EPJ Web of Conferences **126**, 04044 (2016)
ICNFP 2015
DOI: 10.1051/epjconf/201612604044

Correlations and fluctuations in p+p and Be+Be at the SPS energies from NA61/SHINE

Andrey Seryakov[1,a], for the NA61/SHINE Collaboration

[1] *Saint Petersburg State University, ul. Ulyanovskaya 1, 198504, Saint Petersburg, Russia*

Abstract. Preliminary results of three different analyses are presented for the lightest collision systems studied in the energy-system size scan program of NA61/SHINE: two-particle correlations in p+p collisions at 20 – 158 GeV/c beam momentum, pseudorapidity correlations in Be+Be collisions at 150A GeV/c and transverse momentum and multiplicity fluctuations of charged particles in p+p (20 – 158 GeV/c) and Be+Be (19A – 150A GeV/c) collisions at the CERN SPS.

1 Introduction

The main goal of the NA61/SHINE fixed target experiment is to uncover properties of the onset of deconfinement by systematic study of collision energy and nuclear mass dependence of hadron production in the region of the threshold for quark-gluon plasma creation. A second aim is to find evidence of a critical point of strongly interaction matter. In this contribution a selected set of preliminary results on fluctuations and correlations from NA61/SHINE [1] is presented. They include:

- Two-particle correlations in p+p collisions at the SPS energy. Their study is widely used in current experiments (RHIC, LHC), as a tool to estimate the influence on multiplicity correlations of different particle sources in heavy ion collisions (see some NA61/SHINE results presented earlier in Refs. [2, 3]).
- Correlations in pseudorapidity in Be+Be collisions at 150A GeV/c. Their study is an effective method for probing the initial conditions for the formation of the QGP [4, 5].
- Multiplicity and transverse momentum fluctuations in p+p [6] and Be+Be collisions at the SPS energy. This analysis is based on measurements of strongly intensive quantities [7], which are preferable to the scaled variance ω, an intensive measure. Intensive quantities are independent of the system size, strongly intensive quantities are in addition independent of the unavoidable system volume fluctuations. The expected signal of the critical point is a non-monotonic dependence of fluctuation measures [8] on the energy and/or the size of the collision system.

1.1 Two-particle correlations

These correlations are defined for two different particles from the same event, that have a difference in pseudo-rapidity $\Delta\eta = \eta_1 - \eta_2$ and azimuthal angle $\Delta\phi = \phi_1 - \phi_2$. The correlation function is calculated

[a] e-mail: seryakov@yahoo.com, andrey.seryakov@spbu.ru

as:

$$C(\Delta\eta,\Delta\phi) = \frac{N^{pairs}_{mixed}}{N^{pairs}_{data}} \frac{S(\Delta\eta,\Delta\phi)}{M(\Delta\eta,\Delta\phi)}; S(\Delta\eta,\Delta\phi) = \frac{d^2N^{signal}}{d\Delta\eta d\Delta\phi}; M(\Delta\eta,\Delta\phi) = \frac{d^2N^{mixed}}{d\Delta\eta d\Delta\phi}; \quad (1)$$

where $S(\Delta\eta,\Delta\phi)$ and $M(\Delta\eta,\Delta\phi)$ are the distributions for pairs from data and mixed events, respectively. The $\Delta\phi$ range is folded. Pseudorapidity is calculated in the center of mass system with the pion mass assumed for all charged particles, allowing to compare our results with the RHIC and LHC results.

1.2 Pseudorapidity correlations

Correlations in pseudorapidity were studied between observables B and F in different pseudo-rapidity windows. The correlation coefficient is calculated as:

$$b_{rel}[B,F] = \frac{<F>}{<B>} \frac{<BF> - <B><F>}{<F^2> - <F>^2}, \quad (2)$$

where $<B>$ and $<F>$ are the event averages in the «backward» and «forward» pseudorapidity windows respectively. In this work we present three types of pseudorapidity correlations:

- Backward multiplicity N_B and forward multiplicity N_F: $b_{rel}[N_B, N_F]$.
- Backward mean transverse momentum $Pt_B = \frac{\sum_{i=1}^{N_B} pt_{B_i}}{N_B}$ and N_F: $b_{rel}[Pt_B, N_F]$.
- Backward and forward mean transverse momenta Pt_B and Pt_F: $b_{rel}[Pt_B, Pt_F]$.

