Strange Charmed Baryons Spectroscopy

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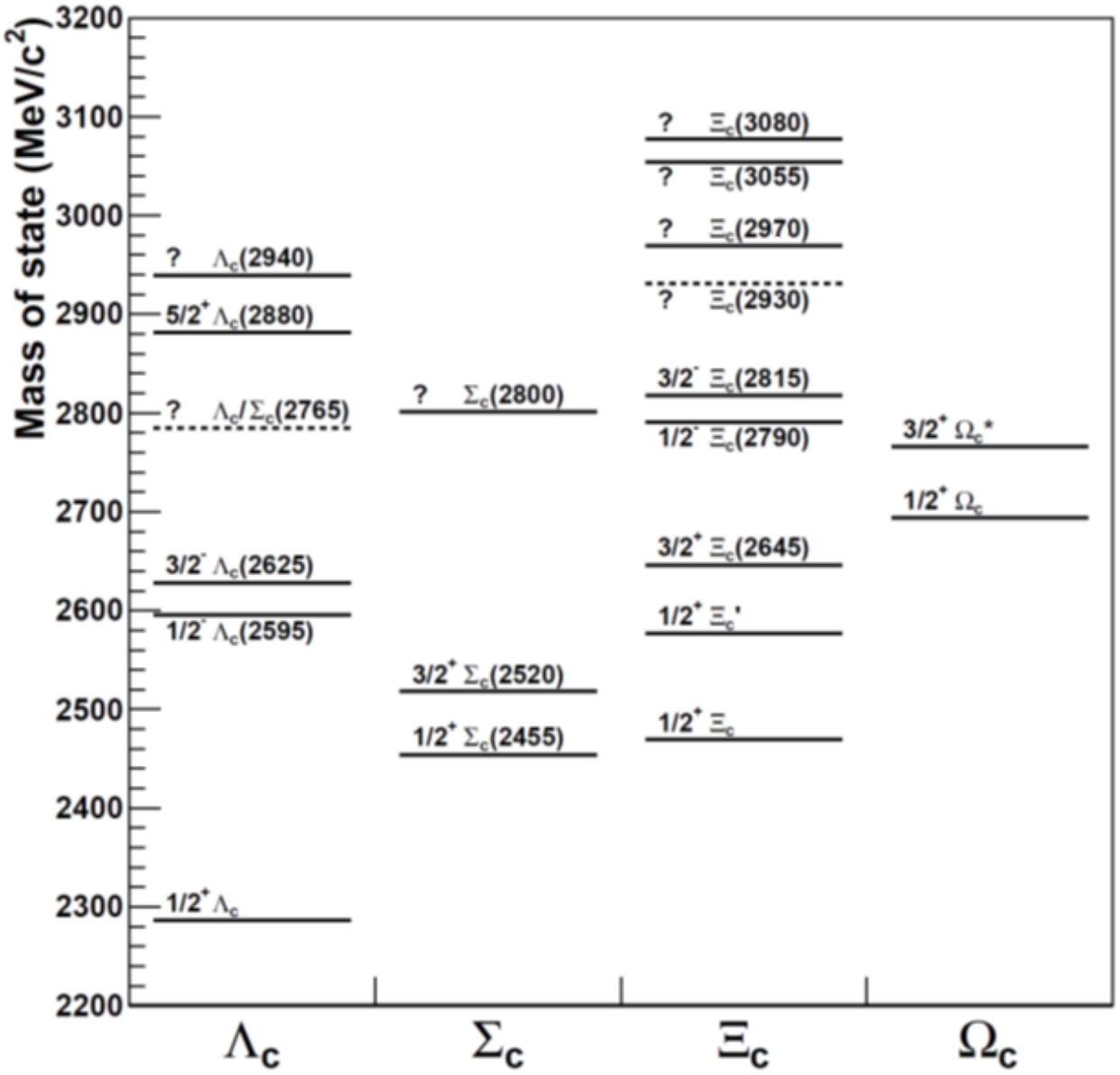
Known Charmed Baryon States



$\mathfrak{B}_c$ = 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**.

