Towards a Full Implementation of Conserved Charges in (2+1) Hydrodynamics

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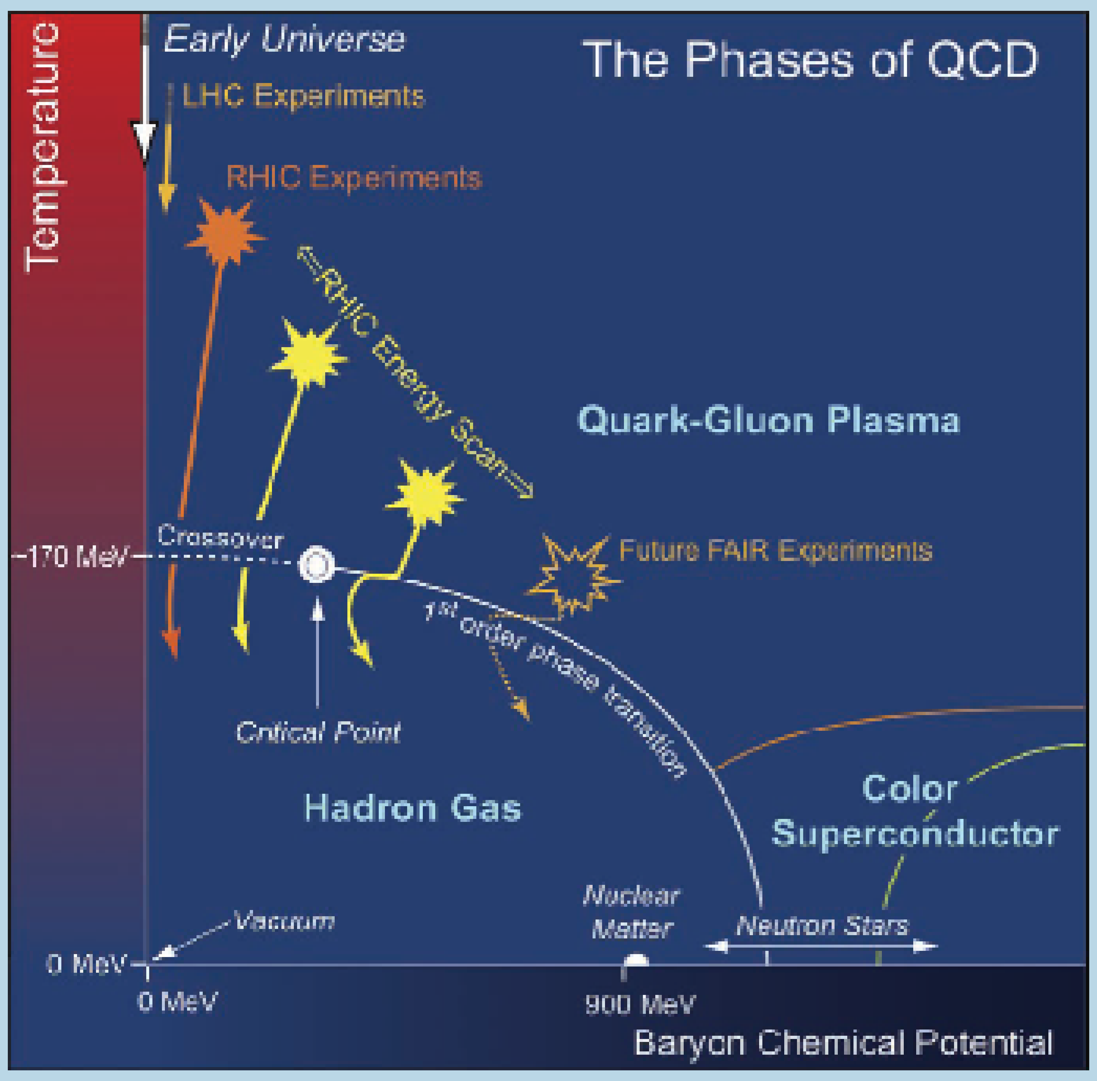
Introduction and Motivation

