In-medium properties of hadrons

- Introduction & Motivation
- Mesons in the medium
  - 'σ'-meson - pion pairs in the medium
  - ω-mesons in the medium
- Nucleon resonances in the medium
  - The $\Delta(1232)$ resonance
  - The second resonance region

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

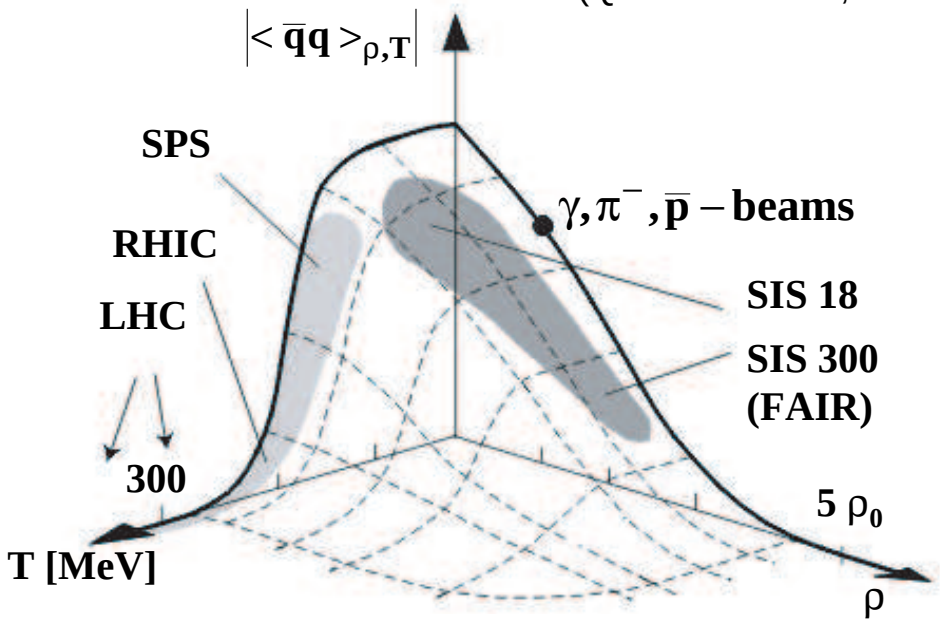
- effects on in-medium hadron properties
  - Brown-Rho scaling of masses:

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

    (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.)



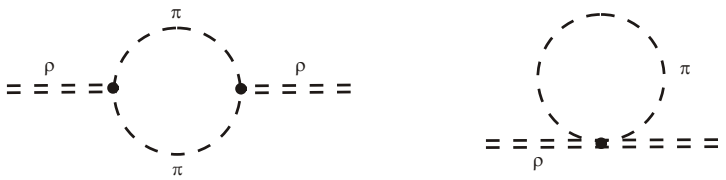
Coupling of mesons to resonance-hole states

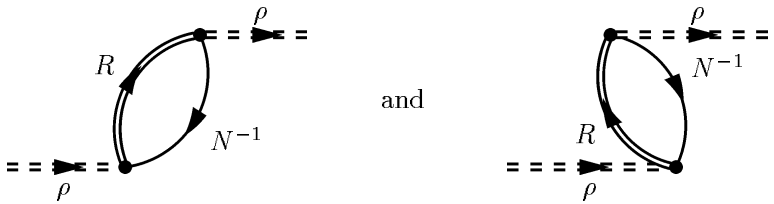
- well known example: coupling of pion to Δ-hole states $\rightarrow$ in-medium properties of Δ
- self-consistent calculation of meson and nucleon resonance spectral functions from coupling to resonance-hole states (Peters et al. NPA632((1998)109, Post et al., nucl-th/0309085)

meson and baryon self-energies from diagrams like:

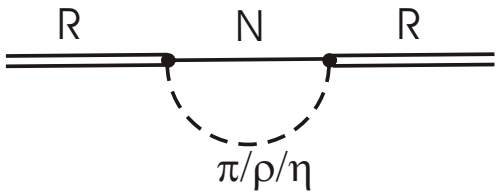
- in vaccum:
- in medium:

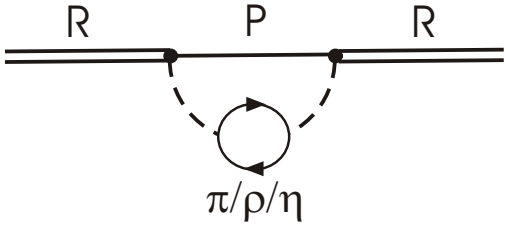
- mesons:





- baryons:

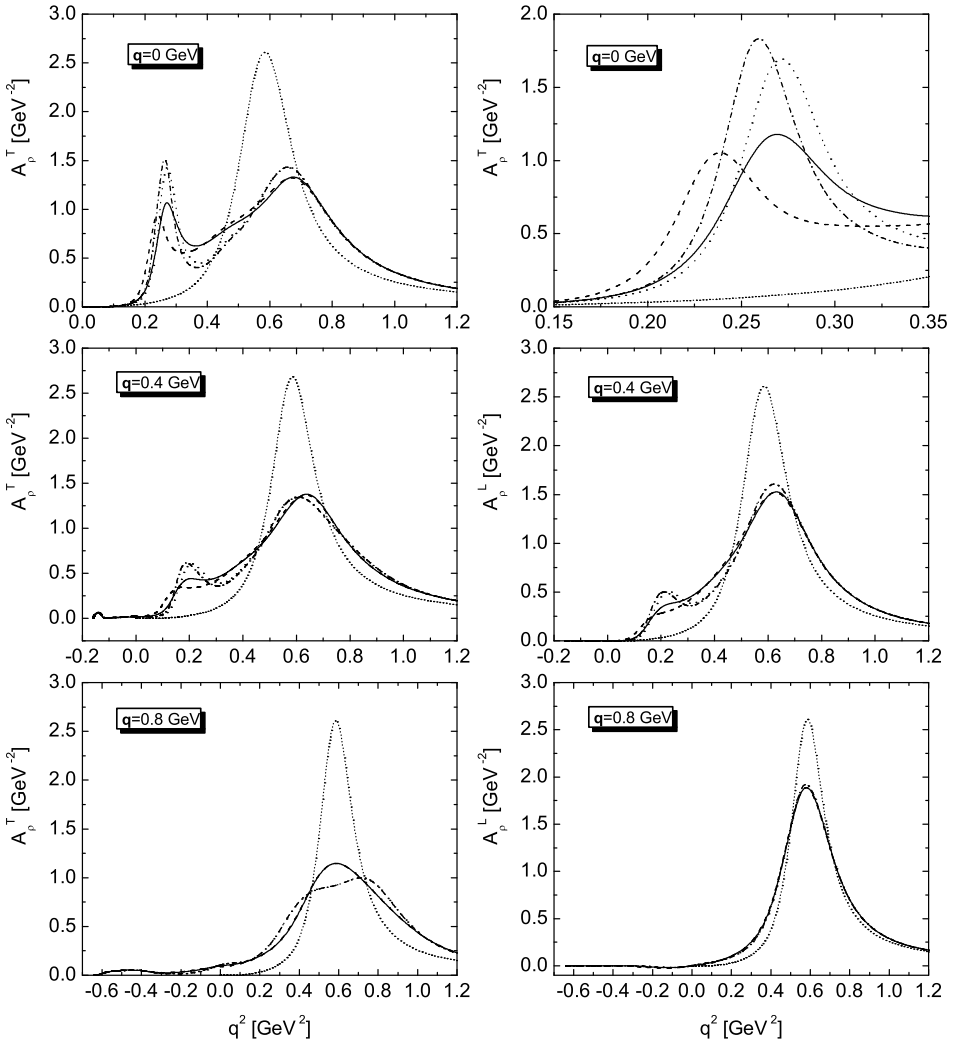




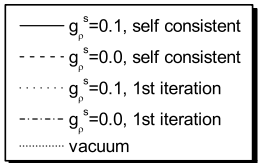
- In-medium spectral functions:
  - mesons: $\mathcal{A}_M^{med}(q) = -\frac{1}{\pi}\mathcal{I}m\frac{1}{q^2-m_M^2-\Pi_{vac}(q)-\Pi_M(q)}$
  - baryons: $\rho^{med}(k) = -\frac{1}{\pi}\mathcal{I}m\frac{1}{k^2-m_R^2-\Sigma_{med}(k)}$

in-medium spectral functions of the ρ-meson

- ρ spectral functions: (M. Post et al., nucl-th/0309085)



transverse

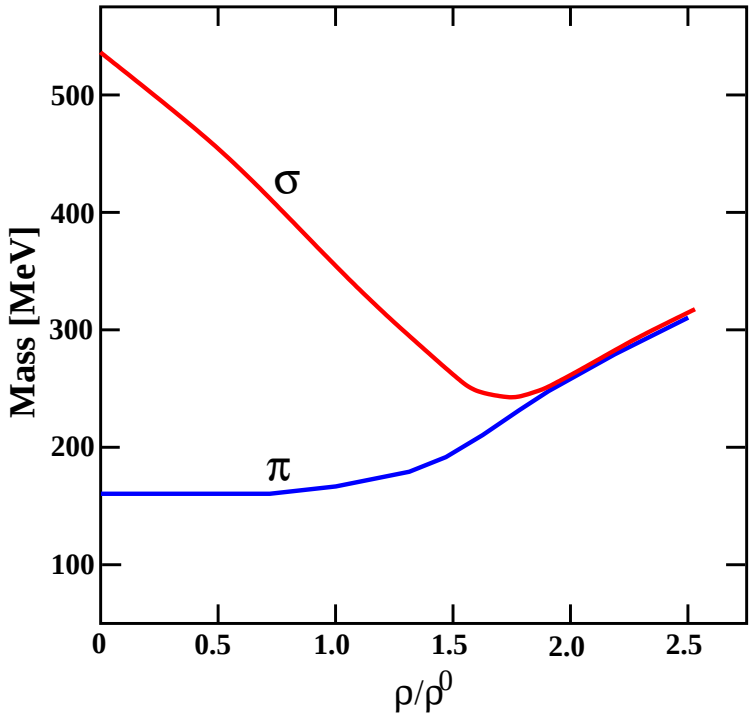


longitudinal

- at low momenta pronounced double-bump structure from s-wave coupling to the $D_{13}(1520)$ $(3/2^- \rightarrow 1/2^+ + 1^-)$
- around q=400 MeV: influence of D_{13} reduced, onset of broadening due to p-wave coupling of higher lying resonances ($F_{35}(1905)$, $P_{13}(1720)$)
- around q=800 MeV:
  broadening of transverse part due to p-wave coupling of higher lying resonanes, almost no broadening of longitudinal part (does not couple to p-waves, coupling to s-waves small at large q)

mesons in matter: the 'σ' and partial chiral symmetry restoration

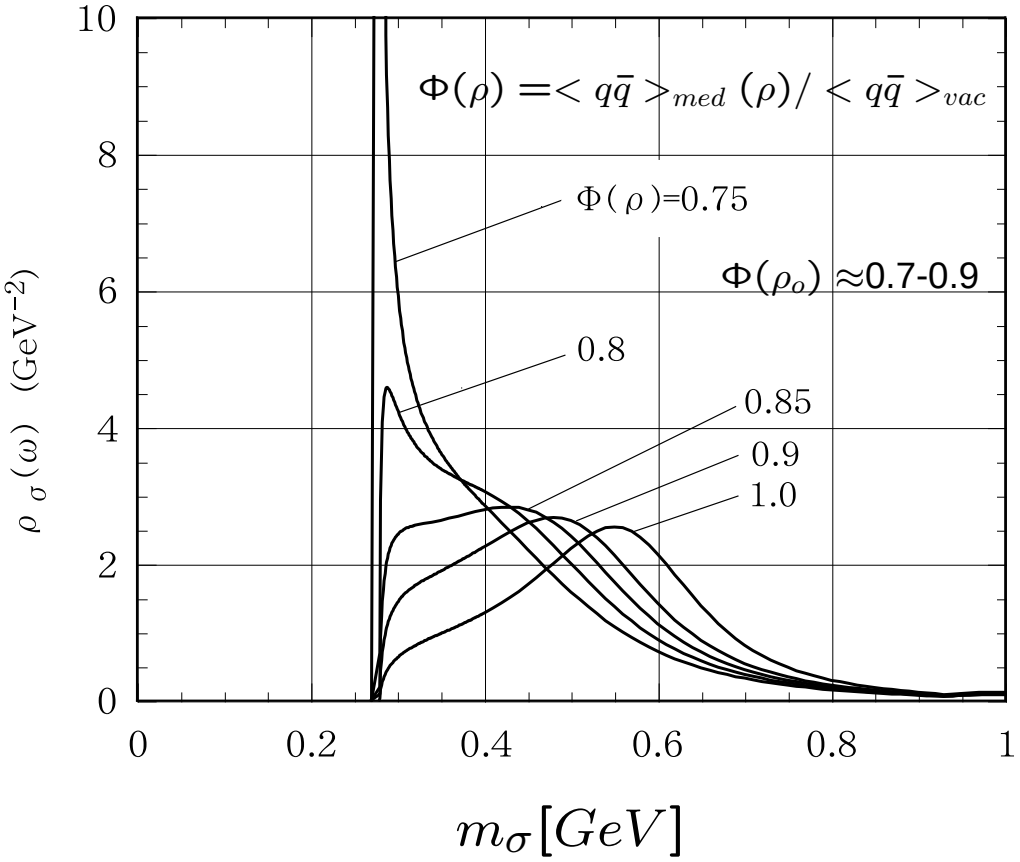
- predicted dependence of σ-mass on density (V.Bernard et al.):



- masses of chiral partners degenerate in chiral limit

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

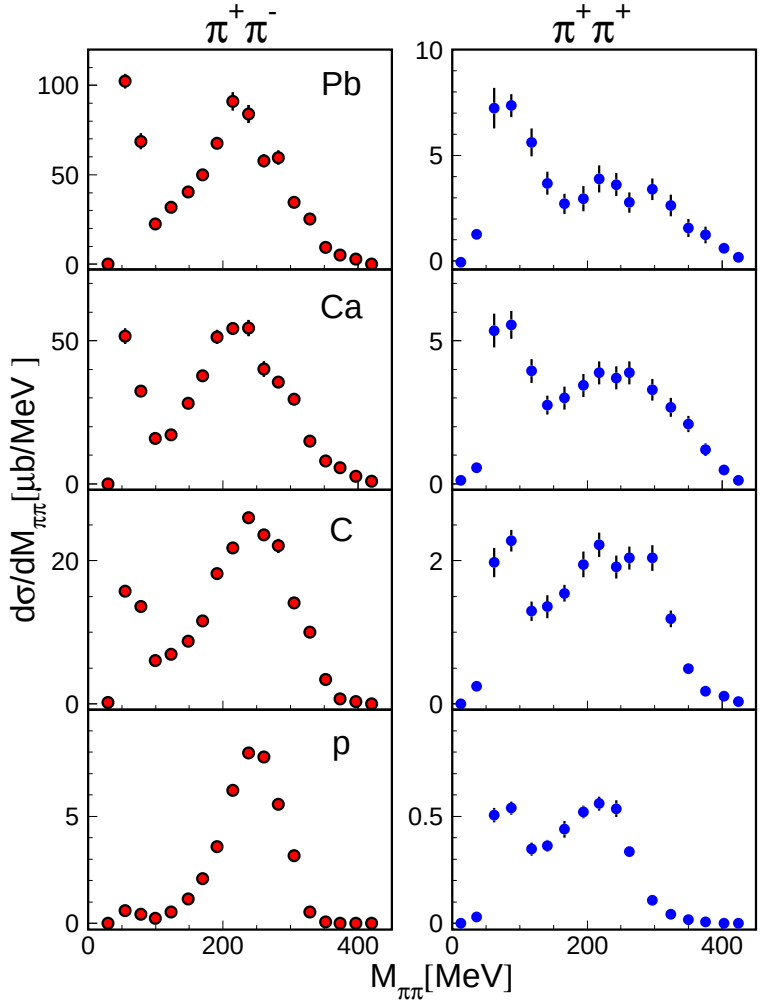
- σ spectral function, expected effects on $\sigma \rightarrow \pi^o\pi^o, \pi^+\pi^-$ (Schuck et al., Hatsuda et al., Rapp et al.)



