Collective flow in heavy ion collisions from SIS to SPS energies

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Collective effects, such as the transverse flow of particles produced in ultrarelativistic heavy ion collisions, are very important for the study of the nuclear equation of state (EOS) and for the search of a predicted transition to the quark-gluon plasma (QGP). At present the transverse flow is believed to be one of the most clear signals to detect the creation of the QGP in heavy-ion experiments. This explains the great interest of both experimentalists and theoreticians in the collective flow phenomenon [1].

The distribution of the particles in the azimuthal plane can be presented as [2]

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

where ϕ is the azimuthal angle between the momentum of the particle and the reaction plane. The first two coefficients, v_1 and v_2, colloquially known as directed and elliptic flow, are the amplitudes of the first and second harmonics in the Fourier expansion of the azimuthal distribution, respectively. The directed and elliptic flow of hadrons in heavy-ion collisions is very sensitive to the EOS of the nuclear medium. The formation of small domains of a QGP phase might happen already at the SPS energies or even below. Accompanied by the hadronization this enforces a softening of the EOS due to the dropping pressure. Thus, the disappearance of the directed flow in midrapidity range can be considered as an indication of a new state of matter. This conclusion is supported by hydrodynamic simulations with and without the QGP phase.

Microscopic models, which do not imply the QGP formation, describe the dynamics of nuclear collisions at energies up to $\sqrt{s} \approx 2A$ GeV in terms of reactions between hadrons and their excited states, resonances. At higher energies additional degrees of freedom, strings, should be taken into account to describe correctly the processes of multiparticle production. We employ the quantum molecular dynamics (QMD) model [3] at the SIS energies, while at the AGS and SPS energies the quark-gluon string model (QGSM) [4] is applied. For the simulations at $1A$ GeV, $11.6A$ GeV, and $160A$ GeV, we choose light (S+S) and heavy (Au+Au and Pb+Pb) symmetric systems [5].

The deviations of the nucleon directed flow from the straight line behavior start to develop already at AGS energies (Fig. 1) due to the shadowing effect, which plays a decisive role in the competition between normal flow and antiflow in (semi)peripheral heavy-ion collisions. Hadrons, emitted with small rapidities at the onset of the collision in the antiflow area can propagate freely, while their counterparts will be absorbed by the flying massive spectators. The signal becomes stronger with the rise of the impact parameter and with the rise of the incident energy. In the latter case the spectators are more Lorentz-contracted and more hadrons can be emitted unscreened with small rapidities in the direction of antiflow. This effect should appear in semicentral collisions with $b \leq 3$ fm at RHIC energies, and can mimic the softening of the EOS of hot and dense nuclear matter. However, the disappearance of directed flow due to shadowing is more distinct for light systems, such as S+S or Ca+Ca, while in the QGP case the effect should be more pronounced in heavy systems. Thus, one can distinguish between the two phenomena by the comparison of the directed flow of nucleons in the midrapidity range in light and heavy-ion collisions.

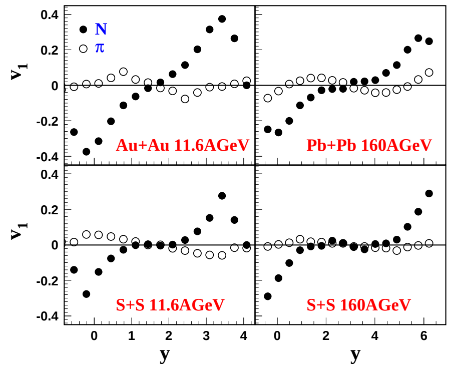

Figure 1: $v_1^{N,\pi}(y)$ in min. bias events at AGS and SPS.

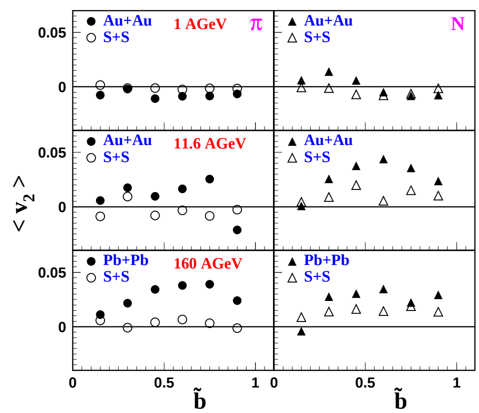

Figure 2: The mean elliptic flow of N's and π's in light and heavy system colliding at SIS, AGS, and SPS energies.

The elliptic flow of nucleons and pions is found to change its orientation from out-of-plane at $1A$ GeV to in-plane at $11.6A$ GeV (Fig. 2). The effect can be explained by stronger Lorentz-contraction of colliding nuclei. Also, at higher colliding energies the contracted spectators leave the reaction zone faster, thus giving space for the growth of elliptic flow in the reaction plane [5].

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