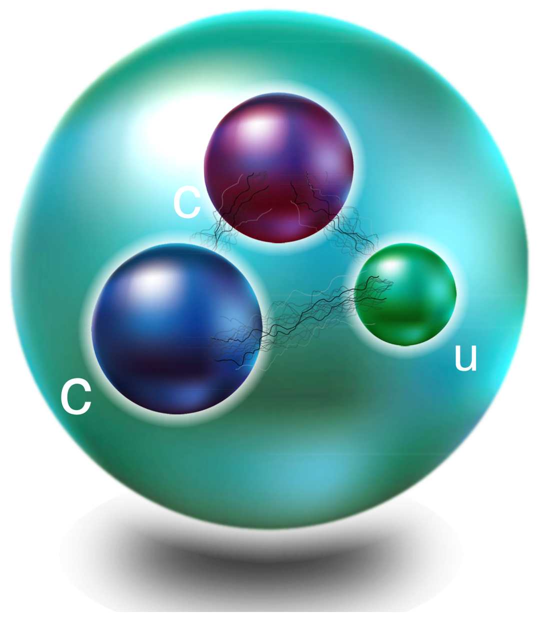
双粲十年，硕果赓新

于福升

兰州大学



The 6th LHCb workshop @ Guangzhou, 2026.05.23

2016

2017

2026

Doubly Heavy Baryon Decays @ LHCb

Fu-Sheng Yu (于福升)

Lanzhou University

2016.12.26 @ UCAS

Thank Dr. Ji-Bo He to give me this project and push me a lot!

In collaboration with Run-Hui Li, Ying Li, Cai-Dian Lü, Wei Wang, Zhen-Xing Zhao, Zhi-Tian Zou

Non-leptonic decays of Ξ_{cc}^{++}

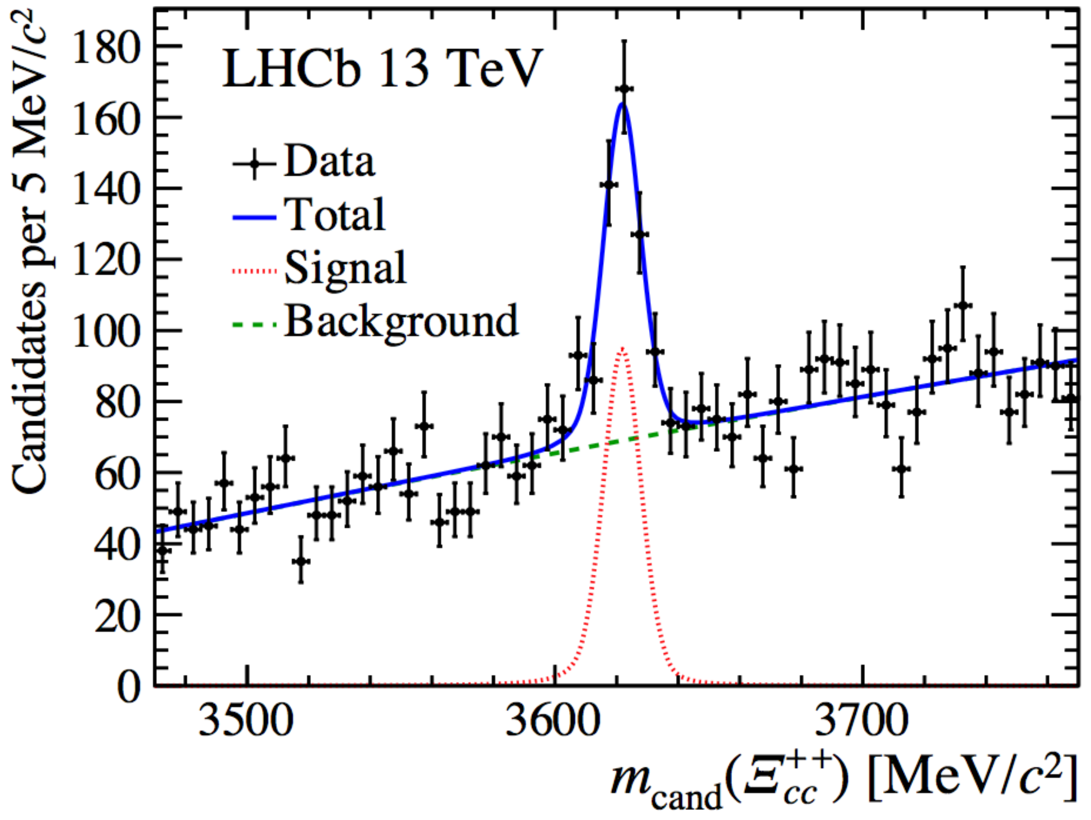
Modes	Br(first)($\times 10^{-3}$)	Br(final)($\times 10^{-3}$)	Representation
$p(D^+/D^0\pi^+)$	8.	0.2	Ccm Vcd Vud
$p(D_s^+/D^0K^+)$	0.4	0.01	Ccm Vcd Vus
$(pK^-\pi^+/\Sigma^+)(D^+/D^0\pi^+)$	80.	2.	Ccm Vcs Vud
$(pK^-\pi^+/\Sigma^+)(D_s^+/D^0K^+)$	3.	0.1	Ccm Vcs Vus
$(\Lambda_c^+\pi^+)(\pi^+\pi^-)$	3.	0.2	-(Ct Vcd Vud)
$(\Lambda_c^+\pi^+)(K^+\pi^-)$	0.2	0.008	Ct Vcd Vus
$(\Lambda_c^+\pi^+)(K^-\pi^+)$	50.	3.	Ct Vcs Vud
$(\Lambda_c^+\pi^+)(K^+K^-)$	2.	0.08	Ct Vcs Vus
$\Lambda_c^+\pi^+$	30.	1.	Ccb Vcd Vud + T Vcd Vud
$\Lambda_c^+K^+$	1.	0.06	Ccb Vcd Vus + T Vcd Vus
$(\Lambda_c^+\pi^+K^-/\Xi_c^+)\pi^+$	400.	20.	Ccb Vcs Vud + T Vcs Vud
$(\Lambda_c^+\pi^+K^-/\Xi_c^+)K^+$	20.	0.9	Ccb Vcs Vus + T Vcs Vus

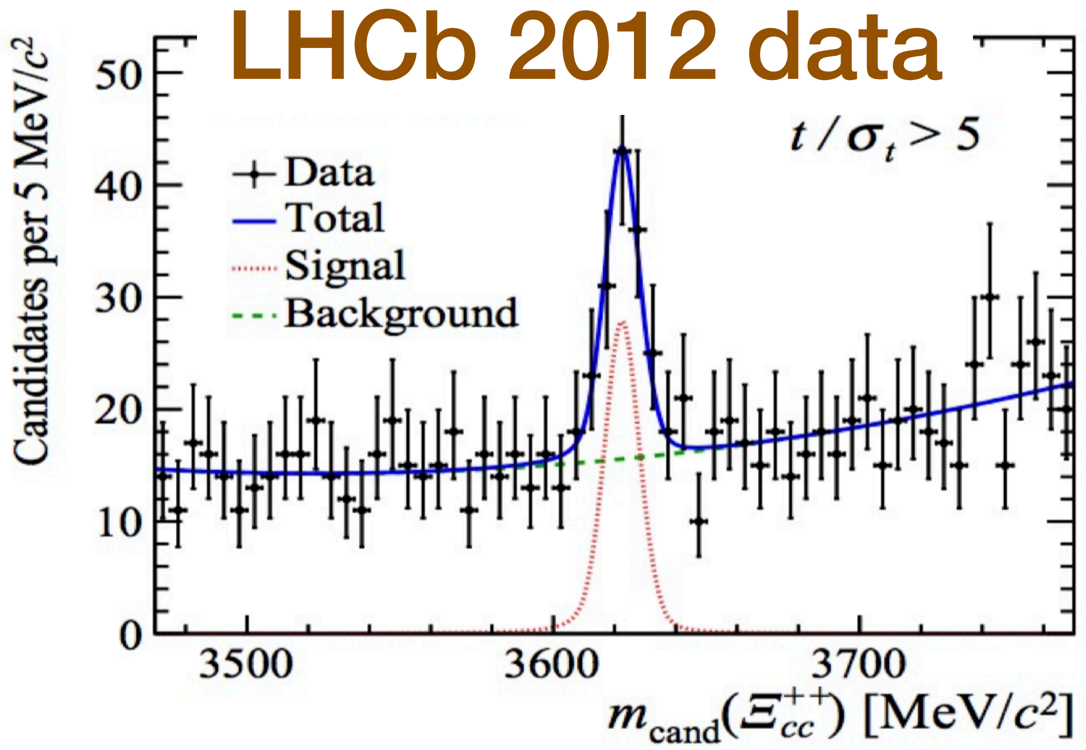
- discovery channels: Br=O($10^{-3\sim-4}$)

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

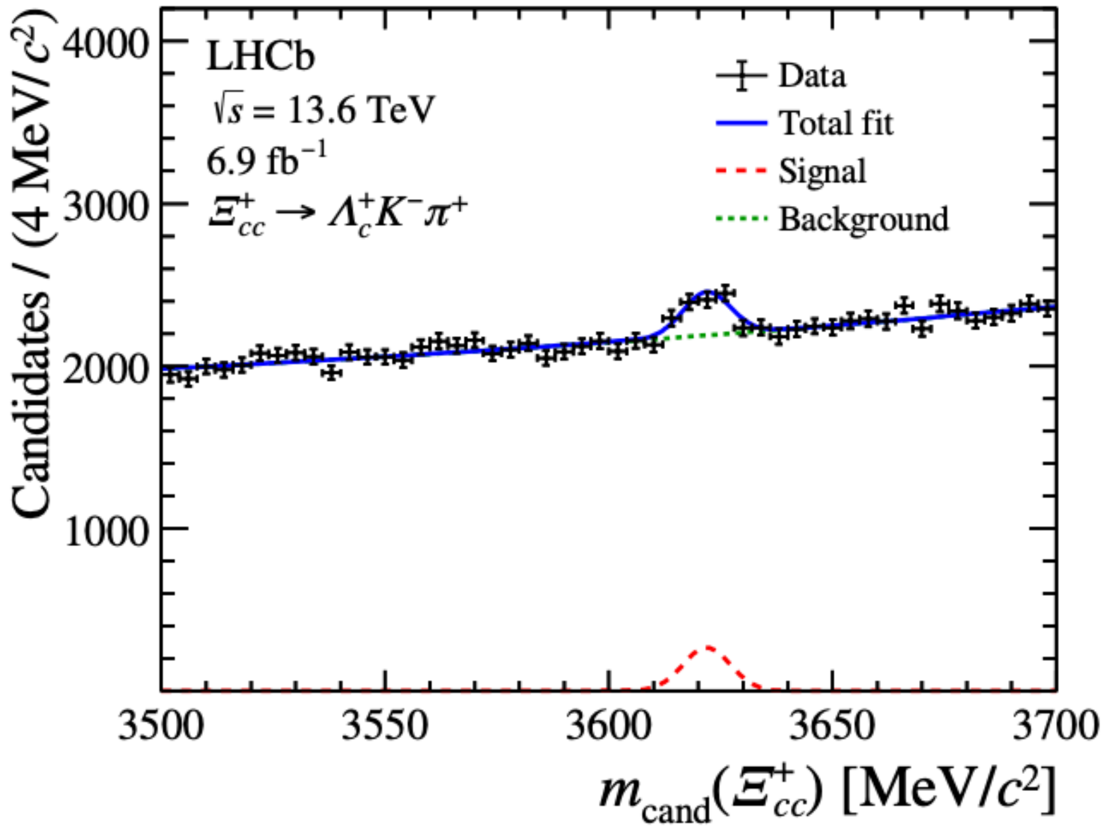
34

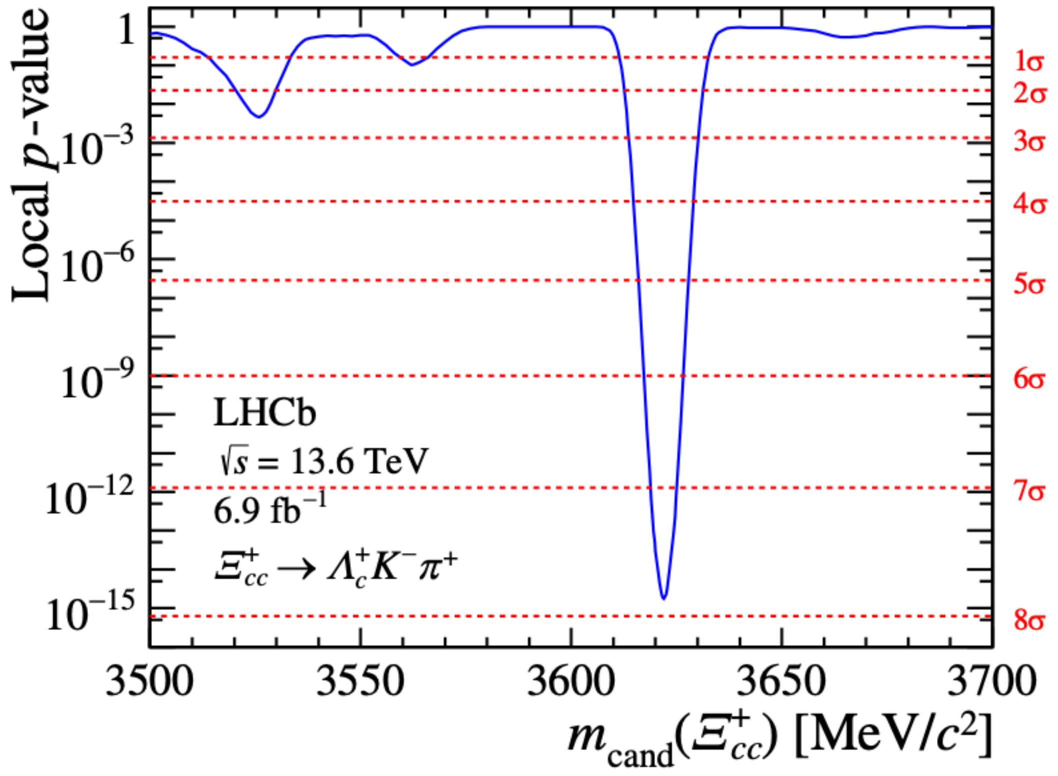
$\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$



