Conference Paper

Forward-backward correlations between mean transverse momenta in Pb–Pb collisions with ALICE

Igor Altsybeev (for the ALICE collaboration)

Saint-Petersburg State University, 7/9 Universitetskaya nab., St. Petersburg, 199034 Russia

Abstract

Forward-backward (FB) correlations are considered to be a powerful tool for the exploration of the early dynamics of hadronic interactions. The FB correlation functions can be constructed from different observables calculated event-by-event in two separated pseudorapidity regions. We report measurements of event-by-event average transverse momentum correlations for charged particles in two separated pseudorapidity regions in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ and 5.02 TeV recorded with ALICE at the LHC. The event-by-event mean transverse momenta correlations are robust against volume fluctuations and thus the centrality determination methods, which provides higher sensitivity to the properties of the initial state and evolution of the medium created in A–A collisions. The strength of the FB correlation is calculated for different centralities of the Pb–Pb collisions. Results are compared with Monte Carlo event generators, such as HIJING and AMPT.

Corresponding Author:
Igor Altsybeev
i.altsybeev@spbu.ru

Received: 25 December 2017
Accepted: 2 February 2018
Published: 9 April 2018

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the ICPPA Conference Committee.

1. Introduction

Studies of Forward-Backward (FB) correlations are performed between observables in two separated pseudo-rapidity intervals $\Delta\eta_F$ and $\Delta\eta_B$, which are conventionally referred to as forward and backward windows. The FB correlations are created predominantly at the early stages of the collision [1] and arise in such initial state models as Color Glass Condensate [2] and String Fusion [3]. The FB correlations are sensitive to event-by-event fluctuations of number and properties of particle-emitting sources elongated in rapidity, and in later stages of the system evolution the correlations can be modified by medium and final state effects.

The strength of the FB correlation is usually characterized by the correlation coefficient b_{corr}, which is obtained from a linear regression analysis of the event-averaged quantity measured in the backward rapidity hemisphere ($\langle B\rangle_F$) as a function of the quantity measured in the forward hemisphere (F):

$$\langle B\rangle_F = a + b_{corr} \cdot F. \quad (1)$$

Alternatively, the b_{corr} can be determined using the Pearson correlation coefficient:

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

where angular brackets denote averaging over events. Different dynamical variables can be chosen in F and B windows in order to study correlations between them. In conventional FB measurements, multiplicities of charged particles n_F and n_B within the windows are chosen. We refer to this kind of FB correlations as $n-n$ correlations, and formulae (1) and (2) for them as

$$\langle n_B\rangle_{n_F} = a + b_{corr}^{n-n} \cdot n_F \quad b_{corr}^{n-n} = \frac{\langle n_B n_F\rangle - \langle n_B\rangle\langle n_F\rangle}{\langle n_F^2\rangle - \langle n_F\rangle^2}. \quad (3)$$

The forward-backward multiplicity correlations have been previously studied in a large number of colliding systems, for instance, in $p\bar{p}$ [4], pp [5] and Au–Au [6] collisions.

Charged particle multiplicity is an *extensive* quantity, therefore the strength of the FB $n-n$ correlations is affected by the so-called “volume fluctuations” (i.e., in Glauber-like models, by event-by-event fluctuations of the number of participating nucleons), which complicates the interpretation of the experimental values of this observable. To suppress this contribution, one may consider other, *intensive* observables within the observation windows. In particular, the mean transverse momentum of particles in a given event can be determined within each of the F and B windows, given by the expressions $F \equiv \overline{p_F} = \sum_{j=1}^{n_F} p_T^{(j)}/n_F$ and $B \equiv \overline{p_B} = \sum_{i=1}^{n_B} p_T^{(i)}/n_B$ [7]. Then the formulae (1) and (2) for the correlation strength are expressed as

$$\langle\overline{p_F}\rangle_{\overline{p_B}} = a + b_{corr}^{\overline{p_T}-\overline{p_T}} \cdot \overline{p_F} \quad b_{corr}^{\overline{p_T}-\overline{p_T}} = \frac{\langle\overline{p_F}\,\overline{p_B}\rangle - \langle\overline{p_F}\rangle\langle\overline{p_B}\rangle}{\langle\overline{p_F}^2\rangle - \langle\overline{p_F}\rangle^2}. \quad (4)$$

In this work, FB correlations between charged primary particles have been measured with the ALICE detector in Pb–Pb collisions at $\sqrt{s_{NN}}$ =2.76 and 5.02 TeV. We first show an analysis of FB multiplicity correlations and after that present results on FB correlations between mean-p_T.

