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The charge balance function with HYDJET++ model in heavy ion collisions at LHC*

A. Chernyshov,[†] G. K. Eyyubova,[‡,¶] V. L. Korotkikh,[‡] I. P. Lokhtin,[‡]
L. V. Malinina,[‡] S. V. Petrushanko,[‡] A. M. Snigirev[‡] and E. E. Zabrodin[‡,§]

[†]*Faculty of Physics, Lomonosov Moscow State University, Moscow 119991, Russia*

[‡]*Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow 119991, Russia*

[§]*Department of Physics, University of Oslo, PB 1048 Blindern, N-0316 Oslo, Norway*

[¶]*eiiubova@lav01.sinp.msu.ru*

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The data on charge balance function in Pb+Pb collisions at center-of-mass energy 2.76 TeV per nucleon pair are analyzed with the HYDJET++ model. For central collisions, the width of the charge balance function at low transverse momentum intervals is larger in the model than in data. An approach, which takes into account the event-by-event charge conservation, has been implemented into the thermal part of the model at the stage of hadron production. This approach implies two particle charge correlations with a certain length and allows to reproduce experimental widths.

Keywords: Relativistic heavy-ion collisions; charge correlations; balance function.

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1. Introduction

There are number of signals which are used as powerful tools to probe the properties of the system created in high energy collisions. Correlation phenomena play an important role in these studies. Among them, correlations of electric charges provide valuable insight into the charge creation mechanism. Due to conservation of quantum numbers, a negative charge is produced at approximately the same spacetime

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[¶]Corresponding author.

for each positive charge. In experiment, two-particle charge-dependent correlations are studied with the balance function (BF):

$$B(\Delta\eta) = \frac{1}{2}\left[\frac{\langle N_{+-}(\Delta\eta)\rangle - \langle N_{++}(\Delta\eta)\rangle}{\langle N_{+}\rangle} + \frac{\langle N_{-+}(\Delta\eta)\rangle - \langle N_{--}(\Delta\eta)\rangle}{\langle N_{-}\rangle}\right], \tag{1}$$

where $\Delta\eta$ is a relative pseudorapidity of two particles, $\Delta\eta = \eta_1 - \eta_2$. $\langle N_{ab}\rangle$ denotes the average number of pairs per trigger particle a over events with corresponding charge combination $ab\,(a, b = +, -)$, while $\langle N_a\rangle$ denotes the average number of single particles over events with a corresponding charge. Each term is corrected for acceptance limitation, reflecting the fact that number of pairs in limited η region has maximum at $\Delta\eta = 0$. The BF is sensitive probe of the production mechanism of balancing charges and their transport, including quantum statistics,[1] radial flow,[2] the Coulomb effect and others.

The width of the balance function measured for particles with low transverse momenta by the ALICE Collaboration[3] increases for more peripheral collisions. This centrality dependence is not reproduced by many competing generators as HIJING[4] and AMPT.[5] It is also a challenge for hydrodynamics-motivated statistical model approach, like HYDJET++ model,[6] since soft particles are produced in grand canonical ensemble assumption, where the charge conservation takes place in mean only. Nevertheless, the reasonable modification of the current version of the HYDJET++ model allows us to reproduce effectively the experimentally observed centrality dependence of the balance function.

2. HYDJET++ Model

The HYDJET++ model[6] simulates relativistic heavy-ion collisions as a superposition of two components: the soft, hydro-type state and the hard state, thus allowing to study the soft and hard physics simultaneously. The soft component is based on the adapted event generator FAST MC.[7,8] It uses hadronic degrees of freedom and starts at freeze-out. There are chemical and thermal freeze-out hypersurfaces prescribed by the parametrization of relativistic hydrodynamics with preset freeze-out conditions. Particle multiplicities are calculated using the effective thermal volume approach and are proportional to the number of participating nucleons for a given impact parameter in a A+A collision. To simulate the elliptic and triangular flow effects, the hydro-inspired parametrization for the momentum and spatial anisotropy of soft hadron emission source is implemented.[6]

The hard component employs PYTHIA[9] for simulations of hard parton-parton scattering processes and parton hadronization. The parton propagation through the expanding medium is modeled and their energy losses due to parton rescattering and gluon radiation are taken into account within PYQUEN model.[10] Partons produced in (semi)hard processes with the momentum transfer lower than $p_T^{\min}$ are considered as soft and are not included into hard component multiplicity. The $p_T^{\min}$ is the input parameter of the model and it regulates the contribution of soft and hard components to the total multiplicity. For the considered collision energy, this parameter is $p_T^{\min} = 8.2\,\text{GeV}/c$.

