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- Pre-symposium of INPC 2007 -

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η-mesic nuclei formation induced by meson beam at J-PARC

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Satoru Hirenzaki (Nara WU)

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

D.Jido, E.Kolomeitsev, H.Nagahiro, S.Hirenzaki, in preparation
H.Nagahiro, D.Jido, S.Hirenzaki, in preparation

Introduction

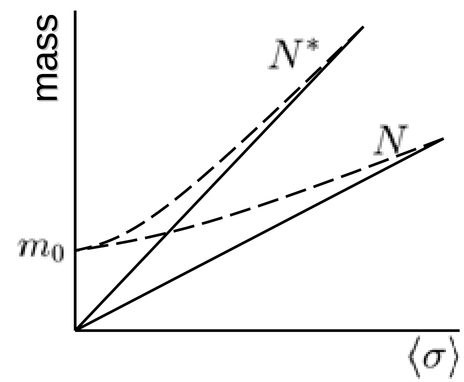
- η-mesic nuclei
  - works for η-mesic nuclei
    - (π^+,p) * Liu, Haider, PRC34(1986)1845 [theo]
      * Chiang, Oset, and Liu, PRC44(1988)738 [theo]
      * Chrien *et al.*, PRL60(1988)2595 [exp] → negative result
    - (d,^{3}He) * Hayano, Hirenzaki, Gilltzer, EPJ.A6(1999)99 [theo]
      * D. Jido, 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-light-nucleus system : TAPS@MAMI(2004) [exp]
    - etc… (ex. (γ,η) @ Tohoku, etc …)
  - strong coupling to N*(1535) [J^P= ½$^-$] resonance
    - **in-medium properties of N*(1535) ←→ η-mesic nuclei**
      - Chiral doublet model … N* mass reduction in medium
      - Chiral unitary model … no change N* mass in medium
- formation of η-mesic nuclei induced by meson beam
  - π and K beams are available at J-PARC → <u>(π^+,p) reaction</u>
    - with the chiral doublet model & chiral unitary model
    - appropriate kinematics
  - reconsideration of (π^+,p) experiment at 1988
    - Why did they get the negative result ?

Chiral models for N*(1535) in medium

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 nucleon

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

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

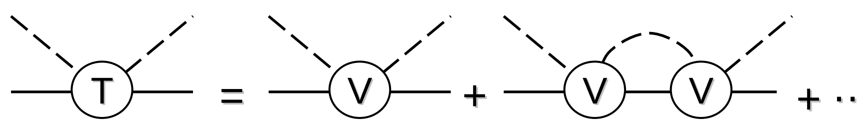
reduction of mass difference in the nuclear medium

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 KΣ**



coupled channel Bethe-Salpater eq. in medium

no Pauli blocking for Σ in nuclear medium

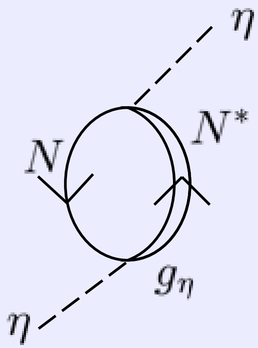
No mass shifts of N & N* are expected in the nuclear medium

η-nucleus interaction ~ N* dominance model ~

optical potential

$$V_{\rm opt} = \frac{g_\eta^2}{2\mu} \frac{\rho}{\omega - (m_{N^*}(\rho) - m_N(\rho)) + i\Gamma_{N^*}(s;\rho)/2} + \text{(cross term)}$$

η self-energy



Chiang, Oset, Liu PRC44(1991)738

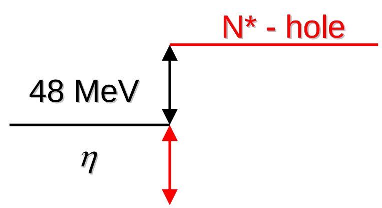
Jido, Nagahiro, Hirenzaki, PRC66(2002)045202

