GRADUATE SCHOOL OF SCIENCE
FACULTY OF SCIENCE
KYOTO UNIVERSITY

Experimental studies of η'-nucleon and η'-nucleus interaction at J-PARC

Hiroyuki Fujioka (Kyoto Univ.)

Contents

- η′-nucleus interaction and η′ mesic nucleus
- η′-nucleon interaction and (possible) η′N bound state

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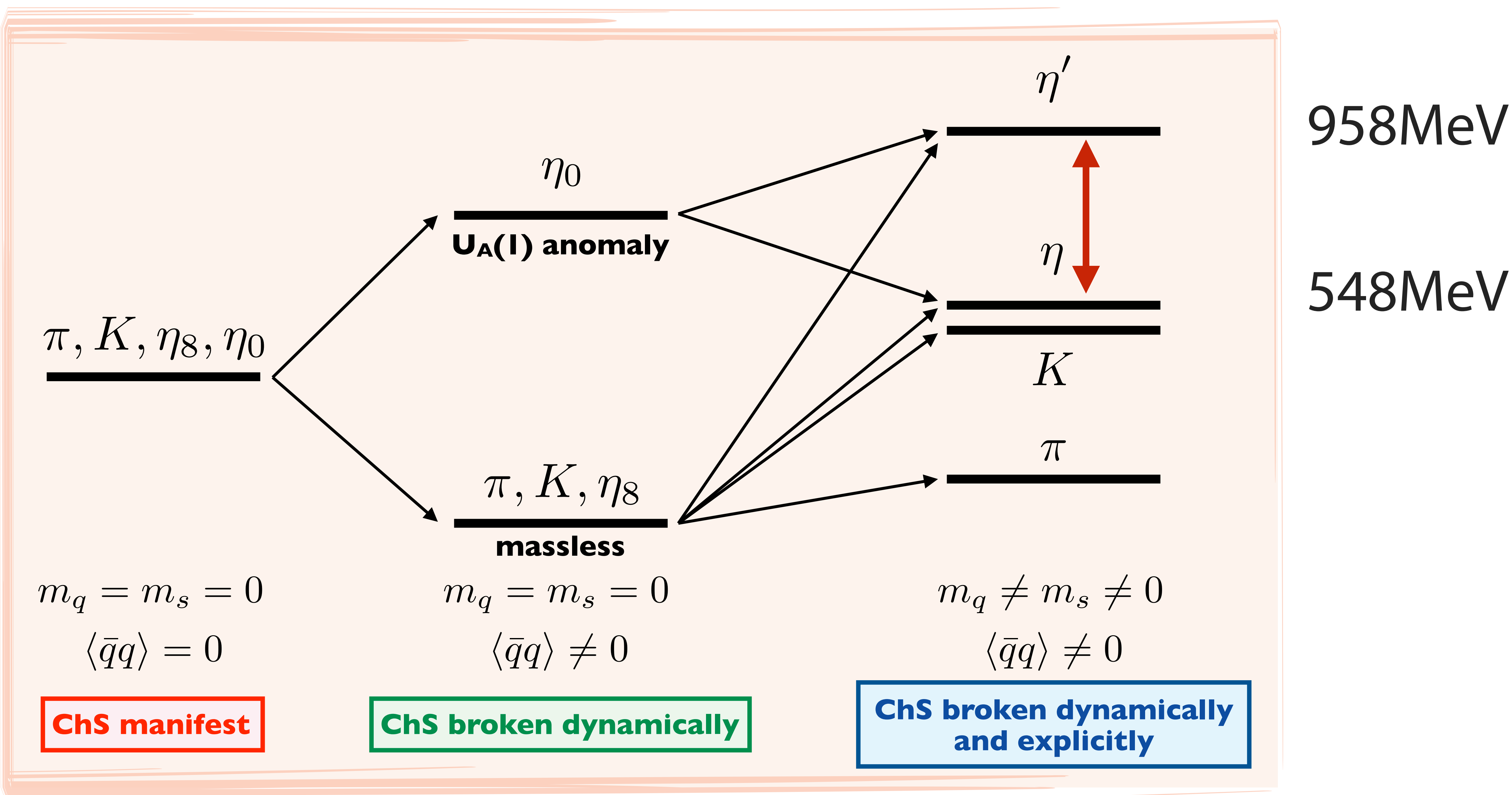
irrelevant to η′

- d*(2380) dibaryonic state at J-PARC

pseudoscalar mesons in broken chiral symmetry

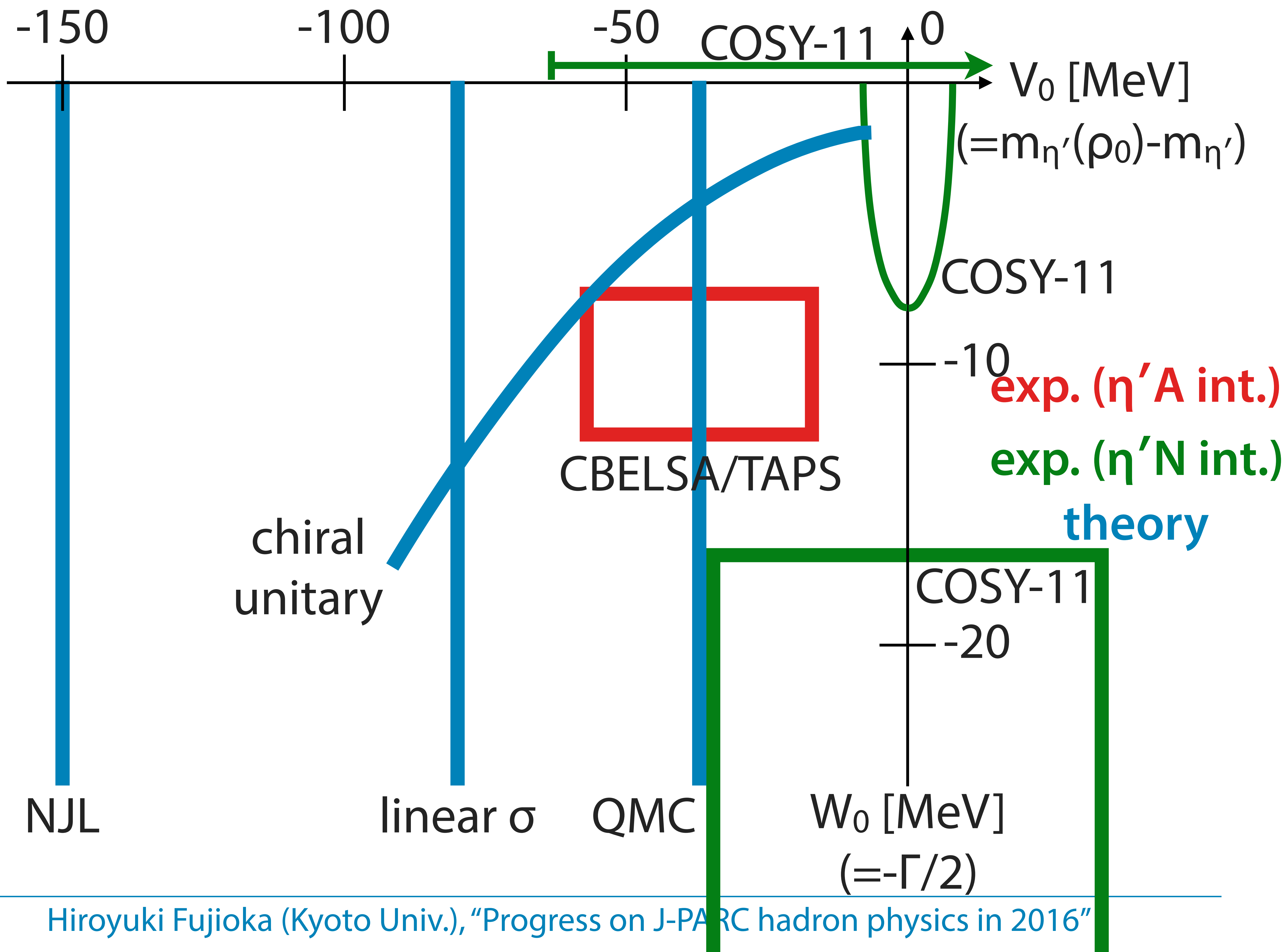


Nagahiro et al., PRC 87, 045201 (2013)

η′ meson in medium

- At finite density/temperature, chiral symmetry will be partially restored
  - cf. deeply-bound pionic atom
  - large mass reduction, as a consequence of suppression of the anomaly effect?
- optical potential: $V(r)=(V_0+iW_0)\rho(r)/\rho_0$
  - $|V_0|$= (mass reduction), $2|W_0|$= (absorption width)

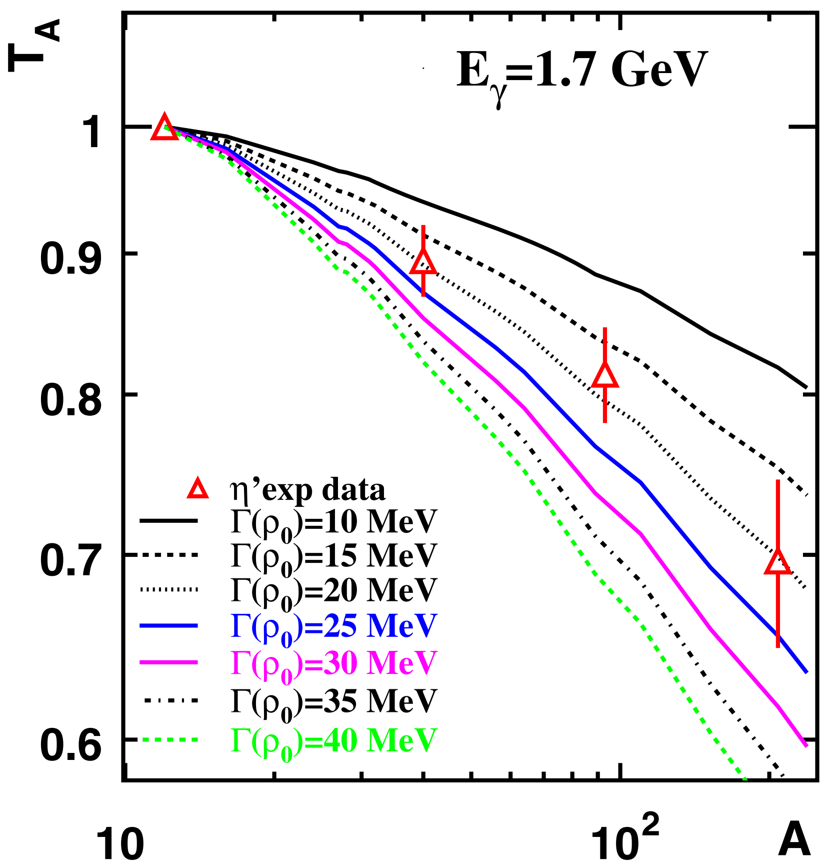
η′ optical potential: state of the art



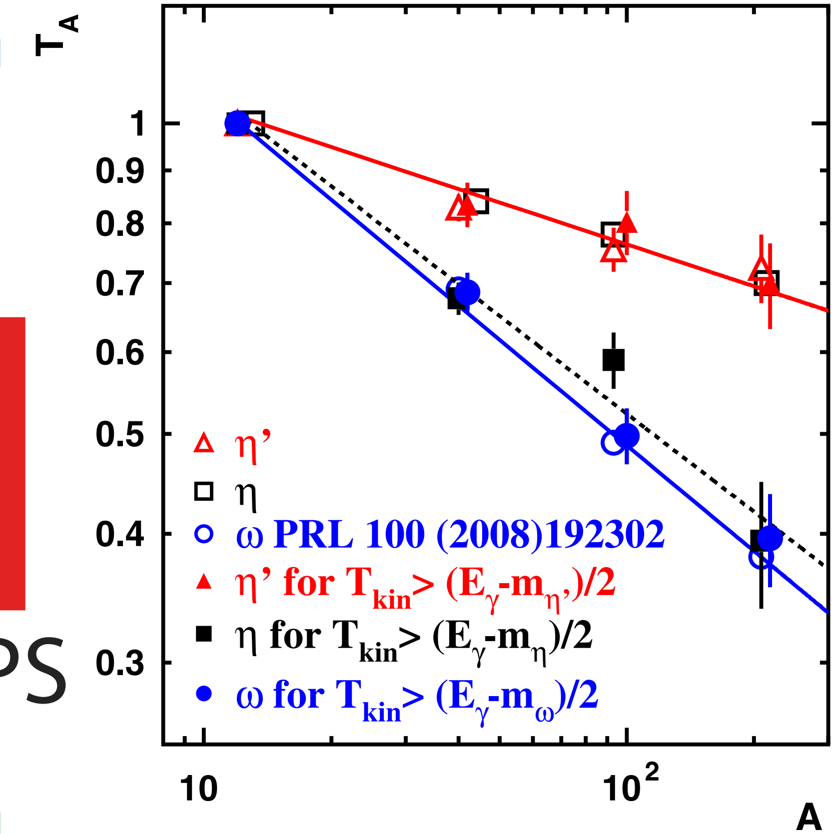
transparency ratio measurement

transparency ratio

$$T_A = \frac{\sigma(\gamma A \to \eta' X)}{A \cdot \sigma(\gamma N \to \eta' X)}$$



