

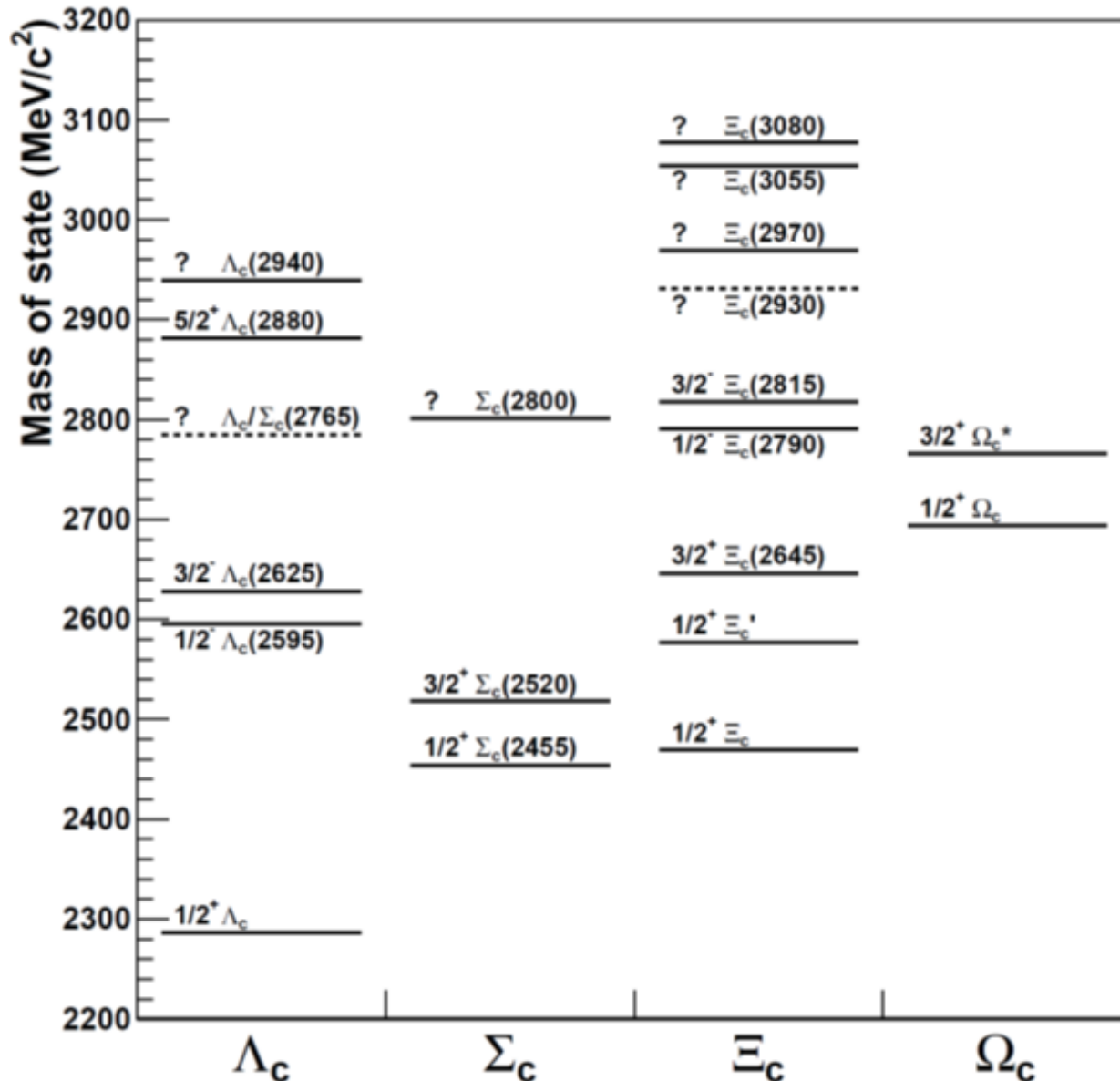
# Excited Charmed Baryons

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# Known Charmed Baryon States



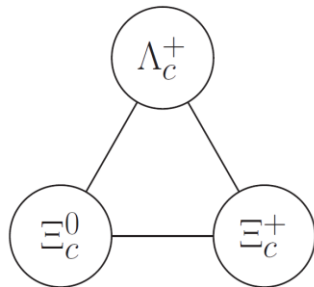
$$\mathcal{B}_c = c + \text{diquark}$$

Quark content of diquark:

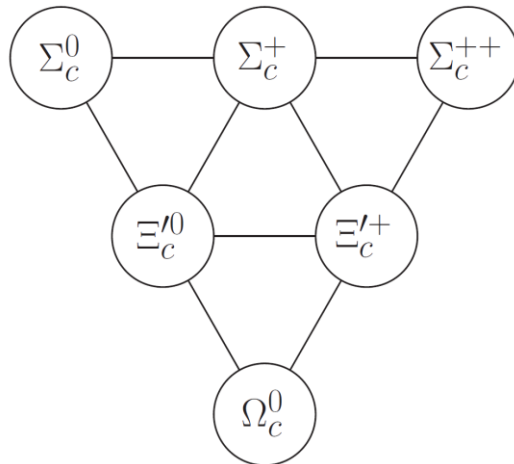
- $qq$  with isospin 0 (flavor antisymmetric) —  $\Lambda_c$  family;
- $qq$  with isospin 1 (flavor symmetric) —  $\Sigma_c$  family;
- $qs$  with isospin  $\frac{1}{2}$  —  $\Xi_c$  family;
- $ss$  with isospin 0 (flavor symmetric) —  $\Omega_c$  family.

# Ground States

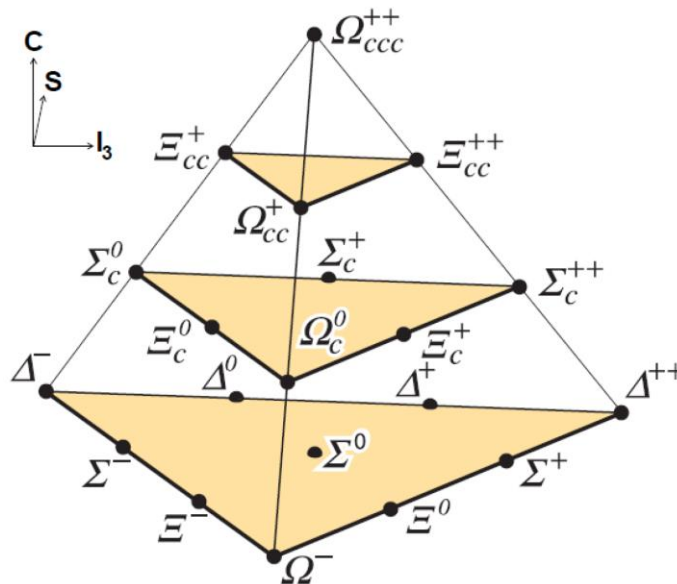
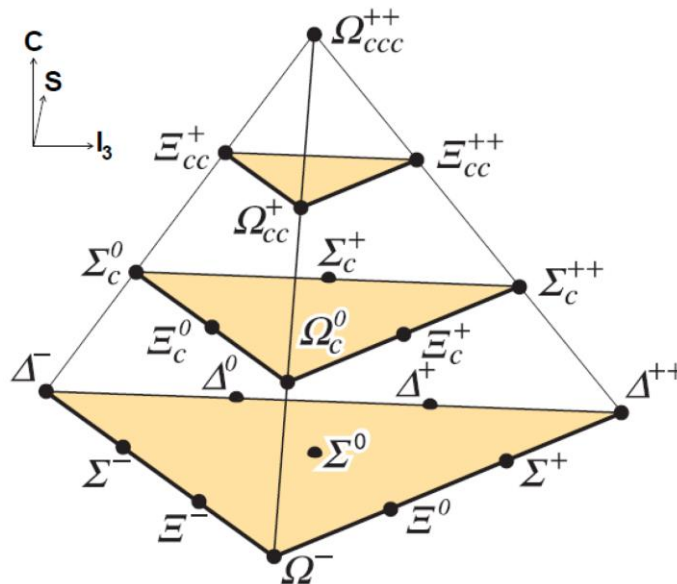
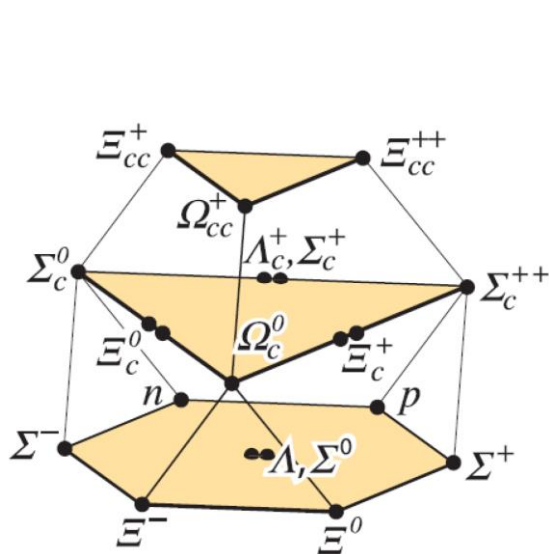
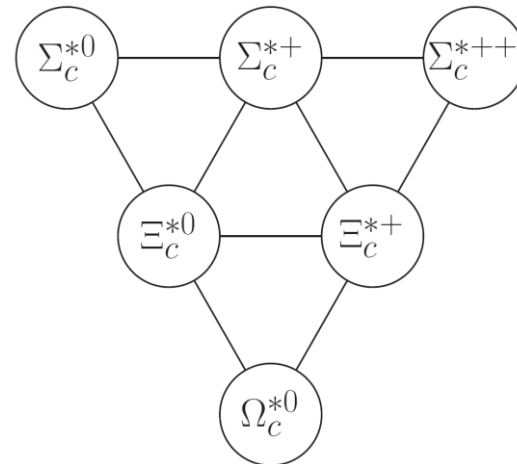
$$j = 0, J^P = \frac{1}{2}^+$$



