MENU 2023, October 16-20, 2023, Johannes Gutenberg University of Mainz

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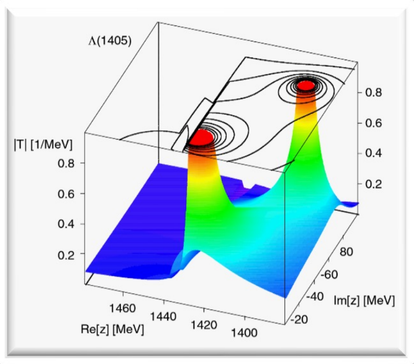
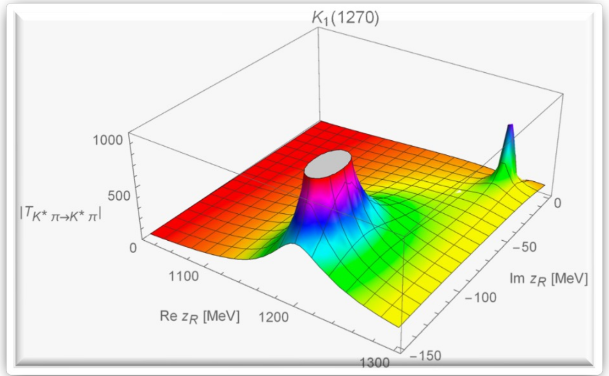
Two-pole structures as a universal phenomenon dictated by coupled-channel chiral dynamics

Li-Sheng Geng（耿立升）@ Beihang U.



2307.11631 , Jia-Ming Xie, Jun-Xu Lu， **LSG***, Bing-Song Zou



Contents

$\Lambda(1405)$: why is it special

PDG

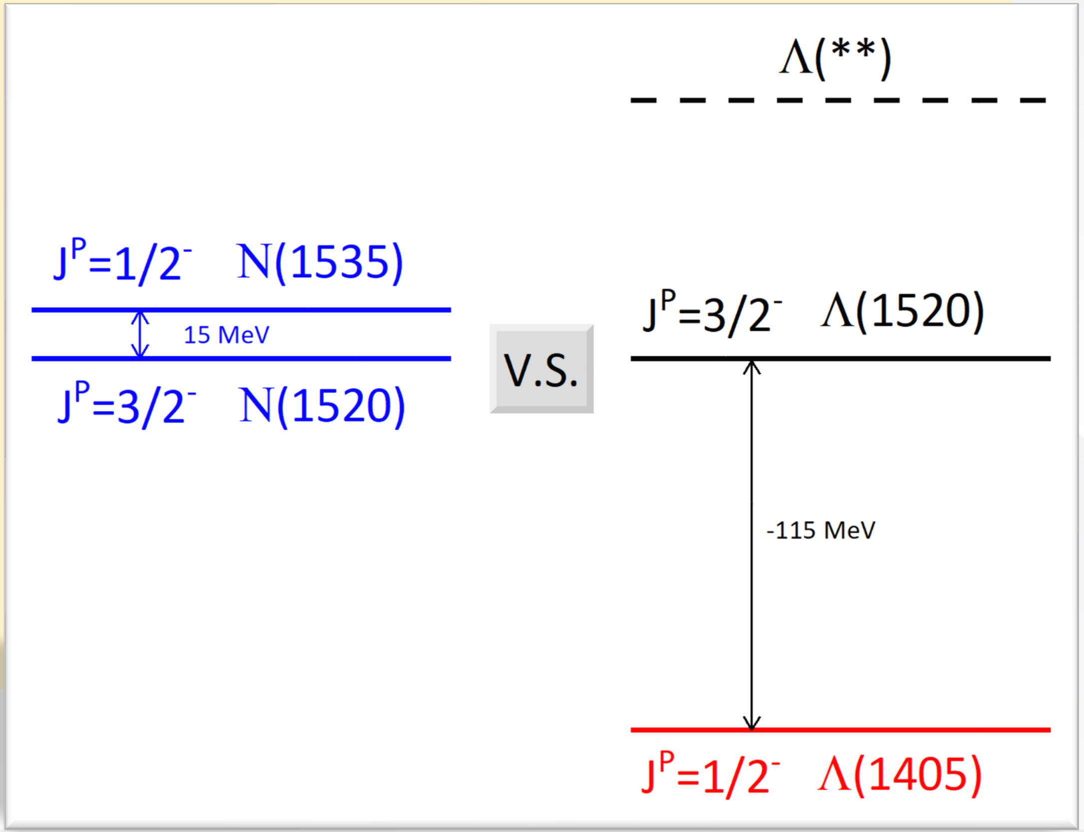
$I(J^P) = 0(1/2^-), S = -1$

$M = 1405.1^{+1.3}_{-1.0}$ MeV, $\Gamma = 50.5 \pm 2.0$ MeV

In the constituent quark model, $\Lambda(1405)$ is the first P-wave orbital excitation of the ground-state baryon $\Lambda(1115)$

Two puzzles

Low mass vs. N*(1535)
large spin splitting vs. $\Lambda(1520)$



$\Lambda(1405)$: predicted before discovery as $\bar{K}N$ b state

Possible Resonant State in Pion-Hyperon Scattering

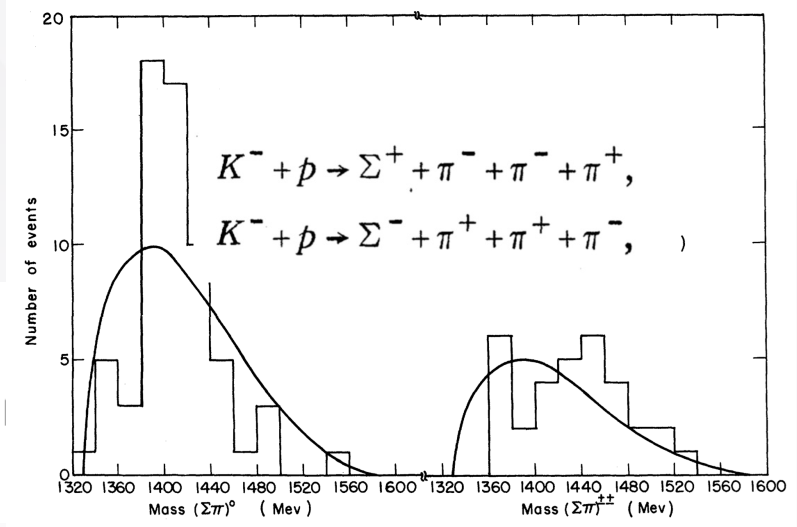
R. H. Dalitz and S. F. Tuan
Phys. Rev. Lett. **2**, 425 – Published 15 May 1959

Prediction 1959

Study of Resonances of the $\Sigma - \pi$ System

Margaret H. Alston, Luis W. Alvarez, Philippe Eberhard, Myron L. Good, William Graziano, Harold
Stanley G. Wojcicki
Phys. Rev. Lett. **6**, 698 – Published 15 June 1961

Discovery 1961

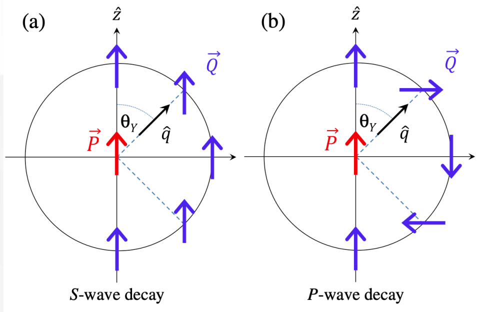


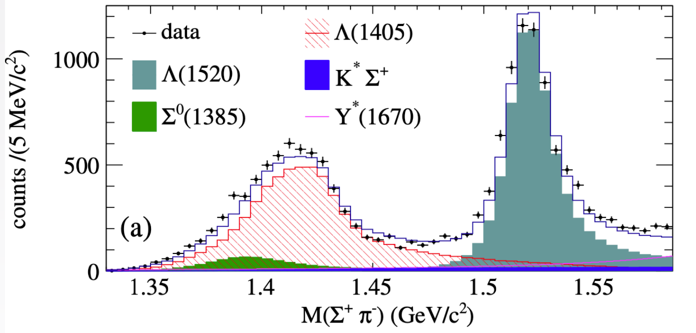
Spin and parity measurement of the $\Lambda(1405)$ baryon

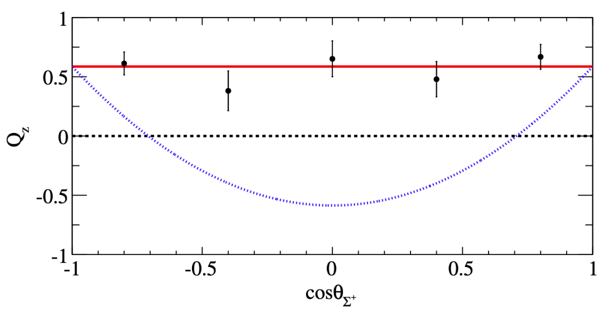
$$\gamma + p \rightarrow K^+ + \Lambda(1405)$$

K. Moriya *et al.* (CLAS Collaboration)
Phys. Rev. Lett. **112**, 082004 – Published 28 February 2014

Spin&Parity 2014

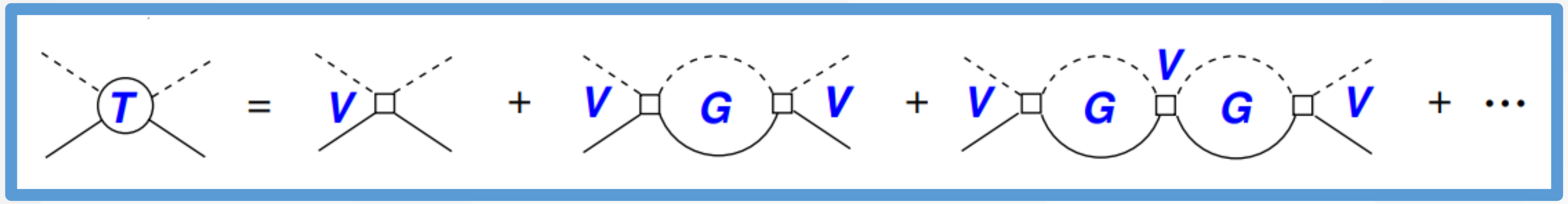




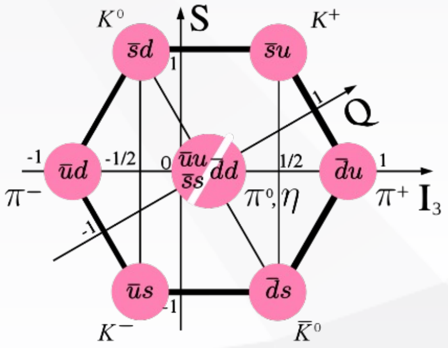


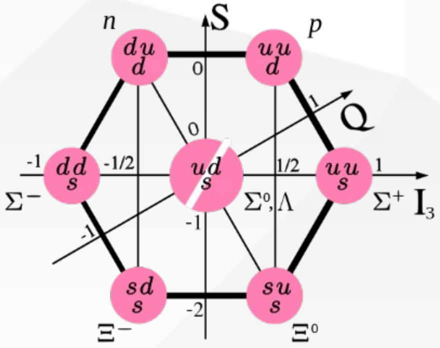
$\Lambda(1405)$ as a dynamically generated state

- $\bar{K}N$ bound state **dynamically generated** in **chiral unitary approaches**, which combine chiral dynamics and coupled channel unitarity.