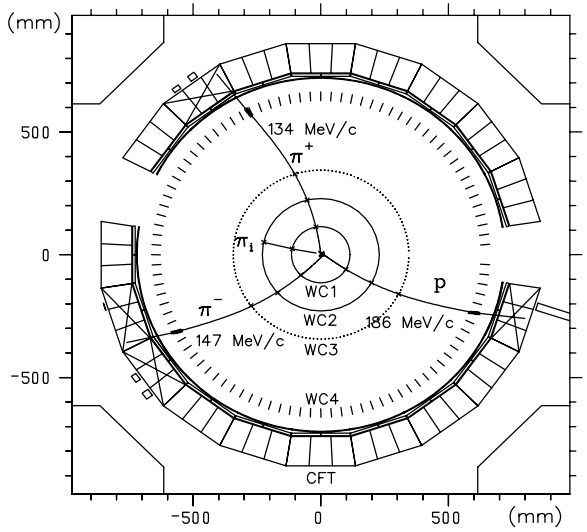
first experimental 'evidence': $\pi A \rightarrow A'\pi\pi$ studied at CHAOS

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

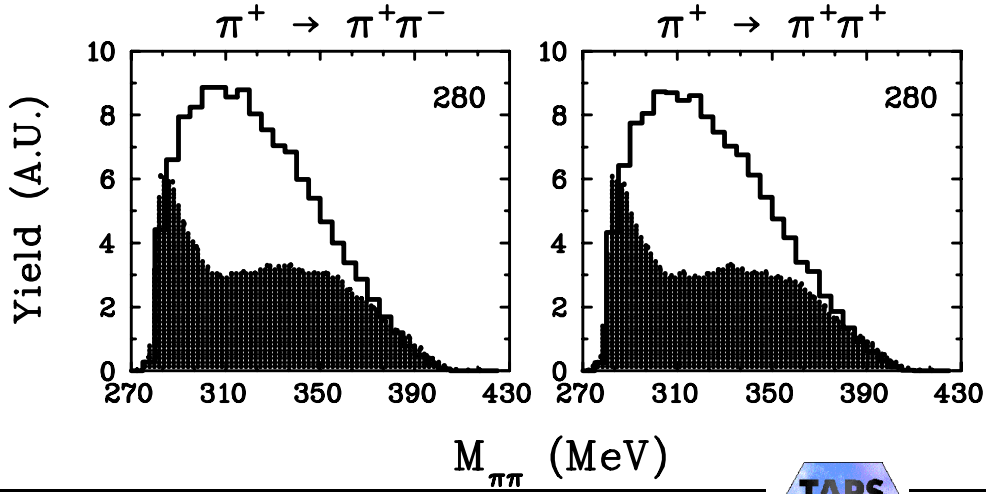
(Bonutti et al.)



- The CHAOS setup



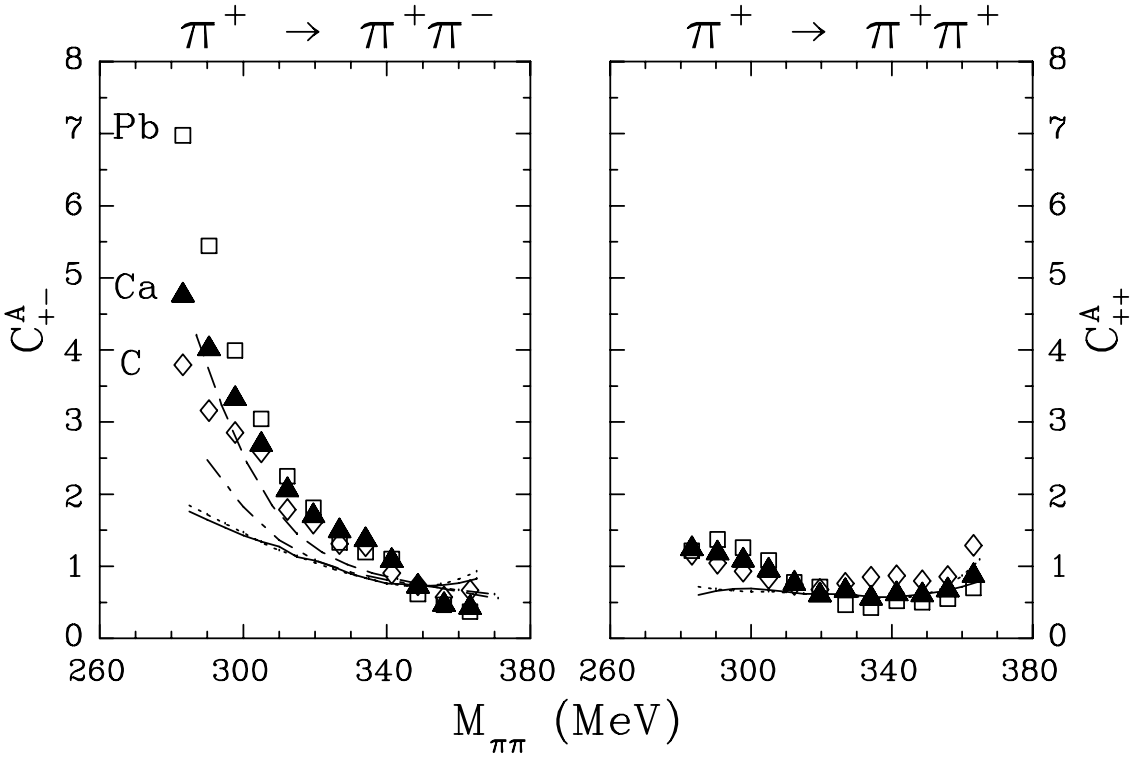
- phase space seen with CHAOS



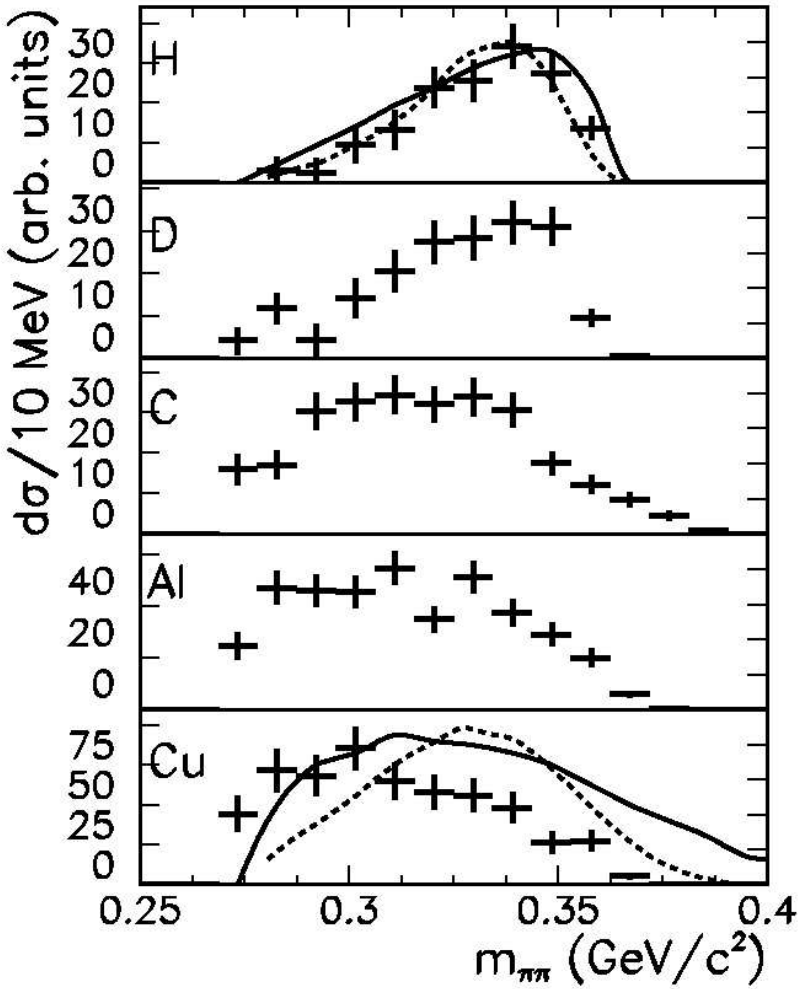
pion induced double π production: results

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

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

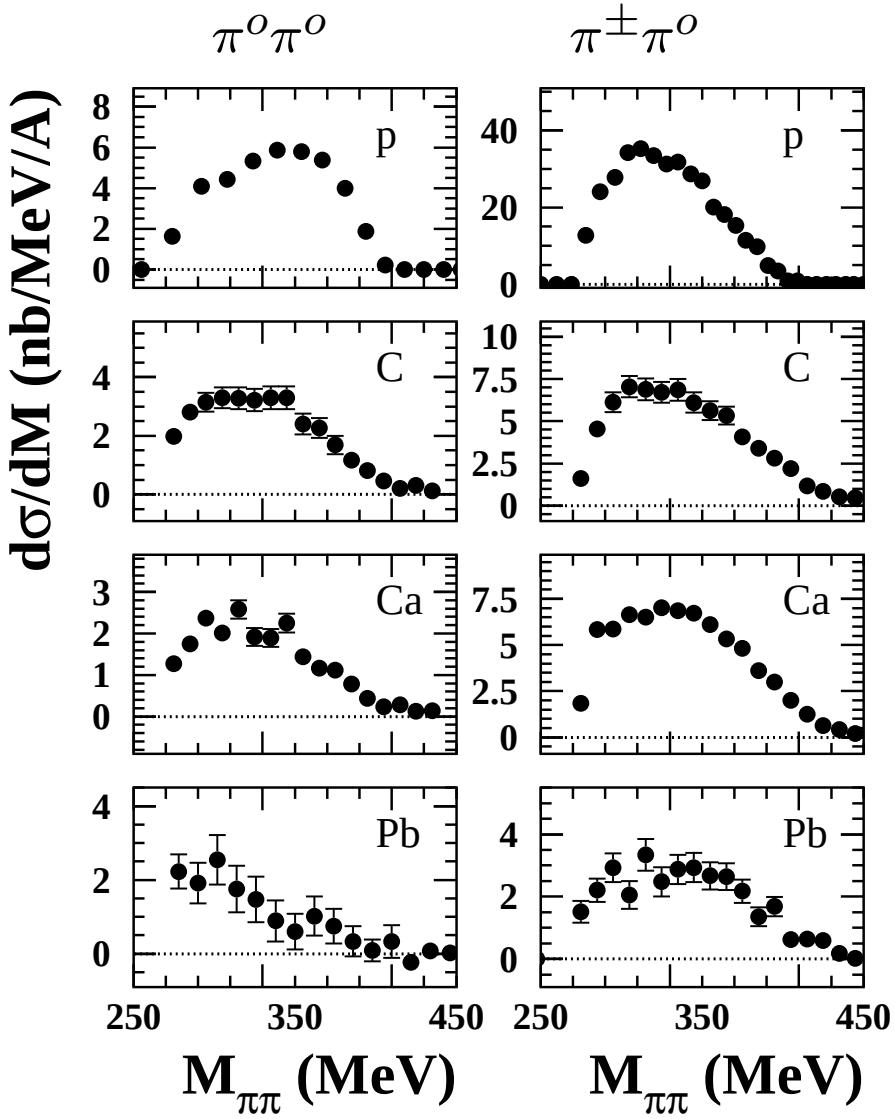


- Crystal Ball@BNL: (S. Starostin et al.)
  $\pi^- A \rightarrow A' \pi^o \pi^o$ reaction

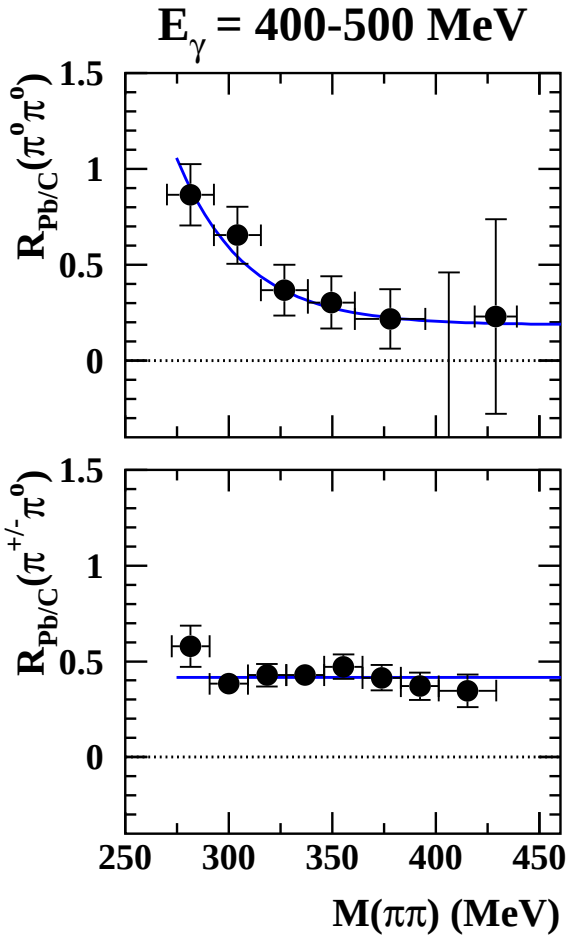


photon induced double π production: results (TAPS)

