

Forward-Backward Correlations in Proton-Proton Collisions at the LHC energy: A Model Based Study

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Introduction

- Forward-backward (FB) correlations, a robust tool to explore both the Long Range Correlations (LRC) and the Short Range Correlations (SRC) in high energy collisions
- The long range FB correlations (in pseudorapidity(η) range, $|\eta| > 1$) may be due to the multiparticle interactions, originated at very early stages of the collisions
- The short range FB correlations ($|\eta| < 1$) are mainly due to the independent sources like jets/minijets or resonances^[1, 2]

FB correlations: the observables^[3]

- Selection of some F and B quantities in pseudorapidity intervals, symmetrically located in the forward and backward direction respectively
- Calculation of the FB correlation strength using Pearson Correlation Coefficient formula as:

$$b_{\text{corr}} = \frac{\langle FB \rangle - \langle F \rangle \langle B \rangle}{\langle F^2 \rangle - \langle F \rangle^2}$$

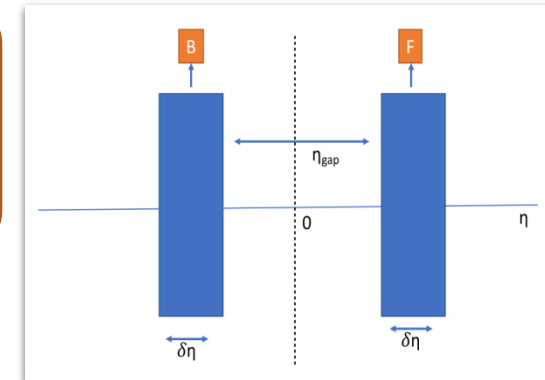
FB Correlations: Classifications

- $n - n$, the correlations between charged-particle multiplicities
- $p_T - p_T$, the correlations between mean or summed transverse momenta of charged particles
- $p_T - n$, the correlations between mean or summed transverse momenta in one pseudorapidity interval and the multiplicity of charged particles in another pseudorapidity interval

Here, we have explored first two types of FB correlation strengths using Pearson Correlation Coefficients:

$$b_{\text{corr}}(\text{mult}) = \frac{\langle N_f N_b \rangle - \langle N_f \rangle \langle N_b \rangle}{\langle N_f^2 \rangle - \langle N_f \rangle^2}$$

$$b_{\text{corr}}(\Sigma p_T) = \frac{\langle \Sigma p_{T_f} \Sigma p_{T_b} \rangle - \langle \Sigma p_{T_f} \rangle \langle \Sigma p_{T_b} \rangle}{\langle (\Sigma p_{T_f})^2 \rangle - \langle \Sigma p_{T_f} \rangle^2}$$



Schematic diagram of F and B regions of certain pseudorapidity width ($\delta\eta$) and separated by a pseudorapidity gap (η_{gap})

The EPOS3 model^[4]

- EPOS stands for: Energy conserving multiple scattering; Partons, parton ladders and strings; Off shell remnants; Saturation
- Universal approach for collision systems: pp, pA, AA
- Initial conditions: Gribov-Regge multiple scattering approach, elementary object => Pomeron => parton ladder
- Core-corona approach to separate fluid and jet hadrons. Different regions of interaction =>
 - higher string density: core, no jet parton escape
 - lower string density: corona, escape of jet parton
- Core undergoes full collective expansion producing Quark Gluon Plasma => a complete 3+1D viscous hydrodynamic evaluation applied
- Parton-hadron transition: realistic equation-of-state, compatible with lattice gauge results
- Hadronization: using standard Cooper-Frye formalism with subsequent hadronic cascade (UrQMD)

FB correlation coefficients studied for:

- gap between the FB windows (η_{gap})
- width of FB windows ($\delta\eta$)
- minimum transverse momentum ($p_{T\text{min}}$)
- different multiplicity classes

