Particle distributions from hydrodynamics

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Introduction

Two analytical solutions for accelerating hydrodynamics are derived to describe the relativistic p+p collisions and heavy ion collisions in Rindler coordinate.

• An exact solution of ideal hydrodynamics is used to estimate the initial thermodynamic density at RHIC and LHC[1].

• A perturbative solution of viscous hydrodynamics (with the Navier-Stokes correction) is obtained. $\sqrt{S_{NN}} = 5.44$ TeV Xe+Xe collisions and $\sqrt{S_{NN}} = 13$ TeV p+p collisions results are predicted[2].

Conservation Law

The conservation laws for temperature profile in Rindler coordinate are:

$$\tau\frac{\partial T}{\partial \tau}+\tanh(\Omega-\eta_s)\frac{\partial T}{\partial \eta_s}+\frac{\Omega'}{\kappa}T=\frac{\Pi_d}{\kappa}\frac{\Omega'^2}{\tau}\cosh(\Omega-\eta_s), \quad (1)$$

$$\tanh(\Omega-\eta_s)\left[\tau\frac{\partial T}{\partial \tau}+T\Omega'\right]+\frac{\partial T}{\partial \eta_s}= \frac{\Pi_d}{\tau}(2\Omega'(\Omega'-1)+\Omega''\coth(\Omega-\eta_s))\sinh(\Omega-\eta_s), \quad (2)$$

where Ω is the flow element rapidity, and Π_d is a function of shear viscosity and bulk viscosity.

Final state observations

Final state spectra are yielded from hydrodynamic solutions[1, 2] and Cooper-Frye formula,

$$\frac{d^2N}{2\pi p_T dp_T dy} = \frac{g}{(2\pi)^3}\int p_\mu d\Sigma^\mu f, \quad (3)$$

The relationship between $\sqrt{S_{NN}}$ and acceleration parameter λ is

$$\lambda = 1 + A\left(\sqrt{S_{NN}}/\sqrt{S_0}\right)^{-B}. \quad (4)$$

The improving initial energy density is:

$$\epsilon_{\rm corr} = (2\lambda-1)(\frac{\tau_f}{\tau_0})^{\lambda-1}\frac{\langle E\rangle}{S_\perp \tau_0 R^2}\frac{dN}{dy}|_{y=y_0}. \quad (5)$$

Conclusion and summary

• In a limit η_s region, CKCJ [1] model presents new solutions of ideal hydrodynamics.

• CNC [1] model can be using to estimate the initial thermodynamic quantities.

• Accelerating viscous hydrodynamics [2] is an effective theory to study the effect of both longitudinal accelerate and viscosity.

References and Acknowledgements

[1] M. Csanád, et. al, Universe 3 (2017) no.1, 9.
Z. F. Jiang, et.al, arXiv: 1711.10740.
T. Csörgő,et.al, arXiv: 1805.01427.

[2] Z. F. Jiang, et.al, in perpartion.

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Exact solution of ideal hydrodynamic[1]

Exact solution of ideal hydrodynamic can be obtained in Rindler coordinate. One can extracted **acceleration parameter characteristics** from precise $dN/d\eta$ and obtained a series of **improved initial energy density estimation** (for RHIC and LHC).

The **temperature profile** is

$$T(\tau,H)=T_0\left(\frac{\tau_0}{\tau}\right)^{\frac{1+\lambda^*}{\kappa}}\frac{1}{\nu(s)}\left[1+\frac{\kappa-1}{\lambda-1}\sinh^2(H)\right]^{\frac{1+\lambda^*}{2\kappa}}. \quad (6)$$

where H is a parameter related to η_s.

