LONG-RANGE CORRELATIONS IN PbPb COLLISIONS AT 158 A*GeV

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Abstract

We present the 1st results of the event-by-event study of long-range correlations between event mean p_t and charged particle multiplicity using NA49 experimental data in two separated rapidity intervals in 158 A*GeV PbPb collisions at the CERN SPS. Noticeable long range correlations are found. The most striking feature is the negative p_t-n correlation observed for the central PbPb collisions. Results are compared to the predictions of the HIJING event generator and of the String Fusion Model favoring a string fusion hypothesis.

Key-words: experiment, relativistic heavy ions, color strings fusion, long-range correlations.

1. Introduction

These investigations are motivated by the predictions of the string fusion model [1] pointing to the possibility of observation of long-range correlations as a signature of a string fusion phenomenon. Such a phenomenon is expected to occur at the large string density values reached in high energy nucleus-nucleus collisions [2]. So they were proposed for studies in ALICE at the LHC [3], and now a careful choice of the observables is in progress (see [6], [7]).

Meanwhile it is extremely interesting to apply these ideas to the existing experimental data obtained at the SPS and RHIC energies.

Up to now the experimental study of long-range correlations in nucleus-nucleus interactions was performed only for multiplicities in [5] (SS collisions at 200A·GeV).

The large acceptance detector NA49 at the SPS at CERN provides the opportunity for studies of various types of correlations. So, in this work we present the 1st results of the event-by-event study of long-range correlations between event mean p_t and charged particle multiplicity using NA49 experimental data obtained in two separated rapidity intervals in 158 A*GeV PbPb collisions at the CERN SPS.

The following types of correlations were investigated:

1) n_B-n_F - the correlations between the charged particle multiplicities in backward and forward rapidity intervals,

2) p_{tB}-p_{tF} - the correlations between the event mean transverse momentum obtained in the backward window and the event mean transverse momentum in the forward rapidity window,

3) p_{tB}-n_F and n_B-p_{tF} - the correlations between the event mean transverse momentum in one rapidity interval and the charged particle multiplicity in another interval.

Experimental results are compared to the predictions of the HIJING event generator and of the String Fusion Model (SFM).

2. Long Range correlations. Experimental method

The data were collected by the NA49 large acceptance detector [8] in 1996 at the CERN SPS in collisions of a Pb beam at 158 A GeV/c energy ($\sqrt{s}$=17.3 GeV per nucleon) with a Pb target foil.

The details on the NA49 installation and standard raw data treatment procedure (track reconstruction, event centrality definition, trigger efficiency etc), can be found elsewhere [8], [9]. These details were taken into account both in our data treatment procedures and in the theoretical (SFM) analysis.

A total of about 129000 minimum bias events were considered. Aditionally we used also high statistics samples of 161000 events for the 1st centrality class and 194000 events for the 2nd centrality class obtained with a central trigger.

Two windows in rapidity were chosen to be named "backward" ($y_B \in (-0.29, 0.33)$) and "forward" ($y_F \in (0.91, 2.0)$) for the event-by-event studies.

We define for each event the following observables: the number of charged particles n registered in a given "backward" or "forward" window (n_B or n_F) and the relevant event mean transverse momenta p_{tB} or p_{tF} of these particles (see [3]).

Then the following 2D distributions were accumulated event-by-event: (n_B,n_F), (p_{tB},n_F) and (p_{tB},p_{tF}). After that we define for each plot the average value of the variable in the "backward" window at the fixed value of the variable in the "forward" window. So we obtain the following plots: $< n_B >_{n_F}$ and $< p_{tB} >_{n_F}$ vs. n_F and $< p_{tB} >_{p_{tF}}$ vs. p_{tF} (in a way similar to [3]).

One of the main features of the results is the linear dependence observed for the majority of these correlation functions. So we applied linear parameterizations, an example for the n-n correlations is:

$$< n_B >_{n_F} = a + \beta_{nn} \cdot n_F$$

here the strength of the correlation is measured by the coefficient β_{nn}. In case of p_t-p_t and p_t-n correlations the coefficients $\beta_{p_tp_t}$ and β_{p_tn} were defined in a similar manner.

Various long-range correlations between these observables were studied for minimum bias events as well as for several classes of collision centrality defined in Table.1 and Fig.1.

Table 1: Fraction in % of inelastic cross-section for centrality event classes

	class-1	class-2	class-3
%	< 5	5-12.5	12.5-23.5
Nch	800 - 1500	700 - 1300	400 - 1200
Ev	0-9250	9250-14670	14670-21190
	class-4	**class-5**	**class-6**
%	23.5-33.5	33.5-43.5	> 43.5
Nch	200 -900	100 - 700	10 - 500
Ev	21190-26080	26080-29340	29340-36000

Here Nch denotes the region of event multiplicity, Ev (GeV/c) the region of energy Eveto recorded by the zero-degree calorimeter for a given class.

