Multiplicity, Transverse Momentum and Forward-Backward Long Range Correlations

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Contents:

1. **Transverse momentum fluctuations**
2. **Multiplicity fluctuations**
3. **Long range correlations**

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WHY EVENT-BY-EVENT FLUCTUATIONS?

Non-statistical event-by-event fluctuations in relativistic heavy ion collisions has been proposed as as **probe of phase instabilities near de QCD phase transition.**

The fluctuations of the mean transverse momentum or mean multiplicity are related to the fundamental properties of the system, so may reveal information about the **QCD phase boundary.**

A phase transition in the evolution of the system created in relativistic heavy ion collisions may lead to a **divergence of the specific heat** which could be observed as **event-by-event fluctuations.**

EVENT-BY-EVENT P_T FLUCTUATIONS

Event-by-event fluctuations of p_T have been measured at SPS and RHIC

Behaviour of the non-statistical fluctuations as a function of the centrality of the collision:

- grow as the centrality increases
- maximum at mid centralities
- decrease at larger centralities

Different mechanisms have been proposed in order to explain those data:

- complete or partial equilibration
- critical phenomena
- production of jets
- string clustering or string percolation.

We are going to use:
CLUSTERING OF COLOR SOURCES

(Armesto, Braun, Ferreiro, Pajares, PRL77 (96) 3736)

• Color strings are stretched between the projectile and target

• Strings = Particle sources: particles are created via sea $q\bar{q}$ production in the field of the string

• Color strings = Small areas in the transverse space filled with color field created by the colliding partons

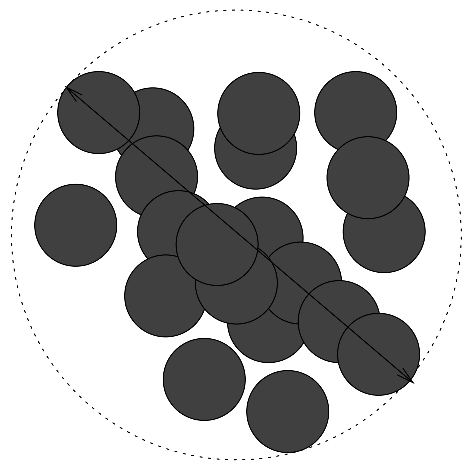
• With growing energy and/or atomic number of colliding particles, the number of sources grows

• So the elementary color sources start to overlap, forming clusters, very much like disk in the 2-dimensional percolation theory

• In particular, at a certain critical density, a macroscopic cluster appears, which marks the percolation phase transition

• So we try to introduce a phase transition (≡QGP?)
(N. Armesto et al., PRL77 (96); J.Dias de Deus et al., PLB491 (00); M. Nardi and H. Satz).

• How?: Strings fuse forming clusters. At a certain critical density η_c (central PbPb at SPS, central AgAg at RHIC, central SS at LHC) a macroscopic cluster appears which marks the percolation phase transition (second order, non thermal).



$\eta = N_{st}\frac{S_1}{S_A}\ , \quad S_1 = \pi r_0^2, \quad r_0 = 0.2\ \text{fm}, \quad \eta_c = 1.1 \div 1.2.$

• Hypothesis: clusters of overlapping strings are the sources of particle production, and central multiplicities and transverse momentum distributions are little affected by rescattering.

• For a cluster of n overlapping strings covering an area S_n we calculate the multiplicity and p_T of the produced particles :

Color charge of the cluster=Vectorial sum of the strings charges

$$\vec{Q}_n = \sum_{i=1}^{n} \vec{Q}_{1i} \qquad \langle \vec{Q}_{1i} \cdot \vec{Q}_{1j} \rangle = 0 \qquad \vec{Q}_n^2 = n\vec{Q}_1^2$$

$$Q_n = \sqrt{\frac{nS_n}{S_1}} Q_1 \qquad \mu_n = \sqrt{\frac{nS_n}{S_1}} \mu_1 \qquad \langle p_T^2 \rangle_n = \sqrt{\frac{nS_1}{S_n}} \langle p_T^2 \rangle_1$$

