Experimental review on conventional heavy flavor spectroscopy

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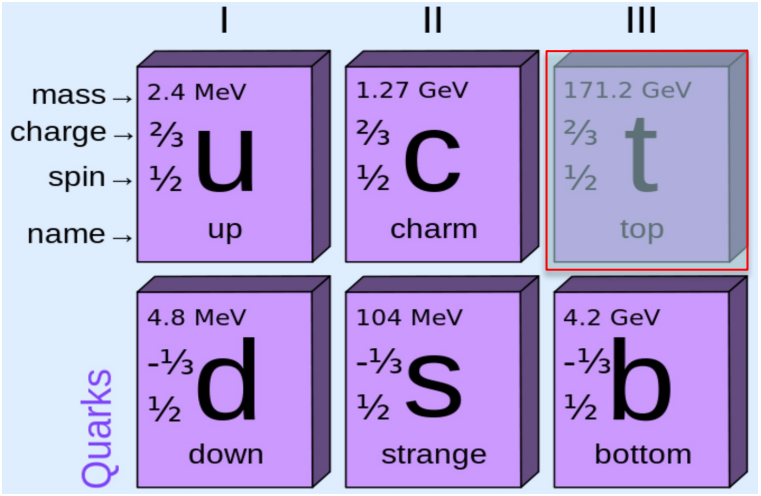
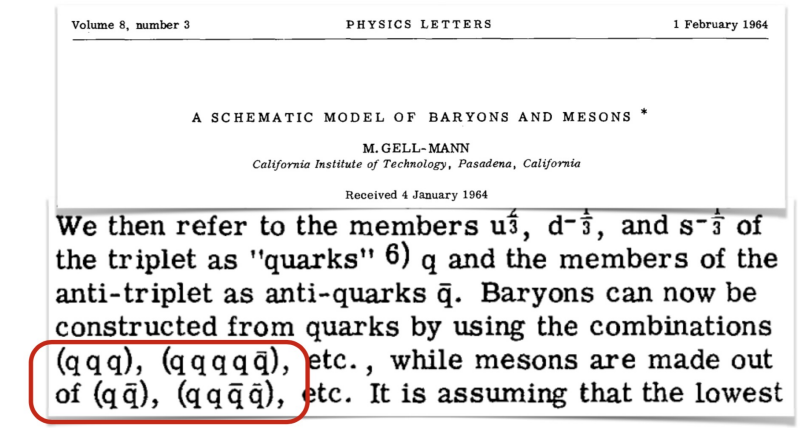
第六届强子谱与强子结构研讨会

(August 27-30, 2023)

Quark model & Strong interaction

- Flavor: *u, d, s, c, b, t*
- Color: R, G, B
- Hadron: Colorless
  - Meson: $Q\bar{q}$
  - Baryon: $Qqq^{(\prime)}$





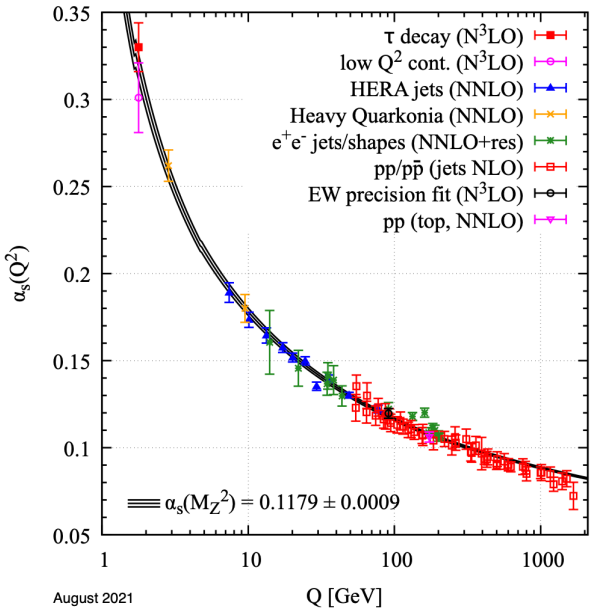
Volume 8, number 3 PHYSICS LETTERS 1 February 1964

A SCHEMATIC MODEL OF BARYONS AND MESONS *

M. GELL-MANN
California Institute of Technology, Pasadena, California

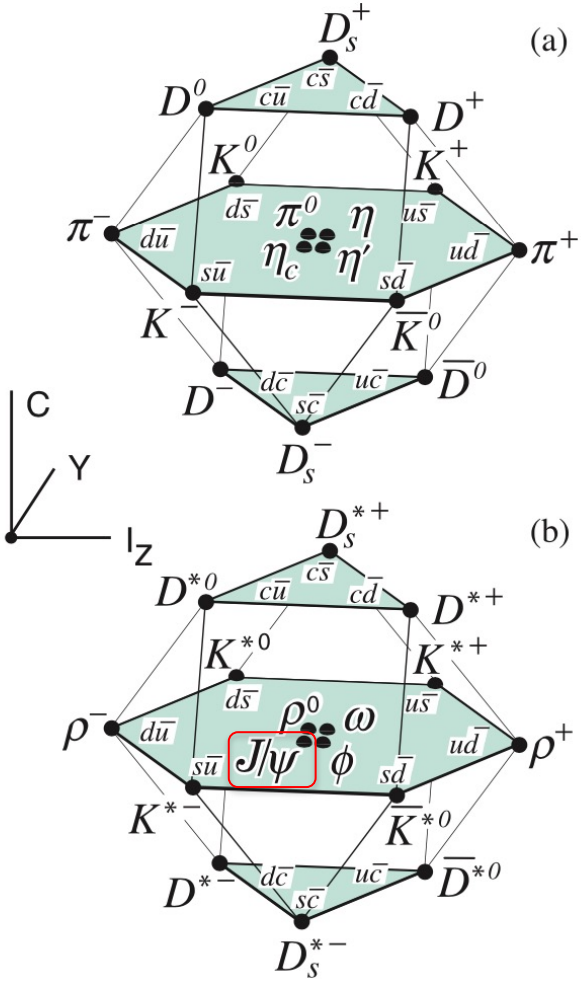
Received 4 January 1964

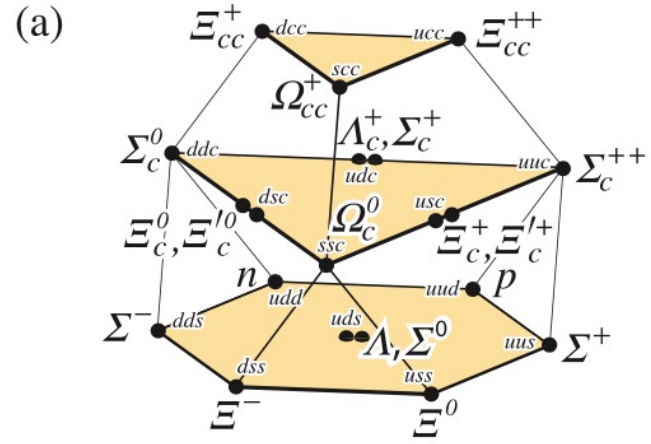
We then refer to the members $u^{\frac{2}{3}}$, $d^{-\frac{1}{3}}$, and $s^{-\frac{1}{3}}$ of the triplet as "quarks" [6] q and the members of the anti-triplet as anti-quarks $\bar{q}$. Baryons can now be constructed from quarks by using the combinations (qqq), $(qqqq\bar{q})$, etc., while mesons are made out of $(q\bar{q})$, $(qq\bar{q}\bar{q})$, etc. It is assuming that the lowest

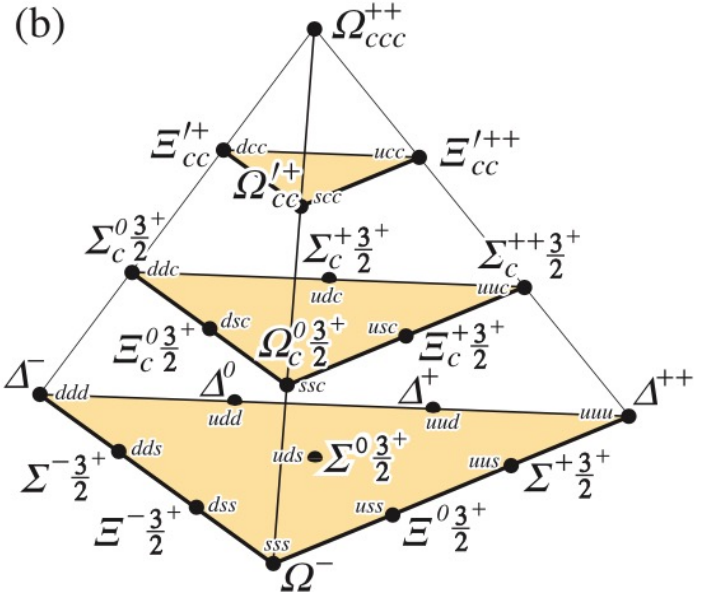


SU(4)

- Meson/Baryon by *u,d,s,c*





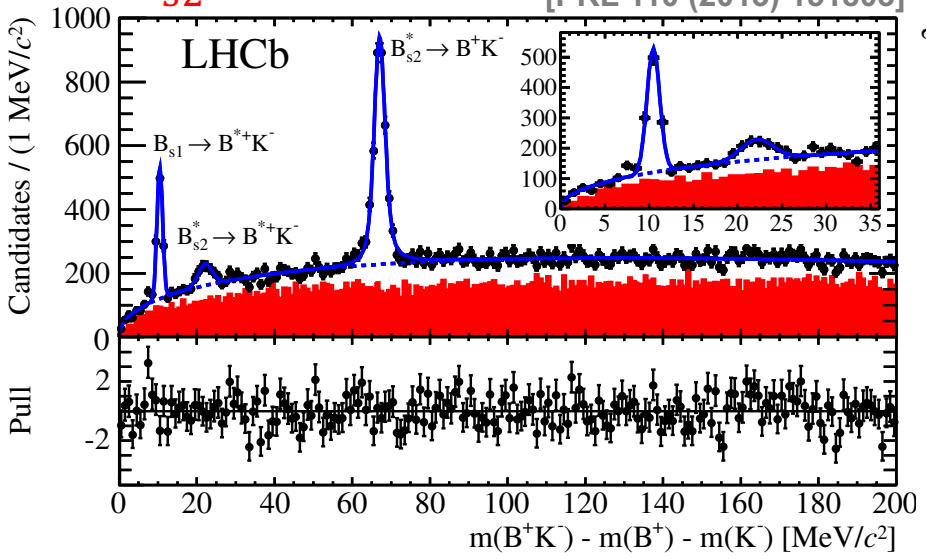


Samuel C.C.Ting

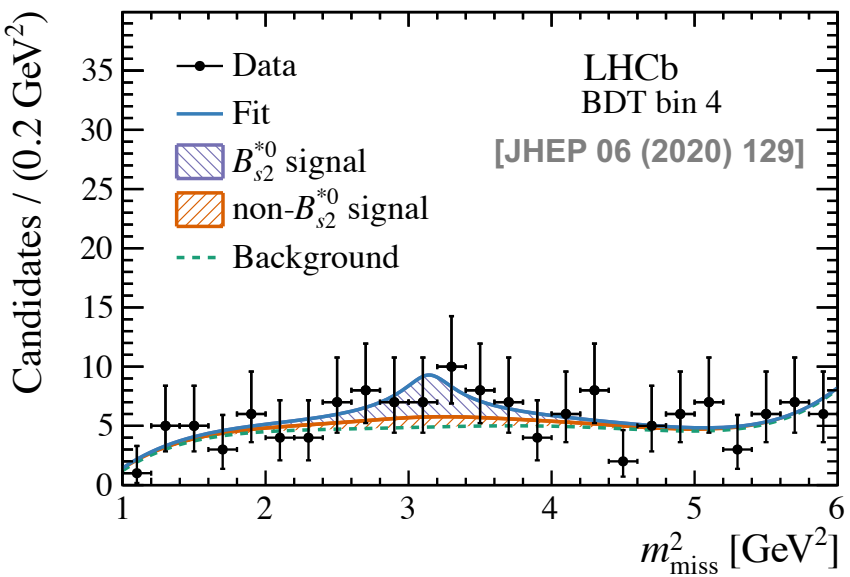
Hadron spectroscopy

- Test our knowledge of QCD: mass & width
- Today's discovery, tomorrow's precision tool
  - B_{s2}^{*0} state, used to tag B^+, E_{miss} reconstruction

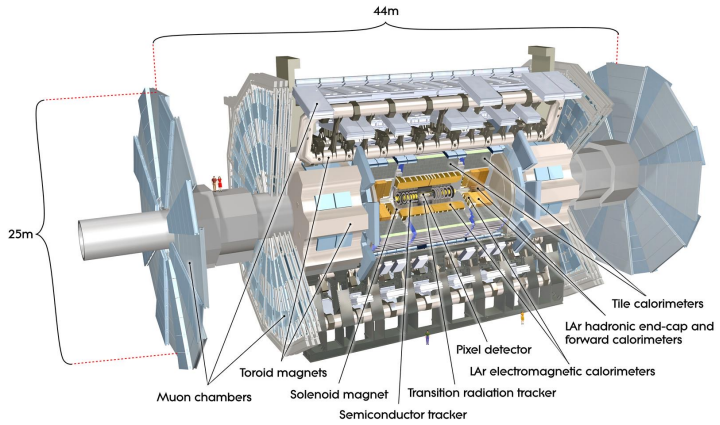
$B_{s2}^{*0} \to B^+K^-$ [PRL 110 (2013) 151803]

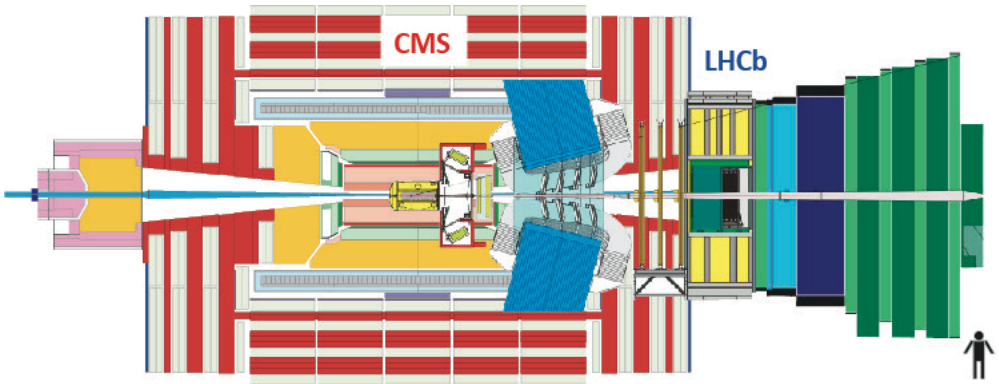


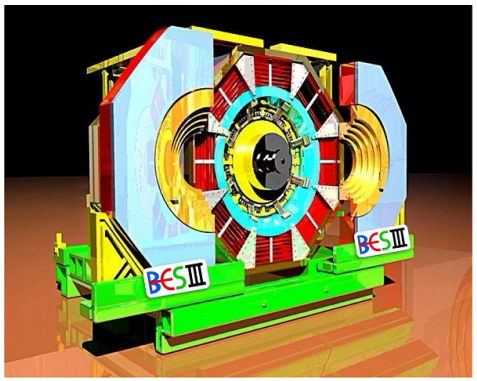
$B_{s2}^{*0} \to B^+(\to K^+\mu^-\tau^+)K^-$

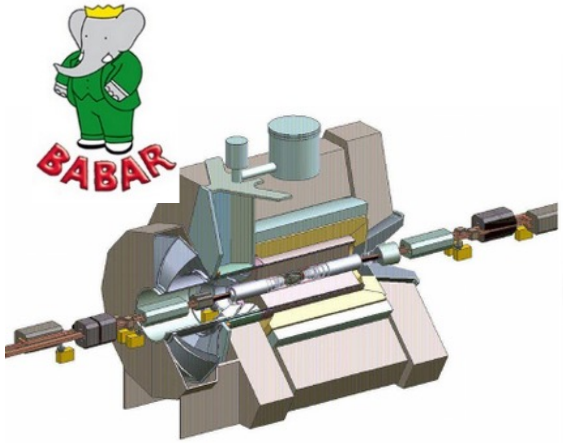


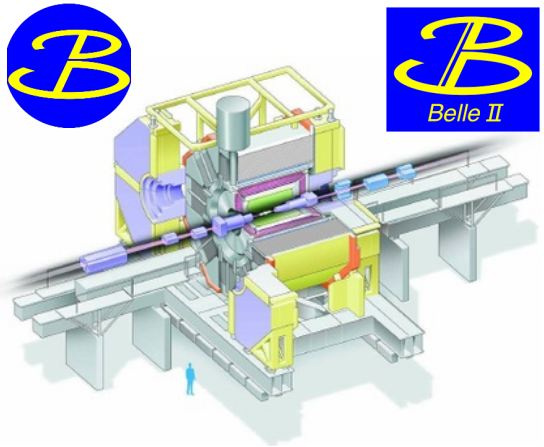
Present main players











New excited D_s^+ state $(c\bar{s})$

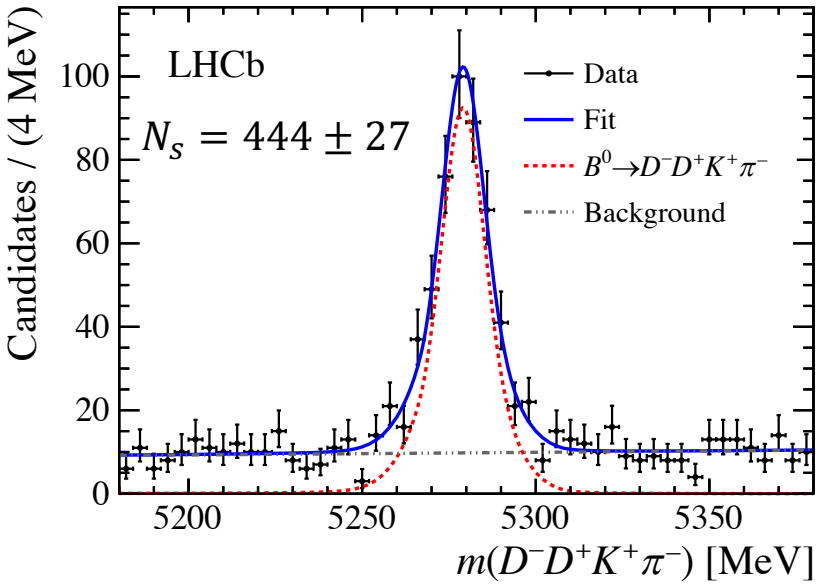
- $D_{s0}(2590)^+$, observed in $B^0 \to D^- D^+ K^+ \pi^-$
  - Candidate for $D_s(2^1S_0)^+$, radial excitation

