$\Xi(1690)$ as a $\bar{K}\Sigma$ molecular state

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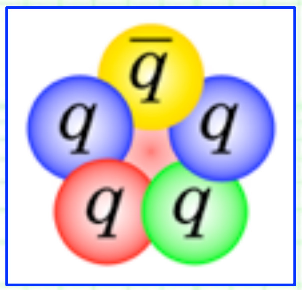
[1] T. S. , Prog. *Theor. Exp. Phys. Letters*, in press [arXiv:1505.02849 [hep-ph]].

1. Introduction

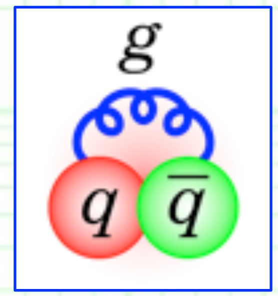
++ Ξ(1690) as an exotic hadron ? ++

- **Exotic hadrons** --- not same quark component as ordinary hadrons = not qqq nor $q\bar{q}$. <-- Do exotic hadrons really exist ???

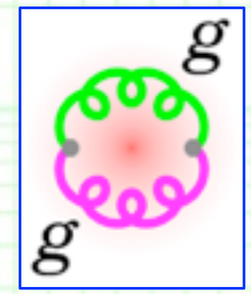


Penta-quarks

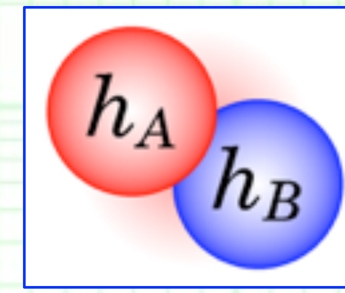
Tetra-quarks



Hybrids



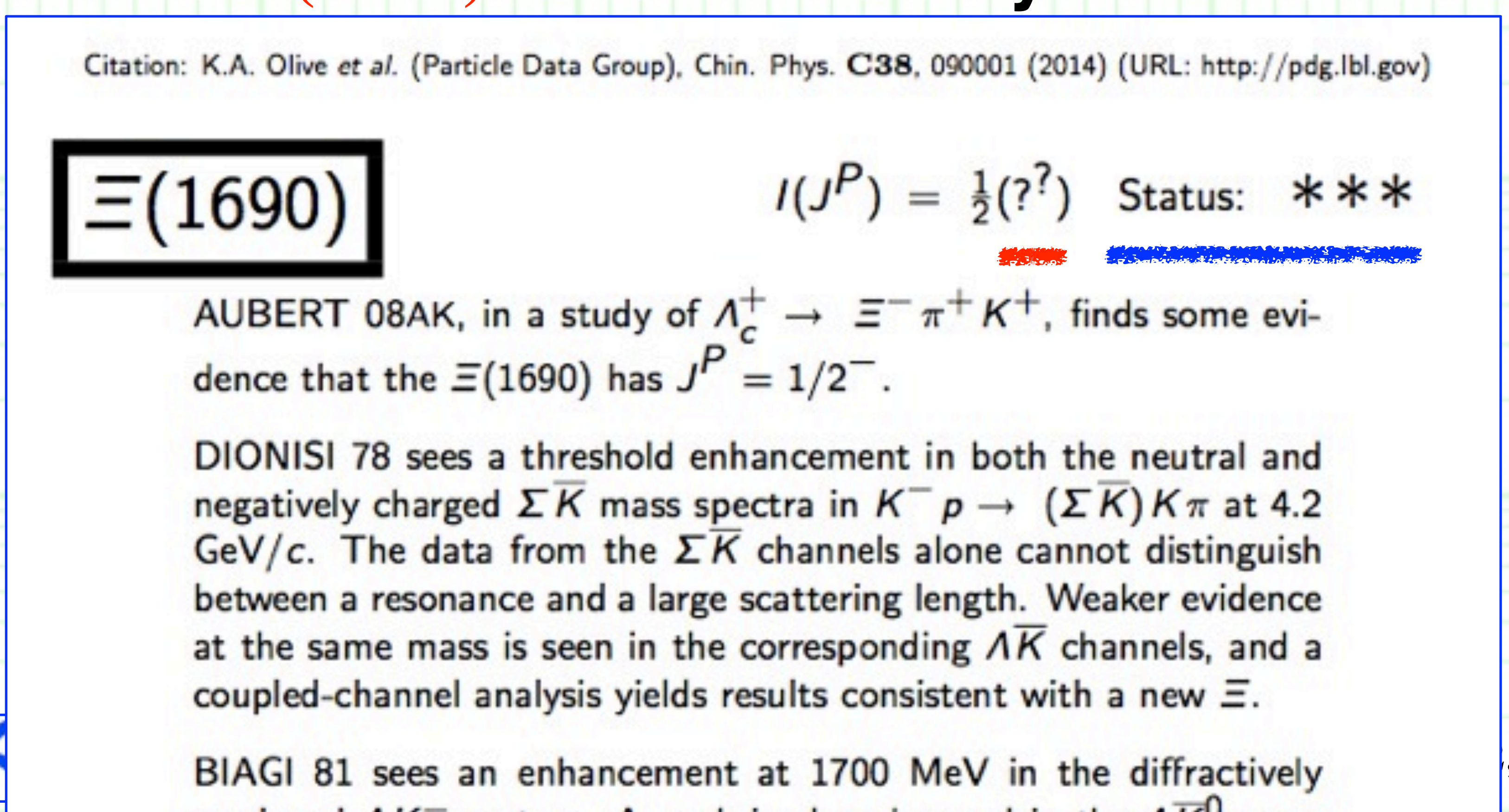
Glueballs



Hadronic molecules

...

- **The Ξ(1690) resonance** may be an exotic hadron.



Citation: K.A. Olive *et al.* (Particle Data Group), Chin. Phys. **C38**, 090001 (2014) (URL: http://pdg.lbl.gov)

Ξ(1690) $I(J^P) = \frac{1}{2}(?^?)$ Status: ∗∗∗

AUBERT 08AK, in a study of $\Lambda_c^+ \to \Xi^- \pi^+ K^+$, finds some evidence that the Ξ(1690) has $J^P = 1/2^-$.

DIONISI 78 sees a threshold enhancement in both the neutral and negatively charged $\Sigma\overline{K}$ mass spectra in $K^- p \to (\Sigma\overline{K}) K\pi$ at 4.2 GeV/c. The data from the $\Sigma\overline{K}$ channels alone cannot distinguish between a resonance and a large scattering length. Weaker evidence at the same mass is seen in the corresponding $\Lambda\overline{K}$ channels, and a coupled-channel analysis yields results consistent with a new Ξ.

BIAGI 81 sees an enhancement at 1700 MeV in the diffractively

- □ Mass: 1690 ± 10 MeV.
- □ Width: < 30 MeV, but a relatively **narrow width** has been reported.

Particle Data Group.

1. Introduction

++ Experiments of the Ξ(1690) resonance ++

- Historically Ξ(1690) was discovered as **a threshold enhancement in both the neutral and charged $\bar{K}\Sigma$ mass spectra** in the $K^- p \to (\bar{K}\Sigma) K \pi$ reaction at 4.2 GeV/c.

