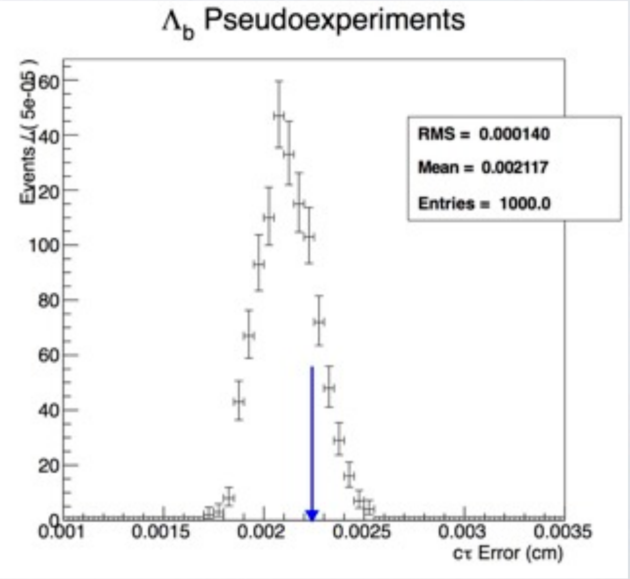
Requirement	$\tau_{B_d}(\mu m)$	$\tau_{\Lambda_b}(\mu m)$
Nominal	452.2 ± 7.6	390.7 ± 22.4
Allow multiple candidates/event	451.7 ± 7.6	390.2 ± 22.4
No V^0 collinearity cut	448.3 ± 7.4	388.5 ± 22.2
No V^0 distance and significance cut	454.6 ± 7.6	390.5 ± 22.0
No $\Delta R(\mu^+, \mu^-)$ cut	451.5 ± 7.5	395.5 ± 22.3
No B Isolation cut	449.6 ± 7.4	394.1 ± 22.4
No $p_T(J/\psi)$ cut	452.6 ± 7.6	391.6 ± 22.3
No $p(B)$ cut	452.2 ± 7.6	390.7 ± 22.4
No vertex $\chi^2(B)$ cut	455.1 ± 7.7	387.1 ± 22.7
No p_T threshold cut	448.3 ± 7.5	390.0 ± 23.3
* $p_T(V^0) > 1.4$ GeV/c	433.8 ± 6.5	398.1 ± 23.6
$p_T(V^0) > 1.6$ GeV/c	441.5 ± 7.0	397.3 ± 23.0
$p_T(V^0) > 1.8$ GeV/c	452.2 ± 7.6	390.7 ± 22.4
$p_T(V^0) > 2.0$ GeV/c	453.5 ± 7.9	387.7 ± 22.9
$p_T(V^0) > 2.2$ GeV/c	444.4 ± 8.1	407.0 ± 23.4
$p_T(V^0) > 2.4$ GeV/c	447.0 ± 8.7	401.8 ± 24.1

σ_{max} (μm)	$\tau_{B_d}(\mu m)$	$\tau_{\Lambda_b}(\mu m)$
100	452.0 ± 7.5	391.3 ± 22.2
150	452.9 ± 7.6	391.8 ± 22.3
200	453.0 ± 7.6	391.0 ± 22.4
300	452.2 ± 7.6	390.7 ± 22.4

CONSISTENCY CHECKS (3)

- Debugged the maximum likelihood fit code by generating pseudo-experiments:
  - We recover the input lifetime.
  - We find a lifetime error consistent with expectations.





And other checks...

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