Polarization and decay of charm baryons at LHCb

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on behalf of the IFIC-LHCb group

IFIC Scientific Day, L3: flavour and quark matter
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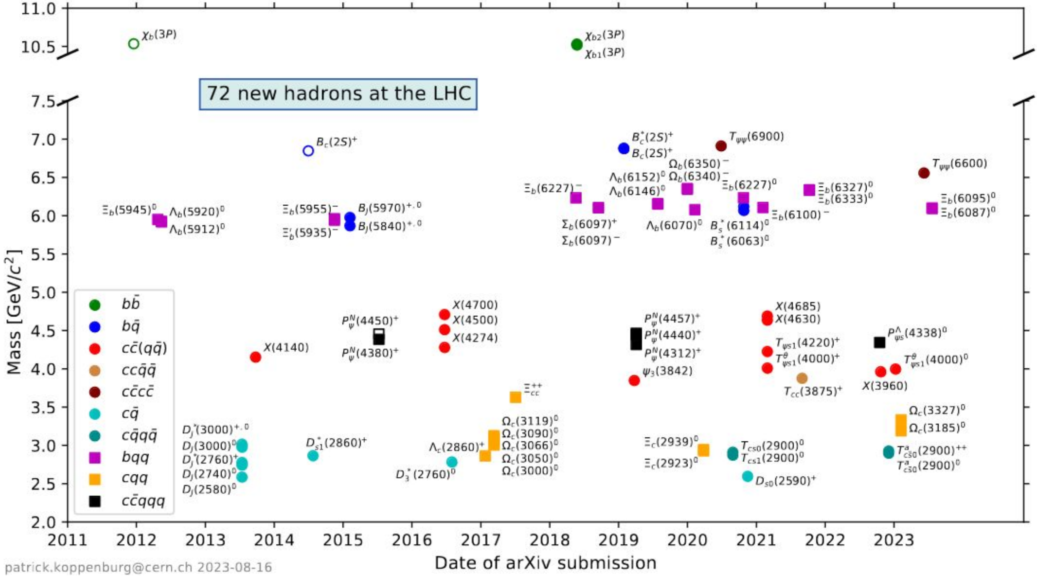
Introduction

- With Run 1 and Run 2 data, the LHC experiments have uncovered 72 new hadronic states (64 of those at LHCb)

- Some recent results include
  - Observations of excited Ω_c^0 and Ξ_c^0 states
  - Searches for doubly charmed and beauty-charm baryons
  - Amplitude analysis and polarisation measurement of $\Lambda_c^+ \to pK^- \pi^+$

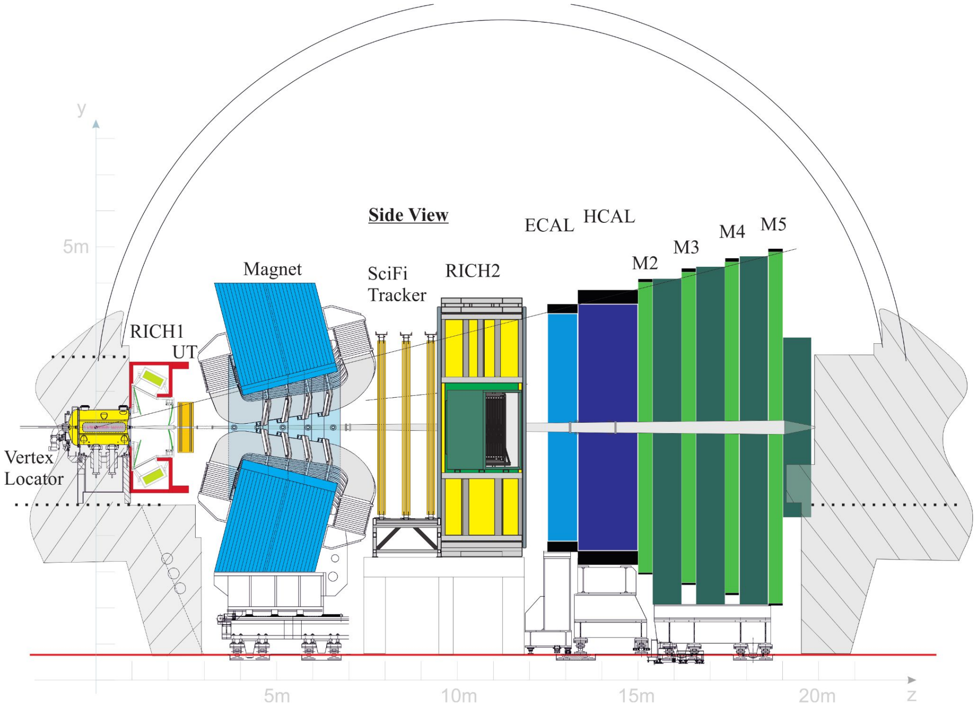
- Opportunities for measurement of EDM/MDM of charm baryons at LHC

[P. Koppenburg, 2023]

