The Ξ(1820) resonance, one or two poles?

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Content

Two pole structures

Λ(1405)

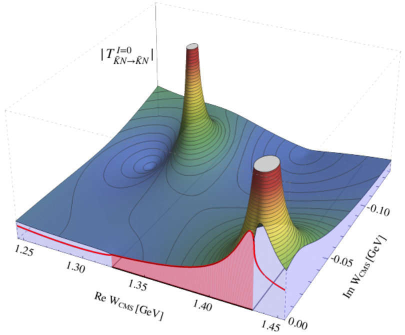
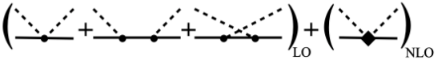


Figure taken from Review of the Λ(1405), Mai (2020)

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



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 $p \to -p$ gives a solution

Two pole structures

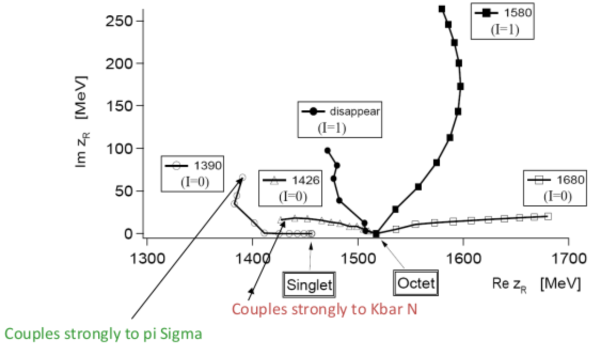
Poles of S=-1 J ^{P} =1/2 $^-$ Resonances

Jido, Oller, Oset, Ramos, Meissner NPA03

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

$$M_i(x) = M_0 + x(M_i - M_0),$$
$$m_i^2(x) = m_0^2 + x(m_i^2 - m_0^2),$$
$$a_i(x) = a_0 + x(a_i - a_0),$$

X ∈ [0,1]



Two pole structures

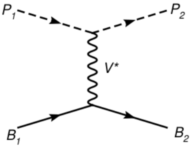
- At LO the interaction is diagonal $V_{\alpha\beta} = -\frac{1}{4f^2} C_{\alpha\beta}(k^0 + k'^0)$.

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

- At NLO the accidental symmetry of the two octects is slightly broken ($\Delta M_8 \simeq 15$ MeV) **Guo, Kamiya, Mai, Meissner PLB23**
- The most important features obtained at LO remain at NNLO. **(L0) Jido, Oller, Oset, Ramos, Meissner NPA03** **(NNLO) Lu, Geng, Doering, Mai PRL23**

$$(LO) \quad \sqrt{s_0} : 1390 - i\,66, \quad 1426 - i\,16$$
$$(NNLO) \quad \sqrt{s_0} : 1392 \pm 8 - i\,(100 \pm 15),\; 1425 \pm 1 - i\,(13 \pm 4)$$

Weinberg-Tomozawa dominates



The $\Xi(1820)$

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

New results from BESIII One or two poles?

Ablikim, 2308.15206 (2023)

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

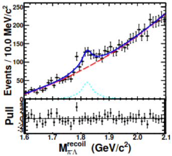
Resonance	$I(J^P)$	M (MeV/c^2)	Γ (MeV)
$\Xi(1690)^-$	$1/2(1/2^-)$	$1685^{+3}_{-2} \pm 12$	$81^{+10}_{-9} \pm 20$
$\Xi(1820)^-$	$1/2(3/2^-)$	$1821^{+2}_{-3} \pm 3$	$73^{+6}_{-5} \pm 9$

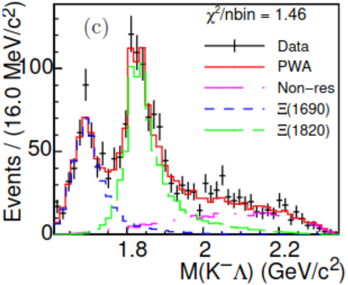
$\psi(3686) \to K^- \Lambda \bar{\Xi}^+$

PDG average:

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

$e^+e^- \to \Xi(1820)^- \bar{\Xi}^+$ **BESIII, PRL20**





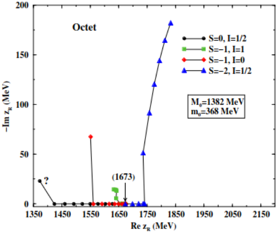
The Ξ(1820)

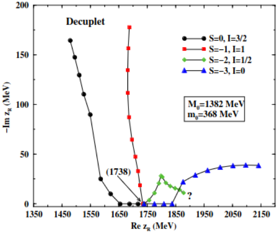
Sarkar, Oset, Vicente-Vacas, NPA05

Extension of the Λ(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	$\|g_i\|$
$\Sigma^*\overline{K}$	$1.9 + i0.7$	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
ΩK	$0.1 - i0.7$	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 $x = 0.9$.





