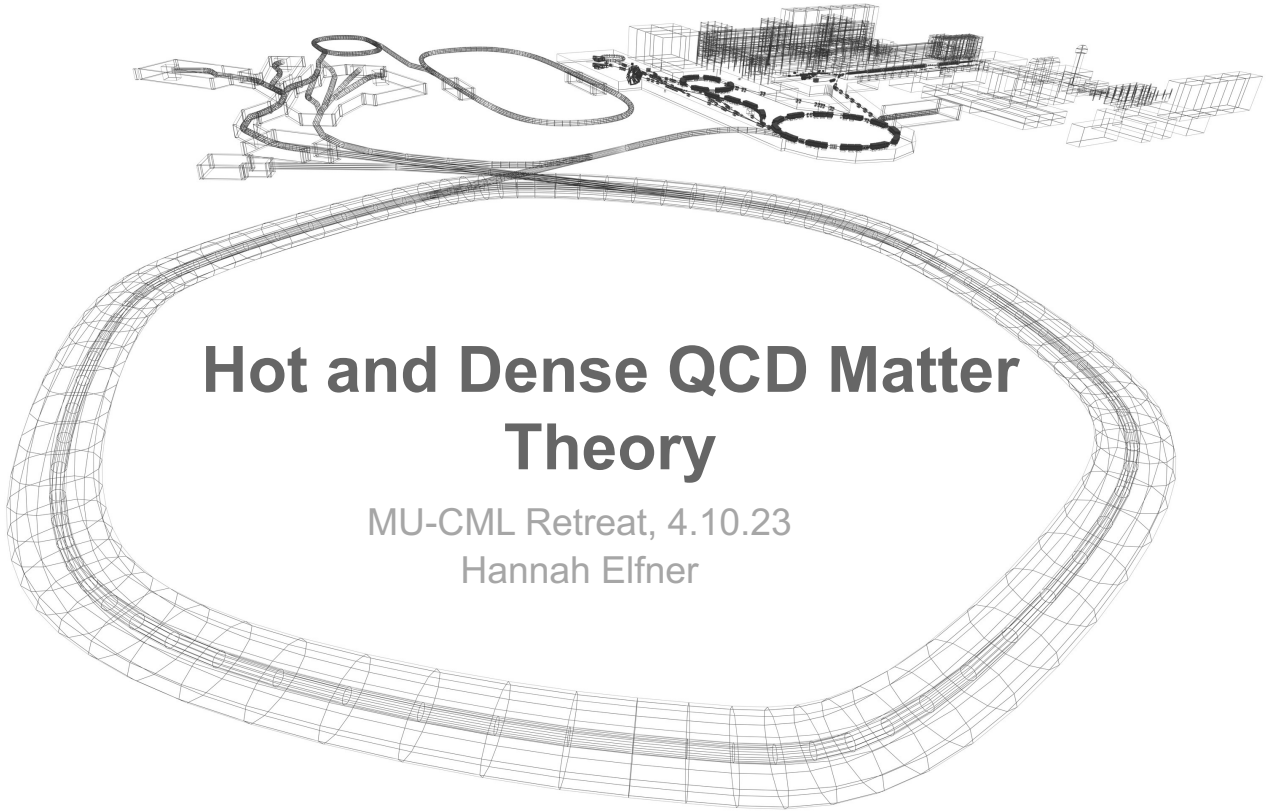


Hot and Dense QCD Matter Theory

MU-CML Retreat, 4.10.23

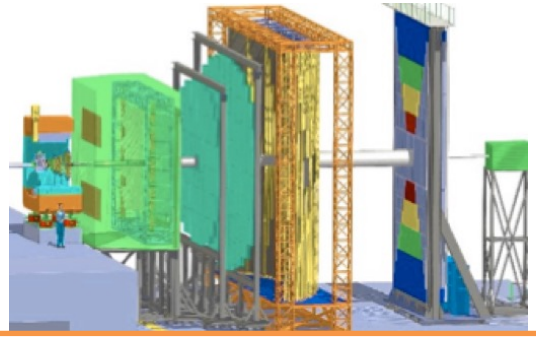
Hannah Elfner

Why Theory?

- Theoretical calculations are necessary to make predictions based on established knowledge
- Test of fundamental theory in experiment
- Interpretation of complex measurements rarely possible without theoretical input
- Turn experimental discoveries into new theoretical developments