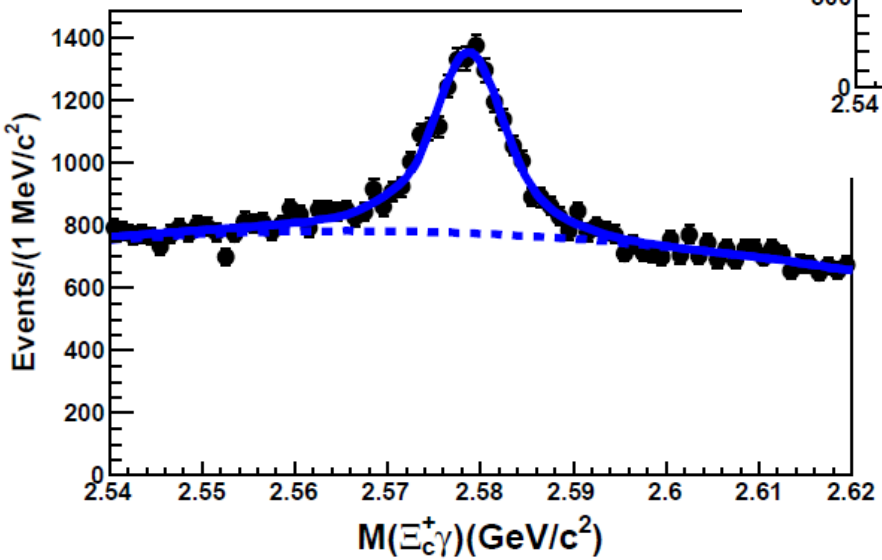
Ξ_c Family: PDG'2016

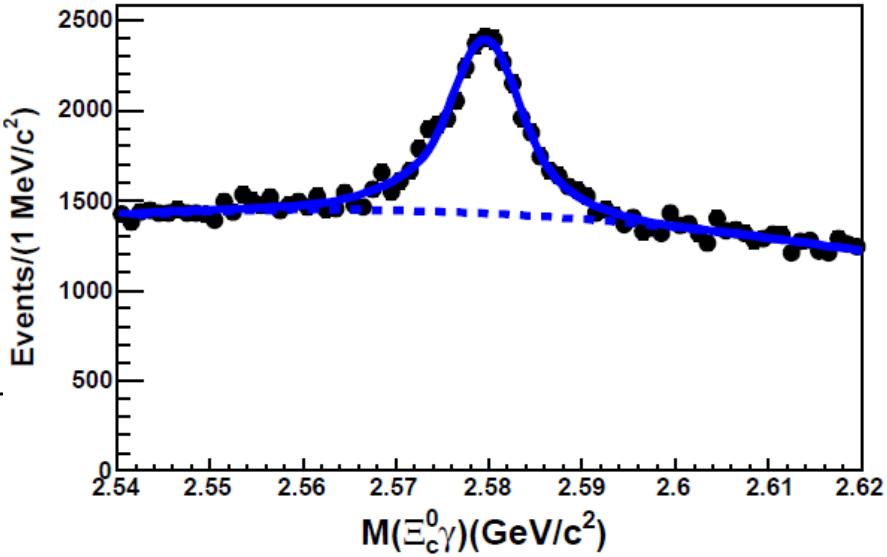
State	Decay mode	Mass, MeV/c^2	Width, MeV	J^P
$\Xi_c'^+$	$\Xi_c^+\gamma$	2575.7 ± 3.0		$\frac{1}{2}^+$
$\Xi_c'^0$	$\Xi_c^0\gamma$	2577.9 ± 2.9		$\frac{1}{2}^+$
$\Xi_c(2645)^+$	$\Xi_c^0\pi^+$	2645.9 ± 0.5	2.6 ± 0.4	$\frac{3}{2}^+$
$\Xi_c(2645)^0$	$\Xi_c^+\pi^-$	2645.9 ± 0.5	< 5.5 @ 90% CL	$\frac{3}{2}^+$
$\Xi_c(2790)^+$	$\Xi_c'^0\pi^+$	2789.1 ± 3.2	< 15 @ 90% CL	$\frac{1}{2}^-$
$\Xi_c(2790)^0$	$\Xi_c'^+\pi^-$	2791.9 ± 3.3	< 12 @ 90% CL	$\frac{1}{2}^-$
$\Xi_c(2815)^+$	$\Xi_c^+\pi^+\pi^-$, $\Xi_c(2645)^0\pi^+$	2816.6 ± 0.9	< 3.5 @ 90% CL	$\frac{3}{2}^-$
$\Xi_c(2815)^0$	$\Xi_c^0\pi^+\pi^-$, $\Xi_c(2645)^+\pi^-$	2819.6 ± 1.2	< 6.5 @ 90% CL	$\frac{3}{2}^-$
$\Xi_c(2930)^0$	$\Lambda_c^+K^-$	2931 ± 6	36 ± 13	
$\Xi_c(2970)^+$	$\Lambda_c^+K^-\pi^+$, $\Sigma_c^{++}K^-$, $\Xi_c(2645)^0\pi^+$	2970.7 ± 2.2	17.9 ± 3.5	
$\Xi_c(2970)^0$	$\Xi_c(2645)^+\pi^-$	2968.0 ± 2.6	20 ± 7	
$\Xi_c(3055)^+$	$\Sigma_c^{++}K^-$	3055.1 ± 1.7	11 ± 4	
$\Xi_c(3055)^0$				
$\Xi_c(3080)^+$	$\Lambda_c^+K^-\pi^+$, $\Sigma_c^{++}K^-$, $\Sigma_c(2520)^{++}K^-$	3076.94 ± 0.28	4.3 ± 1.5	
$\Xi_c(3080)^0$	$\Lambda_c^+K_S^0\pi^-$, $\Sigma_c^0K_S^0$, $\Sigma_c(2520)^0K_S^0$	3079.9 ± 1.4	5.6 ± 2.2	

Decays to Ξ_c: Ξ_c' Isodoublet

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

$$\Xi_c' \to \Xi_c \gamma$$





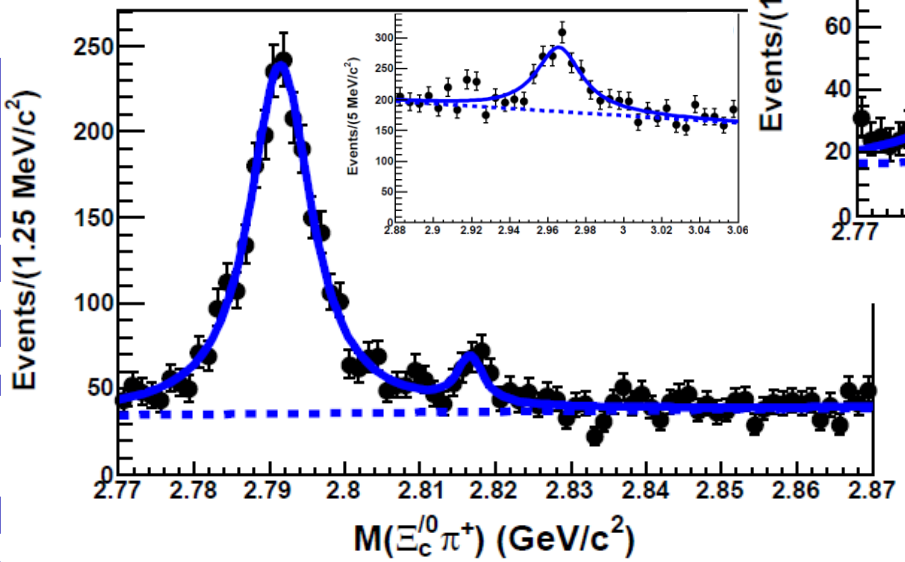
$$M_{\Xi_c'^+} - M_{\Xi_c^+} = (110.5 \pm 0.1[stat.] \pm 0.4[syst.])\ MeV/c^2$$
$$M_{\Xi_c'^0} - M_{\Xi_c^0} = (108.3 \pm 0.1[stat.] \pm 0.4[syst.])\ MeV/c^2$$

