Studies of Dilepton Production with UrQMD

Transport Calculations vs. Coarse-grained Dynamics

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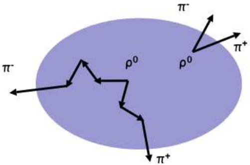
H-QM Helmholtz Research School Quark Matter Studies

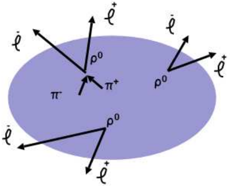
HGS-HIRe for FAIR

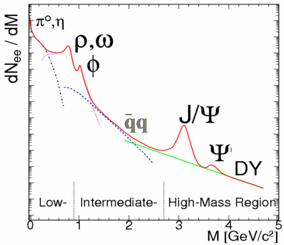
Overview

Why Dileptons...?

- Dileptons represent a clean and penetrating probe of hot and dense nuclear matter
- Reflect the whole dynamics of a collision
- Once produced they do not interact with the surrounding matter (no strong interactions)
- Aim of studies
  - In-medium modification of vector meson properties
  - Chiral symmetry restoration







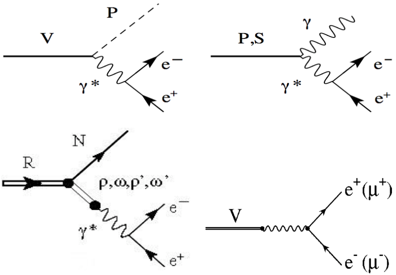
Ultra-relativistic Quantum Molecular Dynamics

- Hadronic non-equilibrium transport approach
- Includes all baryons and mesons with masses up to 2.2 GeV
- Two processes for resonance production in UrQMD (at low energies)
  - **Collisions** (e.g. $\pi\pi \rightarrow \rho$)
  - **Higher resonance decays** (e.g. $N^* \rightarrow N + \rho$)
- Resonances either decay after a certain time or are absorbed in another collision (e.g. $\rho + N \rightarrow N^*_{1520}$)
- **No explicit in-medium modifications!**

Resonance	Mass	Width
N^*_{1440}	1.440	350
N^*_{1520}	1.515	120
N^*_{1535}	1.550	140
N^*_{1650}	1.645	160
N^*_{1675}	1.675	140
N^*_{1680}	1.680	140
N^*_{1700}	1.730	150
N^*_{1710}	1.710	500
N^*_{1720}	1.720	550
N^*_{1900}	1.850	350
N^*_{1990}	1.950	500
N^*_{2080}	2.000	550
N^*_{2190}	2.150	470
N^*_{2220}	2.220	550
N^*_{2250}	2.250	470
Δ_{1232}	1.232	115
Δ^*_{1600}	1.700	350
Δ^*_{1620}	1.675	160
Δ^*_{1700}	1.750	350
Δ^*_{1900}	1.840	260
Δ^*_{1905}	1.880	350
Δ^*_{1910}	1.900	250
Δ^*_{1920}	1.920	200
Δ^*_{1930}	1.970	350
Δ^*_{1950}	1.990	350

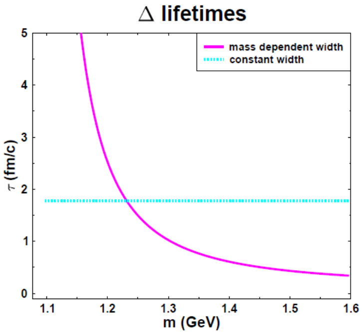
Dilepton sources in UrQMD

- **Dalitz Decays**
  $\Rightarrow \pi^0, \eta, \eta', \omega, \Delta$
  $\mathrm{P} \to \gamma + e^+e^-$
  $\mathrm{V} \to \mathrm{P} + e^+e^-$
- **Direct Decays**
  $\Rightarrow \rho^0, \omega, \phi$



- Dalitz decays are decomposed into the corresponding decays into a virtual photon and the subsequent decay of the photon via electromagnetic conversion.
- Form factors for the Dalitz decays are obtained from the **vector-meson dominance** model (VMD).
- Assumption: Resonance can continuously emit dileptons over its whole lifetime (Time Integration Method / "Shining")

Δ(1232) Resonance in UrQMD



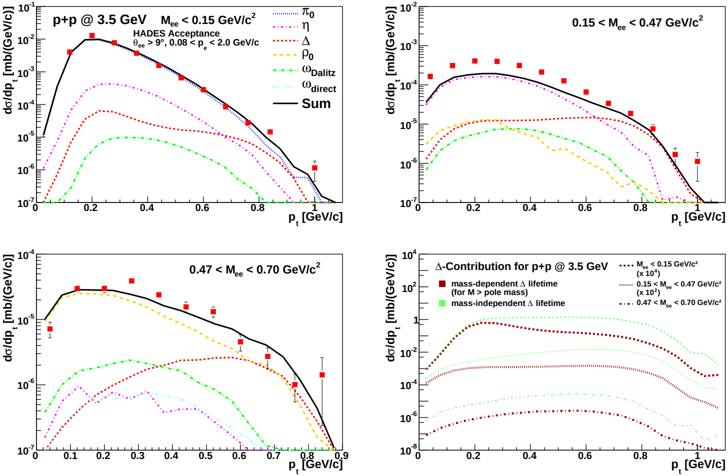
- In UrQMD mass dependent widths are used, but the lifetime is mass-independent $\tau=1/\Gamma(m_{pole})$ to avoid unphysically high lifetimes for low masses
- <u>Now:</u> We use mass-dependent (partial) width:

$$\Gamma_{i,j}(M) = \Gamma^{i,j}_{pole} \frac{M_{pole}}{M}$$

⇒ Still differences between transport models (parametrizations, cross-sections, form factors)

⇒ **Pion beam** might help to finally fix the Delta issue!

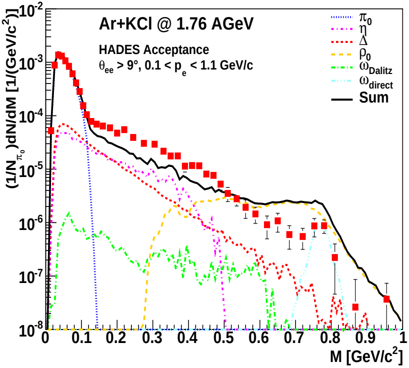
p_t Spectra for p + p @ 3.5 GeV

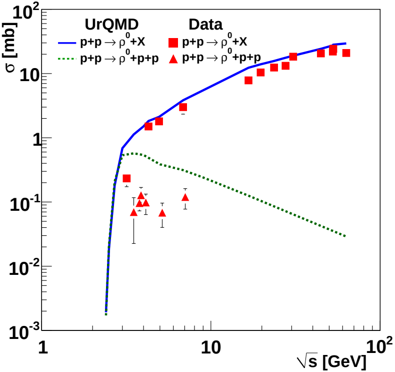


- Transverse momentum spectra at 3.5 GeV are described well with the mass-dependent Δ

Room for improvements...

- We see an excess in heavy-ion collisions (e.g. Ar+KCl @ 1.76 AGeV) not yet described by the model
- Recent HADES measurements indicate that our ρ^0 cross-section is to high at the threshold





Challenges

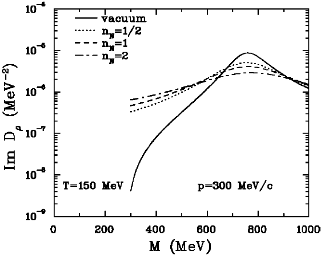
- Cross-section not implemented explicitly but intermediate baryonic resonances are used
- Some cross-sections are even unmeasured or unmeasurable (especially for ρ and Δ lack of data)
- General difficulties of the transport approach at high density:
  - Off-shell effects
  - Multi-particle collisions

$\Rightarrow$ **How can we avoid these problems?**

Coarse Graining

- We take an ensemble of UrQMD events and span a grid of small space time cells for which T and μ_B are calculated
- Equation of state for a **free hadron gas** without any phase transition is used [D. Zschiesche et al., Phys. Lett. B547, 7 (2002)]
- The ρ dilepton emission of each cell is calculated using the **thermal equilibrium rate** [R. Rapp, J. Wambach, Adv. Nucl. Phys. 25, 1 (2000)]

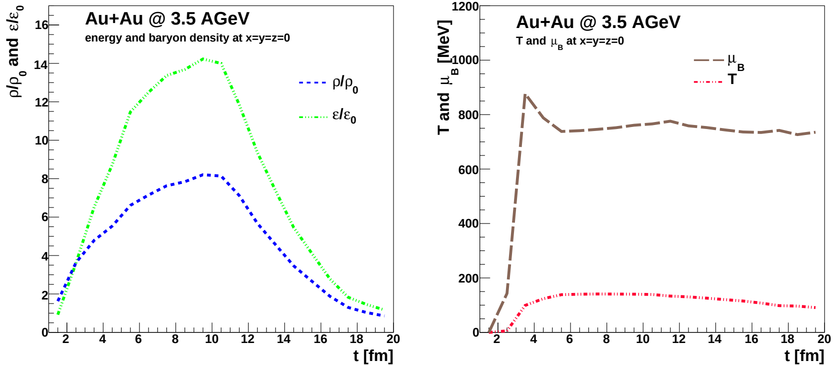
$$\frac{d^8 N_{\rho\to ll}}{d^4x d^4q} = -\frac{\alpha^2 m_\rho^4}{\pi^3 g_\rho^2}\frac{L(M^2)}{M^2} f_B(q_0;T) \mathrm{Im} D_\rho(M,q;T,\mu_B)$$



- In-medium self energies of the ρ (for ImD_ρ) were calculated using empirical scattering amplitudes from resonance dominance

[V. L. Eletsky et al., Phys. Rev. C64, 035303 (2001)]

