Measurements of b-hadron lifetimes and effective lifetimes at LHCb

On behalf of the LHCb Collaboration

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Outline

- ➢ b-hadron lifetimes: a little bit about HQE
- ➢ B_s effective lifetime measurements in different decay modes
- ➢ Precision measurement of the Λ_b baryon lifetime in $J/\psi\ pK^-$ final state

All measurements are based on 1 fb^{-1} of LHCb data

b-hadron lifetimes: theory

- The decay of b-flavored hadrons are dominated by the weak decay of the b quark
- If the contribution of lighter quarks are ignored, all b-flavored hadrons have the same lifetime $\tau_{B^0} \sim \tau_{B^+} \sim \tau_{B_s^0} \sim \tau_{\Lambda_b^0}$
- Presence of the spectator quarks causes the lifetime difference
- Most useful theoretical tool for numerical prediction, is the Heavy Quark Expansion (HQE)
  - Predicts the properties of hadrons containing a heavy quark
  - Allow us to extract the CKM matrix element $|V_{ub}|$ and $|V_{cb}|$ from measurements of inclusive semileptonic B meson decays.

HQE Predictions

$$\frac{\tau(B^-)}{\tau(B_d)} = 1 + O(1/m_b^3)\,,$$
$$\frac{\tau(B_s)}{\tau(B_d)} = (1.00 \pm 0.01) + O(1/m_b^3)\,,$$
$$\frac{\tau(\Lambda_b)}{\tau(B_d)} = 0.98 + O(1/m_b^3)\,.$$

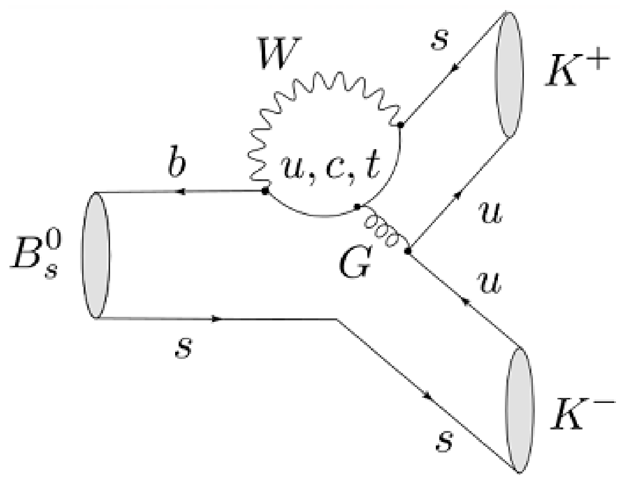
Neubert, Sachrajda
NPB 483,339(1997)

$B_s \rightarrow K^+K^-$ effective lifetime (i)

- The decay $B_s \rightarrow K^+K^-$ is dominated by a penguin diagram and hence sensitive to the physics beyond the SM at loop level.
- The final state K^+K^- is a CP-even eigenstate, so in the SM the decay is produced by the light (L) B_s mass eigensate

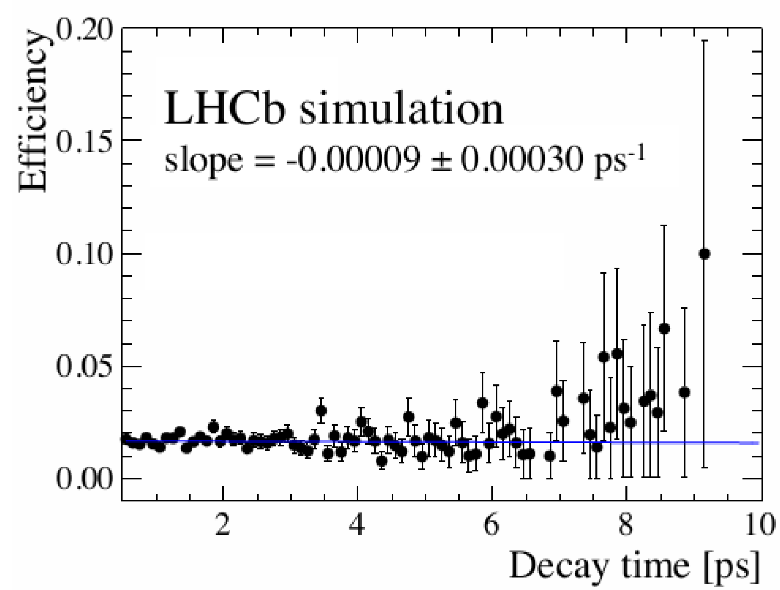
$\Rightarrow$ **$\tau_{KK} = \tau_L$**, assuming no CP violation

