Search for Ξ_{cc}^{+} with $\Xi_c^{+}\pi^{+}\pi^{-}$ decay at LHCb

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Outline

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Introduction

- Doubly heavy-baryons are of key importance for completing the baryon spectrum
- Shedding light on perturbative and non-perturbative QCD dynamics
  - Theoretical prediction mass region: **$3500\sim3700$ MeV/c^2**
  - Isospin splitting of **a few MeV/c^2** between Ξ_{cc}^{+} and Ξ_{cc}^{++}
  - Theoretical prediction Ξ_{cc}^{+} lifetime region: **$50\sim250$ fs** (~3-4 times shorter than Ξ_{cc}^{++})
- Some large branching fractions of Ξ_{cc}^{+} and Ξ_{cc}^{++} decays (relative to $\Xi_{cc}^{++} \to \Sigma_c^{++}(2455)\overline{K}^{*0}$)

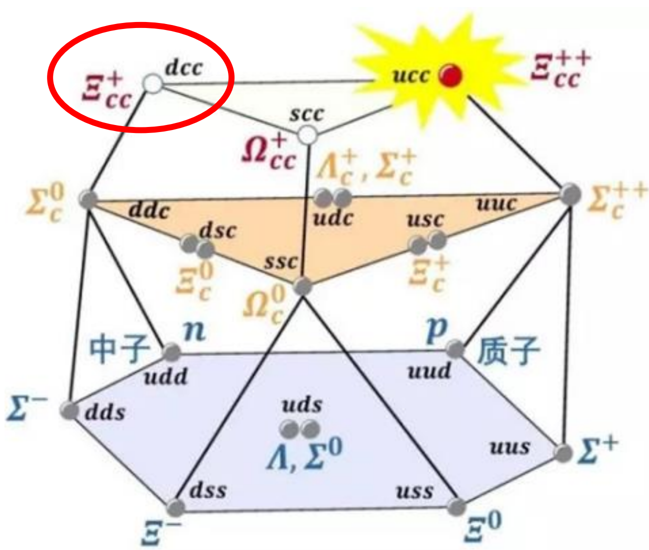
$$\mathcal{R}_\tau = \frac{\tau_{\Xi_{cc}^{+}}}{\tau_{\Xi_{cc}^{++}}} = 0.25\sim0.37$$

Baryons	Modes	$\mathcal{B}_{\rm LD}$
$\Xi_{cc}^{++}(ccu)$	$\Sigma_c^{++}(2455)\overline{K}^{*0}$	defined as 1
	pD^{*+}	0.04
	pD^{+}	0.0008
$\Xi_{cc}^{+}(ccd)$	$\Lambda_c^{+}\overline{K}^{*0}$	$(\mathcal{R}_\tau/0.3)\times 0.22$
	$\Sigma_c^{++}(2455)K^{-}$	$(\mathcal{R}_\tau/0.3)\times 0.01$
	$\Xi_c^{+}\rho^{0}$	$(\mathcal{R}_\tau/0.3)\times 0.04$
	ΛD^{+}	$(\mathcal{R}_\tau/0.3)\times 0.004$
	pD^{0}	$(\mathcal{R}_\tau/0.3)\times 0.001$

