Study of excited Ξ baryons based on the ALICE experiment

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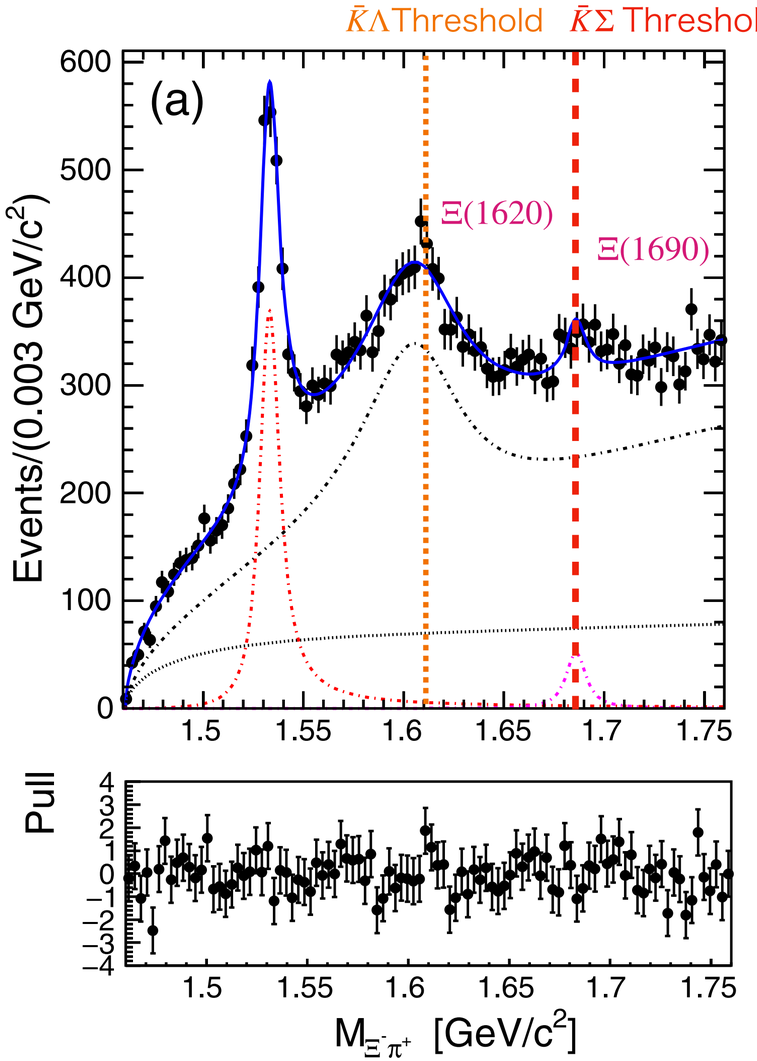
Motivation by Belle

- $\Xi(1620)$ and $\Xi(1690)$ peaks in the $\Xi_c \to \pi\pi\Xi$ spectrum by Belle collaboration [1].
- Peaks are close to thresholds of $\bar{K}\Lambda$ and $\bar{K}\Sigma$?
- Threshold effect in the spectrum?



Invariant mass distribution of $\pi\Xi$ in the $\Xi_c \to \pi\pi\Xi$ decay [1].

[1]Belle collaboration, M.Sumihama et al., Phys. Rev. Lett. 122, 072501 (2019).

Motivation by ALICE

- The scattering length of $K^-\Lambda$ was determined with femtoscopy in Pb-Pb collisions by ALICE experiment as $f_0 = 0.27 + 0.40i$ fm[2].
- The scattering length f_0 determines real and imaginary part of threshold.
  - Aim of this talk
- Construction of the model of $\Xi(1620)$ which reproduces the Belle data.
- Construction of the model of $\Xi(1620)$ which reproduces the ALICE data.

