Forward-backward spherocity correlations in pp collisions at $\sqrt{s}$ = 13 TeV

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by

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Forward-backward Spherocity correlations in pp collisions at $\sqrt{s}$=13 TeV

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This report tried to determine the Spherocity(S_0) correlation between forward-backward pseudorapidities in a Proton-Proton collision ("Beams:idA= 2212" and "Beams:idB= 2212"). The observable S_0 is investigated in the Monte Carlo Model Pythia 8.307 in order to better understand results from experimental data obtained in the ALICE detector at CERN. The aim of this experiment is to reproduce a simulation and use the features proposed by Pythia to find out the unexpected outcomes. The analysis is conducted using ($\Delta\eta$) two-particle correlations. The influence of the Multiple Parton Interactions on the general distribution of the tracks around the collision is also investigated.

I. INTRODUCTION

Until recently, the measurements used to constrain physics models of high-energy particle collisions came primarily from experiments done at the previous generations of accelerators, such as the SPS, LEP, and the Tevatron. In particular, studies of "minimum-bias" and underlying-event physics have been widely used to constrain the poorly known nonfactorizable and non-perturbative aspects of Monte Carlo (MC) event generators. These generators are, in turn, used ubiquitously over a continually expanding range of energies and intensities, for both high- and low-transeverse momentum processes. MC "tunes" that rely exclusively on these older data sets are, however, becoming outmoded by a new generation of high-energy experiments, performed at the Large Hadron Collider (LHC). The extrapolation of previous results to the higher energies and large acceptances of the LHC experiments is associated with significant uncertainties, and the demands on both theoretical and experimental precision are becoming ever more stringent. The importance of reevaluating the physics models, and of retuning them in situ, has therefore been highlighted in several recent studies.

II. THEORY

A. Theoretical Background

The primary physics motivation for the present study is based on the concept of the chromoelectric flux tubes (quark-gluon strings or Pomerons exchanged between the colliding hadrons) - the objects stretched in rapidity that might be formed at the very early stages of hadron-hadron collisions. These colour strings may interact, and, in the case of sufficiently high density, string fusion may produce new strings of higher colour. This recent phenomenon of string fusion could be one of the mechanisms leading to the QGP formation. It was shown that studying forwards-backwards correlations of particle production in collisions of two nuclei at high energies may allow distinguishing between the string fusion, cluster formation and decay processes. The long-range correlations(LRC) between various observables, measured in sufficiently separated rapidity intervals, may appear as the signal relevant to string fusion. At the same time, the decay of clusters of particles and resonances is marked by increased short-range correlations(SRC). Recently, similar predictions for the LRC also appeared in the model of color glass condensation and plasma flux tubes, originating from forming so-called "glasma" flux tubes at early collision stages. However, these models (SFM and CGC) differ in the predictions of the behaviour of multiplicity correlation strength with the centrality of the collision. The presence of strong long-range backwards-forward multiplicity correlations extended to several units of pseudorapidity was demonstrated for the MC event generator. In addition, the multiple parton interactions (MPI), considered by PYTHIA, might also be responsible for the fluctuation in the number of color strings, and, therefore, could be one of the potential contributors to the LRC. In all approaches shown above the LRC are produced by the fluctuating number of particle emitting sources (strings), formed in the collision, although the dynamical origin of the sources might be different. Therefore, the detailed experimental studies of the correlation strength and its rapidity structure are crucial for understanding of the physics of the hadron collision process in general.

B. Spherocity

Transverse spherocity:- In the present work, the mid-rapidity charged hadron transverse spherocity, S_0, is used to characterize the events through the geometrical distribution of the p_{T} 's of the charged hadrons, which is by definition collinear and infrared safe. The restriction to the transverse plane avoids the bias from the boost along the beam axis. It is defined for a unit transverse vector

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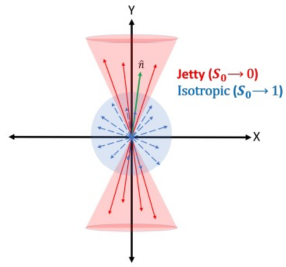

FIG. 1: A schematic picture showing transverse spherocity distribution of a hadronic collision.