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

potential nature

$$m_\eta - (m_{N^*} - m_N) < 0$$

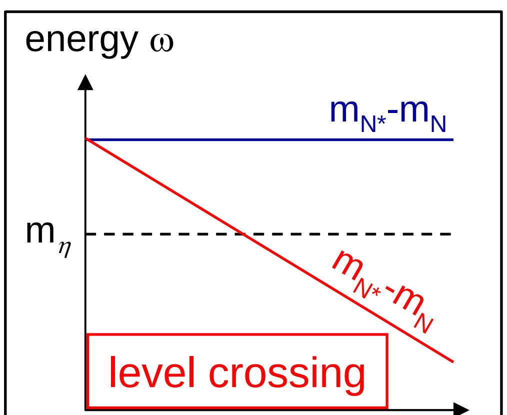
attractive



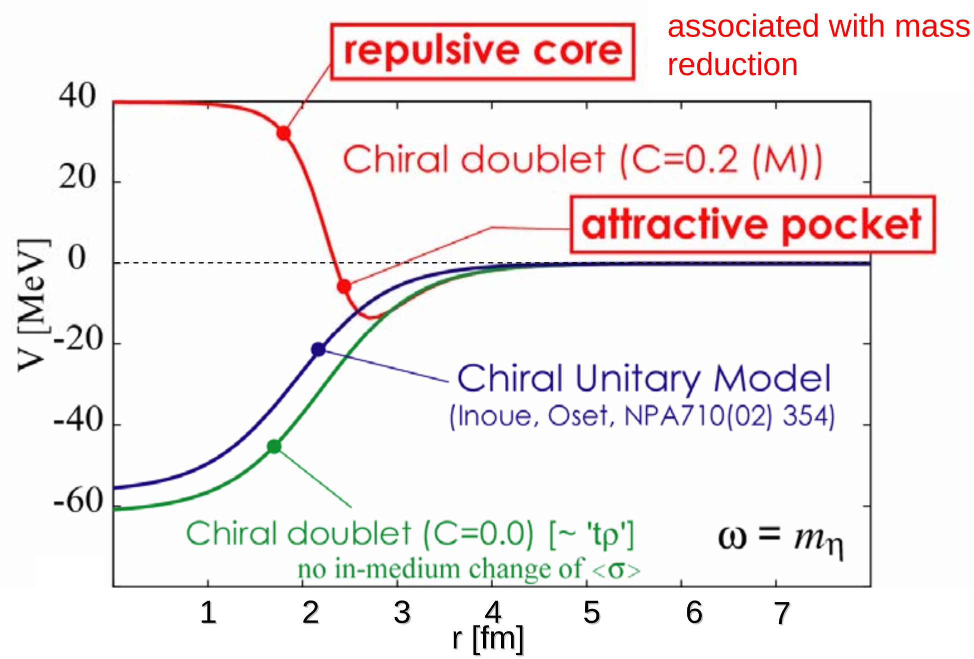
medium effect

$$m_\eta - (m_{N^*}(\rho) - m_N(\rho)) > 0$$

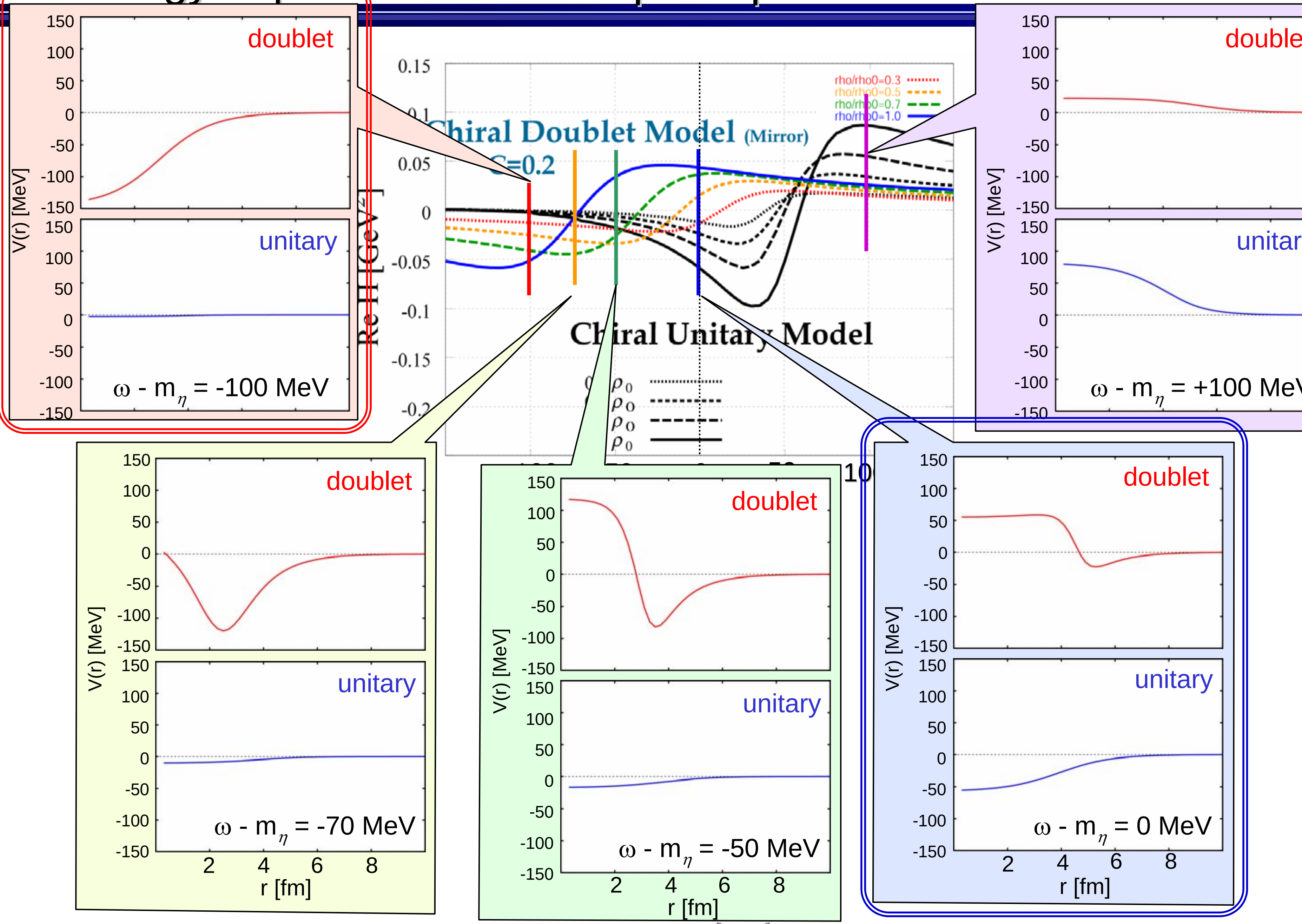
repulsive



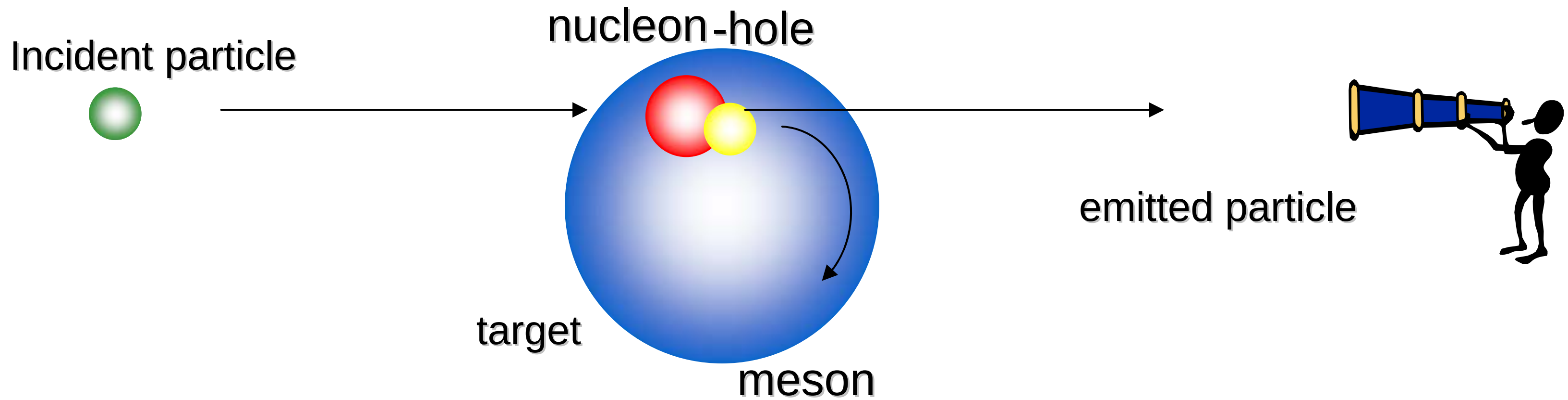
Jido, Kolomeitsev, Nagahiro, Hirenzaki in preparation



Energy dependence of the optical potentials



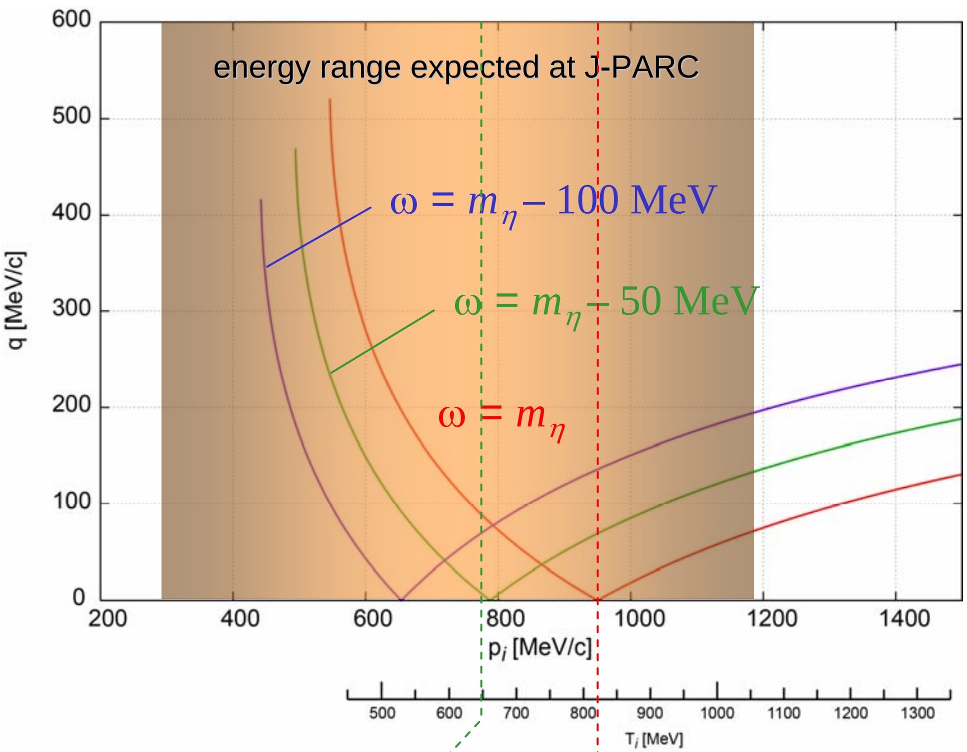
Missing mass spectroscopy : one nucleon pick-up



