

BESIII 实验上超子谱及超子衰变

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第十一届手征有效场论研讨会

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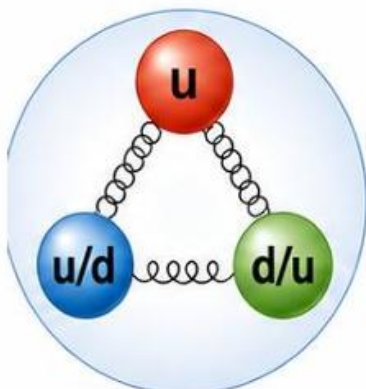
Outline

- **Introduction**
- **Excited hyperon states at BESIII**
 - Confirmation of $\Lambda(2325)$
 - Observation of new state $\Sigma(2330)$
 - Measurement of $\Xi(1690)$ & $\Xi(1820)$
 - Observation of New state $\Xi(1720)$
 - Observation of new state $\Omega(2109)$
 - New radiative decay modes of $\Lambda(1520)$ and $\Lambda(1670)$
- **Summary**

From Nucleons to SU(3) Flavor Sector

Nucleon sector (SU(2))

Nucleons (p, n)

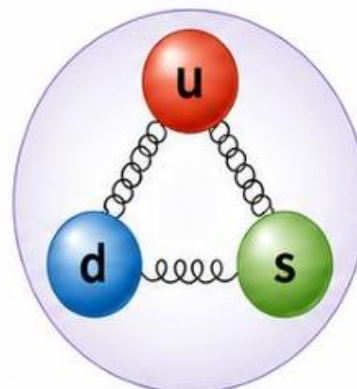


- Well-established spectrum
- Many states observed
- Quantum numbers relatively well determined

Extend to
SU(3) flavor
sector

Strange baryons (SU(3))

Hyperons (Λ , Σ , Ξ , Ω , ...)

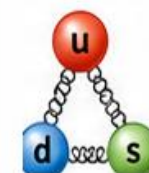


- Rich predicted spectrum
- Many states unobserved
- Quantum numbers & decays poorly determined

What we learn



Flavor
symmetry
breaking



Quark
dynamics

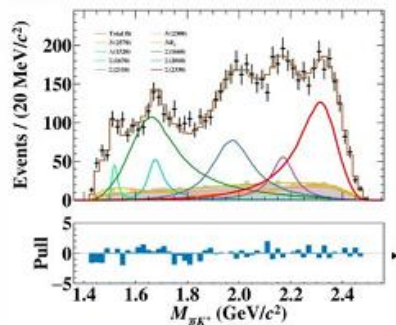


Baryon
structure



Strange baryons probe flavor-symmetry breaking and quark dynamics in the SU(3) sector.

Which excited states exist?



Mass spectrum

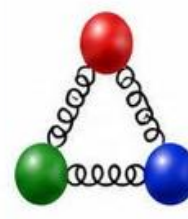


Missing states

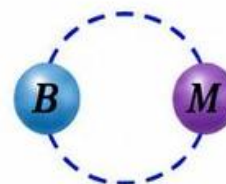
J^P
 $\frac{1}{2}^+, \frac{3}{2}^-,$
 $\frac{5}{2}^+, \frac{7}{2}^-, \dots$
Spin-parity J^P

- Many predicted hyperons remain unobserved
- Masses, widths, J^P and decay modes require PWA

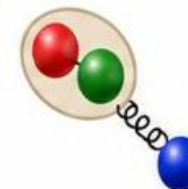
How are they structured?



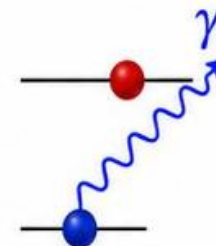
qqq core



meson-baryon
cloud



diquark
correlation



electromagnetic
transition

- Transition amplitudes probe wave functions
- Radiative decays test quark models and SU(3)



Spectroscopy + decays $\Rightarrow$ spectrum and internal structure

Status of excited Hyperons: Λ^* & Σ^*

9 four-star Λ^* , **5** four-star Σ^* , many states to be confirmed, measured, and observed. $\Lambda(1405)$ puzzle, $\Sigma(1385)$ and $\Sigma(1380)$

- Two-pole structure of $\Lambda(1405)$

Table 83.1: Comparison of the pole positions of $\Lambda(1405)$ in the complex energy plane from next-to-leading order chiral unitary coupled-channel approaches including the SIDDHARTA constraint. The lower two results also include the CLAS photoproduction data.

approach	pole 1 [MeV]	pole 2 [MeV]
Refs. [14, 15], NLO	$1424_{-23}^{+7} - i 26_{-14}^{+3}$	$1381_{-6}^{+18} - i 81_{-8}^{+19}$
Ref. [17], Fit II	$1421_{-2}^{+3} - i 19_{-5}^{+8}$	$1388_{-9}^{+9} - i 114_{-25}^{+24}$
Ref. [18], solution #2	$1434_{-2}^{+2} - i 10_{-1}^{+2}$	$1330_{-5}^{+4} - i 56_{-11}^{+17}$
Ref. [18], solution #4	$1429_{-7}^{+8} - i 12_{-3}^{+2}$	$1325_{-15}^{+15} - i 90_{-18}^{+12}$

- Pentaquark models predict a possible Σ^* around 1360MeV with $J^P=1/2^-$

- Evidences for $\Sigma(1380)$ @ BESIII

Phys. Rev. Lett. **134**, 021901

Table 82.1: The status of the Λ resonances. Only those with an overall status of *** or **** are included in the main Baryon Summary Table. Decay channels other than $N\bar{K}$ and $\Sigma\pi$ are only given for *** and **** resonances.

Particle	J^P	Overall status	Status as seen in —		
			$N\bar{K}$	$\Sigma\pi$	Other channels
$\Lambda(1116)$	$1/2^+$	****			$N\pi$ (weak decay)
$\Lambda(1380)$	$1/2^-$	**	**	**	
$\Lambda(1405)$	$1/2^-$	****	****	****	
$\Lambda(1520)$	$3/2^-$	****	****	****	$\Lambda\pi\pi, \Lambda\gamma, \Sigma\pi\pi$
$\Lambda(1600)$	$1/2^+$	****	***	****	$\Lambda\pi\pi, \Sigma(1385)\pi$
$\Lambda(1670)$	$1/2^-$	****	****	****	$\Lambda\eta$
$\Lambda(1690)$	$3/2^-$	****	****	***	$\Lambda\pi\pi, \Sigma(1385)\pi$
$\Lambda(1710)$	$1/2^+$	*	*	*	
$\Lambda(1800)$	$1/2^-$	***	***	**	$\Lambda\pi\pi, N\bar{K}^*$
$\Lambda(1810)$	$1/2^+$	***	**	**	$N\bar{K}^*$
$\Lambda(1820)$	$5/2^+$	****	****	****	$\Sigma(1385)\pi$
$\Lambda(1830)$	$5/2^-$	****	****	****	$\Sigma(1385)\pi$
$\Lambda(1890)$	$3/2^+$	****	****	**	$\Sigma(1385)\pi, N\bar{K}^*$
$\Lambda(2000)$	$1/2^-$	*	*	*	
$\Lambda(2050)$	$3/2^-$	*	*	*	
$\Lambda(2070)$	$3/2^+$	*	*	*	
$\Lambda(2080)$	$5/2^-$	*	*	*	
$\Lambda(2085)$	$7/2^+$	**	**	*	
$\Lambda(2100)$	$7/2^-$	****	****	**	$N\bar{K}^*$
$\Lambda(2110)$	$5/2^+$	***	**	**	$N\bar{K}^*$
$\Lambda(2325)$	$3/2^-$	*	*		
$\Lambda(2350)$	$9/2^+$	***	***	*	
$\Lambda(2585)$		*	*		

Table 82.2: The status of the Σ resonances. Only those with an overall status of *** or **** are included in the main Baryon Summary Table. Decay channels other than $N\bar{K}$, $\Lambda\pi$ and $\Sigma\pi$ are only given for *** and **** resonances.

