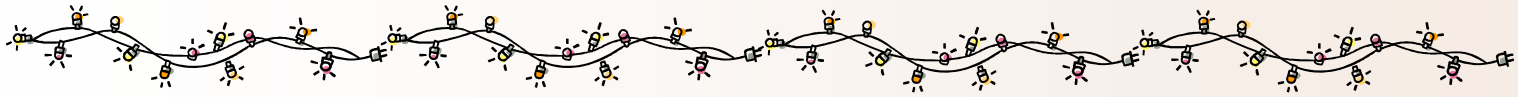
KEK研究会
『J-PARCの物理：ハドロン・原子核研究の新しい局面』

高エネルギー加速器研究機構 素粒子原子核研究所
2008年 8月 7日(木)

Formation of mesic nuclei by (π,N) reactions



Hideko Nagahiro (永廣　秀子)　RCNP, Osaka Univ.

Contents :

- **η-mesic nuclei** formation with p_π ~ 800 MeV/c
  - » in-medium properties of N*(1535)
  - » level crossing phenomena

- **ω-mesic nuclei** formation with p_π ~ 1.8GeV/c
  - » observation possibility of in-medium ω property
    - V_0 = - (159,29i) MeV : (attractive)
    - V_0 = - (100,50i) MeV : (attractive)
    - with N*(1520) resonance : (repulsive)

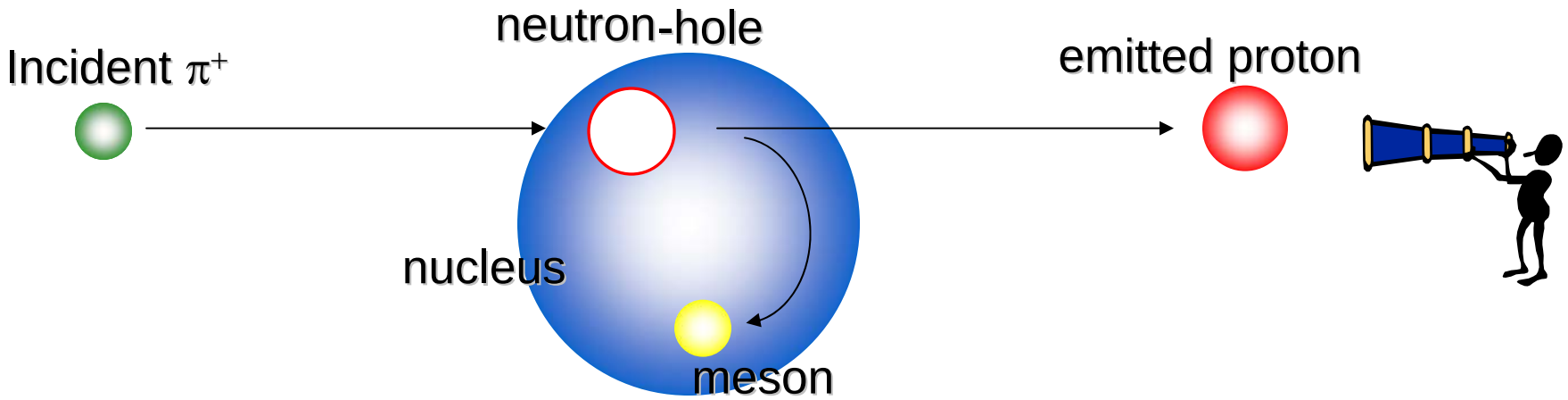
- H.N., D.Jido and S.Hirenzaki, NPA761(05)92
- H.N., D.Jido, S.Hirenzaki, PRC68(03)035205
- D.Jido, H.N. and S.Hirenzaki, PRC66(02)045202

- H.N., D.Jido, S.Hirenzaki, *in preparation*
- D.Jido, E.E.Kolomeitsev, H.N., S.Hirenzaki, Appears in NPA
- K.Itanashi, H.Fujioka, S.Hirenzaki, D.Jido, H.N., Letter of Intent for J-PARC, July 2007

[Ref.]
- H.N., D.Jido, S.Hirenzaki, NPA761 (05) 92
- M. Kaskulov, H.N., S. Hirenzaki, E. Oset, PRC75(07)064616

Introduction

Missing mass spectroscopy



Candidate reactions : recoil-free production

- (d,^{3}He) reaction …established method π atom formation (96, 98, 01)
  S.Hirenzaki, H.Toki, T.Yamazaki, PRC44(91)2472, …
  K.Itahashi, *et al.*, PRC62(00)025202, …
- (γ,p) reaction … smaller distortion effect
  M.Kohno, H.Tanabe PLB231(89)219
  E.Marco, W.Weise, PLB502(01)59 … etc.
- **(π,N) reaction** … pion beam at J-PARC
  Chrien *et al.*, PRL60(1988)2595
  Liu, Haider, PRC34(1986)1845

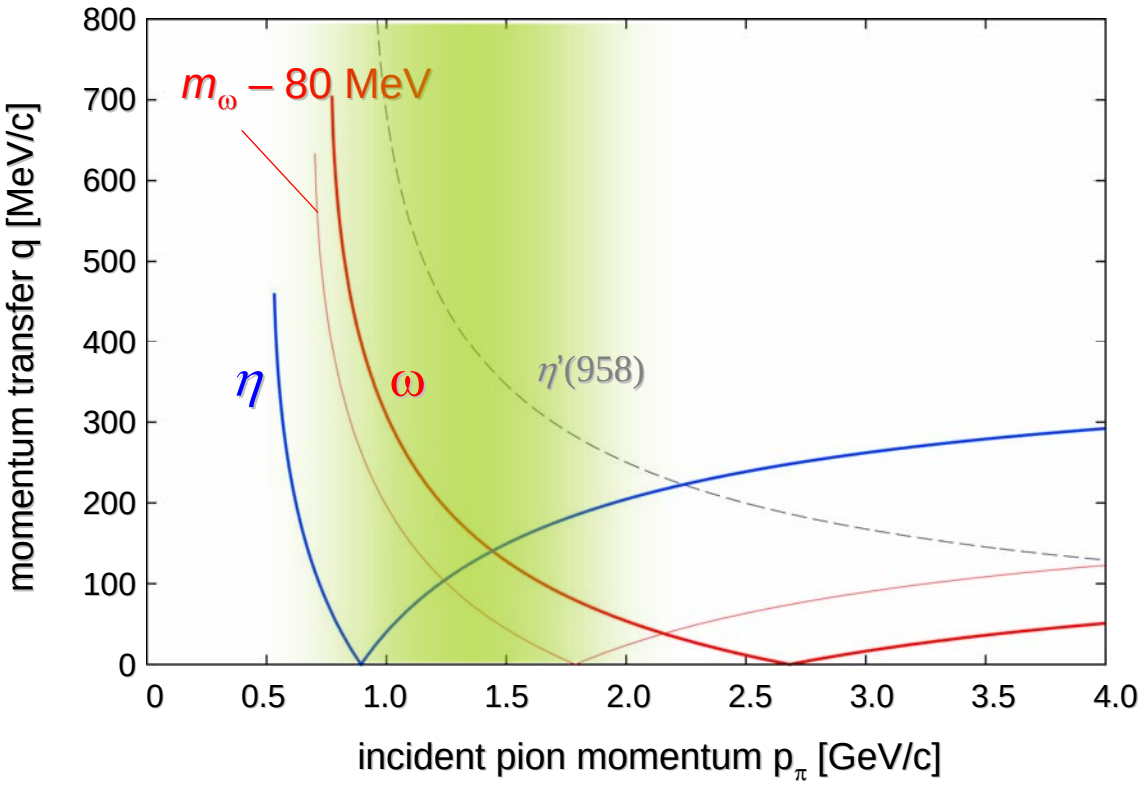
meson production in recoil-free kinematics

magic momentum in (π,N) reaction

η meson ... p_π ~ 0.8 - 0.9 GeV/c

ω meson ... p_π ~ 2.5 GeV/c

p_π ~ 1.8 GeV/c → m_ω – 80 MeV



η mesic nuclei formation

works for η mesic nuclei (η-nucleus systems)