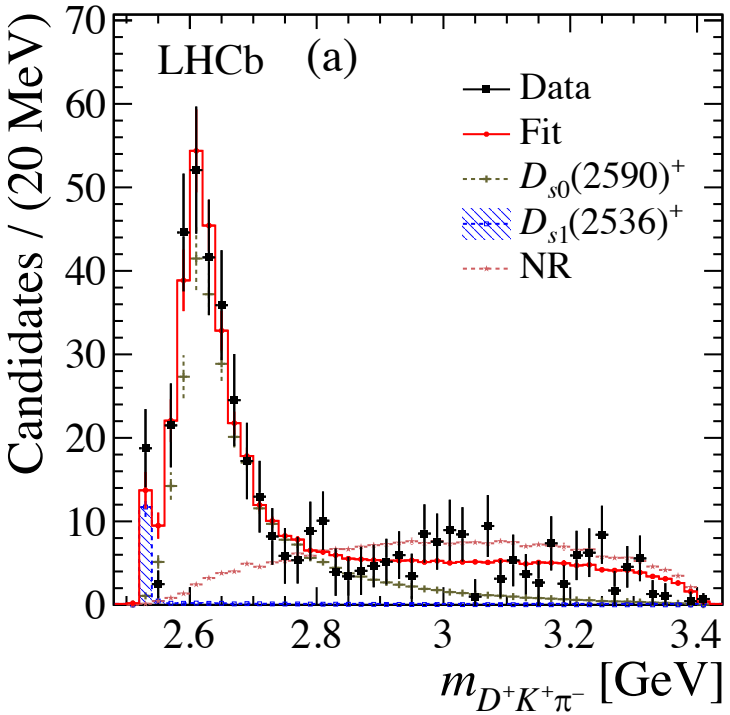
$m = 2591 \pm 6 \pm 7$ MeV

$\Gamma = 89 \pm 16 \pm 12$ MeV

$J^P = 0^-$

[PRL 126 (2021) 122002]

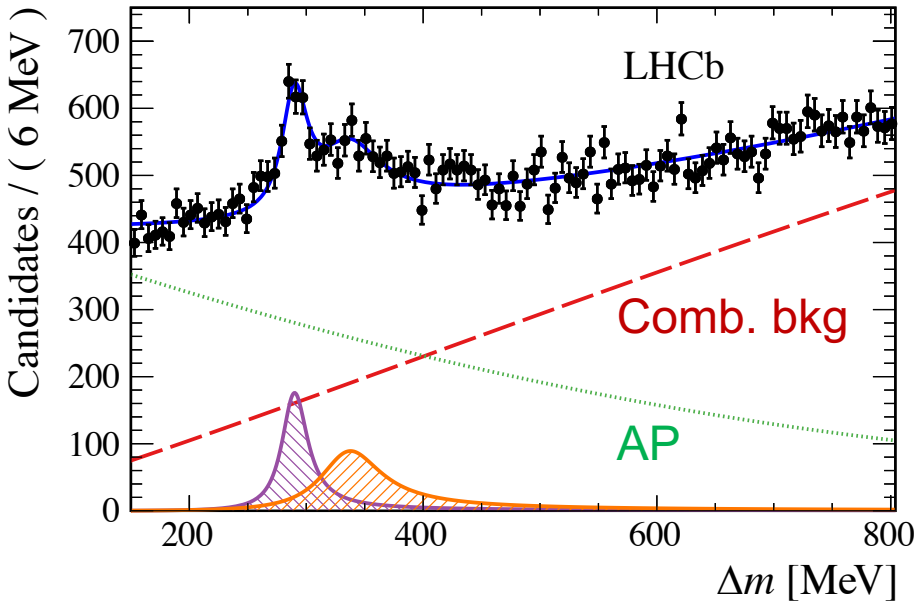




New excited B_s^0 states $(\bar{b}s)$

- Observed in $m(B^+K^-)$
  - directly to B^+K^-
  - through $B^{*+}K^-$

[EPJC 81 (2021) 601]

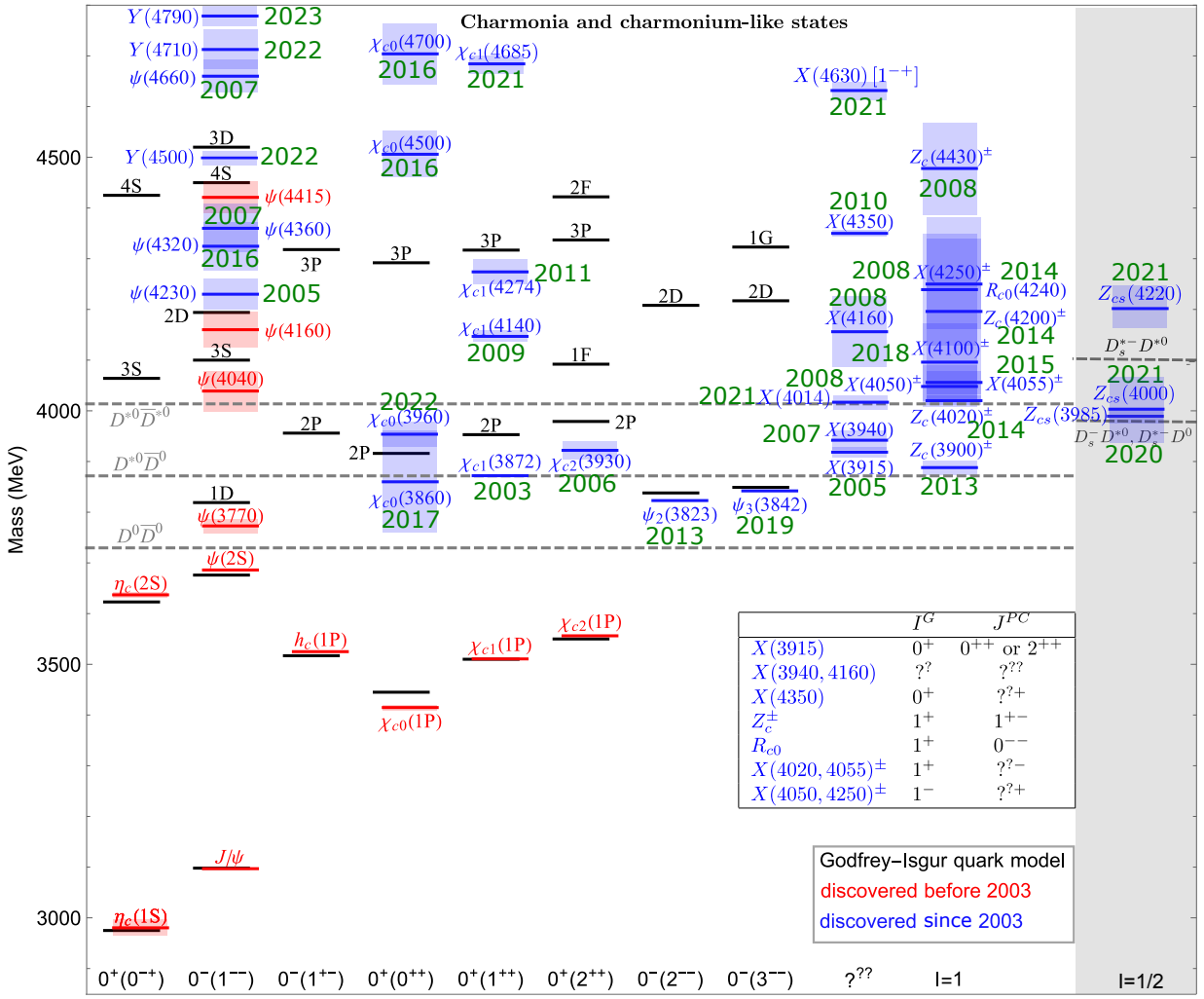


$$m_1 = 6063.5 \pm 1.2\ (\text{stat}) \pm 0.8\ (\text{syst})\ \text{MeV},$$
$$\Gamma_1 = 26 \pm 4\ (\text{stat}) \pm 4\ (\text{syst})\ \text{MeV},$$
$$m_2 = 6114 \pm 3\ (\text{stat}) \pm 5\ (\text{syst})\ \text{MeV},$$
$$\Gamma_2 = 66 \pm 18\ (\text{stat}) \pm 21\ (\text{syst})\ \text{MeV},$$
$$f_1 = 0.47 \pm 0.11\ (\text{stat}) \pm 0.15\ (\text{syst}),$$

if through $B^{*+}K^-, B^{*+} \to B^+\gamma$

$$m_1 = 6108.8 \pm 1.1\ (\text{stat}) \pm 0.7\ (\text{syst})\ \text{MeV},$$
$$\Gamma_1 = 22 \pm 5\ (\text{stat}) \pm 4\ (\text{syst})\ \text{MeV},$$
$$m_2 = 6158 \pm 4\ (\text{stat}) \pm 5\ (\text{syst})\ \text{MeV},$$
$$\Gamma_2 = 72 \pm 18\ (\text{stat.}) \pm 25\ (\text{syst})\ \text{MeV},$$
$$f_1 = 0.42 \pm 0.11\ (\text{stat}) \pm 0.16\ (\text{syst}).$$

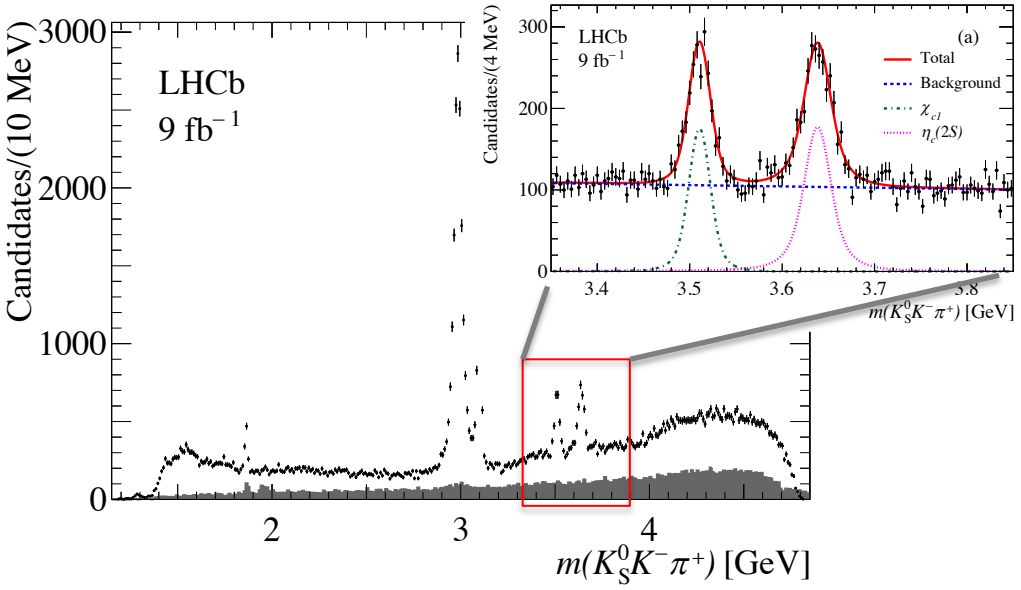
Charmonium(like) states



[F.-K. Guo (郭奉坤), PoS LATTICE 2022 (2023) 232]

Charmonium in $B \to \left(K_S^0 K\pi\right)K$ $(c\bar{c})$

- Best single measurement of $\eta_c, \eta_c(2S)$ mass/width

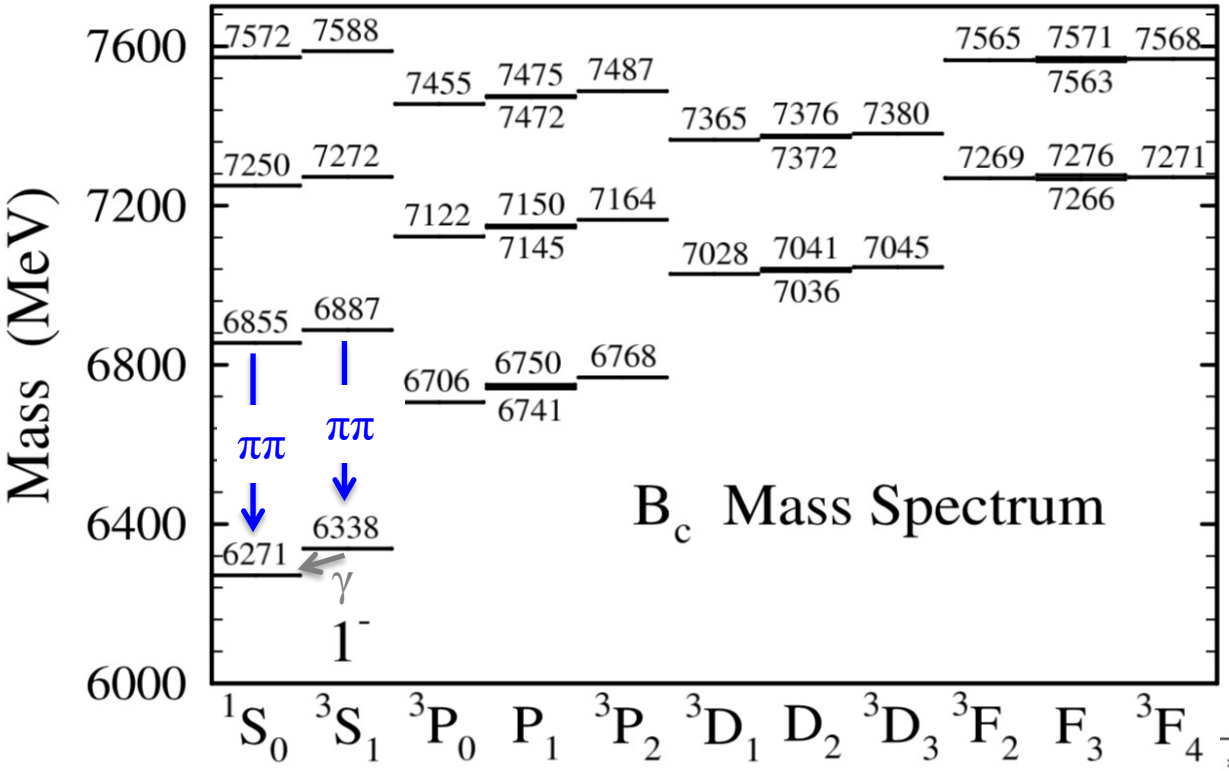


Final state	p-val. [%]	Res.	Mass [MeV]	Width [MeV]	Yield
$K_S^0K^+K^-\pi^+$	16.3	η_c	$2984.84 \pm 0.23 \pm 1.01$	$30.0 \pm 0.7 \pm 0.2$	17700 ± 190
		J/ψ	$-0.27 \pm 0.11 \pm 0.61$	0.0929 (fixed)	3386 ± 70
$K_S^0K^+K^+\pi^-$	1.5	η_c	$2985.19 \pm 0.24 \pm 1.88$	$29.4 \pm 0.8 \pm 0.8$	17210 ± 210
		J/ψ	$-0.81 \pm 0.11 \pm 0.67$		3310 ± 80
Average		η_c	$2985.01 \pm 0.17 \pm 0.89$	$29.7 \pm 0.5 \pm 0.2$	
		J/ψ	$-0.54 \pm 0.08 \pm 0.45$		
$K_S^0K^+K^-\pi^+$	46.6	$\eta_c(2S)$	$3636.92 \pm 0.71 \pm 1.50$	$11.70 \pm 2.04 \pm 1.39$	1960 ± 80
		χ_{c1}	$3509.32 \pm 0.70 \pm 0.84$	0.88 (fixed)	1300 ± 50
$K_S^0K^+K^+\pi^-$	5.3	$\eta_c(2S)$	$3639.28 \pm 0.84 \pm 3.83$	$9.18 \pm 2.67 \pm 1.70$	1720 ± 100
		χ_{c1}	$3510.35 \pm 0.69 \pm 1.00$		1460 ± 70
Average		$\eta_c(2S)$	$3637.90 \pm 0.54 \pm 1.40$	$10.77 \pm 1.62 \pm 1.08$	
		χ_{c1}	$3509.84 \pm 0.69 \pm 0.64$		

