Study of event by event $\langle p_T \rangle$ fluctuations in small collision systems at LHC energies with percolation color sources

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Abstract

We present a study of the event by event mean transverse momentum fluctuations in high multiplicity pp and p-Pb collision systems at LHC energies in the framework of the String Percolation Model as a function of multiplicity. We found that data can be naturally described by the clustering of color sources that take place in the small collision systems in a similar manner as it does in heavy ion collisions.

Event by event $\langle p_T \rangle$ fluctuations

The study of event by event fluctuations was proposed as a probe of the properties of the hot and dense matter generated in high-energy heavy-ion collisions. The phase transition of the strong interacting matter or the existence of a critical point in the phase diagram may go along with critical fluctuations of thermodynamic quantities, which can be reflected in dynamical event-by-event fluctuations of the mean transverse momentum of final-state charged particles. $\langle p_T \rangle$ fluctuations have their origins on p_T correlations of the particles initial states, such as resonances decays or jets.

Color String Percolation Model

Particle production sources on the String Percolation Model (SPM) are color strings stretching between the colliding hadrons. The streched strings break and decay into new partons which produce new strings (Schwinger mechanism).

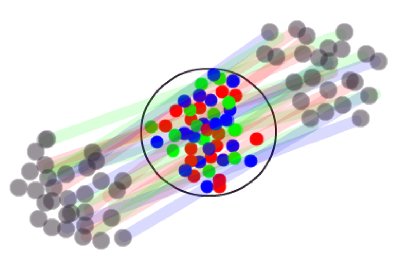

Figure 1: Representative scheme of the color string between partons.

By increasing the energy or the system size, the string density will increases and the strings will start to overlap to form macroscopic clusters.

When a critical disc density $\zeta^t \simeq 1.12 - 1.5$ is reached (homogenous or Woods-Saxon nuclear distribution profile), a conected system is created which marks a phase transition.
The disk density is defined as:

$$\zeta^t = \left(\frac{r_0}{R_p}\right)^2 N_s \quad (1)$$

Other important parameter is the color Reduction factor, which Reduces the color production on clusters with the increasing of the numer of strings.

$$F(\zeta^t) = \sqrt{\frac{1 - e^{-\zeta^t}}{\zeta^t}} \quad (2)$$

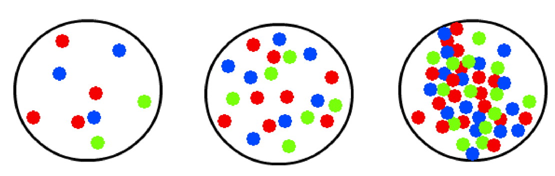

Figure 2: Representative scheme of isolated discs, cluster formation and percolation.

Event by event $\langle p_T \rangle$ fluctuations on the SPM

The variable F_{p_T} measures the $\langle p_T \rangle$ fluctuations as a function of the number of participants on collisions. F_{p_T} quantifies the observed fluctuations deviations of the statistically independent particle emission.

$$F_{p_T} = \frac{\omega_{data} - \omega_{random}}{\omega_{random}} \quad (3)$$

where ω is given by $\omega = \frac{\sqrt{\langle p_T^2 \rangle - \langle p_T \rangle^2}}{\langle p_T \rangle}$.

$$F_{p_T} = \frac{\phi}{\sqrt{\langle z^2 \rangle}} = \frac{1}{\sqrt{\langle z^2 \rangle}}\sqrt{\frac{\langle Z^2 \rangle}{\langle \mu \rangle}} - 1 \quad (4)$$

For each particle we define a $z_i = p_{T_i} - \langle p_T \rangle$ and also a $Z_i = \sum_{j=1}^{N_i} z_j$, with N_i the numer of particles produced in an event i.

$$\langle z^2 \rangle = \frac{\sum_{i=1}^{N_{eventos}} \sum_j \left(\frac{n_j S_{nj}}{S_1}\right)^{1/2} \mu_1 \left[\left(\frac{n_j S_1}{S_{nj}}\right)^{1/4} \langle p_T \rangle_1 - \langle p_T \rangle\right]^2}{\sum_{i=1}^{N_{eventos}} \sum_j \left(\frac{n_j S_{nj}}{S_1}\right)^{1/2} \mu_1} \quad (5)$$

$$\frac{\langle Z^2 \rangle}{\langle \mu \rangle} = \frac{\sum_{i=1}^{N_{eventos}} \left[\sum_j \left(\frac{n_j S_j}{S_1}\right)^{1/2} \mu_1 \left[\left(\frac{n_j S_1}{S_{n_j}}\right)^{1/4} \langle p_T \rangle_1 - \langle p_T \rangle\right]\right]^2}{\left[\sum_{i=1}^{N_{eventos}} \sum_j \left(\frac{n_j S_{n_j}}{S_1}\right)^{1/2} \mu_1\right]} \quad (6)$$

