Observation of the doubly charmed baryon Ξ_{cc}^{++}

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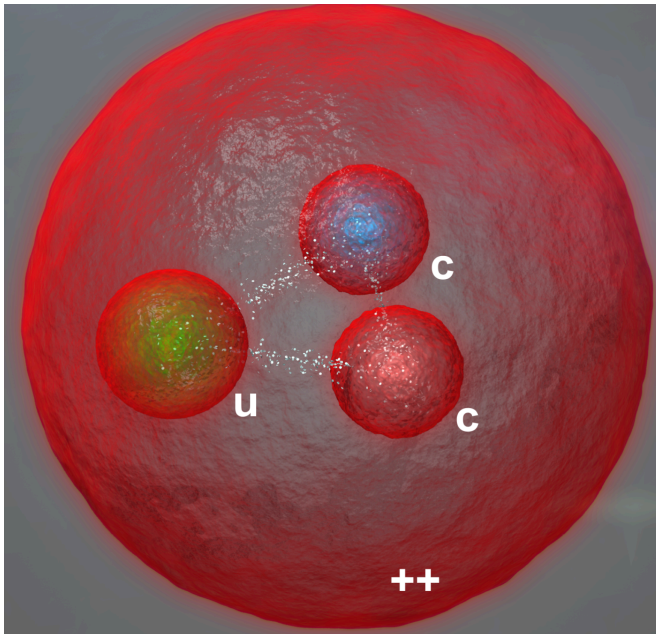
Heavy hadron spectroscopy workshop
CERN, 17th-18th July 2017

Outline

- LHCb experiment
- Observation of Ξ_{cc}^{++} by LHCb arXiv: 1707.01621
- Summary



$\Xi_{cc}^{++}: ccu$

The LHCb experiment

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

LHCb experiment

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

Aiming for precision measurements in b, c flavor sectors, covering $2 < \eta < 5$

Challenges for hadron spectroscopy: hadronic background and particle mis-identification

Tracking system (particle reconstruction)
- $\epsilon(\text{Tracking}) \sim 96\%$
- $\delta p/p \sim 0.5\%$-1% (5-200 GeV)
- $\sigma(m_{B\to hh}) \approx 22$ MeV

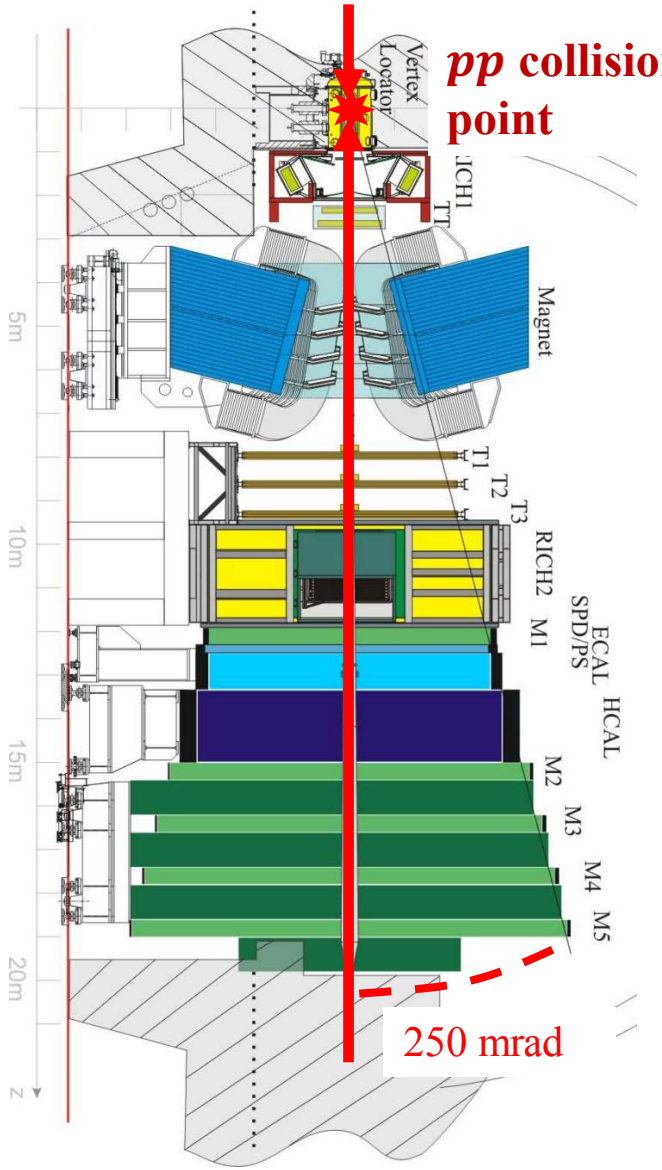
Separating neighboring structures

Vertex Locator (vertex reconstruction)
- Impact parameter resolution: 20μm
- Decay time resolution: 45 fs ($\tau_b \sim 1.5$ ps)

Identifying weak decays

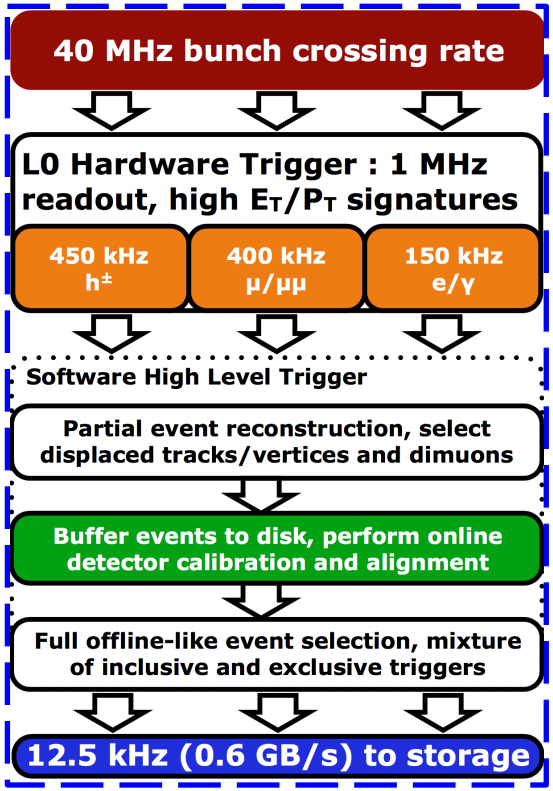
RICH detectors ($K/\pi/p$ separation)
- $\epsilon(K \to K) \sim 95\%$ with $\epsilon(\pi \to K) \sim 5\%$
- $\epsilon(p \to p) \sim 95\%$ with $\epsilon(\pi \to p) \sim 5\%$

Distinguishing K and p from π

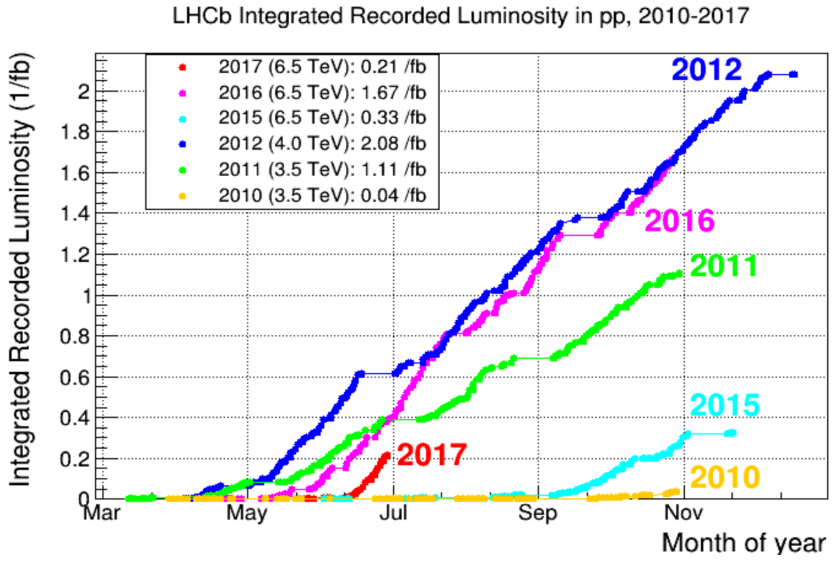


Data samples

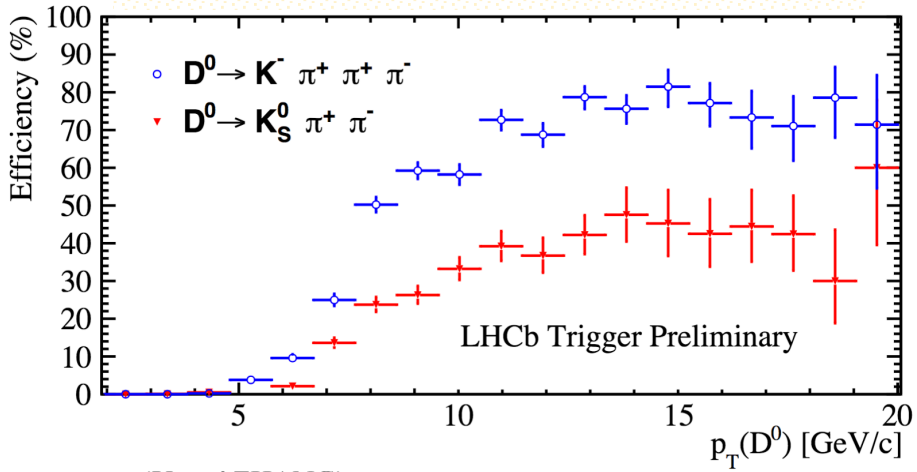
- Run I: 1. fb^{-1} at 7 TeV (2011) + 2. fb^{-1} at 8 TeV (2012)
- Run II: 0.3 fb^{-1} (2015) + 1.7 fb^{-1} (2016) at 13 TeV
- Dedicated software trigger scheme



pp collisions



Efficient trigger for hadronic channels



Observation of the doubly charmed baryon Ξ_{cc}^{++}

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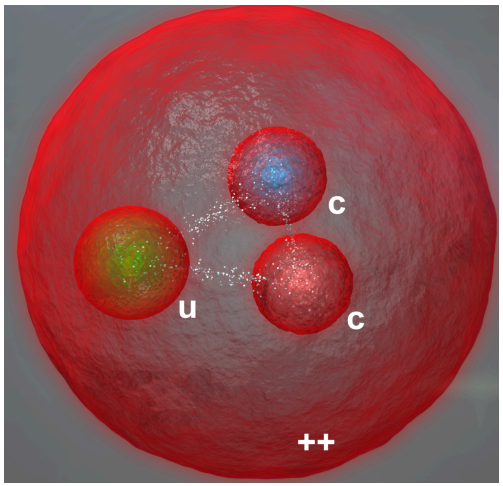
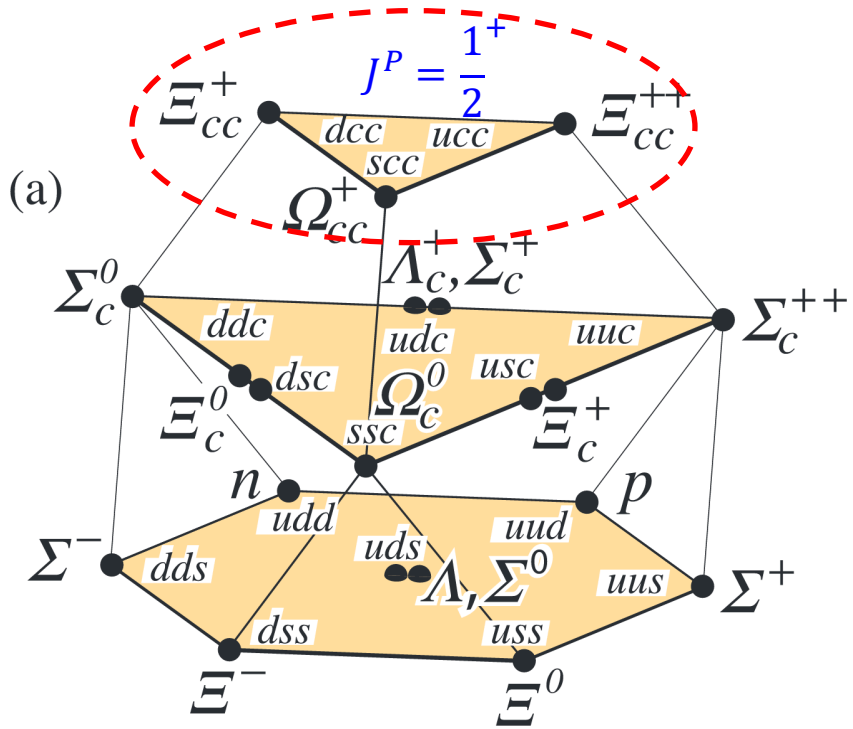
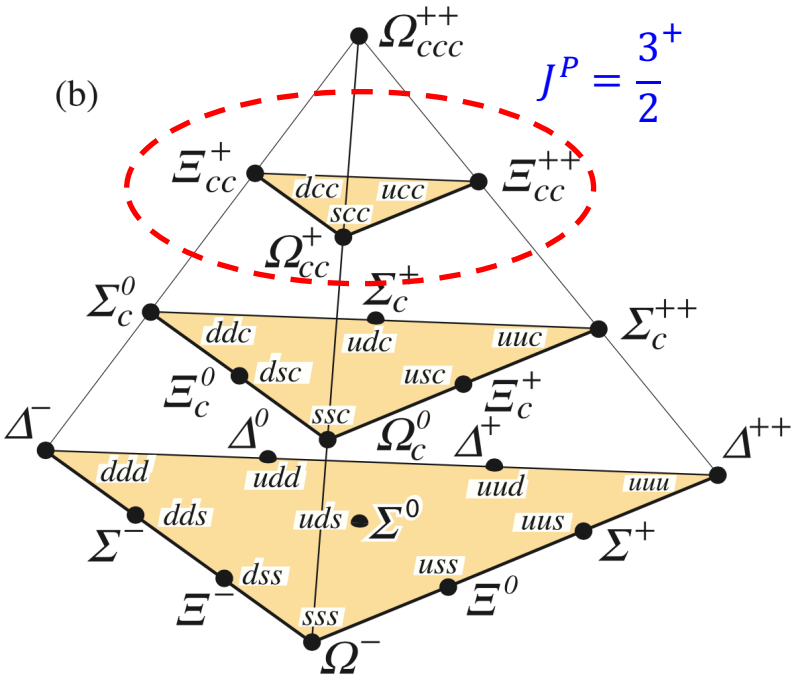


$\Xi_{cc}^{++}: ccu$

The doubly charm baryons

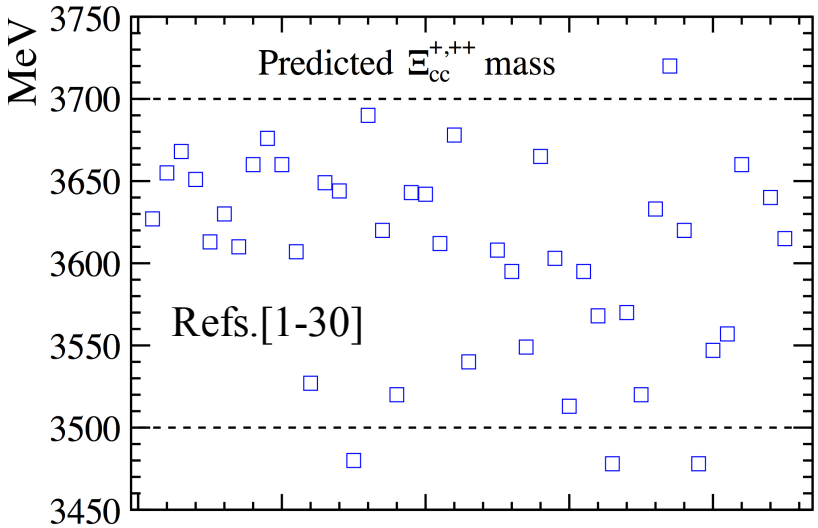
- Two SU(4) baryon 20-plets with $J^P = \frac{1}{2}^+$ and $J^P = \frac{3}{2}^+$, each contains a SU(3) triplet with two charm quarks: $\Xi_{cc}^+(ccd),\ \Xi_{cc}^{++}(ccu),\ \Omega_{cc}^+(ccs)$
- $J^P = \frac{3}{2}^+$ expected to decay to $\frac{1}{2}^+$ states via strong/electromagnetic interaction
- $J^P = \frac{1}{2}^+$ states decay weakly with a c quark transformed to lighter quarks





Mass and lifetime

- Many theoretical calculations for masses and lifetimes of ground states
- Masses by phenomenological models
  - $\Xi_{cc}^{+,++}$: most of them with $3.5 - 3.7$ GeV. Mass splitting between Ξ_{cc}^{+} and Ξ_{cc}^{++} only a few MeV due to u, d symmetry
  - $M(\Omega_{cc}^{+}) \approx M(\Xi_{cc}) + 0.1$ GeV



