In-Medium Spectral Functions and Dilepton Production within a Coarse-Graining Approach

Stephan Endres[1,2], Hendrik van Hees [1,2], Janus Weil [2], Marcus Bleicher [1,2]

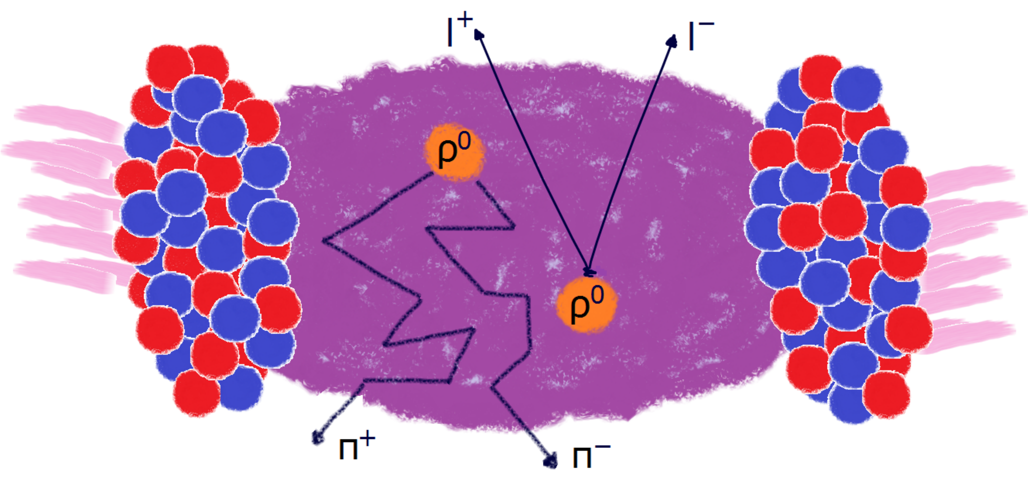
[1]Institut für Theoretische Physik der Goethe-Universität, Max-von-Laue-Straße 1, 60438 Frankfurt am Main, Germany
[2]Frankfurt Insitute for Advanced Studies, Ruth-Moufang-Straße 1, 60438 Frankfurt am Main, Germany

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

FIAS Frankfurt Institute for Advanced Studies

Motivation

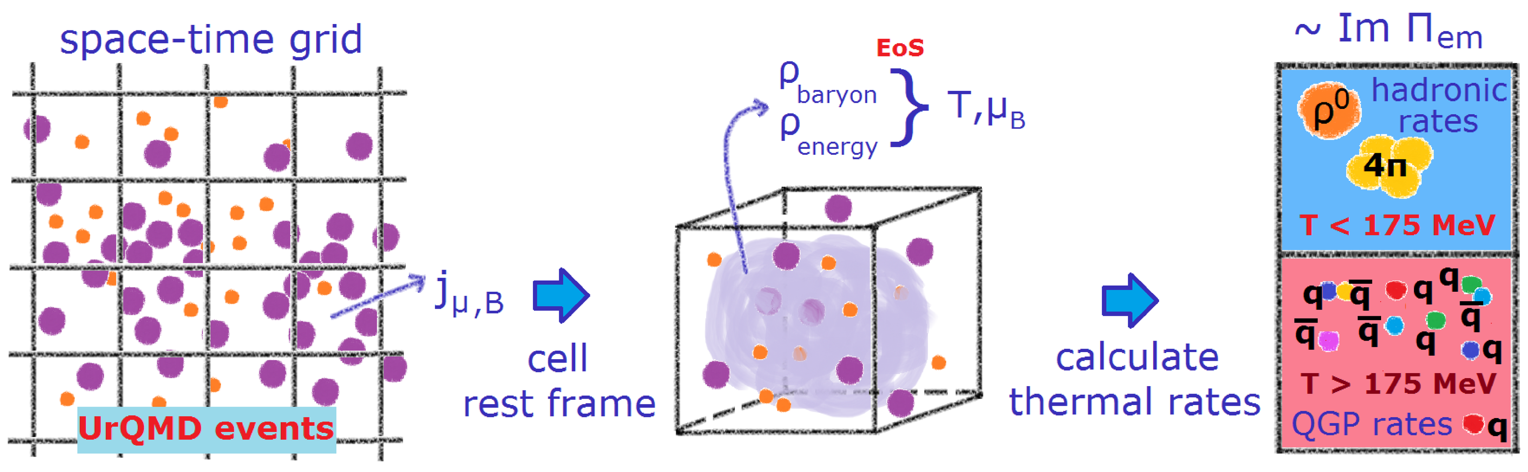
- Dileptons represent a clean and penetrating probe of hot and dense nuclear matter, as they do not interact strongly
- Aims of studies are **in-medium modifications of vector meson properties** and **chiral symmetry restoration**



