

Study of the doubly charming particles at LHCb

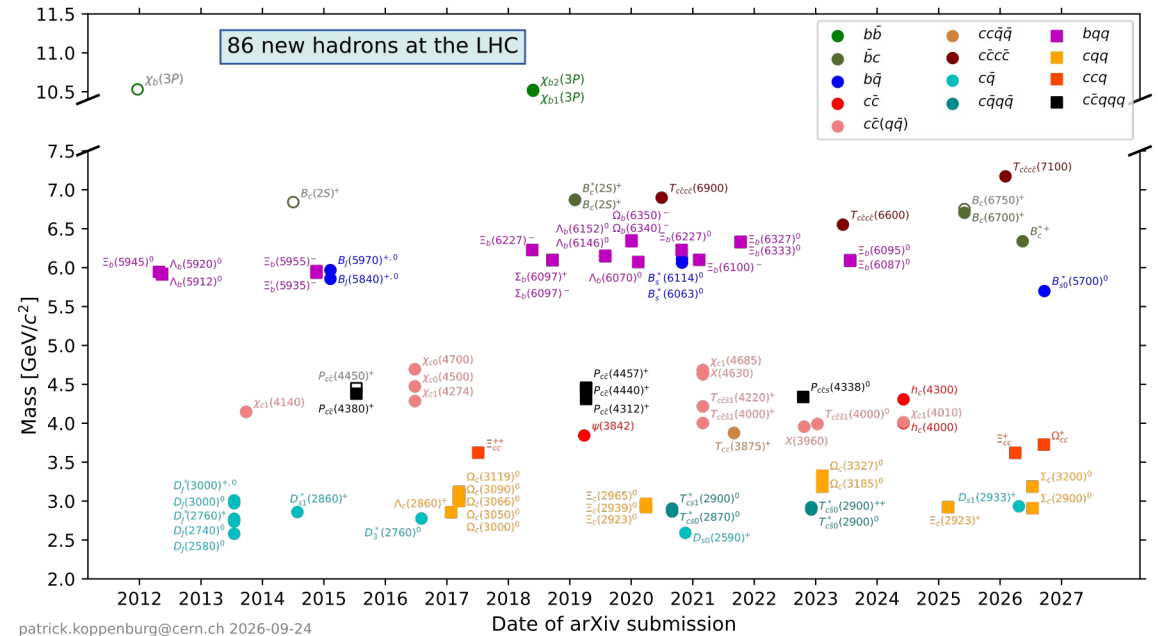
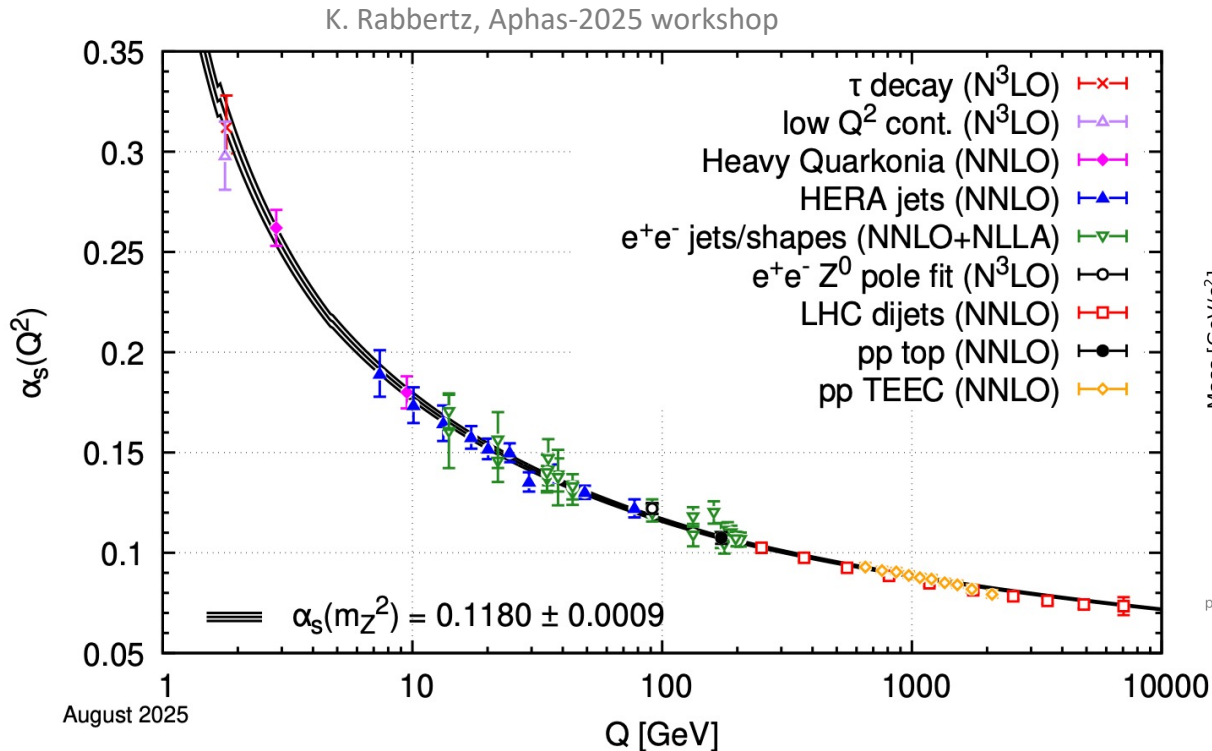
Jibo HE (University of Chinese Academy of Sciences)

Seminar at STFC-RAL

2nd Oct 2026

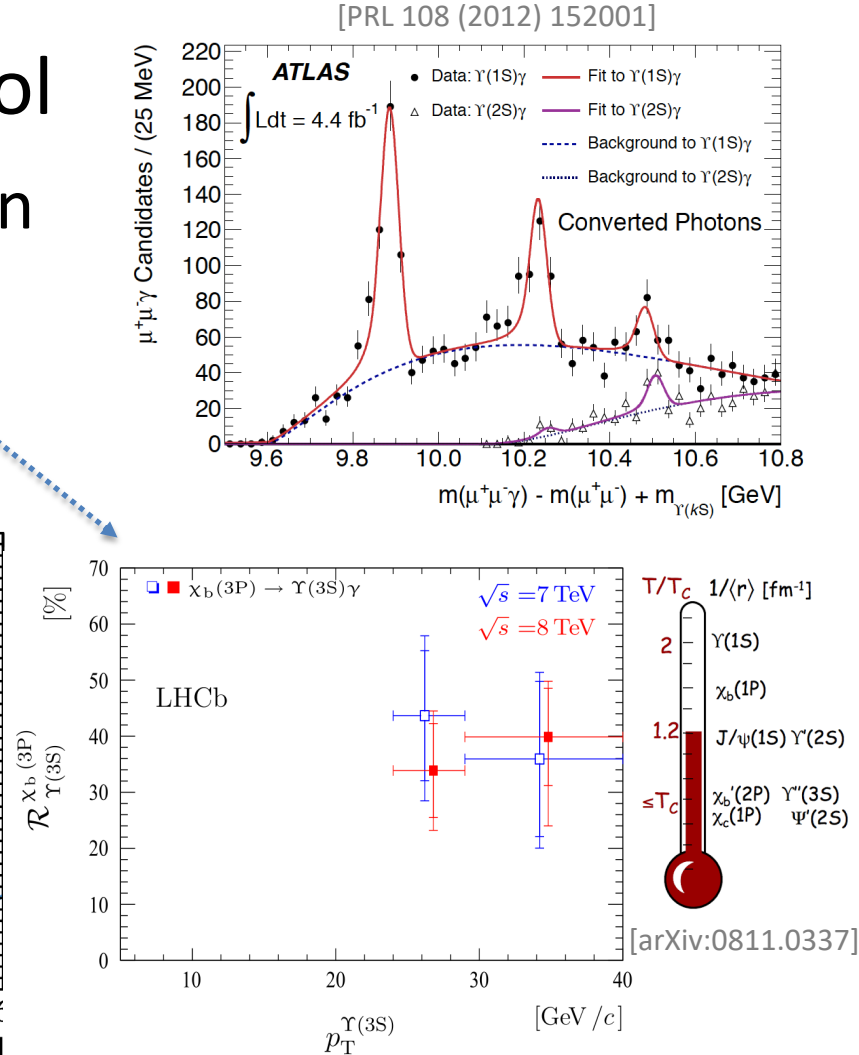
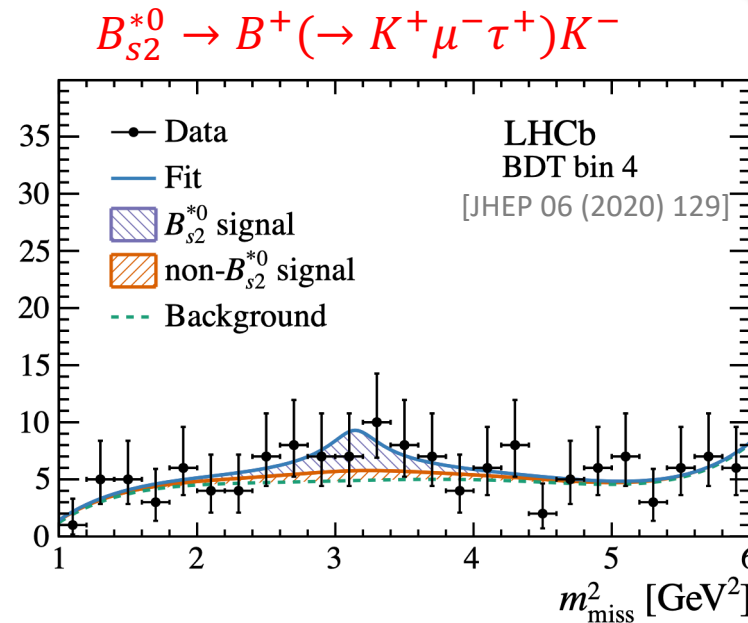
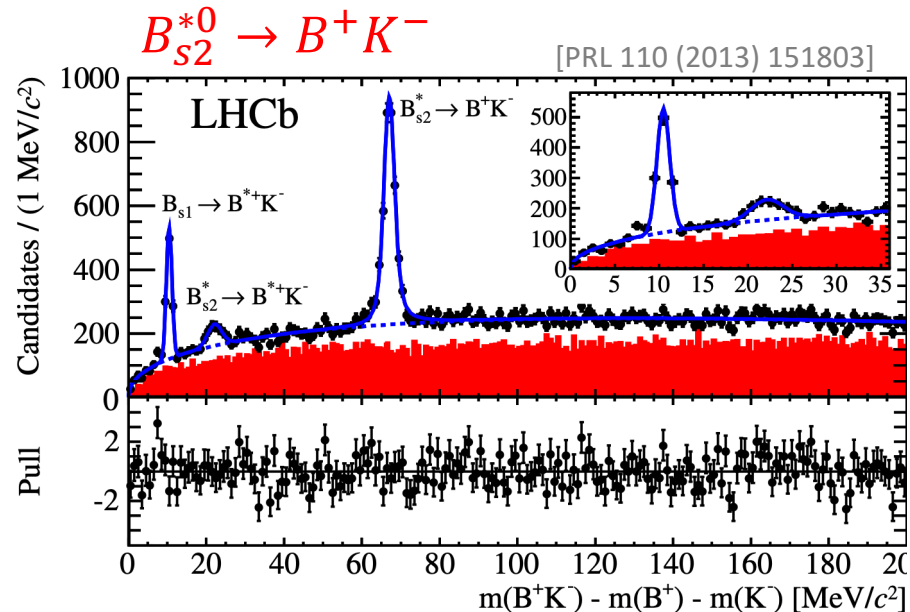
Introduction

- Particle zoo v1 $\Rightarrow$ Quark model; Particle zoo v2?
- Experimental measurements required to determine the nature of particles & calibrate LQCD



Introduction

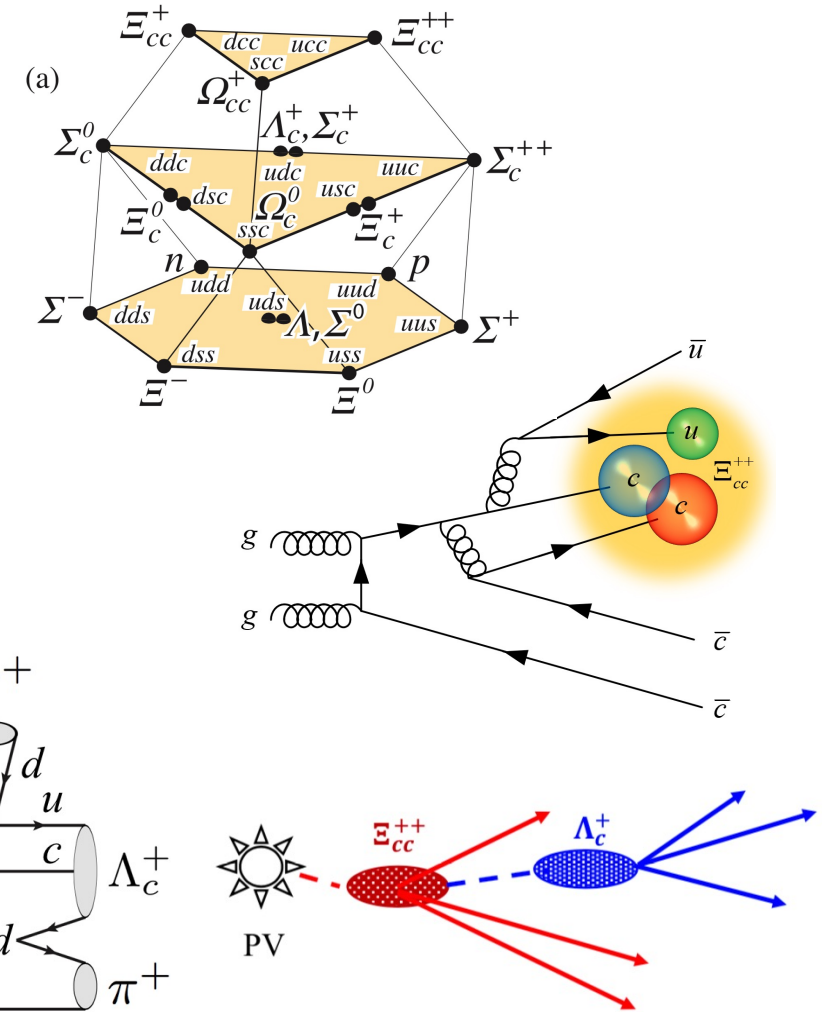
- Today's discovery, tomorrow's precision tool
 - B_{s2}^{*0} state, used to tag B^+ , E_{miss} reconstruction
 - $\chi_b(3P)$; $\Upsilon(3S)$ NOT free from feed-down



Doubly charmed baryon

(ccq)

- Unique system to study QCD
- Mass [e.g., S. Fleck, J.M. Richard, Prog. Theor. Phys. 82 (1989) 760]
 - $M(\Xi_{cc})$: 3.5-3.7 GeV; $M(\Omega_{cc}^+)$: +0.1-0.2 GeV
- Production at LHC [C.H. Chang *et al.*, PRD 73 (2006) 094022]
 - $\sigma(\Xi_{cc}) \approx 40 \text{ nb @ 13 TeV}$
- Lifetime [e.g., V.V. Kiselev *et al.*, PRD 60 (1999) 014001]
 - $\tau(\Xi_{cc}^{++}) > \tau(\Omega_{cc}^+) > \tau(\Xi_{cc}^+)$
- Decays [e.g., F.-S. Yu *et al.*, CPC 42 (2018) 051001]



Beauty/charm production

- Large production cross-section @ 7 TeV

- Minibias ~ 60 mb

- Charm ~ 6 mb

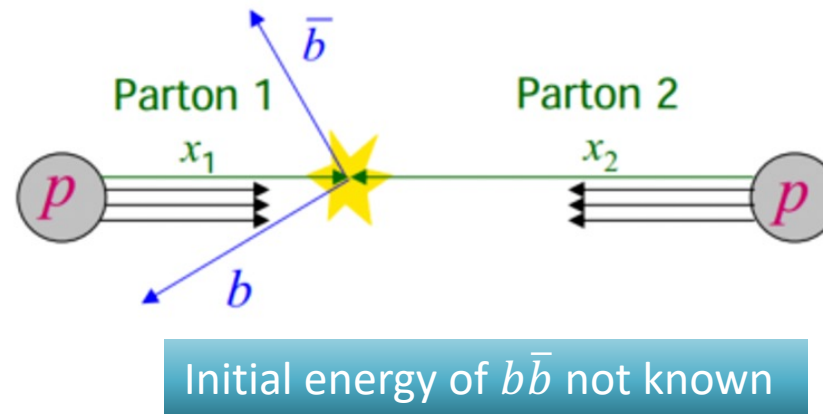
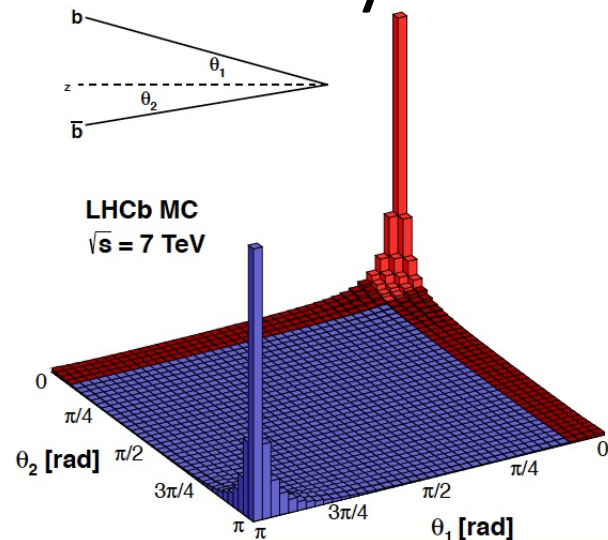
- Beauty ~ 0.3 mb c.f. 1nb @ $\Upsilon(4S)$



Flavour factory!

