Estimating the Temperature and Chemical Potential in the Forward and Backward Rapidity Regions at RHIC and LHC

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Outline

- McLerran-Venugopalan model for glasma
- Energy-momentum conservation to compute excitation energy and rapidity loss of the projectile and target nuclei
- Use space-time picture to estimate compression of the nuclei
- Estimate initial temperature and chemical potential using an equation of state
- Can the experiments be done?

Energy-Momentum Conservation

$$d\mathcal{P}_P^\mu = -T^{\mu\nu}_{\rm glasma} d\Sigma_\nu$$

Projectile four-momentum/area: $\mathcal{P}_P^\mu = (\mathcal{E}_P, 0, 0, \mathcal{P}_P)$

hypersurface: $d\Sigma_\nu = (dz, 0, 0, -dt)$

Glasma energy-momentum tensor:

$$T^{\mu\nu}_{\rm glasma} = \begin{pmatrix} \mathcal{A}+\mathcal{B}\cosh 2\eta & 0 & 0 & \mathcal{B}\sinh 2\eta \\ 0 & \mathcal{A} & 0 & 0 \\ 0 & 0 & \mathcal{A} & 0 \\ \mathcal{B}\sinh 2\eta & 0 & 0 & -\mathcal{A}+\mathcal{B}\cosh 2\eta \end{pmatrix}$$

Initial Conditions and Input Parameters

UV Cut-off Scale: $3\,\mathrm{GeV} \leq \mathrm{Q} \leq 5\,\mathrm{GeV}$

Initial energy density from Heinz et al.

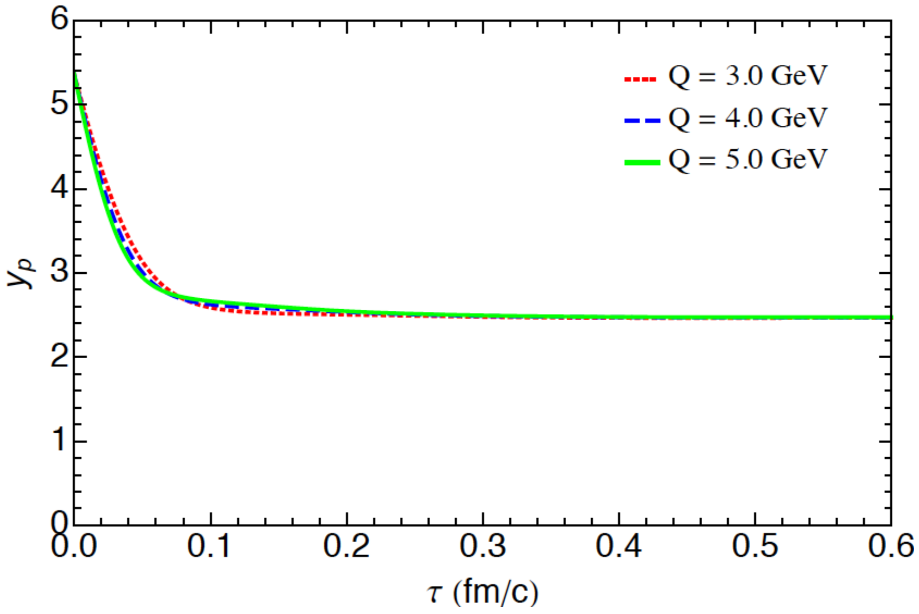
$$\varepsilon_0(r_\perp) = \varepsilon_0(r_\perp = 0)\left(\frac{T_A(r_\perp)}{T_A(0)}\right)^2$$

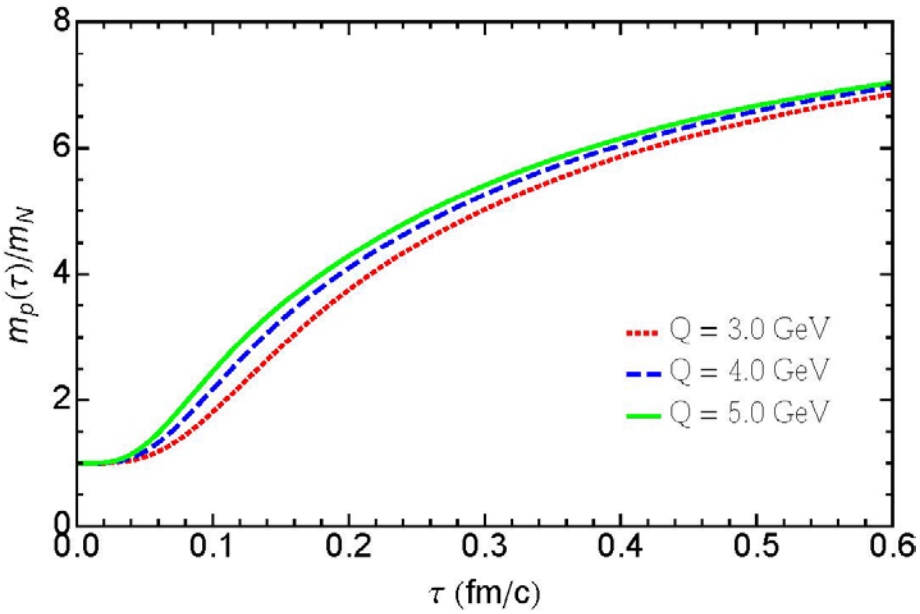
$$T_A(\vec{r}_\perp) = \int_{-\infty}^{+\infty} \rho_A(\vec{r}_\perp, z)\, dz$$

Au-Au (200 GeV) $\varepsilon(r_\perp = 0, \tau = 0.6\,\mathrm{fm/c}) = 30\,\mathrm{GeV/fm}^3$

Pb-Pb (5.02 TeV) $\varepsilon(r_\perp = 0, \tau = 0.6\,\mathrm{fm/c}) = 132\,\mathrm{GeV/fm}^3$

