η'-nucleus optical potential and the search for η' mesic states in photo nuclear reactions

Mariana Nanova
II. Physikalisches Institut
JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

for CBELSA/TAPS Collaboration

Outline:

- motivation
- experimental approaches for determining the η'-nucleus optical potential:
  - imaginary part of the potential - transparency ratio measurement
  - real part of the potential:
    - excitation function of the η'-meson
    - momentum distribution
- search for η'-nucleus bound states
- summary

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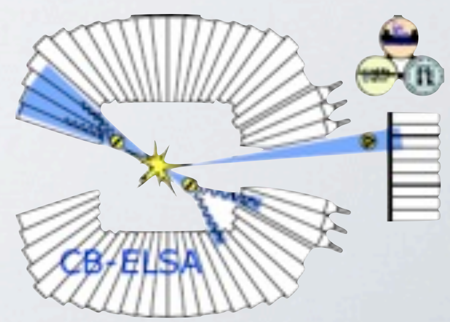
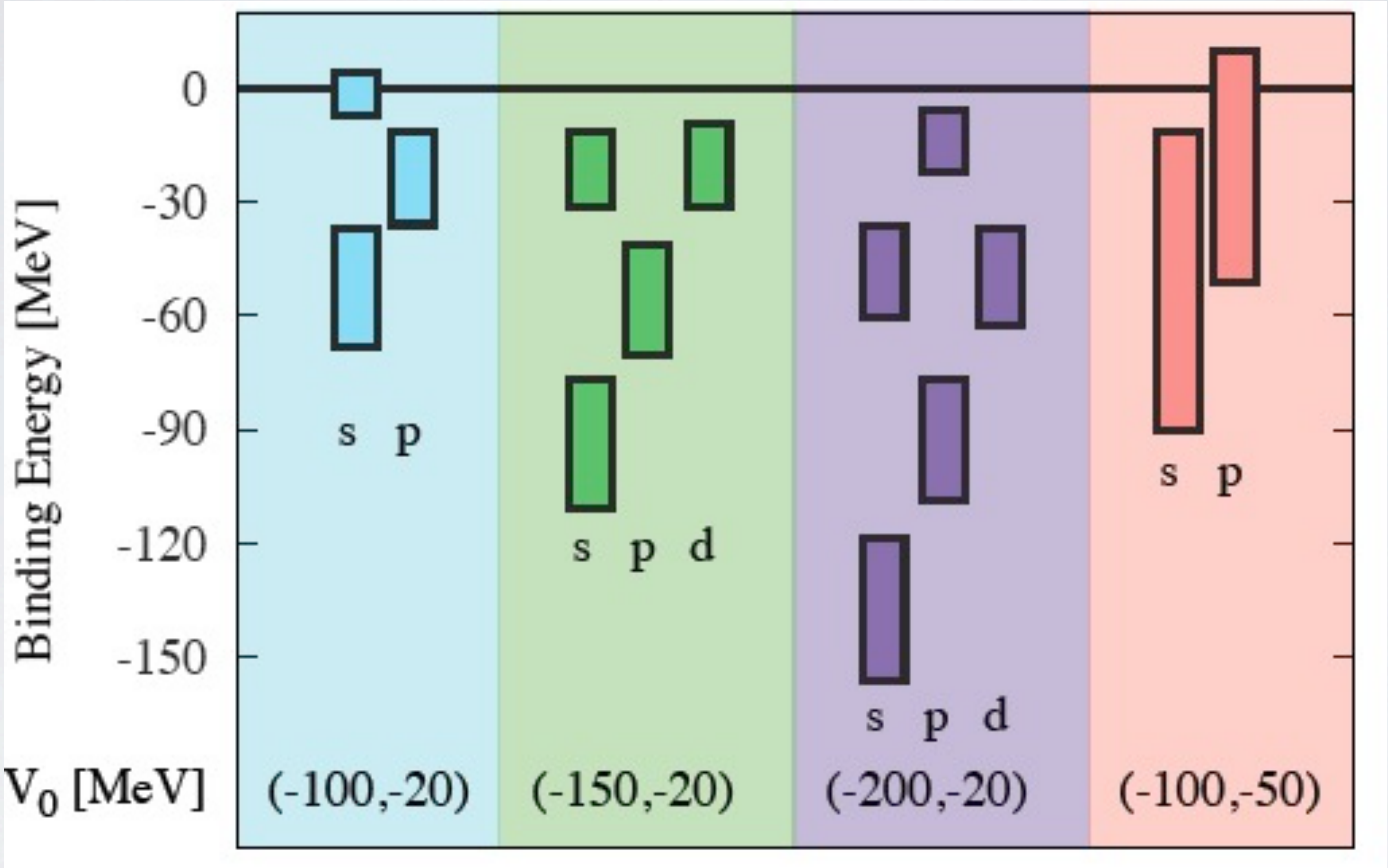
YITP Workshop on Hadron in Nucleus,
31st Oct.-2nd Nov. 2013, Kyoto, Japan



search for η'-meson-nucleus bound states

prediction of η'-^{12}C bound states and their width for different η' -meson nucleus potentials

D. Jido et al., PRC 85 (2012) 032201



$U(\rho) = V(\rho) + i\,W(\rho)$

many states with width Γ << binding energy predicted

more strongly bound states for deeper potentials

$W(\rho_0) \approx$ -10 MeV from M. Nanova et al., PLB 710 (2012) 600

Experimental approaches to determine the meson-nucleus optical potential

meson-nucleus optical potential

$$U(r) = V(r) + iW(r)$$

meson mass shift

$$V(r) = \Delta m(\rho_0) \cdot \frac{\rho(r)}{\rho_0}$$

meson absorption

$$W(r) = -\Gamma_0/2 \cdot \frac{\rho(r)}{\rho_0}$$
$$= -\frac{1}{2} \cdot \hbar c \cdot \rho(r) \cdot \sigma_{inel} \cdot \beta$$

line shape analysis:
direct determination of Δm

excitation function:
provides information about the depth of V(r)

meson momentum distribution:
provides information about the depth of V(r)

meson-nucleus-bound states:
direct determination of E_{bin} (Δm)

