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Imaging the initial condition by higher order event anisotropy v_n , multi-particle correlation and direct photon v_2 from the RHIC-PHENIX experiment

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Defining the initial condition is one of the most important but difficult tasks for studying the properties of Quark Gluon Plasma (QGP) in high-energy heavy-ion collisions. Recent results from RHIC-PHENIX experiment especially on higher order event anisotropy v_n, multi-particle correlation with trigger angle selection relative to the reaction plane and direct photon elliptic flow v_2 in 200 GeV Au+Au collisions from RHIC-PHENIX experiment are shown and their relation to the initial condition and dynamical evolution of the system is discussed.

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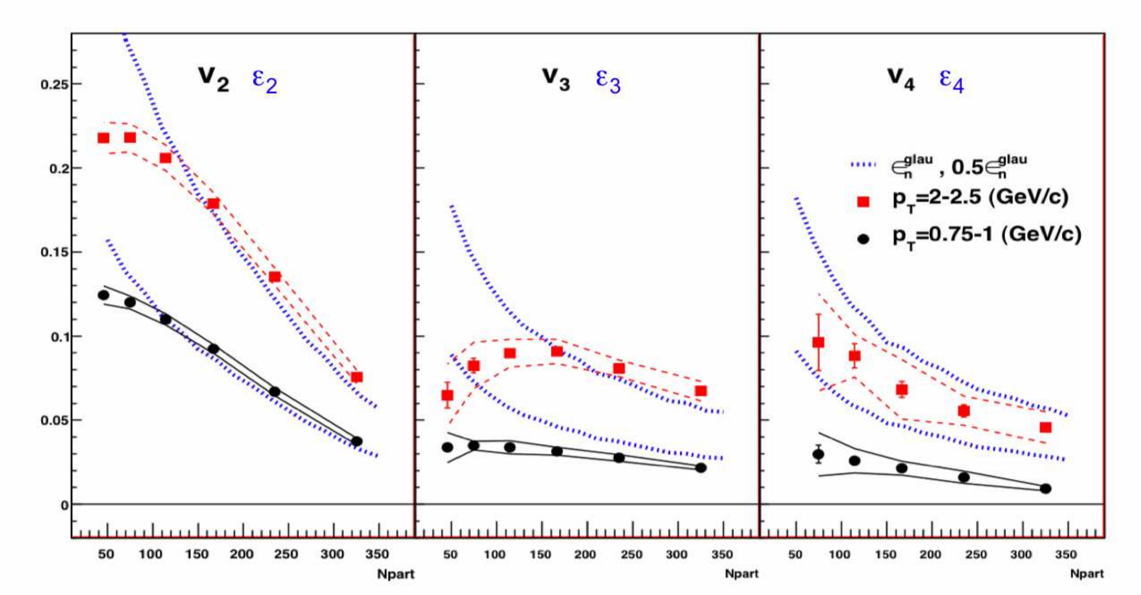

Figure 1: Centrality dependence of higher order event anisotropy parameters v_2, v_3 and v_4 as a function of number of participants at 200 GeV Au+Au collisions [1], which is compared with higher order eccentricities ε_n from Glauber Monte Carlo simulation

1. Higher order event anisotropy v_n

Fig.1 shows the centrality dependence of measured higher order event anisotropy parameters v_n as a function of number of participants at 200 GeV Au+Au collisions for charged particles at two transverse momentum regions ($0.75 < p_T < 1$ GeV/c) and ($2 < p_T < 2.5$ GeV/c) at mid-rapidity [1]. The data are compared with the higher order eccentricity ε_n calculated with Glauber Monte Carlo simulation. The general trend between v_n and ε_n has similar centrality dependence, which can be taken as a confirmation of the initial geometrical participant fluctuation as a dominant source of the observed higher order event anisotropy, however some reduction of the measured v_n at peripheral collisions relative to the ε_n would indicate that the size of initial volume is also important (needed) to be observed as the final event anisotropy in momentum space after the system expansion/evolution.

Identified hadron v_3 for $\pi^{+/-}$, $K^{+/-}$, p and $\overline{p}$ are shown in Fig.2 as a function of transverse momentum at 200 GeV for mid-central Au+Au collisions [2]. Particle mass dependence of v_3 is seen below 1.5 GeV/c in p_T which is rather similar to previously observed trend in v_2, that can be understood with thermal freeze-out with radial expansion as described by a hydro-dynamic feature. While at higher p_T region above 2 GeV/c, the reversing order of v_3 between meson and baryon also seems to be observed just like the number of constituent quark scaling of v_2. This at least tells us that the v_3 also reflect the quark coalescence like hadronization and the collective expansion of the system.

