In-medium properties of η‘ meson

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for CBELSA/TAPS Collaboration

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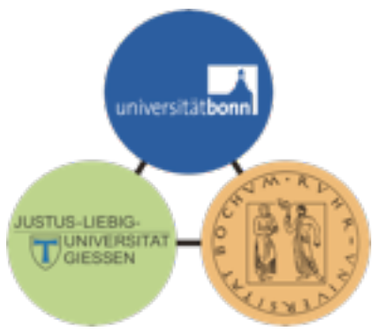
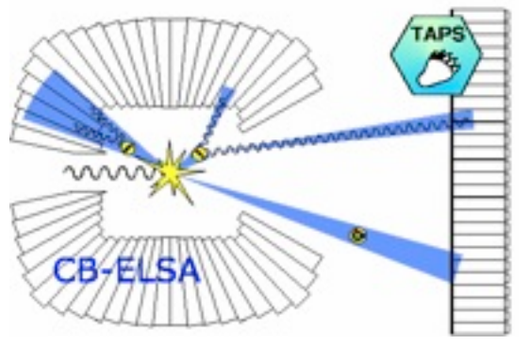
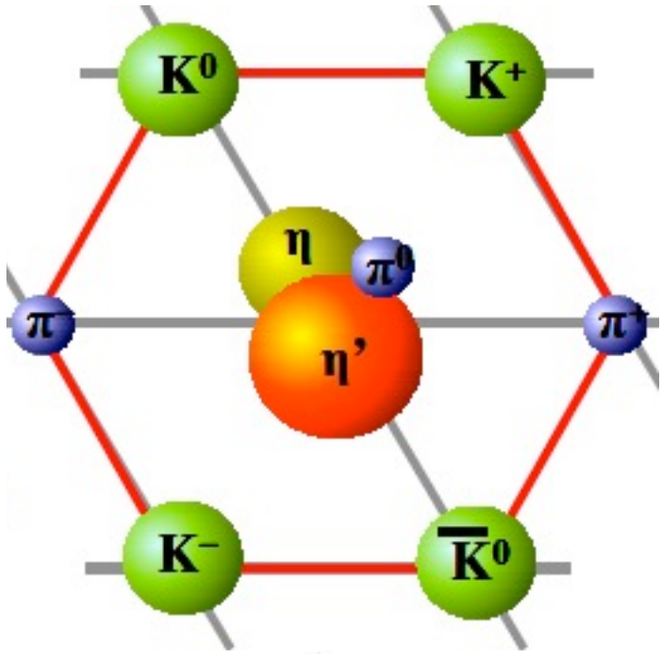




outline

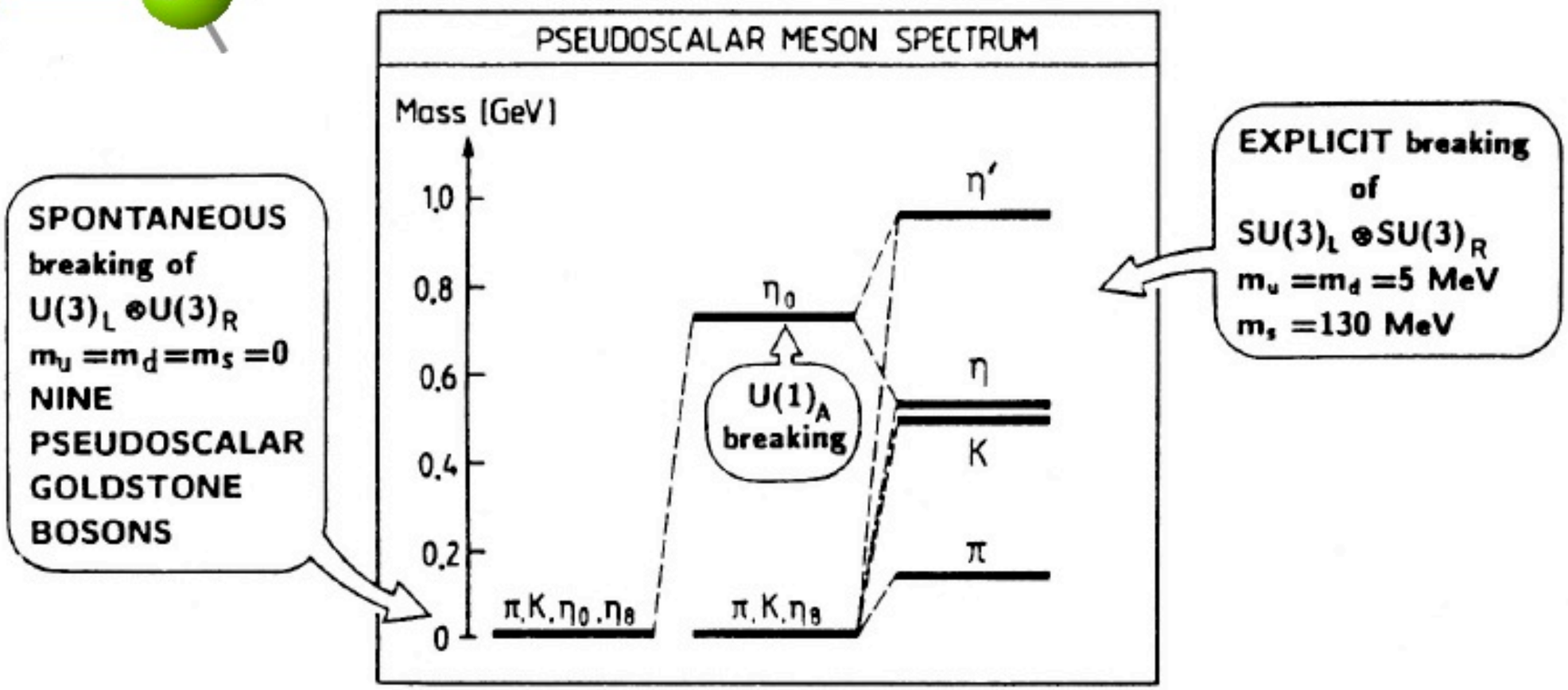
- motivation
- experimental approaches for studying the in-medium properties of η' meson
- experimental setup
- η' photoproduction on proton and deuteron
- η' photoproduction on nuclei
  - reconstruction of the η' meson
  - transparency ratio (T_A) measurements
  - comparison with the T_A of other mesons
- summary & outlook

