# Selection of Correlated Groups of Secondary Particles in Nucleus-Nucleus Interaction

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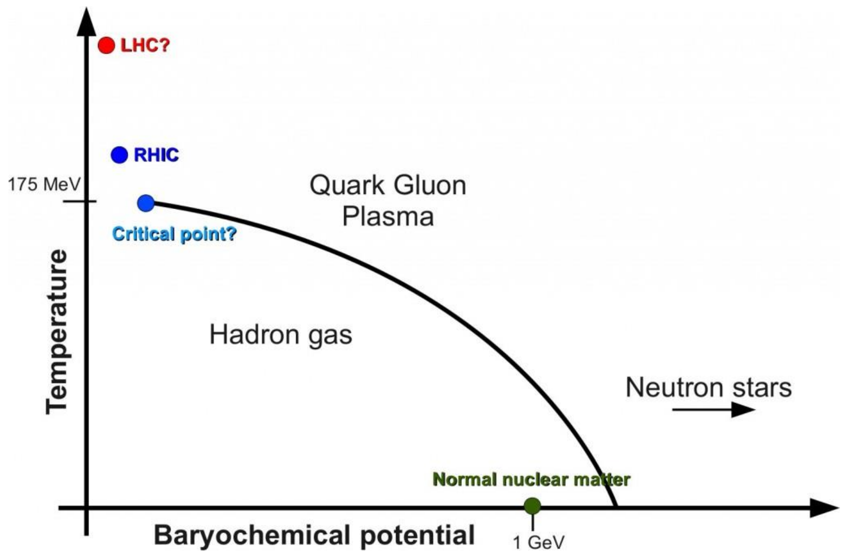
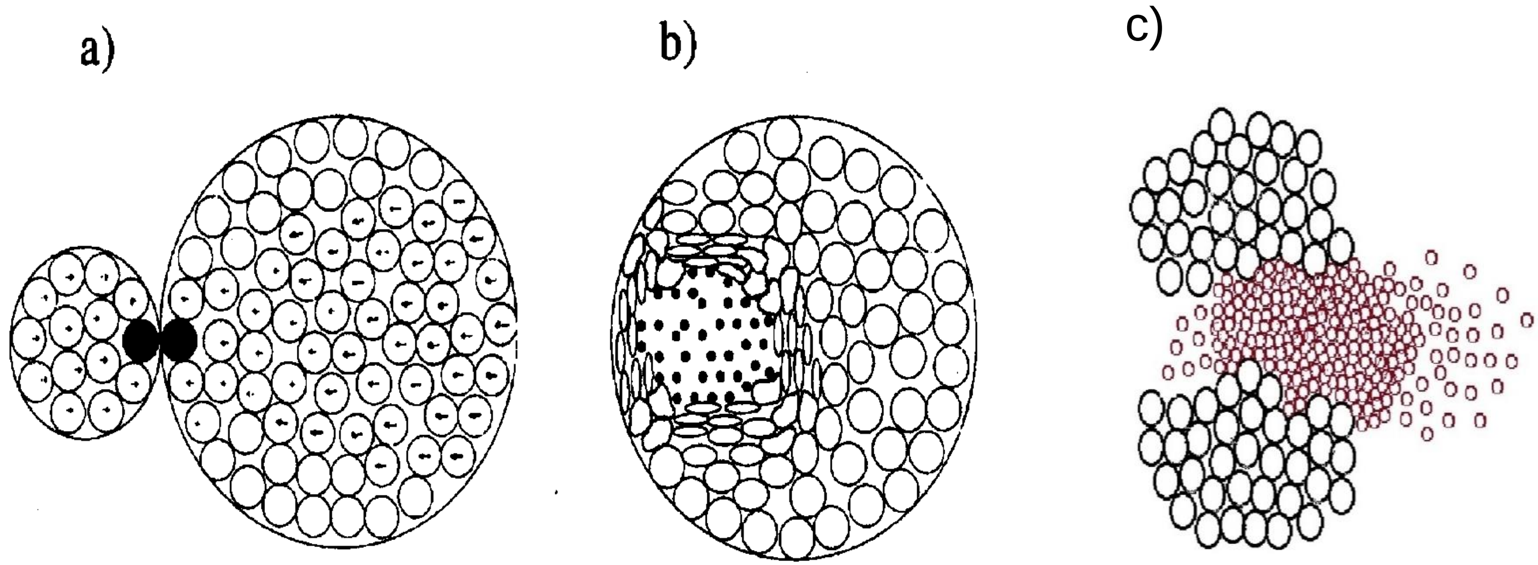



According to the present-day conceptions, in interaction of nuclei at high energy the hadron matter transits into a state of the quark-gluon plasma (QGP), in which the quarks and gluons stay in a quasi-free state.

The expansion of secondary particles, formed from a plasma bunch, leads to the collective nature of the formation of secondary particles.



The studies of QGP phase transition are mostly focused on the two directions of research.

1. The first direction is related to the investigations of the interactions of heavy nuclei at the maximally-available energies.

   RHIC (Relativistic Heavy-Ion Colliders) of the Brookhaven National Laboratory
   LHC (Large Hadron Colliders) of the European Center for Nuclear Research (CERN)

2. The second direction is focused on the area of energies within the range from several GeV to few dozens of GeV.

First, it is considered that the investigations around the critical point of the phase transition into the quark-gluon plasma will give a possibility to get the quality new results on the process dynamics.