Transparency ratio measurement

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

experimental observable to extract the in-medium width of the meson

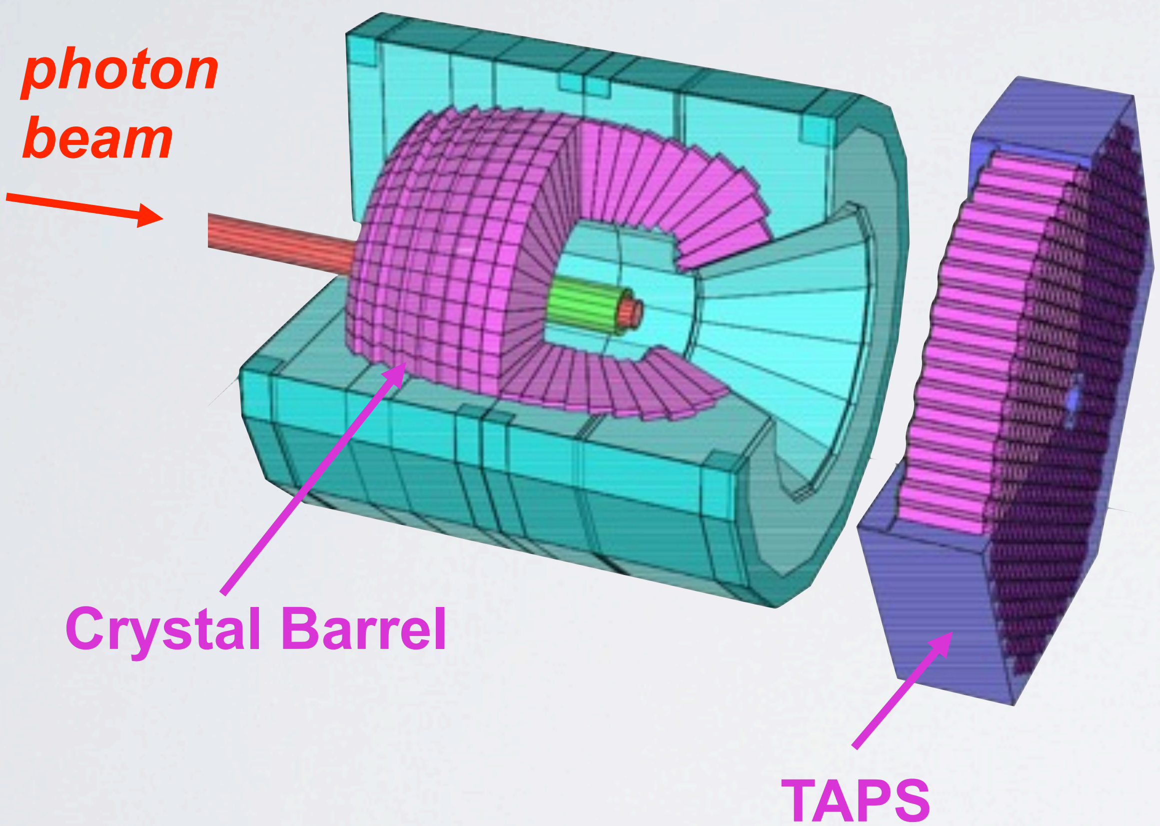
Crystal Barrel/TAPS@ELSA Experiment

http://www.cb.uni-bonn.de

photoproduction of η’ meson

beamtime 2003

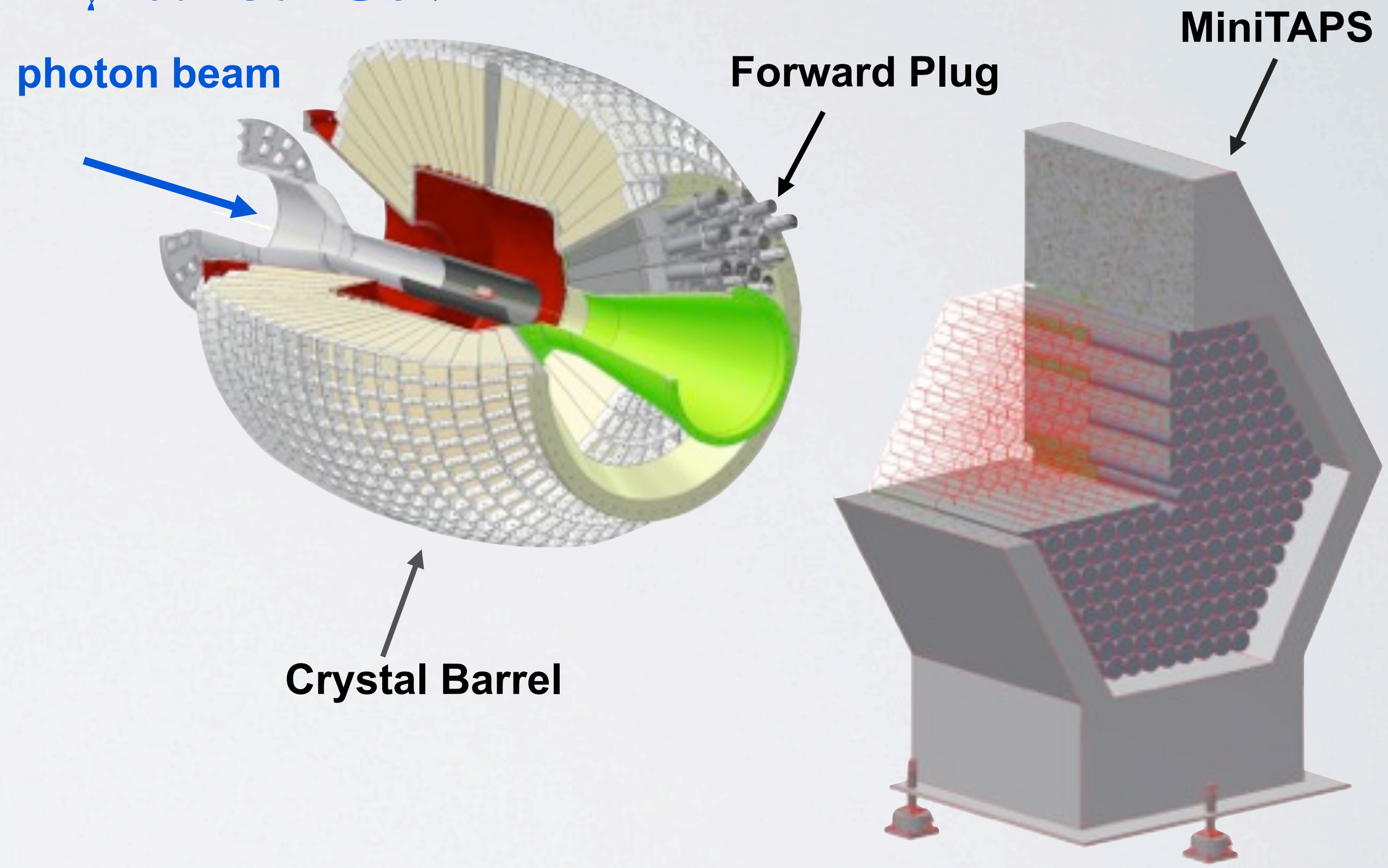
E_γ=0.5-2.6 GeV



solid target: ^{12}C, ^{40}Ca, ^{93}Nb and ^{208}Pb

beamtime 2009

E_γ=0.7-3.1 GeV



solid target: ^{12}C

4π photon detector: ideally suited for identification of multiphoton final states

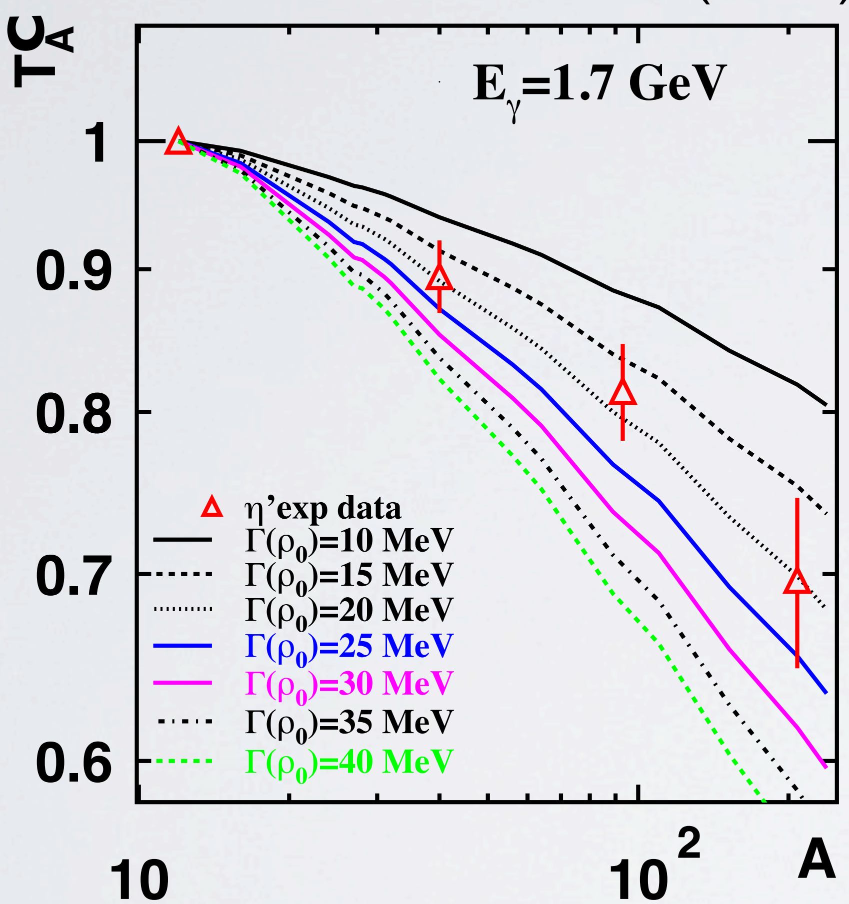
$$\eta' \rightarrow \pi^0\pi^0\eta \rightarrow 6\gamma$$ BR 8.1%

The imaginary part of the η'-nucleus potential

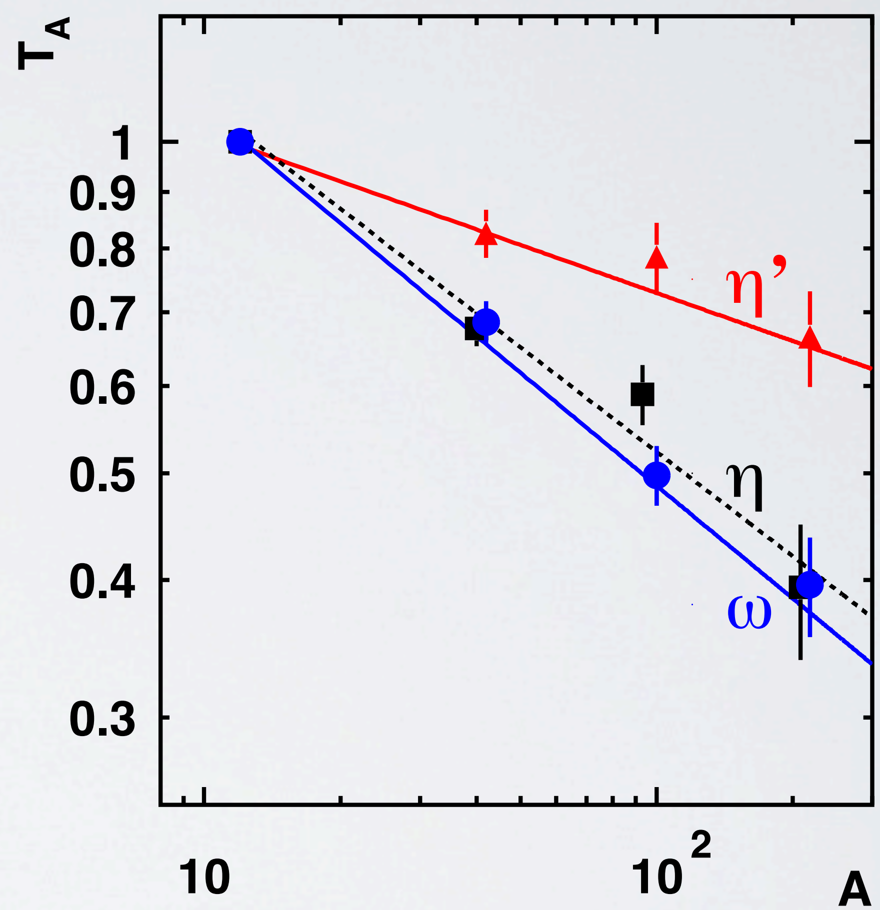
E_γ = 1500 - 2200 MeV; photoproduction of η' meson off ^{12}C, ^{40}Ca, ^{93}Nb and ^{208}Pb

$$T_A^C = \frac{12 \cdot \sigma_{\gamma A \to \eta' X}}{A \cdot \sigma_{\gamma C \to \eta' X}}$$ normalized to carbon

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



comparison with other mesons



at low density approximation:

$$\Gamma(\rho) = -\frac{Im\Pi(\rho)}{E} \sim \rho v \sigma_{inel} \quad ; \; \Gamma(\rho) = \Gamma(\rho_0)\frac{\rho}{\rho_0}$$

⇨ $\Gamma_{\eta'}(<|p_{\eta'}|> \approx 1.05$ GeV/c) ≈ 15-25 MeV;

