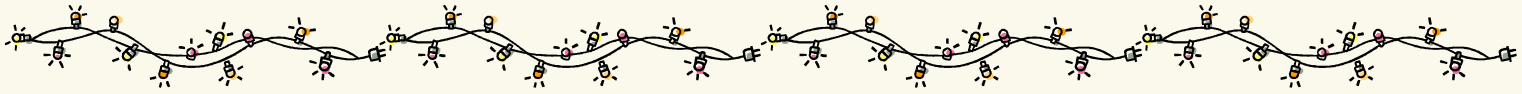
Fundamental Problems in Subatomic Physics 2026
Cairns, Australia 25 Sep. 2026

A coupled-channel study of the nature of the Ω_c states



Hideko NAGAHIRO
Nara Women's University / RCNP

Collaboration with: Qi-Fang Lü (Hunan Normal U.), Atsushi Hosaka (RCNP)

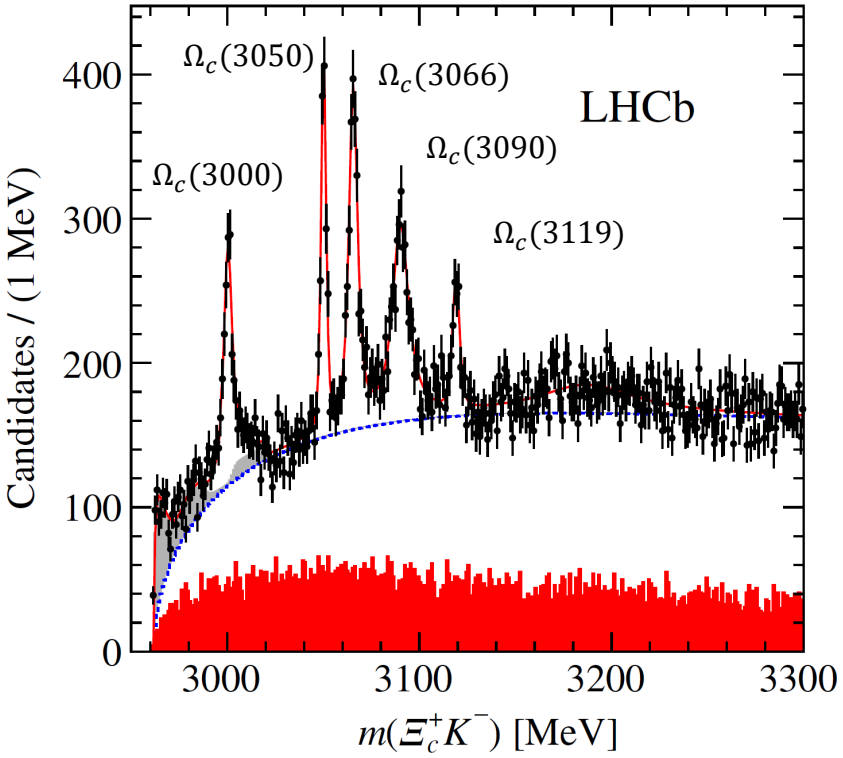
Based on :

- Y. Zhang, Q.-F. Song, Q.-F. Lü, H. Nagahiro, A. Hosaka, Physical Review **D112**(25)034035
- H. Nagahiro, Q.-F. Lü, A. Hosaka *in preparation*

Newly observed narrow Ω_c excited states ~ ssc

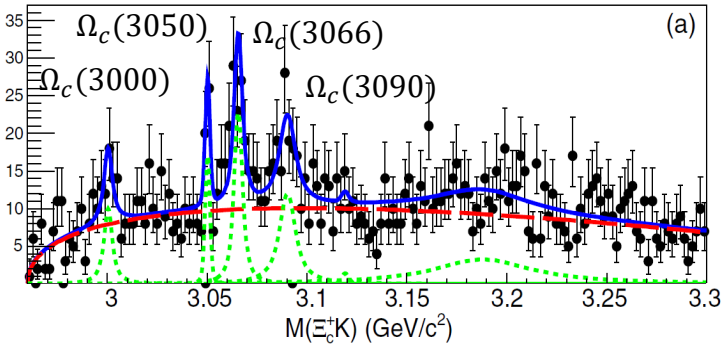
5 narrow peaks in invariant mass distribution of $\Xi_c \bar{K} \sim ssc$

LHCb, PRL118(2017)182001

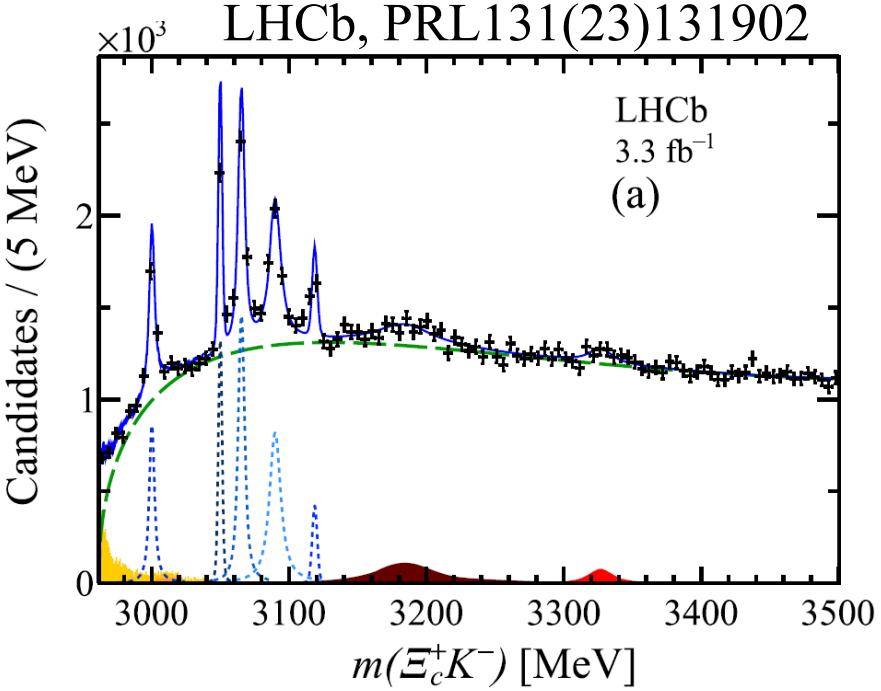


→ 5 λ-mode excitations ?

Belle, PRD97(2018)051102(R)



LHCb, PRL131(23)131902



5 low-lying Ω_c in the conventional quark model with HQSS

- ✓ lowest-lying P-wave states → **λ-mode excitation**
- ✓ **Heavy quark spin symmetry (HQSS)**

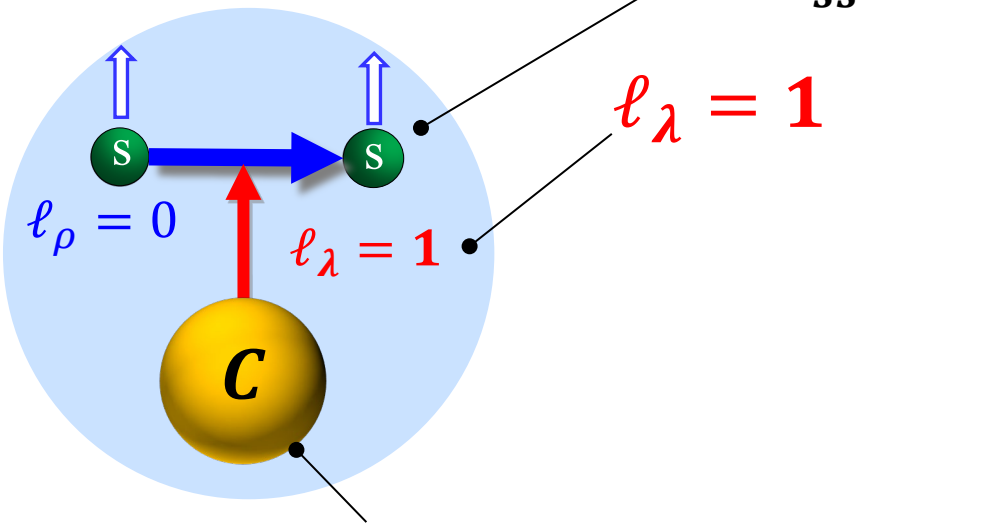
  light quark "spin" $j = (S_{ss} + \ell_\lambda)$ conservation

$$\left[\left[S_{ss}, \psi_{1p}(\lambda)\psi_{0s}(\rho)\right]^{j}, S_c\right]^{J}$$

$$J = j + S_c$$

good quantum number

$S_{ss} = 1$ (bad diquark)



$S_c = 1/2$ charm spin

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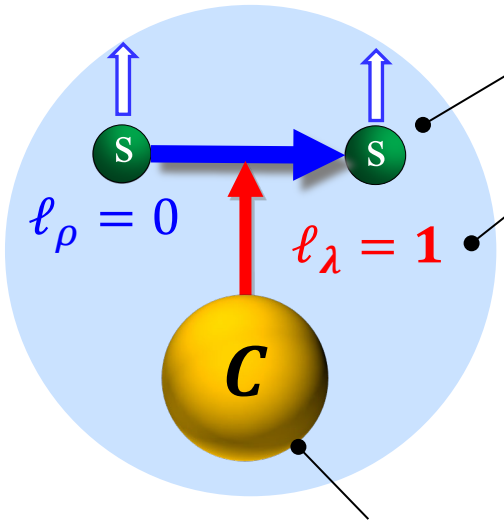
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$\boldsymbol{S_{ss} = 1}$

$\boldsymbol{\ell_\lambda = 1}$

$\boldsymbol{j = 0}$ $\boldsymbol{j = 1}$ $\boldsymbol{j = 2}$

$S_c = 1/2$ charm spin

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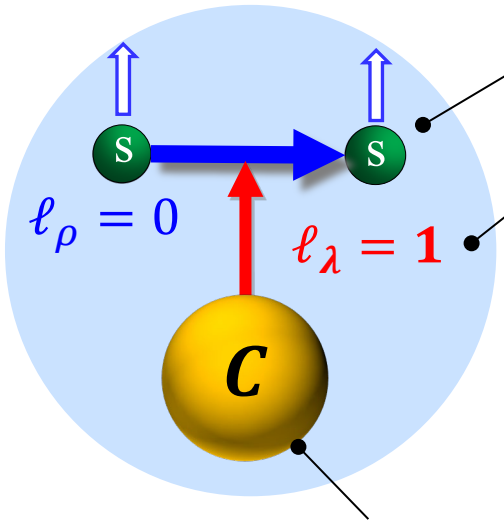
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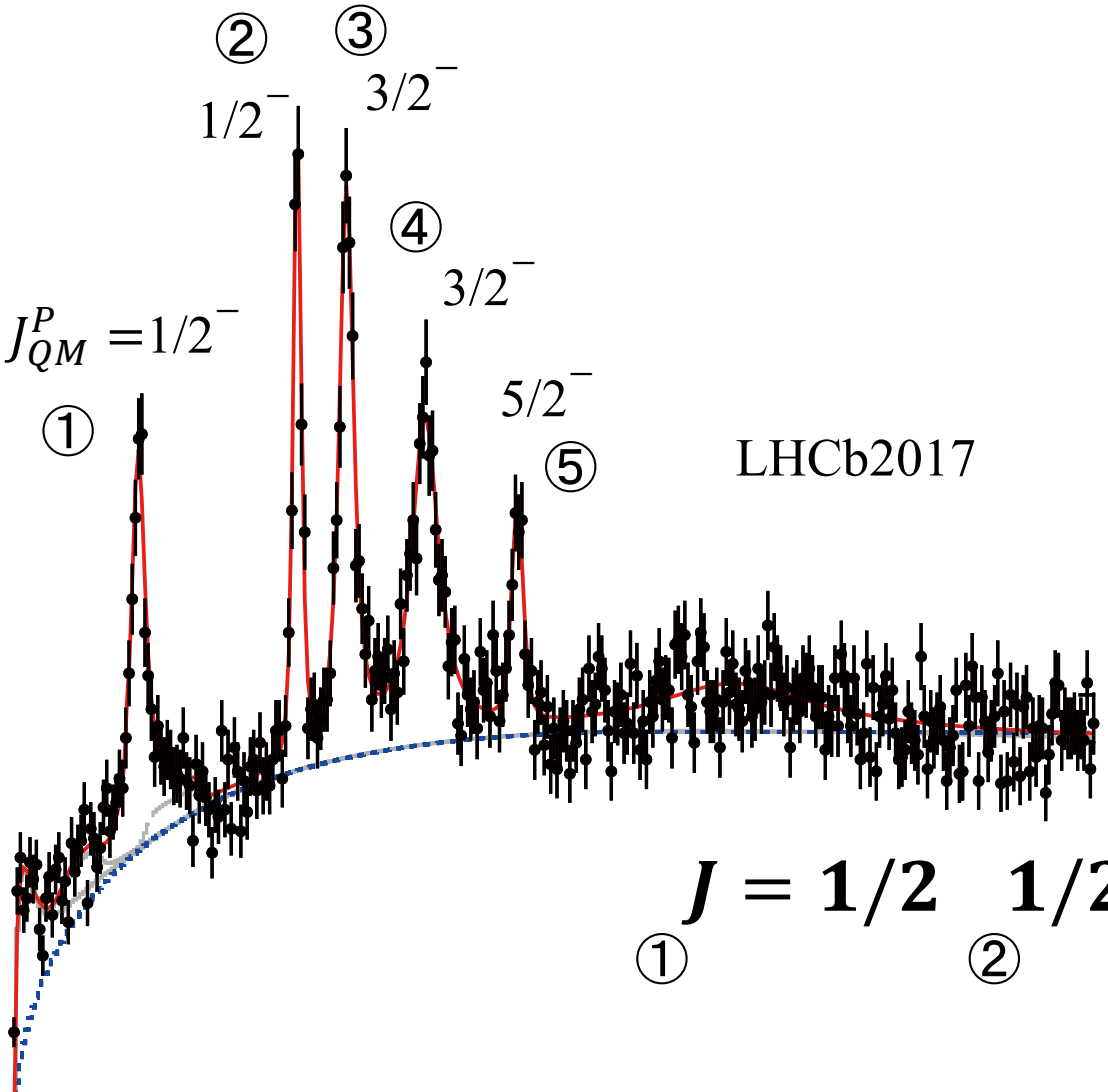
$j = 0$ $j = 1$ $j = 2$

