Fluctuations, Instabilities and Collective Dynamics

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Introduction

➢ Fluid dynamical processes became a dominant direction of research in high energy heavy ion reactions. The Quark Gluon Plasma formed in these reactions has low viscosity [1], which leads to significant fluctuations and turbulent instabilities [2]. One has to study and separate these two effects [3], but this is not done yet in experiments. When such separation is performed, both fluctuations and new collective effects, like rotation and turbulence and the arising polarization [4] and two particle correlations [5] can be studied. The polarization arises from the shear flow based on the equipartition principle between local flow vorticity [6] and particle spin. Vorticity increases with beam energy in peripheral collisions, while higher temperatures counteract spin alignment. Due to these two effects polarization is expected to be observable at lower energies also [6].

Parametrization of flow data:

$$\frac{d^3N}{dy\,dp_t\,d\phi} = \frac{1}{2\pi}\frac{d^2N}{dy\,dp_t}\Big[1 + 2v_1(y,p_t)\cos(\phi-\Psi_1^{EP}) + 2v_2(y,p_t)\cos(2(\phi-\Psi_2^{EP})) + \cdots\Big],$$

➢ The parameters v_n and Ψ_n are averages for a set of data. The angles are measured vs. the EbE reaction plane. These can be separated to Collective Flow and Random Fluctuation component based on symmetries [3]:

$$v^{Coll.}_{n\,\substack{even\\odd}}\cos[n(\phi-\Psi_n^{EP})] = \frac{1}{2}\left[{}^{c}v_n(\mathbf{y},p_t) \pm {}^{c}v_n(-\mathbf{y},p_t)\right]\cos(n\phi)$$

$$v^{Fluct.}_{n\,\substack{even\\odd}}\cos[n(\phi-\Psi_n^{EP})] = \frac{1}{2}\left[{}^{c}v_n(\mathbf{y},p_t) \mp {}^{c}v_n(-\mathbf{y},p_t)\right]\cos(n\phi) + {}^{s}v_n(\mathbf{y},p_t)\ \sin(n\phi)$$

where the flow parameters can be obtained from the primary ones as:

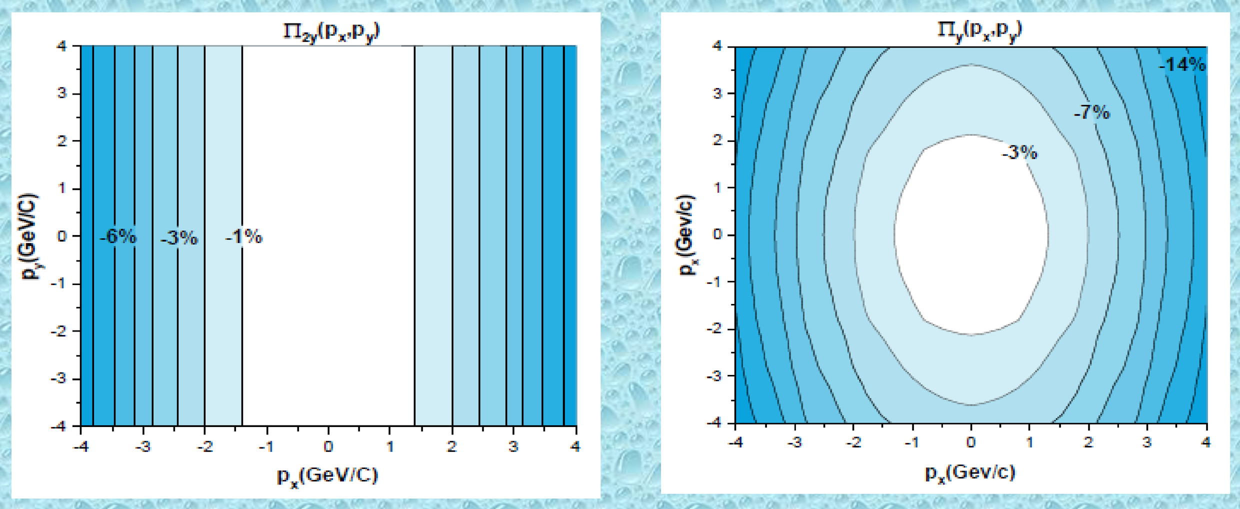
$${}^{c}v_n \equiv v_n\cos(n(\Psi_n^{EP})) \quad \text{and} \quad {}^{s}v_n \equiv v_n\sin(n(\Psi_n^{EP}))$$

➢ Notice that the Collective Flow part has only cosine azimuthal component, due to mirror symmetry across the Reaction Plane (RP), while the random part has both sine and cosine components.

