Measurement of the lifetime of the doubly charmed baryon Ξ_{cc}^{++} at LHCb

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Outline

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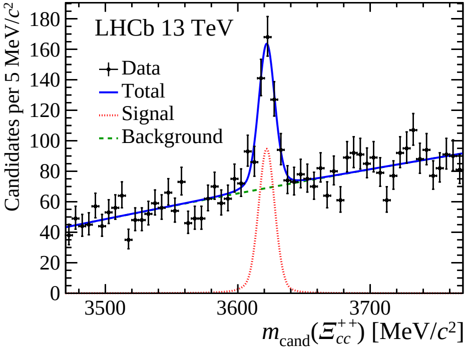
- Introduction
- Analysis strategy
- LHCb detector
- Data samples and selection
- Fit method and results
- Systematics and robustness checks
- Conclusion

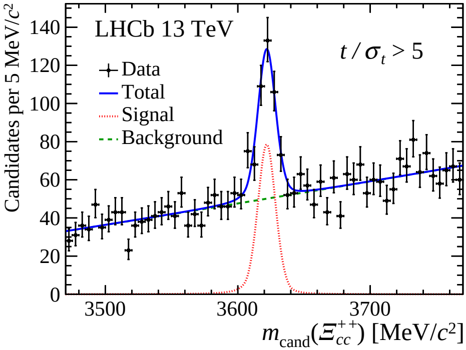
Observation of Ξ_{cc}^{++} at LHCb

PRL 119 (2017) 112001



- Measured mass of Ξ_{cc}^{++} consistent with theoretical predictions
  $3621.40 \pm 0.72\,(\mathrm{stat}) \pm 0.27\,(\mathrm{syst}) \pm 0.14\,(\Lambda_c^+)\,\mathrm{MeV}/c^2$
- Not in the same isospin-doublet as the SELEX "Ξ_{cc}^{+}" state
  $\Delta M = 103 \pm 2\,\mathrm{MeV}/c^2$

Motivation of the lifetime measurement



- Further confirm the observed state is the $J = 1/2$ Ξ_{cc}^{++}
- Necessary ingredient for theoretical predictions of BRs
- Provide info for experimental searches of doubly heavy baryons
- Test various predictions in QCD models

Predictions of lifetime of Ξ_{cc}^{++} ($J = 1/2$)

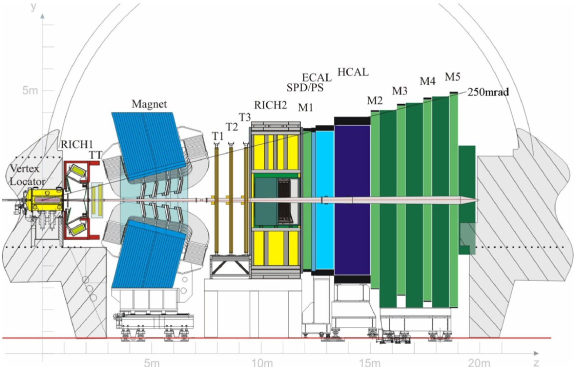
- In the range of $[0.20, 1.05]\,\mathrm{ps}$ (see backup for references)
  - Diquark model, effective constituent model, NRQCD potential model, harmonic oscillator model, etc.
  - Important roles of spectator
  - Pauli interference
- $\tau(\Xi_{cc}^{++}) \sim$ 3-4 $\times\, \tau(\Xi_{cc}^{+})$
  - Destructive Pauli interference in Ξ_{cc}^{++} decays
  - W^+ exchange between c and d quarks only in Ξ_{cc}^{+} decays

Analysis strategy

- The same data sample used for the mass measurement
  - Specific hardware trigger to ease efficiency estimation
- Measure decay time distribution relative to $\Lambda_b^0 \to \Lambda_c^+ \pi^- \pi^+ \pi^-$
  - Correct the difference in acceptances with simulated sample
- Weighted unbinned maximum likelihood fit
  - Use histograms for acceptances and Λ_b^0 decay time distributions
- Verify major systematics using resampling techniques

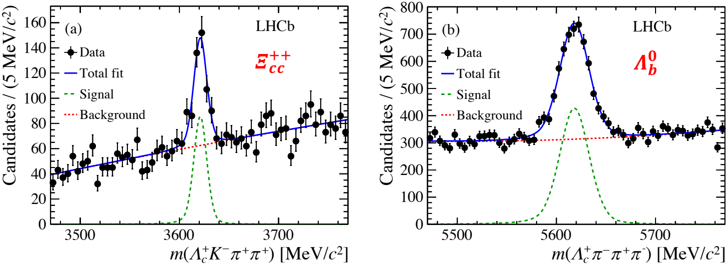
The LHCb detector

JINST 3 (2008) S08005, IJMPA 30 (2015) 1530022



- Excellent vertexing, tracking and hadron PID
  - Allow for precise measurement of decay time $t \equiv \frac{\vec{p}\cdot\vec{r}}{p^2} \times m$