[PRD 108 (2023) 032010]

B_c^+ spectroscopy

- B_c has a rich spectrum



[S.Godfrey, PRD 70 (2004) 054017]

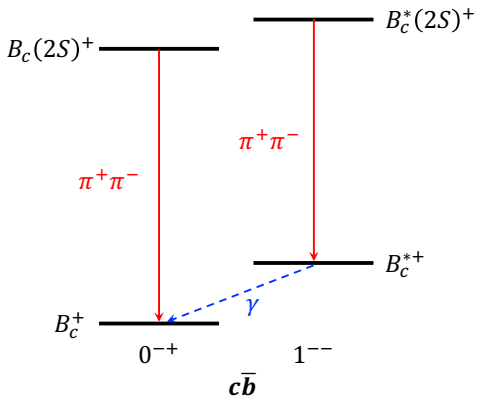
State	Decay	GKLRY *	Godfrey †
1^3S_1	$1^1S_0+\gamma$	100	100
1^3P_2	$1^3S_1+\gamma$	100	100
$1P_1'$	$1^3S_1+\gamma$	6	12.1
	$1^1S_0+\gamma$	94	87.9
$1P_1$	$1^3S_1+\gamma$	87	82.2
	$1^1S_0+\gamma$	13	17.8
1^3P_0	$1^3S_1+\gamma$	100	100
2^1S_0	$1^1S_0+\pi\pi$	74	88.1
	$1P_1'+\gamma$		9.4
	$1P_1+\gamma$		2.0
	$1^3S_1+\gamma$		0.5
2^3S_1	$1^3S_1+\pi\pi$	58	79.6
	$1^3P_2+\gamma$		8.0
	$1P_1'+\gamma$		1.0
	$1P_1+\gamma$		6.6
	$1^3P_0+\gamma$		4.0
	$2^1S_0+\gamma$		0.01
	$1^1S_0+\gamma$		0.8

* [I. P. Gouz, *et al.*, Phys. Atom. Nucl. 67 (2004) 1559]

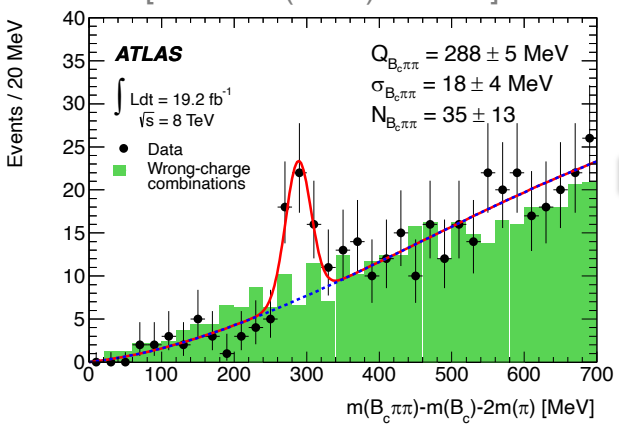
† [S.Godfrey, PRD 70 (2004) 054017]

Observation of $B_c^{(*)}(2S)^+$ $(\bar{b}c)$

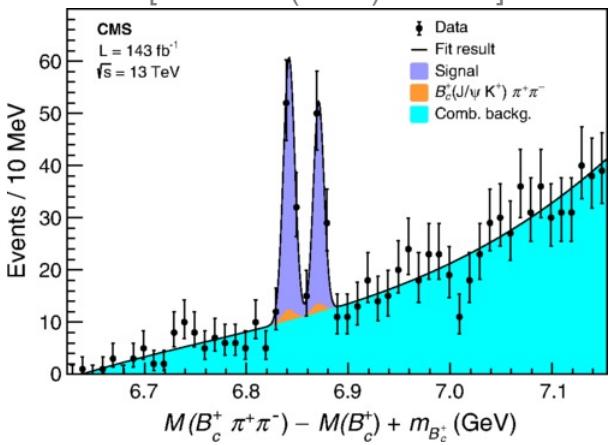
- Mixture (?) by ATLAS, then both states by CMS and LHCb

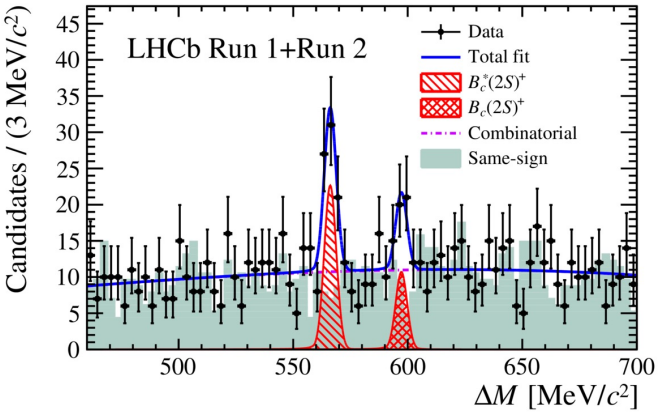


[PRL 113 (2014) 212004]



[PRL 122 (2019) 132001]





[PRL 122 (2019) 232001]

LHCb

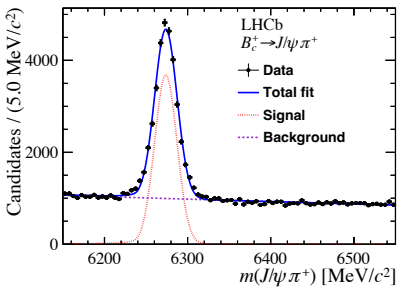
$$M(B_c(2^3S_1)^+)_{\text{rec}} = 6841.2 \pm 0.6(\text{stat}) \pm 0.1(\text{syst}) \pm 0.8(B_c^+)\ \text{MeV}/c^2$$
$$M(B_c(2S)^+) = 6872.1 \pm 1.3(\text{stat}) \pm 0.1(\text{syst}) \pm 0.8(B_c^+)\ \text{MeV}/c^2$$
$$M(B_c(2S)^+) - M(B_c^*(2S)^+)_{\text{rec}} = 31.0 \pm 1.4(\text{stat}) \pm 0.0(\text{syst})\ \text{MeV}/c^2$$

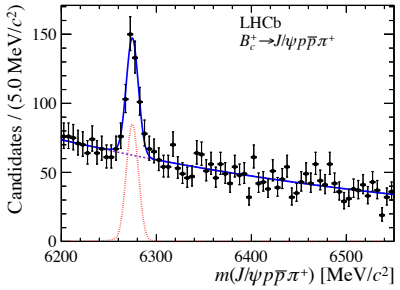
CMS

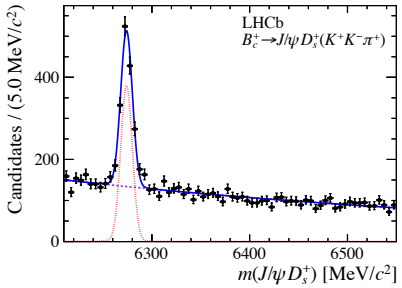
$$M(B_c(2^3S_1)^+)_{\text{rec}} = 6842.0 \pm 1.0(\text{stat}) \pm 0.0(\text{syst}) \pm 0.8(B_c^+)\ \text{MeV}/c^2$$
$$M(B_c(2S)^+) = 6871.0 \pm 1.2(\text{stat}) \pm 0.8(\text{syst}) \pm 0.8(B_c^+)\ \text{MeV}/c^2$$
$$M(B_c(2S)^+) - M(B_c^*(2S)^+)_{\text{rec}} = 29.0 \pm 1.5(\text{stat}) \pm 0.7(\text{syst})\ \text{MeV}/c^2$$

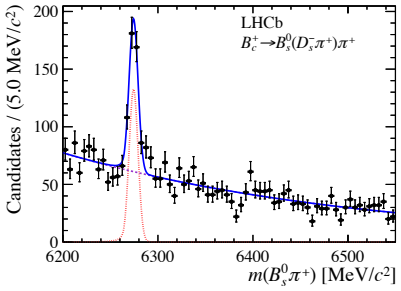
B_c^+ mass measurement $(\bar{b}c)$

- Six decay modes, with all Run1+2 data, precision improved by a factor of 2

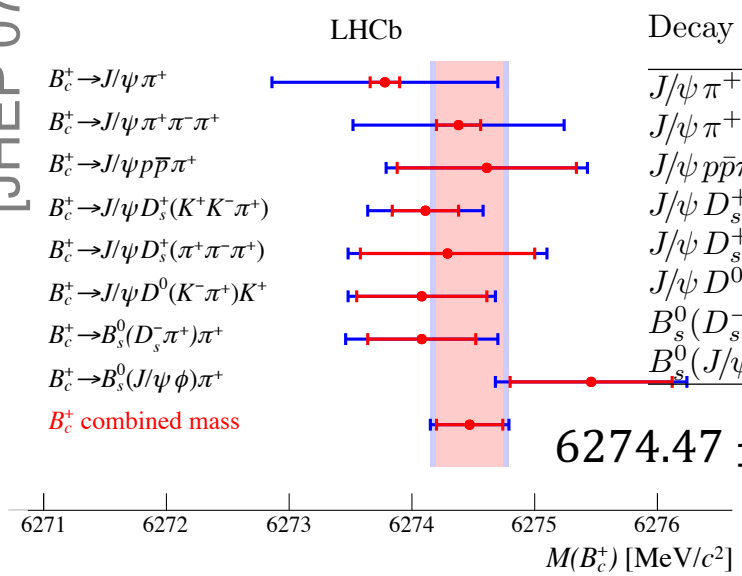








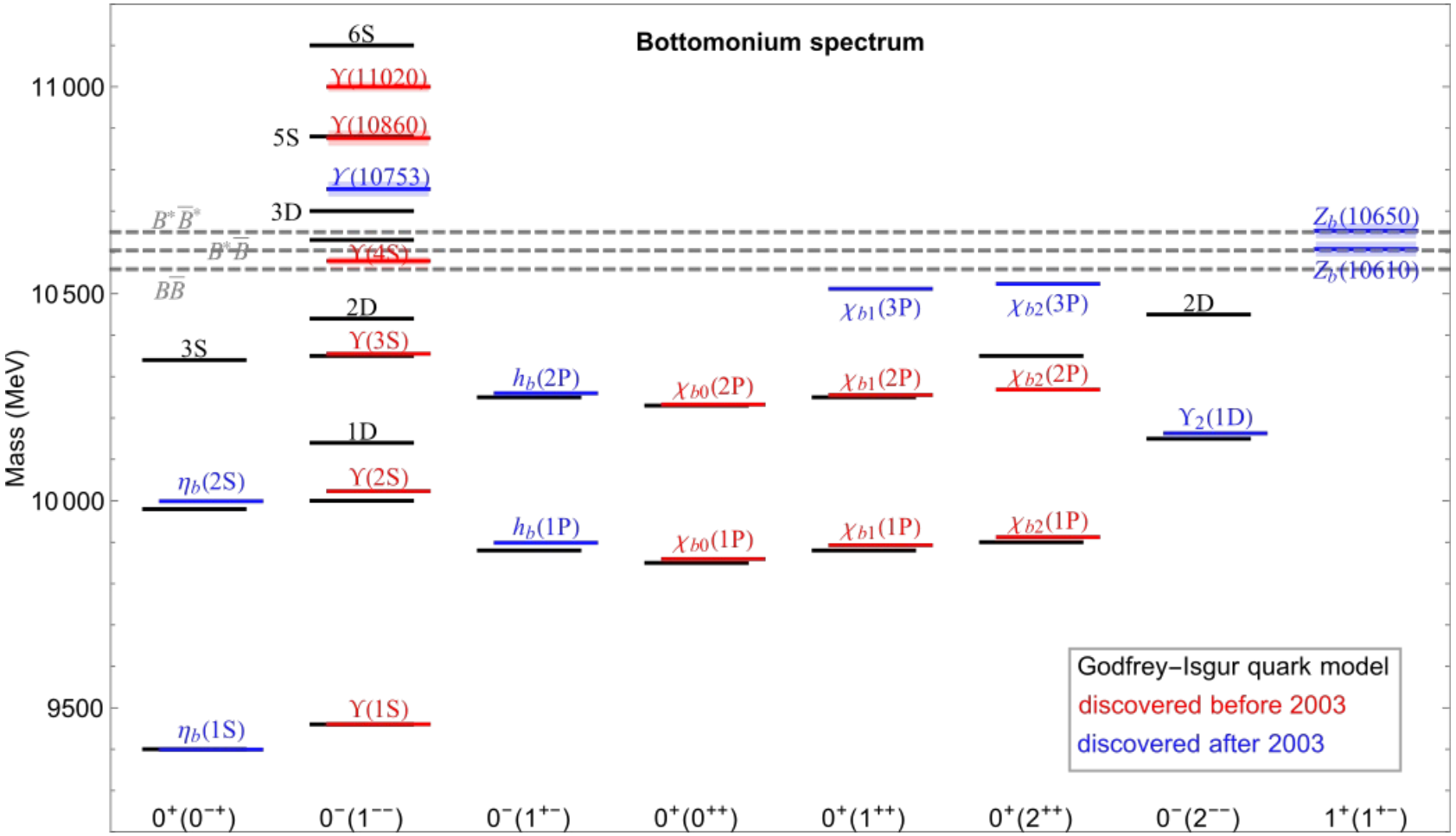
[JHEP 07 (2020) 123]



Decay mode	Yield	Fitted mass [MeV/c^2]	Corrected mass [MeV/c^2]	Resolution [MeV/c^2]
$J/\psi\pi^+$	25181 ± 217	6273.71 ± 0.12	6273.78 ± 0.12	13.49 ± 0.11
$J/\psi\pi^+\pi^-\pi^+$	9497 ± 142	6274.26 ± 0.18	6274.38 ± 0.18	11.13 ± 0.18
$J/\psi p\bar{p}\pi^+$	273 ± 29	6274.66 ± 0.73	6274.61 ± 0.73	6.34 ± 0.76
$J/\psi D_s^+(K^+K^-\pi^+)$	1135 ± 49	6274.09 ± 0.27	6274.11 ± 0.27	5.93 ± 0.30
$J/\psi D_s^+(\pi^+\pi^-\pi^+)$	202 ± 20	6274.57 ± 0.71	6274.29 ± 0.71	6.63 ± 0.67
$J/\psi D^0(K^-\pi^+)K^+$	175 ± 21	6273.97 ± 0.53	6274.08 ± 0.53	3.87 ± 0.57
$B_s^0(D_s^-\pi^+)\pi^+$	316 ± 27	6274.36 ± 0.44	6274.08 ± 0.44	4.67 ± 0.48
$B_s^0(J/\psi\phi)\pi^+$	299 ± 37	6275.87 ± 0.66	6275.46 ± 0.66	5.32 ± 0.74

$6274.47 \pm 0.27 \pm 0.17$ MeV, taken as WA by PDG

Bottomonium(like) states

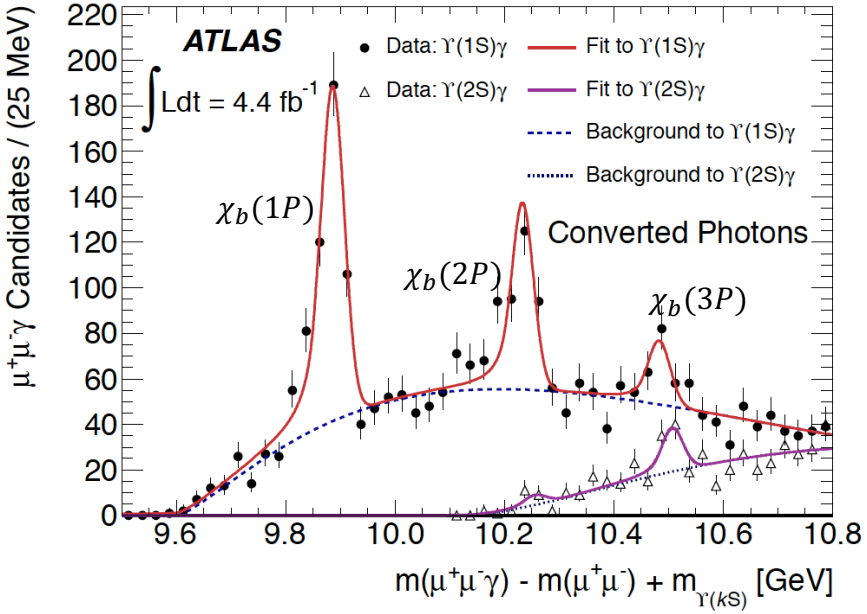


[F.-K. Guo (郭奉坤), PoS LATTICE 2022 (2023) 232]