Rapidity Loss and Excitation Energy (central core) for Au-Au

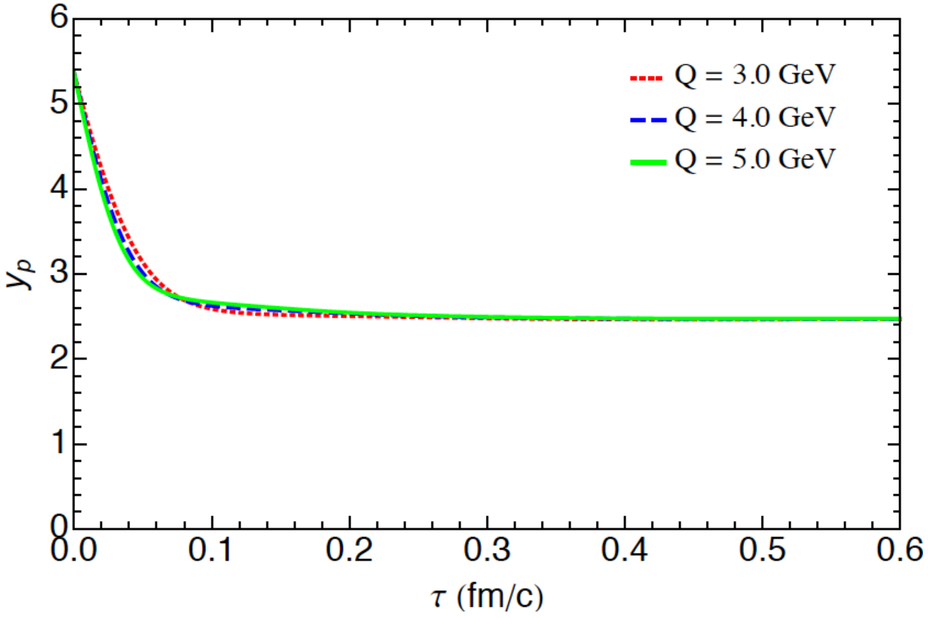




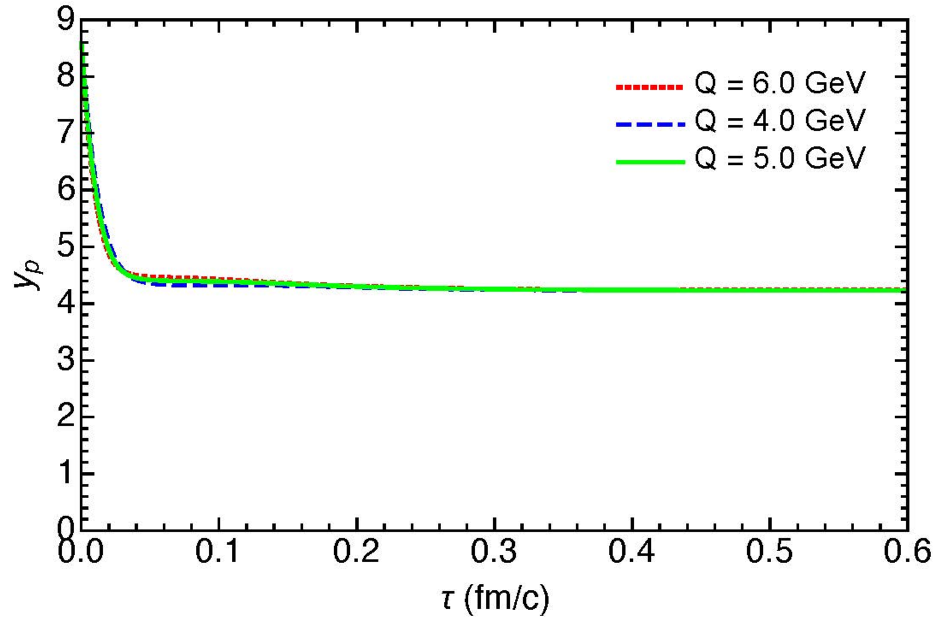
$$y = \frac{1}{2} \ln \frac{E + P_z}{E - P_z}, \qquad v_z = \tanh y$$

Rapidity Loss (central core)

Au-Au

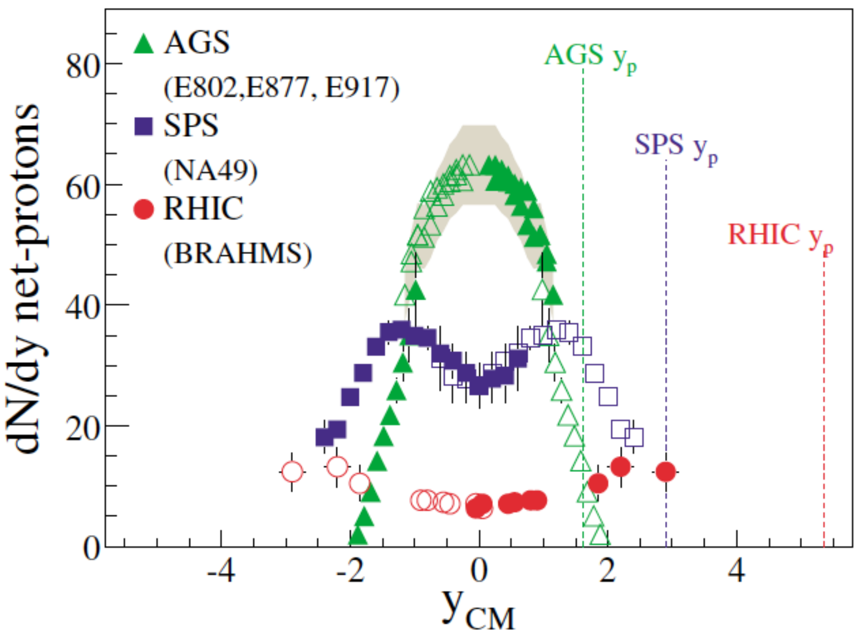


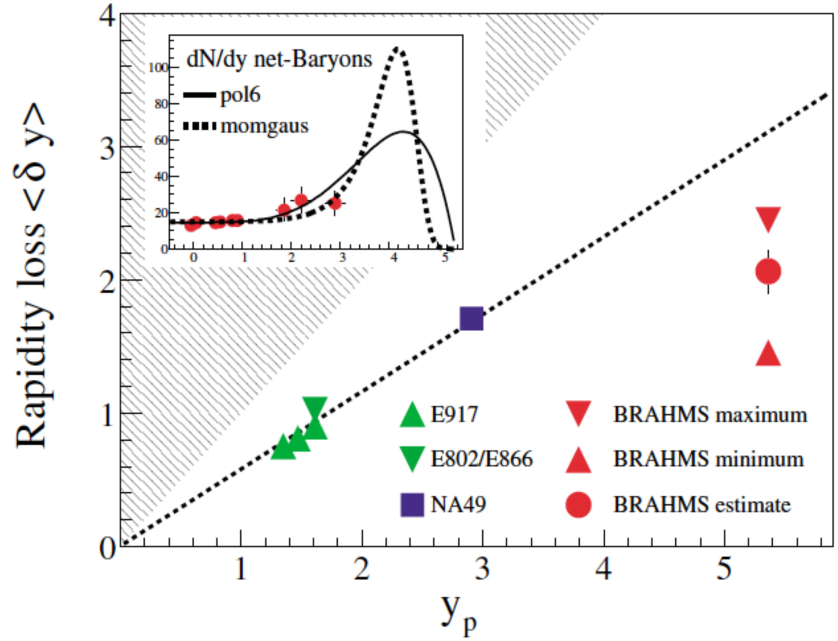
Pb-Pb



$$y = \frac{1}{2} \ln \frac{E + P_z}{E - P_z}, \qquad v_z = \tanh y$$

Baryon Stopping Data (0-10% centrality)