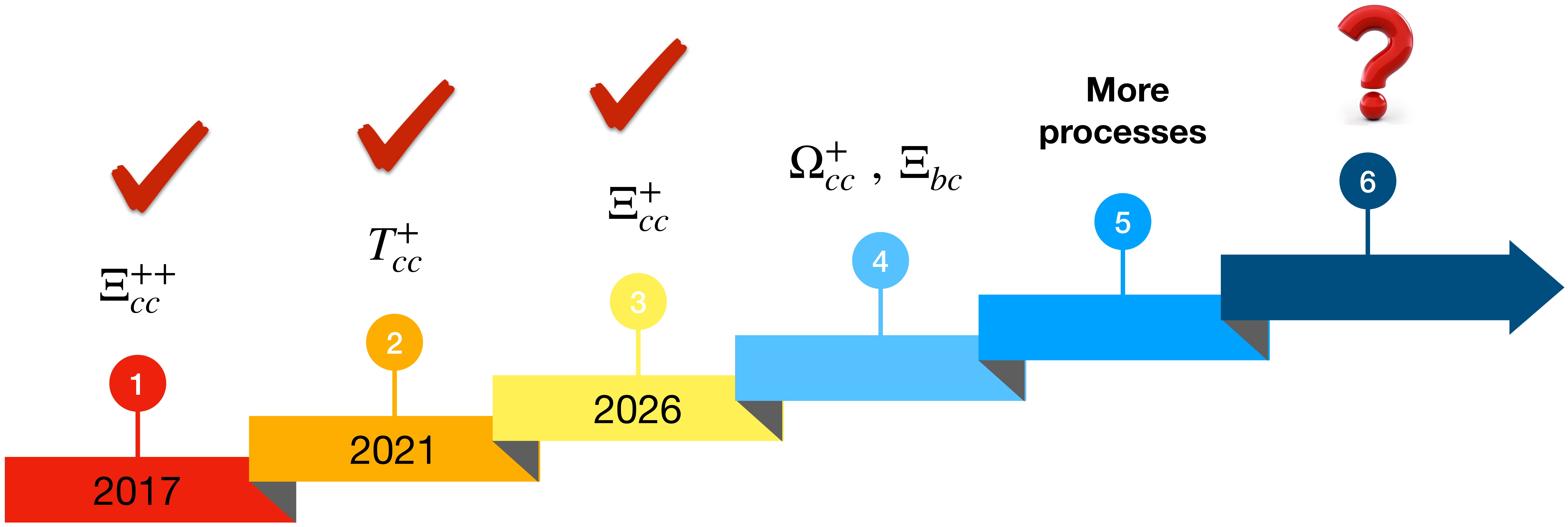


$\Xi_{cc}^{+} \to \Lambda_c^+ K^- \pi^+$

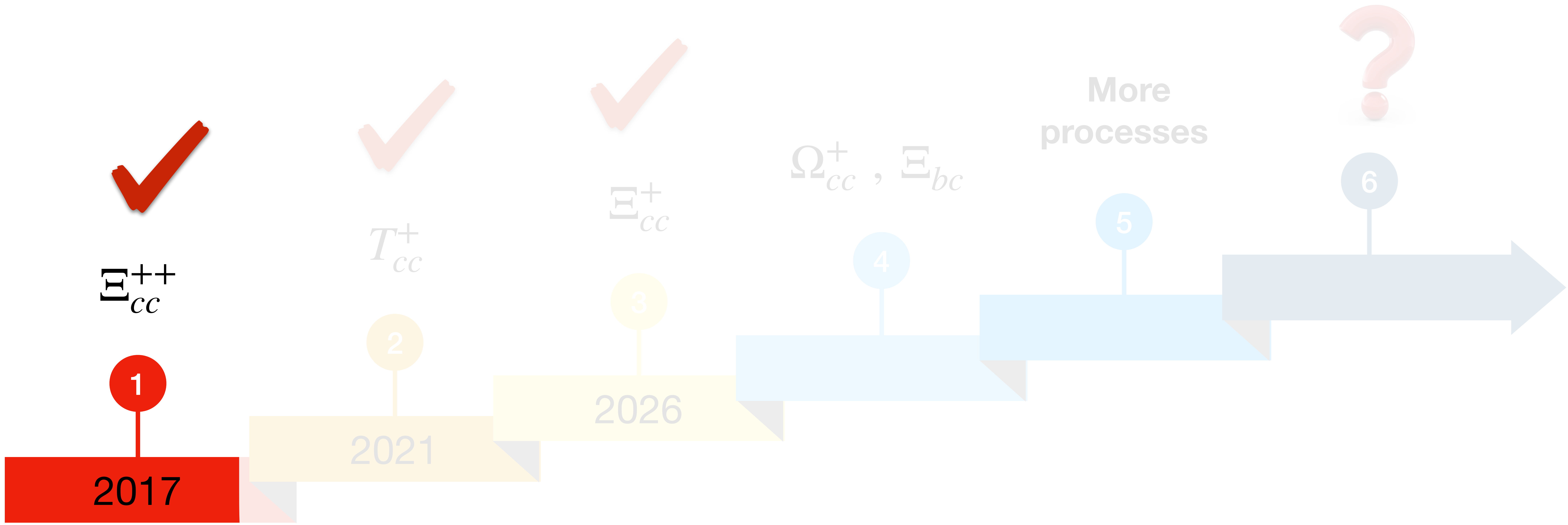




Double-heavy hadrons



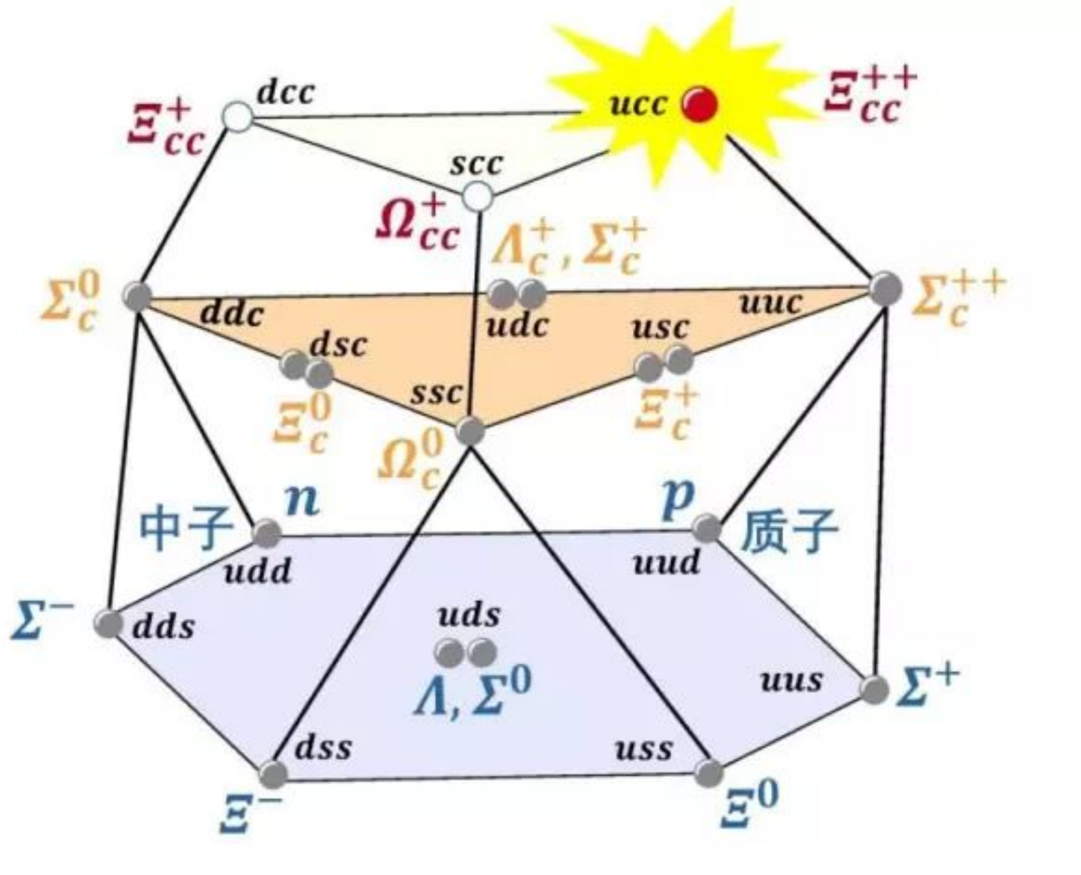
Double-heavy hadrons



Why double-heavy baryons?

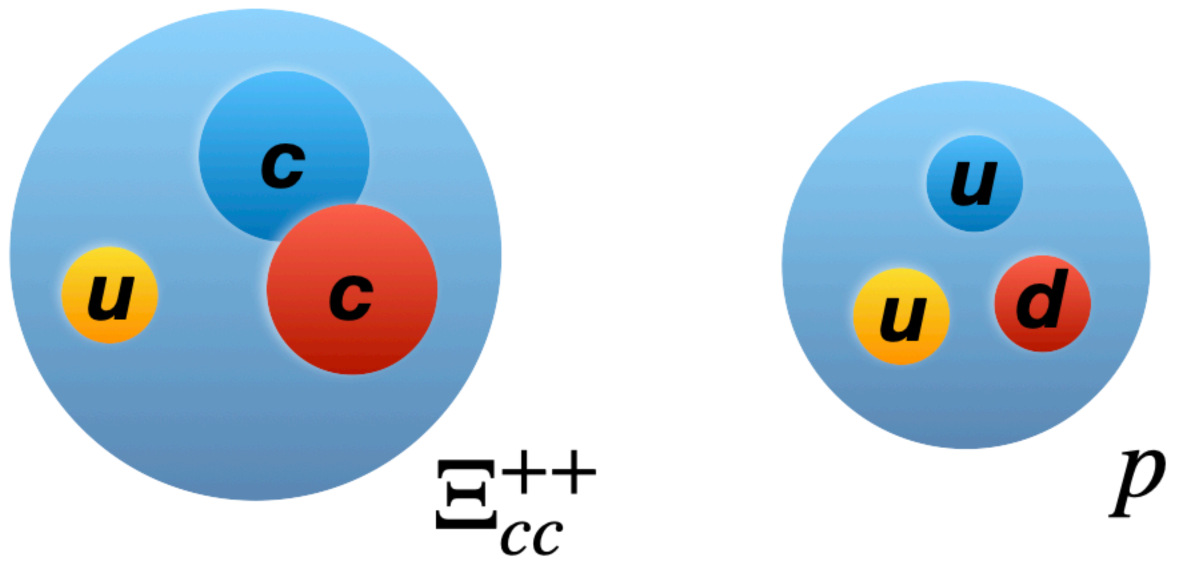
- Double-charm baryons are predicted in SU(4) quark model

  De Rujula, Georgi and Glashow, 1975;
  Jaffe, J. E. Kiskis, 1976; Ponce, 1979



- A heavy ‘double-star’ system with an attached light ‘planet’, much different from light baryons

- Open a new window for QCD properties



Role of Decay in the observation

- Two problems in the exp searches: Production and Decay

$$N \propto \sigma \cdot BR$$

- Production problem was solved at the beginning of LHC running

$$\sigma(pp \to \Xi_{cc}) \sim \sigma(pp \to B_c)$$

C.H.Chang, C.F.Qiao, J.X.Wang, X.G.Wu, 2005, 2006

X.G.Wu, Sci.China.PMA, 2020

- Decay properties are the key problem in the LHCb searches of doubly charmed baryons.

FSY, Sci.China.PMA, 2020

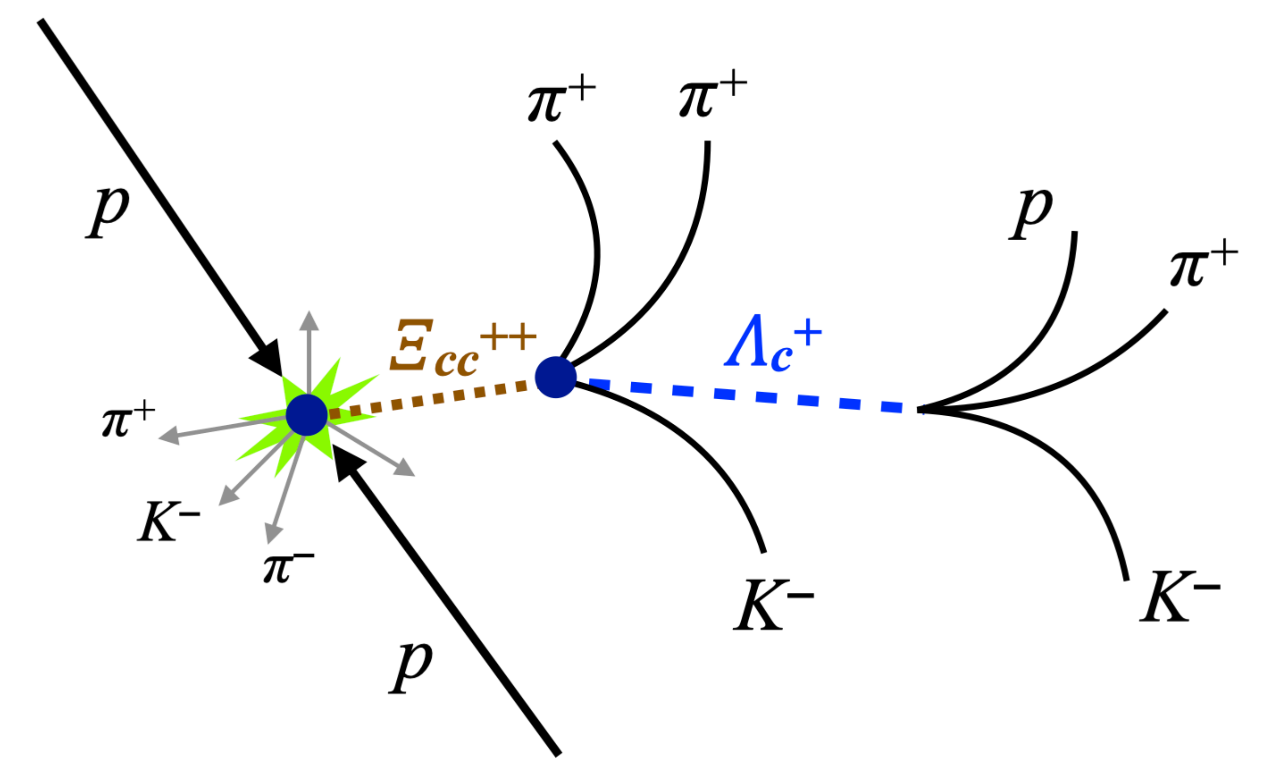
- Statistics requires: largest branching ratios and easily detected

Lifetime is important

1. Longer lifetime ⇒ Larger branching ratios

$$BR_i = \Gamma_i \cdot \tau$$

2. Longer lifetime ⇒ Higher efficiency to reject backgrounds in hadron colliders



- Large ambiguity in predictions
- But less ambiguity in the ratio

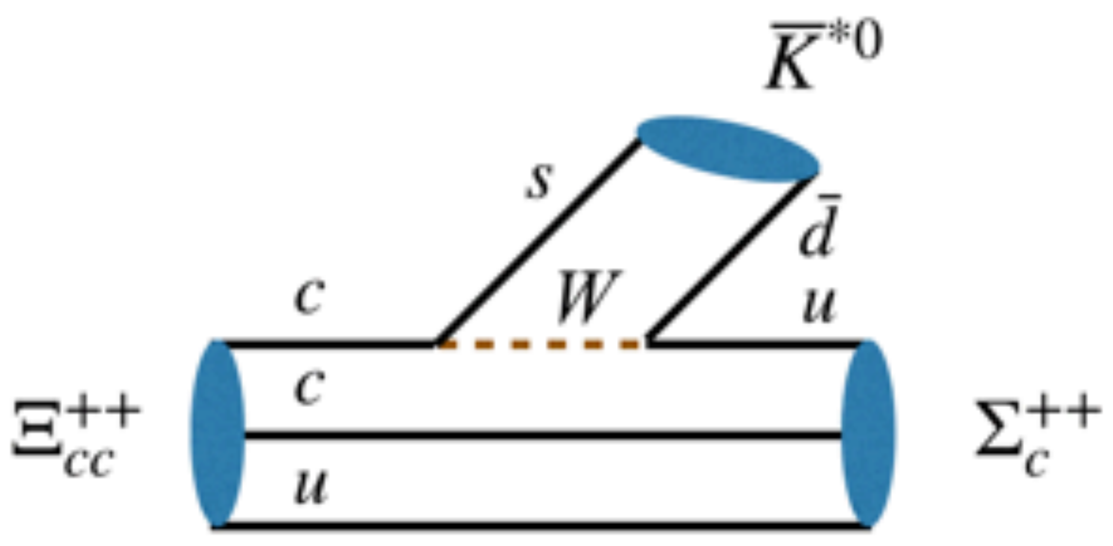
$$\tau(\Xi_{cc}^{++}) \gg \tau(\Xi_{cc}^{+})$$

- Recommend Ξ_{cc}^{++} rather than Ξ_{cc}^{+}

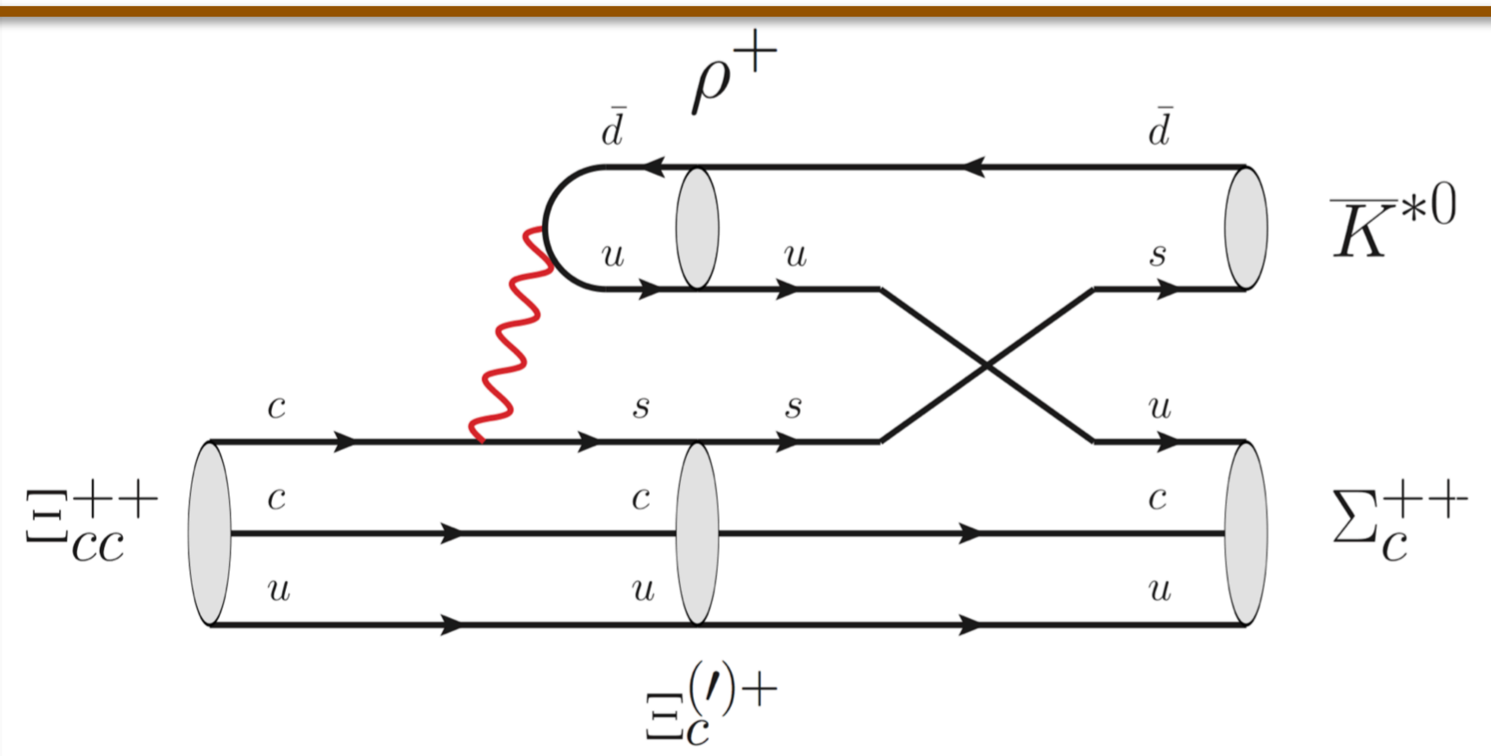
Literatures	Ξ_{cc}^{++} (fs)	Ξ_{cc}^{+} (fs)
Karliner, Rosner, 2014	185	53
Kiselev, Likhoded, 2002	460±50	160±50
Chang, Li, Li, Wang, 2007	670	250
Cheng, Shi, 2018	250	45