The large number of physical observables measured in heavy-ion collisions during RHIC and LHC operation can be successfully described in the framework of the HYDJET++ model. For instance, $\pi^{\pm}\pi^{\pm}$ correlation radii,[11] centrality and momentum dependence of second and higher-order harmonic coefficients,[12] flow fluctuations,[13] jet quenching effects,[14,15] and angular dihadron correlations.[16]

3. Description of the BF in the Model

In the HYDJET++ model, there are charge correlations in hard part due to exact charge conservation during parton-parton scattering and hadronization process and in soft part due to resonance decay. Figure 1 shows the charge balance function versus $\Delta\eta$ in the HYDJET++ model for midcentral Pb+Pb collisions (with centrality 20–30%) at $\sqrt{s_{\rm NN}} = 2.76\,\text{TeV}$ separately for each component, soft and hard, as well as for direct soft hadrons only. The resulting total value is also displayed. The BF is calculated for particles with transverse momenta $0.3 < p_T < 1.5\,\text{GeV}/c$. As one can see, there are no charge correlations for direct soft hadrons in each event, since they are produced in the statistical model approach where charge is conserved in mean only. In a given momentum region the resulting total balance function is mainly dominated by the balance function of the soft component, since the majority of particles is soft. The balance function for the soft component has been already studied[17] in the framework of the FASTMC event generator[7,8] for RHIC energies.

Figure 2 shows the width of the BF in HYDJET++ model in comparison with the experimental data,[3,18] measured in three transverse momentum intervals for the trigger and the associated particle.

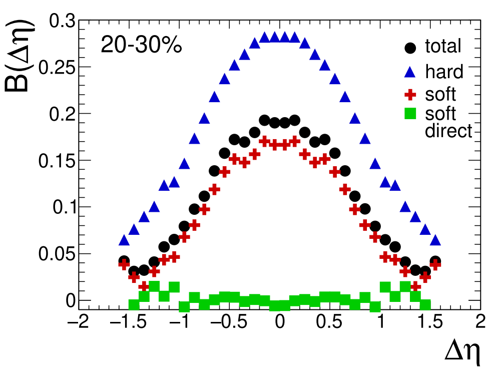

Fig. 1. Balance function versus $\Delta\eta$ for midcentral Pb+Pb collisions (20–30%) at $\sqrt{s_{\rm NN}} = 2.76$ TeV in HYDJET++ for each component, soft (crosses), hard (triangles), also for primordial soft hadrons (squares), together with the resulting total value (circles).

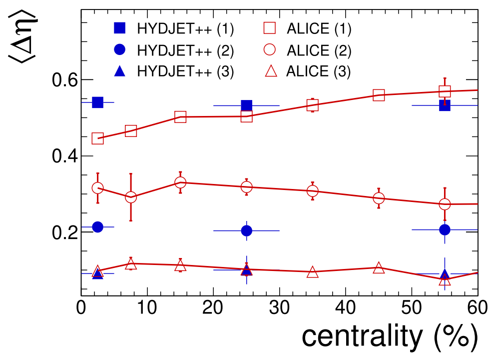

Fig. 2. Centrality dependence of the balance function widths $\langle\Delta\eta\rangle$ in Pb+Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV. The model calculations with default versions of HYDJET++ are compared to the ALICE data [3,18] for three transverse momentum intervals labeled in the text as (1), (2) and (3). Lines are drawn to guide the eye.

(1) $0.3 < p_{T\rm trig,accos} < 1.5$ GeV$/c$,
(2) $2 < p_{T,\rm assoc} < 3 < p_{T,\rm trig} < 4$ GeV$/c$
(3) $3 < p_{T,\rm assoc} < 8 < p_{T,\rm trig} < 15$ GeV$/c$

