Role of the $\Lambda(1670)$ resonance in the $\psi(3686) \to \Lambda\bar{\Lambda}\eta$ reaction

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N. Ikeno and E. Oset, Phys. Lett. B **880**, 140825 (2026)

15th International Workshop on the Physics of Excited Nucleons

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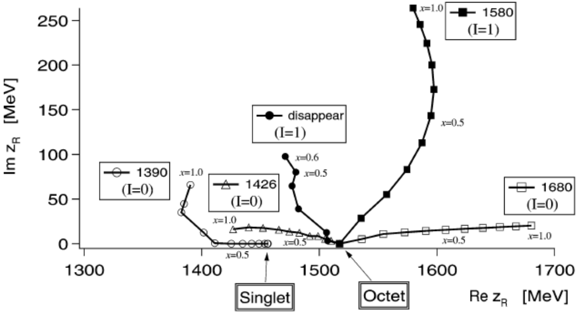
The $\Lambda(1670)$ resonance

Chiral unitary approach

E. Oset, A. Ramos and C. Bennhold, PLB 527 (2002)

$$\bar{K}N,\ \pi\Sigma,\ \eta\Lambda,\ K\Xi \Longrightarrow \Lambda(1670),\ \Lambda(1405)$$

Dynamically generated by coupled-channel meson–baryon interactions.



Pole trajectories obtained by varying the SU(3)-breaking parameter x.

D. Jido, J. A. Oller, E. Oset, A. Ramos, U.-G. Meißner, NPA 725, (2003).

In the SU(3) limit, the $\Lambda(1405)$ ($\Lambda(1420)$) and the $\Lambda(1670)$ have the same dynamical origin. Their mass difference, about 250 MeV, arises from SU(3)-breaking effects in the propagation of intermediate meson–baryon channels with physical masses.

The nature of the $\Lambda(1670)$ remains an open issue.

The study of the $\Lambda(1670)$ in different reactions

- Chiral unitary studies predict a channel dependence in the $\Lambda_c \to \pi^+ MB$ decay:

$$\Lambda(1405) \text{ appears in } \pi\Sigma, \qquad \Lambda(1670) \text{ in } \eta\Lambda.$$

K. Miyahara, T. Hyodo and E. Oset, Phys. Rev. C 92, 055204 (2015)

- This prediction was confirmed by the Belle observation of $\Lambda_c^+ \to \Lambda\pi^+\eta$, where a clear $\Lambda(1670)$ signal was found. J.-J. Xie and L.-S. Geng, Eur. Phys. J. C 76, 496 (2016); J. Y. Lee et al. (Belle), Phys. Rev. D 103, 052005 (2021)

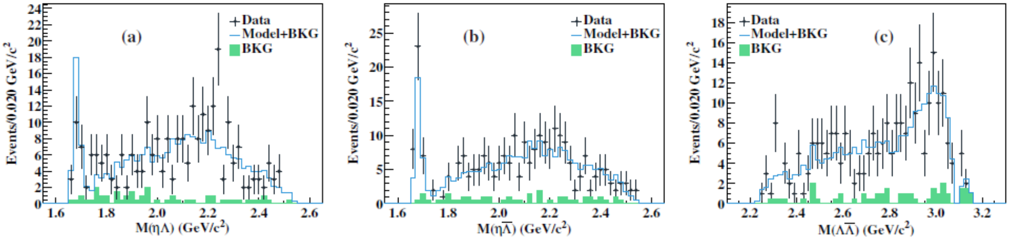
Reaction-dependent line shapes

- In $\Lambda_c^+ \to pK^-\pi^+$, a cusp-like enhancement appears near the $\eta\Lambda$ threshold. Its line shape is affected by interference with tree-level contributions. S. B. Yang et al. (Belle), Phys. Rev. D 108, L031104 (2023); R. Aaij et al. (LHCb), Phys. Rev. D 108, 012023 (2023)
- In the isospin-forbidden $J/\psi \to \Lambda\bar{\Sigma}\eta$ decay, the leading tree-level term vanishes, providing a cleaner test. M. Ablikim et al. (BESIII), arXiv:2601.07617 (2026); L. R. Dai, W.-T. Lyu and E. Oset, arXiv:2602.09136 (2026)

Different reactions provide complementary tests of the dynamical origin of the $\Lambda(1670)$.

