Photoabsorption and Photoproduction on Nuclei in the Resonance Region

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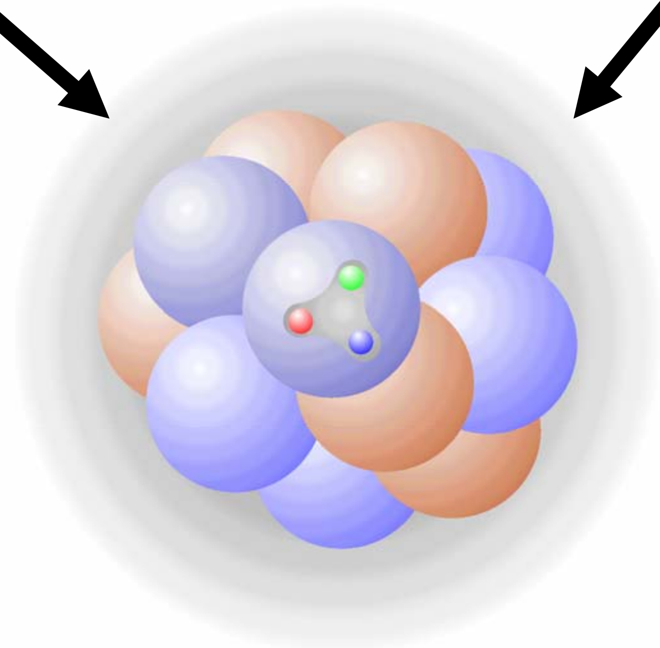
First Workshop on Quark-Hadron Duality
Frascati, June 6-8, 2005

Hadron Physics

electromagnetic probes

hadronic probes

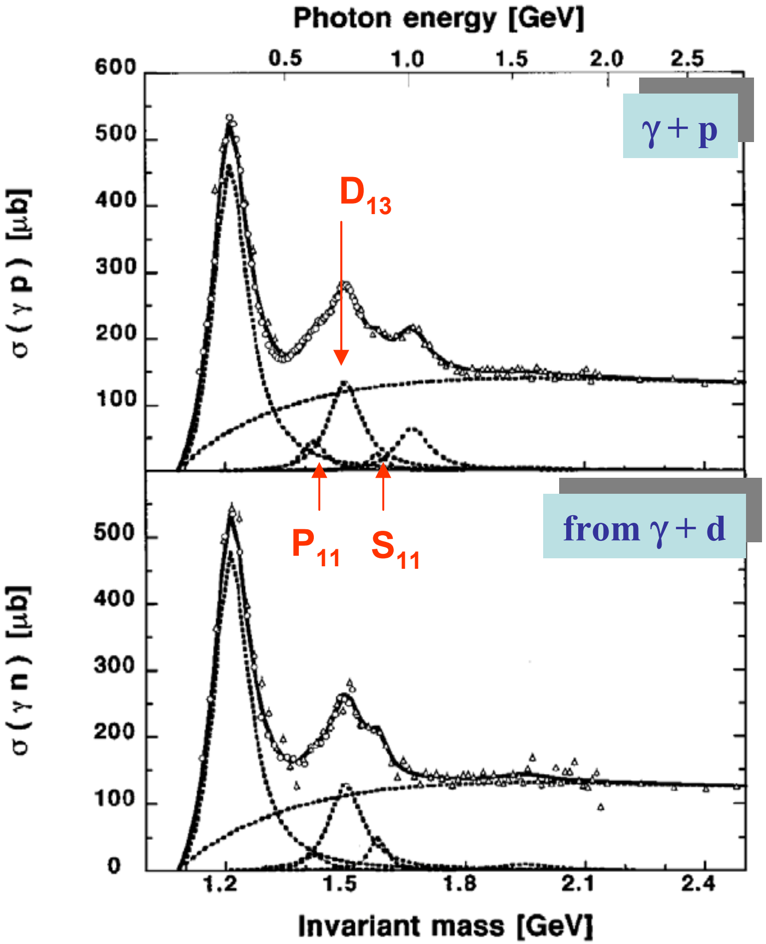


COSY
KEK
GSI
CERN
PSI
RHIC

- Why are quarks confined within hadrons?
- How are hadrons constructed from their constituents?
- What is the relation of parton degrees of freedom and the low energy structure of hadrons?
- Do glueballs (ggg) and hybrids (qqg) exist?
- What is the origin of hadron masses ?
- How are hadrons modified when embedded in nuclei ?
- What is the role of chiral symmetry ?

