

# The $\Xi(1820)$ resonance, one or two poles?

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## Introduction

- Two pole structures
- The  $\Xi(1820)$

## Formalism

- Meson-baryon decuplet interaction

## Results

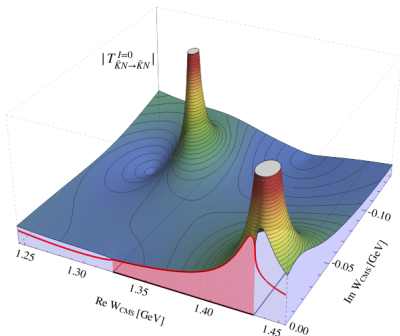
- Reaction mechanisms to detect the two-pole

## Conclusions

# Two pole structures



$\Lambda(1405)$



2nd Riemann Sheet

$$\frac{1}{\sqrt{s} - M_R + i\Gamma/2}$$

$$\Gamma/2 = \beta p$$

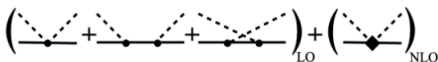
$$\sqrt{s} = a + ib$$

$$\frac{1}{a - M_R + ib + i\beta p}$$

Change  $p \rightarrow -p$   
gives a solution

Figure taken from Review of the  $\Lambda(1405)$ , Mai (2020)

$\pi\Sigma, \bar{K}N$



# Two pole structures

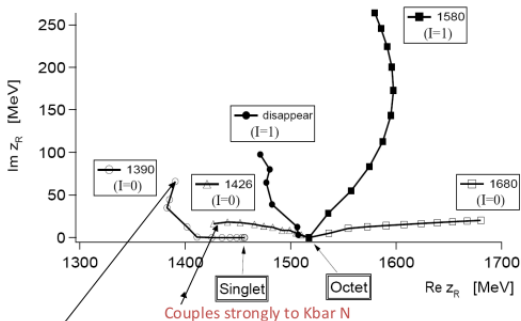


Poles of  $S=-1$   $J^P=1/2^-$  Resonances

$$8 \otimes 8 = 1 \oplus 8_s \oplus 8_a \oplus 10 \oplus \overline{10} \oplus 27$$

Jido, Oller, Oset, Ramos, Meissner NPA03

$$\begin{aligned} M_i(x) &= M_0 + x(M_i - M_0), \\ m_i^2(x) &= m_0^2 + x(m_i^2 - m_0^2), \\ a_i(x) &= a_0 + x(a_i - a_0), \end{aligned} \quad x \in [0,1]$$



Couples strongly to pi Sigma

Update with LQCD data, Zhuang, Molina, Lu, Geng, 2405.07686 (2024)



- ▶ At LO the interaction is diagonal  $V_{\alpha\beta} = -\frac{1}{4f^2} C_{\alpha\beta} (k^0 + k'^0)$ .

$$V_{\alpha\beta} = \text{diag}(6, 3, 3, 0, 0, -2) \quad \alpha, \beta = 1, 8, 8', 10, \bar{10}, 27 \quad (1)$$

- ▶ At NLO the accidental symmetry of the two octets is slightly broken ( $\Delta M_8 \simeq 15$  MeV) [Guo, Kamiya, Mai, Meissner PLB23](#)
- ▶ The most important features obtained at LO remain at NNLO.  
(LO) [Jido, Oller, Oset, Ramos, Meissner NPA03](#)  
(NNLO) [Lu, Geng, Doering, Mai PRL23](#)

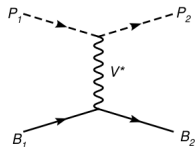
$$(LO) \quad \sqrt{s_0} : 1390 - i66, \quad 1426 - i16$$

$$(NNLO) \quad \sqrt{s_0} : 1392 \pm 8 - i(100 \pm 15), \quad 1425 \pm 1 - i(13 \pm 4)$$

## Weinberg-Tomozawa dominates

BaSc, PRL132 (2024)

Talk of Z. Zhuang on Thursday 5.35pm, 2405.07686 (2024)



# The $\Xi(1820)$



Other two-pole states:  $K_1(1270)$ ,  $D^*(2400)$ ,  $Y(4260)$ ...