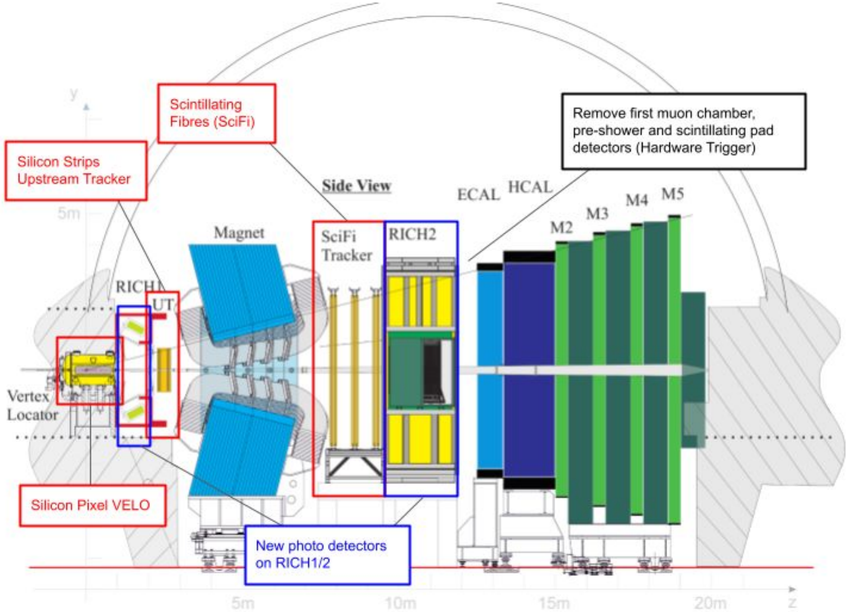


The LHCb detector

- Single arm forward spectrometer, pseudo-rapidity coverage $2 < \eta < 5$
- Initially designed for heavy flavour physics studies of charm and beauty hadrons
- During the Long Shutdown 2 (LS2) most of the sub-detectors systems have been upgraded for operation during Run 3 (2022-2025) onward
- Increased instantaneous luminosity from $4 \times 10^{32}\ cm^2s^{-1} \rightarrow 2 \times 10^{33}\ cm^2s^{-1}$

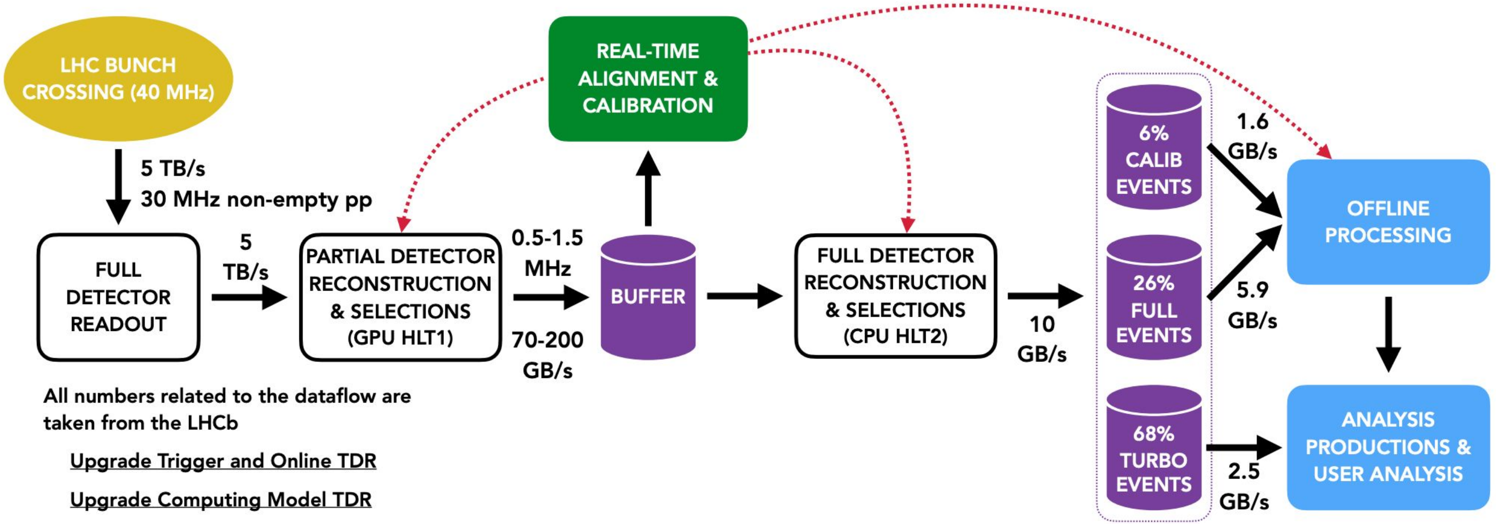


The LHCb detector



- Major changes include a new tracking system and the fully software-based trigger system
- Increased sensitivity to flavour physics channels of interest but also a capability for triggering on other signatures like Long Lived Particles (LLPs). Turning the LHCb into a general purpose detector in the forward region

