Lifetime and mass measurements at LHCb

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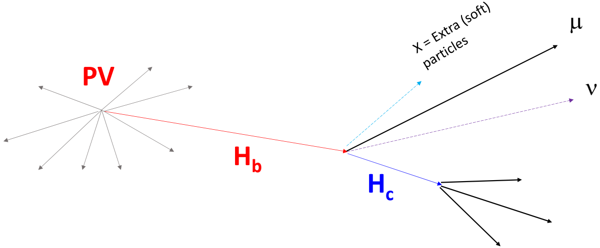
Lifetime measurements at LHCb

- LHCb can perform very precise relative lifetime measurements of mesons and baryons.
- Common technique: Fit the decay time spectrum of particle H with a template function to extract the lifetime. *e.g.*
- $S(t_{\text{rec}}) = f(t_{\text{rec}}) \cdot g(t_{\text{rec}}) \cdot \beta(t_{\text{rec}})$
    - $f(t_{\text{rec}})$: Signal template from simulation with full selection applied
    - $g(t_{\text{rec}}) \equiv \frac{e^{-t_{\text{rec}}/\tau_{\text{fit}}}}{e^{-t_{\text{rec}}/\tau_{\text{sim}}}}$, where τ_{fit} is fitted for.
    - $\beta(t_{\text{rec}})$: To account for difference between data and simulation in track reconstruction for tracks far from the beam line.
- And then use a well-measured decay-time of an abundant resonance to normalize to.

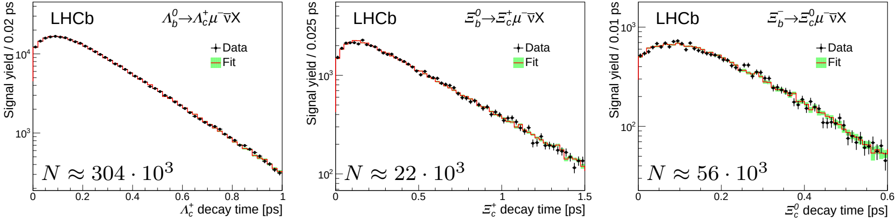
Charm hadron lifetimes (I)



- Lifetime measurements are an important to the Heavy Quark Expansion (HQE), as sub-leading terms are sensitive to spectator quark masses.
- Λ_c^+, Ξ_c^+ and Ξ_c^0 lifetimes last measured almost 20 years ago with limited statistics.
- Use semileptonic decays of Λ_b^0, Ξ_b^+ and Ξ_b^0 baryons:
    - Large number of events and relatively low background due to displacement.

[Phys. Rev. D 100, 032001]

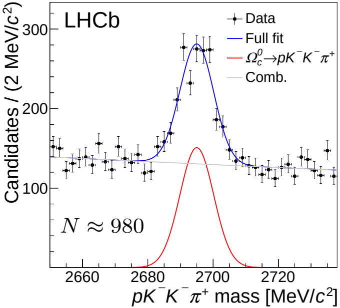
Charm hadron lifetimes (II)

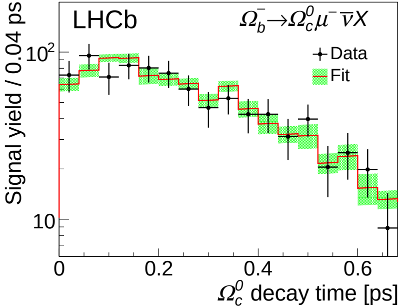


- Measure $r_{H_c} \equiv \frac{\tau_{H_c}}{\tau_{D^+}}$ with as simultaneous fit to r_{H_c} and D^+ lifetime, to cancel systematic effects
- Use template from simulation, and fit for the lifetime difference between simulation and data.
- Using the known D^+ lifetime:
  - $\tau_{\Lambda_c^+} = (203.5 \pm 1.0 \pm 1.3 \pm 1.4)$ fs
  - $\tau_{\Xi_c^+} = (456.8 \pm 3.5 \pm 2.9 \pm 3.1)$ fs
  - $\tau_{\Xi_c^0} = (154.5 \pm 1.7 \pm 1.6 \pm 1.0)$ fs
- Most precise measurements to date.

