(3+1)D hydrodynamic simulation and related projects

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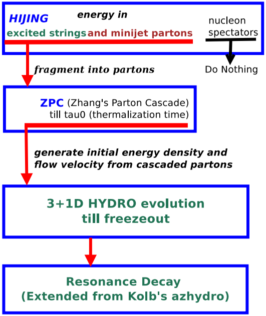
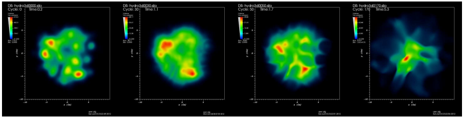
Outline for section 1

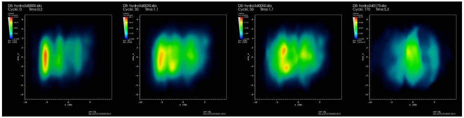
(3+1)D ideal hydro code. Phys.Rev. C86 (2012) 024911



Transverse plane



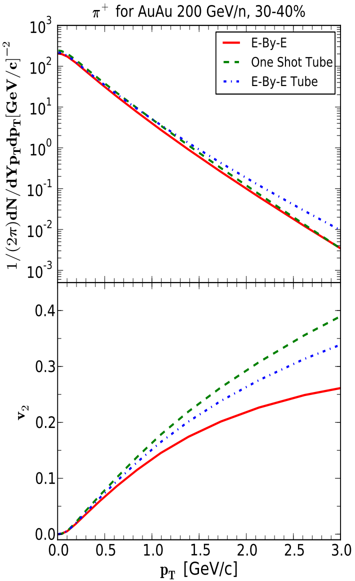
Reaction plane

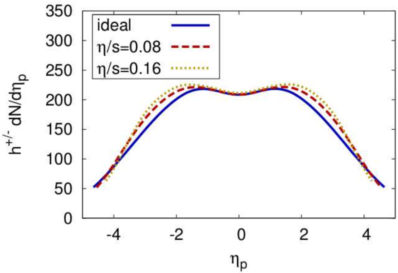


Modules:

1. HIJING+ZPC for fluctuating ini. conditions
2. FCT-SHAST for hydro evolution
3. Projection method for freeze out hypersf calculation.
4. Smooth spectral and resonance decay

The effect of longitudinal fluctuation. Nucl.Phys. A904-905 (2013) 811c-814c

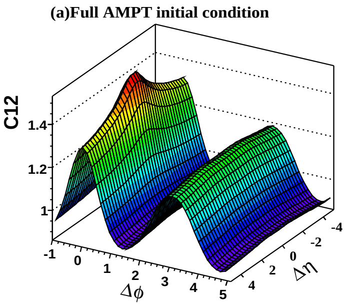




- The effect of shear viscosity on longitudinal expansion from MUSIC (shoulder).
- Reason: $\pi^{\eta\eta} \approx -(\pi^{xx} + \pi^{yy})$.
- Negative $\pi^{\eta\eta}$ will in principle reduce the effect of longitudinal fluctuation.
- It's interesting to see the effect of longitudinal fluctuation with viscosity.

Longitudinal fluctuations on di-hadron correlation

AuAu 200 GeV/n Centrality $30-40\%$, $2\ \mathrm{GeV/c} \le p_t^{trig}, p_t^{assoc} \le 3\ \mathrm{GeV/c}$.



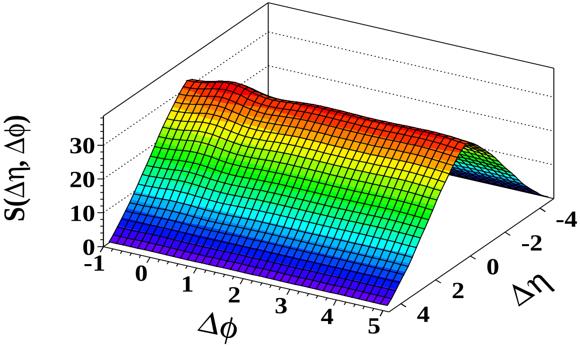
- Without longitudinal fluctuation, di-hadron correlation is constant along rapidity direction

Di-hadron correlation and per-trigger particle yield in hydro

Formula

$$C12(\Delta\eta, \Delta\phi) = S(\Delta\eta, \Delta\phi)/B(\Delta\eta, \Delta\phi) \quad (1)$$

$$S(\Delta\eta, \Delta\phi) = \frac{1}{N_{trig}} \frac{d^2 N^{same}}{d\Delta\eta d\Delta\phi} \quad (2)$$