1.3 Multiplicity and transverse momentum fluctuations

The strongly intensive quantities Δ and Σ proposed in Refs. [9] are defined as:

$$\Delta[A,B] = \frac{1}{C_\Delta}(<B>\omega[A] - <A>\omega[B]), \quad (3)$$

$$\Sigma[A,B] = \frac{1}{C_\Sigma}(<B>\omega[A] + <A>\omega[B] - 2(<AB> - <A><B>)), \quad (4)$$

where A and B are extensive event variables and $\omega[A] = \frac{<A^2>-<A>^2}{<A>}$ is the scaled variance. For the study of multiplicity-transverse momentum fluctuations we use the scalar sum of transverse momenta $A = Pt = \sum_{i=1}^{N} pt_i$ and the track multiplicity $B = N$ with normalization factors $C_\Delta = C_\Sigma =< N > \omega[pt]$.

2 Analysis procedure

All results were corrected for biases due to trigger, off-line selection, track and event selection etc. by using events obtained from the EPOS 1.99 model event generator and comparing results before and after GEANT detector simulation and reconstruction. Electrons and positrons were removed by a dE/dx cut. Possible effects from hard scattering were reduced by a cut on particle transverse momentum $pt < 1{,}5$ GeV/c. All results were calculated inside the NA61/SHINE acceptance, the influence of which will be shown for the example of the EPOS 1.99 model in the next chapter. Only statistical errors are shown for pseudo-rapidity correlations. More information on the two-particle correlation and fluctuation analysis procedure for p+p collisions can be found in Ref. [6] and Ref. [2] respectively. The centrality of Be+Be collisions was determined by using information from the Projectile Spectator Detector [1].

DOI: 10.1051/epjconf/201612604044

3 Two-particle correlations in p+p collisions

The correlation function $C(\Delta\eta, \Delta\phi)$ for p+p collisions for pair combinations of various charges at 158 GeV/c and for different energies is shown in figures 1 and 2 respectively. There are several notable structures: the first is a maximum at $(\Delta\eta, \Delta\phi) = (0, \pi)$, likely a result of resonance decays and momentum conservation. The maximum is stronger for unlike-sign pairs and significantly weaker for same charge pairs. The second is an enhancement at $(\Delta\eta, \Delta\phi) = (0, 0)$, probably due to Coulomb interactions (unlike-sign pairs) and quantum statistics (same charge pairs). The maximum decreases and the enhancement increases with growing collision energy.

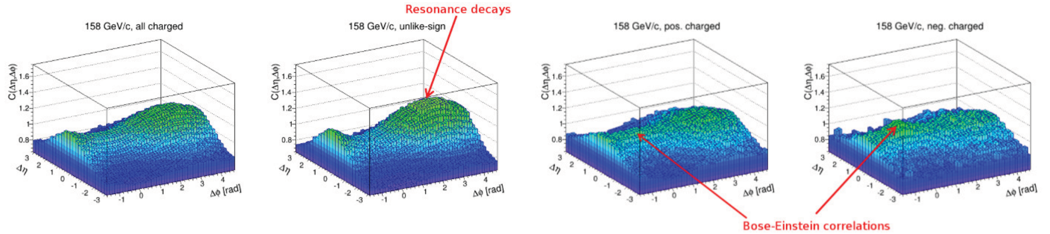

Figure 1. Results on $\Delta\eta\Delta\phi$ correlations for inelastic p+p interactions at 158 GeV/c. From left to right: results for all, unlike-sign, positive and negative charged particles. The maximum at $(\Delta\eta, \Delta\phi) = (0, \pi)$ is probably a result of resonance decays and momentum conservation. The enhancement at $(\Delta\eta, \Delta\phi) = (0, 0)$ is likely due to Coulomb interactions and quantum statistics.