Comparison with data

By fitting the transverse momentum distributions data [4], we obtain the string density corresponding to the different multiplicities for pp collisions at $\sqrt{s} = 0.9$, 2.76 and 7 TeV. We aproach the terms $\langle \sum_j n_j \rangle$ and $\frac{S_{nj}}{S_1}$ from equations (5) and (6) as $\langle \sum_j n_j \rangle \sim N_s$ and $\frac{S_{nj}}{S_1} \sim \epsilon \left(\frac{R_p}{r_0}\right)^2$, with ϵ an effective centrality.

$$\epsilon = \left(\frac{R_p}{r_0}\right)^2 \frac{\zeta^t}{N_s^{max}} = \frac{\zeta^t}{\zeta^t_{max}} \quad (7)$$

With these approximation we can consider F_{p_T} from equation (4) as a function of $\langle p_T \rangle$, N_s and ϵ function, where we have a dependence of ζ^t and $F(\zeta^t)$ in $\langle p_T \rangle$ and ϵ respectively.

$$\sqrt{\frac{\langle Z^2 \rangle}{\langle \mu_1 \rangle}} \simeq \left[N_s \langle p_T \rangle_1^2 \mu_1 - 2N_s^{3/4} \epsilon^{1/4} \left(\frac{R_p}{r_0}\right)^{1/2} \langle p_T \rangle_1 \langle p_T \rangle + + N_s^{1/2} \epsilon^{1/2} \left(\frac{R_p}{r_0}\right) \mu_1 \langle p_T \rangle^2\right]^{1/2} \quad (8)$$

$$\sqrt{\langle z^2 \rangle} \simeq \left[N_s^{1/2} \epsilon^{1/2} \left(\frac{r_0}{R_p}\right) \langle p_T \rangle_1^2 - 2N_s^{1/4} \epsilon^{1/4} \left(\frac{r_0}{R_p}\right)^{\frac{1}{2}} \langle p_T \rangle_1 \langle p_T \rangle + \langle p_T \rangle^2\right]^{1/2} \quad (9)$$

For comparing with the experimental measurements [4], we need to use the two particle correlator C_m for multiplicity class m and the $\langle p_T \rangle$ relative fluctuations ($\sqrt{C_m}/M(p_T)_m$) for multiplicity class m.

We can relate $C = \langle \Delta p_{T,i}, \Delta p_{T,j} \rangle$ with F_{p_T} as:

$$\langle \Delta p_{Ti}, \Delta p_{Tj} \rangle \simeq 2F_{p_T} \frac{var(p_T)}{\langle N \rangle} \quad (10)$$

With $\langle N \rangle$ being the mean multiplicity and $var(p_T)$ the variance of p_T.