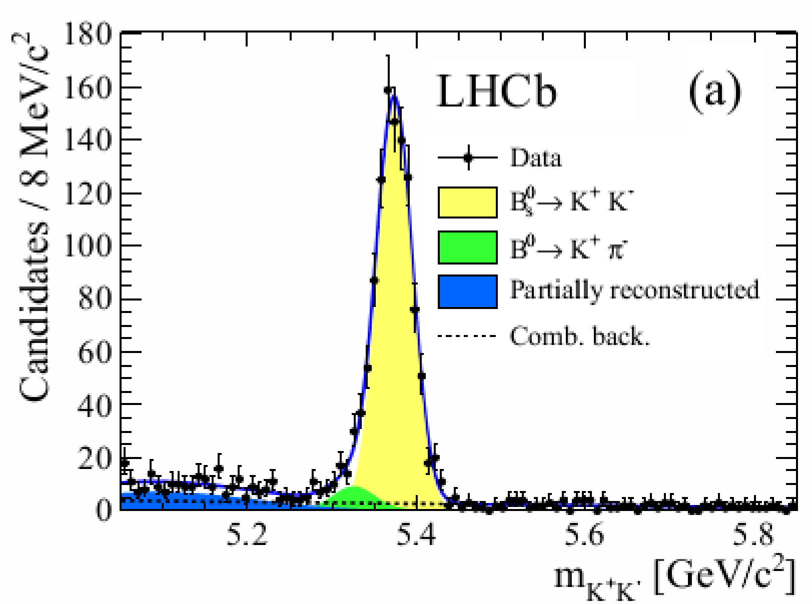
- In the SM the effective lifetime is predicted to be τ_{KK} = 1.40±0.02 ps (Eur. Phys.J C71,1532)



$B_s \to K^+K^-$ effective lifetime (ii)

- Analysis uses minimal lifetime biasing selection
  - No selections on lifetime biasing variables like impact parameters or flight distance
  - decay time >0.5 ps is used to avoid the potential edge effect introduced by the trigger requirement decay time >0.3 ps
- Trigger and event selections are based on the Neural Network
- Flat acceptance verified on simulation

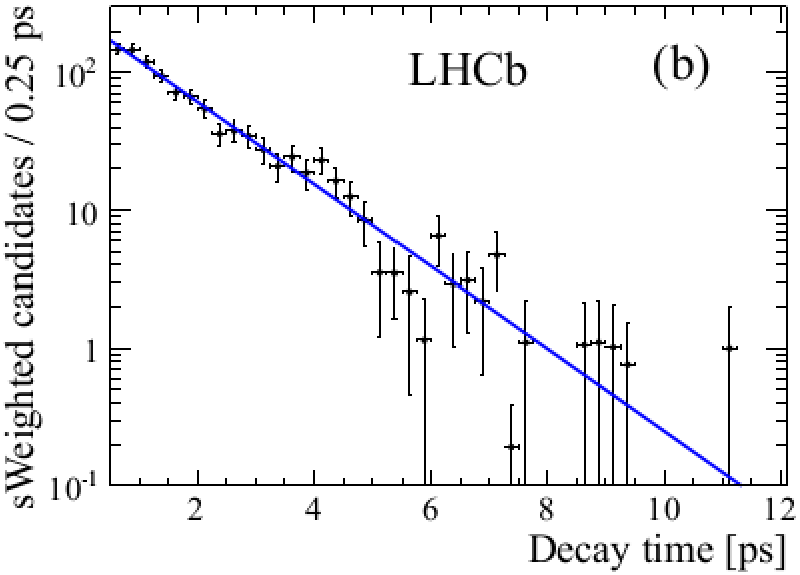




- Mass fit is performed to determine the sWeights to isolate signal decay time distribution from the residual background.
- There are 997± 34 $B_s \to K^+K^-$ decays after full selection

$B_s \to K^+K^-$ effective lifetime (iii)

World's best



τ_{KK} = 1.455 ± 0.046 ± 0.006 ps

Published in PLB 716, 393 (2012)

Agrees the SM prediction very well, consistent with previous independent LHCb measurement using 37 pb^{-1} data. (PLB 707, 349)

Systematic sources	Uncertainty on τ_{KK} [fs]
Reconstruction efficiency	5
Signal model	1
Background model	1
Length scale	1
Minimum decay time requirement	1
Production asymmetry	2
Total	6

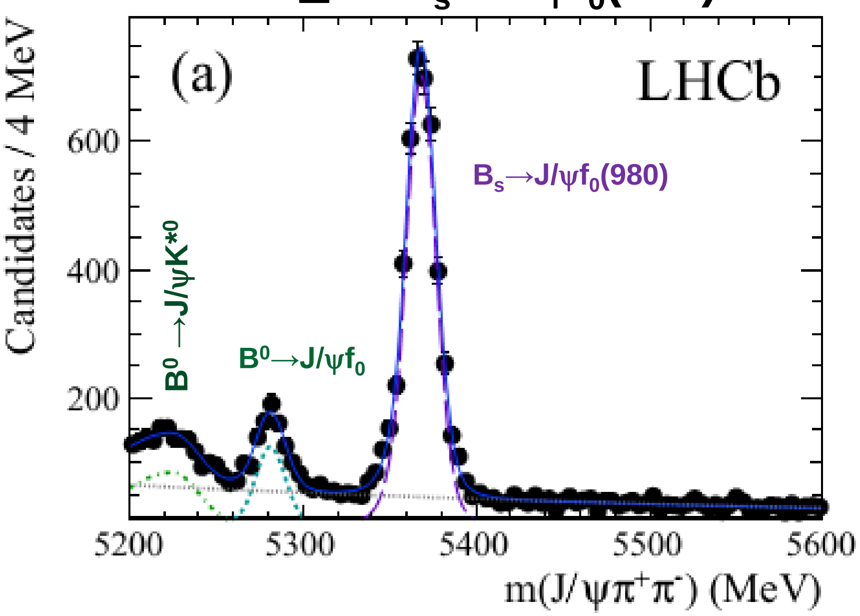
$B_s \rightarrow J/\psi\ f_0(980)$ effective lifetime (i)

- The final state $J/\psi\ f_0(980)$ is a CP-odd eigenstate.
- Measured CP violation in this final state is small, hence can be produced by the decay of heavy (H) B_s mass eigensate.

