ストレンジネスを含むエキゾチックハドロン

D. Jido
(Yukawa Institute, Kyoto)

high intensity beam @ J-PARC

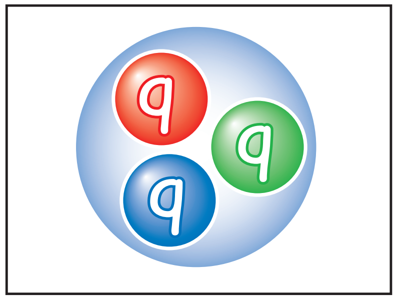
kaon hadron spectroscopy
(resonance hunting)

pion mesons in nuclei

η mesonic nuclei
η' mesonic nuclei

What is exotic hadron ??

success of constituent quark model



good intuitive picture for hadron structure

constituent quarks in low-lying baryons

mass spectra of low lying hadrons can be understood by

Gell-Mann Okubo Mass Formula SU(3) flavor symmetry with a small breaking by quark masses

Octet baryon (N, Λ, Σ, Ξ)

$$m_\Sigma - m_N = \frac{1}{2}(m_\Xi - m_N) + \frac{3}{4}(m_\Sigma - m_\Lambda)$$

254 MeV 248 MeV

Decuplet baryon (Δ, Σ*, Ξ*,Ω)

$$m_{\Sigma^*} - m_\Delta = m_{\Xi^*} - m_{\Sigma^*} = m_\Omega - m_{\Xi^*}$$

152 MeV 149 MeV 139 MeV

3% level agreement

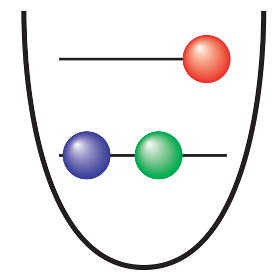
Typical mass scale >> SU(3) breaking

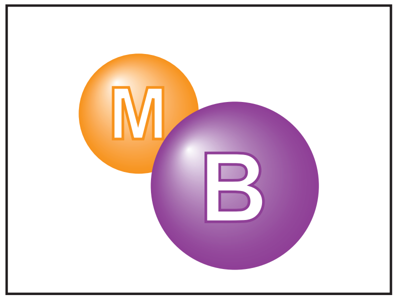
Symmetry of quarks is realized in baryon spectra through constituent quarks

exotic hadron :

hadrons which are not simply explained by quark model

What is exotic hadron ??





excited states

open decay modes

coupled channels

quark model states should obtain "corrections" from scattering states

meson cloud

bound and resonance states produced by hadron dynamics

interplay of hadron dynamics and quark dynamics

not clearly distinct

model dependent

but interaction ranges are different (scale separation)

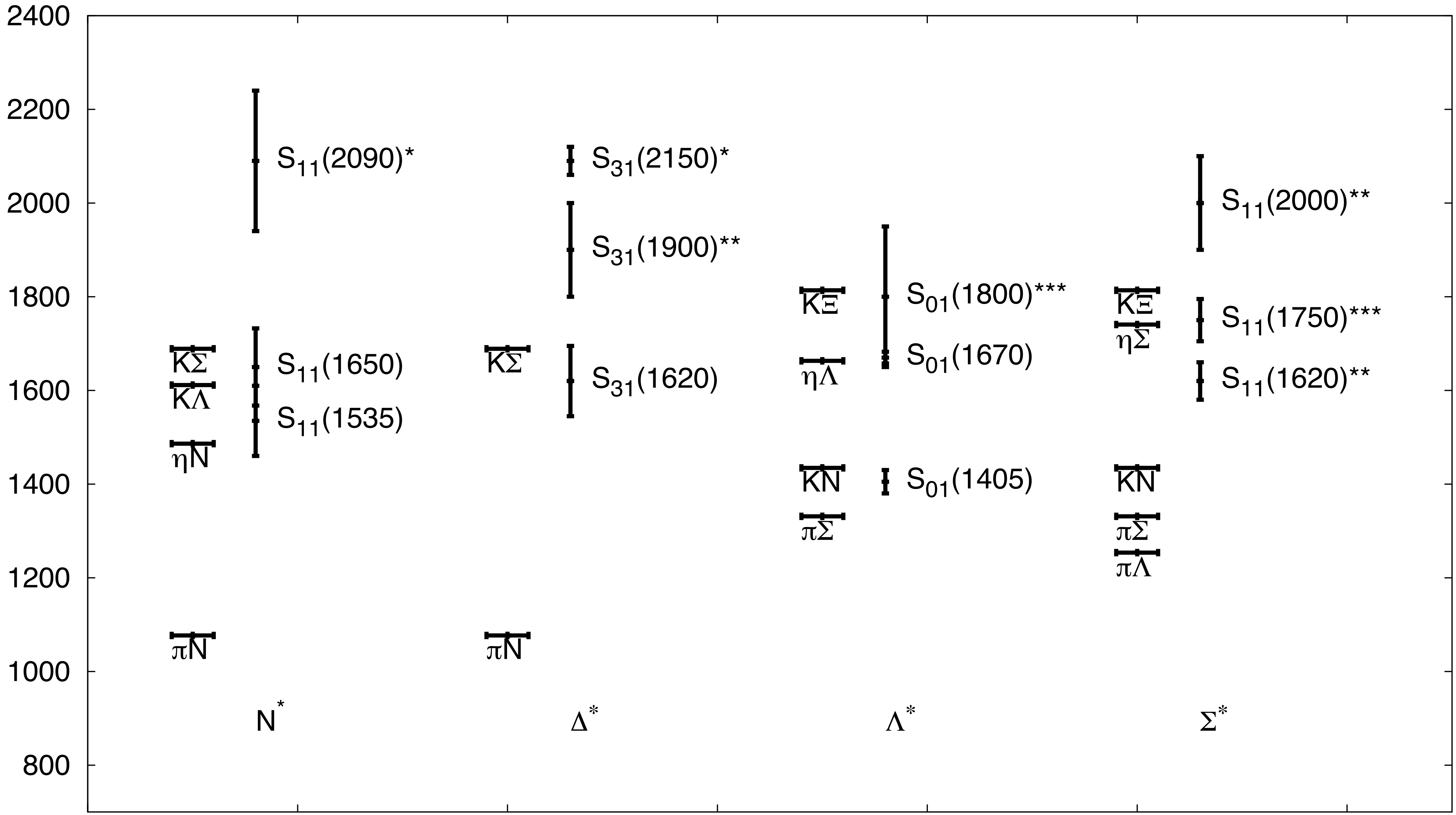
hadron size ~ 0.8 fm

help intuitive understanding

chiral partner

S-wave excited baryons

spin 1/2, parity -



Interpretation of pole

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

chiral unitary model

Lippmann-Schwinger eq.

$$T = V + VGT$$

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

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

chiral unitary model

model parameters tuned so as to

a) reproduce scattering data

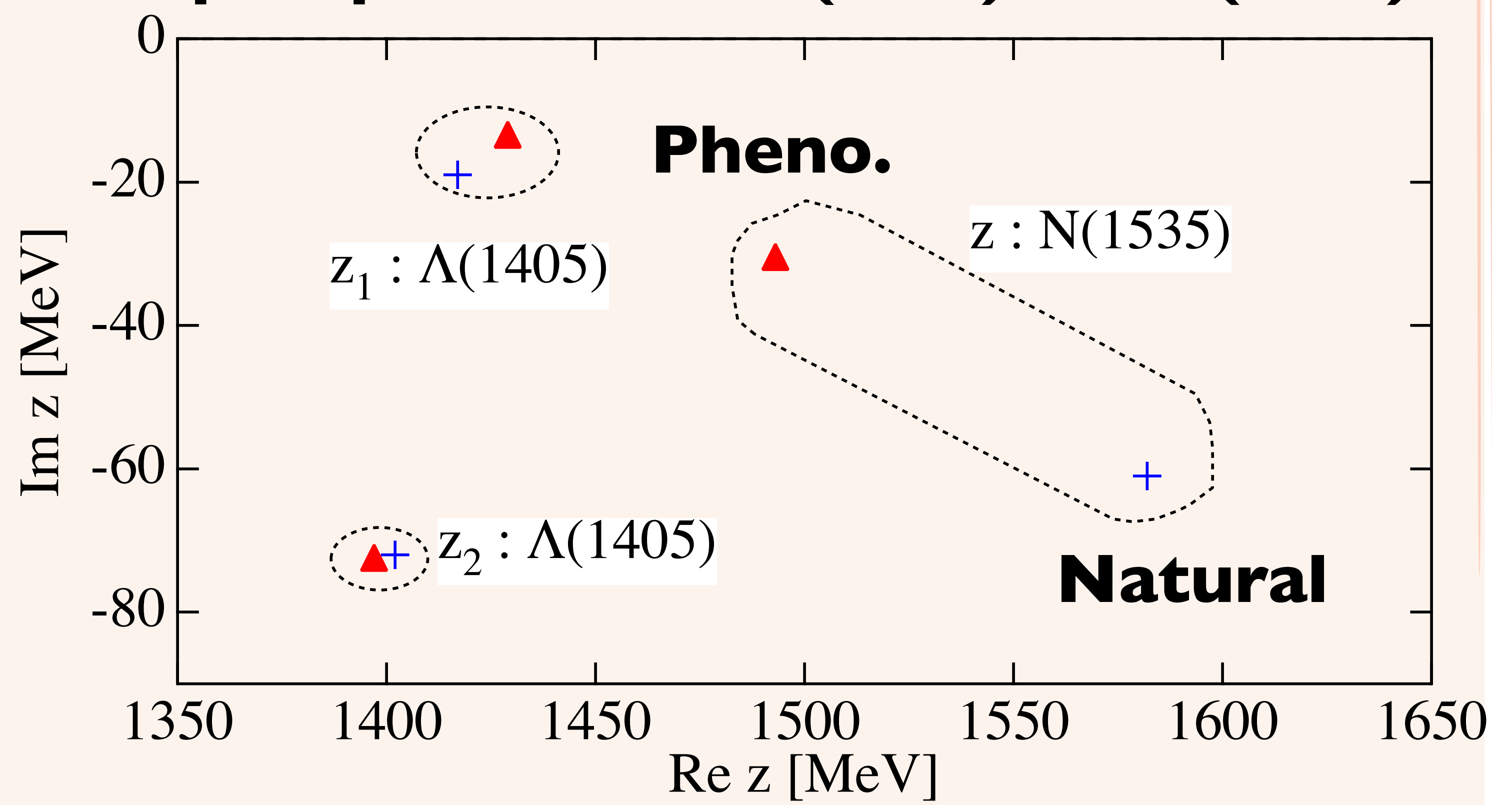
▲ **Pheno.**

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)

ch

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.

chiral unitary model

model parameters tuned so as to

a) reproduce scattering data

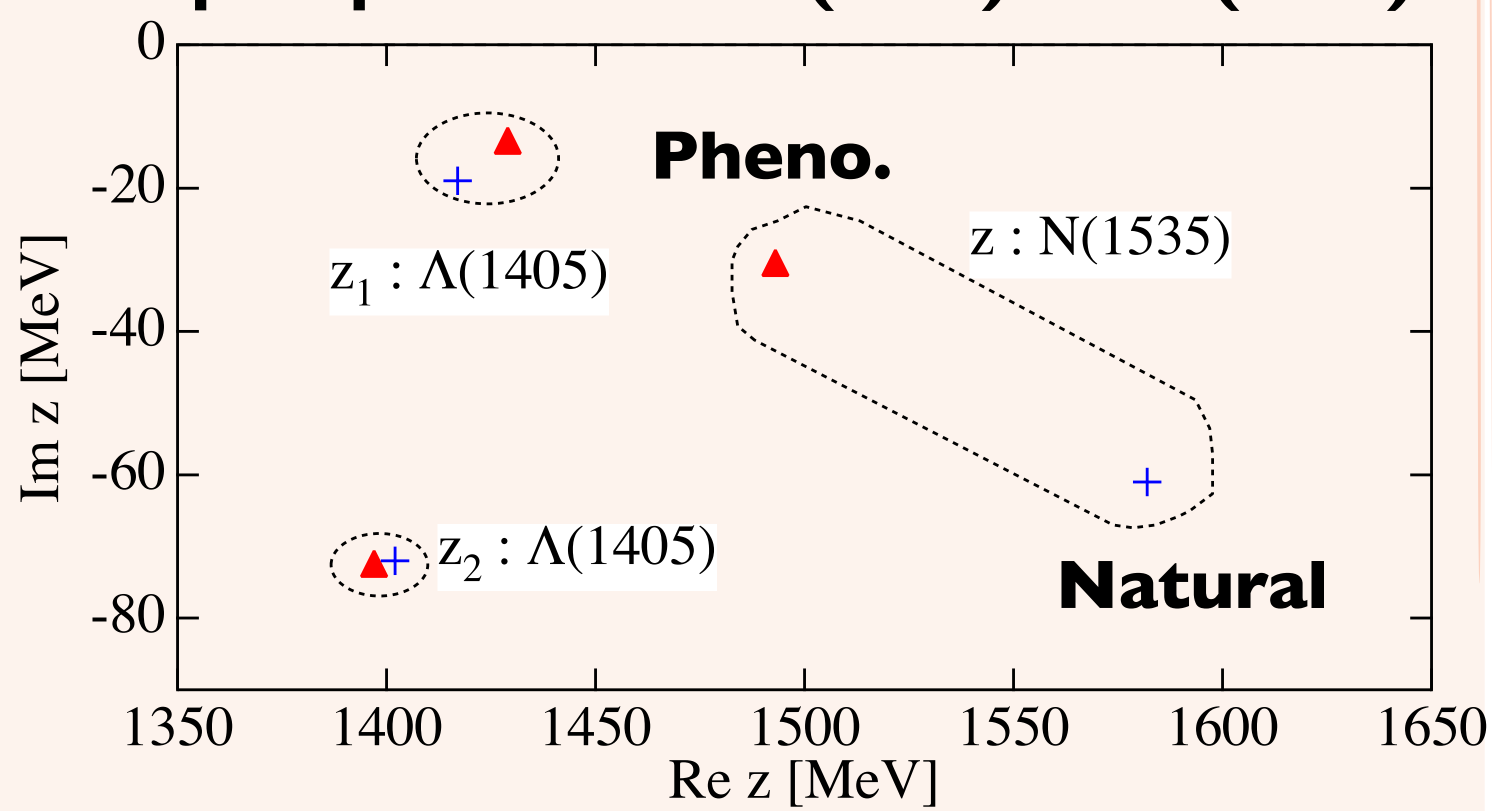
▲ **Pheno.**

b) exclude quark-origin states theoretically

\+ **Natural**

V : WT term

pole positions of N(1535) and Λ(1405)

