Experimental approaches for extracting in-medium properties of hadrons from photo nuclear reactions

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

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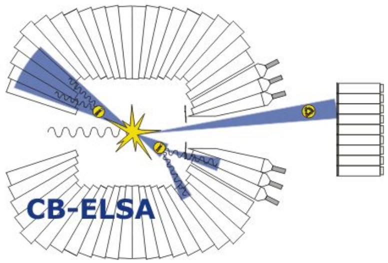
- motivation
- In-medium properties of mesons from the measurement of
  - a.) meson line shape
  - b.) the transparency ratio
  - c.) the meson momentum distribution
  - d.) the excitation function for photoproduction off nuclei
- CBELSA/TAPS (Bonn) and Crystal Ball/TAPS (Mainz) results on in-medium properties of the ω meson
- in-medium properties of the η' meson (talk by M. Nanova, Thursday 18:00)
- summary and conclusions

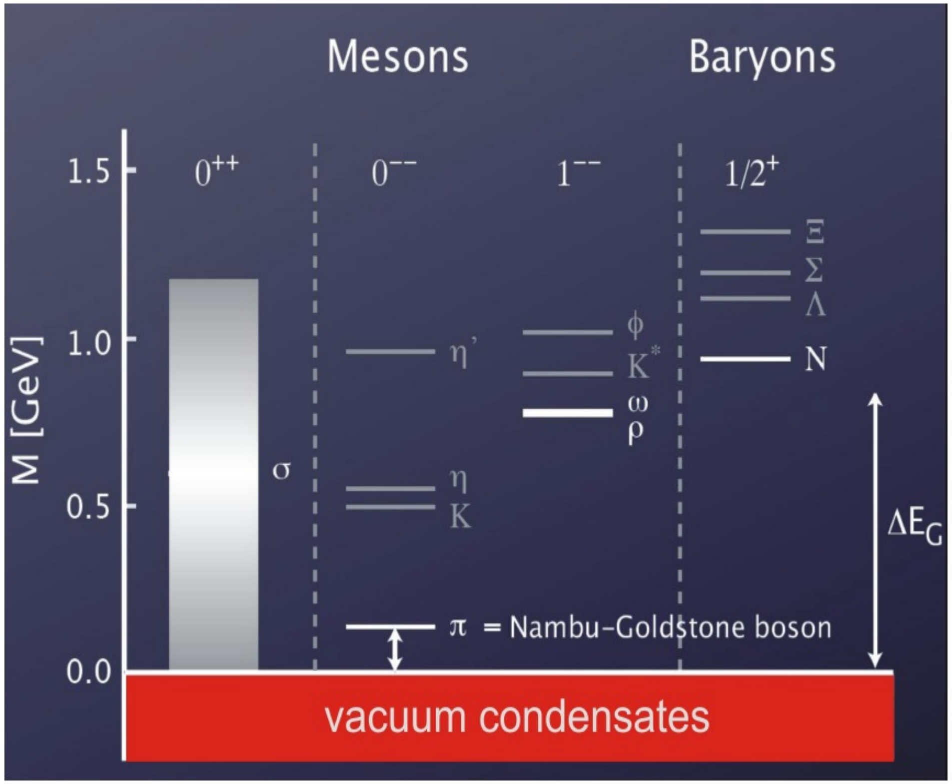


33rd International School of Nuclear Physics
Erice, Sicily, Sept. 16-24, 2011

A2 Collaboration

hadron masses

J.Wambach



- QCD-vacuum: complicated structure characterized by condensates
- in the nuclear medium: condensates are changed

→ change of the hadronic excitation energy spectrum

V. Bernard and U.-G. Meißner, NPA 489 (1988) 647

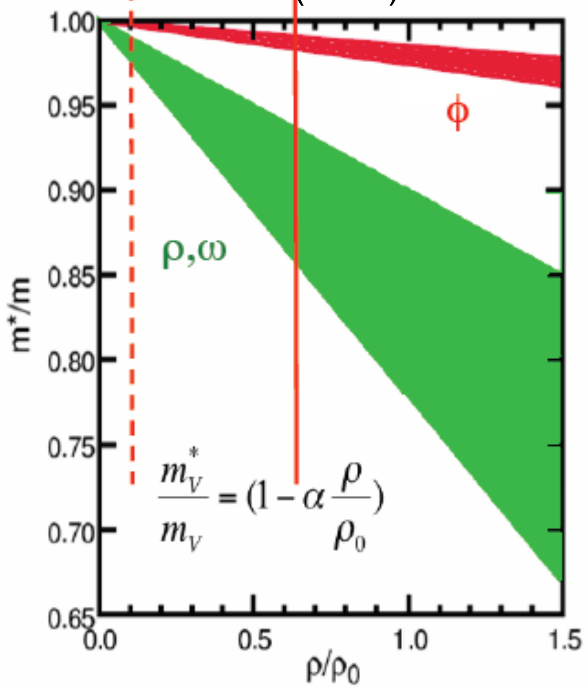
G.E.Brown and M. Rho, PRL 66 (1991) 2720 $\frac{m^*}{m} \approx \frac{\langle \bar{q}q \rangle^*}{\langle \bar{q}q \rangle} \approx 0.8 \, (\rho \approx \rho_0)$

T.Hatsuda and S. Lee, PRC 46 (1992) R34 $\frac{m_V^*}{m_V} = \left(1 - \alpha \frac{\rho_B}{\rho_0}\right) ; \; \alpha \approx 0.18$

⇒ widespread theoretical and experimental activities to search for in-medium modifications of hadrons

Model predictions for in-medium masses of mesons

T. Hatsuda, S.Lee
PRC 46 (1992) R34



drop of ρ,ω mass by
≈ 10% at average
nuclear density of 0.6 ρ_0

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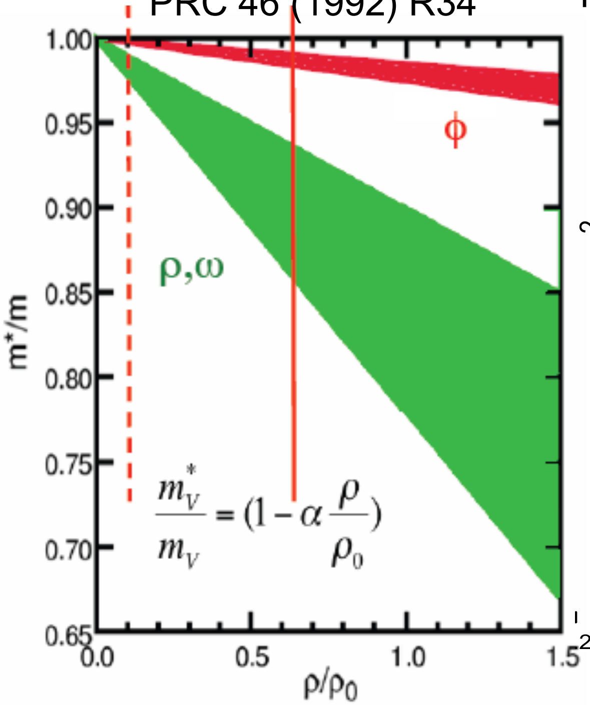
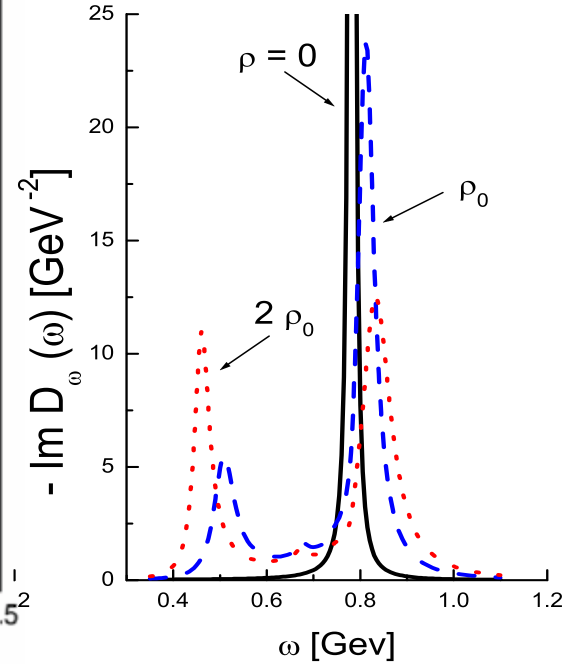