Fundamental Theory

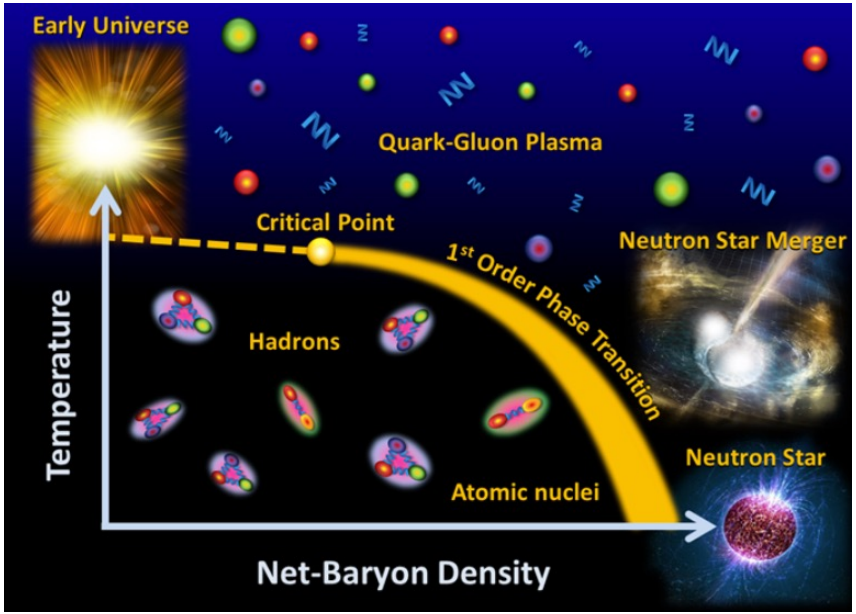
$$\mathcal{L}_{\mathrm{QCD}} = \bar{\psi}_i \left(i\gamma^\mu (D_\mu)_{ij} - m\,\delta_{ij} \right) \psi_j - \frac{1}{4} G^a_{\mu\nu} G^{\mu\nu}_a$$



Experimental Measurements

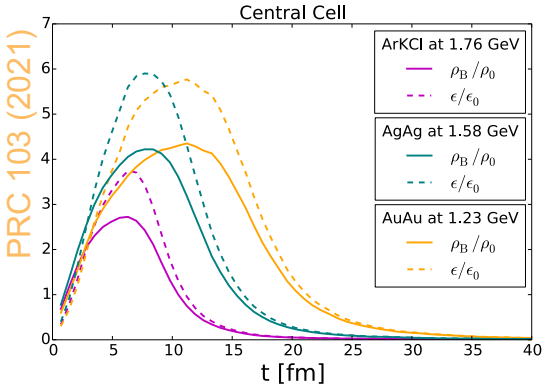
Hot and Dense QCD Matter

- Major goals of heavy-ion research:
  - Properties of hot and dense QCD matter
  - Exploration of the QCD phase diagram
- To connect final results in the detector with QCD input, sophisticated dynamical evolution is necessary
- Relativistic hydrodynamics and transport theory are the main approaches pursued here

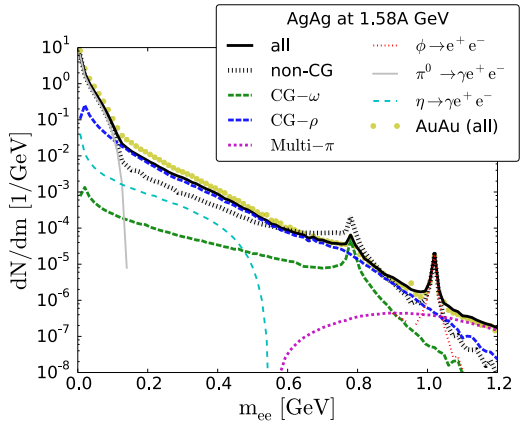


Webpage CBM collaboration

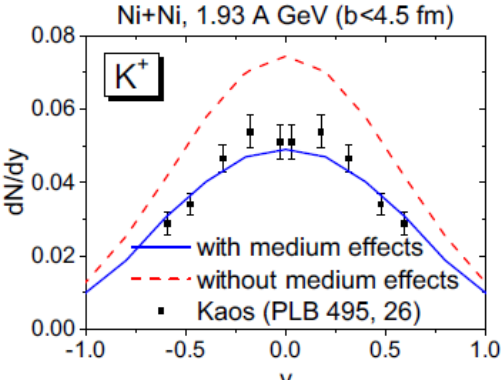
Observables for Medium Modifications

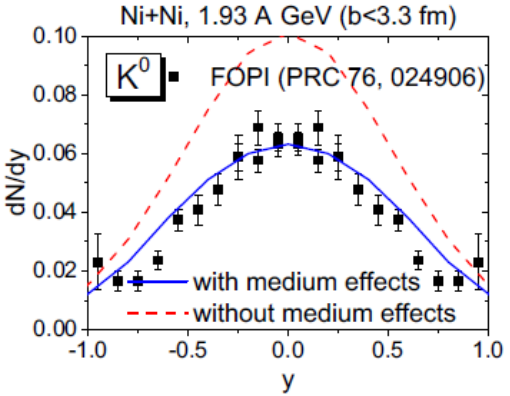


PRC 103 (2021)



- In heavy-ion collisions at GSI high densities are reached over extended time period
- Predictions for HADES AgAg dilepton spectra surprisingly similar to Au+Au results
- G-matrix approach for in-medium potentials for kaons indicates significant effects for strangeness production
- Collective flow is also affected





PRC 103 (2021)

