Correlations between mean transverse momenta

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3rd International Conference on the Initial Stages in High-Energy Nuclear Collisions - InitialStages2016

1. Abstract and motivation

The study of the correlations between observables in two separated rapidity windows (the so called long-range forward-backward correlations) has been proposed [1] as a signature of the string fusion and percolation phenomenon [2], which is one of the collectivity effects in ultrarelativistic heavy ion collisions. Later it was realized [3-5] that the investigations of the forward-backward correlations between intensive observables, such e.g. as mean-event transverse momenta, enable to obtain more clear signal about the initial stage of hadronic interaction, including the process of string fusion, compared to usual forward-backward multiplicity correlations.

In the present work, as an example, we consider the correlation between mean-event transverse momenta of charged particles in separated rapidity intervals [4,5]:

$$p_{tB} = \frac{1}{n_B}\sum_{i=1}^{n_B}|\mathbf{p}_{tB}^i| \qquad p_{tF} = \frac{1}{n_F}\sum_{i=1}^{n_F}|\mathbf{p}_{tF}^i|$$

We demonstrate that this type of correlation, being robust against the volume fluctuations and the details of the centrality determination, makes a clear signal, allowing comparison between models and the experiment.

The calculations are fulfilled both in the simple model with string fusion by introducing a lattice in transverse plane [5-7] and in the framework of dipole-based Monte Carlo string fusion model [8,9].

References

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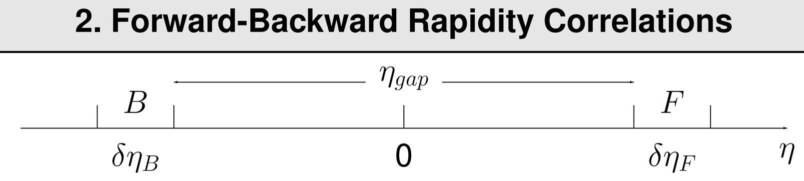
2. Forward-Backward Rapidity Correlations



$\langle B\rangle_F = f(F)$ - the FB correlation function

$\langle B\rangle_F = a + b_{BF}F$ - the linear regression

The correlation coefficient:

$$b_{BF} = \frac{\langle FB\rangle - \langle F\rangle\langle B\rangle}{\langle F^2\rangle - \langle F\rangle^2} = \frac{cov(F,B)}{D_F} \qquad (1)$$

For a correlation between relative variables, $F/\langle F\rangle$ and $B/\langle B\rangle$:

$$b_{FB}^{rel} = \frac{\langle F\rangle}{\langle B\rangle} b_{FB} \ . \qquad (2)$$

Observables: B, F.

n_B, n_F - the extensive variables $\Rightarrow$ b_{nn}

p_{tB}, p_{tF} - the intensive variables $\Rightarrow$ $b_{p_tp_t}$

The Long-Range multiplicity Correlations (LRC): b_{nn} at large η_{gap}.
A. Capella and A. Krzywicki, Phys.Rev.D**18**, 4120 (1978)

The locality of strong interaction in rapidity $\Rightarrow$ SRC
(SRC - Short-Range Correlations).

The event-by-event variance in the number of cut pomerons (strings) $\Rightarrow$ LRC.

But event-by-event fluctuations in the number of cut pomerons (strings) (the "volume" fluctuations) do not lead to the correlation between the intensive variables, e.g. the p_{tB}-p_{tF} correlation ($b_{p_tp_t}$).

So the LR p_{tB}-p_{tF} correlation indicates the fluctuations in "quality" of sources.

3. Versions of string fusion

local fusion (overlaps)
M.A. Braun, C. Pajares Eur.Phys.J.**C16**, 349, (2000)

$$\langle n\rangle_k = \mu_0\sqrt{k}\ S_k/\sigma_0\ , \quad \langle p_t^2\rangle_k = p_0^2\sqrt{k}\ , \quad k = 1,2,3,... \qquad (3)$$

global fusion (clusters)
M.A.Braun, F. del Moral, C.Pajares, Phys.Rev.**C65**, 024907, (2002)

$$\langle p_t^2\rangle_{cl} = p_0^2\sqrt{k_{cl}}\ , \quad \langle n\rangle_{cl} = \mu_0\sqrt{k_{cl}}S_{cl}/\sigma_0\ , \quad k_{cl} = k\sigma_0/S_{cl} \qquad (4)$$