Theoretical uncertainties not included

- Masses by lattice QCD computations

$M(\Xi_{cc}) \approx 3.6$ GeV
$M(\Omega_{cc}^{+}) \approx 3.7$ GeV

Refs.[31-46]

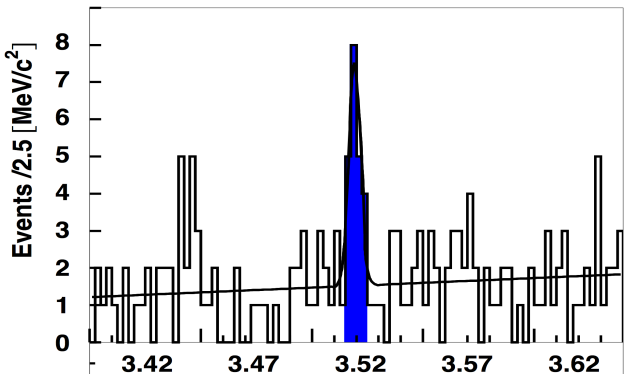
- Lifetimes
  - Expect $\tau(\Xi_{cc}^{++}(ccu)) \gg \tau(\Xi_{cc}^{+}(ccd))$
  - Most calculations give $\tau(\Xi_{cc}^{++}) \in [\,200 - 700]$ fs

Refs.[5, 6, 12 49-52]

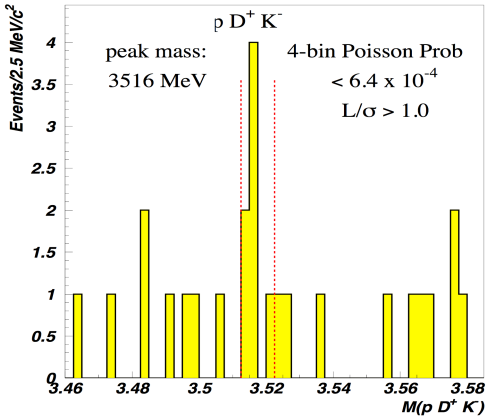
Experimental studies of Ξ_{cc}^{+}

- SELEX claimed to observe $\Xi_{cc}^{+}(ccd)$ in $\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-}\pi^{+}$ and $pD^{+}K^{-}$ decays
  - Mass: 3518.7 ± 1.7 MeV PRL 89 (2002) 112001, PLB 628 (2005) 18

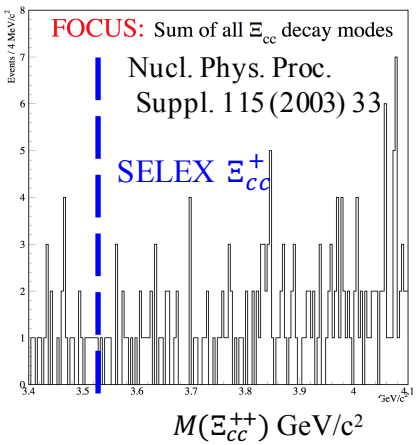
$\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-}\pi^{+}$



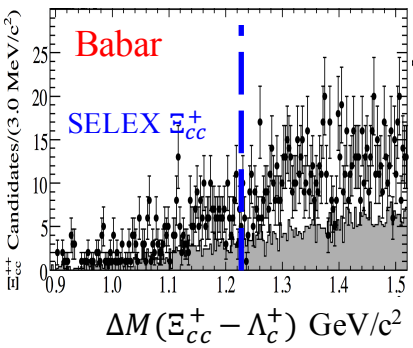
$\Xi_{cc}^{+} \to pD^{+}K^{-}$



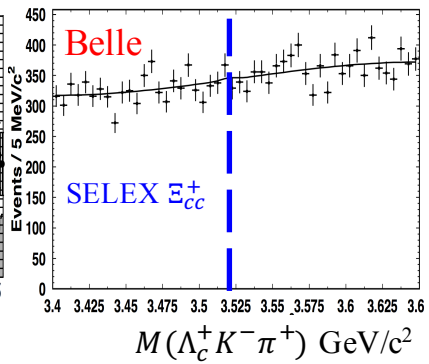
- Not confirmed by FOCUS, BaBar, Belle and LHCb in much larger Λ_c^{+} samples



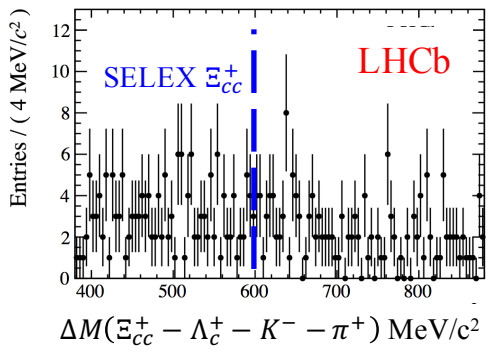
PRD 74 (2006) 011103



PRL 97 (2006) 162001



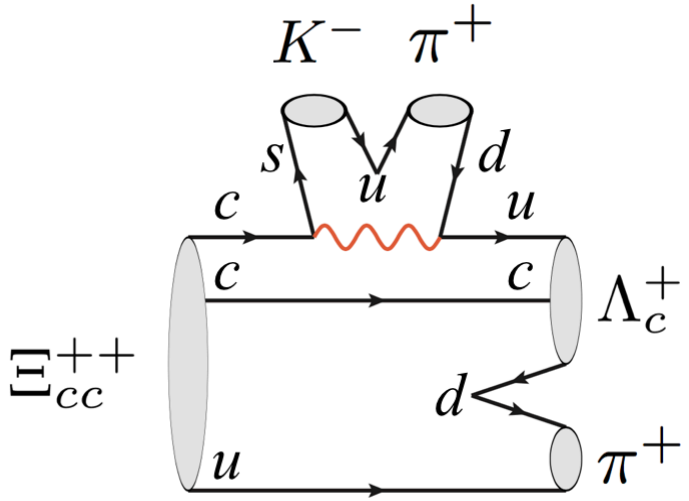
JHEP 12 (2013) 090

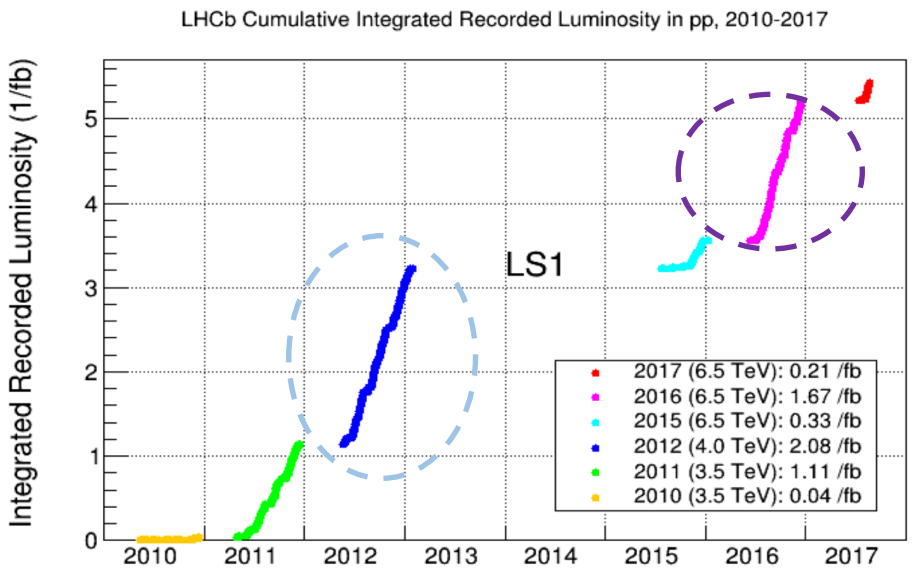


Searching for $\Xi_{cc}^{++}(ccu)$

- Expected to have longer lifetime than Ξ_{cc}^{+}, higher sensitivity at LHCb
- Decay: $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$, branching fraction up to 10% Refs. [56]
- Data sample: LHCb run II at $\sqrt{s} = 13$ TeV, ~1.7 fb^{-1}
  - Dedicated exclusive trigger ensuring high efficiency, full event reconstruction at trigger level
  - Run I data (2012) also analyzed for cross-check

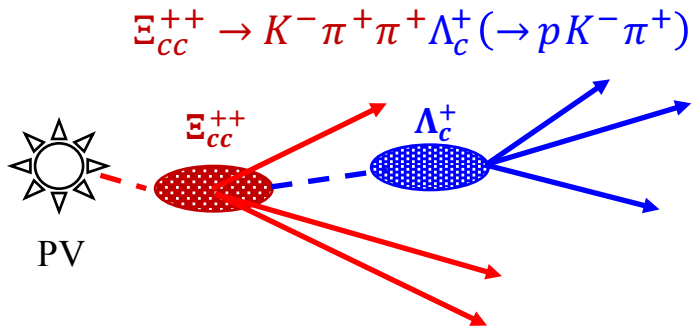
$\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$

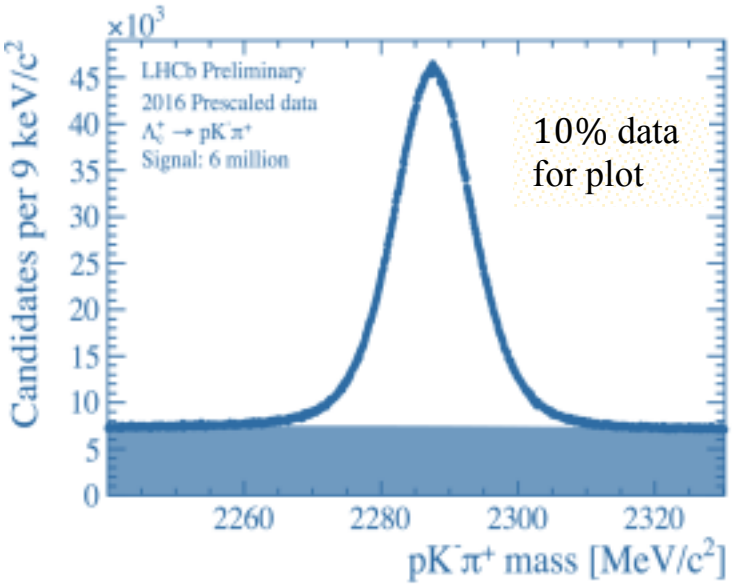


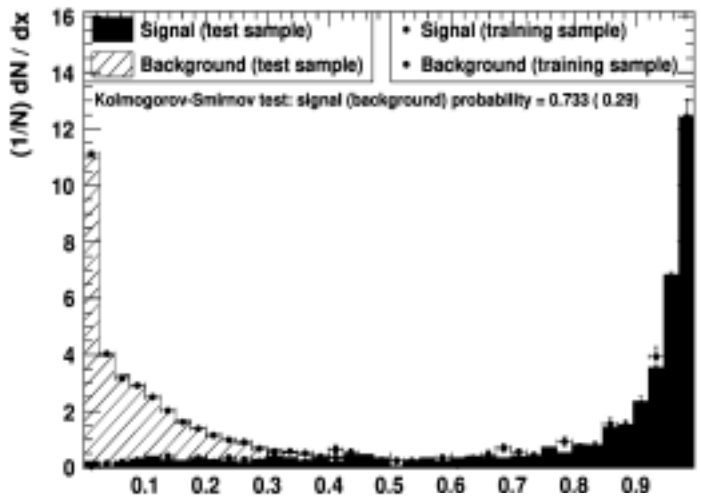


Candidate selection

- $\Lambda_c^+ \to pK^-\pi^+$:
  - p, K^-, π^+ tracks: positive particle ID, not produced from primary vertices
  - Λ_c^+: good vertex quality, separated from primary vertices
  - p, K^-, π^+ tracks and Λ_c^+ have large p_T
- $\Xi_{cc}^{++} \to \Lambda_c^+ K^-\pi^+\pi^+$: multivariate selector
  - Decay fit quality
  - p_T of decay products
  - Ξ_{cc}^{++} vertex separation from PV





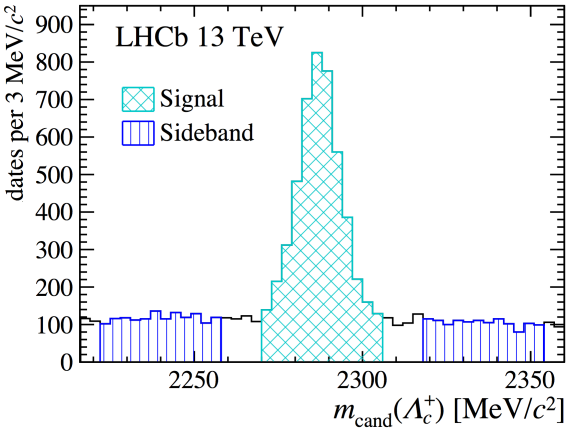


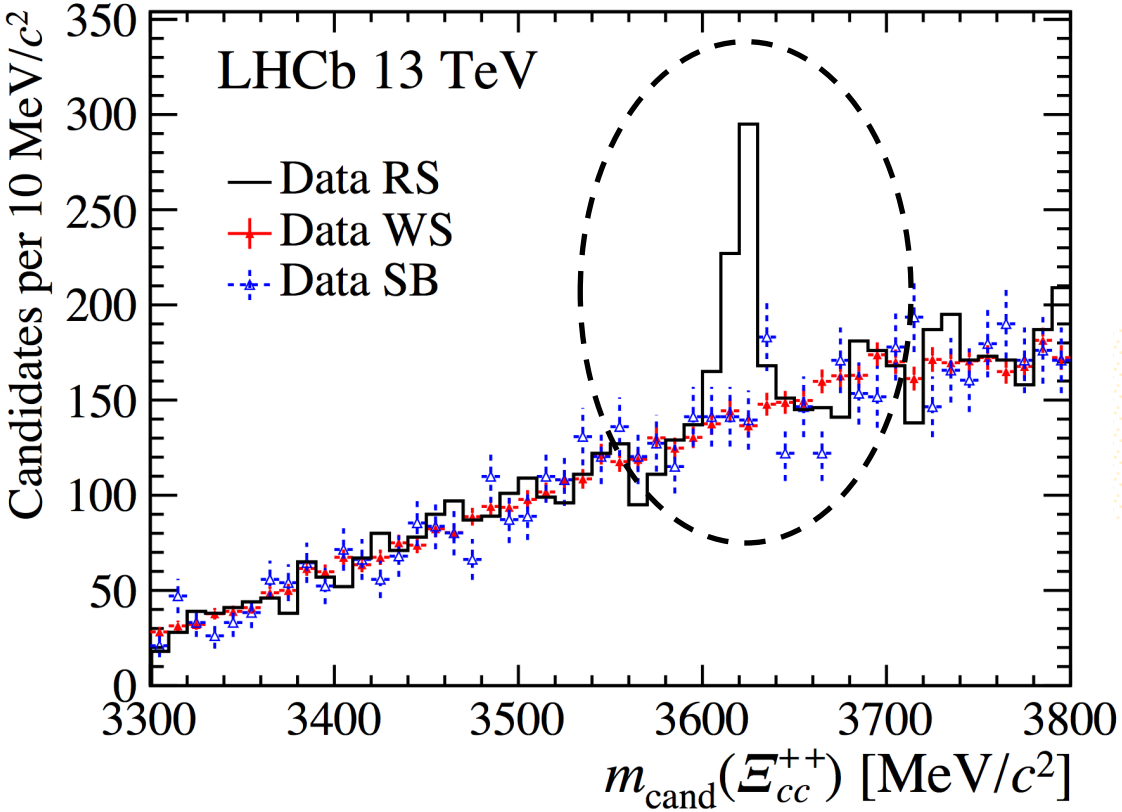
Multivariate selector

$\Lambda_c^+ K^- \pi^+ \pi^+$ mass distribution

arXiv: 1707.01621

- A significant structure in right sign (RS) combinations
- Not present in wrong sign (WS) combinations
- Not observed for Λ_c^+ background candidates
- Distributions similar except the peak in RS