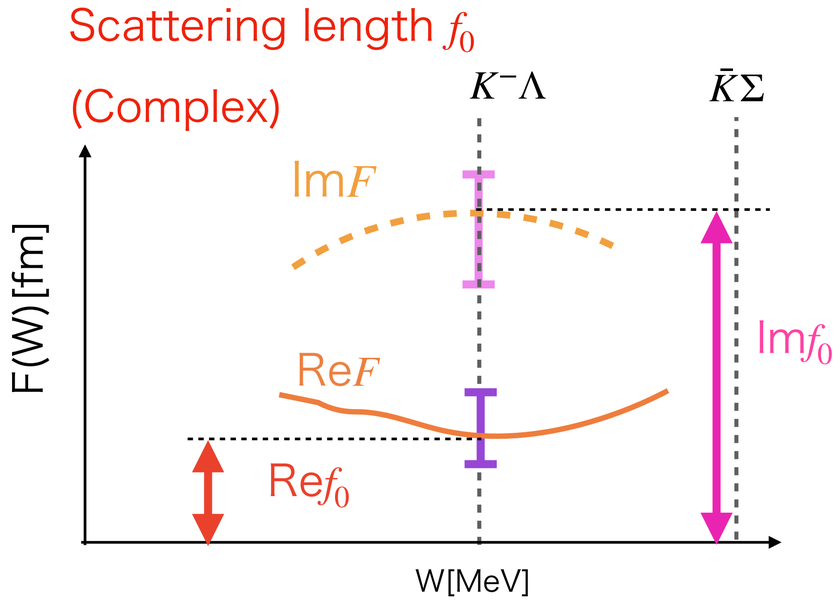


Image of the scattering length on spectrum

The error bar of real part of length

The error bar of imaginary part of length

[2]S. Acharya et al. (ALICE Collaboration)Phys. Rev. C **103**, 055201

Formulation

Coupled-channel meson-baryon scattering amplitude $T_{ij}(W)$ at total energy W.

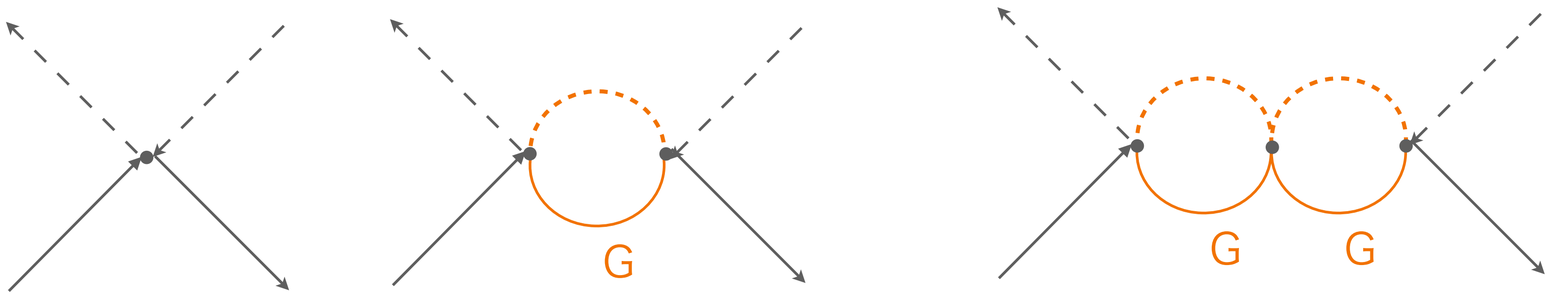
Scattering equation

$$T_{ij}(W) = V_{ij}(W) + V_{ik}(W)\,G_k(W)\,T_{kj}(W)$$

$V_{ij}(W)$···Interaction kernel

$G_i(W)$···Loop function

$$T_{ij}(W) = V_{ij}(W) + V_{ik}(W)G_k(W)V_{kj}(W) + V_{ik}(W)G_k(W)V_{kl}(W)G_l(W)V_{lj}(W) + \cdots$$



Meson-baryon
multiple scattering

The solution of the equation is obtained as

$$T_{ij}(W) = [[V(W)]^{-1} - G(W)]^{-1}_{ij}$$

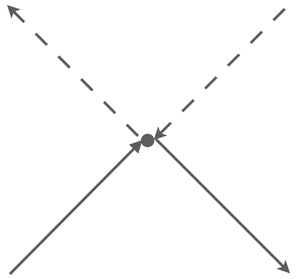
Formulation

$V_{ij}(W)$…Interaction kernel (Weinberg-Tomozawa term)
s-wave interaction satisfying chiral low energy theorem.

$$V_{ij}(W) = -\frac{C_{ij}}{4f_i f_j} N_i N_j (2W - M_i - M_j)$$

f_i : Meson decay constant, C_{ij} : Group theoretical coefficient,

M_i : Baryon Mass, N_i : kinematical coefficient



$G_i(W, a_i)$…Loop function
(Divergence renormalized by dimensional regularization)

$$G_i(W) \to G_i(W, a_i)$$

W:Total energy, a_i:subtraction constant

Scattering amplitude of previous study

Previous work about $\Xi(1620)$ [3]

