Measurements with doubly-charmed baryon at LHCb

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2018年9月15日

Outline

- Introduction
- LHCb detector
- Recent results on charmed baryons
  - Rediscovery of Ξ_{cc}^{++}, with $\Xi_c^{+}\pi^{+}$
  - Ξ_{cc}^{++} lifetime measurement

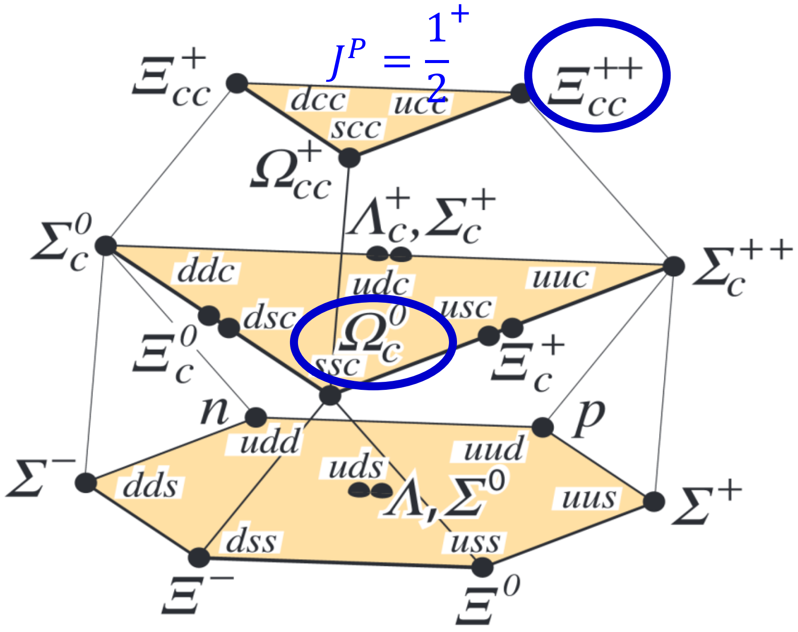
Submitted to PRL, arXiv: 1807.01919

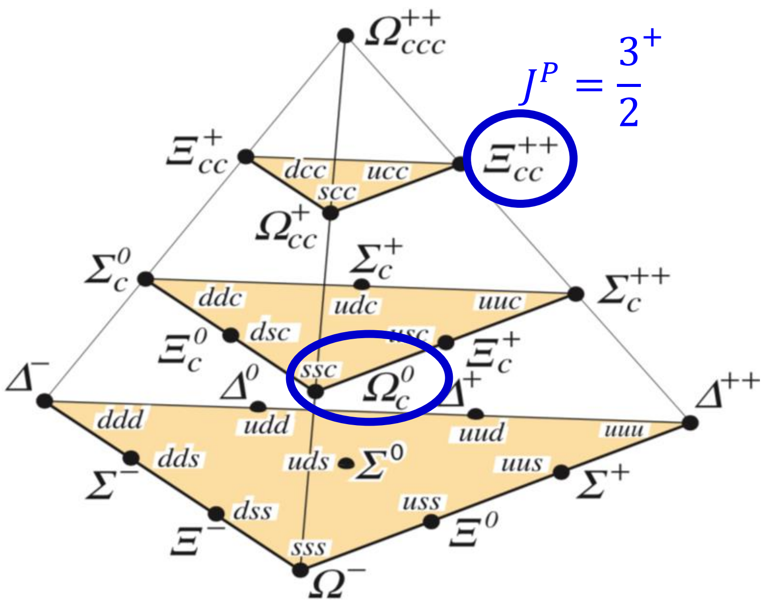
Phys. Rev. Lett. 121, 052002 (2018)

- Summary

Success of the constituent quark model

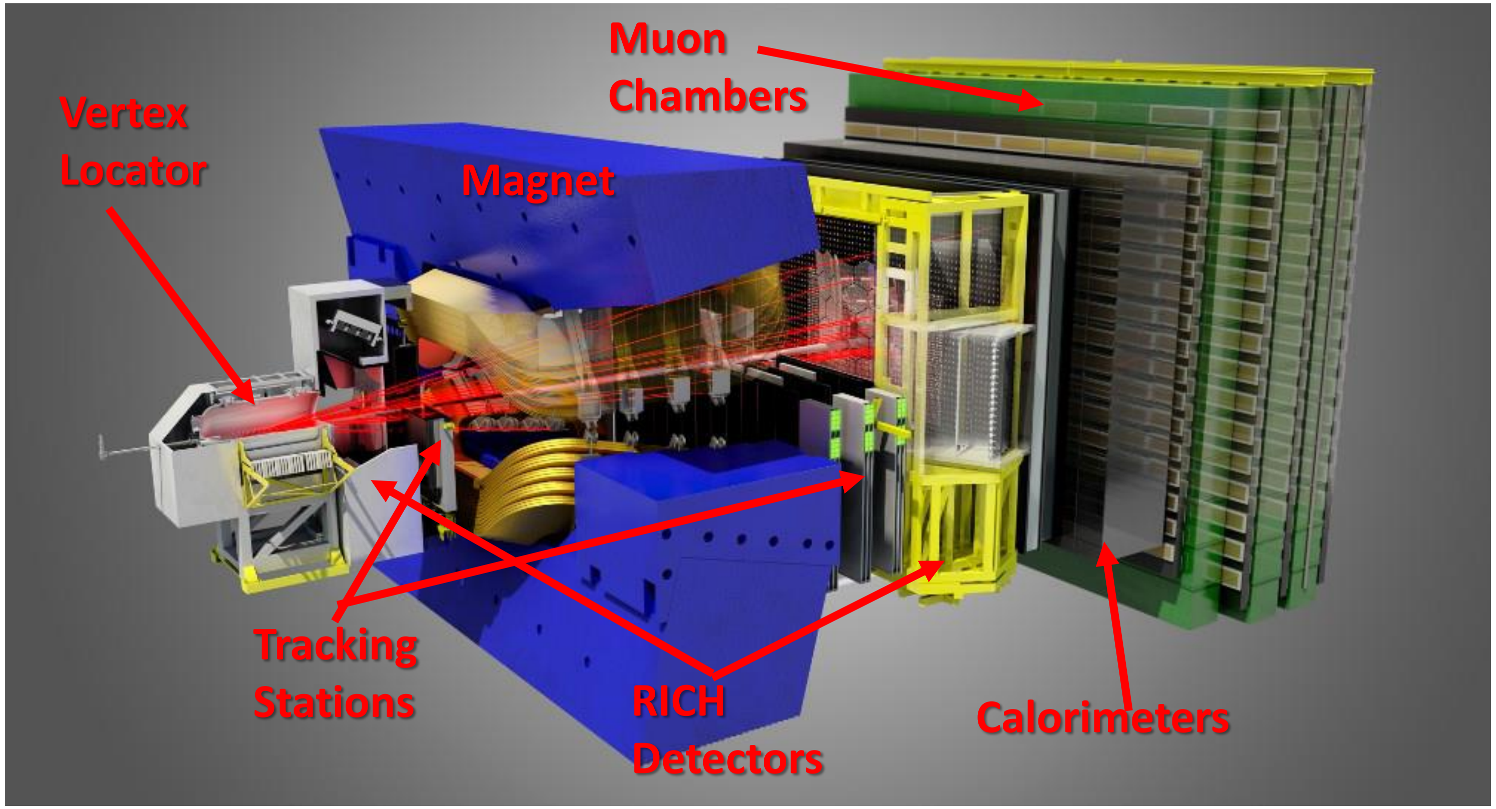
- Quark model, introduced by Gell-Mann and Zweig, in 1964
  - Construct the numerous hadrons using quarks
  - SU(4) and SU(5) to include new quarks: charm (c), and bottom (b)





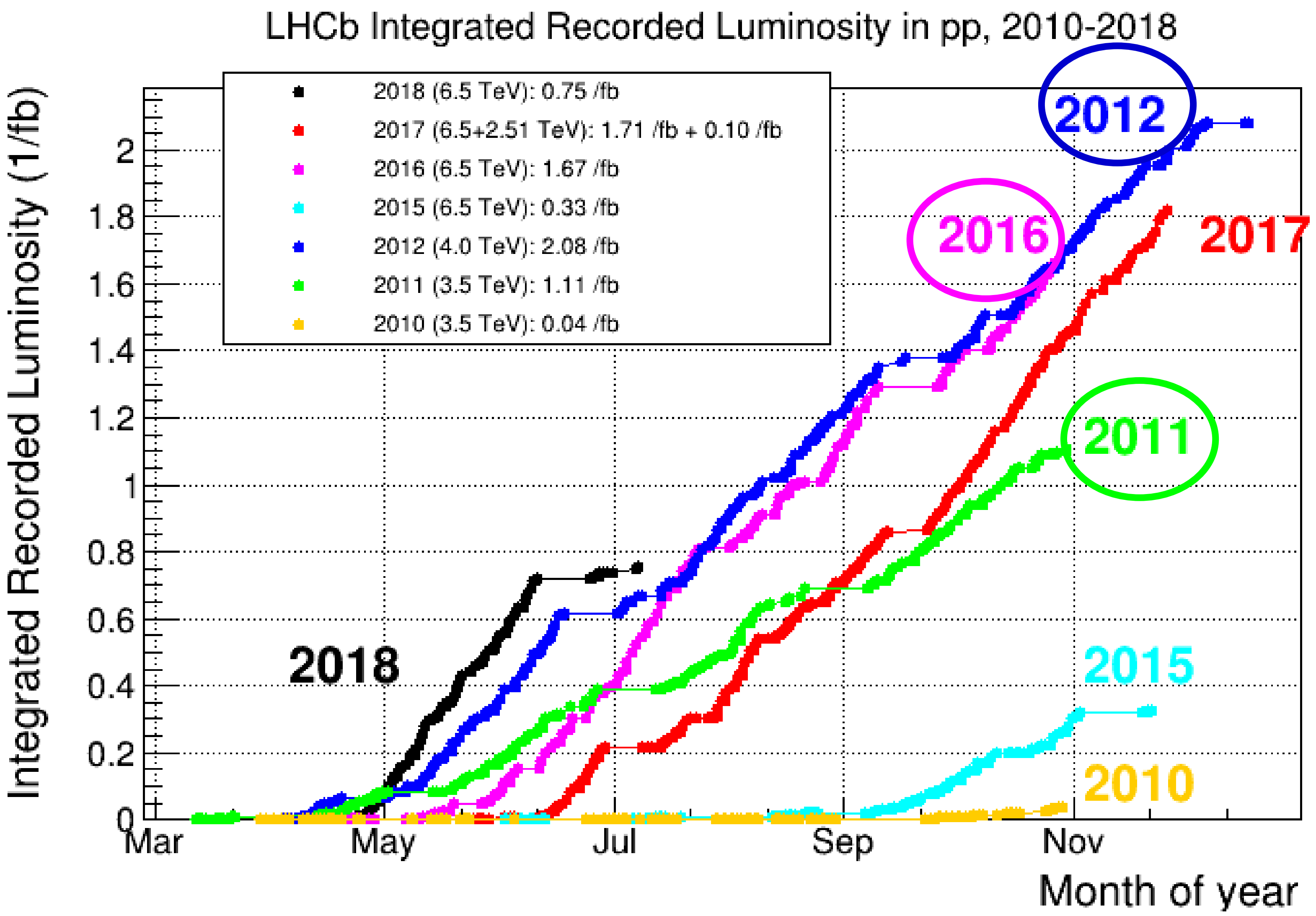
JINST 3 (2008) S08005
IJMPA 30 (2015) 1530022

