Dynamically generated baryons states

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In principle, all the hadron states are dynamically generated in QCD.
Discuss dynamically generated states in terms of hadronic degrees of freedom.

chiral unitary approach

origin (interpretation) of resonance pole

form factor of baryon resonance

hadronic molecular states (kaonic few-body system)

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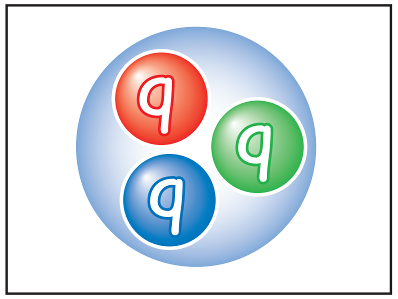
What are effective constituents in baryon resonance ??

- quarks and gluons are fundamental constituents of hadrons

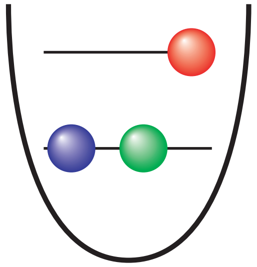
but, current quarks are not effective constituents to understand hadron structure

Effective constituents in hadron

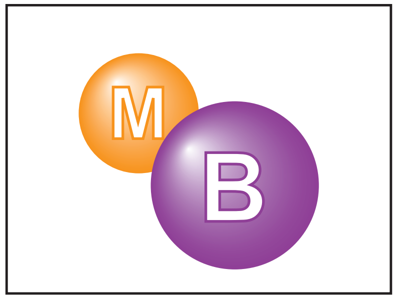


constituent quarks confined in a single potential

in this picture, symmetry of quarks is realized in
baryon spectra through constituent quarks



ex. p-state excitation of quark for baryon resonances
chiral partners: N(1535) chiral partner of nucleon ??



hadrons interacting inter-hadron force

decaying resonance → large hadronic components

inter-hadron dynamics is important

mixture of them

quark source + hadron cloud

Dynamical description of resonance

take chiral unitary model as an example: most of dynamical descriptions are based on the same concept but with different ingredients

calculate scattering amplitude, in which resonances are expressed as poles in complex energy plane

Lippmann-Schwinger eq.

$$T = V + VGT$$

ingredients

G: loop function (model space) — guarantee ***unitarity***

V: kernel potential (dynamics) — given by ***chiral Lagrangian***

If these ingredients are written in terms of hadrons, the scattering amplitude is described by hadron dynamics.

dynamically generated state

state obtained without explicit pole terms in kernel potential *V*

explicit pole term represents state outside of model space (quark-origin state)

dynamically generated state = hadronic composite state ??

here we will see not all the states described in this way are hadronic composites

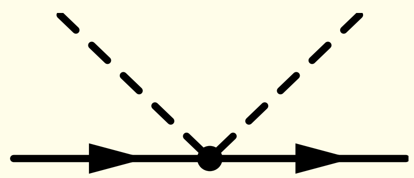
Chiral unitary approach

V: kernel potential (dynamics) a la **Chiral Perturbation Theory**

in s-wave

interactions are well organized in terms of momentum expansion

- leading term (WT term)



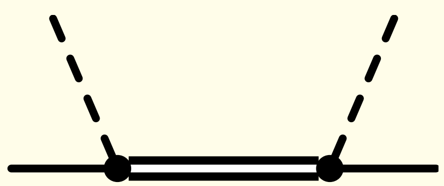
contact interaction

coming from t-channel vector meson exchange

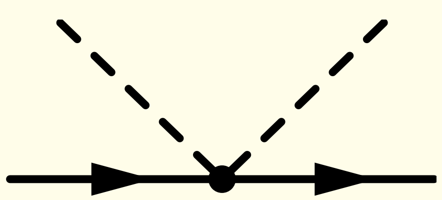
→ **no source for s-channel baryon resonances**

- higher order terms

in these terms dynamics beyond hadronic description can be hidden



explicit s-channel resonance contributions



$\mathcal{O}(p^2)$

contact terms also can have source of resonances

ex. Δ in higher order of πN chiral lagrangian

Once we use these interactions, the hidden resonances can be **reconstructed.**

For interactions derived not from chiral effective theory, it is hard to interpret their origins.

This kind of discussion is important for the interpretation of the resonance structure, but in the description of resonance how to construct the resonance is not an issue.

Chiral unitary approach

$$T = V + VGT$$

it is necessary to regularize the loop function

G: loop function (model space)

meson baryon loop function (regularization) — once-subtracted dispersion relation

$$G(s) = -a(s_0) - \frac{1}{2\pi}\int_{s^+}^{\infty} ds' \left(\frac{\rho(s')}{s' - s - i\epsilon} - \frac{\rho(s')}{s' - s_0} \right),$$

two-body phase space $\rho(s)$

regularization → renormalization constant

free parameters to be fitted by experiments

in the regularization procedure, one fixes high-momentum behavior which is not controlled in the present model space. This means that some contributions coming from outside of the model space can be hidden in the regularization parameters.

(In cut-off scheme the situation is same. Form factors can have information off model space.)

Here we show that the hidden contribution can be excluded from formulation by theoretical requirement on the renormalization constant.
(natural renormalization scheme)

Natural renormalization scheme

Hyodo, Jido, Hosaka, PRC78, 025203 ('08)

Let us propose a suitable renormalization condition for meson-baryon picture

"natural" renormalization condition

$$G(W) \sim \sum_n \frac{1}{W - E_n}$$

1) consistency with meson-baryon picture

there are no states below the threshold

$$G(W) \leq 0 \qquad W \leq M + m$$

satisfied automatically by 3 dim. cutoff regularization

2) consistency with chiral (loop) expansion

$T(W) = V(W)$ at some point in $M \leq W \leq M + m$

$$G(W) = 0$$

$$T = V + VGT$$

since the loop function is a decreasing function in terms of energy below the threshold, these two conditions can be satisfied by

$$G(M; a_{\rm natural}) = 0$$

proposed in different contexts by Igi-Hikasa and Lutz-Kolomeitsev

natural size of a obtained in 3 dim. cutoff with 630 MeV

Interpretation of pole

Hyodo, Jido, Hosaka, PRC78, 025203 ('08)

no source of state originated by quarks (out of model space)

if we use **WT interaction** in V and take **natural renormalization** scheme in G

$$T(W) = \frac{1}{V_{WT}^{-1}(W) - G(W;a)}$$

compare consequences from two different renormalization schemes

chiral unitary model

model parameters tuned so as to

a) reproduce scattering data

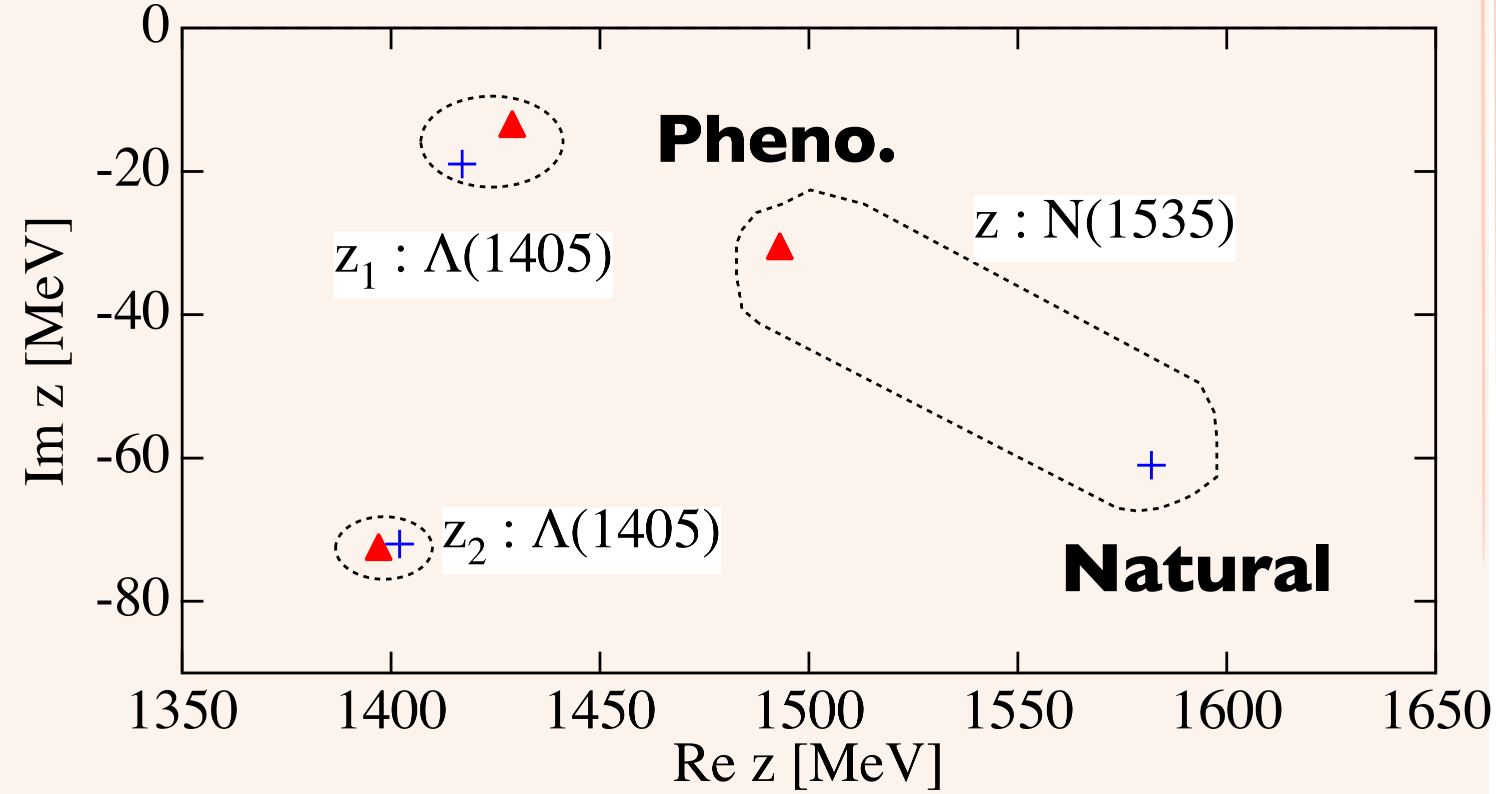
▲ **Pheno.**

b) exclude quark-origin states theoretically

\+ **Natural**

V : WT term

pole positions of N(1535) and Λ(1405)



Λ(1405) has mostly meson-baryon components.

