Observation of the doubly charmed baryon Ξ_{cc}^{+} with the upgraded LHCb detector

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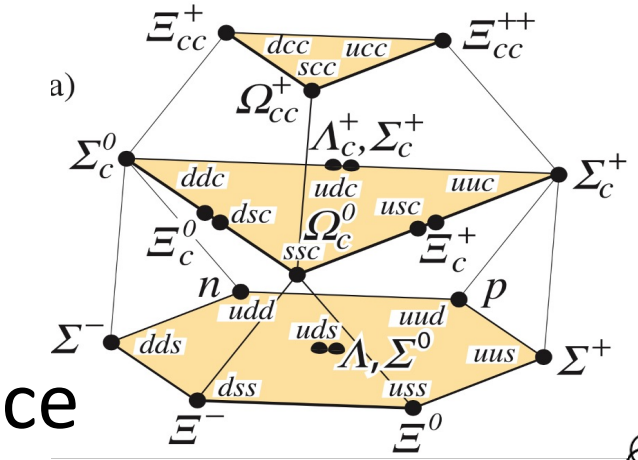
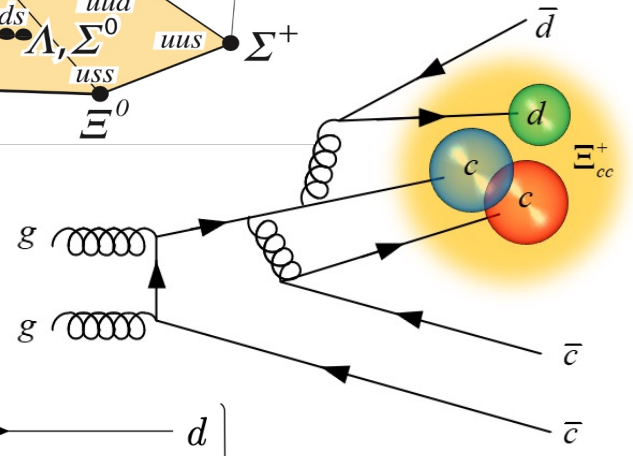
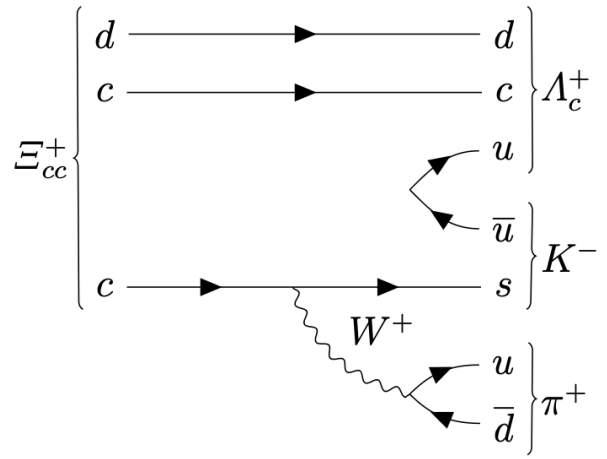
Introduction

- Doubly charmed baryon,
  unique system for testing QCD
- Production @ 13 TeV, in LHCb acceptance
  - $\sigma(\Xi_{cc}^{+}) \approx \sigma(\Xi_{cc}^{++}) \sim 40$ nb, $\sigma(\Omega_{cc}^{+}) \sim 13$ nb
- Mass
  - $M(\Xi_{cc}^{+}) \approx M(\Xi_{cc}^{++})$: 3.62 GeV,
    $M(\Omega_{cc}^{+})$, +0.1-0.2 GeV
- Lifetime
  - $\tau(\Xi_{cc}^{+}) \ll \tau(\Omega_{cc}^{+}) < \tau(\Xi_{cc}^{++}) = 256$ fs

[C.H. Chang *et al.*, PRD 73 (2006) 094022]

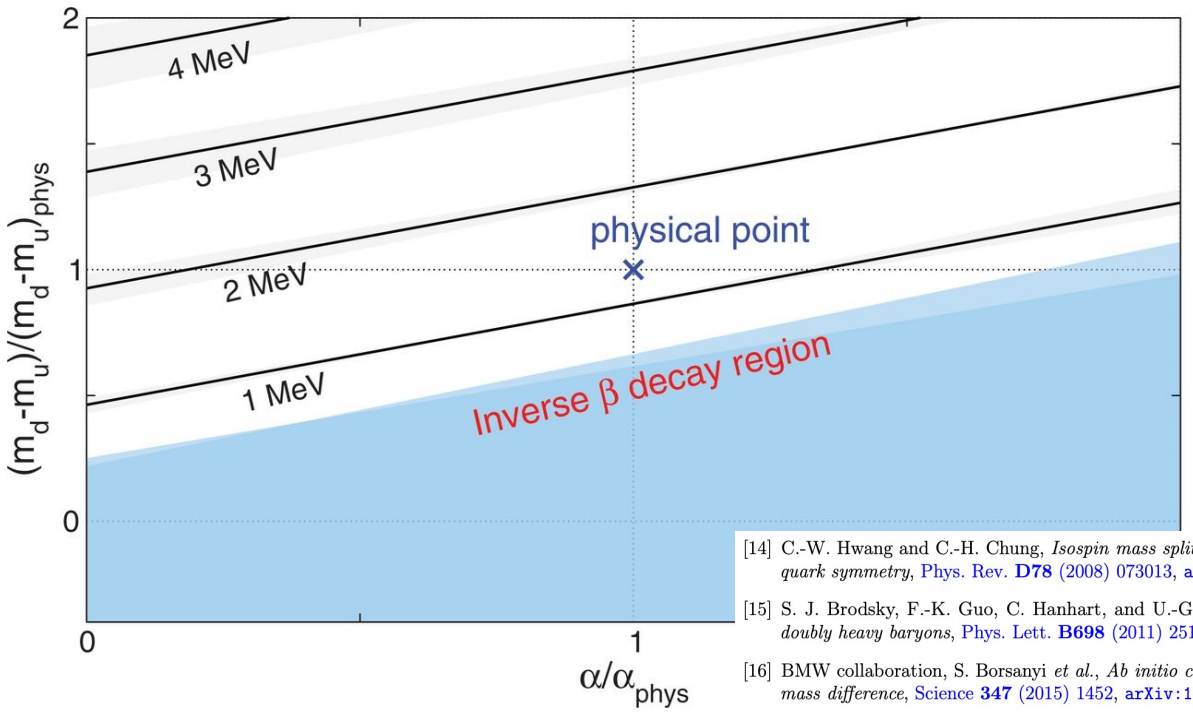






Why Ξ_{cc}^{+} still interesting after observing Ξ_{cc}^{++}?

- Ξ_{cc}^{+} (ccd), isospin partner to $\Xi_{cc}^{++}(ccu)$, like neutron to proton
- $M(\Xi_{cc}^{+}) < M(\Xi_{cc}^{++})$, QED wins the competition with QCD!



	Mass splitting [MeV]	QCD [MeV]	QED [MeV]
$\Delta N = n - p$	1.51(16)(23)	2.52(17)(24)	−1.00(07)(14)
$\Delta\Sigma = \Sigma^- - \Sigma^+$	8.09(16)(11)	8.09(16)(11)	0
$\Delta\Xi = \Xi^- - \Xi^0$	6.66(11)(09)	5.53(17)(17)	1.14(16)(09)
$\Delta D = D^{\pm} - D^0$	4.68(10)(13)	2.54(08)(10)	2.14(11)(07)
$\Delta\Xi_{cc} = \Xi_{cc}^{++} - \Xi_{cc}^{+}$	2.16(11)(17)	−2.53 (11)(06)	4.69(10)(17)
$\Delta_{CG} = \Delta N - \Delta\Sigma + \Delta\Xi$	0.00(11)(06)	−0.00 (13)(05)	0.00(06)(02)

[14] C.-W. Hwang and C.-H. Chung, *Isospin mass splittings of heavy baryons in heavy quark symmetry*, Phys. Rev. **D78** (2008) 073013, arXiv:0804.4044.

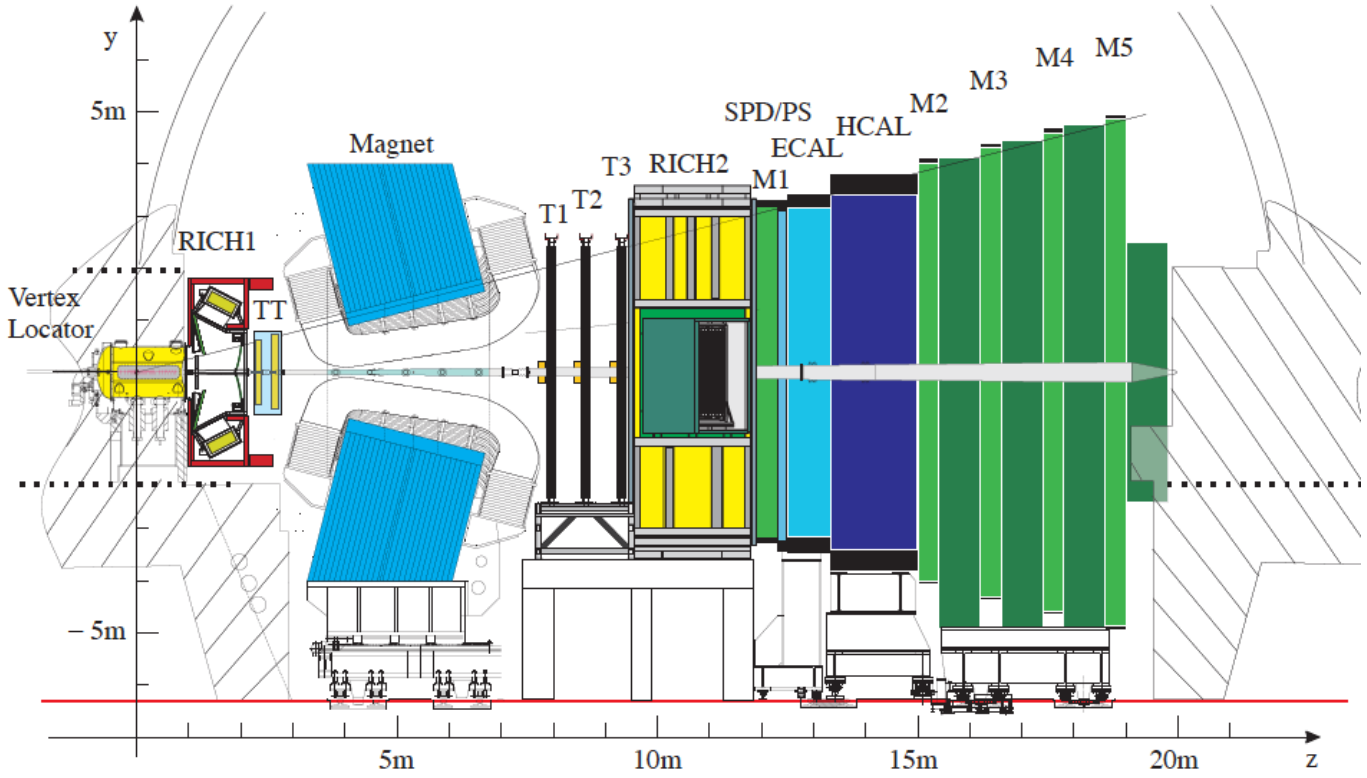
[15] S. J. Brodsky, F.-K. Guo, C. Hanhart, and U.-G. Meißner, *Isospin splittings of doubly heavy baryons*, Phys. Lett. **B698** (2011) 251, arXiv:1101.1983.

[16] BMW collaboration, S. Borsanyi *et al.*, *Ab initio calculation of the neutron-proton mass difference*, Science **347** (2015) 1452, arXiv:1406.4088.

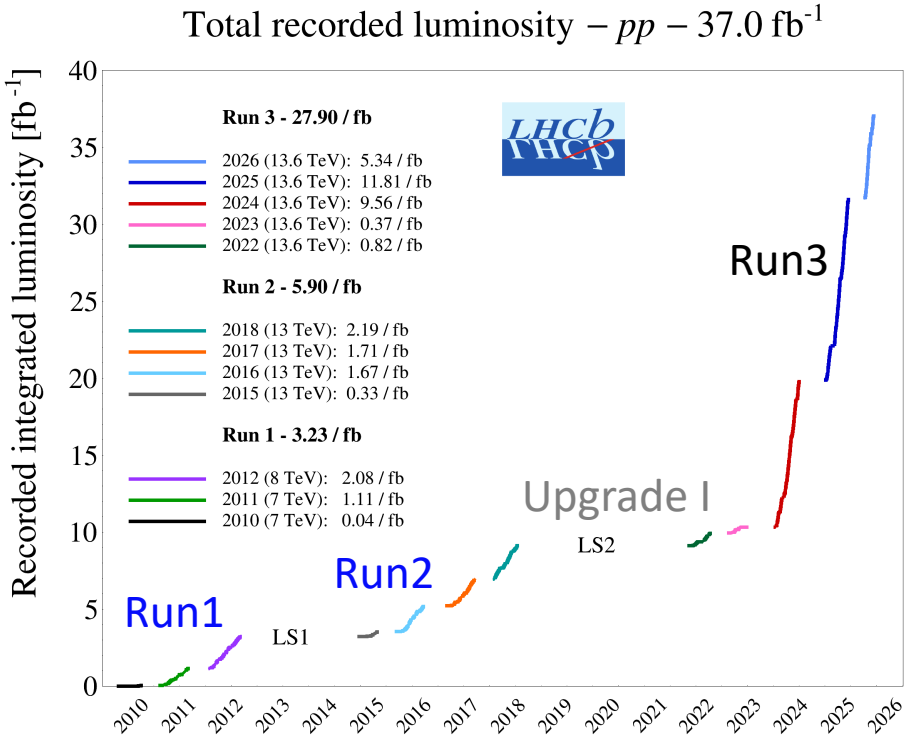
[17] K.-W. Wei, B. Chen, and X.-H. Guo, *Masses of doubly and triply charmed baryons*, Phys. Rev. **D92** (2015) 076008, arXiv:1503.05184.

[18] M. Karliner and J. L. Rosner, *Isospin splittings in baryons with two heavy quarks*, Phys. Rev. **D96** (2017) 033004, arXiv:1706.06961.

