Measurement of beauty hadron spectroscopy and productions at CMS

Frank Meier
University of Nebraska-Lincoln
on behalf of the CMS collaboration

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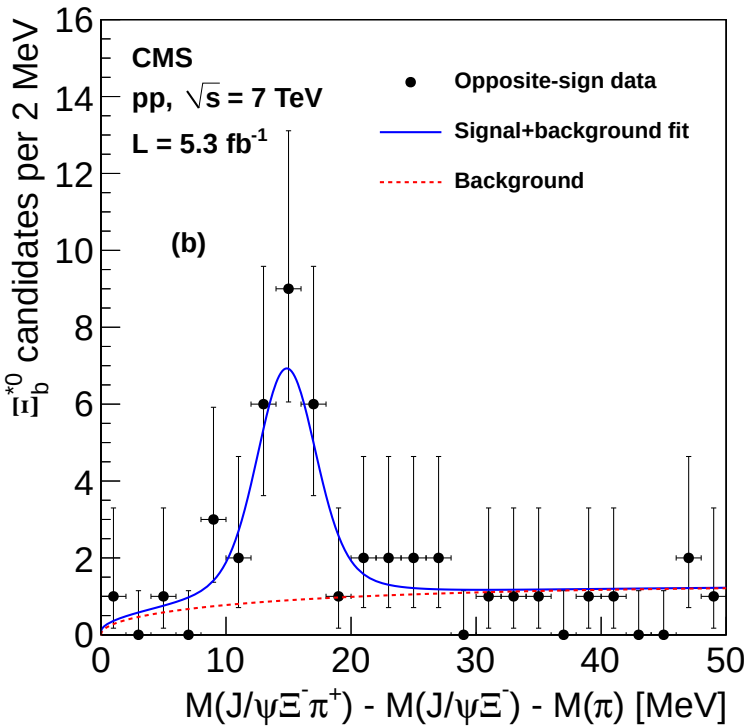
Introduction

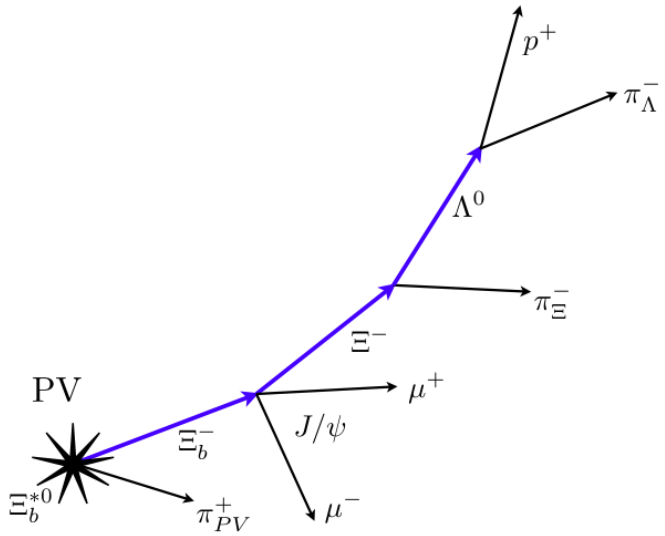
- CMS has access to a rich spectrum of B-physics measurements via muon triggers and a superb tracker
- I'm going to show:
  - Examples of what we achieved.
  - This includes some new results, presented for the first time.

B hadron spectroscopy: Ξ_b^{*0}

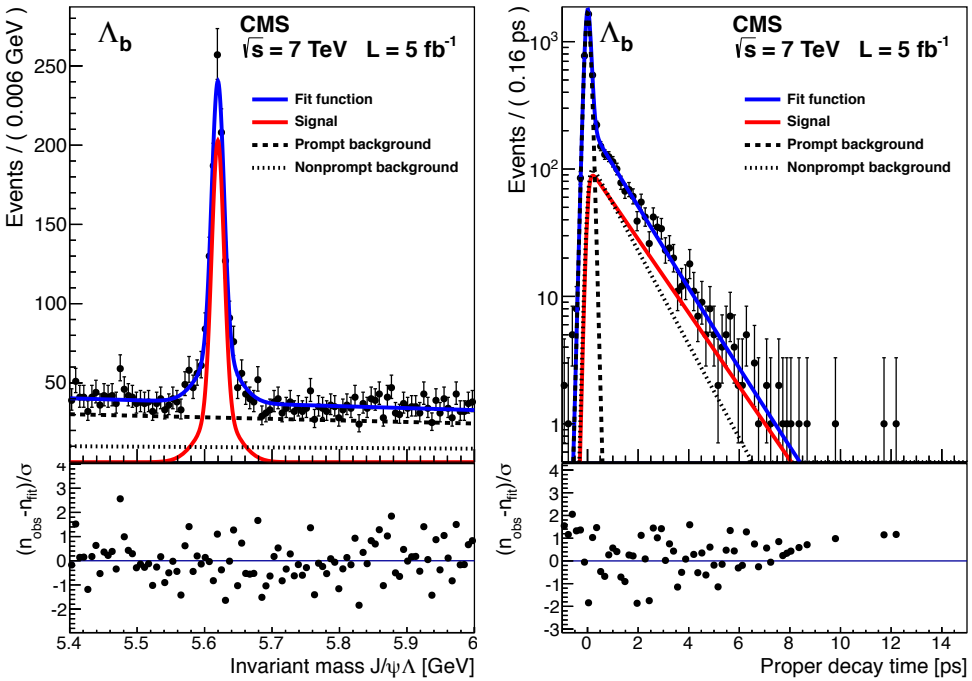


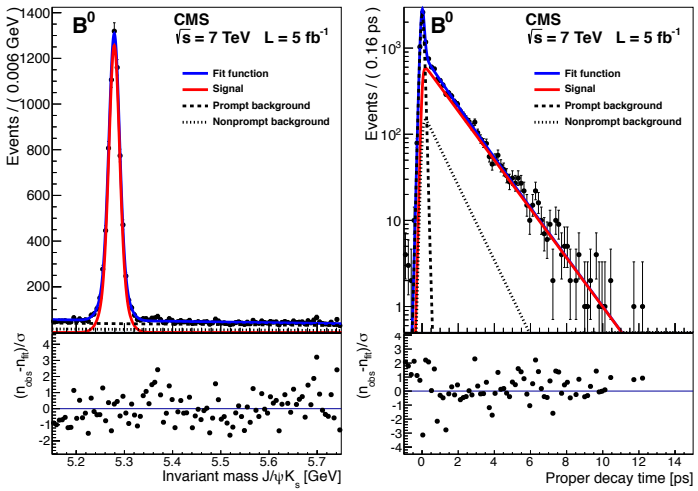
First observation of a strong b baryon decay to $\Xi_b^- + \pi^+$

Reconstruction uses 6 charged tracks, some with displacements due to lifetimes.