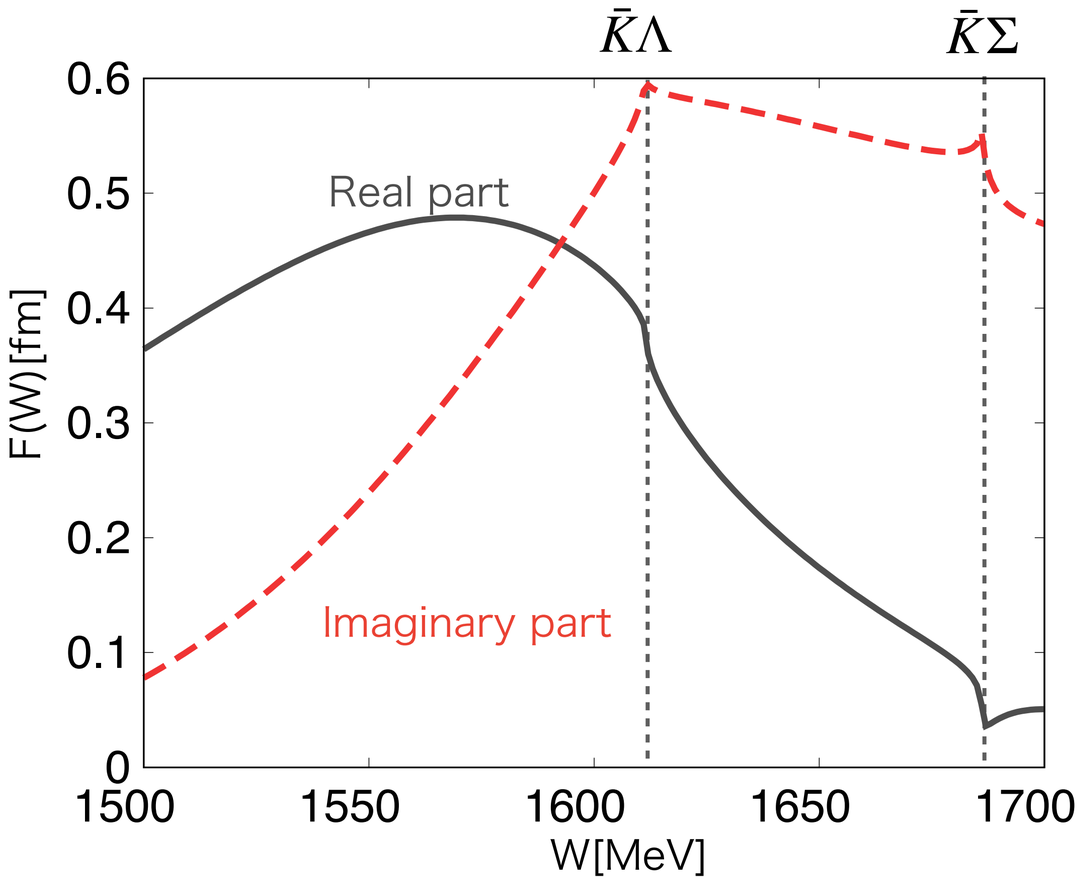
$a_i = -2$ (all channels)

$M_R = 1607$ MeV, $\Gamma_R = 280$ MeV.

- Scattering amplitude F of $\pi\Xi$

$$F(W) = -\frac{2M_1 T_{11}(W)}{8\pi W}$$

No distinct peak of imaginary part due to broad decay width



[3] A.Ramos, E.Oset and C.Bennhold Phys. Rev. Lett. 89.252001 (2002).

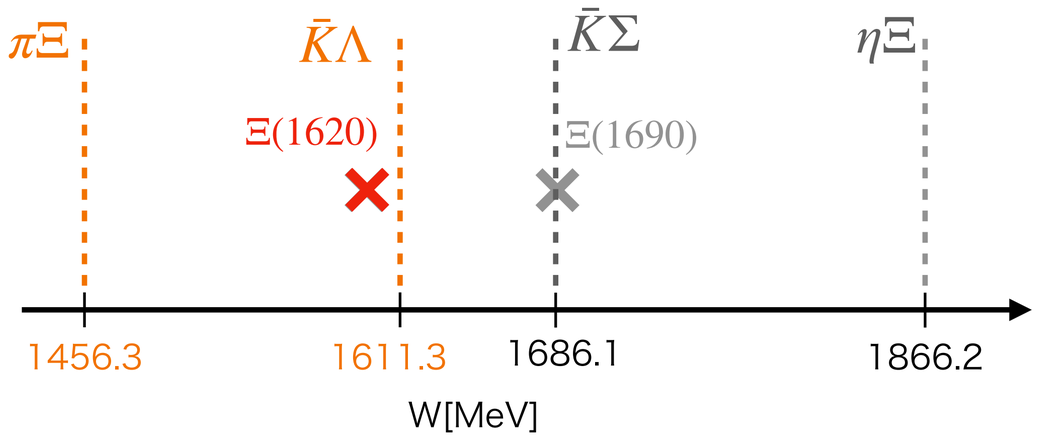
Model for Belle result

- Belle result : $M_R = 1610\ \mathrm{MeV},\ \Gamma_R = 60\ \mathrm{MeV}$
- Based on the peak position, we define

  $z_{\mathrm{ex}} = [1610 - 30i]\ \mathrm{MeV}.$
- z_{th} : Pole in theoretical model

$$\Delta z = |z_{\mathrm{th}} - z_{\mathrm{ex}}|$$

- We minimize Δz by adjusting subtraction constants $a_{\pi\Xi}$ and $a_{\bar{K}\Lambda}$[4].