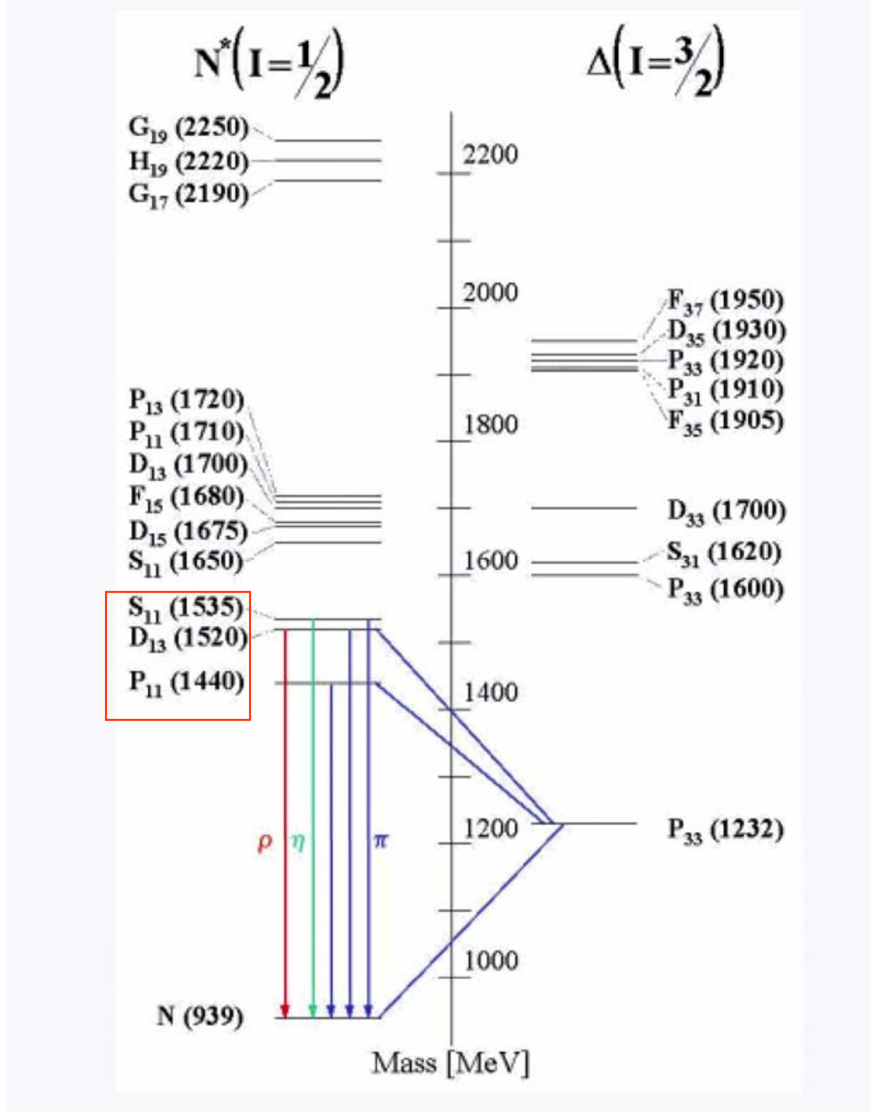
Photoabsorption on Nucleons

N. Bianchi et al. PRC 54(1996) 1688

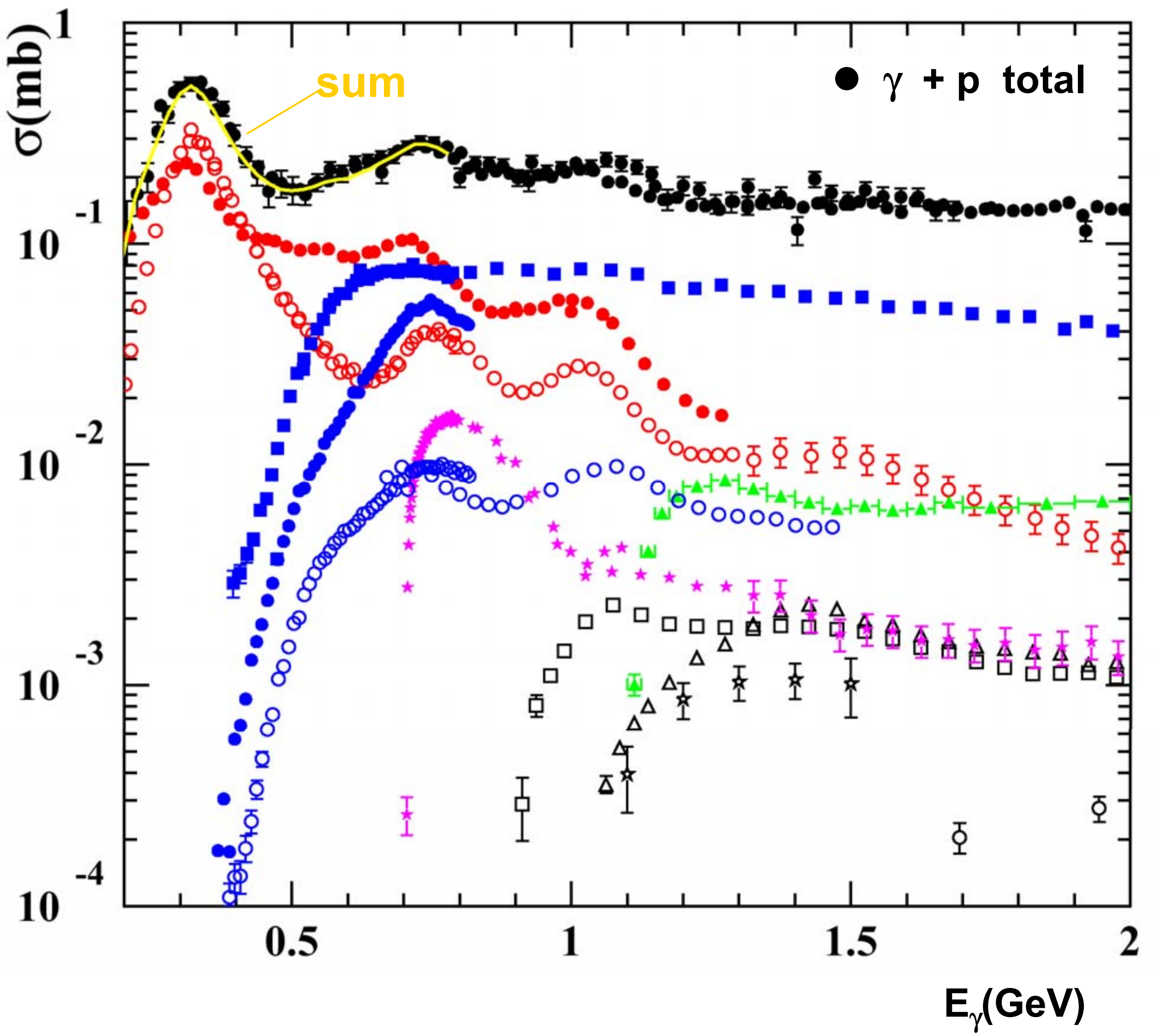


- broad and overlapping resonances
- characteristic meson decay
- tagging of resonances

Excited States of the Nucleon



Meson Photoproduction from the Proton



partly preliminary!

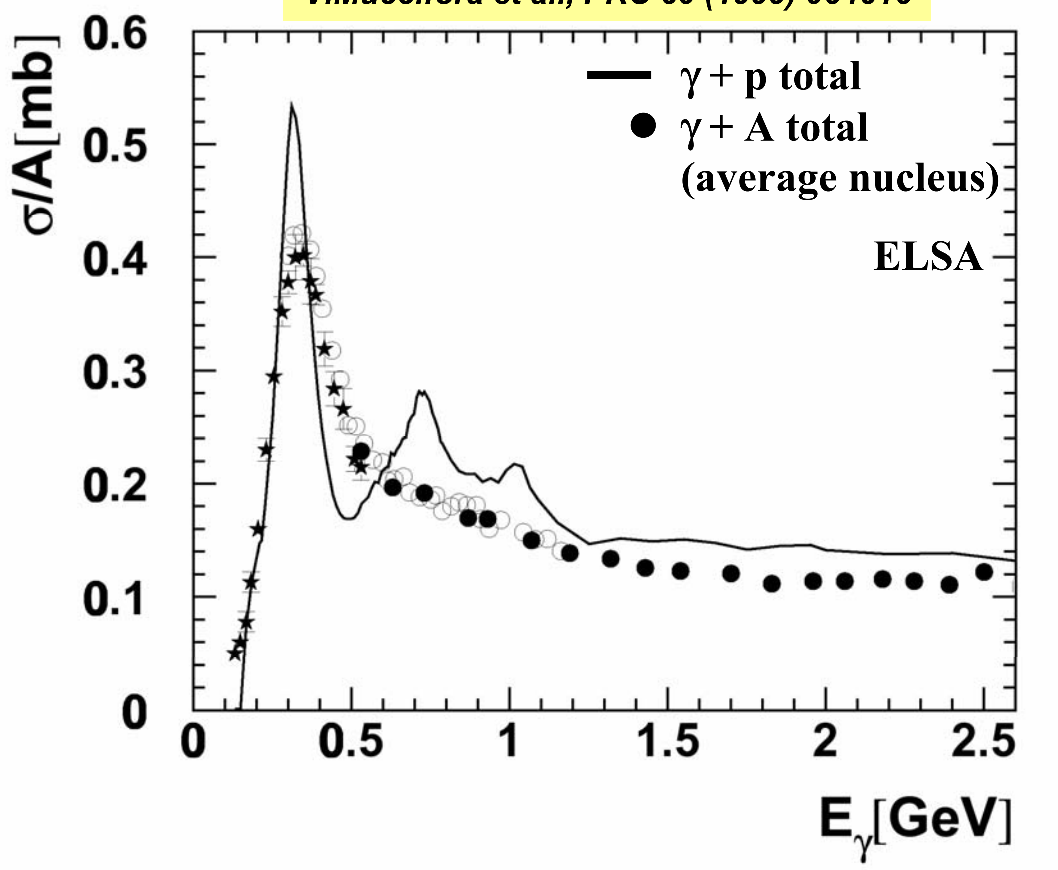
SAPHIR (Bonn)
CBELSA (Bonn)
DAPHNE, TAPS (Mainz)
GRAAL (Grenoble)

○ π^o
● π^+
■ $\pi^+\pi^-$
● $\pi^+\pi^o$
○ $\pi^o\pi^o$
★ η
▲ ω
□ $K^+\Lambda$
△ $K^+\Sigma^o$
✡ $K^o\Sigma$
○ ϕ

Nuclear Photoabsorption: γ + A

total cross section per nucleon

V.Muccifora et al., PRC 60 (1999) 064616



evidence for medium modification:
no resonance structures
above 0.6 GeV

- $D_{13} \rightarrow N\rho$ decay branch
Mosel et al.

- modified $\pi\pi$ interaction/ interferences
Hirata et al.
Oset et al.