For strings without interaction:

$$S_n = nS_1 \qquad Q_n = nQ_1 \qquad \Longrightarrow \qquad \mu_n = n\mu_1 \qquad \langle p_T^2 \rangle_n = \langle p_T^2 \rangle_1$$

For strings with max overlapping:

$$S_n = S_1 \qquad Q_n = \sqrt{n} Q_1 \qquad \Longrightarrow \qquad \mu_n = \sqrt{n} \mu_1 \qquad \langle p_T^2 \rangle_n = \sqrt{n} \langle p_T^2 \rangle_1$$

IN THE CLUSTERING APPROACH:

The behaviour of the p_T fluctuations can be understood as follows:

- **At low density**: most of the particles are produced by individual strings with the same $< p_T >_1$

  $\Rightarrow$ **fluctuations are small**

- **At large density** above the critical point: only one cluster

  $\Rightarrow$ **fluctuations are not expected either** $''equilibration''$

- **Just below the percolation critical density**: Large number of clusters formed by different number of strings, different size and different $< p_T >_n$

  $\Rightarrow$ **fluctuations are maximal**

Variables to measure event-by-event p_T fluctuations

F_{p_T} quantifies the deviation of the observed fluctuations from statistically independent particle emission

$$F_{p_T} = \frac{\omega_{data} - \omega_{random}}{\omega_{random}}, \qquad \omega = \frac{\sqrt{<p_T^2> - <p_T>^2}}{<p_T>}$$

$$\phi = \sqrt{\frac{<Z^2>}{<\mu>}} - \sqrt{< z^2 >}$$

$z_i = p_{T\,i} - < p_T >$ is defined for each particle
$Z_i = \sum_{j=1}^{N_i} z_j$ is defined for each event

$$F_{p_T} = \frac{\phi}{\sqrt{<z^2>}} = \frac{1}{\sqrt{<z^2>}}\sqrt{\frac{<Z^2>}{<\mu>}} - 1$$

• Mean cluster multiplicity and mean cluster p_T:

$$< \mu >_n = \sqrt{\frac{nS_n}{S_1}} < \mu >_1 \, , \;\; < p_T >_n = \left(\frac{nS_1}{S_n}\right)^{1/4} < p_T >_1$$

where $< \mu >_1$ and $< p_T >_1$ correspond to the mean multiplicity and the mean transverse momentum of the particles produced by one individual string.

• In order to obtain the mean p_T and the mean multiplicity of the collision at a given centrality:sum over all clusters and average over all events:

$$< \mu > = \frac{\sum_{i=1}^{N_{events}} \sum_j < \mu >_{n_j}}{N_{events}} \, , \;\; < p_T > = \frac{\sum_{i=1}^{N_{events}} \sum_j < \mu >_{n_j} < p_T >_{n_j}}{\sum_{i=1}^{N_{events}} \sum_j < \mu >_{n_j}}$$

• Introducing our formula for the multiplicity of the cluster μ_{n_j} and the mean momentum $< p_T >_{n_j}$ we get:

$$< p_T >= \frac{\sum_{i=1}^{N_{events}} \sum_j \left(\frac{n_j S n_j}{S_1}\right)^{1/2} \mu_1 \left(\frac{n_j S_1}{S n_j}\right)^{1/4} < p_T >_1}{\sum_{i=1}^{N_{events}} \sum_j \left(\frac{n_j S n_j}{S_1}\right)^{1/2} \mu_1}$$