$$j = 1, J^P = \frac{1}{2}^+$$

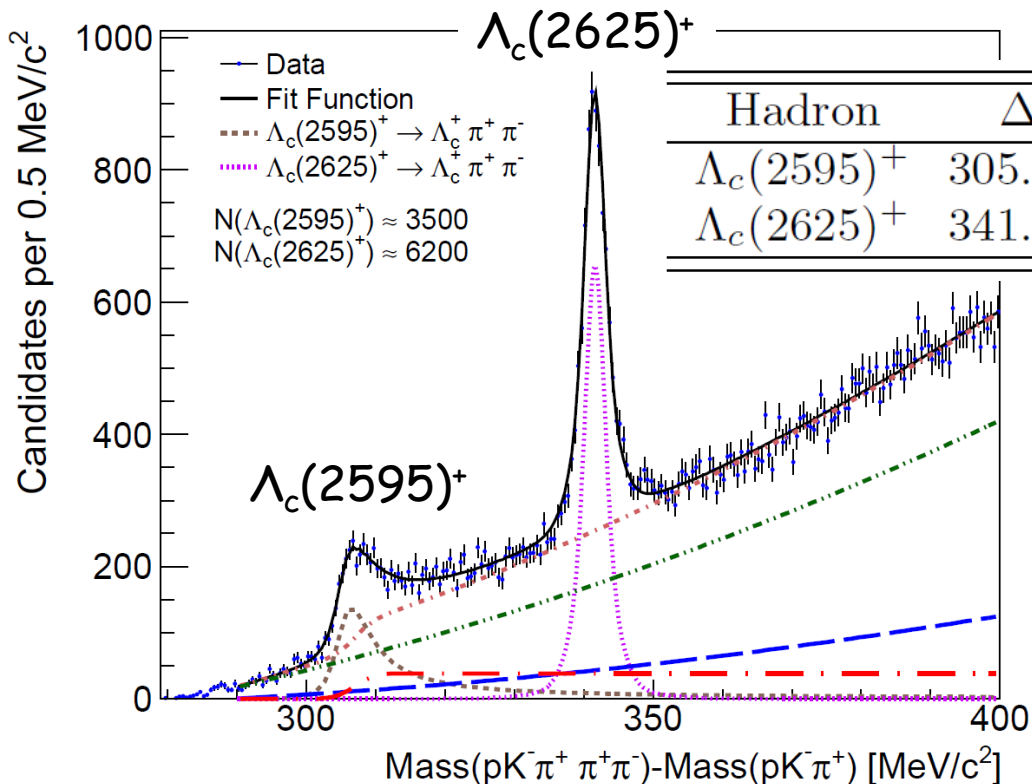


$$j = 1, J^P = \frac{3}{2}^+$$



# $\Lambda_c$ Family

State	Decay mode	Mass, MeV/ $c^2$	Width, MeV	$J^P$
$\Lambda_c(2595)^+$	$\Lambda_c^+ \pi^+ \pi^-$ , $\Sigma_c \pi$	$2592.3 \pm 0.3$	$2.6 \pm 0.6$	$\frac{1}{2}^-$
$\Lambda_c(2625)^+$	$\Lambda_c^+ \pi^+ \pi^-$ , $\Sigma_c \pi$	$2628.11 \pm 0.19$	$< 0.97$ @ 90% CL	$\frac{3}{2}^-$
$\Lambda_c(2765)^+$	$\Lambda_c^+ \pi^+ \pi^-$ , $\Sigma_c \pi$	$2766.6 \pm 2.4$	$\sim 50$	
$\Lambda_c(2880)^+$	$\Lambda_c^+ \pi^+ \pi^-$ , $\Sigma_c \pi$ , $\Sigma_c(2520)\pi$ , $D^0 p$	$2881.5 \pm 0.4$	$5.8 \pm 1.1$	$\frac{5}{2}^+$
$\Lambda_c(2940)^+$	$D^0 p$ , $\Sigma_c \pi$	$2939.3^{+1.4}_{-1.5}$	$17^{+8}_{-6}$	



Hadron	$\Delta M$ [MeV/ $c^2$ ]	$\Gamma$ [MeV/ $c^2$ ]
$\Lambda_c(2595)^+$	$305.79 \pm 0.14 \pm 0.20$	$h_2^2 = 0.36 \pm 0.04 \pm 0.07$
$\Lambda_c(2625)^+$	$341.65 \pm 0.04 \pm 0.12$	

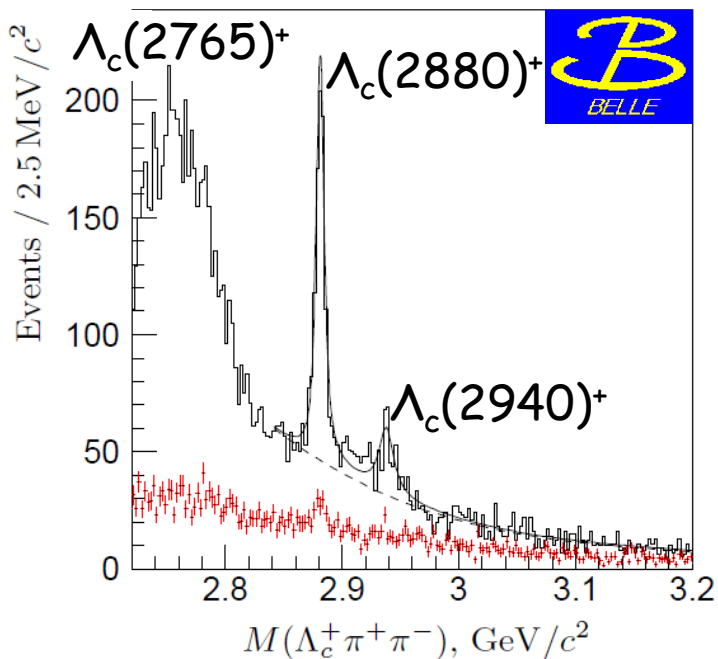
[T. Aaltonen *et al.* (CDF collaboration), Phys. Rev. D **84**, 012003 (2011)]

# $\Lambda_c$ Family

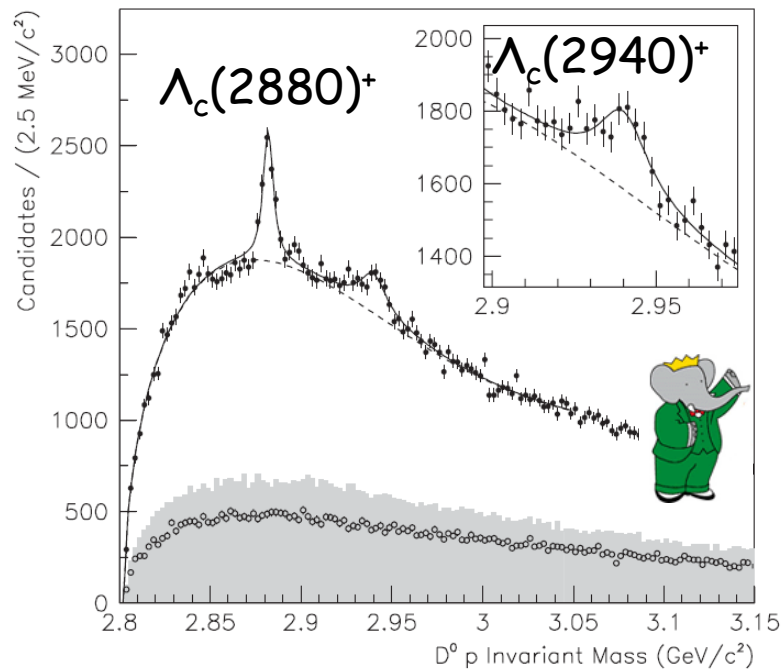
State	Decay mode	Mass, MeV/ $c^2$	Width, MeV	$J^P$
$\Lambda_c(2595)^+$	$\Lambda_c^+ \pi^+ \pi^-$ , $\Sigma_c \pi$	$2592.3 \pm 0.3$	$2.6 \pm 0.6$	$\frac{1}{2}^-$
$\Lambda_c(2625)^+$	$\Lambda_c^+ \pi^+ \pi^-$ , $\Sigma_c \pi$	$2628.11 \pm 0.19$	$< 0.97$ @ 90% CL	$\frac{3}{2}^-$
$\Lambda_c(2765)^+$	$\Lambda_c^+ \pi^+ \pi^-$ , $\Sigma_c \pi$	$2766.6 \pm 2.4$	$\sim 50$	
$\Lambda_c(2880)^+$	$\Lambda_c^+ \pi^+ \pi^-$ , $\Sigma_c \pi$ , $\Sigma_c(2520)\pi$ , $D^0 p$	$2881.5 \pm 0.4$	$5.8 \pm 1.1$	$\frac{5}{2}^+$
$\Lambda_c(2940)^+$	$D^0 p$ , $\Sigma_c \pi$	$2939.3^{+1.4}_{-1.5}$	$17^{+8}_{-6}$	

$$\Lambda_c \rightarrow \Sigma_c^{0,++} \pi^\pm$$

$$\Lambda_c \rightarrow D^0 p$$



[R. Mizuk *et al.* (Belle Collaboration), Phys. Rev. Lett. **98**, 262001 (2007)]