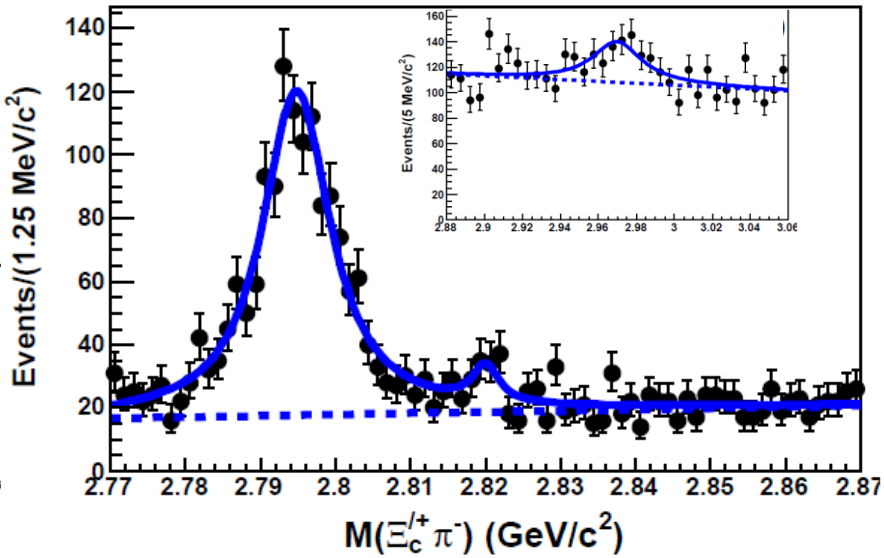
[J. Yelton *et al.* (Belle Collaboration), Phys. Rev. D **94**, 052011 (2016)]

Decays to Ξ_c: $\Xi_c(2790)$ Isodoublet

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

$$\Xi_c(2790) \rightarrow \Xi_c'\pi$$





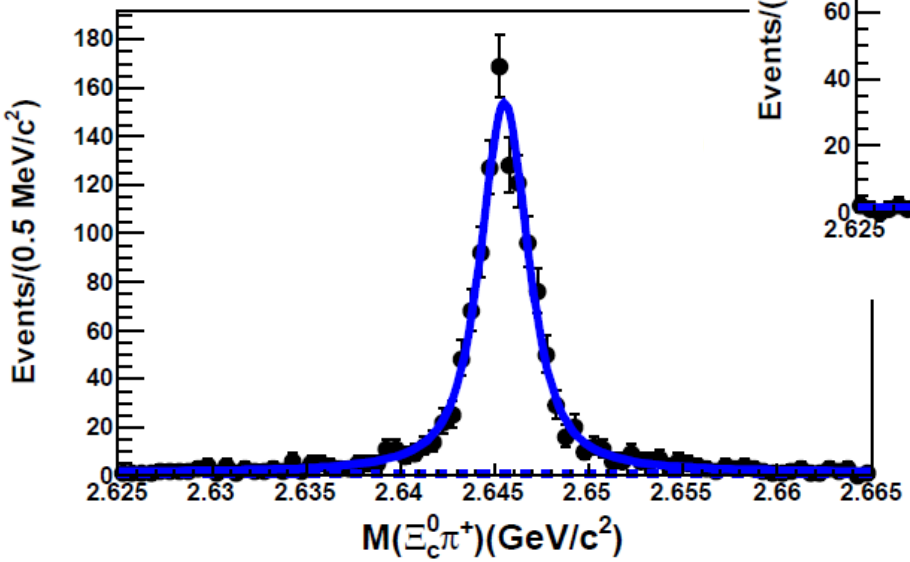
$$M_{\Xi_c(2790)^+} - M_{\Xi_c'^0} = (213.2 \pm 0.2[stat.] \pm 0.1[syst.])\ MeV/c^2$$
$$\Gamma_{\Xi_c(2790)^+} = (8.9 \pm 0.6[stat.] \pm 0.8[syst.])\ MeV$$
$$M_{\Xi_c(2790)^0} - M_{\Xi_c'^+} = (215.7 \pm 0.2[stat.] \pm 0.1[syst.])\ MeV/c^2$$
$$\Gamma_{\Xi_c(2790)^0} = (10.0 \pm 0.7[stat.] \pm 0.8[syst.])\ MeV$$

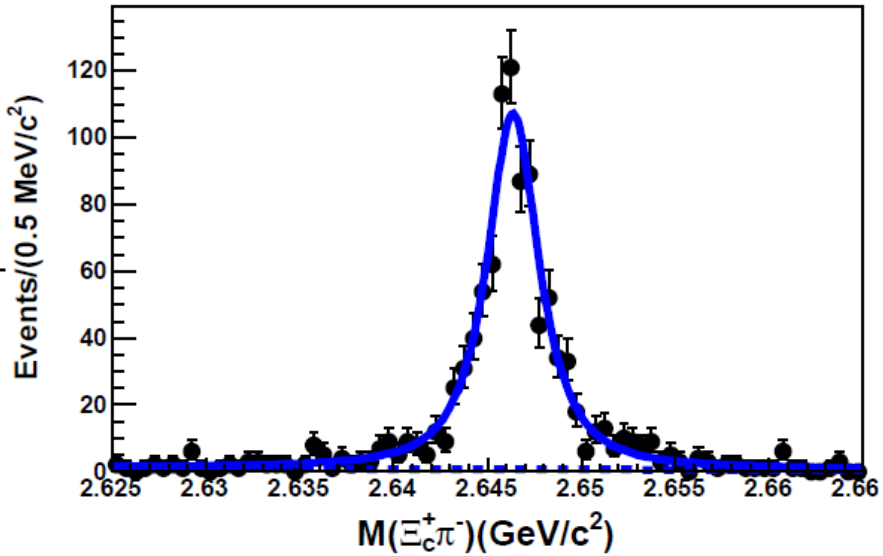
[J. Yelton *et al.* (Belle Collaboration), Phys. Rev. D **94**, 052011 (2016)]