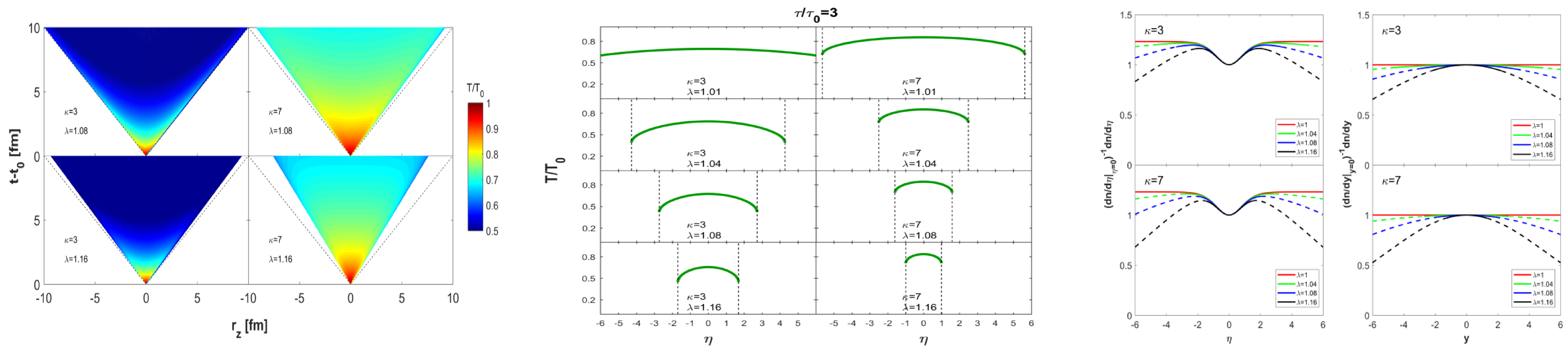

Figure. 1: **Left:** Heat map of temperature evolution from new CKCJ solutions[1]. **Mid:** The interesting temperature profile for limit η_s. **Right:** Effective pseudo-rapidity distribution. Detailed work for CKCJ, arXiv: 1805.01427.

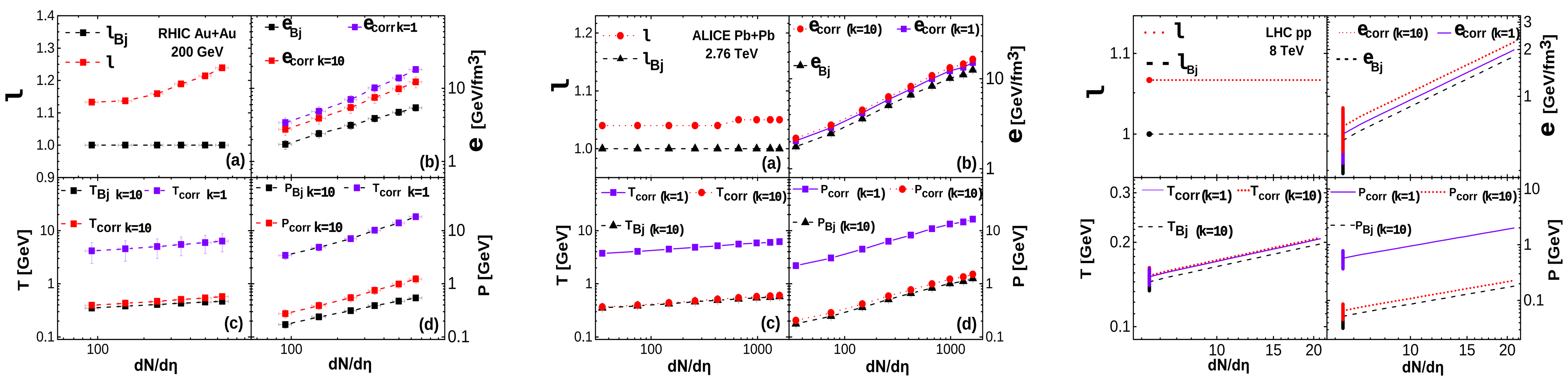

Figure. 2: Accelerate parameter λ evolution, initial energy density, pressure estimation, and temperature profile for RHIC and LHC p+p & A+A collisions. For detailed calculation, see Z. F. Jiang, arXiv: 1711.10740..