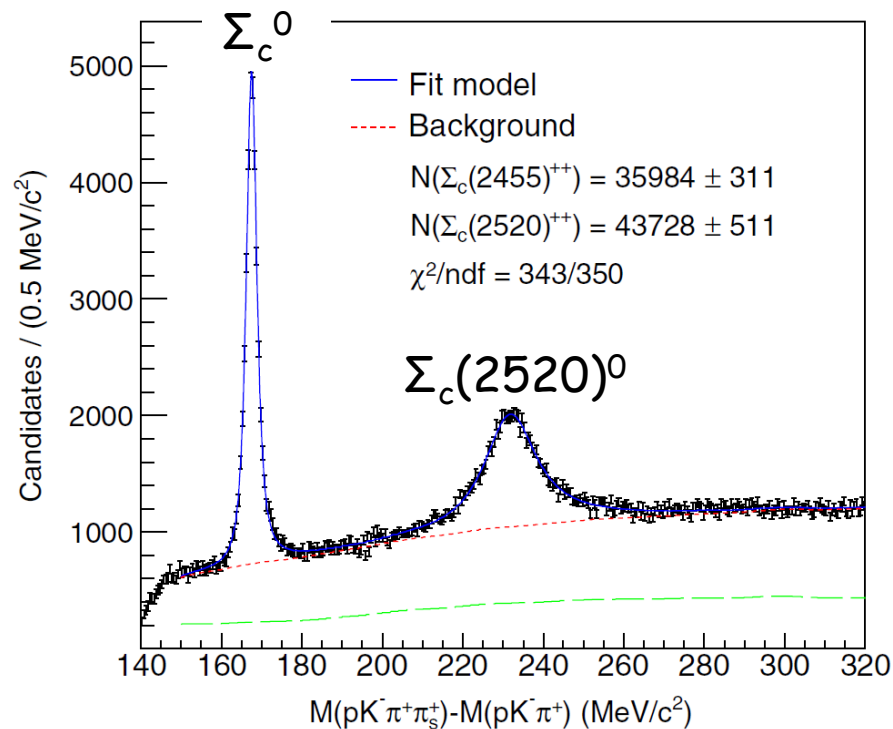
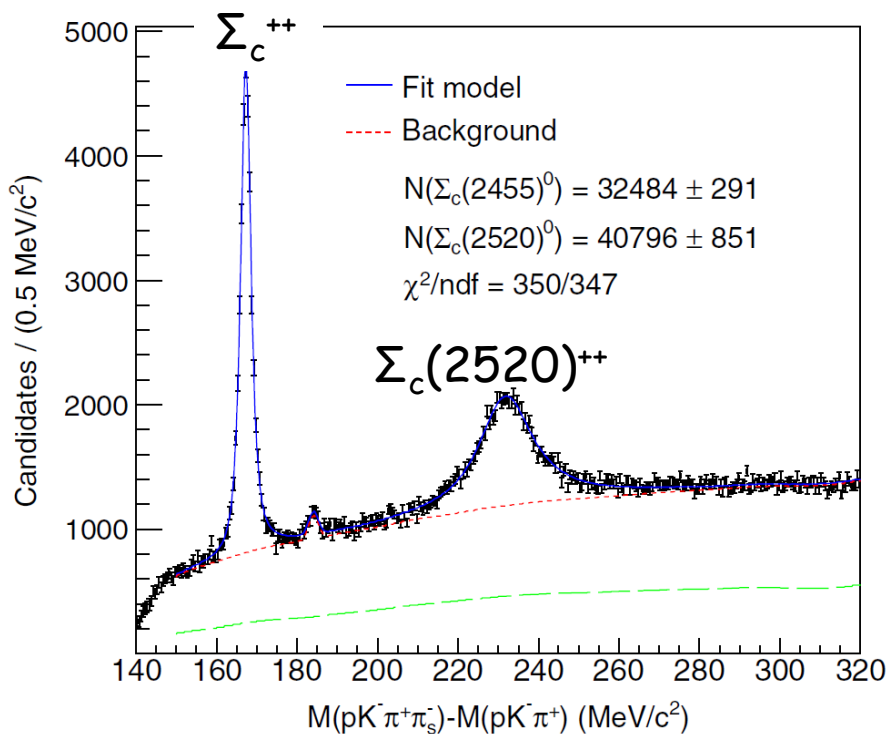


[B. Aubert *et al.* (BaBar Collaboration), Phys. Rev. Lett. **98**, 012001 (2007)] #5

# $\Sigma_c$ Family

State	Decay mode	Mass, MeV/ $c^2$	Width, MeV	$J^P$
$\Sigma_c(2520)^{++}$	$\Lambda_c^+ \pi^+$	$231.95^{+0.17}_{-0.12}$	$14.78^{+0.3}_{-0.4}$	$\frac{1}{2}^+$
$\Sigma_c(2520)^+$	$\Lambda_c^+ \pi^0$	$231.0 \pm 2.3$	$< 17$ @ 90% CL	$\frac{1}{2}^+$
$\Sigma_c(2520)^0$	$\Lambda_c^+ \pi^-$	$232.02^{+0.15}_{-0.14}$	$15.3^{+0.4}_{-0.5}$	$\frac{1}{2}^+$
$\Sigma_c(2800)^{++}$	$\Lambda_c^+ \pi^+$	$514^{+4}_{-6}$	$75^{+22}_{-17}$	$\frac{3}{2}^-$
$\Sigma_c(2800)^+$	$\Lambda_c^+ \pi^0$	$505^{+14}_{-5}$	$62^{+60}_{-40}$	$\frac{3}{2}^-$
$\Sigma_c(2800)^0$	$\Lambda_c^+ \pi^-$	$519^{+5}_{-7}$	$72^{+22}_{-15}$	$\frac{3}{2}^-$

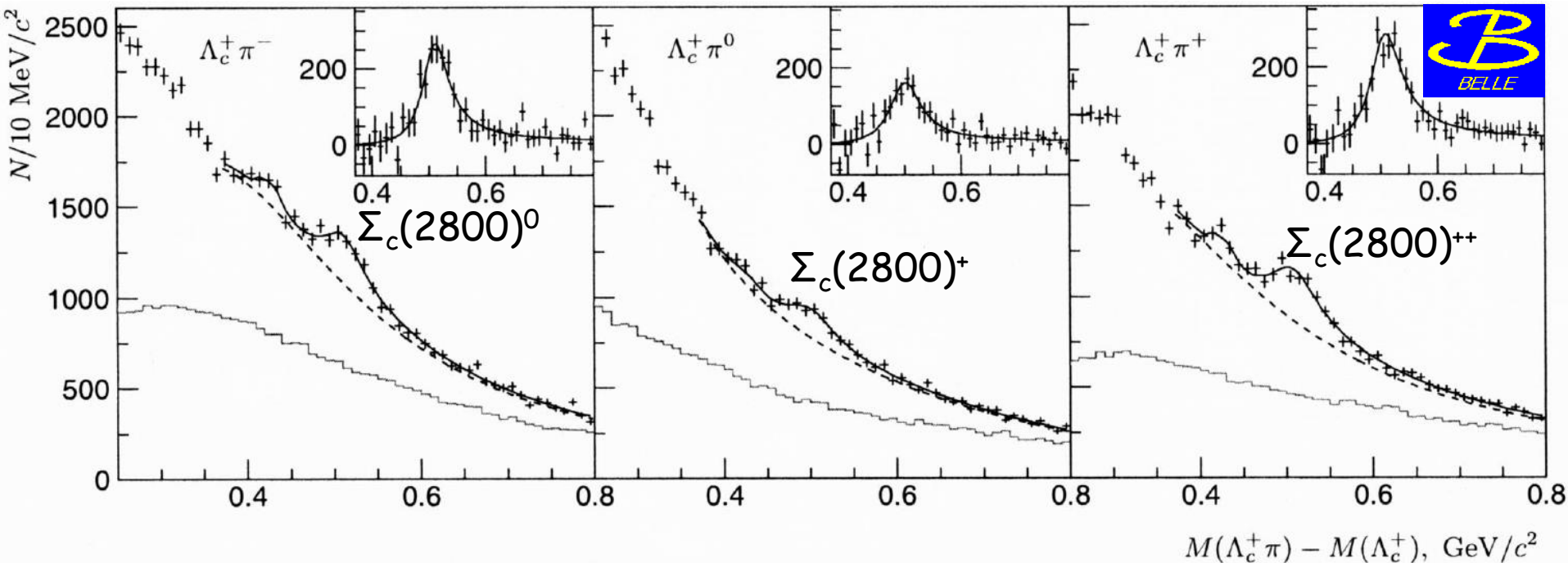
	$\Delta M_0$ (MeV/ $c^2$ )	$\Gamma$ (MeV/ $c^2$ )	$M_0$ (MeV/ $c^2$ )
$\Sigma_c(2455)^0$	$167.29 \pm 0.01 \pm 0.02$	$1.76 \pm 0.04^{+0.09}_{-0.21}$	$2453.75 \pm 0.01 \pm 0.02 \pm 0.14$
$\Sigma_c(2455)^{++}$	$167.51 \pm 0.01 \pm 0.02$	$1.84 \pm 0.04^{+0.07}_{-0.20}$	$2453.97 \pm 0.01 \pm 0.02 \pm 0.14$
$\Sigma_c(2520)^0$	$231.98 \pm 0.11 \pm 0.04$	$15.41 \pm 0.41^{+0.20}_{-0.32}$	$2518.44 \pm 0.11 \pm 0.04 \pm 0.14$
$\Sigma_c(2520)^{++}$	$231.99 \pm 0.10 \pm 0.02$	$14.77 \pm 0.25^{+0.18}_{-0.30}$	$2518.45 \pm 0.10 \pm 0.02 \pm 0.14$