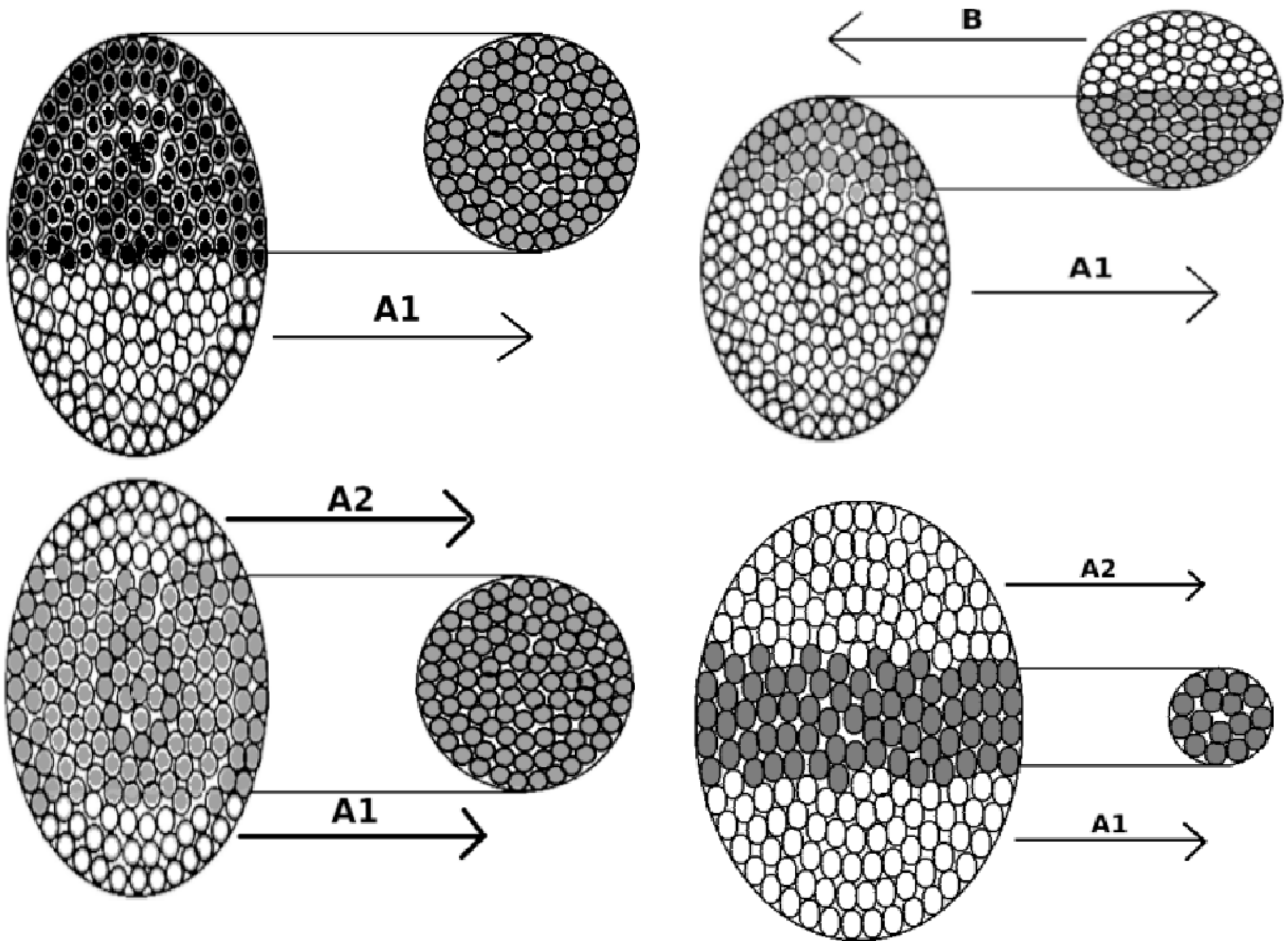
Second, according to the theoretical predictions, - a mixed phase of the ‘excited hadronic matter’, which includes both the free quarks and gluons, and the protons with neutrons, must be formed within the range of the energies.

This problem is one of the key justifications for several major international experiments, such as follows:

BES (beam-energy scan) experiment on the RHICs;
NA61 experimental program of the low-energy examination in the SPS at the CERN;
FAIR (Facility for Antiproton and Ion Research) Darmstadt;
NICA (Nuclotron-Based Ion Collider Facility) Dubna.

The expansion of secondary particles, formed from a plasma bunch, depends (not only mass and energy of interacting nuclei, but also) on the geometry of the colliding nuclei.

The initial state, about which it is usually very little direct experimental information, leads to significant peculiarities in the distribution of secondary particles.