$\rho_0 = 0.17$ fm^{-3}; $\sigma^{\eta'}_{inel} \approx 3$ -10 mb

η' interaction with nuclear matter much weaker than for η, ω mesons

W(ρ=ρ$_0$)= -Γ$_0$/2 = - (7.5-12.5) MeV

The real part of the η'-nucleus potential

J. Weil, U. Mosel and V. Metag, PLB 723 (2013) 120

E. Paryev, J. Phys. G: Nucl. Part. Phys. 40 (2013) 025201
based on γp→ η'p and γn→ η'n exp. data

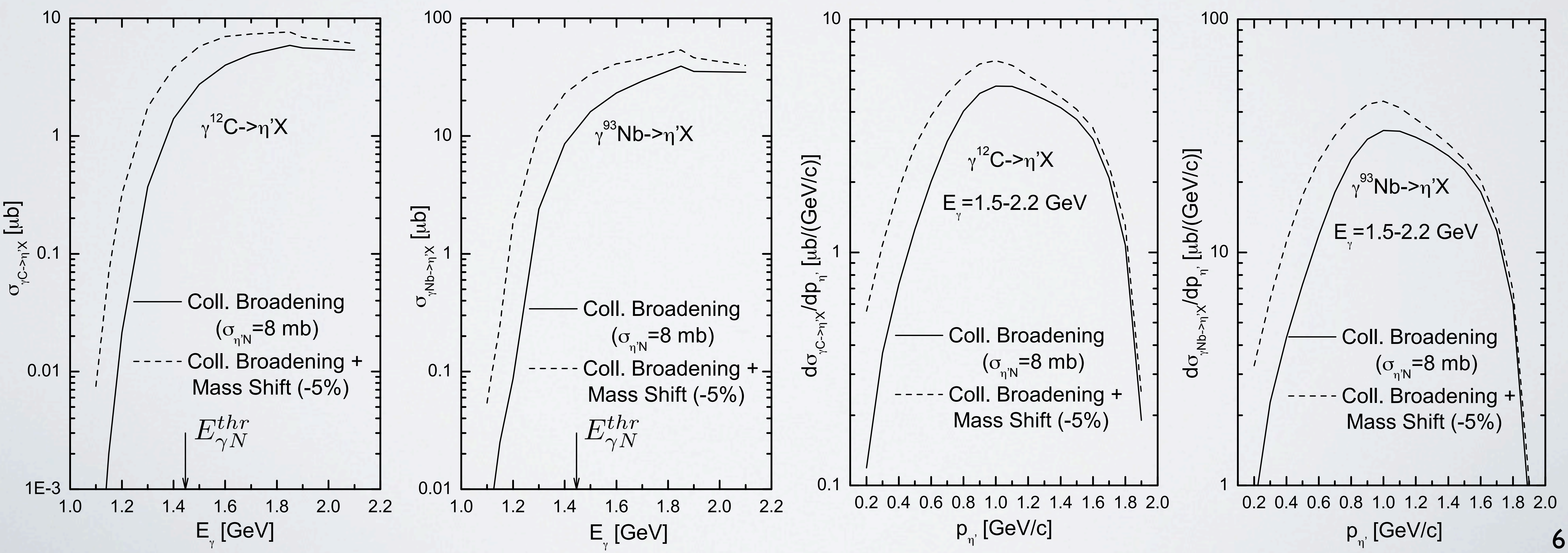
- measurement of the excitation function of the meson:

in case of dropping mass -
higher meson yield for given √s
because of increased phase space
due to lowering of the production threshold

- measurement of the momentum distribution of the meson:

in case of dropping mass - when leaving the nucleus hadron has to become on-shell;
mass generated at the expense of kinetic energy

⇨ downward shift of momentum distribution

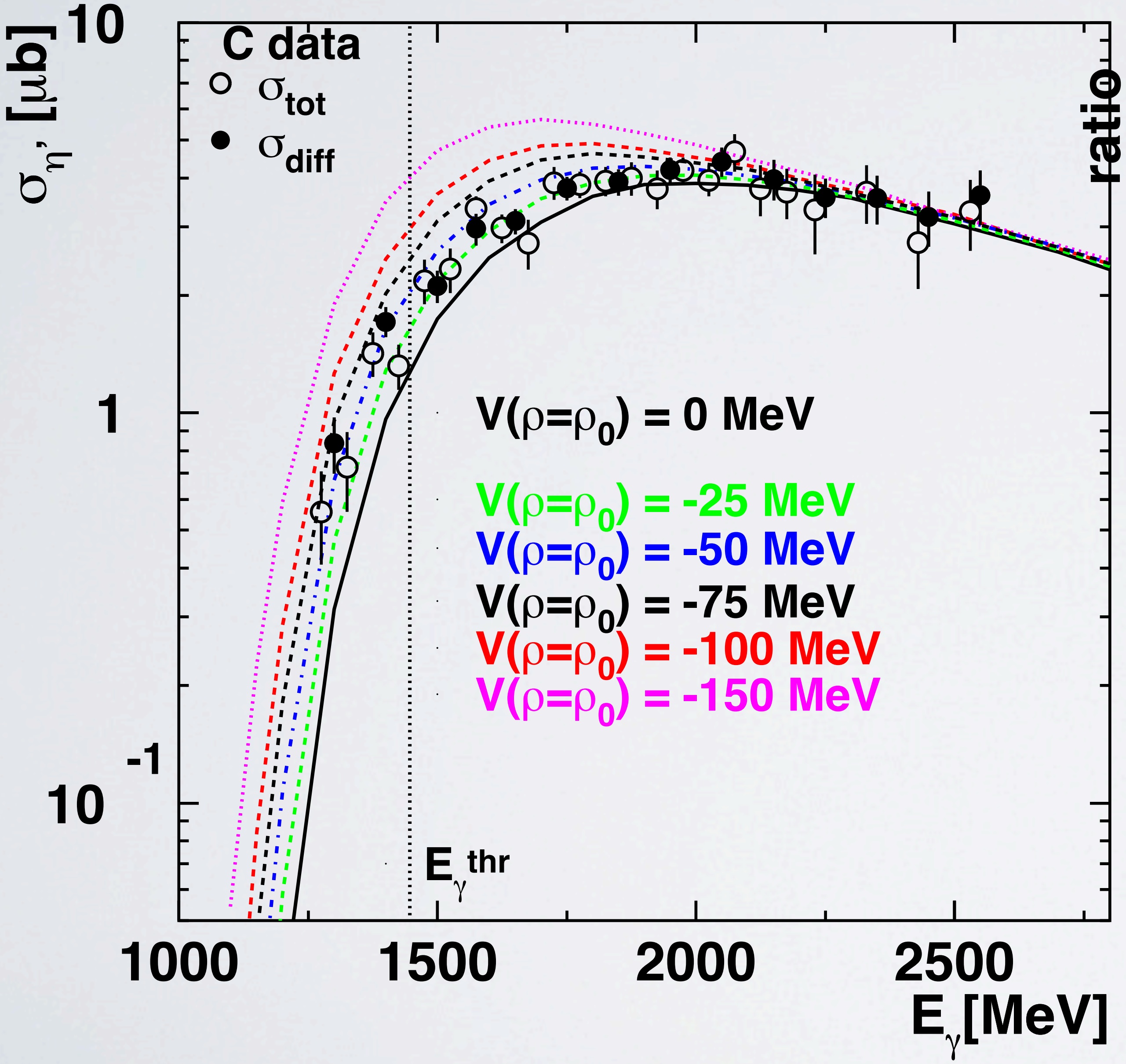


excitation function for η' photoproduction off C

comparison of CBELSA/TAPS data with
calculations by E. Paryev, J. Phys. G: Nucl. Part. Phys. 40 (2013) 025201
and priv. communication

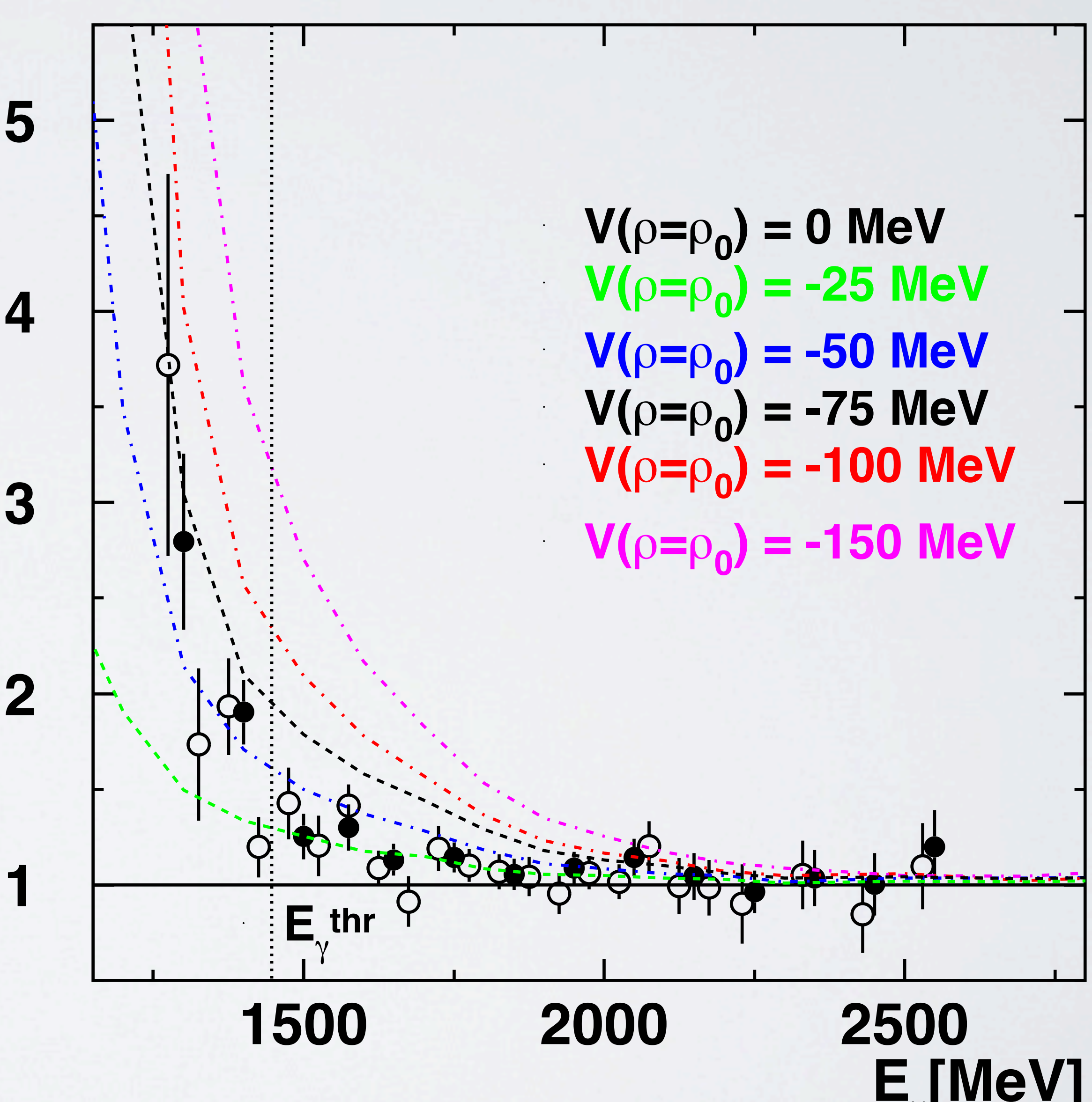
decay mode: $\eta' \rightarrow \pi^0\pi^0\eta$

excitation function



calculations normalized to data for
E_γ = 2000-2500 MeV; downscaled by 1.2

exp. data and the 5 scenarios divided by the calculation for scenario $V(\rho=\rho_0)=0$ MeV