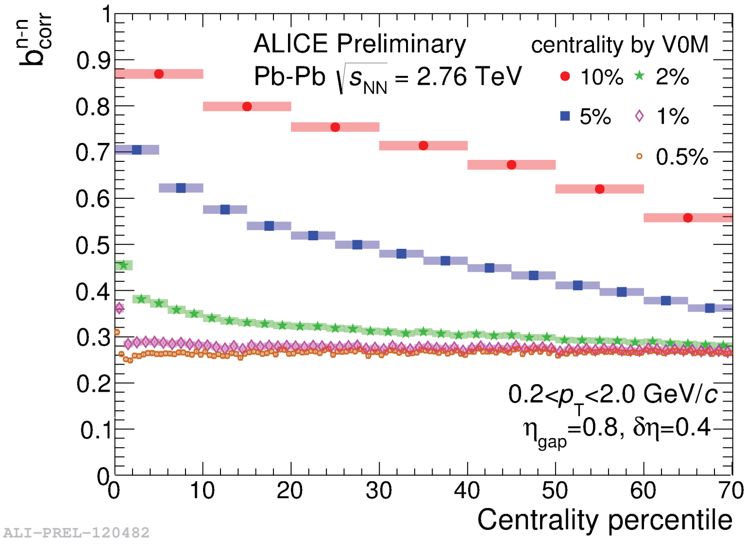
2. Forward-backward correlations between multiplicities

In the ALICE setup, charged particles are reconstructed using combined information from the Inner Tracking System (ITS) and the Time Projection Chamber (TPC). Both detectors are located inside the ALICE solenoid with a field of 0.5 T and have full azimuthal coverage for track reconstruction within a pseudo-rapidity window of $|\eta| < 0.8$ [8]. Centrality of Pb–Pb collisions is determined using the signals from the V0 detectors – two forward scintillator arrays with coverage $-3.7 < \eta < -1.7$ and $2.8 < \eta < 5.1$. Alternatively, centrality can be estimated using the signal from spectators in the Zero-Degree Calorimeters coupled with the response from a small electromagnetic calorimeter ZEM (ZDCvsZEM estimator), as well as using the number of clusters counted in the second layer of the Silicon Pixel Detector covering $|\eta| < 1.4$ (CL1 estimator) [9]. Centrality classes are defined as percentiles of the multiplicity distributions.

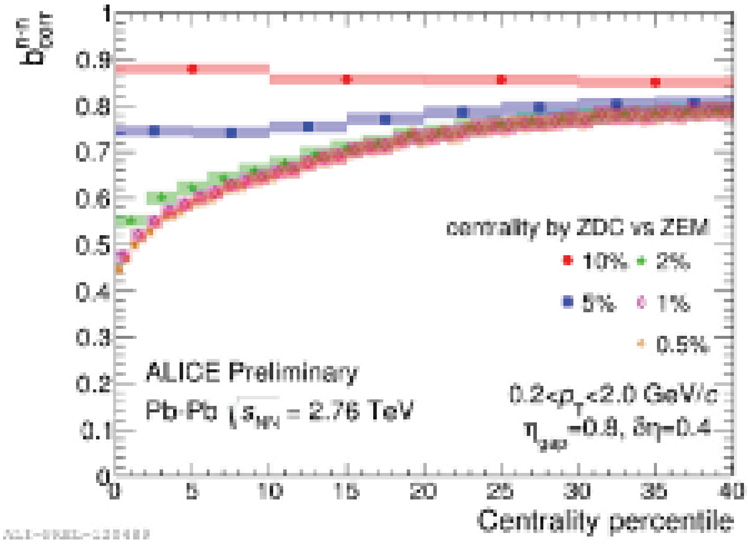
A pair of η intervals chosen for this FB correlation analysis are (-0.8, -0.4) and (0.4, 0.8), which have a width $\delta\eta = 0.4$ and pseudorapidity separation $\eta_{gap} = 0.8$. Such a separation allows short-range effects from (mini-)jets and resonance decays to be reduced. A "soft" p_T-range of 0.2-2.0 GeV/c was chosen for the study. The numbers of Pb–Pb events selected for analysis are 12×10^6 at $\sqrt{s_{NN}} = 2.76$ TeV and 49×10^6 at 5.02 TeV.

