Pole structure of $\Lambda(1405)$ reviewed

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Outline:

1. Introduction
2. Chirally motivated $\bar{K}N$ interactions
3. Dynamically generated resonances/poles
4. One or two $\Lambda(1405)$ poles?
5. Yet another $\bar{K}N$ model (preliminary!)
6. Summary

Introduction

the enigmatic nature of Λ(1405) keeps our interest for more than 60 years

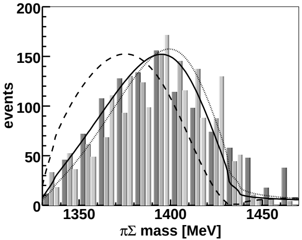
- in 1959 Dalitz and Tuan predicted a subthreshold resonance in their K-matrix analysis of $K^- p$ data; confirmed 2 years later in the $\pi\Sigma$ mass spectra in the $K^- p \longrightarrow \pi\pi\pi\Sigma$ reaction
- Λ(1405) $1/2^-$ is much lighter than $N^*(1535)$ and a potential spin-orbit partner Λ(1520) $3/2^-$ which is difficult to explain within a standard constituent quark model
- hadronic molecule, a loosely bound $\bar{K}N$ state? a pentaquark?
- most common interpretation - $\bar{K}N$ quasi-bound state submerged in $\pi\Sigma$ continuum, a result of coupled channels $\pi\Sigma - \bar{K}N$ dynamics
- unitary coupled channels approaches based on effective chiral Lagrangian generate two poles related to Λ(1405) (Oller, Meißner in 2001)

More in reviews:
T. Hyodo, D. Jido - Prog. Part. Nucl. Phys. 67 (2012) 55
M. Mai - arXiv:2010.00056 [nucl-th]

Introduction

Λ(1405) in experimental data on $\pi\Sigma$ mass distributions

relatively old *compatible* experiments:
Thomas (1973), Hemingway (1984), ANKE (2008).

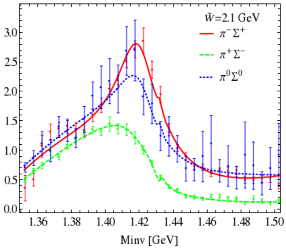


A.C., J. Smejkal - Nucl. Phys. A 881 (2012) 115

$$\frac{dN_{\pi\Sigma}}{dM} \sim \left| T_{\pi\Sigma,\pi\Sigma}(I=0) + r_{KN/\pi\Sigma}\, T_{\pi\Sigma,\bar{K}N}(I=0)\right|^2 p_{\pi\Sigma}$$

HADES (2013) would fit in nicely too.

new experiments:
HADES (2013) - $pp \longrightarrow pK^+\pi\Sigma$
CLAS (2013) - $\gamma p \longrightarrow K^+\pi\Sigma$
J-PARC (2016) - $K^-d \longrightarrow n\pi\Sigma$
future - weak decays of heavy hadrons, e.g. $\Lambda_c \longrightarrow \pi^+ MB$, $MB = \pi\Sigma$ or $\bar{K}N$



CLAS data reproduction

M. Mai, U.-G. Meißner - Eur. Phys. J. A 51 (2015) 30

Introduction

Λ(1405) theory outreach:

theoretical models developed to describe the $\bar{K}N$ system at energies close to threshold, dominated by the Λ(1405) resonance $\Longrightarrow$ $\bar{K}N$ amplitudes

↓↓↓

$\bar{K}NN$ $\bar{K}NNN$ few-body systems

? narrow measurable states

interpretation of $K^- pp$ structures observed by FINUDA@DAΦNE, DISTO@Saclay, E15@J-PARC

kaonic deuterium atom

predictions for the SIDDHARTA-2 experiment

Fadeeev type and variational calculations

↓↓↓

$\bar{K}$-nucleus interaction

strongly attractive and absorptive

$$V_{\rm opt}(\rho) \sim t_{\bar{K}N}(\rho)\, \rho$$

? optical potential depth:

phenomenology $V_{\rm opt}$=**(150-200)** MeV

chiral models $V_{\rm opt}$=**(50-60)** MeV

? existence of sufficiently narrow K^-–nuclear bound states

related issue: **kaon propagation in hot and dense nuclear matter**

heavy ion collisions, kaon condensation, neutron stars structure

Chirally motivated $K^- N$ interactions

$\bar{K}N - \pi\Sigma$ system (+ add-ons, mostly more MB)
meson octet - baryon octet coupled channels interactions

involved channels	$\pi\Lambda$	$\pi\Sigma$	$\bar{K}N$	$\eta\Lambda$	$\eta\Sigma$	$K\Xi$
thresholds (MeV)	1250	1330	1435	1660	1740	1810

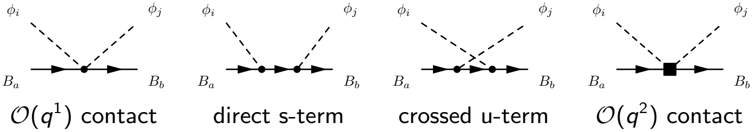
adding the meson singlet for ηN, $\eta' N$ - *P. Bruns, A.C., NPA 992 (2019) 121630*

- strongly interacting multichannel system with an s-wave resonance, the $\Lambda(1405)$, just below the $K^- p$ threshold
- modern theoretical treatment based on effective chiral Lagrangians
- effective potentials constructed to match the chiral meson-baryon amplitudes up to LO or NLO order
- Lippmann-Schwinger (or Bethe-Salpeter) equation to sum the major part of the perturbation series
- low energies around threshold - only s-wave considered in most approaches

Chirally motivated $K^- N$ approaches

N. Kaiser, P.B. Siegel, W. Weise - Nucl. Phys. A 594 (1995) 325

Schematic picture:



Parameters: f_π, f_K, f_η - meson decay constants
$D \simeq 3/4$, $F \simeq 1/2$ - axial vector couplings, $g_A = F + D$
b_0, b_D, b_F, four d's - second order couplings

Some NLO LECs can be fixed by GMO mass splitting formulas and by a relation to the πN sigma term,

$$\sigma_{\pi N} = -2m_\pi^2(2b_0 + b_D + b_F)$$

Chirally motivated $K^- N$ approaches

effective separable potentials constructed to match the chiral amplitudes

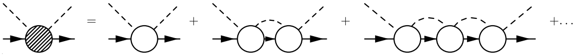
$$V_{ij}(k, k'; \sqrt{s}) = g_i(k^2)\, v_{ij}(\sqrt{s})\, g_j(k'^2)$$

$$v_{ij}(\sqrt{s}) = -\frac{C_{ij}(\sqrt{s})}{4\pi f_i f_j} \sqrt{\frac{M_i M_j}{s}}$$

- energy dependent couplings C_{ij} determined by the chiral SU(3) symmetry
- the formfactors $g_j(k) = 1/[1 + (k/\alpha_j)^2]$ account naturally for the off-shell effects with the inverse ranges α_j fitted to the low energy $\bar{K}N$ data

Lippmann-Schwinger equation used to solve exactly the loop series

$$T = V + V\ G\ T$$



Chirally motivated $K^- N$ approaches

$$F_{ij}(k, k'; \sqrt{s}) = g_i(k^2)\, f_{ij}(\sqrt{s})\, g_j(k'^2)$$
$$f_{ij}(\sqrt{s}) = \left[(1 - v \cdot G(\sqrt{s}))^{-1} \cdot v \right]_{ij}$$

with a loop Green function (in a free space)

$$G_n(\sqrt{s}) = -4\pi \int \frac{d^3p}{(2\pi)^3} \frac{g_n^2(p^2)}{k_n^2 - p^2 + \mathrm{i}0} = \frac{(\alpha_n + \mathrm{i}k_n)^2}{2\alpha_n} \left[g_n(k_n) \right]^2$$

nuclear medium treatment

$$G_n(\sqrt{s}) = -4\pi \int_{\Omega_i(\rho)} \frac{d^3p}{(2\pi)^3} \frac{g_n^2(p^2)}{k_n^2 - p^2 - \Pi_i(\omega_i, E_i, \vec{p}; \rho) + \mathrm{i}0}$$