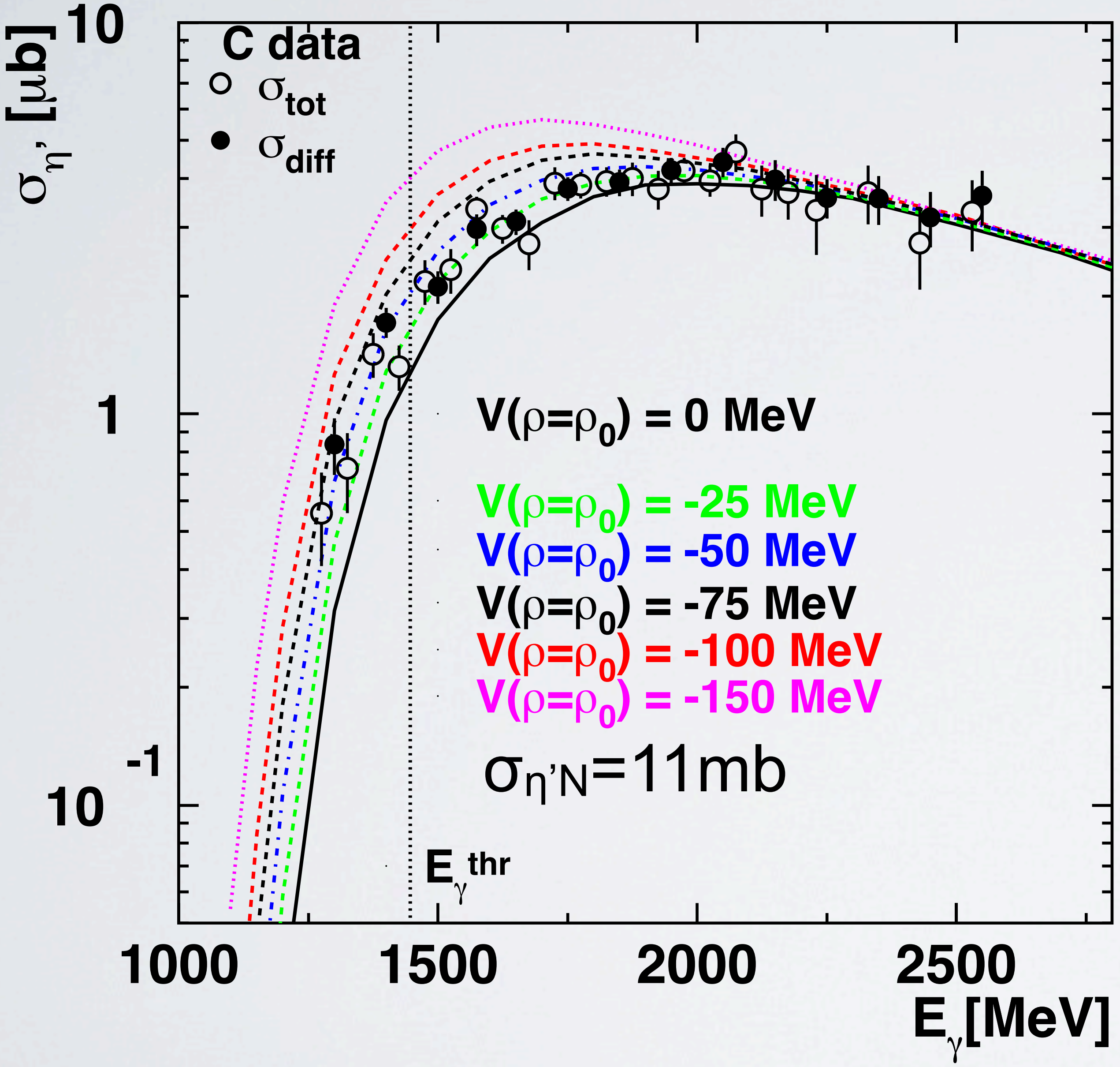


strong mass shift not supported by data

estimation of the real part of the η'-nucleus potential from the η' excitation function

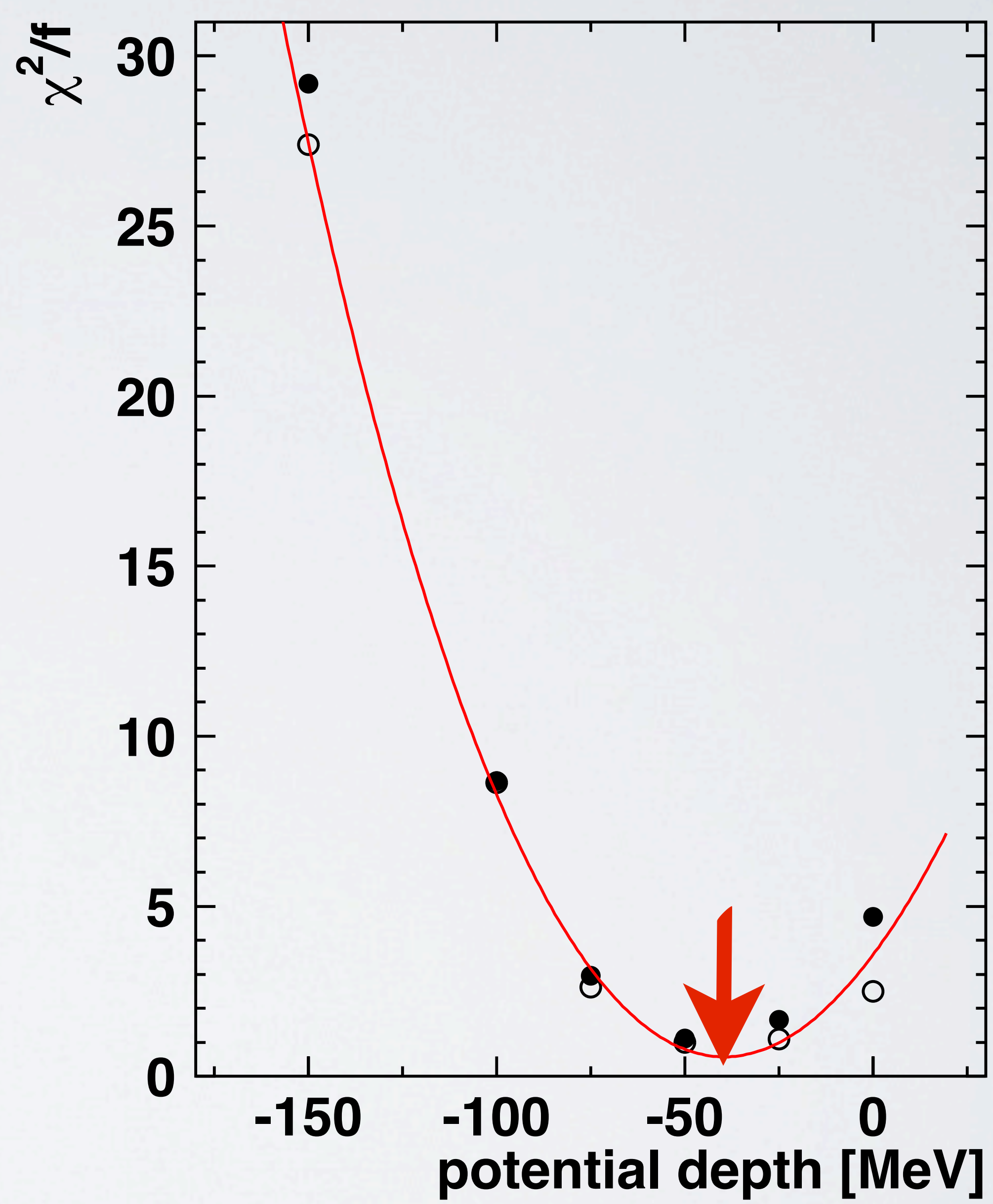
M. N. et al., paper accepted for publication in PLB

excitation function



V(ρ=ρ0) = -40±6 MeV

significance test



χ^2-fit of the data with the calculated excitation functions for the 6 scenarios

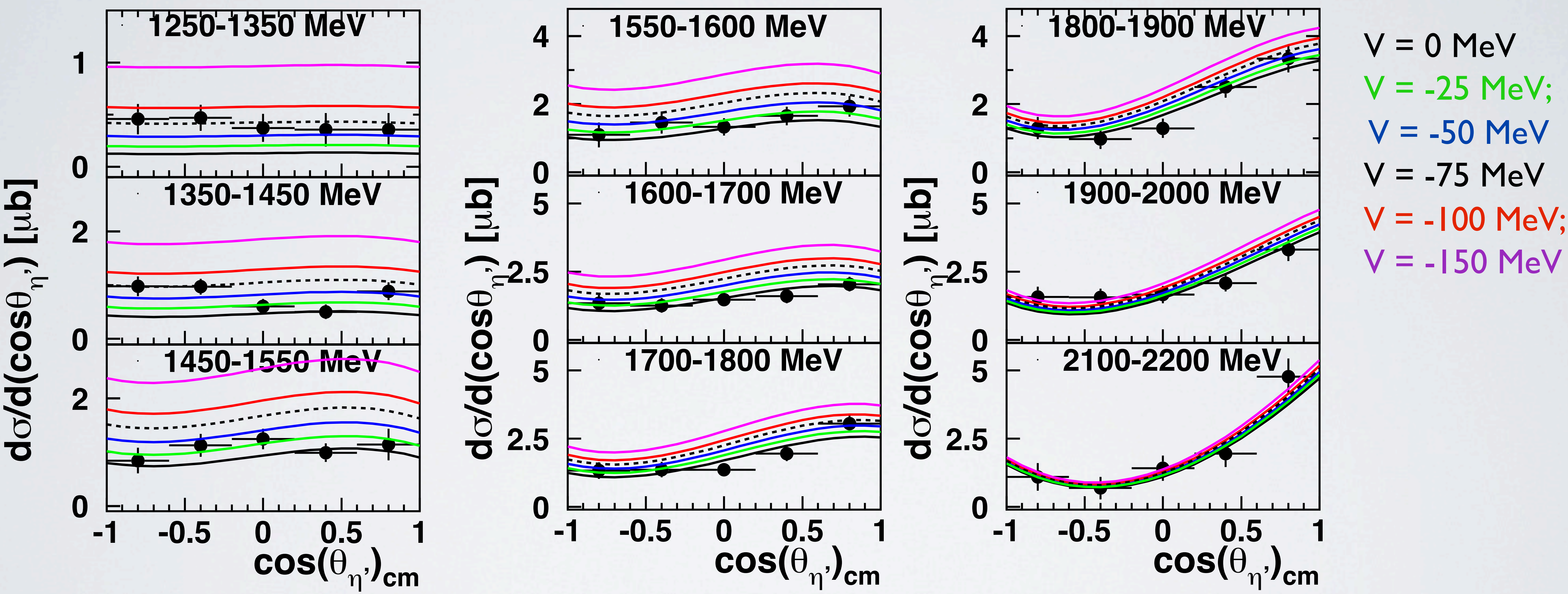
experimental data on η' photoproduction off ^{12}C