- » (π^+,p) * Liu, Haider, PRC34(1986)1845 [theo]
  * Chiang, Oset, and Liu, PRC44(1988)738 [theo]
  * Chrien *et al.*, PRL60(1988)2595 [exp]
  * Kohno, Tanabe, PLB231(1989)219; NPA519(1990)755 [theo]
- » $(d,^3He)$ * Hayano, Hirenzaki, Gilltzer, EPJ.A6(1999)99 [theo]
  * D. Jido, H.Nagahiro, S. Hirenzaki, PRC66(2002)045202 [theo]
  * Exp. at GSI (Yamazaki, Hayano group) 2005-6 [exp]
- » (γ,p) * H.Nagahiro, D.Jido, S.Hirenzaki, NPA761(2005)92 [theo]
- » η-^{3}He system : PRL92(04)252001:TAPS@MAMI [exp] ←→ "Comment" by Hanhart, PRL94(05)049101.

etc… (ex. (γ,η) @ Tohoku, etc …)

interests in η-mesic nuclei

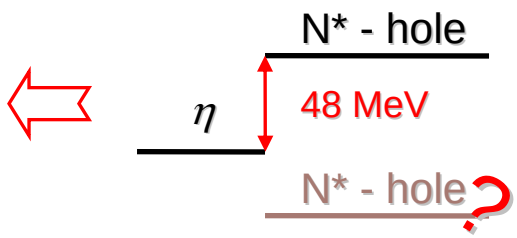
- » η -nucleon system : strongly couples to **N*(1535) resonance**
  - → affects **η-nucleus optical potential**
  - → we can see **in-medium behavior of N*(1535)**

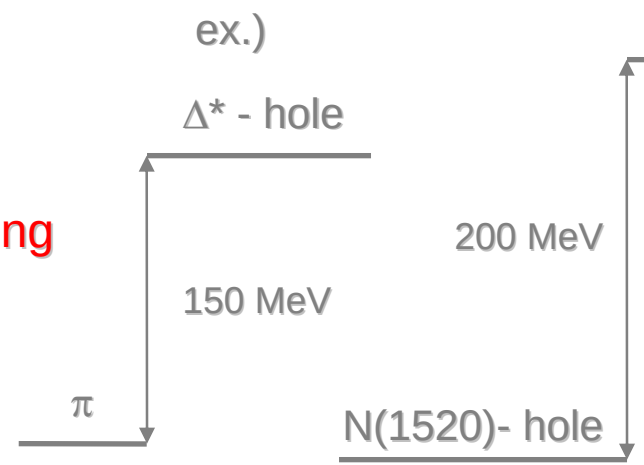
» Levels are close ⇒ chance of level crossing

What happens ?

Why happen ?

How observe?



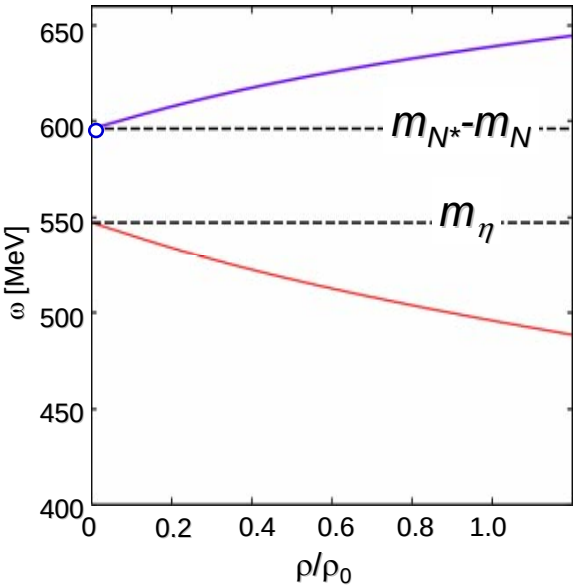


level crossing between η and N*-*hole* mode

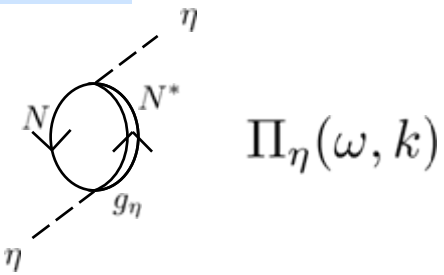
in-medium η propagator (**infinite matter**)

$$D_\eta(\omega,k)=\frac{1}{\omega^2-k^2-m_\eta^2-\Pi_\eta(\omega,k)}$$

pole-flow



self-energy



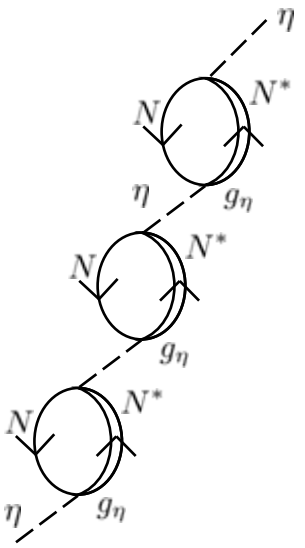
$\Pi_\eta(\omega,k)$

$g_\eta \simeq 2.0\,(\Gamma_{N^*\to\eta N} \simeq 75\ \mathrm{MeV})$

N* dominance

Chiang, Oset, Liu PRC44(1991)738
Jido, Nagahiro, Hirenzaki, PRC66(2002)045202

propagator (Green's function)



two branches

η meson branch and N*-h branch

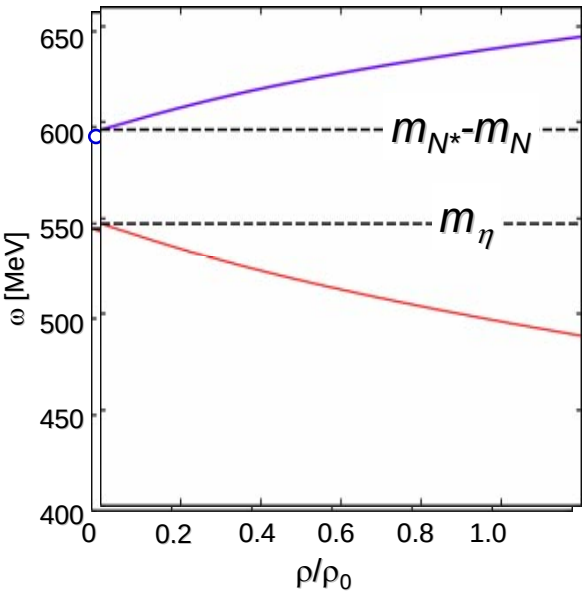
T. Waas, W. Weise, NPA 625 (1997) 287.
T.Inoue, E.Oset, NPA710(02)354