Chin. Phys. C42 (2018) 051001

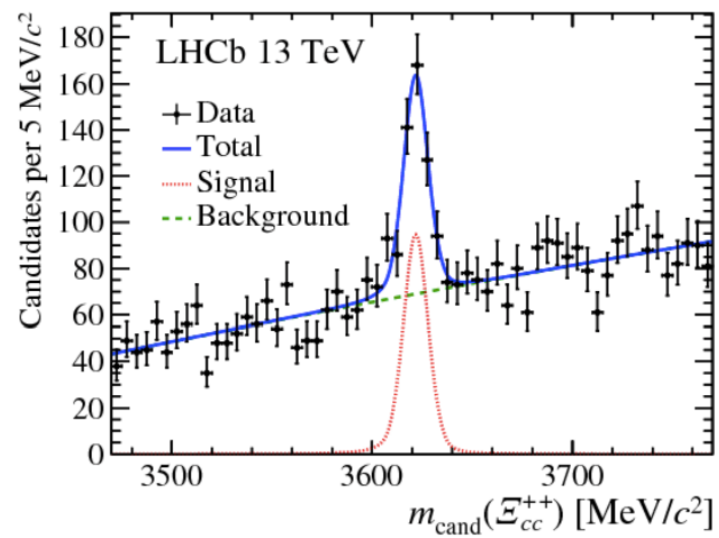
Experimental searches for Ξ_{cc}^{+}

- Search Ξ_{cc}^{+} have a long history
  - SELEX reported the observation of Ξ_{cc}^{+} (**Phys. Rev. Lett. 89 (2002) 112001, Phys. Lett. B628 (2005) 18**)
  - No confirmed by FOCUS, BaBar, LHCb and Belle (**Nucl, Phys. Proc. Suppl. 115 (2003) 33, Phys. Rev. D74 (2006) 011103, JHEP 12 (2013) 090, Phys. Rev. D89 (2014) 052003**)



- First observed Ξ_{cc}^{++} by LHCb at 2017

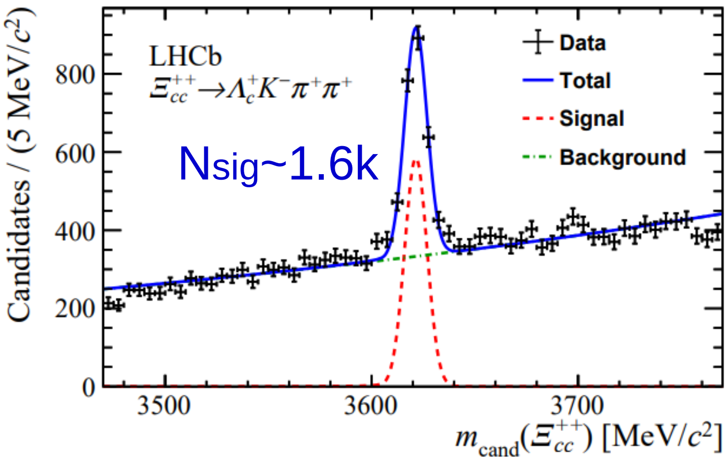
- The mass of Ξ_{cc}^{++} is $\mathbf{3621.55 \pm 0.23\ (stat) \pm 0.30\ (syst)\ MeV/c^2}$
  - **JHEP 02 (2020) 049**
- The lifetime of Ξ_{cc}^{++} is $\mathbf{0.256^{+0.024}_{-0.022}(stat) \pm 0.014(syst)\ fs}$
  - **Phys. Rev. Lett. 121 (2018) 052002**