- integration domain $\Omega_i(\rho)$ is limited by the Pauli principle in the $\bar{K}N$ channels
- Π_i represents a sum of meson and baryon self-energies in channel i
- $\Pi_{\bar{K}} \sim F_{\bar{K}N}\, \rho \;\Rightarrow\;$ selfconsistent treatment required

Chirally motivated $K^- N$ approaches

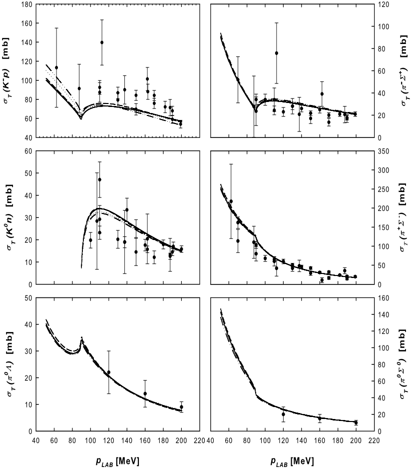
- Kyoto-Munich (KM)
  Y. Ikeda, T. Hyodo, W. Weise, Nucl. Phys. A 881 (2012) 98
- Murcia (M_I, M_{II})
  Z. H. Guo, J. A. Oller, Phys. Rev. C 87 (2013) 035202
- Bonn (B_2, B_4)
  M. Mai, U.-G. Meißner - Eur. Phys. J. A 51 (2015) 30
- Prague (P)
  A. C., J. Smejkal, Nucl. Phys. A 881 (2012) 115
- Barcelona (BCN)
  A. Feijoo, V. Magas, À. Ramos, Phys. Rev. C 99 (2019) 035211

Model parameters (couplings, inverse interaction ranges or subtraction constants) fixed in fits to low energy $K^- p$ data (and more in some cases).

Comparative analysis of the first four approaches presented in
A. C., M. Mai, U.-G. Meißner, J. Smejkal - Nucl. Phys. A 954 (2016) 17

$K^- p$ data (at and above threshold)

low energy cross sections:



threshold branching ratios:

$$\gamma = \frac{\Gamma(K^- p \to \pi^+ \Sigma^-)}{\Gamma(K^- p \to \pi^- \Sigma^+)} = 2.36 \pm 0.04$$

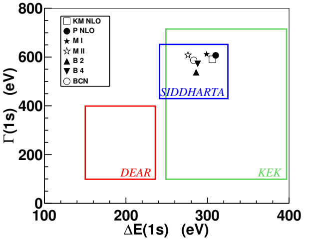
$$R_c = \frac{\Gamma(K^- p \to \mathrm{charged})}{\Gamma(K^- p \to \mathrm{all})} = 0.664 \pm 0.011$$

$$R_n = \frac{\Gamma(K^- p \to \pi^0 \Lambda)}{\Gamma(K^- p \to \mathrm{neutral})} = 0.189 \pm 0.015$$

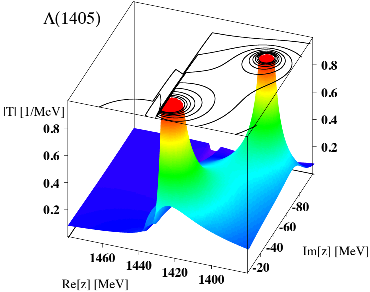
kaonic hydrogen:

$$\Delta E_N(1s) = 283 \pm 36(stat.) \pm 6(syst.)\ \mathrm{eV}$$

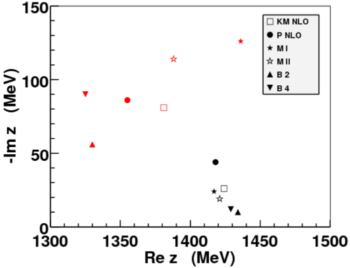
$$\Gamma(1s) = 541 \pm 89(stat.) \pm 22(syst.)\ \mathrm{eV}$$