level crossing between η and N*-*hole* mode

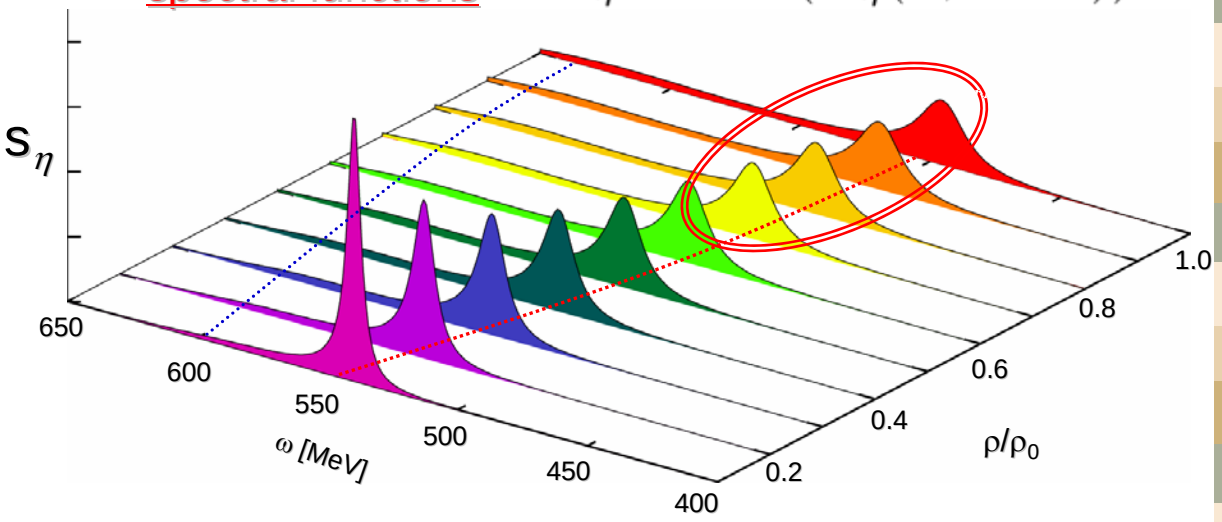
in-medium η propagator (infinite matter)

$$D_\eta(\omega, k) = \frac{1}{\omega^2 - k^2 - m_\eta^2 - \Pi_\eta(\omega, k)}$$

pole-flow



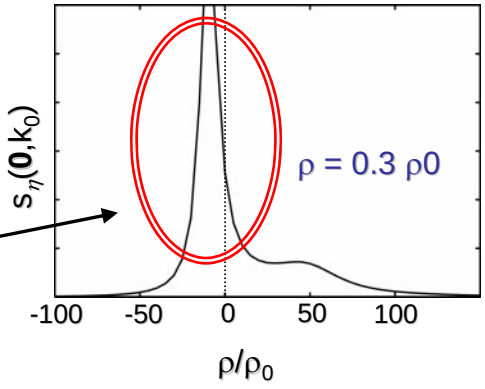
spectral functions $S_\eta = -\mathrm{Im}(D_\eta(\omega, k=0))$



Chiral Unitary approach

T. Waas, W. Weise, NPA 625 (1997) 287

T. Inoue E.Oset, NPA710(02)354, Fig.8

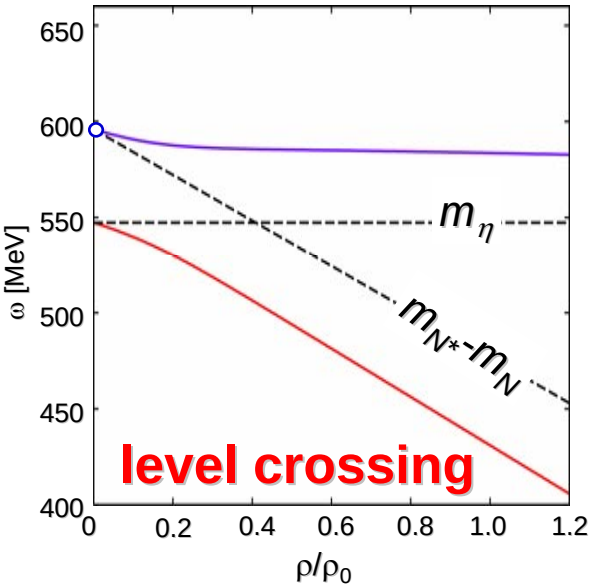


level crossing between η and N*-*hole* mode

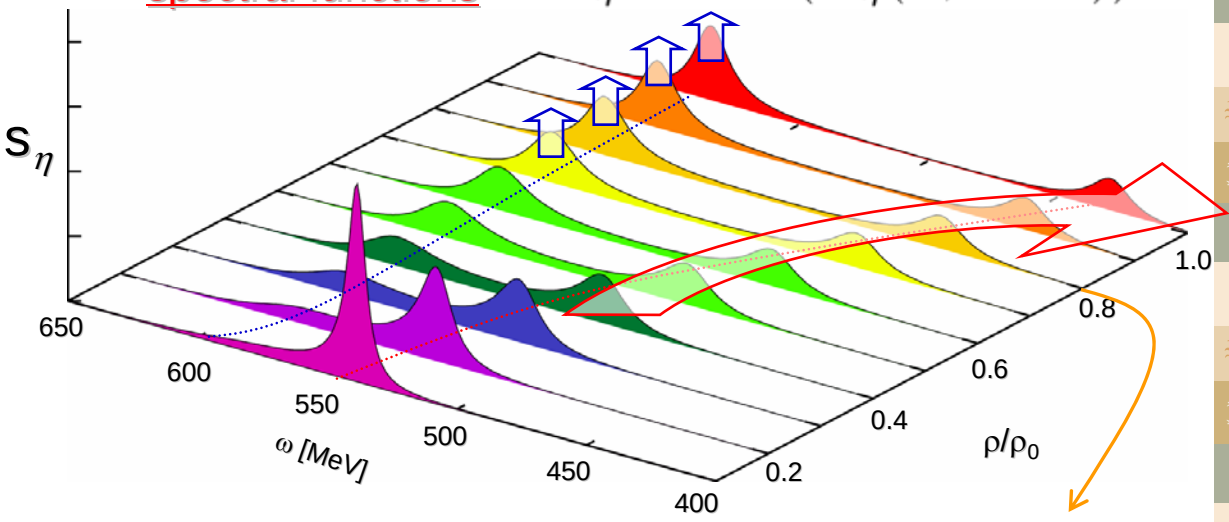
in-medium η propagator (infinite matter)