- The goal of the Beam Energy Scan II project is to continue the search for a critical end point in the QCD phase diagram
- Relativistic viscous hydrodynamics has been extremely successful in describing data
- Initial conditions for charge distributions (baryon number, strangeness, electric) could be subject to fluctuations which propagate through the hydrodynamics, to the final state
- The dynamical behavior of transport coefficients is not well understood

The goal of this project is to study the effects of dynamic transport coefficients on the system's evolution and to quantify how small scale initial state fluctuations can emerge in final state observables

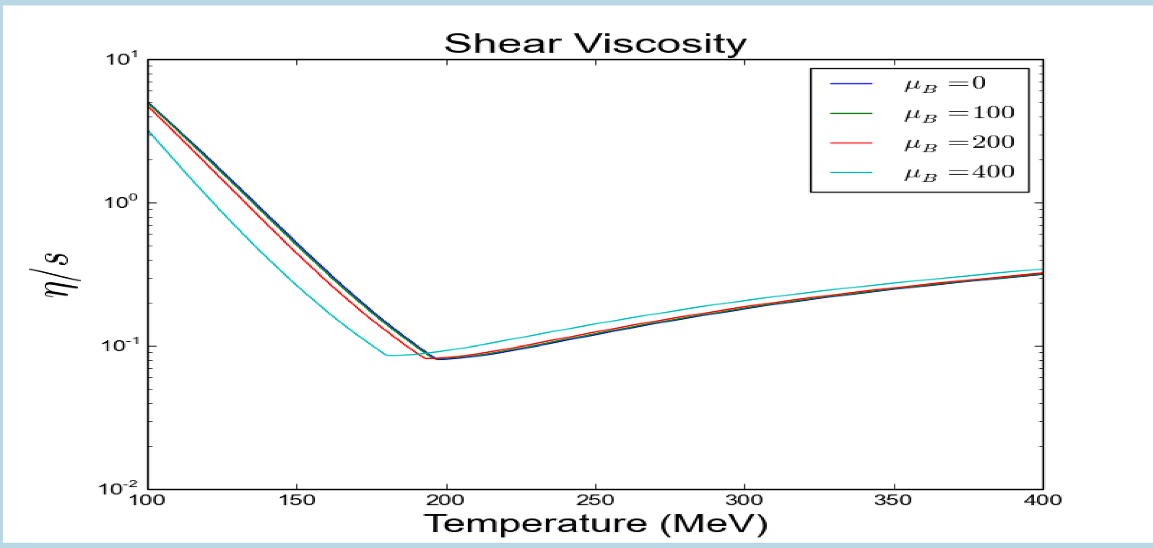


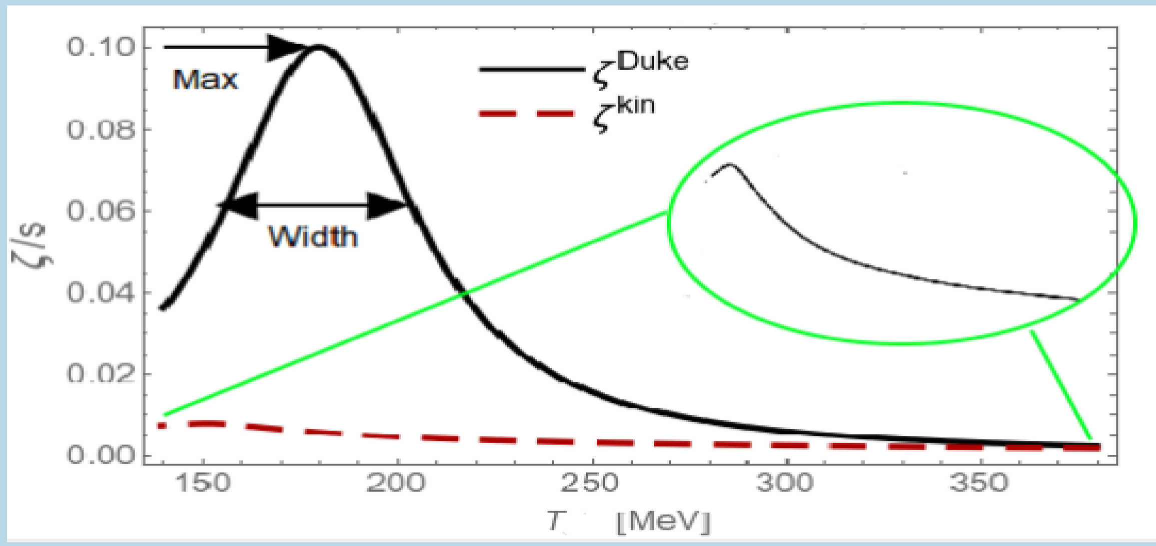
Hydrodynamic Model

- A simple Bjorken expansion can be used to begin to study effects qualitatively [1][2]