Bethe-Salpeter Equation





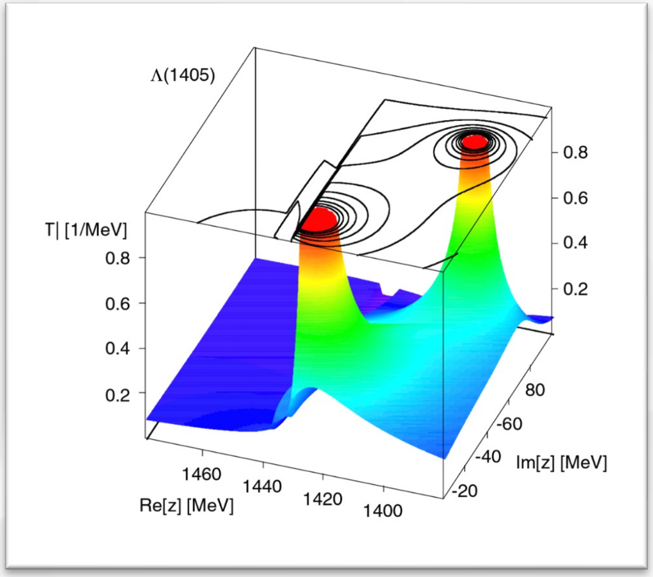
Weinberg-Tomozawa potential

$$V_{ij} = -\frac{C_{ij}}{4f^2}(E_i + E_j)$$

- LO&NLO, Kaiser, Siegel, Weise, NPA594, 325(1995), **720** citations
- LO, Oset and Ramos, NPA635, 99(1998), 839 citations
- NLO, Oller and Meissner, PLB500, 263(2001), **883** citations

$\Lambda(1405)$-dynamical generated two-pole structure!

- Isopin 0, four coupled channels: $\boldsymbol{\pi\Sigma(1330)}$, $\boldsymbol{\bar{K}N(1433)}$, $\eta\Lambda(1662)$, $K\Xi(1813)$
- Renormalization scale $\mu = 630$ MeV, with four different $a_i(\mu)$
- Two poles: $W_H = 1424.3 - 17.1i$, $W_L = 1389.1 - 64.1i$



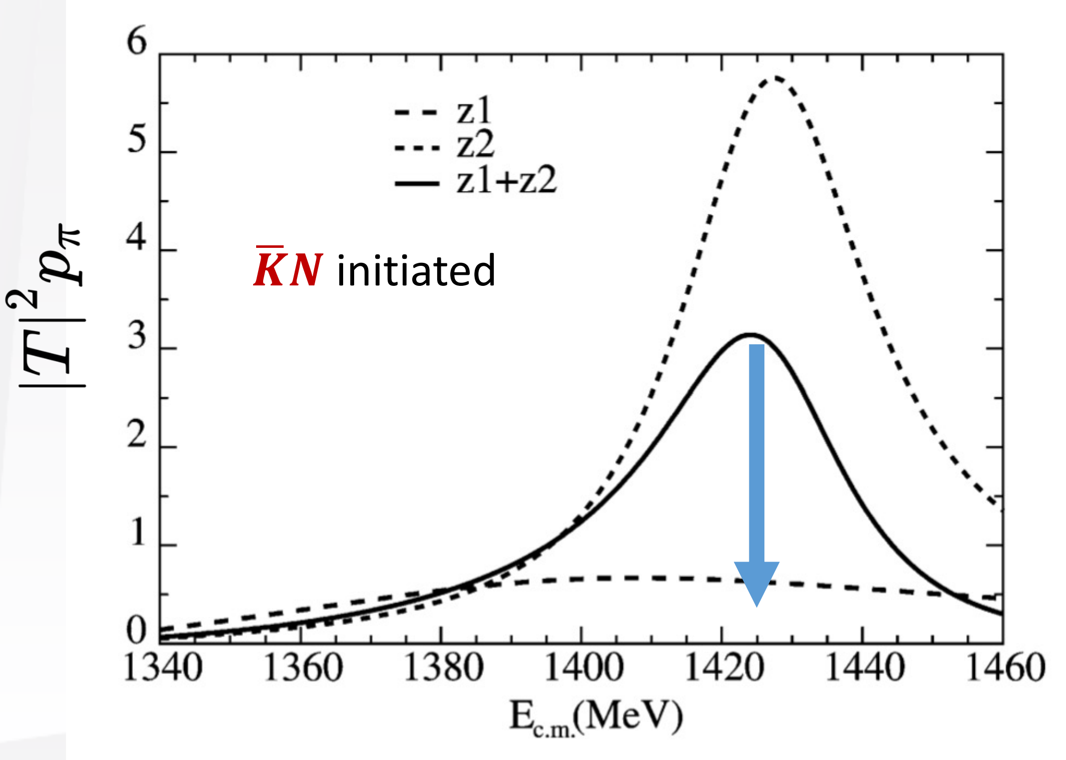
	$\Lambda(1405)$	
z_R (MeV)	$1390 - 66i$	$1426 - 16i$
$\lvert g_i\rvert(\pi\Sigma)$	2.9	1.5
$\lvert g_i\rvert(\bar{K}N)$	2.1	2.7
$\lvert g_i\rvert(\eta\Lambda)$	0.77	1.4
$\lvert g_i\rvert(K\Xi)$	0.61	0.35

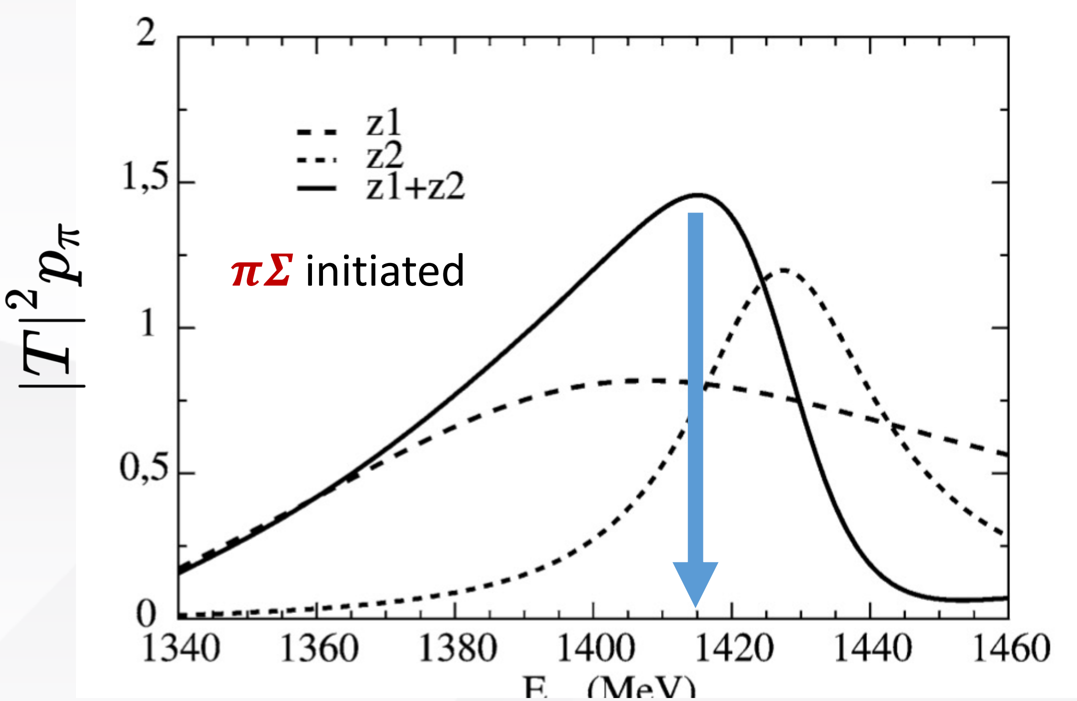
Oller and Meissner, PLB500, 263(2001)
Jido, Oller, Oset, Ramos, and Meissner, NPA725, 181 (2003)
Hyodo and Jido, PPNP67, 55 (2012)

$\Lambda(1405)$-dynamical generated two-pole structure!

$$g^{R_1}_{\bar{K}N}\frac{1}{W-M_{R_1}+i\Gamma_{R_1}/2}g^{R_1}_{\pi\Sigma}+g^{R_2}_{\bar{K}N}\frac{1}{W-M_{R_2}+i\Gamma_{R_2}/2}g^{R_2}_{\pi\Sigma},$$

$$g^{R_1}_{\pi\Sigma}\frac{1}{W-M_{R_1}+i\Gamma_{R_1}/2}g^{R_1}_{\pi\Sigma}+g^{R_2}_{\pi\Sigma}\frac{1}{W-M_{R_2}+i\Gamma_{R_2}/2}g^{R_2}_{\pi\Sigma}$$





Oller and Meissner, PLB500(2001)263
Jido, Oller, Oset, Ramos, and Meissner, NPA725, 181 (2003)
Hyodo and Jido, PPNP67, 55 (2012)

