Initial energy density of p+p and A+A collisions

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Hydrodynamic Solutions

Exact, explicit solutions of accelerating relativistic hydrodynamics allow for a simple and natural description of highly relativistic p+p collisions and heavy ion collisions. An exact analytic solution for velocity field and pressure in Rindler coordinate$(\tau, \eta_R) = (\sqrt{t^2 - r^2}, \frac{1}{2}\ln\frac{t+r}{t-r})$ reads

$$v = \tanh \lambda \eta_{\mathrm{R}}, \tag{1}$$

$$p = p_0 \left(\frac{\tau_0}{\tau}\right)^{\lambda \mathrm{d}\frac{\kappa+1}{\kappa}} \left(\cosh(\frac{\eta_R}{2})\right)^{-(\mathrm{d}-1)\phi_\lambda}, \tag{2}$$

where λ is the acceleration parameter.

Table I. Solution parameters

case	λ	d	κ	ϕ_λ
(a)	2	$\in \mathbb{R}$	d	0
(b)	$\frac{1}{2}$	$\in \mathbb{R}$	1	$\frac{k+1}{k}$
(c)	$\frac{3}{2}$	$\in \mathbb{R}$	$\frac{4d-1}{3}$	$\frac{k+1}{k}$
(d)	1	$\in \mathbb{R}$	$\in \mathbb{R}$	0
(e)	$\in \mathbb{R}$	1	1	0

Pseudo-rapidity Distribution

A finite pseudo-rapidity distribution $dN/d\eta$ is yielded by these hydrodynamic solutions, which can be used to extracte the QGP acceleration parameter λ.

$$\frac{dN}{d\eta} \simeq N_0 \frac{\bar{p}_T \cosh\eta}{\sqrt{m^2 + \bar{p}_T^2 \cosh^2\eta}} \times \cosh^{-\frac{\alpha}{2}-1}(\frac{y}{\alpha}) \exp\{-\frac{m}{T_f}\cosh^{\alpha}(\frac{y}{\alpha})\}, \tag{3}$$

with $\alpha = \frac{2\lambda-1}{\lambda-1}$, $T_{eff} = T_f + \frac{m\langle\mu_t\rangle^2}{1+m/T_f}$, $\bar{p}_T = \frac{T_{eff}}{1+\sigma^2 y^2}$, and N_0 is a normalization parameter.

Improved ϵ_{ini} Estimation

Bjorken's energy density estimation

$$\epsilon_{\mathrm{Bj}} = \frac{\langle E\rangle dN}{(R^2\pi)\tau_0 d\eta_0} = \frac{\langle E\rangle}{(R^2\pi)\tau_0}\left.\frac{dN}{d\eta}\right|_{\eta=\eta_0}. \tag{4}$$

When the acceleration effect is taken into account, the corrected initial energy density estimation is:

$$\epsilon_{\mathrm{corr}} = \epsilon_{\mathrm{Bj}}(2\lambda-1)(\frac{\tau_f}{\tau_0})^{\lambda-1}. \tag{5}$$

References

[1] T. Csörgő, M. I. Nagy, and M. Csanád, *A New family of simple solutions of perfect fluid hydrodynamics*, Phys. Lett. B**63**, 306(2008), arXiv: 0605070.

[2] M. Csanád, T. Csörgő, ZeFang. Jiang and ChunBin. Yang, *Initial energy density of $\sqrt{s}$ = 7 and 8 TeV p+p collisions at the LHC*, in: Universe, Special Issue On Quark-Gluon Plasma in the Early Universe and in Relativistic Heavy-Ion Collisions, arXiv:1609.07176.

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Pseudo-rapidity distribution at RHIC and at LHC

Acceleration effect is extremely sensitive to quantify QGP properties and to investigate the QGP initial state. One can extracted **acceleration parameter characteristics** from precise $dN/d\eta$ for different centralities (Eq.1-3 and Table I case.e) and obtained a series of **improved initial energy density estimation** (for RHIC and LHC).