• For the quantities $< z^2 >$ and $< Z^2 >$ we obtain:

$$< z^2 >= \frac{\sum_{i=1}^{N_{events}} \sum_j \left(\frac{n_j S n_j}{S_1}\right)^{1/2} \mu_1 \left[\left(\frac{n_j S_1}{S n_j}\right)^{1/4} <p_T>_1 - <p_T>\right]^2}{\sum_{i=1}^{N_{events}} \sum_j \left(\frac{n_j S n_j}{S_1}\right)^{1/2} \mu_1}$$

and

$$\frac{< Z^2 >}{< \mu >} = \frac{\sum_{i=1}^{N_{events}} \left[\sum_j \left(\frac{n_j S n_j}{S_1}\right)^{1/2} \mu_1 \left[\left(\frac{n_j S_1}{S n_j}\right)^{1/4} <p_T>_1 - <p_T>\right]\right]^2}{\sum_{i=1}^{N_{events}} \sum_j \left(\frac{n_j S n_j}{S_1}\right)^{1/2} \mu_1}$$

$$F_{p_T} = \frac{\phi}{\sqrt{< z^2 >}} = \frac{1}{\sqrt{< z^2 >}} \sqrt{\frac{< Z^2 >}{< \mu >} - 1}$$

In order to compute F_{p_T} we need:

- A **Monte Carlo code for the cluster formation**, in order to compute the number of strings that come into each cluster and the area of the cluster

- We do not use a Monte Carlo code for the decay of the cluster, since we apply **analytical expressions for the transverse momentum and the multiplicities** of the clusters

- We also need **the value of** μ_1 –multiplicity produced by one individual string–. The total multiplicity per unit rapidity produced by one string has been taken as $\mu_{0\,tot} \simeq 1$