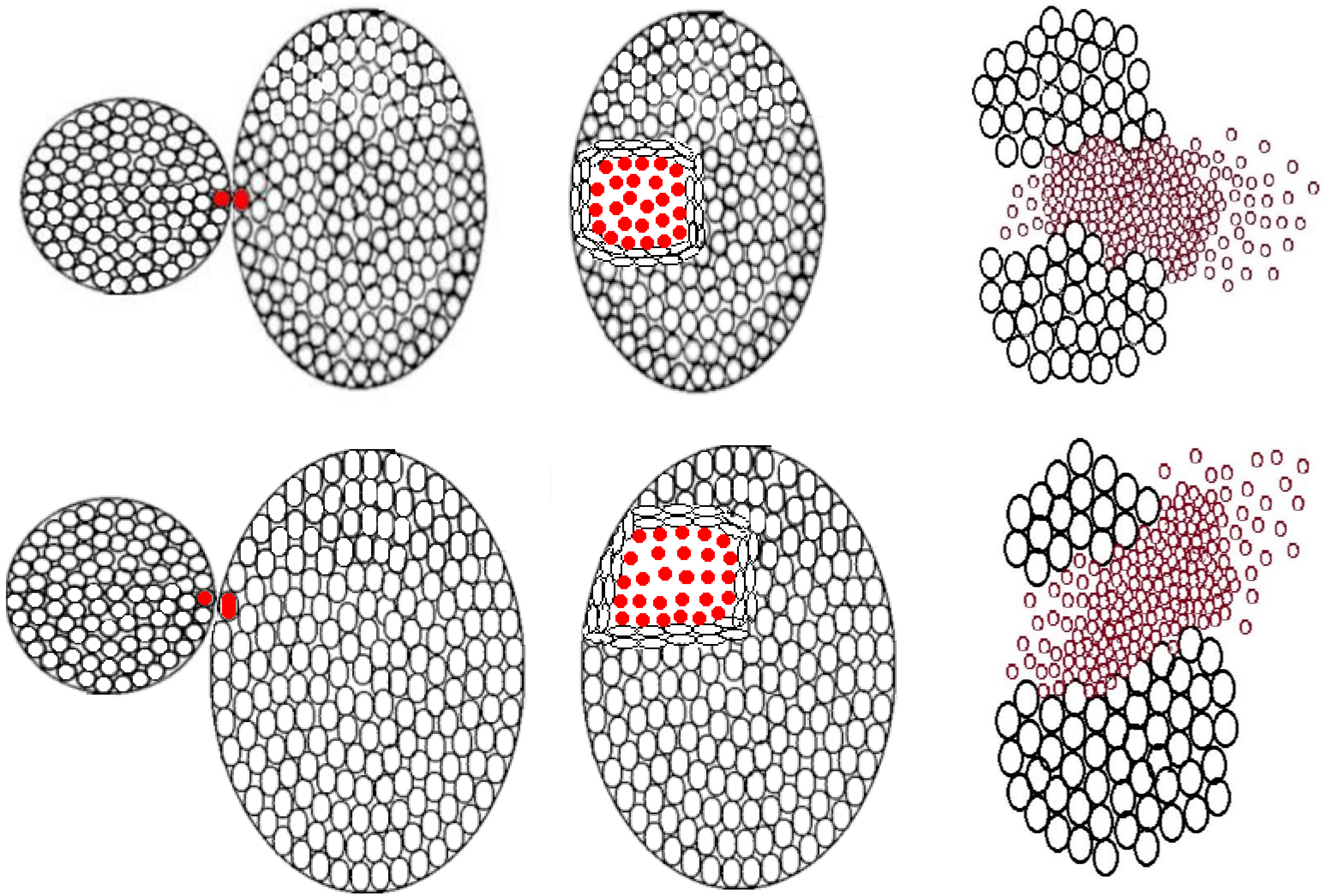

Study of the fragmentation characteristics of the interaction allows to estimate impact parameters, to separate central and peripheral interaction.

In peripheral interactions in most of the events only one multi-charged fragment $N_f$=1, is revealed.

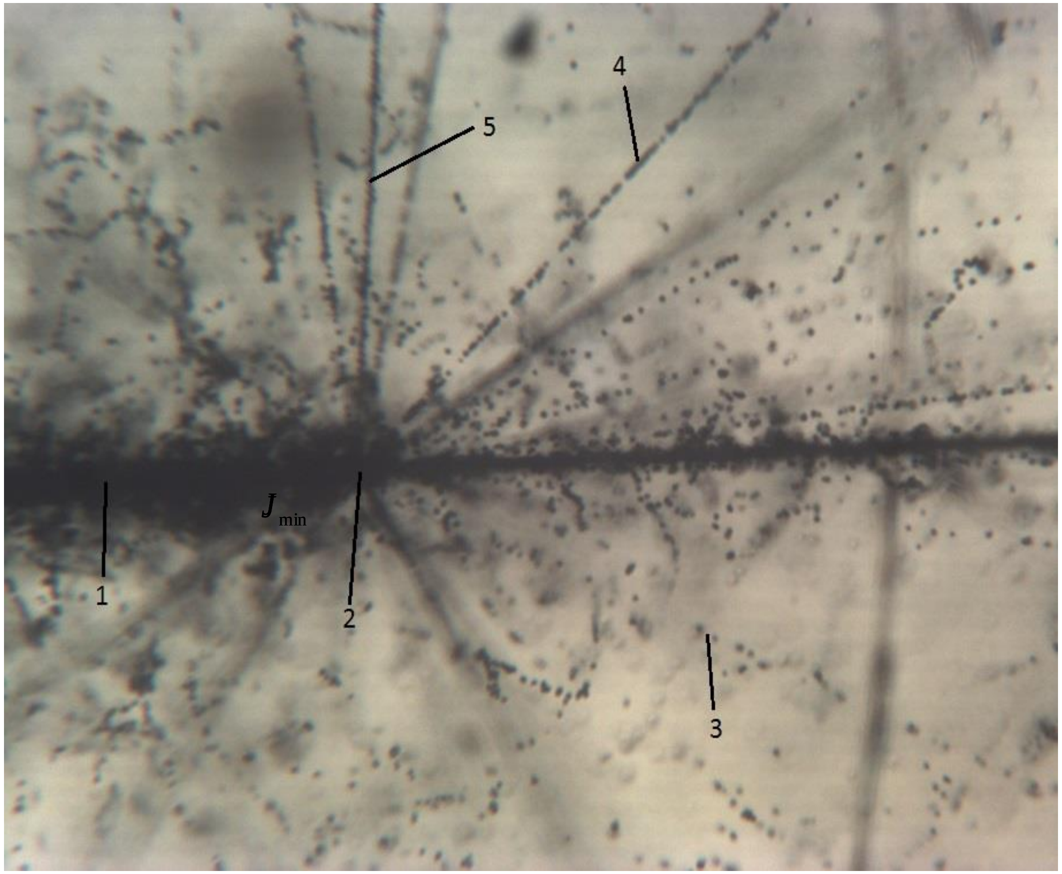
In central collisions of sharply asymmetric nuclei the events with few multi-charged fragments are more probable.

In central collisions the number of interacting particles is maximal.

If collision is non-central one, then quark-gluon plasma expands in different directions not equally.
As result it can bring to significant difference in pseudorapidity distribution of central and peripheral collisions.