B hadron spectroscopy: Λ_b^0 lifetime





Measured in $\Lambda_b^0 \to J/\psi\Lambda^0$

$\tau = 1.503 \pm 0.051 \pm 0.031\,\text{ps}$

$m = 5619.7 \pm 0.5\,\text{GeV}/c^2$

Control channel: $B^0 \to J/\psi K_s$

$\tau = 1.526 \pm 0.019\,\text{ps}$

(PDG: $1.519 \pm 0.007\,\text{ps}$)

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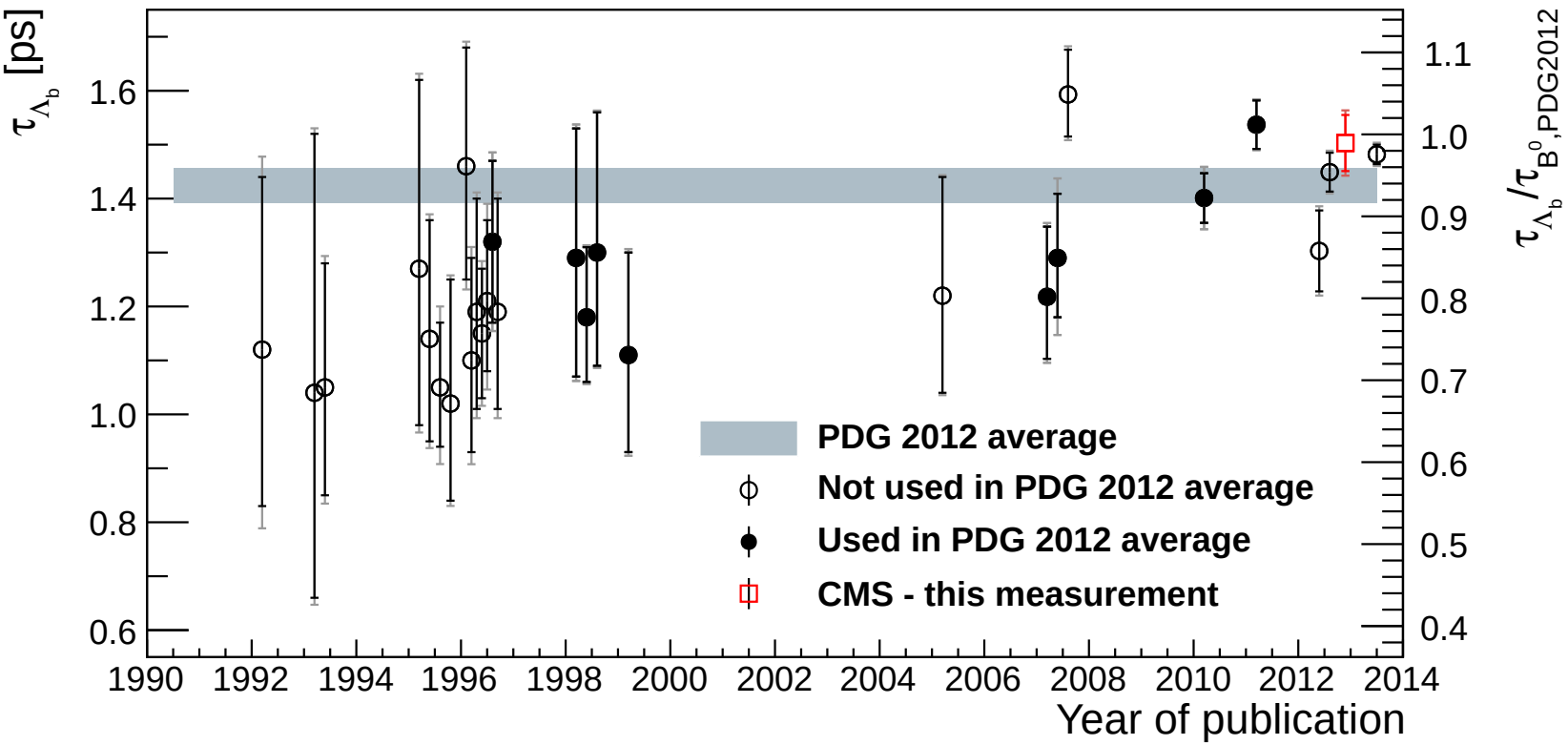
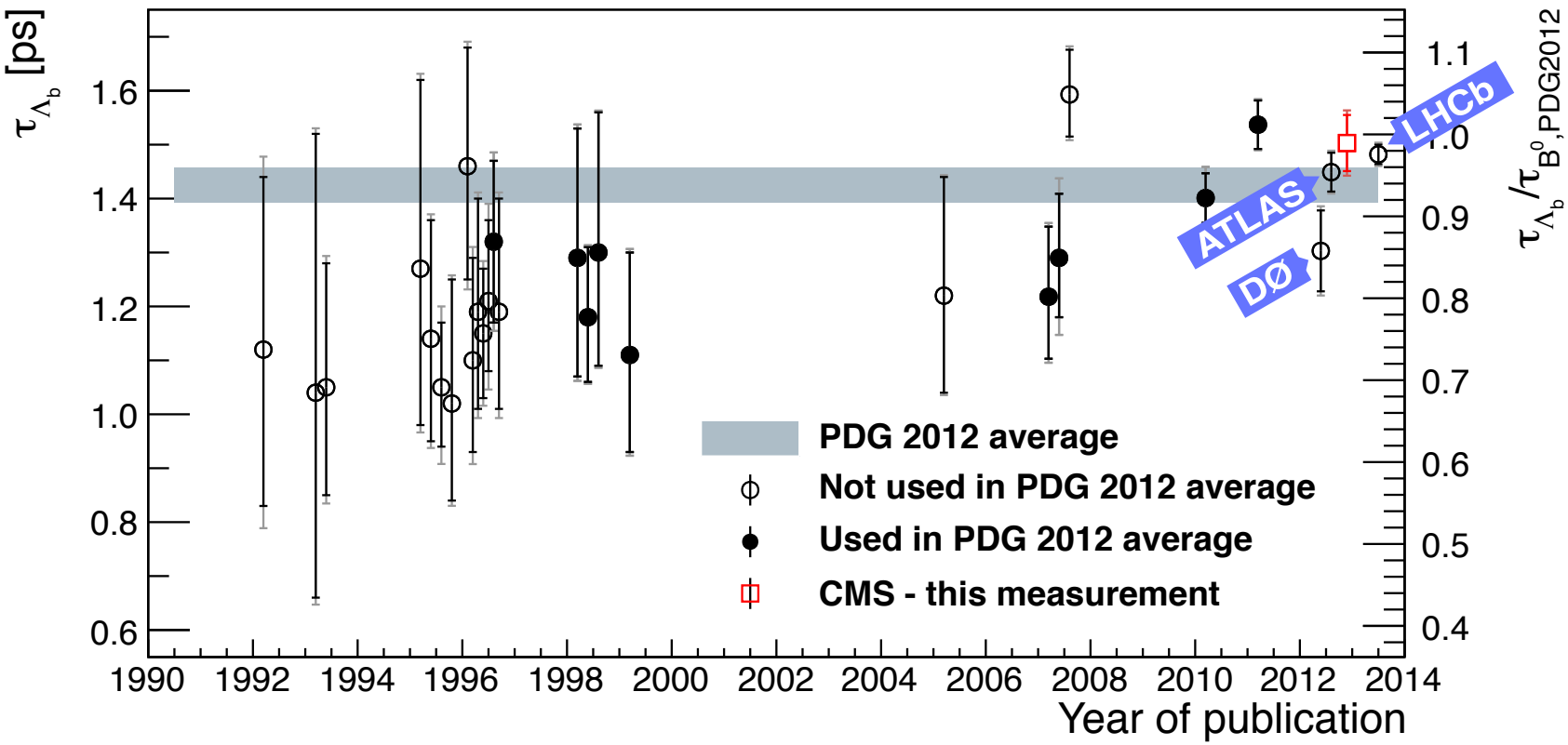
B hadron spectroscopy: Λ_b^0 lifetime



Shows the tendency towards longer observed Λ_b^0 lifetimes over time.

Note: First theories favoured a lifetime ratio $\frac{\tau(\Lambda_b^0)}{\tau(B^0)}$ of $0.9 \ldots 1.0$.

B hadron spectroscopy: Λ_b^0 lifetime



Shows the tendency towards longer observed Λ_b^0 lifetimes over time.