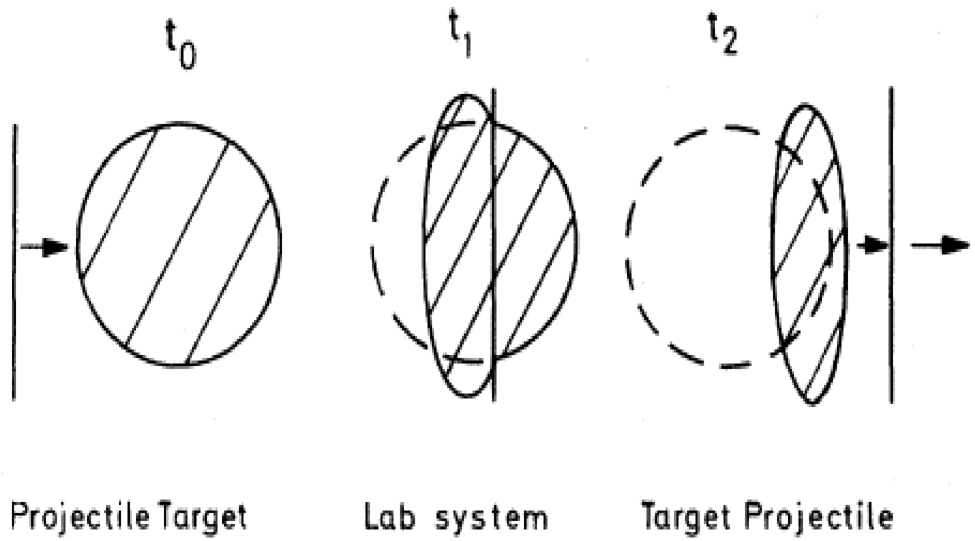




I. G. Bearden, et al. [BRAHMS Collaboration], PRL 93, 102301 (2004)

$$1.45 < \langle \delta y \rangle < 2.45$$

Nuclear Compression



$$\Delta z = (1 - v) z$$

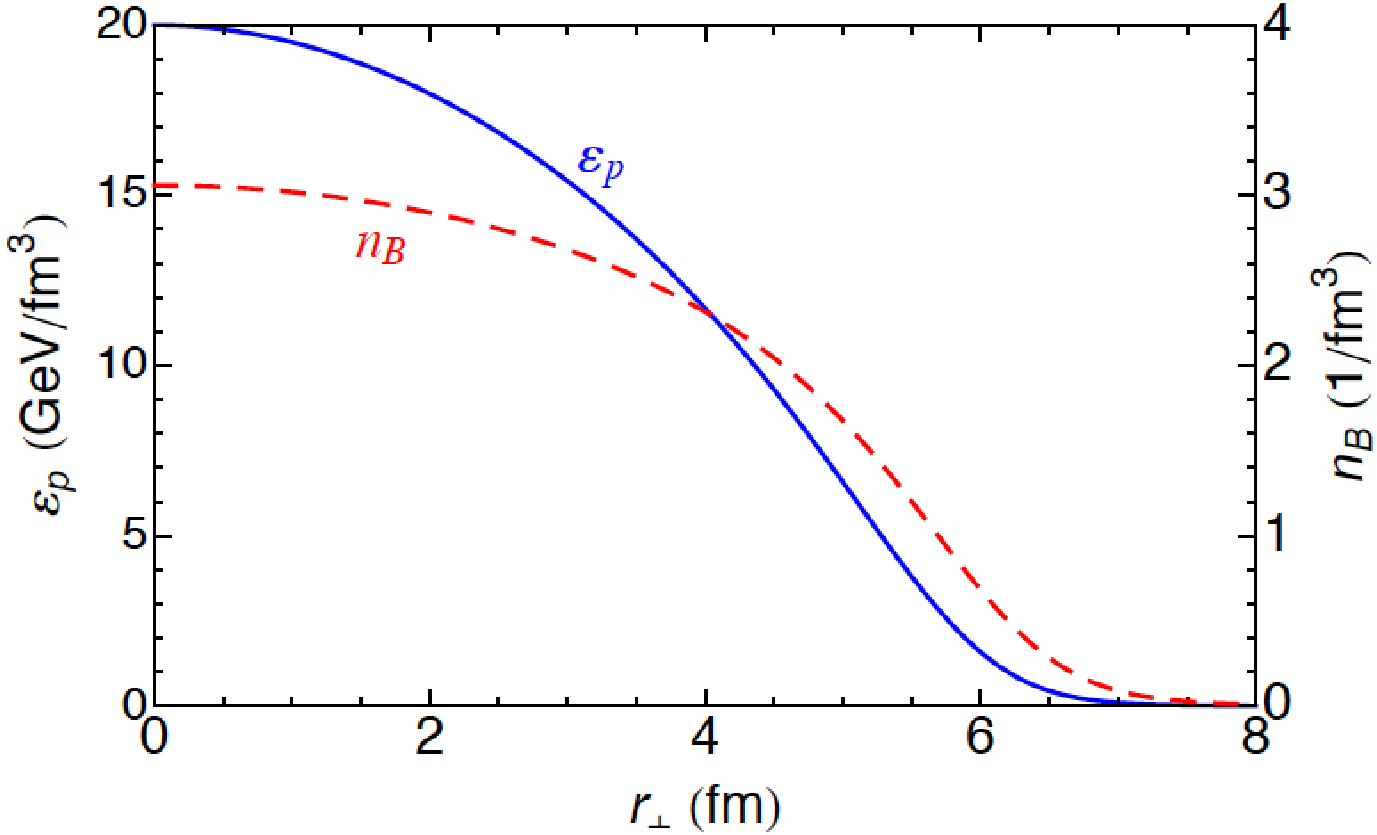
$$\Delta z' = \gamma \Delta z = e^{-\Delta y} z$$