pseudoscalar meson nonet



S. Klimt et al., Nucl. Phys. A516 (1990) 429

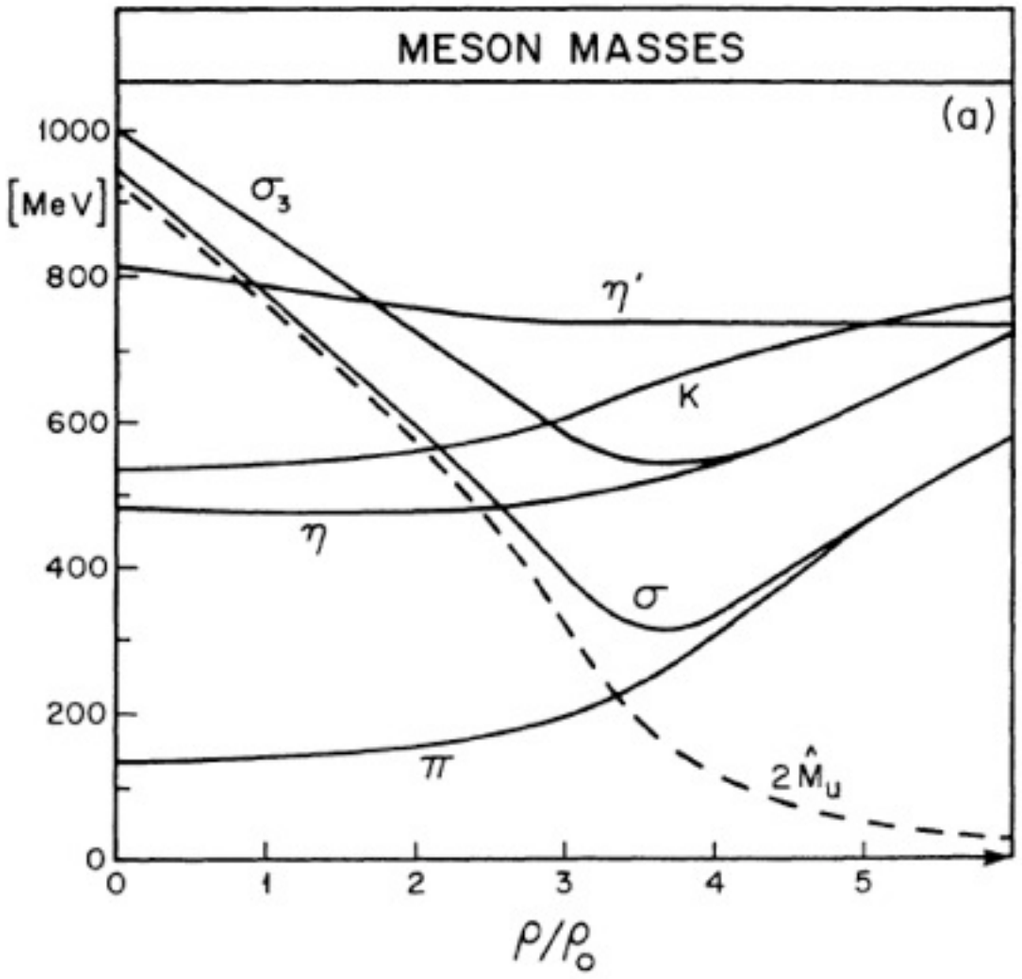
The NJL Model



masses as a result of symmetry breaking

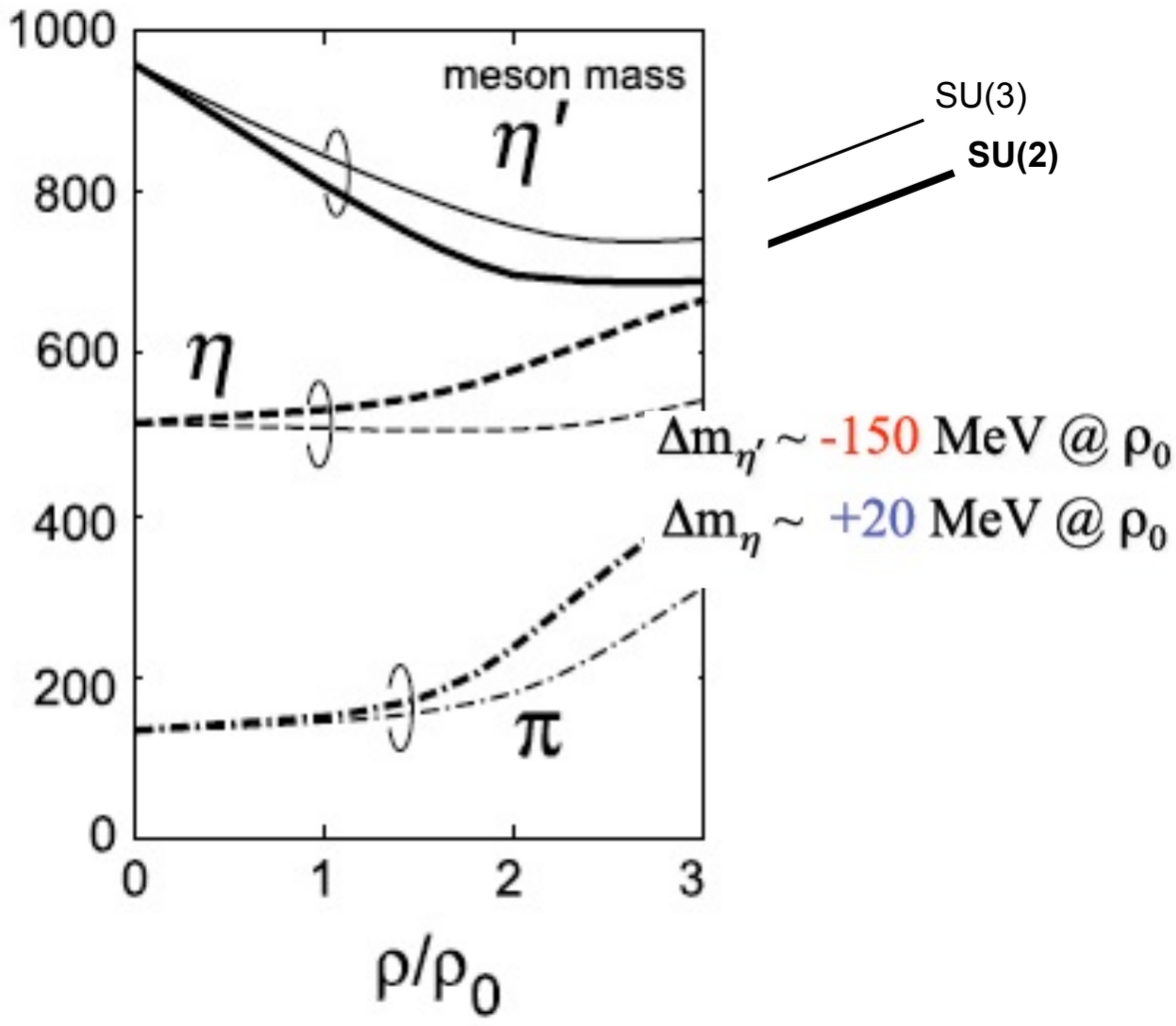
predicted in-medium properties of the η' meson

V. Bernard und U.G. Meissner, Phys. Rev. D 38 (1988) 1551



the mass of the η' meson is almost independent of density

H. Nagahiro, M. Takizawa and S. Hirenzaki, Phys. Rev. C 74 (2006) 045203



mass changes of η and η' mesons in the nuclear medium

η'(958) mesic nuclei formation

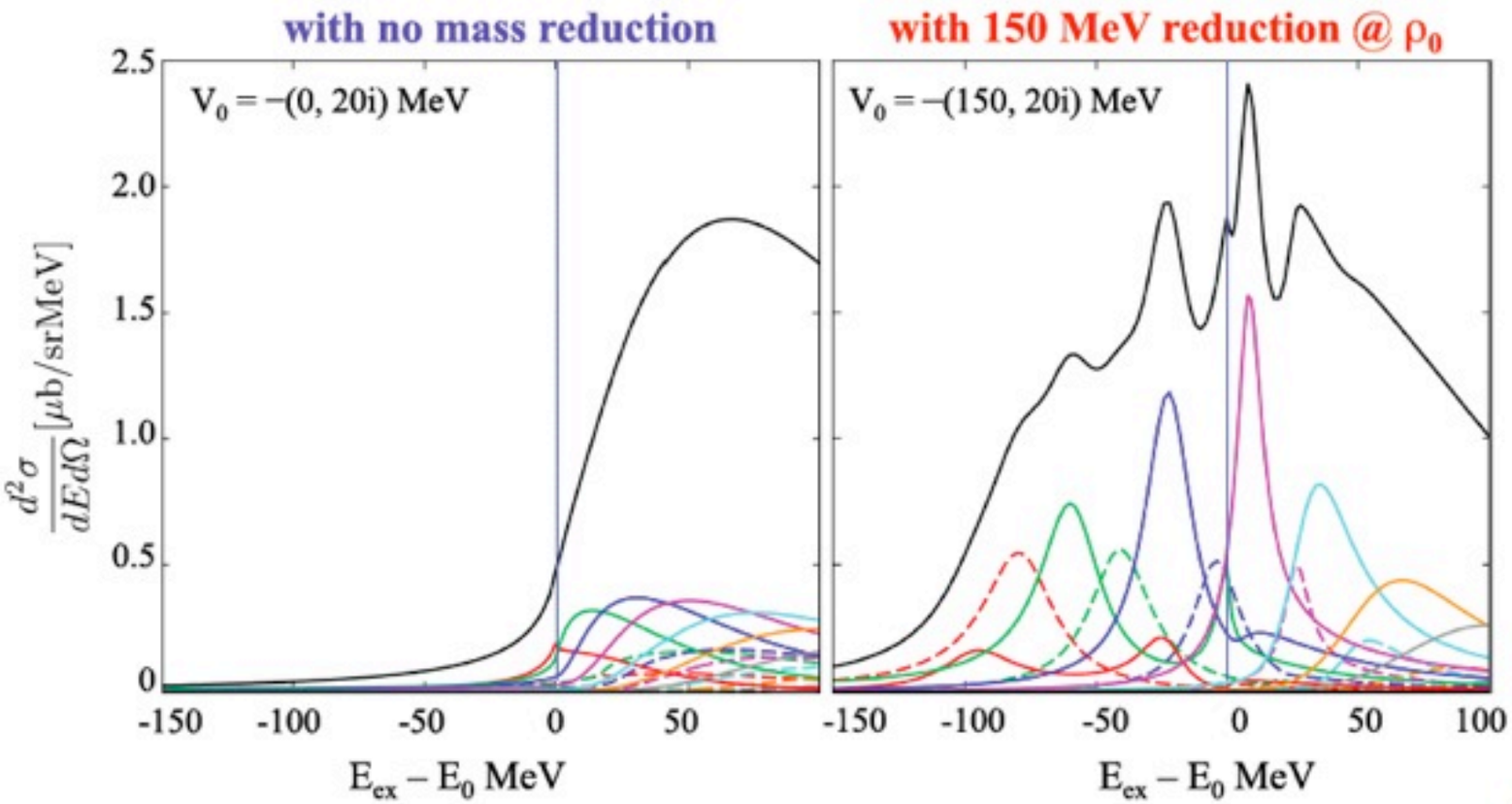
❖ many theoretical works

in vacuum/ at finite temperature/ at finite density

- ✧ R. D. Pissarski, R. Wilczek, PRD 29(1984)338
- ✧ T. Kunihiro, T. Hatsuda, PLB 206(1988) 385
- ✧ T. Kunihiro, PLB 219(1989) 363
- ✧ Bernard, R. L. Jaffe and U. G. Meissner, NPB 308(1988) 753
- ✧ Y. Kohyama, K. Kubodera and M. Takizawa, PLB 208(1988) 165
- ✧ K. Fukushima, K. Onshi, K. Ohta, PRC 63(2001) 045203
- ✧ P. Costa et al., PLB 560(2003) 171, PRC 70(2004) 025204
- ✧ A. Ramos, E. Oset, arXiv: 1010.5603 [nucl-th]

D. Jido, H. Nagahiro and S. Hirenzaki, arXiv 1109.0394 [nucl-th]

$^{12}C(\pi^+,p)\eta'$ @ p_π = 1.8 GeV



E. Oset: $V(\rho_0)$ = 30 - 50 MeV
(priv. commun. - Saturday, 17th Sept.)

❖ limited experimental information at finite density:

indirect evidence for reduction of η' mass in the hot medium (PHENIX & STAR data)
T. Csörgö, R. Vèrtesi and J. Sziklai
Phys. Rev. Lett. 105 (2010) 182301
Phys. Rev. C 83 (2011) 054903

How to study in-medium properties of the η' meson?

talk by V. Metag on Sunday, 18th Sept., at 10:10 - overview on the experimental approaches to study in-medium properties of hadrons