## New results from BESIII One or two poles?

Ablikim, PRD109 (2024)

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

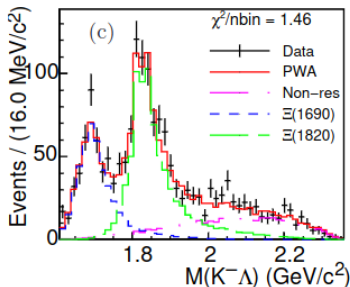
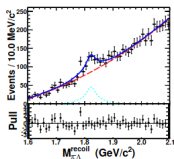
Resonance	$I(J^P)$	M (MeV/ $c^2$ )	$\Gamma$ (MeV)
$\Xi(1690)^-$	$1/2(1/2^-)$	$1685^{+3}_{-2} \pm 12$	$81^{+10}_{-9} \pm 20$
$\Xi(1820)^-$	$1/2(3/2^-)$	$1821^{+3}_{-3} \pm 3$	$73^{+6}_{-5} \pm 9$

$$\psi(3686) \rightarrow K^- \Lambda \Xi^+$$

PDG average:

$$M = 1823 \pm 5, \Gamma = 24^{+15}_{-10}$$

$e^+e^- \rightarrow \Xi(1820)^- \Xi^+$  **BESIII, PRL20**



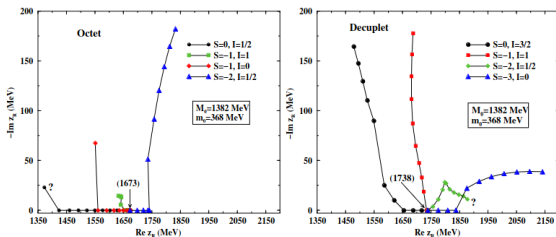


## Sarkar, Oset, Vicente-Vacas, NPA05

### Extension of the $\Lambda(1405)$ work to the decuplet of baryons

$z_R$	1863 - $i14(x = 0.9)$		1832 - $i182$		1920 - $i137$		2162 - $i19$	
	$g_i$	$ g_i $	$g_i$	$ g_i $	$g_i$	$ g_i $	$g_i$	$ g_i $
$\Sigma^* \bar{K}$	$1.9 + i0.7$	2.0	$1.8 - i1.1$	2.1	$1.1 + i0.1$	1.1	$0.3 - i0.4$	0.5
$\Xi^* \pi$	$0.5 + i0.9$	1.1	$2.3 - i1.8$	2.9	$1.1 - i1.7$	2.0	$0.2 + i0.7$	0.7
$\Xi^* \eta$	$2.5 + i0.2$	2.6	$1.4 + i1.3$	1.9	$3.5 + i1.7$	3.8	$0.4 - i0.3$	0.5
$\Omega K$	$0.1 - i0.7$	0.7	$2.3 - i0.9$	2.4	$1.6 - i0.4$	1.7	$2.1 + i0.9$	2.3

Table 13: Couplings of the resonances with  $S = -2$  and  $I = \frac{1}{2}$  to various channels. Note that the couplings for the 1877 MeV resonance are evaluated at  $x = 0.9$ .



$$10 \otimes 8 = 8 \oplus 10 \oplus 27 \oplus 35 \quad C_{\alpha\beta} = \text{diag}(6, 3, 1, -3) \quad (a = -2)$$