N(1535) needs some other components than meson-baryon.

Interpretation of pole

Hyodo, Jido, Hosaka, PRC78, 025203 ('08)

in natural regularization with WT interaction,

Λ(1405) successfully reproduced, N(1535) not so satisfactorily

it is interesting to see which kind of interaction is necessary to reproduce phenomenological description in the natural renormalization.

phenomenological renormalization condition

$$T(W) = \frac{1}{V_{WT}^{-1}(W) - G(W; a_{\text{pheno.}})} \qquad V_{WT}(W) = -\frac{C}{2f^2}(W - M)$$

natural renormalization condition

$$T(W) = \frac{1}{V^{-1}(W; a_{\text{natural}}) - G(W; a_{\text{natural}})}$$

Finally the interaction kernel in the natural renormalization condition can be expressed as the WT term and a pole term.

$$V(W; a_{\text{natural}}) = V_{WT}(W) + \frac{C}{2f^2}\frac{(W - M)^2}{W - M_{\text{eff.}}} \qquad M_{\text{eff.}} \equiv M - \frac{2f^2}{C\Delta a}$$

WT term **pole term**

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phenomenological renormalization condition

pole mass in effective int.

$$M_{\text{eff.}}^{\Lambda^*} \simeq 7.9[\text{GeV}]$$

$$M_{\text{eff.}}^{N^*} = 1693 \pm 37i\ [\text{MeV}]$$

quark model state ? chiral partner of N ??

Do not take the values seriously, because these values strongly depend on the details of model parameters.

$$V^{-1}(W; a_{\text{natural}}) = G(W; a_{\text{natural}})$$

Finally the interaction kernel in the natural renormalization condition can be expressed as the WT term and a pole term.

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WT term **pole term**

Applications of dynamical description

although coupled channel approach can contain some components other than meson and baryon, this is a good description of resonances in terms of hadrons.

with this description, we can calculate properties of baryon resonances:

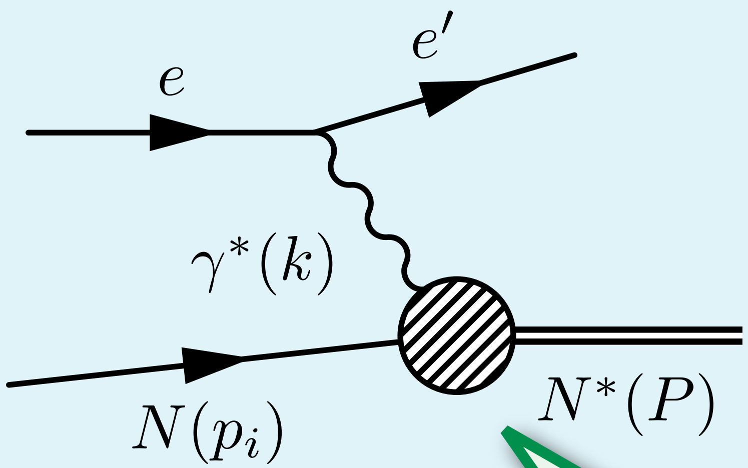
magnetic moments of Λ(1405)	DJ, Hosaka, Nacher, Oset, Ramos RPC66, 025203 (02)
radiative decay of Λ(1405)	Geng, Oset, Doring, EPJA32, 201 (07)
helicity amplitude of N(1535)	DJ, Doring, Oset, PRC77, 065207 (08)
electromagnetic mean squared radii of Λ(1405)	Sekihara, Hyodo, DJ, PLB669, 133 (08)
helicity amplitudes of Λ(1670) and Λ(1405)	Doring, DJ, Oset EPJA45, 319 (10)
electromagnetic form factors of Λ(1405)	Sekihara, Hyodo, DJ, PRC83, 055202(11)

many applications for reaction calculations

- coupled channel approach
  - describes both resonance and nonresonant scattering states
  - available for direct comparison with experimental data

Transition amplitude in chiral unitary model

Jido, Döring, Oset, PRC77, 065207 (08)

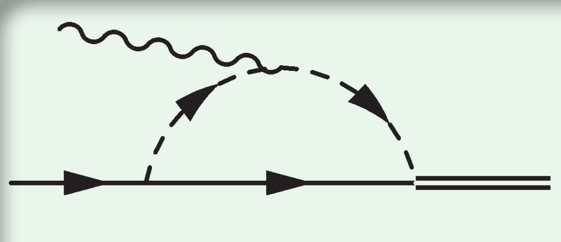


Idea

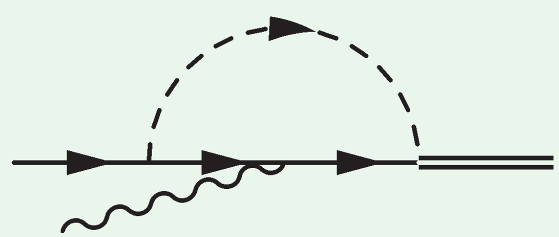
- take chiral unitary model for N(1535) structure
- external current couples via meson and baryon

relevant diagrams of one loop

Gauge invariant assures cancellation of divergence



meson pole term

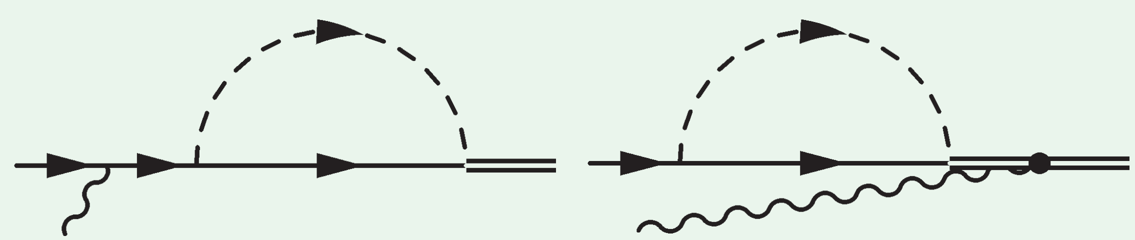


baryon pole term

1/M

Kroll-Ruderman term

Z-diagram



necessary for gauge invariance

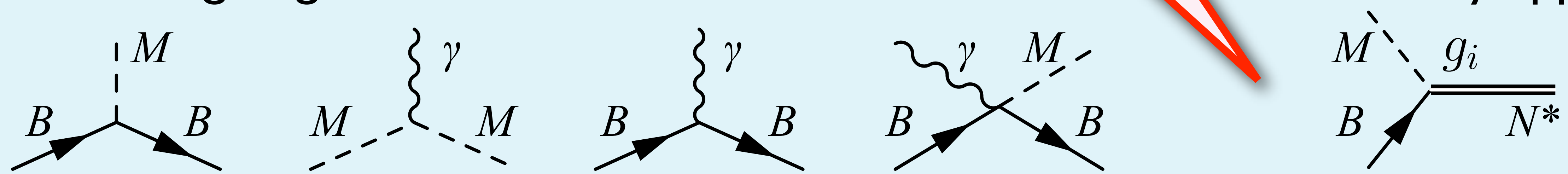
Transition amplitude in chiral unitary model

elementary vertices

g_i characterizes structure of N*

chiral Lagrangian

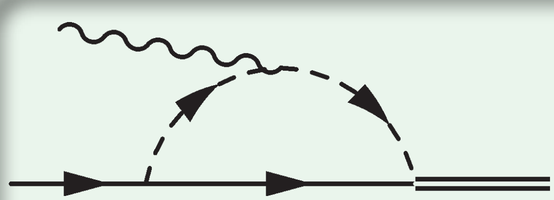
chiral unitary approach



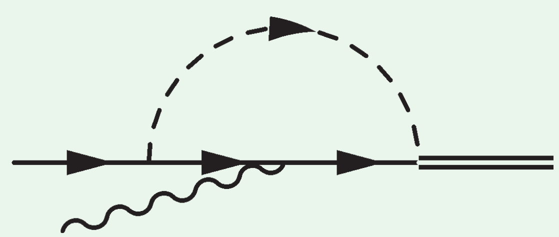
meson-baryon | photon-meson | photon-baryon | Kroll-Ruderman | residue of pole

relevant diagrams of one loop

Gauge invariant assures cancellation of divergence



meson pole term



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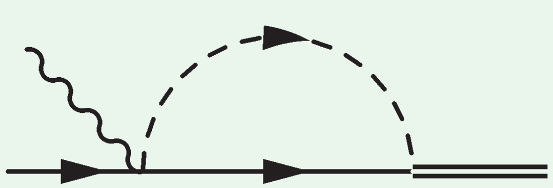
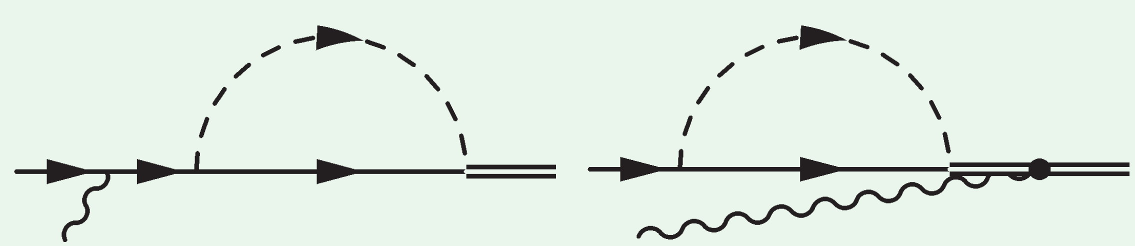


Kroll-Ruderman term



necessary for gauge invariance

Result $A_{1/2}$ amplitude for p*

Jido, Döring, Oset, PRC77, 065207 (08)

