Progress Report for Project B04

The electro-weak response of hot and dense QCD matter

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CRC-TR 211 Strong-interaction matter under extreme conditions

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HGS-HIRe for FAIR Helmholtz Graduate School for Hadron and Ion Research

What the Project Promised

- (i) Effective hadronic theory for nuclear and neutron matter
- (ii) Vector and axial-vector spectral functions at high baryon chemical potential
- (iii) Signals of strong-interaction matter in heavy-ion collisions and astrophysics

(i) Effective hadronic theory: Goals and Timeline

Goals:

- Parity-doublet model with fluctuating (axial-)vector mesons
- Realistic EoS for nuclear and neutron matter
- Location of chiral PT and chiral CEP
- Dynamics in the effective theory from microscopic transport

Timeline:

2021 Nuclear matter phase diagram, including baryonic fluctuations, of parity-doublet model at finite μ_B, μ_I and T (✓)

2022 PDM phase diagram with full mesonic fluctuations, fluctuating vector mesons, phenomenology of liquid-gas transition (X)

2023 Provide EoS for neutron matter to B09 X

(i) Effective hadronic theory: Where Are We?

- PDM phase diagram
  - μ_B, T with fluctuating baryons at $\mu_I = 0$ ✓
  - S. Cardona: Isospin dependence in mean field to extract PDM thermodynamics (✓)
  - M. Recchi: Isospin dependence in RG-invariant mean field approach (∼)
  - L. Smekal: Similar work done for QM model in context of A08
- Fluctuating vector mesons
  - Consistent formulation of fluctuating vector fields ✓
  - F. Rennecke, A. Tripolt: Improved truncation for fluctuating mesons (PAUSED)
- NS EoS and GW observables
  - Once μ_I dependence finished X

Compared to planned timeline, we are behind time.

(ii) (Axial-)Vector SF: Goals and Timeline

Goals:

- (Axial-)Vector spectral functions at high baryon chemical potential
- Electromagnetic response
- Response to weak interactions

Timeline:

2021 Calculate EM spectral functions from FRG on (T, μ_B)-grid along heavy-ion collision trajectories ✓

2022 Construct EM-current-current correlation functions as functions of temperature and baryon chemical potential close to liquid-gas and chiral PT (✓)

2023 Calculate (axial-)vector spectral functions from aFRG flows of extended parity-doublet model at finite temperature and density for nuclear and neutron matter (✓)

(ii) (Axial-)Vector SF: Where Are We?

- A. Tripolt, M. Wiest: EM spectral functions are computed from vector spectral functions via Vector Dominance Model ✓
- Fully functional code exists to calculate vector spectral functions at any (T, μ_B) ✓
- Observables for neutron matter need the work with isospin-dependence first (∼)
- Electromagnetic spectral functions with an EM gauged Lagrangian X

Compared to planned timeline, we are slightly behind time.

(iii) Signals (HIC & Astro): Goals and Timeline

Goals:

- Electromagnetic signals of PT and CP in heavy-ion collisions
- Gravitational waves and thermal neutrinos from neutron-star mergers

Timeline:

2021 Test microscopic transport models simulations against new set of experimental data; Establish baseline for further comparisons (✓)

2022 Calculate dilepton yields and slopes close to possible phase transitions ✓

2023 Evaluate μ_I dependence of dilepton rates when changing to neutron matter X

(iii) Signals (HIC & Astro): Where Are We?

- HADES data unavailable for comparison yet X
- M. Wiest, F. Seck:
  - Extensive model comparisons ✓
  - Dilepton yields calculated ✓
  - Code exists to calculate dilepton yield for any spectral functions provided ✓

Compared to planned timeline, we are on time.

Additional Opportunities and Directions

- Virtual photon polarization & dilepton flow
  - F. Seck: Method to predict virtual photon polarization in heavy ion collisions with any given spectral function. Tested against HADES and NA60 data.
  - M. Wiest: feedback of baryonic fluctuations in pion propagators into vector spectral functions.
  - F. Seck, R. Hirayama: Dilepton flow carries imprint of early hadronic flow and carries information on phase transitions, nuclear potentials.
- Representation theory
  - L. Smekal, C. Kummer: Formulation of fluctuating spin $\frac{3}{2}$ baryon investigations
  - Will be valuable for necessary inclusion of higher baryon resonances into PDM
- F. Rennecke, L. Smekal: Non-Hermitian hessian in dense nuclear matter from in-medium mixing

B04: Outlook

- Mostly on schedule
- Better understand effective degrees of freedom
- Isospin dependence and neutron matter is work in progress
- Synergies with B09 and A03
- Drop weak spectral functions and neutrino observables
- Shifted interest: Differential observables provide deeper understanding of phase structure