Figure 1 shows the centrality dependence of the FB correlation strength b_{corr}^{n-n} between multiplicities in the two windows. The centrality estimator used for panel (a) is the V0 detector. For wide centrality classes of 10% width (red filled circles), the correlation strength grows towards more central collisions, as it was observed by the STAR collaboration for Au–Au collisions [6]. However, for smaller class widths (5, 2, 1 and 0.5%) the values of b_{corr}^{n-n} drop and the centrality trend flattens, because the contribution from the volume fluctuations is suppressed for narrower centrality classes.

Panel (b) shows values of b_{corr}^{n-n} in classes of centrality determined by the ZDCvsZEM estimator. It can be seen that the trends are very different in comparison with the V0-based results. This is because acceptance and resolution of the ZDCvsZEM estimator is distinct from those of the V0, therefore, volume fluctuations inside centrality classes are different. Moreover, a cross-correlation between ZDC with the central-barrel region is also not the same as in case of the V0, and it is known also that resolution of the ZDC worsens towards more peripheral collisions [9]. All these effects contribute to b_{corr}^{n-n}. Therefore, in view of a dramatic dependence of FB multiplicity correlation strength on centrality class determination, theoretical interpretation of the experimental results should be done with care.



(a)



(b)

Figure 1: Strength of the FB multiplicity correlations as a function of centrality in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV. Centrality classes of different width are determined by the V0 (a) and by the ZDCvsZEM (b). Systematic uncertainties are shown as rectangles (widths correspond to the sizes of centrality classes), statistical uncertainties are smaller than marker sizes.

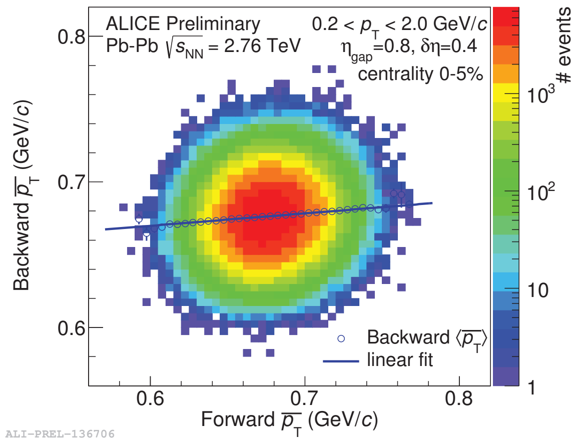
3. Forward-backward correlations between event-mean transverse momenta

Instead of multiplicities, correlations between event-mean p_T have been studied for the same FB window pair. Figure 2 (a) shows an event-by-event distribution of $\overline{p_F}$ versus $\overline{p_B}$ for centrality class 0–5% (centrality is determined by the V0 estimator). For a linear regression analysis, event-averaged values in the backward window ($\langle\overline{p_B}\rangle$) are calculated for each $\overline{p_F}$ bin: panel (b) demonstrates this for several centrality classes of 5% width. One may note that correlation functions are linear in narrow centrality classes, therefore each function can be quantified by the correlation strength $b_{corr}^{\overline{p_T}-\overline{p_T}}$, which corresponds to the slope of the linear fit line. Note, that for too wide classes the linearity of the correlation functions may be broken: an extreme case is shown in panel (c) for the 0–80% class. Therefore, to interpret the meaning of $b_{corr}^{\overline{p_T}-\overline{p_T}}$, it is important to look at the correlation functions themselves.