M. Lutz et al., NPA 706 (2002) 431



drop of ρ,ω mass by ≈ 10% at average nuclear density of 0.6 ρ_0

structure in spectral function due to coupling to baryon resonances

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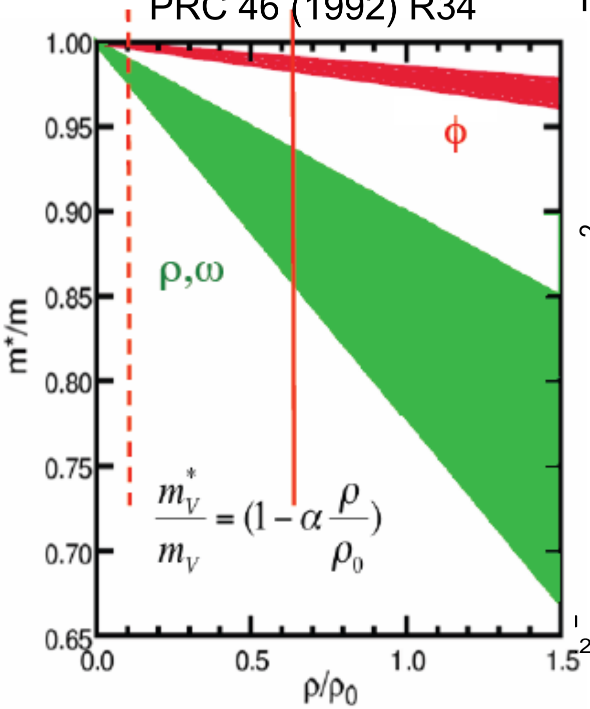

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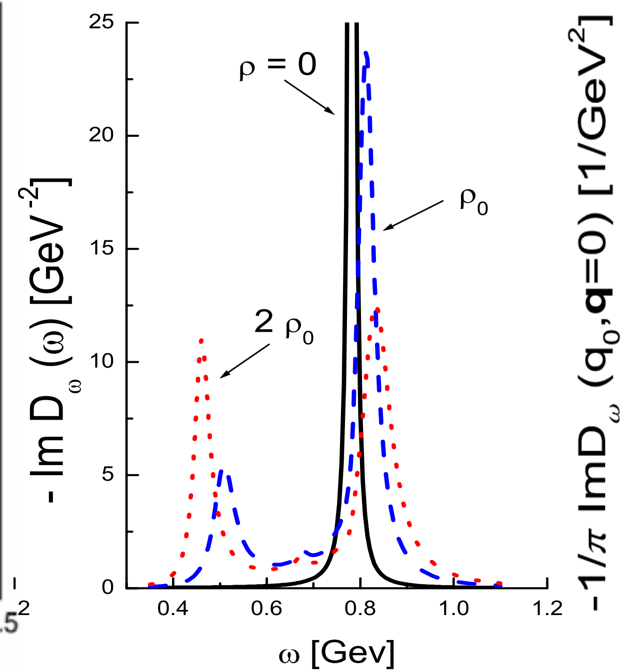

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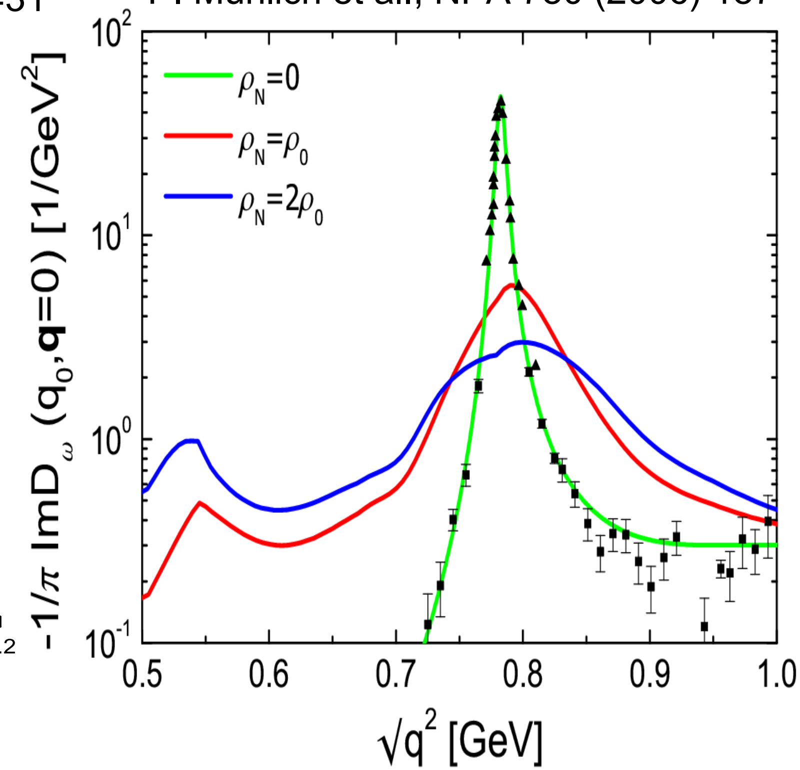
P. Mühlich et al., NPA 780 (2006) 187



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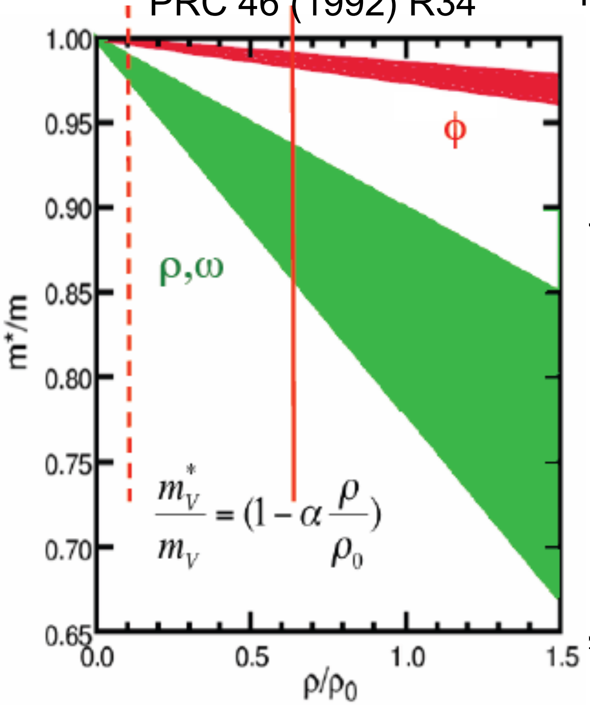

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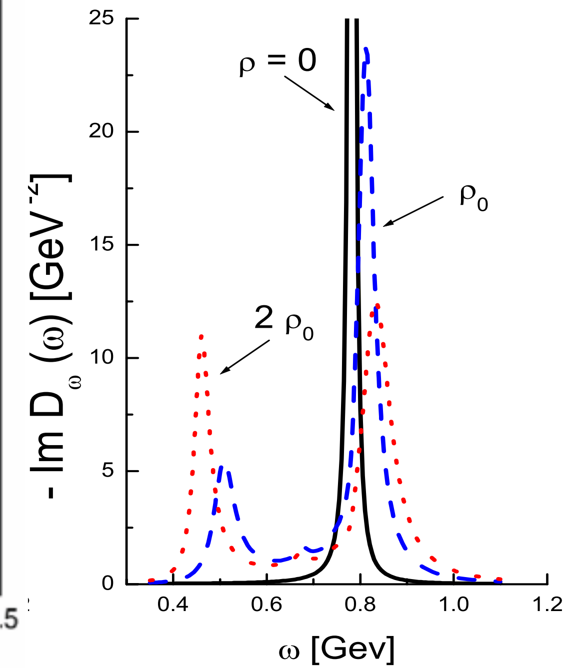