Decay amplitudes

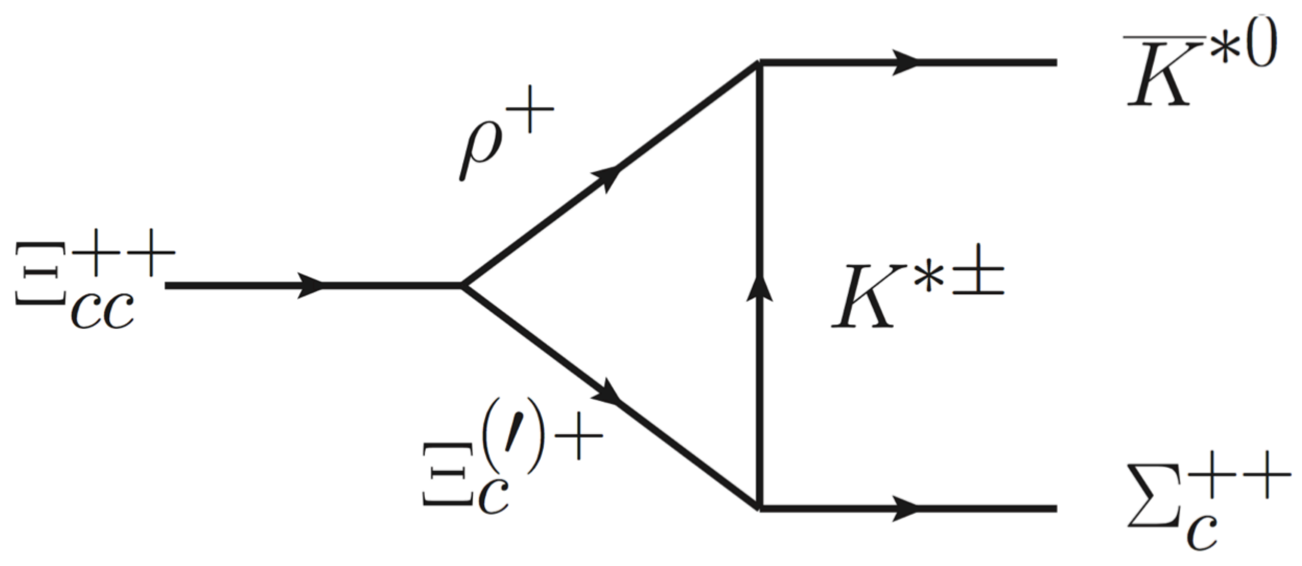
- Short-distance contributions: factorization
- Long-distance contributions: FSI rescattering



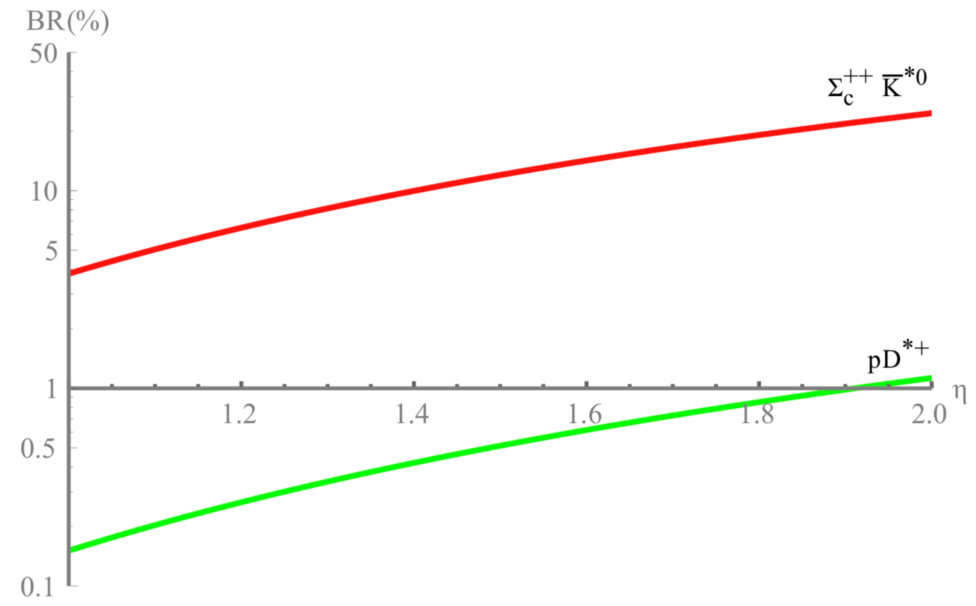
Topology: C



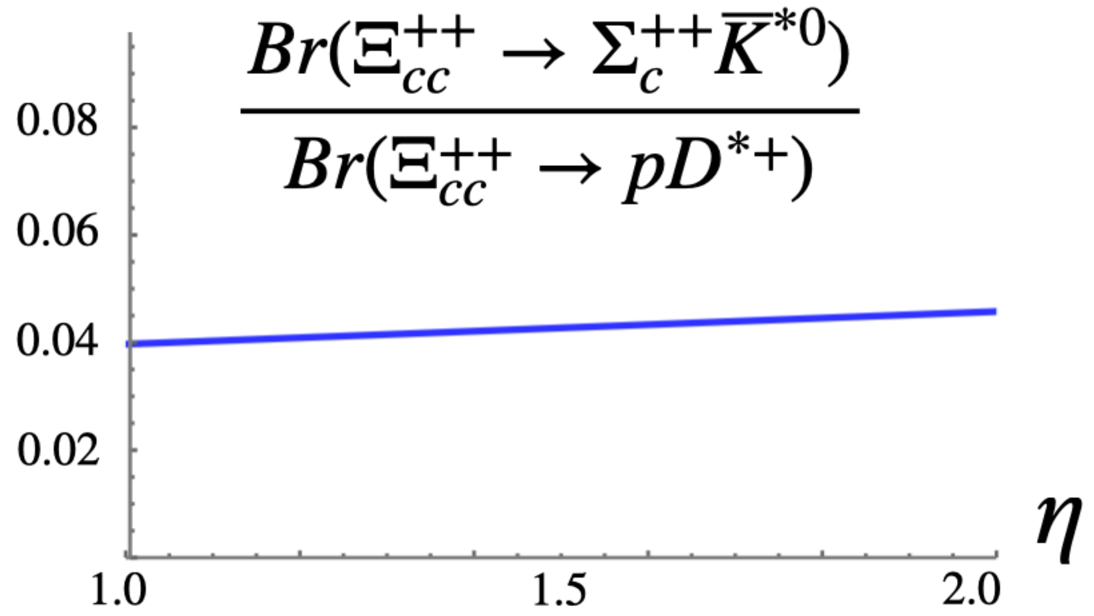
quark exchange



hadronic triangle



- Theoretical uncertainty is under control in the **ratio** of branching fractions of different processes



1703.09086

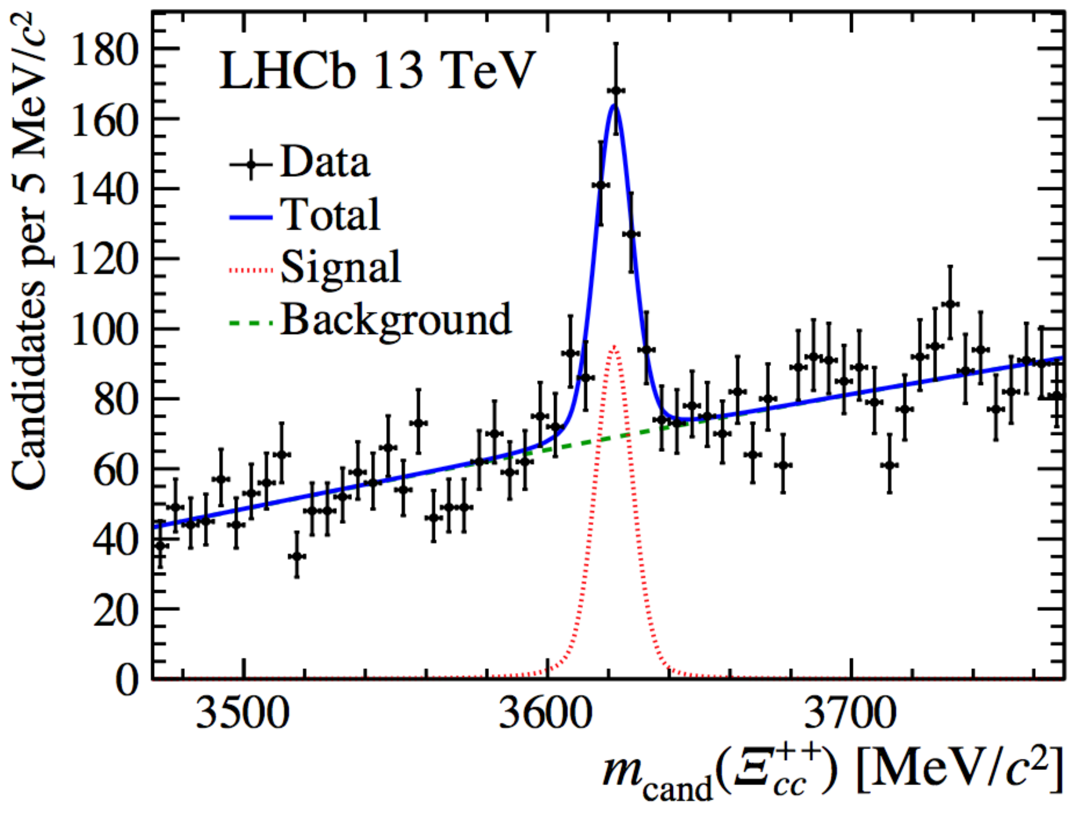
2102.00961

Chinese Physics C Vol. 42, No. 5 (2018) 051001

Discovery potentials of doubly charmed baryons *

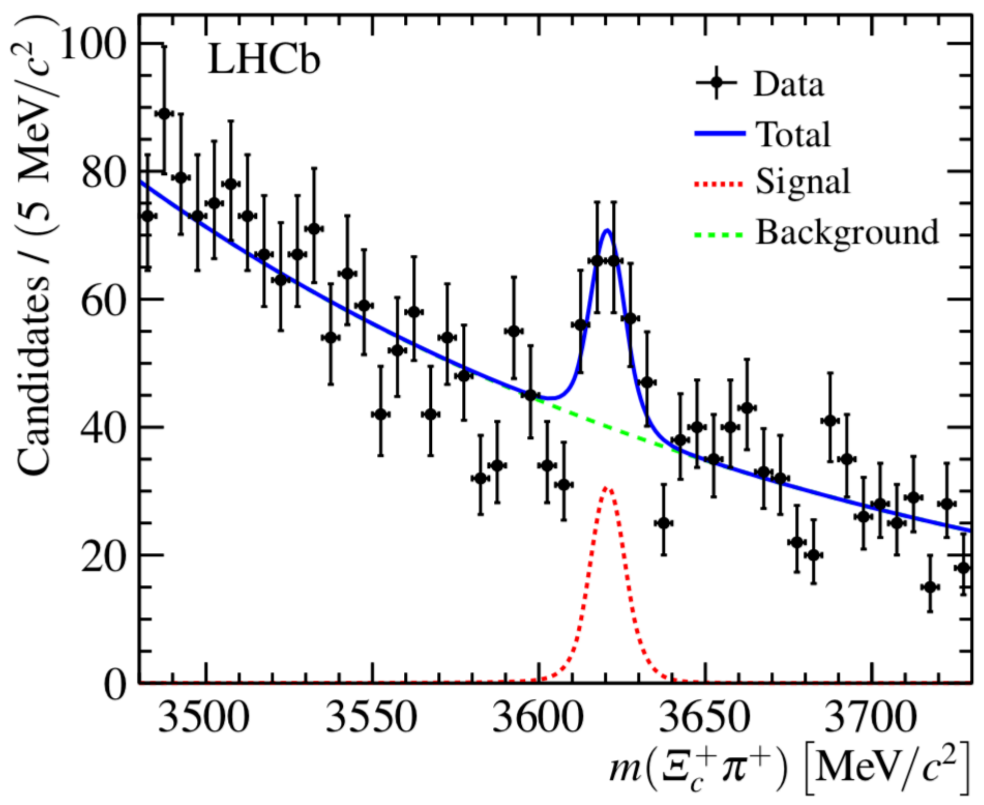
Fu-Sheng Yu(于福升)[1,2;1)] Hua-Yu Jiang(蒋华玉)[1,2] Run-Hui Li(李润辉)[3] Cai-Dian Lü(吕才典)[4,5;2)]
Wei Wang(王伟)[6;3)] Zhen-Xing Zhao(赵振兴)[6]

$\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$ and $\Xi_c^+ \pi^+$ are the most favorable decay modes



July 2017

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



July 2018

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

Implications of Ξ_{cc}^{++} for hadron spectroscopy

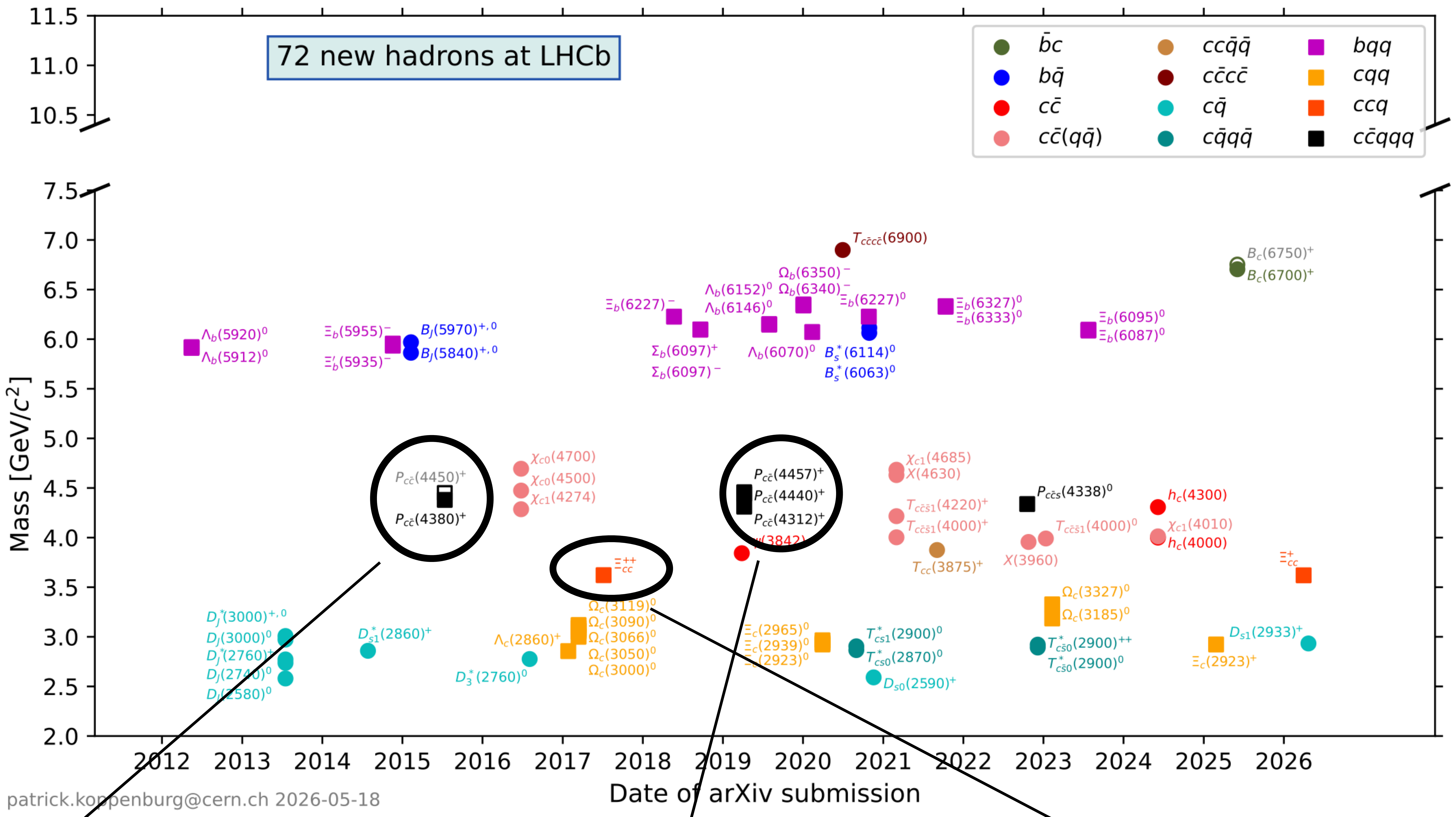
☑强子周期表：增加一个新的周期

	2夸克	3夸克	4夸克	5夸克
纯轻	π, K	p, n, Λ	$a_0(980)$	$\Lambda(1405)$?
单重Q	D, B	Λ_c, Λ_b	$T_{c\bar{s}}(2900)$	$\Lambda_c(2940)$?
双重$Q\overline{Q}$	$J/\Psi, \Upsilon$		$Z_c(3900)$	$P_c(4312)$
双重QQ		Ξ_{cc}		

☑粒子数据表：增加一个新的粒子种类

The Review of Particle Physics (PDG)

Implications of Ξ_{cc}^{++} for hadron spectroscopy



Observation of $J/\psi p$ Resonances Consistent with Pentaquark States in $\Lambda_b^0 \to J/\psi K^- p$ Decays #2

LHCb Collaboration • Roel Aaij (CERN) et al. (Jul 13, 2015)

Published in: *Phys.Rev.Lett.* 115 (2015) 072001 • e-Print: 1507.03414 [hep-ex]

pdf links DOI cite claim

reference search 2,150 citations

Observation of a narrow pentaquark state, $P_c(4312)^+$, and of two-peak structure of the $P_c(4450)^+$ #9

LHCb Collaboration • Roel Aaij (NIKHEF, Amsterdam) et al. (Apr 8, 2019)