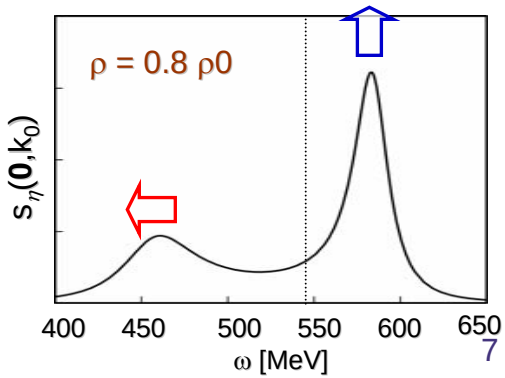
$$D_\eta(\omega,k)=\frac{1}{\omega^2-k^2-m_\eta^2-\Pi_\eta(\omega,k)}$$

N*-hole mass reduction (20%@ρ_0)



spectral functions $S_\eta=-\mathrm{Im}(D_\eta(\omega,k=0))$





- level repulsion yields ...
  - lower pole goes downward
    → deeply bound η ?
- level mixing …
  - strength of upper pole > that of lower pole

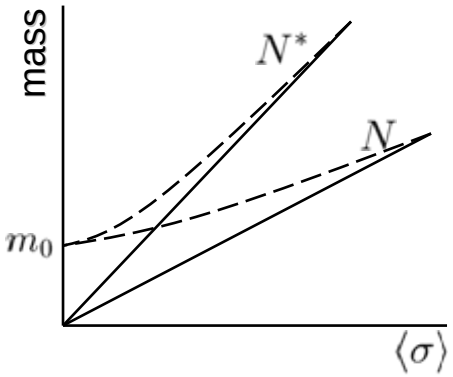
Jido, Kolomeitsev, Nagahiro, Hirenzaki e-Print: arXiv:0801.4834 [nucl-th]

What causes the level crossing ? : partial restoration of chiral symmetry

Chiral doublet model

DeTar, Kunihiro PRD39(89)2805
Jido, Nemoto, Oka, Hosaka NPA671(00)471
Jido, Oka, Hosaka PTP106(01)873
Kim, Jido, Oka NPA640(98)77

N* : Chiral partner of nucleon



mass difference of N* and N

$$m_N^*(\rho) - m_{N^*}^*(\rho) = (1 - C\frac{\rho}{\rho_0})(m_N - m_{N^*})$$

C ~ 0.2 : strength of chiral restoration at the saturation density ρ_0

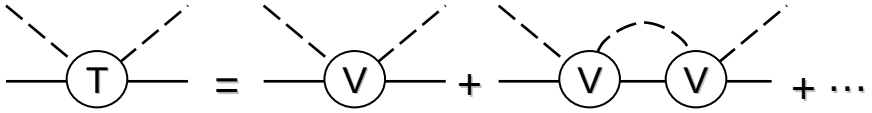
reduction of mass difference in the nuclear medium

Chiral unitary model

Kaiser, Siegel, Weise PLB362(95)23
Waas, Weise NPA625(97)287
Garcia-Recio, Nieves, Inoue, Oset PLB550(02)47
Inoue, Oset NPA710(02)354

N* : resonance dynamically generated
in meson-baryon scattering

→ quasi bound state of $K\Sigma$



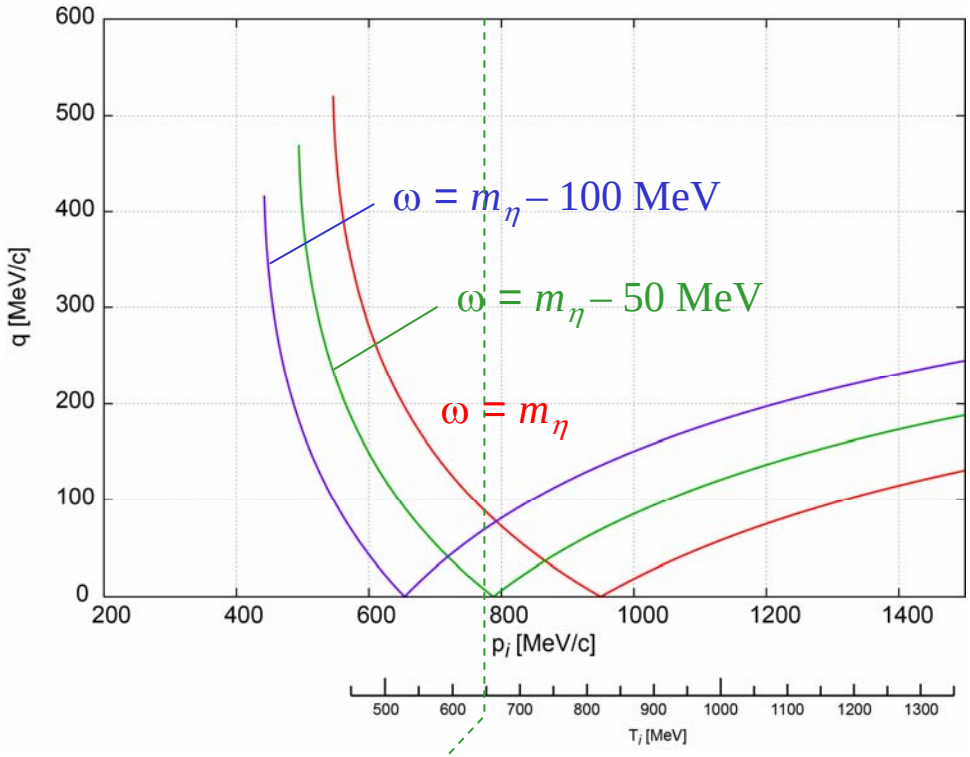
coupled channel Bethe-Salpater eq. in medium

no Pauli blocking for Σ in nuclear medium

No mass shifts of N* is expected in the nuclear medium

$^{12}C(\pi^+,p)^{11}C_\eta$ reaction

momentum transfer : **forward proton angle (0 degree)**



T_π = 650 MeV (p_π ~ 777 MeV/c) → $\left(\frac{d\sigma}{d\Omega}\right)^{Lab.} = 2.4\text{mb/sr}$

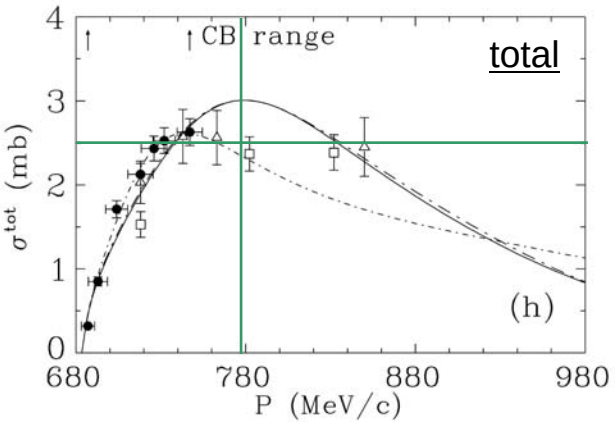
elementary cross section

$$\pi^- p \rightarrow \eta n$$

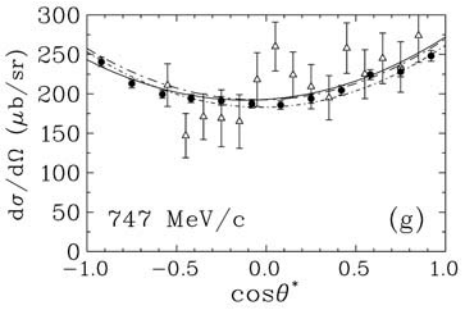
$$\pi^+ n \rightarrow \eta p$$

S.Prakhov *et al.*, [Crystal Ball Collaboration] PRC72,015203 (2005).