LHCb detector



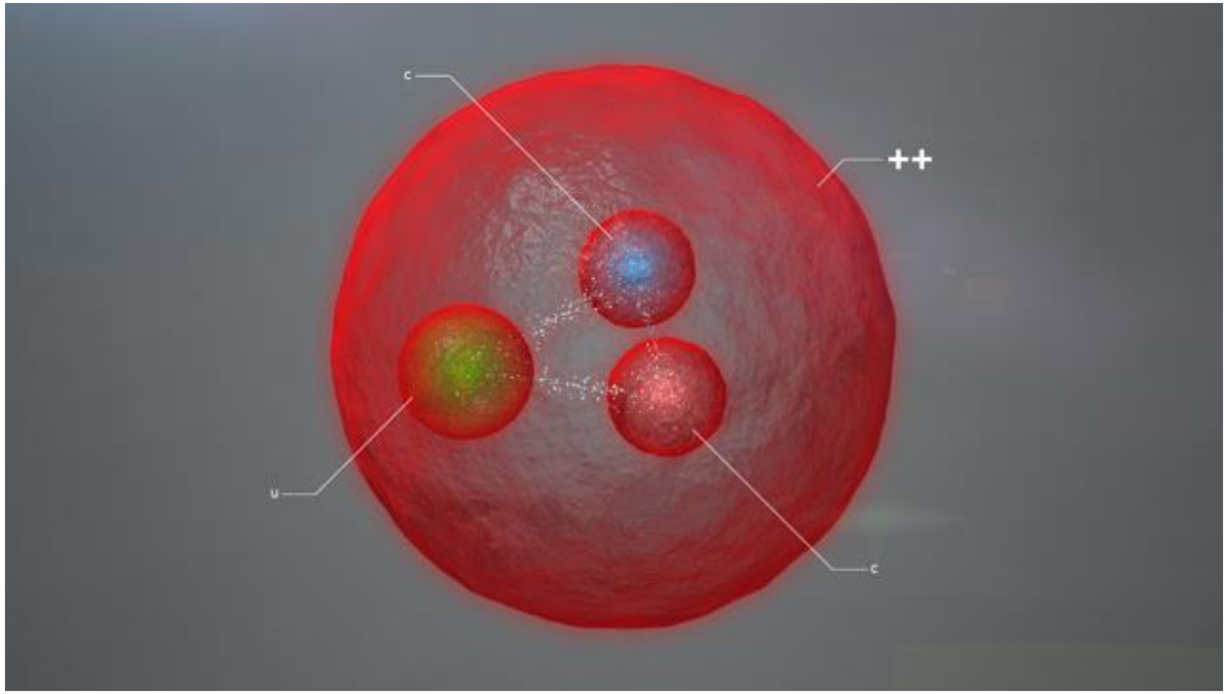
- LHCb is a forward spectrometer suited for b, c hadrons: $2 < \eta < 5$
- Momentum resolution:
  - 0.5% at 5 GeV, 1.0% at 200 GeV
- Excellent track and vertex reconstruction
- Good PID separation

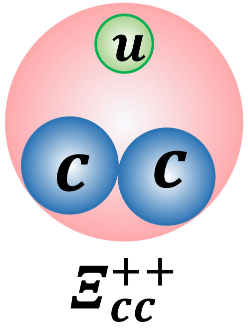
LHCb integrated luminosity



Today's talk with **2016 ($1.7\ \mathrm{fb}^{-1}$)** data

Thanks to the LHC team!

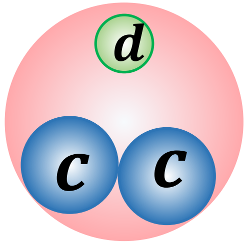




Rediscovery of Ξ_{cc}^{++}

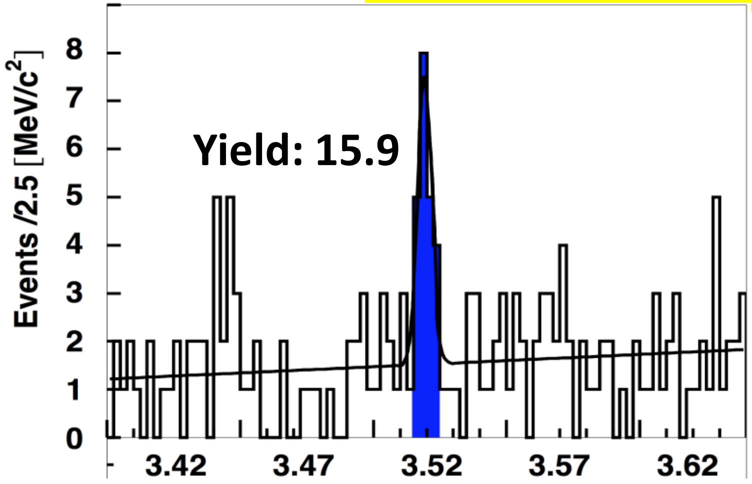
Studies of Ξ_{cc} by SELEX experiment

- SELEX (Fermilab E781) claimed observation of $\Xi_{cc}^{+}(ccd)$ in $\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+}$ and $\Xi_{cc}^{+} \to p D^{+} K^{-}$ decays
  - <u>Short lifetime</u>: $\tau(\Xi_{cc}^{+}) < 33$ fs @90% CL, but not zero
  - <u>Large production</u>: $R = \frac{\sigma(\Xi_{cc}^{+}) \times \mathrm{BF}(\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+})}{\sigma(\Lambda_c^{+})} \sim 20\%$
  - <u>Mass (combined):</u> 3518.7 ± 1.7 MeV

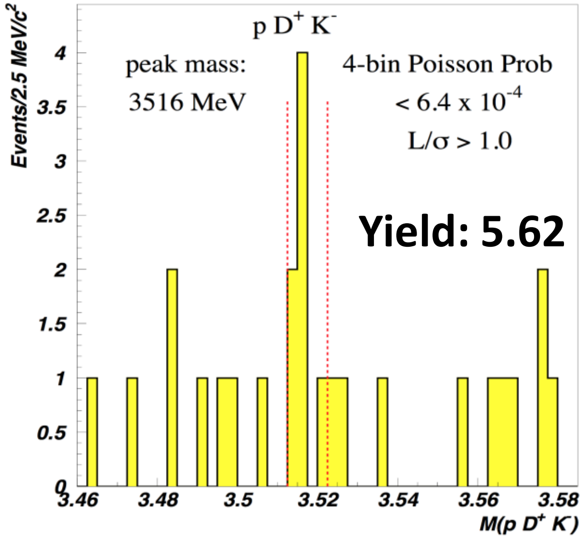


Ξ_{cc}^{+}

$\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+}$ **PRL 89 (2002) 112001**



$\Xi_{cc}^{+} \to p D^{+} K^{-}$ **PLB 628 (2005) 18**



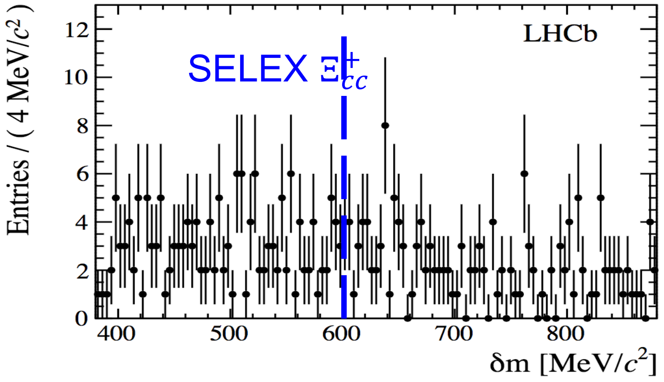
No confirmation from other experiments

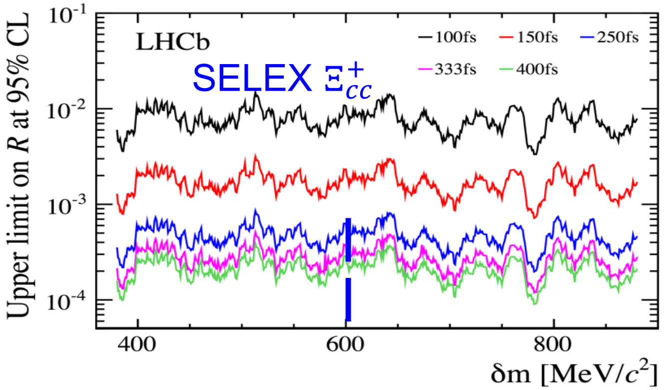
- Fixed target: **FOCUS** (Fermilab E831) **Nucl. Phys. Proc. Suppl. 115 (2003) 33**
  - Studies charm hadrons produced in photon-nuclear fixed target collisions

- Electron colliders: **Babar, Belle** **BaBar: PRD 74 (2006) 011103** **Belle: PRL 97 (2006) 162001**
  - Large Λ_c^+ yields, 0.6 (0.8) M at Babar (Belle)

- Hadron Collider: **LHCb**

JHEP 12 (2013) 090

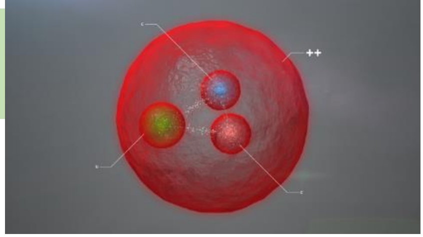




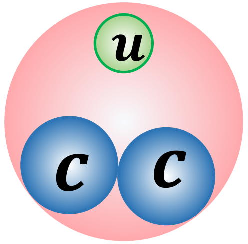
Observation of Ξ_{cc}^{++}

06/07/2017

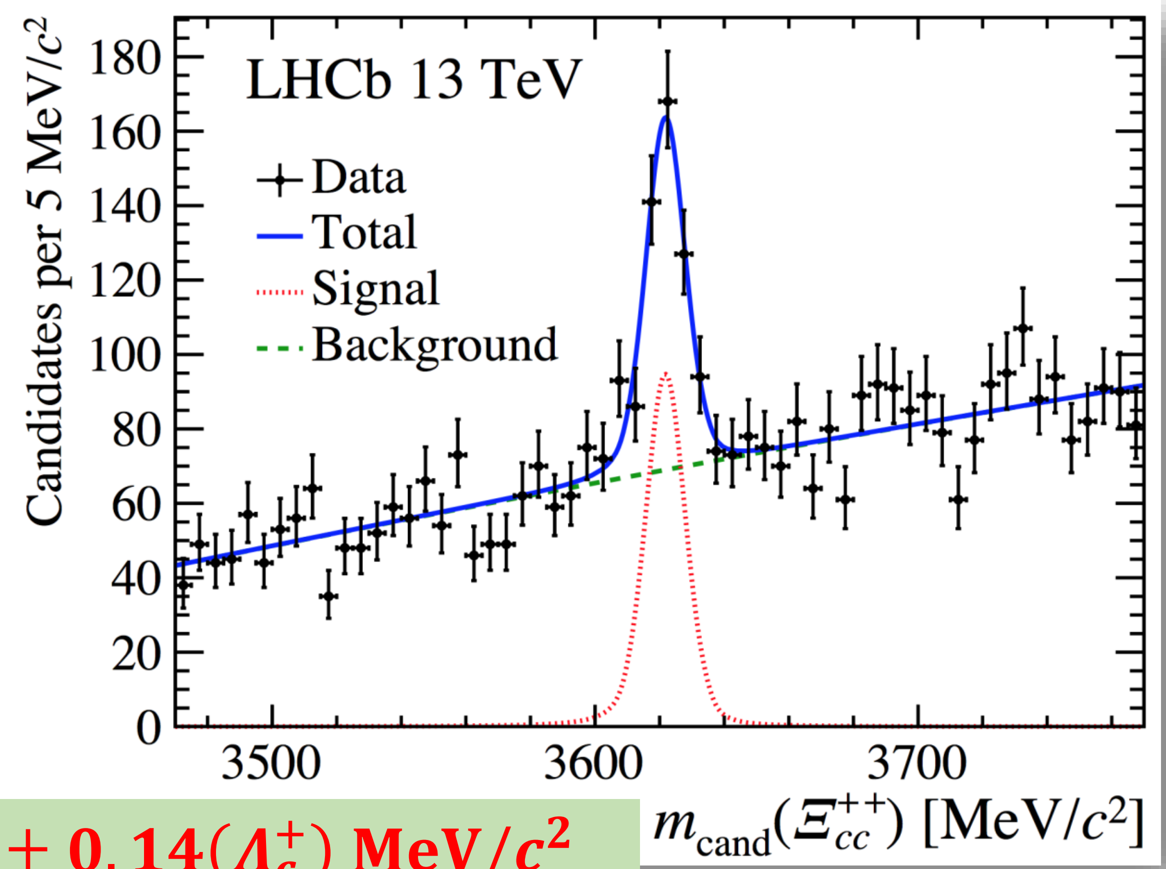
Phys. Rev. Lett. 119, 112001 (2017)



- $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$ observed by LHCb using 2016 data
  - Signal yield: 313 ± 33
  - Local significance > 12σ
  - Decaying only via weak interaction



