Modeling Heavy-ion Collisions at Non-zero Chemical Potentials

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Standard model of HIC needs to be extended to finite baryon densities. In this work we

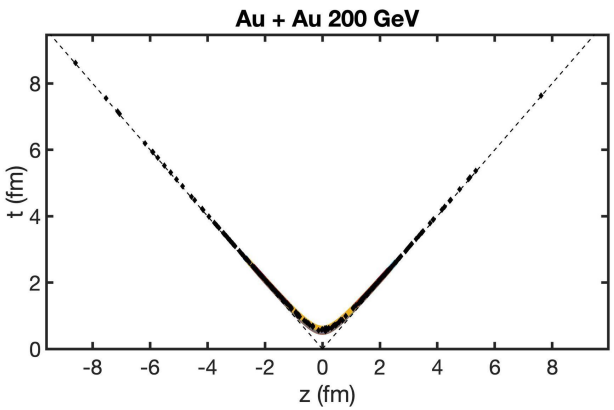
- Present a new LEXUS based initial state model
- Use a new crossover equation of state
- Calculate departure functions using a quasiparticle model at finite baryon densities
- Use these new developments to do a baseline calculation for observables at RHIC BES energies

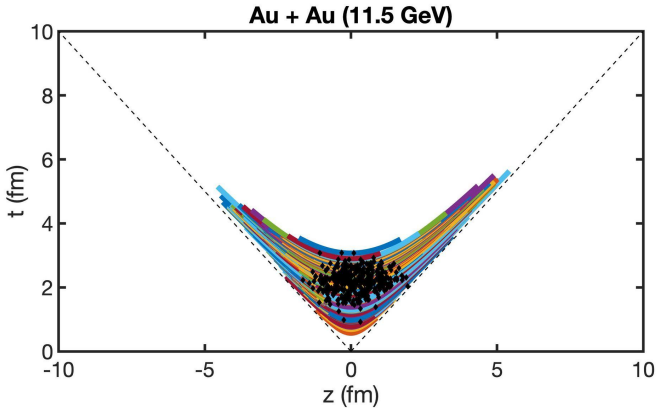
LEXUS Based Initial State Model

- LEXUS linearly extrapolates nucleon-nucleon collision data to nucleus-nucleus collision Jeon and Kapusta (1997)
- Nucleons are sampled from WS distribution, Lorentz contracted and do binary collisions
- Probability of momentum loss in a binary collision is

$$P(y_{loss}) = \frac{cosh(2y_0 - y_{loss})}{sinh(2y_0) - sinh(y_0)}$$

- Overall normalization is fixed

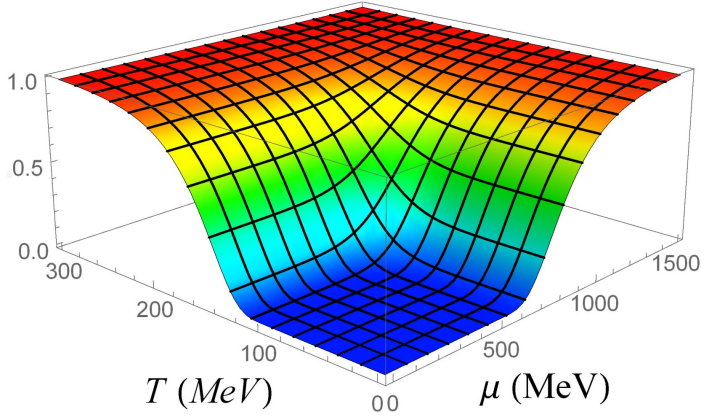




Hydrodynamics with Crossover Equation of State

- Matching of equation of state between QGP and HRG is done using a switching function Albright, Kapusta and Young (2015)

$$P(t,\mu) = S(T,\mu)P_{\mathrm{QGP}}(T,\mu) + [1 - S(T,\mu)]P_{\mathrm{HRG}}(T,\mu)$$



- No critical point in this calculation

- MUSIC was dynamically initialized using the energy-momentum and baryon density deposition from our initial state Schenke, Jeon and Gale (2010), Denicol, Gale, Jeon, Monnai, Shen and Schenke (2018)

$$\partial_\nu T^{\mu\nu} = T^\mu$$
$$\partial_\mu J^\mu = J$$

Departure Functions

- Departure functions account for non-equilibrium corrections at freezeout

$$f_a = f_a^{\mathrm{eq}}(1+\phi_a)$$

$$\phi_a = -A_a \partial_\rho u^\rho - B_a p_a^\nu D_\nu \left(\frac{\mu_B}{T}\right) + C_a p_a^\mu p_a^\nu \left(D_\mu u_\nu + D_\nu u_\mu + \frac{2}{3}\Delta_{\mu\nu}\partial_\rho u^\rho\right)$$

- Worked in the relaxation time approximation with $\tau_a(E_a) = \tau' E_a$

Albright and Kapusta (2016)
Chakraborty and Kapusta (2017)