$$\frac{\partial \epsilon}{\partial \tau} = -\frac{\epsilon + p + \pi^\xi_\xi + \Pi}{\tau} \qquad \frac{\partial \pi^\xi_\xi}{\partial \tau} = -\frac{\pi^\xi_\xi}{\tau_\pi} + \frac{4\eta'}{3\tau_\pi \tau} - \frac{4\pi^\xi_\xi}{3\tau} \qquad \frac{\partial \Pi}{\partial \tau} = -\frac{\Pi}{\tau_\Pi} - \frac{\zeta}{\tau_\Pi \tau}$$

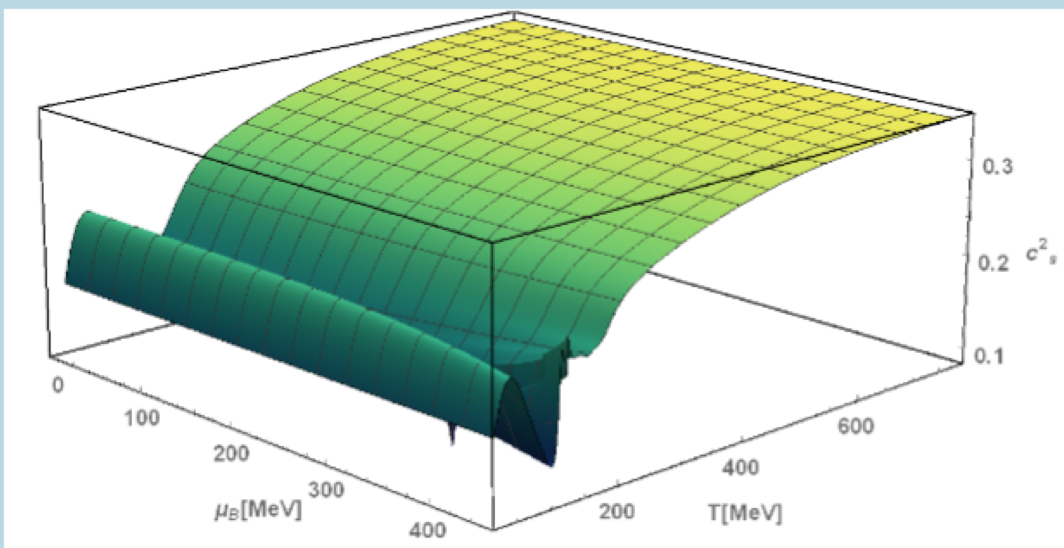
- This is a (0+1) hydrodynamic system, since it evolves strictly in time
- We model the behavior of transport coefficients to be in line with physical expectations
  - On The Left: Shear viscosity with dynamical minimum, pushed to lower temperatures at higher chemical potential
  - On The Right: Two models for bulk viscosity, one as a function of speed of sound, the other with fully controlled max, width, and T_c [3][4]