Ξ_{cc}^{++}

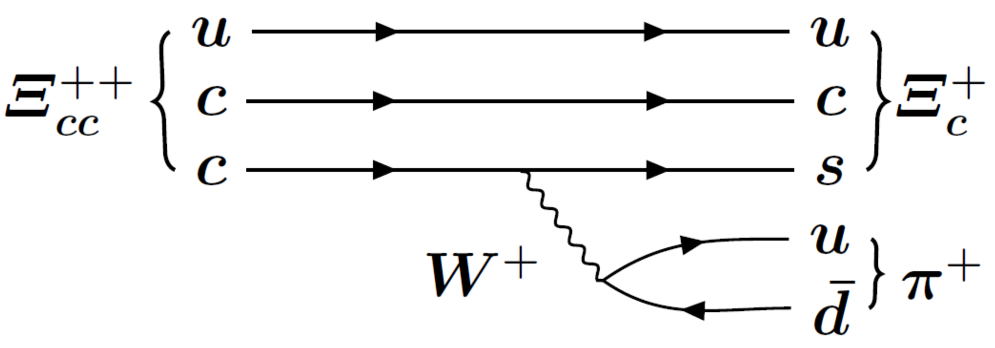


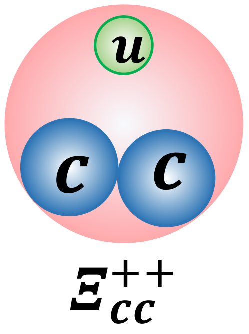
$$3621.40 \pm 0.72(\text{stat}) \pm 0.27(\text{syst}) \pm 0.14(\Lambda_c^+)\ \text{MeV}/c^2$$

F.-S. Yu et al., Chin. Phys. C 42, 051001 (2018)

Search for $\Xi_{cc}^{++} \to \Xi_c^+ \pi^+$

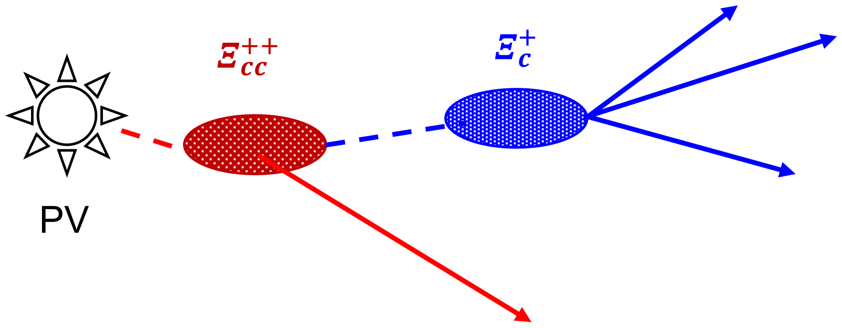
- $\Xi_{cc}^{++} \to \Xi_c^+ \pi^+$: one of the best channels to confirm Ξ_{cc}^{++}
  - $BR(\Xi_{cc}^{++} \to \Xi_c^+ \pi^+) \sim \mathcal{O}(1\%)$ **Prediction**
  - $BR(\Lambda_c^+ \to p^+ K^- \pi^+)$~(6.35%), **Measurement**
    $BR(\Xi_c^+ \to p^+ K^- \pi^+)$~(2%) **Prediction**
  - Fewer tracks (4 tracks) → higher efficiency





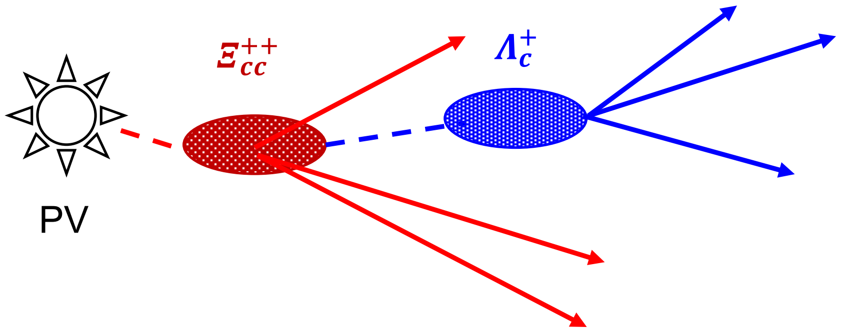
Signal and control channels

- Signal channel: $\Xi_{cc}^{++} \to \Xi_c^+ \pi^+$, with $\Xi_c^+ \to pK^-\pi^+$
- Control channels:
  - $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$, with $\Lambda_c^+ \to pK^-\pi^+$
  - $\Lambda_b^0 \to \Lambda_c^+ \pi^+ \pi^- \pi^-$, $\Lambda_b^0 \to \Lambda_c^+ \pi^-$, with $\Lambda_c^+ \to pK^-\pi^+$
  - Λ_b^0 data is used to calibrate trigger efficiency, and life time measurement



$\Xi_{cc}^{++} \to \pi^+ \Xi_c^+ (\to pK^-\pi^+)$

Signal channel



$\Xi_{cc}^{++} \to K^-\pi^+\pi^+\Lambda_c^+ (\to pK^-\pi^+)$

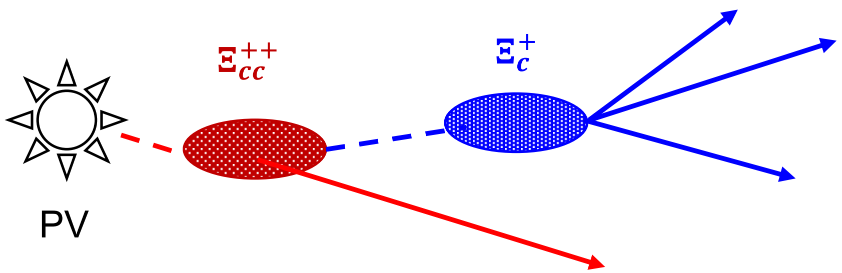
Control channel

Event selection

- **Hadron trigger**: hardware trigger (p, K, π), and high level software trigger (Ξ_c^+)
- **Final state hadrons, p, K, π**: particle ID, not produced from primary vertex (PV)
- **Λ_c^+ or Ξ_c^+**: good vertex quality, separated from PV
- **Multivariate selector** is used to further suppress the backgrounds
  - p_T, decay angle, vertex fitting quality, IP χ^2, flight distance

As a follow-up analysis of $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$, $\Xi_{cc}^{++} \to \Xi_c^+ \pi^+$ has similar selection cuts as in previous analysis.

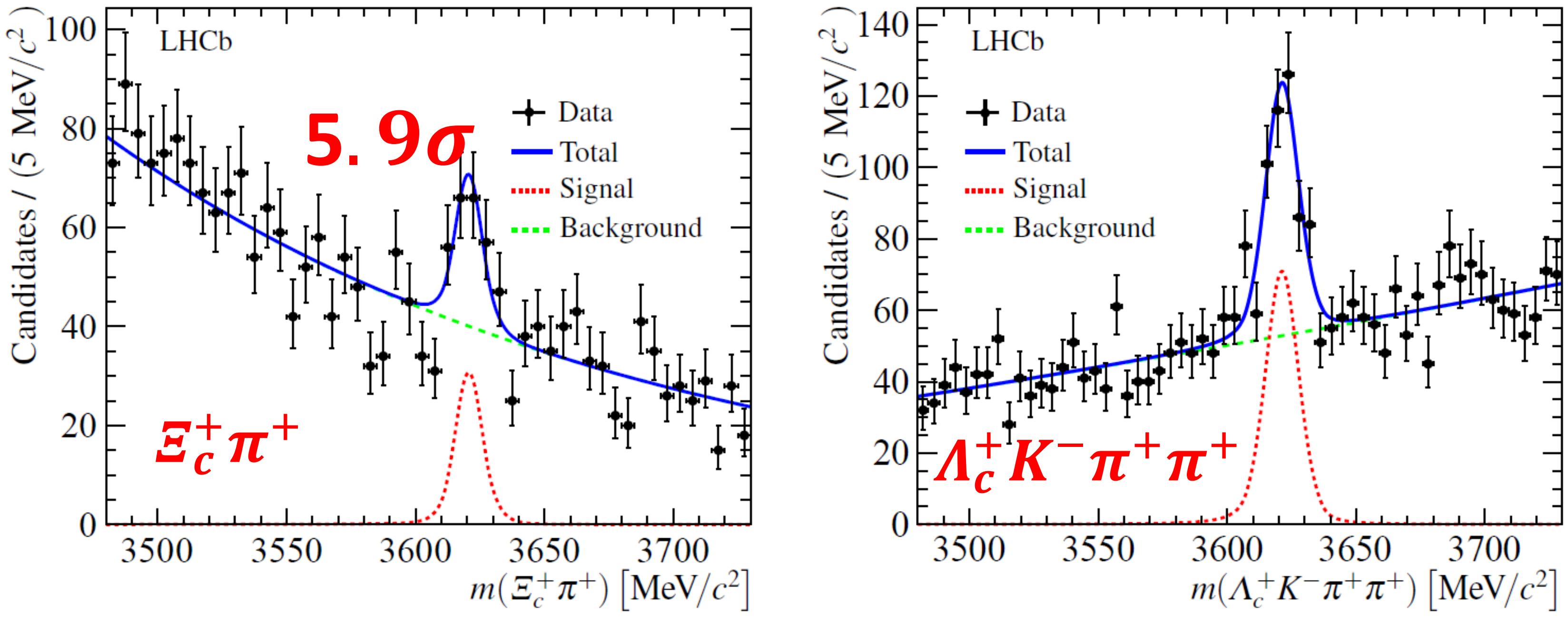
$\Xi_{cc}^{++} \to \pi^+ \Xi_c^+ (\to pK^- \pi^+)$



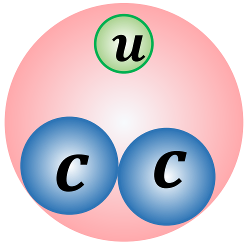
Mass fit

- **Signal**: Double-Sided Crystal-Ball + Gaussian
- **Background**: Exponential function
- $M(\Xi_{cc}^{++}) = M(\Xi_c^+\pi^+) - M(\Xi_c^+) + M_{PDG}(\Xi_c^+)$

Yields: (2016)
$\Xi_c^+\pi^+: 91 \pm 20$
$\Lambda_c^+K^-\pi^+\pi^+: 289 \pm 35$



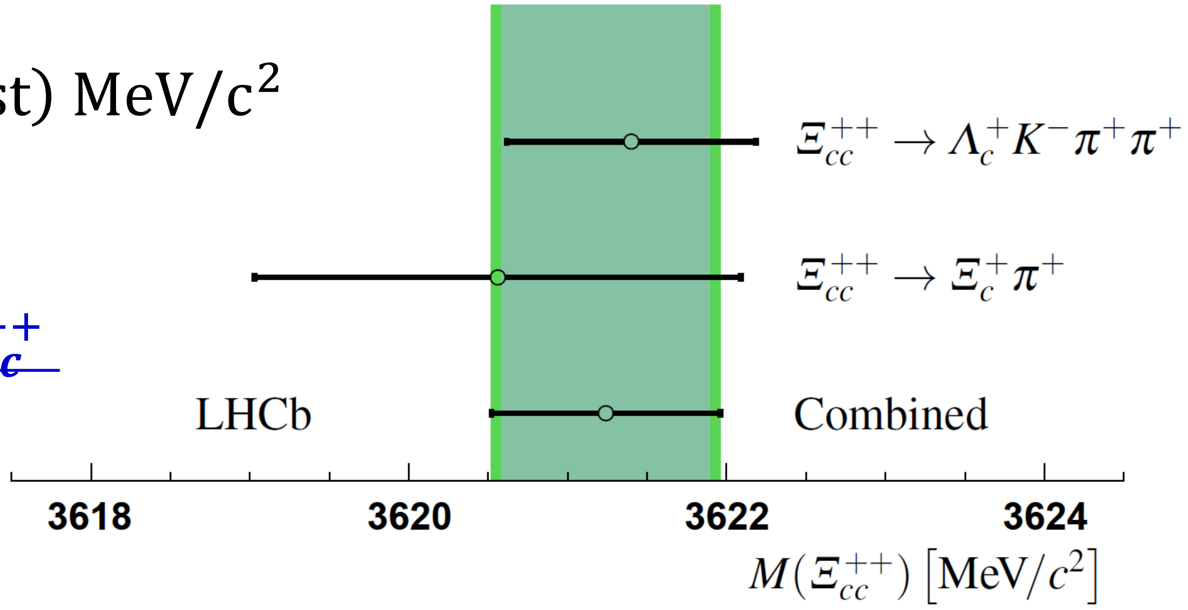
Mass measurement



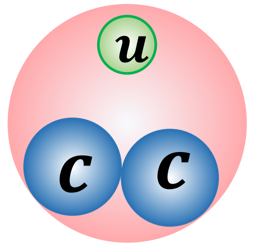
Ξ_{cc}^{++}

- The measured Ξ_{cc}^{++} mass is (with $\Xi_c^+\pi^+$ channel):
  - $\mathbf{3620.56 \pm 1.5\ (\mathit{stat}) \pm 0.4\ (\mathit{syst}) \pm 0.3\ (\Xi_c^+)\ MeV/\mathit{c}^2}$
- Consistent with $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$ result:
  - $3621.40 \pm 0.72\ (stat) \pm 0.27\ (\mathrm{syst}) \pm 0.14\ (\Lambda_c^+)\ \mathrm{MeV/c^2}$
- **Combined results**:
  - $3621.24 \pm 0.65\ (stat) \pm 0.31\ (\mathrm{syst})\ \mathrm{MeV/c^2}$