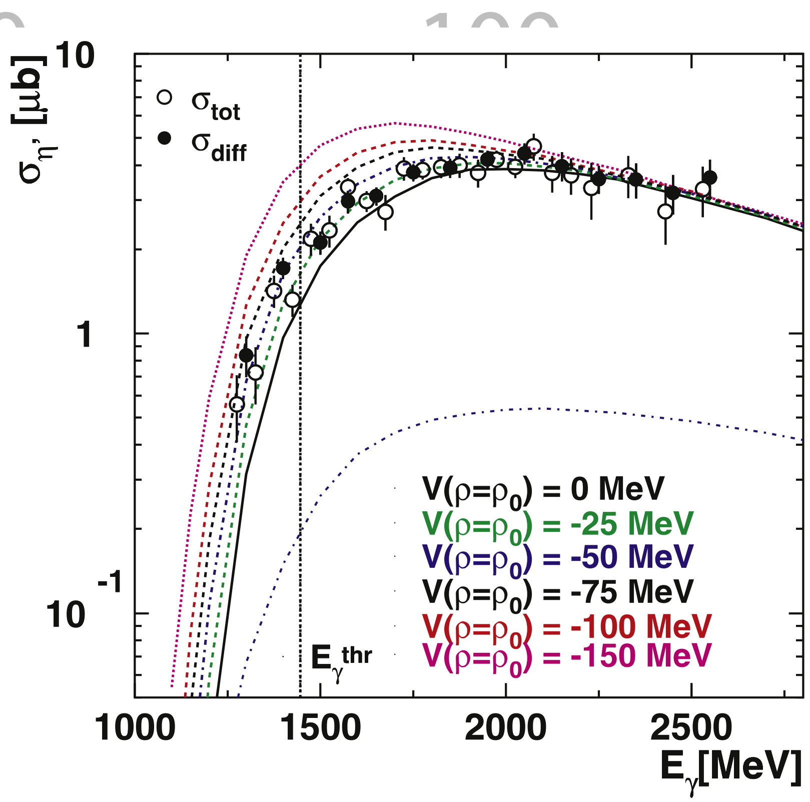
CBELSA/TAPS

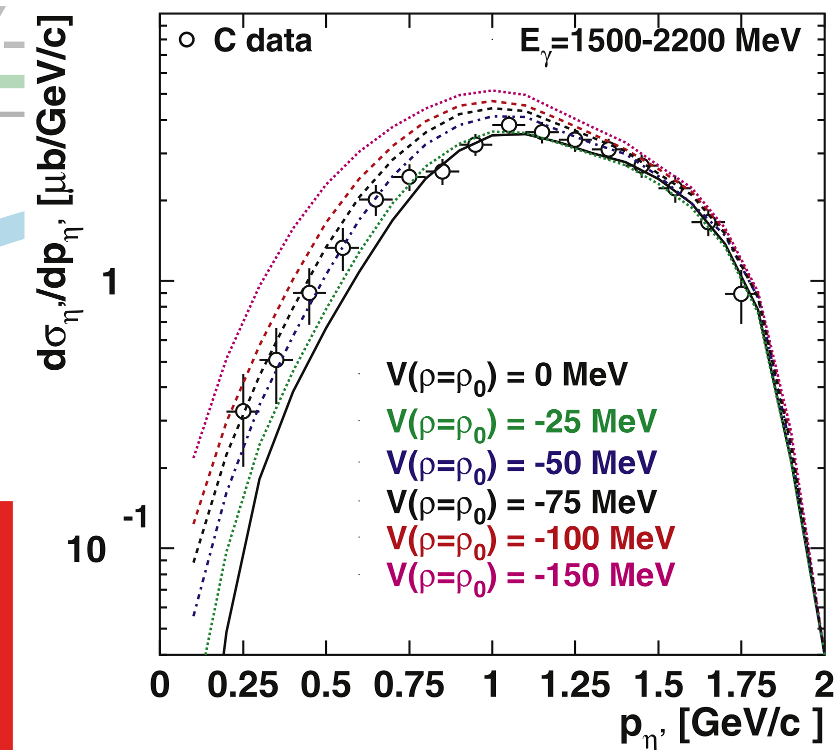


→ Γ=15–25MeV at $\rho=\rho_0$

for $\langle p_{\eta'} \rangle \sim$1.05GeV/c

Nanova et al., PLB 710, 600 (2012)





CBELSA/TAPS

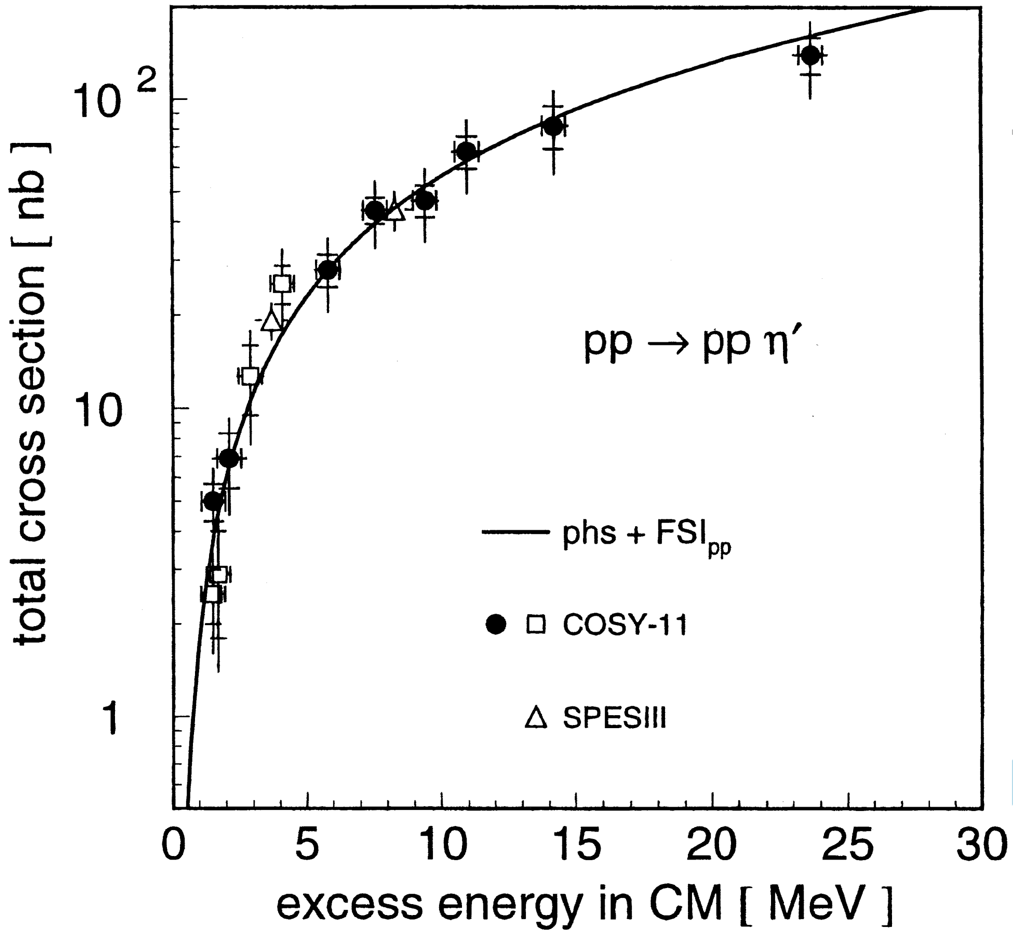
$V_0 = -(40\pm6)$ MeV

$V_0 = -(32\pm11)$ MeV

$V_0 = -(37\pm10_{stat}\pm10_{syst})$ MeV

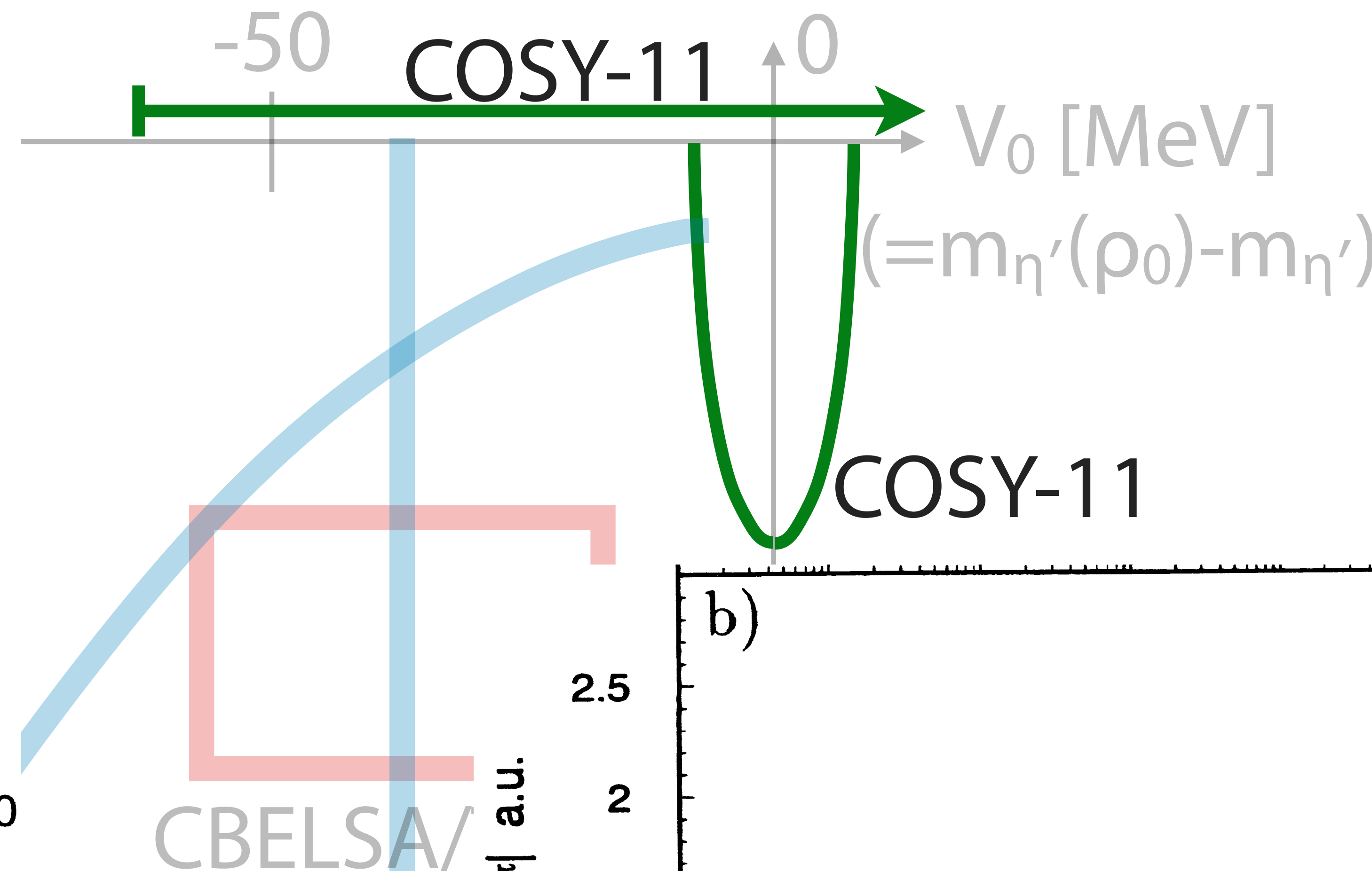
Nanova et al., PLB 727, 417 (2013)

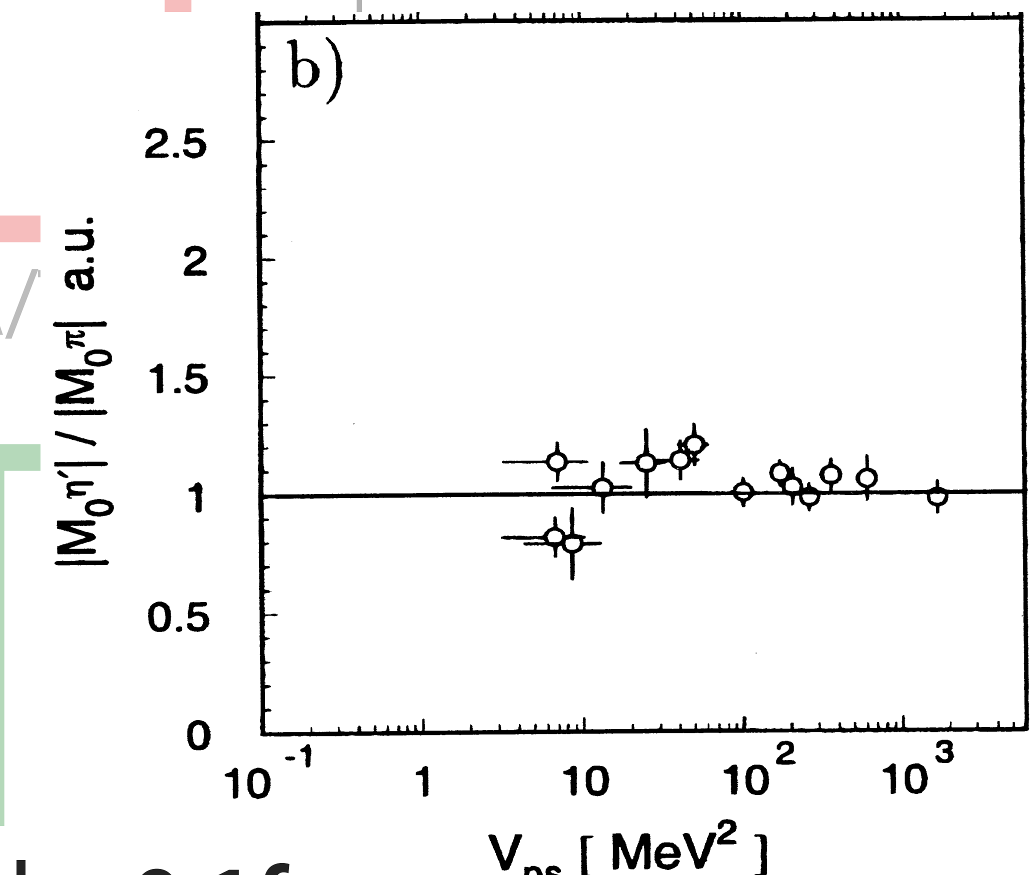
elementary process : pp→ppη′



Moskal et al., PLB 474, 416 (2000)