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

Meson-baryon decuplet interaction

Jenkins, Manhohar PLB91

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

and $\mathcal{D}^{\nu}T^{\mu}_{abc} = \partial^{\nu}T^{\mu}_{abc} + (\Gamma^{\nu})^{d}_{a}T^{\mu}_{dbc} + (\Gamma^{\nu})^{d}_{b}T^{\mu}_{adc} + (\Gamma^{\nu})^{d}_{c}T^{\mu}_{abd}$.

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

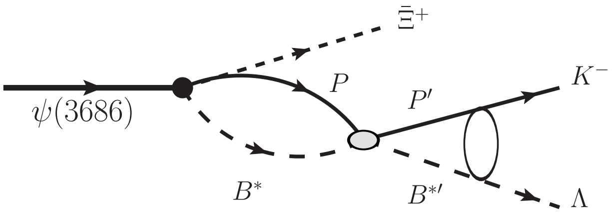
$$V_{ij} = -\frac{1}{4f^2}C_{ij}(k^0 + k'^0),$$

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

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

Production of the Ξ(1820) state

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



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

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

Production of the Ξ(1820) state

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

W arbitrary weight

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

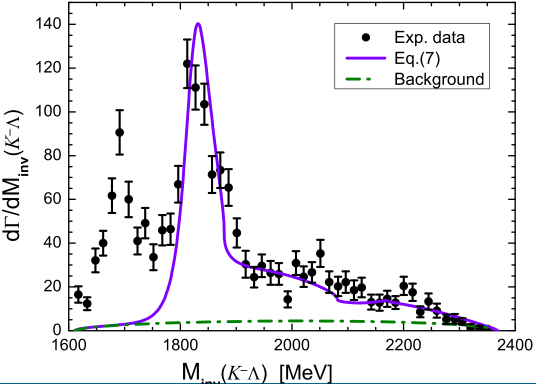
Background:

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

Exp. data BESIII

2308.15206 (2023)

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



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

Poles	$\lvert g_i \rvert$	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	$-1.77 + 2.45i$	$K\Omega$

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

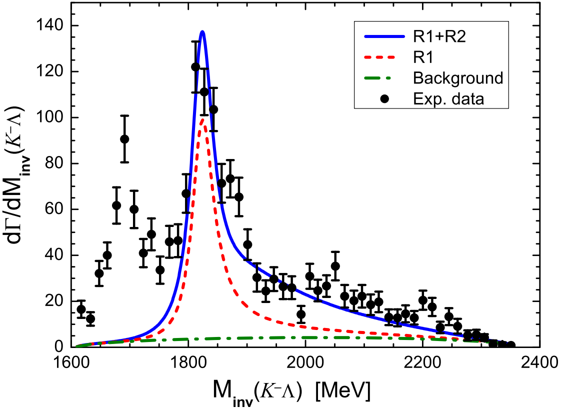
The two-pole of the Ξ(1820)

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

Poles

$M_{R_1} = 1822$ MeV
$\Gamma_1 = 45$ MeV

$M_{R_2} = 1870$ MeV
$\Gamma_2 = 200$ MeV



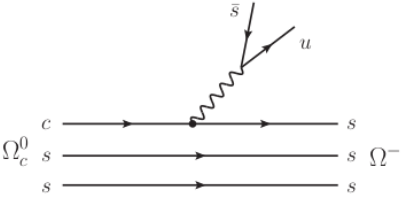
Reaction mechanisms to detect the two-pole

We have investigated the reactions:

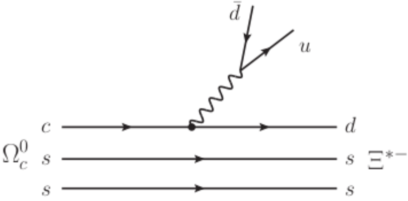
$$\Omega_c \to \pi^+ \, \Xi(1820) \to \pi^+\pi^0 \, \Xi^{*-} \; (\pi^-\Xi^{*0}),$$

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

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



(a)