Confirm previous LHCb observation of Ξ_{cc}^{++}



Branching fraction measurement



Ξ_{cc}^{++}

- The ratio of branching fraction is defined as:

$$\mathcal{R} = \frac{\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^{+}\pi^{+})}{\mathcal{B}(\Xi_{cc}^{++} \to \Lambda_c^{+}K^{-}\pi^{+}\pi^{+})} \times \frac{\mathcal{B}(\Xi_c^{+} \to pK^{-}\pi^{+})}{\mathcal{B}(\Lambda_c^{+} \to pK^{-}\pi^{+})}$$

$$= \frac{N(\Xi_c^{+}\pi^{+})}{N(\Lambda_c^{+}K^{-}\pi^{+}\pi^{+})} \cdot \frac{\varepsilon(\Lambda_c^{+}K^{-}\pi^{+}\pi^{+})}{\varepsilon(\Xi_c^{+}\pi^{+})}$$

No direct branching fraction measurement of $\Xi_c^{+} \to pK^{-}\pi^{+}$ from experiments.

- Measure the signal yields and efficiency for each channel
- $\mathcal{R} = 0.035 \pm 0.009\ (stat) \pm 0.003\ (syst)$
  - Consistent with prediction

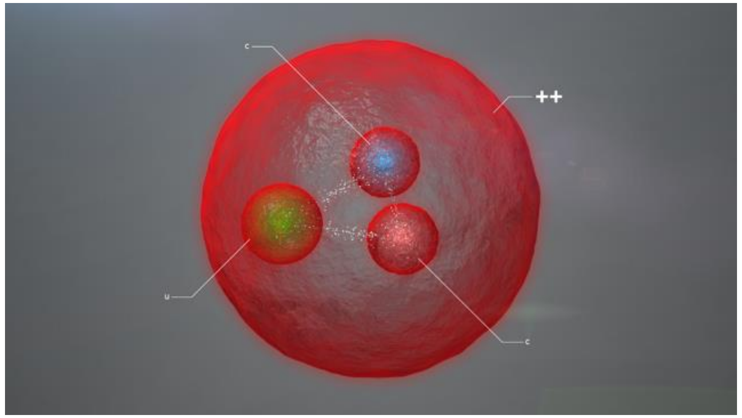
F.-S. Yu et al., Chin. Phys. C 42051001 (2018)

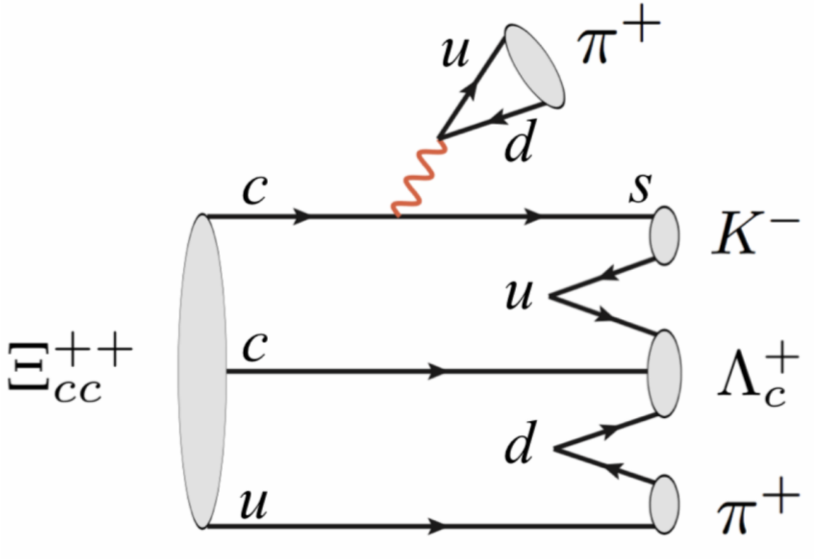
Uncertainty

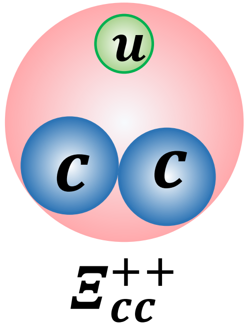
$\Xi_{cc}^{++} \to \Xi_c^+ \pi^+$ channel

Source	Mass [MeV/c^2]	$\mathcal{R}(\mathcal{B})$ [%]
Momentum calibration	0.38	—
Selection bias correction	0.10	—
Fit model	0.05	5.2
Relative efficiency	—	6.5
Simulation modelling	—	1.2
Selection	—	0.7
Sum in quadrature	0.40	8.5

With limited statistics of both signal and control samples, the dominated uncertainty is statistical uncertainty (1.5 MeV, 0.009)







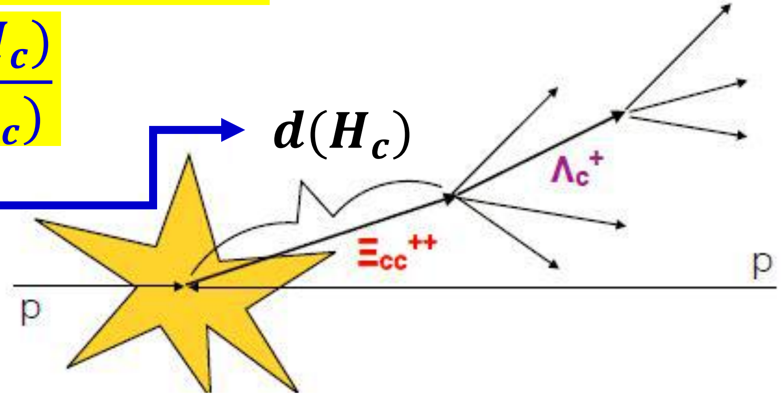
First measurement of the lifetime of Ξ_{cc}^{++}

Ξ_{cc}^{++} lifetime

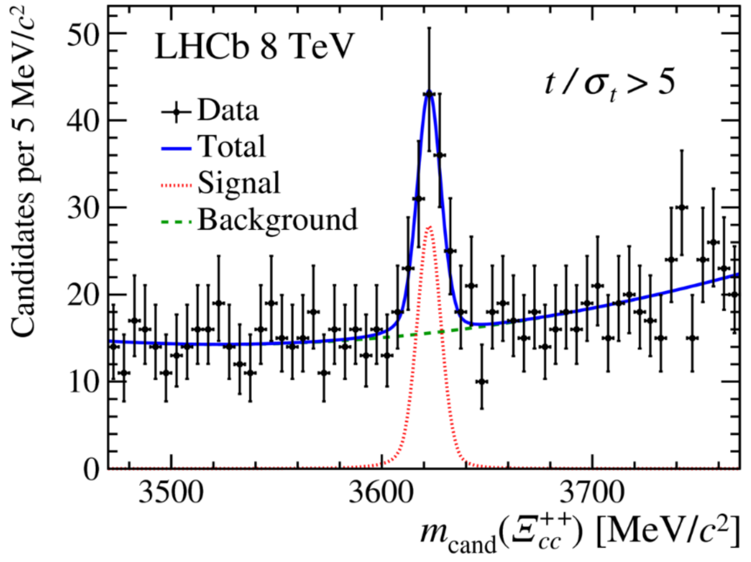
- Inconsistent with zero in the observation paper
- A lifetime measurement is critical:
  - Confirm it is a weakly decay
  - Necessary ingredient for theoretical prediction of BR
  - Important information for experimental exploration of Ξ_{cc}^{++}
  - Test various predictions in QCD models

Decay time measurement:

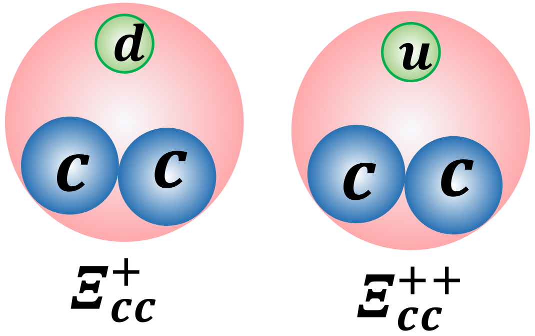
$$\tau(H_c) = d(H_c)\frac{m(H_c)}{p(H_c)}$$



Phys. Rev. Lett. 119, 112001 (2017)

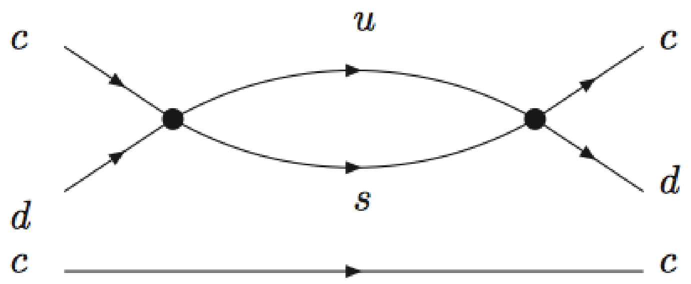


Predictions: long lived Ξ_{cc}^{++}

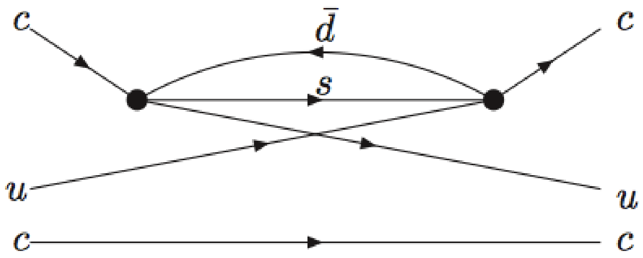


- Predicted $\tau(\Xi_{cc}^{++})$ in range of [0.20, 1.05] ps
  - Diquark model, effective constituent model, NRQCD potential model, harmonic oscillator model …
  - Significant non-spectator contribution from Pauli-Interference diagrams

W-exchange



Pauli-interference



- $\tau(\Xi_{cc}^{++})\sim 3-4\ \tau(\Xi_{cc}^{+})$
  - Destructive Pauli interference in Ξ_{cc}^{++} decays
  - W-exchange between c and d quarks only in Ξ_{cc}^{+} decays

Analysis strategy

- Same data sample, event selection as previous Ξ_{cc}^{++} observation
  - Specific trigger requirement to simplify trigger efficiency determination
  - Signal yields (2016): 313 → 304

- **Measure decay time distribution relative to $\Lambda_b^0 \to \Lambda_c^+ \pi^+ \pi^- \pi^-$**
  - Acceptance correction based on MC

- Weighted unbinned maximum likelihood fit (sFit)