Published in: *Phys.Rev.Lett.* 122 (2019) 22, 222001 • e-Print: 1904.03947 [hep-ex]

pdf links DOI cite datasets claim

reference search 1,043 citations

Observation of the doubly charmed baryon Ξ_{cc}^{++} #17

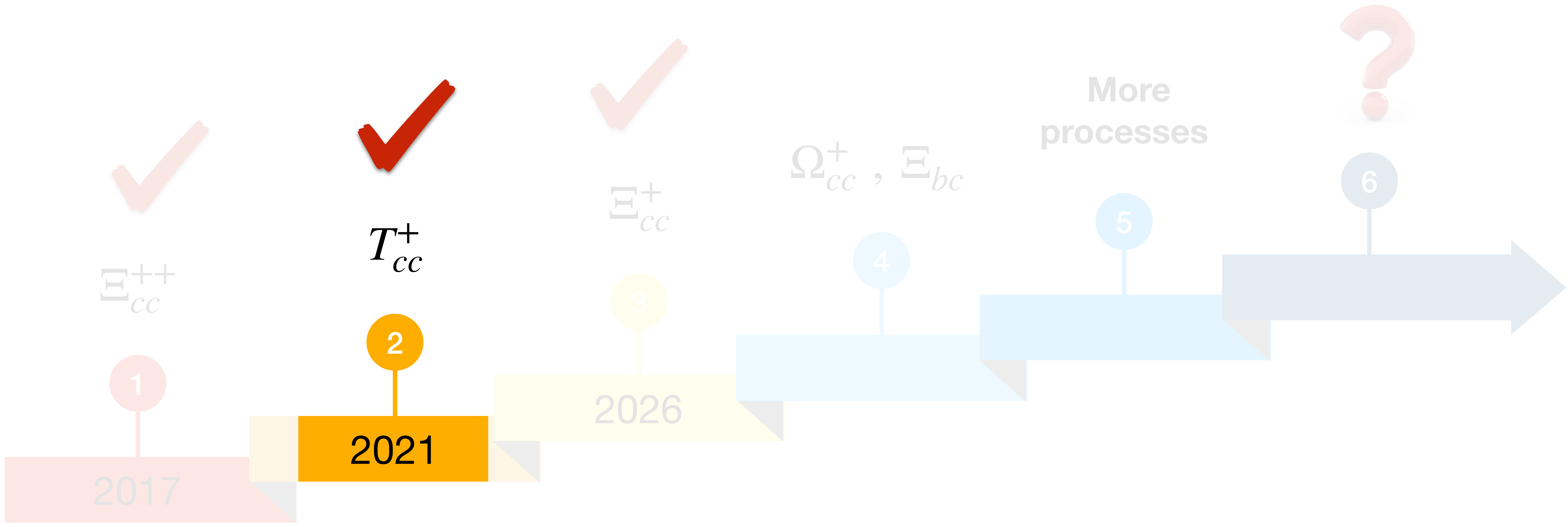
LHCb Collaboration • Roel Aaij (CERN) et al. (Jul 5, 2017)

Published in: *Phys.Rev.Lett.* 119 (2017) 11, 112001 • e-Print: 1707.01621 [hep-ex]

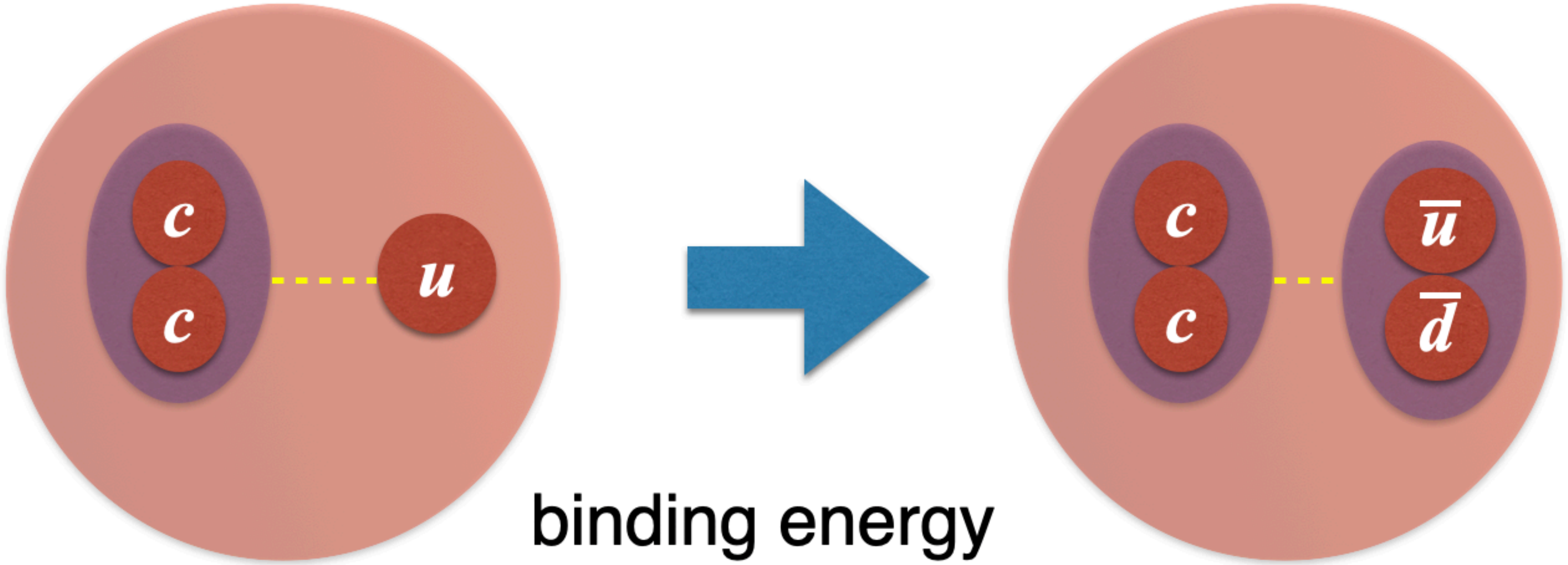
pdf links DOI cite claim

reference search 669 citations

Double-heavy hadrons



Implications of Ξ_{cc}^{++} for hadron spectroscopy



binding energy
of cc-diquark

Ξ_{cc}^{+}

cc-Tetraquark

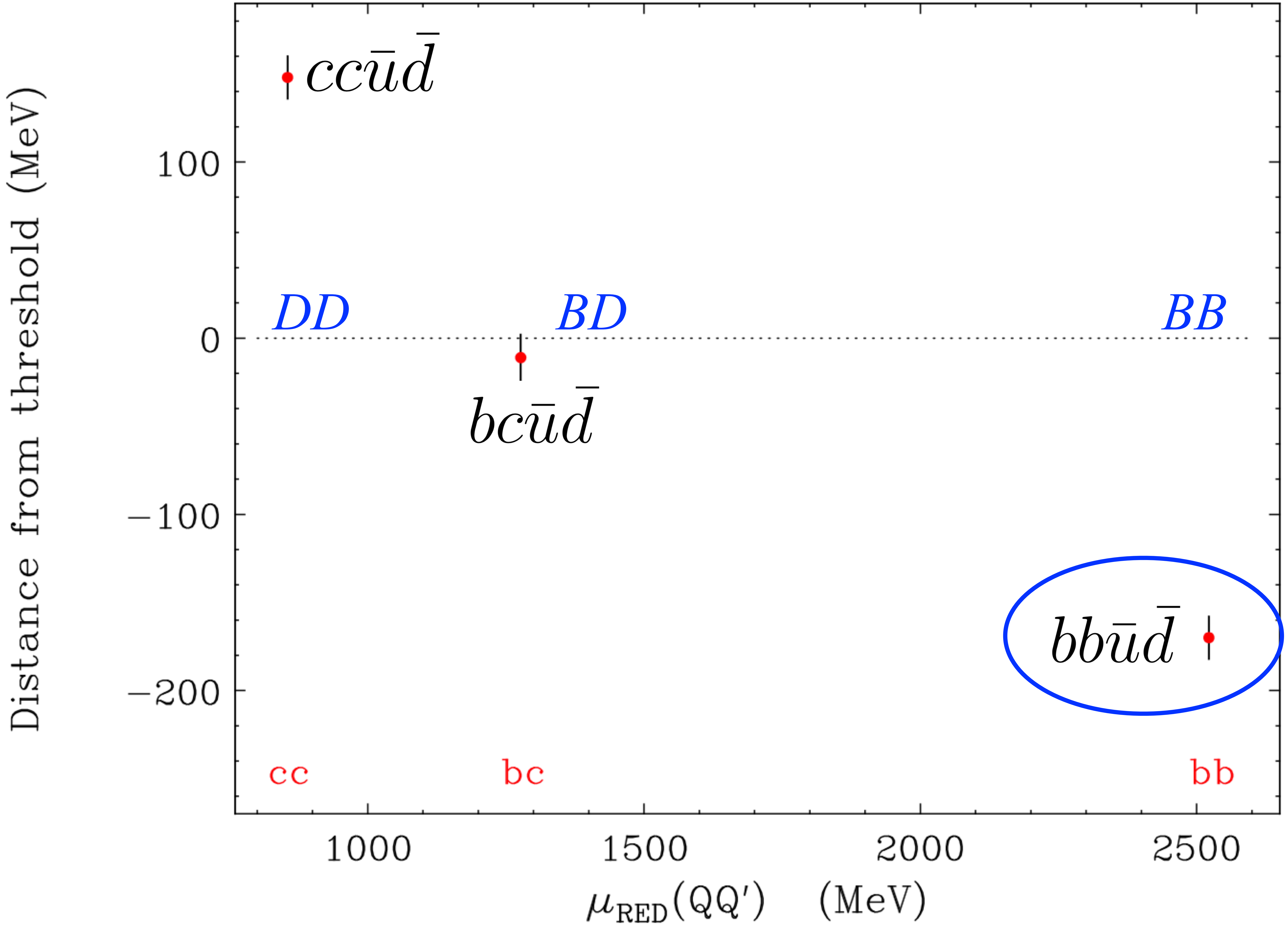
[LHCb, 1707.01621]

[Karliner, Rosner, 1707.07666]

[Eichten, Quigg, 1707.09575]

MeV

[Karliner, Rosner, 1707.07666]



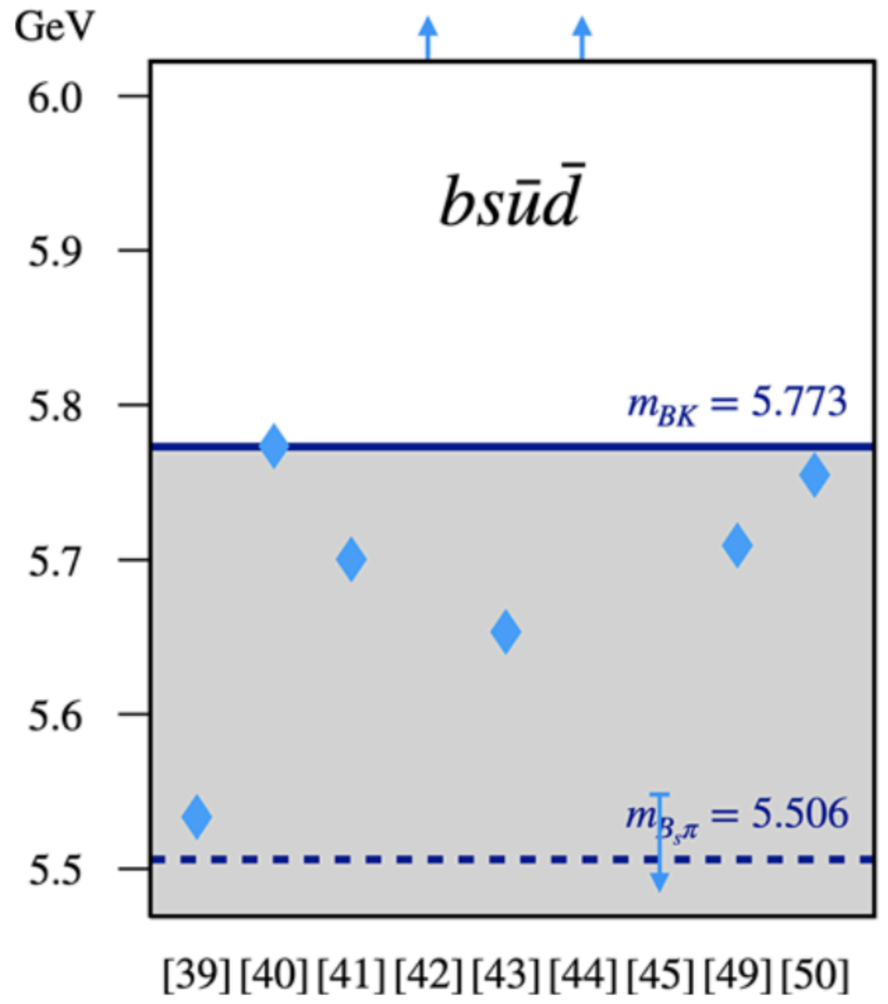
thresholds

Weakly decay tetraquark

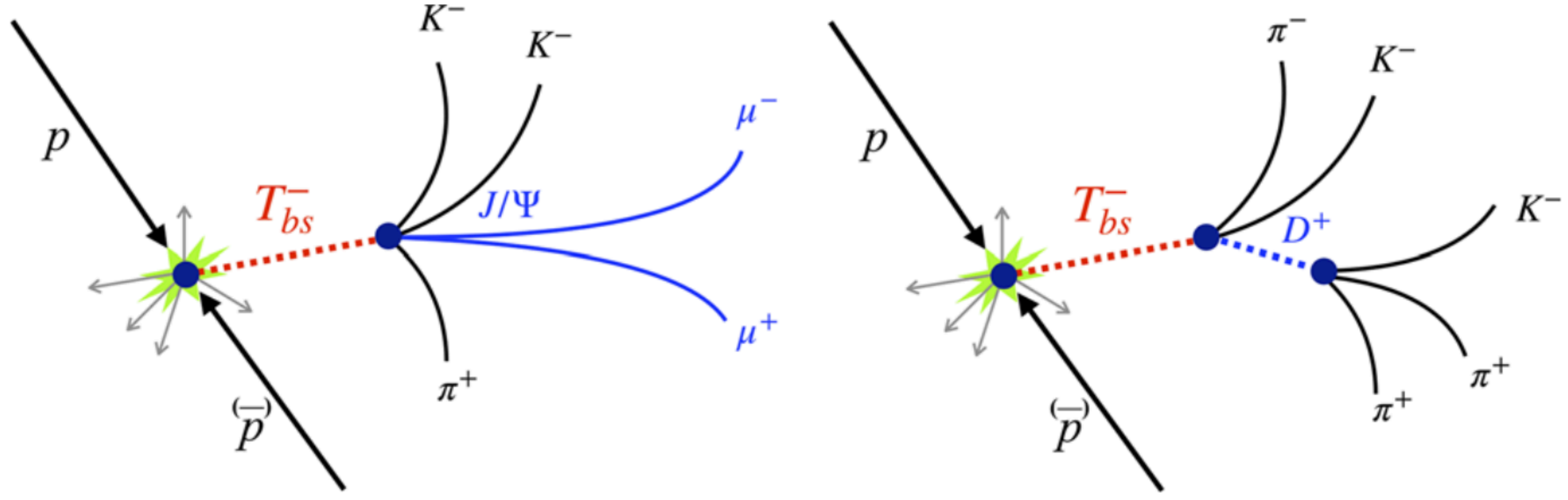
But difficult to observe by low production and decay rate

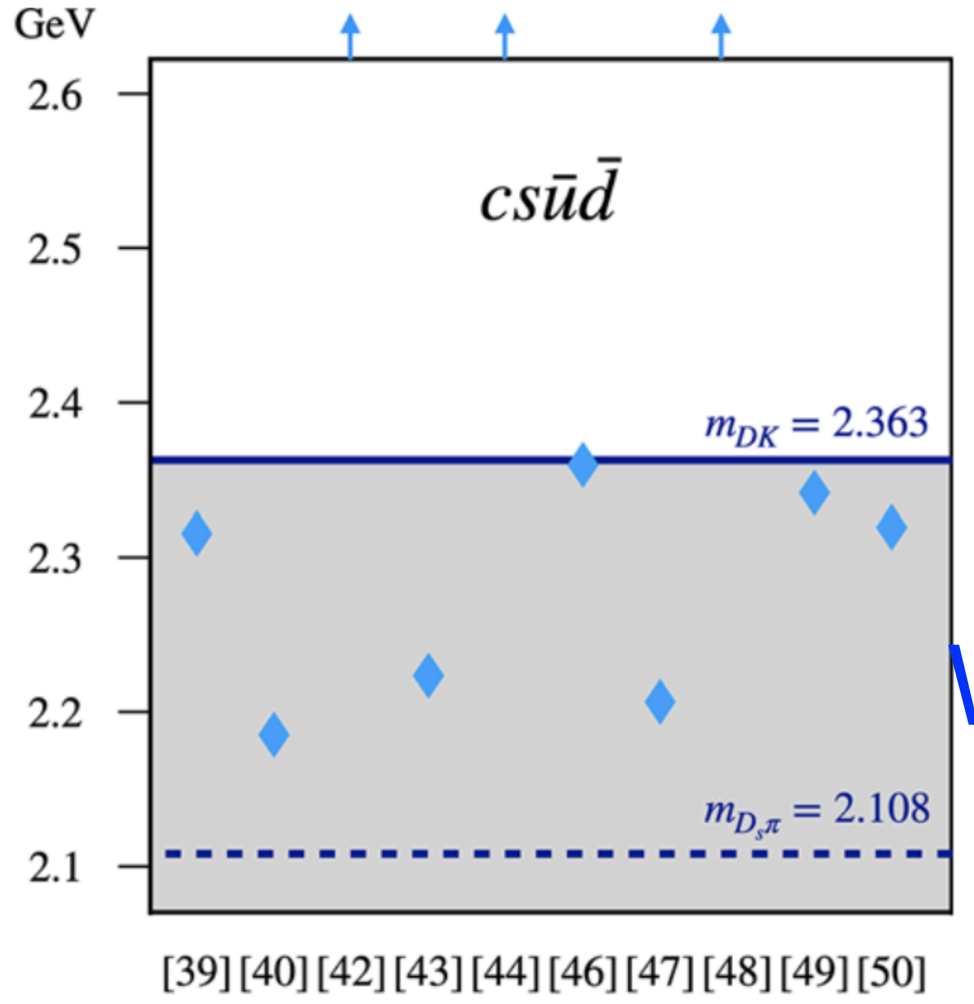
Weak-decay searches for $Qs\bar{u}\bar{d}$ tetraquarks