In the rest frame of the **Target**

In the rest frame of the **Fireball**

R. Anishetty, P. Koehler and L. McLerran, Phys. Rev. D22, 2793 (1980)
L. P. Csernai, Phys. Rev. D 29, 1945 (1984)
M. Gyulassy and L. P. Csernai, Nucl. Phys. A460, 723 (1986)

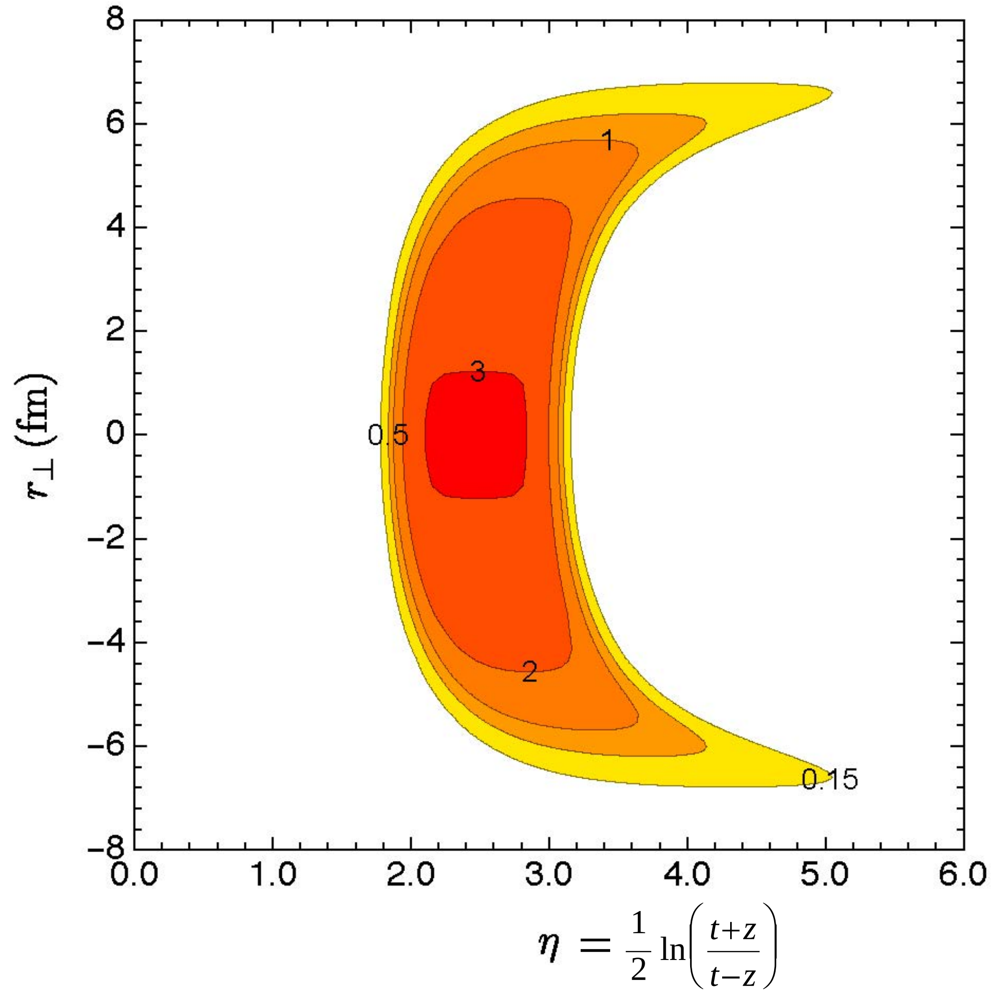
Baryon and Energy Densities Au-Au



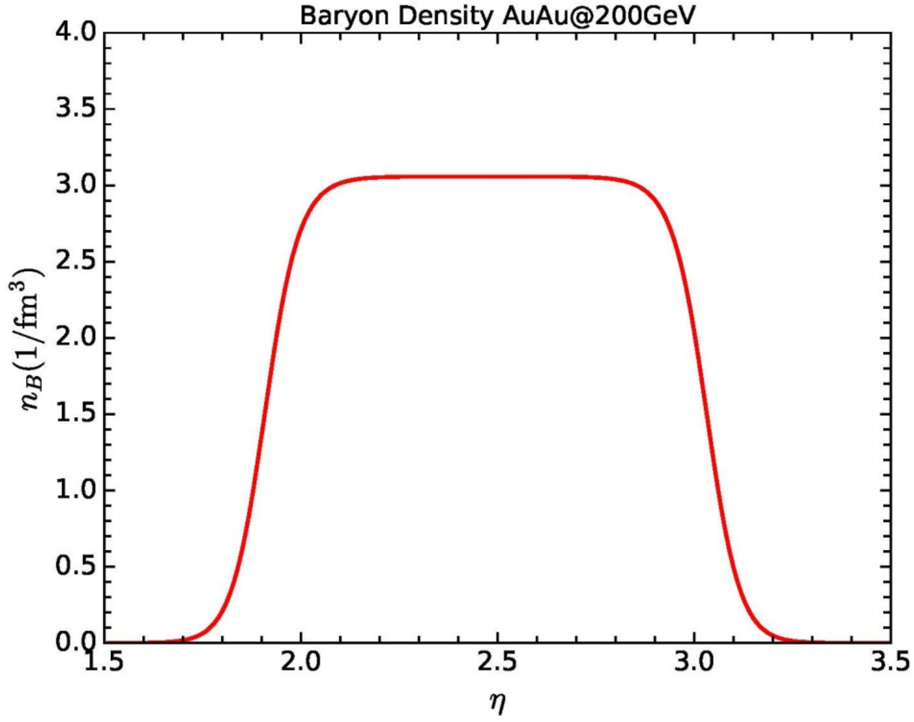
$$n_B(\vec{r}_\perp, z=0) = e^{\Delta y} n_0(\vec{r}_\perp, z=0)$$

