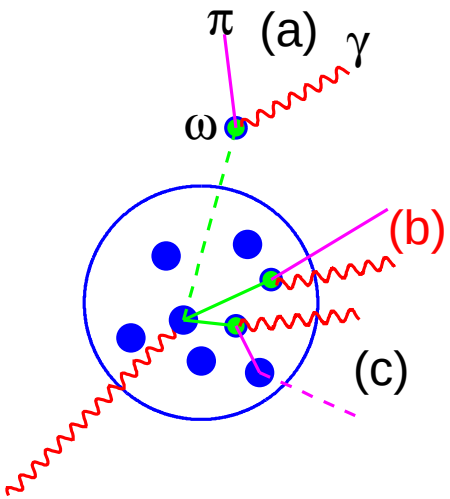
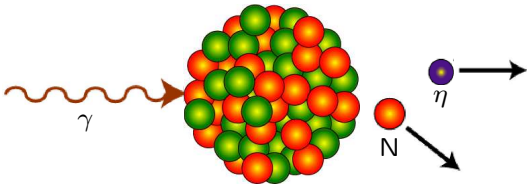
In-medium properties of hadrons

- Introduction & Motivation
- Mesons in the medium
  - ω-mesons in the medium
  - 'σ'-meson - pion pairs in the medium



- Nucleon resonances in the medium
  - Modified spectral functions?
  - Meson - nucleus FSI

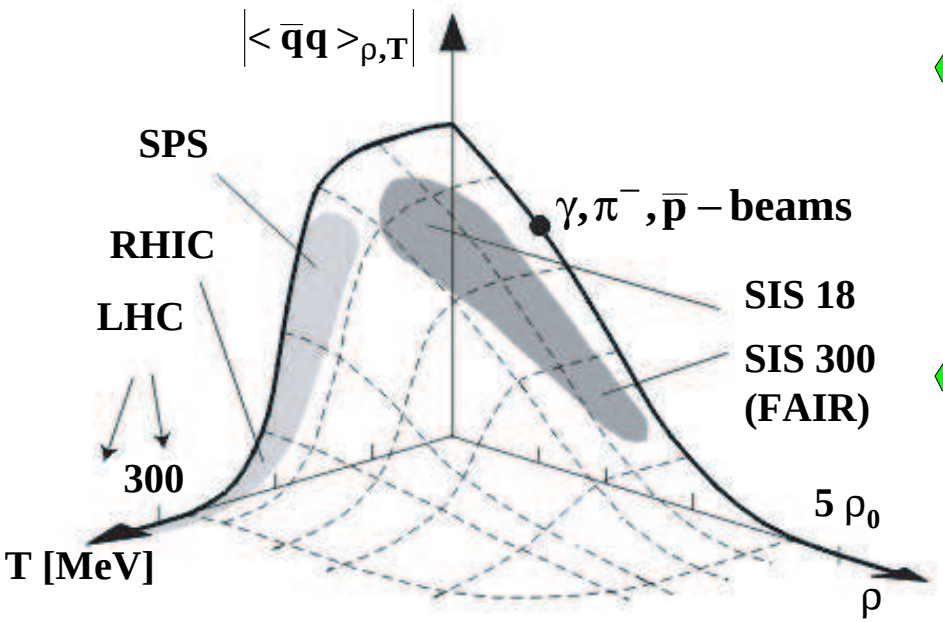


Partial restoration of chiral symmetry

- temperature and density dependence of chiral condensate
  (Nambu, Jona-Lasinio model)

  M. Lutz, S. Klimt, W. Weise,

  Nucl. Phys. A542 (1992) 521



- effects on in-medium hadron properties
  - Brown-Rho scaling of masses:

    $m^\star_{\sigma,\rho,\omega}/m_{\sigma,\rho,\omega} \approx m^\star_N/m_N \approx f^\star_\pi/f_\pi$

    (G.E. Brown, M. Rho, PRL 66 (1991)2720)
  - density scaling of meson masses:

    $m^\star_{\sigma,\rho} = m_{\sigma,\rho}(1-\alpha_{\sigma,\rho}\frac{\rho_N}{\rho_o}) \quad \alpha \approx 0.2$

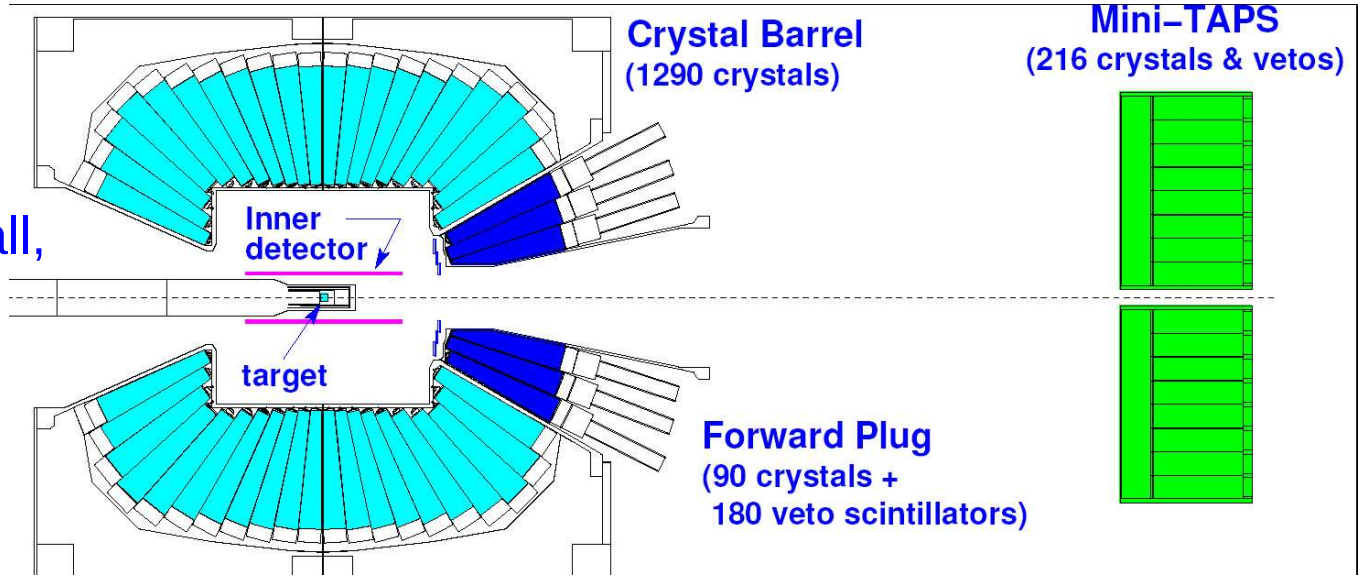
    (QCD sum rules, C.M.Ko; lin. sigma model, Hatsuda et al.)
  - many different model predictions,
    some with some w/o significant mass shifts,
    many with modification of widths,
    momentum dependent effects,...
  - some experimental evidence from
    di-lepton production in heavy ion reactions:
    CERES: D. Adamova et al., PRL 91 (2003) 042301;
    NA60: S. Damjanovic et al., nucl-ex/0510044

experimental setups - Ball, Barrel and TAPS and ...

- Bonn ELSA accelerator:

  Crystal Barrel (CsI),
  TAPS (BaF_2) forward wall,
  inner detectors

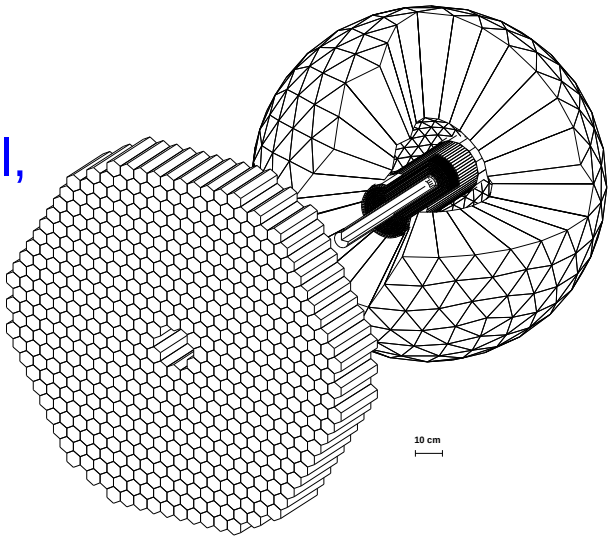
  $E_\gamma \leq$ 3.5 GeV,
  lin. pol.: available,
  circ. pol.: available

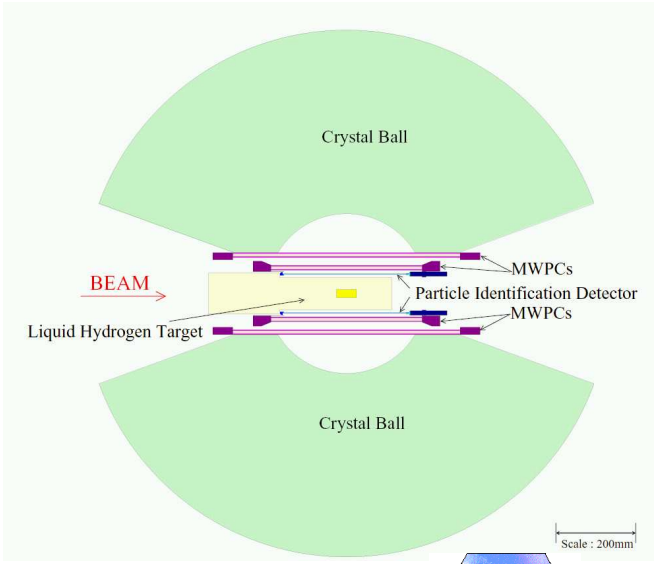


- Mainz MAMI accelerator:

  Crystal Ball (NaJ),
  TAPS (BaF_2) forward wall,
  inner detectors

  $E_\gamma \leq$ 0.8 (1.5) GeV,
  lin. pol.: available,
  circ. pol.: available





photoproduction of ω-mesons from nuclei

- study of ω mesons in (dense) nuclear matter is planned for heavy ion reactions via the Dalitz decay of the ω (HADES@GSI)

- TAPS/Crystal Barrel@Bonn experiments for photoproduction of ω mesons in normal dense nuclear matter

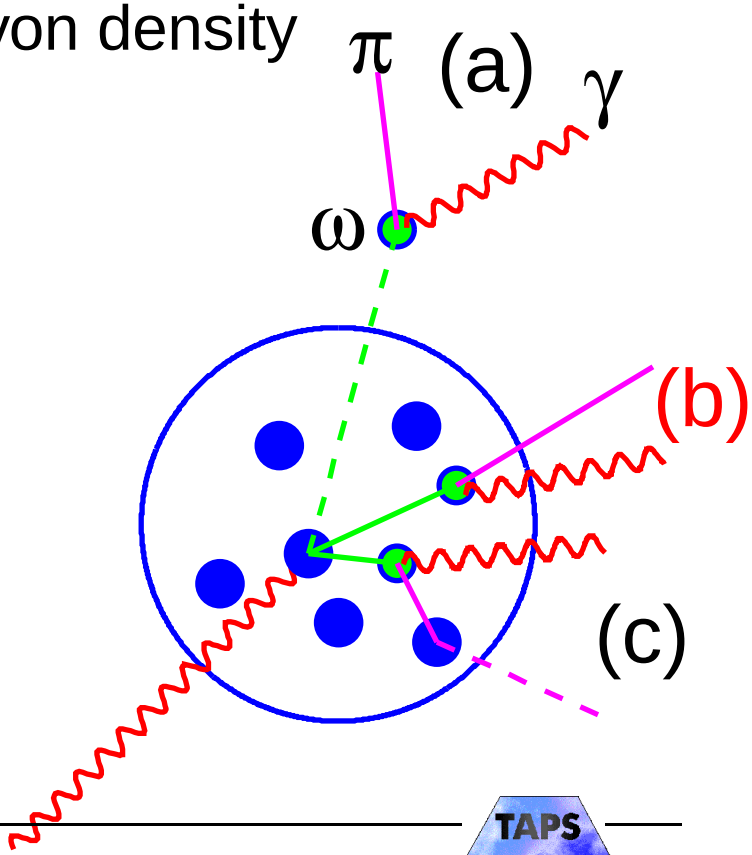
  - no complications from rapidly varying baryon density
  - ω identifi ed via $\omega \longrightarrow \pi^o\gamma$

    $\longrightarrow$ much larger branching ratio

    (8.5 % for $\pi^o\gamma$, 7×10^{-5} for e^+e^-)

    $\longrightarrow$ almost no background from broad ρ-meson

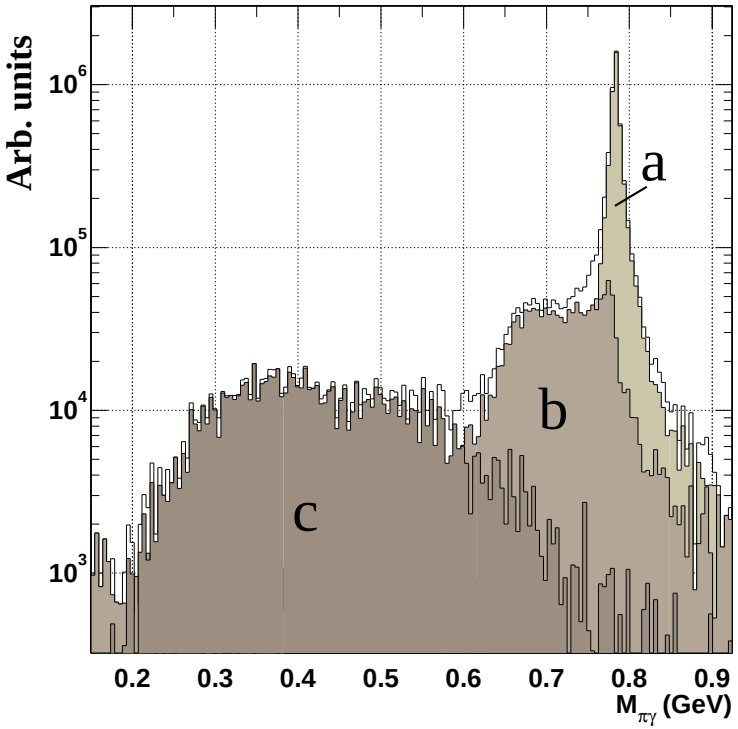
    ($\pi^o\gamma$ branching 8×10^{-4})
  - but: complication from FSI of π^o-meson

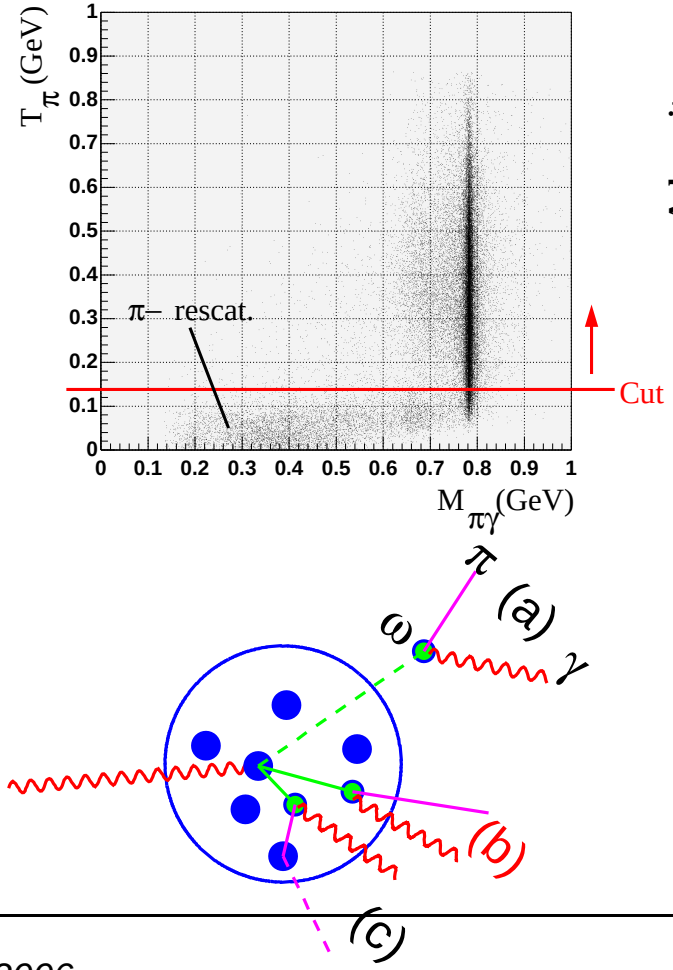


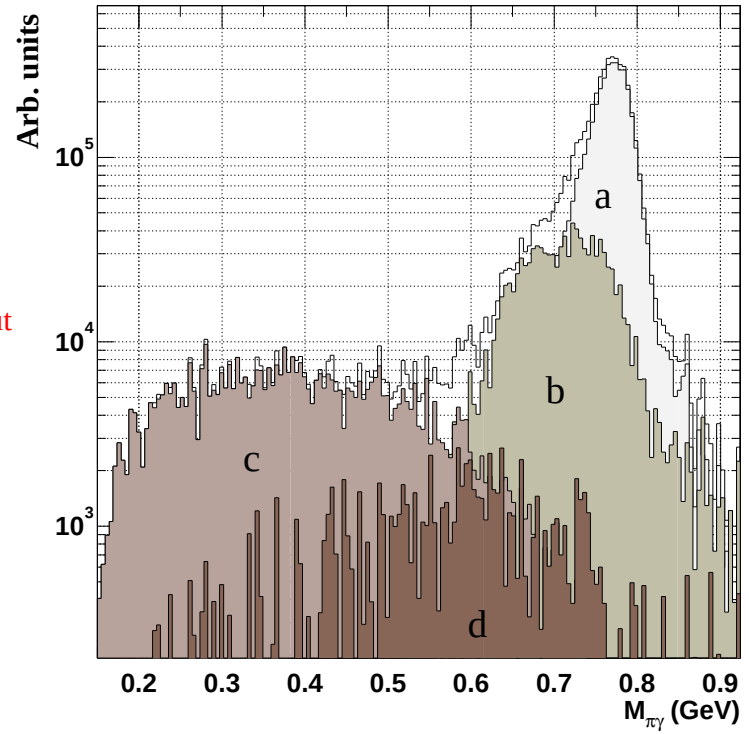
photoproduction of ω-mesons from nuclei - simulation

(J.G. Messchendorp et al.)

- simulation with transport model including predicted ω in-medium spectral function:
- re-scattered pions suppressed with cuts on kinematics
- including instrumental resolution and $2\pi^o$ background





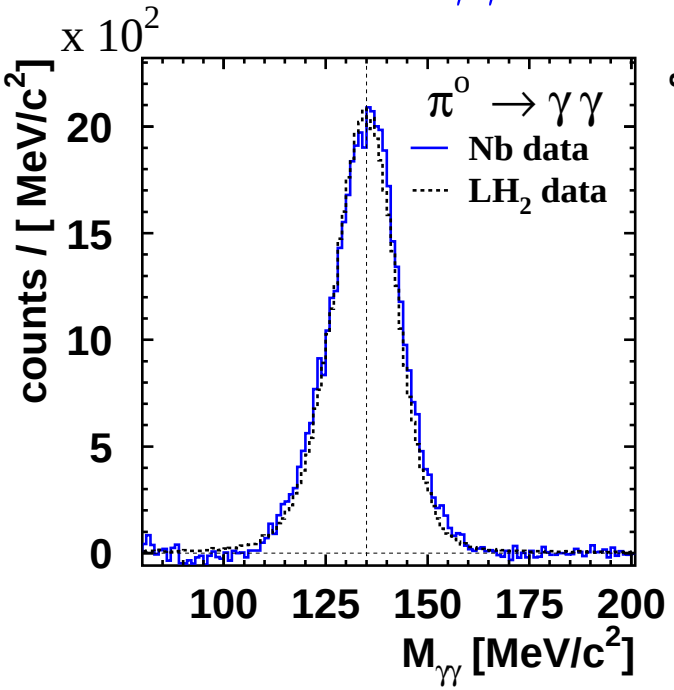


invariant mass distributions: π^o, η, η'

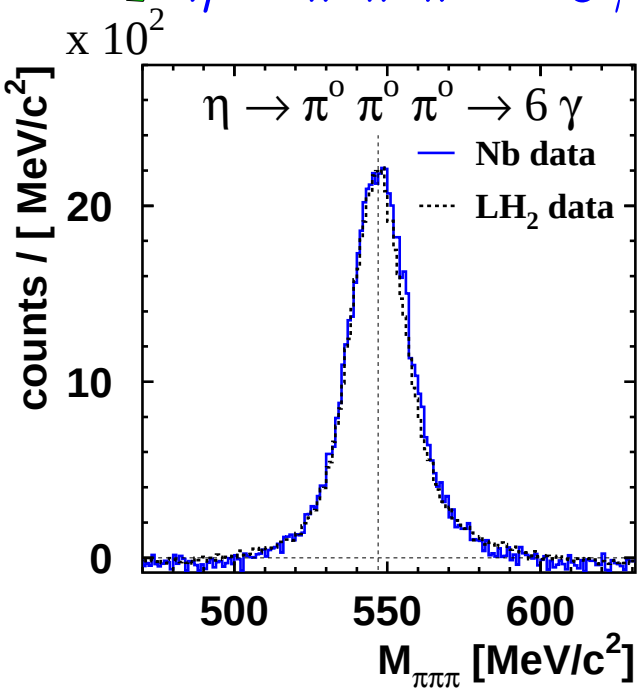
(D. Trnka et al. (TAPS/Crystal Barrel@ELSA, PRL 94 (2005) 192303)

- comparison of invariant mass spectra: free proton - Nb nucleus

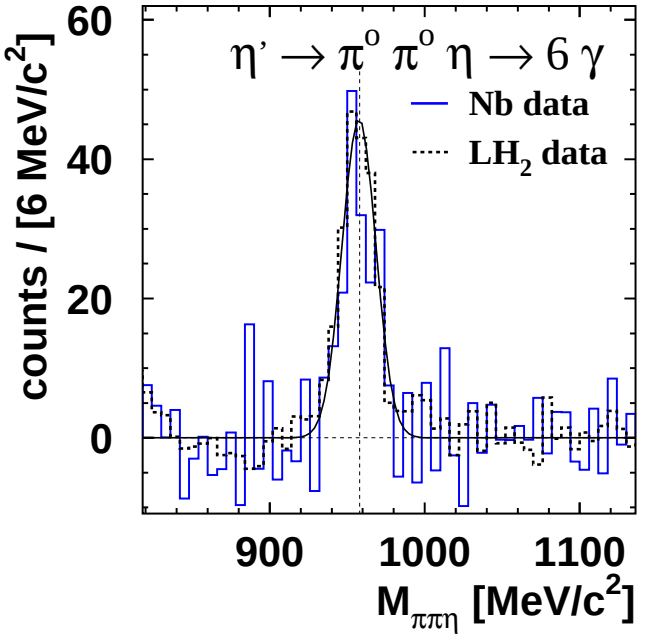
- $\pi^o \to \gamma\gamma$



- $\eta \to \pi^o\pi^o\pi^o \to 6\gamma$



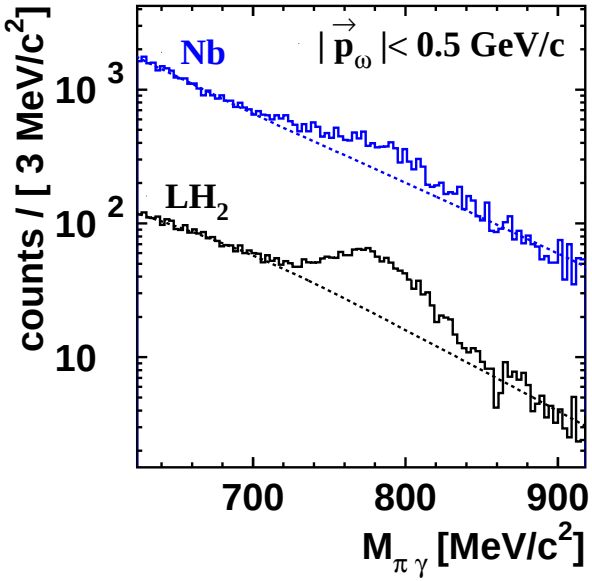
- $\eta' \to \pi^o\pi^o\eta \to 6\gamma$