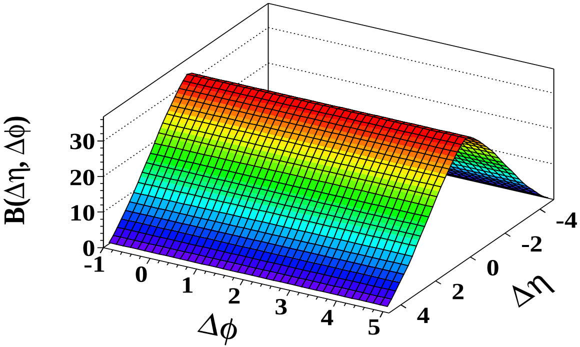


Di-hadron correlation and per-trigger particle yield in hydro

Formula

$$C12(\Delta\eta, \Delta\phi) = S(\Delta\eta, \Delta\phi)/B(\Delta\eta, \Delta\phi) \quad (1)$$

$$B(\Delta\eta, \Delta\phi) = \frac{1}{N_{trig}} \frac{d^2 N^{mixd}}{d\Delta\eta d\Delta\phi} \quad (2)$$

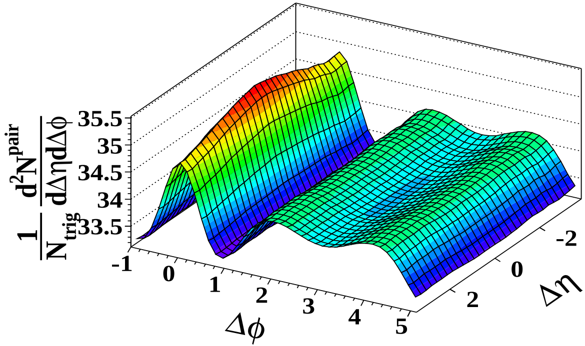


Di-hadron correlation and per-trigger particle yield in hydro

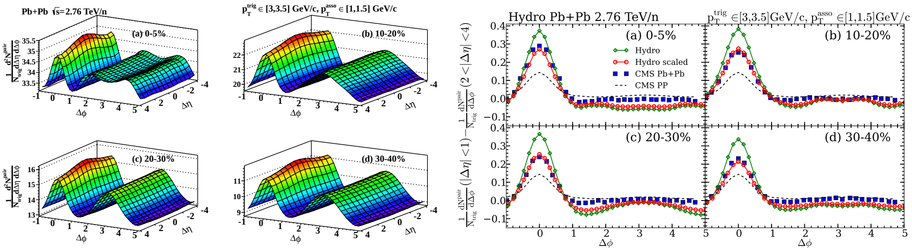
Formula

$$C12(\Delta\eta, \Delta\phi) = S(\Delta\eta, \Delta\phi)/B(\Delta\eta, \Delta\phi) \quad (1)$$

$$\frac{1}{N_{trig}} \frac{d^2 N^{pair}}{d\Delta\eta d\Delta\phi} = \frac{S(\Delta\eta, \Delta\phi)}{B(\Delta\eta, \Delta\phi)} \times B(0,0) \quad (2)$$



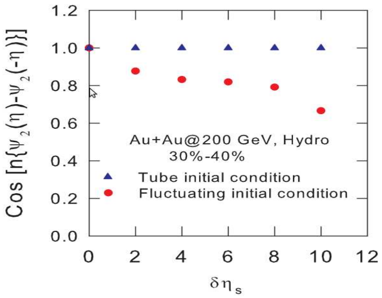
Di-hadron correlation in e-b-e hydro. arXiv:1309.6735



- The near side peak is decreasing with centrality, because most central collisions have the biggest collective flow.
- Ideal hydro over-estimated v_n and long range correlation. (But it's subtracted). Viscous hydro will give better description.
- η/s may affect di-hadron correlation along η direction due to the intrinsic feature of $\pi^{\eta\eta}$.
- MC freeze out + UrQMD after burner may also change di-hadron correlation (future).

Outline for section 2

Event plane correlation



- We are comparing the event-plane correlation as a function of $\Delta\eta$ between hydro and transport model (almost finished).
- Collaborate with Victor Roy, GuangYou Qin and XinNian Wang.
- See also: Phys.Rev. C84 (2011) 054908 by Hannah et. al

Relativistic Lattice Boltzmann Method for (3+1)D viscous hydro

$$p^\mu \nabla_\mu f \;-\; F^\alpha \partial_\alpha^{(p)} f = -\frac{p^\mu u_\mu}{\tau_R}(f - f_{eq}) \tag{3}$$

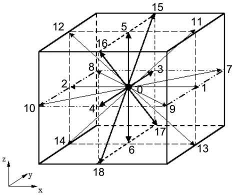
$$T^{\mu\nu} \;=\; \int d\chi p^\mu p^\nu f(t,x,p) \tag{4}$$

where $\int d\chi = \int \frac{dp^4}{(2\pi)^3}\delta(p^\mu p_\mu - m^2)2\theta(p^0)$. Work with Paul Romatschke.