Non-relativistic calculation

Experimental extraction

$$A_{1/2}(Q^2) = \sqrt{\frac{W\Gamma_{N^*}}{2m_p b_\eta}\sigma(W,Q^2)}$$

σ: total cross section of γp → ηp

$$T \sim \langle \eta N | H_\eta | N^* \rangle \langle N^* | H_\gamma | \gamma N \rangle$$

photo-transition

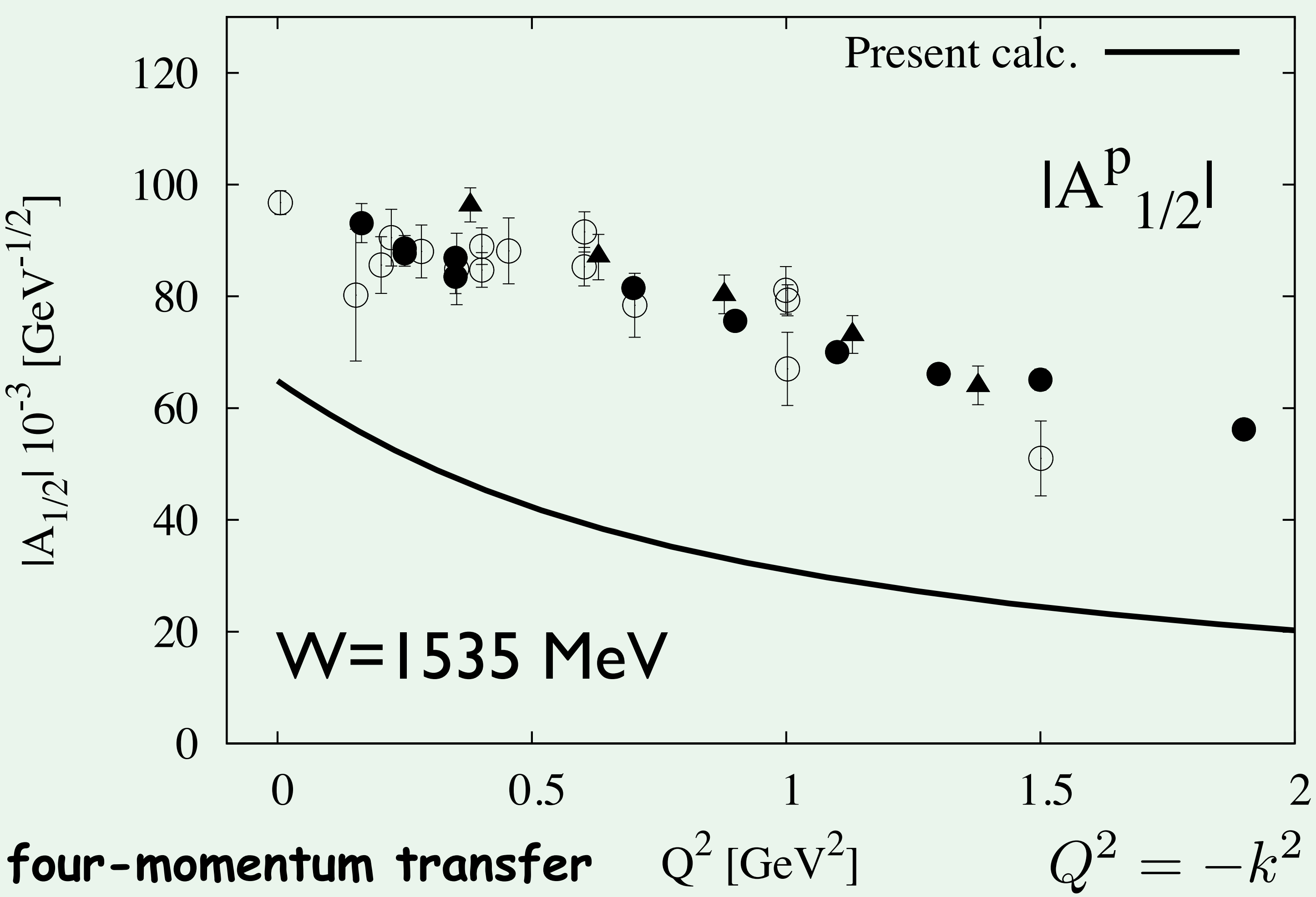
Γ_N^* **N* total width**

Data	150 MeV
ChUM	74 MeV

b_η **branching ratio**

Data	55%
ChUM	70%

factor 1.6 larger



Experimental data

B. Krusche et al., Phys. Rev. Lett. 74 (1995) 3736.
H. Denizli et al. [CLAS Collaboration], Phys. Rev. C76, 015204 (2007)
R. Thompson et al. [CLAS Collaboration], Phys. Rev. Lett. 86, 1702 (2001)
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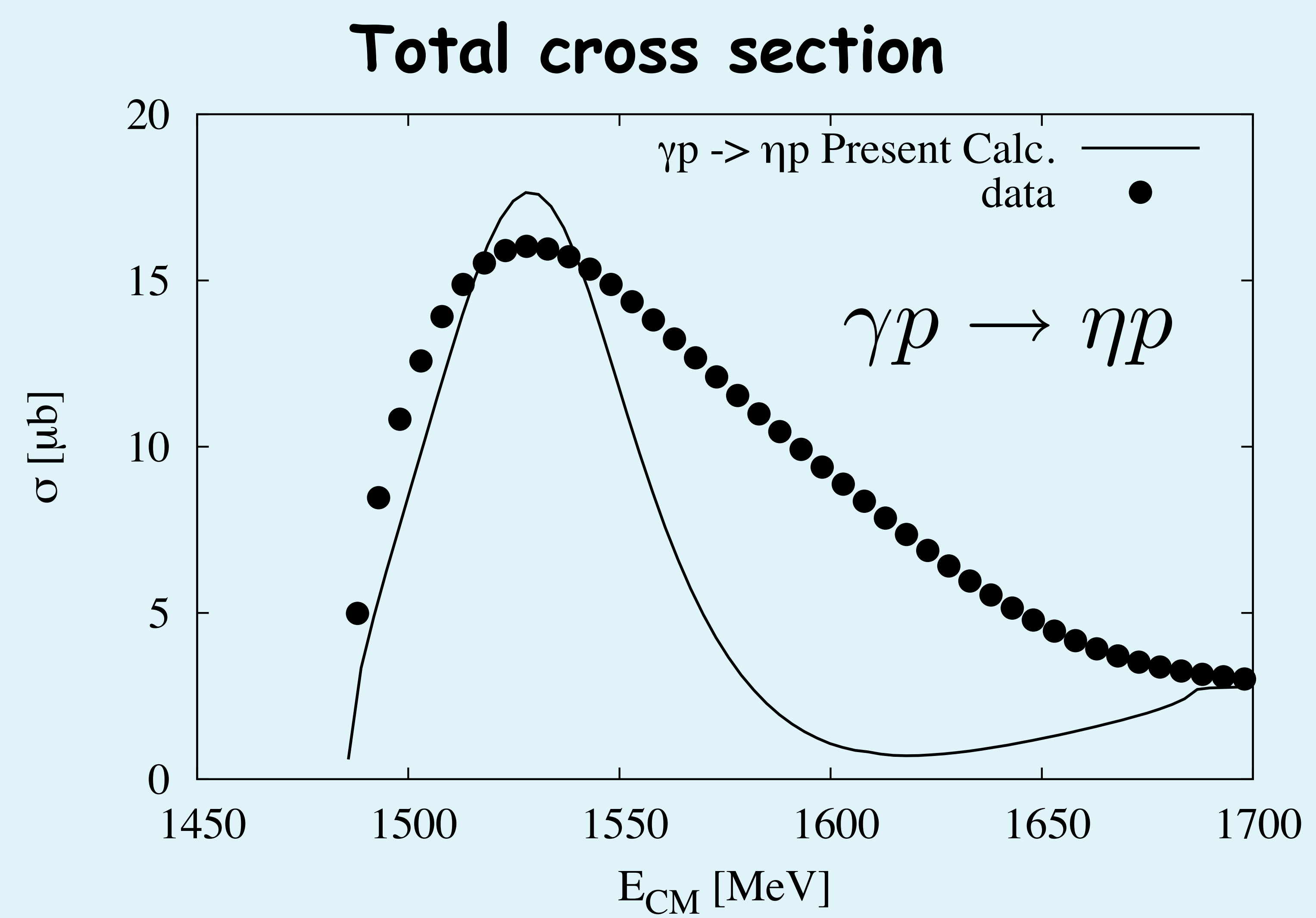

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Further results

Jido, Döring, Oset, PRC77, 065207 (08)

Values of $A_{1/2}$ at Q^2=0 $[10^{-3}\ \mathrm{GeV}^{-1/2}]$

	our model	PDG
p*	64.88	90±30
n*	-51.54+7.21i	-46±27

need to fix normalization

Ratios of $A_{1/2}$

	our model	Exp.
n*/p*	-0.79+0.11i	-0.84±0.15
modulus	0.80	0.819±0.018
IV/IS	8.94-1.06i	
modulus	9.00	10.0±0.7

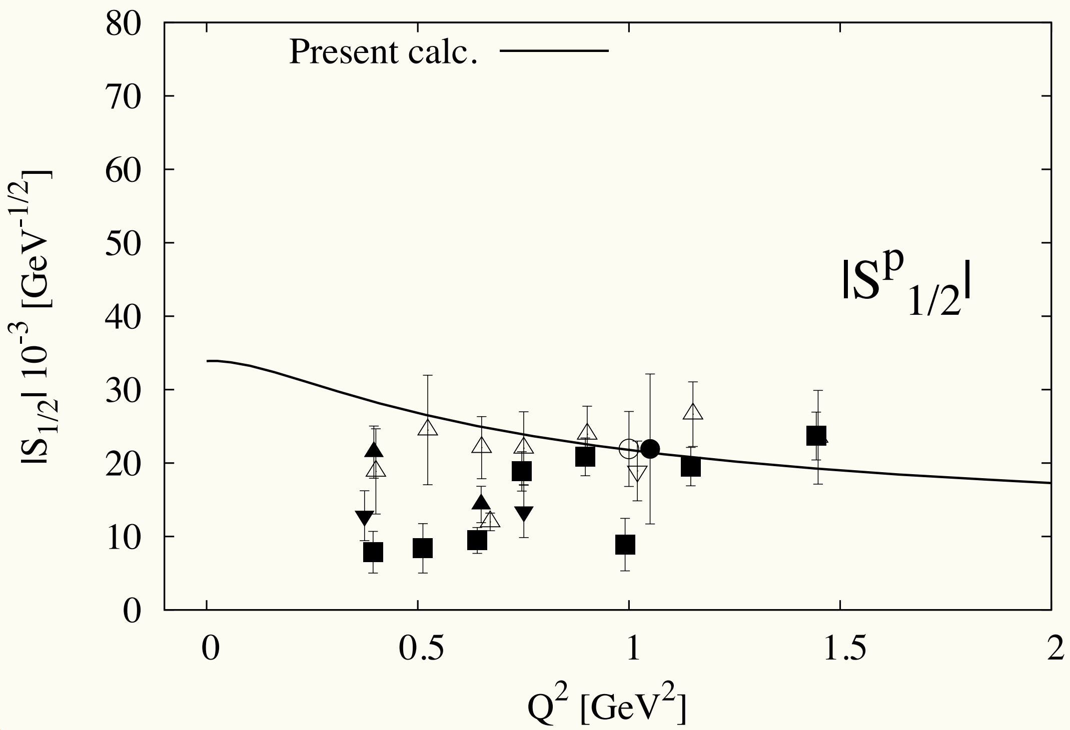
isovector dominance

free from norm. problem

$S_{1/2}$ amplitude for p*

negative phase respect to $A_{1/2}$

consistent with data



What we learn

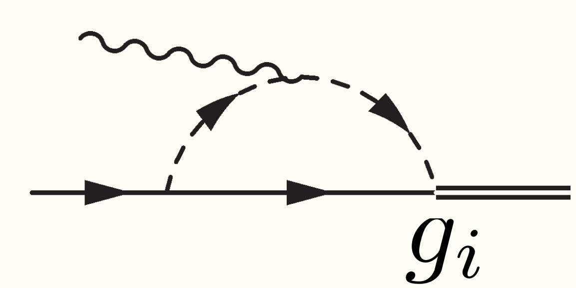
Jido, Döring, Oset, PRC77, 065207 (08)