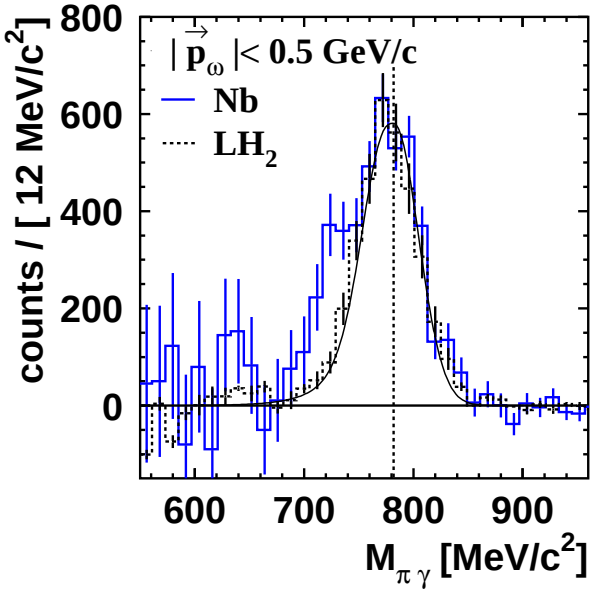


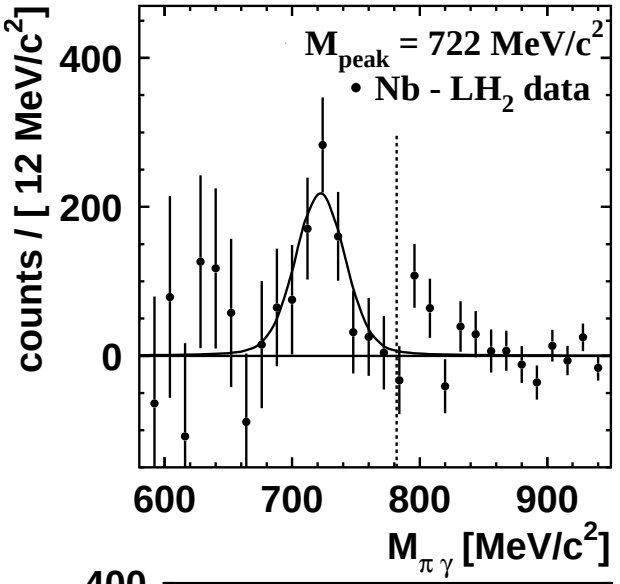
$\Longrightarrow$ detector response understood, no artificial effects for nuclear targets

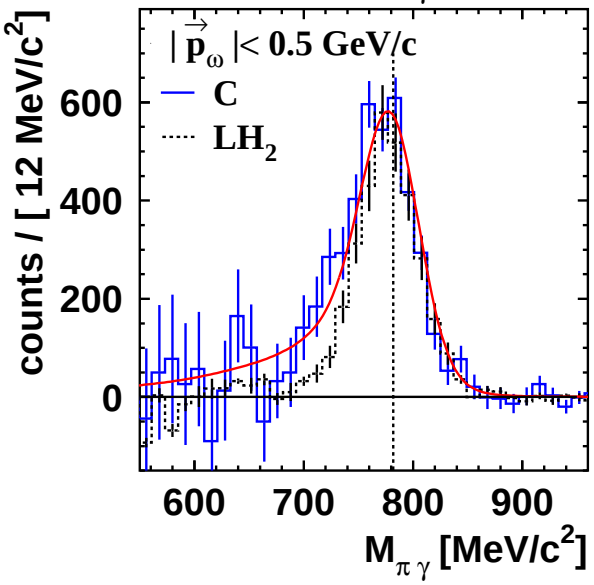
invariant mass distributions: ω-mesons

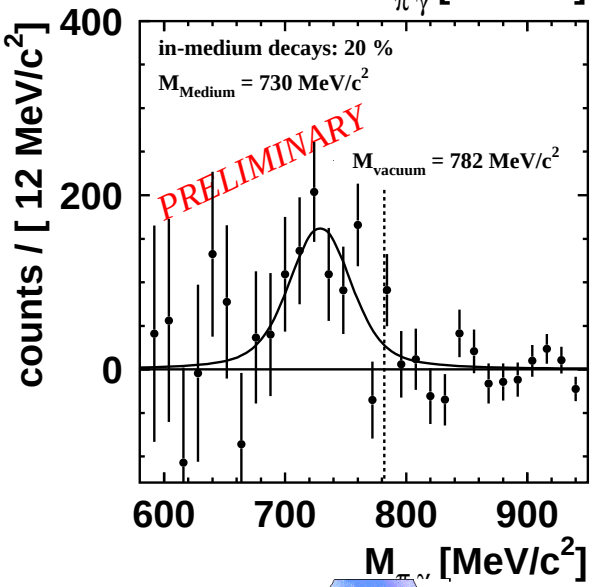
- comparison: free proton - C, Nb nuclei (D. Trnka et al., PRL 94 (2005) 192303)









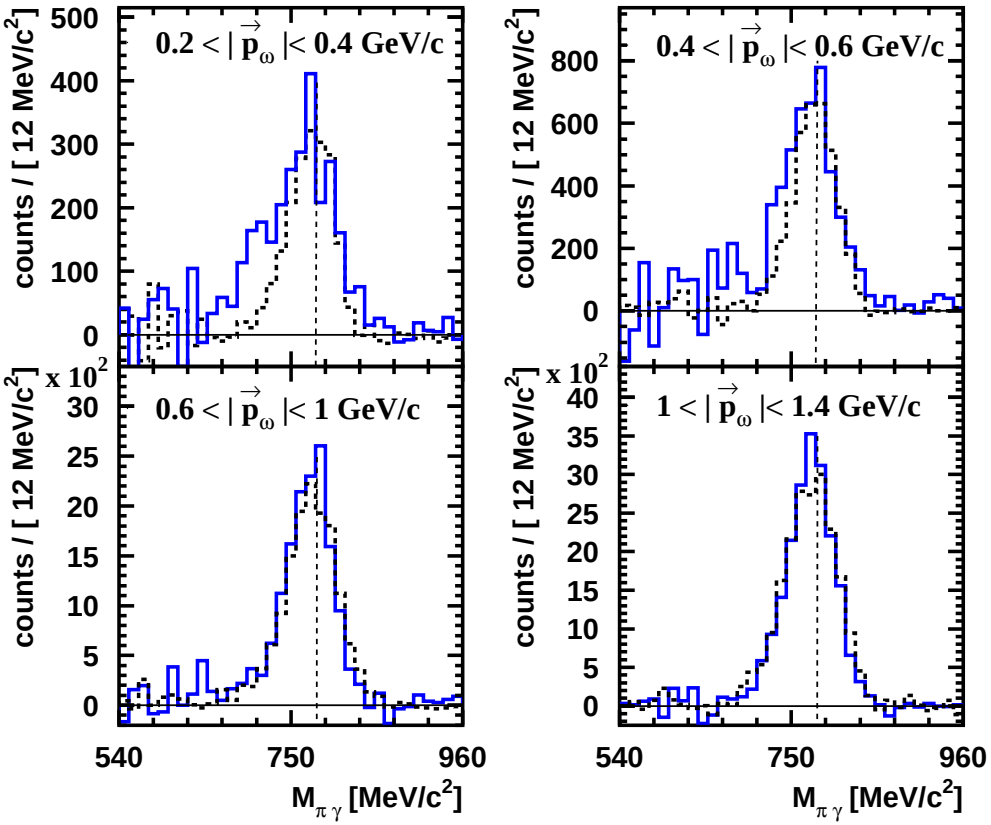


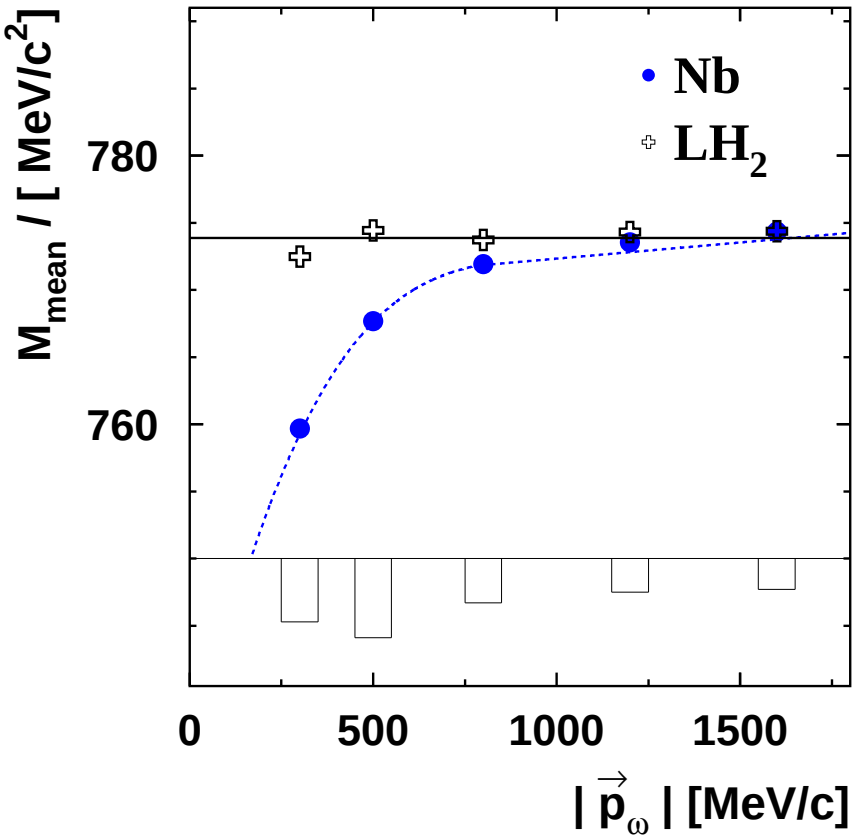
- fi rst evidence for in-medium modifi cation of the ω meson
- Possible -but not completely model independent - interpretation as mass shift
- Analysis of possible width modifi cation (mass number scaling in progress

invariant mass distributions: ω-mesons

(D. Trnka et al., PRL 94 (2005) 192303)

- momentum dependence of mass shift





pion pairs in the nuclear medium - the 'σ' in nuclear matter

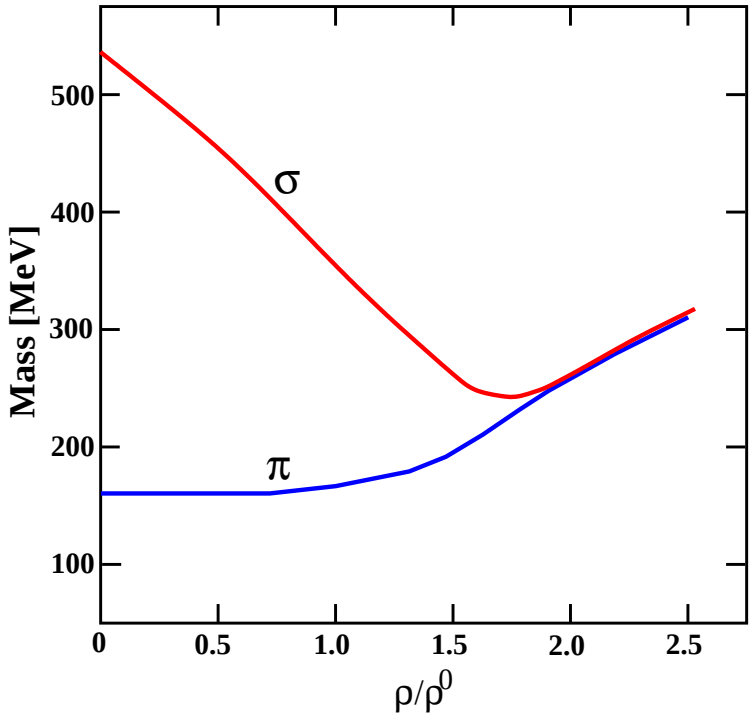
Introduction & Motivation

Results from pion and photon induced reactions

- pion induced $\pi^+\pi^-$ production (CHAOS@TRIUMF)
- pion induced $\pi^o\pi^o$ production (Crystal BAll@BNL)
- photon induced $\pi^o\pi^o$ production (TAPS@MAMI)

predictions for scalar mesons in matter: the 'σ'

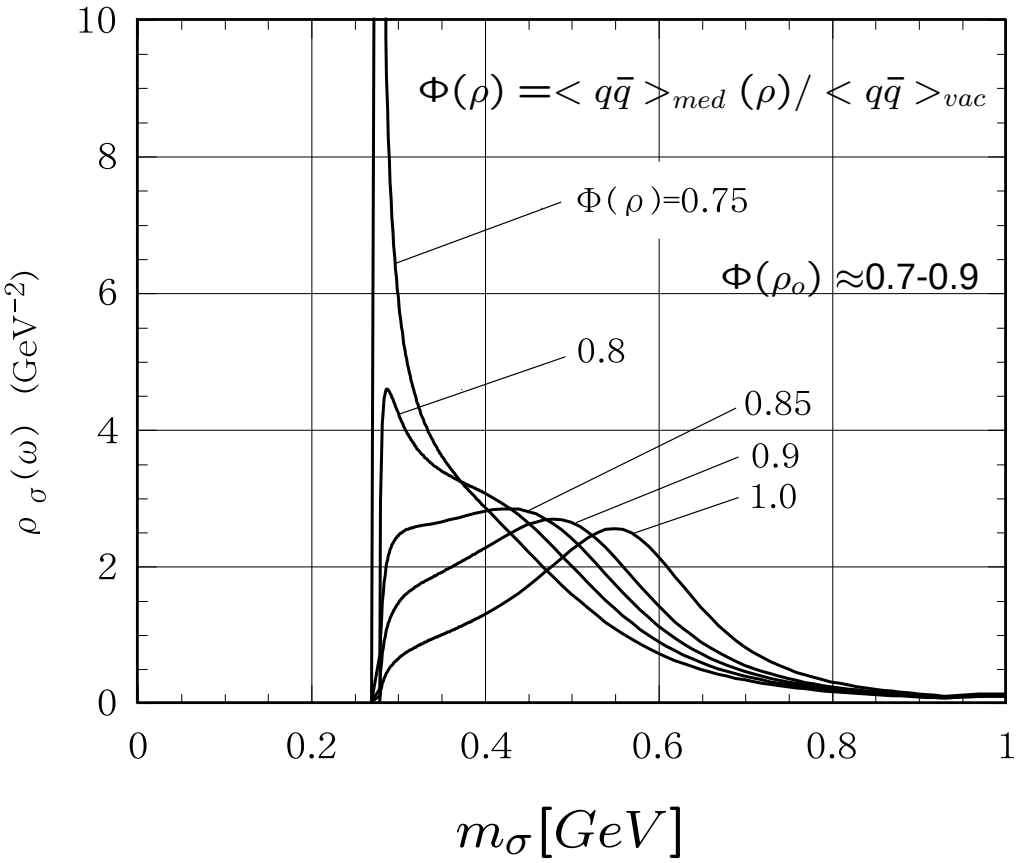
- predicted dependence of σ-mass on density (V.Bernard et al.):



- masses of chiral partners degenerate in chiral limit

$$m_\sigma = m_{\sigma_o}(1 - \alpha\rho/\rho_o)$$

- σ spectral function, expected effects on $\sigma \rightarrow \pi^o\pi^o, \pi^+\pi^-$ (Schuck et al., Hatsuda et al., Rapp et al.)

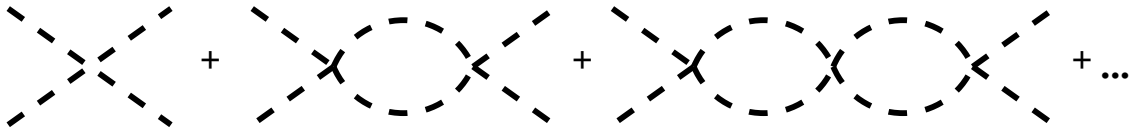


$\pi\pi$ interaction in the chiral unitary model

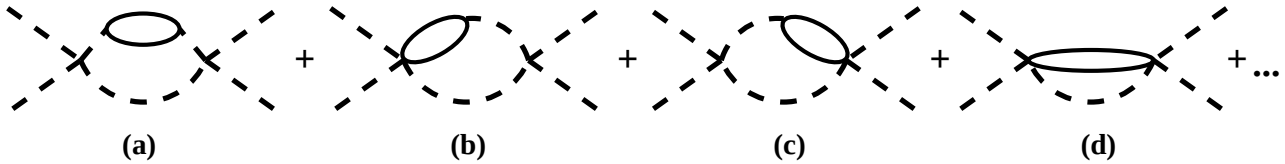
(L. Roca, M.J. Vicente Vacas & E. Oset)

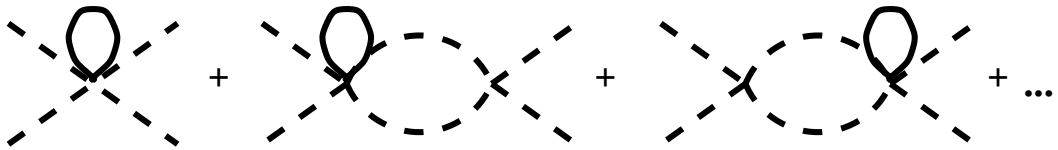
- σ dynamically generated as pole of the $\pi\pi$ scattering amplitude

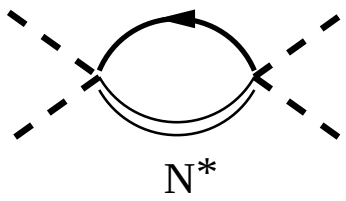
  $\pi\pi$-interaction in vacuum:



- $\pi\pi$-interaction in the medium, coupling to ph, Δh, $N^\star h$:

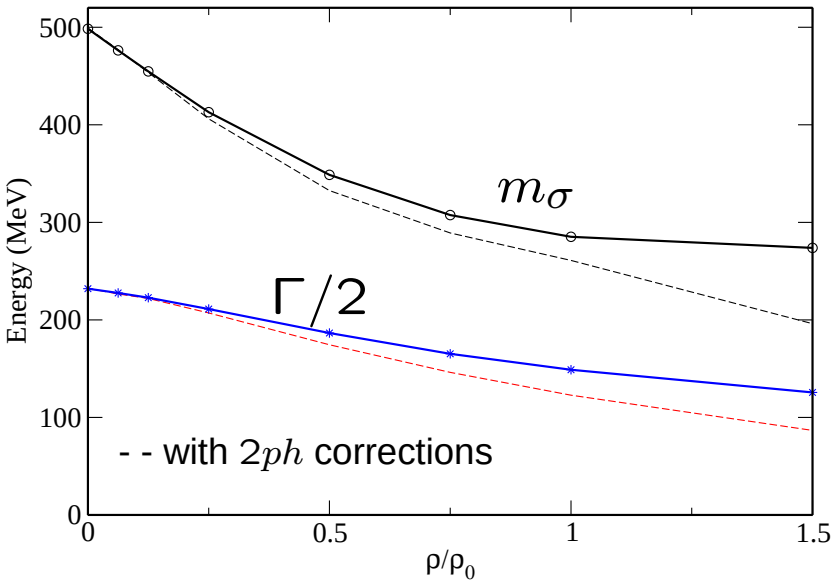






in particular Roper $P_{11}(1440)$

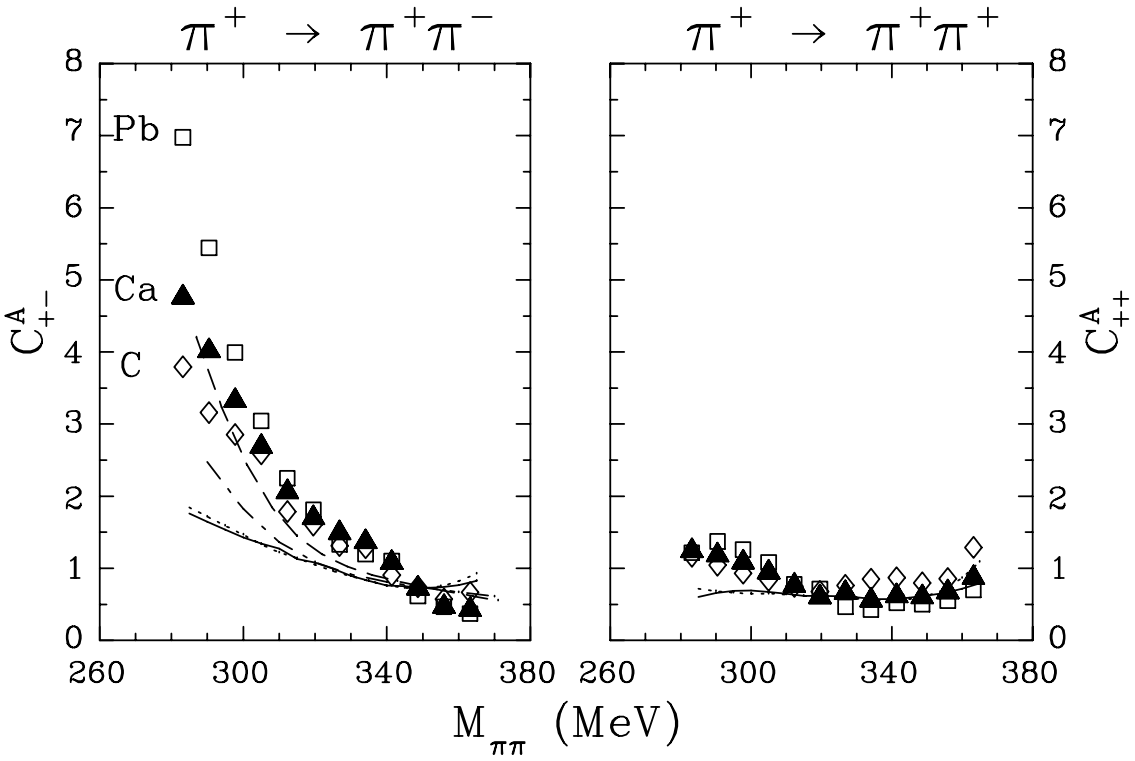
- drop of 'σ' mass and width with increasing density