Particle	J^P	Overall status	Status as seen in —			Other channels
			$N\bar{K}$	$\Lambda\pi$	$\Sigma\pi$	
$\Sigma(1193)$	$1/2^+$	****				$N\pi$ (weak decay)
$\Sigma(1385)$	$3/2^+$	****		****	****	$\Lambda\gamma$
$\Sigma(1580)$	$3/2^-$	*	*	*	*	
$\Sigma(1620)$	$1/2^-$	*	*	*	*	
$\Sigma(1660)$	$1/2^+$	***	***	***	***	
$\Sigma(1670)$	$3/2^-$	****	****	****	****	
$\Sigma(1750)$	$1/2^-$	***	***	**	***	$\Sigma\eta$
$\Sigma(1775)$	$5/2^-$	****	****	****	**	
$\Sigma(1780)$	$3/2^+$	*	*	*	*	
$\Sigma(1880)$	$1/2^+$	**	**	*	*	
$\Sigma(1900)$	$1/2^-$	**	**	*	**	
$\Sigma(1910)$	$3/2^-$	***	*	*	**	
$\Sigma(1915)$	$5/2^+$	****	***	***	***	
$\Sigma(1940)$	$3/2^+$	*	*	*	*	
$\Sigma(2010)$	$3/2^-$	*	*	*	*	
$\Sigma(2030)$	$7/2^+$	****	****	****	**	$\Delta(1232)\bar{K}, N\bar{K}^*, \Sigma(1385)\pi$
$\Sigma(2070)$	$5/2^+$	*	*	*	*	
$\Sigma(2080)$	$3/2^+$	*		*	*	
$\Sigma(2100)$	$7/2^-$	*	*	*	*	
$\Sigma(2110)$	$1/2^-$	*	*	*	*	
$\Sigma(2230)$	$3/2^+$	*	*	*	*	
$\Sigma(2250)$		**	**	*	*	
$\Sigma(2455)$		*	*			
$\Sigma(2620)$		*	*			
$\Sigma(3000)$		*	*	*		
$\Sigma(3170)$		*				

Status of excited Hyperons: Ξ^* & Ω^*

Even less information about Ξ^* . **Only 1** four-star Ξ^* well established, $\Xi(1530)$.

Table 1. Our estimate of the status of the Ξ resonances. Only those with an overall status of *** or **** are included in the Baryon Summary Table.

Particle	J^P	Overall status	Status as seen in —				
			$\Xi\pi$	ΛK	ΣK	$\Xi(1530)\pi$	Other channels
$\Xi(1318)$	1/2+	****					Decays weakly
$\Xi(1530)$	3/2+	****	****				
$\Xi(1620)$		**	**				
$\Xi(1690)$		***	**	***	**		
$\Xi(1820)$	3/2-	***	**	***	**	**	
$\Xi(1950)$		***	**	**		*	
$\Xi(2030)$		***		**	***		
$\Xi(2120)$		*		*			
$\Xi(2250)$		**					3-body decays
$\Xi(2370)$		**					3-body decays
$\Xi(2500)$		*		*	*		3-body decays

**** Existence is certain, and properties are at least fairly well explored.
 *** Existence ranges from very likely to certain, but further confirmation is desirable and/or quantum numbers, branching fractions, *etc.* are not well determined.
 ** Evidence of existence is only fair.
 * Evidence of existence is poor.

Few information about Ω^*

Ω BARYONS ($S = -3, I = 0$)		
$\Omega^- = s s s$		
Ω^-	3/2 ⁺	****
$\Omega(2012)^-$	? ⁻	***
$\Omega(2250)^-$		***
$\Omega(2380)^-$		**
$\Omega(2470)^-$		**

measurement of the mass, width and production of $\Xi(1820)$ need to be improved; spin-parity of $\Xi(1690)$ to be determined, the existence of $\Xi(1620)$ to be investigated, new states to be found...