Decays to Ξ_c: $\Xi_c(2645)$ Isodoublet

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

$$\Xi_c(2645) \equiv \Xi_c^*$$
$$\Xi_c(2645) \to \Xi_c\pi$$





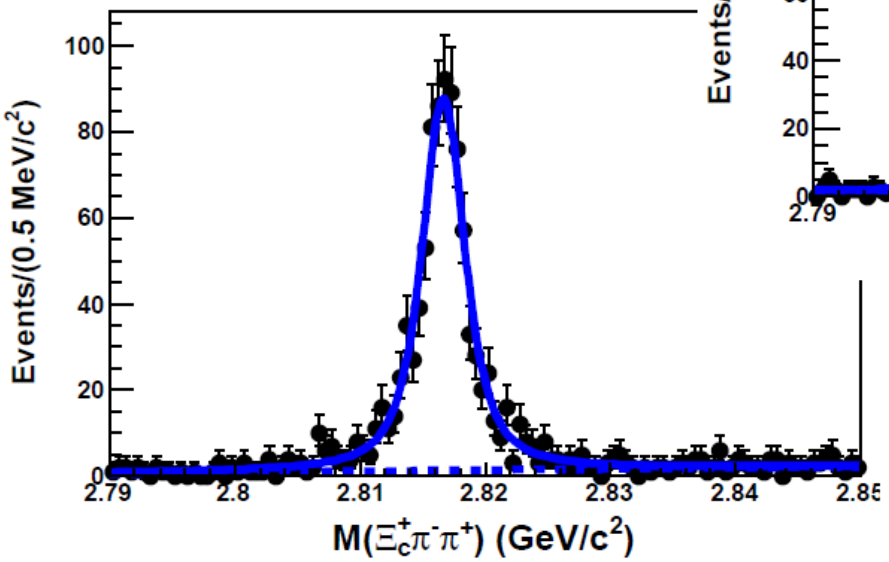
$$M_{\Xi_c(2645)^+} - M_{\Xi_c^0} = (174.66 \pm 0.06[stat.] \pm 0.07[syst.])\ MeV/c^2$$
$$\Gamma_{\Xi_c(2645)^+} = (2.06 \pm 0.13[stat.] \pm 0.13[syst.])\ MeV$$
$$M_{\Xi_c(2645)^0} - M_{\Xi_c^+} = (178.46 \pm 0.07[stat.] \pm 0.07[syst.])\ MeV/c^2$$
$$\Gamma_{\Xi_c(2645)^0} = (2.35 \pm 0.18[stat.] \pm 0.13[syst.])\ MeV$$

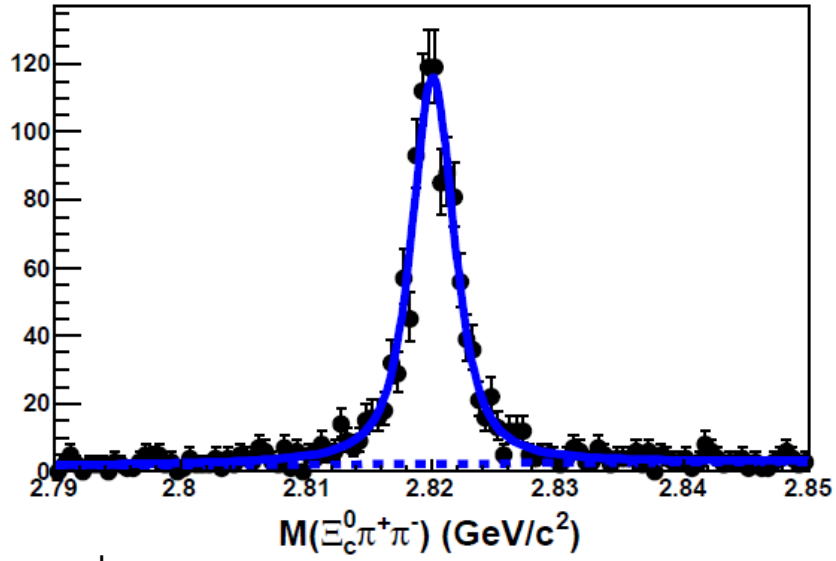
[J. Yelton *et al.* (Belle Collaboration), Phys. Rev. D **94**, 052011 (2016)]

Decays to Ξ_c: $\Xi_c(2815)$ Isodoublet

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

$$\Xi_c(2815) \rightarrow \Xi_c^* \pi$$





$$M_{\Xi_c(2815)^+} - M_{\Xi_c^+} = (348.80 \pm 0.08[stat.] \pm 0.06[syst.])\ MeV/c^2$$

$$\Gamma_{\Xi_c(2815)^+} = (2.43 \pm 0.20[stat.] \pm 0.17[syst.])\ MeV$$

$$M_{\Xi_c(2815)^0} - M_{\Xi_c^0} = (349.35 \pm 0.08[stat.] \pm 0.07[syst.])\ MeV/c^2$$

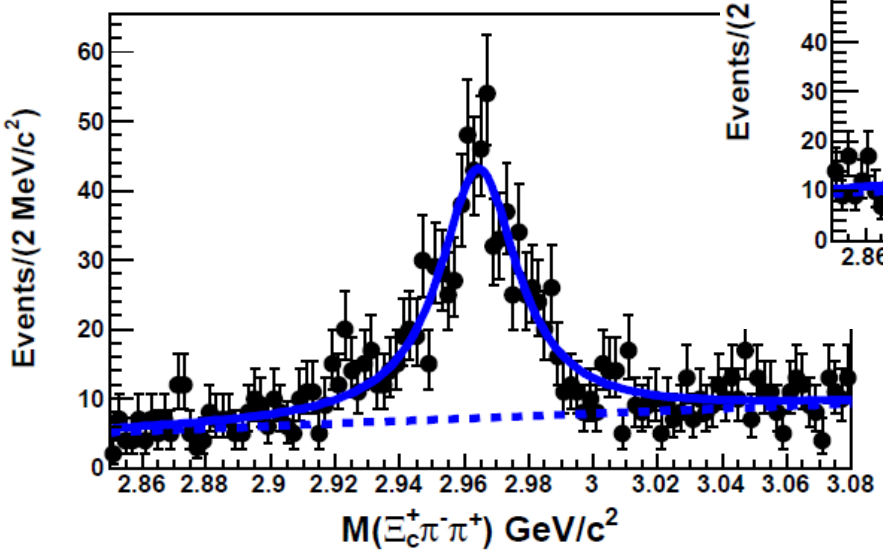
$$\Gamma_{\Xi_c(2815)^0} = (2.54 \pm 0.18[stat.] \pm 0.17[syst.])\ MeV$$