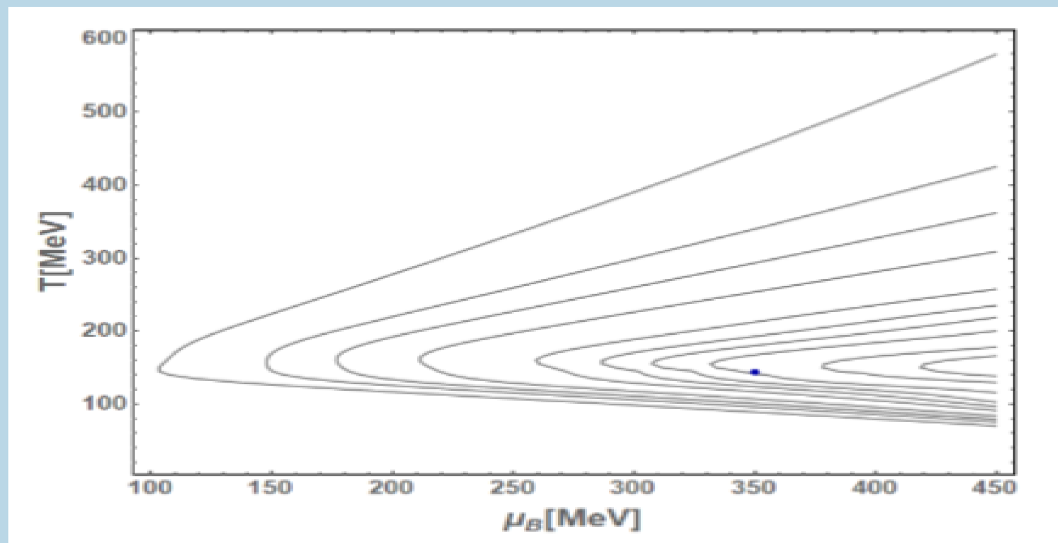




Thermodynamic Model

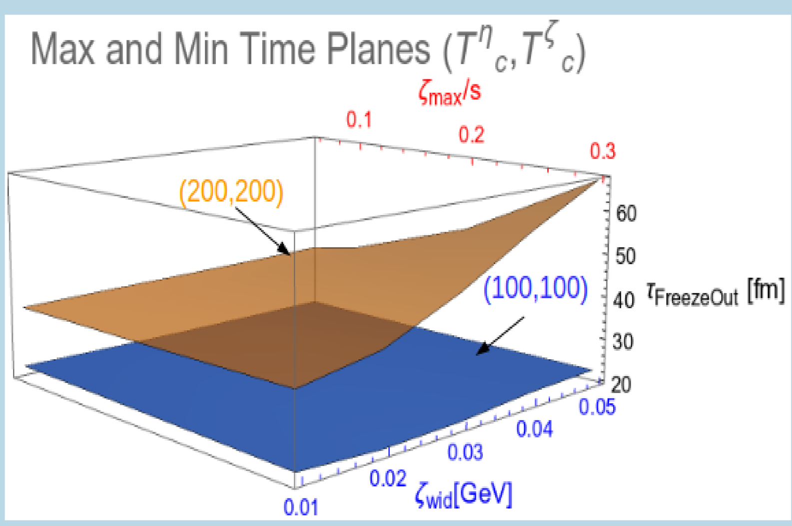
- Traditionally, hydrodynamics assumes local equilibrium for fluid cells so that the equations are closed with the thermodynamic equation of state (EOS)
- The relevant equation of state for strongly interacting matter is the Nuclear EOS
  - At $\mu_B = 0$, Lattice calculation are matched to a Hadron Resonance Gas description across the transition
  - The finite density and critical point EOS used in this work was found by mapping (T, μ_B) to the 3D Ising variables (r, h) [5]