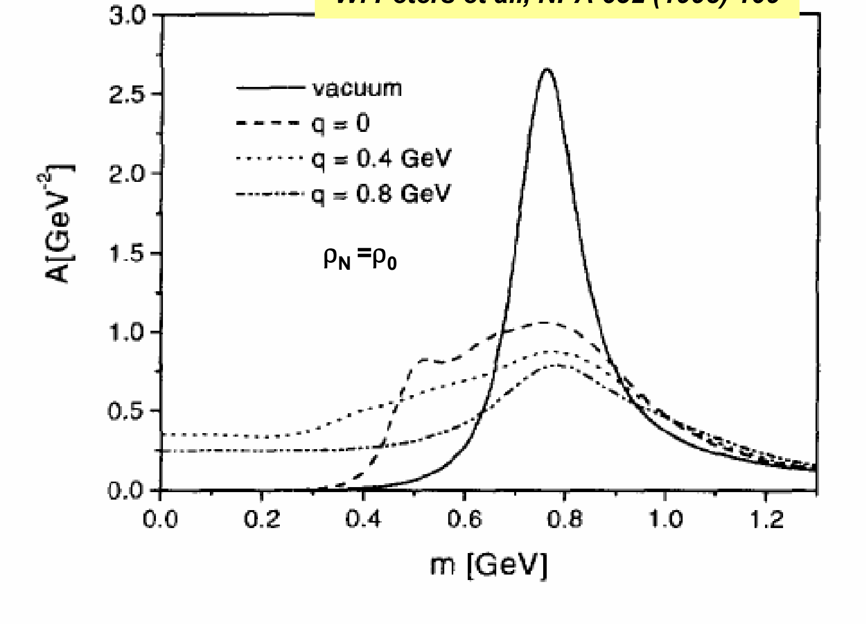
→ resonance broadening in medium ?

↓

study meson production
(quasifree production)

ρ Meson in the Nuclear Medium

W. Peters et al., NPA 632 (1998) 109

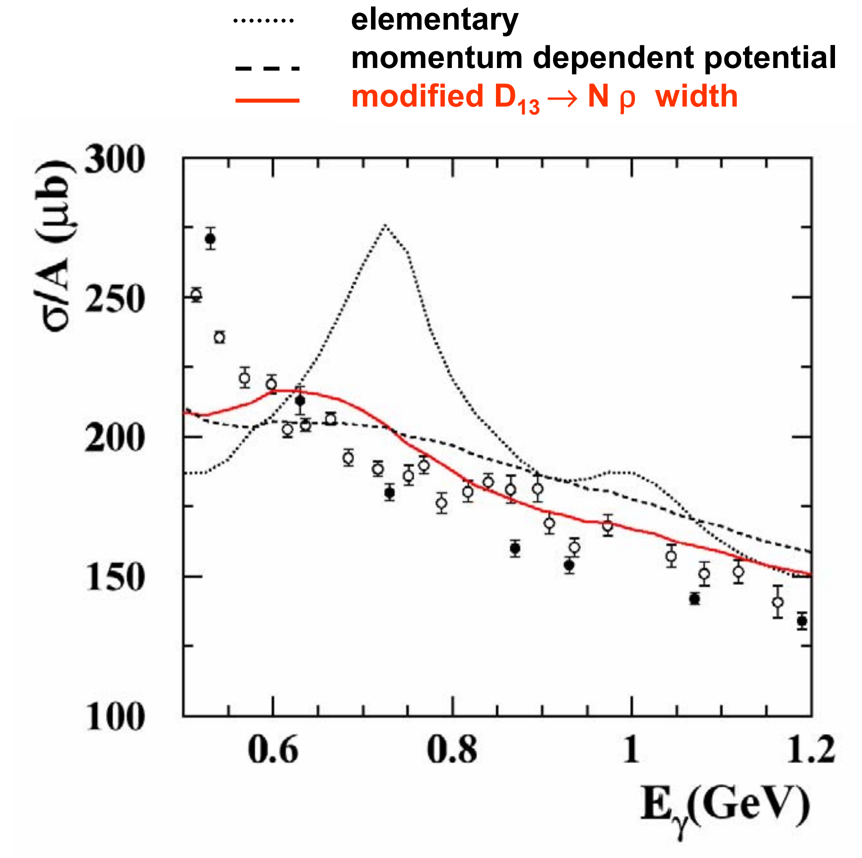


prediction:
in-medium broadening of ρ meson
⇔ coupling to D_{13} (1520)

effect on
$\rho \rightarrow e^+ e^-$
$\rho \rightarrow \pi\pi$

effect on photoabsorption:

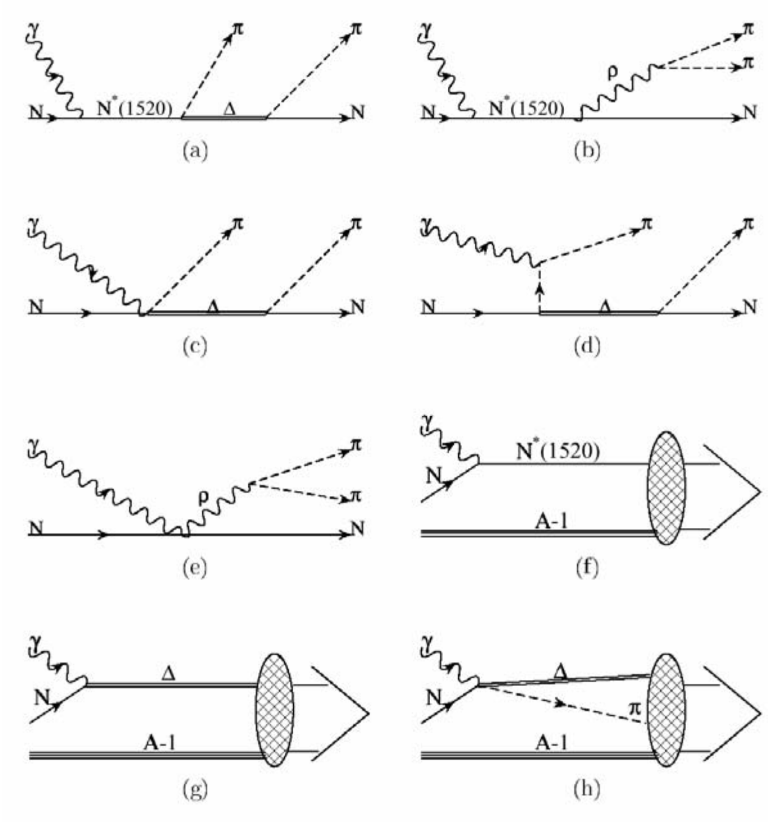
J. Lehr et al., NPA 671 (2000) 503

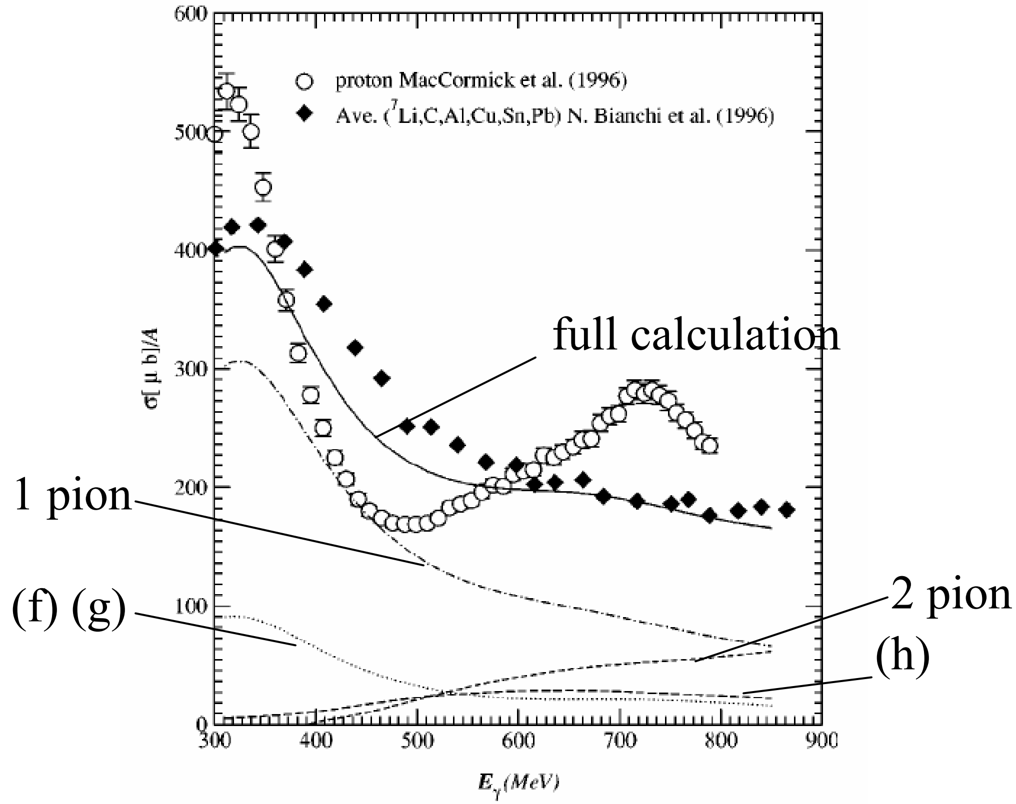


- **modified $D_{13} \rightarrow N\rho$ width**
- **depletion of 2. resonance region possible**