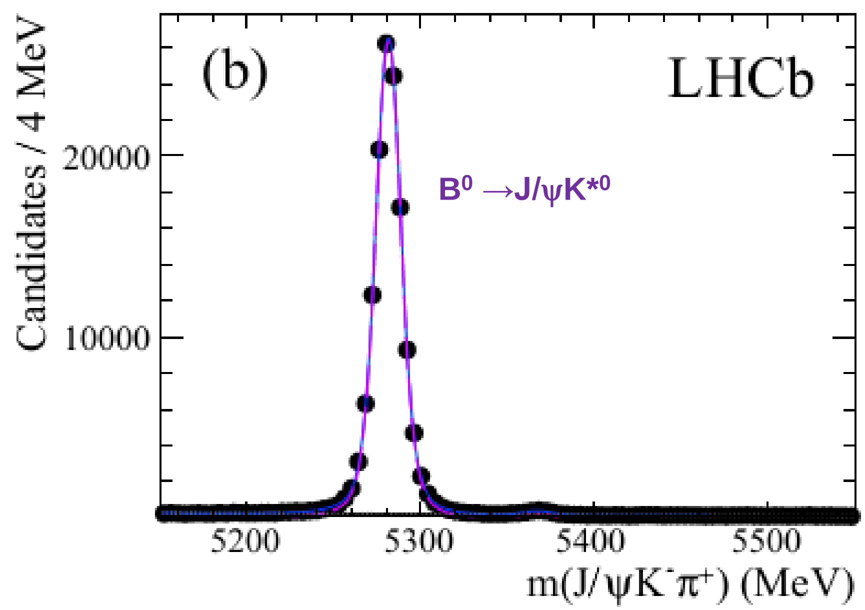
$\Rightarrow \tau_{J/\psi f0} = \tau_H$, assuming no CP violation

- Lifetime measured relative to $B^0 \rightarrow J/\psi K^{*0}$
  - Both decay channels have similar kinematics, hence most of the systematic cancel in ratio

