Subproject B5: Hadrons in nuclear matter

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Prof. Dr. Horst Lenske

Institut für Theoretische Physik
Universität Giessen

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Research subjects:

- Electro- and photoproduction of hadrons in nuclear media
  - Coherent production mechanisms (Prof. R. Shyam)
  - Incoherent nuclear reactions (BUU)
- Coupled-channel calculations of elementary interactions
- Spectral functions from many-body theory
  - Hadrons in nuclear matter
  - Quarks in quark matter

Selected topics:

1. In-medium vector mesons and γA reactions
2. $\pi\pi$ photoproduction off nuclei
3. Hypernuclei production with hadronic and electromagnetic probes (Prof. R. Shyam)

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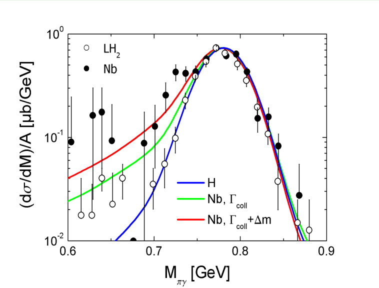
The ω meson in nuclear matter

P. Mühlich, V. Shklyar, S. Leupold, U. Mosel

The ω in matter

Exp – CBELSA/TAPS

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



Calculation – BUU

P. Mühlich at al. EPJ A20 (2004) 499

- quasi-free production

$$\gamma N \to \omega X$$

- dynamical spectral function

$$\mathcal{A}_\omega(k_0, \mathbf{k}, \rho_N(\mathbf{r}))$$

- FSI (absorption, in-/elastic collisions)

Presuming single-peak structure in-medium, the data suggest

$$m^*_\omega(\rho_N) \simeq m^o_\omega \left(1 - 16\% \frac{\rho_N}{\rho_0}\right)$$

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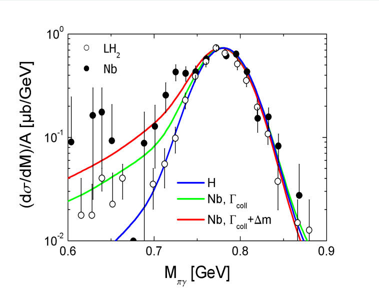

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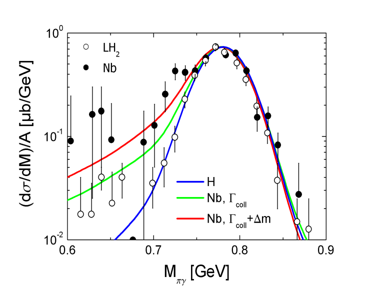

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- What are the physical processes giving rise to these changes?
  $\Longrightarrow$ pion cloud modifications, mixing, resonance-hole formation,...
- What do the changes tell about in-medium QCD?
  $\Longrightarrow$ QCD sum rules, quark and gluon condensates
- Consistency with sum rules?
  $\Longrightarrow$ Sum rules hardly consistent with substantial mass shift!
- Particular shape of in-medium spectrum?
  $\Longrightarrow$ Shift of peak, broadening, additional peaks...

Need for ...

- complementary experimental information
- hadronic models

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- Most hadronic models: **No substantial mass shift!**
- But:

F. Klingl et al., NPA650 (1999) 299:

- Caveat:
  - $m_\omega = 782$ MeV, $m_N = 938$ MeV

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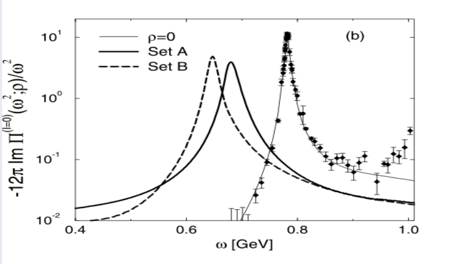

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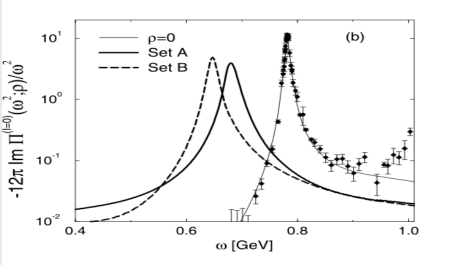