Note: First theories favoured a lifetime ratio $\frac{\tau(\Lambda_b^0)}{\tau(B^0)}$ of $0.9 \ldots 1.0$.

B_c BR ratios: $B_c \to \mathrm{J}/\psi\pi^+$ and $B_c \to \mathrm{J}/\psi\pi^+\pi^+\pi^-$

- New result, presented here for the first time.
- Later today the public result should appear here: `https://twiki.cern.ch/twiki/bin/view/CMS/PhysicsResultsBPH12011`
- We report on two branching ratios:

$$\frac{\sigma(B_c) \times \mathrm{Br}(B_c \to \mathrm{J}/\psi\pi^+)}{\sigma(\mathrm{B}^+) \times \mathrm{Br}(\mathrm{B}^+ \to \mathrm{J}/\psi K^+)}$$

$$\frac{\mathrm{Br}(B_c \to \mathrm{J}/\psi\pi^+\pi^+\pi-)}{\mathrm{Br}(B_c \to \mathrm{J}/\psi\pi^+)}$$

- Phase space covered: $p_T(B_c) > 15\mathrm{GeV/c}$ and $|y(B_c)| < 1.6$.
- NB: Charge conjugate modes included throughout this talk.

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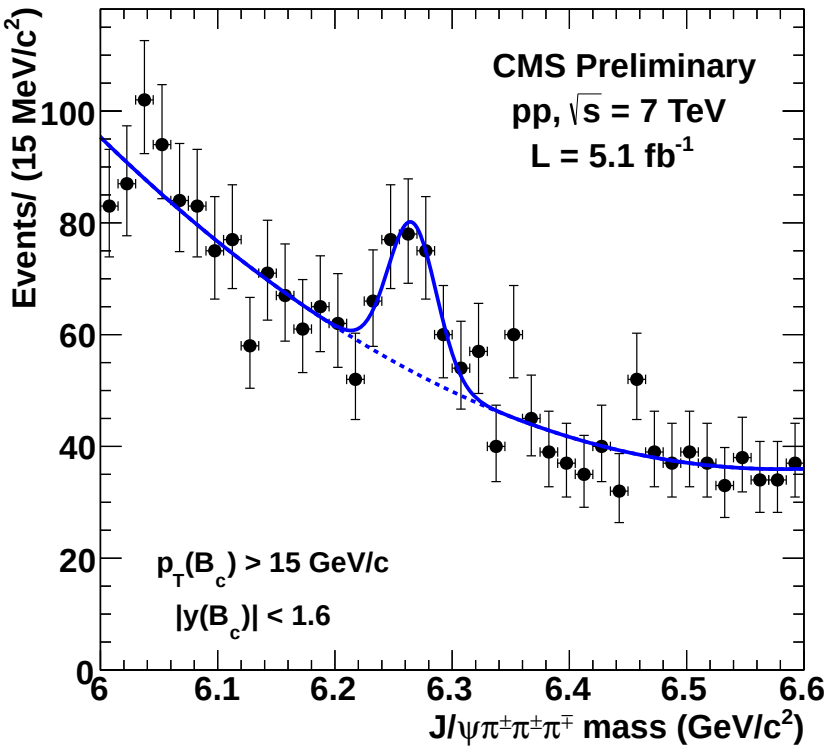
B_c BR ratios: The particle

A few facts:

- mass: $6.2745 \pm 0.0018\,\mathrm{GeV/c^2}$
- lifetime: $0.452 \pm 0.033\,ps$
- quark content: bc
- only observable at hadron machines (so far)
- observed in a broad list of decays (first observation):
  $B_c \to \mathrm{J}/\psi\mu\nu$ (CDF), $B_c \to \mathrm{J}/\psi\pi$ (CDF),
  $B_c \to \mathrm{J}/\psi\pi\pi\pi$ (LHCb/CMS), $B_c \to \psi(2S)\pi$ (LHCb),
  $B_c \to \mathrm{J}/\psi D_s$ (LHCb), $B_c \to \mathrm{J}/\psi D_s^*$ (LHCb),
  $B_c \to \mathrm{B_s}\pi$ (LHCb), and $B_c \to \mathrm{J}/\psi KK\pi$ (LHCb)
  Note: The last three lines were added just recently.

Values mentioned were taken from the PDG tables

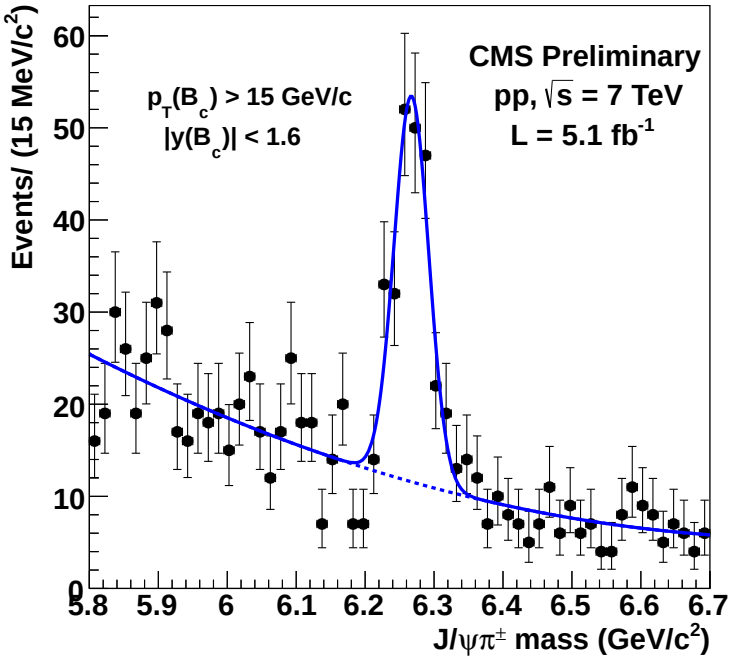
B_c BR ratios: Selection

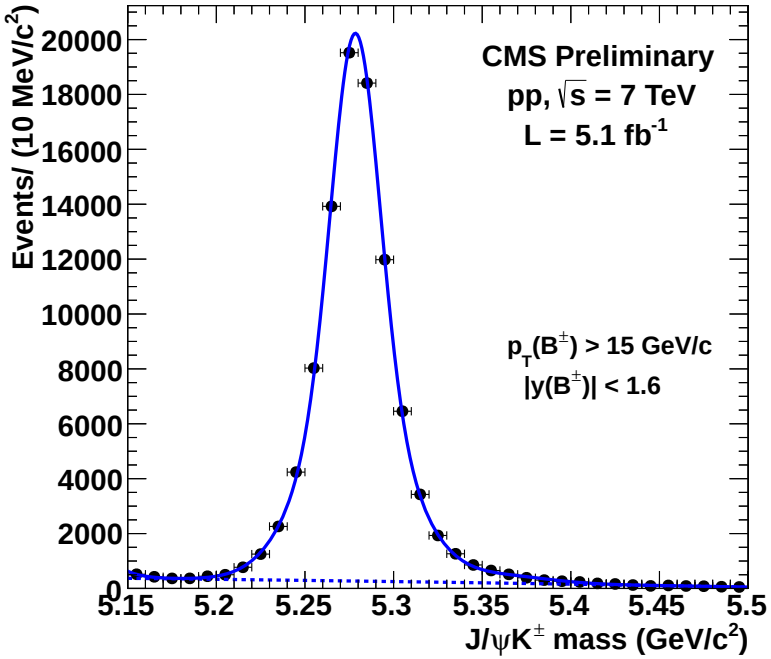


- J/ψ trigger: Mass region around J/ψ (2.9 – 3.3 GeV/c) and displaced vertex (3 σ significance)
- Tracks $|\eta| < 2.4$
- Kinematic vertex fit, constraining $\mu\mu$-invariant mass to J/ψ mass
- Tighter selection cuts applied later on to optimize $\frac{S}{\sqrt{S+B}}$.
- Mass fit uses Gaussian (signal) and Chebyshev polynomials (2$^{\text{nd}}$ order)