Model predictions - Λ(1405) resonance



Hyodo, Jido - Prog. Part. Nucl. Phys. 67 (2012) 55

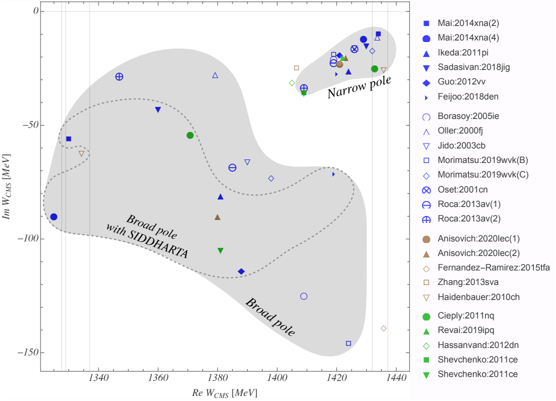


A.C., Mai, Meißner, Smejkal - NPA 954 (2016) 17

- the *higher* pole around 1425 MeV couples more strongly to $\bar{K}N$, the *lower* pole is much further from the real axis and has larger coupling to $\pi\Sigma$
- all models tend to agree on the position of the $\bar{K}N$ related pole
- the data are not very sensitive to the position of the $\pi\Sigma$ related pole
- illustrative picture: $\bar{K}N$ bound state submerged in $\pi\Sigma$ continuum

Model predictions - Λ(1405) resonance

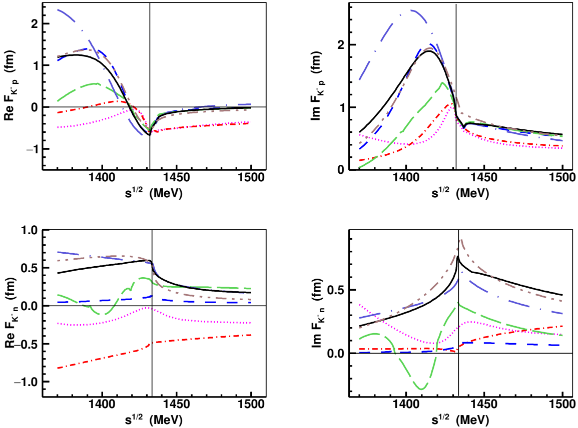
all recent (year ≥ 2000) Λ(1405) poles predictions



M. Mai - arXiv:2010.00056 [nucl-th]

Model predictions - $K^- N$ amplitudes (free space)

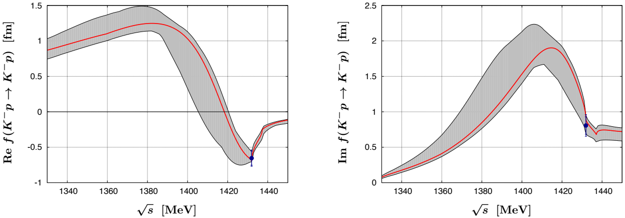
$K^- p$ and $K^- n$ elastic amplitudes



B_2 (dotted, purple), B_4 (dot-dashed, red), M_I (dashed, blue), M_{II} (long-dashed, green), P (dot-long-dashed, violet), BCN (dot-dot-dashed, brown), KM (continuous, black)

Model predictions - $K^- N$ amplitudes (free space)

For a comparison, uncertainty bands provided in
Y. Ikeda, T. Hyodo, W. Weise, Nucl. Phys. A 881 (2012) 98



bands calculated by varying the KM_{NLO} model parameters to get the $K^- p$ scattering length within SIDDHARTA experimental error bars

the theoretical ambiguities below the $\bar{K}N$ threshold are much larger than indicated by such uncertainty bounds provided for a specific model and a given χ^2 local minimum !!!

Model predictions - K^-N amplitudes (free space)

the $I = 1$ sector is not restricted by the fitted experimental data leading to varied predictions for the K^-n scattering amplitude

New data needed !!!