# $\Sigma_c$ Family

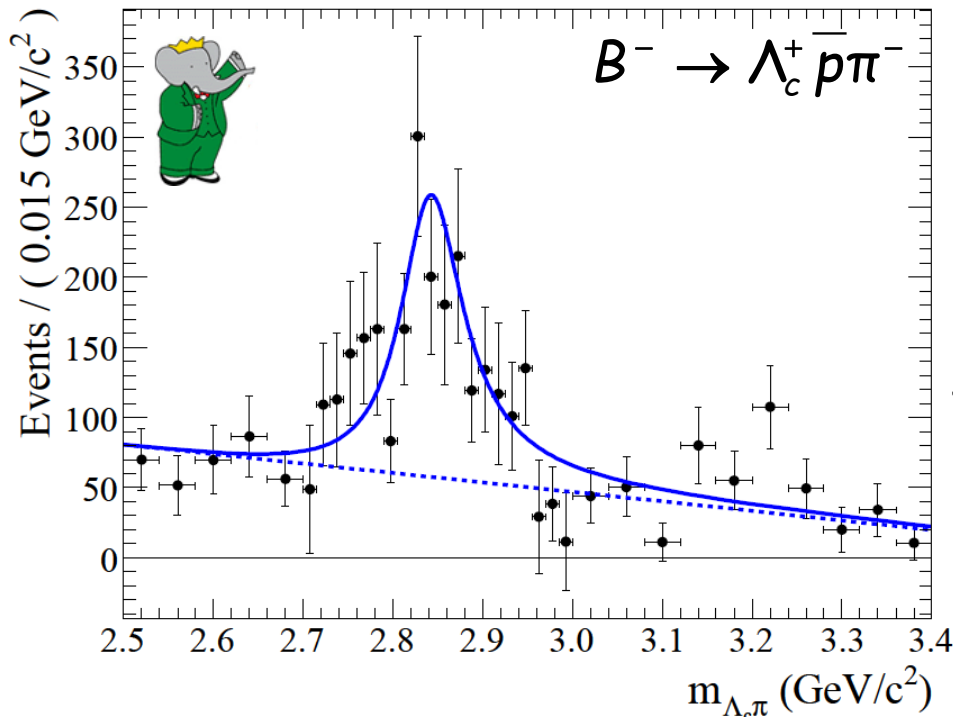
State	Decay mode	Mass, $\text{MeV}/c^2$	Width, MeV	$J^P$
$\Sigma_c(2520)^{++}$	$\Lambda_c^+ \pi^+$	$231.95^{+0.17}_{-0.12}$	$14.78^{+0.3}_{-0.4}$	$\frac{3}{2}^+$
$\Sigma_c(2520)^+$	$\Lambda_c^+ \pi^0$	$231.0 \pm 2.3$	$< 17$ @ 90% CL	$\frac{3}{2}^+$
$\Sigma_c(2520)^0$	$\Lambda_c^+ \pi^-$	$232.02^{+0.15}_{-0.14}$	$15.3^{+0.4}_{-0.5}$	$\frac{3}{2}^+$
$\Sigma_c(2800)^{++}$	$\Lambda_c^+ \pi^+$	$514^{+4}_{-6}$	$75^{+22}_{-17}$	$\frac{3}{2}^-$
$\Sigma_c(2800)^+$	$\Lambda_c^+ \pi^0$	$505^{+14}_{-5}$	$62^{+60}_{-40}$	$\frac{3}{2}^-$
$\Sigma_c(2800)^0$	$\Lambda_c^+ \pi^-$	$519^{+5}_{-7}$	$72^{+22}_{-15}$	$\frac{3}{2}^-$

State	$\Delta M, \text{MeV}/c^2$	$\Gamma, \text{MeV}$
$\Sigma_c(2800)^0$	$515.4^{+3.2+2.1}_{-3.1-6.0}$	$61^{+18+22}_{-13-13}$
$\Sigma_c(2800)^+$	$505.4^{+5.8+12.4}_{-4.6-2.0}$	$62^{+37+52}_{-23-38}$
$\Sigma_c(2800)^{++}$	$514.5^{+3.4+2.8}_{-3.1-4.9}$	$75^{+18+12}_{-13-11}$



# $\Sigma_c$ Family

State	Decay mode	Mass, $\text{MeV}/c^2$	Width, MeV	$J^P$
$\Sigma_c(2520)^{++}$	$\Lambda_c^+ \pi^+$	$231.95^{+0.17}_{-0.12}$	$14.78^{+0.3}_{-0.4}$	$\frac{3}{2}^+$
$\Sigma_c(2520)^+$	$\Lambda_c^+ \pi^0$	$231.0 \pm 2.3$	$< 17$ @ 90% CL	$\frac{3}{2}^+$
$\Sigma_c(2520)^0$	$\Lambda_c^+ \pi^-$	$232.02^{+0.15}_{-0.14}$	$15.3^{+0.4}_{-0.5}$	$\frac{3}{2}^+$
$\Sigma_c(2800)^{++}$	$\Lambda_c^+ \pi^+$	$514^{+4}_{-6}$	$75^{+22}_{-17}$	$\frac{3}{2}^-$
$\Sigma_c(2800)^+$	$\Lambda_c^+ \pi^0$	$505^{+14}_{-5}$	$62^{+60}_{-40}$	$\frac{3}{2}^-$
$\Sigma_c(2800)^0$	$\Lambda_c^+ \pi^-$	$519^{+5}_{-7}$	$72^{+22}_{-15}$	$\frac{3}{2}^-$



Fit Parameter	Value	PDG Value [8]
$m_R$ ( $\text{GeV}/c^2$ )	$2.846 \pm 0.008$	$2.802^{+0.004}_{-0.007}$
$\Gamma_R$ (MeV)	$86^{+33}_{-22}$	$61^{+28}_{-18}$

[B. Aubert et al. (BaBar Collaboration), Phys. Rev. D **78**, 112003 (2008)]

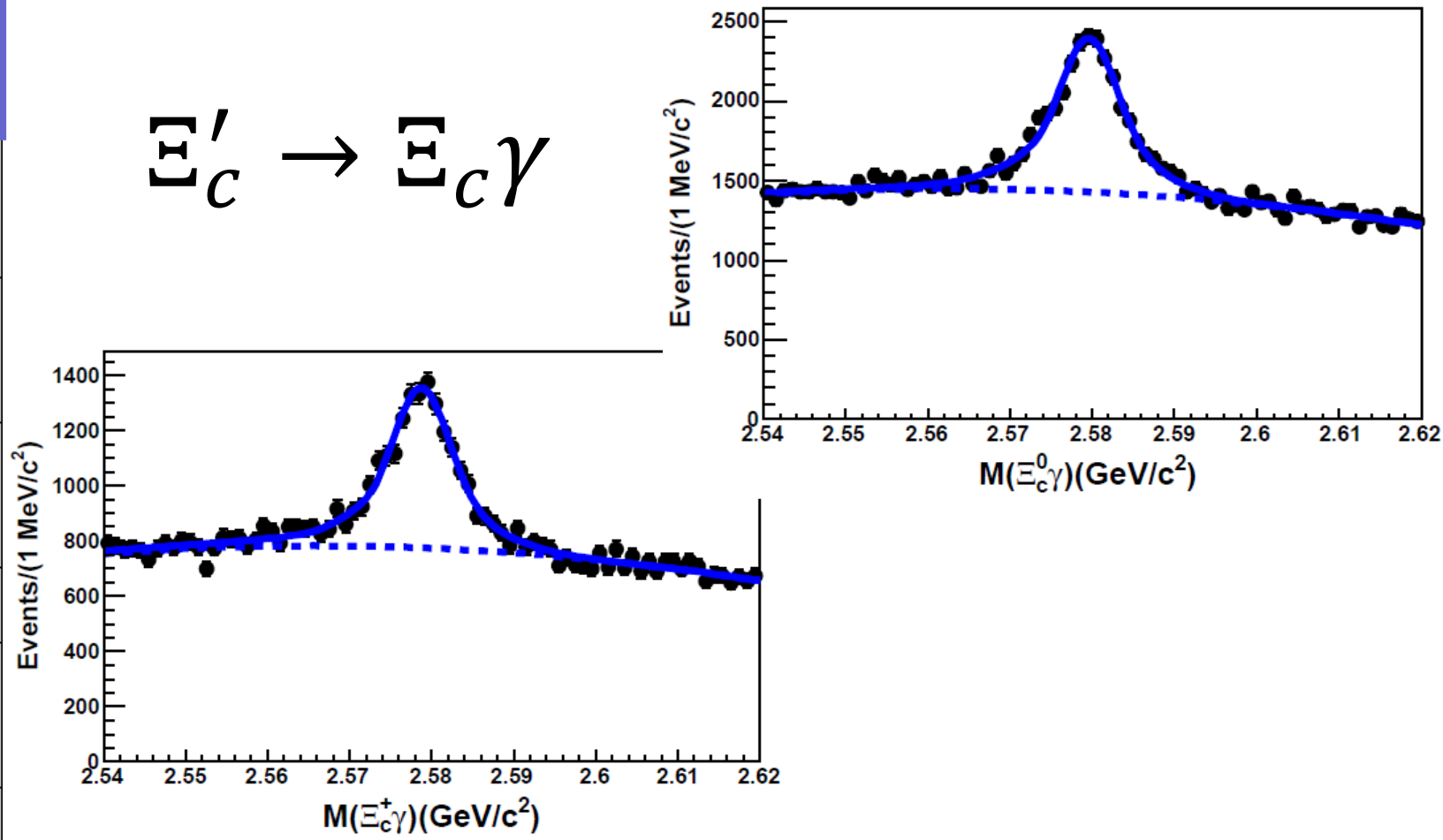
# $\Xi_c$ Family: PDG'2016

State	Decay mode	Mass, MeV/ $c^2$	Width, MeV	$J^P$
$\Xi_c^{\prime+}$	$\Xi_c^+\gamma$	$2575.7 \pm 3.0$		$\frac{1}{2}^+$
$\Xi_c^{\prime0}$	$\Xi_c^0\gamma$	$2577.9 \pm 2.9$		$\frac{1}{2}^+$
$\Xi_c(2645)^+$	$\Xi_c^0\pi^+$	$2645.9 \pm 0.5$	$2.6 \pm 0.4$	$\frac{3}{2}^+$
$\Xi_c(2645)^0$	$\Xi_c^+\pi^-$	$2645.9 \pm 0.5$	$< 5.5$ @ 90% CL	$\frac{3}{2}^+$
$\Xi_c(2790)^+$	$\Xi_c^{\prime0}\pi^+$	$2789.1 \pm 3.2$	$< 15$ @ 90% CL	$\frac{1}{2}^-$
$\Xi_c(2790)^0$	$\Xi_c^{\prime+}\pi^-$	$2791.9 \pm 3.3$	$< 12$ @ 90% CL	$\frac{1}{2}^-$
$\Xi_c(2815)^+$	$\Xi_c^+\pi^+\pi^-, \Xi_c(2645)^0\pi^+$	$2816.6 \pm 0.9$	$< 3.5$ @ 90% CL	$\frac{3}{2}^-$
$\Xi_c(2815)^0$	$\Xi_c^0\pi^+\pi^-, \Xi_c(2645)^+\pi^-$	$2819.6 \pm 1.2$	$< 6.5$ @ 90% CL	$\frac{3}{2}^-$
$\Xi_c(2930)^0$	$\Lambda_c^+K^-$	$2931 \pm 6$	$36 \pm 13$	
$\Xi_c(2970)^+$	$\Lambda_c^+K^-\pi^+, \Sigma_c^{++}K^-, \Xi_c(2645)^0\pi^+$	$2970.7 \pm 2.2$	$17.9 \pm 3.5$	
$\Xi_c(2970)^0$	$\Xi_c(2645)^+\pi^-$	$2968.0 \pm 2.6$	$20 \pm 7$	
$\Xi_c(3055)^+$	$\Sigma_c^{++}K^-$	$3055.1 \pm 1.7$	$11 \pm 4$	
$\Xi_c(3055)^0$				
$\Xi_c(3080)^+$	$\Lambda_c^+K^-\pi^+, \Sigma_c^{++}K^-, \Sigma_c(2520)^{++}K^-$	$3076.94 \pm 0.28$	$4.3 \pm 1.5$	
$\Xi_c(3080)^0$	$\Lambda_c^+K_S^0\pi^-, \Sigma_c^0K_S^0, \Sigma_c(2520)^0K_S^0$	$3079.9 \pm 1.4$	$5.6 \pm 2.2$	#9