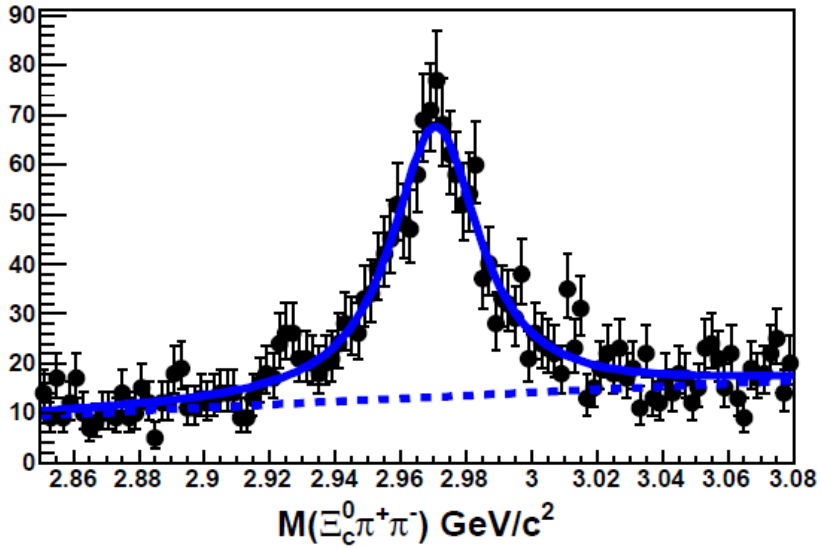
[J. Yelton *et al.* (Belle Collaboration), Phys. Rev. D **94**, 052011 (2016)]

Decays to Ξ_c: $\Xi_c(2970)$ Isodoublet

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

$$\Xi_c(2970) \rightarrow \Xi_c^* \pi$$





$$M_{\Xi_c(2970)^+} - M_{\Xi_c^+} = (498.1 \pm 0.8[stat.] \pm 0.2[syst.])\ MeV/c^2$$

$$\Gamma_{\Xi_c(2970)^+} = \left(28.1 \pm 2.4[stat.]^{+1.0}_{-5.0}[syst.]\right)\ MeV$$

$$M_{\Xi_c(2970)^0} - M_{\Xi_c^0} = (499.9 \pm 0.7[stat.] \pm 0.2[syst.])\ MeV/c^2$$

$$\Gamma_{\Xi_c(2970)^0} = \left(30.3 \pm 2.3[stat.]^{+1.0}_{-1.8}[syst.]\right)\ MeV$$

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

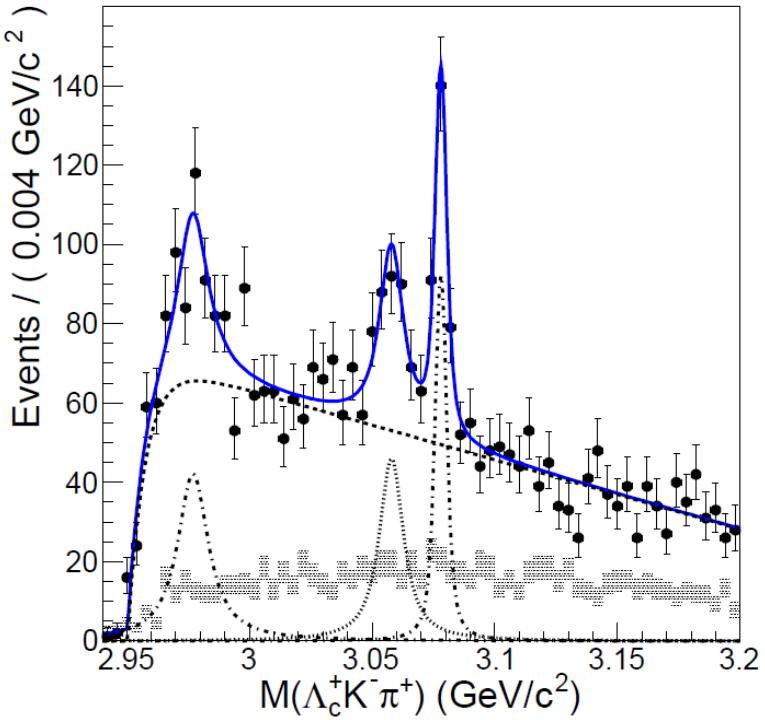
Ξ_c Family: Decays to Ξ_c

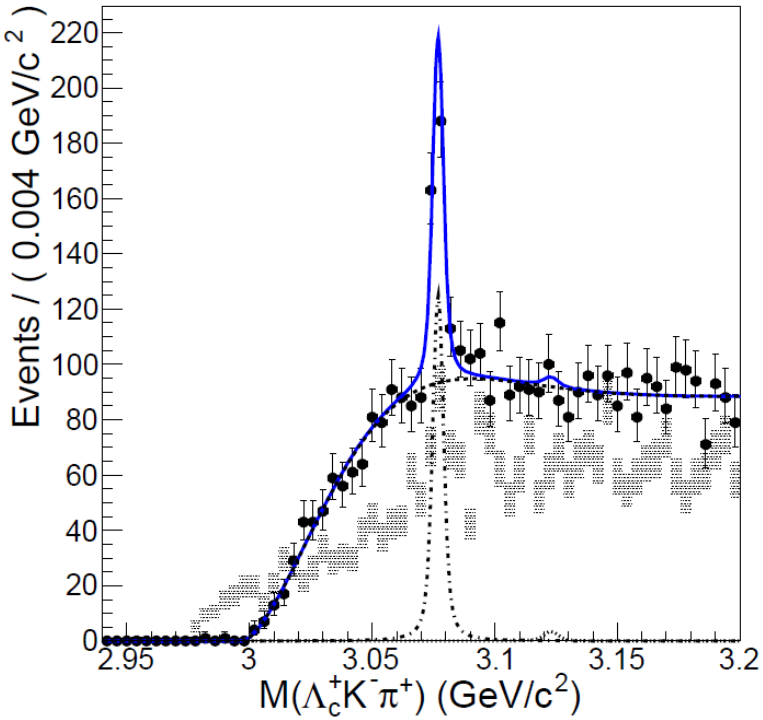
Particle	Yield	Mass	$M - M(\Xi_c)$	$M - M(\Xi_c')$	Width
$\Xi_c'^+$	7055 ± 211	$2578.4 \pm 0.1 \pm 0.4^{+0.3}_{-0.4}$	$110.5 \pm 0.1 \pm 0.4$		
PDG		2575.6 ± 3.0	107.8 ± 3.0		
$\Xi_c'^0$	11560 ± 276	$2579.2 \pm 0.1 \pm 0.4^{+0.3}_{-0.4}$	$108.3 \pm 0.1 \pm 0.4$		
PDG		2577.9 ± 2.9	107.0 ± 2.9		
$\Xi_c(2645)^+$	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 $\Lambda_c(\Sigma_c)$