$\chi_{b1,2}(3P)$

- With converted photons, better resolutions

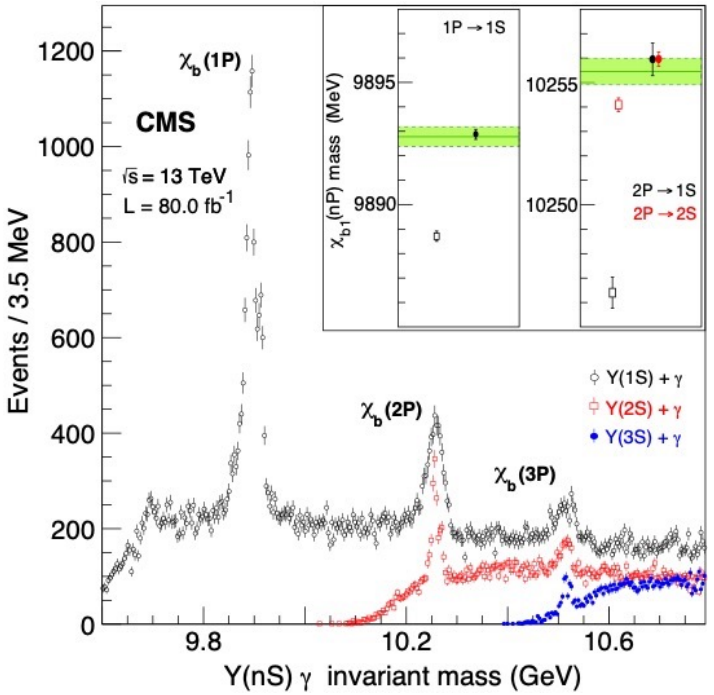
[PRL 108 (2012) 152001]

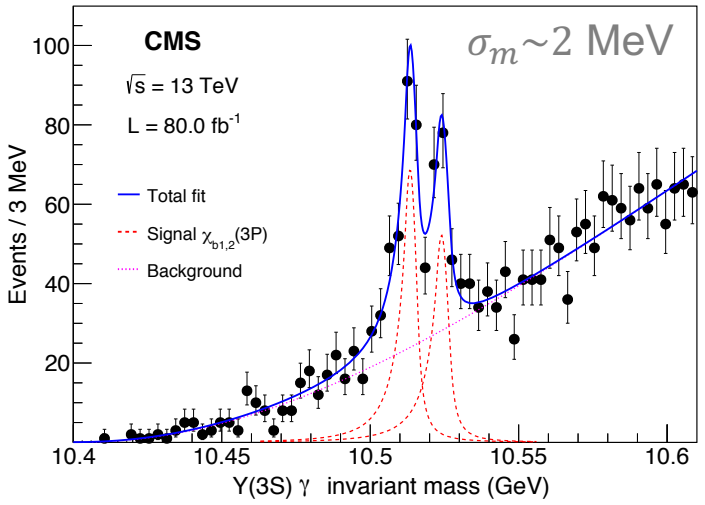


$m = 10530 \pm 5 \pm 9$ MeV

$$\Rightarrow \begin{matrix} m_1 = 10513.42 \pm 0.41 \pm 0.18 \text{ MeV} \\ m_2 = 10524.02 \pm 0.57 \pm 0.18 \text{ MeV} \end{matrix}$$

[PRL 121 (2018) 092002]



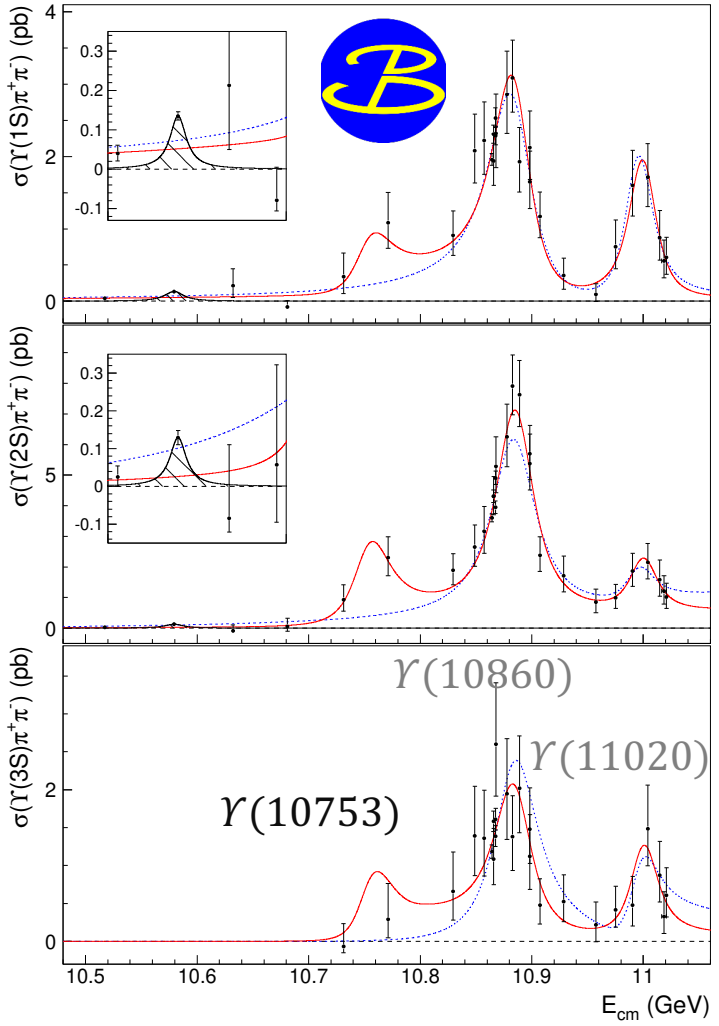


New structure $\Upsilon(10753)$

- In the E-dependence of $e^+e^- \to \Upsilon(nS)\pi^+\pi^-$ cross-sections

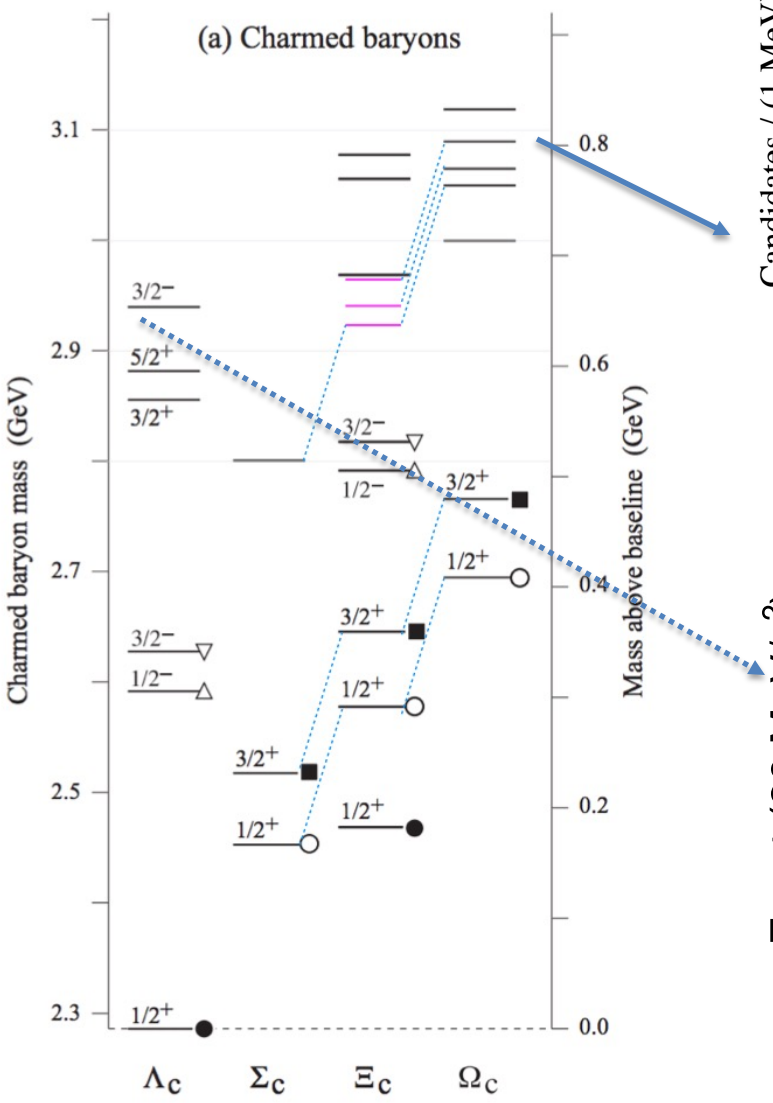
$M = 10752.7 \pm 5.9^{+0.7}_{-1.1}$ MeV
$\Gamma = 35.5^{+17.6}_{-11.3}{}^{+3.9}_{-3.3}$ MeV

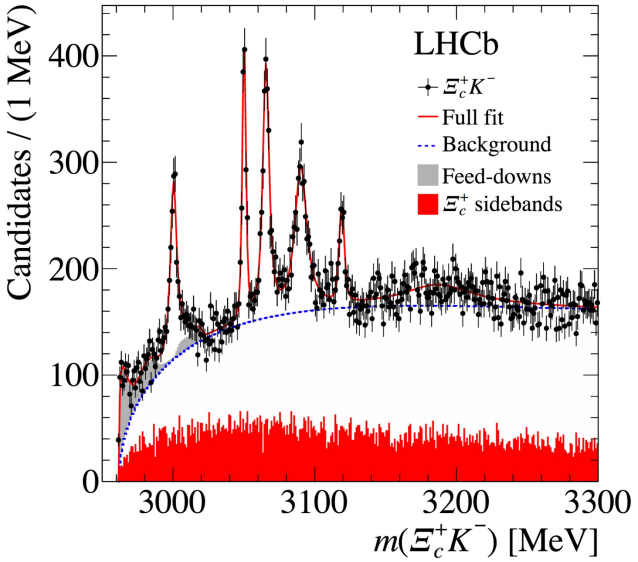
[JHEP 10 (2019) 220]



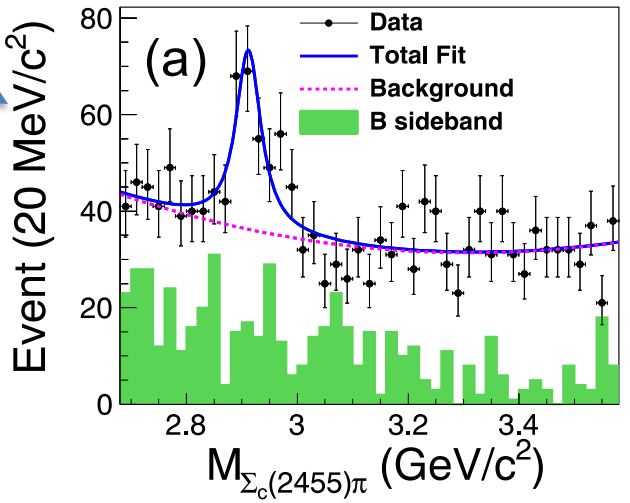
w/ new structures
w/o new structures

Charmed baryon spectroscopy





[PRL 118 (2017) 182001]



[PRL 130 (2023) 031901]

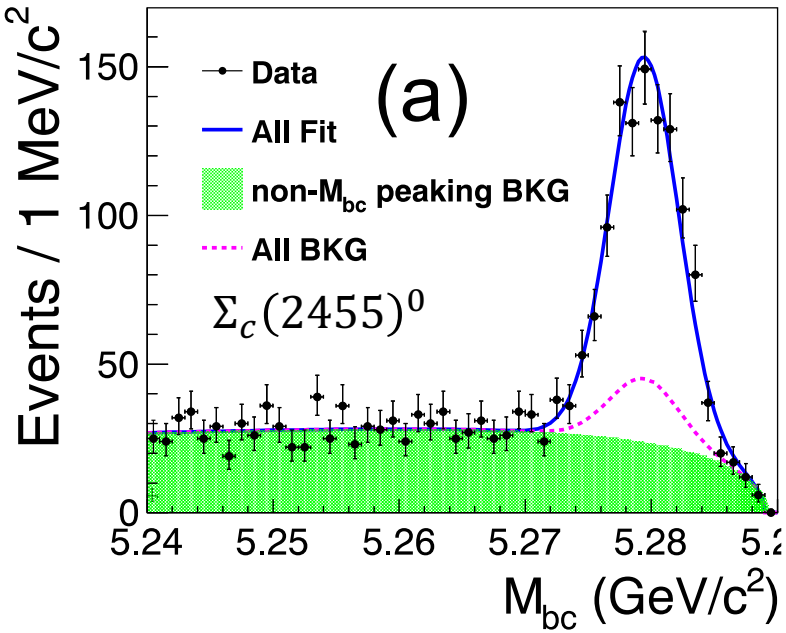
Evidence of $\Lambda_c^+(2910)$ (cud)

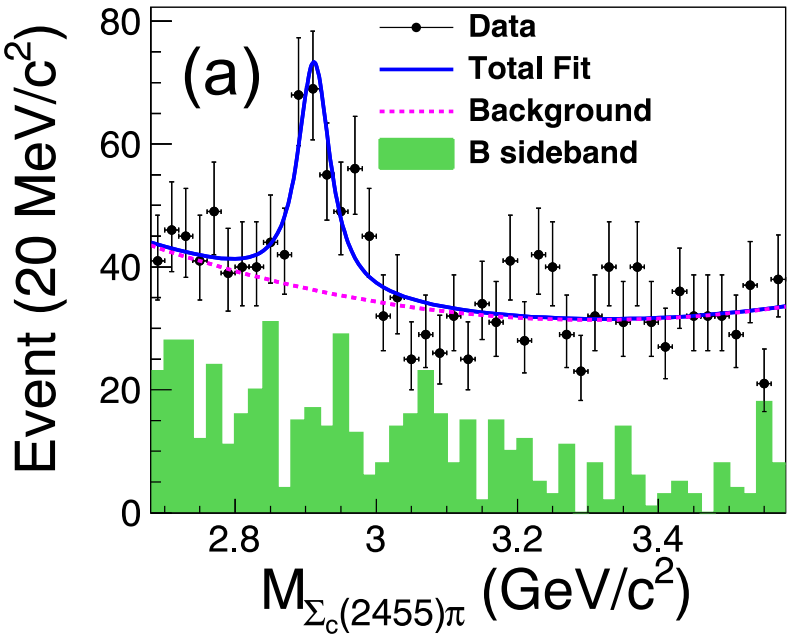
- In $\bar{B}^0 \to \Sigma_c(2455)^{++/0}\pi^{\mp}\bar{p}$ decays, 4.2σ, good candidate as $\Lambda_c^+(1/2-, 2P)$

$m = 2913.8 \pm 5.6 \pm 3.8$ MeV

$\Gamma = 51.8 \pm 20.0 \pm 18.8$ MeV

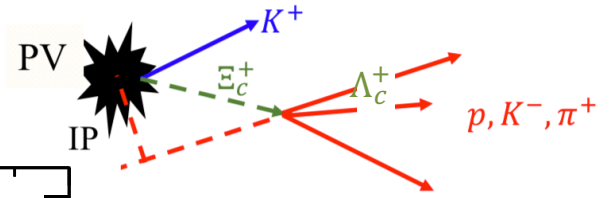
[PRL 130 (2023) 031901]

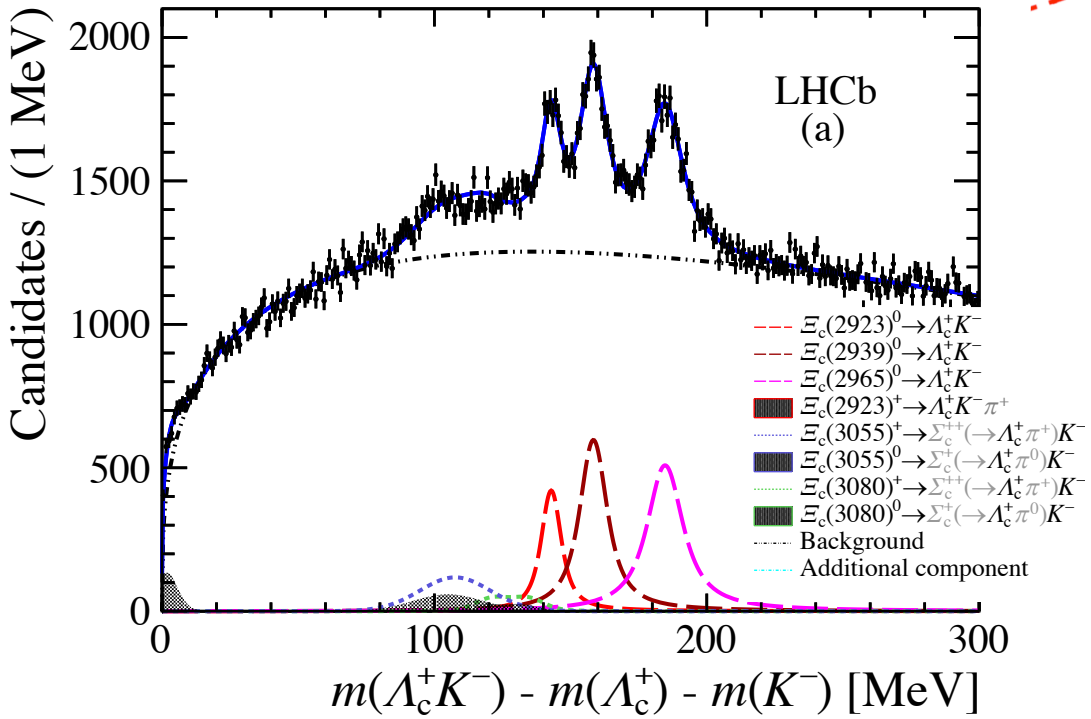


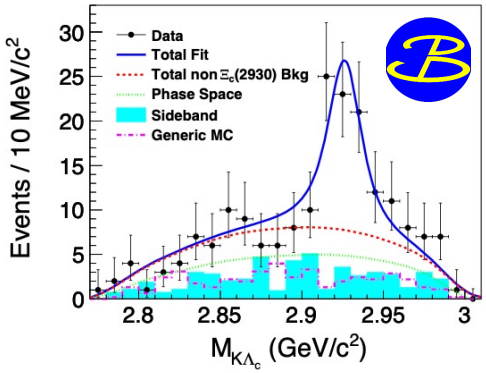


Observation of excited Ξ_c^0 states (csd)

- Three excited Ξ_c^0 states







[EPJC 78 (2018) 252]

$\Xi_c(2930)^0$ resolved to two states?