# Decays to $\Xi_c$ : $\Xi_c'$ Isodoublet

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

$$\Xi_c' \rightarrow \Xi_c \gamma$$

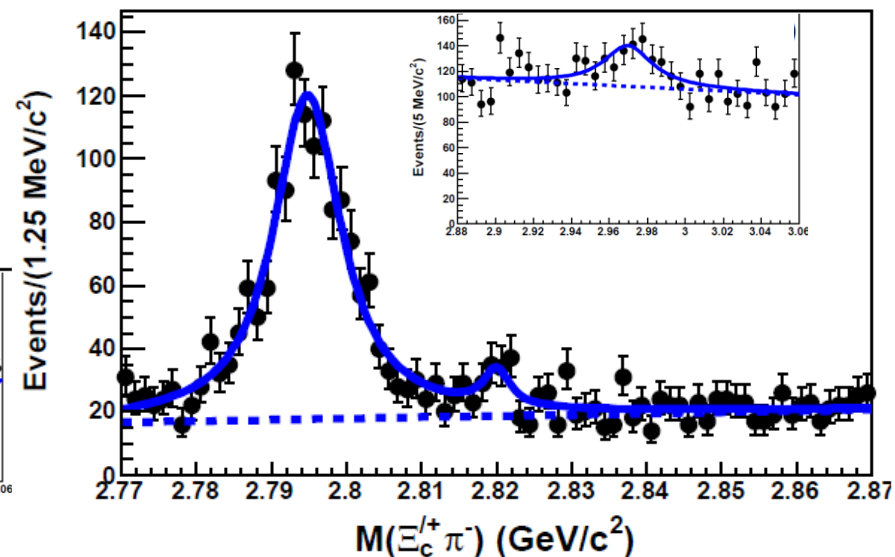
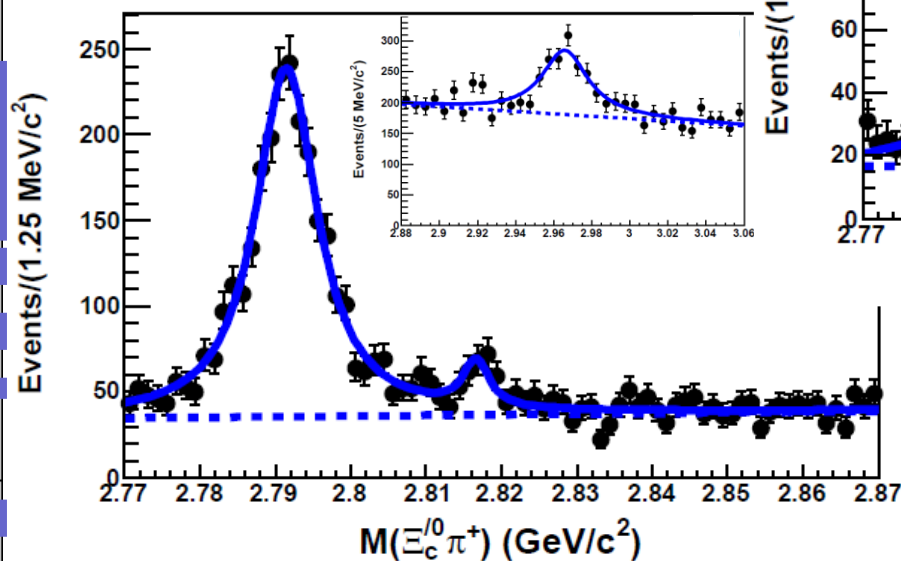
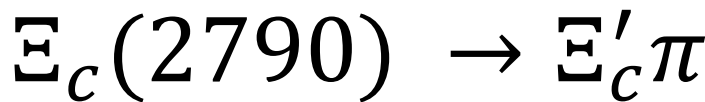


$$M_{\Xi_c'^+} - M_{\Xi_c^+} = (110.5 \pm 0.1[stat.] \pm 0.4[syst.]) \text{ MeV}/c^2$$

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

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

$\Xi_c^{\prime+}$
$\Xi_c^{\prime0}$
$\Xi_c(2645)^+$
$\Xi_c(2645)^0$
$\Xi_c(2790)^+$
$\Xi_c(2790)^0$
$\Xi_c(2815)^+$
$\Xi_c(2815)^0$
$\Xi_c(2930)^0$
$\Xi_c(2970)^+$
$\Xi_c(2970)^0$
$\Xi_c(3055)^+$
$\Xi_c(3055)^0$
$\Xi_c(3080)^+$
$\Xi_c(3080)^0$



$$M_{\Xi_c(2790)^+} - M_{\Xi_c^{\prime0}} = (213.2 \pm 0.2[\text{stat.}] \pm 0.1[\text{syst.}]) \text{ MeV}/c^2$$

$$\Gamma_{\Xi_c(2790)^+} = (8.9 \pm 0.6[\text{stat.}] \pm 0.8[\text{syst.}]) \text{ MeV}$$

$$M_{\Xi_c(2790)^0} - M_{\Xi_c^{\prime+}} = (215.7 \pm 0.2[\text{stat.}] \pm 0.1[\text{syst.}]) \text{ MeV}/c^2$$

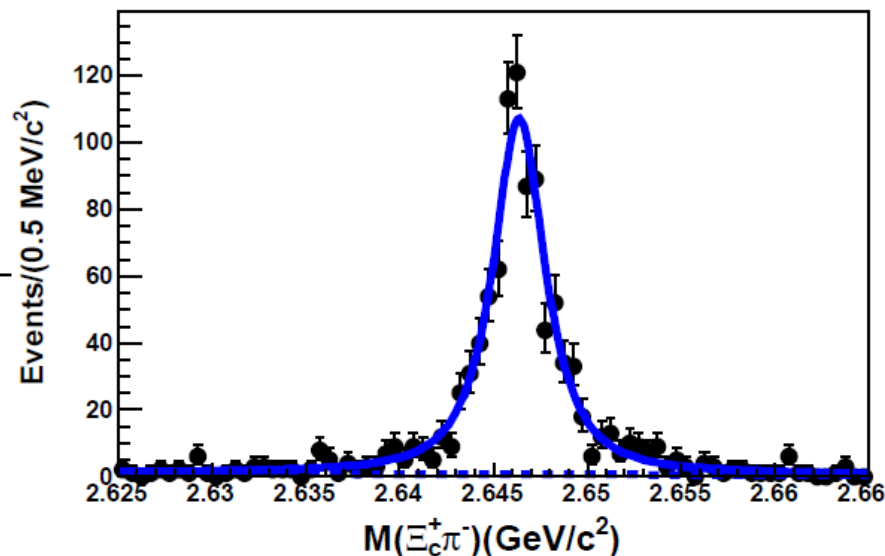
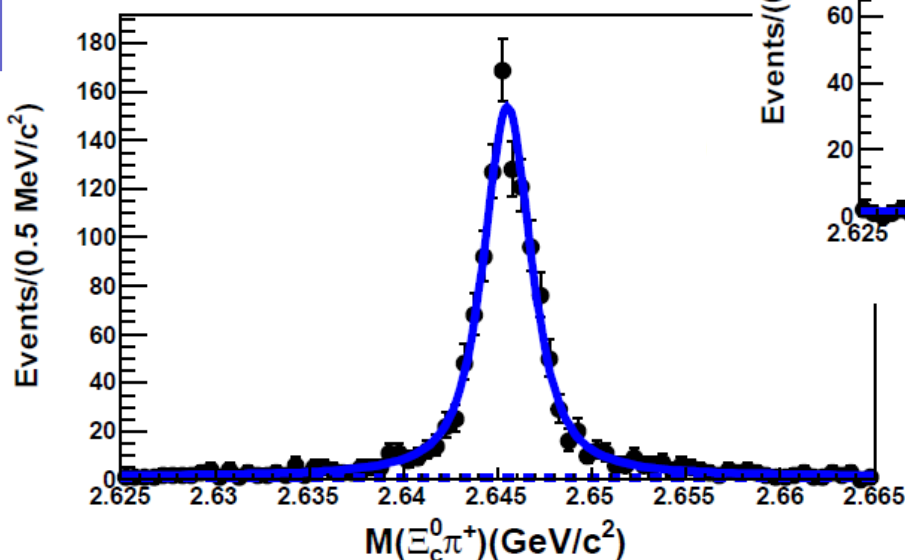
$$\Gamma_{\Xi_c(2790)^0} = (10.0 \pm 0.7[\text{stat.}] \pm 0.8[\text{syst.}]) \text{ MeV}$$

