Azimuthal correlation in nuclear collisions at FAIR energy

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The upcoming Compressed Baryonic Matter (CBM) experiment [1] to be held at the Facility for Anti-proton Ion Research (FAIR), is dedicated to explore a color deconfined QCD matter at high baryon density and low/moderate temperature. The presence of strong collectivity in the QCD matter is studied through the anisotropic azimuthal distribution of the final state hadrons [2]. However, it would be also interesting to study the correlation among the final state particles in different azimuthal windows. In this report we use the neighbouring bin correlation function

$$C_{m_1,m_2} = \frac{\langle n_{m_1} n_{m_2} \rangle}{\langle n_{m_1} \rangle \langle n_{m_2} \rangle} - 1,$$

where m_1 and m_2 are the positions of the two cells in the phase space concerned, and n_m is the number of particles present in the m^{th} cell [3]. If there is no correlation among the particles then C_{m_1,m_2} should vanish. In our analysis we divided the 2π azimuthal angle space into bins of equal size. If $m_1 = m$ and $m_2 = m+1$, then the quantity $C_{m,m+1}$ is called the neighbouring bin correlation function, which measures the local correlation among the particles at different azimuthal positions. Our understanding of the QCD matter at FAIR energy lacks experimental evidences. As a result we have to rely on models and Monte Carlo simulations. In this report we have employed the AMPT [4] model, both in its default and the string melting (SM) version, to simulate a million Au + Au events at $E_{\mathrm{lab}} = 30A$ GeV. The two versions of the model differ in their hadronization mechanisms. In FIG. 1 we show the centrality dependence of the neighbouring bin correlation for the AMPT (default and SM) model. The correlation patterns are almost identical in both versions of the model. At the highest centrality the correlation pattern is of $\sin^2\phi$ type, then it tends to be flat in the mid-central collisions, and finally becomes like $\cos^2\phi$ for the most peripheral collsions. In the peripheral colliisons, the correlation is strongest at $\phi = 0$, π, and 2π, which is an obvious characteristics of the in-plane flow stemming out from the anisotropic expansion [5].

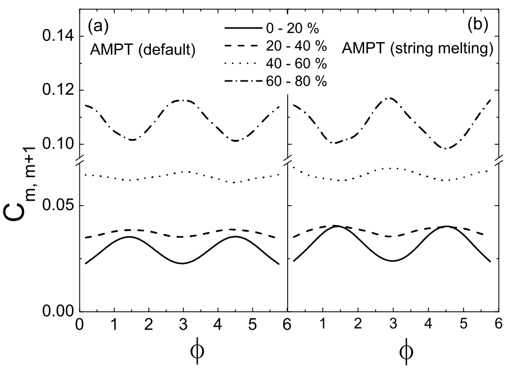

FIG. 1: (a) Centrality dependence of neighbouring bin correlation in the AMPT model for Au + Au collisions at $E_{\mathrm{lab}} = 30A$ GeV.

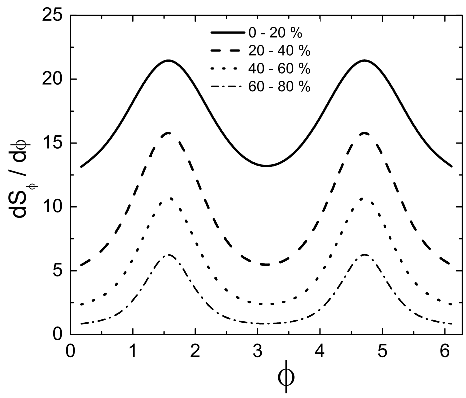

FIG. 2: Azimuthal distribution of the overlap area at different centralities.

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However, in central collisons the neighbouring bin to bin correlation is found to be strongest in the out-of-plane direction, that is at $\phi = \pi/2$ and $3\pi/2$. This kind of out-of-plane flow has also been observed at SIS energies [6], and is understood in terms of the strong initial interaction among the participating nucleons. In FIG. 2 we plot the azimuthal distribution of the participants at different centralities. The number of participating nucleons ($N_{\rm part}$) at a specific azimuthal window is approximated to be preportional to the geometric area (S_ϕ) of the overlapping zone of the colliding nuclei within that window ($d\phi$), and its distribution can be approximated as,

$$\frac{dN_{\rm part}}{d\phi} \propto \frac{dS_\phi}{d\phi} = \frac{a^2b^2}{2(b^2sin^2\phi + a^2cos^2\phi)},$$

where a and b are, respectively the semi-major and semi-minor axis of the overlapping ellipsoid. It is undoubtedly noticed that the azimuthal distribution of the participants follow a $\sin^2\phi$ type of dependence. The amplitude of the distribution increases from most peripheral collisions to 20 - 40 % centrality, and thereafter decreses gradually with further increase in the centrality. The head on collisions are azimuthally symmetric and so the distribution at such centralities should be flat. The same nature has also been noticed (not shown here) in the correlation pattern for the 0 - 5 % most central events. We therefore conclude that anisotropic expansion and initial interaction among the participants are two competing processes that result in the observed pattern of neighbouring bin azimuthal correlation among final state particles. In the peripheral collisions the overlap area is small, the number of participants is less, but the asymmetry between the major and minor axis of the overlap ellipse is large enough that generates a pressure gradient. Thus the anisotropic expansion dominates over the initial interaction - *in-plane flow.* In contrary, in the central events the overlap area is large, asymmetry in the overlap region is much less, but the initial interaction among the participants is very strong to dominate over the nearly negligible anisotropic expansion - *out-of-plane flow.* In

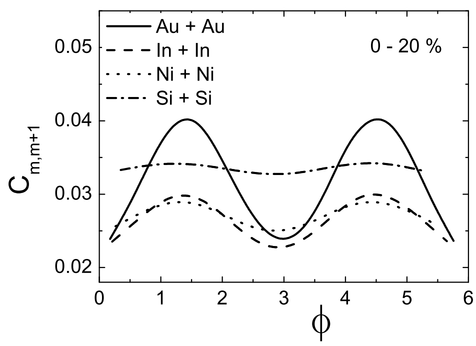

FIG. 3: Neighbouring azimuthal-bin correlation patterns in different systems in the AMPT (SM) model at $E_{\rm lab} = 30A$ GeV

FIG. 3 we present the correlation pattern over a wide range of system size for 0 - 20 % centrality at $E_{\rm lab} = 30A$ GeV. The same $\sin^2\phi$ type dependence is once again observed. It is also seen that the amplitude of correlation is maximum for the largest system i.e. Au + Au, a little less in In + In and Ni + Ni systems, and almost flat in the Si + Si system. It seems that the initial interactions are strongest in Au + Au system and weakest in Si + Si, which justifies our argument related to the out-of-plane flow in central collisions. This is a preliminary investigation and other aspects of the effects of correlation on collective flow at FAIR energies need to be critically examined in future.

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