E_γ = 1250 - 2600 MeV $\quad \eta' \rightarrow \pi^0\pi^0\eta \rightarrow 6\gamma \quad$ BR: 8.1%

sensitivity to different scenarios

E. Ya. Paryev, priv. communication

below threshold at threshold above threshold



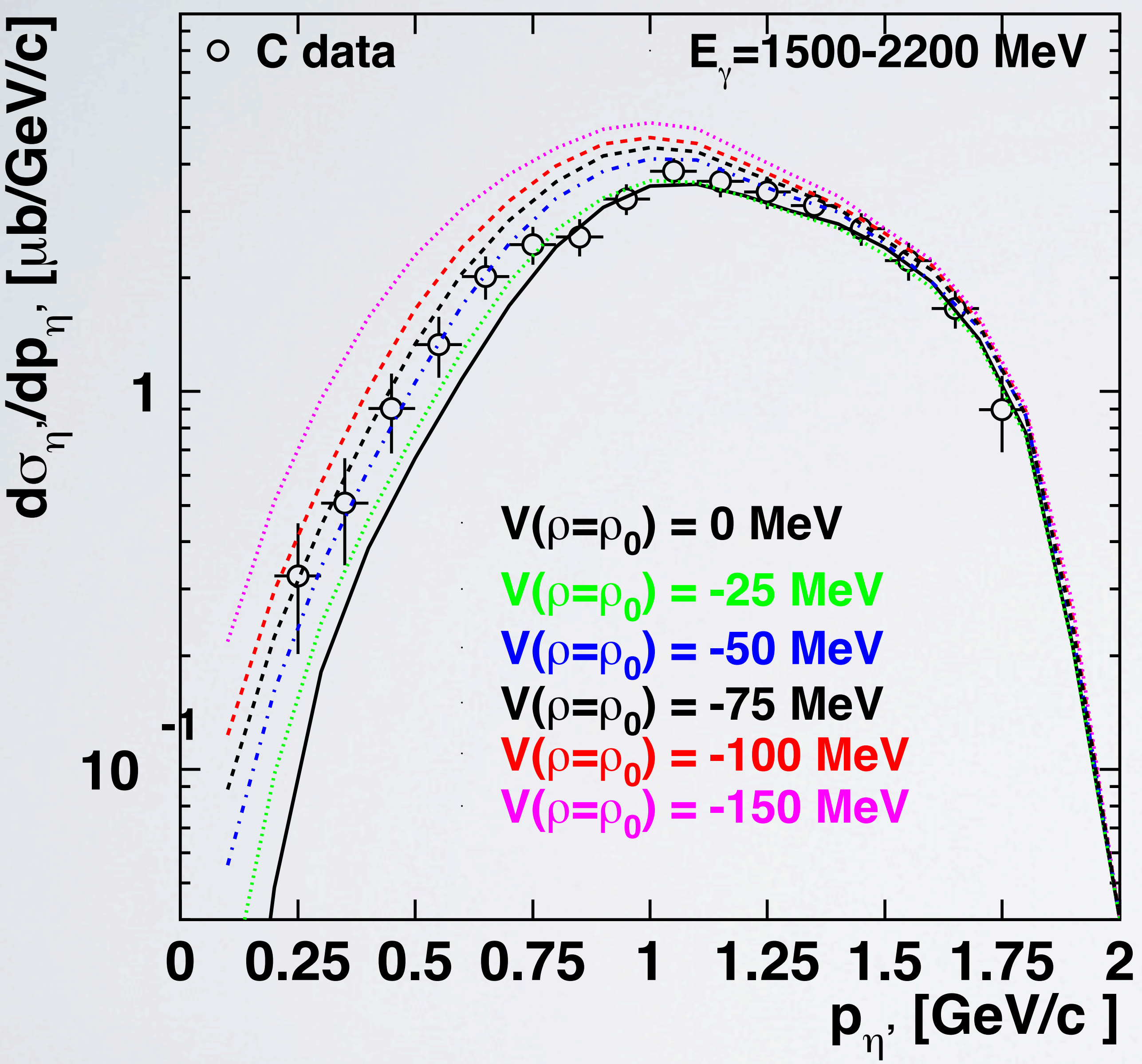
high sensitivity to different scenarios at threshold

strong mass shift not supported by data

η' momentum distribution off C

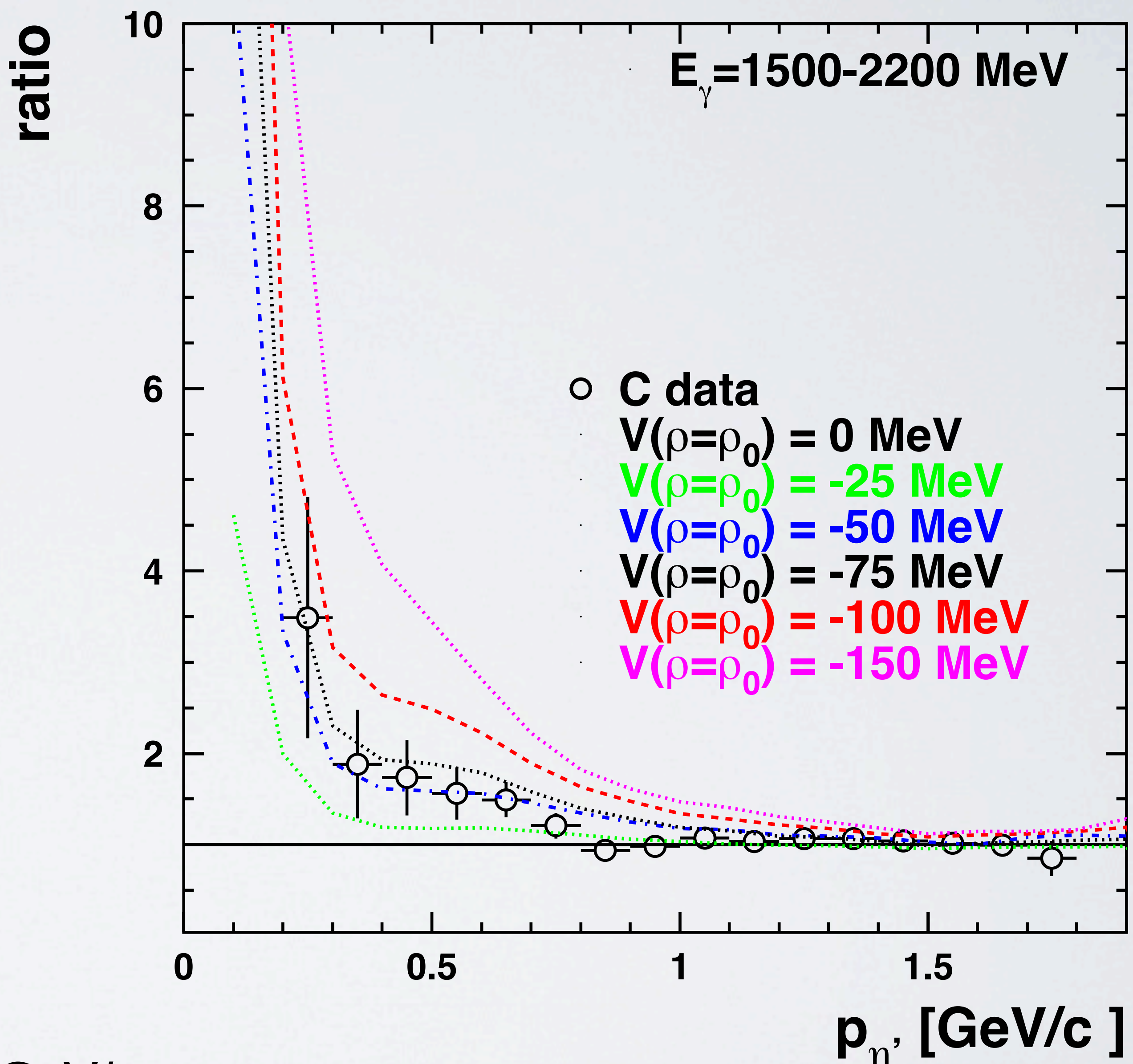
comparison of CBELSA/TAPS data with calculations by
E. Paryev, J. Phys. G: Nucl. Part. Phys. 40 (2013) 025201 and priv. communication

momentum distribution



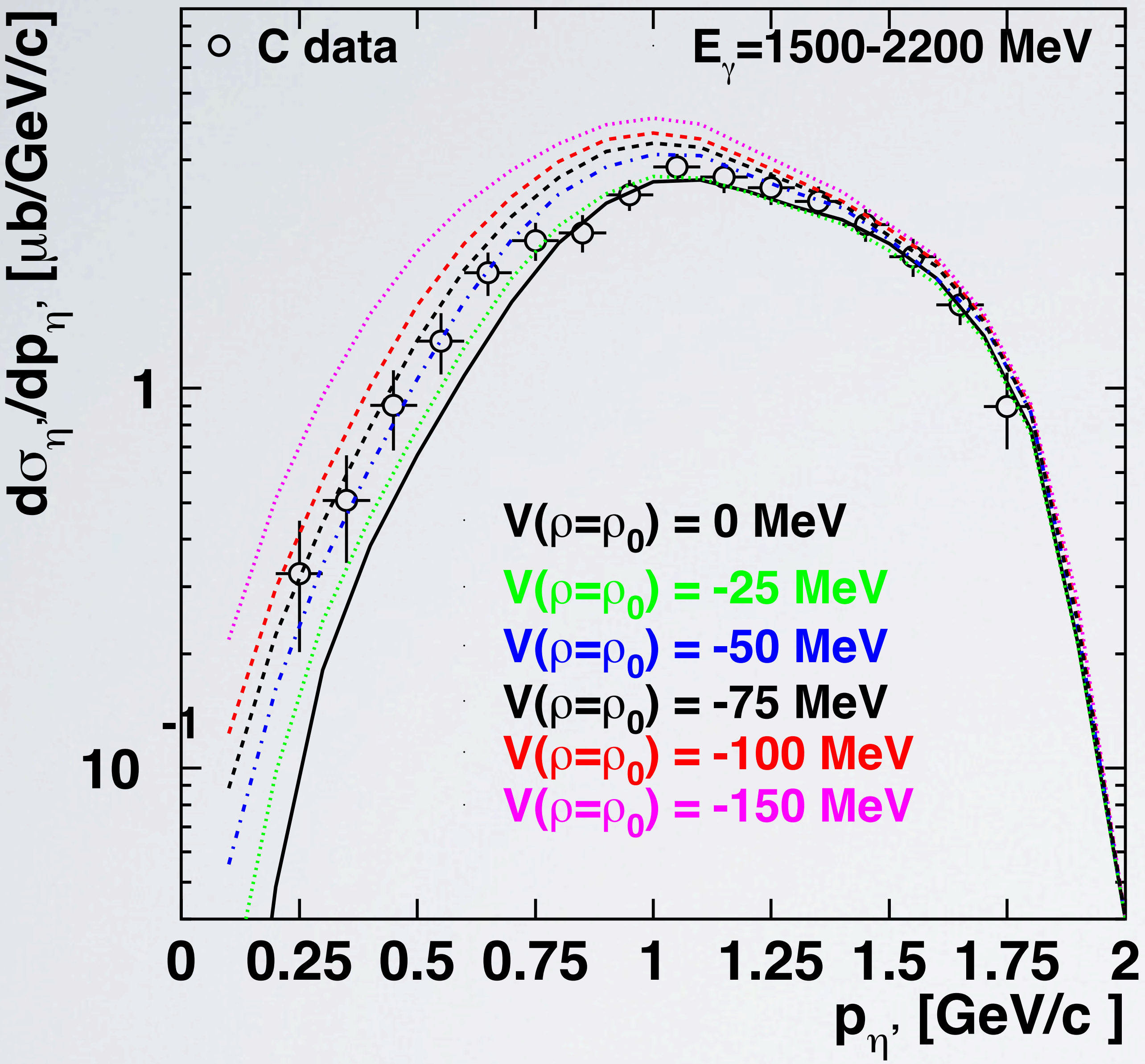
calculation normalized to data in p = 1.5-1.8 GeV/c, downscaled by 1.2

