Origin of resonances in chiral dynamics

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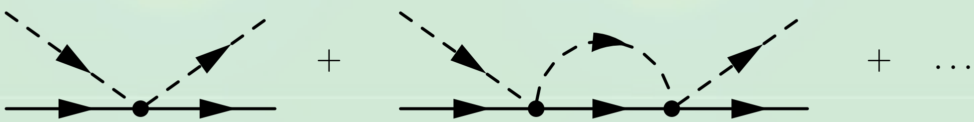
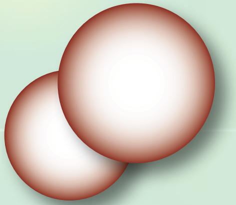
Classification of resonances

Resonances in two-body scattering

- Knowledge of interaction (potential)
- Experimental data (cross section, ...)

Dynamical state: two-body molecule, quasi-bound state, ...

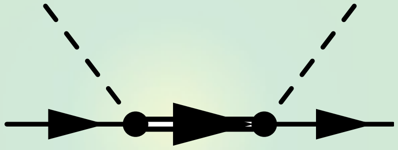


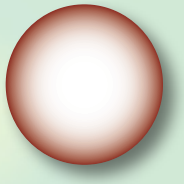


e.g.) Deuteron in NN, positronium in e^+e^-, ...

CDD pole: elementary particle, independent state, ...

L. Castillejo, R.H. Dalitz, F.J. Dyson, Phys. Rev. 101, 453 (1956)





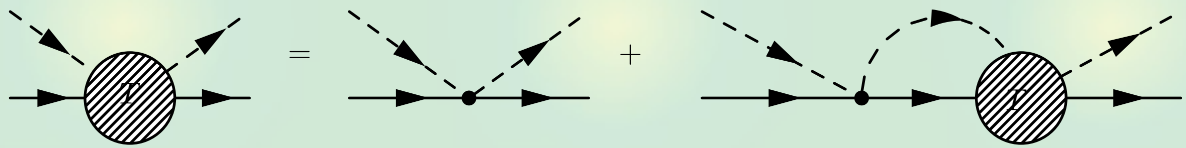
e.g.) J/Ψ in e^+e^-, ...

Chiral unitary approach

Description of meson-baryon scattering, s-wave resonances

- Interaction <-- chiral symmetry
- Amplitude <-- unitarity (coupled channel)

$$T = \frac{1}{V^{-1} - G}$$



V ~ interaction : ChPT at given order

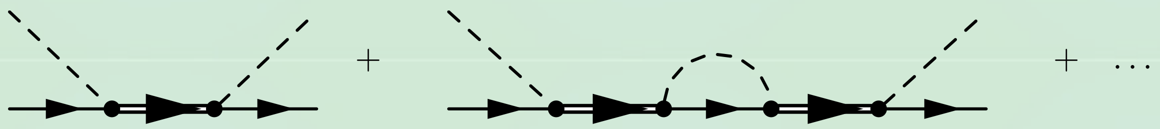
G ~ loop function : subtraction constant (cutoff)

N. Kaiser, P. B. Siegel, W. Weise, Nucl. Phys. A594, 325 (1995),
E. Oset, A. Ramos, Nucl. Phys. A635, 99 (1998),
J. A. Oller, U. G. Meissner, Phys. Lett. B500, 263 (2001),
M.F.M. Lutz, E. E. Kolomeitsev, Nucl. Phys. A700, 193 (2002),
.... many others

By construction, generated resonances are all dynamical? → **Not always...**

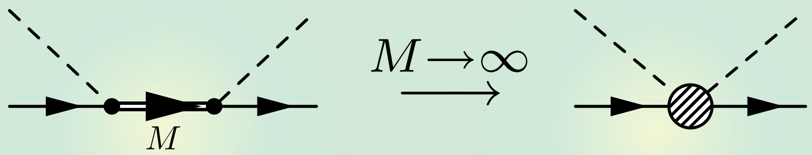
(Known) CDD pole in chiral unitary approach