4040±75 $B_s \rightarrow J/\psi f_0(980)$

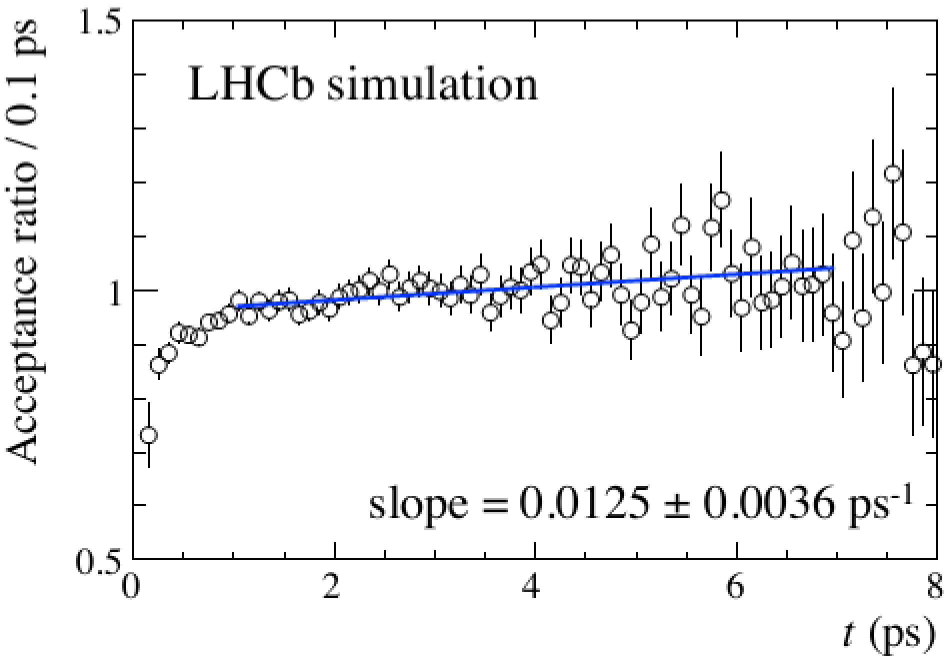


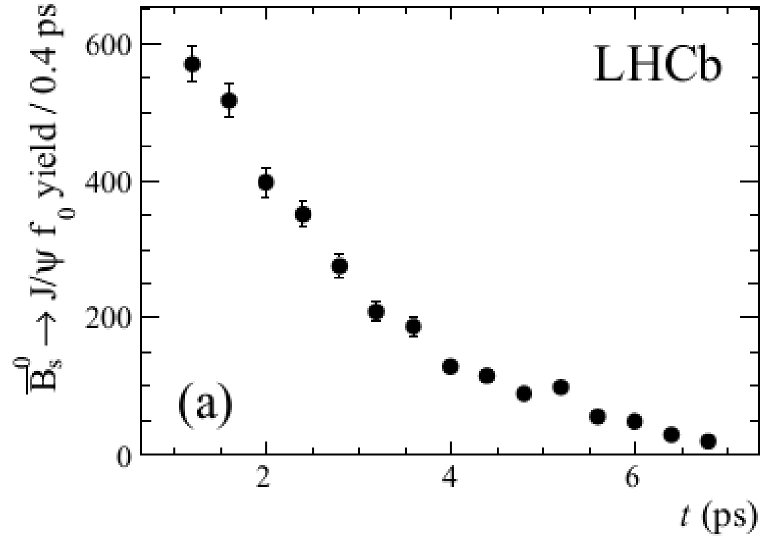
131920±400 $B^0 \rightarrow J/\psi K^{*0}$

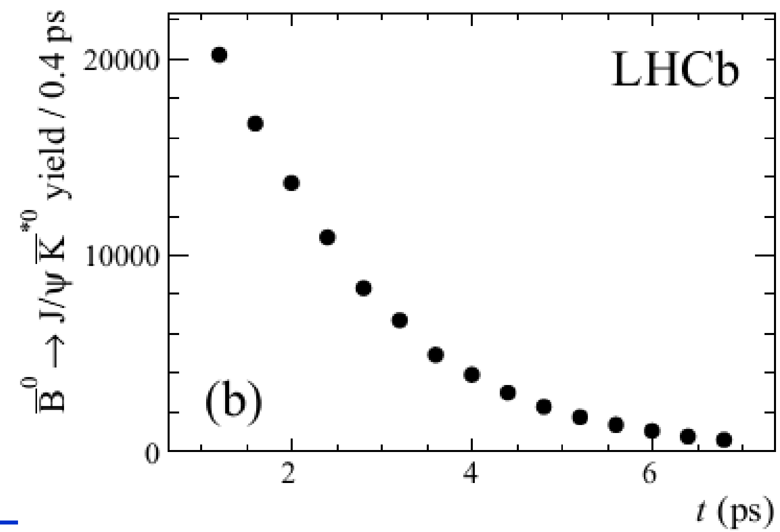


$B_s \to J/\psi\, f_0(980)$ effective lifetime (ii)

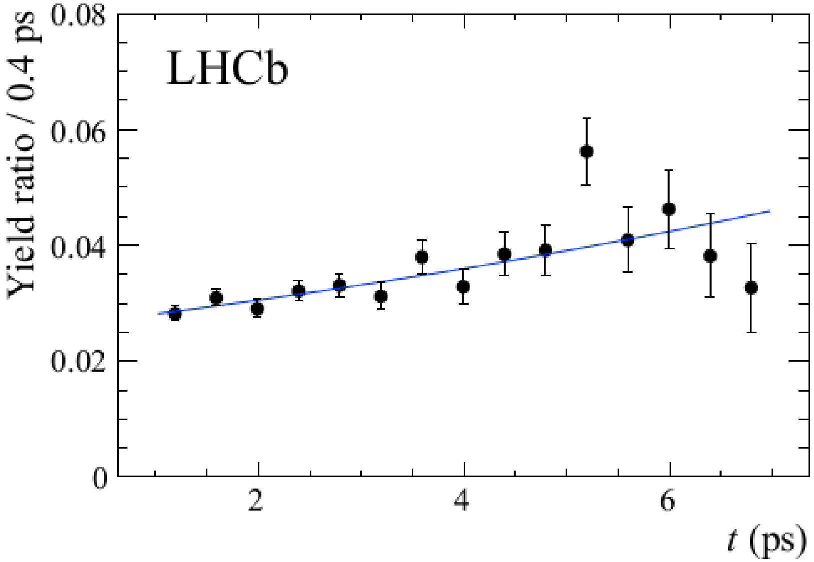
- Multivariate selections are used
- Compare the signal yields in 15 bins of decay time
- Ratio of acceptances is consistent with straight line above 1.0 ps, which is taken into account







$B_s \to J/\psi\, f_0(980)$ effective lifetime (iii)



Fit for the width difference, $1/\tau_{J/\psi f0}$ $-1/\tau_{J/\psi K^*}$

$1/\tau_{J/\psi f0} - 1/\tau_{J/\psi K^*} = -0.070 \pm 0.014 \pm 0.001$ ps^{-1}

$\tau_{J/\psi f0} = 1.700 \pm 0.040 \pm 0.026$ ps

World's best

$\Gamma_H = 0.588 \pm 0.014 \pm 0.009$ ps^{-1}
(with additional systematic due to possible non-zero ϕ_s)

