Nature of S-wave baryon resonances

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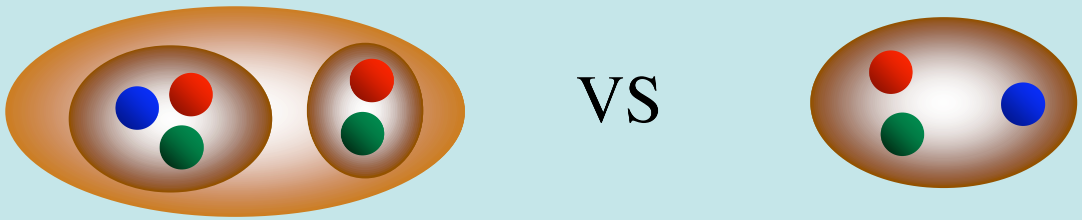
Topics of discussion:

Hadron resonances ~ Λ(1405), N(1530), …

Hadronic molecules, quark components

$q\bar{q}$ correlation, single particle nature



1. Introduction

Hadrons of Low Energy QCD

- Quark models, Soliton models, Hybrids, and so on
- Lattice, Sum rule, AdS/CFT

We want to know dynamics of:

Confinement, Mass generation,

Spontaneous breaking of chiral symmetry (Nambu)

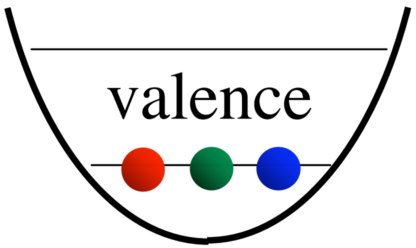
Practical Questions here:

- What are relevant degrees of freedom (quasi-particles)
- How they manifest in hadron structures

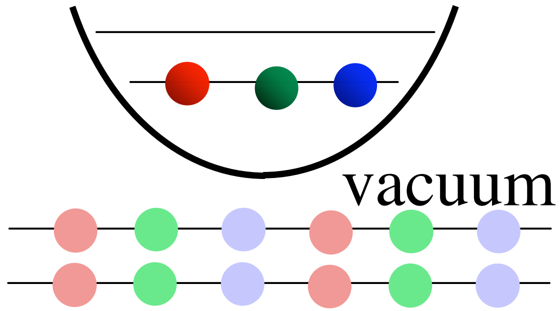
More Specifically

Single quark ??

Multi (collective) quarks ??