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



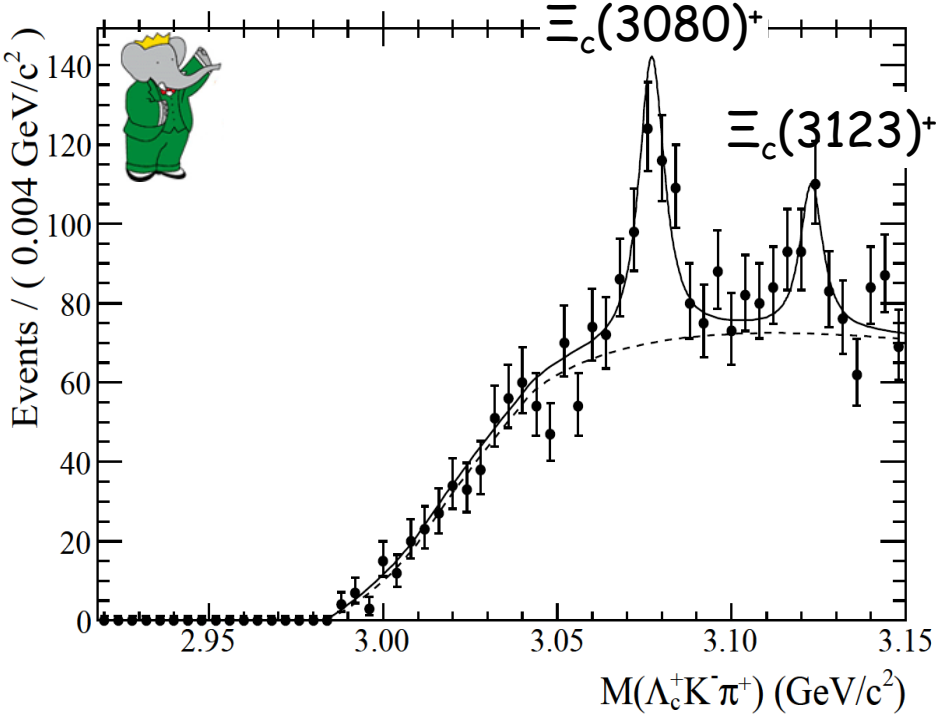


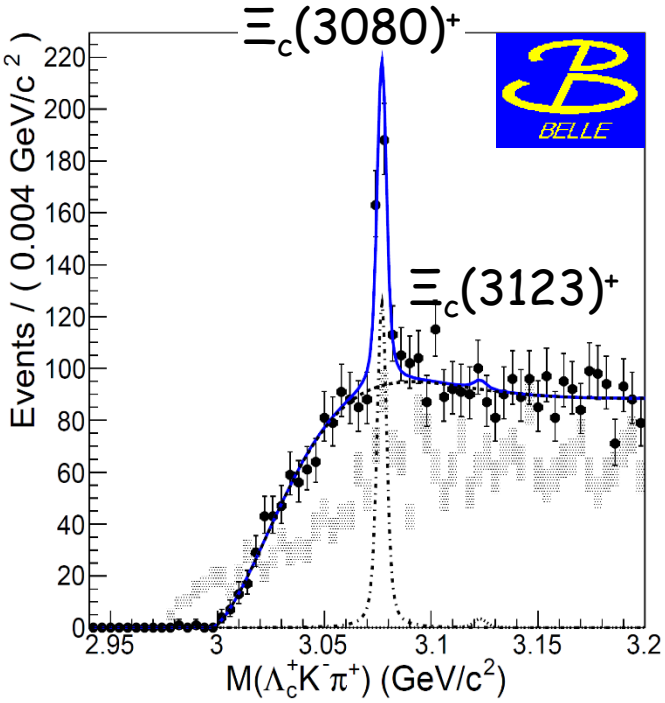
Particle	Mass (MeV/c^2)	Width (MeV/c^2)
$\Xi_c(2970)^+$	$2974.9 \pm 1.5 \pm 2.1$	$14.8 \pm 2.5 \pm 4.1$
$\Xi_c(3055)^+$	$3058.1 \pm 1.0 \pm 2.1$	$9.7 \pm 3.4 \pm 3.3$
$\Xi_c(3080)^+(\Sigma_c)$	$3077.9 \pm 0.4 \pm 0.7$	$3.2 \pm 1.3 \pm 1.3$
$\Xi_c(3080)^+(\Sigma_c^*)$	$3076.9 \pm 0.3 \pm 0.2$	$2.4 \pm 0.9 \pm 1.6$

[Y. Kato, T.Iijima *et al.* (Belle Collaboration), Phys. Rev. D **89**, 052003 (2014)]

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

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





	$\Xi_c(3123)^+$
Mass (MeV/c^2)	$3122.9 \pm 1.3 \pm 0.3$
Width (MeV)	$4.4 \pm 3.4 \pm 1.7$
Significance	$3.6\,\sigma$ $(3.0\,\sigma)$