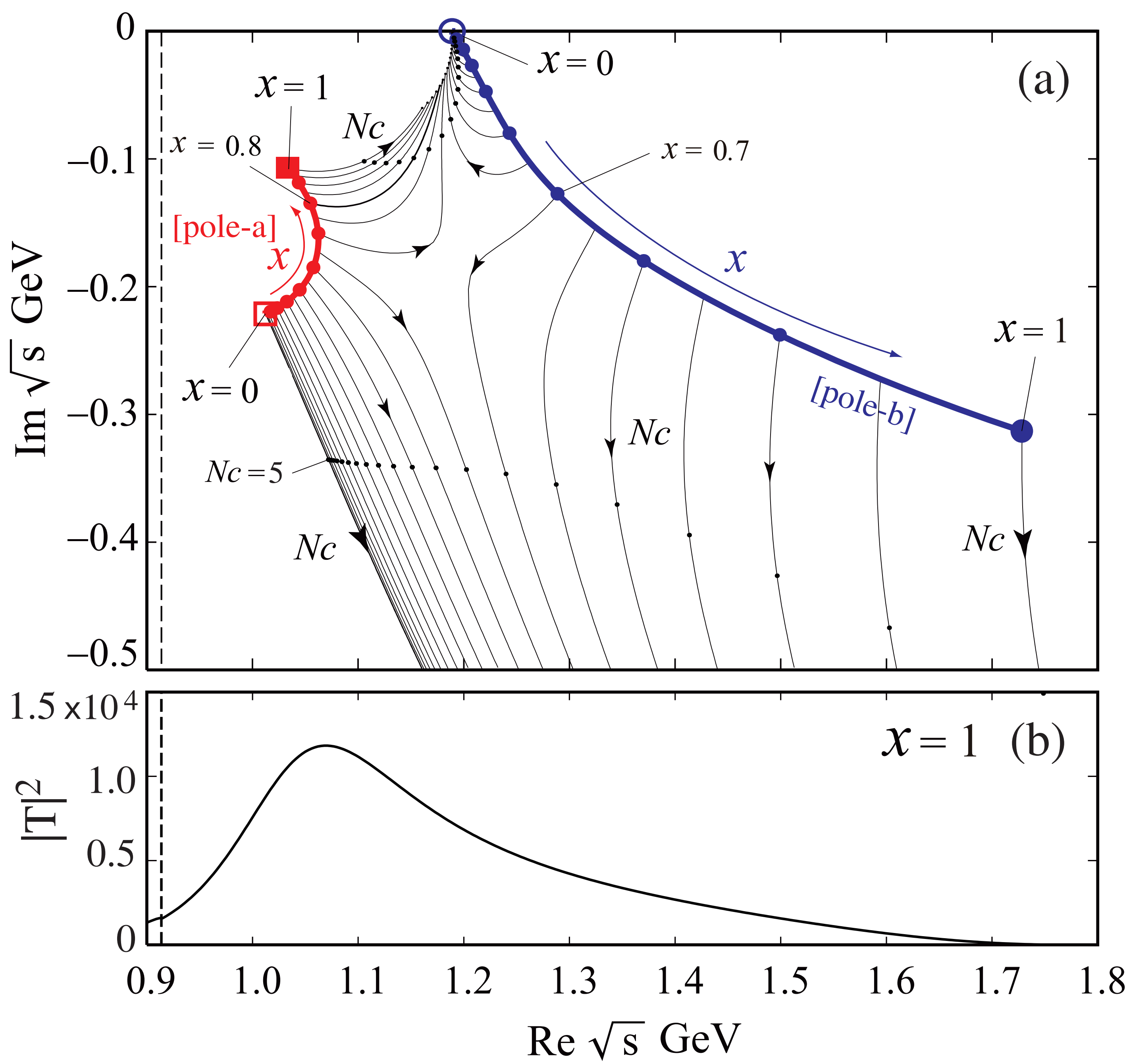


Λ(1405) has mostly meson-baryon components.

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

Mixing in a_1 meson

a_1 : ρπ resonance & quark core

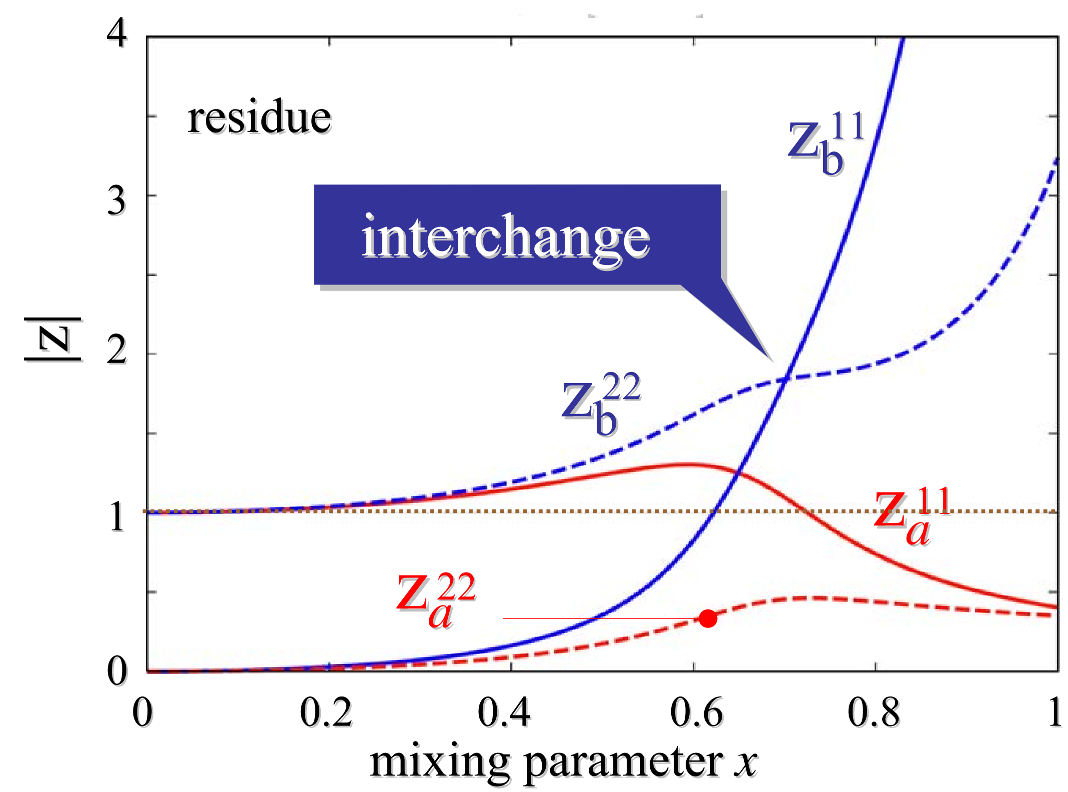


$$[\hat{D}_{\text{full}}]^{11} = \frac{z_a^{11}}{E - E_a} + \frac{z_b^{11}}{E - E_b} + \text{(regular)}$$

$$[\hat{D}_{\text{full}}]^{22} = \frac{z_a^{22}}{E - E_a} + \frac{z_b^{22}}{E - E_b} + \text{(regular)}$$

$$|a\rangle = \sqrt{z_a^{11}}\,|\,\bullet\bullet\,\rangle + \sqrt{z_a^{22}}\,|\,\bullet\,\rangle$$

$$|b\rangle = \sqrt{z_b^{11}}\,|\,\bullet\bullet\,\rangle + \sqrt{z_b^{22}}\,|\,\bullet\,\rangle$$



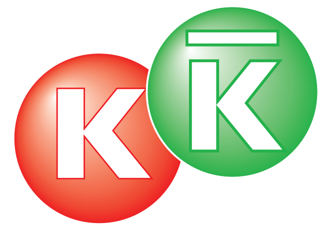
Nagahiro, Nawa, Ozaki, Jido, Hosaka, PRD (2011)

Kaonic few-body systems

Λ(1405)

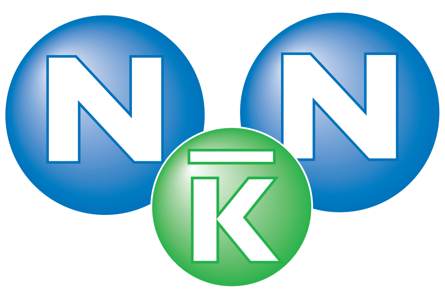
BE ~10 MeV (30 MeV)

f_0(980), a_0(980)



BE ~10 MeV

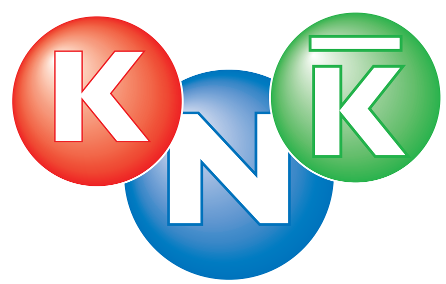
K^{bar}NN



BE ~20 MeV
or more

K^{bar}KN

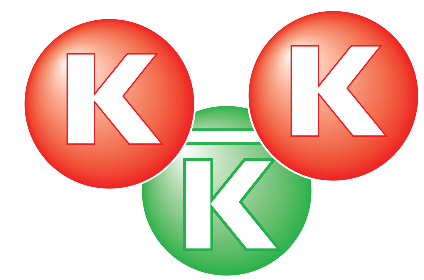
N*
$J^P=1/2^+$



a new N* resonance N(1910)
BE ~20 MeV

K^{bar}KK

K*
$J^P=0^-$



1420 ~ 1465 MeV
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)

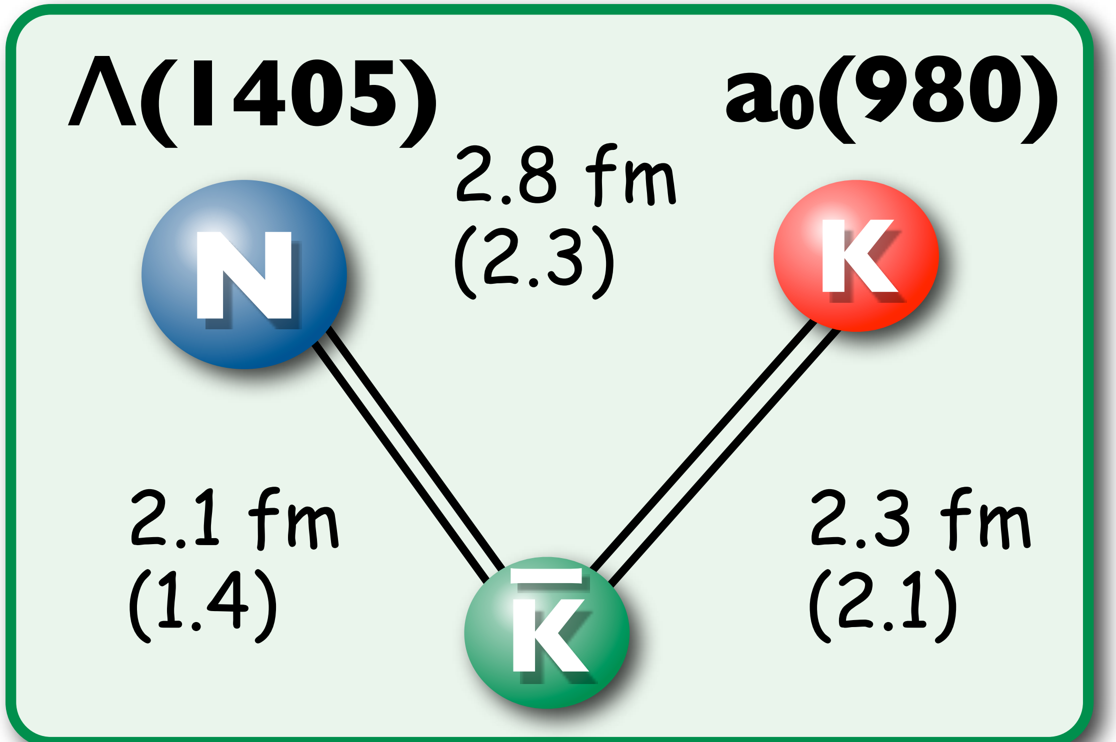
pion is too light to be bound in range of strong interaction