- For shear correction, we get $C_a = \frac{\tau'}{2T}$ where $\tau' = \frac{\eta}{2Tw}$
- We can calculate the thermal conductivity and associated departure function

$$\lambda = \tau' T^2 \left[\left(\frac{s}{n_B}\right)^2 \chi_{\mu\mu} - 2\left(\frac{s}{n_B}\right)\chi_{T\mu} + \chi_{TT}\right]$$

$$B_a = \tau'\left(b_a - \frac{n_B}{w}E_a\right) - b(T,\mu_B)$$

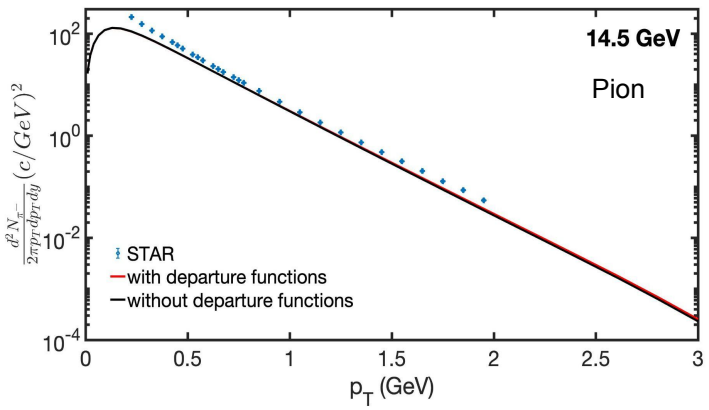
$$b = \frac{\tau' T}{w^2}\left[Ts(T\chi_{T\mu} + \mu_B\chi_{\mu\mu}) - Tn_B(T\chi_{TT} + \mu_B\chi_{T\mu}) - n_B w\right]$$

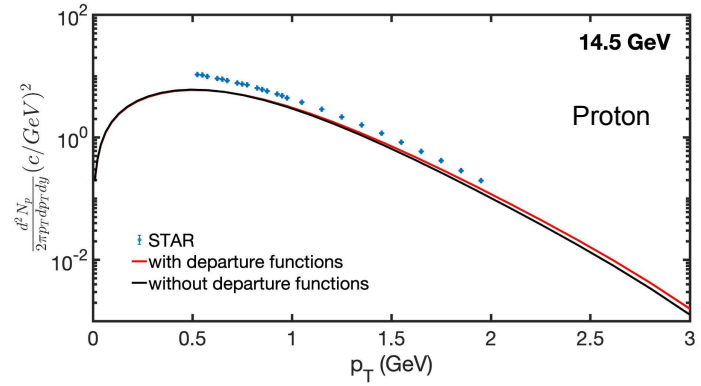
where we have susceptibilities

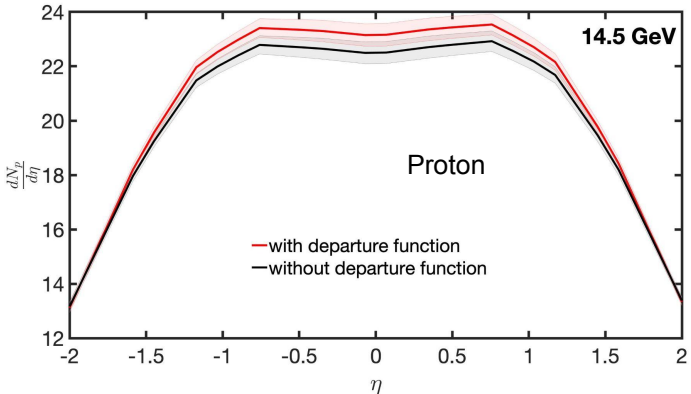
$$\chi_{xy} = \frac{\partial^2 P(T,\mu)}{\partial x \partial y}$$

Results

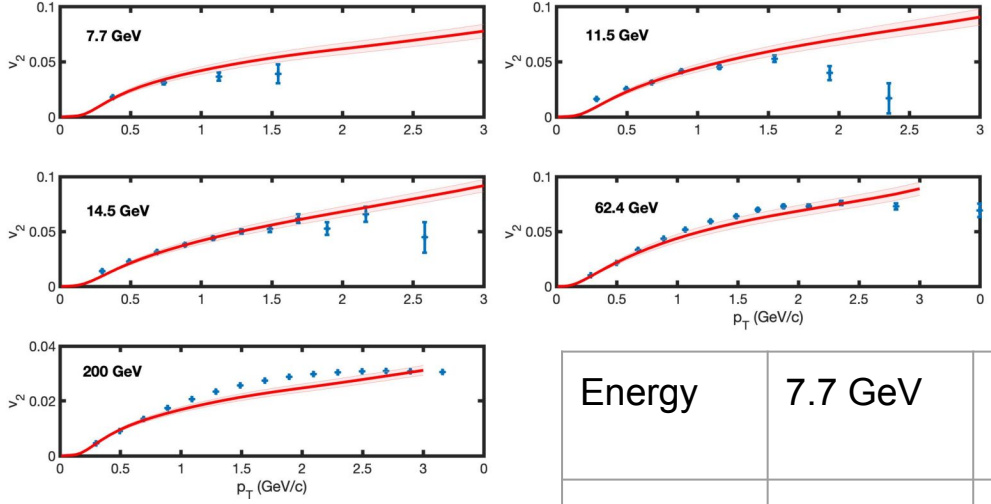
- Better agreement with data for pion than for proton. No initial flow, hadronic afterburner or bulk viscosity
- Neutron to proton conversion will also enhance proton yield
- Better agreement with data for lower energy than higher energies (not shown here)







Results



- Pion v2 is shown here
- Larger value of η/s was needed for 7.7 GeV collisions
- Inclusion of pre-hydro flow may require a larger η/s

Energy	7.7 GeV	11.5 GeV	14.5 GeV	62.4 GeV	200 GeV
η/s	0.14	0.08	0.08	0.08	0.08

- A new baseline calculation for RHIC-BES energies using a LEXUS based initial state, a crossover EOS without critical point and departure functions at finite baryon densities
- **Next step:** Include critical point and a first order phase transition

See Joe Kapusta's talk, Session T03, Tue 10:10