RS : $\Xi_{cc}^{++} \to K^- \pi^+ \pi^+ \Lambda_c^+$

WS: $\Xi_{cc}^{++} \to K^- \pi^+ \pi^- \Lambda_c^+$

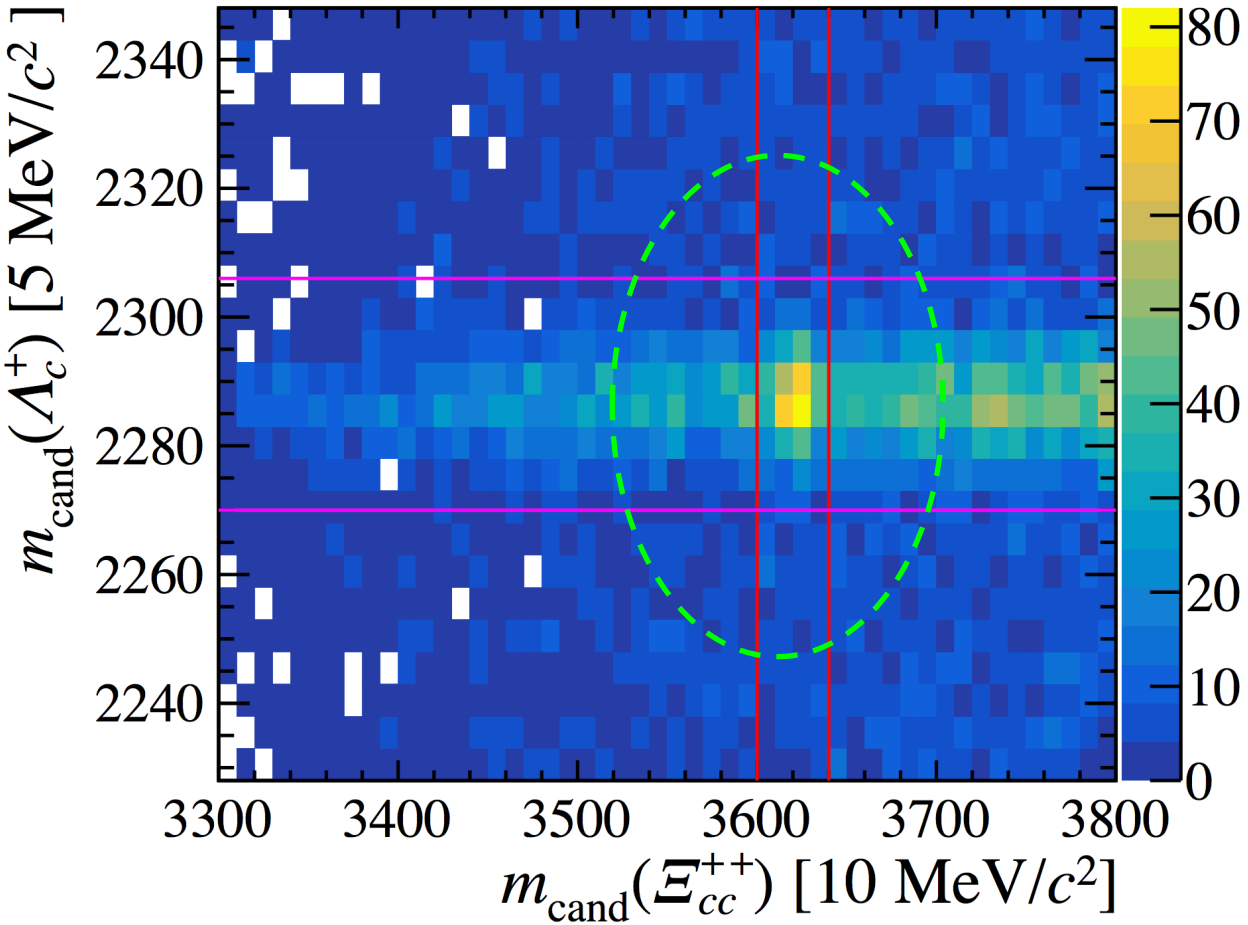
SB : Λ_c^+ in mass sideband

More tests

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

- Signal candidates only present in Λ_c^+ signal region

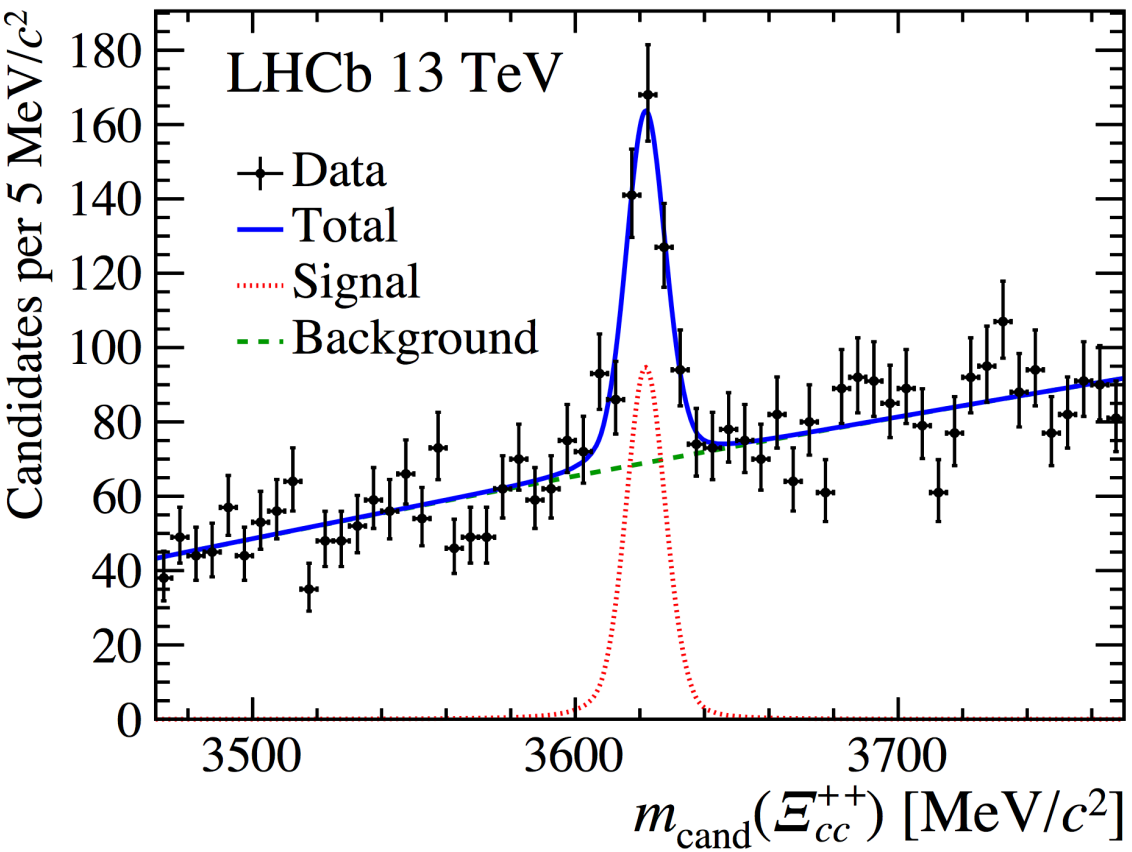
arXiv: 1707.01621



Fitting the mass peak

- Studying Λ_c^+-mass corrected mass: $m_{\text{cand}}(\Xi_{cc}^{++}) = m(\Lambda_c^+ K^- \pi^+) - m(\Lambda_c^+) + m_{\text{PDG}}(\Lambda_c^+)$
  - Signal yield: 313 ± 33
  - Resolution: 6.6 ± 0.8 MeV, consistent with simulated value
  - Local significance $> 12\sigma$

arXiv: 1707.01621



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$$m(\Xi_{cc}^{++}) = 3621.40 \pm 0.72(\text{stat}) \pm 0.27(\text{syst}) \pm 0.14(\Lambda_c^+)\ \text{MeV}$$

$$m(\Xi_{cc}^{++}) - m(\Lambda_c^+) = 1134.94 \pm 0.72(\text{stat}) \pm 0.27(\text{syst})\ \text{MeV}$$

Systematic uncertainties

Source	Value $[\text{MeV}/c^2]$
Momentum-scale calibration	0.22
Selection bias correction	0.14
Unknown Ξ_{cc}^{++} lifetime	0.06
Mass fit model	0.07
Sum of above in quadrature	0.27
Λ_c^+ mass uncertainty	0.14

Fitting the mass peak

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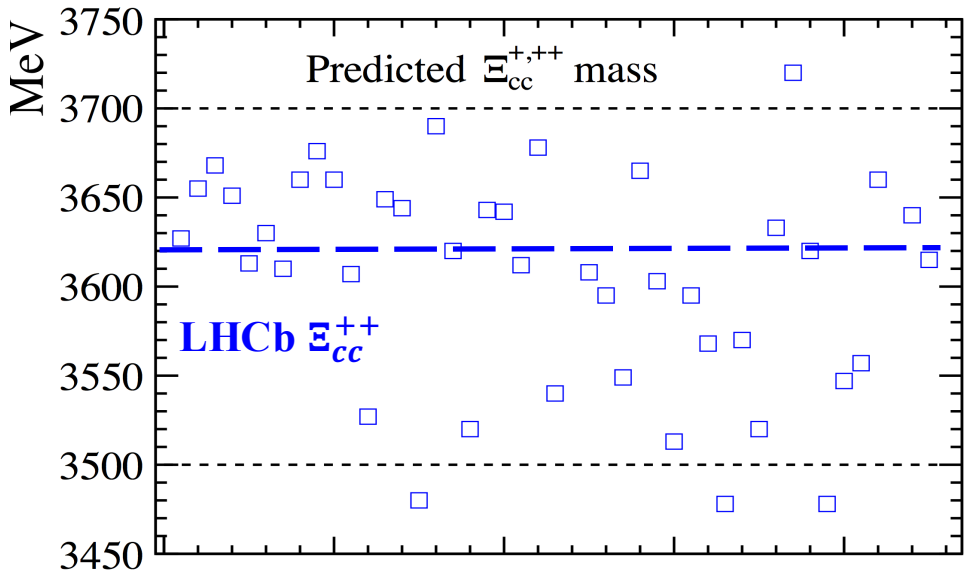
$$m(\Xi_{cc}^{++}) = 3621.40 \pm 0.72(\text{stat}) \pm 0.27(\text{syst}) \pm 0.14(\Lambda_c^+) \text{ MeV}$$
$$m(\Xi_{cc}^{++}) - m(\Lambda_c^+) = 1134.94 \pm 0.72(\text{stat}) \pm 0.27(\text{syst}) \text{ MeV}$$

Value consistent with many theoretical calculations



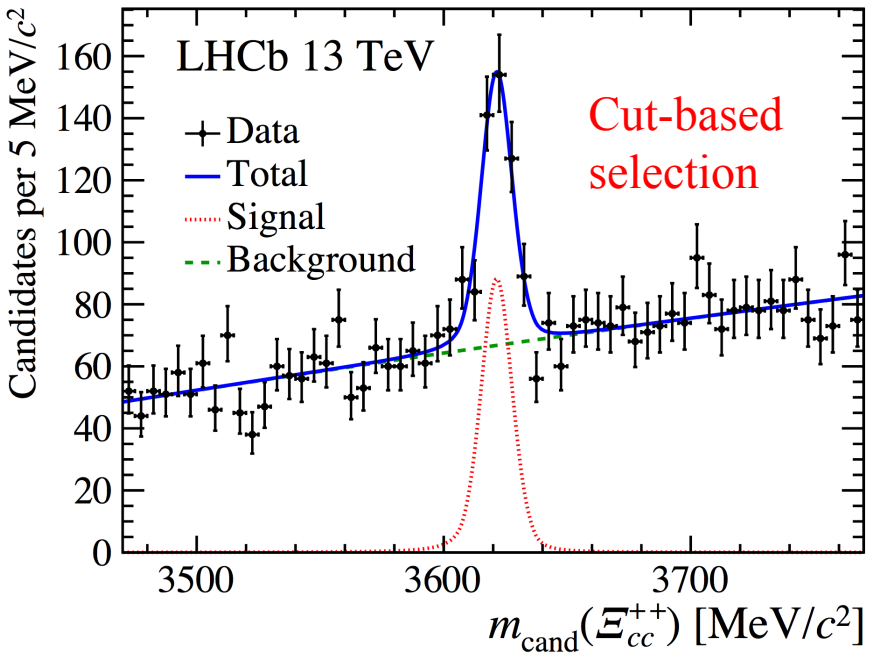
Refs.[1-30]

More tests

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

1. Multiple candidates: not creating fake narrow structure
2. Checking combinations of tracks from Λ_c^+ and Ξ_{cc}^{++}: not peaking
3. MVA efficiency as a function of mass: very smooth
4. Varying threshold value of MVA selector: structure stays significant
5. Varying particle ID selections: no peaking structure emerging in WS combinations, structure stays in RS sample
6. Using a cut based selection instead of using MVA, requiring good vertex fit quality, Ξ_{cc}^{++} vertex displaced and tracks are not produced from PV: peak significance $> 12\sigma$

arXiv: 1707.01621



More tests

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

- Signal peak presents in run I data sample with significance $> 7\sigma$

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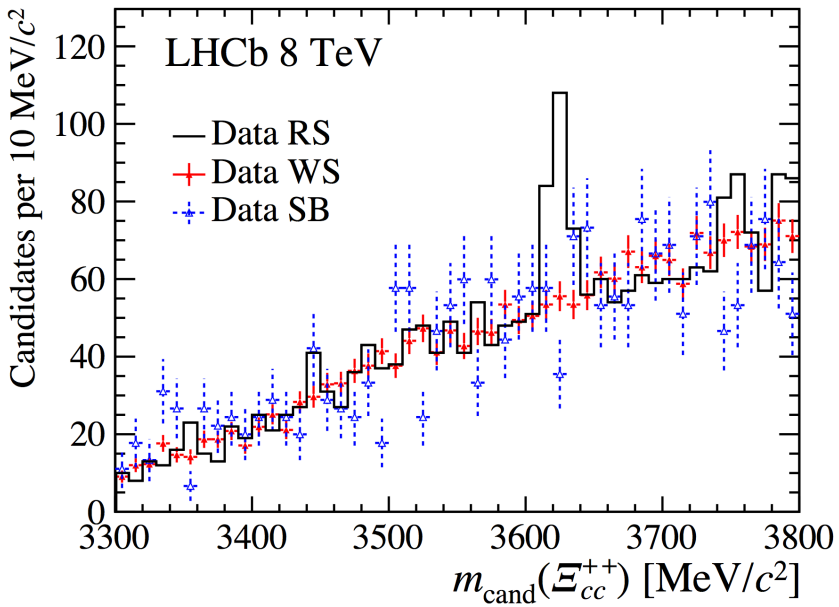

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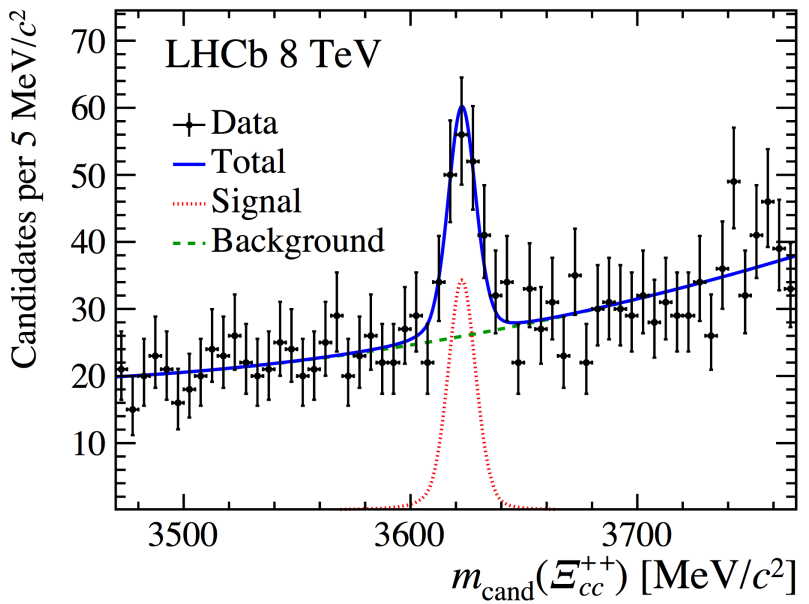


$N(\Xi_{cc}^{++} \to \Lambda_c^+ K^-\pi^+\pi^+) = 113 \pm 21$

Resolution: 6.6 ± 1.4 MeV

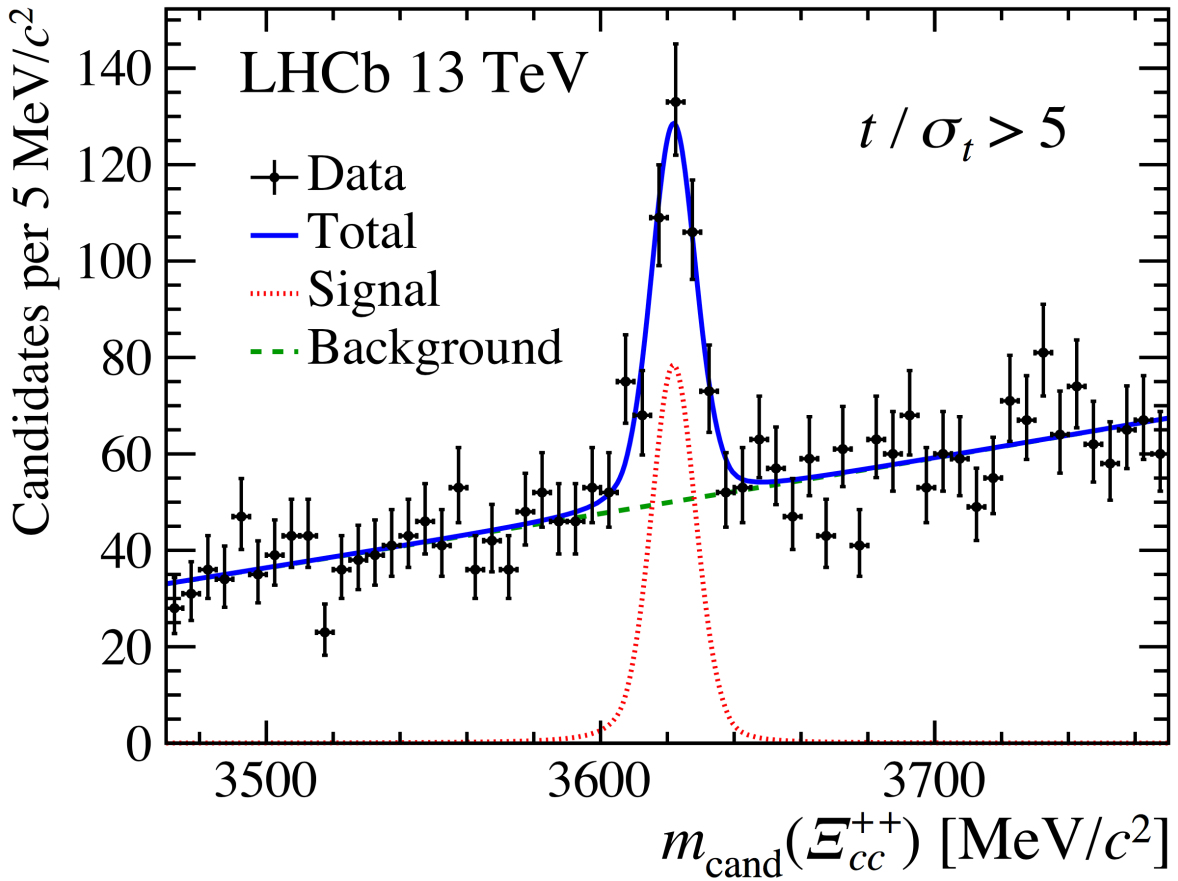
$\Delta m(\text{run I, run II}) = 0.8 \pm 1.4$ MeV

Consistent between two samples

Signal properties

- Peaking structure remains significant ($> 12\sigma$) after requiring minimum decay time, $t > 5\sigma_t$. It is indeed a weak decay.

