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

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HYDJET++ event generator
(HYDrodynamics + JETs)

I.Lokhtin, A.Snigirev, Eur. Phys. J. C 46 2011 (2006)
I.Lokhtin, L.Malinina, S.Petrushanko, A.Snigirev, I.Arsene, K.Tywoniuk, Comp.Phys.Comm. 180 779 (2009)

http://lokhtin.web.cern.ch/lokhtin/hydjet++/

HYDJET++ is designed to simulate symmetric A+A collisions at high energy (RHIC, LHC), can be extended to intermediate energy (NICA, FAIR).

Collision event is represented as a mixture of two part:

- hadron production at thermalised stage based on hydrodynamical ideas
- hard parton-parton interactions (pQCD calculations), parton energy loss simulation with futher hadronisation

The model calculations on soft and hard probes of quark-gluon plasma (including collective flow, different kinds of particle correlations, jets, D and B mesons, etc.) agree well with the experimental data.

HYDJET++ event generator
(HYDrodynamics + JETs)

Hard “jet” component:

PYTHIA w/o hadronization

↓

PYQUEN (PYthia QUENched)

http://lokhtin.web.cern.ch/lokhtin/pyquen/

I.P.Lokhtin, A.M.Snigirev, Eur. Phys. J. 45 (2006) 211

Parton rescattering & energy loss (collisional, radiative) + emitted gluons

↓

Parton hadronization and final particle formation
PYTHIA6.4 with hadronization

Soft hydro-type component:

is based on the adapted **FAST MC** model:

N.S.Amelin, R.Lednisky, T.A.Pocheptsov, I.P.Lokhtin, L.V.Malinina, A.M.Snigirev, Yu.A.Karpenko, Yu.M.Sinyukov, Phys. Rev. C 74 (2006) 064901, N.S.Amelin, R.Lednisky, I.P.Lokhtin, L.V.Malinina, A.M.Snigirev, Yu.A.Karpenko, Yu.M.Sinyukov, I.C.Arsene, L.Bravina, Phys. Rev. C 77 (2008) 014903

- multiplicities are determined assuming thermal equilibrium;
- hadrons are produced on the hypersurface represented by a parameterization of relativistic hydrodynamics with given freeze-out conditions;
- decays of hadronic resonances are taken into account (360 particles from SHARE data table) with “home-made" decayer;
- Set of parameters is tuned in order to describe experimental data
- Written within ROOT framework (C++)

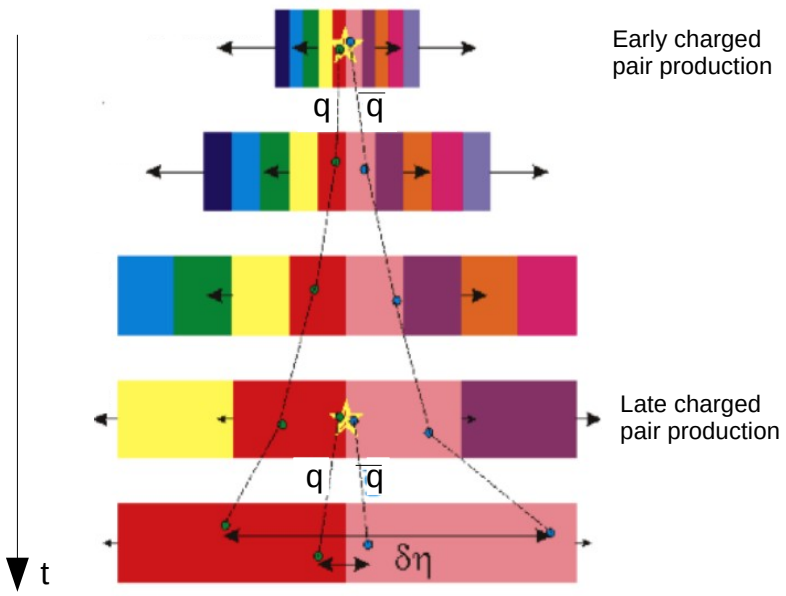
Contributions of two components are regulated by a parameter: minimal p_T of hard parton-parton scattering.

Charge Balance Function

Two-particle correlations of charged particles, with (η_1, φ_1) and (η_2, φ_2), $\Delta\eta = \eta_1 - \eta_2$; $\Delta\varphi = \varphi_1 - \varphi_2$

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

$\langle N_{+-}(\Delta\eta)\rangle$ is the average number of opposite-charge pairs, separated with $\Delta\eta$. The correlations are corrected for background (pairs from mixed events).