FSY, 1709.02571

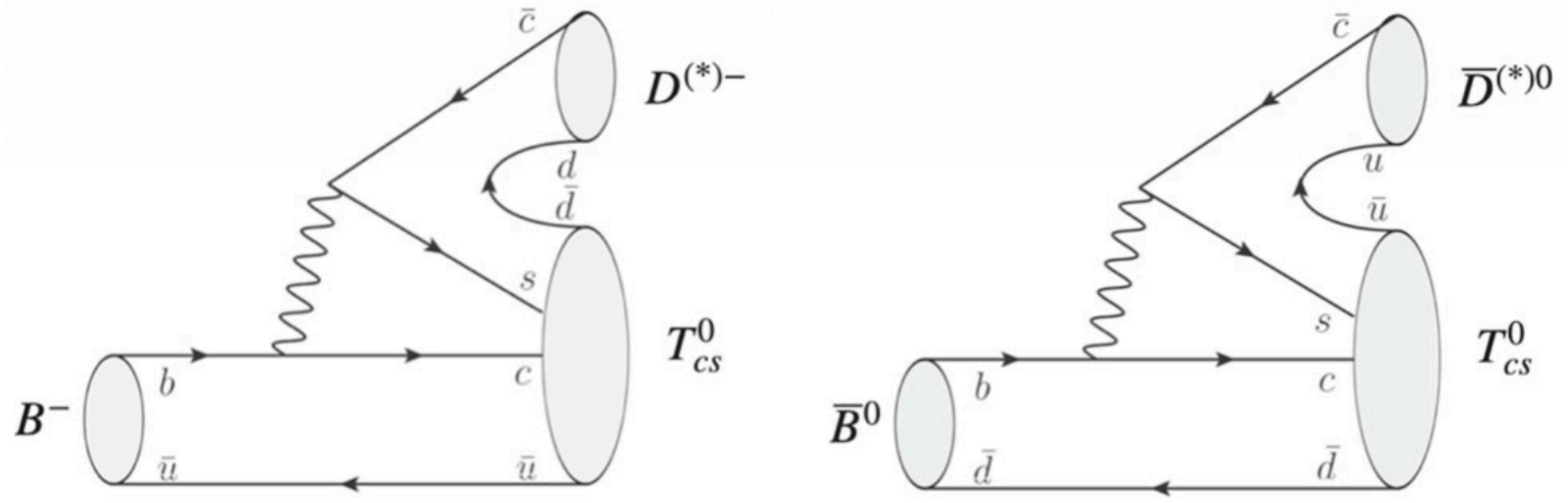


Weakly decay





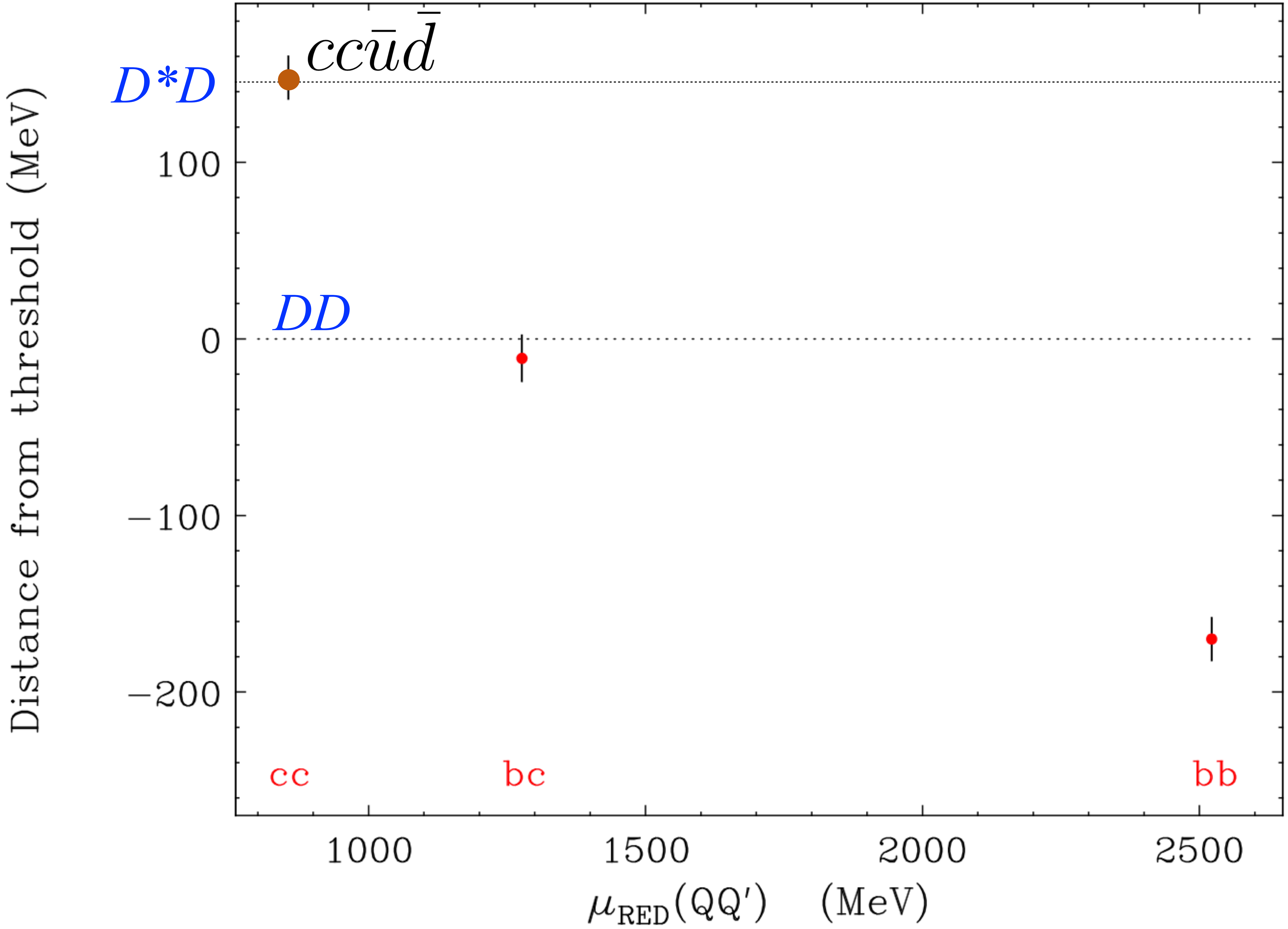
Weakly decay



$$T_{cs}^0 \to K^- K^- \pi^+ \pi^+$$

MeV

[Karliner, Rosner, 1707.07666]



Reduced masses of diquarks

Fully reconstructed: $T_{cc}^{+} \to D^0 D^{*+}$

Compared with $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$ $\quad u \leftrightarrow \bar{u}\bar{d}$

Production

final prod $\quad f_{\Lambda_b} / f_{B_u} \sim 0.5$

primarily prod $\quad f_{\Sigma_b^{(*)}} / f_{\Lambda_b} \sim 1$

$$\frac{f_{T_{cc}}}{f_{\Xi_{cc}}} \sim \frac{1}{4}$$

Decay $\quad Br(\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+)\ Br(\Lambda_c^+ \to p K^- \pi^+)$ one track more

10% $\quad$ 6% $\quad$ 1/3

$$\sim Br(T_{cc} \to D^0 D^{*+})\ Br(D^{*+} \to D^0 \pi^+)\ Br(D^0 \to K^- \pi^+)^2$$

1/2 $\quad$ 2/3 $\quad$ $(4\%)^2$

$$\longrightarrow Br(T_{cc})/Br(\Xi_{cc}^{++}) \sim 1/4$$

LHCb Run 2: 1500 events of $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+ \longrightarrow$ 100 events of Tcc

Qin, Shen, **FSY**, 2008.08026

Discovery of T_{cc}

Discovery potentials of double-charm tetraquarks

We find that their production cross sections at the LHCb with $\sqrt{s} = 13$ TeV reach $\mathcal{O}(10^4)$ pb, which indicate that the LHCb has collected $\mathcal{O}(10^8)$ such particles. Through the decay channels of $T^{\{cc\}}_{[\bar{u}\bar{d}]} \to D^+K^-\pi^+$ or $D^0D^+\gamma$ (if stable) or $T^{\{cc\}}_{[\bar{u}\bar{d}]} \to D^0D^{*+}$ (if unstable), it is highly hopeful that they get discovered at the LHCb in the near future. We also discuss the productions and decays of the double-charm tetraquarks at future Tera-Z factories.

branching fractions of $T^{\{cc\}}_{[\bar{u}\bar{d}]}$ decays is the same as the observed Ξ^{++}_{cc}. Comparing with the production rates between double-charm tetraquarks and baryons, and considering around 2×10^3 events of Ξ^{++}_{cc} with the current LHCb data, the signal yields of $T^{\{cc\}}_{[\bar{u}\bar{d}]}$ would be $\mathcal{O}(10^2)$ at LHCb, and will reach $\mathcal{O}(10^3)$ at LHCb Run III. Thus it is hopefully expected that the double-charm tetraquark will be observed in the near future. Although the production rates are smaller at the future Z factories, it is also expected to be observed at the Tera-Z factories due to the smaller backgrounds.

- Correct discovery channel
- Correct signal yields

Qin, Shen, **FSY**, 2008.08026

nature physics LETTERS
https://doi.org/10.1038/s41567-022-01614-y
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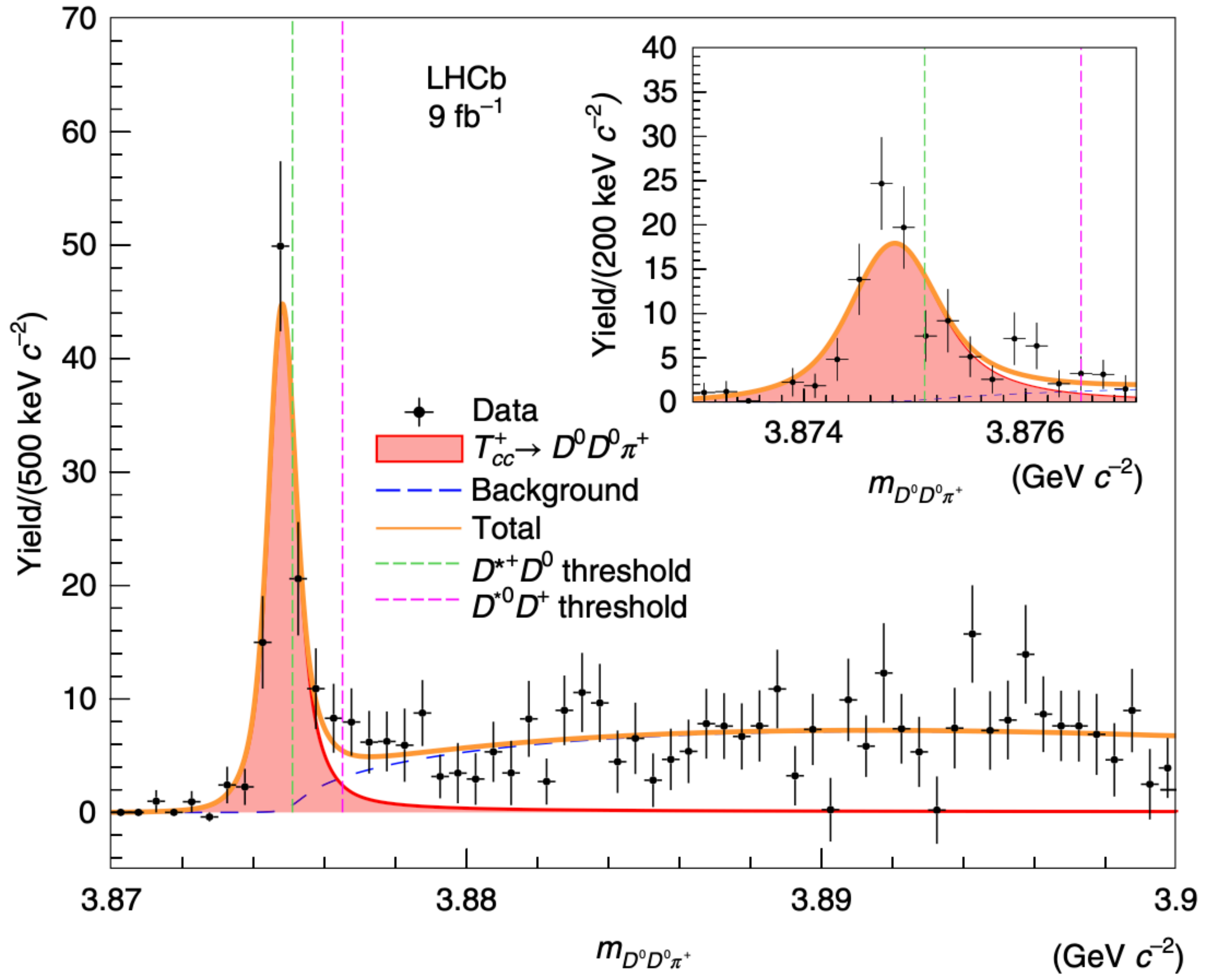
Observation of an exotic narrow doubly charmed tetraquark

LHCb Collaboration*

NATURE PHYSICS | VOL 18 | JULY 2022 | 751–754 |

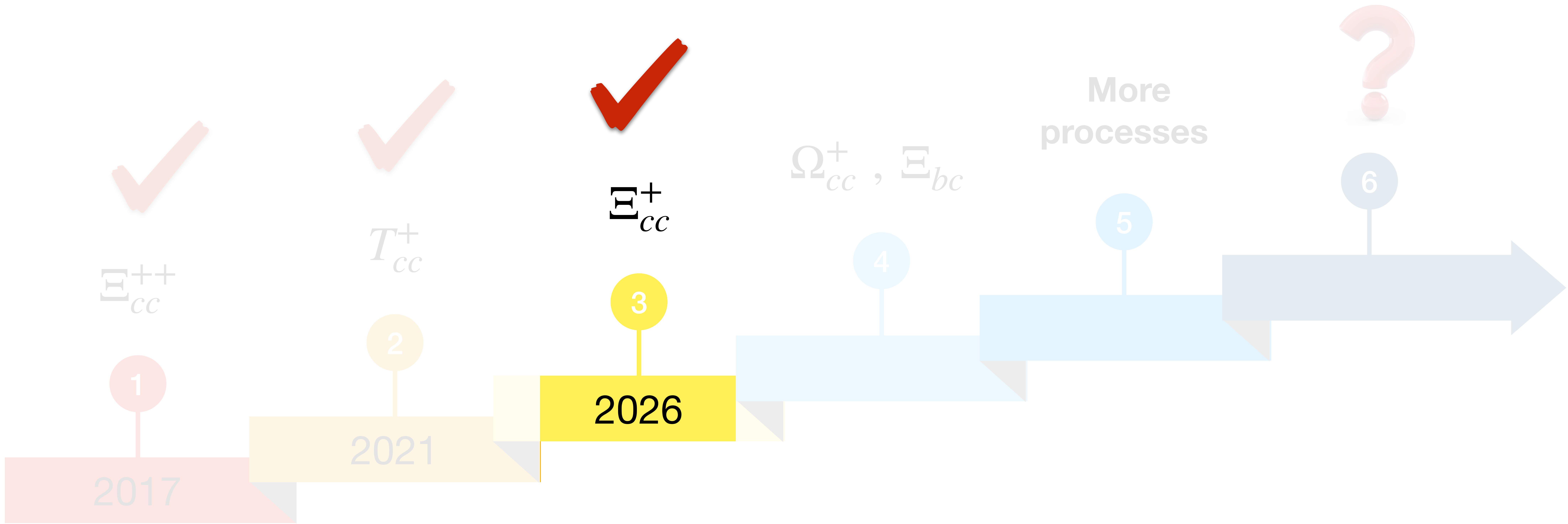


Parameter	Value
N	117 ± 16

Implications of Ξ_{cc}^{++} for hadron spectroscopy

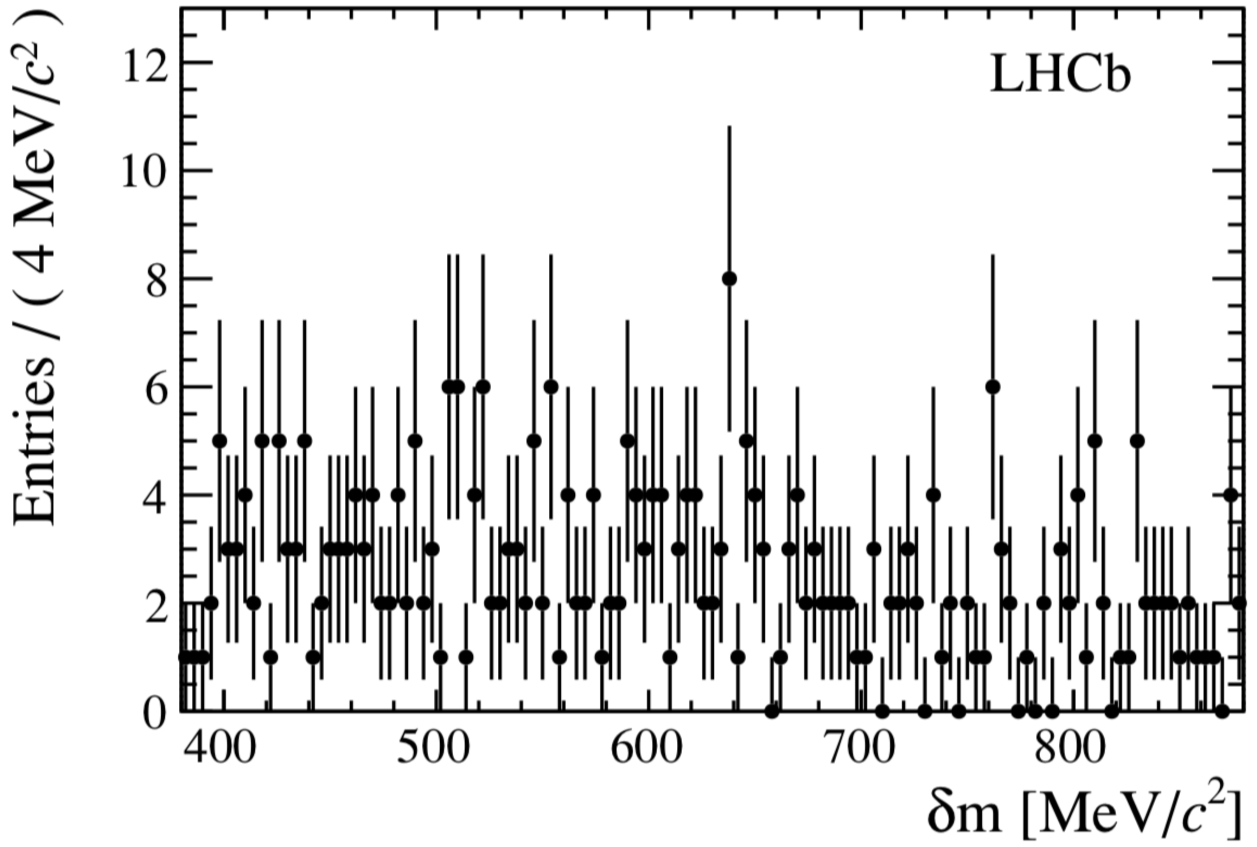
	2夸克	3夸克	4夸克	5夸克
纯轻	π, K	p, n, Λ	$a_0(980)$	$\Lambda(1405)$?
单重Q	D, B	Λ_c, Λ_b	$T_{c\bar{s}}(2900)$	$\Lambda_c(2940)$?
双重$Q\overline{Q}$	$J/\Psi, \Upsilon$		$Z_c(3900)$	$P_c(4312)$
双重QQ		Ξ_{cc}	T_{cc}	?