Results

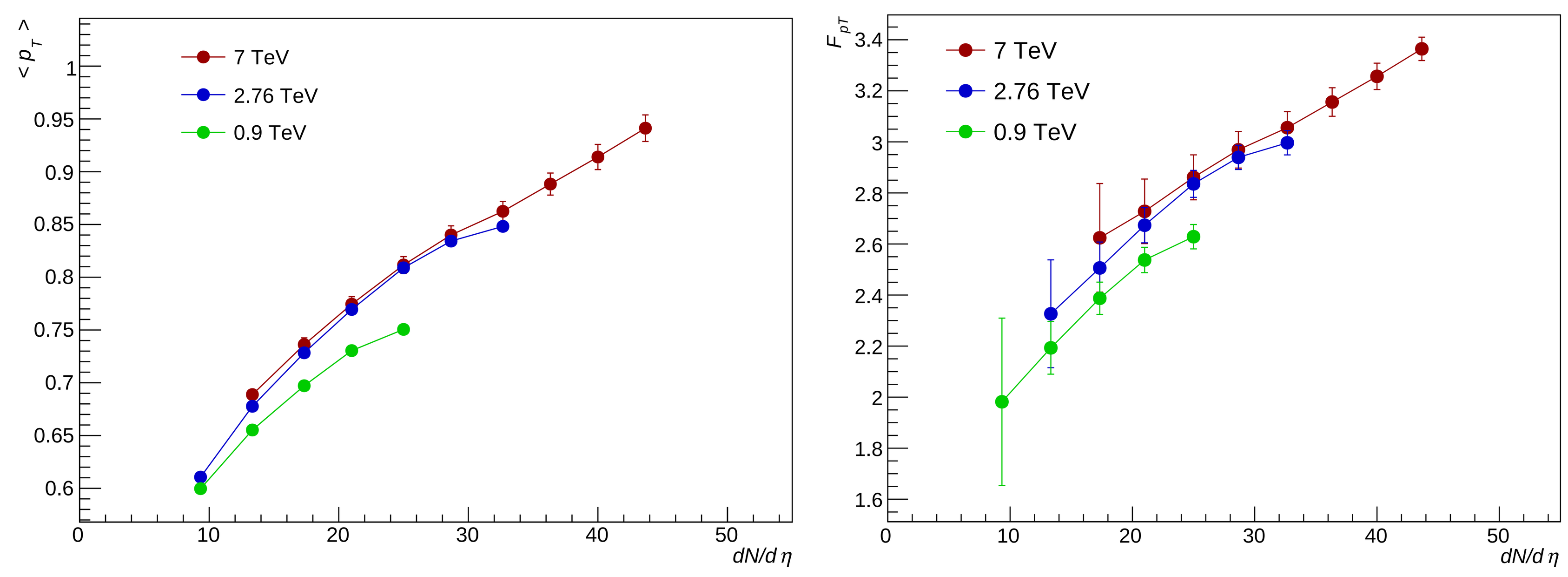

Figure 3: Mean transverse momentum and event by event fluctuation function F_{p_T} with data from [4]

Conclusions

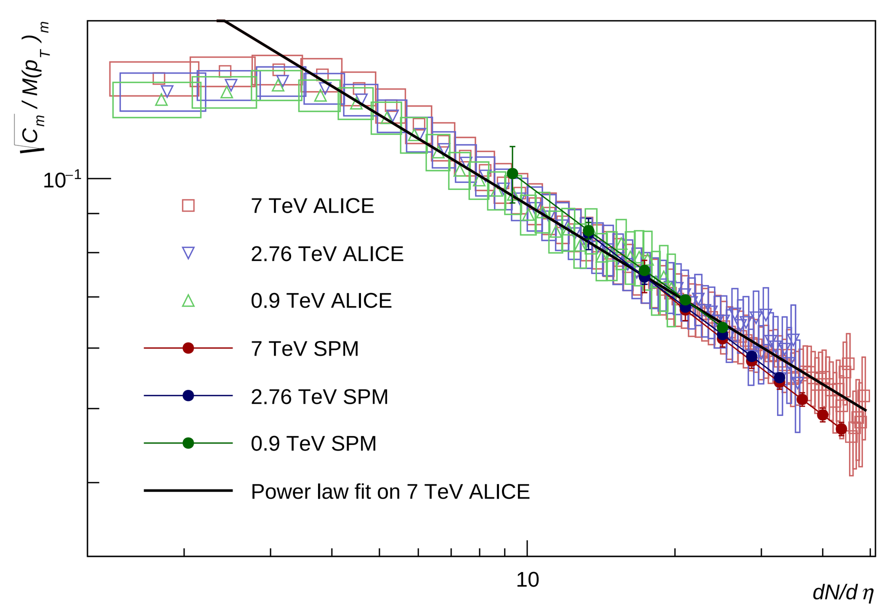

Figure 4: SPM $\sqrt{C_m}/M(p_T)_m$ results with data from [4] adjusted with a power law (ax^b, with $a = 0.227 \pm 0.008$ and $b = -0.39 \pm 0.012$).