All b -hadrons:
 $B^+, B^0, B_s^0, \Lambda_b^0, B_c^+, \dots$

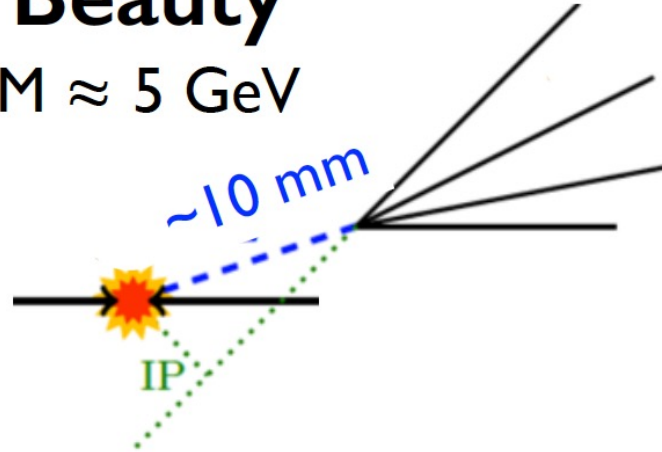
- Predominantly in forward/backward cones



Beauty/charm signature

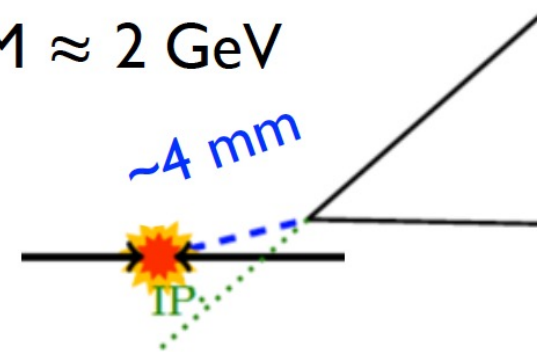
Beauty

$M \approx 5 \text{ GeV}$



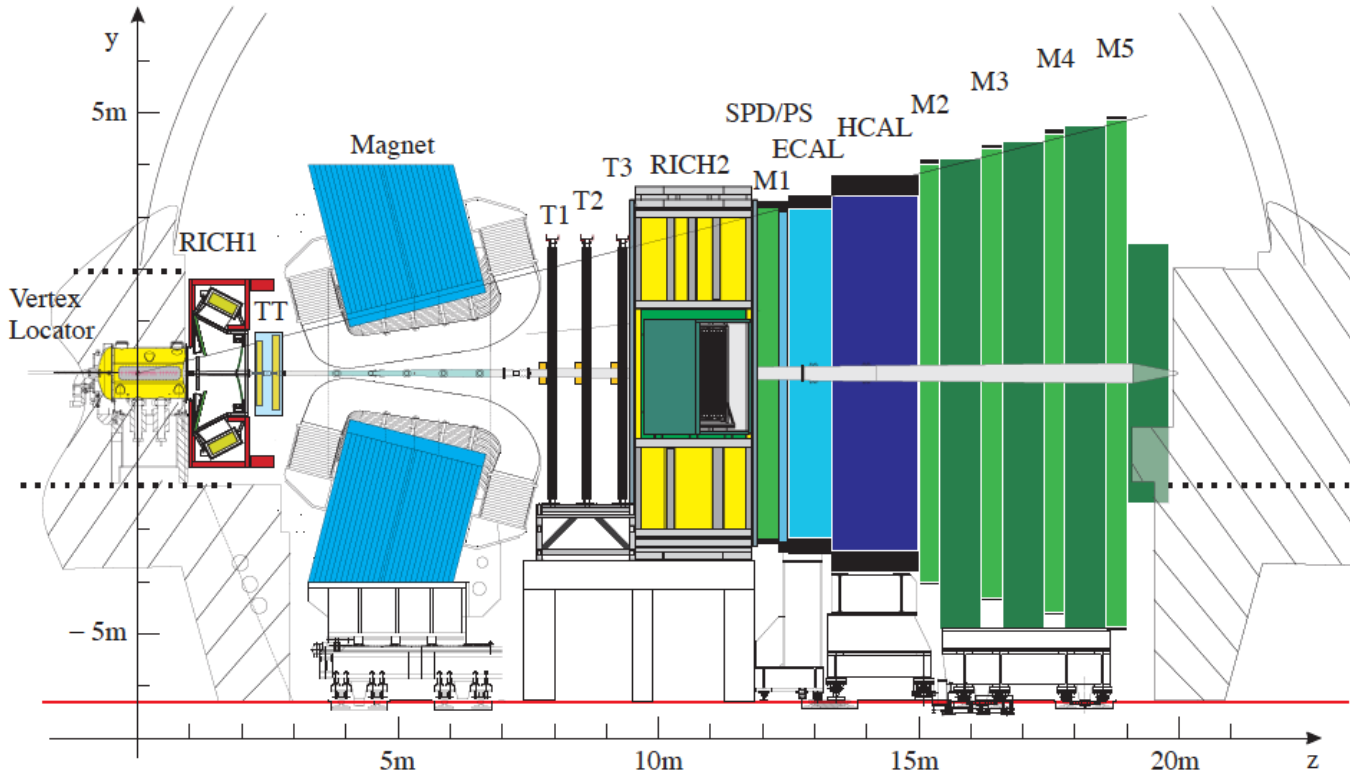
Charm

$M \approx 2 \text{ GeV}$



- Compared with minimum bias (background)
 - Relatively high mass $\rightarrow$ high *transverse momentum*
 - Relatively long lifetime $\rightarrow$ large impact parameter (IP)
- Requires excellent vertexing, tracking, particle-identification

The LHCb experiment



Vertex Locator

$$\sigma_{PV,x/y} \sim 10 \mu\text{m}, \sigma_{PV,z} \sim 60 \mu\text{m}$$

Tracking (TT, T1-T3)

$$\Delta p/p: 0.4\% \text{ at } 5 \text{ GeV}/c, \text{ to } 0.6\% \text{ at } 100 \text{ GeV}/c$$

RICHs

$$\varepsilon(K \rightarrow K) \sim 95\%, \text{ mis-ID rate } (\pi \rightarrow K) \sim 5\%$$

Muon system (M1-M5)

$$\varepsilon(\mu \rightarrow \mu) \sim 97\%, \text{ mis-ID rate } (\pi \rightarrow \mu) = 1 - 3\%$$

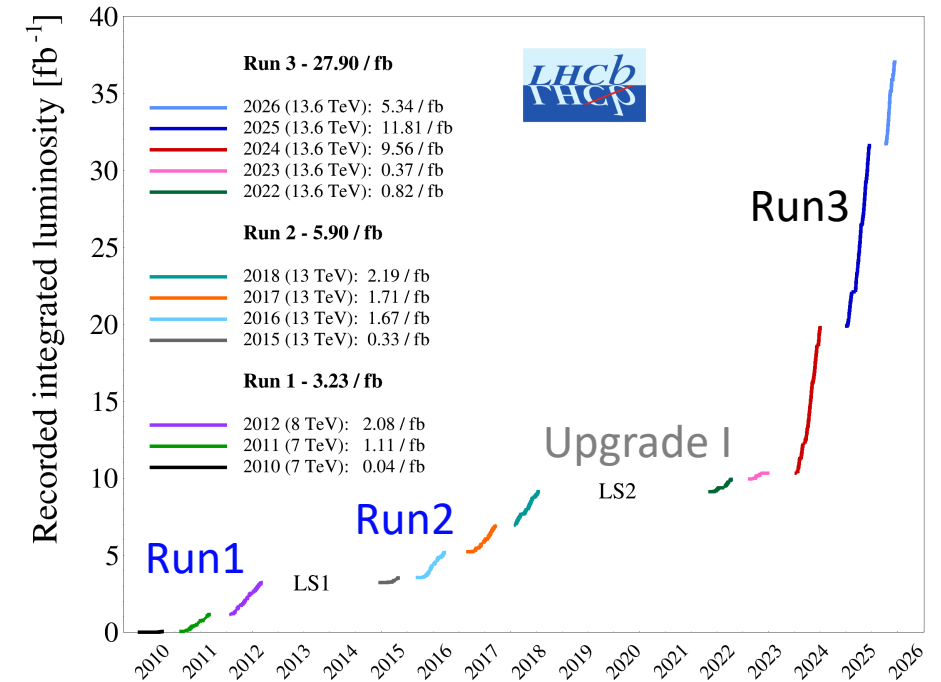
ECAL

$$\sigma_E/E \sim 10\%/\sqrt{E} \oplus 1\% \text{ (E in GeV)}$$

HCAL

$$\sigma_E/E \sim 70\%/\sqrt{E} \oplus 10\% \text{ (E in GeV)}$$

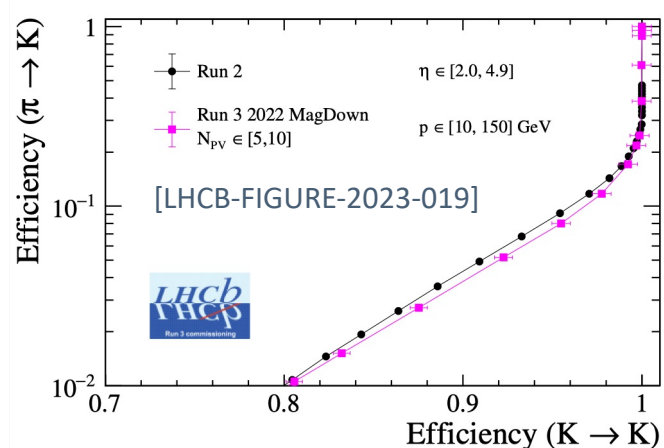
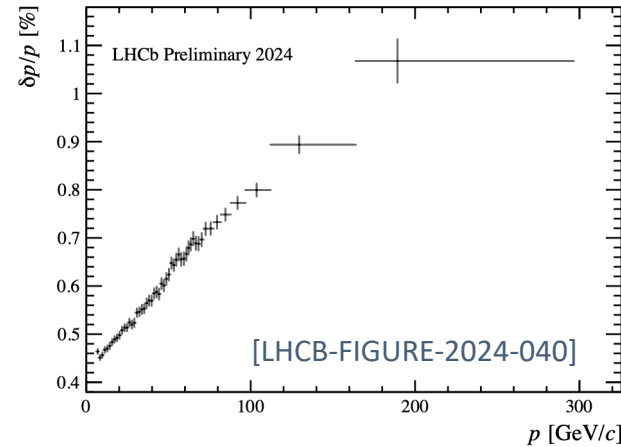
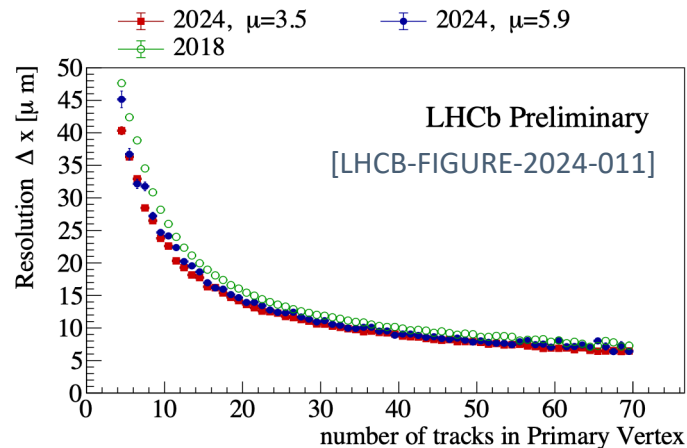
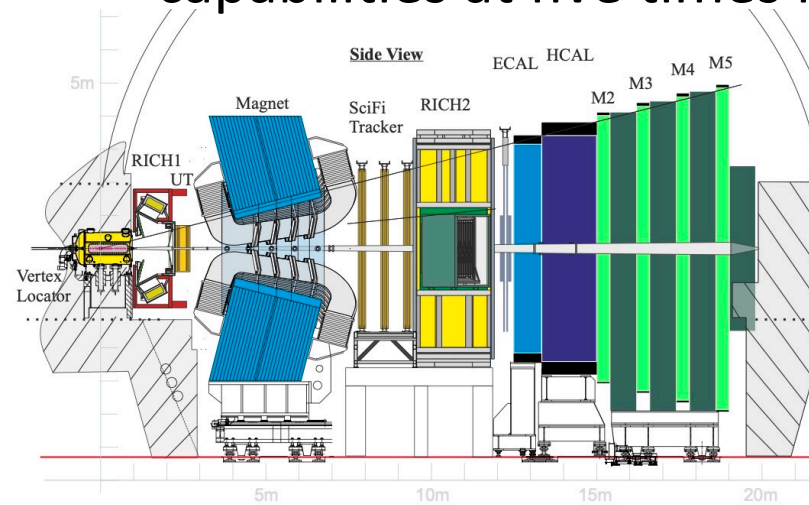
Total recorded luminosity – $pp - 37.0 \text{ fb}^{-1}$



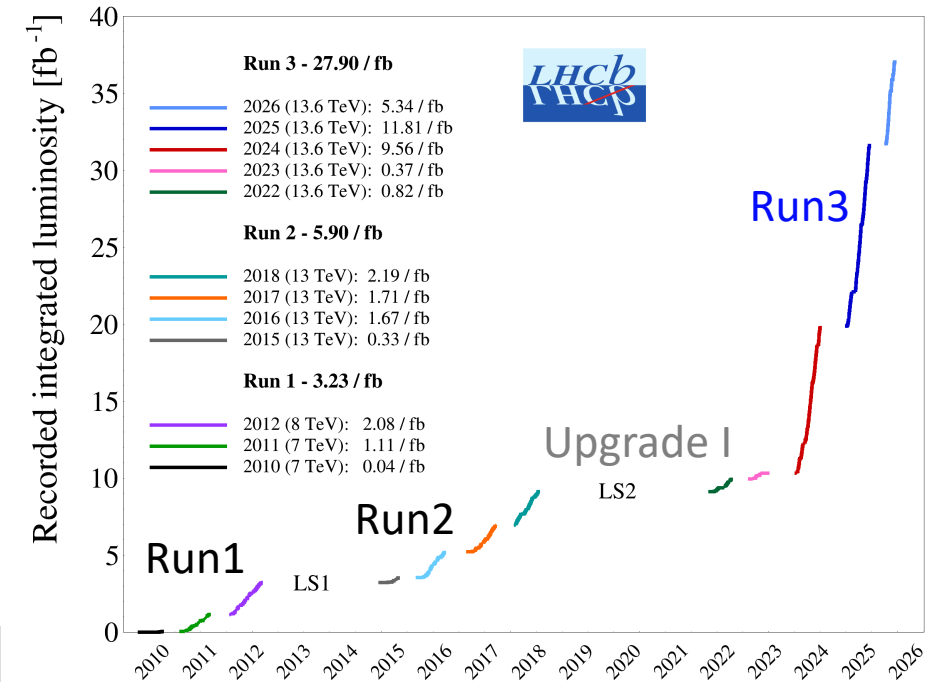
- **Run1-2 (2010-2018)**
 - Luminosity: $\sim 9 \text{ fb}^{-1}$
 - Yields, complementary to ATLAS/CMS
 - Muon modes: Down to zero p_T
 - Hadronic modes: **Unique**

The LHCb Upgrade

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

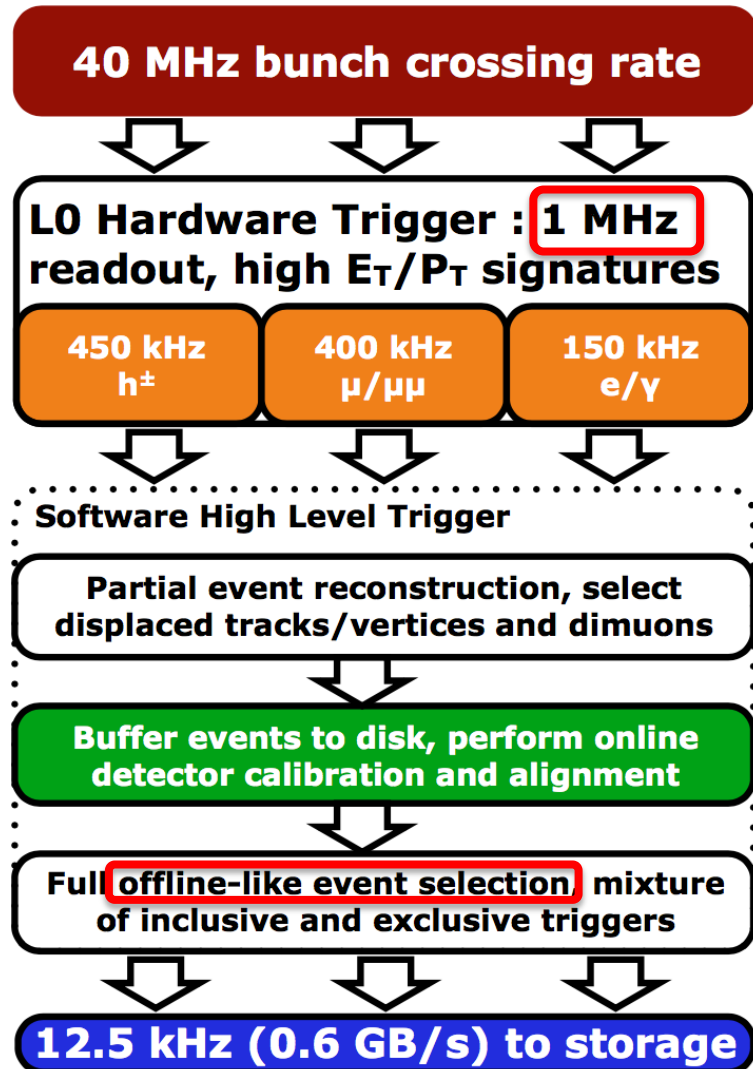


Total recorded luminosity – pp – 37.0 fb^{-1}



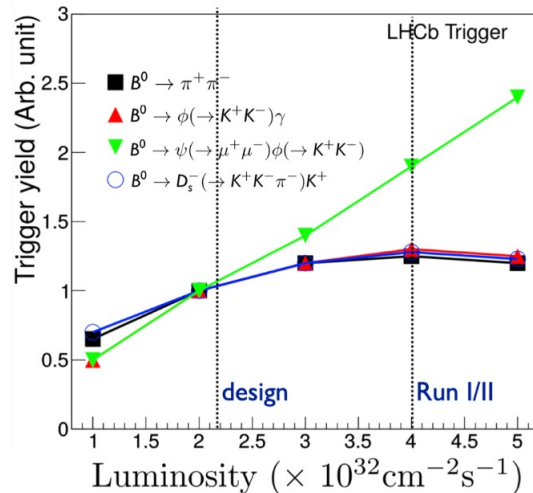
- Run3 (2024-2026)
 - Luminosity: $\sim 28 \text{ fb}^{-1}$
 - Yields, compared to Run 1+2
 - Muon modes ~ 4
 - Hadronic modes ~ 8 (higher trigger eff.)