- **in-medium mass?**

  line shape analysis: not applicable;

  η' meson decays outside of nucleus;

$$\lambda_{dec} = \hbar c/\Gamma_0 = 1000 fm >>> R_{nucl}$$

- **in-medium width?**

  attenuation measurement of the η' meson flux

experimental observable to extract the in-medium witdh of the meson:

transparency ratio:

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

measure for the loss of meson flux through inelastic processes in the nucleus
applicable for any meson irrespective of lifetime

ω: M. Kotulla et al., (CBELSA/TAPS), PRL 100 (2008)192302
M. H. Wood et al., (CLAS), PRL 105 (2010) 112301

Φ: T. Ishikawa et al., (Spring8), PLB 608 (2005) 215

Crystal Barrel/TAPS@ELSA Experiment

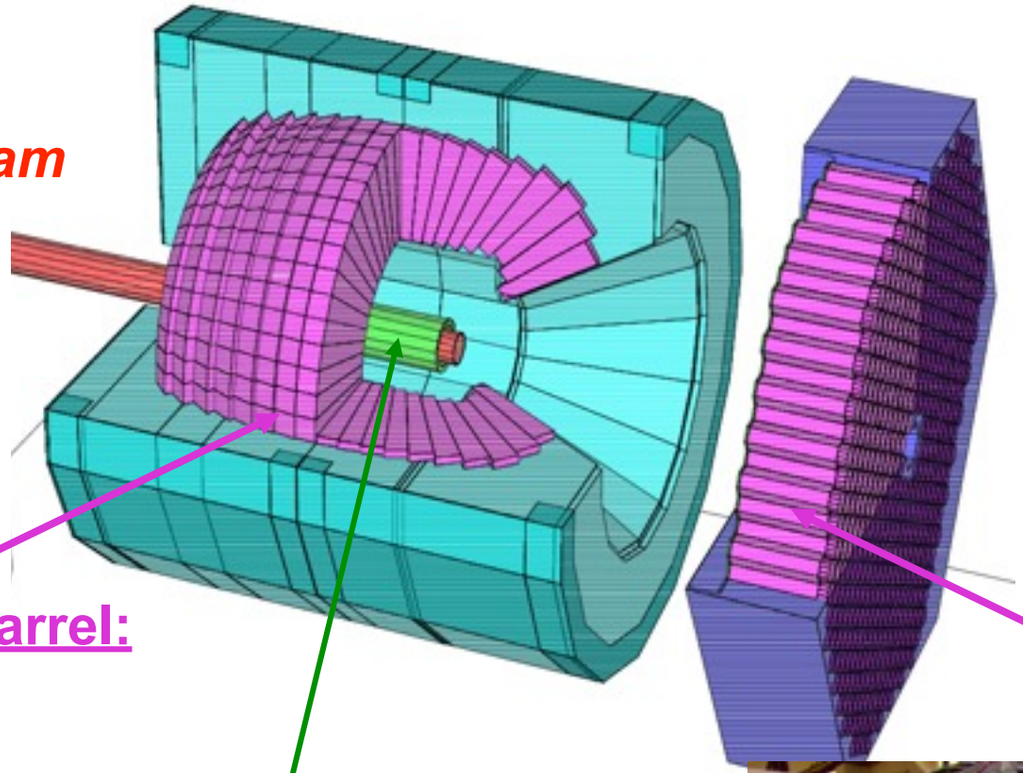
http://www.cb.uni-bonn.de