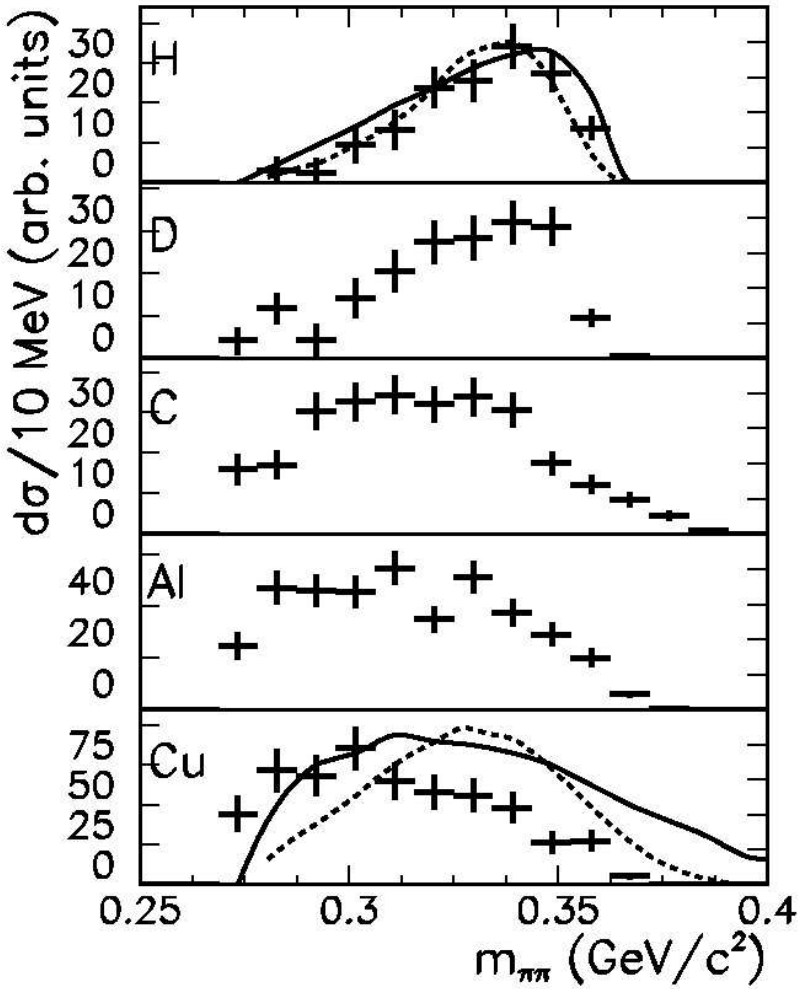
pion induced double π production: results

- CHAOS collaboration:(Bonutti et al.)
  composite ratio:

$$C^A \equiv \left(\frac{d\sigma}{dm}/\sigma\right)_A / \left(\frac{d\sigma}{dm}/\sigma\right)_p$$

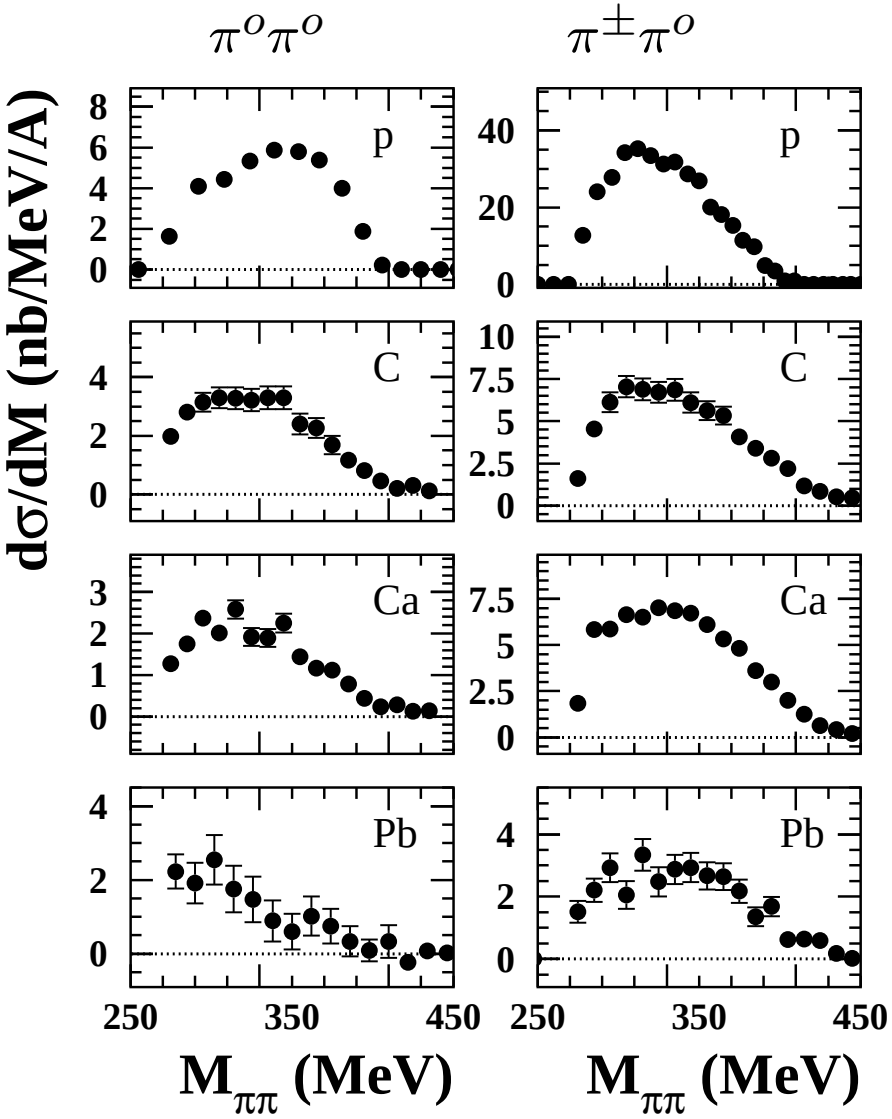


- Crystal Ball@BNL: (S. Starostin et al.)
  $\pi^- A \rightarrow A'\pi^o\pi^o$ reaction

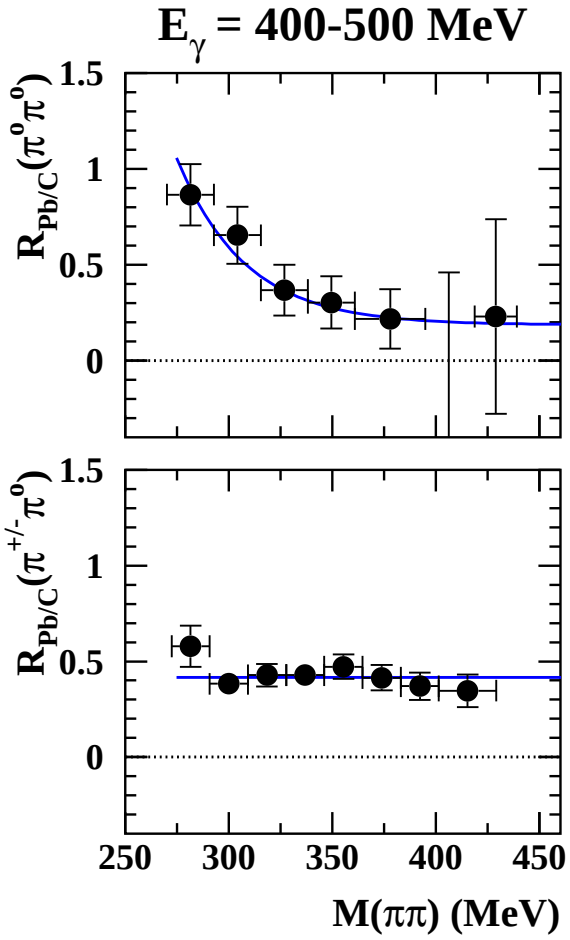


photon induced double π production: results (TAPS)

- invariant mass distributions $\pi^o\pi^o$ and $\pi^\pm\pi^o$:



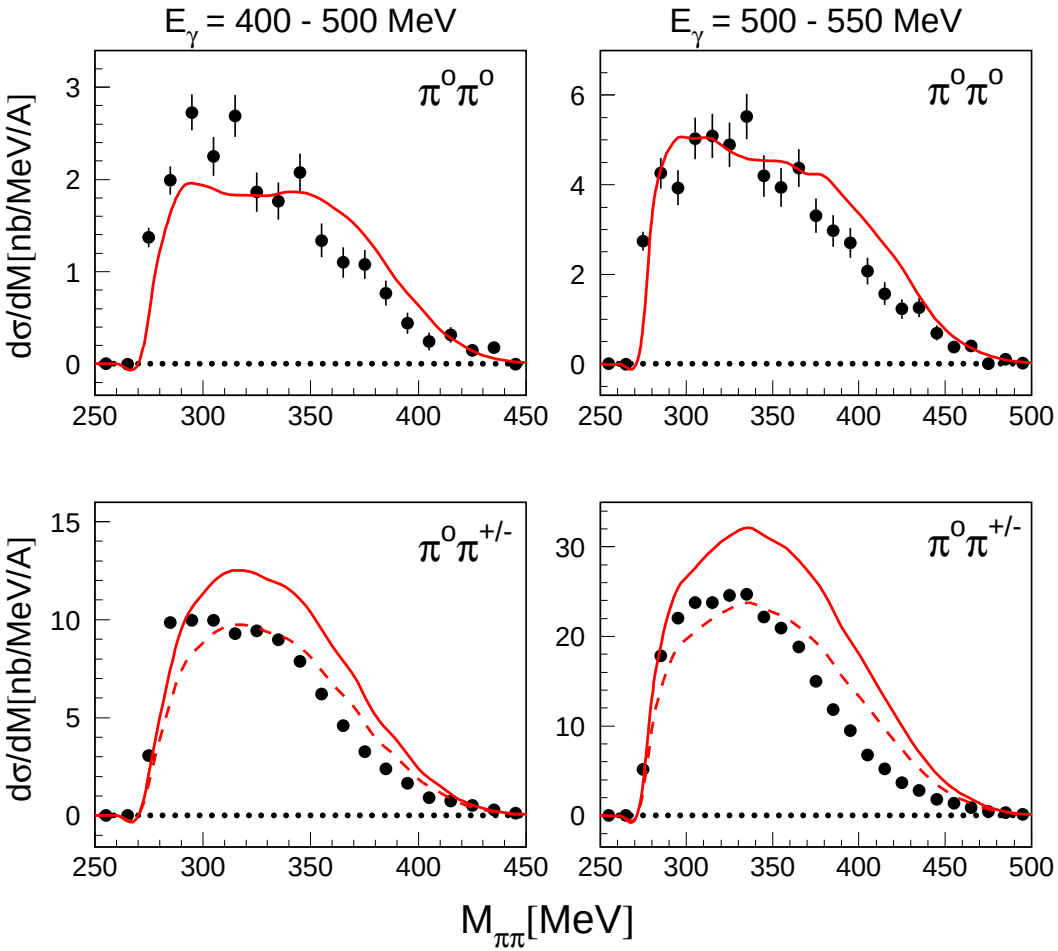
- Ratio: $R_{Pb/C} \equiv \left(12\frac{d\sigma}{dm}\right)_{Pb} / \left(208\frac{d\sigma}{dm}\right)_{C}$

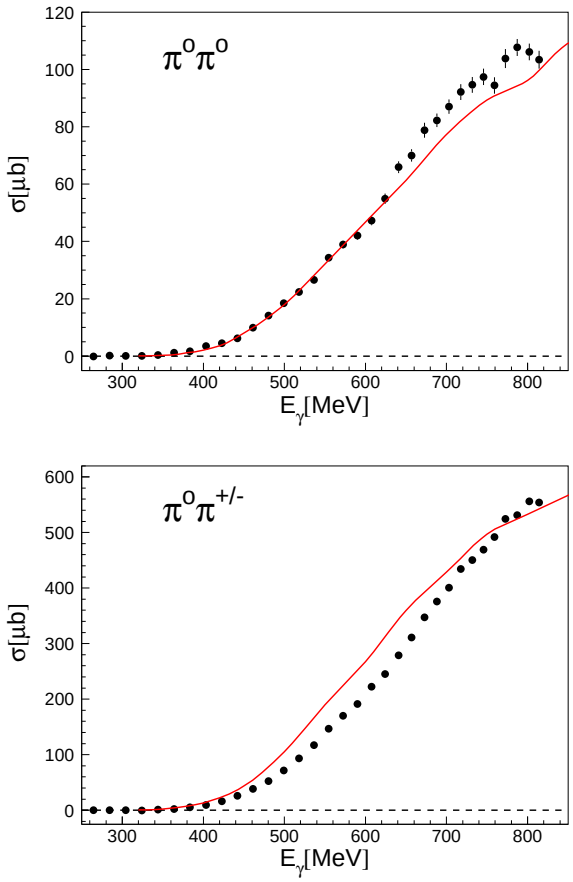


- mass shift with increasing mass A only for $\pi^o\pi^o$

comparison to BUU-model calculations: ^{40}Ca

- invariant mass distributions
- total cross sections

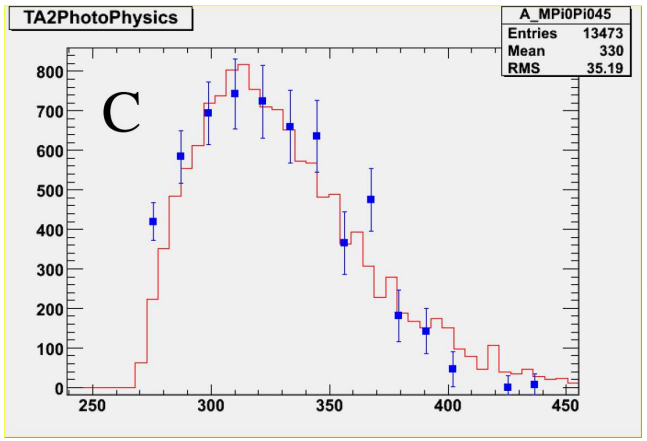


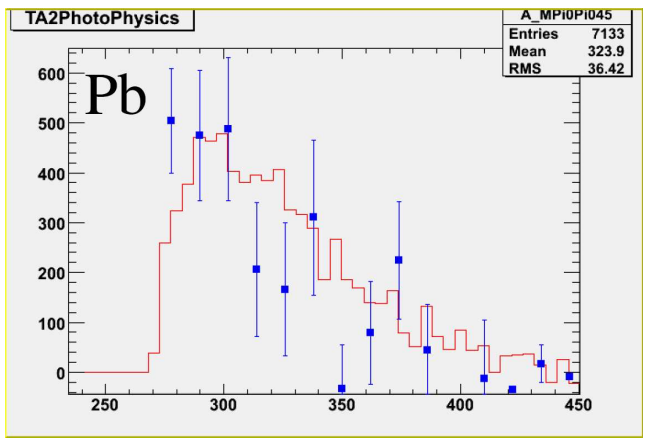


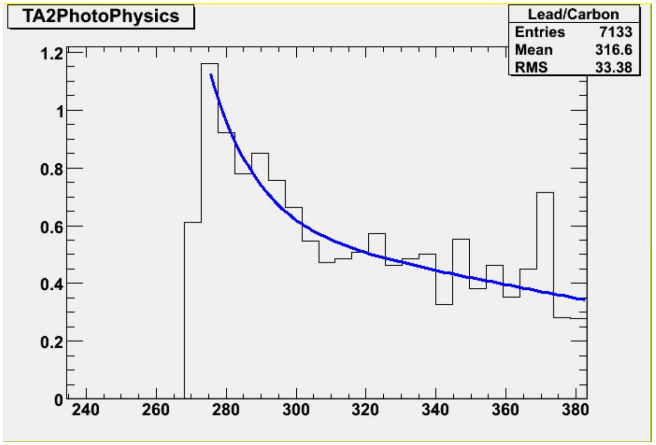
- Data: F. Bloch et al.(Basel), in prep.
- Model: O. Buss et al. (Giessen), nucl-th/0502031

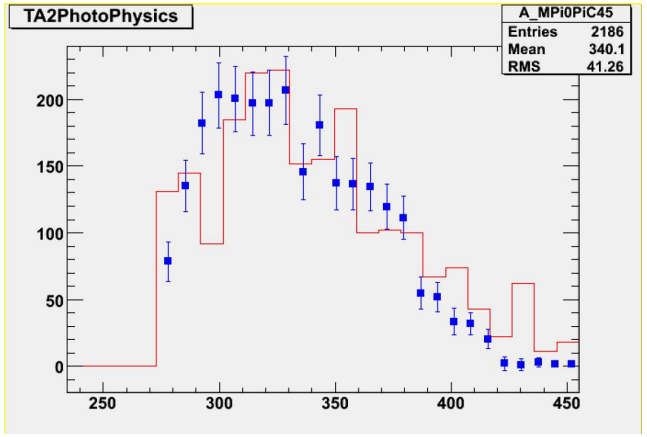
photon induced double π production: new results

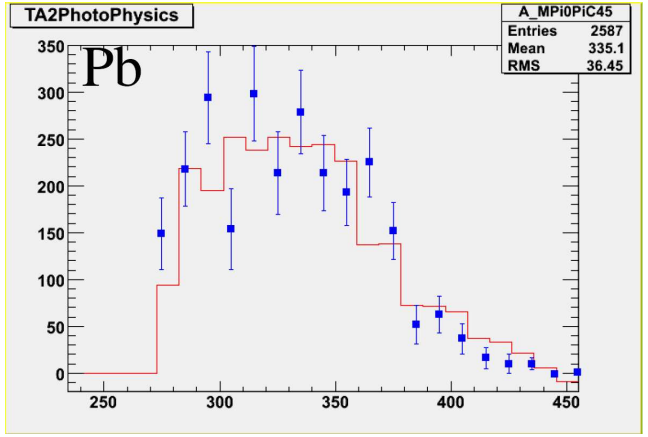
- new high statistics measurement with Crystal Ball and TAPS:

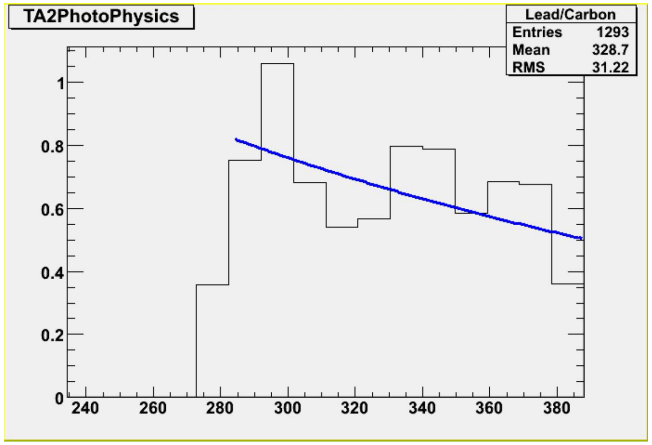












- Very preliminary results (no effi ciency correction., only small part of total data for $\pi^o\pi^\pm$)
  S. Lugert and R. Gregor (Giessen) et al.

summary: mesons in nuclear matter

- results for the photoproduction of ω mesons from nuclei show first evidence for the predicted influence of the ω in-medium spectral function on the line shape (TAPS/CBarrel at ELSA)
- high statistics measurements proposed for TAPS/CBall at MAMI C

- predictions from different models for in-medium modifications of scalar - isoscalar pion pairs ('σ'-meson)
- pion and photon induced reactions show some evidence for this effect
- new high statistics measurement with TAPS/CBall for detailed study of the photon induced reaction under analysis

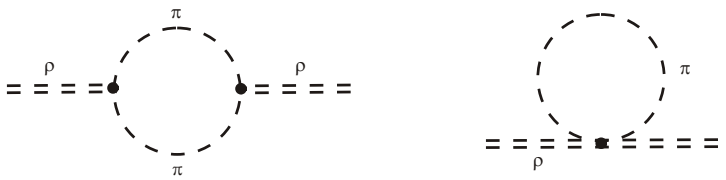
Coupling of mesons to resonance-hole states

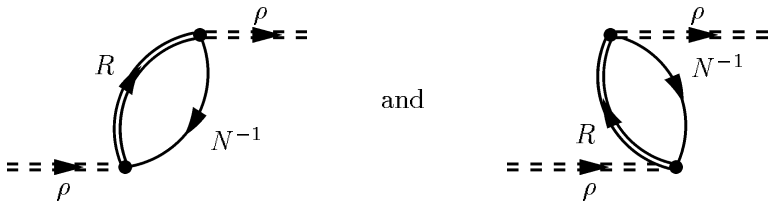
- well known example: coupling of pion to Δ-hole states $\rightarrow$ in-medium properties of Δ
- self-consistent calculation of meson and nucleon resonance spectral functions from coupling to resonance-hole states (Peters et al. NPA632((1998)109, Post et al., nucl-th/0309085)

meson and baryon self-energies from diagrams like:

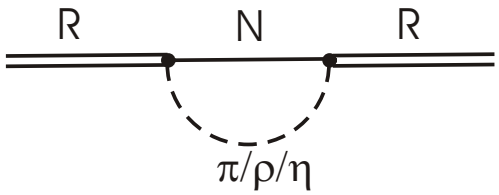
- in vaccum:
- in medium:

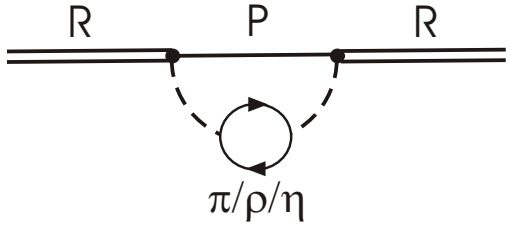
- mesons:





- baryons:

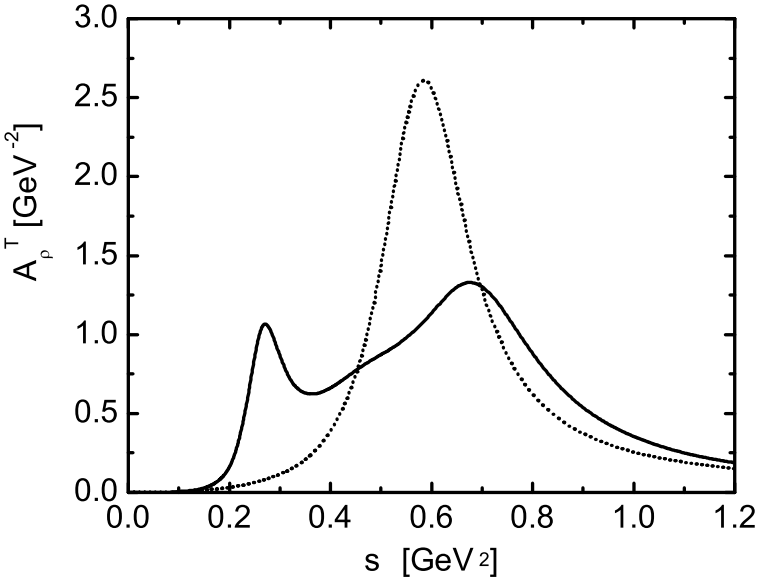




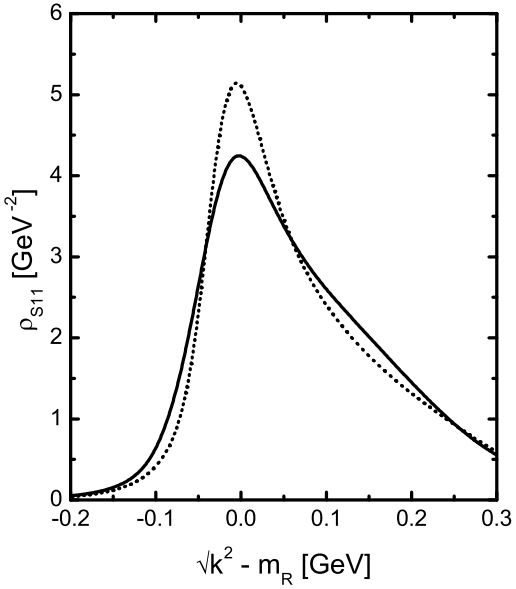
- In-medium spectral functions:
  - mesons: $\mathcal{A}_M^{med}(q) = -\frac{1}{\pi}\mathcal{I}m\frac{1}{q^2-m_M^2-\Pi_{vac}(q)-\Pi_M(q)}$
  - baryons: $\rho^{med}(k) = -\frac{1}{\pi}\mathcal{I}m\frac{1}{k^2-m_R^2-\Sigma_{med}(k)}$

in-medium spectral functions of nucleon resonances

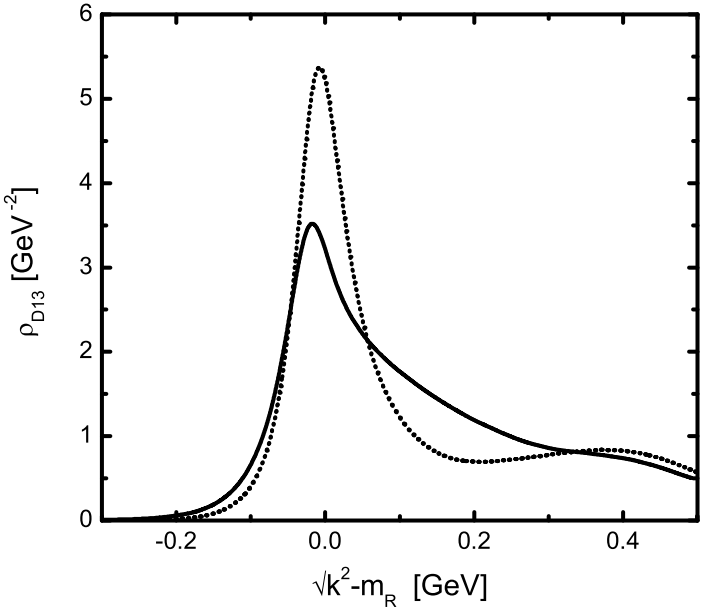
- modified ρ spectral function from coupling to resonance - hole states (dependend on momentum, different longi-tudinal and transverse ρ)



- spectral function of $S_{11}(1535)$ almost unmodified, largest effects from Pauli-blocking of $N\eta$ channel and modified ρ spectral function.



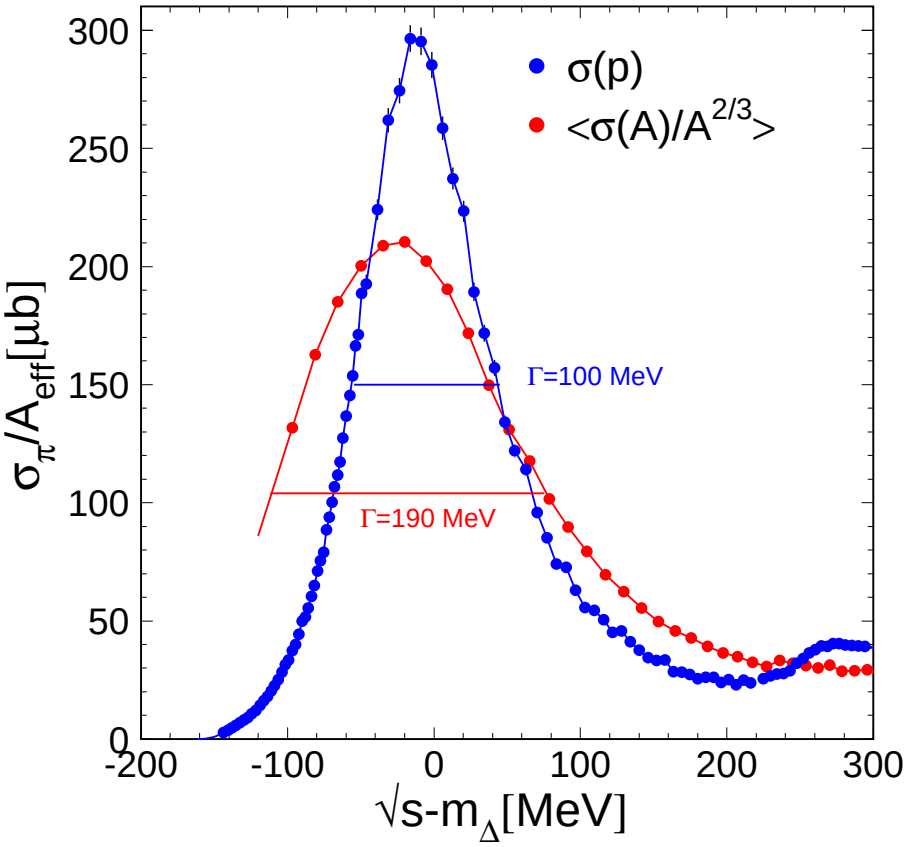
- spectral function of $D_{13}(1520)$ significant modification due to strong coupling to the $N\rho$ channel



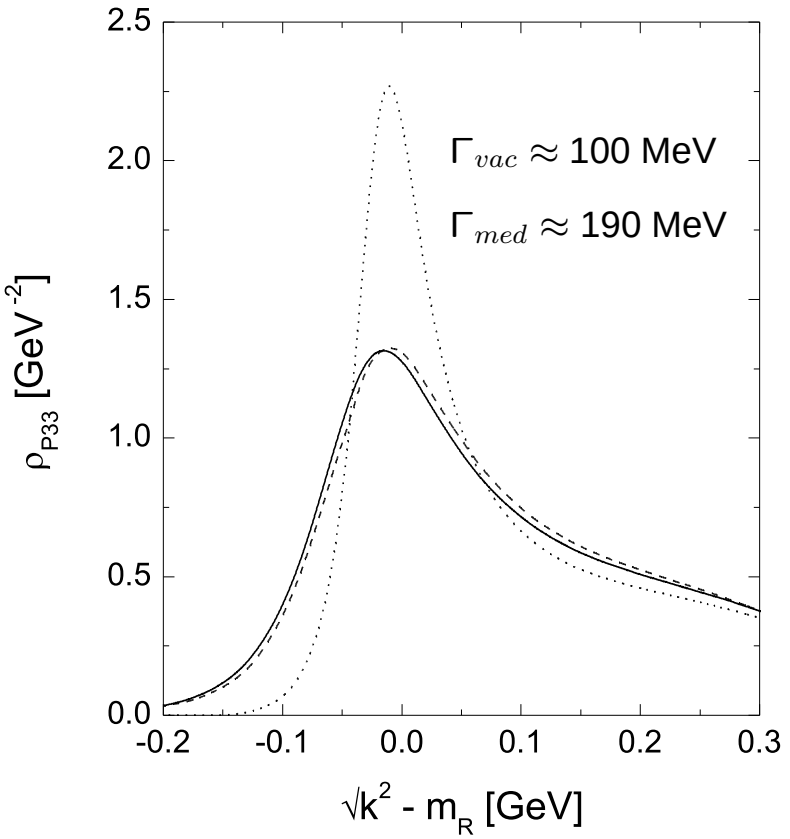
M. Post, J. Lehr, U. Mosel,
Nucl. Phys. A 741 (2004) 81

single π^o photoproduction and the Δ resonance

- total cross section in Δ region



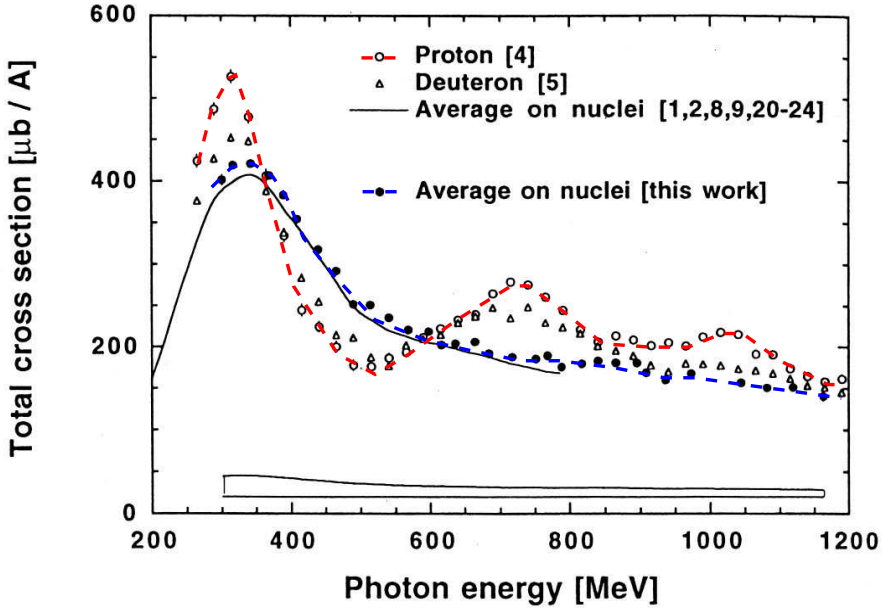
- predicted spectral functions (Post et. al.)

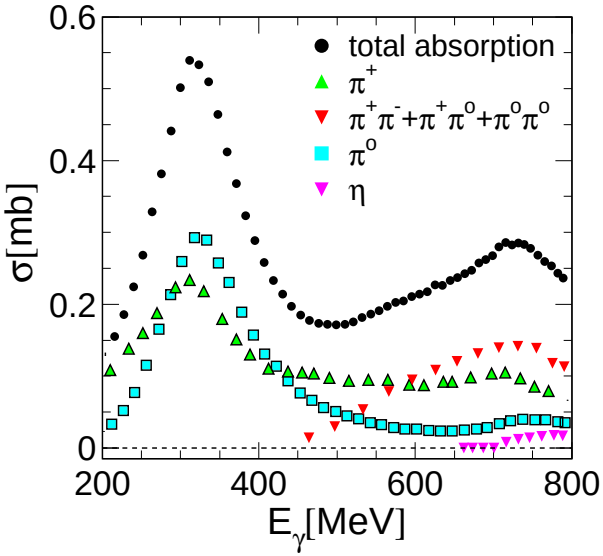


- broadening of Δ to $\approx$ 190 MeV, comparable results found in analysis of coherent π^o photoproduction (Rambo et al., Drechsel et al., Krusche et al.)

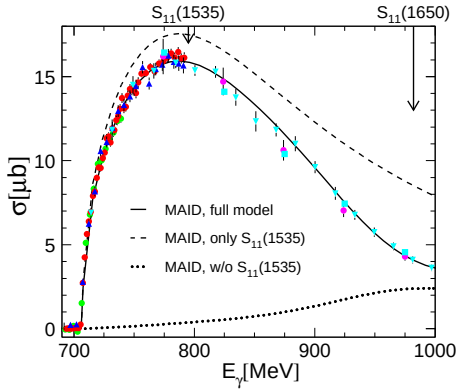
the second resonance region - where are the resonances gone?

- total photoabsorption from nucleon and nuclei
- partial xsections off the proton

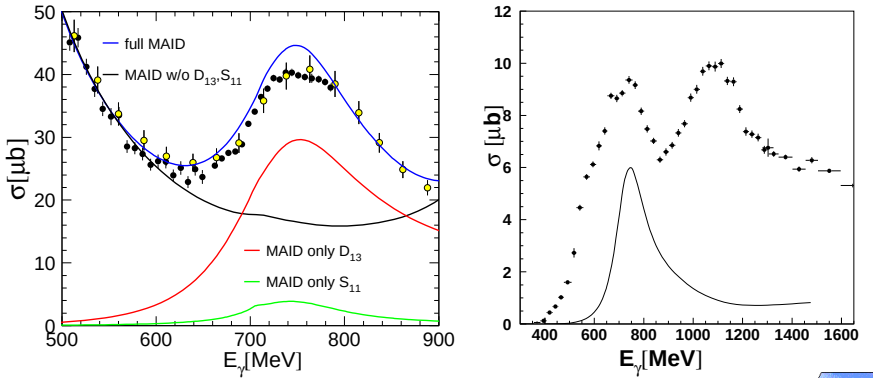




- $S_{11}(1535)$: η-channel

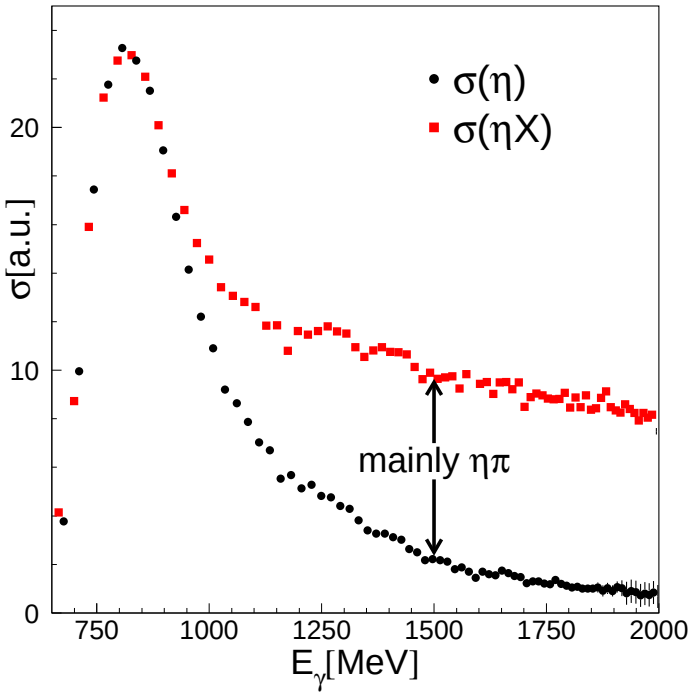


- $D_{13}(1520)$: π^o or $2\pi^o$-channel

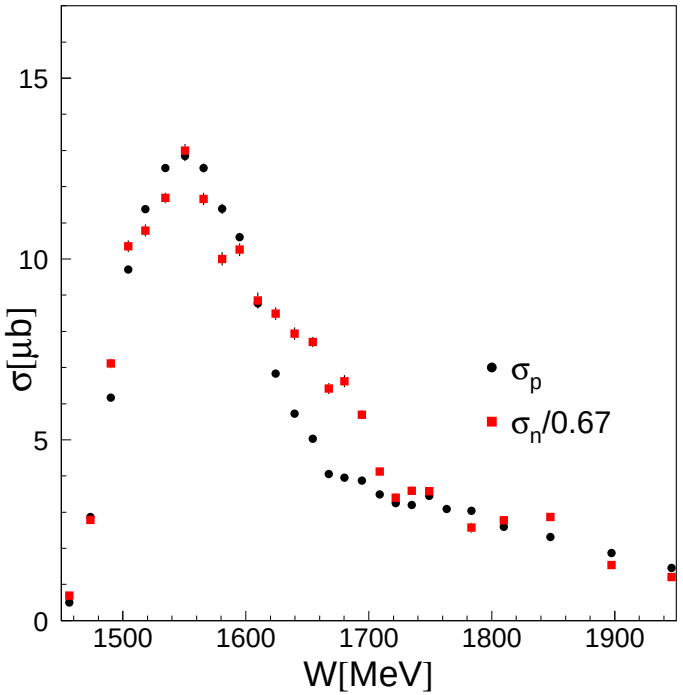


quasifree $\gamma N \rightarrow N\eta$ total cross sections

- inclusive off deuteron



- exclusive off p, n

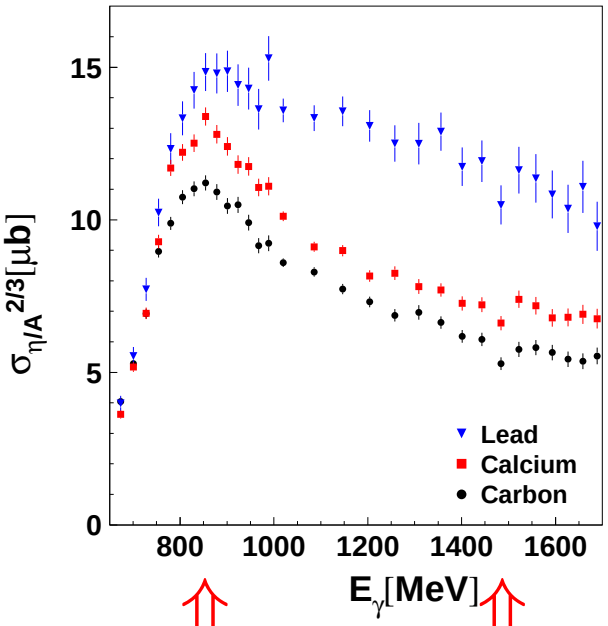


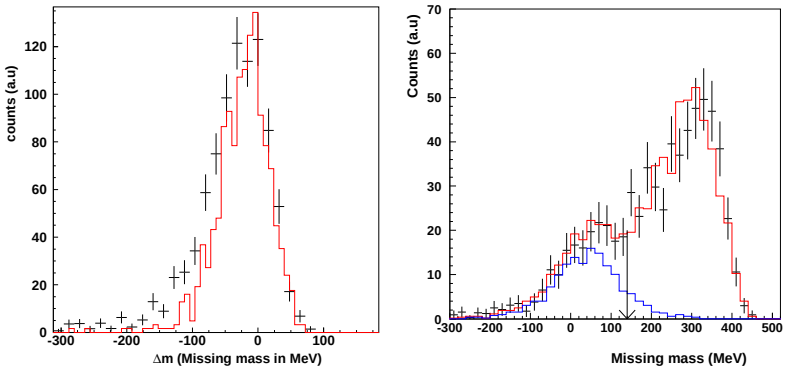
- contributons from $\eta\pi$ final states at higher incident photon energy
- different excitation function for neutron
  (resonance with stronger electromagnetic coupling for neutron than for proton)

I. Jaegle et al., preliminary

total cross sections for η photoproduction off nuclei

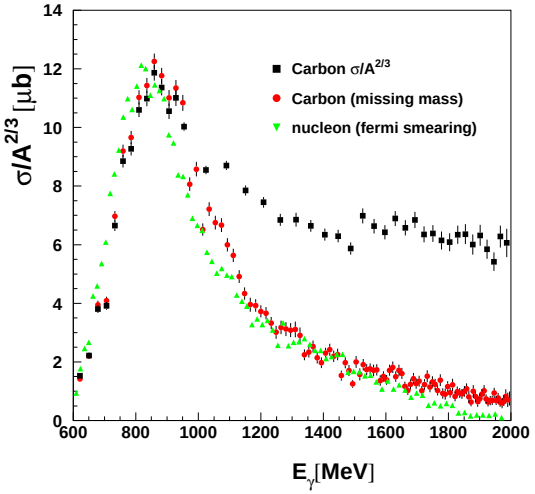
- inclusive excitation functions $\gamma A \rightarrow \eta X$

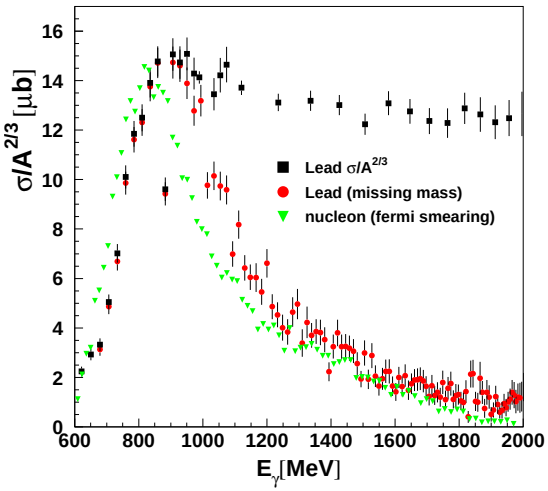




- missing mass distributions

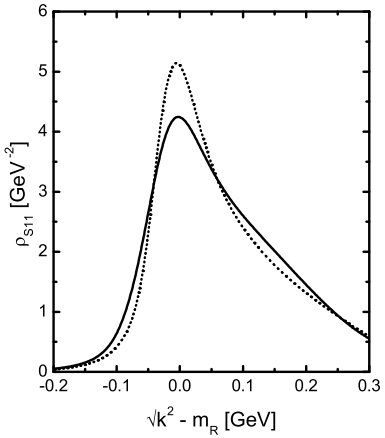
- ... and after cut on quasifree $\gamma A \rightarrow (A-1)N\eta$





⇒ at most small in-medium modifi cation of $S_{11}(1535)$
- as expected by model predictions -

predicted in-medium line-shape of $S_{11}(1535)$ resonance from self-consistent calculation of meson and resonance spectral functions (coupling of mesons to resonance - hole states, coupling of resonances to modifi ed mesons):



