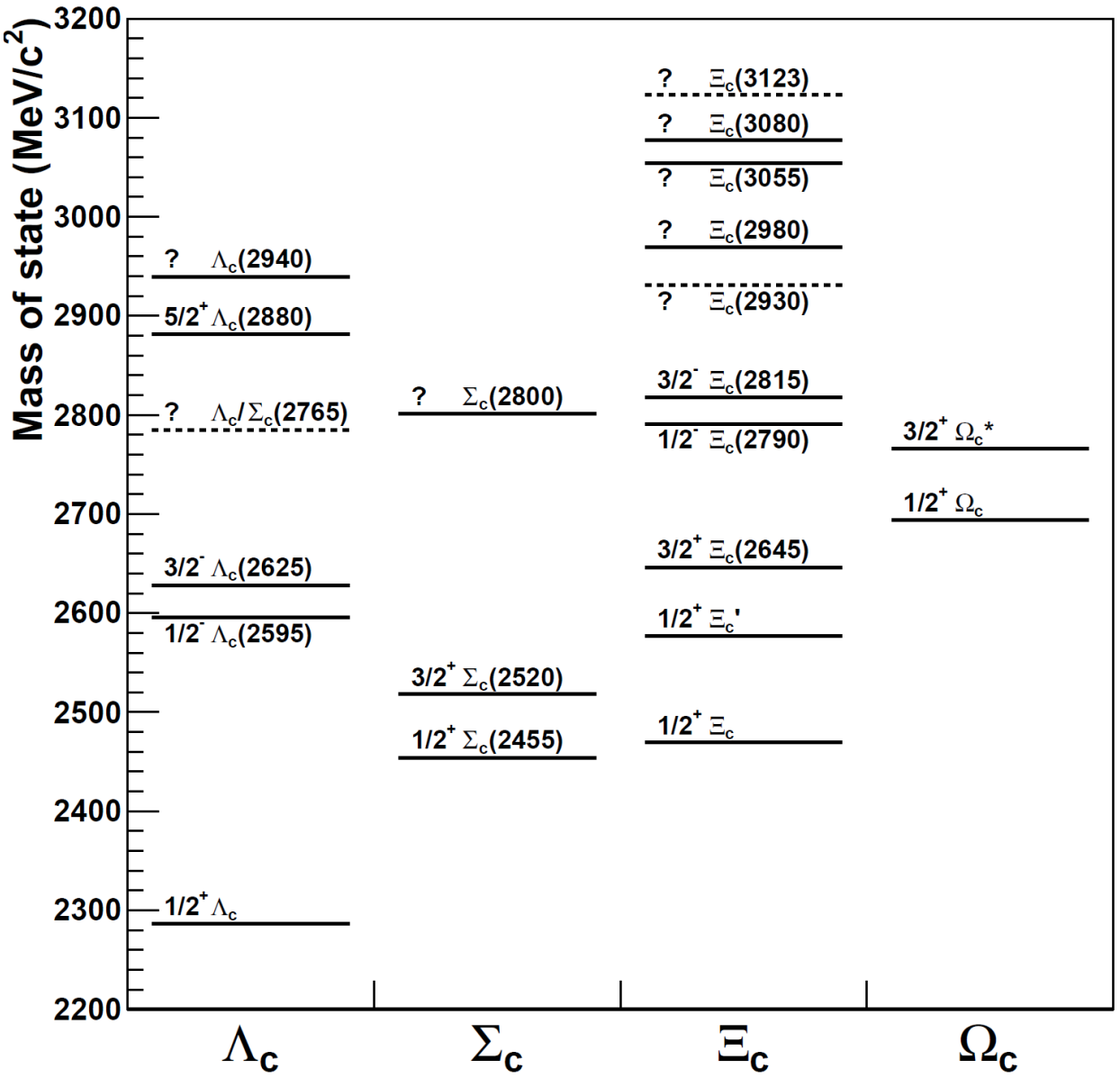
Latest results in heavy baryons spectroscopy

Elena Solovieva
Moscow Institute of Physics and Technology
Lebedev Physical Institute of the RAS

Known Charmed Baryon States



$\mathfrak{B}_c$ = c + diquark

Quark content of diquark:

- *qq* with isospin 0 (flavor antisymmetric) — Λ_c **family**;
- *qq* with isospin 1 (flavor symmetric) — Σ_c **family**;
- *qs* with isospin $\frac{1}{2}$ — Ξ_c **family**;
- *ss* with isospin 0 (flavor symmetric) — Ω_c **family**.

Ξ_c Family

State	Decay mode	Mass, MeV/c^2	Width, MeV	J^P
$\Xi_c'^+$	$\Xi_c^+\gamma$	2577.4 ± 1.2		$\frac{1}{2}^+$
$\Xi_c'^0$	$\Xi_c^0\gamma$	2578.8 ± 0.5		$\frac{1}{2}^+$
$\Xi_c(2645)^+$	$\Xi_c^0\pi^+$	2645.53 ± 0.31	2.14 ± 0.19	$\frac{3}{2}^+$
$\Xi_c(2645)^0$	$\Xi_c^+\pi^-$	2646.32 ± 0.31	2.35 ± 0.22	$\frac{3}{2}^+$
$\Xi_c(2790)^+$	$\Xi_c'^0\pi^+$	2792.0 ± 0.5	8.9 ± 1.0	$\frac{1}{2}^-$
$\Xi_c(2790)^0$	$\Xi_c'^+\pi^-$	2792.8 ± 1.2	10.0 ± 1.1	$\frac{1}{2}^-$
$\Xi_c(2815)^+$	$\Xi_c^+\pi^+\pi^-$, $\Xi_c(2645)^0\pi^+$, $\Xi_c^{0\prime}\pi^+$	2816.67 ± 0.31	2.43 ± 0.26	$\frac{3}{2}^-$
$\Xi_c(2815)^0$	$\Xi_c^0\pi^+\pi^-$, $\Xi_c(2645)^+\pi^-$, $\Xi_c^{+\prime}\pi^-$	2820.22 ± 0.32	2.54 ± 0.25	$\frac{3}{2}^-$
$\Xi_c(2930)^0$	$\Lambda_c^+K^-$	$2928.9^{+3.1}_{-12.4}$	19.5^{+10}_{-12}	
$\Xi_c(2970)^+$	$\Lambda_c^+K^-\pi^+$, $\Sigma_c^{++}K^-$, $\Xi_c(2645)^0\pi^+$, $\Xi_c^{0\prime}\pi^+$	2969.4 ± 0.8	$20.9^{+2.4}_{-3.5}$	
$\Xi_c(2970)^0$	$\Xi_c(2645)^+\pi^-$, $\Xi_c^{+\prime}\pi^-$	2967.8 ± 0.8	$28.1^{+3.4}_{-4.0}$	
$\Xi_c(3055)^+$	$\Sigma_c^{++}K^-$, ΛD^+	3055.9 ± 0.4	7.8 ± 1.9	
$\Xi_c(3055)^0$	ΛD^0	3059.0 ± 0.8	6.4 ± 2.4	
$\Xi_c(3080)^+$	$\Lambda_c^+K^-\pi^+$, $\Sigma_c^{++}K^-$, $\Sigma_c(2520)^{++}K^-$, ΛD^+	3077.2 ± 0.4	3.6 ± 1.1	
$\Xi_c(3080)^0$	$\Lambda_c^+K_S^0\pi^-$, $\Sigma_c^0K_S^0$, $\Sigma_c(2520)^0K_S^0$	3079.9 ± 1.4	5.6 ± 2.2	