- Pole at complex plane

$$z = M_R - \frac{i}{2}\Gamma_R$$

M_R…Mass of resonance

Γ_R …Decay width of resonance

[4]T.Nisihibuchi and T.Hyodo, EPJ Web of Conferences 271, 10002 (2022)

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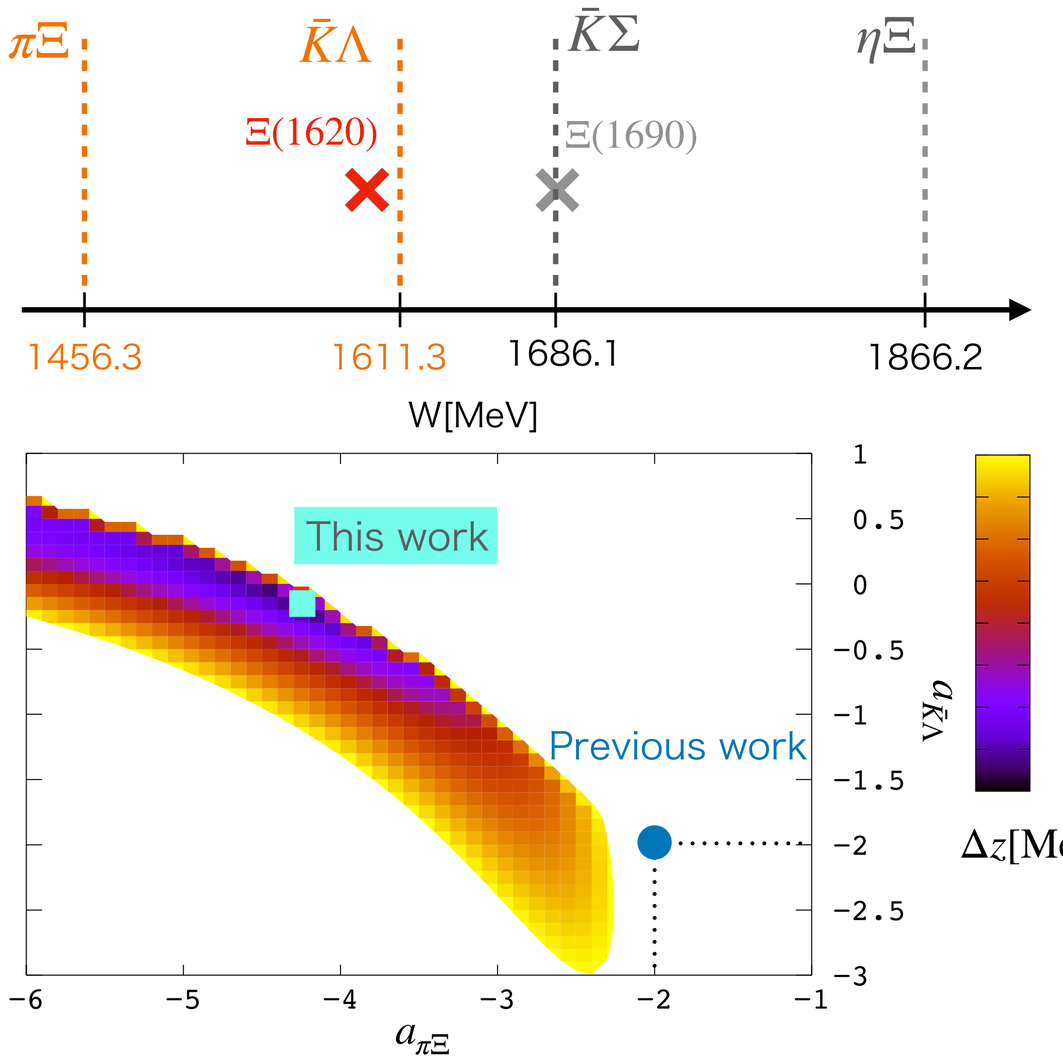
  $\Delta z = 0.1$MeV is achieved