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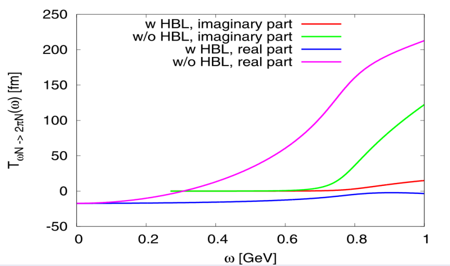

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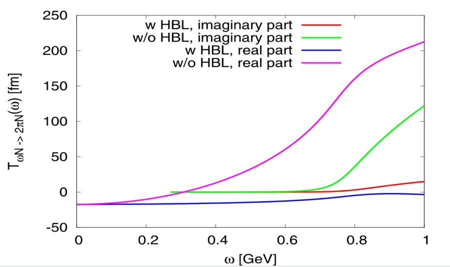

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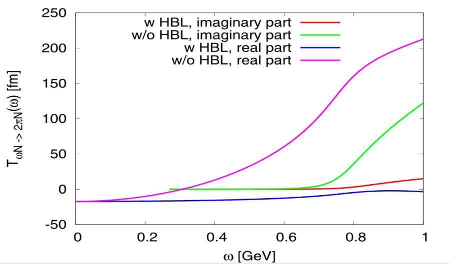

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  - $m_\omega = 782$ MeV, $m_N = 938$ MeV

    $\Rightarrow$ **Heavy-baryon limit NOT justified!**
  - no resonances included
  - **channel $\omega N \to \pi\pi N$ not constrained by any data!**

The ω in matter

How can ωN forward scattering amplitude be obtained?

- Coupled-channel problem!

- Solution by K-matrix approximation
- Include all resonances with $J^P = 1/2^\pm, 3/2^\pm, 5/2^\pm$
- Calculate channels $\gamma N, \pi N, 2\pi N, \eta N, \omega N, K\Lambda, K\Sigma$

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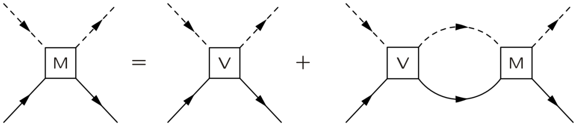

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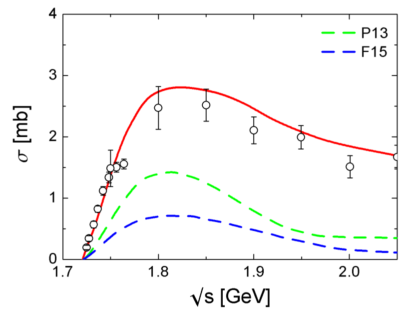
- Solution
- Include a
- Calculat

$\pi^- p \longrightarrow \omega n$



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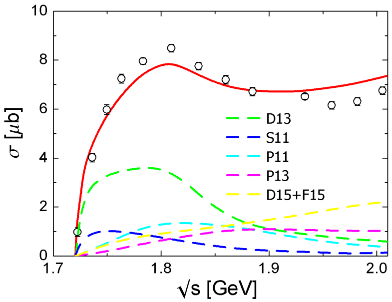

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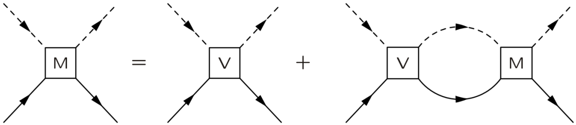

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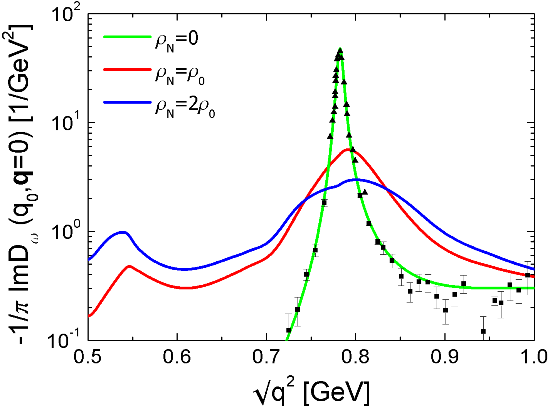
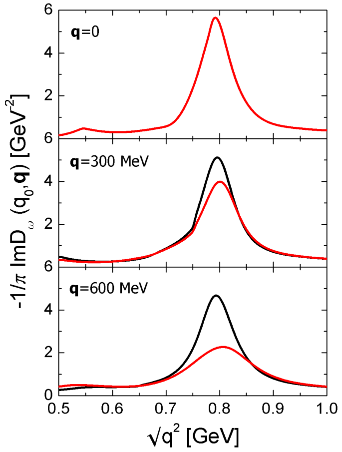
- Need as much experimental data as possible!
- Obtain ωN amplitude maximally constrained by data!
  - in particular: $\omega N \to \pi\pi N$ constrained by inelasticity