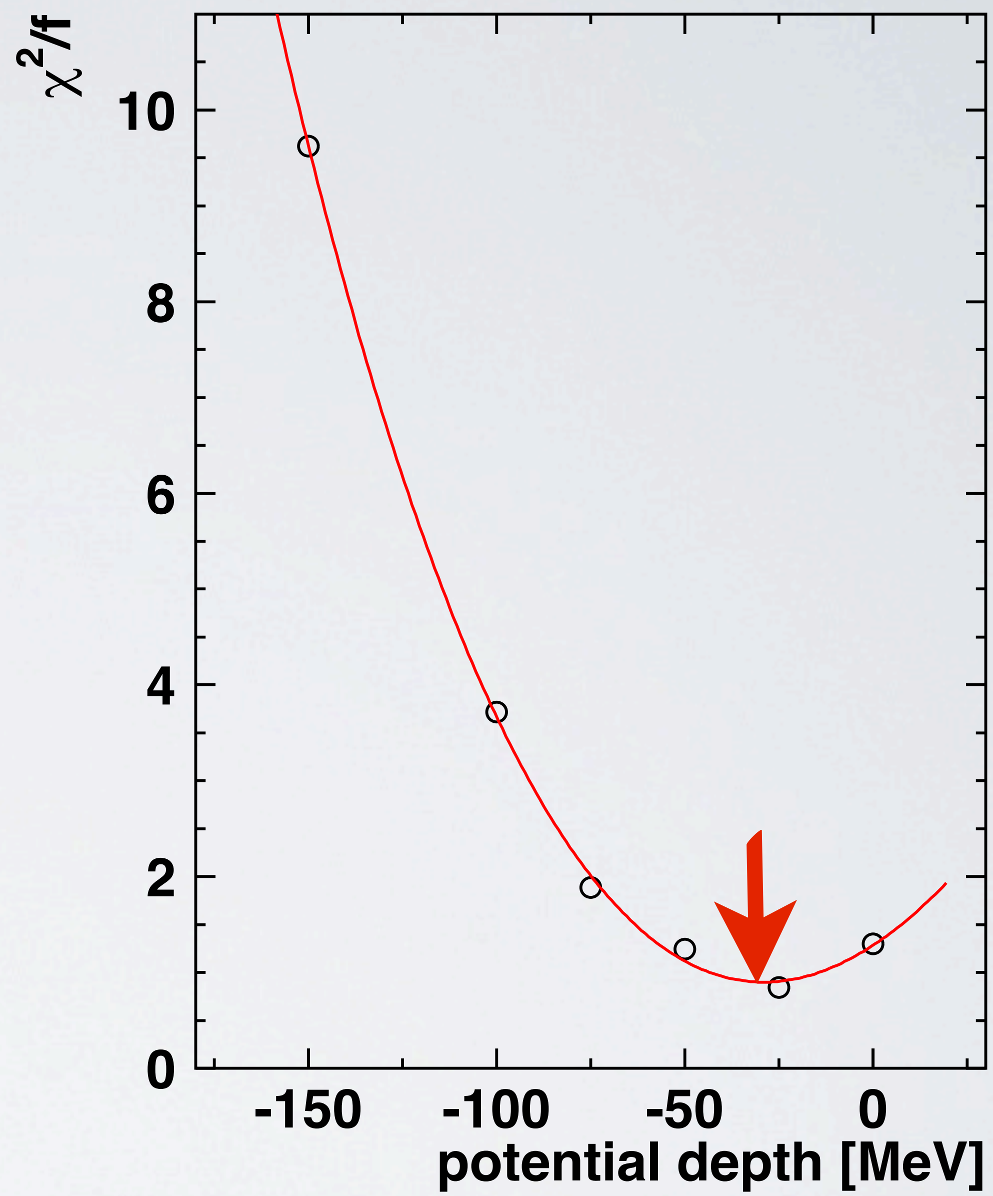
exp. data and the 5 scenarios divided by the calculation for scenario $V(\rho=\rho_0)$=0 MeV



data favour $V(\rho=\rho_0) \approx$ -50 MeV ⇨ attractive!

estimation of the of η'-nucleus potential depth from the η' momentum distribution





$V(\rho=\rho_0)$ = -32±11 MeV

consistent with predictions by:

S. Bass and A.W.Thomas, Acta Phys. Pol. B 41 (2010) 2239

H. Nagahiro et al., PLB 709 (2012) 87.

$W(\rho=\rho_0)$ = -10±2.5 MeV, M. Nanova et al., PLB 710 (2012) 600.

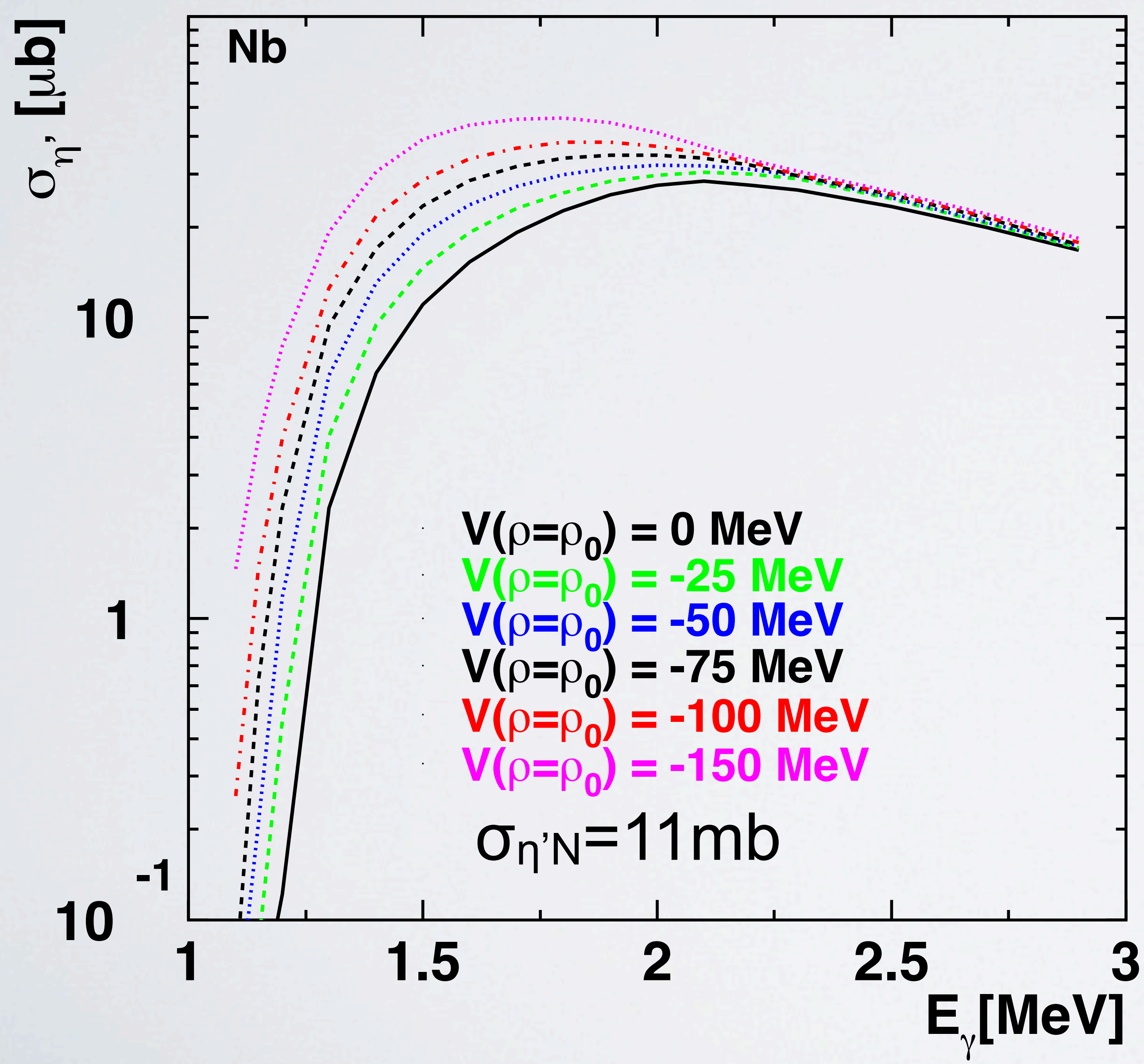
|V |>> |W| ! ⇨ search for η' mesic states promising