- Transition form factors of N* calculated in meson-baryon picture are consistent with data

$A_{1/2}$ and $S_{1/2}$ for p*
n/p ratio of $A_{1/2}$ at Q^2=0 — sign and magnitude
total cross section of $\gamma p \to \eta p$

normalization problem of helicity amplitudes
need to determine N* parameters precisely

N(1535) structure : chiral unitary model g_i
meson cloud picture for photon couplings



- meson-baryon component in N(1535)

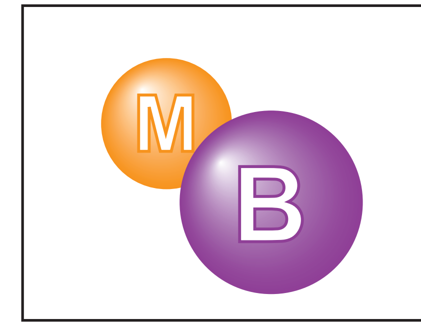
sources of resonances in regularization constant
no coupling of photon to quarks
quark component less important in helicity amplitude in low Q^2

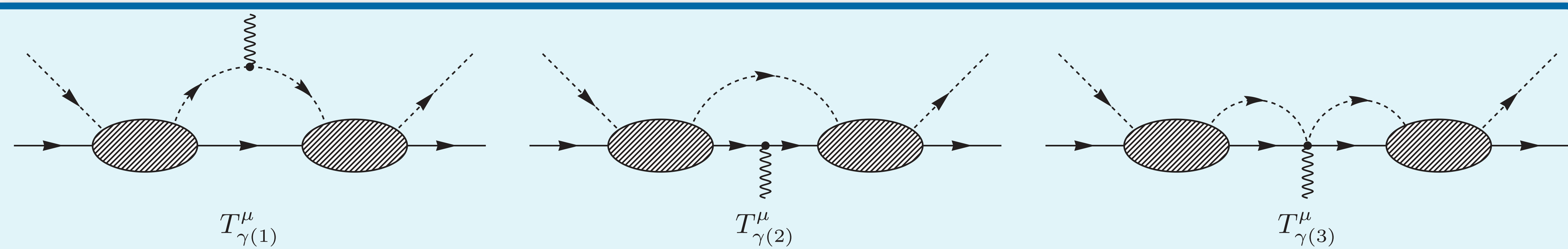
Form factors of Λ(1405)

Sekihara, Hyodo, DJ, PLB669, 133 (2008); PRC83, 055202 (2011)

Λ(1405): quasibound state of $K^{bar}N$ with 10~30 MeV

theoretical calculation (chiral unitary model)





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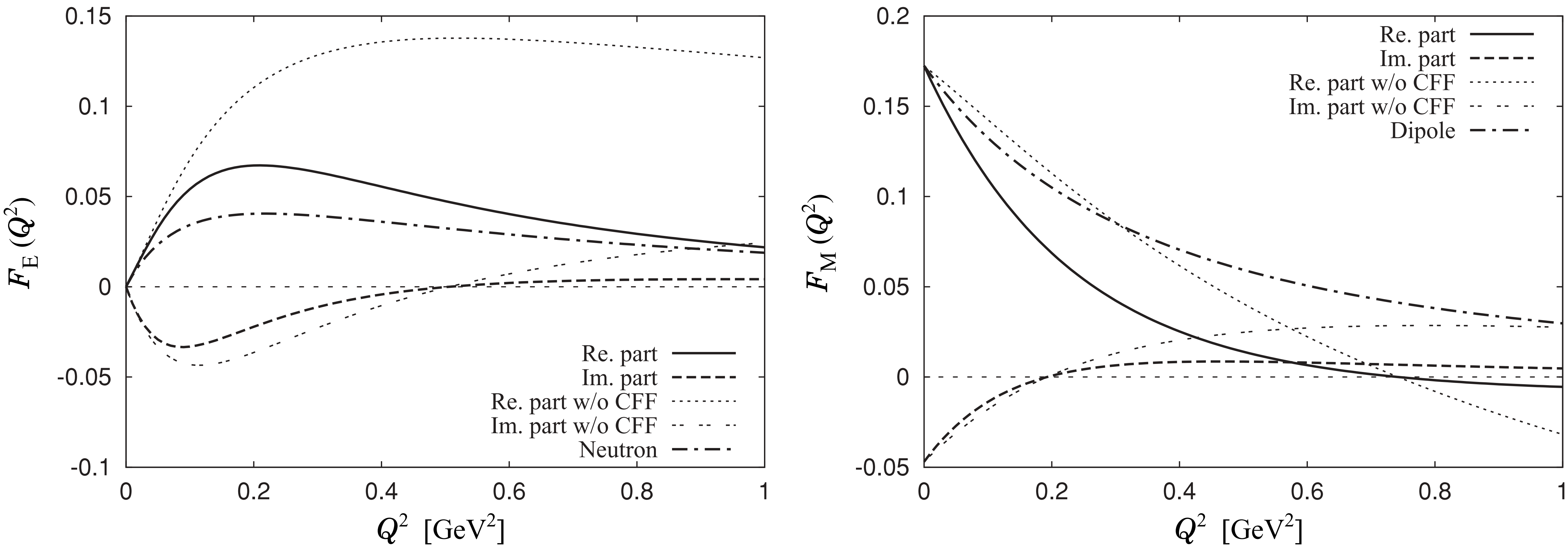

FIG. 5. Electromagnetic form factors of the Λ(1405) state on the higher pole position Z_2, together with the empirical form factors of the neutron. Left (right) panel shows the electric (magnetic) form factor F_E (F_M). The label "w/o CFF" represents the result without inclusion of the common form factor in Eq. (59). The parameter c in the dipole form factor is chosen to be $c = \mathrm{Re}[F_M(Q^2 = 0)]$, the real part of the magnetic moment of the Λ(1405).

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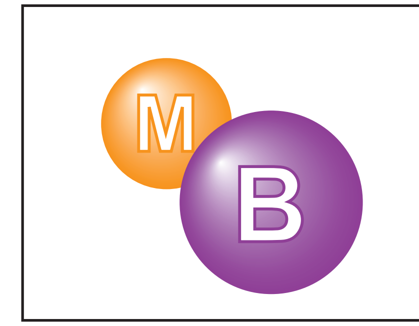
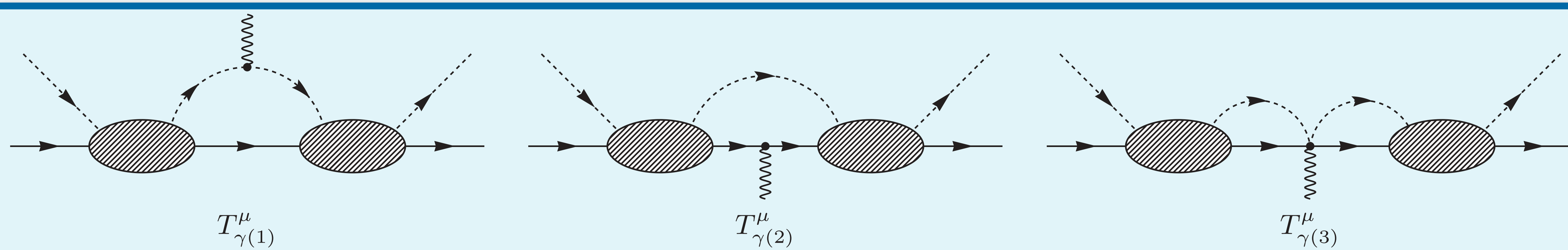




Electromagnetic radii

$\langle r^2 \rangle_{\rm E} = -0.13 + 0.30i \quad [{\rm fm}^2]$ moduls $|\langle r^2 \rangle_{\rm E}| = 0.33 \quad [{\rm fm}^2]$

complex number remove decay chan. $\langle r^2 \rangle_{\rm E} = -0.52 \quad [{\rm fm}^2]$

spatially extended almost real Kaon surrounding nucleon
larger radius than **neutron charge radius**