Ξ_c Family: Decays to Ξ_c

Particle	Yield	Mass	$M - M(\Xi_c)$	$M - M(\Xi_c')$	Width
$\Xi_c'^+$	7055 ± 211	$2578.4 \pm 0.1 \pm 0.4^{+0.3}_{-0.4}$	$110.5 \pm 0.1 \pm 0.4$		
PDG		2575.6 ± 3.0	107.8 ± 3.0		
$\Xi_c'^0$	11560 ± 276	$2579.2 \pm 0.1 \pm 0.4^{+0.3}_{-0.4}$	$108.3 \pm 0.1 \pm 0.4$		
PDG		2577.9 ± 2.9	107.0 ± 2.9		
$\Xi_c(2645)^+$	1260 ± 40	$2645.58 \pm 0.06 \pm 0.07^{+0.28}_{-0.40}$	$174.66 \pm 0.06 \pm 0.07$		$2.06 \pm 0.13 \pm 0.13$
PDG		2645.9 ± 0.5	175.0 ± 0.6		$2.6 \pm 0.2 \pm 0.4$
$\Xi_c(2645)^0$	975 ± 36	$2646.43 \pm 0.07 \pm 0.07^{+0.28}_{-0.40}$	$178.46 \pm 0.07 \pm 0.07$		$2.35 \pm 0.18 \pm 0.13$
PDG		2645.9 ± 0.5	178.0 ± 0.6		< 5.5
$\Xi_c(2790)^+$	2231 ± 103	$2791.6 \pm 0.2 \pm 0.1 \pm 0.4^{+0.3}_{-0.4}$	$320.7 \pm 0.2 \pm 0.1 \pm 0.4$	$213.2 \pm 0.2 \pm 0.1$	$8.9 \pm 0.6 \pm 0.8$
PDG		2789.8 ± 3.2	318.2 ± 3.2		< 15
$\Xi_c(2790)^0$	1241 ± 72	$2794.9 \pm 0.3 \pm 0.1 \pm 0.4^{+0.3}_{-0.4}$	$323.8 \pm 0.2 \pm 0.1 \pm 0.4$	$215.7 \pm 0.2 \pm 0.1$	$10.0 \pm 0.7 \pm 0.8$
PDG		2791.9 ± 3.3	324.0 ± 3.3		< 12
$\Xi_c(2815)^+$	941 ± 35	$2816.73 \pm 0.08 \pm 0.06^{+0.28}_{-0.40}$	$348.80 \pm 0.08 \pm 0.06$		$2.43 \pm 0.20 \pm 0.17$
PDG		2816.6 ± 0.9	348.7 ± 0.9		< 3.5
$\Xi_c(2815)^0$	1258 ± 40	$2820.20 \pm 0.08 \pm 0.07^{+0.28}_{-0.40}$	$349.35 \pm 0.08 \pm 0.07$		$2.54 \pm 0.18 \pm 0.17$
PDG		2819.6 ± 1.2	348.8 ± 1.2		< 6.5
$\Xi_c(2970)^+$	916 ± 55	$2966.0 \pm 0.8 \pm 0.2^{+0.3}_{-0.4}$	$498.1 \pm 0.8 \pm 0.2$		$28.1 \pm 2.4^{+1.0}_{-5.0}$
PDG		2970.7 ± 2.2			17.9 ± 3.5
$\Xi_c(2970)^0$	1443 ± 75	$2970.8 \pm 0.7 \pm 0.2^{+0.3}_{-0.4}$	$499.9 \pm 0.7 \pm 0.2$		$30.3 \pm 2.3^{+1.0}_{-1.8}$
PDG		$2968.0 \pm 2.6 \pm 0.5$			20 ± 7

[J. Yelton *et al.* (Belle Collaboration), Phys. Rev. D **94**, 052011 (2016)]

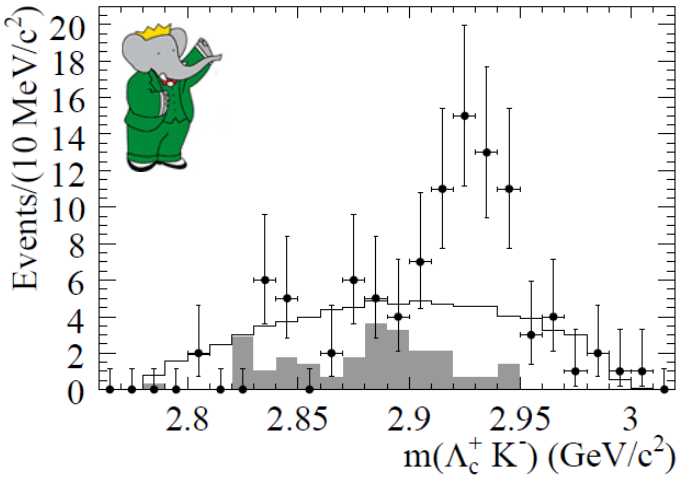
Ξ_c Family: Decays to $\Lambda_c(\Sigma_c)$