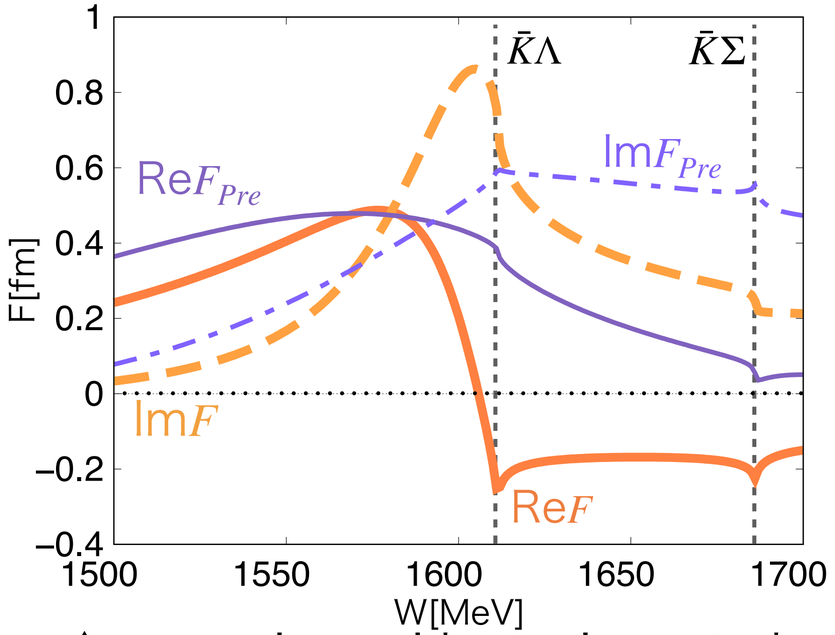
  at $a_{\pi\Xi} = -4.19$ and $a_{\bar{K}\Lambda} = -0.14$.



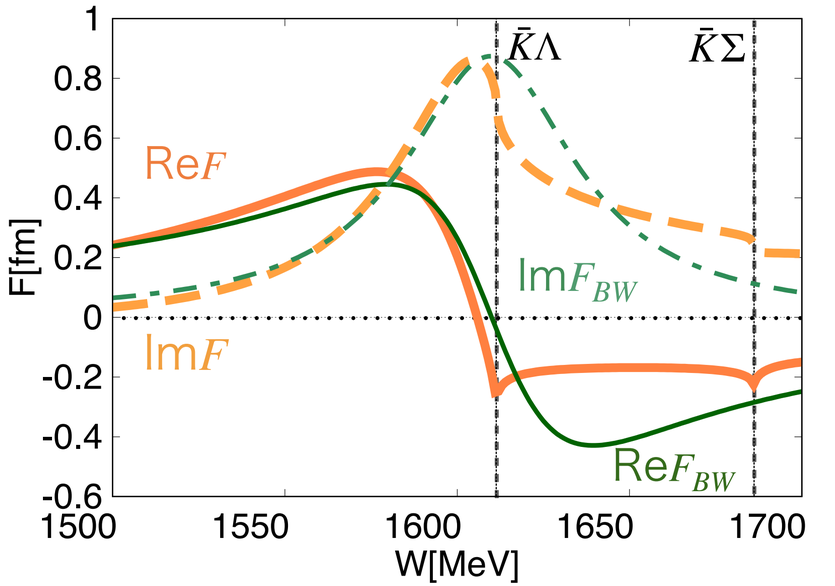
[4]T.Nisihibuchi and T.Hyodo, EPJ Web of Conferences 271, 10002 (2022)

Model for Belle result

- Ξ(1620)in this study (Thick lines)
- Previous study and Breit-Wigner distribution with a pole at the same position (Thin lines)
- In comparison with previous study, there is a distinct peak on real axis like Belle result.
- In comparison with Breit-Wigner distribution, the peak position is shifted and the shape is distorted by the threshold effect.



▲comparison with previous study



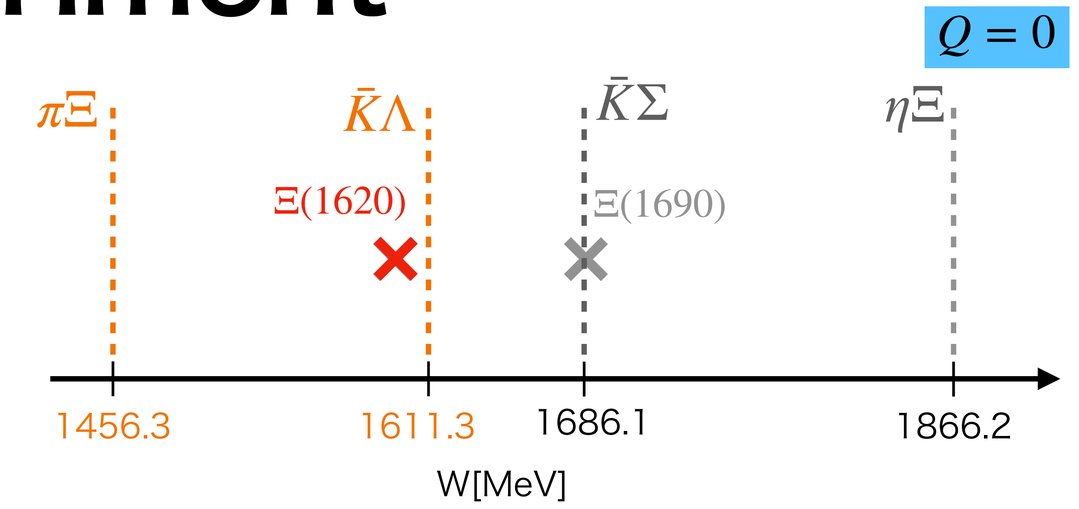
▲comparison with Breit-Wigner distribution