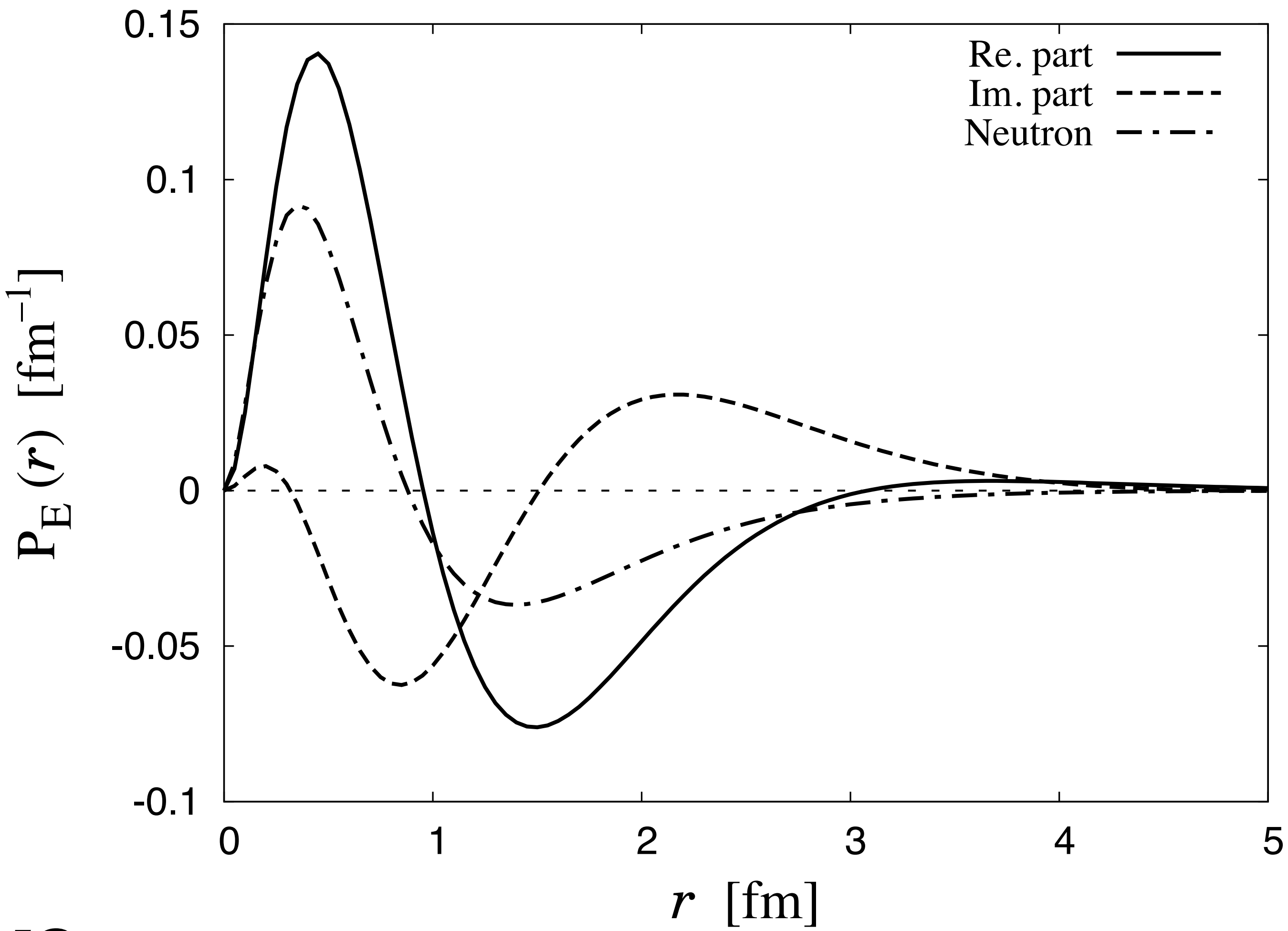
$\langle r^2 \rangle_{\rm E} = -0.12 \quad [{\rm fm}^2]$ virtual pion cloud

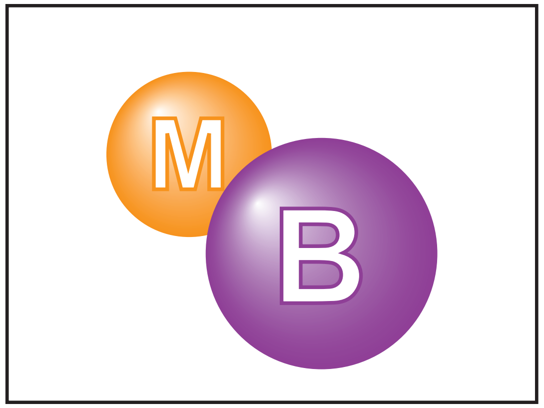
negative charge radius K^- spreads widely around proton

Form factors of Λ(1405)

Sekihara, Hyodo, DJ, PLB669, 133 (2008); PRC83, 055202 (2011)

Electric charge distribution





negative charge radius

K^- spreads widely around proton

Hadronic molecular states

✓ composite vs elementary ?? they are mixed. Let us consider one extreme side.

Hadronic molecular state

hadrons are constituents (nesting-box structure, Verschachtelung)

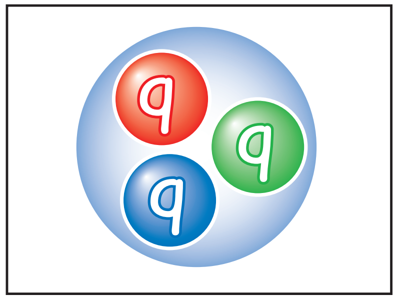
governed by hadron dynamics, not inter-quark dynamics (confinement force)

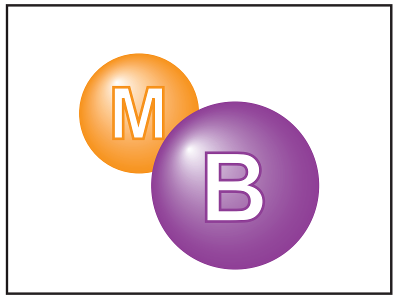
inter-hadron distance > confinement size

larger than typical size of hadron

ex) nucleus : bound state of baryons

deuteron, ^{3}He, triton (NNN), hypertriton (Λpn)





Meson constituents

resonance with decay width (quasibound state)

transition to lighter mesons (pion)

absorptive decay modes, no meson number conservation

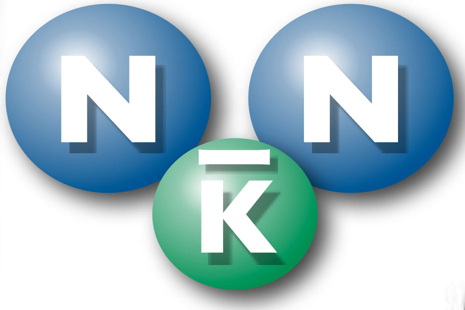
real particles are constituents

different from virtual pion cloud

physics of threshold

Λ(1405)

K^{bar}NN



size of bound state

hadronic molecular states can be realized in limited situation.

for short range interaction

asymptotic wavefunction

$$\psi(x) = (\text{const.}) \times \frac{\exp\left(-\sqrt{2\mu B_{\rm E}}x\right)}{x}$$

μ: reduced mass
B_E: binding energy

relative distance

$$\langle x^2 \rangle = \frac{1}{4\mu B_{\rm E}}$$

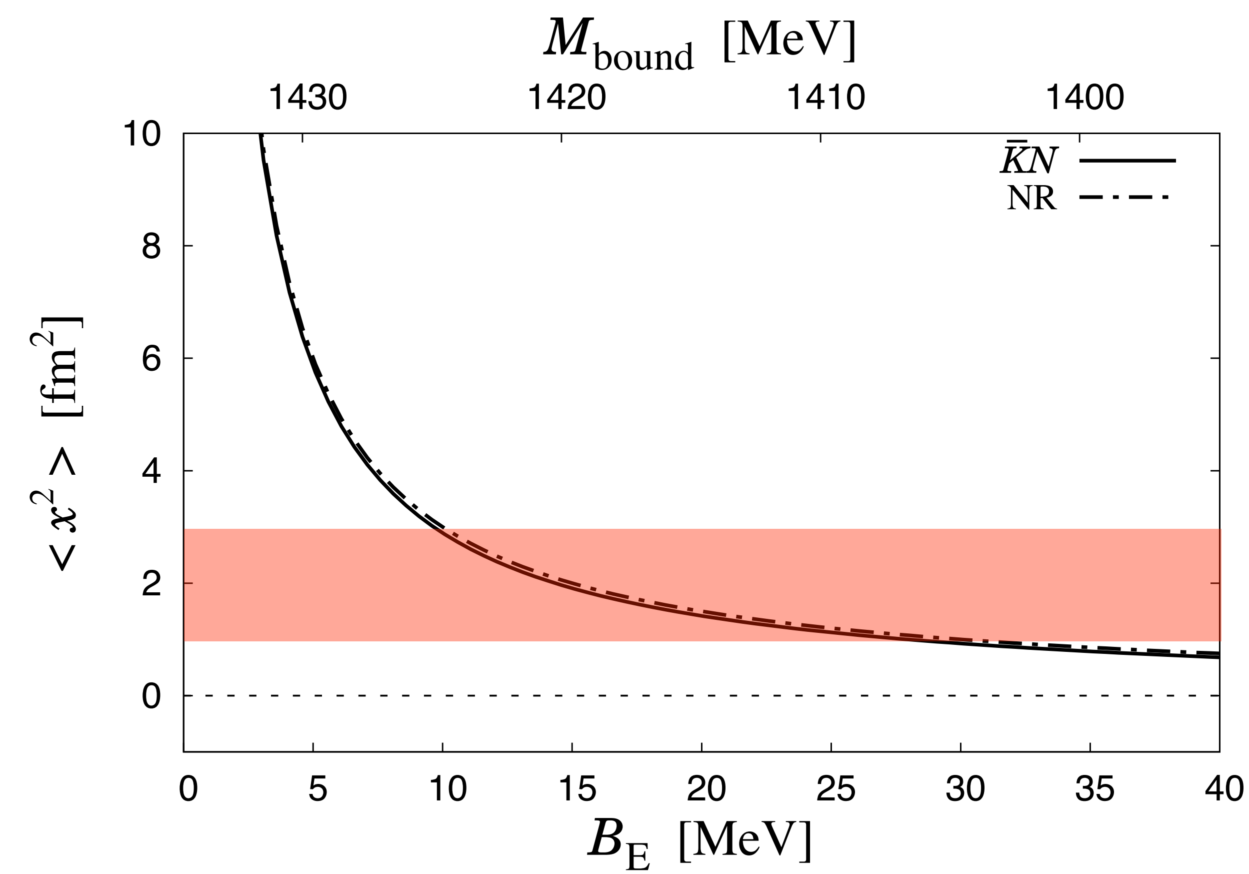
for bound state with 30 MeV B.E

KbarN system ~ 1 fm size

typical hadron size ~ 1 fm

for deeper bound states

two hadron are overlapped
quark dynamics should be relevant
picture of hadronic molecular is broken down



K$^{\rm bar}$N system

Peculiarities of K meson

Y. Kanada-En'yo, DJ, **PRC78, 025212 (2008)**
DJ, Y. Kanada-En'yo, **PRC78, 035203 (2008)**

pion is too light to be bound in range of strong interaction

kaon has moderate mass and interaction strength

- Nambu-Goldstone boson

smaller mass compared with typical hadron mass scale

chiral effective theory can be applied

strong s-wave attraction in $K^{bar}N$ and $K^{bar}K$ ⇒ two-body quasibound states

- heavy particle

half of nucleon mass

small kinetic energy in bound systems (BE ~ 10-30 MeV)

non-relativistic potential model with decay channels

isospin averaged mass

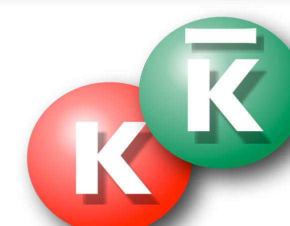
$$m_K = 495.7 \text{ MeV}$$
$$m_N = 938.9 \text{ MeV}$$

Kaons are different from pions in the energies of our interest !!