# Meson-baryon decuplet interaction



## Jenkins, Manohar PLB91

$$\mathcal{L} = -i\bar{T}^\mu \not{\partial} T_\mu, \quad T^\mu \text{ is the spin decuplet field} \quad (2)$$

$$\text{and } \mathcal{D}^\nu T_{abc}^\mu = \partial^\nu T_{abc}^\mu + (\Gamma^\nu)_a^d T_{dbc}^\mu + (\Gamma^\nu)_b^d T_{adc}^\mu + (\Gamma^\nu)_c^d T_{abd}^\mu.$$

$$\Gamma^\nu = \frac{1}{2}(\xi \partial^\nu \xi^\dagger + \xi^\dagger \partial^\nu \xi), \quad \xi^2 = U = e^{i\sqrt{2}\Phi/f} \quad (3)$$

$$V_{ij} = -\frac{1}{4f^2} C_{ij}(k^0 + k'^0),$$

$$T = [1 - VG]^{-1} V$$

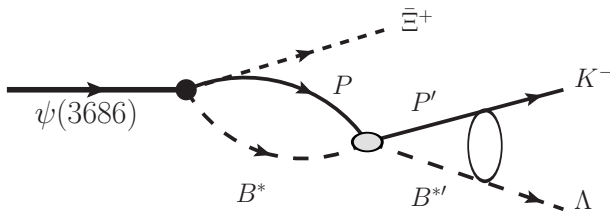
$C_{ij}$	$\Sigma^* \bar{K}$	$\Xi^* \pi$	$\Xi^* \eta$	$\Omega K$
$\Sigma^* \bar{K}$	2	1	3	0
$\Xi^* \pi$		2	0	$\frac{3}{\sqrt{2}}$
$\Xi^* \eta$			0	$\frac{3}{\sqrt{2}}$
$\Omega K$				3



# Production of the $\Xi(1820)$ state



$$\psi(3686) \rightarrow \Xi(1820)\bar{\Xi}^+ \rightarrow K^- \Lambda \bar{\Xi}^+$$



$$t = \sum_j A_j \vec{\epsilon}_\psi \cdot \vec{p}_{\Xi} G_j(PB^*) T_{ji} C_i \tilde{k}^2 \sim \sum_{ij} D_{ij} \tilde{k}^2 \vec{\epsilon}_\psi \cdot \vec{p}_{\Xi} T_{ji}$$

$$G(s) = 2m_1 \int_0^{q_{\max}} \frac{d^3q}{(2\pi)^3} \frac{\omega_1(q) + \omega_2(q)}{2\omega_1(q)\omega_2(q)} \frac{1}{s - (\omega_1(q) + \omega_2(q))^2 + i\epsilon}$$

# Production of the $\Xi(1820)$ state



$$\frac{d\Gamma}{dM_{\text{inv}}(K^-\Lambda)} = \frac{1}{(2\pi)^3} \frac{1}{4M_\psi^2} p_\Xi \tilde{k} \sum \sum |t|^2 = W p_\Xi^3 \tilde{k}^5 \sum_{ij} |D_{ij} T_{ji}|^2$$

$W$  arbitrary weight

$$\tilde{k} = \frac{\lambda^{1/2}(M_{\text{inv}}^2, m_K^2, m_\Lambda^2)}{2M_{\text{inv}}}$$

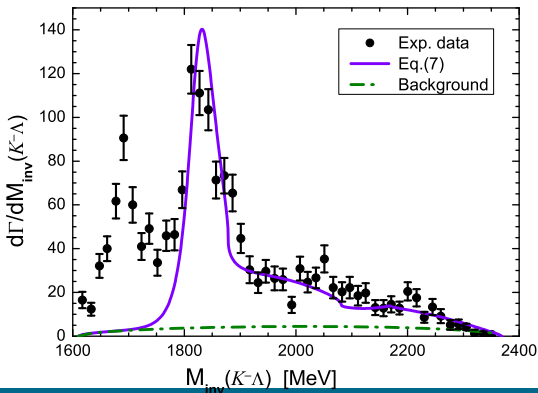
Background:

$$C p_\Xi \tilde{k}$$

Exp. data BESIII

2308.15206 (2023)