BESIII: Hyperon Factory



10.1 billion J/ψ events



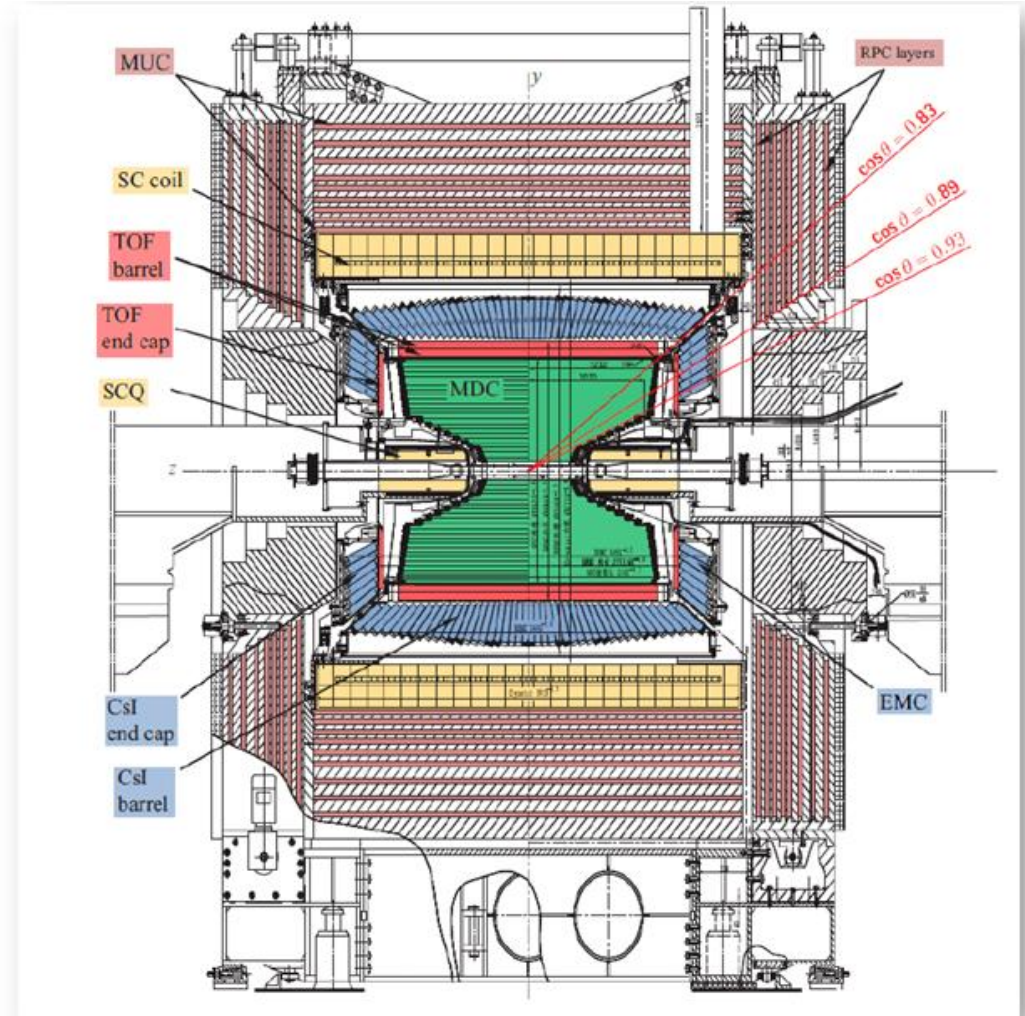
2.7 billion $\psi(3686)$ events



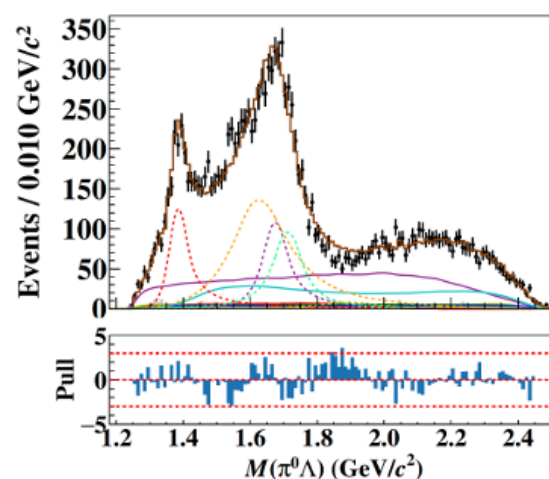
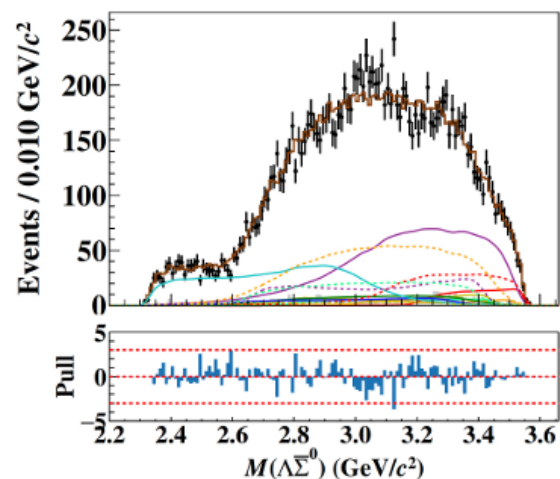
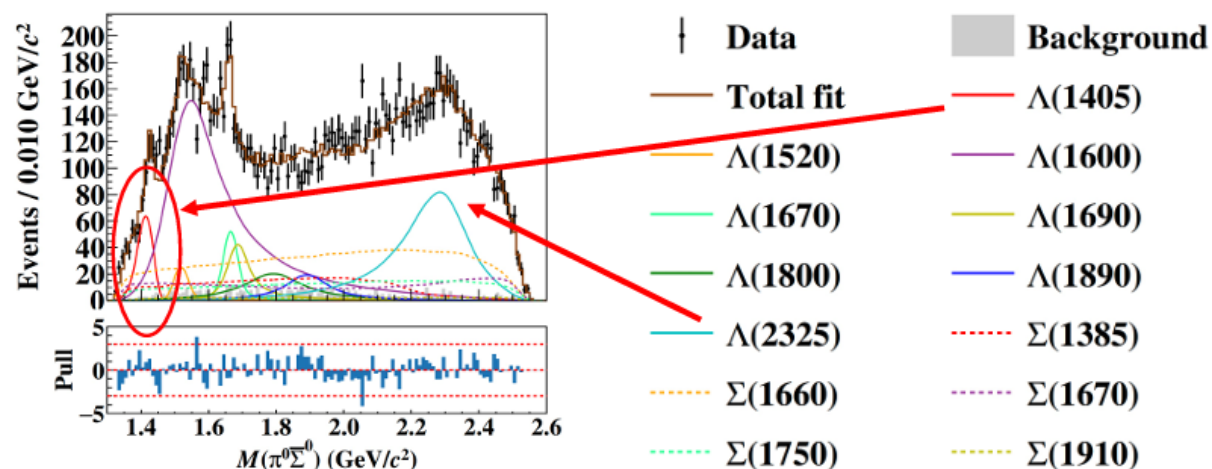
e^+e^- clean environment



Excellent tracking, PID
and photon detection



Large data samples enable rare channels and amplitude analyses.

Λ^* @ BESIII 272 M $\psi(3686)$ samplePartial wave analysis of $\psi(3686) \rightarrow \Lambda \bar{\Sigma}^0 \pi^0 + \text{c.c.}$ **Confirmation of $\Lambda(2325)$** 

Resonance	Mass (MeV/ c^2)	Width (MeV)	$\mathcal{B} (\times 10^{-5})$
$\Lambda(1405)$	...	...	$0.44 \pm 0.05 \pm 0.12$
$\Lambda(1520)$	$1519.9 \pm 1.6 \pm 4.8$	$20.6 \pm 1.9 \pm 0.6$	$0.19 \pm 0.05 \pm 0.05$
$\Lambda(1600)$	$1570.5 \pm 4.6 \pm 12.1$	$228.1 \pm 11.9 \pm 34.8$	$4.49 \pm 0.25 \pm 1.23$
$\Lambda(1670)$	$1667.5 \pm 2.3 \pm 3.6$	$30.2 \pm 4.2 \pm 8.7$	$0.33 \pm 0.07 \pm 0.09$
$\Lambda(1690)$	$1691.1 \pm 4.4 \pm 15.7$	$72.3 \pm 4.7 \pm 18.3$	$0.55 \pm 0.11 \pm 0.10$
$\Lambda(1800)$	$1800.9 \pm 13.3 \pm 12.6$	$208.8 \pm 14.5 \pm 36.7$	$0.60 \pm 0.15 \pm 0.18$
$\Lambda(1890)$	$1897.2 \pm 9.6 \pm 6.2$	$149.2 \pm 13.5 \pm 4.1$	$0.47 \pm 0.10 \pm 0.09$
$\Lambda(2325)$	$2306.5 \pm 6.3 \pm 17.1$	$227.1 \pm 12.2 \pm 47.8$	$2.93 \pm 0.20 \pm 0.26$
$\Sigma(1385)$	$1388.2 \pm 1.9 \pm 3.3$	$60.5 \pm 3.6 \pm 6.3$	$1.30 \pm 0.11 \pm 0.19$
$\Sigma(1660)$	$1643.2 \pm 4.5 \pm 7.6$	$221.3 \pm 13.1 \pm 41.1$	$3.53 \pm 0.29 \pm 0.63$
$\Sigma(1670)$	$1679.7 \pm 3.4 \pm 4.3$	$87.0 \pm 6.4 \pm 8.9$	$1.60 \pm 0.25 \pm 0.38$
$\Sigma(1750)$	$1714.9 \pm 4.2 \pm 7.3$	$97.2 \pm 9.8 \pm 9.7$	$1.39 \pm 0.23 \pm 0.32$
$\Sigma(1910)$	$1912.1 \pm 10.6 \pm 33.6$	$225.1 \pm 24.5 \pm 46.0$	$0.23 \pm 0.10 \pm 0.06$