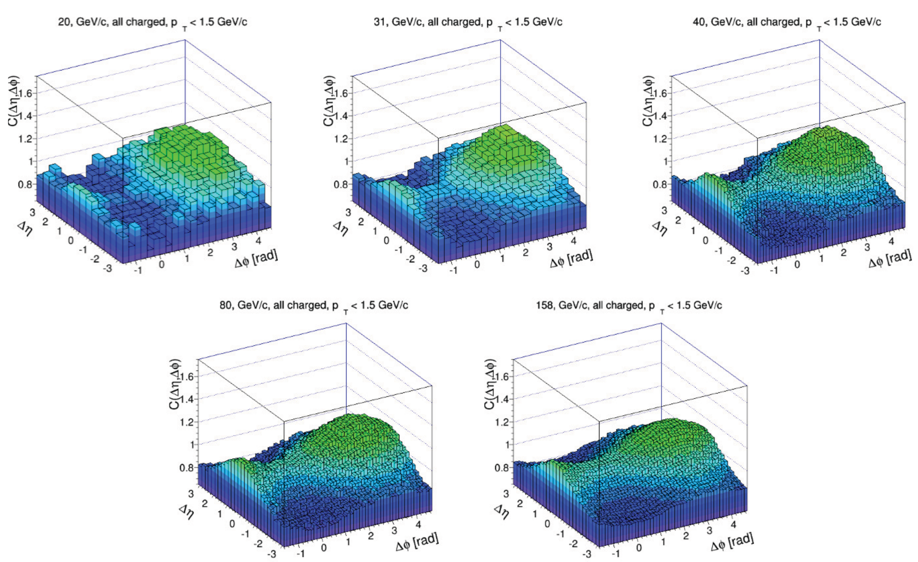

Figure 2. Energy dependence of $\Delta\eta\Delta\phi$ correlations for inelastic p+p interactions.

Results of calculations with the EPOS 1.99 and UrQMD models are also in figure 3 for 20 and 158 GeV beam momentum. A comparison with the data (left column) shows that the EPOS model predictions are consistent with the measurements whereas the UrQMD calculations are not.

 DOI: 10.1051/epjconf/201612604044

The model results in the NA61/SHINE acceptance and 4π acceptance are very similar (compare figure 4 center and right).