Charge Balance function probes properties and evolution of created system:

- Gives insight into charge creation mechanism
- Sensitive to collective motion (radial flow)

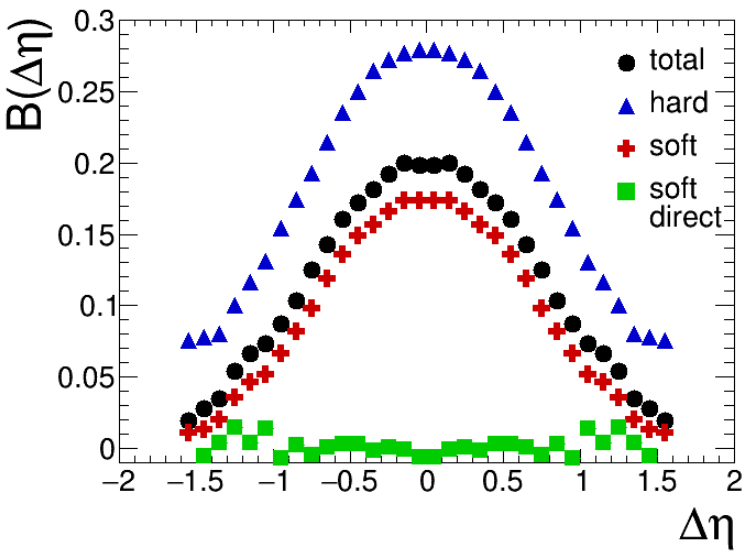
It is suggested, that the width of the BF is smaller in the case if particles creation at the late stage of system evolution and is affected by radial flow.

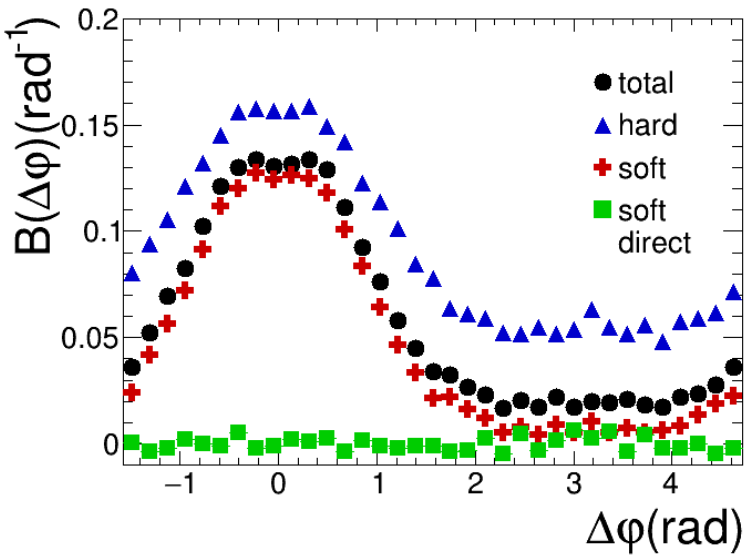
Charge Balance Function

Sources of charge 2-particle correlations in HYDJET++ :

- Hard component (pQCD) accounts for charge local conservation →charge 2-particle correlation in final state
- Soft component implements resonance decay → charge 2-particle correlation for secondary hadrons
- Soft component: charge conservation is only fulfilled in average (grand canonical approach) → no charge correlations for direct particle in a single event