- 13 resonances detected
- **Strong existence of $\Lambda(2325)$: $J^P = \frac{3}{2}^-$**
- Flatté-like and chiral dynamics model for $\Lambda(1405)$ dipole structure $\Rightarrow$ distinguishable due to the limited statistics

Σ^* @BESIII 272 M $\psi(3686)$ sample

Observation of a New Excited Σ State in $\psi(3686) \rightarrow \bar{p} K^+ \Sigma^0 + c. c.$

- PWA on 6100 ± 86 $\psi(3686) \rightarrow \bar{p} K^+ \Sigma^0 + c. c.$ events

- $\text{Br} = (2.44 \pm 0.20 \pm 0.08) \times 10^{-5}$
 or $(1.73 \pm 0.29 \pm 0.06) \times 10^{-5}$

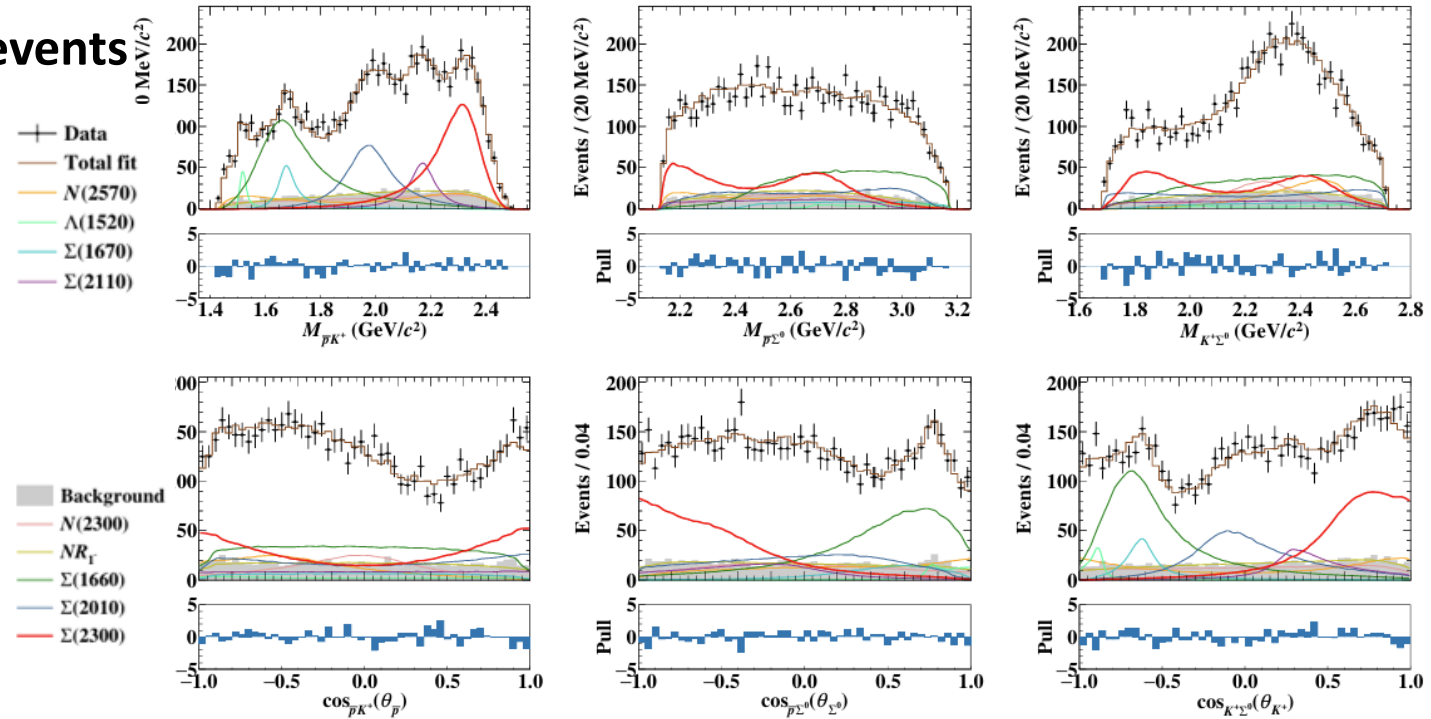
- N^* and Σ^* states are measured in PWA

- New excite state observed: $\Sigma(2330)$

- $m = 2334.7 \pm 7.9 \pm 16.0 \text{ MeV}/c^2$
- $\Gamma = 206.3 \pm 9.5 \pm 18.4 \text{ MeV}$
- $J^P = \frac{3}{2}^-$
- $\text{Br} = (4.47 \pm 0.58 \pm 1.52) \times 10^{-6}$
- Significance: 11.9σ
- Compatible with the [predicted \$1F\(3/2^-\)\$ state](#)

Significance of $\Sigma(2330)$ with different J^P hypotheses

J^P	ΔN_{LL}	ΔN_{dof}	S (σ)
$1/2^-$	20.1	6	5.1
$1/2^+$	48.9	6	8.9
$3/2^-$	85.7	8	11.9
$3/2^+$	71.2	8	10.7
$5/2^-$	74.1	8	11.0
$5/2^+$	53.7	8	9.1
$7/2^-$	44.3	8	8.0



Resonance	Mass (MeV/c^2)	Width (MeV)	$\mathcal{B} (\times 10^{-6})$
$N(2300)$	$2285.3 \pm 13.8 \pm 26.1$	$335.9 \pm 14.6 \pm 21.6$	$1.95 \pm 0.53 \pm 0.58$
$N(2570)$	$2577.9 \pm 14.8 \pm 33.2$	$255.1 \pm 14.6 \pm 19.7$	$2.28 \pm 0.53 \pm 0.67$
$\Lambda(1520)$	—	—	$0.49 \pm 0.10 \pm 0.14$
$\Sigma(1660)$	$1680.5 \pm 13.8 \pm 21.3$	$247.7 \pm 15.8 \pm 18.8$	$5.84 \pm 0.69 \pm 1.55$
$\Sigma(1670)$	$1680.5 \pm 4.1 \pm 11.0$	$73.4 \pm 9.1 \pm 7.1$	$1.22 \pm 0.38 \pm 0.28$
$\Sigma(2010)$	$1980.1 \pm 10.0 \pm 18.1$	$192.5 \pm 13.3 \pm 13.3$	$3.11 \pm 0.50 \pm 0.92$
$\Sigma(2110)$	$2172.4 \pm 6.3 \pm 10.9$	$107.2 \pm 9.3 \pm 10.2$	$1.17 \pm 0.23 \pm 0.38$
$\Sigma(2330)$	$2334.7 \pm 7.9 \pm 16.0$	$206.3 \pm 9.5 \pm 18.4$	$4.47 \pm 0.58 \pm 1.52$

