HIJING Model Prediction On Squeeze-Out of Particles in Nucleus-Nucleus Interactions at Super High Energies

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Abstract

Elliptic flow of hard partons ($P > 5$ GeV), squeeze-out of soft partons ($P \leq 5$ GeV) and produced particles are predicted in the framework of the HIJING model. They are caused due to jet quenching and heterogeneity of the interaction region.

Collective flows of produced particles and nuclear fragments in nucleus-nucleus interactions have been studied for the last 15 years (see the latest reviews in [1, 2, 3]). Five years ago, the so-called radial flow of nuclear fragments was discovered in central collisions of gold nuclei at intermediate energies (see [4] – [8]). Recently, it was recognized that the elliptic flow of produced particles changes its sign at energies 5 – 10 GeV/nucleon [9]. It is astonishing that the collective flows are saved in interactions of lead nuclei at the energy of 158 GeV/nucleon [10]. They may be observed at RHIC and LHC.

Now, it is commonly accepted that the hot and compressed nuclear matter is created in a central participant region (a reaction zone) formed by the overlap of projectile and target nuclei during the early stage of the nucleus-nucleus collisions at intermediate energies. This compression leads to the flow in the reaction plane where the majority of spectators are concentrated. The direction perpendicular to the reaction plane is the only direction where the nuclear matter might escape during the whole collision time without being hindered by either the target or projectile nucleus [11]. As a consequence, this leads to a jet-like emission pattern, also referred to as ”out-of-plane squeeze-out” [12]. Squeeze-out was first predicted by a hydrodynamic model [12]. In terms of microscopic models, the collective motions are caused by (re)scattering. Providing that the mean free path of the particles is smaller than the dimensions of the spectators, the (re)scattering leads to exactly the same picture.

It is hard to expect that this scenario will be realized at RHIC. Nevertheless, the direct HIJING model calculations presented in the Fig. 1 show a clear preferential emission of mid-rapidity particles in the direction perpendicular to the reaction plane (at $\varphi \sim 90^\circ$ and $\varphi \sim 270^\circ$). In the
figure, we plot the azimuthal distributions $dN/d\varphi$ of charged and neutral particles with $|\eta| \leq 5.4$ around the beam axis in $Au + Au$-interactions at $\sqrt{s_{NN}} = 200$ GeV. $\varphi$ is the azimuthal angle of a particle relative to the azimuth of the reaction plane. Since HIJING model [13] does not take into account the interactions of produced particles with spectator matter, it is clear that the effect is caused by the jet quenching [14] and heterogeneity of the interaction region.

In the HIJING model [13], energy losses of hard partons (jet quenching) are imitated by production of soft collinear gluons. For example, the partons associated with $i$-th wounded nucleon of nucleus A having radius-vector $\vec{r}_i = (x_i, y_i)$ in the plane perpendicular to the reaction plane (in the impact parameter plane) (see fig. 2) can interact with either the wounded nucleons of A nucleus or with the wounded nucleons of B nucleus. Interaction takes place if the impact parameter in the collision of the parton of $i$-th nucleon having transverse momentum $\vec{P}_T$ with $j$-th nucleons of B nucleus is less than 1 fm.

$$b' = \frac{|[\vec{P}_T \times (\vec{r}_j - \vec{b}/2 - (\vec{r}_i + \vec{b}/2))]|}{|\vec{P}_T|} \leq 1 \ (fm).$$

The energy loss of the parton is determined as

$$\Delta E = C \frac{|[\vec{P}_T \cdot (\vec{r}_j - \vec{b}/2 - (\vec{r}_i + \vec{b}/2))]|}{|\vec{P}_T|},$$

$C = \langle dE/dz \rangle = 2$ GeV/fm is the average energy loss per unit of length. This energy loss is ascribed to a new gluon associated with $j$-th nucleon of B nucleus collinear to the parton.

Since the density of the wounded nucleons in the impact parameter plane at non-zero impact parameter is heterogeneous (it has y-size large than x-size, see Fig. 2), a condition for the flow effects appears. For example, a parton disposed in the center of the region and flown with $\varphi \sim 90^\circ$, or $270^\circ$ to the X-axis will loose in the average more energy than a parton flown with $\varphi \sim 0^\circ$, or $180^\circ$. As it was said above, the energy losses are imitated by soft gluon production. So, the soft gluons will have to be preferential emitted perpendicular to the impact parameter vector. The hard gluons will have to do the same, but to be emitted alonge the impact parameter vector. The calculations presented in the Fig. 3 confirm these expectations.

1In the subroutine QUENCH of the HIJING program the quantities $\pm b/2$ are omitted. There were another mistakes in the subroutine. The corrected version of the HIJING model see at home-page [http://nt3.phys.columbia.edu/people/molnard/OSCAR/](http://nt3.phys.columbia.edu/people/molnard/OSCAR/)
As seen, there must be elliptic flow of the partons with $P_g > 5$ GeV with amplitude $v_2 \approx 0.003 \pm 0.006$, and squeeze-out of the partons with $P_g \leq 5$ GeV with amplitude $v_2 \approx -0.006 \pm -0.019$ in $Au + Au$ interactions at $\sqrt{s_{NN}} = 200$ GeV according to the HIJING model.

Strings are formed in the HIJING model from the partons. Observable hadrons appear at the string fragmentation. Thus, the squeeze-out presented in the calculations of the Fig. 1 is caused by the processes.

According to the Fig. 1, the amplitude of the squeeze-out flow increases with increasing the particle momentum. For example, at $b < 9$ fm $v_2 = -0.001, -0.002, -0.008$ for the particles with $P \leq 2$ GeV, $2 < P \leq 5$ Gev, and $P > 5$ GeV, respectively. The amplitude vanishes in peripheral interactions. The maximum flow can be at intermediate values of the impact parameter (see the bottom row of the Fig. 1).

It should be note, that the accounting of the energy losses in the HIJING program is implemented too simple, and asymmetric with respect to A and B nuclei. In principle, there must be a normal cascade production of the gluons. Though, the heterogeneity of the wounded nucleon distribution in the impact parameter plane, what can be calculated as in the HIJING model, as in the quasi-eikonal approach [15] is a real source of flow effects in nucleus-nucleus interactions. We believe that the flows will be discovered in current RHIC experiments.

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Figure 1: Azimuthal distributions of particles in Au+Au interactions
Figure 2: a) Geometry of a collision in the impact parameter plane. b) Wounded nucleon density in the reaction zone.
Figure 3: Azimuthal distributions of partons in Au+Au interactions. Open and closed points present the calculations with quenching of jet associated only with A, or B nucleus, respectively.