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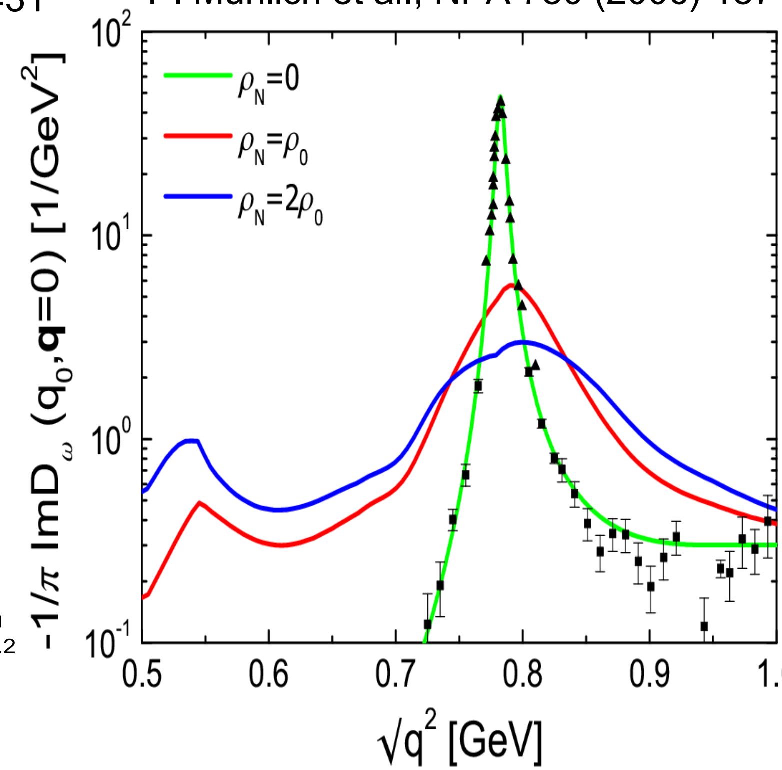

drop of ρ,ω mass by ≈ 10% at average nuclear density of 0.6 ρ_0

structure in spectral function due to coupling to baryon resonances

- broadening of ω spectral function due to inelastic channels

experimental task: search for { **mass shift ? broadening ? structures ?** } **of hadronic spectral function**

experimental approaches for studying in-medium effects

1. Measurement of meson line shape: M ➔ $X_1 + X_2$

$\Rightarrow$ in-medium mass shift ?
broadening ? structures ?

$$\mu_H(\rho,\vec{p}) = \sqrt{(p_1 + p_2)^2}$$

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• ensure that decays occur in the medium: select shortlived mesons:
decay length s = βγ·cτ comparable to nuclear dimensions

for $\beta\gamma = \frac{p}{mc} \approx 1$ s ≈ 1.3 fm (ρ) ; 23 fm (ω) ; 46 fm (φ)

cut on low meson momenta for ω and φ mesons

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- avoid distortion of 4-momentum vectors by final state interactions
  $\Rightarrow$ dilepton spectroscopy: $\rho, \omega, \phi \rightarrow e^+e^-$

  disadvantage: branching ratio $\approx 10^{-4} - 10^{-5}$

  decay mode used in our experiments: $\omega \rightarrow \pi^0\gamma \rightarrow \gamma\gamma\gamma$ br=8.9%

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sensitive to nuclear density at decay point !!!!

experimental approaches for studying in-medium effects

sensitive to nuclear density at production point !!!!

2. Measurement of the transparency ratio: $T_A = \frac{\sigma_{\gamma A \to VX}}{A \cdot \sigma_{\gamma N \to VX}}$

production probability per nucleon within nucleus compared to production probability on free nucleon

$\Rightarrow$ absorption $\Rightarrow$ in-medium width;
applicable to any meson lifetime

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In case of a dropping in-medium mass: when leaving the nucleus hadron has to become on-shell; mass generated at the expense of kinetic energy; applicable to any meson lifetime

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4. Measurement of the excitation function

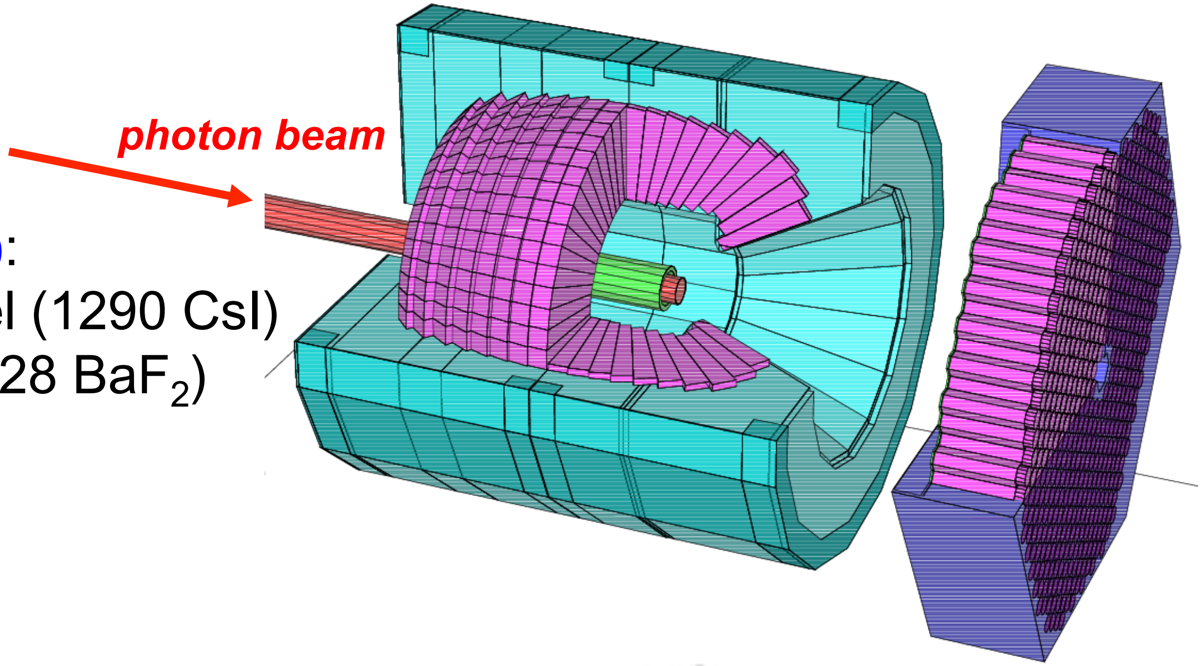
$\Rightarrow$ in-medium mass shift, broadening

for given $\sqrt{s}$ higher meson yield in case of dropping mass

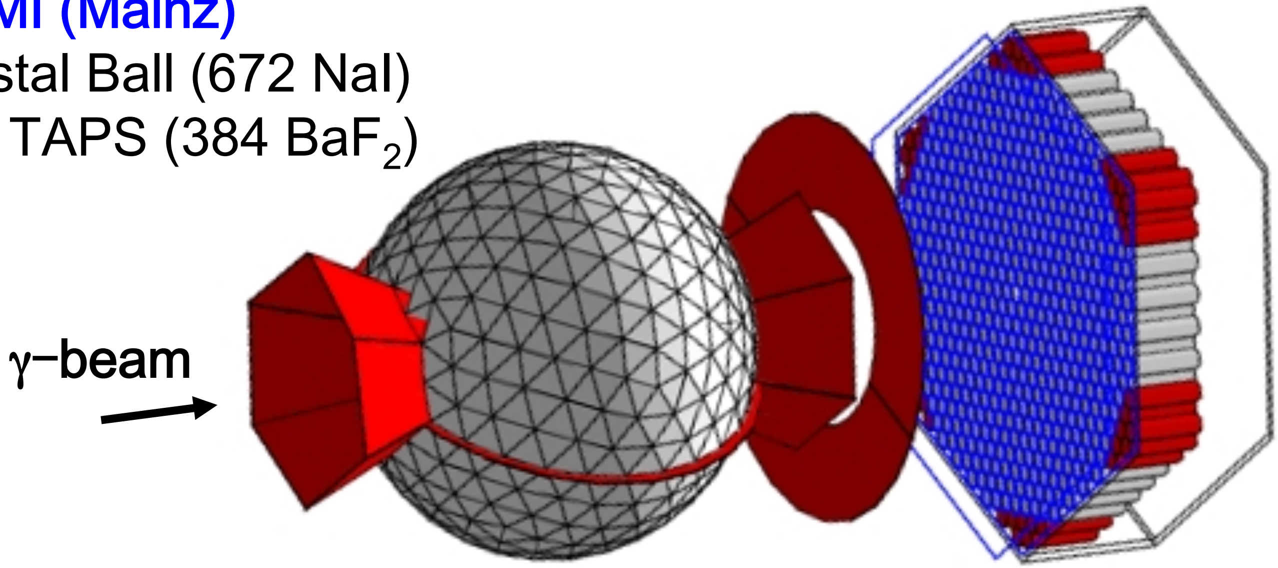
Experimental setups

4π photon detectors
$\omega \rightarrow \pi^0 \gamma \rightarrow 3\gamma$

ELSA (Bonn):
Crystal Barrel (1290 CsI)
and TAPS (528 BaF_2)



MAMI (Mainz)
Crystal Ball (672 NaI)
and TAPS (384 BaF_2)



ω in-medium width

In-medium ω = quasi-particle; properties reflect interaction with the medium;

additional inelastic channels removing ω -mesons, e.g. $\omega N \rightarrow \pi N$

→ shortening of ω -lifetime; increase in width

in-medium ω inelastic width proportional to ω absorption: $\Gamma(\rho,|\vec{p}_\phi|) \propto \rho v \sigma_{abs}$

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$\omega \rightarrow \pi^0 \gamma$

transparency ratio:

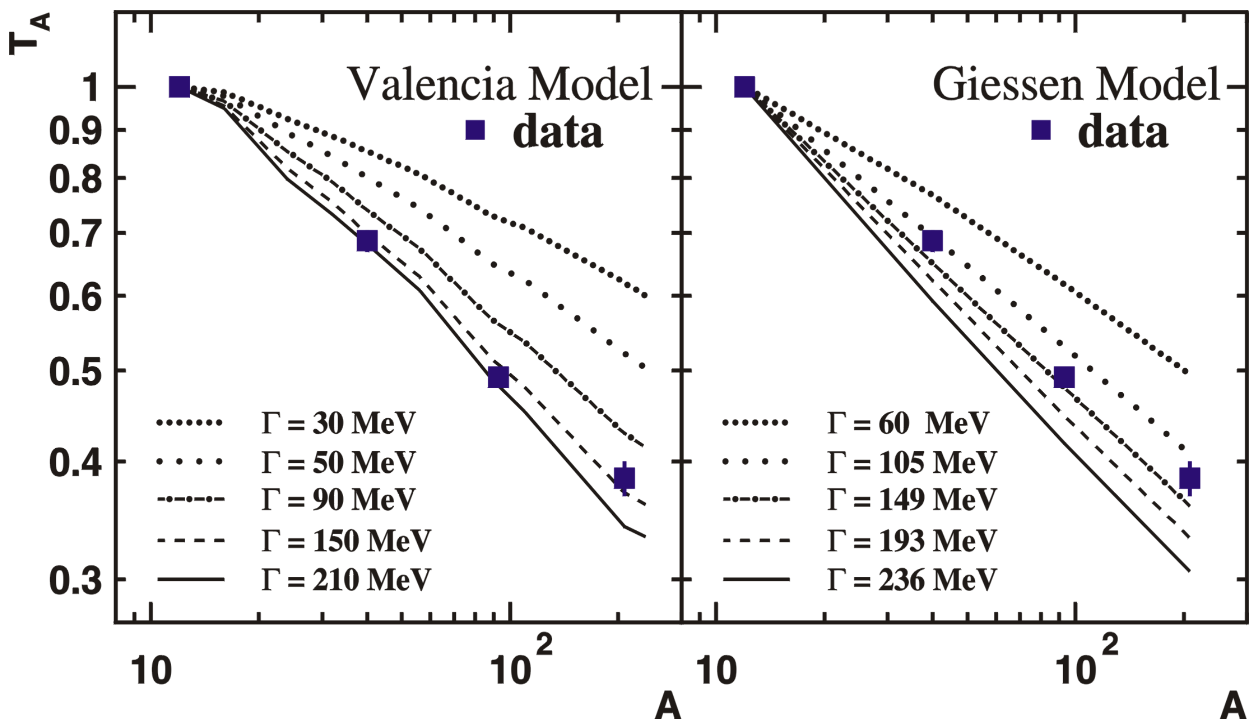
$$T_A = \frac{\sigma_{\gamma A \rightarrow \omega X}}{A \cdot \sigma_{\gamma N \rightarrow \omega X}}$$

normalized to C

comparison to transport model calculations:

M. Kaskulov, E. Hernandez, E. Oset EPJ A 31 (2007) 245

P. Mühlich and U. Mosel NPA 773 (2006) 156



comparison to data $\Gamma(\rho_0, <|\vec{p}_\omega|> \approx 1.1 \text{ GeV/c}) \approx 130\text{-}150$ MeV

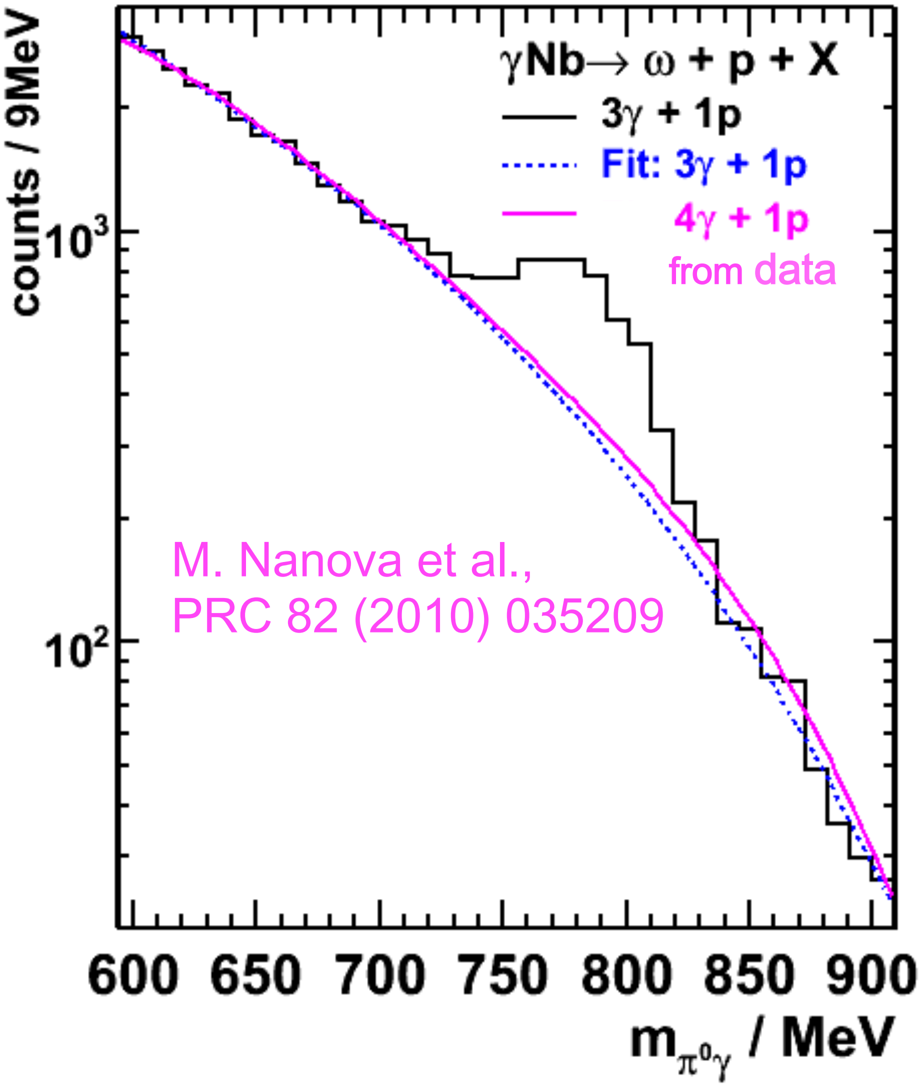
ω is broadened in the medium by a factor ≈16!!

in-medium ω width comparable to free ρ width !!

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

$\omega \rightarrow \pi^0\gamma$ lineshape analysis

Main problem: background subtraction



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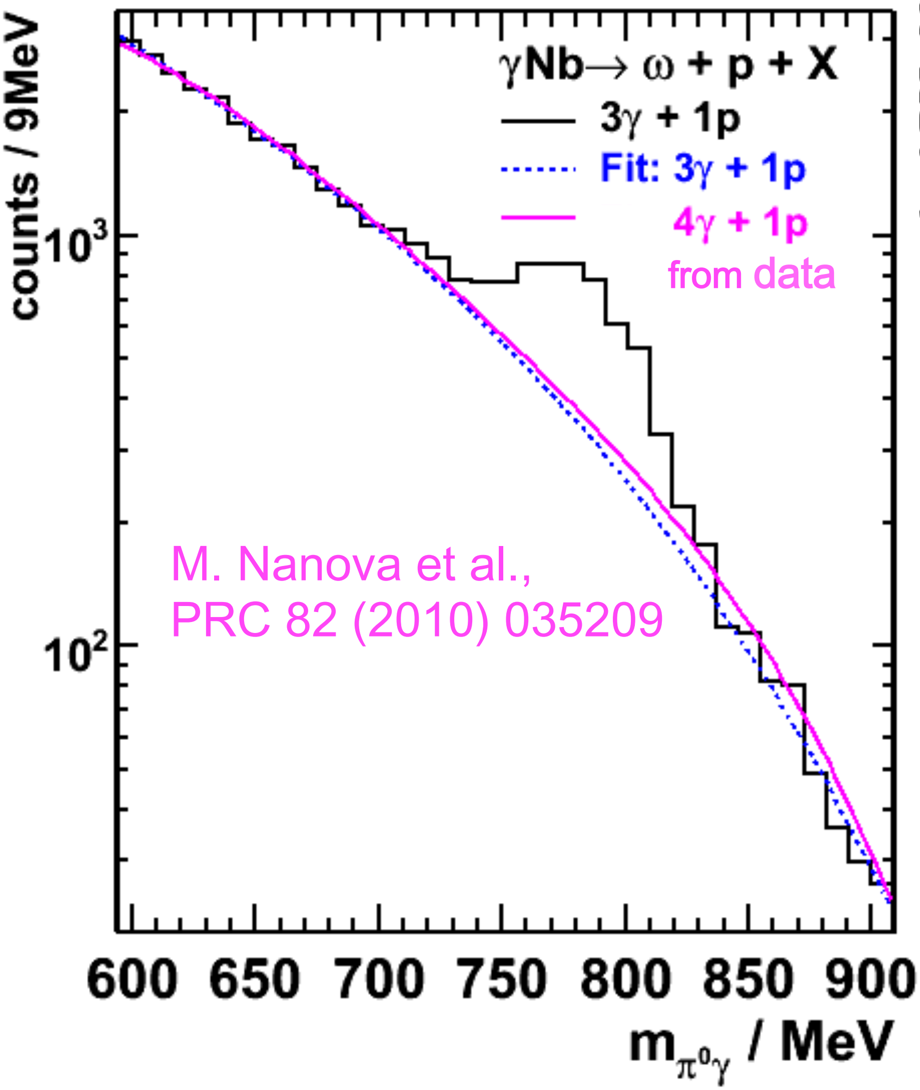