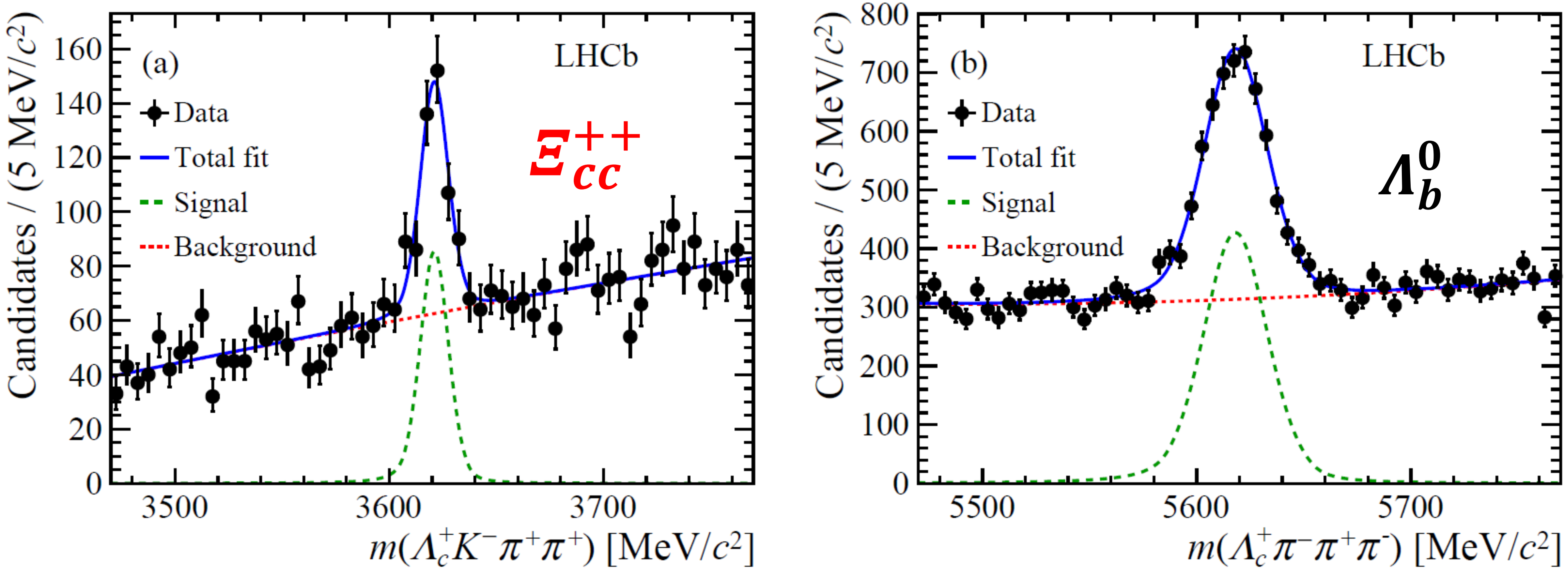
Y. Xie, arXiv:0905.072

$$f_{\Xi_{cc}^{++}}(t) = f_{\Lambda_b^0}(t) \times \frac{\epsilon_{\Xi_{cc}^{++}}}{\epsilon_{\Lambda_b^0}} \times e^{-\left(\frac{t}{\tau_{\Xi_{cc}^{++}}} - \frac{t}{\tau_{\Lambda_b^0}}\right)}$$

Selected candidates

- **Signal**: Double-sided Crystal-Ball + Gaussian
- **Background**: 2nd order Chebychev

Yields: (2016)
Ξ_{cc}^{++}: 304±35
Λ_b^0: 3379 ± 119



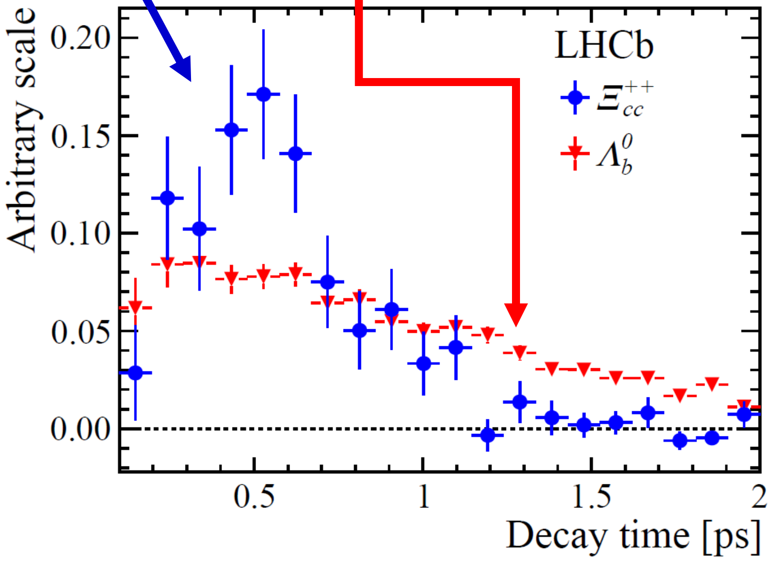
Lifetime fit

$$f_{\Xi_{cc}^{++}}(t) = f_{\Lambda_b^0}(t) \times \frac{\epsilon_{\Xi_{cc}^{++}}}{\epsilon_{\Lambda_b^0}} \times e^{-\left(\frac{t}{\tau_{\Xi_{cc}^{++}}} - \frac{t}{\tau_{\Lambda_b^0}}\right)}$$

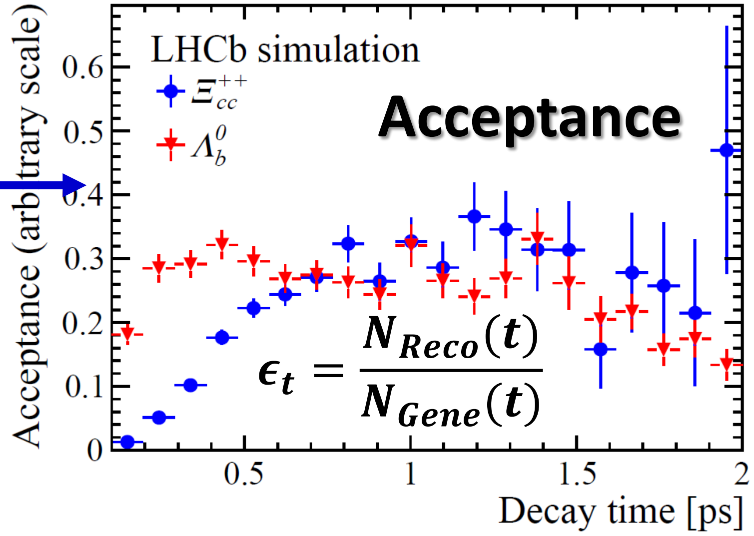
PDG 2018

$\tau_{\Lambda_b^0} = 1.470 \pm 0.010$ ps (PDG)

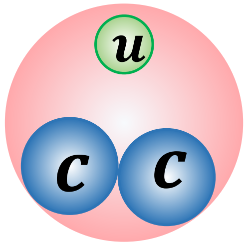
Free parameter



Background subtracted decay time distributions

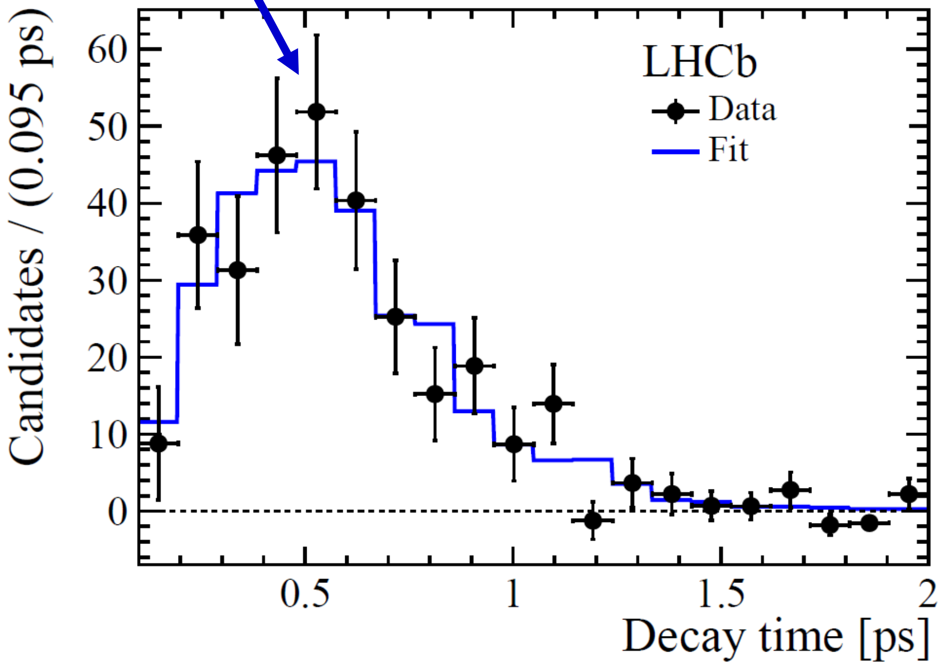


Lifetime fit



Ξ_{cc}^{++}

$$f_{\Xi_{cc}^{++}}(t) = f_{\Lambda_b^0}(t) \times \frac{\epsilon_{\Xi_{cc}^{++}}}{\epsilon_{\Lambda_b^0}} \times e^{-\left(\frac{t}{\tau_{\Xi_{cc}^{++}}} - \frac{t}{\tau_{\Lambda_b^0}}\right)}$$



$$\tau(\Xi_{cc}^{++}) = 0.256^{+0.024}_{-0.022}\ \mathrm{ps}$$

Systematic Uncertainty

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

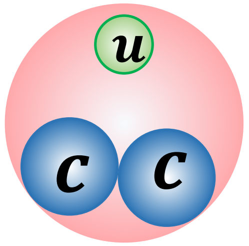
- **Binning**:
  - Systematics due to binned acceptance estimated with pseudo experiments
- **Resonant**:
  - Weight MC to match $M(K^-\pi^+\pi^+)$ (for Ξ_{cc}^{++}), and $M(\pi^-\pi^+\pi^-)$ (for Λ_b^0) distributions in data

Measured results: $\boldsymbol{\tau(\Xi_{cc}^{++}) = 0.256^{+0.024}_{-0.022}(\mathrm{stat}) \pm 0.014\,(\mathrm{syst})\ \mathrm{ps}}$

Cross-checks and Results

- Various cross-checks had been done: no evidence of other effects
  - Charge: Ξ_{cc}^{++} vs. $\bar{\Xi}_{cc}^{--}$
  - Magnet polarities: Down vs. Up
  - Number of PV
- Binned χ^2 fit: consistent with nominal result
- Λ_b^0 lifetime using simulation-based acceptance correction, consistent with PDG Value

Confirmation of Ξ_{cc}^{++} with $\Xi_c^+\pi^+$ channel
First measurement of Ξ_{cc}^{++} lifetime: weakly decay



Ξ_{cc}^{++}

Summary

- LHCb detector is designed for the heavy flavour physics
- LHCb has made significant progresses in the study of **doubly-charmed baryon: Ξ_{cc}^{++}**
  - Confirmation of the observation of Ξ_{cc}^{++} using $\Xi_c^+\pi^+$ channel
  - Measurement of Ξ_{cc}^{++} lifetime: long lifetime as expected

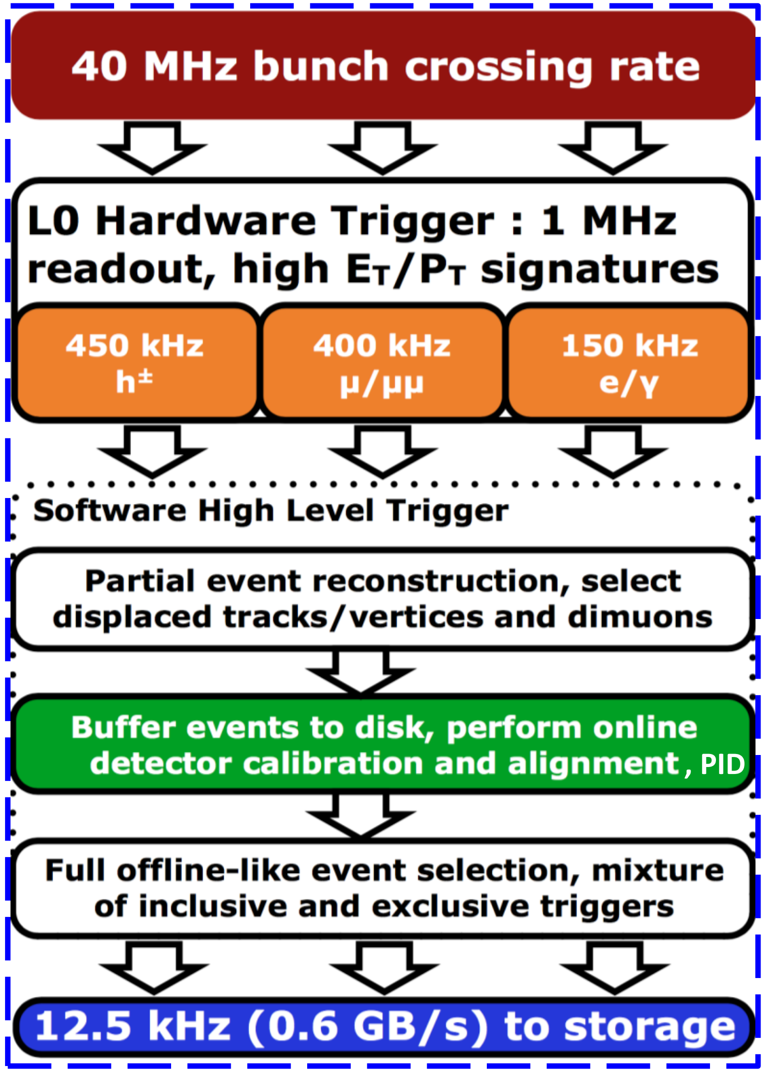
- More data collected in Run-II

Stay tuned for new results !