FLUCTUATIONS AT RHIC

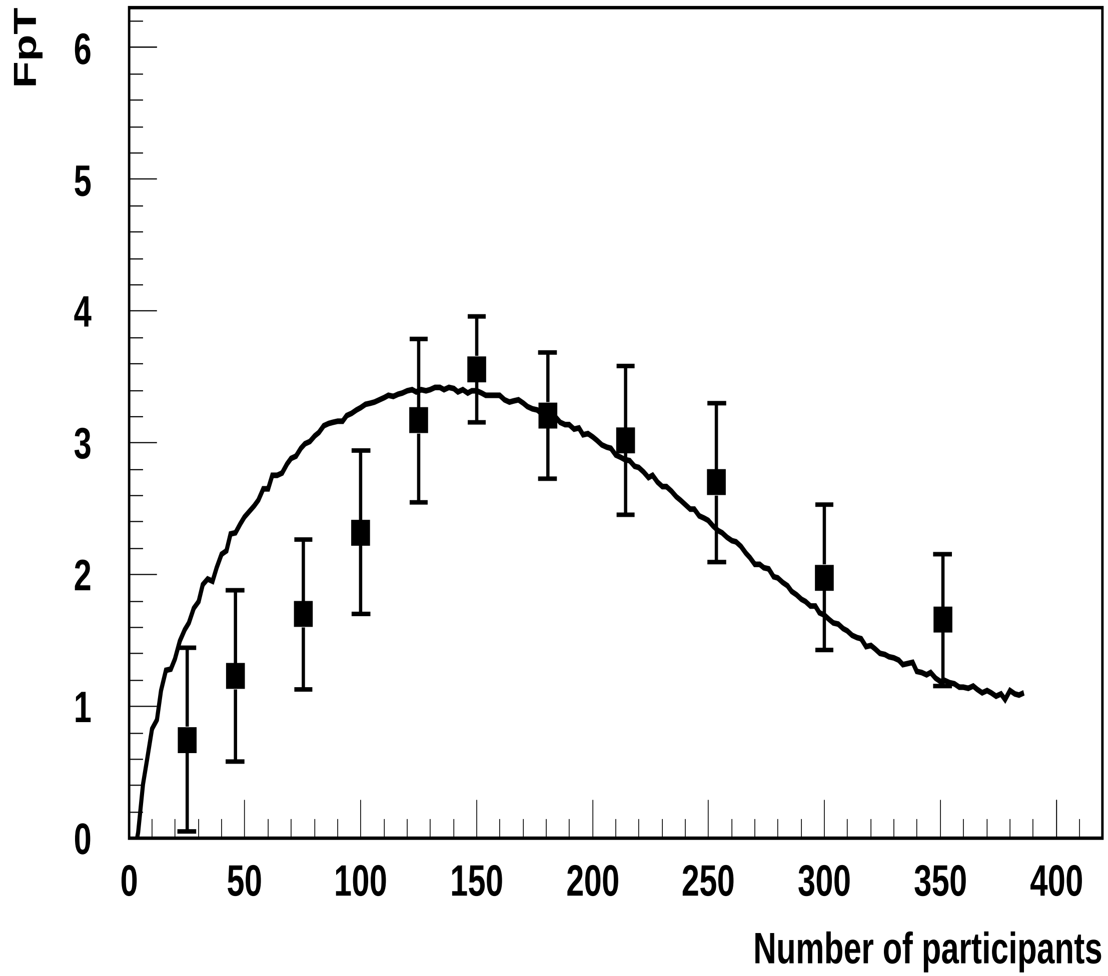


Figure 1: $F_{p_T}(\%)$ versus the number of participants. Experimental data from PHENIX at $\sqrt{s} = 200$ GeV are compared with our results (solid line).