$\Xi_c'^+$
$\Xi_c'^0$
$\Xi_c(2645)^+$
$\Xi_c(2645)^0$
$\Xi_c(2790)^+$
$\Xi_c(2790)^0$
$\Xi_c(2815)^+$
$\Xi_c(2815)^0$
$\Xi_c(2930)^0$
$\Xi_c(2970)^+$
$\Xi_c(2970)^0$
$\Xi_c(3055)^+$
$\Xi_c(3055)^0$
$\Xi_c(3080)^+$
$\Xi_c(3080)^0$

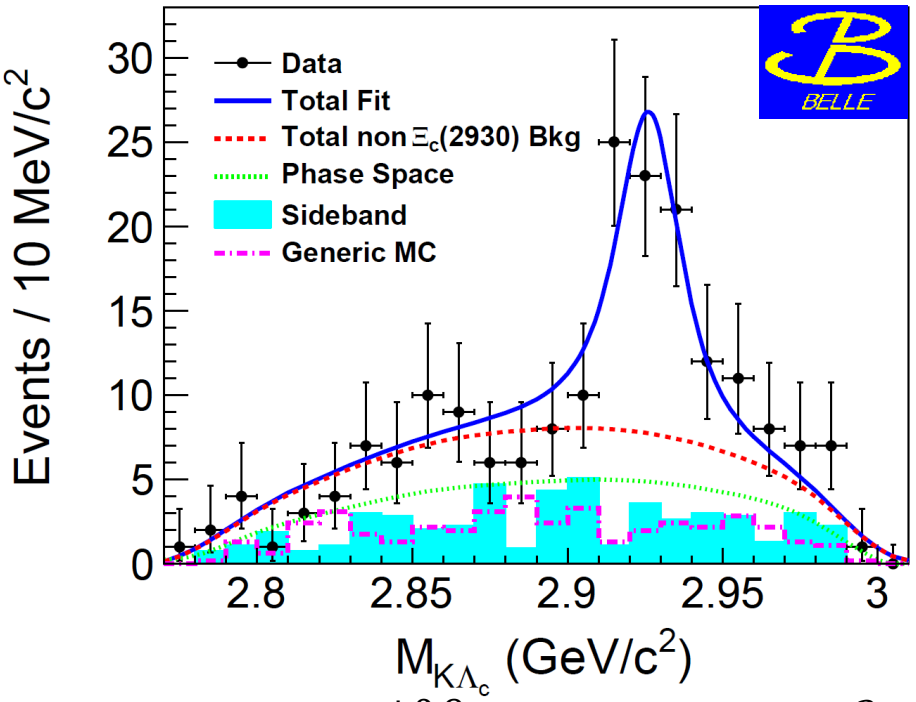
$B^- \to \Lambda_c^+ \overline{\Lambda_c}^- K^-$

$m_{\Xi_c(2930)^0} = (2931 \pm 3[stat.] \pm 5[syst.])\ MeV/c^2$

$\Gamma_{\Xi_c(2930)^0} = (36 \pm 7[stat.] \pm 11[syst.])\ MeV$



[B. Aubert *et al.* (BaBar Collaboration), Phys. Rev. D **77**, 031101 (2008)]



$m_{\Xi_c(2930)^0} = (2928.9 \pm 3.0[stat.]^{+0.9}_{-12.0}[syst.])\ MeV/c^2$

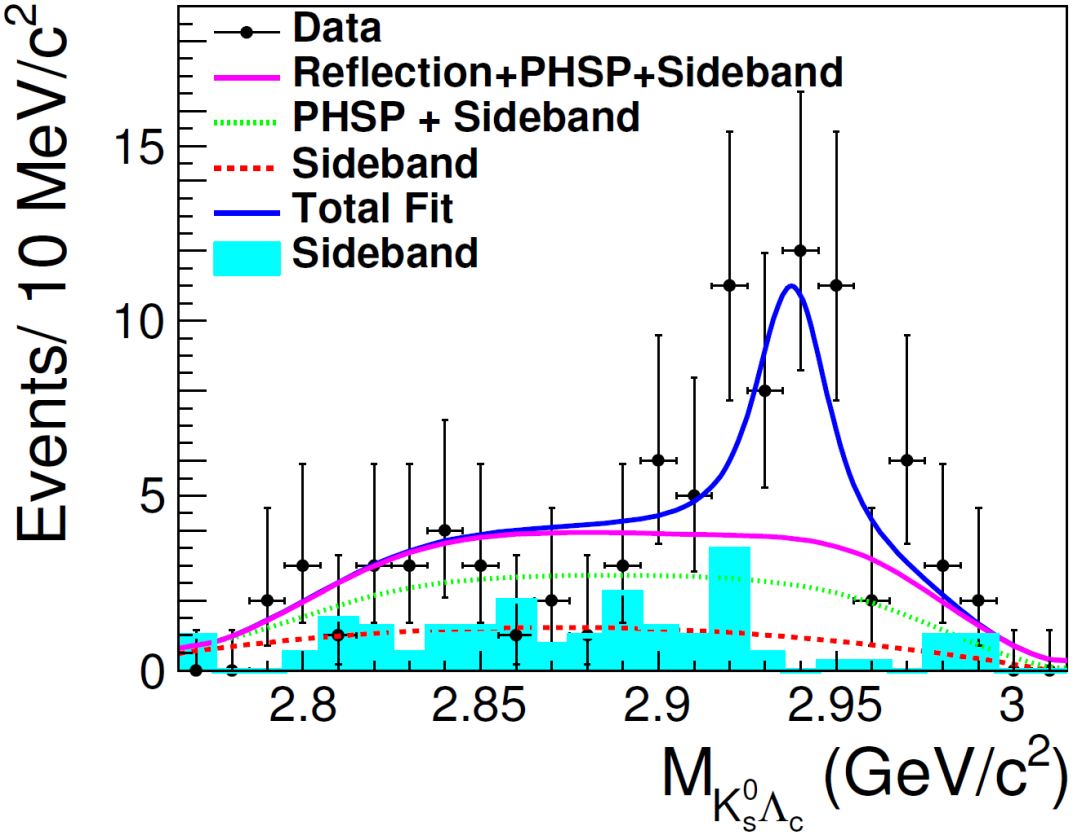
$\Gamma_{\Xi_c(2930)^0} = \left(19.5 \pm 8.4[stat.]^{+5.9}_{-7.9}[syst.]\right) MeV$