Ξ^* @BESIII 448M $\psi(3686)$ events

Study of excited Ξ states in $\psi(3686) \rightarrow K^- \Lambda \Xi^+ + c.c.$

- PWA of $\psi(3686) \rightarrow K^- \Lambda \Xi^+ + c.c.$ 1572 $\pm$ 45 events
- 1st PWA on Ξ^* states
- 1st measurement of J^P of $\Xi(1690)$ & $\Xi(1820)$
- Learn more about the excited hyperon spectrum.

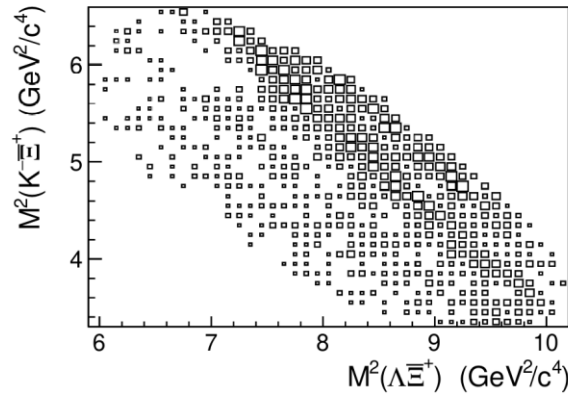
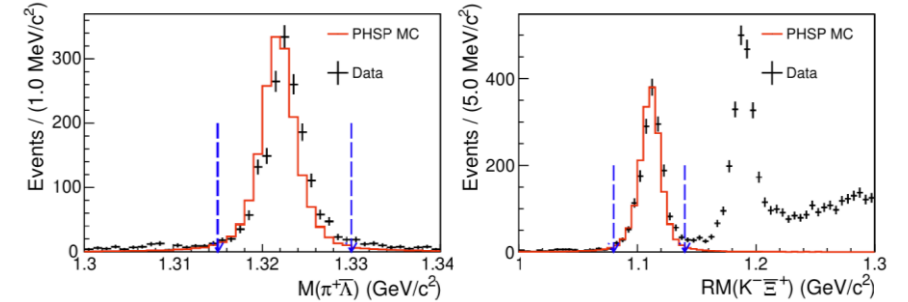


TABLE VI. Results obtained for $I(J^P)$, mass and width for each component. The first (second) uncertainty is statistical (systematic).

Resonance	$I(J^P)$	M (MeV/ c^2)	Γ (MeV)
$\Xi(1690)^-$	$1/2(1/2^-)$	$1685_{-2}^{+3} \pm 12$	$81_{-9}^{+10} \pm 20$
$\Xi(1820)^-$	$1/2(3/2^-)$	$1821_{-3}^{+2} \pm 3$	$73_{-5}^{+6} \pm 9$

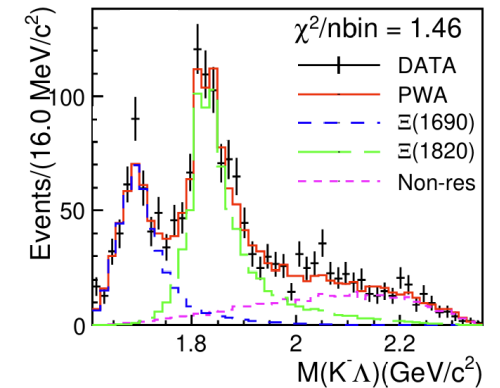
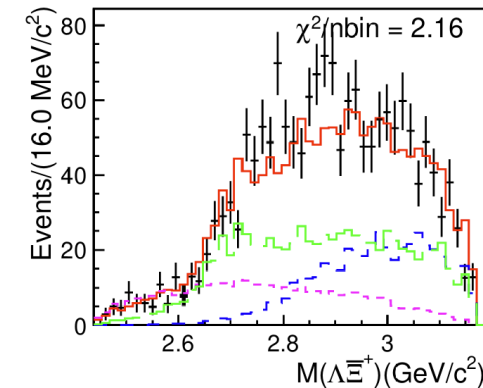
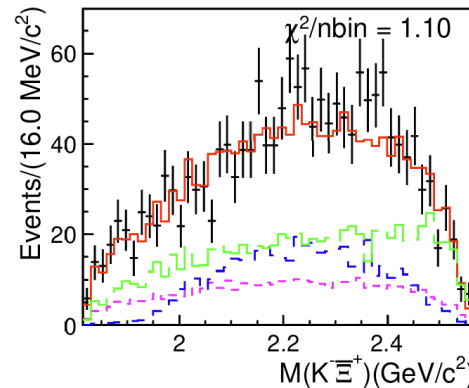
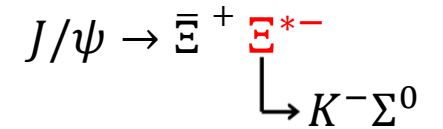


TABLE VII. Branching fraction results; the first (second) uncertainty is statistical (systematic).

Resonance	Branching fraction
$\mathcal{B}(\psi(3686) \rightarrow \Xi(1690)^- \Xi^+ + c.c.) \times \mathcal{B}(\Xi(1690)^- \rightarrow K^- \Lambda)$	$(1.06 \pm 0.10 \pm 0.31) \times 10^{-5}$
$\mathcal{B}(\psi(3686) \rightarrow \Xi(1820)^- \Xi^+ + c.c.) \times \mathcal{B}(\Xi(1820)^- \rightarrow K^- \Lambda)$	$(1.78 \pm 0.10 \pm 0.32) \times 10^{-5}$
$\psi(3686) \rightarrow K^- \Lambda \Xi^+ + c.c.$	$(3.60 \pm 0.10 \pm 0.24) \times 10^{-5}$