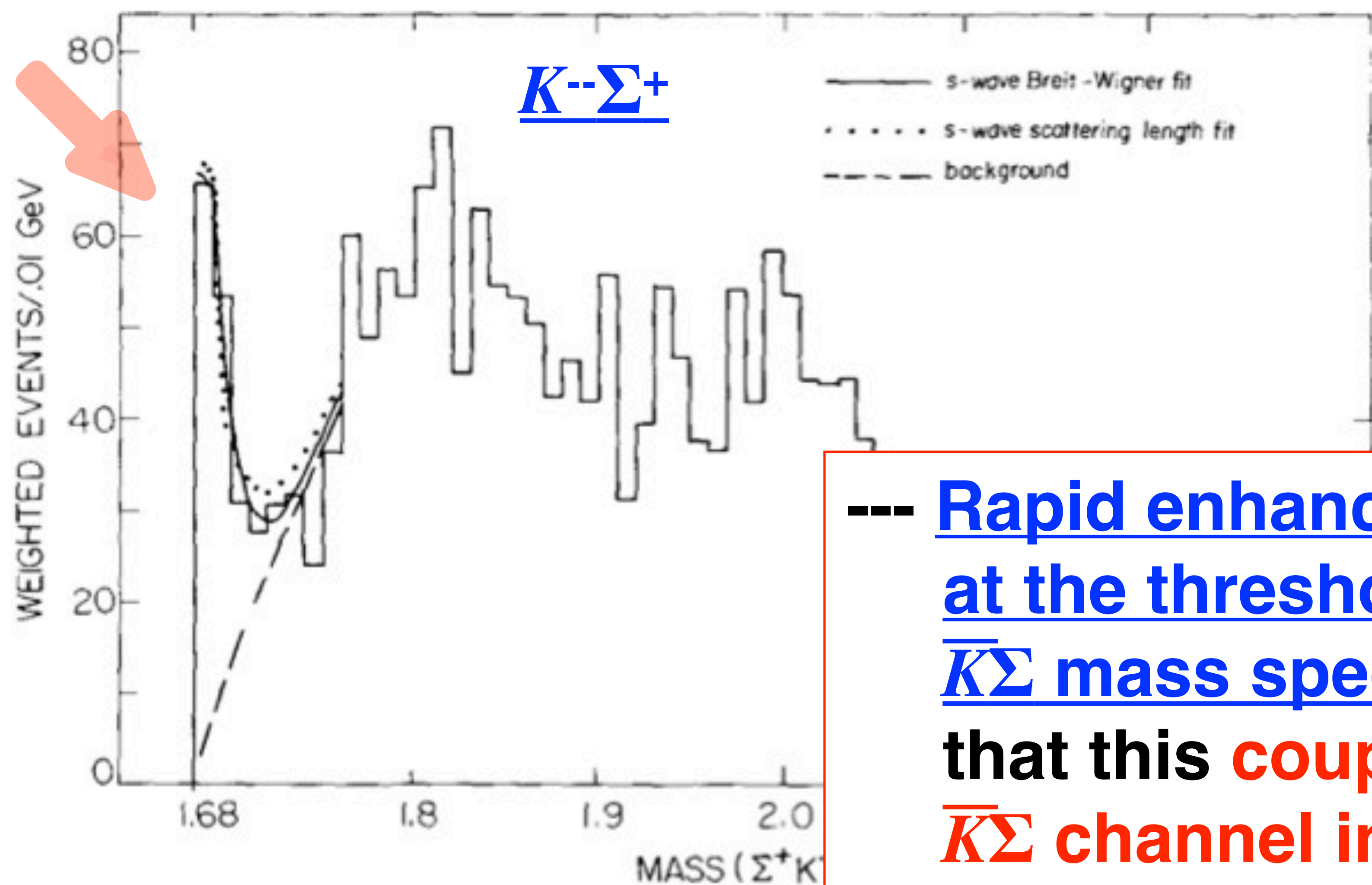


Fig. 1. The $\Sigma^+ K^-$ mass spectrum for the reaction $K^- p \to \Sigma^+ K^- K^+ \pi^-$ after
The origin of the curves is indicated.

--- Rapid enhancement at the threshold of the $\bar{K}\Sigma$ mass spectra implies that this **couples to the $\bar{K}\Sigma$ channel in s wave**.
<=> $J^P = 1/2^-$ is implied.

C. Dionisi *et al.*, *Phys. Lett.* B80 (1978) 145.

1. Introduction

++ Experiments of the Ξ(1690) resonance ++

- Ξ(1690) has been observed and investigated in several experiments.
  - Especially small total decay width and tiny branching fraction to the πΞ state have been reported, for instance:

$\Gamma = 10 \pm 6$ MeV

M. I. Adamovich *et al.* [WA89 Collab.], *Eur. Phys. J.* C5 (1998) 621.

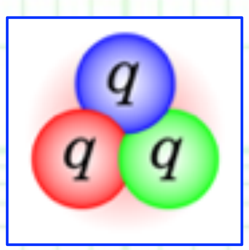
$\Gamma(\pi\Xi)/\Gamma(\bar{K}\Sigma) < 0.09$

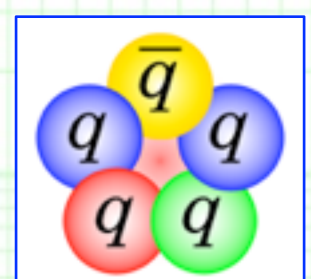
Particle Data Group.

- However, the small decay width and tiny BR fraction to πΞ bring a difficulty, assuming $J^P = 1/2^-$ for Ξ(1690).

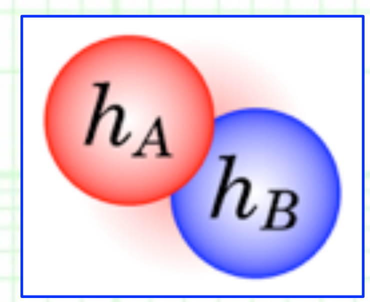
--- Naive quark models inevitably predict decay to πΞ to some extent

--> Ξ(1690) might have a non-trivial structure than usual qqq state ?





or



--- But its properties and structure are still unclear.

1. Introduction

++ Theories of the Ξ(1690) resonance ++

- Ξ(1690) and other Ξ* resonances has been investigated in several theoretical frameworks as well, for instance:

  - Quark models.

    K. T. Chao, N. Isgur and G. Karl, *Phys. Rev.* D23 (1981) 155;
    S. Capstick and N. Isgur, *Phys. Rev.* D34 (1986) 2809;
    M. Pervin and W. Roberts, *Phys. Rev.* C77 (2008) 025202;
    L. Y. Xiao and X. H. Zhong, *Phys. Rev.* D87 (2013) 094002;
    N. Sharma, A. Martinez Torres, K. P. Khemchandani and H. Dahiya, *Eur. Phys. J.* A49 (2013) 11;
    ...

  - Skyrme model.

    Y. Oh, *Phys. Rev.* D75 (2007) 074002.

  - Chiral unitary approach.

    A. Ramos, E. Oset and C. Bennhold, *Phys. Rev. Lett.* 89 (2002) 252001;
    C. Garcia-Recio, M. F. M. Lutz and J. Nieves, *Phys. Lett.* B582 (2004) 49;
    D. Gamermann, C. Garcia-Recio, J. Nieves and L. L. Salcedo, *Phys. Rev.* D84 (2011) 056017.

1. Introduction

++ Ξ* resonances in chiral unitary approach ++

- **Ξ* resonances in chiral unitary approach.**

--- Based on the combination of the chiral perturbation theory and the unitarization of the scattering amplitude.

$(\frac{1}{2}, -2)$		$[\pi\Xi]$ 7.5	5.6	seen	2.6
$\Xi(1620)^{*}$		$[\bar{K}\Lambda]$ 5.2	2.8	seen	−1.5
$M \approx 1620$	1565	$[\bar{K}\Sigma]$ 0.7	2.6	0	−0.8
$\Gamma = 23$	247	$[\eta\Xi]$ 0.3	4.9	0	0.3
$(\frac{1}{2}, -2)$		$[\pi\Xi]$ 0.02	0.1	seen	−0.1
$\Xi(1690)^{***}$		$[\bar{K}\Lambda]$ 0.16	6.0	seen	0.9
$M = 1690 \pm 10$	1663	$[\bar{K}\Sigma]$ 5.15	3.1	seen	−2.5
$\Gamma = 10 \pm 6$	4	$[\eta\Xi]$ 2.28	3.2	0	−1.7

□ Systematic studies were done for several Ξ* states together with many other resonances.

C. Garcia-Recio, M. F. M. Lutz and J. Nieves, *Phys. Lett.* B582 (2004) 49.

8 (1134)	2037–24i	0.6	0.6	0.3	0.2	0.3	↑0.5	1.5	0.6	**1.8**	**2.4**	1.1	0.2	1.0	**2.1**	
10 (70)	1729–46i	0.6	1.4	0.4	↑1.6	1.4	**2.1**	1.0	0.4	**3.3**	1.5	0.4	0.2	1.6	1.0	Ξ(1950) ★★★
8 (70)	1651–2i	0.2	0.3	↑**2.2**	1.3	1.0	**2.6**	0.2	0.6	0.9	0.4	0.2	**1.7**	0.4	0.2	Ξ(1690) ★★★
8 (56)	1577–139i	**2.6**	↑**1.7**	0.5	0.1	0.8	1.0	0.7	0.1	0.6	1.3	0.3	0.1	0.2	1.2	Ξ(1620) ★

--- Narrow width for Ξ(1690) ! But its mass is lower than Exp. value.

D. Gamermann, C. Garcia-Recio, J. Nieves and L. L. Salcedo, *Phys. Rev.* D84 (2011) 056017.

1. Introduction

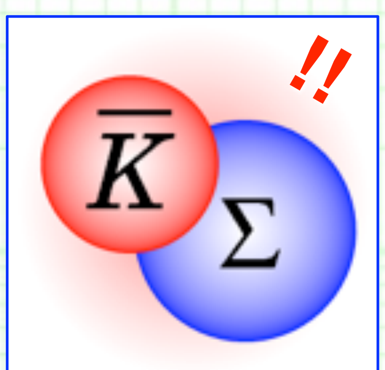
++ In this study ... ++

- In this study we concentrate on the phenomena near the $\bar{K}\Sigma$ threshold and on the $\Xi(1690)$ resonance.

- By using the chiral unitary approach and adjusting parameters, we show the narrow $\Xi(1690)$ state, which was studied in the previous studies, can exist near the $\bar{K}\Sigma$ threshold with $J^P = 1/2^-$, and it reproduces experimental mass spectra qualitatively well.

- We investigate and clarify properties of the $\Xi(1690)$ state, including its small decay width, molecular structure, etc.

--- We especially show that the $\Xi(1690)$ resonance can be indeed an s-wave $\bar{K}\Sigma$ molecular state in terms of the compositeness.