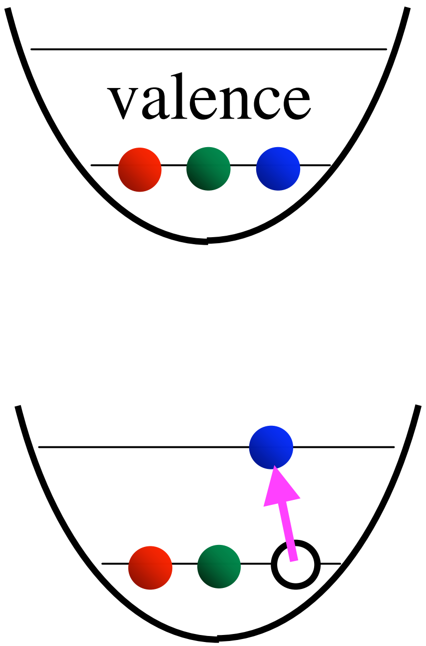
Ground



Importance of ground and excited states

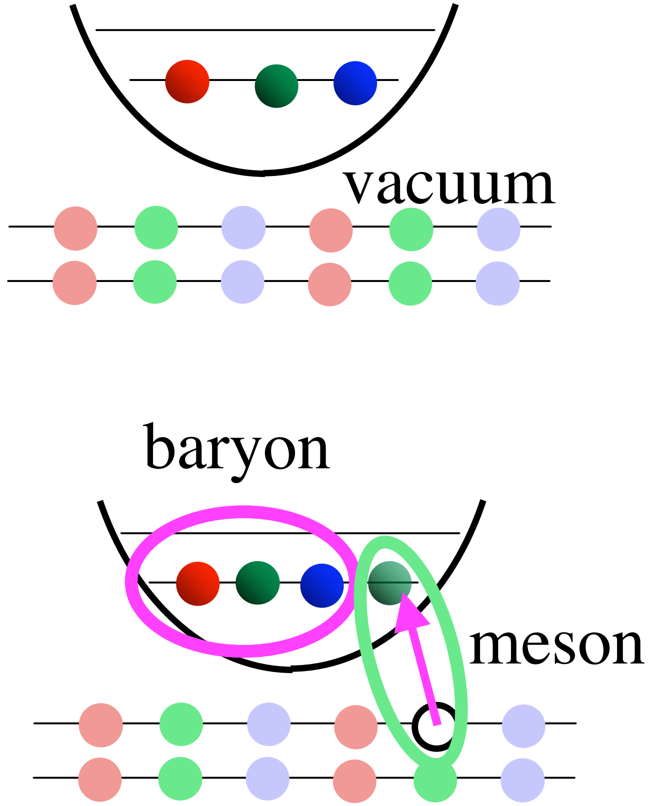
Single quark ??

Multi (collective) quarks ??



Ground

Excited

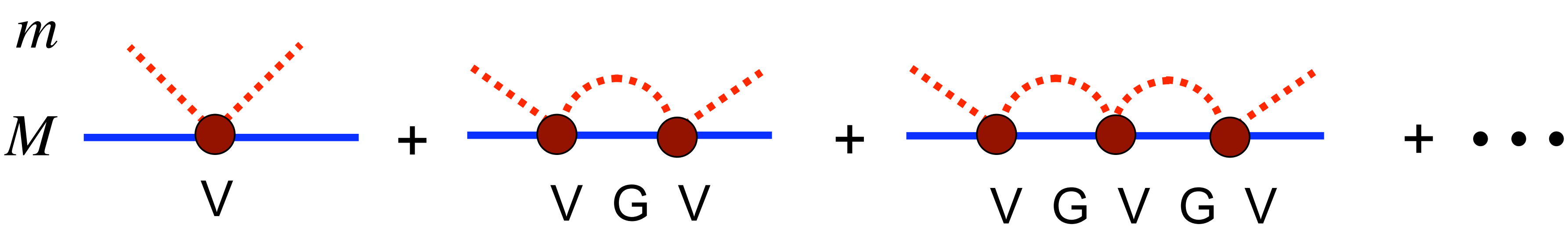


Meson-baryon molecule

2. Unitarized χPT

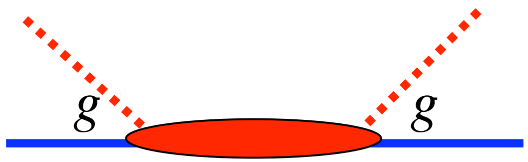
$\bar{K}N$-$\pi\Sigma$ scattering for $\Lambda(1405)$
Oset and Ramos, NPA635, 99 (1998)

Successful in S-wave Meson-baryon scattering: $J^P = 1/2^-$



$$T(\sqrt{s}) = V_{WT} + V_{WT} G(\sqrt{s}) T(\sqrt{s})$$

Dynamically generated resonance



$$T(\sqrt{s}) = g \frac{1}{\sqrt{s} - M_R + \frac{i}{2}\Gamma} g$$

a-parameter

(Renormalization parameter)