NUCLEAR PHOTOABSORPTION AT PHOTON ENERGIES BETWEEN 300 AND 850 MEV

HIRATA, KATAGIRI, OCHI, AND TAKAKI PHYSICAL REVIEW C **66**, 014612 (2002)





• cooperative effect of the interference in two-pion photoproduction processes
• collision broadening of Δ and N*(1520)
• pion distortion in the nuclear medium

<u>the change of the interference effect by the medium plays an important role</u>

Medium Effects

on baryon resonances:

- **Fermi-motion** $\Gamma \nearrow$
- **meson decay** $\Gamma \searrow$

  $N^* \rightarrow N + meson$ **(Pauli blocking)**
- **collisional broadening** $\Gamma \nearrow$

  $N^*N \rightarrow N^*N$
- **quenching** **reduction of meson yield**

  $N^*N \rightarrow NN$
- **N*-propagation** **mass / width**

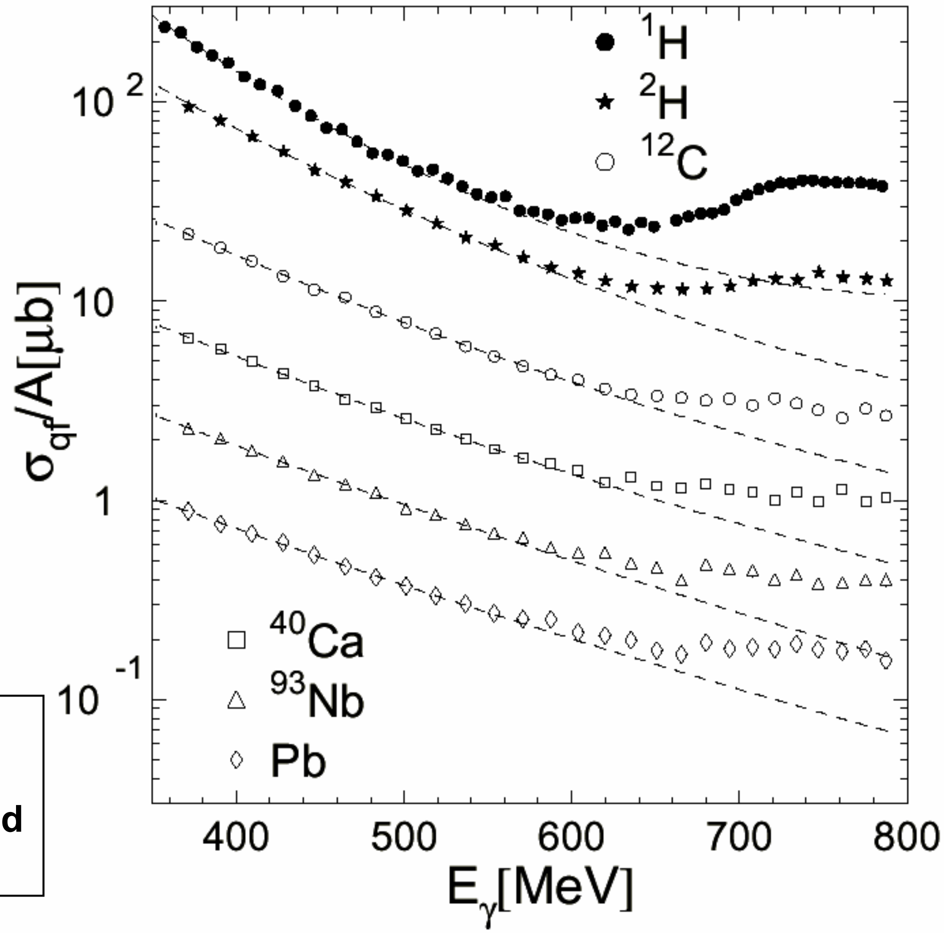
  self energy

investigating the second resonance region:
- **comparison of heavier nuclei with deuteron**
- **resonance contribution qualitatively not changed**

no indication for broadening or depletion

A(γ , π°)

B. Krusche et al., PRL 86 (2001) 4764



on mesons:

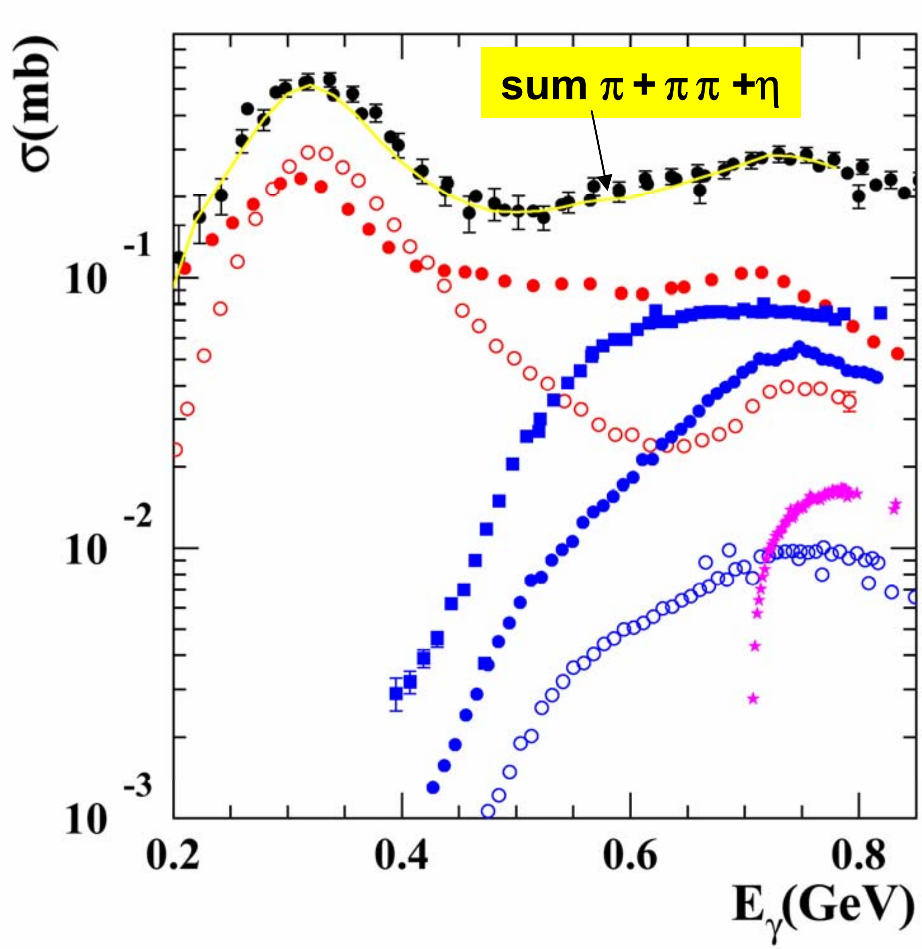
absorption/rescattering

modified meson-meson interaction

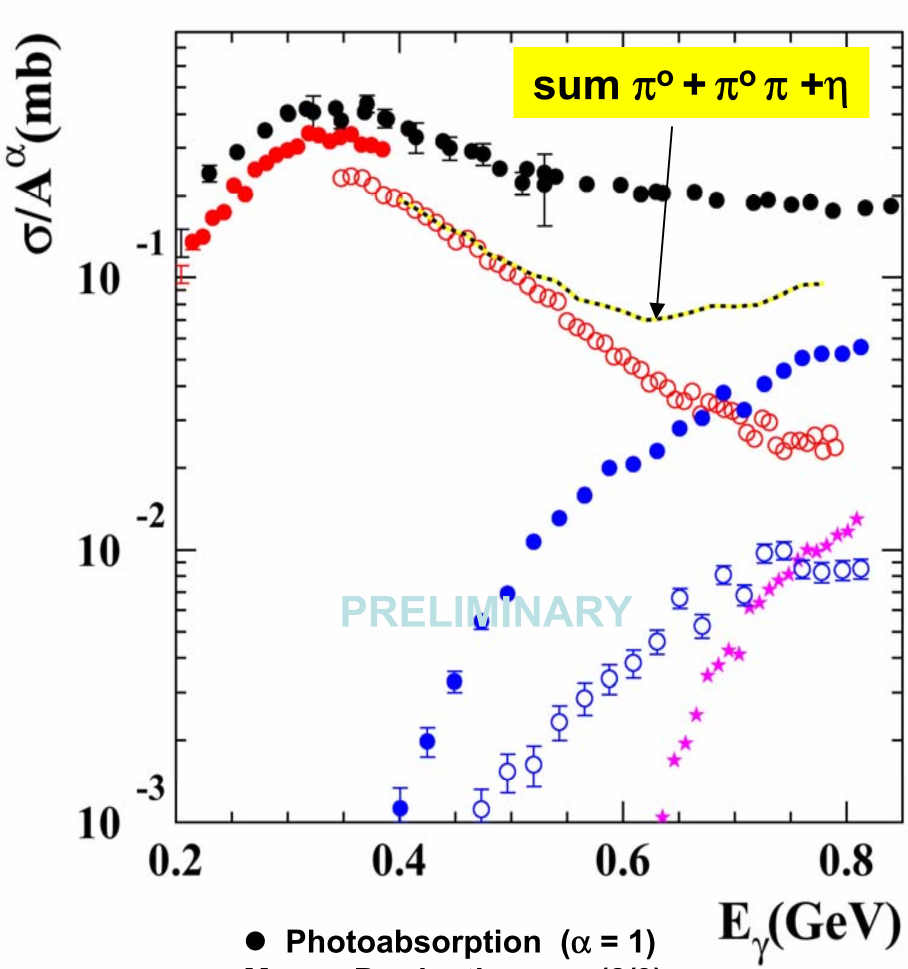
chiral symmetry restoration

meson-resonance coupling

Meson Photoproduction from the Proton



Meson Photoproduction from Nuclei



● Photoabsorption ($\alpha = 1$)
Meson Production $\alpha = (2/3)$

○ p, C (γ , π^o)
● p, C (γ , π^+)

■ p (γ , $\pi^+ \pi^-$)
● p, Pb (γ , $\pi^+ \pi^o$)
○ p, Pb (γ, $\pi^o \pi^o$)

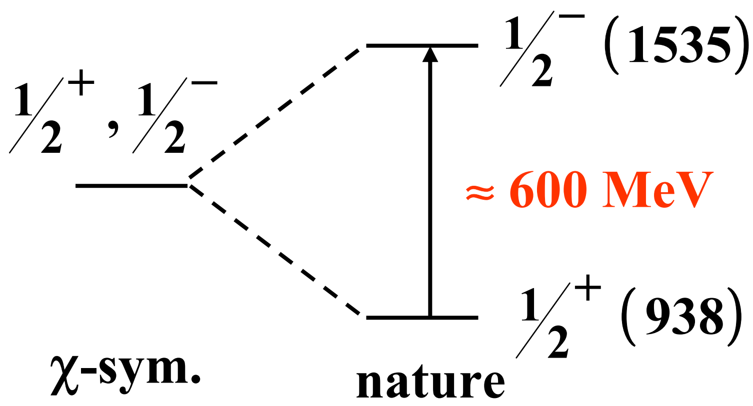
★ p, Pb (γ , η)

S.Schadmand

The Role of Chiral Symmetry Breaking

$m_N = 938$ MeV >> $m_q \approx 5 - 10$ MeV
determined by interaction among partons

- **chiral symmetry = fundamental symmetry of QCD for massless quarks**
- **chiral symmetry broken on hadron level**



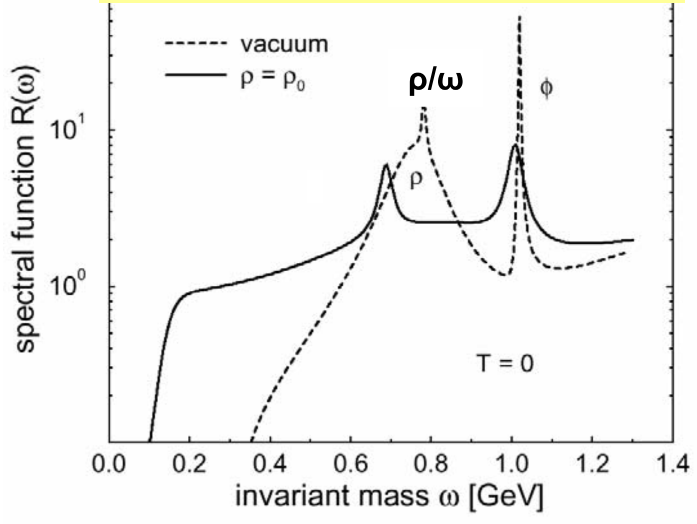
To understand the origin of mass:

can we (partially) restore chiral symmetry?

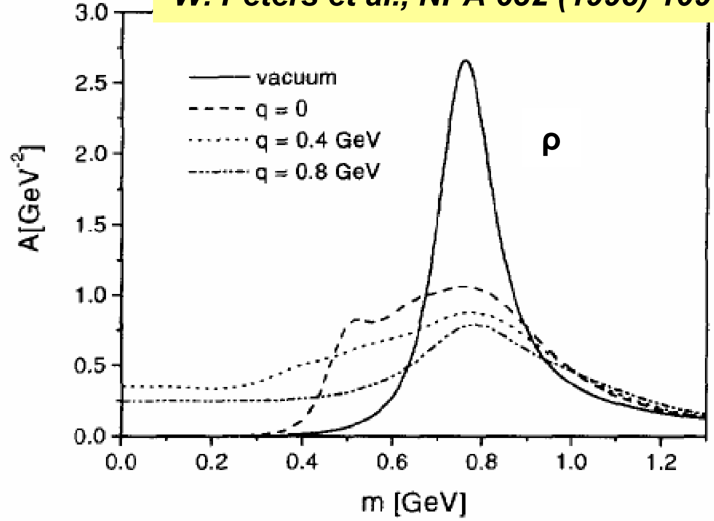
<u>changes of hadron properties in the nuclear medium</u>