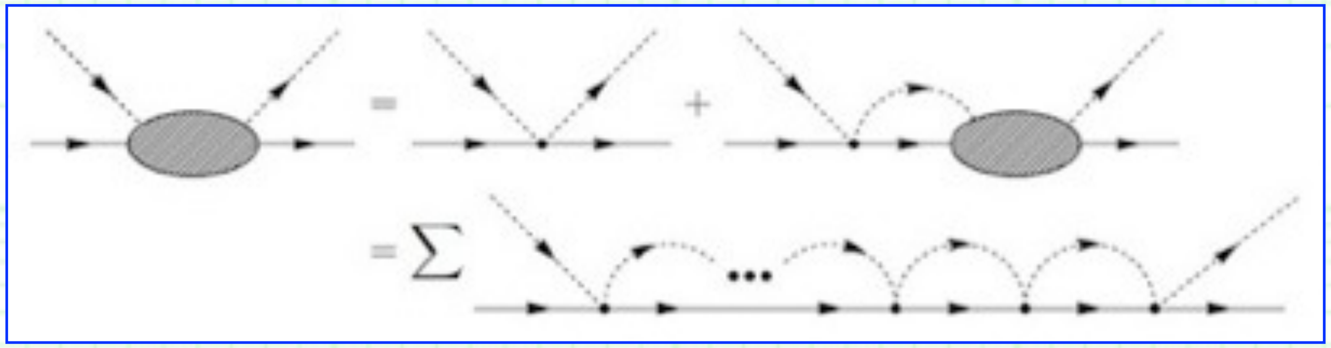
Hyodo-Jido-Hosaka (2012), Aceti-Oset (2012), Nagahiro-Hosaka (2014), ...
See Hyodo, *Int. J. Mod. Phys.* A28 (2013) 1330045;
also T. S. , Hyodo and Jido, *PTEP* (2015) 063D04.

2. Formulation

++ Chiral unitary approach ++

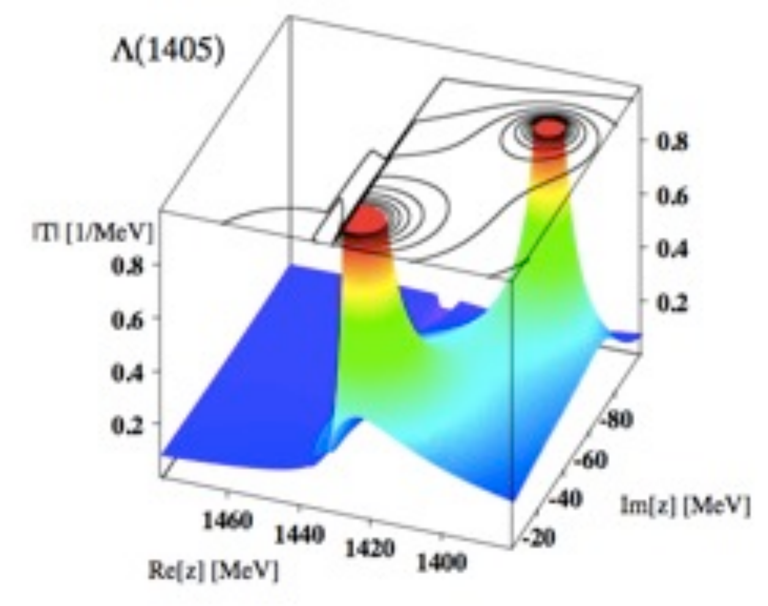
- We employ **the chiral unitary approach** for the *s*-wave $\bar{K}\Sigma$-$\bar{K}\Lambda$-$\pi\Xi$-$\eta\Xi$ coupled-channels scattering.

$$T_{jk}(w) = V_{jk}(w) + \sum_{l} V_{jl}(w) G_l(w) T_{lk}(w)$$



--- The chiral unitary approach is **most successful in the $\bar{K}N$ interaction and $\Lambda(1405)$**.

Kaiser-Siegel-Weise (1995), Oset-Ramos (1998), Oller-Meissner (2001), Lutz-Kolomeitsev (2002), Jido *et al.* (2003), … .



Hyodo and Jido (2012).

- In this study we use **the Weinberg-Tomozawa interaction** for the interaction kernel V.

--- The leading order term of ChPT in *s* wave:

$$V_{jk}(w) = -\frac{C_{jk}}{4 f_j f_k}(2w - M_j - M_k)\sqrt{\frac{E_j + M_j}{2M_j}}\sqrt{\frac{E_k + M_k}{2M_k}}$$

<-- We have **no free parameters in the interaction kernel**.

2. Formulation

++ Chiral unitary approach ++

- For the loop function G we take a covariant expression:

$$G_j(w) = i \int \frac{d^4 q}{(2\pi)^4} \frac{1}{(P/2+q)^2 - m_j^2 + i0} \frac{2M_j}{(P/2-q)^2 - M_j^2 + i0}$$

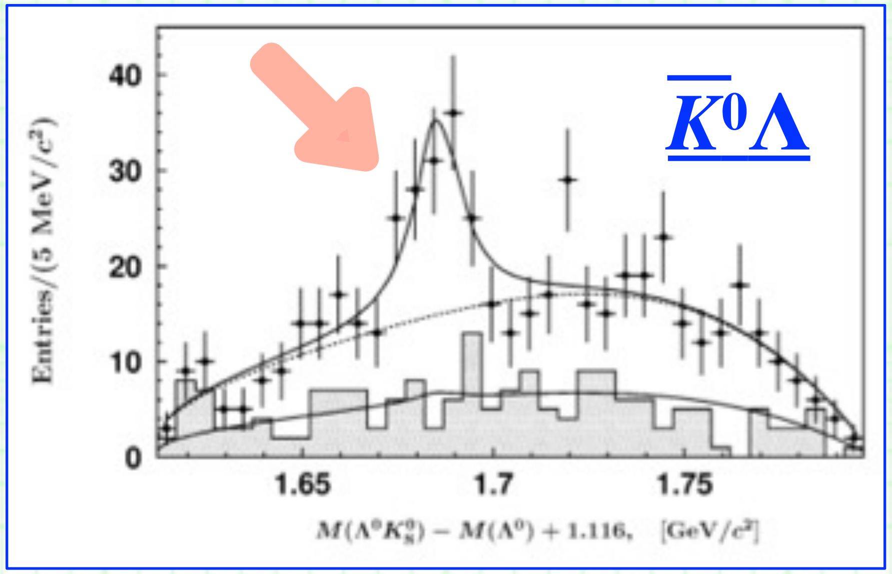
  - The integral is calculated with the dimensional regularization, and an infinite constant is replaced with a subtraction constant in each channel.

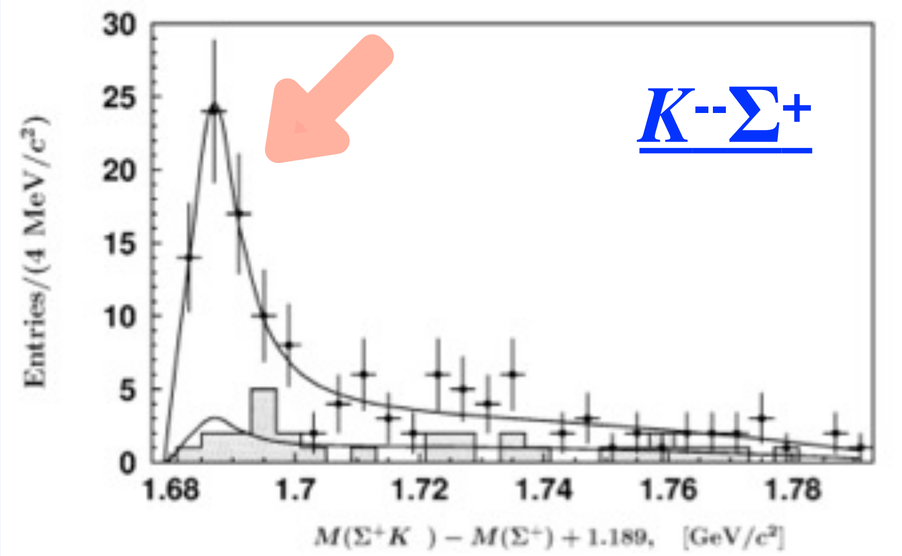
--> Subtraction constants are free parameters.

  - We assume the isospin symmetry for the subtraction constants, so we have 4 free parameters ($a_{K\Sigma}$, $a_{K\Lambda}$, $a_{\pi\Xi}$, and $a_{\eta\Xi}$), which are fixed so as to reproduce the mass spectra by Belle.

--- Neutral Ξ(1690).