Loop function ~ divergent

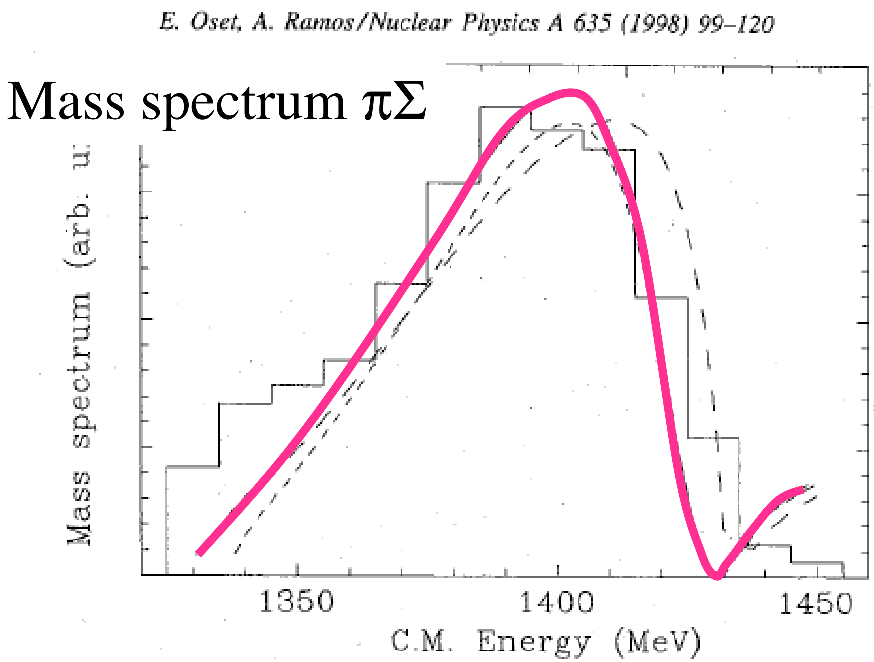
$$G(\sqrt{s}) = \frac{2M_T}{(4\pi)^2}\Big\{\underline{a(\mu)} + \ln\frac{M_T^2}{\mu^2} + \frac{m^2 - M_T^2 + s}{2s}\ln\frac{m^2}{M_T^2}$$
$$+ \frac{\bar{q}}{\sqrt{s}}[\ln(s - (M_T^2 - m^2) + 2\sqrt{s}\bar{q}) - \ln(-s + (M_T^2 - m^2) + 2\sqrt{s}\bar{q})$$
$$+ \ln(s + (M_T^2 - m^2) + 2\sqrt{s}\bar{q}) \qquad - \ln(-s - (M_T^2 - m^2) + 2\sqrt{s}\bar{q})]\Big\}$$