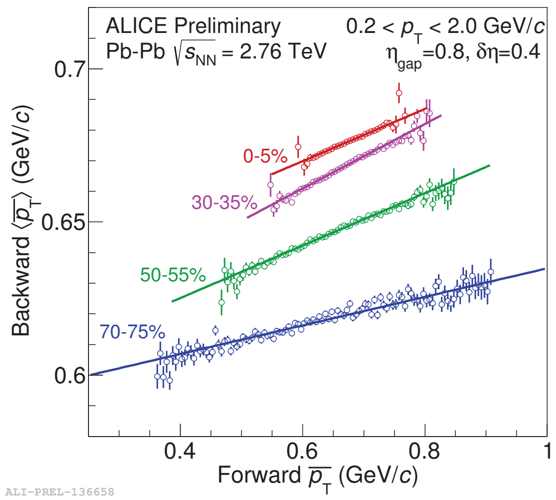
The centrality dependence of $b_{corr}^{\overline{p_T}-\overline{p_T}}$ is presented in Figure 3 (a). Since mean-p_T is an intensive observable, the results are independent of volume fluctuations and therefore are robust to changes of the centrality class width, if the classes are not too wide (points for 10, 5 and 2% classes are shown). Moreover, different centrality estimators also provide consistent results (panel b). The small deviations in the centrality range 20–40% for the ZDC-based results can be attributed to a reduced centrality resolution of the ZDC in this centrality range, mentioned above. The correlation strength $b_{corr}^{\overline{p_T}-\overline{p_T}}$ rises from peripheral to mid-central and drops towards central collisions. This characteristic shape persists also at $\sqrt{s_{_{NN}}} = 5.02$ TeV energy of Pb–Pb collisions (Figure 4, a). Also, the same behavior is seen for windows of smaller width $\delta\eta = 0.2$ with different gaps between them (panel b): the results for $\eta_{gap} = 1.2$ and 0.6 are on top of each other, while values for adjacent FB windows ($\eta_{gap} = 0$, blue squares) are slightly higher due to short-range correlations. The short-range contribution is most pronounced for peripheral events and decreases towards central events.

The positive values of $b_{corr}^{\overline{p_T}-\overline{p_T}}$ seen above are related to the event-by-event fluctuations of the event-averaged transverse momentum of particles. The origin of these mean-p_T fluctuations can be attributed, for example, to event-by-event fluctuations of the initial size of the fireball, which is reflected in pressure gradients at a later stage of a collision [10]. What is more difficult, however, is to capture correctly the *shape* of the centrality dependence of the $b_{corr}^{\overline{p_T}-\overline{p_T}}$. Qualitatively, the same shape was obtained in the Monte Carlo implementation of the string fusion model [11], where fluctuations of initial densities provide different patterns of overlapping strings, and changes of tension of fused strings affect p_T of particles emitted when the strings break.

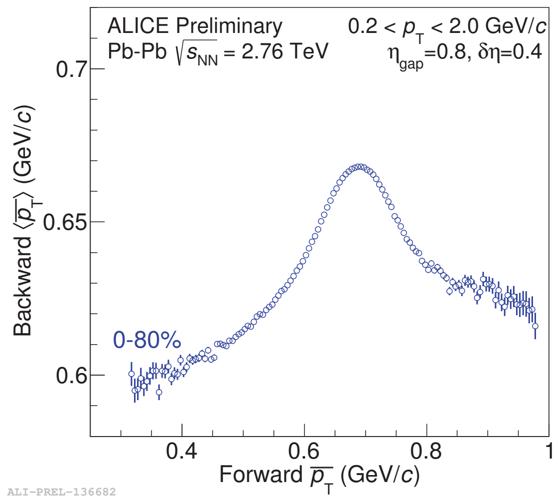
Figure 5 compares the FB mean-p_T correlation strength with calculations in Monte Carlo generators. HIJING demonstrates weak correlations with no dependence on centrality. Small positive values of $b_{corr}^{\overline{p_T}-\overline{p_T}}$ in this generator can be attributed to back-to-back jets, which hit both F and B windows. AMPT generally reproduces the shape of the centrality dependence, however, it does not reproduce the magnitude. Switching off rescattering or string melting mechanisms leads to a rise of $b_{corr}^{\overline{p_T}-\overline{p_T}}$, the underlying reasons for this need to be investigated further. Calculations of the mean-p_T correlations in some other event generators are given in [12].