Our motivation: $\psi(3686) \to \Lambda\bar{\Lambda}\eta$ reaction

BESIII M. Ablikim et al. (BESIII), Phys. Rev. D 106, 072006 (2022)



- BESIII observed a clear peak near the $\Lambda(1670)$ region in the $M_{\eta\Lambda}$ spectrum, described by a Breit–Wigner resonance.

Our study

- We investigate whether the observed $\Lambda(1670)$ signal can be dynamically generated through meson–baryon final-state interactions.
- We test whether the three invariant-mass distributions can be described simultaneously within a common framework.

Theoretical study of $\psi(3686) \to \Lambda\bar{\Lambda}\eta$

We first look at the flavor structure of the $\psi \to B\bar{B}P$, with B a baryon of the SU(3) octet and P a pseudoscalar meson. Since $\psi(3686)$ is a $c\bar{c}$ state, a scalar object in SU(3), then we can construct SU(3) invariant combinations of $B\bar{B}P$. Finally, we obtain as

$$\langle \bar{B}PB \rangle, \qquad \langle \bar{B}BP \rangle.$$

Equivalent structures were used in Y. B. He, X. H. Liu, L. S. Geng, F. K. Guo and J. J. Xie, PRD**113**, L051501 (2026)

$$\mathcal{L}_\psi = \tilde{D}\,\langle \bar{B}\gamma_\mu\gamma_5\{P,B\}\rangle\,\psi^\mu + \tilde{F}\,\langle \bar{B}\gamma_\mu\gamma_5[P,B]\rangle\,\psi^\mu.$$

The relative strength $\tilde{D}/\tilde{F}$ determines the relative weights of the primary meson–baryon channels.

The SU(3) matrices for B, $\bar{B}$, and P, with $\bar{B}$ denoting the antibaryon matrix

$$P = \begin{pmatrix} \frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{3}}\eta & \pi^+ & K^+ \\ \pi^- & -\frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{3}}\eta & K^0 \\ K^- & \bar{K}^0 & -\frac{1}{\sqrt{3}}\eta \end{pmatrix}, \qquad B = \begin{pmatrix} \frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & \Sigma^+ & p \\ \Sigma^- & -\frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & n \\ \Xi^- & \Xi^0 & -\frac{2}{\sqrt{6}}\Lambda \end{pmatrix}.$$

Primary production amplitudes from SU(3)

To obtain the final $\Lambda\bar{\Lambda}\eta$ state, we single out the terms containing a Λ or a $\bar{\Lambda}$ together with the corresponding meson–baryon. From the two flavor structures, we assign the relative weights $\tilde{A}$ and $\tilde{B}$ as

$$\tilde{A}\,\langle \bar{B}PB\rangle + \tilde{B}\,\langle \bar{B}BP\rangle.$$

By taking into account the isospin multiplets (K^+, K^0), $(\bar{K}^0, -K^-)$, $(\Xi^0, -\Xi^-)$, (p, n), we can write