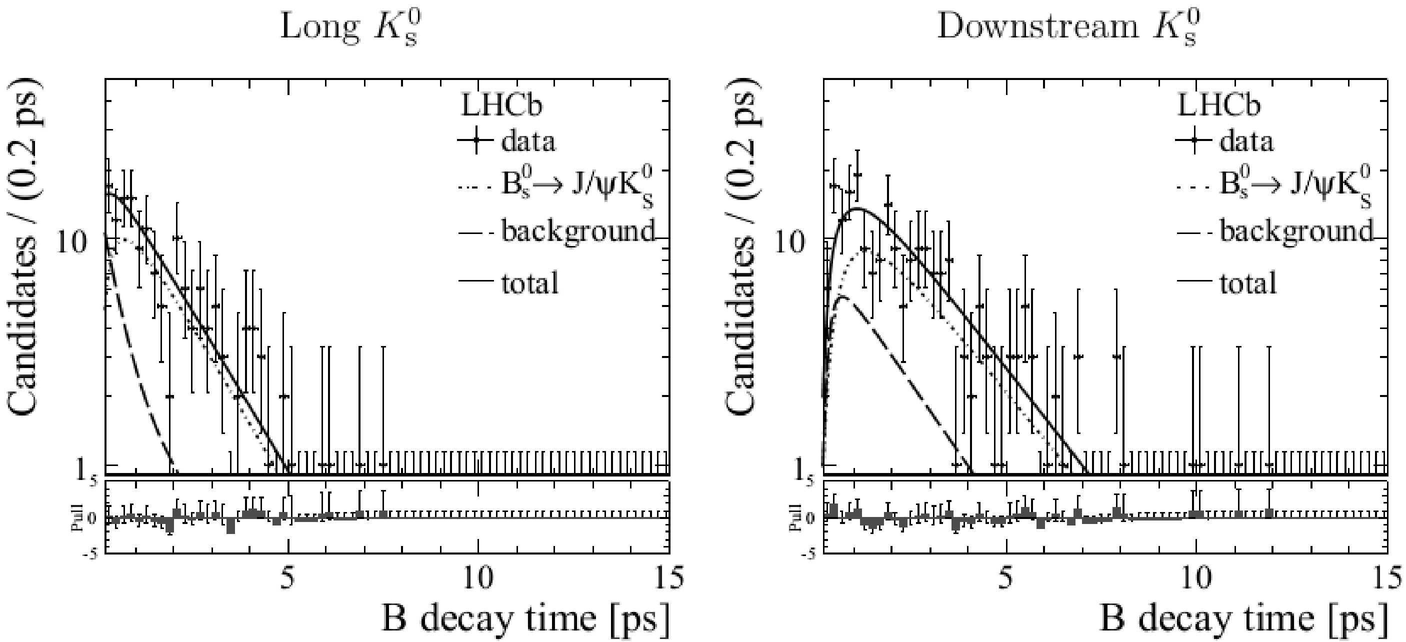
Published in PRL 109, 152002 (2012)

Systematic uncertainties

Source	Uncertainty (ps)
Signal mass shape	0.001
Background mass shape	0.010
Kaon identification	0.007
Acceptance	0.018
Statistical bias	0.012
CP-even component	0.001
$\overline{B}^0$ lifetime [17]	0.009
Sum in quadrature	0.026

$B_s \to J/\psi K_s$ effective lifetime

The final state $J/\psi K_s$ is another CP-odd eigenstate.



$\tau_{J/\psi Ks}$ = 1.75 ± 0.12 ± 0.07 ps

Measurement is consistent with the SM prediction,
$\tau_{J/\psi Ks}$ = 1.639±0.022 ps (Eur. Phys.J C71,1532)

Published in
NPB 873, 275 (2013)

$B_s \rightarrow J/\psi\ \phi$ and $B_s \rightarrow J/\psi\ \pi^+\pi^-$

- The final state in $J/\psi\phi$ is an admixture of CP even and CP odd. An angular analysis is used to separate different CP eigenstates.
- The final state $J/\psi\pi^+\pi^-$ is purely CP odd (>98% see PRD 86, 052006). No angular analysis is needed.

See the talk "Measurement of ϕ_s at LHCb" by Olivier Leroy for more details

From fit to $B_s \rightarrow J/\psi\ \phi$

$\Gamma_s = (\Gamma_H+\Gamma_L)/2 = 0.663 \pm 0.005 \pm 0.006\ ps^{-1}$

$\Delta\Gamma_s = (\Gamma_L-\Gamma_H) = 0.100 \pm 0.016 \pm 0.003\ ps^{-1}$

Simultaneous fit to $B_s \rightarrow J/\psi\ \phi$ and $B_s \rightarrow J/\psi\ \pi^+\pi^-$

$\Gamma_s = (\Gamma_H+\Gamma_L)/2 = 0.661 \pm 0.004 \pm 0.006\ ps^{-1}$

$\Delta\Gamma_s = (\Gamma_L-\Gamma_H) = 0.106 \pm 0.011 \pm 0.007\ ps^{-1}$

$\Delta\Gamma_s > 0$, implies the Heavy mass eigenstate lives longer.