$|\mathrm{Re}\, a_{\eta' N}| < 0.8\mathrm{fm}$





NJL

linear σ

$|a_{\eta' N}| \sim 0.1\mathrm{fm}$

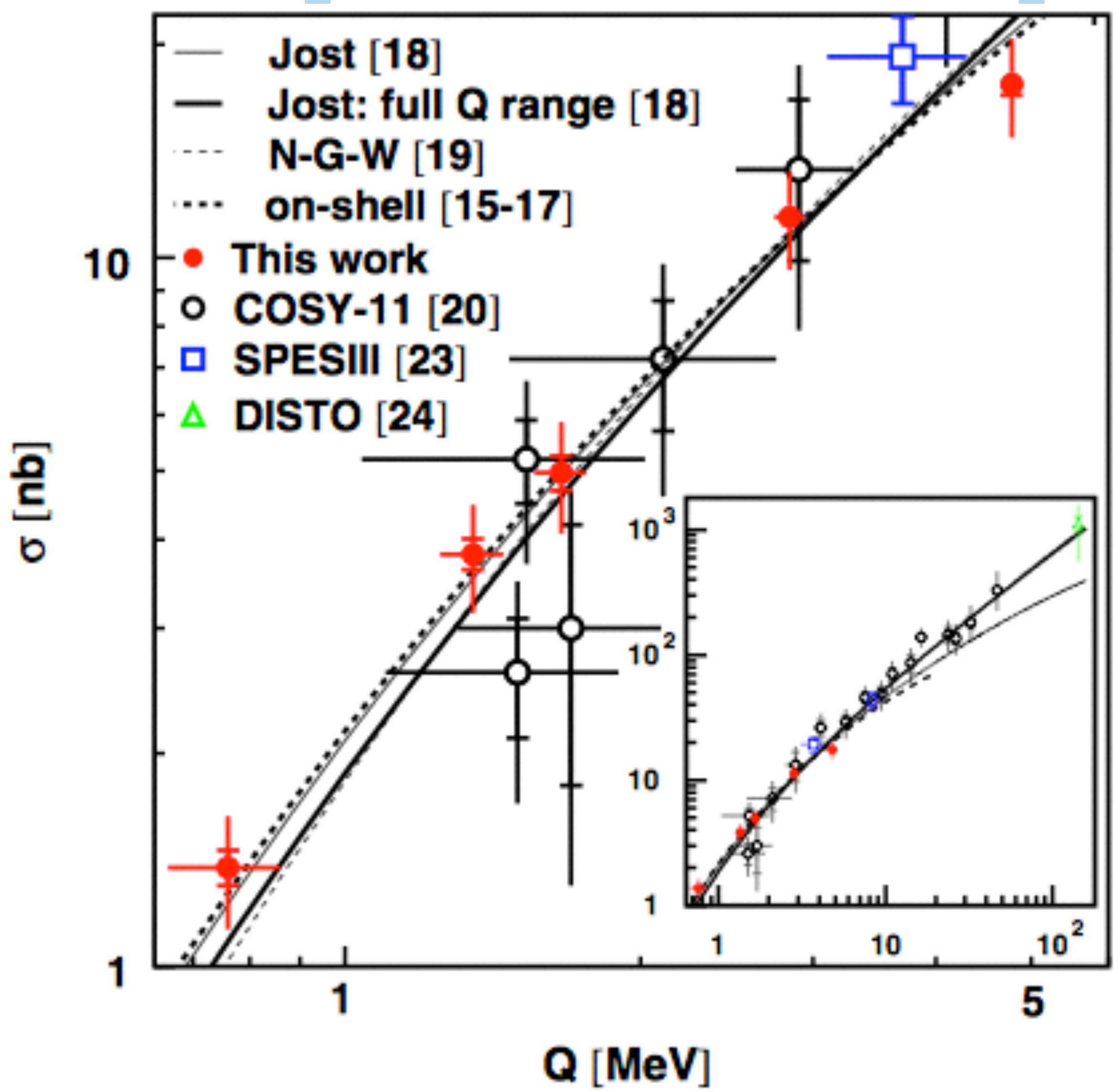
Moskal et al., PLB 482, 356 (2000)

elementary process : pp→ppη′

-150 -100 -50 COSY-11 0

V_0 [MeV]

Czerwiński et al., PRL 113, 062004 (2014)



Re $a_{\eta' N}$ = 0±0.43 fm

Im $a_{\eta' N} = 0.37^{+0.40}_{-0.16}$ fm

Y-11

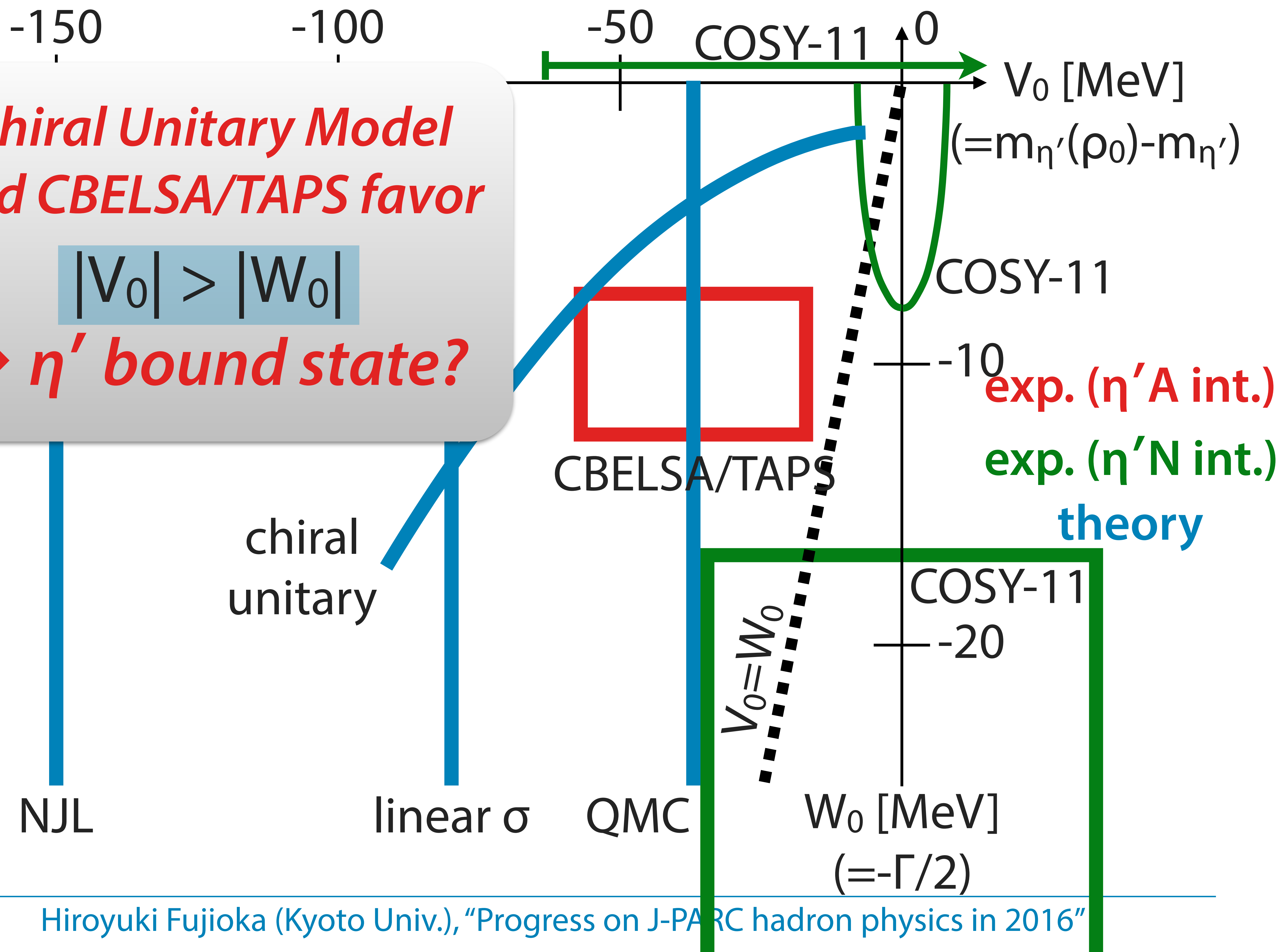
CBELSA/TAPS

COSY-11

-20

NJL linear σ QMC W_0 [MeV] (=-Γ/2)

η′ optical potential: state of the art



Chiral Unitary Model and CBELSA/TAPS favor

$|V_0| > |W_0|$

→ η′ bound state?

Searching for η′ mesic nuclei

- (p,d) reaction @ GSI and FAIR

K. Itahashi, HF et al., PTP 128, 601 (2012)

*First experiment in August 2014, **Y.K. Tanaka et al., in preparation***

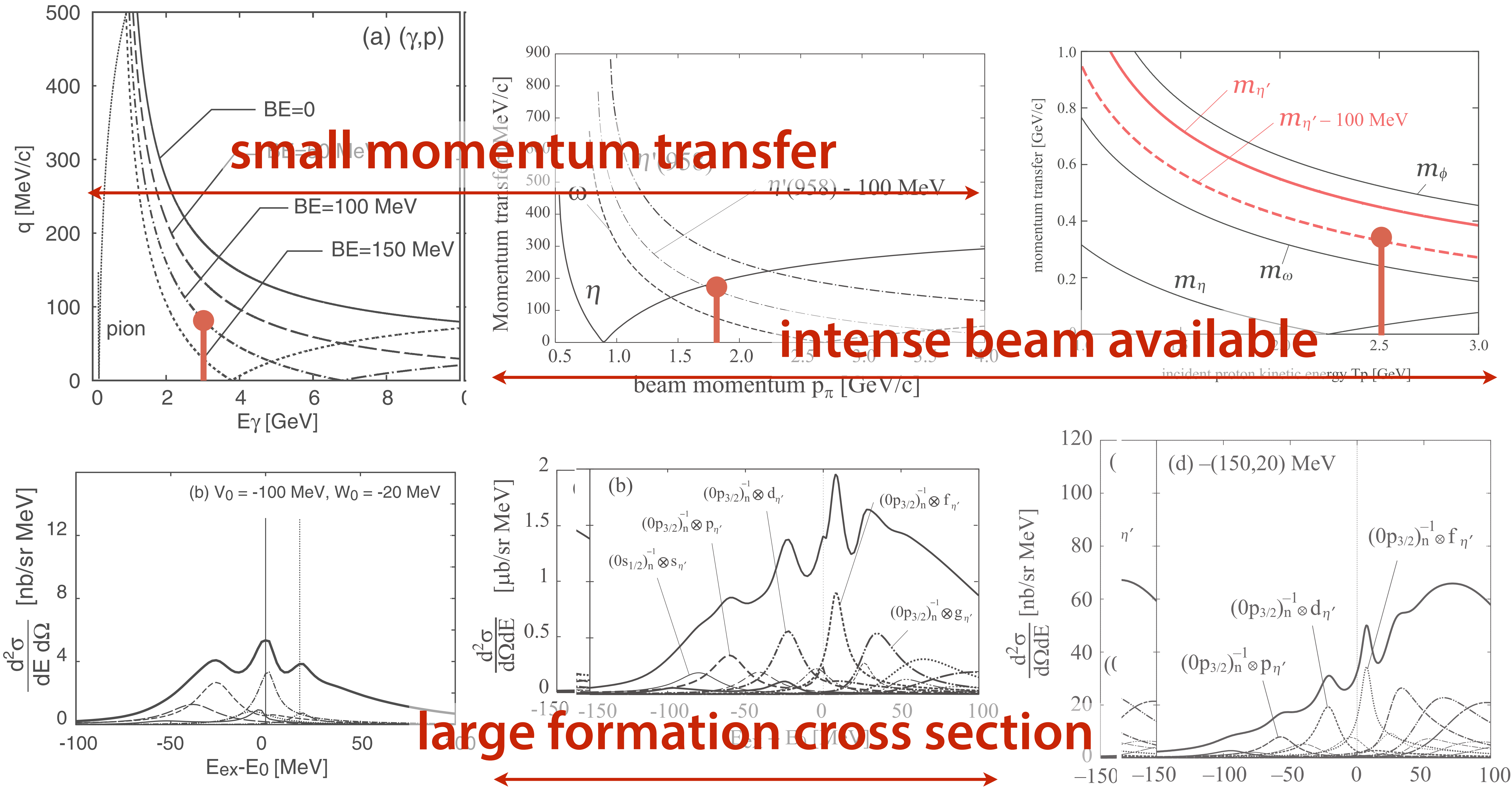
- (γ,p) reaction @ LEPS2/SPring-8
  @ BGO-OD/ELSA