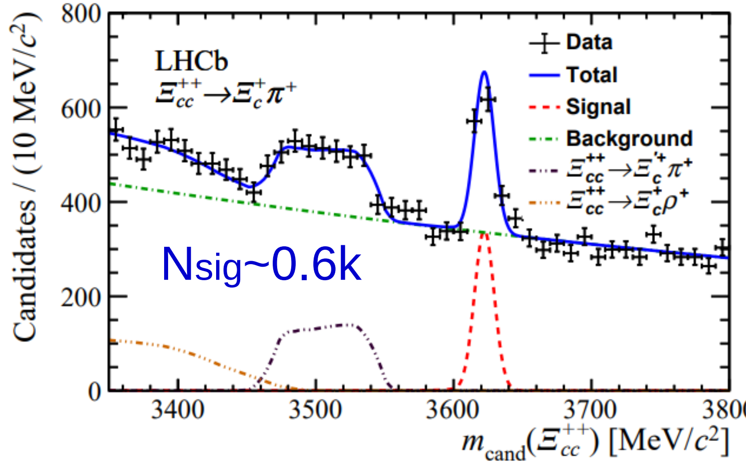


PRL 119 (2017) 112001

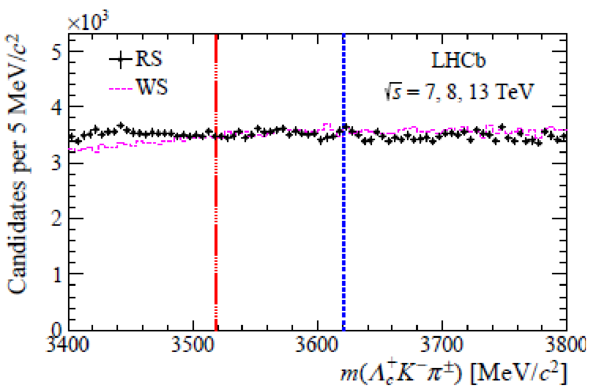
Latest studies of Ξ_{cc}^{+} at LHCb

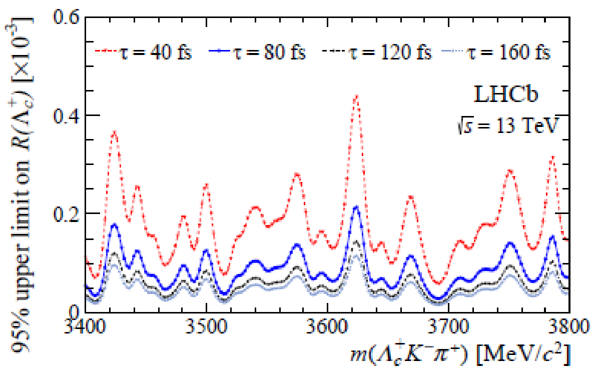
- High accumulated yields for Ξ_{cc}^{++} at LHCb 2016~2018 **JHEP 02 (2020) 049**

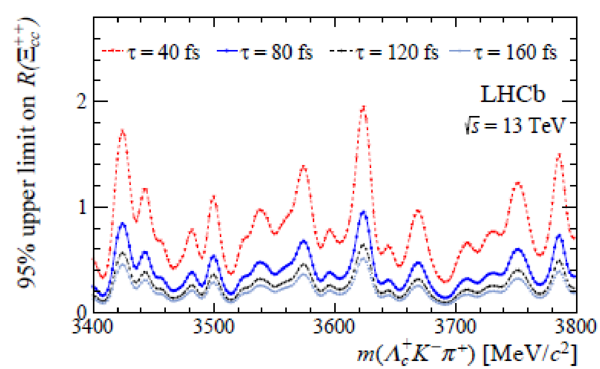




- Production cross-section of Ξ_{cc}^{+} is expected to be similar to Ξ_{cc}^{++}
  - Search for the Ξ_{cc}^{+} in $\Lambda_c^+\pi^+K^-$ using Run-I and Run-II data
  - No significant signal, setting the upper limit