- (d,^{3}He) : established by studies of pionic atom formation
  - theory … S.Hirenzaki, H.Toki, T.Yamazaki, PRC44(91)2472, …
  - experiment … K.Itahashi et al., PRC62(00)025202, …
    - › η-mesic nuclei formation : D.Jido,H.N.,S.Hirenzaki, PRC66(02)045202, H.N.,D.Jido,S.Hirenzaki, PRC68(03)035205.
- (γ,p) : smaller distortion effect
  - ω-nucleus … Marco, Weise, PLB502(01)59
  - π-atom … Hirenzaki, Oset, PLB527(02)69
    - › η-mesic nuclei formation : H.N., D.Jido,S.Hirenzaki, NPA761(05)92.
- (π^+,p) : could be possible at J-PARC ?
  - › secondary meson beam, π, K, …

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

momentum transfer : forward angle (0 degree)



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

T_π = 820 MeV (p_π ~ 950 MeV/c) → $$\left(\frac{d\sigma}{d\Omega}\right)^{Lab.} = 0.64\mathrm{mb/sr}$$

elementary cross section

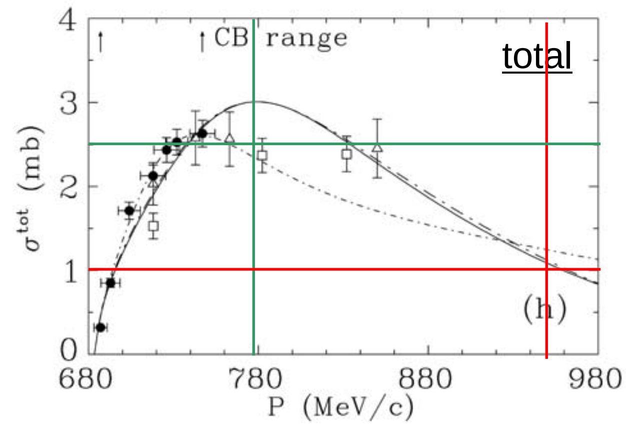
$$\pi^- p \rightarrow \eta n$$

↓

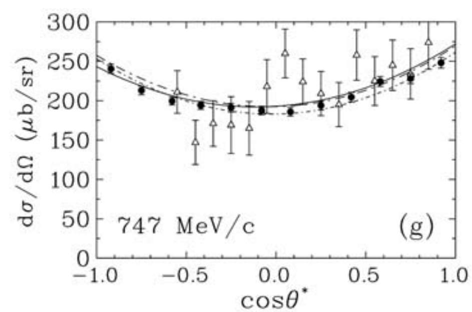
$$\pi^+ n \rightarrow \eta p$$

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

total cross section



angular distribution ~ flat

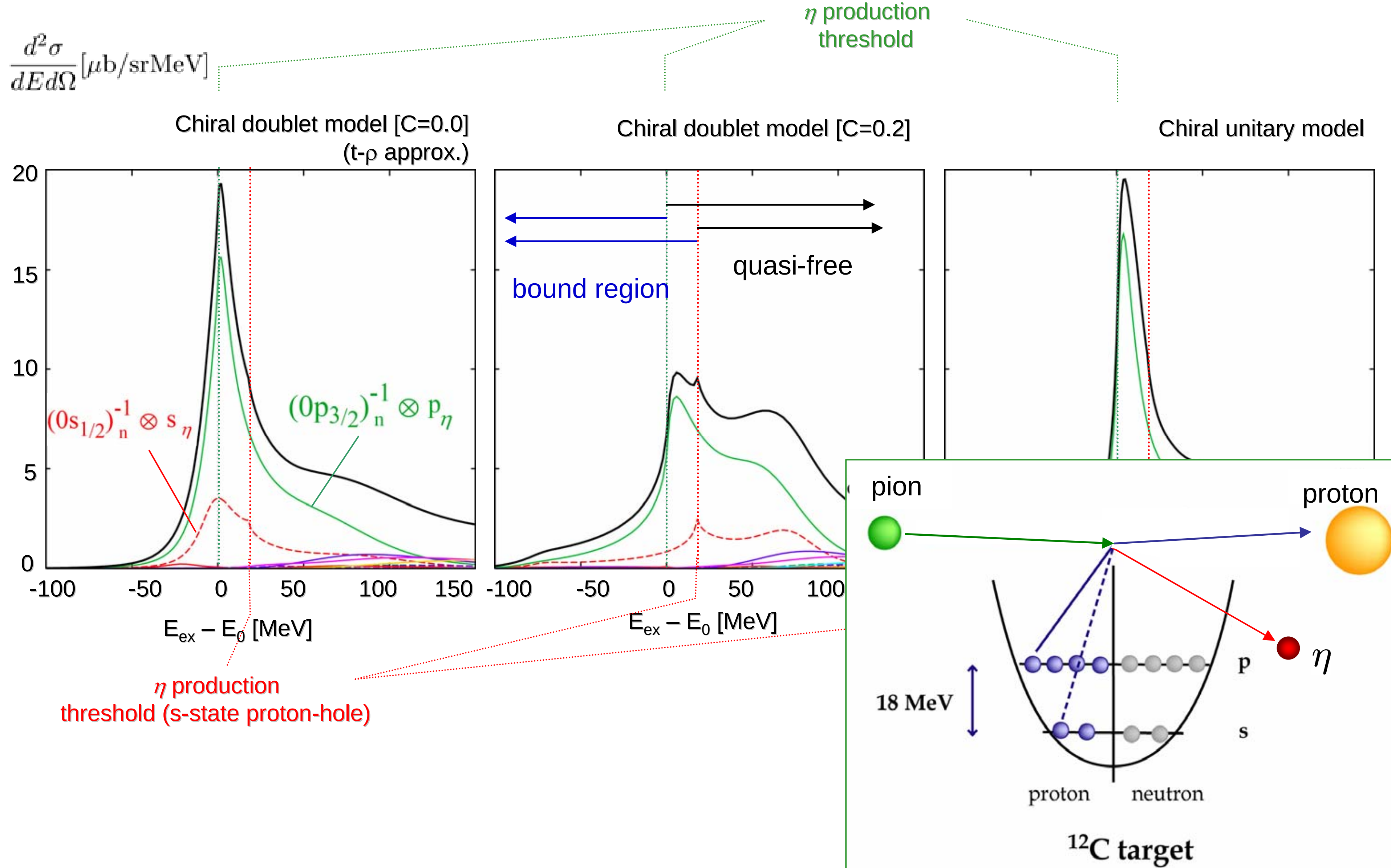


* Morimatsu, Yazaki NPA435(85)727
NPA483(88)493

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

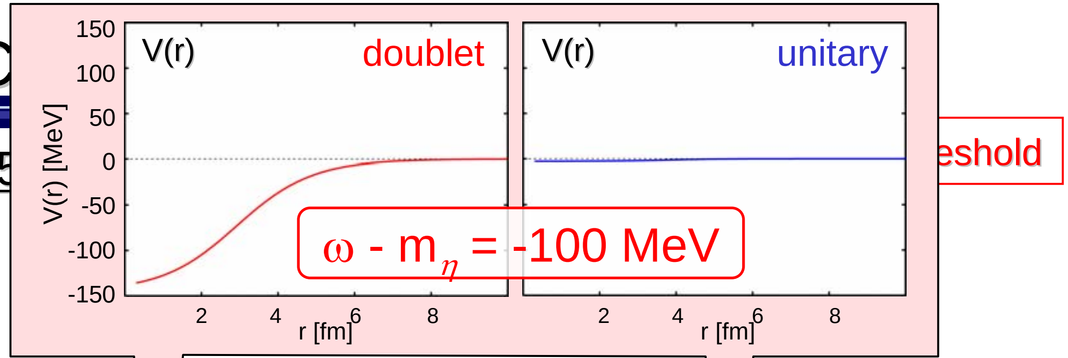
T_π = 820 MeV (p_π = 950 MeV/c) : θ = 0 deg. (Lab)