Event selection



- 2016 data collected by LHCb, corresponding to $\mathcal{L} = 1.7\,\mathrm{fb}^{-1}$
- Hardware and dedicated software trigger
- Offline multivariate selection (multilayer perceptron)
- Signal: Gaussian + double-sided Crystal Ball
  Background: 2^{nd} order Chebychev
- $N_{\Xi_{cc}^{++}} = 304 \pm 35$, $N_{\Lambda_b^0} = 3397 \pm 119$

Signal PDF of Ξ_{cc}^{++} in data

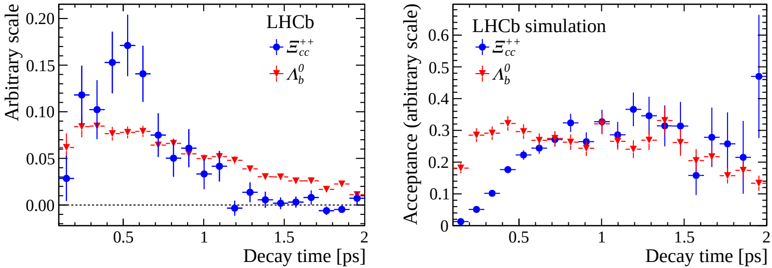
- Background subtracted with sPlot technique using the mass as discriminant
- Signal PDF

$$\mathcal{P}(t) = h_{\Lambda_b^0}(t) \times \frac{\varepsilon_{\Xi_{cc}^{++}}(t)}{\varepsilon_{\Lambda_b^0}(t)} \times \exp\left[-\left(\frac{t}{\tau_{\Xi_{cc}^{++}}} - \frac{t}{\tau_{\Lambda_b^0}}\right)\right]$$

where

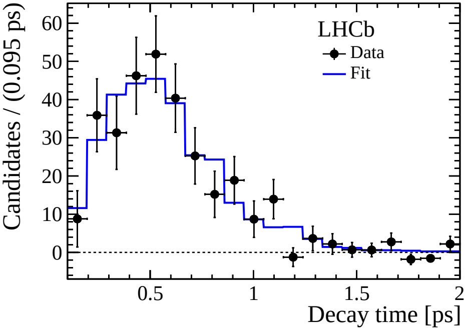
- $h_{\Lambda_b^0}(t)$: decay time distribution of Λ_b^0 data
- $\frac{\varepsilon_{\Xi_{cc}^{++}}(t)}{\varepsilon_{\Lambda_b^0}(t)}$: decay time acceptance ratio determined from simulated samples
- $\tau_{\Lambda_b^0} = 1.470 \pm 0.010\,\mathrm{ps}$: PDG value of Λ_b^0 lifetime

Decay time distributions and acceptances



- Decay time range: 0.1-2.0 ps in 20 even bins
- Backgrounds in data subtracted uisng sPlot technique using the mass as discriminant
- Acceptances determined using p_{T}-weighted simulated sample

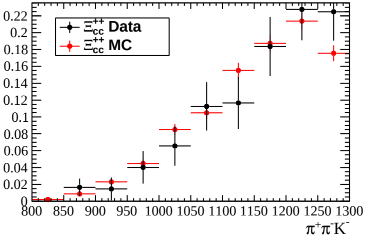
The fit result and statistical uncertainty

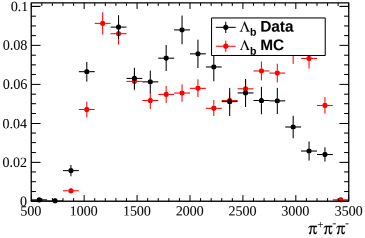


- The fit result: $\tau_{\Xi_{cc}^{++}} = 0.256^{+0.022}_{-0.020}\,\mathrm{ps}$
- Limited sample size of simulated and real data: $\sigma = 0.009\,\mathrm{ps}$
- $\tau_{\Xi_{cc}^{++}} = 0.256^{+0.024}_{-0.022}\,(\mathrm{stat})\,\mathrm{ps}$

Systematic uncertainty: resonant structure

- Weight the *hhh* mass of the simulated sample to background-subtracted data
- $\Delta\tau_{\Xi_{cc}^{++}} = 0.011\,\mathrm{ps}$