The colliding beam energy dependence of constituent quark number scaled v_2 as a function of quark number scaled m_T - *mass* is shown in Fig.3 for three different energies at 2.76 TeV, 200 GeV

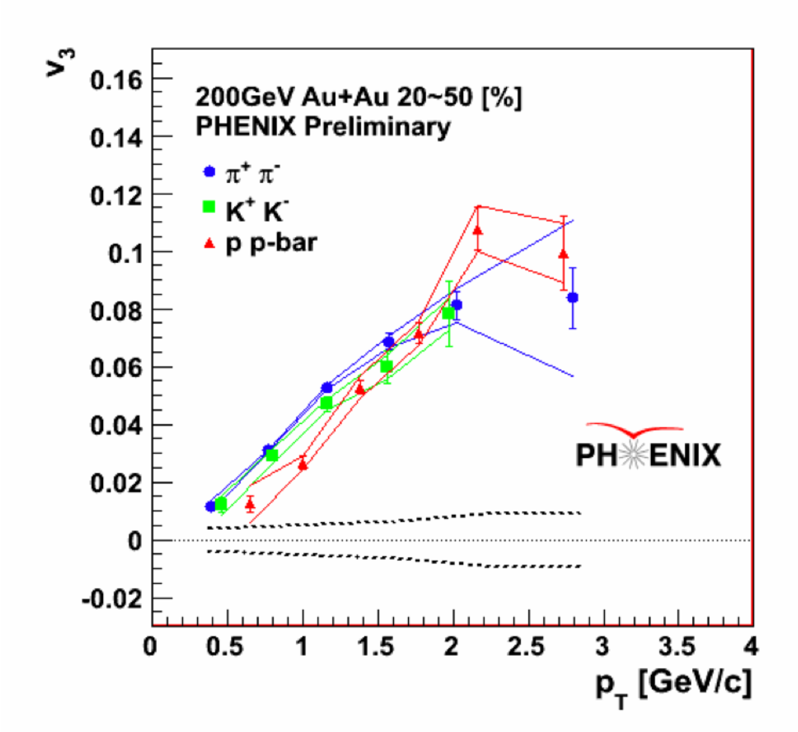

Figure 2: Transverse momentum dependence of v_3 for identified pions, Kaons and (anti-)protons at 200 GeV Au+Au mid-central collisions. Systematic error which is common for all three particle species is represented separately around zero. [2]

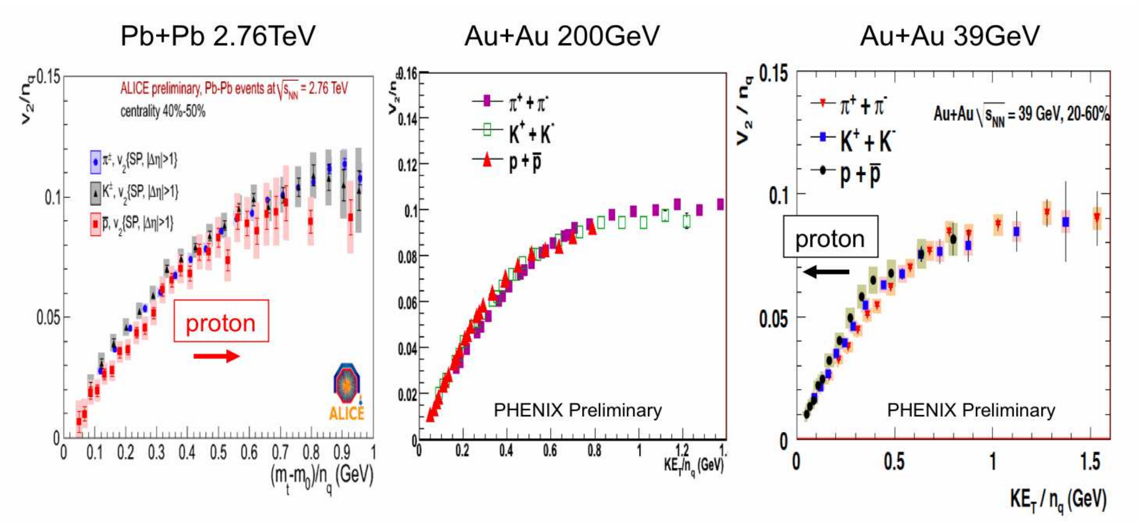

Figure 3: Number of constituent quark n_q scaling of v_2 as a function of $(m_T$ - $mass)$ / n_q for π, K, p and $\overline{p}$ for three different colliding energies at 2.76 TeV [3], 200 GeV and 39 GeV