Events and Cuts

- Minimum-bias EPOS3 simulated events with hydro and without hydro in pp collisions at $\sqrt{s} = 13$ TeV
- Events are selected with a minimum of two charged particles in the chosen kinematic intervals
- Analysis has been carried out following ALICE^[5] and ATLAS^[6] kinematics



ALICE kinematics
[following 0.9, 2.76 and 7 TeV cuts]

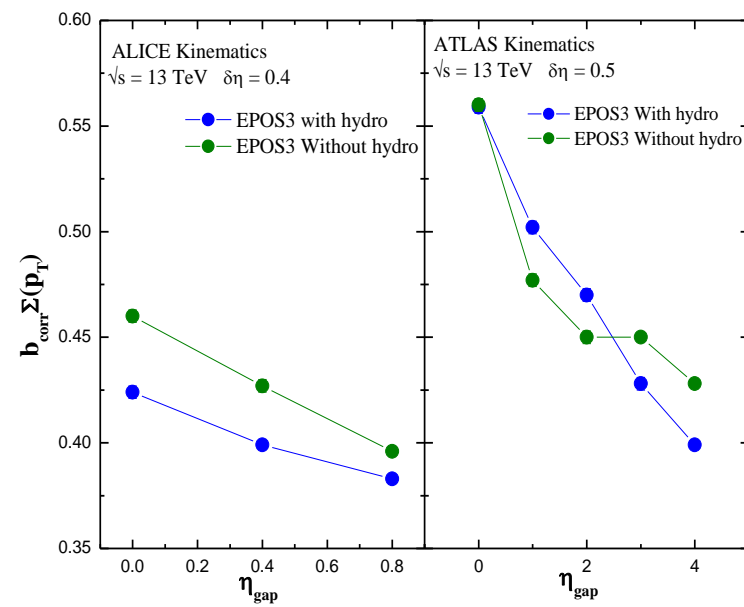
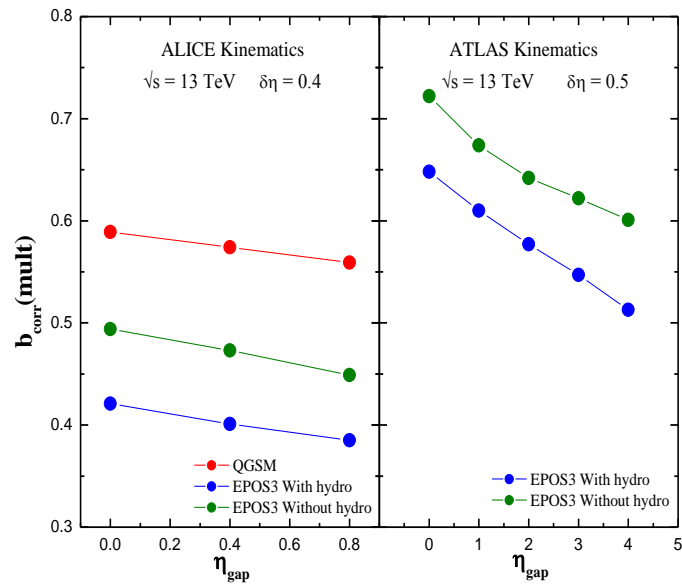
$0.3 < p_T < 1.5$ (GeV) & $|\eta| < 0.8$
 $\delta\eta = 0.2, 0.4, 0.6, 0.8$ & $\eta_{\text{gap}} = 0, 0.4 \text{ \& } 0.8$

ATLAS kinematics
[following 0.9 and 7 TeV cuts]

$p_T > 0.1$ (GeV) & $|\eta| < 2.5$
 $\delta\eta = 0.5$ & $\eta_{\text{gap}} = 0, 1, 2, 3 \text{ \& } 4$

