Elliptic flow in heavy ion collisions

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Introduction

A large amount of energy is dumped into a very small volume, when two heavy nuclei collide, and the observations have been recorded for different energy ranges and from light to heavy nuclei in laboratories. Many detectable signals and experimental observables are recorded at different stages and one of the important signals is the **elliptic-flow.** The Lorentz contracted nuclei pass through each other, and after the initial binary collisions the interacting system reaches to a local thermal equilibrium, and the pressure gradients arise which lead to anisotropic momentum distribution of particles which is defined as elliptic flow. The yield of various hadrons can be characterized by Fourier expansion, and the second coefficient defines the elliptic flow (v_2). The relativistic hydrodynamical models are able to explain and picture very well.

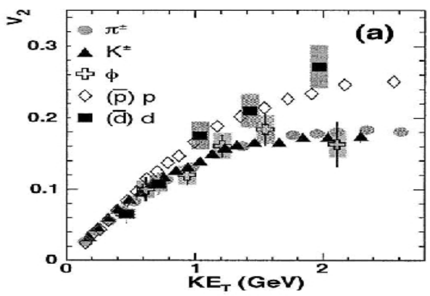

Fig. 1 The plot between v_2 and transverse kinetic energy KE_T [3].

In the figure 1, at RHIC low energies, the elliptic flow is positive and indicates the in plane momentum anisotropy. With growing energy the spectators escape faster from the region and the bouncing off-plane dynamics is less dominating. At high beam energy v_2 again becomes positive indicates that the pressure gradient developed in plane is dominated over other factors. This observation leads to the creation of an opaque and strongly interacting partonic matter.

The flow and correlation studies:

The elliptic flow measured in Cu+Cu and Au+Au collisions, at $\sqrt{S_{NN}}$ =200 GeV, as a function of number of participating nucleons, is shown in figure 2. As the elliptic flow is driven by the azimuthal anisotropy in the initial stage of the collision, signals for most central Cu+Cu collisions should be small. But the observed signals were significantly large [1]. Further the results of observed elliptic flow were explained well by the consideration of event by event fluctuations in the initial geometry [1]. The anisotropy of the initial geometry can be characterized by the eccentricity of the transverse shape of the initial nuclear overlap region [2] and it may play a key role to find and understand the source of ridge and broad away side structures in particle correlation measurements.

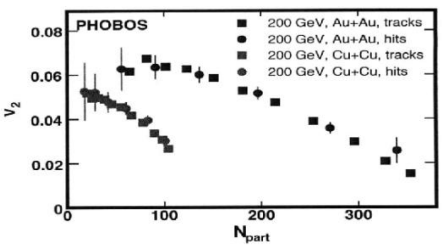

Fig. 2 Elliptic flow (v_2)as a function of number of participating nucleons in Au+Au and Cu+Cu collisions at $\sqrt{S_{NN}}$= 200 GeV [1].

Eccentricity and the elliptic flow

The azimuthal anisotropy in the particle production is characterized by the Fourier transformation with respect to the reaction plane angle ψ_r as-

$$\frac{1}{N}\frac{dN}{d\phi} = \frac{1}{2\pi}\left\{1 + \sum_n 2v_n \cos\left(n(\phi - \psi_r)\right)\right\} \quad (1)$$

Here the second coefficient v_2 is defined as the elliptic flow. The eccentricity in general is quantified as the anisotropy of the collision geometry-

$$\varepsilon = \frac{<y^2-x^2>}{<y^2+x^2>} \quad (2)$$

Here x and y are the transverse coordinates along and perpendicular to the reaction plane respectively. At high densities and vanishingly small mean free path, the elliptic flow signals are supposed to be saturated at a value imposed by hydrodynamical calculations. Also it is expected to be zero for azimuthally symmetric system, and for small anisotropies in the initial geometry the elliptic flow should be proportional to eccentricity.

The Glauber modeling for eccentricity calculation

The Monte-Carlo Glauber models are very useful in providing good results for the quantities where event by event fluctuations are significant [4]. The shape of the interaction region is elliptic and strongly dependent on the impact parameter in the non-central collisions. The initial space anisotropy can be characterized by the eccentricity [5] as-

$$\varepsilon_{RP} = \frac{\sigma_y^2-\sigma_x^2}{\sigma_y^2+\sigma_x^2} \quad \& \quad \varepsilon_{PP} = \sqrt{\frac{(\sigma_y^2-\sigma_x^2)^2+4\sigma_{xy}^2}{\sigma_y^2+\sigma_x^2}} \quad (3)$$

Where σ_x^2, σ_y^2 and σ_{xy}^2, are the event-by-event co-variances of the participant nucleon distributions projected on the transverse axes, x and y.

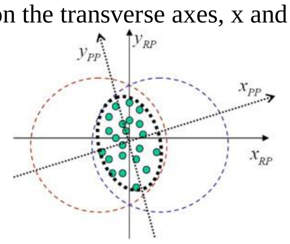

Fig. 3 The reaction plane and participant plane in the collision region.

The participant plane eccentricity changes with the number of participating nucleons and their positions and thus with the energy. The results for Au+Au, and Cu+Cu collisions at different energies provide good understanding of event-by-event fluctuations consideration. The elliptic flow coefficient v_2 is also a measure of the momentum anisotropy as-

$$v_2 = \langle\frac{p_x^2-p_y^2}{p_x^2+p_y^2}\rangle \quad (4)$$

There are factors which may affect the proportionality between the elliptic flow and eccentricity and can dampen this transformation, like viscosity. When the anisotropy is measured event-by-event the fluctuations may be due to three reasons: statistical fluctuations arise due to finite number of particles observed, secondly the elliptic flow fluctuations and other may be the many-particle correlations, defined as non-flow correlations. Different analyses methods are able to calculate elliptic flow fluctuations.

Conclusions

The elliptic flow is an important parameter which may be a tool to reflect the reaction dynamics. The elliptic flow changes with energy and a positive v_2 coefficient means the in-plane flow, while the negative v_2 means the out-of-plane flow. Proportionality is found between initial geometry eccentricity and the elliptic flow. Ideal hydrodynamics don't explain the v_2 coefficient at all p_T range. Calculations made using hydrodynamics with non-zero shear viscosity η, also the consideration of non-flow effects, and other factors can help to understand the flow fluctuations. An understanding of these phenomena can be achieved by considering elliptic flow.

References

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