- (π^+,p) reaction @ J-PARC

HF and K. Itahashi, EoI submitted in 2012

comparison among different reactions

(γ,p) **(π⁺,p)** **(p,d)**



H. Nagahiro et al., PTP Suppl. 186, 316 (2010)

H. Nagahiro et al., PRL 94, 232503 (2005)

H. Nagahiro et al., PRC 87, 045201 (2013)

J-PARC hadron experimental facility

HIHR beamline

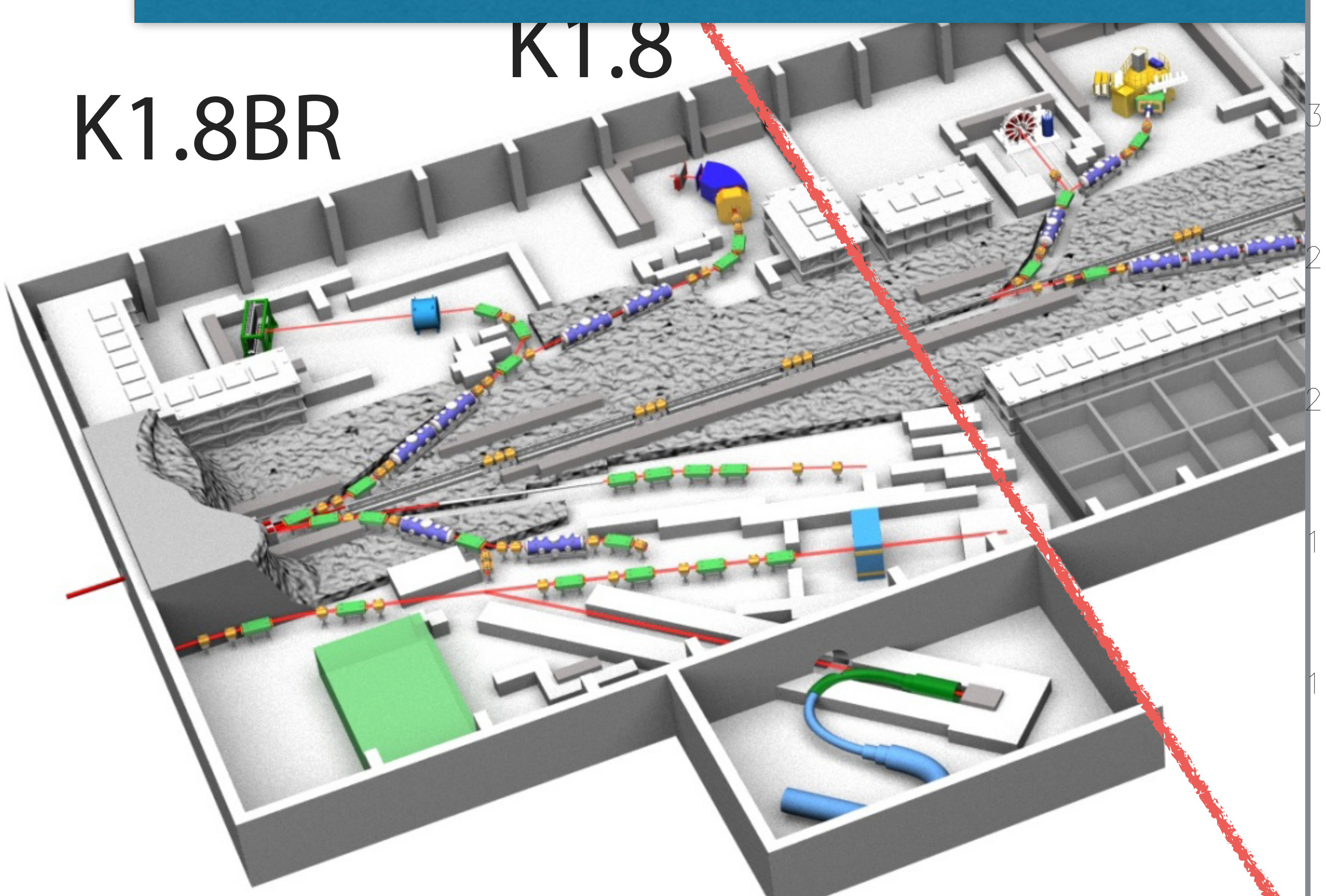
High **I**ntensity: ~10^9 π/sec

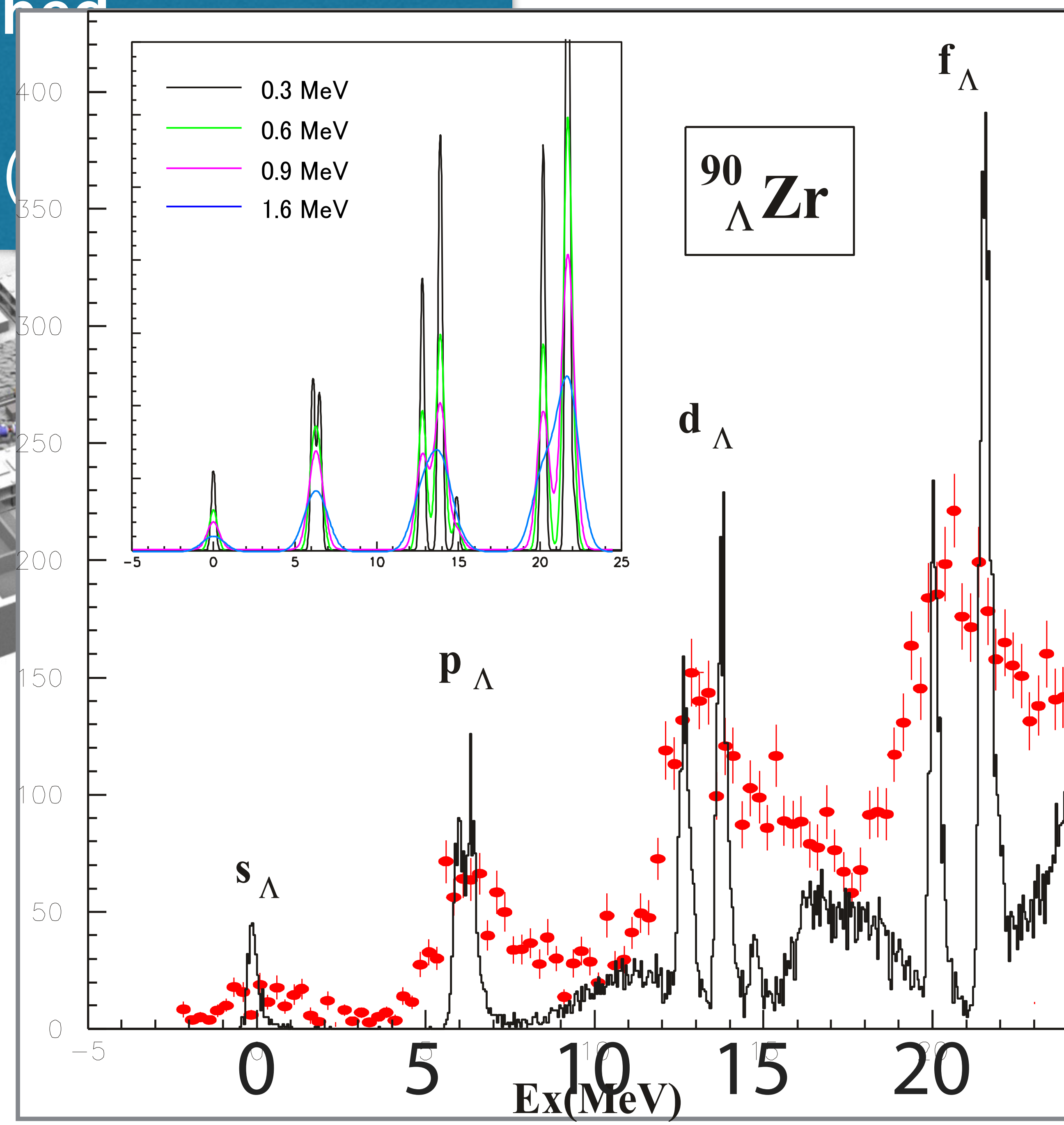
High **R**esolution: dispersion-match

one of planned experiments :

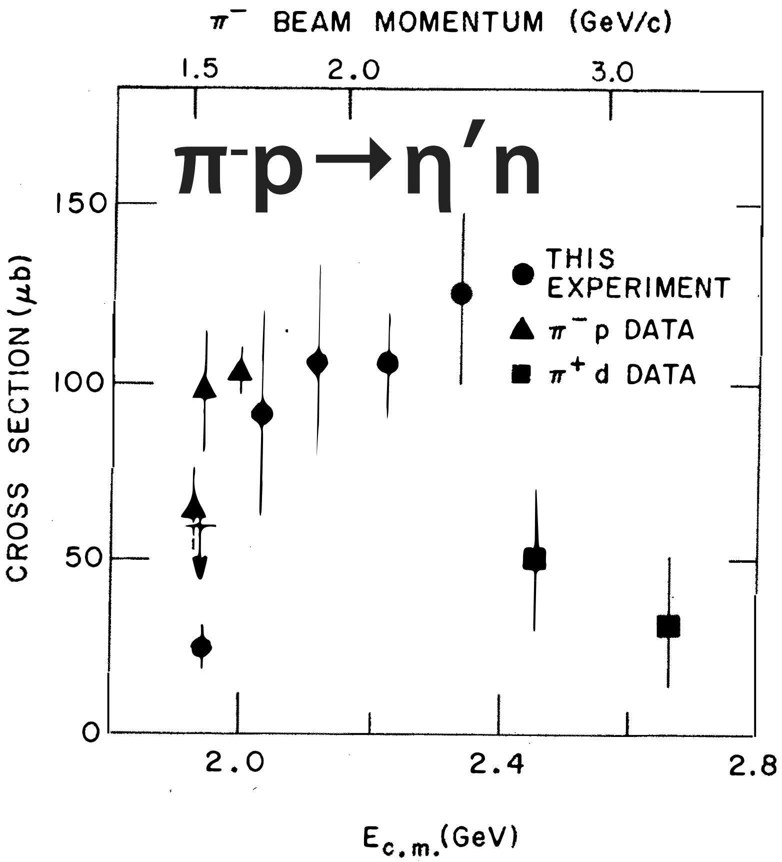
Λ hypernuclear spectroscopy with (

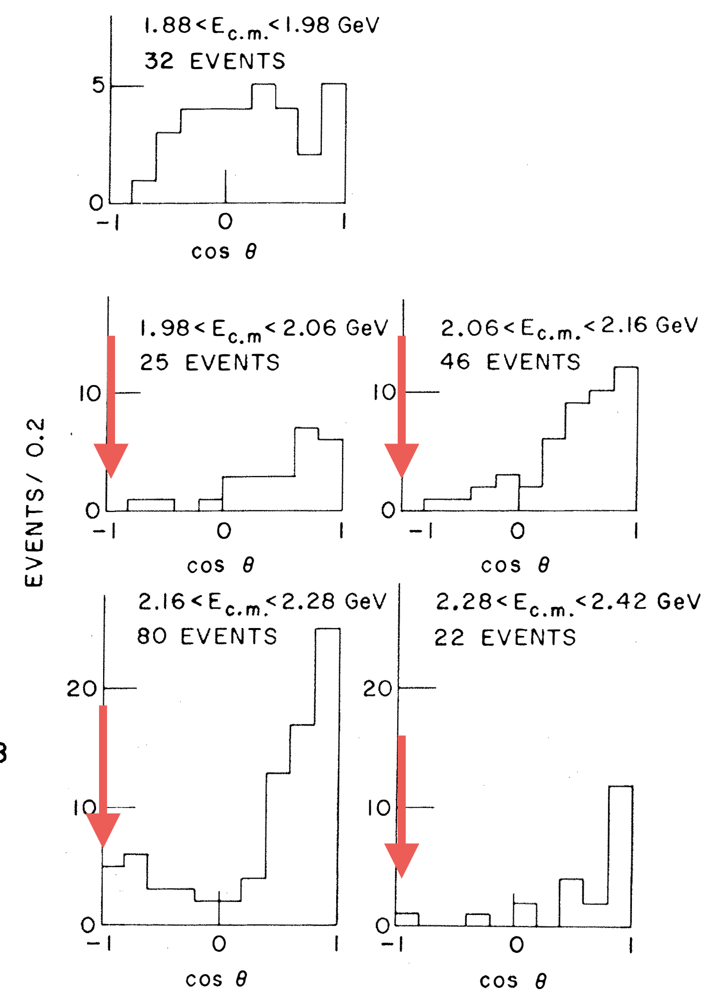
Noumi et al., LoI -08 (2003)





pion-induced η′ production

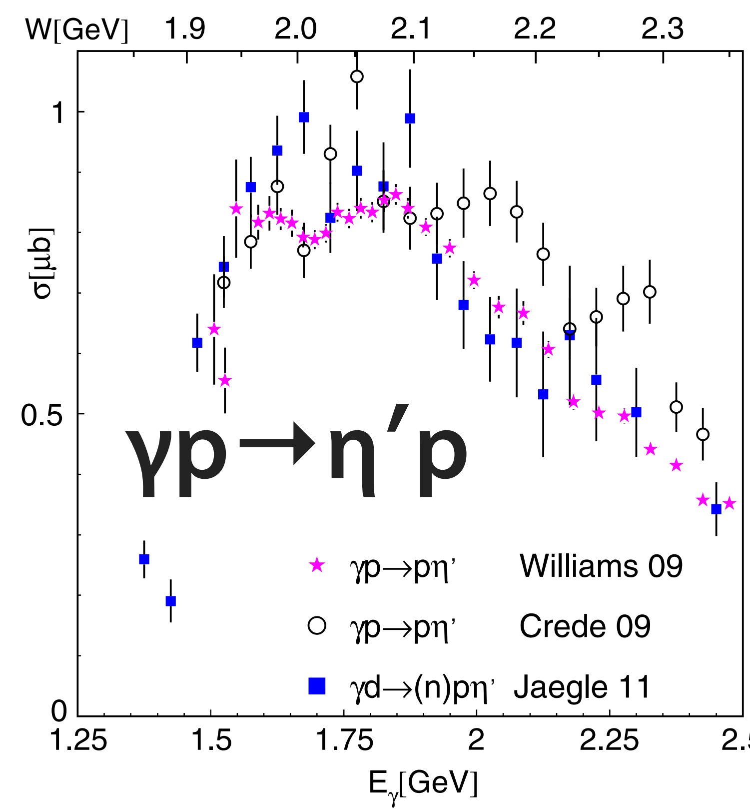


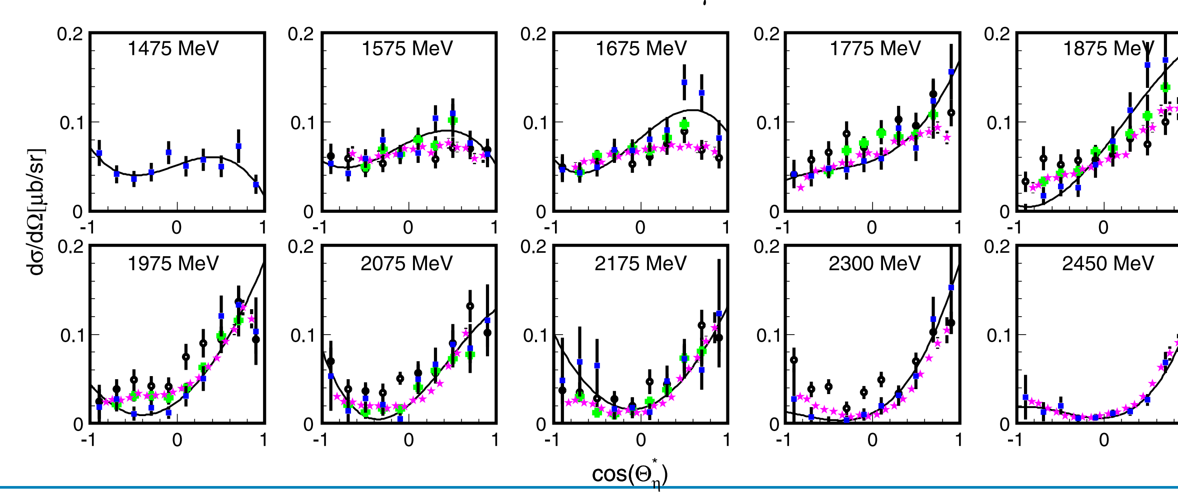


R.K. Rader et al., PRD 6, 3059 (1972)

cf. η′ photoproduction

B. Krusche and C. Wilkin, Prog. Part. Nucl. Phys. 80, 43 (2015)

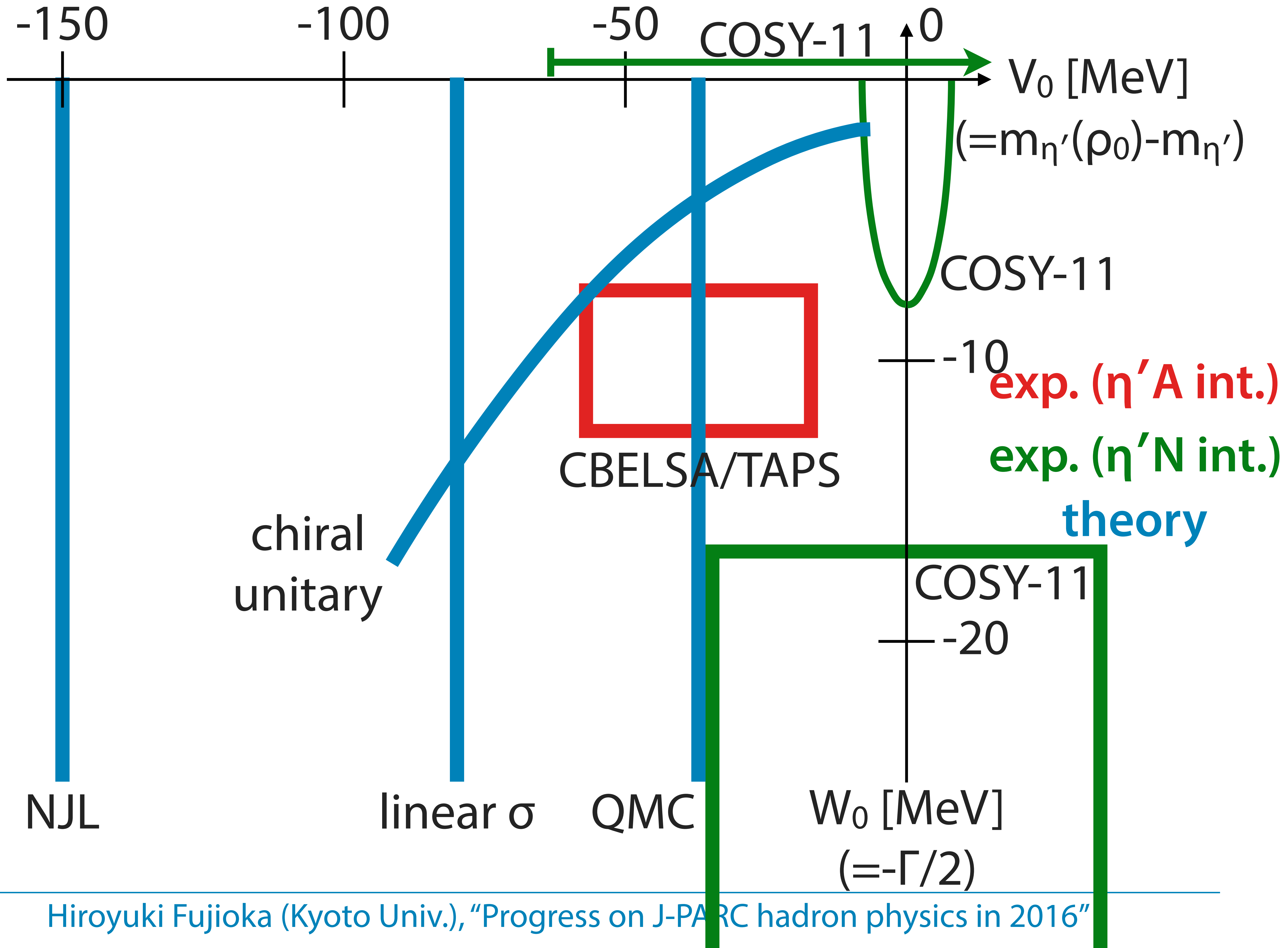




more information needed for the optimization of π^- beam momentum

(large $d\sigma/d\Omega^{(lab)}$ favored)

η′ optical potential: state of the art



possible existence of η'N bound state

(large) mass reduction of η' in nucleus

NJL, linear-σ, QMC
CBELSA/TAPS

con... ng??