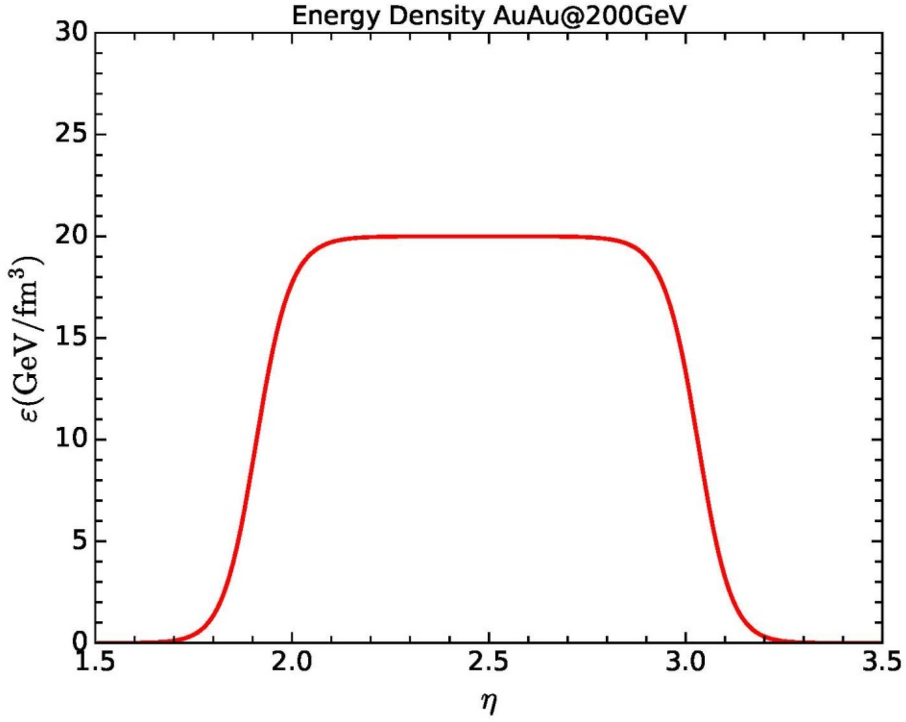
$$\varepsilon_P = M_P(\tau = 0.6\ \mathrm{fm/c})\, \mathrm{n_B}$$