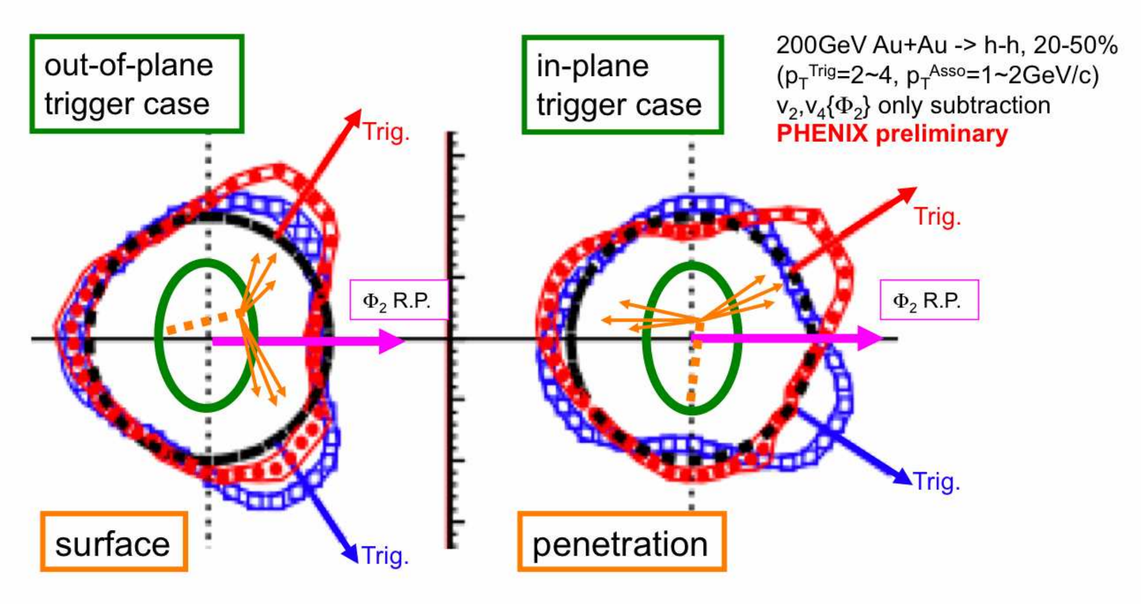

Figure 4: Two particle azimuthal correlation function with respect to the trigger angle relative to the event plane Φ_2 for (out-of-plane trigger: left) and (in-plane trigger: right), represented in polar coordinate by fixing the Φ_2 plane as x-axis at 200 GeV mid-central Au+Au collisions

and 39 GeV. At lower beam energy at RHIC, the proton v_2 is shifted towards lower p_T than the other light hadrons compared to the highest beam energy at RHIC, on the other hand it is shifted towards higher p_T at LHC beam energy than at RHIC beam energies. This is a clear evidence of increased radial expansion with increasing the beam energy from the lower RHIC beam energy up to the LHC beam energy and somewhat accidental quark number scaled v_2 especially at the small (m_T - *mass*) / n_q region for the highest beam energy at RHIC 200 GeV. However the major part of quark number scaling of v_2 should be taken around $2 < p_T < 3$ GeV/c where the v_2 saturates, which can still be considered as a significant discovery of the n_q scaling of v_2 over the wide range of beam energy from 39 GeV holding up to 2.76 TeV.

