Eccentricity scaling of the elliptic flow of final state hadrons and thermalization at LHC

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Introduction

The collision of heavy nuclei at ultra-relativistic energies is the only known tool to produce quark-gluon plasma (QGP) in the laboratory. The elliptic flow (v_2) of the emitted final state hadrons is believed to carry the signature of thermalization of the hot and dense medium produced in the collisions. v_2 is quantified as the second Fourier coefficient of the ansiotropic azimuthal distribution of the emitted hadrons in non-central heavy-ion collisions. It originates as a result of initial spatial anisotropy of overlap zone of the two colliding nuclie at non-zero impact parameter. This spatial anisotropy transcends into the momentum anisotropy via anisotropic pressure gradients, leading to more number of particles being emitted along the short axis of the overlap region. Since v_2 develops due to re-interactions among the produced particles in the fireball, the study of v_2 can give an idea about the degree of the equilibration attained in the collision.

Elliptic flow and incomplete thermalization

In non-central heavy-ion collisions, the overlap area in the transverse plane has a almond like shape, with a short axis parallel to the impact parameter and long axis perpendicular to it. In the limit of very small mean free path, where re-scatterings among the produced particles are frequent enough to drive the system quickly to local thermal equilibrium, particles tend to go more in the direction of steepest pressure gradients along the short axis and thus converting the initial state spatial anisotropy into a final state momentum anisotropy. The magnitude of this effect is quantified by the elliptic flow (v_2), defined as

$$v_2 = < cos2(\phi - \psi_R) > \qquad (1)$$

where ϕ is the azimuthal angle of an outgoing particle and ψ_R is the reaction plane angle. The angular brackets denote average over many final state hadrons over many events. As v_2 results from re-interactions inside the fireball, it is used to probe the local thermal equilibrium in relativistic nuclear collisions. If the produced matter undergoes complete equilibration, it behaves like an ideal fluid and the resulting v_2 scales with the spatial eccentricity ϵ of the overlap zone and becomes independent of the transverse size R. In case of incomplete thermalization, the scale invariance is broken and $\frac{v_2}{\epsilon}$ becomes dependent on the Knudsen number $K = \lambda/R$, where λ denotes the mean free path. In ref. [1, 2] the authors argue that the centrality and system size dependence of v_2 measured in $\sqrt{s_{NN}} = 200$ GeV Au+Au and Cu+Cu collisions at RHIC can be interpreted in a simple model based on eccentricity scaling and incomplete thermalization. Explicit model comparisons with then available data indicate that even for most central Au+Au collisions at RHIC, the observed v_2 is at least 25% below the so called ideal fluid limit. This hint of partial equilibration in the data enables one to estimate the effective partonic cross section in the deconfined plasma and it's viscosity to entropy density ratio. In the present contribution, we plan to extend these calculations to higher energies, $\sqrt{s_{NN}} = 2.76$ TeV and $\sqrt{s_{NN}} = 5.02$ TeV Pb-Pb collisions at the LHC.

The eccentricity scaling of v_2 can be modelled as

$$\frac{v_2}{\epsilon} = \frac{v_2^{hydro}}{\epsilon} \frac{1}{1 + K/K_0} \qquad (2)$$

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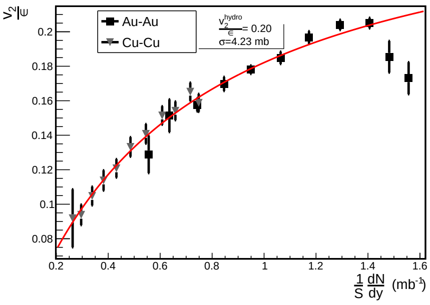

FIG. 1: Variation of eccentricity scaled elliptic flow with the density,assuming Glauber initial conditions for $\sqrt{s_{NN}}$ = 200 GeV Cu+Cu and Au+Au collisions at RHIC.

where v_2/ϵ is the largest in the ideal fluid limit $K \rightarrow 0$. Viscous effects appearing as first order corrections to this limit are linear in K. For large values of λ, far from the equilibrium, $v_2/\epsilon\ K^{-1}$, the inverse Knudsen number which gives the average number of collisions a particles undergoes before escaping the medium. K^{-} can be shown to be related to the average final state hadron multiplicity via

$$\frac{1}{K} = \frac{\sigma}{S_T}\frac{dN}{dy}c_s \tag{3}$$

where dN/dy denotes the total multiplicity per unit rapidity, σ denotes the partonic cross section, S_T denotes the transverse area of the overlap zone and c_s denotes the speed of sound in the medium. Using this formulation in ref. [2], the authors have analyzed the RHIC v_2 data measured by PHOBOS collaboration, for Cu+Cu and Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. Two different initial conditions namely the Glauber Monte Carlo (MC) and the color glass condensate (CGC) were employed to model the initial matter distributions between the two colliding nuclei. The density dependence of the eccentricity scaled elliptic flow is seen to nicely described by Eq. 2, with nearly 30% deviation from ideal hydrodynamics, even for most central Au+Au collisions. For MC Glauber (CGC) conditions, they obtained $\sigma = 4.3 \pm 0.6$ (5.5 ± 0.5) mb and $v_2^{hydro}/\epsilon = 0.3 \pm 0.02$ (0.22 ± 0.01). In our present calculations, before going to LHC energies, we first compare our calculations with these available results. For modeling the initial conditions, we use PHOBOS Glauber MC code. The fit results of the RHIC data for Au+Au and Cu+Cu collision systems are shown in Fig. 1 and we obtain $\sigma = 4.23 \pm 0.27$ mb and $v_2^{hydro}/\epsilon = 0.21 \pm 0.02$. Our obtained value of σ is in close agreement with the previous analysis. However the extracted value of v_2^{hydro}/ϵ is lesser by around 30%. Work is under progress to analyze the LHC data for various collision systems at different collision energies.

Summary

In summary we investigate the centrality and system size dependence of the measured v_2 of the final state hadrons in the heavy-ion collisions at RHIC and LHC energies. Within a perfect thermalization scenario, v_2 would scale with the initial eccentricity of the fireball. A breaking of the scaling behavior would indicate the presence of viscous effects and deviation from the complete thermalization, as already observed at RHIC. The foreseen contribution would extend these studies to the LHC and analyze the plethora of data collected by different experiments at different energies.

References

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