The LHCb experiment



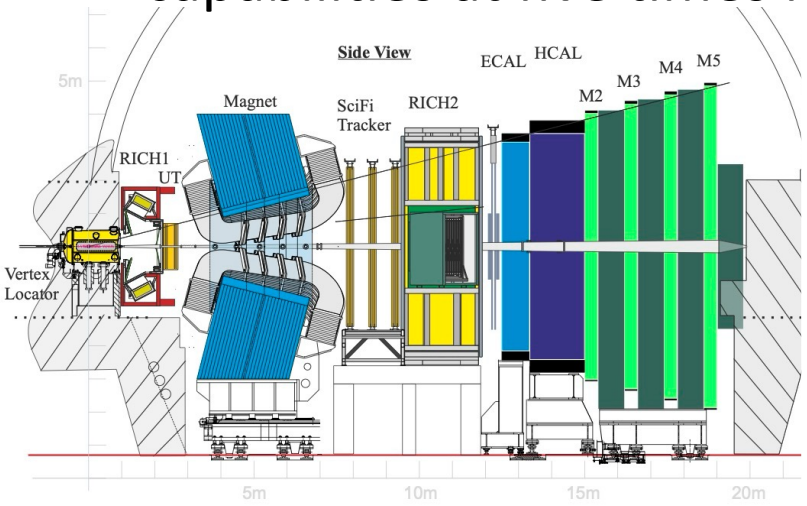
Vertex Locator	$\sigma_{PV,x/y} \sim 10\ \mu m$, $\sigma_{PV,z} \sim 60\ \mu m$
Tracking (TT, T1-T3)	$\Delta p/p$: 0.4% at 5 GeV/c, to 0.6% at 100 GeV/c
RICHs	$\varepsilon(K \to K) \sim 95\%$, mis-ID rate $(\pi \to K) \sim 5\%$
Muon system (M1-M5)	$\varepsilon(\mu \to \mu) \sim 97\%$, mis-ID rate $(\pi \to \mu) = 1-3\%$
ECAL	$\sigma_E/E \sim 10\%/\sqrt{E} \oplus 1\%$ (E in GeV)
HCAL	$\sigma_E/E \sim 70\%/\sqrt{E} \oplus 10\%$ (E in GeV)

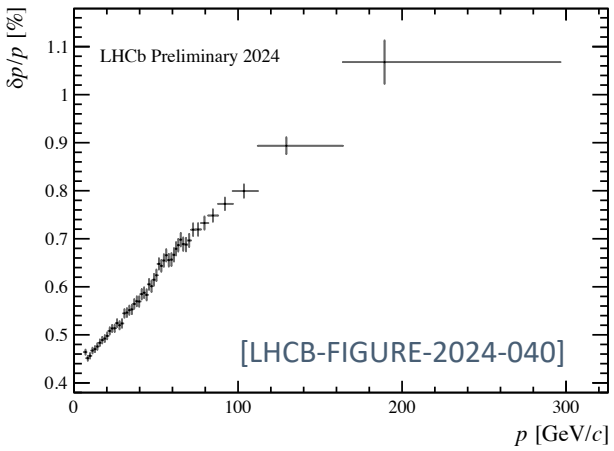


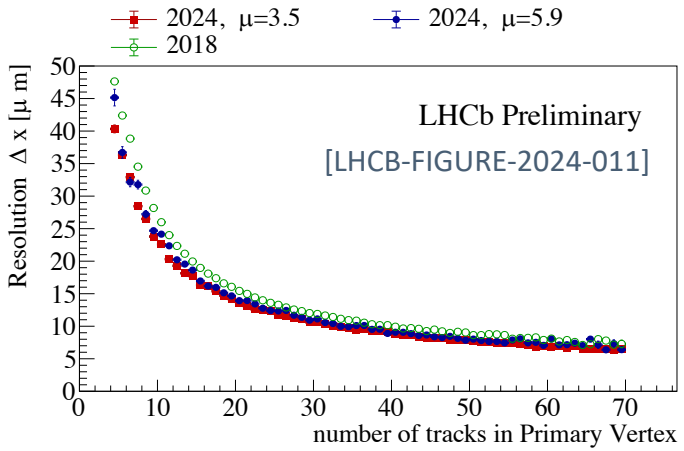
- Run1-2 (2010-2018)
  - Luminosity: ~9 fb^{-1}
  - Yields, complementary to ATLAS/CMS
    - Muon modes: Down to zero p_T
    - Hadronic modes: Unique

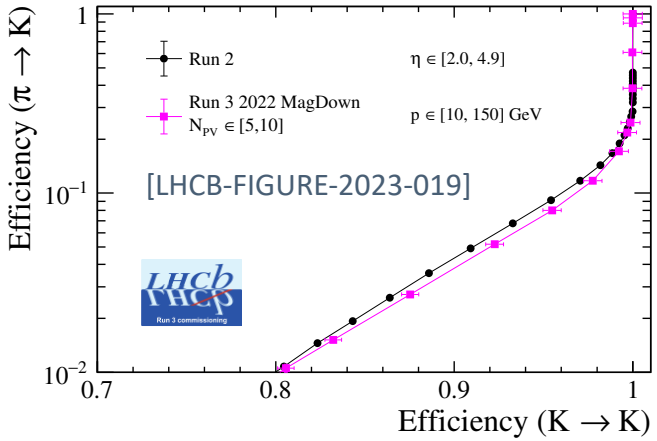
The LHCb Upgrade

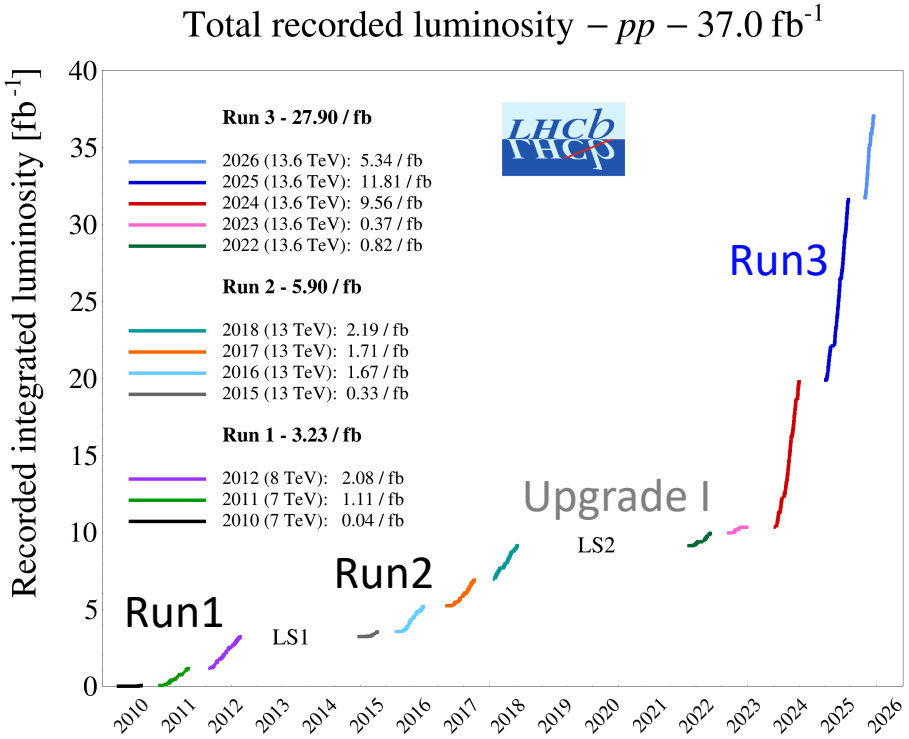
- Detector mostly renewed to achieve enhanced capabilities at five times higher luminosity





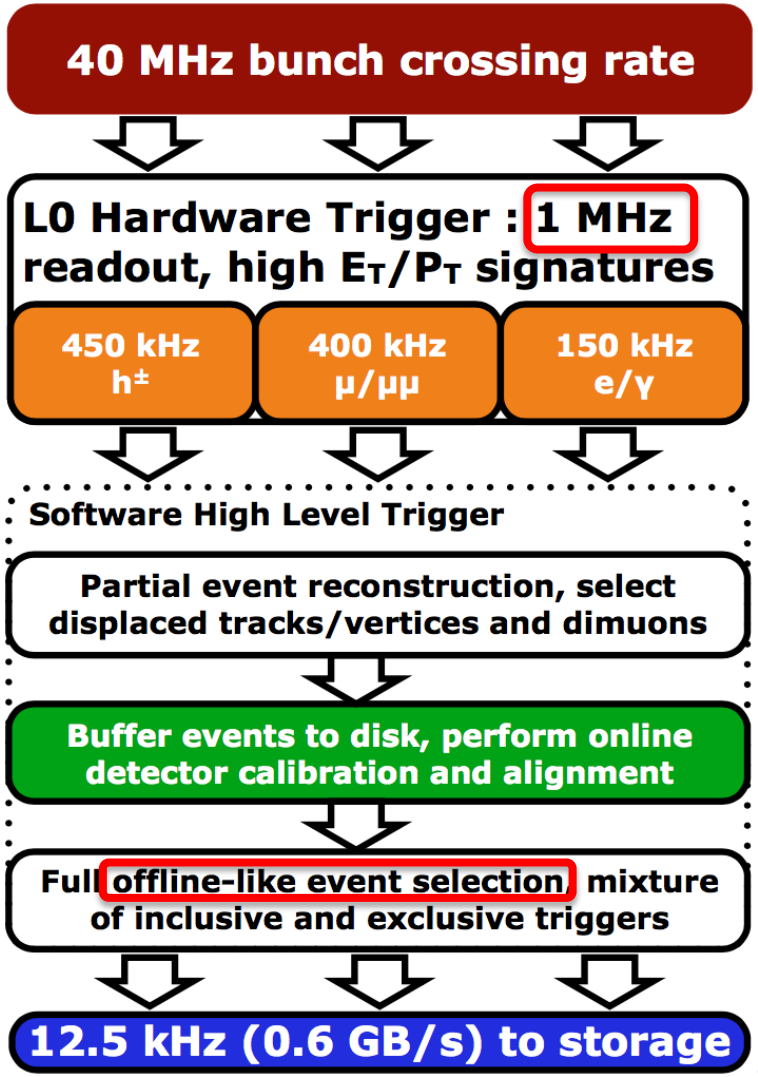






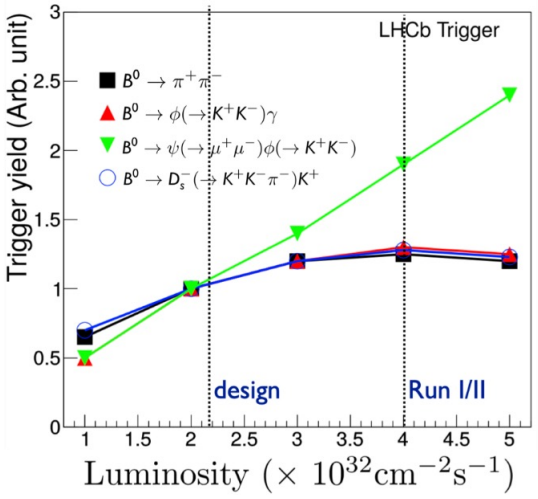
- Run3 (2024-2026)
  - Luminosity: ~28 fb^{-1}
  - Yields, compared to Run 1+2
    - Muon modes ~4
    - Hadronic modes ~8 (higher trigger eff.)

The LHCb trigger (2018)



- L0, Hardware
  - $p_{\mathrm{T}}(\mu_1) \times p_{\mathrm{T}}(\mu_2) > (1.5\ \mathrm{GeV})^2$
  - $p_{\mathrm{T}}(\mu) > 1.8\ \mathrm{GeV}$
  - $E_{\mathrm{T}}(e) > 2.4\ \mathrm{GeV}$
  - $E_{\mathrm{T}}(\gamma) > 3.0\ \mathrm{GeV}$
  - $E_{\mathrm{T}}(h) > 3.7\ \mathrm{GeV}$
- High Level Trigger
  - Stage1, p_{T}, IP
  - Stage2, full selection

The LHCb trigger (Run3)



Software High Level Trigger

Partial event reconstruction, select displaced tracks/vertices and dimuons

Buffer events to disk, perform online detector calibration and alignment

Full offline-like event selection, mixture of inclusive and exclusive triggers

12.5 kHz (0.6 GB/s) to storage

L0 removed

30 MHz inelastic event rate (full rate event building)

Software High Level Trigger

Full event reconstruction, inclusive and exclusive kinematic/geometric selections

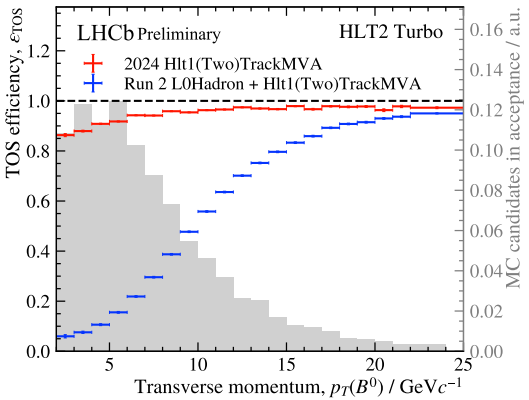
Buffer events to disk, perform online detector calibration and alignment

Add offline precision particle identification and track quality information to selections

Output full event information for inclusive triggers, trigger candidates and related primary vertices for exclusive triggers

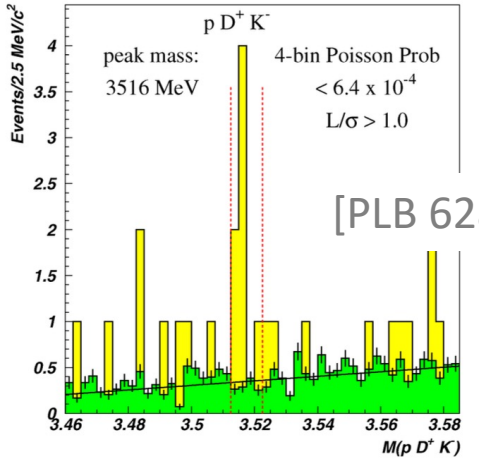
2-5 GB/s to storage

[LHCB-FIGURE-2024-030]



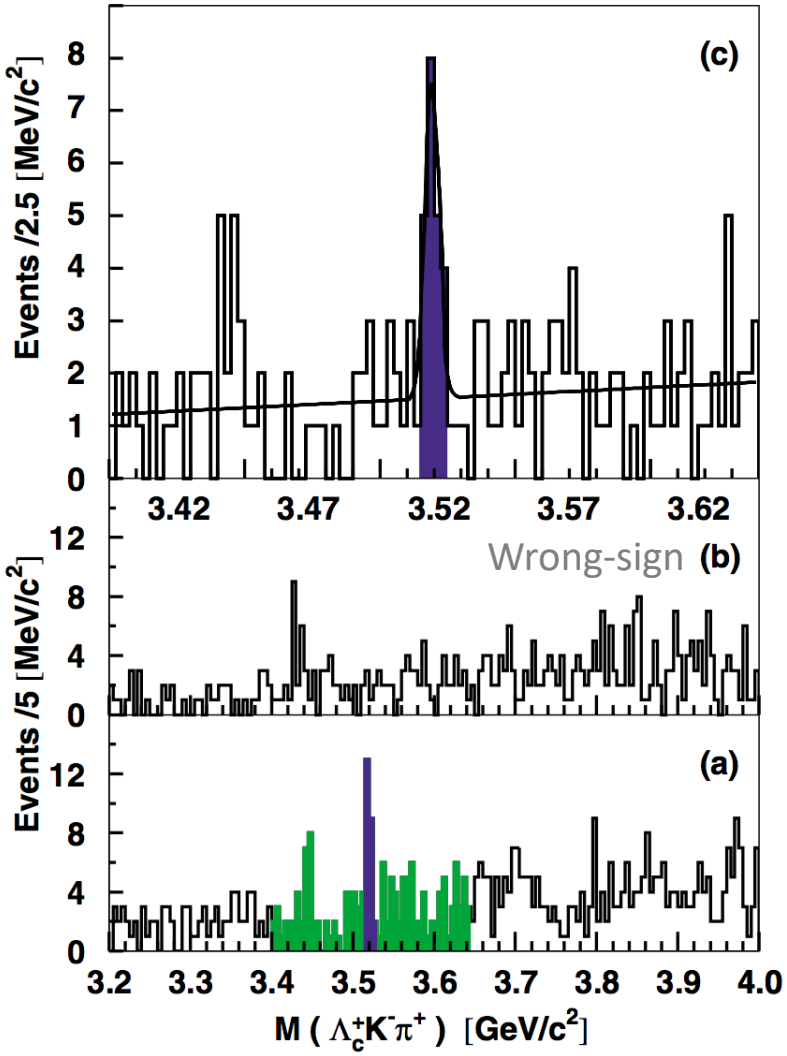
Ξ_{cc}^{+} @ SELEX

- SELEX claimed $\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+}$ (6.3σ)
  - M: 3519 ± 1 MeV
  - τ: <33 fs @90%CL
  - σ_{prod}: 20% Λ_c^{+} from Ξ_{cc}^{+}
- Also $\Xi_{cc}^{+} \to p D^{+} K^{-}$



