Directed flow and early thermalization

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Abstract

The generation of the directed flow of particles emitted from the fireball created in heavy-ion collisions at RHIC is described using a 3+1D hydrodynamical model. The initial density of the tilted fireball is constructed as a sum of contributions from forward and backward going participants. Our model reproduces the experimentally observed negative directed flow in a wide range of central pseudorapidities and reproduces correctly the scaling of the directed flow when going from Au-Au to Cu-Cu systems [1]. The directed flow is a very sensitive measure of the pressure equilibration in the first **1** fm/c of the evolution, it is strongly reduced in the presence of even a very short pressure anisotropy. Our calculations show that the system must thermalize fast ($<$ **0.25**fm/c). This suggests that the matter behaves as a strongly coupled system already at the first stages [2]

Collective flow

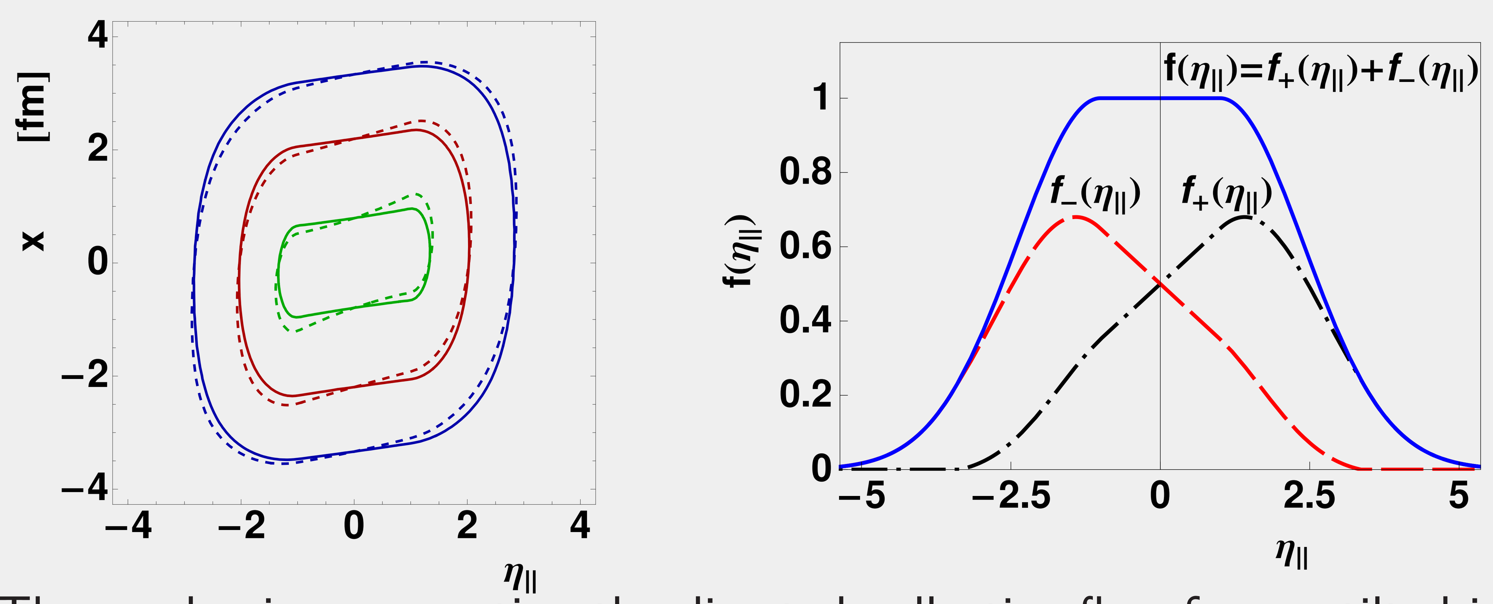
For non-central collisions the interaction region is azimuthally asymmetric and asymmetric emissions of particles takes place as a results of the collective expansions of matter. The effect can be quantified in therms of Fourier coefficients in the expansion of the measured particle spectra

$$\frac{dN}{d^2p_\perp d\eta} = \frac{dN}{2\pi p_\perp dp_\perp d\eta}(1 + 2v_1\cos(\phi) + 2v_2\cos(2\phi) + \ldots)$$

The coefficient $\mathbf{v_1}$ of the directed flow is measured at RHIC energies. It is zero at zero rapidity for collisions for symmetric nuclei, and becomes negative (positive) when moving to forward (backward) pseudorapidities η.

Initial conditions

The formation of the directed flow in ultrarelativistic collisions requires a mechanism that breaks the symmetry with respect to the collisions axis and some effective transverse and longitudinal acceleration of the fluid elements. The asymmetric emission in space-time rapidity from forward and backward going wounded nucleons [3] results in a tilt of the initial fireball away from the collisions axis [left panel]. Therefore we take the initial profile as a sum of two contribution $\mathbf{f_+}$ and $\mathbf{f_-}$ representing the emissions from forward and backward going participant nucleons[right panel].