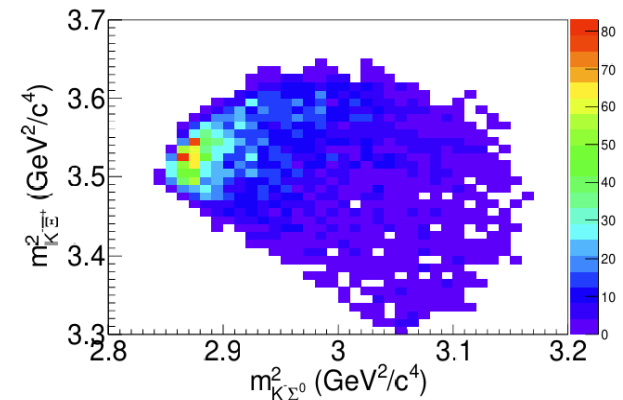
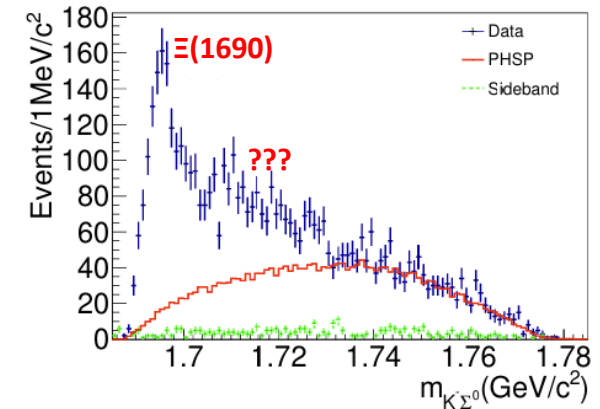
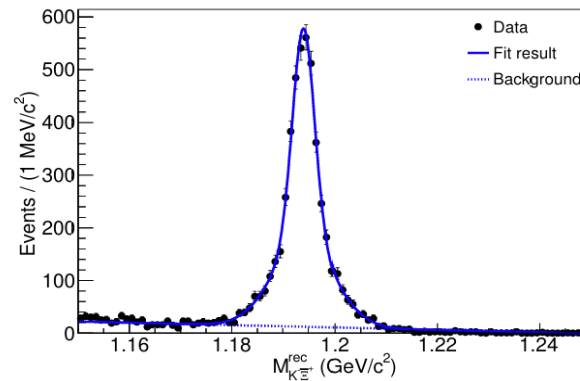
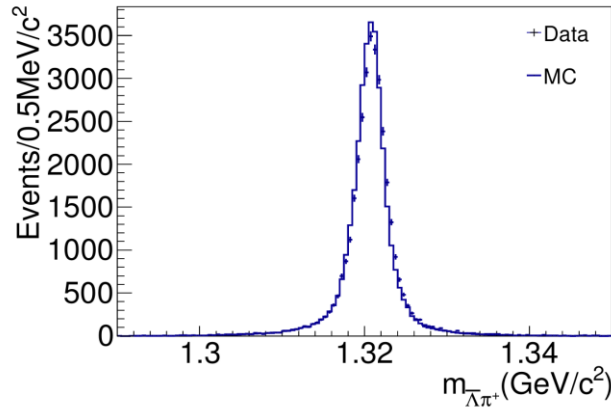
Ξ^* @ BESIII 10087 M J/ψ sample

Observation of a Doubly-strange Hyperon $\Xi(1720)$ in $J/\psi \rightarrow K^- \Sigma^0 \bar{\Xi}^+ + c.c.$



- **1st observation** of the decay $J/\psi \rightarrow K^- \Sigma^0 \bar{\Xi}^+ + c.c..$ with Significant **excited states**.

4545 $\pm$ 73 events



$$Br(J/\psi \rightarrow K^- \Sigma^0 \bar{\Xi}^+ + c.c.) = (2.68 \pm 0.04 \pm 0.17) \times 10^{-5}$$

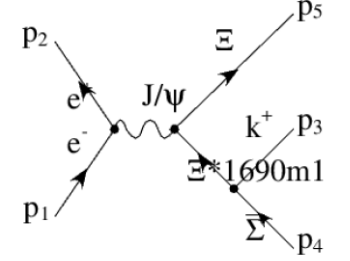
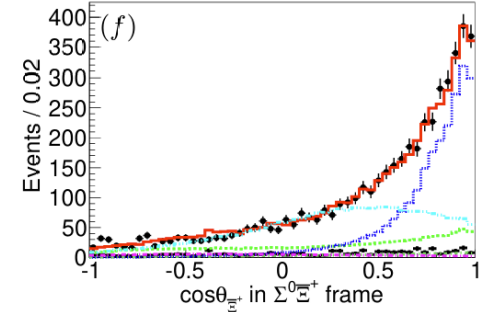
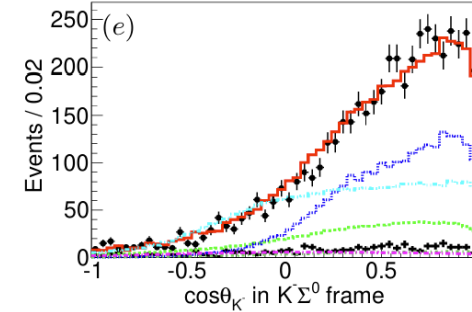
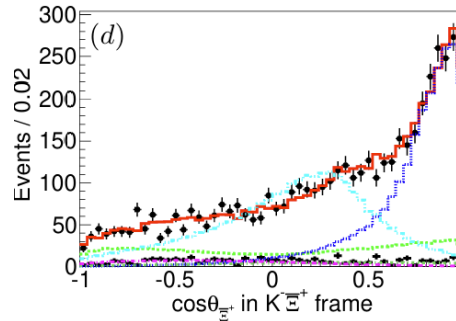
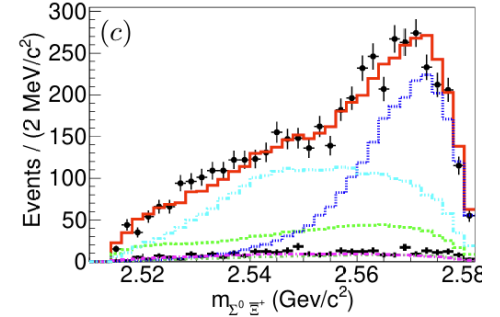
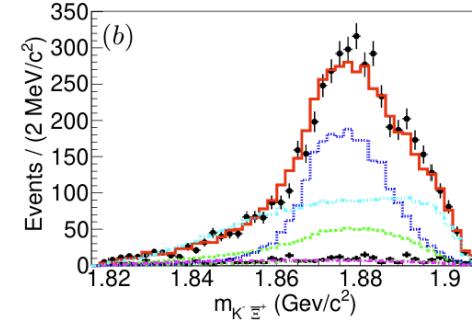
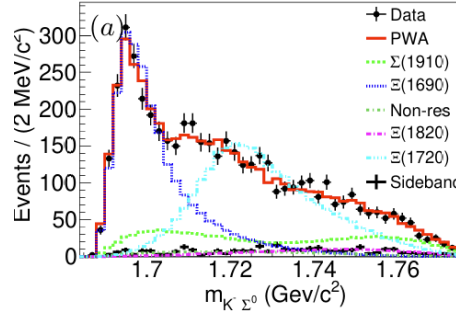
Partial Wave Analysis result

- Precise measurement of $\Xi(1690)$

- $m = 1695 \pm 0.9 \pm 0.9 \text{ MeV}/c^2$
- $\Gamma = 12.8 \pm 1.8 \pm 7.6 \text{ MeV}$
- $J^P = \frac{1}{2}^-$
- $\text{Br} = (1.86 \pm 0.54 \pm 0.68) \times 10^{-5}$