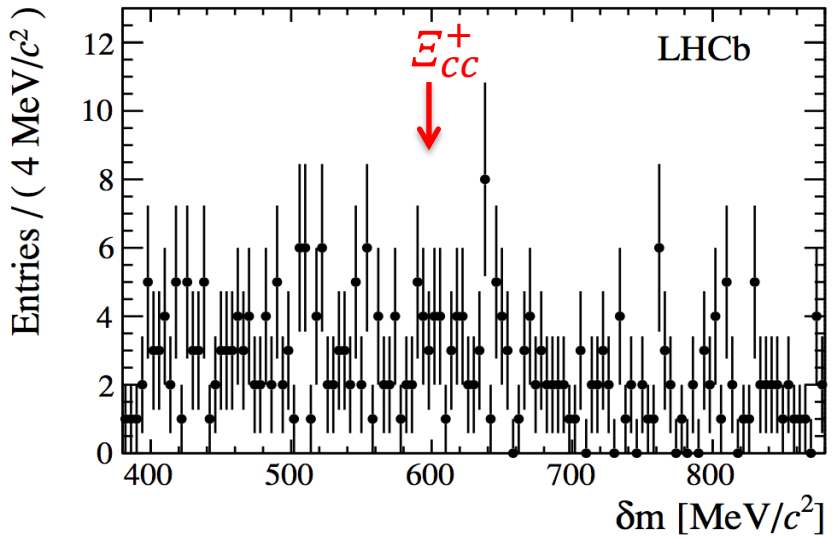
[PLB 628 (2005)18]

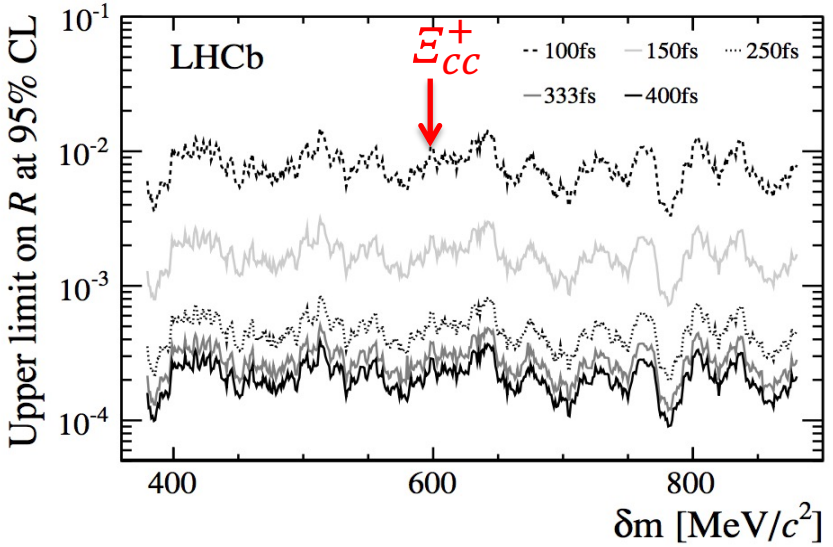
[PRL 89 (2002) 112001]



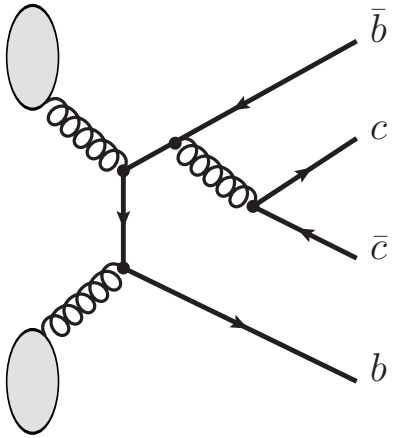
Ξ_{cc} @ LHCb & others

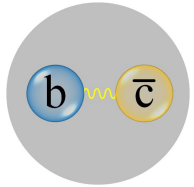
- SELEX results not confirmed by FOCUS, Babar, Belle & LHCb
- $\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+}$ searched by LHCb with 2011 data



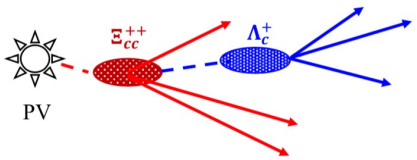


- However, LHCb already had lots of B_c^{+} events, and double-charm events…



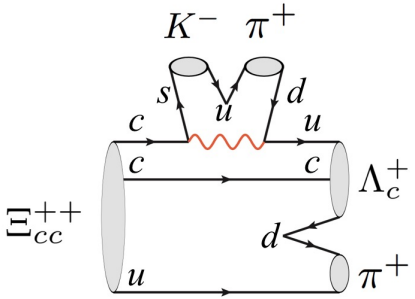


Observation of Ξ_{cc}^{++}

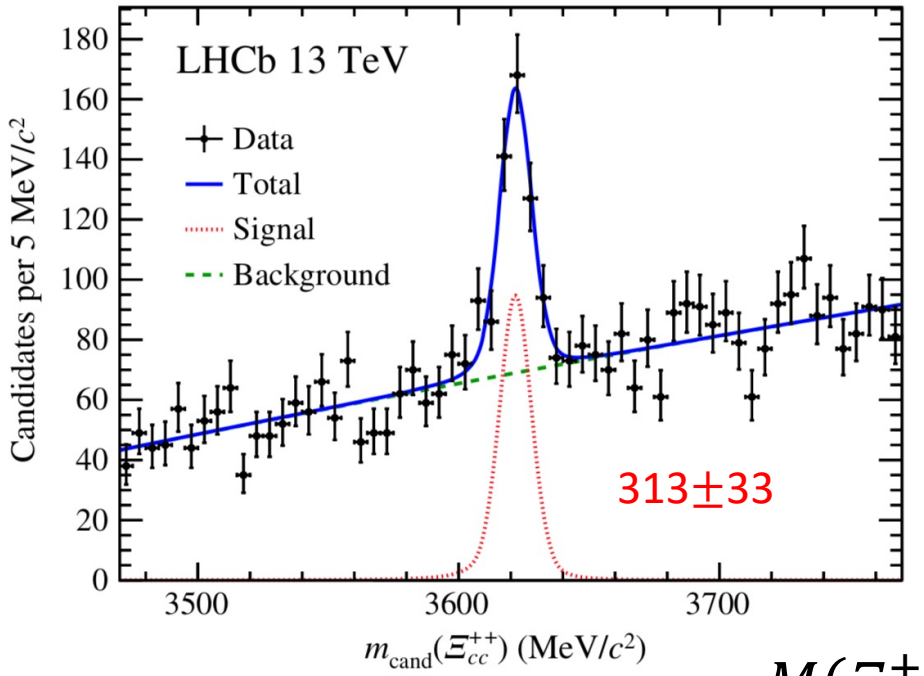


[F.-S. Yu *et al.*, CPC 42 (2018) 051001]

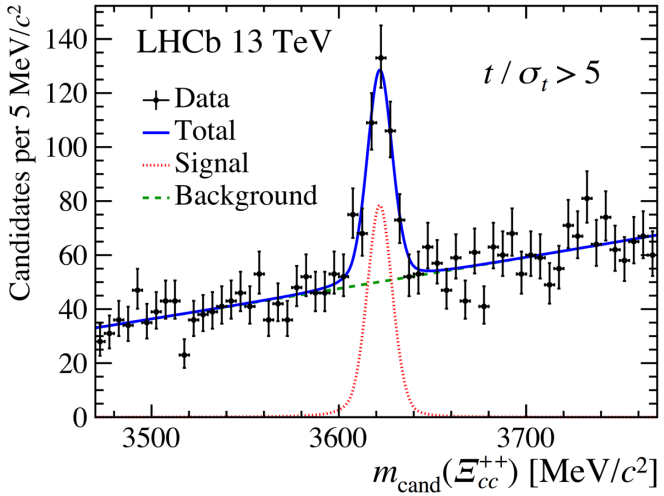
- $\Lambda_c^+ K^- \pi^+ \pi^+$ identified as the most promising channel
- First observation, in 2016 (>12σ) & Run1 (>7σ)

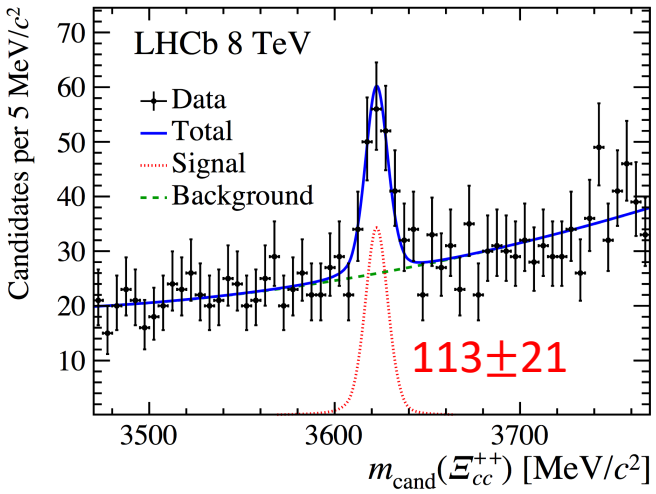


[PRL 119 (2017) 112001]



Weakly decay!





$$M(\Xi_{cc}^{++}) = 3621.40 \pm 0.72 \pm 0.27 \pm 0.14\,(\Lambda_c^+)\ \mathrm{MeV}/c^2$$

Observation of Ξ_{cc}^{++}

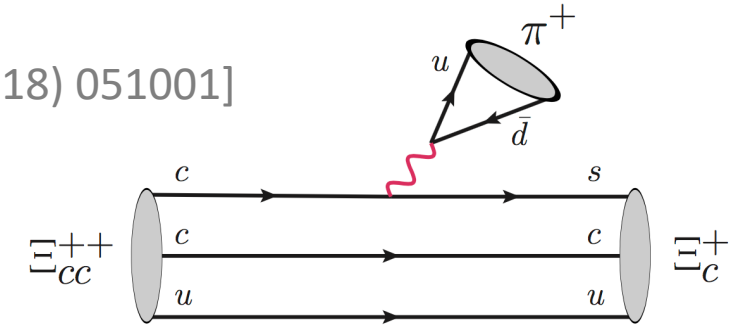
[F.-S. Yu *et al.*, CPC 42 (2018) 051001]

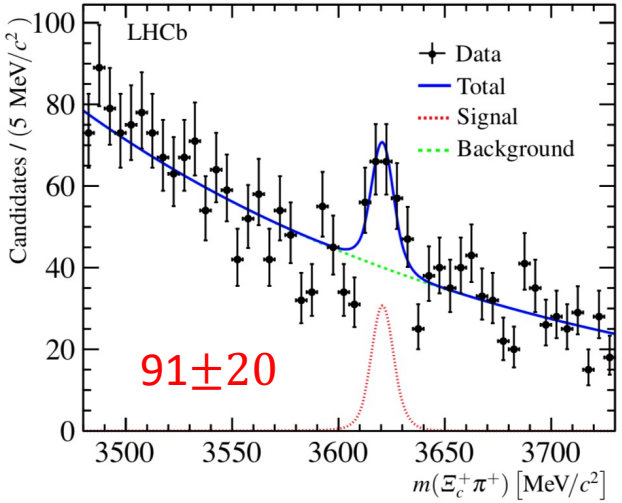
- $\Xi_{cc}^{++} \to \Xi_c^+ \pi^+$ expected to have large BR
  - Rule of thumb: 2 less tracks, 10 times higher eff.
- Re-discovery with 2016 data, 5.9σ
- BR ratio measured

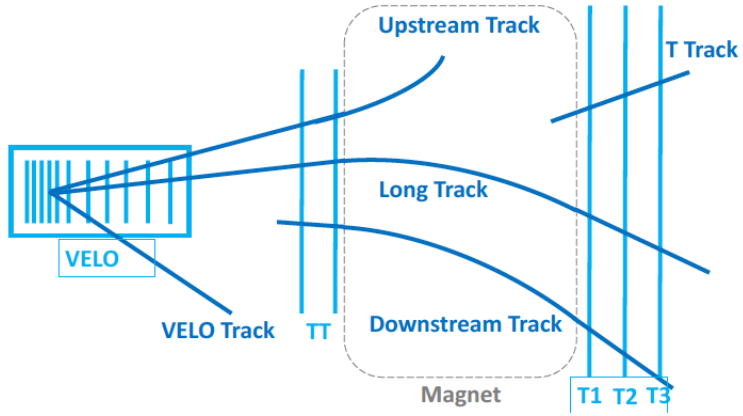
$$\frac{\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^+ \pi^+) \cdot \mathcal{B}(\Xi_c^+ \to pK^-\pi^+)}{\mathcal{B}(\Xi_{cc}^{++} \to \Lambda_c^+ K^-\pi^+\pi^+) \cdot \mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)}$$

$$= 0.035 \pm 0.009 \pm 0.003$$

[PRL 121 (2018) 162002]







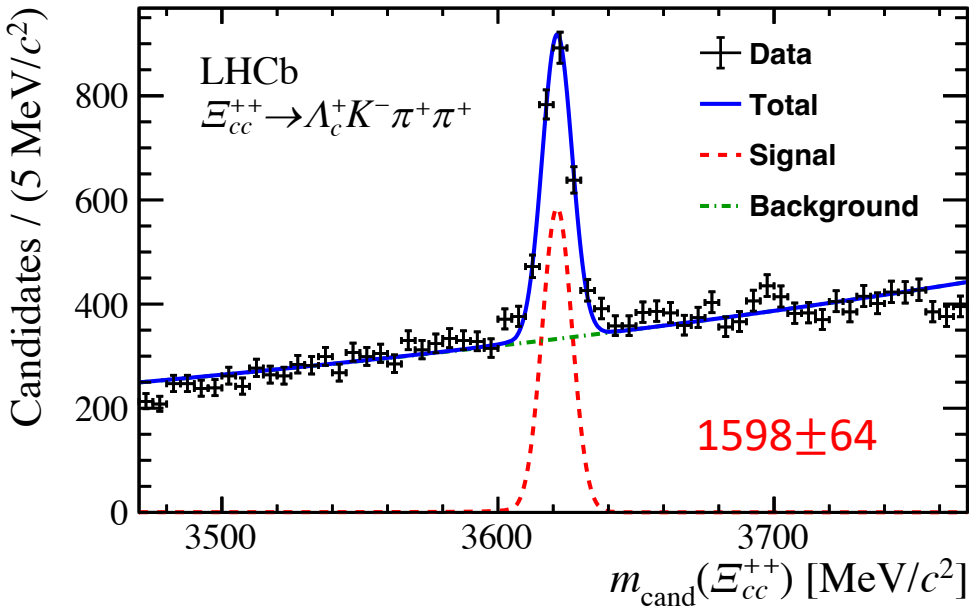
Not very good at hyperon…

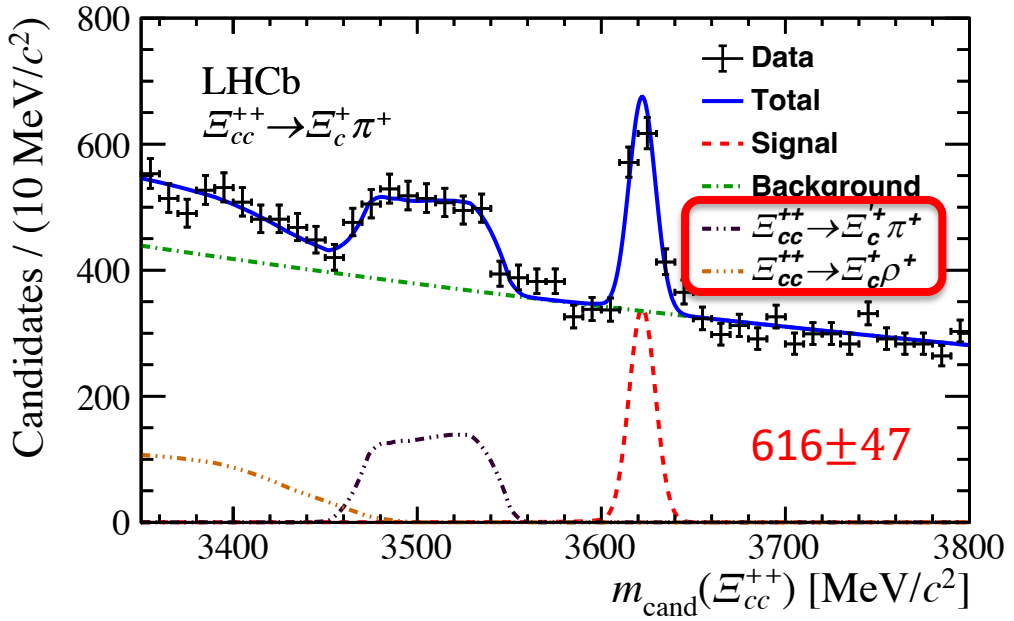
UROP

Precision measurement of $M(\Xi_{cc}^{++})$

- Preparing to search for excited states, selection re-optimised
- 5-6 times signal yields with a factor of 3 data