4π photon detector

targets: ^{12}C, ^{40}Ca, ^{93}Nb, ^{208}Pb

photon beam

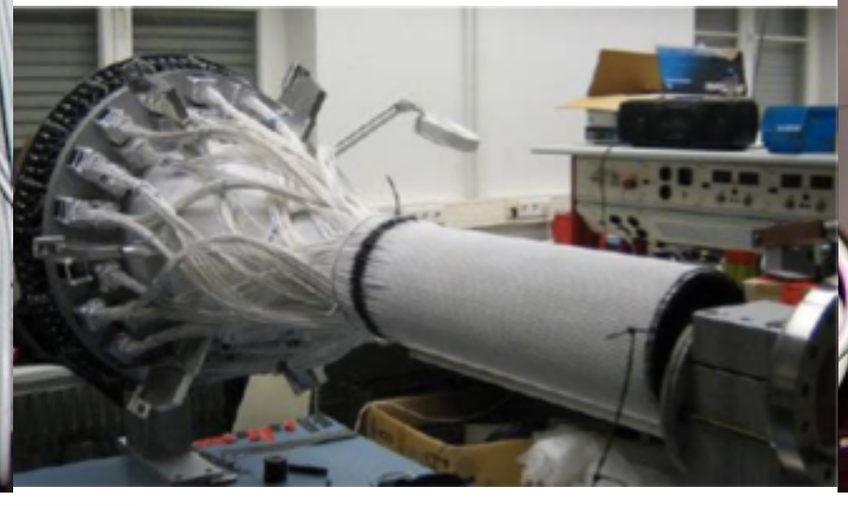
E_γ=0.5-2.6 GeV

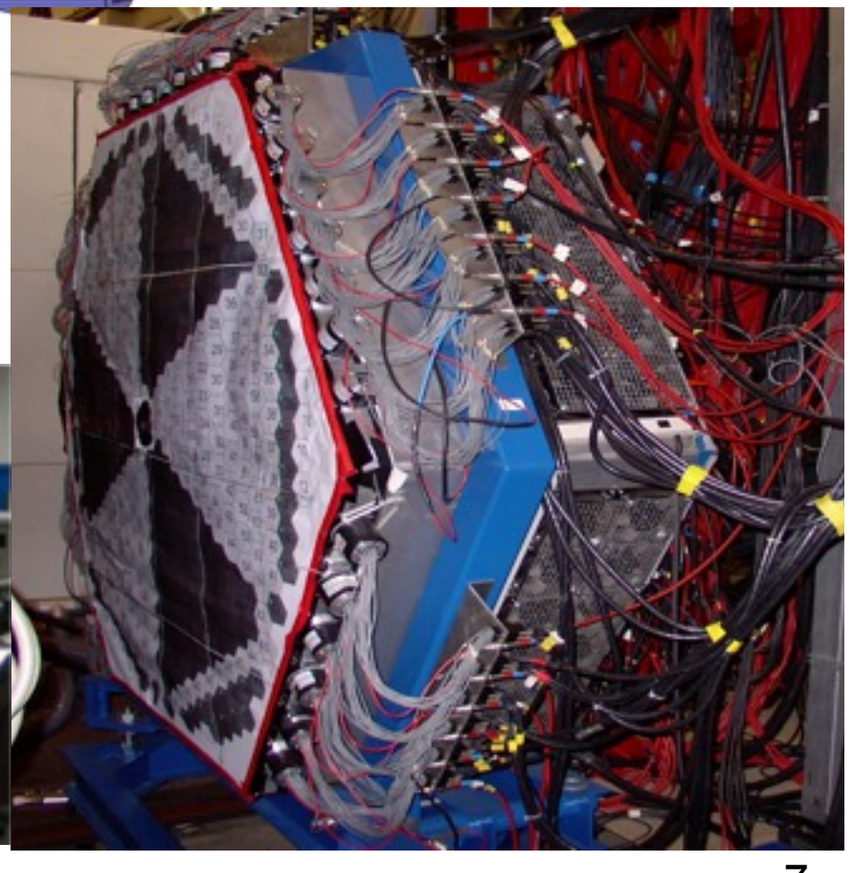


Crystal Barrel:
1290 CsI

TAPS:
528 BaF_2

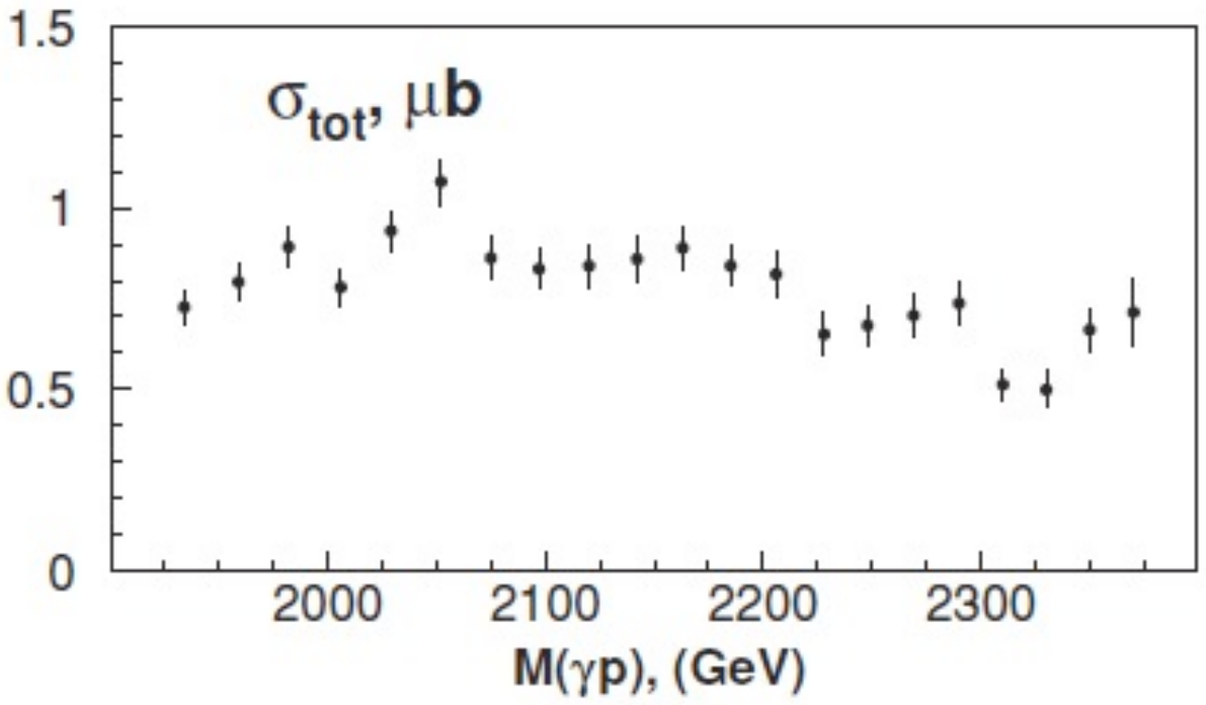
SciFi Detector





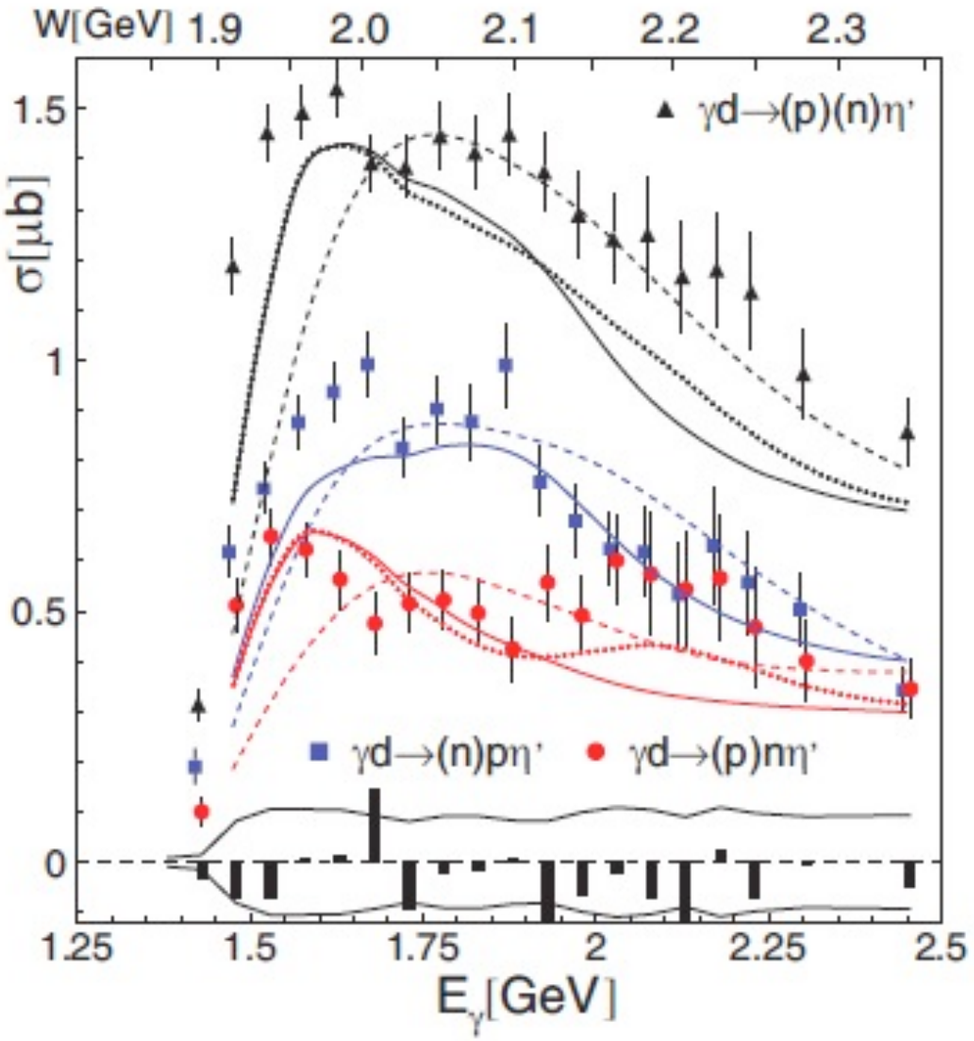
photoproduction of η‘ meson on proton and deuteron

V. Crede et al.,
Phys. Rev. C 80 (2009) 055202



total cross section determined
exploiting full angular coverage

I. Jaegle et al., Eur. Phys. J. A 47(2011) 11



--- η’-MAID model
W.T. Chiang et al.,
*PRC **68** (2003) 045202*
P_{11}, P_{13} (1950 MeV), D_{13}

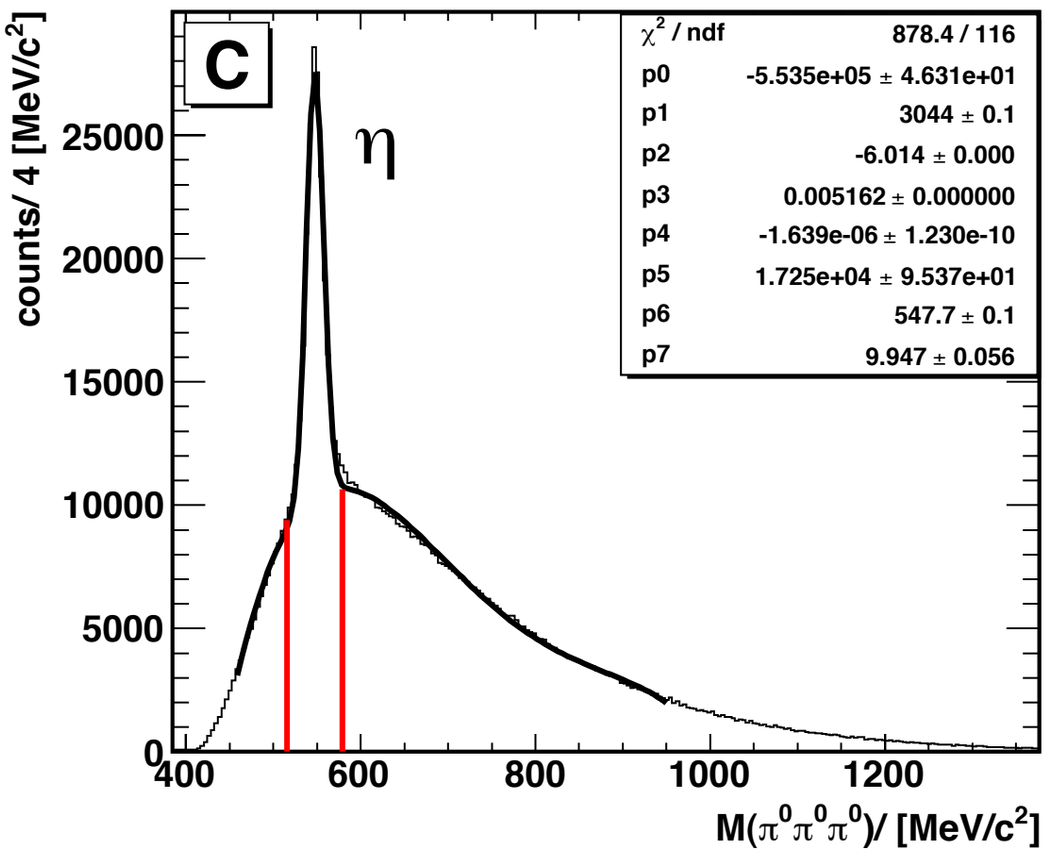
NH model
K. Nakayama, H. Haberzettl,
*PRC **73** (2006) 045211,*
*PRC **69** (2004) 065212*