The LHCb detector



All numbers related to the dataflow are taken from the LHCb

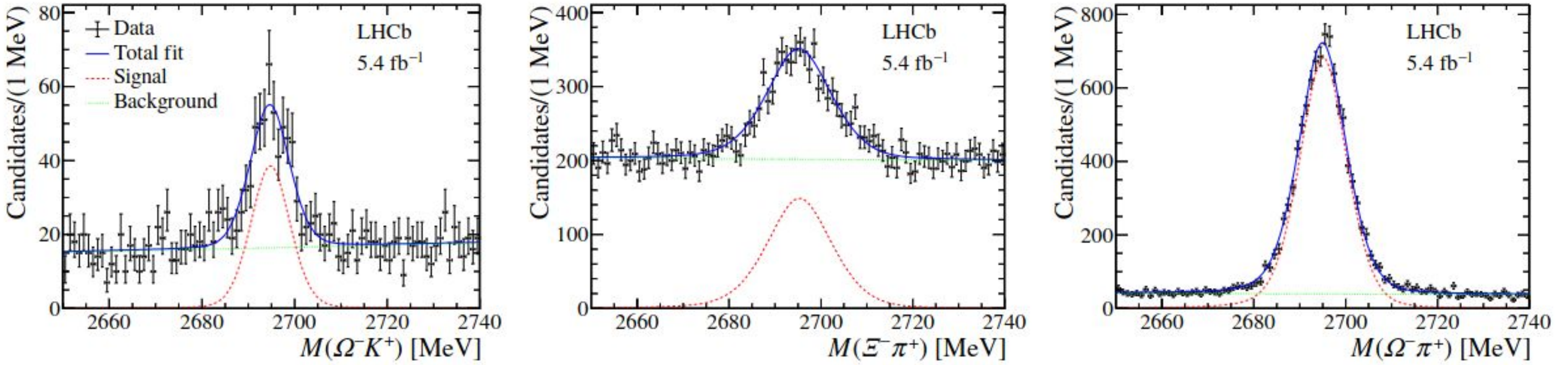
Upgrade Trigger and Online TDR

Upgrade Computing Model TDR

- Hardware trigger L0 has been completely removed
- HLT1 implemented on GPUs
  - Rate reduction 30 MHz → 1 MHz (70-200 GB/s
  - Partial reconstruction, real time calibration and alignment
- HLT2 implemented on CPUs
  - Output rate 10 GB/s
  - Trigger lines rely on offline quality reconstructed objects.
  - Full Reconstruction and selection.

Observation of Ω_c^0 decays into two-body hadronic modes

First observation of singly Cabibbo-suppressed $\Omega_c^0 \to \Omega^- K^+$ and $\Omega_c^0 \to \Xi^- \pi^+$



[arXiv:2308.08512v1]

$$\frac{\mathcal{B}(\Omega_c^0 \to \Omega^- K^+)}{\mathcal{B}(\Omega_c^0 \to \Omega^- \pi^+)} = 0.0608 \pm 0.0051\,(\text{stat}) \pm 0.0040\,(\text{syst}),$$

$$\frac{\mathcal{B}(\Omega_c^0 \to \Xi^- \pi^+)}{\mathcal{B}(\Omega_c^0 \to \Omega^- \pi^+)} = 0.1581 \pm 0.0087\,(\text{stat}) \pm 0.0043\,(\text{syst}) \pm 0.0016\,(\text{ext}).$$