[Y.B. Li, C.P. Shen *et al.* (Belle Collaboration), Eur. Phys. J. C **78**, 252 (2018)]

Ξ_c Family: Decays to $\Lambda_c(\Sigma_c)$

$\Xi_c'^+$ $\Xi_c'^0$
$\Xi_c(2645)^+$ $\Xi_c(2645)^0$
$\Xi_c(2790)^+$ $\Xi_c(2790)^0$
$\Xi_c(2815)^+$ $\Xi_c(2815)^0$
$\Xi_c(2930)^0$
$\Xi_c(2970)^+$ $\Xi_c(2970)^0$
$\Xi_c(3055)^+$ $\Xi_c(3055)^0$
$\Xi_c(3080)^+$ $\Xi_c(3080)^0$

$B^0 \to \Lambda_c^+ \overline{\Lambda_c}^- K_S^0$



$m_{\Xi_c(2930)^+} = (2942.3 \pm 4.4[stat.] \pm 1.6[syst.])\ MeV/c^2$

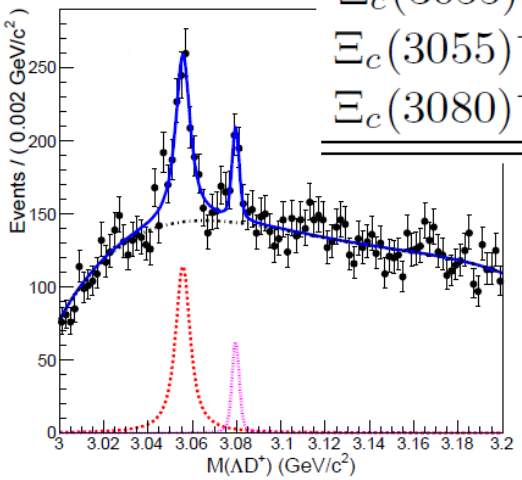
$\Gamma_{\Xi_c(2930)^+} = (14.8 \pm 8.8[stat.] \pm 7.1[syst.])\ MeV$

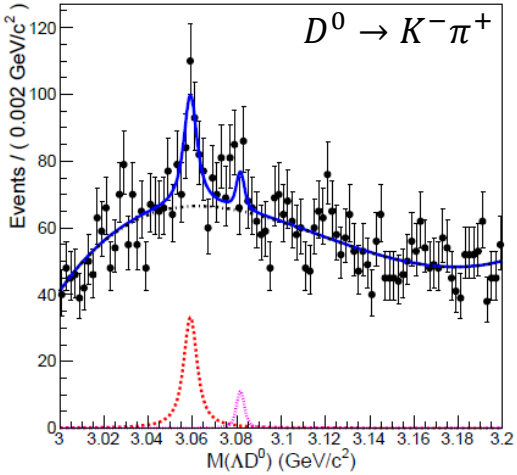
[Y.B. Li, C.P. Shen *et al.* (Belle Collaboration), arXiv:1806.09182 [hep-ex]]

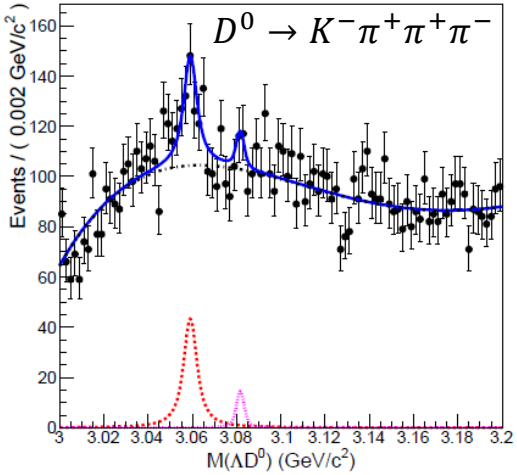
Ξ_c Family: Decays to ΛD

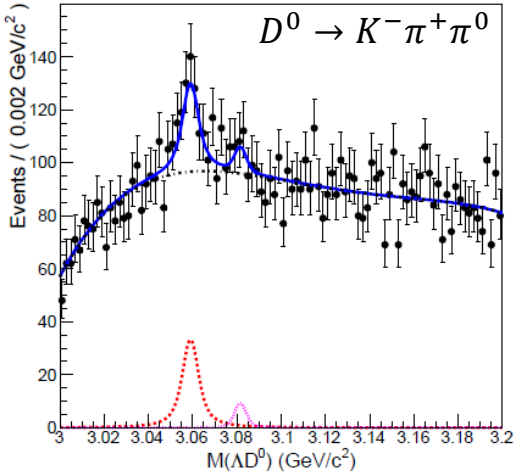
$\Xi_c'^+$
$\Xi_c'^0$
$\Xi_c(2645)^+$
$\Xi_c(2645)^0$
$\Xi_c(2790)^+$
$\Xi_c(2790)^0$
$\Xi_c(2815)^+$
$\Xi_c(2815)^0$
$\Xi_c(2930)^0$
$\Xi_c(2970)^+$
$\Xi_c(2970)^0$
$\Xi_c(3055)^+$
$\Xi_c(3055)^0$
$\Xi_c(3080)^+$
$\Xi_c(3080)^0$

Resonance	Mass (MeV/c^2)	Width (MeV)	Significance (σ)
$\Xi_c(3055)^0$	$3059.0 \pm 0.5 \pm 0.6$	$6.4 \pm 2.1 \pm 1.1$	8.6
$\Xi_c(3055)^+$	$3055.8 \pm 0.4 \pm 0.2$	$7.0 \pm 1.2 \pm 1.5$	11.7
$\Xi_c(3080)^+$	$3079.6 \pm 0.4 \pm 0.1$	< 6.3	4.8