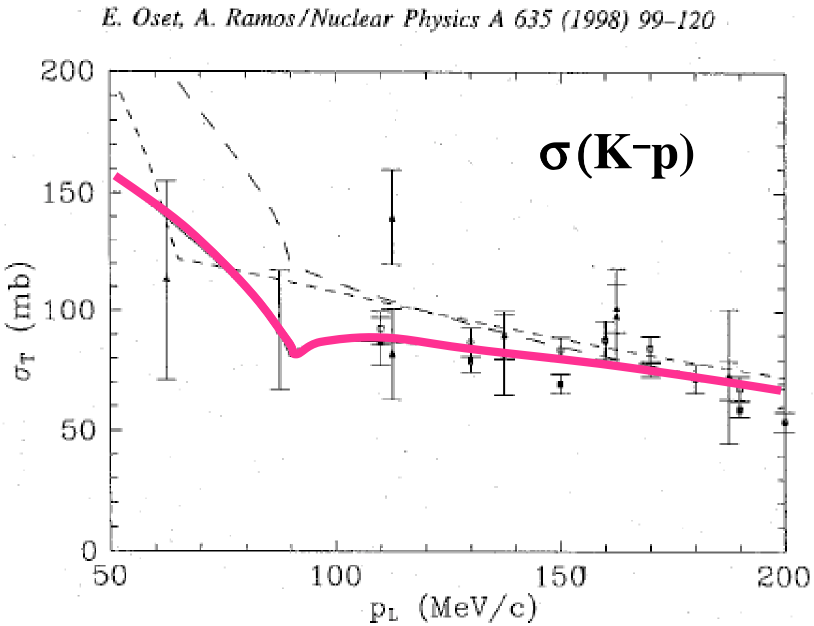
a is determined to reproduce data

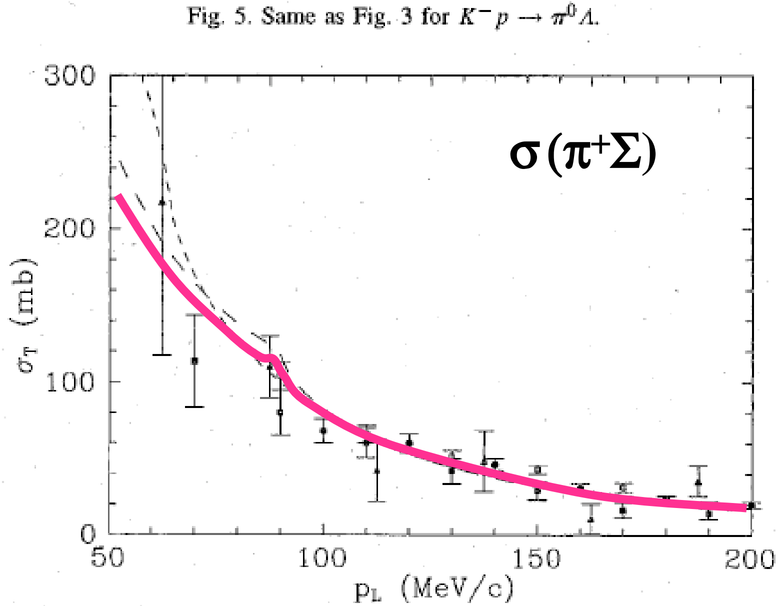
=> $a_{phenomenological}$

K^-p scattering and Λ(1405)

Oset and Ramos,
NPA635, 99 (1998)