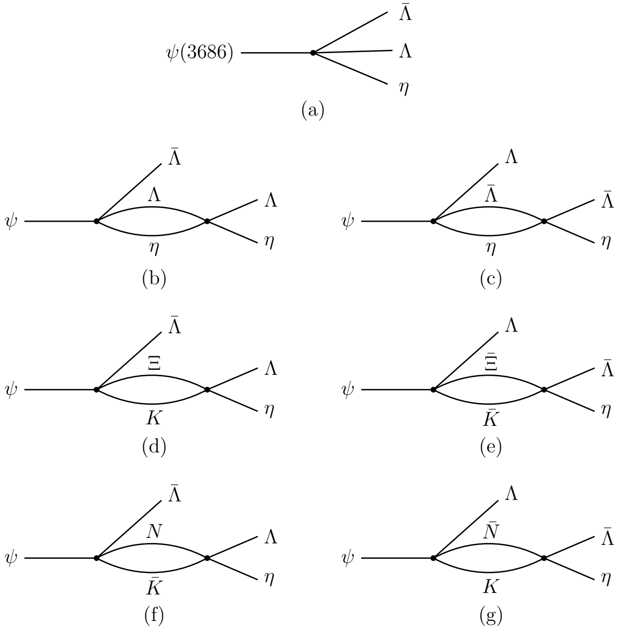
$$\begin{aligned}
\psi \to & \frac{\bar{\Lambda}}{\sqrt{6}}\Big\{(2\tilde{B}-\tilde{A})\sqrt{2}\,|K\Xi, I=0\rangle + (\tilde{B}-2\tilde{A})\sqrt{2}\,|\bar{K}N, I=0\rangle\Big\} \\
& + \frac{\Lambda}{\sqrt{6}}\Big\{(2\tilde{B}-\tilde{A})\sqrt{2}\,|\bar{K}\bar{\Xi}, I=0\rangle + (\tilde{B}-2\tilde{A})\sqrt{2}\,|K\bar{N}, I=0\rangle\Big\} \\
& - \frac{1}{3\sqrt{3}}(\tilde{A}+\tilde{B})\,\eta\Lambda\bar{\Lambda},
\end{aligned}$$

The $\pi\Sigma$ terms are omitted in the present calculation, because their couplings to the $\Lambda(1670)$ are very small.

E. Oset, A. Ramos and C. Bennhold, PLB 527,99 (2002)

Up to an overall normalization, the relevant parameter is $\tilde{A}/\tilde{B}$.

Production mechanism



The final $\Lambda\bar{\Lambda}\eta$ state in the $\psi(3686)$ decay is produced through two mechanisms:

1. direct production (tree-level) of $\eta\Lambda\bar{\Lambda}$
2. meson–baryon rescattering:

$$\eta\Lambda,\ K\Xi,\ \bar{K}N \longrightarrow \eta\Lambda,$$
$$\eta\bar{\Lambda},\ \bar{K}\bar{\Xi},\ K\bar{N} \longrightarrow \eta\bar{\Lambda}.$$

The $\Lambda(1670)$ is generated dynamically through meson–baryon rescattering

Spin structure of the production amplitude

The production vertex contains the axial-vector structure

$$t \equiv -\overline{u}_B(\boldsymbol{p})\,\gamma_\mu\gamma_5\,v_{\bar{B}}(\boldsymbol{p}')\,\epsilon^\mu = \overline{u}_B(\boldsymbol{p})\,\gamma^i\gamma_5\,v_{\bar{B}}(\boldsymbol{p}')\,\epsilon^i, \qquad \epsilon^0 = 0$$

in the ψ rest frame. We write the Dirac spinors in the nonrelativistic form and keep terms up to first order in the momenta. This gives

$$\overline{u}(\boldsymbol{p})\gamma^i\gamma_5 v(\boldsymbol{p}\,') \longrightarrow \chi^\dagger\left[\frac{p^i}{2m} + \frac{p'^i}{2m'} + i\epsilon_{ijk}\sigma_k\left(\frac{p'^j}{2m'} - \frac{p^j}{2m}\right)\right]\chi'.$$

After including the direct production and rescattering contributions, the amplitude can be written as

$$t = \left[D\left(\frac{p^i_\Lambda}{2m_\Lambda} - i\epsilon_{ijk}\sigma_k\frac{p^j_\Lambda}{2m_\Lambda}\right) + D'\left(\frac{p^i_{\bar{\Lambda}}}{2m_\Lambda} + i\epsilon_{ijk}\sigma_k\frac{p^j_{\bar{\Lambda}}}{2m_\Lambda}\right)\right]\epsilon^i.$$

D and D' contain the dynamical information from the direct production and the final-state interaction.