(a)

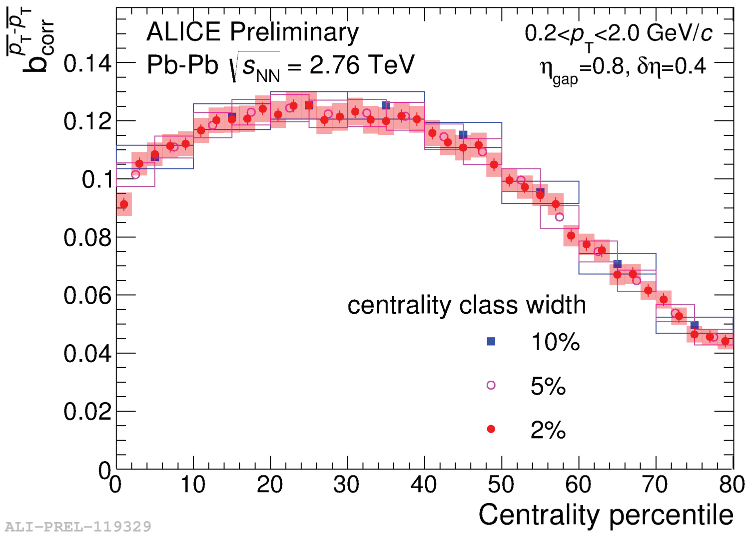


(b)

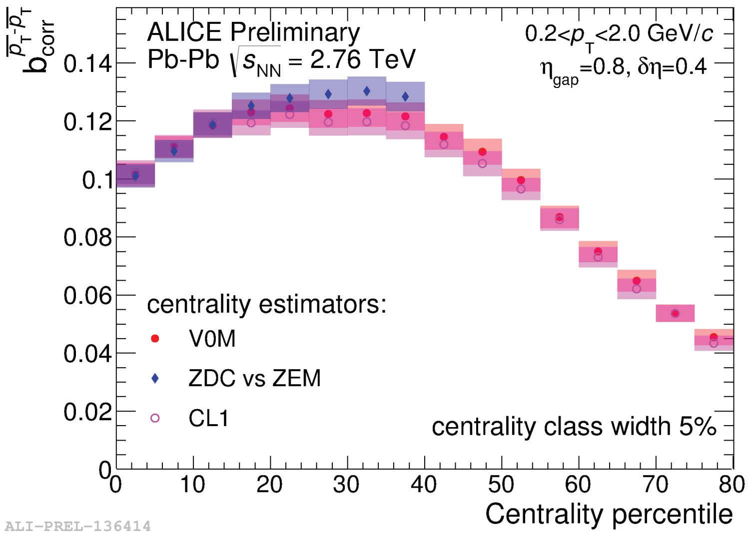


(c)

Figure 2: Mean p_T in Backward window vs mean p_T in Forward window (with corresponding profile) in class 0–5% (a), profiles with linear fits for several centrality classes of 5% width (b) and profile for wide centrality class 0–80% (c). Centrality is determined by the V0 detector.