Structure of N*(1910)

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

1) relativistic potential model

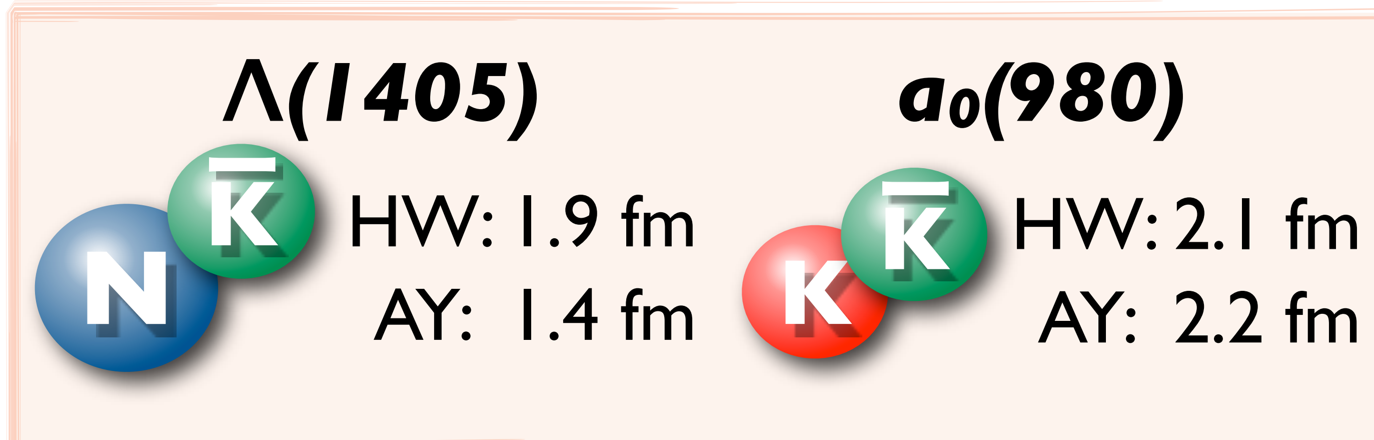
spatial structure



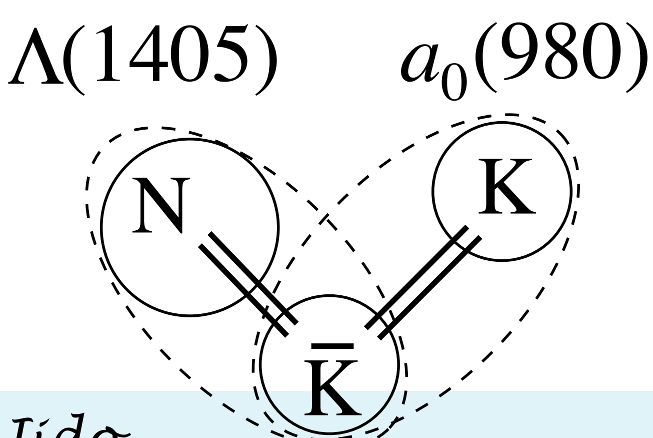
r.m.s radius: **1.7 fm** cf. 1.4 fm for ^{4}He

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

mean hadron density: **0.07 hadrons/fm³**



- 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)

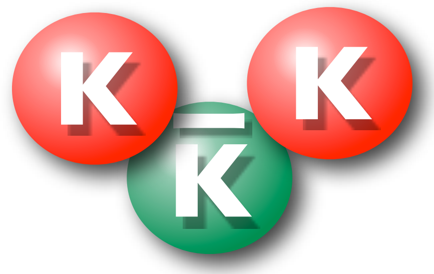
Friday, 10 June 2011

K^{bar}KK system

Kaon Ball

K*

J^P=0$^-$



A. Martinez Torres, DJ, Y. Kanada-En'yo, PRC (2011), 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**

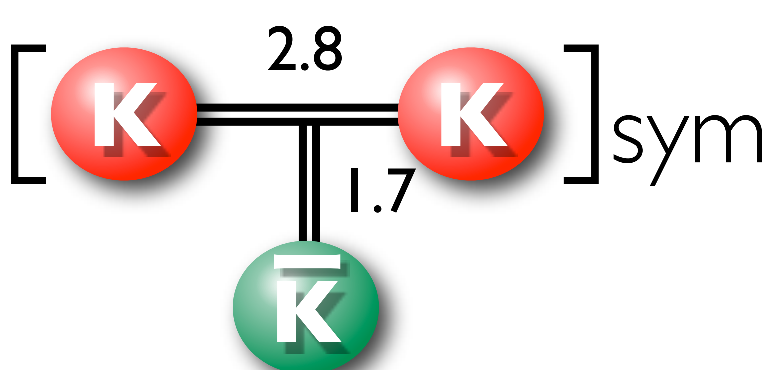
K-K distance: **2.8 fm**

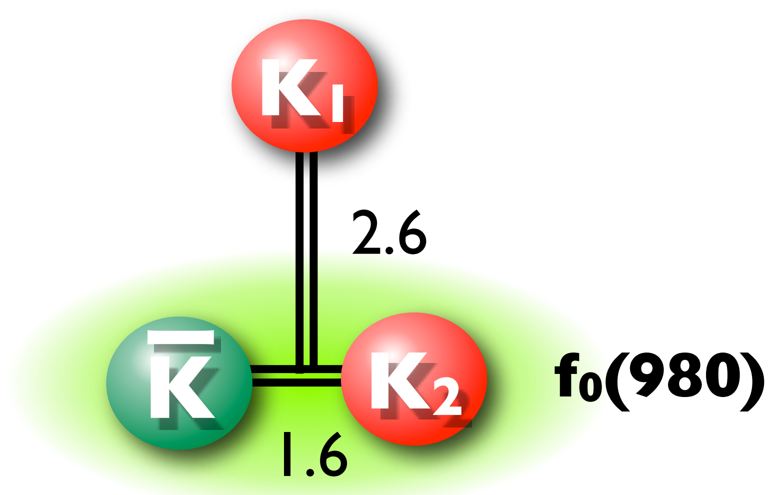
(KK)-K^{bar} distance: **1.7 fm**

before symetrization ...

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

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





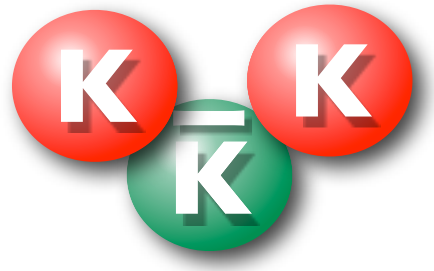
role of repulsive KK interaction

$K^{bar}KK$ system

Kaon Ball

K^*

$J^P=0^-$



A. Martinez Torres, DJ, Y. Kanada-En'yo, PRC (2011), 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)

- 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.

Other interests

spectroscopy and resonance hunting

interactions among hadrons

fundamental quantities

baryon spectroscopy of S=-2 sector

basic information on strange matter

SU(3) symmetry

scattering of S=+1

fundamental parameters for kaon

no strong resonances

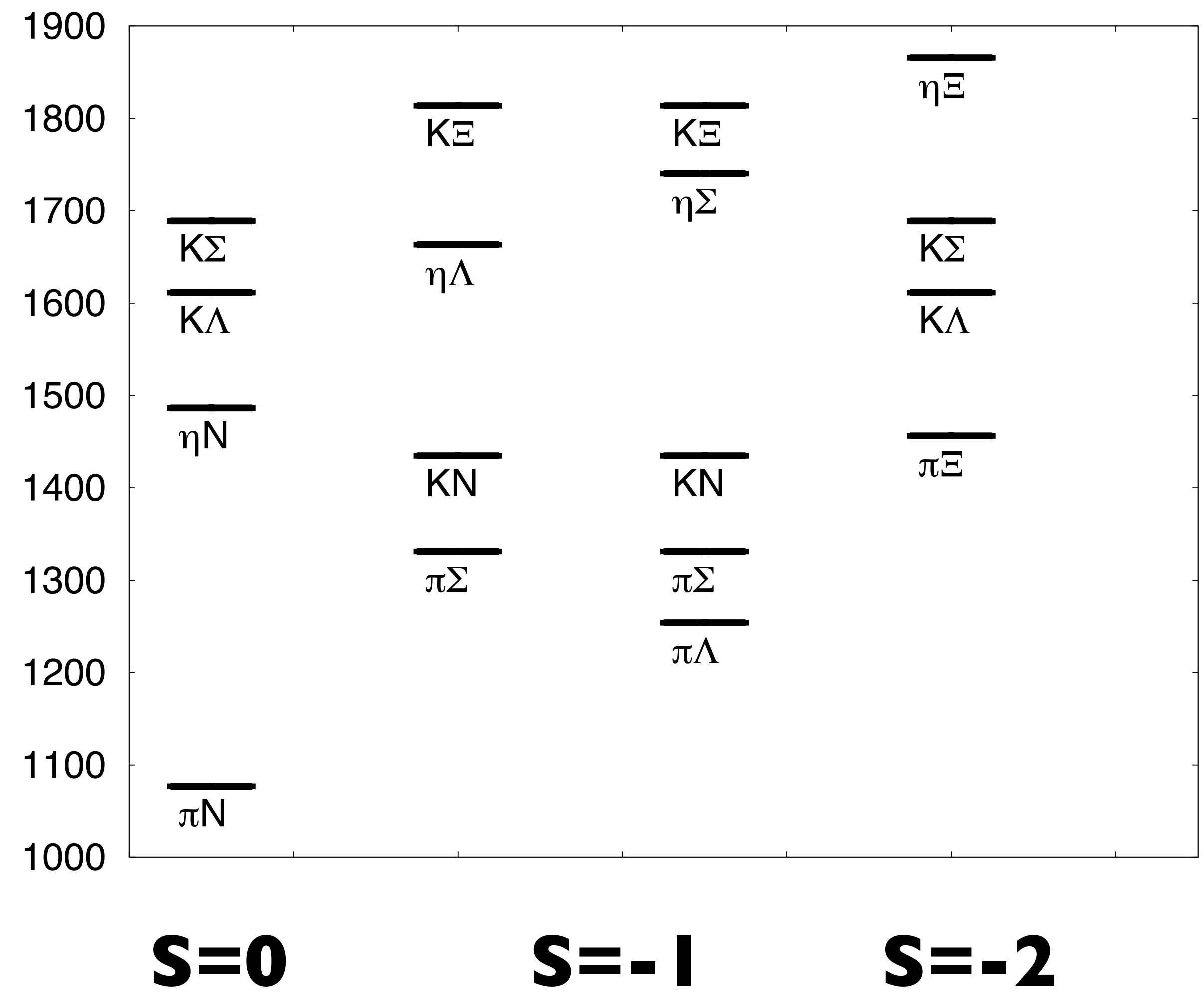
check of ChPT for strange sector

Λ(1405) vs Λ(1520)

hadron dynamics vs quark dynamics

quark model

masses of 2nd resonances, LS splitting



Mesons in nuclei @ J-PARC

intensive pion beam $^{12}\mathrm{C}(\pi^+, p)$

formation and spectroscopy of mesonic nuclei

η mesonic nuclei

K.Itanashi, H.Fujioka, S.Hirenzaki, D.Jido, H.Nagahiro,
Letter of Intent for J-PARC 2007

η' mesonic nuclei

main collaborators : Nagahiro, Hirenzaki

Mesons in nuclei

recipe *create mesons in nuclei*

observe energy spectrum

compare in-vacuum spectrum

modification of mass and width by many-body effects

ex. mass shift

$$mN \to mN$$

width

$$mN \to \pi N$$

$$mNN \to NN$$

interaction between meson and nuclei

in-medium self-energy of meson

mode mixing **B*-hole mode** meson in nucleus can excite surrounding nucleons

extract **more fundamental and universal quantities**

ex. quark condensate $\langle \bar{q}q \rangle$

Partial restoration of chiral symmetry

effective reduction of quark condensate in nuclear medium

$$\langle \bar{q}q \rangle^* / \langle \bar{q}q \rangle < 1$$

hadronic quantities closely connected to dynamical breaking

1) **pion decay constant**

deeply bound pionic atom

K. Suzuki et al., PRL92 (04) 072302.

DJ, Hatsuda, Kunihiro, PLB 670 (08) 109.

2) **spectrum of sigma meson**

ππ production off nuclei

Hatsuda, Kunihiro, PRL55 (1985), 158.

Hatsuda, Kunihiro, Shimizu, PRL82 (99) 2840.

DJ, Hatsuda, Kunihiro, PRD63 (01) 011901. etc.

3) **mass difference of chiral partners**

ρ-a_1 N-N*

Weinberg, PRL18 (67) 507.