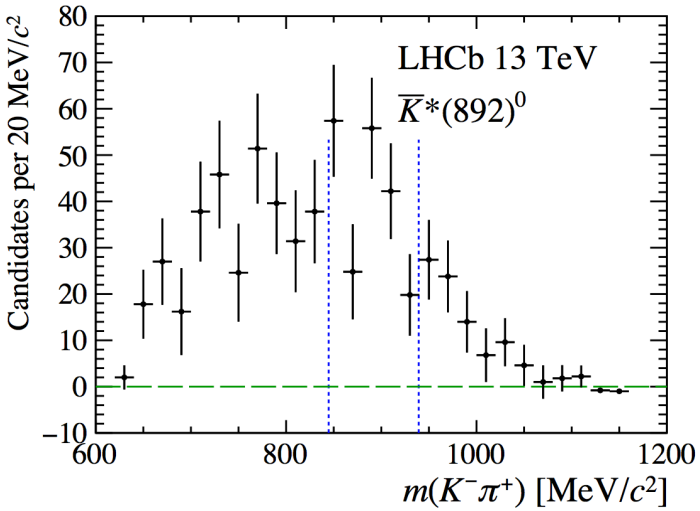
arXiv: 1707.01621

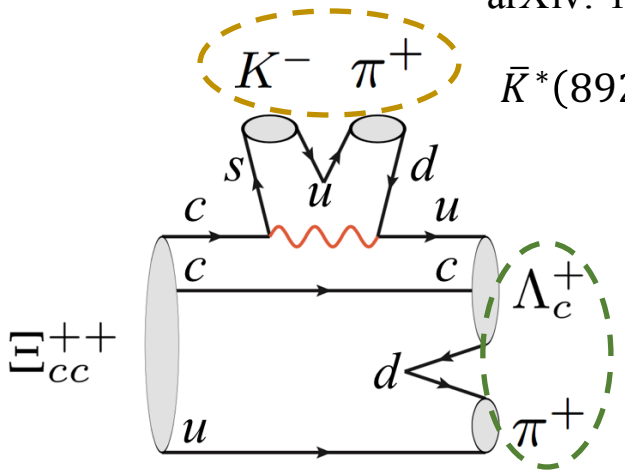


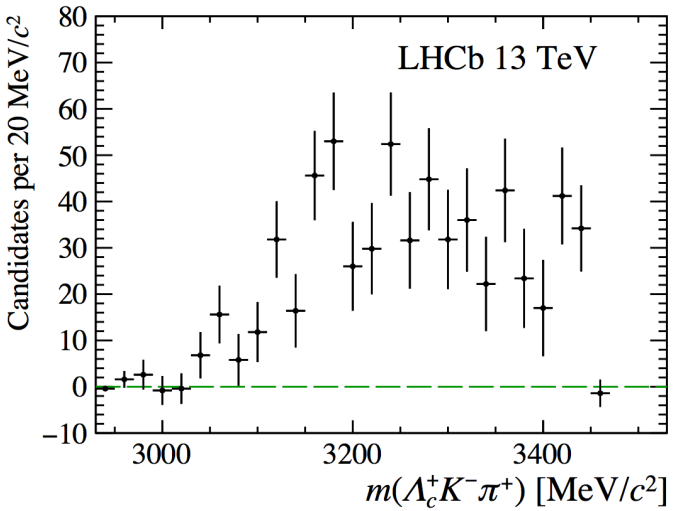
Signal properties

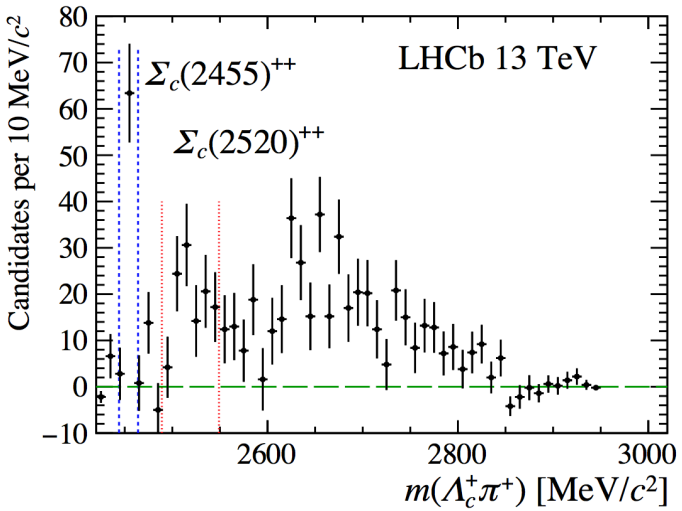
- Intermediate resonances: $\overline{K}^*(892)^0, \Sigma_c(2455)^{++}, \Sigma_c(2520)^{++}$

arXiv: 1707.01621







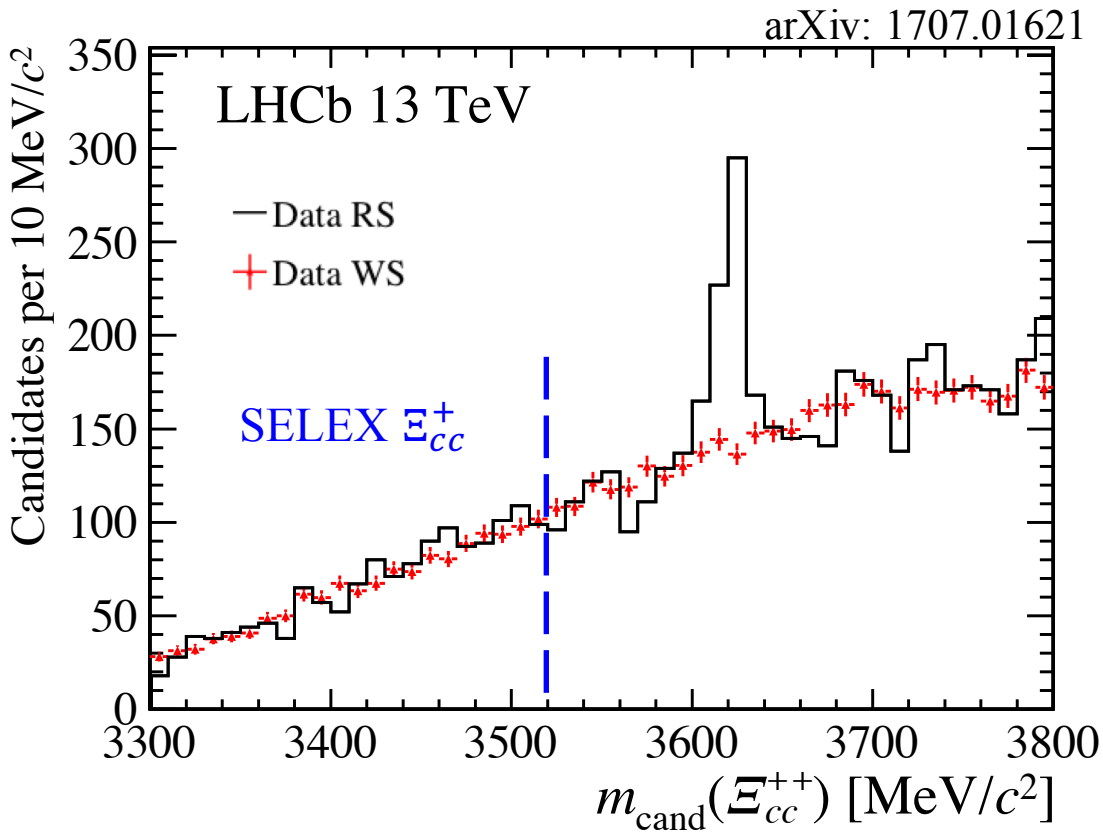


Comparison with SELEX

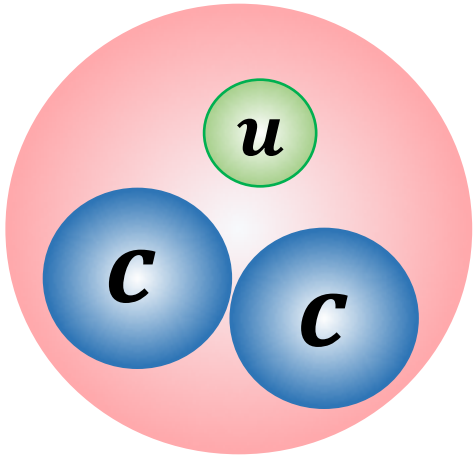
- Large mass difference: $m(\Xi_{cc}^{++})_{\text{LHCb}} - m(\Xi_{cc}^{+})_{\text{SELEX}} = 103 \pm 2$ MeV
  - Narrow structures observed by both experiments
  - Inconsistent with being isospin partners

Refs. [46-48]

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

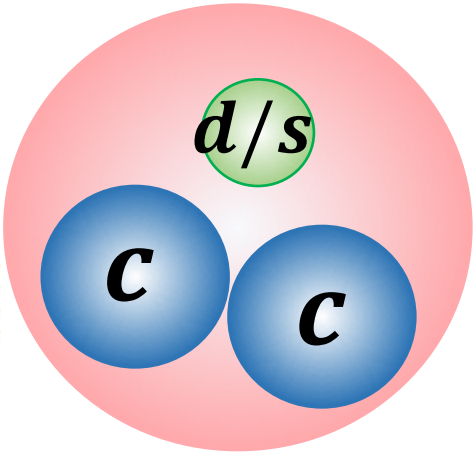


Prospects

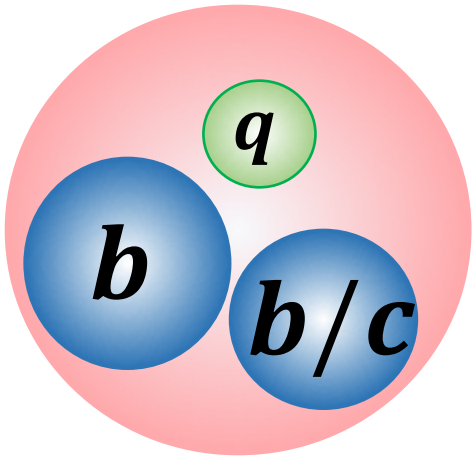


Ξ_{cc}^{++}

- Other decay modes
- Lifetime
- Production
- Spin-parity



- Searching for Ξ_{cc}^{+}, Ω_{cc}^{+}



- Doubly heavy baryons with *b* quark(s)

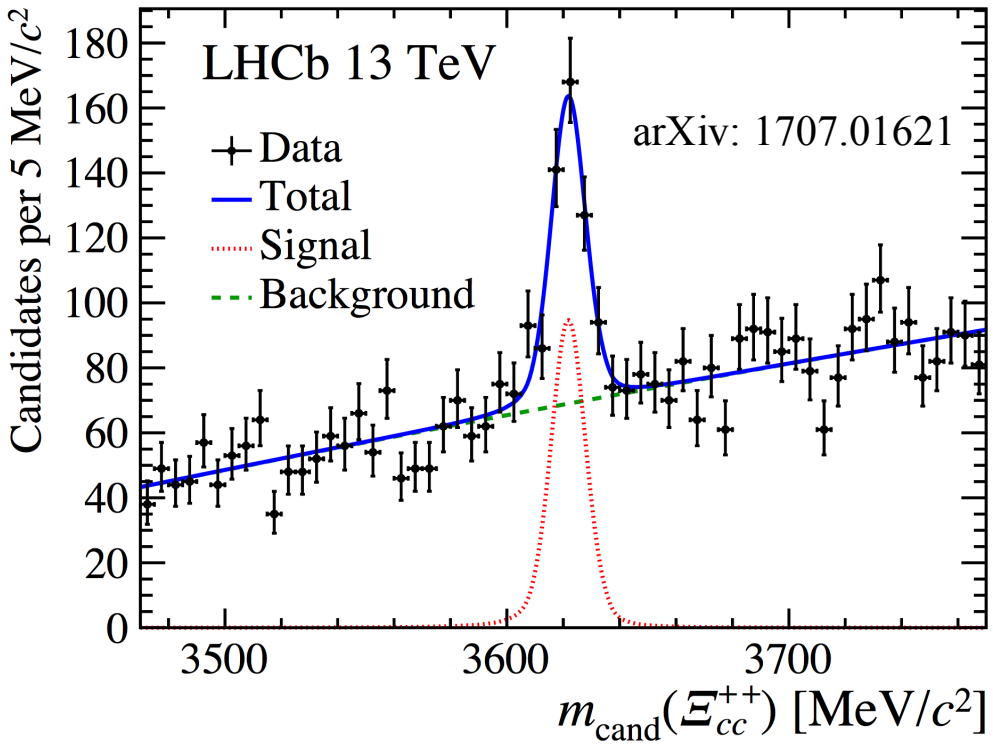
- The excited states?
- New systems for CP violations

Summary

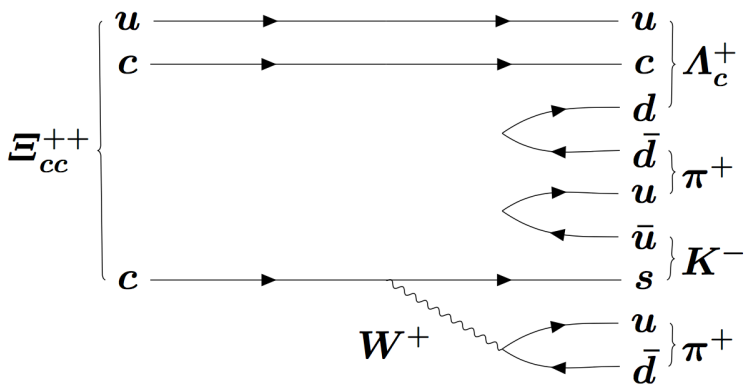
- LHCb observed the $\Xi_{cc}^{++}(ccu)$ state in the $\Lambda_c^+ K^- \pi^+ \pi^+$ decay
  - Mass 3621.40 ± 0.78 (tot) MeV inconsistent with Ξ_{cc}^+ observed by SELEX being its isospin partner
  - Mass consistent with predictions by many models
  - Opens new window for charm/bottom hadron spectroscopy studies