FLUCTUATIONS AT SPS

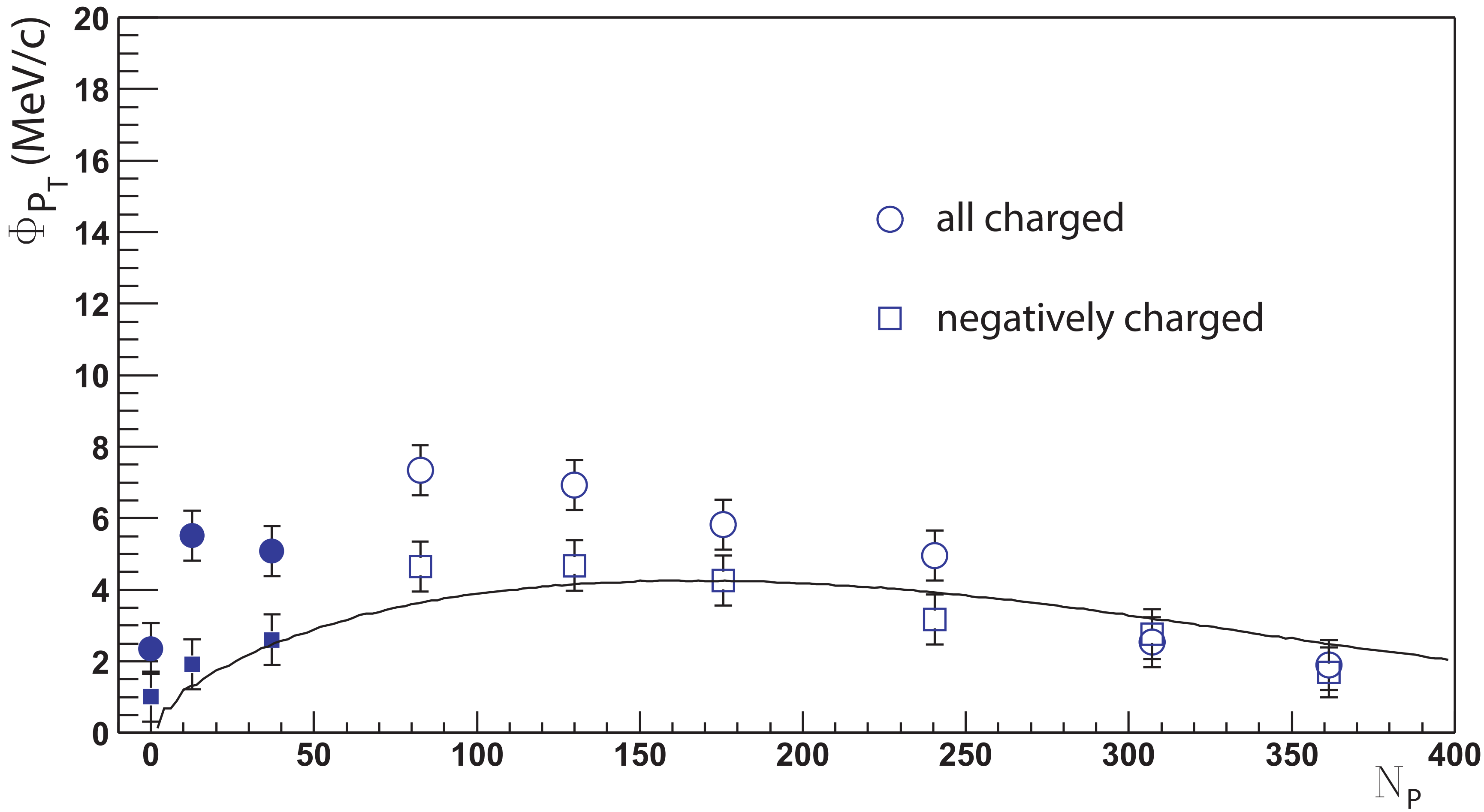


Figure 2: ϕ_{p_T} versus the number of participants. Experimental data from NA49 Collaboration at SPS energies are compared with our results (solid line).

Our formula for the scaled variance obeys:

$$\frac{Var(\mu)}{<\mu>} = 1 + <\mu>_1 \frac{\left\langle \left(\sum_j \sqrt{\frac{n_j S_{n_j}}{S_1}} \right)^2 \right\rangle - \left\langle \sum_j \sqrt{\frac{n_j S_{n_j}}{S_1}} \right\rangle^2}{\left\langle \sum_j \sqrt{\frac{n_j S_{n_j}}{S_1}} \right\rangle},$$

In order to obtain the scaled variance we have calculated $<\mu^2>$:

$$<\mu^2> = \frac{1}{N_{events}} \left[\sum_{i=1}^{N_{events}} \left(\sum_j \sqrt{\frac{n_j S_{n_j}}{S_1}} \right)^2 <\mu>_1^2 + \sum_{i=1}^{N_{events}} \sum_j \sqrt{\frac{n_j S_{n_j}}{S_1}} <\mu>_1 \right]$$

where we have supposed that the multiplicity of each cluster follows a Poissonian of mean value $<\mu>_{n_j}$, $<\mu^2>_{n_j} = <\mu>_{n_j}^2 + <\mu>_{n_j}$.

Behaviour of the scaled varianza

• **Low density limit** –isolated strings that do not interact–:

$$\frac{Var(\mu)}{<\mu>} = 1 + <\mu>_1 \frac{<N_s^2> - <N_s>^2}{<N_s>} \simeq 1 + <\mu>_1$$

where N_s corresponds to the number of strings that, for a fixed number of participants: $\frac{<N_s^2> - <N_s>^2}{<N_s>} \simeq 1$ (Poissonian distribution).

• **In the large density regime** –all the strings fuse into a single cluster that occupies the whole interaction area–:

$$\frac{Var(\mu)}{<\mu>} = 1 + <\mu>_1 \frac{\left\langle \left(\sqrt{\frac{N_s S_A}{S_1}} \right)^2 \right\rangle - \left\langle \sqrt{\frac{N_s S_A}{S_1}} \right\rangle^2}{\left\langle \sqrt{\frac{N_s S_A}{S_1}} \right\rangle} \simeq 1$$

where S_A is the nuclear overlap area.

The second element of the r.h.s. of this equation tends to zero.