(a)

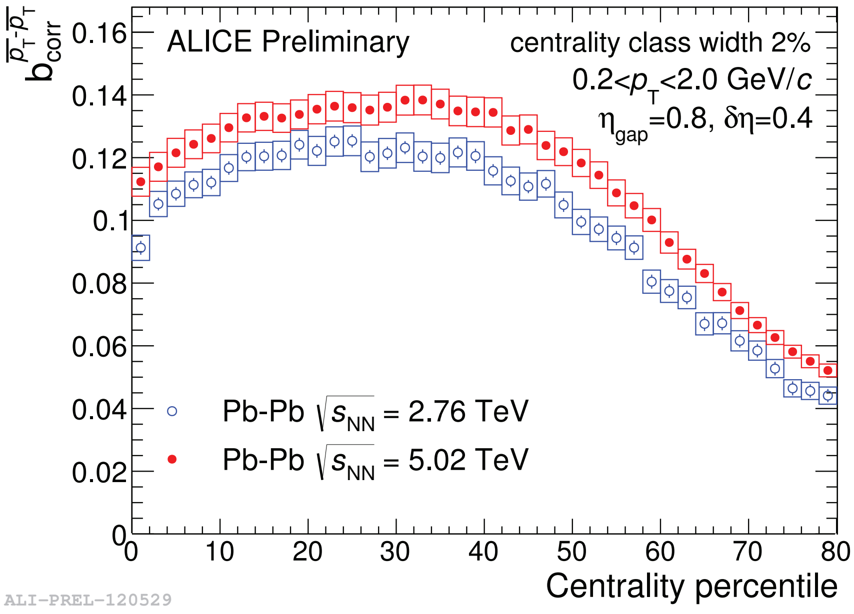


(b)

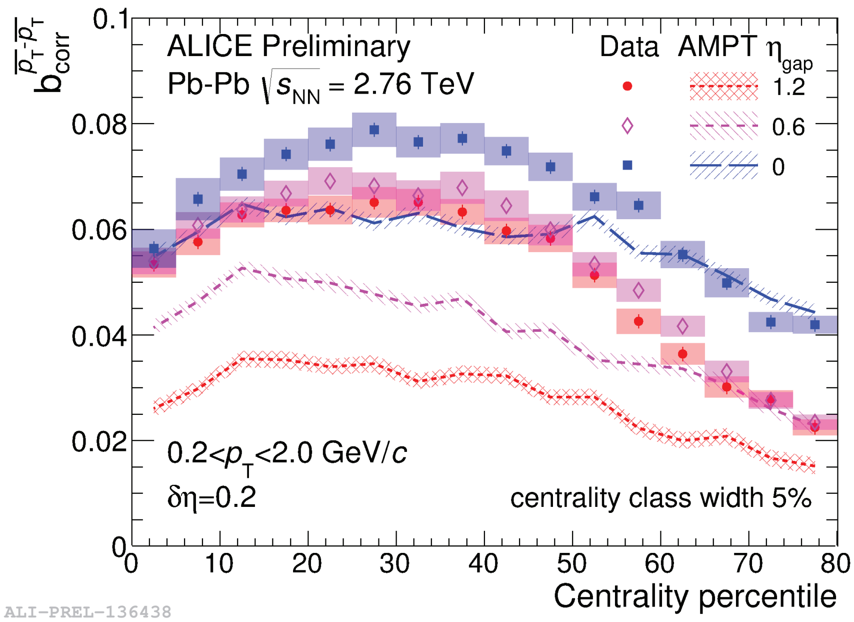
Figure 3: Dependence of $b_{corr}^{\overline{p_T}-\overline{p_T}}$ on centrality for classes of 10, 5 and 2% widths, determined by the V0 (a). Results for centrality classes of 5% width determined by the V0, ZDCvsZEM and CL1 estimators (b).

