The newly observed $\Omega(2012)$ *as a* $\bar{K}\Xi^*(1530)$ *hadronic molecule*

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Outline

Motivation

$\bar{K}\Xi^*(1530)$ *and* $\eta\Omega$ *interactions in s wave*

Include $\bar{K}\Xi$ *in d wave*

Summary

Observation of an Excited Ω^- Baryon

PHYSICAL REVIEW LETTERS 121, 052003 (2018)

(The Belle Collaboration)

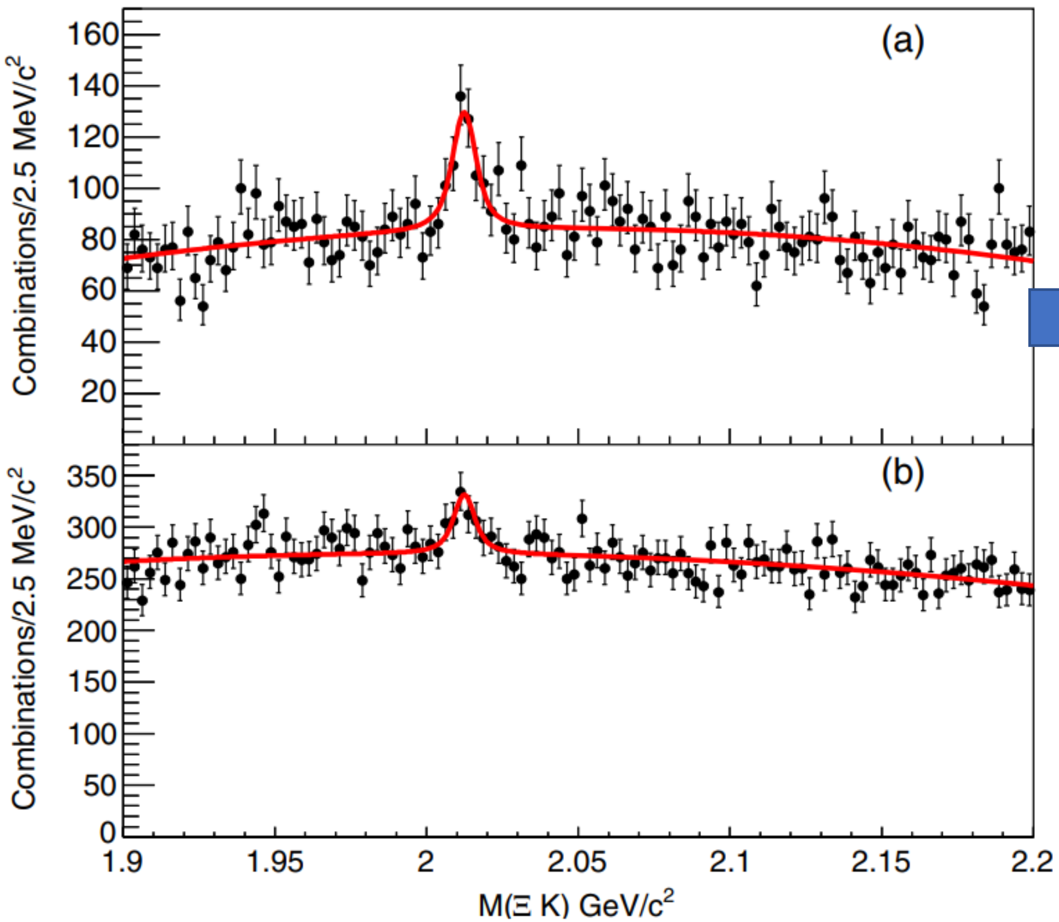


FIG. 2. The (a) $\Xi^0 K^-$ and (b) $\Xi^- K_S^0$ invariant mass distributions in data taken at the $\Upsilon(1S)$, $\Upsilon(2S)$, and $\Upsilon(3S)$ resonance energies. The curves show a simultaneous fit to the two distributions with a common mass and width.

$$M = 2012.4 \pm 0.7 \pm 0.6\ \mathrm{MeV}$$

$$\Gamma = 6.4^{+2.5}_{-2.0} \pm 1.6\ \mathrm{MeV}$$

Narrow width

$$\rightarrow \bar{K}\Xi\ in\ d - wave$$

$$preferred\ J^P = \frac{3}{2}^-$$

$$and\ I = 0$$

XI Baryons (S = -2, I = 1/2)

Note on Xi Resonances	Xi(1950)
Xi0	Xi(2030)
Xi-	Xi(2120)
Xi(1530)	Xi(2250)
Xi(1620)	Xi(2370)
Xi(1690)	Xi(2500)
Xi(1820)	

Collapse Xi Baryons table

Omega Baryons (S = -3, I = 0)

- Omega-
- Omega(2012)-
- Omega(2250)-
- Omega(2380)-
- Omega(2470)-

Collapse Omega Baryons table

Citation: M. Tanabashi *et al.* (Particle Data Group), Phys. Rev. D **98**, 030001 (2018) and 2019 update

$\boxed{\Omega(2012)^-}$

$I(J^P) = 0(?^-)$ Status: ∗∗∗

Seen in $\Xi^0 K^-$ and $\Xi^- K^0_S$ decays with a combined significance of 8.3 standard deviations.

$\Omega(2012)^-$ MASS

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
2012.4±0.7±0.6	520	YELTON	18A	BELL	In $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$

$\Omega(2012)^-$ WIDTH

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
$\mathbf{6.4^{+2.5}_{-2.0}\pm1.6}$	520	YELTON	18A	BELL	In $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$

$\Omega(2012)^-$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	$\Xi^0 K^-$	seen
Γ_2	$\Xi^- K^0$	seen

SSS

Before "the observation"

Chiral quark Model Predictions

W.L. Wang, F. Huang, Z.Y. Zhang, Y.W. Yu and F. Liu, $\Omega\omega$ states in a chiral quark model, Commun. Theor. Phys. 48, 695 (2007).