Backup

Comput. Phys. Commun. 208 (2016) 35-42
Int. J. Mod. Phys. A 30, 1530022 (2015)

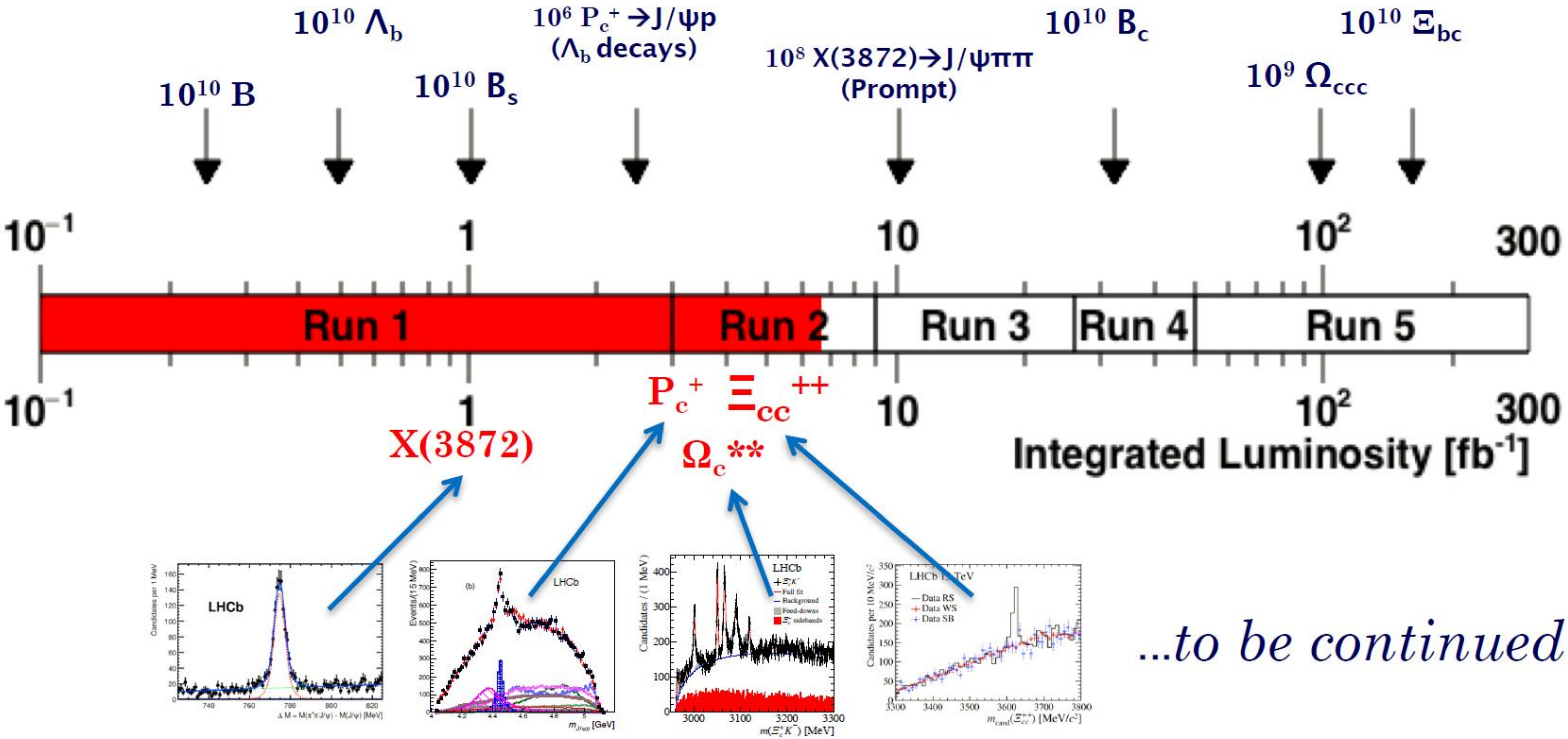
LHCb trigger



- Run real-time alignment and calibration of the detector
- Data buffered out of first software trigger stage
- Second software trigger runs asynchronously
- Permits Turbo real-time analysis strategy
  - Candidates reconstructed at the trigger level saved directly for offline analysis + (online alignment and calibration)

The first two analyses of today's talk benefit from the Turbo stream.

Hadron spectroscopy @ LHCb



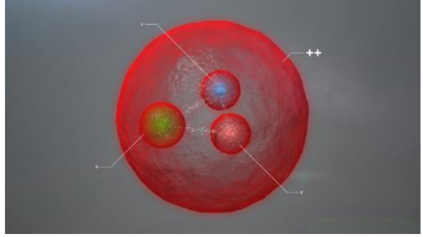
...to be continued

Prospects

- Searching for Ξ_{cc}^{++} with more channels: $\Xi_c^+\pi^+$, $\Lambda_c^+\pi^+, pD^+K^-\pi^+ \ldots$
- Measurement of the Ξ_{cc}^{++} lifetime
- Measurement of the production cross-section
- Confirming its spin-parity: ½$^+$
- Searching for its isospin partner Ξ_{cc}^+ in a larger sample than the previous measurement
- Searching for Ω_{cc}^+
- Doubly heavy baryons with bottom quark: $\Xi_{bc}, \Omega_{bc}, \Xi_{bb} \ldots$
- The excited states?
- And new systems for CP violations

Observation of Ξ_{cc}^{++}

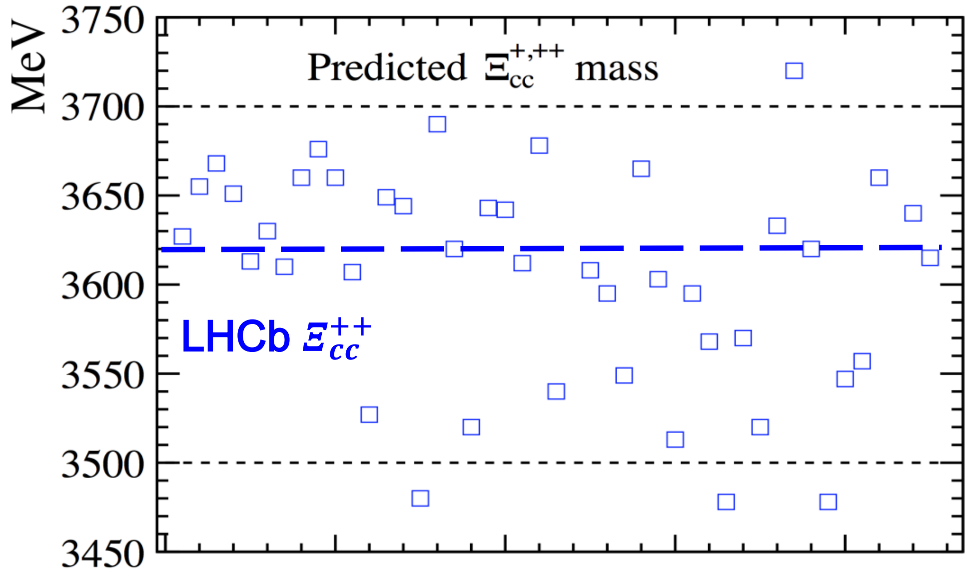
11/07/2017

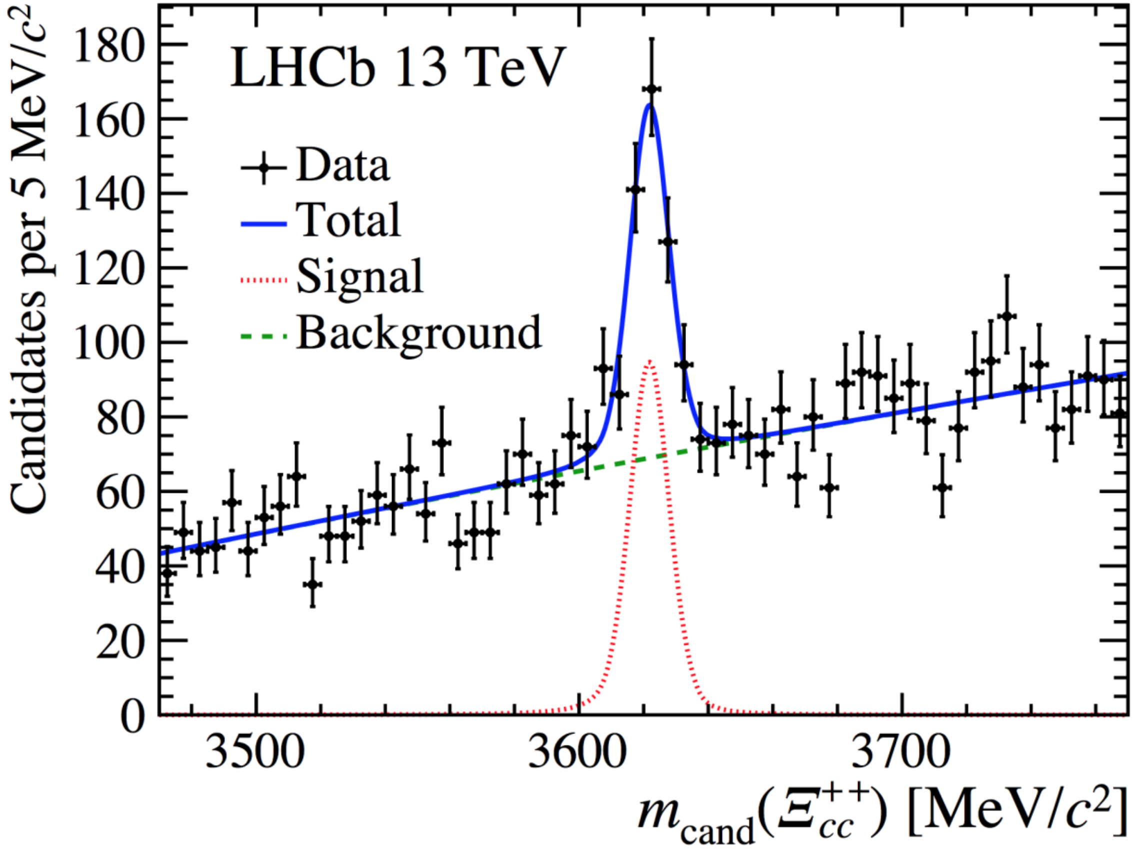


- $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$ observed by LHCb experiment using 2016 data

Phys. Rev. Lett. 119, 112001 (2017)