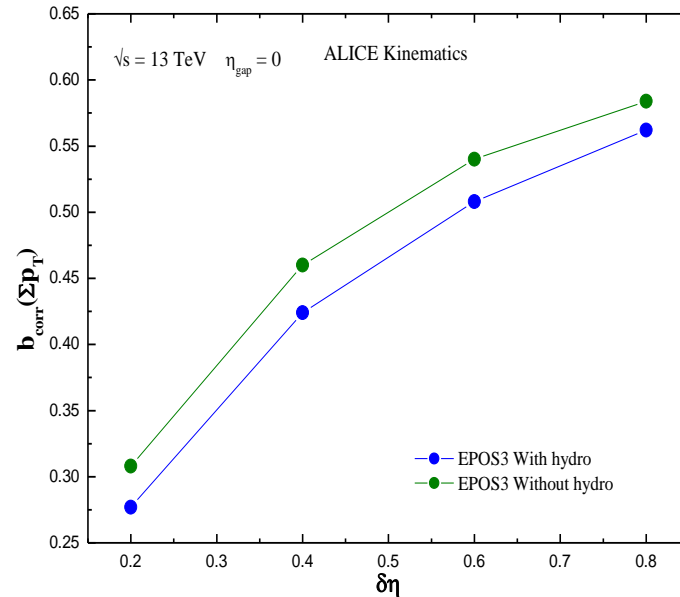
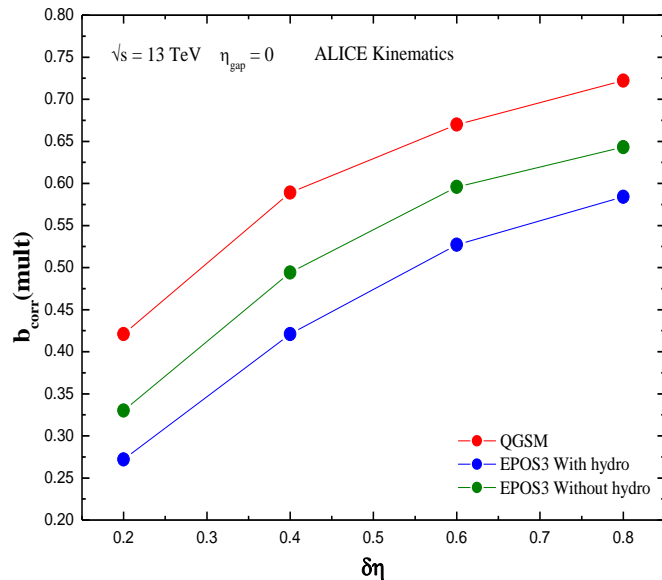
Weightage average of FB correlation coefficient:

- As a function of centre-of-mass energies for 0.9, 2.76, 7 TeV (our previous study^[7]) and 13 TeV (this analysis)



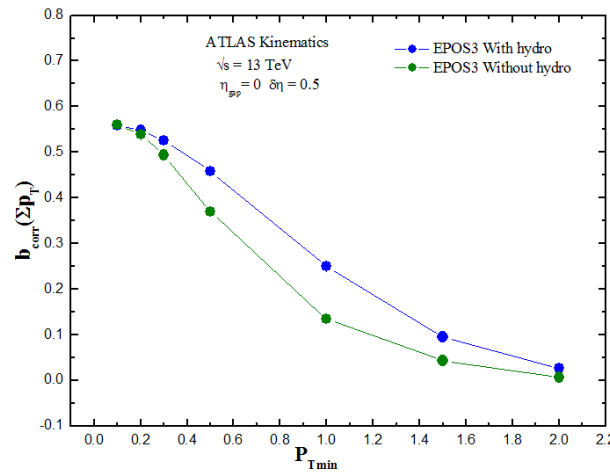
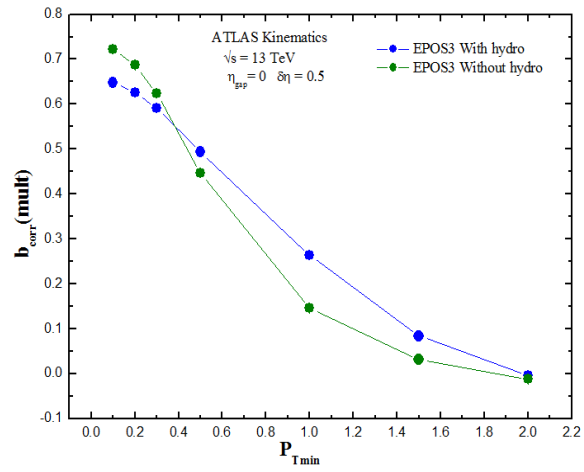
FB multiplicity and momentum correlations $[\eta_{gap}]$