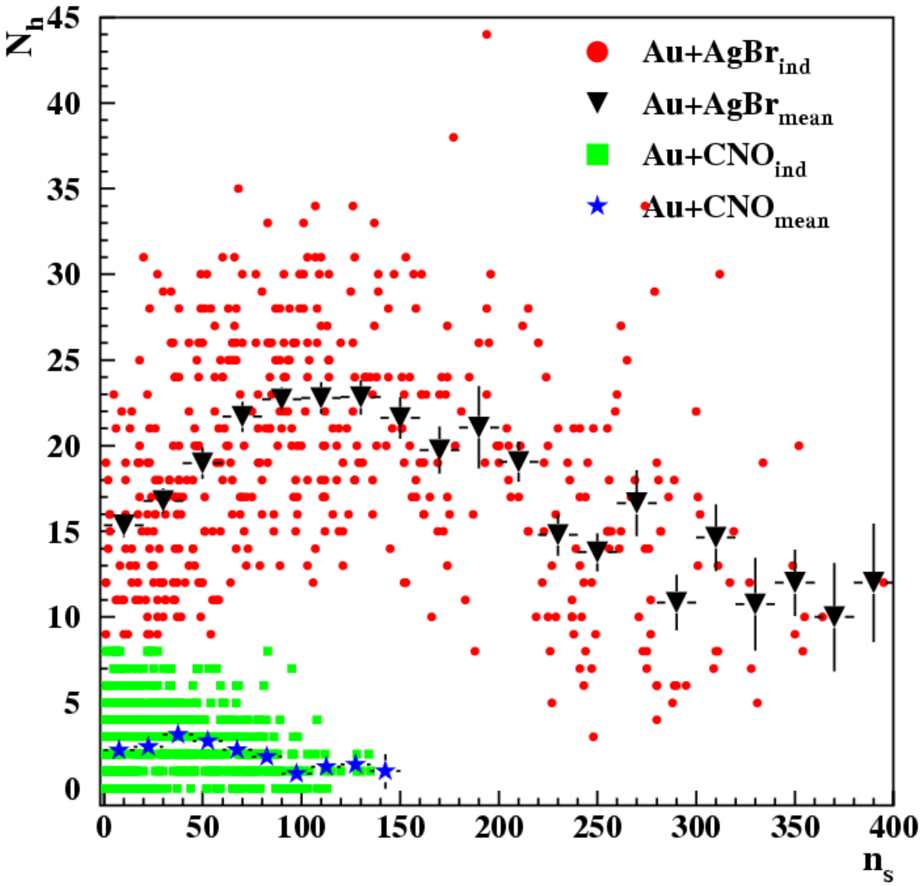
# For analysis it was used experimental data of $^{197}Au + Em$ 10.7 A·GeV.




| | Au+Em (10,7 A·GeV) with $n_s$=85, $n_g$=8, $n_b$=12, $n_{Z1}$=4, $n_{Z2}$=4, $n_{Z3}$=4 |
|---|---|
| 1 - | Projectile nucleus; |
| 2 - | Center of interaction; |
| 3 - | S-particle (thin track); |
| 4 - | g-частицы (grey track) ; |
| 5 - | b-частицы (black track) . |

Classification of secondary particles was conducted in accordance with generally accepted photoemulsion technique criteria:
*b*-particles – fragments of the target nucleus with kinetic energy per nucleon $E_k$ < 26 MeV and visual range R < 3mm **(protons and more heavy fragments of target nucleus);**
*g*-particles – fragments of the target nucleus with kinetic energy per nucleon 26 $\leq E_k \leq$ 400 MeV and visual range R > 3mm, with relative ionization $J/J_{min}$> 1.4, where $J_{min}$ is the ionization, corresponding to one-charged fragments of the projectile nucleus **(protons of target nucleus);**
*h*-particles – the sum total *g*- и *b*-particles **($N_h=n_b+n_g$)** ;
*s*-частицы – one-charged relativistic particles from interaction region with relative ionization $J/J_{min}$< 1.4 and with kinetic energy per nucleon $E_k$ > 400 MeV **(π± -mesons, protons of the projectile nucleus).**

The method of nuclear emulsion is labour-consuming enough, but in comparison with other approaches, investigating interactions of nuclei, is the most informative. The nuclear photoemulsion has high spatial resolution. It allows to observe the impact act in 4π-geometry of experiment. The most of other methods have essential dead zones in which secondary particles are not registered. The nuclear emulsion includes different nuclei (H,CNO,Ag,Br). It gives possibilities to analyze interaction of different nuclei in the same experimental conditions.



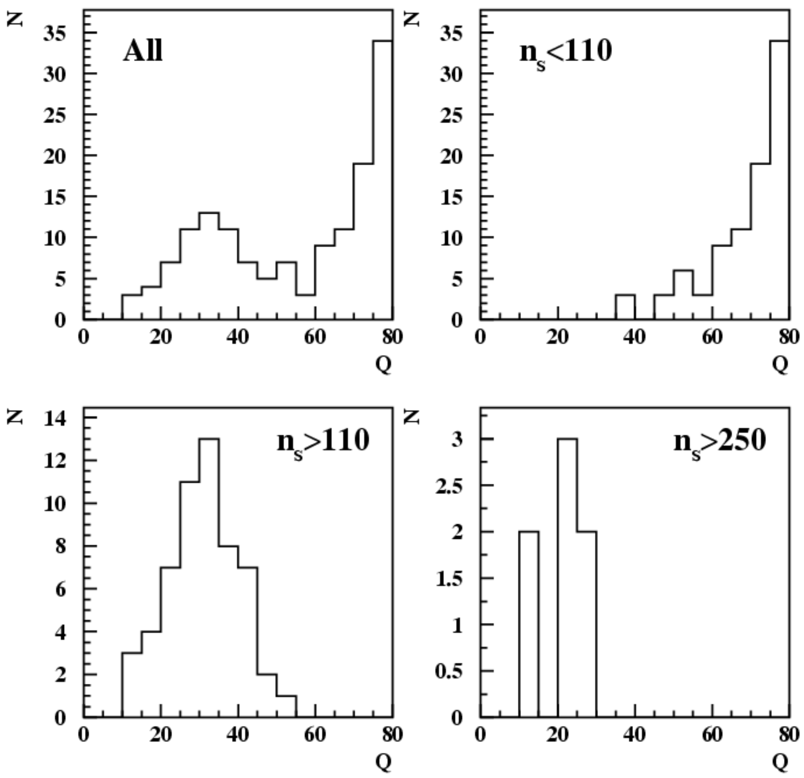

The dependence of total number of fragments of the target nucleus ($N_h=n_b+n_g$) and the number of shower particles $n_s$ for interaction of heavy nuclei of gold $^{197}$Au with the energy of 10.7 AGeV with heavy (AgBr) and light (CNO) emulsion nuclei

One of the best ways to estimate the degree of centrality of interaction and separation of events with light and heavy emulsion nuclei is the dependence of the number of fragments of the target nucleus $N_h$ and multiplicity of $n_s$ particles.

For *Au+AgBr* interactions average distribution growth in the area to $n_s$~110. Then decrease and reach a plateau at $n_s$>250.

Similar behavior shows and *Au+CNO* distribution, but at lower multiplicities: $n_s$~40 и $n_s$>100, correspondingly.

