RAPIDITY FLUCTUATIONS IN THE INITIAL STATE* **

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We analyze two-particle pseudorapidity correlations in a simple model, where strings of fluctuating length are attached to wounded nucleons. The obtained straightforward formulas allow us to understand the anatomy of the correlations, *i.e.*, to identify the component due to the fluctuation of the number of wounded nucleons and the contribution from the string length fluctuations. Our results reproduce qualitatively and semiquantitatively the basic features of the recent correlation measurements at the LHC.

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In this paper (for details, see Ref. [1]), we analyze the recently measured two-particle pseudorapidity correlations [2,3] in a simple model with wounded nucleons pulling strings of fluctuating length. The charges pulling the strings can be interpreted as the wounded nucleons [4] (*cf.* Fig. 1). Importantly, the longitudinal position of the other end-point of the string is randomly distributed over the available space-time rapidity range. The assumption that

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the initial entropy distribution is generated by strings whose end-points are randomly distributed is similar to the mechanism of Ref. [5]. It was also used in modeling the particle production in the fragmentation region [6].

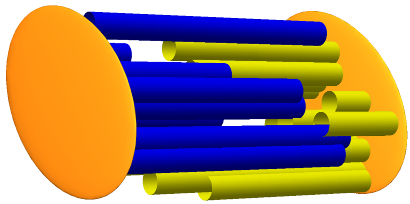

Fig. 1. Strings of fluctuating end-points extending along the space-time rapidity.

The two-particle correlation is defined as

$$C(\eta_1,\eta_2) = \frac{\langle \rho(\eta_1,\eta_2)\rangle}{\langle \rho(\eta_1)\rangle \langle \rho(\eta_2)\rangle}\,, \tag{1}$$

where $\rho(\eta_1,\eta_2)$ and $\rho(\eta)$ denote the distribution functions for pairs and single particles, and $\langle . \rangle$ stands for averaging over events. To minimize spurious effects, the ATLAS Collaboration [2] uses a measure obtained from $C(\eta_1,\eta_2)$ by dividing it with its marginal projections, namely

$$C_N(\eta_1,\eta_2) = \frac{C(\eta_1,\eta_2)}{C_p(\eta_1)C_p(\eta_2)}\,, \tag{2}$$

where $C_p(\eta_{1,2}) = \int_{-Y}^{Y} \mathrm{d}\eta_{2,1}\, C(\eta_1,\eta_2)$ and $Y = 2.4$ determines the experimental acceptance range for $\eta_{1,2}$. Moreover, the correlation functions are conventionally normalized to unity,

$$\overline{C}(\eta_1,\eta_2) = \frac{C(\eta_1,\eta_2)}{\int_{-Y}^{Y}\mathrm{d}\eta_1 \int_{-Y}^{Y}\mathrm{d}\eta_2\, C(\eta_1,\eta_2)}\,, \tag{3}$$

and analogously for $\overline{C}_N(\eta_1,\eta_2)$.

The details of the derivation of the formulas for the correlation function listed below are presented in Ref. [1]. The number of wounded nucleons in the two colliding nuclei is denoted as N_A and N_B, and $N_\pm = N_A \pm N_B$. The cases with $r = 1$ and $r = 0$ correspond to, respectively, present or absent string length fluctuations. We introduce the scaled rapidities

$$u_{1,2} = \eta_{1,2}/y_b\,, \tag{4}$$

with y_b denoting the rapidity of the beam. Then, in the general case,

$$C(\eta_1,\eta_2) = 1 + \frac{1}{[\langle N_+\rangle + \langle N_-\rangle\, u_1]\,[\langle N_+\rangle + \langle N_-\rangle\, u_2]}$$

$$\times\Big\{ \langle N_+\rangle \left[r(1-u_1u_2-|u_1-u_2|)+s(\omega)(1+r+s(1-r)u_1u_2-r|u_1-u_2|)\right]$$
$$+\langle N_-\rangle\, s(\omega)(u_1+u_2)+\mathrm{var}(N_+)+\mathrm{var}(N_-)u_1u_2+\mathrm{cov}(N_+,N_-)(u_1+u_2)\Big\}\,, \quad (5)$$