Model predictions for ρ and ω mesons

T. Renk et al., PRC 66, 014902, 2002

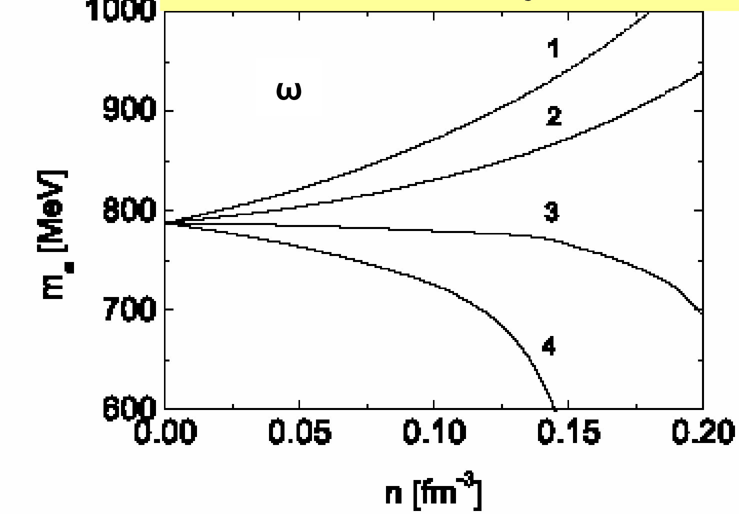


W. Peters et al., NPA 632 (1998) 109



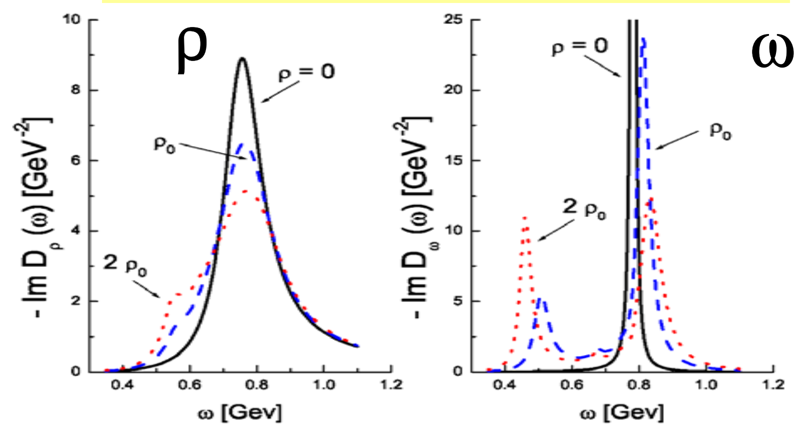
hadronic many body effects

S. Zschocke et al., Phys. Lett. B 562 (2003) 62



variation in ω-mass due to density dependence of 4 quark condensate

M. Lutz et al., Nucl. Phys. A 706 (2002) 431



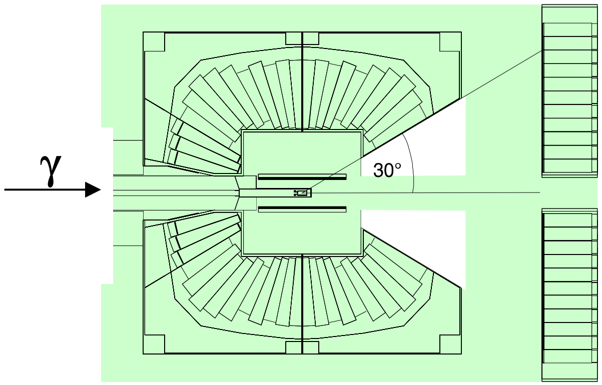
structure in spectral function due to coupling to baryon resonances

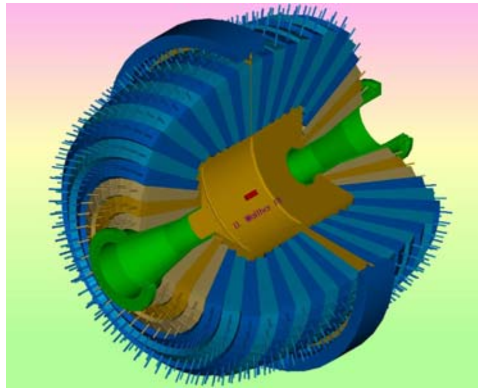
Experimental Method: 4π Photon Spectrometer