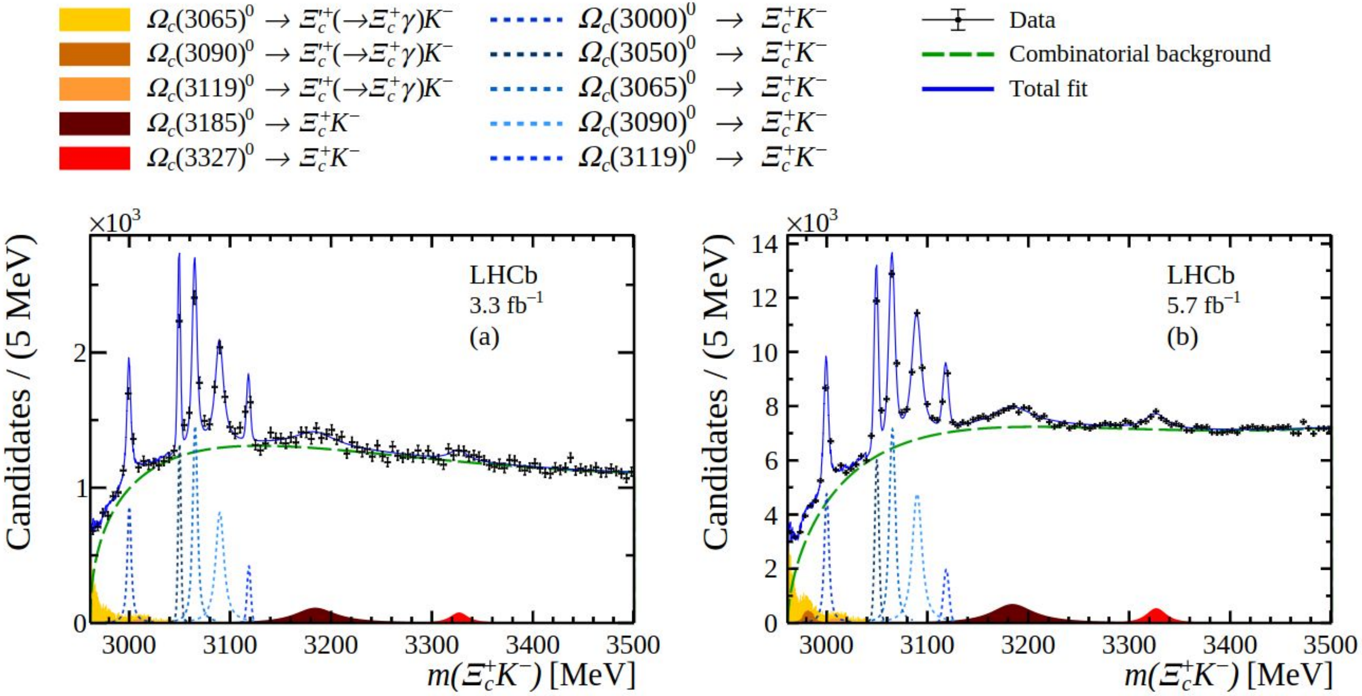
Measurement of the Ω_c^0 mass using the decay $\Omega_c^0 \to \Omega^- \pi^+$

$$M(\Omega_c^0) = 2695.28 \pm 0.07\,(\text{stat}) \pm 0.27\,(\text{syst}) \pm 0.30\,(\text{ext})\,\text{MeV}/c^2$$

New Ω_c^0 states decaying to the $\Xi_c^+K^-$ final state

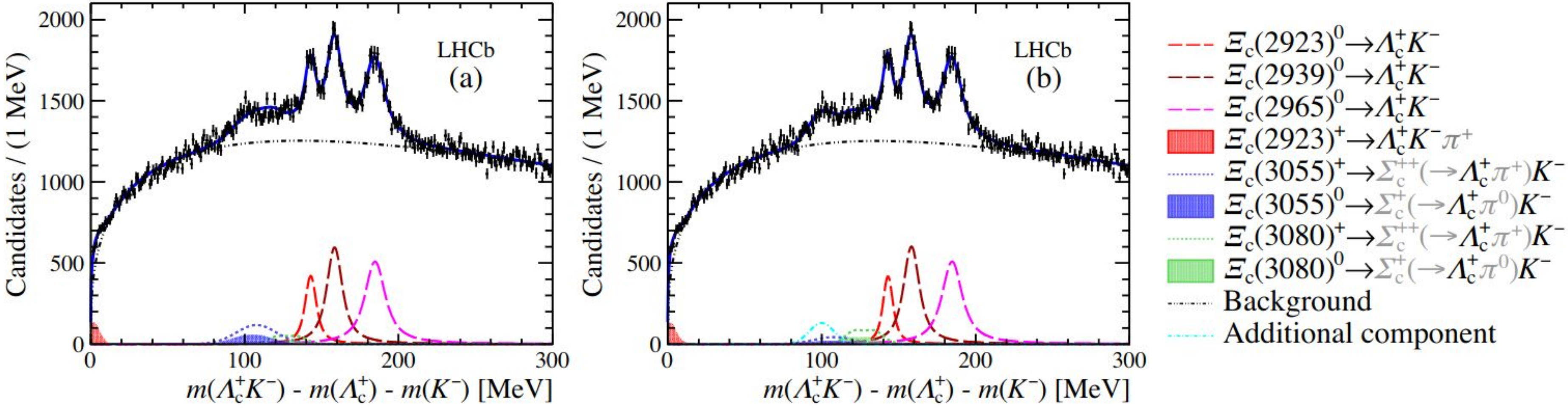
Two new excited states $\Omega_c(3185)^0$ and $\Omega_c(3327)^0$ observed and five previously observed states are confirmed $\Omega_c(3000)^0$, $\Omega_c(3050)^0$, $\Omega_c(3065)^0$, $\Omega_c(3090)^0$, and $\Omega_c(3119)^0$