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

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

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

$$\Xi_c(2645) \rightarrow \Xi_c \pi$$



$$M_{\Xi_c(2645)^+} - M_{\Xi_c^0} = (174.66 \pm 0.06[stat.] \pm 0.07[syst.]) \text{ MeV}/c^2$$

$$\Gamma_{\Xi_c(2645)^+} = (2.06 \pm 0.13[stat.] \pm 0.13[syst.]) \text{ MeV}$$

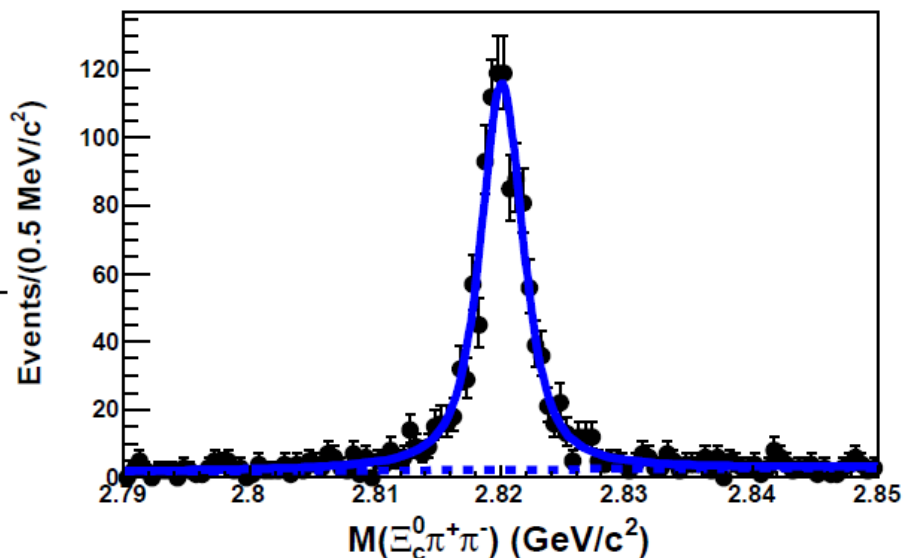
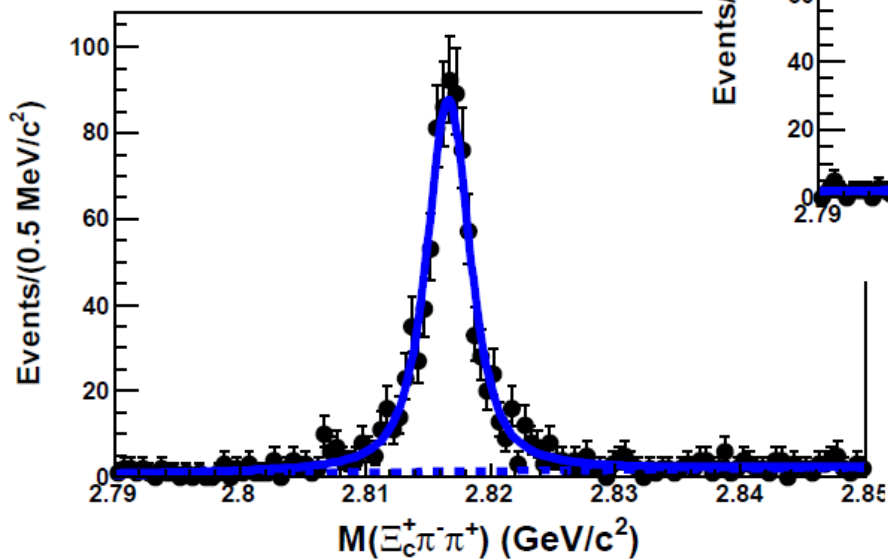
$$M_{\Xi_c(2645)^0} - M_{\Xi_c^+} = (178.46 \pm 0.07[stat.] \pm 0.07[syst.]) \text{ MeV}/c^2$$

$$\Gamma_{\Xi_c(2645)^0} = (2.35 \pm 0.18[stat.] \pm 0.13[syst.]) \text{ MeV}$$

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

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

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



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

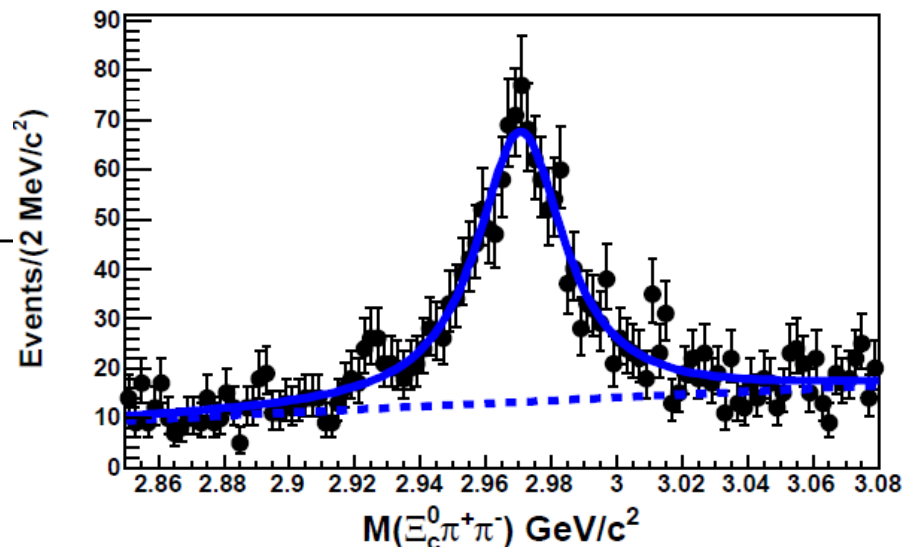
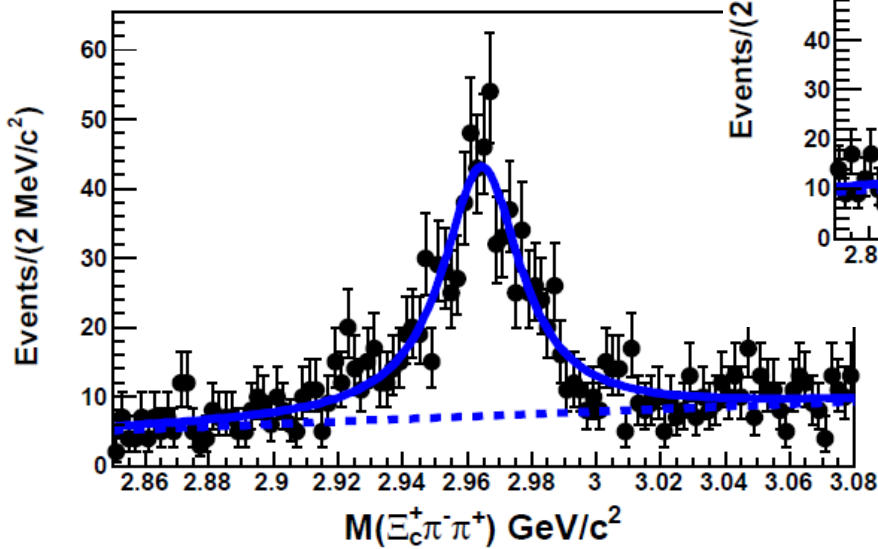
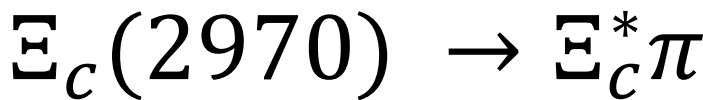
$$\Gamma_{\Xi_c(2815)^+} = (2.43 \pm 0.20[\text{stat.}] \pm 0.17[\text{syst.}]) \text{ MeV}$$

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

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

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

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



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

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

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

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

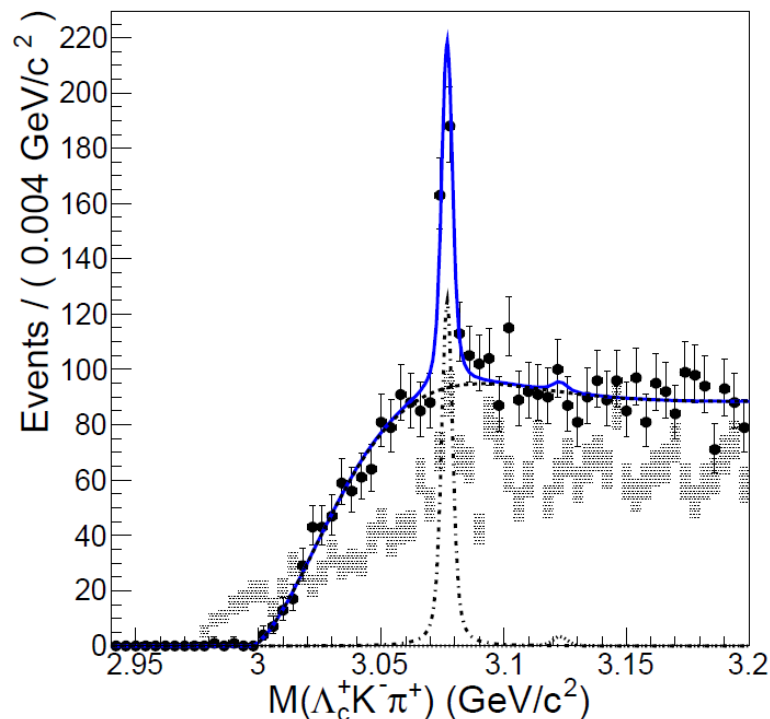
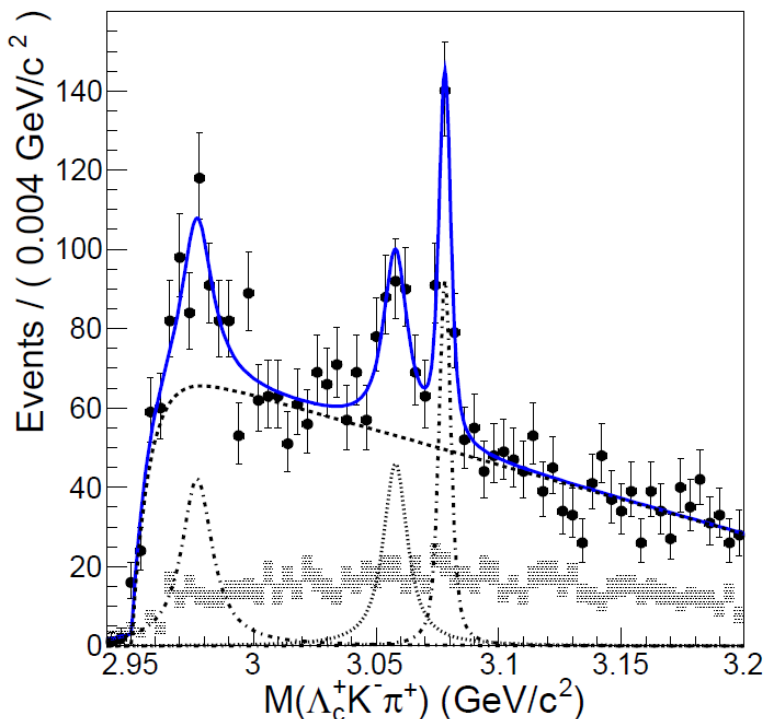
# $\Xi_c$ Family: Decays to $\Xi_c$