$\hat{\mathbf{n}}$ which minimizes the ratio below:

$$S_0 = \frac{\pi^2}{4}\left(\frac{\sum_i \left|\overrightarrow{p_{\mathrm{T}_i}} \times \hat{\mathbf{n}}\right|}{\sum_i p_{\mathrm{T}_i}}\right)^2$$

By construction, the limits of the variable are related to specific configurations in the transverse plane.

$$S_0 = \begin{cases} 0 & \text{"pencil-like" limit (hard events)} \\ 1 & \text{"isotropic" limit (soft events)} \end{cases} .$$

In this study, inelastic pp collisions were generated with Pythia 8.307 tune pp 14(Monash); this tune describes qualitatively many features of the LHC pp data . The event shape was computed considering only primary charged particles at mid-rapidity ($|\eta| < 1$) and in the transverse momentum interval $0.5 < P_{\mathrm{T}}$ GeV/c. Transverse spherocity was only defined for events with more than two hadrons. Different observables like jet production and identified hadron production were studied at mid-rapidity for different S_0 and multiplicity (N_{ch}) intervals. Event shapes studied by experiments at LHC, e.g. ATLAS [24] and ALICE [25], have shown an interesting result: a good agreement between data and models is observed for the average event shape, while the event shape distributions exhibit large discrepancies. This is a very important message: the average measurements do not contain enough information; hence, care needs to be taken when extracting physics from models. For example, in the concrete case of the event generators reported in following references , they significantly overestimate the contribution of back-to-back jet events and underestimate the contribution of isotropic events at high multiplicity.

C. Experimental setup, event and track selection

Charged primary particles are reconstructed with the central barrel detectors combining information from the Inner Tracking System (ITS) and the Time Projection Chamber (TPC). Both detectors are located inside the 0.5 T solenoidal field.

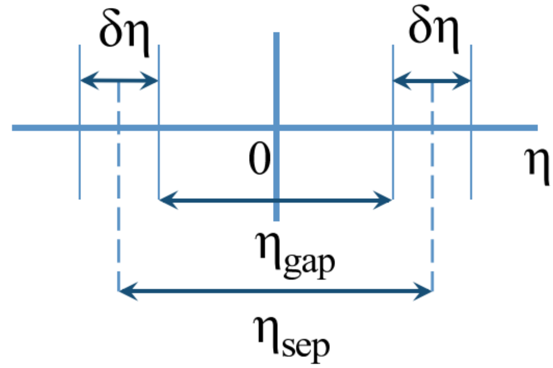

FIG. 2: Illustration of the variables $\delta\eta$, η_{gap} and η_{sep} used in the present analysis.

The ITS is composed of 3 different types of coordinate-sensitive Si-detectors. It consists of 2 silicon pixel innermost layers (SPD), 2 silicon drift (SDD) and 2 silicon strip (SSD) outer detector layers. The design allows for two-particle separation in events with a multiplicity up to 100 charged particles per cm^2. The SPD detector covers the pseudorapidity ranges $|\eta| < 2$ for inner and $|\eta| < 1.4$ for outer layers, acceptances of SDD and SSD are $|\eta| < 0.9$ and $|\eta| < 1$, respectively. All ITS elements have a radiation length of about $1.1\% X_0$ per layer. The ITS provides reliable charged particle tracking down to transverse momenta of 0.1GeV/c, ideal for the study of low- p_{T} (soft) phenomena. The TPC has an acceptance of $|\eta| < 0.9$ for tracks which reach the outer radius of the TPC and up to $|\eta| < 1.5$ for tracks that exit through the endcap of the TPC.