$J = 1/2$ $1/2$ $3/2$ $3/2$ $5/2$

5 states for $\Omega_c(1P_\lambda)$

low-lying Ω_c in the conventional quark model



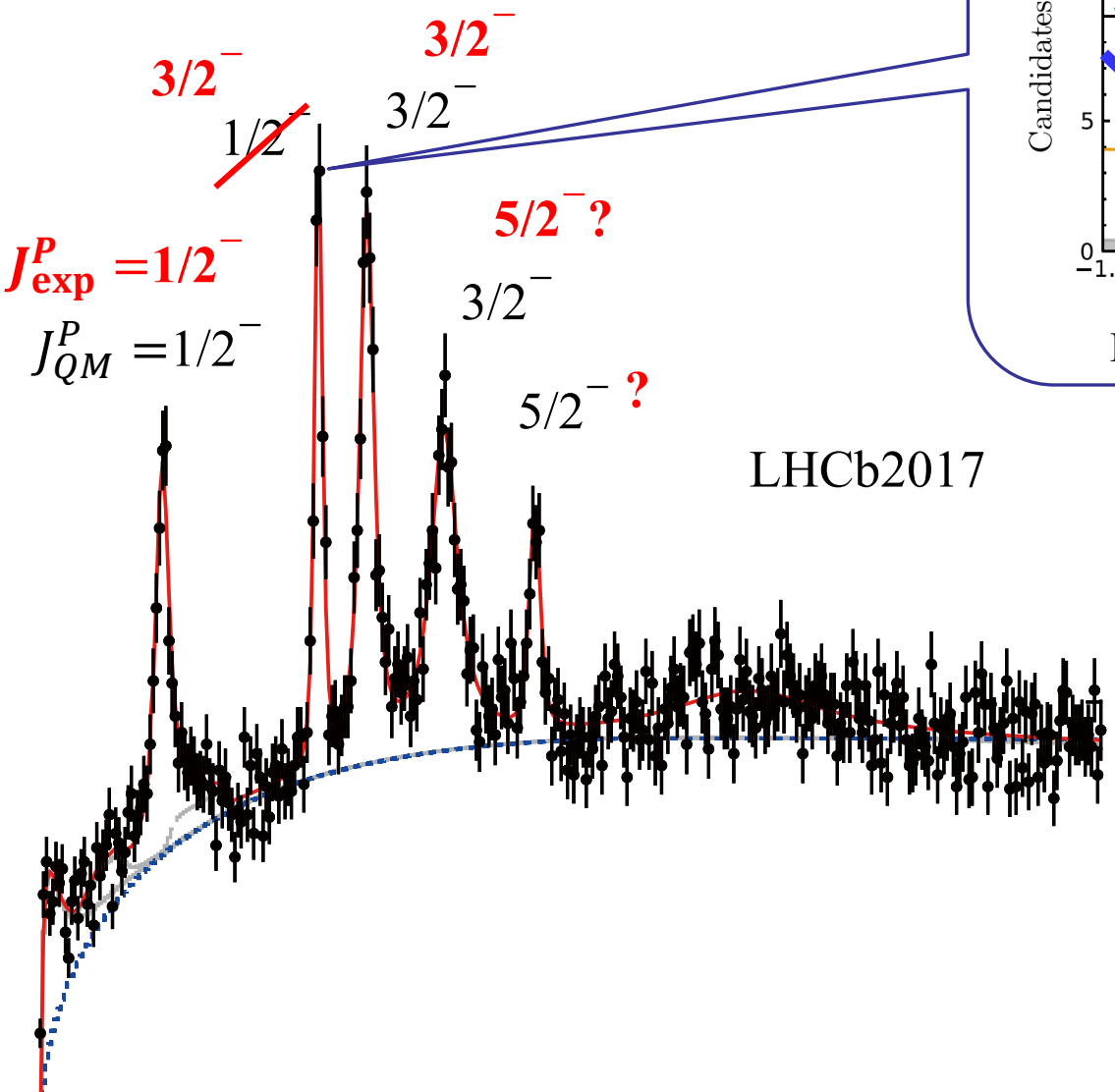


$$J = 1/2 \quad 1/2 \quad 3/2 \quad 3/2 \quad 5/2$$

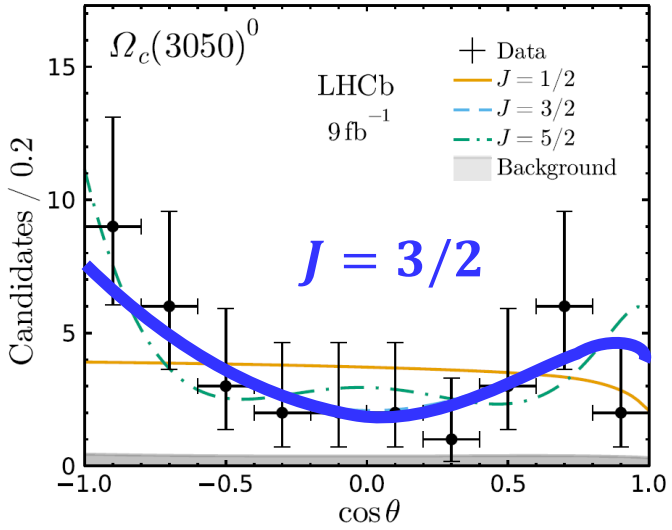
① ② ③ ④ ⑤

Difficulties of the Quark Model

Problem-1:
spin assignment does not follow the data



Angular distribution

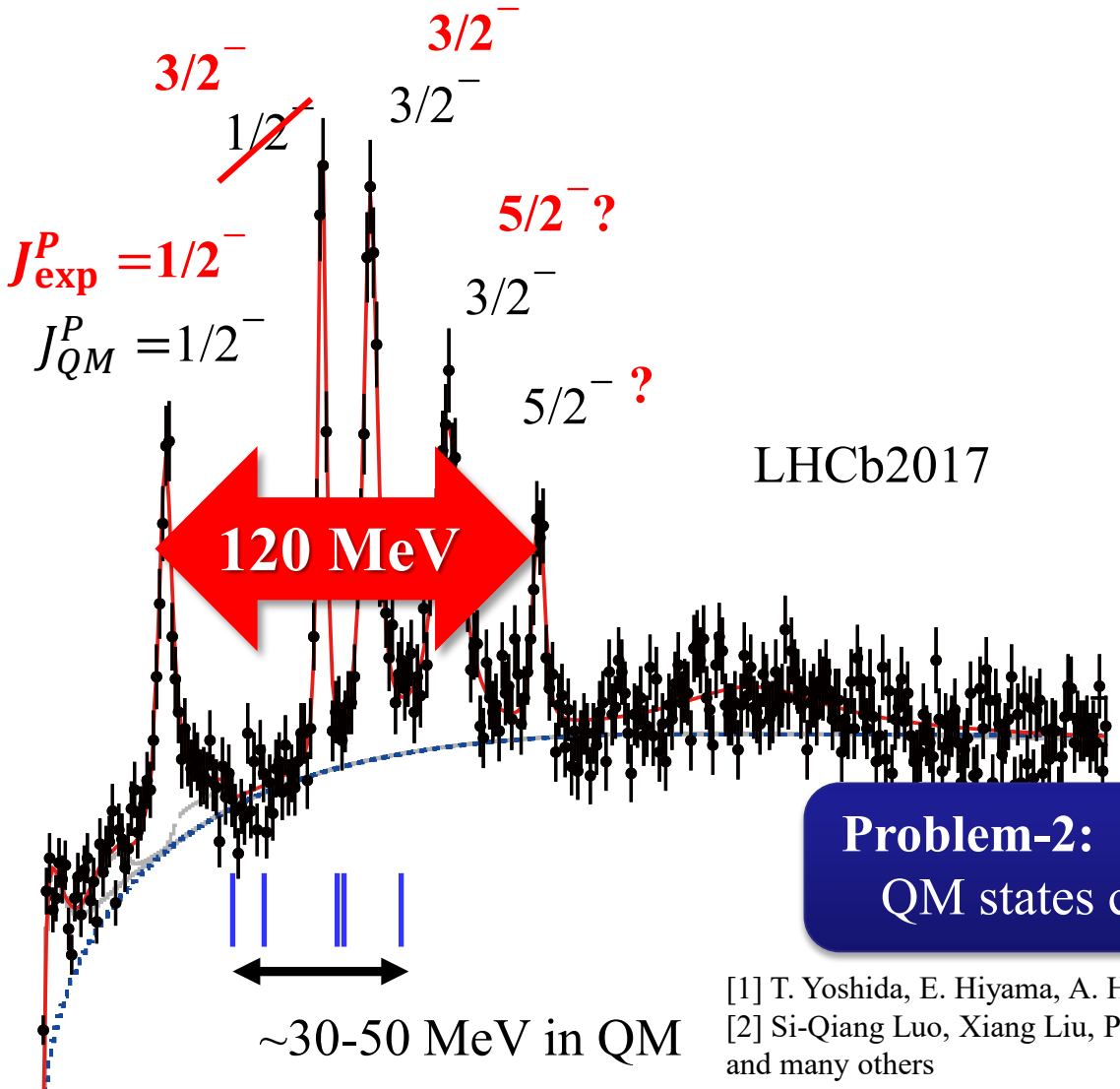


LHCb, PRD104(21)L091102

Difficulties of the Quark Model

Problem-1:
spin assignment does not follow the data





Problem-2:
QM states concentrate in a narrow range

[1] T. Yoshida, E. Hiyama, A. Hosaka, M. Oka, and K. Sadato, PRD92(15)114029
[2] Si-Qiang Luo, Xiang Liu, PRD107(23)074041
and many others

Difficulties of the Quark Model

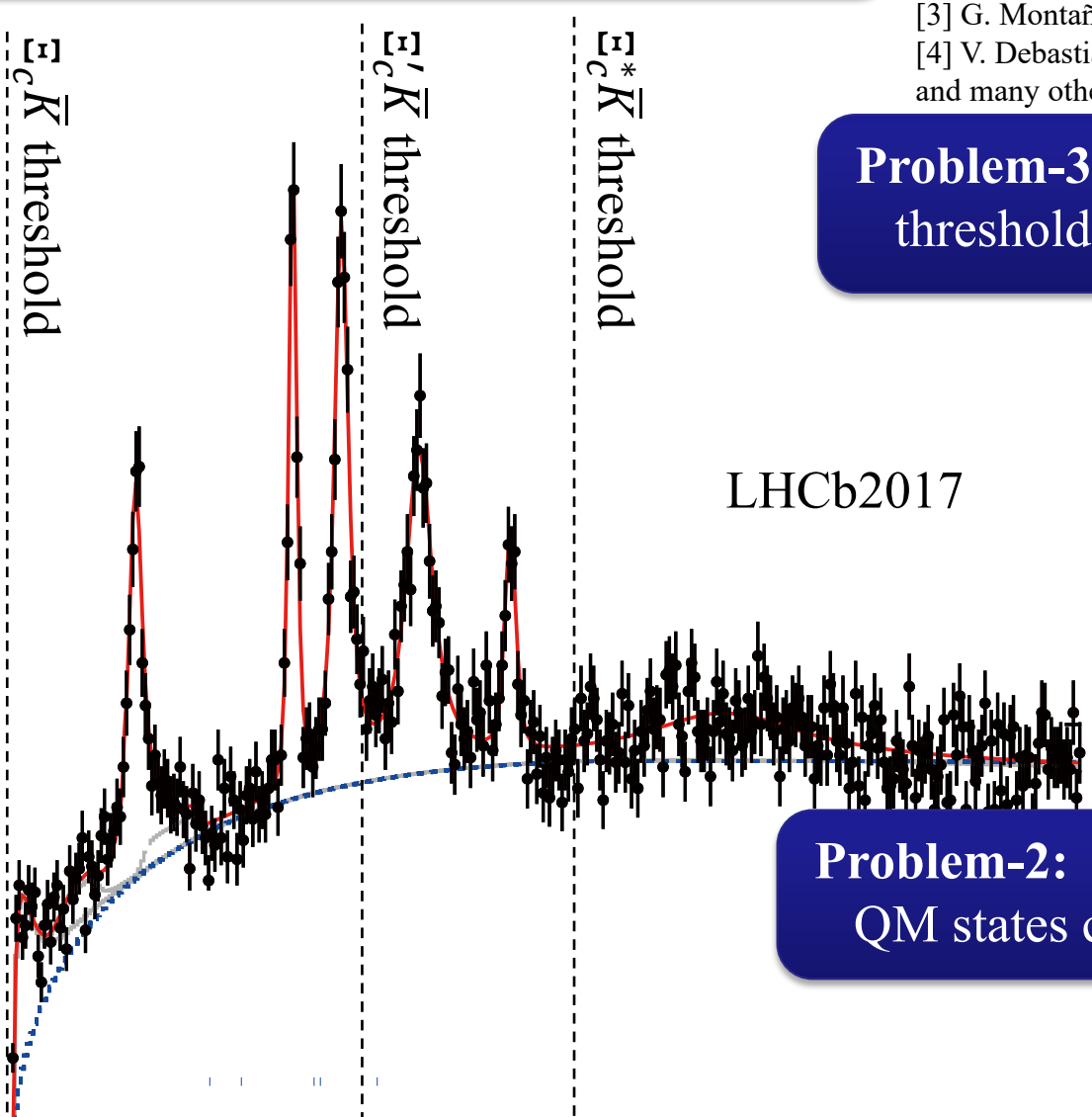
Problem-1:
spin assignment does not follow the data



[3] G. Montaña, A. Feijoo, A. Ramos, EPJA54(18)64
[4] V. Debastiani, J. Dias,W. Liang, E. Oset, PRD97(18)094035
and many others

Problem-3:
threshold nearby → molecule ?





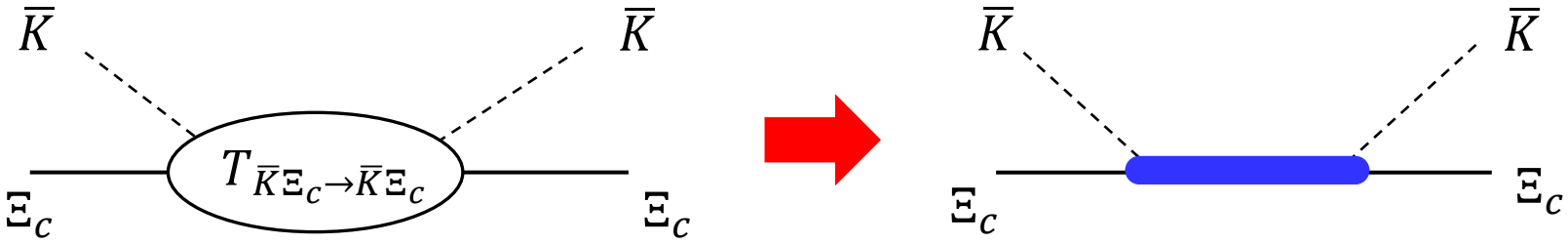
Problem-2:
QM states concentrate in a narrow range

Our strategy to obtain Ω_c baryon

Ξ_c^* Ξ_c'

We perform coupled-channel calculation for $\bar{K}\Xi_c$ amplitude…

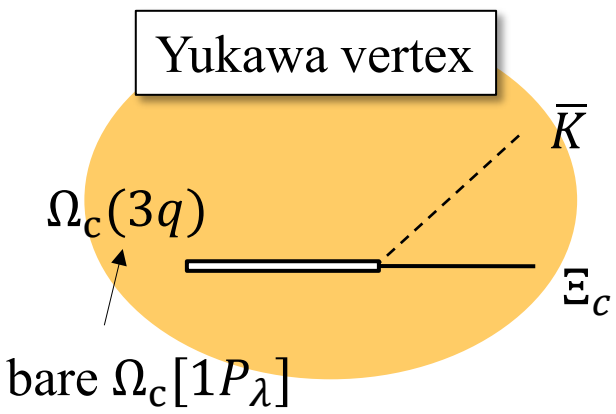
$\Xi_c(j = 0, 1/2^-)$
$\Xi_c'(j = 1, 1/2^-)$
$\Xi_c^*(j = 1, 3/2^-)$

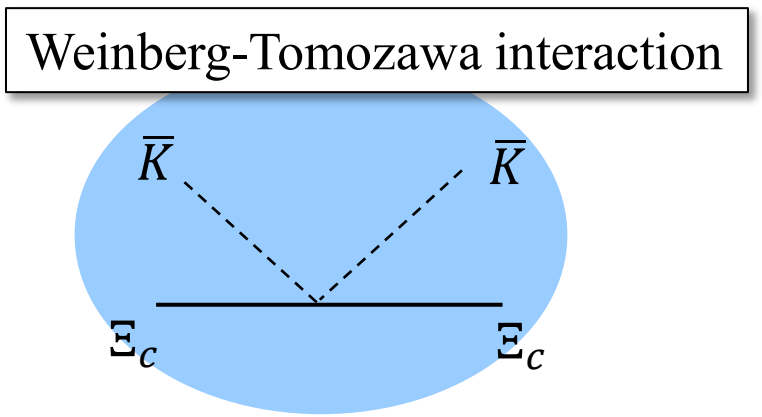


… and see the poles appearing in the amplitude

Necessary diagrams

by the conventional quark model + quark-meson Lagrangian w/ χS





baryon state

quarks ssc

$$|\Omega_c^{3q}, J\rangle = N \sum_{\{\ell,s\}} \int \frac{d^3p_\rho}{(2\pi)^3} \int \frac{d^3p_\lambda}{(2\pi)^3} \psi_\rho(\vec{p}_\rho)\psi_\lambda(\vec{p}_\lambda)|s_1(p_1)s_2(p_2)c(p_3)\rangle$$

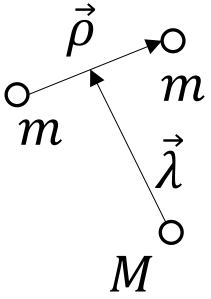
same for Ξ_c

summing up to make the total spin J of Ω_c^{3q}

flavor and spin combination

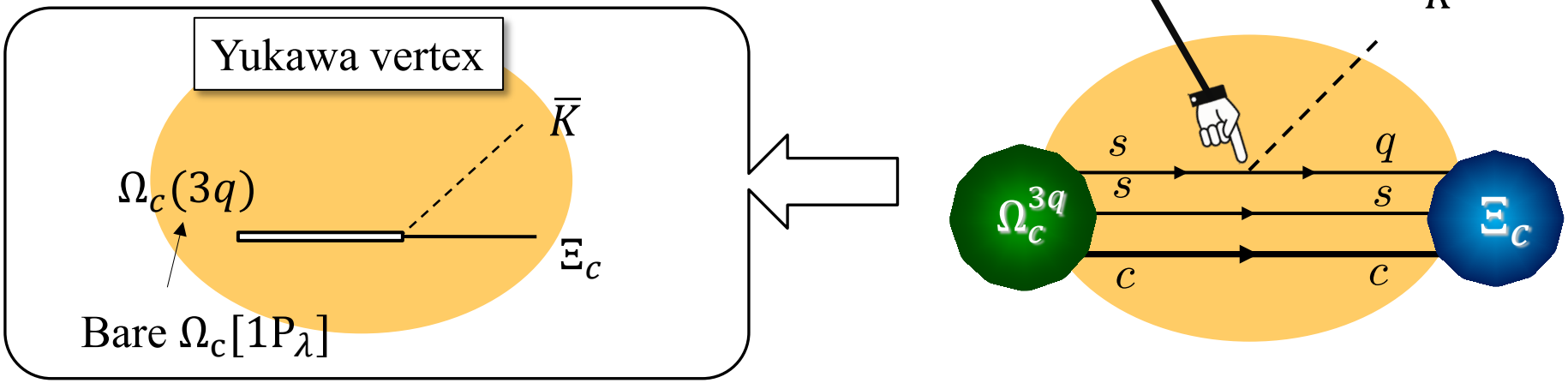
$$|\Omega_c^{3q}\rangle = |ssc\rangle \otimes \left[\left[S_{ss}, \psi_{1p}(\lambda)\psi_{0s}(\rho)\right]^j, \chi_c\right]^J$$

$$|\Xi_c\rangle \sim \frac{1}{\sqrt{2}}(qs + sq)c \otimes \left[\left[S_{qs}, \psi_{0s}(\lambda)\psi_{0s}(\rho)\right]^j, \chi_c\right]^J$$



Meson-quark coupling

$$\mathcal{L}(x) = \frac{g_A}{2f_K}\bar{q}(x)\gamma_\mu\gamma_5 q(x)\partial^\mu\phi(x)$$



Quark-meson interactions :

Chiral Lagrangian

$$\mathcal{L} = \bar{q}\left(i\partial_\mu\gamma^\mu - g f_\pi U_5\right)q$$

$$U_5 = e^{i\phi\gamma_5/f_\pi} = \xi_5^2$$

SU(3) meson matrix

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

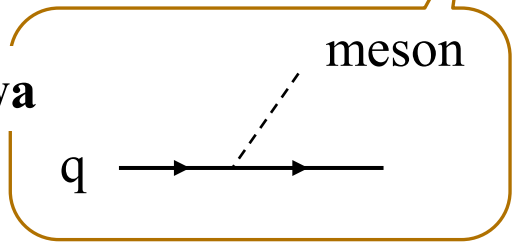
Constituent quark field $\psi = \xi_5 q$