$T_{33} (\Xi^* \eta)$



# The two-pole of the $\Xi(1820)$



Poles	$ g_i $	$g_i$	channels
$1824 - 31i$	3.22	$3.22 - 0.096i$	$\bar{K}\Sigma^*$
	1.71	$1.55 + 0.73i$	$\pi\Xi^*$
	2.61	$2.58 - 0.38i$	$\eta\Xi^*$
	1.62	$1.47 + 0.67i$	$K\Omega$
$1875 - 130i$	2.13	$0.29 + 2.11i$	$\bar{K}\Sigma^*$
	3.04	$-2.07 + 2.23i$	$\pi\Xi^*$
	2.20	$1.11 + 1.90i$	$\eta\Xi^*$
	3.03	$-1.77 + 2.45i$	$K\Omega$

$$q_{\text{max}} = 830 \text{ MeV}, f = 1.28f_{\pi}$$

# The two-pole of the $\Xi(1820)$



$$T = \frac{A}{M_{\text{inv}} - M_{R_1} + i\frac{\Gamma_1}{2}} + \frac{B}{M_{\text{inv}} - M_{R_2} + i\frac{\Gamma_2}{2}}, \quad (4)$$

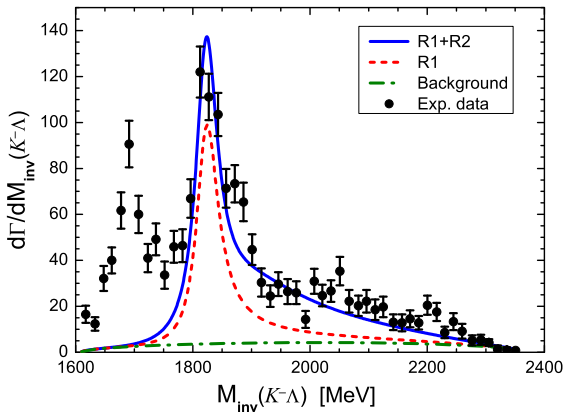
## Poles

$$M_{R_1} = 1822 \text{ MeV}$$

$$\Gamma_1 = 45 \text{ MeV}$$

$$M_{R_2} = 1870 \text{ MeV}$$

$$\Gamma_2 = 200 \text{ MeV}$$



# Reaction mechanisms to detect the two-pole

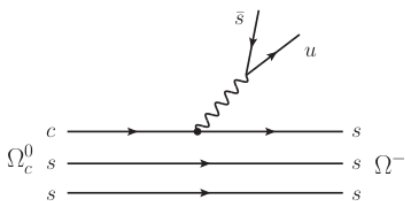


We have investigated the reactions:

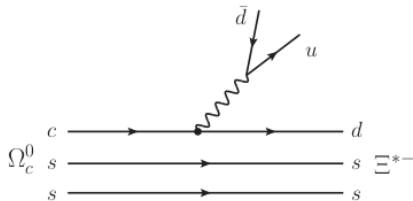
$$\Omega_c \rightarrow \pi^+ \Xi(1820) \rightarrow \pi^+ \pi^0 \Xi^{*-} (\pi^- \Xi^{*0}),$$

$$\Omega_c \rightarrow \pi^0 \Xi(1820) \rightarrow \pi^0 \pi^+ \Xi^{*-} (\pi^0 \Xi^{*0}),$$

$$\Omega_c \rightarrow \eta \Xi(1820) \rightarrow \eta \pi^+ \Xi^{*-} (\pi^0 \Xi^{*0}).$$



(a)

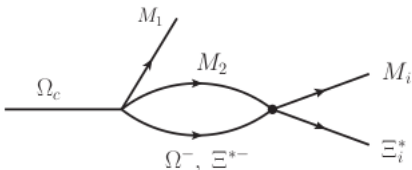


(b)