Kapusta, Shuryak, PRD49 (94) 4694.

DeTar, Kunihiro, PRD39 (89) 2805. etc.

4) **mass of eta' meson**

etc.

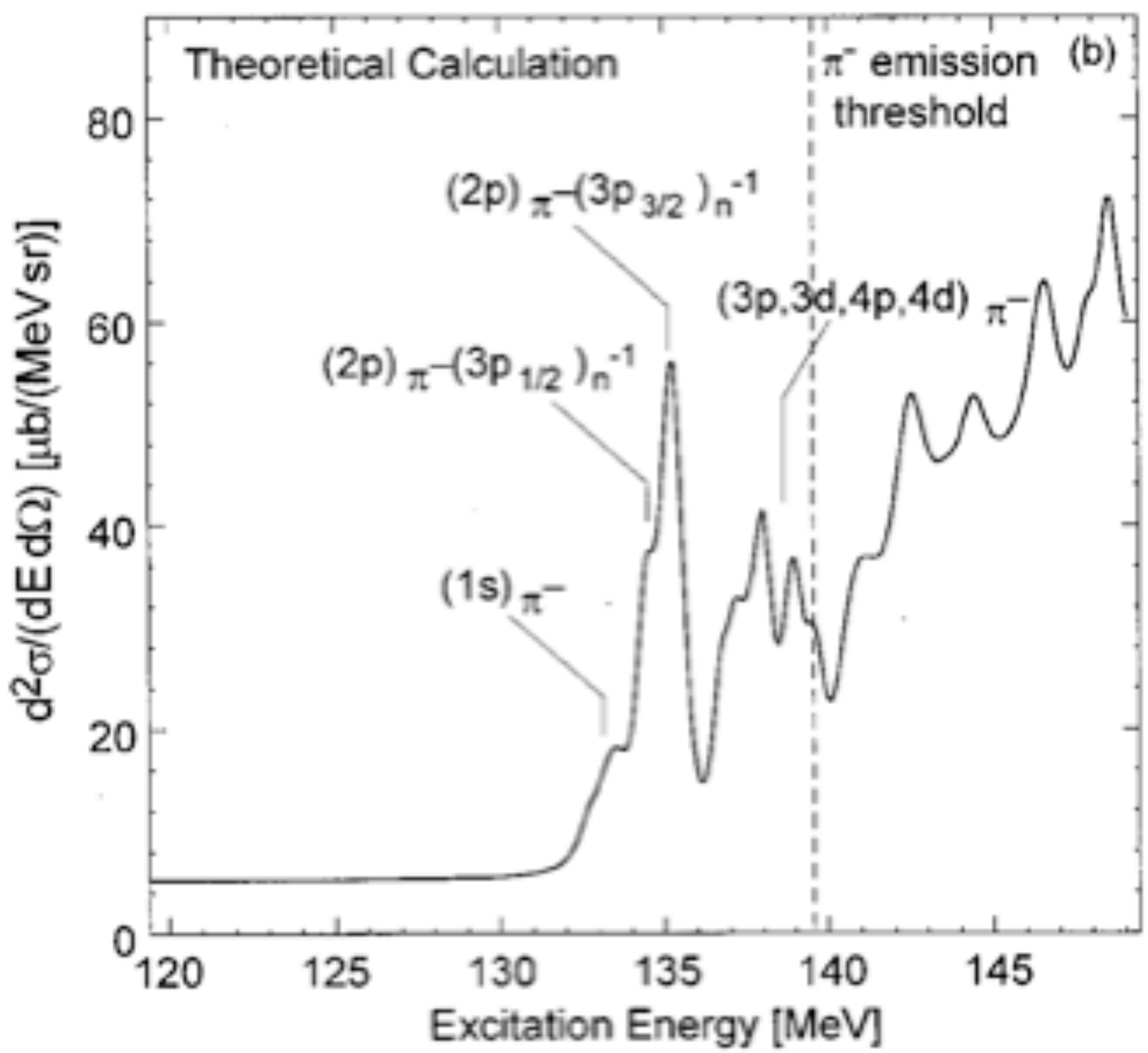
Deeply bound pionic atom

established existence of the bound states

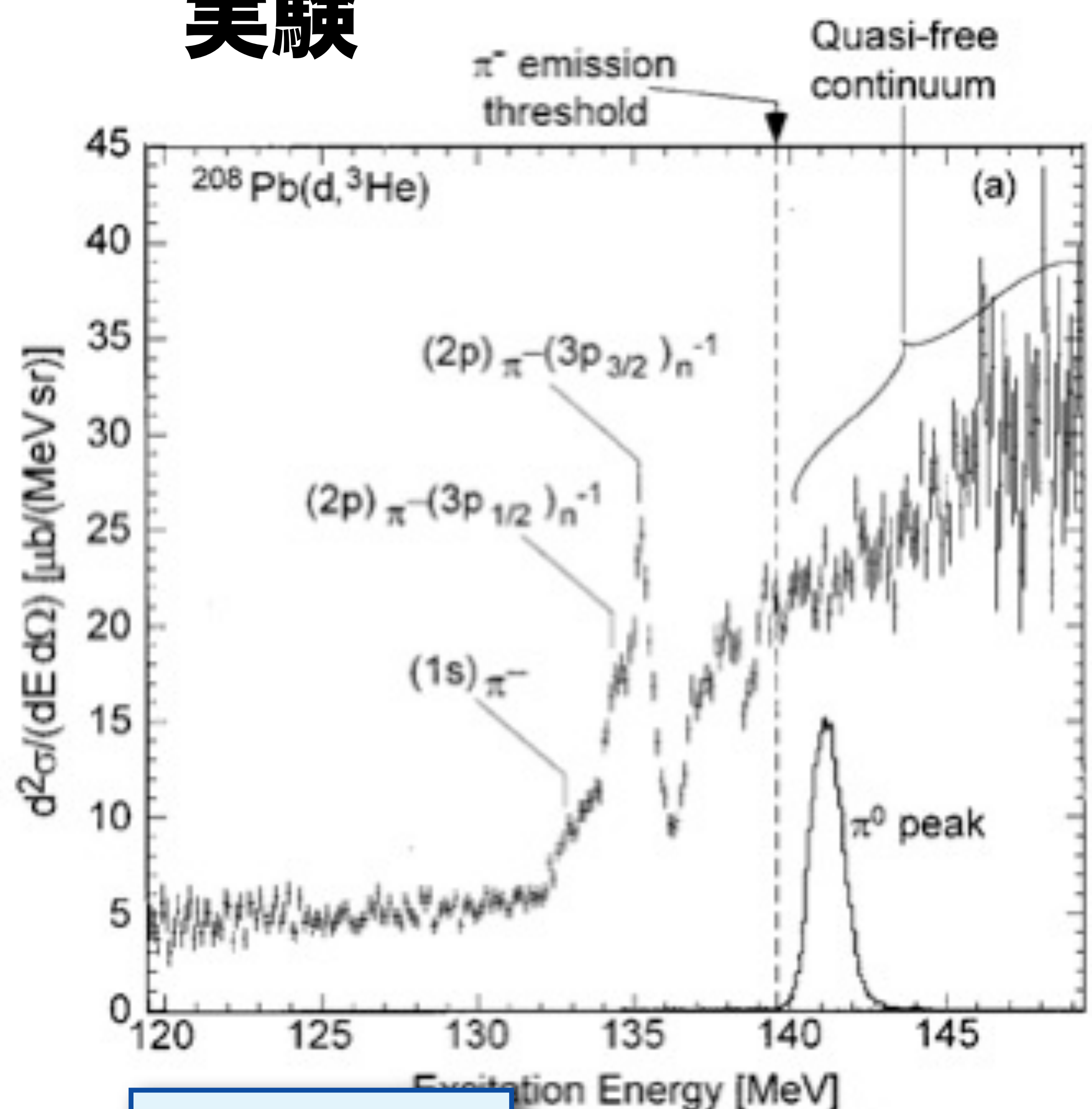
physical quantities successfully extracted

$^{208}\mathrm{Pb}(d,{}^{3}\mathrm{He})$

理論



実験



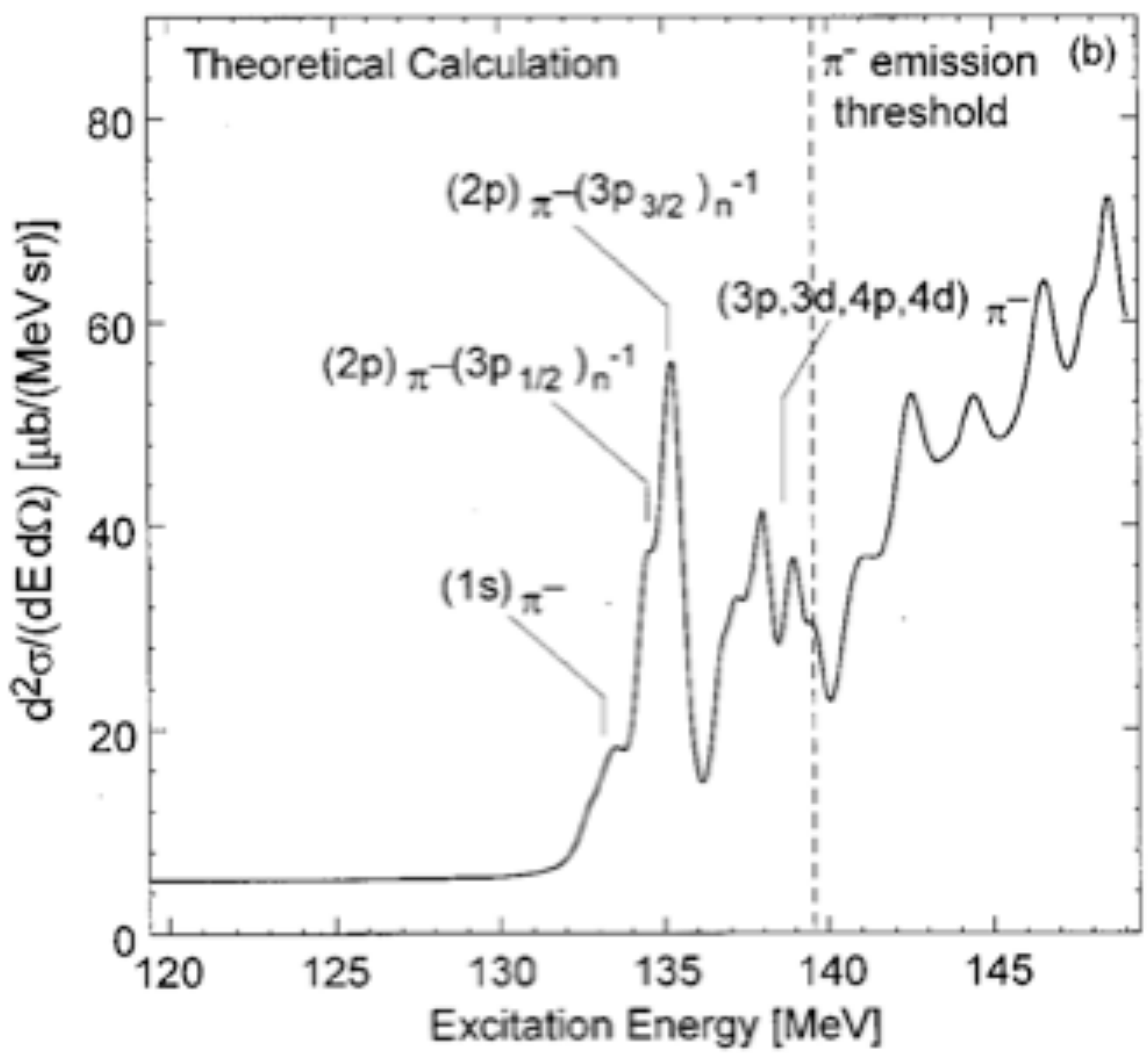
Itahashi et al.
PRC62, 025202 (00)