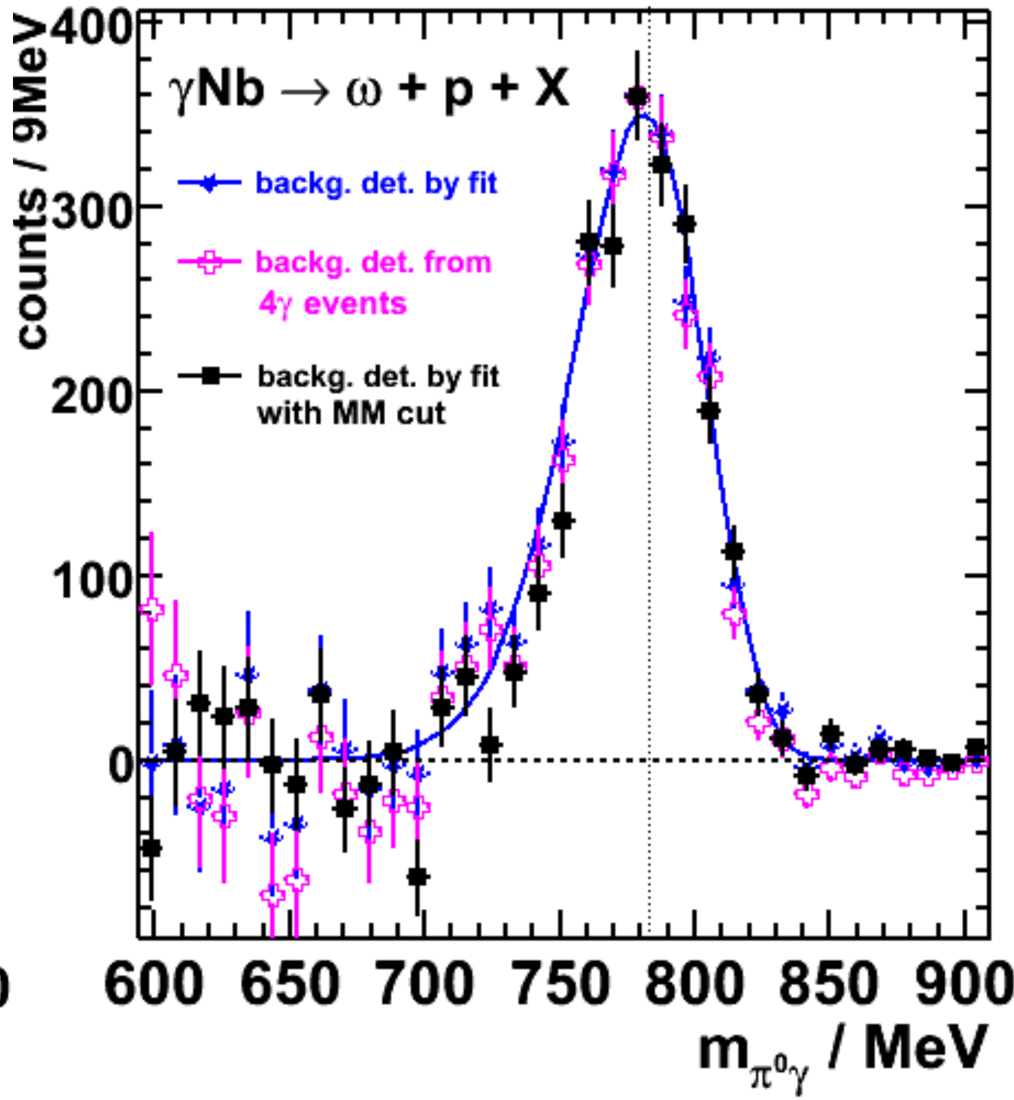

➔ Systematic uncertainties due to different background subtraction approaches

ω lineshape analysis (E_γ = 900 – 1300 MeV)

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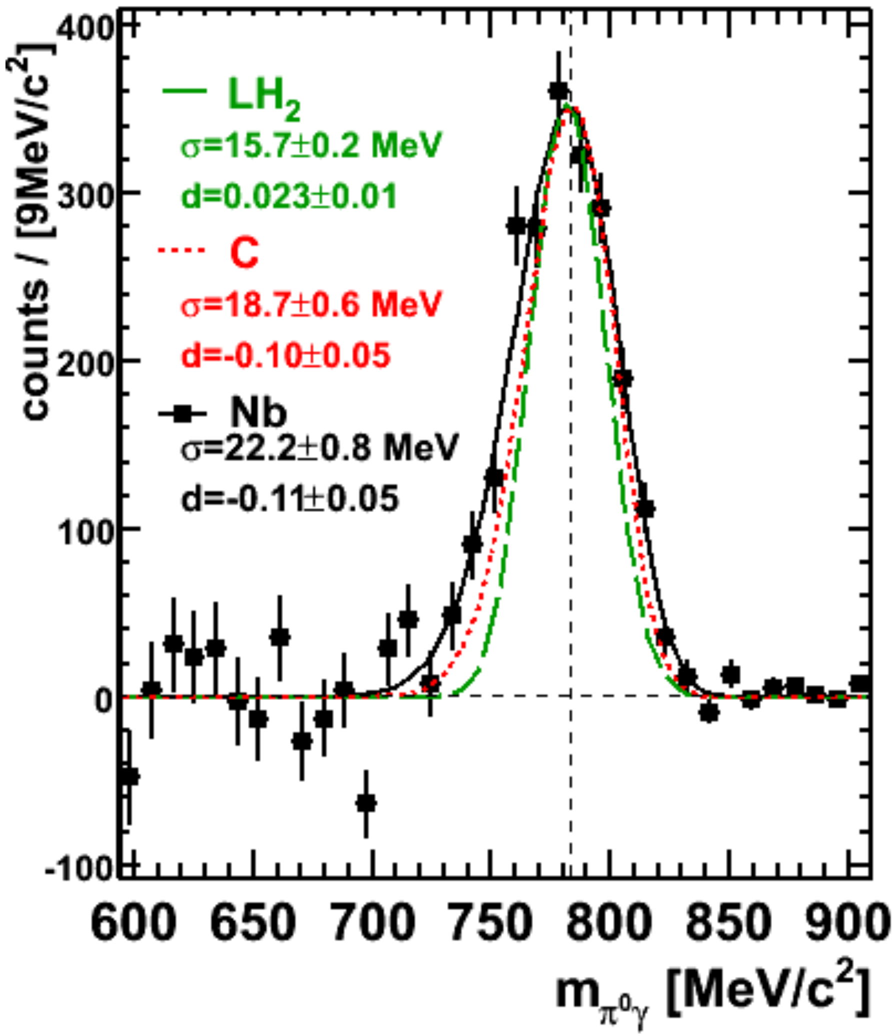

no significant structure in spectral function;
signal on Nb slightly broader than on C, LH_2;
consistent with in-medium broadening of ω