excitation function for η’ photoproduction off Nb

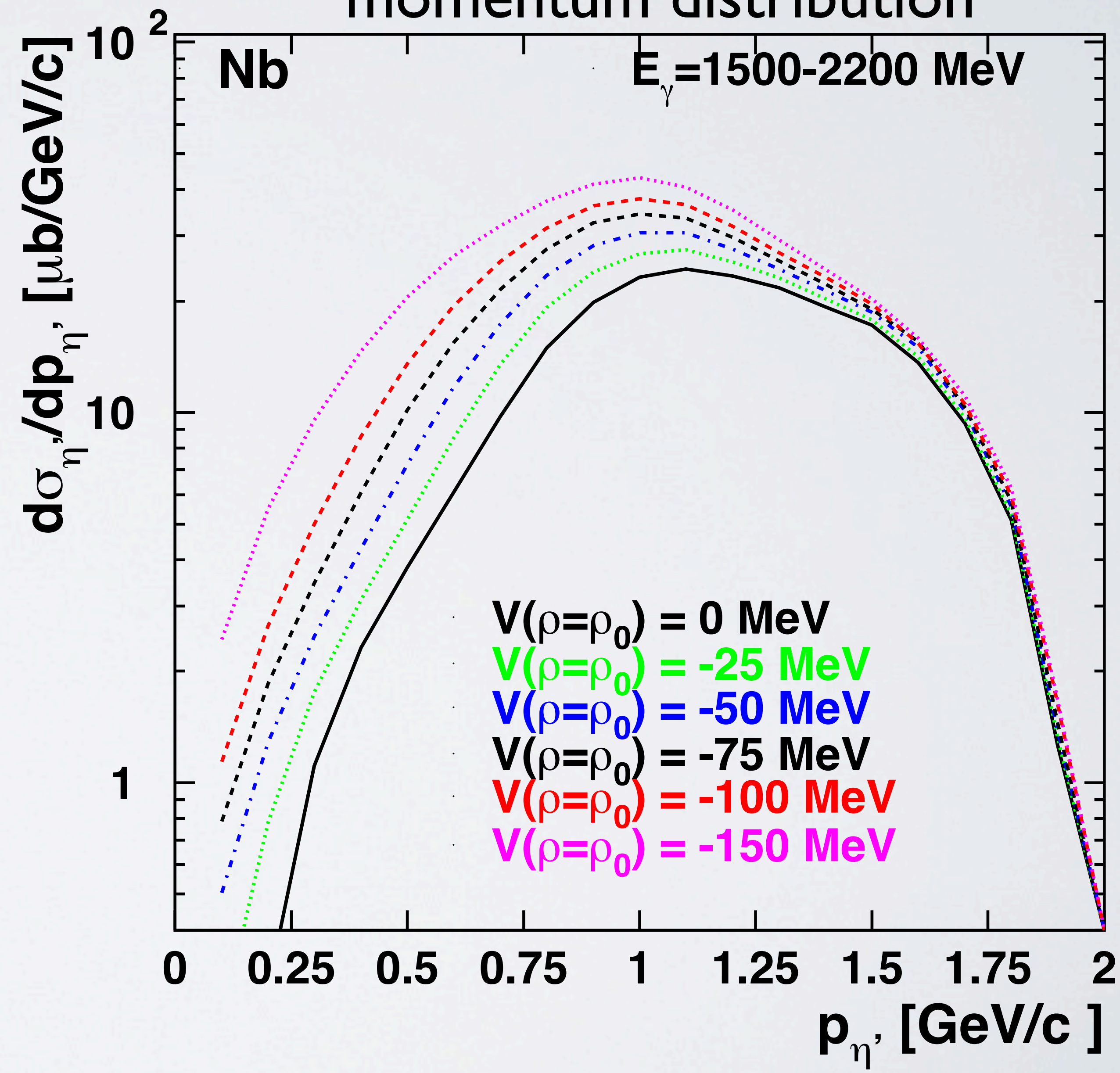
data will be taken with CB/TAPS detector system at ELSA
Nov. 2013 / Jan. 2014

E. Paryev, private communication

excitation function



momentum distribution



summary

1. Imaginary part of the η'- nucleus optical potential determined from transparency ratio measurements:

$$W(\rho=\rho_0)=-\Gamma_0/2 = -10\pm2.5 \text{ MeV}$$

2. Real part of the η'- nucleus optical potential determined from:

   a. measurement of the excitation function of the η'-meson

$$V(\rho=\rho_0) = -40\pm6 \text{ MeV}$$

   b. measurement of the momentum distribution of the η'-meson

$$V(\rho=\rho_0) = -32\pm11 \text{ MeV}$$

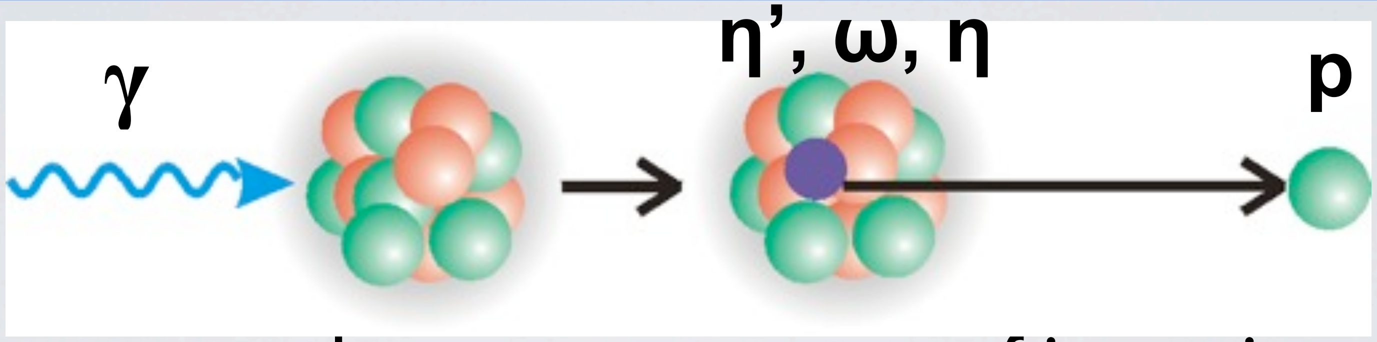
$$U_{\eta'A}(\rho=\rho_0) = -(37\pm10(\text{stat}) \pm10(\text{syst})+i(10\pm2.5)) \text{ MeV}$$

first (indirect) observation of in-medium mass shift of η' at $\rho=\rho_0$ and T=0

3. η'-nucleus optical potential - experiment needed off Nb to confirm the result

$|V| \gg |W|$! ⇨ η' promising candidate for mesic states

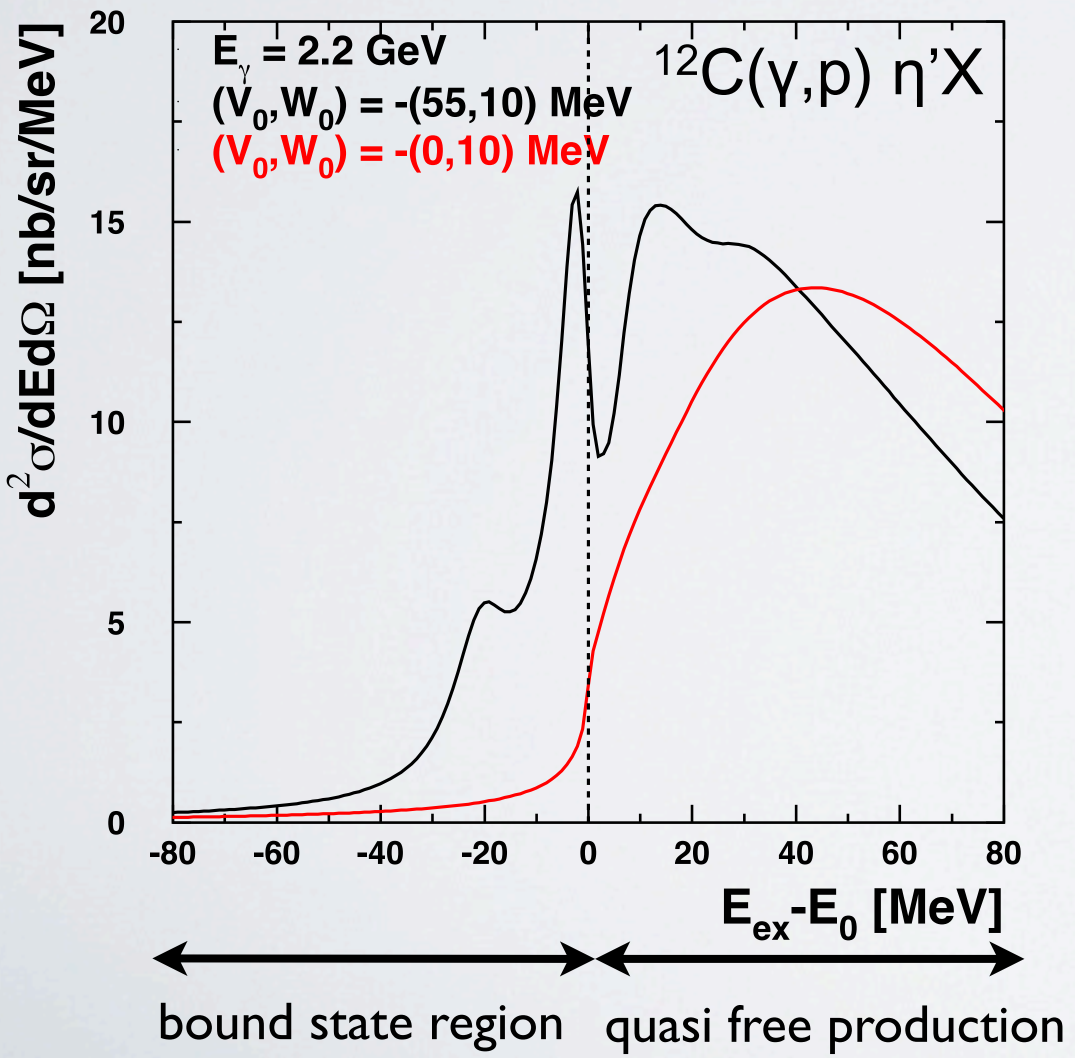
population of η', ω, η-mesic states in photo induced reactions



forward going proton takes up momentum of incoming photon beam, leaving meson almost at rest

⇒ captured by nucleus in case of an attractive interaction

H. Nagahiro, private communication



two ways of measuring excitation energy of mesic nucleus:

1.) missing mass spectrometry:

measure spectrum of forward going proton

2.) measure kinetic energy of decay products of mesic state

outlook

missing mass spectrometry:

1) FRS@GSI

$^{12}C(p,d)\ \eta'X$ @ 2.5 GeV

K. Itahashi *et al.*, Prog. Theo. Phys. 128(2012) 601

next talk: Y. Tanaka

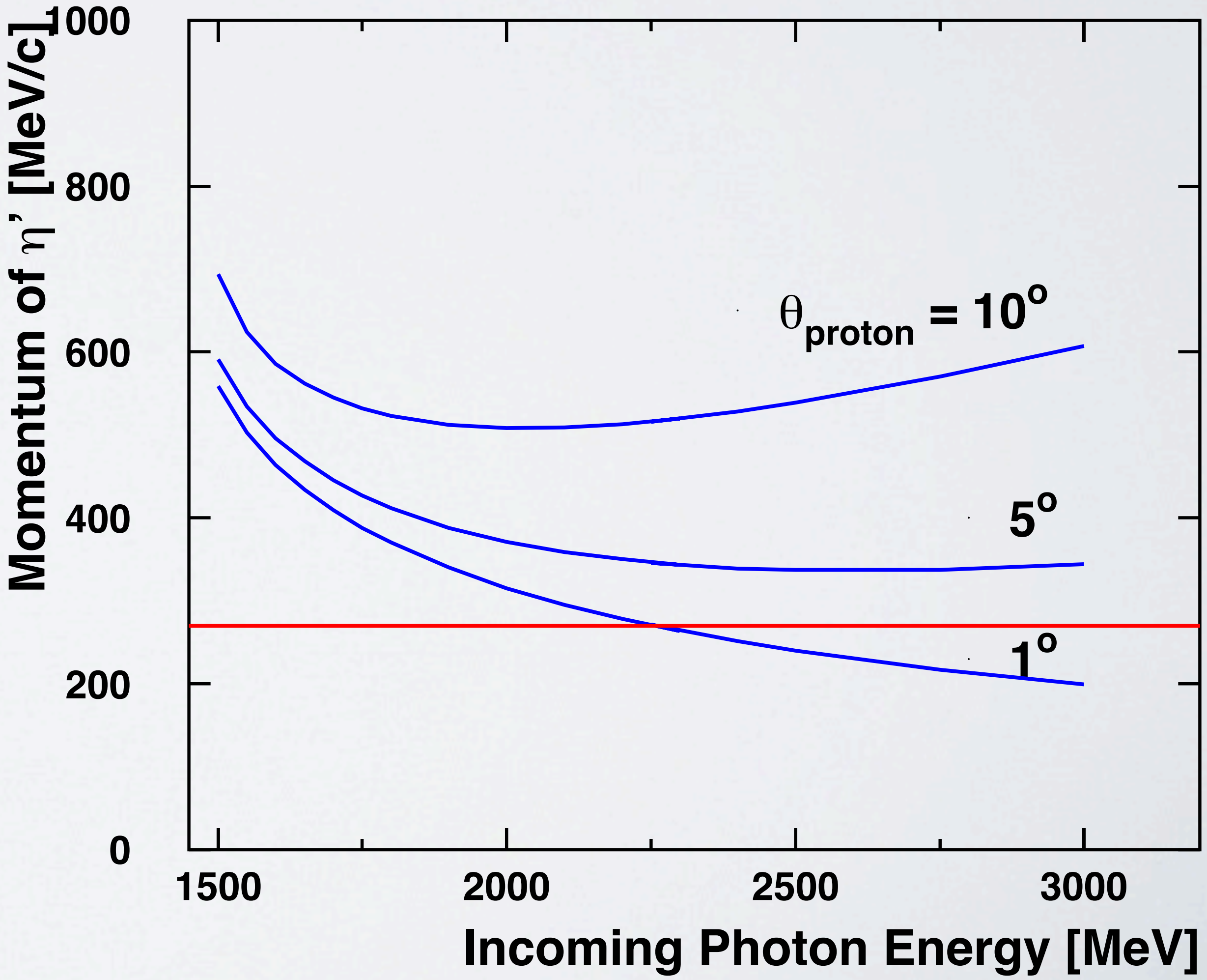
2) BGO-OD@ELSA

$^{12}C(\gamma,p)\ \eta'X$ @ 2.8 GeV

approved proposal: ELSA/3-2012-BGO

a potential of 37 MeV depth will support η' momenta up to 270 MeV/c

momentum transfer to η'



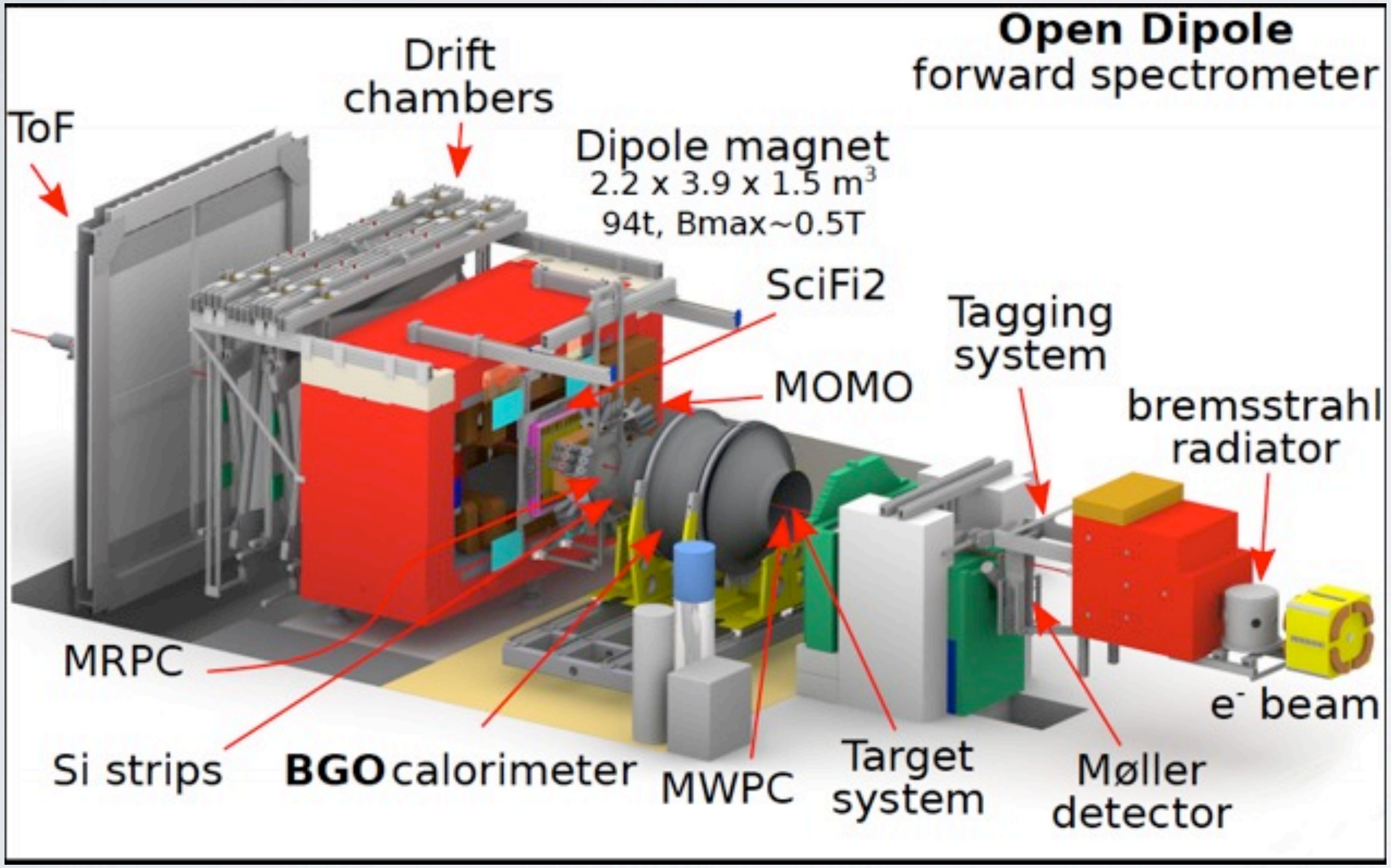
search for η'-mesic states in photo nuclear reaction

measurement of η'N formation and decay

BGO-OD@ELSA

H. Schmieden, P. Levi Sandri

$^{12}C(\gamma,p)\ \eta' X$ @ 2.8 GeV



4π acceptance

charged and neutral particle ID

- **BGO ball:**

a highly segmented calorimeter-ideal for neutral meson detection

- **Forward spectrometer:**

tracking detectors,
dipole magnet,
drift chambers and
TOF walls -
charged particle ID and momentum reconstruction

$\Delta p/p \approx$ 1-2 %

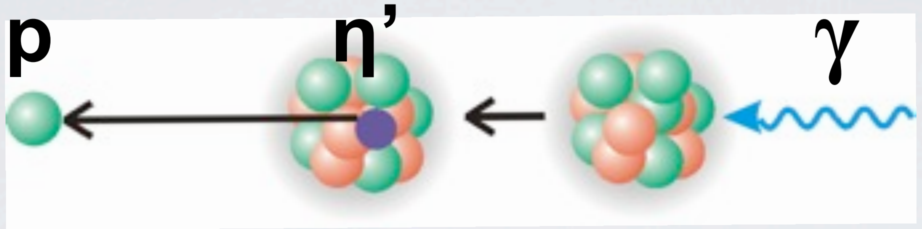
BGO-OD ideally suited for inclusive and semi-exclusive measurement

approved proposal: ELSA/3-2012-BGO

search for η'-mesic states in photo nuclear reactions

measurement of formation and decay of η'-nucleus bound state

$^{12}C(\gamma,p)\,\eta' X$ @ 2.8 GeV with BGO-OD@ELSA

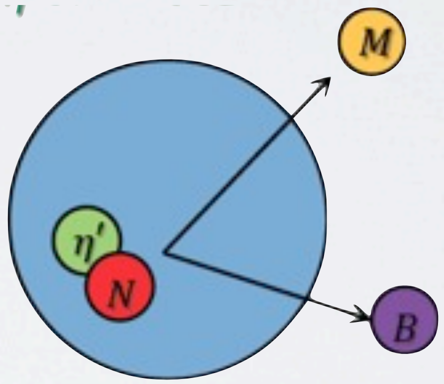


1. inclusive measurement: missing mass spectrometry

measurement of p momentum $\Delta p/p \approx$ 1-2 %

2. semi-exclusive measurement:

measurement of p in coincidence with decay of η'-mesic state



$\eta' N \rightarrow M\, B$

$\eta' N \rightarrow \eta N$

about 70% of all η'-mesic states decay by emission of lighter mesons; predominantly by $\eta' N \rightarrow \eta N$

E. Oset and A. Ramos, PLB 704 (2011) 334

BGO-OD ideally suited for measurement of η in coincidence with forward going proton