- new precise data for the isovector $K^-p \longrightarrow \pi^0\Lambda$ and isoscalar $K^-p \longrightarrow \pi^0\Sigma^0$ reactions at as low energies as possible are highly desired
- $\pi\Sigma$ mass spectra at subthreshold energies should help provided we understand the process dynamics
- the $K_L^0 p \longrightarrow K^+\Xi^0$ reaction (I=1) to be measured at KLF@JLAB
- decays of heavy baryons into channels including MB(S=-1), e.g. $\Lambda_b \longrightarrow J/\Psi\,\Lambda(1405)$, measured at LHC
- kaonic deuterium measurement (AMADEUS, Frascati) will also add to the picture

Dynamically generated resonances/poles

Where do the poles come from? (demonstration for the Prague approach)
The amplitude has poles for complex energies z (equal to $\sqrt{s}$ on the real axis) if a determinant of the inverse matrix is equal to zero,

$$\det|f^{-1}(z)| = \det|v^{-1}(z) - G(z)| = 0$$

The origin of the poles can be traced to the

zero coupling limit: $C_{ij} = 0$ for $i \neq j$ (interchannel couplings switched off)

for $C_{i,j\neq i} = 0$ the condition for a pole of the amplitude becomes

$$\prod_n [1/v_{nn}(z) - G_n(z)] = 0$$

There will be a pole in channel n at a Riemann sheet $[+/-]$ (phys./unphys.) if the following condition is satisfied for any complex energy z:

$$\frac{4\pi f_n^2}{C_{nn}(z)}\,\frac{z}{M_n} + \frac{(\alpha_n + \mathrm{i}k_n)^2}{2\alpha_n}\,[g_n(k_n)]^2 = 0$$

Only states with nonzero diagonal couplings $C_{i,j=i}$ can generate the poles!

Dynamically generated resonances/poles

What channels have nonzero diagonal couplings?
For simplicity, we first look only at the leading order WT term couplings

Sample results for the P_{WT} model:

sector	channel	ZCL state	resonance
	$\pi\Sigma$	resonance	Λ(1405)
$I = 0$	$\bar{K}N$	bound	Λ(1405)
	$K\Xi$	bound	Λ(1670)
	$\pi\Sigma$	resonance	—
$I = 1$	$\bar{K}N$	virtual	K^-n amplitude
			$\pi\Sigma$ photoproduction (CLAS data)
	$K\Xi$	virtual	Σ(1750)

In general, the exact situation (existence of a ZCL pole in a given channel) depends on the model parameters (subtraction constants, NLO contributions that generate sufficiently large couplings C_{nn})

Dynamically generated resonances/poles

Notation: Each Riemann sheet is labeled by the signs of the imaginary parts of the CMS momenta in the meson-baryon channels ordered according to their thresholds. The poles may move from one Riemann sheet to another one by crossing the real axis through the branch cuts.

For $I = 0$ the RS [++++] is the physical sheet, for $I = 1$ it is the [+++++] RS. The Riemann sheets accessed by crossing the real axis in between the $\pi\Sigma$ and $\bar{K}N$ thresholds are [-+++] and [- -+++], respectively.

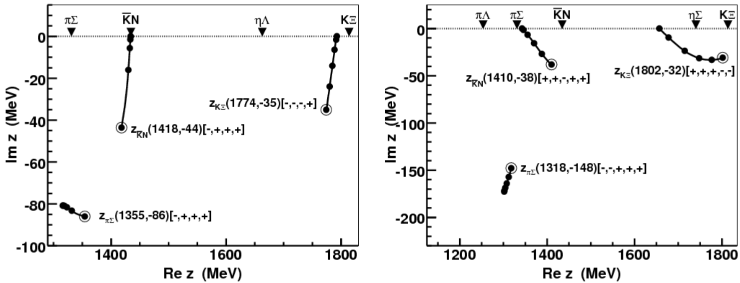
R.J. Eden, J.R. Taylor (1964):

- Each pole observed in the ZCL will develop into multiplets of shadow poles observed at Riemann sheets with the same original sign (+/-) in the respective channel.
- Physical observables are affected by the pole that is closest to the physical region in the limit of physical (fully switched on) interchannel couplings.
- This dominant pole and any other shadow pole may switch roles when the model parameters are varied, the couplings of various channels to a specific pole evolve was well.