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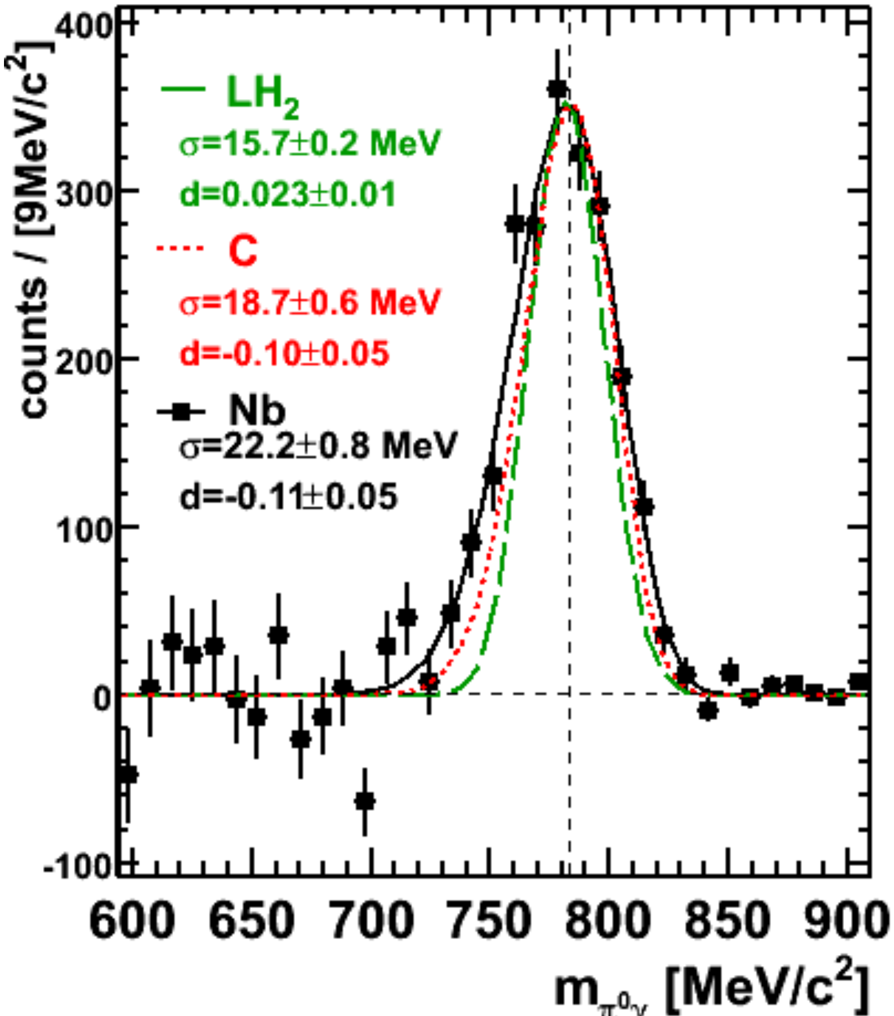
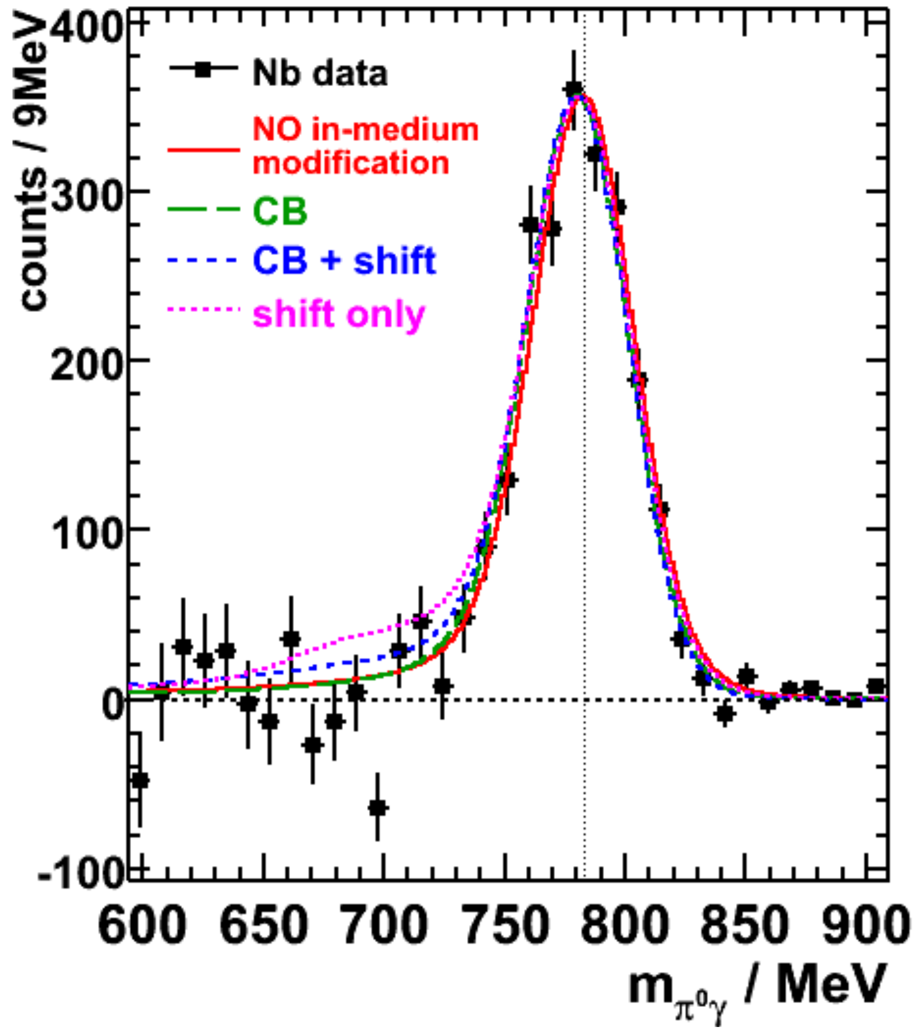


comparison to GiBUU (J. Weil, U. Mosel)



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Shift only scenario less likely, limited sensitivity to in-medium scenarios

Limited sensitivity of line shape analysis

- lineshape analysis sensitive to background subtraction:

  M. Kaskulov, E. Hernandez, E.Oset, EPJA 31 (2007) 245

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

  M. Nanova et al., PRC 82 (2010) 035209; EPJA 47 (2011) 16;

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- experimentally observed mass distribution = convolution of spectral function with branching ratio into channel being studied

$$\frac{d\sigma_{H\to X_1 X_2}}{d\mu} \sim A(\mu)\cdot\frac{\Gamma_{H\to X_1 X_2}}{\Gamma_{tot}(\mu)}$$

F. Eichstaedt et al.,
Prog. Theo. Phys. Suppl. 168 (2007) 495

ω yield reduced by increase of in-medium width ($\Gamma_{med} \approx 16 \bullet \Gamma_{vac}$)

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Prog. Theo. Phys. Suppl. 168 (2007) 495

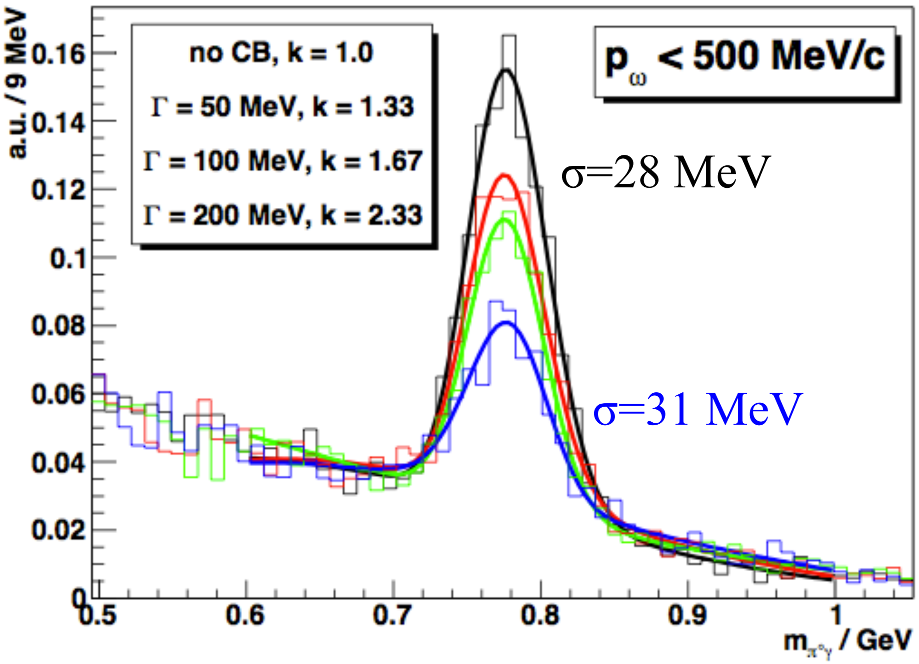
ω yield reduced by increase of in-medium width ($\Gamma_{med} \approx 16\bullet\Gamma_{vac}$)

- reduced in-medium yield spread out in mass,
  difficult to distinguish from background

S. Leupold, V. Metag, U. Mosel, Int. J. Mod. Phys. E 19 (2010) 147; ArXiv:0907.2388

Study of ω in-medium signal in GiBUU simulations

Stefan Friedrich, Janus Weil



- Intensity of $\omega \rightarrow \pi^0\gamma$ signal reduced with increasing collisional width since ω mesons are removed in the nuclear medium via inelastic channels (like $\omega N \rightarrow \pi N$).