Stay tuned for upcoming results

Thank you



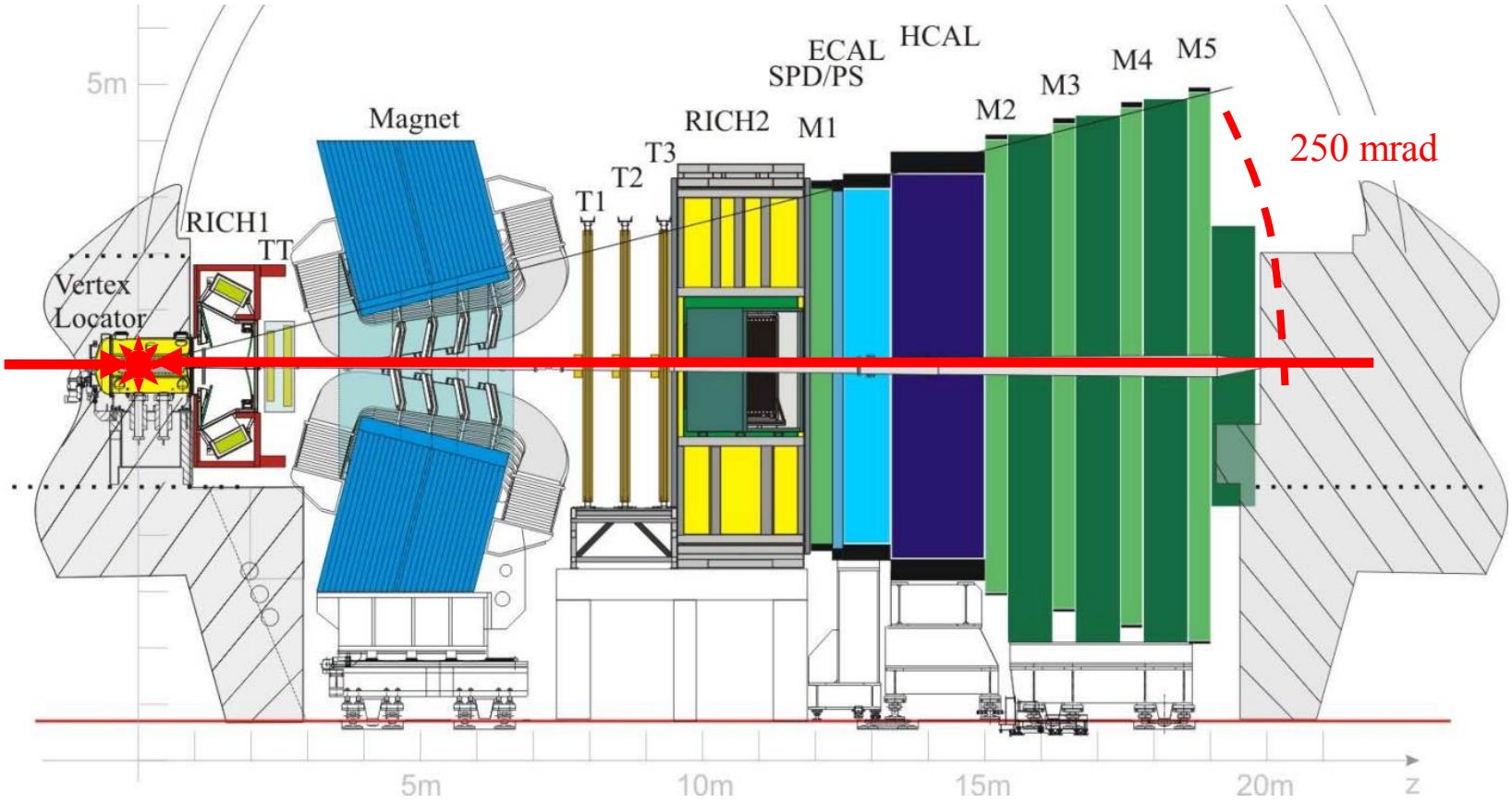
Backup slides



LHCb experiment

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

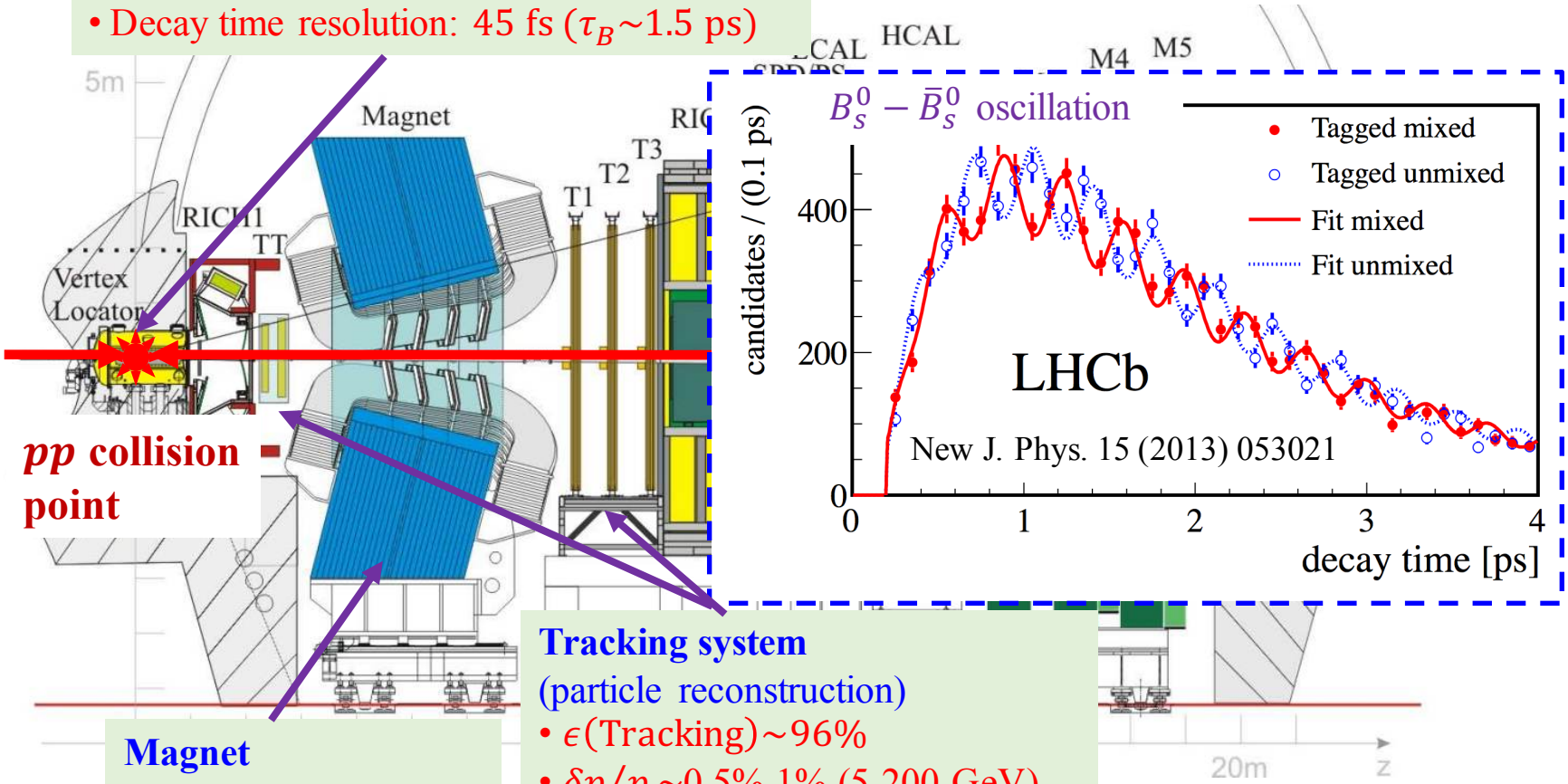
Aiming for precision measurements in b, c flavor sectors
Acceptance: $2 < \eta < 5$



LHCb experiment

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

Vertex Locator (vertex reconstruction)
- Impact parameter resolution: 20μm
- Decay time resolution: 45 fs (τ_B~1.5 ps)



***pp* collision point**

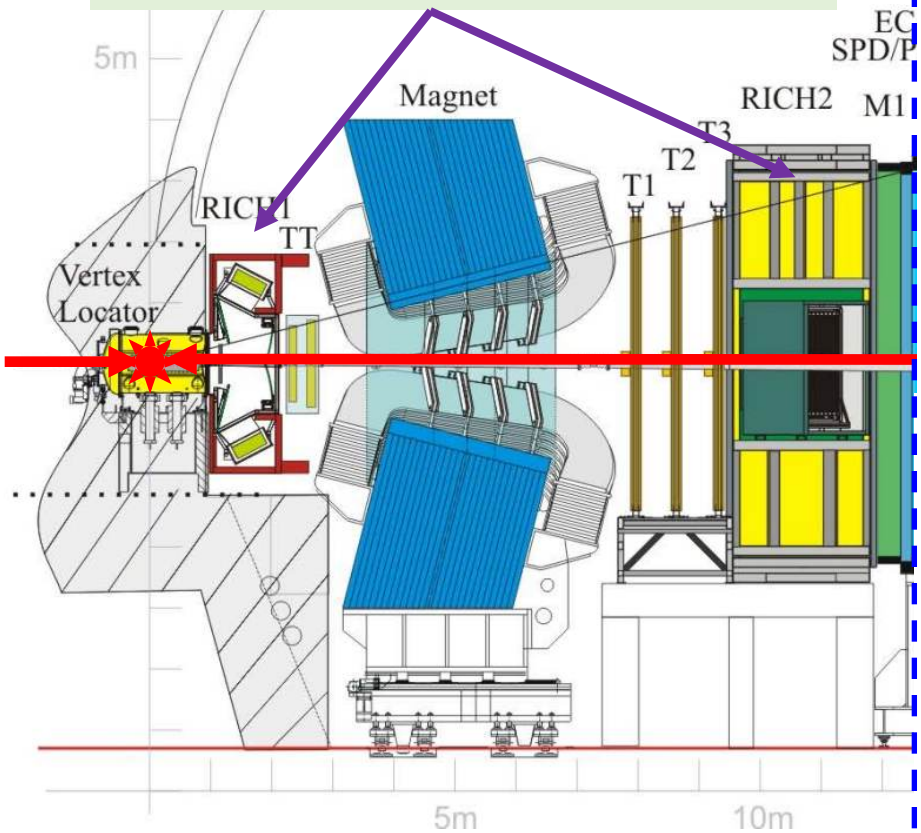
Magnet
Bending power: 4 Tm

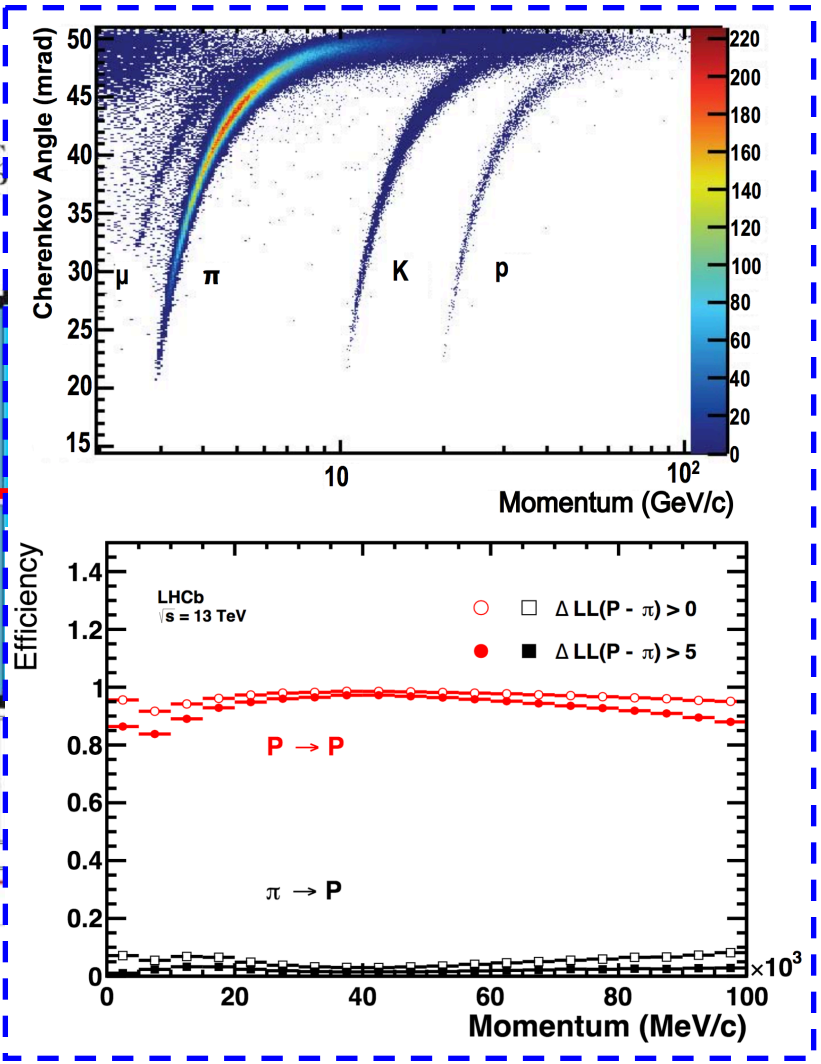
Tracking system
(particle reconstruction)
- ϵ(Tracking)~96%
- $\delta p/p$ ~0.5%-1% (5-200 GeV)
- $\sigma(m_{B\to hh}) \approx 22$ MeV

LHCb experiment

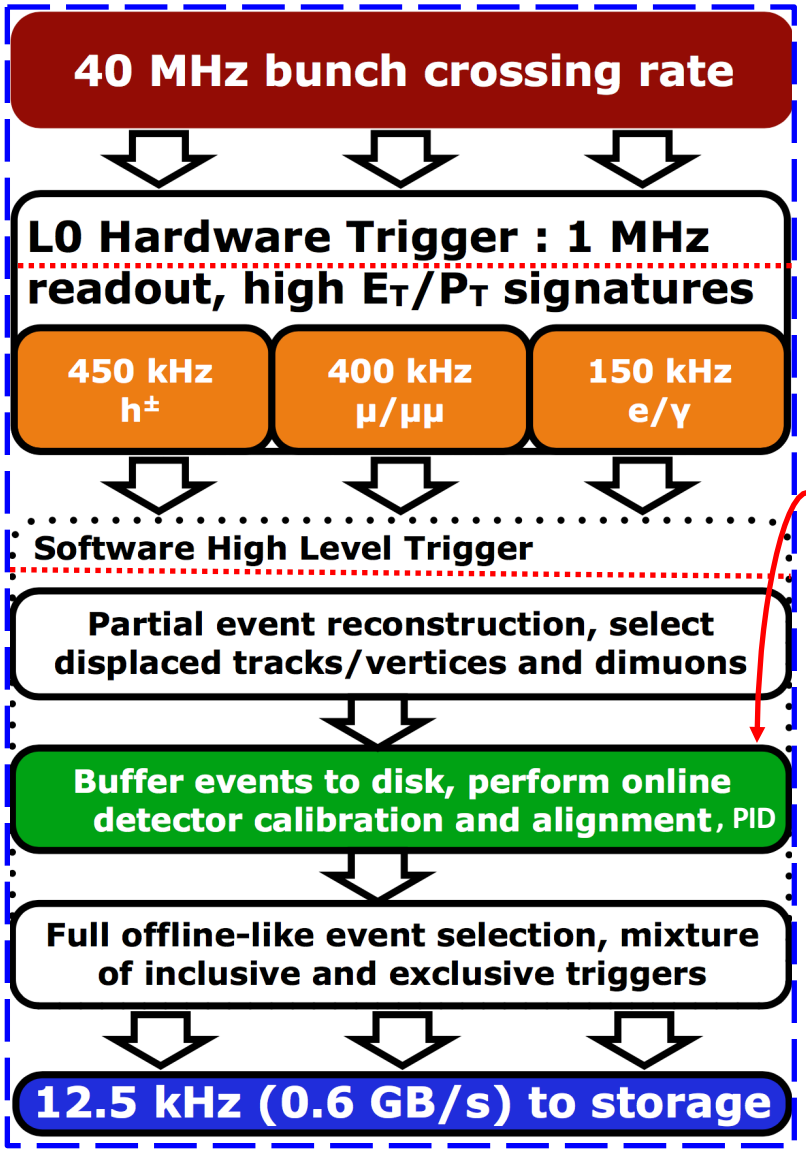
JINST 3 (2008) S08005
IJMPA 30 (2015) 1530022

RICH detectors ($K/\pi/p$ separation)
- $\epsilon(K \to K)$~95%
- Mis-ID $\epsilon(\pi \to K)$~5%





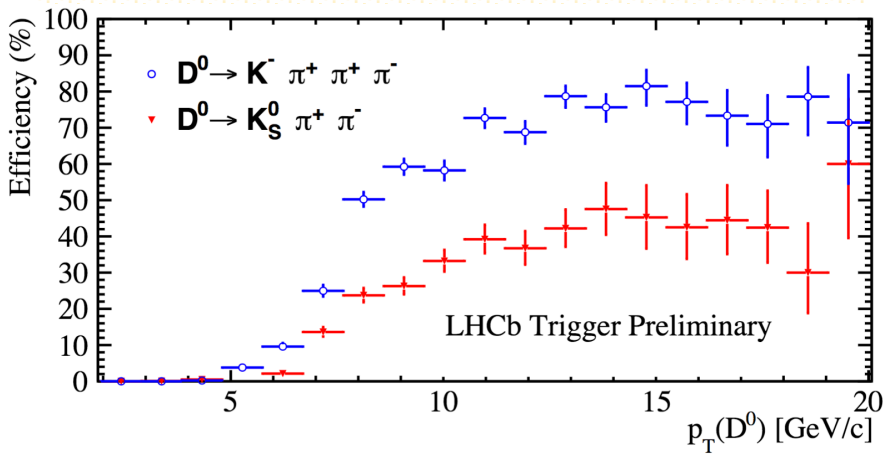
LHCb trigger



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

Run II Turbo stream:
Candidates reconstructed at trigger level saved for offline analyses directly