Most precise measurement to date

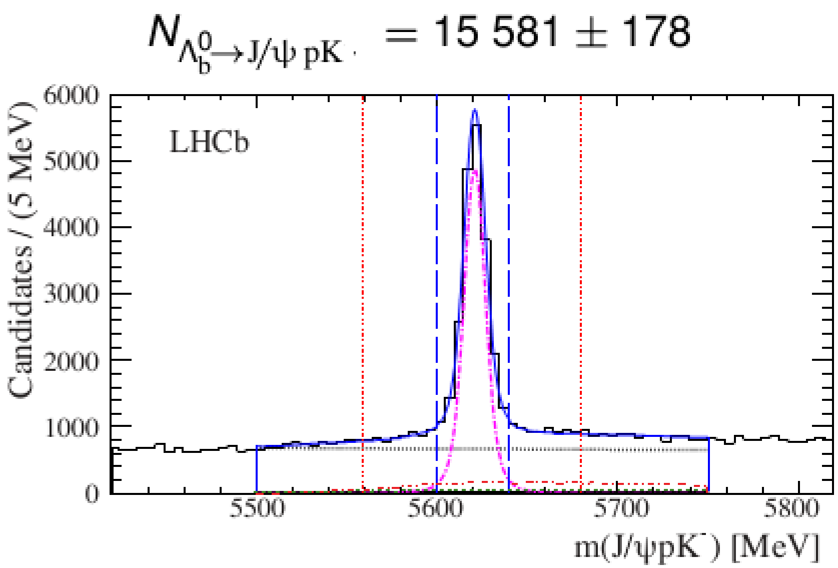
Published in PRD 87, 112010 (2013)

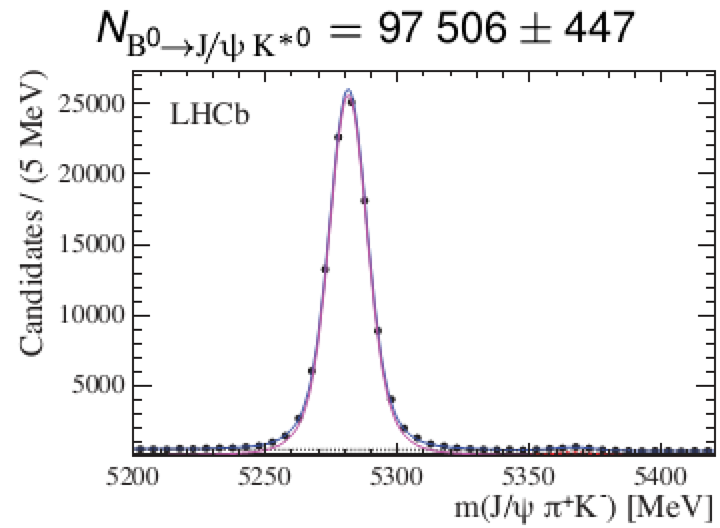
Λ_b lifetime

- One of the unsolved mystery of the b-hadron lifetime measurements was the Λ_b lifetime:
  - Long-standing discrepancy between theory and experiments
  - An early prediction from HQE was that the Λ_b lifetime was almost equal to that of the B^0 meson but shorter by 1–2%. (PRD 56, 2783; NPB 483, 339; PLB 379, 267; PLB 468, 143)
  - Predictions were challenged by LEP measurements: 2002 CKM average was

    $\tau_{\Lambda b}/\tau_{B0}$ = 0.798±0.052 (arXiv/hep-ph:0304132)
  - Subsequent (controversial) calculations lowered the expected values of $\tau_{\Lambda b}/\tau_{B0}$ to get closer to the data. (PRD 68, 114006; PRD 70, 094031; PTP 99, 271)
  - More recent measurements from CDF, ATLAS and CMS using $\Lambda_b \rightarrow J/\psi \Lambda^0$ have indicated larger values but with relatively large uncertainties.

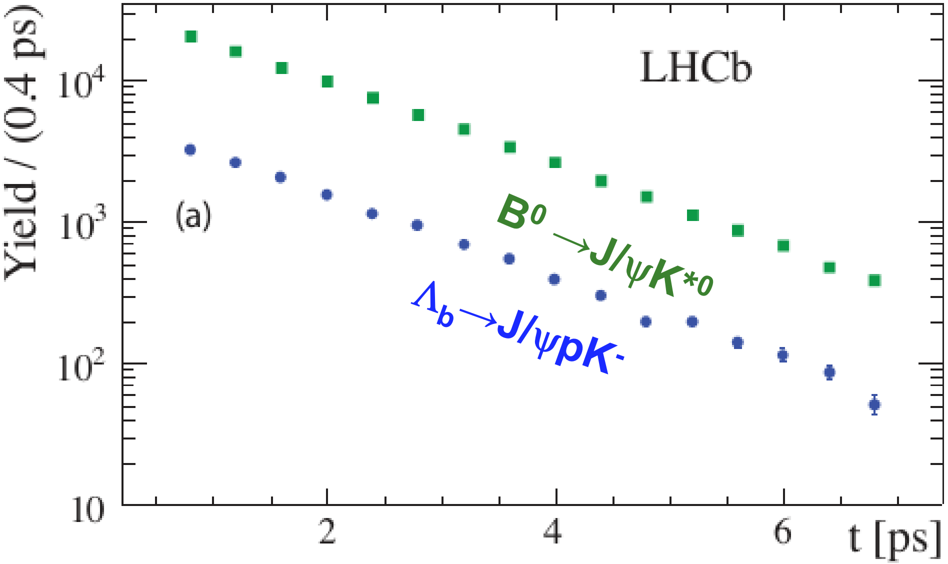
$\Lambda_b \rightarrow J/\psi p K^-$ lifetime (i)