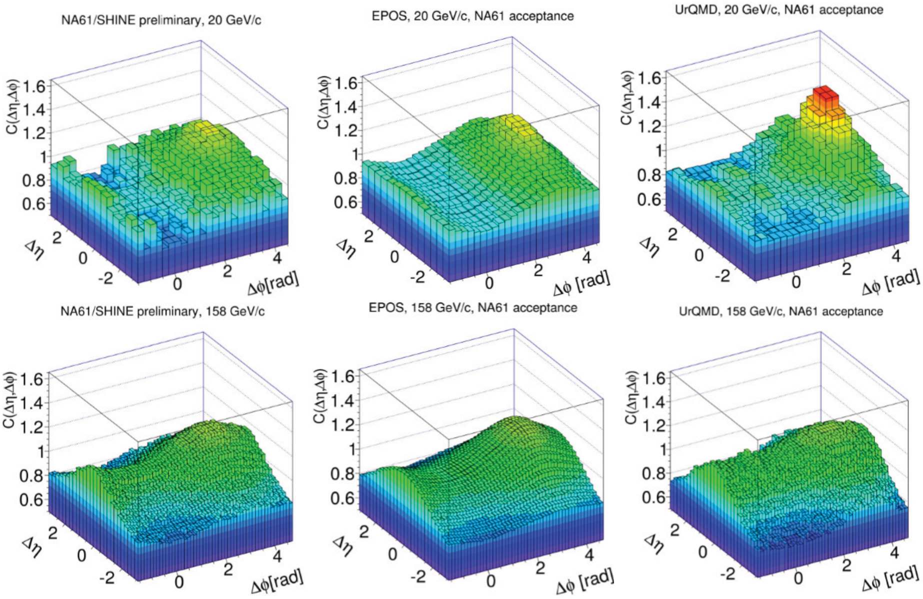

Figure 3. $\Delta\eta\Delta\phi$ correlations for all charged particles in inelastic p+p interactions at 20 (upper row) and 158 (bottom row) GeV/c. NA61/SHINE (left column), EPOS 1.99 inside the NA61/SHINE acceptance (middle column) and UrQMD in the NA61/SHINE acceptance (right column).

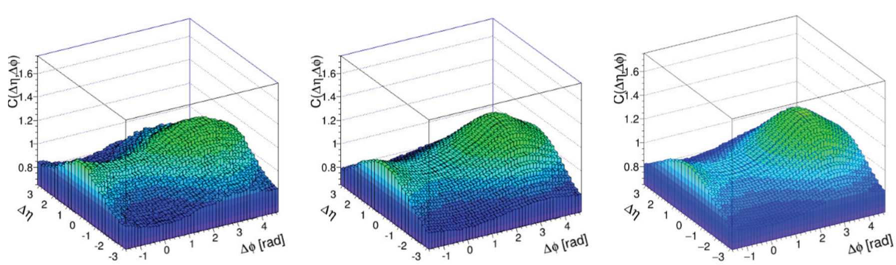

Figure 4. $\Delta\eta\Delta\phi$ correlations for all charged particles inside the NA61/SHINE acceptance in inelastic p+p interactions at 158 GeV/c. NA61/SHINE (left), EPOS 1.99 inside the NA61/SHINE acceptance (middle) and EPOS 1.99 in full 4π acceptance (right).

4 Pseudorapidity correlations in Be+Be 150A GeV/c for the 0-20% most central collisions

In this work two sets of pseudorapidity windows B and F were used: short-range (figure 5 left) and with fixed forward window (figure 5 right). A strong dependence of the correlations on the window position is observed. EPOS 1.99 describes the data only qualitatively. Significant multiplicity–mean transverse momentum long-range correlations were observed (figure 10) that might be a signal of collective effects.

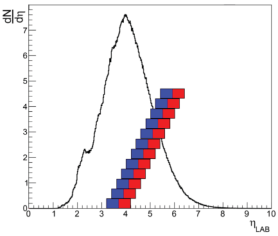

Figure 5. Illustration of connected (left) and disconnected (right) windows configurations superimposed on the inclusive pseudorapidity distribution inside the NA61/SHINE acceptance.

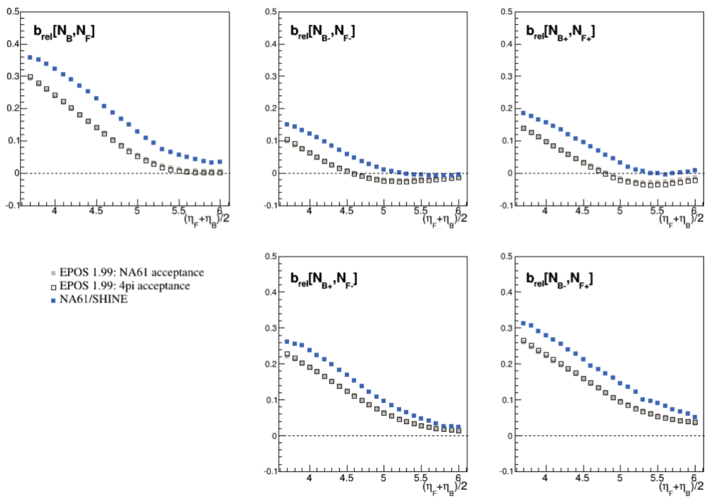

Figure 6. Correlation coefficient of multiplicities for different charge combinations as a function of pseudorapidity of the B and F windows connection point (see figure 5 left) for the 0-20% most central Be7+Be9 collisions at 150A GeV/c. EPOS 1.99 model predictions inside the NA61/SHINE acceptance (grey squares) and in 4π-acceptance (open squares) are shown for comparison.