High trigger efficiency for hadronic channels



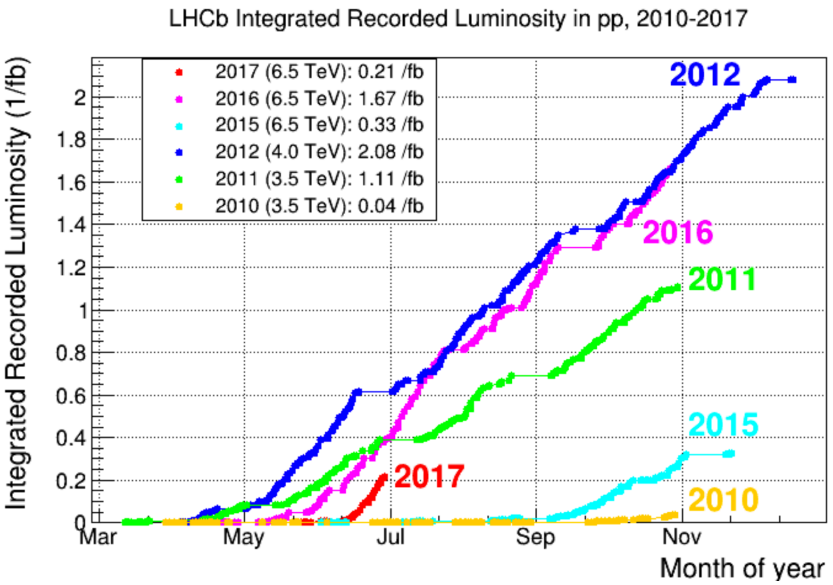
Data samples

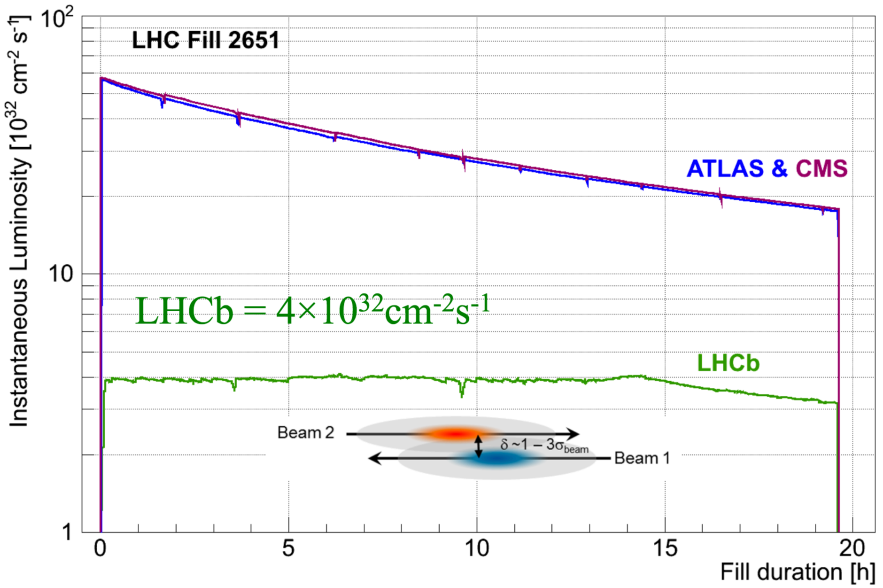
- Run I: 1. fb^{-1} at 7 TeV (2011) + 2. fb^{-1} at 8 TeV (2012)
- Run II: 0.3 fb^{-1} (2015) + 1.7 fb^{-1} (2016) at 13 TeV

pp collisions

Luminosity levelling to run at its optimal instantaneous luminosity:

Stable running conditions benefiting reconstruction and calibration

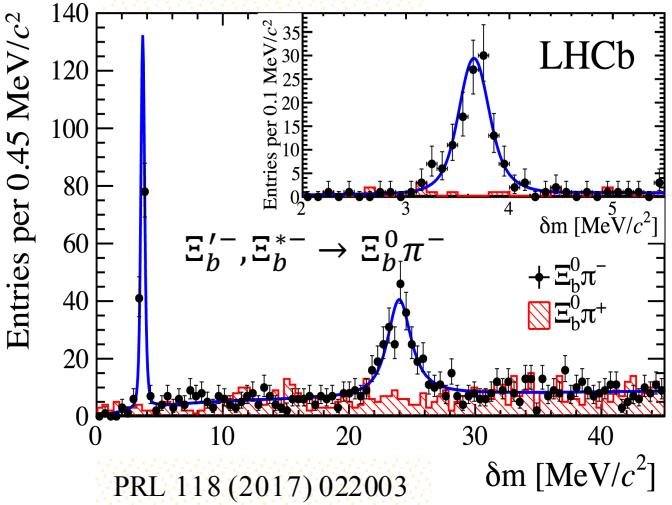




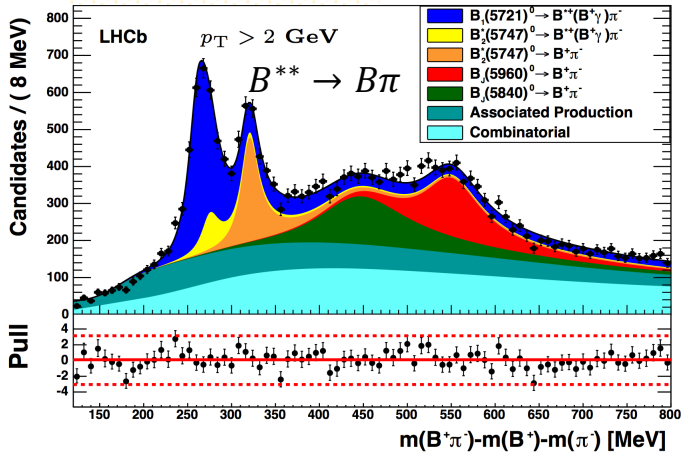
LHCb: observations of new hadrons

- With excellent tracking, particle identification and efficient trigger system, LHCb is a unique laboratory for hadron spectroscopy studies

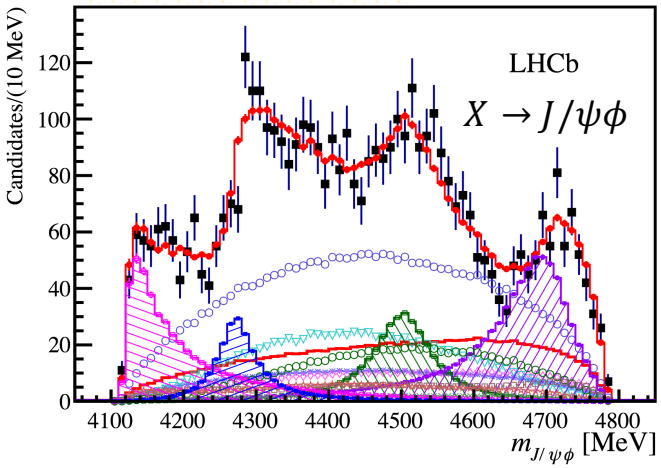
PRL 114 (2015) 062004



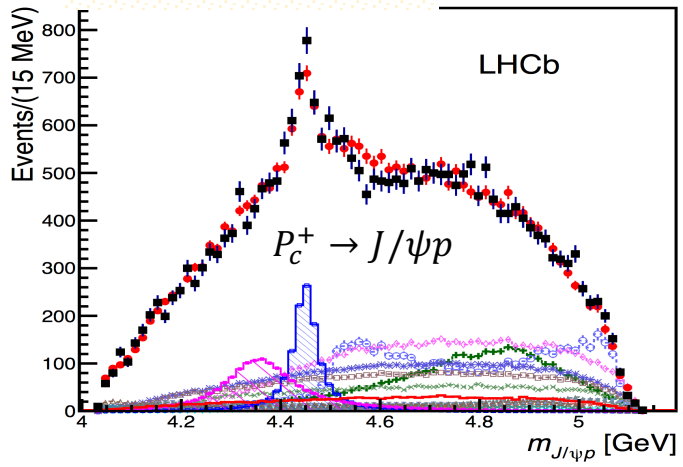
JHEP 1504 (2015) 024



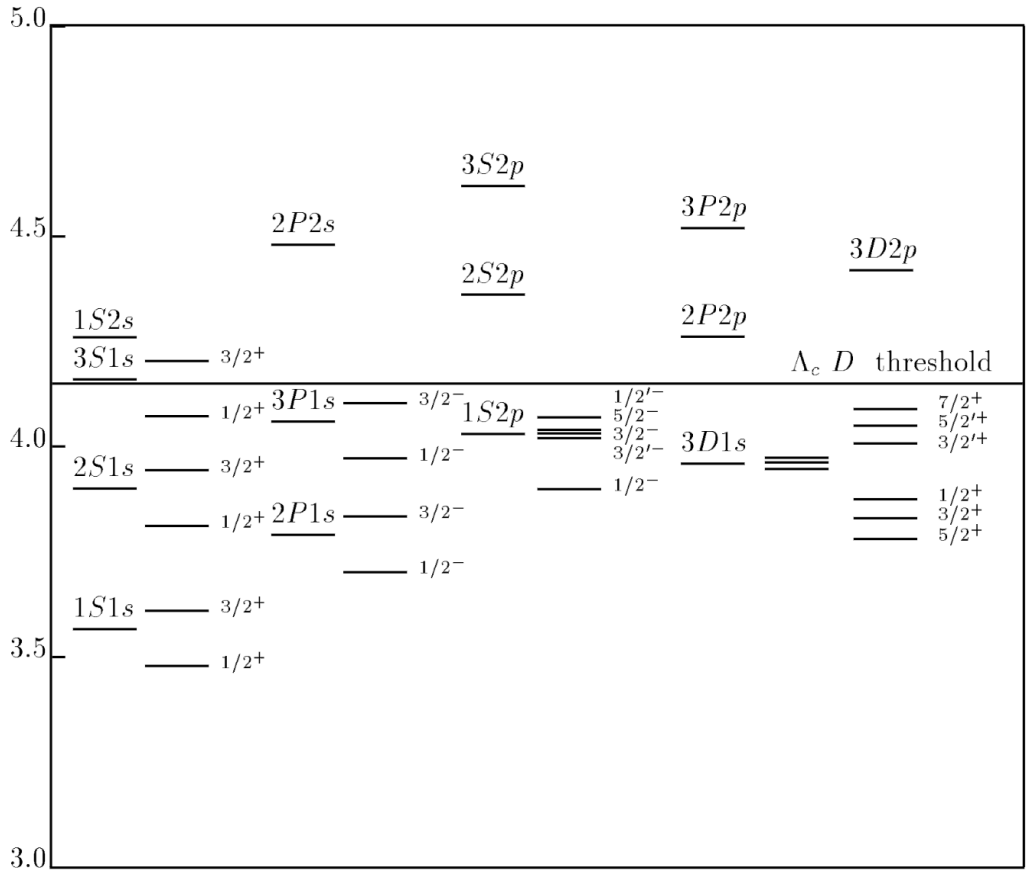
PRL 118 (2017) 022003

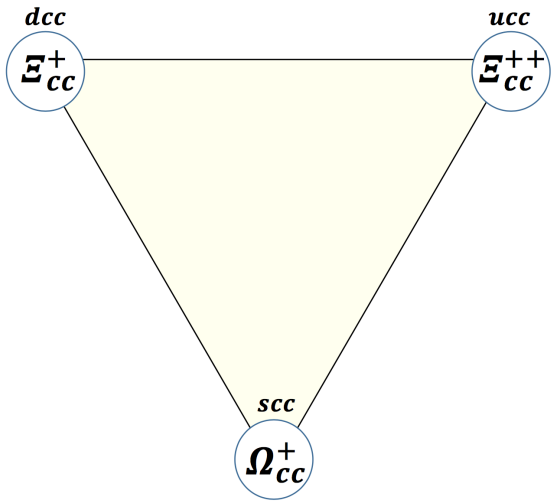


PRL 115 (2015) 072001



Ξ_{cc} spectroscopy





Lifetimes of $\frac{1}{2}^+$ states

	PDG
D^0	0.410 ± 0.002
D_s^+	0.500 ± 0.007
D^+	1.040 ± 0.007
$D_b^+(B_c^+)$	0.507 ± 0.009
$\Lambda_c^+(cud)$	0.200 ± 0.006
$\Xi_c^0(csd)$	0.112 ± 0.012
$\Xi_c^+(csu)$	0.442 ± 0.026
$\Omega_c^0(css)$	0.069 ± 0.012

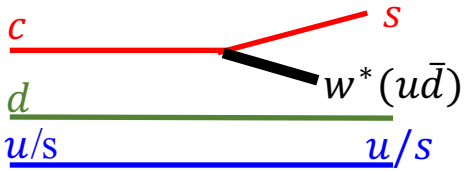
ps

- Spectator model predicts almost equal lifetimes
  - True for bottom hadrons: 1.5 ps $\pm$ 10%
  - True for charm semi-leptonic decay width:

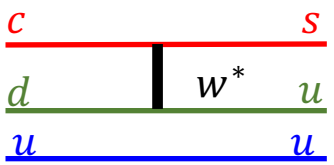
$$\Gamma(H_c \to l\nu_l X) = \frac{\mathrm{Br}(H_c \to l\nu_l X)}{\tau_{H_c}} \approx 0.3\ \mathrm{ps}^{-1}$$

- But charm hadron lifetimes known to vary a lot
- Explained by non-spectator decays and Pauli interference, qualitatively

Spectator (Γ_s)



W-exchange (W)

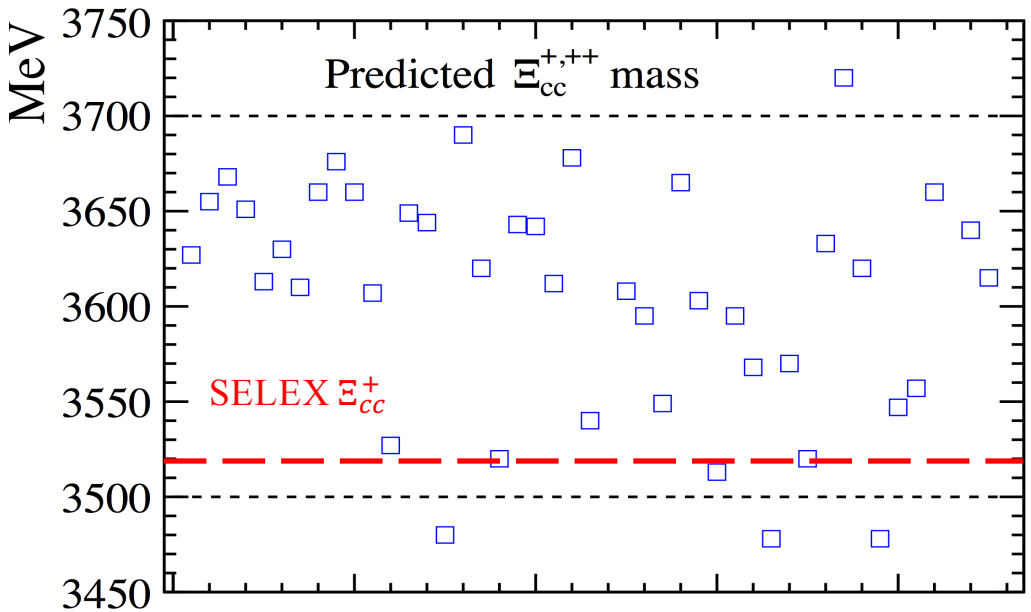


  - Destructive/constructive interference ($\Gamma_s^{-/+}$): $cuq/csq \to suq/ssq(u\bar{d})$
  - W-exchange process (enhancement): $cdq \to suq$
  - $\Gamma(\Xi_c^0 : W + \Gamma_s^+) > \Gamma(\Lambda_c^+ : W + \Gamma_s^-) > \Gamma(\Xi_c^+ : \Gamma_s^{+-})$
- Expectation: $\tau(\Xi_{cc}^{++}(ccu)) \gg \tau(\Xi_{cc}^{+}(ccd))$
- Calculations give $\tau(\Xi_{cc}^{++}) \in [\,200 - 700\,]$ fs Refs.[5, 6, 12 49-52]

Studies of Ξ_{cc} by SELEX experiment

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

Very puzzling



Refs.[1-30]