Spectral function

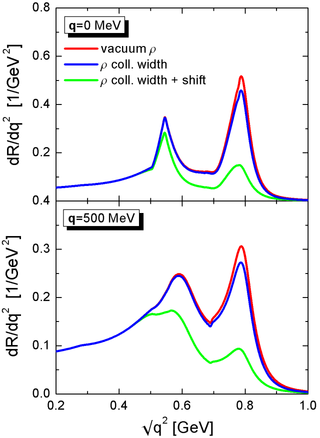


Momentum dependence



ω – Results

$\omega \longrightarrow \pi^0\gamma$ rate at $\rho_N = \rho_0$



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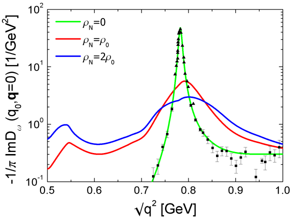

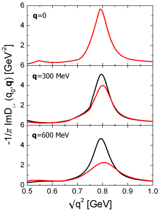

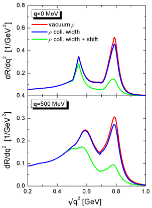

The ω in nuclear matter

- substantial broadening
- resonance-hole strength at low masses
- but: almost **no mass shift!**

ω photoproduction off nuclei

P. Mühlich, U. Mosel

ω attenuation

$$T_A \equiv \frac{\sigma_{\gamma A}}{A\sigma_{\gamma N}}$$ "Nuclear transparency ratio" (TR)

photon-nucleus cross section

$$\sigma_{\gamma A} = \int d^3 r \rho(\mathbf{r}) \sigma_{\gamma N} \exp\left[-\sigma_{VN}^{\mathrm{inel}} \int_z^\infty dz' \rho(\mathbf{b}, z')\right]$$

vectormeson self-energy and total VN cross section

$$-\frac{\mathrm{Im}\Pi_V}{\omega} = \gamma \Gamma_V^{\mathrm{coll}} = \rho \sigma_{VN} v_{VN}$$

$\Rightarrow$ TR is a measure for $\sigma_{VN}^{\mathrm{inel}}$

$$T_A = \frac{\pi R^2}{A\sigma_{VN}} \{1 + \mathcal{O}((\lambda_0/R))\} \qquad \lambda_0 = (\sigma_{VN}\rho_0)^{-1}$$

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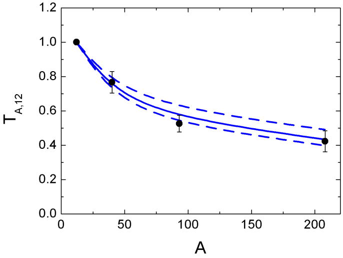
ω attenuation – Results

Data: D. Trnka *et al.*

CBELSA/TAPS (2006)



Inelastic x-section

$\Rightarrow \sigma_{\omega N}^{\mathrm{inel}} = 32\ \mathrm{mb}$

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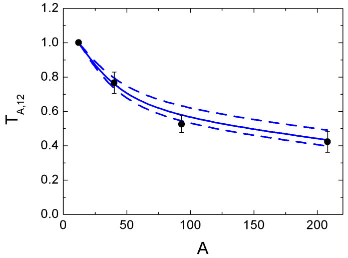

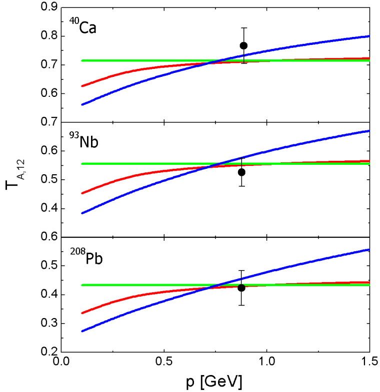

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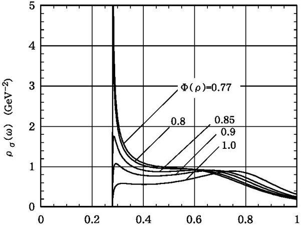
Measurement of $\sigma_{\mathrm{inel}}(\mathbf{p})$!