The LHCb trigger (2018)



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

The LHCb trigger (Run3)



L0 removed

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

30 MHz inelastic event rate (full rate event building)

Software High Level Trigger

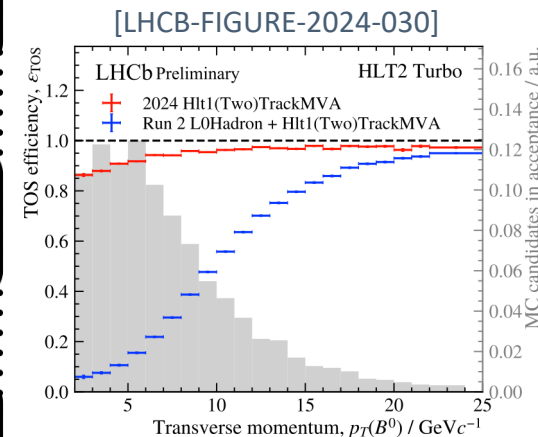
Full event reconstruction, inclusive and exclusive kinematic/geometric selections

Buffer events to disk, perform online detector calibration and alignment

Add offline precision particle identification and track quality information to selections

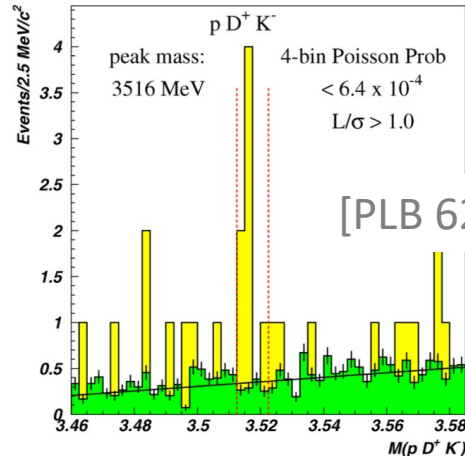
Output full event information for inclusive triggers, trigger candidates and related primary vertices for exclusive triggers

2-5 GB/s to storage

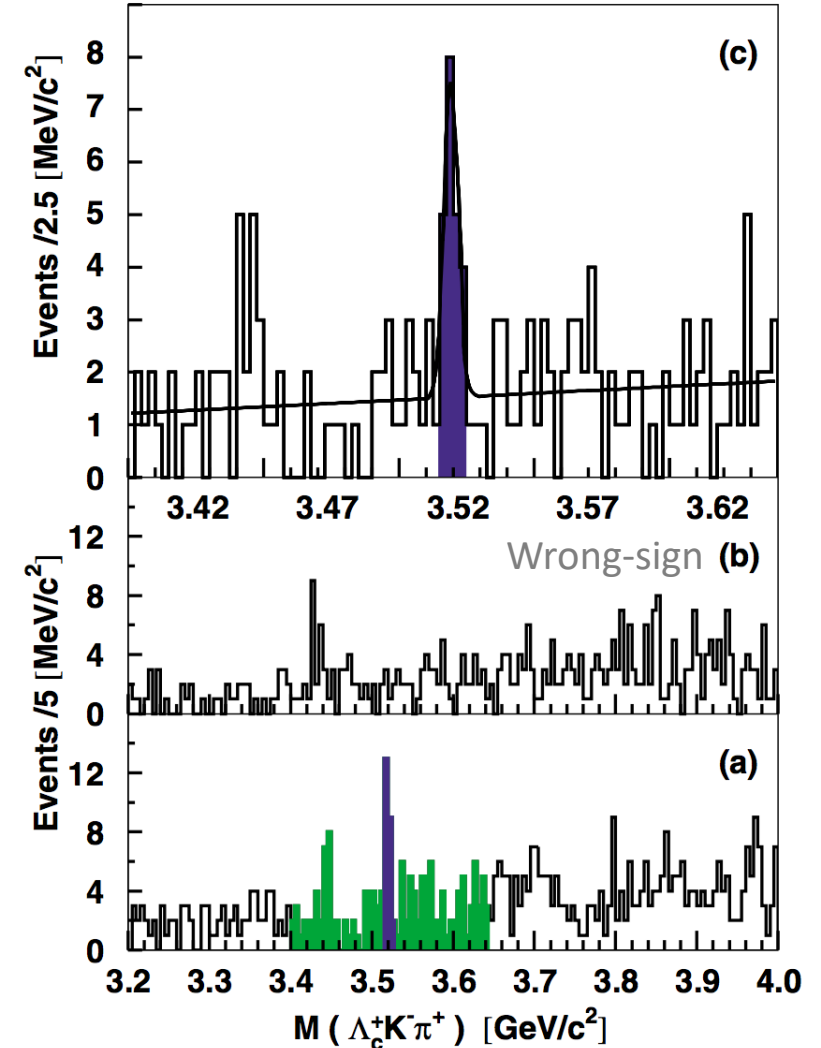


Ξ_{cc}^+ @ SELEX

- SELEX claimed $\Xi_{cc}^+ \rightarrow \Lambda_c^+ K^- \pi^+$ (6.3σ)
 - $M: 3519 \pm 1 \text{ MeV}$
 - $\tau: < 33 \text{ fs @90\%CL}$
 - $\sigma_{\text{prod}}: 20\% \Lambda_c^+$ from Ξ_{cc}^+
- Also $\Xi_{cc}^+ \rightarrow p D^+ K^-$

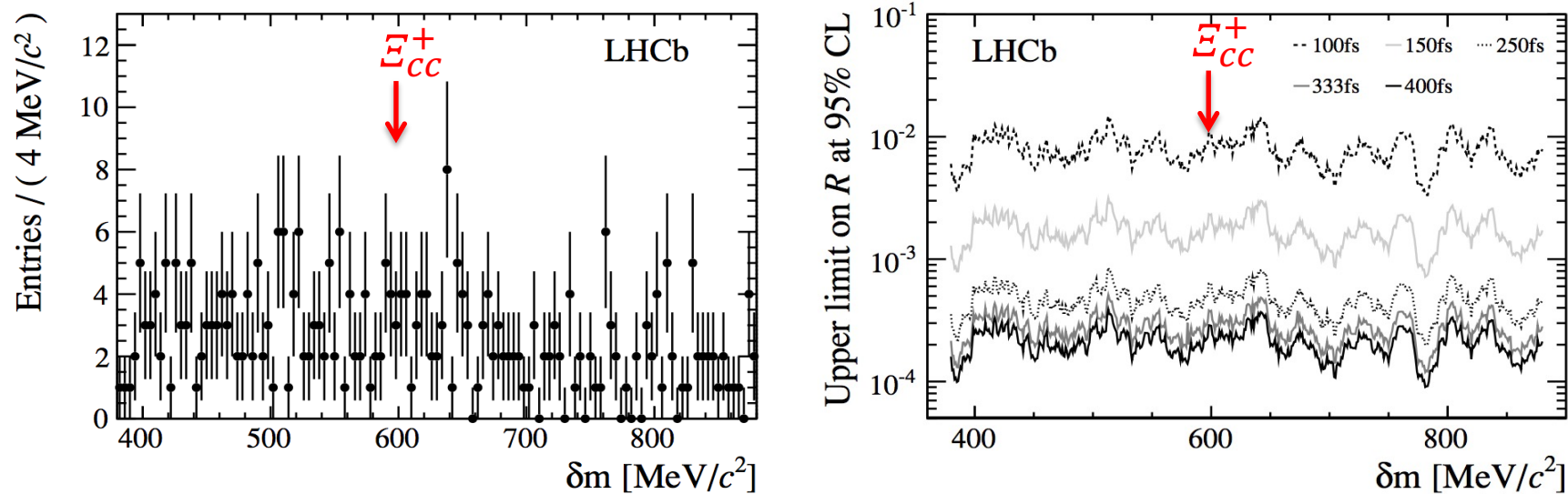


[PRL 89 (2002) 112001]

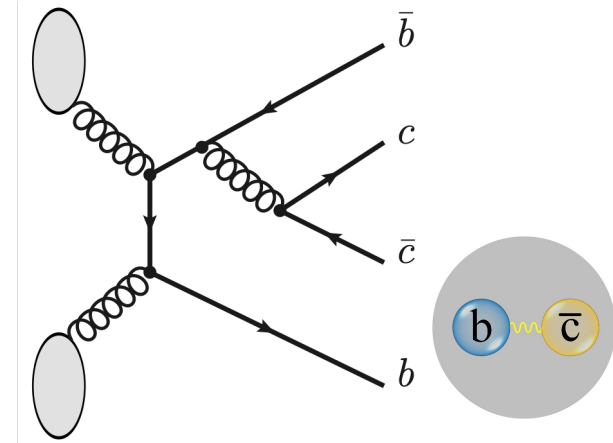


E_{cc} @ LHCb & others

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



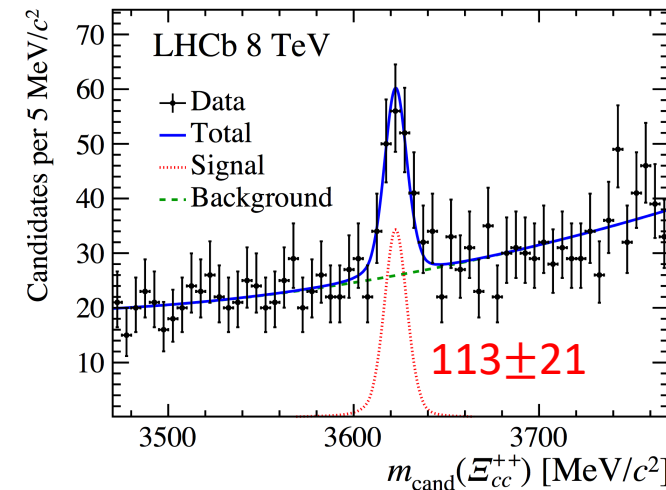
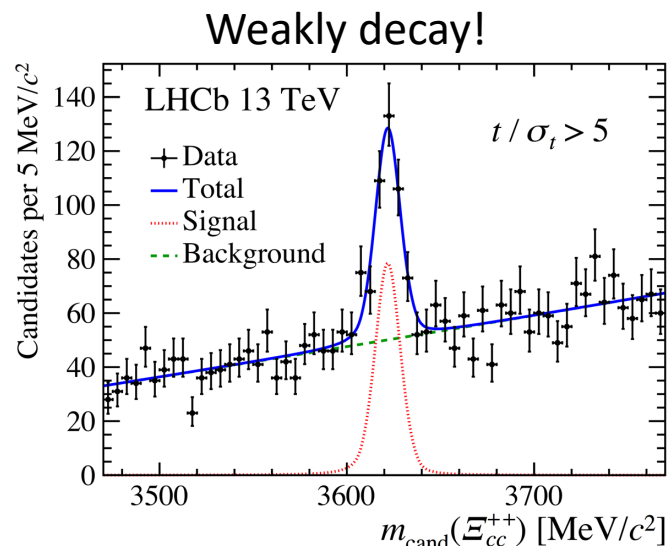
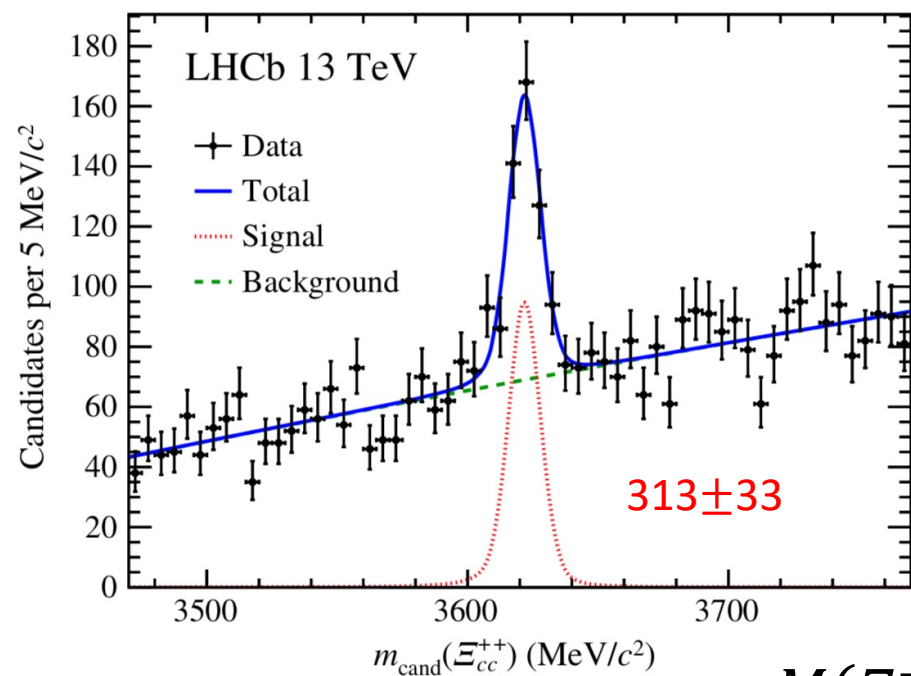
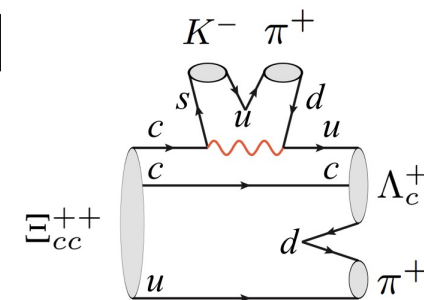
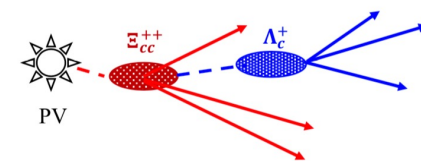
- However, LHCb already had lots of B_c^+ events, and double-charm events...



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 ($>12\sigma$) & Run1 ($>7\sigma$)



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

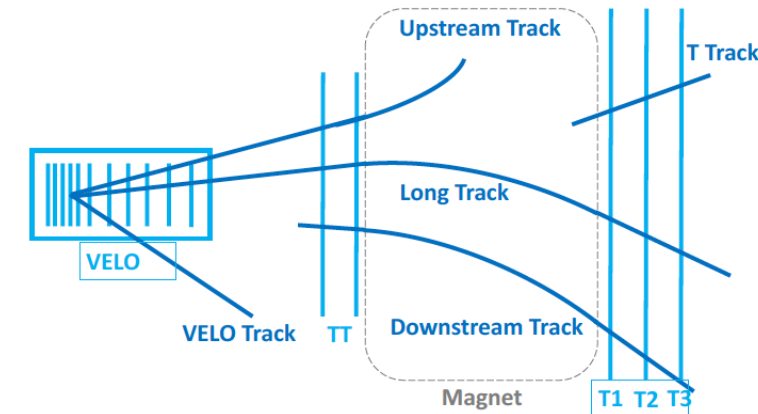
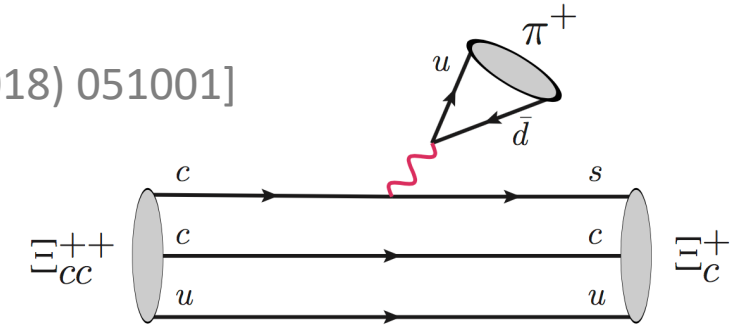
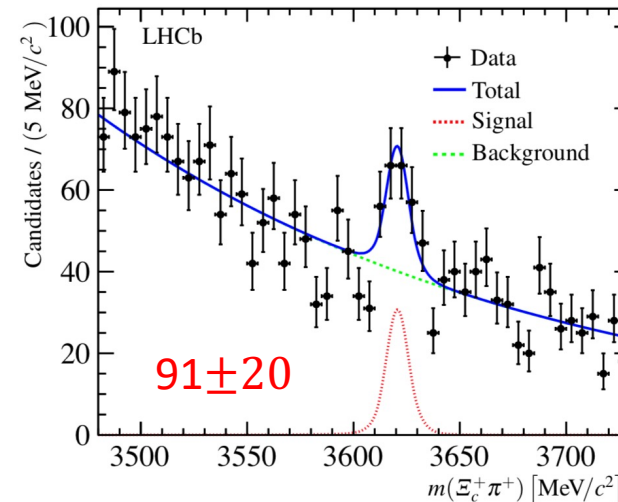
Observation of Ξ_{cc}^{++}

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

- $\Xi_{cc}^{++} \rightarrow \Xi_c^+ \pi^+$ 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

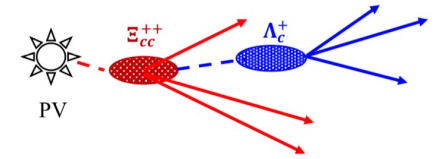
$$\frac{\mathcal{B}(\Xi_{cc}^{++} \rightarrow \Xi_c^+ \pi^+) \cdot \mathcal{B}(\Xi_c^+ \rightarrow p K^- \pi^+)}{\mathcal{B}(\Xi_{cc}^{++} \rightarrow \Lambda_c^+ K^- \pi^+ \pi^+) \cdot \mathcal{B}(\Lambda_c^+ \rightarrow p K^- \pi^+)}$$

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

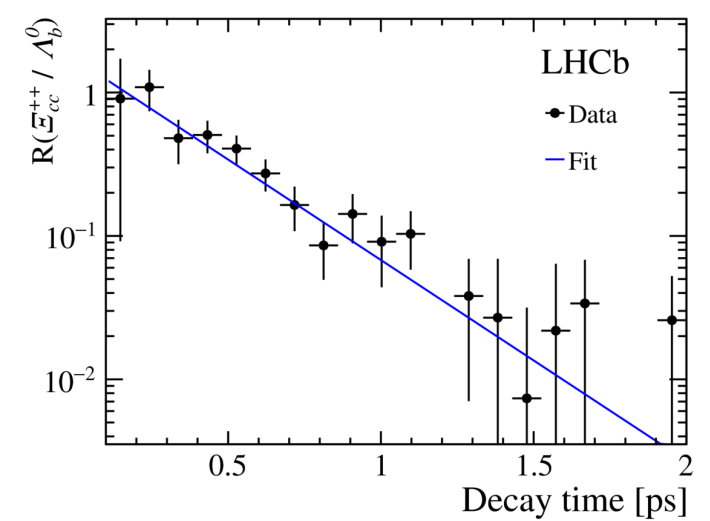
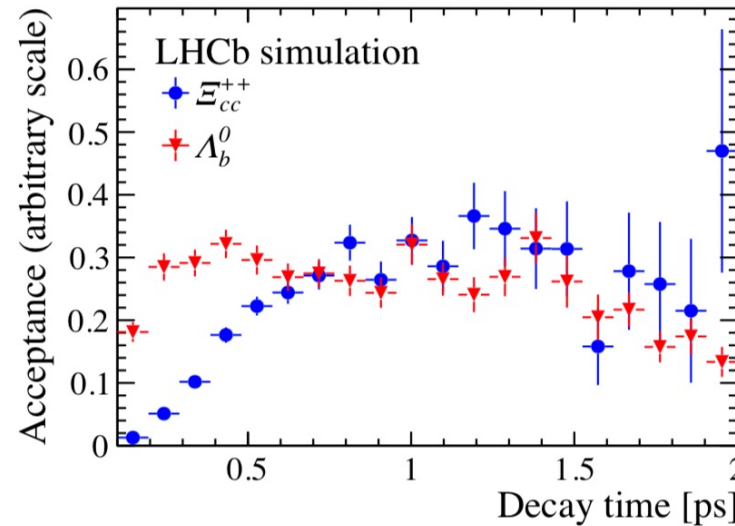
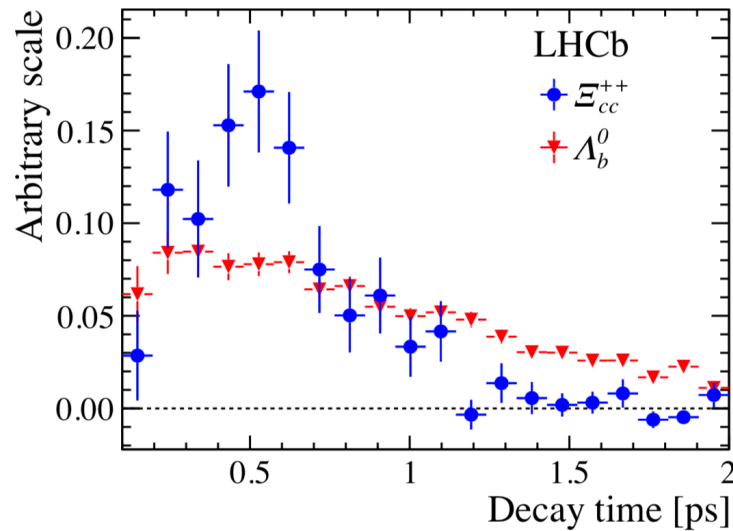


Not very good at hyperon...