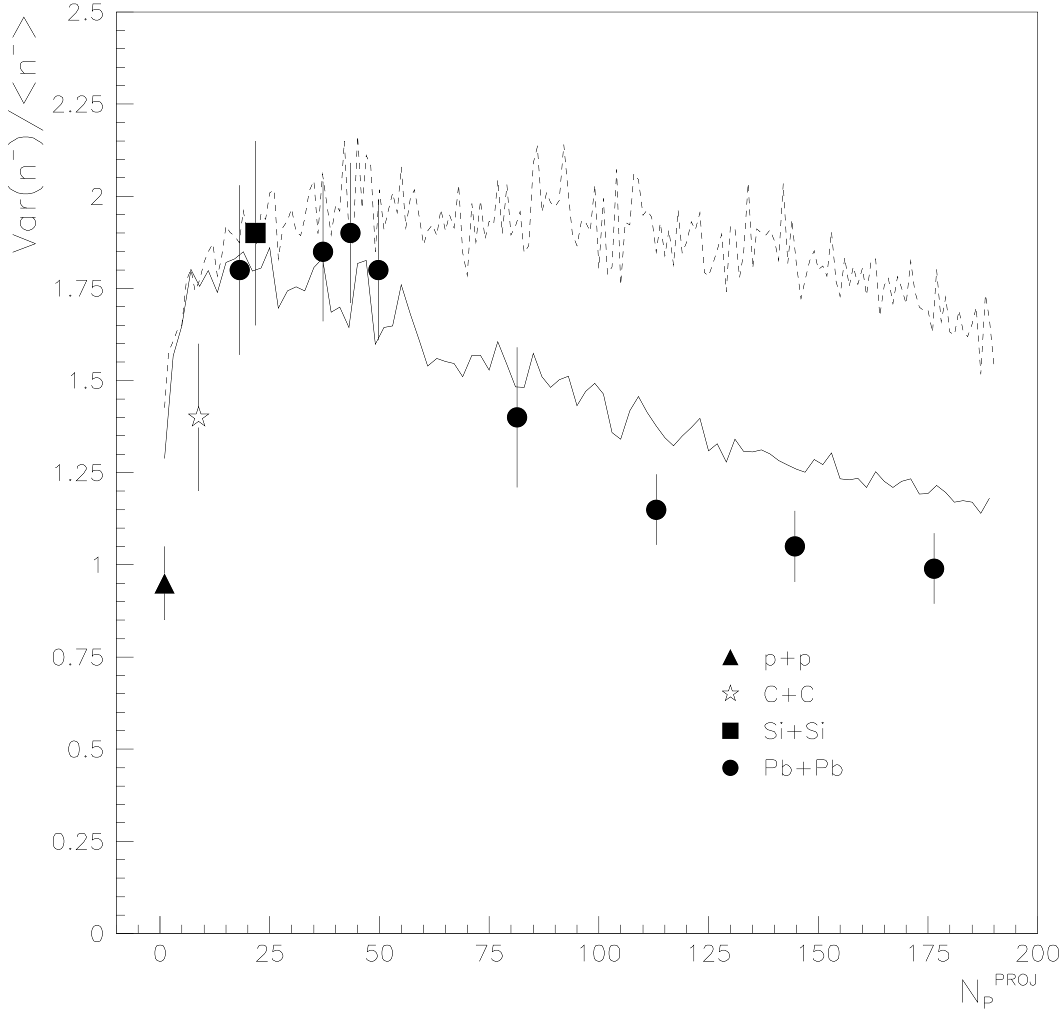


Figure 3: Our results for the scaled variance of negatively charged particles in Pb+Pb collisions at P_{lab} =158 AGeV/c compared to NA49 experimental data. The dashed line corresponds to our result when clustering formation is not included, the continuous line takes into account clustering.

• We find a non-monotonic dependence of the multiplicity fluctuations with the number of participants.

The centrality behaviour of these fluctuations is very similar to the one found for the mean p_T fluctuations.

• In our approach, the mechanism responsible for multiplicity and mean p_T fluctuations is the formation of clusters of strings that introduces correlations between the produced particles.

• On the other hand, p_T fluctuations have been attributed to jet production in peripheral events, combined with jet suppression in central events.

• However, this hard-scattering interpretation can not be applied to SPS energies, so it does not explain the non-monotonic behaviour of the mean p_T fluctuations neither the relation between mean p_T and multiplicity fluctuations at SPS energy.