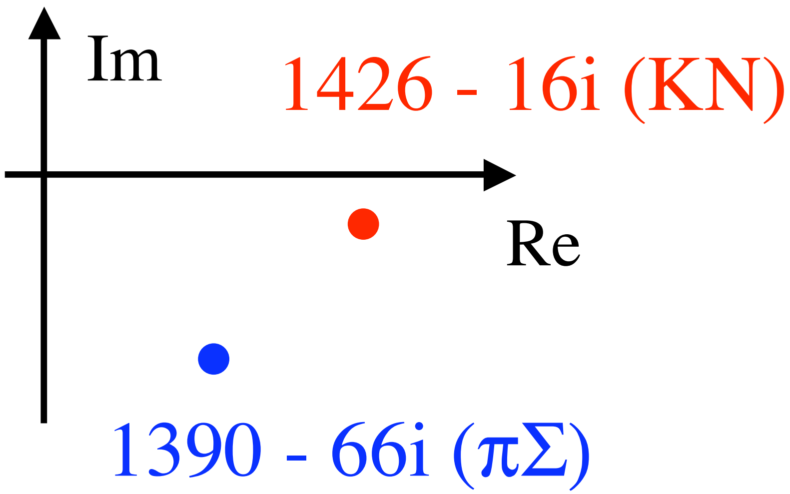


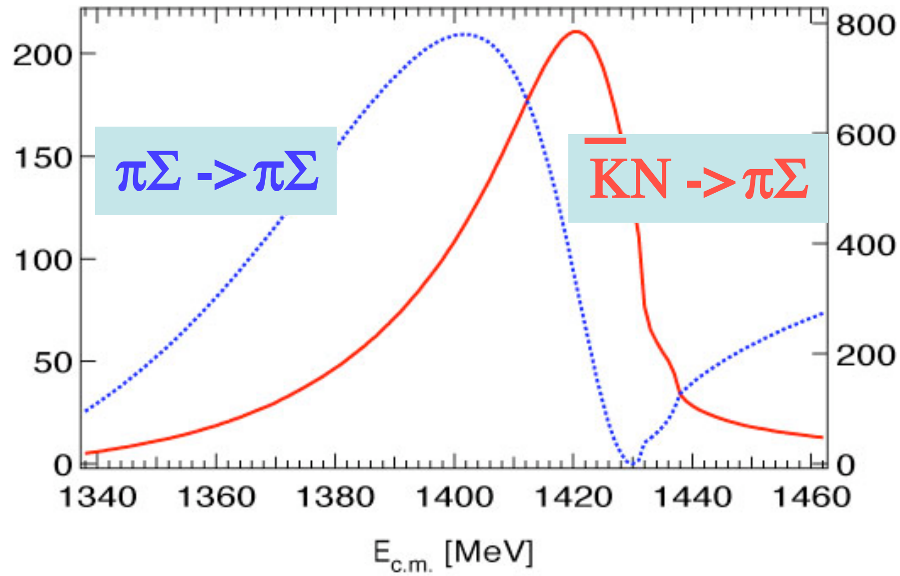




Two poles for Λ(1405)

Jido-Oller-Oset-Ramos-Meissner,
Nucl.Phys.A725:181-200,2003: nucl-th/0303062





Questions:

- Do they suggest hadronic excitation?

  => *hadronic correlation (effective d.o.f)*
- Any other components?

  => *Quark originated, or CDD-like pole*

To answer them:

Define *dynamically generated states*

*for **hadronic molecule***

3. Nature of resonances

Dynamical generation

In meson-baryon scatt.

$$T(\sqrt{s}) = V_{WT} + V_{WT}G(\sqrt{s})T(\sqrt{s})$$

$$G(\sqrt{s}) = \frac{2M_T}{(4\pi)^2}\Big\{\underline{a(\mu)} + \ln\frac{M_T^2}{\mu^2} + \frac{m^2 - M_T^2 + s}{2s}\ln\frac{m^2}{M_T^2}$$
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$a(\mu)$ is arbitrary

⇒ Impose conditions to determine theoretically a_{natural}

G-function

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$a(\mu)$ is arbitrary

$\Rightarrow$ Impose conditions to determine theoretically $\boldsymbol{a}_{\mathbf{natural}}$

G-function

If the resulting scattering equation produces a resonance

=> ***dynamically generated resonance*** ~ ***hadronic molecule***

(1) Requirement from mB scattering

$$G(\sqrt{s}) \sim i\int \frac{d^4q}{(2\pi)^4} \frac{2M}{(P-q)^2 - M^2 + i\varepsilon} \frac{1}{q^2 - m^2 + i\varepsilon} \sim \sum_n \frac{1}{\sqrt{s} - E_n}$$