- 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 $\pi^o\pi^o$

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 identified via $\omega \longrightarrow \pi^o\gamma$

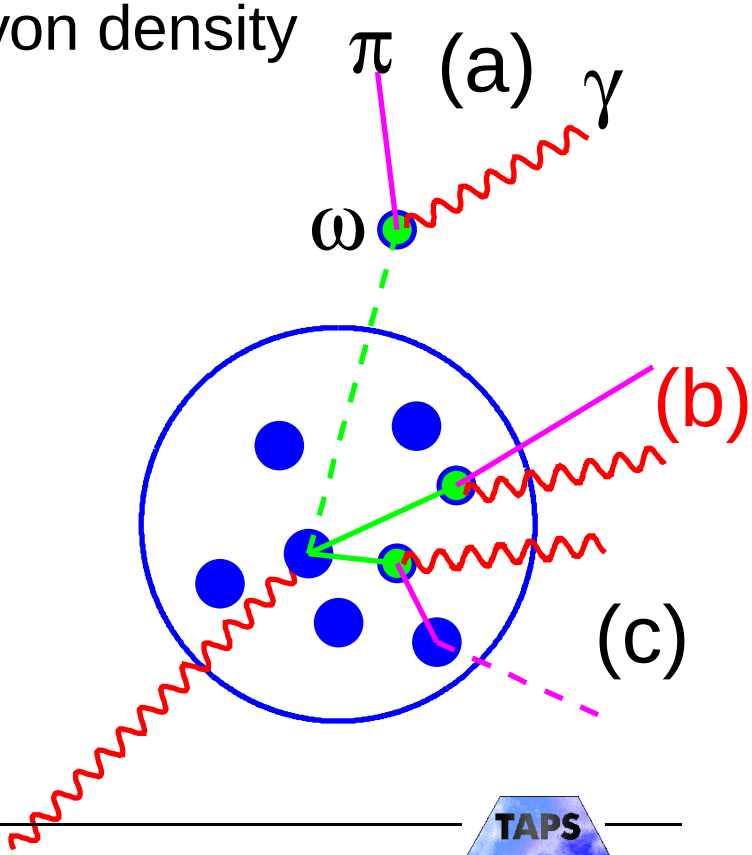
    $\longrightarrow$ much larger branching ratio

    (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})

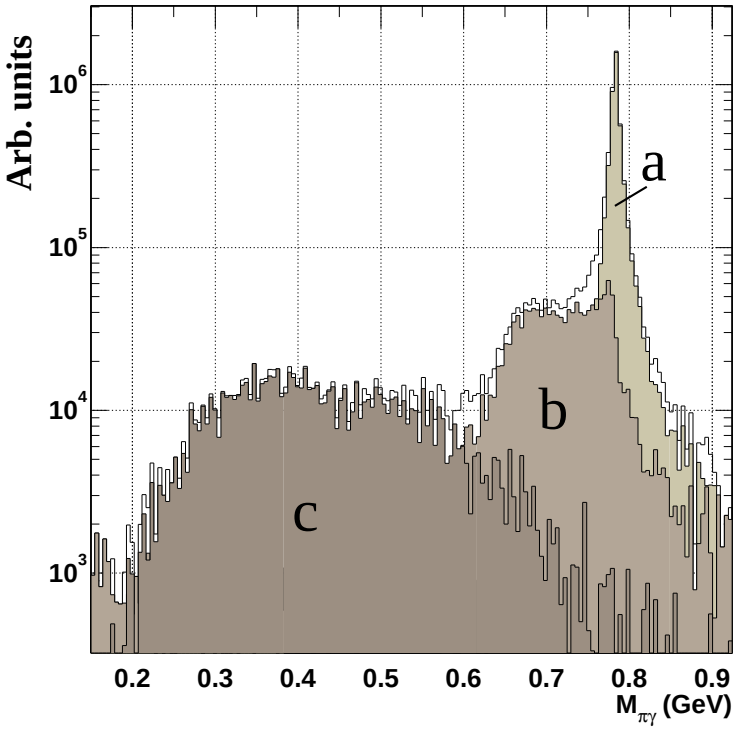
  - but: complication from FSI of π^o-meson

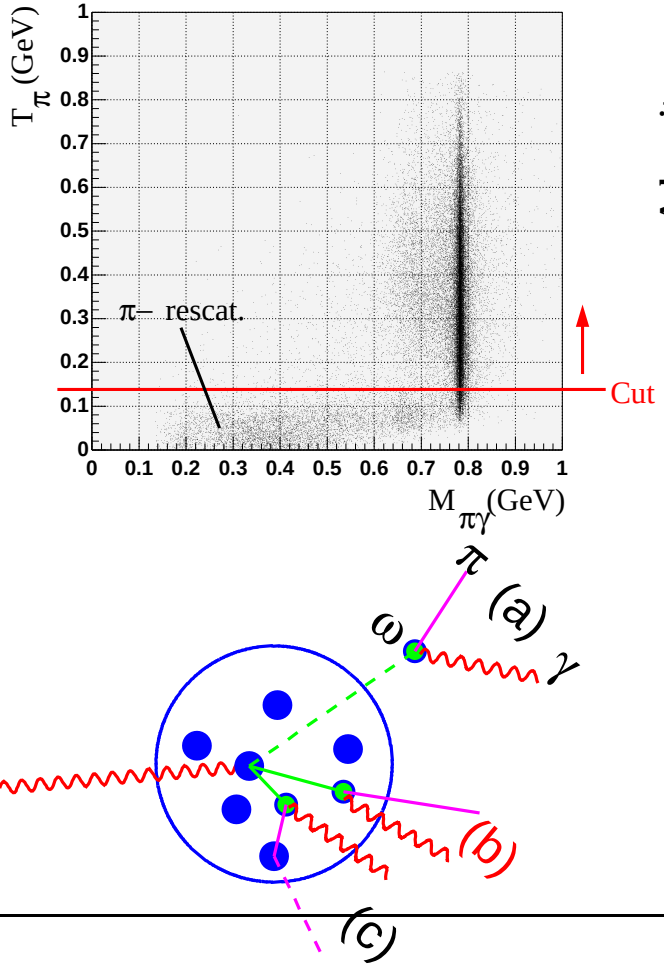


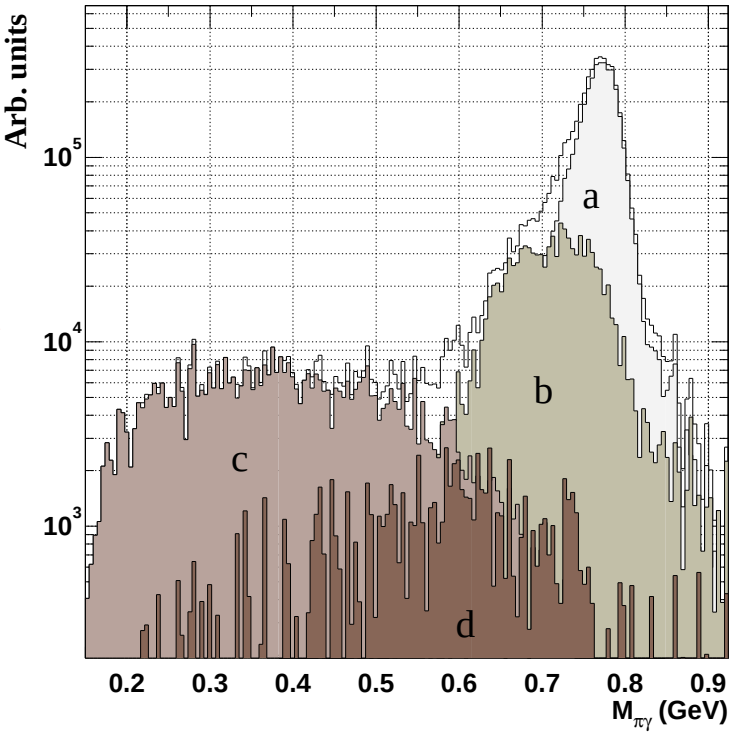
photoproduction of ω-mesons from nuclei - simulation

(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



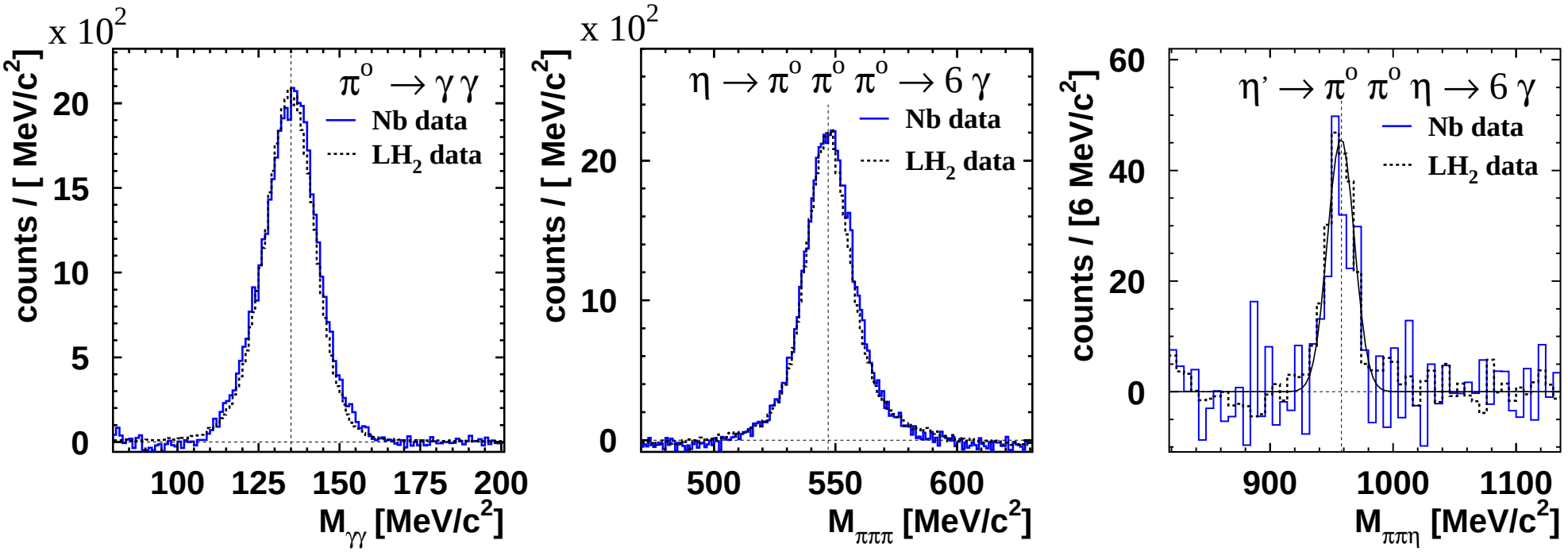




invariant mass distributions: π^o, η, η'

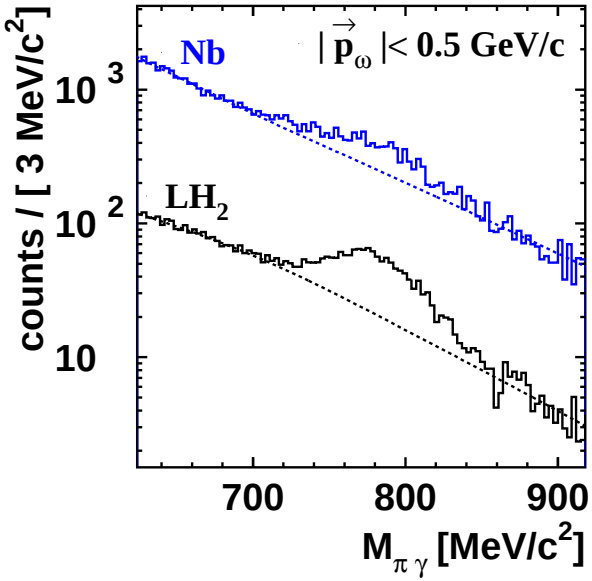
(D. Trnka et al., PRL 94 (2005) 192303)

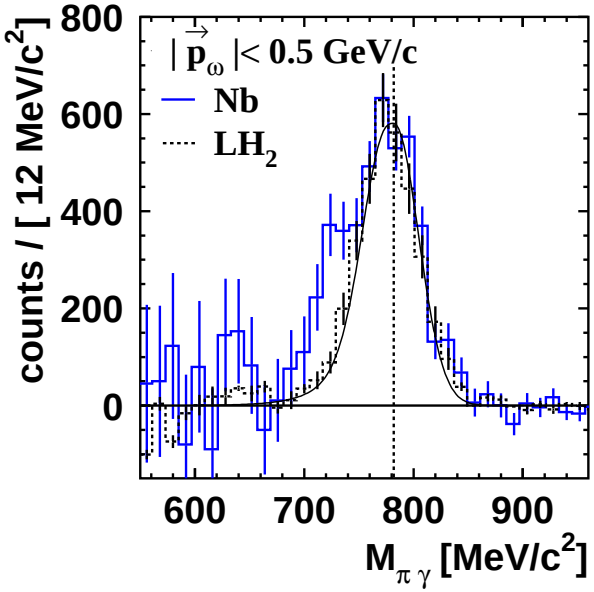
- comparison: free proton - Nb nucleus

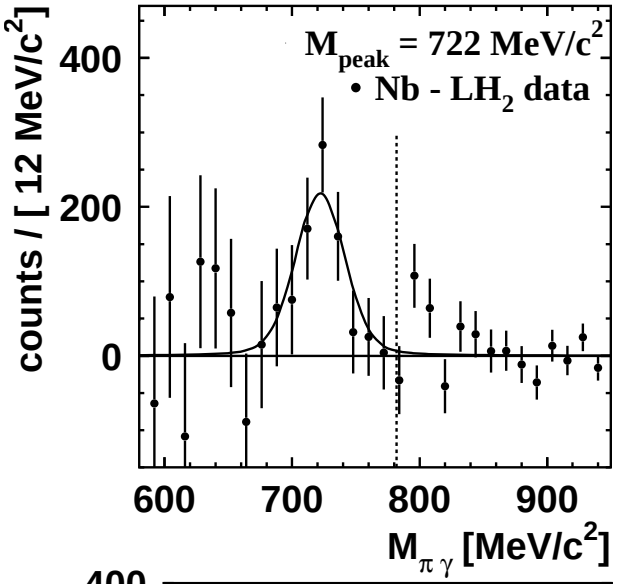


invariant mass distributions: ω-mesons

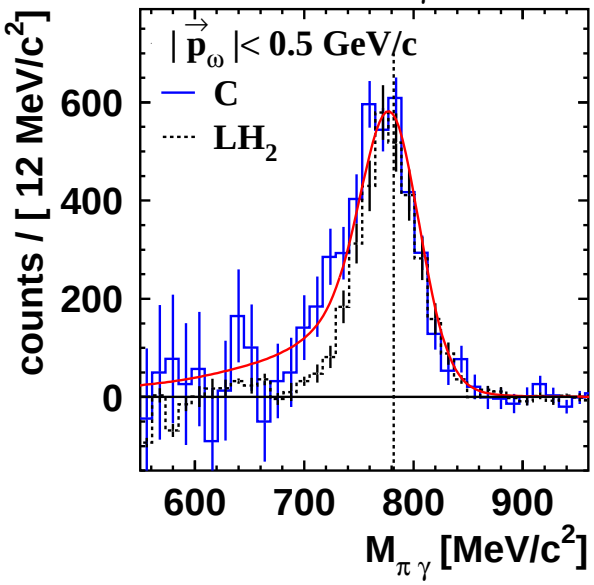
- comparison: free proton - C, Nb nuclei (D. Trnka et al., PRL 94 (2005) 192303)