➢ This separation can only be done if the RP and CM are identified for every single collision in the experimental sample [3].

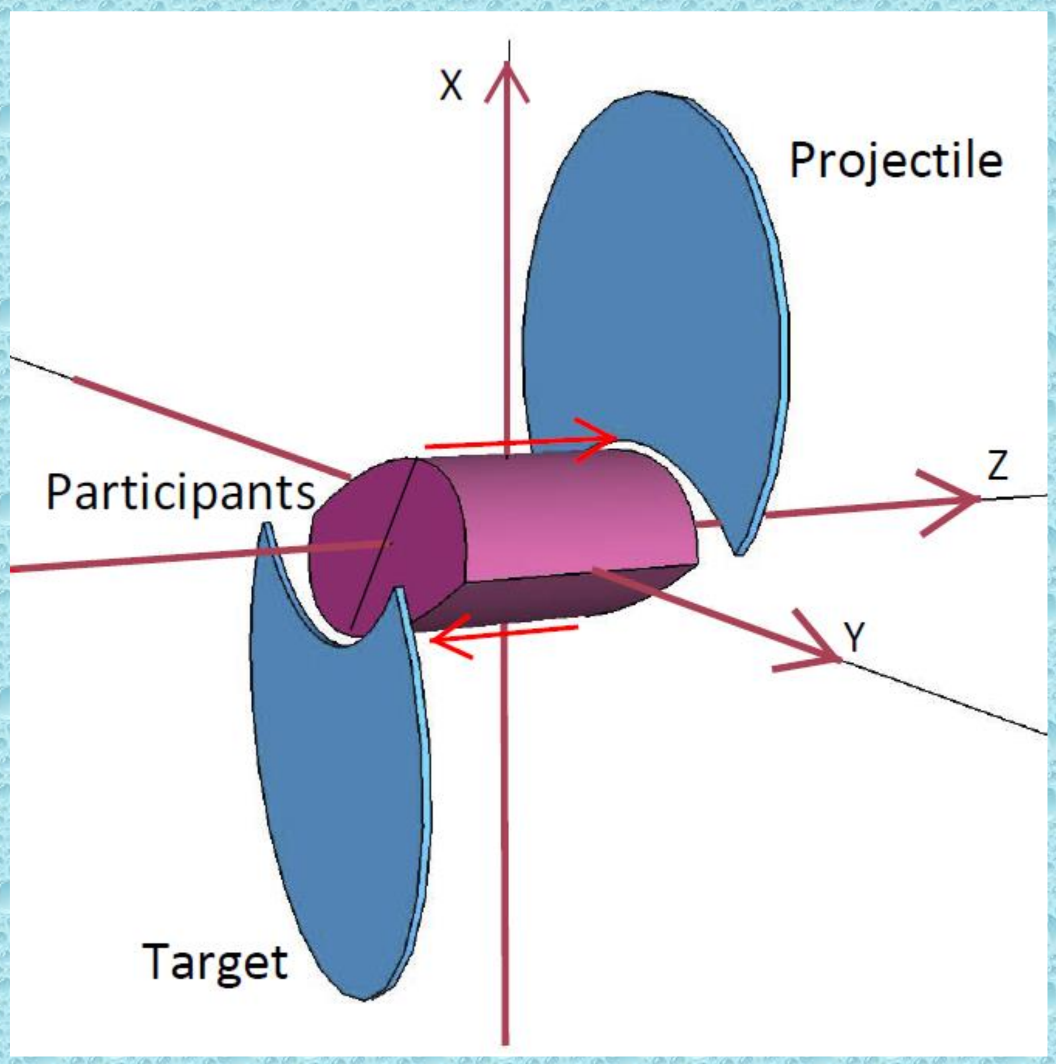
➢ If the RP and CM are identified we can determine also the consequences of rotation, shear, and vorticity, like the *Λ* polarization, or the Differential HBT analysis indicating the rotation of the system.