Ξ_{cc}^{++} lifetime



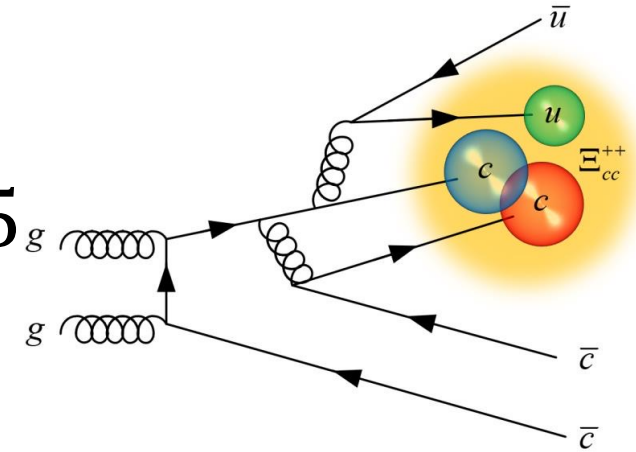
- Control mode, $\Lambda_b^0 \rightarrow \Lambda_c^+ 3\pi$



- $\tau(\Xi_{cc}^{++}) = 0.256_{-0.022}^{+0.024} \pm 0.014$ ps, at lower side prediction: 0.2-1.05ps
- Weakly decay nature established!

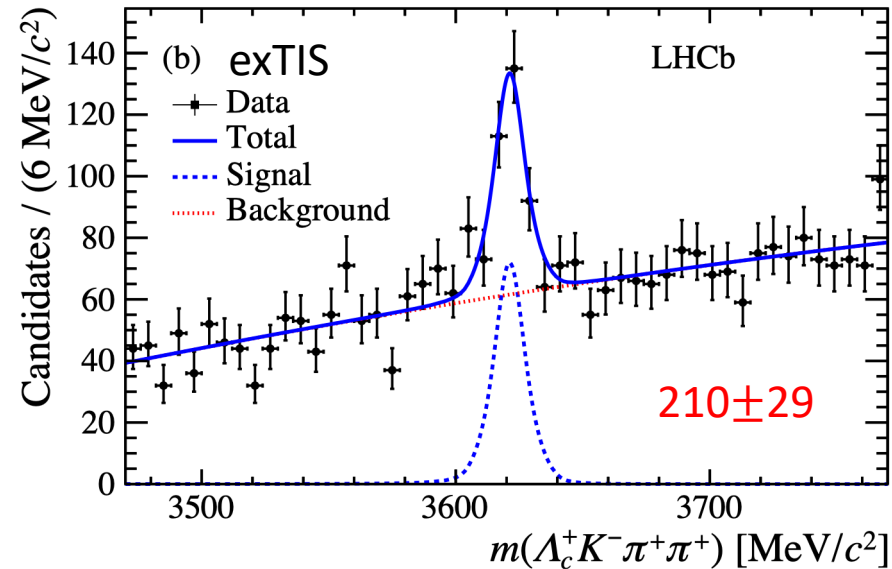
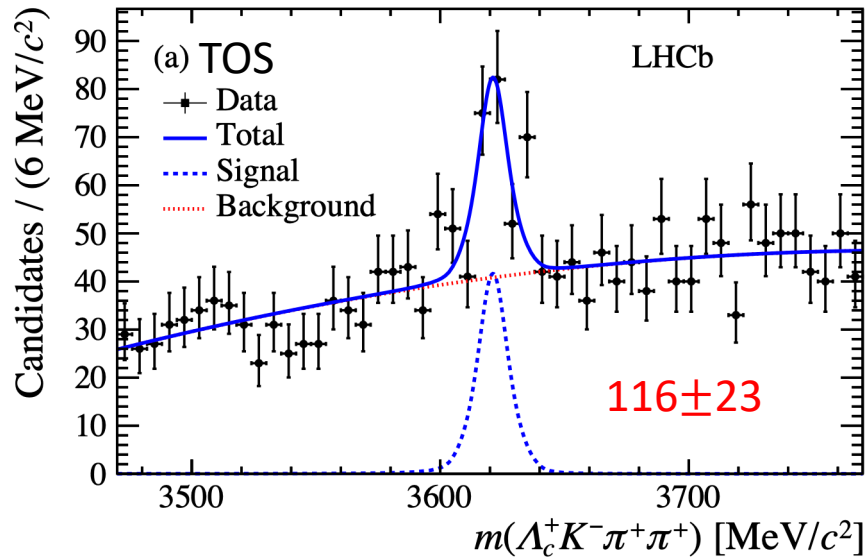
Ξ_{cc}^{++} production

- Relative to Λ_c^+ , in $4 < p_T < 15$ GeV, $2 < y < 4.5$
- Accompanying $\bar{c}\bar{c}$ dominates in trigger



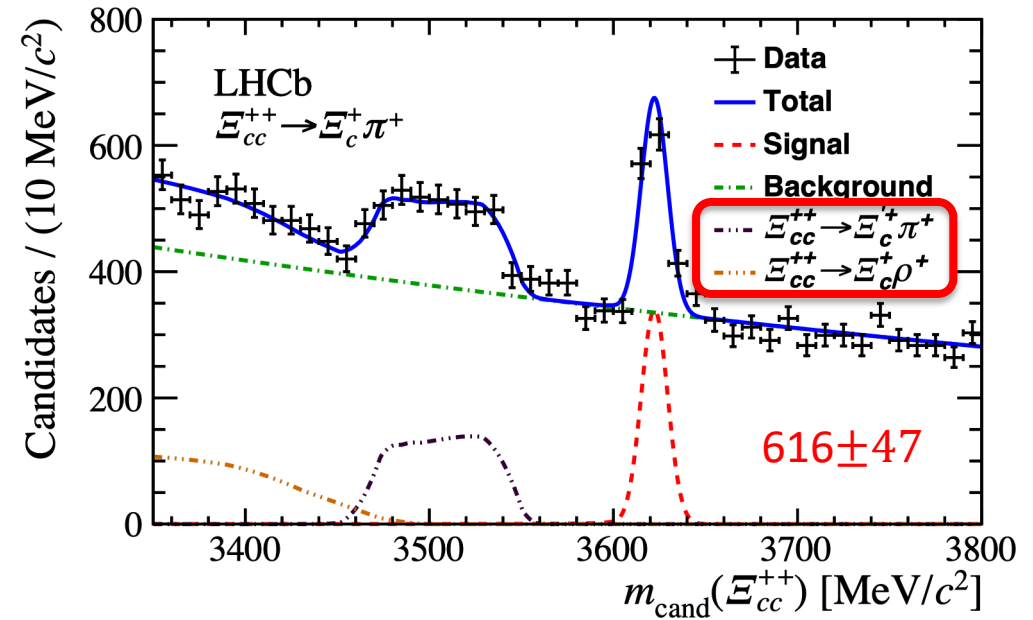
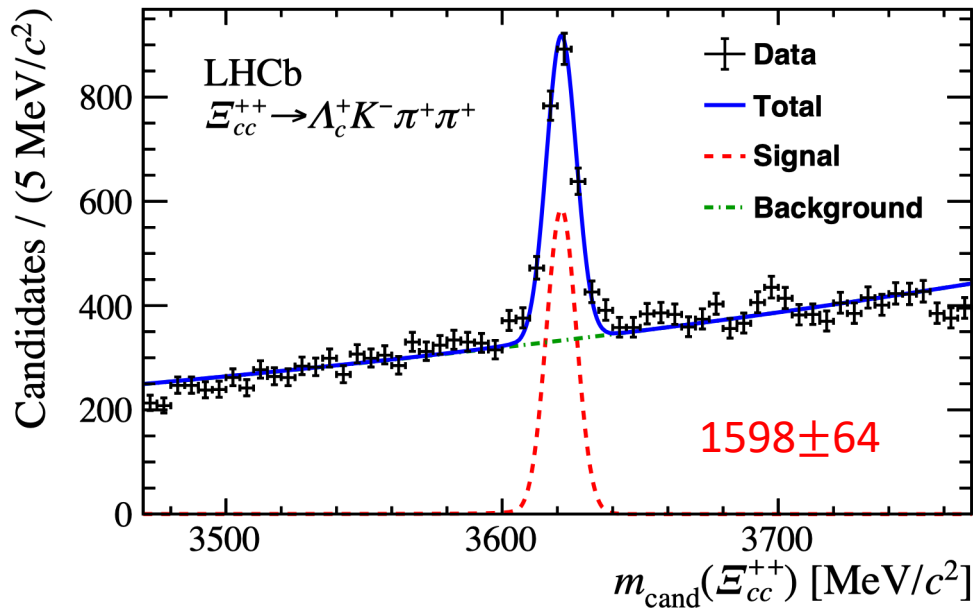
$$\frac{\sigma(\Xi_{cc}^{++})}{\sigma(\Lambda_c^+)} \mathcal{B}(\Xi_{cc}^{++} \rightarrow \Lambda_c^+ K^- \pi^+ \pi^+) = (2.22 \pm 0.27 \pm 0.29) \times 10^{-4}$$

SELEX, 20% Λ_c^+ from Ξ_{cc}^+ ?



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

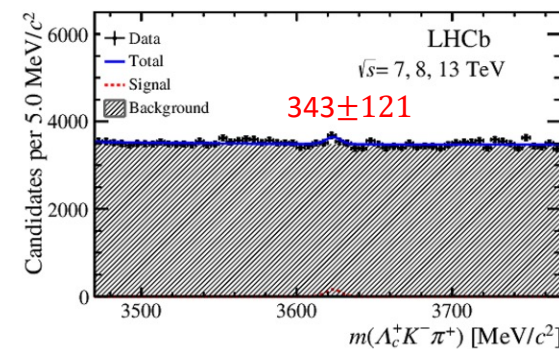
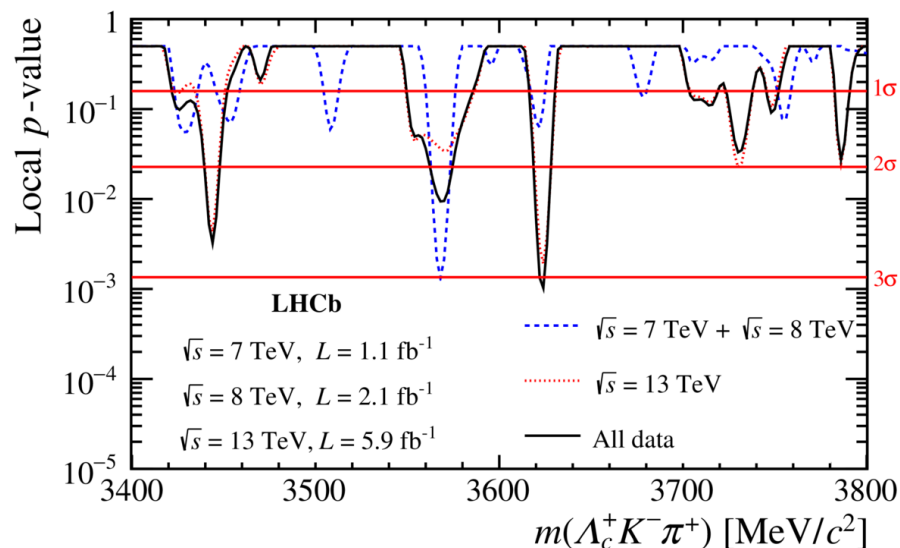
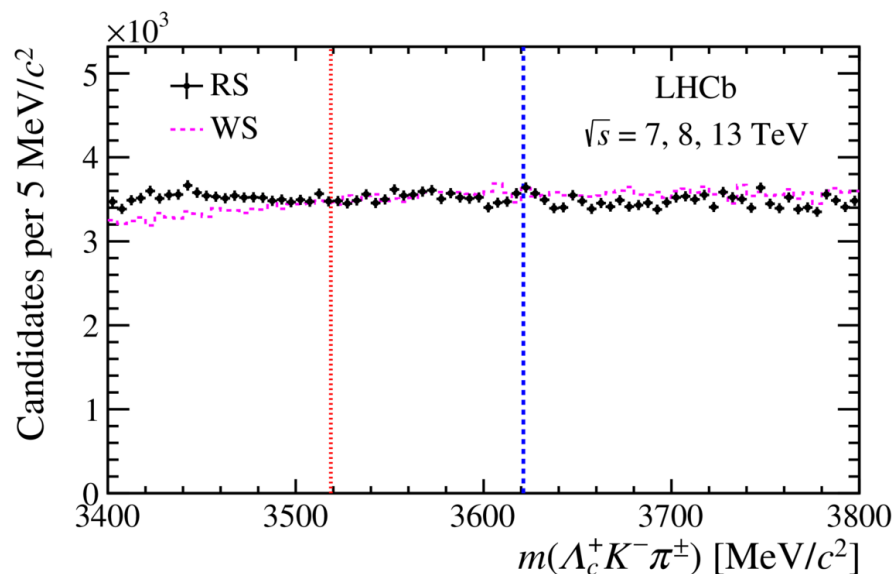
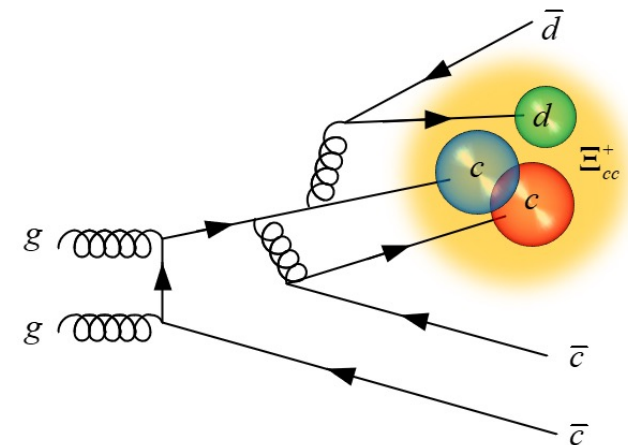
- Preparing to search for excited states, selection re-optimised
- 5-6 times signal yields with a factor of 3 data



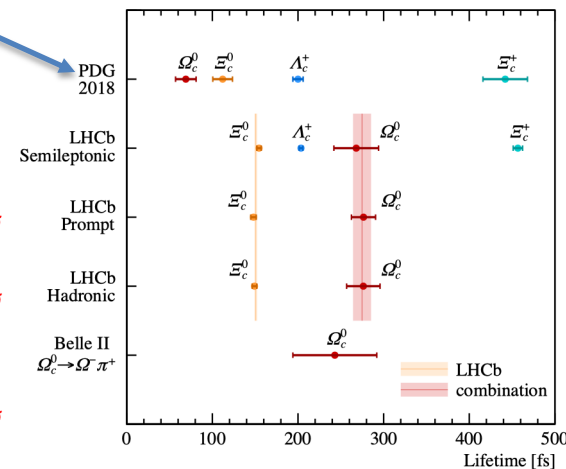
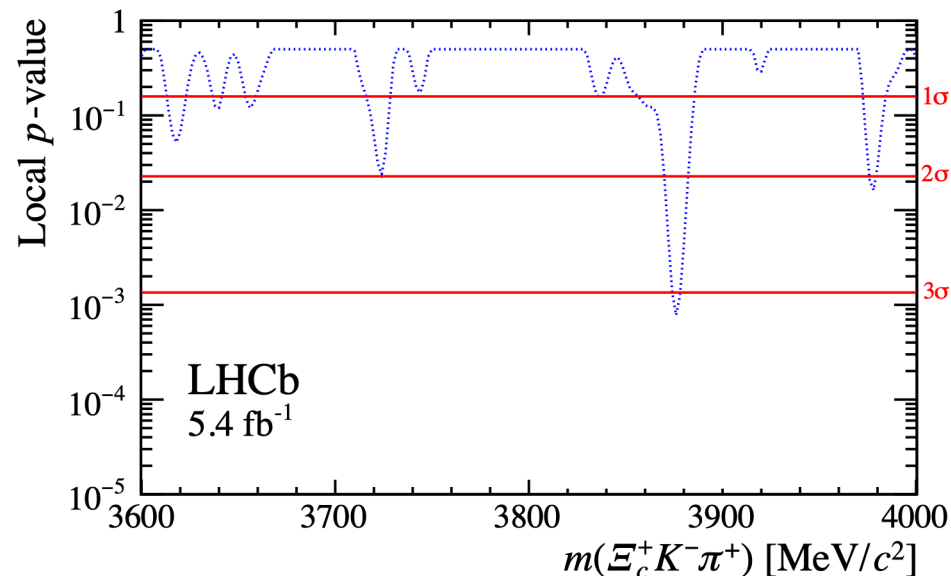
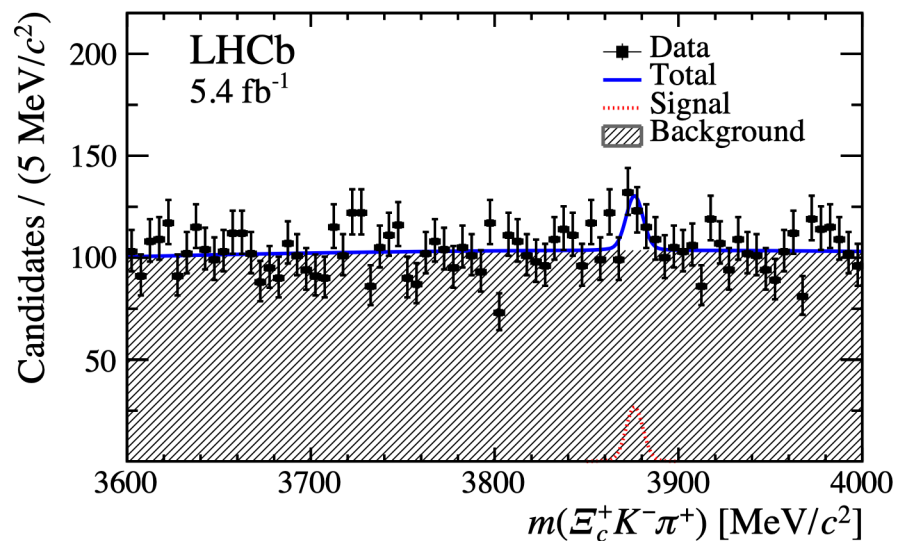
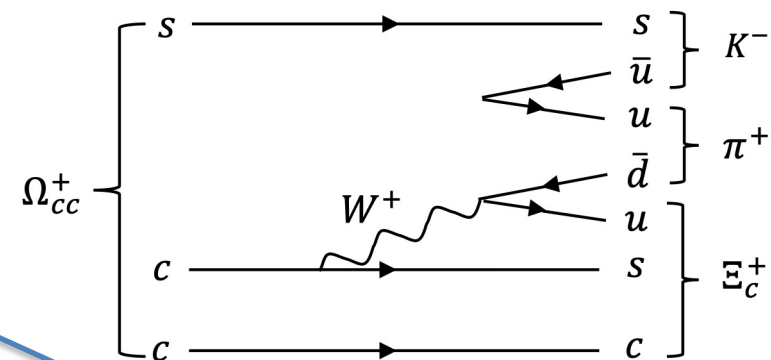
$$M(\Xi_{cc}^{++}) = 3621.55 \pm 0.23 \pm 0.30 \text{ MeV}/c^2 \quad \text{taken as WA by PDG}$$

