Dilepton Signature of a First-Order Phase Transition

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Goal

CRC-TR 211

- Calculate dilepton invariant mass spectra of heavy-ion collisions
- Extract excitation functions of temperature, life time of heavy-ion collisions
- Predict dilepton signature of a first order phase transition

- Method of choice: **Coarse Graining**
  - ➥ bulk evolution from microscopic transport
  - ➥ apply equilibrium rates locally

$L(M^2)$: Phase space factor
$f^{BE}(q_0,T)$: Bose-Einstein factor
$\mathrm{Im}\Pi_{EM}$: Electromagnetic spectral function

$$\frac{dN_{ll}}{d^4x d^4q} = -\frac{\alpha_{EM}^2}{\pi^3 M^2} L(M^2) f^{BE}(q_0,T)\mathrm{Im}\Pi_{EM}(M,q,\mu_B,T)$$

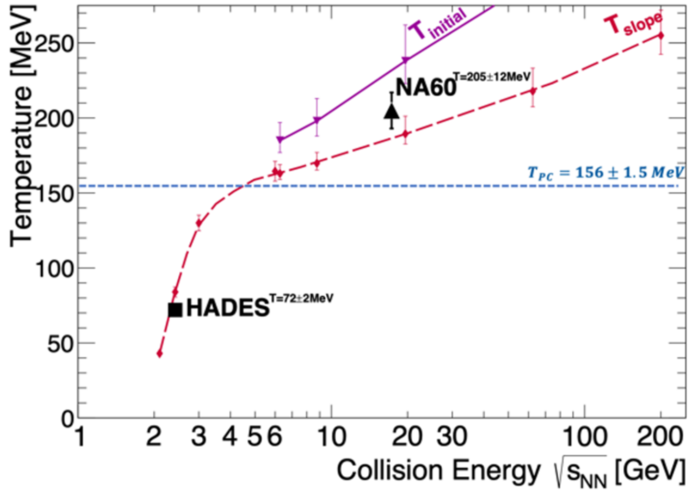
McLerran-Toimela, Phys. Rev. D 31 (1985), p. 545)

$$\Pi_{EM}^{\mu\nu}(q_0,q,\mu_B,T) = -i\int d^4x e^{iqx}\Theta(x^0)\langle[j^\mu(x),j^\nu(0)]\rangle_{T,\mu_B}$$

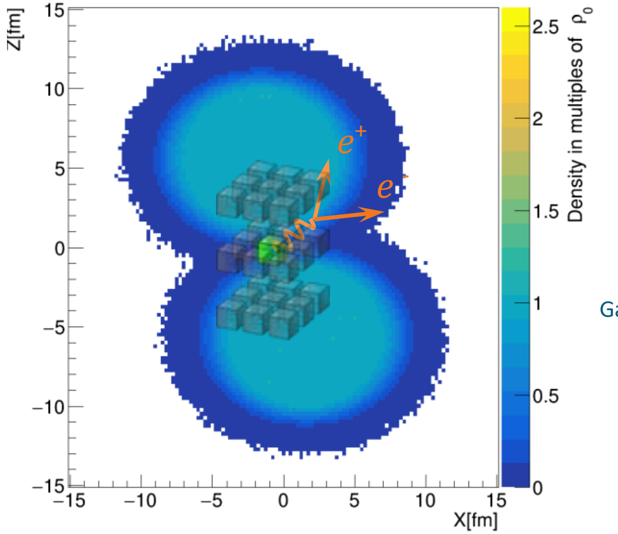
$$j_{EM}^\mu = \sum_{q=u,d,s} \bar{q}\gamma^\mu q e_q = \frac{1}{\sqrt{2}} j_\rho^\mu + \frac{1}{3\sqrt{2}} j_\omega^\mu + \frac{1}{3} j_\phi^\mu$$

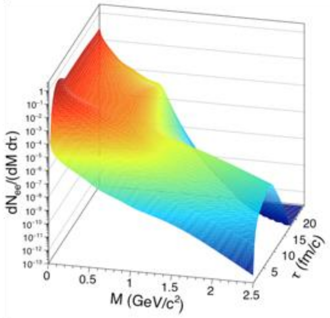
Takeaway: Dilepton yield depends on T, μ_B (ρ_B), is obtained by integrating over space-time and 4-momentum, ρ is short lived and gives largest contribution