- Reflect **whole dynamics of a collision**, from first nucleon-nucleon reactions to final freeze-out $\Rightarrow$ Correct description of dynamics essential!
- Transport models $\longrightarrow$ Difficult to implement medium modifications
- Fireball models $\longrightarrow$ Might oversimplify the physics
- **How can one combine a microscopic description of nuclear reactions with in-medium spectral functions?**

The Coarse-Graining Approach

- An ensemble of several hundred events from calculations with the UrQMD model (Bass 1998, *Prog. Part. Nucl. Phys.* 41) is put on a **grid of small space time cells**
- For each cell we determine the baryon current j_B and use Eckart's definition to determine the rest frame properties for **energy and baryon densities**
- Use **equation of state** to calculate the local **temperature** T and and **baryochemical potential** μ_B
- Pion and kaon chemical potentials are extracted in Boltzmann approximation
- Equation of state for a **free hadron gas** (Zschiesche 2002, *Phys. Lett.* B547) without any phase transition is used
- To account for QGP emission at high collision energies, we assume that cells with T above 175 MeV contribute only to the Quark-Gluon radiation



- Lepton pair emission is calculated for each cell of the 3+1-dimensional grid, using **thermal equilibrium rates** per four-volume and four-momentum from a bath at T and μ_B as related to the retarded current-current correlator (Rapp 2000, *Adv. Nucl. Phys.* 25):

$$\frac{d^8N_{ll}}{d^4x d^4q} = -\frac{\alpha^2 L(M^2)}{\pi^3 \quad M^2} f_B(q_0;T)\mathrm{Im}\Pi^{\mu}_{em,\mu}(M,q;T,\mu_B) \qquad (1)$$

with lepton phase space $L(M^2)$ and Bose factor f_B
- For the **vector meson dilepton emission** we apply in-medium spectral functions calculated from hadronic many-body theory (Rapp 1997, *NPA* 617)
- As the largest in-medium modification is expected for the ρ we concentrate on this contribution here
- Medium modifications of the ρ propagator D_ρ include interactions with pion cloud of hadrons and direct scatterings off mesons and baryons:

$$D_\rho \propto \frac{1}{M^2 - m_\rho^2 - \Sigma^{\rho\pi\pi} - \Sigma^{\rho M} - \Sigma^{\rho B}} \qquad (2)$$

- To account for non-equilibrium effects of the pion dynamics, we implement the chemical potential μ_π as an overall fugacity factor $z_\pi = \exp(\mu_\pi/T)$
- **QGP contribution** is evaluated as $q\bar{q}$ annihilation with hard thermal loop improvement (Braaten 1990, *PRL* 64)
- Emission from **multi-pion annihilation** is taking the mixing effect on the vector-isovector current correlation function into account (van Hees 2008, *NPA* 806):

$$\Pi_V(q) = (1-\varepsilon)z_\pi^4\Pi^{vac}_{V,4\pi} + \frac{\varepsilon}{2}z_\pi^3\Pi^{vac}_{A,3\pi} + \frac{\varepsilon}{2}(z_\pi^4 + z_\pi^5)\Pi^{vac}_{A,5\pi} \qquad (3)$$

with the mixing parameter ε

Results & Discussions

- Coarse-Graining of UrQMD gives a **realistic picture** of the collision evolution (see Fig.1)
- Energy and baryon density are by no means homogeneous in the whole fireball $\Rightarrow$ Different **expansion dynamics** might lead to significantly differing dilepton spectra