Summary of systematic uncertainties

Source	Uncertainty (ps)
Signal and background mass models	0.005
Correlation of mass and decay-time	0.004
Binning	0.001
Data-simulation differences	0.004
Resonant structure of decays	0.011
Hardware trigger threshold	0.002
Simulated Ξ_{cc}^{++} lifetime	0.002
Λ_b^0 lifetime uncertainty	0.001
Sum in quadrature	0.014

- Dominated by the resonant structure of decays
- Final result

$$\tau_{\Xi_{cc}^{++}} = 0.256^{+0.024}_{-0.022}\,(\mathrm{stat}) \pm 0.014\,(\mathrm{syst})\,\mathrm{ps}$$

- Statistical uncertainty dominates

Robustness checks

- Consistency between sub-samples
  - Electric charge
  - Magnetic polarity
  - Number of primary vertices
- Fitted Λ_b^0 lifetime to be $1.474 \pm 0.077\,\mathrm{ps}$, confirming that decay time acceptance is well-described by simulation
- Alternative fit result
  - Binnined χ^2 fit to the ratio of efficiency-corrected decay time distributions of Ξ_{cc}^{++} and Λ_b^0 decays
  - $\tau_{\Xi_{cc}^{++}} = 0.264^{+0.026}_{-0.023}\,(\mathrm{stat}) \pm 0.015\,(\mathrm{syst})\,\mathrm{ps}$

Conclusions

PRL 121 (2018) 052002

- First measurement of Ξ_{cc}^{++} lifetime

$$\tau_{\Xi_{cc}^{++}} = 0.256^{+0.024}_{-0.022}\,(\mathrm{stat}) \pm 0.014\,(\mathrm{syst})\,\mathrm{ps}$$

- Within theoretical prediction of $[0.20, 1.05]\,\mathrm{ps}$
- Further confirm the weakly decay nature of the observed Ξ_{cc}^{++}
- Imply $\tau_{\Xi_{cc}^{+}} \sim 0.060\text{-}0.090\,\mathrm{ps}$, important information for the Ξ_{cc}^{+} search

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Please Stay Tuned!

Backup

Predictions of Ξ_{cc}^{++} lifetime

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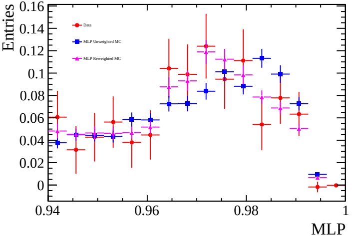
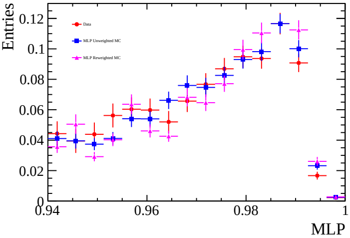
[16] C.-H. Chang, T. Li, X.-Q. Li, and Y.-M. Wang, *Lifetime of doubly charmed baryons*, Commun. Theor. Phys. **49** (2008) 993, arXiv:0704.0016.

[17] A. V. Berezhnoy and A. K. Likhoded, *Doubly heavy baryons*, Phys. Atom. Nucl. **79** (2016) 260, [Yad. Fiz. 79, 151 (2016)].

Systematic uncertainty: discrepency between simulated and real data

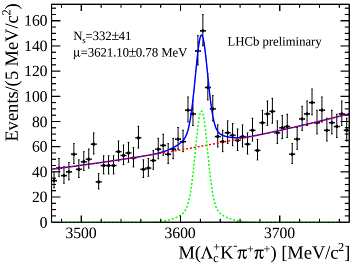
- Weight the MVA response of simulated sample to data
- $\Delta\tau_{\Xi_{cc}^{++}} = 0.004\,\mathrm{ps}$

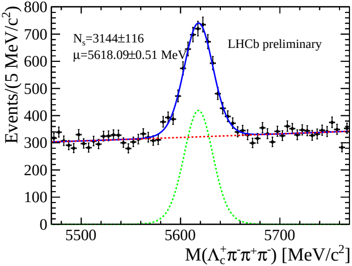




Systematic uncertainty: Models of mass fit

- Use alternative models
  Signal: double Gaussian
  Background: exponential
- $\Delta\tau_{\Xi_{cc}^{++}} = 0.005\,\mathrm{ps}$





Systematic uncertainty: decay-time and mass correlation

- Significant dependence of background mass slope parameter on decay-time
- Alternative sWeight calculation
  - Simultaneous mass fits in 4 bins of decay-time
  - Allow different background slopes
- $\Delta\tau_{\Xi_{cc}^{++}} = 0.004\,\mathrm{ps}$