For the present analysis, minimum bias pp events are used. The minimum-bias trigger required a hit in one of the forward scintillator counters (VZERO) or in one of the two SPD layers. . In this way, a uniform acceptance in the central pseudorapidity region $|\eta| < 0.8$ is ensured. The data samples for $\sqrt{s} = 13$TeV comprise 1×10^6 events, respectively. Only runs with a low probability of producing several separate events per bunch crossing (so-called pile-up events) were used in this analysis.

To obtain high tracking efficiency and to reduce efficiency losses due to detector boundaries, tracks are selected with $p_{\mathrm{T}} > 0.5$GeV/c in the pseudorapidity range $|\eta| < 2.5$. Additionally, at least two hits in the ITS must be associated with the track. Tracks are also rejected if their distance of closest approach (DCA) to the reconstructed event vertex is larger than 0.3 cm in either the transverse or the longitudinal plane. For the chosen selection criteria, the tracking efficiency for charged particles with $p_{\mathrm{T}} > 0.5$GeV/c is about 80%.

The ALICE TPC is the main tracking detector of the central rapidity region. The TPC, together with the ITS, provides charged particle momentum measurement, particle identification and vertex determination with good momentum and dE/dx resolution as well as two-track separation of identified hadrons and leptons in the p_{T} region below 10GeV/c.

D. Forward-Backward Correlation

Forward-backward (FB) correlations are a powerful tool for studying the initial stages of pp collisions. FB correlations are studied in two intervals of pseudorapidity (η), which are selected one in the forward ($\eta > 0$) and another in the backward($\eta < 0$) hemispheres in the center-of-mass system.

The FB correlation strength is characterized by the correlation coefficient b_{corr} . This value is defined via a linear regression of the average value of a given quantity B measured in the backward hemisphere $\left(\langle B\rangle_F\right)$ as a function of the value of another quantity F measured in the forward hemisphere. Note that F and B can describe the kinematic quantity or distinct quantities.

$$\langle B\rangle_F = a + b_{\text{corr}} \cdot F.$$

Taking F and B particle multiplicities, the relation (1) becomes $\langle n_{\mathrm{B}}\rangle_{n_{\mathrm{F}}} = a + b_{\text{corr}} \cdot n_{\mathrm{F}}$, which was first experimentally observed in UA5 and discussed in following refrences. FB correlations between multiplicities have been recently studied in pp and $\mathrm{Au}-\mathrm{Au}$ collisions by STAR at RHIC, and in pp collisions by ATLAS and ALICE at LHC.

FB correlation studies are more informative when decoupled into short-range and long-range components. Short-range correlations (SRC) are localized over a small range of η, typically up to one unit. They are induced by various short-range effects like decays of clusters or resonances and jet and mini-jet-induced correlations. Long-range correlations (LRC) extend over a broader range in η and originate from fluctuations in the number and properties of particle emitting sources, e.g. clusters, cut pomerons, strings, mini-jets, etc. In the ALICE paper, the "classical" approach to the long-range correlation analysis in two pseudorapidity intervals was expanded using additional azimuthal (φ) sectors within these windows. This approach allows for a more thorough investigation of the SRC, LRC, and their contributors, which can provide more substantial constraints on phenomenological string models.

multiplicity of charged particles in another η interval ($p_T - n$). In our present analysis, we have explored the first two types of FB correlation in detail. The FB correlation strength is measured in a coordinate system with origin $\eta = 0$, which is the collision vertex. Two η intervals are selected: one in the forward ($\eta > 0$) and another in the backward hemispheres ($\eta < 0$) in the centre-of-mass system. FB Spherocity correlation coefficient b_{corr} (Spherocity) has been estimated using the following formula of Pearson Correlation Coefficients.

$$b_{corr}(\text{ Spherocity }) = \frac{\left\langle S_f S_b\right\rangle - \left\langle S_f\right\rangle\left\langle S_b\right\rangle}{\left\langle S_f^2\right\rangle - \left\langle S_f\right\rangle^2},$$

Here, S_f and S_b are the Spherocities in F and B window respectively.

