Puzzles of multiplicity

Elena Kokoulina, Vladimir Nikitin
LHEP JINR, Dubna, Russia

Introduction

High energy physics began with registration of usual charged hadrons: protons and pions. Later the number of kinds of secondary particles significantly increased. All of them were produced at high energy collisions of hadrons, nuclei or leptons. Different models and theoretical approaches began to develop for the description of *multiparticale production*.

It is known that statistical (R. Hagedorn) and hydrodynamic (L. Landau) models, and also quantum chromodynamics can explain only few phenomena of multiparticle production. Up to now there is no complete understanding of the mechanism of this phenomenon. The main reason is the absence of theoretical and experimental approaches to understand the process of hadronization - how invisible quarks and gluons are transformed to observable hadrons. That is why there is significant discrepancy between theoretical predictions and experimental data for *multiplicity* (number of secondary particles) behavior.

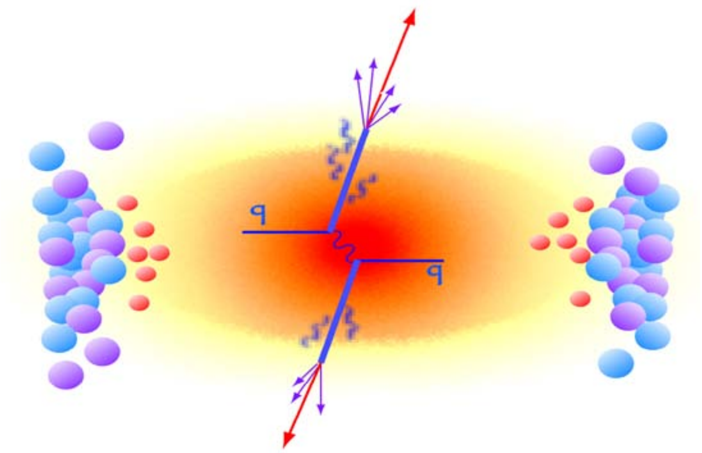

Fig. 1. Scheme of the relativistic heavy ion interaction: quark-gluon scattering and hadron jet formation.

Project Thermalization is carried out at U-70 accelerator and aimed at studying multiparticle production under *extreme* conditions. We investigate events with the number of secondary particles significantly more than the mean multiplicity (*extreme multiplicity*). In this case we can produce the dense medium at the initial moment of the collision. The formation of the quark-gluon system with the following transformation to hadrons under the extreme conditions can give additional information concerning multiplicity processes. Manifestation of the collective behavior of secondary particles will help to understand better the above tasks. Our studies are closely related future plans of JINR (NICA/MPD, Dubna) and IHEP (U-70, Protvino): relativistic light and heavy ions.

The SVD-2 setup

Project Thermalization is carried out at SVD-2 setup (Spectrometer with Vertex Detector) on the extracted 50-GeVproton beam at U-70 accelerator (IHEP, Protvino). The setup SVD-2 has been manufactured by SVD collaboration. The installation is capable to detect the events with high multiplicity of the charged particles. The lower energy threshold of the photon registration is equal to 200 MeV. The trigger system selects rare events with the preset value of multiplicity (so called a trigger level) $n_{ch} > 4$, 6 and more. The magnetic spectrometer has the momentum resolution ~ 1,5% in the interval of p = 0.3-5.0 GeV/c.

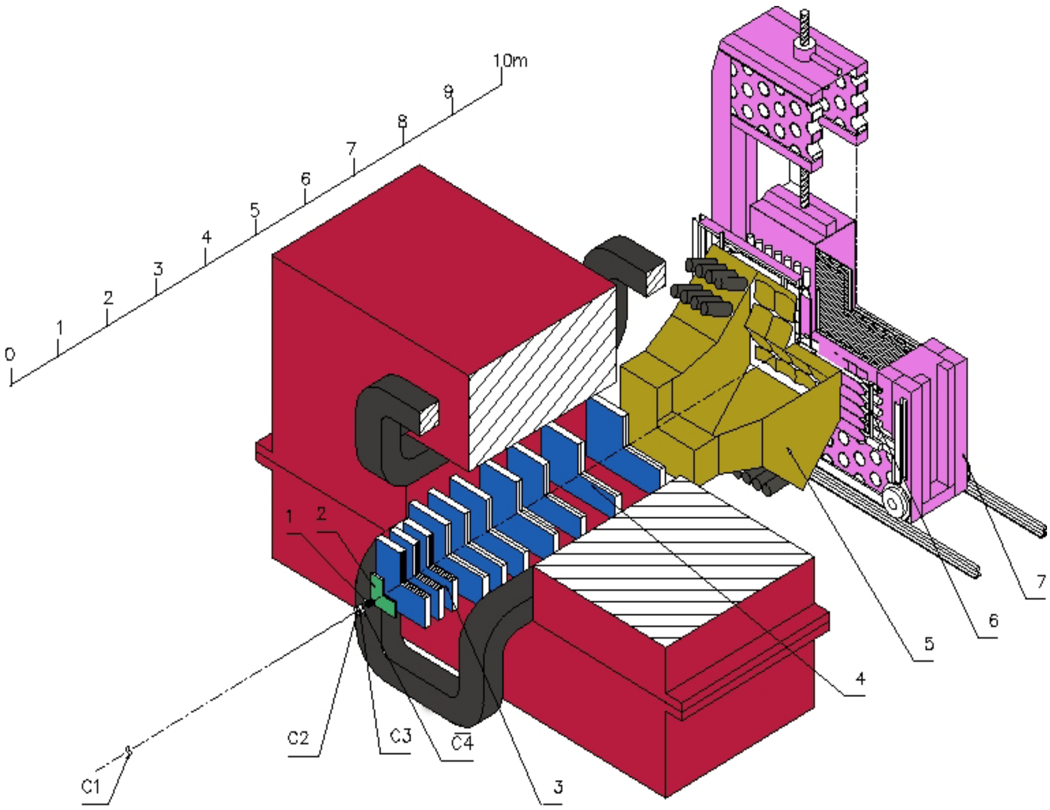

Fig. 2. Scheme of SVD-2 setup.