Rapp and v. Hess, PLB 753 (2016) 586
Galatyuk et al.: EPJA 52 (2016) 131
Bazavov et al. [HotQCD], PLB 795 (2019) 15-21



Density at time 0.5 fm/c





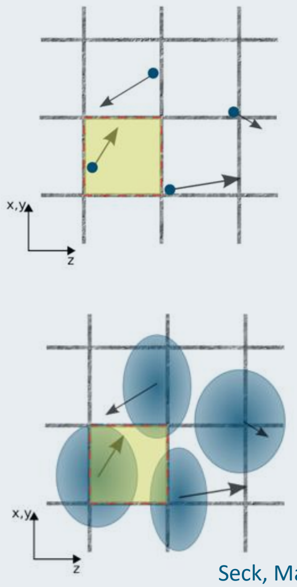
Galatyuk, Rapp-Wambach SF

Determination of bulk properties

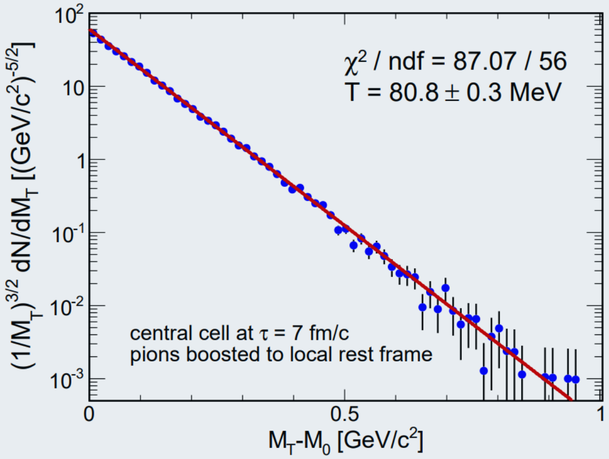
- No bulk properties with discrete entities?
  - Particles as gaussians:

$$P(\vec{x},\vec{x}_0) = \frac{\gamma}{\sqrt{2\pi}\sigma} e^{-\frac{(x-x_0)^2+(y-y_0)^2+\gamma^2(z-z_0)^2}{2\sigma^2}}$$

- Determination of temperatures: exponential fit to transverse mass spectra of pions
  - $m_t = \sqrt{E^2 - p_z^2}$