Double-heavy hadrons

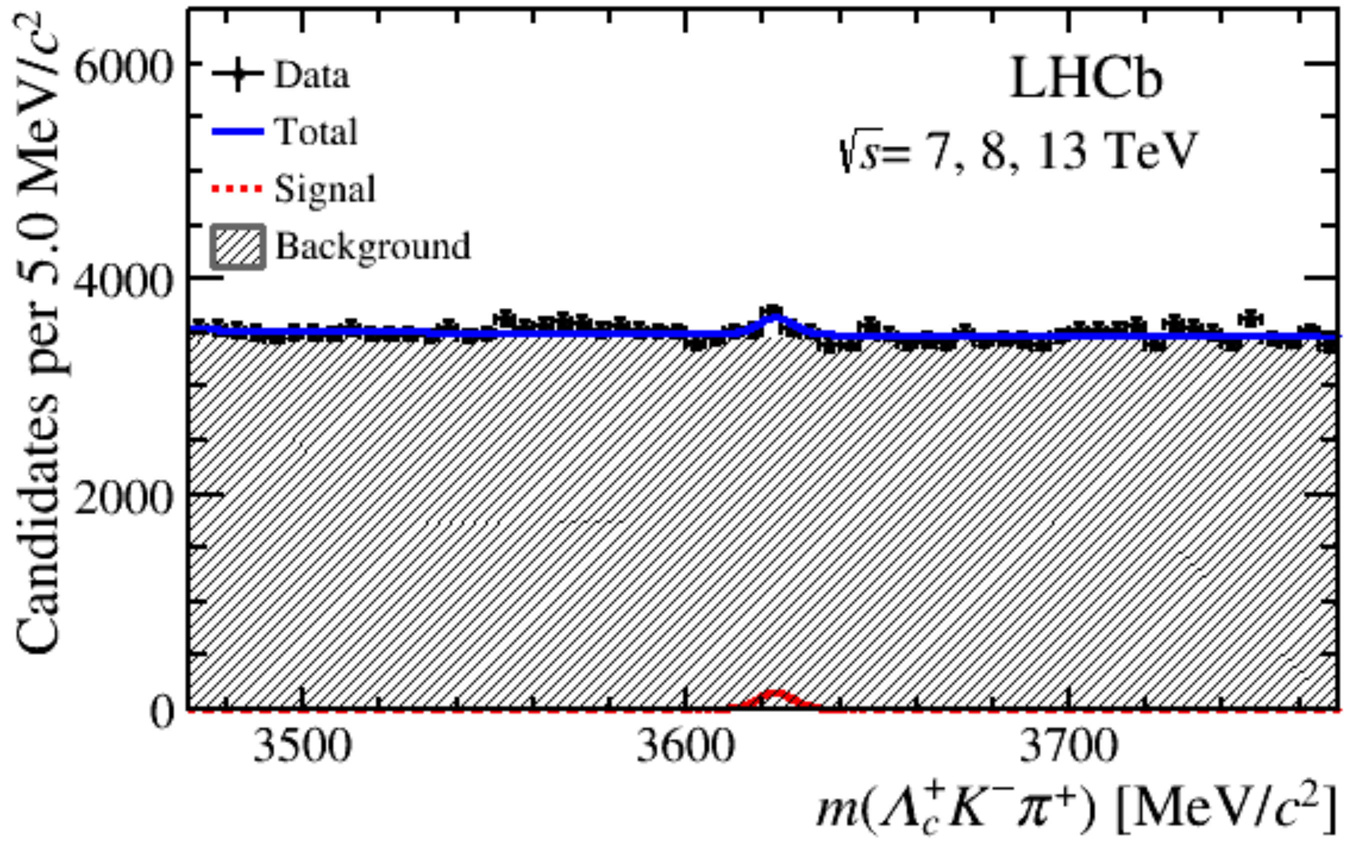


$$\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+}$$

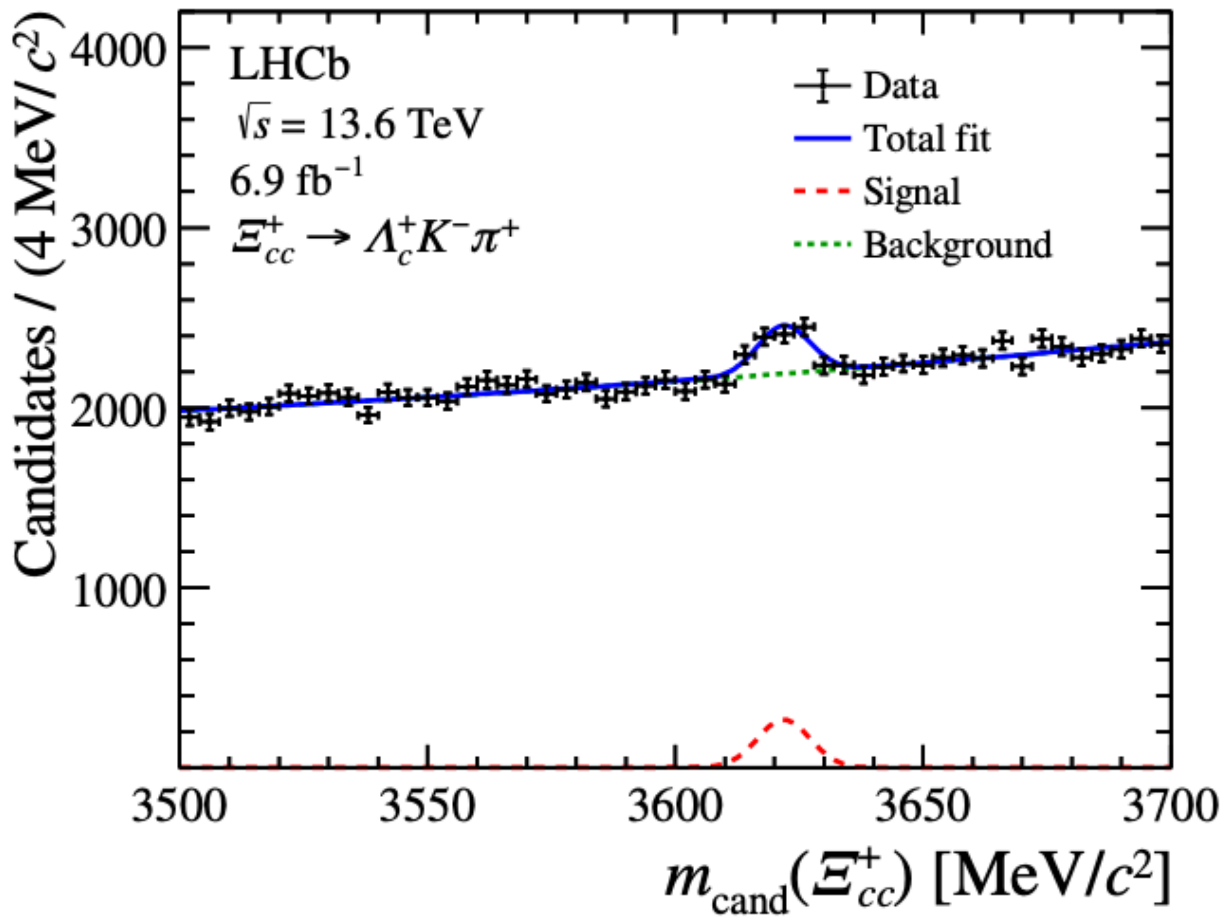
LHCb 2013



LHCb 2019



LHCb 2026



Double-charm baryons: Ξ_{cc}^{+}

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

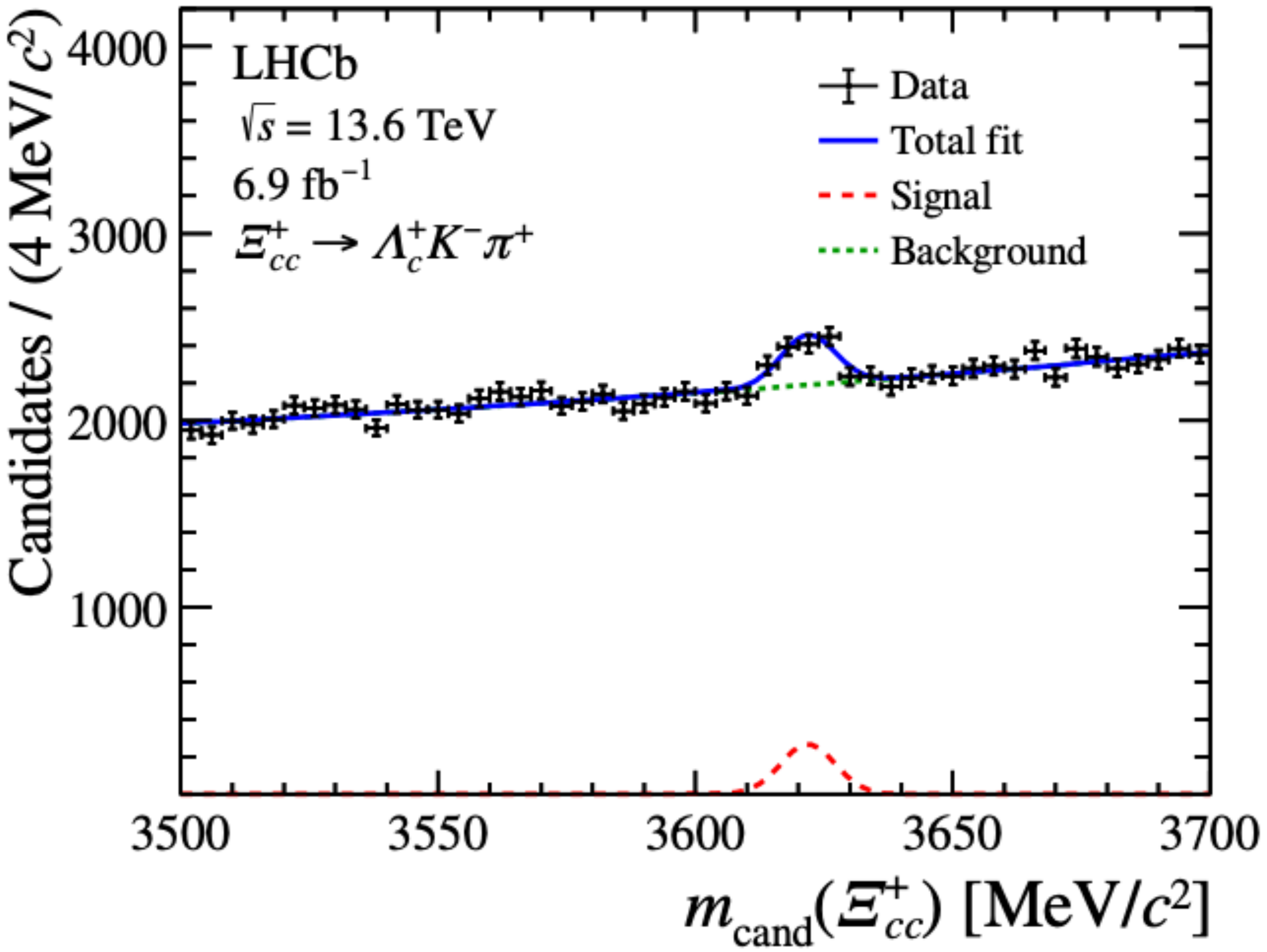
Chinese Physics C Vol. 42, No. 5 (2018) 051001

Discovery potentials of doubly charmed baryons *

Fu-Sheng Yu(于福升)[1,2;1)] Hua-Yu Jiang(蒋华玉)[1,2] Run-Hui Li(李润辉)[3] Cai-Dian Lü(吕才典)[4,5;2)]
Wei Wang(王伟)[6;3)] Zhen-Xing Zhao(赵振兴)[6]

baryons	modes	$\mathcal{B}_{\rm LD}$
$\Xi_{cc}^{++}(ccu)$	$\Sigma_c^{++}(2455)\overline{K}^{*0}$	defined as 1
	pD^{*+}	0.04
	pD^{+}	0.0008
$\Xi_{cc}^{+}(ccd)$	$\Lambda_c^{+}\overline{K}^{*0}$	$(\mathcal{R}_\tau/0.3)\times0.22$
	$\Sigma_c^{++}(2455)K^{-}$	$(\mathcal{R}_\tau/0.3)\times0.01$
	$\Xi_c^{+}\rho^{0}$	$(\mathcal{R}_\tau/0.3)\times0.04$
	ΛD^{+}	$(\mathcal{R}_\tau/0.3)\times0.004$
	pD^{0}	$(\mathcal{R}_\tau/0.3)\times0.001$

$\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+}$ is the most promising



LHCb, 2603.28456

Double-charm baryons: Ξ_{cc}^{+}

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

$\mathcal{BR}(\Xi_{cc}^{+} \to \Xi_{c}^{+}\rho^{0}) \in [0.4\%, 2.5\%]$

L.J.Jiang, R.H.Li, *et al*, 1810.00541

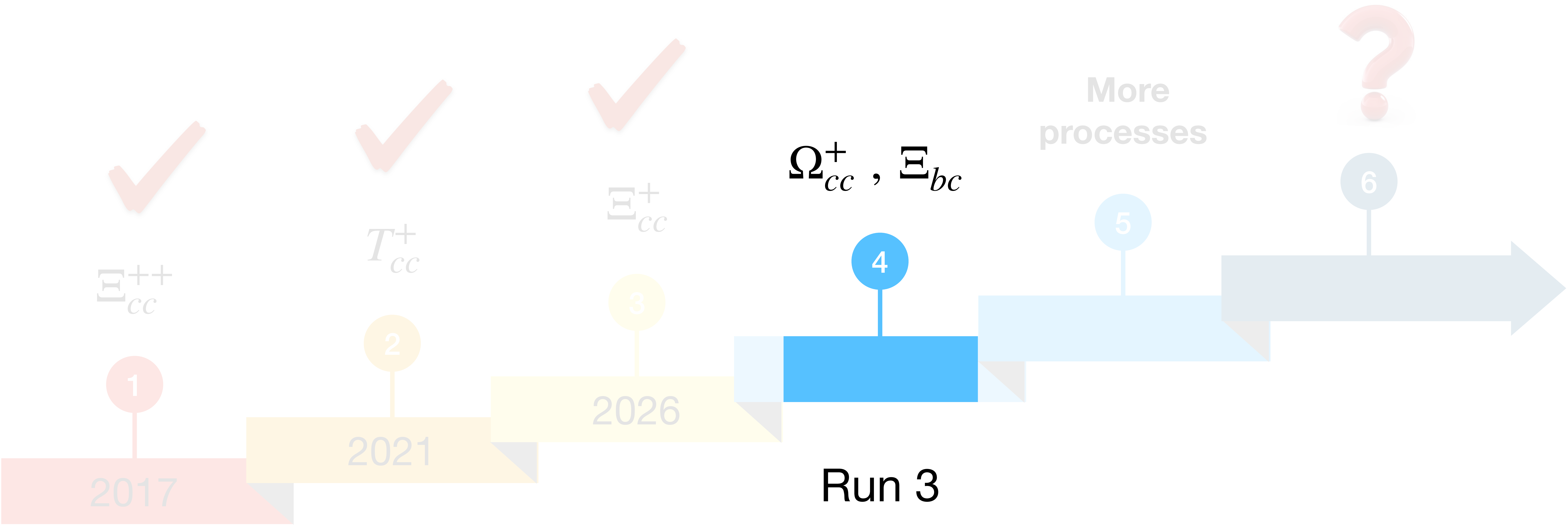
$\Xi_{cc}^{+} \to \Xi_{c}^{0}\pi^{+}$

$BR(\Xi_{cc}^{+} \to \Xi_{c}^{0}\pi^{+}) \sim 5\,\%$

J.J.Han, F.S.Yu *et al*, 2101.12019

Xiao-Hui Hu, et al, 2403.09511

Double-heavy hadrons



Double-charm baryon: Ω_{cc}^{+}

Lifetimes:

$\mathcal{B}_{QQ}$		τ
Ξ_{cc}^{++}	LO	3.96(1.93)(17)(−33)(−18)
	NLO	2.67(94)(2)(−7)(+12)
Ξ_{cc}^{+}	LO	0.48(7)(4)(+5)(+2)
	NLO	0.47(7)(4)(+5)(0)
Ω_{cc}^{+}	LO	1.42(41)(5)(+4)(−3)
	NLO	1.79(62)(4)(+2)(+15)