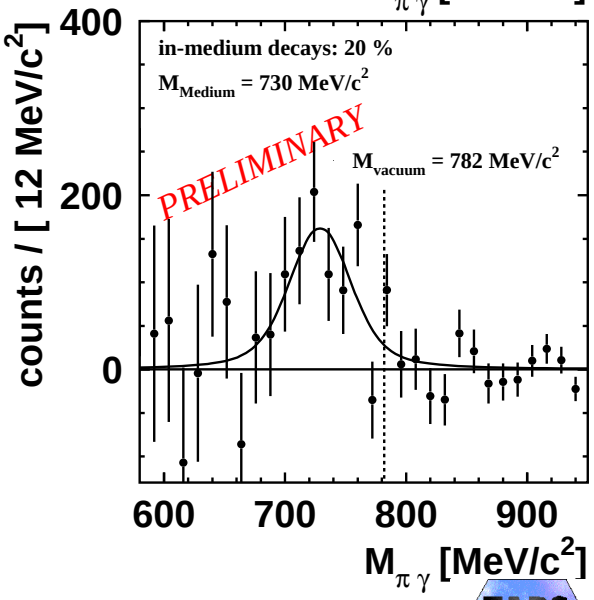






- first evidence for in-medium mass shift of the ω meson

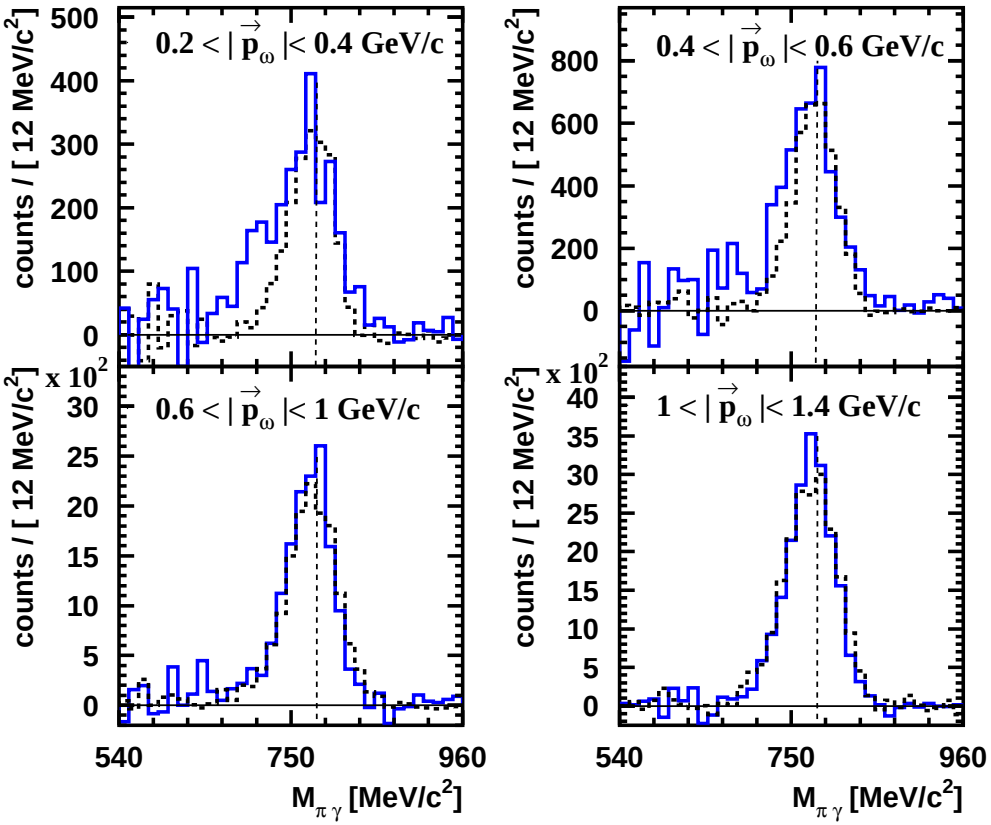


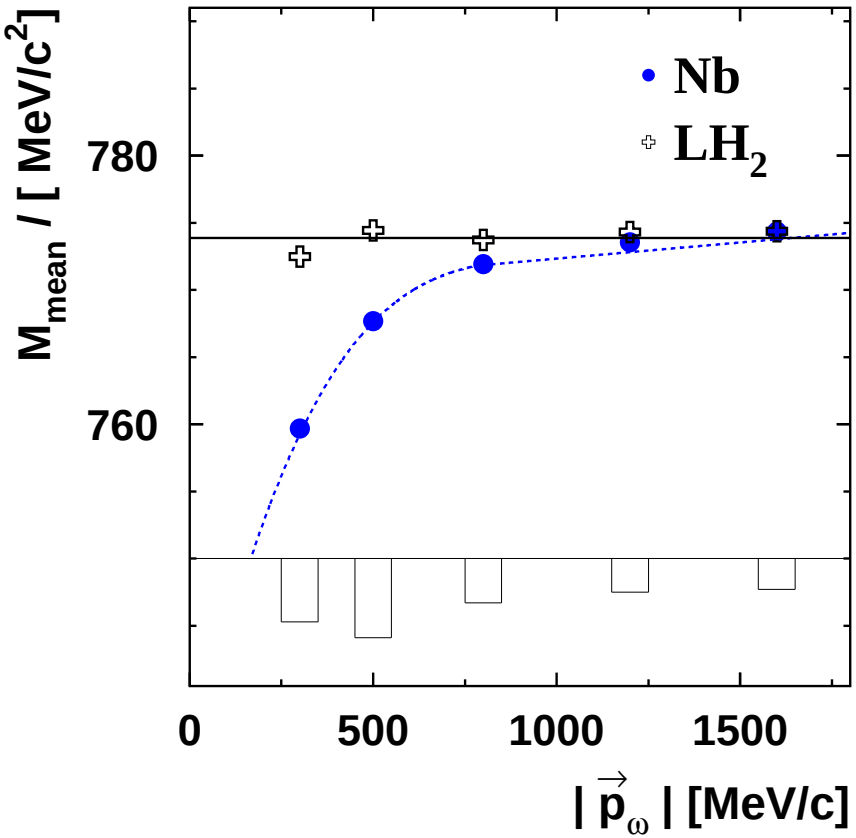


invariant mass distributions: ω-mesons

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

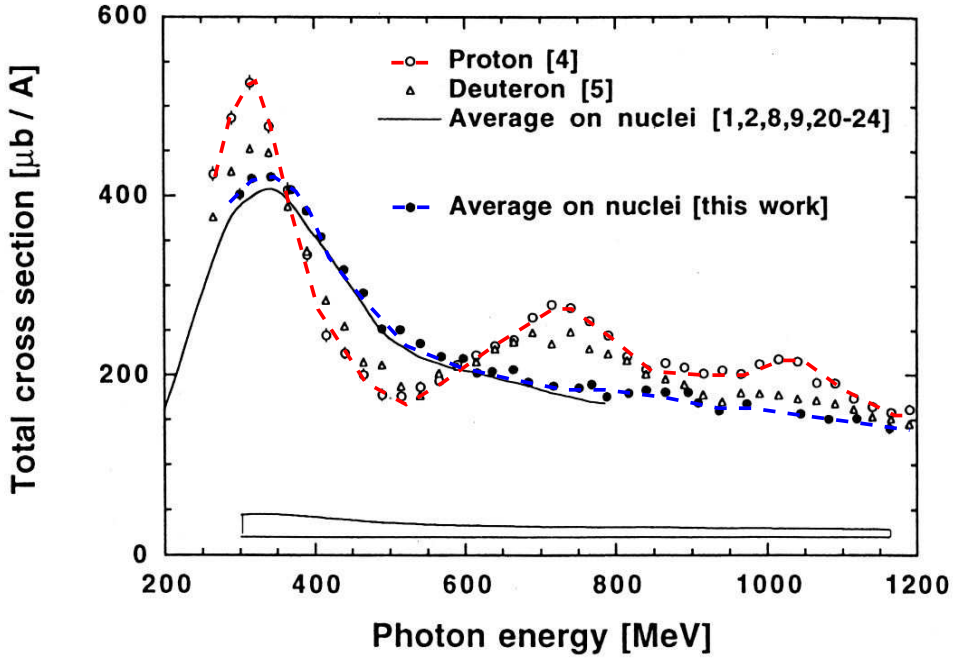
- momentum dependence of mass shift

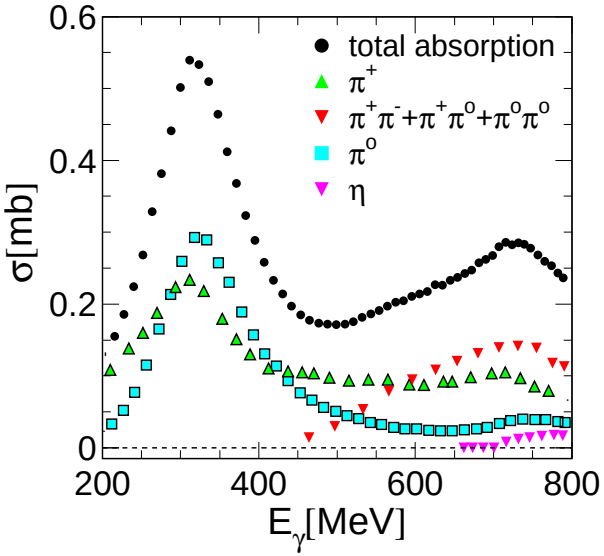




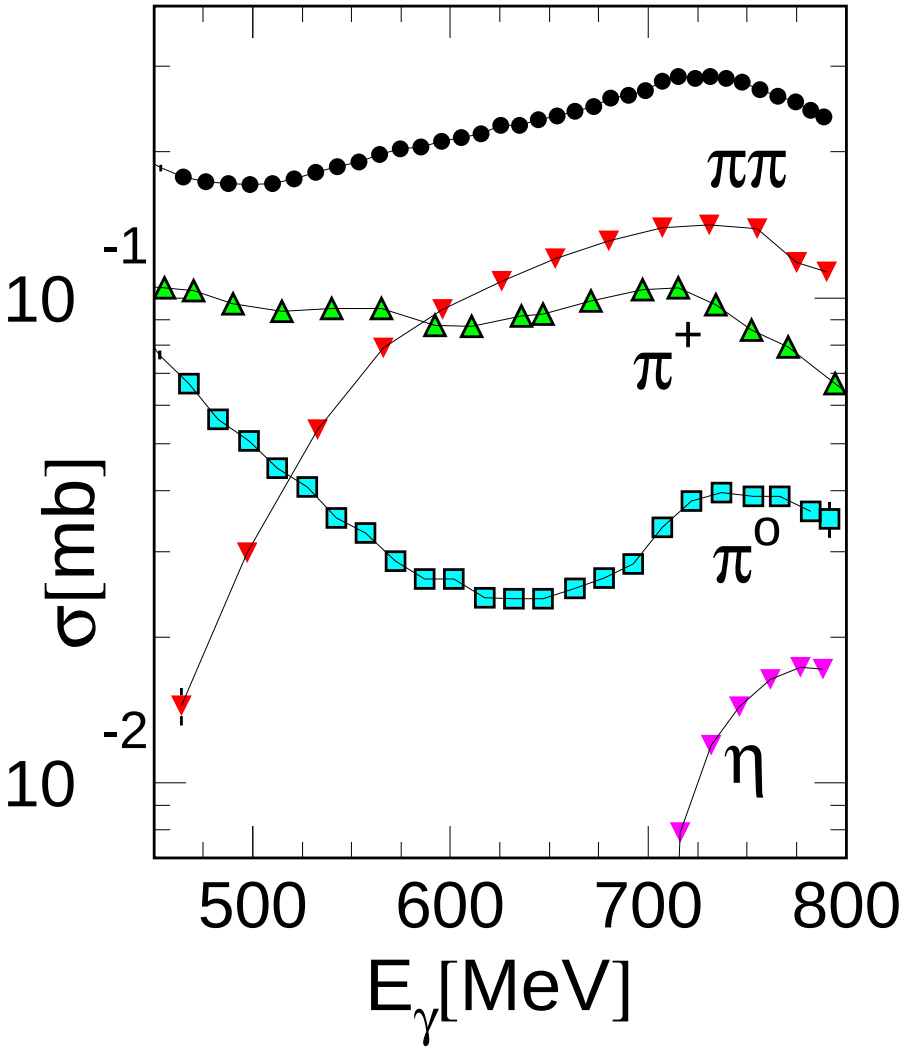
the second resonance region - where are the resonances gone?