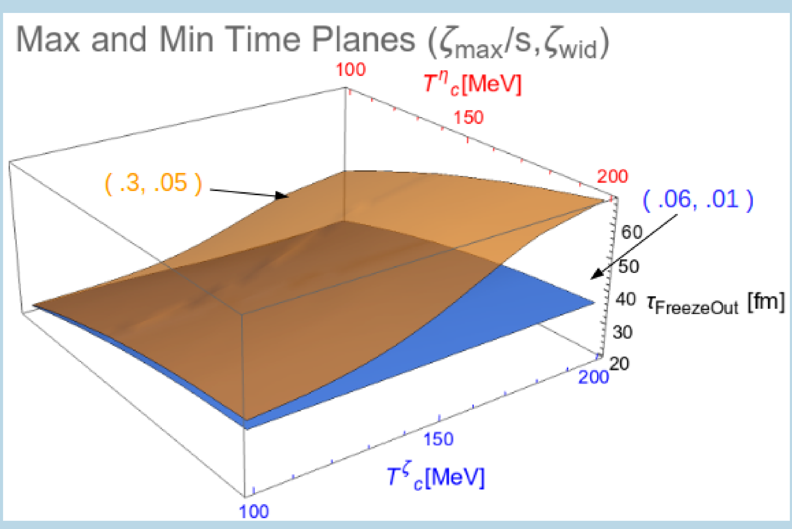




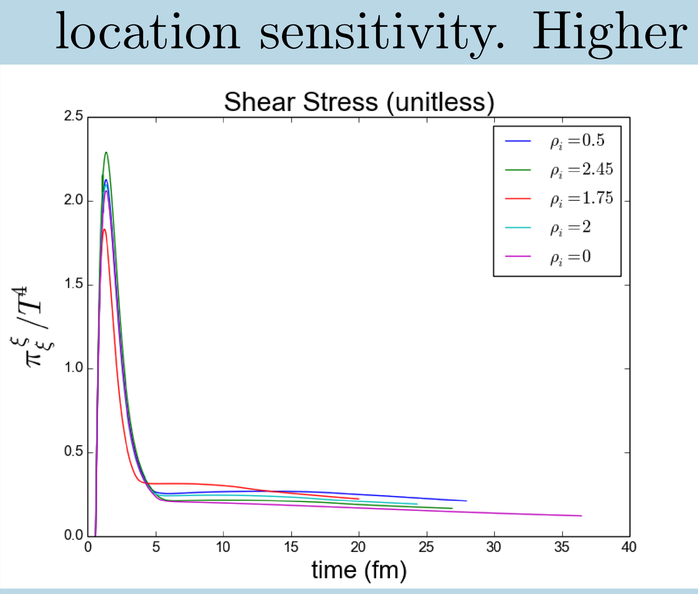
On The Left: Speed of sound as a funtcion of (T, μ_B), On The Right: Isentropic trajectories in (T, μ_B) plane.