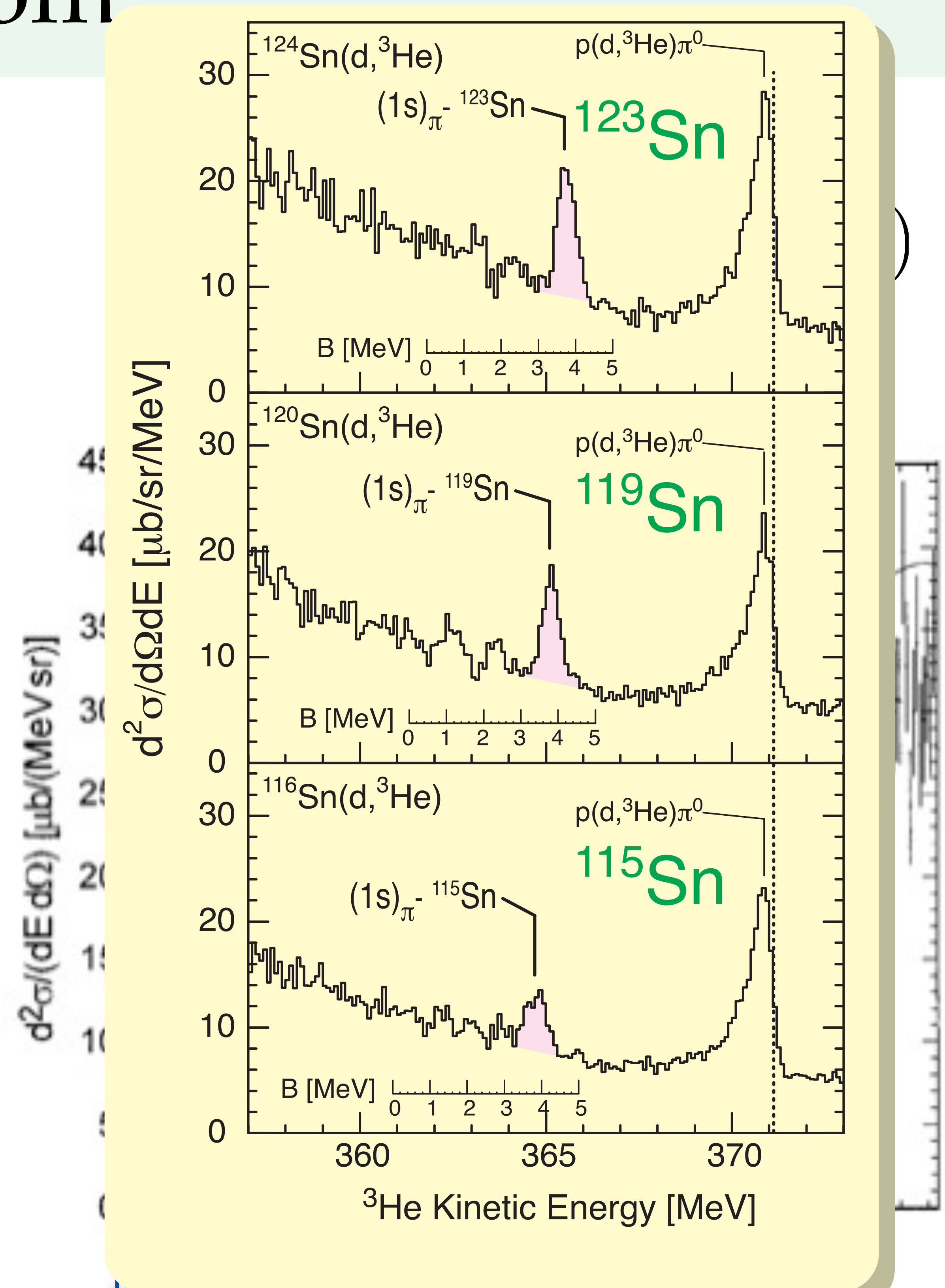
Deeply bound pionic atom

established existence of the bound states

physical quantities successfully extracted

理論





Itahashi et al.

K. Suzuki et al., PRL92 (04) 072302.

Nuclear bound state of meson

complementary methods

scattering

elastic scattering — π-nucleus scattering @ 20 MeV

meson production — vector mesons

(quasi) bound state

advantage

fixed quantum number

mesons are in nuclei

quasi static

unnecessary dynamical evolution

demerit

formation of one-body potential

well-separated bound states

Nuclear bound state of meson

complementary methods

scattering

elastic scattering — π-nucleus scattering @ 20 MeV

meson production — vector mesons

(quasi) bound state

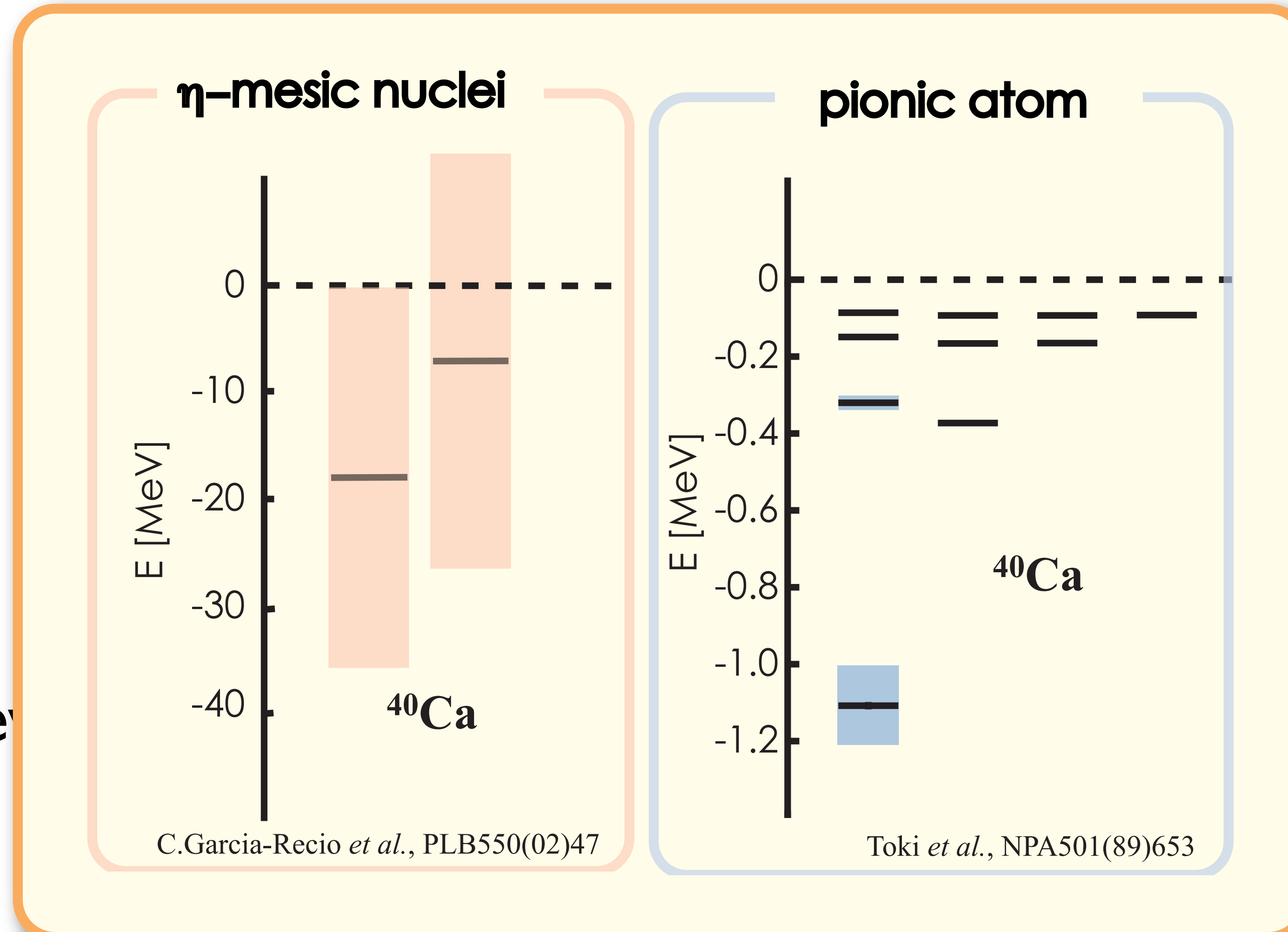
advantage

fixed quantum number

mesons are in nuclei

quasi static

unnecessary dynamical e



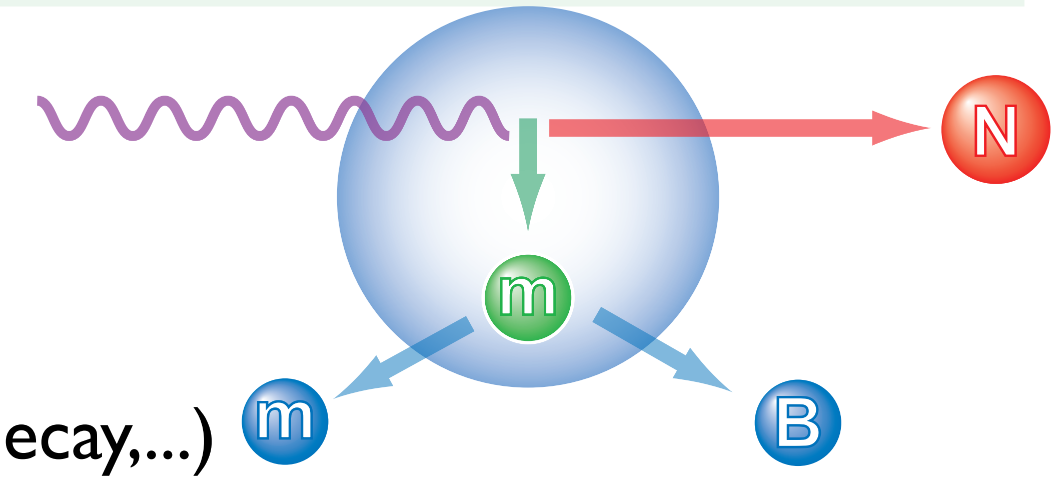
demerit

formation of one-body potential

well-separated bound states

Missing mass spectroscopy

formation reaction of bound states



observe spectra of final nucleon (missing mass)

identification of meson in nuclei (energy, isospin,decay,...)

observing decays helps to reduce the background

η: N(1535)→πN K: Λ(1405)→πΣ

nucleon pick-up

convolution of hole states and meson partial waves

recoilless selection rule

$$s_N^{-1} \otimes s_m,\ p_N^{-1} \otimes p_m, \ldots$$

Eta mesonic nuclei

η meson: neutral charge no electromagnetic interaction
purely strong interaction

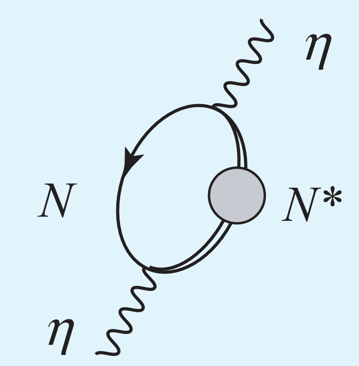
ηN interaction is attractive

expect η bound states in nuclei (Haider, Liu)

experimental attempts, but not yet clearly observed

large width due to strong absorption

ηN → πN, ηNN → NN, etc



ηN strongly couples to N(1535)

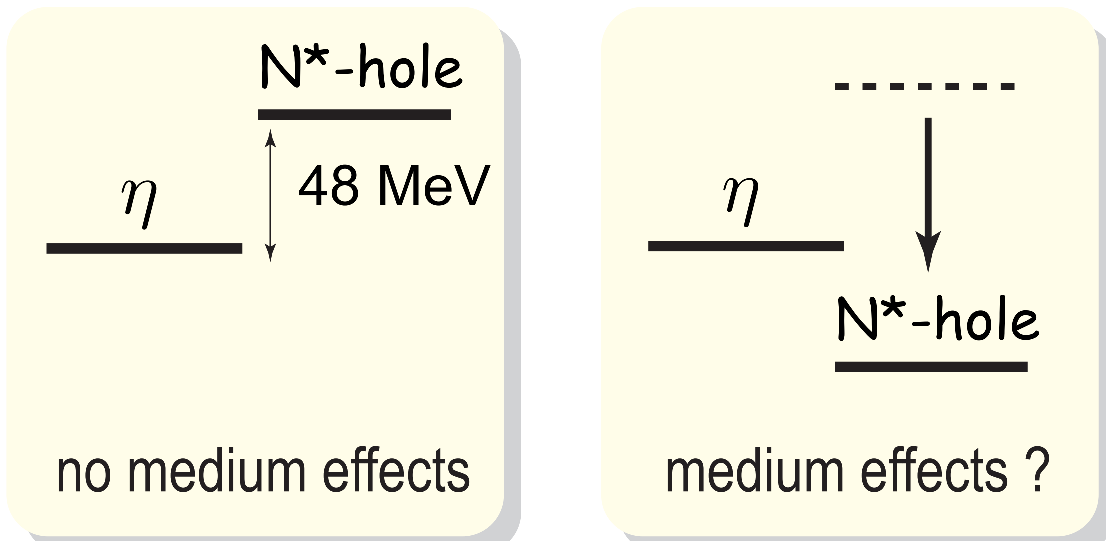
in-medium η meson ⇔ in-medium N(1535)