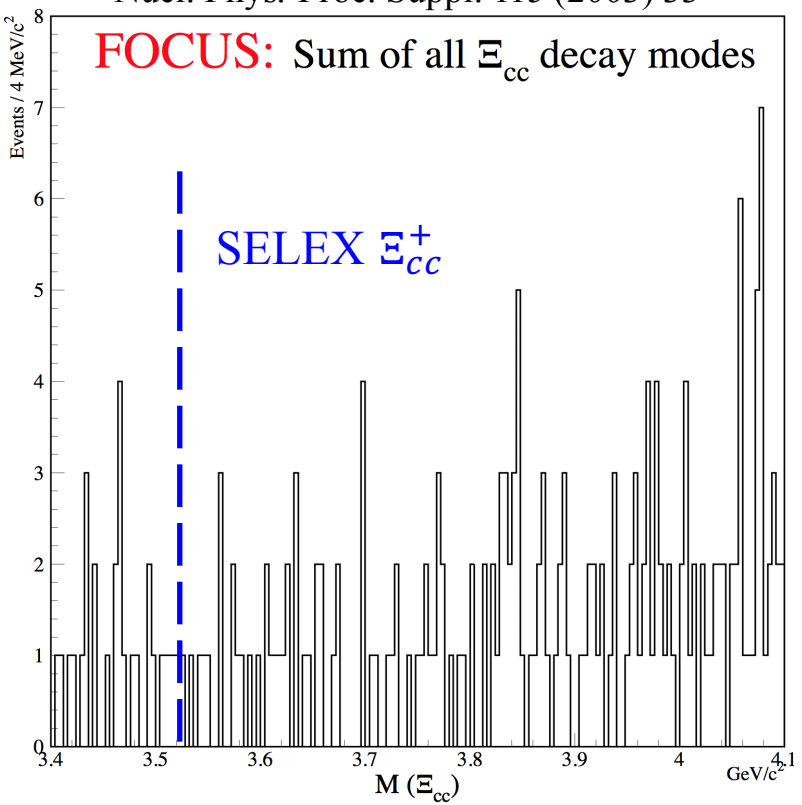
Studies of Ξ_{cc} by FOCUS

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

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

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

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

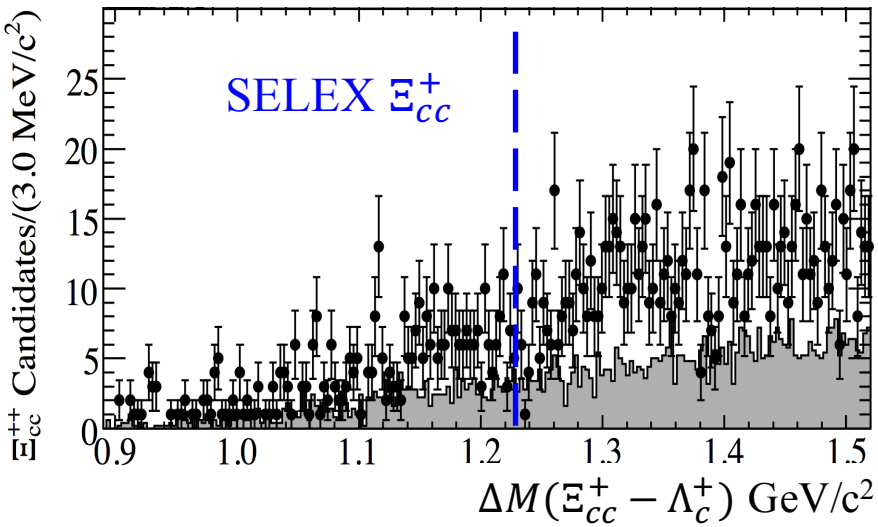


Studies of Ξ_{cc} by BaBar and Belle

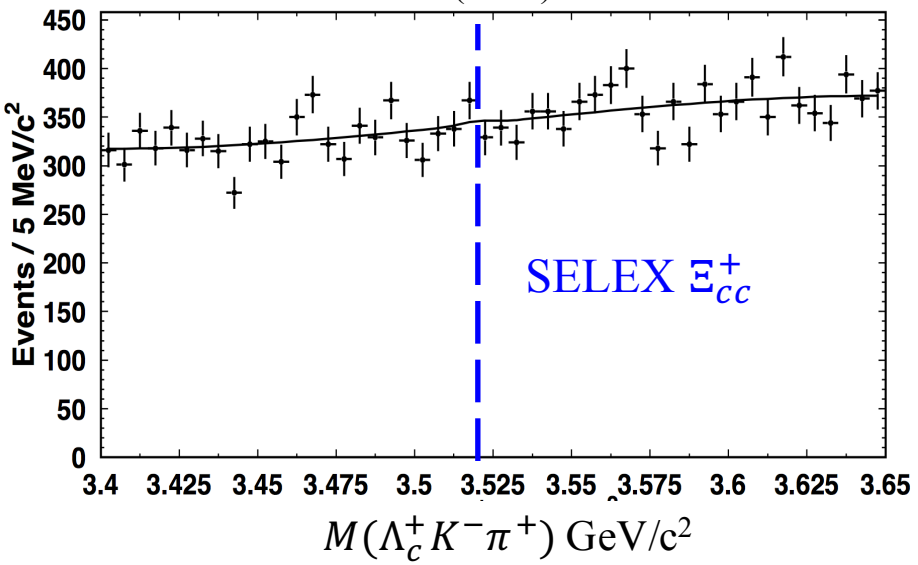
- e^+e^- colliders working at $\Upsilon(4S)$ mass $\sqrt{s} = 10.58$ GeV
- Large Λ_c^+ yields: ≈ 0.6 M at BaBar, ≈ 0.8 M at Belle
- SELEX-like Ξ_{cc}^+ signal not confirmed in $\Xi_{cc}^+ \to \Lambda_c^+ K^- \pi^+$ decays

$$R = \frac{\sigma(\Xi_{cc}^+) \times \mathrm{BF}(\Xi_{cc}^+ \to \Lambda_c^+ K^- \pi^+)}{\sigma(\Lambda_c^+)} < 2.7\times10^{-4}\ \text{(BaBar)}\quad 1.5\times10^{-4}\ \text{(Belle)}\ @\ 95\%\ \text{CL}$$

BaBar: PRD 74 (2006) 011103



Belle: PRL 97 (2006) 162001



Studies of Ξ_{cc}^{+} by LHCb

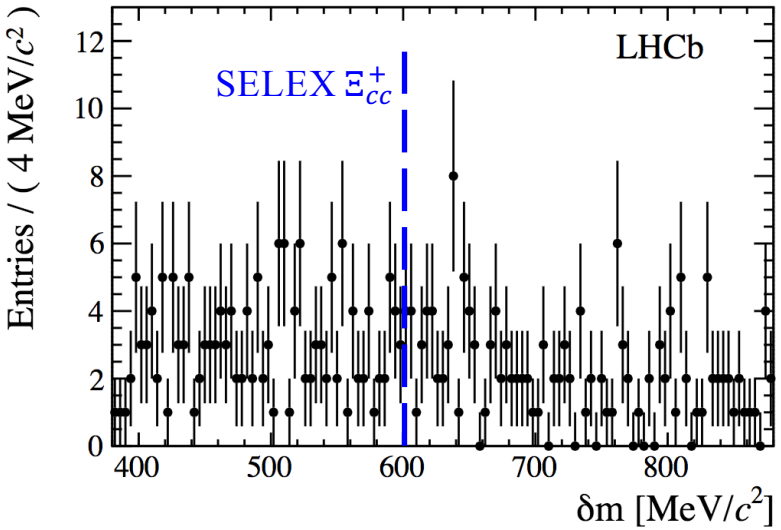
JHEP 12 (2013) 090

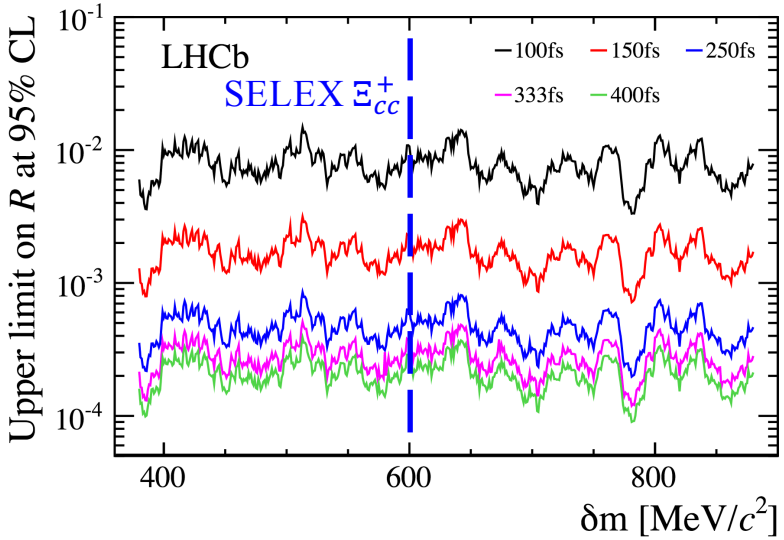
- LHCb searched for $\Xi_{cc}^{+} \to \Lambda_c^+ K^- \pi^+$ decay with 0.65 fb^{-1} of 7 TeV data
  - $N(\Lambda_c^+) \approx 0.8$ M, requiring high-p_T
  - No significant peaking structure observed with $m \in [3.3, 3.8]$ GeV
  - Experiment sensitivity strongly depends on Ξ_{cc}^{+} lifetime

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

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

Increased by ~40 from 100 fs to 400 fs



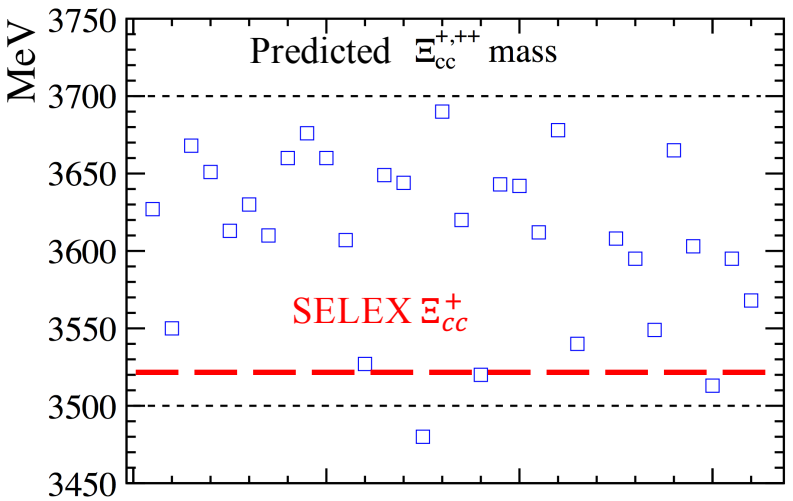


$$\delta m = m\left([pK^-\pi^+]_{\Lambda_c^+} K^-\pi^+\right) - m\left([pK^-\pi^+]_{\Lambda_c^+}\right) - m(K^-) - m(\pi^+)$$

Studies of Ξ_{cc} by SELEX experiment

- $\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+}$
  - Number of inclusive Λ_c^{+} signals: ≈ 1650
  - 15.9 signals over 6.1 ± 0.5 background candidates with significance of 6.3σ
  - Mass: $m(\Xi_{cc}^{+}) = 3519 \pm 2$ MeV
  - Lifetime: $\tau(\Xi_{cc}^{+}) < 33$ fs @90% CL, but non zero lifetime
  - Production: $R = \frac{\sigma(\Xi_{cc}^{+}) \times \mathrm{BF}(\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+})}{\sigma(\Lambda_c^{+})} \sim 20\%$, much large than most model predictions of $\sim 0.1\%$
- $\Xi_{cc}^{+} \to p D^{+} \pi^{-}$
  - 5.62 signals over 1.38 ± 0.18 background candidates with 4.8σ
  - Mass: $m(\Xi_{cc}^{+}) = 3518 \pm 3$ MeV
  - Confirms the observed small lifetime
  - A few percent of D^{+} produced from $\Xi_{cc}^{+} \to p D^{+} \pi^{-}$ decay

Combined mass: 3518.7 ± 1.7 MeV

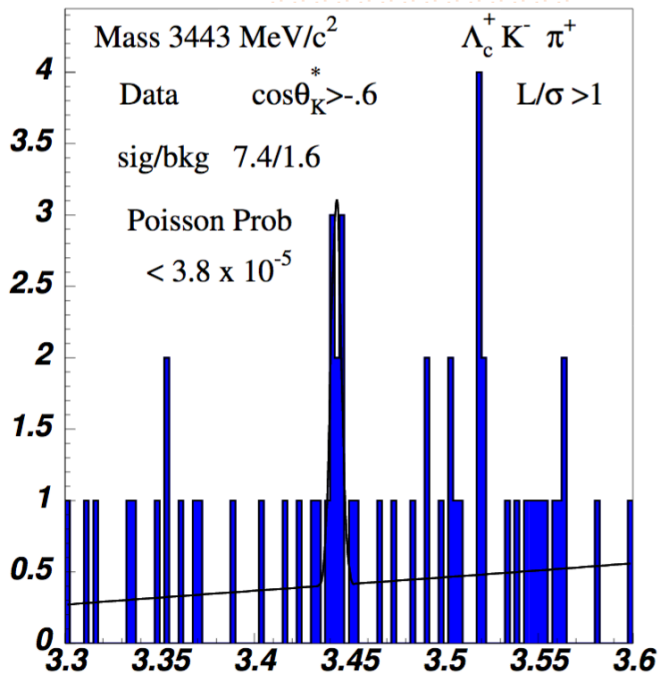


Studies of Ξ_{cc} by SELEX experiment

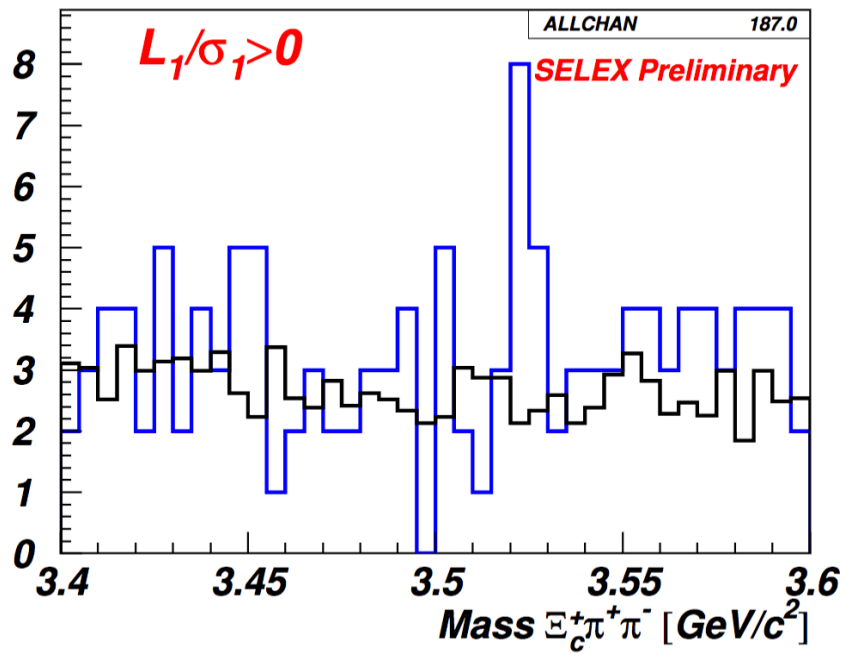
- SELEX (Fermilab E781) collides high energy hyperon beams (Σ^-, p) with nuclear targets, dedicated to study charm baryons
- Claims by SELEX (conference reports)
  - Evidence of lower mass $\Xi_{cc}^+ \to \Lambda_c^+ K^- \pi^+$
  - Evidence of $\Xi_{cc}^+ \to \Xi_c^+ \pi^+ \pi^-$ decay

https://www-selex.fnal.gov/

$M \approx 3.45$ GeV



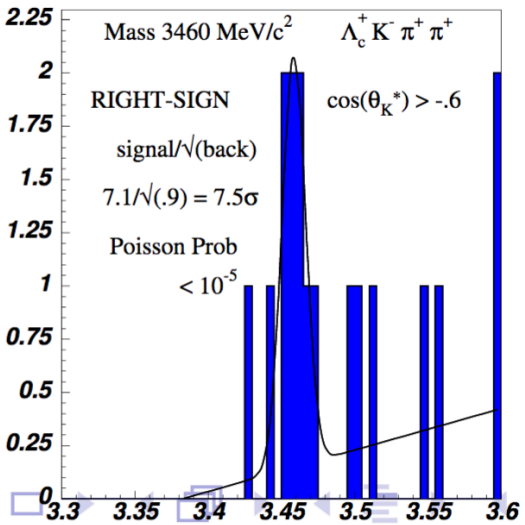
$\Xi_{cc}^{++} \to \Xi_c^+ \pi^+ \pi^-$



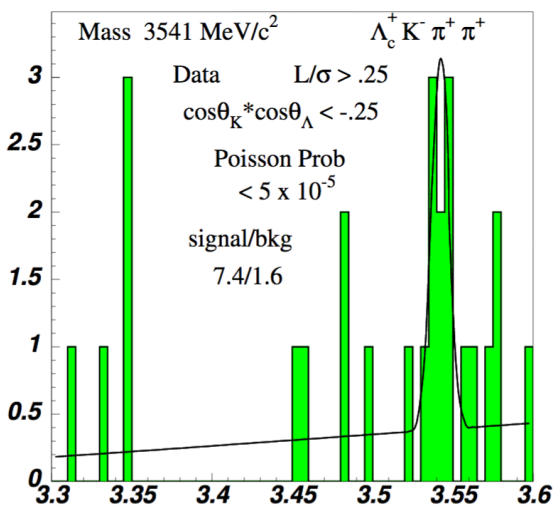
Studies of Ξ_{cc} by SELEX experiment

- SELEX (Fermilab E781) collides high energy hyperon beams (Σ^-, p) with nuclear targets, dedicated to study charm baryons
- Claims by SELEX (conference reports)
  - Evidence of lower mass $\Xi_{cc}^+ \to \Lambda_c^+ K^- \pi^+$
  - Evidence of $\Xi_{cc}^+ \to \Xi_c^+ \pi^+ \pi^-$ decay
  - Evidence of $\Xi_{cc}^{(*)++} \to \Lambda_c^+ K^- \pi^+ \pi^+$: three of them