K. Abe *et al.* [Belle Collab.], *Phys. Lett.* B524 (2002) 33.

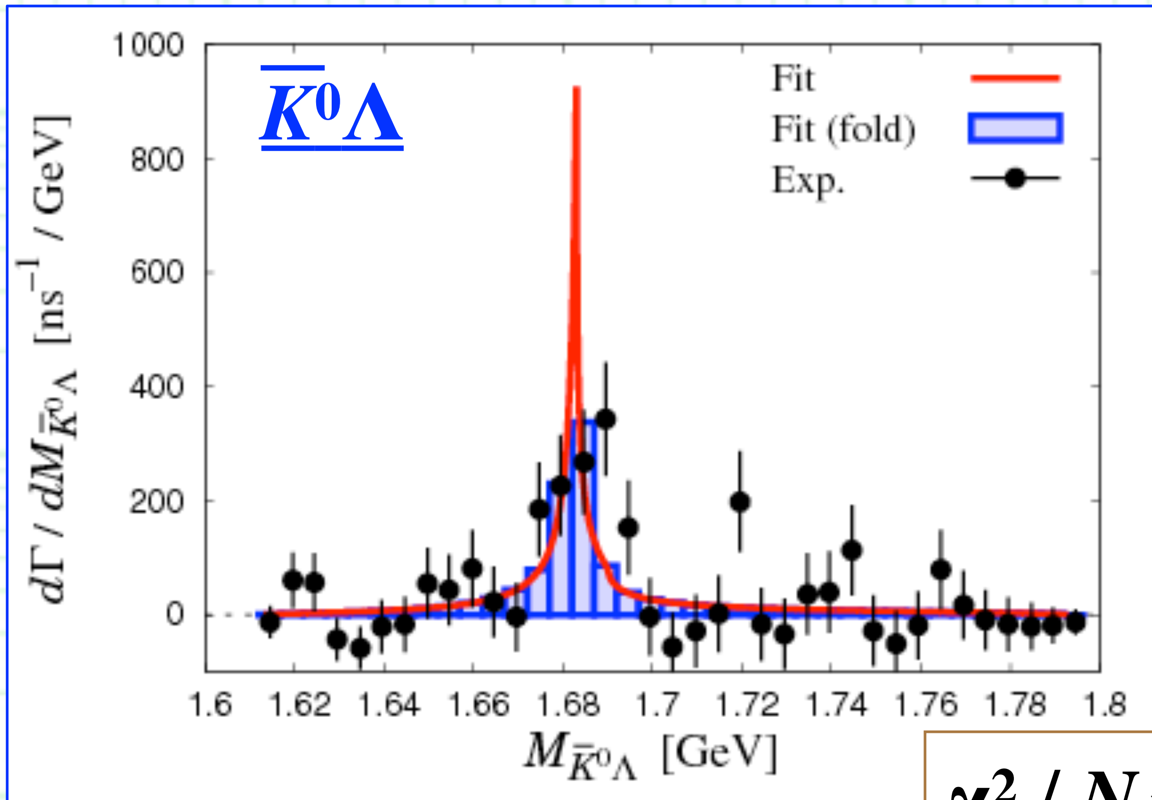


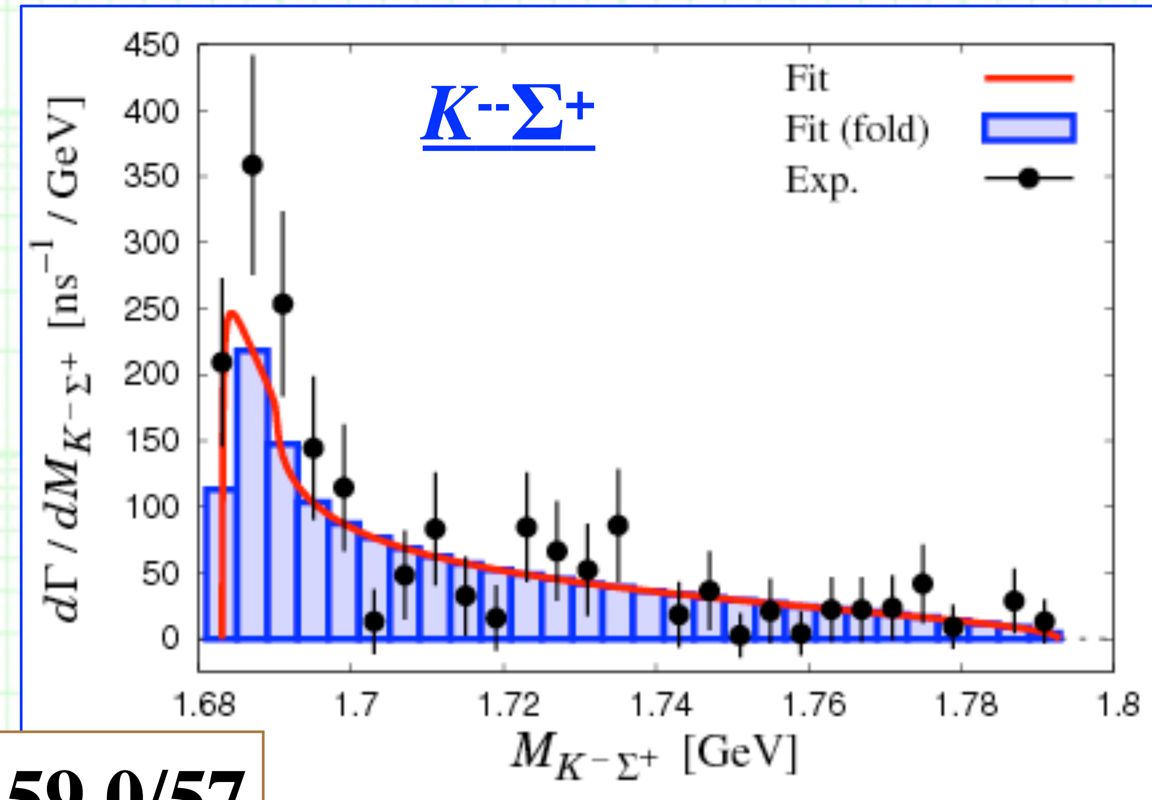


3. Results and discussions

++ Fitting to the Belle data ++

- We fix **4 free parameters** ($a_{K\Sigma}$, $a_{K\Lambda}$, $a_{\pi\Xi}$, and $a_{\eta\Xi}$) **so as to reproduce the mass spectra by Belle**. The result of the best fit is:





$\chi^2 / N_{\mathrm{d.o.f}} = 59.0/57$

- Background of the Belle data is subtracted.
- Relative scale between $\bar{K}^0\Lambda$ and $K^-\Sigma^+$ is fixed with the branching fractions:

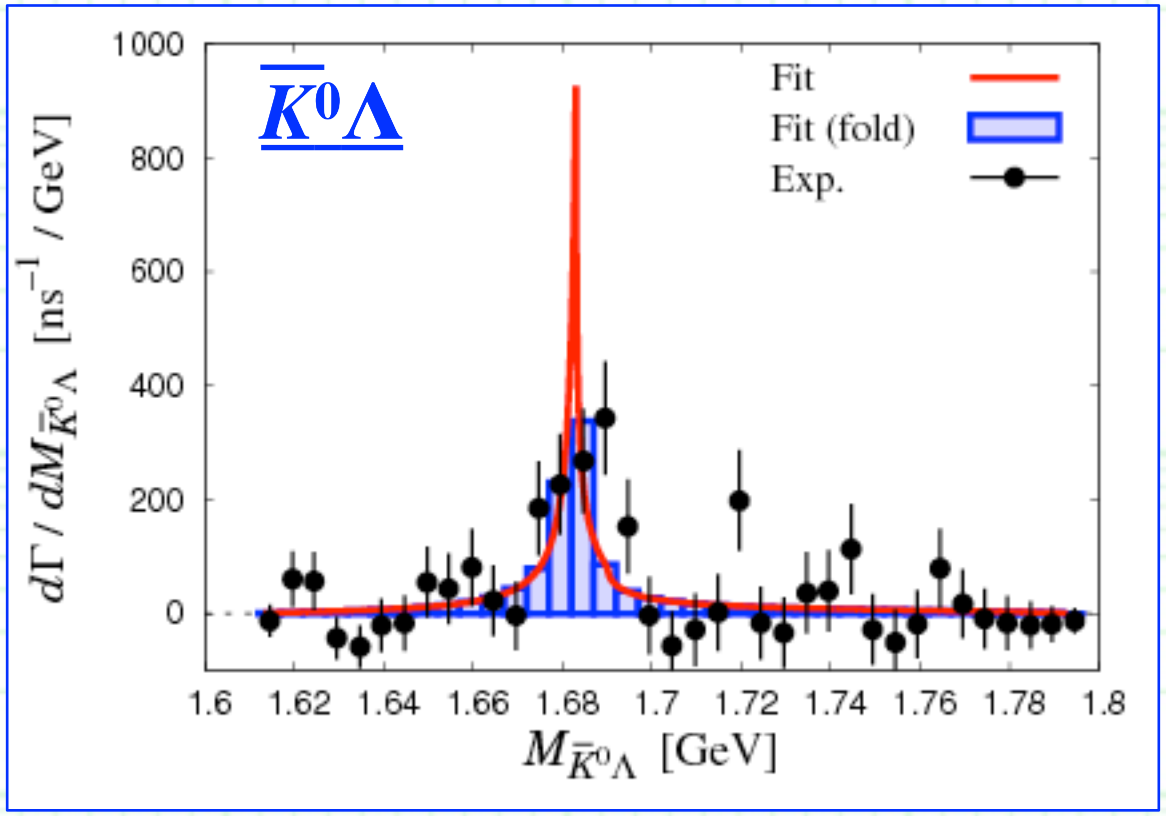
$$\mathcal{B}[\Lambda_c^+ \to \Xi(1690)^0 K^+ \to (K^-\Sigma^+)K^+] = (1.3 \pm 0.5) \times 10^{-3}$$