LONG RANGE CORRELATIONS

• A measurement of such correlations is the backward–forward dispersion

$$D^2_{BF} =< n_B \, n_F > - < n_B >< n_F >$$

where n_B (n_F) is the number of particles in a backward (forward) rapidity

• In a superposition of independent sources model, D^2_{BF} is proportional to the fluctuations (D^2_N) on the number of independent sources (It is assumed that Forward and backward are defined in such a way that there is a rapidity window $\Delta\eta \geq 1.0$ to eliminate short range correlations).

• Cluster formation implies a decreasing number of independent sources. Therefore D_{BF} decreases.

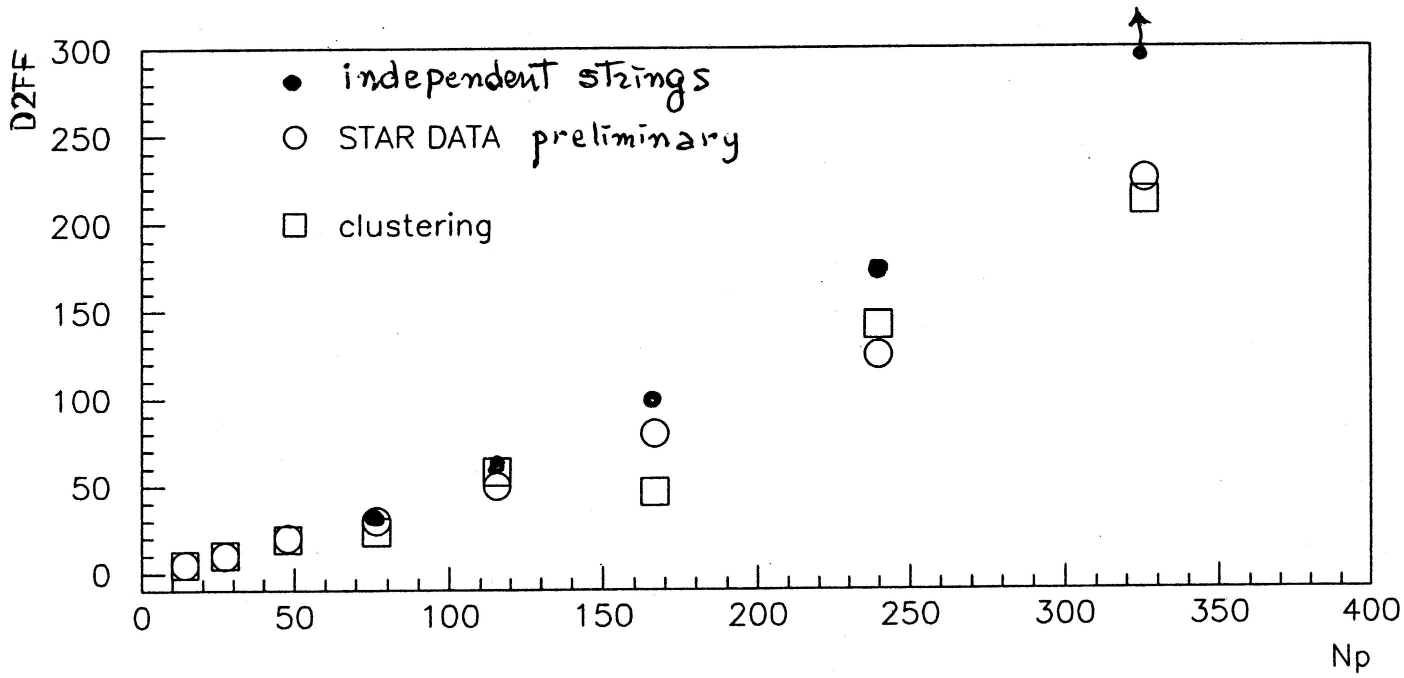