Dynamically generated resonances/poles

Pole movements upon scaling the nondiagonal interchannel couplings

$C_{i,j\neq i}$ replaced by $x \cdot C_{i,j\neq i}$



P_{NLO} model, left panel: isoscalar states, right panel: isovector states
The pole positions in the physical limit are emphasized with large empty circles.
The triangles at the top of the real axis indicate the channel thresholds.

Dynamically generated resonances/poles

Pole content of the considered models

resonance	models / ZCL channels					
	P_{NLO}	KM_{NLO}	M_I	M_{II}	B_2	B_4
$\Lambda_1(1405)$	$\pi\Sigma$	$\pi\Sigma$	$\pi\Sigma$	$\pi\Sigma$	$\pi\Sigma$	$\pi\Sigma$
$\Lambda_2(1405)$	$\bar{K}N$	$\bar{K}N$	$\bar{K}N$	$\eta\Lambda$	$\eta\Lambda$	$\bar{K}N$
$\Lambda(1670)$	$K\Xi$	—	$K\Xi$	$K\Xi$	—	$K\Xi$
$\bar{K}N(I=1)$	$\bar{K}N$	$\eta\Sigma$	$\bar{K}N$	$\bar{K}N$	—	—
$\Sigma(1750)$	$K\Xi$	—	—	$K\Xi$	—	$K\Xi$

M_{II} and B_2 models generate the $\Lambda_2(1405)$ pole from the $\eta\Lambda$ ZCL bound state.

earlier reports on the isovector $\bar{K}N$ related pole:

J. Oller, U.-G. Meißner - Phys. Lett. B 500 (2001) 263

D. Jido, J.A. Oller, E. Oset, A. Ramos, U.-G. Meißner - NPA 725 (2003) 181

A.C., E. Friedman, A. Gal, D. Gazda, J. Mareš - PRC 84 (2011) 045206

A.C., J. Smejkal - Few Body Syst. 54 (2013) 1183

One or two Λ(1405) poles?

The multichannel chiral approaches generate two Λ(1405) poles !!!
questioned recently in J. Révai - Few Body Syst. 59 (2018) 49

$$T(p', p; \sqrt{s}) = V(p', p; \sqrt{s}) + \int d^3q\, V(p', q; \sqrt{s}) \frac{2\mu}{k^2 - q^2 + i\epsilon} T(q, p; \sqrt{s})$$

on-shell factorisation: the loop momentum q in the argument of T and V replaced by its on-shell value k, then T and V pulled out of the integral
equivalent to introducing tad-pole contributions to the interaction kernel V that can be absorbed into a renormalisation of the meson-baryon vertex

J. Révai put this procedure under question demonstrating that the $\pi\Sigma$ related pole disappears if the off-shell part of the loop function integral is not dropped

- very specific form of the potential V adopted
- non-relativistic treatment of the *MB* energies and momenta

One or two Λ(1405) poles?

only Weinberg-Tomozawa term considered, taken in a form

$$\langle q_i|V_{ij}|q_j\rangle = u_i(q_i)\,\langle q_i|v_{ij}|q_j\rangle\,u_j(q_j) = u_i(q_i)\,\lambda_{ij}\left(m_i + \frac{q_i^2}{2\mu_i} + m_j + \frac{q_j^2}{2\mu_j}\right)u_j(q_j)$$

with the central piece equivalent to the on-shell form $(2\sqrt{s} - M_i - M_j)$
and a dipole form-factor $u_i(q) = \left[1/(1+q^2/\beta_i^2)\right]^2$

parameters β_j fitted to the $\bar{K}N$ data for both choices

result: one pole vs two poles

However, ...

One or two Λ(1405) poles?