B_c BR ratios: Selection

Similar strategies for the other decay channels:





Channel	Events
$B_c^+ \to \mathrm{J}/\psi\pi^+\pi^+\pi^-$	92 ± 27
$B_c^+ \to \mathrm{J}/\psi\pi^+$	176 ± 19
$\mathrm{B}^+ \to \mathrm{J}/\psi K^+$	90398 ± 357

B_c BR ratios: Efficiencies

Accurate knowledge of efficiencies paramount for measuring a branching ratio. Two approaches were used:

- 1π channel: Efficiency determined in bins of p_T
- 3π channel: 5-body final state phase space sampling (see following slide)

Efficiencies determined using simulated events and applied to data on a per-event basis.

B_c BR ratios: Efficiencies

In the 3π channel, a fit function was used to describe the efficiency.

- A non-resonant simulation sample has been used to study the efficiency as a function of a complete set of parameters for a 5-body final state.
- Fit function:

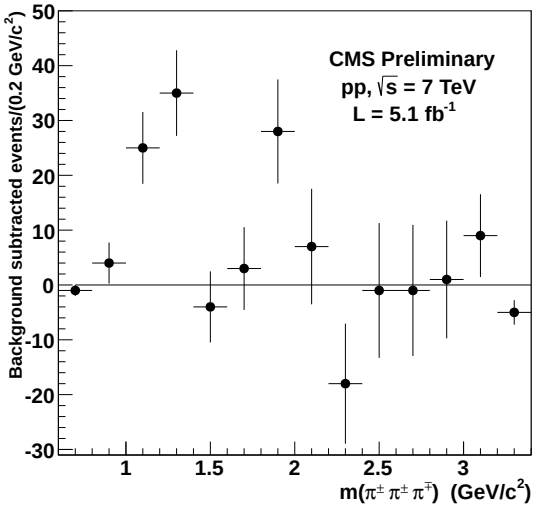
$$\epsilon = |p_0 + p_1 \cdot x + p_2 \cdot y + p_3 \cdot z + p_4 \cdot w + p_5 \cdot r + p_6 \cdot t + p_7 \cdot s|$$

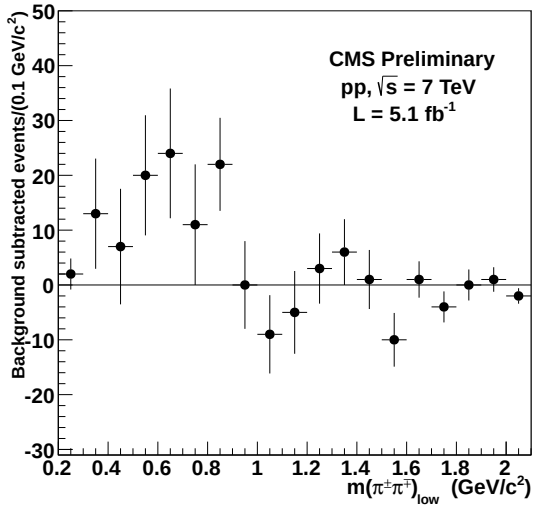
- Parameters p_i determined using an unbinned maximum likelihood fit
- Components mean:

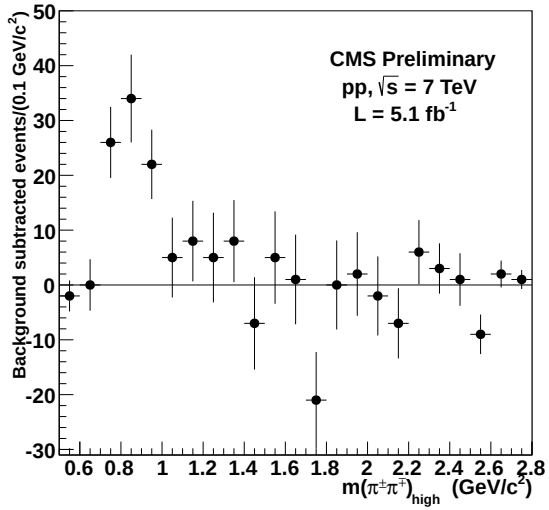
$x = m^2(\mu^+\pi^+)_{low}$ $\quad y = m^2(\pi^+\pi^-)_{high}$ $\quad z = m^2(\mu^+\pi^-)$
$w = m^2(\pi^+\pi^+)$ $\quad r = m^2(\mu^-\pi^+)_{low}$ $\quad t = m^2(\mu^-\pi^+)_{high}$
and $s = m^2(\mu^-\pi^-)$

B_c BR ratios: $B_c \to J/\psi\pi^+\pi^+\pi^-$ peculiarities

The decay $B_c \to J/\psi\pi^+\pi^+\pi^-$ can go through resonances. Hints for $a_1^+(1260)$ and $\rho^0(770)$ are indeed visible:







- The efficiency evaluated in this way is independent of the decay dynamics

B_c BR ratios: Systematic uncertainties

Source	Values in %	
	$\frac{\sigma(B_c)\times \mathrm{Br}(B_c\to \mathrm{J}/\psi\pi^+)}{\sigma(\mathrm{B}^+)\times \mathrm{Br}(\mathrm{B}^+\to \mathrm{J}/\psi K^+)}$	$\frac{\mathrm{Br}(B_c\to \mathrm{J}/\psi\pi^+\pi^+\pi-)}{\mathrm{Br}(B_c\to \mathrm{J}/\psi\pi^+)}$
Split sample	0	7.4
Fit variant	5.6	10.7
MC finite size	2.2	4.1
Efficiency binning	4.1	1.6[1]
Efficiency fit function	N/A	8.6
Tracking efficiency	N/A	7.8
Dimuon significance cut	N/A	+5
Total	7.3	$^{+19}_{-18}$
Lifetime B_c	$^{+10.9}_{-5.2}$	N/A

[1] Affects 1π channel only

B_c BR ratios: Results

- $B_c \to \mathrm{J}/\psi\pi^+$:

$$\frac{\sigma(B_c) \times \mathrm{Br}(B_c \to \mathrm{J}/\psi\pi^+)}{\sigma(\mathrm{B}^+) \times \mathrm{Br}(\mathrm{B}^+ \to \mathrm{J}/\psi K^+)} =$$
$$\left(0.48 \pm 0.05(\mathrm{stat.}) \pm 0.04(\mathit{syst.}) \, {}^{+0.05}_{-0.03}(\tau_{B_c})\right) \times 10^{-2}$$

This result is complementary to LHCb:
$(0.68 \pm 0.10(\mathrm{stat.}) \pm 0.03(\mathrm{syst.}) \pm 0.05(\mathrm{lifetime})) \times 10^{-2}$ †

- $B_c \to \mathrm{J}/\psi\pi^+\pi^+\pi^-$:

$$\frac{\mathrm{Br}(B_c \to \mathrm{J}/\psi\pi^+\pi^+\pi-)}{\mathrm{Br}(B_c \to \mathrm{J}/\psi\pi^+)} = 2.43 \pm 0.76(\mathrm{stat.}) \, {}^{+0.46}_{-0.44}(\mathit{syst.})$$

In good agreement to LHCb ($2.41 \pm 0.30 \pm 0.33$ ‡)

- CMS covers $p_T(B_c) > 15\mathrm{GeV/c}$ and $|y(B_c)| < 1.6$, LHCb $p_T(B_c) > 4\mathrm{GeV/c}$ and $2.5 < |\eta(B_c)| < 5$

†LHCb-PAPER-2012-028
‡LHCb-PAPER-2011-044

Conclusions

- Despite not having been explicitly built for B physics, CMS has nice results. Just highlighted some.
- Discovered a new baryon: $\Xi_b^- + \pi^+$.
- Λ_b^0 lifetime, lifetime puzzle seems to be settled.
- And we have a nice new result on B_c branching ratios.