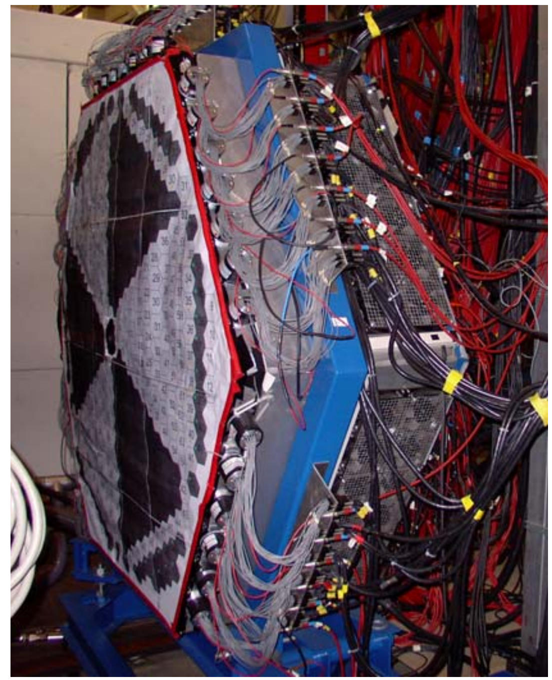
ELSA
E_e =3.5 GeV

Crystal Barrel

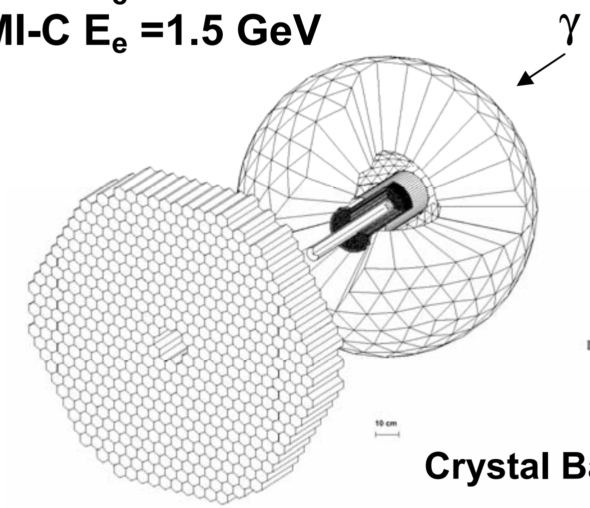
CBELSA/TAPS



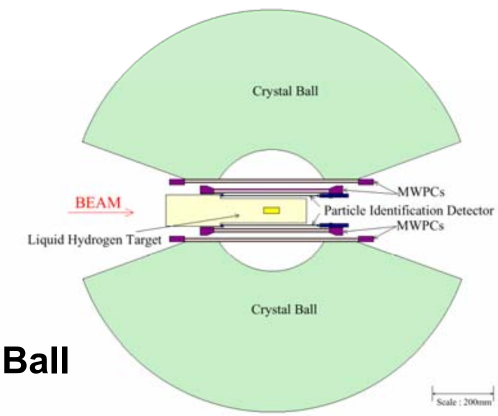




MAMI-B E_e =0.82 GeV
MAMI-C E_e =1.5 GeV



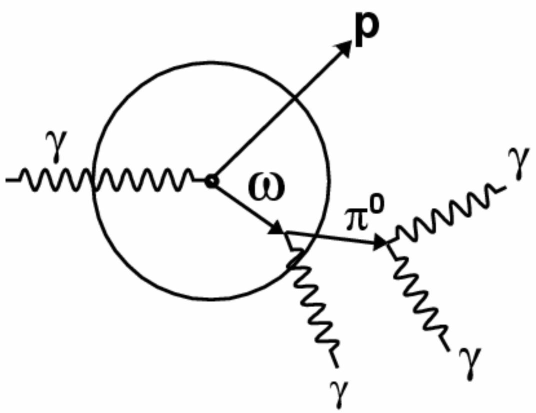
Crystal Ball

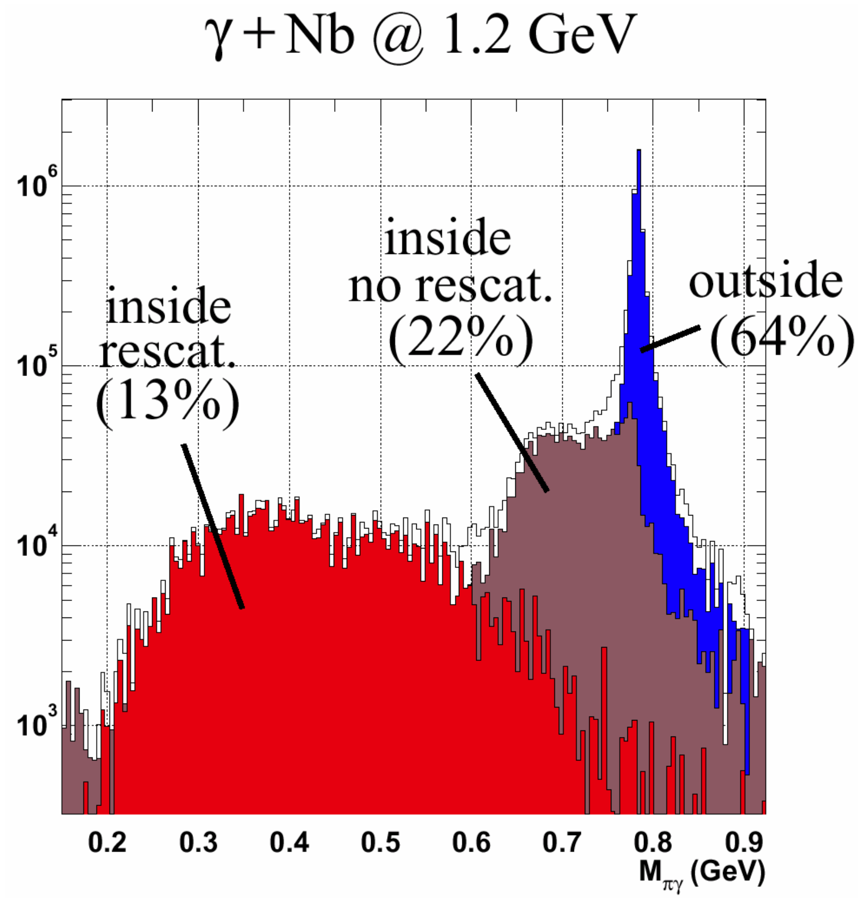


Crystal Ball@MAMI/TAPS

ω-mass in nuclei from photonuclear reactions

J.G.Messchendorp et al., EPJ A11 (2001) 95





advantage:

- $\pi^o\gamma$ large branching ratio (8 %)
- no ρ-contribution ($\rho \rightarrow \pi^o\gamma : 7 \cdot 10^{-4}$)

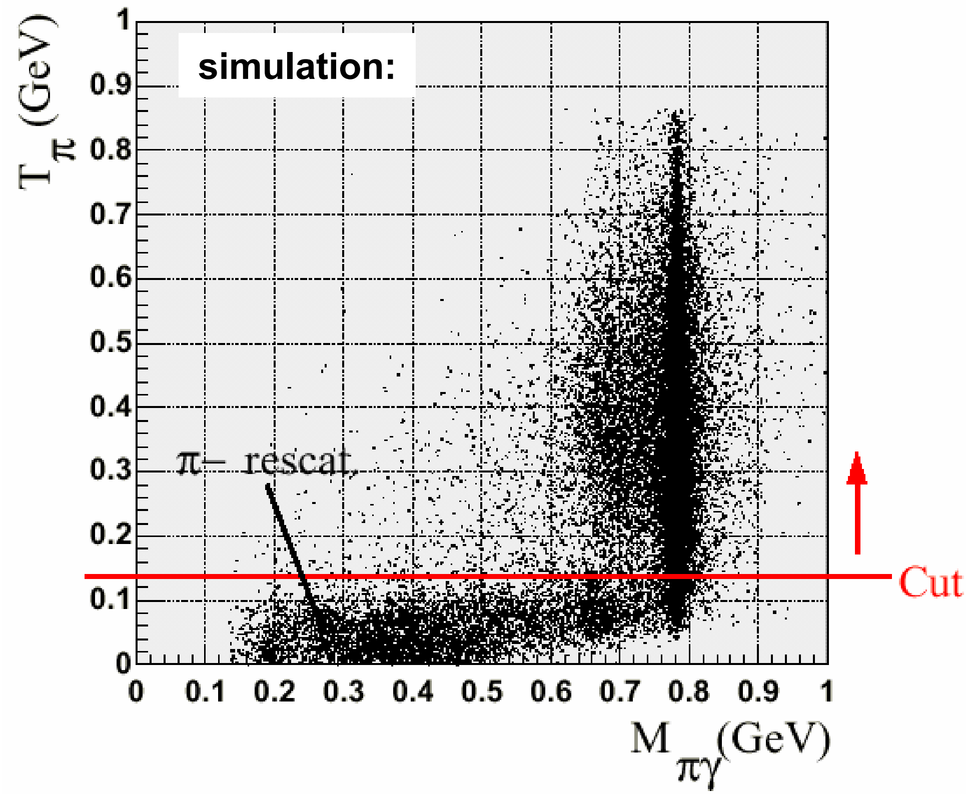
disadvantage:

- π^o-rescattering
- background reactions: $\gamma A \rightarrow 2\pi^o + X$
- mass resolution

ω-mass in nuclei from photonuclear reactions

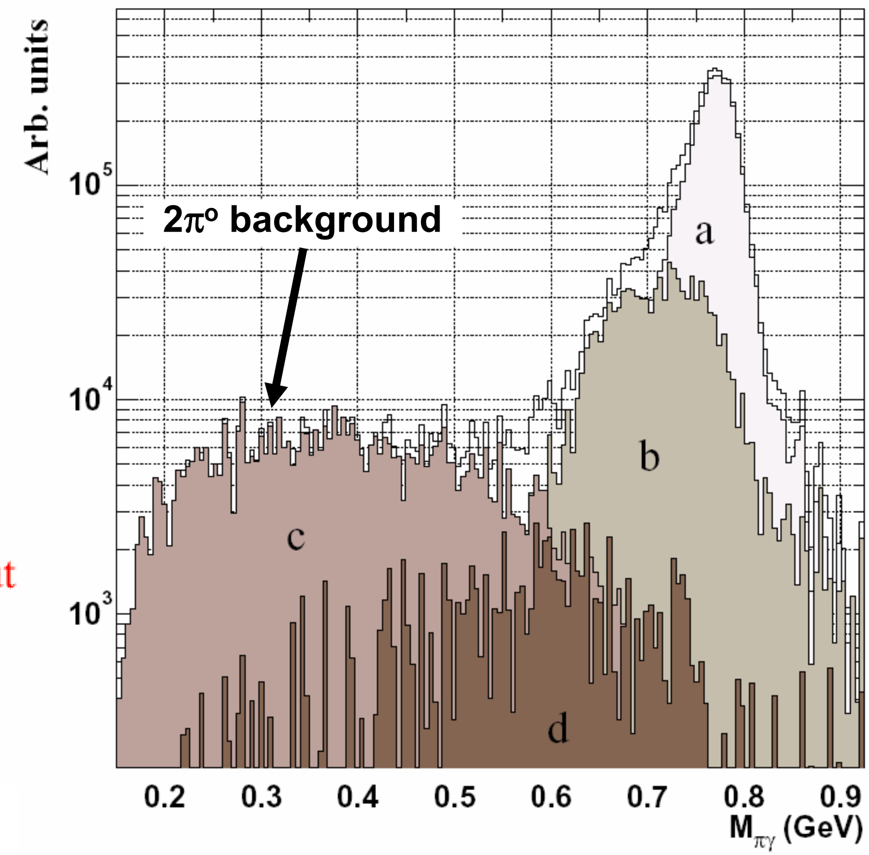
J.G.Messchendorp et al., EPJ A11 (2001) 95