Evidence for the two-pole structure of the $\Lambda(1405)$ state

PRL **95,** 052301 (2005) PHYSICAL REVIEW LETTERS week ending 29 JULY 2005

Evidence for the Two-Pole Structure of the $\Lambda(1405)$ Resonance

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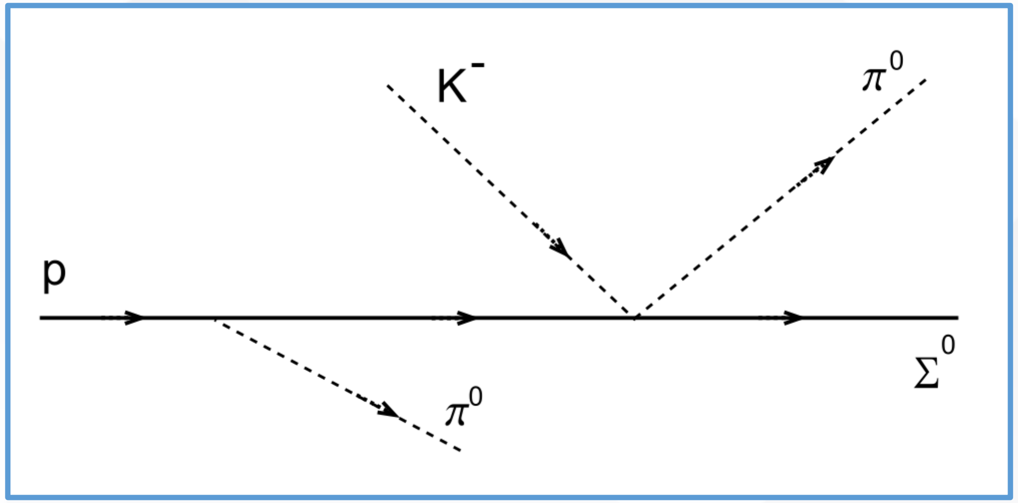
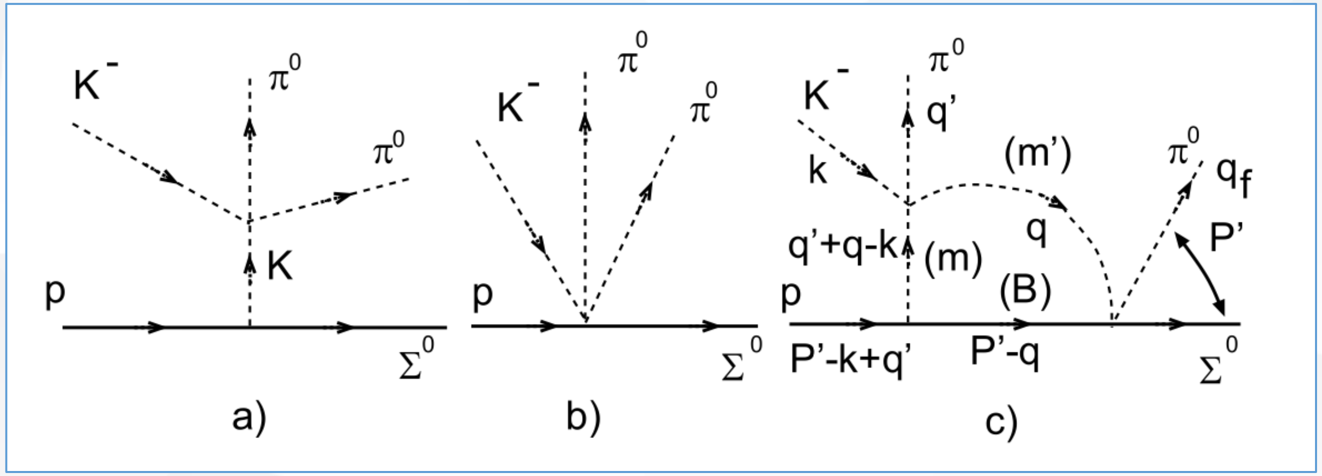
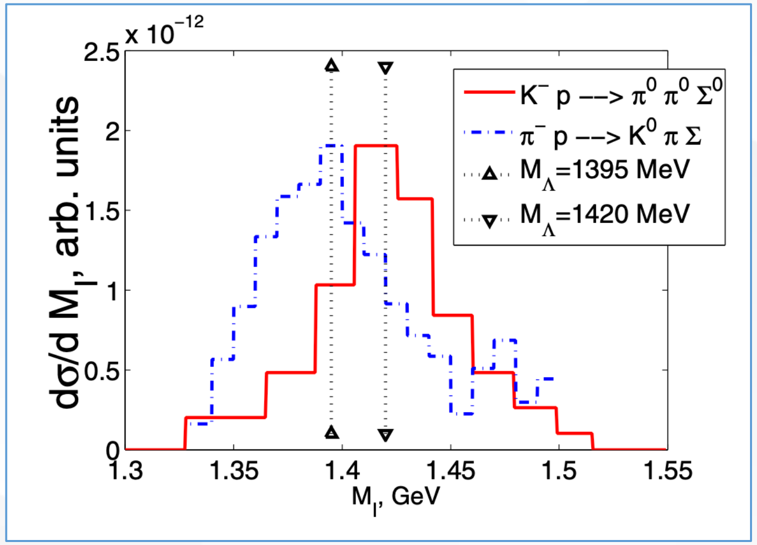
[2]*Departament d'Estructura i Constituents de la Matéria, Universitat de Barcelona, Diagonal 647, 08028 Barcelona, Spain*

(Received 7 March 2005; published 28 July 2005)

The $K^- p \to \pi^0\pi^0\Sigma^0$ reaction is studied within a chiral unitary model. The distribution of $\pi^0\Sigma^0$ states forming the $\Lambda(1405)$ shows, in agreement with a recent experiment, a peak at 1420 MeV and a relatively narrow width of $\Gamma = 38$ MeV. The mechanism for the reaction is largely dominated by the emission of a π^0 prior to the $K^- p$ interaction leading to the $\Lambda(1405)$. This ensures the coupling of the $\Lambda(1405)$ to the $K^- p$ channel, thus maximizing the contribution of the second state found in chiral unitary theories, which is narrow and of higher energy than the nominal $\Lambda(1405)$. This is unlike the $\pi^- p \to K^0\pi\Sigma$ reaction, which gives more weight to the pole at lower energy and with a larger width. The data of these two experiments, together with the present theoretical analysis, provide firm evidence of the two-pole structure of the $\Lambda(1405)$.

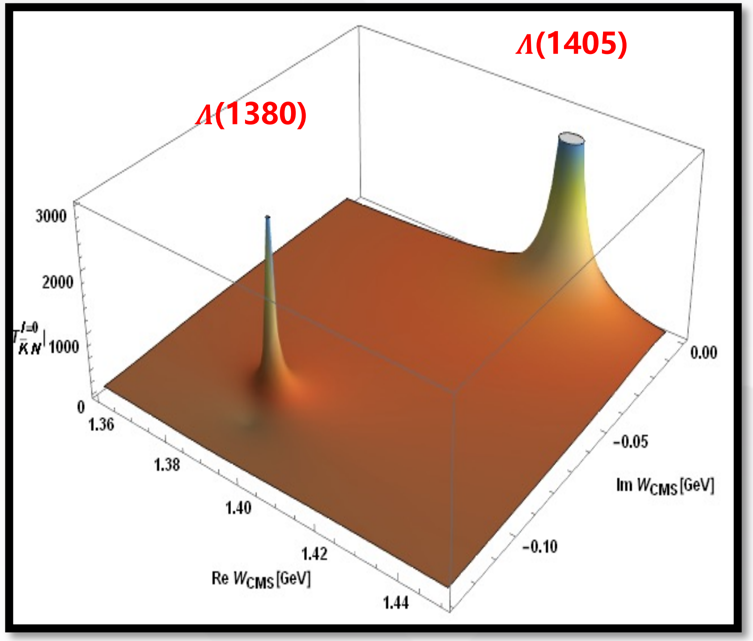


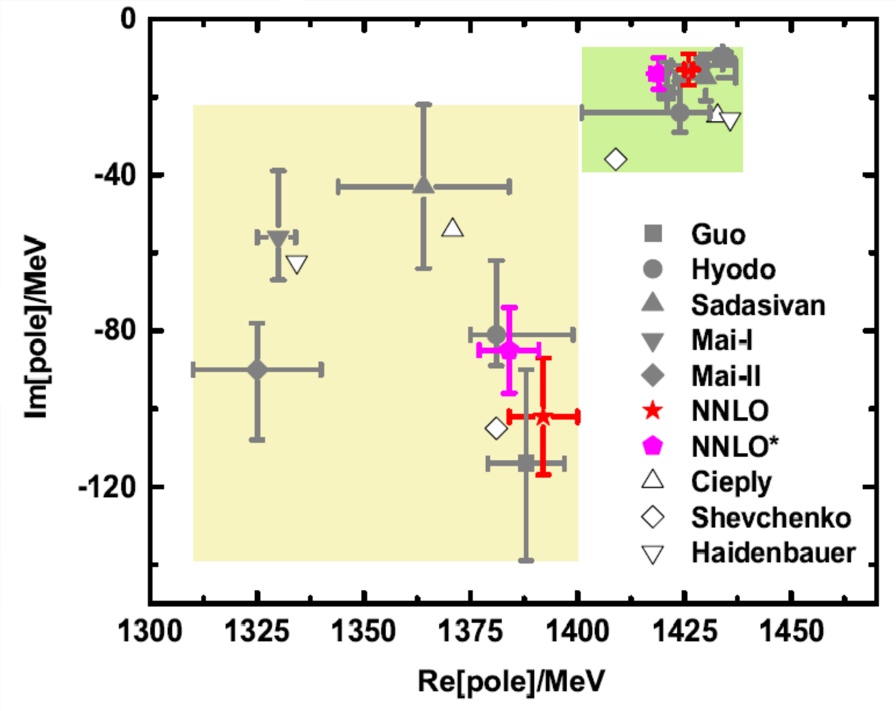




The two-pole structure persists at N2LO

Meson-baryon scattering up to N2LO, Jun-Xu Lu, LSG*, M. Doering and M. Mai, PRL130, 071902(2023)