Local Baryon Density for Au-Au



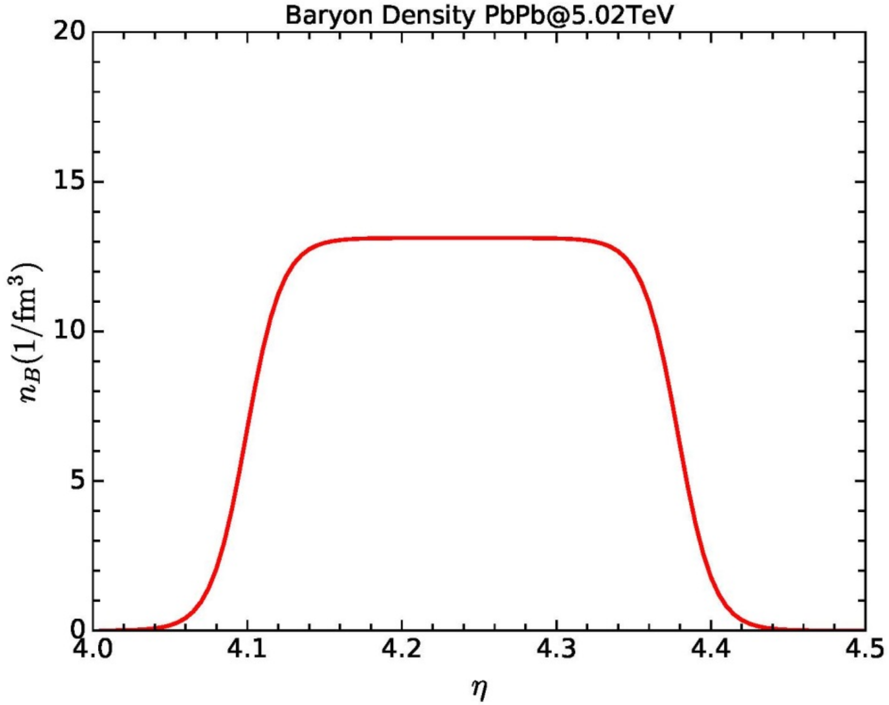
Contours in units of baryons/fm^3

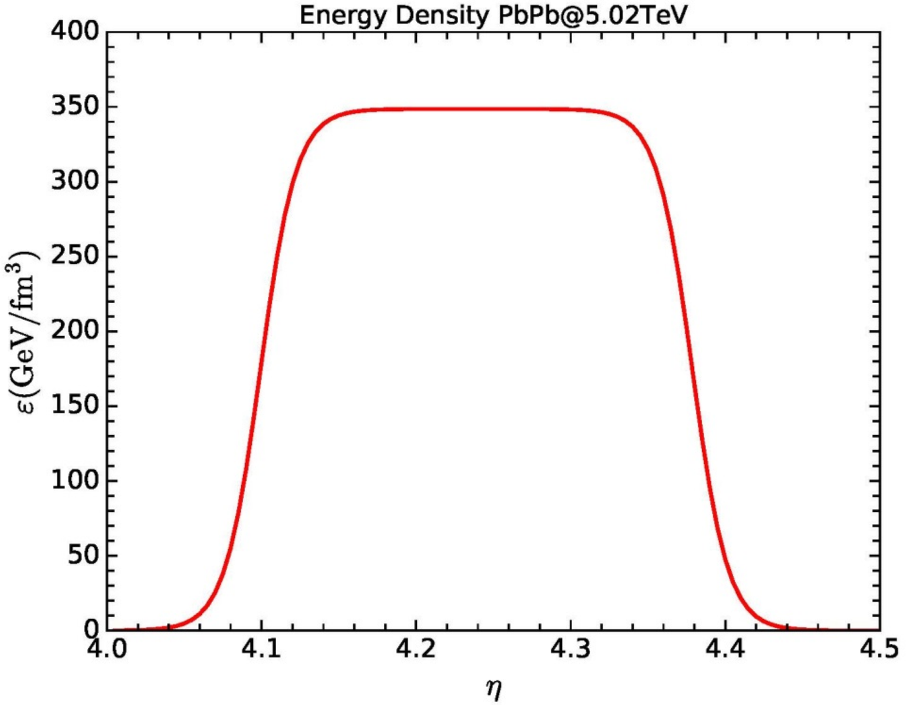




Central core of b=0 collisions Au-Au

$$\eta = \frac{1}{2}\ln\left(\frac{t+z}{t-z}\right)$$

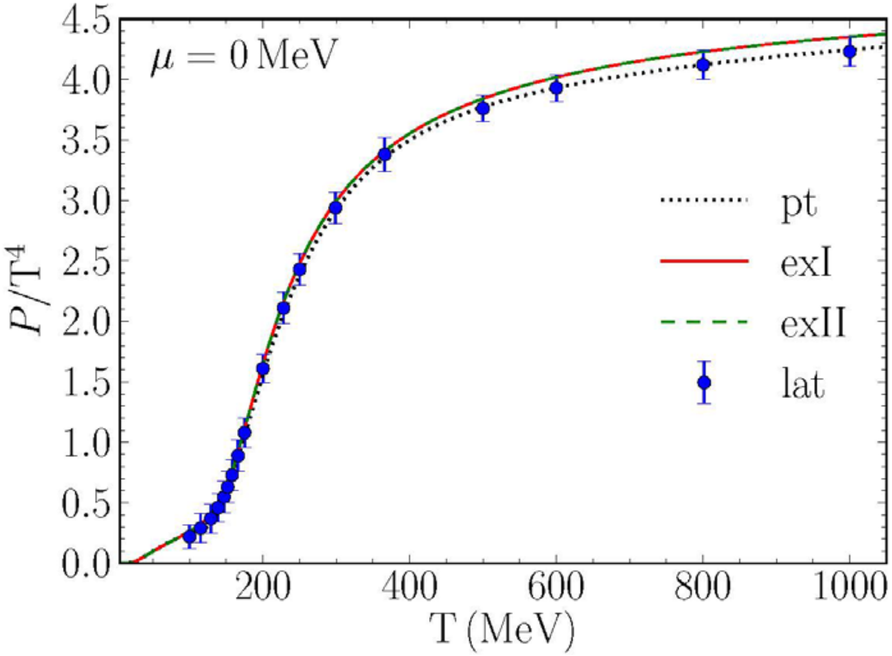


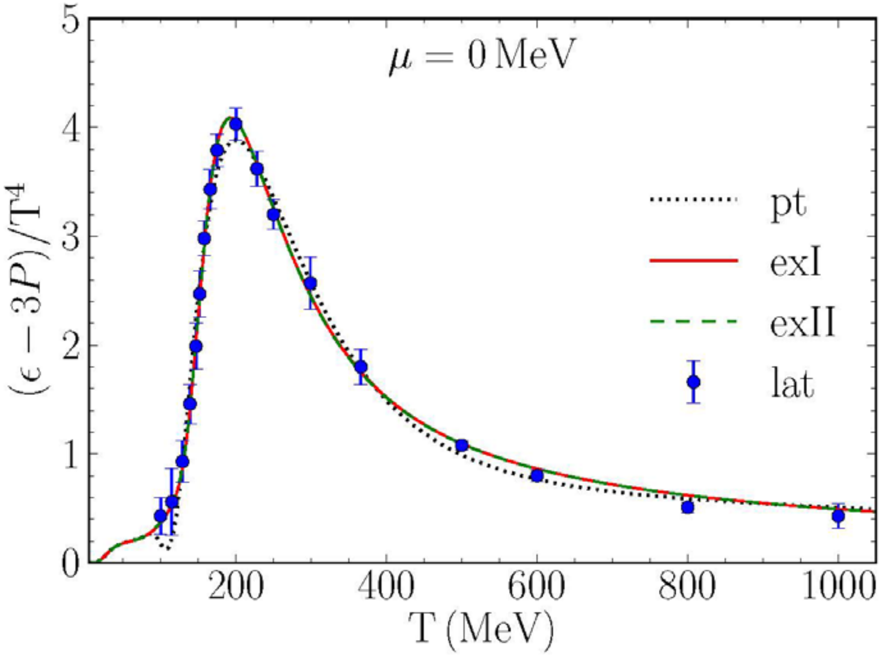


Central core of b=0 collisions Pb-Pb

$$\eta = \frac{1}{2}\ln\left(\frac{t+z}{t-z}\right)$$