Ξ_{cc}^+ search

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

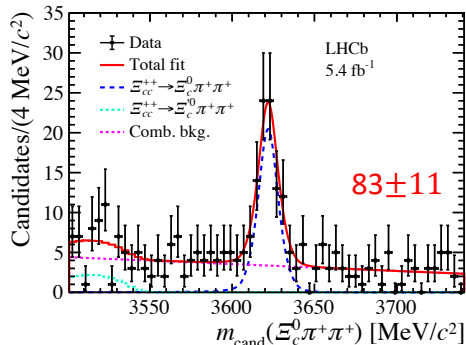
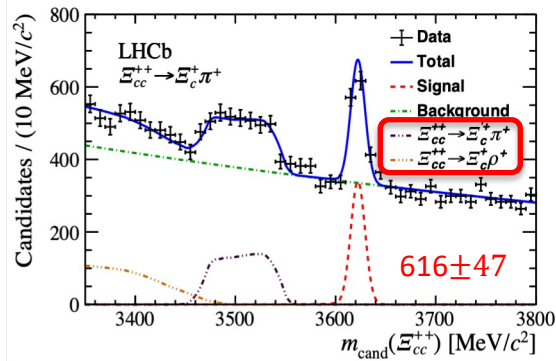
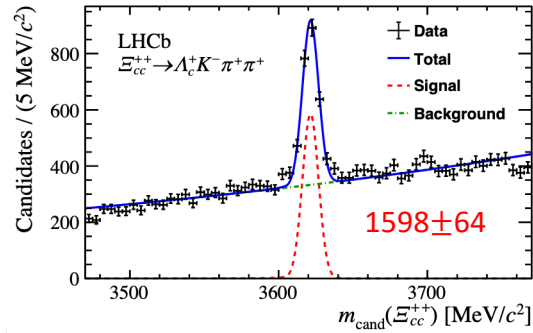


- $E_c^+ K^- \pi^+$ chosen for the first search using Run-2 data, as Ω_c^0 lifetime WAS too short
- No significant signal after considering LEE



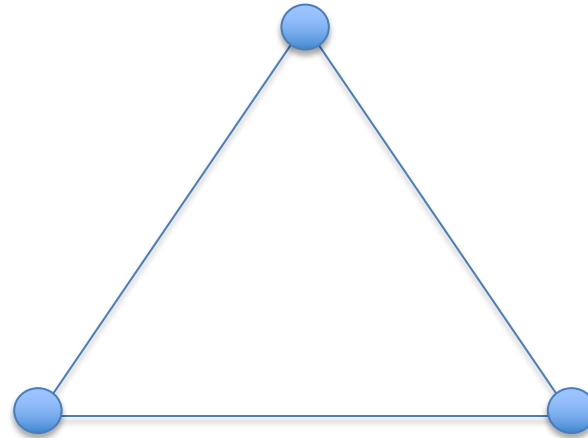
[JHEP 09 (2025) 157]

Doubly heavy baryons w/ Run1-2 data



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

Ω_{cc}^+ (ccs)



Ξ_{cc}^{++} (ccu)

Ξ_{cc}^+ (ccd)

Observation [PRL 119 (2017) 112001]

Mass [JHEP 02 (2020) 049]

Lifetime [PRL 121 (2018) 052002]

Production [CPC 44 (2020) 022001]

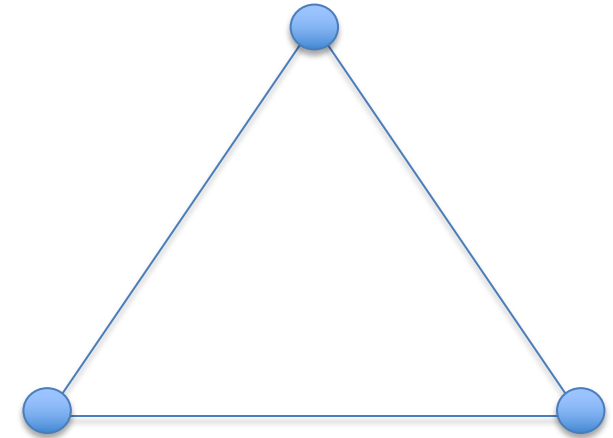
Decay $\Xi_c^+ \pi^+$ [PRL 121 (2018) 162002]

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

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

First search [CPC 45 (2021) 093002]

Ω_{bc}^0 (bcs)



Ξ_{bc}^+ (bcu)

Ξ_{bc}^0 (bcd)

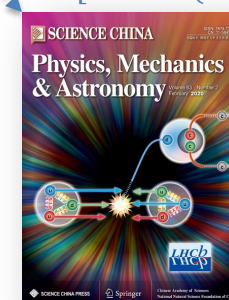
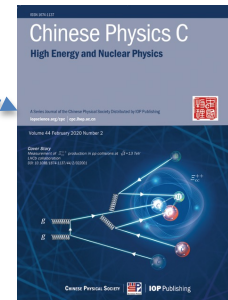
First search

First search

Hint

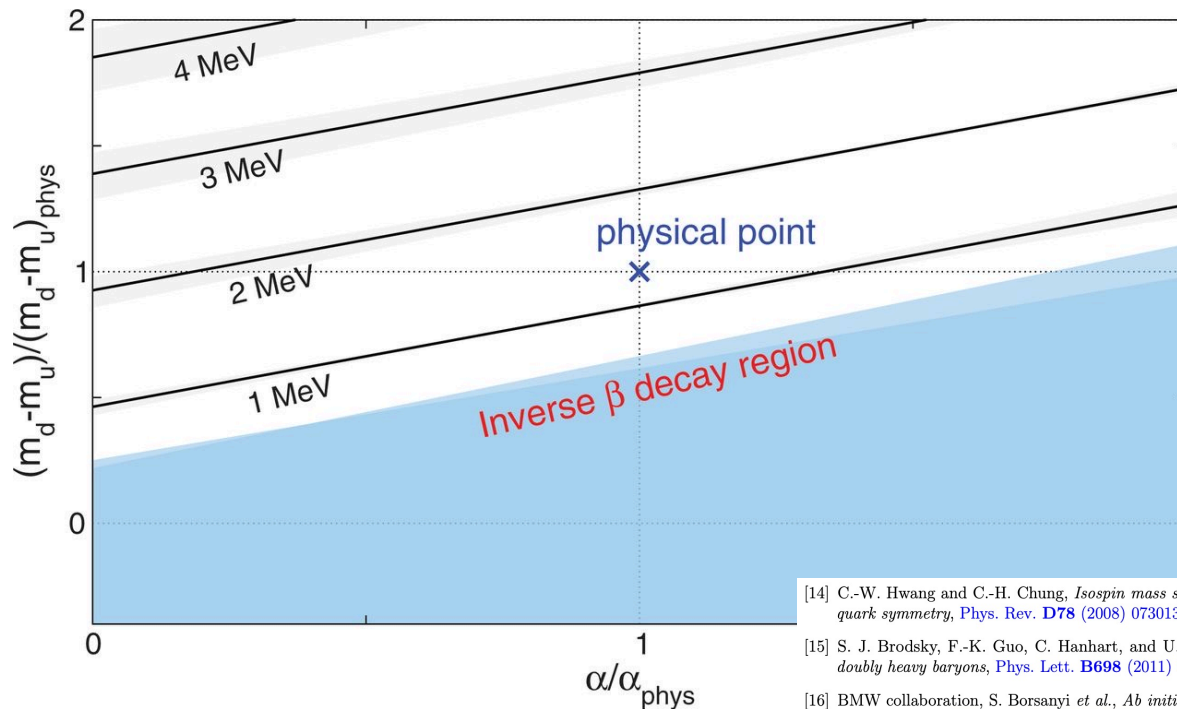
[JHEP 11 (2020) 095]

[CPC 47 (2023) 093001]



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

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



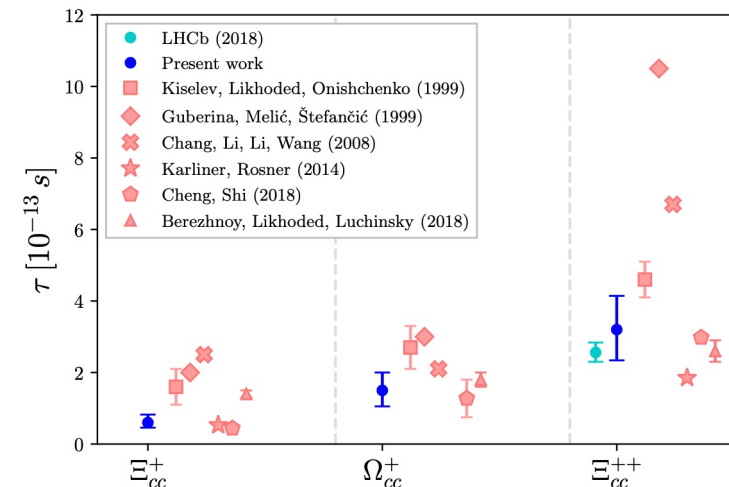
	Mass splitting [MeV]	QCD [MeV]	QED [MeV]
$\Delta N = n - p$	1.51(16)(23)	2.52(17)(24)	-1.00(07)(14)
$\Delta \Sigma = \Sigma^- - \Sigma^+$	8.09(16)(11)	8.09(16)(11)	0
$\Delta \Xi = \Xi^- - \Xi^0$	6.66(11)(09)	5.53(17)(17)	1.14(16)(09)
$\Delta D = D^\pm - D^0$	4.68(10)(13)	2.54(08)(10)	2.14(11)(07)
$\Delta \Xi_{cc} = \Xi_{cc}^{++} - \Xi_{cc}^+$	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. D* **78** (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. B* **698** (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. D* **92** (2015) 076008, [arXiv:1503.05184](#).
- [18] M. Karliner and J. L. Rosner, *Isospin splittings in baryons with two heavy quarks*, *Phys. Rev. D* **96** (2017) 033004, [arXiv:1706.06961](#).

Ξ_{cc}^+ lifetime

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

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



Revisiting lifetimes of doubly charmed baryons

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 $\Gamma_{\pm}^{\text{int}}$ even becomes negative. This implies that the subleading corrections are too large to justify the validity of the HQE. Demanding the rate $\Gamma_{\pm}^{\text{int}}$ to be positive for a sensible HQE, we conjecture that the Ω_{cc}^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.

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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

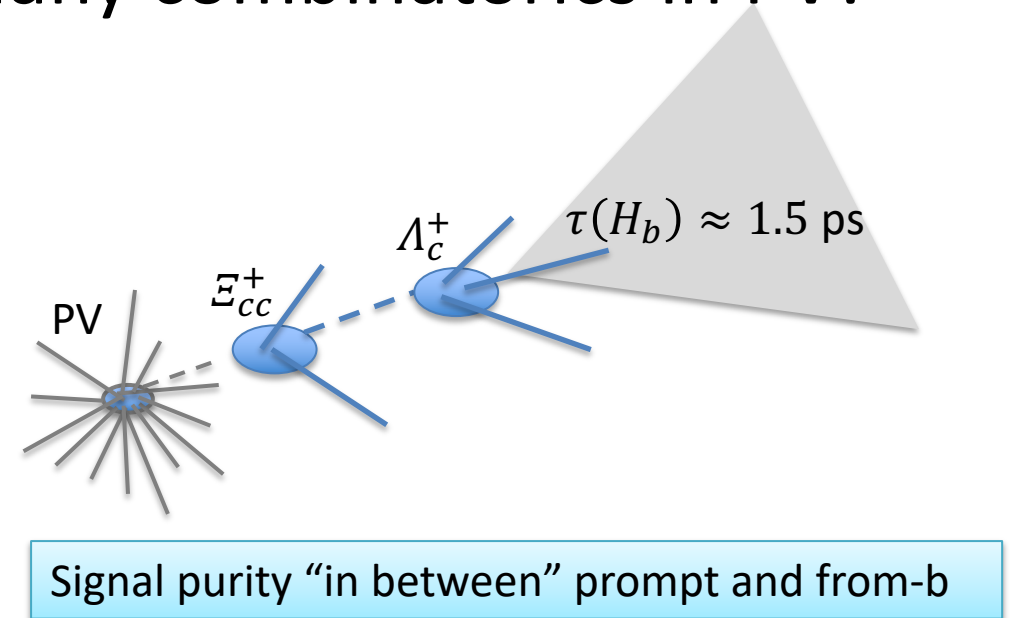
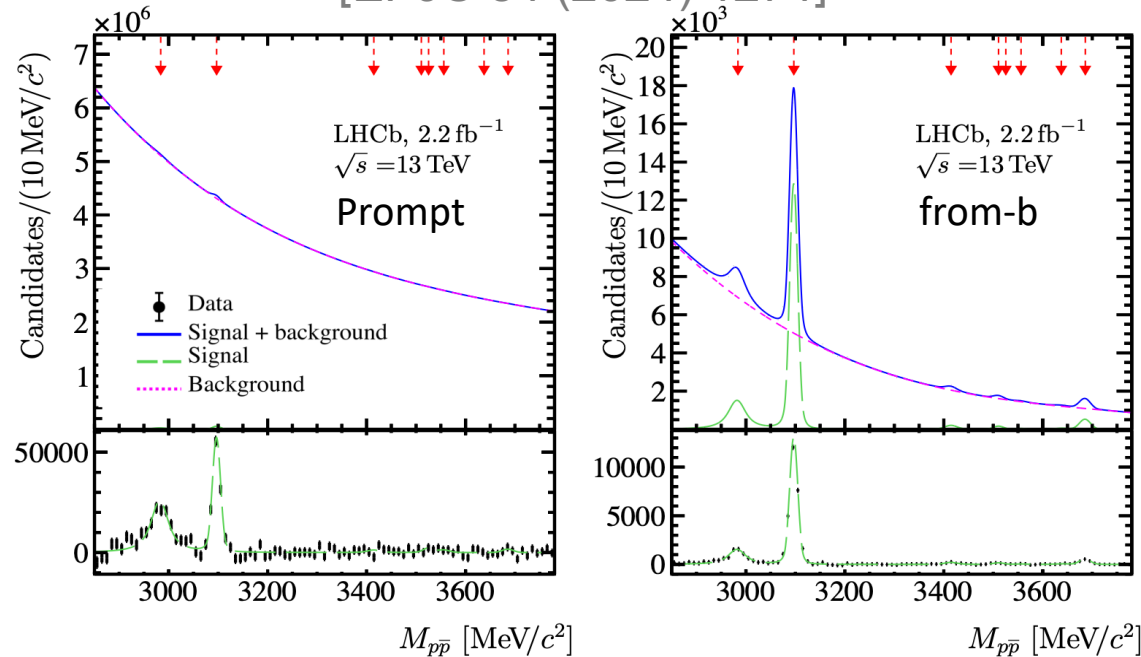
$$\tau(\Xi_{cc}^+) < \tau(\Omega_{cc}^+) < \tau(\Xi_{cc}^{++}),$$

while the predicted lifetime $\tau(\Xi_{cc}^{++}) = 0.32 \pm 0.5_{-0.7}^{+0.8}$ 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 $\tau(\Omega_{cc}^+)/\tau(\Xi_{cc}^{++}) = 0.52 \pm 0.13_{-0.02}^{+0.03}$.

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!
- $\eta_c(1S) \rightarrow p\bar{p}$ as an example, too many combinatorics in PV!