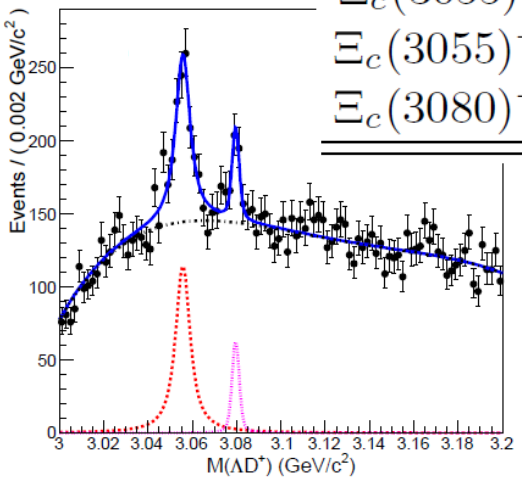
[B. Aubert *et al.* (BaBar Collaboration), Phys. Rev. D **77**, 012002 (2008)]

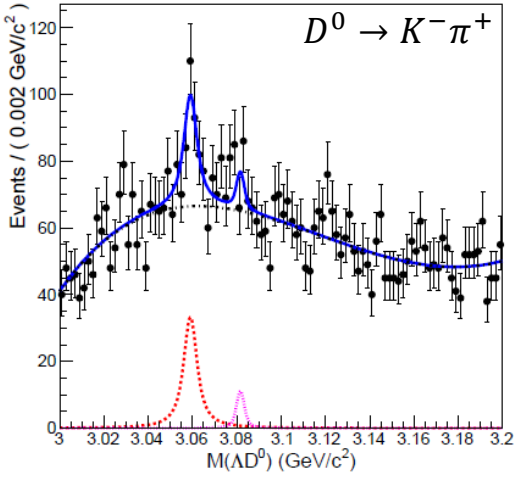
[Y.Kato, T.Iijima *et al.* (Belle Collaboration), Phys. Rev. D **89**, 052003 (2014)]

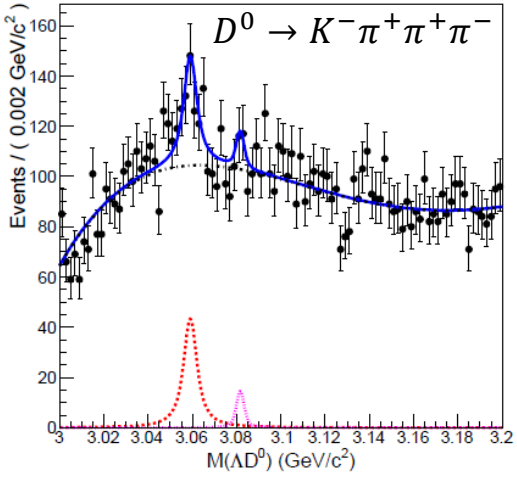
Ξ_c Family: Decays to ΛD

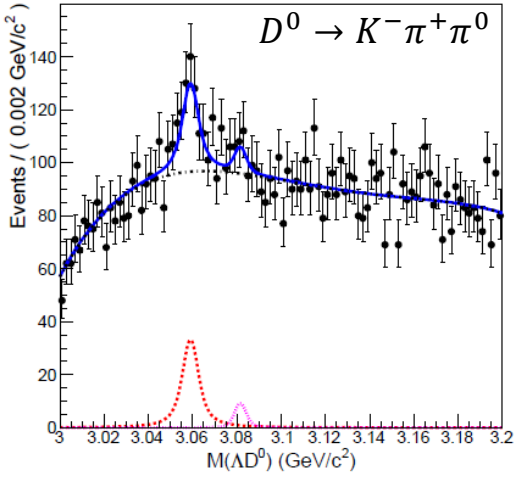
$\Xi_c'^+$
$\Xi_c'^0$
$\Xi_c(2645)^+$
$\Xi_c(2645)^0$
$\Xi_c(2790)^+$
$\Xi_c(2790)^0$
$\Xi_c(2815)^+$
$\Xi_c(2815)^0$
$\Xi_c(2930)^0$
$\Xi_c(2970)^+$
$\Xi_c(2970)^0$
$\Xi_c(3055)^+$
$\Xi_c(3055)^0$
$\Xi_c(3080)^+$
$\Xi_c(3080)^0$

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







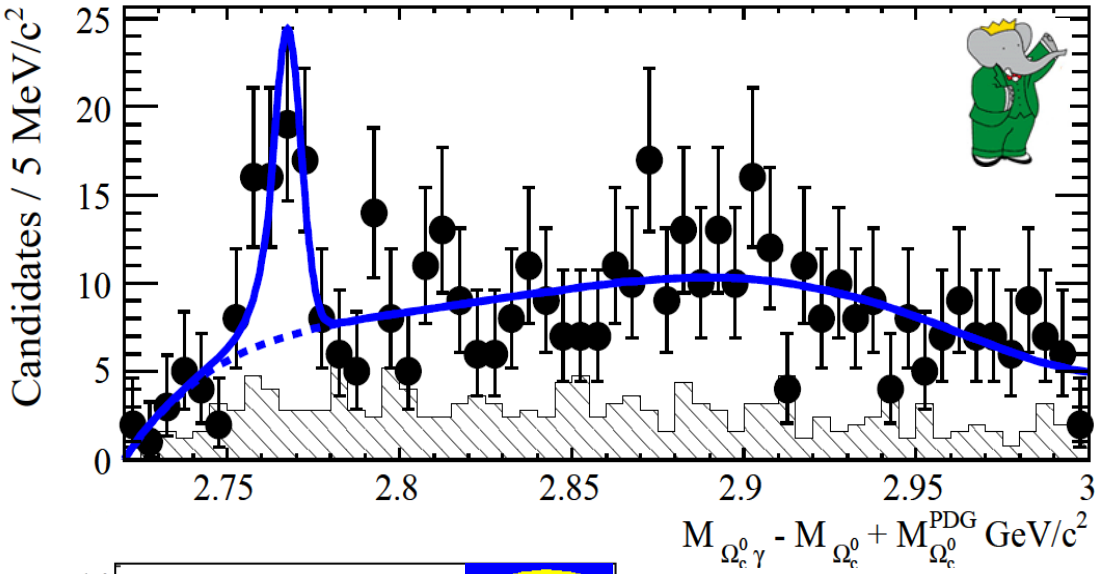


[Y.Kato, T.Iijima *et al.* (Belle Collaboration), Phys. Rev. D **94**, 032002 (2016)]