Explicit resonance field in V (interaction)

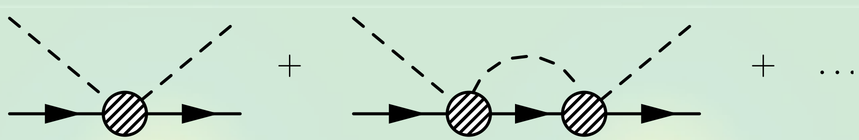


U.G. Meissner, J.A. Oller, Nucl. Phys. A673, 311 (2000)
D. Jido, E. Oset, A. Ramos, Phys. Rev. C66, 055203 (2002)

Contracted resonance propagator in higher order V



G. Ecker, J. Gasser, A. Pich, E. de Rafael, Nucl. Phys. B321, 311 (1989)
V. Bernard, N. Kaiser, U.G. Meissner, Nucl. Phys. A615, 483 (1997)



J.A. Oller, E. Oset, J.R. Pelaez, Phys. Rev. D59, 074001 (1999)

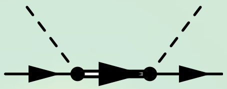
Is that all? subtraction constant?

CDD pole in subtraction constant?

Phenomenological (standard) scheme
--> V is given, “a” is determined by data

$$T = \frac{1}{(V^{(1)})^{-1} - G(\underline{a})}$$ **leading order**

$$T = \frac{1}{(V^{(1)} + V^{(2)})^{-1} - G(\underline{a'})}$$ **next to leading order**

↑pole  **?**

“a” represents the effect which is not included in V.
CDD pole contribution in G?

Natural renormalization scheme
--> fix “a” first, then determine V

to exclude CDD pole contribution from G,
based on theoretical argument.

Natural renormalization condition

Conditions for natural renormalization

- Loop function G should be negative below threshold.
- T matches with V at low energy scale.

"a" is uniquely determined such that

$$G(\sqrt{s} = M_T) = 0, \quad \Leftrightarrow \quad T(M_T) = V(M_T)$$

matching with low energy interaction

K. Igi, K. Hikasa, Phys. Rev. D59, 034005 (1999)
U.G. Meissner, J.A. Oller, Nucl. Phys. A673, 311 (2000)

crossing symmetry (matching with u-channel amplitude)

M.F.M. Lutz, E. Kolomeitsev, Nucl. Phys. A700, 193 (2002)

We regard this condition as the exclusion of the CDD pole contribution from G.

Two renormalization schemes

Phenomenological scheme

V is given by ChPT (for instance, leading order term),
fit cutoff in G to data

Natural renormalization scheme

determine G to exclude CDD pole contribution,
V is to be determined

Same physics (scattering amplitude T)

$$T = \frac{1}{V_{\mathrm{ChPT}}^{-1} - G(a_{\mathrm{pheno}})} = \frac{1}{(V_{\mathrm{natural}})^{-1} - G(a_{\mathrm{natural}})}$$

↑Effective interaction
Origin of the resonance

Pole in the effective interaction

Leading order V : Weinberg-Tomozawa term

$$V_{\mathrm{WT}} = -\frac{C}{2f^2}(\sqrt{s} - M_T)$$

C/f² : coupling constant
no s-wave resonance

$$T^{-1} = V_{\mathrm{WT}}^{-1} - G(a_{\mathrm{pheno}}) = (V_{\mathrm{natural}})^{-1} - G(a_{\mathrm{natural}})$$

↑ChPT ↑data fit ↑given

Effective interaction in natural scheme

$$V_{\mathrm{natural}} = -\frac{C}{2f^2}(\sqrt{s} - M_T) + \frac{C}{2f^2}\frac{(\sqrt{s} - M_T)^2}{\sqrt{s} - M_{\mathrm{eff}}}$$

pole!

