Observing In-Medium Properties of Vector Mesons in Elementary Nuclear Reactions

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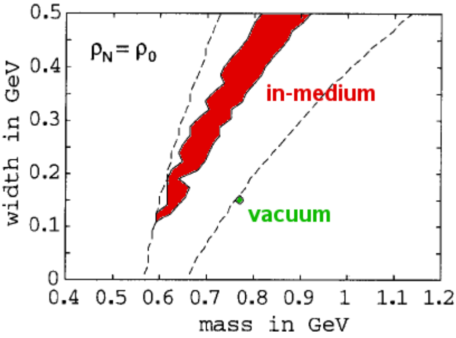
Introduction

- aim: study in-medium properties of vector mesons via elementary nuclear reactions (γ-, p- or π-induced)
- emphasis in this talk: $\gamma A \rightarrow \omega X \rightarrow \pi^0 \gamma X$ (as measured by CB/TAPS)
- simulate this process with the GiBUU transport model
- idea: observe $\omega \rightarrow \pi^0 \gamma$ decays in the nuclear medium
- $\Rightarrow$ learn about in-medium effects (collisional broadening and possibly mass shift of the ω)
- not discussed here: in-medium properties via dileptons

Physics Motivation

- how do vector mesons behave inside a hadronic medium?
- theoretical predictions:
  1. collisional broadening $\Leftrightarrow$ absorption
  2. mass shift (up/down?) $\Leftrightarrow$ ωN potential

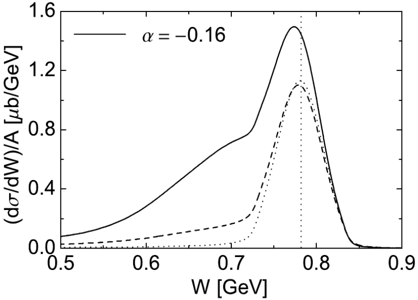


- Brown/Rho (effective Lagrangian approach): $m_V^*(\rho_0)/m_V \approx 0.8$
- Hatsuda/Lee (using QCD sum rules, neglecting width): $m_V^*(\rho)/m_V \approx 1 - \alpha(\rho/\rho_0)$, $\alpha \approx 0.16 \pm 0.06$
- extended sum-rule analysis by Leupold/Peters/Mosel, including finite width (NPA 628, 1998)

History: Previous Results

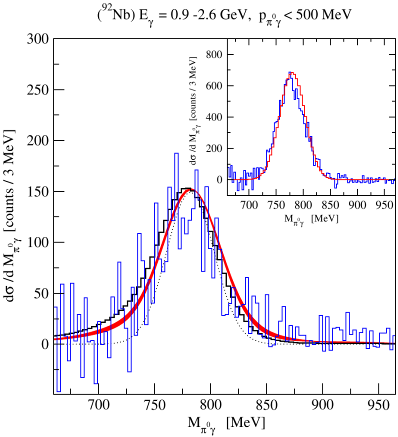
Mühlich, PhD thesis:

$\gamma + {}^{40}\text{Ca},\ E_\gamma = 0.9 - 1.2$ GeV



Kaskulov/Oset, EPJ A31 (2007):

$\gamma + {}^{92}\text{Nb},\ E_\gamma = 0.9 - 2.6$ GeV



The GiBUU Transport Model

- semi-classical hadronic transport model
- unified framework for various types of reactions (pA, πA, γA, eA, νA, AA) and observables
- modular and well-documented Fortran code
- collaborative effort, SVN-based multi-user environment
- publicly available releases (open source),
  soon to be released: GiBUU 1.3
- http://gibuu.physik.uni-giessen.de
- cf. talks by Leitner (HK40.4), Gallmeister (HK16.6), Gaitanos (HK3.9), Larionov (HK20.6), Lalakulich (T21.2), Lappo-Danilevski (HK9.8)

GiBUU

The Giessen Boltzmann-Uehling-Uhlenbeck Project

The BUU equation

- BUU equation describes time evolution of phase space density $f_i(\vec{r}, t, \vec{p}, \mu)$ for each particle species i ($i = N, \Delta, \pi, \rho, ...$):

$$\left(\partial_t + (\nabla_{\vec{p}} H_i)\nabla_{\vec{r}} - (\nabla_{\vec{r}} H_i)\nabla_{\vec{p}}\right) f_i(\vec{r}, t, \vec{p}, \mu) = I_{coll}[f_i, f_j, ...]$$

- collision term I_{coll}:
  - depends on all f_i $\Rightarrow$ coupled-channel problem
  - contains gain and loss terms
  - decays of unstable particles
  - two-body scattering processes
  - three-body reactions
- Hamiltonian H_i:
  - hadronic mean-field potential
  - Coulomb potential
  - off-shell transport incorporated through "off-shell potential"