The Eveto energy window size (ΔEveto) was varied around the relevant central values inside Ev for a given centrality class in order to study the effect of its influence on n-n, p_t-p_t and p_t-n correlation coefficients. A kind of plateau in the correlation coefficients was reached at the values of ΔEveto windows that are comparable with the intrinsic resolution

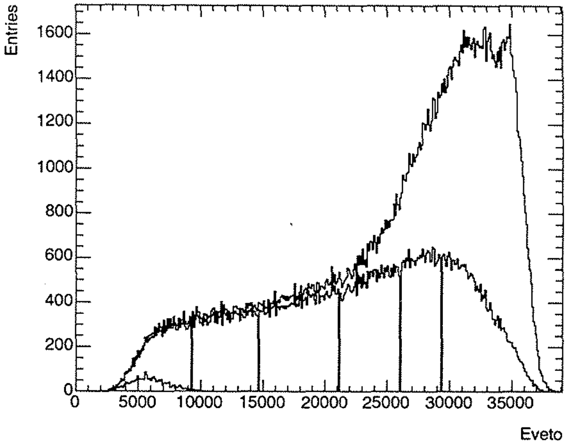

Figure 1: NA49 Eveto calorimeter spectra (Eveto values are in GeV) before and after all cuts applied. Positions of the Eveto intervals selected for centrality analysis of long-range correlations are indicated by the vertical bars. The Eveto data sample defined by the events forming the "plateau" region of the correlation plots is also shown separately inside the 1st class (see text)

(about 2900GeV) of the zero-degree calorimeter. Thus the influence of the class width could be excluded, keeping only the unavoidable finite Eveto resolution influence on the final results.

The final values of correlation coefficients extracted by the variation of ΔEveto are shown vs. collision centrality class in Fig.2, 3 (Black squares are the experimental data. Only statistical errors are shown. Straight lines are to guide the eye.)

The following picture is found:

1) Strong n-n long range correlations are obtained for all centrality classes. A monotonous decrease of the n-n correlation coefficient is observed from peripheral towards central collisions (from 0.35 to about 0.1), see Fig.2.

2) The p_t-p_t correlations are noticeable (about one error bar at present level of statistics) only in the peripheral region (the 5th and 6th centrality classes), therefore they are not shown here.

3) The p_t-n correlations demonstrate a tendency to move from *positive* values in the peripheral collisions region to *negative* for the central collisions, see Fig.3. Negative correlation values are obtained for the 1st ($\beta_{p_t n} = -0.00008 \pm 0.00001$ (GeV/c)) and the 2nd ($\beta p_t n = -0.00003 \pm 0.00001$ (Gev/c)) centrality classes.

Minimum bias event data were also analysed. Plots of the long range forward-backward correlations of charged particles obtained for minimum bias PbPb collisions at $\sqrt{s}$=17.3 GeV are presented below in Figs.4,5,6.

A number of intriguing features was observed:

1) A linear dependence of $< n_B >_{n_F}$ on n_F is seen in the region of forward multiplicities up to the values of n_F about 210. A "plateau" is observed at higher values of n_F (see Fig.4).

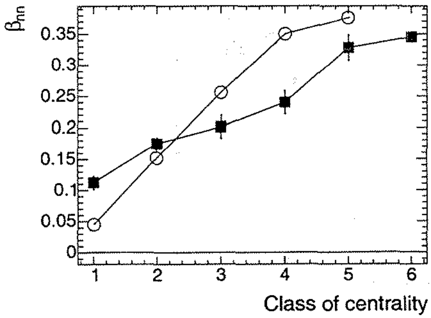

Figure 2: Long range forward-backward n-n correlation coefficients (squares) vs. centrality class for PbPb collisions at $\sqrt{s}$=17.3 GeV. Open circles: String Fusion Model. Horizontal line: the absence of correlations as described by the SFM "without fusion"

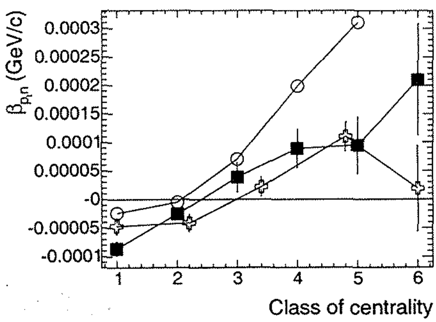

Figure 3: Long range forward-backward p_t-n correlation coefficients (squares) vs. centrality class for PbPb collisions at $\sqrt{s}$=17.3 GeV. Open crosses: HIJING; Open circles: String Fusion Model. Horizontal line: SFM "without fusion"

2) The dependence of $< p_{tB} >_{n_F}$ on n_F is very close to linear in the interval n_F between 50-210. "A plateau" , or p_{tB} "saturation" at the level of about 0.36 GeV/c is also observed at values of forward multiplicities n_F higher than 210 (see Fig.5). The picture is qualitatively similar to the one for pp-collisions at 31GeV and 63 GeV [10].