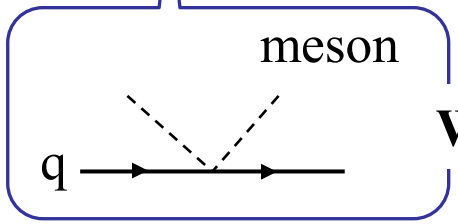
$$\mathcal{L} = \bar{\psi}\xi_5^\dagger\left(i\partial_\mu\gamma^\mu - g f_\pi \xi_5^2\right)\xi_5^\dagger\psi = \bar{\psi}\left(i\partial_\mu\gamma^\mu + (\xi_5^\dagger i\partial_\mu\gamma^\mu\xi_5^\dagger) - g f_\pi\right)\psi$$

$$\xi_5^\dagger\partial_\mu\gamma^\mu\xi_5^\dagger = -\frac{i}{2}\partial_\mu\gamma^\mu\phi\gamma_5 - \frac{1}{8}\left(\partial_\mu\gamma^\mu\phi\cdot\phi - \phi\cdot\partial_\mu\gamma^\mu\phi\right) + \mathcal{O}(\phi^3)$$

$$\therefore\ \mathcal{L}_{\text{int}} = \frac{1}{2}\bar{\psi}\not{\partial}\phi\gamma_5\psi - \frac{i}{8}\bar{\psi}(\partial\phi\cdot\phi - \phi\cdot\not{\partial}\phi)\psi$$

Yukawa





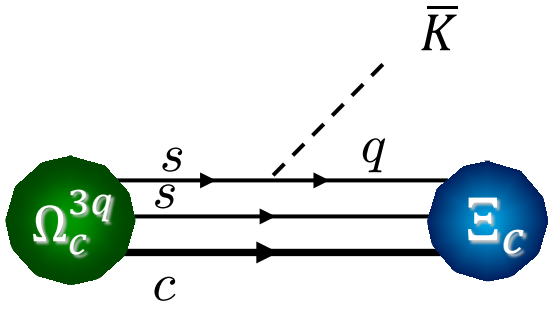
Weinberg-Tomozawa

A model that accommodates both three-quark and molecular Ω

Systematic calculation for Ω(2012) in a coupled-channel approach

Model containing the both of $\Omega_c(3q)$ and $\Omega_c(\bar{K}\Xi_c)$ molecule

$\Omega_c(3q) \to \bar{K}\Xi_c$



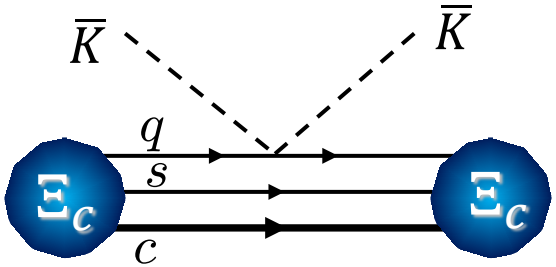
Meson-quark coupling : axial-vector type

$$\mathcal{L} = \frac{g_A}{2f_K}\bar{q}\gamma_\mu\gamma_5 q\partial^\mu\phi$$

Yukawa

$$t_{\text{Yukawa}} = c_0\frac{g_A}{f_K}\frac{\omega_K\alpha_\lambda}{m_s}$$

$\bar{K}\Xi_c \to \eta\Omega_c(gs)$



Weinberg-Tomozawa interaction

$$\mathcal{L} = -\frac{i}{8f_K^2}\bar{q}\gamma_\mu(\partial^\mu\phi\phi - \phi\partial^\mu\phi)q$$

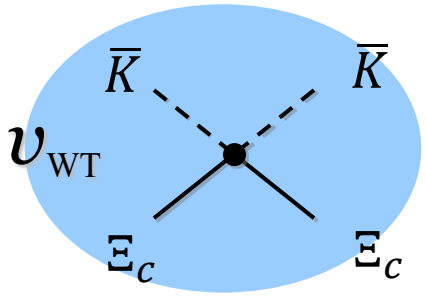
$$t_{WT} = \frac{D_{ij}}{4f_K^2}\left(2\sqrt{s} - M_{\Omega_{gs}} - M_{\Xi^*}\right)$$

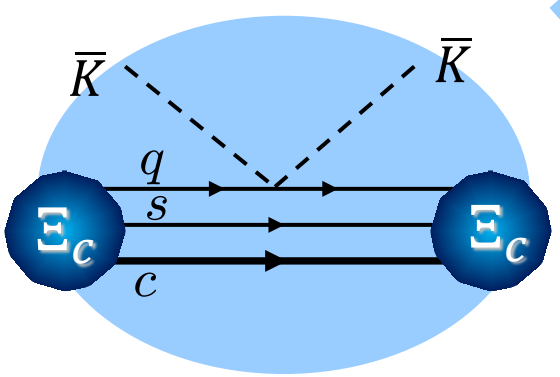
Dynamically generated resonances : molecular $\Omega_c(\bar{K}\Xi_c)$ baryon

Ω_c as $\bar{K}\Xi_c$ molecule

Weinberg-Tomozawa interaction



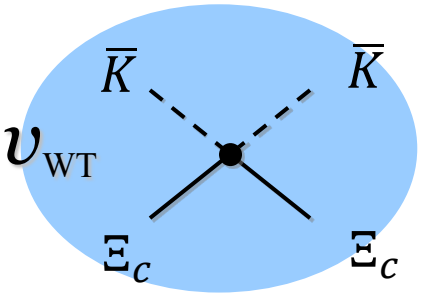




Dynamically generated resonances : molecular $\Omega_c(\bar{K}\Xi_c)$ baryon

Ω_c as $\bar{K}\Xi_c$ molecule





Summing up infinite number of diagrams

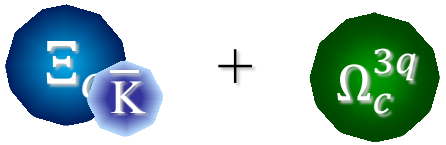
$$t_{\bar{K}\Xi_c\to\bar{K}\Xi_c} = \frac{v_{WT}}{1 - v_{WT}G}$$



dynamically generates
the molecular Ω_c

Formalism : bare Ω_c^{3q} contribution through additional interaction

mixed states of $\Omega_c(\bar{K}\Xi_c)$ and bare $\Omega_c(3q)$

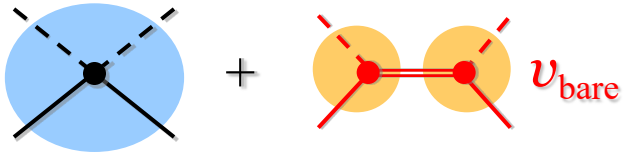


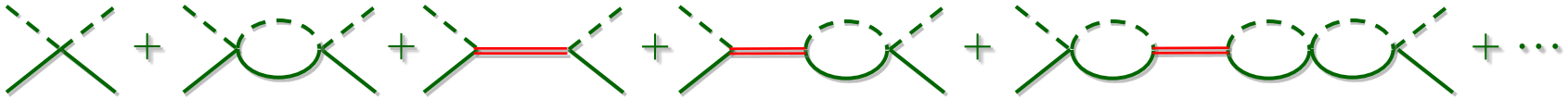
Bare Ω_c(3q) contributes as an additional interaction v_{bare}

full scattering amplitude of $\bar{K}\Xi_c \to \bar{K}\Xi_c$

$$t_{\bar{K}\Xi_c \to \bar{K}\Xi_c} = \frac{v_{WT} + v_{\text{bare}}}{1 - (v_{WT} + v_{\text{bare}})\, G}$$

$\Omega_c(3q)$ pole term





= mixed physical Ω_c

Parameters :

Quark Model parameters for wave function

light quark mass $m = 450$ MeV

charm quark mass $M = 1500$ MeV

Gaussian range parameter $\alpha_\lambda = 387$ MeV (H.O. wave function)

Interaction and cut-off

Decay constant $f_K = 111$ MeV

Axial coupling constant $\boldsymbol{g_A^q = 0.75}$

Cut-off of the loop function $\boldsymbol{\Lambda = 500}$ **MeV**

Reproduces the decay width of
$\Lambda_c(2595/2625) \to \Sigma_c\pi$
$\Sigma_c(2455/2420) \to \Lambda_c\pi$
pretty well. [1]

natural as hadronic scale

[1] H. Nagahiro, S. Yasui, A. Hosaka, M. Oka, H. Noumi, PRD95(17)014023

Bare masses of $\Omega_c^{3q}(1P_\lambda)$

free parameters with conditions

- ✓ in the range 3020–3060
- ✓ Mass-ordering for J^P

$\Omega_c^{3q}(0; 1/2^-)$ 3020 MeV

$\Omega_c^{3q}(1; 1/2^-)$ 3040 MeV

$\Omega_c^{3q}(1; 3/2^-)$ 3060 MeV

Coupled channels : Assume Heavy-Quark Spin Symmetry







(j, J^P)	Three-quark state	Meson-Baryon channel
$(0, 1/2^-)$	$\Omega_c^{3q}(0; 1/2^-)$	
$(1; 1/2^-)$	$\Omega_c^{3q}(1; 1/2^-)$	
$(1; 3/2^-)$	$\Omega_c^{3q}(1;\ 3/2^-)$	
$(2; 3/2^-)$	$\Omega_c^{3q}(2; 3/2^-)$	
$(2; 5/2^-)$	$\Omega_c^{3q}(2;\ 5/2^-)$	

Coupled channels : Assume Heavy-Quark Spin Symmetry



(j, J^P)	Three-quark state	Meson-Baryon channel
$(0, 1/2^-)$	$\Omega_c^{3q}(0; 1/2^-)$	$\Xi_c(0; 1/2^+)\bar{K}$
$(1; 1/2^-)$	$\Omega_c^{3q}(1; 1/2^-)$	$\Xi_c'(1; 1/2^+)\bar{K}$, $\Omega_c(1; 1/2^+)\eta$
$(1; 3/2^-)$	$\Omega_c^{3q}(1; 3/2^-)$	$\Xi_c^*(1; 3/2^+)\bar{K}$, $\Omega_c^*(1; 3/2^+)\eta$
$(2; 3/2^-)$	$\Omega_c^{3q}(2; 3/2^-)$	*No coupling in s-wave*
$(2; 5/2^-)$	$\Omega_c^{3q}(2; 5/2^-)$	*No coupling in s-wave*

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$(1; 3/2^-)$	$\Omega_c^{3q}(1; 3/2^-)$	$\Xi_c^*(1; 3/2^+)\bar{K}$, $\Omega_c^*(1; 3/2^+)\eta$
$(2; 3/2^-)$	$\Omega_c^{3q}(2; 3/2^-)$	*No coupling in s-wave*
$(2; 5/2^-)$	$\Omega_c^{3q}(2; 5/2^-)$	*No coupling in s-wave*

Physical state = pure 3q

Coupled channels : Assume Heavy-Quark Spin Symmetry

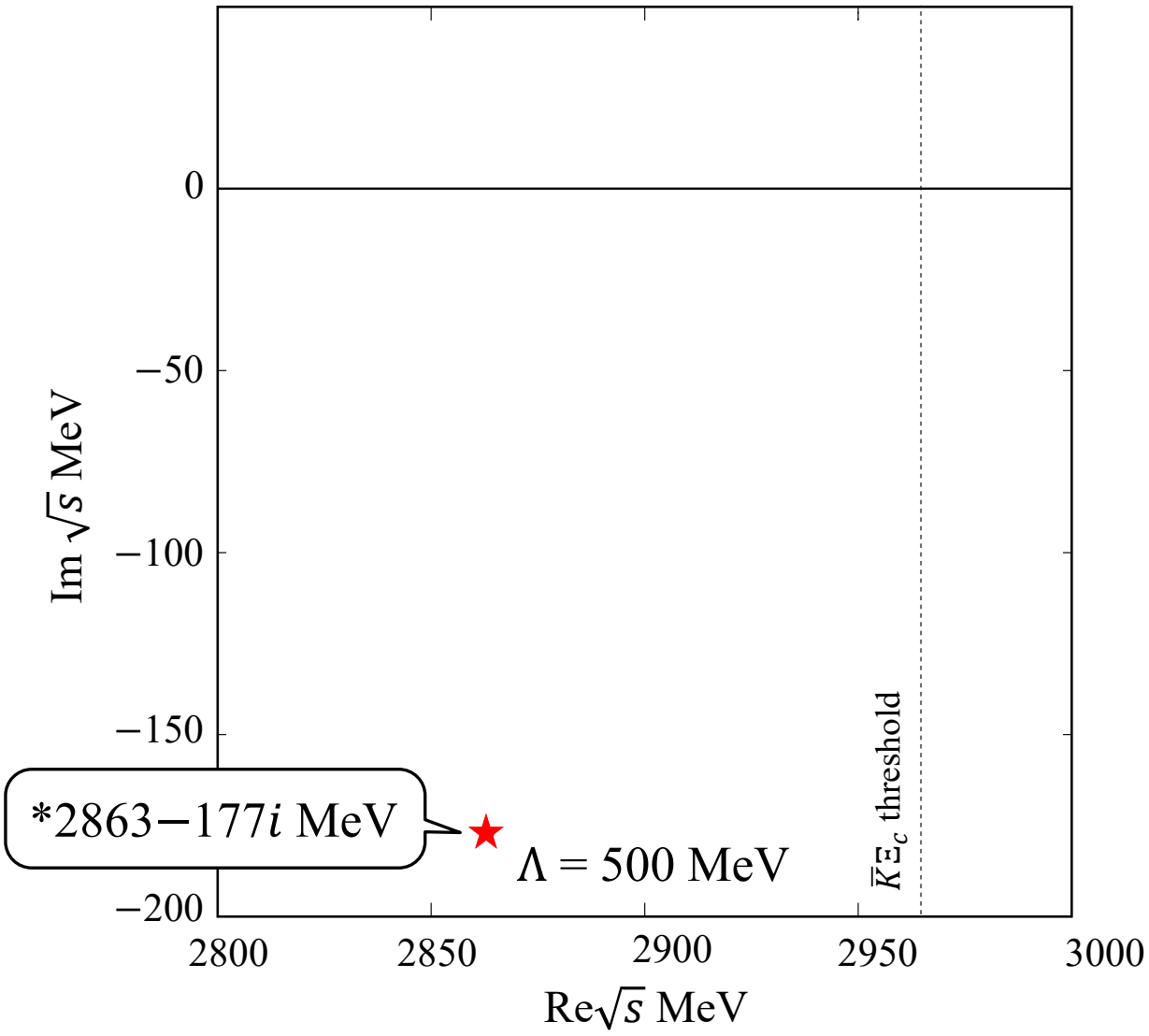


(j, J^P)	Three-quark state	Meson-Baryon channel
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Physical state = pure 3q

Numerical Results : $j = 0, J^P = 1/2^-$ system

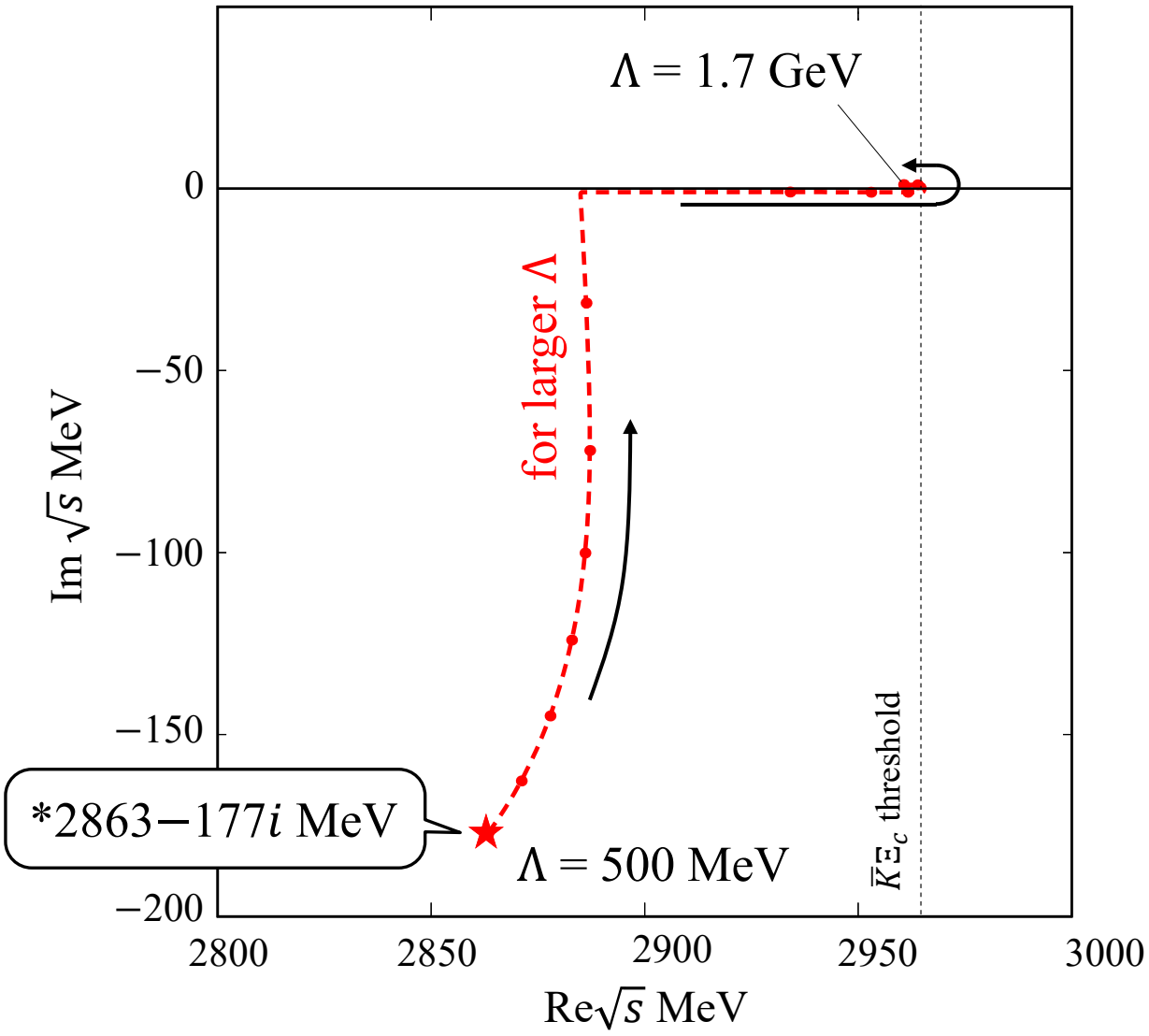
Pole flow of the **pure molecule (WT) pole**