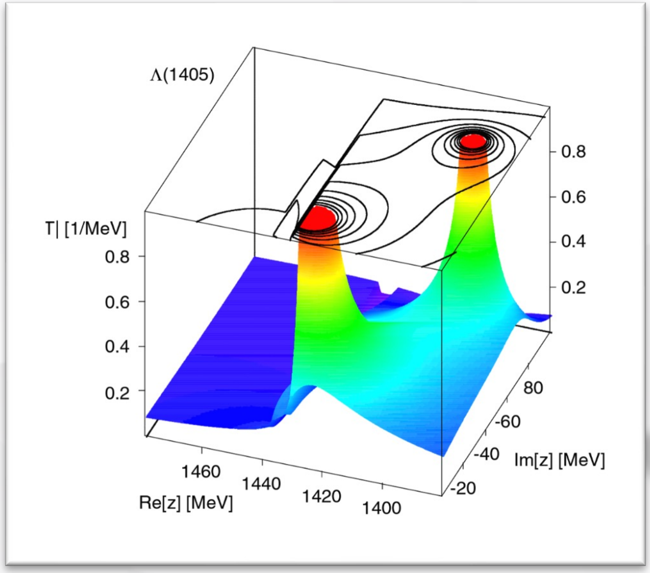




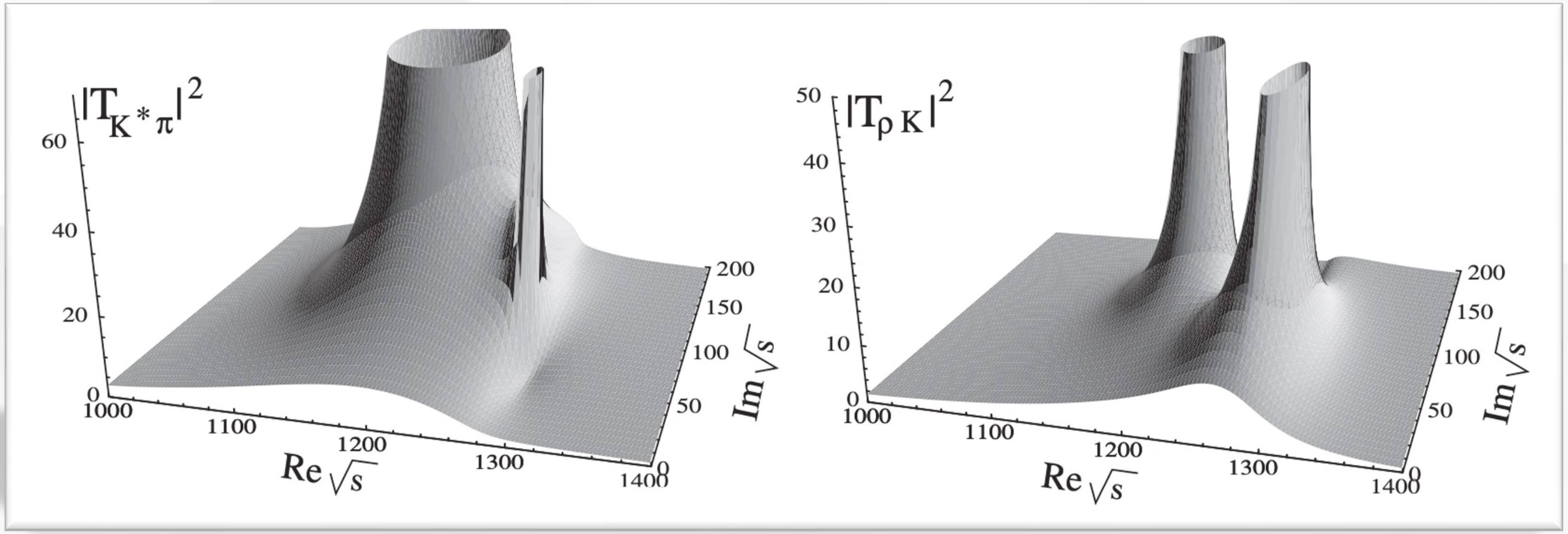
		Pole positions [MeV]	$\lvert g_{\pi\Sigma}\rvert$ [GeV]	$\lvert g_{\eta\Lambda}\rvert$ [GeV]	$\lvert g_{\bar{K}N}\rvert$ [GeV]	$\lvert g_{K\Xi}\rvert$ [GeV]
NNLO	$\Lambda(1380)$	$1392 \pm 8 - i(102 \pm 15)$	6.40 ± 0.10	3.01 ± 0.15	2.31 ± 0.10	0.45 ± 0.01
	$\Lambda(1405)$	$1425 \pm 1 - i(13 \pm 4)$	2.15 ± 0.07	5.45 ± 0.24	4.99 ± 0.08	0.58 ± 0.02
NNLO*	$\Lambda(1380)$	$1384 \pm 7 - i(85 \pm 11)$	3.26 ± 0.11	0.87 ± 0.02	2.04 ± 0.11	0.61 ± 0.02
	$\Lambda(1405)$	$1419 \pm 2 - i(14 \pm 4)$	3.24 ± 0.17	0.42 ± 0.02	6.01 ± 0.12	0.81 ± 0.03

Proper definition of two-pole structures!

- Two-pole structures refer to the fact that two dynamically generated states, **one resonant and one bound, are located close to each other** between two coupled channels and with a mass difference smaller than the sum of their widths.
- Two poles overlap, which can create the impression that **there is only one state in the invariant mass distribution** of their decay products.

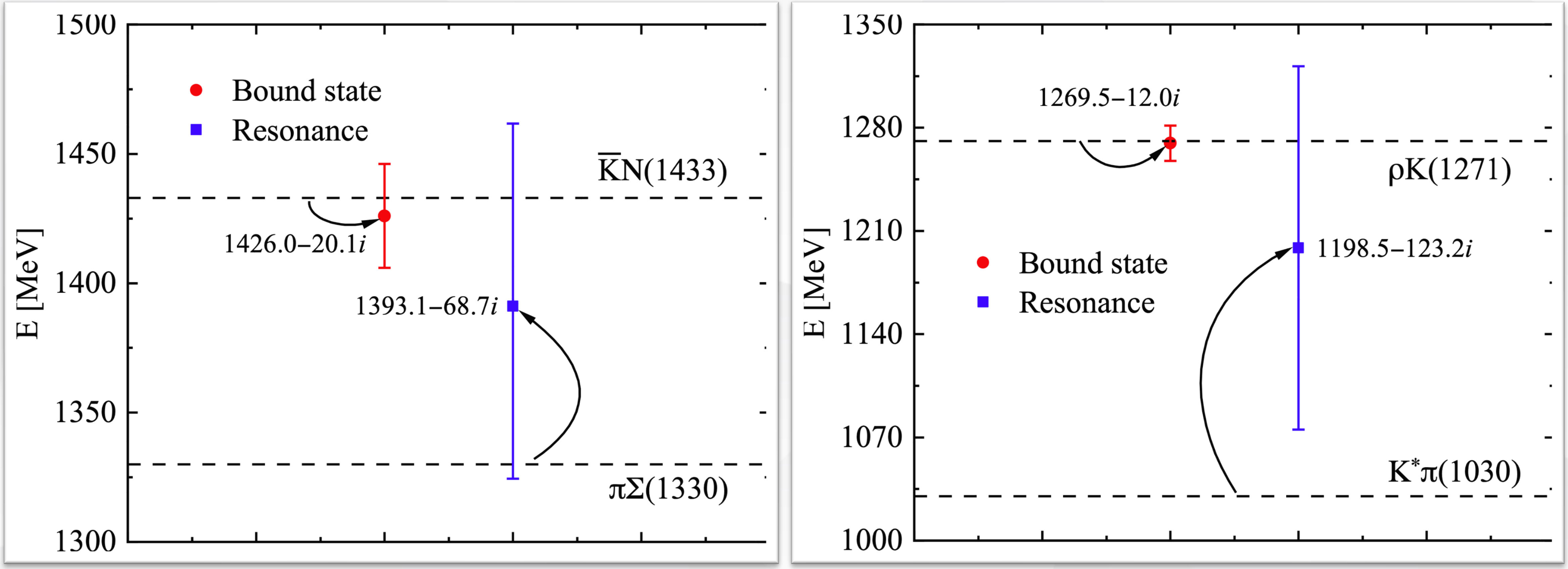


Hyodo and Jido, PPNP67, 55 (2012)



LSG, Oset, Roca, and Oller, PRD**75,** 014017 (2007)

Two prominent examples: $\Lambda(1405)$ and $K_1(1270)$



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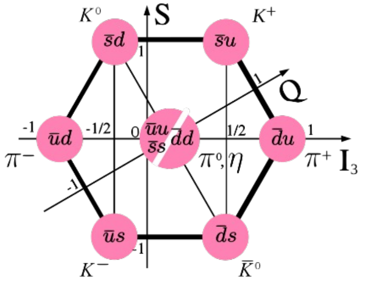
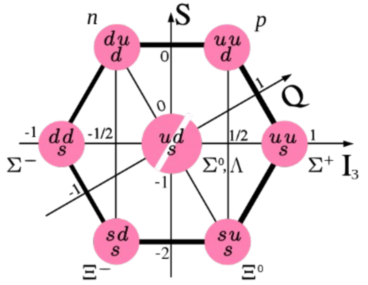
SU(3) group-theoretical explanation





☐ SU(3) symmetry decomposition

$$8 \otimes 8 = 1 \oplus 8_s \oplus 8_a \oplus 10 \oplus \overline{10} \oplus 27$$

Baryon octet-NGB octet

Potential in this basis

$$V_{\alpha\beta} = \mathrm{diag}(6, 3, 3$$

attractive

Is this the whole story?