Thank you for your attention

and thanks to all who contributed: LHC, CMS, B physics group

NB: Website featuring public CMS B-physics results:
`https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH`

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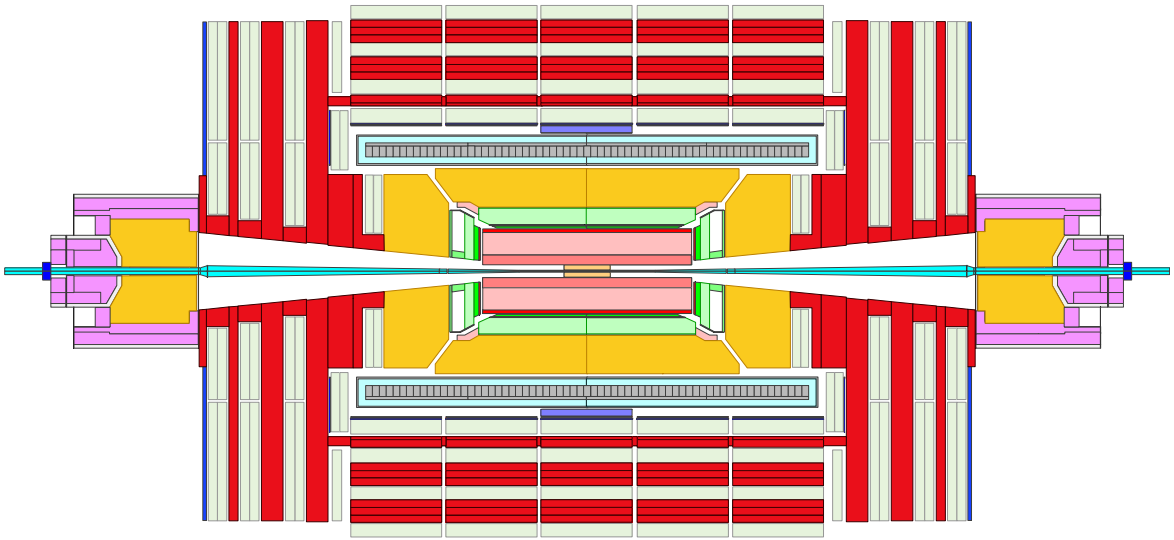
BACKUP

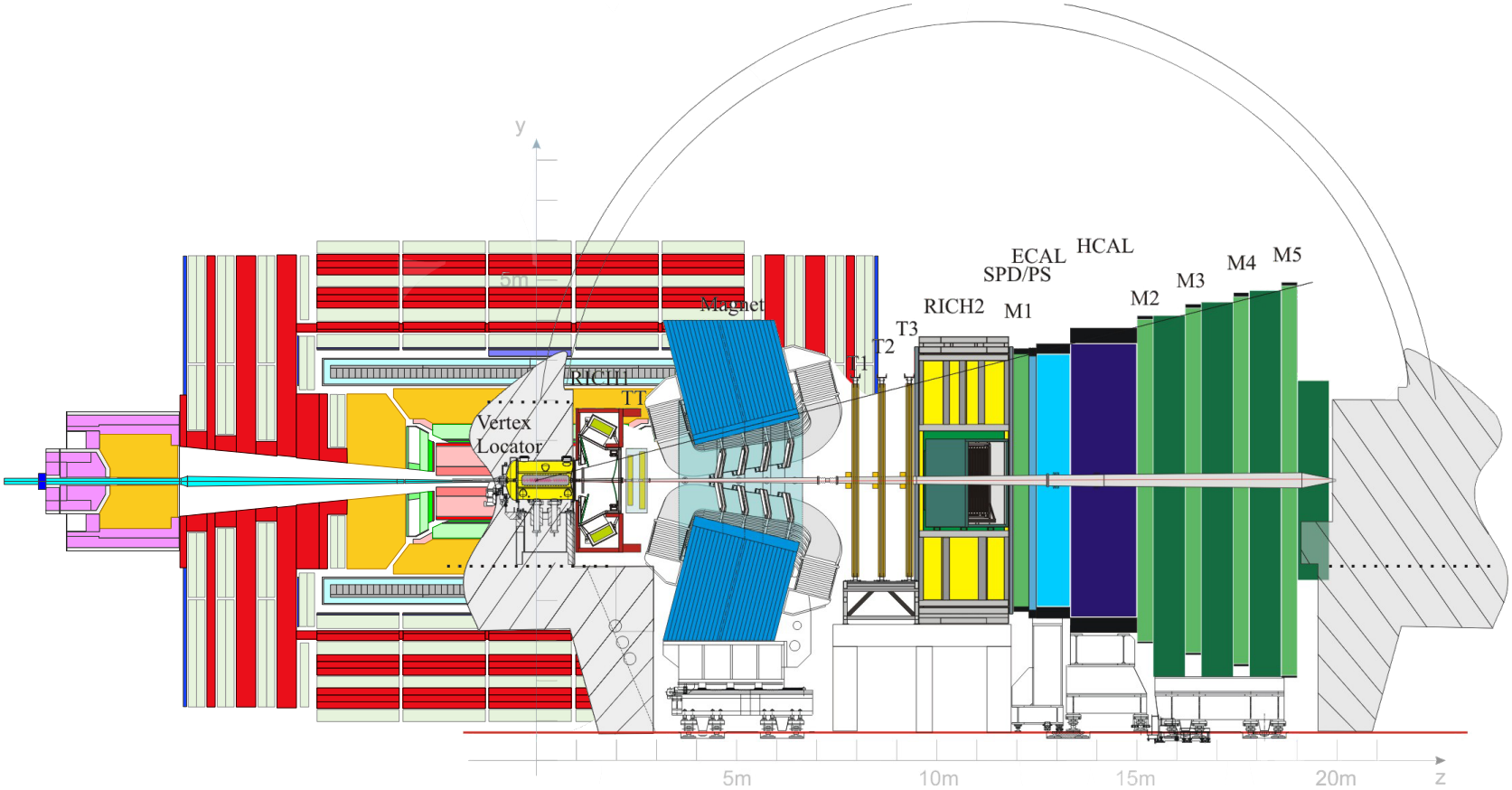
Backup slides

This is CMS. You already know it, I guess.