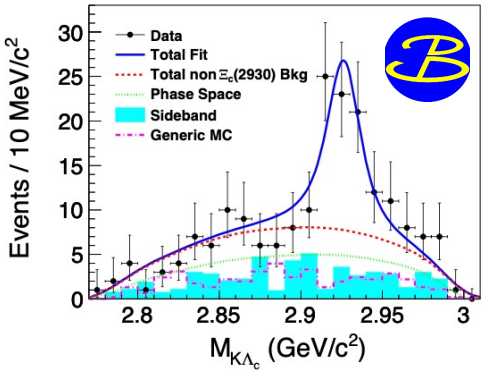
[PRL 124 (2020) 222001]

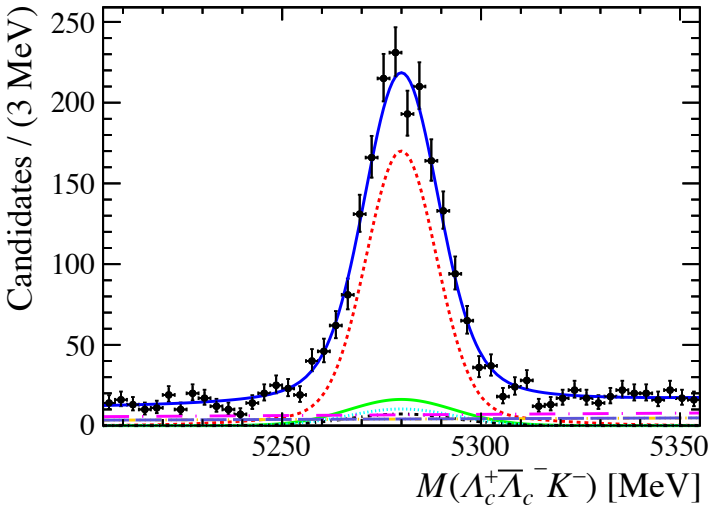
Resonance	Peak of ΔM [MeV]	Mass [MeV]	Γ [MeV]
$\Xi_c(2923)^0$	$142.91 \pm 0.25 \pm 0.20$	$2923.04 \pm 0.25 \pm 0.20 \pm 0.14$	$7.1 \pm 0.8 \pm 1.8$
$\Xi_c(2939)^0$	$158.45 \pm 0.21 \pm 0.17$	$2938.55 \pm 0.21 \pm 0.17 \pm 0.14$	$10.2 \pm 0.8 \pm 1.1$
$\Xi_c(2965)^0$	$184.75 \pm 0.26 \pm 0.14$	$2964.88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

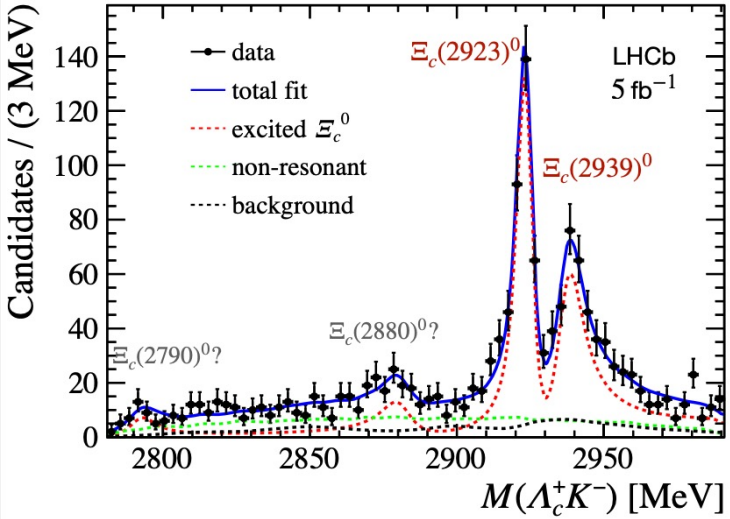
Ξ_c^{**0} in B^+ decay (csd)

- $B^+ \to \Lambda_c^+ \bar{\Lambda}_c^- K^+$
  - $\Xi_c(2923)^0$ and $\Xi_c(2939)^0$ confirmed
  - Evidence for a new state $\Xi_c(2880)^0$

State	Mass (MeV)	Width (MeV)	Significance
$\Xi_c(2880)^0$	$2881.8 \pm 3.1 \pm 8.5$	$12.4 \pm 5.2 \pm 5.8$	3.8σ
$\Xi_c(2923)^0$	$2924.5 \pm 0.4 \pm 1.1$	$4.8 \pm 0.9 \pm 1.5$	$>10\sigma$
$\Xi_c(2939)^0$	$2938.5 \pm 0.9 \pm 2.3$	$11.0 \pm 1.9 \pm 7.5$	$>10\sigma$







[PRD 108 (2023) 012020]

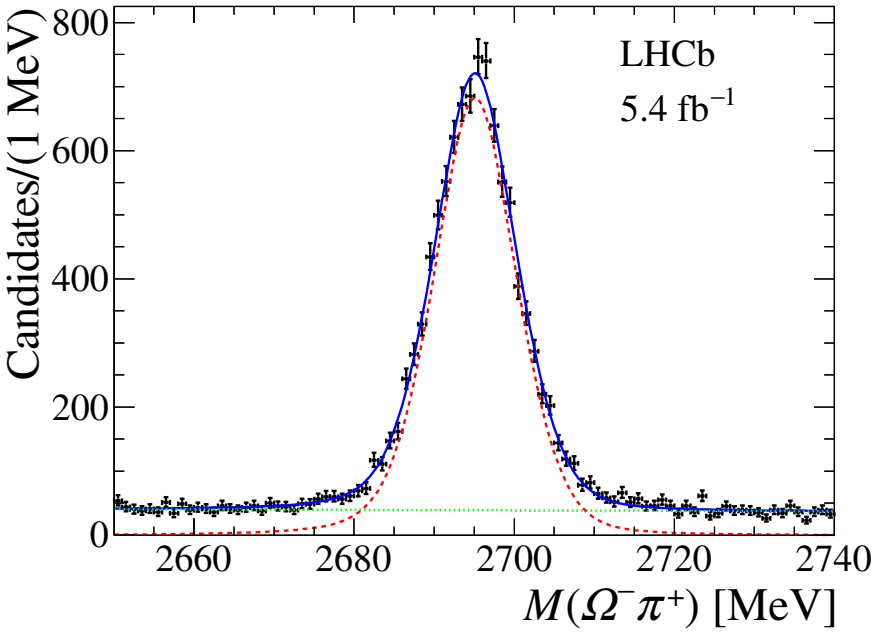
Ω_c^0 mass (css)

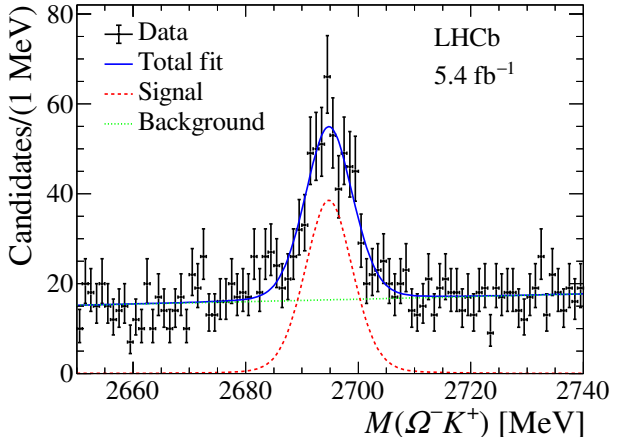
- Best measurement of Ω_c^0 mass while observing its CS decays $\Omega^- K^+, \Xi^- \pi^+$

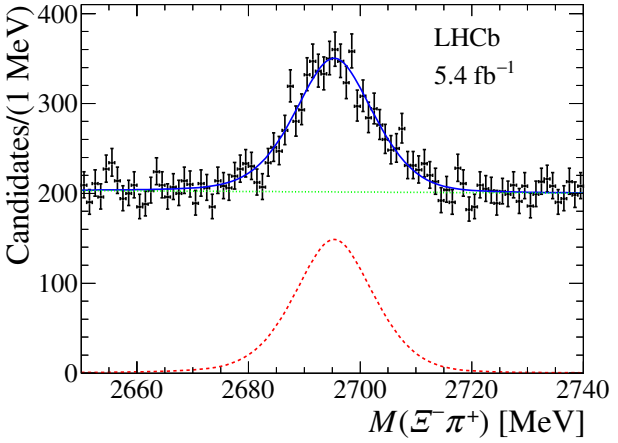
[arXiv:2308.08512]

$m(\Omega_c^0) = 2695.28 \pm 0.07 \pm 0.27 \pm 0.30$ MeV

2695.2 ± 1.7 MeV, PDG 2023



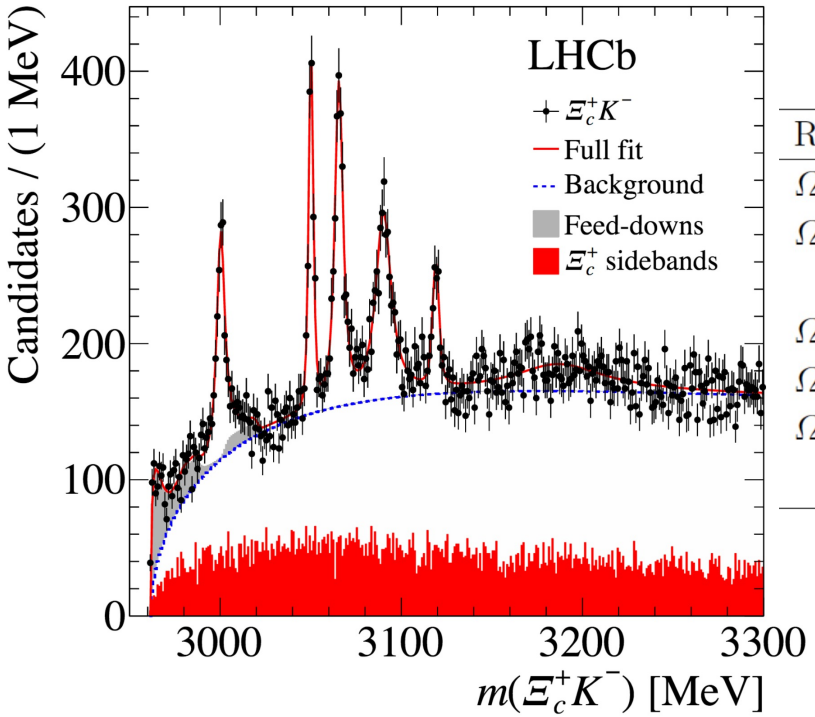




Observation of excited Ω_c^0 states

- Five states observed in $m(\Xi_c^+ K^-)$ in 2017, nature unclear
  - Excited Ω_c^0 (css), molecular, pentaquark $(cssq\bar{q})$?

[PRL 118 (2017) 182001]

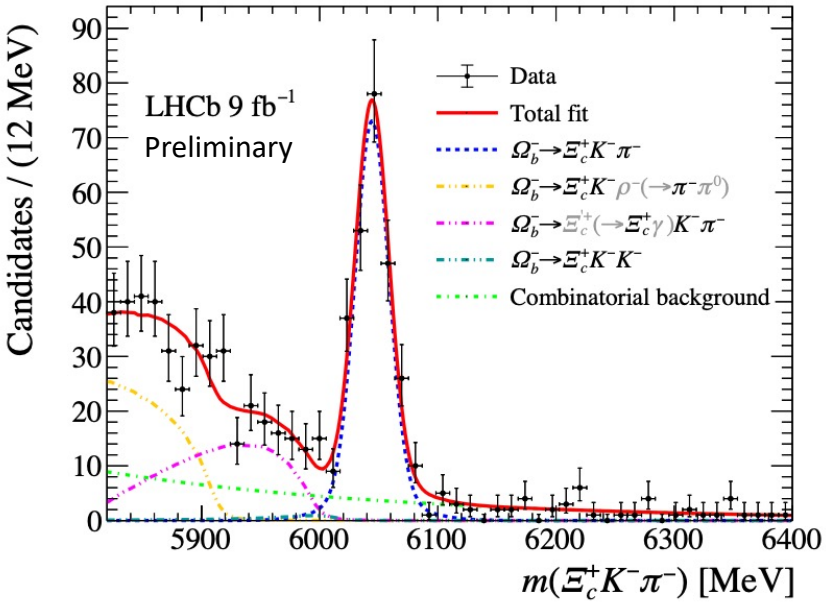


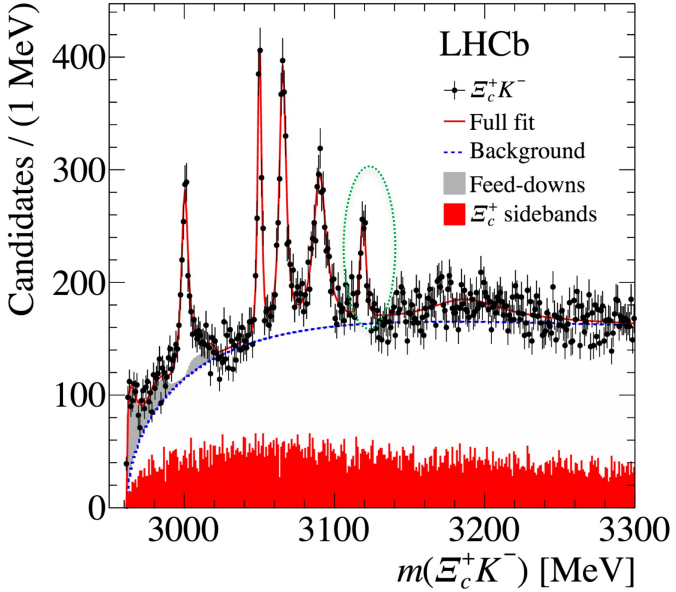
Resonance	Mass (MeV)	Γ (MeV)	$N_\sigma = \sqrt{\Delta\chi^2}$
$\Omega_c(3000)^0$	$3000.4 \pm 0.2 \pm 0.1^{+0.3}_{-0.5}$	$4.5 \pm 0.6 \pm 0.3$	20.4
$\Omega_c(3050)^0$	$3050.2 \pm 0.1 \pm 0.1^{+0.3}_{-0.5}$	$0.8 \pm 0.2 \pm 0.1$	20.4
		$< 1.2\,\text{MeV}, 95\%\ \text{CL}$	
$\Omega_c(3066)^0$	$3065.6 \pm 0.1 \pm 0.3^{+0.3}_{-0.5}$	$3.5 \pm 0.4 \pm 0.2$	23.9
$\Omega_c(3090)^0$	$3090.2 \pm 0.3 \pm 0.5^{+0.3}_{-0.5}$	$8.7 \pm 1.0 \pm 0.8$	21.1
$\Omega_c(3119)^0$	$3119.1 \pm 0.3 \pm 0.9^{+0.3}_{-0.5}$	$1.1 \pm 0.8 \pm 0.4$	10.4
		$< 2.6\,\text{MeV}, 95\%\ \text{CL}$	

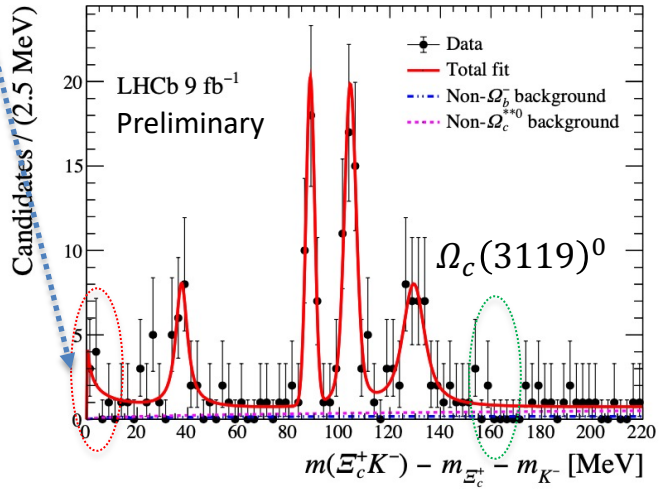
Ω_c^{**0} in Ω_b^- decay (css)