**Single cabibbo suppress**  $\sim \cos \theta_c \sin \theta_c$



Reaction  $\Omega_c \rightarrow M_1 M_i \Xi^*$



## Hadronization

$$u\bar{s} \rightarrow \sum_i u\bar{q}_i q_i \bar{s} = P_{1i} P_{i3} = (P^2)_{13}$$

$$= \left( \frac{\pi^0}{\sqrt{2}} + \frac{\eta}{\sqrt{3}} \right) K^+ + \pi^+ K^0 - \frac{1}{\sqrt{3}} K^+ \eta.$$

$$u\bar{d} \rightarrow \sum_i u\bar{q}_i q_i \bar{d} = P_{1i} P_{i2} = (P^2)_{12}$$

$$= \left( \frac{\pi^0}{\sqrt{2}} + \frac{\eta}{\sqrt{3}} \right) \pi^+ + \pi^+ \left( -\frac{\pi^0}{\sqrt{2}} + \frac{\eta}{\sqrt{3}} \right) + K^+ \bar{K}^0.$$

$$P = \begin{pmatrix} \frac{\pi^0}{\sqrt{2}} + \frac{\eta}{\sqrt{3}} & \pi^+ & K^+ \\ \pi^- & -\frac{\pi^0}{\sqrt{2}} + \frac{\eta}{\sqrt{3}} & K^0 \\ K^- & \bar{K}^0 & -\frac{\eta}{\sqrt{3}} \end{pmatrix}$$



## Weak vertices

$$W^+ PP: \langle [P, \partial_\mu P] W^\mu T_- \rangle$$

Gasser&Leutwyler, Ann84

$$c\bar{S}W : \sim \gamma^\mu (1 - \gamma_5)$$

## Weak transition:

$$\langle \Omega^- (\Xi^{*-}) | \vec{S}^+ \cdot (\vec{p}_1 - \vec{p}_2) | \Omega_c^0 \rangle$$

$$1) \Omega_c^0 \rightarrow \pi^+ \pi^0 \Xi^{*-}$$

$$t_{1a} = C \langle \Omega^- | \vec{S}^+ \cdot \vec{p}_{\pi^+} | \Omega_c^0 \rangle t'_{1a}$$

$$t'_{1a} = G_{K^0 \Omega^-} (W) t_{K^0 \Omega^-, \pi^0 \Xi^{*-}} (W),$$

$$t_{1b} = C \langle \Xi^{*-} | \vec{S}^+ \cdot \vec{p}_{\pi^+} | \Omega_c^0 \rangle t'_{1b}$$

$$t'_{1b} = -\sqrt{\frac{2}{3}} [1 + G_{\pi^0 \Xi^{*-}} (W) t_{\pi^0 \Xi^{*-}, \pi^0 \Xi^{*-}} (W)], \quad W = M_{\text{inv}} (\pi^0 \Xi^{*-})$$

## Amplitude structure

$$\int_{|\vec{p}_2| < q_{\text{max}}} \frac{d^3 p_2}{(2\pi)^3} \langle \Omega^- | \vec{S}^+ \cdot (\vec{p}_1 - \vec{p}_2) | \Omega_c^0 \rangle$$

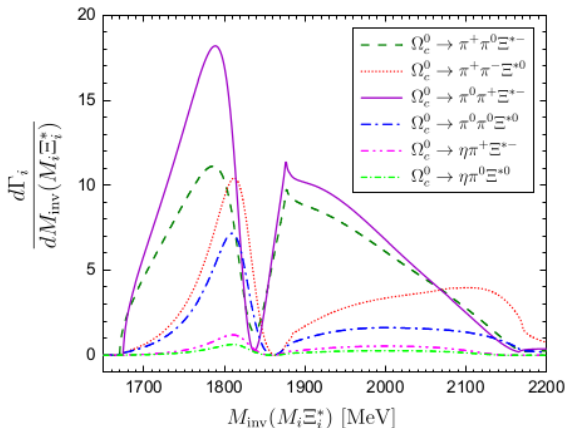
$$\cdot \frac{1}{2\omega(p_2)} \frac{m_B}{E_B(p_2)} \frac{1}{M_{\text{inv}} - \omega(p_2) - E_B(p_2) + i\epsilon}$$