N(1535) is a candidate of chiral partner of nucleon

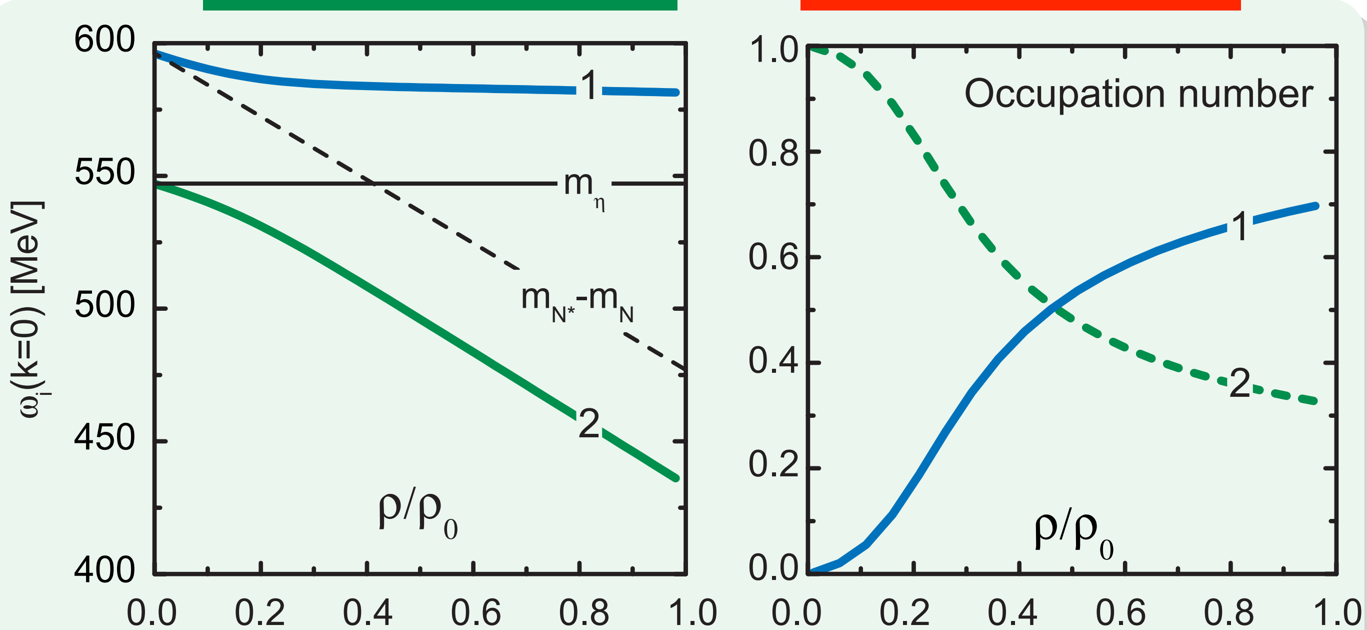
eta mesonic nuclei probe chiral symmetry of baryon

Spectral function of in-medium eta meson

Reduction of the mass difference of N and N*
causes level crossing between η and N*-hole



Attractive **Repulsive**

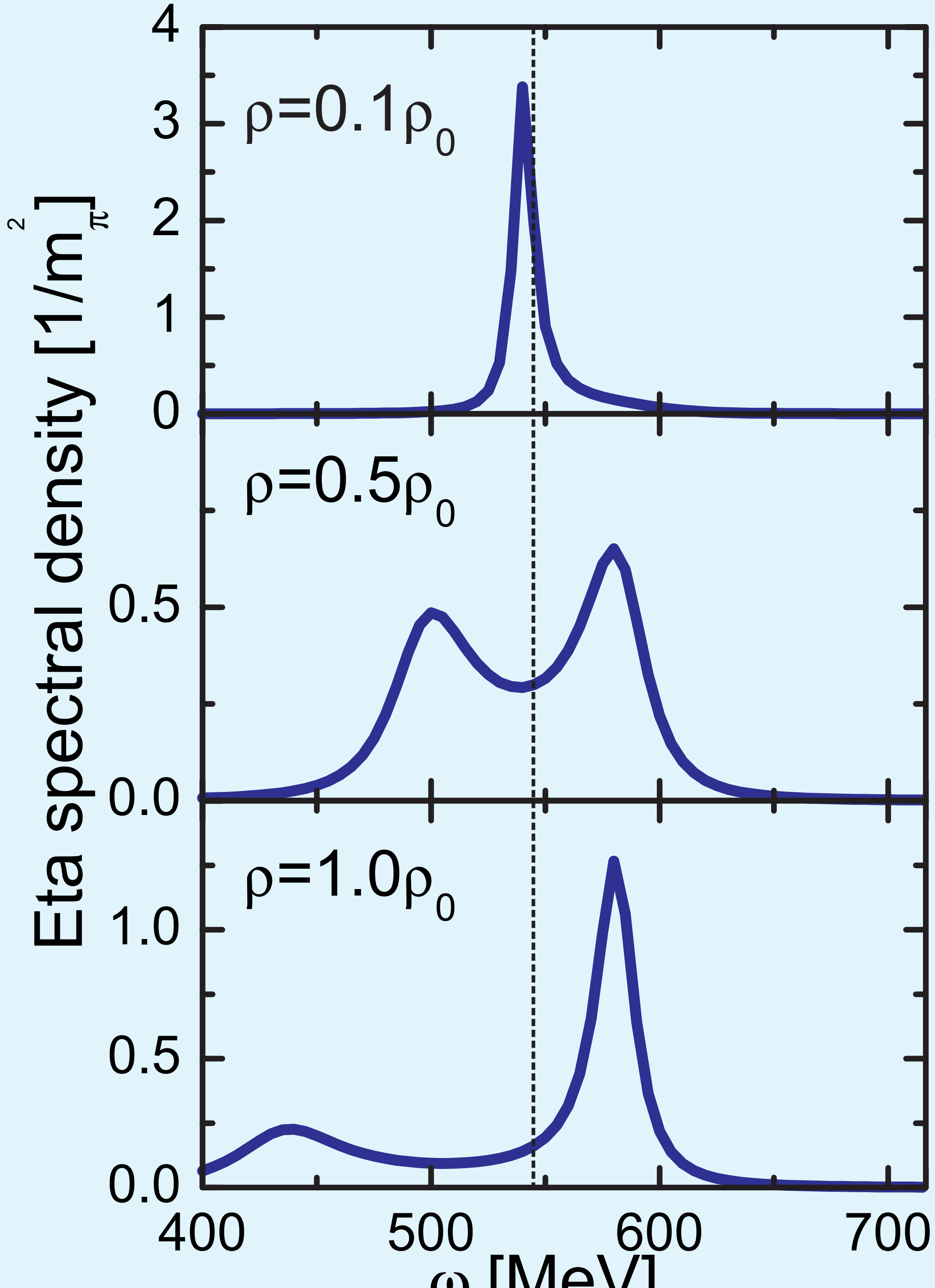


$$G_\eta(\omega) = \sum_i \frac{Z_i}{\omega - \omega_i}$$

$$Z_i = \left(1 - \frac{\partial V_\eta(\omega)}{\partial \omega}\bigg|_{\omega=\omega_i}\right)^{-1}$$

Spectral function

$$S(\omega) = -\mathrm{Im}\, G_\eta(\omega)$$

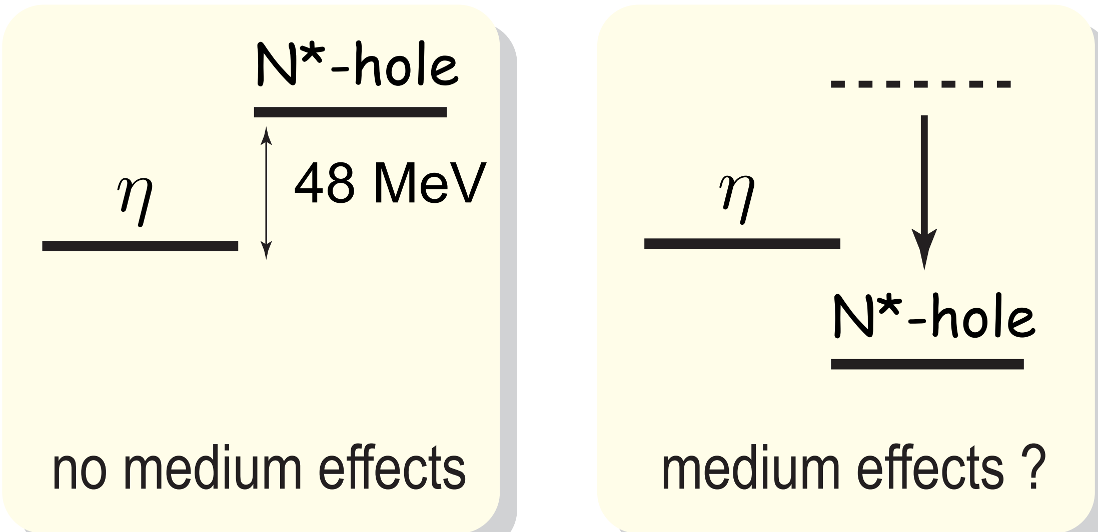


Jido, Nagahiro, Hirenzaki, PRC66, 045202 ('02)
Nagahiro, Jido, Hirenzaki, PRC68, 035205 ('03), NPA761,92 ('05)
Jido, Kolomeitsev, Nagahiro, Hirenzaki, NPA811, 158 ('08)

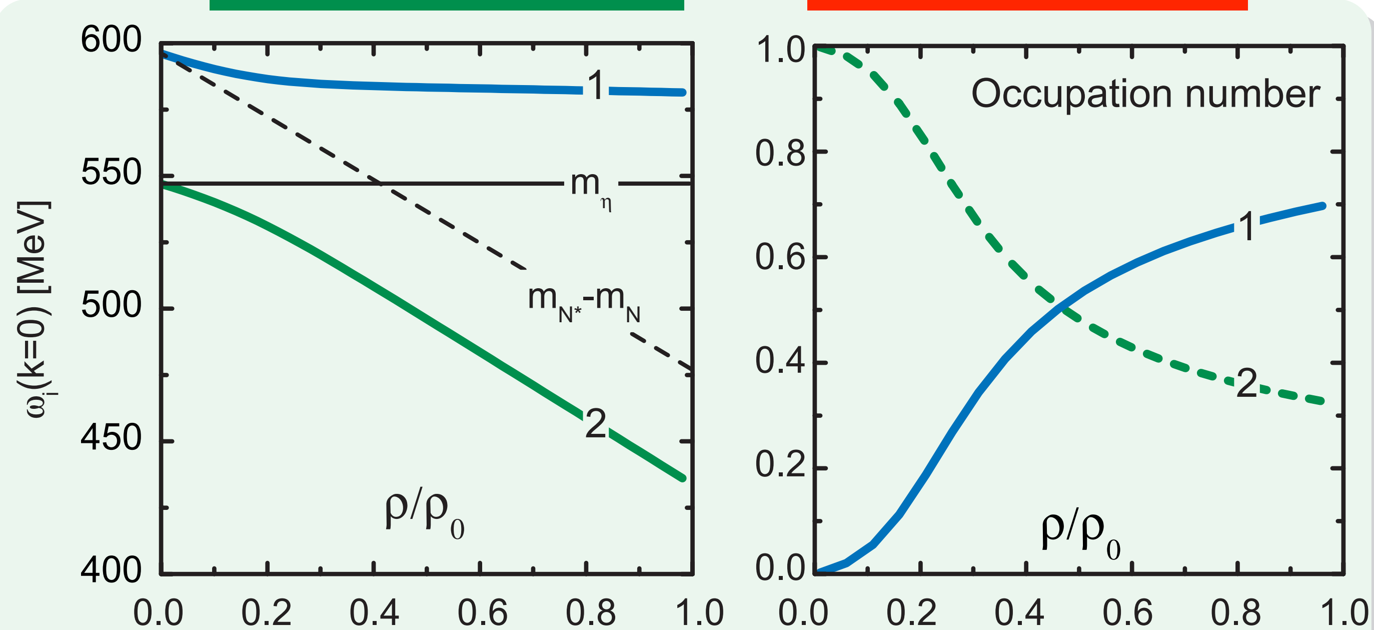
D. Jido

Spectral function of in-medium eta meson

Reduction of the mass difference of N and N* causes level crossing between η and N*-hole