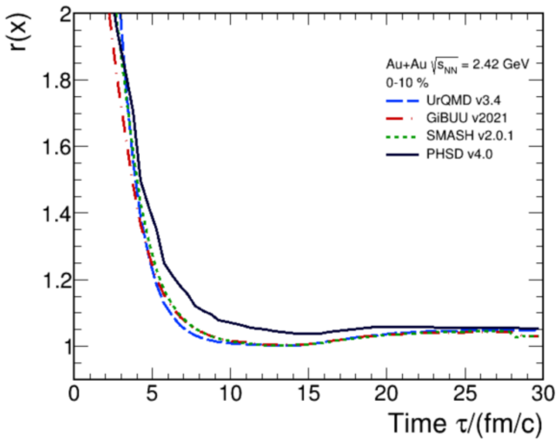


Seck, Master thesis 2015

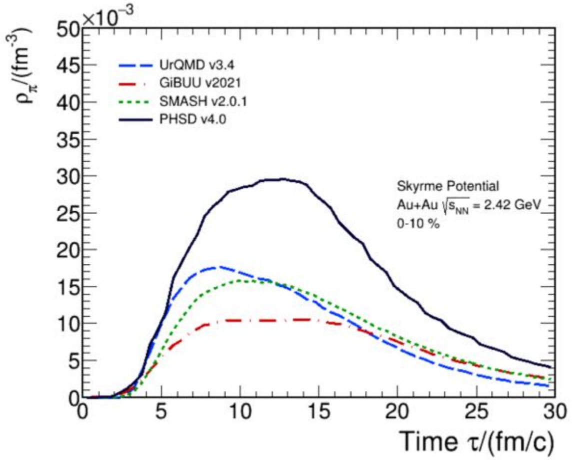


Seck et al., Eur.Phys.J.A 52 (2016) 5, 131

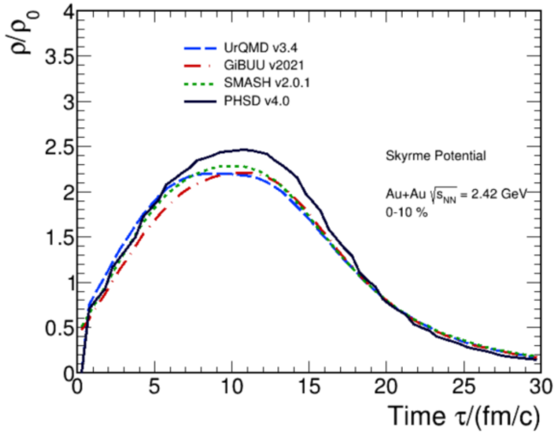
Relaxation function



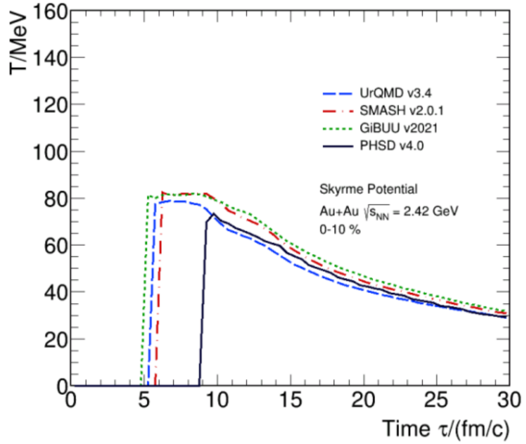
Pion density



Baryon density

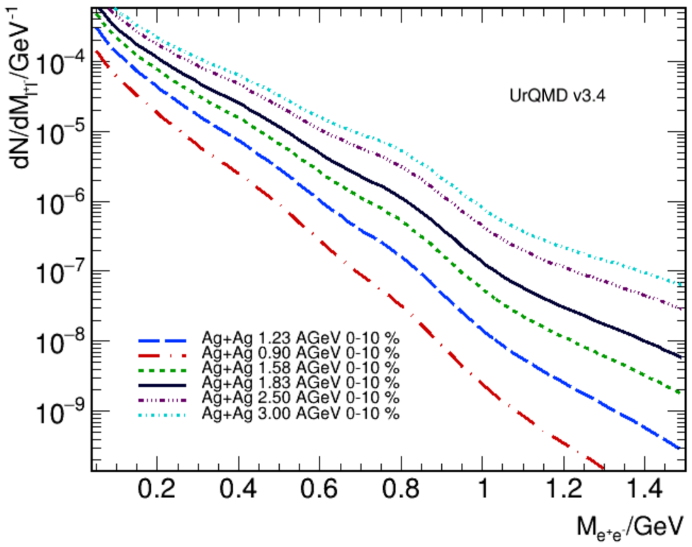


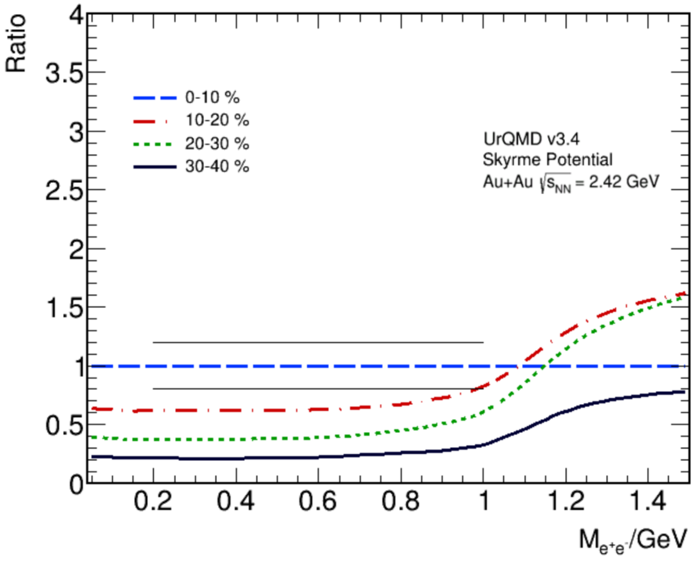
Temperature



Energy, model and centrality dependence of spectra