Phys. Rev. Lett. 131 (2023) 131902



New Ξ_c^0 baryons decaying to $\Lambda_c^+K^-$ decays

Phys. Rev. Lett. 124, (2020) 222001

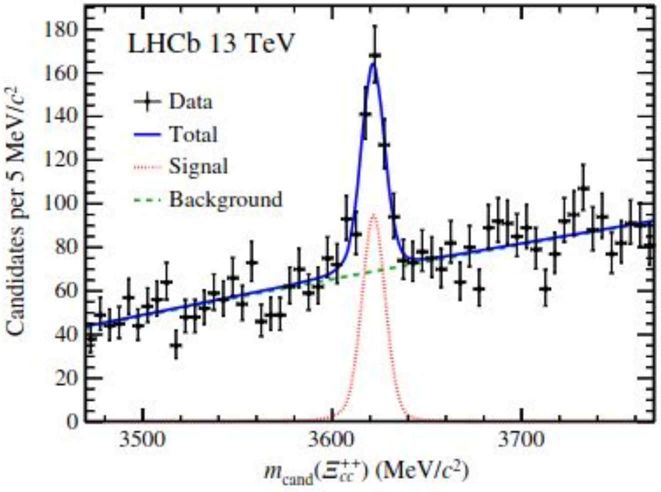


Two new $\Xi_c(2923)^0$ and $\Xi_c(2939)^0$ states found. The $\Xi_c(2965)^0$ is very close to the known $\Xi_c(2970)^0$ but with significantly different natural width and mass

Resonance	Peak of ΔM [MeV]	Mass [MeV]	Γ [MeV]
$\Xi_c(2923)^0$	$142.91 \pm 0.25 \pm 0.20$	$2923.04 \pm 0.25 \pm 0.20 \pm 0.14$	$7.1 \pm 0.8 \pm 1.8$
$\Xi_c(2939)^0$	$158.45 \pm 0.21 \pm 0.17$	$2938.55 \pm 0.21 \pm 0.17 \pm 0.14$	$10.2 \pm 0.8 \pm 1.1$
$\Xi_c(2965)^0$	$184.75 \pm 0.26 \pm 0.14$	$2964.88 \pm 0.26 \pm 0.14 \pm 0.14$	$14.1 \pm 0.9 \pm 1.3$

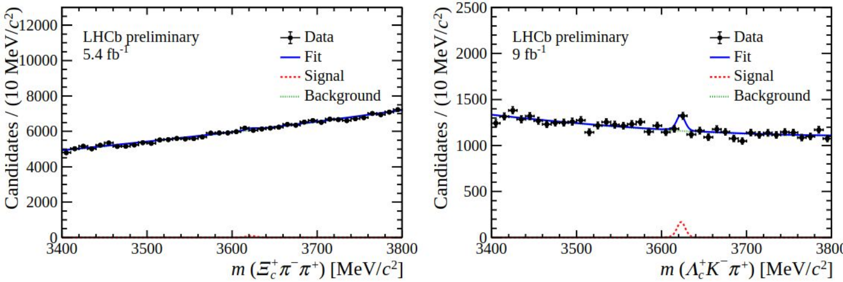
Doubly charmed baryons at LHCb

In 2017 LHCb reported the first observation of the doubly charmed baryon Ξ_{cc}^{++} in the $\Lambda_c^+K^-\pi^+\pi^+$ final state was announced by the LHCb collaboration

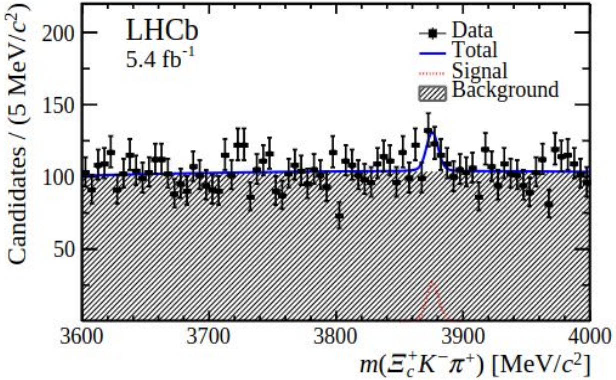


[Phys. Rev. Lett. 119, 112001](#)

Searches for Ξ_{cc}^+ and Ω_{cc}^+



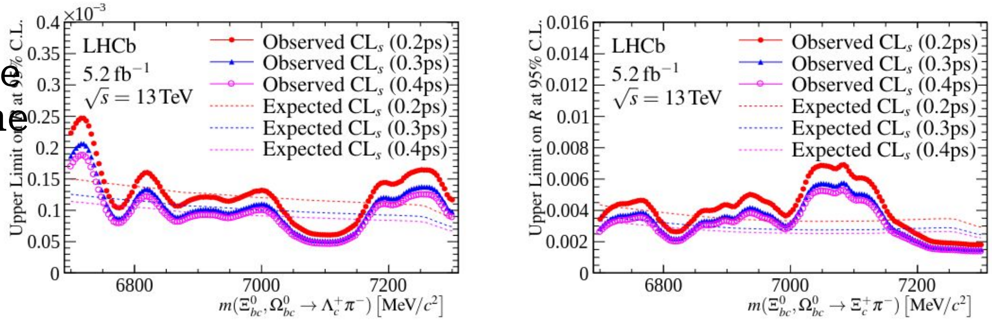
[JHEP 63, (2020) 221062](#)



[Sci. China Phys. Mech. Astron. 12, (2021) 107](#)