$\pi\pi$ production in nuclei

P. Mühlich, O. Buss, L. A.-Ruso, U. Mosel

$(\gamma, \pi\pi)$ in nuclei



mass[GeV]

Shift of spectral strength to lower masses and a more narrow width in the Medium

e.g. Bernard et al. [Phys Rev Lett 59 (1989)],

Hatsuda et al [Phys Rev Lett B367 (1999)],...

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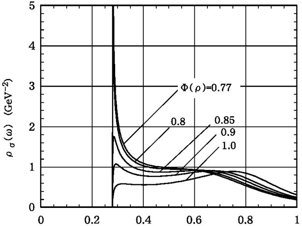

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Experiment

- J. Messchendorp *et al.*, **TAPS** (2002)
- F. Bloch *et al.*, **CBTAPS** (2006)

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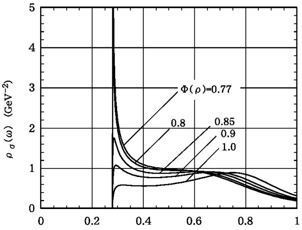

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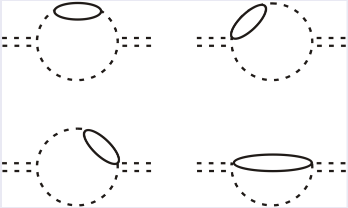
In-medium 2π propagator



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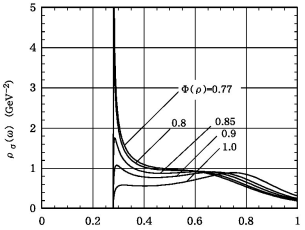

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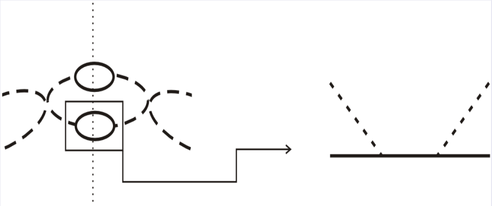
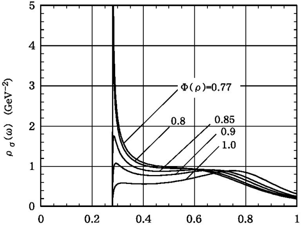
Incoherent FSI



$(\gamma, \pi\pi)$ in nuclei



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A$(\gamma, \pi\pi)$

- In-medium shift of $\pi\pi$ strength and FSI not independent!
- Incoherent π FSI crucial!

$(\gamma, \pi\pi)$ in nuclei

Initial state

- Microscopic model for $\gamma N \to N' \pi\pi$ as event generator

  Tejedor, Oset, NPA 600 (1996); Nacher et al , NPA 695 (2001)
- Total cross sections scaled to match experiment
- No medium modifications in the propagators
- Fermi motion, nuclear mean field, Pauli blocking

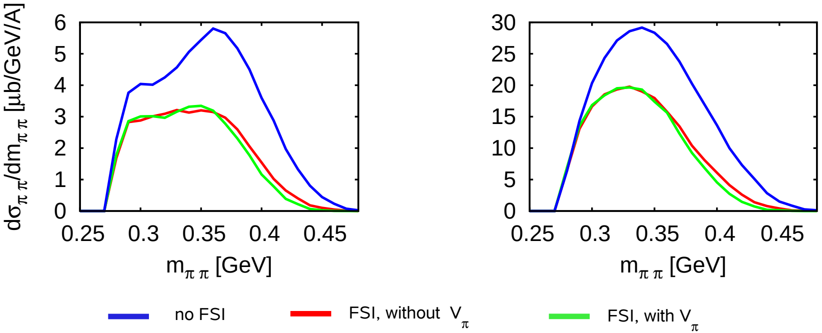
Final State

- BUU transport (absorption, elastic scattering, charge exchange)
- in-medium π dispersion relation ($\to$ O. Buss)
  - study of πA reactions, double-charge exchange