- New doubly-strange hyperon $\Xi(1720)$

- $m = 1721 \pm 5.2 \pm 3.4 \text{ MeV}/c^2$
- $\Gamma = 31.3 \pm 18.3 \pm 15.4 \text{ MeV}$
- $J^P = \frac{3}{2}^+$
- $\text{Br} = (1.22 \pm 0.42 \pm 0.83) \times 10^{-5}$
- Significance: $>10\sigma$
- $\sim 200 \text{ MeV}/c^2$ below the lowest $\frac{3}{2}^+$ state predicted by models



J^P	$\frac{1}{2}^-$	$\frac{1}{2}^+$	$\frac{3}{2}^-$	$\frac{3}{2}^+$
ΔS for $\Xi(1690)$	-	76	333	85
ΔS for $\Xi(1720)$	59	57	71	-

Ω^* @BESIII 4.13-4.70 GeV 19 fb⁻¹

Evidence for Two Excited Ω^- Hyperons

- **New state observed: $\Omega(2109)^-$**

with a significance of **4.1σ**

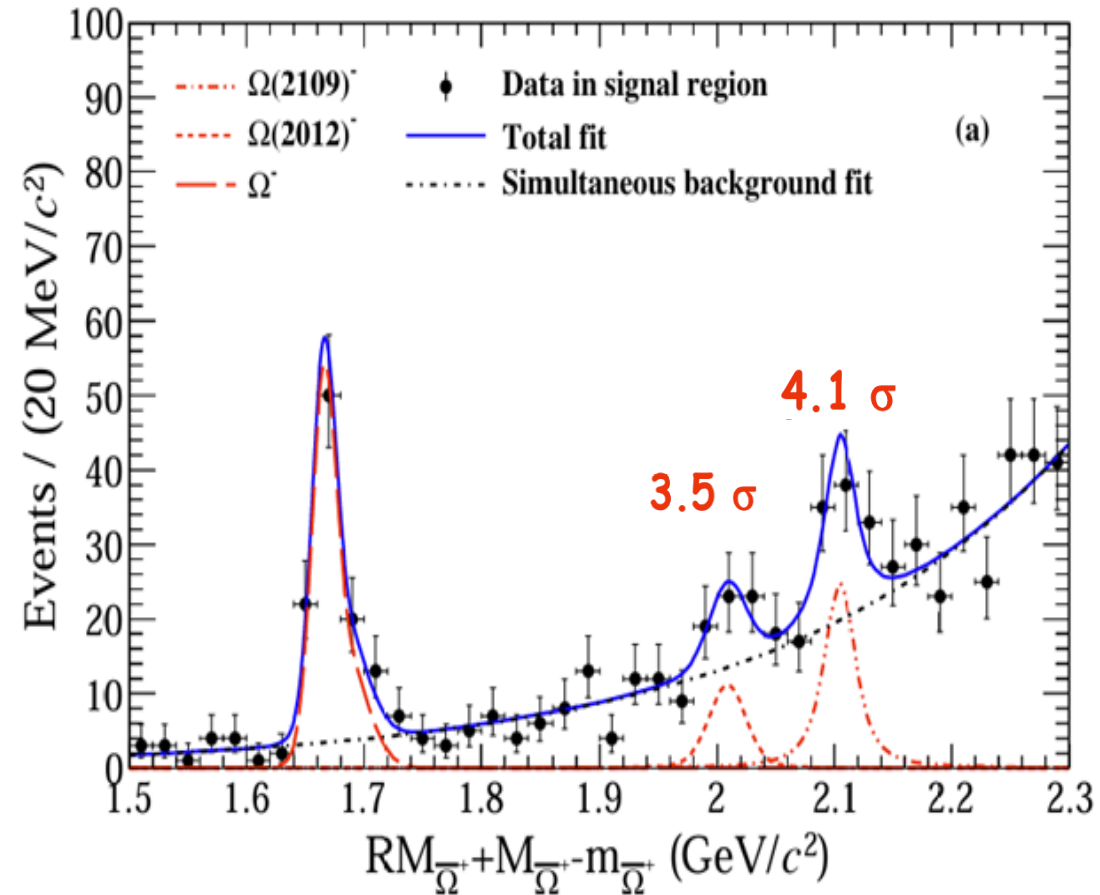
mass : $2108.5 \pm 5.2_{\text{stat}} \pm 0.9_{\text{syst}} \text{ MeV}/c^2$

width: $18.3 \pm 16.4_{\text{stat}} \pm 5.7_{\text{syst}} \text{ MeV}$

- **New production mechanism of $\Omega(2012)^-$**

with a significance of **3.5σ**

$$e^+e^- \rightarrow \Omega(2109)^- \bar{\Omega}^+$$

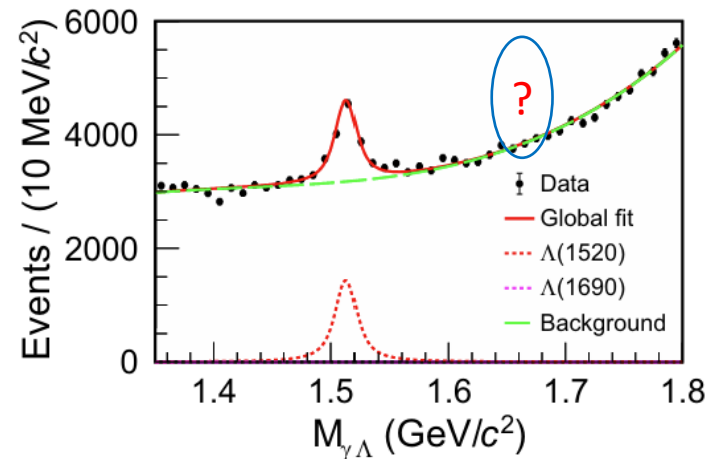


Radiative decays of Λ^* @BESIII 10087 M J/ψ sample

Observation of the Electromagnetic Radiative Decays of the $\Lambda(1520)$ and $\Lambda(1690)$ to $\gamma\Sigma^0$

Study resonant structure in $J/\psi \rightarrow \gamma\Lambda\bar{\Lambda}$ and $\gamma\bar{\Lambda}\Sigma^0$

- $\Lambda(1520) \rightarrow \gamma\Lambda$
4043 $\pm$ 247 events

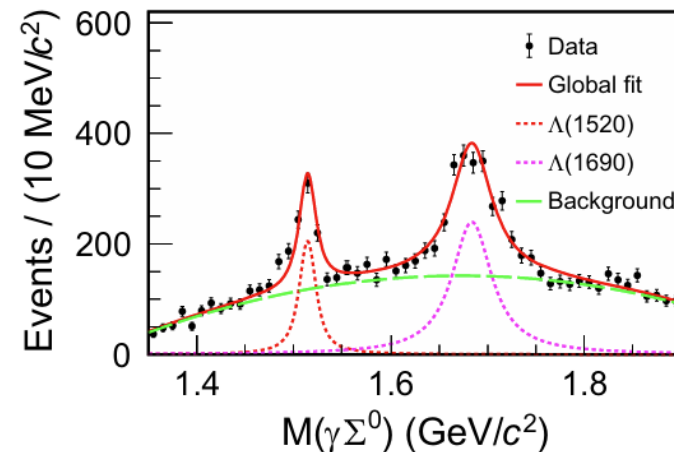


- $\Lambda(1690) \rightarrow \gamma\Lambda$?
No signal observed!