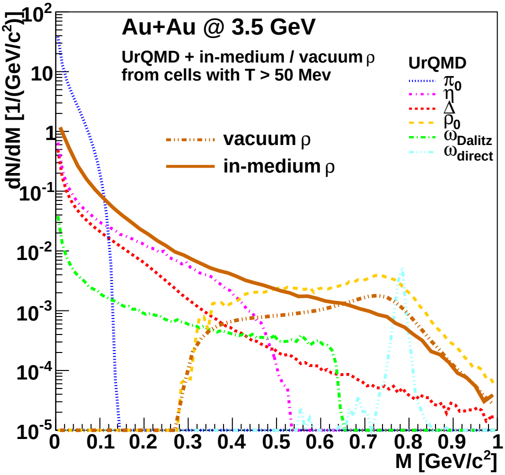
Densities, Temperature and Chemical Potential



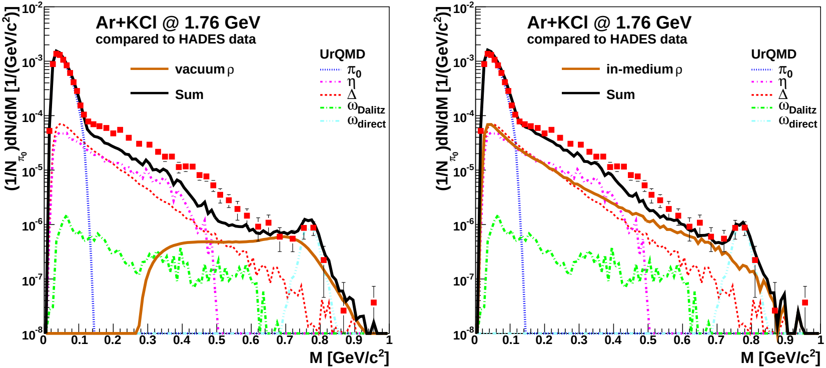
- For a central cell in an Au+Au collision @ 3.5 AGeV we get up to 15 times ϵ_0 and 10 times ρ_0
- Temperature $T \approx 140$ MeV and baryon chemical potential $\mu_B \approx 800$ MeV

Au+Au @ 3.5 AGeV

- The UrQMD ρ contribution as well as the coarse-graining results for the vacuum and in-medium spectral functions are shown
- In-medium ρ “melts” away at the pole mass while it becomes dominant at lower masses

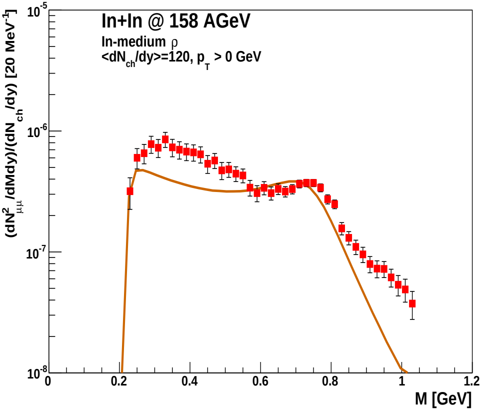


Ar + KCl @ 1.76 AGeV



- Comparison to existing HADES data shows that the in-medium ρ helps to describe the invariant mass spectra for heavy-ion reactions

First look at NA60



- **Chiral EoS** is used for the NA60 calculation (including chiral symmetry restoration and phase transition)

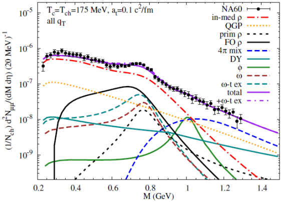
  [J. Steinheimer et al., J. Phys. G38 (2011)]

- In-medium ρ contribution to dimuon excess
- 4π and QGP contribution have to be added

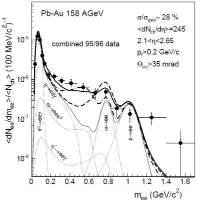
$\Rightarrow$ Currently used Eletsky spectral function can not describe the low-mass tail excess dimuons $\rightarrow$ Check different EoS and spectral functions in the next step

Outlook

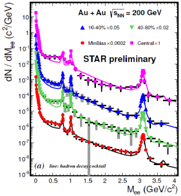
- Careful adjustment of dilepton production in UrQMD, especially via the ρ channel
- Coarse-graining to be done higher energies, with all contributions, and compared to NA60, CERES, RHIC data



[Rapp, Hees]



[CERES Collab.]



[STAR Collab.]

- Investigation of diffent equations of state
- Further dilepton calculations with hybrid model (transport + hydro)
- Waiting for HADES Au+Au data and for the pion beam!

Summary

- New approach to combine realistic transport caluclations with in-medium modified spectral functions for vector mesons
- Non-equilibrium treatment highly non-trivial $\Rightarrow$ Use **equilibrium** rates for a **coarse-grained transport dynamics**
- First calculations for Ar+KCl @ 1.76 GeV show that we get a good description of the invariant mass spectrum
- Further work in progress...!