Dilepton Production in Elementary Nuclear Reactions

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Outline

- Introduction
- Physics Motivation
- Experimental Situation
- Calculating Dilepton Spectra
- Background Processes
- In-Medium Effects
- Offshell Transport
- Outlook

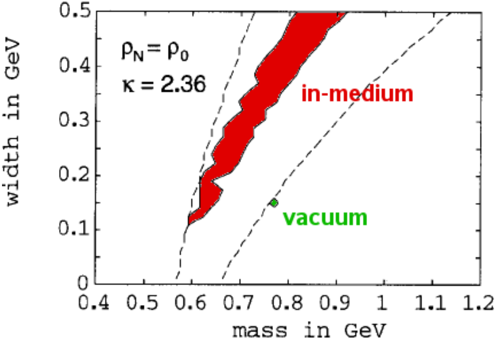
GiBUU

Introduction

- aim: study e^+e^- spectra from elementary nuclear reactions (γ-, p- or π-induced) to learn about in-medium properties of vector mesons
- active experiments: g7@JLAB, E325@KEK, HADES@GSI
- not discussed here: heavy-ion collisions
- advantages of elementary collisions:
  - cleaner environment, nucleus close to ground state
  - defined density, predicted effects are large enough at ρ_0
- also not discussed: hadronic decays of vector mesons
- advantage of dileptons: interact only electromagnetically, undisturbed by strong nuclear forces
  $\Rightarrow$ can carry in-medium information outside
  (only small Coulomb corrections)
- disadvantage: small branching ratios ($\sim 10^{-5}$)

Physics Motivation

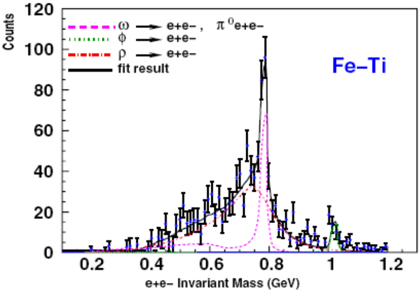
- how do vector mesons behave inside a hadronic medium?
- theoretical predictions:
  - collisional broadening
  - mass shift (up/down?)



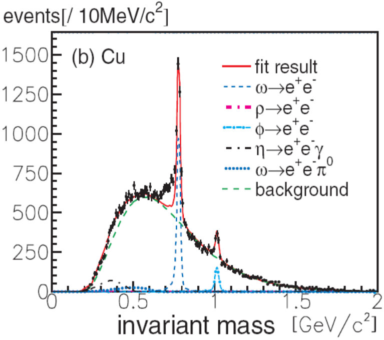
- Brown/Rho (effective Lagrangian approach): $m_V^*(\rho_0)/m_V \approx 0.8$
- Hatsuda/Lee (using QCD sum rules, neglecting width): $m_V^*(\rho)/m_V \approx 1 - \alpha(\rho/\rho_0)$, $\alpha \approx 0.16 \pm 0.06$
- extended sum-rule analysis by Leupold/Peters/Mosel, including finite width (nucl-th/9708016)

g7@JLAB vs. E325@KEK

- $\gamma A \rightarrow e^+ e^- X$
- $E_\gamma \approx 0.6...3.8 GeV$
- no significant mass shift: $\alpha = 0.02 \pm 0.02$
- consistent with collisional broadening



- $pA \rightarrow e^+ e^- X$
- 12 GeV protons
- mass shift: $\alpha = 0.092 \pm 0.002$
- no broadening!



The GiBUU Transport Model

- product of 20 years of BUU research in Giessen
- unified framework for various types of reactions (pA, πA, γA, eA, νA, AA) and observables
- modern, modular and well-documented Fortran code ($\sim$ 200.000 LOC)
- collaborative effort, SVN-based multi-user environment
- since 2008: publicly-available Open-Source releases
- http://gibuu.physik.uni-giessen.de

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"

Dilepton Sources

hadron decays contributing to the dilepton spectrum:

direct decays:

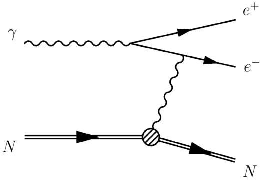
- $\rho^0 \longrightarrow e^+e^-$
- $\omega \longrightarrow e^+e^-$
- $\phi \longrightarrow e^+e^-$

Dalitz decays:

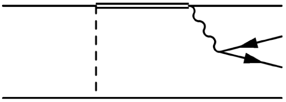
- $\omega \longrightarrow \pi^0 e^+e^-$
- $\pi^0 \longrightarrow e^+e^-\gamma$
- $\eta \longrightarrow e^+e^-\gamma$
- $\Delta \longrightarrow Ne^+e^-$

plus other background contributions:

Bethe-Heitler process:



NN-/πN-Bremsstrahlung:



Calculating Dilepton Spectra

- easiest case: γN reaction (elementary process)
- mass-differential cross section for $\gamma N \to VX \to e^+e^-X$:

$$\frac{d\sigma}{d\mu} = \sigma_{\gamma N \to VX}(s) \cdot \mathcal{A}_V(\mu) \cdot BR_{V \to e^+e^-}(\mu)$$

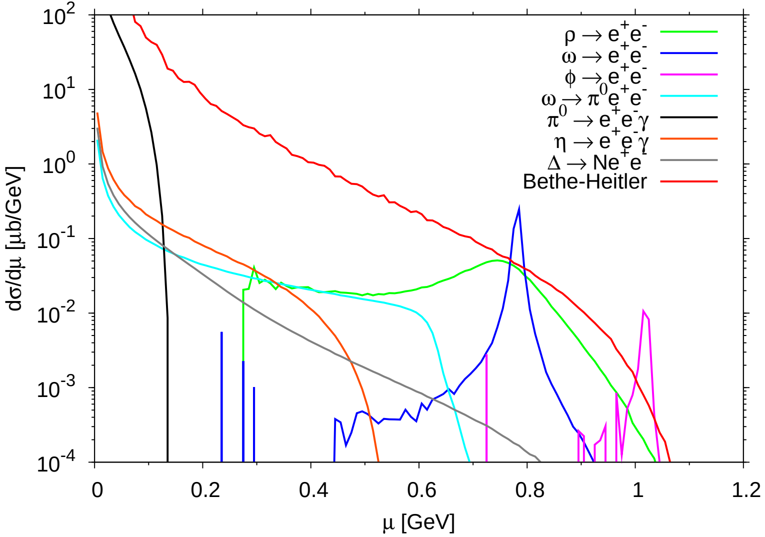
- $\sigma_{\gamma N \to VX}(s)$: inclusive photoproduction of a VM
- $V \to e^+e^-$ decay width (from VMD):

$$\Gamma_{V \to e^+e^-}(\mu) = C_V \frac{m_V^4}{\mu^3}$$

- on a nucleus (using GiBUU transport model):

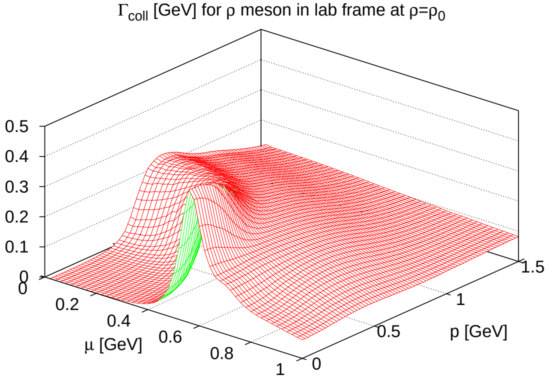
$$\frac{dN_{V \to e^+e^-}}{d^3p\,d\mu} = \int_0^\infty dt\,d^3r \frac{1}{(2\pi)^3} f_V(\vec{r}, t, \vec{p}, \mu) \frac{\Gamma_{V \to e^+e^-}(\mu)}{\gamma}$$

$\gamma + {}^{12}C$ @ 1.5GeV (vacuum spectral functions)



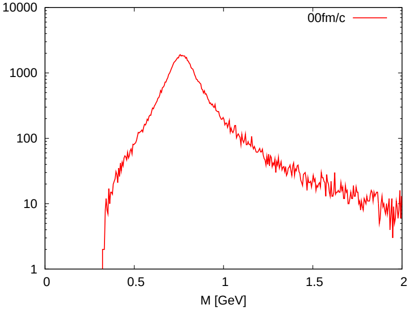
Collisional Broadening

- in medium: $\Gamma_{tot} = \Gamma_{vac} + \Gamma_{coll}$
- $\Gamma_{coll} = \rho < v_{rel}\sigma_{VN} >$ (low density approximation, in lab frame)
- contributing processes: $VN \rightarrow \pi N, \pi\pi N, VN, R$
- in practice: lookup table $\Gamma_{coll}(m, |\vec{p}|, \rho_p, \rho_n)$



Off-Shell Transport

- based on off-shell EOMs for test particles, found by S. Leupold (nucl-th/9909080), Cassing/Juchem (nucl-th/9903070)
- construct an "off-shell potential" which fulfills these EOMs
- put this into a Hamiltonian $H = \sqrt{\mu^2 + \vec{p}^2 + Re(\Sigma)}$
- where either $\mu = m_0 + V_{nr}$ or $\mu^2 = m_0^2 + V_{rel}^2$
- using the full width (as obtained from the collision term) results in various problems (tachyons, cut-off effects, ...)



Outlook

- improve off-shell transport
- apply cuts on momentum, opening angle, etc
- investigate influence of formation time in $\gamma N \to VN$
- extend Bremsstrahlung calculation (beyond SPA)
- work on π-induced reactions (together with H. van Hees)
- compare simulated spectra to data: KEK, HADES, JLAB?
  (requires applying detector acceptance etc)
- ...