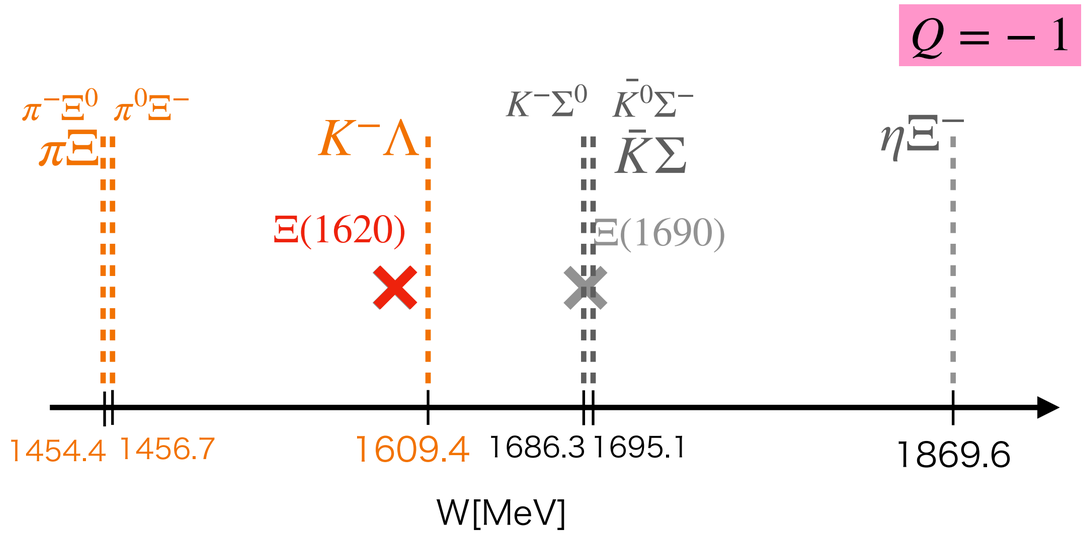
Model for ALICE experiment

- f_0…the scattering length of $K^-\Lambda$
- ALICE experiment: $f_{\mathrm{ALICE}} = 0.27 + 0.40i$ fm
- Previous work: $f_0 = -0.07 + 0.21i$ fm
- Belle model: $f_0 = -0.75 + 0.93i$ fm
- We construct the model with f_{ALICE}.
- f_{th} : scattering length in theoretical model

$$\Delta f = |f_{\mathrm{th}} - f_{\mathrm{ALICE}}|$$

- We minimize Δf by adjusting subtraction constants $a_{\pi\Xi}$ and $a_{\bar{K}\Lambda}$.