- $\Omega_b^- \to \Xi_c^+ K^- \pi^-$
  - Same four peaks observed, except $\Omega_c(3119)^0$
  - Structure at threshold (4.3σ)

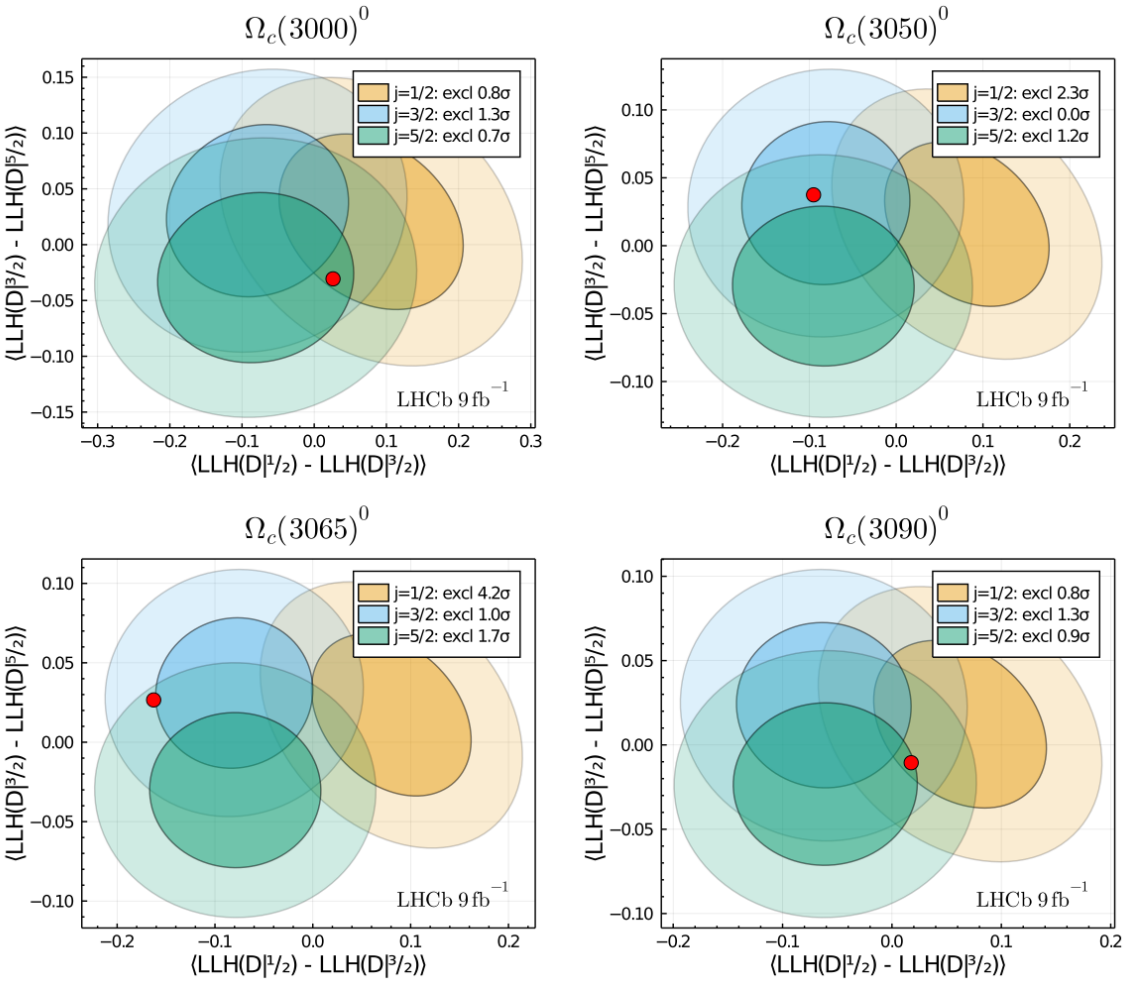
[PRD 104 (2021) L091102]







- Spin of Ω_c^{**0} probed, not conclusive yet
  - Assignment of (1/2, 1/2, 3/2, 3/2) rejected by 3.5σ

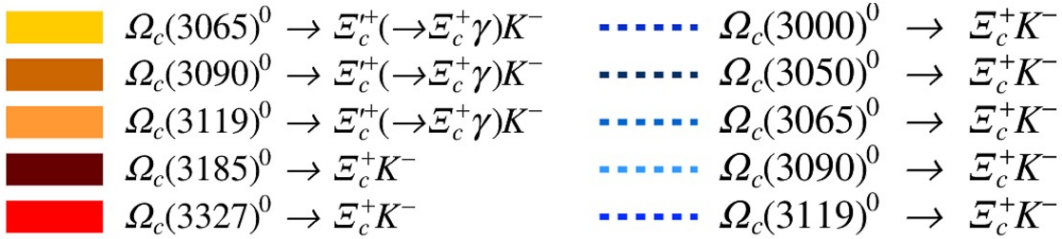


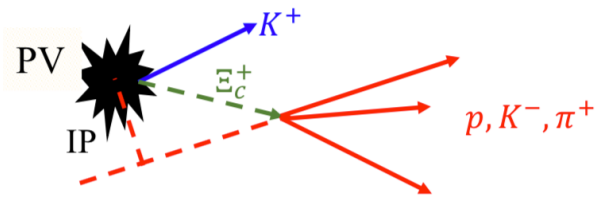
[PRD 104 (2021) L091102]

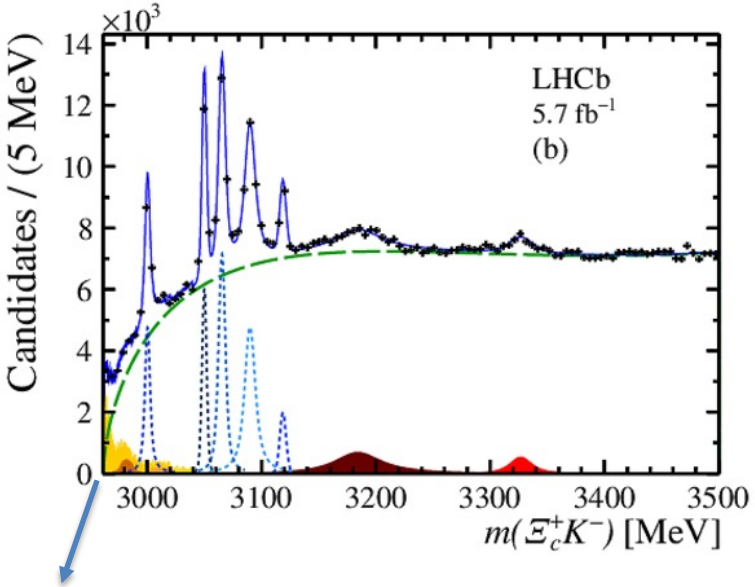
Two new charmed hadrons

- Two new $\Omega_c(3185)^0, \Omega_c(3327)^0$ in 2023

[arXiv:2302.04733, accepted by PRL]





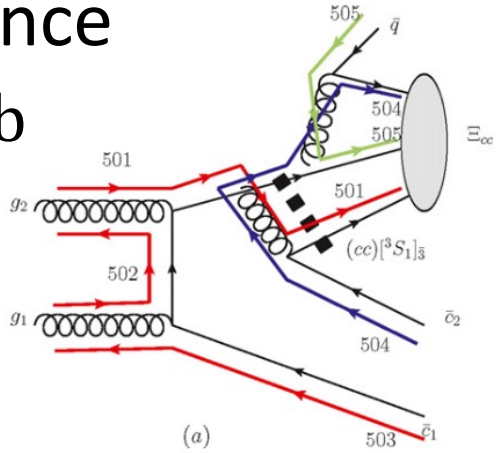


Resonance	m (MeV)	Γ (MeV)
$\Omega_c(3000)^0$	$3000.44 \pm 0.07^{+0.07}_{-0.13} \pm 0.23$	$3.83 \pm 0.23^{+1.59}_{-0.29}$
$\Omega_c(3050)^0$	$3050.18 \pm 0.04^{+0.06}_{-0.07} \pm 0.23$	$0.67 \pm 0.17^{+0.64}_{-0.72}$
		< 1.8 MeV, 95% CL
$\Omega_c(3065)^0$	$3065.63 \pm 0.06^{+0.06}_{-0.06} \pm 0.23$	$3.79 \pm 0.20^{+0.38}_{-0.47}$
$\Omega_c(3090)^0$	$3090.16 \pm 0.11^{+0.06}_{-0.10} \pm 0.23$	$8.48 \pm 0.44^{+0.61}_{-1.62}$
$\Omega_c(3119)^0$	$3118.98 \pm 0.12^{+0.09}_{-0.23} \pm 0.23$	$0.60 \pm 0.63^{+0.90}_{-1.05}$
		< 2.5 MeV, 95% CL
$\Omega_c(3185)^0$	$3185.1 \pm 1.7^{+7.4}_{-0.9} \pm 0.2$	$50 \pm 7^{+10}_{-20}$
$\Omega_c(3327)^0$	$3327.1 \pm 1.2^{+0.1}_{-1.3} \pm 0.2$	$20 \pm 5^{+13}_{-1}$

Difficult to distinguish threshold structure and feed-down

Doubly heavy baryons

- Production @ 13 TeV, in LHCb acceptance
  - $\sigma(\Xi_{cc}^{++}) = \sigma(\Xi_{cc}^{+})$~40 nb, $\sigma(\Omega_{cc}^{+})$~13 nb
  - $\sigma(\Xi_{bc}^{+}) = \sigma\left(\Xi_{bc}^{0}\right)$~17 nb, $\sigma\left(\Omega_{bc}^{0}\right)$~5 nb

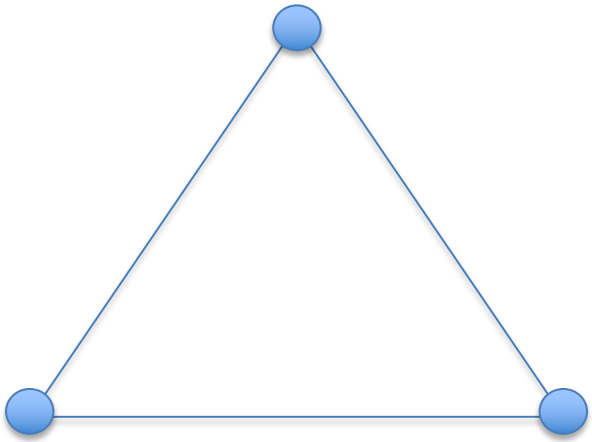


- Mass
  - $M(\Xi_{cc}^{+}) \approx M(\Xi_{cc}^{++})$: 3.5-3.7 GeV, $M(\Omega_{cc}^{+})$, +0.1-0.2 GeV
  - $M(\Xi_{bc}^{+}) \approx M\left(\Xi_{bc}^{0}\right)$: 6.8-7.1 GeV, $M(\Omega_{bc}^{0})$, +0.05-0.1 GeV
- Lifetime
  - $\tau(\Xi_{cc}^{+}) \approx \tau(\Omega_{cc}^{+}) \approx \frac{1}{3}\tau(\Xi_{cc}^{++})$, $\tau(\Xi_{cc}^{++})$: 0.2-1.05 ps
  - Ξ_{bc}^{+}, Ξ_{bc}^{0}, Ω_{bc}^{0}: 0.1-0.5 ps

Summary of DHB studies

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

$\Omega_{cc}^{+}\ (ccs)$



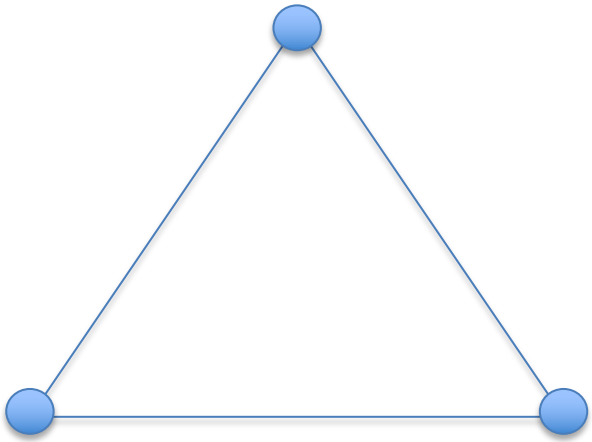
$\Xi_{cc}^{++}\ (ccu)$ $\Xi_{cc}^{+}\ (ccd)$

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]

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

First search [CPC 45 (2021) 093002]

$\Omega_{bc}^{0}\ (bcs)$



$\Xi_{bc}^{+}\ (bcu)$ $\Xi_{bc}^{0}\ (bcd)$

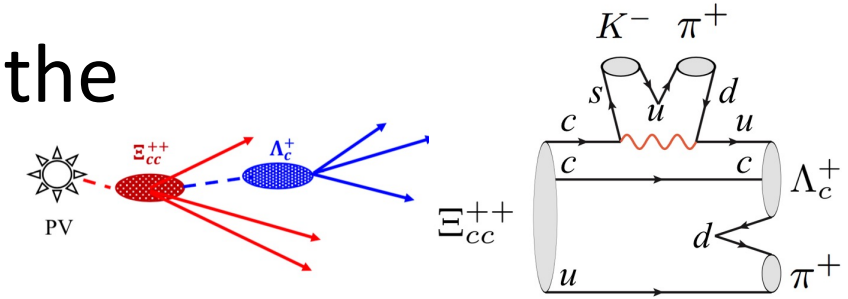
First search
Hint
[CPC 47 (2023) 093001]

First search
[JHEP 11 (2020) 095]

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

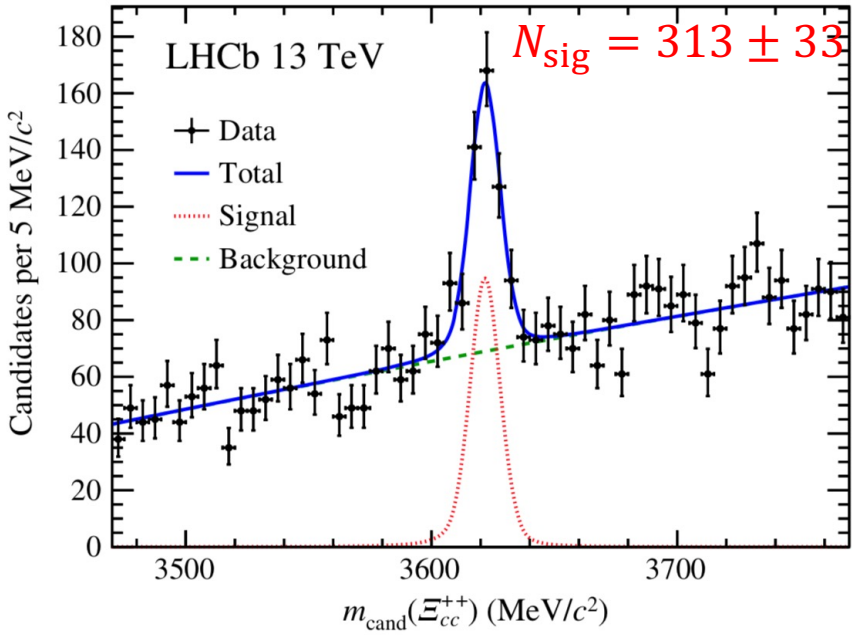
- $\Lambda_c^+ K^- \pi^+ \pi^+$ identified as the most promising channel

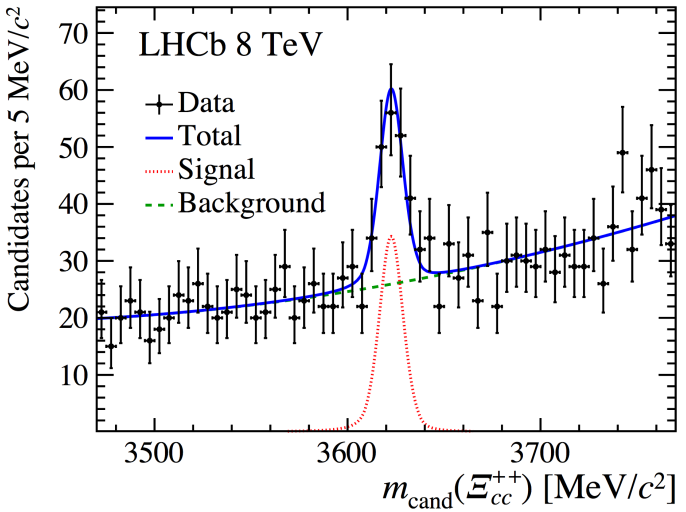
[F.-S. Yu *et al.*, CPC 42 (2018) 051001]



- First observation, in 2016 (>12σ) & Run-I (>7σ)

[PRL 119 (2017) 112001]