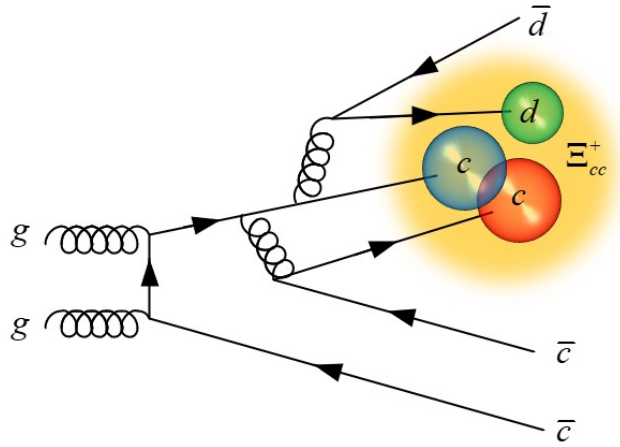
[JHEP 02 (2020) 049]





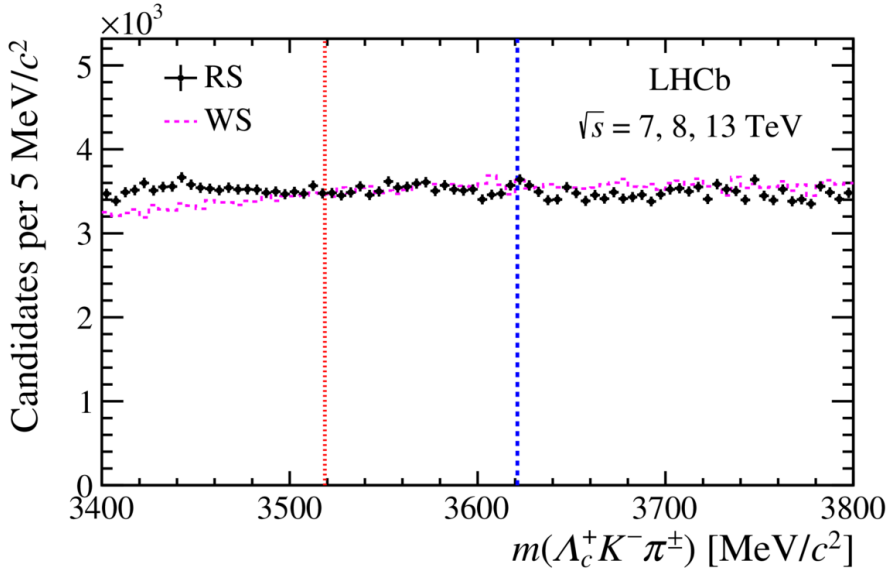
$$M(\Xi_{cc}^{++}) = 3621.55 \pm 0.23 \pm 0.30 \text{ MeV}/c^2$$ taken as WA by PDG

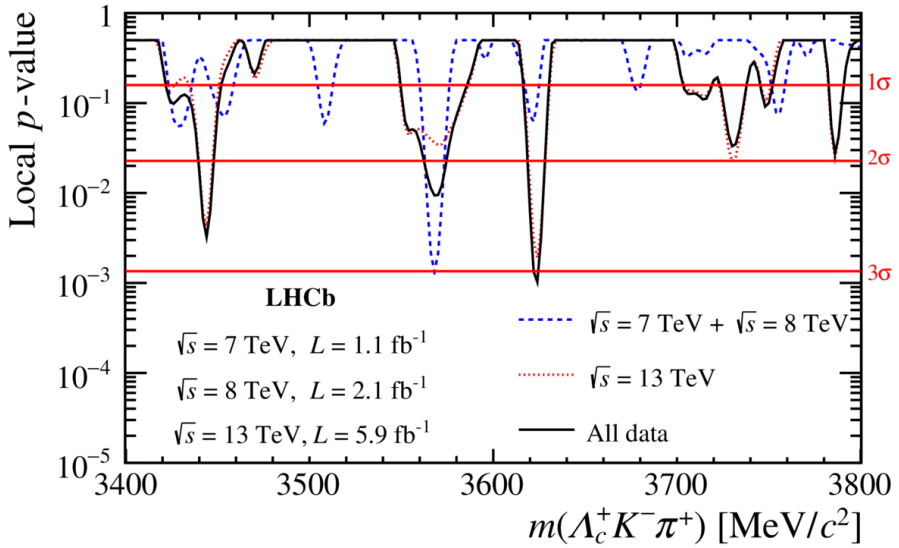
Ξ_{cc}^{+} search

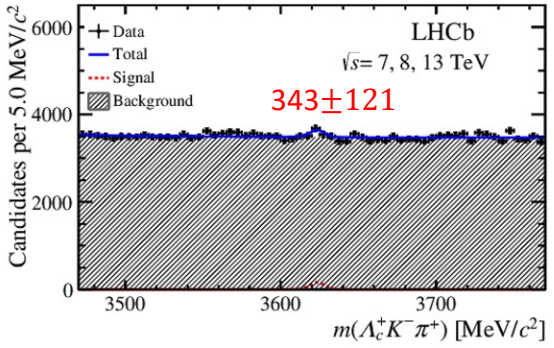


- Updated w/ $\Lambda_c^+ K^- \pi^+$ using all Run1-2 data
- $\tau(\Xi_{cc}^{+})$: (0 fs, 80 fs) × (non)observation
- Evidence at Ξ_{cc}^{++}, w/ local (global) significance 3.1σ (1.7σ)

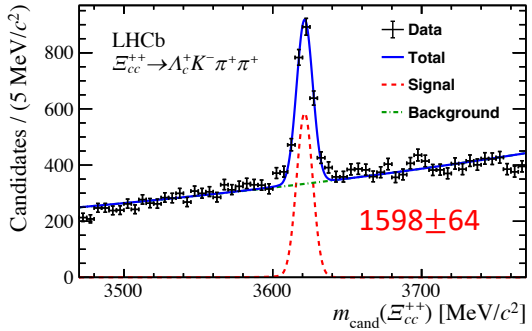
[SCPMA 63 (2020) 221062]

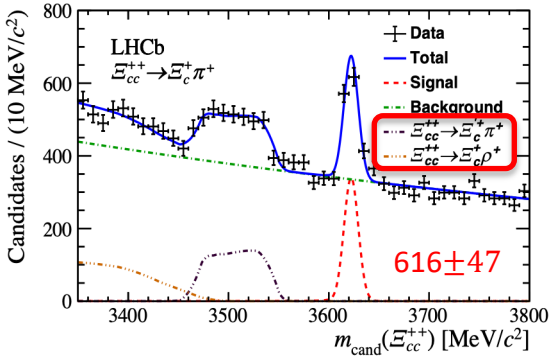


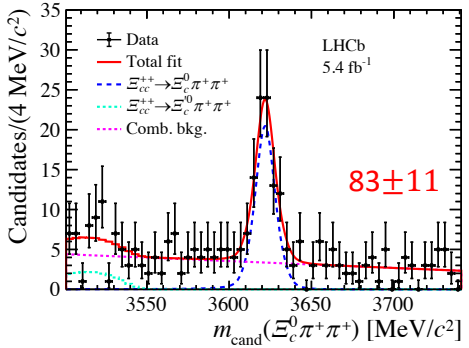




Doubly heavy baryons w/ Run1-2 data

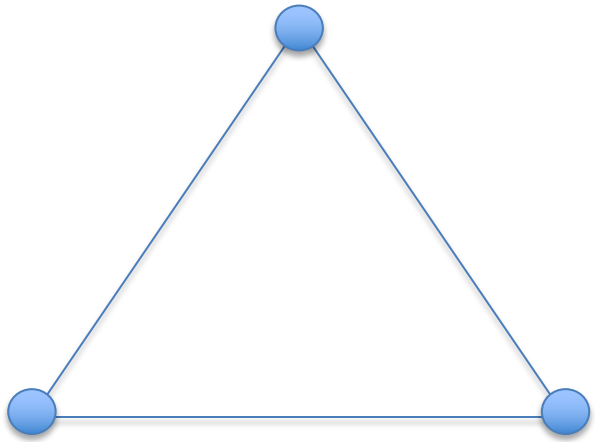






First search, Hint[SCPMA 64 (2021) 101062]

Ω_{cc}^+ (ccs)



Ξ_{cc}^{++} (ccu)

Observation[PRL 119 (2017) 112001]

Mass[JHEP 02 (2020) 049]

Lifetime[PRL 121 (2018) 052002]

Production[CPC 44 (2020) 022001]

Decay $\Xi_c^+\pi^+$[PRL 121 (2018) 162002]

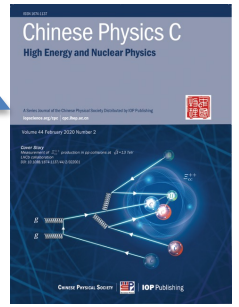
$\Xi_c'^+\pi^+$[JHEP 05 (2022) 038]

$\Xi_c^0\pi^+\pi^+$[JHEP 10 (2025) 136]

Ξ_{cc}^+ (ccd)

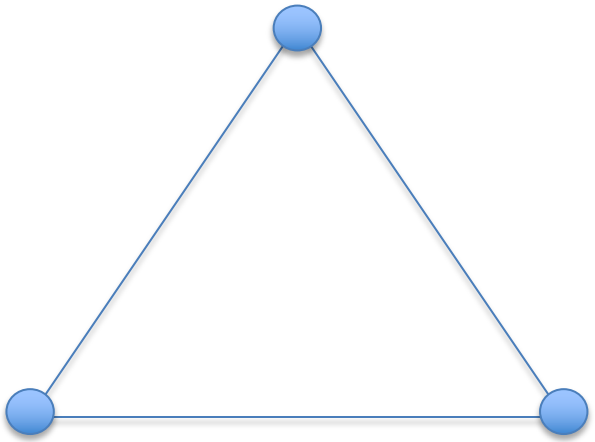
Hint/Evidence

[SCPMA 63 (2020) 221062, JHEP 12 (2021) 107]



First search[CPC 45 (2021) 093002]

Ω_{bc}^0 (bcs)

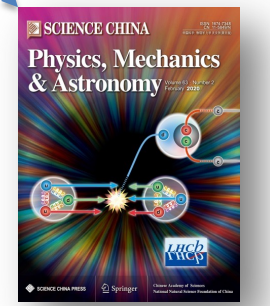


Ξ_{bc}^+ (bcu)

First search

Hint

[CPC 47 (2023) 093001]



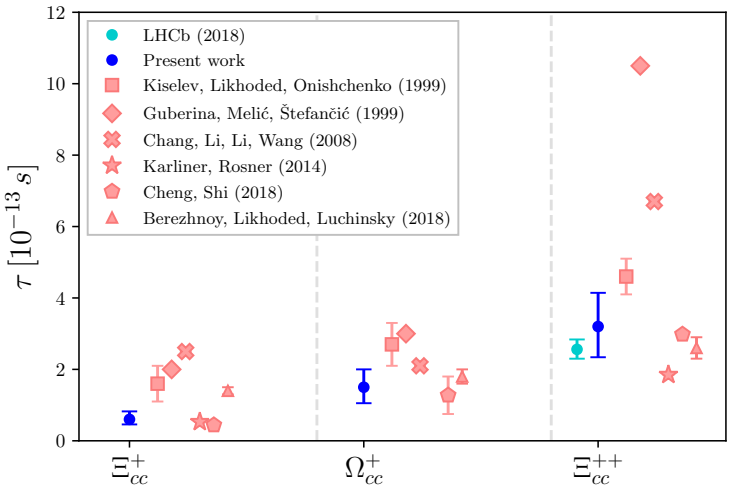
Ξ_{bc}^0 (bcd)

First search

[JHEP 11 (2020) 095]

Ξ_{cc}^{+} lifetime

- Theoretical predictions updated following $\tau(\Xi_{cc}^{++})$ measured by LHCb
- $\tau(\Xi_{cc}^{+}) \approx 45$ fs, used as the baseline



PHYSICAL REVIEW D **98,** 113005 (2018)

Lifetimes of doubly charmed baryons

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The lifetimes of doubly charmed hadrons are analyzed within the framework of the heavy quark expansion (HQE). Lifetime differences arise from spectator effects such as W-exchange and Pauli interference. The Ξ_{cc}^{++} baryon is longest-lived in the doubly charmed baryon system owing to the destructive Pauli interference absent in the Ξ_{cc}^{+} and Ω_{cc}^{+}. In the presence of dimension-seven contributions, its lifetime is reduced from $\sim 5.2 \times 10^{-13}$ s to $\sim 3.0 \times 10^{-13}$ s. The Ξ_{cc}^{+} baryon has the shortest lifetime of order 0.45×10^{-13} s due to a large contribution from the W-exchange box diagram. It is difficult to make a precise quantitative statement on the lifetime of Ω_{cc}^{+}. Contrary to Ξ_{cc} baryons, $\tau(\Omega_{cc}^{+})$ becomes longer in the presence of dimension-seven effects and the Pauli interference $\Gamma_{+}^{\rm int}$ even becomes negative. This implies that the subleading corrections are too large to justify the validity of the HQE. Demanding the rate $\Gamma_{+}^{\rm int}$ to be positive for a sensible HQE, we conjecture that the Ω_c^0 lifetime lies in the range of $(0.75 \sim 1.80) \times 10^{-13}$ s. The lifetime hierarchy pattern is $\tau(\Xi_{cc}^{++}) > \tau(\Omega_{cc}^{+}) > \tau(\Xi_{cc}^{+})$ and the lifetime ratio $\tau(\Xi_{cc}^{++})/\tau(\Xi_{cc}^{+})$ is predicted to be of order 6.7.