III. RESULTS

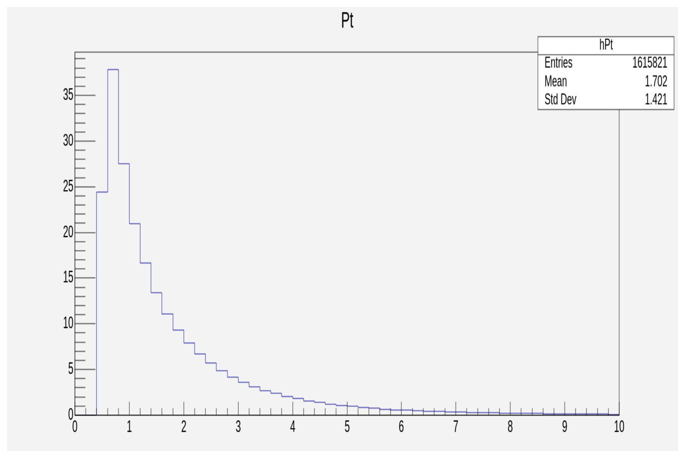

FIG. 3: Transverse Momentum Distribution

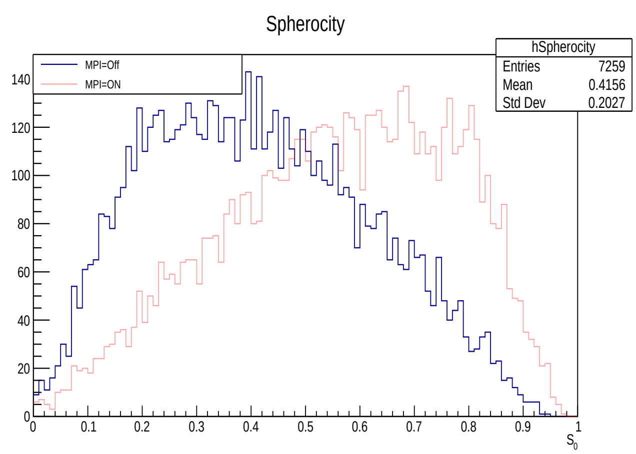

FIG. 4: Effect of MPI on Spherocity disribution

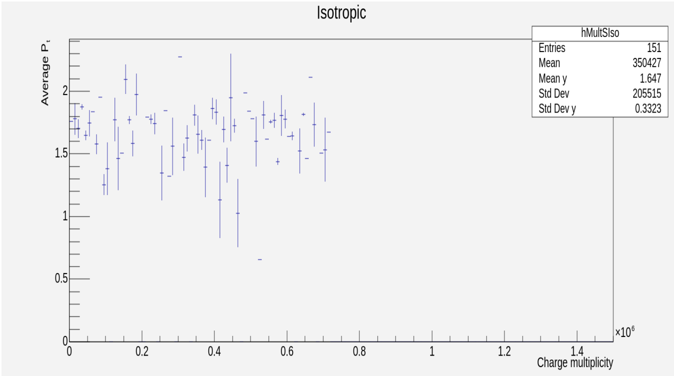

FIG. 5: Isotropic events distribution(events having $S_0 > 0.8$)

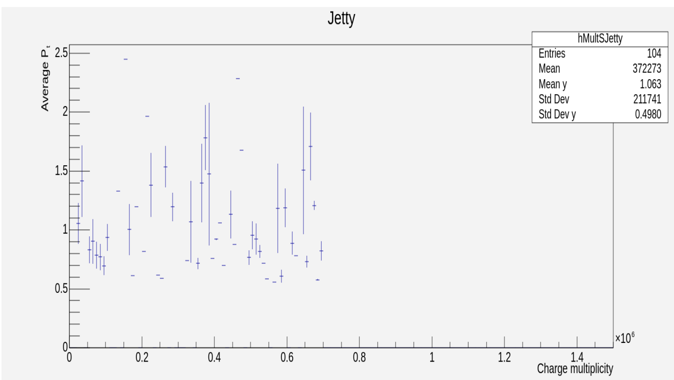

FIG. 6: Jetty events distributions (events having $S_0 < 0.2$)