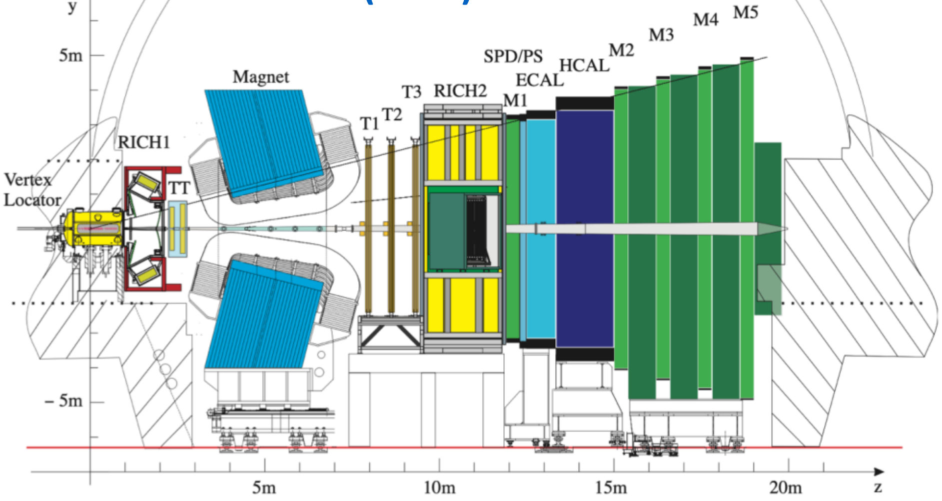


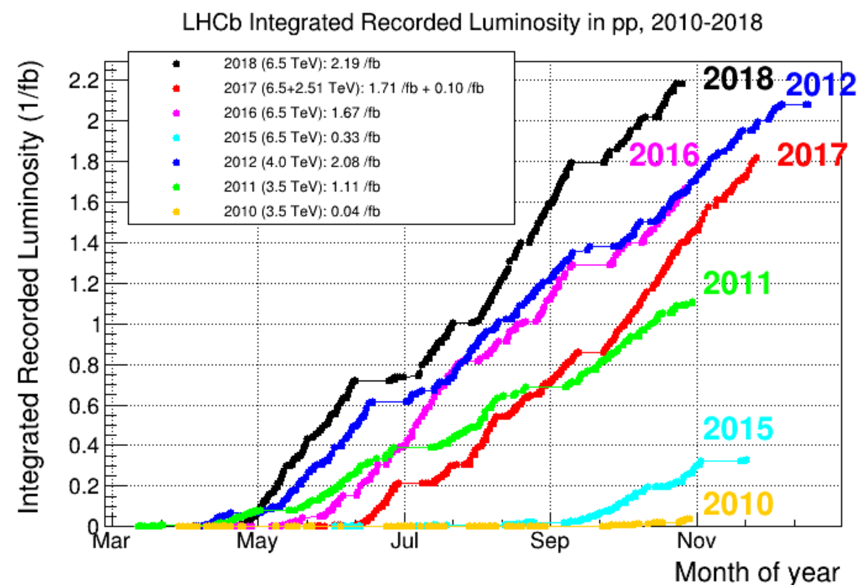
Sci.China-Phys.Mech.Astron.63, 221062 (2020)

LHCb detector and data–taking

- Acceptance $2 < \eta < 5$, with excellent vertexing, tracking, PID

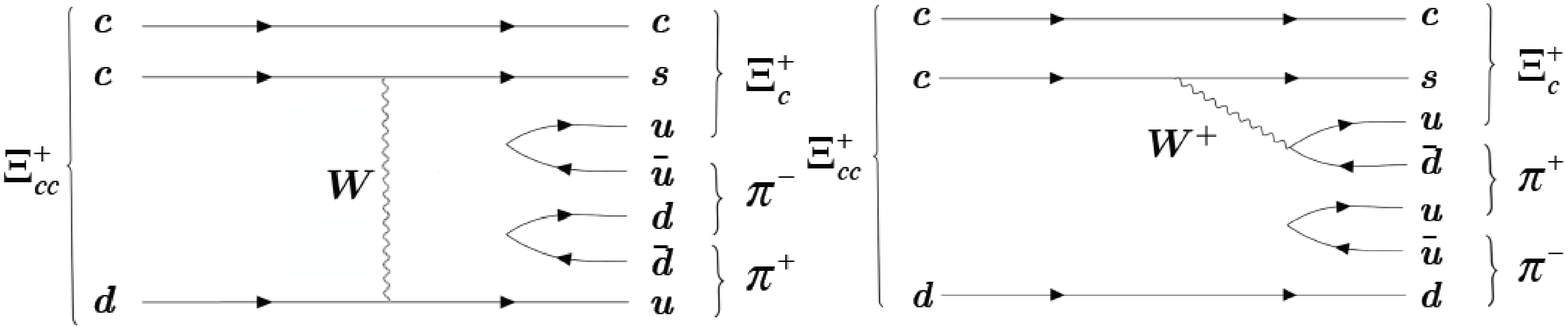
JINST 3 (2008) S08005





- Run1 (2011-2012):1 fb^{-1} @ 7 TeV 2 fb^{-1} @ 8 TeV
- Run2 (2015-2018): 5.9 fb^{-1} @ 13 TeV

Searching for $\Xi_{cc}^{+} \to \Xi_{c}^{+}\pi^{+}\pi^{-}$



- Expecting large hadronic backgrounds, a MVA-based "online" pre-selection applied

- All final states
  - large P_T
  - Tight PID required

- Ξ_{cc}^{+}
  - Good vertex

- Ξ_{c}^{+}
  - large P_T
  - $2450{\sim}2488\ \mathrm{MeV}/c^2$

The machine learning

- Multivariate selector further explores
- Selector optimized using simulated decays for signal
- The combinatorial background is represented by same-sign pions (SSP) $\Xi_c^+\pi^-\pi^-$