DOI: 10.1051/epjconf/201612604044

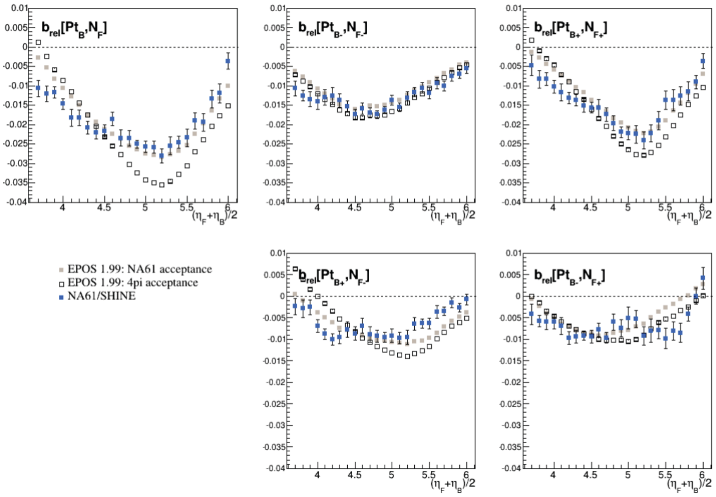

Figure 7. Correlation coefficient of event mean transverse momenta and multiplicity for different charge combinations as a function of pseudorapidity of the *B* and *F* windows connection point (see figure 5 left) for the 0-20% most central Be7+Be9 collisions at 150A GeV/c. EPOS 1.99 model predictions inside the NA61/SHINE acceptance (grey squares) and in 4π-acceptance (open squares) are shown for comparison.

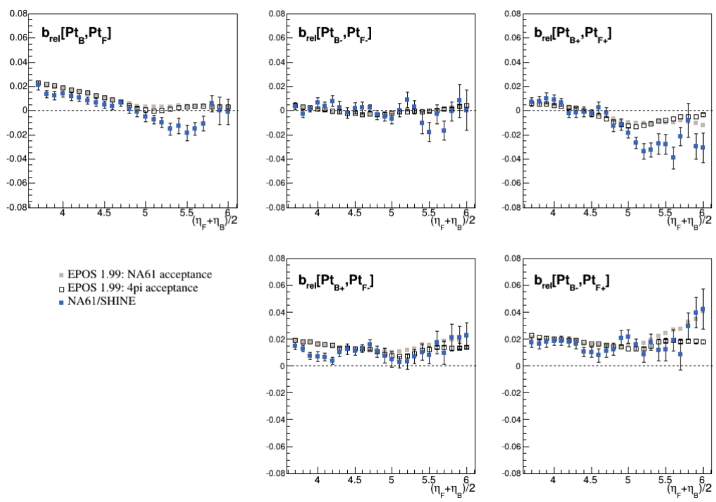

Figure 8. Correlation coefficient of event mean transverse momenta for different charge combinations as a function of pseudorapidity of the *B* and *F* windows connection point (see figure 5 left) for the 0-20% most central Be7+Be9 collisions at 150A GeV/c. EPOS 1.99 model predictions inside the NA61/SHINE acceptance (grey squares) and in 4π-acceptance (open squares) are shown for comparison.