The version of SFM with the finite lattice in transverse plane [5-7]

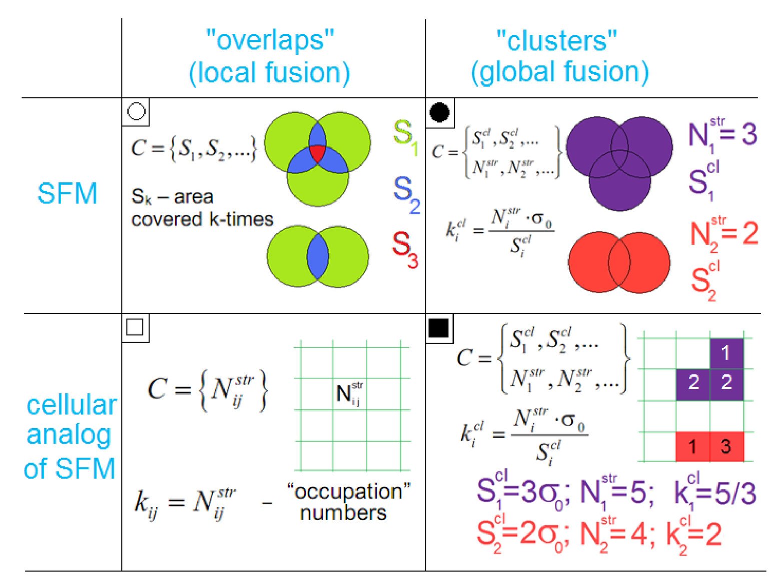


Figure 1: *Various versions of string fusion*

4. The model

Averaging over the configurations:

$$C_\eta = \{\eta_1, ..., \eta_M\}\ , \qquad (5)$$

$$C = \{C_\eta, C_n^F, C_n^B, C_p^F, C_p^B\}\ , \qquad (6)$$

$$C_n^F = \{n_1^F, ..., n_M^F\}\ ,\ C_n^B = \{n_1^B, ..., n_M^B\}\ , \qquad (7)$$

$$C_p^F = \{p_1^{1F}, ..., p_1^{n_1^F F}; ...; p_M^{1F}, ..., p_M^{n_M^F F}\}\ . \qquad (8)$$

Then

$$n_F = \sum_{i=1}^{M} n_i^F\ , \quad p_F \equiv \frac{1}{n_F}\sum_{i=1}^{M}\sum_{j=1}^{n_i^F} p_i^{jF} \qquad (9)$$

and the same for the p_B and n_B. The Gaussian weights:

$$P(C_\eta) = \prod_{i=1}^{M}\frac{1}{\sqrt{2\pi d_{\eta_i}}}\exp\left\{-\frac{(\eta_i - \overline{\eta}_i)^2}{2d_{\eta_i}}\right\}, \qquad (10)$$

$$d_{\eta_i} \equiv \overline{\eta_i^2} - \overline{\eta}_i^2 = \omega_\eta\overline{\eta}_i \gg 1\ . \qquad (11)$$

$$\sum_{C_\eta} = \prod_{i=1}^{M}\sum_{\eta_i=0}^{\infty} \Rightarrow \prod_{i=1}^{M}\int_0^\infty d\eta_i \qquad (12)$$

$$P_{C_\eta}(C_n^F) = \prod_{i=1}^{M}\frac{1}{\sqrt{2\pi d_{n_i^F}(\eta_i)}}\exp\left\{-\frac{[n_i^F - \overline{n}_i^F(\eta_i)]^2}{2d_{n_i^F}(\eta_i)}\right\}. \qquad (13)$$

$$d_{n_i^F}(\eta_i) = \omega_\mu\overline{n}_i^F(\eta_i) \gg 1\ . \qquad (14)$$

$$\overline{n}_i^F = \mu_F\,\overline{n}(\eta_i) = \mu_F\sqrt{\eta_i} \qquad (15)$$

and the same for $\overline{n}_i^B$. For transverse momentum distributions with one dimentional parameter $\tilde{p}$, due to dimensional reasons:

$$d_{p_i}(\eta_i) = \gamma\overline{p}^2(\eta_i)\ , \qquad (16)$$

where in string fusion model it is supposed that $\tilde{p} \sim \sqrt[4]{\eta_i}$ and hence

$$\overline{p}(\eta_i) = p_0\sqrt[4]{\eta_i}\ . \qquad (17)$$

The $\gamma \sim 1/2$ and depends only of the shape of the distribution:

$\varphi(p)$	γ
$\sim \exp(-p^2/\tilde{p}^2)$	$\frac{4-\pi}{\pi}$
$\sim \exp(-p/\tilde{p})$	$\frac{1}{2}$
$\sim [1/(1+p/\tilde{p})]^m$	$\frac{m-1}{2(m-4)}$

5. The asymptotic of the p_t-p_t correlation coefficient

For large homogeneous string density, $\overline{\eta}_i = \overline{\eta} \gg 1$ we find the following explicit analytical asymptotic of the LR correlation coefficient between mean-event transverse momenta [7]:

$$b_{p_tp_t}^{rel} = \frac{\omega_\eta\mu_F}{\omega_\eta\mu_F + 16\gamma\sqrt{\overline{\eta}}} = \frac{a}{1+a} \qquad a = \frac{\omega_\eta\mu_F}{16\gamma\sqrt{\overline{\eta}}}\ . \qquad (18)$$

M - scaling, $\quad\omega_\mu$ - scaling, $\quad\frac{\omega_\eta\mu_F}{\gamma\sqrt{\overline{\eta}}}$ - scaling

The existence of two small parameters: $1/M$ and $1/\overline{\eta}$ was used, as

$$M \sim \frac{S}{\sigma_{str}} \sim \frac{R_A^2}{r_{str}^2} \sim 10^3$$

for Pb-Pb collisions ($R_A = 7 \div 8$ fm, $r_{str} = 0.2 \div 0.3$ fm)
and $\overline{\eta} \sim 10$ at LHC energy (see below).

The same M - scaling in $b_{p_tp_t}$, as in b_{nn} and b_{p_tn}, is not trivial. It takes place only for the correlation between Mean Event Transverse Momenta, defined above. If the p_t-p_t correlation coefficient between transverse momenta of two particles is defined as

$$\bar{b}_{p_tp_t} \equiv \frac{I_2(p_{t1}, p_{t2})}{I(p_{t1})I(p_{t2})} - 1\ ,$$

where $I(p_{t1})$ and $I_2(p_{t1}, p_{t2})$ are single and double inclusive cross sections, than [6] its LR part decreases as

$$\bar{b}_{p_tp_t} \sim \frac{1}{N sources} \sim \frac{1}{M}$$

and hence it is very small, e.g. for PbPb interactions at LHC energy, in which the number the sources (strings) is of order of few thousand.

For $b_{p_tp_t}$ we have additional ω_μ - scaling, compared with b_{nn} and b_{p_tn} asymptotics. Recall that ω_μ characterizes the fluctuations in the number of particles produced from a string.

Instead of ω_μ - dependence for $b_{p_tp_t}$ we have the γ - dependence. The γ characterizes the transverse momentum distribution from one initial string (see table). For a distribution with one dimensional parameter it does not depends on string fusion, then it can be found from data:

$$\gamma = \frac{\langle\langle p_t^2\rangle\rangle - \langle\langle p_t\rangle\rangle^2}{\langle\langle p_t\rangle\rangle^2}\ ,$$

note that the $\langle\langle ...\rangle\rangle$ means averaging over tracks from all events.

Also we have the same $\mu_F/\sqrt{\overline{\eta}}$ - scaling for $b_{p_tp_t}$ asymptotic, as for b_{nn} and b_{p_tn}. (see below).

6. MC simulations

In MC simulations at not large string density, instead of (10), (11) and (13), (14), we have used the BD for $\omega < 1$, the NBD for $\omega > 1$ and the Poisson distribution for $\omega = 1$.

In the simple model with string fusion on a transverse lattice [5,7] we have the results shown in Figs.2 and 3.