$$M_{\mathrm{eff}} = M_T - \frac{16\pi^2 f^2}{C M_T \Delta a}, \quad \Delta a = a_{\mathrm{pheno}} - a_{\mathrm{natural}}$$

There is always a pole for $a_{\mathrm{pheno}} \neq a_{\mathrm{natural}}$

- small deviation <=> pole at irrelevant energy scale
- large deviation <=> pole at relevant energy scale

Pole in the effective interaction

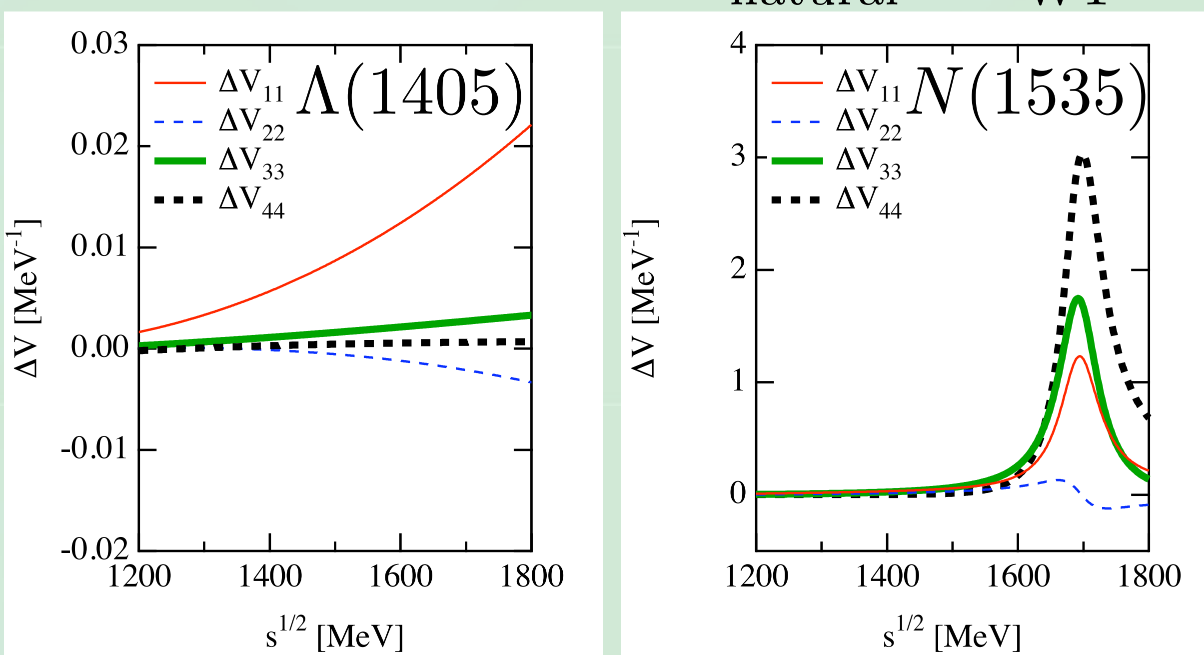
$$T^{-1} = V_{\mathrm{WT}}^{-1} - G(a_{\mathrm{pheno}}) = (V_{\mathrm{natural}})^{-1} - G(a_{\mathrm{natural}})$$

Pole in the effective interaction (M_{eff}) : pure CDD pole

$z_{\mathrm{eff}}^{\Lambda^*} \sim 7.9\ \mathrm{GeV}$ **irrelevant!**

$z_{\mathrm{eff}}^{N^*} = 1693 \pm 37i\ \mathrm{MeV}$ **relevant?**

Difference of interactions $\Delta V \equiv V_{\mathrm{natural}} - V_{\mathrm{WT}}$



==> Important CDD pole contribution in N(1535)

Comparison of pole positions

Pole of the full amplitude : physical state ▲

$$z_1^{\Lambda^*} = 1429 - 14i \text{ MeV}, \quad z_2^{\Lambda^*} = 1397 - 73i \text{ MeV}$$