After summing over final spins and averaging over the initial polarization, we obtain

$$\overline{\sum}\sum|t|^2 = \frac{1}{6m_\Lambda^2}\left[3|D|^2\,\boldsymbol{p}_\Lambda^2 + 3|D'|^2\,\boldsymbol{p}_{\bar{\Lambda}}^2 - 2\,\mathrm{Re}(DD'^*)\,\boldsymbol{p}_\Lambda\cdot\boldsymbol{p}_{\bar{\Lambda}}\right].$$

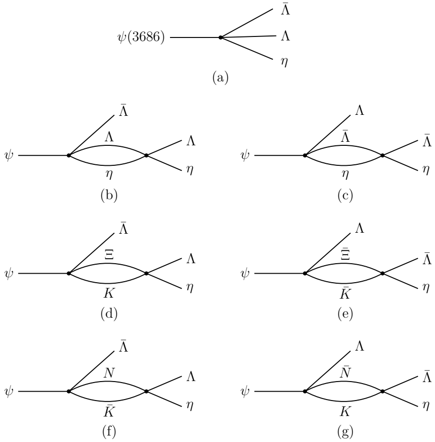
Dynamical functions in the production amplitude

$$t = \left[D \left(\frac{p^i_\Lambda}{2m_\Lambda} - i\epsilon_{ijk}\sigma_k \frac{p^j_\Lambda}{2m_\Lambda} \right) + D' \left(\frac{p^i_{\bar\Lambda}}{2m_\Lambda} + i\epsilon_{ijk}\sigma_k \frac{p^j_{\bar\Lambda}}{2m_\Lambda} \right) \right] \epsilon^i .$$

The D' is related to $\Lambda(1670)$ generated in the $\eta\Lambda$ channel, D is $\bar{\Lambda}(1670)$ generated in the $\eta\bar{\Lambda}$ channel.

For example,

$$\begin{aligned} D' = & -\frac{1}{3\sqrt{3}}(\tilde{A}+\tilde{B}) \\ & -\frac{1}{3\sqrt{3}}(\tilde{A}+\tilde{B})\, G_{\eta\Lambda}\big(M_{\rm inv}(\eta\Lambda)\big)\, t_{\eta\Lambda,\eta\Lambda}\big(M_{\rm inv}(\eta\Lambda)\big) \\ & +\frac{1}{\sqrt{3}}(2\tilde{B}-\tilde{A})\, G_{K\Xi}\big(M_{\rm inv}(\eta\Lambda)\big)\, t_{K\Xi\to\eta\Lambda}\big(M_{\rm inv}(\eta\Lambda)\big) \\ & +\frac{1}{\sqrt{3}}(\tilde{B}-2\tilde{A})\, G_{\bar{K}N}\big(M_{\rm inv}(\eta\Lambda)\big)\, t_{\bar{K}N\to\eta\Lambda}\big(M_{\rm inv}(\eta\Lambda)\big). \end{aligned}$$



We take into account that $t_{BP,B'P'} = t_{\bar{B}\bar{P},\bar{B}'\bar{P}'}$.

Transition amplitude for $BP \to \eta\Lambda$

The transition amplitudes $t_{BP\to\eta\Lambda}$ are obtained as matrix elements of the chiral unitary T matrix.

E. Oset and A. Ramos, NPA **635**, 99-120 (1998): E. Oset, A. Ramos and C. Bennhold, PLB **527**, 99-105 (2002)

The coupled channels are

$$\bar{K}N, \qquad \pi\Sigma, \qquad \eta\Lambda, \qquad K\Xi.$$

The amplitude T is given by

$$T = [1 - VG]^{-1}V, \qquad V_{ij} = -C_{ij}\frac{k^0 + k'^0}{4f_i f_j},$$

where f_i is the decay constant, and the loop function G is regularized with the cut-off $q_{\mathrm{max},i}$.