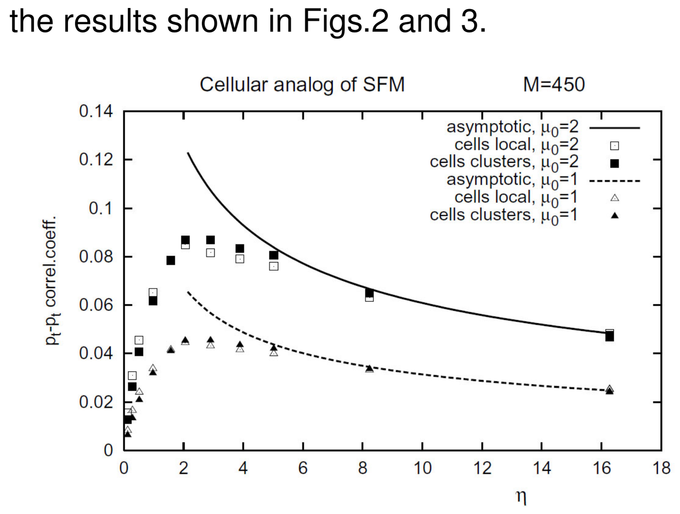


Figure 2: *MC results for the correlation coefficient $b_{p_tp_t}$ at $M = 450$ with poissonian distributions, $\omega_\eta = \omega_\mu = 1$ [5].*

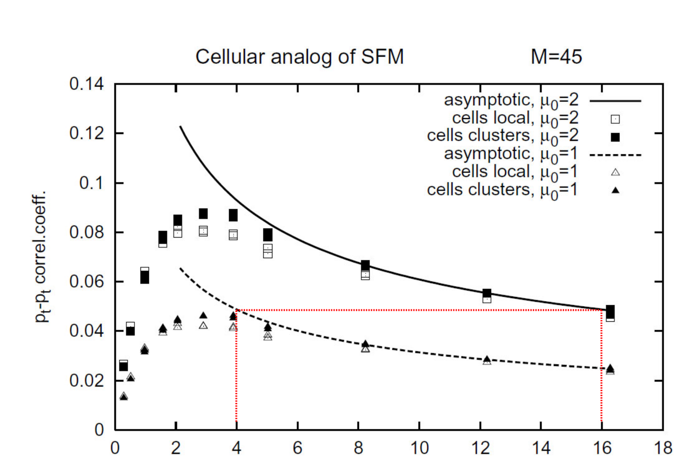


Figure 3: *The same as in Fig.2, but for $M = 45$. Red dash lines illustrate $\mu_F/\sqrt{\overline{\eta}}$-scaling, valid only for the asymptotics.*

Analysis shows that we have M-scaling in wide region $\overline{\eta} \gg 1/M$ (compare the Figs.2 and 3). It's broken only at small total number of strings at $\overline{N} = M\overline{\eta} \sim 1$, when we have to take into account that in any inelastic collision at least one string is formed.

The $\mu_F/\sqrt{\overline{\eta}}$-scaling is valid only in asymptotic region $\overline{\eta} \gg 1$ (Fig.3).

7. Energy and centrality dependencies of the $b_{p_tp_t}$

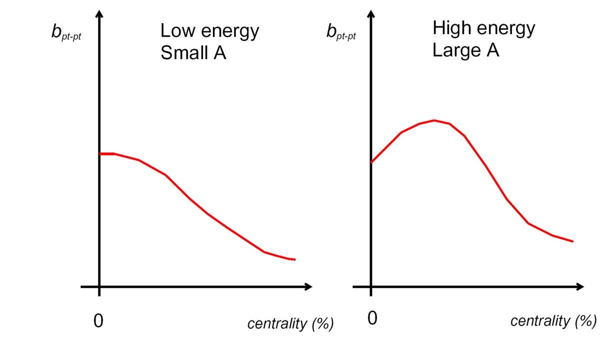


Figure 4: *Qualitative $b_{p_tp_t}$ energy and centrality behavior, following from the existence of the $b_{p_tp_t}$ maximum in Figs.2 and 3 at $\overline{\eta} = 3 \div 4$.*

We have taken into account that
RHIC Au+Au at 200 GeV (centrality 0-10%) $\overline{\eta}$=2.88±0.09,
LHC Pb+Pb at 2.76 TeV (centrality 0-5%) $\overline{\eta}$=10.56±1.05.
J. Dias de Deus, A.S. Hirsch, C. Pajares, R.P. Scharenberg, B.K. Srivastava Eur.Phys.J. C **72** (2012) 2123.