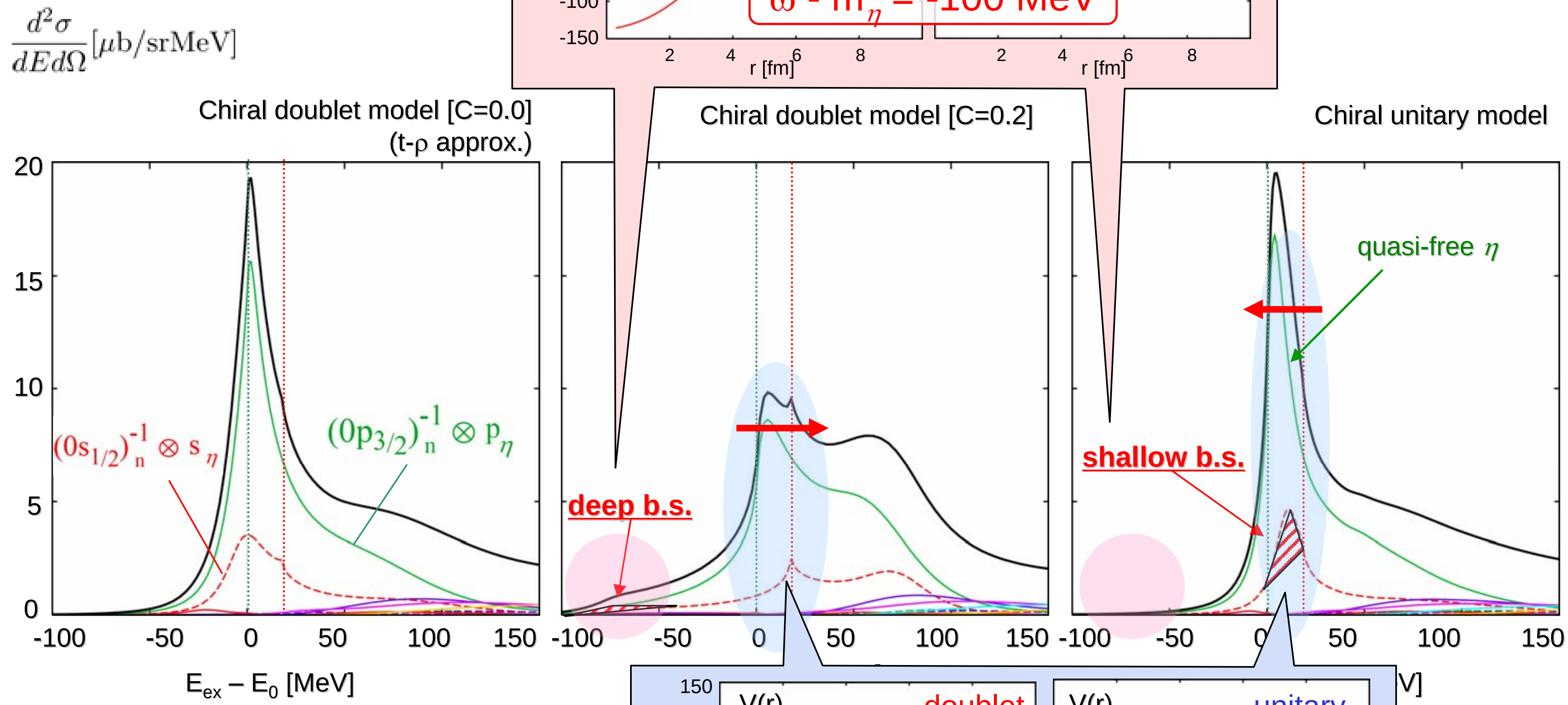
recoilless at η threshold

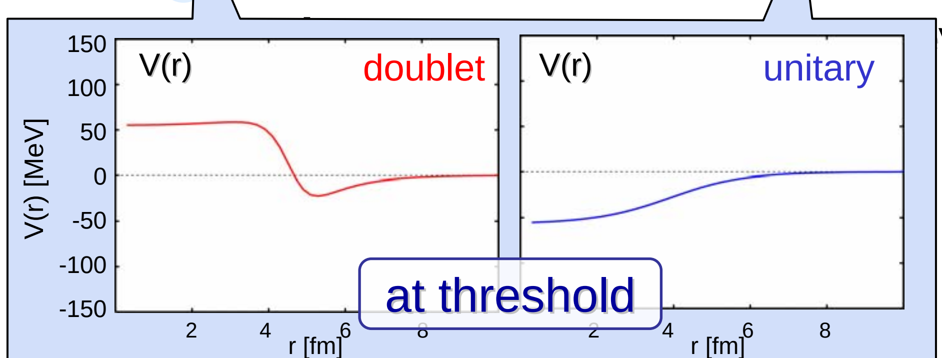


(π^+,p) spectra : ^{12}C

T_π = 820 MeV (p_π = 95







1. Total spectra shapes are different.
2. There exist bound state in both models.
   - deep b.s. in doublet model
   - shallow b.s. in unitary model
3. No peak structure