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

H.Y.Cheng, C.W.Liu, 2604.10939

$\Omega_{cc}^{+} \to \Xi_c^{+} K^{-} \pi^{+}$

$\mathcal{BR}(\Omega_{cc}^{+} \to \Xi_c^{+} \overline{K}^{*0}) \in [0.5\%, 3.3\%]$ — L.J.Jiang, R.H.Li, *et al*, 1810.00541

$Br(\Omega_{cc}^{+} \to \Xi_c^{+} \overline{K}^{*0}) = (2.5 \pm 0.7)\,\%$ — Xiao-Hui Hu, et al, in preparation

$\Omega_{cc}^{+} \to \Omega_c^{0} \pi^{+}$

$BR(\Omega_{cc}^{+} \to \Omega_c^{0} \pi^{+}) \sim 6\,\%$ — J.J.Han, F.S.Yu *et al*, 2101.12019

$\Omega_c^{+} \to p K^{-} K^{-} \pi^{+}$

$Br(\Omega_{cc}^{+} \to \Omega_c^{+} \pi^{+}) = (6.8 \pm 1.3)\,\%$ — Xiao-Hui Hu, et al, 2403.09511

Double-charm baryon: Ξ_{bc}^+

Lifetimes:

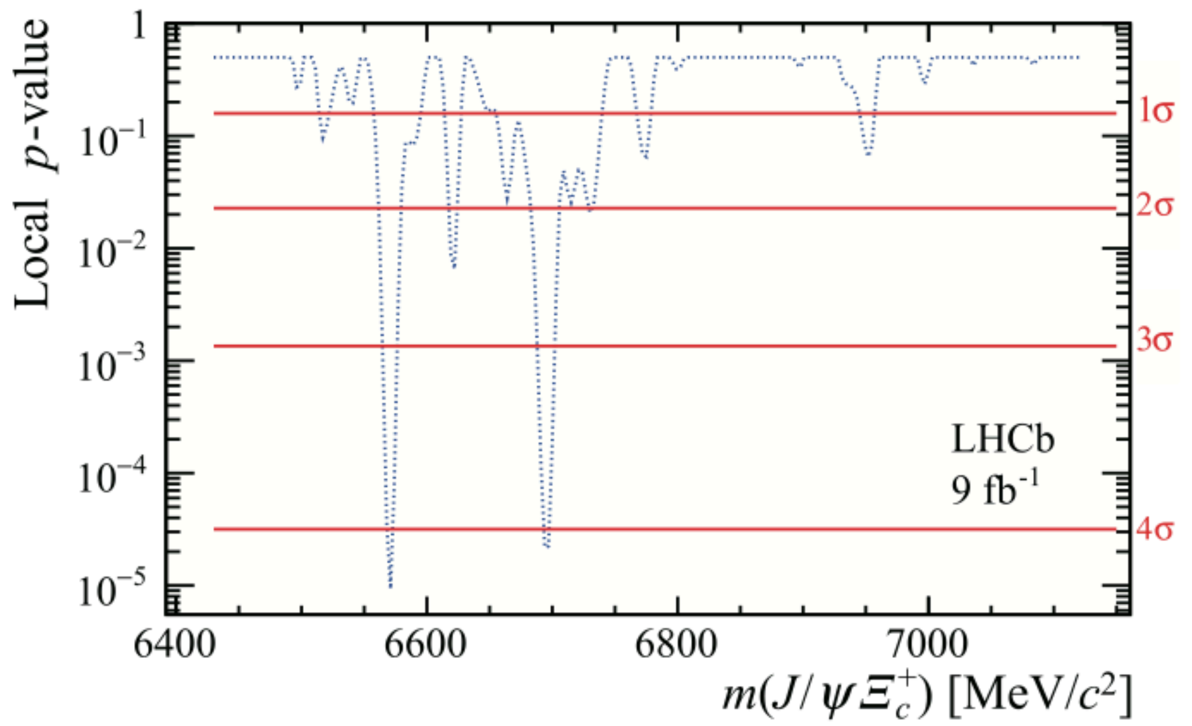
Observable	$\overline{\text{MS}}$	Kinetic	Υ
$\tau(\Xi_{bc}^+)$ [ps]	$0.37 \pm 0.03\,^{+0.09}_{-0.14}$	$0.29 \pm 0.02\,^{+0.02}_{-0.05}$	$0.29 \pm 0.02\,^{+0.03}_{-0.04}$
$\tau(\Xi_{bc}^0)$ [ps]	$0.19 \pm 0.02\,^{+0.04}_{-0.06}$	$0.16 \pm 0.02\,^{+0.01}_{-0.03}$	$0.17 \pm 0.02\,^{+0.02}_{-0.03}$
$\tau(\Omega_{bc}^0)$ [ps]	$0.27 \pm 0.03\,^{+0.05}_{-0.08}$	$0.22 \pm 0.03\,^{+0.01}_{-0.02}$	$0.23 \pm 0.02\,^{+0.02}_{-0.03}$

$\tau(\Xi_{bc}^0) \lesssim \tau(\Omega_{bc}^0) < \tau(\Xi_{bc}^+)$

Dulibić, et al, 2605.04967

$\Xi_{bc}^+ \to \Xi_c^+ J/\psi$

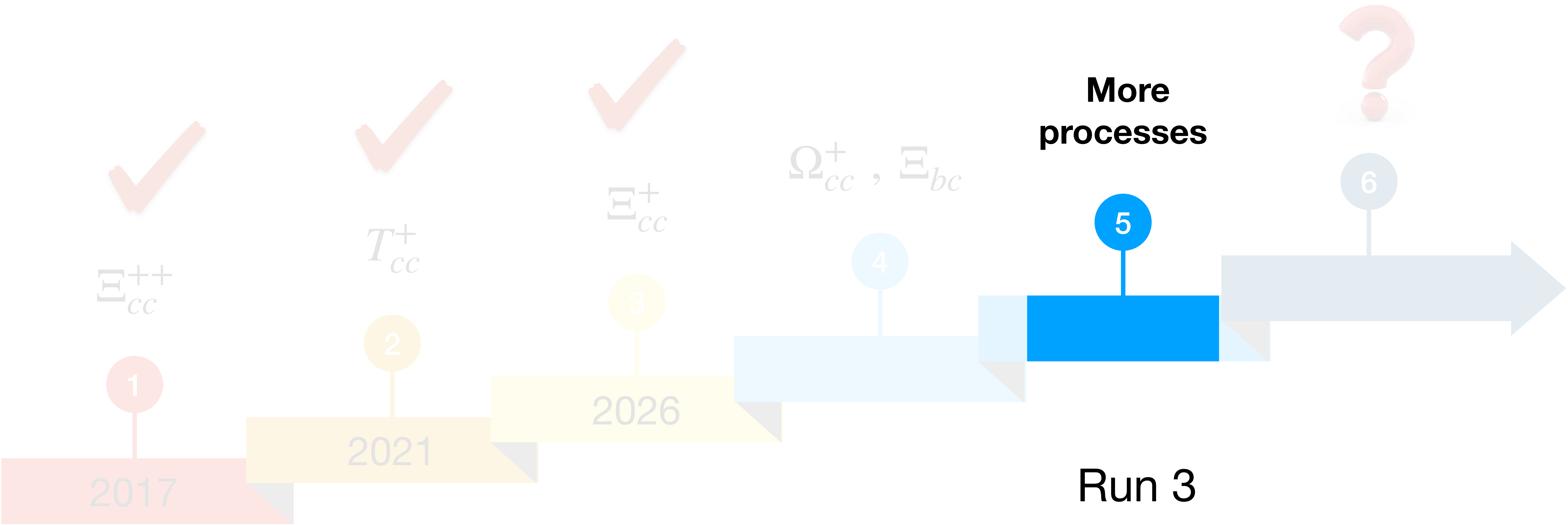
LHCb, 2204.09541: 4σ local significance



Xiao-Hui Hu, et al, 2512.09705 : $\mathcal{B}(\Xi_{bc}^+ \to \Xi_c^+ J/\psi) = \left(1.55^{+0.50}_{-0.42}\right) \times 10^{-4}$

Controlled by $\Lambda_b^0 \to \Lambda J/\psi$

Double-heavy hadrons

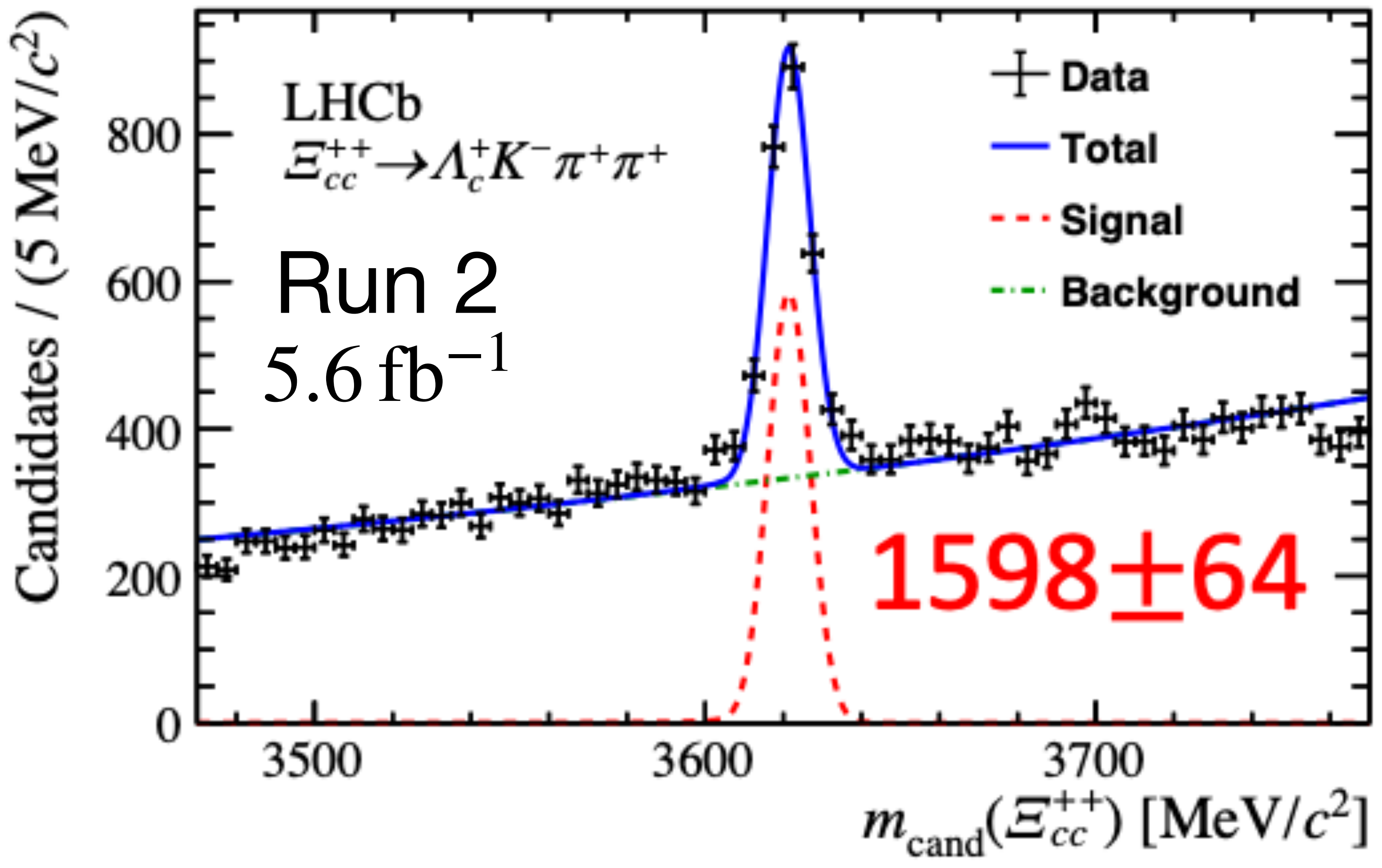


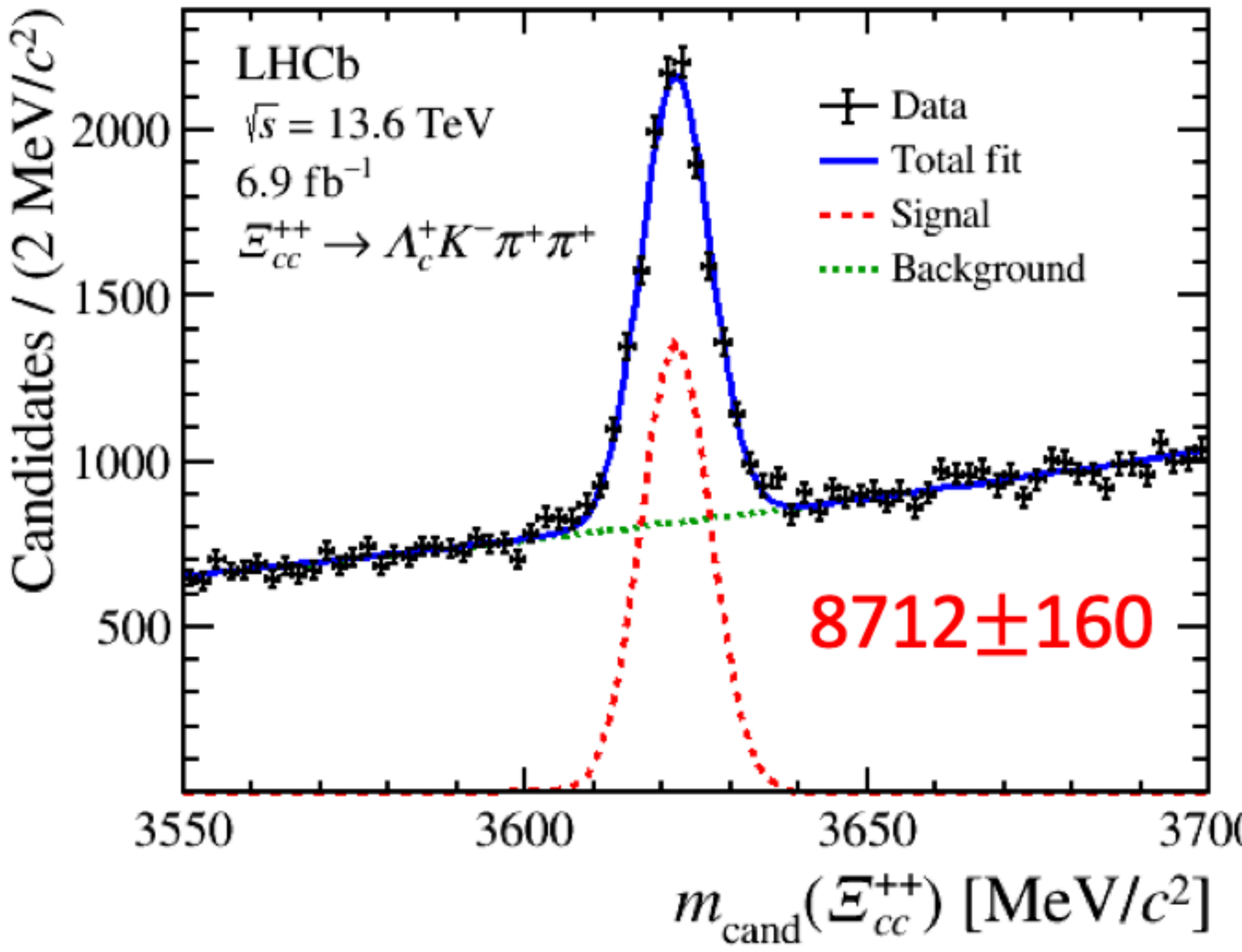
Large data samples in $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$

- Efficiency increased by a factor of 4, compared with Run2

See Jibo's talk

LHCb, 2603.28456





Total events in Run 1+2+3: **30000.** From Jibo.