For $M < \sqrt{s} < M + m$ (threshold), $G(\sqrt{s}) < 0$

Negative *G*

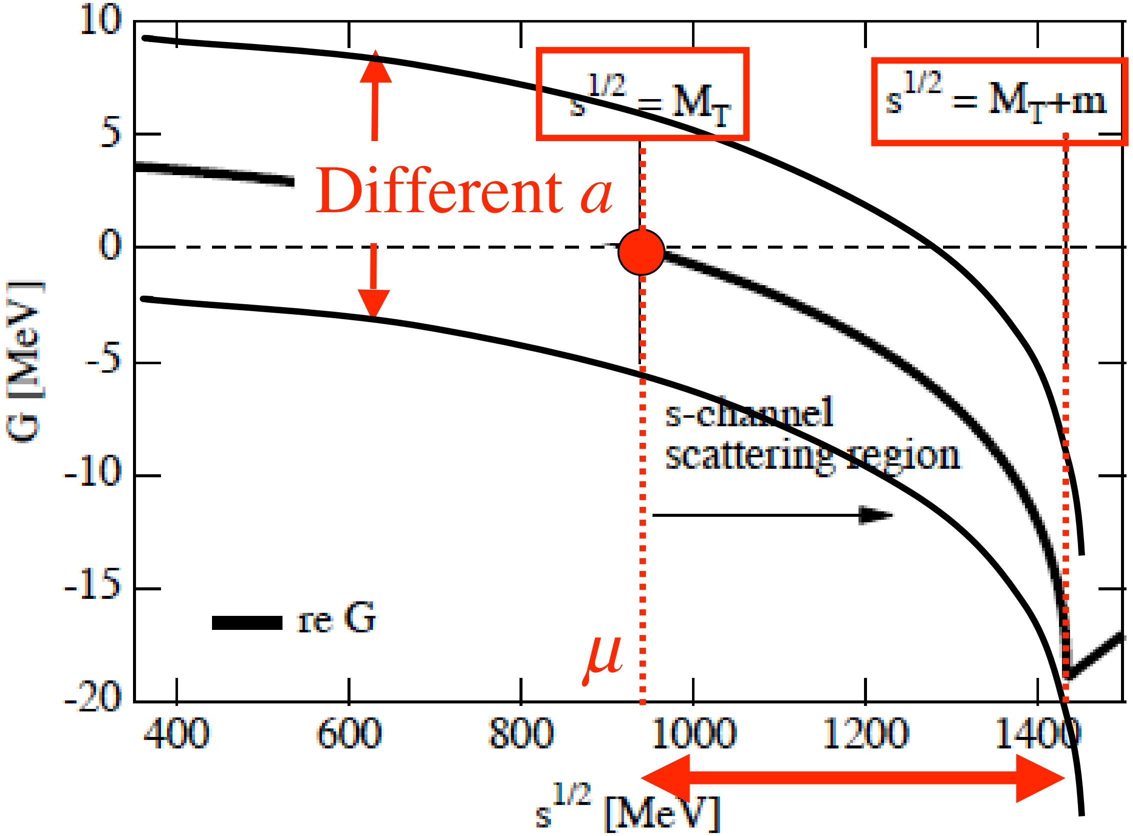
(2) Matching

Near the threshold, $T(E)$ coincides with $V_{\chi PT}(E)$

$$T(\mu) = V_{\chi PT} \rightarrow G(\sqrt{s} = M) = 0$$

Requirements (1) and (2) uniquely determines *a*

G function with *a*



In this way, a_{natural} has been given

When $a_{\text{pheno}} \neq a_{\text{natural}}$

$$G(\sqrt{s},a) = \frac{2M_T}{(4\pi)^2}\left\{\underline{a(\mu)} + \ln\frac{M_T^2}{\mu^2} + \frac{m^2 - M_T^2 + s}{2s}\ln\frac{m^2}{M_T^2} + \dots\right.$$ additive

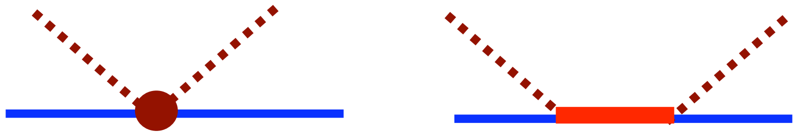
$$G(\sqrt{s},a_{pheno}) = G(\sqrt{s},a_{natural}) + \underbrace{\frac{2M}{(4\pi)^2}\left(a_{pheno} - a_{natural}\right)}_{\Delta A}$$

$$T(\sqrt{s})_{pheno} = \frac{1}{V_{WT}{}^{-1} - G(\sqrt{s},a_{pheno})} = \frac{1}{V_{WT}{}^{-1} + \Delta A - G(\sqrt{s},a_{natural})}$$

$$V_{natural}{}^{-1} \equiv V_{WT}{}^{-1} + \Delta A$$

$$\Rightarrow V_{natural}(\sqrt{s}) = \frac{1}{V_{WT}{}^{-1} + \Delta A} = V_{WT} + \frac{C}{2f^2}\frac{\left(\sqrt{s} - M\right)^2}{\sqrt{s} - M_{eff}}$$