The Λ Polarization



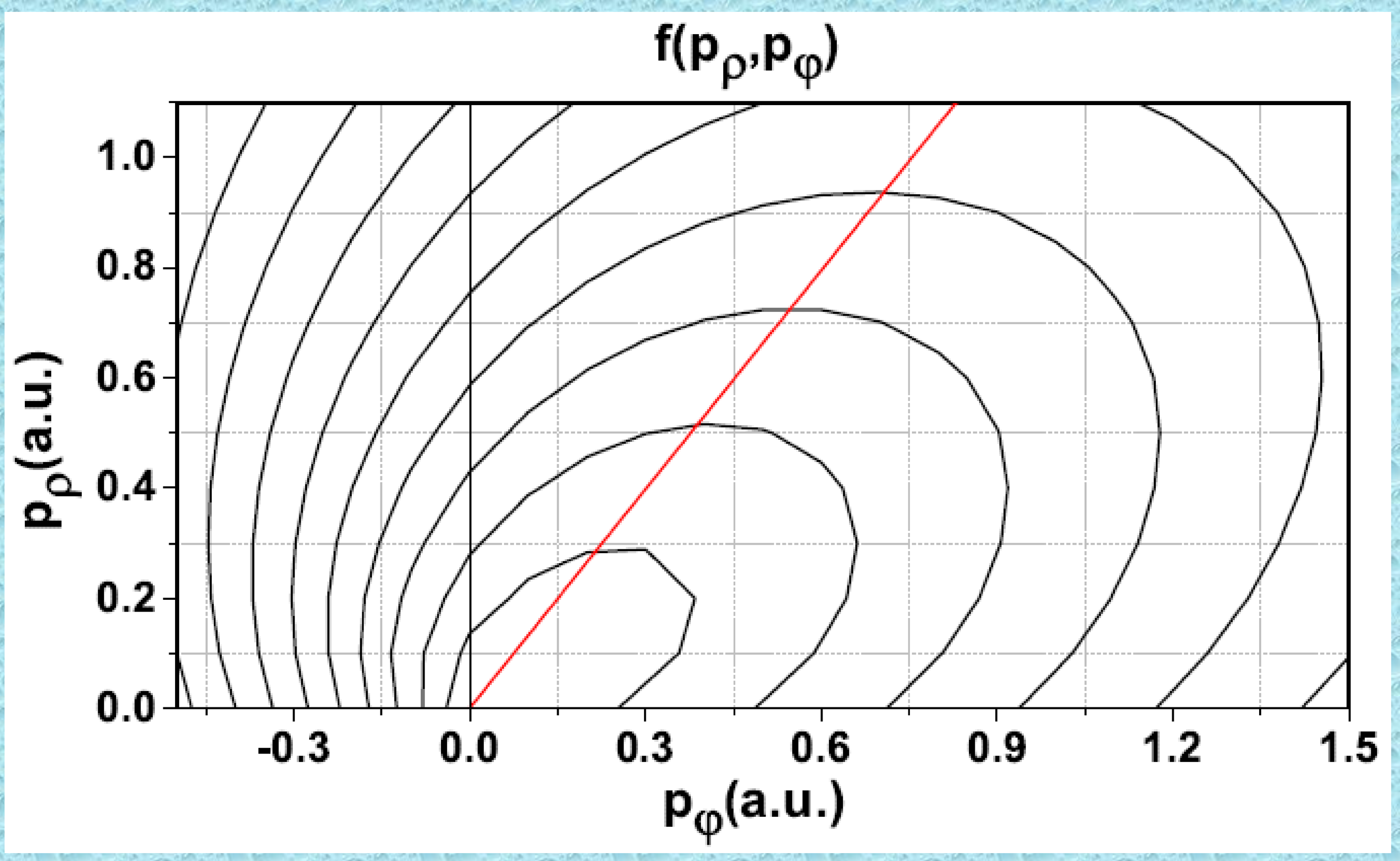
➢ Fig. 1. The **y** component of polarization reaches -16% in the corners, much larger than the x and z components [7].

Configuration:



➢ Fig. 2. Sketch of peripheral heavy ion collisions at high energy. The total *(-y directed)* angular momentum of the interaction region, is orthogonal to the [x,z] reaction plane.

Azimuthal asymmetry in *p* space



➢ Fig. 3. The phase space asymmetry of an azimuthally symmetric, but rotating and expanding source. This can be detected by Differential HBT [8].

Conclusions

➢ We can separate new Collective Flow effects from Random Fluctuations in peripheral collisions.

➢The rotation and the arising polarization can be detected, and provide information on the EoS and transport properties of QGP

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