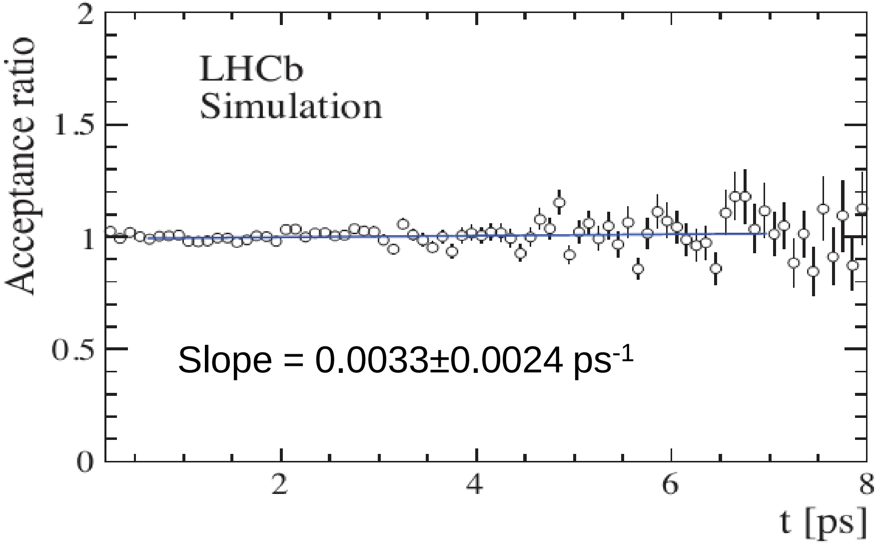


- Multivariate selections are used
- No selections on lifetime biasing variables like impact parameters or flight distance
- First observation of the decay mode $\Lambda_b \rightarrow J/\psi p K^-$, branching fraction measurement is under study
- The method is similar to that used $B_s \rightarrow J/\psi f_0(980)$ effective lifetime measurement. (PRL 109, 152002)

$\Lambda_b \rightarrow J/\psi p K^-$ lifetime (ii)

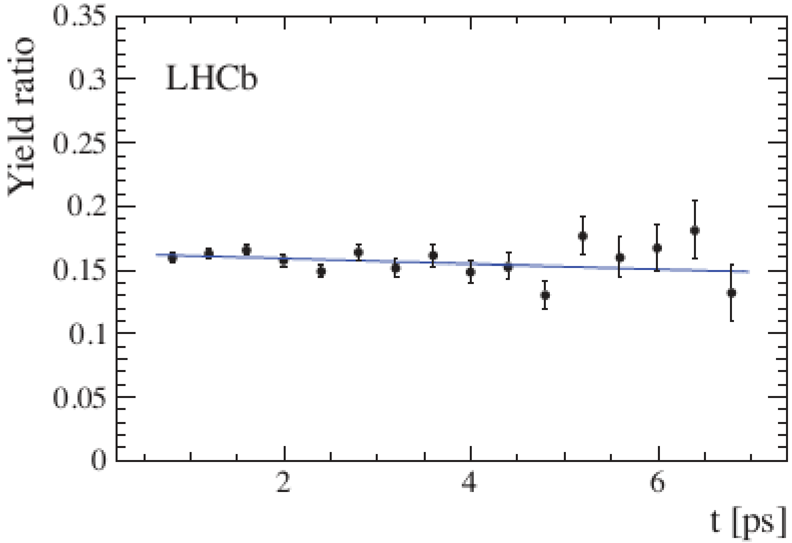


Samples are partitioned in 16 bins of decay time.



Ratio of acceptances is flat verified on simulation

$\Lambda_b \rightarrow J/\psi p K^-$ lifetime (ii)