η'N bound state?

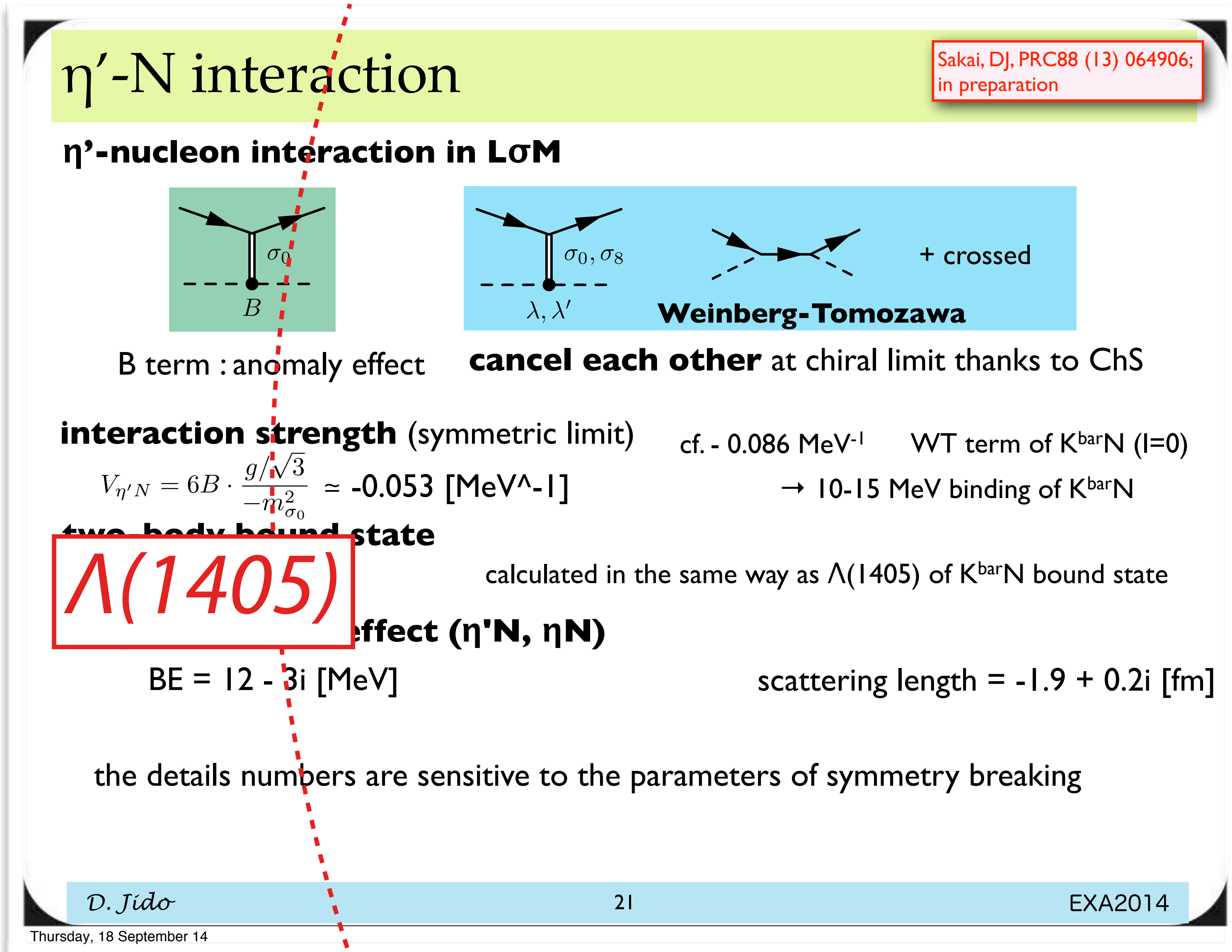
small η'N scattering length

$$\mathrm{Re}\ a_{\eta' N} = 0 \pm 0.43\ \mathrm{fm}$$

$$\mathrm{Im}\ a_{\eta' N} = 0.37^{+0.40}_{-0.16}\ \mathrm{fm}$$

Czerwiński et al., PRL 113, 062004 (2014)

attractive interaction between $\bar{K}$ and nucleon (nucleus)



Λ(1405)

D. Jido, EXA2014

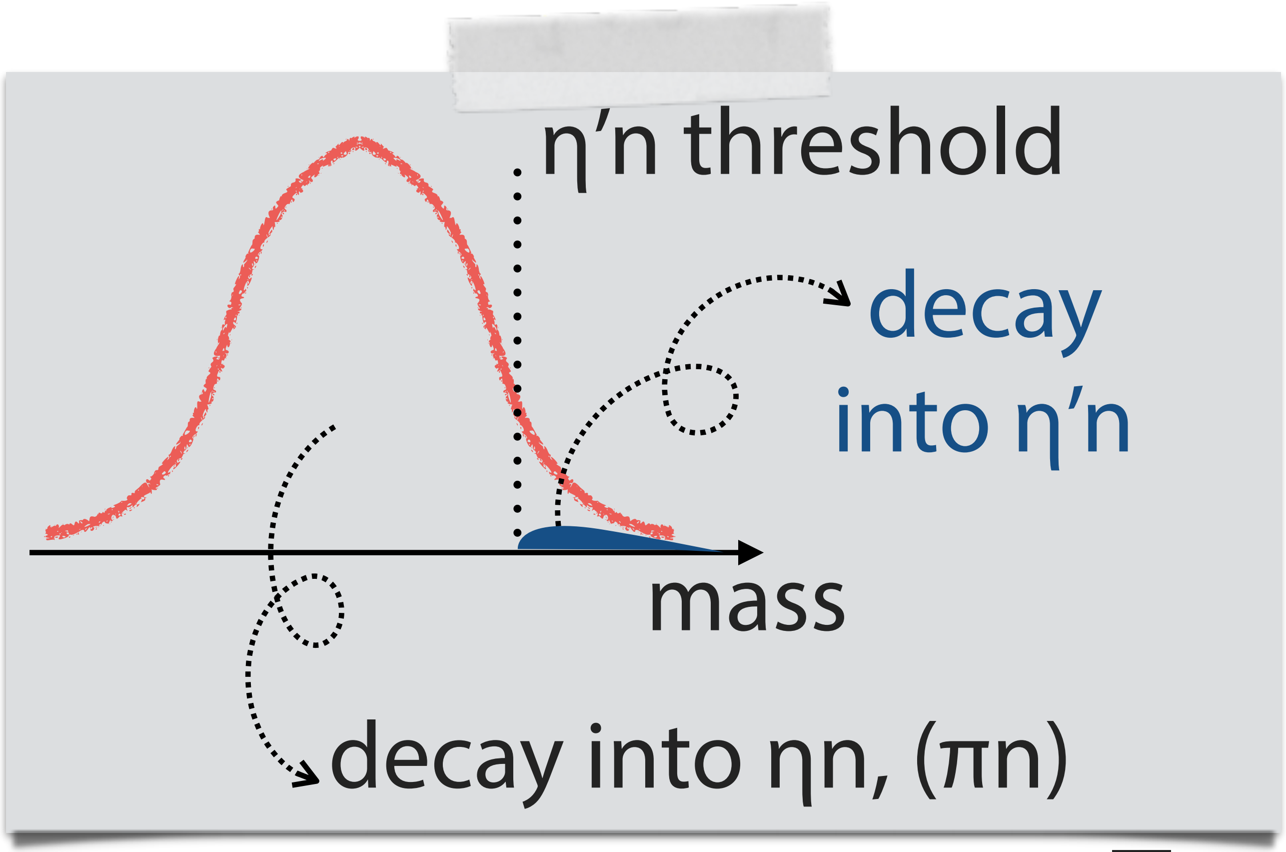
$\bar{K}N$ scattering length, repulsive shift of K^-p 1s atomic state

Searches for η'N bound state

- direct search
  - γ+d→(η'n)+p or π^++d→(η'p)+p (cf. K^-+d→Λ(1405)+n)
  - γ+p→(η'n)→η+p
    π^-+p→(η'n)→η+n

LEPS

- indirect search
  - π^-+p→(η'n)→η'+n
    - signature of η'n bound state just above η'n threshold?
    - (merit) background-free *(as far as N* dominance model is valid)*
    - (demerit) only sensitive in case of small B.E. ~ Γ



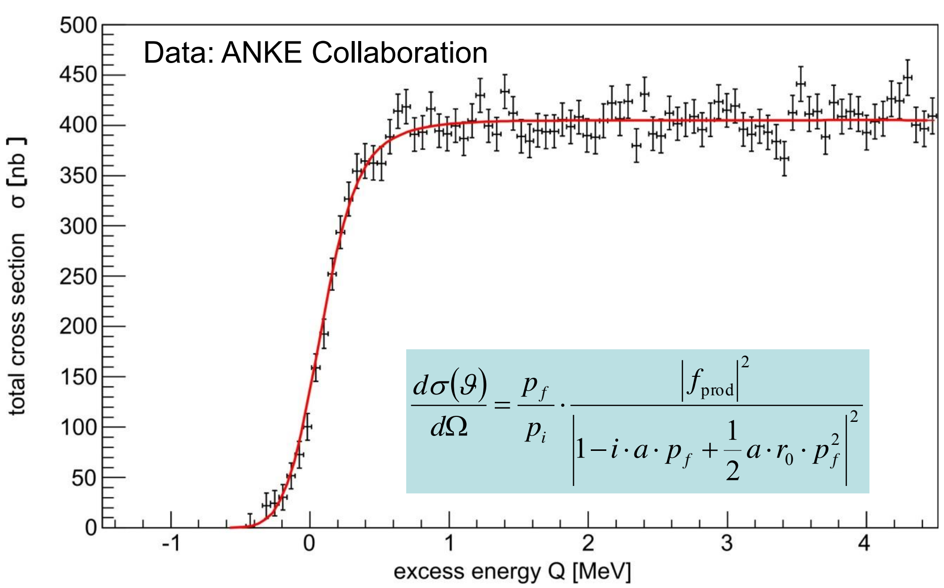
cf. $f_0(980)$, $a_0(980)$ → $K\bar{K}$

cf. η-^{3}He system

WESTFÄLISCHE WILHELMS-UNIVERSITÄT MÜNSTER

The Reaction d+p → ^{3}He+η

Fit to data very close to threshold: Only s-wa



$$\frac{d\sigma(\vartheta)}{d\Omega} = \frac{p_f}{p_i} \cdot \frac{|f_{prod}|^2}{\left|1 - i \cdot a \cdot p_f + \frac{1}{2} a \cdot r_0 \cdot p_f^2\right|^2}$$

Fit

- C le
- C ra
- Fi w ad

Alfons Khoukaz

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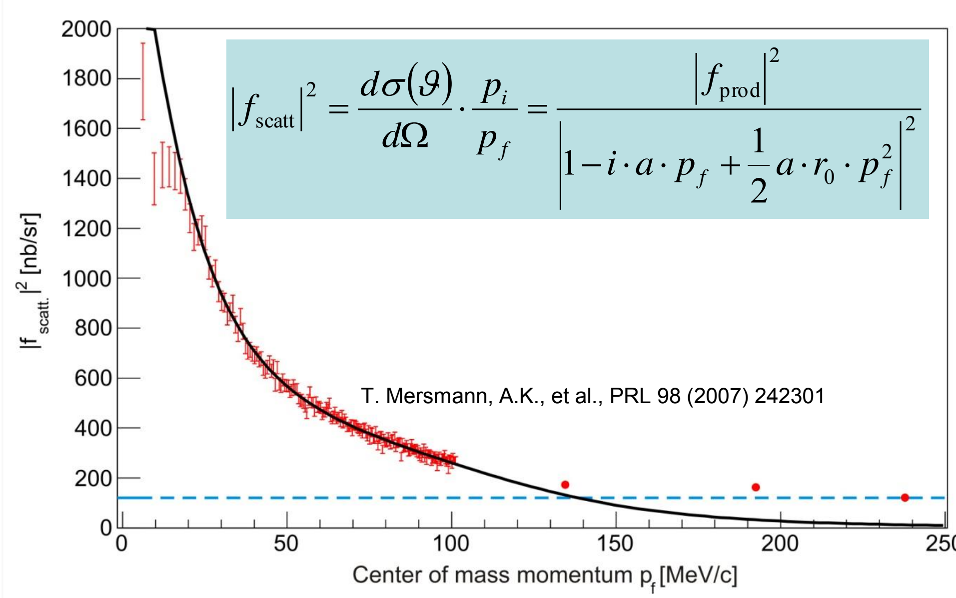
The d+p → ^{3}He+η Scattering Amplitude

Extracted scattering amplitude (Q > 0 MeV)



$$|f_{scatt}|^2 = \frac{d\sigma(\vartheta)}{d\Omega} \cdot \frac{p_i}{p_f} = \frac{|f_{prod}|^2}{\left|1 - i \cdot a \cdot p_f + \frac{1}{2} a \cdot r_0 \cdot p_f^2\right|^2}$$

- Scattering amplitude decreases rapidly with increasing final state momentum p_f
- Scattering amplitude almost constant at high energies

→ strong FSI in η^{3}He system

Alfons Khoukaz

→ quasi-bound or virtual η^{3}He state

A. Khoukaz et al., HIN2013

previous measurement (in 1970s, at RAL)