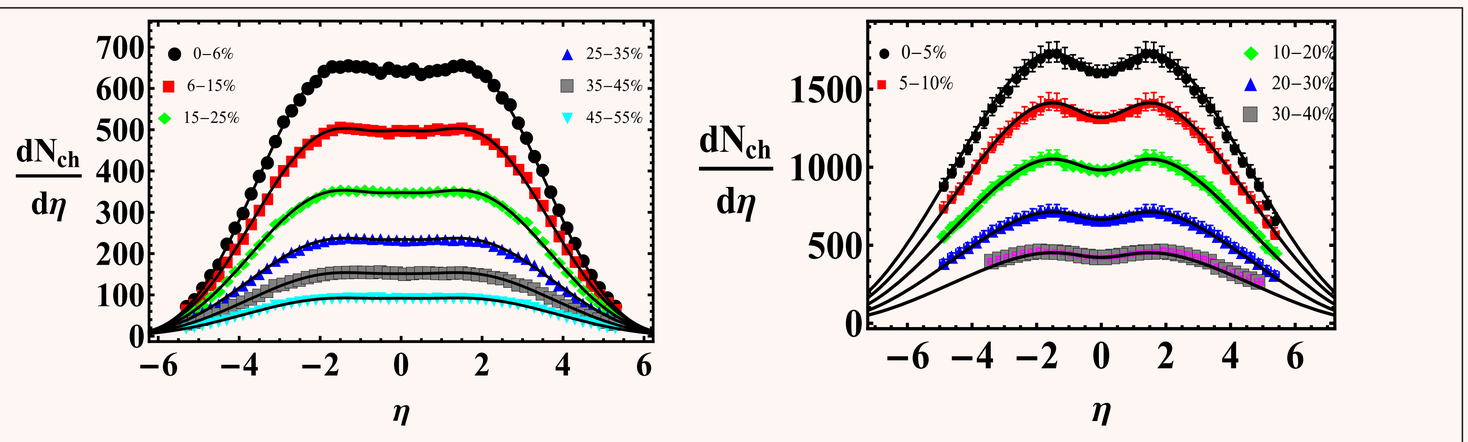

Fig. 1: Left: 200 GeV Au+Au Collision. Right: 2.76 TeV Pb+Pb collision. Charged particle pseudorapidity distribution: Relativistic hydrodynamic solution (solid line)+The data from RHIC and LHC (color dots).

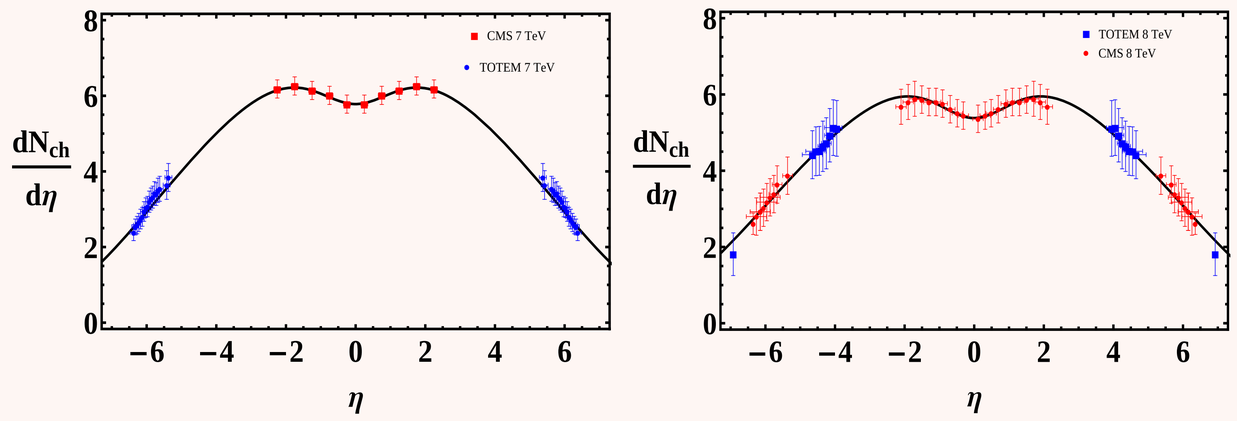

Fig. 2: 7 and 8 TeV p+p collision. Extracted λ with $\mathbf{dN/d\eta}$: Relativistic hydrodynamic solution (solid line)+The data from LHC (color dots).

Improved initial estimation combined RHIC and LHC

In our previous work [1], we given a advanced estimation of the initial energy density in high energy collisions. Here we focus on the more **systematic domain of initial estimation** at RHIC and LHC, which takes acceleration effects (i.e. the work done by the pressure, and the modified change of the volume elements) into account(Eq. 4-5).