The width of the balance function distribution is defined as

$$\langle\Delta\eta\rangle = \sum_i^k [B(\Delta\eta_i)\Delta\eta_i] / \sum_i^k B(\Delta\eta_i), \tag{2}$$

where $B(\Delta\eta_i)$ is the balance function value for each bin $\Delta\eta_i$, k is running over all bins in the entire intervals of $\Delta\eta$ for low-transverse momentum region and in the narrow interval within $3\sigma_{\rm Gauss}$ for high-transverse momentum (2) and (3), in accordance with experimental calculations. The centrality dependence of the BF widths for low-transverse momentum region is observed in experiment, which is not reproduced by HYDJET++ model with default parameters. For higher transverse momentum regions the balance function is getting narrower, moreover, the centrality dependence of the widths practically vanishes. With increasing transverse momentum, namely for p_T of the trigger and the associated particles corresponding to the case (3) the default model results describe the experimental data much better since these transverse momentum intervals are dominated by hard component of the model, in which the exact charge conservation takes place at each stage. The decrease of the width with increasing transverse momentum can be understood in the following way: particles with higher transverse momenta are created closer to the beginning of parton cascade, where the charge correlations are stronger.

In order to describe BF widths in soft sector the modification of the charge creation mechanisms of soft direct hadrons is implemented into the HYDJET++ model. It takes into account the charge conservation explicitly in each event. Namely, the pair production (particle–antiparticle) is introduced for charged direct

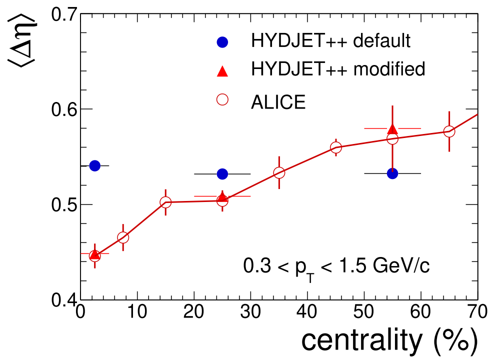

Fig. 3. Centrality dependence of the balance function widths in Pb+Pb collisions at $\sqrt{s_{\rm NN}} = 2.76\,\text{TeV}$ with default (full circles) and modified version of HYDJET++ (triangles) in which the exact charge conservation is taken into account. Open circles indicate the experimental data. Lines are drawn to guide the eye.

hadrons. The pseudorapidities and the azimuthal angles of the partner are distributed around the pseudorapidities and the azimuthal angles of corresponding original particles, providing the charge conservation locally. The Gaussian distribution with a certain σ_η, σ_φ depending on centrality is used. These parameters are tuned to reproduce the experimental data. Thus, some "characteristic length of charge correlation" is introduced. Figure 3 shows a centrality dependence of the balance functions width $\langle\Delta\eta\rangle$ for HYDJET++ model with the implemented approach in comparison with experimental data by ALICE.[3] The model reproduces the experimental centrality dependence of widths rather well with the σ_η increasing for more peripheral collisions. It can be understood in the following way: the number of the characteristic elementary volumes, in which the charge is explicitly conserved, decreases since the area of the nuclear overlap region becomes smaller.

4. Conclusions

We performed a phenomenological analysis of charge balance function in Pb+Pb collisions at $\sqrt{s_{\rm NN}} = 2.76\,\text{TeV}$ within HYDJET++ model, which has two components: a hydrodynamics-motivated thermal part with resonances and a hard pQCD part. At relatively low transverse momentum interval, the experimental balance function is much narrow at central collisions, indicating that there are other sources for charge correlations besides resonance decays. The centrality dependence of the experimental balance function widths is also not reproduced by the model. With increasing transverse momentum the default model results describe experimental data much better. In these transverse momentum intervals, the contribution from the hard component of the model grows and the transition to the single source of charge correlations occurs, namely, the charge correlations in jets for which the exact charge conservation takes place at each stage.

The modification of soft components is introduced which includes the charge conservation explicitly in a statistical approach. This procedure has been implemented for the first time in Monte Carlo event generators of a such kind. The approach allows to reproduce experimental widths of the balance function with charge correlations length depending on centrality.

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ORCID

G. K. Eyyubova https://orcid.org/0000-0002-2453-343X
V. L. Korotkikh https://orcid.org/0000-0001-6270-2604
I. P. Lokhtin https://orcid.org/0000-0002-4457-8678
L. V. Malinina https://orcid.org/0000-0003-1723-4121
S. V. Petrushanko https://orcid.org/0000-0003-0210-9061
A. M. Snigirev https://orcid.org/0000-0003-2952-6156
E. E. Zabrodin https://orcid.org/0000-0003-3093-6769

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