Light Nuclei and Equation of State

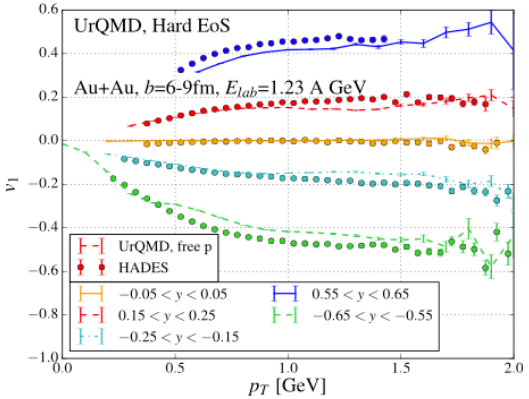
- Highly differential collective flow measurements from HADES collaboration
- Understanding of light nuclei production is important

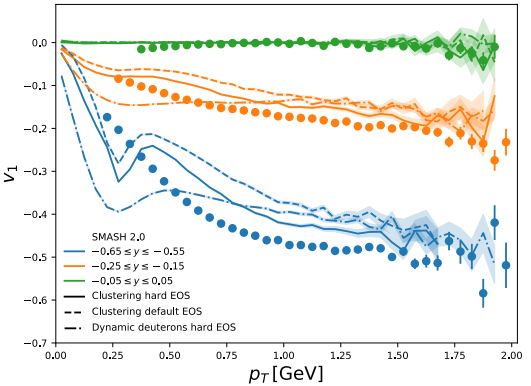
  See also arXiv:2106.14839

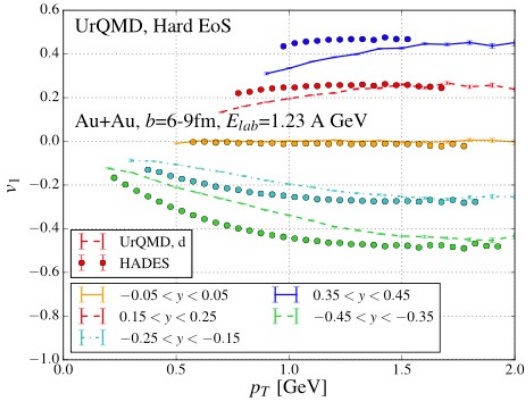
- Microscopic deuteron production compared with coalescence approach

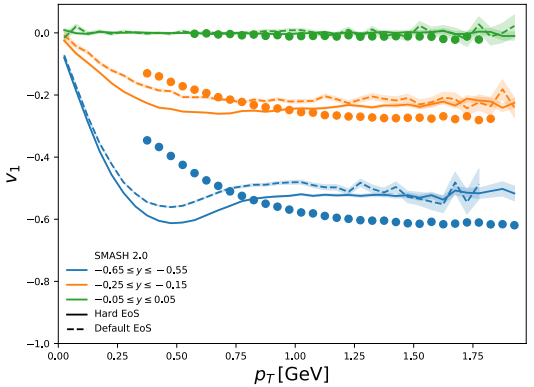
  Left: JPG 47 (2020)
  Right: arXiv: 2012.11454

- **Future:** Extract equation of state of nuclear matter with Bayesian analysis









Plans for 2028+

- Maintain a research program focused on the support of the experimental campaigns at GSI/FAIR, HADES, CBM, ALICE
- Tools: Open source transport codes and relativistic hydrodynamics
- Main themes:
  - Nuclear equation of state and connection to astrophysics
  - Medium modification of resonances
  - Properties of hot and dense QCD matter under extreme conditions
  - Electromagnetic probes
  - Light cluster production and properties
- Exploit connections to other areas within NUSTAR (e.g. nucleon correlations, hypernuclei production) and hadron physics (e.g. modeling of hadron properties)

More Plans

- Extracting from the novel FAIR experimental data information on the EoS
- Investigating signatures of the 1st order phase transition
- Searching for signatures of in-medium and subthreshold effects on the strangeness and charm production at FAIR
- (a bit exotic) : investigation of possible indications of physics beyond the standard model (in particular - dark matter candidates) within heavy-ion data
- Focus on ultra rare observables, which becomes possible due to the outstanding luminosity of FAIR
- This opens the road for fluctuations and correlations, charm and dileptons
- Overcome the coarse graining method for dileptons

Overview of Resources

Permanent Personel

Hot and Dense QCD Matter
Hannah Elfner
Elena Bratkovskaya
Marcus Bleicher
Horst Stöcker

- Good mixture of senior/junior personel through hirings over last ~10 years
- In addition: 2 postdoc positions
- Relying heavily on third party funding, e.g. group by H.E.:
  - 1 postdoc by GSI and 1 PhD student F&E
  - 2 postdocs and 5 PhD students by CRC-TR, ELEMENTS, etc
- Need for HPC

Department	CPU-Core hours /year	Storage (scratch)	Storage (home)	RAM per core
Hot and Dense QCD Matter (Status)	10 million (the+hyihp)	150 TB	120 GB	50 MB-13 GB
Hot and Dense QCD Matter (in 5 years)	30 million	300 TB	10 TB	Up to 20 GB

+ Support for open source code development