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

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

# $\Xi_c$ Family: Decays to $\Lambda_c(\Sigma_c)$

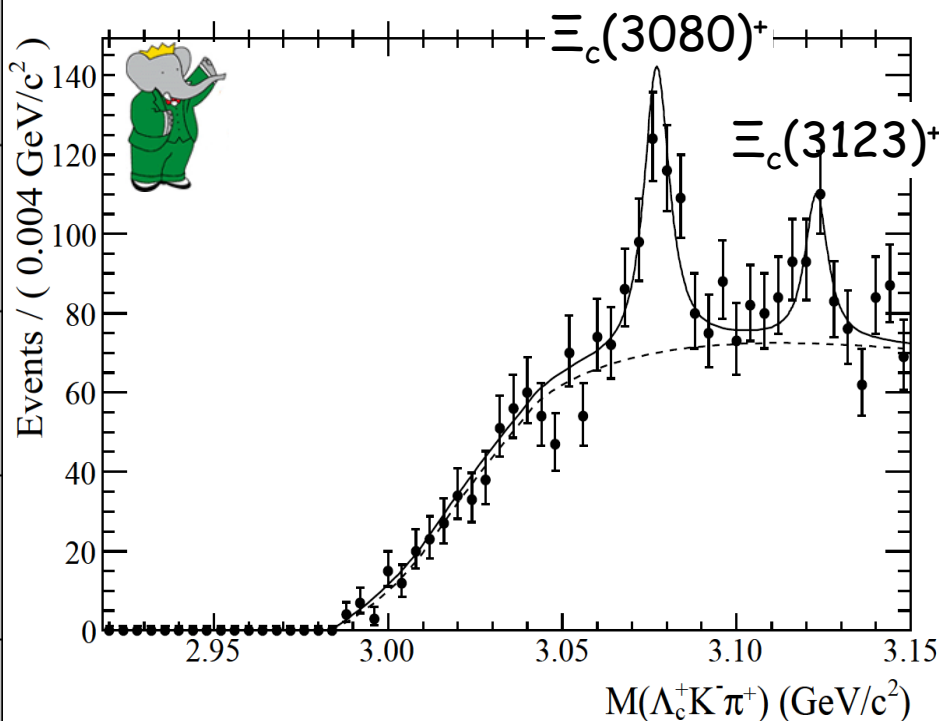
$\Xi_c^{\prime+}$
$\Xi_c^{\prime0}$
$\Xi_c(2645)^+$
$\Xi_c(2645)^0$
$\Xi_c(2790)^+$
$\Xi_c(2790)^0$
$\Xi_c(2815)^+$
$\Xi_c(2815)^0$
$\Xi_c(2930)^0$
$\Xi_c(2970)^+$
$\Xi_c(2970)^0$
$\Xi_c(3055)^+$
$\Xi_c(3055)^0$
$\Xi_c(3080)^+$
$\Xi_c(3080)^0$



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

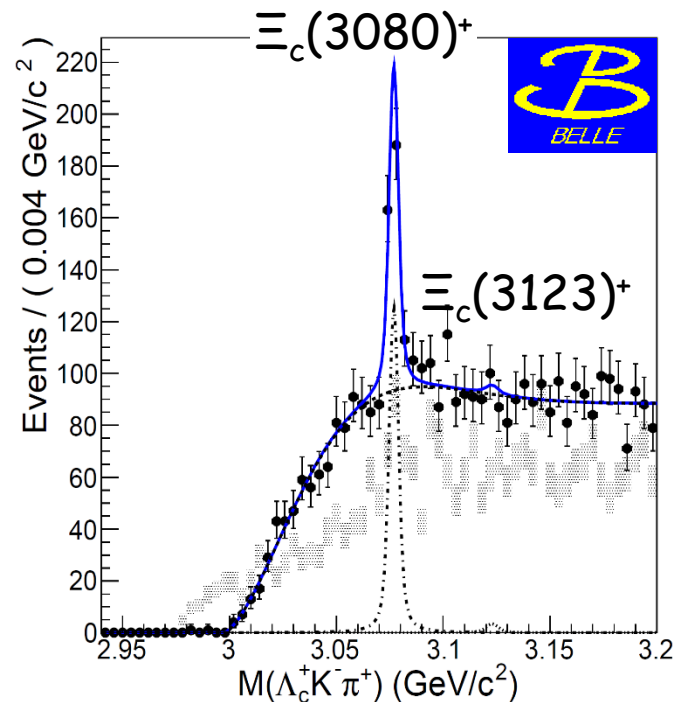
# $\Xi_c$ Family: Decays to $\Lambda_c(\Sigma_c)$

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



$\Xi_c(3123)^+$	
Mass (MeV/c <sup>2</sup> )	$3122.9 \pm 1.3 \pm 0.3$
Width (MeV)	$4.4 \pm 3.4 \pm 1.7$
Significance	$3.6 \sigma \text{ (} 3.0 \sigma \text{)}$

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

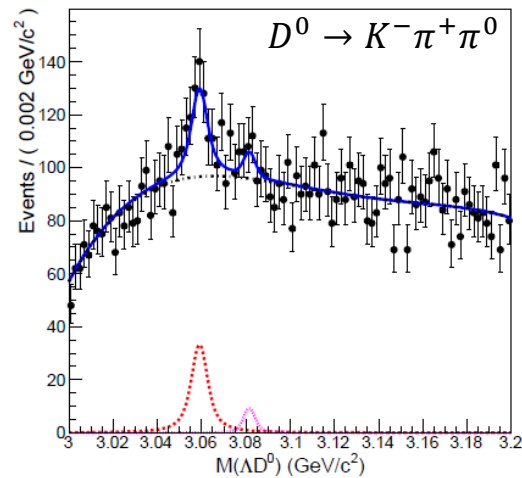
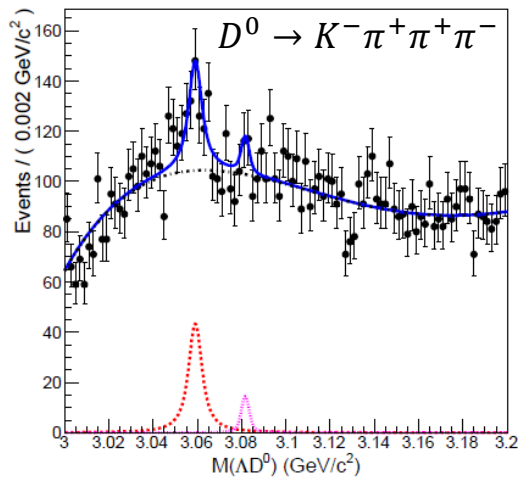
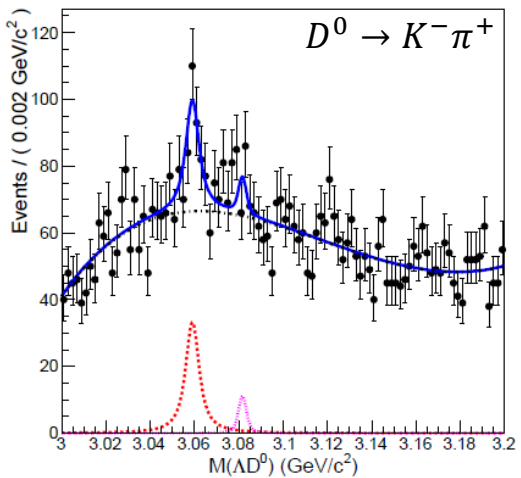
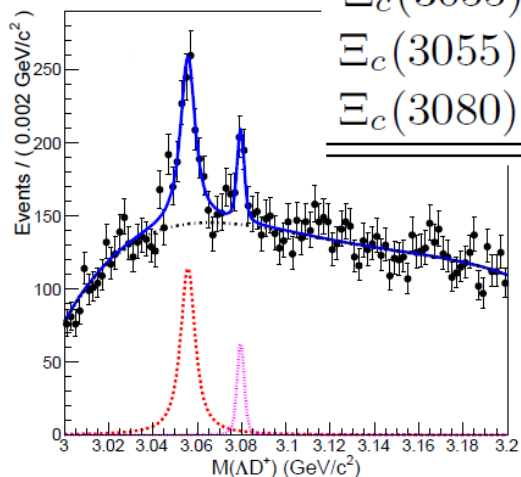


[Y.Kato, T.Iijima *et al.* (Belle Collaboration), Phys. Rev. D **89**, 052003 (2014)]

# $\Xi_c$ Family: Decays to $\Lambda D$

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

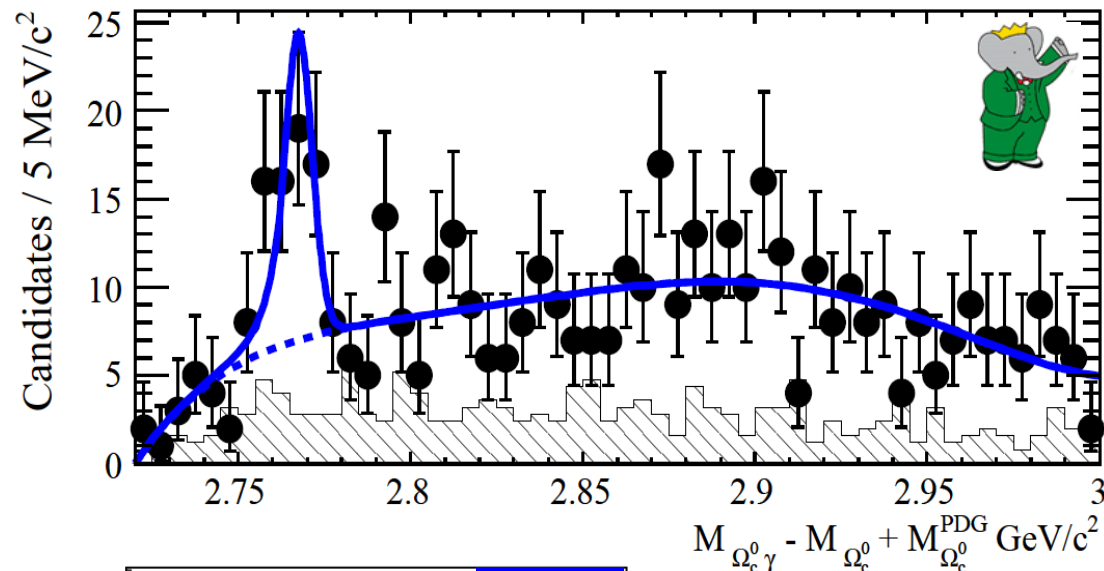
Resonance	Mass (MeV/ $c^2$ )	Width (MeV)	Significance ( $\sigma$ )
$\Xi_c(3055)^0$	$3059.0 \pm 0.5 \pm 0.6$	$6.4 \pm 2.1 \pm 1.1$	8.6
$\Xi_c(3055)^+$	$3055.8 \pm 0.4 \pm 0.2$	$7.0 \pm 1.2 \pm 1.5$	11.7
$\Xi_c(3080)^+$	$3079.6 \pm 0.4 \pm 0.1$	$< 6.3$	4.8