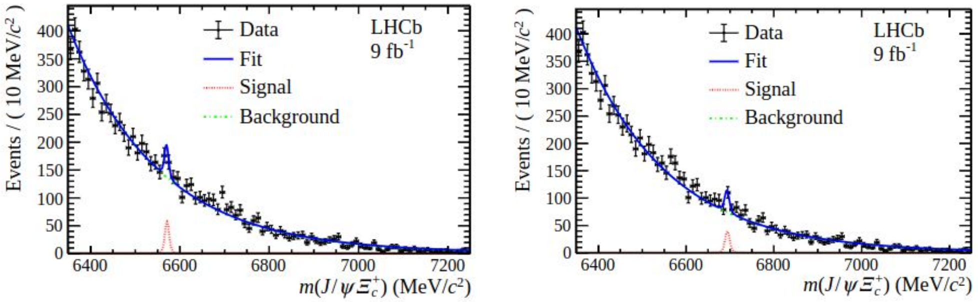
Searches of beauty-charm baryons

- **Ξ_{bc}^{0} and Ω_{bc}^{0} decays to $\Lambda_c^{+}\pi^{-}$ and $\Xi_c^{+}\pi^{-}$**
  No evidence is found. Limits are set on the ratio of production cross-section times the branching fraction wrt to the control channels at 95% CL for different lifetime hypothesis



[Chin. Phys. C 45 (2021) 093002]

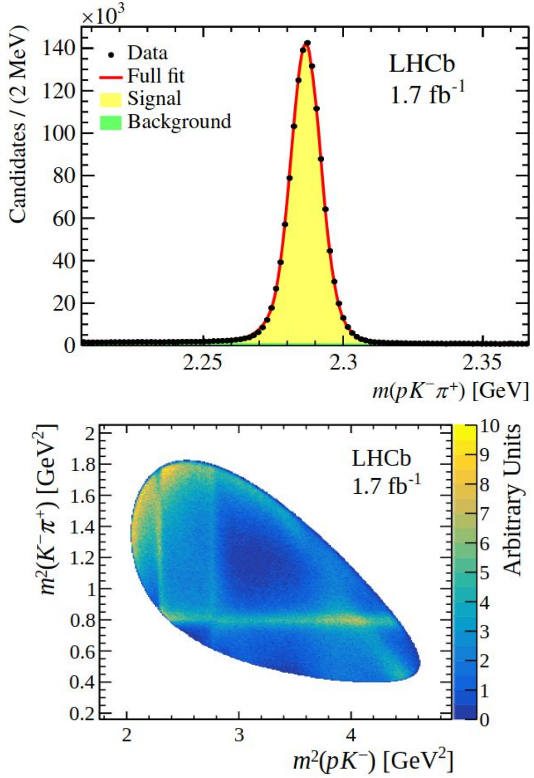
- **Ξ_{bc}^{+} decaying to $J/\psi\Xi_c^{+}$**
  Two peaking structures are seen with a local (global) significance of 4.3 (2.8) and 4.1 (2.4)



[Chin. Phys. C 47 (2023) 093001]

Amplitude analysis of $\Lambda_c^+ \to pK^-\pi^+$ and Λ_c^+ polarization

Model Dependent Amplitude Analysis of semileptonic (SL) Λ_c^+ decays and polarization measurement of Λ_c^+