total cross section



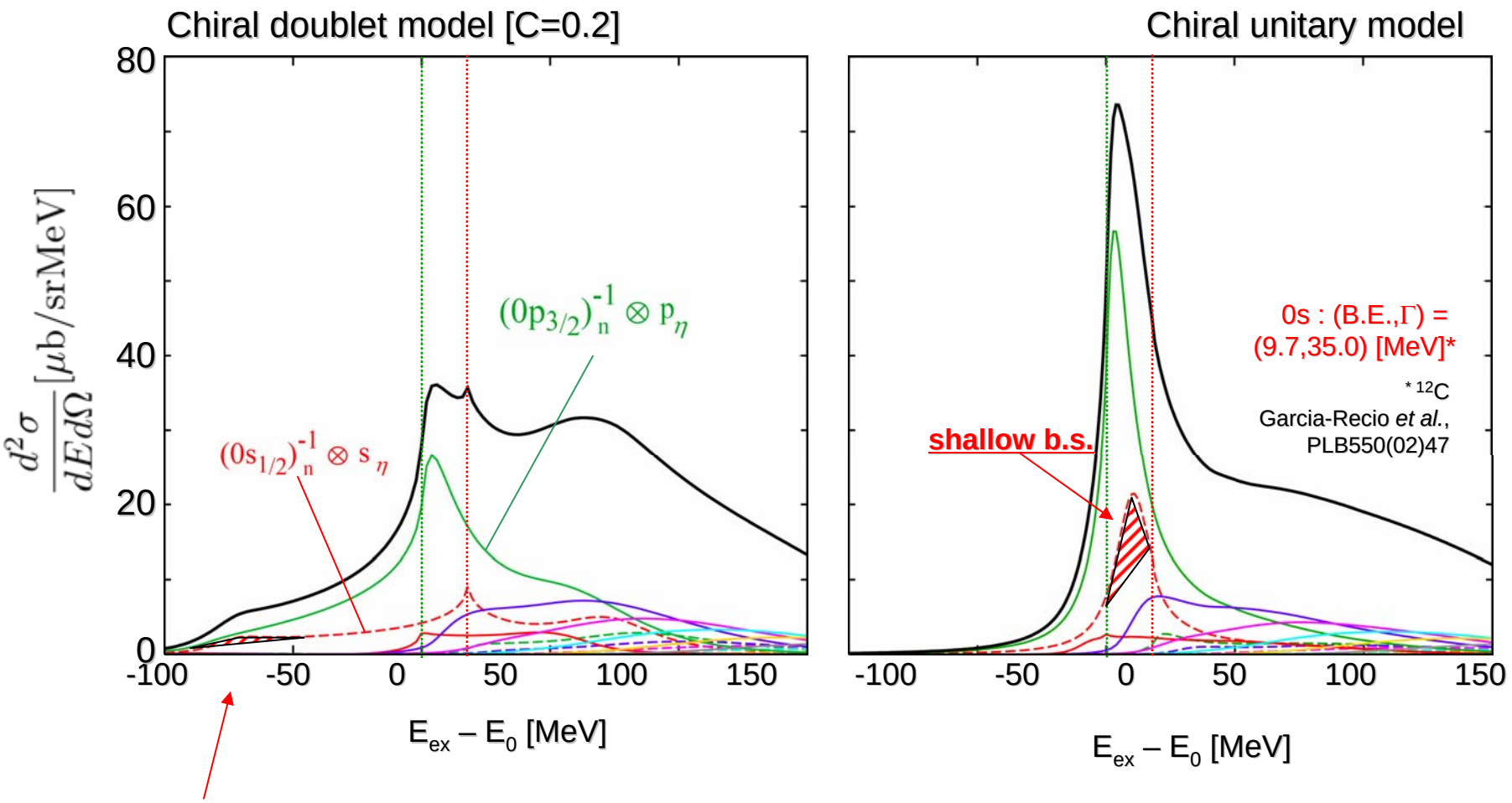
angular distribution ~ flat

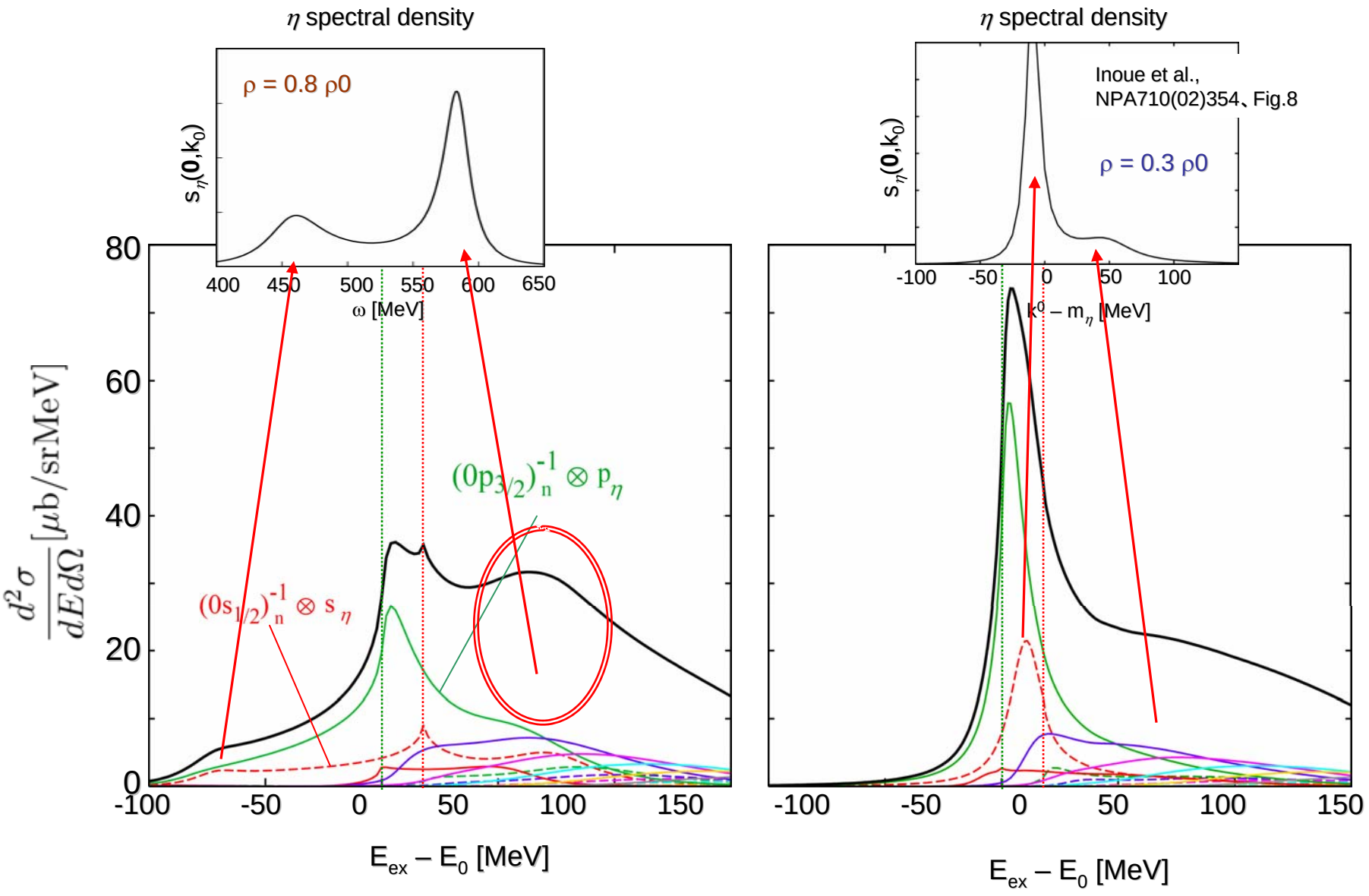


[Morimatsu, Yazaki NPA435(85)727, NPA483(88)493]

(π^+,p) spectra : ^{12}C target : Green's function method

T_π = 650 MeV (p_π = 777 MeV/c) : θ = 0 deg. (Lab)

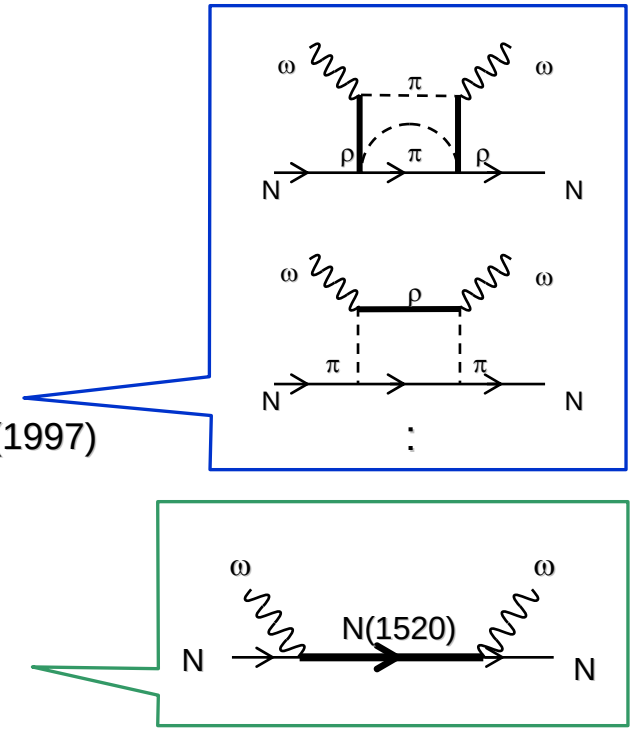




K.Itanashi, H.Fujioka, S.Hirenzaki, D.Jido, H.Nagahiro, Letter of Intent for J-PARC 2007

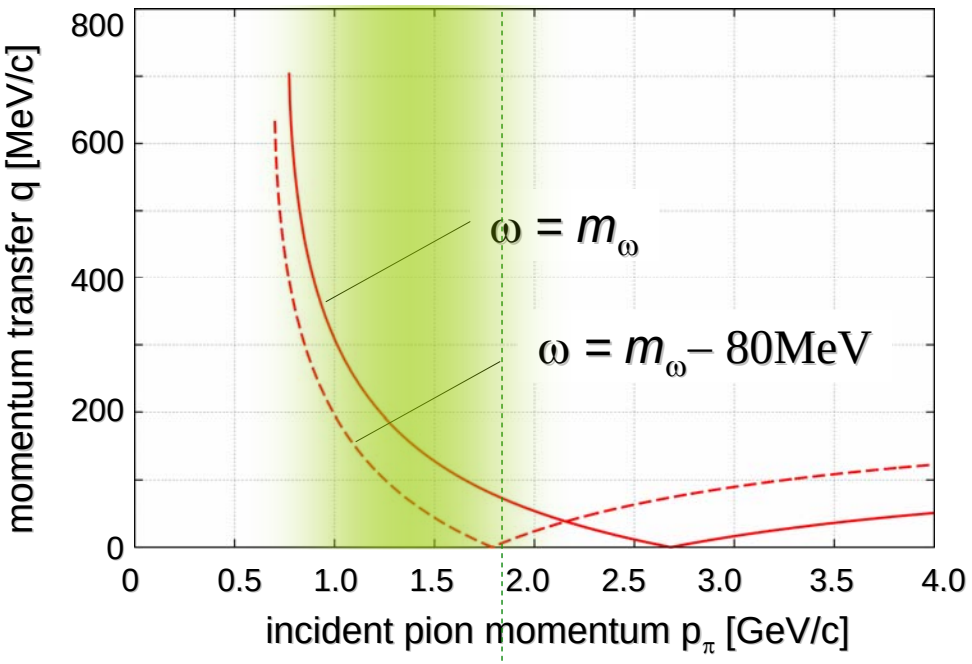
ω mesic nuclei formation

- ω meson properties in medium
  - » various models/approaches
    - › scaling rule
      - – Brown and Rho, PRL66, 2720 (1991)
    - › QCD sum rule
      - – Hatsuda and Lee, PRC46, 34 (1992).
    - › SU(3) chiral Lagrangian
      - – Klingl, Kaiser and Weise, NPA624, 527 (1997)
      - – Klingl, Waas, Weise, NPA650(99)299
      - – Marco, Weise, PLB502(01)59
    - › couples to N*(1520)-hole
      - – Lutz, Wolf, Friman, NPA706, 431 (2002)