M. Post, J. Lehr, U. Mosel,
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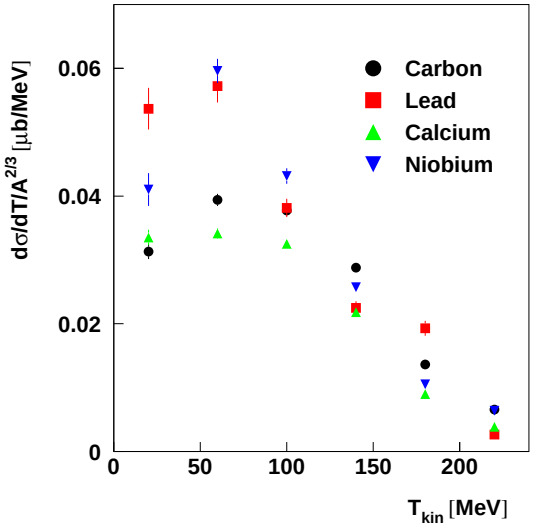
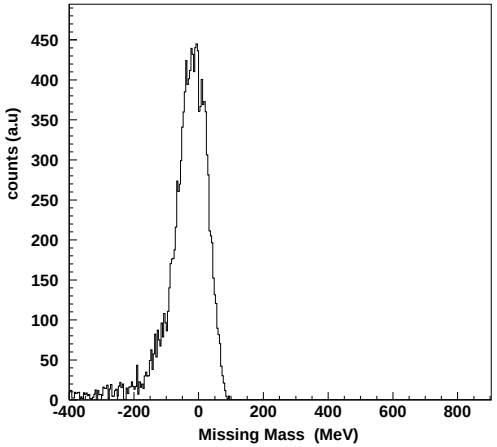
TAPS

kinetic energy distributions for η photoproduction off nuclei

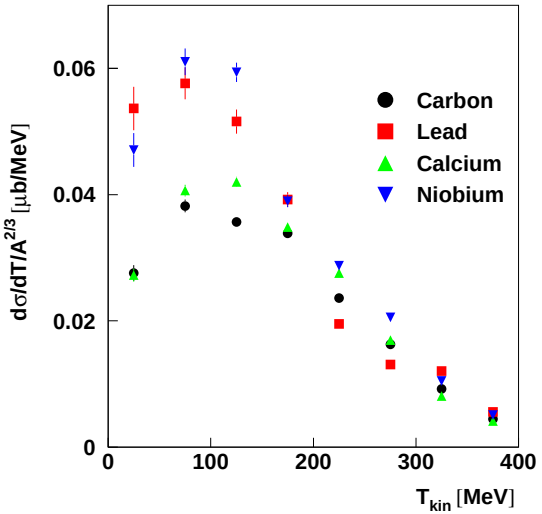
E_γ=650 - 835 MeV



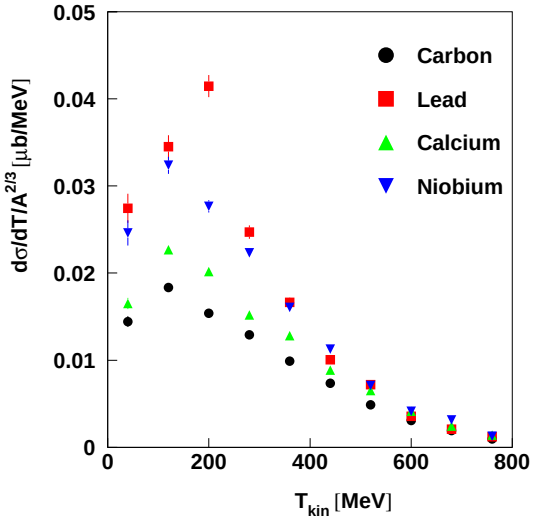
corresponding missing mass

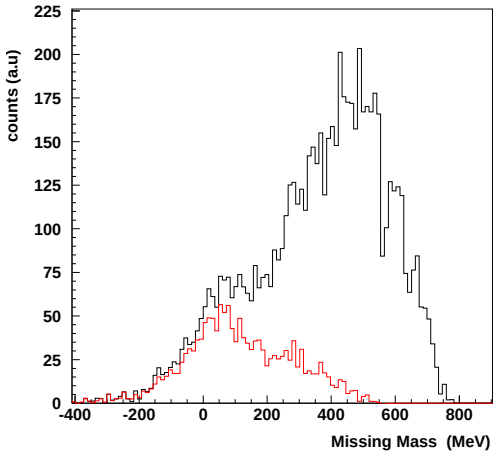


E_γ= 835 - 1060 MeV

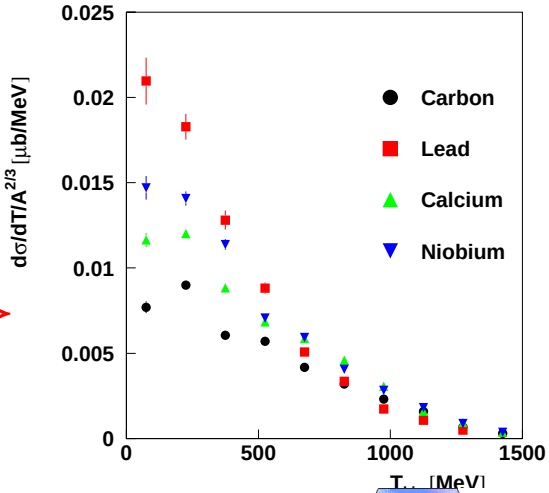


E_γ=1060 - 1550 MeV



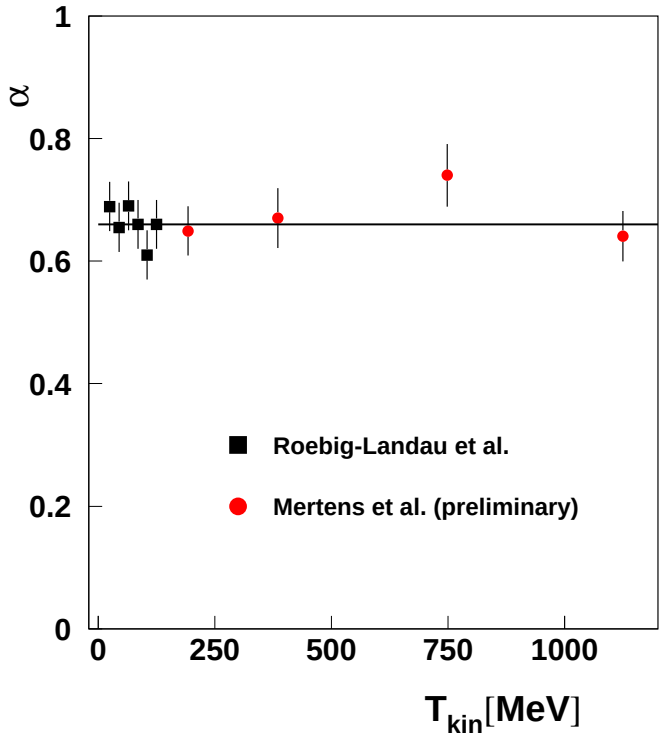


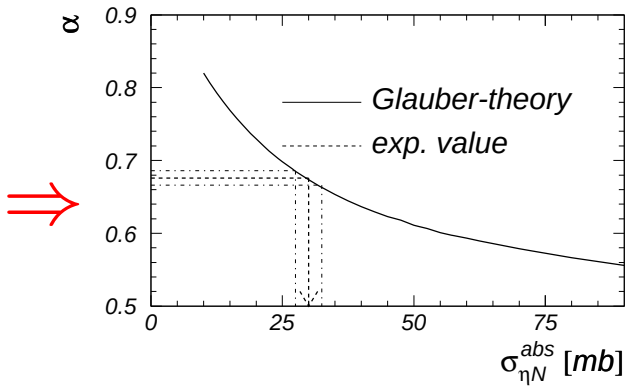
E_γ=1550 - 2200 MeV

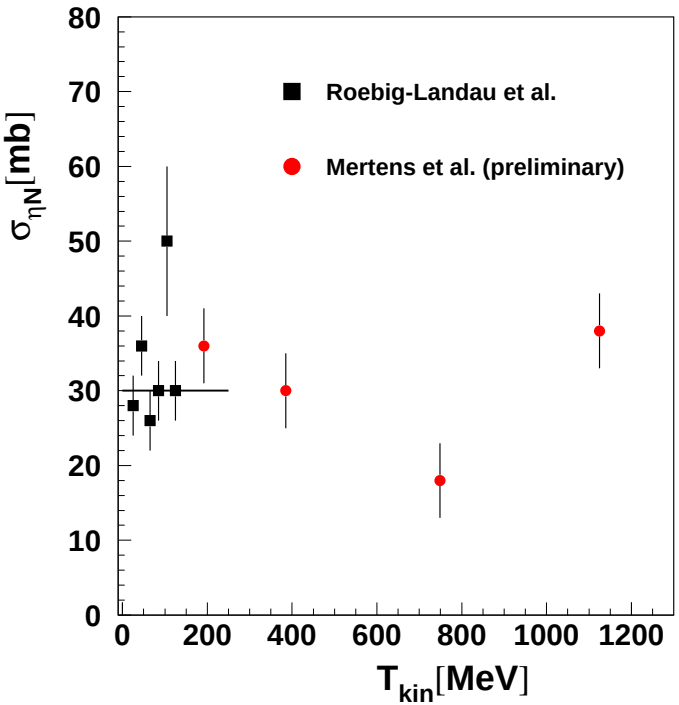


absortpion cross section for η mesons from nucleons

- mass dependence fitted with $\sigma(A) \propto A^{\alpha}$
  $\Rightarrow \alpha \simeq 2/3$
  $\Rightarrow$ strong absorption
- connection between α and $\sigma_{\eta N}$ via Glauber model
- absorption cross section $\sigma_{\eta N}$

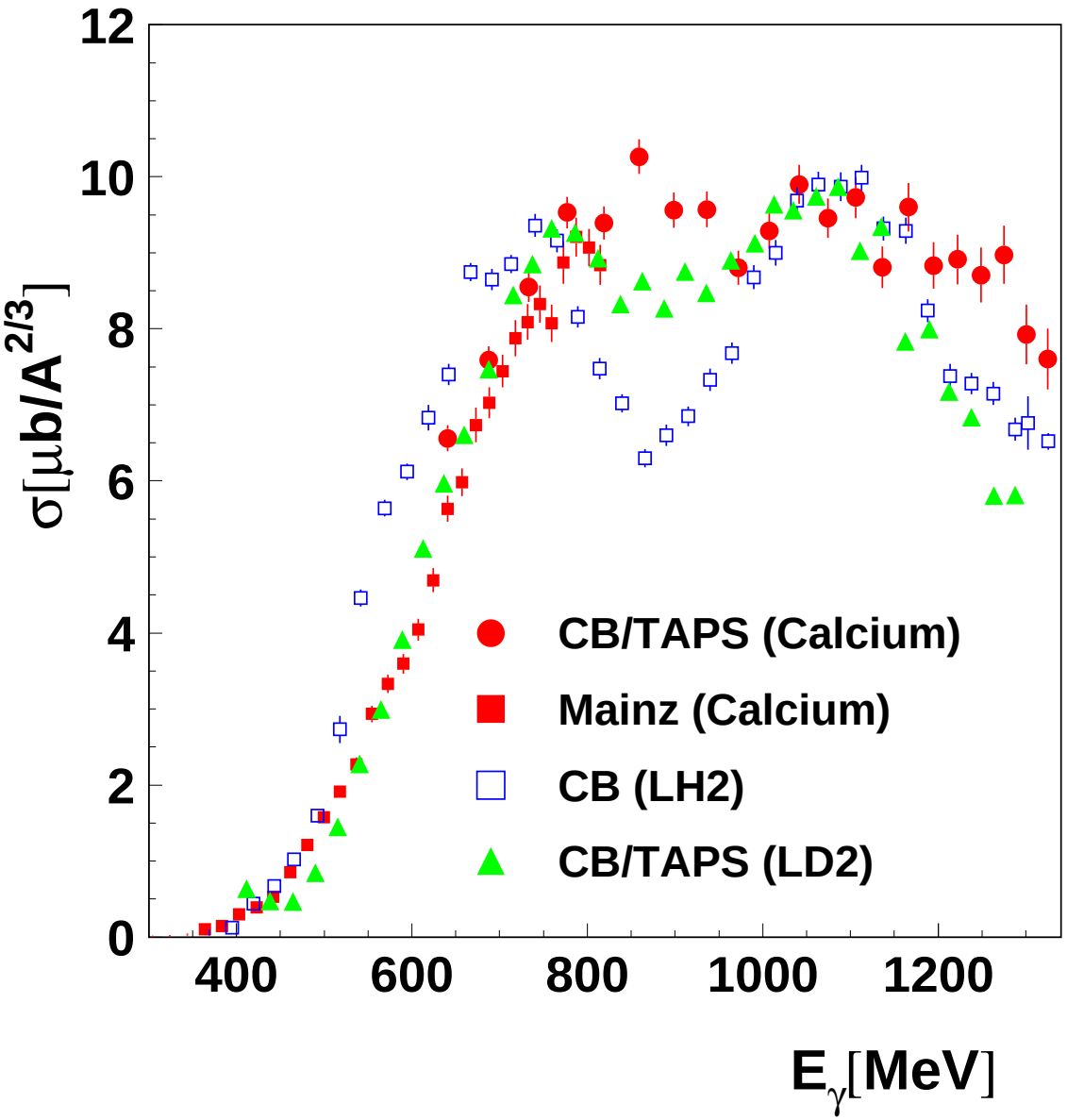




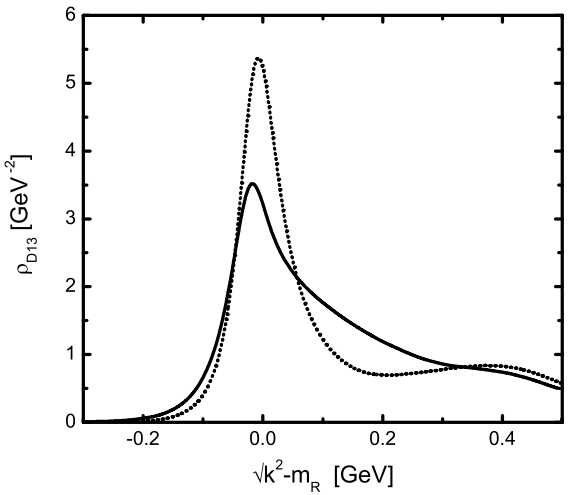


- $\sigma_{\eta N}(T_\eta) \simeq$ 30mb almost constant up to T_η = 1 GeV $\Rightarrow$ mean free path $\lambda \simeq 2fm$

double π^0 photoproduction from nucleons and nuclei



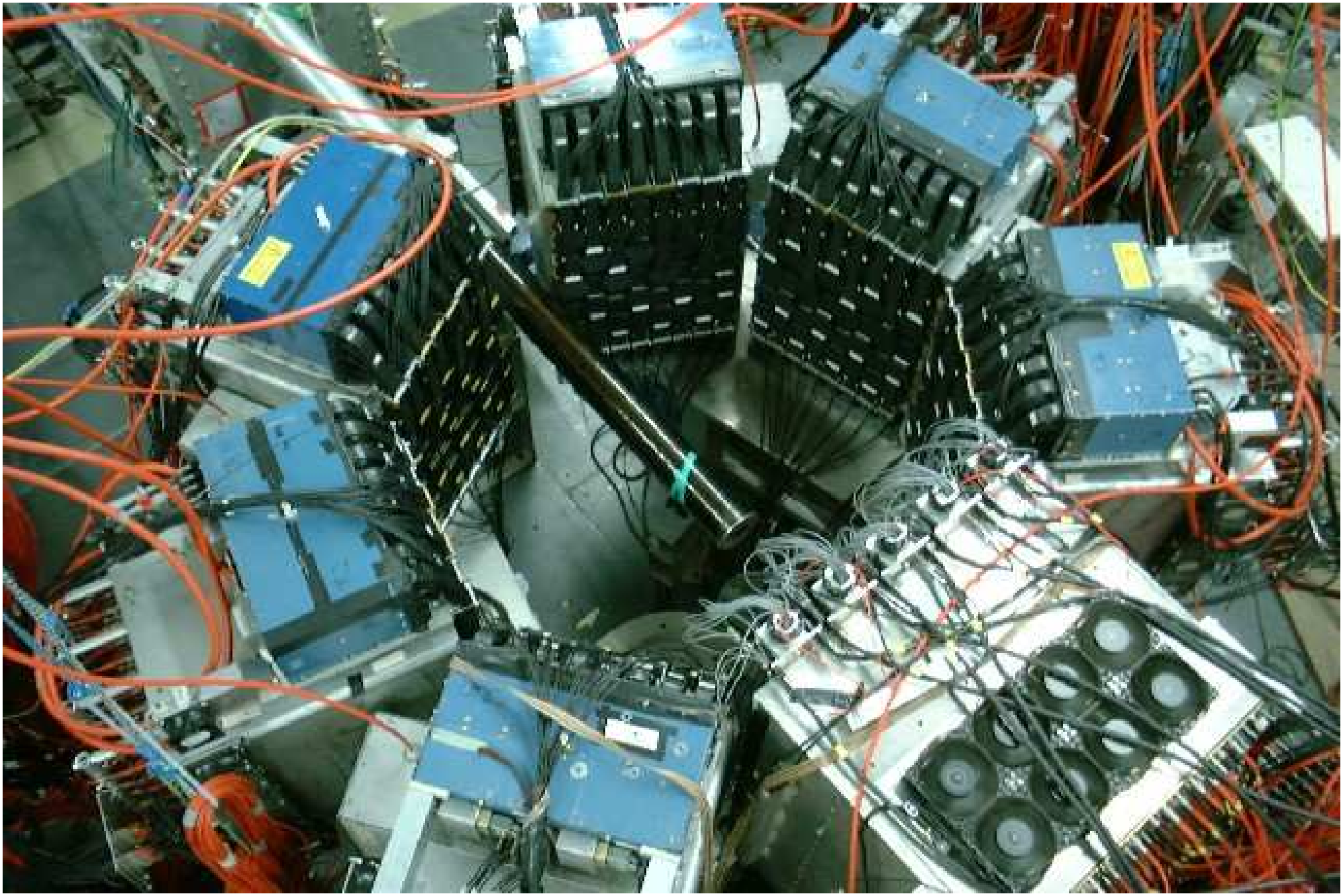
- 'bump'-structure already signifi cantly reduced for deuteron (not only Fermi smearing, also different n,p cross sections)
- much stronger effect for nuclei, needs detailed analysis via comparison to model calculations. Compare to predicted in-medium spectral function of $D_{13}(1520)$.



summary

- results for the photoproduction of ω mesons from nuclei show first evidence for an in-medium modification of the spectral function of the ω (CBarrel/TAPS@ELSA)
- pion and photon induced reactions show some evidence for in-medium modifications of scalar - isoscalar pion pairs ('σ'-meson)
- results for in-medium spectral functions of nucleon resonances consistent with preditions:
  - no significant effect on S_{11} resonance
  - possibly some suppression of D_{13} resonance (still under analysis)

- Many thanks to the PhD students who did the hard work:
  R. Gregor, S. Janssen, S. Lugert, D. Trnka, (Giessen);
  F. Bloch, I. Jaegle, T. Mertens (Basel)

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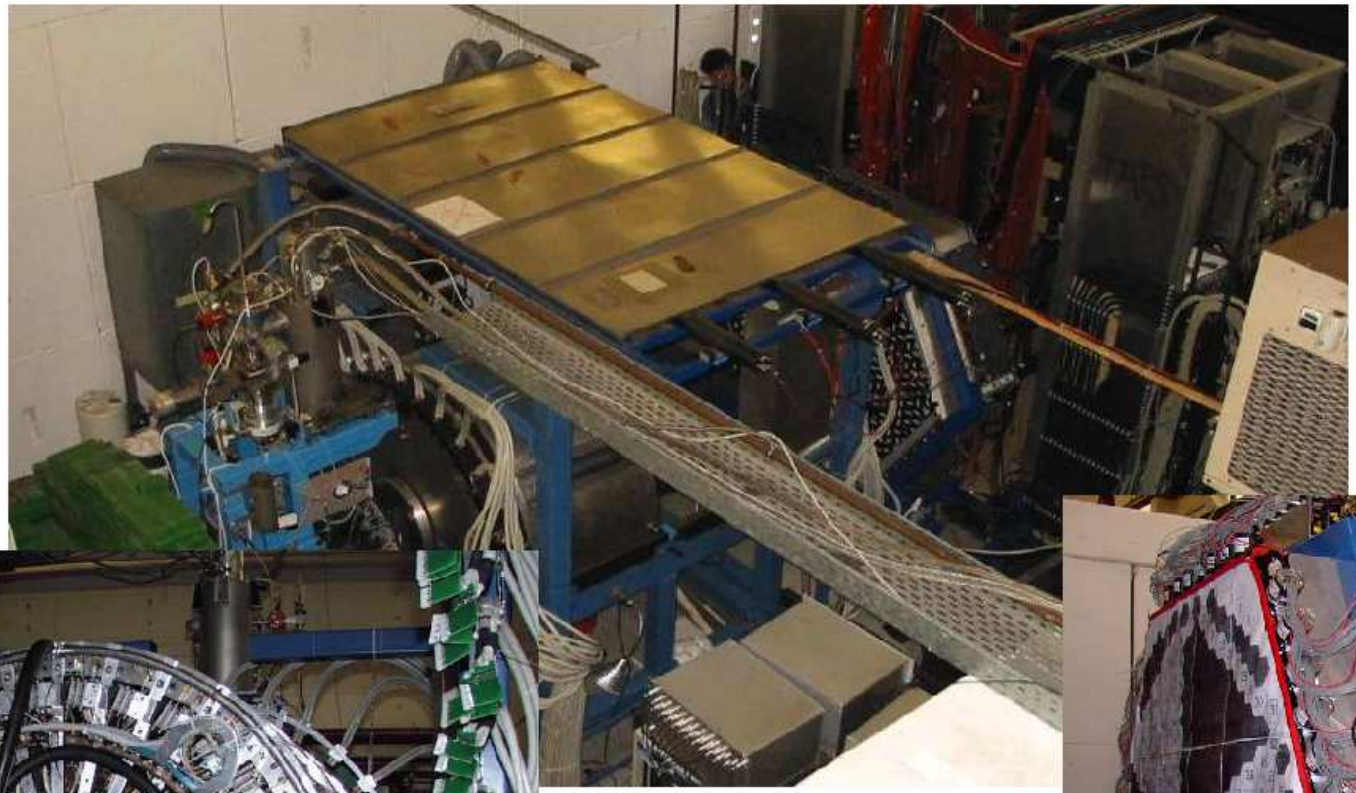
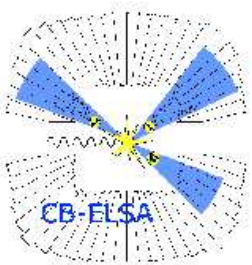
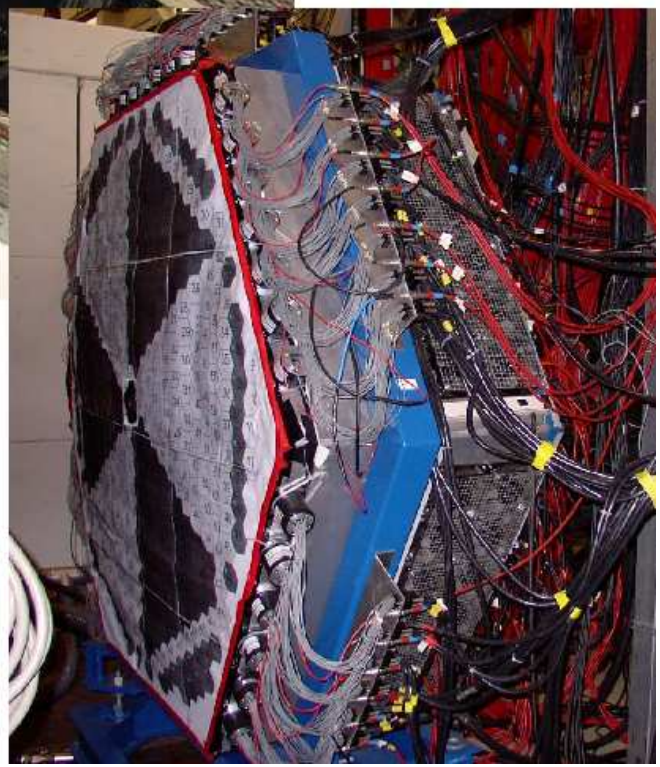
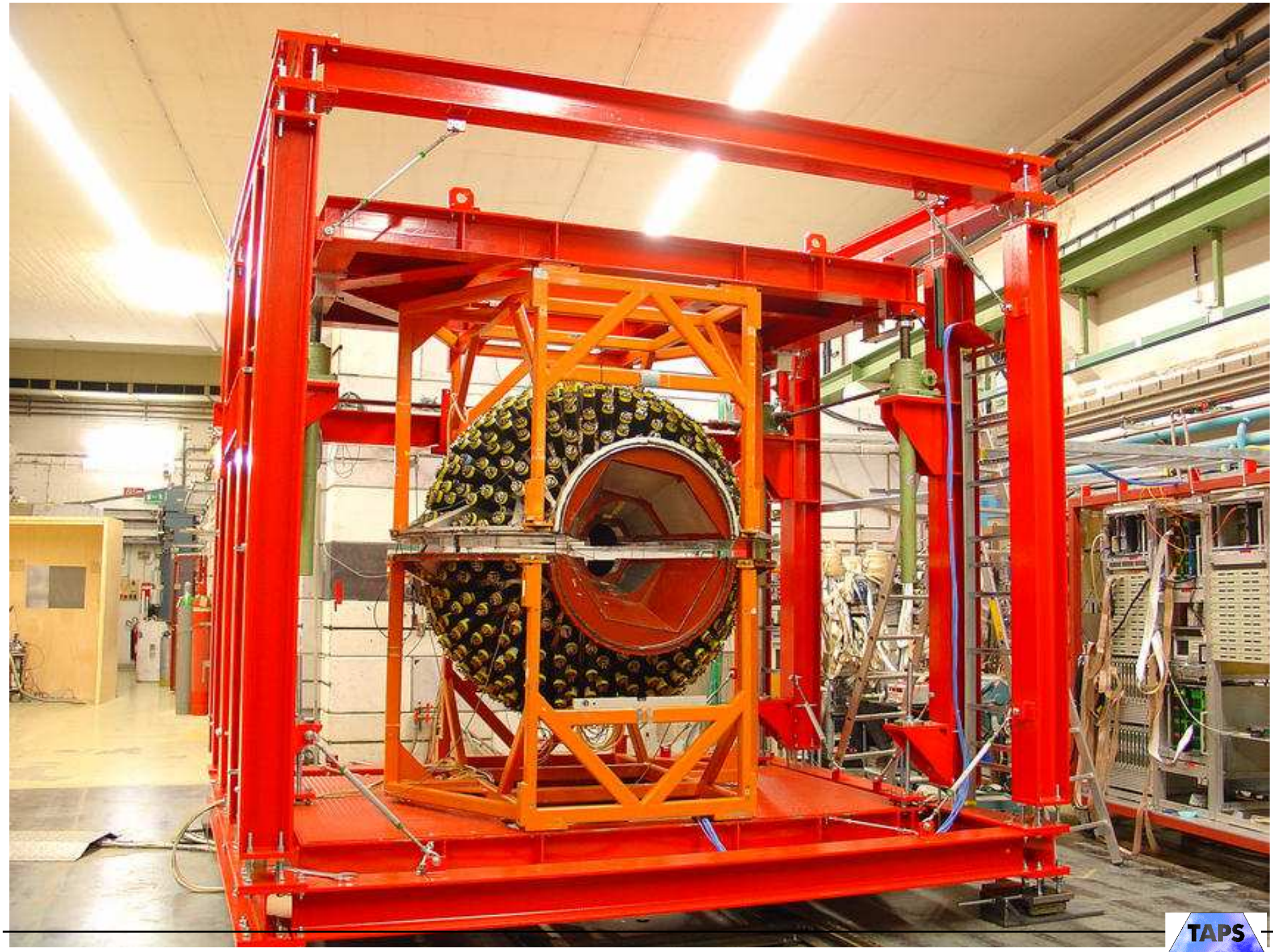
untere Seite - oben