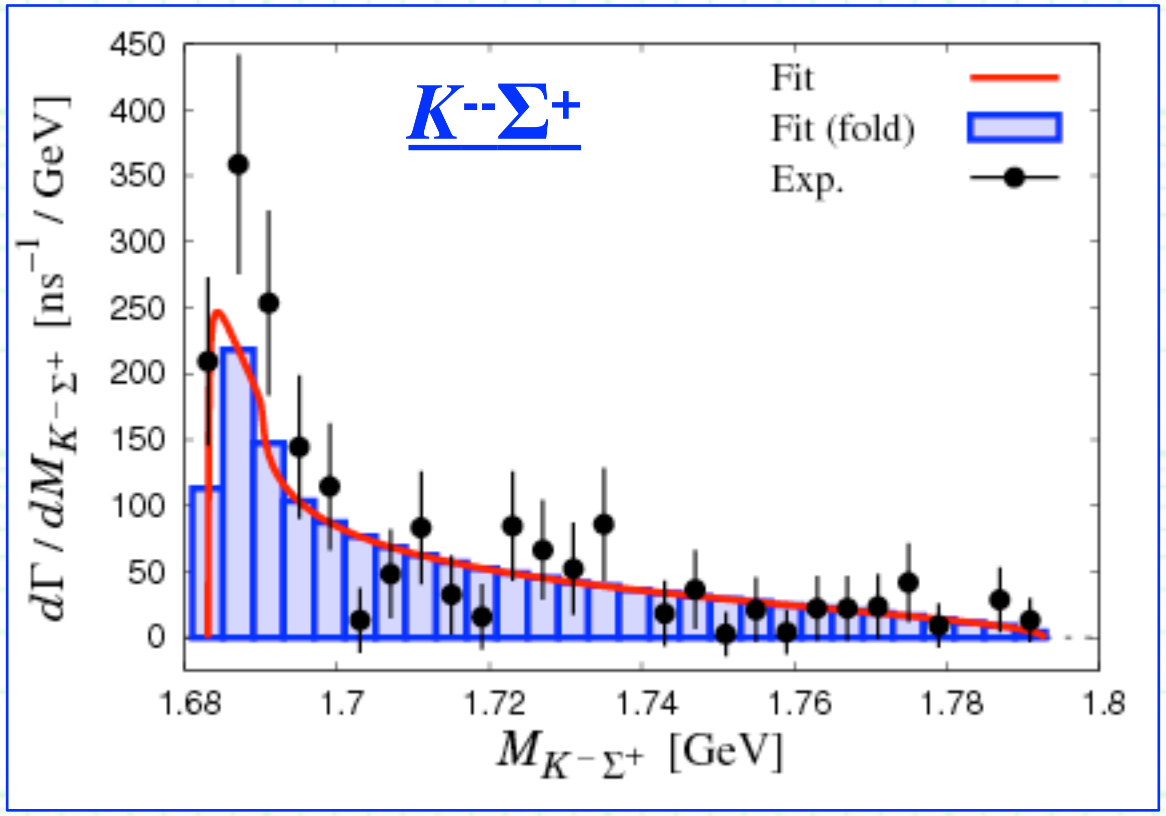
$$\mathcal{B}[\Lambda_c^+ \to \Xi(1690)^0 K^+ \to (\bar{K}^0\Lambda)K^+] = (8.1 \pm 3.0) \times 10^{-4}$$

3. Results and discussions

++ Fitting to the Belle data ++

- We fix 4 free parameters ($a_{K\Sigma}$, $a_{K\Lambda}$, $a_{\pi\Xi}$, and $a_{\eta\Xi}$) so as to reproduce the mass spectra by Belle. The result of the best fit is:





1. The Belle data on $\Xi(1690)$ are reproduced qualitatively well with very small width ~ 1 MeV.

--- We can calculate the ratio

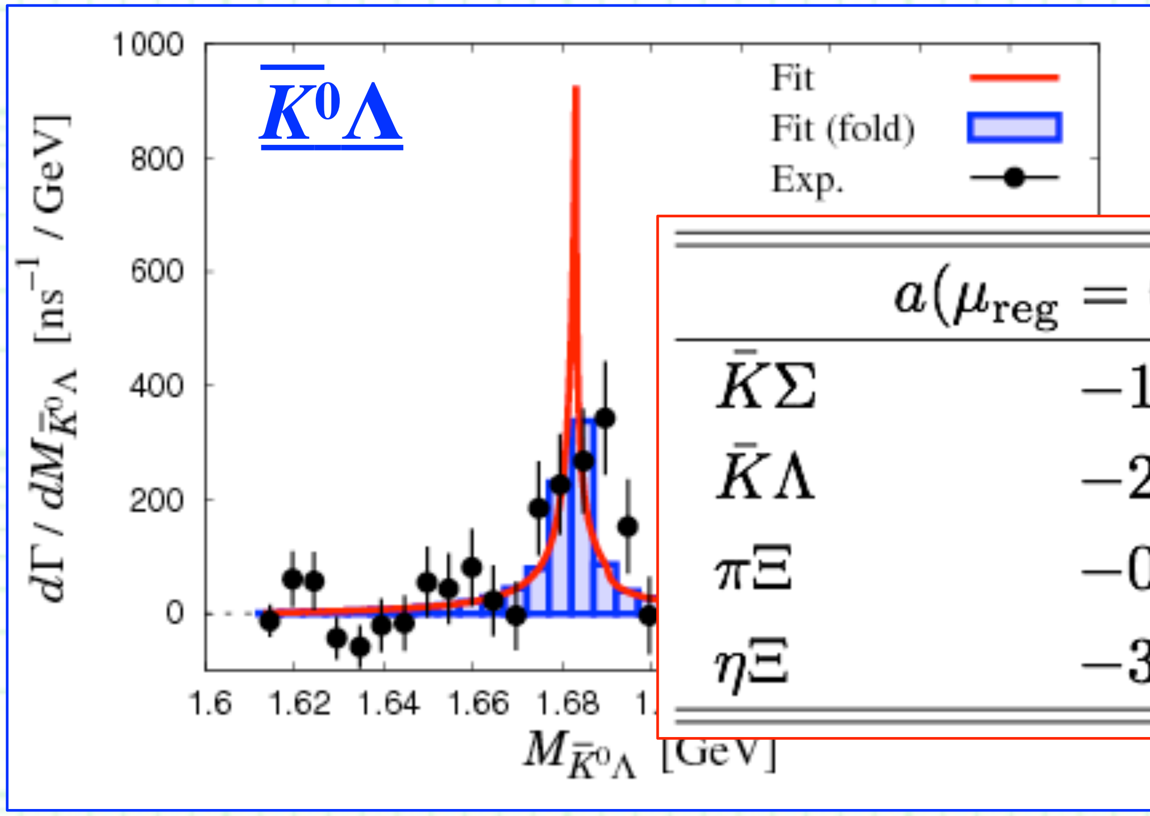
$$R \equiv \frac{\mathcal{B}[\Lambda_c^+ \to \Xi(1690)^0 K^+ \to (K^- \Sigma^+) K^+]}{\mathcal{B}[\Lambda_c^+ \to \Xi(1690)^0 K^+ \to (\bar{K}^0 \Lambda) K^+]}$$

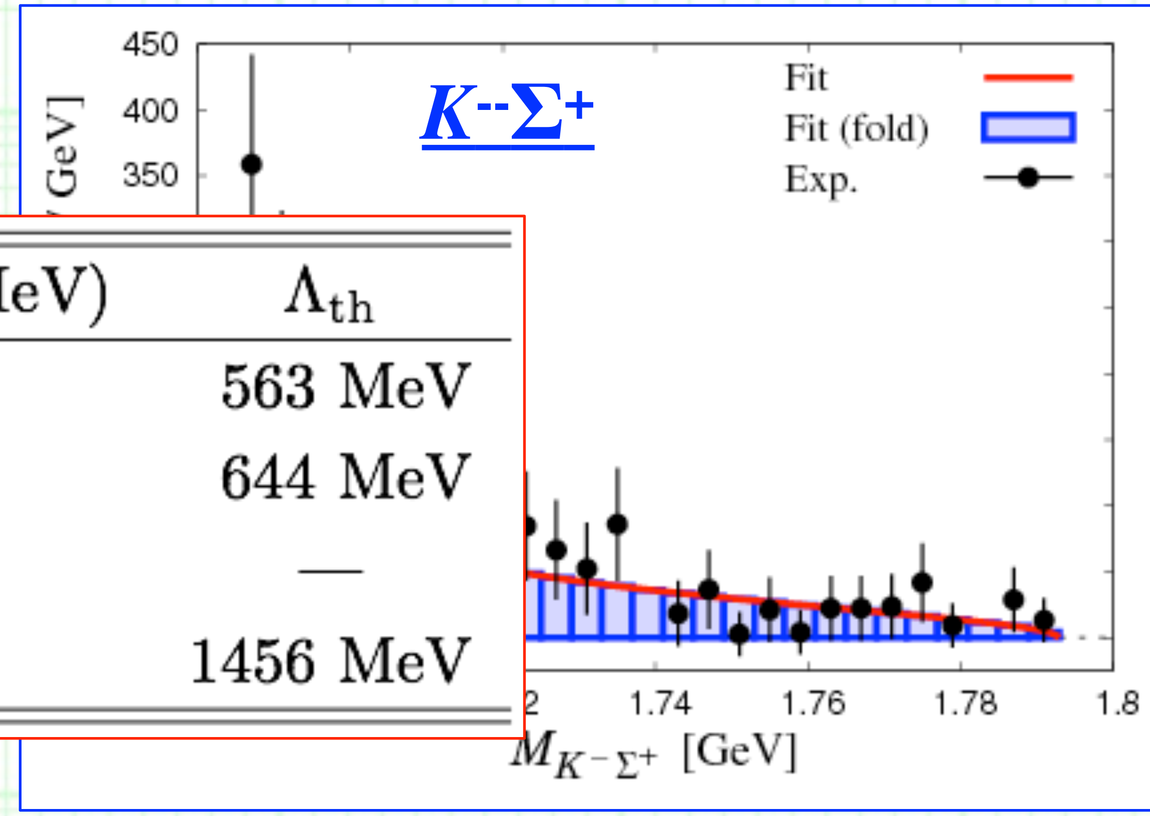
$R_{\rm th} = 1.06$ <=> $R_{\rm exp} = 0.62 \pm 0.33$. --- In 2σ errors.