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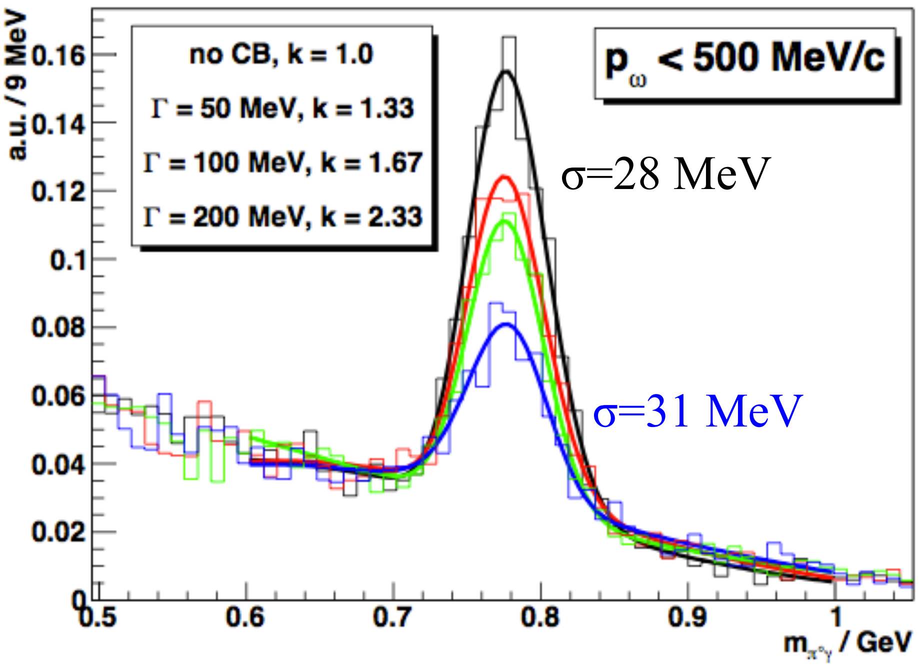

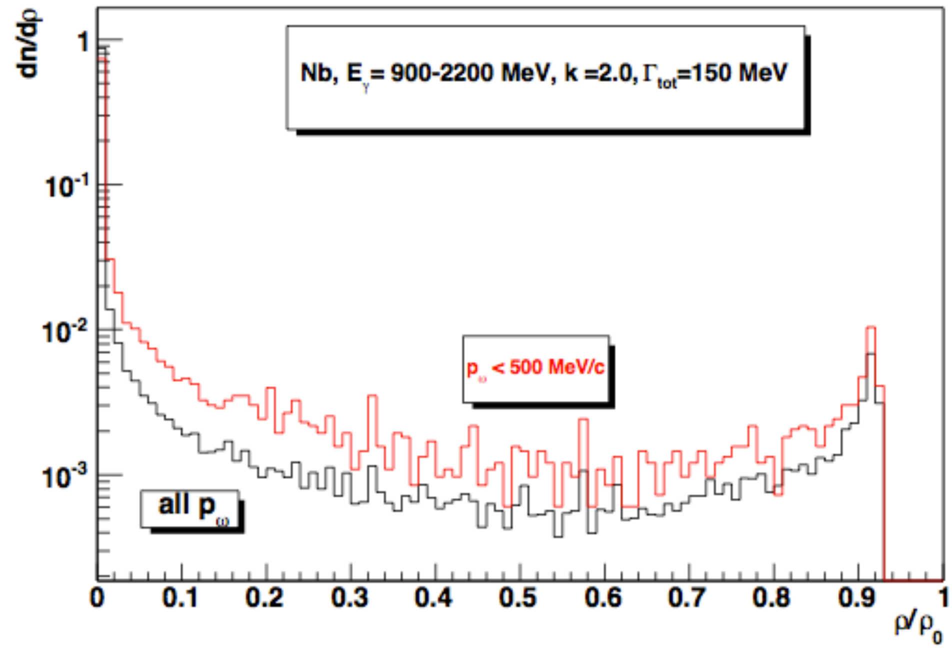

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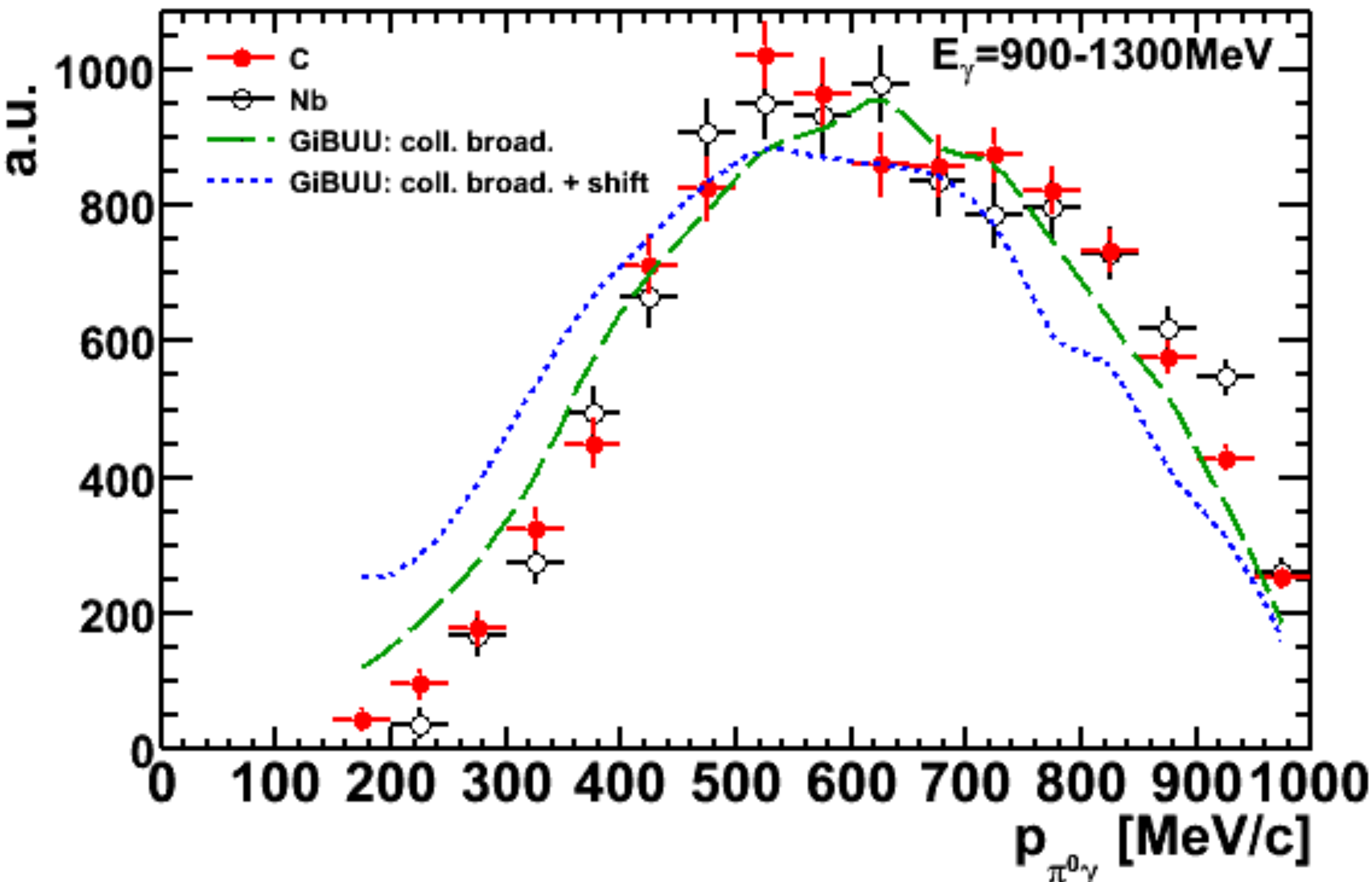
- only 20 % of all ω decays occur at densities $\rho > 0.1\rho_0$ even for $p_\omega < 500$ MeV/c

- ω decays occur over a wide range of densities, thereby smearing out any density-dependent signal

Comparison of ω momentum distribution to GiBUU calculations

comparison to different in-medium scenarios (E_γ = 900 – 1300 MeV)