TAPS and the Crystal Barrel

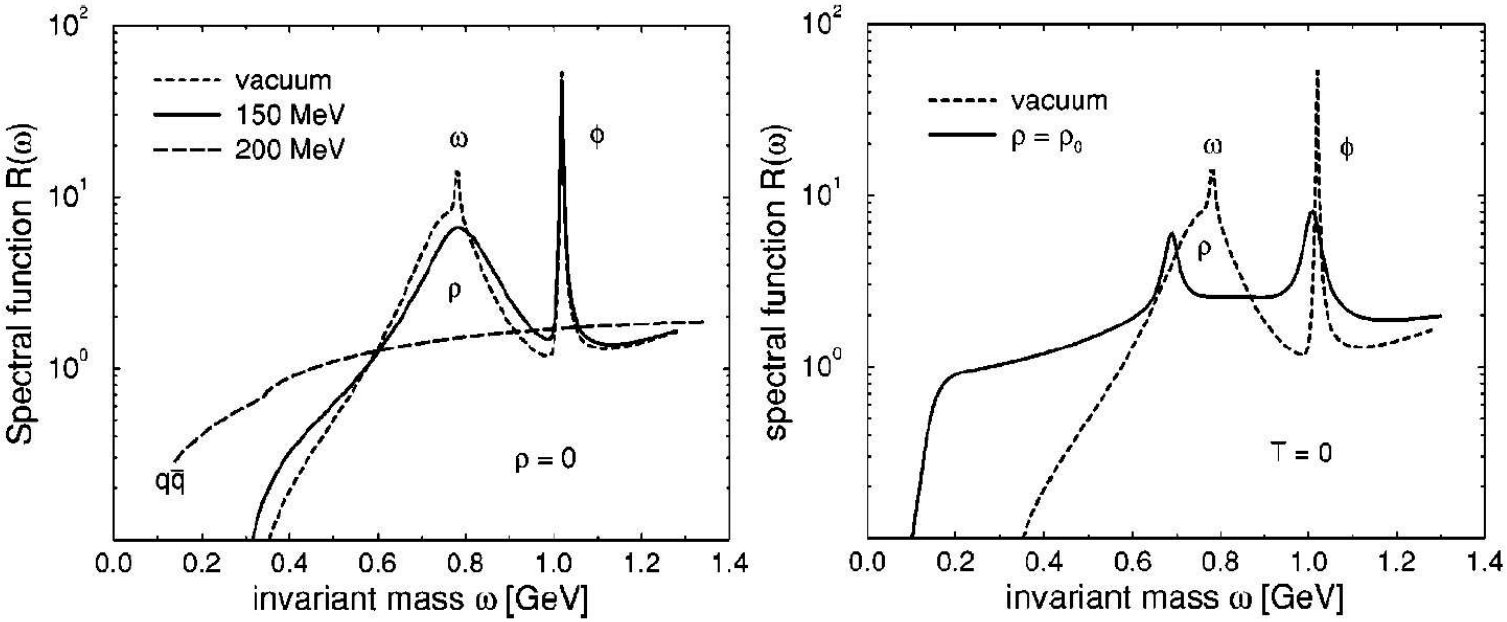








Predictions for in-medium mass changes of vector mesons
- just one example -



T. Renk, R. Schneider, W. Weise, Phys. Rev. C66 (2002) 014902

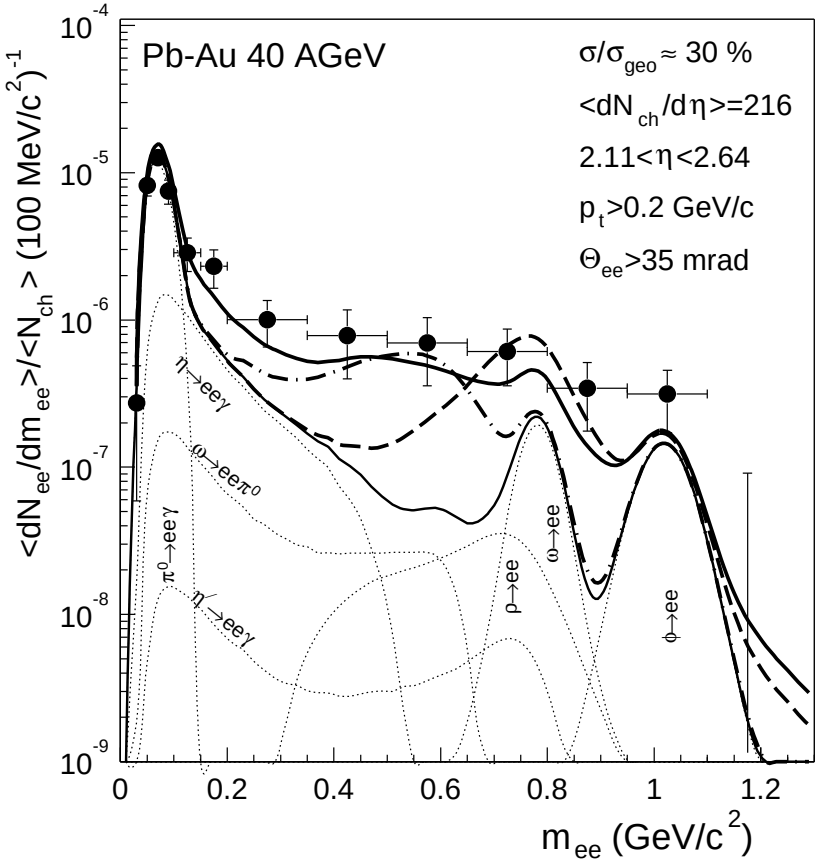
- experimental approach: dilepton spectroscopy: $\rho, \omega, \Phi \rightarrow e^+e^-$
- reconstruction of invariant mass from 4-momenta of decay products:

$$m_\omega = \sqrt{(p_1 + p_2)^2}$$

- advantage: no final state interaction

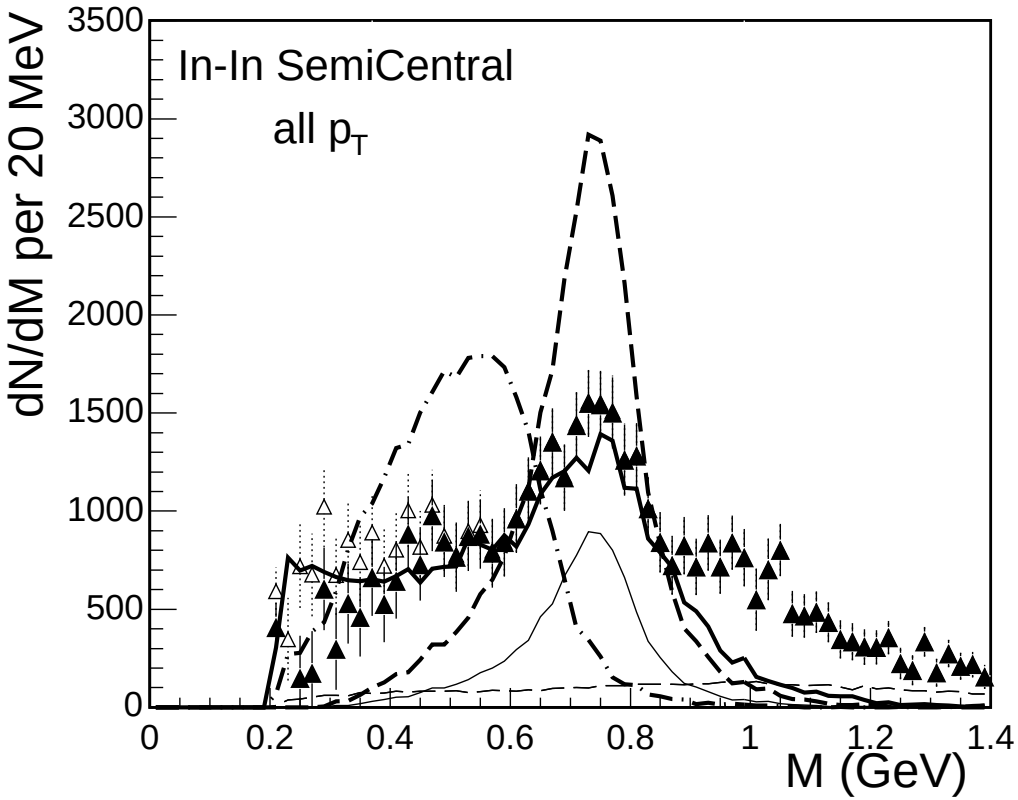
some evidence for in-medium modifications of vector mesons

- e^+e^- spectra from CERES: enhancement of di-leptons around $m_{e^+e^-}$=0.2 -0.6 GeV



D. Adamova et al., PRL 91 (2003) 042301

- $\mu^+\mu^-$ spectra from NA60: broadening but no shift of mass of ρ

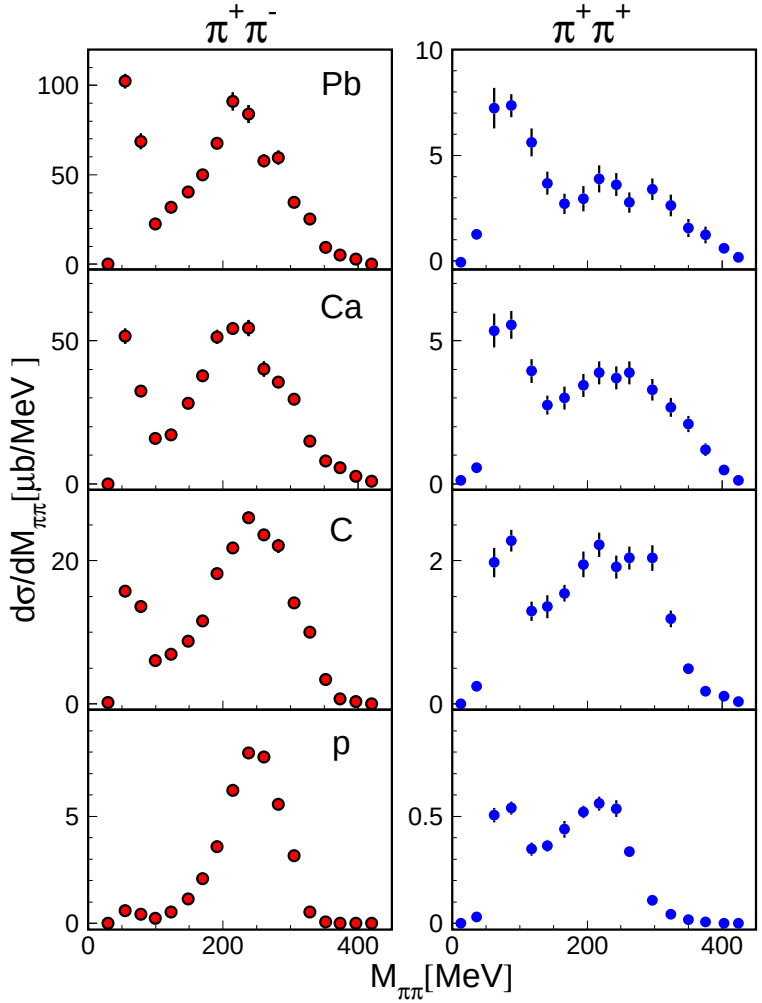


S. Damjanovic et al., nucl-ex/0510044

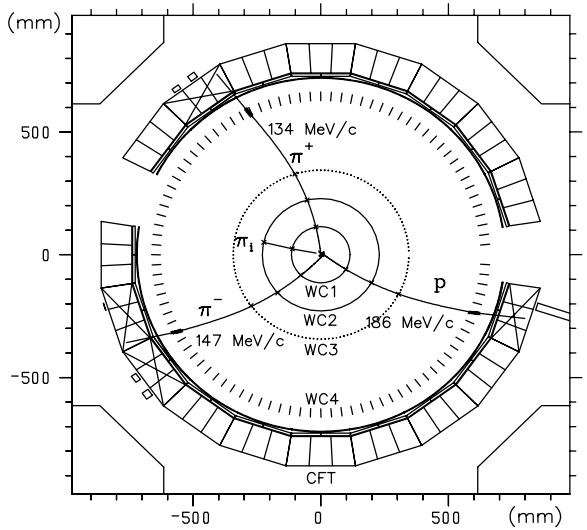
first experimental 'evidence': $\pi A \rightarrow A'\pi\pi$ studied at CHAOS

- invariant mass distributions for $\pi^+\pi^-$ and $\pi^+\pi^+$ final states:

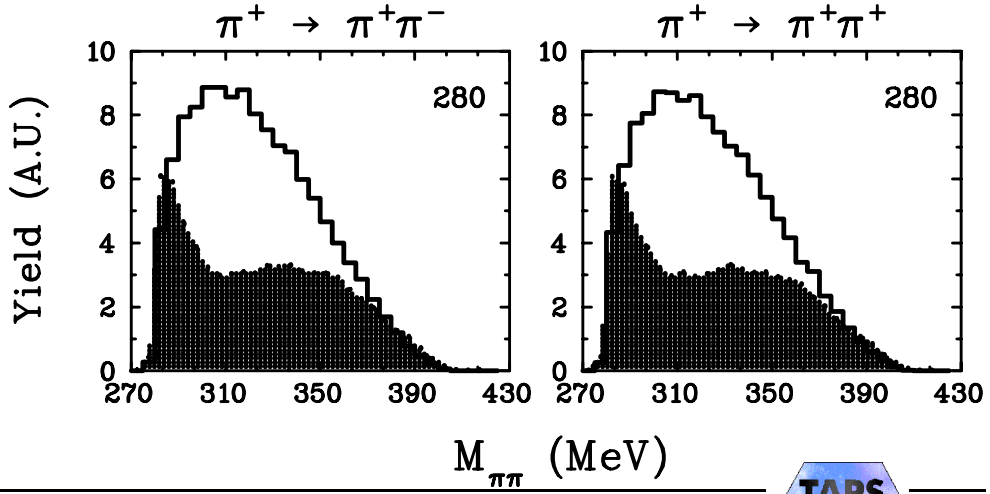
(Bonutti et al.)



- The CHAOS setup

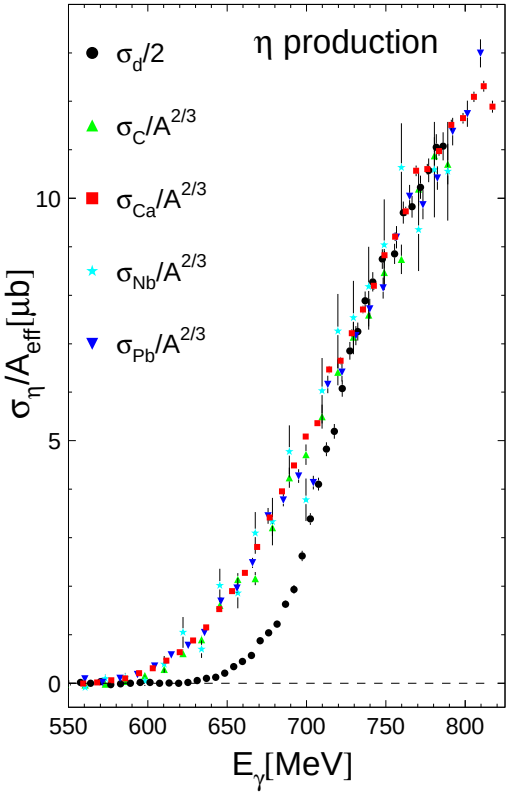


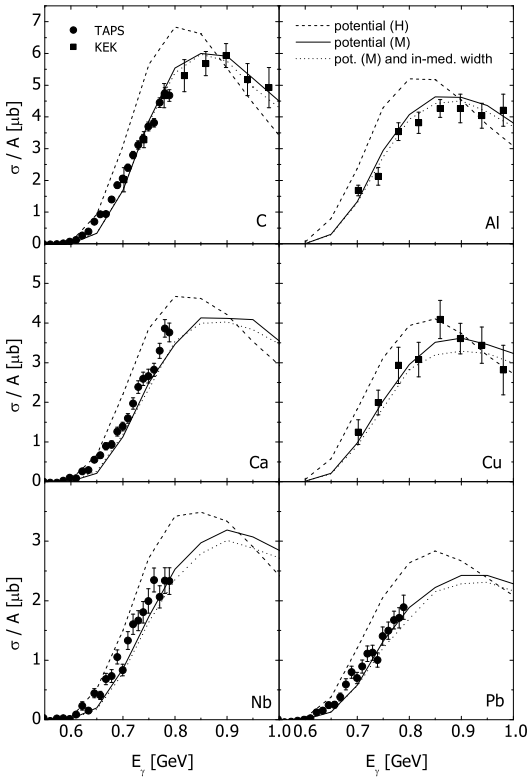
- phase space seen with CHAOS



η and single π^o production: S_{11} and D_{13} resonances

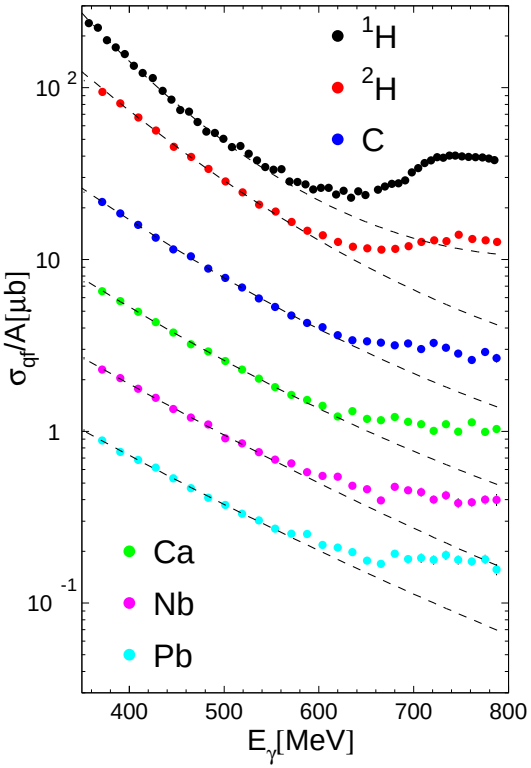
- η production

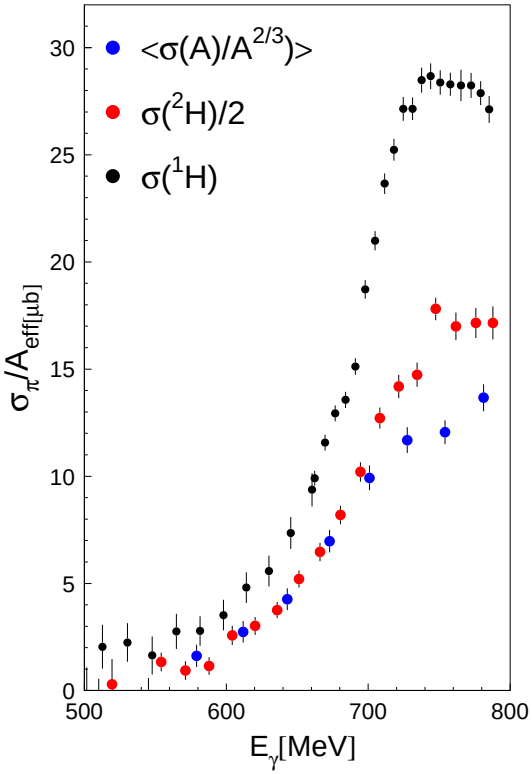




- perfect scaling with $A^{2/3}$,
  comparison to BUU calculation (Lehr et al.)
  no significant broadening, additional
  width of $\approx$ 30 MeV consistent with data