[EPJC 84 (2024) 1274]



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 baseline
- New decay modes added:

$$- \Xi_{cc}^+ \rightarrow \Xi_c^0 \pi^+$$

$$- \Xi_{cc}^+ \rightarrow D^+ p K^-$$

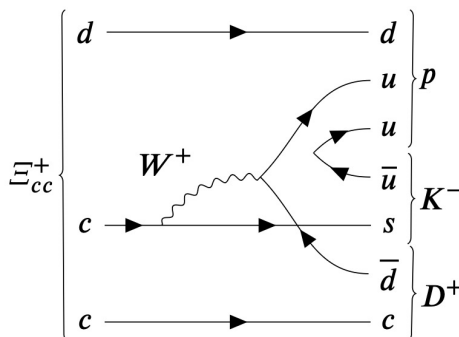
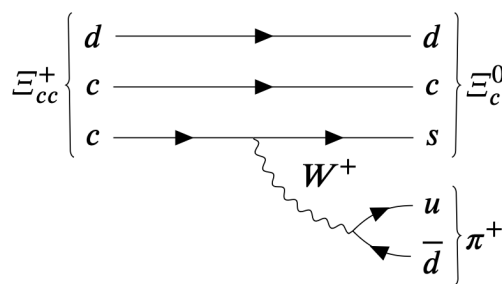
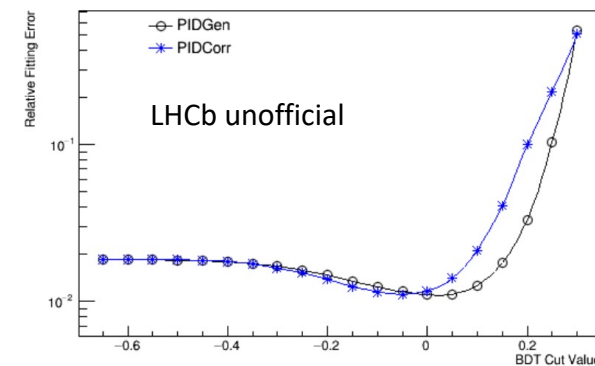


表 3.1 衰变过程 $\Xi_{cc}^+ \rightarrow \Lambda_c^+ K^- \pi^+$ 的触发选择条件和效率。

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

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



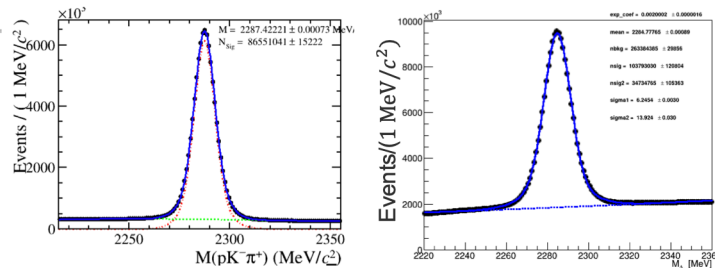
Joined the efforts to understand new detector

- Linnuo Zhang, CERN summer student project

Λ_c^+ in LHCb Run3 data

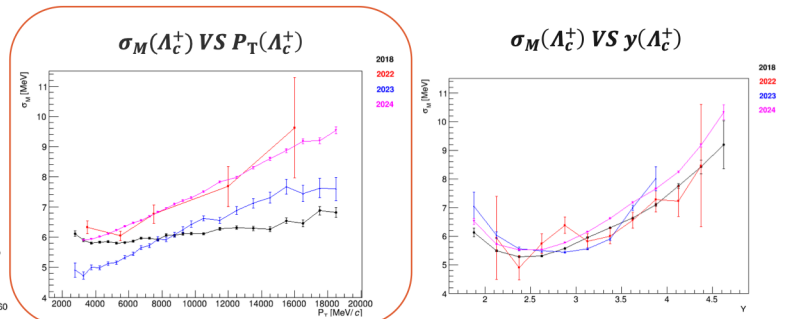
- Number of Λ_c^+ events in 2018 data: 8.6×10^7
- Number of Λ_c^+ events in part of 2024 data (before including UT): 1.3×10^8

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



more $\Lambda_c^+ \rightarrow$ expect more E_{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

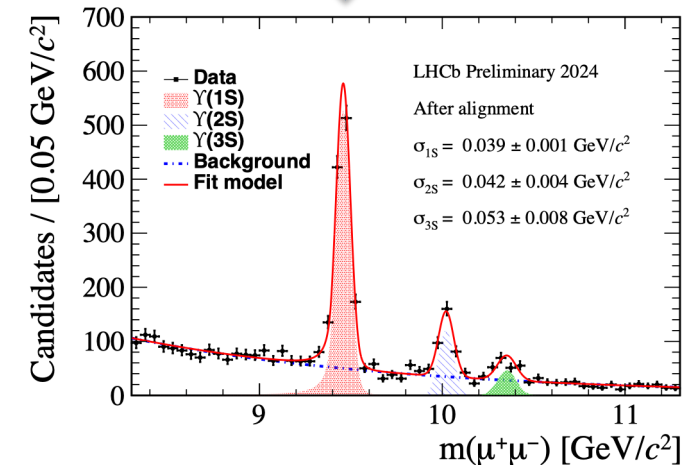
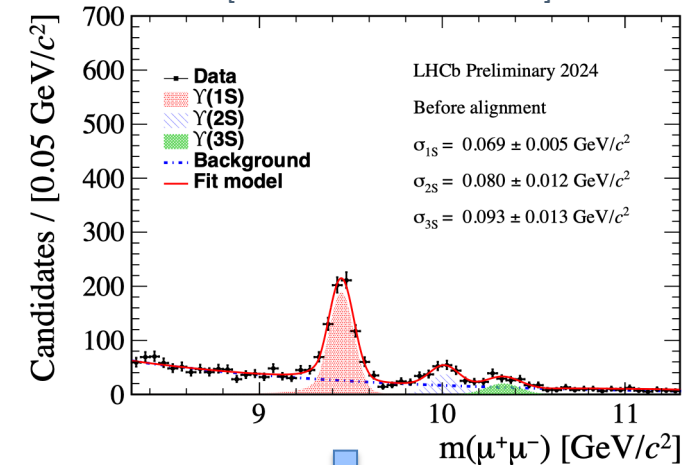
Dear AL,
Following a chat with Vincenzo after the running meeting of last week, Linnuo (in CC) has made the plots of the Lambda_c+ to pK- pi+ mass resolution as a function of P_T and y for 2022/2023/2024 and 2018 data, as attached. So, in general, the dependence on P_T is stronger for Run-3. We hope this adds a bit info on understanding the mass resolution in Run-3 data. Now this is joined in Lc PFC, it might be more clear if one bins in P_T of a muon from the Jpsi decay.
BTW: Linnuo is a summer student working with Monica and me, on (re)discovery of Xi in LHCb Run3 data.
Cheers, Jibo



Linnuo Zhang | (Re)discovery of the Doubly Charmed Baryon in LHCb Run-3 Data

29 August 2024

[LHCb-FIGURE-2024-037]

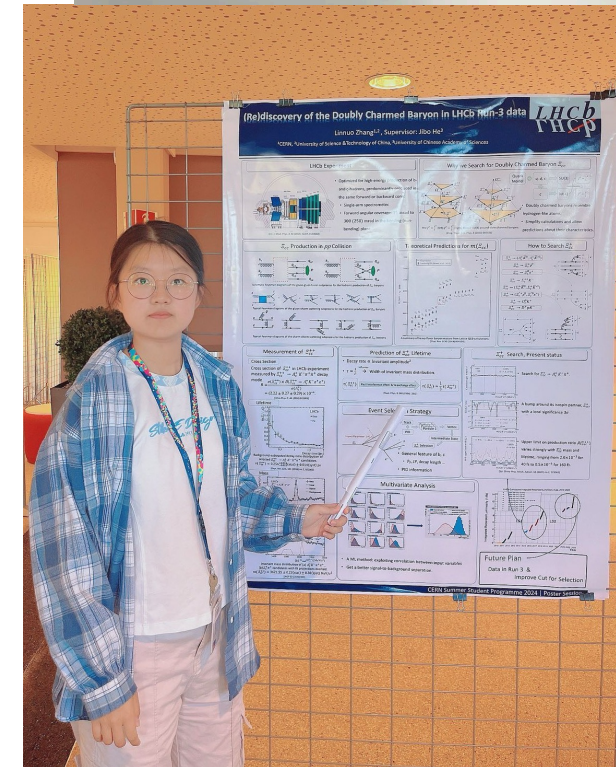
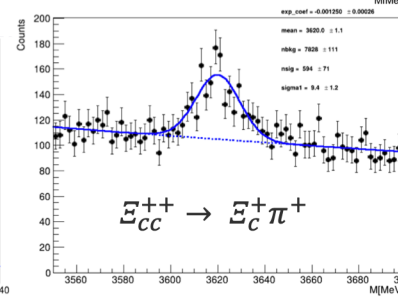
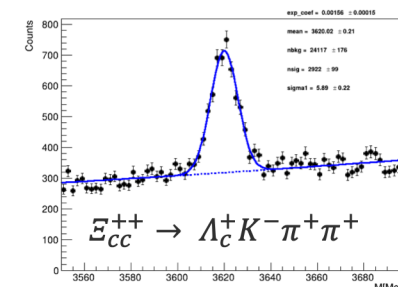
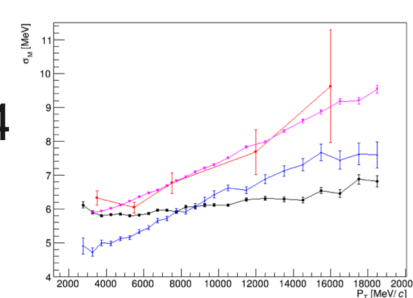
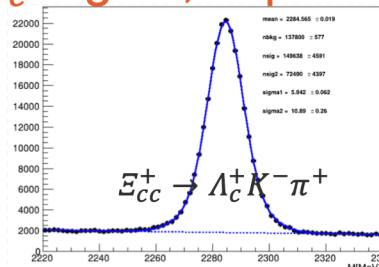


Rediscovery of Ξ_{cc}^{++} in 2024 data

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

Summary

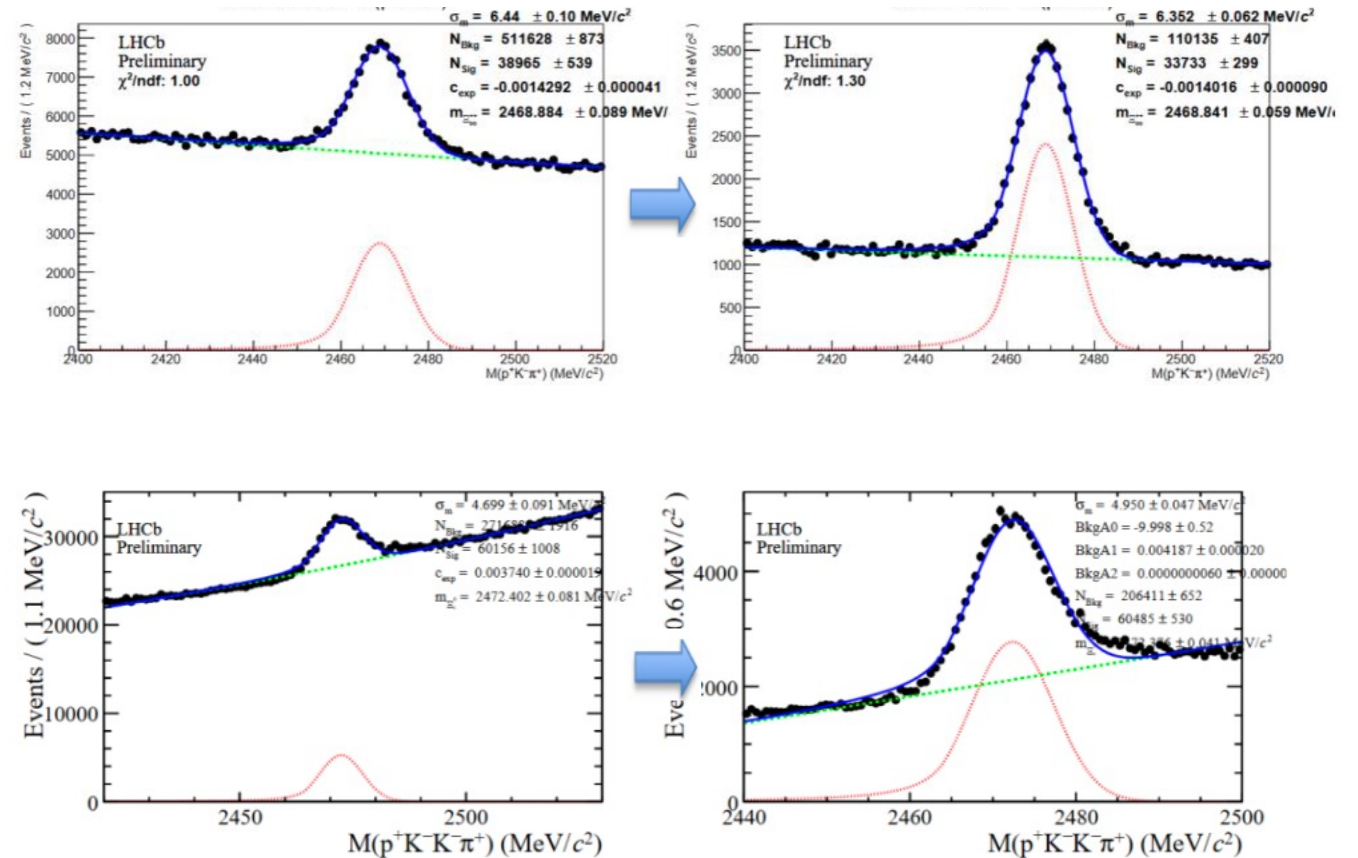
- Studied Λ_c^+ mass resolution as functions of P_T , y in 2024 sent to alignment group
- Studied and optimized event selection for:
 - $\Xi_{cc}^{++} \rightarrow \Lambda_c^+ K^- \pi^+ \pi^+$, twice signals in part of 2024 data, compared to signals in Run 2
 - $\Xi_{cc}^{++} \rightarrow \Xi_c^+ \pi^+$,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



First Chinese Winner of the LHCb best summer student

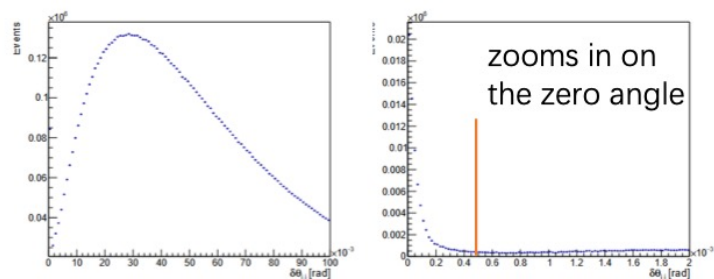
BDT-based trigger for H_c

- Shuyu Han, UROP student
- $E_c^+ \rightarrow pK^- \pi^+$
 - Keep 90% signal, while suppressing bkg to its 20%
- $E_c^0 \rightarrow pK^- K^- \pi^+$
 - Keep all signal, while suppressing bkg to its 10%

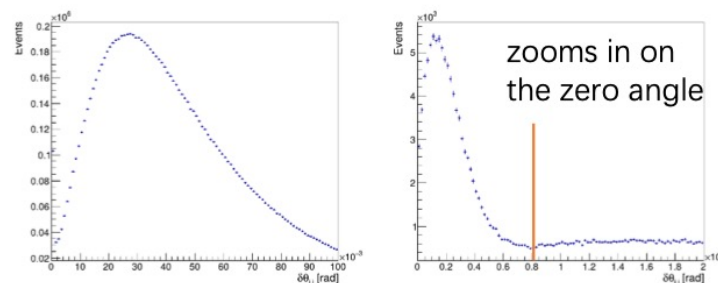


Ξ_{cc}^+ search w/ 2024

- Shuyu Han, undergraduate thesis. E.g., clone removal
 - Different distribution with new detector

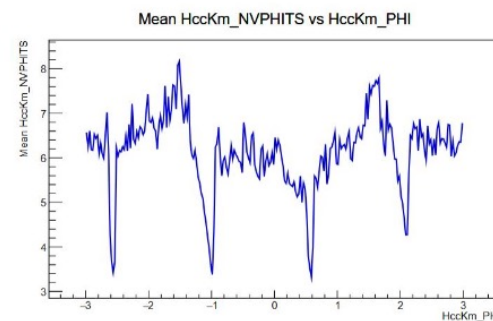
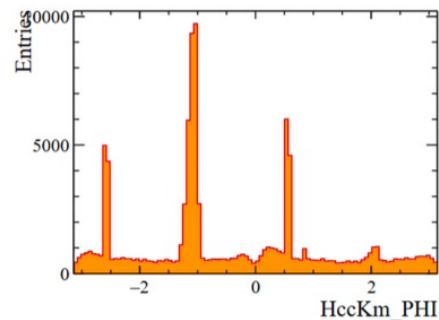
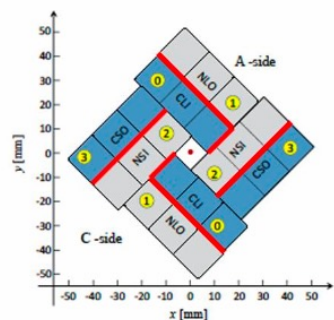


In run2 WS



In 2024 WS

- More detailed studies point to VELO



Moriond EW 2026

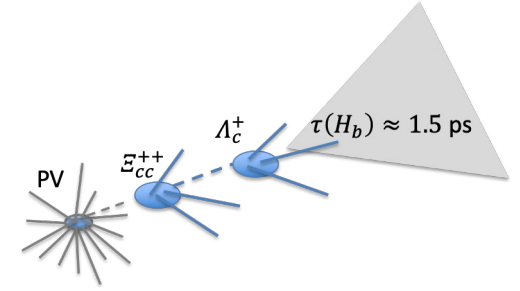


Monday Afternoon : Flavour
Convener: Roberto Salerno

11 Search for the Ξ_{cc}^+ baryon in the $\Lambda^+ c \bar{K}^+ \pi^+$ final state with the LHCb Upgrade I detector
Speaker: Shuyu Han
[1_SHan-v1.pdf](#)

5' YSF talk prompted to 10+5'

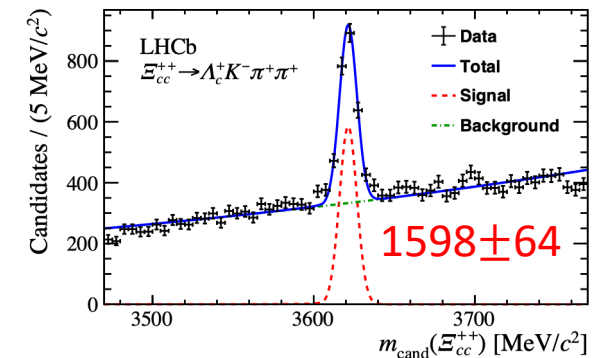
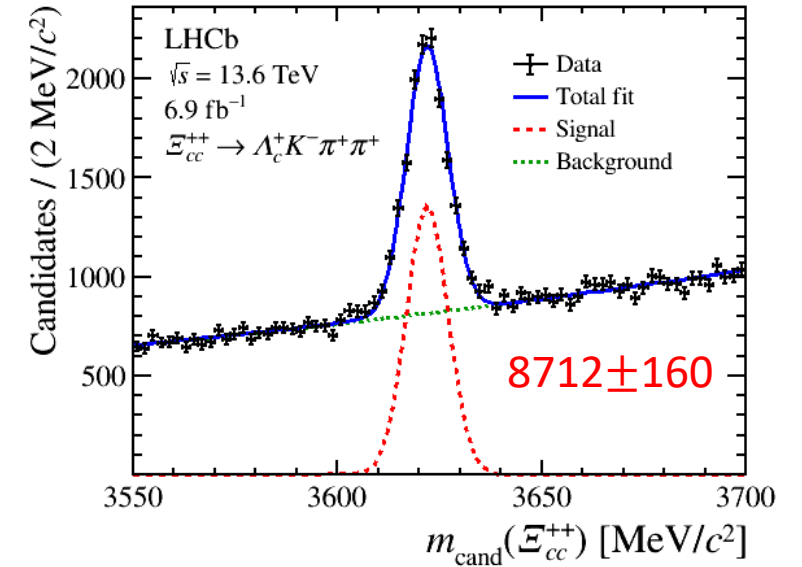
Control mode: Ξ_{cc}^{++} in 2024



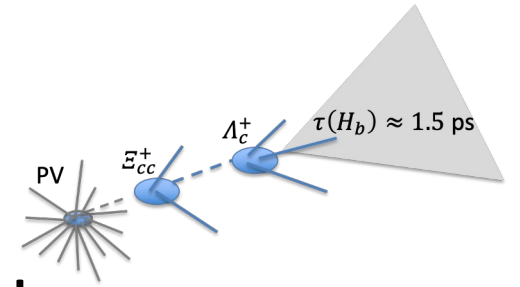
- Event-Selection (early measurement)
 - Several iterations. BDT trained w/ Λ_c^+ in data, included in BDT for Ξ_{cc}^{++} (p_T , χ_{IP}^2 , PID)
 - BDT without PID as cross-check
- Efficiency increased by a factor of 4, compared with Run2
- Mass consistent with Run2

