Plans for the Analysis of Charge Balance Functions in the MPD experiment

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27 January 2022

Motivation for the Analysis

The law of charge conservation establishes strong correlations between charged particles and their momenta. To study these correlations, among other observables, the **Charge Balance Function** is proposed. **The function is sensitive to the time the correlation was established and thus provides information on hadronization time point.** In hydrodynamic approach the CBF width is proportional to the inverse strength of the collective flow in the system allowing to estimate collective effects as well. **All that raises a question whether the CBF is dependent on the phase transition type providing great opportunity for the Monte-Carlo study within the MPD.**

Charge Balance Functions

Charge is locally conserved in heavy-ion collisions. Correlations between balancing charges (electric charge, baryon number, and strangeness) can be studied by measuring charge balance functions. They represent the probability, given the observation of a charge q, of seeing its balancing charge $-q$ at some relative rapidity Δy and relative azimuthal angle $\Delta\varphi$.

One of the definitions of the charge balance function [Phys.Rev.C 104, 014906 (2021)] is given bellow

$$B(\Delta y, \Delta\varphi) = \frac{1}{2}\int dy_1\, d\varphi_1\, dy_2\, d\varphi_2\, \delta(y_1 - y_2 - \Delta y)\, \delta(\varphi_1 - \varphi_2 - \Delta\varphi) \left\{ \frac{P_{pn} - P_{pp}}{P_p} + \frac{P_{np} - P_{nn}}{P_n} \right\},$$

$$\frac{P_{pn}}{P_p} = \frac{P_{pn}(y_1, \varphi_1; y_2, \varphi_2)}{P_p(y_1, \varphi_1)}$$

represents the conditional probability density for observing a negative charge at (y_2, φ_2), given a positive charge at (y_1, φ_1) is observed. Other members are defined similarly.

Charge balance function can be characterized by its width defined as follows

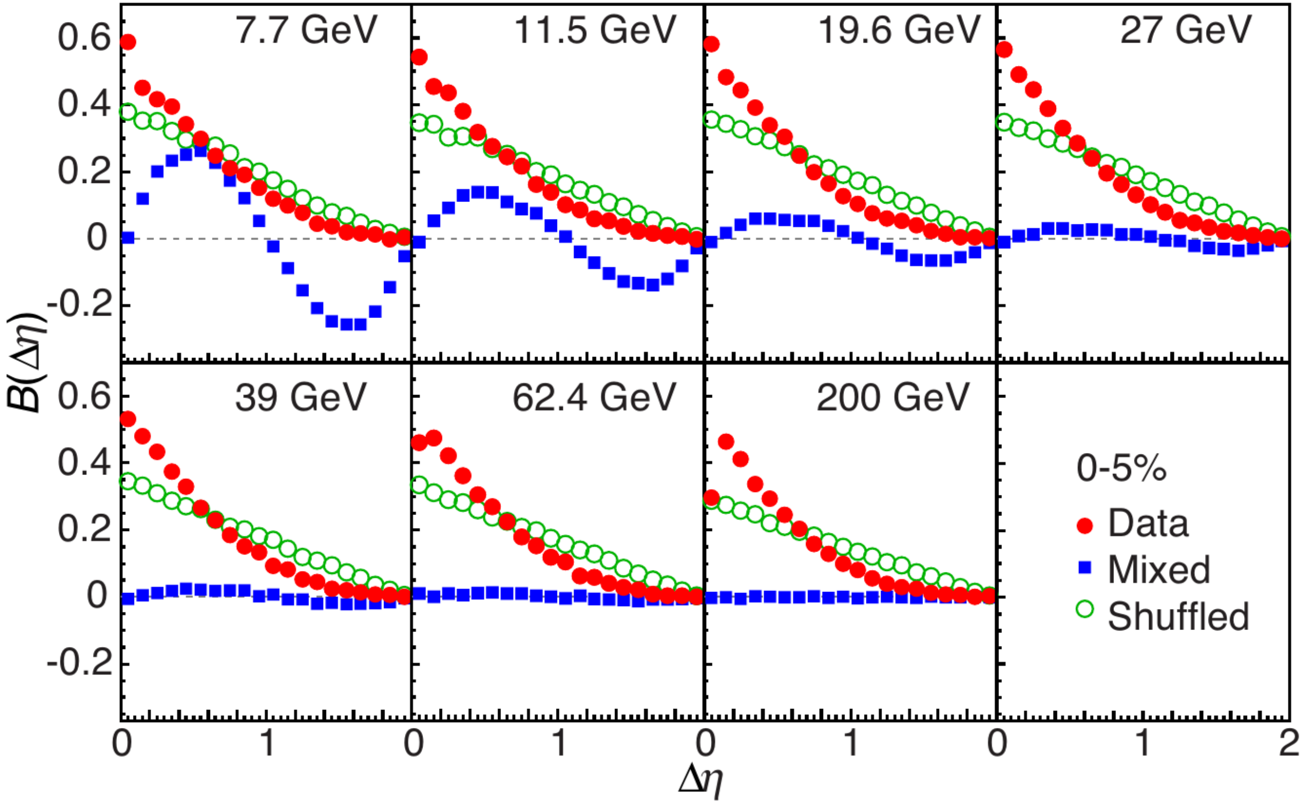
$$\langle \Delta\eta \rangle = \frac{\sum_i B_i \Delta\eta_i}{\sum_i B_i},$$