$3\,\text{fb}^{-1}$ @ $7, 8$ TeV

Ω_c lifetime (I)

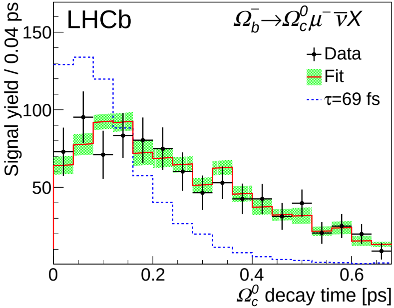


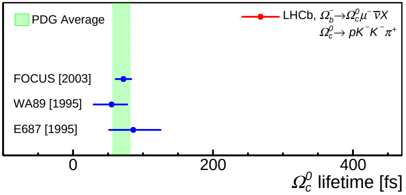


- Use the same strategy with $\Omega_c(\to pK^-K^-\pi^+)$ from $\Omega_b \to \Omega_c \mu\nu X$ decays
- $\tau_{\Omega_c} = (268 \pm 24 \pm 10 \pm 2)$ fs

$3\,\text{fb}^{-1}$ @ 7, 8 TeV

Ω_c lifetime (II)

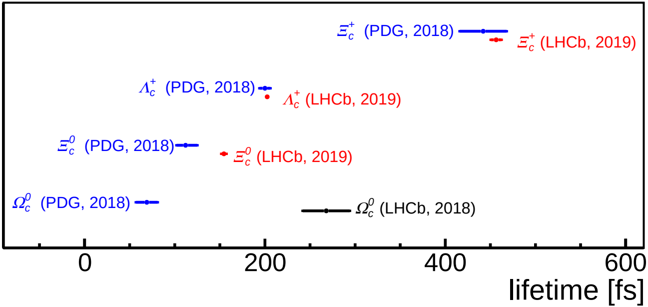




- World average value: (69 ± 12) fs,
- *i.e.* $\approx$ 4x smaller....

$3\,\text{fb}^{-1}$ @ $7, 8\,\text{TeV}$

Charm hadron lifetimes (III)

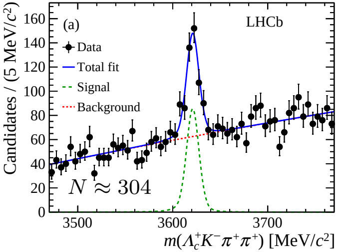


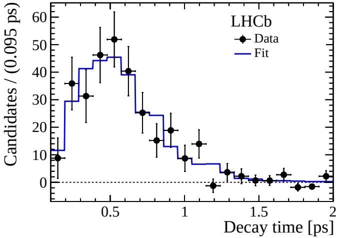
- Good agreement for Λ_c^+ and Ξ_c^+ values, 3.3σ discrepancy for Ξ_c^0, 4x larger value for Ω_c.
  - Expect: $\tau_{\Xi_c^+} > \tau_{\Lambda_c^+} > \tau_{\Xi_c^0} > \tau_{\Omega_c^0}$
  - Measured: $\tau_{\Xi_c^+} > \tau_{\Omega_c^0} > \tau_{\Lambda_c^+} > \tau_{\Xi_c^0}$,
- Could be due to smaller interference effect between spectator s and s from $c \to sW^+$, or a larger effect of additional higher-order contributions.

$3\,\mathrm{fb}^{-1}$@ $7, 8$ TeV

Ξ_{cc}^{++} lifetime

see Matt Needham's talk on spectroscopy





- Measure lifetime of $\Xi_{cc}^{++}(\to \Lambda_c^+ K^- \pi^+ \pi)$ with respect to $\Lambda_b^0 \to \Lambda_c^+ \pi^- \pi^+ \pi^-$
- $\tau_{\Xi_{cc}^{++}} = (0.256^{+0.024}_{-0.022} \pm 0.014)$ ps
- $\tau_{\Xi_{cc}^{+}}$ is predicted to be shorter by a factor 3∼4 (additional W exchange between c and s), can help in searching for the state.

$1.7\,\text{fb}^{-1}$ @ 13 TeV

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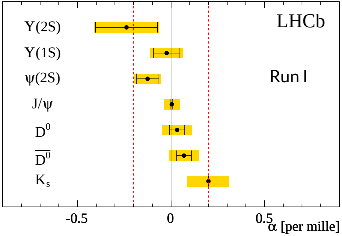
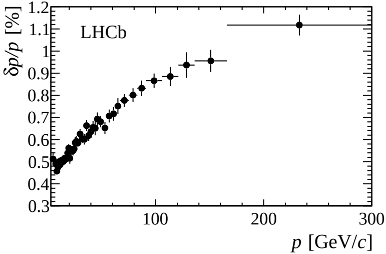
Mass measurements in LHCb