3) The events with multiplicities higher than 210 that are forming the "plateau" region of the correlation plots (about 2000 events out of 129000 total) represent a fraction of the 1st centality class (see the Fig.1).

4) A complicated non-linear behavior of $< p_{tB} >_{p_{tF}}$ vs. p_{tF} is discovered (see Fig.6). This non-linear dependence of $< p_{tB} >_{p_{tF}}$ on p_{tF} has a "bump" that reaches about 0.35 GeV/c at values of p_{tF} of about 0.35 GeV/c.

3. Analysis of Long Range correlations for PbPb at 158 A*GeV

There could be at least two reasons for the experimentally observed *negative values* of the p_t-n long-range correlation coefficients obtained in the present work for the very central PbPb collisions at 158 A*GeV under the condition of the narrow Eveto window:

(i) String Fusion effects for *fixed* number of participants;

(ii) Kinematical constraints due to the energy conservation in string production and decay.

We first compared the observed long-range correlations with the standard event generator HIJING [11].

Normalization factors were applied for the HIJING multiplicty values (0.7 for the forward and 0.42 for the backward rapidity window.) Another factor = 0.9 was also applied for the HIJING mean p_t values in order to take into account the experimental acceptance cuts. In case of HIJING we did not use the detailed acceptance parametrization or trigger event cuts, because the main goal was to obtain a general trend.

These normalizations enable us to reproduce the data both for the centrality dependence of correlation coefficients (see Fig.3) and for the minimum bias events (see Fig.4,5,6).

The reason for this is, first of all, that a collectivity phenomenon is included in the HIJING model phenomenologically in the form of the Cronin effect that accounts for the growth of the mean p_t with the multiplicity.

Secondly, the observed *negative* correlations are reproduced by HIJING for the 1st centrality class under the condition of a narrow Eveto window. This means that the kinematical constraints on the string decay play an important role at the given energies.

One has to keep in mind, that the observation of these *"negative correlations"* could be damped by such nuclear density effects as fluctuations in the number of participants leading to *"positive correlations"*. So, the observed transition from *negative* to *positive* long range correlations (reproduced in HIJING) is simply related to the relative increase of the fluctuations in the number of nucleon-nucleon collisons for the peripheral events.

A microscopic explanation of these phenomena was obtained in the framework of a simplified MC String Fusion Model[12], [13].

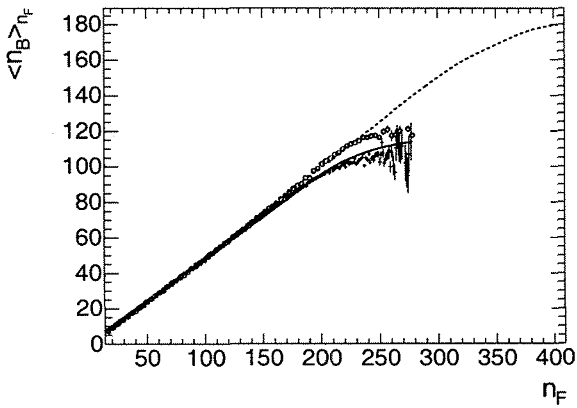

Figure 4: The average backward multiplicity $< n_B >$ at fixed n_F vs. values of n_F . Crosses: experimental data. Solid curve: SFM. Open circles: HIJING (normalized, see text). Dotted curve: SFM calculations without string fusion

The model is based on the assumption of the interaction of overlapping strings (quark-gluon string fusion) and it takes into account the changes of the mean values of the observables in the case of overlap. The increase of the tension in the area of K overlapping strings gives rise to an increase of the mean p_t^2 and the mean number of particles, emitted from this area, proportional to $\sqrt{K}$. At the same time, in case of the non-overlapping strings (non-interacting strings) the multiplicity of charged particles is just proportional to the total number of strings, while the mean p_t stays constant.