Energy dependence



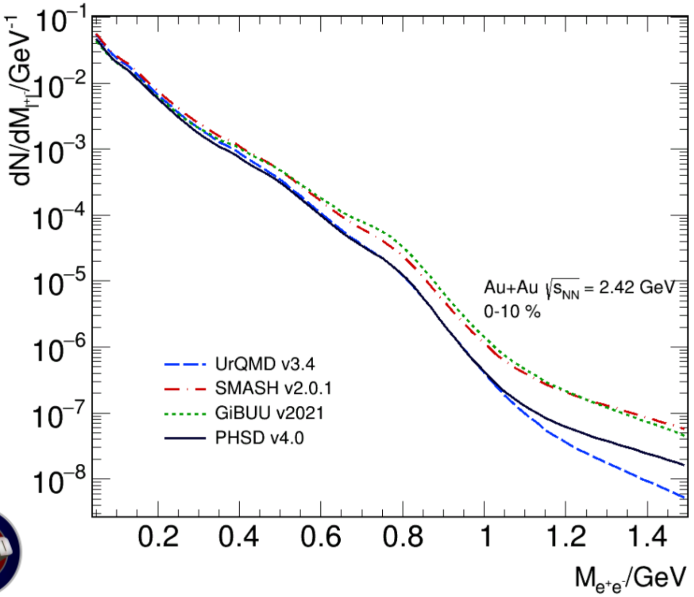


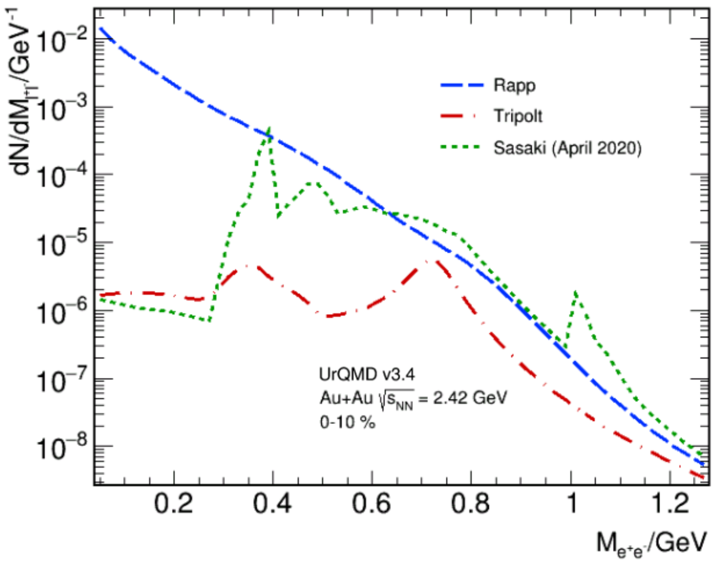
Centrality dependence (ratio)

[HADES] *Eur.Phys.J.A* 54 (2018) 5, 85

Model dependence

Prog. Part. Nucl. Phys. 41 (1998) 225-370
J. Phys. G: Nucl. Part. Phys. 25 (1999) 1859-1896
Nucl. Phys. A 831 (2009) 215-242
Phys. Rev. C 78 (2008) 034919
Phys. Rept. 512 (2012) 1-124
JHEP05 (2006) 026
Comput. Phys. Comm. 178 (2008)
Phys. Rev. C 94, 054905 (2016)