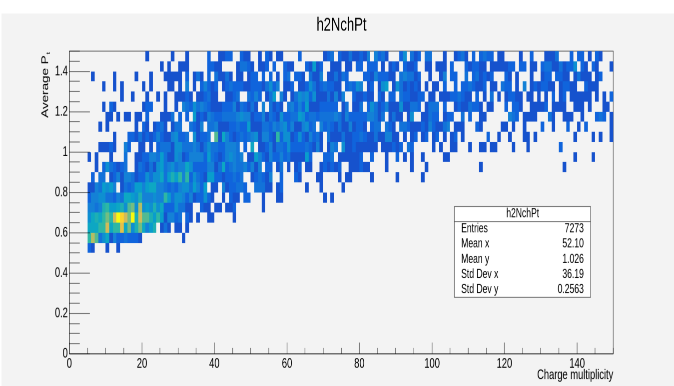

FIG. 7: 2-D Histogram of Sum of tracks and Average momentum

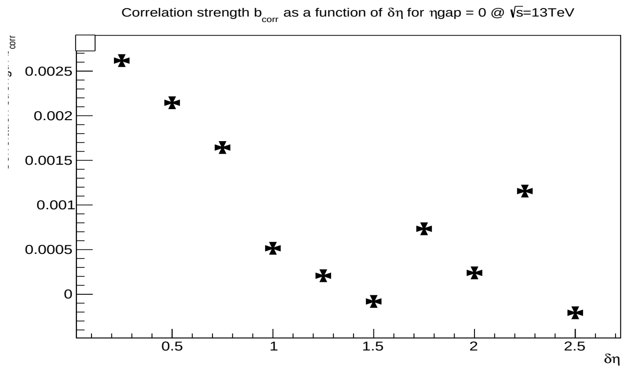

FIG. 8: Correlations between Spherocity in forwards-backwards pseudorapidity $\delta\eta$

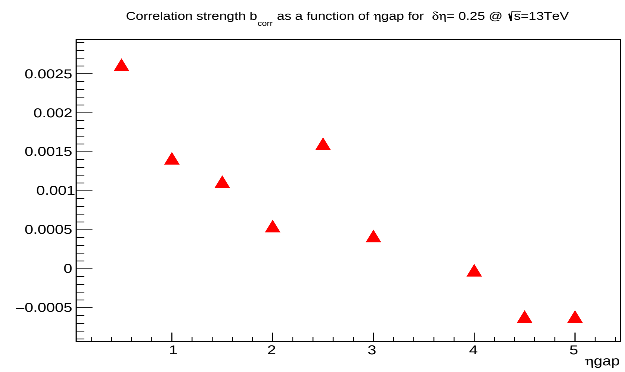

FIG. 9: Correlation strength b_{corr} as a function of ηgap for $\delta\eta = 0.25$ @ $\sqrt{s} = 13TeV$ η- gap Correlation strength b_{corr}

IV. CONCLUSIONS

1. The transverse spherocity has been used to study the influence of the multiparton interactions on the final state in pp collisions. It was demonstrated that the number of multi-parton interactions is strongly correlated with the Isotropic events, at least up to a point where a saturation of the number of multi-parton interactions occurs. The transverse spherocity selection allows for identifying and analysing two extreme cases: the jetty-like and the isotropic events at the two ends of the transverse spherocity spectrum. Different studies were done: jet production identified particle ratios and blast-wave analysis. The results show the benefits of the combined multiplicity and event shape analysis. We conclude that more widespread use of event shape variables in the data study may give us a much better understanding of the details of the collisions.

2. it was observed that Pearson correlation coefficient b_{corr} was decreasing with increasing width of window ($\delta\eta$) and also decreasing with increasing ηgap.

However, fluctuations at endpoints were observed. it might be due to less data.

V. REFERENCES

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