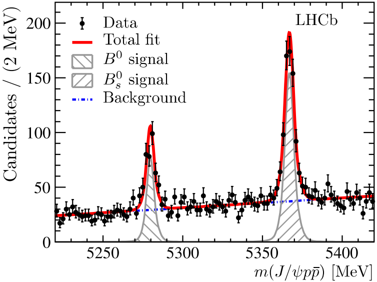


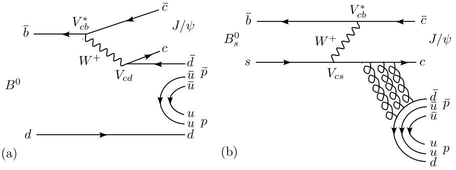


- LHCb has performed world's best mass measurements of many hadrons.
- Need to correct for non-unity momentum scale α: Fix scale at abundant resonance with well-measured mass (*e.g.* J/ψ), derive scale factor, check with other resonances.
  - About 0.03% uncertainty on scale factor for LHCb measurements.
- Find balance between decays with large number of events (*e.g.* $B^+ \to J/\psi\, K^+$) and decays with small Q-value.

[Phys. Rev. Lett. 122, 191804]

Mass measurements in $B^0/B_s^0 \to J/\psi\, p\bar{p}$ (I)





- First observation of the decays $B^0_{(s)} \to J/\psi\, p\bar{p}$.
- $\mathcal{B}(B^0 \to J/\psi\, p\bar{p}) = (4.51 \pm 0.40 \pm 0.44) \cdot 10^{-7}$
- $\mathcal{B}(B_s^0 \to J/\psi\, p\bar{p}) = (3.58 \pm 0.19 \pm 0.39) \cdot 10^{-6}$: much higher than expected $\mathcal{O}(10^{-9})$
  - Resonant contribution?
- Very small Q value: Can do precise mass measurements.

$5.2\,\text{fb}^{-1}$ @ $7, 8, 13\,\text{TeV}$

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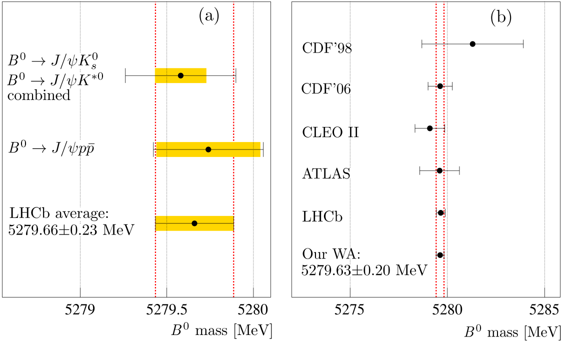
[Phys. Rev. Lett. 122, 191804]

Mass measurements in $B^0 \to J/\psi\, p\bar{p}$ (II)

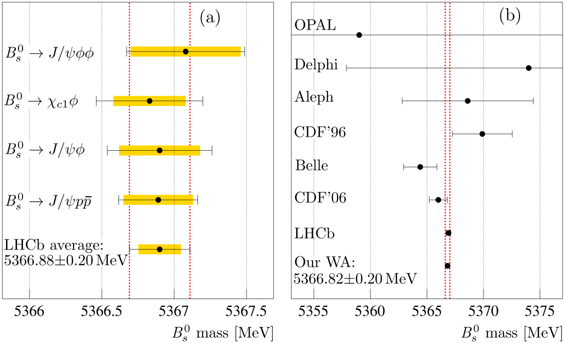


- Most precise single B^0 mass measurement (from LHCb and worldwide).

$5.2\,\text{fb}^{-1}$ @ 7, 8, 13 TeV

[Phys. Rev. Lett. 122, 191804]

Mass measurements in $B_s^0 \to J/\psi\, p\bar{p}$ (III)



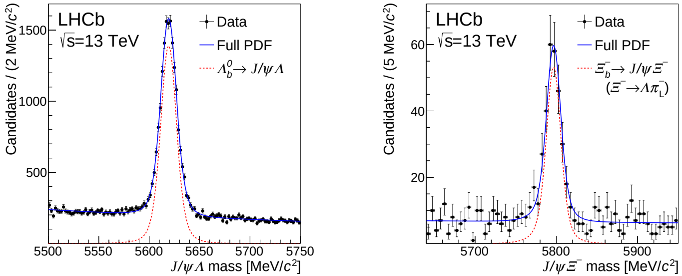
- Most precise single B_s^0 mass measurement (from LHCb and worldwide).

$5.2\,\mathrm{fb}^{-1}$ @ $7, 8, 13\,\mathrm{TeV}$

[Phys. Rev. D 99, 052006]

Ξ_b^- mass measurement

see Marcello Rotondo's talk for the production measurements



- Measure the mass difference between Λ_b^0 and Ξ_b^- baryons, using the $\Lambda_b^0 \to J/\psi\, \Lambda$ and $\Xi_b^- \to J/\psi\, \Xi$ decays.
  - $\delta m = (177.30 \pm 0.39 \pm 0.15)\ \mathrm{MeV}/c^2$
  - $m(\Xi_b^-) = (5796.70 \pm 0.39 \pm 0.15 \pm 0.17)\ \mathrm{MeV}/c^2$
- Most precise measurement of $m(\Xi_b^-)$ to date, in agreement with previous measurements.