8. Results in dipole-based MC SFM model

In more realistic dipole-based Monte Carlo string fusion model [8,9] we have studied different colliding systems at RHIC and LHC energies.

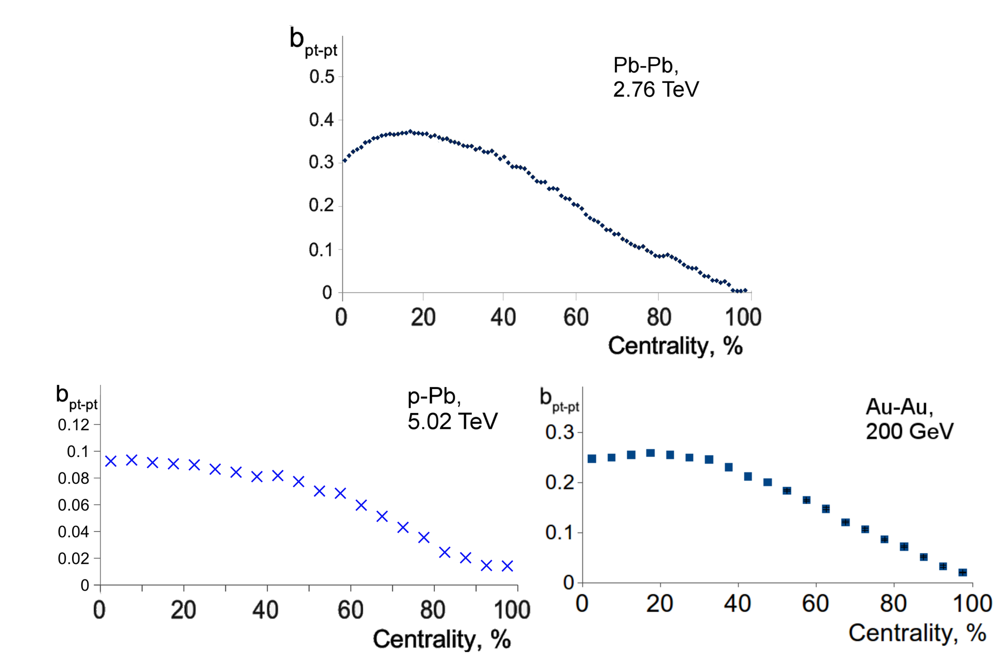


Figure 5: *Centrality dependence of b_{pt-pt} for Pb-Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV, for p-Pb at $\sqrt{s_{NN}}$=5.02 TeV and Au-Au at $\sqrt{s_{NN}}$=200 GeV. MC simulations at r_{str}=0.2 fm.*

The results show that non-monotonic behaviour of b_{pt-pt} with centrality is achieved in heavy ion collisions at LHC, while in Au-Au collisoins at RHIC and p-Pb at LHC the string density is not enough to provide a decline of the correlation coefficient for most central collisions.

9. Summary and conclusions

The dependence of the correlation strength between mean-event transverse momenta on the collision centrality is obtained for different initial energies. It is shown that above RHIC energy the dependence reveals the decline of the correlation coefficient for most central collisions, reflecting the attenuation of color field fluctuations due to the string fusion at large string density.

It is also found that contrary to the correlation between transverse momenta of single particles the strength of the correlation between mean-event transverse momenta of particles in two separated rapidity intervals is not decreasing with the total number of produced strings, remaining significant even in the case of Pb-Pb collisions, in which the total number of strings can reach several thousand.

So the long-range correlation between mean-event transverse momenta, being robust against the volume fluctuations and the details of the centrality determination, enables to obtain the signatures of string fusion at the initial stage of hadronic interaction in relativistic heavy ion collisions at LHC energy.

The authors acknowledge Saint-Petersburg State University for the research grant 11.38.242.2015.