Perturbative solution of viscous hydrodynamics[2]

By introducing the Navier-Stokes correction, we obtain **a perturbative solution** which takes acceleration into account the effects of longitudinal acceleration and viscosity.

The new **temperature profile** is

$$T(\tau,\eta_s)=T_0\left(\frac{\tau_0}{\tau}\right)^{\frac{1+\lambda^*}{\kappa}}\left[\exp[-\frac{1}{2}\lambda^*(1-\frac{1}{\kappa})\eta_s^2]+\frac{R_0^{-1}}{\kappa-1}\left(2\lambda^*+\exp[-\frac{1}{2}\lambda^*(1-\frac{1}{\kappa})\eta_s^2]-(2\lambda^*+1)\left(\frac{\tau_0}{\tau}\right)^{\frac{\kappa-\lambda^*-1}{\kappa}}\right)\right]. \quad (7)$$

where $\lambda^* = \lambda - 1$ the longitudinal acceleration parameter, equation of state $\varepsilon = \kappa P$, R_0^{-1} the Reyonlds number.

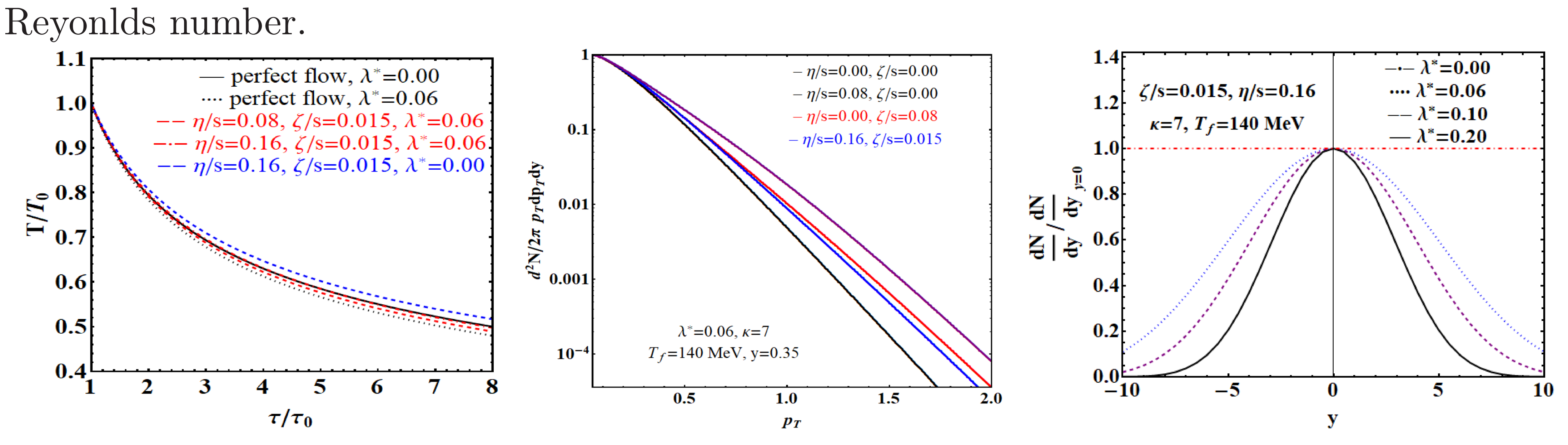

Figure. 3: **Left:** Temperature profile, Viscosity effect vs. Accelerate effect. **Mid:** Transverse momentum distribution, viscosity is important! **Right:** Rapidity distribution for different accelerate (Academic study).