$$\cdot t_{M_2 B, M_i \Xi_i^*} (M_{\text{inv}} (M_i \Xi_i^*)),$$

# Reaction mechanisms to detect the two-pole



$$\frac{d\Gamma_i}{dM_{\text{inv}}(M_i\Xi_i^*)} = \frac{1}{(2\pi)^3} \frac{1}{4M_{\Omega_c}^2} p_i \tilde{q}_i \bar{\Sigma} \Sigma |t_i|^2, \quad \bar{\Sigma} \Sigma |t_i|^2 = C^2 \frac{2}{3} \tilde{p}_i^2 |\tilde{t}_i|^2, \quad i = 1, 6$$

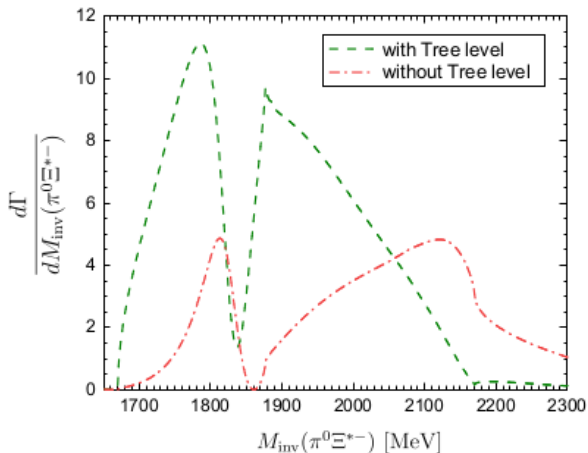




# Reaction mechanisms to detect the two-pole



Two of the reactions,  $\Omega_c^0 \rightarrow \pi^+\pi^0\Xi^{*-}$ ,  $\Omega_c^0 \rightarrow \pi^0\pi^+\Xi^{*-}$ , include the tree level mechanism.





One the other hand, we have

$$\begin{aligned}
 \Omega_c^0 &\rightarrow \pi^+ \Xi(1820) \rightarrow \pi^+ \bar{K}^0 \Sigma^{*-} (K^- \Sigma^{*0}), \\
 \Omega_c^0 &\rightarrow \pi^0 \Xi(1820) \rightarrow \pi^0 \bar{K}^0 \Sigma^{*0} (K^- \Sigma^{*+}), \\
 \Omega_c^0 &\rightarrow \eta \Xi(1820) \rightarrow \eta \bar{K}^0 \Sigma^{*0} (K^- \Sigma^{*+}).
 \end{aligned}
 \tag{5}$$

Note that, in principle, **decay of R cannot happen**, since:

$$m_{\bar{K}} + m_{\Sigma^*} = 1878 \text{ MeV} \tag{6}$$

However,  $\Gamma_{\Sigma^*} = 37.2 \text{ MeV}$ . Then,

$$S_{\Sigma^*}(M_{\text{inv}}(\Sigma^*)) = -\frac{1}{\pi} \text{Im} \frac{1}{M_{\text{inv}}(\Sigma^*) - M_{\Sigma^*} + i\Gamma_{\Sigma^*}(M_{\text{inv}}(\Sigma^*))/2},$$