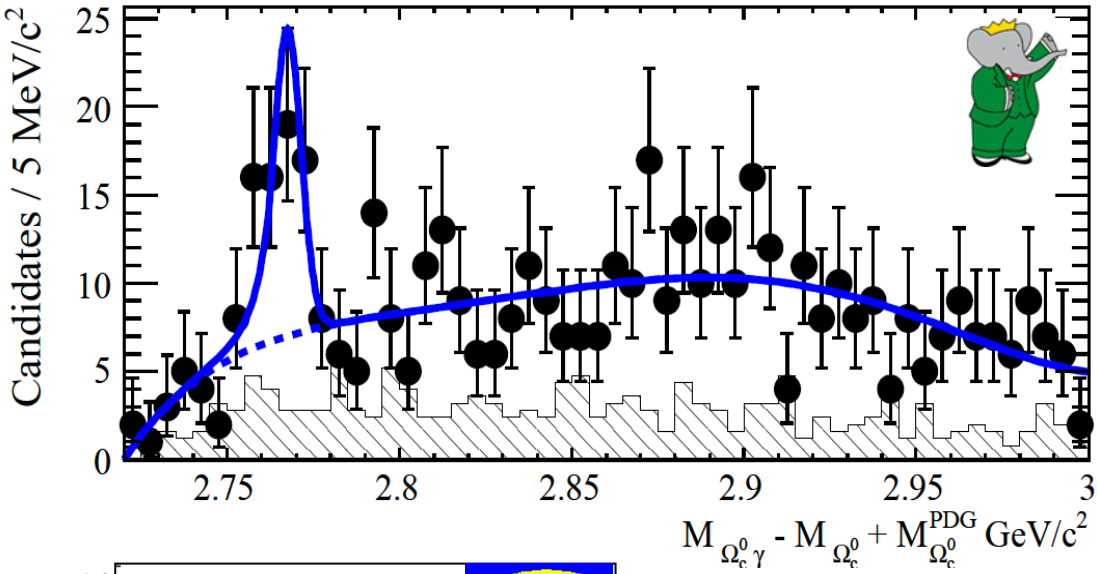






[Y. Kato, T. Iijima *et al.* (Belle Collaboration), Phys. Rev. D **94**, 032002 (2016)]

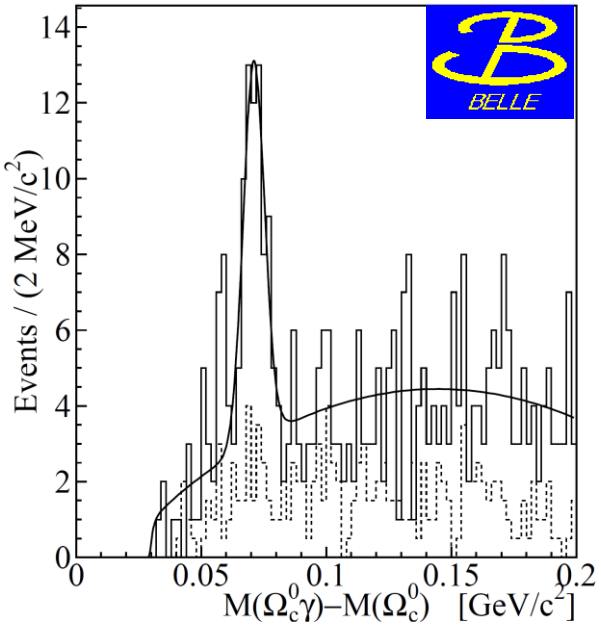
Ω_c Family



$$\Omega_c^{*0} \to \Omega_c^0 \gamma$$

$[70.8 \pm 1.0(stat.) \pm 1.1(syst.)]\ MeV/c^2$

[B. Aubert *et al.* (BaBar Collaboration), Phys. Rev. Lett. **97**, 232001 (2006)]

