In-Medium Properties of Vector Mesons in a Transport Approach

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HGS-HIRe for FAIR
Helmholtz Graduate School for Hadron and Ion Research
1. motivation: in-medium physics

2. the GiBUU transport model

3. dileptons from HADES:
   - $p + p @ 3.5$ GeV
   - $p + Nb @ 3.5$ GeV

4. conclusions

[not covered here: photoproduction of omega mesons on nuclei, as measured by CB/TAPS, cf. EPJ A47 (2011)]
Motivation: Hadrons in Medium

- how do vector mesons behave inside a hadronic medium?
- Hatsuda/Lee: mass shift
  \[ m^*_V(\rho)/m_V \approx 1 - \alpha(\rho/\rho_0), \]
  \[ \alpha \approx 0.16 \pm 0.06 \]
- collisional broadening (LDA): \( \Gamma_{coll} = \rho < v_{rel} \sigma_{VN} > \)
- extended sum-rule analysis by Leupold/Peters/Mosel, including finite width (NPA 628, 1998)
- coupling to resonances can introduce additional structures in the spectral function (Post, 2003)
The GiBUU Transport Model

- BUU-type hadronic transport model
- unified framework for various types of reactions ($\gamma A, eA, \nu A, pA, \pi A, AA$) and observables
- BUU equ.: space-time evolution of phase space density

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

- Hamiltonian $H_i$:
  - hadronic mean fields, Coulomb, “off-shell potential”
- collision term $I_{coll}$:
  - decays and scattering processes (2- and 3-body)
  - low energy: resonance model, high energy: PYTHIA
- http://gibuu.physik.uni-giessen.de

GiBUU
The Giessen Boltzmann-Uehling-Uhlenbeck Project
P+p @ 3.5 GeV, mass spectrum

Data (A. Rustamov)
GiBUU total

ρ → e+e-
ω → e+e-
φ → e+e-
ω → π0e+e-
π0 → e+e-γ
η → e+e-γ
Δ → Ne+e-
η' → e+e-γ

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Dalitz decay

- transition form factor $\Delta \rightarrow N\gamma^*$
  - space-like region: data from electroproduction
  - basically unknown in time-like region (no data)
- best available guess for time-like region:
  - two-component quark model (Wan/Iachello, IJMP A20, 2005)
    \[ F \sim (1 - \gamma e^{i\theta} q^2)^{-2} \cdot F_\rho(q^2) \]

\[ |F(q^2)|^2 \]

\[ q^2 [\text{GeV}^2] \]

\[ \text{d}\sigma/\text{d}m_{\text{ee}} [\mu\text{b}/\text{GeV}] \]

\[ \text{dilepton mass } m_{\text{ee}} [\text{GeV}] \]

\[ \text{N-}\Delta \text{ trans. FF (Wan/Iachello)} \]

\[ \text{data (A. Rustamov)} \quad \text{GiBUU total} \]

\[ \rho \rightarrow e^+e^- \quad \omega \rightarrow e^+e^- \quad \phi \rightarrow e^+e^- \]

\[ \omega^0 \rightarrow e^+e^- \quad \pi^0 \rightarrow e^+e^-\gamma \quad \eta \rightarrow e^+e^-\gamma \]

\[ \Delta \rightarrow N^+e^- \]
\( p + p \) @ 3.5 GeV, \( p_T \) AND RAP. SPECTRA

- \( p_T \): perfect agreement (when including Delta FF!)
- small discrepancies at forward rapidity (filtering problem?)

J. Weil (JLU Giessen) IN-MEDIUM PROPERTIES OF VECTOR MESONS
cocktail composition basically fixed by p+p
(elementary cross sections, branching ratios, form factors, ...)
use p+p as a base line for p+Nb
additional medium effects:
  1) FSI, absorption, rescattering
  2) secondary production processes
  3) modified spectral functions
vector mesons in medium:
  \( \rho \): sensitive to direct modification of mass spectrum?
  \( \omega/\phi \): transparency ratio / absorption
unfortunately p+p still leaves us with some uncertainties
(largest one: Delta form factor)
Delta: no form factor needed
omega absorption: consistent with TAPS transparency ratio
P+ Nb@3.5 GeV, mass spectrum

VM: collisional broadening

- consistent treatment of collisional broadening / absorption
- slightly better agreement

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In-medium properties of vector mesons
P+Nb@3.5 GeV, mass spectrum

VM: coll. broad. + mass shift (16%)

data (M. Weber)
GiBUU total
ρ → e^+e^-
ω → e^+e^-
φ → e^+e^-
ω → π^0e^+e^-
π^0 → e^+e^-γ
η → e^+e^-γ
Δ → Ne^+e^-

- rho strength shifted downward
- even better agreement
Conclusions

1. VM properties in (cold) nuclear matter: a challenging problem!

2. GiBUU: a valuable tool to study in-medium physics

3. HADES: we need to understand elementary reactions before we can draw hard conclusions on p+A and A+A

   (in particular: we need to understand the transition form factor of the Delta Dalitz decay)
Back-Up Slides
$\Delta^+$ production cross sections (inclusive/exclusive)

$\sigma_{pp}$ [mb]
$sqrt(s)$ [GeV]

$pp \rightarrow p\Delta^+$
$pp \rightarrow \Delta^+X$
$pp \rightarrow p\Delta^+$

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**ω Dalitz decay:** \( ω → π^0 e^+ e^- \)

- inclusive \( ω \) production cross section fixed by \( ω → e^+ e^- \), BR(\( ω → e^+ e^- \)) well known: \( 7.2 \cdot 10^{-5} \)
- \( ω \) Dalitz branching also well known
- form factor fixed by NA60 data (Arnaldi et al., PLB 677)

![Graph showing the form factor for various models and data sets.](image)
DIRECT $\eta$ DECAY: $\eta \rightarrow e^+ e^-$

- exp. upper limit (WASA, Berlowski et al., PRD 77, 2008):
  \[ \text{BR}(\eta \rightarrow e^+ e^-) < 2.7 \cdot 10^{-5} \]
- HADES might be able to push down this limit ...
- theor. prediction (Browder et al., PRD 56, 1997):
  \[ \text{BR}(\eta \rightarrow e^+ e^-) \approx 10^{-9} \]

![Graph showing the production of dileptons from various processes]

- $\eta \rightarrow e^+ e^-$
- current exp. limit (WASA)
- $\text{d} \sigma / \text{d}m_{ee}$ [µb/GeV]
- $m_{ee}$ [GeV]
- data (A. Rustamov)
- GiBUU total
- $\rho \rightarrow e^+ e^-$
- $\omega \rightarrow e^+ e^-$
- $\phi \rightarrow e^+ e^-$
- $\omega^0 \rightarrow \pi^0 e^+ e^-$
- $\pi^0 \rightarrow e^+ e^- \gamma$
- $\eta \rightarrow e^+ e^- \gamma$
- $\Delta \rightarrow N e^+ e^-$
- $\eta \rightarrow e^+ e^-$
Pion Observables

- Pions are important for normalization.
- Can serve as a cross check for dilepton spectra.
- GiBUU nicely describes inclusive pion data by HARP (Gallmeister, NPA 826, 2009).

![Graphs showing pion observables at 3 GeV and 12 GeV](image-url)
**Slow vs. Fast Sources**

HADES: $p + p \@ 3.5$ GeV ($p < 800$ MeV)

HADES: $p + p \@ 3.5$ GeV ($p > 800$ MeV)

**In-medium properties of vector mesons**