- Correlation coefficient $b_{corr}(\text{mult}/\Sigma p_T)$ decreases with η_{gap} for both ALICE and ATLAS kinematics for EPOS3 generated pp events at $\sqrt{s} = 13$ TeV with and without hydro



FB multiplicity and momentum correlations $[\delta\eta]$

- Correlation coefficient $b_{corr}(\text{mult}/\Sigma p_T)$ increases non-linearly with $\delta\eta$ for both ALICE and ATLAS kinematics for EPOS3 generated pp events at $\sqrt{s} = 13$ TeV with and without hydro
- $b_{corr}(\text{mult})$ as a function of η_{gap} and $\delta\eta$ are compared to the Quark Gluon String Model (QGSM)^[8] ➔ qualitative agreement



FB multiplicity and momentum correlations [p_{Tmin}]

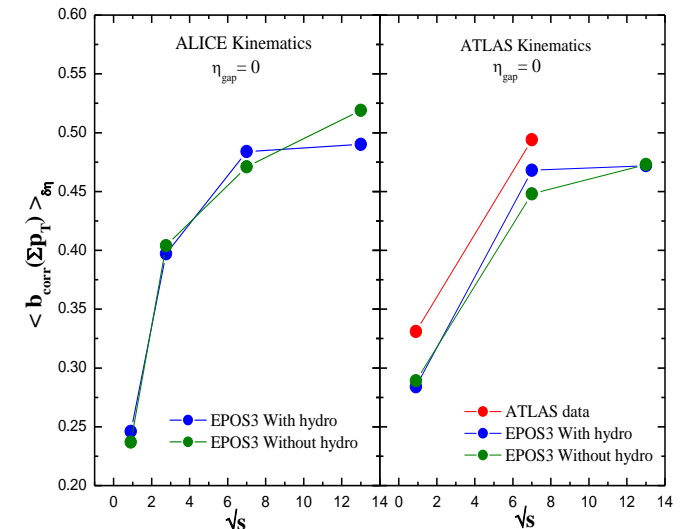
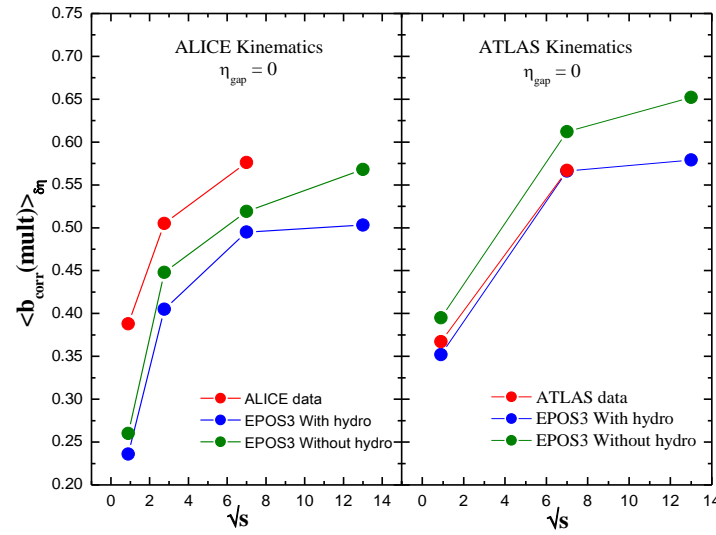
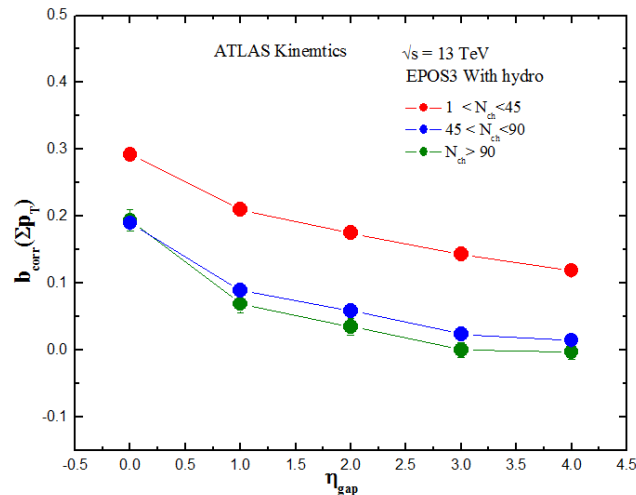
- Correlation coefficient $b_{corr}(\text{mult}/\Sigma p_T)$ decreases with increasing p_{Tmin} of the charged particles for ATLAS kinematics for EPOS3 generated pp events at $\sqrt{s} = 13 \text{ TeV}$ with and without hydro