HYDJET++ Pb+Pb at $\sqrt{s_{NN}}$ =2.76 TeV, 0-5%, 0.3<p_T<1.5 GeV



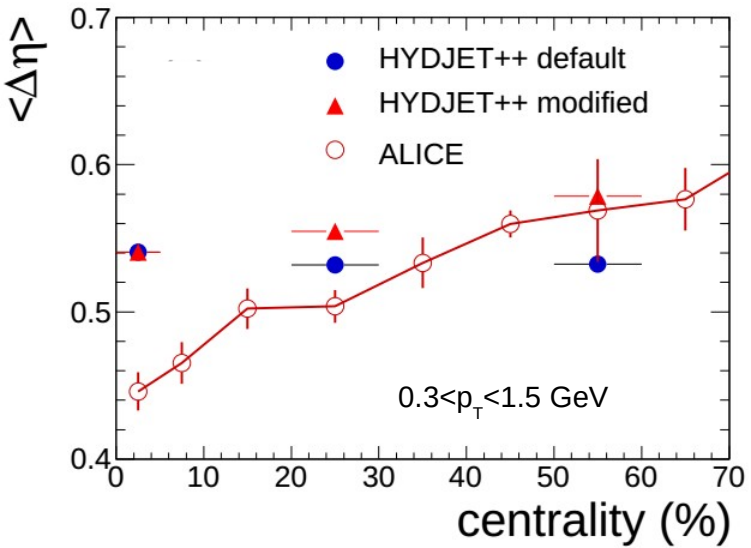


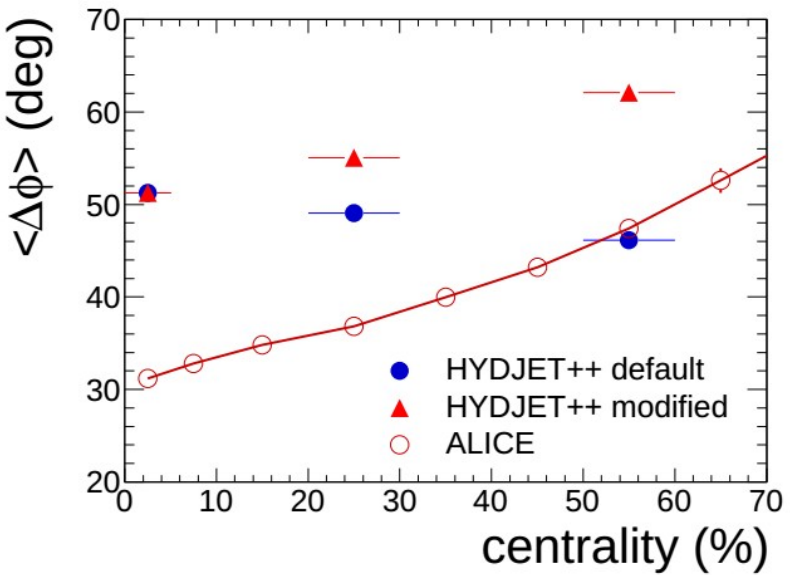
The width of BF for hard component is larger at given p_T range.

Charge Balance Function width

Balance function width: $\langle \Delta\eta \rangle = \sum_{i=1}^{k} [B(\Delta\eta_i) \cdot \Delta\eta_i] / \sum_{i=1}^{k} B(\Delta\eta_i)$

(ALICE Collaboration), Phys. Lett. B 723, 267 (2013).



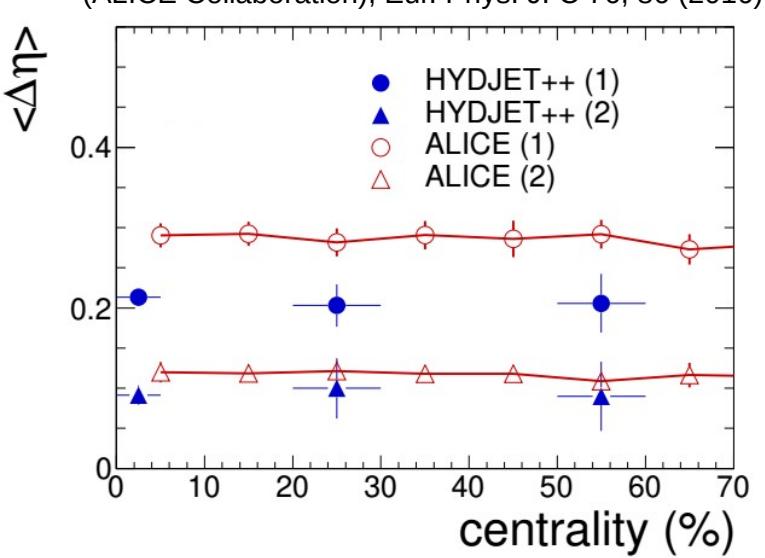


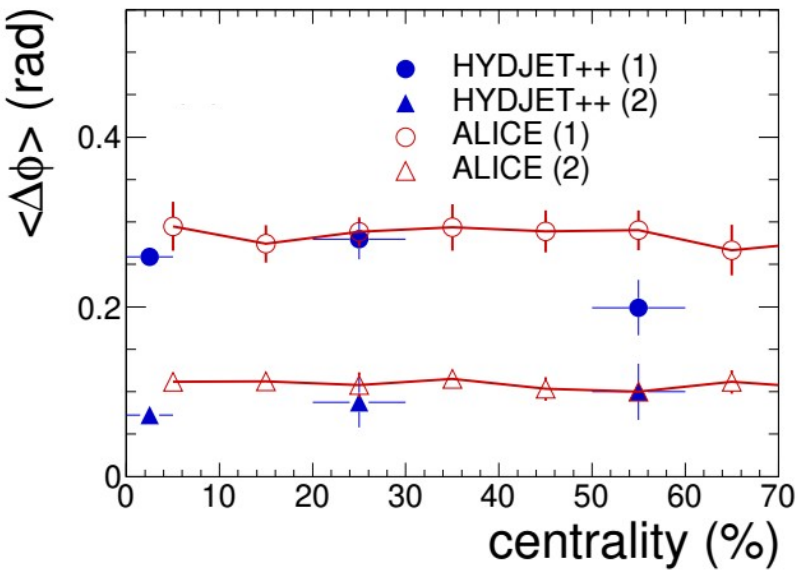
- Default HYDJET++ model doesn't describe the experimental centrality dependence. The width of BF due to final state charge correlations (resonance decay) and parton fragmentation in hard processes is not enough to reproduce data for central collisions.