  - » experimental works
    - › invariant mass
      - – p + A → ω + X at KEK E325 : (M.Naruki *at al.*, PRL96(06)092301 etc.)
      - – γ + A → ω + X → $\pi^0\gamma$ +X' by ELSA-TAPS : (D.Trnka *et al.*, PRL94(05)192303)
    - › **missing mass**
      - – (γ,p) reaction at SPring-8 LEPS (N.Muramatsu, LEPS group)
      - – **(π,N) reaction at J-PARC** (K.Ozawa and R.S.Hayano, LoI for J-PARC, '07)

pion kinetic energy and elementary cross section

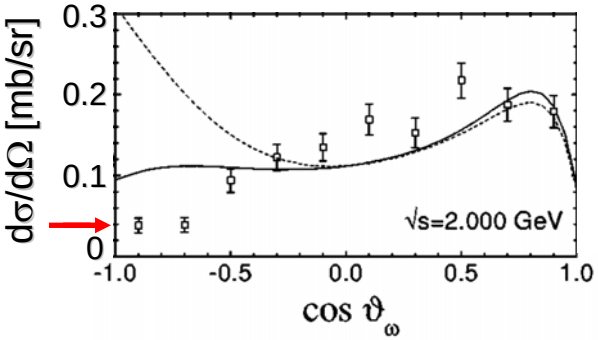


p_π = 1.8 GeV/c

... recoilless at ~ m_ω – 80MeV

elementary cross section

$$\pi^- + p \rightarrow \omega + n$$



G.Penner and U.Mosel, PRC65(02)055202, Fig.4
data: J.S.Danburg et al., Lawrence Radiation Lab. PRD2(1970)2564

$$\left(\frac{d\sigma}{d\Omega}\right)^{CM}_{n(\pi^+,p)\omega} = 0.04\ \mathrm{mb/sr}$$

$$\left(\frac{d\sigma}{d\Omega}\right)^{Lab.}_{n(\pi^+,p)\omega} = 0.17\ \mathrm{mb/sr}$$