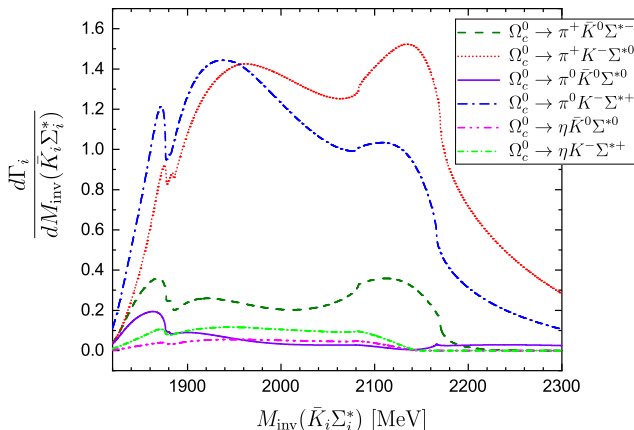
where

$$\Gamma_{\Sigma^*}(M_{\text{inv}}(\Sigma^*)) = \Gamma_{\Sigma^*,\text{on}} \frac{M_{\Sigma^*}}{M_{\text{inv}}(\Sigma^*)} \left( \frac{\tilde{p}_\pi}{\tilde{p}_{\pi,\text{on}}} \right)^3$$

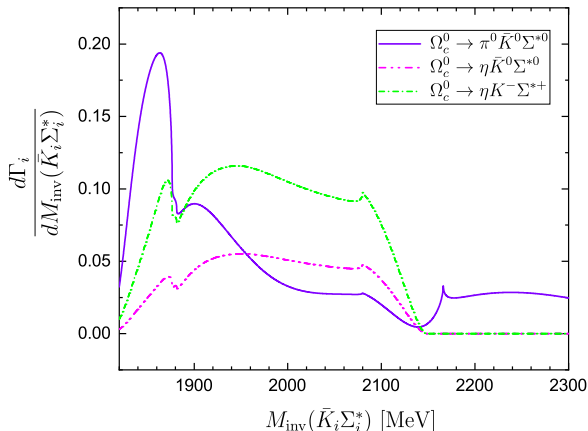
# Reaction mechanisms to detect the two-pole



$$\frac{d\Gamma_i}{dM_{\text{inv}}(\bar{K}\Sigma^*) dM_{\text{inv}}(\Sigma^*)} = \frac{\Gamma_{\Sigma^* \rightarrow \pi\Lambda}}{\Gamma_{\Sigma^*, \text{on}}} \mathcal{S}_{\Sigma^*}(M_{\text{inv}}(\Sigma^*)) \frac{1}{(2\pi)^3} \frac{1}{4M_{\Omega_c}^2} p_i \tilde{q}_i \bar{\Sigma} \Sigma |t_i^{(K)}|^2$$



# Reaction mechanisms to detect the two-pole



Sign of a new resonance  $\Xi$  around 2100 – 2200 MeV. BESIII paper.



- ▶ We observe that the  $\Xi(1820)$  has a two-pole structure, with **one narrow pole around 1820 MeV**, and  $\Gamma \sim 60$  MeV and a **broad pole around 1870 MeV**.
- ▶ We have proposed **different reactions**:

$$1) \Omega_c^0 \rightarrow \pi^+ \pi^0 \Xi^{*-} (\pi^- \Xi^{*0})$$

$$2) \Omega_c^0 \rightarrow \pi^0 \pi^+ \Xi^{*-} (\pi^0 \Xi^{*0})$$

$$3) \Omega_c^0 \rightarrow \eta \pi^+ \Xi^{*-} (\pi^0 \Xi^{*0})$$

$$4) \Omega_c^0 \rightarrow \pi^+ \bar{K}^0 \Sigma^{*-} (K^- \Sigma^{*0})$$

$$5) \Omega_c^0 \rightarrow \pi^0 \bar{K}^0 \Sigma^{*0} (K^- \Sigma^{*+})$$

$$6) \Omega_c^0 \rightarrow \eta \bar{K}^0 \Sigma^{*0} (K^- \Sigma^{*+})$$

In the first kind of reactions, a peak around the lower pole and dip around the the second peak, due to destructive interference (similarly to the case of the  $f_0(500)$  and the  $f_0(980)$ , [Pelaez, PRept16](#)).

In the second kind, the reflection of both peaks are visible above the threshold.