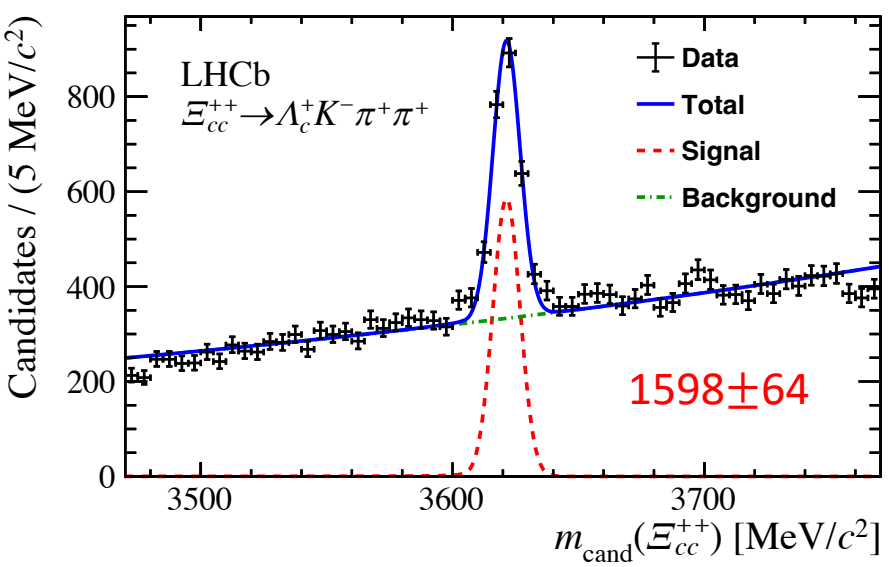


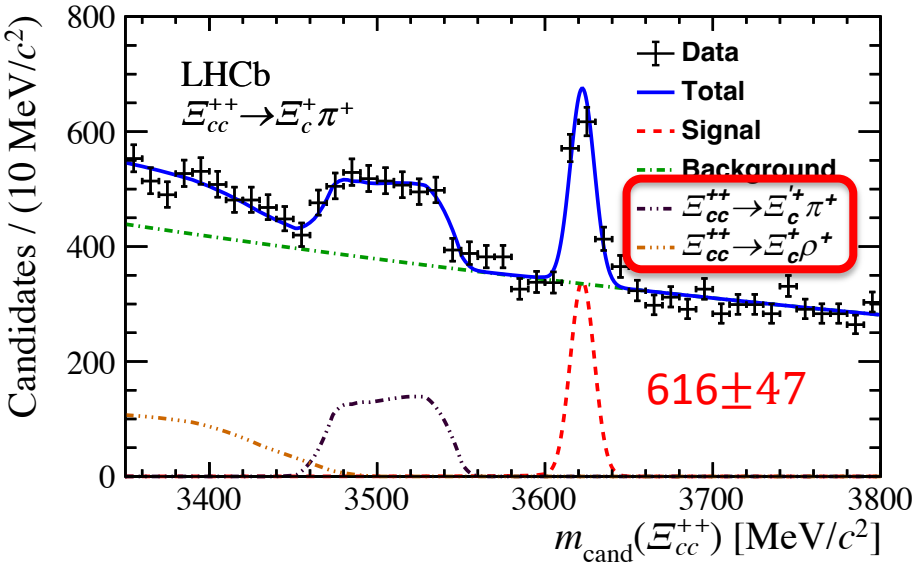
$3621.40 \pm 0.72(\text{stat.}) \pm 0.27(\text{syst.}) \pm 0.14(\Lambda_c^+)$ MeV/c^2

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

- UROP, preparing to search for excited states, event-selection re-optimised

[JHEP 02 (2020) 049]





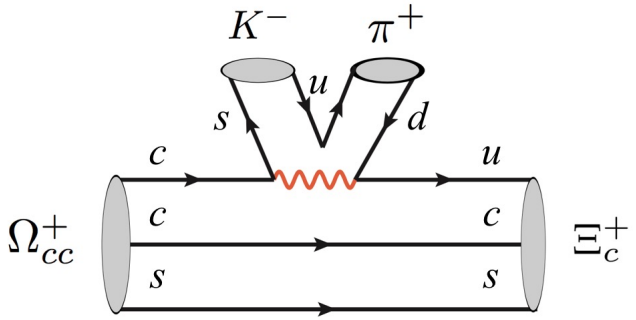
$$m(\Xi_{cc}^{++}) = 3621.55 \pm 0.23 \pm 0.30 \text{ MeV}/c^2$$

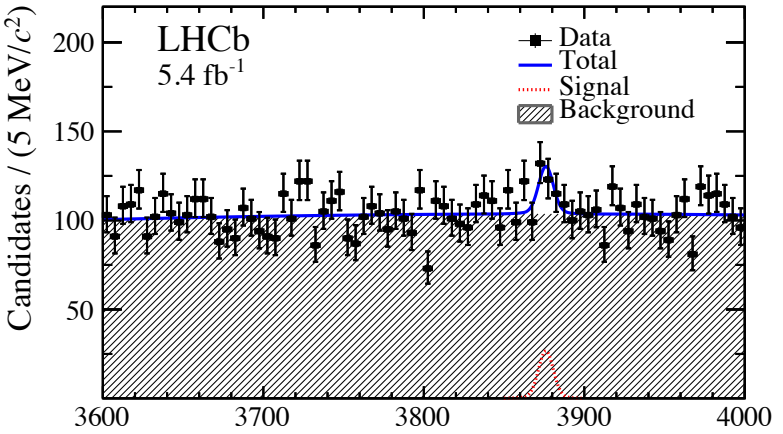
c.f., $3620.6 \pm 0.65 \pm 0.31$ MeV/c^2

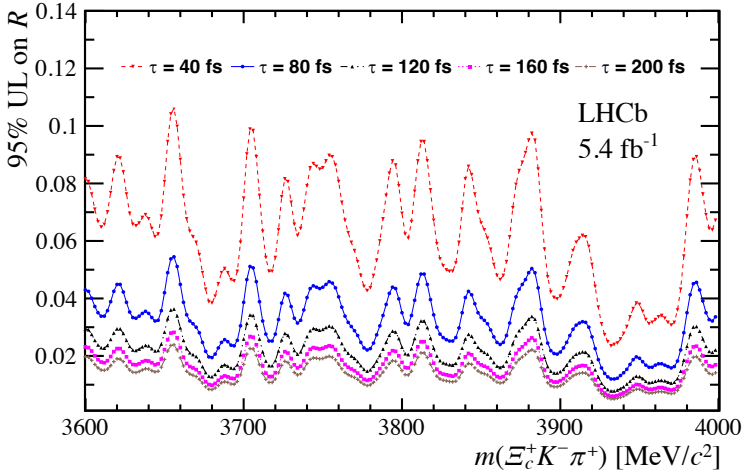
Search for Ω_{cc}^{+} (ccs)

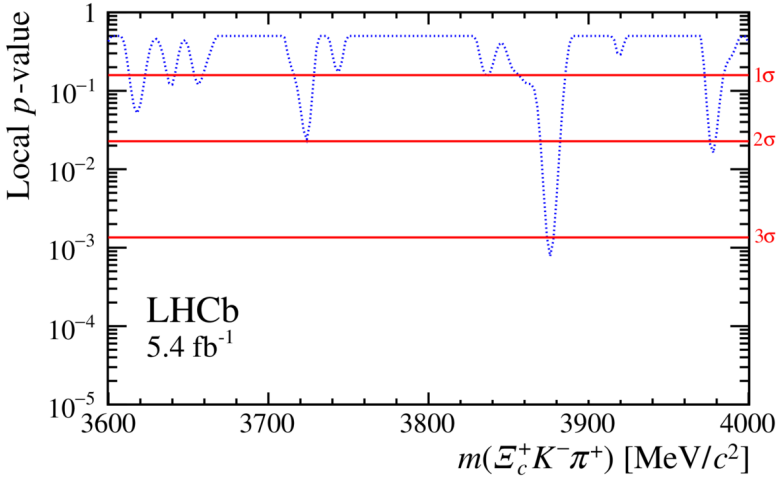
- $\Omega_{cc}^{+} \to \Xi_c^{+} K^{-} \pi^{+}$
  - Hint at 3876 MeV, local (global) significance of 3.2σ (1.8σ)
  - Production relative to Ξ_{cc}^{++}

[SCPMA 64 (2021) 101062]



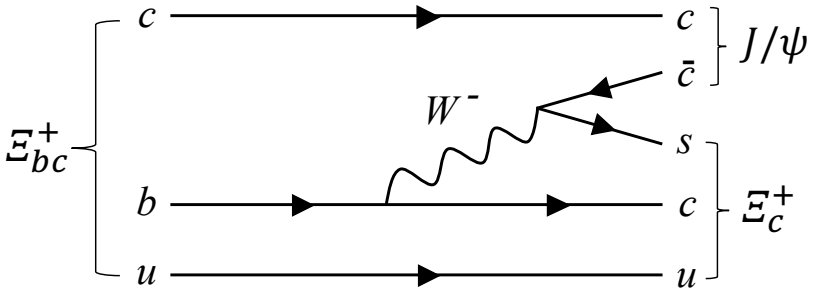


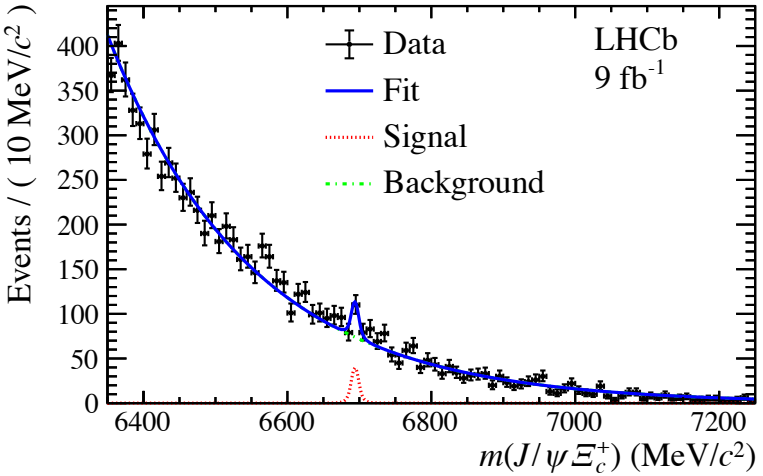


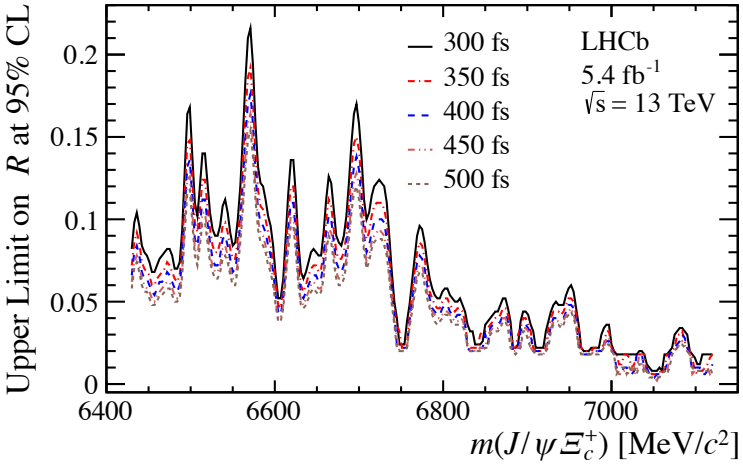


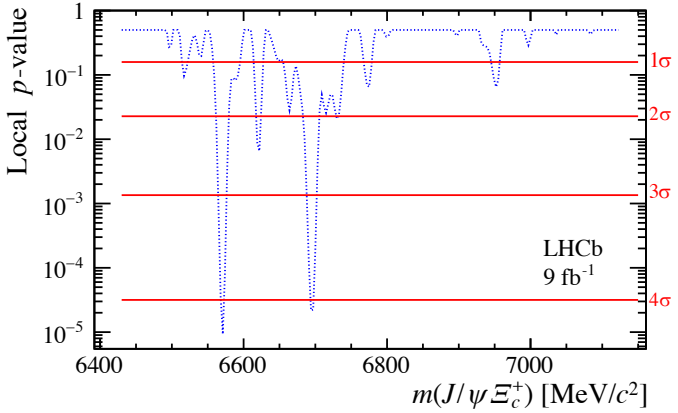
Search for Ξ_{bc}^{+} (bcu)

- $\Xi_{bc}^{+} \to J/\psi \Xi_c^{+}$
  - Hints at 6571、6694 MeV, w/ local (global) sig. of 4.3σ (2.8σ), 4.1σ (2.4σ)
  - Production relative to $B_c^{+} \to J/\psi D_s^{+}$



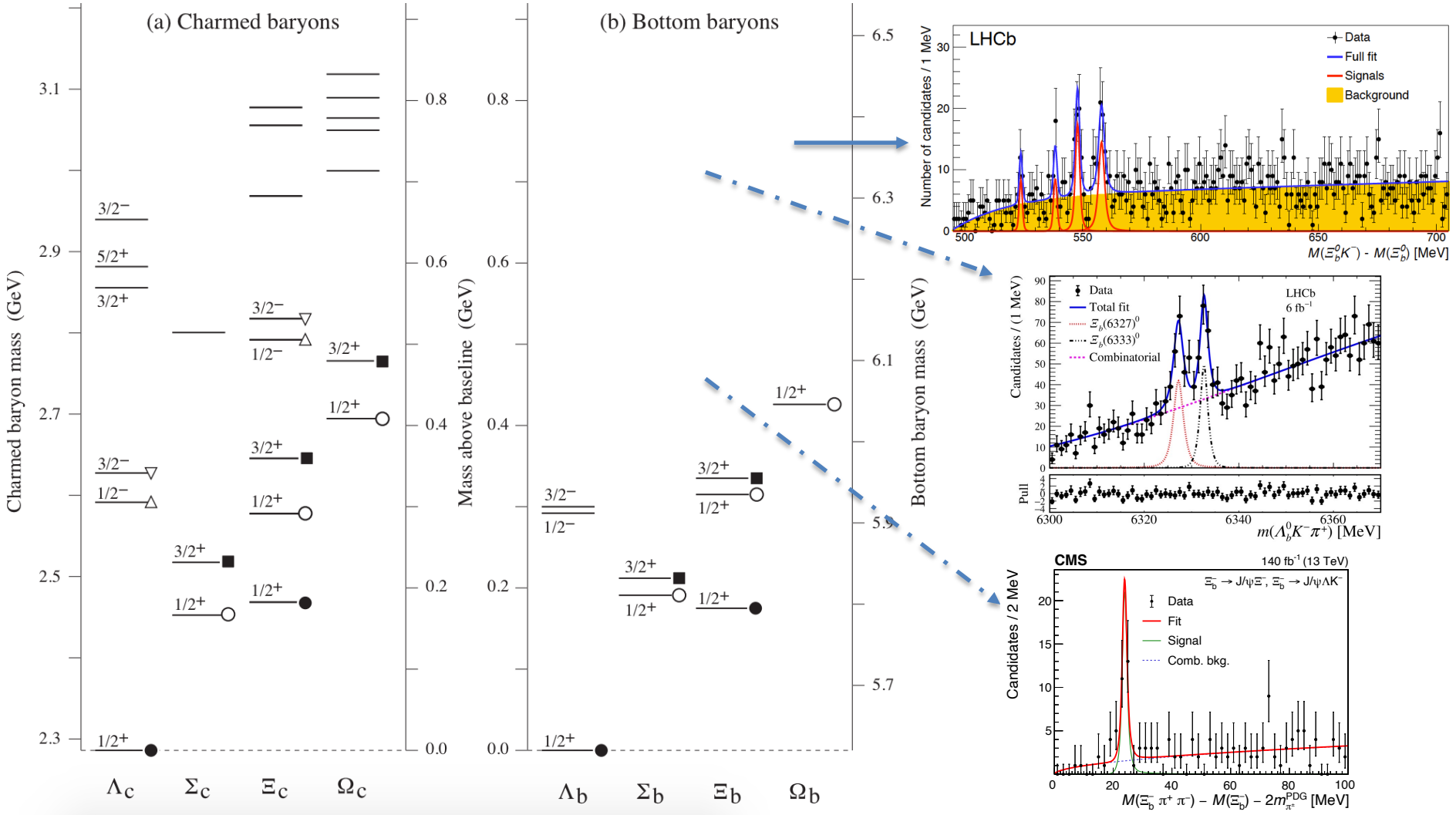






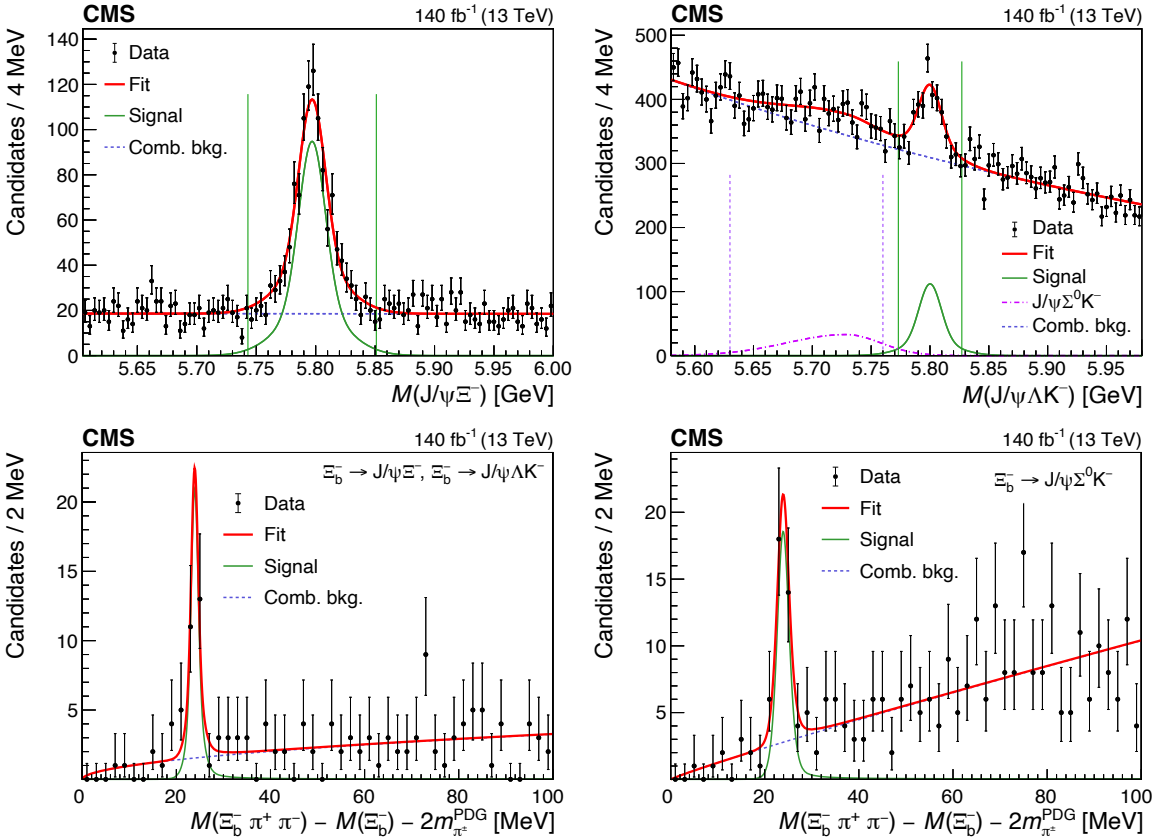
[CPC 47 (2023) 093001]