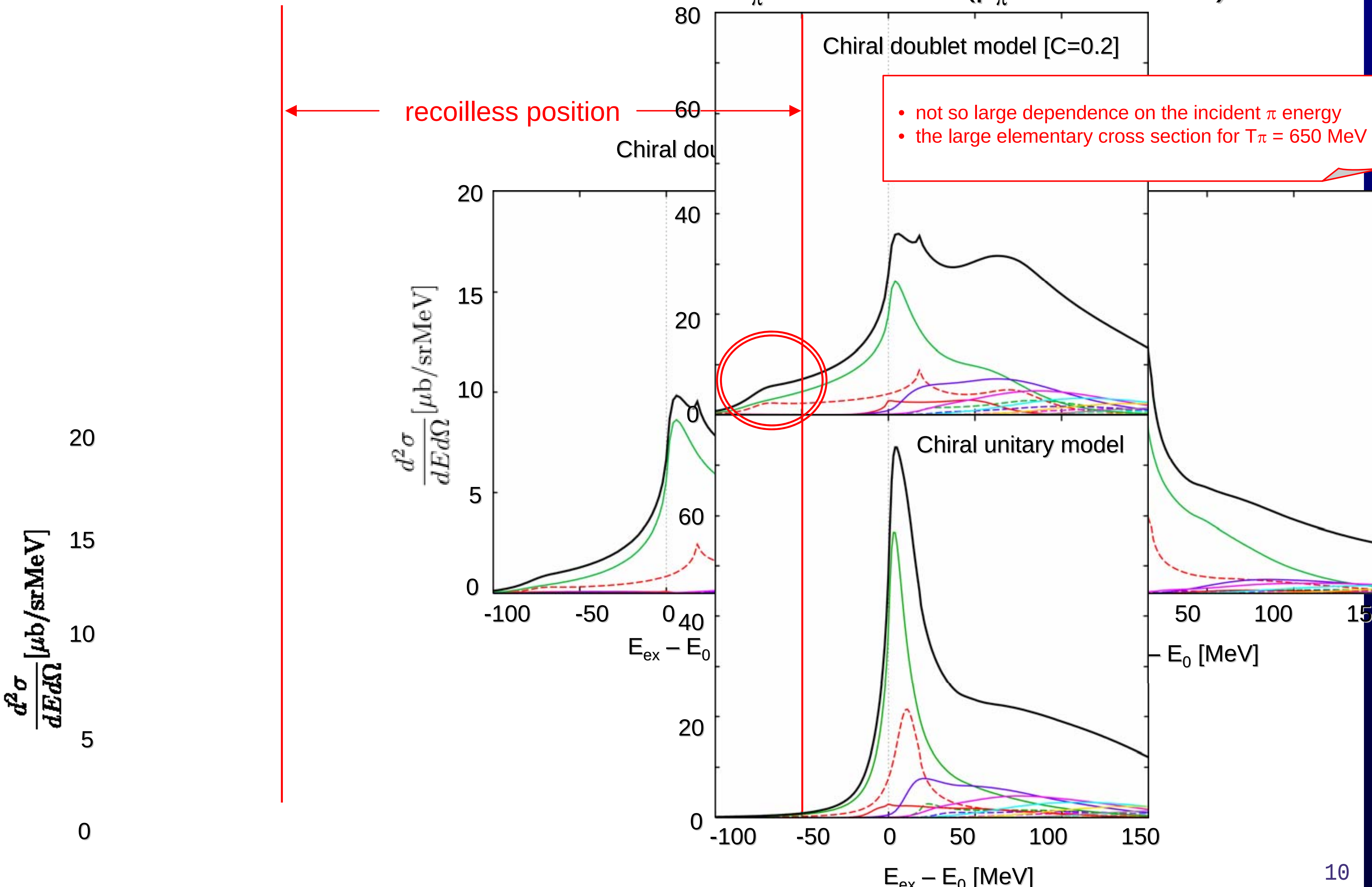
We must observe whole shape (not peak)

(π^+,p) spectra : ^{12}C target : incident energy dependence

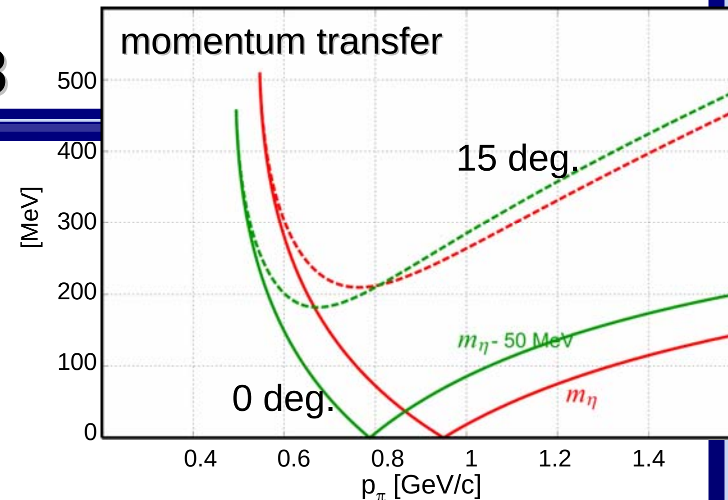
T_π = 820 MeV (p_π = 950 MeV/c)

T_π = 650 MeV (p_π = 777 MeV/c)

- not so large dependence on the incident π energy
- the large elementary cross section for T_π = 650 MeV



(π^+,p) spectra : past experiment in 1988

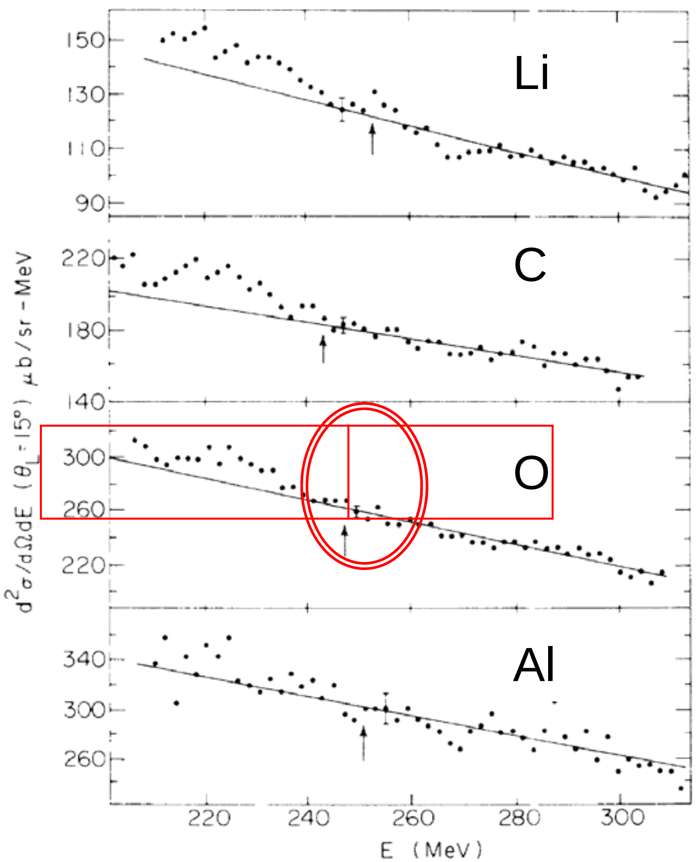


- Chrien et al., PRL60(1988)2595
  - » p_π = 800 MeV/c
  - » proton angle : 15 deg. (Lab.)
  - » search for predicted narrow bound state

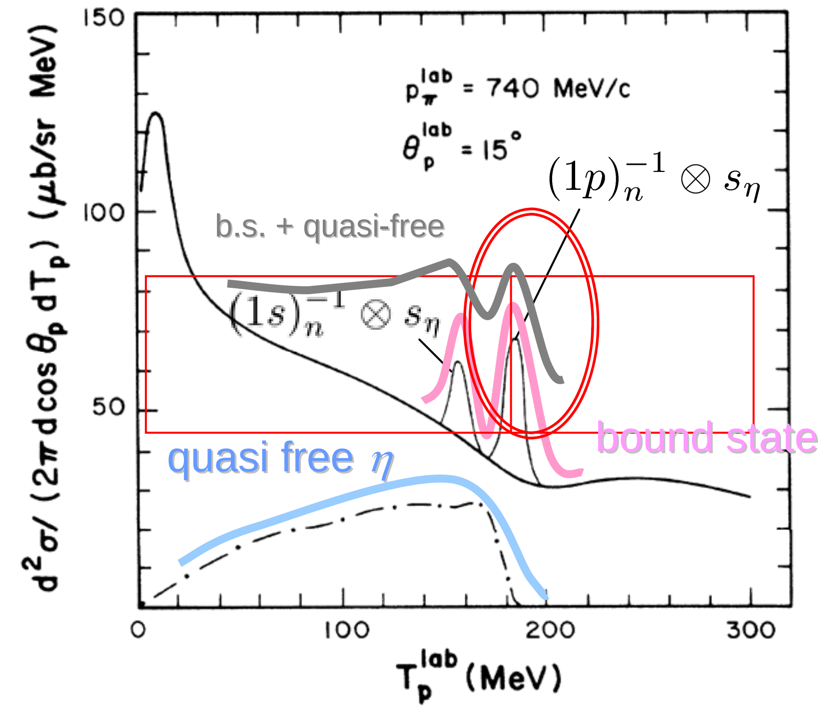
    (ex. Γ ~ 10 MeV)