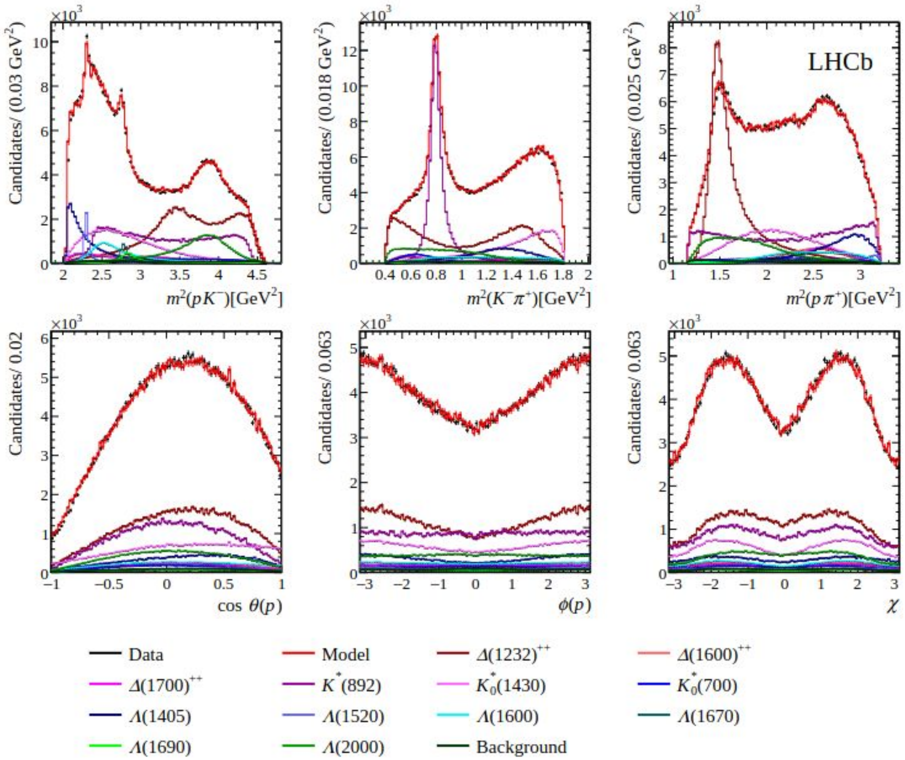


Resonance	J^P	Mass (MeV)	Width (MeV)
$\Lambda(1405)$	$1/2^-$	1405.1	50.5
$\Lambda(1520)$	$3/2^-$	1515–1523	10–20
$\Lambda(1600)$	$1/2^+$	1630	250
$\Lambda(1670)$	$1/2^-$	1670	30
$\Lambda(1690)$	$3/2^-$	1690	70
$\Lambda(2000)$	$1/2^-$	1900–2100	20–400
$\Delta(1232)^{++}$	$3/2^+$	1232	117
$\Delta(1600)^{++}$	$3/2^+$	1640	300
$\Delta(1700)^{++}$	$3/2^-$	1690	380
$K_0^*(700)$	0^+	824	478
$K^*(892)$	1^-	895.5	47.3
$K_0^*(1430)$	0^+	1375	190

Phys. Rev. D 108 (2023) 012023

Amplitude analysis of $\Lambda_c^+ \to pK^-\pi^+$ and Λ_c^+ polarization

Large sensitivity of the $\Lambda_c^+ \to pK^-\pi^+$ decay to the polarization



Distributions in the *lab system*

Component	Value (%)
P_x (lab)	$60.32 \pm 0.68 \pm 0.98 \pm 0.21$
P_y (lab)	$-0.41 \pm 0.61 \pm 0.16 \pm 0.07$
P_z (lab)	$-24.7 \pm 0.6 \pm 0.3 \pm 1.1$
P_x $(\tilde{B})$	$21.65 \pm 0.68 \pm 0.36 \pm 0.15$
P_y $(\tilde{B})$	$1.08 \pm 0.61 \pm 0.09 \pm 0.08$
P_z $(\tilde{B})$	$-66.5 \pm 0.6 \pm 1.1 \pm 0.1$

Measured Λ_c^+ polarization components

Phys. Rev. D 108 (2023) 012023

Λ_c^+ polarimetry

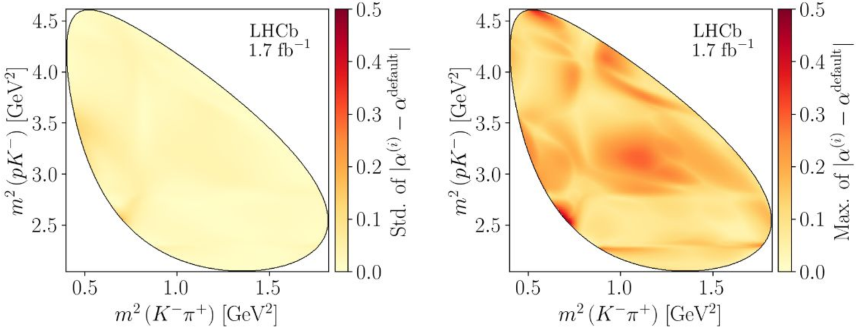
The differential decay rate in a polarized decay

$$\frac{\Phi}{\Gamma}\frac{d\Gamma}{d\Phi} \propto 1 + \vec{P}\cdot\vec{h}$$

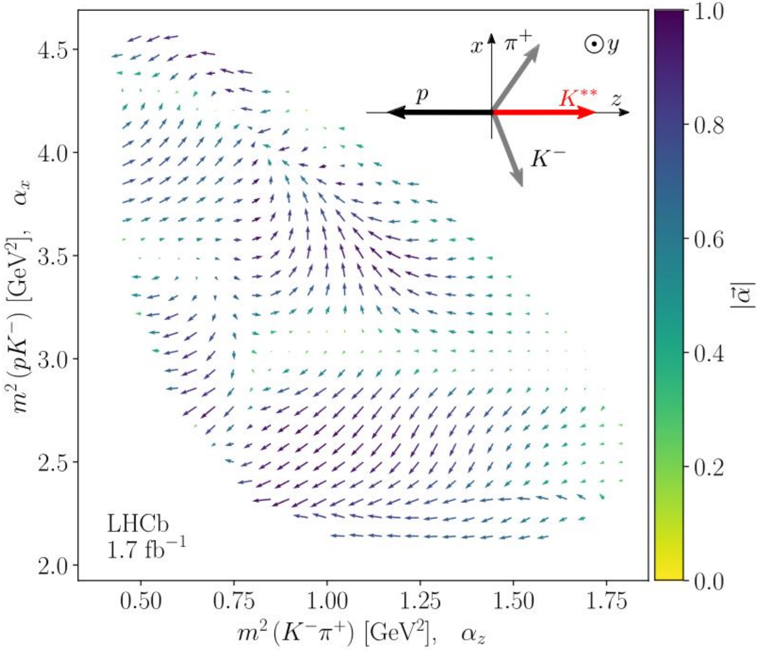
$\vec{P}$ is the polarization vector and $\vec{h}$ the polarimeter vector

