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HYDJET++ model for the ultra-relativistic heavy-ion collisions: new results and developments

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HYDJET++ model combines the description of soft processes with the treatment of hard partons propagating medium. The model is employed for the analysis of PbPb collisions at LHC energies, particularly, the azimuthal anisotropy phenomena, flow, femtoscopy, hard probes. The influence of geometric and dynamical anisotropies on the development of flow harmonics and, simultaneously, on the second- and third-order oscillations of femtoscopy radii were studied. The interplay of soft hydro-like processes and jets is able to describe the violation of the mass hierarchy of meson and baryon elliptic and triangular flows at transverse momentum $p_{\mathrm{T}} > 2$ GeV/c, the fall-off of the anisotropic flow harmonics at intermediate transverse momenta, and the worsening of the number-of-constituent-quark (NCQ) scaling of elliptic/triangular flow at LHC compared to RHIC energies. The cross-talk of elliptic and triangular flows leads to emergence of higher order harmonics in the model and to appearance of ridge structure in dihadron angular correlations in a broad pseudorapidity range. Recently, the model was further extended to describe quantitatively the event-by-event fluctuations of the anisotropic flow. The model calculations agree well with the experimental data.

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1. Introduction. HYDJET++ model

The basic features of the HYDJET++ model are described in [1]. The model combines two components corresponding to soft and hard processes. The soft part of the model has no evolution stage from the initial state until hadronization, but rather represents a thermal hadron production already at the freeze-out hypersurface in accordance with the prescriptions of ideal hydrodynamics adapted from the event generator FAST MC [2]. The hard part of the model is based on PYTHIA [3] and PYQUEN [4] generators, which simulate parton-parton collisions, parton radiative energy loss, and hadronization. The latest available via internet version of HYDJET++ is 2.3 [5].

2. Results

It was demonstrated that the HYDJET++ model can describe the properties of the hadronic state created in AuAu collisions at RHIC at center-of-mass energy per nucleon pair $\sqrt{s_{\rm NN}} = 200$ GeV [1]. We have applied HYDJET++ with tuned input parameters to reproduce the LHC data from PbPb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV. HYDJET++ allows us to reproduce the LHC data on centrality and pseudorapidity dependence of charged particle multiplicity, tranverse momentum $p_{\rm T}$-spectra, nuclear modification factor $R_{\rm AA}$ (up to $p_{\rm T} \sim 100$ GeV/c), $\pi^{\pm}\pi^{\pm}$ correlation radii in central PbPb collisions, and $p_{\rm T}$- and η-dependencies of the elliptic flow coefficient v_2 [6].

The effects of possible non-elliptic shape of the initial overlap of the colliding nuclei are implemented in HYDJET++ by the modulation of the final freeze-out hypersurface with the appropriate fitting triangular coefficient [7]. This modulation is not correlated with the direction of the impact parameter, and two independent “strong” lower azimuthal harmonics, elliptical v_2 and triangular v_3, being obtained as a result. Interference between v_2 and v_3 generates as “overtones” both even and odd higher azimuthal harmonics, v_4, v_5, v_6, etc. This mechanism allows HYDJET++ to reproduce the LHC data on $p_{\rm T}$- and centrality dependencies of the anisotropic flow coefficients v_n (n=2÷4) up to $p_{\rm T} \sim 5$ GeV/c and 40% centrality, and also the basic trends for pentagonal v_5 and hexagonal v_6 flows. Our study [8] favors the idea that basic features of the hexagonal flow v_6 can be understood in terms of the interplay of elliptic and triangular flows.

The analysis of dihadron angular correlations measured in PbPb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV with the HYDJET++ model was done [9]. It was shown that the structure called a “ridge” in dihadron angular correlations could appear just as the interplay of v_2 and v_3.

The triangular flow v_3 of charged inclusive and identified hadrons is studied within the HYDJET++ model in PbPb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV and centralities 0–50% [10]. Mass ordering effect is obtained: the flow of mesons is stronger than that of baryons. The interplay of hard and soft processes leads to breaking of the mass ordering of triangular flows, because jet particles start to dominate spectra of heavy hadrons at larger p_T compared to those of light hadrons. The resonance decays modify the spectra towards the number-of-constituent-quark (NCQ) scaling fulfillment for v_3, whereas jets are the main source of the scaling violation at energies of LHC.

Event-by-event harmonic flow coefficients measured in PbPb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV are interpreted within the HYDJET++ model in [11]. It is shown that the simple modification of the model via introducing the distribution over spatial anisotropy parameters permits HYDJET++

to reproduce both elliptic and triangular flow fluctuations and related to it eccentricity fluctuations of the initial state at the LHC energy.

The phenomenological analysis of charmed meson and charmonium production in PbPb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV was done within the HYDJET++ model [12]. The significant part of D mesons, unlike J/ψ mesons, seems to be in a kinetic equilibrium with hot hadronic matter.

PYQUEN model [4] was applied to simulate medium-modified inclusive jet production at $\sqrt{s_{\rm NN}} = 2.76$ TeV [13]. The contribution from wide-angle radiative energy loss dominates.

We have studied the influence of geometric and dynamical anisotropies on the development of flow harmonics and, simultaneously, on the second- and third-order oscillations of femtoscopy radii [14]. It was shown that the merely geometric anisotropy provides the results which anticorrelate with the experimental observations of either v_2 (or v_3) or second-order (or third-order) oscillations of the femtoscopy radii. Decays of resonances significantly increase the emitting areas but do not change the phases of the radii oscillations. In contrast to the spatial deformations, the dynamical anisotropy alone provides the correct qualitative description of the flow and the femtoscopy observables simultaneously. However, one needs both types of the anisotropy to match quantitatively the experimental data.

The various mechanisms of $B^{\pm}$ meson suppression have been analyzed recently with HYDJET++ model [15]. It has been shown that the contributions of nuclear shadowing and jet quenching into $B^{\pm}$ meson suppression are comparable at $p_{\rm T} \sim 10$ GeV/c. Then the relative contribution of jet quenching gets stronger with increasing $p_{\rm T}$, and totally dominates at $p_{\rm T} > 30$ GeV/c. Since $B^{\pm}$ meson suppression factor $R_{\rm AA}$ due to jet quenching (nuclear shadowing) decreases (increases) with $p_{\rm T}$, the interplay between the two effects results in a weak (roughly constant) $p_{\rm T}$-dependence of $R_{\rm AA}$. This observation is consistent with the trend seen in the CMS data [16].

3. Conclusions

The combination of the soft and hard components in HYDJET++ model allows us to describe a number of physical observables at ultra-relativistic heavy-ion collisions. Further modificaions of the model can open new horizons for understanding of the hot matter and the quark-gluon plasma.

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