The channel-dependent parameters f_i and $q_{\mathrm{max},i}$ were determined by fitting the high-resolution data from LHCb and Belle (LHCb, PRD **108**, 012023 (2023), Belle, PRD **108**, L031104 (2023)).

M.-Y. Duan, M. Bayar and E. Oset, PLB 857, 139003 (2024)

We use the same parameter set in the present calculation. It gives the $\Lambda(1670)$ pole position:

$$M_{\Lambda(1670)} - \frac{i}{2}\Gamma_{\Lambda(1670)} = (1669.40 \pm 1.06) - i(21.46 \pm 1.76)\ \mathrm{MeV}.$$

Invariant-mass distributions

For the three-body decay, the double-differential decay width is

$$\frac{d^2\Gamma}{dM_{12}\,dM_{23}} = \frac{1}{(2\pi)^3}\frac{2M_\Lambda\,2M_{\bar\Lambda}}{32m_\psi^3}\overline{\sum}\sum|t|^2\,2M_{12}\,2M_{23}.$$

For the present reaction, we label the particles as

$$\Lambda(1), \qquad \eta(2), \qquad \bar\Lambda(3), \qquad M_{ij}^2 = (p_i + p_j)^2.$$

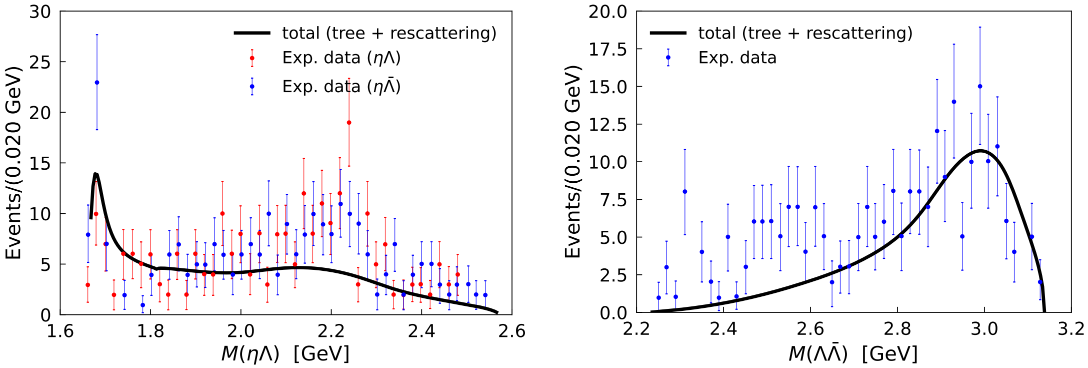
Thus,

$$M_{12} = M_{\eta\Lambda}, \qquad M_{23} = M_{\eta\bar\Lambda}, \qquad M_{13} = M_{\Lambda\bar\Lambda}.$$

Integrating over the kinematically allowed range of M_{23}, we obtain $d\Gamma/dM_{12}$. The other two invariant-mass distributions are obtained by cyclically permuting the particle labels.

The same amplitude gives all three invariant-mass projections.

Numerical Results: $\eta\Lambda$ ($\eta\bar{\Lambda}$) and $\Lambda\bar{\Lambda}$ mass distributions



- The narrow peak in $M_{\eta\Lambda}$ is generated by the $\Lambda(1670)$ through $\eta\Lambda$ rescattering.
- The tree-level and $\Lambda(1670)$ rescattering contributions alone cannot reproduce the data, especially the broad strength around $M_{\eta\Lambda} \simeq 2.2$ GeV.