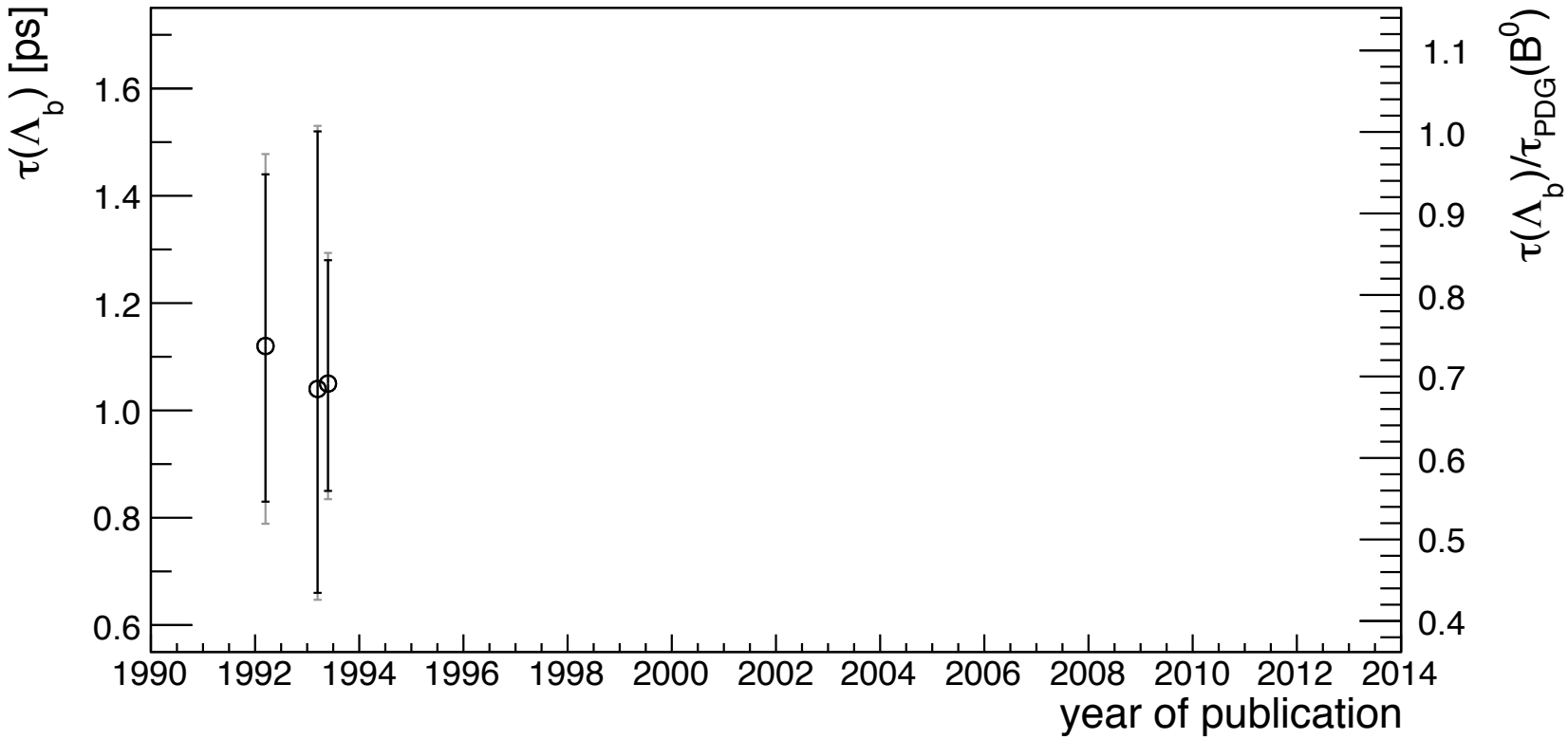
Backup slides

And this is LHCb, superimposed approximately to scale.



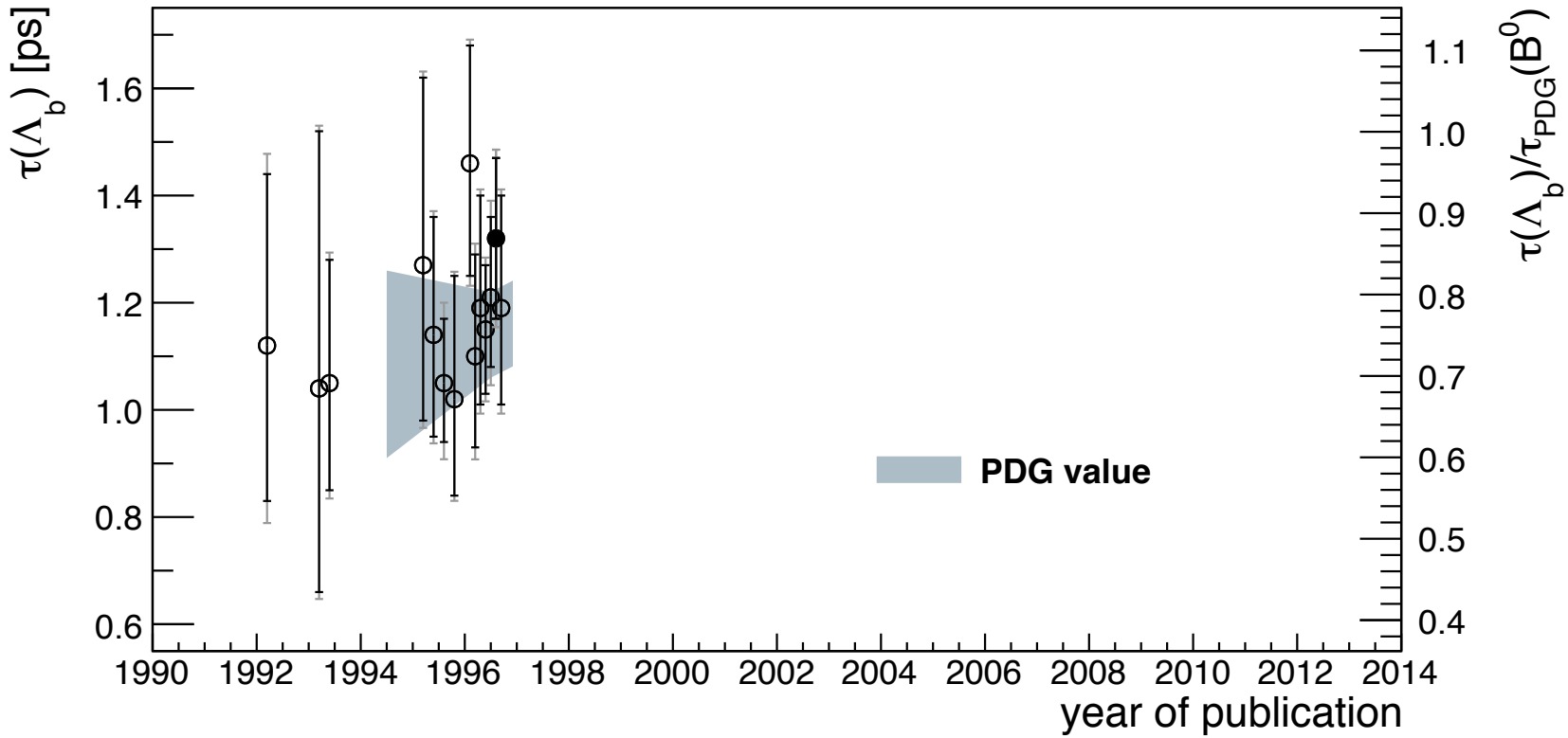
The two experiments coverage in pseudorapidity adds up.