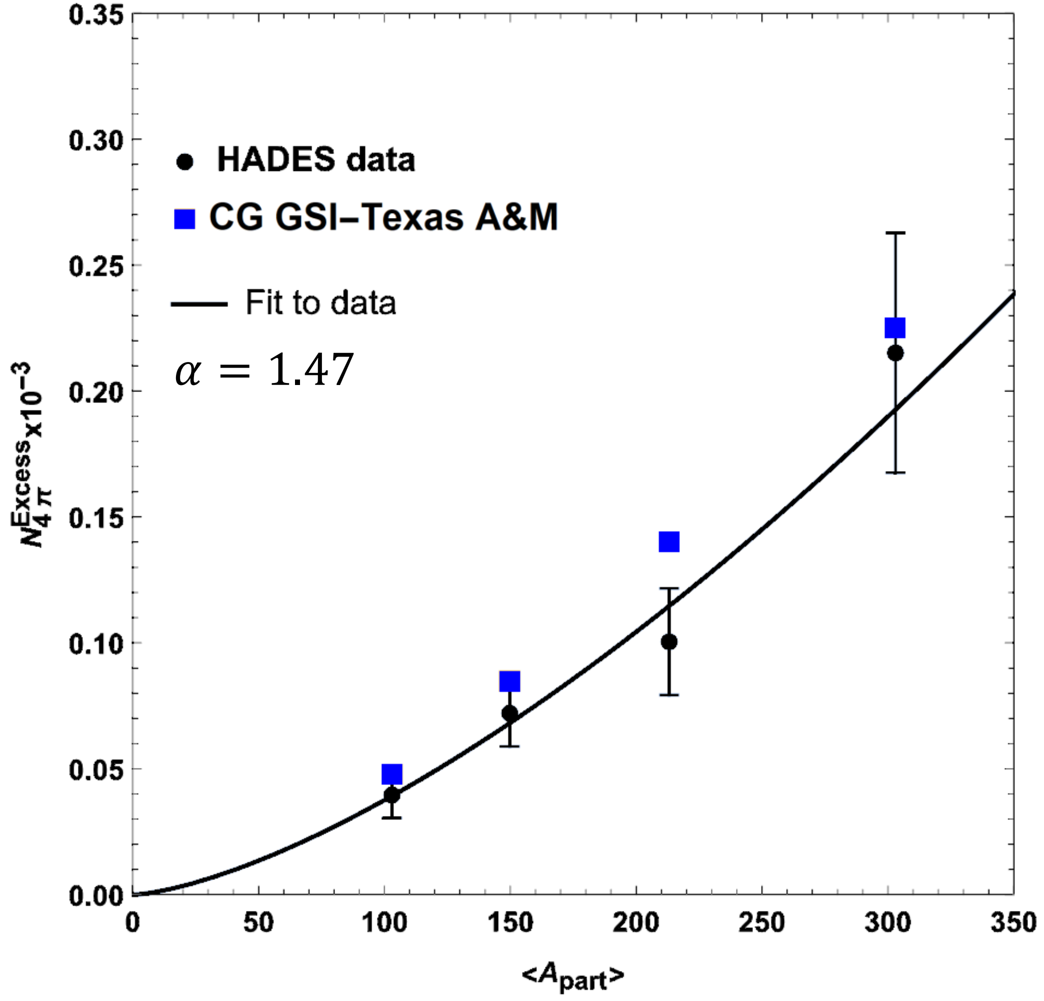


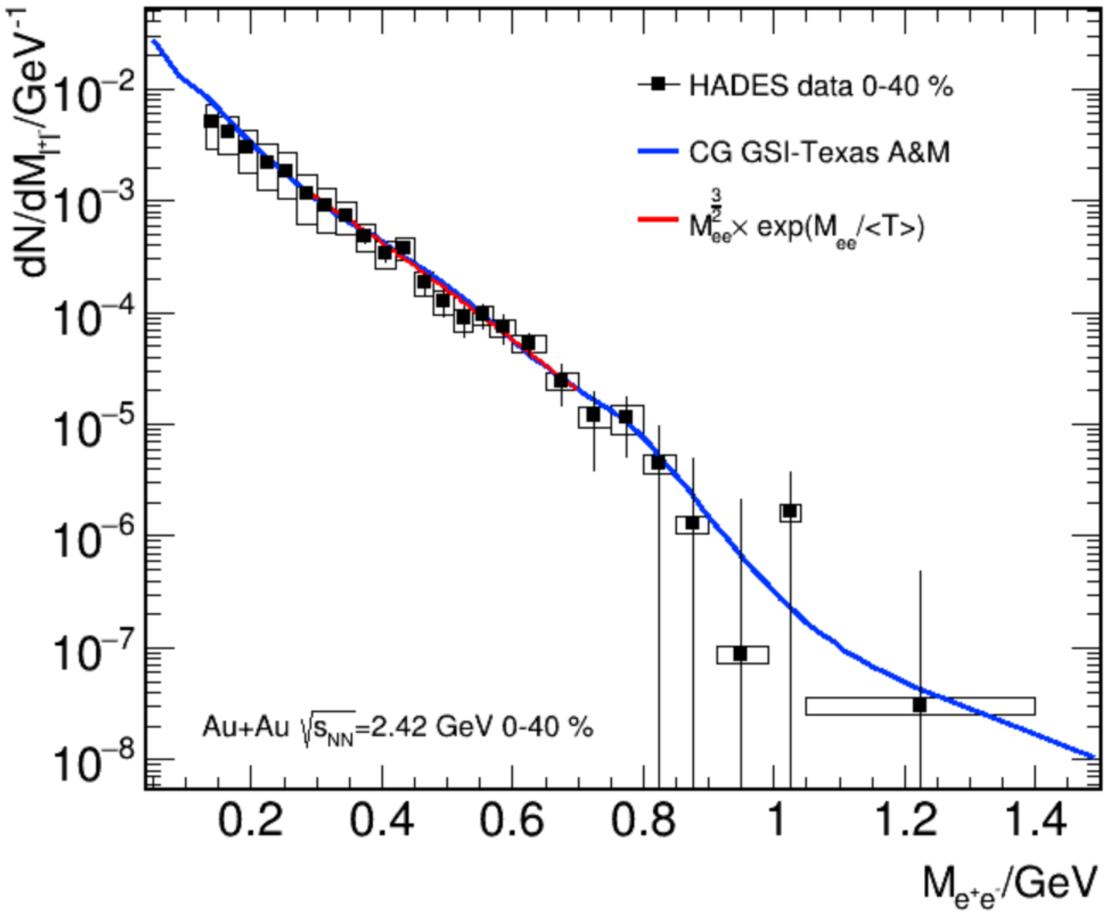


Spectral functions

Spectral function: Rapp and Wambach, Eur.Phys.J. A6 (1999)
Sasaki, Phys.Lett.B 801 (2020) 135172