DOI: 10.1103/PhysRevD.98.113005

Revisiting lifetimes of doubly charmed baryons

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ABSTRACT: We present updated predictions for lifetimes of doubly charmed baryons, within the heavy quark expansion, including available NLO α_s contributions and newly-computed terms in the $1/m_c$ series. Our improved results confirm the expected hierarchy

$$\tau(\Xi_{cc}^{+}) < \tau(\Omega_{cc}^{+}) < \tau(\Xi_{cc}^{++})\,,$$

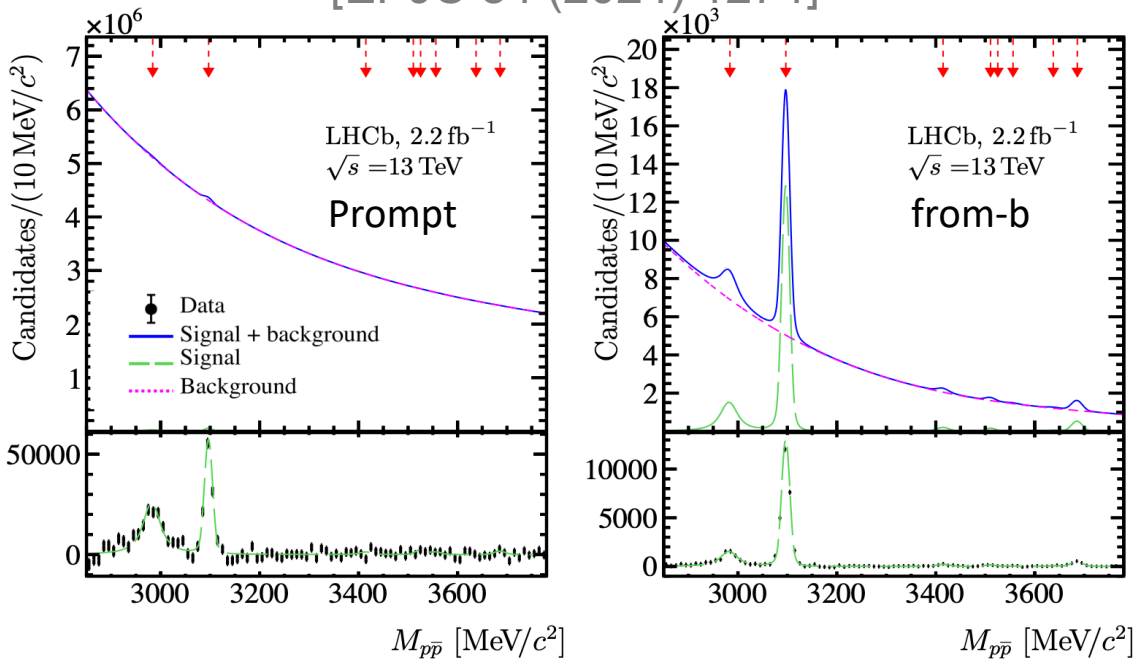
while the predicted lifetime $\tau(\Xi_{cc}^{++}) = 0.32 \pm 0.5^{+0.8}_{-0.7}$ ps is consistent with the recent LHCb determination. We provide predictions for the lifetime ratios of the Ξ_{cc}^{+} and Ω_{cc}^{+} baryons relative to the Ξ_{cc}^{++} baryon, namely $\tau(\Xi_{cc}^{+})/\tau(\Xi_{cc}^{++}) = 0.22 \pm 0.05 \pm 0.04$ and $\tau(\Omega_{cc}^{+})/\tau(\Xi_{cc}^{++}) = 0.52 \pm 0.13^{+0.03}_{-0.02}$.

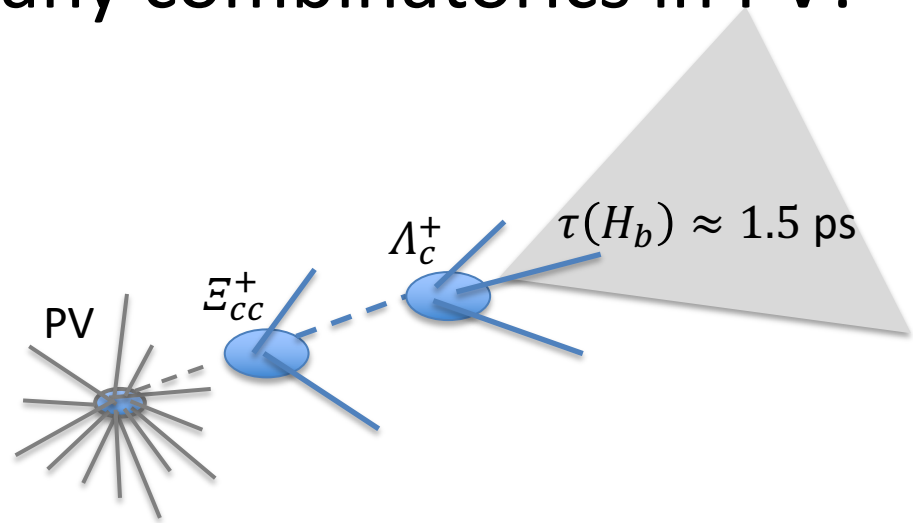
JHEP07(2023)061

Selection strategy

- Should we still use lifetime info when $\tau(\Xi_{cc}^{+}) \approx 45$ fs, which is close to $\sigma_t \approx 50$ fs? Yes!
- $\eta_c(1S) \to p\bar{p}$ as an example, too many combinatorics in PV!

[EPJC 84 (2024) 1274]





Signal purity "in between" prompt and from-b

UROP

Preparing for Run3

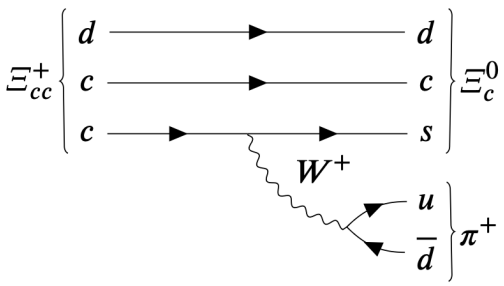
- Run1-2 re-visited, undergraduate thesis of Danyi Zhang
- $\Lambda_c^+ K^- \pi^+$ re-optimised
  - p_{T} cuts relaxed, w/ unparked Λ_c^+
  - PID added in BDT training
  - $\tau(\Xi_{cc}^+) \approx 45$ fs as the baseline
- New decay modes added:
  - $\Xi_{cc}^+ \to \Xi_c^0 \pi^+$
  - $\Xi_{cc}^+ \to D^+ p K^-$

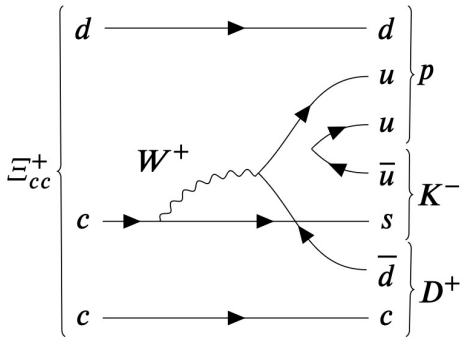
Special commendation of the LHCb best summer student

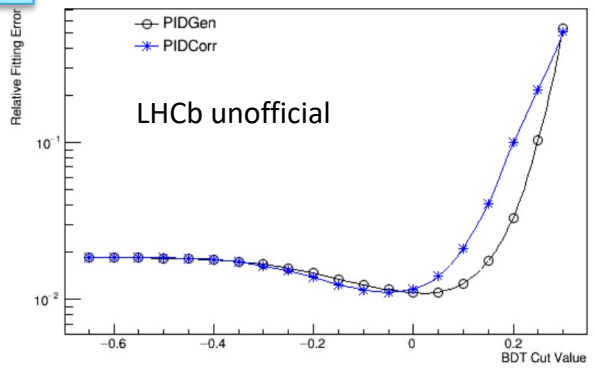
表 3.1 衰变过程 $\Xi_{cc}^+ \to \Lambda_c^+ K^- \pi^+$ 的逾举触发选择条件和效率。

Table 3.1 The efficiency of the the exclusive turbo line selections for $\Xi_{cc}^+ \to \Lambda_c^+ K^- \pi^+$ decay.

Particle	Selection	Events	Efficiency
	Proton $p_{\mathrm{T}} > 200$ MeV/c	121589	$(99.81 \pm 0.01)\%$
	Kaon $p_{\mathrm{T}} > 200$ MeV/c	119526	$(98.30 \pm 0.04)\%$
	Pion $p_{\mathrm{T}} > 200$ MeV/c	112556	$(94.17 \pm 0.07)\%$
	Proton χ^2_{IP} to own PV >6	63855	$(56.73 \pm 0.15)\%$
	Kaon χ^2_{IP} to own PV >6	43976	$(68.87 \pm 0.18)\%$
Λ_c^+ daughters	Pion χ^2_{IP} to own PV >6	33402	$(75.96 \pm 0.20)\%$
	Λ_c^+ filght distance χ^2 to PV>16	33234	$(99.50 \pm 0.04)\%$
	Λ_c^+ $p_{\mathrm{T}} > 1000$ MeV/c	33231	$(99.99 \pm 0.01)\%$
	Proton particle ID $\mathrm{DLL}_{p\pi}$ >10	29778	$(89.61 \pm 0.17)\%$
	Kaon particle ID $\mathrm{DLL}_{K\pi}$ >10	24630	$(82.71 \pm 0.22)\%$
	Pion particle ID $\mathrm{DLL}_{K\pi}$ <0	20511	$(83.28 \pm 0.24)\%$
	Kaon $p_{\mathrm{T}} > 500$ MeV/c	18251	$(88.98 \pm 0.22)\%$
	Pion $p_{\mathrm{T}} > 500$ MeV/c	13440	$(73.64 \pm 0.33)\%$
	Kaon particle ID $\mathrm{DLL}_{K\pi}$ >10	11797	$(87.78 \pm 0.28)\%$
Ξ_{cc}^+ daughters	Pion particle ID $\mathrm{DLL}_{K\pi}$ <0	10620	$(90.02 \pm 0.28)\%$
	Sum of p_{T} >2000	18296	$(100.00 \pm 0.00)\%$
	Kaon χ^2_{IP} to PV>1	15748	$(86.07 \pm 0.26)\%$
	Pion χ^2_{IP} to PV>1	14010	$(88.96 \pm 0.25)\%$
Ξ_{cc}^+	χ^2_{IP} to PV>25	13584	$(96.96 \pm 0.15)\%$
	DIRA>0.99	13231	$(97.40 \pm 0.14)\%$







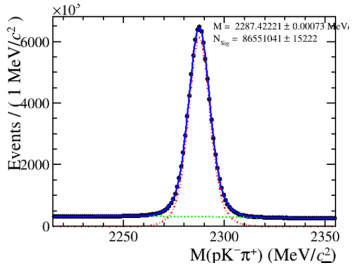
Joined the efforts to understand new detector

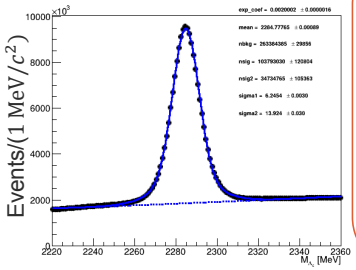
- Linnuo Zhang, CERN summer student project

Λ_c^+ in LHCb Run3 data

- **Number of Λ_c^+ events in 2018 data: 8.6×10^7**
- **Number of Λ_c^+ events in part of 2024 data (before including UT): 1.3×10^8**

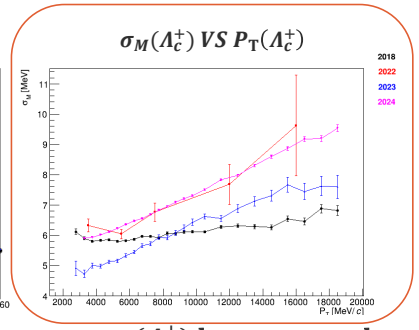
$\Lambda_c^+(\rightarrow pK^-\pi^+)$ mass distribution





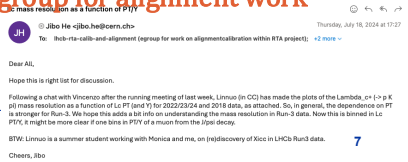
more $\Lambda_c^+ \rightarrow$ expect more Ξ_{cc}

$\Lambda_c^+(\rightarrow pK^-\pi^+)$ mass resolution (July 16)



$\sigma_M(\Lambda_c^+)$ has stronger dependence on $P_T(\Lambda_c^+)$ in Run3

Shared this result to egroup for alignment work


Dear All,

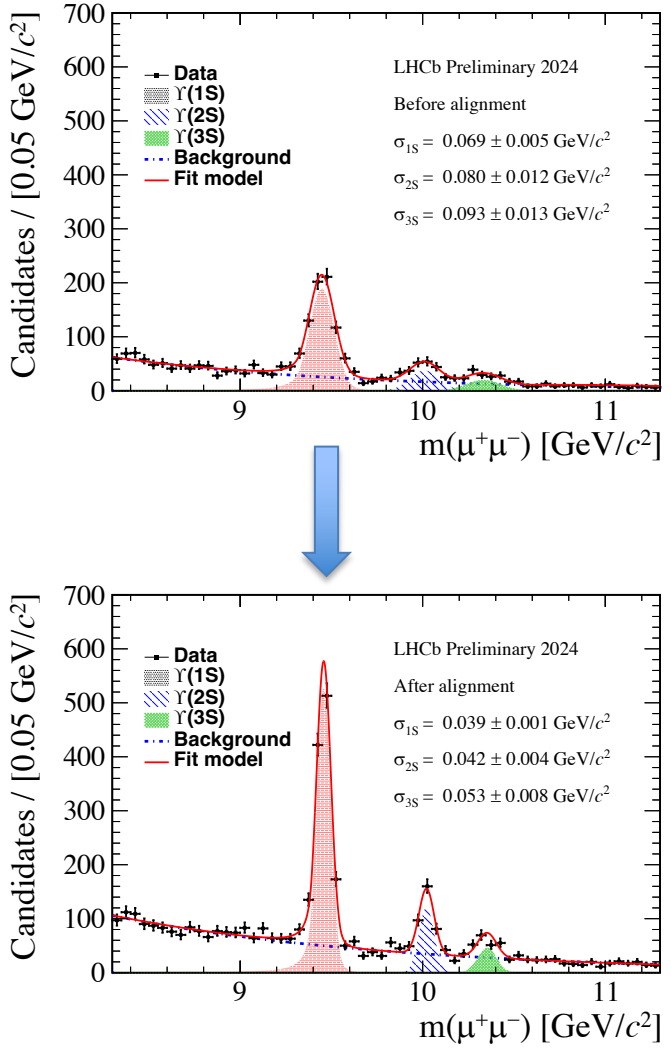
Hope this is right list for discussion.

Following a chat with Vincenzo after the running meeting of last week, Linnuo (in CC) has made the plots of the Lambda_c+ (-> p K pi) mass resolution as a function of Lc PT (and Y) for 2022/23/24 and 2018 data, as attached. So, in general, the dependence on PT is stronger for Run-3. We hope this adds a bit info on understanding the mass resolution in Run-3 data. Now this is binned in Lc PT/Y, it might be more clear if one bins in PT/Y of a muon from the J/psi decay.

BTW: Linnuo is a summer student working with Monica and me, on (re)discovery of Xicc in LHCb Run3 data.