→ negative results (bound state was not observed)

Chrien at al., PRL60(88)2595, Fig.1

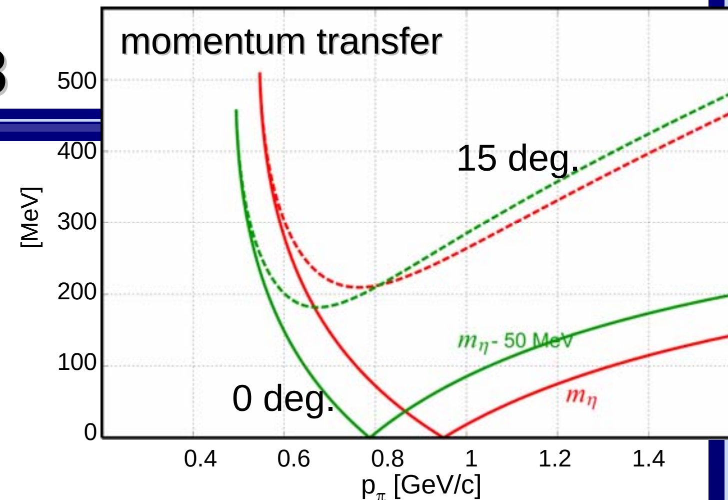


Liu, Haider, PRC34(86)1845, Fig.7



(B.E, Γ/2) = (2.65, 4.77) [MeV]

(π^+,p) spectra : past experiment in 1988



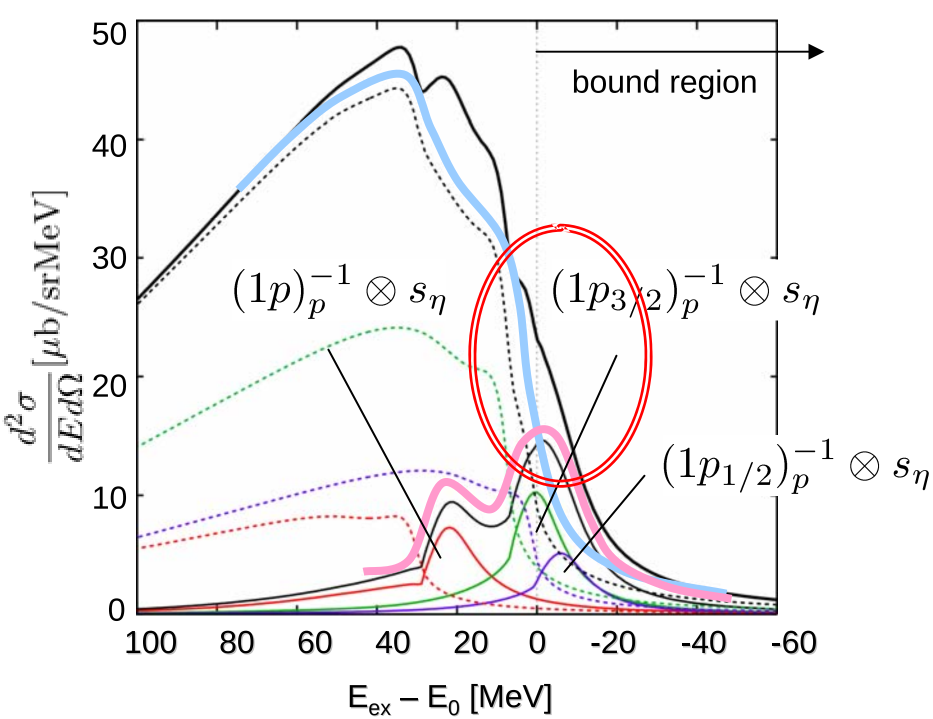
Liu & Haider did not seriously consider :

- quasi-free contribution [Also commented in Kohno et al, NPA519(90)755]
  - » virtual η absorption (due to Imaginary potential)
  - → The peak structure is hidden in quasi-free contribution

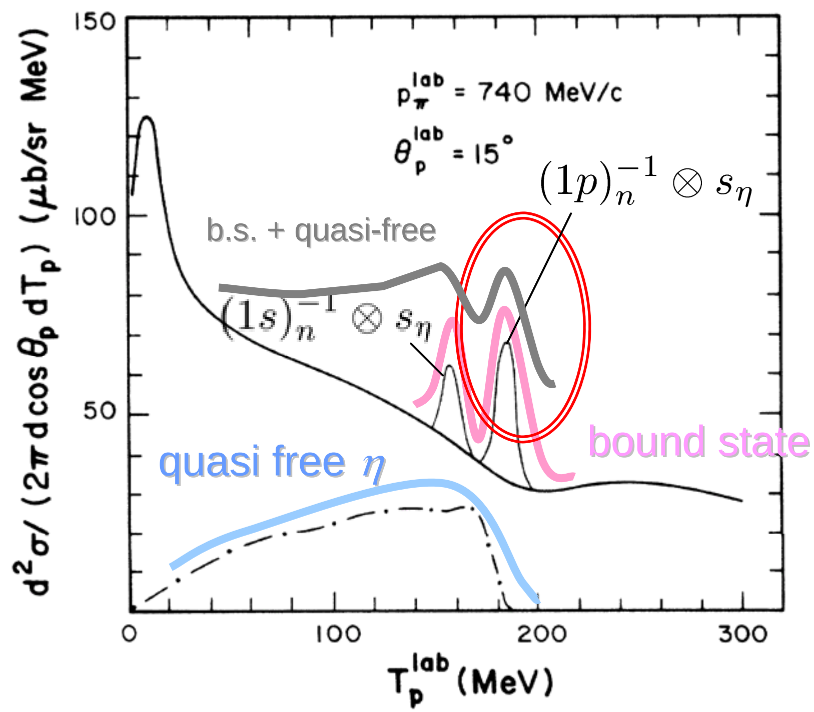
$$a_0 = (0.28 + 0.19i)$$

Liu, Haider, PRC34(86)1845

green function method (V_0,W_0) = -(34,15) [MeV]



Liu, Haider, PRC34(86)1845, Fig.7

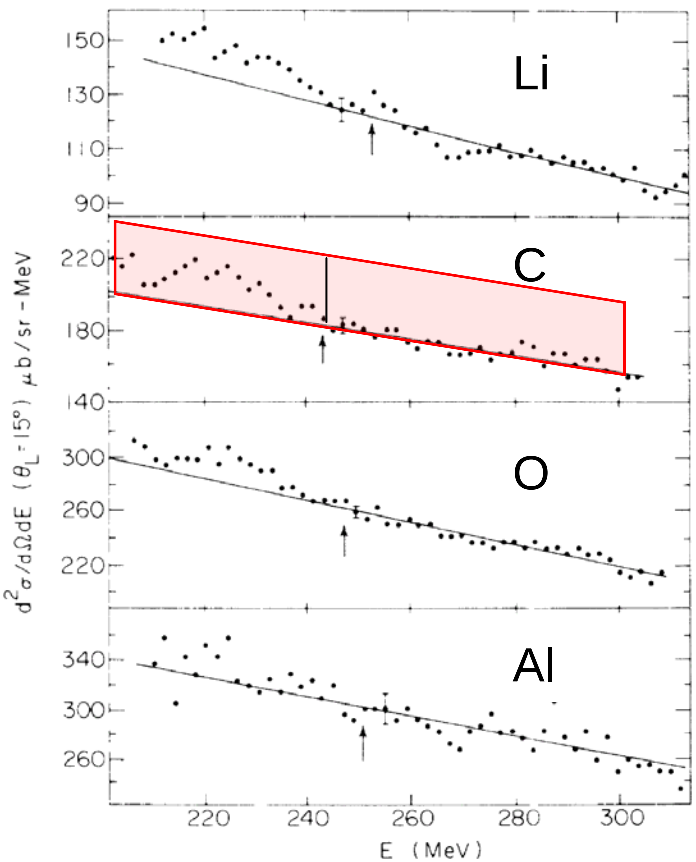


(B.E, $\Gamma/2$) = (2.65, 4.77) [MeV]