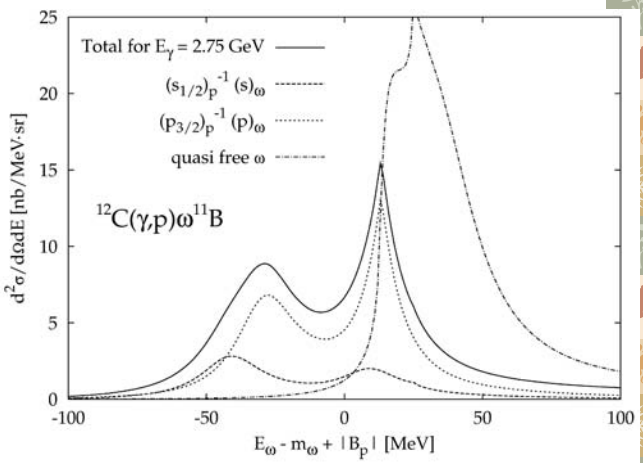
cf.) η production at p_π=800 MeV/c

$$\left(\frac{d\sigma}{d\Omega}\right)^{Lab.} = 2.4\mathrm{mb/sr}$$

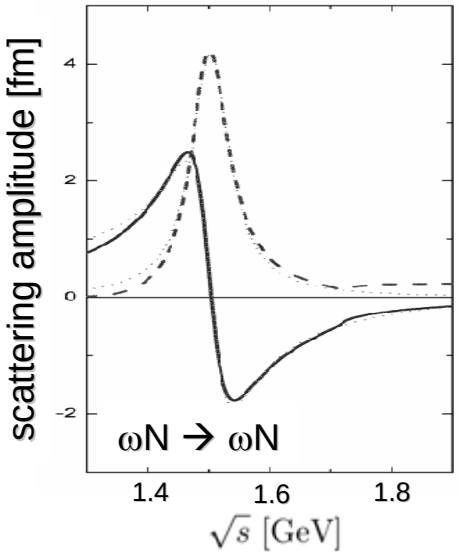
less than 1/10

potentials which we use here

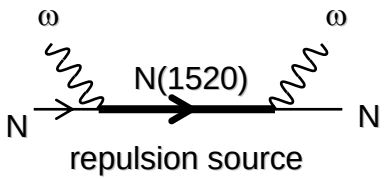
- $V_0 = -(156, 29i)$ MeV
  - » corresponds to ... works with SU(3) chiral Lagr
    - – Klingl, Kaiser and Weise, NPA624(97)527,Klingl, W
    - – Marco, Weise, PLB502(01)59
- $V_0 = -(100, 50i)$ MeV
  - » less attraction and large absorption
- $V_0 = -(0, 50i)$ MeV
  - » no attraction and large absorption
- with N*(1520)-hole mode with $g_{\omega NN^*}$ obtained in Lutz et al., NPA706, 431 (2002)

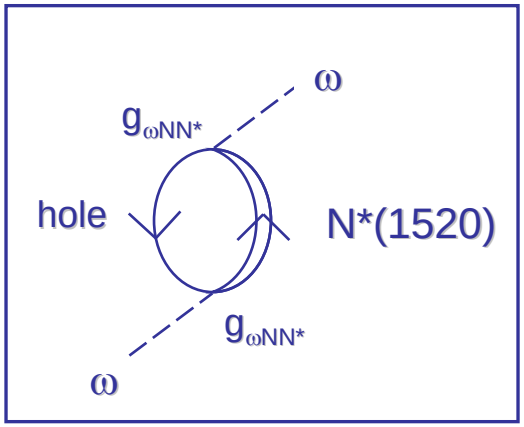


$$V(r) = V_0 \frac{\rho(r)}{\rho_0}$$



M. Lutz et al.,NPA706 (02) 431





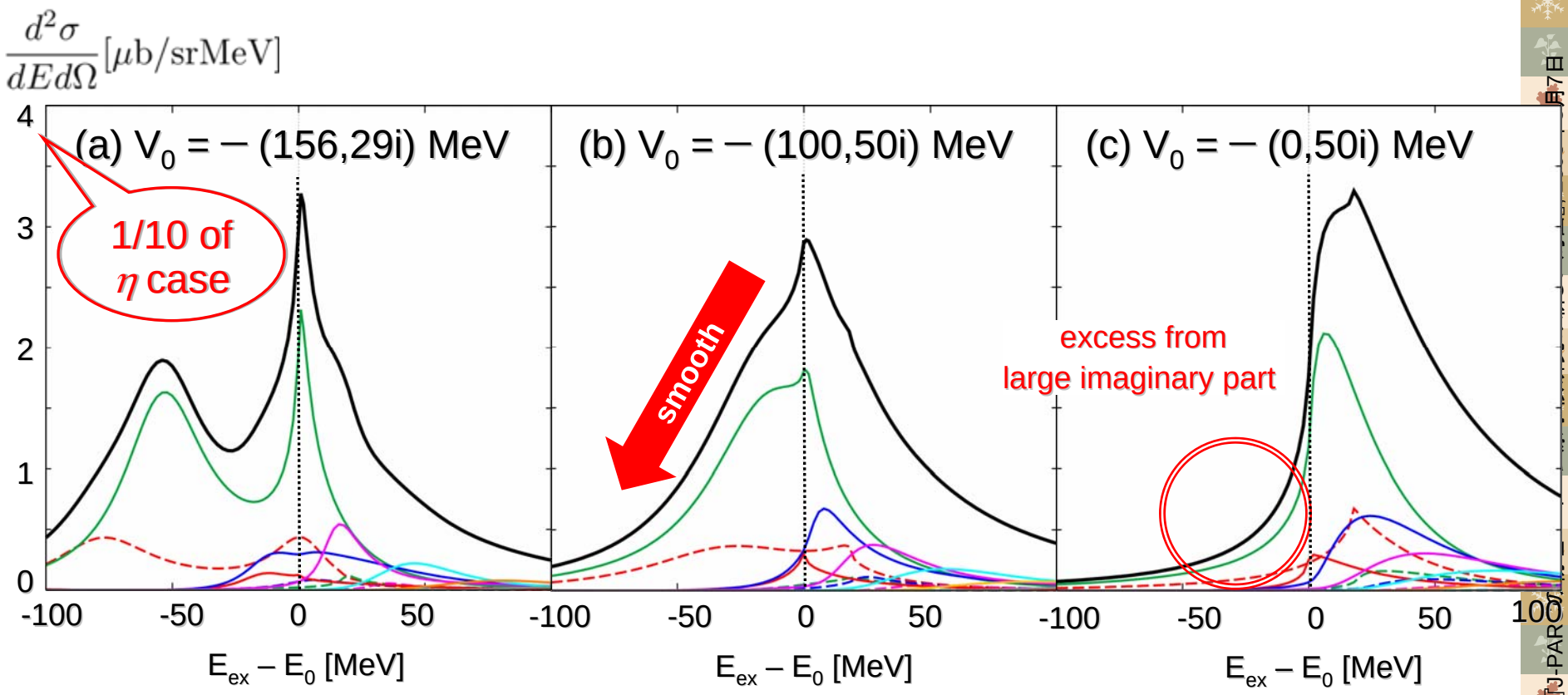
numerical results : calculated with Green's function method[1]