* **virtual pole** in the second Riemann sheet below the threshold

Numerical Results : $j = 0, J^P = 1/2^-$ system

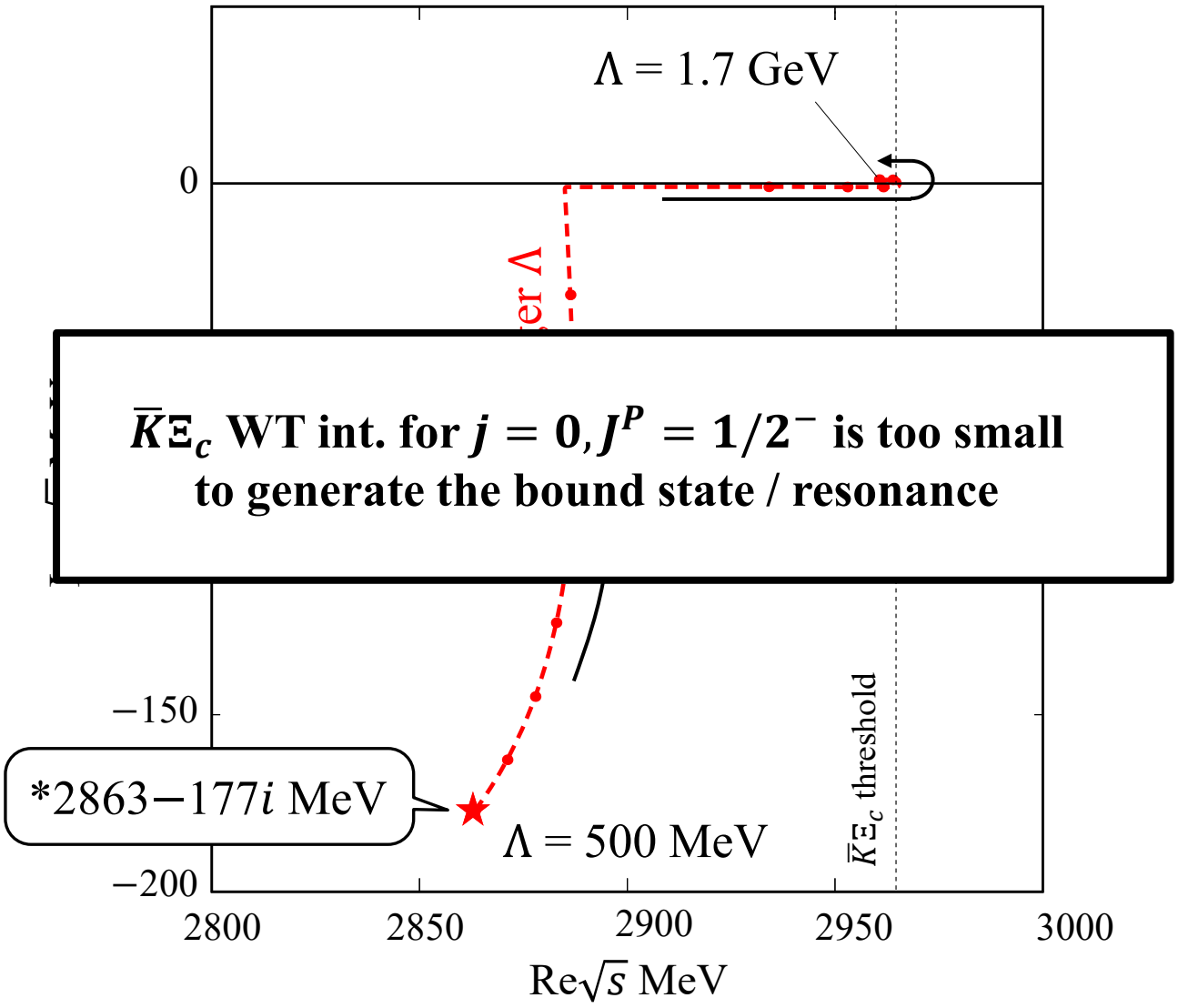
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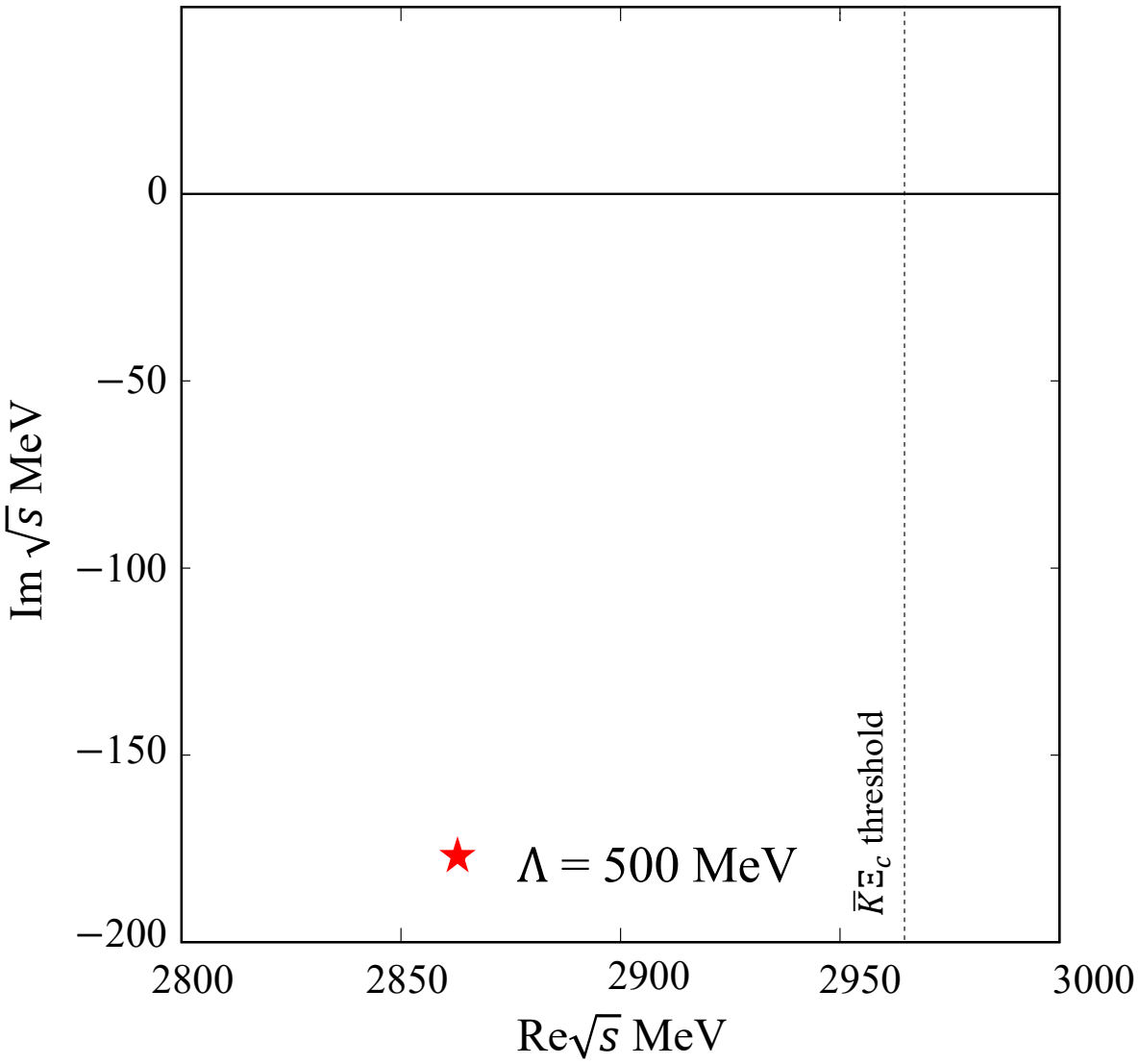
Numerical Results : $j = 0, J^P = 1/2^-$ system

Pole flow of the **pure molecule (WT) pole**

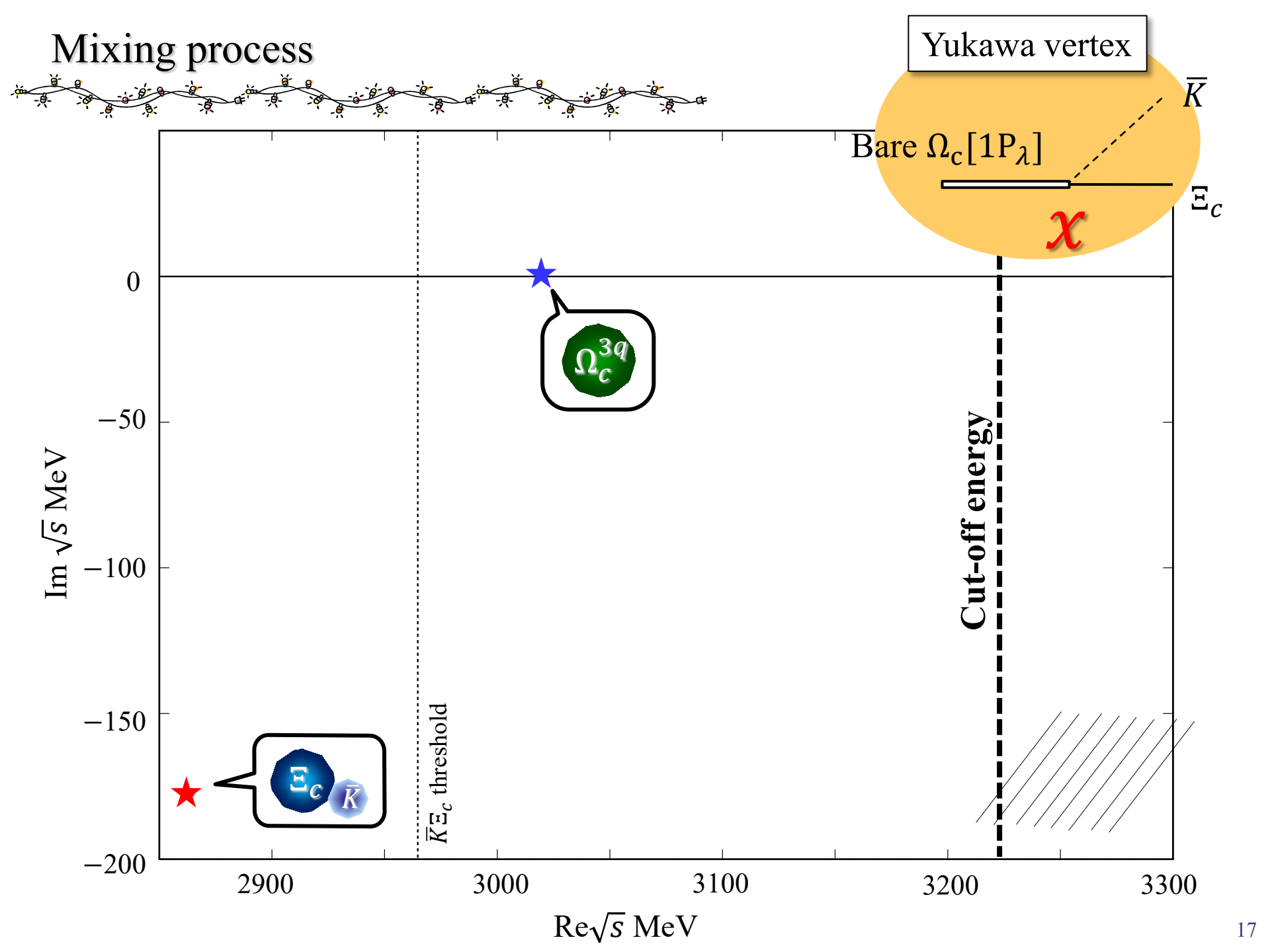


* **virtual pole** in the second Riemann sheet below the threshold

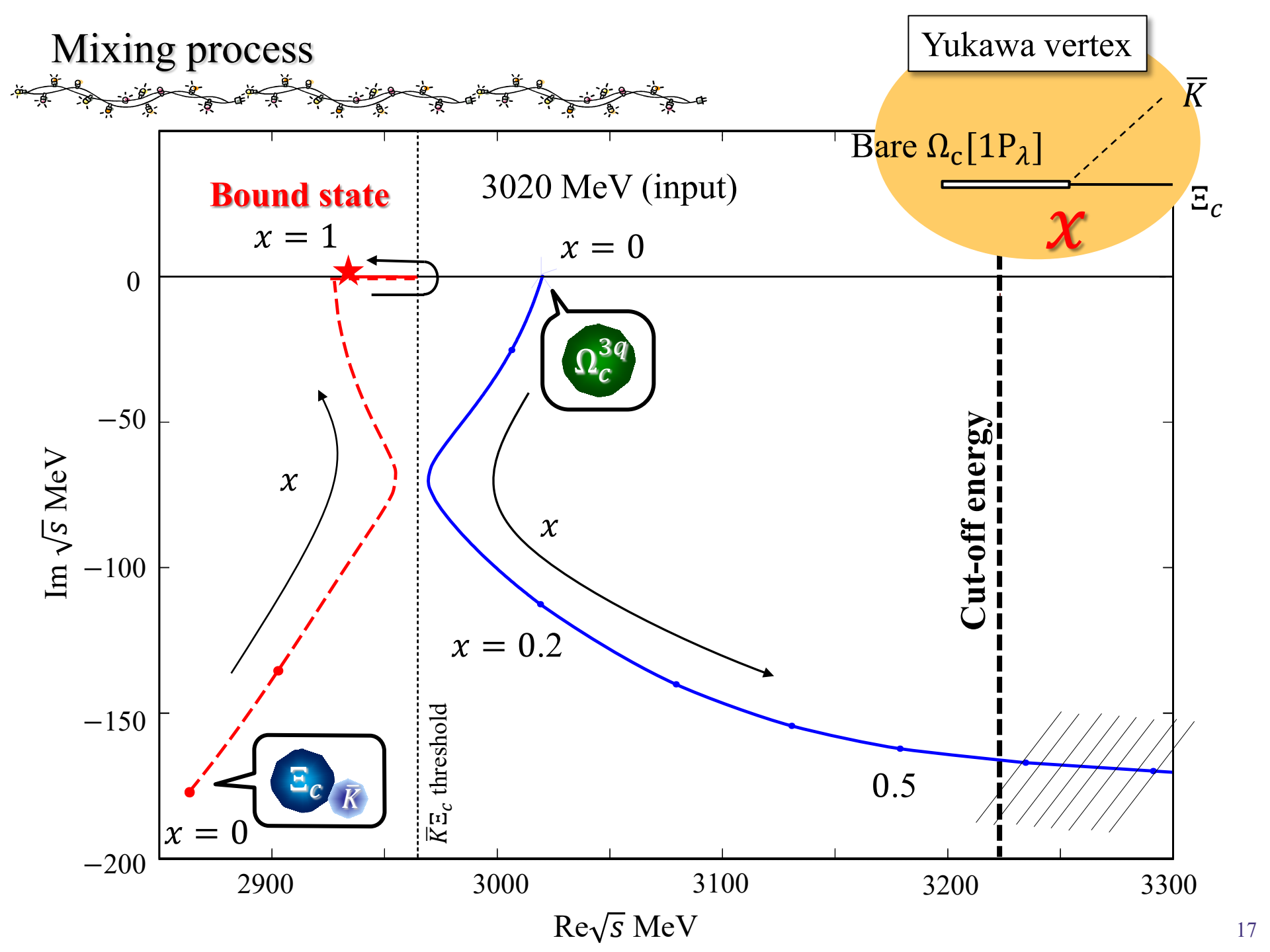
Numerical Results : $j = 0, J^P = 1/2^-$ system