- π^o production



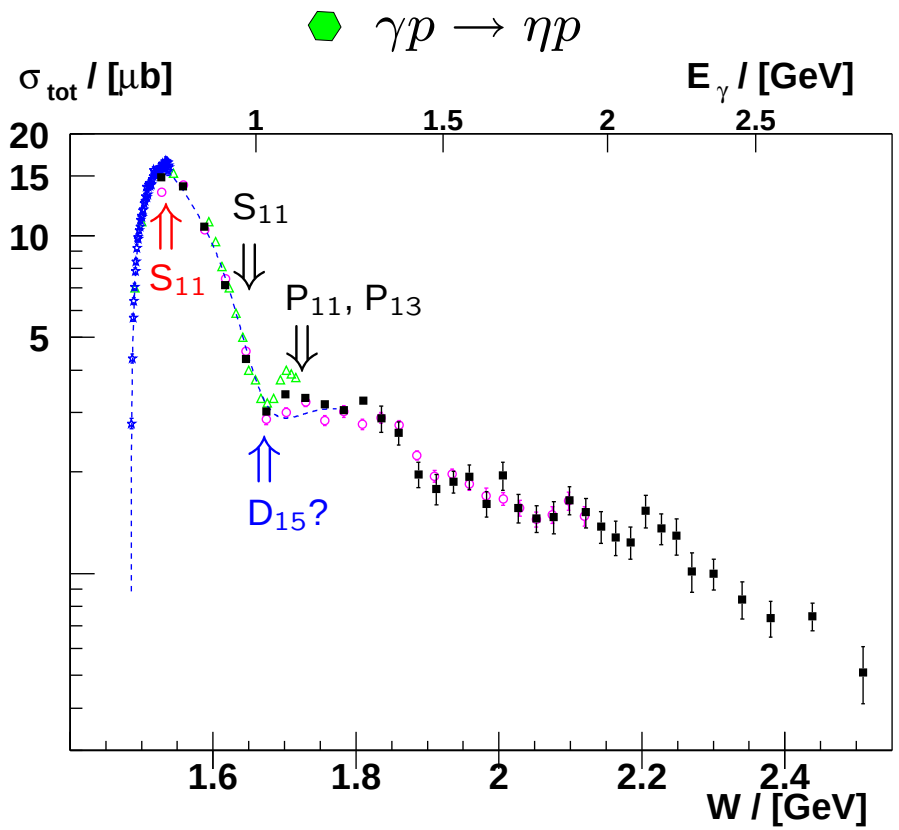


- suppression of the D_{13} peak
  (but already for d!)
  shape for nuclei could be consistent
  with predicted spectral function

resonances coupling to η photoproduction

branching ratios and elm. couplings (PDG):

state	b_η [%]	$A^p_{1/2}$	$A^p_{3/2}$	$A^n_{1/2}$	$A^n_{3/2}$
• $D_{13}(1520)$:	0.23±0.04	-24	166	59	139
• $S_{11}(1535)$:	30 - 55	90		-46	
• $S_{11}(1650)$:	3 - 10	53		-15	
• $D_{15}(1675)$:	0 ± 1	19	15	-43	-58
• $F_{15}(1680)$:	0 ± 1	-15	133	29	-33
• $D_{13}(1700)$:	0 ± 1				
• $P_{11}(1710)$:	6.2±1.0				
• $P_{13}(1720)$:	4±1				



- $D_{15}(1675)$ has stronger electromagnetic coupling to the neutron than to the proton
- $D_{15}(1675)$ parameters quite uncertain:

  $A^p_{1/2}$=6 - 34, $A^p_{3/2}$=3-30, $A^n_{1/2}$=-(21-57), $A^n_{3/2}$=-(30-77)

  b_η=0 − 1% (PDG)

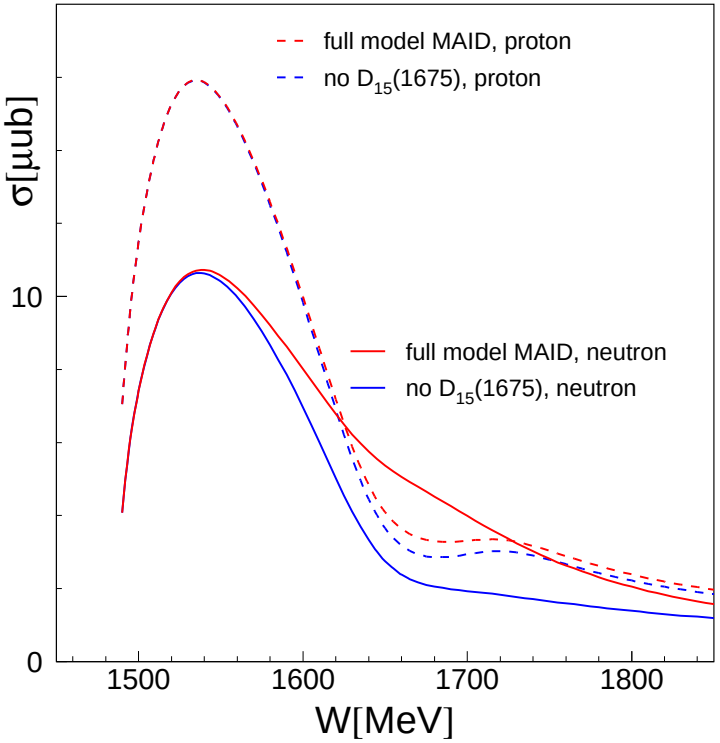
  b_η=17% (ETA-MAID, Chiang et al.)

Data:

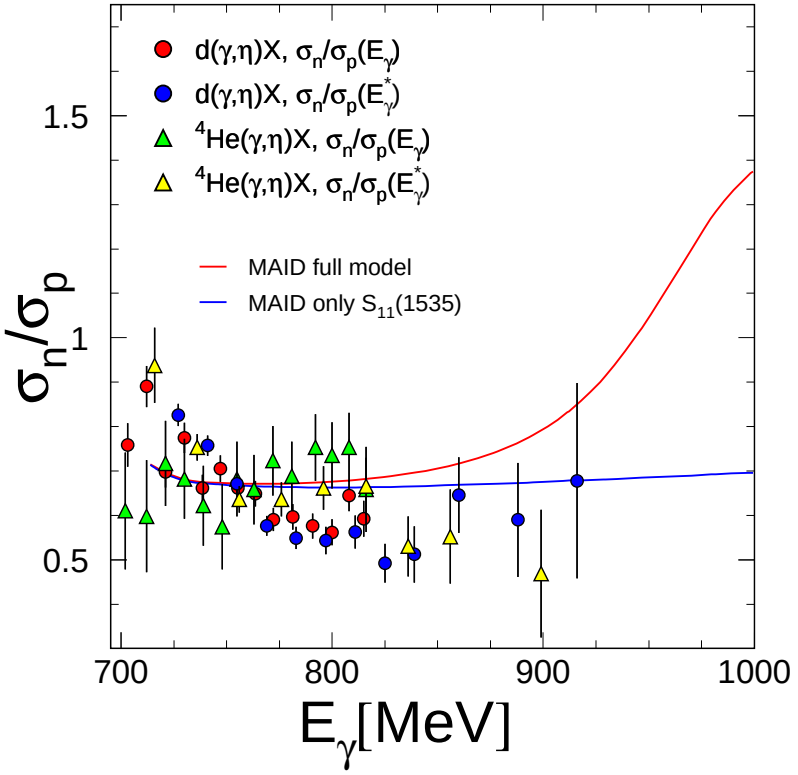
- TAPS: B. Krusche et al., PRL74 (195) 3736
- GRAAL: F. Renard et al., PLB528 (2002) 215
- CLAS: M. Dugger et al., PRL89 (2002) 222002
- Crystal Barrel: V. Crede et al., PRL94 (2005) 012004

what is expected for $n(\gamma,\eta)n$ - why is it interesting?

- total cross sections for proton and neutron from MAID model with and without $D_{15}(1675)$
  (Eta-MAID, W.T. Chiang et al., NPA 700 (2002) 429)



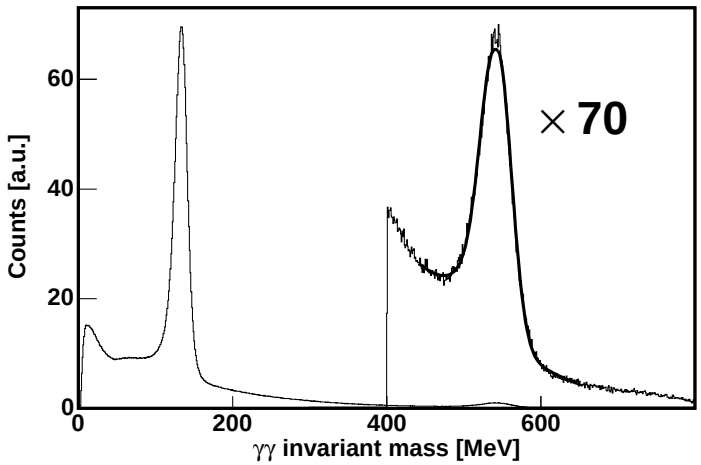
- previous data from MAMI only at lower incident photon energies



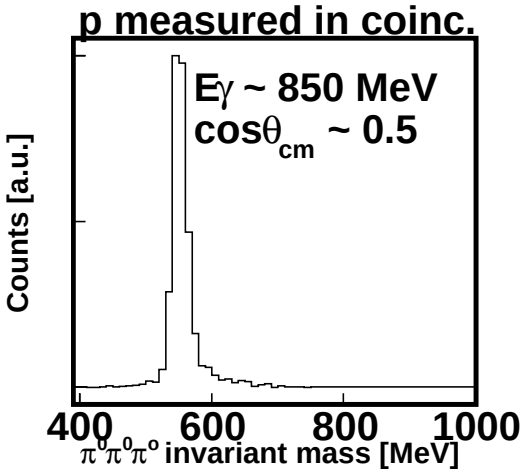
- predictions from chiral soliton models: P_{11}-like state of the anti-decuplet has strong photon-coupling to the neutron and large ηN decay branching ratio

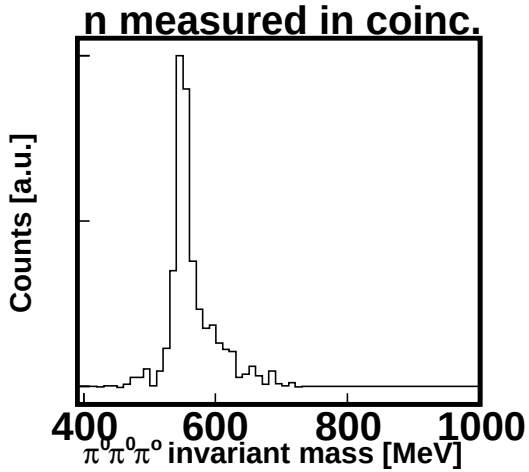
Identification of η-mesons

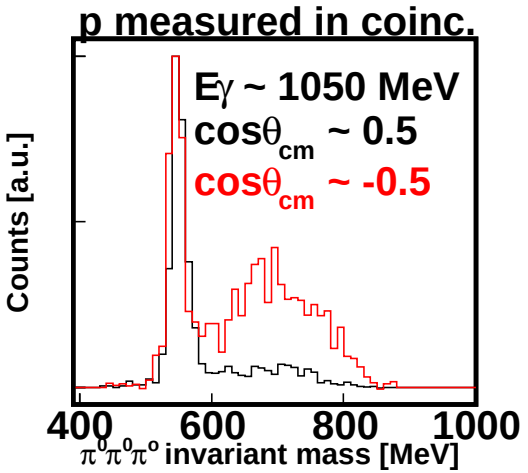
- decay channel: $\eta \rightarrow 3\pi^o \rightarrow 6\gamma$
- select events with 7 hits
- invariant mass off all photon pairs

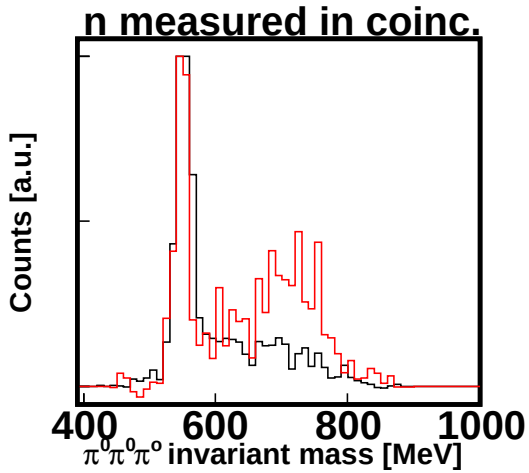


- cut on π^o invariant mass
- select best combination of 6γ to $3\pi^o$ by χ^2-test
- use π^o mass as constraint, construct $3\pi^o$ invariant mass







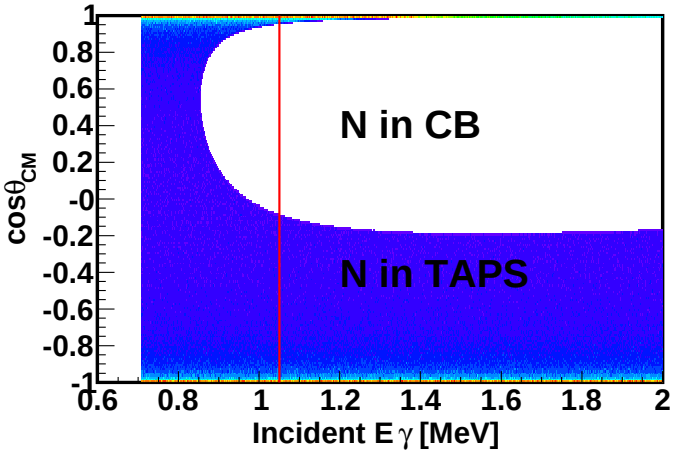


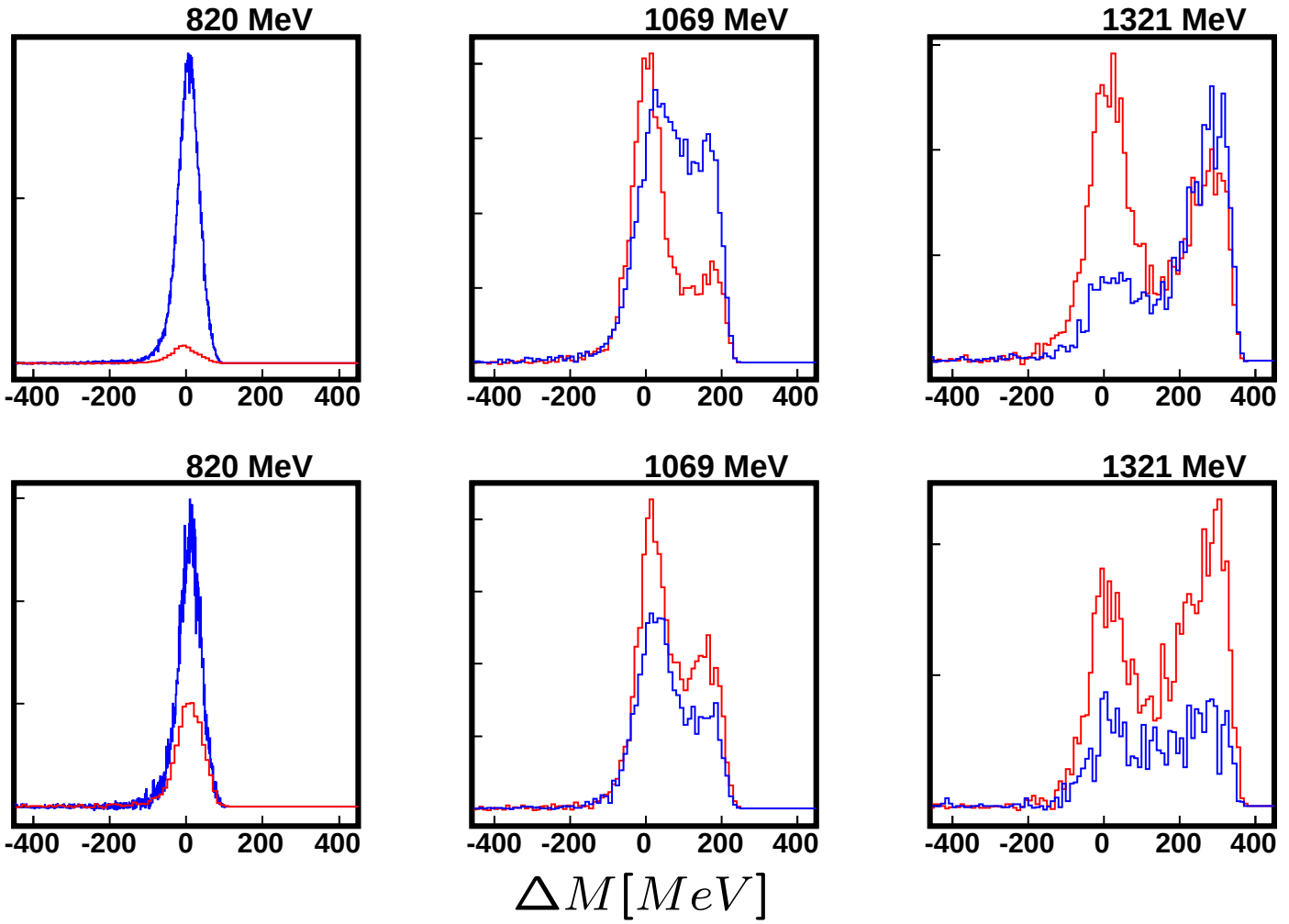
Identification of single η photoproduction - missing mass

- mass of recoil nucleon treated as missing particle: $m_N^2 = (\mathbf{P}_\gamma - \mathbf{P}_\eta)^2$

proton in CB

proton in TAPS



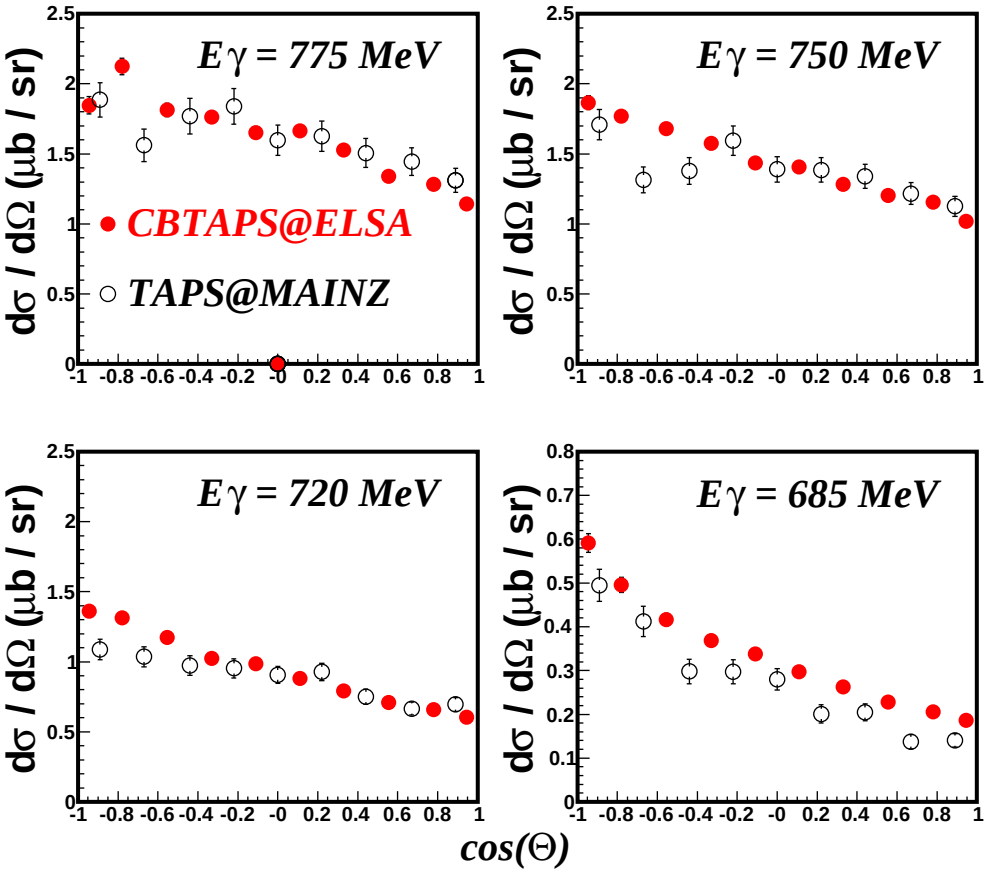


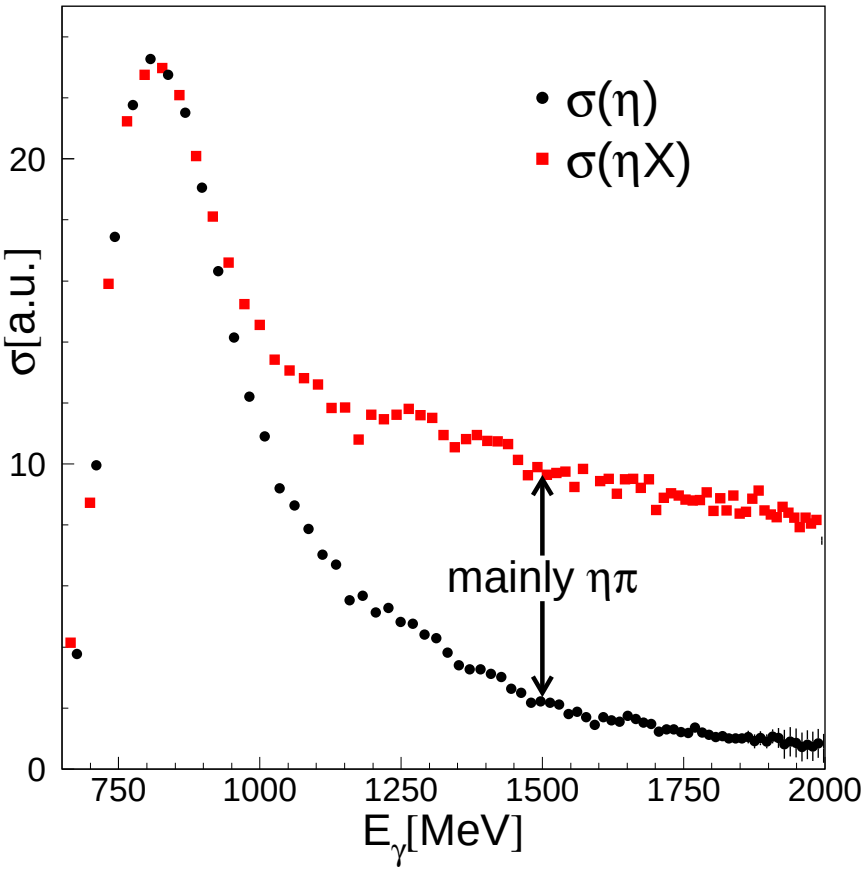
neutron in CB

neutron in TAPS

A check: inclusive η-photoproduction from deuterium

- comparison: inclusive data at low energy
- total cross sections: η and ηX





- good agreement with previous low energy data
  background from $\eta\pi$ final states removed with cuts on reaction kinematics