FB momentum correlations [Mult]

- $b_{corr}(\Sigma p_T)$ decreases with the increasing minimum multiplicity at a fixed η_{gap} for pp collisions at $\sqrt{s} = 13 \text{ TeV}$ showing the fusion of strings into core in the EPOS3 framework

FB multiplicity and momentum correlations [\sqrt{s}]

- $\delta\eta$ -weightage average of $b_{corr}(\text{mult}/\Sigma p_T)$ as a function of centre-of-mass energy shows an increasing trend from lower to higher energies for both ALICE and ATLAS kinematics for EPOS3 generated pp events with and without hydro



Summary

- Similar to our previous findings in pp collisions at $\sqrt{s} = 0.9, 2.76 \text{ \& } 7 \text{ TeV}$ using EPOS3 model^[7], FB multiplicity and momentum correlation strengths decrease with η_{gap} and increase non-linearly with $\delta\eta$ at $\sqrt{s} = 13 \text{ TeV}$
- The FB correlation coefficients decrease with the increasing $p_{T\text{min}}$ using EPOS3 with and without hydro events at $\sqrt{s} = 13 \text{ TeV}$ confirming a gradual transition from soft to hard processes in high energy pp collisions.
- $b_{\text{corr}}(\sum p_T)$ decreases with increasing multiplicity at a fixed η_{gap} and becomes lowest in high-multiplicity events
- $\delta\eta$ -weightage average of both multiplicity and momentum correlation coefficients as a function of centre-of-mass energy shows that it tends to saturate at very high energy. Such model based observation in pp collisions adds more valuable information encouraging experimental measurements at the higher energies.

References

1. A. Capella and A. Krzywicki, Phys. Rev. D18, 4120 (1978).
2. K. Alpgard *et al.* (UA5 Collaboration), Phys. Lett. 123B, 361 (1983).
3. B. Alessandro *et al.* (ALICE Collaboration), J. Phys. G32, 1295 (2006).
4. K. Werner, B. Guiot, Iu. Karpenko, and T. Pierog, Phys. Rev. C89, 064903 (2014).
5. J. Adam *et al.* (ALICE Collaboration), J. High Energy Phys. 05, 097 (2015).
6. G. Aad *et al.* (ATLAS Collaboration), J. High Energy Phys. 07, 019 (2012).
7. Mitali Mondal *et al.*, Phys. Rev. D102, 014033 (2020).
8. E. Cuautle, E. Dominguez, and I. Maldonado, Eur. Phys. J. C79, 626 (2019).