Mixing process

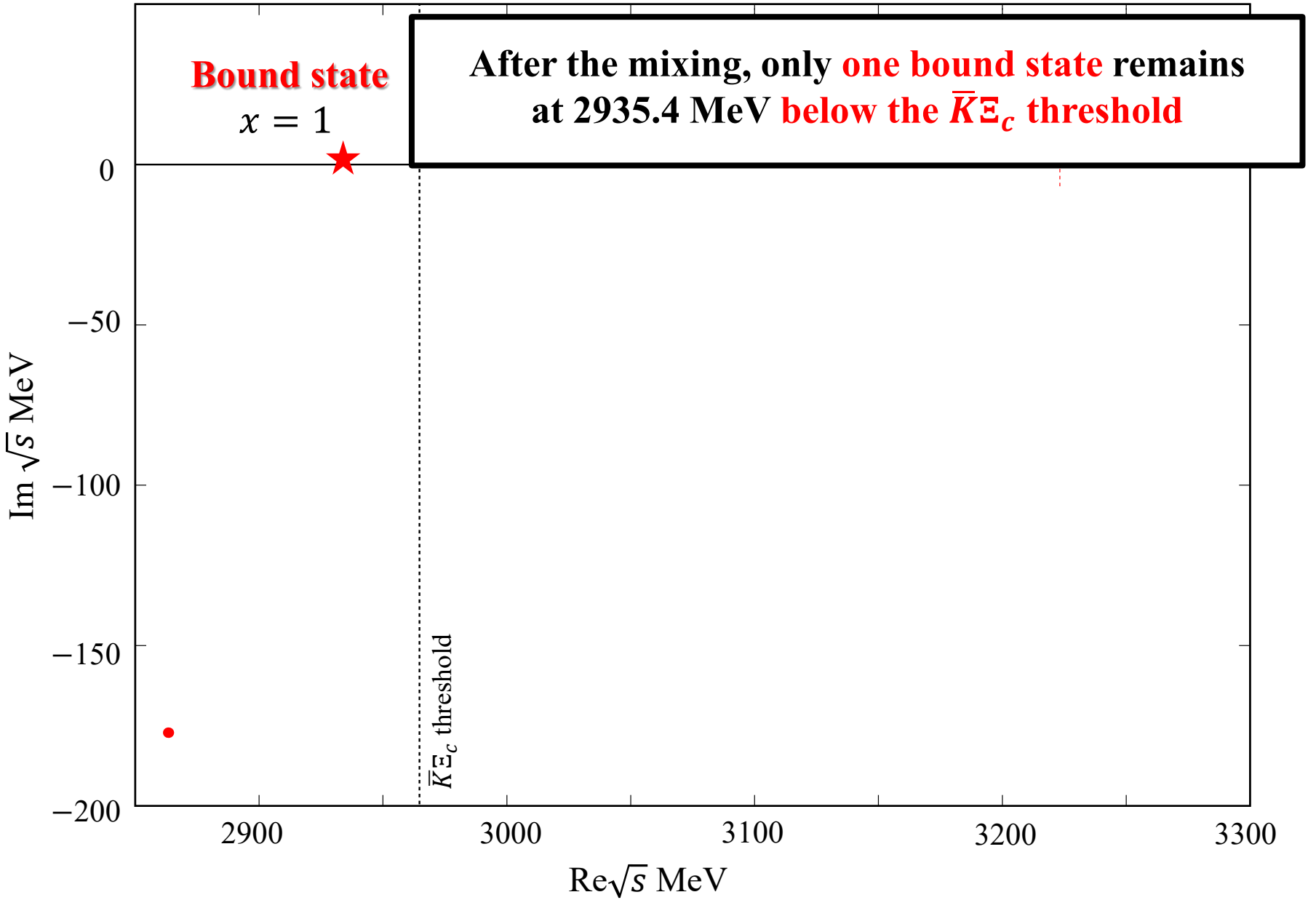


Mixing process



Physical pole for $j = 0, J^P = 1/2^-$ system : **Bound state**

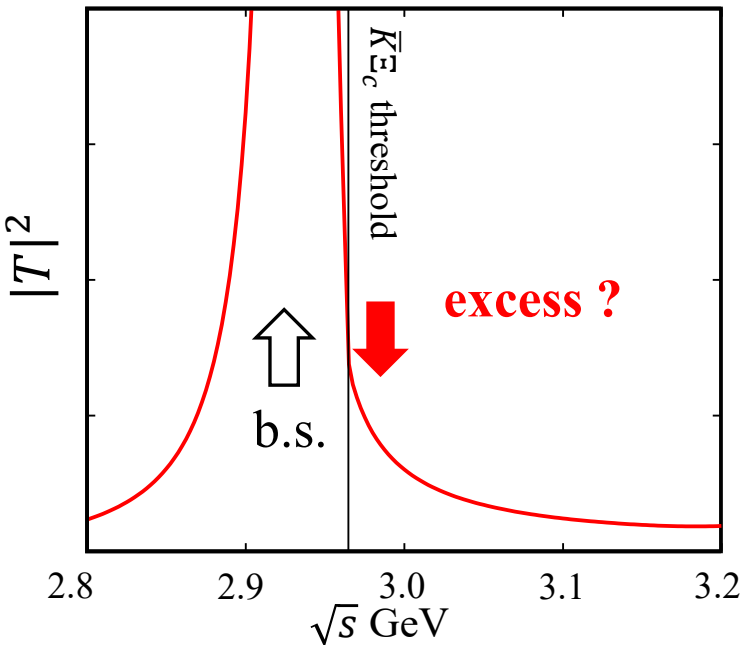




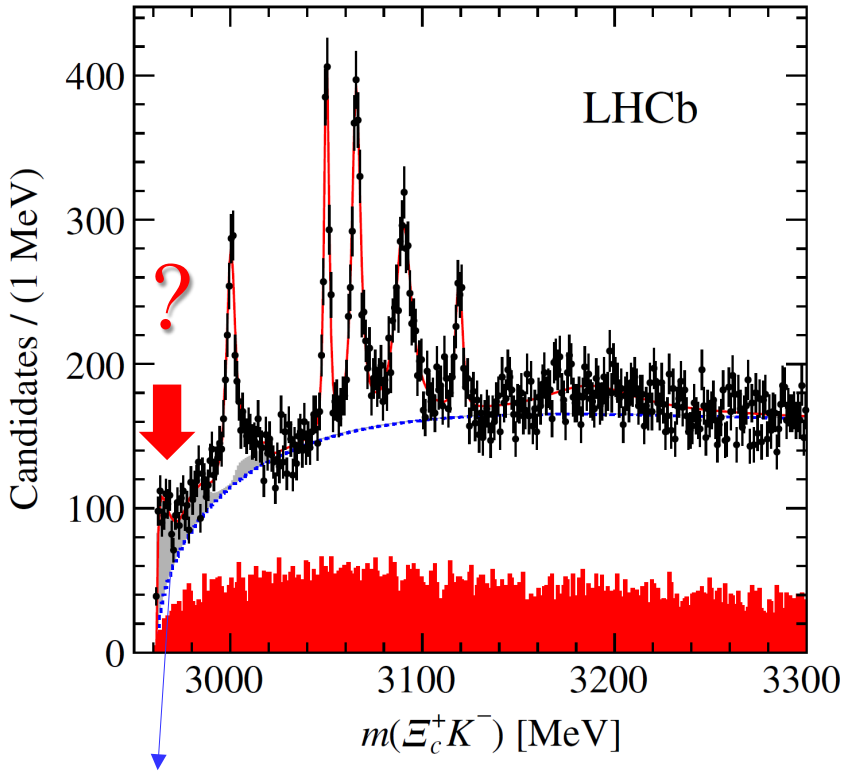
Physical pole for $j = 0, J^P = 1/2^-$ system : **Bound state**

After the mixing, only one bound state remains at 2935.4 MeV below the $\bar{K}\Xi_c$ threshold

$\bar{K}\Xi_c \to \bar{K}\Xi_c$ amplitude



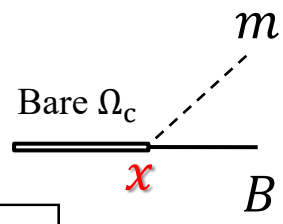
LHCb, PRL118(2017)182001

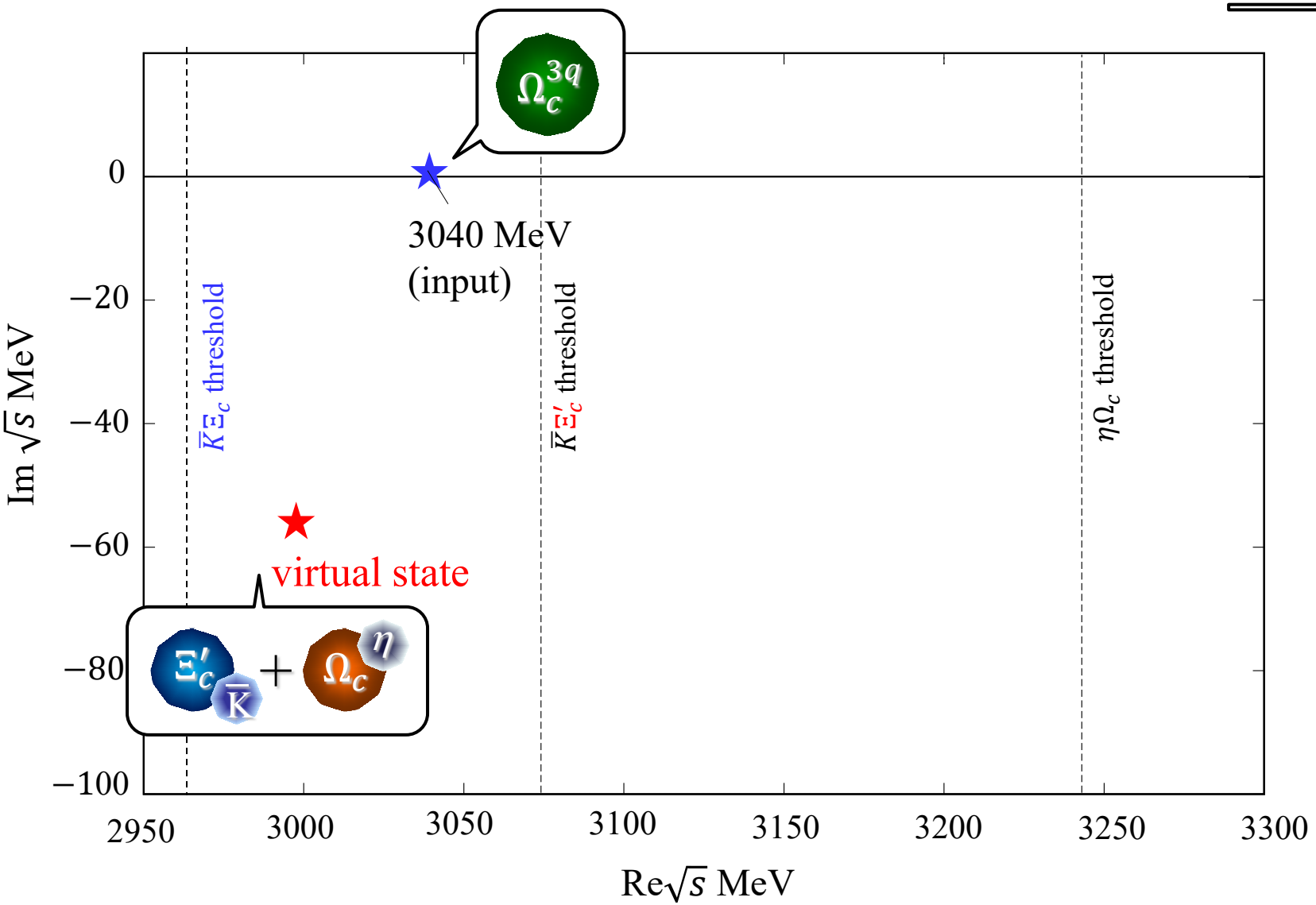


$\Omega_c(X)^0 \to K^-\Xi_c' \to K^-\Xi_c\gamma$? [PRL118]

Numerical Results : $j = 1, J^P = 1/2^-$ system

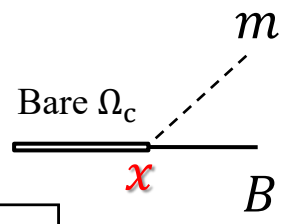
This system does not couple to $\bar{K}\Xi_c (j = 0)$ system with HQSS

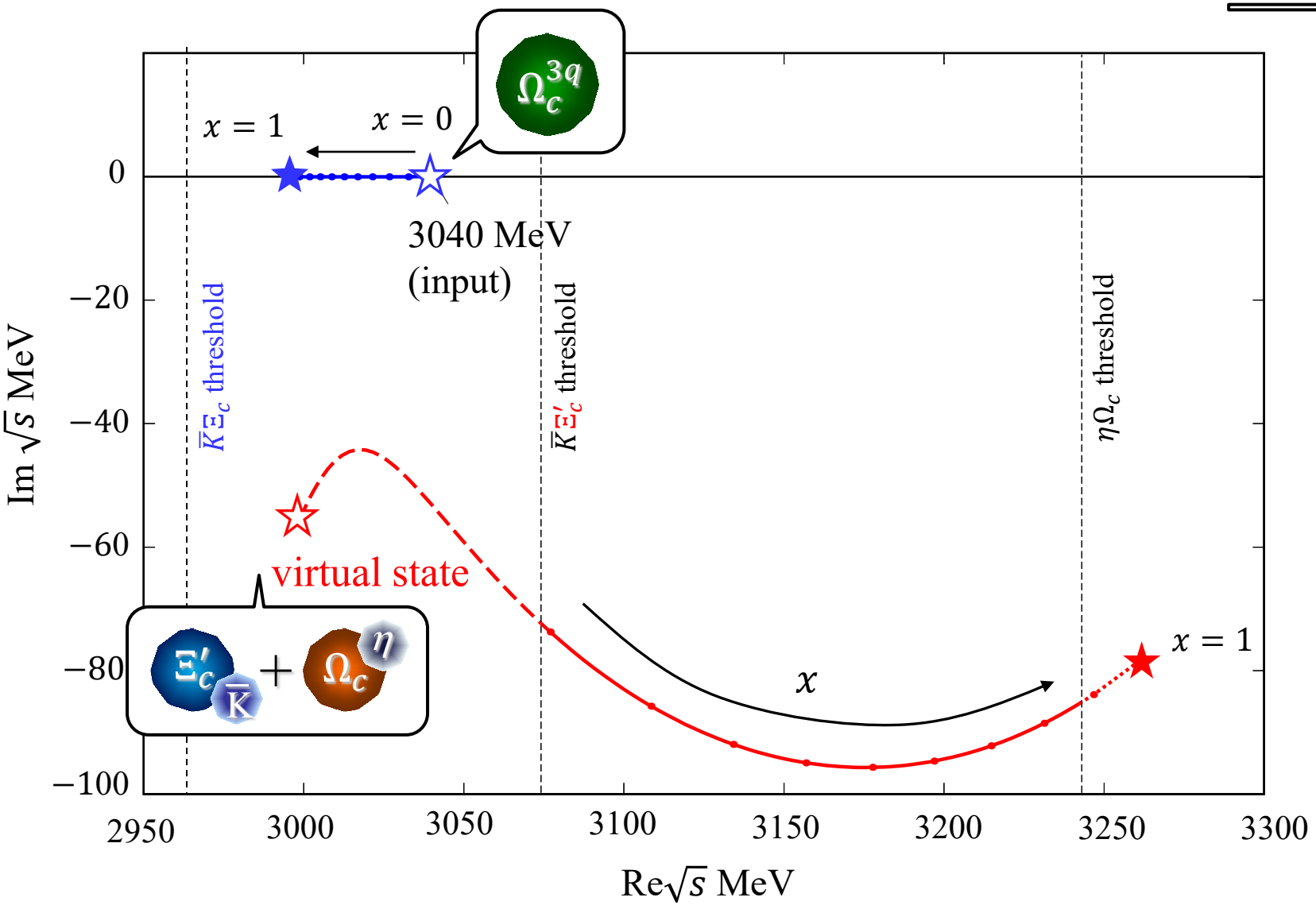




Numerical Results : $j = 1, J^P = 1/2^-$ system

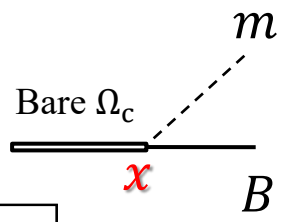
This system does not couple to $\bar{K}\Xi_c (j = 0)$ system with HQSS