After TMVA

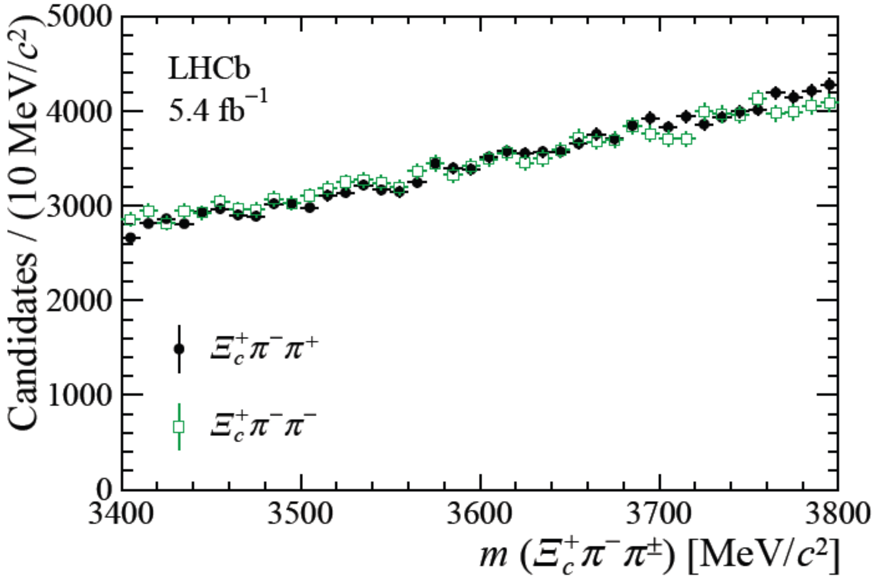
- The signal efficiency of 18%
- The background rejection of about 99.9%.

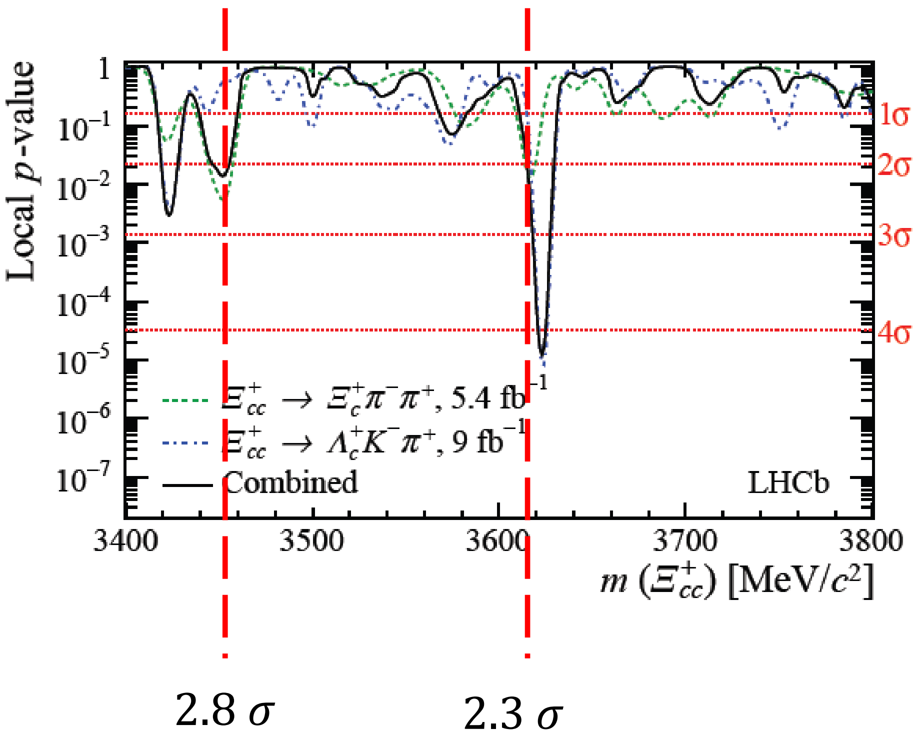
Variable
sum(Ξ_{cc}^+ bachelor p_{T})
log(Ξ_{cc}^+ χ^2_{vtx}/ndf) - Ξ_c^+ mass and Ξ_{cc}^+ PV constraints
(Ξ_c^+ p_{T}) / (sum of the Ξ_{cc}^+ daughters p_{T})
Ξ_{cc}^+ maximum DOCA (between any pairs of daughters)
log(Ξ_{cc}^+ χ^2_{IP})
log(Ξ_c^+ χ^2_{IP})
(Ξ_c^+ χ^2_{IP}) / (sum of the Ξ_{cc}^+ daughters χ^2_{IP})
Ξ_c^+ maximum DOCA (between any pairs of daughters)
Ξ_c^+ χ^2_{vtx}/ndf
Ξ_{cc}^+ DIRA(PV)
sum(Ξ_c^+ daughters p_{T})
(Ξ_c^+ proton p) / (sum of the Ξ_c^+ daughters p)
log(Ξ_{cc}^+ χ^2_{vtx}/ndf)
log(Ξ_{cc}^+ χ^2_{FD})
log(Ξ_c^+ χ^2_{FD})