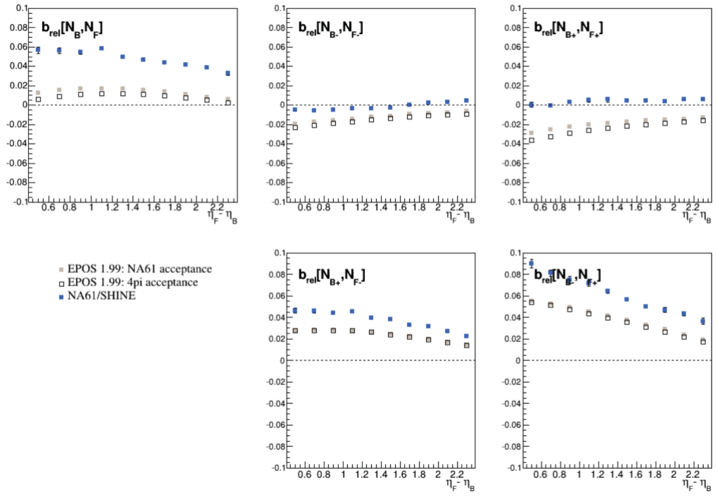

Figure 9. Correlation coefficient of multiplicities for different charge combinations as a function of pseudorapidity distance between B and F windows (see figure 5 right) for the 0-20% most central Be7+Be9 collisions at 150A GeV/c. EPOS 1.99 model predictions inside the NA61/SHINE acceptance (grey squares) and in 4π-acceptance (open squares) are shown for comparison.

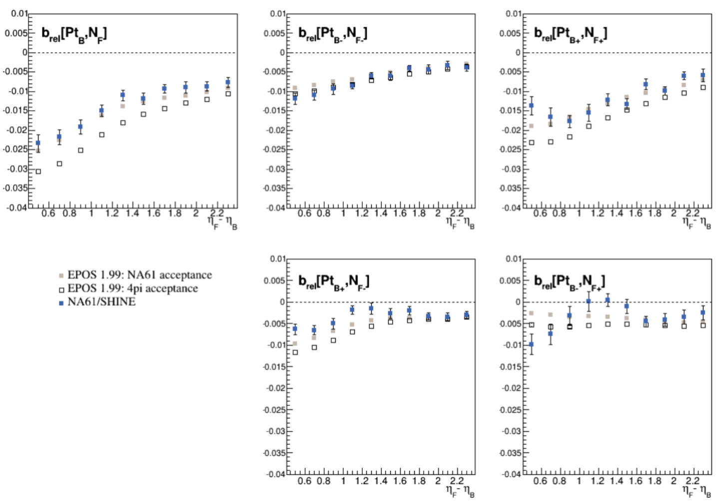

Figure 10. Correlation coefficient of event mean transverse momenta and multiplicity for different charge combinations as a function of pseudorapidity distance between B and F windows (see figure 5 right) for the 0-20% most central Be7+Be9 collisions at 150A GeV/c. EPOS 1.99 model predictions inside the NA61/SHINE acceptance (grey squares) and in 4π-acceptance (open squares) are shown for comparison.

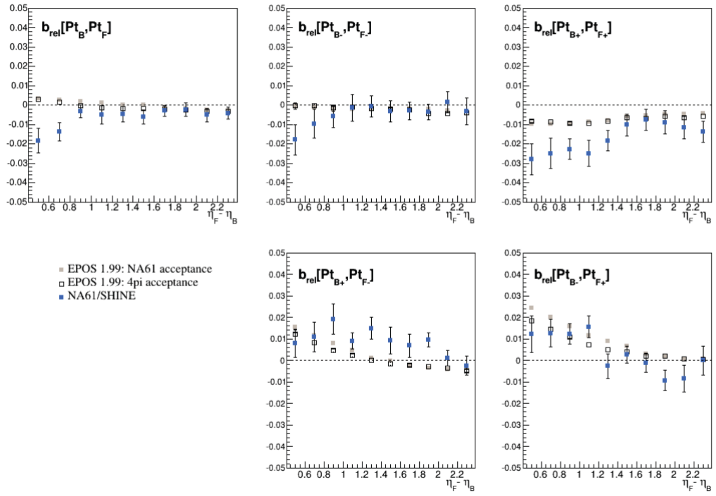

Figure 11. Correlation coefficient of event mean transverse momenta for different charge combinations as a function of pseudorapidity distance between B and F windows (see figure 5 right) for the 0-20% most central Be7+Be9 collisions at 150A GeV/c. EPOS 1.99 model predictions inside the NA61/SHINE acceptance (grey squares) and in 4π-acceptance (open squares) are shown for comparison.