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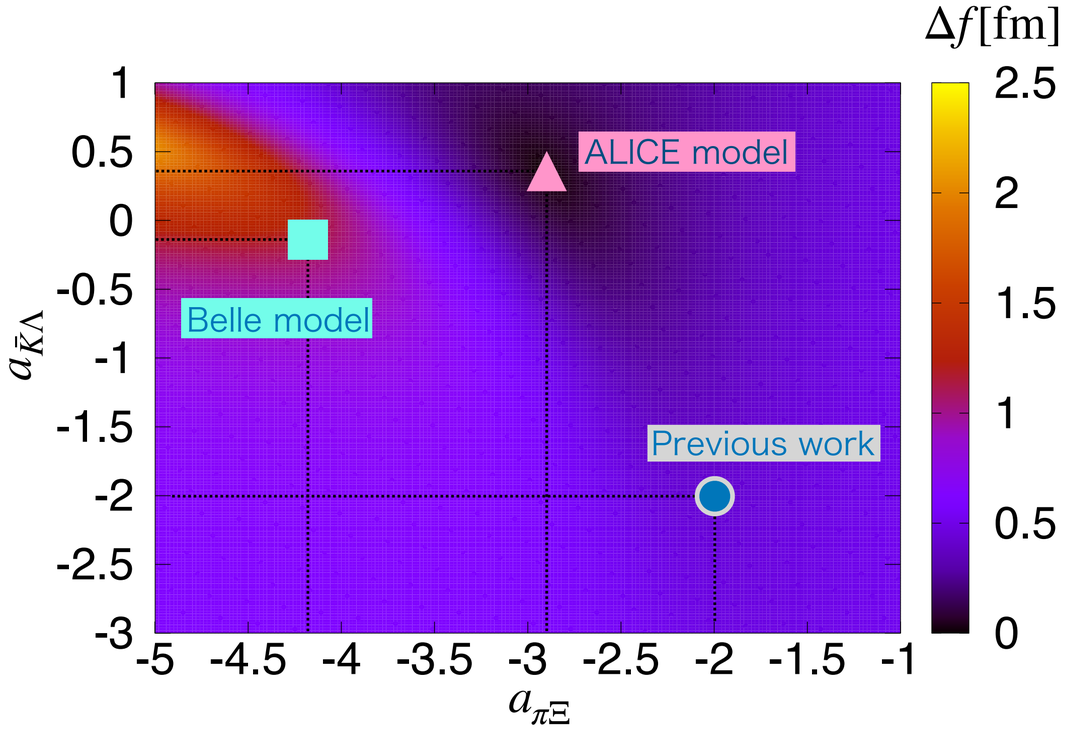
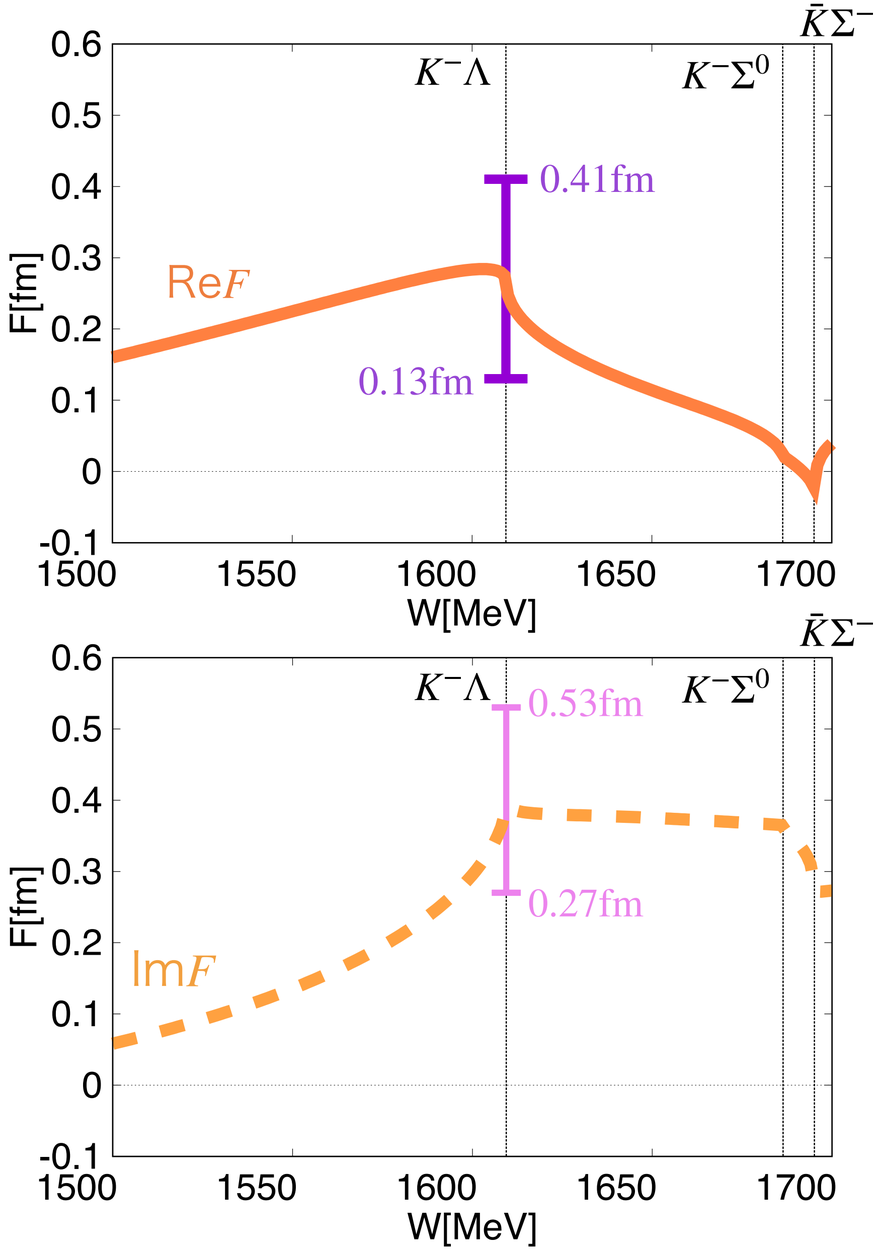