- total photoabsorption from nucleon and nuclei



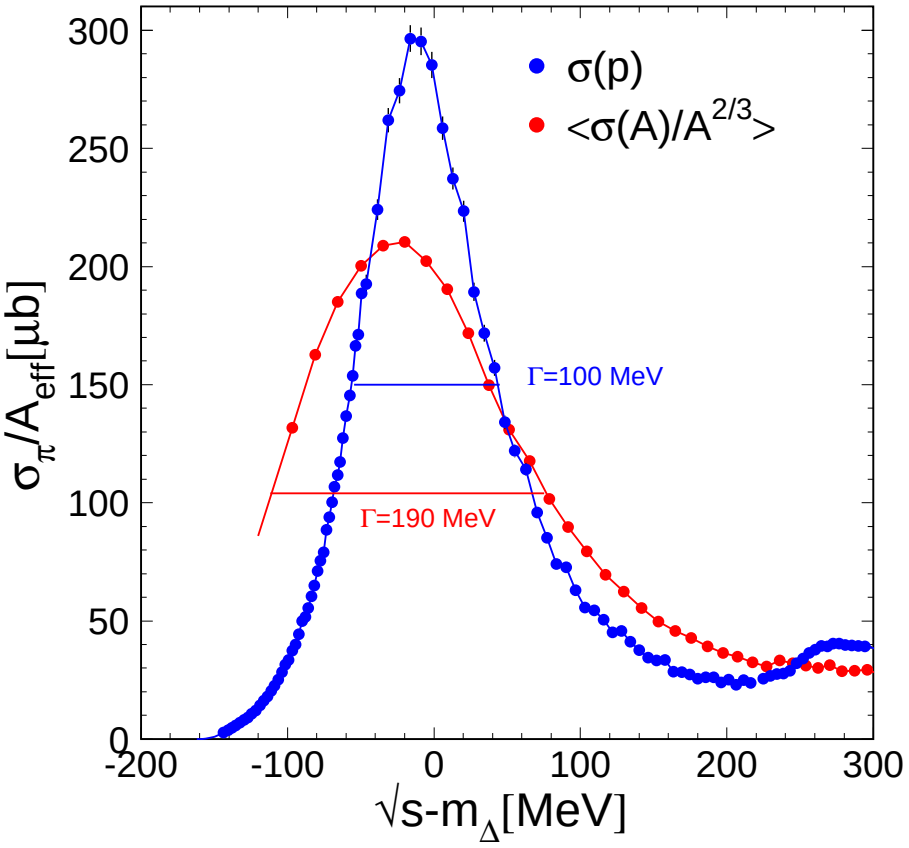


- partial cross sections in the second resonance bump of the proton

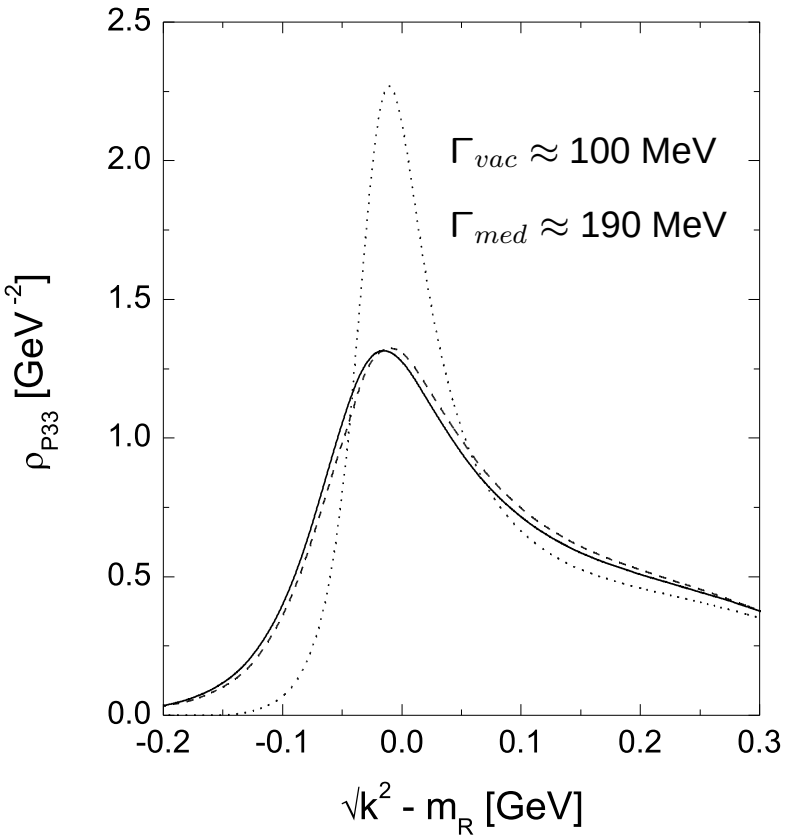


single π^o photoproduction and the Δ resonance

- total cross section in Δ region



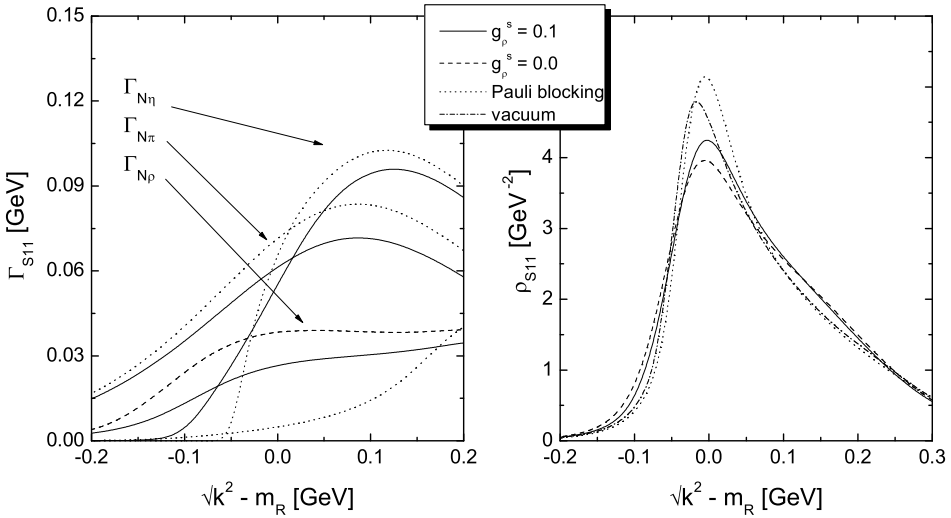
- predicted spectral functions (Post et. al.)



- 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.)

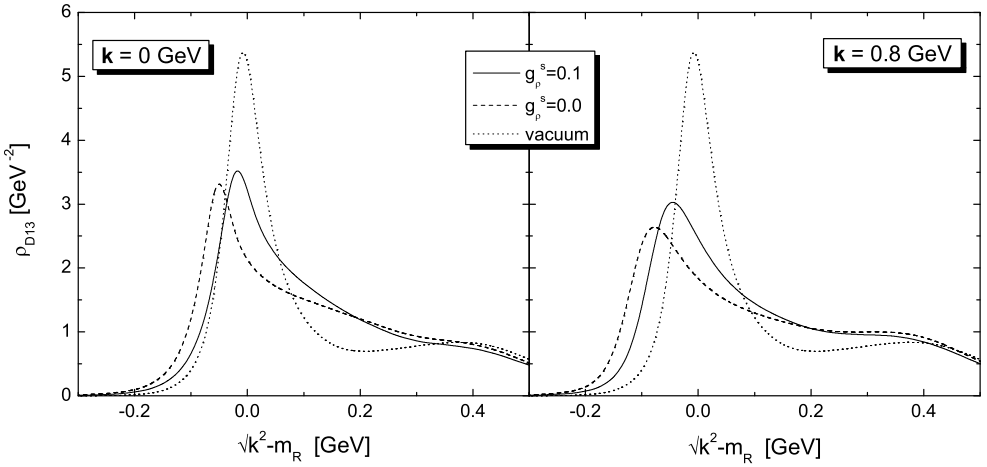
in-medium spectral functions of nucleon resonances

- spectral function of $S_{11}(1535)$



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

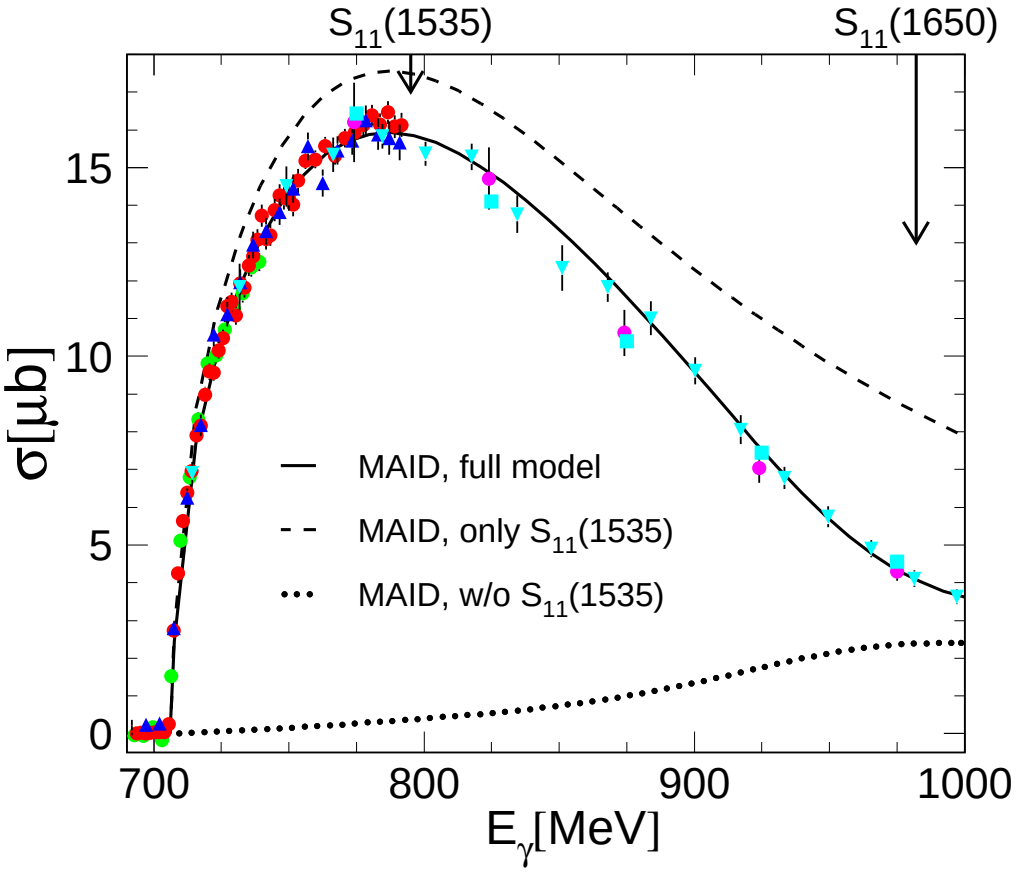
- spectral function of $D_{13}(1520)$

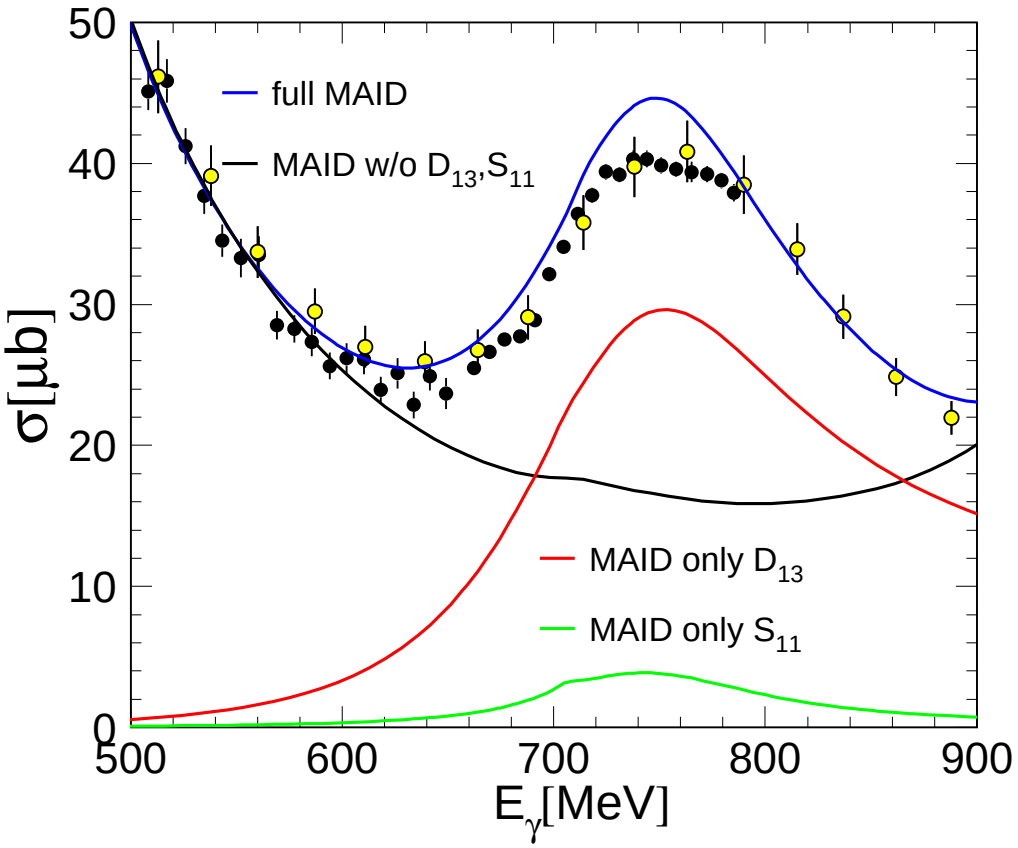


- significant modification of $D_{13}(1520)$ spectral function due to strong coupling to the $N\rho$ channel

contribution of resonances to $N\eta$ and $N\pi^o$

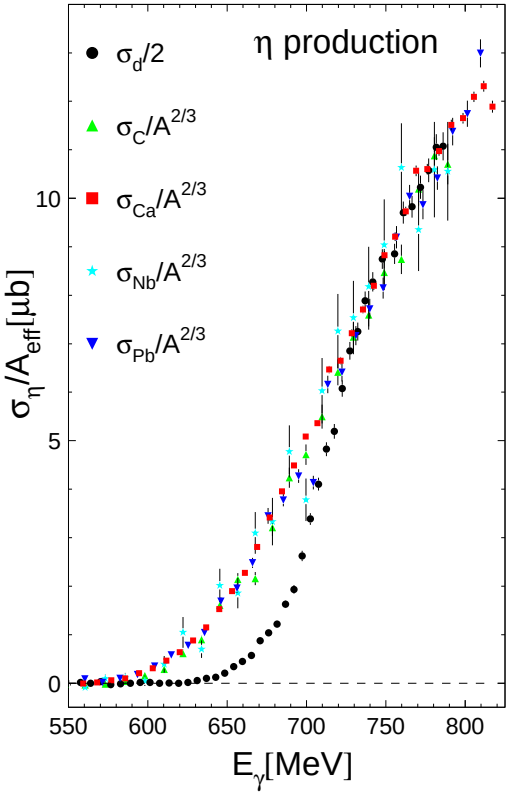
- η-photoproduction: dominated by excitation of the $S_{11}(1535)$ resonance
- π^o-photoproduction: dominated by excitation of the $D_{13}(1520)$ resonance