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	$\frac{3}{2}^-$
$\Xi_c(2930)^0$	$\Lambda_c^+K^-$	2931 ± 6	36 ± 13	
$\Xi_c(2970)^+$	$\Lambda_c^+K^-\pi^+$, $\Sigma_c^{++}K^-$, $\Xi_c(2645)^0\pi^+$, $\Xi_c^{0\prime}\pi^+$	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	

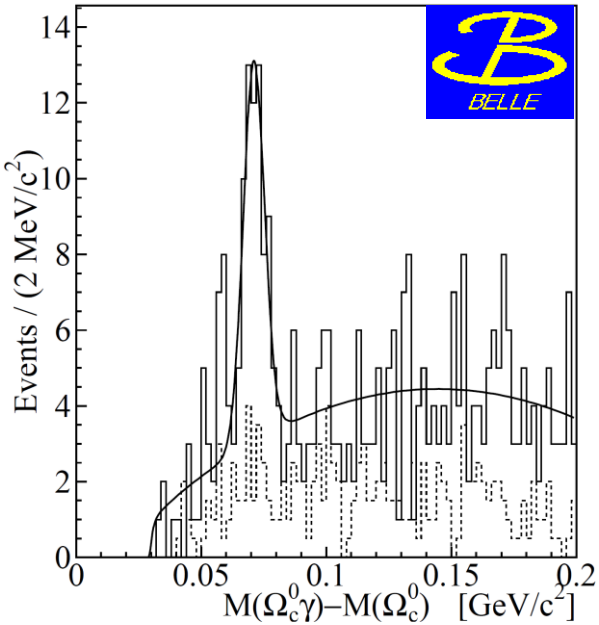
Ω_c Family



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

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

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



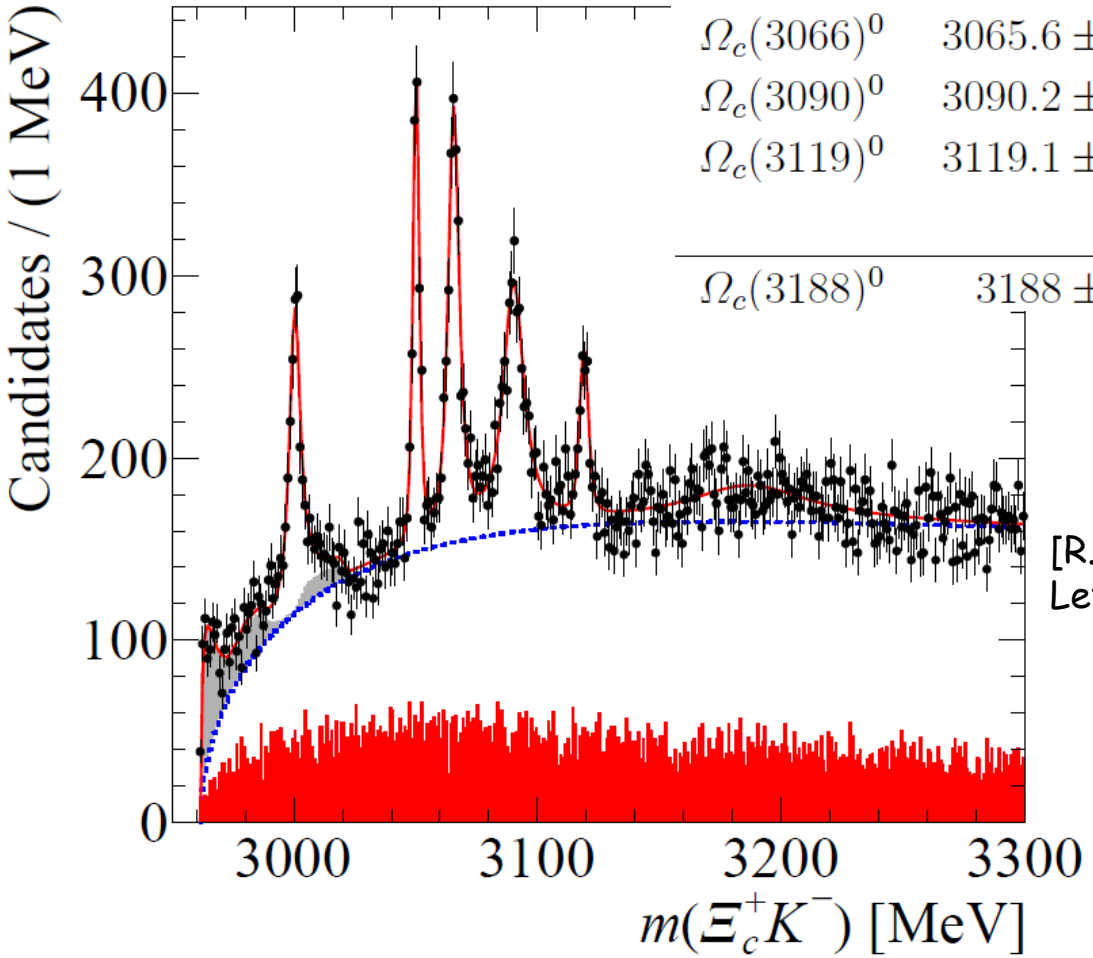
$$\Delta M_{\Omega_c^0} = \left[70.7 \pm 0.9(stat.)^{+0.1}_{-0.9}(syst.)\right]\ MeV/c^2$$

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

Ω_c Family

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

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 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 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)]

Conclusions

- Recently observed excited Ω_c states present a unique opportunity to test and further improve theoretical models, that predict properties of heavy hadrons.
- More accurate Ξ_c mass values is of both practical and theoretical interest, and knowing their widths can then lead to measurements of the matrix elements of their decays. These matrix elements are also applicable to other excited charm and bottom baryons.
- No direct measurements of the J^P of any of the excited strange charmed baryons are available. Constraints on the quantum numbers can be inferred only from the decay pattern.
- Interesting feature is that highly excited charmed baryons can decay to a charm meson and a non-charm baryon.