Flow vorticity in Peripheral high-energy heavy ion collisions

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Introduction

- The peripheral high energy heavy ion collisions have substantial angular momentum, the QGP formed in these reactions has low viscosity and leads to instability and rotation of the matter.
- The Kelvin Helmohotz Instability (KHI) effect has been predicted in our 3+1 relativistic fluid model by using the particle in cell method.

Definitions

In three dimensional space, the vorticity is: $\omega \equiv \frac{1}{2}\mathbf{rot}\ v = \frac{1}{2}\nabla \times v$

v is 3-velocity (v_x, v_y, v_z). The circulation is:

$$\Gamma = \oint_C \mathbf{v}\, dl = \int_A 2\omega\, d\mathbf{A}$$

A is the surface surround by a closed curve C.

- the classical vorticity in the reaction [x,z] plane is:

$$\omega_y \equiv \omega_{xz} = -\omega_{zx} \equiv \frac{1}{2}(\partial_z v_x - \partial_x v_z)$$

- The relativistic vorticity tensor is:

$$\omega^{\mu}_{\nu} \equiv \frac{1}{2}(\nabla_\nu u^\mu - \nabla^\mu u_\nu)$$

Here $u^\mu = \gamma(1, v)$ is 4-velocity. In the reaction plane:

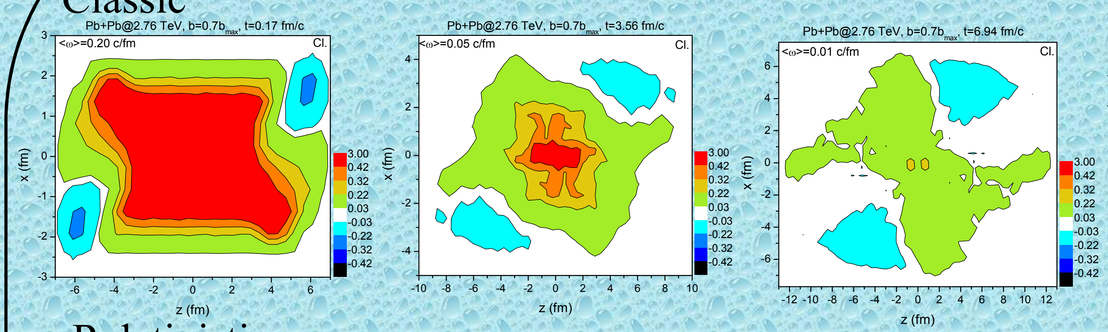
$$\omega^x_z = -\omega^z_x = \frac{1}{2}(\partial_z \gamma v_x - \partial_x \gamma v_z) = \frac{1}{2}\gamma(\partial_z v_x - \partial_x v_z) + \frac{1}{2}(v_x \partial_z \gamma - v_z \partial_x \gamma)$$

- Energy weighted vorticity : $\Omega_{zx} \equiv \sum_{ik}^{N_{cell}} \frac{E_{ik}}{(E_{tot}/N_{cell})}\omega_{zx}(i,k)$

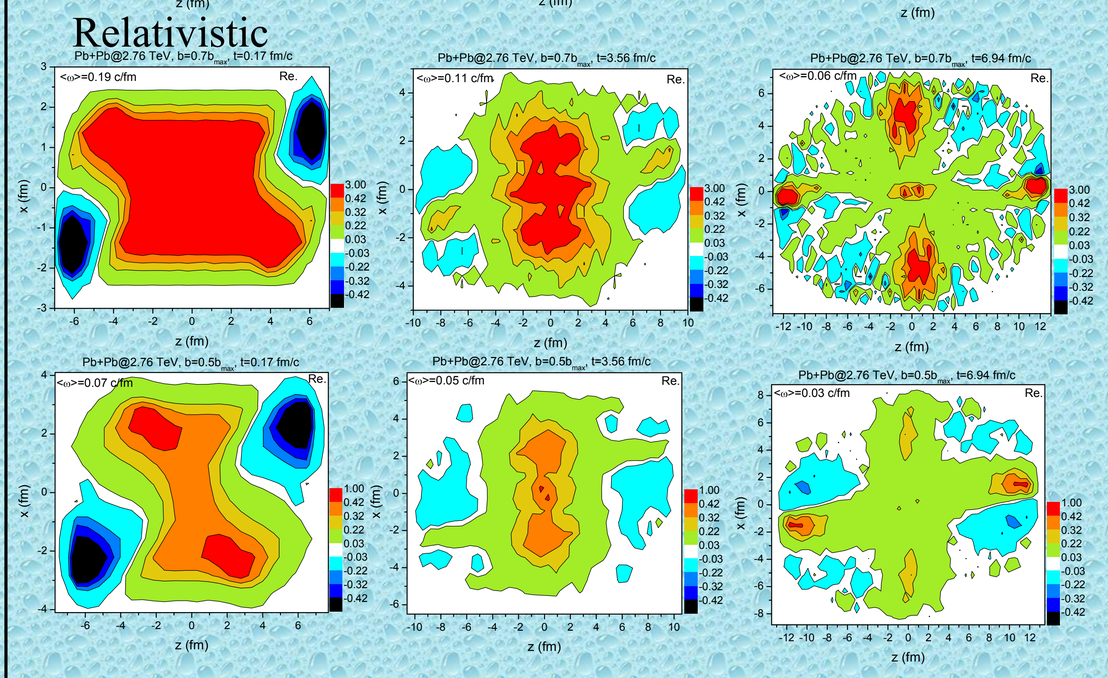
E_{ik} is the energy of one cell (i,k) and E_{tot} is the total energy for one [x,z] plane . N_{cell} is the cell number of this [x,z] plane.

vorticity at LHC energy

Classic



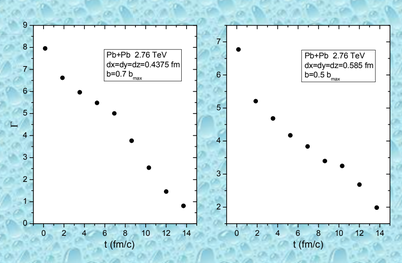
Relativistic



- The overall vorticity is positive, originates from the initial shear
- initial average vorticity~3 times larger due to asymmetry and the edge shear is larger
- Decrease with time due to the expansion and viscous dissipation.