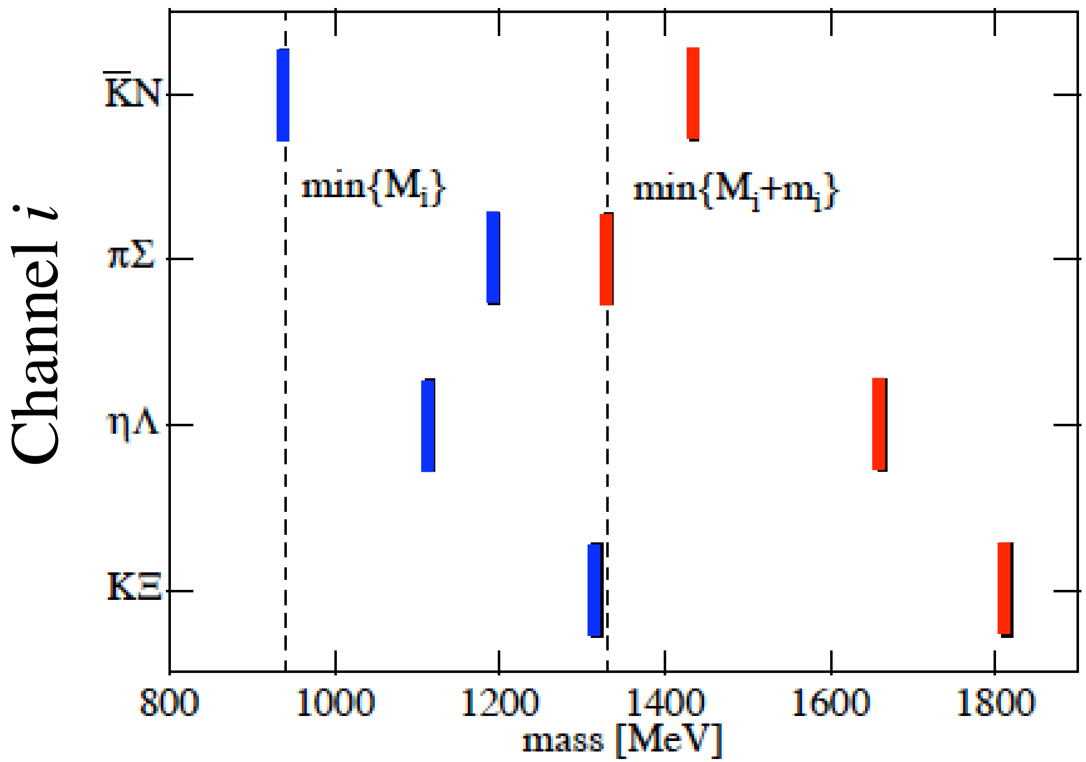
$$M_{eff} = M - \frac{16\pi^2 f^2}{CM\,\Delta a}$$



Low energy int + Pole (quark origin)?

Realistic case for Λ(1405), N(1530)

Coupled channel S = -1, I = 0

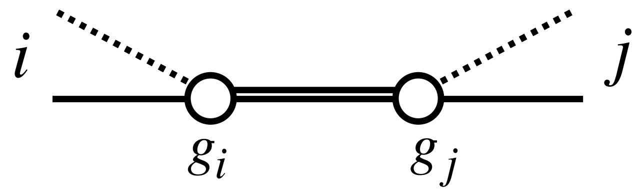


$$V_{\rm natural}(\sqrt{s}) = \frac{1}{V_{WT}^{-1} + \Delta A}$$

is a matrix equation.

Pole in $\sqrt{s}$ are complex.

$$V_{\rm natural}(\sqrt{s}) \sim \frac{g_i g_j}{\sqrt{s} - z_{\rm eff}}$$



Subtraction constants

TABLE I: Natural values and phenomenological values [43] for the subtraction constants with the regularization scale $\mu = M_i$.

Λ(1405)