2. Multi-particle correlation

Two particle azimuthal correlation analysis has been used to test the almond shaped geometry by selecting the trigger particle azimuthal angle relative to the 2nd order event plane Ψ_2. The in-plane or out-of-plane trigger angle selection as well as left or right trigger angle selection with respect to the event plane would give us an additional handle to test the geometrical dependence of correlation function via azimuthal distribution of associate particle for a given trigger particle selection. However one has to keep in mind that the observed effect and dependence can also be given by the dynamical elliptic expansion which is stronger in the direction of the in-plane compared to the out-of-plane, which can not really be distinguished from the effect of geometrical thickness which is thinner in the direction of the in-plane, so that it has less suppression at the in-plane direction. [4, 5, 6]

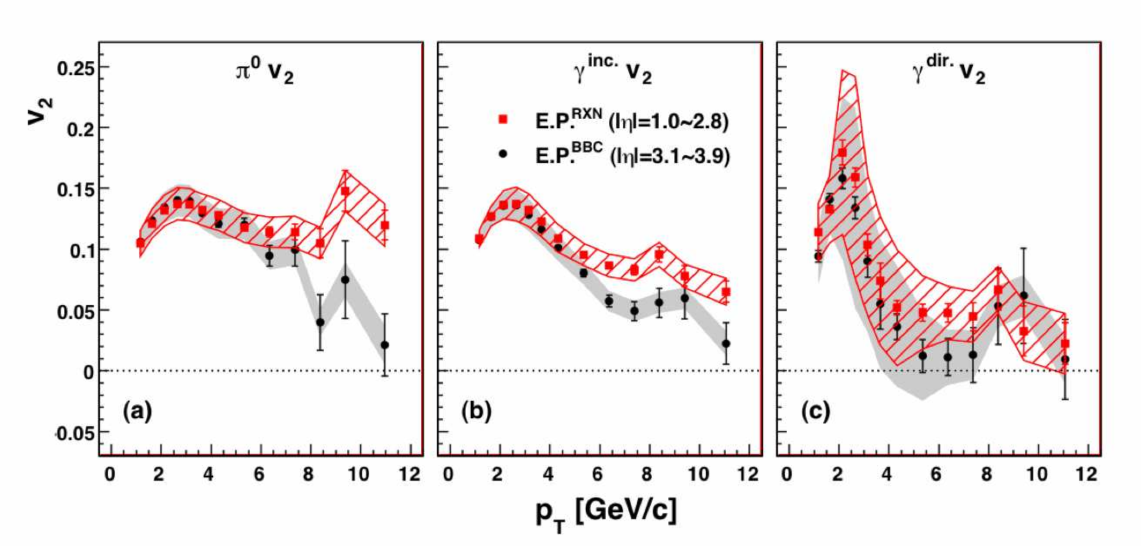

Figure 5: π^0, inclusive photon and direct photon v_2 as a function of transverse momentum at 200 GeV Au+Au minimum bias collisions, with respect to the event planes defined at two different rapidities ($1.0 < |\eta| < 2.8$) and ($3.1 < |\eta| < 3.9$) [7]

The measured correlation functions between trigger particle at $2 < p_T < 4$ GeV/c and associate particle at $1 < p_T < 2$ GeV/c at 200 GeV mid-central Au+Au collisions are shown in Fig.4 for four different trigger angle selections with respect to the Ψ_2, left panel for out-of-plane trigger case and right panel for in-plane trigger case, solid circle (red) or open square (blue) symbols are for the left or right angle selections with respect to the Ψ_2. Surface-like and penetration-like effects can be seen depending on the out-of-plane and in-plane selections as indicated in the small drawings in left and right panels, respectively. Since the v_3 effect is not subtracted here, the observed triangular shape in the correlation function is rather strong, but the left-right asymmetry in the azimuthal distribution of associated particle is clearly visible, where the sign of asymmetry flips between the left and right angle selection, which can also be understood by the geometrical thickness or the dynamical expansion.

3. Direct photon v_2

In order to extract the direct photon v_2, the precise measurement of π^0 and inclusive photon v_2 and the precise knowledge of relative yield of direct photon compared with the total inclusive photon are all essential over the wide p_T range. The observed large fraction of direct photon at high p_T and the significantly non-zero yield of direct photon at low p_T have enabled us to extract the direct photon v_2 with a good precision over the wide range of p_T. Clearly small v_2 of direct photon at high p_T is consistent with non-suppressed prompt photon production dominance, while the comparable v_2 signal of direct photon with other hadrons at low p_T can not be explained by earlier stage of thermal photon in most of hydro-dynamical model estimations, instead, the experimental data may indicate the dominant photon yield at low p_T is from the later stage of QGP after the expansion.

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4. Summary

The recent results on higher order event anisotropy v_n, multi-particle correlation with trigger angle selection relative to the event plane and direct photon elliptic flow v_2 from RHIC-PHENIX experiment are presented. These experimental results and their physics implications are discussed, especially focusing on their relation to the initial and final geometrical image as well as the dynamical expansion.

References

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