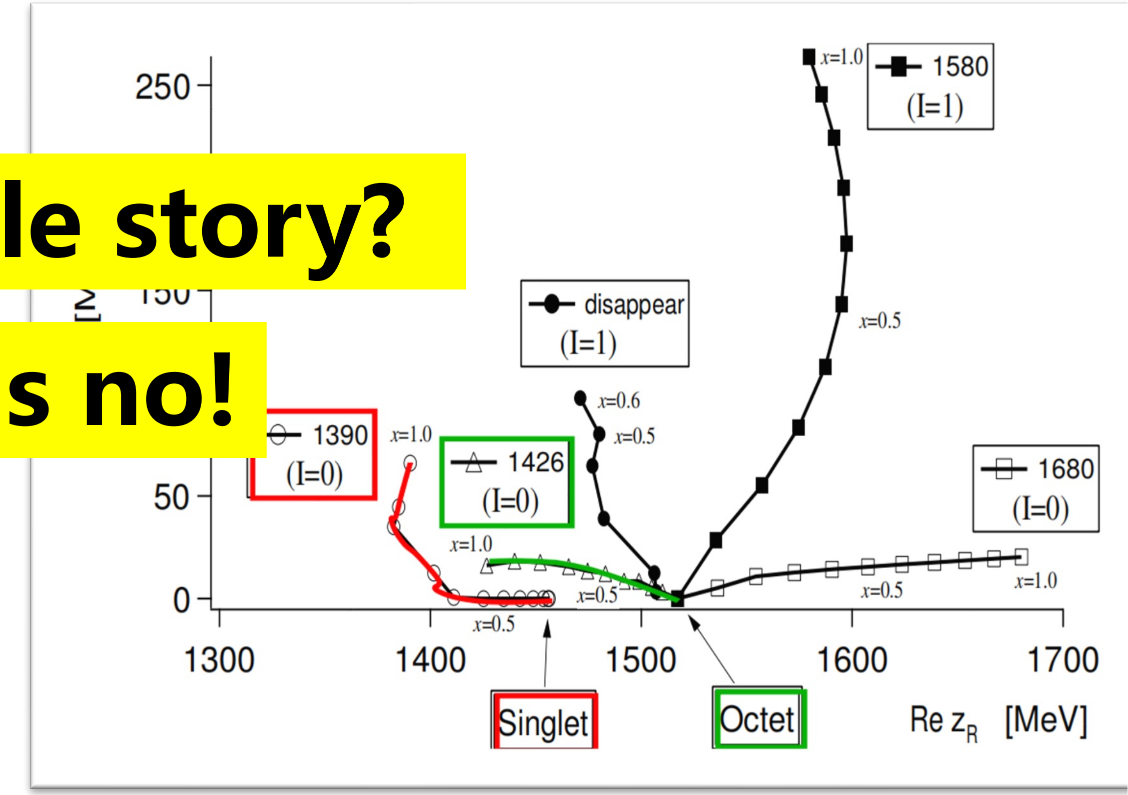
The answer is no!

☐ SU(3) symmetry breaking

$$M_i(x) = M_0 + x(M_i - M_0),$$

$$m_i^2(x) = m_0^2 + x\left(m_i^2 - m_0^2\right),$$

$$a_i(x) = a_0 + x(a_i - a_0),$$



Jido, Oller, Oset, Ramos, and Meissner, NPA725, 181(2003)

Feng-Kun Guo et al., 2308.07658

Contents

Three questions to ask/answer (not by flavor sym.)

Q1 Is the coupling between $\bar{K}N$ and $\pi\Sigma$ important?

Q2 How does the nature of the Nambu-Goldstone bosons play a role?

Q3 Whether is the energy dependence of the WT potential relevant?

Weinberg-Tomozawa Interaction (leading order)

- Leading order interaction between a NGB and a ground-state baryon

$$\mathcal{L}_{PB}^{\mathrm{WT}} = \frac{1}{4f^2}\mathrm{Tr}\left(\bar{\mathcal{B}} i\gamma^{\mu}\left[\Phi\partial_{\mu}\Phi - \partial_{\mu}\Phi\Phi, \mathcal{B}\right]\right)$$

$$\Phi = \begin{bmatrix} \frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta_8 & \pi^+ & K^+ \\ \pi^- & -\frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta_8 & K^0 \\ K^- & \bar{K}^0 & -\frac{2}{\sqrt{6}}\eta_8 \end{bmatrix} \qquad \mathcal{B} = \begin{bmatrix} \frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & \Sigma^+ & p \\ \Sigma^- & -\frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & n \\ \Xi^- & \Xi^0 & -\frac{2}{\sqrt{6}}\Lambda \end{bmatrix}$$

- The Weinberg-Tomozawa (WT) potential--parameter free

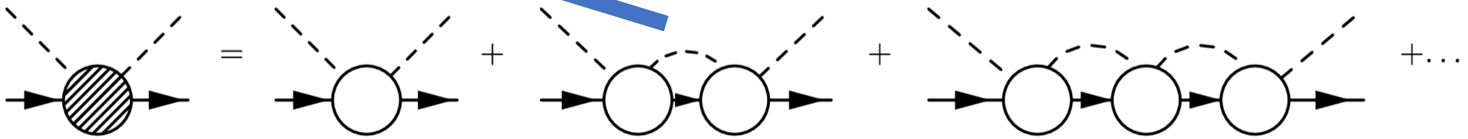
$$V_{ij} = -\frac{C_{ij}}{4f^2}\left(2\sqrt{s} - M_i - M_j\right) = -\frac{C_{ij}}{4f^2}\left(E_i + E_j\right)$$

Xiu-Lei Ren, Mon.17:10 (spectroscopy)

$\Lambda(1405)$--dynamically generated in Chiral Unitary Approaches

- Chiral dynamics &. Coupled-channel unitarity

$$T = (1 - VG)^{-1} V$$



- Loop function

$$G_k\left(\sqrt{s}; a_k(\mu)\right) = \frac{2M_k}{16\pi^2}\left\{a_k(\mu) + \frac{m_k^2 - M_k^2 + s}{2s}\ln\frac{m_k^2}{M_k^2} + \ln\frac{M_k^2}{\mu^2} + \frac{p_k(\sqrt{s})}{\sqrt{s}}\ln\left(\frac{\phi_{++}\phi_{+-}}{\phi_{-+}\phi_{--}}\right)\right\}$$

$$\phi_{\pm\pm} \equiv \pm s \pm \left(M_k^2 - m_k^2\right) + 2\sqrt{s}\,p_k\left(\sqrt{s}\right)$$

Dim. Regularization

$$G_{\mathrm{cut}} = \int_0^\Lambda \frac{q^2 dq}{2\pi^2}\frac{E_M + E_m}{2E_M E_m}\frac{2M}{s - (E_M + E_m)^2 + i\epsilon}$$

Cutoff regularization

- Dynamically generated state — singularities of unitarized amplitude T

See, e.g., Oller, Oset, and Ramos, PPNP45, 157 (2000)

Q1: Is the coupling between $\bar{K}N(1433)$and $\pi\Sigma$ important?

- To simplify the discussion, consider only the **two most relevant channels** around 1400 MeV: $\bar{K}N(1433)$, $\pi\Sigma(1330)$--equivalent to the full four-body analysis
  - With the subtraction constants: $\boldsymbol{a_{\bar{K}N} = -1.95}$, $\boldsymbol{a_{\pi\Sigma} = -1.92}$, **we obtain two poles:** $\boldsymbol{W_H = 1426.0 - 20.1i}$, $\boldsymbol{W_L = 1393.1 - 68.7i}$ (to be compared with the four-channel results) $W_H = 1424.3 - 17.1i$, $W_L = 1389.1 - 64.1\mathrm{i}$)

- **We gradually turn off the intra-channel coupling to see what happens**

Zero coupling limit, see, e.g.,
Hyodo et al, Phys.Rev.C 77 (2008) 035204
A. Cieplý et al, Nucl. Phys. A, 954:17-40, 2016.

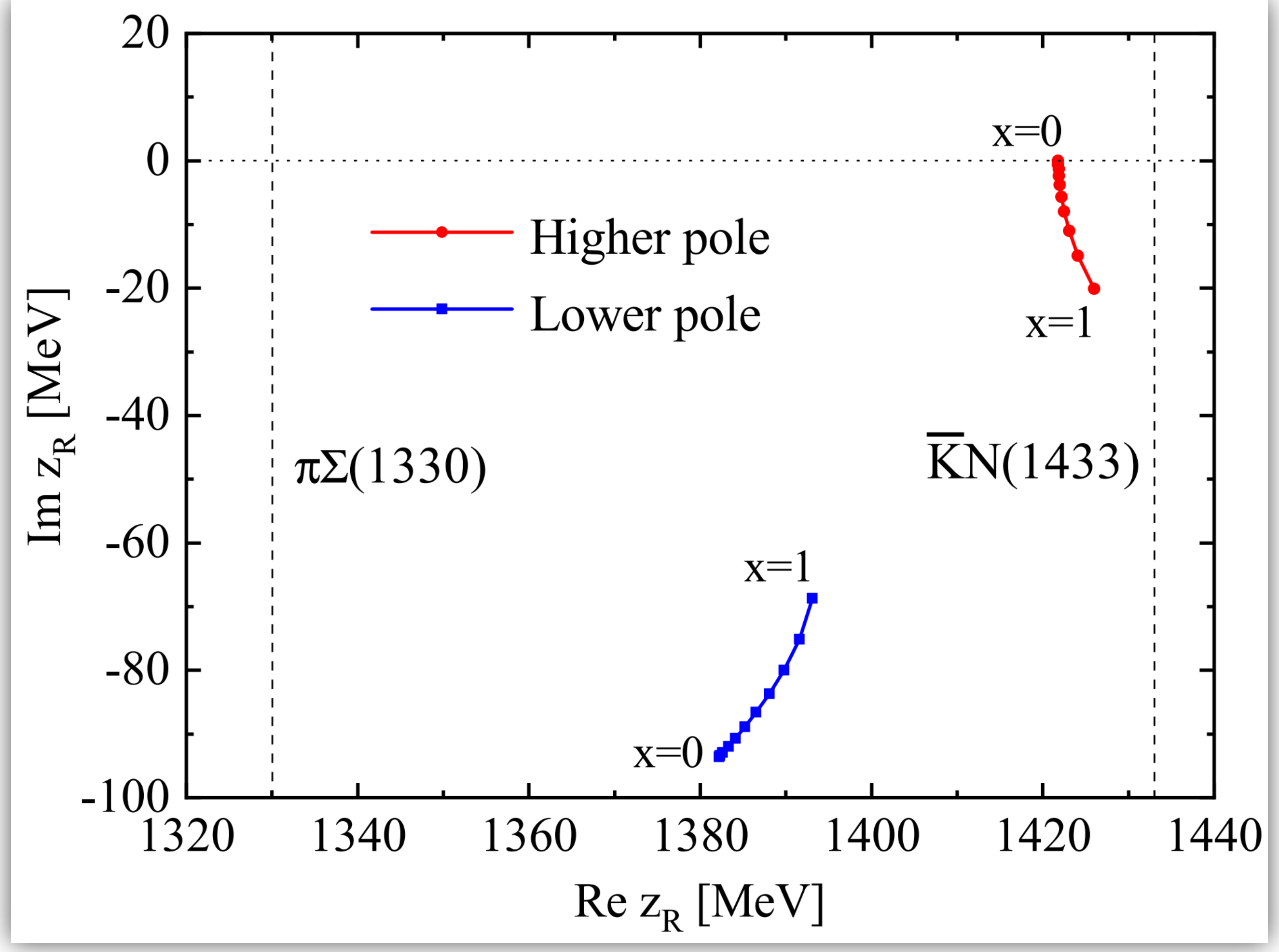
Q1: Is the coupling important?