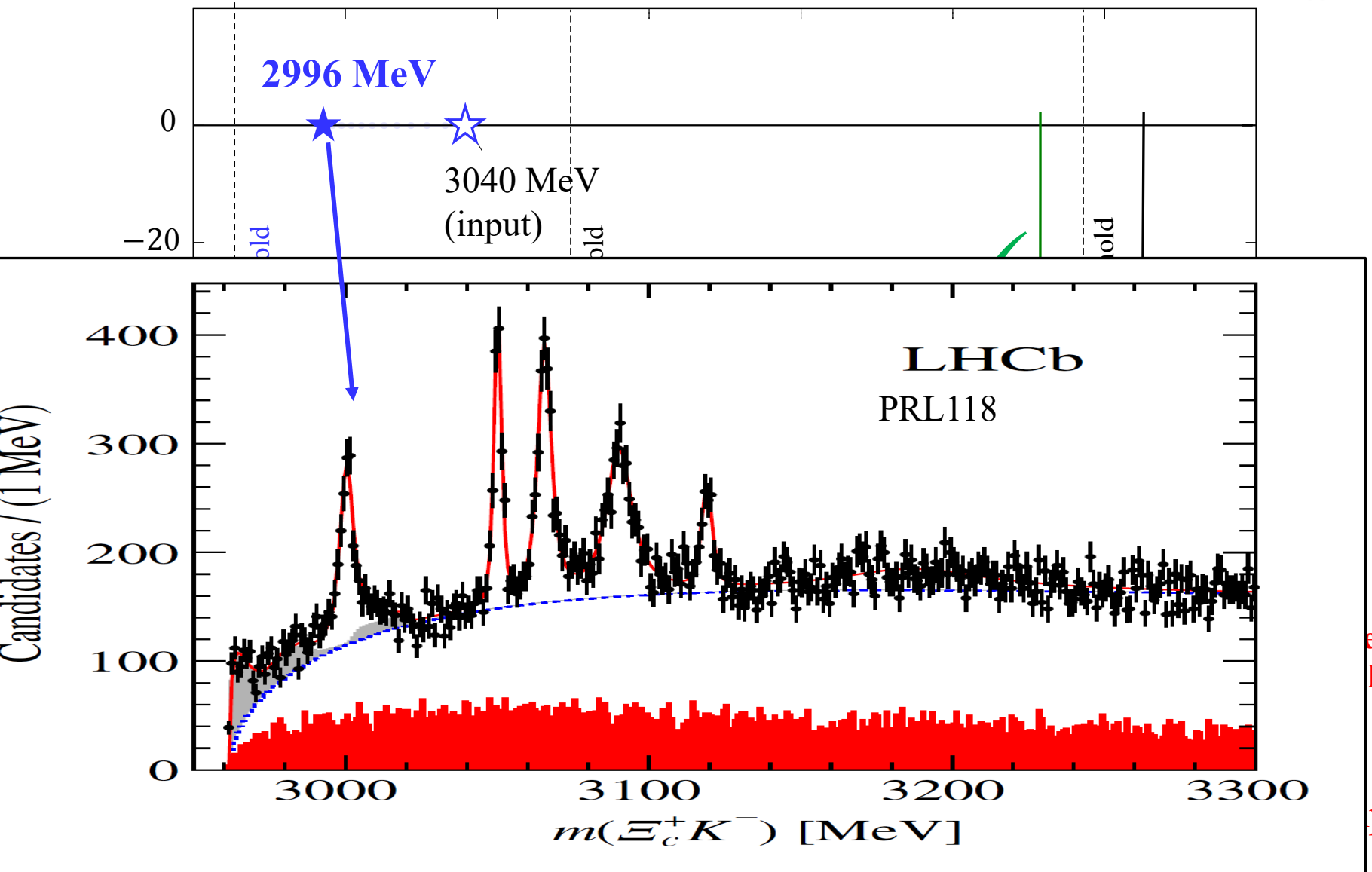




Numerical Results : $j = 1, J^P = 1/2^-$ system

This system does not couple to $\bar{K}\Xi_c(j = 0)$ system with HQSS



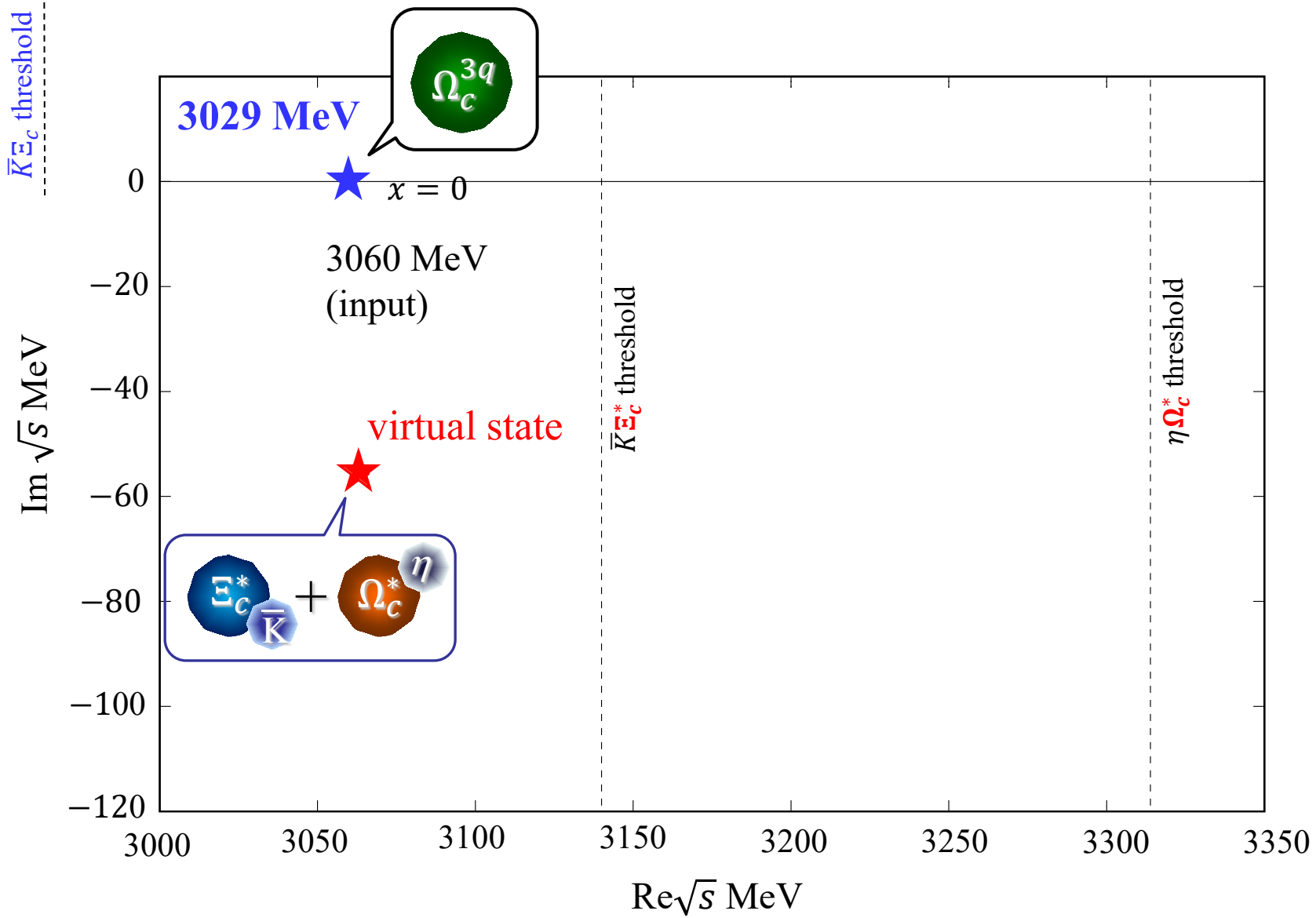


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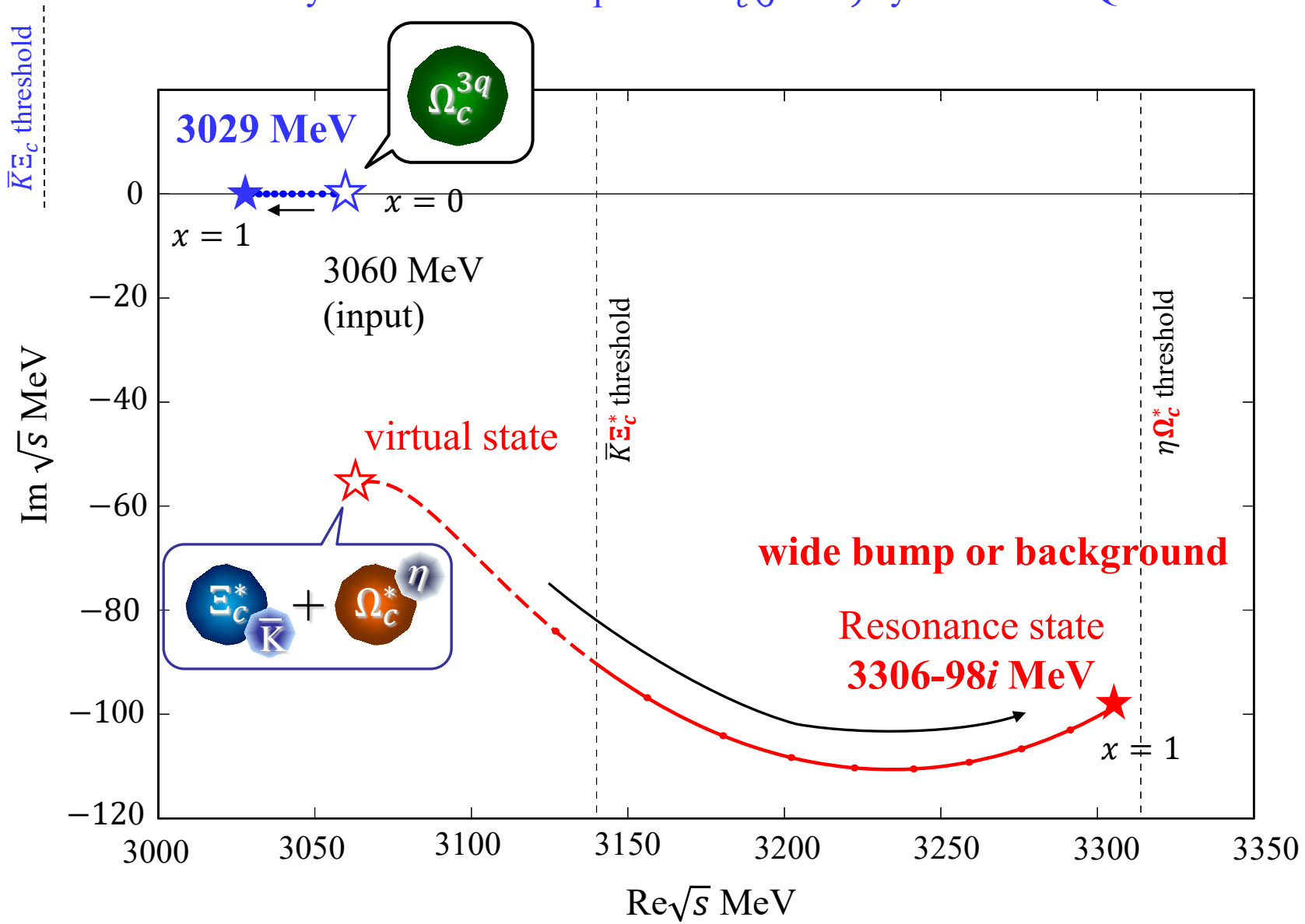
Numerical Results : $j = 1, J^P = 3/2^-$ system

This system does not couple to $\bar{K}\Xi_c(j = 0)$ system with HQSS



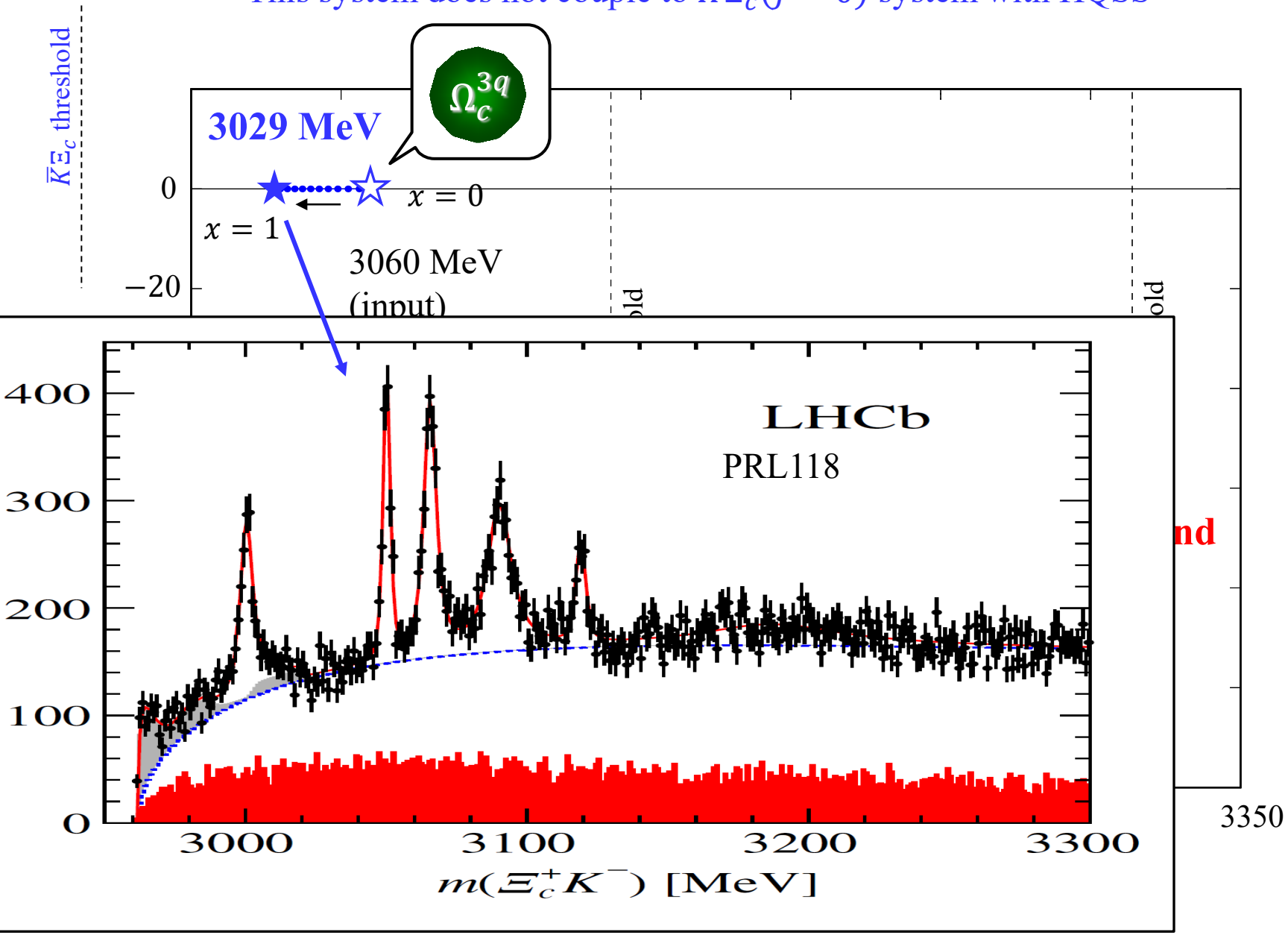
Numerical Results : $j = 1, J^P = 3/2^-$ system

This system does not couple to $\bar{K}\Xi_c(j = 0)$ system with HQSS

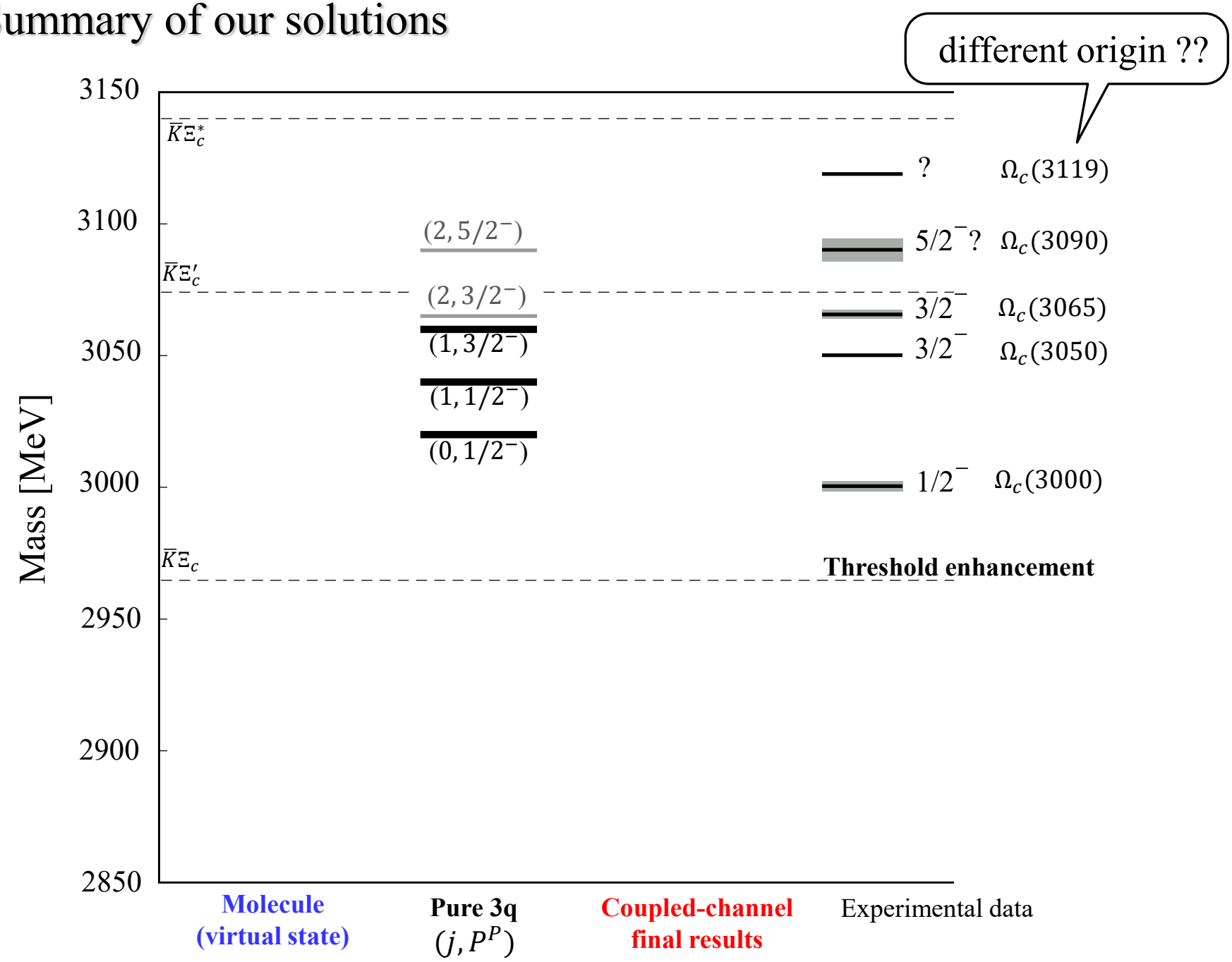


Numerical Results : $j = 1, J^P = 3/2^-$ system

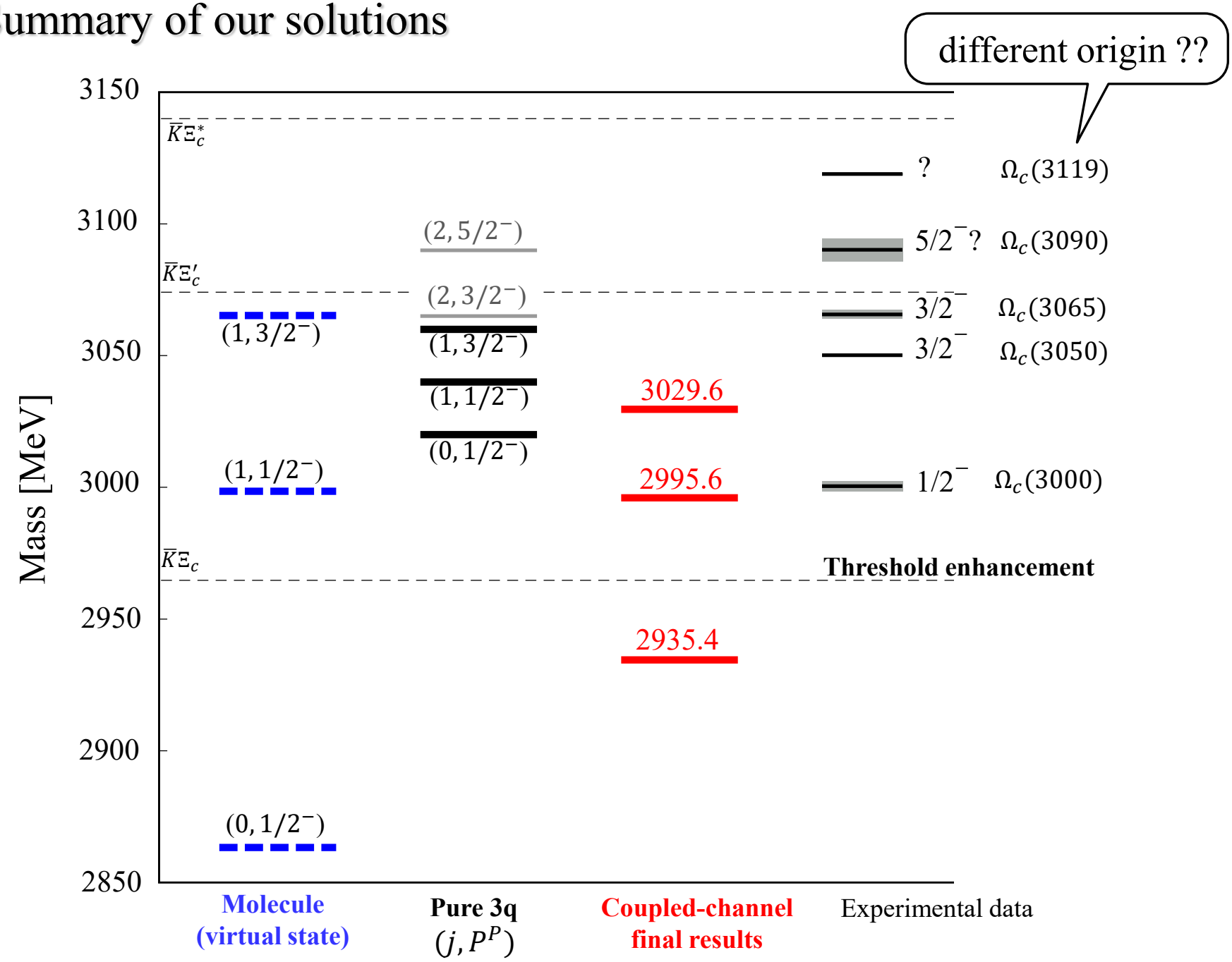
This system does not couple to $\bar{K}\Xi_c(j = 0)$ system with HQSS