Beauty baryons



Observation of $\Xi_b(6100)^-$ (bsd)

- $\Xi_b(6100)^-$ with $\Xi_b^-\pi^+\pi^-$



$m = 6100.3 \pm 0.2 \pm 0.1$ MeV, $\Gamma < 1.9$ MeV at 95% CL

[PRL 126 (2021) 252003]

$\Xi_b(6327)^0$ and $\Xi_b(6333)^0$ (bsu)

- Observed in $\Lambda_b^0 K^- \pi^+$, consistent w/ 1D doublets

$$m_{\Xi_b(6327)^0} = 6327.28\,^{+0.23}_{-0.21}(\text{stat}) \pm 0.12(\text{syst}) \pm 0.24(m_{\Lambda_b^0})\ \text{MeV}$$

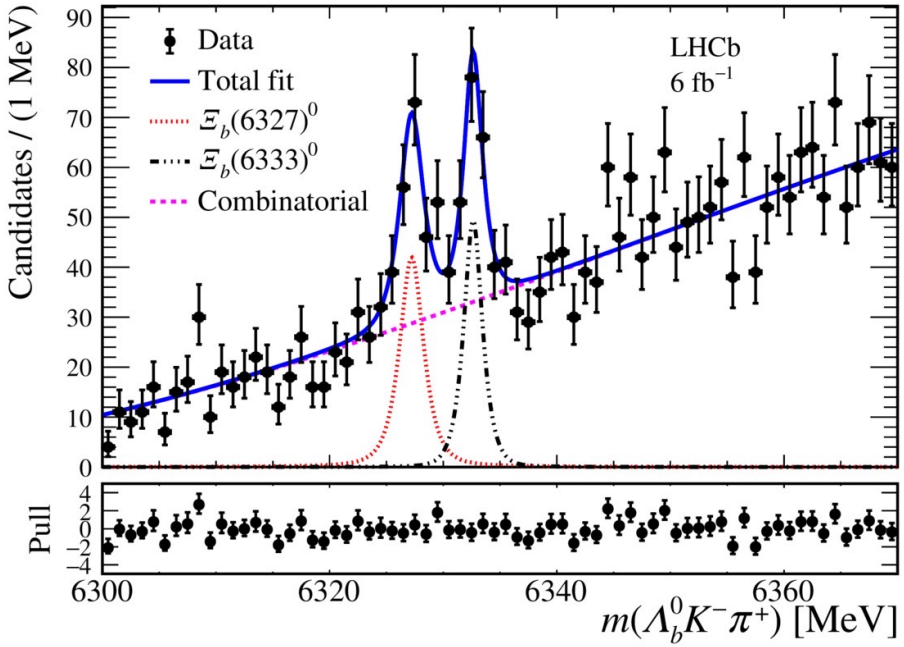
$$m_{\Xi_b(6333)^0} = 6332.69\,^{+0.17}_{-0.18}(\text{stat}) \pm 0.03(\text{syst}) \pm 0.22(m_{\Lambda_b^0})\ \text{MeV}$$

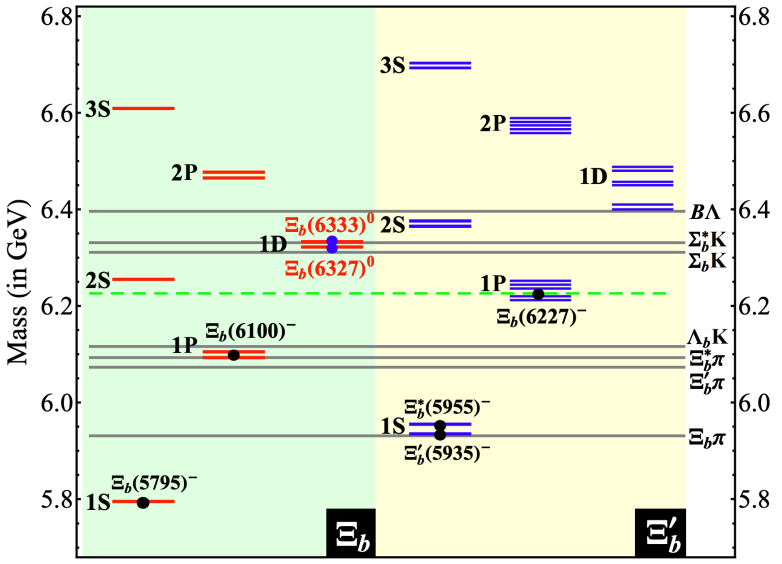
$$\Delta m \equiv m_{\Xi_b(6333)^0} - m_{\Xi_b(6327)^0} = 5.41\,^{+0.26}_{-0.27}(\text{stat}) \pm 0.12(\text{syst})\ \text{MeV}$$

$$\Gamma_{\Xi_b(6327)^0} < 2.20\ (2.56)\ \text{MeV at 90\% (95\%) CL}$$

$$\Gamma_{\Xi_b(6333)^0} < 1.60\ (1.92)\ \text{MeV at 90\% (95\%) CL}$$

[PRL 128 (2022) 162001]





[B. Chen *et al.*, PRD 98 (2018) 031502(R)]

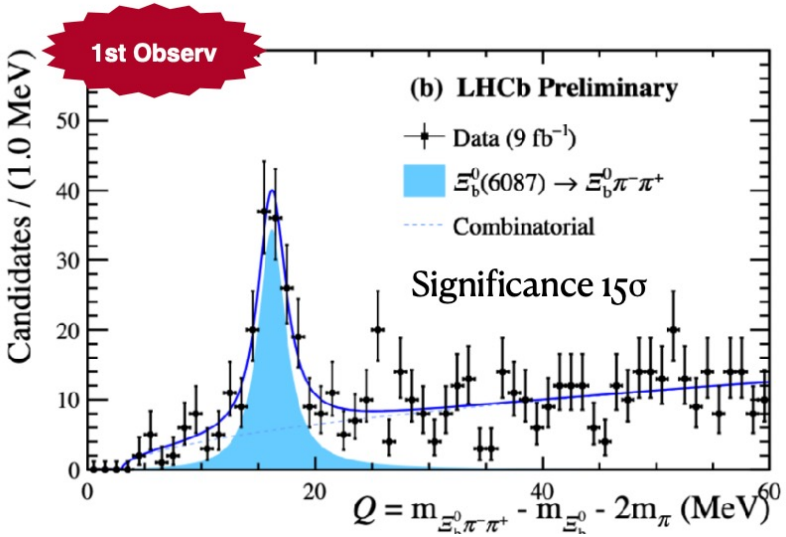
$\Xi_b(6087)^0$ and $\Xi_b(6095)^0$ (bsu)

- Two new states observed
  - $\Xi_b(6087)^0 \to \Xi_b'(\Xi_b^0\pi^-)\pi^+$
  - $\Xi_b(6095)^0 \to \Xi_b^{*-}(\Xi_b^0\pi^-)\pi^+$

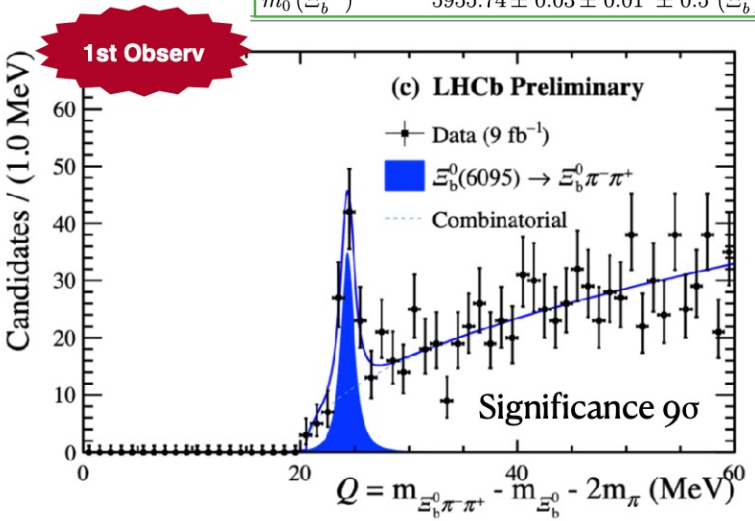
[LHCb-Paper-2023-008]

	Value [MeV]	
Q_0 $(\Xi_b^-(6100))$	$23.60 \pm 0.11 \pm 0.02$	Confirmation
Γ $(\Xi_b^-(6100))$	$0.94 \pm 0.30 \pm 0.08$	
m_0 $(\Xi_b^-(6100))$	$6099.74 \pm 0.11 \pm 0.02 \pm 0.6$ (Ξ_b^-)	
Q_0 $(\Xi_b^0(6087))$	$16.20 \pm 0.20 \pm 0.06$	1st Observ
Γ $(\Xi_b^0(6087))$	$2.43 \pm 0.51 \pm 0.10$	
m_0 $(\Xi_b^0(6087))$	$6087.24 \pm 0.20 \pm 0.06 \pm 0.5$ (Ξ_b^0)	
Q_0 $(\Xi_b^0(6095))$	$24.32 \pm 0.15 \pm 0.03$	
Γ $(\Xi_b^0(6095))$	$0.50 \pm 0.33 \pm 0.11$	
m_0 $(\Xi_b^0(6095))$	$6095.36 \pm 0.15 \pm 0.03 \pm 0.5$ (Ξ_b^0)	
Q_0 (Ξ_b^{*0})	$15.80 \pm 0.02 \pm 0.01$	Improvements
Γ (Ξ_b^{*0})	$0.87 \pm 0.06 \pm 0.05$	
m_0 (Ξ_b^{*0})	$5952.37 \pm 0.02 \pm 0.01 \pm 0.6$ (Ξ_b^-)	
Q_0 $(\Xi_b^{'-})$	$3.66 \pm 0.01 \pm 0.00$	
Γ $(\Xi_b^{'-})$	$0.03 \pm 0.01 \pm 0.03$	
m_0 $(\Xi_b^{'-})$	$5935.13 \pm 0.01 \pm 0.00 \pm 0.5$ (Ξ_b^0)	
Q_0 (Ξ_b^{*-})	$24.27 \pm 0.03 \pm 0.01$	
Γ (Ξ_b^{*-})	$1.43 \pm 0.08 \pm 0.08$	
m_0 (Ξ_b^{*-})	$5955.74 \pm 0.03 \pm 0.01 \pm 0.5$ (Ξ_b^0)	

1st Observ



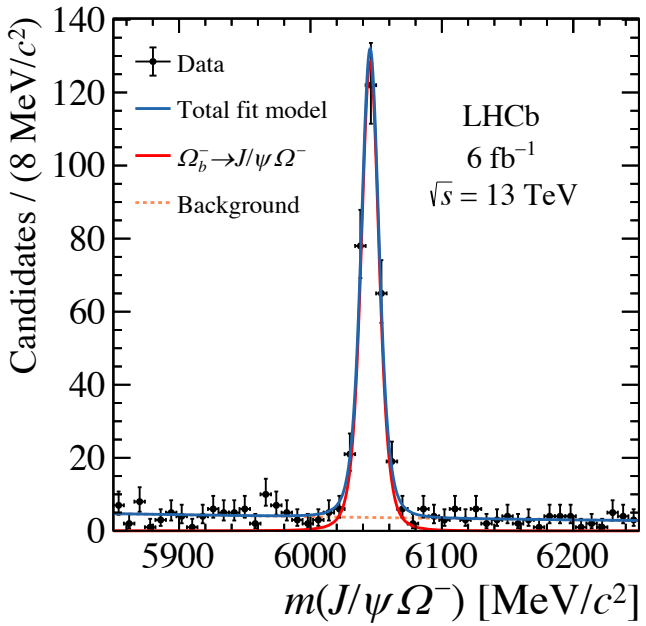
1st Observ

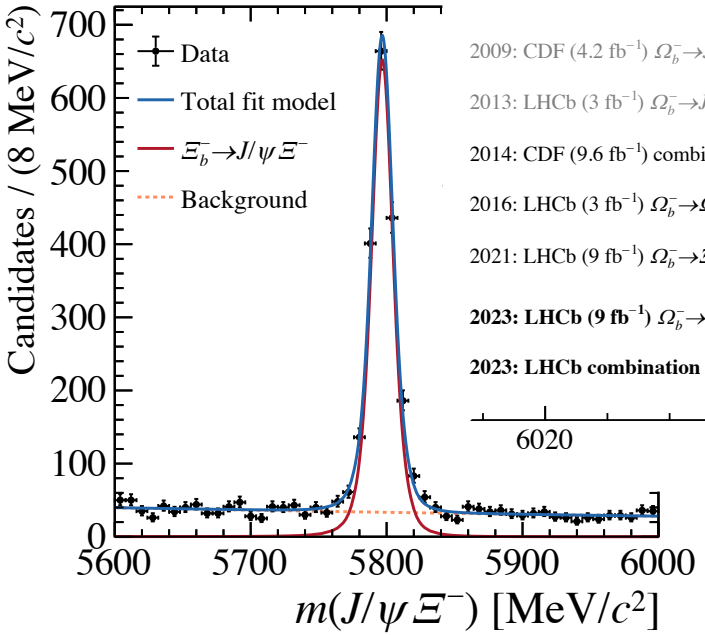


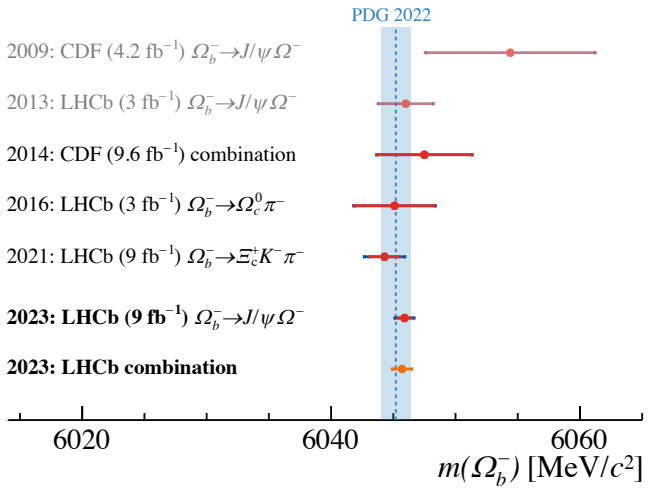
Ω_b^- mass (bss)

- Mass difference measured using $\Omega_b^- \to J/\psi\Omega^-(\Lambda K^-)$ and $\Xi_b^- \to J/\psi\Xi^-(\Lambda\pi^-)$

[arXiv:2305.15329]







$$m(\Omega_b^-) - m(\Xi_b^-) = 248.54 \pm 0.51 \pm 0.38 \text{ MeV}$$
$$m(\Omega_b^-) = 6045.9 \pm 0.5 \pm 0.6 \text{ MeV}$$

Summary

- Many results on the conventional heavy flavor spectroscopy in the past years
  - Meson: $D_{s0}(2590)^+, B_c^{(*)}(2S)^+$
  - Quarkonium: $\Upsilon(10753)$
  - Charmed baryon: excited Ω_c/Ξ_c states
  - Doubly heavy baryon: Ξ_{cc}^{++}
  - Beauty baryon: excited Ω_b/Ξ_b states

  Much more will come soon, stay tuned
- Your suggestions are always welcome