- Sometimes, it is a measured

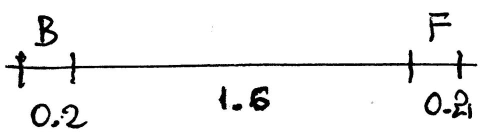
$$< n_B >= a + b n_F$$

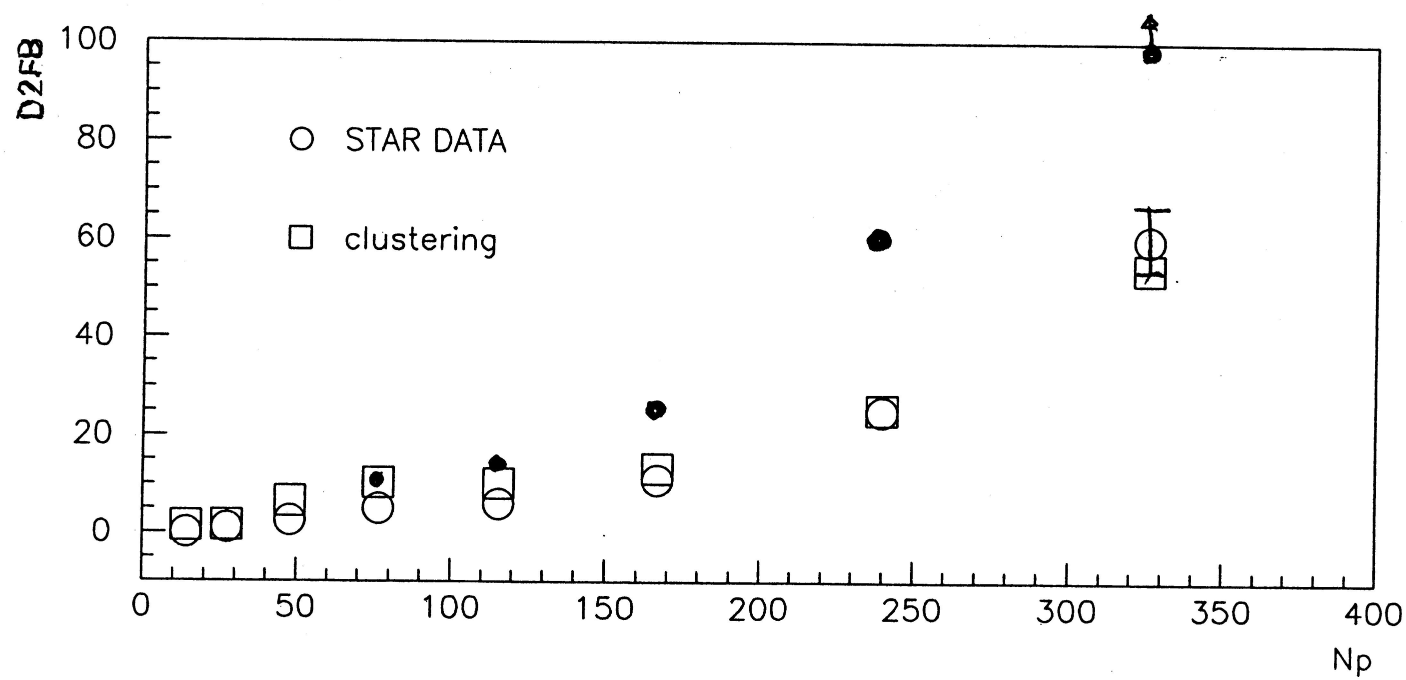
with

$$b \equiv D^2_{BF} / D^2_{FF}$$

- b in pp increases with energy. In hA increases with A
- Clustering of strings implies a supression of b


D2FF
independent strings
STAR DATA preliminary
clustering
Np


B
F
0.2
1.6
0.2


D2FB
STAR DATA
clustering
Np

CONCLUSIONS

• P_T and multiplicity fluctuations an reasonable well described in a color clustering approach.

• LONG Range correlations are supressed in comparison with models based on independent scatterings.

• D_{BF} is well described by the percolation of color sources.