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

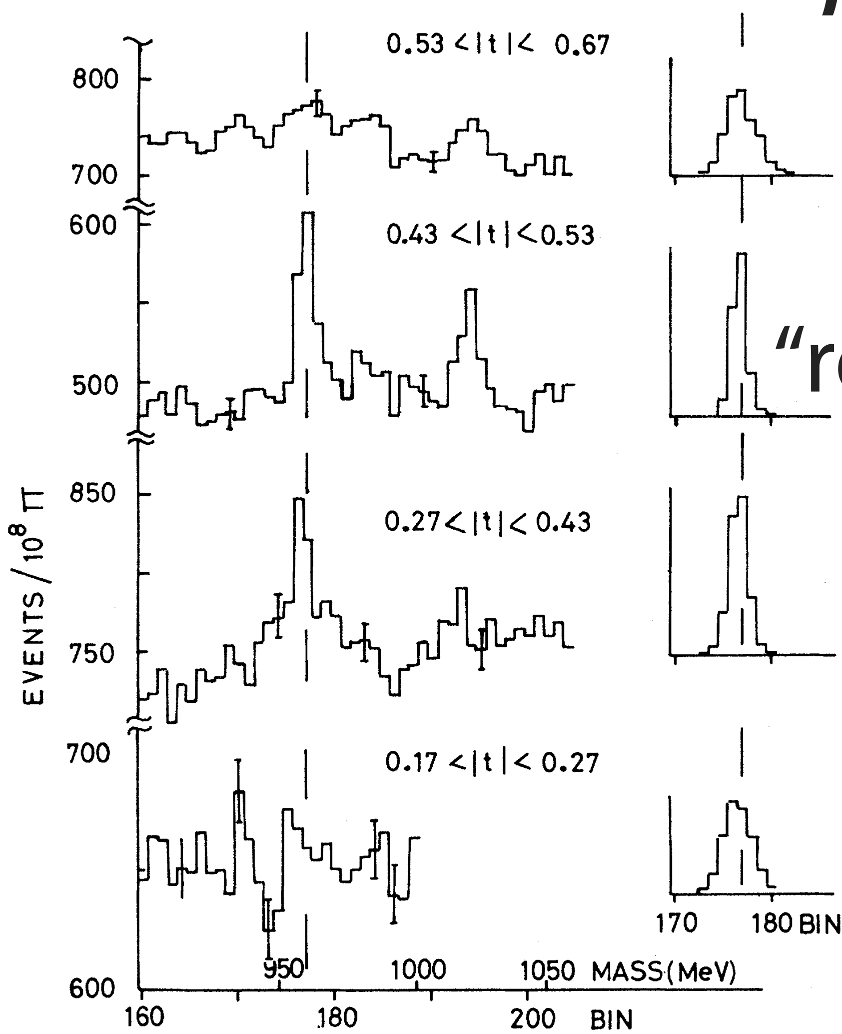


FIG. 15. Mass spectra between about 900 and 1060 MeV for several intervals of t. No decay selection has been used. Note the expanded scales. The X^0 and ϕ both show clearly near threshold. On the right are the X^0 signals predicted for a pure S-wave cross section normalized to the value close to threshold ($t = -0.45$). It appears that $d\sigma/dt$ falls for t both greater and less than this value. There is also some indication of a drop in the background levels near bin 185.

D. Binnie et al., PRD 8, 2789 (1973)

"reanalysis"

σ/p^*

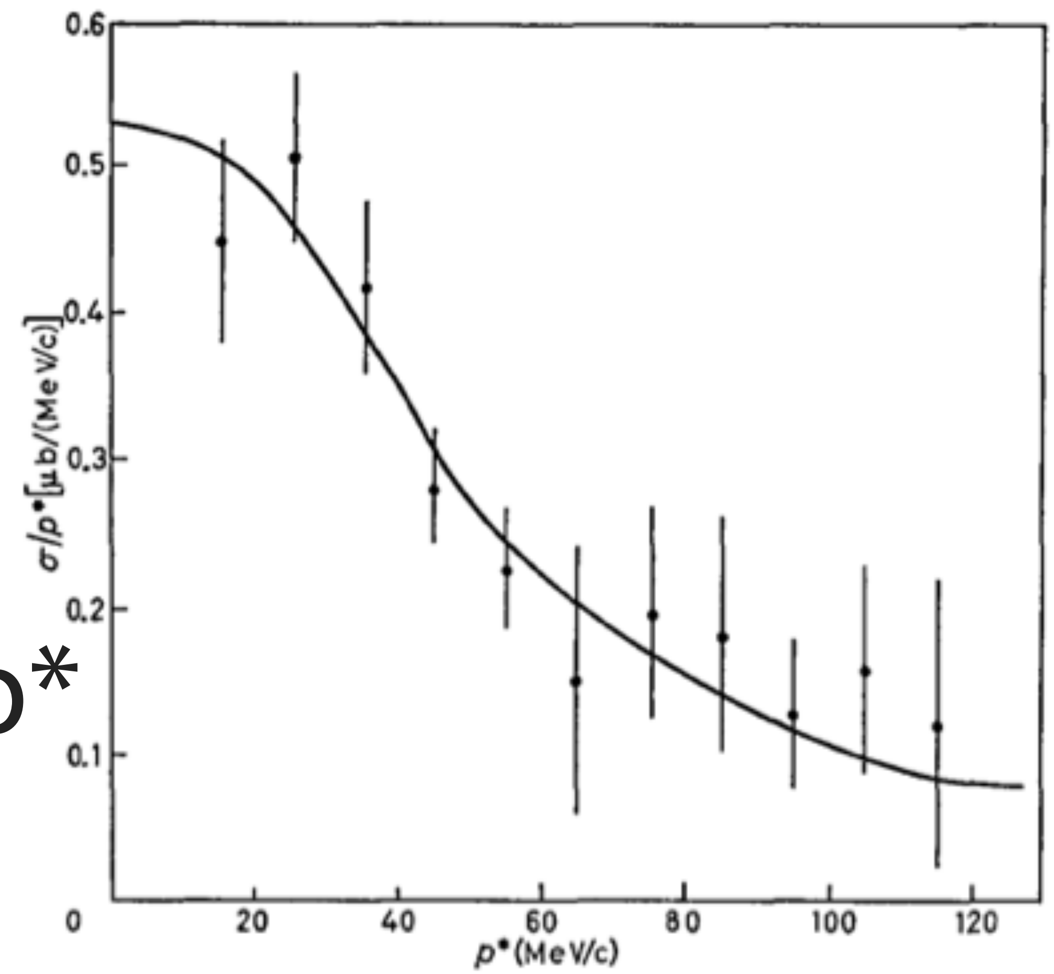


Fig. 5. – $E_0 = 1889.3$ MeV, $\Gamma_{el} = 1.36^{+5.8}_{-0.7}$ MeV, $\Gamma_0 = 1.2^{+9.2}_{-0.9}$ MeV, $J = \frac{1}{2}$, $\gamma = 0.015$.

P. G. Moyssides et al., Nuovo Cimento 75, 163 (1983)

"an alternative explanation … could lie in a rapid modulation of the cross section by an s-channel effect such as a narrow N*."

previous measurement (in 1970s, at RAL)

$$\sigma_{X^0 n} = \frac{2}{3}\,\frac{\pi \lambda\!\!\!^{-2}(J+\frac{1}{2})\Gamma_{el}\Gamma_{X^0 n}}{(E-E_0)^2+\frac{1}{4}(\Gamma_{el}+\Gamma_{X^0 n}+\Gamma_0)^2}$$

$\Gamma_{X^0 n}$ = width for decay into $X^0 n$,

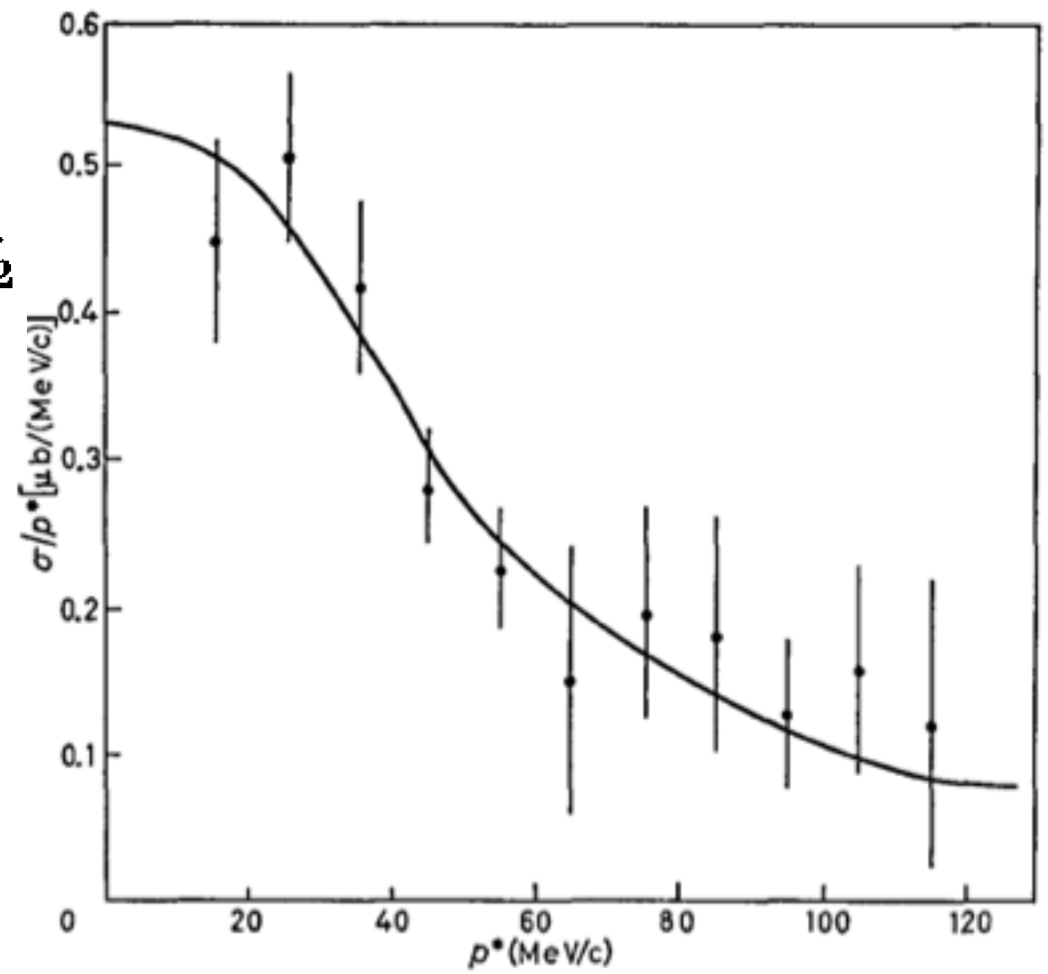
Γ_{el} = width of $X^0 n$ resonance of rest mass E_0,

Γ_0 = partial width to all other channels,

E = total c.m.s. energy,

J = angular momentum of $\mathcal{N}^*$.

[X^0 stands for η′.]



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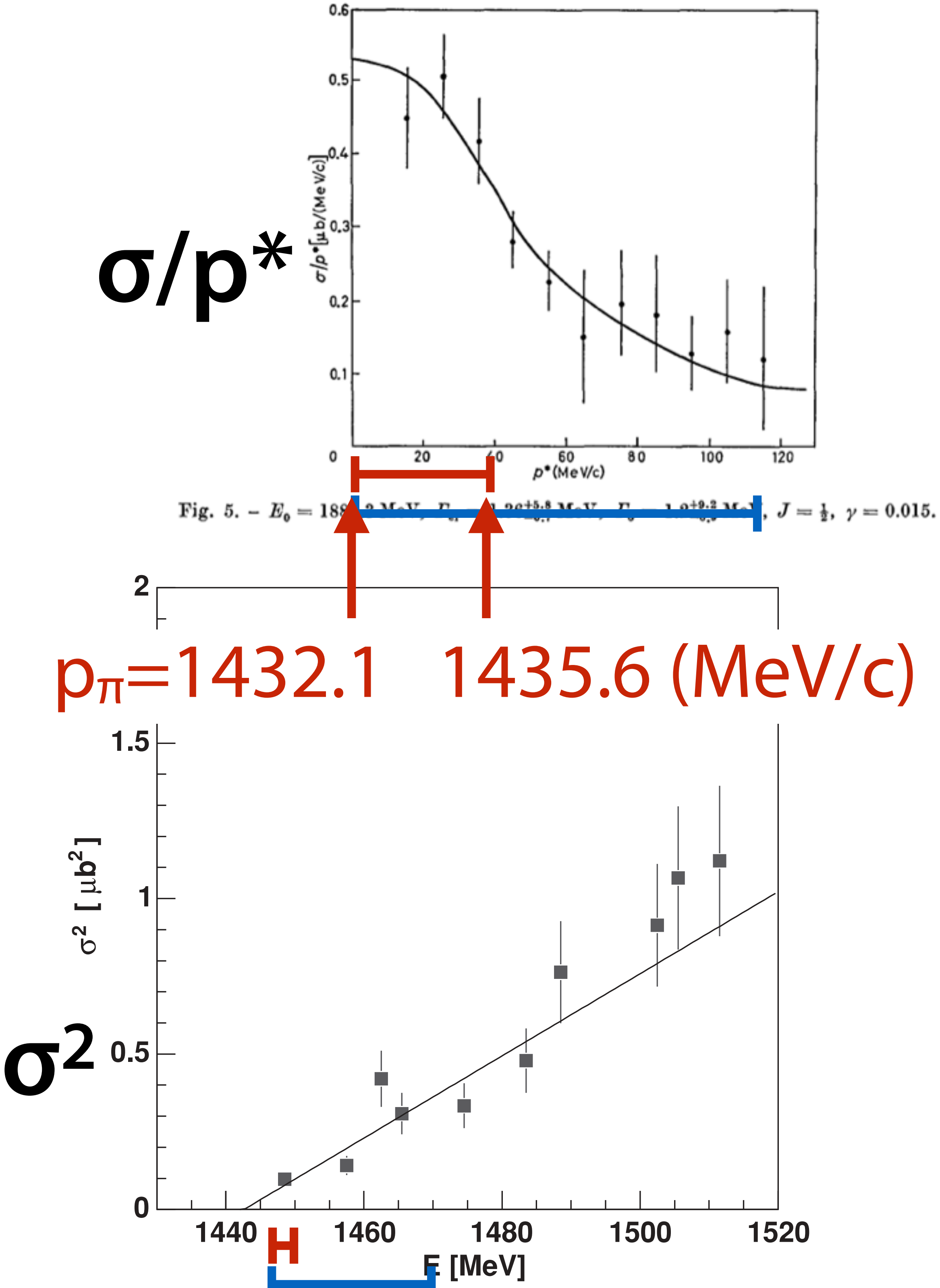
P. G. Moyssides et al., Nuovo Cimento 75, 163 (1983)

