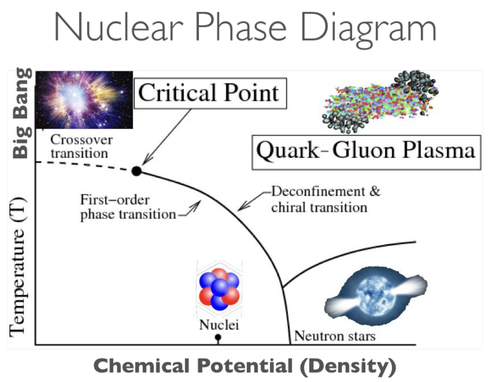
5-D Modeling of Quark-Gluon Plasma in Heavy-Ion Collisions

Robert C Meadows and Antonio Tamayo

Physics background



Quark-gluon plasma (QGP) occurs at high temperature and density, as seen in heavy-ion collisions at Brookhaven National Lab. The quarks and gluons move freely, and the plasma behaves like a perfect liquid. We analyze the phase transition from ordinary nuclear to QGP matter using 5-D modeling.

Black hole in curved spacetime

String theory results suggest the quantum theory of the strong nuclear force is also described by a 5-D gravity theory in curved spacetime. Including a black hole allows us to study the thermodynamics of the plasma. This theory yields an equation of motion that we solve computationally for the chiral field:

$$\chi'' + \left(\frac{f'}{f} + 3A' - \Phi'\right)\chi' - \frac{e^{2A}}{f}\left(m_5^2\chi + \lambda\chi^3 + \frac{\gamma}{2\sqrt{2}}\chi^2\right) = 0,$$

Dilaton Field — Chiral Field — Curvature — Blackness function — 5-D mass

Curvature: Negatively curved Anti-de Sitter spacetime

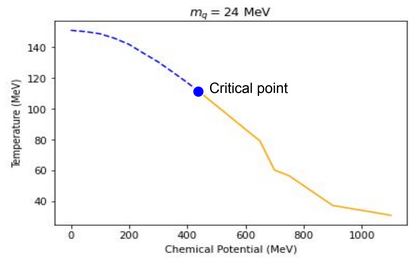
Blackness function: Determines black hole type. We use a charged black hole to include chemical potential.

Dilaton: Sets the overall energy scale.

5-D mass: Varies with energy scale in this model

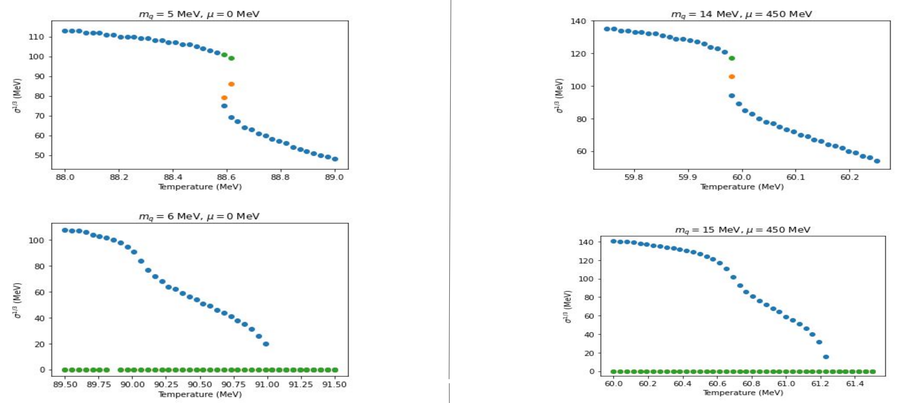
Phase transition results

- The plot at right shows a critical point when three quark flavors are included.
- Below, we explore the effect of changing the running mass parameter.
- We also check for the expected behavior in the two-flavor case. A 2nd-order transition is expected at zero quark mass, but there may be evidence of a 1st-order transition.

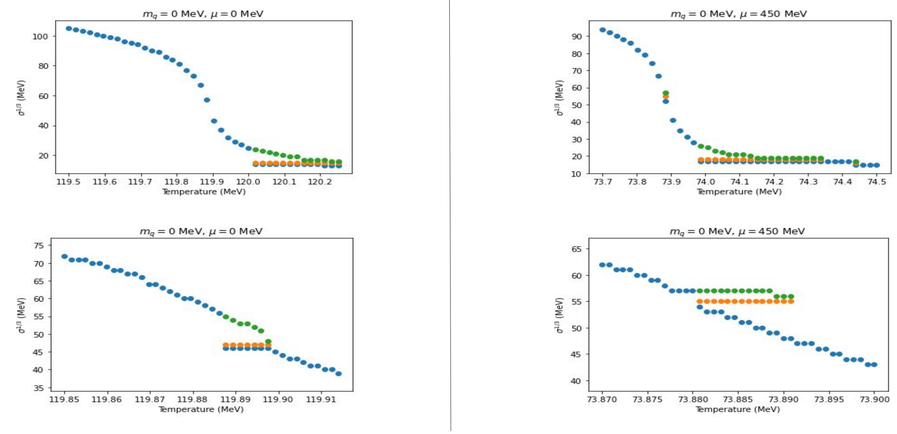


Zero Chemical Potential | Large Chemical Potential

Running mass



Checking 2-flavor

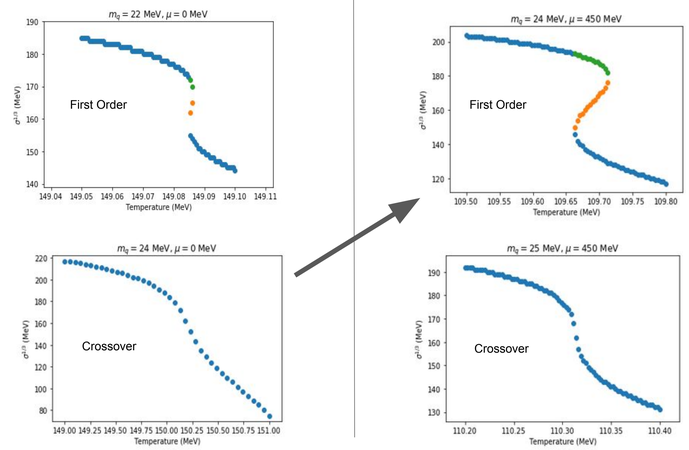


Computational solutions

The equation of motion is solved numerically. The chiral condensate (σ) is varied until the boundary conditions are satisfied.

We look for the temperature where σ transitions to a lower value, and whether this transition is continuous.

Zero Chemical Potential | Large Chemical Potential



Phase transition types differ depending on the chemical potential. At zero chemical potential, quark mass of 24 MeV exhibits crossover (continuous) behavior, while at a large chemical potential the same quark mass exhibits a first-order (discontinuous) transition.

Acknowledgements / References

Dr. Sean Bartz, advisor

Indiana State University SURE Program

Indiana State University Physics and Chemistry Department

Fang, et. al. arXiv:1810.12525, 1805.05019