W.L. Wang, F. Huang, Z.Y. Zhang, Y.W. Yu and F. Liu, A Possible Omega pi molecular state, Eur. Phys. J. A32, 293 (2007).

W.L. Wang, F. Huang, Z.Y. Zhang and F. Liu, Xi anti-K interaction in a chiral model, J. Phys. G35, 085003 (2008).

W.L. Wang, F. Huang, Z.Y. Zhang and F. Liu, omega phi states in chiral quark model, Mod. Phys. Lett. A25, 1325 (2010).

Five-quark picture Predictions

C.S. An, B.C. Metsch and B.S. Zou, Mixing of the low-lying three- and five-quark Ω states with negative parity, Phys. Rev. C87, 065207 (2013).

C.S. An and B.S. Zou, Low-lying Ω states with negative parity in an extended quark model with Nambu-Jona-Lasinio interaction, Phys. Rev. C89, 055209 (2014).

S.G. Yuan, C.S. An, K.W. Wei, B.S. Zou and H.S. Xu, Spectrum of low-lying sssqqbar configurations with negative parity, Phys. Rev. C87, 025205 (2013).

Quark Model Predictions

$$Strangenss\ \ -2\ and\ \ -3\ baryons\ in\ a\ quark\ model\ with\ chromodymics$$

$$\textbf{Kuang Ta Chao}, Nathan\ Isgur, and\ Gabriel\ Karl,\ \textbf{PRD23}, \textbf{155}\ (\textbf{1981}).$$

$$M_{\Omega^*} = 2020\ \text{MeV}\ with\ J^P = \frac{3}{2}^-$$

Chiral Unitary Approach Prediction

Baryonic resonances from baryon decuplet-meson octet interaction

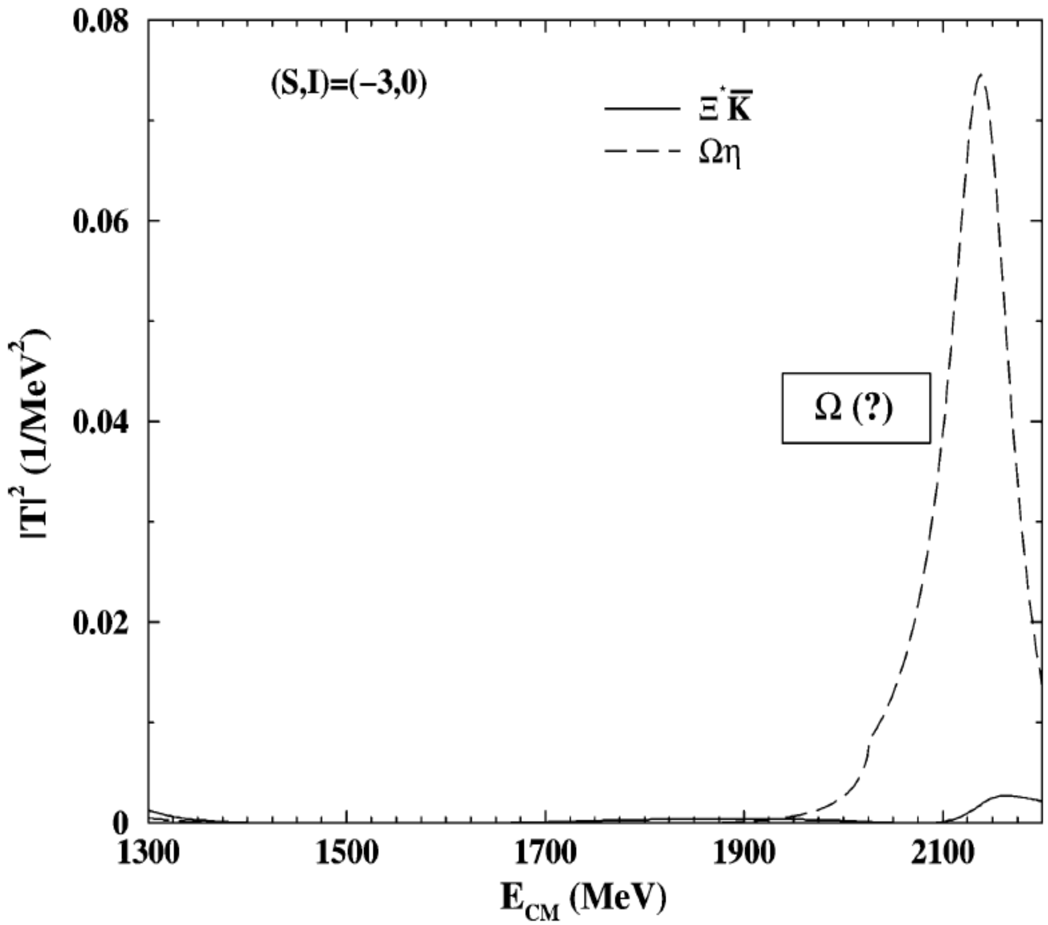
Sourav Sarkar*, E. Oset, M.J. Vicente Vacas

Nuclear Physics A 750 (2005) 294–323

Couplings of the resonance with $S = -3$ and $I = 0$ to various channels

z_R	$2141 - i38$	
	g_i	$\|g_i\|$
$\Xi^*\bar{K}$	$1.1 - i0.8$	1.4
$\Omega\eta$	$3.3 + i0.4$	3.4

Two channels are in s-wave.