- Multiply a factor $0 \leq x \leq 1$, to the off-diagonal matrix elements of the WT potential

$$C_{ij} = \begin{bmatrix} 3 & -\sqrt{\frac{3}{2}}x \\ & 4 \end{bmatrix}$$

- Even in the limit of **complete decoupling** ($x = 0$), there are still two poles:

$$W_H = 1421.8 - 0i,$$
$$W_L = 1382.2 - 93.6i$$



Coupling is relevant for the decay into the lower channel

Q2: How does the nature of NG bosons play a role?

□The diagonal chiral WT potential

$$V_{\bar{K}N-\bar{K}N}\left(\sqrt{s}\right) = -\frac{6}{4f^2}E_{\bar{K}} = -\frac{6}{4f^2}\sqrt{m_{\bar{K}}^2 + q^2},$$
$$V_{\pi\Sigma-\pi\Sigma}\left(\sqrt{s}\right) = -\frac{8}{4f^2}E_{\pi} = -\frac{8}{4f^2}\sqrt{m_{\pi}^2 + q^2}.$$

$m_K = 496$ MeV
$m_\pi = 138$ MeV

➢**Explicit chiral symmetry breaking leads to $m_\pi \ll m_K$**. As a result, close to the thresholds, the $\bar{K}N(1433)$ interaction is stronger than the $\pi\Sigma(1330)$ one, which leads to **a $\bar{K}N(1433)$ bound state**

➢**The small pion mass combined with the q^2(energy)-dependence** of the interaction is responsible for the dynamical generation of **a $\pi\Sigma(1330)$ resonance**

Role of explicit chiral symmetry breaking

- **To study pole trajectories as a function of the light-quark (pion) mass dependence, we need the pion mass dependence of the mesons and baryons**

$$m_K^2 = 0.291751 + 0.670652 m_\pi^2.$$

$$M_B(m_\pi) = M_0 + M_B^{(2)} = M_0 + \sum_{\phi=\pi,K} \xi_{B,\phi} m_\phi^2$$

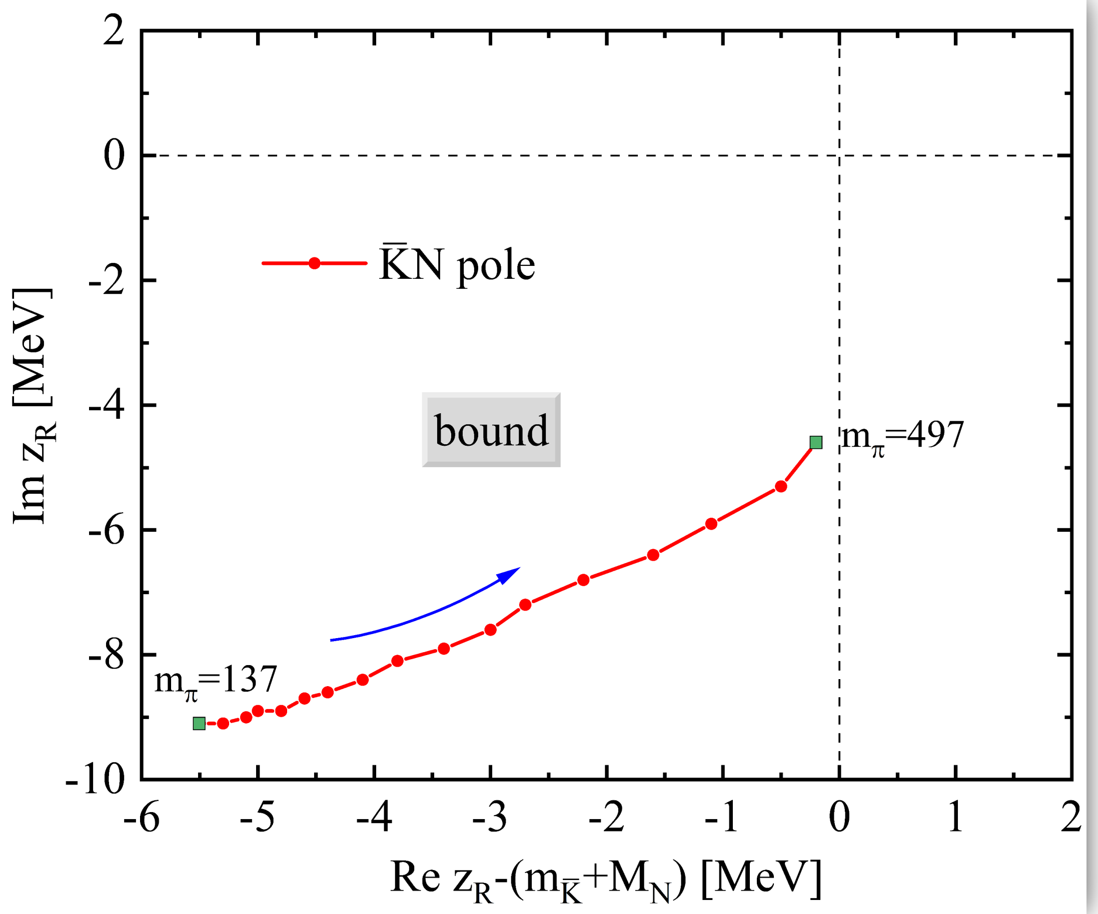
Ren, LSG*, Camalich, Meng, and Toki, JHEP**12**, 073 (2012)

- M_0 is the chiral limit of the baryon mass.
- $\xi_{B,\phi}$ are the relevant parameters containing three low-energy constants, fitted to the lattice QCD data of the **PACS-CS** Collaboration.

Aoki et al. (PACS-CS), PRD**79**, 034503 (2009)

Variation of higher pole with m_π: simple

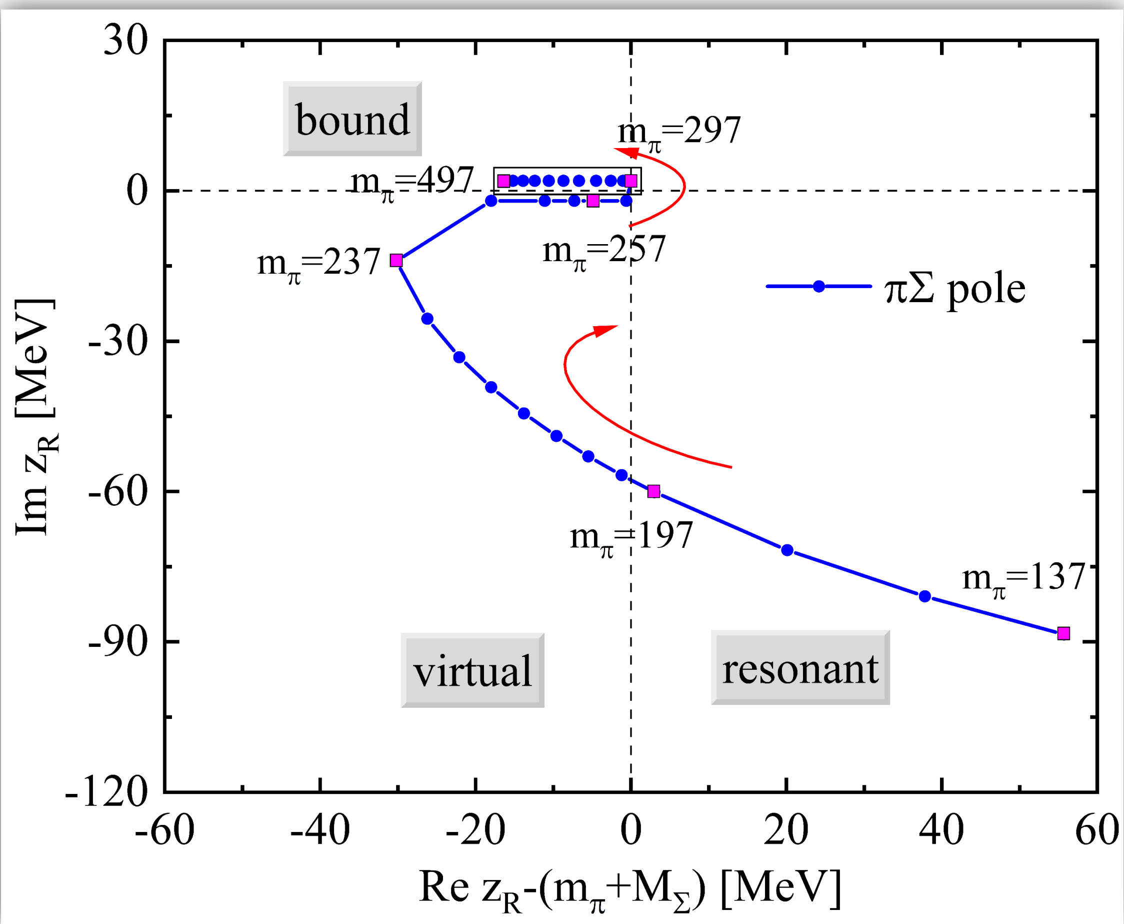
- **As m_π increases**, both the real and the imaginary parts of the higher pole decrease, which indicates that **the effective $\bar{K}N$ attraction becomes weaker and the coupling to $\pi\Sigma$ decreases as well.**
- Note that the two thresholds increase as well as m_π increases.



Variation of lower pole with m_π: complicated

- For $m_\pi \approx 200$ **MeV**, , it becomes **a virtual resonance** from a resonant state.

- For a pion mass about **300 MeV**, it becomes **a bound state** and remains so up to the pion mass of **500 MeV.**



The evolution of the lower pole clearly demonstrates the chiral dynamics underlying the two-pole structure of $\Lambda(1405)$.