4. Summary

In summary, it is shown that the strength of forward-backward correlations between multiplicities heavily depends on the centrality determination procedure (type of centrality estimator and class width), therefore, any physics conclusions should be made very carefully. The FB correlations between mean-p_T have been measured for the first time in ALICE in Pb–Pb collisions. Correlations of this type are robust against volume fluctuations and thus the centrality determination methods, and, therefore, provide higher sensitivity to the properties of the initial state and evolution of the medium



(a)



(b)

Figure 4: Centrality dependence of $b_{corr}^{\overline{p_T}-\overline{p_T}}$ (a) at two energies of Pb–Pb collisions $\sqrt{s_{NN}}$ =2.76 and 5.02 TeV, and (b) for three η gaps between F and B windows η_{gap} =1.2, 0.6 and 0. Lines correspond to calculations with AMPT event generator. Centrality by the V0 detector.

created in A-A collisions. The correlation strength rises from peripheral to mid-central and drops towards central collisions. This evolution with centrality is described by some models qualitatively, but not quantitatively.

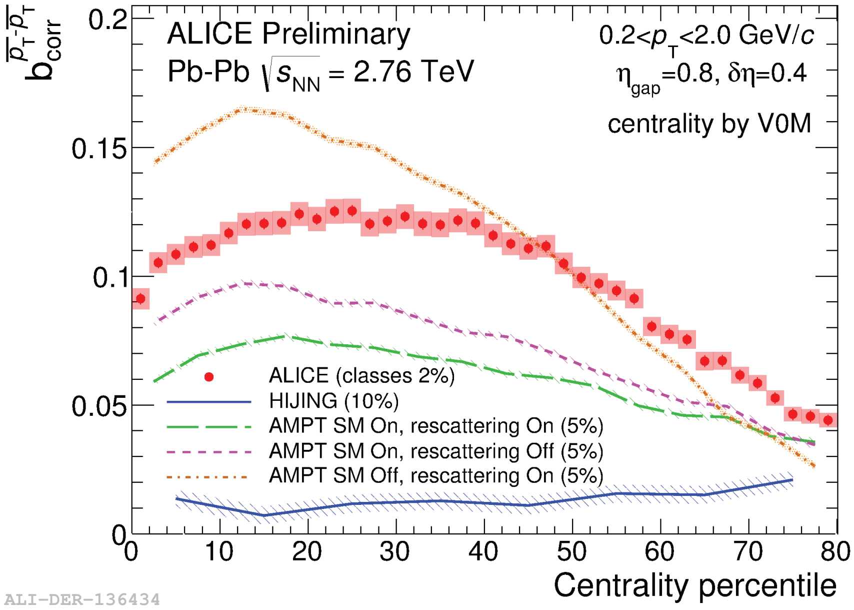


Figure 5: Correlation strength $b_{corr}^{\overline{p_T}-\overline{p_T}}$ between the FB windows (-0.8, -0.4) and (0.4, 0.8) in comparison with event generators: HIJING (blue solid line) and tunes of the AMPT (dashed lines).

Acknowledgements

This work is supported by the Russian Science Foundation, grant 17-72-20045.

References

[1] A. Dumitru *et al.*, *Nucl. Phys.* A **810** 91–108 (2008).

[2] L. McLerran, *Nucl. Phys.* A **699** 73 (2002).

[3] M. Braun *et al.*, *Phys. Lett.* B **287** 154 (1992).

[4] UA5 Collaboration, *Z.Phys.* C **37** 191 (1988).

[5] ALICE Collaboration, *JHEP* **1505** 097 (2015).

[6] STAR Collaboration, *Phys. Rev. Lett.* **103** 172301 (2009).

[7] ALICE Collaboration, *J. Phys. G: Nucl. Part. Phys.* **32** 1295 (2006).

[8] ALICE Collaboration, *Int. J. Mod. Phys.* A **29** 1430044 (2014).

[9] ALICE Collaboration, *Phys. Rev. C* **88**, 044909 (2013).

[10] P. Bozek, W. Broniowski, *Phys. Rev.* C **96**, 014904 (2017), arXiv:1701.09105.

[11] V. Kovalenko, V. Vechernin, *EPJ Web of Conferences* **66** 04015 (2014), arXiv:1308.6618.

[12] V. Kovalenko, V. Vechernin, *J. Phys. Conf. Ser.* **798** 012053 (2017), arXiv:1611.07274.