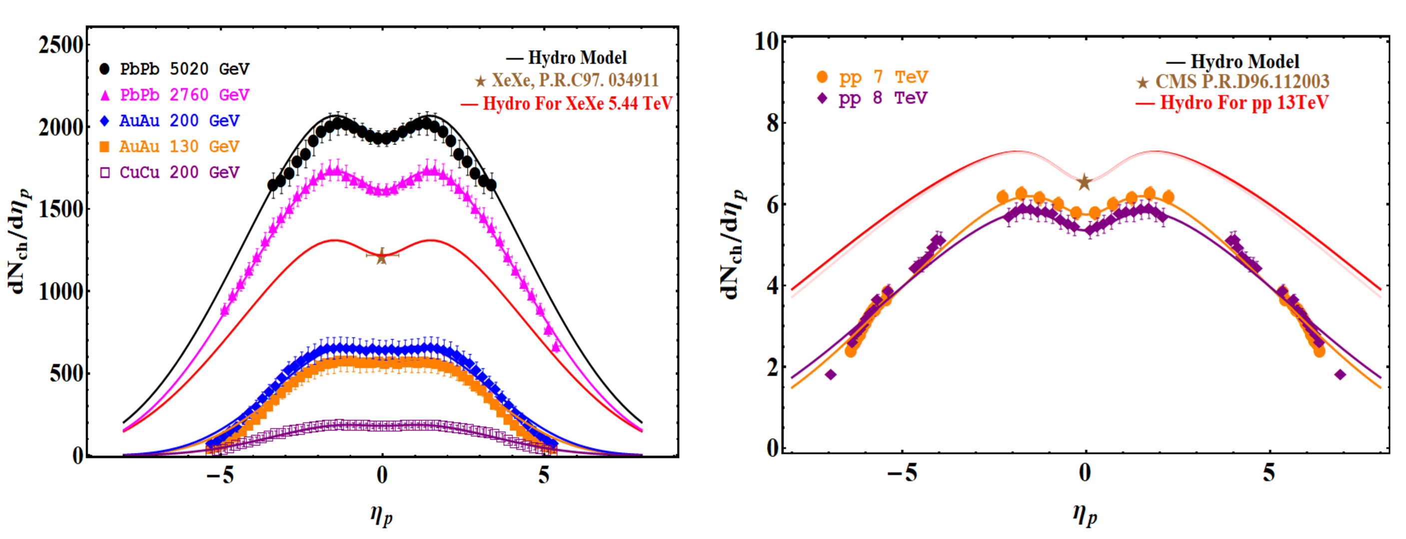

Table 1. Table of parameters from hydrodynamic fits in the text. Centrality for Au+Au and Cu+Cu is $0-6\%$, centrality for Pb+Pb is $0-5\%$. The Chi-square χ^2 is calculated from the statistical uncertainly.

$\sqrt{S_{NN}}$ /[GeV]		$\frac{dN}{d\eta}\Big\vert_{\eta=\eta_0}$	λ^*	χ^2/NDF
130	Au+Au	563.9±59.5	0.075±0.001	9.41/53
200	Au+Au	642.6±61.0	0.062±0.001	2.22/53
200	Cu+Cu	179.5±17.5	0.060±0.001	2.55/53
2760	Pb+Pb	1615±39.0	0.035±0.001	5.50/41
5020	Pb+Pb	1929±47.0	0.032±0.001	60.0/27
5440	Xe+Xe	1218±46.0[40]	0.030±0.001	−/−
7000	p + p	5.78 ±0.01	0.015±0.002	0.25/45
8000	p + p	5.36 ±0.02	0.013±0.001	1.10/58
13000	p + p	6.57 ±0.09[38]	0.008±0.005	−/−

Figure. 4: The pseudo-rapidity distributions from our model calculation compared to the RHIC and LHC experimental data. Left: different nucleus-nucleus colliding systems at RHIC & LHC, prediction for $\sqrt{S_{NN}} =$ **5.44 TeV Xe+Xe** collisions results from hydrodynamics. Right: prediction for 7 TeV and 8 TeV, and $\sqrt{S_{NN}}$ = **13 TeV p+p** collisions prediction. A=0.045 and B=0.23 for A+A collisions and $A = 0.12$ and $B = 1.07$ for p+p collisions, $\sqrt{S_0} = 1$ GeV.