The $\Xi^*\bar{K}$ and $\Omega\eta$ Interaction Within a Chiral Unitary Approach*

Si-Qi Xu (徐思琦),[1,2] Ju-Jun Xie (谢聚军),[2,3,†] Xu-Rong Chen (陈旭荣),[2] and Duo-Jie Jia (贾多杰)[1]

Commun. Theor. Phys. **65** (2016) 53–56

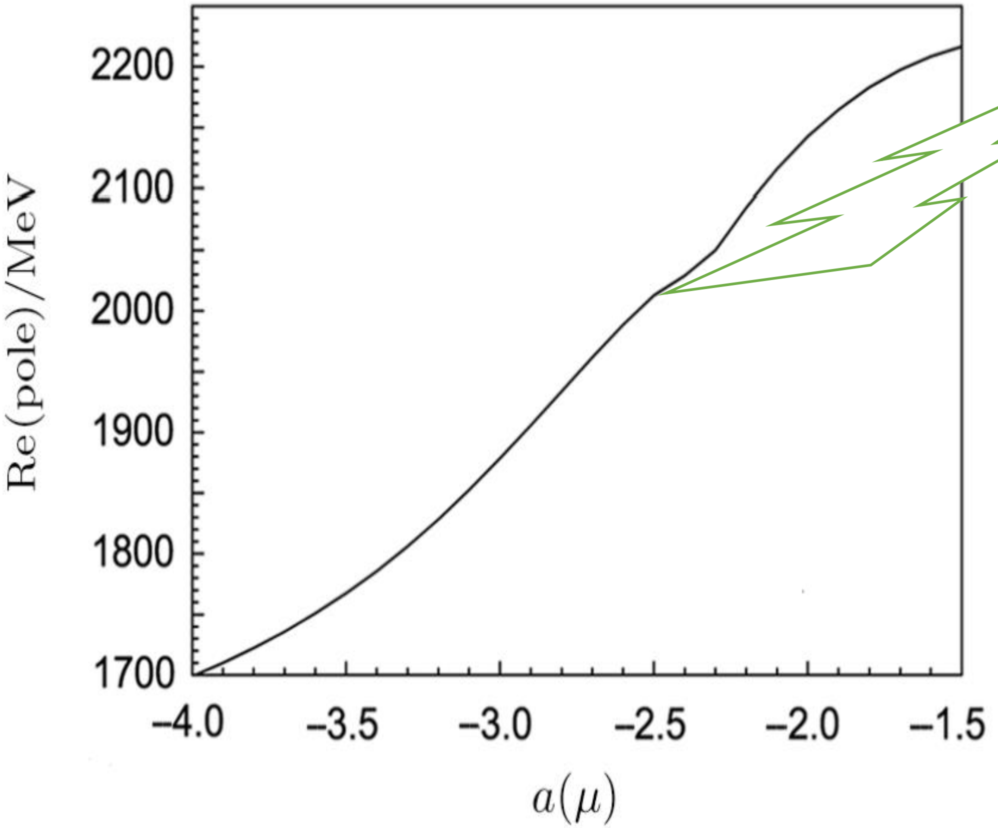


Fig. 3 Results of varying $a(\mu)$ over the $3/2^-$ Ω resonance mass.

$M = 2012.7$ MeV, *below the threshold of* $\bar{K}\Xi^*(1530)$,

with $a_\mu = -2.5$ *and* $\mu = 700$ MeV

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

$$C_{11} = 0\,,\ C_{12} = C_{21} = 3\,,\ C_{22} = 0\,.$$

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

$$\begin{aligned} G_l = \frac{2M_l}{16\pi^2}\Big\{ & a_l(\mu) + \ln\frac{M_l^2}{\mu^2} + \frac{m_l^2 - M_l^2 + s}{2s}\ln\frac{m_l^2}{M_l^2} \\ & + \frac{q_l}{\sqrt{s}}[\ln(s - (M_l^2 - m_l^2) + 2q_l\sqrt{s}) \\ & + \ln(s + (M_l^2 - m_l^2) + 2q_l\sqrt{s}) \\ & - \ln(-s + (M_l^2 - m_l^2) + 2q_l\sqrt{s}) \\ & - \ln(-s - (M_l^2 - m_l^2) + 2q_l\sqrt{s})]\Big\}\,, \end{aligned}$$

After "the observation"

Quark Model

J^P *could be* $3/2^-$, *but,*

$1/2^-$ *cannot be completely excluded.*

L.Y. Xiao and X.H. Zhong, Phys. Rev. D 98, 034004 (2018).

Z.Y. Wang, L.C. Gui, Q.F. Lü, L.Y. Xiao and X.H. Zhong, Phys. Rev. D98,114023 (2018).

M.S. Liu, K.L. Wang, Q.F. Lü and X.H. Zhong, Phys. Rev. D101, 016002 (2020) .

Hadronic molecule

T.M. Aliev, K. Azizi, Y. Sarac and H. Sundu, Phys. Rev. D98, 014031 (2018); arXiv:1806.01626.

M.V. Polyakov, H.D. Son, B.D. Sun and A. Tandogan, Phys. Lett. B792, 315 (2019); arXiv:1806.04427.

M.P. Valderrama, Phys. Rev. D98, 054009 (2018); arXiv:1807.00718.

Y.H. Lin and B.S. Zou, Phys. Rev. D98, 056013 (2018); arXiv:1807.00997.

T.M. Aliev, K. Azizi, Y. Sarac and H. Sundu, Eur. Phys. J. C78, 894 (2018); arXiv:1807.02145.

R. Pavao and E. Oset, Eur. Phys. J. C78, 857 (2018); arXiv:1808.01950.

Y. Huang, M.Z. Liu, J.X. Lu, J.J. Xie and L.S. Geng, Phys. Rev. D98, 076012 (2018); arXiv:1807.06485.

J^P *should be* $3/2^-$, *and large decay width to* $\bar{K}\pi\Xi$.