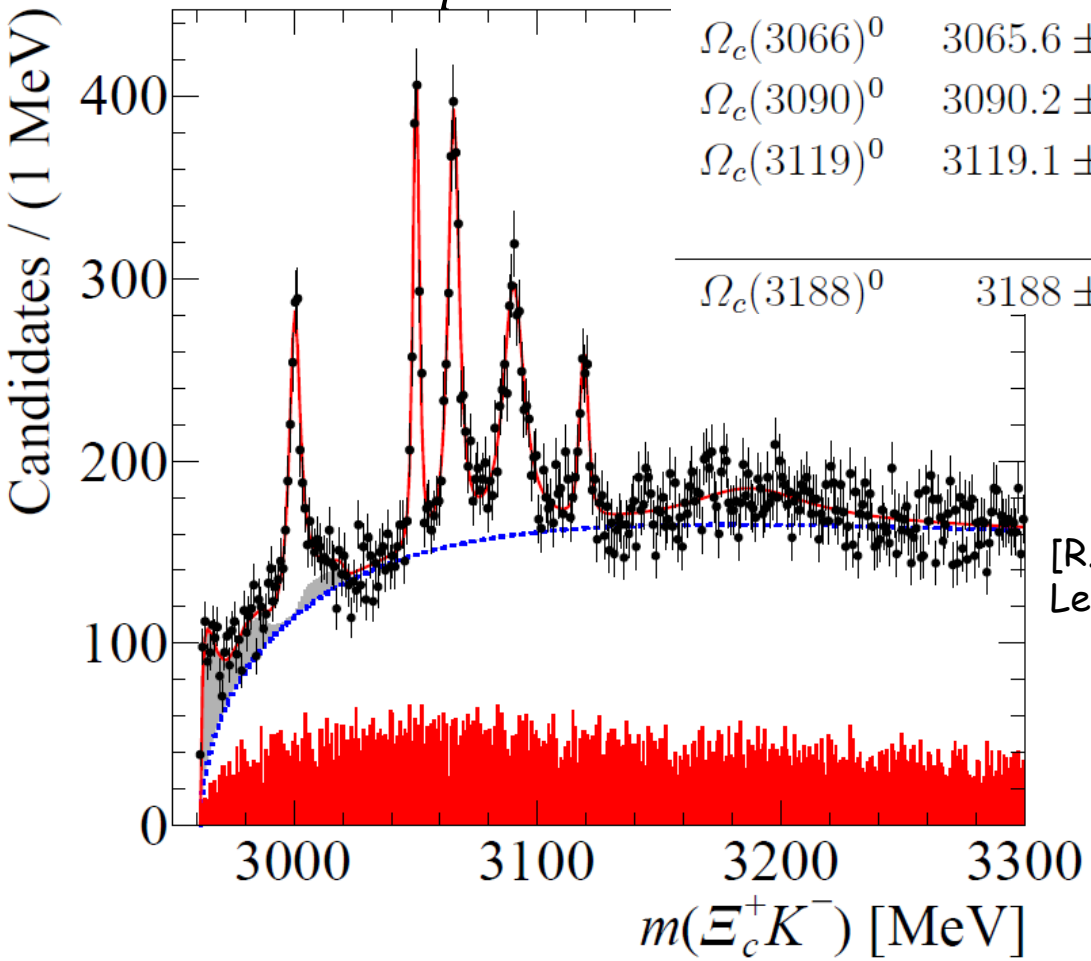


$$\Delta M_{\Omega_c^0} = \left[70.7 \pm 0.9(stat.)^{+0.1}_{-0.9}(syst.)\right]\ MeV/c^2$$

[E. Solovieva, R. Chistov *et al.* (Belle Collaboration), Phys. Lett. B **672**, 1 (2009)]

Ω_c Family

$$\Omega_c(X)^0 \to \Xi_c^+ K^-$$
$$\downarrow$$
$$pK^-\pi^+$$



Resonance	Mass (MeV)	Γ (MeV)	N_σ
$\Omega_c(3000)^0$	$3000.4 \pm 0.2 \pm 0.1^{+0.3}_{-0.5}$	$4.5 \pm 0.6 \pm 0.3$	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
		$< 1.2\,\text{MeV}, 95\%$ 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
		$< 2.6\,\text{MeV}, 95\%$ CL	
$\Omega_c(3188)^0$	$3188 \pm 5 \pm 13$	$60 \pm 15 \pm 11$	

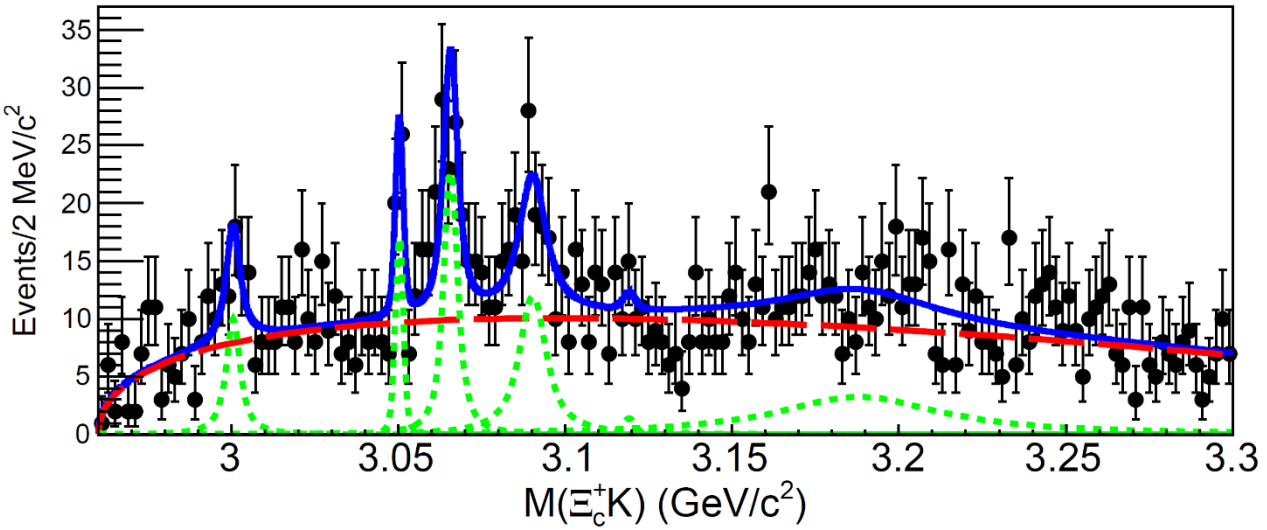
[R. Aaij *et al.* (LHCb Collaboration), Phys. Rev. Lett. **118**, 182001 (2017)]

Ω_c Family

$$\Omega_c(X)^0 \to \Xi_c^+ K^-$$

$$\downarrow$$

$$\Xi^-\pi^+\pi^+, \Lambda K^-\pi^+\pi^+, \Xi^0\pi^+, \Xi^0\pi^+\pi^-\pi^+, \Sigma^+K^-\pi^+, \Lambda K_S^0\pi^+, \Sigma^0 K_S^0\pi^+$$