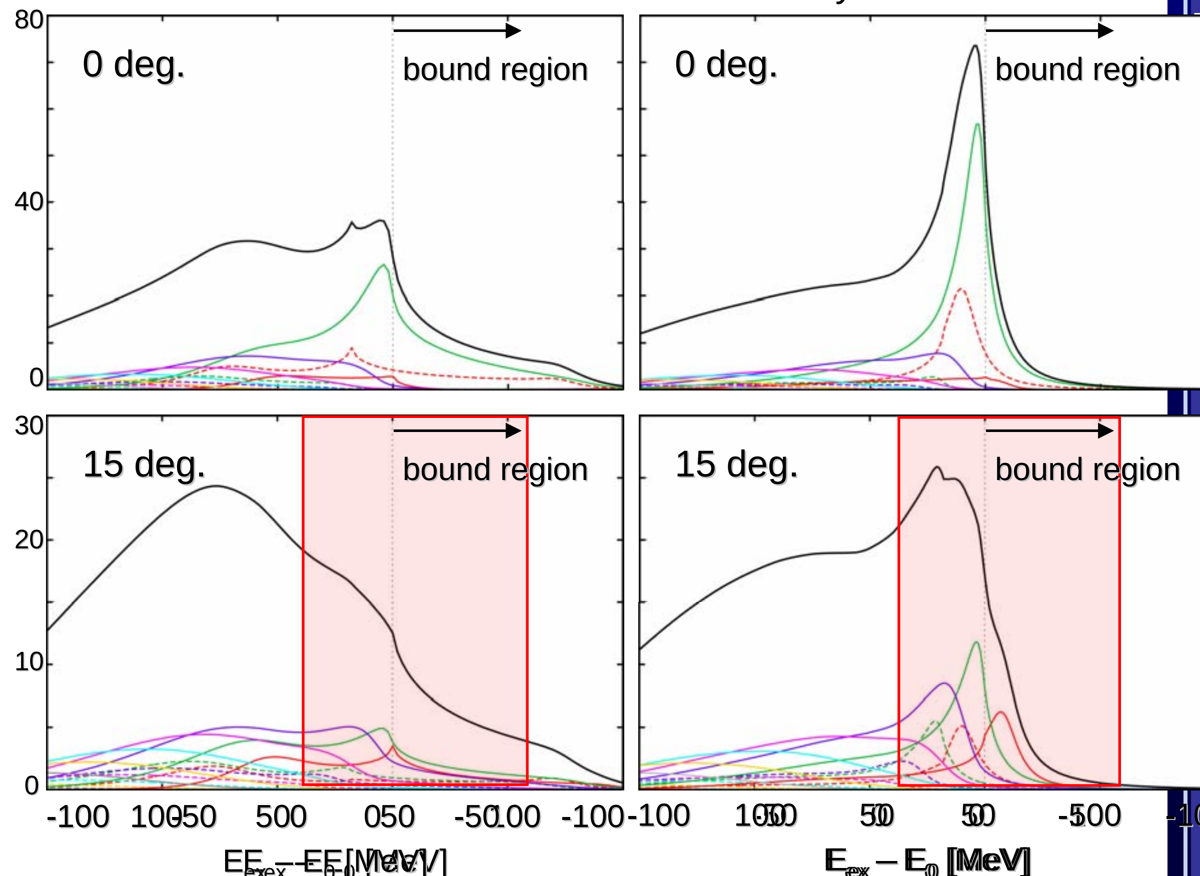
(π^+,p) spectra : comparison of our calc. with the exp. data

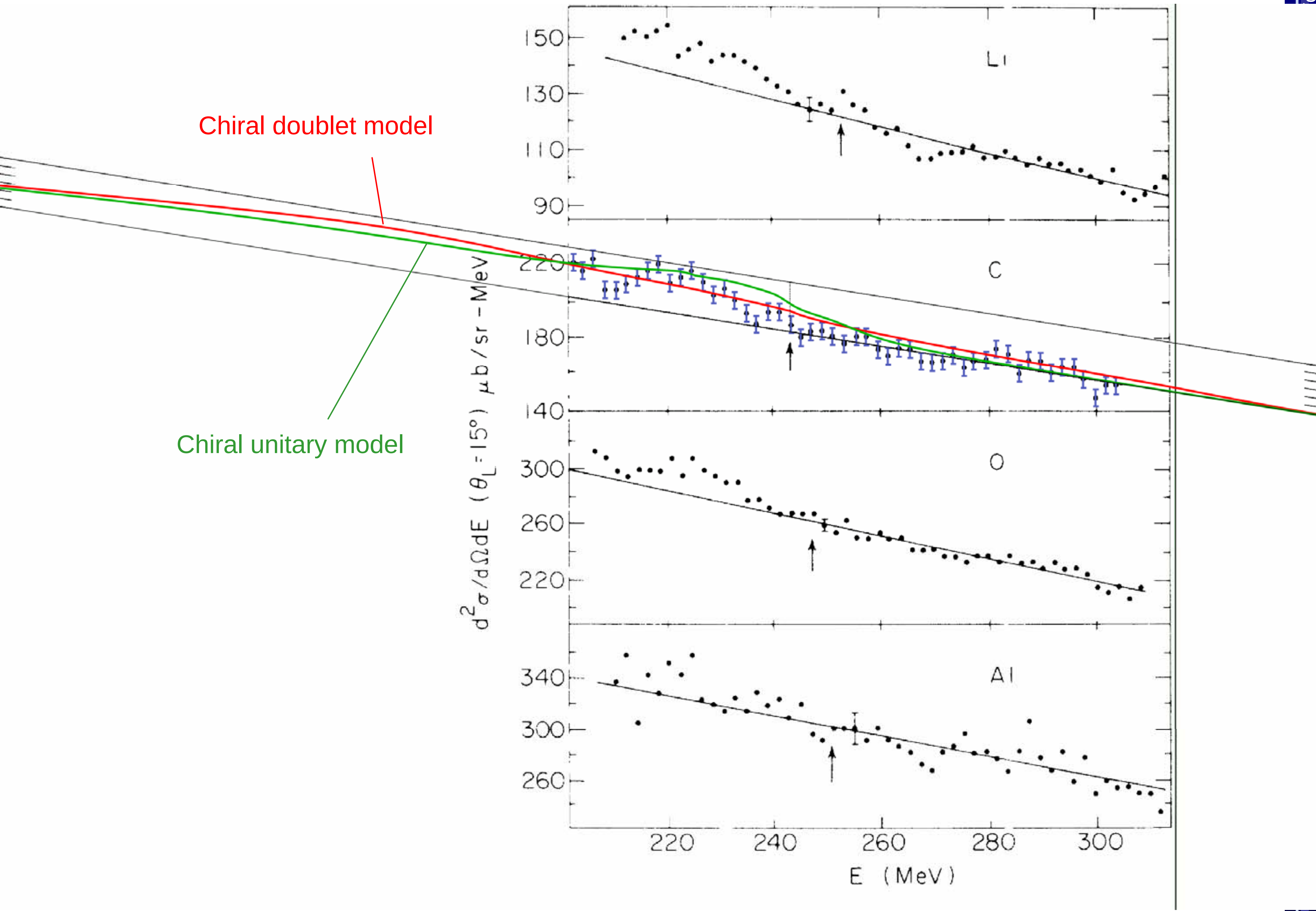
- Chrien et al., PRL60(1988)2595
  - » p_π = 800 MeV/c
  - » proton angle : <u>15 deg. (Lab.)</u>