Mass distributions and signal significance

➢ Reduced uncertainty on the mass of the Ξ_{cc}^{+} arXiv:2109.07292

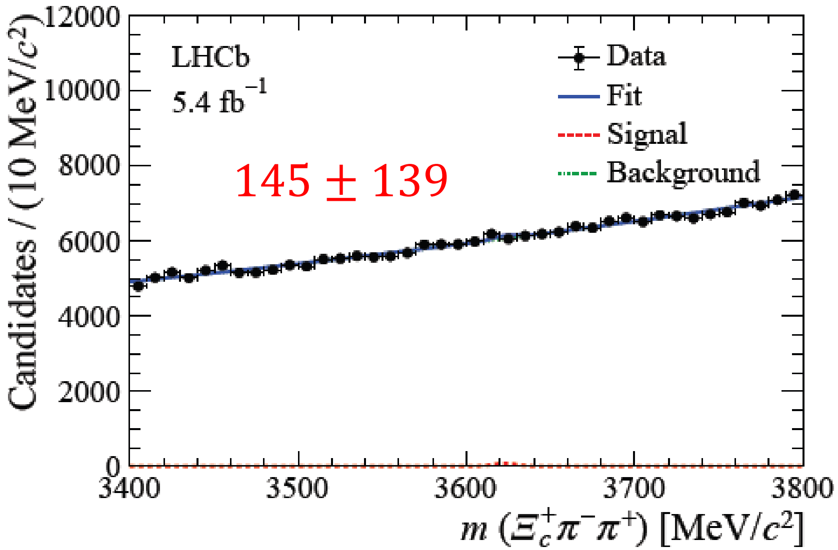
$$m(\Xi_c^+\pi^+\pi^-) \equiv m([\Xi_c^+\pi^+\pi^-]_{\Xi_{cc}^+}) - m([pK^-\pi^+]_{\Xi_c^+}) + m(\Xi_c^+),$$

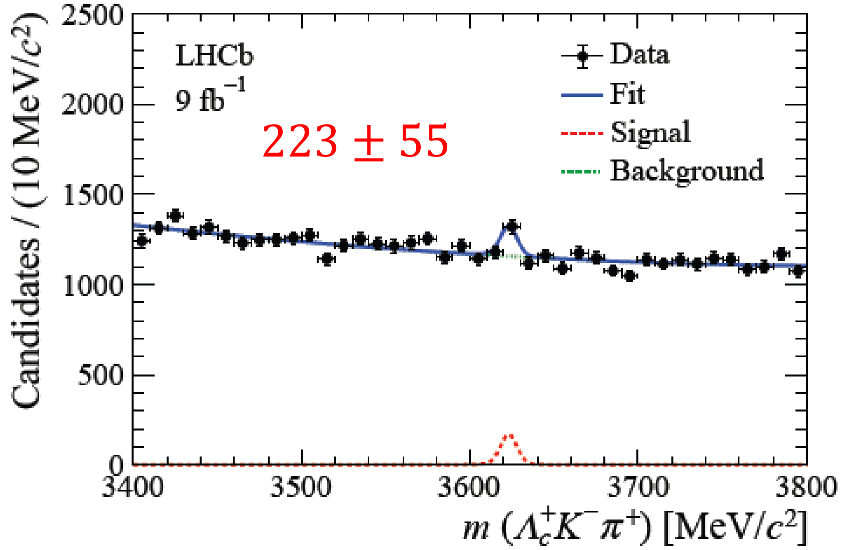




Simultaneous fit to mass

- The sum of a Gaussian function and a Crystal Ball Function for signal
- An exponential function for $\Xi_c^+\pi^+\pi^-$ and second-order Chebyshev polynomial for $\Lambda_c^+\pi^+K^-$