P. Bruns, A.C. - Nucl. Phys. A 996 (2020) 121702

We were able to rewrite the Révai's algebraic T-matrix solution as

$$T_{\rm on}(k) = u(k)\left[\tilde{W}_{\rm JR}^{-1} - G_{\rm on}\right]^{-1} u(k)\,,$$

where the effective potential $\tilde{W}_{\rm JR}$ is again a real coupled-channel matrix depending only on the on-shell momenta k^2,

$$\tilde{W}_{\rm JR} = [1+\lambda I_0]^{-1}\left(\bar{\gamma}\lambda + \lambda\bar{\gamma} - \lambda I_1 \lambda\right)[1+I_0\lambda]^{-1}\ ,$$

where $\gamma(q) = \frac{q^2}{2\mu} + m$, $\bar{\gamma} = \gamma(k)$ and the tad-pole integrals are

$$I_n := \frac{4\pi}{(2\mu)^n}\int_0^\infty dq\, q^2 (u(q))^2 (q^2 - k^2)^n$$

In this form, the on-shell approximation is quite transparent, equivalent to neglecting the integrals I_n.

One or two Λ(1405) poles?

The JR amplitude gives scattering lengths that do not vanish in the SU(3) chiral limit! Demonstration: one channel case, at threshold ($k = 0$ and $\bar{\gamma} = m$)

$$a_{0+}^{\mathrm{JR}} = -4\pi^2\mu \left[\frac{(1+\lambda I_0)^2}{2\lambda m - \lambda I_1 \lambda} + 4\pi^2\mu \frac{5\beta}{16} \right]^{-1}$$

on-shell approximation: $I_0,\ I_1 \to 0,\ a_{0+} \sim \mathcal{O}(m)$
off-shell effects in: $I_{0,1} \neq 0,\ a_{0+} \sim \mathcal{O}(m^0)$

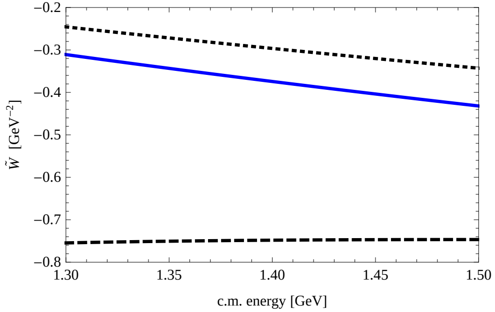
The JR approach violates the chiral symmetry!

The origin of this violation can be traced to the use of non-relativistic kinematics.

One or two Λ(1405) poles?

A proper relativistic treatment is possible, though the respective formulas are much more complicated.
The effective relativistic potential, a counterpart of $\tilde{W}_{\rm JR}$, can be written as

$$\tilde{W}_{\rm BC}(\sqrt{s}) = \sqrt{\frac{E_B + M}{\mu}}\, \frac{\mathcal{W}(\sqrt{s})}{4(2\pi)^3\sqrt{s}} \left[1 + (I_B(\beta) - I_M(\beta))\, \frac{\mathcal{W}(\sqrt{s})}{2\sqrt{s}}\right]^{-1} \sqrt{\frac{E_B + M}{\mu}}$$



$\bar{K}N(I=0)$ effective kernels: $W_{\rm WT}$ (dotted), $\tilde{W}_{\rm JR}$ (dashed), $\tilde{W}_{\rm BC}$ (blue)

One or two Λ(1405) poles?

the corresponding amplitudes satisfy the chiral symmetry strictures,

$$a^{\bar{K}N,I=0}_{0+,\mathrm{BC}} \sim \mathcal{O}(m)$$

Model parameters, inverse ranges β_j, determined in fits to kaonic hydrogen data, $K^- p$ threshold branching ratios and cross sections. The ratio of the meson decay constants fixed as $F_K/F_\pi = 1.193^{n-1}$ providing two models BC_1 and BC_2.