Compare to lattice results from Fodor et al. with point hadrons and with excluded volumes.





$$P(T) = \left(1 - S(T)\right) P_{had}(T) + S(T) P_{qg}(T)$$

$$S(T) = \exp\left[-(T_0/T)^n\right] \qquad r_{proton} = 0.580 \text{ or } 0.655\text{ fm}$$

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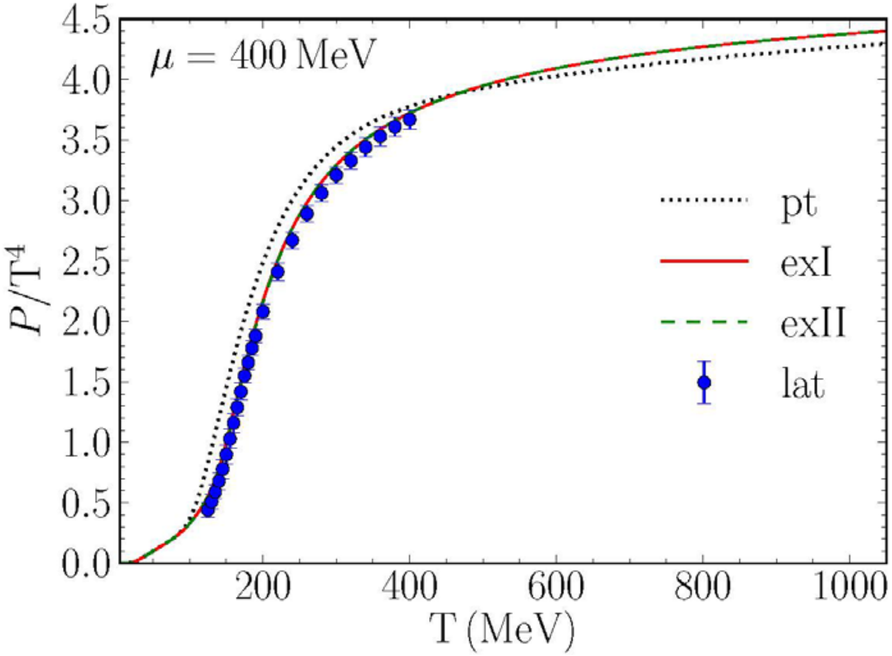
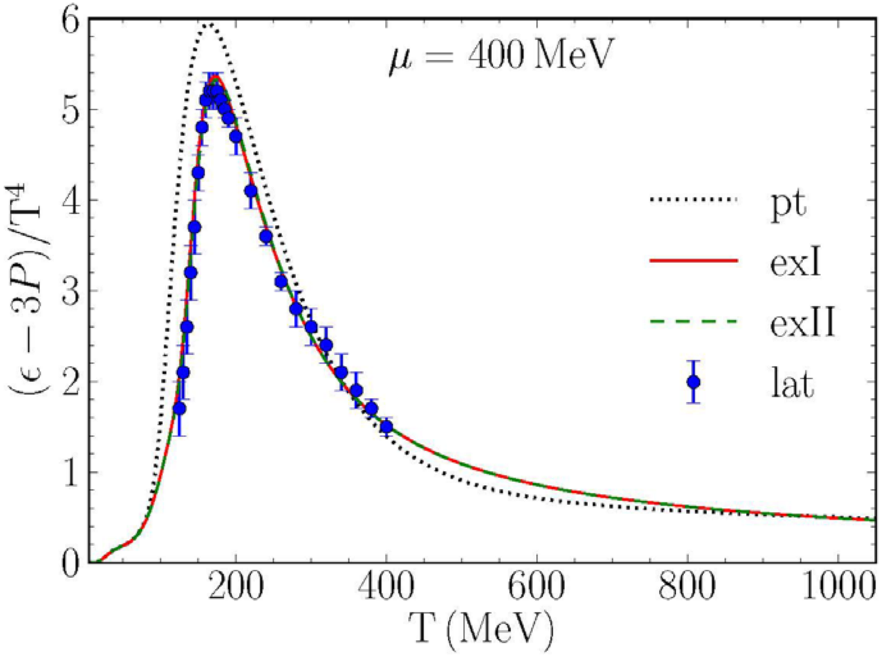
Compare to lattice results from Fodor et al. with point hadrons and with excluded volumes.