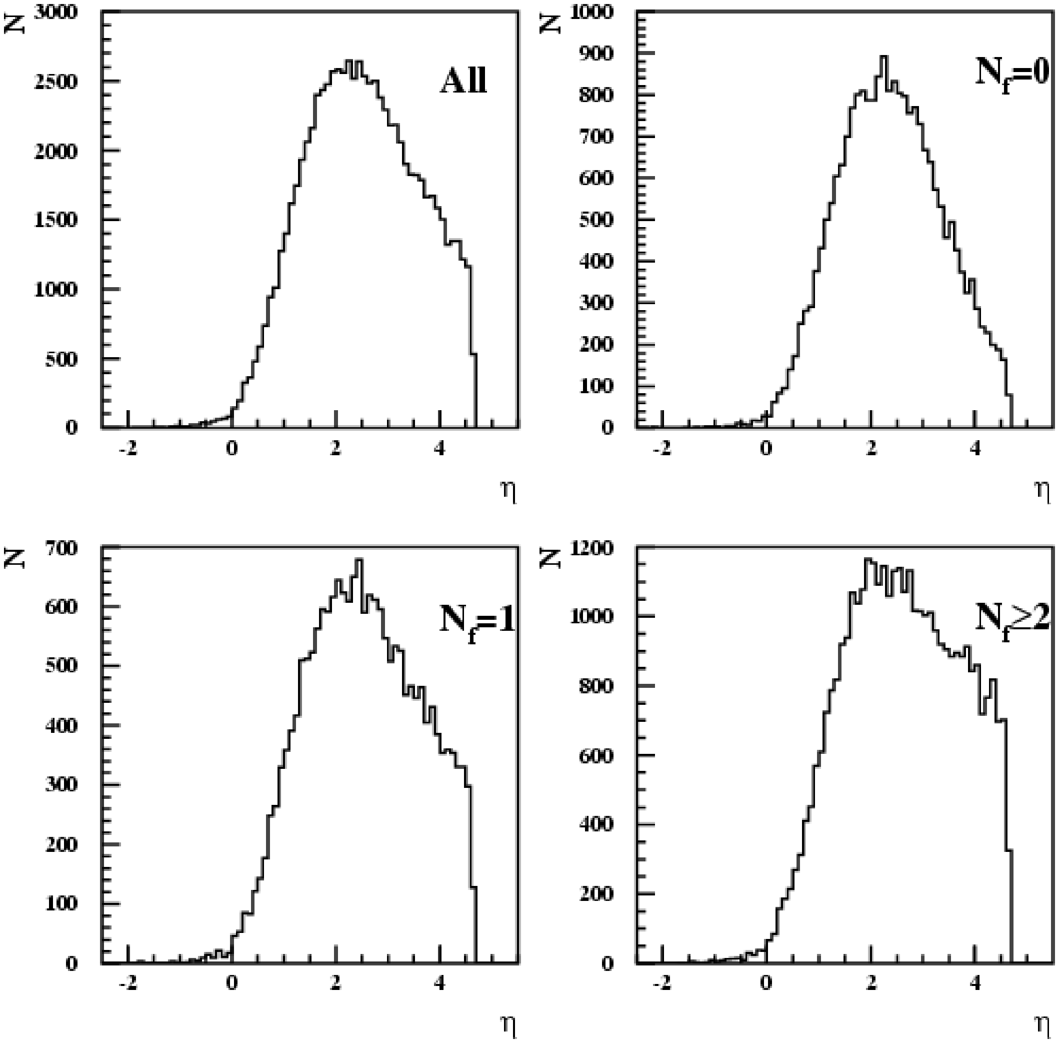
This behavior reflects the degree of centrality of collision.




The distribution of the total charge of fragments of the projectile nucleus
in Au+AgBr interaction with one multi-charged fragment $N_f$ = 1 for different $n_s$ multiplicity

This assumption is confirmed by the difference of the total charge of fragments of the projectile nucleus for the different areas of change $n_s$ .

Peak at the maximal values $Q$ is connected with peripheral events of different degrees of perifericos on the growing branch of the average $N_h$-$n_s$ curve, and the peak in the region of small values Q is connected with central events of different degrees of centrality on the descending branch of the average $N_h$-$n_s$ curve.