In-Medium Effects

Collisional Broadening

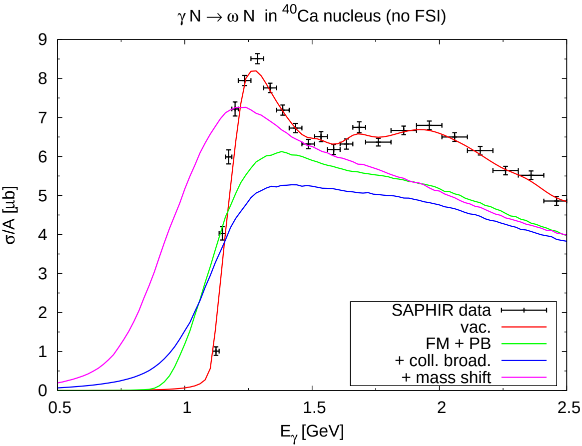
- in medium: $\Gamma_{tot} = \Gamma_{vac} + \Gamma_{coll}$
- $\Gamma_{coll} = \rho\langle v_{rel}\sigma_{VN}\rangle$ (low density approx. in lab frame)
- contributing processes: $VN \to \pi N, \pi\pi N, R, ...$
- in practice: use $\Gamma_{coll} = const. \approx 80...150\,\text{MeV}$ (from transparency measurements)

Off-Shell Transport

- based on off-shell EOMs for test particles, found by S. Leupold (NPA 672, 2000), Cassing/Juchem (NPA 665, 2000)
- construct an "off-shell potential" which fulfills these EOMs
- $\mu^2 = m_0^2 + \chi \cdot \Gamma_{tot}$
- "off-shell parameter" $\chi = (\mu^2 - m_0^2)/\Gamma_{tot} = const.$
- major difference to BUU model used by Mühlich

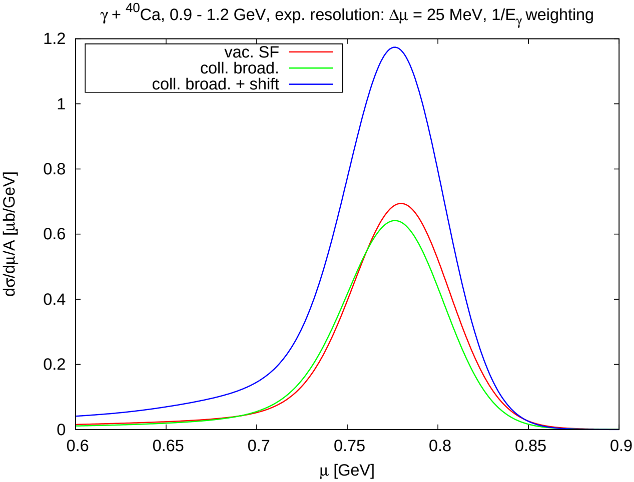
Photo-production of ω mesons

$$\sigma_{\gamma N \to VN} = \frac{1}{16\pi k_{cm} s} \int_{m_\pi}^{\sqrt{s}-m_N} d\mu \left| \mathcal{M}_{\gamma N \to VN}(\sqrt{s}) \right|^2 \mathcal{A}_V(\mu, \rho) p_{cm}(\mu)$$



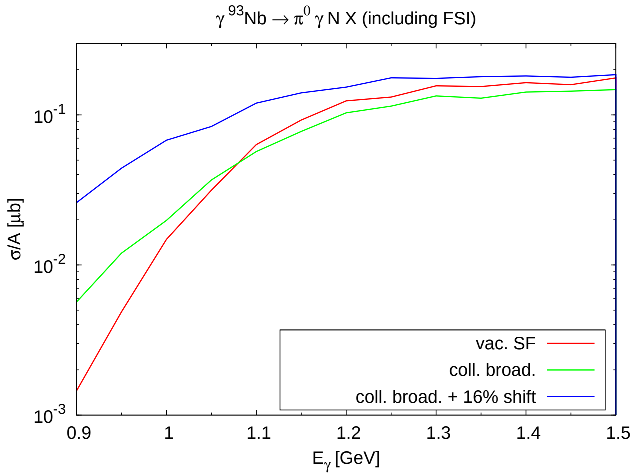
$\pi^0\gamma$ Inv. Mass Spectrum

- main effect: change of peak height (due to ω prod. XS)
- shape: only minor modifications, dominated by exp. resolution



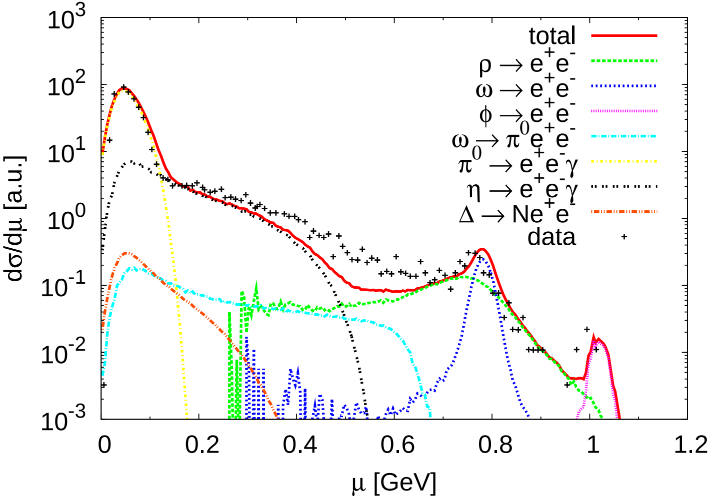
ω Excitation Function

- production cross section $\otimes$ $\pi^0\gamma$ branching ratio $\otimes$ absorption



Outlook

- dileptons from HADES: p+p @ 3.5 GeV



Summary

1. $\pi^0\gamma$ spectrum shows little sensitivity to in-medium effects, also at low energies!
2. current simulations show discrepancy with Mühlich's results (not yet fully resolved)
3. off-shell transport matters!
4. alternative (more promising) approach to ω in medium: excitation function