3. Results and discussions

++ Fitting to the Belle data ++

- We fix 4 free parameters ($a_{K\Sigma}$, $a_{K\Lambda}$, $a_{\pi\Xi}$, and $a_{\eta\Xi}$) so as to reproduce the mass spectra by Belle. The result of the best fit is:





	$a(\mu_{\rm reg} = 630$ MeV)	$\Lambda_{\rm th}$
$\bar{K}\Sigma$	-1.98	563 MeV
$\bar{K}\Lambda$	-2.07	644 MeV
$\pi\Xi$	-0.75	—
$\eta\Xi$	-3.31	1456 MeV

1. The Belle data on Ξ(1690) are reproduced qualitatively well.

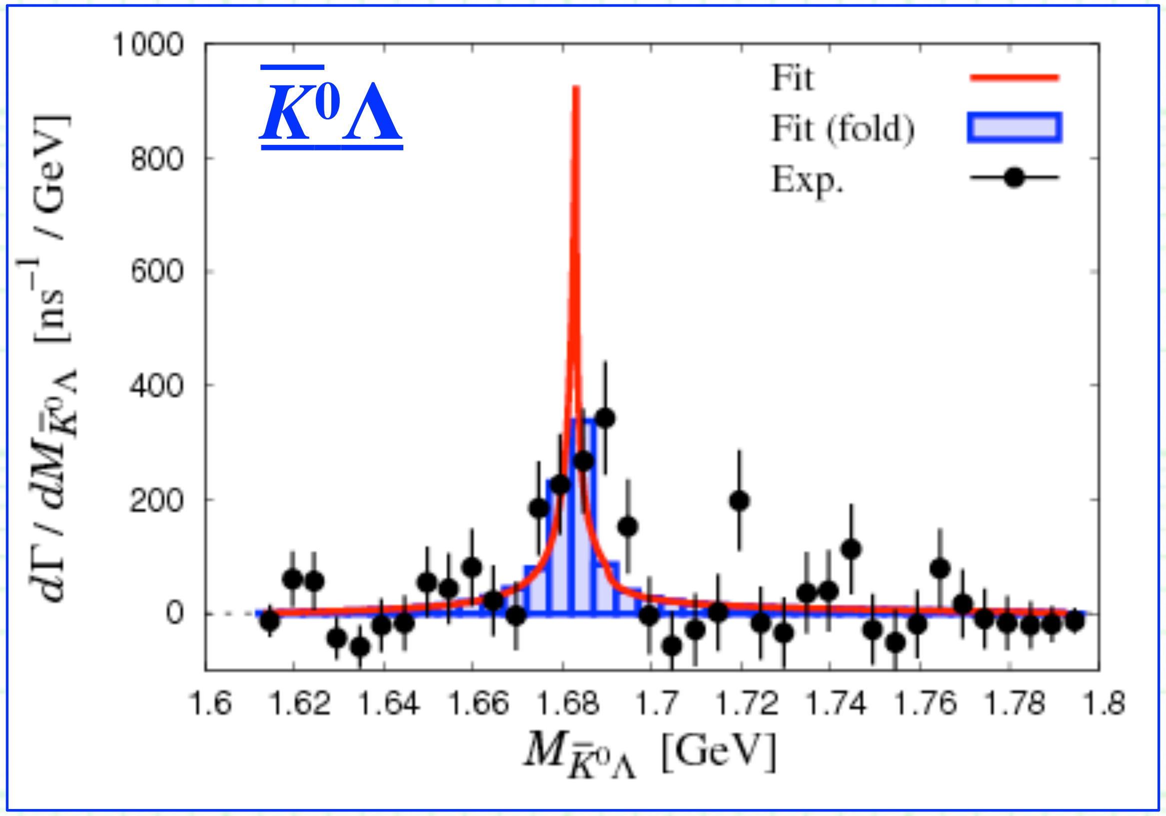
2. Subtraction constants are "natural" (except for $a_{\pi\Xi}$), as the values of the corresponding three-dimensional cut-off at the threshold, $\Lambda_{\rm th}$, is about 500 - 1500 MeV.

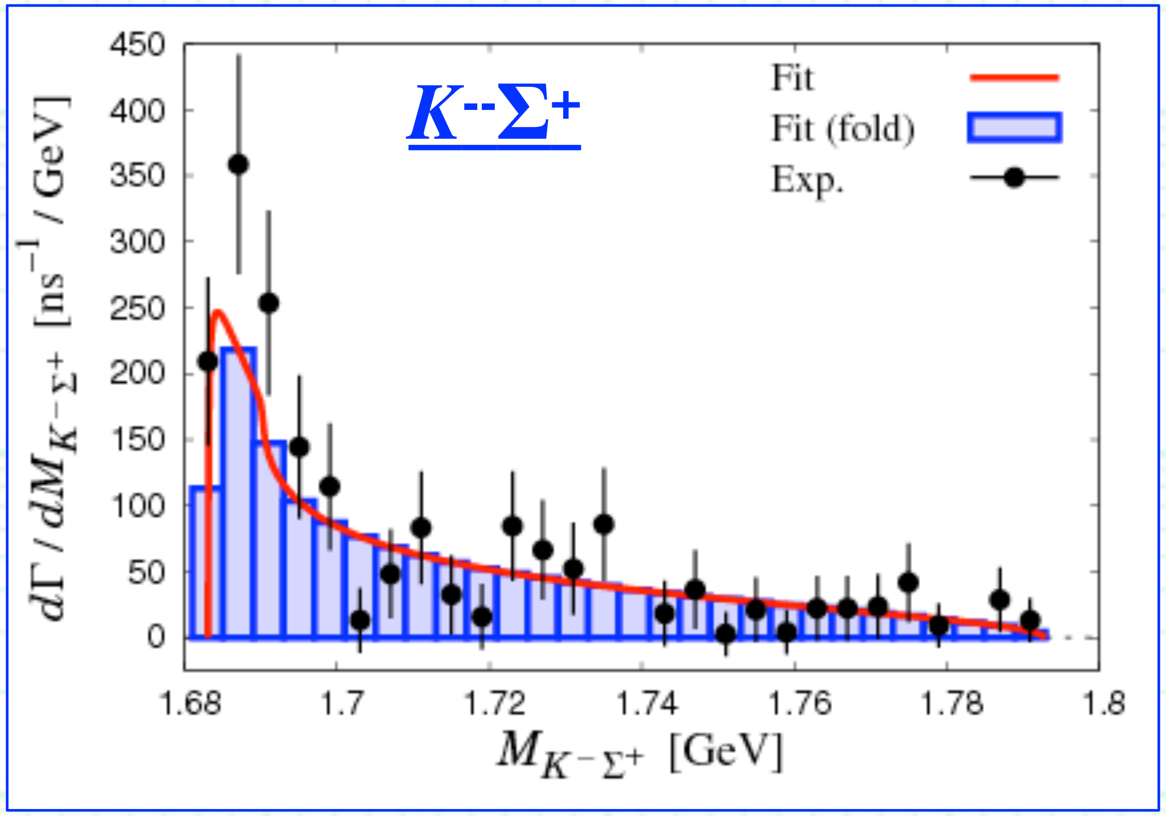
--- The πΞ channel negligibly contributes to Ξ(1690).

3. Results and discussions

++ Fitting to the Belle data ++

- We fix 4 free parameters ($a_{K\Sigma}$, $a_{K\Lambda}$, $a_{\pi\Xi}$, and $a_{\eta\Xi}$) so as to reproduce the mass spectra by Belle. The result of the best fit is:





1. The Belle data on $\Xi(1690)$ are reproduced qualitatively well.
2. Subtraction constants are "natural" (except for $a_{\pi\Xi}$).
3. The $\Xi(1690)$ pole is dynamically generated at 1684.3 -- 0.5 *i* MeV, whose real part is between the $K^-\Sigma^+$ and the $\bar{K}^0\Sigma^0$ thresholds.