Cheers, Jibo

[LHCB-FIGURE-2024-037]

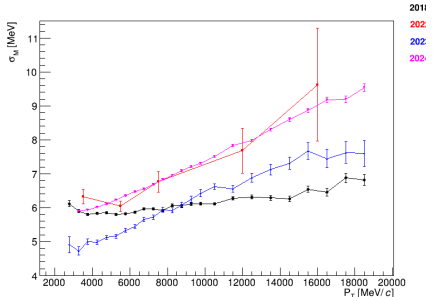


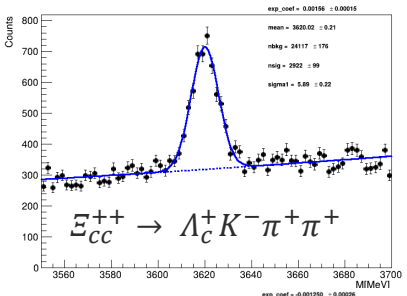
Rediscovery of Ξ_{cc}^{++} in 2024 data

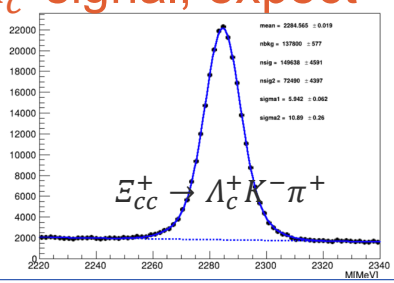
- Extensive studies on Ξ_{cc}^{++} in 2024, old/new BDTs

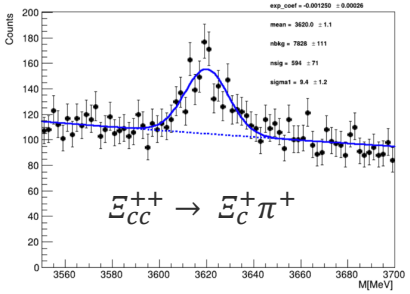
Summary

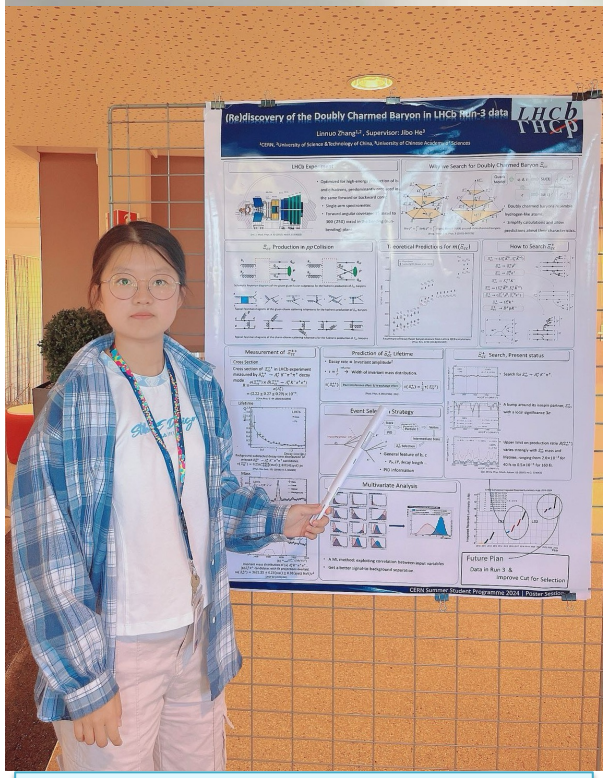
- Studied Λ_c^+ mass resolution as functions of P_T, y in 2024 sent to alignment group
- Studied and optimized event selection for:
  - $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$, twice signals in part of 2024 data, compared to signals in Run 2
  - $\Xi_{cc}^{++} \to \Xi_c^+ \pi^+$, better sig-to-bkg ratio with new MVA model
  - $\Xi_{cc}^{+} \to \Lambda_c^+ K^- \pi^+$, blind analysis, more Λ_c^+ signal, expect 1st observation of Ξ_{cc}^{+} w/ 2024 data











First Chinese Winner of the LHCb best summer student

UROP

BDT-based trigger for H_c

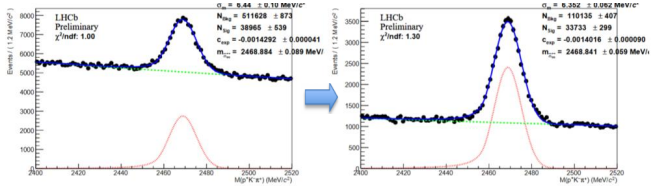
- Shuyu Han, UROP student

触发算法开发

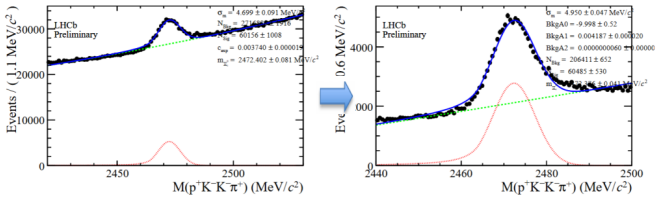
University of Chinese Academy of Sciences

- $\Xi_c^+ \to pK^-\pi^+$:
  信号数少，与Λ_c^+衰变末态相同，应用Λ_c^+训练的模型

保留90%信号，本底压低至20%



- $\Xi_c^0 \to pK^-K^-\pi^+$:
  训练变量中增加一个K^-



保留全部信号，本底压低至10%

- 触发算法加入2024年取数；2025年经迭代进一步提高性能，可用于其他粒子（双粲重子）的重建

触发算法	带宽 (kHz)	独占带宽 (kHz)	平均事例大小 (kB)	总带宽 (GB/s)
Λ_c^+ cut-based	0.374	0.0645	72	0.0269
Ξ_c^+ cut-based	0.361	0.0774	48.4	0.0175
Ξ_c^0 cut-based	0.142	0.0516	92.9	0.0132
Λ_c^+ MVA-based	0.181	0	64	0.0116
Ξ_c^+ MVA-based	0.155	0	56.5	0.00874
Ξ_c^0 MVA-based	0.0258	0	101	0.00261

[Update] Studies on bandwidth reduction for Λ_c trigger lines in Run 3 (20'+15')
报告人: Shuyu Han (University of Chinese Academy of Sciences (CN))
Lc2pKpi_TMVA_202...
Charm WG meeting（2024.4.10）

[Update] MVA-based trigger lines for charmed baryons (15 + 10')
报告人: Shuyu Han (University of Chinese Academy of Sciences (CN))
MVA based Turbo li...
Charm WG meeting（2024.7.17）

6

UROP

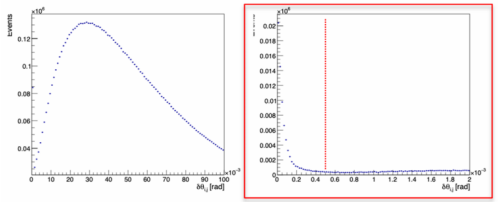
Ξ_{cc}^{+} search w/ 2024

- Shuyu Han, undergraduate thesis

去除克隆

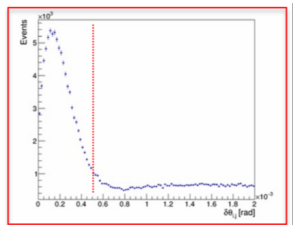
中国科学院大学 University of Chinese Academy of Sciences

克隆事例：重建算法将一根真实径迹错误地重建为两根径迹
- 主要发生在同电荷粒子间
- 要求两条径迹张角小且动量差别不大
- 使用Ξ_{cc}^{+}组合本底($\Lambda_c^+ K^- \pi^-$)样本研究



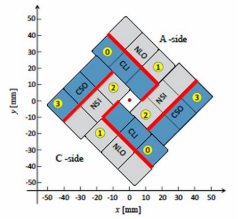
运行二期的 WS 样本中末态粒子张角分布　将角度范围缩小至 0 附近的情况

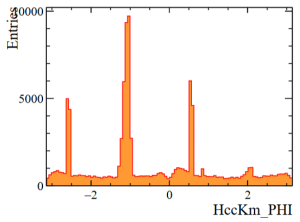
- 二期运行中张角的选择条件定为0.5 mrad
- 三期运行：发现张角分布变宽，条件应该加严



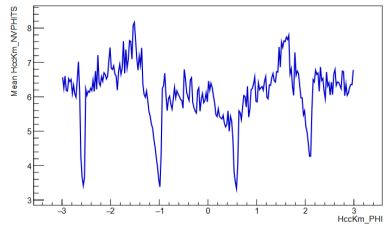
2024 年 WS 样本中末态粒子夹角分布，将角度范围缩小至 0 附近的情况

- 张角分布峰值右移(克隆事例增多)的原因：顶点探测器
  - 克隆径迹的φ值分布出现三个明显峰值
  - 峰值位置与升级后顶点探测器的重叠位置吻合
  - 径迹在顶点探测器平均击中数目少而径迹数多





来自 Ξ_{cc}^{++} 的 K^- 的 ϕ 值分布



来自 Ξ_{cc}^{++} 的 K^- 在 VELO 中的平均击中数目随 ϕ 值的变化

在最小夹角 < 0.0007 的条件下

Studies of opening angle and clones in 2024 data (doubly charmed baryon)
报告人: Shuyu Han (University of Chinese Academy of Sciences (CN))
Opening_angle_Shu... General Performance Meeting（2025.4.7）

Studies of opening angle and clones in 2024 data (doubly charmed baryon)
报告人: Shuyu Han (University of Chinese Academy of Sciences (CN))
Opening_angle_Shu... RTA: Reconstruction WP2 meeting（2025.4.15）

9

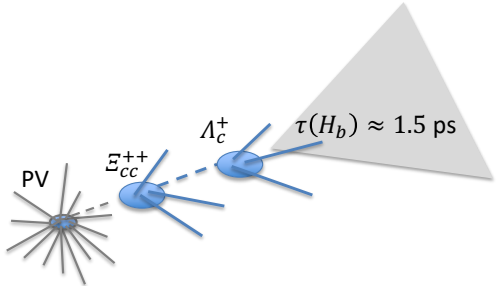
Moriond EW 2026

Monday Afternoon : Flavour
Convener: Roberto Salerno

11 Search for the Ξ+cc baryon in the Λ+cK−π+ final state with the LHCb Upgrade I detector
Speaker: Shuyu Han
1_SHan-v1.pdf

5’ YSF talk prompted to 10+5’

Control mode: Ξ_{cc}^{++} in 2024

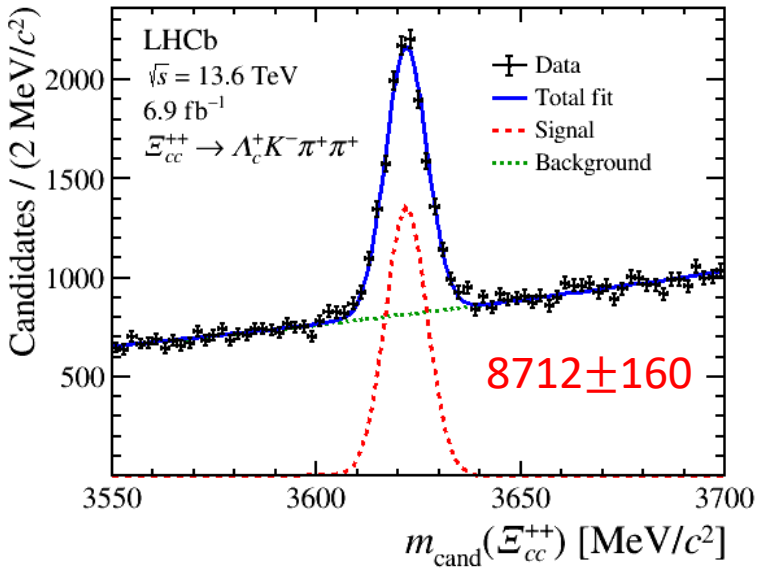


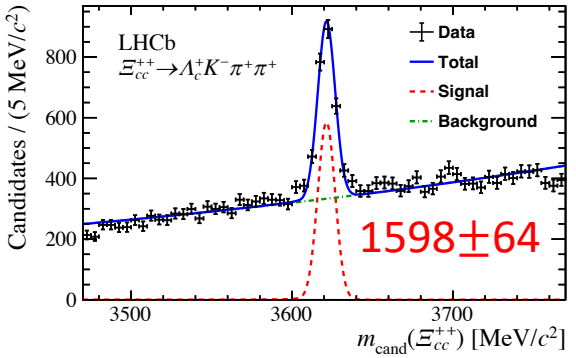
- Event-Selection (early measurement)
  - Several iterations. BDT trained w/ Λ_c^+ in data, included in BDT for Ξ_{cc}^{++} (p_{T}, χ^2_{IP}, PID)
  - BDT without PID as cross-check
- Efficiency increased by a factor of 4, compared with Run2
- Mass consistent with Run2

$$M(\Xi_{cc}^{++}) = 3621.74 \pm 0.10\ \mathrm{MeV}/c^2$$

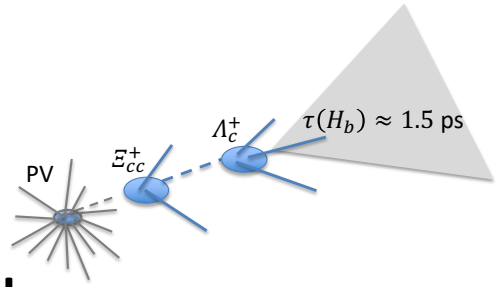
c.f., $3621.55 \pm 0.23 \pm 0.30\ \mathrm{MeV}/c^2$

[arXiv:2603.28456]



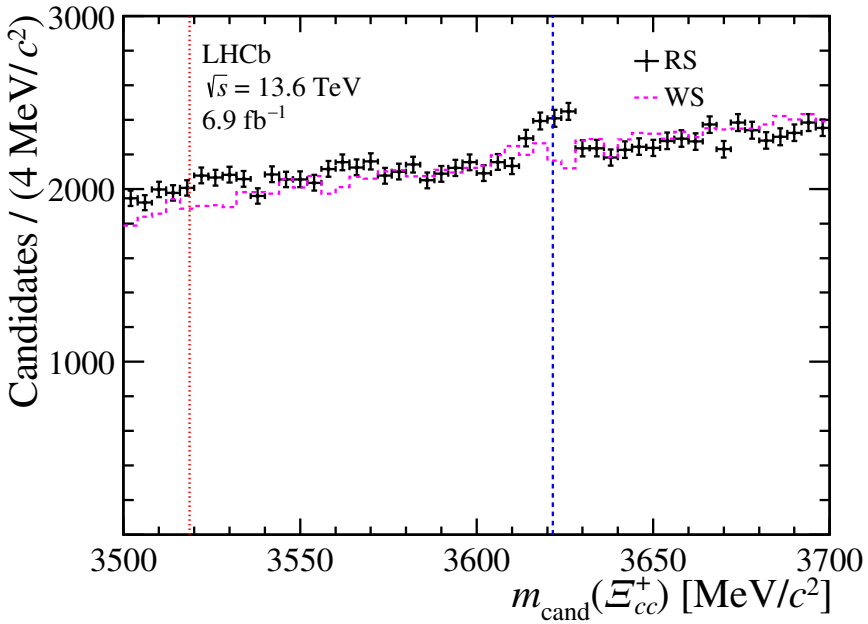


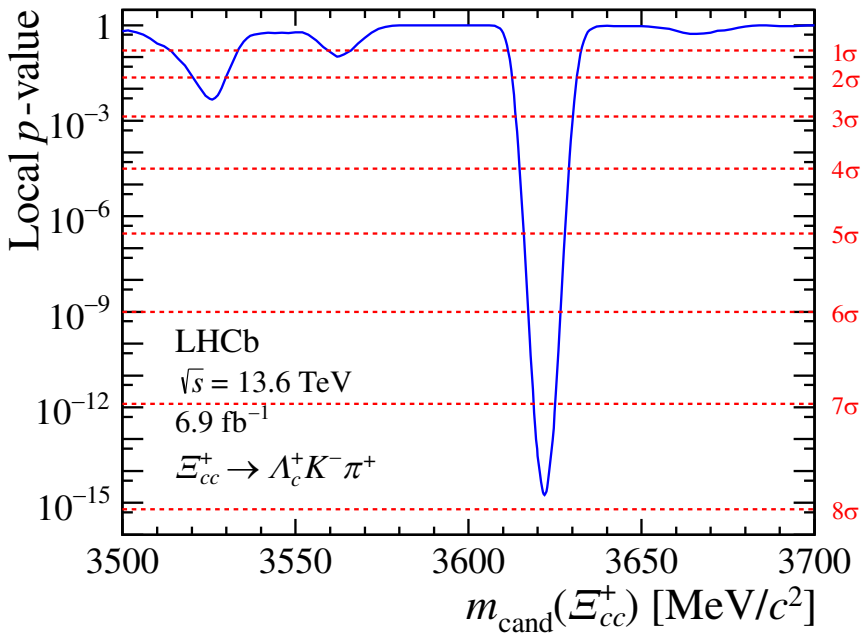
Signal mode: Ξ_{cc}^{+} in 2024



- Event-Selection, similar strategy to Ξ_{cc}^{++}, many checks
  - Effects of $\tau(\Xi_{cc}^{+})$, no fake peaks in wrong-sign, Λ_c^+ sidebands…
- After unblinding, first observation!