The mechanism generating the directed collective flow from a tilted initial source can be understood when considering the acceleration equations of relativistic hydrodynamics. For small initial times the accelerations in the transverse $\mathbf{x}$ and longitudinal (space-time rapidity) $\eta_\parallel$ directions are

$$\partial_\tau v_x = -\frac{\partial_x P_\perp}{\epsilon + P}$$

$$\partial_\tau Y = -\frac{\partial_{\eta_\parallel} P_\parallel}{\tau(\epsilon + P)}$$

According to the above equations, the acceleration of the fluid elements in the tilted source generates anti-flow ($\mathbf{v_1} < \mathbf{0}$ for $\eta > \mathbf{0}$). It should be stressed that generating the directed flow requires non-zero gradients of both the transverse $\mathbf{P_\perp}$ and longitudinal $\mathbf{P_\parallel}$ pressures.

References

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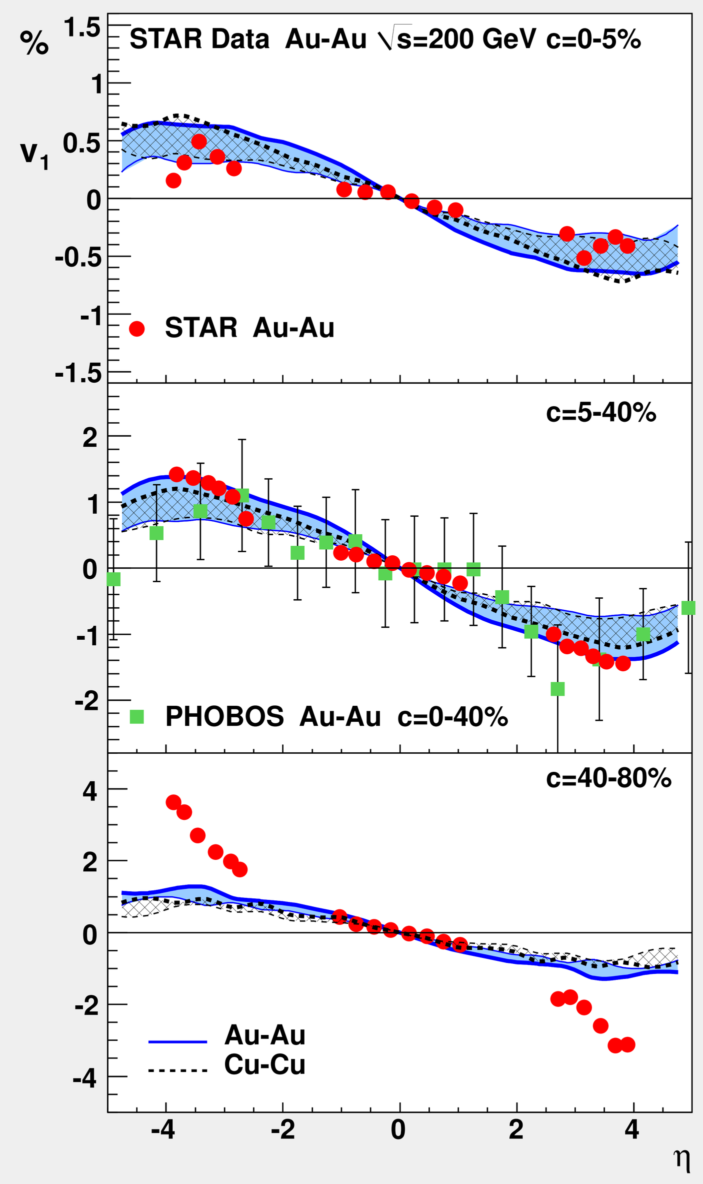
Directed flow

Using our 3+1 dimensional hydrodynamic model with a tilted source we have calculated the directed flow of charged particles. The thick solid lines represent the results for Au-Au collisions and dashed lines correspond to Cu-Cu collisions. The experimental data [4-5] are reproduced in the central rapidity region in a satisfactory way. The shaded bands in the figure represent the uncertainty of the model.