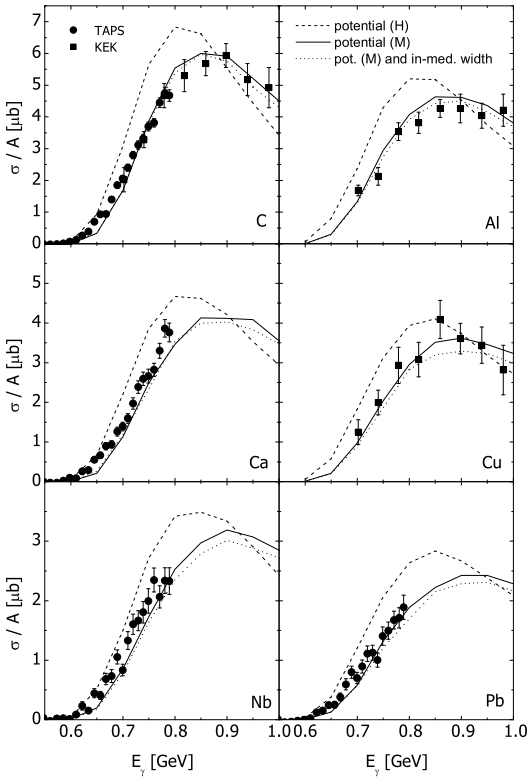




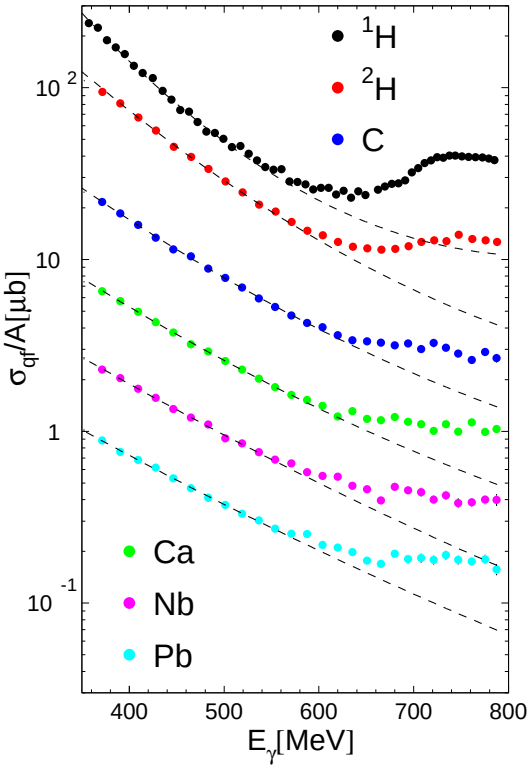
η and single π^o production: S_{11} and D_{13} resonances

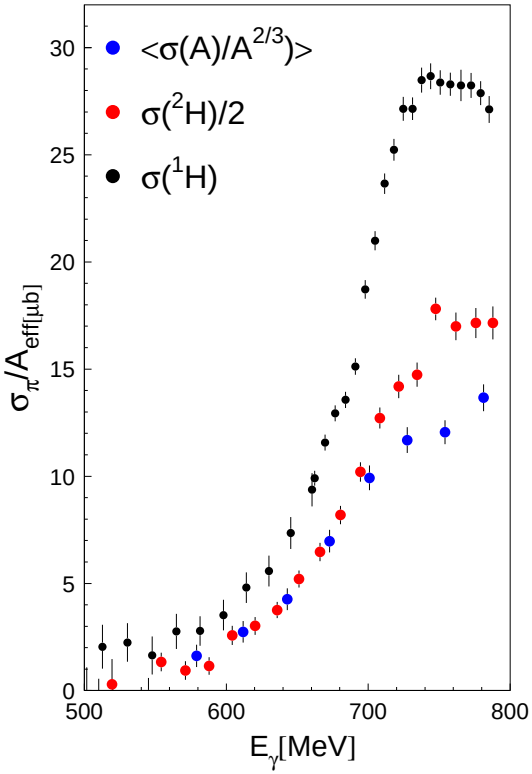
- η production





- π^o production





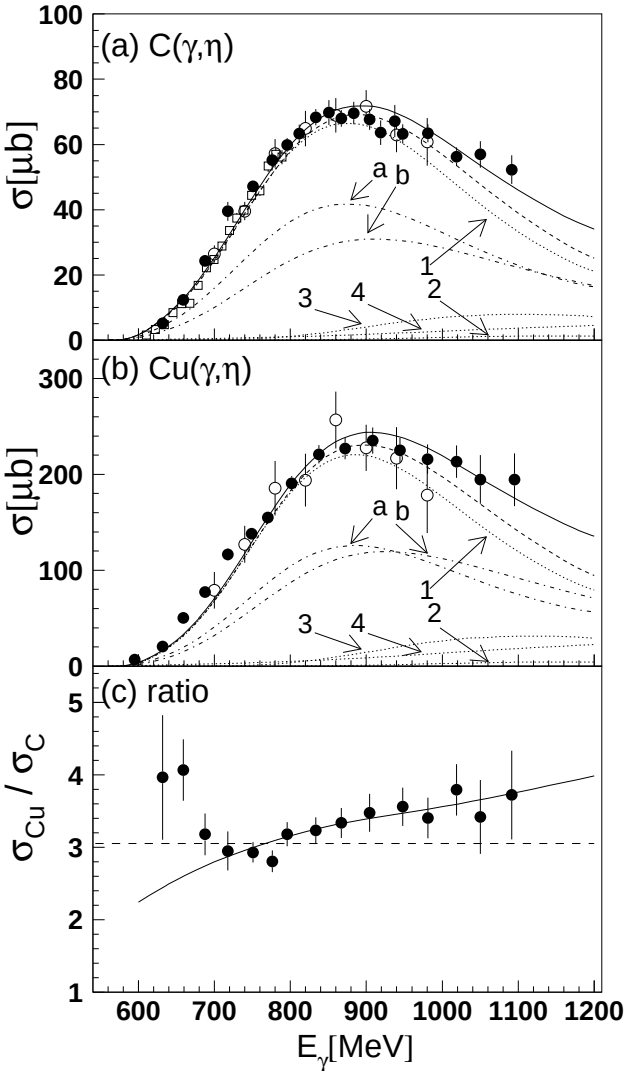
- perfect scaling with $A^{2/3}$,
  comparison to BUU calculation (Lehr et al.)
  no significant broadening, additional
  width of $\approx$ 30 MeV consistent with data

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

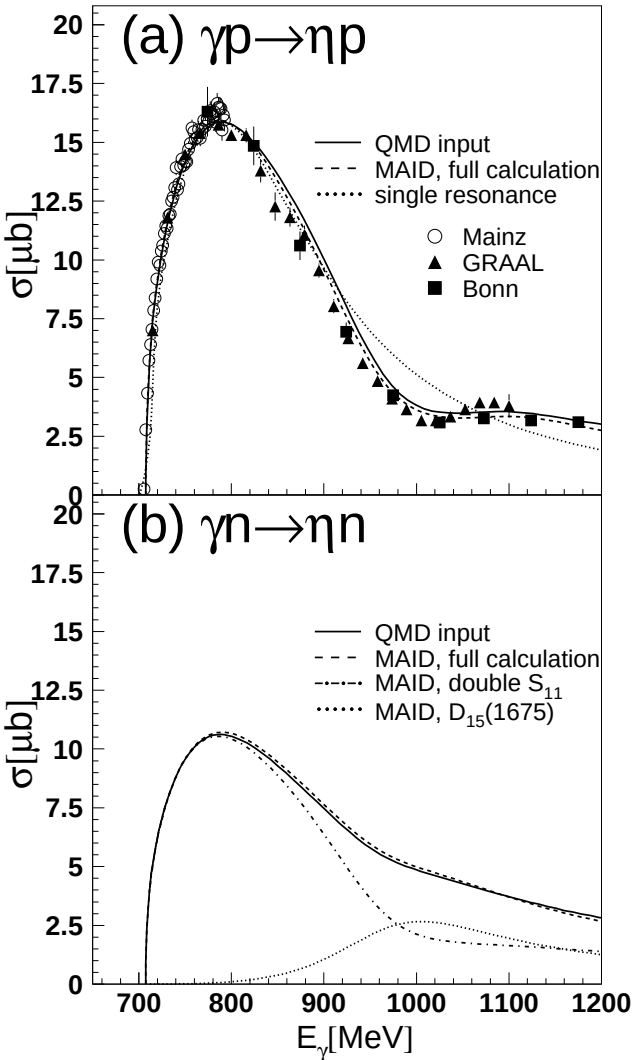
new results for η photoproduction from nuclei

T. Kinoshita et al., nucl-ex/0509022

- excitation functions for C, Cu

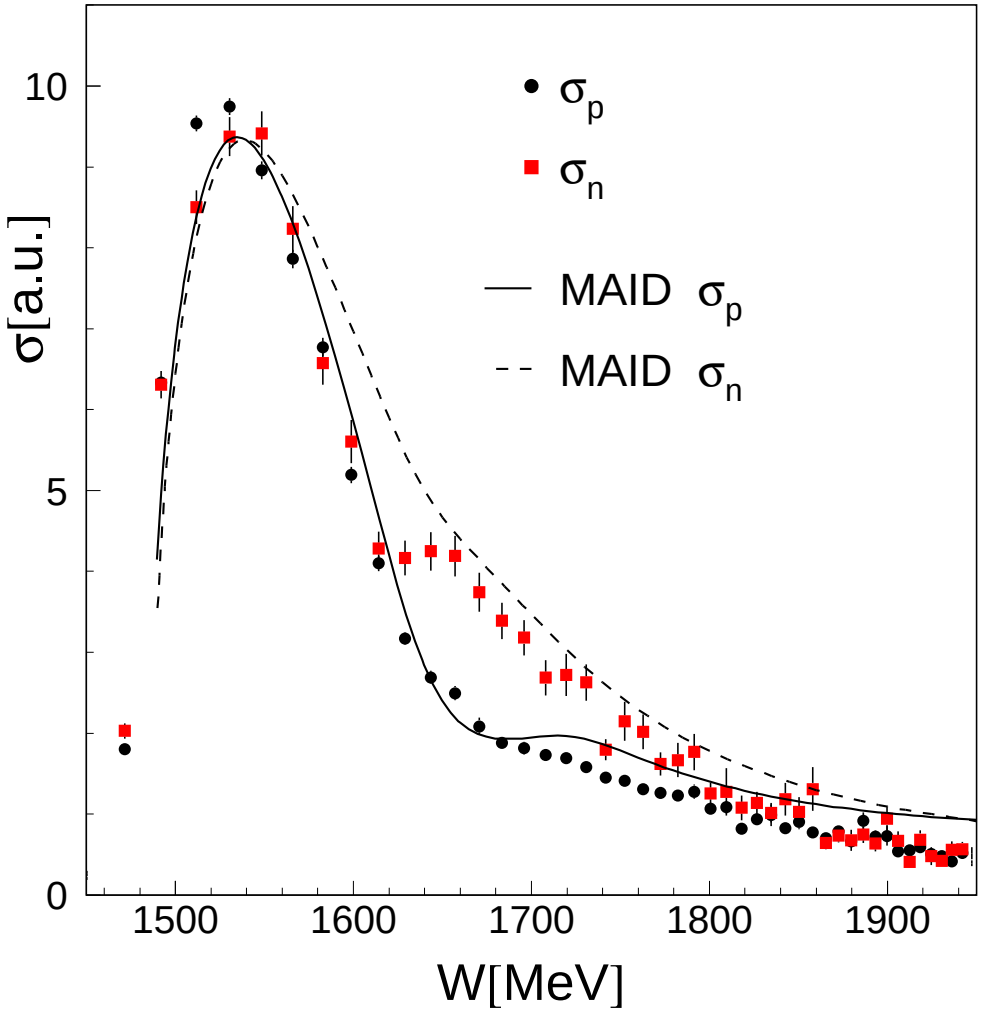


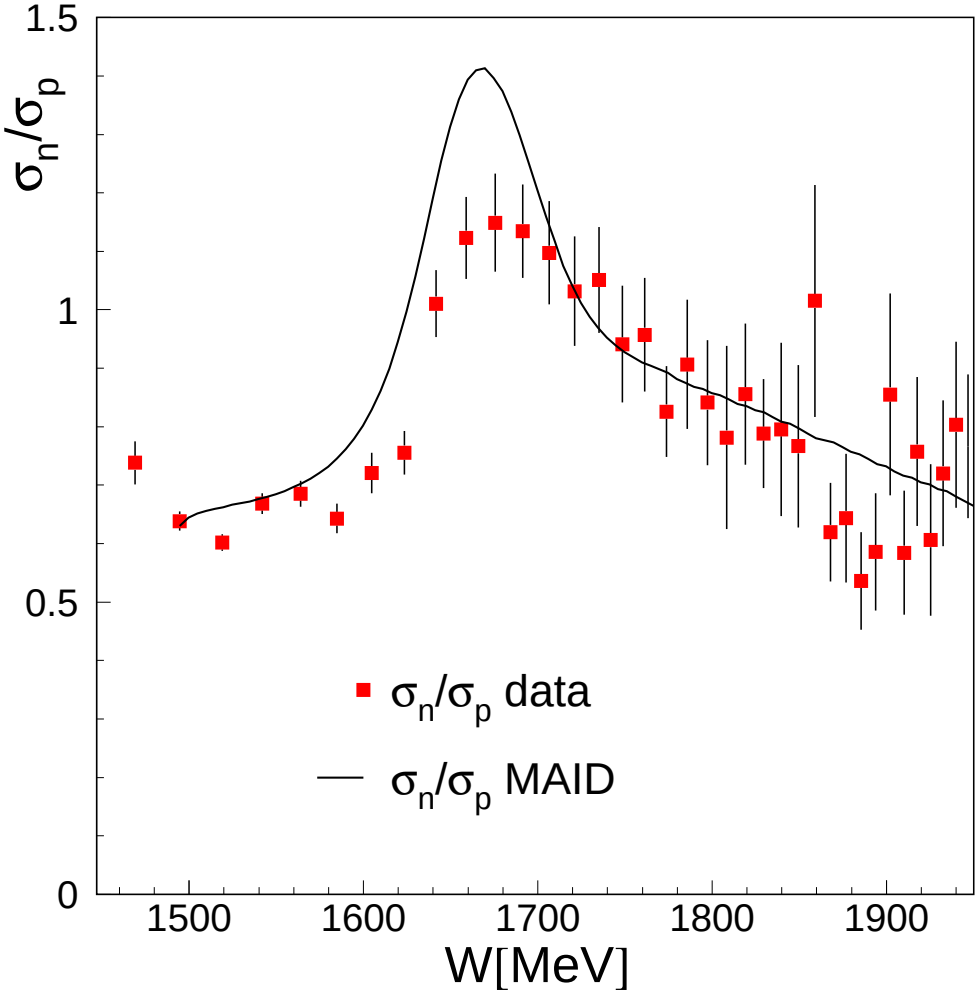
- excitation functions for the nucleon



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

Preliminary results from Crystal Barrel/TAPS@ELSA, I.Jaegle et al.