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

Two-body decays are more interesting in theory

Intermediate states

$\Sigma_c^{++}(\to \Lambda_c^+ \pi^+)$ $\overline{K}^{*0}(\to K^- \pi^+)$

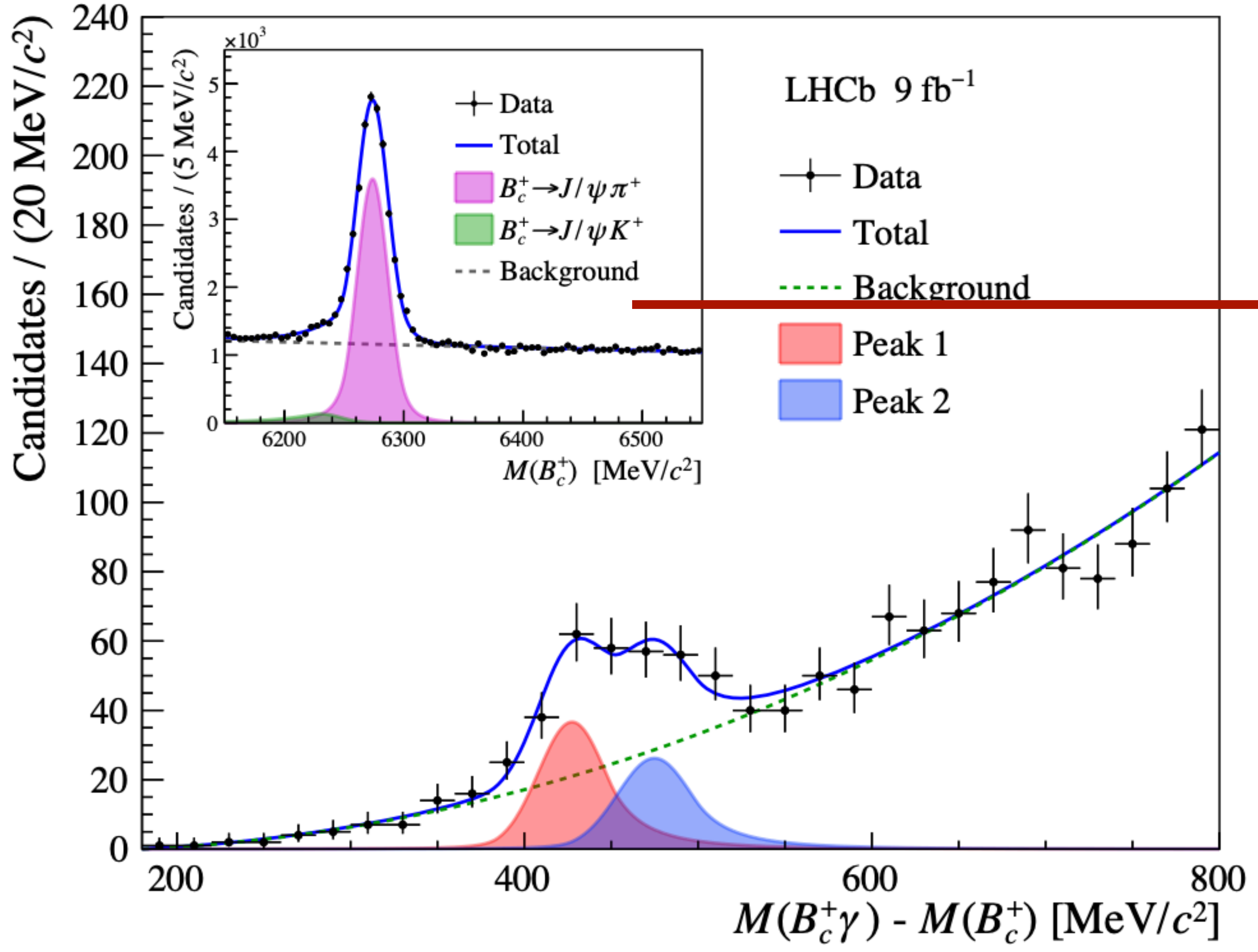
$\Xi_c^{*+}(\to \Lambda_c^+ K^- \pi^+)$

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

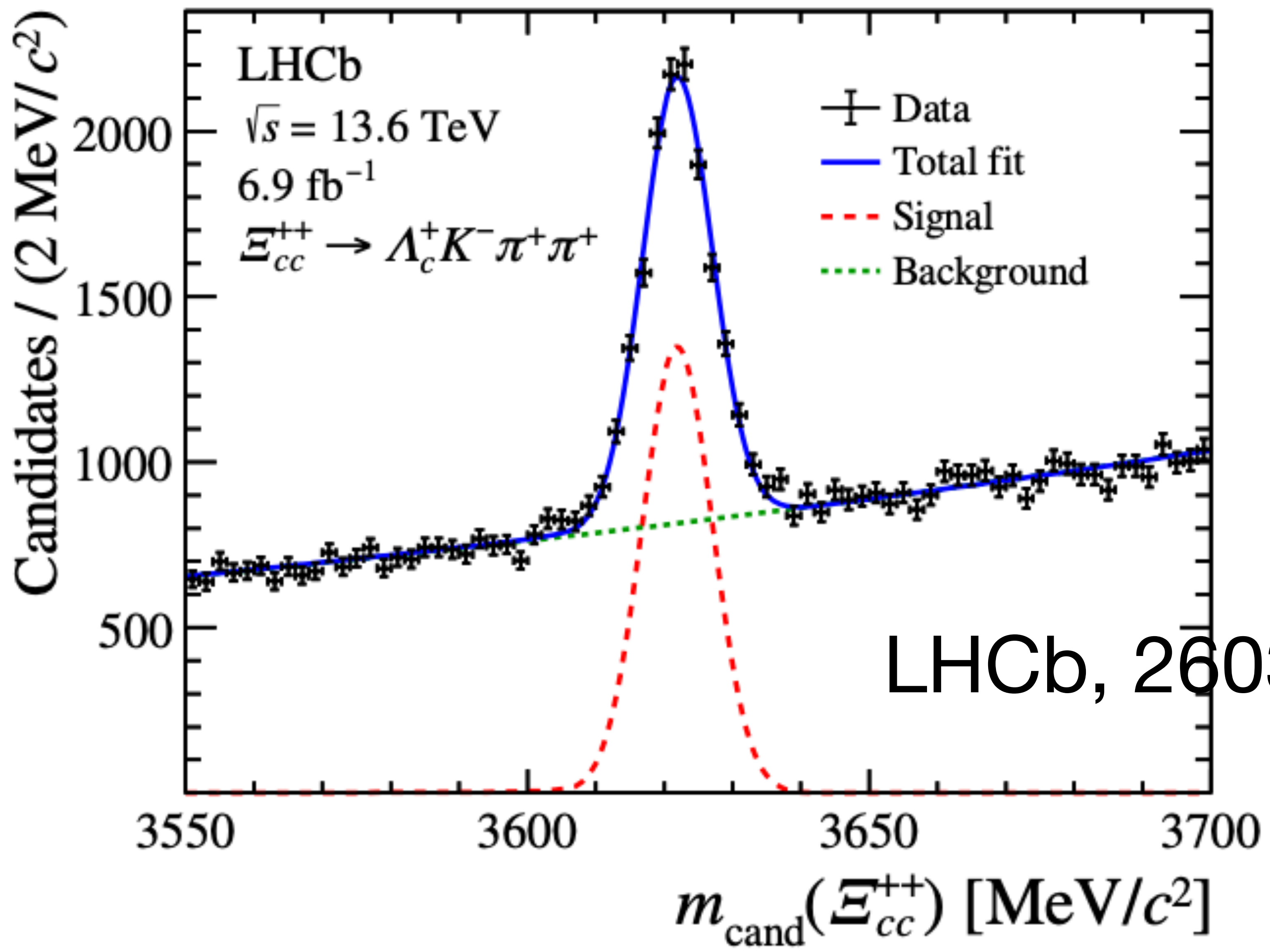
Might be easier due to identified π^+

Excited state: $\Xi_{cc}^{*++} \to \Xi_{cc}^{++}\gamma$

$B_c(1P)^+ \to B_c^+\gamma$



LHCb, 2507.02149



LHCb, 2603.28456

Production in heavy quark symmetry:

$$\Xi_{cc}(1/2) : \Xi_{cc}^*(3/2) = 1 : 2$$

Similarly $\Xi_{cc}^{*+} \to \Xi_{cc}^{++}\pi^-$

Proposal: inclusive Ξ_{bc} search

- Generally, inclusive decays have (1) larger branching ratios but (2) lower detection efficiencies

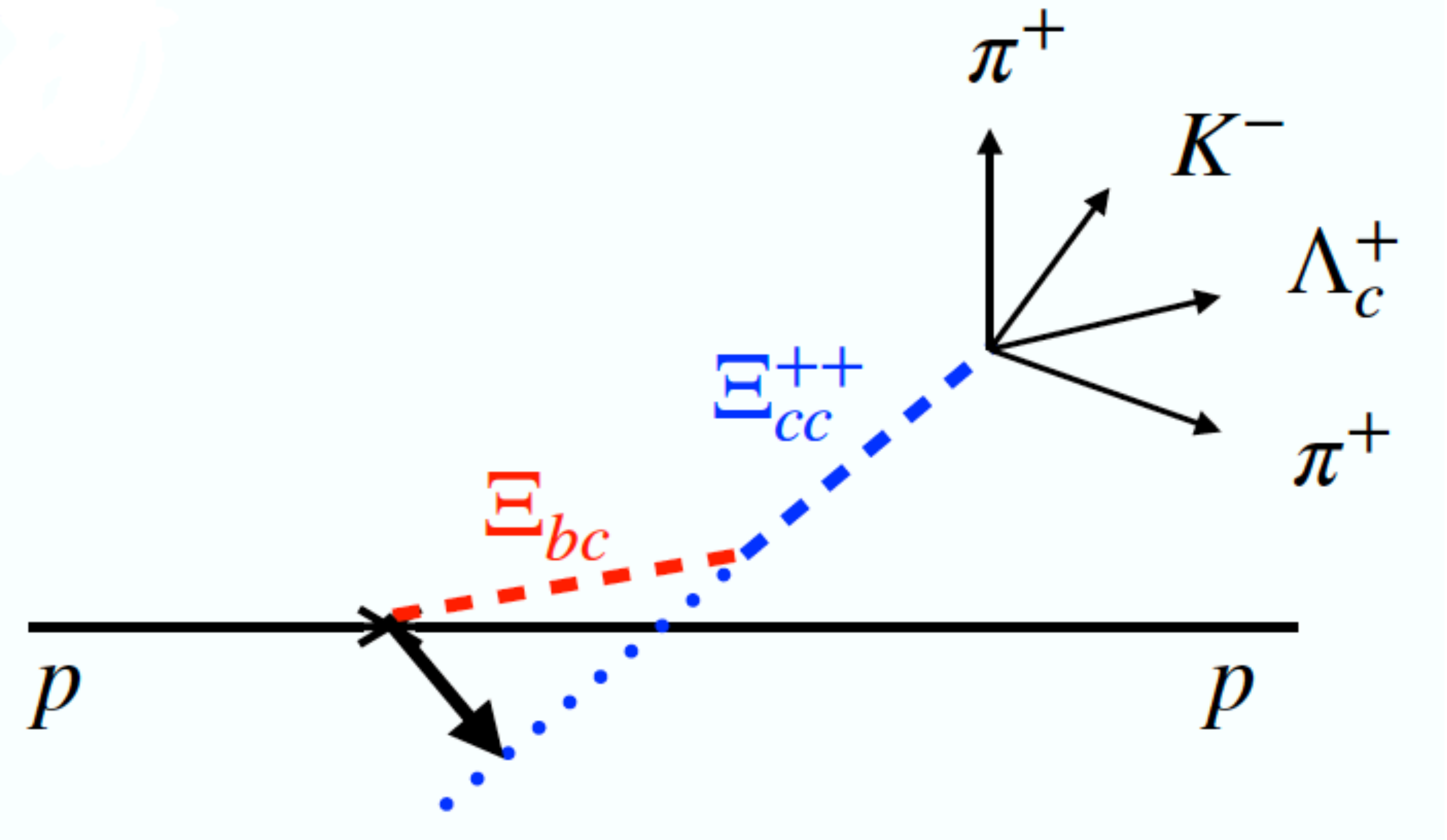
  Basically impossible at hadron colliders

- However, for $\Xi_{bc} \to \Xi_{cc}^{++} + X$, the efficiency can be large by making use of the inform of displaced vertex

  Inspired by the proposal to search for Ξ_{bb} via $\Xi_{bb} \to B_c + X$ [Gershon,Poluektov,1810.06657]

- Ξ_{bc} is (almost) the only source for displaced Ξ_{cc}'s

- The $B_c \to \Xi_{cc}^{++} + X$ decay is highly suppressed



$$B(\Xi_{bc}^{+} \to \Xi_{cc}^{++} + X) \approx 6\% \times \frac{\tau_{\Xi_{bc}^{+}}}{400\text{fs}}$$

Qin, Shi, Wang, Yang, **FSY**, Zhu, 2108.06716

Decay asymmetries of $\Xi_{cc}^{++} \to \Xi_c^+ \pi^+$

PHYSICAL REVIEW D **111,** 076002 (2025)

Final-state rescattering mechanism of double-charm baryon decays: $\mathcal{B}_{cc} \to \mathcal{B}_c P$

Xiao-Hui Hu,[1,2,*] Cai-Ping Jia,[3,†] Ye Xing,[1,‡] and Fu-Sheng Yu[2,4,§]

Channels	CKM	$\mathcal{B}_{SD}[10^{-3}]$	$\mathcal{B}_{LD}[10^{-3}]$	$\mathcal{B}_{tot}[10^{-3}]$	α	β	γ
$\Xi_{cc}^{++} \to \Xi_c^+ \pi^+$	CF	$60.70^{+1.12}_{-1.11}$	$2.67^{+1.30+2.37}_{-0.82-1.50}$	$39.70^{+2.97+6.47}_{-2.73-6.33}$	$-0.43^{+0.03+0.04}_{-0.02-0.03}$	$0.13^{+0.06+0.07}_{-0.04-0.05}$	$-0.89^{+0.01+0.01}_{-0.00-0.01}$

Cabibbo-suppressed decay: $\Xi_{cc}^{++} \to \Lambda_c^+ \pi^+$

Channels	CKM	$\mathcal{B}_{SD}[10^{-3}]$	$\mathcal{B}_{LD}[10^{-3}]$	$\mathcal{B}_{tot}[10^{-3}]$	α	β	γ
$\Xi_{cc}^{++} \to \Xi_c^+ \pi^+$	CF	$60.70^{+1.12}_{-1.11}$	$2.67^{+1.30+2.37}_{-0.82-1.50}$	$39.70^{+2.97+6.47}_{-2.73-6.33}$	$-0.43^{+0.03+0.04}_{-0.02-0.03}$	$0.13^{+0.06+0.07}_{-0.04-0.05}$	$-0.89^{+0.01+0.01}_{-0.00-0.01}$
$\Xi_{cc}^{++} \to \Lambda_c^+ \pi^+$	SCS	$3.44^{+0.06}_{-0.06}$	$0.18^{+0.11+0.17}_{-0.06-0.11}$	$4.08^{+0.17+0.32}_{-0.13-0.25}$	$-0.26^{+0.06+0.11}_{-0.05-0.10}$	$0.19^{+0.04+0.06}_{-0.04-0.06}$	$-0.95^{+0.01+0.02}_{-0.00-0.01}$

X.H.Hu, C.P.Jia, Y.Xing, FSY, PRD2025

$$Br(\Lambda_c^+ \to pK^-\pi^+) \sim 10\ Br(\Xi_c^+ \to pK^-\pi^+)$$

Motivation: CP violation

Channels	$\mathcal{A}_{CP}^{dir}[10^{-3}]$	$\alpha_{CP}[10^{-3}]$	$\beta_{CP}[10^{-3}]$	$\gamma_{CP}[10^{-3}]$
$\Xi_{cc}^{++} \to \Lambda_c^+ \pi^+$	$-0.52^{+0.07+0.22}_{-0.02-0.18}$	$-0.26^{+0.03+0.09}_{0.03-0.14}$	$-0.53^{+0.02+0.03}_{-0.03-0.02}$	$0.04^{+0.00+0.00}_{-0.00-0.01}$

Semi-leptonic decay: $\Xi_{cc}^{++} \to \Xi_c^+ \mu^+ \nu_\mu$

Eur. Phys. J. C (2017) 77:781
https://doi.org/10.1140/epjc/s10052-017-5360-1

THE EUROPEAN PHYSICAL JOURNAL C

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Regular Article - Theoretical Physics

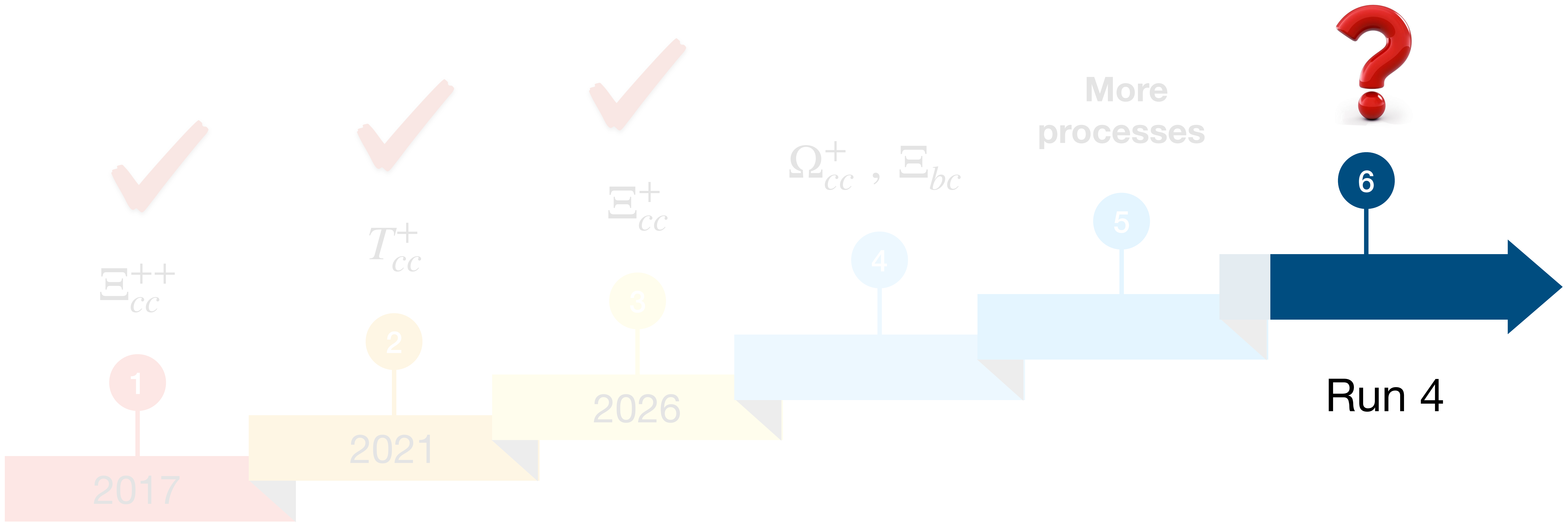
Weak decays of doubly heavy baryons: the 1/2 → 1/2 case

Wei Wang[1,a], Fu-Sheng Yu[2,b], Zhen-Xing Zhao[1,c]

Channels	Γ/GeV	$\mathcal{B}$	Γ_L/Γ_T
$\Xi_{cc}^{++} \to \Lambda_c^+ l^+ \nu_l$	1.05×10^{-14}	4.81×10^{-3}	8.52
$\Xi_{cc}^{++} \to \Sigma_c^+ l^+ \nu_l$	9.60×10^{-15}	4.38×10^{-3}	1.28
$\Xi_{cc}^{++} \to \Xi_c^+ l^+ \nu_l$	1.15×10^{-13}	5.25×10^{-2}	9.99

Many other similar predictions

Double-heavy hadrons



Summary

- The decade-long search for doubly charmed baryons has led to significant progress in particle physics.
- With the large statistics of LHCb Run 3, more and more important results can be anticipated.

Thank you!