Strong decay modes $\bar{K}\Xi$ and $\bar{K}\Xi\pi$ of the $\Omega(2012)$ in the $\bar{K}\Xi(1530)$ and $\eta\Omega$ molecular scenario

PHYSICAL REVIEW D **98**, 076012 (2018)

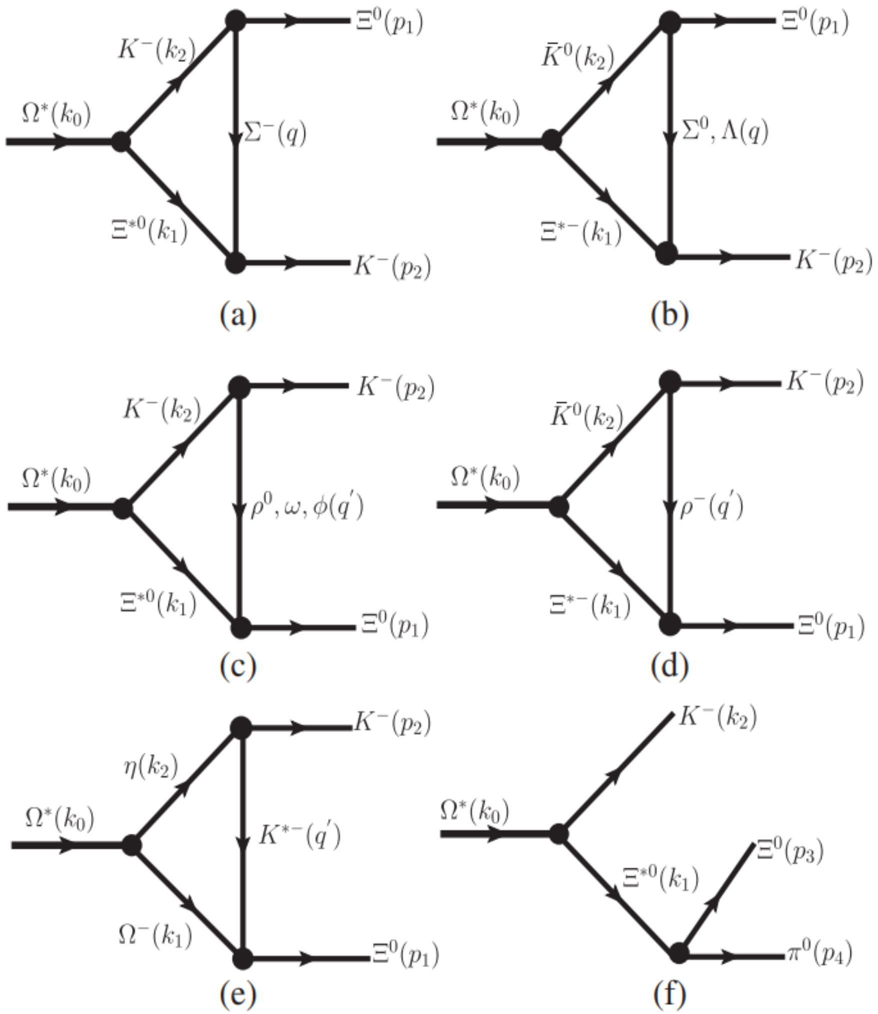


FIG. 1. Feynman diagrams contributing to the decays of the $\Omega(2012)$ to $\bar{K}\Xi$ and $\bar{K}\Xi\pi$.

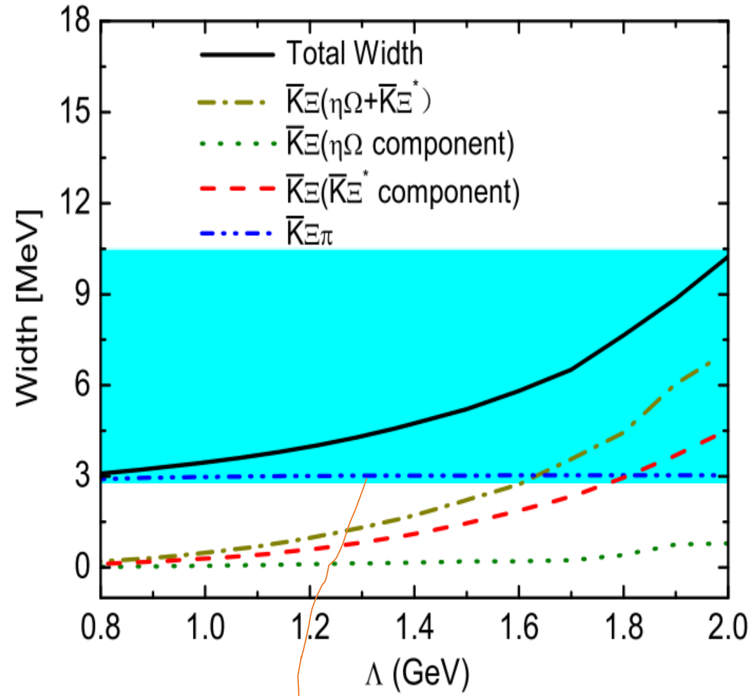


FIG. 2. Total decay width of the $\Omega(2012)$ as a function of the parameter Λ. The cyan error bands correspond to the experimental decay width [1].

Should be 0.8 MeV

Coupled channels dynamics in the generation of the $\Omega(2012)$ resonance

Eur. Phys. J. C (2018) 78:857

R. Pavao[a], E. Oset

$$F = -\frac{1}{4f^2}(k^0 + k'^0)$$

$$V = \begin{array}{cc} & \begin{array}{ccc} \bar{K}\Xi^* & \eta\Omega & \bar{K}\Xi \end{array} \\ & \left(\begin{array}{ccc} 0 & 3F & \alpha q^2 \\ 3F & 0 & \beta q^2 \\ \alpha q^2 & \beta q^2 & 0 \end{array}\right) \begin{array}{c} \bar{K}\Xi^* \\ \eta\Omega \\ \bar{K}\Xi \end{array} \end{array}$$

$$G_{\bar{K}\Xi}(\sqrt{s}) = \int_{|\vec{q}|<q'_{\max}} \frac{d^3q}{(2\pi)^3} \frac{(q/q_{on})^4}{2\omega_{\bar{K}}(\vec{q})} \frac{M_\Xi}{E_\Xi(\vec{q})} \frac{1}{\sqrt{s} - \omega_{\bar{K}}(\vec{q}) - E_\Xi(\vec{q}) + i\epsilon},$$