$E_\gamma = (400 - 500)$ MeV

$\gamma C \to X\ \pi^0\pi^0$

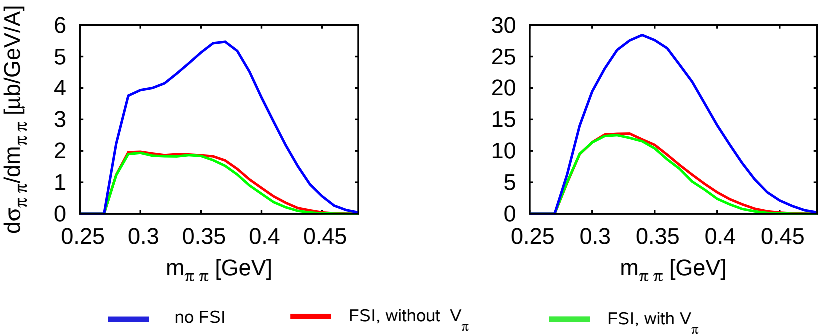
$\gamma C \to X\ \pi^\pm\pi^0$



$(\gamma, \pi\pi)$ – Results

$E_\gamma = (400 - 500)$ MeV

$\gamma\, Ca \to X\ \pi^0\pi^0$ $\qquad$ $\gamma\, Ca \to X\ \pi^\pm\pi^0$



$(\gamma, \pi\pi)$ – Results

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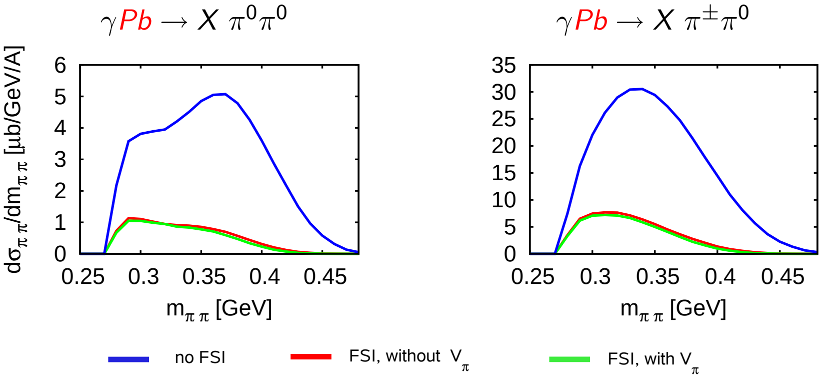

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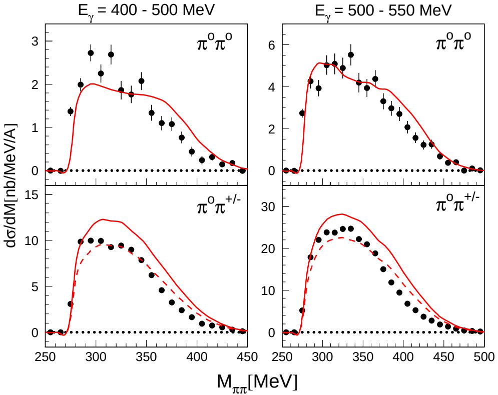
F. Bloch et al., **CBTAPS** (2006)



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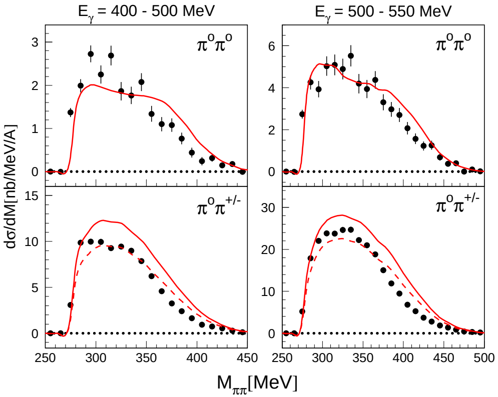

$\Rightarrow$ Traditional FSI account for A-evolution.

Summary

The ω in nuclear matter

- substantial broadening, no mass shift, low lying resonance-hole strength
- need for additional experimental information

(γ, ω) in nuclei

- reaction $A(\gamma, \omega)$ sensitive to $\sigma^{\mathrm{inel}}_{\omega N}(p)$
- $\sigma^{\mathrm{inel}}_{\omega N}(\langle p \rangle = 900\ \mathrm{MeV}) \simeq 32\ \mathrm{mb}$

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Future perspectives

In general:

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