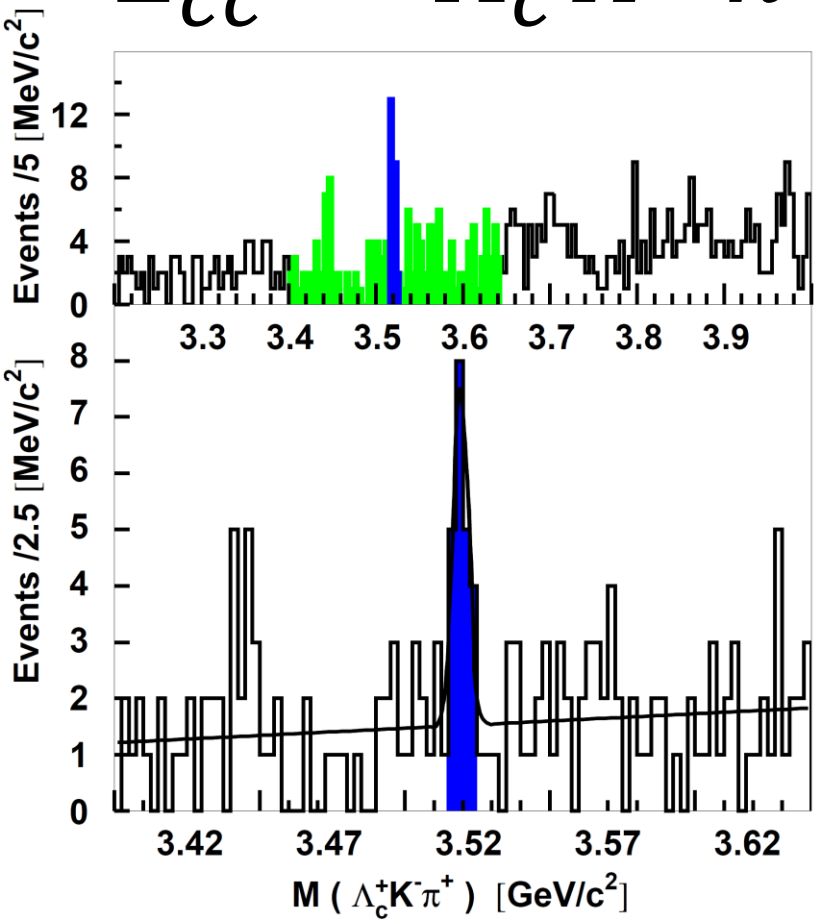


Ω_c Excited state	3000	3050	3066	3090	3119	3188
Yield	37.7 ± 11.0	28.2 ± 7.7	81.7 ± 13.9	86.6 ± 17.4	3.6 ± 6.9	135.2 ± 43.0
Significance	3.9σ	4.6σ	7.2σ	5.7σ	0.4σ	2.4σ
LHCb mass	$3000.4 \pm 0.2 \pm 0.1$	$3050.2 \pm 0.1 \pm 0.1$	$3065.5 \pm 0.1 \pm 0.3$	$3090.2 \pm 0.3 \pm 0.5$	$3119 \pm 0.3 \pm 0.9$	$3188 \pm 5 \pm 13$
Belle mass (with fixed Γ)	$3000.7 \pm 1.0 \pm 0.2$	$3050.2 \pm 0.4 \pm 0.2$	$3064.9 \pm 0.6 \pm 0.2$	$3089.3 \pm 1.2 \pm 0.2$	···	$3199 \pm 9 \pm 4$

[J. Yelton *et al.* (Belle Collaboration), Phys. Rev. D **97**, 051102 (2018)]

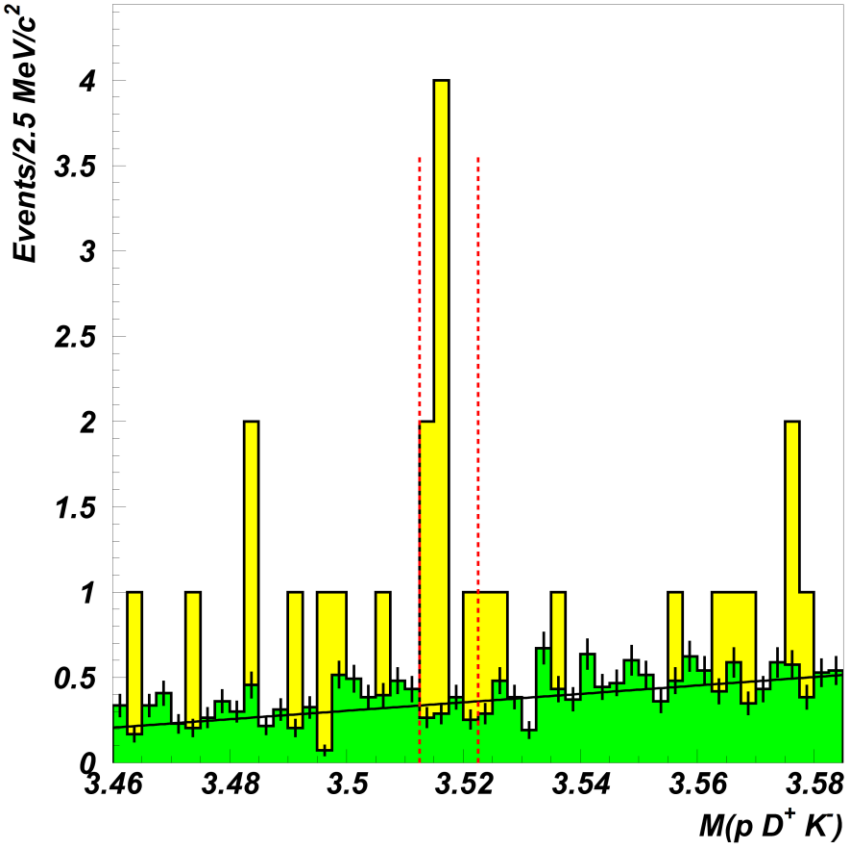
Ξ_{cc} Family

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



[M. Mattson *et al.* (SELEX Collaboration), Phys. Rev. Lett. **89**, 112001 (2002)]