where B_i is a value of the balance function in the i-th bin. Similar definition is given for the $\langle\Delta\varphi\rangle$ width. They represent average charge separation in rapidity and azimuthal angle respectively.

Charge balance function widths provide information on charge separation time. For example, long range correlations (wide distribution) display early charge separation, and vice versa late charge separation leads to a narrower distribution, i.e. short range correlations.

Experimental Status

Charge balance functions for heavy-ion collisions were studied experimentally at the SPS [Phys.Rev.C 71 (2005) 034903], RHIC [Phys.Rev.C 82 (2010) 024905], and LHC [Phys.Lett.B 723 (2013) 267].

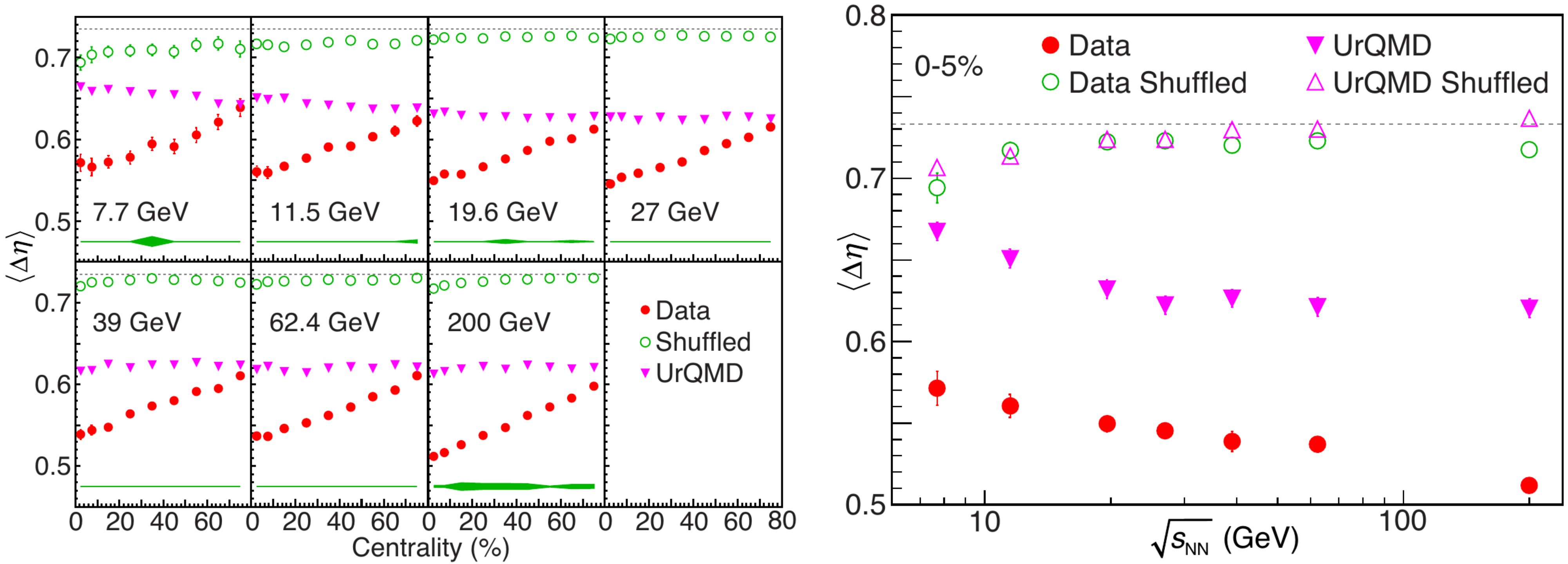


The balance function in terms of $\Delta\eta$ for all charged particles with $0.2 < p_T < 2$ GeV/c from central Au+Au collisions (0-5%) for $\sqrt{s_{NN}}$ from 7.7 to 200 GeV. Mixed CFBs are constructed from mixed events, shuffled CBFs are constructed from tracks with shuffled charges within single event [Phys.Rev.C 94 (2016) 2, 024909].

Experimental Status

There are two interesting experimental observations:

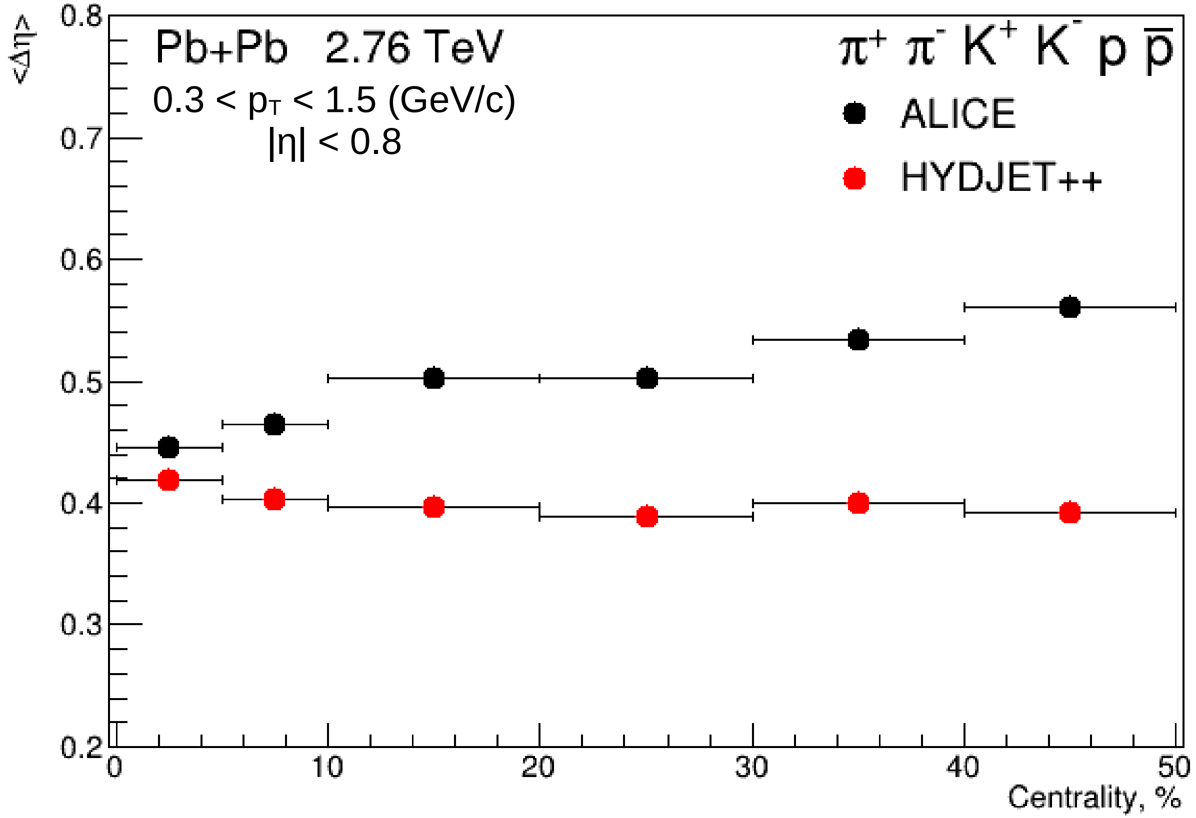
✔ **The balance function width increases with the increase of the centrality of heavy-ion collisions;**
✔ **The width decreases while the energy of the beam increases.**