Λ(1405)

B.E. ~ 10 to 30 MeV

f_0(980), a_0(980)



B.E. ~ 10 MeV

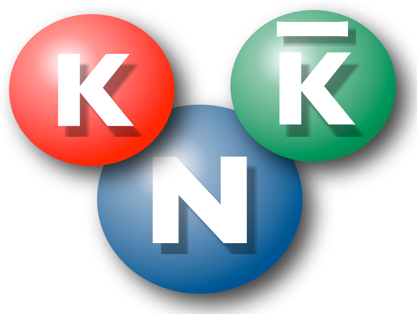
$K\bar{K}N$ system with I=1/2, J^P=1/2$^+$

DJ, Y. Kanada-En'yo, **PRC78, 035203 (2008)**

A prediction of KK^{bar}N quasibound state as an N* resonance

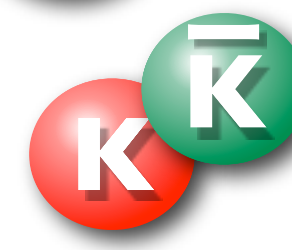
N*

J^P=1/2$^+$



Λ(1405)

f₀(980), a₀(980)

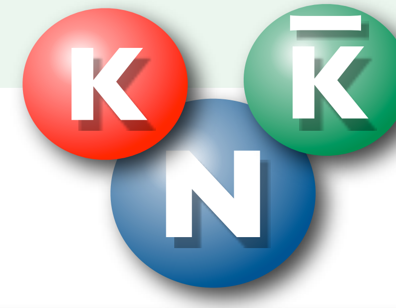


Interactions in KK^{bar}N system

		I=0	I=1	threshold	open channels
$\bar{K}N$	attraction	$\Lambda(1405)$	weak attraction	1434.6 MeV	$\pi\Sigma, \pi\Lambda$
$K\bar{K}$		$f_0(980)$	$a_0(980)$	991.4 MeV	$\pi\pi, \pi\eta$
KN	repulsion	very weak	strong repulsion	1434.6 MeV	no

if 3-body BS << 2-body BS + hadron molecular picture broken down

Theoretical studies of $KK^{bar}N$ system



N*

$J^P=1/2^+$

fix two-body interaction → calculate three-body system

1) non-relativistic potential model

DJ, Y. Kanada-En'yo, **PRC78, 035203 (2008)**

$KK^{bar}N$ single channel

two-body interaction

$K^{bar}N$	Λ(1405) as a quasibound state
$K^{bar}K$	$f_0(980)$ and $a_0(980)$ as quasibound states
KN	adjust repulsive scattering length

2) relativistic Faddeev approach

Martinez Torres, Khemchandani, Oset, **PRC79**, 065207 (2009)

Martinez Torres, DJ, **PRC82**, 038202 (2010)

coupled channels, **$KK^{bar}N$, KπΣ, KπΛ**

two-body subsystem

scattering amplitudes obtained by chiral unitary model in full coupled-channels

meson-baryon	dynamically generated Λ(1405)
meson-meson	dynamically generated $f_0(980)$ and $a_0(980)$

non-resonant background

Results of KK^{bar}N system **N* at 1910 MeV**

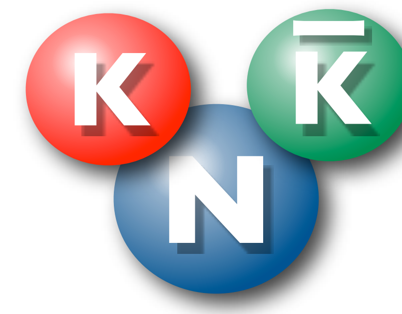
- loosely bound system threshold of KK^{bar}N 1930 MeV

1) non-relativistic potential model

DJ, Y. Kanada-En'yo, **PRC78, 035203 (2008)**

B.E. from KK^{bar}N	width	mass
HW: **19 MeV**	**88 MeV**	**1911 MeV**
AY: **39 MeV**	**98 MeV**	**1891 MeV**

N*



2) relativistic Faddeev approach

Martinez Torres, Khemchandani, Oset, **PRC79**, 065207 (2009)

Martinez Torres, DJ, **PRC82**, 038202 (2010)

read peak position and width

$(K\bar{K}N, K\pi\Sigma, K\pi\Lambda)$

mass: 1922 MeV, width ∼25 MeV

1426 MeV in K^{bar}N, 988 MeV in K^{bar}K

$(K\bar{K}N)$ same result

also found in calculation with fixed centre approximation Xie, Torres, Oset, arXiv:1010.6164

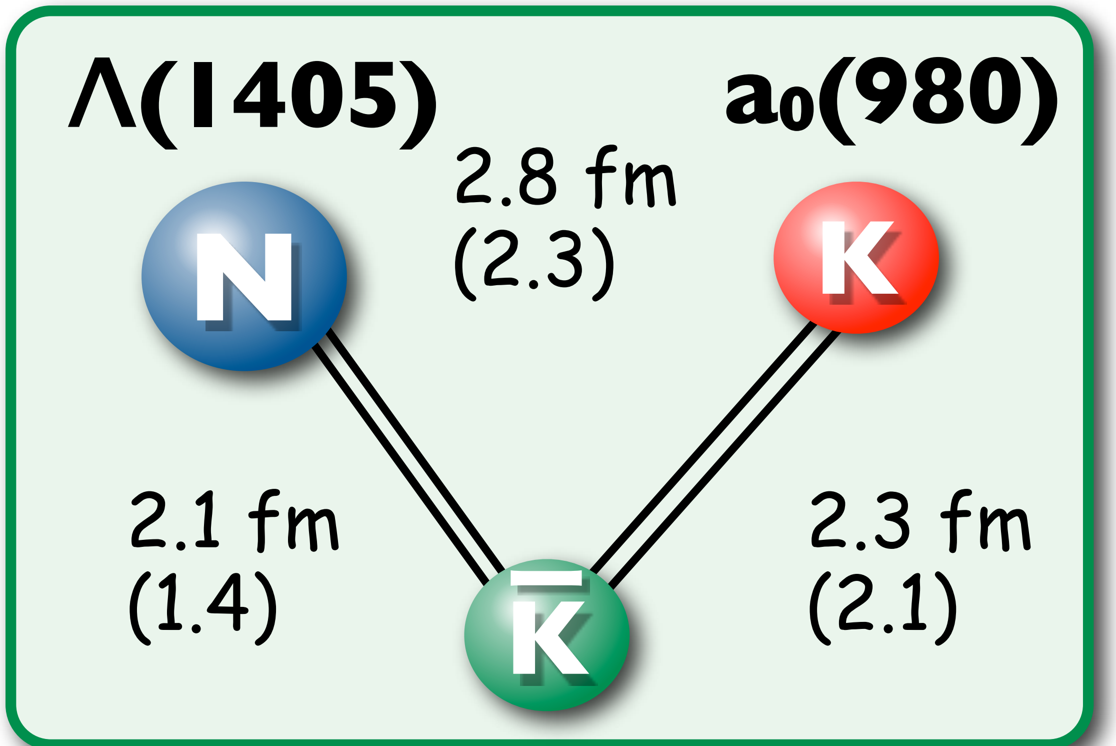
This state is essentially described by KK^{bar}N single channel in three-body configuration

Structure of N*(1910)

1) relativistic potential model

DJ, Y. Kanada-En'yo, **PRC78, 035203 (2008)**

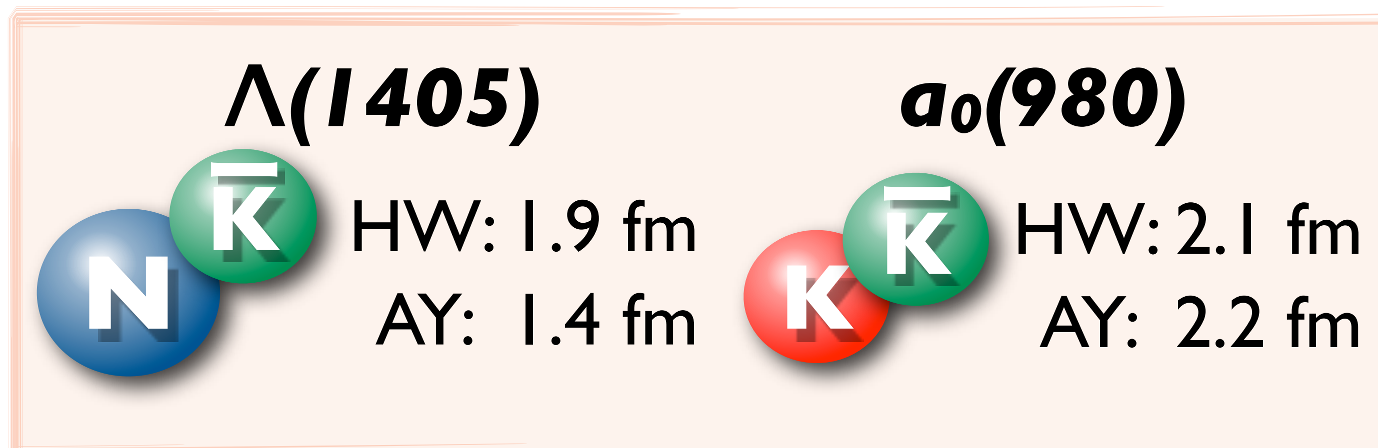
spatial structure



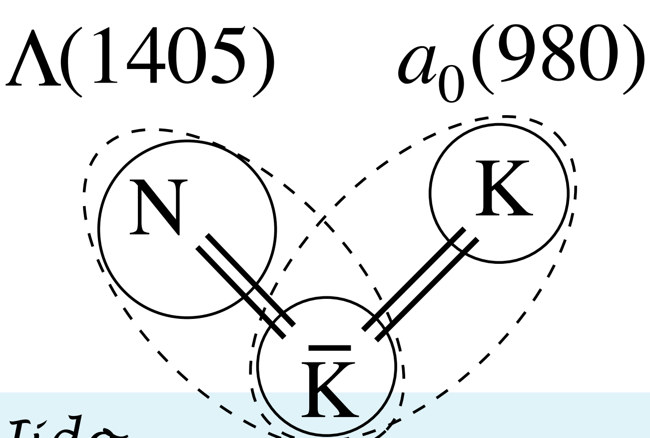
r.m.s radius: **1.7 fm** cf. 1.4 fm for ^{4}He

hadron-hadron distances are comparable with nucleon-nucleon distances in nuclei

mean hadron density: **0.07 hadrons/fm^{3}**



- coexistence of two quasi-bound states keeping their characters



Λ(1405)+K

a_0(980)+N

- main decay modes

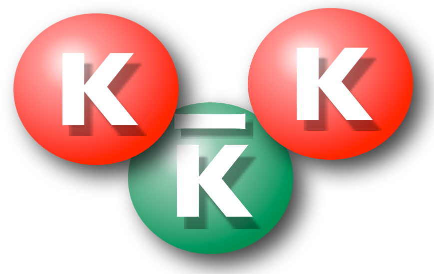
$\pi\Sigma K$ from Λ(1405)