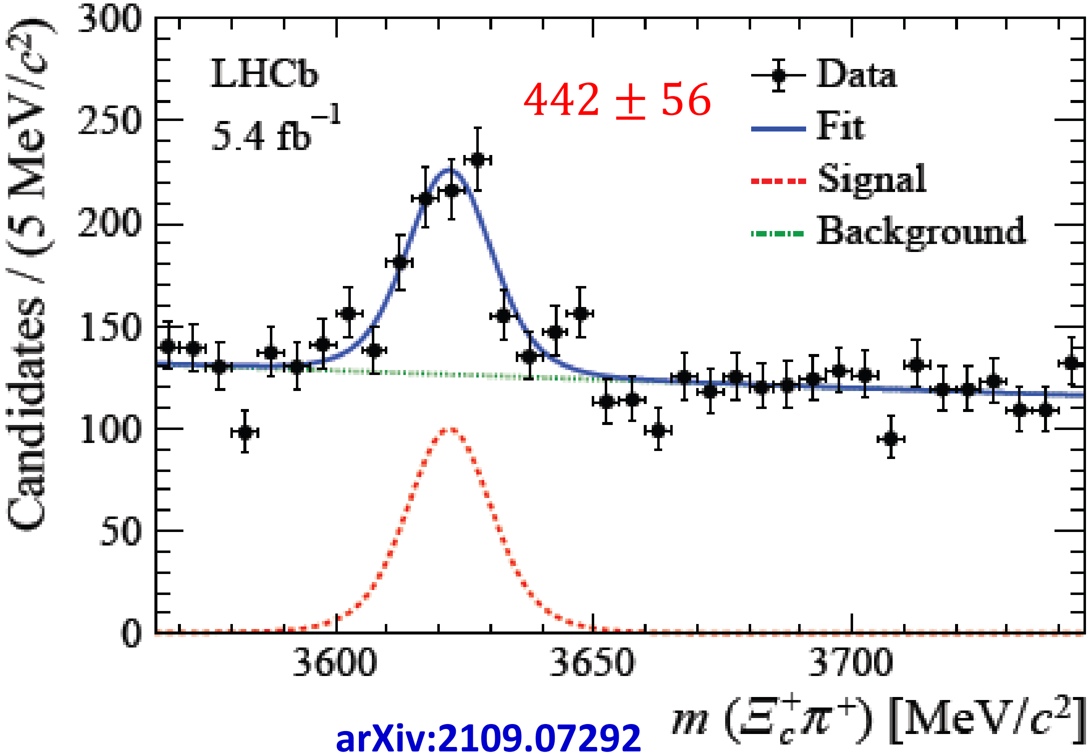




arXiv:2109.07292

Control mode $\Xi_{cc}^{++} \to \Xi_c^+ \pi^+$

- Same selection with signal mode
- Tighter PID
- Obtained more than 400 candidates



arXiv:2109.07292

Diff Ξ_{cc}^{+} lifetime and mass hypotheses

lifetime

- To mimic different lifetime hypotheses t, per-event weight is assigned as $w(t) = \frac{\frac{1}{\tau}\exp(-\frac{t}{\tau})}{\frac{1}{\tau_0}\exp(-\frac{t}{\tau_0})}$, where $\tau_0 = 80$ fs