Extra resonant Λ^* contribution

To describe the missing broad strength around $M(\eta\Lambda) \simeq 2.2$ GeV, we introduce an extra resonant contribution:

$$\tilde{C}\left\{\left|\frac{M_\Lambda^2}{M_{\rm inv}^2(\eta\Lambda) - M_R^2 + iM_R\Gamma_R}\right|^2 + \left|\frac{M_\Lambda^2}{M_{\rm inv}^2(\eta\bar{\Lambda}) - M_R^2 + iM_R\Gamma_R}\right|^2\right\},$$

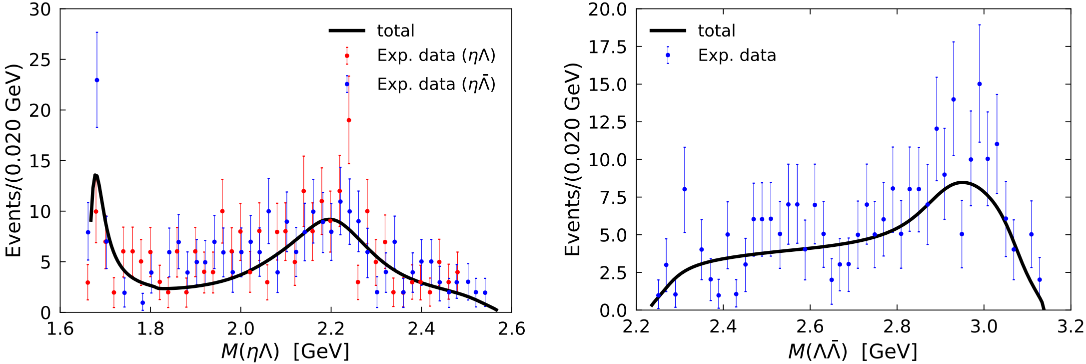
$$M_R = 2200\ \mathrm{MeV}, \qquad \Gamma_R = 200\ \mathrm{MeV},$$

where the strength $\tilde{C}$ is determined by a fit to the data.

Several Λ^* states are listed in this energy region, but their couplings to $\eta\Lambda$ are unknown or small. Therefore, **we do not assign the extra contribution to one specific resonance**.

The extra contribution is added incoherently to $|t|^2$.

Results with extra Λ^* contributions



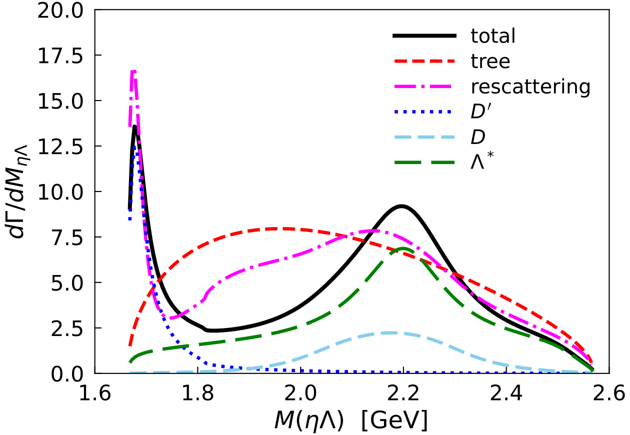
The calculations reproduce the data well when an additional broad Λ^* contribution is included.

Fit with extra Λ^*: $\chi^2/\mathrm{dof} = 1.87 \longrightarrow 1.22$, $\quad \tilde{A}/\tilde{B} = 2.8 \pm 0.2$, $\tilde{C} = (3.3 \pm 0.2) \times 10^{-3}$

Using $\tilde{A} = \tilde{D} + \tilde{F}$ and $\tilde{B} = \tilde{D} - \tilde{F}$, this corresponds to $\tilde{F}/\tilde{D} = 0.47 \pm 0.03$, consistent with the value 0.50 ± 0.06 reported in

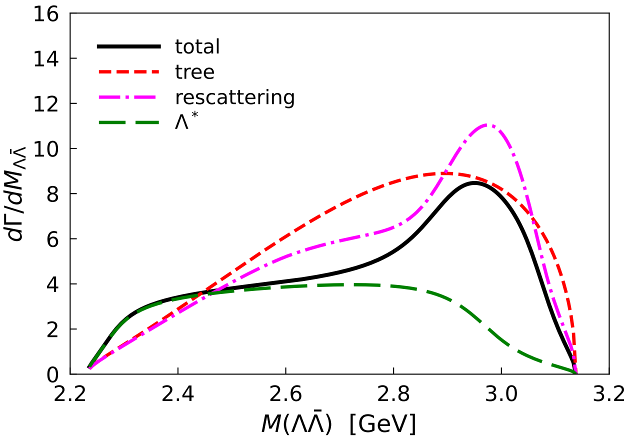
Y. B. He, X. H. Liu, L. S. Geng, F. K. Guo and J. J. Xie, PRD**113**, L051501 (2026)