$\pi\eta N$ from a_0(980)

$K^{bar}KK$ system

Kaon Ball K*

$J^P=0^-$



A. Martinez Torres, DJ, Y. Kanada-En'yo, arXiv:1102.1505 [nucl-th]

threshold: 1488 MeV

potential model **1467 MeV (BE: 21 MeV), width 110 MeV**

Faddeev **1420 MeV, width ~50 MeV**

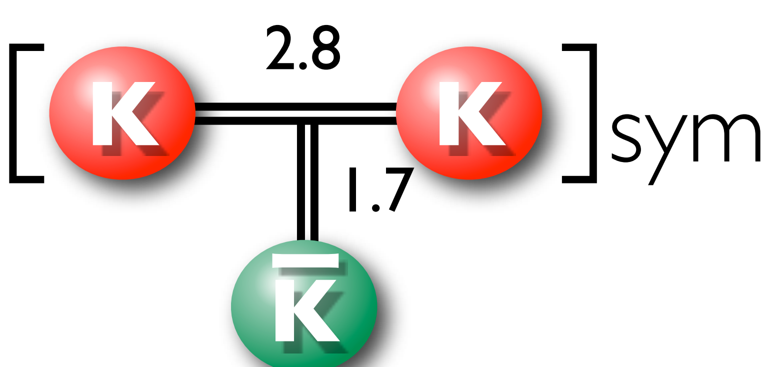
$K^{bar}K$ Inv.Mass : 983 MeV (I=0), 950 MeV (I=1)

spatial structure obtained in potential model

r.m.s radius: **1.6 fm**

K-K distance: **2.8 fm**

(KK)-K^{bar} distance: **1.7 fm**

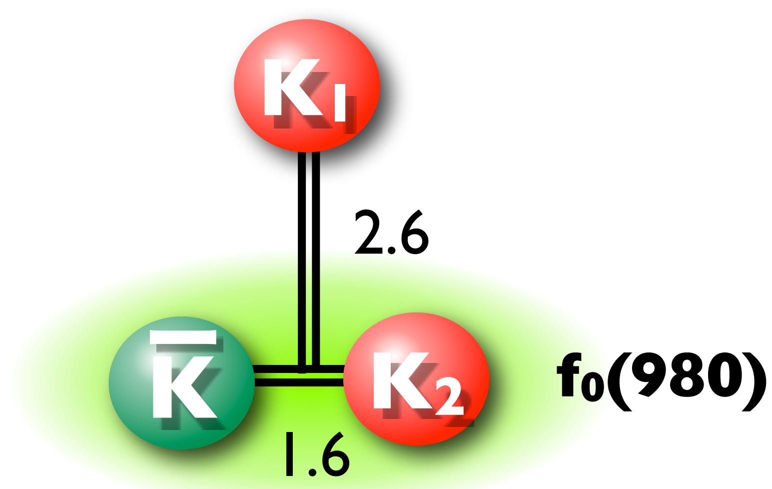


role of repulsive KK interaction

before symetrization ...

K_2-K^{bar} distance: **1.6 fm**

K_1-(K_2K^{bar}) distance: **2.6 fm**

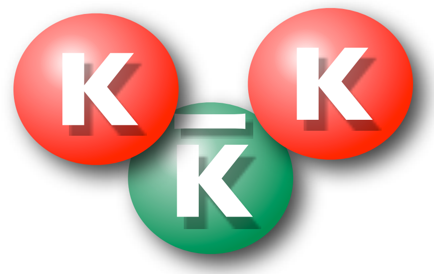


$K^{bar}KK$ system

Kaon Ball

K^*

$J^P=0^-$



A. Martinez Torres, DJ, Y. Kanada-En'yo, arXiv:1102.1505 [nucl-th]

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potential model **1467 MeV (BE: 21 MeV), width 110 MeV**

Faddeev **1420 MeV, width ~50 MeV**

$K^{bar}K$ Inv.Mass : 983 MeV (I=0), 950 MeV (I=1)

- also found in f_0(980)K, a_0(980)K two-body systems

Albaladejo, Oller, Roca, PRD82, 094019 (2010)

PDG

K(1460) seen in Kππ partial wave analyses

omitted from summary table

large width

K(1460) $I(J^P) = \frac{1}{2}(0^-)$

OMITTED FROM SUMMARY TABLE
Observed in $K\pi\pi$ partial-wave analysis.

K(1460) MASS

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
~ 1460	DAUM	81C	CNTR	−	63 $K^-p \to K^-2\pi p$
~ 1400	[1] BRANDENB...	76B	ASPK	±	13 $K^{\pm}p \to K^{+}2\pi p$

[1] Coupled mainly to $K f_0(1370)$. Decay into $K^*(892)\pi$ seen.

K(1460) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	CHG	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
~ 260	DAUM	81C	CNTR	−	63 $K^-p \to K^-2\pi p$
~ 250	[2] BRANDENB...	76B	ASPK	±	13 $K^{\pm}p \to K^{+}2\pi p$

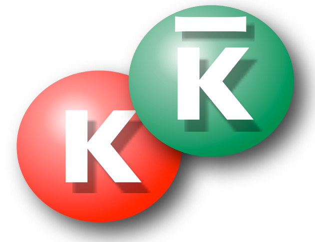
[2] Coupled mainly to $K f_0(1370)$. Decay into $K^*(892)\pi$ seen.

Family of kaonic few-body nuclear systems

Λ(1405)

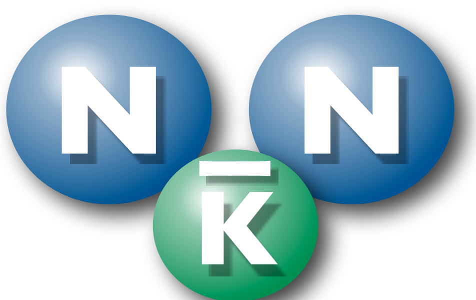
BE ~10 MeV
(or more)

f_0(980), a_0(980)



BE ~10 MeV

K^{bar}NN

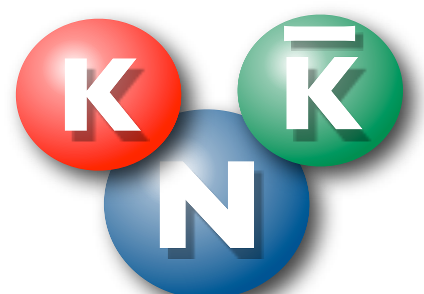


BE ~20 MeV
(or more)

N*

$J^P=1/2^+$

K^{bar}KN

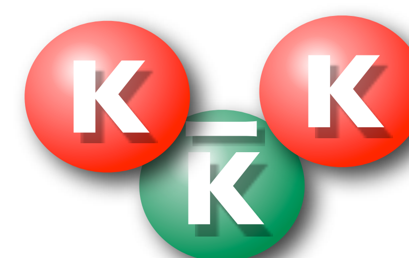


BE ~20 MeV

K*

$J^P=0^-$

K^{bar}KK



BE 20~60 MeV

K^{bar}N and **K^{bar}K** interactions are "similar" in a sense of chiral dynamics

Λ(1405) f_0(980), a_0(980)

pion is too light to be bound in range of strong interaction

Exotic Hadrons from Heavy Ion Collision

Cho et al. (ExHIC collaboration), arXiv:1011.0852
to be published in Phys. Rev. Lett.

Basic ideas

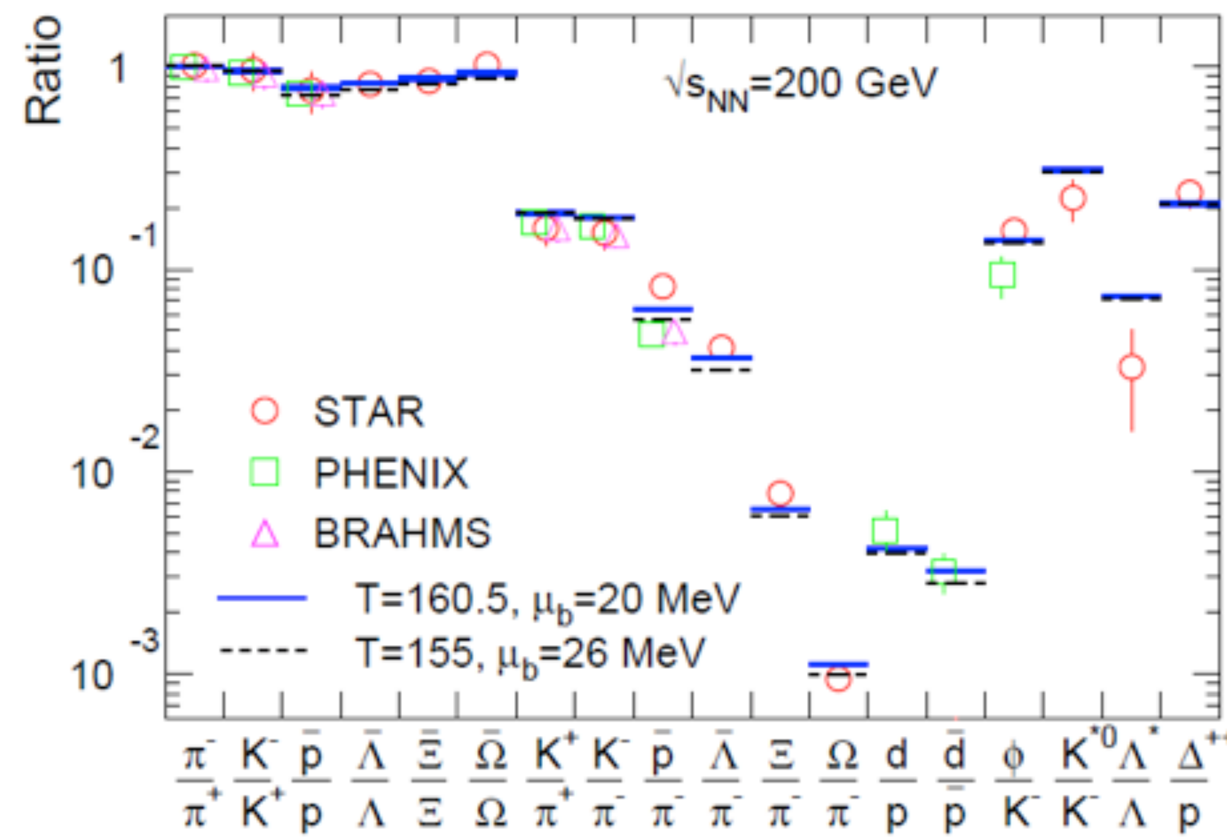
- heavy ion collision as a factory of exotic hadrons
- extract hadron structure from production rates