[arXiv:2603.28456]





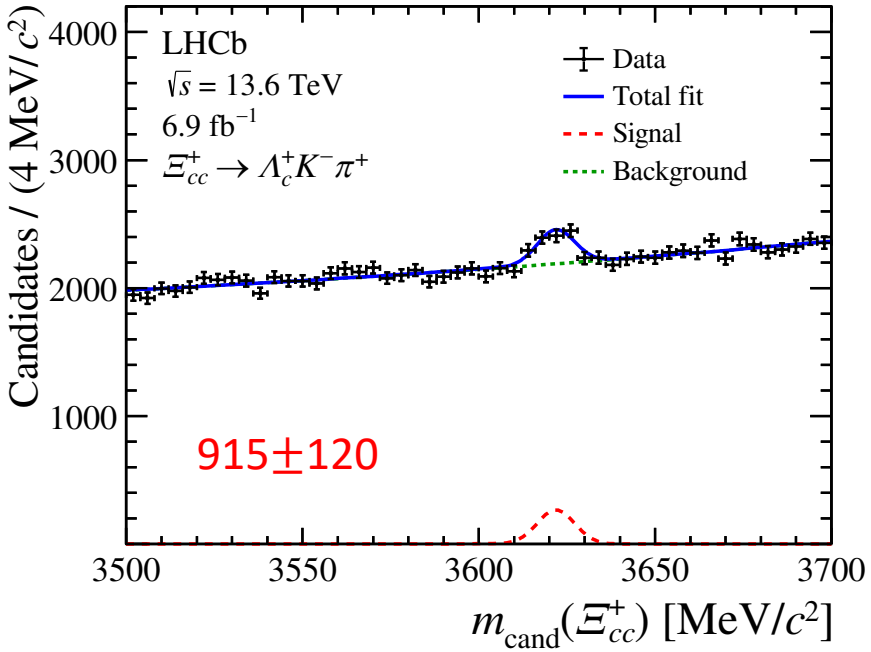
Ξ_{cc}^{+} mass

- Mass, $M(\Xi_{cc}^{+}) = 3619.97 \pm 0.83 \pm 0.26^{+1.90}_{-1.30}$ MeV/c^2

  after correcting for the bias due to FSR and event-selection

- Mass diff., $M(\Xi_{cc}^{+}) - M(\Xi_{cc}^{++}) = -1.77 \pm 0.84 \pm 0.25^{+1.90}_{-1.30}$ MeV/c^2

[arXiv:2603.28456]



Source	$M(\Xi_{cc}^{+})$ [MeV/c^2]	ΔM [MeV/c^2]
Momentum-scale calibration	0.14	0.03
Energy loss	0.10	0.05
Selection bias correction	0.10	0.10
Mass fit model	0.10	0.10
Λ_c^{+} mass uncertainty	0.14	–
Sum in quadrature	0.26	0.15
Ξ_{cc}^{+} lifetime	$^{+1.90}_{-1.30}$	$^{+1.90}_{-1.30}$

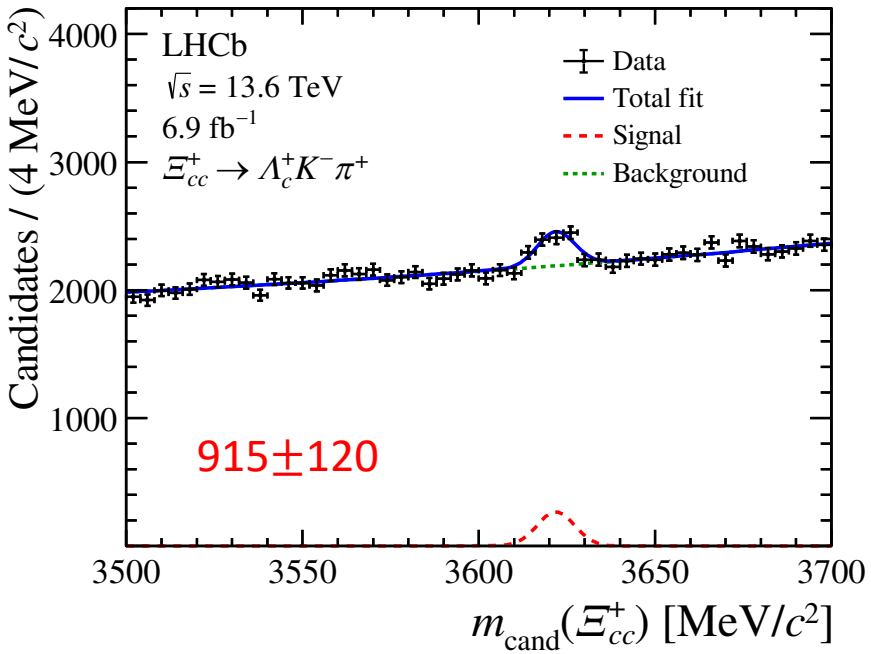
Ξ_{cc}^{+} in Run2

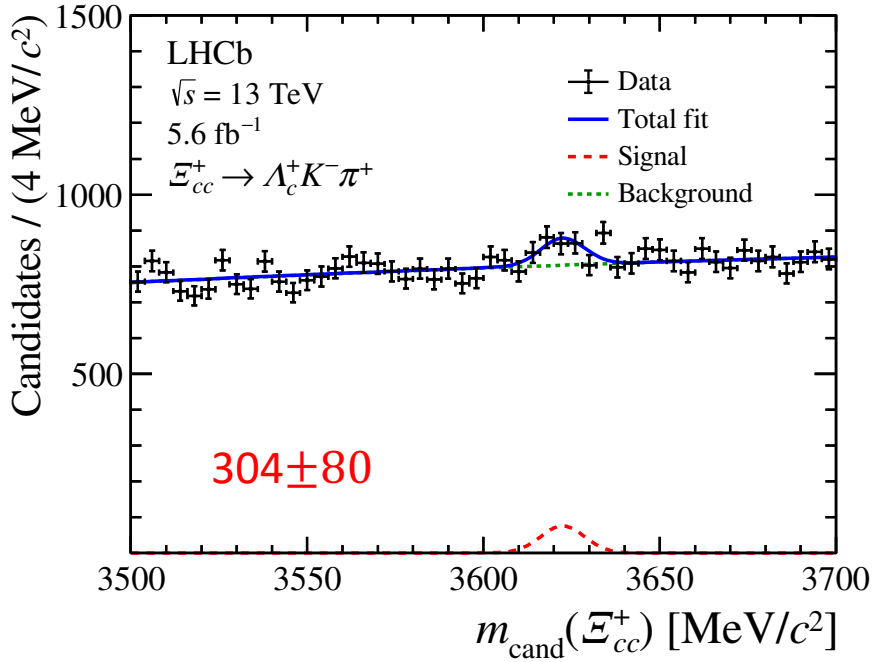
- Signal w/ a local significance of 4σ, $M(\Xi_{cc}^{+}) = 3620.8 \pm 2.2\ \mathrm{MeV}/c^2$, consistent with 2024

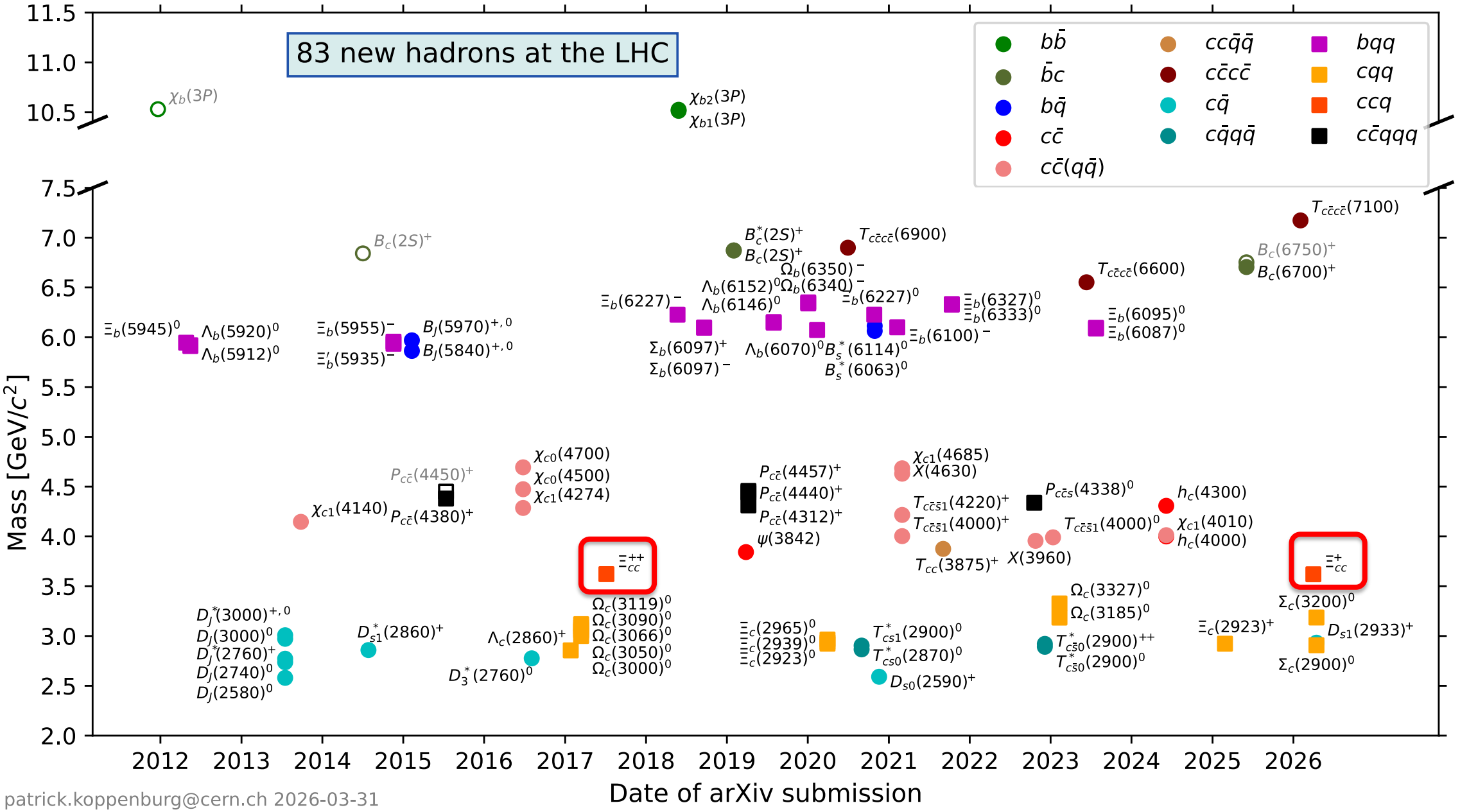
$M(\Xi_{cc}^{+}) = 3619.97 \pm 0.83 \pm 0.26^{+1.90}_{-1.30}\ \mathrm{MeV}/c^2$

- Efficiency in 2024 increased by a factor of 2.5, compared w/ Run2

[arXiv:2603.28456]






83 new hadrons at the LHC
$b\bar{b}$
$\bar{b}c$
$b\bar{q}$
$c\bar{c}$
$c\bar{c}(q\bar{q})$
$cc\bar{q}\bar{q}$
$c\bar{c}c\bar{c}$
$c\bar{q}$
$c\bar{q}q\bar{q}$
bqq
cqq
ccq
$c\bar{c}qqq$
Mass [GeV/c^2]
Date of arXiv submission
$\chi_b(3P)$
$\chi_{b2}(3P)$
$\chi_{b1}(3P)$
$B_c(2S)^+$
$B_c^*(2S)^+$
$B_c(2S)^+$
$T_{c\bar{c}c\bar{c}}(6900)$
$T_{c\bar{c}c\bar{c}}(7100)$
$B_c(6750)^+$
$B_c(6700)^+$
$T_{c\bar{c}c\bar{c}}(6600)$
$\Xi_b(5945)^0$
$\Lambda_b(5920)^0$
$\Lambda_b(5912)^0$
$\Xi_b(5955)^-$
$\Xi_b'(5935)^-$
$B_J(5970)^{+,0}$
$B_J(5840)^{+,0}$
$\Xi_b(6227)^-$
$\Lambda_b(6152)^0$
$\Lambda_b(6146)^0$
$\Omega_b(6350)^-$
$\Omega_b(6340)^-$
$\Xi_b(6227)^0$
$\Xi_b(6327)^0$
$\Xi_b(6333)^0$
$\Xi_b(6100)^-$
$\Xi_b(6095)^0$
$\Xi_b(6087)^0$
$\Sigma_b(6097)^+$
$\Sigma_b(6097)^-$
$\Lambda_b(6070)^0$
$B_s^*(6114)^0$
$B_s^*(6063)^0$
$\chi_{c0}(4700)$
$\chi_{c0}(4500)$
$\chi_{c1}(4274)$
$P_{c\bar{c}}(4450)^+$
$\chi_{c1}(4140)$
$P_{c\bar{c}}(4380)^+$
$P_{c\bar{c}}(4457)^+$
$P_{c\bar{c}}(4440)^+$
$P_{c\bar{c}}(4312)^+$
$\psi(3842)$
$\chi_{c1}(4685)$
$X(4630)$
$T_{c\bar{c}s1}(4220)^+$
$T_{c\bar{c}s1}(4000)^+$
$T_{cc}(3875)^+$
$P_{c\bar{c}s}(4338)^0$
$T_{c\bar{c}s1}(4000)^0$
$X(3960)$
$h_c(4300)$
$\chi_{c1}(4010)$
$h_c(4000)$
Ξ_{cc}^{++}
Ξ_{cc}^{+}
$D_J^*(3000)^{+,0}$
$D_J(3000)^0$
$D_J^*(2760)^+$
$D_J(2740)^0$
$D_J(2580)^0$
$D_{s1}^*(2860)^+$
$\Lambda_c(2860)^+$
$D_3^*(2760)^0$
$\Omega_c(3119)^0$
$\Omega_c(3090)^0$
$\Omega_c(3066)^0$
$\Omega_c(3050)^0$
$\Omega_c(3000)^0$
$\Xi_c(2965)^0$
$\Xi_c(2939)^0$
$\Xi_c(2923)^0$
$T_{cs1}^*(2900)^0$
$T_{cs0}^*(2870)^0$
$D_{s0}(2590)^+$
$\Omega_c(3327)^0$
$\Omega_c(3185)^0$
$T_{c\bar{s}0}^*(2900)^{++}$
$T_{c\bar{s}0}^*(2900)^0$
$\Xi_c(2923)^+$
$\Sigma_c(3200)^0$
$D_{s1}(2933)^+$
$\Sigma_c(2900)^0$