Energy dependence of the balance function widths compared with the widths of the balance functions calculated using events with shuffled charges (on the left). Balance function widths for the most central events (0-5%) compared with balance function widths calculated using events with shuffled charges (on the right) [Phys.Rev.C 94 (2016) 2, 024909].

Some Previous Results on CBF MC Simulations

Previously, CBFs were studied with HYDJET++ model. MC results were compared with available ALICE data. HYDJET++ CBF width displayed no dependence on centrality motivating to try other models as well.



HYDJET++ is a Monte-Carlo event generator written in C++ and Fortran for study of various hadron characteristics in relativistic heavy-ion collisions [Comp.Phys.Com. 180 (2009) 779].

The final state of the reaction in HYDJET++ is presented as a superposition of two independent components:

- **thermal hadronic state (soft);**
- **multipartonic jet state (hard).**

Comparison of centrality dependence of the balance function widths obtained with HYDJET++ MC model and ALICE experiment. Black dots represent ALICE data [Phys.Lett.B 723 (2013) 267], red dots represent HYDJET++ simulations.

Plans for MC Study of CBFs in Heavy-ion Collisions

1) CBF construction code will be developed within the MpdRoot (including $<\Delta\eta>$ and $<\Delta\varphi>$ CBF widths calculation). **Integration into the MpdRoot «Femto» package is possible.**

2) The developed code will be utilized to compute CBFs of Au+Au events on several samples:

- UrQMD;
- vHLLE (1PT);
- vHLLE (XPT).

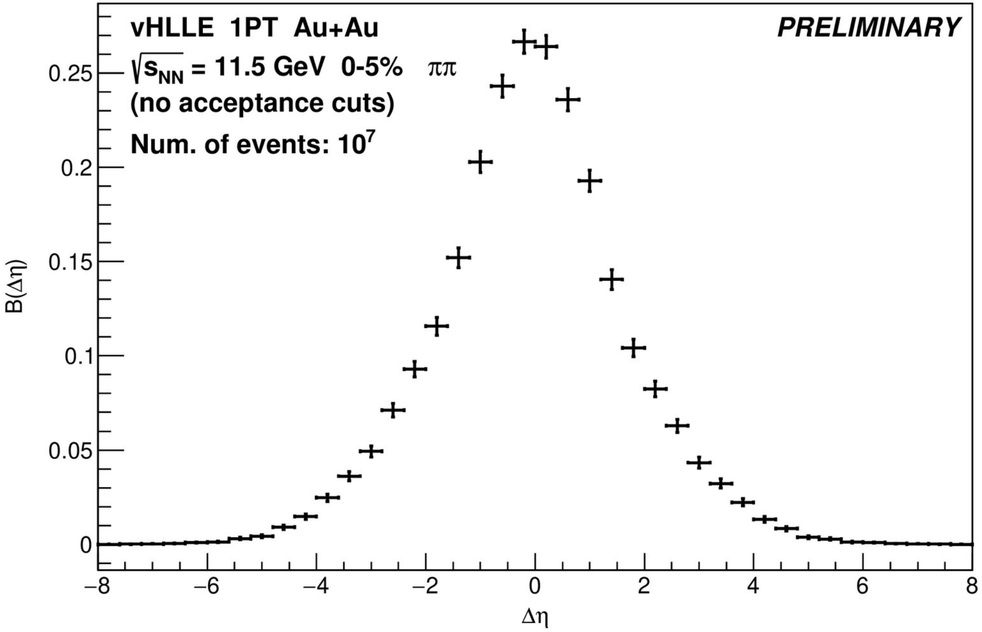
3) **Analysis of the obtained CBFs:** ascertainment of the CBF widths dependence on the beam energy and centrality for all the options above and comparison of the MC results with available STAR data.