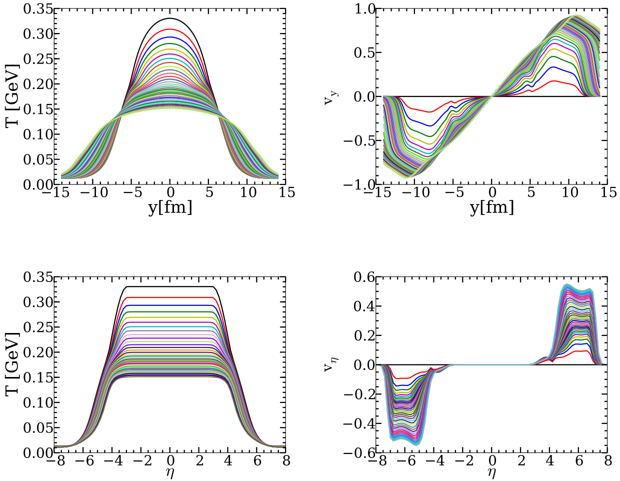
D3Q18 discretization of the f(t,x,p)

$$f \;=\; \sum_i f_i \tag{5}$$

$$u \;=\; \sum_i v_i f_i / (\sum_i f_i) \tag{6}$$

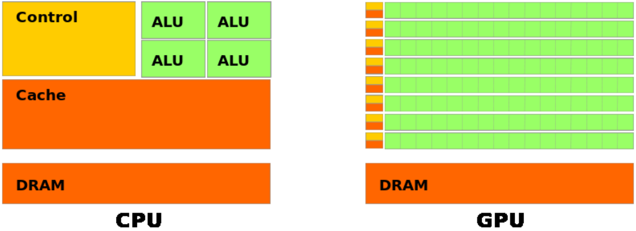


Results from Relativistic Lattice Boltzmann Method



- Transverse: Glauber, $\eta/s = 0.08$, b=7 fm, T0=0.360 GeV, $\tau_0 = 1fm$
- Longitudinal: $H(\eta) = exp(-(|\eta| - 2.95)^2/(2 * 0.6^2)\theta(|\eta| - 2.95))$

GPU parallel.



Pb+Pb 2.76TeV/n, 20-25%

$$\frac{dN}{dY p_T dp_T d\phi} = \frac{g_s}{(2\pi)^3} \int_\Sigma p^\mu d\Sigma_\mu \frac{1}{\exp((p \cdot u - \mu)/T_{FO}) \pm 1} \quad (7)$$

	CPU (i5-430M)	GPU (GT-240M)
Smooth spec. for π^+	7 minutes	30 seconds
MC sampling for $h^{+/-}$	4 minutes	9 seconds

Table: GPU(48 cuda cores) in my laptop is 10-30 times faster than CPU. Recent NVIDIA K20 GPU has 2496 cuda cores.

GPU parallel (other applications).

- Mathematica and MatLab support GPU parallel computing.
- Multiple-Dimensional phase space integration by VEGAS.
- SHAST, RLBM, Jet shower transport, UrQMD to GPU.
- ...

arXiv:1010.2107 by KEK, GTX285, 240 cuda cores, 100 times faster

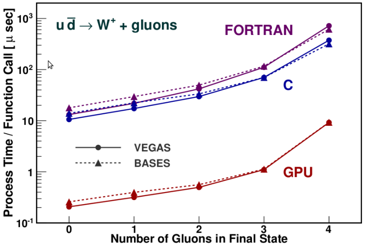
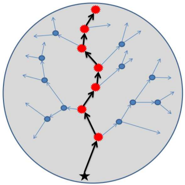


Fig. 1. Process time of a single function call for $u\bar{d} \to W^+(\to \mu^+\nu_\mu) + n$-gluons.

Jet medium interaction

Linearized Boltzmann Jet Transport model (YanZhu, HanLin Li and XN Wang)

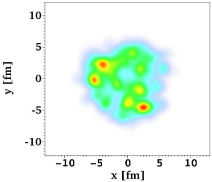


$$p_1\partial f_1(p_1) = -\int d\chi_2 d\chi_3 d\chi_4 (f_1 f_2 - f_3 f_4)|M_{12->34}|^2 \times (2\pi)^4\delta^4(p_1+p_2-p_3-p_4) \quad (8)$$

$$f_2 = 1/(e^{p\cdot u/T} \pm 1) \quad (9)$$

- The recoiled partons $E < E_{cut} \to$ hydro.
- The recoiled partons $E > E_{cut} \to$ jet shower.

Bulk evolution



$$\nabla_\mu T^{\mu\nu} = 0 \quad (10)$$

$$\nabla_\mu T^{\mu\nu} = J^\nu \quad (11)$$

- Run LBT and Hydro twice to get 1st order approximation.

My plane in Budapest

- Learn OpenCL (a parallel language that can run program on both CPU and GPU)
- Using OpenCL for the simple example (Cooper-Fry freeze out)
- Help LuoTan to implement the linear boltzmann transport model (GPU parallel).
  - The pre-defined target here
  - With Mat, Gergely and Luo Tan
- Lattice Boltzmann Code for 3+1D viscous hydro in OpenCL GPU parallel.
- Numerically solve non-extensive hydrodynamics (for P+Pb systems)
  - With Biro (future).