Higher Harmonic Flow in Heavy Ion Collisions at Different Beam Energies

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Introduction

The anisotropic flow in heavy ion collisions at ultra-relativistic energies is expected to provide information about the early stages of the evolution of the system. It may also provide information about the reaction dynamics and fluctuations at the initial stage of the collision [1]. The anisotropic flow arises when the spatial anisotropy at the early times after the collision gets converted into momentum anisotropy [2]. The strength of the anisotropic flow is usually written with a Fourier decomposition of the azimuthal distribution of observed particles relative to the reaction plane. The azimuthal distribution of particles can be expressed as,

$$\frac{dN}{d\emptyset} = \frac{a_0}{2} + \sum_{n=1}^{\infty} (a_n \cos(n\emptyset) + b_n \sin(n\emptyset)) \quad (1)$$

Where, $b_n = 0$ due to reflection symmetry with respect to reaction plane. φ is azimuthal angle of emitted particle w.r.t the reaction plane (Ψ_{RP}).

$$a_0 = a_0 \langle \cos(n\phi) \rangle \equiv a_0 v_n \quad (1a)$$

And the equation (1) becomes,

$$\frac{dN}{d\emptyset} = \frac{a_0}{2} \left[1 + 2 \sum_{n=1}^{\infty} v_n \cos(n\emptyset) \right] \quad (2)$$

Where, v_1 is the directed flow, which measures the amount that the reaction is shifted along x direction. The second harmonics in the Fourier series is known as elliptic flow (v_2), which is most dominant term for anisotropic flow. The third term in Fourier series is triangular flow (v_3), which is supposed to be zero from symmetry for a long period. But recently it is observed that initial lumpiness in energy density v_3 has a finite value.

Elliptic and Triangular Flow

The physics behind the flow phenomenon requires an orientation variation of the initial collision geometry, taking into account fluctuations in the nucleon-nucleon collision points from event to event. The complete orientation is defined by the participant eccentricity [2] and in polar coordinate, given by,

$$\epsilon_2 = \frac{\sqrt{< r^2 \cos(2\phi) >^2 + < r^2 \sin(2\phi) >^2}}{\langle r^2 \rangle}$$

The corresponding reaction plane angle is,

$$\psi_2 = \frac{atan2(< r^2 \cos(2\phi) >, < r^2 \sin(2\phi) >) + 2\pi}{2}$$

In case of flow, the position asymmetry is converted into momentum asymmetry through Fourier series. The pressure gradient is along the direction of reaction plane ψ. As the pressure gradient is largest along the minor axis of the ellipse (for elliptic flow), the collective flow is expected to be largest. As the reaction plane changes event by event. So, the definition of elliptic flow changes and measured over event average and respect to the event plane.

$$v_2 = \langle \cos(2(\phi - \psi_2)) \rangle \quad (3)$$

Similarly, the triangularity (ϵ_3), the reaction plane angle (ψ_3) and the triangular flow (v_3) can be defined as follows [3]:

$$\epsilon_3 = \frac{\sqrt{< r^2\cos(3\phi) >^2 + < r^2\sin(3\phi) >^2}}{\langle r^2 \rangle}$$

$$\psi_3 = \frac{atan2(< r^2\cos(3\phi) >, < r^2\sin(3\phi) >) + 2\pi}{3}$$

$$v_3 = \langle \cos(3(\phi - \psi_3)) \rangle \qquad (4)$$

Results & Discussion

The validation of collective flow harmonics like v_2 and v_3 are checked by AMPT model, with its all-possible and different tunings. The string-melting version with initial and final state ration off of AMPT gives excellent agreements with data at RHIC (from 7.7 GeV to 200 GeV) and LHC (2.76 TeV). In this model all the $K^0{}_s$, φ, π^0 decay channel are on after the hadronic cascade. The comparison plot of elliptic flow (v2) values for different centrality bins at 200 GeV Au-Au collisions with data and from the event generator is given in Fig 1. For other energies we have already checked these values to be close together.

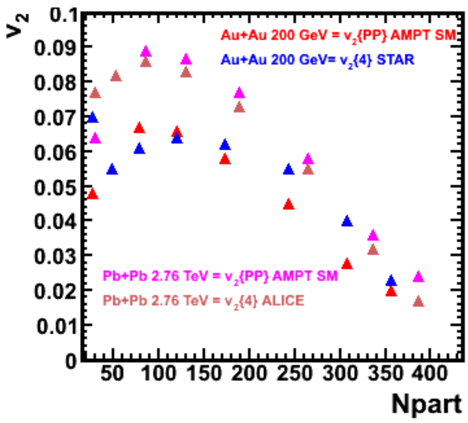

Fig. 1: For $|\eta| < 0.5$ the open circles are the STAR results [3] and the closed circles are the AMPT SM points.

In the same way we plot both v_2 and v_3 in different energies from 7.7 GeV to 2.76 TeV and plot to get an idea about the beam energy dependence of the AMPT model. Results for both v2 and v3 for beam energies from 7.7 GeV to 2.76 TeV are presented in FIgures 2 and 3, respectively, as a function of centrality. The centrality is expressed in terms of number of participating nucleons (Npart).

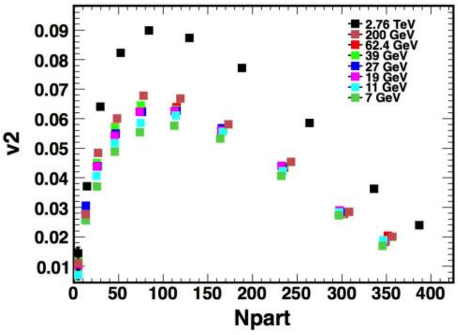

Fig. 2: Elliptic flow (v_2) Vs Npart at different energies ($\sqrt{S_{NN}}$).

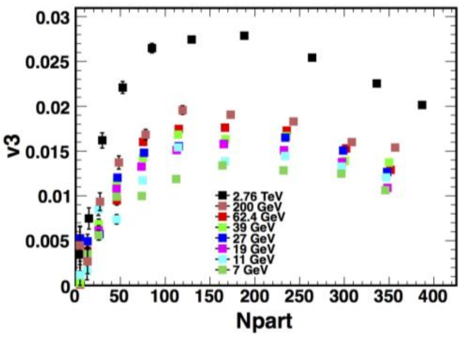

Fig 3: Triangular flow (v_3) Vs Npart at different energies ($\sqrt{S_{NN}}$).

Summary

The v_2 and v_3 values are very close with the experimental results. The values increase with $\sqrt{S_{NN}}$ in both cases and have a non-linear trend with increasing Npart.

References

[1] S. Voloshin and Y. Zhang, Z. Phys. C70, 665 (1996).
[2] B. Alver, G. Roland, Phys. Rev. C81, 054905 (2010).
[3] D. Solanki, P. Sorensen, S. Basu, R. Raniwala and T. K. Nayak, Phys. Lett. B 720, 352 (2013).