compact multi-quark system

vs

loosely bound hadronic molecular system

- **Yield of Normal and Exotic Hadrons**
  - **Statistical model**
    - **Successful to describe yield of normal hadrons at RHIC**
    - **Only sensitive to the mass (not quark content, size, …)**
  - **Coalescence model**
    - **Successful to describ baryons & v2 at RHIC**
    - **Sensitive to quark content and hadron size**



A. Andronic, P. Braun-Munzinger, J. Stachel, NPA772('06)167.

Hadron coalescence vs Quark coalescence

Cho et al. (ExHIC collaboration), arXiv:1011.0852
to be published in Phys. Rev. Lett.

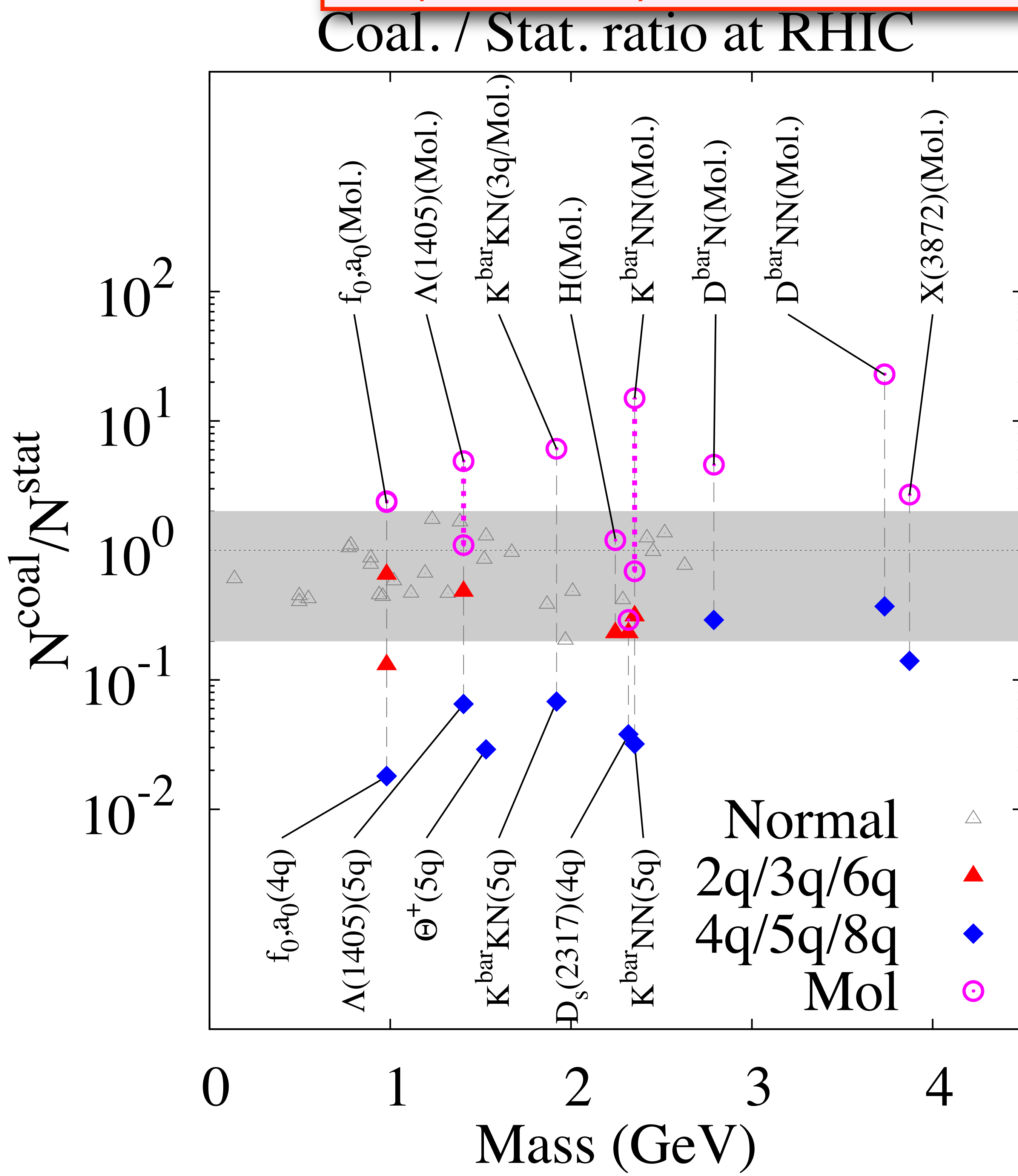
Coal./Stat. ratio: $R_h = N^{coal}/N^{stat}$

Normal hadrons
→ $0.2 < R_h < 2$ (Normal band)

Multi-quark states
→ $R_h < 0.3$

Hadronic molecules
→ Large yields ($R_h > 2$)
for weakly bound states

hadron coalescence after hadronization



Summary

coupled channels approach (chiral unitary model) provides us with

dynamical description in meson-baryon scattering

describe both resonance and nonresonant scattering simultaneously
applicable to reaction calculation

hadronic description

all contents of the models are hadrons.
but, obtained hadron resonances are not necessarily hadronic composite objects.
source of quark dynamics can be hidden everywhere
(interaction terms, form factors, CDD poles,...)
thus, detailed theoretical analyses necessary to interpret the structure

microscopic description in terms of hadrons

fundamental interactions are based on chiral effective theory

calculation of form factors

Summary

effective constituents in baryons structure

constituent quarks in low-lying baryons

hadrons can be effective constituents in some hadron resonances

hadronic molecular states

hadron resonances composed by low-lying hadrons

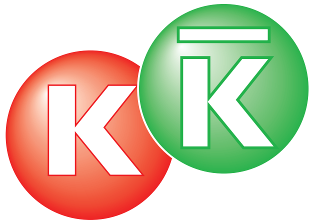
self-bound systems

unique role of Kaon

new category of resonance

Λ(1405)

$f_0(980)$, $a_0(980)$

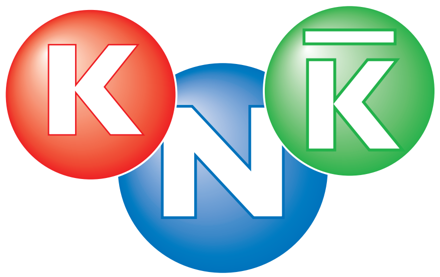


heavy ion collision

factory of exotic hadrons
production rates

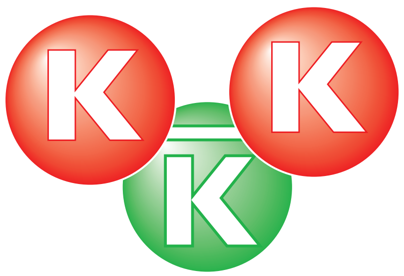
$K^{bar}KN$

N*



$K^{bar}KK$

K*



Collaborators

origin (interpretation) of resonance pole

T. Hyodo, A. Hosaka

Hyodo, DJ, Hosaka, PRC78, 025203 (08)

form factor of baryon resonance

M. Döring, E. Oset

DJ, Döring, Oset, PRC77, 065207 (08)

T. Sekihara, T. Hyodo

Sekihara, Hyodo, DJ, PLB669, 133 (08); PRC83, 055202 (11)

kaonic few-body system

Y. Kanada-En'yo, A.M. Torres

DJ, Y. Kanada-En'yo, PRC78, 035203 (08)

Martinez Torres, DJ, PRC82, 038202 (10)

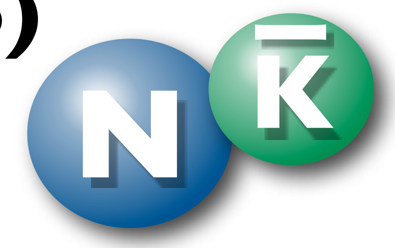
A. Martinez Torres, DJ, Y. Kanada-En'yo, arXiv:1102.1505 [nucl-th]

Kaonic few-body nuclear system

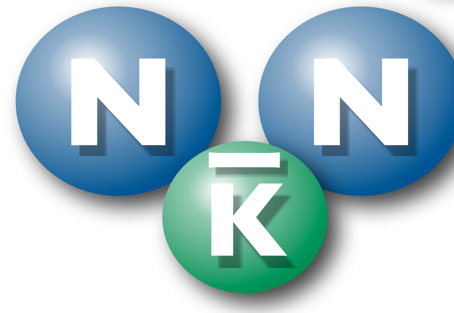
few body nuclear systems with one kaon

Nogami, PL7, 288 (1963)
Akaishi, Yamazaki, PRC64,044005 (02)

Λ(1405)



K^{bar}NN



BE: 10 or 30 MeV

single or coupled channel

achievement in theory : bound with a large width

biding energies of K^{bar}NN system

	single channel		coupled channel		
	ATMS	Variational	Faddeev	Faddeev	Variational
	Akaishi, Yamazaki	Dote, Hyodo, Weise	Shevchenko, Gal, Mares	Ikeda, Sato	Wycech, Green
B.E. [MeV]	48	17-23	50-70	60-95	40-80
Width[MeV]	61	40-70	90-110	45-80	40-85

issue is whether πΣ is active or not