- One may consider the additional increasing of hard part for peripheral collisions to reproduce experimental trend.

Charge Balance Function at high p_T

(ALICE Collaboration), Eur. Phys. J. C 76, 86 (2016).





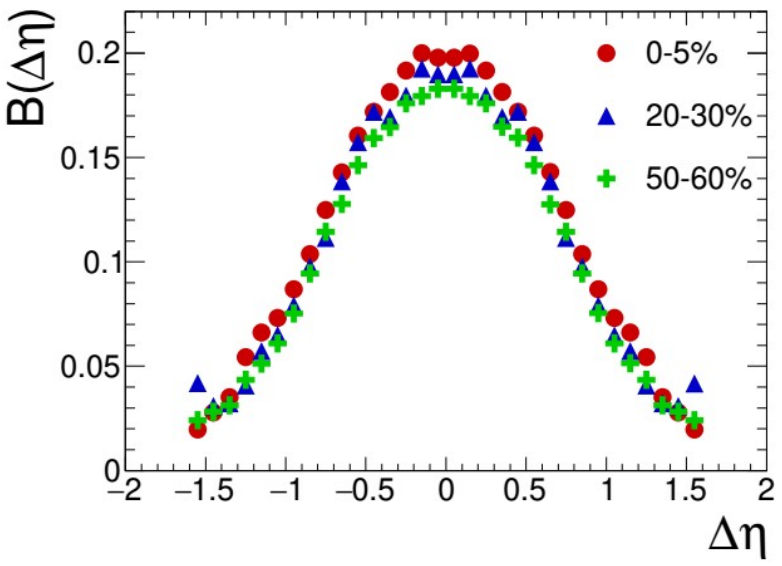
(1) $2.0 < p_{T,\mathrm{assoc}} < 3.0 < p_{T,\mathrm{trig}} < 4.0$ GeV/c and
(2) $3.0 < p_{T,\mathrm{assoc}} < 8.0 < p_{T,\mathrm{trig}} < 15.0$ GeV/c

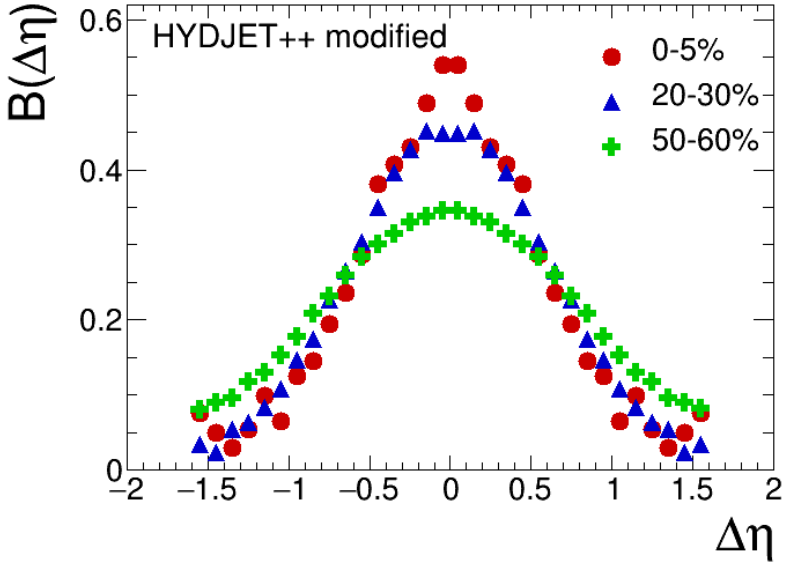
Default HYDJET++ model fairly describe the experimental data on BF width and its centrality dependence for higher p_T range (where hard component is dominant).