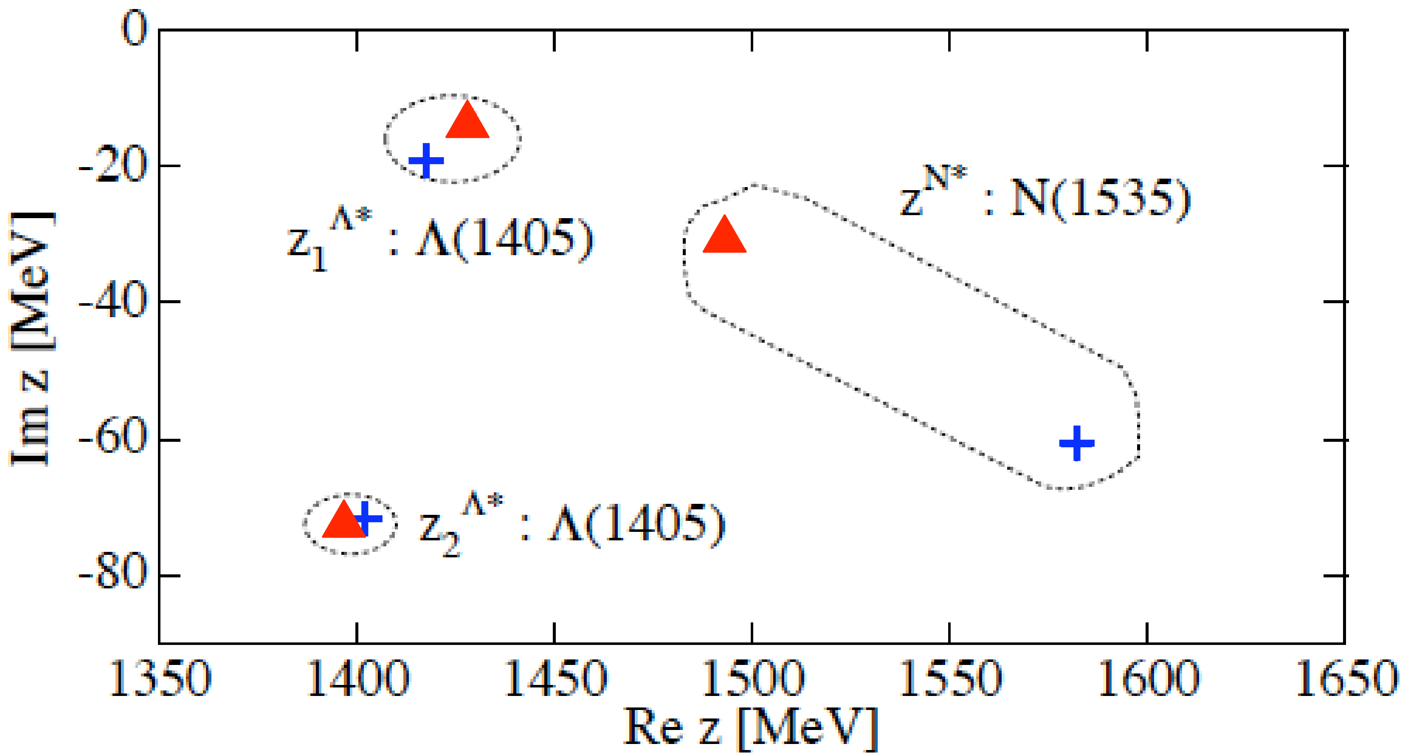
$S=-1$	$\bar{K}N$	$\pi\Sigma$	$\eta\Lambda$	$K\Xi$
$a_{\mathrm{pheno},i}$	-1.042	-0.7228	-1.107	-1.194
$a_{\mathrm{natural},i}$	-1.150	-0.6995	-1.212	-1.138

N*(1535)

$S=0$	πN	ηN	$K\Lambda$	$K\Sigma$
$a_{\mathrm{pheno},i}$	1.509	-0.2920	1.454	-2.813
$a_{\mathrm{natural},i}$	-0.3976	-1.239	-1.143	-1.138

For S =-1 (~Λ(1405)), a_{pheno} and a_{natural} are similar but
For S = 0 (~*N*(1535)), they are very much different

Poles



▲ Natural meson-baryon molecule (= V_{WT} + Natural G)

+ Phenomenological

4. Summary

- We defined dynamical generation
  for meson baryon molecule => $\boldsymbol{a}_{\textbf{natural}}$
- $\boldsymbol{a}_{\textbf{pheno}}$ can be also determined by data

- The difference in a's can be interpreted as pole interaction
  intrinsic (quark) component

- We have proposed a framework to test hadron structure,
  hadronic molecule vs ***valence quarks***