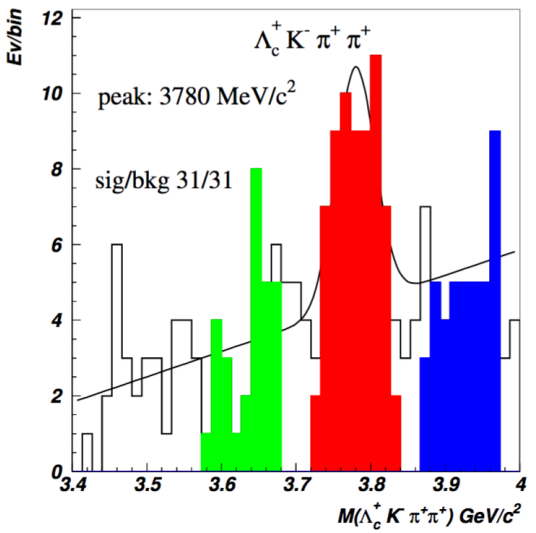
https://www-selex.fnal.gov/



$M \approx 3.46$ GeV



$M \approx 3.54$ GeV

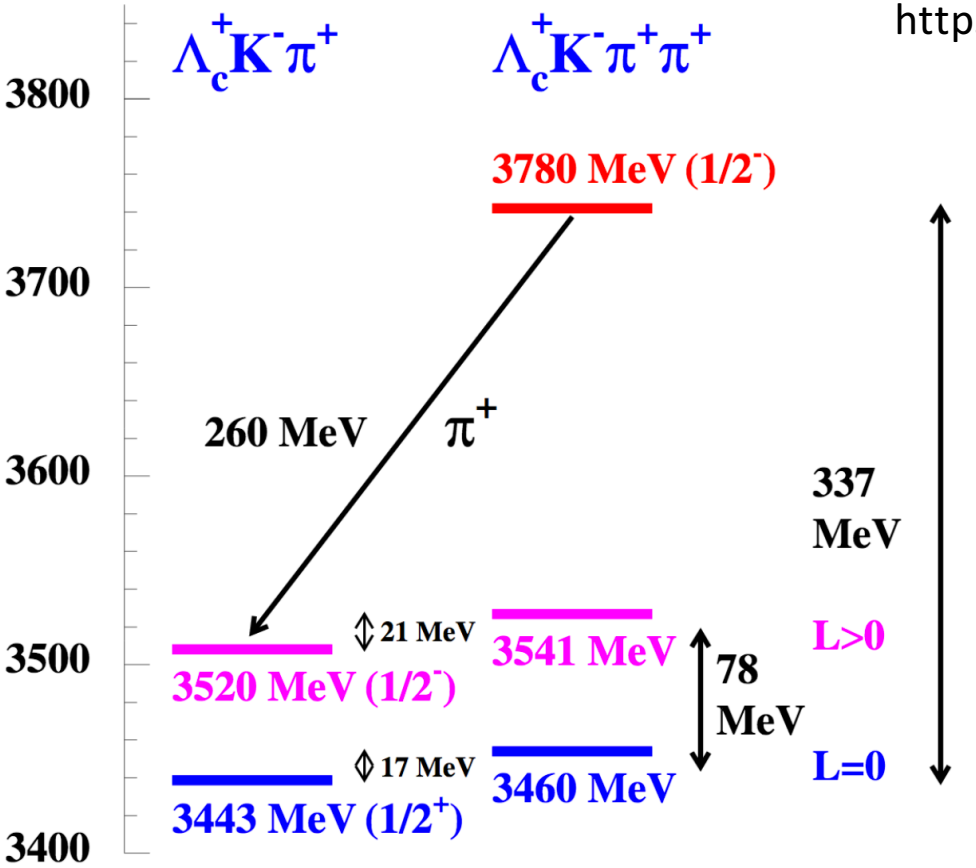


$M \approx 3.78$ GeV

Studies of Ξ_{cc} by SELEX experiment

- SELEX (Fermilab E781) collides high energy hyperon beams (Σ^-, p) with nuclear targets, dedicated to study charm baryons
- Claims by SELEX: consistent spectroscopy

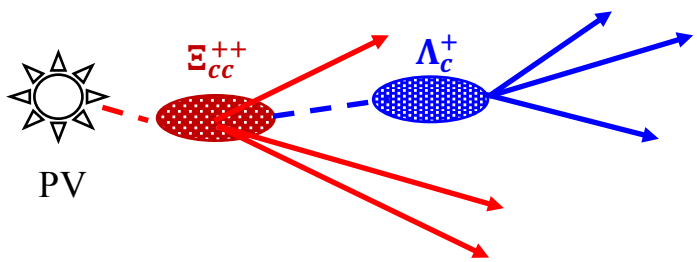
https://www-selex.fnal.gov/



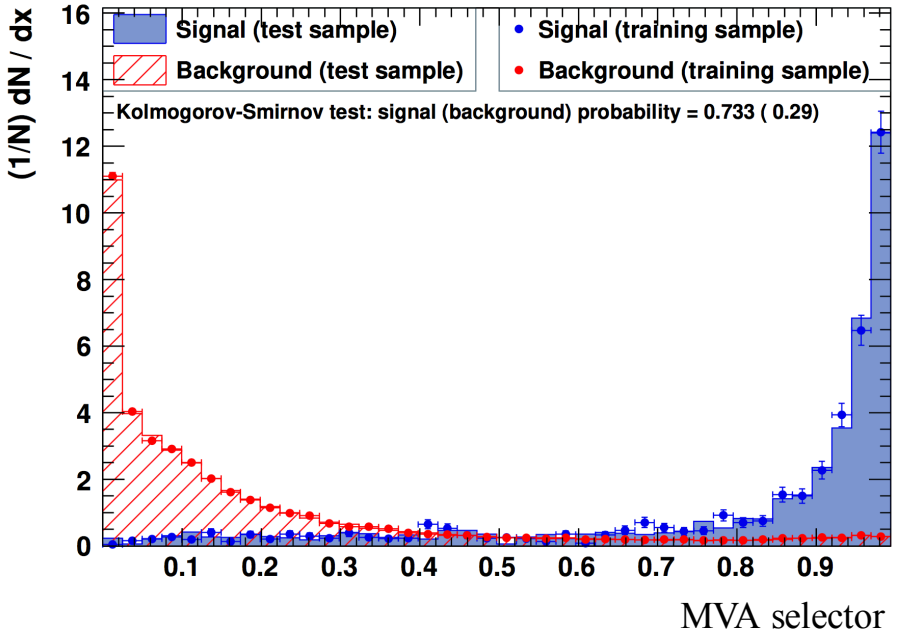
The machine learning

- Λ_c^+ combined with PID-selected $K^-\pi^+\pi^+$ tracks to form Ξ_{cc}^{++} candidates
- Candidates with cloned tracks are removed
- Multivariate selector further explores
  - Decay fit quality
  - Kinematics of final states
  - Ξ_{cc}^{++} vertex separation from PV
    - More sensitive to long lived particles

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

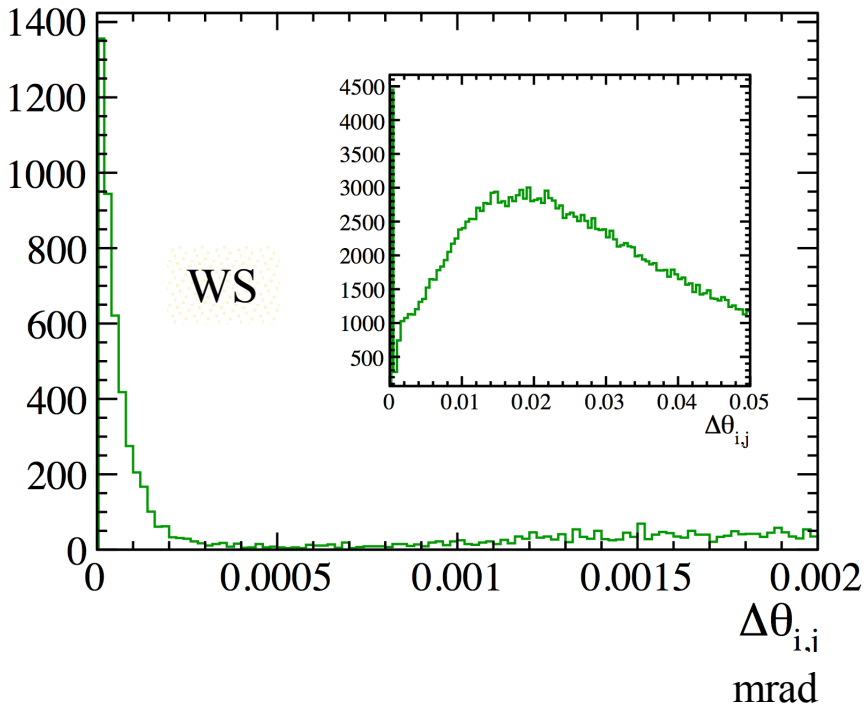


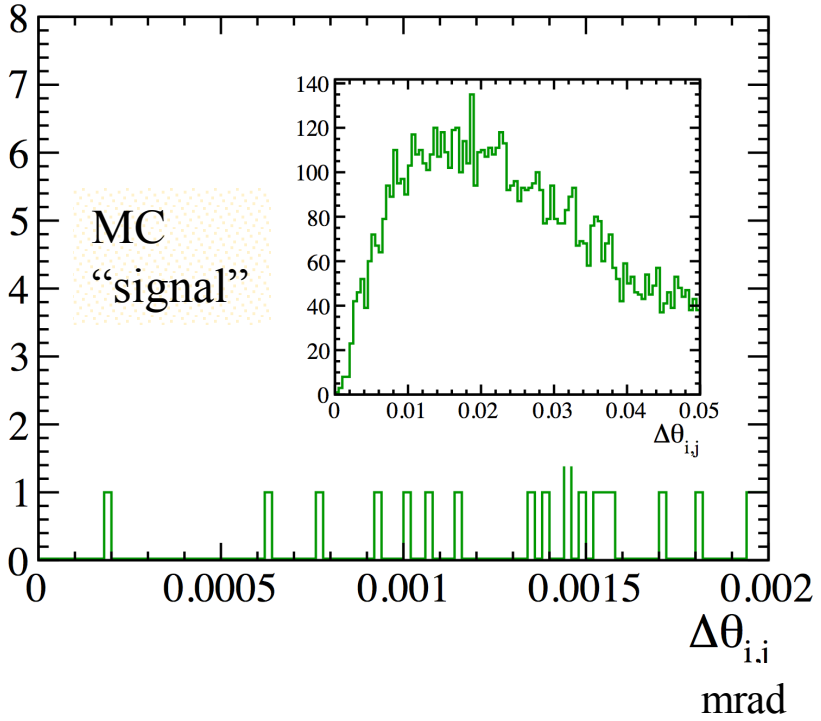
Selector optimized using simulated decays for signals and a wrong-sign control sample representing backgrounds: $\Xi_{cc}^{++} \to K^-\pi^+\pi^-\Lambda_c^+$



Remove clone candidates

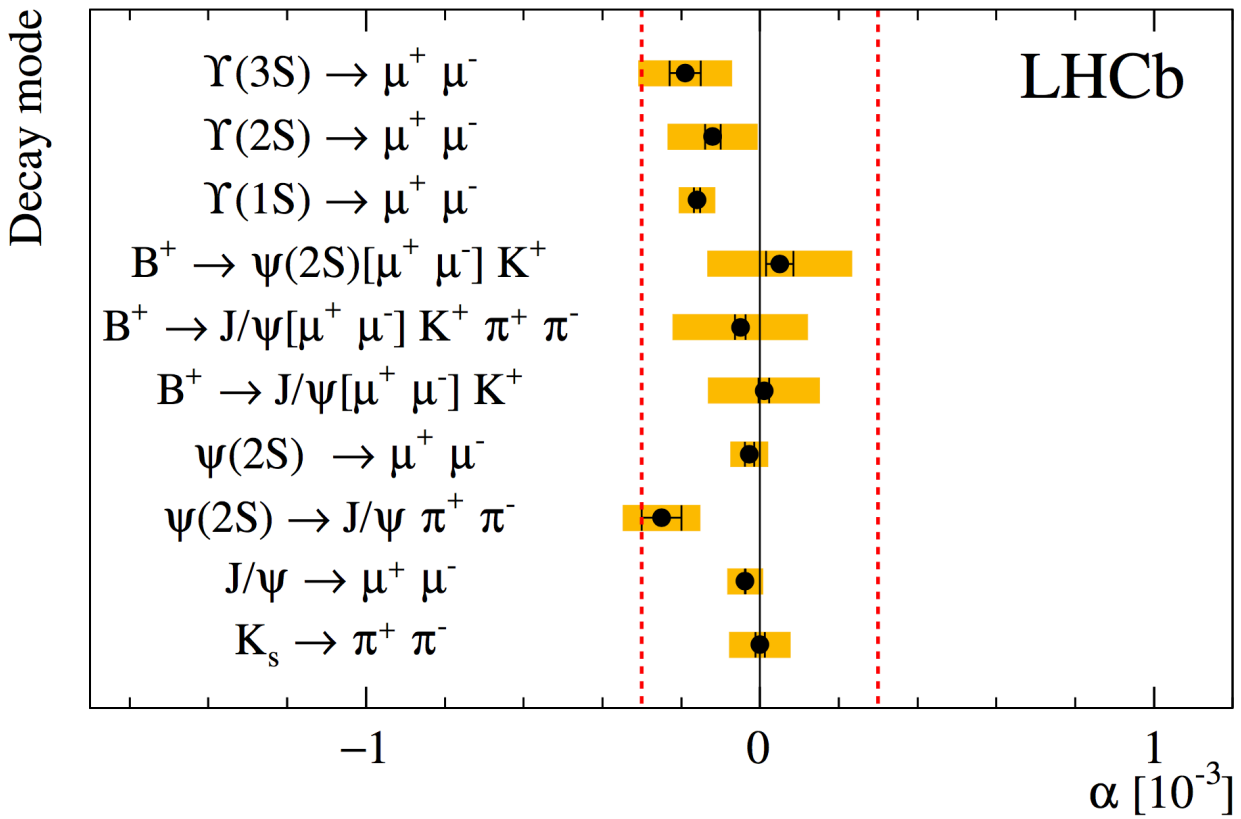
- Clone track pair has smaller angle





Momentum scaling calibration

- Momentum scale calibrated using $J/\psi \to \mu^+\mu^-$ and $B^+ \to J/\psi K^+$ decays, validated using other hadrons
  - ➢ Agree with know values at 0.03%



Prospects

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

A long list of programs

References (not exhaustive)

[1] S. S. Gershtein, V. V. Kiselev, A. K. Likhoded, and A. I. Onishchenko, *Spectroscopy of doubly heavy baryons*, Phys. Atom. Nucl. **63** (2000) 274, arXiv:hep-ph/9811212, [Yad. Fiz. 63, 334 (2000)].

[2] S. S. Gershtein, V. V. Kiselev, A. K. Likhoded, and A. I. Onishchenko, *Spectroscopy of doubly charmed baryons: Ξ_{cc}^{+} and Ξ_{cc}^{++}*, Mod. Phys. Lett. **A14** (1999) 135, arXiv:hep-ph/9807375.

[3] C. Itoh, T. Minamikawa, K. Miura, and T. Watanabe, *Doubly charmed baryon masses and quark wave functions in baryons*, Phys. Rev. **D61** (2000) 057502.

[4] S. S. Gershtein, V. V. Kiselev, A. K. Likhoded, and A. I. Onishchenko, *Spectroscopy of doubly heavy baryons*, Phys. Rev. **D62** (2000) 054021.

[5] K. Anikeev *et al.*, *B physics at the Tevatron: Run II and beyond*, in *Workshop on B physics at the Tevatron: Run II and beyond, Batavia, Illinois, September 23-25, 1999*, 2001. arXiv:hep-ph/0201071.

[6] V. V. Kiselev and A. K. Likhoded, *Baryons with two heavy quarks*, Phys. Usp. **45** (2002) 455, arXiv:hep-ph/0103169.

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