Evolution of $\tau(\Lambda_b^0)$ measurements



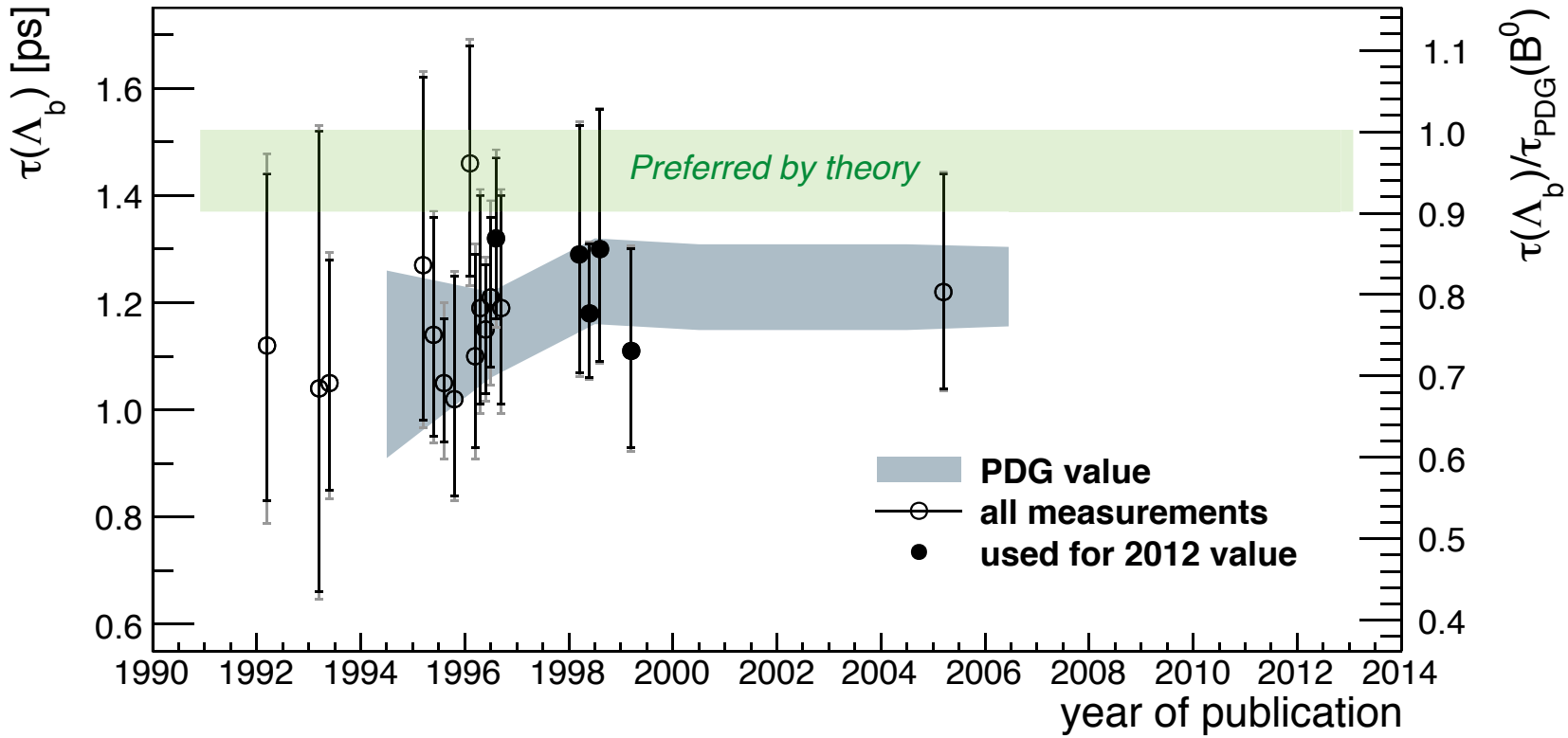
The first measurements were low, but the error bars were large.

Evolution of $\tau(\Lambda_b^0)$ measurements



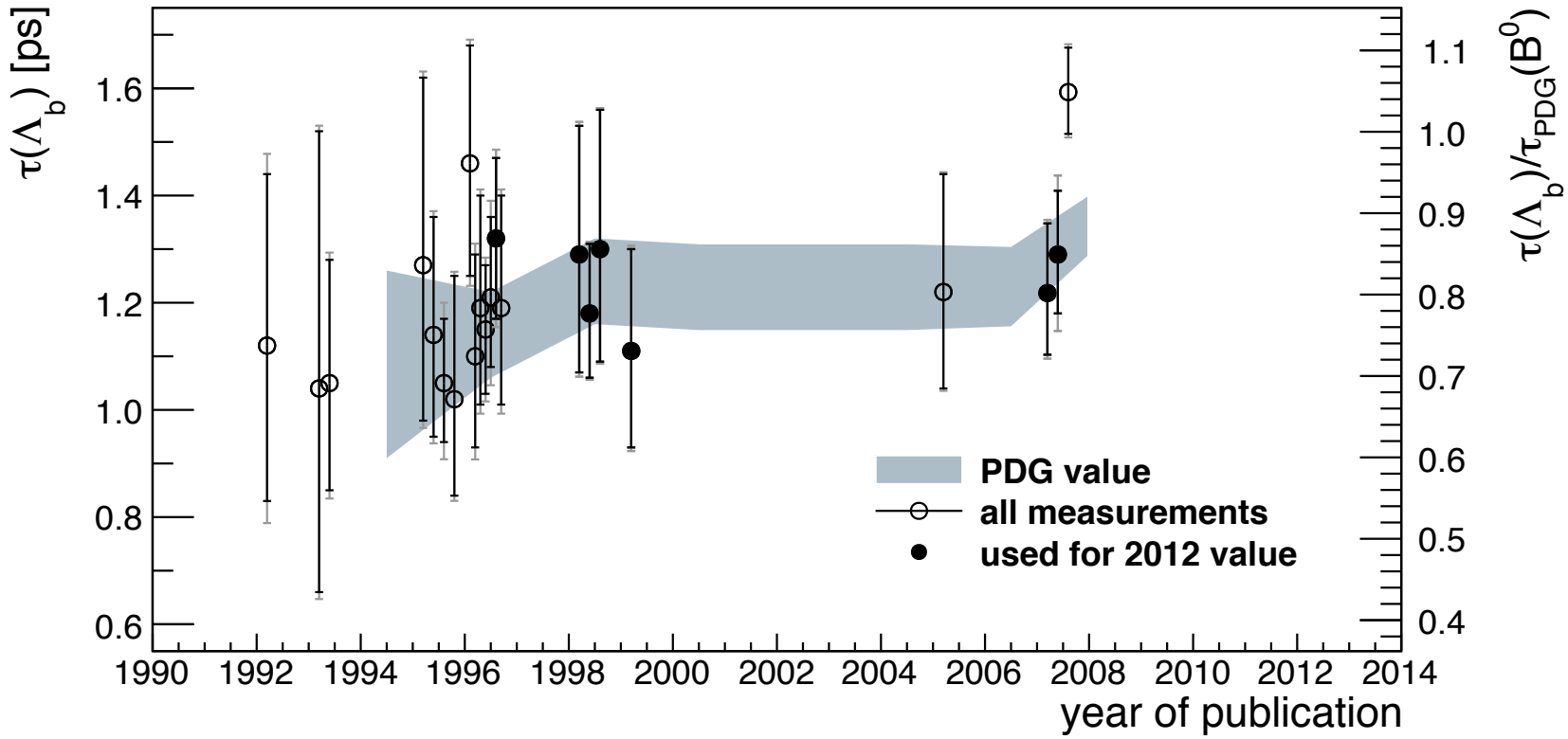
More measurements appeared and PDG started to calculate a *best value*. It seemed that theory was wrong...