Nucleon Identification CB

inner detector:

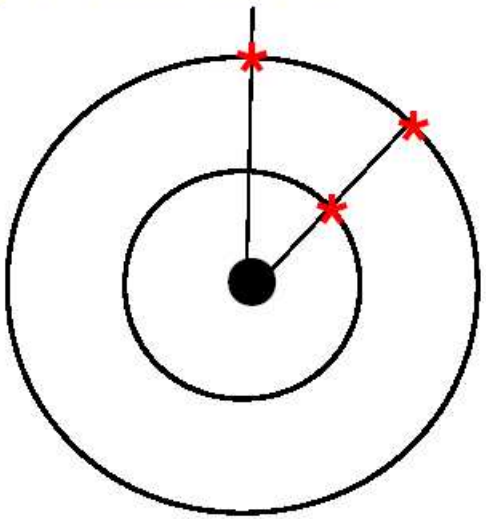
- 3 layers of scintillating fibers

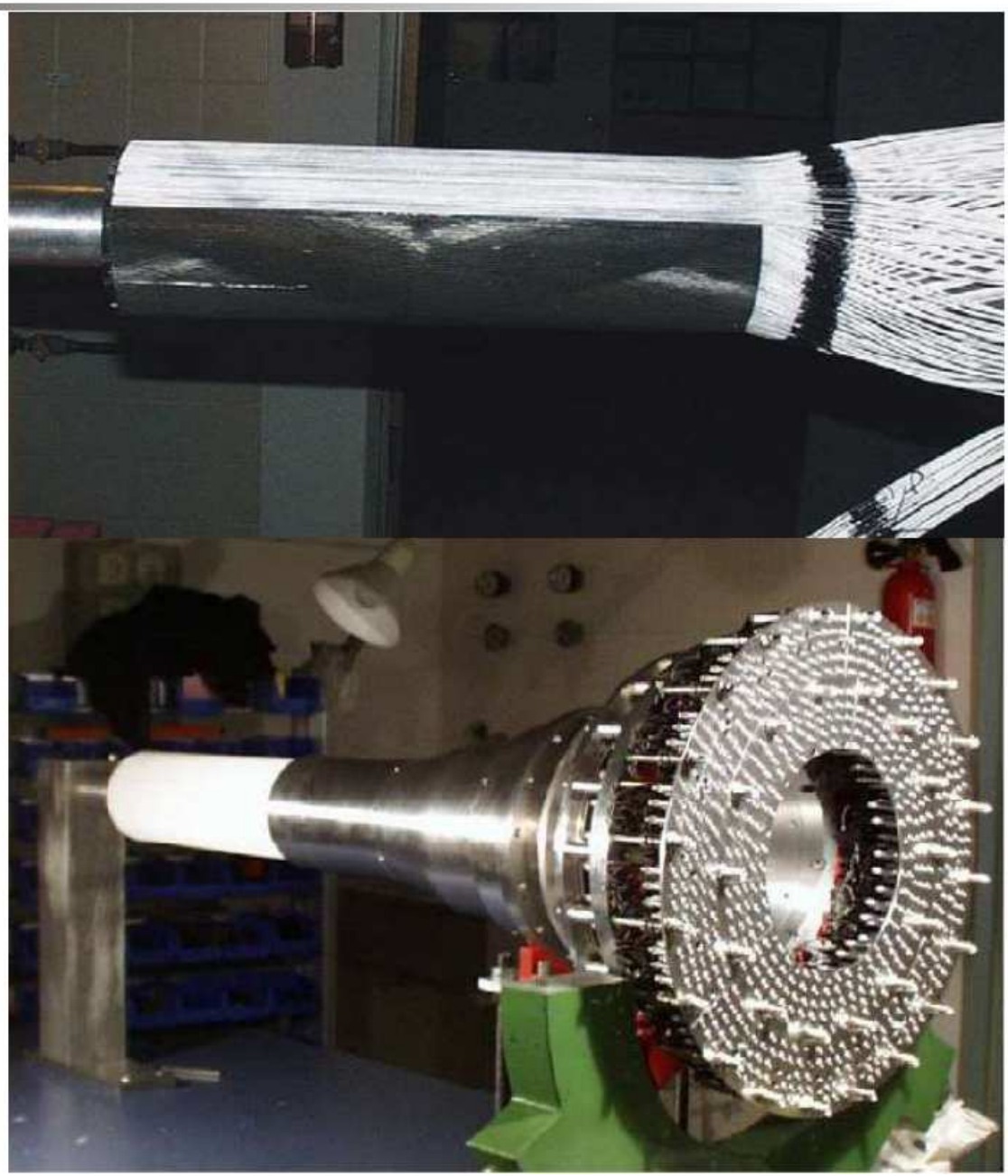
- cylindrical shape

- proton:
2 or 3 layers match a hit in the CB

-neutron:

no layer has fired





Nucleon Identification TAPS

taps veto detector:

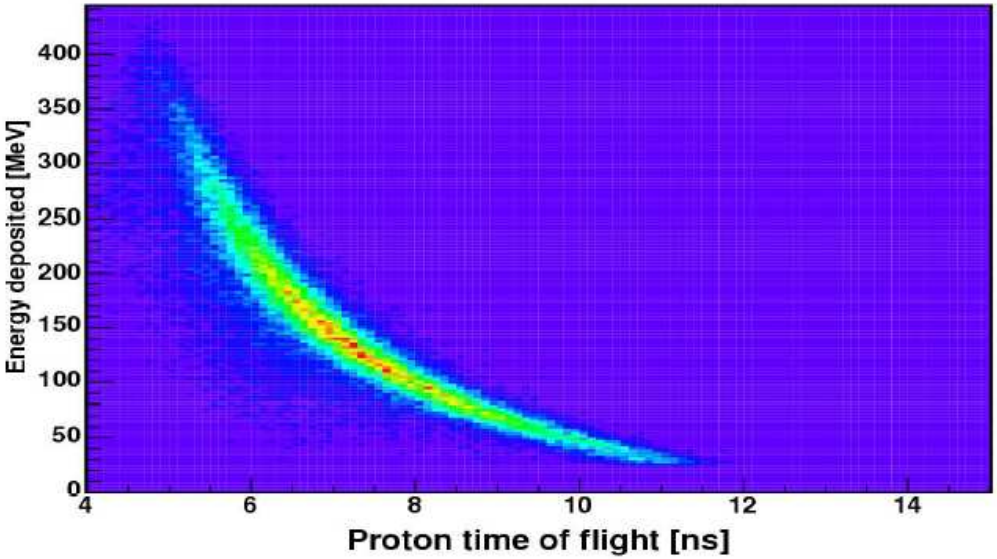
- 5 mm plastic scintillator

- individual for each BaF_2 crystal

- proton:

veto hit in front of BaF_2 crystal

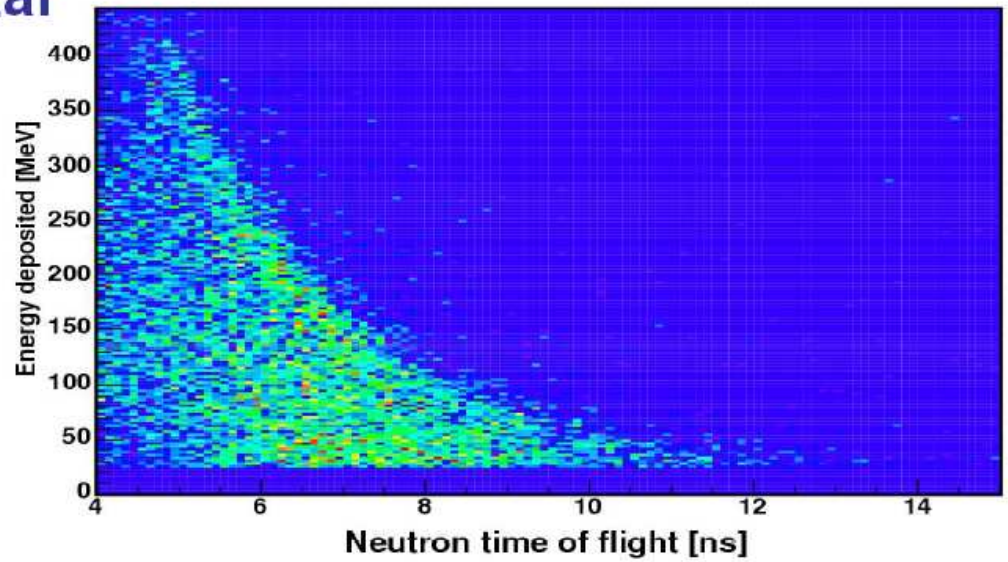
+ E vs TOF

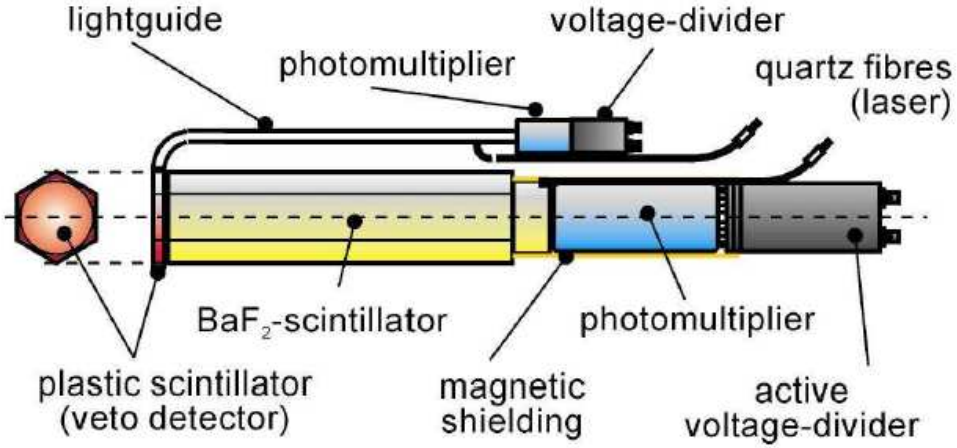


- neutron:

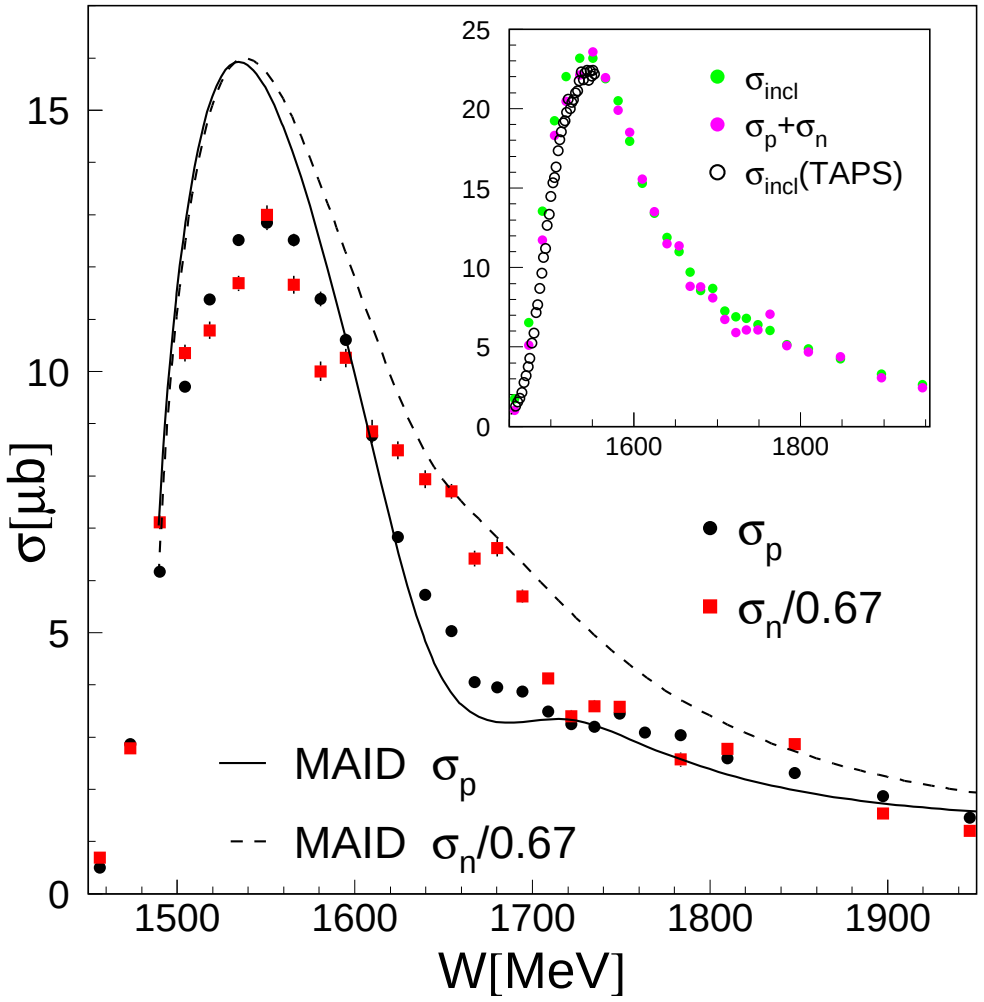
no veto hit in front of BaF_2 crystal

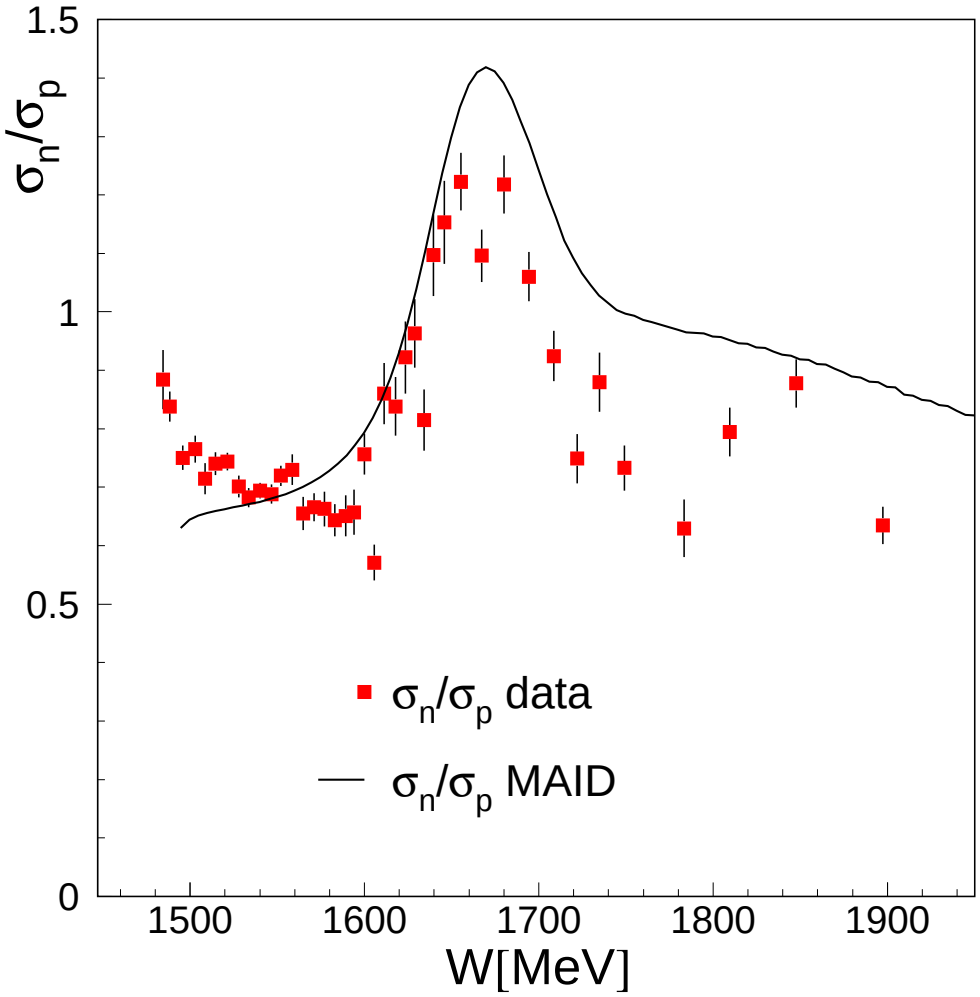
+ E vs TOF





quasifree exclusive $\gamma N \rightarrow N\eta$ total cross sections

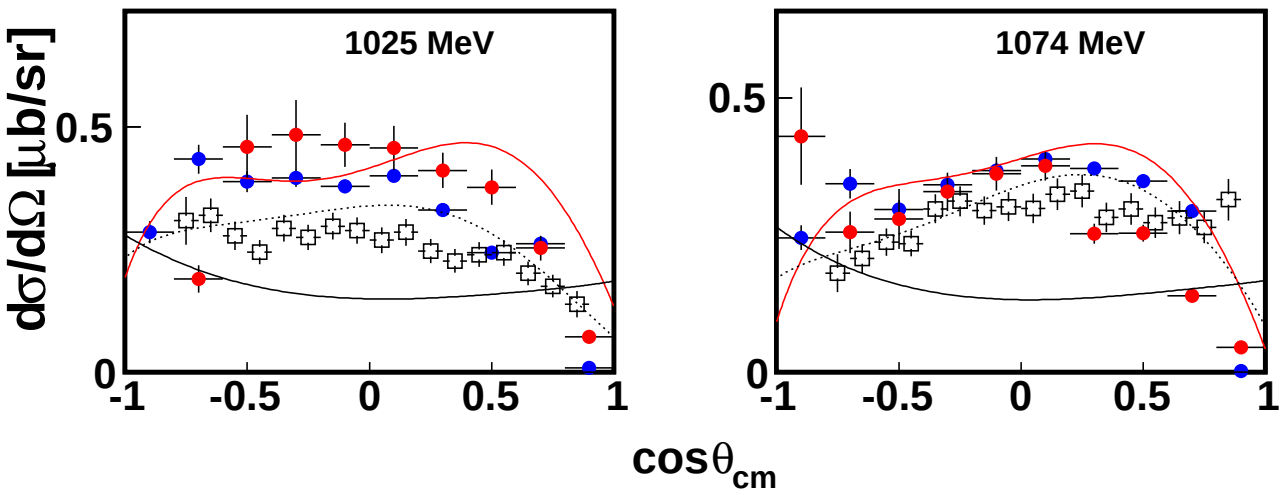




- clear signal for resonance which couples much stronger to neutron than to proton

quasifree $\gamma n \rightarrow n\eta$: angular distributions

- angular distributions around W=1670 MeV

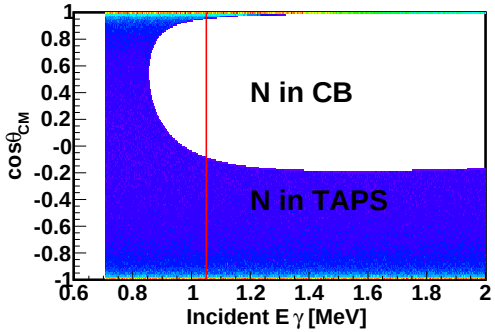


- $\gamma p \rightarrow p\eta$ (free from p)
- $\gamma p \rightarrow p\eta$ (quasifree from d)
- $\gamma n \rightarrow n\eta$ (quasifree from d)

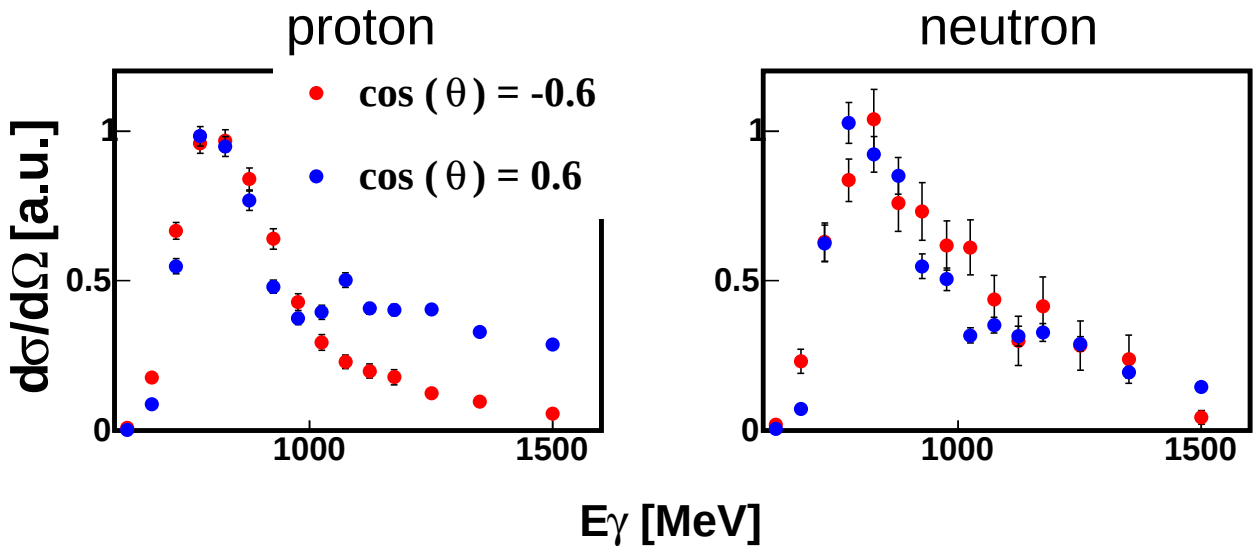
.... MAID proton

MAID neutron

MAID neutron w/o $D_{15}(1675)$



- excitation functions for forward and backward angles



- enhancement in neutron cross section around E_γ=1 GeV for forward and backward angles.
- proton cross section asymmetric due to interference between S_{11} and P-resonances.