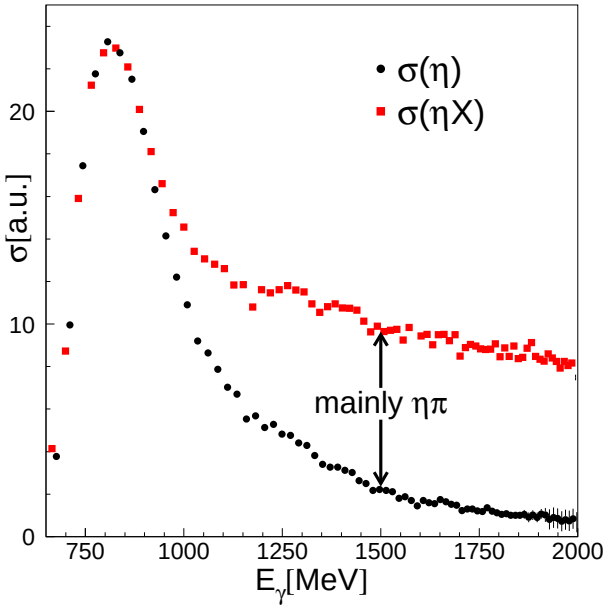




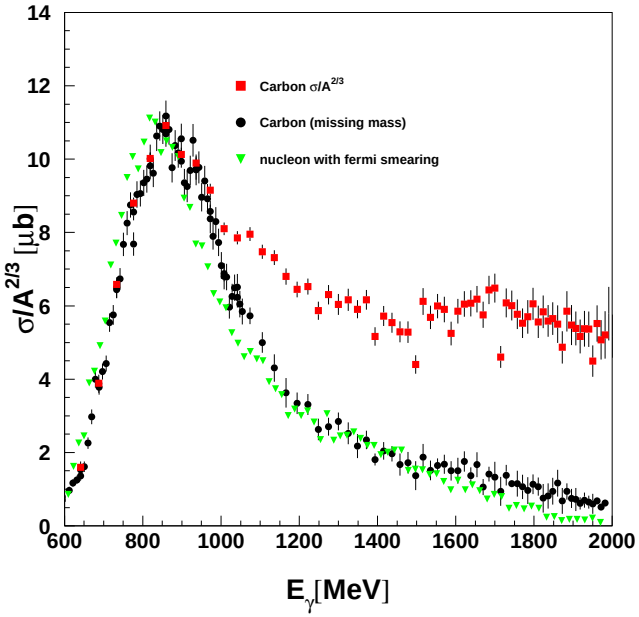
total cross sections from nuclei

Preliminary results from Crystal Barrel/TAPS@ELSA, Th. Mertens et al.

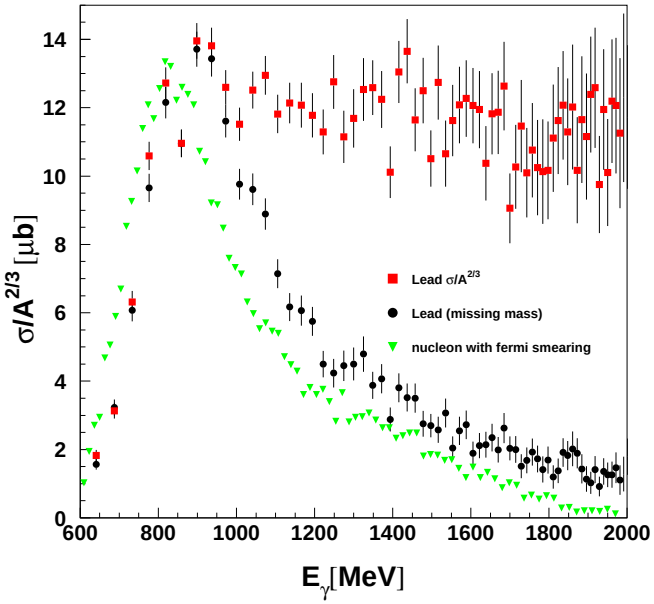
deuteron



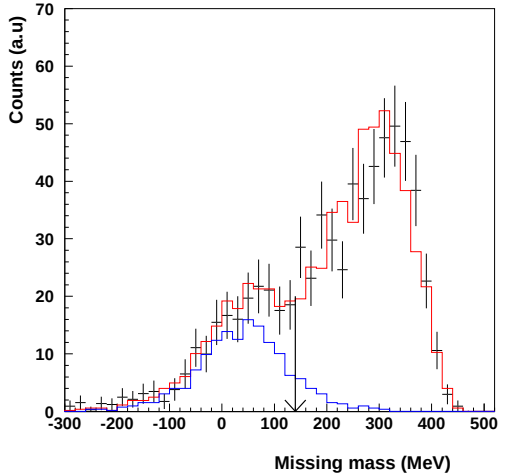
carbon



lead



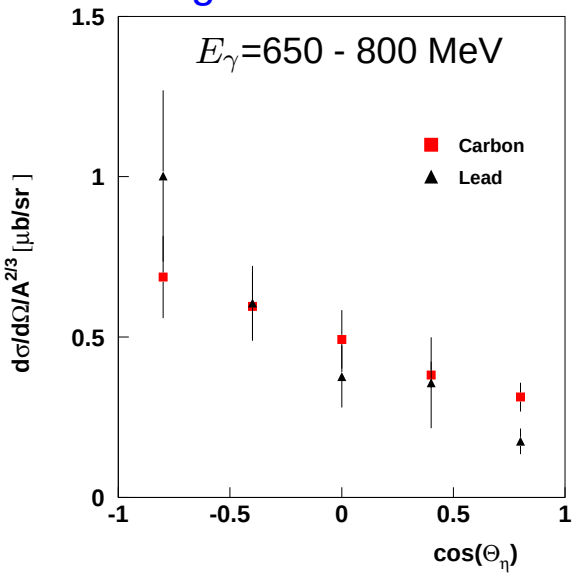
- above 900 MeV photon energy strong contribution from $\pi\eta$ fi nal states (comparable for deuteron, carbon).
- for heavier nuclei increasing contributions from secondary processes like $\gamma N \rightarrow \pi N$, $\pi N \rightarrow \eta N$
- separation with cuts on reaction kinematics (missing mass) $\Rightarrow$

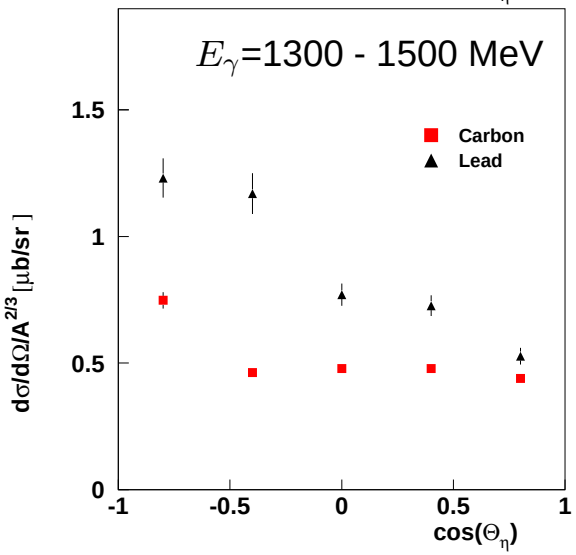


angular and kinetic energy distributions from nuclei

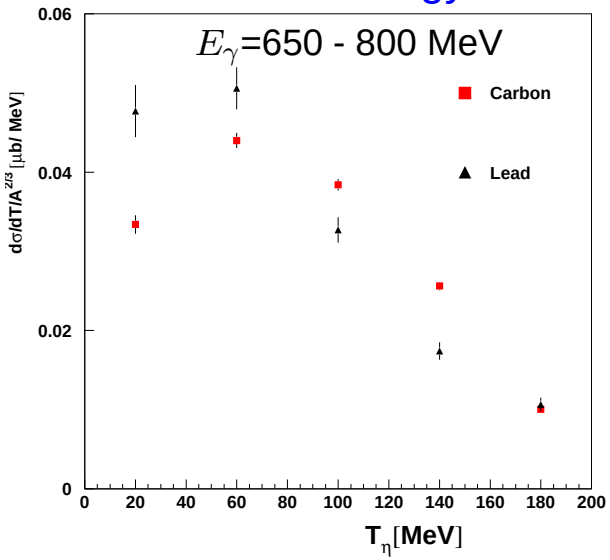
Preliminary results from Crystal Barrel/TAPS@ELSA, Th. Mertens et al.

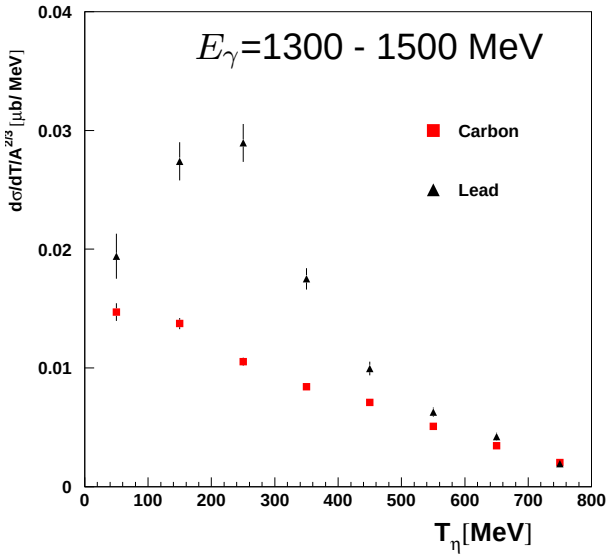
angular distributions





kinetic energy





- for high incident photon energies excess for lead from η mesons with small kinetic energy at backward angles in photon - nucleon cm-system
- behavior as expected for contributions from multi-step processes

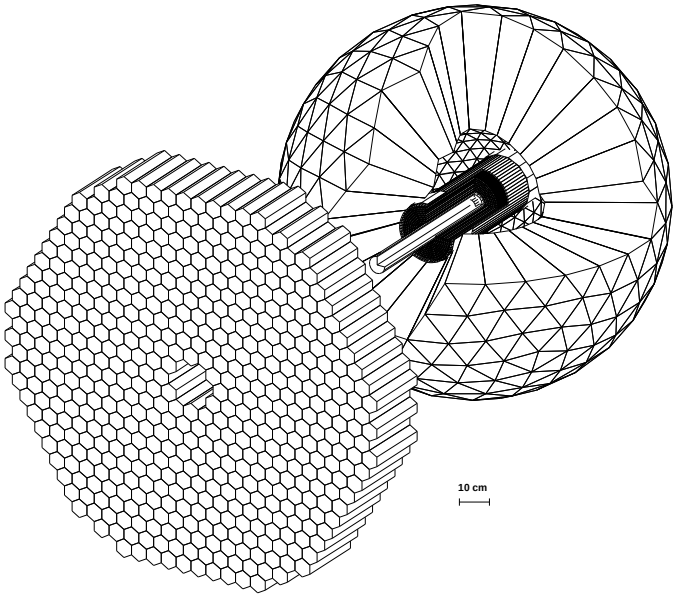
summary and outlook

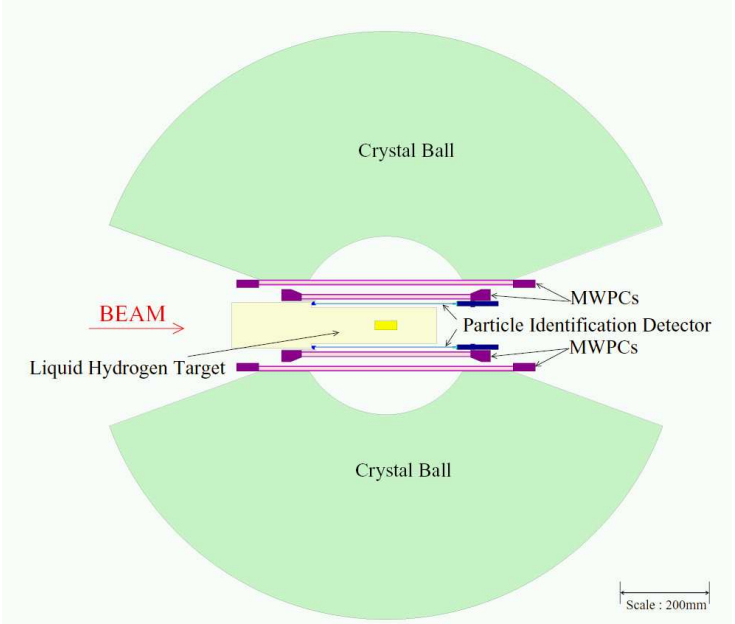
- pion and photon induced reactions show some evidence for in-medium modifications of scalar - isoscalar pion pairs ('σ'-meson)
  - new high statistics data for photoproduction (CBall/TAPS@MAMI)-