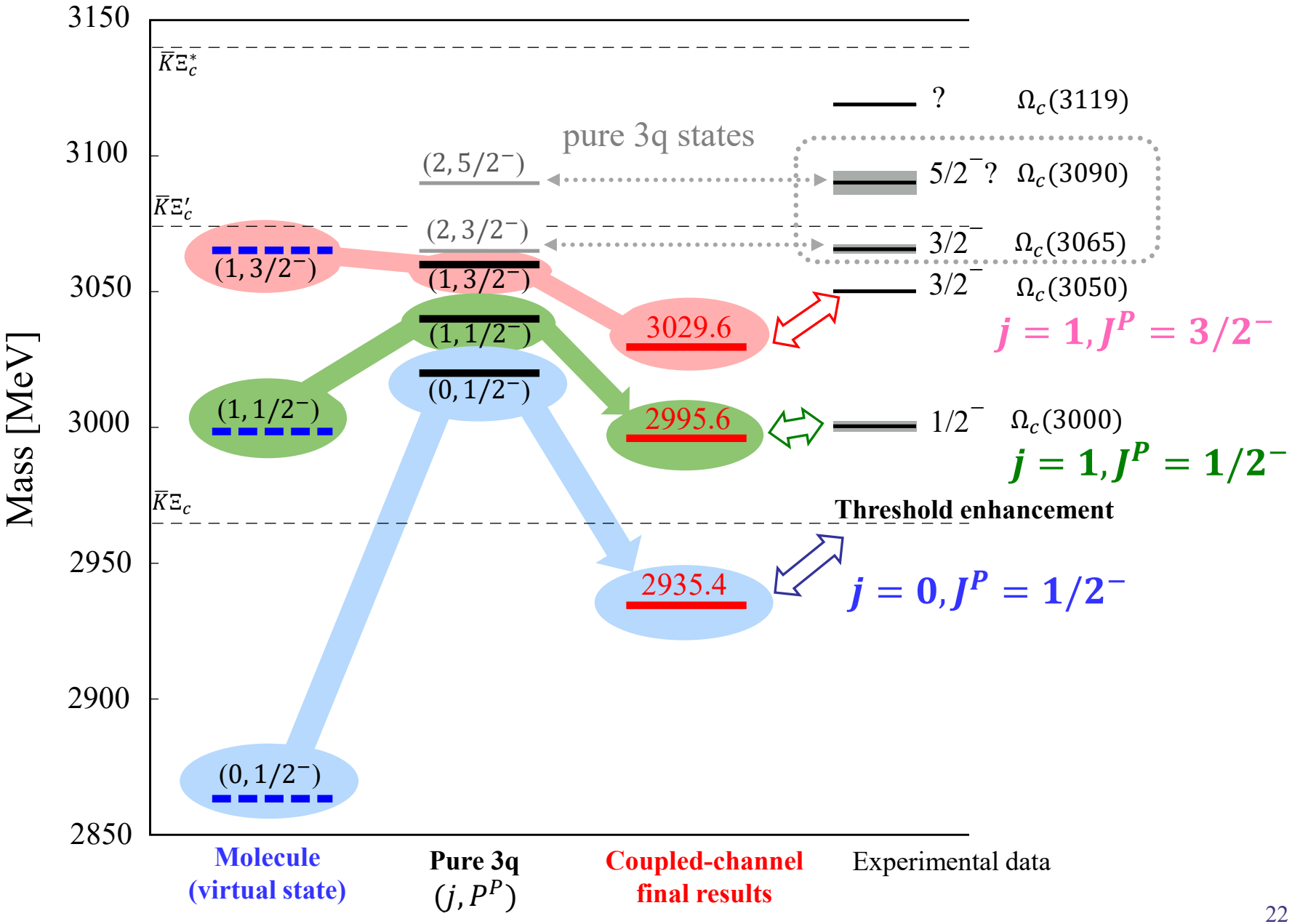
Summary of our solutions



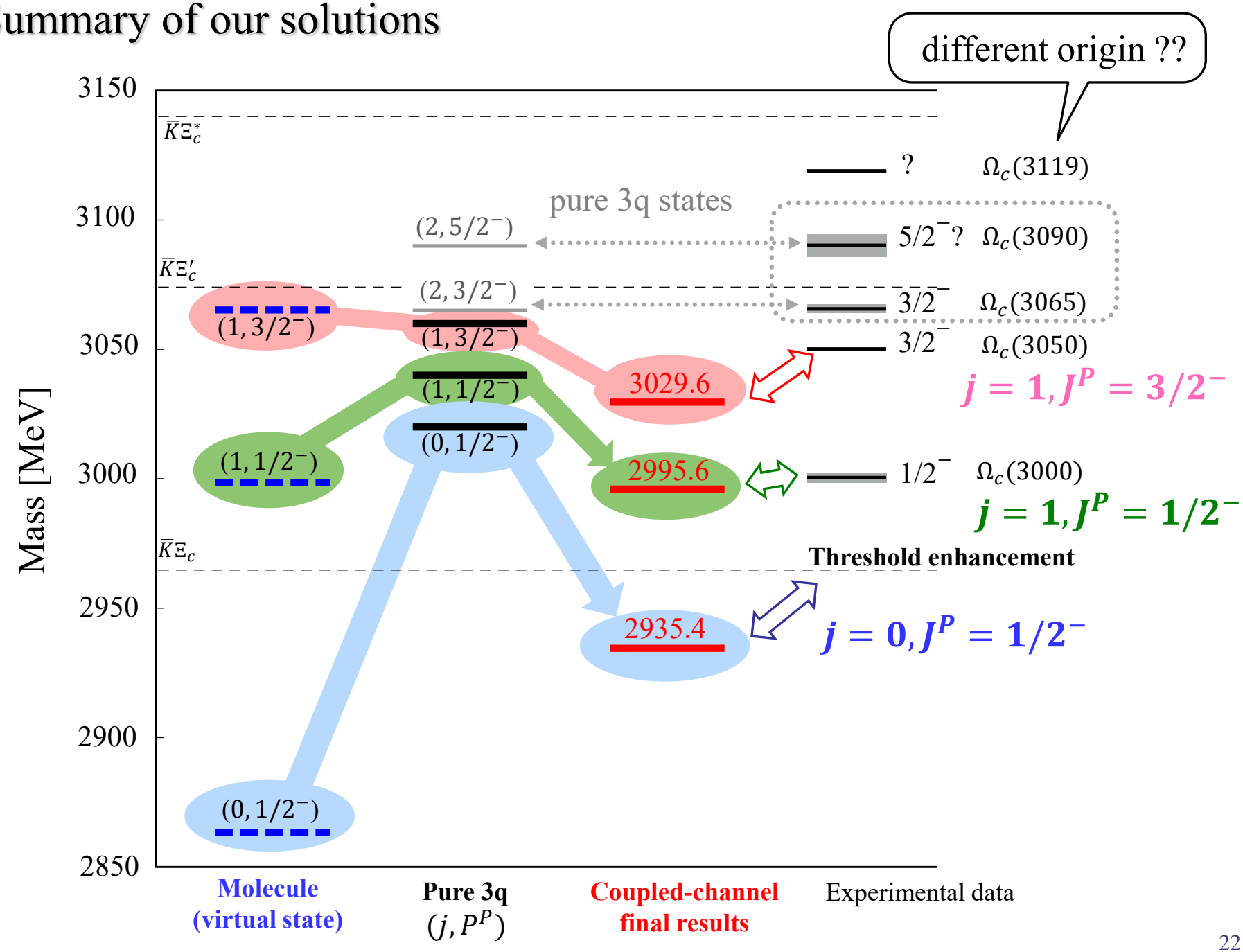
Summary of our solutions



Summary of our solutions



Summary of our solutions



Conclusion

- We performed a systematic analysis of **low-lying Ω_c structures** in a coupled-channel approach, with the number of free parameters kept to a *minimum*
  - by employing a unified framework that accommodates **both three-quark** and **molecular Ω_c states**.

- We can solve the **spin-assignment problem**, demonstrating that the quark-model states *can be compatible* with the experimental data.

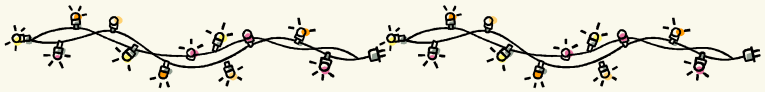
- We found that **the lowest-lying $\Omega_c(1P_\lambda)$ state is a bound state** of $\bar{K}\Xi_c$, which can make the threshold enhancement in the amplitude.
  - Can be found $\Omega_c^*\gamma$??

<u>future work</u>

- the origin or nature of $\Omega_c(3119)$??
- Components of the physical Ω_c's → important d.o.f ?
- Decay properties etc.

→ *to support our interpretations.*

Backup slides



Angular distribution LHCb, PRD104(21)L091102

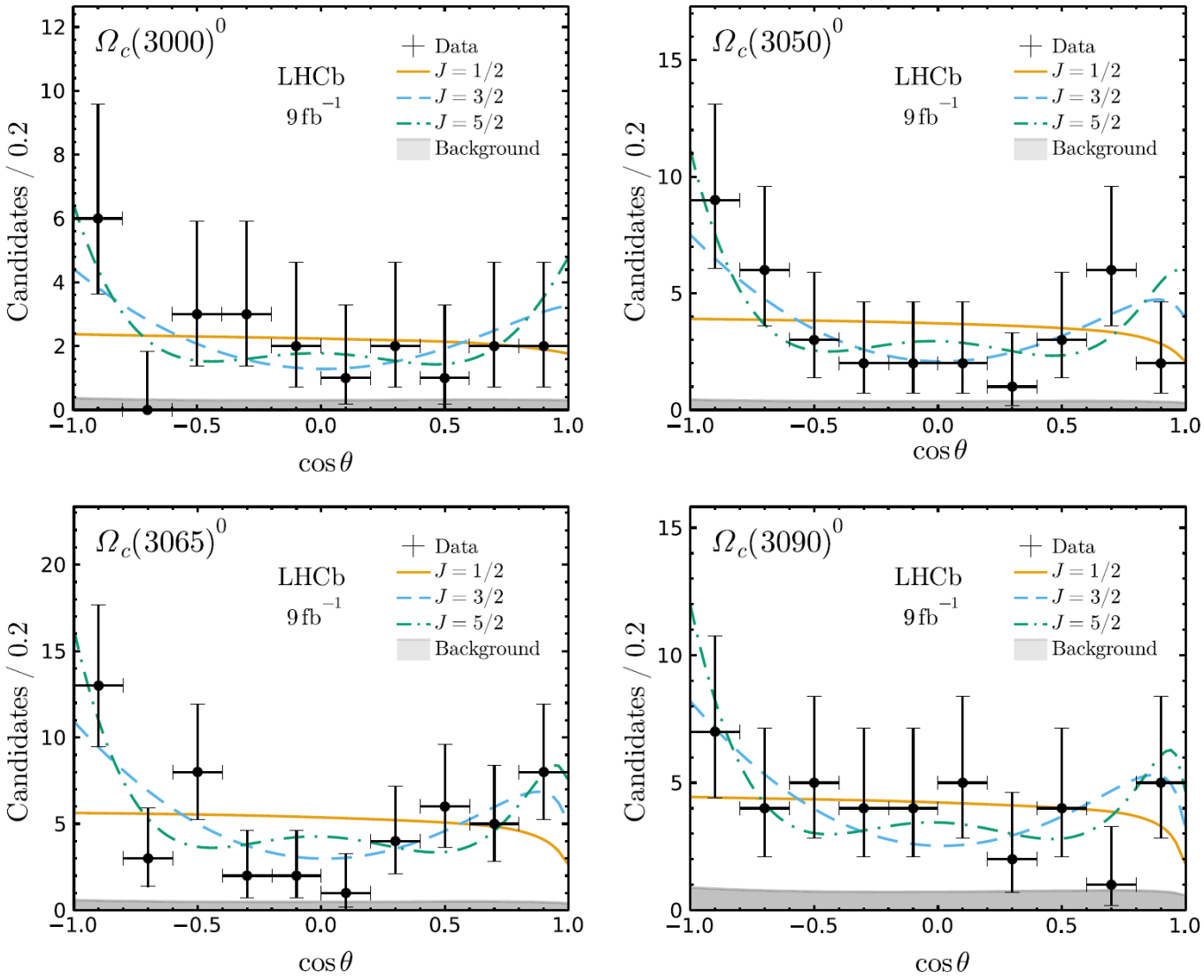
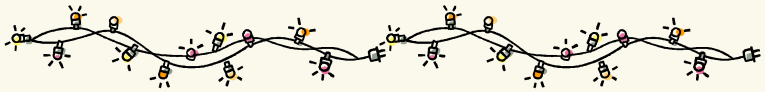


FIG. 4. Distributions of the Ω_c^{**0} helicity angle (θ) in the Ω_b^- decay. Solid, dashed, and dot-dashed lines indicate the expectations under the spin hypotheses, $J = 1/2$, $3/2$, and $5/2$, respectively. The gray shaded area shows the cumulative distribution of the combinatorial and nonresonant $\Xi_c^+ K^-$ backgrounds.

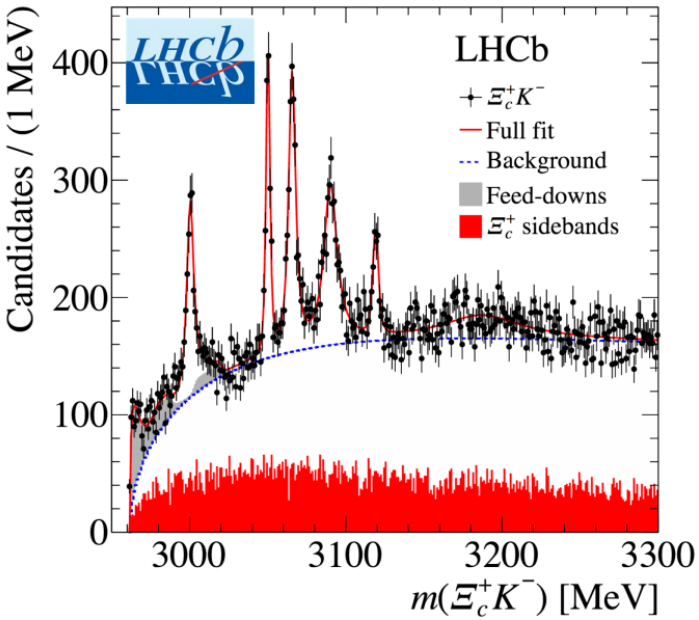
A few slides for Ω_c …



Collaboration with Qi-Fang Lü, his students and Hosaka-san

LHCb 2017

$\Omega_c(3000)^0$	$?(?^?)$	3000.41 ± 0.22	$4.5 \pm 0.6 \pm 0.3$
$\Omega_c(3050)^0$	$?(?^?)$	3050.20 ± 0.13	< 1.2
$\Omega_c(3065)^0$	$?(?^?)$	3065.46 ± 0.28	$3.5 \pm 0.4 \pm 0.2$
$\Omega_c(3090)^0$	$?(?^?)$	3090.0 ± 0.5	$8.7 \pm 1.0 \pm 0.8$
$\Omega_c(3120)^0$	$?(?^?)$	$3119.1 \pm 0.3 \pm 0.9 \pm 0.3$	< 2.6
$\Omega_c(3188)^0$	$?(?^?)$	$3188 \pm 5 \pm 13$	$60 \pm 15 \pm 11$



Observation of five new narrow Ω_c^0 states decaying to $\Xi_c^+ K^-$

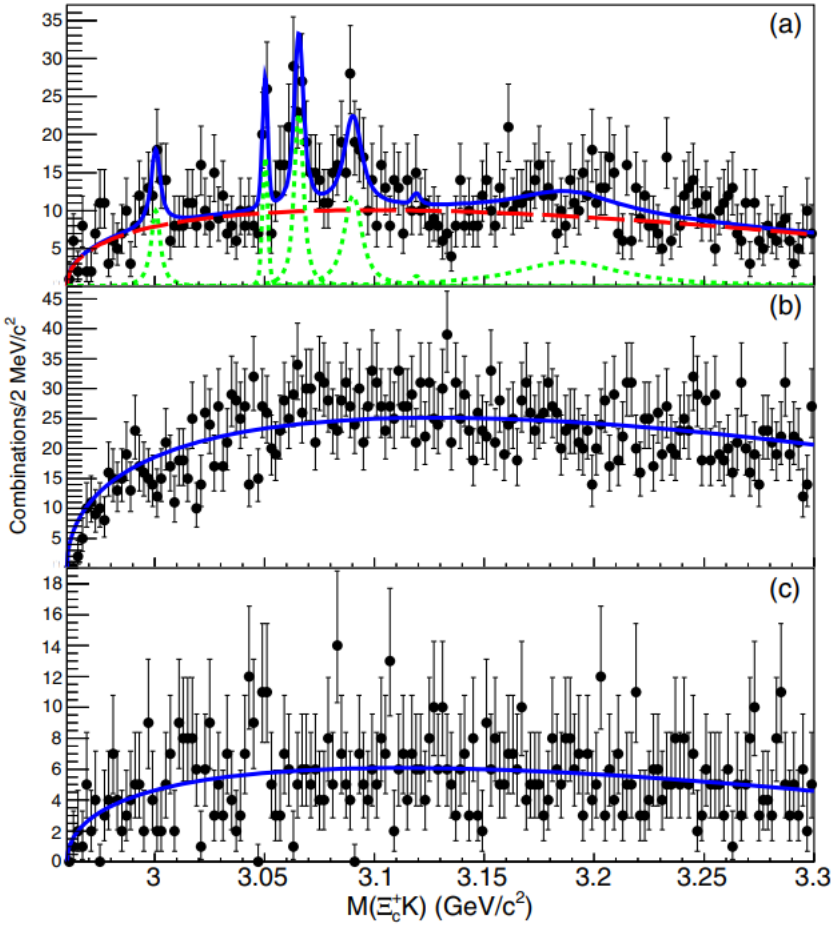
LHCb Collaboration • Roel Aaij (CERN) et al. (Mar 14, 2017)

Published in: *Phys.Rev.Lett.* 118 (2017) 18, 182001 • e-Print: 1703.04639 [hep-ex]

pdf links DOI cite claim reference search 271 citatio

R. Aaij et al., (LHCb Collaboration), Phys. Rev. Lett.118, 182001 (2017).

Belle 2018



To conclude, of the five narrow resonances observed in the $\Xi_c^+ K^-$ mass spectrum by LHCb, we strongly confirm the $\Omega_c(3066)$ and $\Omega_c(3090)$ with very similar parameters and confirm two more—the $\Omega_c(3000)$ and $\Omega_c(3050)$—with less significance, but cannot confirm the $\Omega_c(3119)$. In addition, we present indications that there is wide excess, consistent with that found by LHCb, at higher mass.