η’ coupling to different resonances

photoproduction of η‘ mesons on nuclei

$\eta' \rightarrow \pi^0\pi^0\eta \rightarrow 6\gamma$ BR: 8.1% **CB/TAPS@ELSA**

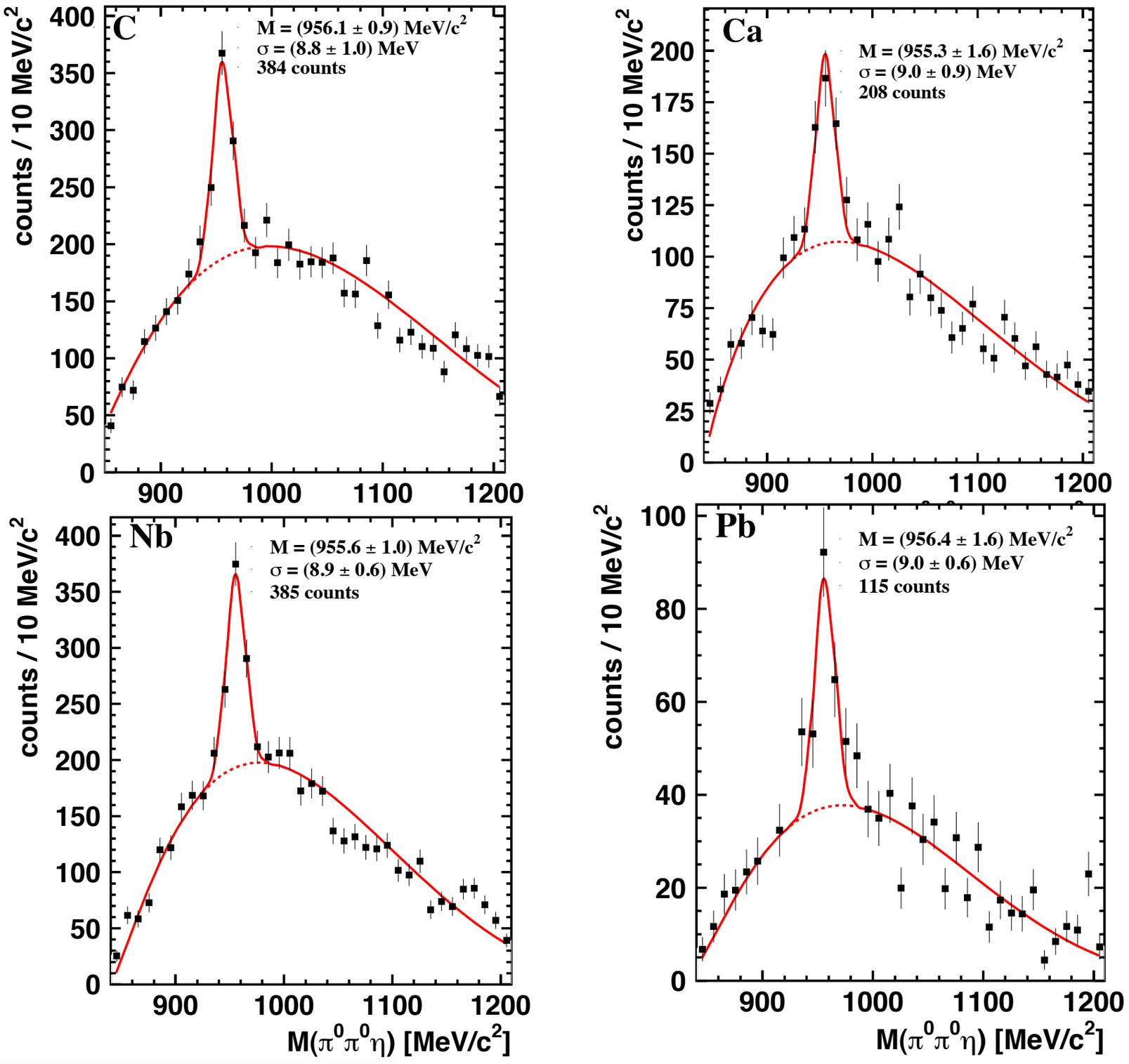
- solid targets: ^{12}C, ^{40}Ca, ^{93}Nb and ^{208}Pb;
  20 mm, 10 mm, 1 mm and 0.6 mm ≲ (6-9)% X_0
- event selection: ≥ 6 neutral particles AND/OR 6n + 1ch
- sum energy of 6 neutral particles > 600 MeV
- competing channel with same final state: $\eta \rightarrow \pi^0\pi^0\pi^0 \rightarrow 6\gamma$
  reconstructed and removed in further analysis



photoproduction of η‘ mesons on nuclei (E_γ=1500-2200 MeV)

$$\gamma A \rightarrow \eta^{'} A' \rightarrow \pi^0\pi^0\eta \rightarrow 6\gamma A'$$

$A=^{12}C, ^{40}Ca, ^{93}Nb, ^{208}Pb$



acceptance

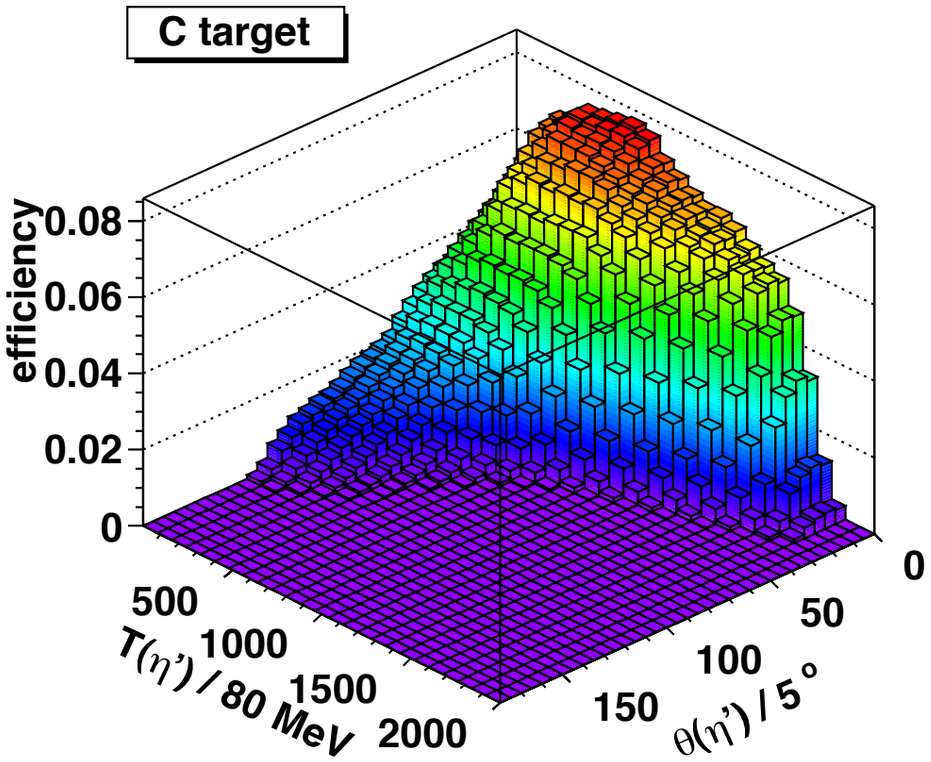
E_γ = 1500 - 2200 MeV

η' MC simulation including trigger conditions

acceptance (T_{kin}, θ^{lab})

independent of any reaction model

'grid method' for acceptance correction (I. Jaegle)



efficiency correction of the data - event by event in (T_{kin}, θ^{lab}) plane

efficiency is slightly different for different solid targets 5-8%

transparency ratio measurements

- **in-medium:** quasi-particle, the properties reflect interaction with the medium

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

- **inelastic processes -** remove the mesons: η′ N→ π N ⇨ shortening of lifetime of the meson; increase the width: $\Gamma(\rho,|p_{\eta'}|) \propto \rho.v.\sigma_{abs}$

- **width determination from T_A** ⇨ estimation of σ_{abs}

problems

- $\sigma_{neutron}$ **mostly unknown** ⇨ normalization of T_A

- **shadowing effect** ⇨ ~ 10 % @ 2 GeV
  N. Bianchi et. al, PRC 54 (1996) 1688
  T. Falter, S. Leupold and U. Mosel, 0102058 [nucl-th]

- **not only absorption; regeneration in two-step processes possible**

normalization to light nucleus (^{12}C) - helps to suppress these effects

in-medium width of the η‘ meson

transparency ratio:

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

normalized to C

parametrization:

$$\sigma(A) = \sigma_0 \cdot A^{\alpha}$$

$$\Rightarrow \quad T_A = A^{\alpha - 1}$$

comparison with T_A for **ω** meson

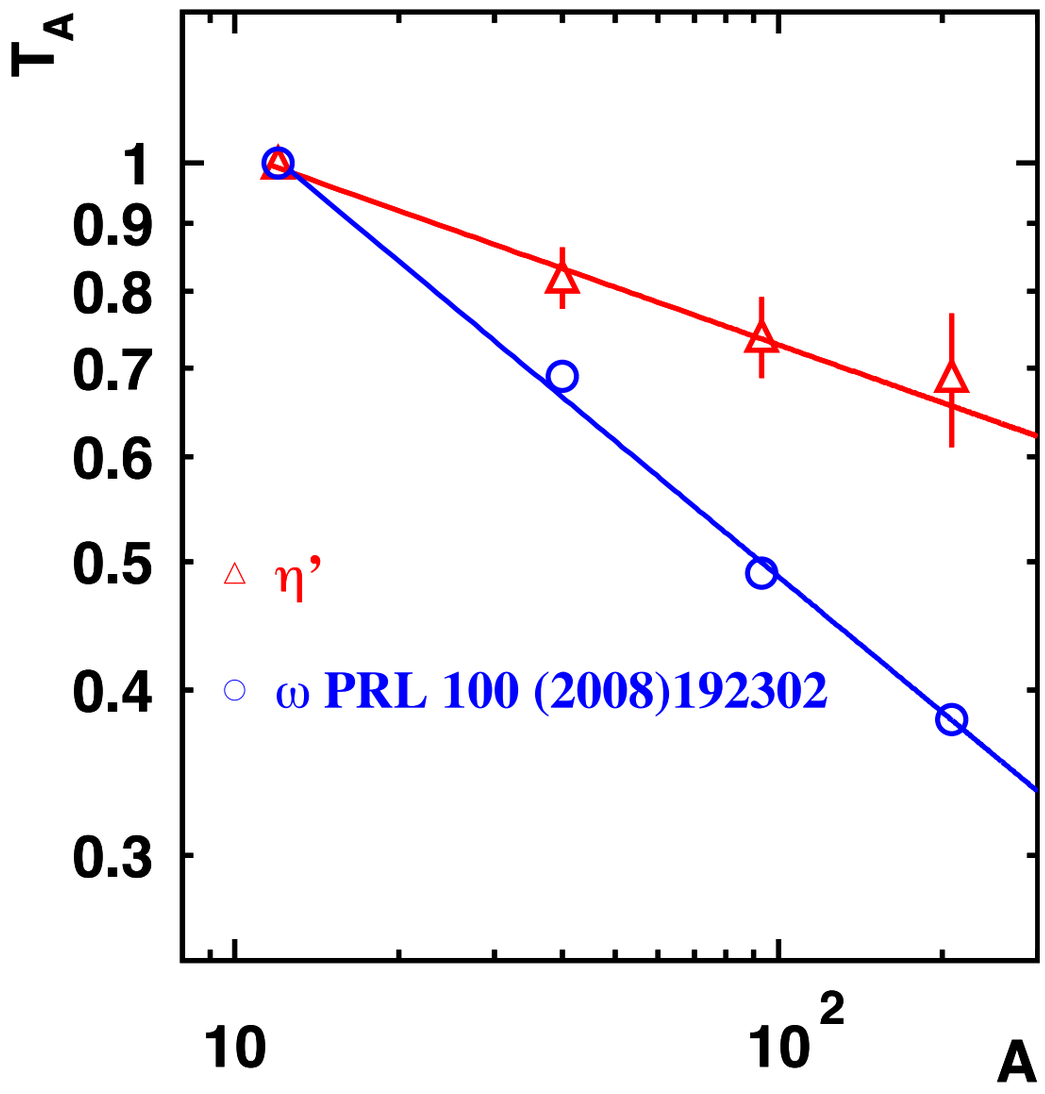
$\Gamma(\rho_0, <|p_\omega|> \approx 1.1$ GeV/c) ≈ 130-150 MeV

M. Kotulla et al. PRL 100 (2008) 192302

η′ absorption weaker than ω absorption!!

but how large is the width??