5 Strongly intensive measures of transverse momentum and multiplicity fluctuations in p+p and Be+Be collisions

Measurements of the strongly intensive quantities $\Delta[Pt, N]$ and $\Sigma[Pt, N]$ are presented in figure 12 as a function of the center of mass energy and the number of wounded nucleons [8]. The dependence is flat, therefore these quantities does not show any evidence of the critical point in p+p and Be+Be collisions at the SPS energies.

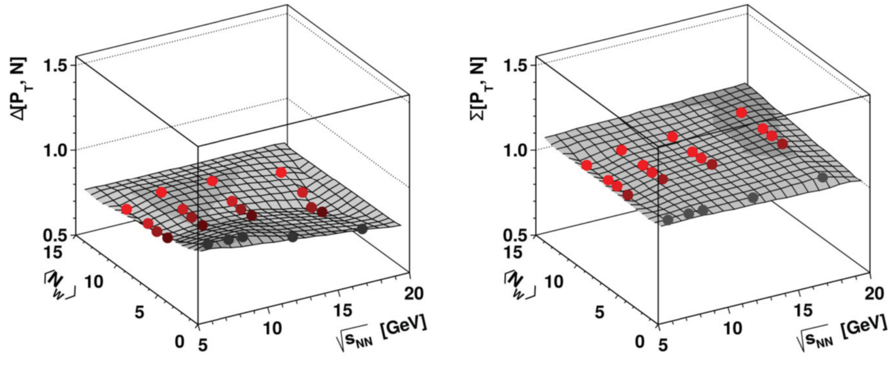

Figure 12. Strongly intensive fluctuation measures $\Delta[Pt, N]$ (left) and $\Sigma[Pt, N]$ (right) for p+p and Be+Be (preliminary results) collisions at several center of mass energies and collision centralities (defined via the mean number of participating nucleons N_w). The flat behaviour means no evidence of the critical point in this region.

6 Conclusions

The 2-particle correlations as function of pseudorapidity and azimuthal angle difference in proton-proton reactions at the SPS energies show structures coming mainly from resonance decays, conservation laws, quantum statistics and Coulomb interactions. Significant multiplicity–mean transverse momentum long-range correlations were observed in Be+Be collisions at 150A GeV/c (figure 10) that can be considered as a signal of collective effects. Strongly intensive fluctuation measures $\Delta[Pt, N]$ and $\Sigma[Pt, N]$ do not show any evidence of the critical point in p+p and Be+Be collisions at the SPS energies.

Acknowledgments

This work was supported by the Federal Agency of Education of the Ministry of Education and Science of the Russian Federation and SPbSU research grant 11.38.193.2014.

References

[1] N.Abgrall et al. (NA61 Coll.), JINST **9**, P06005 (2014).
[2] B.Maksiak for the NA61/SHINE Collaboration, Proceedings of Science PoS (CPOD2014) 055.
[3] A.Seryakov for the NA61/SHINE Collaboration, arXiv:1510.00847 [nucl-ex], J. Phys.: Conf. Ser. **668**, 012077 (2016).
[4] M.Braun and C.Pajares, Phys.Lett.B **287**, 154 (1992).
[5] L.McLerran, Nucl.Phys.A **699**, 73c (2002)
[6] A.Aduszkiewicz et al. (NA61 Coll.), arXiv:1510.00163v2 [hep-ex], submitted to Eur.Phys.J. C (2016).
[7] M.Gorenstein and M.Gazdzicki, Phys.Rev.C **84**, 014904 (2011).
[8] M.Gazdzicki and P.Seyboth, arXiv:1506.08141 [nucl-ex] (2015).
[9] M.Gazdzicki, M.Gorenstein, and M.Mackowiak-Pawlowska, Phys. Rev. C **88**, 024907 (2013).