Pole positions (in MeV) on the [-,+] and [-,-,+] Riemann sheets for the $I=0$ and $I=1$ sectors, respectively.

model	z_1 ($I=0$)	z_2 ($I=0$)	z_3 ($I=1$)
CS	(1432.8, -24.9)	(1370.8, -54.2)	(1408.9,-199.7)
JR	(1422.9, -25.7)	—	(1106.5, -71.6)
BC_1	(1439.9, -23.3)	(1316.0, -6.76)	(1361.1, -166.9)
BC_2	(1437.8, -20.9)	(1251.1, 0.0)	(1337.4, -117.3)

Note: There are two poles but their positions are not where we would like to have them.

One or two $\Lambda(1405)$ poles?

A.V. Anisovich et al. - Eur. Phys. J. A 56 (2020) 5, 139

partial wave analysis of low-energy data on $K^- p$ and $\pi\Sigma$ interactions:

- bubble chamber data on $K^- p \longrightarrow \pi\pi\pi\Sigma$
- $K^- p \longrightarrow \pi^0\pi^0\Lambda$, $\pi^0\pi^0\Sigma^0$ from Crystal Ball at BNL
- $\gamma p \longrightarrow K^+\pi\Sigma$ from CLAS at JLab
- $K^- p$ total cross sections
- kaonic hydrogen from SIDDHARTA at Frascati

Two equivalent solutions found:

- one pole $z = (1421 \pm 3) - \mathrm{i}(23 \pm 3)$ MeV, SU(3) singlet; compatible with the quark-model predictions
- two poles with $z_1 = (1423 \pm 3) - \mathrm{i}(20 \pm 3)$ MeV, SU(3) octet, and a second pole fixed at $z_1 = 1380 - \mathrm{i}90$ MeV, SU(3) singlet; compatible with an earlier analysis by D. Jido et al. - Nucl. Phys. A 725 (2003) 181

Yet another $\bar{K}N$ model (preliminary!)

a new Prague model developed together with P. Bruns

- based on effective chiral Lagrangian (manifestly Lorentz invariant)
- improved treatment of the Born terms
- $\eta\Lambda$ and $\eta\Sigma^0$ cross sections included to cover the Λ(1670) region
- 12 parameters fitted to the data: b_0, b_F, 4 d's, 6 inverse ranges defining the Yamaguchi form factors that regularize the loop function integrals

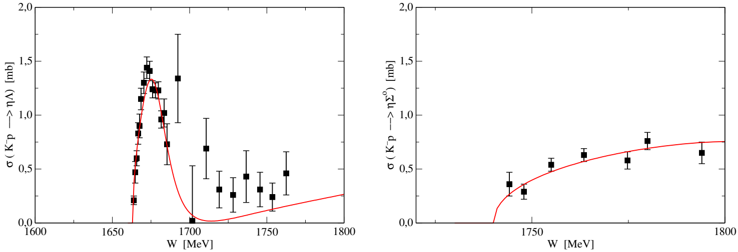
fit quality: $\chi^2/\mathrm{dof} \approx 1.3$

Pole positions (isoscalar sector):

$$\begin{aligned} \Lambda(1405)\quad & z_{\pi\Sigma}[-,+,+,+] = (1353,\ -43)\ \text{MeV} \\ & z_{\bar{K}N}[-,+,+,+] = (1428,\ -24)\ \text{MeV} \\ \Lambda(1670)\quad & z_{K\Xi}[-,-,-,+] = (1677,\ -14)\ \text{MeV} \end{aligned}$$

Yet another $\bar{K}N$ model (preliminary!)

$\eta\Lambda$ and $\eta\Sigma^0$ data reproduction



Our aim: study the SU(3) flavor structure of the poles assigned to Λ(1405) and Λ(1670) in some detail

Summary

- The up-to-date (NLO) chirally motivated $\bar{K}N$ models provide very different predictions for the K^-N amplitudes at subthreshold energies.
- Two Λ(1405) poles in the chiral models. Pole movements on the complex energy manifold give us additional insights on the the dynamically generated meson-baryon resonances. The origin of the poles can be tracked to the nonzero diagonal inter-channel couplings.
- Available experimental data can be reproduced about equally well by models with just one pole in the Λ(1405) region.
- Despite our progress over the last 60 years, the character of Λ(1405) resonance is still not reliably established.

Have a peaceful holidays!