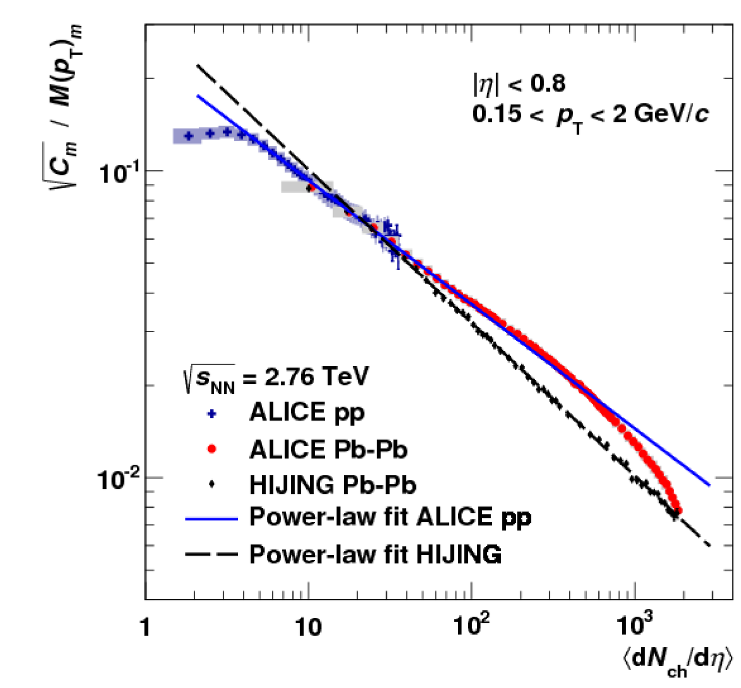

Figure 5: $\sqrt{C_m}/M(p_T)_m$ with the ALICE experimental data [5]

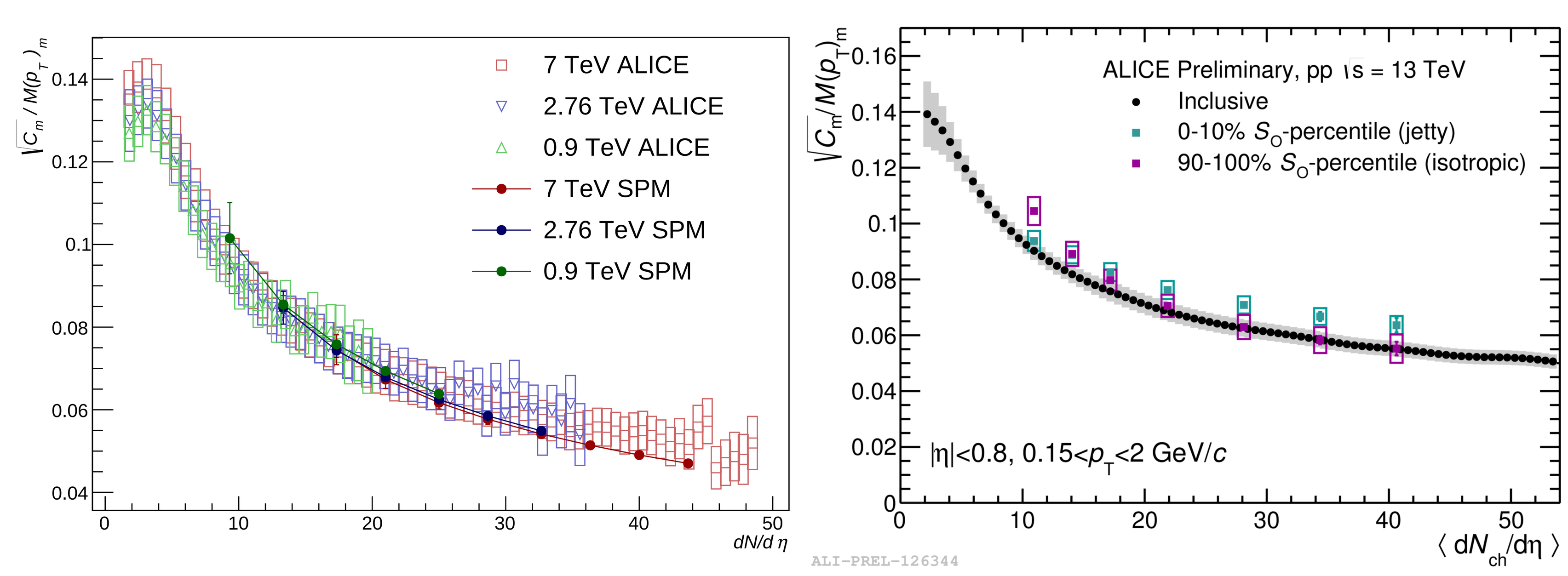

Figure 6: Relative fluctuations $\sqrt{C_m}/M(p_T)_m$ of the SPM compaRed with data from [4]. Event topology contribution for $\sqrt{C_m}/M(p_T)_m$ at 13 TeV with ALICE data [6]

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