Attractive **Repulsive**

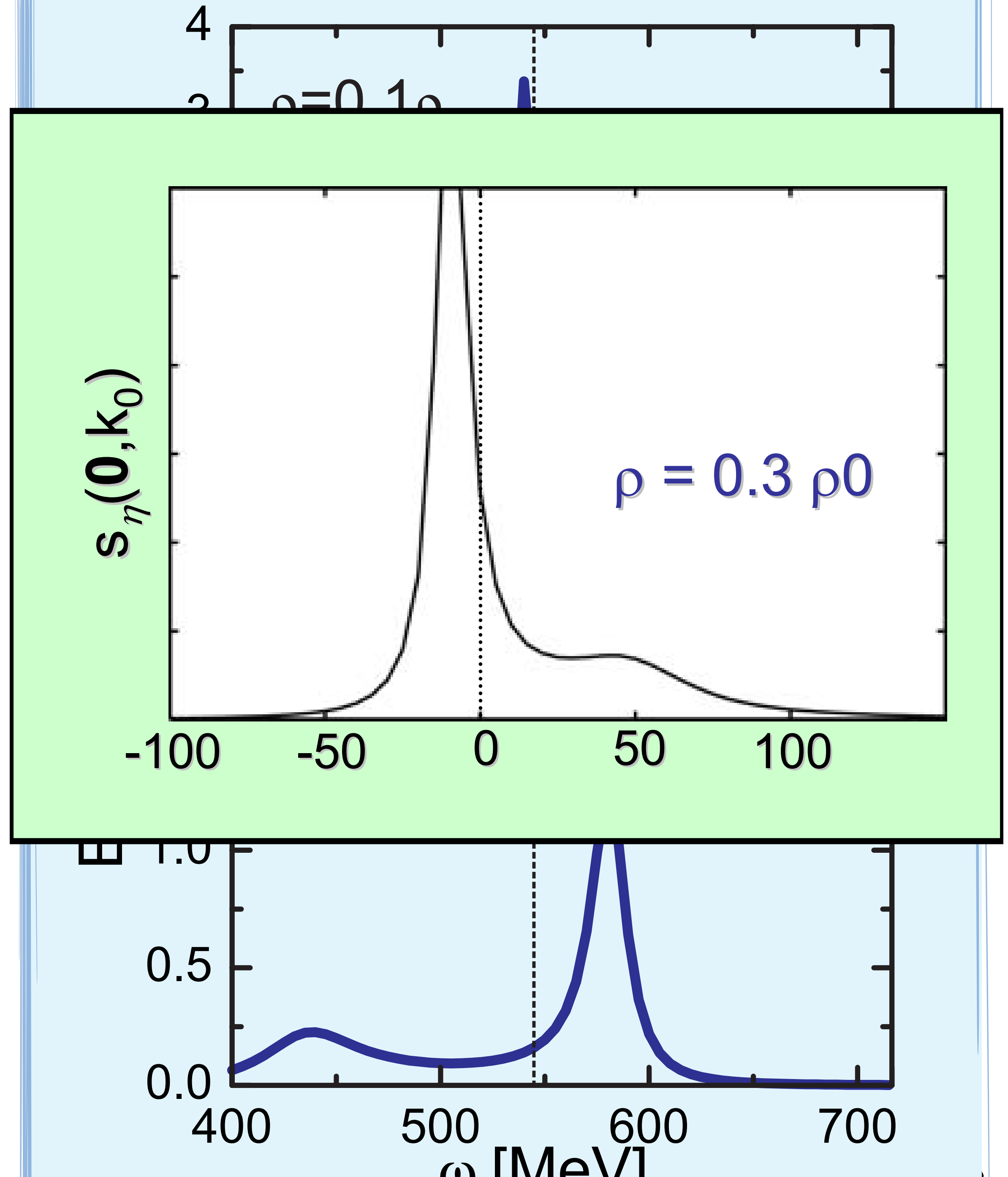


$$G_\eta(\omega) = \sum_i \frac{Z_i}{\omega - \omega_i}$$

$$Z_i = \left(1 - \left.\frac{\partial V_\eta(\omega)}{\partial \omega}\right|_{\omega=\omega_i}\right)^{-1}$$

Spectral function

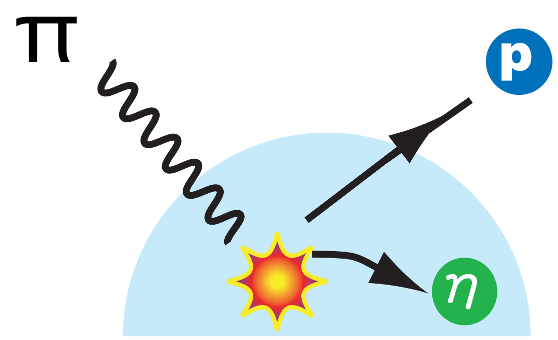
$$S(\omega) = -\mathrm{Im}\, G_\eta(\omega)$$



Jido, Nagahiro, Hirenzaki, PRC66, 045202 ('02)
Nagahiro, Jido, Hirenzaki, PRC68, 035205 ('03), NPA761,92 ('05)
Jido, Kolomeitsev, Nagahiro, Hirenzaki, NPA811, 158 ('08)

Eta mesonic nuclei @ J-PARC

Nagahiro, Jido, Hirenzaki, PRC80, 025205 (09)



consider (π^+,p) reaction

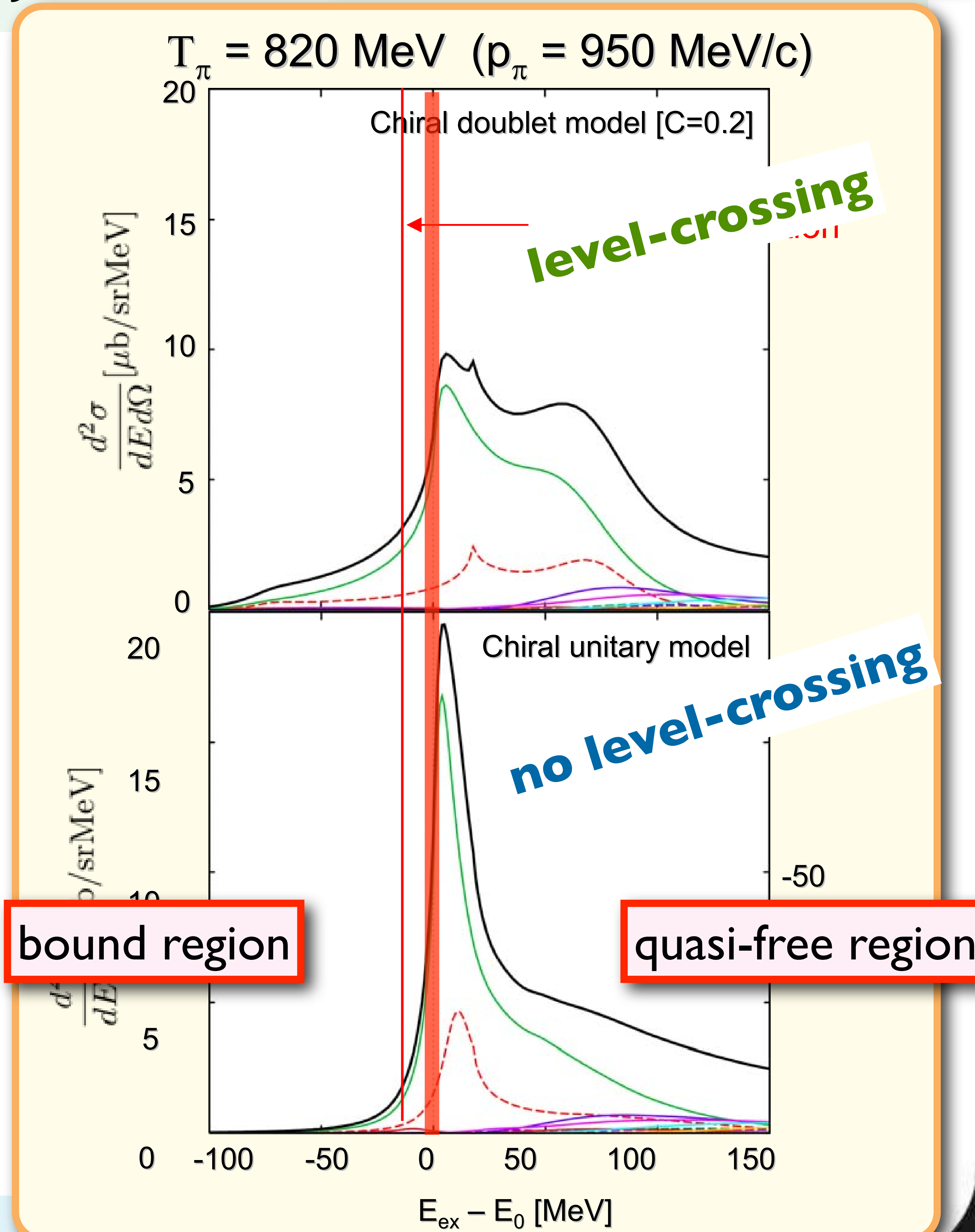
missing mass spectra

of emitted proton

^{12}C target

in recoilless condition
(no momentum transfer)

Green function method
(Morimatsu-Yazaki)



Origin of η′ mass

would be one of the Nambu-Goldstone bosons

$$U(3)_L \otimes U(3)_R \to SU(3)_V \otimes U(1)_V$$

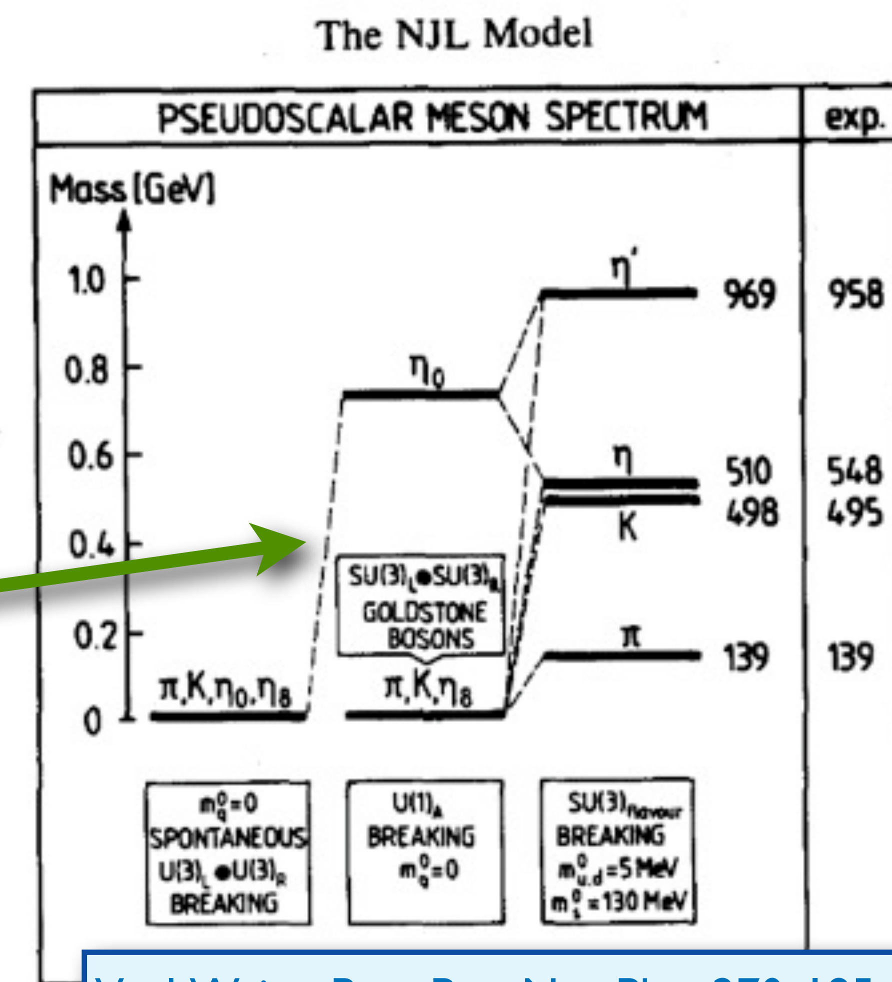
no $U_A(1)$ symmetry due to anomaly

$$SU(3)_L \otimes SU(3)_R \otimes U(1)_V \to SU(3)_V \otimes U(1)_V$$

η_0 is not NG boson

$U_A(1)$ anomaly lifts η' mass up

this argument starts with SB of ChS



Vogl, Weise, Prog.Part.Nuc.Phys.270, 195 (91)

η′ meson in nuclear matter

DJ, Nagahiro, Hirenzaki, in preparation

When chiral symmetry is restored...

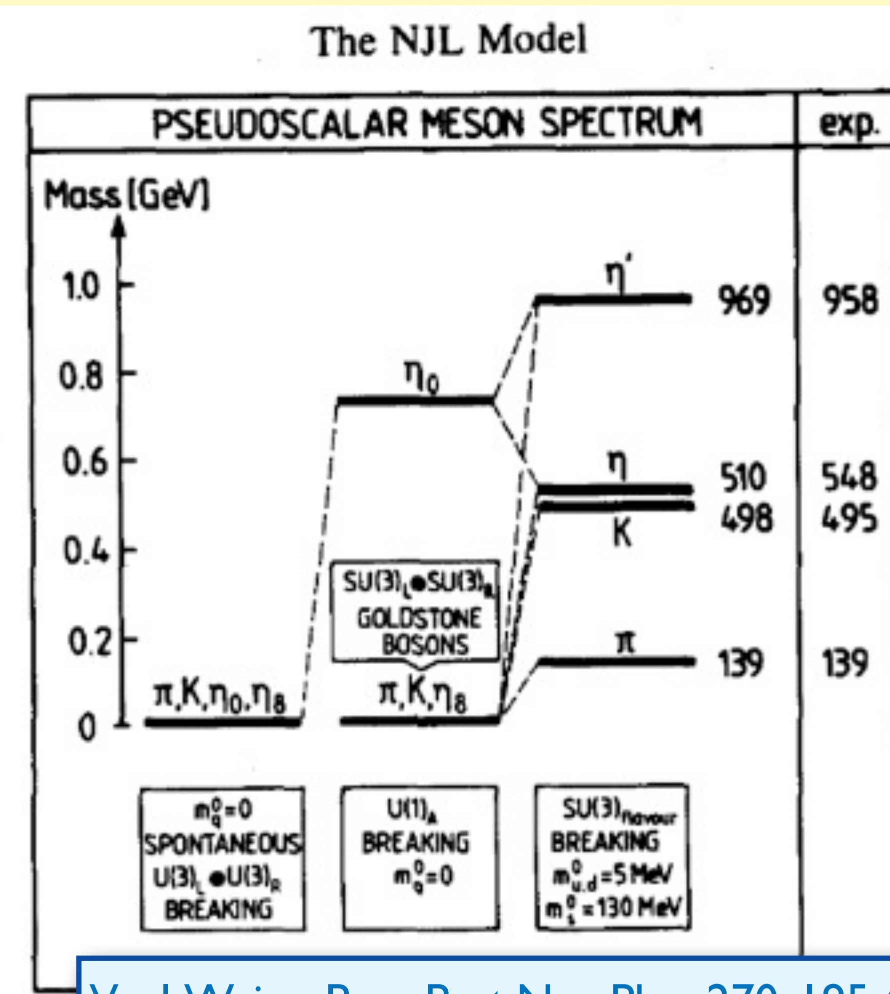
chiral multiplet for pseudoscalar meson

$$(\bar{\mathbf{3}}, \mathbf{3}) \oplus (\mathbf{3}, \bar{\mathbf{3}}) \qquad \bar{q}_i \gamma_5 q_j , \bar{q}_i q_j$$

both octet and singlet contain

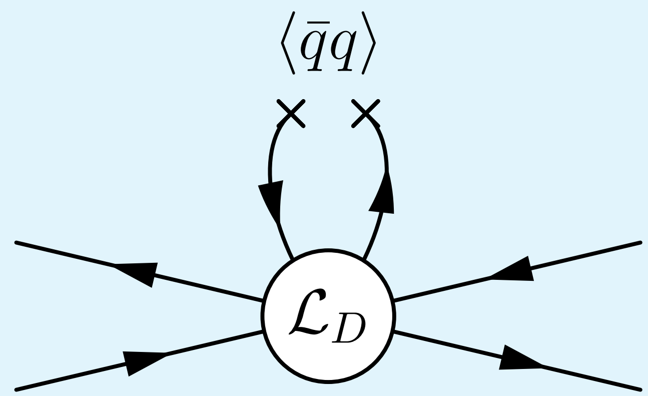
$$\pi, K, \eta_8, \eta_0 \qquad \sigma, a_0, \kappa, f_0$$

should degenerate



Vogl, Weise, Prog.Part.Nuc.Phys.270, 195 (91)