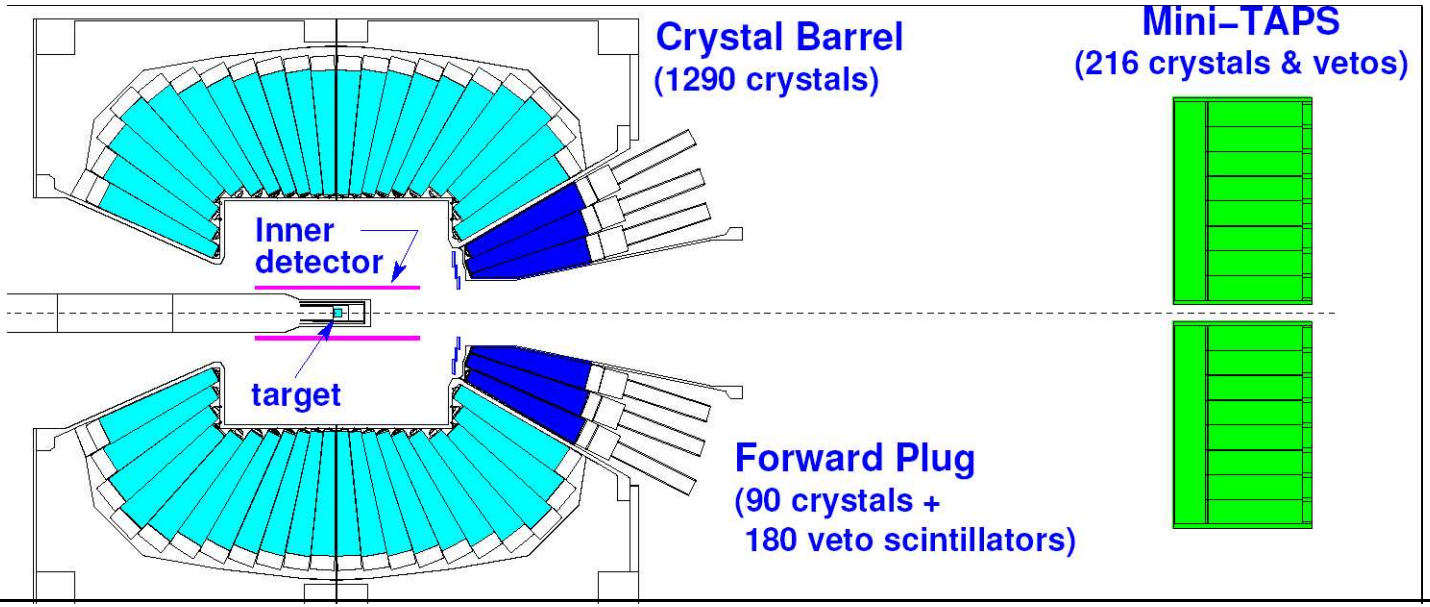
- results for the photoproduction of ω mesons from nuclei show first evidence for the predicted influence of the ω in-medium spectral function on the line shape (CBarrel/TAPS@ELSA)
  -high statistics measurements proposed for CBall/TAPS@MAMI C-

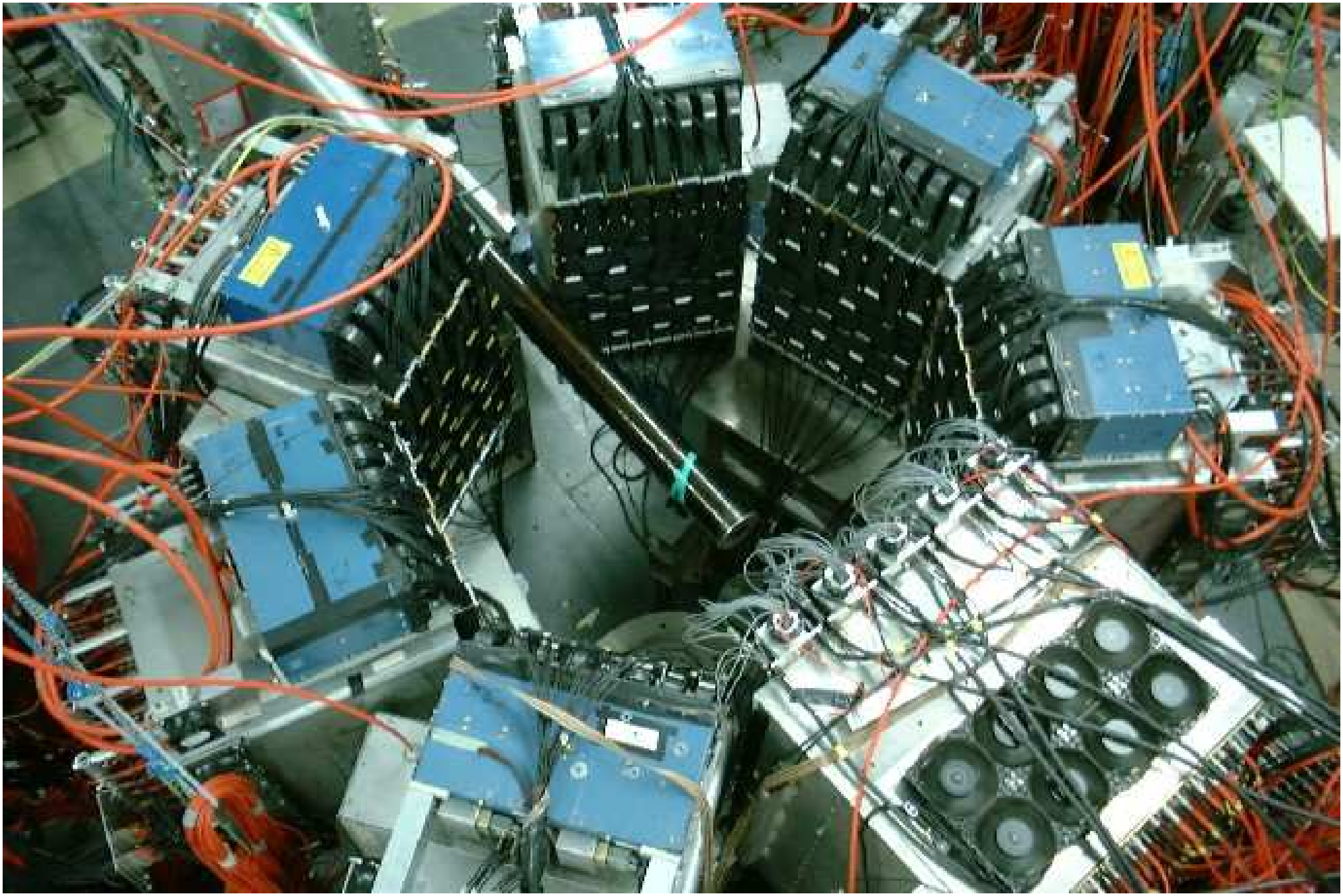
- results for in-medium spectral functions of nucleon resonances consistent with preditions:
  - no significant effect on S_{11} resonance
  - some suppression of D_{13} resonance, but shape not yet established (lack of data above $E_\gamma > 800$ MeV)

experimental setups - Ball, Barrel and TAPS



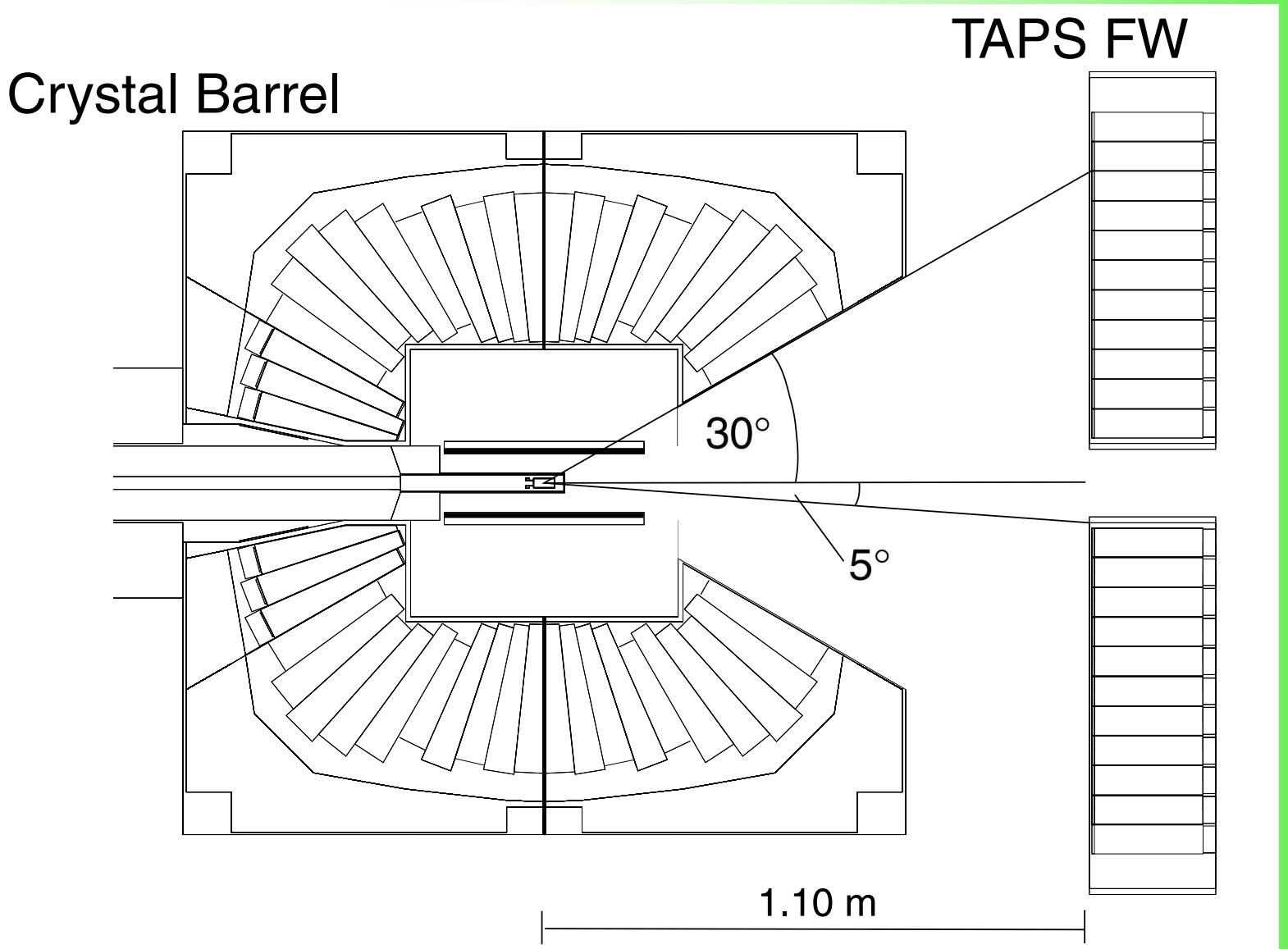


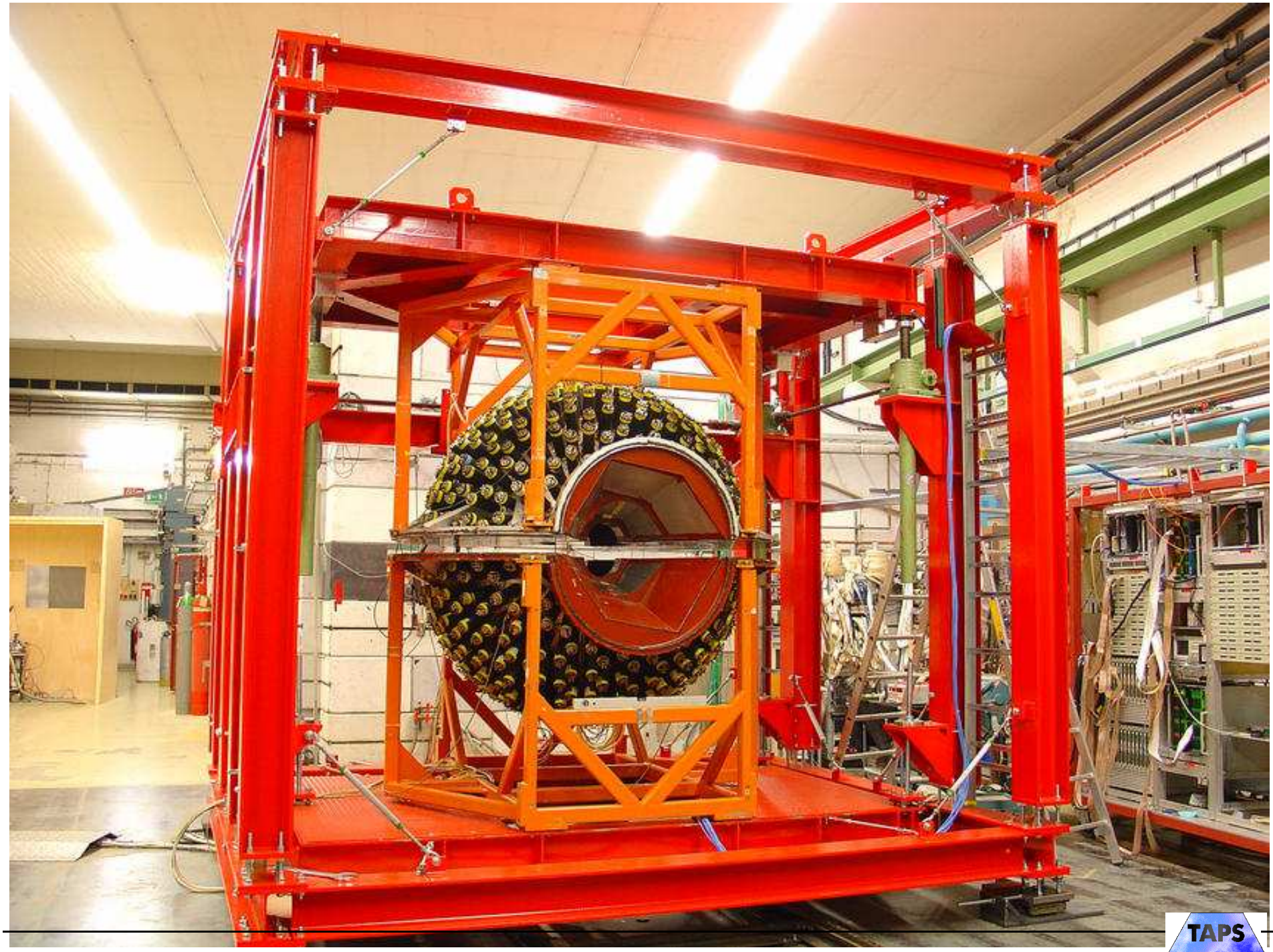





TAPS

CB ELSA Collaboration





B. Krusche, Milos, September 2005