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The discovery helps physicists better understand how the strong force binds particles together

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Thursday 23 Apr 2026, 10:00 → 11:30 Europe/Zurich

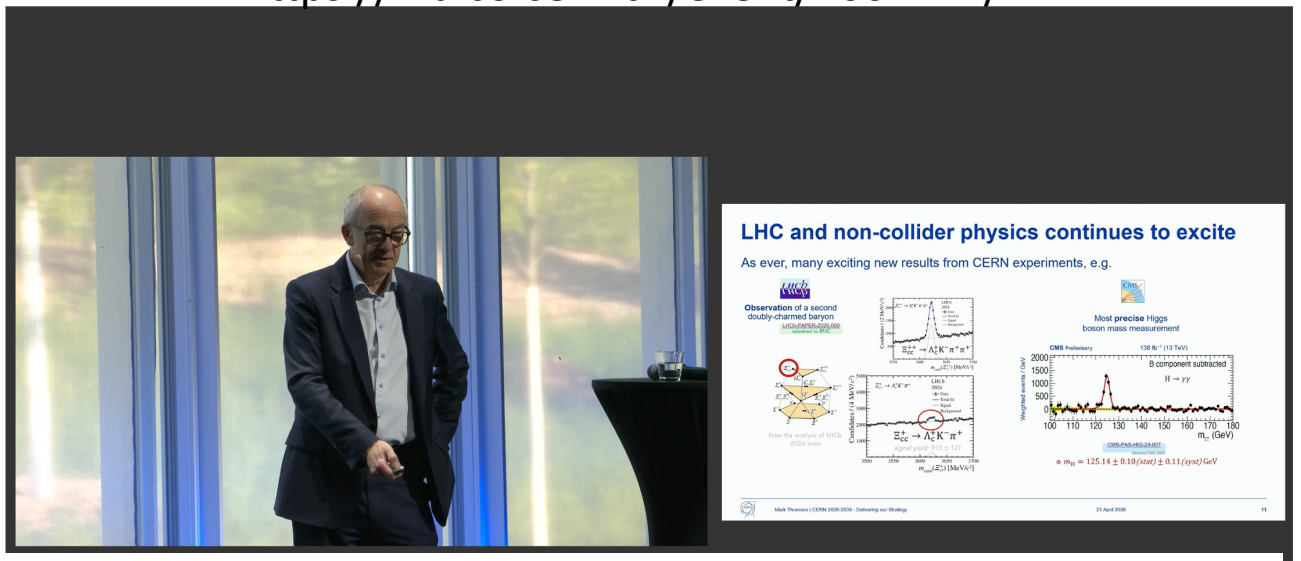
Auditorium Sergio Marchionne (CERN)

Mark Thomson (CERN)

Town Hall

by Mark Thomson

https://indico.cern.ch/event/1661742/



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Physics | News | 17 March, 2026

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"This major result is a fantastic example of how LHCb's unique capabilities play a vital role in the success of the LHC," says Mark Thomson, CERN Director-General. "It highlights how experimental upgrades at CERN directly lead to new discoveries, setting the stage for the transformative science we expect from the High-Luminosity LHC. These achievements are only possible thanks to the exceptional performance of CERN's accelerator complex and the teams who make it all work and to the commitment of the scientists on the LHCb experiment."

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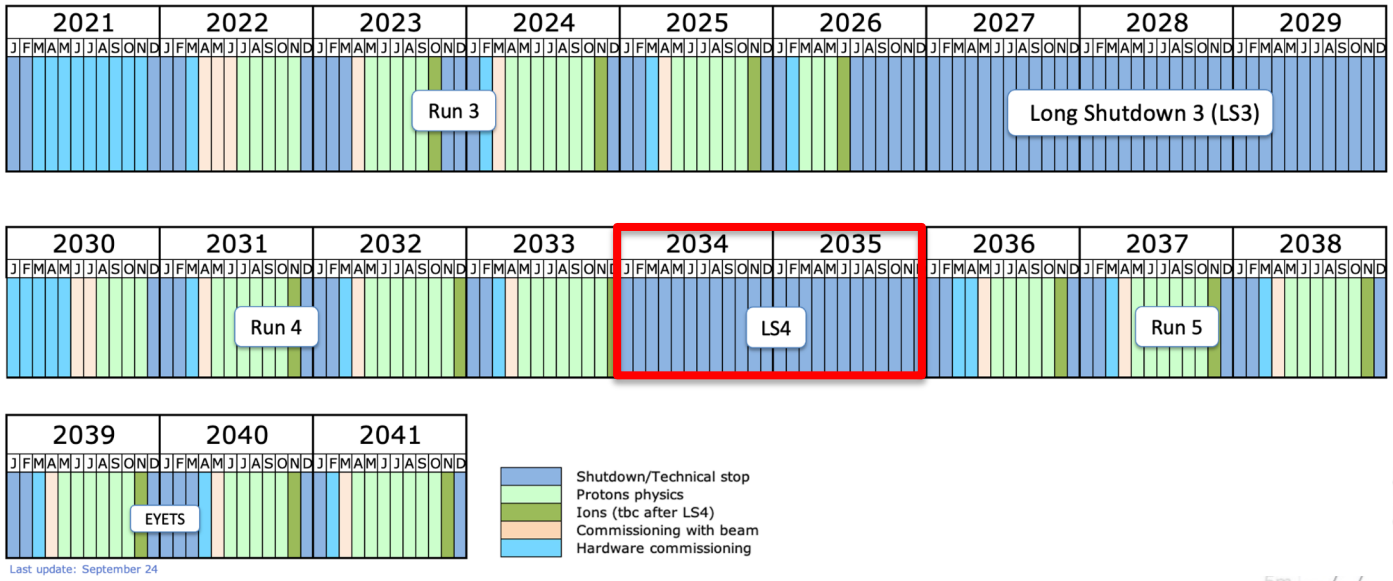
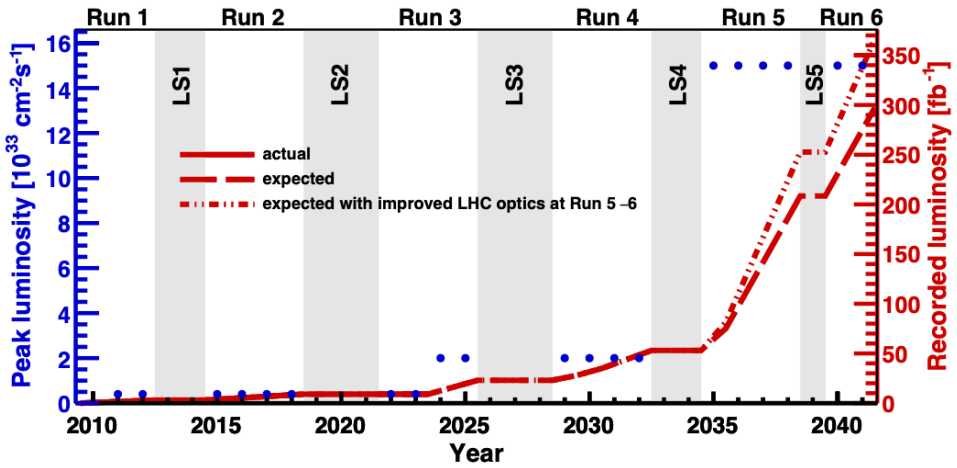
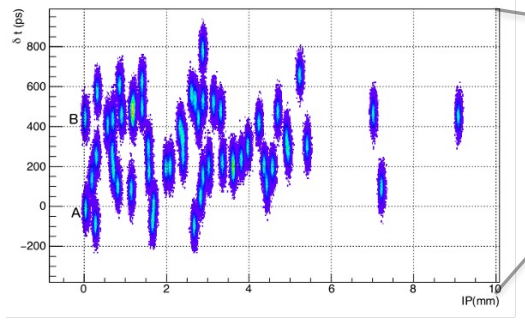
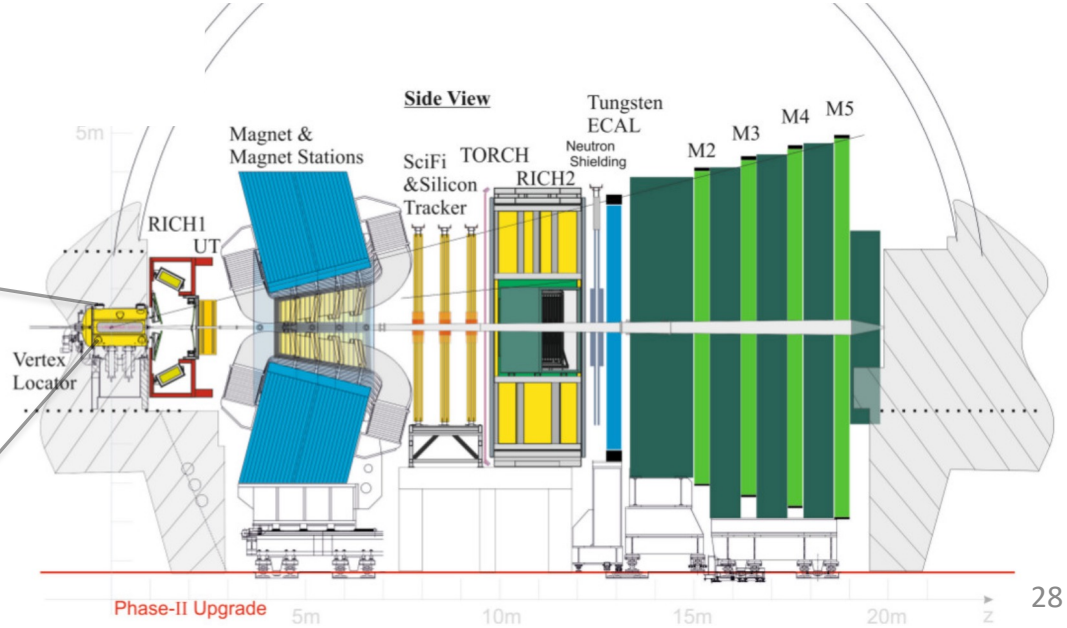
The LHCb upgrades

[CERN-LHCC-2018-027, 2021-012]





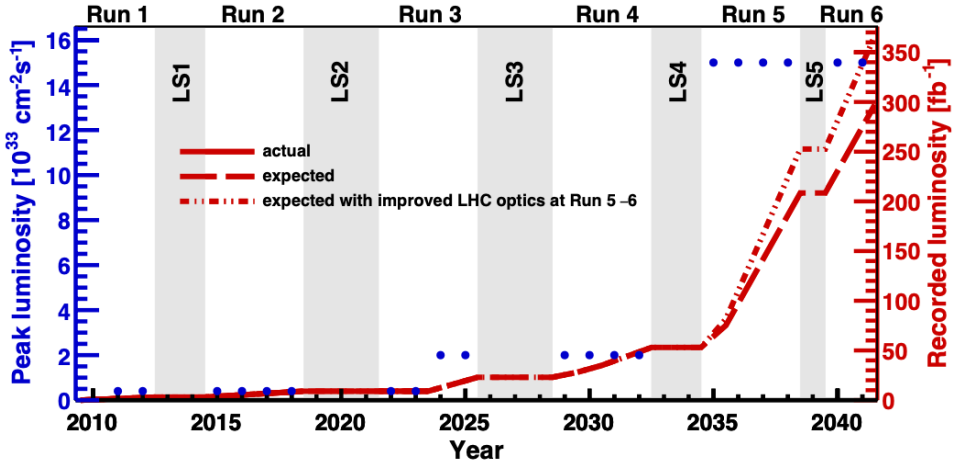


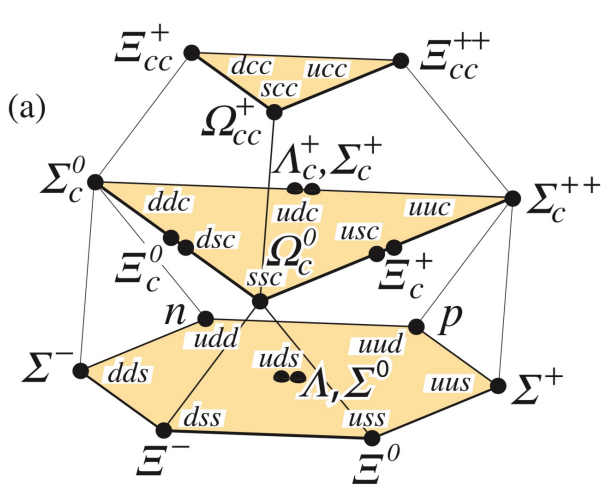


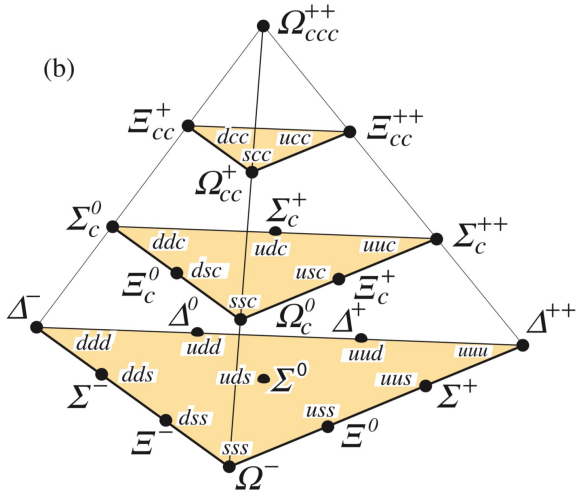
Upgrade II, 4D detector ,
Timing, $\mathcal{O}(10\ \text{ps})$, is essential

Prospects

- LHCb ($9\ \mathrm{fb}^{-1}$)
  - Ξ_{cc}^{++} >1000 signal
  - Ξ_{cc}^{+} Evidence
  - Ω_{cc}^{+} Hint
- LHCb Upgrade ($50\ \mathrm{fb}^{-1}$)
  - Ξ_{cc}^{++} $\mathcal{O}(10\mathrm{k})$ signal, excited states?
  - Ξ_{cc}^{+} $\mathcal{O}(1\mathrm{k})$ signal
  - Ω_{cc}^{+} Observation
- LHCb Upgrade-II ($300\ \mathrm{fb}^{-1}$)
  - Ω_{ccc}^{++}?







Summary

- Upgraded LHCb detector and trigger, efficiency of hadronic modes increased by a factor 2-4!
- Ξ_{cc}^{++}: a factor of 4 sginal yield per fb^{-1}, compared w/ Run2
- Ξ_{cc}^{+}: First new particle observed w/ the upgraded LHCb detector
  - $M(\Xi_{cc}^{+}) = 3619.97 \pm 0.83 \pm 0.26^{+1.90}_{-1.30}\ \mathrm{MeV}/c^2$
  - $M(\Xi_{cc}^{+}) - M(\Xi_{cc}^{++}) = -1.77 \pm 0.84 \pm 0.25^{+1.90}_{-1.30}\ \mathrm{MeV}/c^2$

  consistent with theoretical predictions
- Many thanks to your continued and strong supports