➜ comparison to transport model calculations

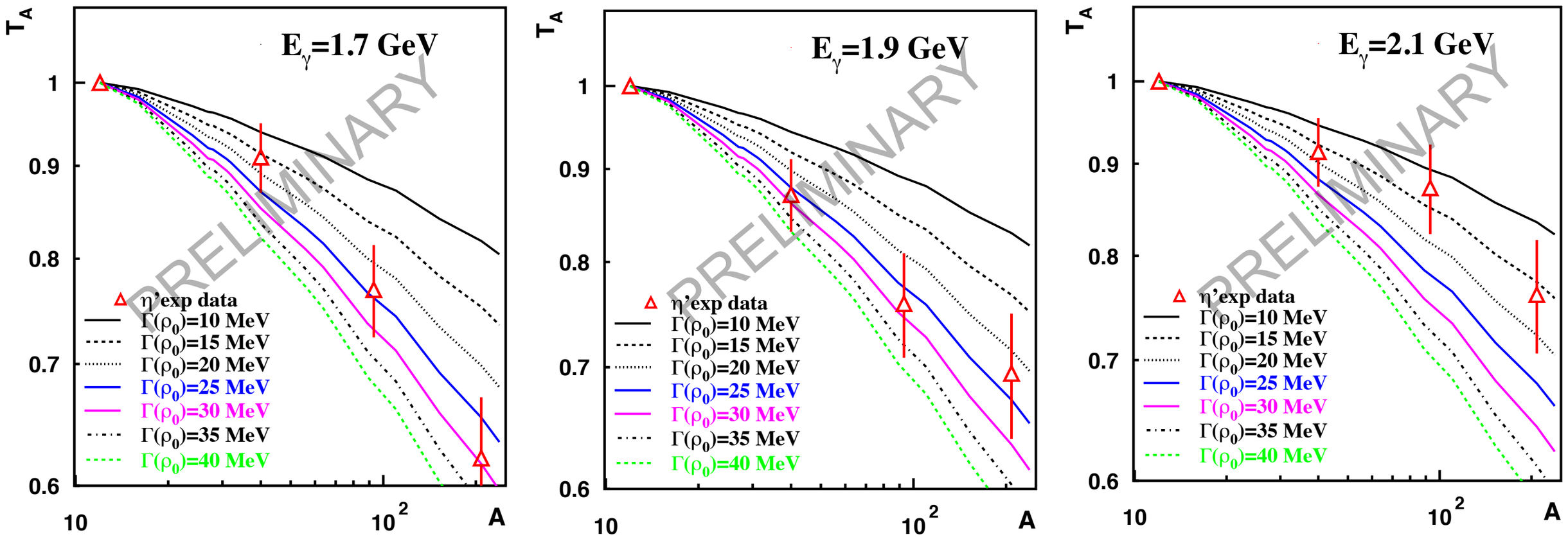


η′ in-medium width and absorption cross section

η′ transparency ratio compared with the calculations by *A.Ramos and E. Oset*

$$\sigma_{\gamma A\to\eta' A'} = C\int d^3r\rho(\vec{r})\frac{1}{2\pi}\int_0^{2\pi} d(\phi^{\eta'}_{\rm c.m.})\frac{1}{2}\int_{-1}^{1} d(\cos\theta^{\eta'}_{\rm c.m.})\frac{d\sigma}{d\Omega}(\gamma p\to\eta' p)P_s(\vec{r})$$

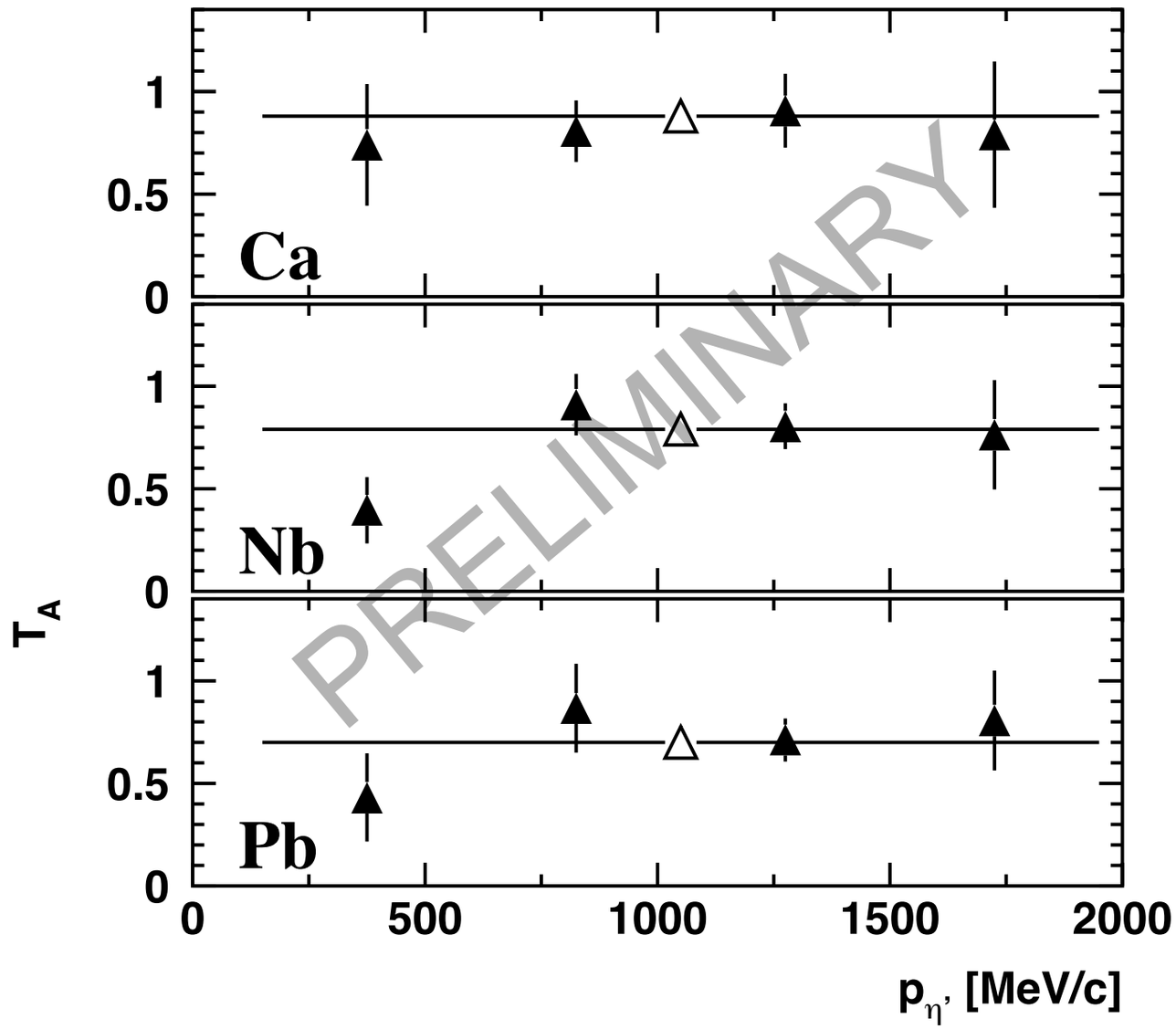
where $P_s(\vec{r})$ is the survival probability $P_s(\vec{r}) = \exp\left[\int_0^{\infty} dl\frac{{\rm Im}\,\Pi_{\eta'}(\rho(\vec{r}\,'))}{|\,\vec{k}_{\eta'}\,|}\right]$ with $\vec{r}\,' = \vec{r} + l\frac{\vec{k}_{\eta'}}{|\,\vec{k}_{\eta'}\,|}$



comparison to data $\Gamma(\rho_0, \langle|\vec{p}_{\eta'}|\rangle \approx 1.05$ GeV/c) ≈ 15-30 MeV

absorption cross section: $\sigma_{\eta' N} = \dfrac{\Gamma_{inel}}{\rho_0\cdot\beta\cdot\hbar\cdot c}$ ≈7-11 mb

momentum dependence of the η′ transparency ratio



Δ: average over all momenta

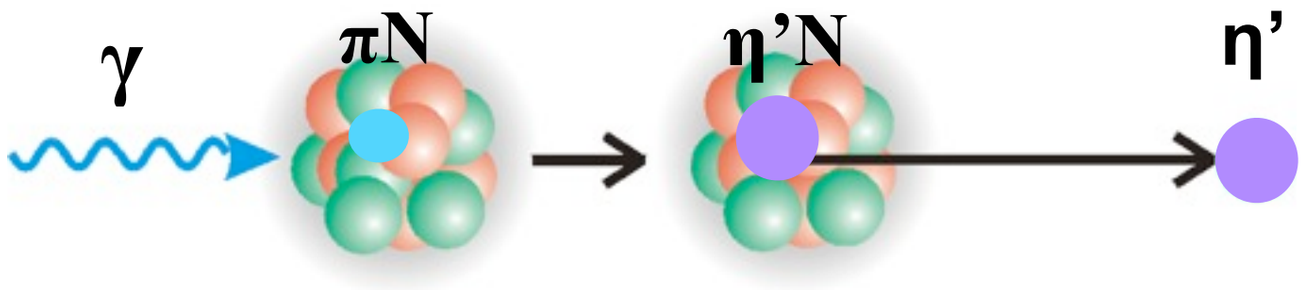
weak variation of T_A with the $p_{\eta'}$
contribution from two-step processes not significant

problems in transparency ratio measurements

- **two-step processes -**

increase the number of mesons:

γN→πN and then πN→ η'N



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

⇨ absorption measurement distorted by two-step production processes

πN→ η'N / σ = 0.1 mb @ p_π ≈1.5 GeV/c

πN→ ωN / σ = 2.5 mb @ p_π ≈ 1.1 GeV/c

πN→ ηN / σ = 3 mb @ p_π ≈ 0.8 GeV/c

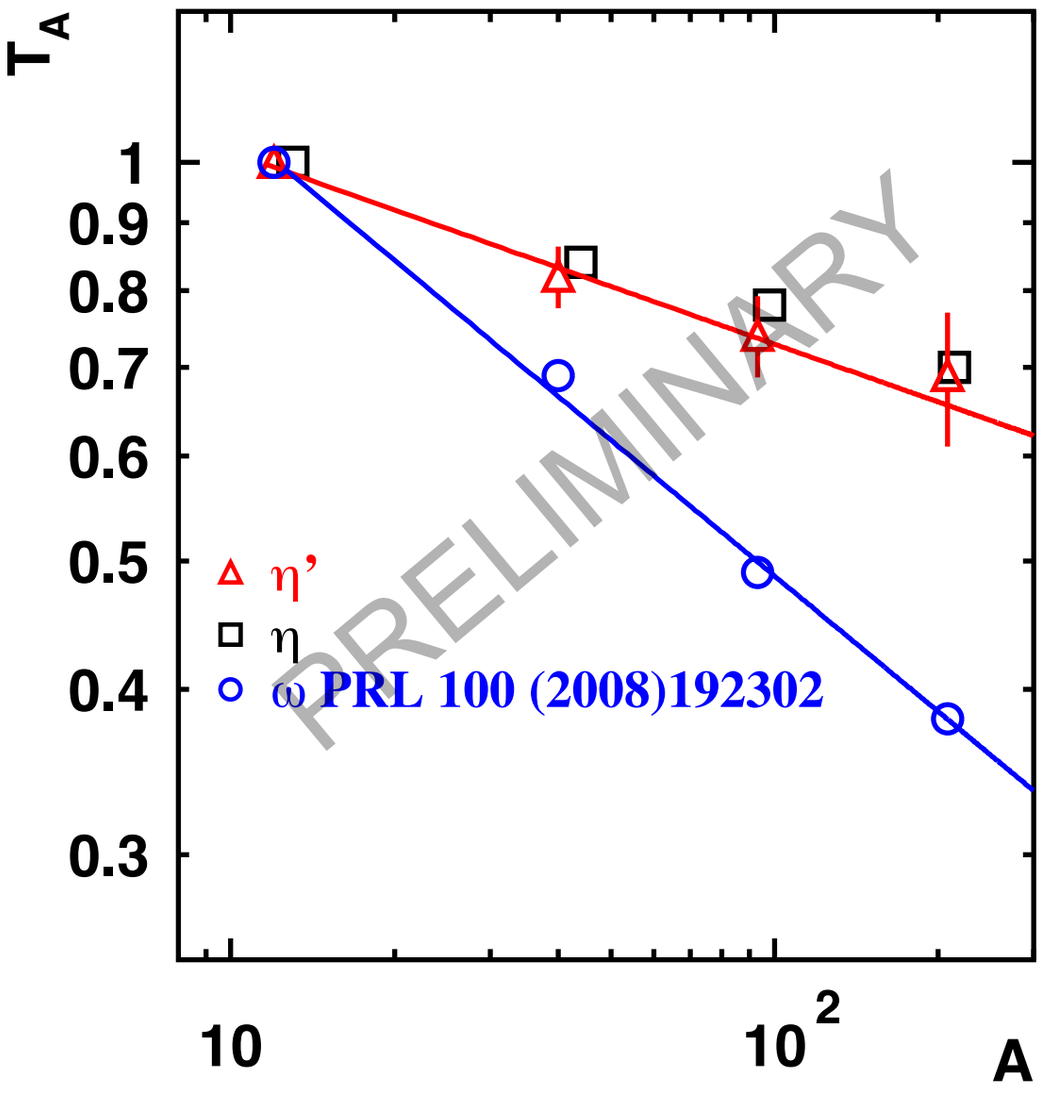
Landolt-Börnstein, New Series Vol. I/12 a (1988)

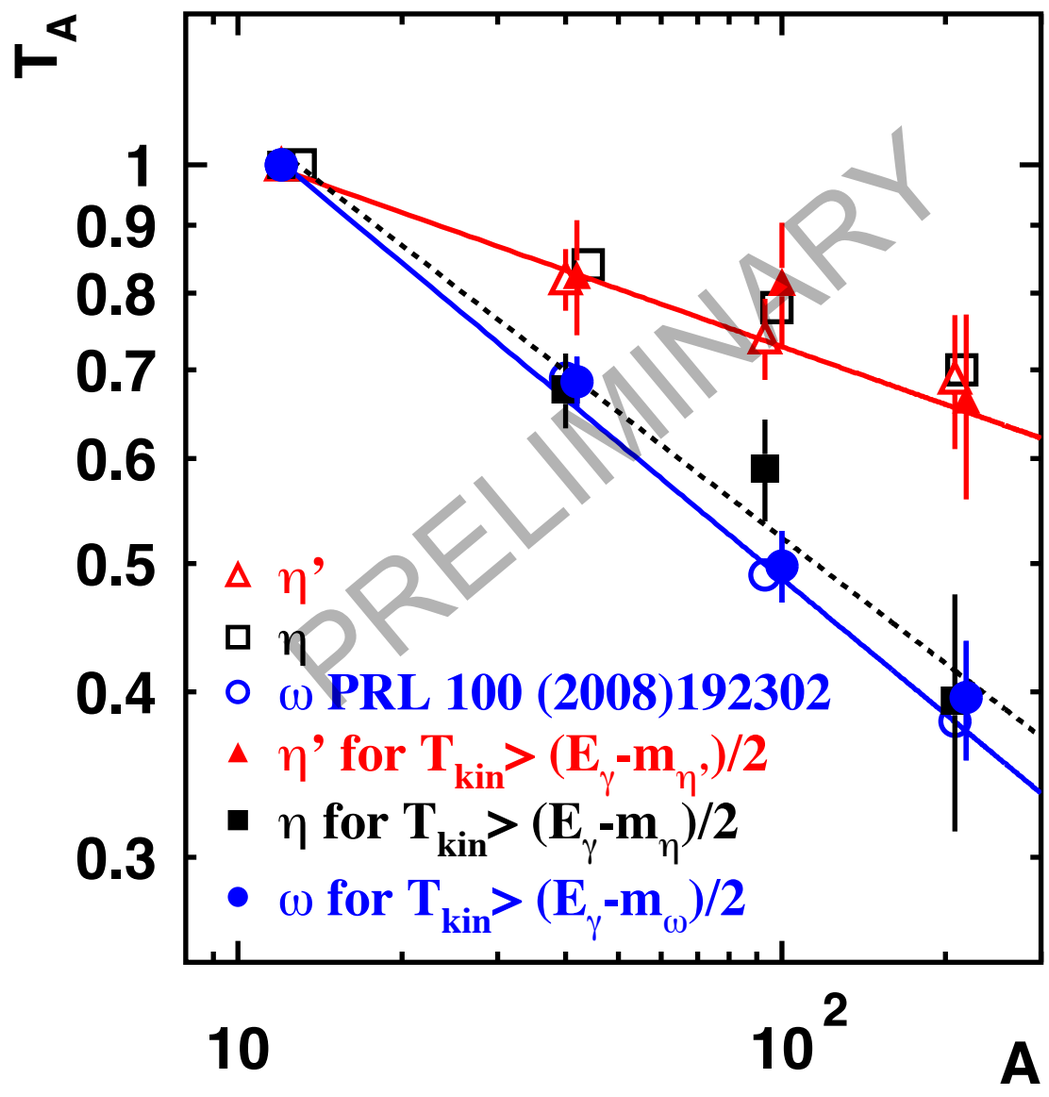
suppressing this process ⇨ select only mesons with higher T_{kin}

comparison with other mesons

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

T. Mertens et al., EPJA 38 (2008) 195
photoproduction of **η meson** on nuclei
two-step processes suppressed by $T_\eta > (E_\gamma - m_\eta)/2$