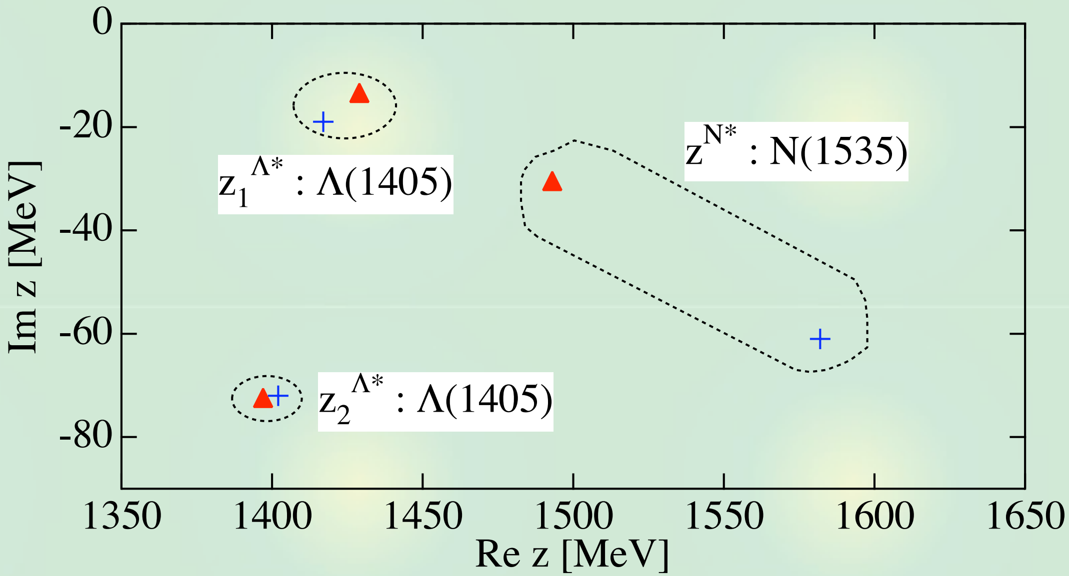
$$z^{N^*} = 1493 - 31i \text{ MeV}$$

two poles for Λ(1405)

Pole of the V_{WT} + natural : pure dynamical +

$$z_1^{\Lambda^*} = 1417 - 19i \text{ MeV}, \quad z_2^{\Lambda^*} = 1402 - 72i \text{ MeV}$$

$$z^{N^*} = 1582 - 61i \text{ MeV}$$



==> Λ(1405) is mostly dynamical state

Summary: formulation

We study the origin (dynamical/CDD) of the resonances in the chiral unitary approach

- **Natural renormalization scheme**

  Exclude CDD pole contribution from the loop function, consistent with N/D.

- **Comparison with phenomenology --> Pole in the effective interaction**

  We extract the CDD pole contribution hiddin in the subtraction constant into effective interaction V_{eff}.

T. Hyodo, D. Jido, A. Hosaka, Phys. Rev. C78, 025203 (2008)

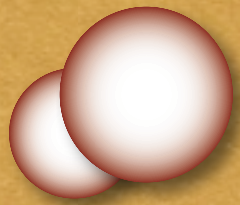
Summary: application to Λ(1405) and N(1535)

Structure of baryon resonances:

- Comparison of natural scheme with phenomenological scheme tells us about the structure of baryon resonance.
- Λ(1405) is mostly dynamical state.

  : consistent with Nc scaling and em size.

  T. Hyodo, D. Jido, L. Roca, Phys. Rev. D77, 056010 (2008)
  L. Roca, T. Hyodo, D. Jido, Nucl. Phys. A809, 65 (2008)
  T. Sekihara, T. Hyodo, D. Jido, Phys. Lett. B669, 133 (2008)



- N(1535) requires CDD pole contribution.

  : a quark origin state?

  : other coupled-channel?