Tripolt, Phys.Rev.D 104 (2021) 5

Thermal dileptons: comparison to HADES data





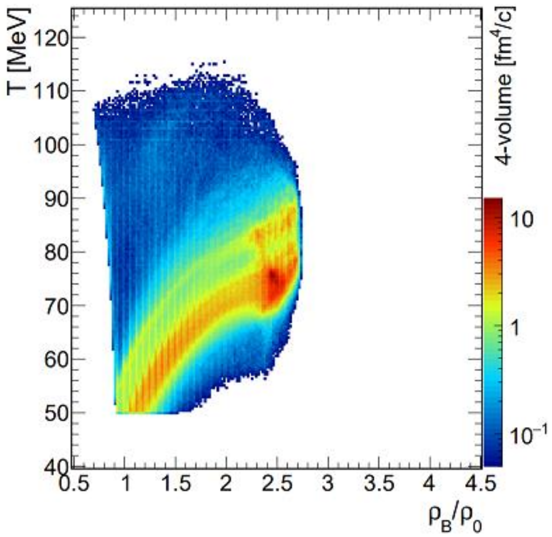
	T/MeV	$N_{e^\pm}/10^{-4}$
CG GSI-Texas A&M	76.5	1.09
HADES	71.8±2.1	1.07±0.3