Lattice QCD study

2307.10413v1

The two-pole nature of the $\Lambda(1405)$ from lattice QCD

John Bulava,[1] Bárbara Cid-Mora,[2] Andrew D. Hanlon,[3] Ben Hörz,[4] Daniel Mohler,[5,2] Colin Morningstar,[6] Joseph Moscoso,[7] Amy Nicholson,[7] Fernando Romero-López,[8] Sarah Skinner,[6] and André Walker-Loud[9]
(for the Baryon Scattering (BaSc) Collaboration)

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[2] *GSI Helmholtz Centre for Heavy Ion Research, Darmstadt, Germany*
[3] *Physics Department, Brookhaven National Laboratory, Upton, New York 11973, USA*
[4] *Intel Deutschland GmbH, Dornacher Str. 1, 85622 Feldkirchen, Germany*
[5] *Institut für Kernphysik, Technische Universität Darmstadt, Schlossgartenstrasse 2, 64289 Darmstadt, Germany*
[6] *Department of Physics, Carnegie Mellon University, Pittsburgh, Pennsylvania 15213, USA*
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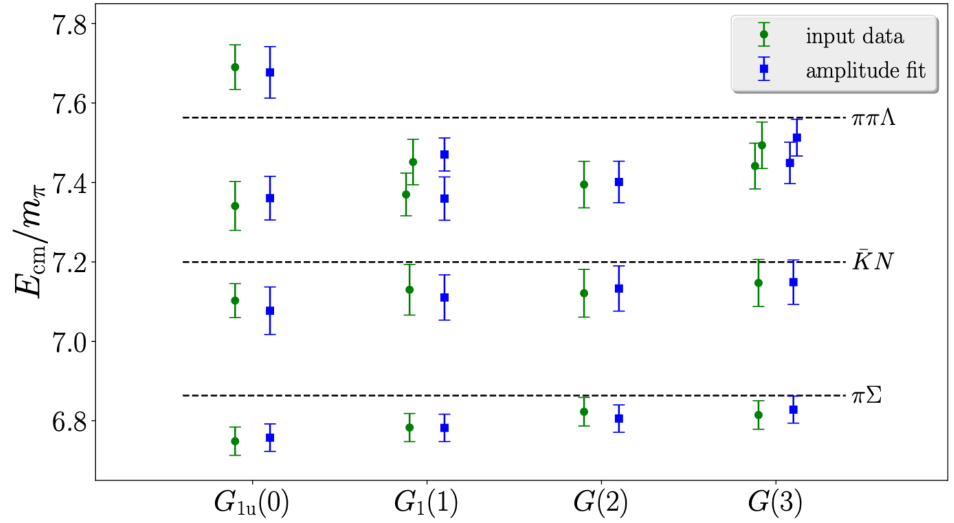
[8] *Center for Theoretical Physics, Massachusetts Institute of Technology, Cambridge, MA 02139, USA*

This letter presents the first lattice QCD computation of the coupled channel $\pi\Sigma$–$\bar{K}N$ scattering amplitudes at energies near 1405 MeV. These amplitudes contain the resonance $\Lambda(1405)$ with strangeness $S=-1$ and isospin, spin, and parity quantum numbers $I(J^P)=0(1/2^-)$. However, whether there is a single resonance or two nearby resonance poles in this region is controversial theoretically and experimentally. Using single-baryon and meson-baryon operators to extract the finite-volume stationary-state energies to obtain the scattering amplitudes at slightly unphysical quark masses corresponding to $m_\pi \approx 200$ MeV and $m_K \approx 487$ MeV, this study finds the amplitudes exhibit a virtual bound state below the $\pi\Sigma$ threshold in addition to the established resonance pole just below the $\bar{K}N$ threshold. Several parametrizations of the two-channel K-matrix are employed to fit the lattice QCD results, all of which support the two-pole picture suggested by $SU(3)$ chiral symmetry and unitarity.

$m_\pi \approx 200$ MeV,
a virtual bound state below $\pi\Sigma$ and a resonant (bound) state just below $\bar{K}N$

$$\det[\widetilde{K}^{-1}(E_{\rm cm}) - B^{P}(E_{\rm cm})] = 0 \qquad \frac{E_{\rm cm}}{m_\pi}\widetilde{K}_{ij} = A_{ij} + B_{ij}\Delta_{\pi\Sigma}$$



Two poles are found on the $(-,+)$ sheet, which is the one closest to physical scattering in the region between the two thresholds. Their locations are

$$\begin{aligned} E_1 &= 1392(9)(2)(16)\ \text{MeV}, \\ E_2 &= [1455(13)(2)(17) - i11.5(4.4)(4)(0.1)]\ \text{MeV}, \end{aligned} \qquad (6)$$

and their couplings

$$\left|\frac{c^{(1)}_{\pi\Sigma}}{c^{(1)}_{\bar{K}N}}\right| = 1.9(4)(6), \qquad \left|\frac{c^{(2)}_{\pi\Sigma}}{c^{(2)}_{\bar{K}N}}\right| = 0.53(9)(10). \qquad (7)$$

Bulava, Mon.10:00 (plenary)
Cid-Mora, Mon.16:50 (spectroscopy)

Quark mass evolution—QCDSF-UKQCD

PACS-CS

$$m_K^2 = 0.291751 + 0.670652 m_\pi^2$$

	M_π	M_K
	155.8	553.7
$*$	295.7	593.5
$*$	384.4	581.4
$*$	411.2	635.0
	569.7	713.2
	701.4	789.0

	m_π	$m_{\bar{K}}$	m_N	m_Σ
QCDSF-UKQCD	203.7	482.0	965.7	1162.8
CLS D200	203.7	486.4	979.8	1193.9

CLS D200 A summary of various hadron masses and decay constants (with normalization $f_\pi^{\text{phys}} \approx 130$ MeV) for the CLS D200 gauge ensemble used in this work. The η mass is taken from Ref. [68], and the pion and kaon decay constants are taken from Ref. [69]. All other masses are determined in Fig. 2.

$m_\pi \approx 200$ MeV, $m_K \approx 485$ MeV

am_π	0.06533(25)	af_π	0.04226(13)
am_K	0.15602(16)	af_K	0.04910(11)
am_η	0.1768(22)	am_Λ	0.3634(14)
am_N	0.3143(37)	am_Σ	0.3830(19)

J. Bulava et al., (2023), arXiv: 2307.10413 [hep-lat]

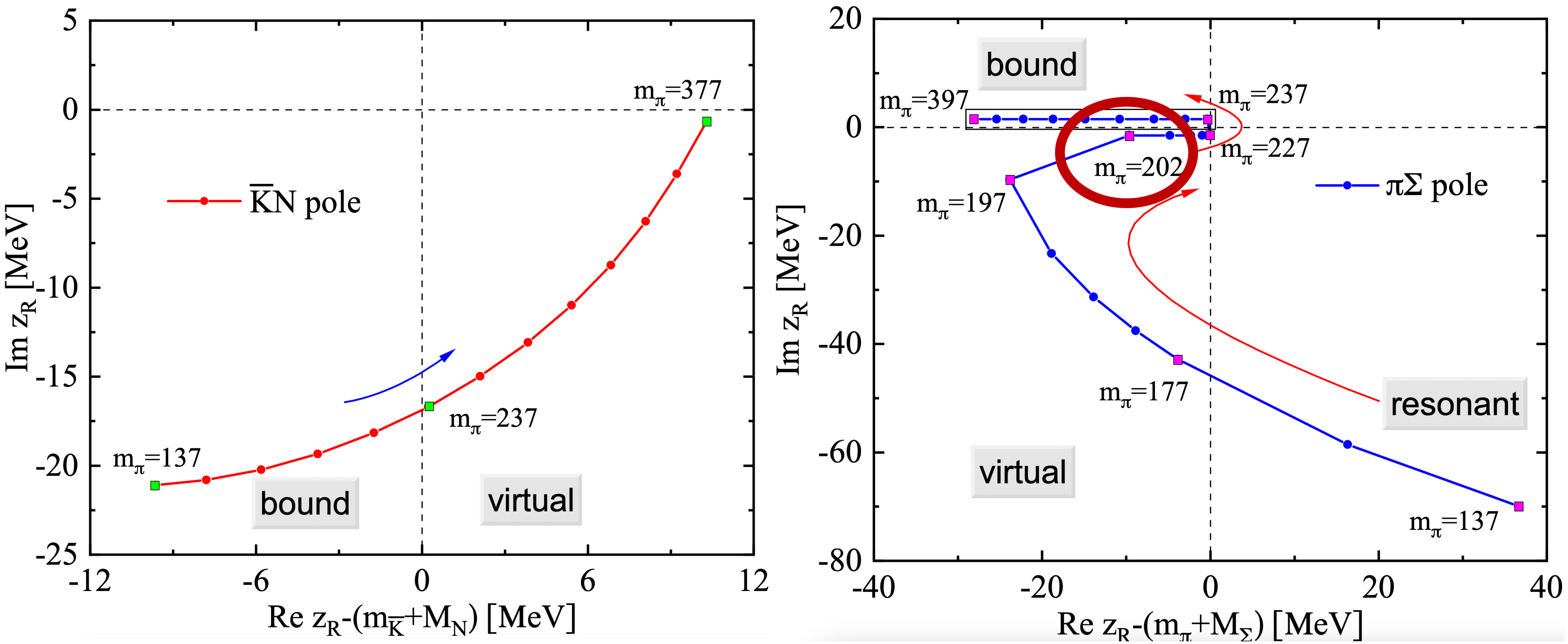
J. Bulava et al., (2023), arXiv: 2307.13471 [hep-lat]

QCDSF-UKQCD

$$M_K^2 = 0.252658 - 0.489594 M_\pi^2$$

	M_π	M_K
	228.9	476.0
	275.2	463.2
$*$	320.4	450.6
	324.2	449.5
	350.7	439.4
	383.0	425.5
	411.5	411.5
	448.8	391.9

Trajectories following the QCDSF setup



- For $m_\pi \approx 200$ **MeV**, a **virtual bound** state coupling more to the $\pi\Sigma$ channel and a higher pole coupling more to the $\bar{K}N$ channel were identified.

Q3: Is energy dependence of WT potential relevant?

$$V_{ij} = -\frac{C_{ij}}{4f^2}\left(2\sqrt{s} - M_i - M_j\right) = -\frac{C_{ij}}{4f^2}\left(E_i + E_j\right)$$

- **Replace the $E_i + E_j$ with $m_i + m_j$**, i.e. eliminate the energy dependence.

- With the original subtraction constants, we obtain only **one pole** at $1413.3 - 13.2i$, corresponding to a $\bar{K}N$ bound state.

- S ion.

The energy dependence is responsible for the emergence of two-pole structures as we defined here.