- $\Lambda(1520) \rightarrow \gamma\Sigma^0$ **First Observation**
621 $\pm$ 53 events

$$\Gamma(\Lambda(1520) \rightarrow \gamma\Sigma^0)$$

$$= (46.8 \pm 6.6(\text{stat.}) \pm 9.3(\text{syst.})) \text{ keV}$$



- $\Lambda(1690) \rightarrow \gamma\Sigma^0$ **First Observation**
1754 $\pm$ 122 events

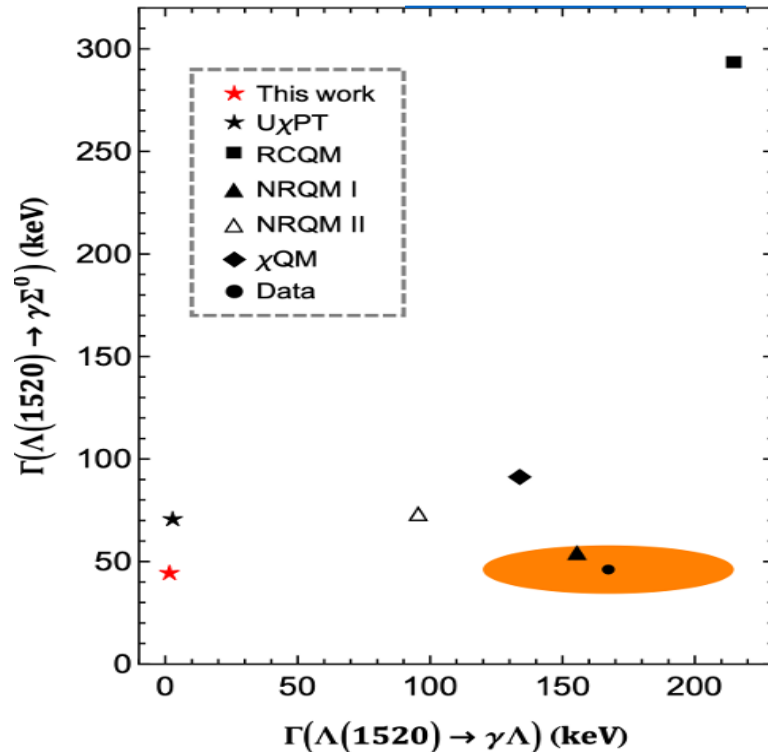
Deviation from theoretical predictions

$$\mathcal{R} \equiv \frac{\mathcal{B}(\Lambda(1520) \rightarrow \gamma \Lambda)}{\mathcal{B}(\Lambda(1520) \rightarrow \gamma \Sigma^0)} = 3.19 \pm 0.34(\text{stat.}) \pm 0.19(\text{syst.})$$

$\sim 7\sigma$ larger than the SU(3) prediction

$$\mathcal{R} \equiv \frac{\mathcal{B}(\Lambda(1520) \rightarrow \gamma \Lambda)}{\mathcal{B}(\Lambda(1520) \rightarrow \gamma \Sigma^0)} \approx 0.3$$

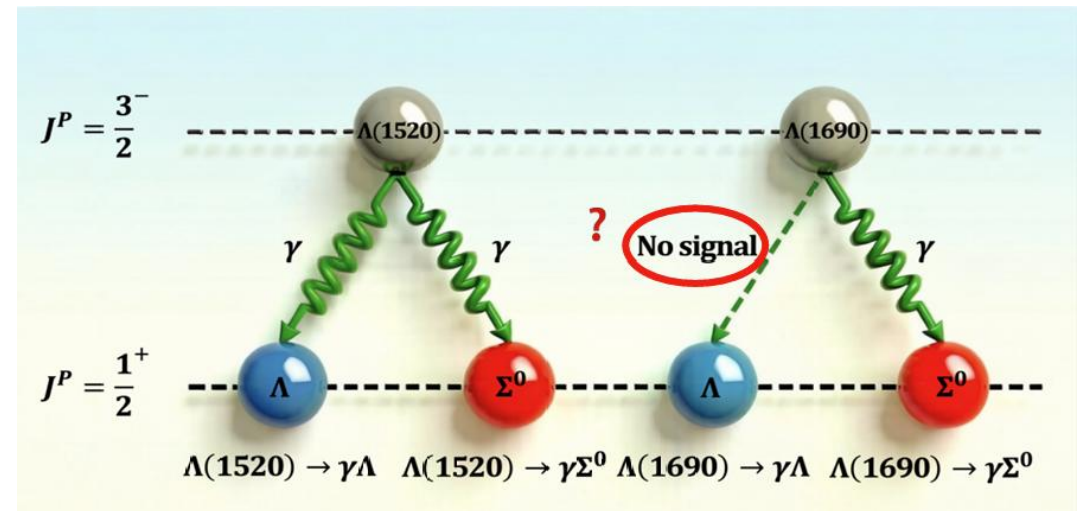
[arXiv:2605.14946](https://arxiv.org/abs/2605.14946)



$$\mathcal{B}(J/\psi \rightarrow \bar{\Lambda} \Lambda(1690)) \times \mathcal{B}(\Lambda(1690) \rightarrow \gamma \Sigma^0) = (6.05 \pm 0.42(\text{stat.}) \pm 0.39(\text{syst.})) \times 10^{-6}$$

$$\mathcal{B}(J/\psi \rightarrow \bar{\Lambda} \Lambda(1690)) \times \mathcal{B}(\Lambda(1690) \rightarrow \gamma \Lambda) < 5.08 \times 10^{-7} \quad (90\% \text{ C.L.})$$

$$\mathcal{R} \equiv \frac{\mathcal{B}(\Lambda(1690) \rightarrow \gamma \Lambda)}{\mathcal{B}(\Lambda(1690) \rightarrow \gamma \Sigma^0)} < 0.08 \quad (90\% \text{ C.L.})$$



summary

- excited hyperon states have been observed and measured @BESIII
 - 1 one* state confirmed: $\Lambda(2325)$
 - 3 new states observed: $\Sigma(2300)$, $\Xi(1720)$, $\Omega(2109)$
 - some states measured...
- New Radiative decays observed in $J/\psi \rightarrow \gamma \Lambda \bar{\Lambda}$ and $\gamma \bar{\Lambda} \Sigma^0$
1st observation of $\Lambda(1520) \rightarrow \gamma \Sigma^0$ and $\Lambda(1690) \rightarrow \gamma \Sigma^0$
- More analysis on excited hyperon states in progress...
new states, new decays, confirmation, precise measurement...

Thank you for your attention!