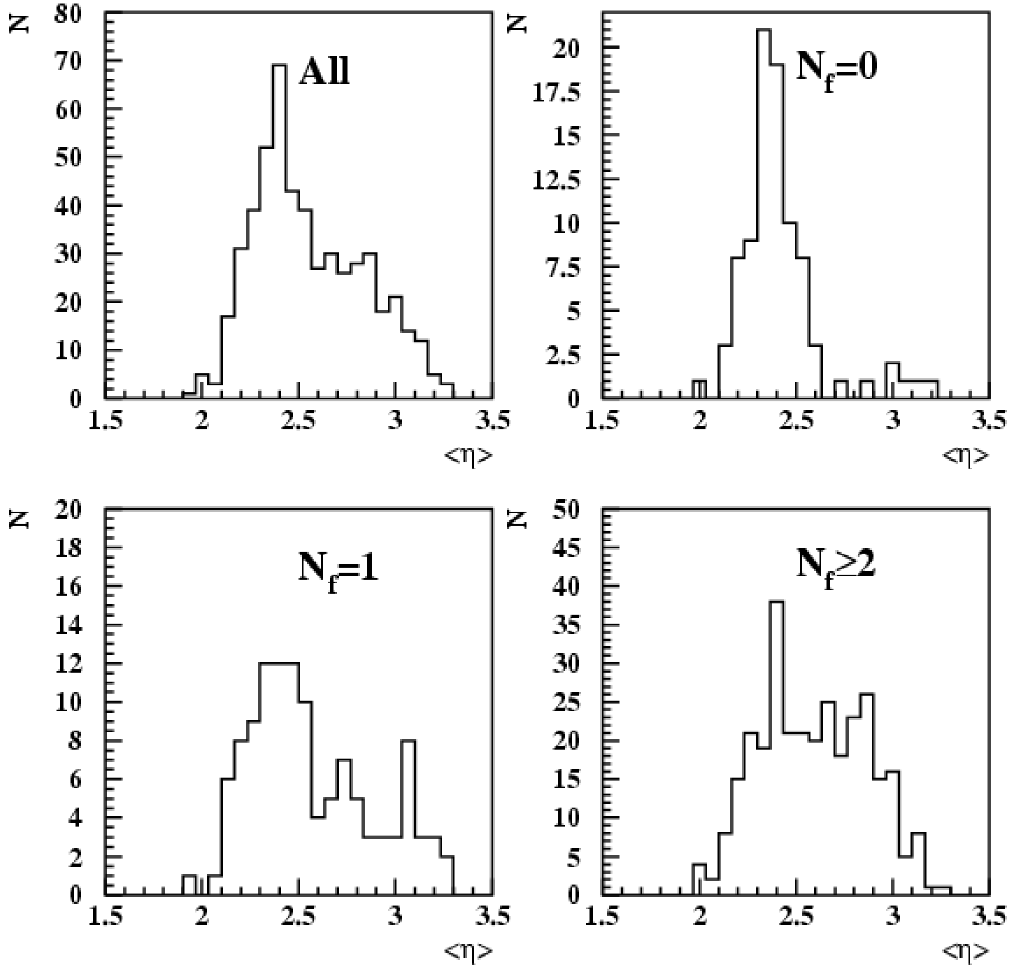

Pseudorapidity distribution for events with different number of multi-charged fragments in interactions of Au+Em 10.7 A GeV

Secondary particles distributions have peculiarities for events with different numbers of multi-charge fragments of projectile nucleus

Pseudorapidity distribution in Au+Em 10.7 A GeV has gauss-like type in events with $N_f=0$

and significantly different from the Gaussian type when $N_f>0$.

Significant contribution of events in the field of large $\eta$, is discovered.




Distribution of average pseudorapidity

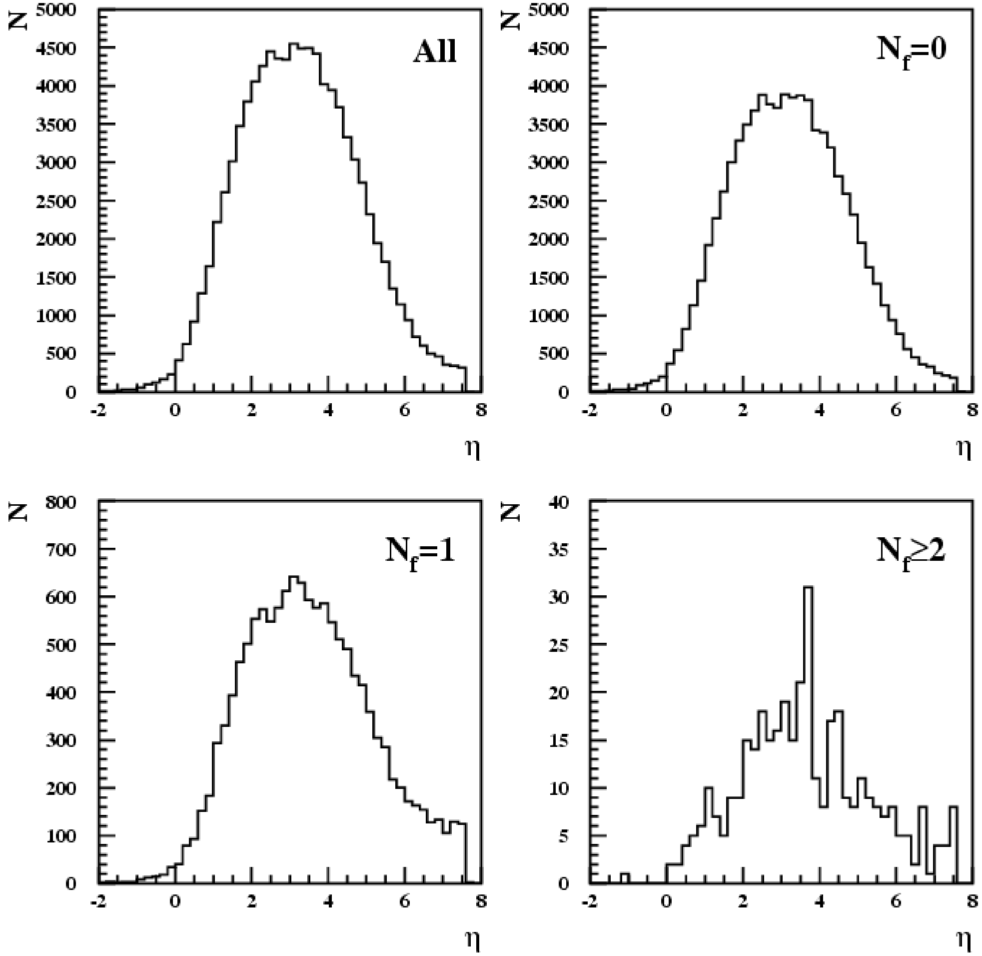
$\langle\eta\rangle = \sum \eta_i / n_s$

in Au+Em 10.7 A GeV with $n_s$>50

In the distribution of all events, gauss-like behaviour distorted by significant contribution of events in the field of large $\langle\eta\rangle$.

The main deposit to the contribution is given by events, which have few multi-charge fragments $N_f \geq 2$.

Events with $N_f$=0 have gauss-like distribution of $\langle\eta\rangle$.