[HADES], Nature Phys. 15(2019) 1040
Spectral function: Rapp and Wambach, Eur.Phys.J. A6 (1999)
[HADES] *Eur.Phys.J.A* 54 (2018) 5, 85

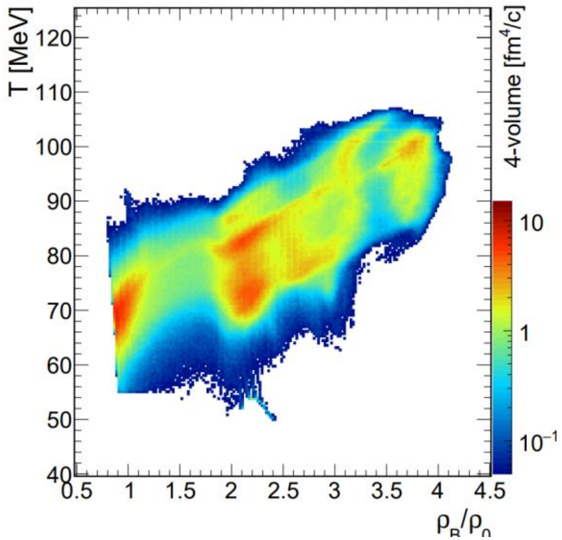
Dilepton signature of a first order phase transition

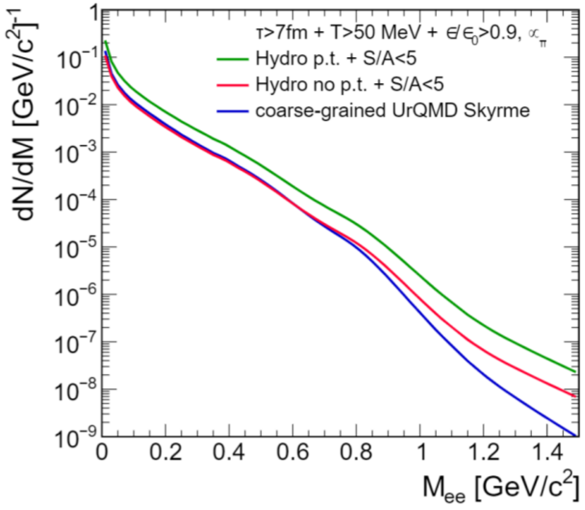
CRC–TR 211

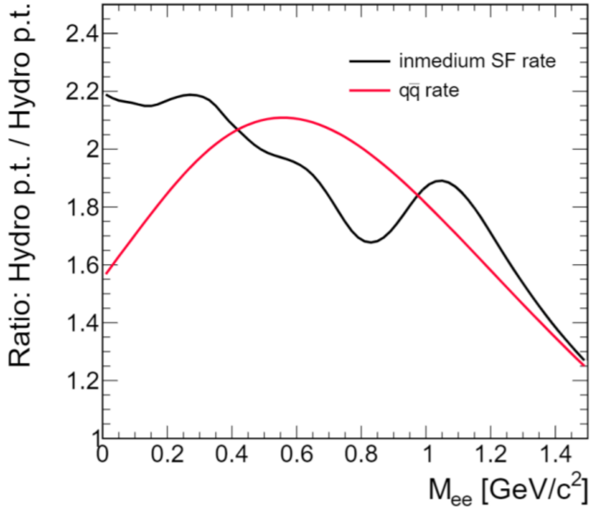
Hydro – no FO PT



Hydro – FO PT







Invariant mass spectra and ratios of dilepton spectra

- Dilepton radiation in Hydrodynamics
  - ➥ Implementation of „strong“ 1st-order transition into CMF/PNJL model by increasing scalar quark couplings
  - ➥ Dilepton radiation increases by factor ~2 for hydro with phase transition

Seck et al. arXiv:2010.04614 [nucl-th]

- Future Plans:
  - ➥ Extend the FRG spectral function to finite momenta
  - ➥ Extract EoS
  - ➥ Feed EoS into UrQMD and other transport models allowing for custom EoS
  - ➥ Calculate excitation function of dilepton temperature and yield for different EoS
  - ➥ Predict dilepton signature of first order chiral phase transition