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

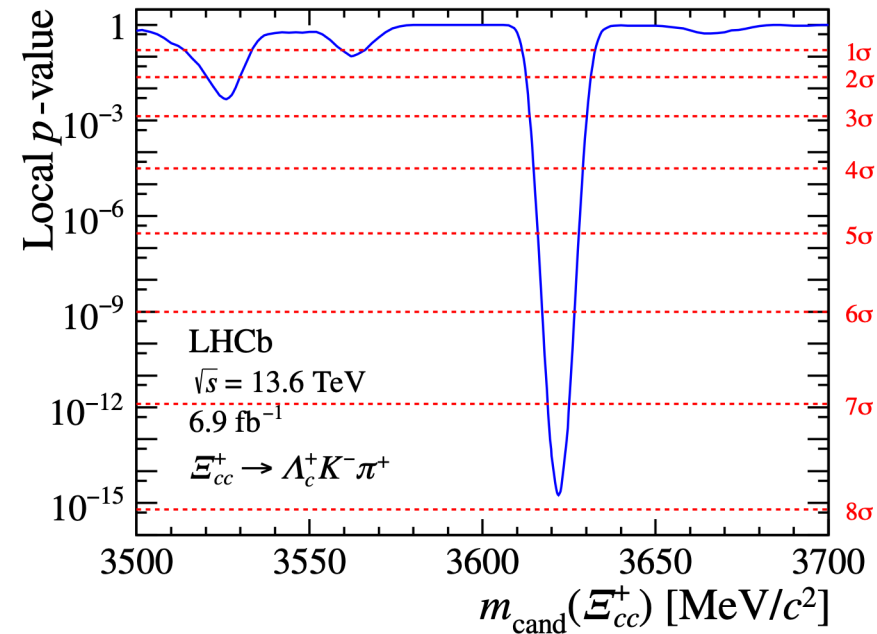
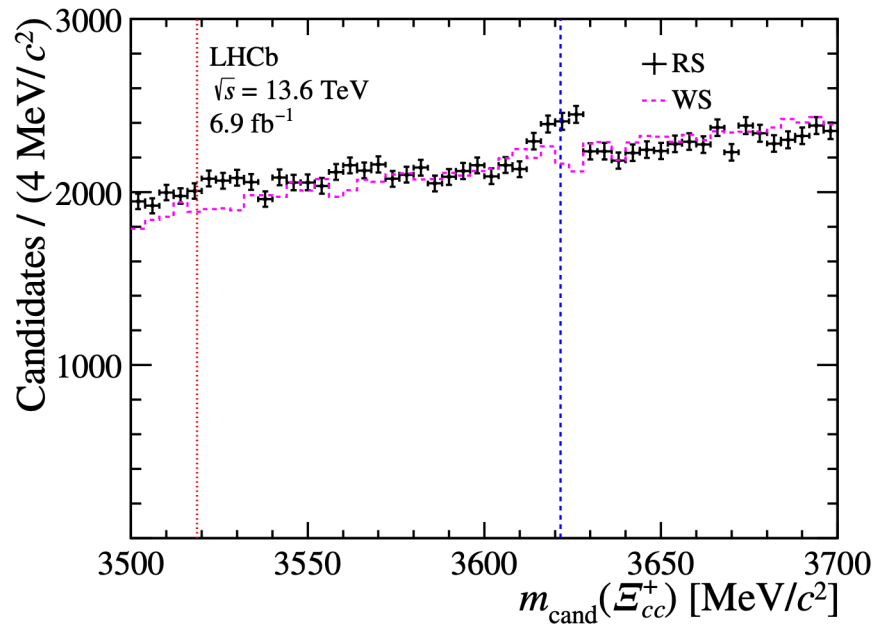
c.f., $3621.55 \pm 0.23 \pm 0.30 \text{ MeV}/c^2$



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!**

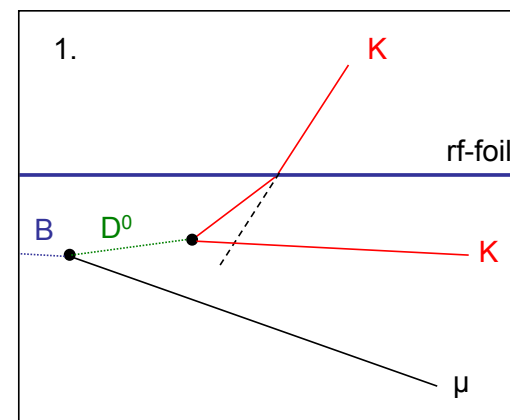


Precision mass measurement

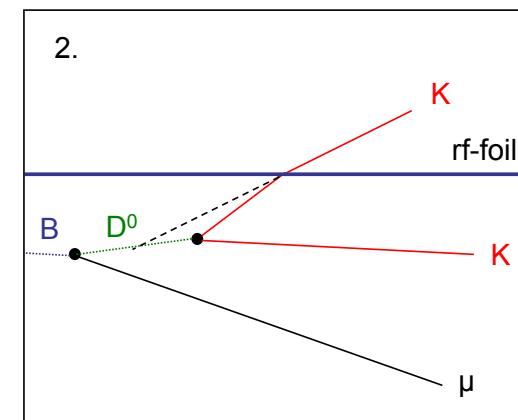
- Bias due to final-state radiation
- Bias due to event-selection
- Momentum scale, as functions of kinematics, multiplicity...

– Ξ_c^0 in the same decay-time range

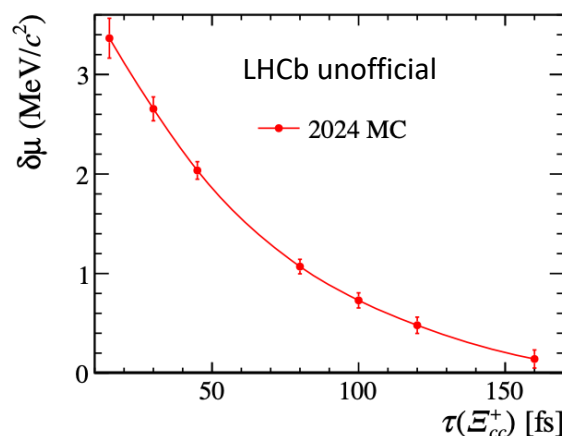
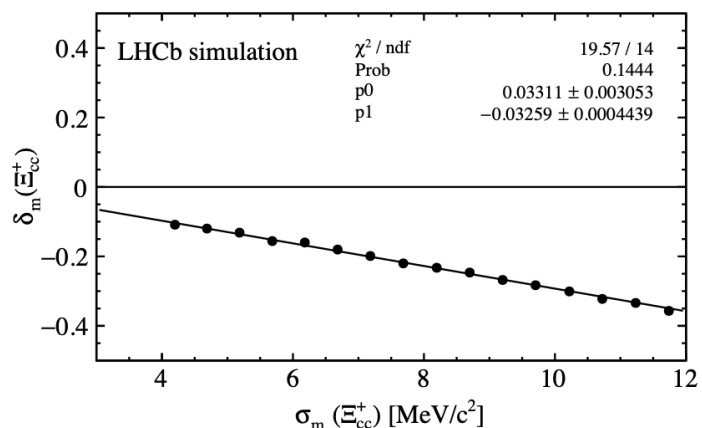
Two examples of multiple scattering Credit: J. Tiburg



- Opening angle larger $\rightarrow$ higher mass
- Reconstructed decay distance too long



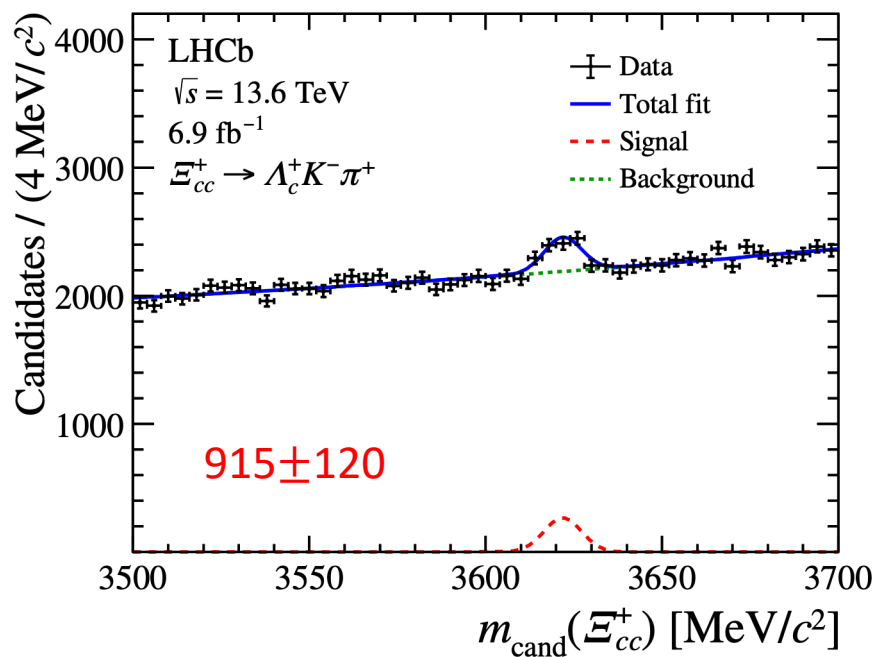
- Opening angle smaller $\rightarrow$ lower mass
- Reconstructed decay distance too short



Reconstructed decay distance and mass are correlated

Ξ_{cc}^+ mass

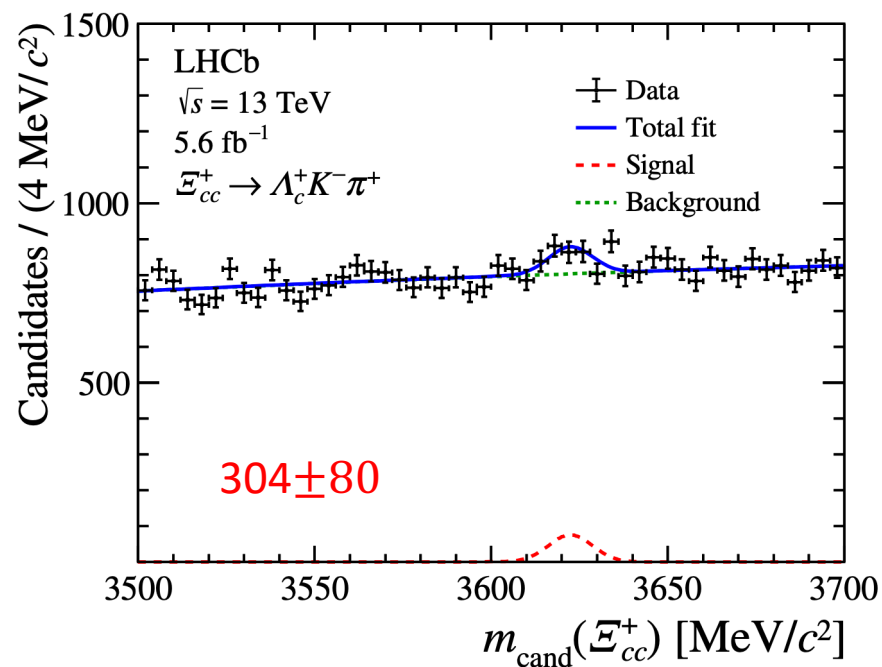
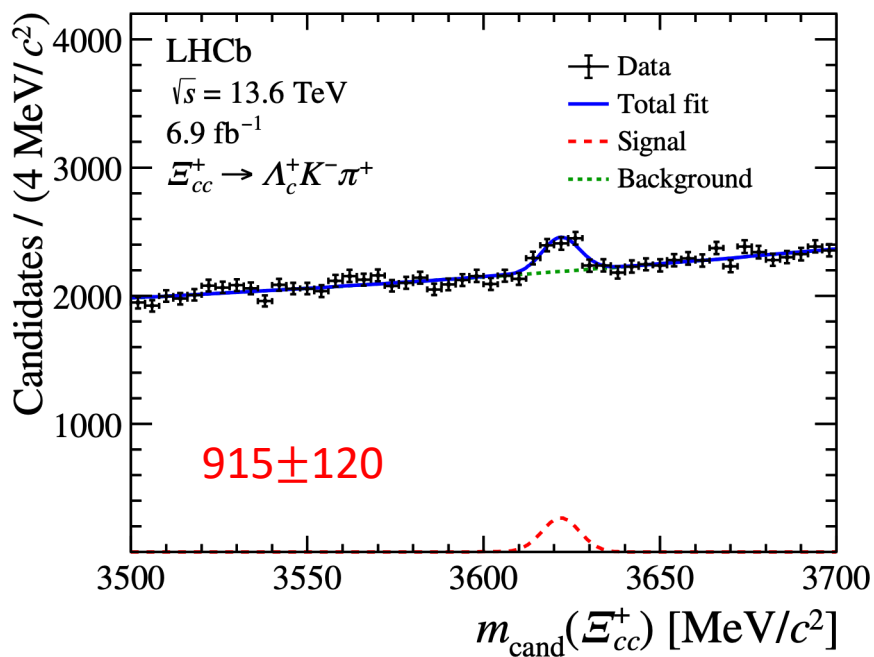
- Mass, $M(\Xi_{cc}^+) = 3619.97 \pm 0.83 \pm 0.26^{+1.90}_{-1.30} \text{ MeV}/c^2$
after correcting for the bias due to FSR and event-selection
- Mass diff., $M(\Xi_{cc}^+) - M(\Xi_{cc}^{++}) = -1.77 \pm 0.84 \pm 0.25^{+1.90}_{-1.30} \text{ MeV}/c^2$



Source	$M(\Xi_{cc}^+) [\text{MeV}/c^2]$	$\Delta M [\text{MeV}/c^2]$
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

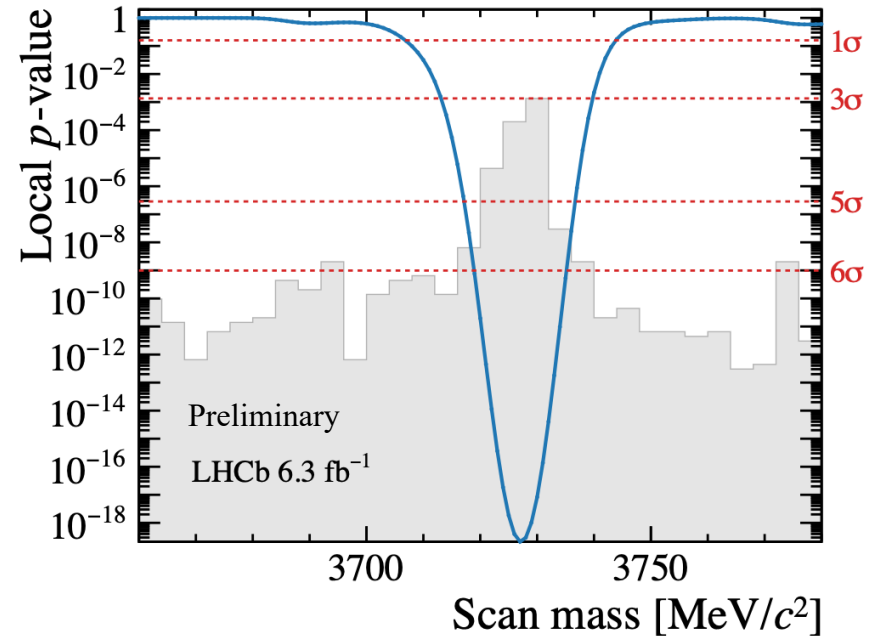
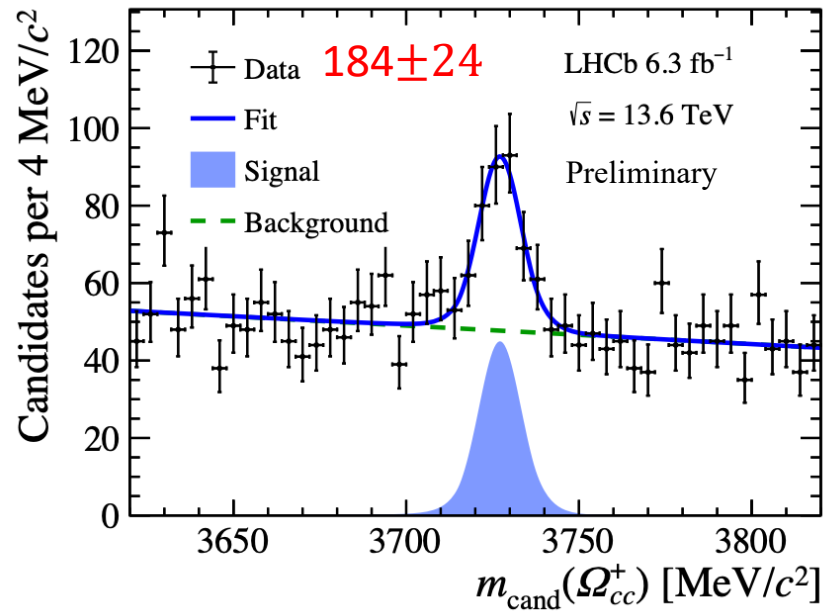
Ξ_{cc}^+ in Run2

- Signal w/ a local significance of 4σ , $M(\Xi_{cc}^+) = 3620.8 \pm 2.2 \text{ MeV}/c^2$, consistent with 2024
 $M(\Xi_{cc}^+) = 3619.97 \pm 0.83 \pm 0.26^{+1.90}_{-1.30} \text{ MeV}/c^2$
- Efficiency in 2024 increased by a factor of 2.5, compared w/ Run2