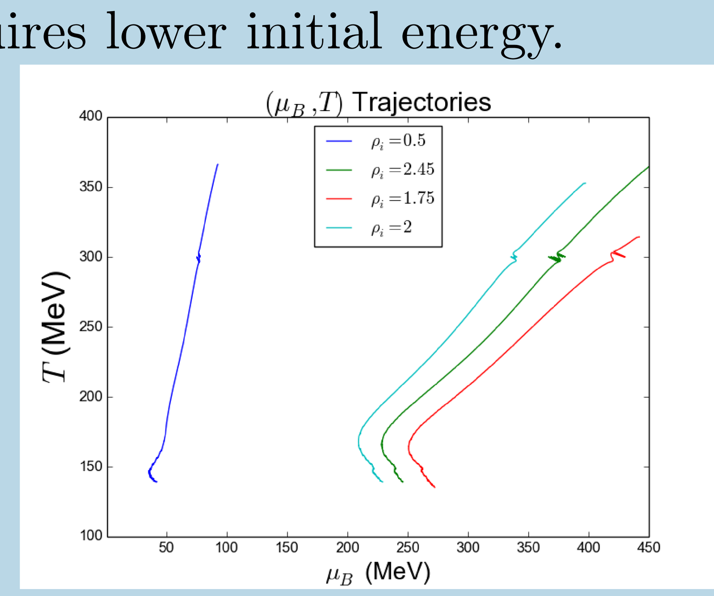
Hydrodynamic Effects





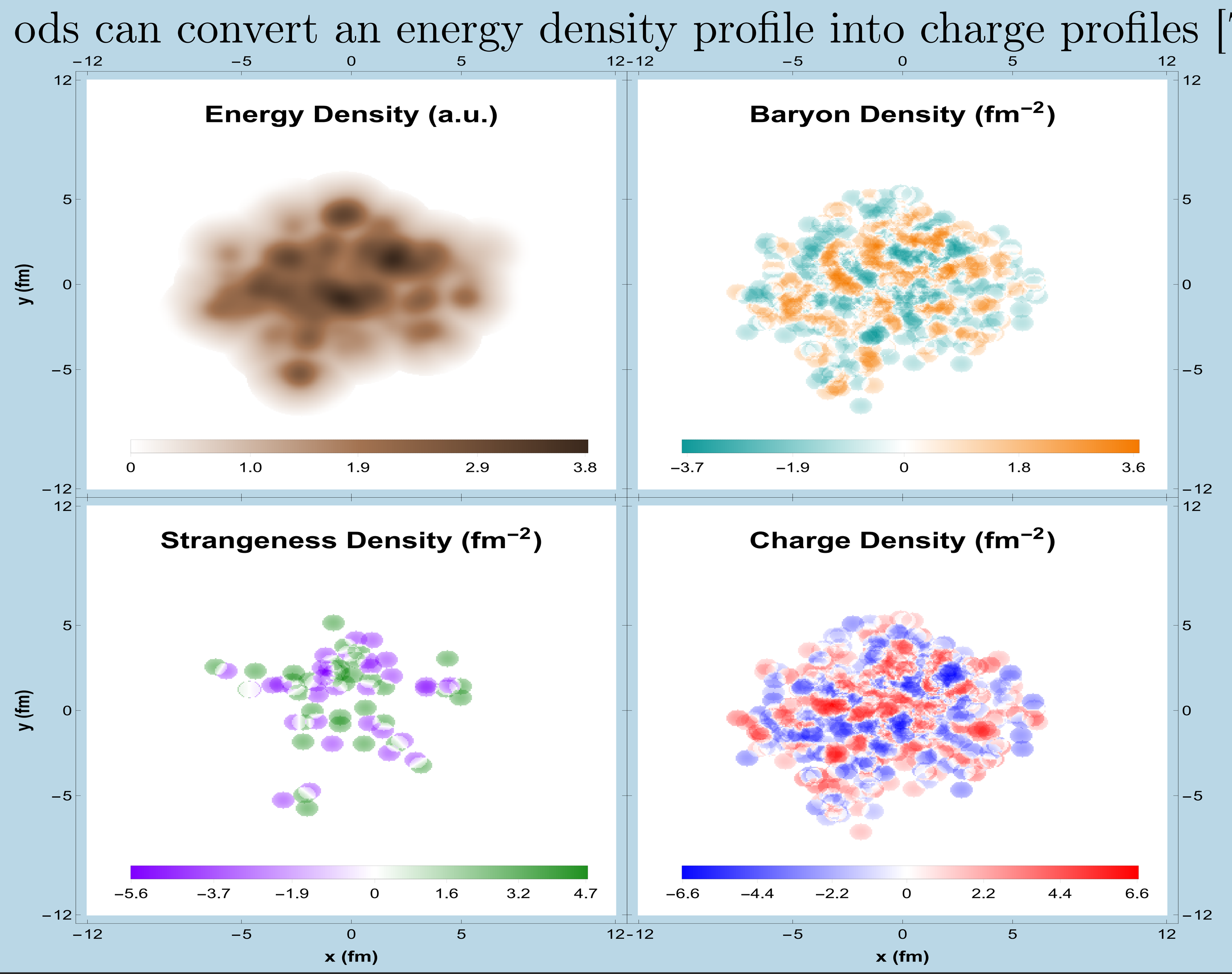
- Not only is the lifetime sensitive to the value of the maxes and minimums, but also at what temperature they occur
  - In central collisions, v_3 has hydro-lifetime sensitivity [6]
- At finite initial baryon densities, there are lifetime effects, and CP location sensitivity. Higher ρ_i requires lower initial energy.





ICCING (Initializing Conserved Charges in Nuclear Geometries)

- Initial transverse charge distributions and their diffusive properties are needed for generalizing to (2+1) hydrodynamics
- Using a CGC framework, gluon splitting probabilities and MC methods can convert an energy density profile into charge profiles [7]



References

[1] P. Romatschke, Int. J. Mod. Phys. E E **27** , 1 (2010); [2] D. Bazow, U. W. Heinz, M. Strickland, Comput. Phys. Commun. **225**, 92, (2018); [4] P. Parotto,Et al. arXiv: 1805.05249; [3] J.E. Bernhard, J. Scott, A. Steffen, Nucl. Phys. A A **967**, 293, (2017); [4] A. Buchel, Phys. Lett. B B **663**, 286, (2008) [5] P. Parotto,Et al. arXiv: 1805.05249; [6] J. Auvinen, H. Peterson, Phys. Rev. C C **88**, (2013); [7] M. Martinez, M. Sievert, D. Wertepny, JHEP **02**, 024, (2019);