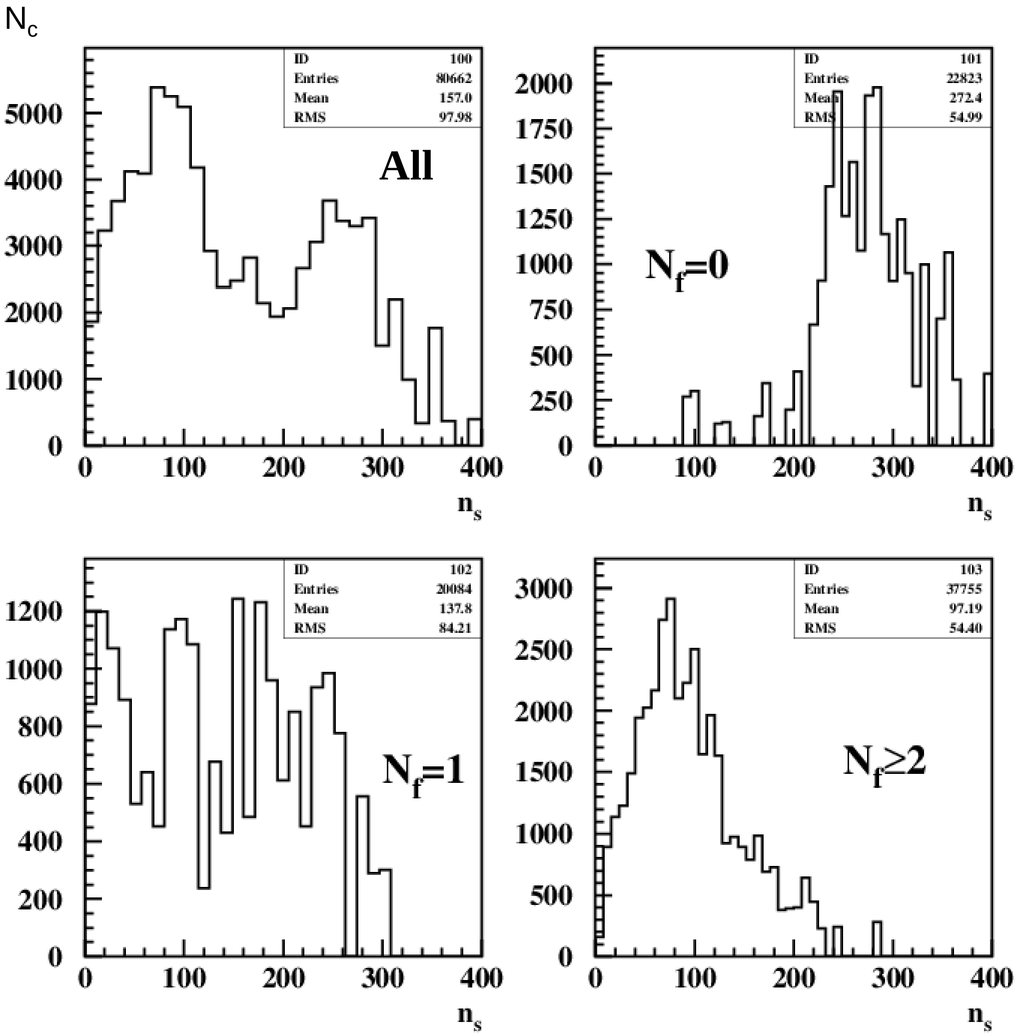



Pseudorapidity distribution for events with different number of multi-charged fragments in interactions of S+Em 200 A GeV

For comparison

Pseudorapidity distribution in S+Em 200 A GeV has gauss-like type

No significant peculiarities




Multiplicative $n_s$-distribution ($N_c=N\cdot n_s$) for events with different number of multi-charge fragments of projectile nucleus in Au+Em 10.7 A GeV

Also interesting results follows from joint analysis of fragmentation parameters and multiplicity distributions.

Multiplicity distribution for All events is distribution with two clear peaks.

Events, which are characterized by full absence of multi-charge fragments $N_f=0$, have large multiplicity. They form the peak with average multiplicity $\langle n_s\rangle \sim 272$.

In events, which have few multi-charge fragments, give main deposit to the peak with $\langle n_s\rangle \sim 97$.

Events with $N_f = 1$ have different multiplicity in wide intervals without clearly expressed peculiarities.

## Peculiarities of secondary particles distribution in individual events it was analyzed by Hurst method.

$$S(k) = \left[ \frac{1}{k} \sum_{i=1}^{k} [\xi_i - <\xi>]^2 \right]^{1/2}.$$

$$R(k) = \underbrace{\max X(m,k)}_{1 \le m \le k} - \underbrace{\min X(m,k)}_{1 \le m \le k}$$

$$X(m,k) = \sum_{i=1}^{m} [\xi_i - <\xi>], \qquad 1 \le i \le m \le k$$

$$<\xi> = \frac{1}{k} \sum_{i=1}^{k} \xi_i.$$

it was analyzed the normalized range versus the size of the pseudorapidity interval ($k=\Delta\eta/\delta\eta$)

$$H(k) = R(k) / S(k)$$

where R(k) and S(k) are a "range" and a standard deviation

using the function

$$H(k) = (ak)^h,$$

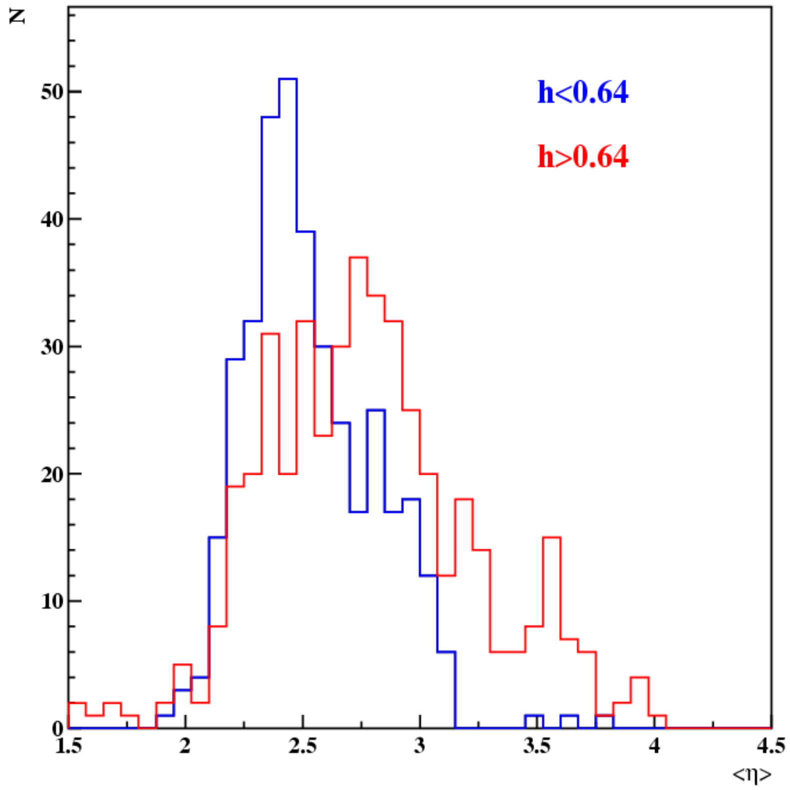
where $a$ and $h$ are two free parameters. $h$ is the correlation index (or Hurst index). If the $\xi$-distribution represents white noise (a completely uncorrelated signal), then $h$= 0.5.
If 0.5<h<1, then $\xi$-distribution are correlated.