$$\gamma + Nb@1.2GeV;\omega \rightarrow \pi^o\gamma$$



reduce rescattering using cut
on kinetic energy of the pion

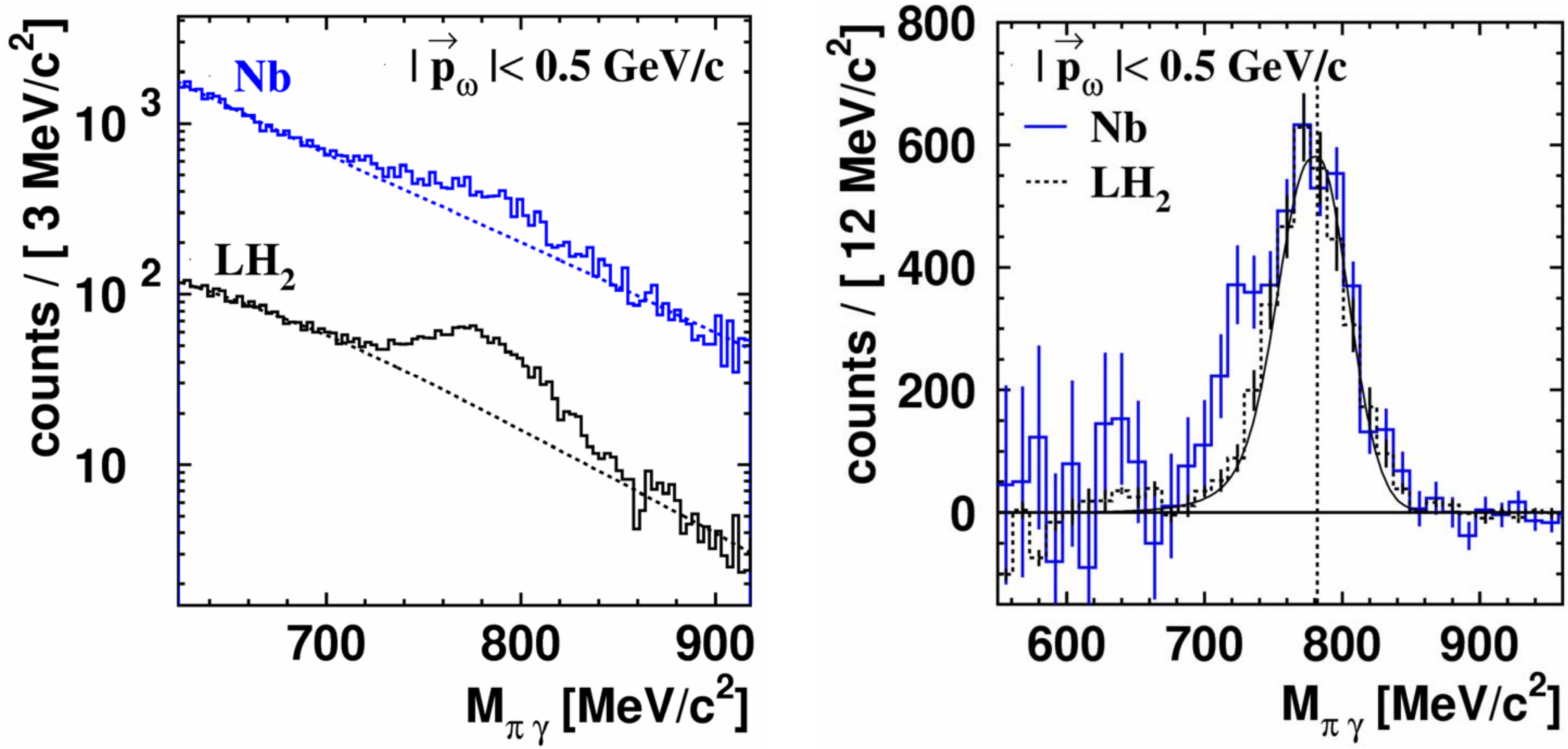
(including detector resolution)



- supression of background in the region of interest
- visible shoulder in lineshape from mass shifted mesons

inclusive $\omega \to \pi^0\gamma$ signal for LH_2 and Nb target

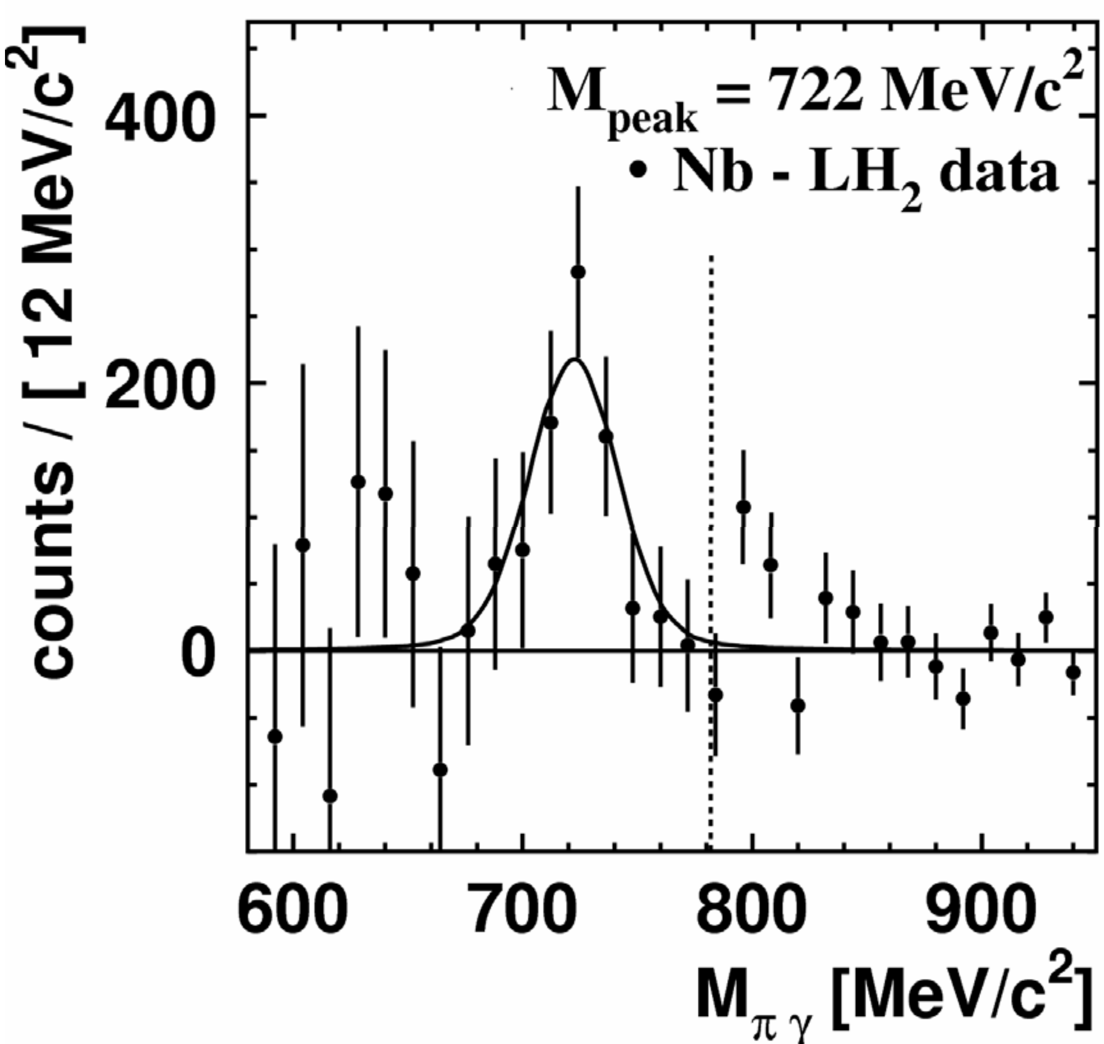
D. Trnka et al. PRL (2005) 192303



difference in line shape of ω signal for proton and nuclear target

contribution from ω in-medium decays

D. Trnka et al. PRL (2005) 192303



ω decays in vacuum removed by subtracting ω mass distribution measured with LH_2 target (75%)

strength of in-medium ω decays concentrated around masses of 722 MeV
⇒ mass drop by about 8% at estimated baryon density of about 0.6 ρ_0

consistent with
$m_\omega = m_0 (1 - 0.14\, \rho/\rho_0)$

2001 - 2003

Indications for Medium Modifications of Mesons

vector mesons

- $\rho \rightarrow e^+e^-$ in ultra-relativistic heavy-ion collisions (CERES/CERN)
- $\rho \rightarrow e^+e^-$ in pA collisions at 12 GeV (KEK)
- $\omega \rightarrow \pi^o\gamma$ by comparison of $p(\gamma,\omega)$ and $A(\gamma,\omega)$ (CBELSA/TAPS @ Bonn)
- $\Phi \rightarrow K^+K^-$ systematics from $A(\gamma,\omega)$ (LEPS@SPRing8)
- π^- $p \rightarrow n\omega$ on bound protons planned at HADES @ GSI

pseudoscalar mesons

- K^+ and K^- mesons from yields in near threshold heavy-ion reactions (KAOS @ GSI)

scalar mesons

- ``σ´´meson: $\pi^o\pi^o$ interaction (TAPS@MAMI, Crystal Ball)

charm sector

- J/ψ , D: experiments planned at PANDA@FAIR

So far, experiments are in accordance with theoretical scenarios for changes of hadron properties in the nuclear medium.

Studying the in-medium behavior of hadrons is a promising approach to learn more about the origin of their mass.