--- This pole exists in the first Riemann sheet of both $\bar{K}\Sigma$ channels.

3. Results and discussions

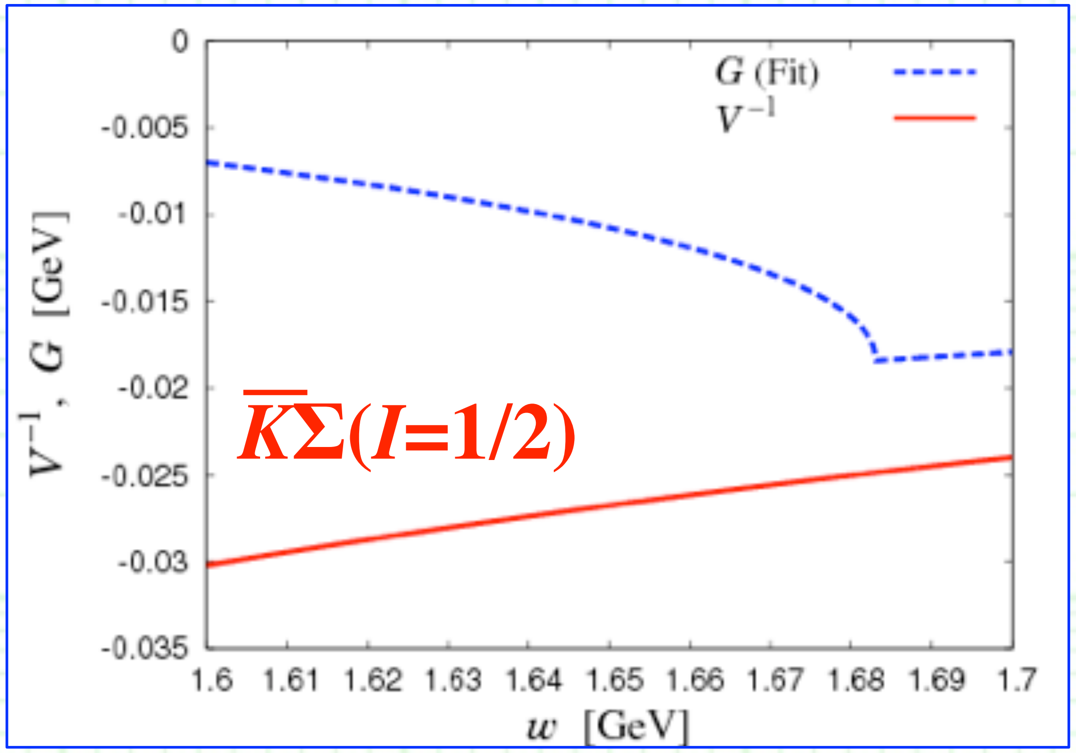
++ Origin of Ξ(1690) ++

- We naively expect that **the Ξ(1690)^0** (pole at 1684.0 -- 0.6 *i* MeV) **would originate from the $\bar{K}\Sigma(I=1/2)$ bound state** generated by the strongly attractive interaction between $\bar{K}\Sigma(I=1/2)$.

--- *cf.* The strongly attractive $\bar{K}N(I=0)$ interaction for Λ(1405).

- However, **the chiral $\bar{K}\Sigma(I=1/2)$ interaction is attractive but not strong enough to generate a bound state** in a single channel case.

--- In contrast to the $\bar{K}N(I=0)$ Int. , which can solely generate a bound state for Λ(1405).



C_{jk}	$\bar{K}\Sigma$	$\bar{K}\Lambda$	$\pi\Xi$	$\eta\Xi$
$\bar{K}\Sigma$	2	0	−1/2	3/2
$\bar{K}\Lambda$	0	0	−3/2	−3/2
$\pi\Xi$	−1/2	−3/2	2	0
$\eta\Xi$	3/2	−3/2	0	0

- This fact implies that the multiple scatterings, such as $\bar{K}\Sigma$ --> ηΞ --> $\bar{K}\Sigma$, assist the $\bar{K}\Sigma$ interaction for Ξ(1690).

3. Results and discussions

++ Small decay width ++

- In addition, the structure of the interaction strength qualitatively explains a remarkable property of $\Xi(1690)^0$, its very small width:
  $\Gamma = -2\,\mathrm{Im}(w_{\rm pole}) \sim 1$ MeV.

C_{jk}	$\bar{K}\Sigma$	$\bar{K}\Lambda$	$\pi\Xi$	$\eta\Xi$
$\bar{K}\Sigma$	2	0	$-1/2$	$3/2$
$\bar{K}\Lambda$	0	0	$-3/2$	$-3/2$
$\pi\Xi$	$-1/2$	$-3/2$	2	0
$\eta\Xi$	$3/2$	$-3/2$	0	0

($I = 1/2$, isospin basis)

1. Transition of $\bar{K}\Sigma$ <--> $\bar{K}\Lambda$ is forbidden at the leading order ($C_{jk} = 0$), so the $\bar{K}\Sigma$ --> $\bar{K}\Lambda$ --> $\bar{K}\Sigma$ multiple process gives zero.
2. $\bar{K}\Sigma$ <--> $\pi\Xi$ is not strong compared to, *e.g.*, $\bar{K}N(I=0)$ <--> $\pi\Sigma$.
   --- $C_{jk} = -0.5$ vs. $-\sqrt{1.5} = -1.22$ … .
3. $\bar{K}\Sigma$ <--> $\eta\Xi$ is the strongest.

C_{jk}	$\bar{K}N$	$\pi\Sigma$	$\eta\Lambda$	$K\Xi$
$\bar{K}N$	3	$-\sqrt{3/2}$	$3/\sqrt{2}$	0
$\pi\Sigma$	$-\sqrt{3/2}$	4	0	$\sqrt{3/2}$
$\eta\Lambda$	$3/\sqrt{2}$	0	0	$-3/\sqrt{2}$
$K\Xi$	0	$\sqrt{3/2}$	$-3/\sqrt{2}$	3

--> As a consequence, the $\eta\Xi$ channel is most important in the multiple scatterings for $\bar{K}\Sigma$ to dynamically generate $\Xi(1690)$ which cannot couple strongly to $\bar{K}\Lambda$ nor $\pi\Xi$.

--- This reproduces small decay width and tiny BR fraction to $\pi\Xi$.

3. Results and discussions

++ Compositeness for Ξ(1690) ++

- **Our Ξ(1690) pole** exists at 1684.3 -- 0.5 *i* MeV, whose real part is **very close to the $K^- \Sigma^+$ threshold** (= 1863.1 MeV).

--- The pole exists in the first Riemann sheet of the $K^- \Sigma^+$ channel.

- "Theorem" (single channel, *s* wave):
  The bound state with the field renormalization const. $Z \sim 0$ naturally appears when the state exists near the threshold, and especially Z vanishes in the limit B --> 0.
  --> The state should be genuinely composite.

T. Hyodo (2014); C. Hanhart, J. R. Pelaez and G. Rios, (2014).

- Therefore, we expect that our Ξ(1690) state should be genuinely $\bar{K}\Sigma$ composite ! (coupled-channels version)

- Indeed, the result of the compositeness X strongly indicates that Ξ(1690) is a $\bar{K}\Sigma$ molecular state.

$X_{K^-\Sigma^+}$	$0.84 - 0.27i$
$X_{\bar{K}^0\Sigma^0}$	$0.11 + 0.15i$
$X_{\bar{K}^0\Lambda}$	$-0.01 + 0.01i$
$X_{\pi^+\Xi^-}$	$0.00 + 0.00i$
$X_{\pi^0\Xi^0}$	$0.00 + 0.00i$
$X_{\eta\Xi^0}$	$0.01 + 0.02i$
Z	$0.06 + 0.09i$

$$\langle \Psi^* | \Psi \rangle = \sum_j X_j + Z = 1$$

Hyodo (2013); T. S. , Hyodo and Jido (2015).

$$X_j = -g_j^2 \left[\frac{dG_j}{dw} \right]_{w=w_{\text{pole}}}, \quad Z = -\sum_{j,k} g_k g_j \left[G_j \frac{dV_{jk}}{dw} G_k \right]_{w=w_{\text{pole}}}$$

4. Summary

++ Summary ++

- We have investigated dynamics of $\bar{K}\Sigma$ and its coupled channels in the chiral unitary approach.
  - We employ the simplest interaction: Weinberg-Tomozawa term.
  - Subtraction constants as free parameters are fixed by fitting the $\bar{K}^0\Lambda$ and $K^-\Sigma^+$ mass spectra to the experimental data.

- As a result, we have found that:
  - The obtained scattering amplitude can qualitatively reproduce the experimental data of the $\bar{K}^0\Lambda$ and $K^-\Sigma^+$ mass spectra.
  - Dynamically generates a Ξ^* pole near the $\bar{K}\Sigma$ threshold as a $\bar{K}\Sigma$ molecule, which can be identified with the $\Xi(1690)^0$ resonance.
  - However, the $\bar{K}\Sigma$ interaction alone is slightly insufficient to bring a $\bar{K}\Sigma$ bound state, so multiple scattering is important for $\Xi(1690)$.
  - The small or vanishing couplings of the $\bar{K}\Sigma$ channel to others can naturally explain small decay width of $\Xi(1690)$.