  - Signal yield: 313 ± 33
  - Local significance > 12
  - Weakly decay

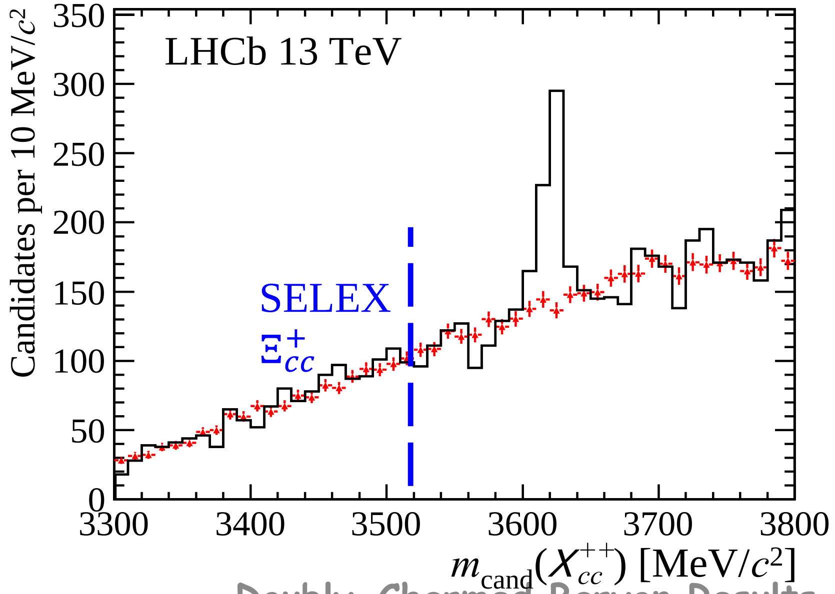




Compared with SELEX results

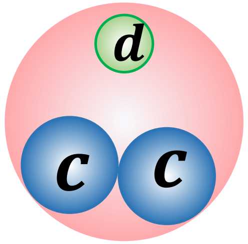
- Large mass difference: $m(\Xi_{cc}^{++})_{\text{LHCb}} - m(\Xi_{cc}^{+})_{\text{SELEX}} = 103 \pm 2$ MeV
  - Inconsistent with being isospin partners

- Production: $N(\Xi_{cc})/N(\Lambda_c^+)$ much smaller in LHCb result

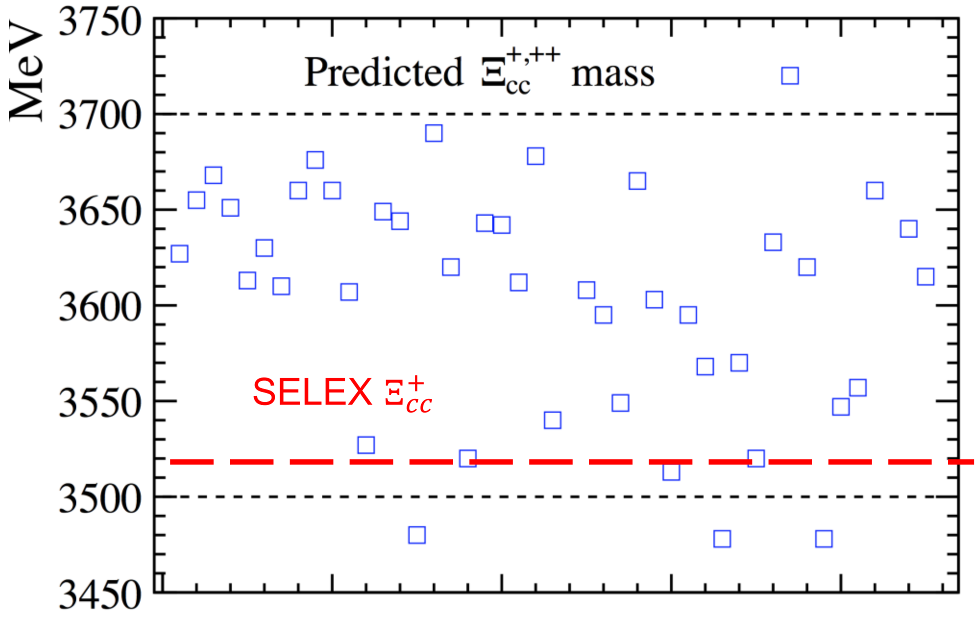


SELEX result in tension with predictions

- Models to determine masses of ground state and excitations:
  - (non-) relativistic QCD potential models, triple harmonic-oscillator potential model, QCD sum rules, bag model or quark model …
  - Predicted $\Xi_{cc}^{+,++}$ masses in range $\mathbf{3.5 - 3.7}$ GeV,
  - Masses of Ξ_{cc}^{+} and Ξ_{cc}^{++} only differ by a few MeV due to u, d symmetry



Ξ_{cc}^{+}



Analysis strategy $\Xi_c^+\pi^+$ (Blinded analysis)

- Event selection of $\Xi_c^+\pi^+$ candidates, 2016 data

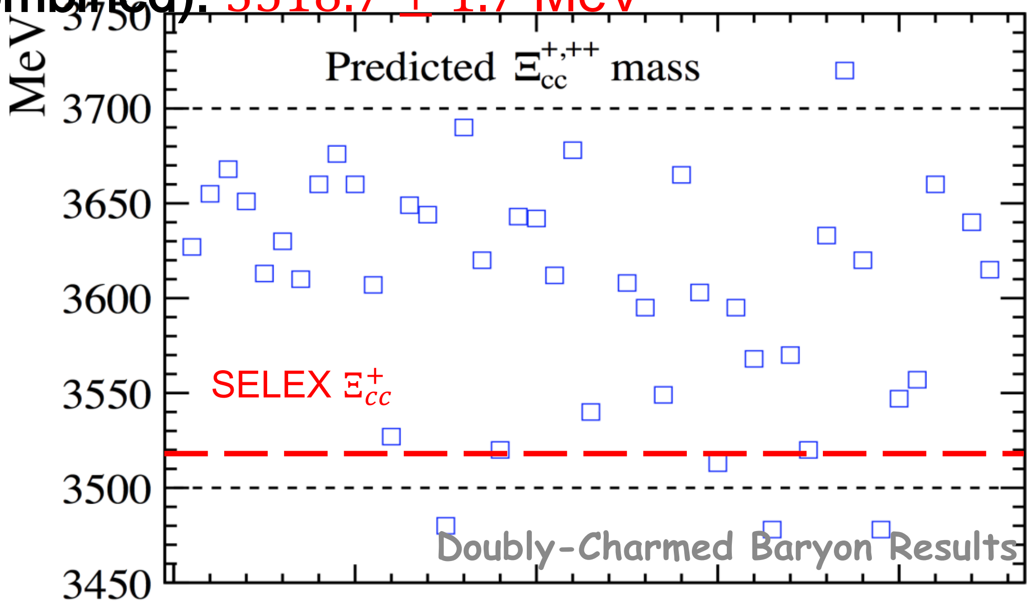
- Multivariate selector to suppress combinatorial background
  - Simulation as signal, data upper sideband as background

- Open signal window
  - $> 3\sigma$ signal: mass measurement, ratio of branching fraction
  - Otherwise: upper limit setting

Studies of Ξ_{cc} by SELEX experiment

- SELEX (Fermilab E781) collides high energy hyperon beams (Σ^-, p) with nuclear targets, dedicated to study charm baryons
- Observed $\Xi_{cc}^+(ccd)$ in $\Xi_{cc}^+ \to \Lambda_c^+ K^- \pi^+$ and $\Xi_{cc}^+ \to pD^+K^-$ decays
  - Signal yields: $15.9\ (\Lambda_c^+ K^- \pi^+)$ and $5.62\ (pD^+K^-)$
  - Short lifetime: $\tau(\Xi_{cc}^+) < 33$ fs @90% CL, but not zero
  - Large production: $R = \frac{\sigma(\Xi_{cc}^+)\times \mathrm{BF}(\Xi_{cc}^+ \to \Lambda_c^+ K^- \pi^+)}{\sigma(\Lambda_c^+)} \sim 20\%$
  - Mass (combined): 3518.7 ± 1.7 MeV

Very puzzling



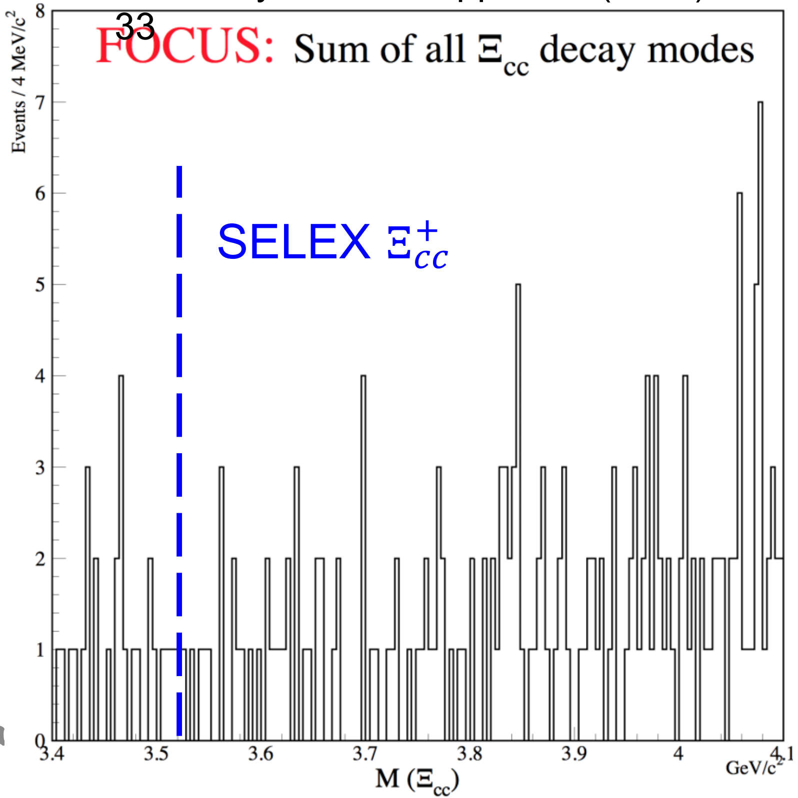
Studies of Ξ_{cc} by FOCUS

- FOCUS (Fermilab E831) studies charm hadrons produced in photon-nuclear fixed target collisions
- FOCUS didn't confirm Ξ_{cc}^{+} observed by SELEX in $\Lambda_c^{+}K^{-}\pi^{+}$decay

Decay Mode	$\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+}$	
Experiment	FOCUS	SELEX
Ξ_{cc} Events	<2.21 @ 90%	15.8
Reconstructed Λ_c	$19,444 \pm 262$	1650
Relative Efficiency	5%	10%
Ξ_{cc}/Λ_c^{+}	<0.23% @ 90%	9.6%
$\frac{\text{SELEX}}{\text{FOCUS}}$ Rel $\frac{\Xi_{cc}}{\Lambda_c}$ Prod	>42 @ 90%	

- Other modes also studied: $\Xi_{cc}^{+} \to \Lambda_c^{+}X$, $D^0X\ D^{+}X$, no SELEX-like signal peak observed

Nucl. Phys. Proc. Suppl. 115 (2003) 33

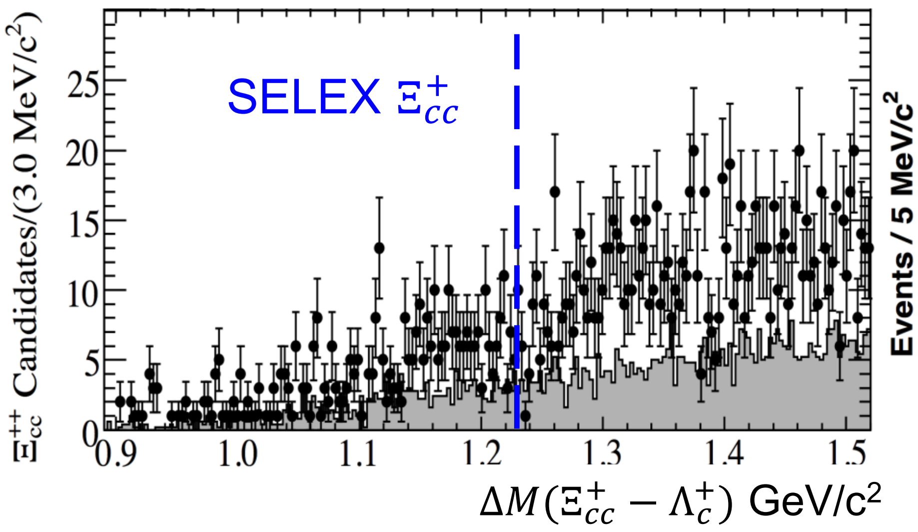


Studies of Ξ_{cc} by BaBar and Belle

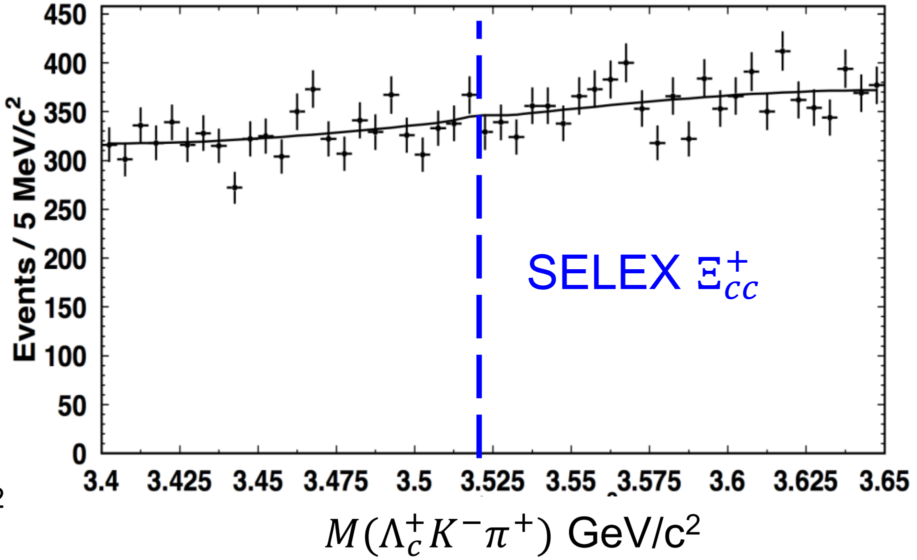
- e^+e^- colliders working at $\Upsilon(4S)$ mass $\sqrt{s} = 10.58$ GeV
- Large Λ_c^+ yields: ≈ 0.6 M at BaBar, ≈ 0.8 M at Belle
- SELEX-like Ξ_{cc}^+ signal not confirmed in $\Xi_{cc}^+ \to \Lambda_c^+ K^- \pi^+$ decays