Evolution of $\tau(\Lambda_b^0)$ measurements



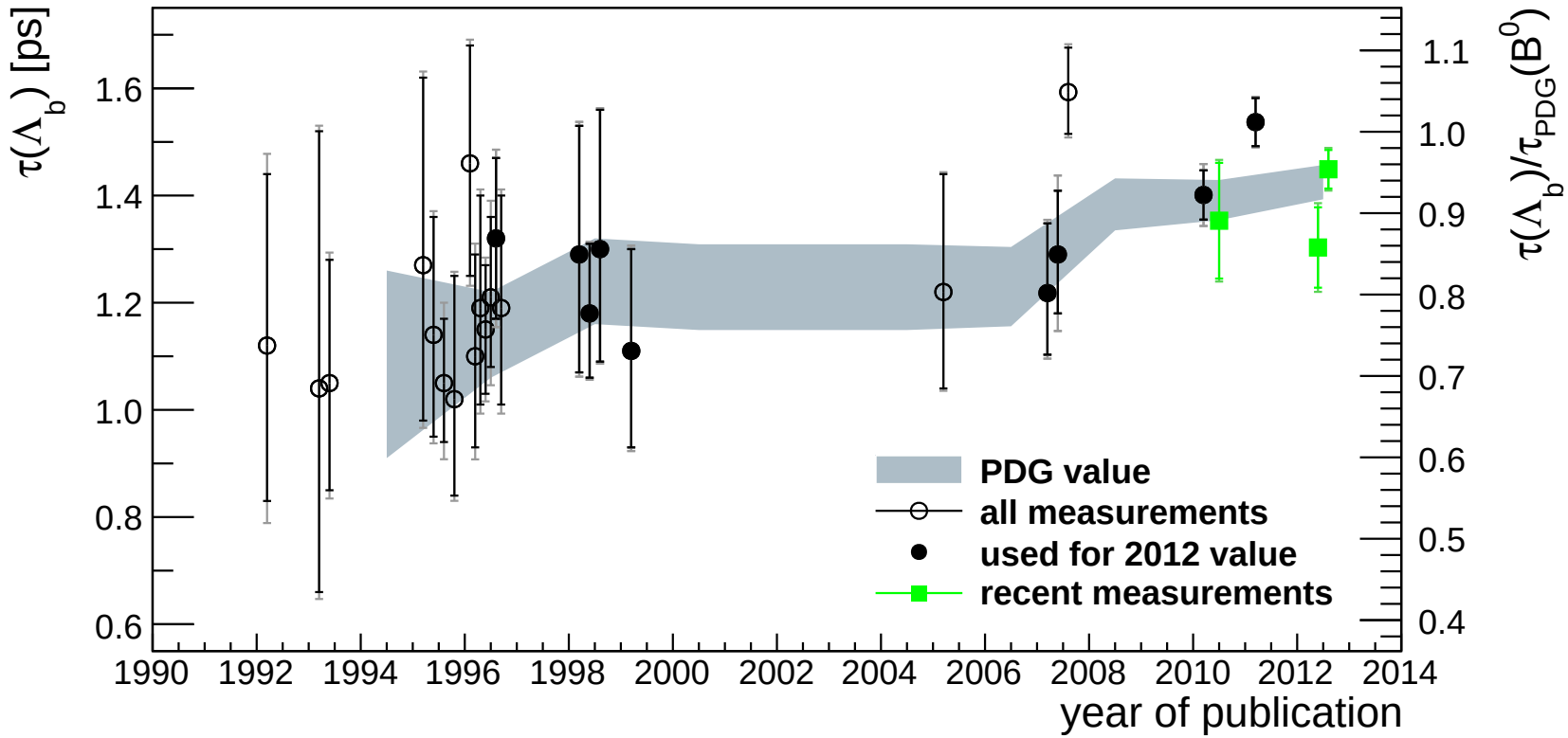
. . . which was supported by more measurements. Theorists started to investigate and added higher order corrections. Not much success, i.e. the predicted ratio $\tau(\Lambda_b^0)/\tau(B^0)$ stayed in a range [0.9,1.0]. (There were few aggressive exceptions, though.)

Evolution of $\tau(\Lambda_b^0)$ measurements



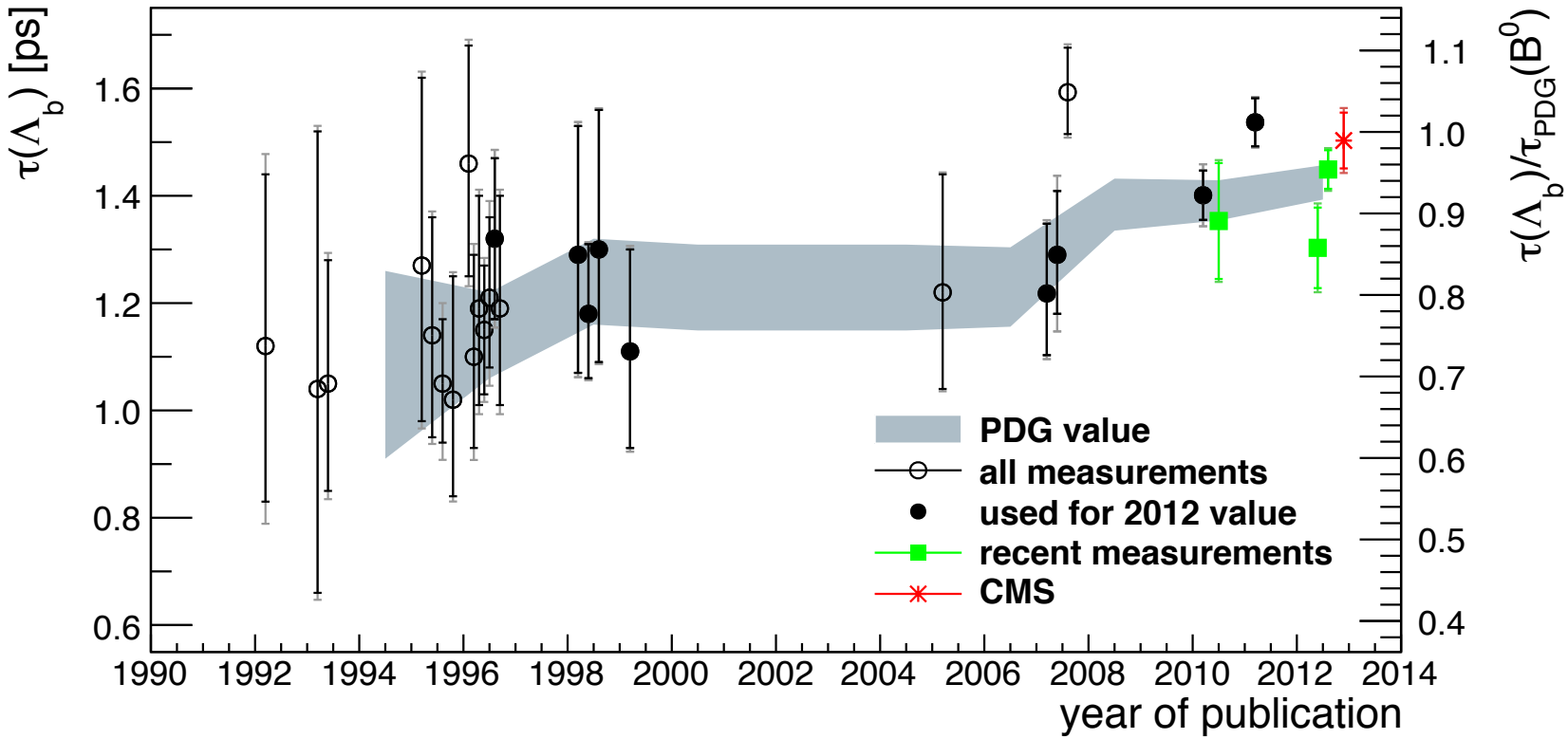
More recent measurements changed the picture.

Evolution of $\tau(\Lambda_b^0)$ measurements



And it looks like it converges.

Evolution of $\tau(\Lambda_b^0)$ measurements



This measurement fits in the picture.