Thank you very much for your kind attention !

Appendix

Appendix

++ Comparison with previous ChUA calculations ++

- The discussion on the $\bar{K}\Sigma$ interaction can be further utilized for comparison of our result on Ξ(1690) (pole at 1684.3 -- 0.5 *i* MeV) with previous ones in chiral unitary approach.

$(\frac{1}{2}, -2)$		$[\pi\Xi]$ 7.5	5.6	seen	2.6
$\Xi(1620)^{*}$		$[\bar{K}\Lambda]$ 5.2	2.8	seen	−1.5
$M \approx 1620$	1565	$[\bar{K}\Sigma]$ 0.7	2.6	0	−0.8
$\Gamma = 23$	247	$[\eta\Xi]$ 0.3	4.9	0	0.3
$(\frac{1}{2}, -2)$		$[\pi\Xi]$ 0.02	0.1	seen	−0.1
$\Xi(1690)^{***}$		$[\bar{K}\Lambda]$ 0.16	6.0	seen	0.9
$M = 1690 \pm 10$	1663	$[\bar{K}\Sigma]$ 5.15	3.1	seen	−2.5
$\Gamma = 10 \pm 6$	4	$[\eta\Xi]$ 2.28	3.2	0	−1.7

<--> Qualitatively similar, but the mass (= real part of the pole position) of our result is 20 - 30 MeV larger than others.

C. Garcia-Recio, M. F. M. Lutz and J. Nieves, *Phys. Lett.* B582 (2004) 49.

8 (1134)	2037–24i	0.6	0.6	0.3	0.2	0.3	↑ 0.5	1.5	0.6	**1.8**	**2.4**	1.1	0.2	1.0	**2.1**	
10 (70)	1729–46i	0.6	1.4	0.4	↑ 1.6	1.4	**2.1**	1.0	0.4	**3.3**	1.5	0.4	0.2	1.6	1.0	Ξ(1950) ⋆⋆⋆
8 (70)	1651–2i	0.2	0.3	↑ **2.2**	1.3	1.0	**2.6**	0.2	0.6	0.9	0.4	0.2	**1.7**	0.4	0.2	Ξ(1690) ⋆⋆⋆
8 (56)	1577–139i	**2.6**	↑ **1.7**	0.5	0.1	0.8	1.0	0.7	0.1	0.6	1.3	0.3	0.1	0.2	1.2	Ξ(1620) ⋆

D. Gamermann, C. Garcia-Recio, J. Nieves and L. L. Salcedo, *Phys. Rev.* D84 (2011) 056017.

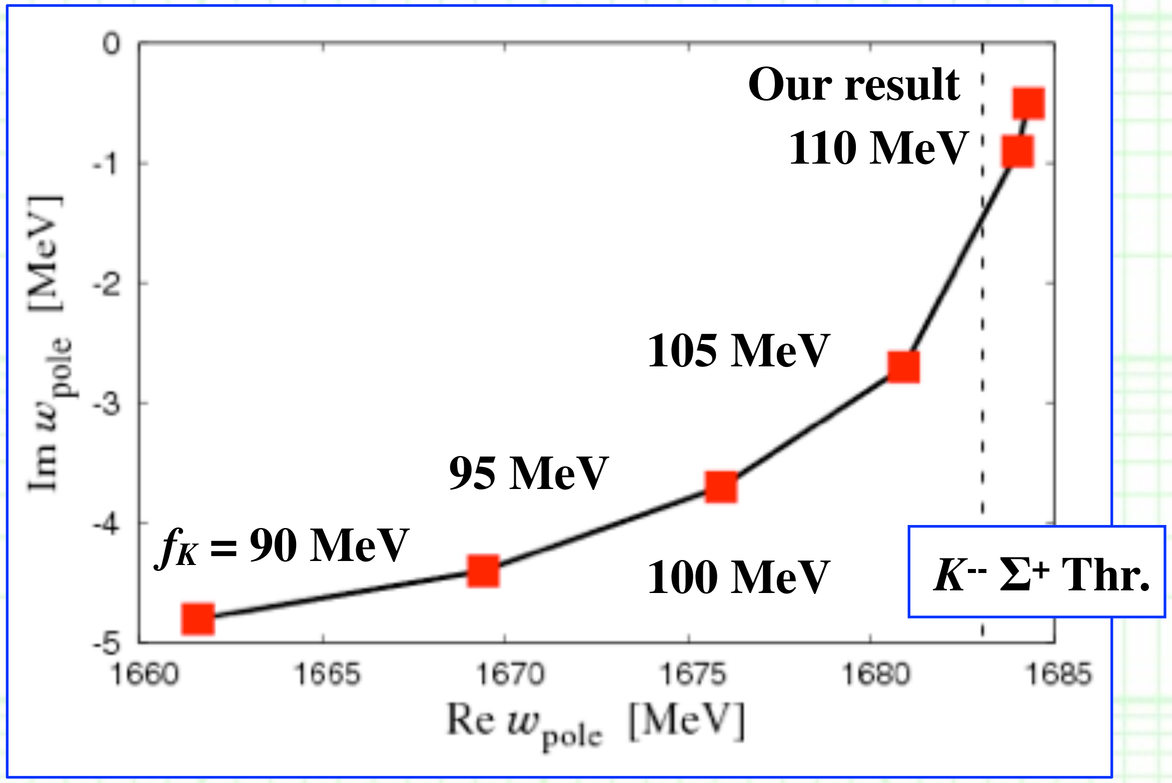
Appendix

++ Comparison with previous ChUA calculations ++

- The discussion on the $\bar{K}\Sigma$ interaction can be further utilized for comparison of our result on Ξ(1690) (pole at 1684.3 -- 0.5 *i* MeV) with previous ones in chiral unitary approach.

  - In Ref. [1] they used the meson decay constant f = 90 MeV in all channels, while we use their physical values (f_K = 110.64 MeV).

--> The Ξ(1690) pole moves as:



  - In Ref. [2] they introduced channels with vector mesons, which would assist more the $\bar{K}\Sigma$ interaction, and hence the mass of Ξ(1690) shifted to lower energies.

[1] C. Garcia-Recio, M. F. M. Lutz and J. Nieves, *Phys. Lett.* B582 (2004) 49.

[2] D. Gamermann, C. Garcia-Recio, J. Nieves and L. L. Salcedo, *Phys. Rev.* D84 (2011) 056017.

Appendix

++ Charged Ξ(1690) ++

- Finally we consider the charged Ξ(1690) in the same parameter set as the neutral one. As a result, we obtain the Ξ(1690)$^{-}$ pole as:

$w_{\rm pole}$	$1693.4 - 10.5i$ MeV
$X_{\bar{K}^0 \Sigma^-}$	$0.86 - 0.50i$
$X_{K^- \Sigma^0}$	$-0.27 + 0.31i$
$X_{K^- \Lambda}$	$-0.02 + 0.04i$
$X_{\pi^- \Xi^0}$	$0.00 + 0.00i$
$X_{\pi^0 \Xi^-}$	$0.00 + 0.00i$
$X_{\eta \Xi^-}$	$0.07 + 0.03i$
Z	$0.36 + 0.12i$

- The Ξ(1690)$^{-}$ pole is located between the $K^-\Sigma^0$ and $\bar{K}^0\Sigma^-$ thresholds; The pole is in the first Riemann sheet of the $\bar{K}^0\Sigma^-$ and $\eta\Xi^-$ channels and in the second Riemann sheet of the $K^-\Lambda$, $K^-\Sigma^0$, $\pi^-\Xi^0$, and $\pi^0\Xi^-$ channels.

- The pole position has a larger imaginary part ~ 10 MeV compared to the neutral case, since it exists above the $\bar{K}^0\Sigma^-$ threshold in its second Riemann sheet and hence the decay to $\bar{K}^0\Sigma^-$ is allowed.

- Although both $X_{K0\Sigma-}$ and $X_{K-\Sigma0}$ have large imaginary part, sum of them is the dominant contribution with its small imaginary part, which implies that the Ξ(1690)$^{-}$ state is also a $\bar{K}\Sigma$ molecular state.

Appendix

++ Outlook ++

- **Theoretical study**:
  - Propose reactions which can clarify properties of the $\Xi(1690)$ resonance in experiments, both neutral and charged states.
  - Predict the $\Xi(1690)$ production cross section.
  - Improvement of model by, *e.g.* , introducing s- and u-channel Born terms.

- **Experimental study**:
  - Determine J^P of the $\Xi(1690)^0$ resonance.
  - Measure the $\bar{K}\Lambda$ and $\bar{K}\Sigma$ mass spectra and ratio of their branching fractions.
  - Furthermore, precise determination of its pole position should be important to discuss the internal structure of $\Xi(1690)$.

--- Flatte parameterization may be necessary since it exists near the $\bar{K}\Sigma$ threshold.