It was analyzed the pseudorapidity fluctuation $\xi$, or the normalized relative deviation of an individual event from average pseudorapidity distribution

## Analysis procedure

1. $\Delta\eta / k = \delta\eta \Rightarrow n_i$
2. $\xi_i = \frac{n_i^e}{n^e} \frac{n}{n_i}$, where

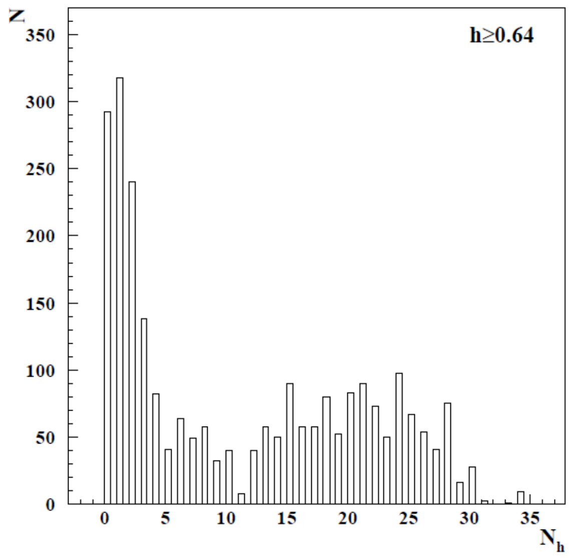
   $n_i^e$ – the number of particles in the i-th bin in the event,
   $n_i = \sum_e n_i^e$ is the total number of particles for all events in the i-th bin,
   $n^e$ – particles number in the event,
   $n = \sum_e n^e$ — the total number of particles for all events.
3. $H(k) = R(k) / S(k)$
4. $k_1 = k/2 \Rightarrow H(k/2)$ … $k_j = k/(2j) \Rightarrow H(k/2j)$
5. $H(k_j) = (ak_j)^h$



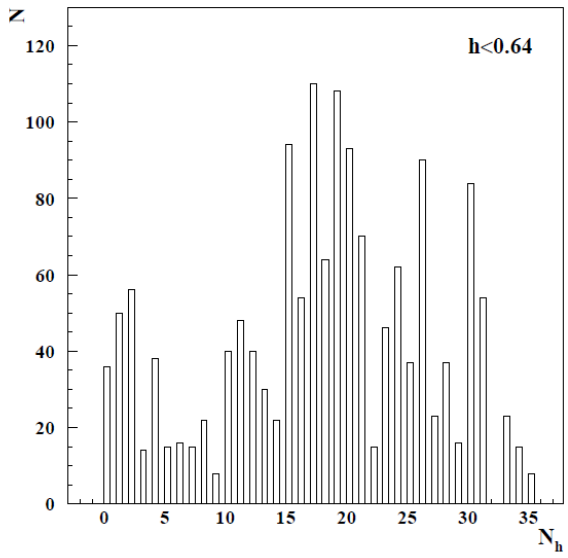

The selection of events it was made on the basis of Hurst index h = 0.64.
The criterion h = 0.64 corresponds to process in which all secondary particles were produced from two-particle decays. And so, this criterion conditionally divides all experimental set into processes, in which certain dynamic multiparticle correlations are observed, and on events, in which multiparticle correlations are absent.

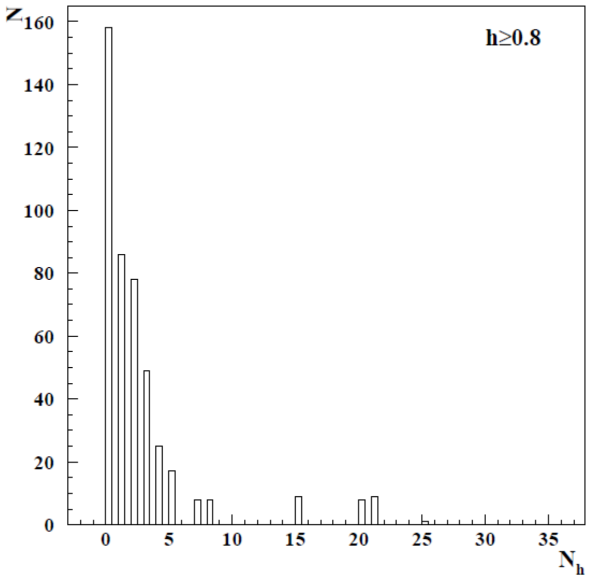
The <η>-distribution of events with multiparticle correlations is shifted to large value of <η> in comparison with uncorrelated events.

The main deposit to disorder of gauss-like behaviour is given by events with h>0.64.




In the most of the events with high Hurst index, the complete destruction of the target nucleus, is discovered.



# CONCLUSION

The dynamics of the interaction of nuclei is depended on not only by the energy and mass of the interacting nuclei, but also on the geometry of the colliding nuclei.

The number of multi-charged fragments of the projectile nucleus ($N_f$) in interactions of sharply asymmetric nuclei depends on the centrality degree of interaction.

The study of the peculiarities of the distribution of secondary particles versus number of multi-charged fragments of the projectile nucleus, is performed.

The events with $N_f$ =1 are separated clearly in the distribution of the total charge of the fragments of a projectile nucleus (Q) depending on the nature of the correlation dependence of the number of fragments of the target nucleus ($N_h$) and the multiplicity of secondary particles from interaction area ($n_s$).

The peak in the field of the maximum values Q characterizes peripheral events with various degree of the perifericos on a growing branch of average $N_h$-$n_s$ curve. And the peak in the field of small values Q characterizes the central events with various degree of centrality on the decreasing branch of average $N_h$-$n_s$ curve.

In the $<\eta>$-distribution of all events,  gauss-like behaviour distorted by significant contribution of events in the field of large $<\eta>$. The main deposit to the contribution is given by events, which have few multi-charge fragments $N_f \geq 2$.

THANK YOU FOR
YOUR ATTENTION