whereas for symmetric collisions ($A = B$), the formula simplifies into

$$C(\eta_1,\eta_2) = 1+\frac{1}{\langle N_+\rangle^2}$$
$$\times\Big\{ \langle N_+\rangle \left[r(1-u_1u_2-|u_1-u_2|)+ s(\omega)(1+r+(1-r)u_1u_2-r|u_1-u_2|)\right]$$
$$+\mathrm{var}(N_+)+\mathrm{var}(N_-)u_1u_2\Big\}\,. \quad (6)$$

To reproduce multiplicity distributions, in particular in p–Pb collisions [1], one needs to overlay a distribution of strength over the Glauber sources, described with a random variable ω, typically taken in the form of a negative binomial. The interpretation here is that the sources (strings) may deposit a randomly fluctuating amount of entropy. The quantity $s(\omega)$ stands for the square of the scaled standard deviation of ω, *i.e.*, $s(\omega) = \mathrm{var}(\omega)/\langle\omega\rangle^2$.

As originally noticed in Ref. [7], fluctuation in the number of wounded nucleons alone ($r = 0$, $s(\omega) = 0$) generates non-trivial longitudinal correlations. Our formula shows, however, that a significant (and long-range in rapidity) part comes from the length fluctuations. The results are depicted in Fig. 2. Results of a similar study for the asymmetric case of p–Pb collisions are shown in Fig. 3.

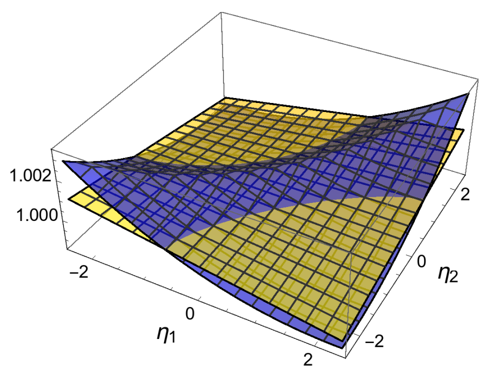

Fig. 2. Correlation function $\overline{C}_N(\eta_1,\eta_2)$ for Pb–Pb collisions at 2.76 TeV for $c = 30$–40%. The flat (lighter color) sheet corresponds to the calculation without the length fluctuations. The sheet with an elongated ridge (darker color) corresponds to the case with the string length fluctuations.

Analytic expressions may be obtained [1] for the a_{nm} coefficients of the expansion in a set of orthonormal polynomials [7, 8].

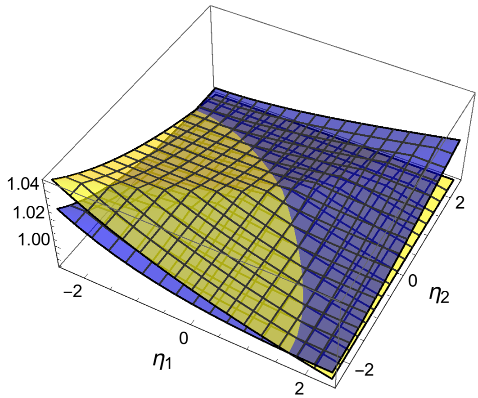

Fig. 3. Correlation functions $\overline{C}(\eta_1, \eta_2)$ (lighter color) and $\overline{C}_N(\eta_1, \eta_2)$ (darker color) for p–Pb collisions at 5.02 TeV.

The features found in our simple model are manifest in advanced models implementing string decays in the early phase of the high-energy collisions [9–12]. Our formulas provide an intuitive understanding for these mechanisms.

We cordially wish Janek Pluta all the best on the occasion of his anniversary. Let the successful Kraków–Warszawa collaboration, animated by Janek long ago, continue for many years to come.

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