[1] Morimatsu, Yazaki NPA435(85)727, NPA483(88)493

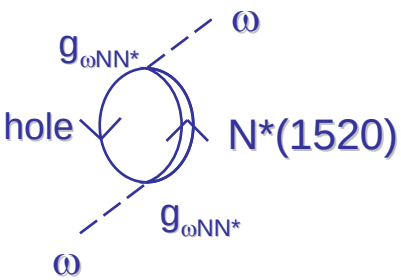
reaction : $^{12}C(\pi^+,p)^{11}C_\omega$

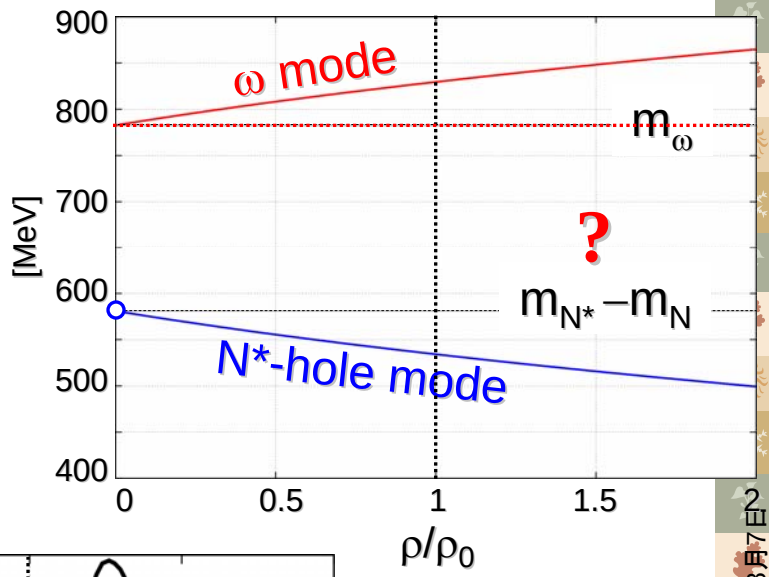
incident pion momentum : p_π = 1.8 GeV/c

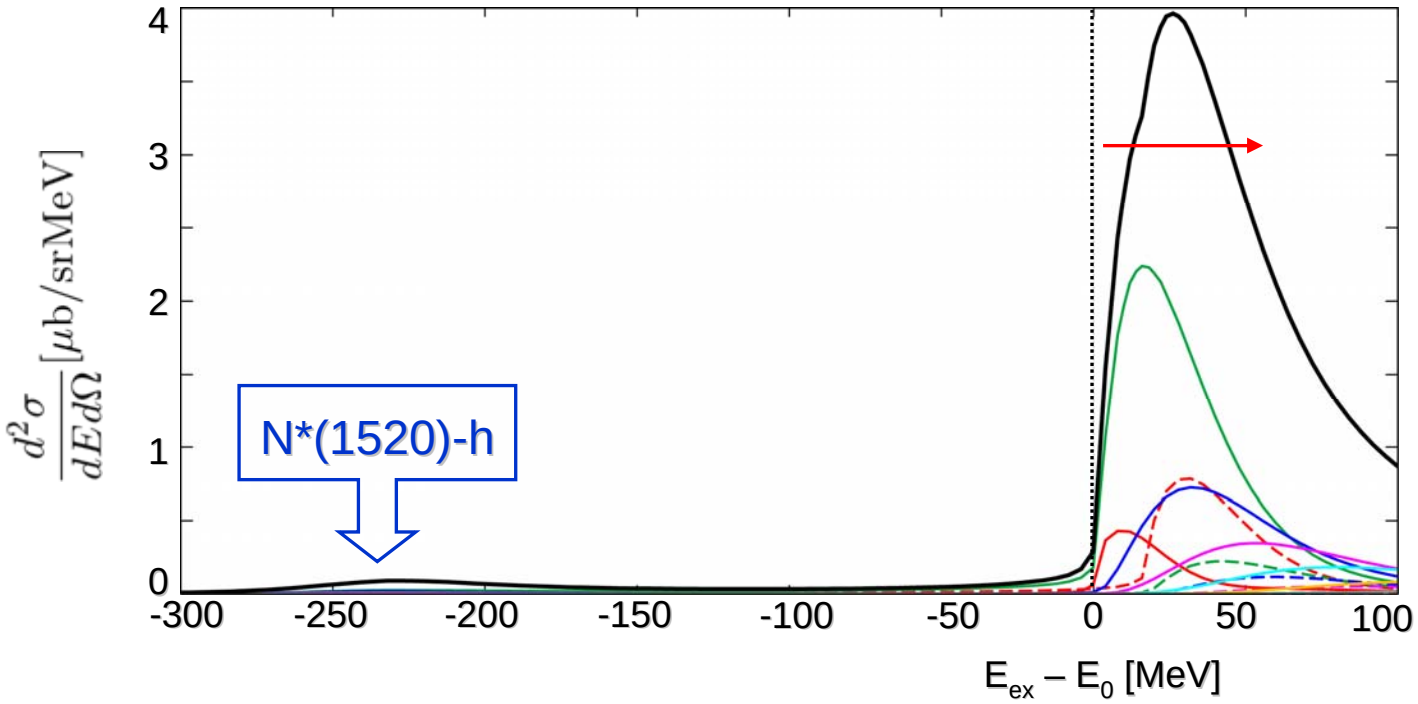
proton angle : 0 degree



N(1520)-*hole* coupling







summary

- η-meson nucleus system
  - **in-medium properties of N*(1535) resonance**
  - chance of level crossing between ηN and N*
    - could be caused by partial restoration of chiral symmetry (Chiral doublet model)
  - phenomena induced by the level crossing
    - deeply bound η ? upper mode enhancement ?
- (π^+,p) reaction (~(π^-, n)) ... possible at J-PARC
  - incident pion kinetic energy
    - T_π = 820 MeV (p_π ~ 950 MeV/c) : recoilless at η threshold
    - T_π = 650 MeV (p_π ~ 777 MeV/c) : recoilless at η threshold – 50 MeV
- ω-meson nucleus system
  - mass shift ? attractive ? repulsive ?
  - experimental feasibilities at J-PARC ... case study
    - V_0 = −(156,29i) MeV ... ref.) Klingl et al., NPA624(97)527, NPA650(99)299
    - V_0= −(100,50i) MeV ... large attraction and large absorption
    - V_0 = −(0,50i) MeV ... no attraction but large absorption
    - with N*(1520)-hole mode ... ref.) Lutz et al., NPA706(02)431
  - signal ~ (signal of eta) / 10
  - microscopic estimation ... future work