# $\Xi_c$ Family

State	Decay mode	Mass, MeV/ $c^2$	Width, MeV	$J^P$
$\Xi_c^{\prime+}$	$\Xi_c^+\gamma$	$2577.4 \pm 1.2$		$\frac{1}{2}^+$
$\Xi_c^{\prime0}$	$\Xi_c^0\gamma$	$2578.8 \pm 0.5$		$\frac{1}{2}^+$
$\Xi_c(2645)^+$	$\Xi_c^0\pi^+$	$2645.53 \pm 0.31$	$2.14 \pm 0.19$	$\frac{3}{2}^+$
$\Xi_c(2645)^0$	$\Xi_c^+\pi^-$	$2646.32 \pm 0.31$	$2.35 \pm 0.22$	$\frac{3}{2}^+$
$\Xi_c(2790)^+$	$\Xi_c^{\prime0}\pi^+$	$2792.0 \pm 0.5$	$8.9 \pm 1.0$	$\frac{1}{2}^-$
$\Xi_c(2790)^0$	$\Xi_c^{\prime+}\pi^-$	$2792.8 \pm 1.2$	$10.0 \pm 1.1$	$\frac{1}{2}^-$
$\Xi_c(2815)^+$	$\Xi_c^+\pi^+\pi^-, \Xi_c(2645)^0\pi^+, \Xi_c^{\prime0}\pi^+$	$2816.67 \pm 0.31$	$2.43 \pm 0.26$	$\frac{3}{2}^-$
$\Xi_c(2815)^0$	$\Xi_c^0\pi^+\pi^-, \Xi_c(2645)^+\pi^-, \Xi_c^{\prime+}\pi^-$	$2820.22 \pm 0.32$	$2.54 \pm 0.25$	$\frac{3}{2}^-$
$\Xi_c(2930)^0$	$\Lambda_c^+K^-$	$2931 \pm 6$	$36 \pm 13$	
$\Xi_c(2970)^+$	$\Lambda_c^+K^-\pi^+, \Sigma_c^{++}K^-, \Xi_c(2645)^0\pi^+, \Xi_c^{\prime0}\pi^+$	$2969.4 \pm 0.8$	$20.9_{-3.5}^{+2.4}$	
$\Xi_c(2970)^0$	$\Xi_c(2645)^+\pi^-, \Xi_c^{\prime+}\pi^-$	$2967.8 \pm 0.8$	$28.1_{-4.0}^{+3.4}$	
$\Xi_c(3055)^+$	$\Sigma_c^{++}K^-, \Lambda D^+$	$3055.9 \pm 0.4$	$7.8 \pm 1.9$	
$\Xi_c(3055)^0$	$\Lambda D^0$	$3059.0 \pm 0.8$	$6.4 \pm 2.4$	
$\Xi_c(3080)^+$	$\Lambda_c^+K^-\pi^+, \Sigma_c^{++}K^-, \Sigma_c(2520)^{++}K^-, \Lambda D^+$	$3077.2 \pm 0.4$	$3.6 \pm 1.1$	
$\Xi_c(3080)^0$	$\Lambda_c^+K_S^0\pi^-, \Sigma_c^0K_S^0, \Sigma_c(2520)^0K_S^0$	$3079.9 \pm 1.4$	$5.6 \pm 2.2$	

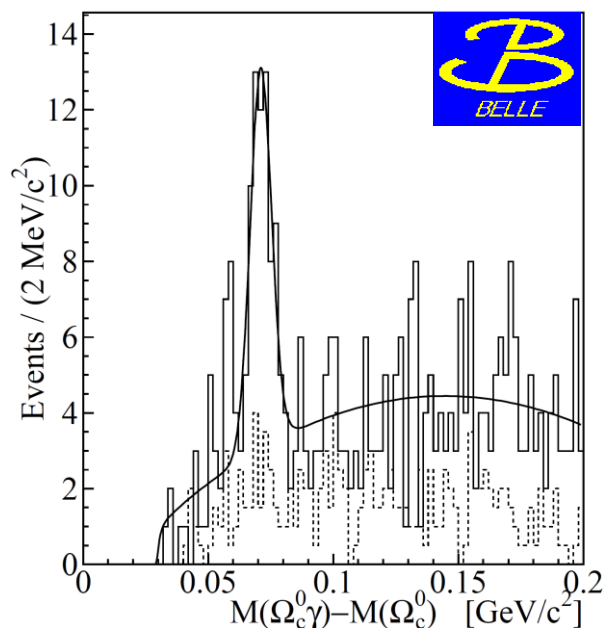
# $\Omega_c$ Family



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

[70.8 ± 1.0(stat.) ± 1.1(syst.)] MeV/c<sup>2</sup>

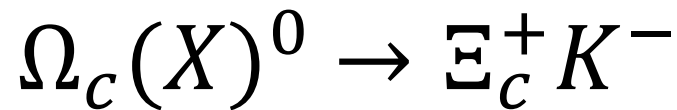
[B. Aubert *et al.* (BaBar Collaboration),  
Phys. Rev. Lett. **97**, 232001 (2006)]



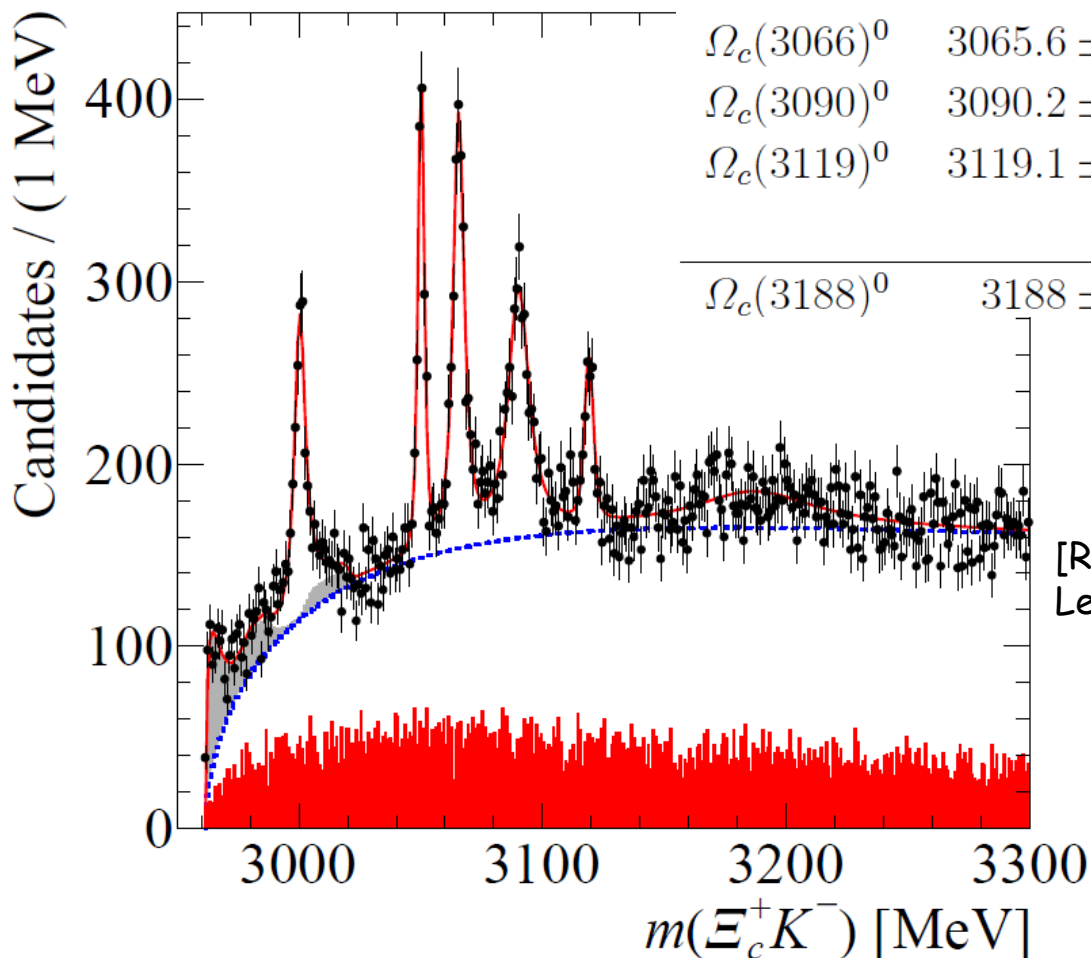
$$\Delta M_{\Omega_c^0} = \left[ 70.7 \pm 0.9(\text{stat.}) \begin{matrix} +0.1 \\ -0.9 \end{matrix} (\text{syst.}) \right] \text{ MeV}/c^2$$

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

# $\Omega_c$ Family



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

- Nature of the  $\Lambda_c(2765)$  state is still an open question.
- More accurate  $\Xi_c$  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 charmed and bottom baryons.
- Recently observed excited  $\Omega_c$  states present a unique opportunity to test and further improve theoretical models, that predict properties of heavy hadrons.
- 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.