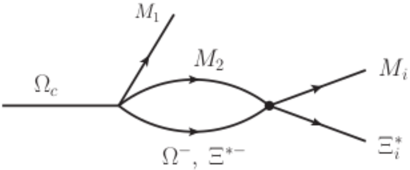


(b)

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

Reaction mechanisms to detect the two-pole

Reaction $\Omega_c \to M_1\, M_i\, \Xi_i^*$



Hadronization

$$
\begin{aligned}
u\bar{s} &\to \sum_i u\bar{q}_i q_i \bar{s} = P_{1i}\, P_{i3} = (P^2)_{13} \\
&= \left(\frac{\pi^0}{\sqrt{2}} + \frac{\eta}{\sqrt{3}}\right) K^+ + \pi^+ K^0 - \frac{1}{\sqrt{3}} K^+ \eta. \\
u\bar{d} &\to \sum_i u\bar{q}_i q_i \bar{d} = P_{1i}\, P_{i2} = (P^2)_{12} \\
&= (\frac{\pi^0}{\sqrt{2}} + \frac{\eta}{\sqrt{3}})\pi^+ + \pi^+(-\frac{\pi^0}{\sqrt{2}} + \frac{\eta}{\sqrt{3}}) + K^+ \bar{K}^0.
\end{aligned}
$$

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

Reaction mechanisms to detect the two-pole

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:

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

Amplitude structure

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

$$\cdot \frac{1}{2\,\omega(p_2)} \frac{m_B}{E_B(p_2)} \frac{1}{M_{\rm inv} - \omega(p_2) - E_B(p_2) + i\varepsilon}$$

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

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

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

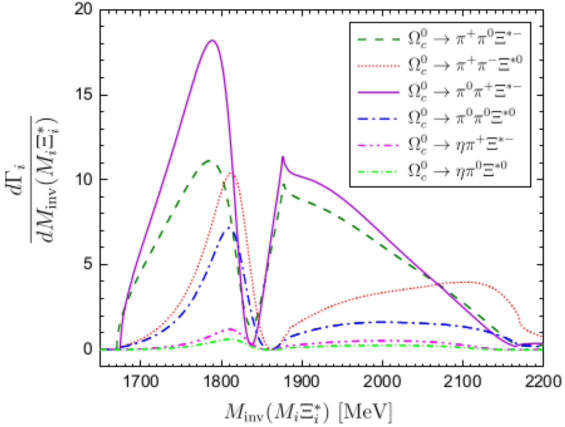
$$t'_{1a} = G_{K^0\Omega^-}(W)\, t_{K^0\Omega^-,\pi^0\Xi^{*-}}(W)),$$

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

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

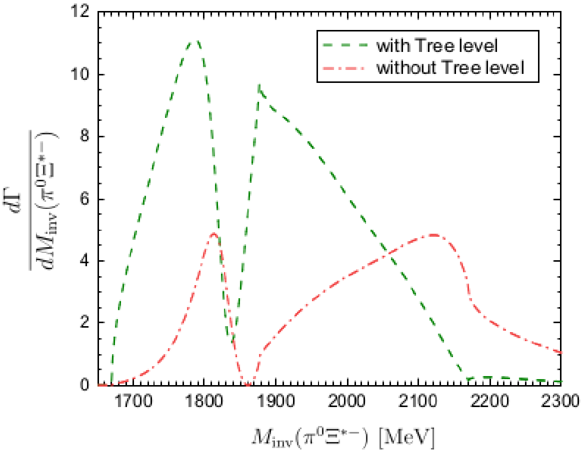
Reaction mechanisms to detect the two-pole

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



Reaction mechanisms to detect the two-pole

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



Conclusions

- 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 six different reactions, four of them, free of the tree level contribution, show a peak around the lower pole and dip around the the second peak, due to destructive interference (similarly to the case of $I = 0$ where the cross section has a broad peak for the $f_0(500)$ and a dip for the $f_0(980)$, Pelaez, PRept16).

1) $\Omega_c^0 \to \pi^+\pi^0\Xi^{*-}$
2) $\Omega_c^0 \to \pi^+\pi^-\Xi^{*0}$
3) $\Omega_c^0 \to \pi^0\pi^+\Xi^{*-}$
4) $\Omega_c^0 \to \pi^0\pi^0\Xi^{*0}$
5) $\Omega_c^0 \to \eta\pi^+\Xi^{*-}$
6) $\Omega_c^0 \to \eta\pi^0\Xi^{*0}$