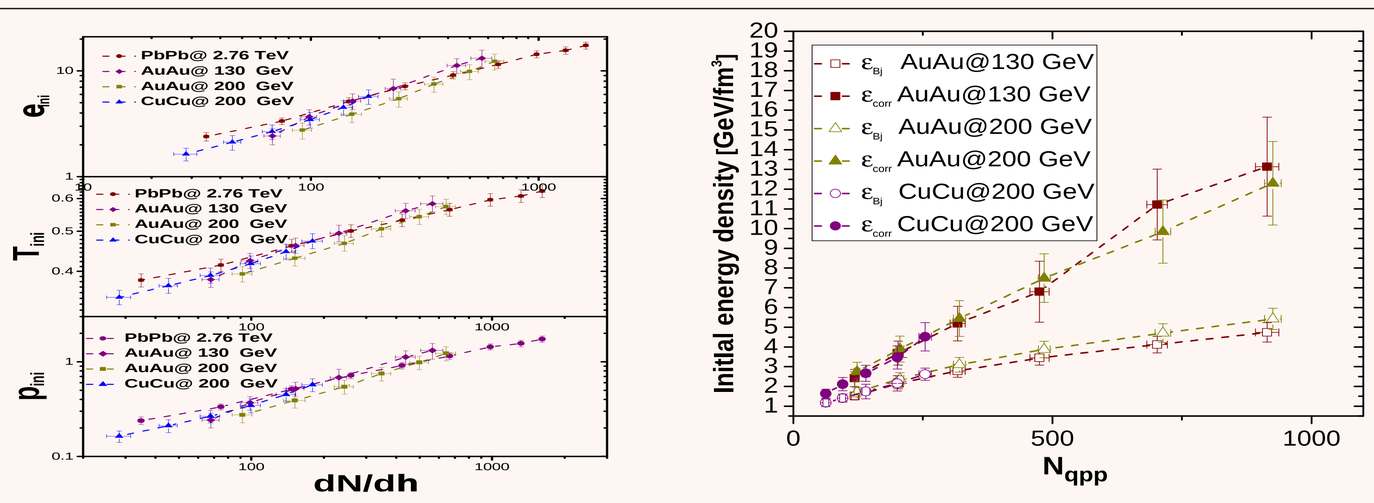

Fig. 3: Left: Initial energy density, temperature and pressure as a function of multiplicity density. Right: Initial energy as a function of quark participant pairs $\mathrm{N_{qpp}}$.

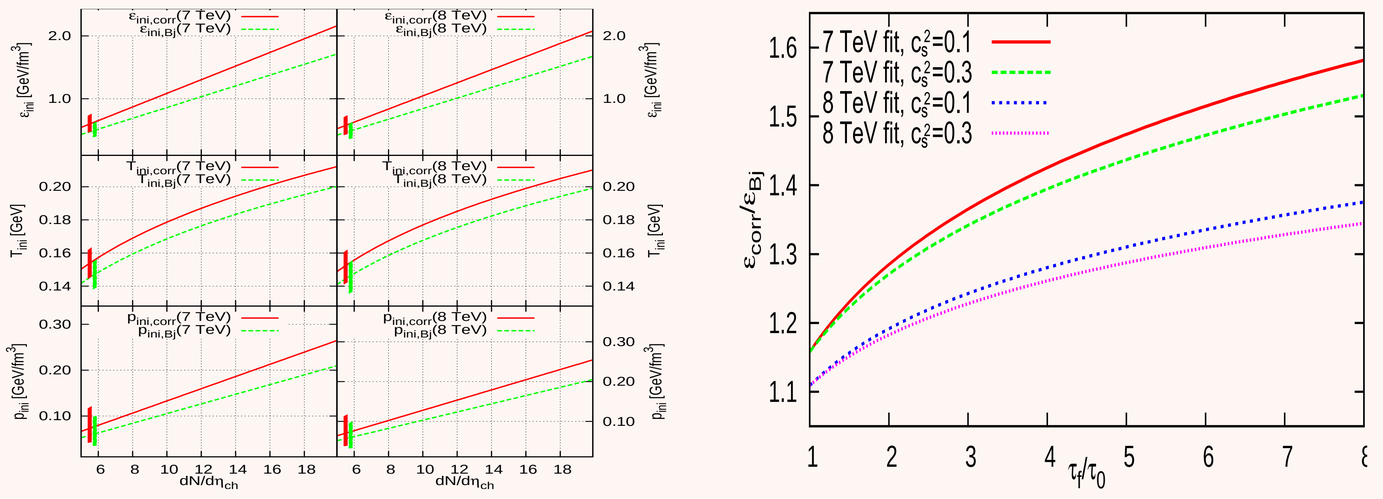

Fig. 4: Left: 7 and 8 TeV p+p collision large pseudo-rapidity distribution and initial energy density correction factor as a function of thermalization time [2]. Right: Initial energy density, temperature and pressure as a function of central multiplicity density at 7(left)and 8(right) TeV.