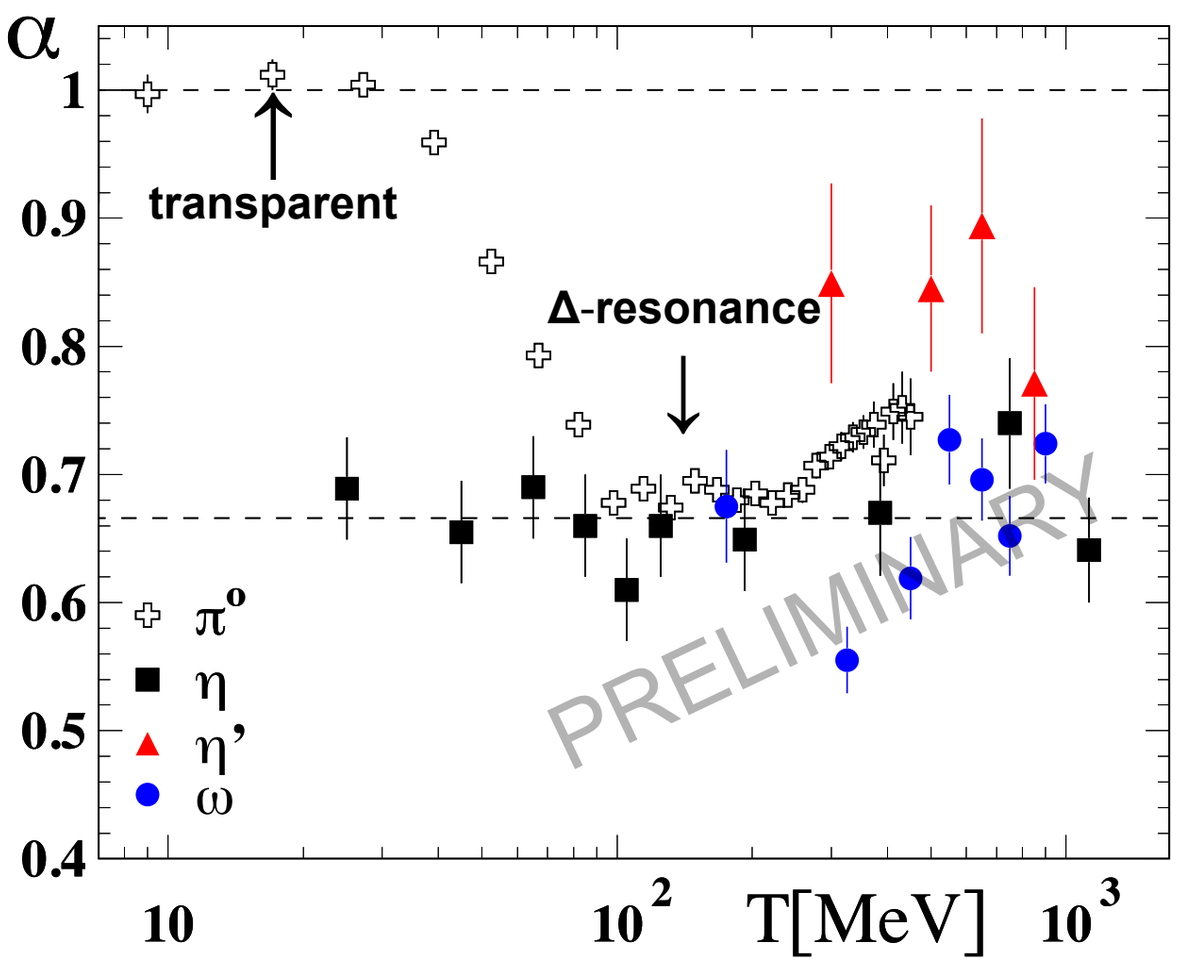
T_A measurement for η meson strongly affected by two-step processes; only little effect for η' and ω mesons

interaction of mesons in nuclear medium

A-scaling of production cross sections as a function of the meson kinetic energy

$\sigma(A) = \sigma_0 \cdot A^{\alpha(T)}$ $\alpha \approx 1.0$: mesons escape from the full **volume**

$\alpha \approx 2/3$: mesons escape only from the **surface**



π^0 mesons:

low energies: only very weak interaction;
strong absorption for higher energies:
resonance excitation

*B. Krusche et al., Eur. Phys. J. A **22**, 277 (2004).*

η mesons:

strong absorption for all T

*M. Röbig-Landau et al., Phys. Lett. B, **373**, 45 (1996).*
*T. Mertens et al., Eur. Phys. J. A **38**, 195 (2008).*

ω mesons:

strong absorption: $\langle\alpha\rangle_T \approx 0.67$;

M. Kotulla et al., Phys. Rev. Lett. 100, 192302 (2008)

η' mesons:

$\langle\alpha\rangle_T \approx 0.84$

η'N interaction weaker than ηN

M. Nanova et al. to be published

summary & outlook

preliminary results about the in-medium properties of η' meson:

- **in-medium width:** 15-30 MeV at $p_{\eta'} \approx 1.05$ GeV/c and $\rho=\rho_0 \Rightarrow \sigma_{\eta' N} \approx 10$ mb
- **transparency ratio** almost independent of η' momentum

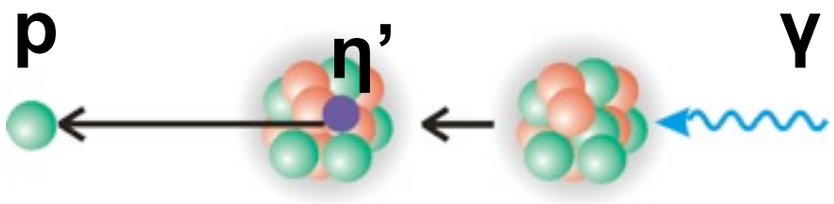
⇒ contribution from **two-step processes not significant**

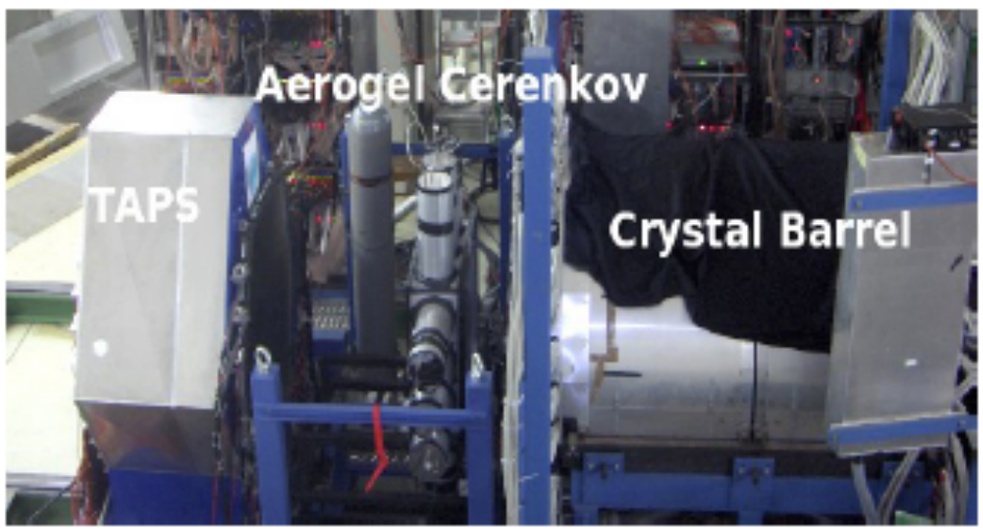
- **cross section measurement $\sigma_A = \sigma_0 \cdot A^{\alpha}$:**

$<\alpha>_T \approx 0.84$ - indication for weaker interaction in nuclear medium compared to η and ω

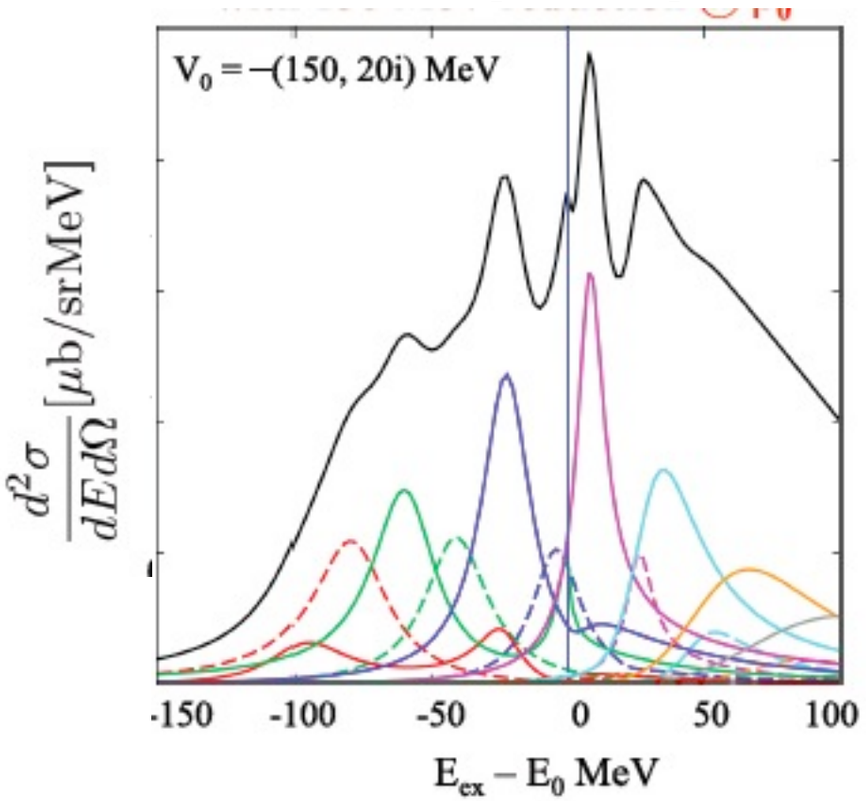
next step: CB/TAPS@ ELSA data on ^{12}C target (E_γ up to 2.9 GeV)

- search for η'- bound states





D. Jido, H. Nagahiro and S. Hirenzaki, arXiv 1109.0394 [nucl-th]



narrow peak for η' mesic state predicted