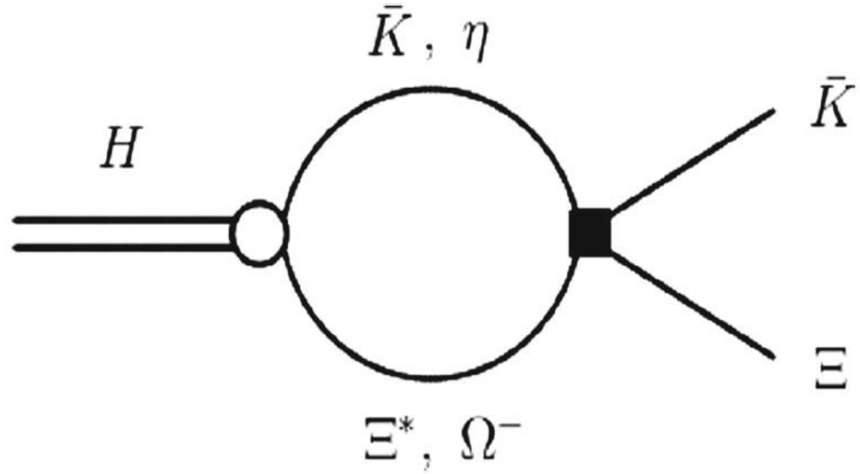


Fig. 2 Decay of $H \to \bar{K}\Xi$ through the creation and re-scattering of the $\bar{K}\Xi^*$ and $\eta\Omega$ pairs

α (10^{-8} MeV^{-3})	β (10^{-8} MeV^{-3})	$q_{\max}$ (MeV)	$(m_{\Omega^*}, \Gamma_{\Omega^*})$ (MeV)	$\Gamma(\bar{K}\Xi)$ (MeV)	$\Gamma(\pi\bar{K}\Xi)$ (MeV)
5.0	0.1	735	(2012.19, 6.36)	3.35	3.01
4.0	1.5	735	(2012.4, 6.2)	3.22	2.98
3.0	3.0	735	(2012.36, 6.19)	3.25	2.94
2.0	4.5	735	(2012.26, 6.23)	3.34	2.89

Search for $\Omega(2012) \to K\Xi(1530) \to K\pi\Xi$ at Belle

PHYSICAL REVIEW D **100,** 032006 (2019)

Using data samples of e^+e^- collisions collected at the $\Upsilon(1S)$, $\Upsilon(2S)$, and $\Upsilon(3S)$ resonances with the Belle detector, we search for the three-body decay of the $\Omega(2012)$ baryon to $K\pi\Xi$. This decay is predicted to dominate for models describing the $\Omega(2012)$ as a $K\Xi(1530)$ molecule. No significant $\Omega(2012)$ signals are observed in the studied channels, and 90% credibility level upper limits on the ratios of the branching fractions relative to $K\Xi$ decay modes are obtained.

$$\mathcal{R}^{\Xi\pi K}_{\Xi K} = \frac{\mathcal{B}(\Omega(2012) \to \Xi(1530)(\to \Xi\pi)K)}{\mathcal{B}(\Omega(2012) \to \Xi K)} < 11.9\%$$

at 90% C.L.

$\mathcal{R}^{\Xi^0\pi^0K^-}_{\Xi^0K^-}$, $\mathcal{R}^{\Xi^-\pi^+K^-}_{\Xi^0K^-}$, $\mathcal{R}^{\Xi^0\pi^-\bar{K}^0}_{\Xi^-\bar{K}^0}$, and $\mathcal{R}^{\Xi\pi K}_{\Xi K}$ to be 9.3%, 81.1%, 21.3%, 30.4%, 7.8%, 25.6%, and 11.9%, respectively. Our result strongly disfavors the molecular interpretation

What should we do next?

Reanalysis of the newly observed Ω^* state in hadronic molecule model

Yong-Hui Lin,[1,2,*] Fei Wang,[2,†] and Bing-Song Zou[1,2,3,‡]

arXiv:1910.13919

parity). It is found that the latest experimental measurements are compatible with the $1/2^+$ and $3/2^+$ $\bar{K}\Xi(1530)$ molecular pictures, while the $5/2^+$ $\bar{K}\Xi(1530)$ molecule shows the larger $\bar{K}\pi\Xi$ three-body decay compared with the $\bar{K}\Xi$ decay as the case of S-wave molecule. Thus, the newly observed $\Omega(2012)$ can be interpreted as the $1/2^+$ or $3/2^+$ $\bar{K}\Xi(1530)$ molecule state according to current experiment data.

The molecular picture for the $\Omega(2012)$ revisited

Natsumi Ikeno,[1,2,*] Genaro Toledo,[2,3,†] and Eulogio Oset[2,‡]

arXiv:2003.07580

channels is obtained from chiral Lagrangians. The transition potential between $\bar{K}\Xi^*$, $\eta\Omega$ and $\bar{K}\Xi$ is taken in terms of free parameters, which together with a cut off to regularize the meson-baryon loops are fitted to the $\Omega(2012)$ data. We find that all data including the recent Belle experiment on $\Gamma_{\Omega^*\to\pi\bar{K}\Xi}/\Gamma_{\Omega^*\to\bar{K}\Xi}$, are compatible with the molecular picture stemming from meson baryon interaction of these channels.