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

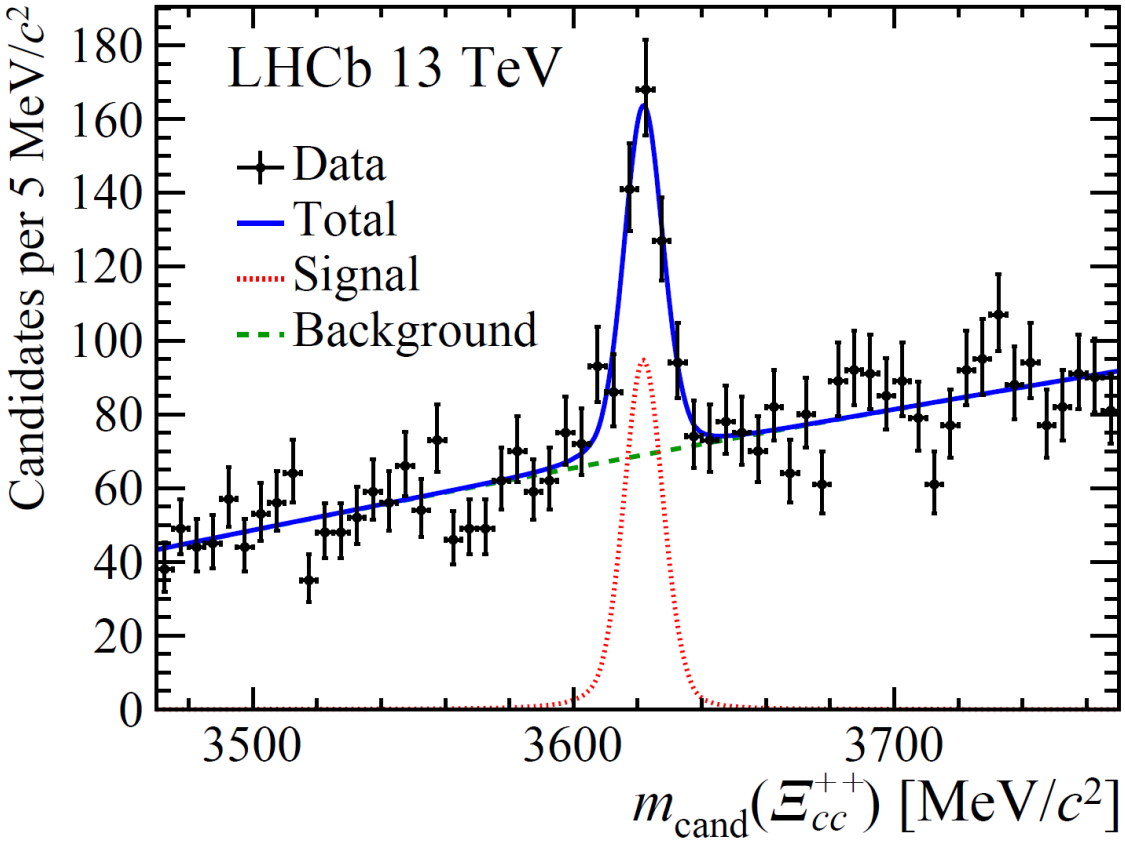


[A. Ocherashvili *et al.* (SELEX Collaboration), Phys. Lett. B **628**, 18 (2005)]

$$m_{\Xi_{cc}^{+}} = (3518.9 \pm 0.9)\ MeV/c^2$$

Ξ_{cc} Family

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



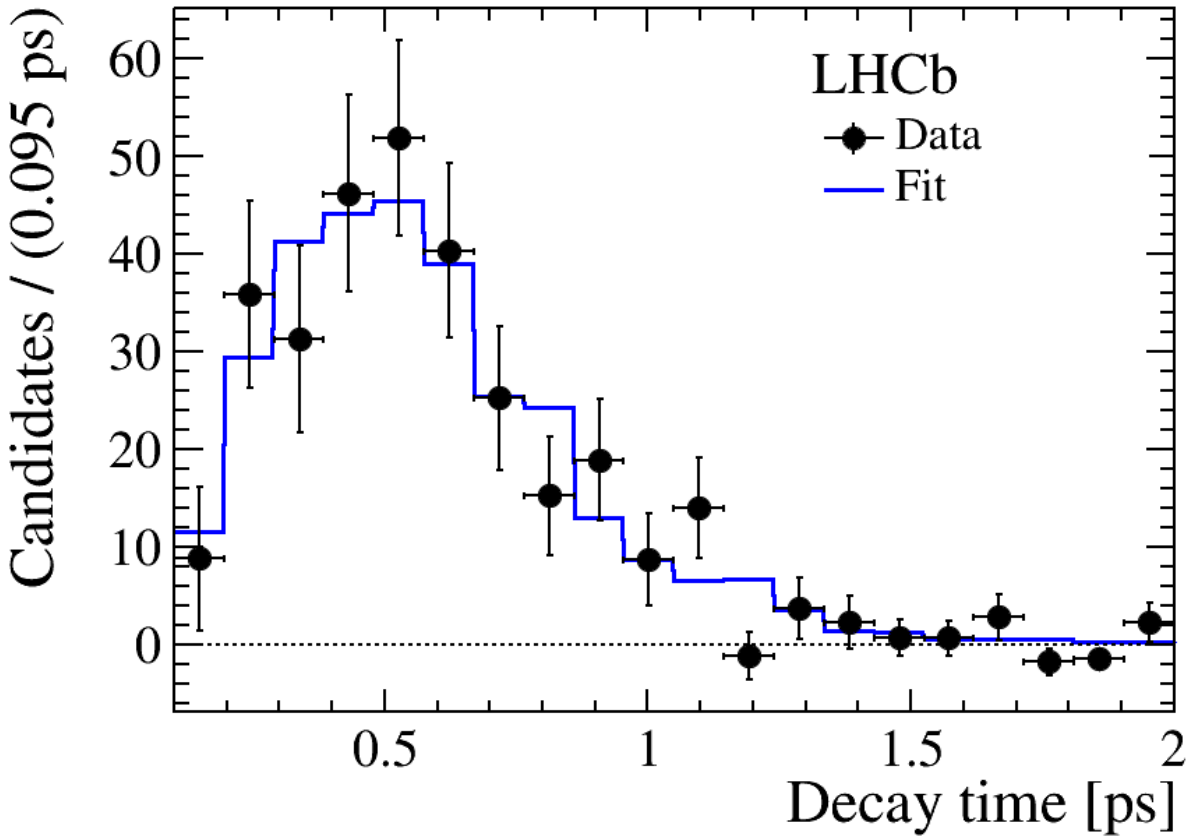
$$m_{\Xi_{cc}^{++}} = (3621.40 \pm 0.72[stat.] \pm 0.27[syst.] \pm 0.72[\Lambda_c^+])\ MeV/c^2$$

$$m_{\Xi_{cc}^{++}} - m_{\Xi_{cc}^{+}} = (103 \pm 2)\ MeV/c^2$$

[R. Aaij *et al.* (LHCb Collaboration), Phys. Rev. Lett. **119**, 112001 (2017)]

Ξ_{cc} Family

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



$$\tau_{\Xi_{cc}^{++}} = (0.256^{+0.024}_{-0.022}[stat.] \pm 0.014[syst.])\ ps$$

[R. Aaij *et al.* (LHCb Collaboration), Phys. Rev. Lett. **121**, 052002 (2018)]

Conclusions

- The Ξ_{cc} state reported by LHCb is consistent with most theoretical expectations, but it is inconsistent with being an isospin partner to the Ξ_{cc} state reported previously by the SELEX Collaboration.
- Recently observed excited Ω_c states present a unique opportunity to test and further improve theoretical models, that predict properties of heavy hadrons.
- Interesting feature is that highly excited charmed baryons can decay to a charm meson and a non-charm baryon.