Different contributions in $\eta\Lambda$ spectra



- **D' contribution:**
  $\Lambda(1670)$ in the $\eta\Lambda$ channel
- **D contribution:**
  the $\bar{\Lambda}(1670)$ in the $\eta\bar{\Lambda}$ channel, and its kinematic reflection produces a broad structure
- **Tree level:**
  Not small, it adds coherently to the rescattering terms
- **Extra Λ^* contribution:**
  Not small, broad strength around $2.2\ \mathrm{GeV}$

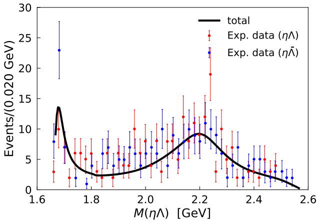
Different contributions in $\Lambda\bar{\Lambda}$ spectra

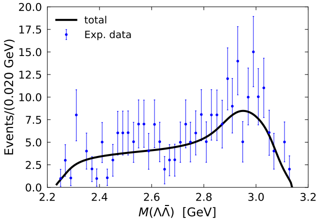


- A peak around 3000 MeV comes from the $\Lambda(1670)$ and $\bar{\Lambda}(1670)$ contributions
- tree level contribution is not small
- Extra Λ^* contribution is require to get the broad strength

Summary

- We studied $\psi(3686) \to \Lambda\bar{\Lambda}\eta$ using the two SU(3) flavor structures allowed for the primary decay.
- The $\Lambda(1670)$ is dynamically generated by meson–baryon final-state interactions.
- Tree-level and rescattering contributions are comparable and interfere in the line shapes.
- An additional broad Λ^* contribution around 2.2 GeV is required.





The results support the dynamical origin of the $\Lambda(1670)$.

M.-Y. Duan, M. Bayar and E. Oset, PLB 857, 139003 (2024)

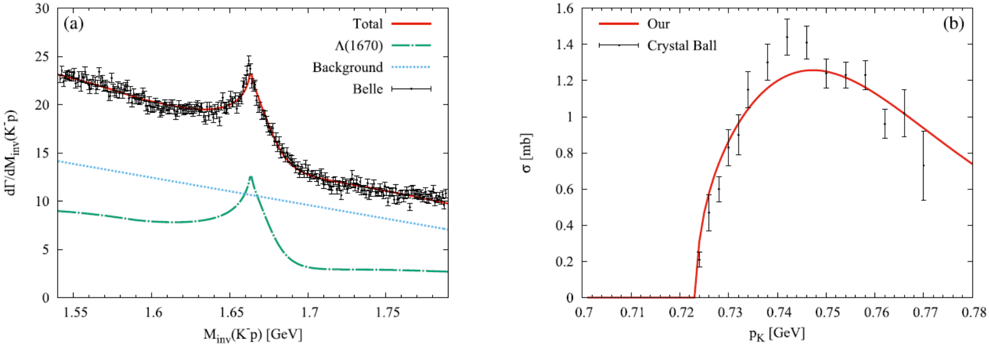
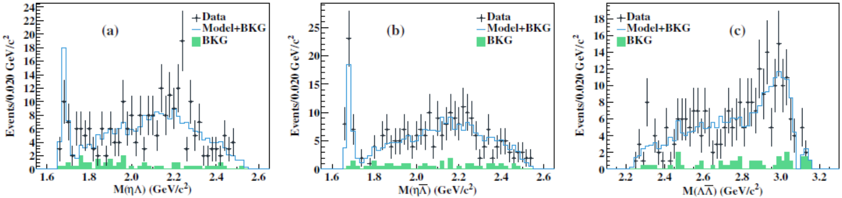


Fig. 4. Results of the fits to the $\Lambda_c^+ \to \pi^+ K^- p$ (a) [20] and $K^- p \to \eta\Lambda$ (b) [32] data.