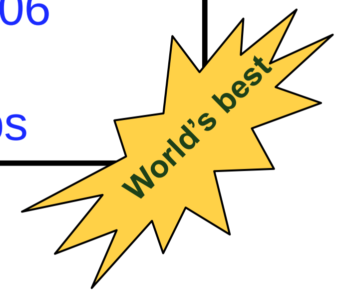


Fit for the width difference, $1/\tau_{\Lambda b} - 1/\tau_{B0}$

$1/\tau_{\Lambda b} - 1/\tau_{B0} = 16.4 \pm 8.2 \pm 4.4\ \text{ns}^{-1}$

$\tau_{\Lambda b}/\tau_{B0} = 0.976 \pm 0.012 \pm 0.006$

$\tau_{\Lambda b} = 1.482 \pm 0.018 \pm 0.012\ \text{ps}$

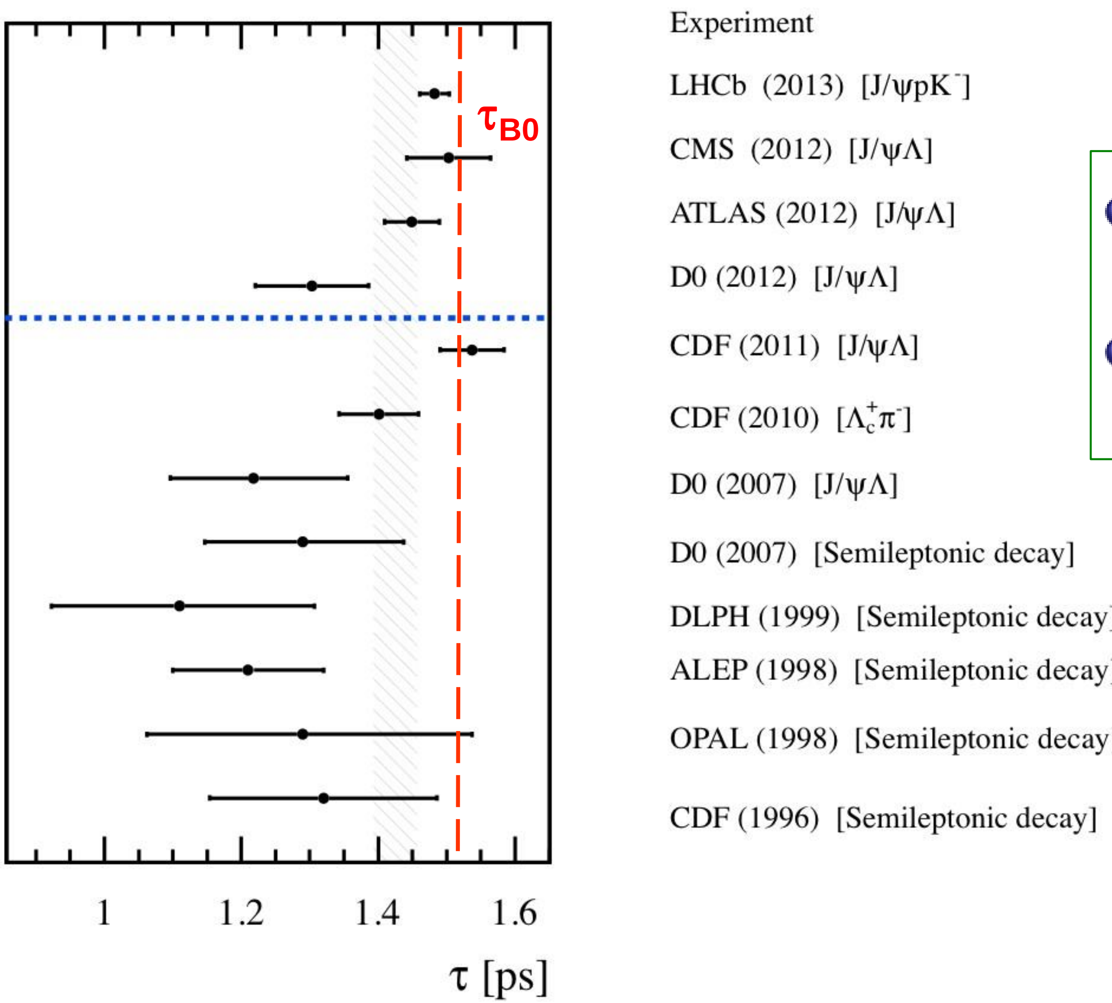


Accepted by PRL
(arXiv:1307.2476)

Systematic uncertainties

Source	$\Delta_{\Lambda B}$ (ns^{-1})	$\tau_{\Lambda_b^0}/\tau_{\overline{B}^0}$	$\tau_{\Lambda_b^0}$ (fs)
Decay time fit range	3.2	0.0045	6.9
Acceptance slope	2.3	0.0033	5.0
Signal shape	1.4	0.0021	3.2
Background model	1.2	0.0017	2.6
pK helicity	0.1	0.0002	0.2
Acceptance function	0.1	0.0001	0.2
$\overline{B}^0$ lifetime	-	0.0001	6.8
Total	4.4	0.0062	11.7

Λ_b lifetime comparison



- Agrees with previous world average
- Most precise measurement to date

Conclusions

- The effective lifetime measurement of B_s meson in various decay modes and the precision lifetime measurement of Λ_b baryon in $J/\psi\, pK^-$ final state are presented:

Effective lifetime of B_s meson

$\tau_{KK} = 1.455 \pm 0.046 \pm 0.006$ ps

$\tau_{J/\psi f0} = 1.700 \pm 0.040 \pm 0.026$ ps

$\tau_{J/\psi Ks} = 1.75 \pm 0.12 \pm 0.07$ ps

Simultaneous fit to $B_s \to J/\psi\, \phi$ and $B_s \to J/\psi\, \pi^+\pi^-$

$\Gamma_s = (\Gamma_H + \Gamma_L)/2 = 0.661 \pm 0.004 \pm 0.006\ ps^{-1}$

$\Delta\Gamma_s = (\Gamma_L - \Gamma_H) = 0.106 \pm 0.011 \pm 0.007\ ps^{-1}$

→

$\tau(B_s) = 1.513 \pm 0.009 \pm 0.014$ ps

$\tau(B_s)/\tau(B^0) = 0.996 \pm 0.006 \pm 0.010$

$\Lambda_b \to J/\psi pK^-$

$\tau_{\Lambda b} = 1.482 \pm 0.018 \pm 0.012$ ps

$\tau_{\Lambda b}/\tau_{B0} = 0.976 \pm 0.012 \pm 0.006$

- Some other lifetime measurements are in progress…

Thank you