$R = \frac{\sigma(\Xi_{cc}^+)\times \mathrm{BF}(\Xi_{cc}^+ \to \Lambda_c^+ K^- \pi^+)}{\sigma(\Lambda_c^+)} < 2.7 \times 10^{-4}$ (BaBar) 1.5×10^{-4} (Belle) @ 95% CL

BaBar: PRD 74 (2006) 011103



Belle: PRL 97 (2006) 162001



Studies of Ξ_{cc}^{+} by LHCb: Run-I

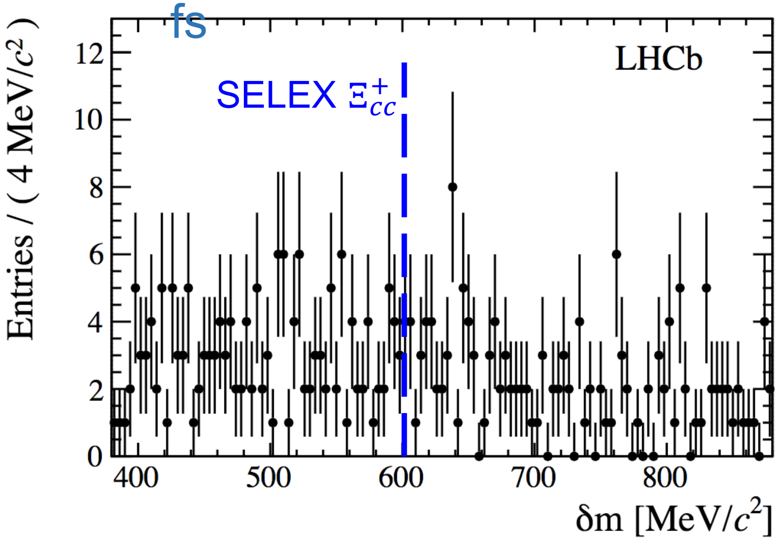
JHEP 12 (2013) 090

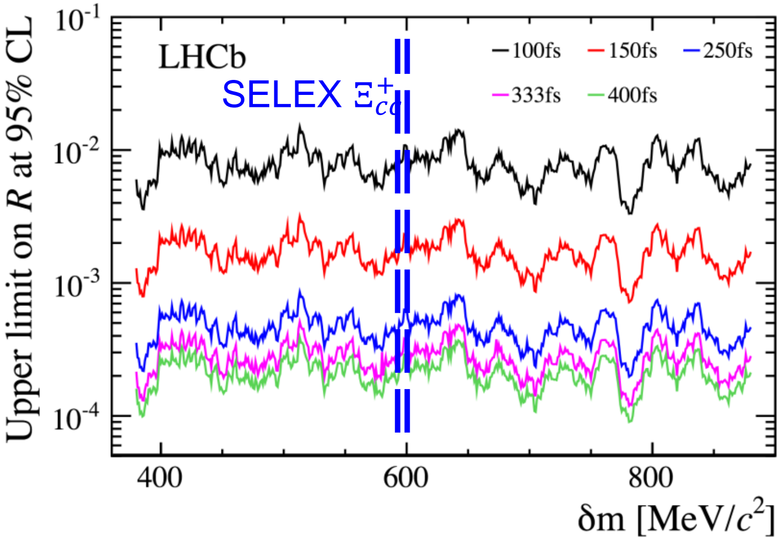
- LHCb searched for $\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+}$ decay with 0.65 fb^{-1} of 7 TeV data
- $N(\Lambda_c^{+}) \approx 0.8$ M, requiring high-p_T
- No significant peaking structure observed with $m \in [3.3, 3.8]$ GeV
- Experiment sensitivity strongly depends on Ξ_{cc}^{+} lifetime

$$R = \frac{\sigma(\Xi_{cc}^{+}) \times \mathrm{BF}(\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+})}{\sigma(\Lambda_c^{+})} < 0.013 \text{ for } \tau = 100 \text{ fs},$$

$< 3.3 \times 10^{-4}$ for $\tau = 400$ fs @95%

Increased by ~40 from 100 fs to 400 fs





$$\delta m = m\left([pK^{-}\pi^{+}]_{\Lambda_c^{+}} K^{-}\pi^{+}\right) - m\left([pK^{-}\pi^{+}]_{\Lambda_c^{+}}\right) - m(K^{-}) - m(\pi^{+})$$

F.-S. Yu et al., Chin. Phys. C 42, 051001 (2018)

$\Xi_c^+\pi^+$ Prediction

$$\mathcal{B}(\Xi_{cc}^{++}\to\Xi_c^+\pi^+)=\left(\frac{\tau_{\Xi_{cc}^{++}}}{300\,\mathrm{fs}}\right)\times 7.2\%.$$

$$\mathcal{B}(\Xi_c^+\to \mathrm{p}\mathrm{K}^-\pi^+)=(2.2\pm0.8)\%.$$

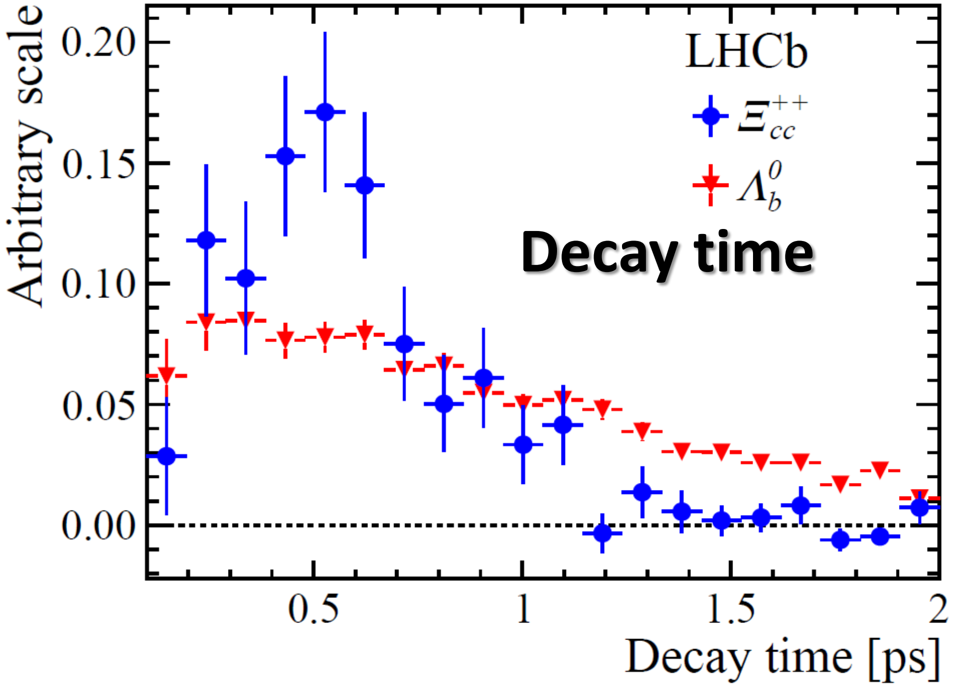
as $\mathcal{B}(\Xi_c^+ \to \mathrm{p}\overline{\mathrm{K}}^{*0})/\mathcal{B}(\Xi_c^+ \to \mathrm{pK}^-\pi^+) = 0.54\pm0.10$ [33]. Besides, the relation $\mathcal{A}(\Xi_c^+ \to \mathrm{p}\overline{\mathrm{K}}^{*0}) = \mathcal{A}(\Lambda_c^+ \to \Sigma^+\mathrm{K}^{*0})$ holds under U-spin symmetry. With the measurement of $\mathcal{B}(\Lambda_c^+ \to \Sigma^+\mathrm{K}^{*0}) = (0.36\pm0.10)\%$ [34], the branching

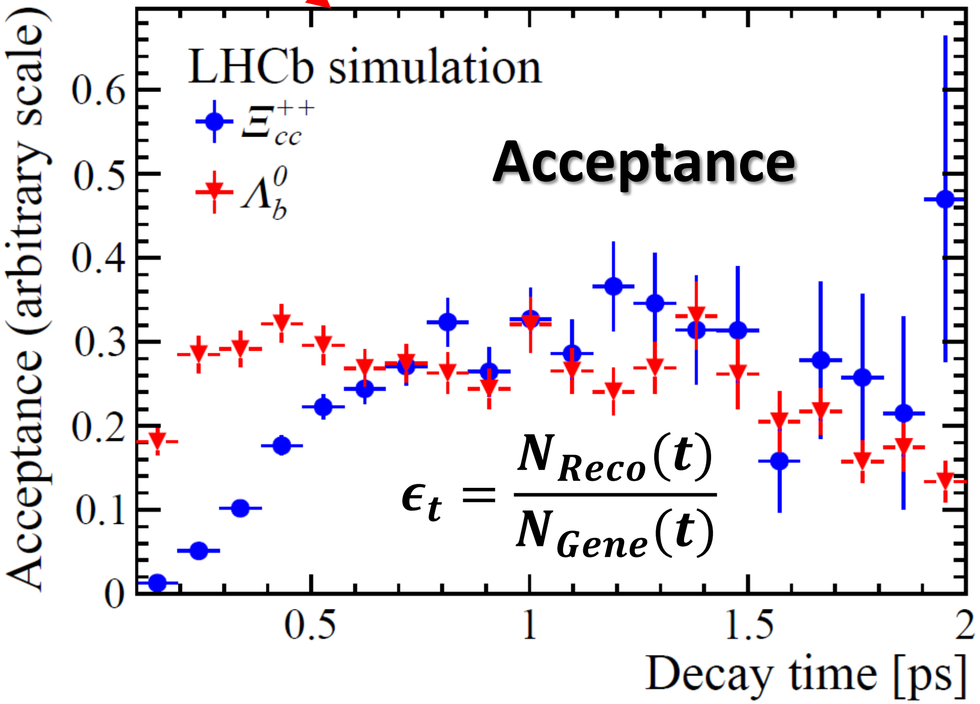
$$\mathcal{B}(\Xi_{cc}^{++}\to\Sigma_c^{++}(2455)\overline{\mathrm{K}}^{*0})=\left(\frac{\tau_{\Xi_{cc}^{++}}}{300\,\mathrm{fs}}\right)\times(3.8\sim24.6)\%, \tag{11}$$

Decay time distributions and acceptance

$$\mathcal{R}(t) = \boxed{\frac{f_{\Xi_{cc}^{++}}(t)}{f_{\Lambda_b^0}(t)}} \times \boxed{\frac{\epsilon_{\Lambda_b^0}(t)}{\epsilon_{\Xi_{cc}^{++}}(t)}} = \mathcal{R}(0)e^{-\left(\frac{1}{\tau_{\Xi_{cc}^{++}}} - \frac{1}{\tau_{\Lambda_b^0}}\right)t}$$

S-weighted data
to subtract background





$\Xi_{cc}^{++}/\Lambda_b^0$ lifetime ratio comparison