binding energy ~8MeV
total width ~3MeV



V. Crede et al., PRC 80, 055202 (2009)

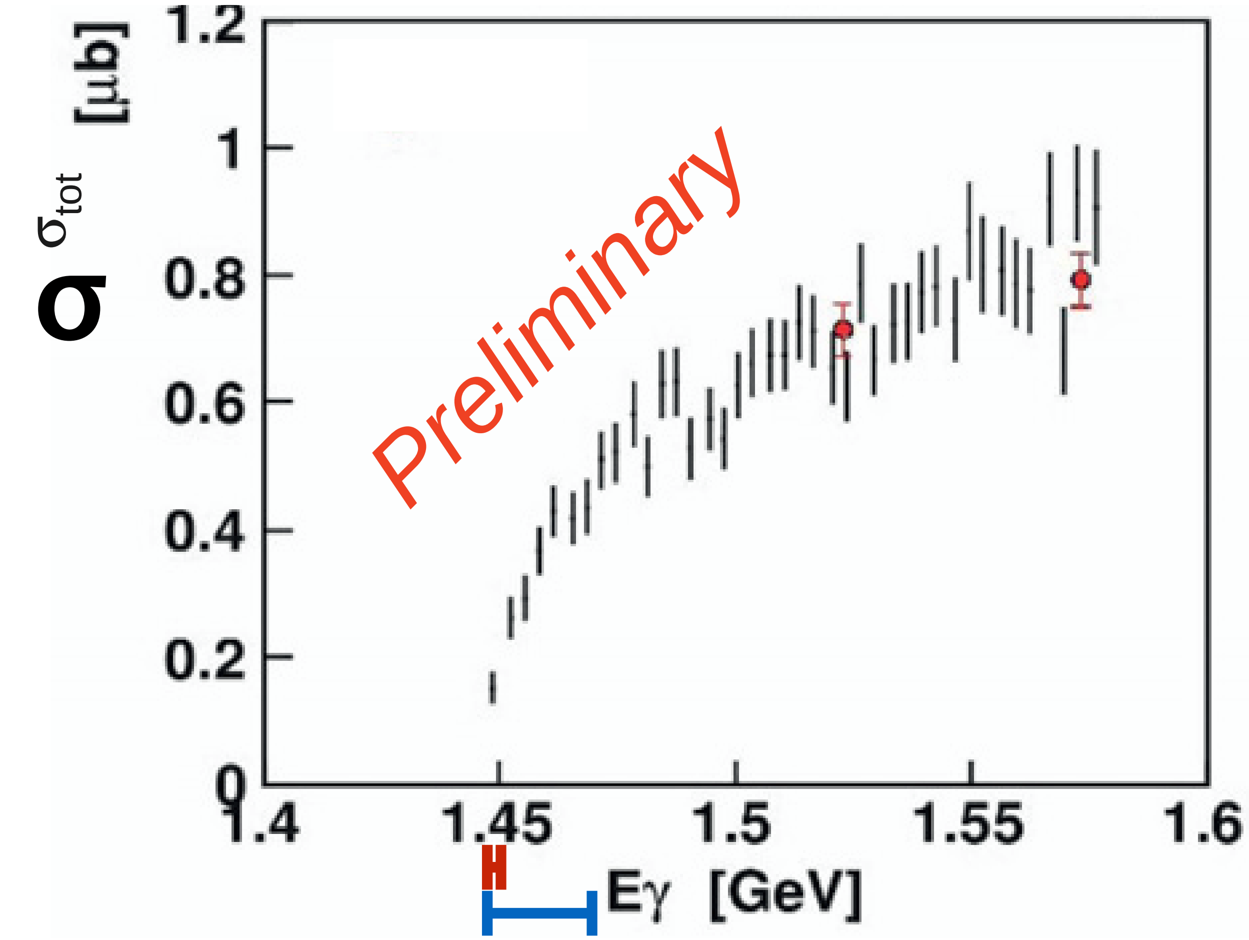


Figure 4. Preliminary total cross section for $\gamma p \to \eta' p$ from the Crystal Ball/TAPS experiment at MAMI-C (black error bars). Uncertainties are of statistical nature only. These data are compared to CBELSA/TAPS results [25]

M. Unverzagt for the A2 collaboration,
EPJ Web of Conferences 72, 00024 (2014)

experiment under consideration

$\pi^- p \rightarrow \eta' n$ *detected by forward neutron counter*

$\eta' \rightarrow \pi^+\pi^-\eta$ B.R.=43%

$\eta \rightarrow \pi^+\pi^-\pi^0$ B.R.=23%

detected by "HypTPC"

@ J-PARC K1.8 (existing beamline)

proposed in E42/E45 collaboration meeting (Sep. 2015)

K. Hosomi, presentation at NSTAR2015

J-PARC E45

Studies of Baryon resonances in $(\pi,2\pi)$ reaction for

- Deeper understanding of non-pertabative QCD
- Preceise measurements of baryon resonance properties
  - Many resonance have not been established experimentally
  - $\pi N \rightarrow \pi\pi N$: "Critical missing piece" for the N* spectroscopy
  - New $\pi N \rightarrow \pi\pi N$ data will provide
    1. significant modifications to the current N* mass
    2. discovery of new N* states.
- Search for new type baryon states
  - e.g. hybrid baryons (qqqg)

NSTAR2015 3

E45 HypTPC Spectrometer

Measure $(\pi,2\pi)$ in large acceptance TPC in dipole magnetic field

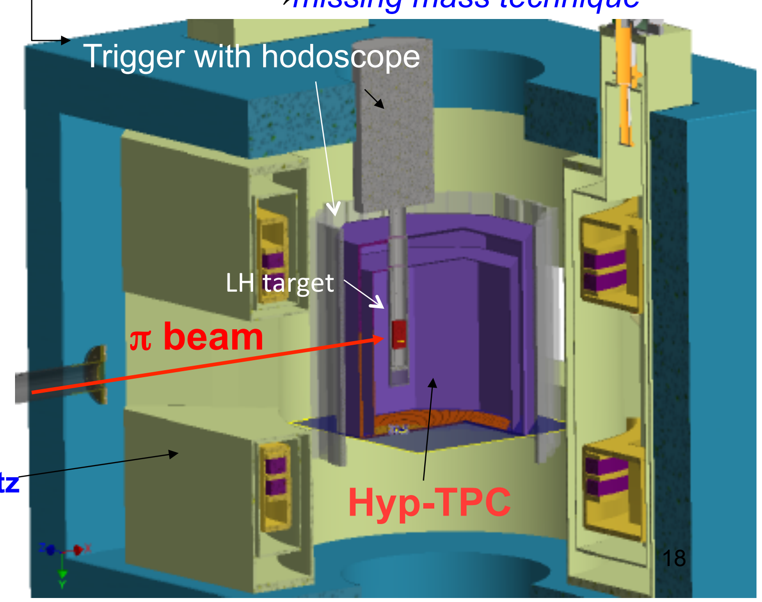
$\pi^- p \rightarrow \pi^+\pi^- n$, $\pi^0\pi^- p$
$\pi^+ p \rightarrow \pi^0\pi^+ p$, $\pi^+\pi^+ n$

2 charged particles + 1 neutral particle
→missing mass technique

$\pi N \rightarrow KY$ (2-body reaction)
$\pi^- p \rightarrow K^0\Lambda$,
$\pi^+ p \rightarrow K^+\Sigma^+$ ($I=3/2$, Δ^*)

π^{+-} beam on liquid-H target
(p= 0.73 – 2.0 GeV/c
W=1.5-2.15 GeV)

LH target: Φ5cm



conclusion

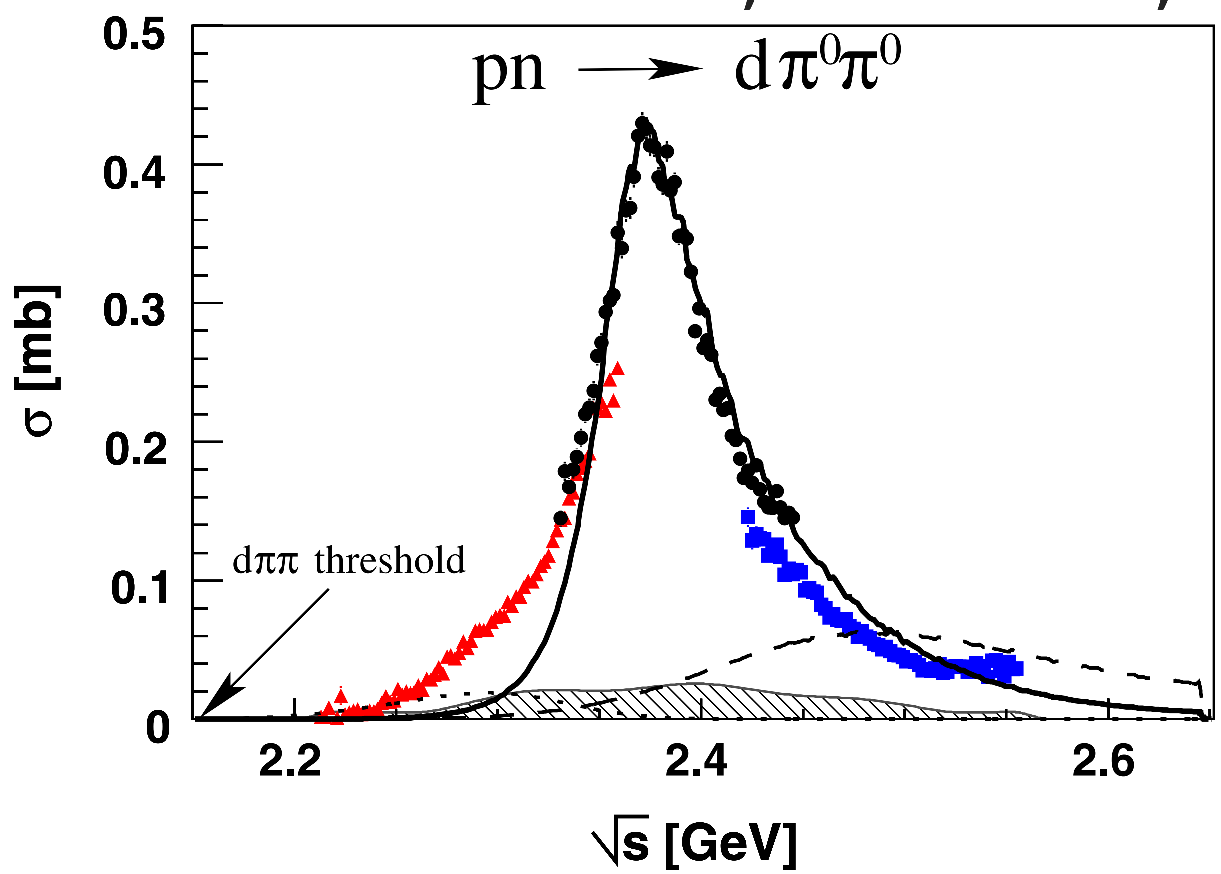
- large mass reduction of η′ in medium (= strong attraction in η′-nucleus interaction) anticipated
  - $^{12}C(\pi^+,p)$ reaction @ J-PARC HIHR beam line
    - re-measurement of elementary cross section ($\pi^- p \rightarrow \eta' n$) necessary
  - possible existence of η′N bound state might be investigated by $\pi^- p \rightarrow \eta' n$ reaction

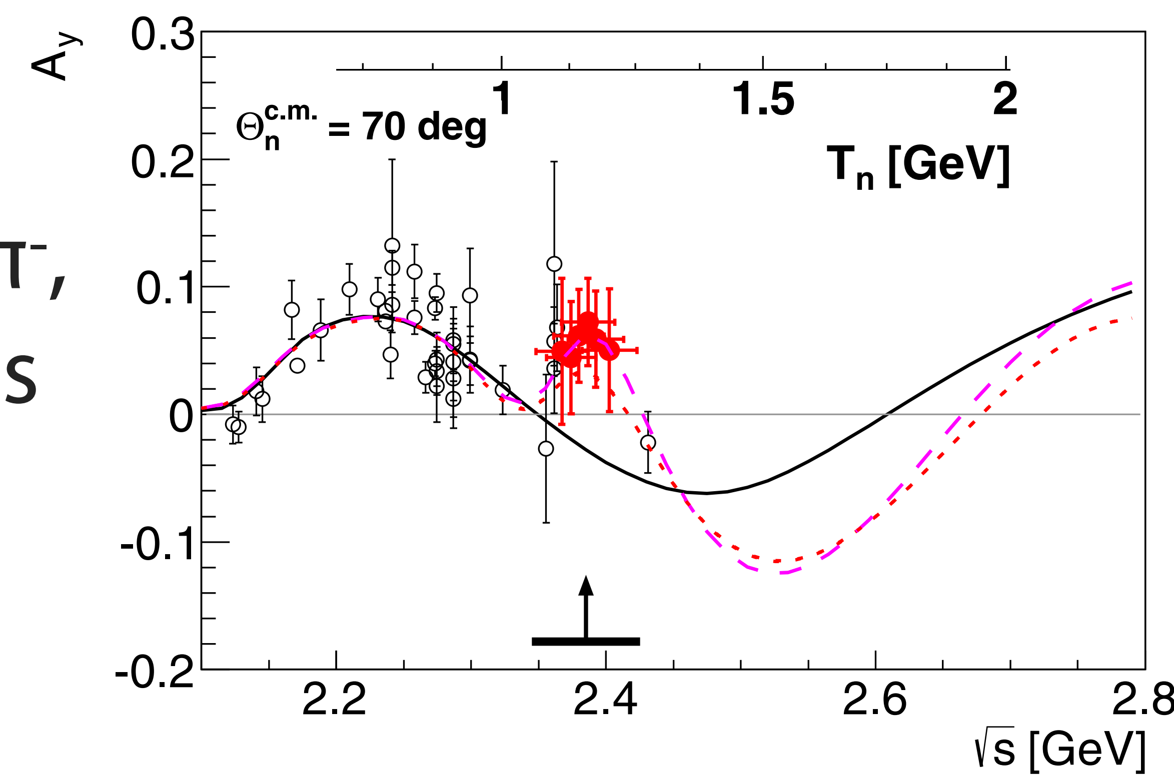
On the possibility of d*(2380) production by diffractive dissociation

Hiroyuki Fujioka (Kyoto Univ.)