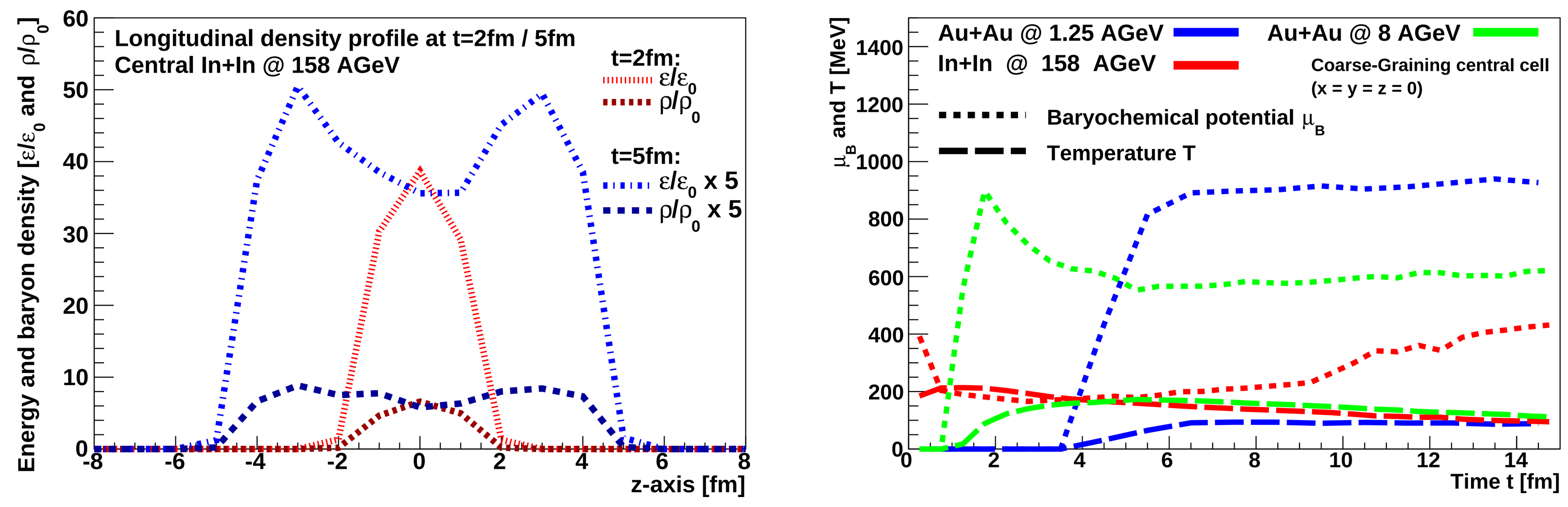


Figure 1: (Left) Longitudinal profile for 158 AGeV In+In collisions at times t=2fm and t=5fm. (Right) Time evolution of temperature and chemical potential in a central cell at different bombarding energies.

- With increasing beam energy **temperature rises** and baryon **chemical potential decreases** $\longrightarrow$ Less baryon dominated at higher energies
- In the NA60 case, the baryon chemical potential is much lower than at SIS and FAIR energies but by no means negligible and still has an important impact

Invariant Mass Spectra - Comparison with Experiment

- Good agreement between our dilepton calculations with the Coarse-Graining approach and experimental data from HADES and NA60 (see Fig.2)
- Comparison with the case of no baryons shows the **importance of baryonic effects** for the low-mass enhancement

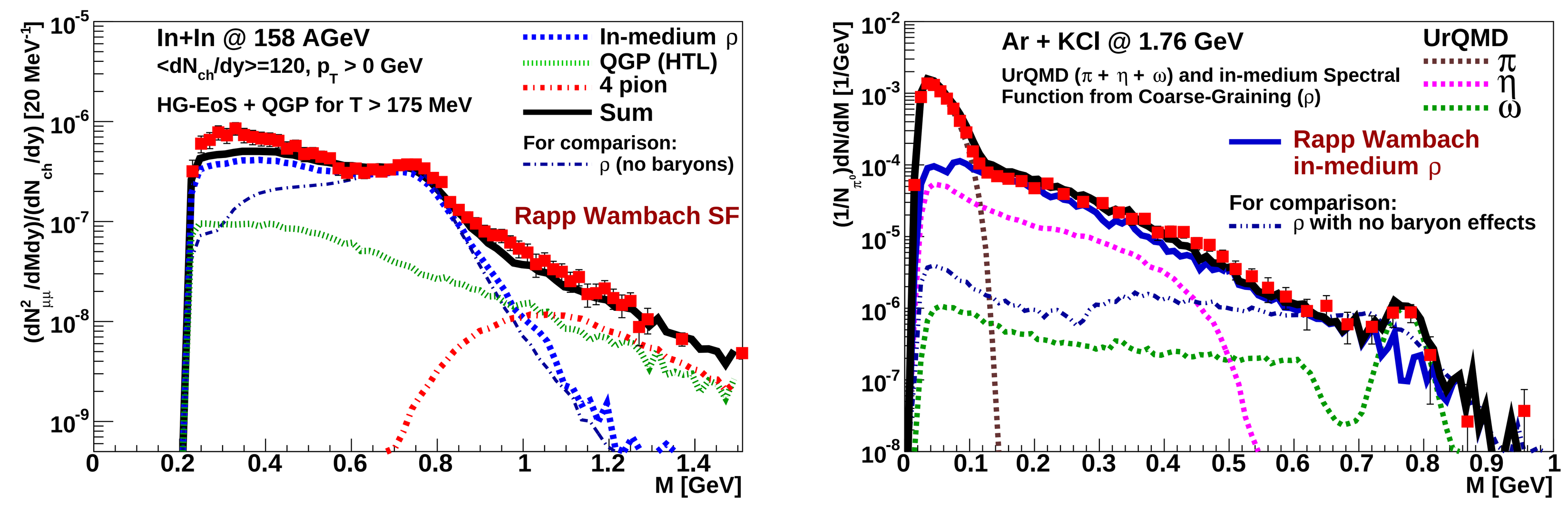


Figure 2: Comparison of our calculations with the invariant mass spectra for the $\mu^+\mu^-$ excess in In+In collisions at 158 AGeV from NA60 (left) and for the e^+e^- yield in Ar+KCl reactions at 1.76 AGeV measured by HADES (right).