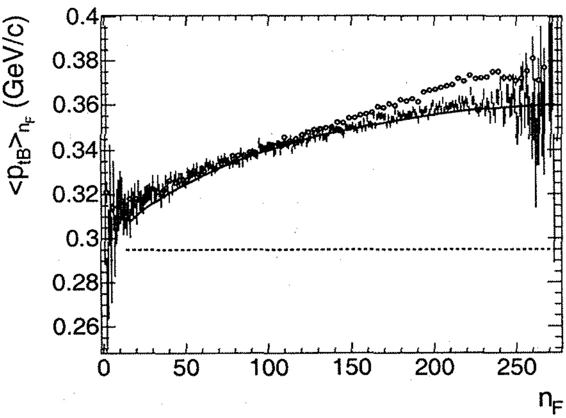

Figure 5: The average transverse momentum $< p_{tB} >$ at fixed n_F vs. values of n_F . HIJING predictions are normalized both for pt and multiplicity. Crosses: experimental data. Solid curve: SFM. Open circles: HIJING (normalized, see text). Dotted curve: SFM calculations without fusion

As to the long range $p_t - n$ and $p_t - p_t$ correlations, they imply the presence of at least two types of particle sources extended in the rapidity space and characterized by different values of mean p_t. So in the case of "no string interaction" the model shows zero forward-backward $p_t - n$ and $p_t - p_t$ correlations. As an example see the results of the SFM calculations without string fusion in Fig.3. SFM Monte-Carlo calculations of the correlations were done both at fixed values of the impact parameter and taking into account its inevitable fluctuations (e.g. due to the finite zero-degree calorimeter resolution). The real nucleon density distribution for the colliding nuclei was used. The specific experimental trigger conditions including the event selection (see Fig.1) were also taken into account in the SFM calculations.

The general growth of the n-n long-range correlation coefficients towards the peripheral collisions observed in case of narrow Eveto windows is well understood in the framework of the SFM (See Fig.2).

The *negative values* of the p_t-n long-range correlation coefficients obtained for the very central collisions in case of narrow Eveto windows and the increase of positive correlations for more peripheral classes were reproduced in the SFM calculations (see Fig.3). It was also confirmed that the observed transition from *the negative* to *the positive* p_t-n long range correlations is related to the trivial relative increase of the fluctuations in the number of nucleon-nucleon collisons in case of the peripheral events.

The results of the Monte-Carlo SFM calculations for the minimum bias PbPb events at $\sqrt{(s)} = 17.3$ GeV using the SFM approach are presented in Fig.4,5,6. One can see that a rather detailed description of minimum bias data is achieved in the framework of the SFM.

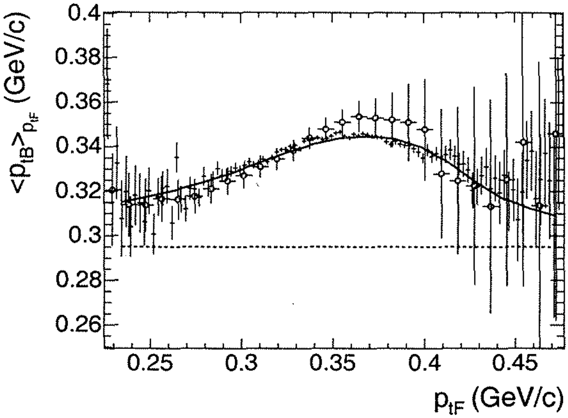

Figure 6: The average backward transverse momentum $< p_{tB} >$ at fixed p_{tF} vs. values of p_{tF}. Crosses: experimental data. Solid curve: SFM. Open circles: HIJING (normalized, see text). Dotted curve: SFM calculations without string fusion

4. Conclusions

1. Experimental evidence for long-range correlations in multi particle production measured in two separated rapidity intervals in PbPb collisions at 158 A*GeV is found.

2. A complicated non-linear dependence of $< n_B >_{n_F}$ and $< p_{tB} >_{n_F}$ on n_F and of $< p_{tB} >_{p_{tF}}$ on p_{tF} is observed for the minimum bias events.

3. The centrality dependence of the correlation coefficients shows the following features:

   1) Strong n-n long range correlations are obtained for all centrality classes. A monotonous decrease of n-n correlation coefficients is observed from peripheral towards central collisions (from 0.35 to about 0.1).

   2) The p_t-p_t correlations are noticeable (about one error bar at present level of statistics) only in the peripheral region (the 5th and 6th centrality classes).

   3) The p_t-n correlations demonstrate a tendency to move from *positive* values in peripheral collision region to *negative* values for the central collisions.

   Negative correlation coefficients $\beta p_t n$ are obtained for the 1st and the 2nd centrality classes, the values are -0.00008 ± 0.00001 GeV/c and -0.00003 ± 0.00001 Gev/c.

   4) The observed transition from *negative* to *positive* long range correlations is described both in HIJING and SFM due to the relative increase of the fluctuations in the number of nucleon-nucleon collisons for the peripheral events.

4. The analysis in the framework of HIJING and SFM indicates that both models are providing a quantative description of the observed long-range correlations in minimum bias events as well as of their centrality dependence. HIJING does this by

a phenomenological increase of the mean p_t for the multiple nucleon-nucleon collisions, while the SFM provides a microscopic explanation of the observed collectivity effects. So, we conclude that the results are favouring the string fusion hypothesis.

5. Further checks of the string fusion hypothesis at higher energies (RHIC and LHC) are very desirable.

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