Chrien at al., PRL60(88)2595, Fig.1



chiral doublet model / chiral unitary model




Chiral doublet model
Chiral unitary model
Li
C
O
Al
$d^2\sigma/d\Omega dE$ (θ_L=15°) μb/sr−MeV
E (MeV)
150
130
110
90
220
180
140
300
260
220
340
300
260
220
240
260
280
300

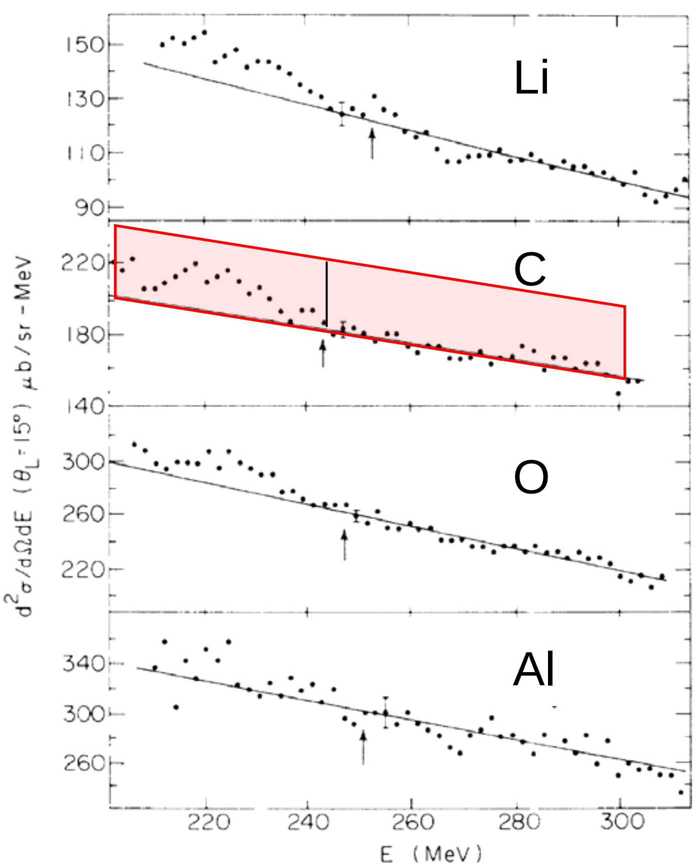
(π^+,p) spectra : comparison of our calc. with the exp. data

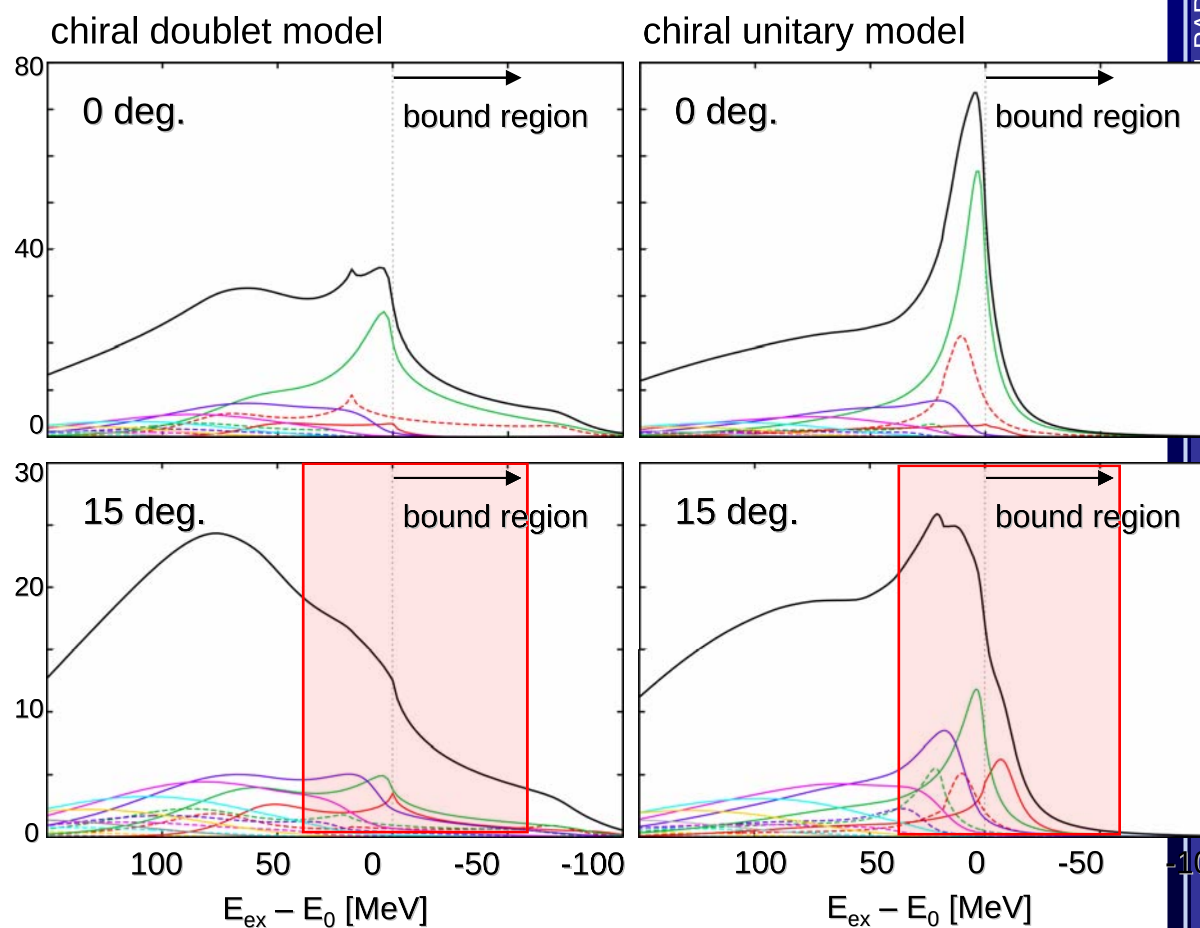
- Chrien et al., PRL60(1988)2595
  - » p_π = 800 MeV/c
  - » proton angle : 15 deg. (Lab.)

• The experimental data is consistent with both model
→ This experimental set-up was not sensitive to N* in-medium

proton angle ~ 0 degree

Chrien at al., PRL60(88)2595, Fig.1





Summary

- Formation of η-mesic nuclei
  - **In-medium properties of N*(1535) resonance**
    - Chiral doublet model : deep bound state(s)
      - pocket-like potential, level crossing of η and N*-hole modes
    - Chiral unitary model : shallow bound state(s)
- (π^+,p) reaction
  - 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
- Reconsideration of the experimental data at 1988 by Chrien *at al.*
  - Is the 15° proton angle appropriate?
    - Not sensitive to the N* properties in-medium
  - We should discuss the whole shape itself in the case that the imaginary part might be large
- The proton angle ~ 0 deg.
- **possible at J-PARC ?**
  - realistic discussion with the experimentalists [H.Fujioka, K.Itahashi]