Revisiting the $\Omega(2012)$ as a hadronic molecule and its strong decays

Jun-Xu Lu,[1] Chun-Hua Zeng,[2,3] En Wang,[4] Ju-Jun Xie,[2,3,4,*] and Li-Sheng Geng[1,4,†]

mode of $\Omega(2012)\to\bar{K}\Xi$. In this work, we revisit the newly observed $\Omega(2012)$ from the molecular perspective where this resonance appears to be a dynamically generated state with spin-parity $3/2^-$ from the coupled channels interactions of the $\bar{K}\Xi^*(1530)$ and $\eta\Omega$ in s-wave and $\bar{K}\Xi$ in d-wave. With the model parameters for the d-wave interaction, we show that the ratio of these decay fractions reported recently by the Belle collaboration can be easily accommodated.

arXiv:2003.07588, accepted by EPJC

$\bar{K}\Xi^*$, $\eta\Omega$ and $\bar{K}\Xi$ in coupled channels

$$
\begin{aligned}
V_{11} &= V_{22} = V_{33} = 0, \\
V_{12} &= V_{21} = -\frac{3}{4f_\pi^2}(k_1^0 + k_2^0), \\
V_{13} &= V_{31} = \alpha q_3^2, \\
V_{23} &= V_{32} = \beta q_3^2,
\end{aligned}
$$

$$
\begin{aligned}
k_1^0 &= \frac{s + m_{\bar{K}}^2 - M_{\Xi^*}^2}{2\sqrt{s}}, \\
k_2^0 &= \frac{s + m_\eta^2 - M_\Omega^2}{2\sqrt{s}},
\end{aligned}
$$

$$G_{11} = \int_0^{\Lambda_1} \frac{d^3q}{(2\pi)^3} \frac{1}{2\omega_1} \frac{M_{\Xi^*}}{E_1} \frac{1}{\sqrt{s} - \omega_1 - E_1 + i\epsilon}$$

$$G_{22} = \int_0^{\Lambda_2} \frac{d^3q}{(2\pi)^3} \frac{1}{2\omega_2} \frac{M_\Omega}{E_2} \frac{1}{\sqrt{s} - \omega_2 - E_2 + i\epsilon}$$

$$G_{33} = \int_0^{\Lambda_3} \frac{d^3q}{(2\pi)^3} \frac{(q/q_3)^4}{2\omega_3} \frac{M_\Xi}{E_3} \frac{1}{\sqrt{s} - \omega_3 - E_3 + i\epsilon}$$

$$q_3 = \frac{\sqrt{[s - (m_{\bar{K}} + M_\Xi)^2][s - (m_{\bar{K}} - M_\Xi)^2]}}{2\sqrt{s}}$$

$$\Downarrow$$

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

Jun-Xu Lu, Chun-Hua Zeng, En Wang, Ju-Jun Xie, and Li-Sheng Geng, arXiv:2003.07588, accepted by EPJC

Pole of scattering amplitude T

$$T_{ij} = \frac{g_{ii} g_{jj}}{\sqrt{s} - z_R}, \qquad Z_R = M_R - i\frac{\Gamma_R}{2}$$

g_{kk} is the coupling of the resonance to the kth channel.

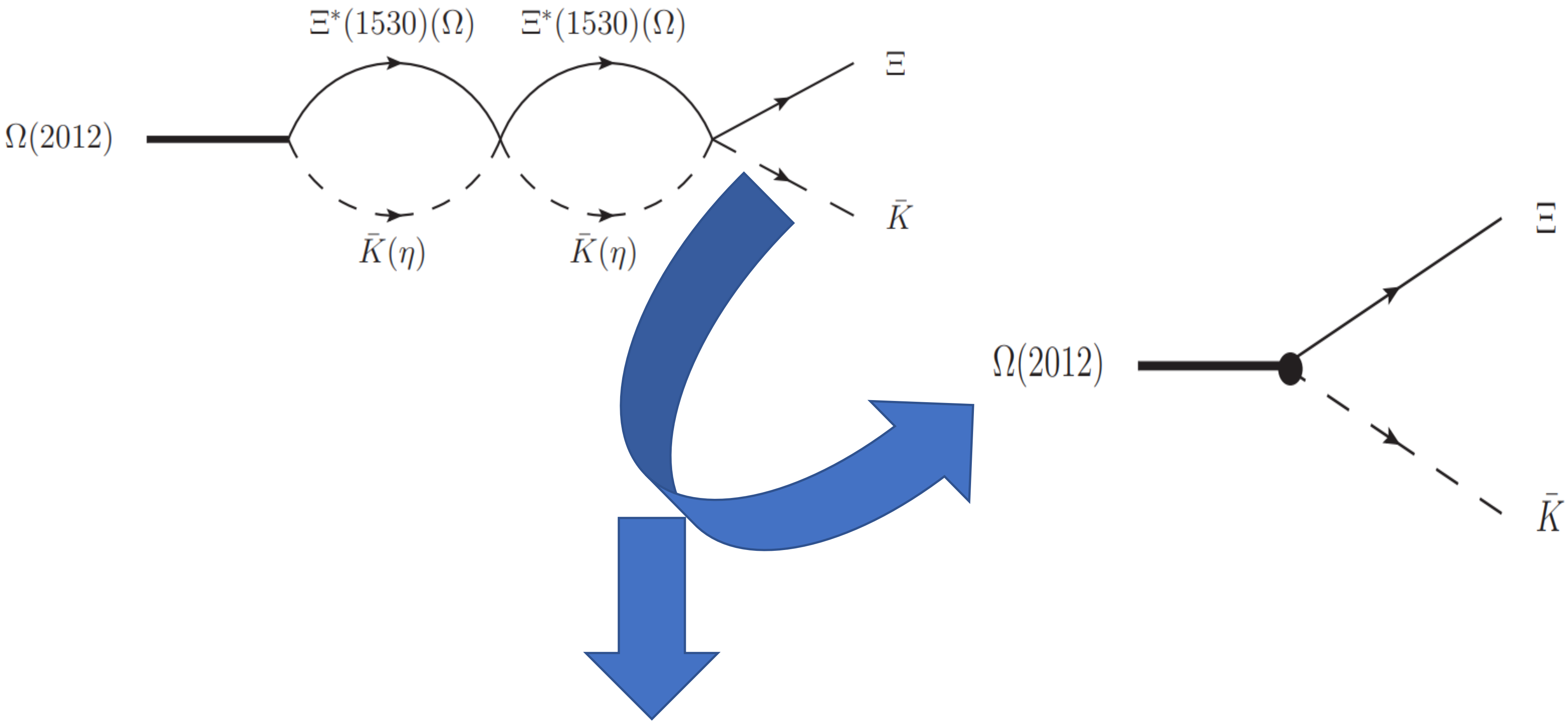
Assumption $\Lambda_1 = \Lambda_2 = \Lambda_3 = q_{\max}$