J. Yelton et al., (Belle Collaboration), Phys. Rev. D.97, 051102 (2018).

LHCb 2021

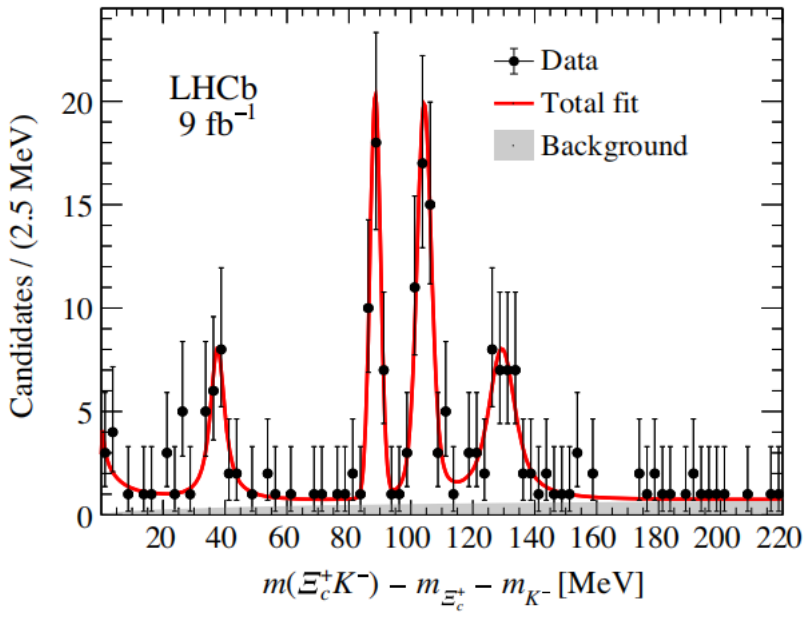
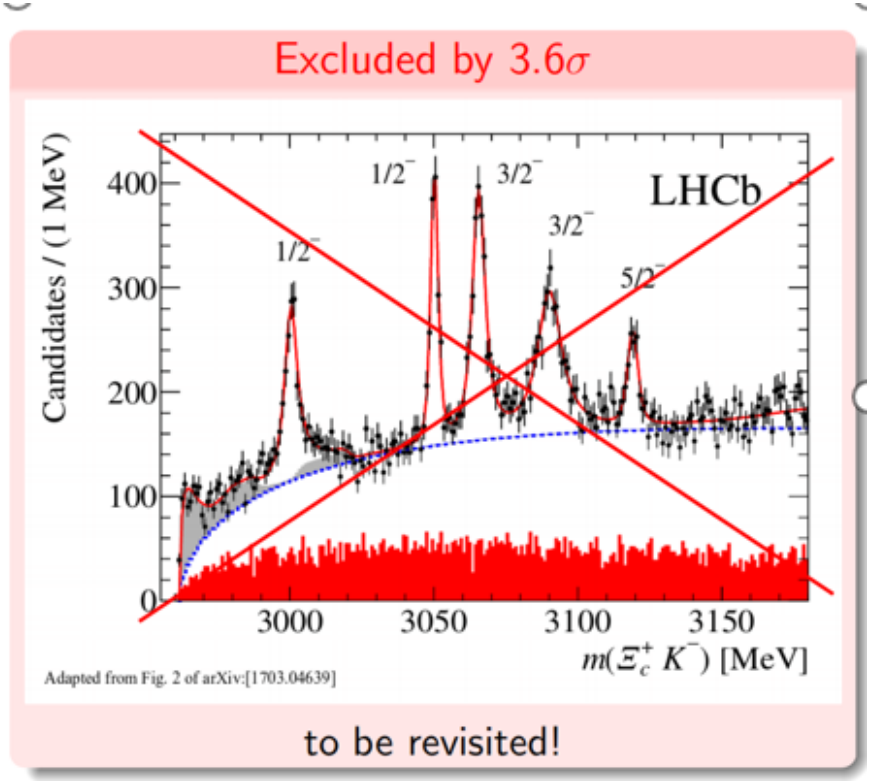


FIG. 3. Distribution of the reconstructed mass difference between the $\Xi_c^+ K^-$ invariant mass and the Ξ_c^+ and K^- masses. The four peaking structures are consistent with being the previously observed $\Omega_c(3000)^0$, $\Omega_c(3050)^0$, $\Omega_c(3065)^0$, and $\Omega_c(3090)^0$ baryons. The distribution shows an enhancement at the threshold, as seen in the previous analysis [16]. The total fit is overlaid in red. The background distribution (gray shaded area) is the combination of the combinatorial and nonresonant $\Xi_c^+ K^-$ backgrounds.



LHCb 2021

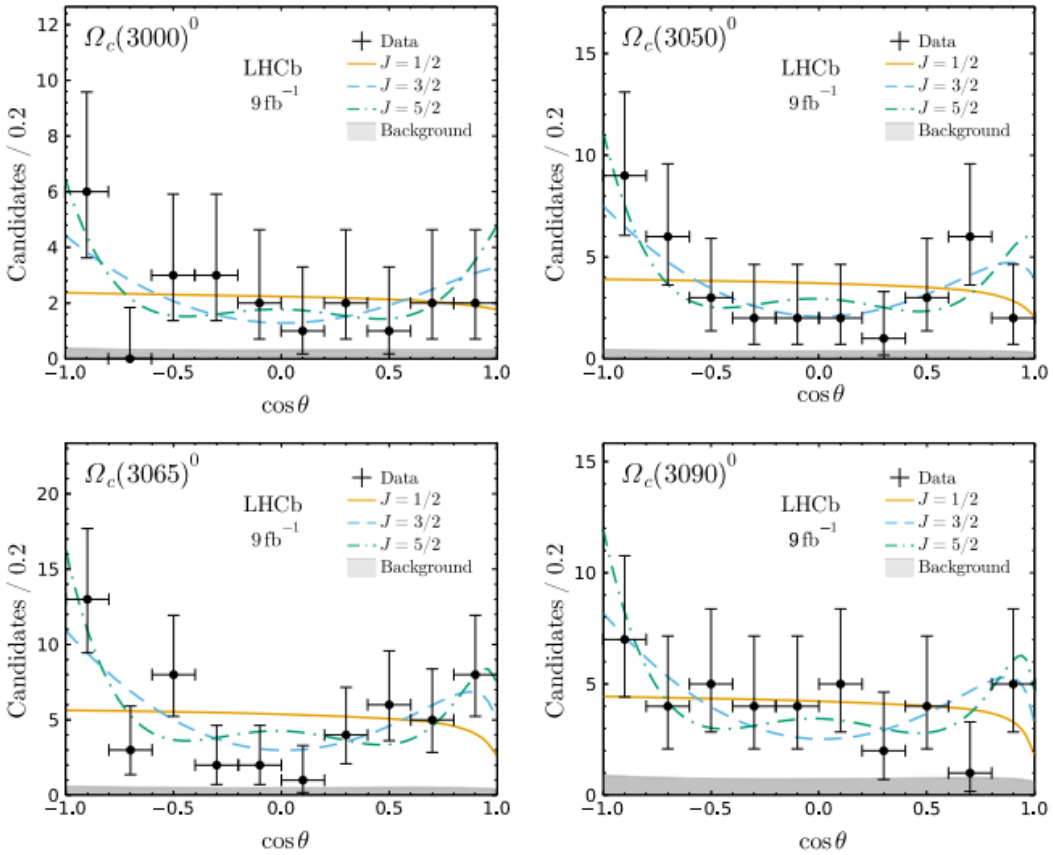
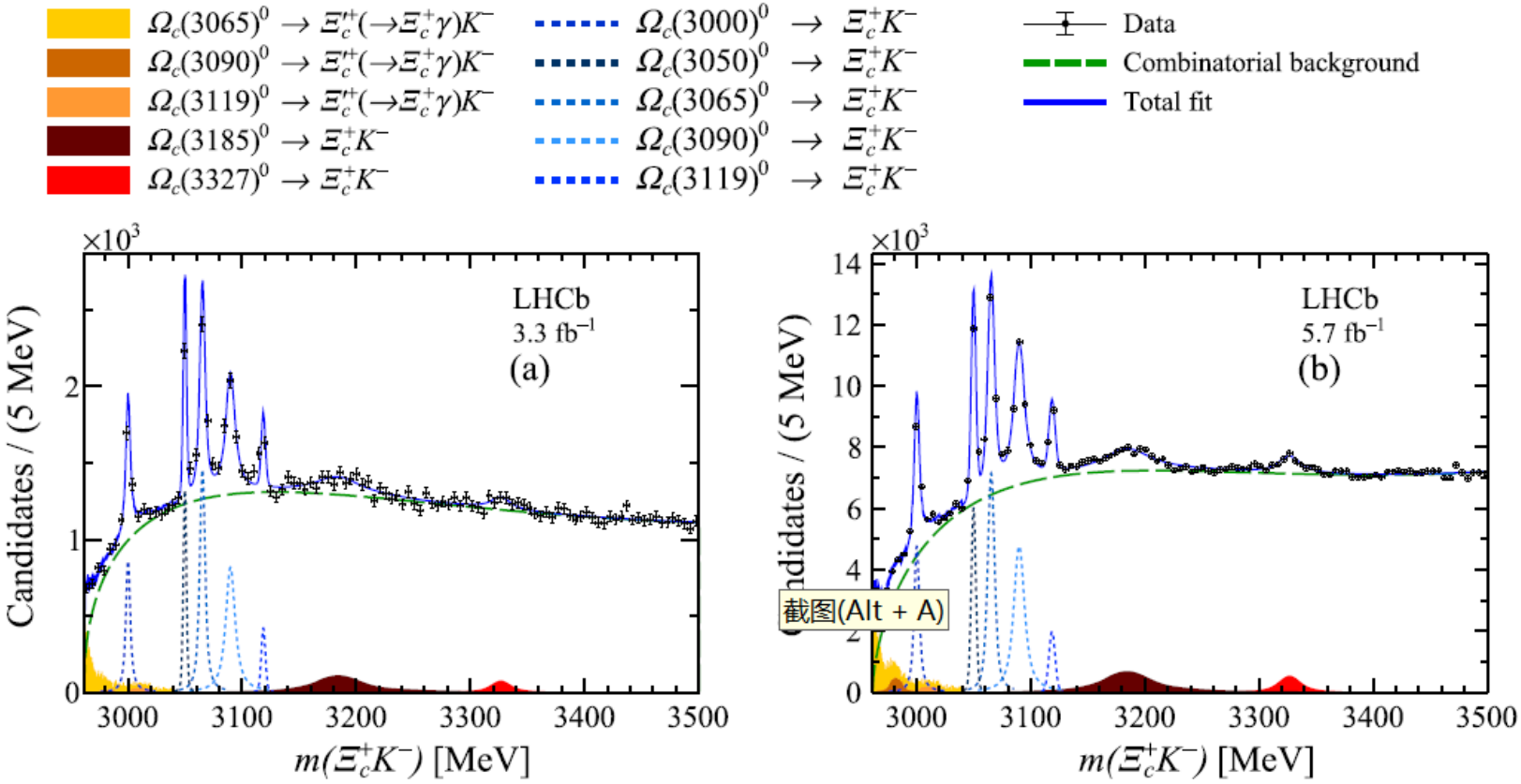


FIG. 4. Distributions of the Ω_c^{**0} helicity angle (θ) in the Ω_b^- decay. Solid, dashed, and dot-dashed lines indicate the expectations under the spin hypotheses, $J = 1/2$, $3/2$, and $5/2$, respectively. The gray shaded area shows the cumulative distribution of the combinatorial and nonresonant $\Xi_c^+ K^-$ backgrounds.

R. Aaij et al., (LHCb Collaboration), Phys. Rev. D 104, 091102 (2021).

LHCb 2023

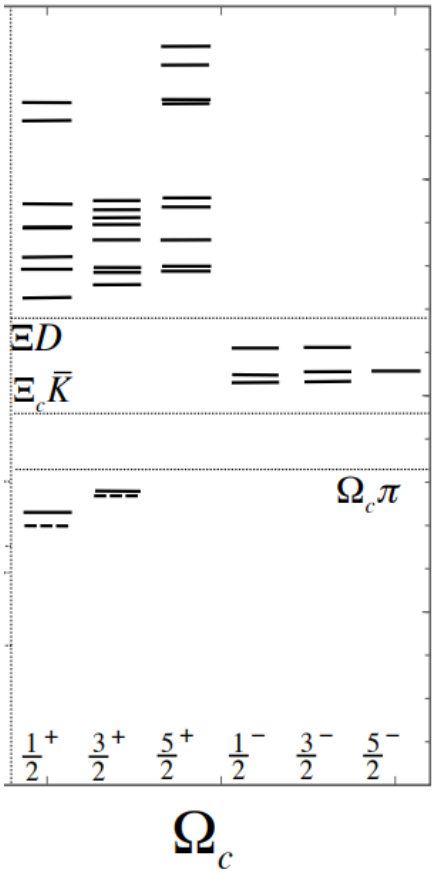


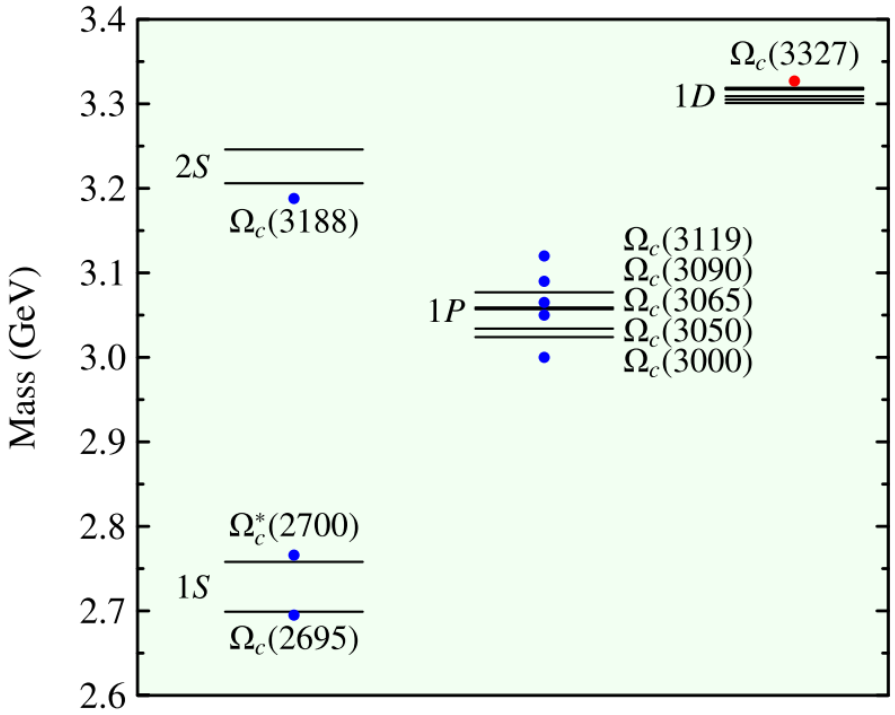
R. Aaij et al., (LHCb Collaboration), Phys. Rev. Lett. 131, 131902 (2023)

Problematic conventional P-wave Ω_c

(c) Ω_c

J^P	Theory [MeV]	Exp. [MeV]
$\frac{1}{2}^+$	2731	2698
	3227	
	3292	
$\frac{3}{2}^+$	2779	2768
	3257	
	3285	
$\frac{5}{2}^+$	3288	
	3299	
	3359	
$\frac{1}{2}^-$	3030	
	3048	
	3110	
$\frac{3}{2}^-$	3033	
	3056	
	3111	
$\frac{5}{2}^-$	3057	
	3477	
	3620	





T. Yoshida, E. Hiyama, A. Hosaka, M. Oka, and K. Sadato, Physical Review D 92, 114029 (2015)
Si-Qiang Luo, Xiang Liu, Physical Review D 107, 074041 (2023)