Table 1
The values and errors of the fitting parameters.

Parameters	f_{K^-p}	$f_{\pi^0\Lambda}$	$f_{\pi^0\Sigma^0}$	$f_{\eta\Lambda}$	$f_{\eta\Sigma^0}$	$f_{K^+\Xi^-}$	$q_{\max,K^-p}$	$q_{\max,\pi^0\Lambda}$	$q_{\max,\pi^0\Sigma^0}$	$q_{\max,\eta\Lambda}$	$q_{\max,\eta\Sigma^0}$	$q_{\max,K^+\Xi^-}$	α	β	C
Values	42.94	40.35	179.54	103.29	108.40	147.15	400.95	860.65	1257.47	828.91	1043.17	1389.43	46.84	0.02	5100.02
Errors	1.45	0.70	1.51	3.85	61.45	4.36	2.40	395.98	48.29	62.86	463.96	80.14	8.66	0.004	426.34

$\psi(3686) \to \Lambda\bar{\Lambda}\eta$ reaction by BESIII, PRD 106, 072006 (2022)



Using the Feynman diagram calculation package [22], a partial wave analysis (PWA) is performed based on an unbinned maximum likelihood fit. In the global fit, resonances are described by a relativistic Breit-Wigner propagator, with the mass and width as free parameters,

$$\mathrm{BW}(s) = \frac{1}{M_{\Lambda^*}^2 - s - iM_{\Lambda^*}\Gamma_{\Lambda^*}}, \tag{1}$$

where s is the squared invariant mass.

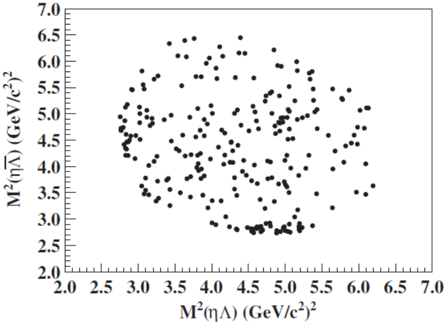


FIG. 4. The Dalitz plot of $M^2(\eta\Lambda)$ versus $M^2(\eta\bar{\Lambda})$.

E. Oset, A. Ramos and C. Bennhold, PLB 527 (2002)

The couplings for the $\Lambda(1670)$ and $\Lambda(1405)$ resonances

In this Erratum we correct the values quoted in Phys. Lett. B 527 (2002) 99–105 for the coupling constants of the $S = -1$ s-wave resonances. In that work the modulus of the couplings should be changed to the modulus squared. Therefore, one should replace Eqs. (13), (14), (16) and (18) by:

$$|g_{\overline{K}N}|^2 = 0.51, \qquad |g_{\pi\Sigma}|^2 = 0.052, \qquad |g_{\eta\Lambda}|^2 = 1.0, \qquad |g_{K\Xi}|^2 = 11, \tag{13}$$

$$|g_{\overline{K}N}|^2 = 0.61, \qquad |g_{\pi\Sigma}|^2 = 0.073, \qquad |g_{\eta\Lambda}|^2 = 1.1, \qquad |g_{K\Xi}|^2 = 12, \tag{14}$$

$$|g_{\overline{K}N}|^2 = 7.4, \qquad |g_{\pi\Sigma}|^2 = 2.3, \qquad |g_{\eta\Lambda}|^2 = 2.0, \qquad |g_{K\Xi}|^2 = 0.12, \tag{16}$$

$$|g_{\overline{K}N}|^2 = 2.6, \qquad |g_{\pi\Sigma}|^2 = 7.2, \qquad |g_{\pi\Lambda}|^2 = 4.2, \qquad |g_{\eta\Sigma}|^2 = 3.5, \qquad |g_{K\Xi}|^2 = 12. \tag{18}$$