$M = 2012.4 \pm 0.9$ MeV $\quad \Gamma = 6.4 \pm 3.0$ MeV $\quad R^{\bar{K}\pi\Xi}_{\bar{K}\Xi} < 11.9\%$

$\alpha < -5 \times 10^{-8}\mathrm{MeV}^{-3},\ \beta > 15 \times 10^{-8}\mathrm{MeV}^{-3}$

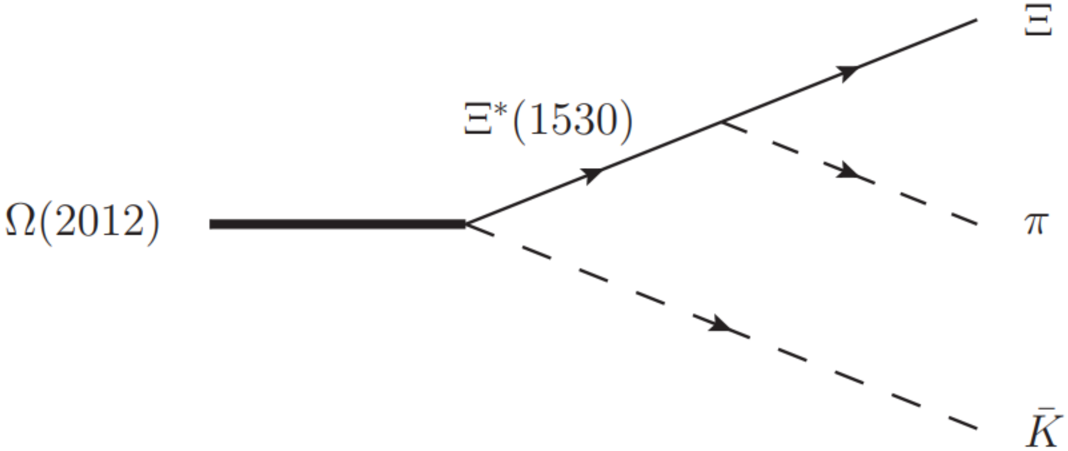
$q_{\max} > 720$ MeV.

Two body decay



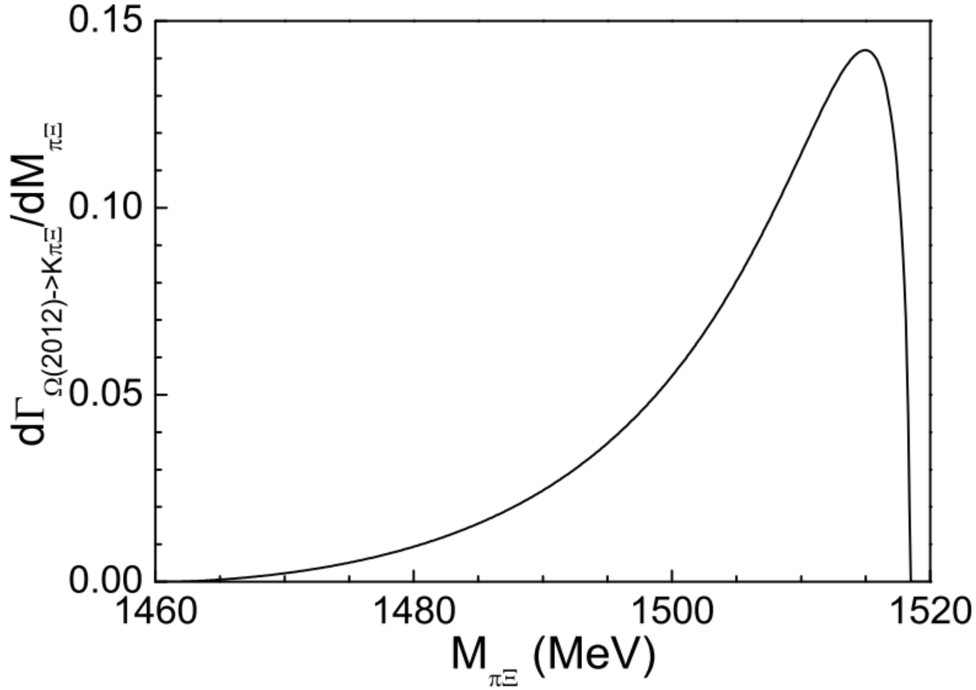
$$\Gamma_{\Omega(2012)\to\bar{K}\Xi} = \frac{|g_{\Omega^*\bar{K}\Xi}|^2}{2\pi}\frac{M_\Xi}{M}q_{\bar{K}}$$

Three body decay



$$\frac{d\Gamma_{\Omega(2012)\to\bar{K}\pi\Xi}}{dM_{\pi\Xi}} = \frac{M_{\pi\Xi}}{\pi^2 M}\frac{|g_{\Omega^*\bar{K}\Xi^*}|^2 p_{\bar{K}}\tilde{\Gamma}_{\Xi^*}}{4(M_{\pi\Xi}-M_{\Xi^*})^2+\tilde{\Gamma}^2_{\Xi^*}},$$

$$\Gamma_{\Omega(2012)\to\bar{K}\pi\Xi} = \int_{m_\pi+M_\Xi}^{M-m_{\bar{K}}} \frac{d\Gamma}{dM_{\pi\Xi}}$$



Very small phase space!!!