M.Thiel, J. Weil, U. Mosel

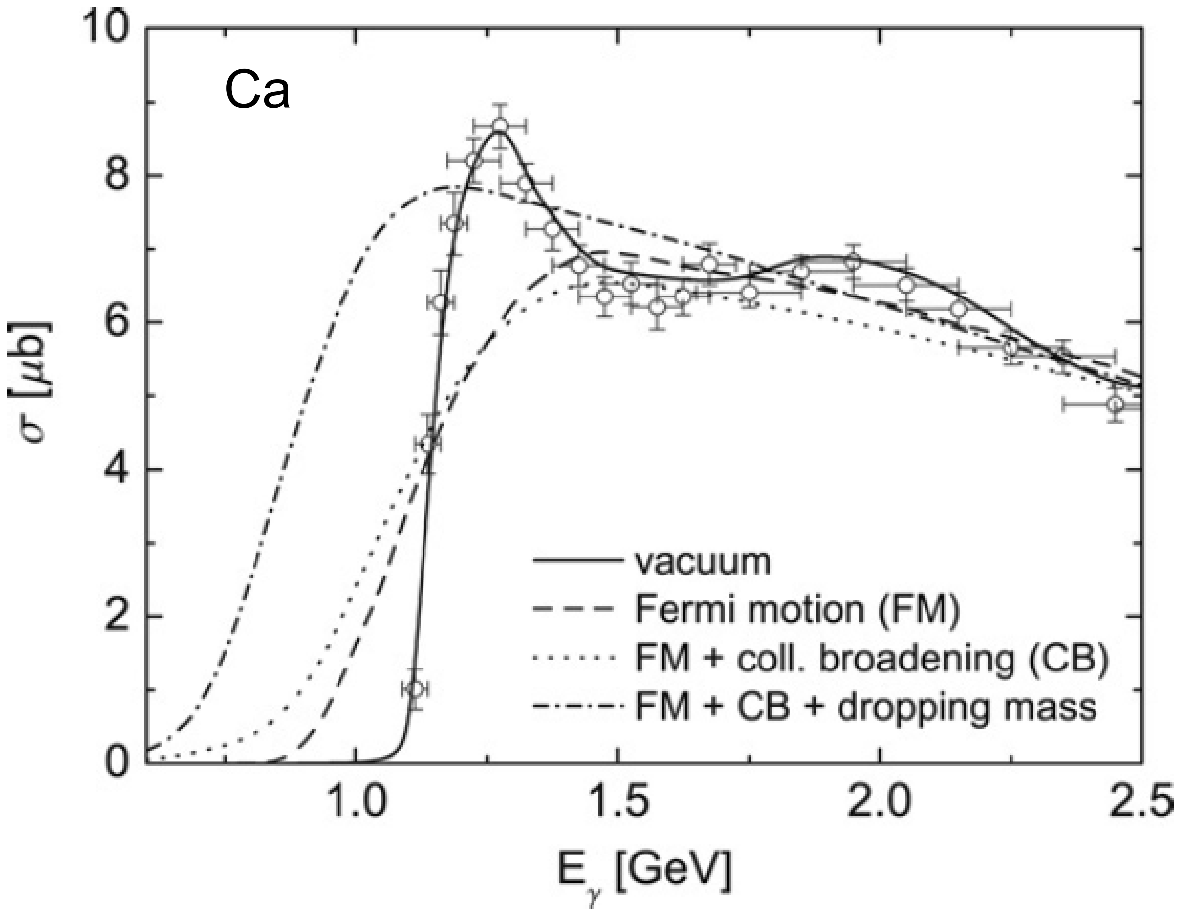


Collisional broadening without mass shift favoured

Measurement of ω excitation function

- additional test for ω broadening and/or mass shift scenario

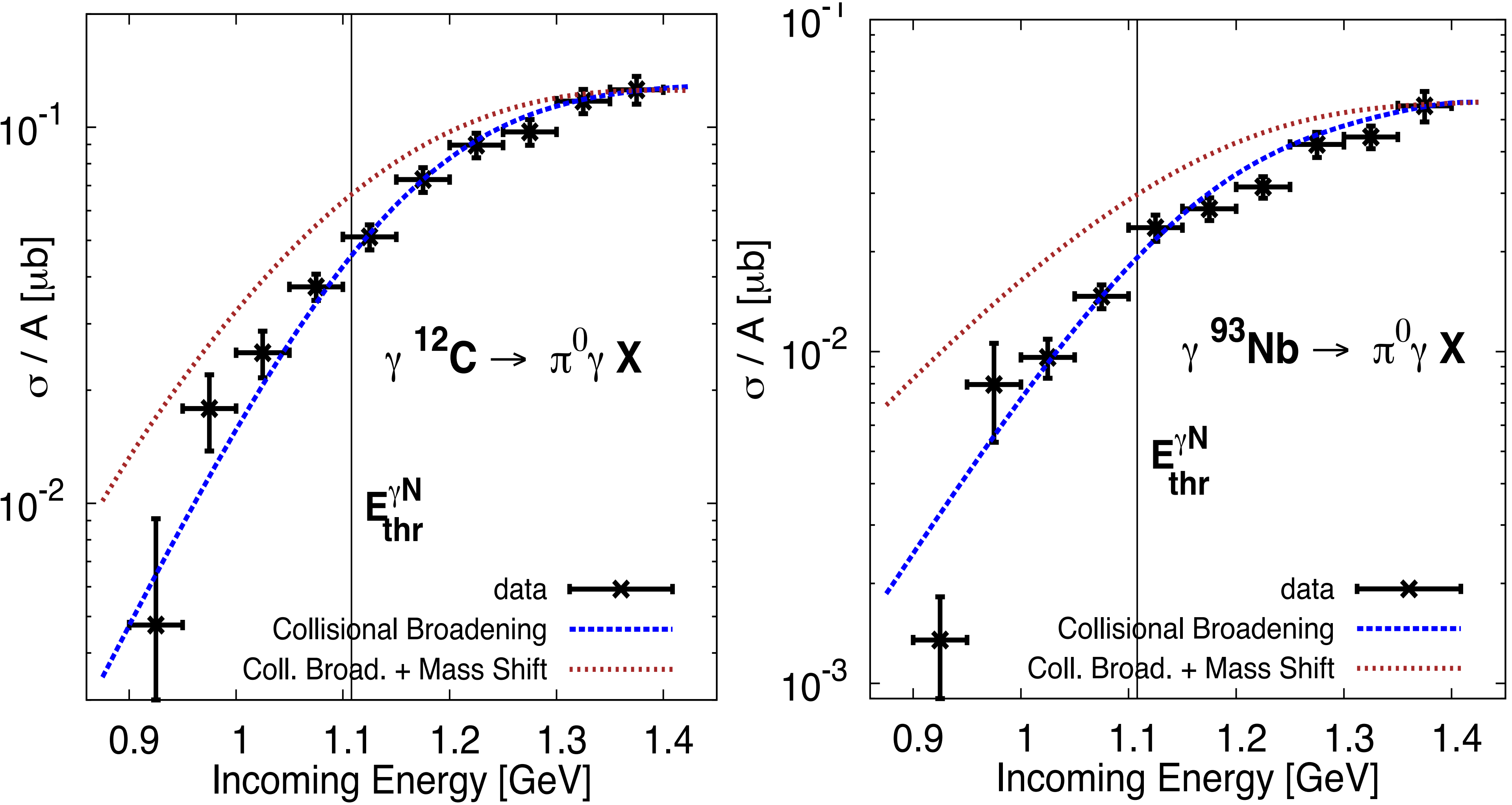
Gi-BUU simulations: P. Mühlich (PhD-thesis, Giessen 2006)
K. Gallmeister et al. Prog. Part. Nucl. Phys. 61 (2008) 283



Enhanced ω yield for dropping mass scenario below production threshold on free nucleon

Comparison of measured excitation function with GiBUU calculations

B. Lemmer, S. Friedrich, H. Berghäuser, M. Thiel, J. Weil



data disfavour „broadening + mass shift“ scenario

and favour „collisional broadening without mass shift“ scenario

Summary and conclusions

- ω line shape analysis has limited sensitivity:
  no evidence for structures or shifts in mass distributions
  sensitive to nuclear density at decay point

- Observables sensitive to nuclear density at the production point:
  applicable to hadrons of any lifetime

- transparency ratio measurement shows strong ω absorption;
  ➔ in-medium width ≈ 130 -150 MeV at ρ_0 for p_ω ≈1.1 GeV/c

- ω momentum distribution favours collisional broadening without mass shift

- ω excitation function favours collisional broadening without mass shift

- search for ω mesic states: analysis still ongoing

hadron spectral functions do change in the nuclear environment