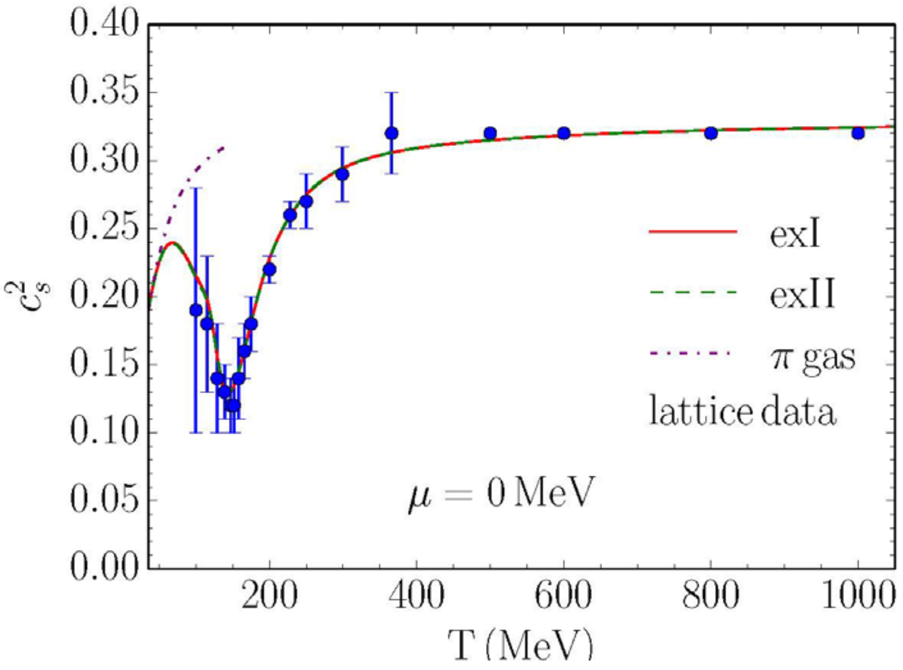


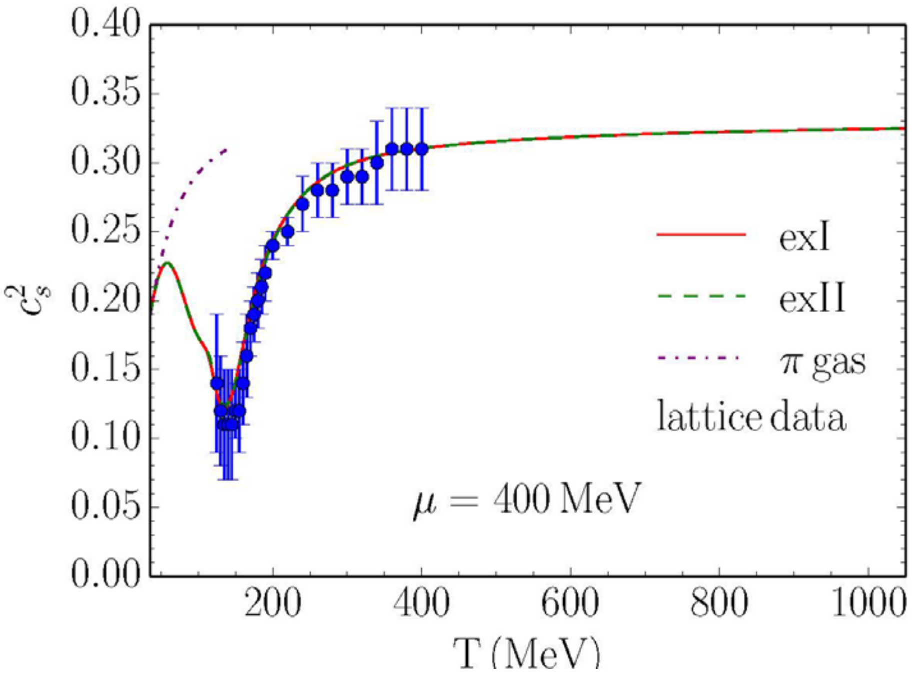


$$P(T) = \left(1 - S(T)\right)P_{had}(T) + S(T)P_{qg}(T)$$

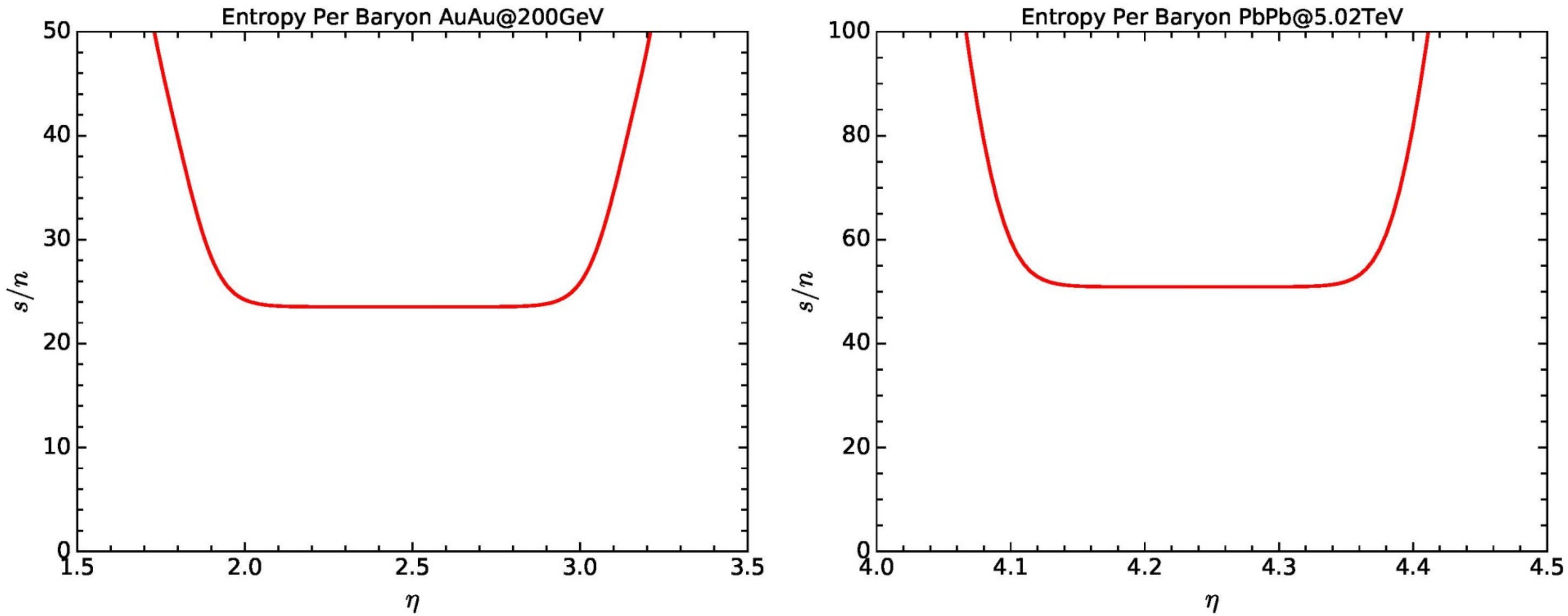
$$S(T) = \exp\left\{-\left[(T/T_0)^n + (\mu/\mu_0)^n\right]^{-1}\right\} \qquad \mu_0 = 3\pi T_0$$

Compare to lattice results from Fodor et al. with point hadrons and with excluded volumes.



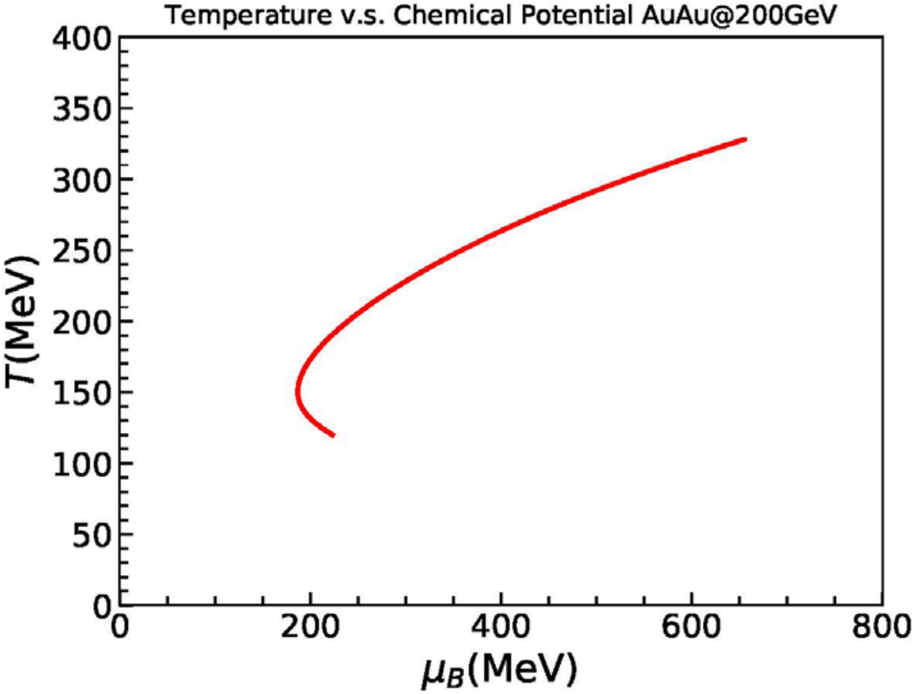


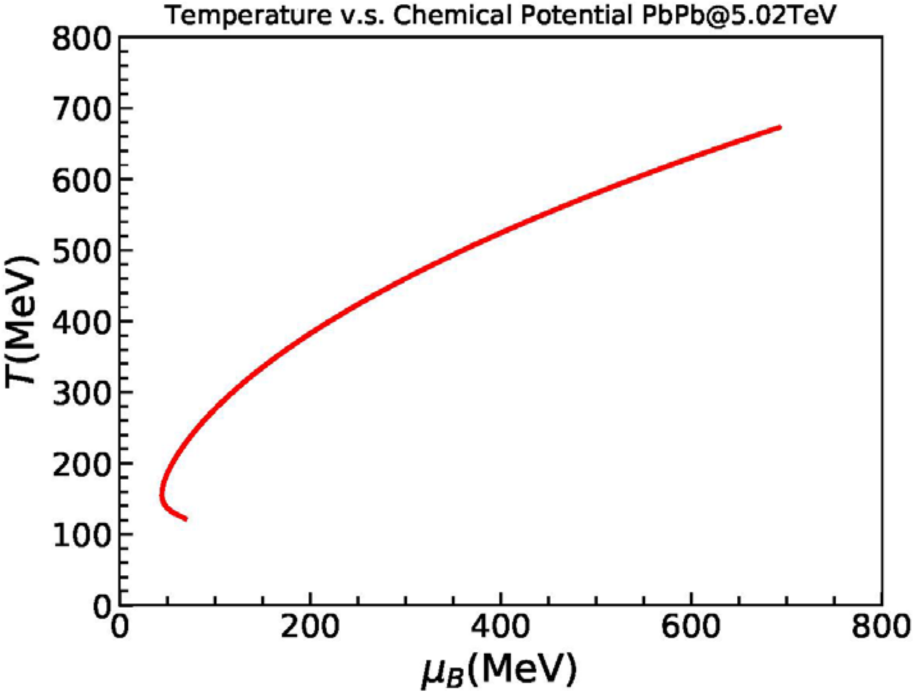
Point hadrons yield anomalous behavior inconsistent with the lattice results.



Equation of state used to obtain entropy density from energy and baryon densities assuming thermalization at 0.6 fm/c.

$s/n = 23.5$ $s/n = 50.9$





Adiabats for the plateau region.

In Progress and the Future

Other projectile-target combinations, non-central collisions

Other models for the glasma energy-momentum tensor

Initial conditions for hydrodynamics

Can measurements be made at these high rapidities?

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