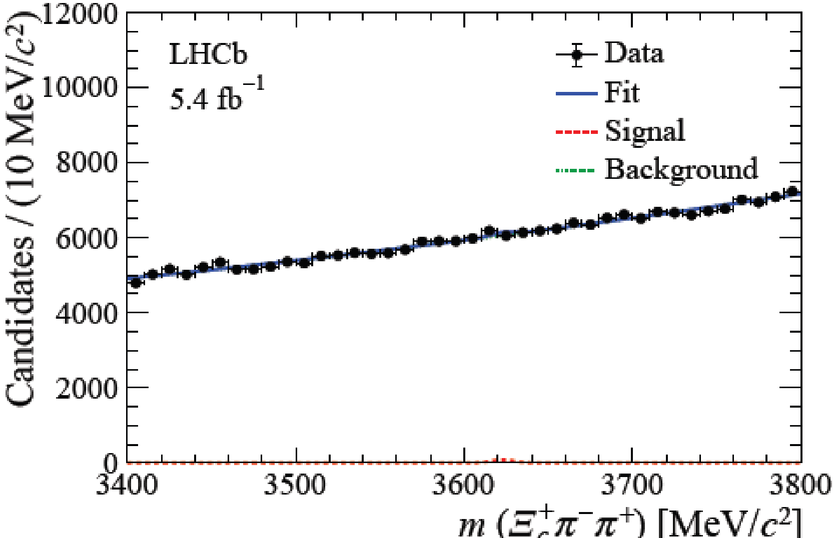
Mass

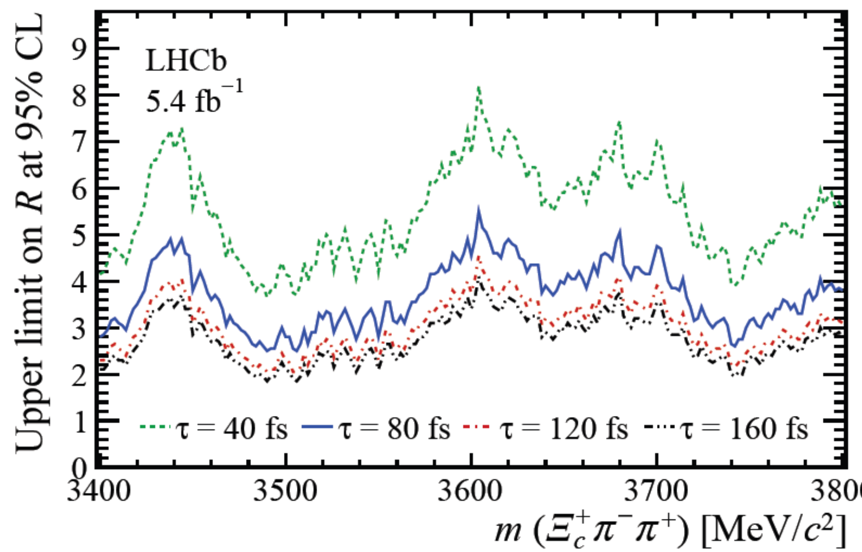
- Generator level MC with $3471, 3521, 3571, 3621, 3671, 3771$ MeV
- Reweighting full simulated sample according generator level daughters' P_T differences with other mass hypotheses

Results

- With 2016, 2017 and 2018 LHCb datasets
- Not observe significant Ξ_{cc}^{+} signal, setting upper limit
- R varying from 2 to 5 at the 95% CL @ $m(\Xi_{cc}^{+}) = 3.4\sim3.8$ GeV
- R for the Ξ_{cc}^{+} lifetime of 80 fs is 4.7 at the 95% CL

Fiducial range: $5 < P_T < 25\ \mathrm{GeV}/c^2$, $2.0 < y < 4.5$





arXiv:2109.07292

$$R \equiv \frac{\sigma(\Xi_{cc}^{+})\mathcal{B}(\Xi_{cc}^{+} \to \Xi_c^{+}\pi^{+}\pi^{-})}{\sigma(\Xi_{cc}^{++})\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^{+}\pi^{+})} = \frac{\varepsilon_{\mathrm{norm}}}{\varepsilon_{\mathrm{sig}}}\frac{N_{\mathrm{sig}}}{N_{\mathrm{norm}}}$$

Summary

- First search for the $\boldsymbol{\Xi_{cc}^{+}}$ baryon with $\boldsymbol{\Xi_{cc}^{+} \to \Xi_{c}^{+}\pi^{+}\pi^{-}}$
- No significant signal is observed
- Upper limit on the ratio of production crosssection times branching fraction to $\boldsymbol{\Xi_{cc}^{++}}$ is set
- Lots of efforts from LHCb-China group on the doubly heavy baryon studies

Thank you!