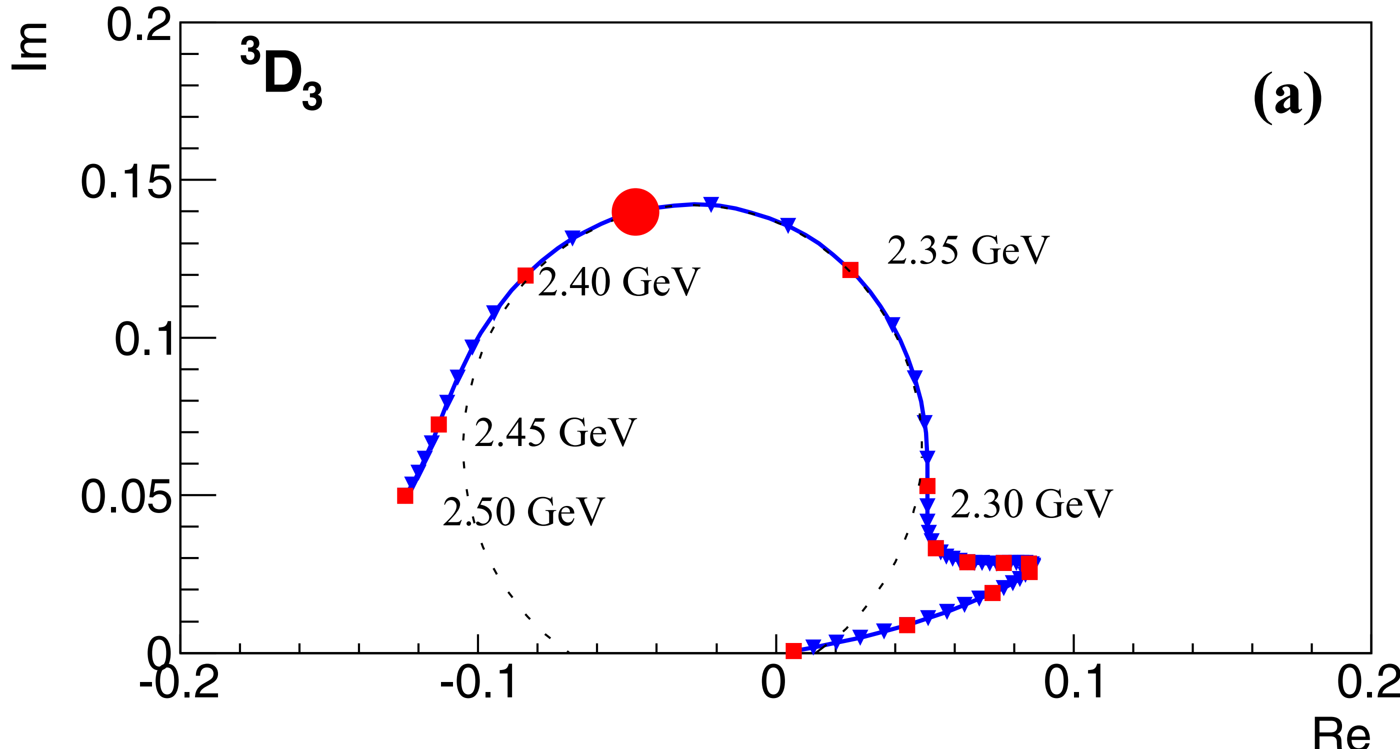
d*(2380) dibaryon resonance (ABC effect)

- confirmed by WASA-at-COSY
- seen in $pn \to d\pi^0\pi^0$, $d\pi^+\pi^-$, $pp\pi^0\pi^-$, $pn\pi^0\pi^0$, $pn\pi^+\pi^-$, and pn channels
- M~2380MeV, Γ~80MeV, $J^P=3^+$





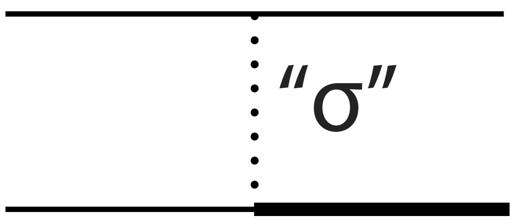
P. Adlarson et al., PRL 106, 242302 (2011)



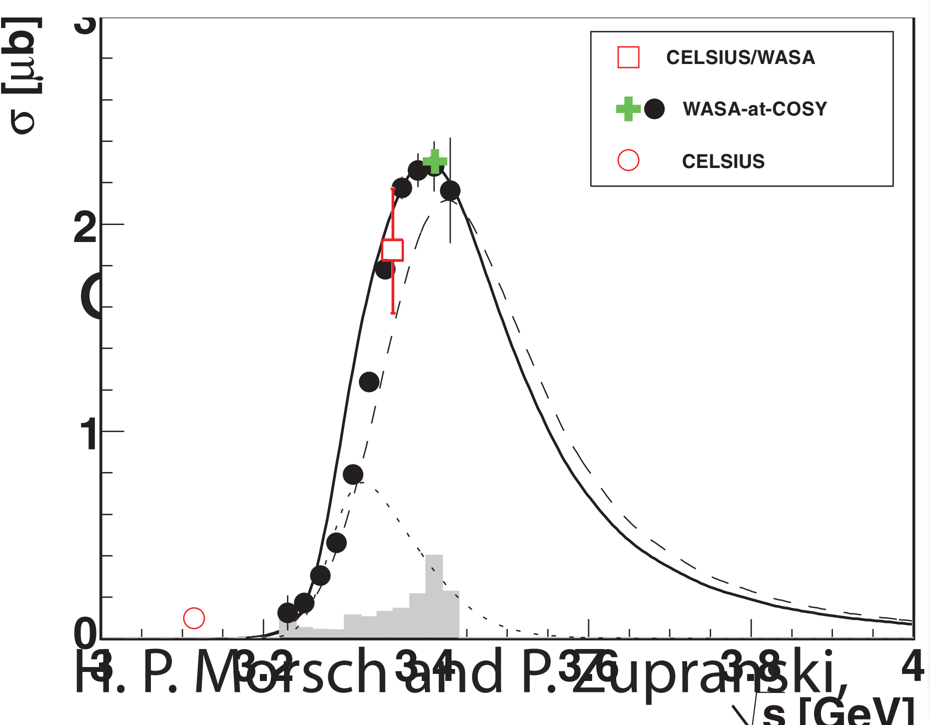
PRC 90, 035204 (2014)

production via diffractive dissociation?

discussion with M.N. Platonova and V.I. Kukulin

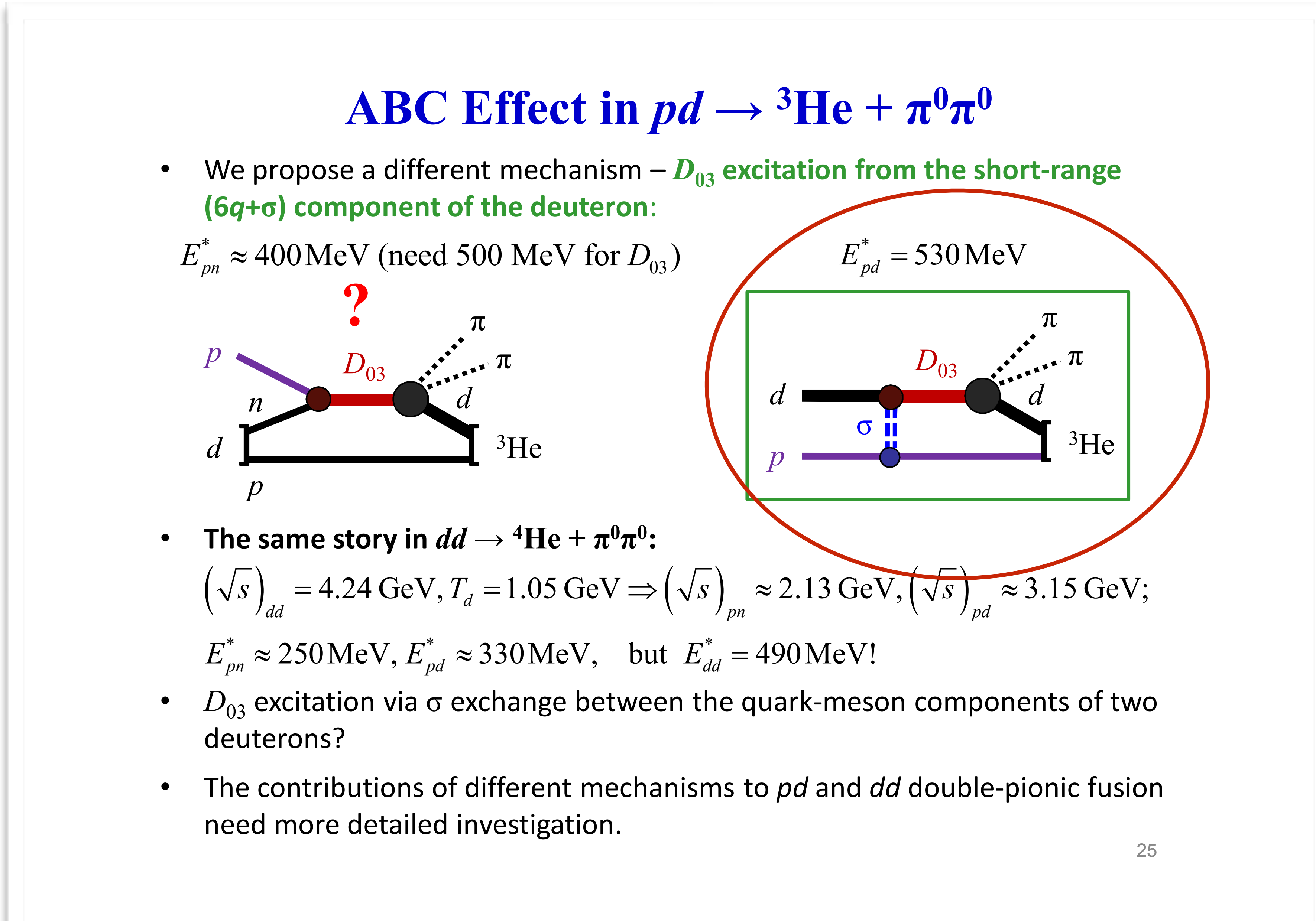


possible at J-PARC high-p beamline?



H. P. Morsch and P. Zupranski, PRC 71, 065203 (2005)

P. Adlarson et al., PRC 91,015201 (2015)



ABC Effect in $pd \to {}^3\mathrm{He} + \pi^0\pi^0$

- We propose a different mechanism – **D_{03} excitation from the short-range (6q+σ) component of the deuteron**:

$E^*_{pn} \approx 400\,\mathrm{MeV}$ (need 500 MeV for D_{03}) ? $E^*_{pd} = 530\,\mathrm{MeV}$

- **The same story in $dd \to {}^4\mathrm{He} + \pi^0\pi^0$:**

$(\sqrt{s})_{dd} = 4.24\,\mathrm{GeV},\ T_d = 1.05\,\mathrm{GeV} \Rightarrow (\sqrt{s})_{pn} \approx 2.13\,\mathrm{GeV},\ (\sqrt{s})_{pd} \approx 3.15\,\mathrm{GeV};$

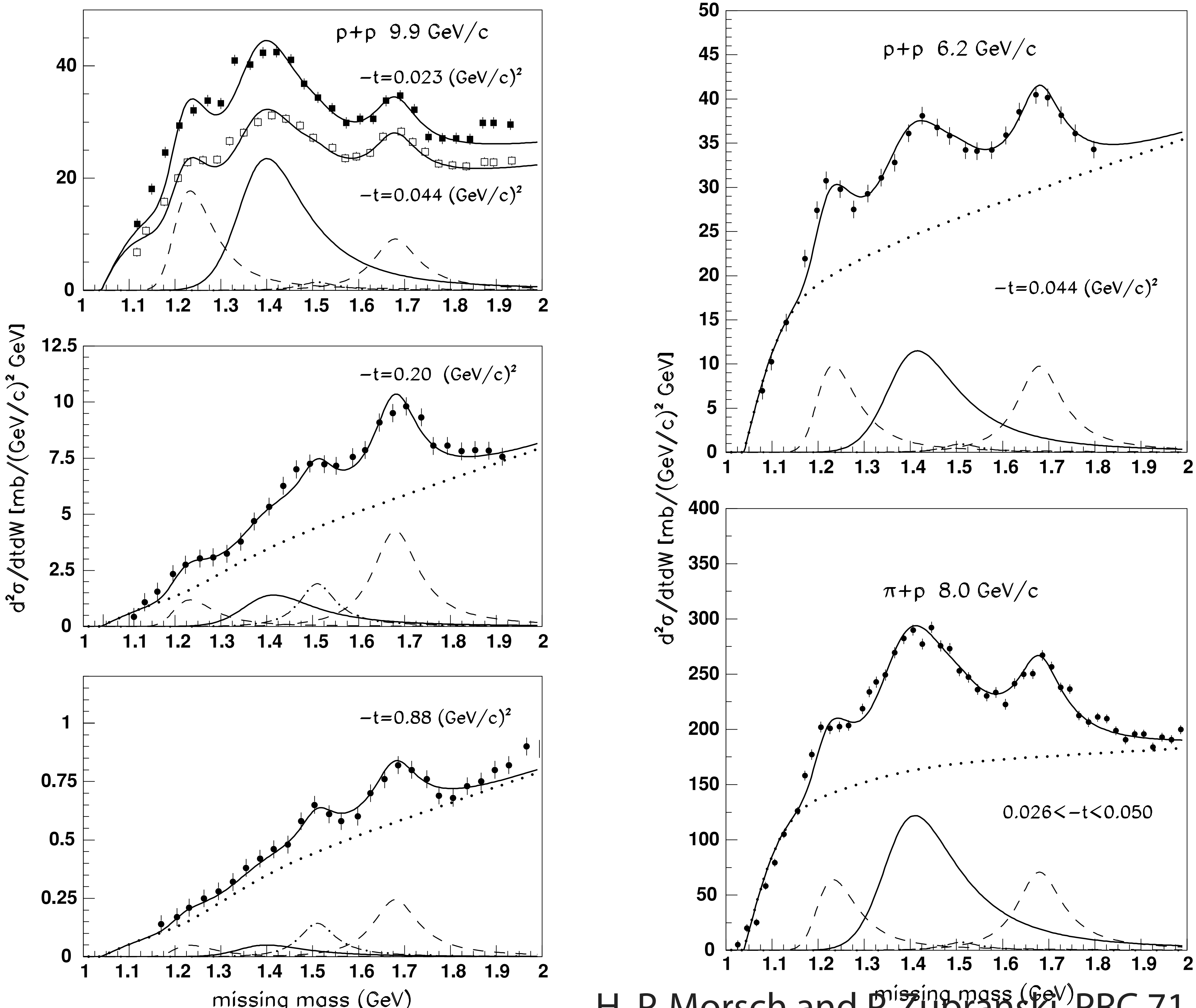
$E^*_{pn} \approx 250\,\mathrm{MeV},\ E^*_{pd} \approx 330\,\mathrm{MeV}$, but $E^*_{dd} = 490\,\mathrm{MeV}!$

- D_{03} excitation via σ exchange between the quark-meson components of two deuterons?
- The contributions of different mechanisms to *pd* and *dd* double-pionic fusion need more detailed investigation.

25

M.N. Platonova, presentation at MENU2013

Roper excitation



H. P. Morsch and P. Zupranski, PRC 71, 065203 (2005)