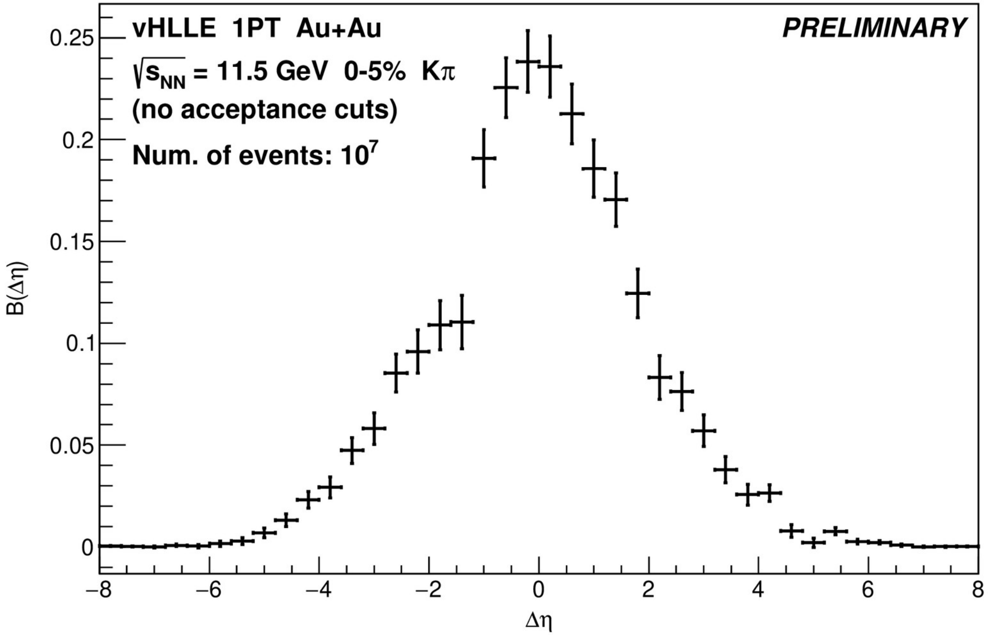
Brief vHLLE Model Description

vHLLE is a (3+1) dimensional relativistic viscous hydrodynamic code based on the Godunov method and the relativistic HLLE (Harten, Lax, van Leer, Einfeldt) approximation for the solution of the Riemann problem for its inviscid part [Comput.Phys.Commun. 185 (2014) 3016-3027]. The code is capable of both treating shock wave configurations accurately and solving the equations of relativistic viscous hydrodynamics in the Israel-Stewart framework with the help of the ideal viscous splitting method. **The primary application of the code is the simulations of the hydrodynamic expansion of QCD matter created in relativistic heavy-ion collisions.**

Preliminary Results on CBF MC Simulations

Recently, preliminary results on CBF MC simulations were obtained with vHLLE (1PT) dataset (Au+Au $\sqrt{s_{NN}}$ = 11.5 GeV 0-5%) for *ππ* and *Kπ* pairs. Both other specie specific and specie integrated CBFs are planned to be computed in the future.





Preliminary MC generator level CBFs for *ππ* and *Kπ* pairs. CBFs are presented as functions of relative pseudorapidity $\Delta\eta = \eta_1 - \eta_2$ while STAR data is presented in terms of an absolute value of the $\Delta\eta$. No acceptance cuts were applied yet to exclude CBF acceptance dependence in preliminary computations.

Summary

- ✔ **The first plans for the analysis of charge balance functions within MPD PWG3 «Femto» group were established.**

- ✔ **Development of the CBF construction code within MpdRoot is underway.**

- ✔ **Sensitivity of the CBF to the quark-hadron phase transition details to be investigated.**

Thanks for Your Attention!