Density plot of Δf on $a_{\bar{K}\Lambda} - a_{\pi\Xi}$ plane

$f_{\mathrm{th}} = 0.27 + 0.40i$ fm is achieved at $a_{\pi\Xi} = -2.90$ and $a_{\bar{K}\Lambda} = 0.36$

Result of model for ALICE

- We plot the scattering amplitude with $a_{\pi\Xi} = -2.90$, $a_{\bar{K}\Lambda} = 0.36$ and $f_{\rm th} = 0.27 + 0.40i$ fm in right figure.
- There are no peaks in the spectrum, but a cusp at the threshold.
- There are no poles on the physically relevant Riemann sheets.



▲The scattering amplitudes of ALICE model

The error bar of real part of $f_{\rm ALICE}$

The error bar of imaginary part of $f_{\rm ALICE}$

Consistency of ALICE and Belle

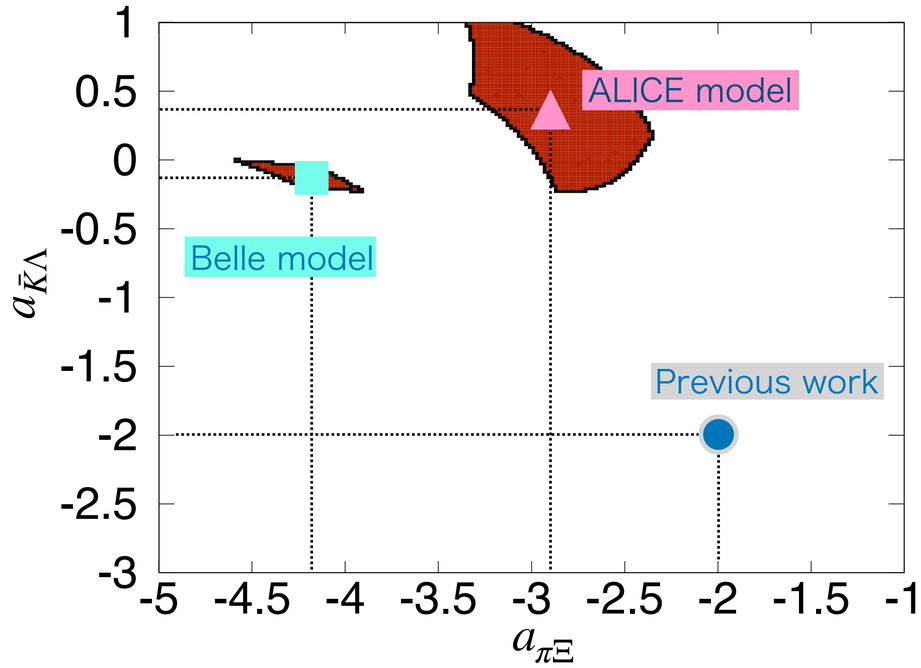
Is there a model which satisfies both Belle and ALICE?

→We consider the error of each experiment.

$$\mathrm{M_R} \simeq 1610.4^{+6.1}_{-7.3}\mathrm{MeV}, \Gamma_R \simeq 59.9^{+5.6}_{-8.5}\mathrm{MeV}$$

$$\mathrm{Re}f_0 \simeq 0.27 \pm 0.14\mathrm{fm}, \mathrm{Im}f_0 \simeq 0.40 \pm 0.13\mathrm{fm}$$

- There is no parameter region which satisfies both ALICE scattering length and the assumption of pole at $\mathrm{M_R} - i\Gamma_R/2$.
- To compare with Belle data, we need to use the $\pi\Xi$ spectrum.



Density plot of Δf on $a_{\bar{K}\Lambda} - a_{\pi\Xi}$ plane

Conclusion

- We construct the model to reproduce the Belle data of the $\pi\Xi$ spectrum and the one to reproduce the $K^-\Lambda$ scattering length by ALICE data.
- We construct the model for Belle with a pole at $1610 - 30i$ MeV. We find that the near-threshold resonance peak is distorted by the threshold effect.
- In the model for ALICE, the scattering amplitude shows the cusp at $K^-\Lambda$ threshold. There are no pole of $\Xi(1620)$ in physically relevant Riemann sheets.
- There is no parameter region which satisfies both ALICE scattering length and the assumption of pole near the $K^-\Lambda$ threshold.

→ Does the ALICE model reproduce Belle $\pi\Xi$ spectrum?

- Future plan: study of $\Xi(1690)$, calculation of $\Xi_c \to \pi\pi\Xi$ decay.