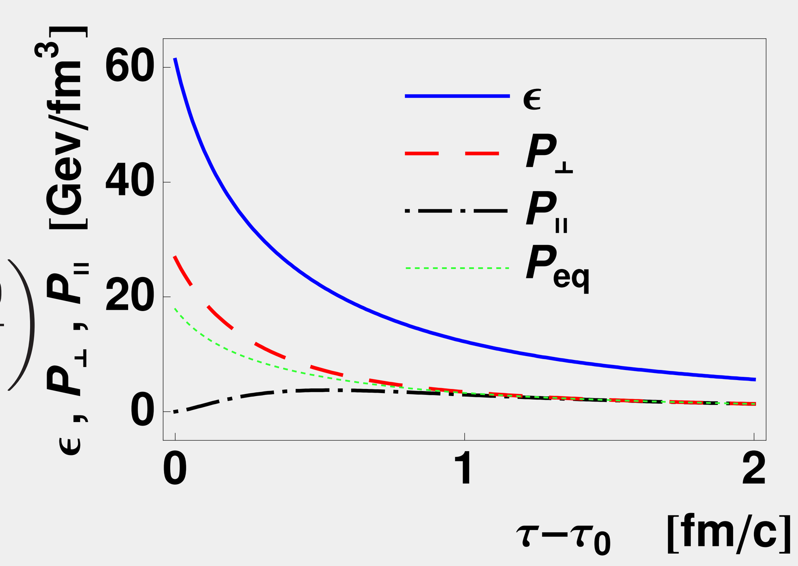


3+1D expansion with off-equilibrium pressure

We study the dynamics of the system with anisotropic pressures. A phenomenological correction is added to the ideal fluid energy-momentum tensor resulting in anizotropic pressures

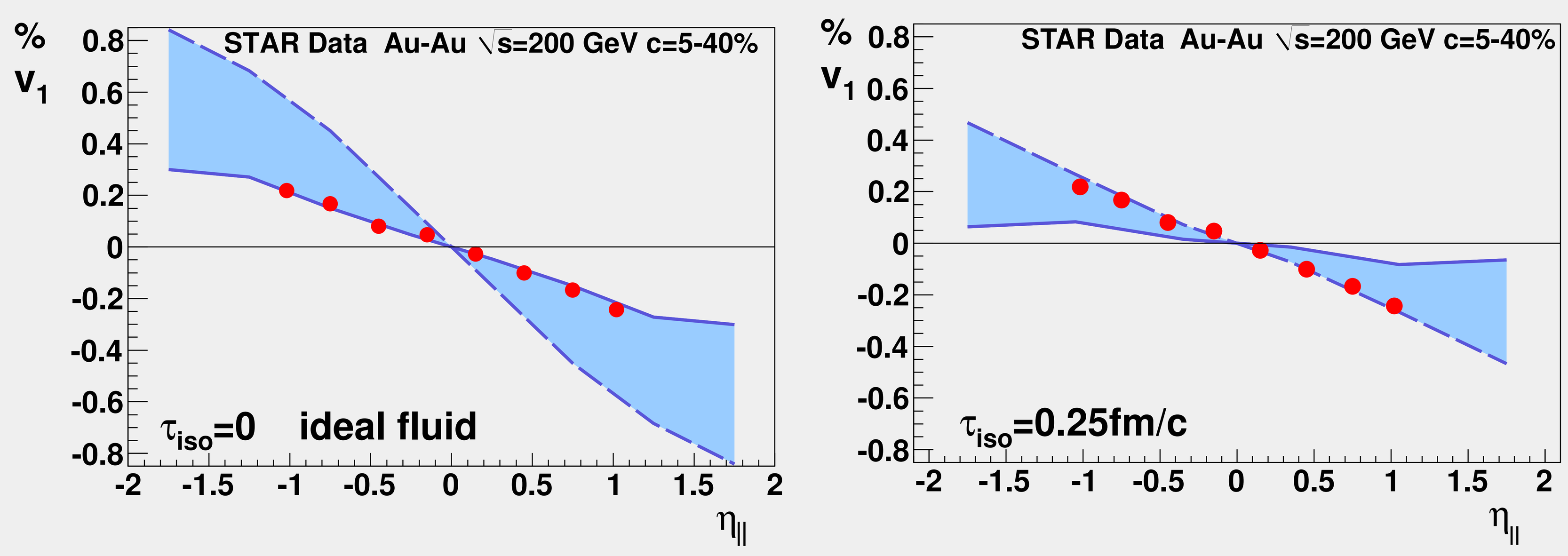
$$P_\perp - P_\parallel = \frac{3}{2}P_{eq}(\tau_0)\exp\left(-\frac{\tau - \tau_0}{\tau_{iso}}\right)$$

It means that initially the longitudinal pressures is zero and that the pressure anisotropy decreases with a relaxation time τ_{iso}.



Early thermalization

To estimate the thermalization time τ_{iso} we use two extreme assumptions for the value of the source tilt within the Glauber model. For the smaller tilt the experimental data are described using $\tau_{iso} = \mathbf{0}$. The expansion of the source with the larger tilt is compatible with the data if the longitudinal pressure is retarded by $\mathbf{0.25}\frac{\mathbf{fm}}{\mathbf{c}}$ with respect to the transverse pressure.



$$0 \le \tau_{iso} \le 0.25\text{fm/c}$$

The conclusion of this analysis is that the isotropization time of the pressure is smaller than $\mathbf{0.25}\frac{\mathbf{fm}}{\mathbf{c}}$. Such a small value of the delay for the appearance of the longitudinal pressure indicates that the system is strongly coupled.

Conclusions

We demonstrate in explicit hydrodynamic calculation that the directed flow

- is **formed in the first stage** of the expansion,
- is built trough a simultaneous action of the **transverse and longitudinal pressures**

Using the directed flow of particle we estimate that the thermalization time is smaller than $\mathbf{0.25}\frac{\mathbf{fm}}{\mathbf{c}}$