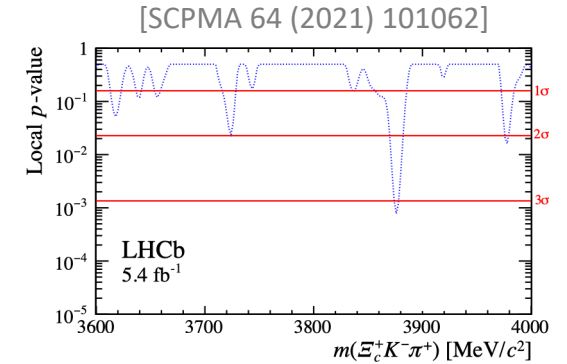
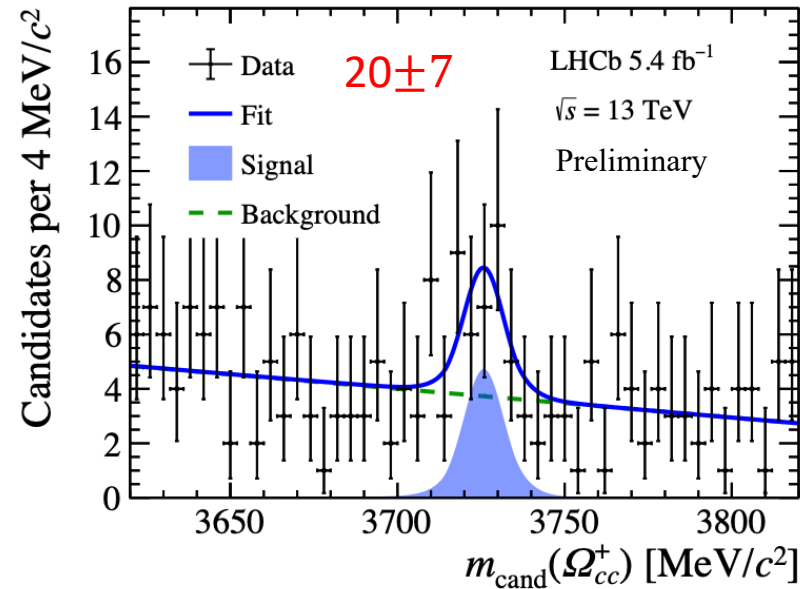
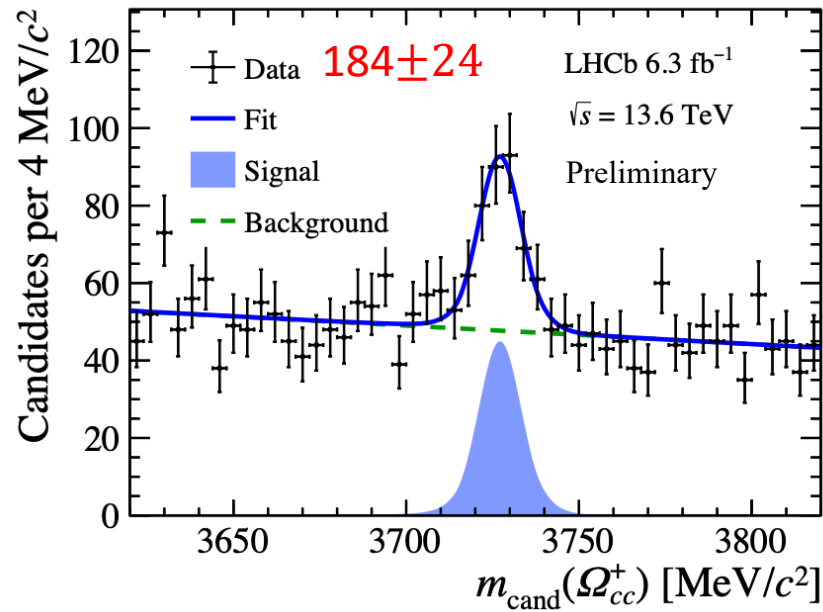
Ω_{cc}^+ in 2024

- Observation using $\Omega_c^0 \pi^+$, global significance 8.7σ
- $M(\Omega_{cc}^+) = 3725.9 \pm 1.0 \pm 0.2 \pm 0.4 (\tau) \pm 0.6 (\text{ext}) \text{ MeV}/c^2$



Ω_{cc}^+ in Run-2

- Local (global) significance of 3.2σ (2.4σ)
- Efficiency increased by a factor of 8!




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LHCb Collaboration discovers new proton-like particle

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

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Town Hall

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

Auditorium Sergio Marchionne (CERN)

Mark Thomson (CERN)

Town Hall

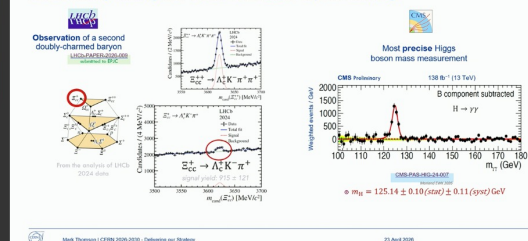
by Mark Thomson

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

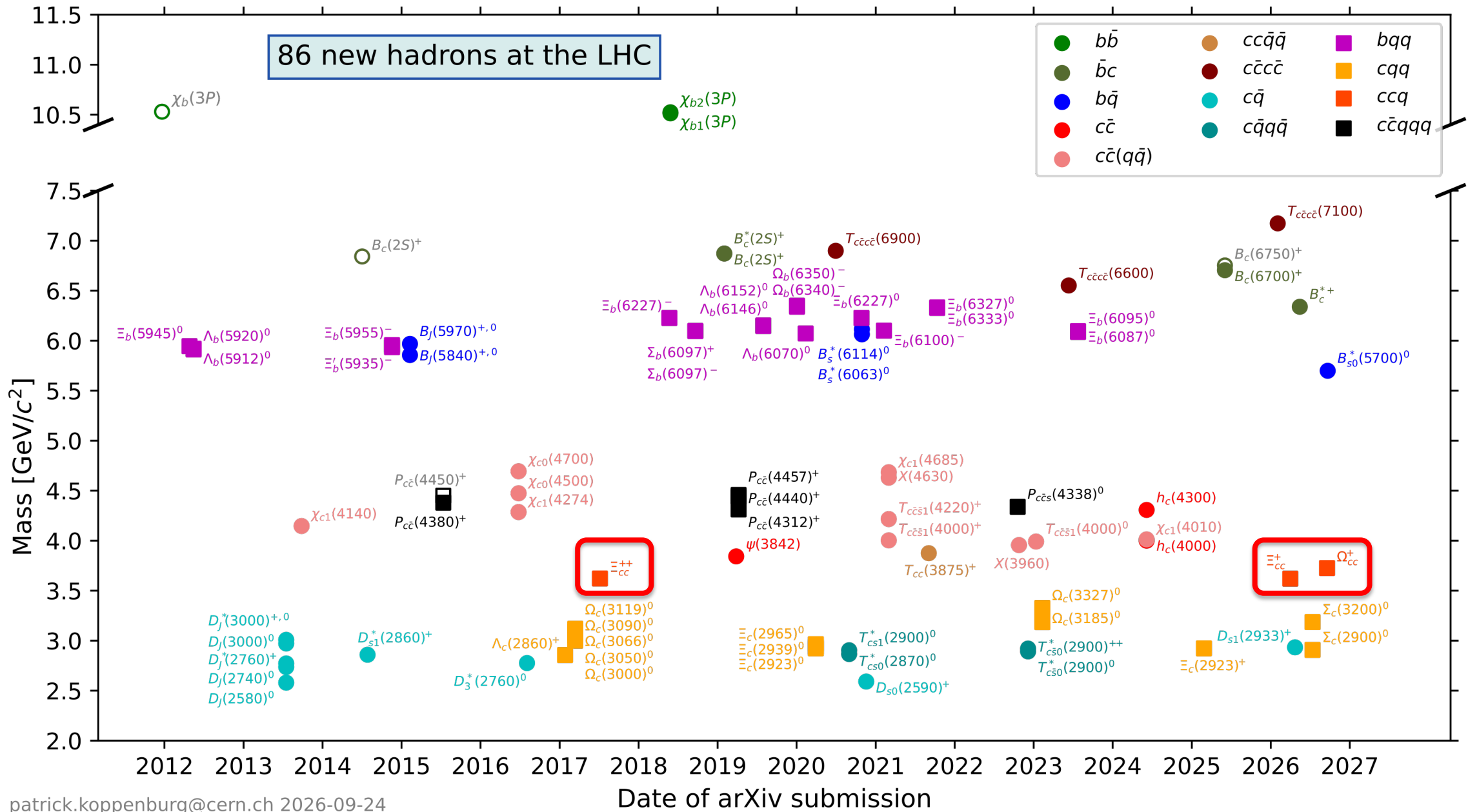


LHC and non-collider physics continues to excite

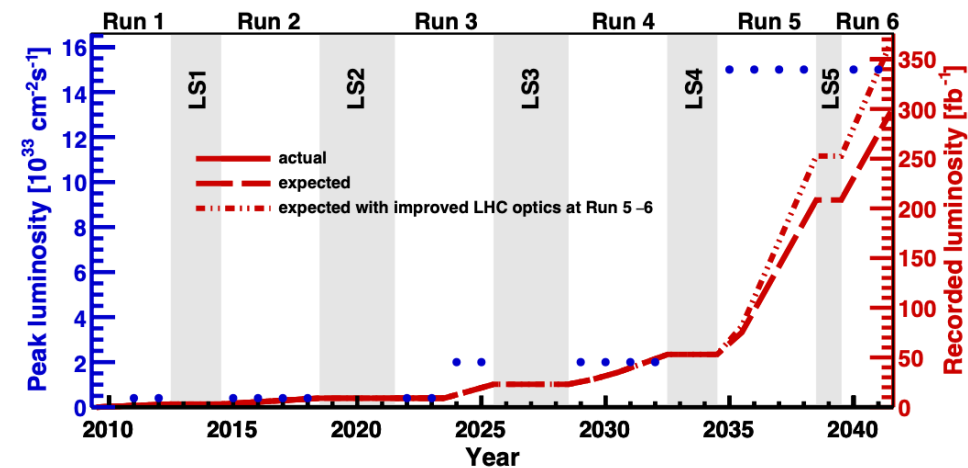
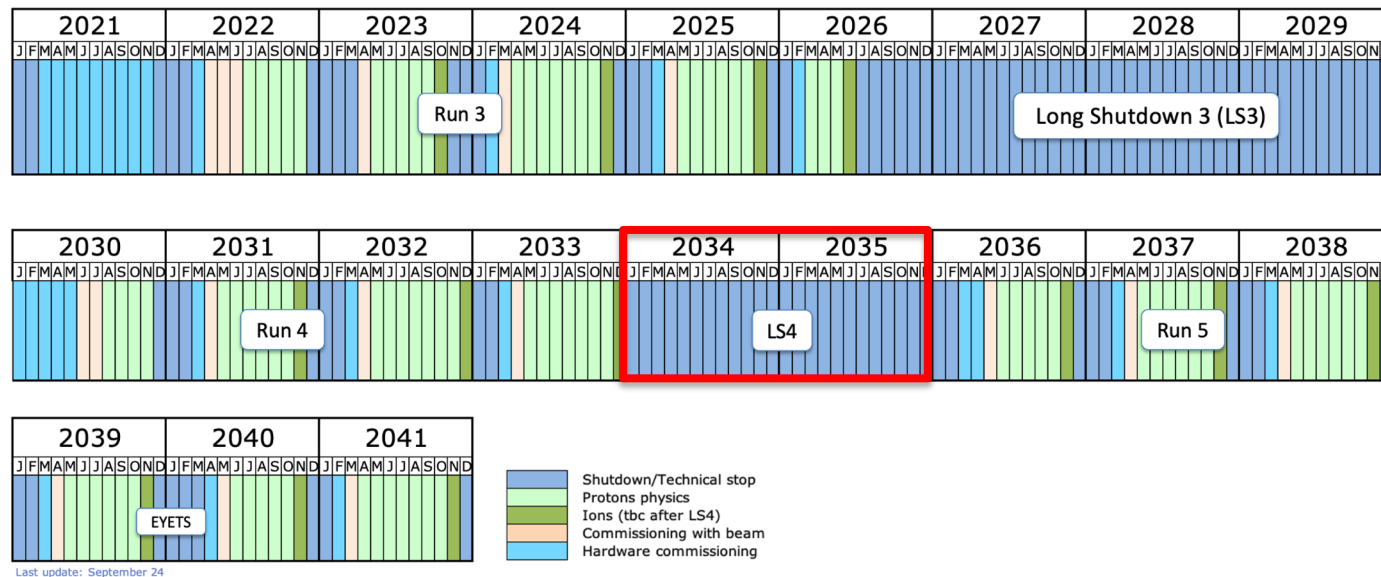
As ever, many exciting new results from CERN experiments, e.g.



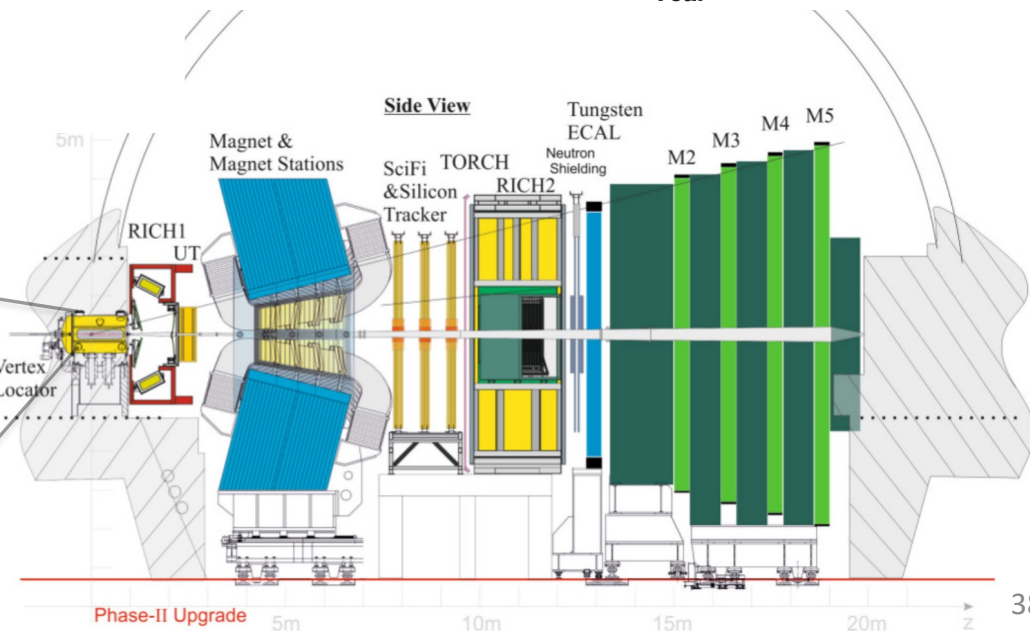
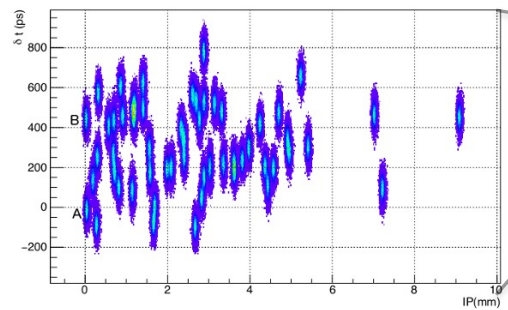
“This major result is a fantastic example of how LHCb’s unique capabilities play a vital role in the success of the LHC,” says Mark Thomson, CERN Director-General. “It highlights how experimental upgrades at CERN directly lead to new discoveries, setting the stage for the transformative science we expect 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.”



The LHCb upgrades

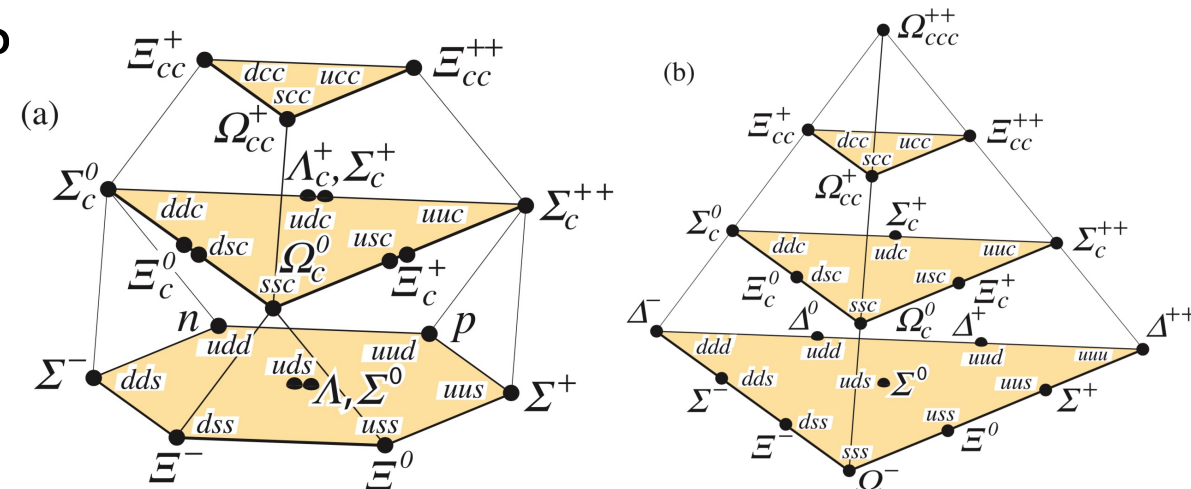
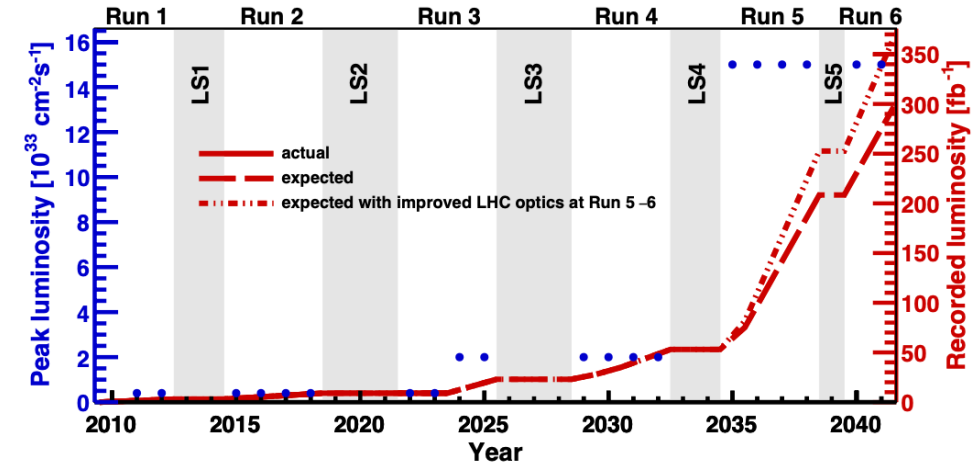


Upgrade II, 4D detector ,
Timing, $\mathcal{O}(10 \text{ ps})$, is essential



Prospects

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



Summary

- Upgraded LHCb detector and trigger, efficiency of hadronic modes increased by a factor 2-4!
- E_{cc}^{++} : a factor of 4 signal yield per fb^{-1} , compared w/ Run2
- E_{cc}^{+} : **First new particle observed w/ the upgraded LHCb detector**
 - $M(E_{cc}^{+}) = 3619.97 \pm 0.83 \pm 0.26_{-1.30}^{+1.90} \text{ MeV}/c^2$
 - $M(E_{cc}^{+}) - M(E_{cc}^{++}) = -1.77 \pm 0.84 \pm 0.25_{-1.30}^{+1.90} \text{ MeV}/c^2$
- Ω_{cc}^{+} : observation
 - $M(\Omega_{cc}^{+}) = 3725.9 \pm 1.0 \pm 0.2 \pm 0.4 (\tau) \pm 0.6 (\text{ext}) \text{ MeV}/c^2$
- Many thanks to your continued and strong supports