Charge Balance Function

The approach to take into account the event-by-event charge conservation in HYDJET++ model has been developed:

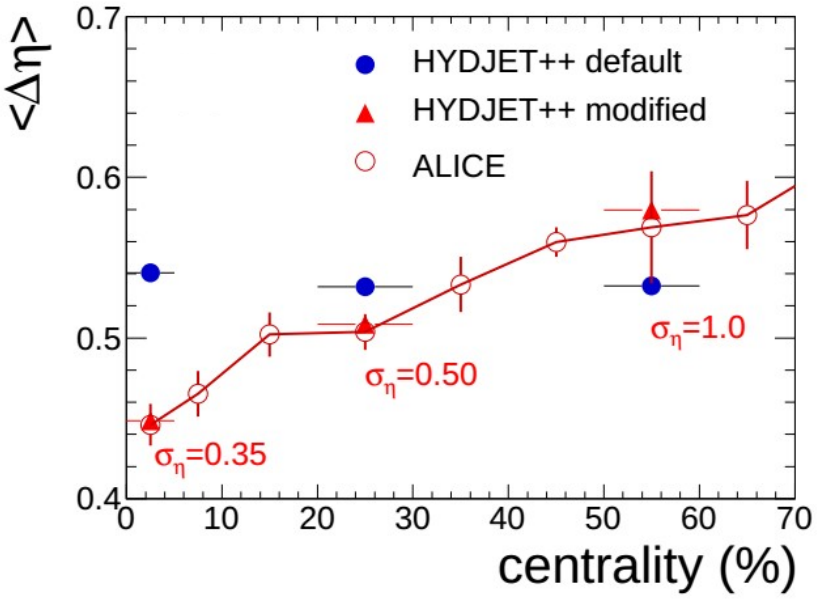
- pair production (particle-antiparticle) is introduced for charged direct hadrons in soft component
- positions of pairs (η_1, φ_1) and (η_2, φ_2) are distributed with Gaussian with certain σ_η, σ_φ

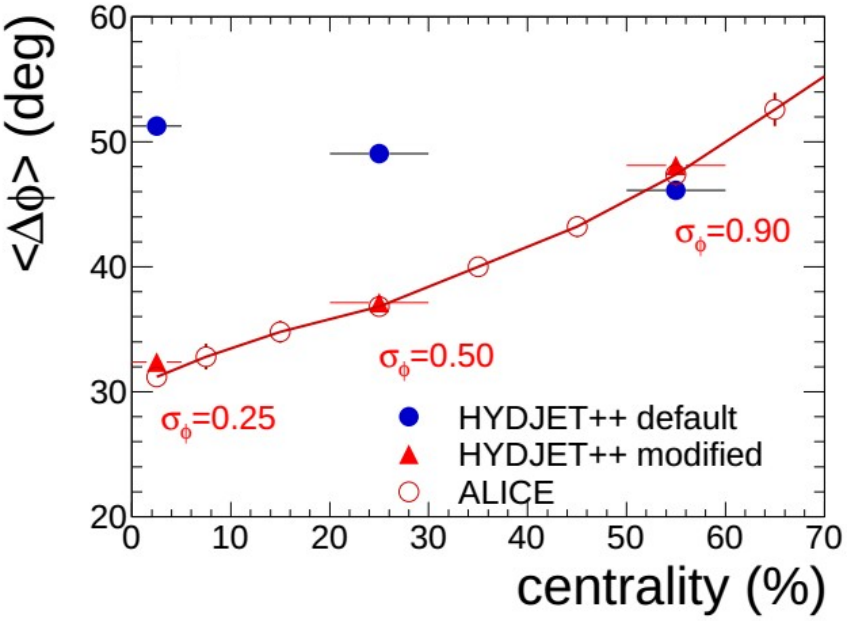




Charge Balance Function

(ALICE Collaboration), Phys. Lett. B 723, 267 (2013).





Experimental data can be reproduced with σ increasing for peripheral collisions → the charge correlations of direct hadrons become weaker, since the number of the independent particle sources, in which the charge is explicitly conserved, decreases.

Summary

- It was shown, that final state charge correlations (resonance decay) and charge correlations due to hard parton production are not enough to reproduce experimental width of the BF at LHC and to describe its centrality dependence.

- The modification of the statistical production mechanism of soft part of the HYDJET++ was implemented for direct hadrons. The approach accounts for the event-by-event charge conservation (at freeze-out stage). It allows to reproduce the experimentally observed centrality dependence of BF in PbPb collisions at LHC energies. **This procedure has been implemented for the first time in Monte Carlo event generators of a such kind.**

- Experimentally observed narrowing of BF for higher p_T is reproduced by HYDJET++ and is determined by hard processes and hadronisation.

The publication is under way:
https://arxiv.org/abs/2211.05874

The end

Thank you!