Dependence of the polarimeter vector on the decay plane can be factored out by a rotation

$$\vec{h} = R(\phi, \theta, \chi)\vec{\alpha}$$

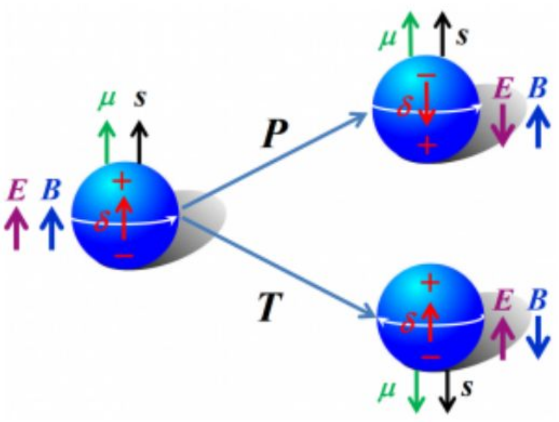


Use amplitude model found to compute the aligned polarimeter vector $\vec{\alpha}$



JHEP07(2023)228

EDM/MDM of charm baryons at LHC



Electric and magnetic dipole moments of spin-½ particles

$$\delta = d\mu_N \frac{\mathbf{S}}{2} \qquad \mu = g\mu_N \frac{\mathbf{S}}{2}$$

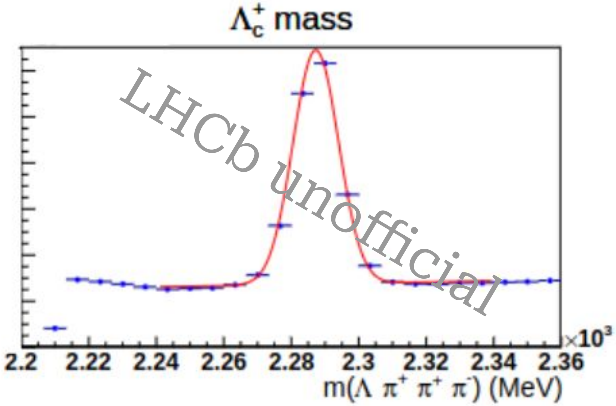
$$H = -\delta \cdot \mathbf{E} - \mu \cdot \mathbf{B} \xrightarrow{P,T} H = +\delta \cdot E - \mu \cdot B$$

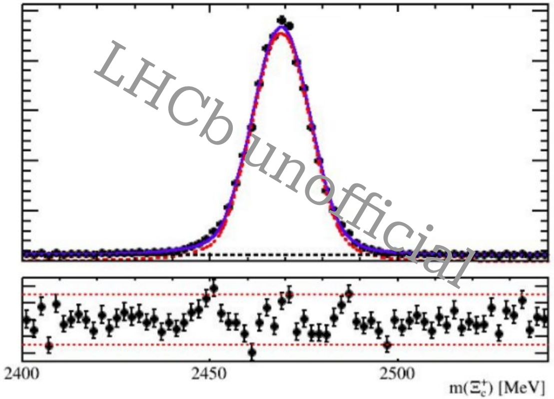
A non-zero **EDM** indicates violation of P and T symmetry
→ CP violation

Measurement of the **MDM** for particle and antiparticle provides a test for the **CPT theorem** and **low energy QCD models**

Unique opportunity for charm baryons produced in a fixed target experiment with bent crystals. $\Lambda_c^+ \to pK^-\pi^+$ and $\Xi_c^+ \to \Xi^-\pi^+\pi^+$ are golden modes
[PRD 103, 072003 (2021)]

Amplitude analysis and polarimetry of charm baryons





Amplitude analysis and polarization measurements ongoing on several other charm baryon decay channels

- $\Xi_c^+ \to \Xi^- \pi^+ \pi^+$
- $\Xi_c^+ \to p K^- \pi^+$
- $\Xi_c^0 \to \Xi^- \pi^+$
- $\Xi_c^0 \to \Xi^- \pi^- \pi^+ \pi^+$
- $\Xi_c^0 \to \Lambda K^- \pi^+$
- $\Lambda_c^+ \to \Lambda \pi^- \pi^+ \pi^+$

Summary

- With Run 1 and Run 2 data LHCb has made the first observation of many new states and performed high precision measurements on many heavy flavour observables

- In the recent years several new charm baryon states have been observed or confirmed and improved limits on searches for other exotic doubly charm and beauty-charm baryon have been performed

- Still several other amplitude analyses and polarisation measurements with charm baryons using Run 2 data to come

- LHCb Upgrade detector will improve sensitivity to charm baryon decays, in particular for channels with intermediate LLPs and a higher luminosity will improve current measurements

Back up