- As the pion mass is much smaller than the kaon mass, the attraction of the $\pi\Sigma$ channel is much weaker than that of the $\bar{K}N$ channel, thus cannot support a bound state.

- **If we increase the attractive potential, we can obtain two bound states, but not a bound state and a resonant state.**

$K_1(1270)$

$I(J^P) = 1/2(1^+), S = 1;\ M = 1253 \pm 7$ MeV, $\Gamma = 90 \pm 20$ MeV

- NGB scattering off (instead of a **baryon**) a vector meson

$$\mathcal{L}_{PV}^{\mathrm{WT}} = -\frac{1}{4f^2}\mathrm{Tr}\left([\mathcal{V}^\mu, \partial^\nu \mathcal{V}_\mu]\,[\Phi, \partial_\nu \Phi]\right)$$

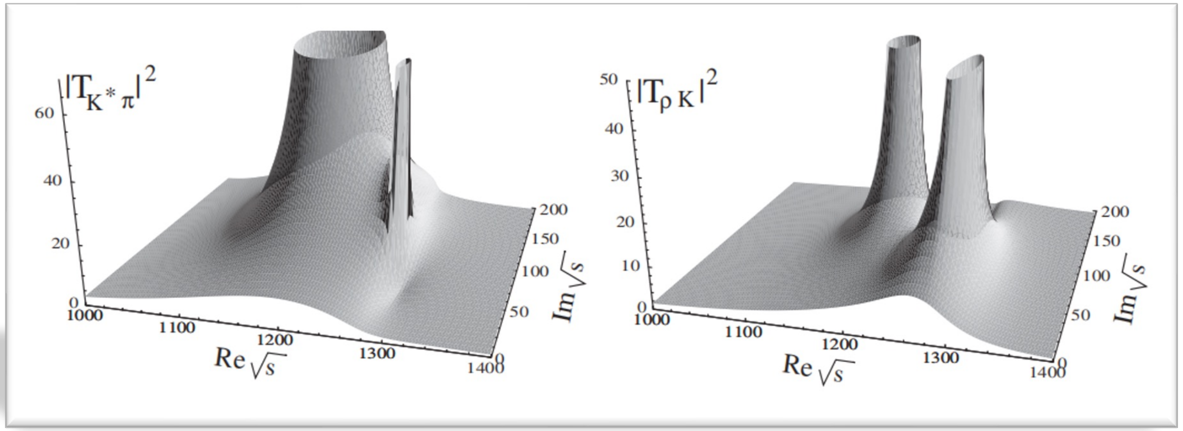
$$V_{ij}(s) = -\,\epsilon^i \cdot \epsilon^j \frac{C_{ij}}{8f^2}\left[3s - \left(M_i^2 + m_i^2 + M_j^2 + m_j^2\right) - \frac{1}{s}\left(M_i^2 - m_i^2\right)\left(M_j^2 - m_j^2\right)\right].$$

Simplified as the light mass of NGB and in the chiral limit of $M_i = M_j \equiv M$

$$V_{ij}(s) = -\epsilon^i \cdot \epsilon^j \frac{C_{ij}}{8f^2} 4M\left(E_i + E_j\right)$$

- Coupled channels: $K^*\pi(1030)$, $\rho K(1271)$, $\omega K(1278)$, $K^*\eta(1440)$, $\phi K(1515)$

$$C_{ij} = \begin{bmatrix} -2 & \frac{1}{2} & \frac{\sqrt{3}}{2} & 0 & -\sqrt{\frac{3}{2}} \\ & -2 & 0 & -\frac{3}{2} & 0 \\ & & 0 & \frac{\sqrt{3}}{2} & 0 \\ & & & 0 & -\sqrt{\frac{3}{2}} \\ & & & & 0 \end{bmatrix}$$

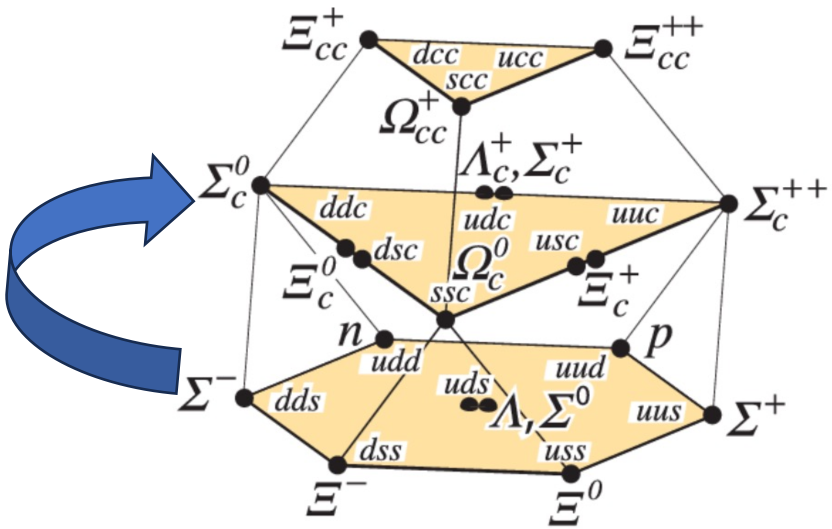


Roca, Oset, and Singh, PRD72, 014002 (2005)

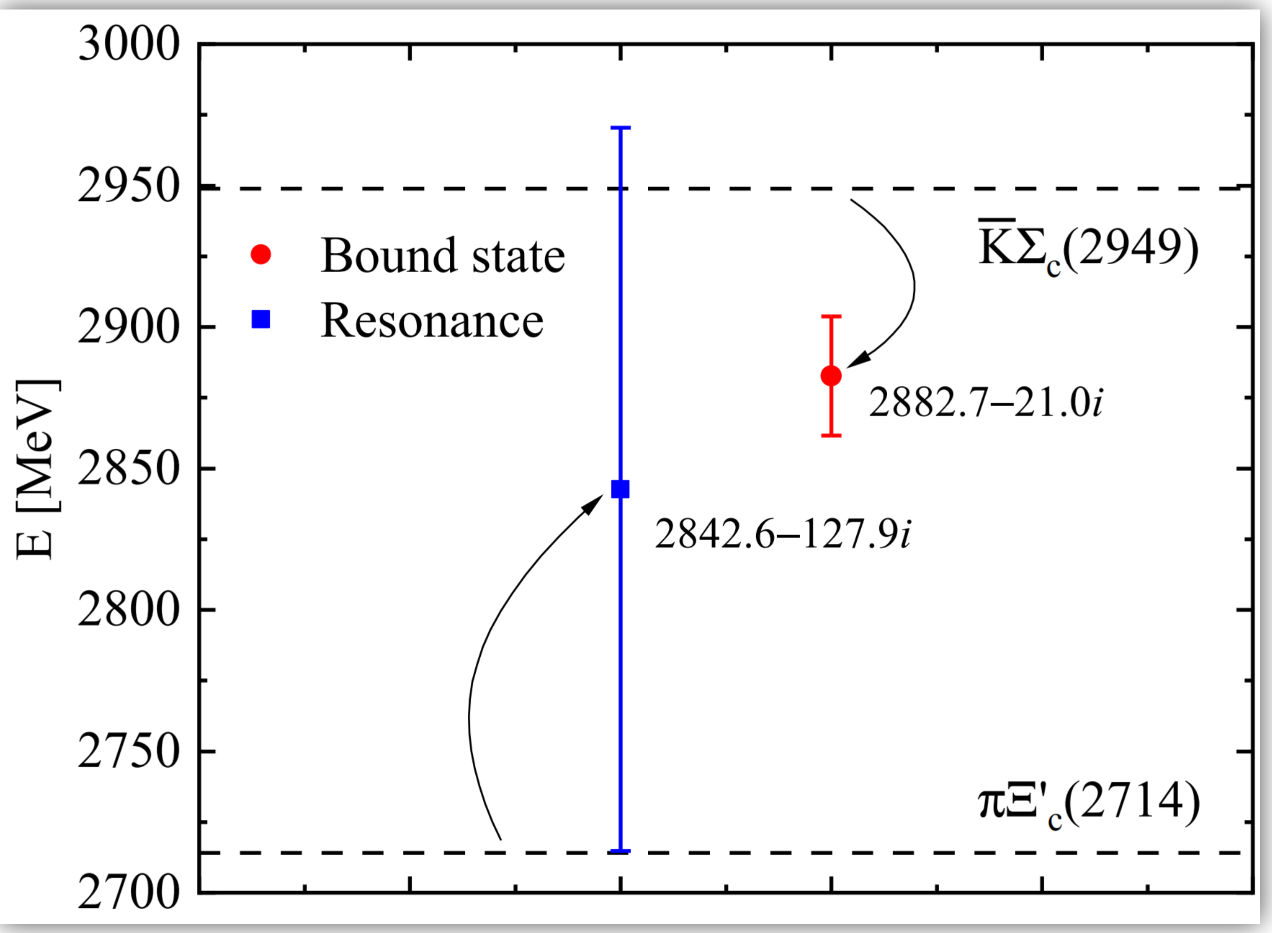
LSG, Oset, Roca, and Oller, PRD**75,** 014017 (2007)

Further two-pole structures: singly charmed baryon

- NGB scattering off a single-charmed baryon



- $\boldsymbol{\bar{K}\Sigma_c(2949)}$, $\boldsymbol{\pi\Xi_c'(2714)}$;
  $\eta\Xi_c'(3125)$, $K\Omega_c(3191)$;
  isospin ½, strangeness -1
  $\Lambda = 800$ MeV



$W_H = 2882.7 - 21.0i \quad W_L = 2842.6 - 127.9i$

Contents

Summary and outlook

1. **Chiral symmetry** strongly constrains the interactions of a heavy matter particle with a NG boson--the Weinberg-Tomozawa potentials.
2. **The NG boson nature of π, K, (and η)** are responsible for the generation of two nearby poles: one bound and one resonant.
3. **The explicit chiral and SU(3) flavor symmetry breaking** dictates that the two relevant **coupled channels** are **close to each other** such that **the lineshapes** of the two states **overlap** and thus create the impression that there is only one state.

Summary and outlook

- We **anticipate such two-pole structures** in other systems governed by the same chiral dynamics and encourage dedicated experimental and lattice QCD studies to verify the chiral dynamics underlying such phenomena.
- We stress that as noted already in the literature **flavor symmetry** also plays a relevant role here, as it **dictates the relative coupling strengths** between different channels.

Thanks a lot for your attention!