$U_A(1)$ anomaly contributes η' mass through ChSB



If partial restoration of chiral symmetry takes place in nuclear matter

we expect strong mass reduction in nuclei $\Delta m_{\eta'} \sim 100$ MeV

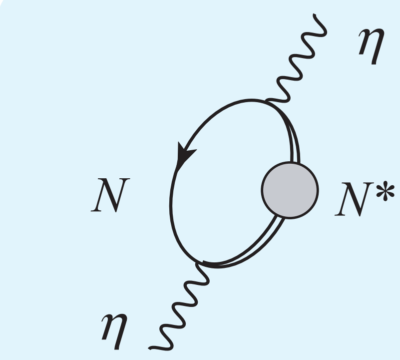
(with 25% PRChS and $m_{\eta'} - m_\eta \approx 400$ MeV)

Narrow width ??

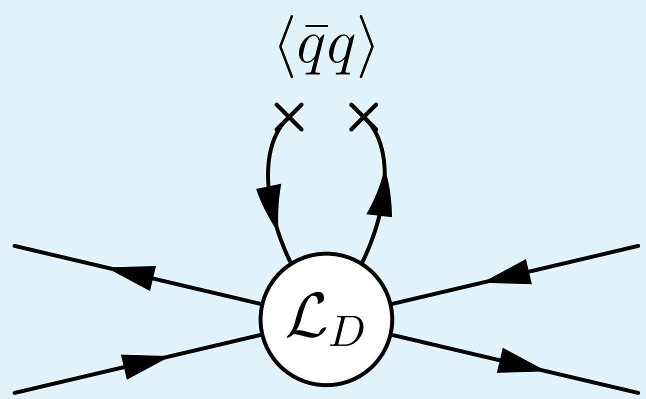
dispersion relation for self-energy

$$\mathrm{Re}V(\omega) = a(\omega_0) + \frac{\omega - \omega_0}{\pi} \mathrm{P} \int d\omega' \frac{\mathrm{Im}V(\omega)}{(\omega' - \omega_0)(\omega' - \omega)}$$

attraction induced by s-channel has same order of absorption



$U_A(1)$ anomaly contributes η' mass through ChSB



contact interaction in hadronic level

This mass reduction does not directly come from nuclear many-body interaction.
Thus the width may be smaller than binding energy.

Current experimental status

RHIC: phenix/star (Low energy pion)

η' mass reduction of at least 200 MeV

Csorgo, Vertesi, Sziklai, PRL 105 (2010) 182301

COSY final state interaction

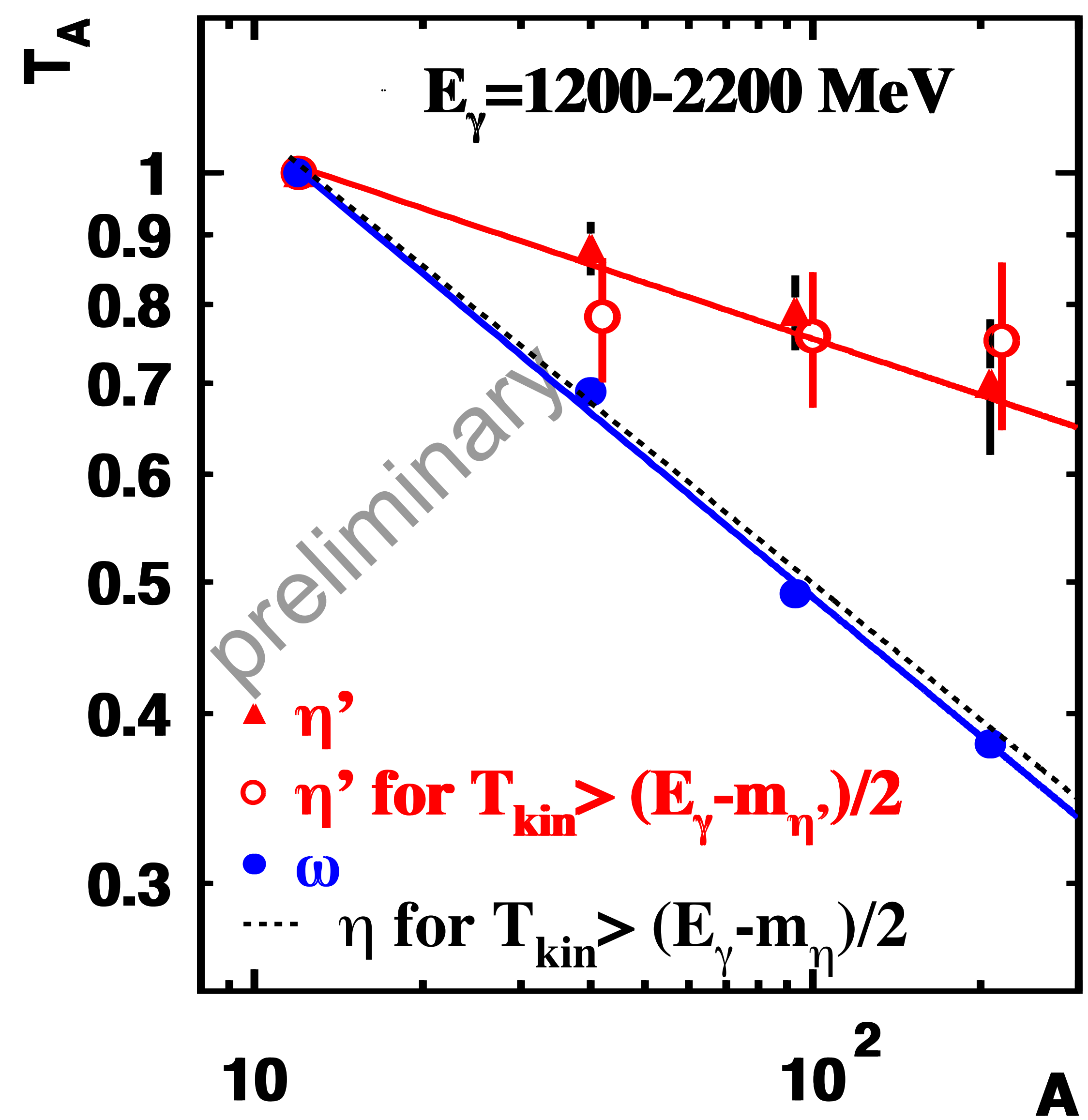
pη' scatt. length ~ 0.1 fm (Δm~10MeV)

Moskal et al, PLB482(2000) 365

CB-ELSA/TAPS

transparency ratio $$T_A = \frac{\sigma_{\gamma A \to \eta' X}}{A \cdot \sigma_{\gamma N \to \eta' X}}$$

normalized to ^{12}C



$\Gamma(\rho_0, <|\vec{p}_{\eta'}|> \approx 0.9$ GeV/c$) \approx$ 25-30 MeV

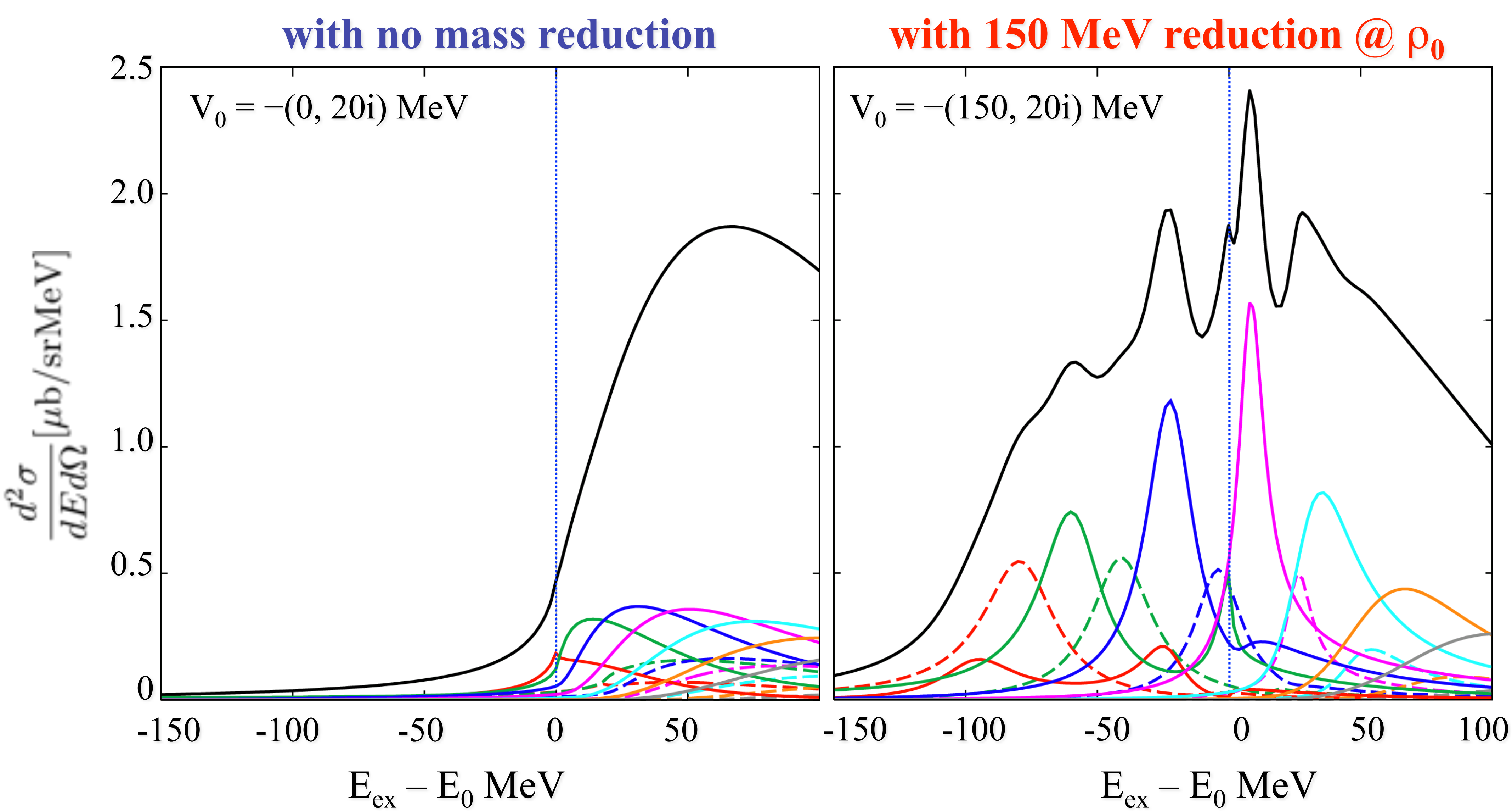
Nanova, talk at Baryon2010

Formation spectrum

H. Nagahiro, PTPS 186, 316 (2010)

$^{12}\mathrm{C}(\pi^+, p)$ p_π=1.8 GeV/c q=200MeV/c

$\pi^+ n \to p\eta'$ $\left(\frac{d\sigma}{d\Omega}\right)^{\mathrm{lab.}} = 100\mu\mathrm{b/st}$



p3/2 hole

s1/2 hole

Friday, 10 June 2011

Summary

hadron spectroscopy

hadron interaction

hadron dynamics vs quark dynamics

understanding and interpretation

fundamental symmetry

from exotic hadron to normal hadron

mesonic nuclei

clear connection to fundamental quantities

partial restoration of chiral symmetry

need clear signal at the beginning

η' meson is bound with a narrow width