The Future: HADES & CBM at FAIR

- The future **FAIR facility** will provide the possibility for further detailed studies of a region of the phase diagram, where we **expect strong baryonic effects and medium-modifications** of spectral functions (see Fig.3 below) due to the high values of μ_B

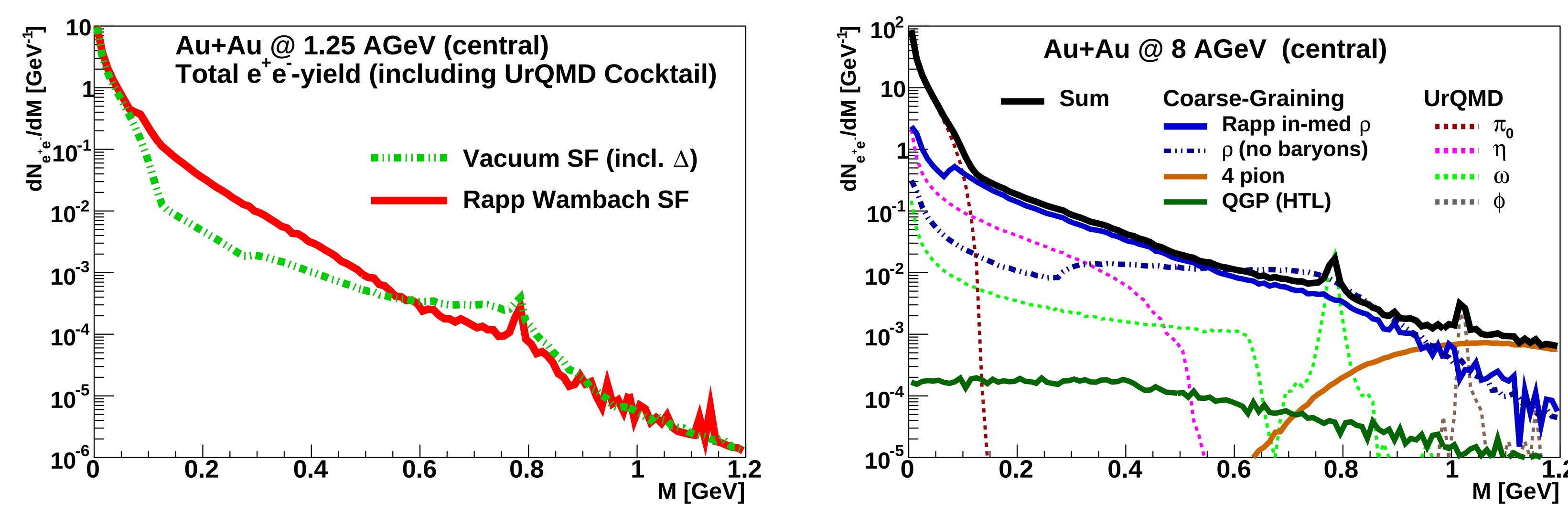


Figure 3: (Left) Total dielectron yield for Au+Au at 1.25 AGeV with an in-medium ρ and, for comparison, a vacuum ρ. (Right) Invariant e^+e^- mass spectrum for Au+Au at 8 AGeV.

Summary & Outlook

- The Coarse-Graining **successfully describes the dilepton yields** at different energies
- Results agree with calculations within a fireball model (e.g. van Hees 2006, *PRL* 97)
- Further studies: Influence of different spectral functions / different EoS on the results

We especially thank Ralf Rapp for providing the in-medium spectral functions (Rapp 1999, *Eur. Phys. J.* A6) and the HADES Collab. for their data and filters

Stephan Endres
Frankfurt Institute for Advanced Studies
endres@th.physik.uni-frankfurt.de
telephone +49-69-798-47532

The authors acknowledge Jan Steinheimer-Froschauer and Tetyana Galatyuk for fruitful discussions. This work was supported by BMBF, HICforFAIR, H-QM and HGS-HIRe.

GEFÖRDERT VOM Bundesministerium für Bildung und Forschung
HIC for FAIR Helmholtz International Center
H-QM Helmholtz Research School Quark Matter Studies
HGS-HIRe for FAIR Helmholtz Graduate School for Hadron and Ion Research