Pseudo-“fitting”

$Fix\ q_{\max}$

$$\chi^2 = \left(\frac{M^{\rm th} - M^{\rm exp}}{\Delta M^{\rm exp}}\right)^2 + \left(\frac{\Gamma^{\rm th} - \Gamma^{\rm exp}}{\Delta \Gamma^{\rm exp}}\right)^2$$

(α, β)	χ^2	χ^2_{min}
(α_1, β_1)	$\chi^{2(1)}_{best}$	
$\vdots$	$\vdots$	
(α_i, β_i)	$\chi^{2(i)}_{best}$	$\Longrightarrow \chi^2_{min} = \chi^{2(k)}_{best}$
$\vdots$	$\vdots$	
(α_N, β_N)	$\chi^{2(N)}_{best}$	

$$\chi^2_{\rm best} < \chi^2_{\rm min} + 1$$

$$\alpha = \alpha_0 \pm \Delta\alpha$$

$$\beta = \beta_0 \pm \Delta\beta$$

$$(\alpha_0, \beta_0) = (\alpha_k, \beta_k)$$

Results

$q_{\max}$ (MeV)	α (10^{-8} MeV^{-3})	β (10^{-8} MeV^{-3})	(M_R, Γ_R) (MeV)	$\lvert g_{\Omega^* \bar{K}\Xi^*}\rvert$	$\lvert g_{\Omega^* \eta\Omega}\rvert$	$\lvert g_{\Omega^* \bar{K}\Xi}\rvert$
735	-6.6 ± 0.8	16.5 ± 0.8	$(2012.3 \pm 0.4, 8.3 \pm 0.6)$	1.83 ± 0.02	3.35 ± 0.06	0.42 ± 0.02
750	-9.9 ± 0.5	18.5 ± 0.5	$(2012.2 \pm 0.4, 7.8 \pm 0.8)$	1.80 ± 0.01	3.46 ± 0.06	0.41 ± 0.03
800	-17.5 ± 0.6	20.6 ± 0.5	$(2012.4 \pm 0.5, 6.4 \pm 1.3)$	1.58 ± 0.02	3.60 ± 0.04	0.37 ± 0.04
850	-20.2 ± 1.0	19.6 ± 0.8	$(2012.4 \pm 0.5, 6.4 \pm 1.1)$	1.39 ± 0.03	3.78 ± 0.04	0.37 ± 0.03
900	-20.8 ± 1.7	17.5 ± 1.1	$(2012.4 \pm 0.5, 6.4 \pm 1.3)$	1.25 ± 0.04	3.85 ± 0.04	0.37 ± 0.04

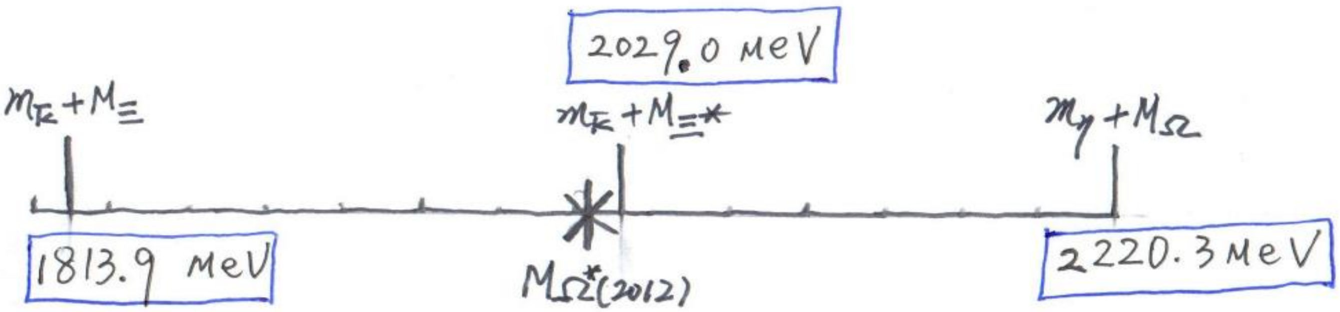
$\Gamma_{\Omega(2012)\to\bar{K}\pi\Xi}$ (MeV)	$\Gamma_{\Omega(2012)\to\bar{K}\Xi}$ (MeV)	Br$[\Omega(2012) \to \bar{K}\pi\Xi]$	Br$[\Omega(2012) \to \bar{K}\Xi]$	R
0.87 ± 0.03	7.32 ± 0.64	$(10.5^{+0.5}_{-0.8})\%$	$(88.4^{+0.5}_{-1.5})\%$	11.88%
0.84 ± 0.04	6.96 ± 0.63	$(9.5^{+0}_{-1.0})\%$	$(90.5^{+0}_{-2.6})\%$	10.50%
0.66 ± 0.02	5.57 ± 1.37	$(10.3^{+1.6}_{-1.7})\%$	$(86.5^{+1.6}_{-2.9})\%$	11.90%
0.51 ± 0.03	5.66 ± 1.07	$(7.9^{+1.9}_{-1.5})\%$	$(88.2^{+1.9}_{-1.6})\%$	9.00%
0.41 ± 0.03	5.73 ± 1.25	$(6.5^{+1.7}_{-1.9})\%$	$(90.0^{+1.7}_{-2.2})\%$	7.22%

Three body decay width is small !!!

1, Small phase space
2, Narrow width of $\Xi^*(1530)$

Summary

We conclude that



the $\Omega(2012)$ is a molecular hadronic state,

dynamically generated from the interactions of $\bar{K}\Xi^*(1530)$ and $\eta\Omega$ in s wave

and $\bar{K}\Xi$ in d wave.

However

一切都是刚刚起步！！！

We need more efforts, both on theoretical and experimental sides.

Thank you very much for your attention!