Average relativistic vorticity

Timestep	Time (fm/c)	Relativistic	Classical	Relativistic	Classical
Reaction plane					
4	0.17	0.02415	0.05839	0.11846	0.14343
84	3.56	0.01677	0.01622	0.07937	0.04845
164	6.94	0.01295	0.00606	0.05116	0.01555
All layers					
4	0.17	0.07241	0.09442	0.19004	0.1971
84	3.56	0.05242	0.03086	0.10685	0.0538
164	6.94	0.0344	0.01185	0.05881	0.0159



- The circulation is decreasing both for the favor and non-favoring KHI configuration.
- average vorticity is larger initially and become smaller at a later time classically.

Shear velocity for Peripheral Collisions

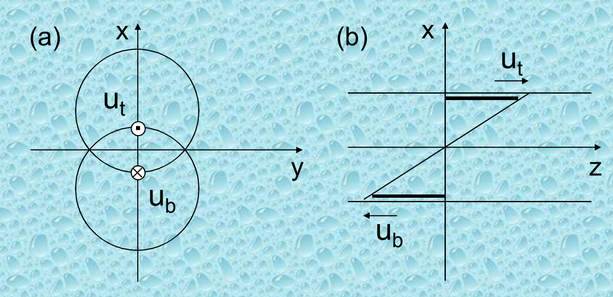


Fig.1 (a) is the collision sketch in the transverse [x,y] plane. The almond shape is the participant ; (b) The velocity profile in [x,z] plane. The top streak goes to the right and the bottom streak moves to the left. The initial angular momentum is streak by streak conserved.

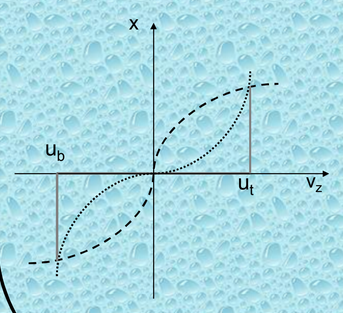
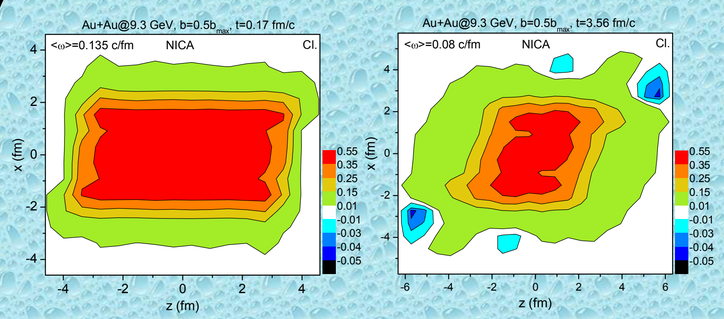
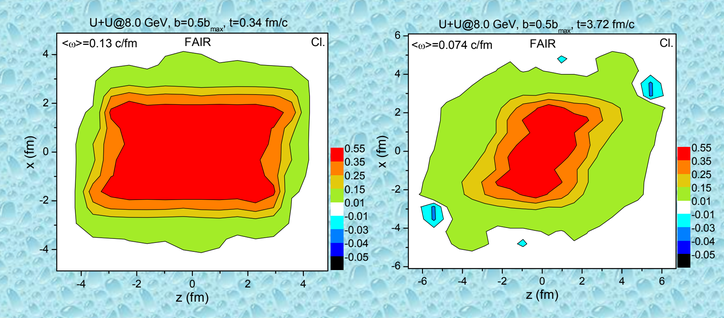


Fig.2 The z-directed velocity as a function of x axis. The dotted dash line is the velocity profile which is favouring the KHI.

vorticity at NICA and FAIR



t (fm/c) (NICA)	vorticity classical (c/fm)
0.17	0.1345
1.02	0.1238
1.86	0.1079
2.71	0.0924
3.56	0.0773



t (fm/c) (FAIR)	vorticity classical (c/fm)
0.34	¥0.1297
2.03	¥0.1020
3.72	¥0.0736
5.42	¥0.0520
7.11	¥0.0377

- The cell size dx=dy=dz is 0.575 fm for NICA and 0.61 for FAIR.
- The QGP formation is assumed in these calculations
- The absent of KHI slows down the formation of the uniform rotation

Conclusions

- development of flow vorticity is studied for LHC, FAIR and NICA energies.
- the vorticity is 10 times larger than the one raised from random fluctuations in transverse plane
- at lower energies the vorticity is smaller but still quite significant
- The DHBT and Polarization can be proposed to detect rotation of the expanding systems.

[1] Csernai, Magas,Wang, PRC 87 (2013) 034906;
[2] Wang, Neda, Csernai, PRC 87 (2013) 024908;
[3] Becattini,Csernai, Wang, PRC 88 (2013) 034905;
[4] Csernai, Wang, Bleicher, Stocker, submitted to PRC.