Beam Energy Scan theory talks summary

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RHIC goals

- Learn properties of quark-gluon plasma
- Probe the Equation of State (EoS) of strongly-interacting matter including search for critical point and phase transition
Proton fluctuations [2112.00240]: only non-critical models available

What do we learn from this measurement?
RHIC results challenging theory II

Proton, pion, light nuclei flow [2112.05424, 2112.04055]

- Large sensitivity to EoS [nucl-th/0208016]
- Negative proton $dv_1/dy$ – EoS softening, likely indication of phase transition [nucl-th/0406018, 1803.02053]
- Notice: maximum $R_{out}^2 - R_{side}^2$ at the same energy range [1411.7931]
- EoS softening at which $(T, \mu)$? Can be far away from chemical freeze-out $(T, \mu)$. Need simulations and Bayesian analysis!
RHIC results challenging theory III

Light nuclei yields, $tp/d^2$ sensitive to spinodal region [2205.11010]

Is RHIC observing a spinodal region?
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Is RHIC observing a spinodal region?
Theoretical approaches, their advantages and challenges

- Hydro+ or fluctuating hydro (+ transport)
  - ✓ Includes critical fluctuations  ❌ only up to 2nd order so far

- Hydro (+ transport)
  - ✓ Easy to build in custom EoS
  - ✓ Easy to adjust viscosity
  - ❌ Handling spectators (important for flow) under development
  - ❌ Handling phase separation under development
  - ❌ Initial state: compression should depend on EoS
  - ❌ Uncertainties at particlization

- Transport
  - ✓ Spectators, initial state compression
  - ✓ No equilibrium assumption
  - ✓ Can handle phase transitions
  - ✓ Can handle critical fluctuations
  - ❌ Harder to build in a custom EoS
  - ❌ Unknown degrees of freedom
Today’s theory talks: focusing on fluctuations

- Mayank’s talk
  - Development of framework to treat hydro fluctuations
  - Including fluctuation-dissipation theorem
  - Rather small influence of thermal fluctuations on observables

- Maneesha’s talk
  - New method: turning hydro fluctuations into particles
  - Tested in hydrodynamics (boost-invariant + radial expansion)
  - Certain sensitivity of proton scaled variance and rapidity correlations to vicinity to the phase trajectory of the fireball and to diffusion parameter

- Jan’s talk
  - Does transport stage change fluctuations? Yes – for kurtosis
  - Tests in equilibrated box: fluctuations in a fixed volume
  - Scattering influences cumulants even when potentials are absent
  - Scattering makes inferring baryon cumulants from proton cumulants harder
Alternative approach: Transport approach with flexible EoS

Flow is very sensitive to the stiffness of EoS
Working towards Bayesian analysis of flow + HBT + fluctuations
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Summary of summary

- **Hydro + afterburner approaches** making progress towards realistic calculation of fluctuations
  - ✓ Account for fluctuation-dissipation theorem [Mayank]
  - ✓ Particlization of fluctuations [Maneesha]
  - ✓ Testing afterburner effects [Jan]
- **Pure transport approaches** need more attention
  - Already results for light nuclei are encouraging: maybe we evidence spinodal region at RHIC
  - Bayesian analysis of flow using transport with tunable equation of state would be helpful – work in progress