$4.6\,\mathrm{fb}^{-1}$ @ 7, 8, 13 TeV

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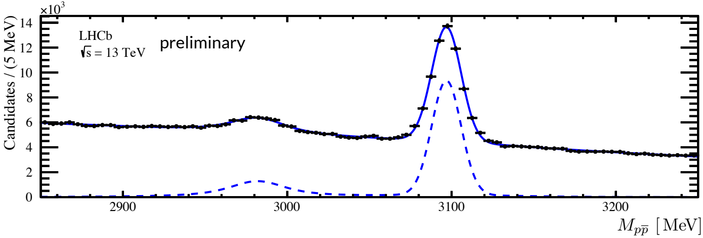
J/ψ and η_c mass difference



- Use non-prompt $\eta_c \to p\overline{p}$ and $J/\psi \to p\overline{p}$ decays to determine the mass difference.
    - Separate prompt and non-prompt with pseudo-proper lifetime $t_z = \frac{\Delta z M_{p\overline{p}}}{p_z} > 80$ fs and PV displacement of protons.
- $\Delta M = (113.0 \pm 0.7)\ \mathrm{MeV}/c^2$, uncertainty completely dominated by statistical uncertainty. Most precise single measurement so far.
- Value is in good agreement with all previous measurements.

$2\,\mathrm{fb}^{-1}$ @ 13 TeV

[magnolia]

Conclusion

- LHCb performed several world's best measurements of hadron lifetimes and masses.
- Most of them are compatible with the world averages, notable exception: Ω_c lifetime is $4\times$ larger than the previously measured value.
- Several measurements are still statistically limited.

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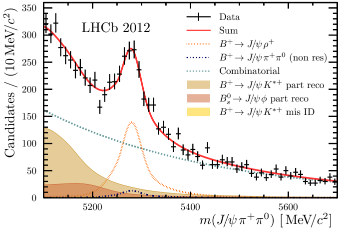
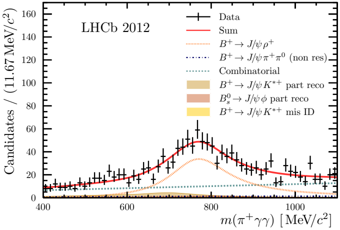
[EPJC 79 (2019) 537]

$B^+ \to J/\psi\,\rho^+$



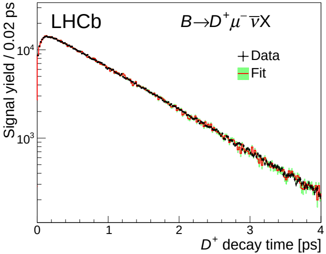


- Measure branching ratio and CP asymmetry of $B^+ \to J/\psi\,\rho^+$, with respect to $B^+ \to J/\psi\,K^+$
- 2D fit to $m(J/\psi\,\pi^+\pi^0)$ and $m(\pi^+\gamma\gamma)$ mass to separate P-wave, S-wave and background.
  - $\mathcal{B}(B^+ \to J/\psi\,\rho^+) = 3.81^{+0.25}_{-0.24} \pm 0.35) \cdot 10^{-5}$
  - $\mathcal{A}^{CP}(B^+ \to J/\psi\,\rho^+) = -0.045^{+0.056}_{-0.057} \pm 0.008$

$3\,\text{fb}^{-1}$ @ $7, 8$ TeV

[Phys. Rev. Lett. 121, 092003] [Phys. Rev. D 100, 032001]

Charm hadron lifetimes suppl.



Source	$r_{\Lambda_c^+}$	$r_{\Xi_c^+}$	$r_{\Xi_c^0}$
Decay-time acceptance	6	13	4
H_c lifetime	4	4	12
H_b lifetime	1	3	0
H_b production spectra	2	4	1
Background subtraction	8	17	7
$H_c(\tau^-,\ D$, random $\mu^-)$	5	11	3
Simulated sample size	4	13	5
Total systematic	13	28	16
Statistical uncertainty	10	34	17

Source	$r_{^0_c}$ (10^{-4})
Decay-time acceptance	13
$\bar{b}$ prod. spectrum	3
$\bar{b}$ lifetime	4
Decay-time resolution	3
Background subtraction	18
$H_c(\tau^-, D)$, random μ^-	8
Simulated sample size	98
Total systematic	101
Statistical uncertainty	230