SVD-2 installation (Fig. 2) consists of liquid hydrogen (nuclear target) (1), a precision vertex detector, PVD, (2), a straw tube chamber or a drift tube tracker, DTT, (3), a magnetic spectrometer, MS, (4), Cherenkov counter, CC, (5), an electromagnetic calorimeter or a detector of gamma –quantum, DeGa, (6, 7), a scintillator hodoscope or the trigger system to select events with high multiplicity.

The main element of SVD-2 setup is PVD. It allows one to reconstruct the interaction vertex with a high degree of accuracy. This detector was constructed on the basis of strip silicon sensors with a step of 50mk. It consists of 10 planes at the following angles: four *X* - planes at 0°, four *Y* – planes at 90° and two oblique planes: *U* and *V* at +/- 10.5° to disentangle tracks in space.

The DTT system consists of three modules, each module has three chambers measuring particle coordinates *U*, *X* and *V*. The chambers of each module are identical, but *U* and *V* planes are turned relatively *Y* axes on angles +/- 10.5°. The middle plane dimension has size 70 × 70 cm^2. Each chamber contains two layers of thin-wall drift tubes with diameter d = 6 mm. The information is read out from the anode wires, which are independent registration channels. Every run it is necessary to calibrate drift tubes. This procedure was elaborated in our group. The coordinate measurement accuracy by means of the drift time of the single tube was found to be about 200 mk.

DeGa consists of 1536 full absorption Cherenkov counters. Radiators from the lead glass have the size of 38 × 38 × 505 mm^3 and are connected with PMT-84-3. The total active area of the detector is 1.8 × 1.2 m^2. The energy resolution on 15 GeV electrons is 12%. The accuracy of γ -quantum coordinate reconstruction is ~ 2 mm.

The suppression of low-multiplicity events is carried out by means of a trigger system. For this purpose the scintillation hodoscope or high-multiplicity (HM) trigger was designed and manufactured. It produces a signal which permits to register events with multiplicity not lower than the specified level (n × MIP, where n is preset number, usually n is equal to 8÷12).

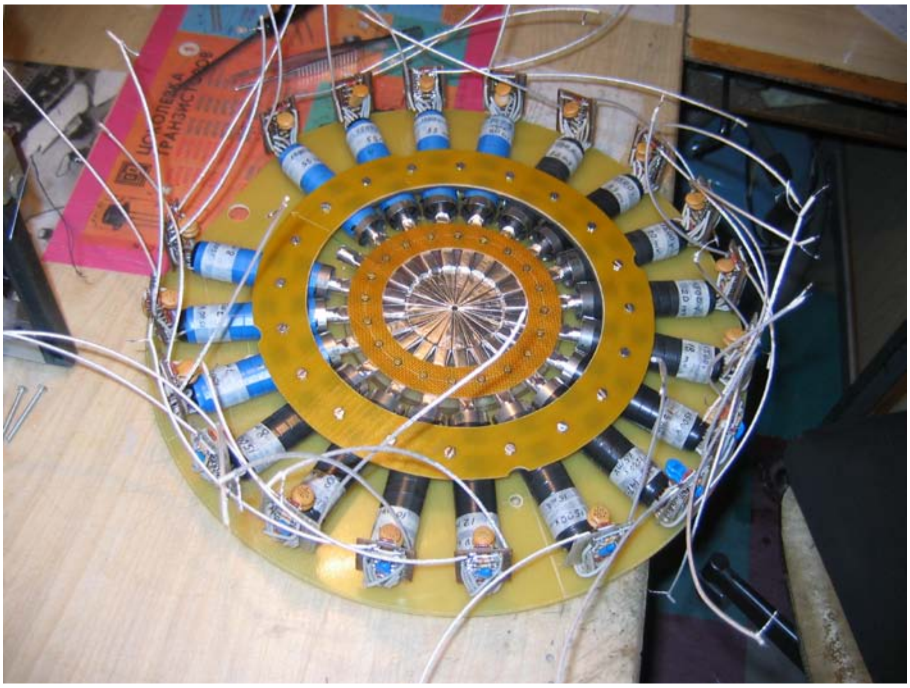

Fig. 3. Scintillator hodoscope.

Collective Phenomena search for

In the extreme multiplicity region we search for the new collective phenomena of secondary particles. They have hadron nature as well as quark-gluon nature. That is why its investigations are important. We have analyzed events with the trigger-level equal to 8 × MIP and a higher level. The experimental angular distributions were obtained at two domains of multiplicity by using vertex detector data without taking into account acceptance corrections and efficiency of setup (at present this work is in progress): with the multiplicity more than 8 and with multiplicity less than 9 charged particles (Fig. 4).

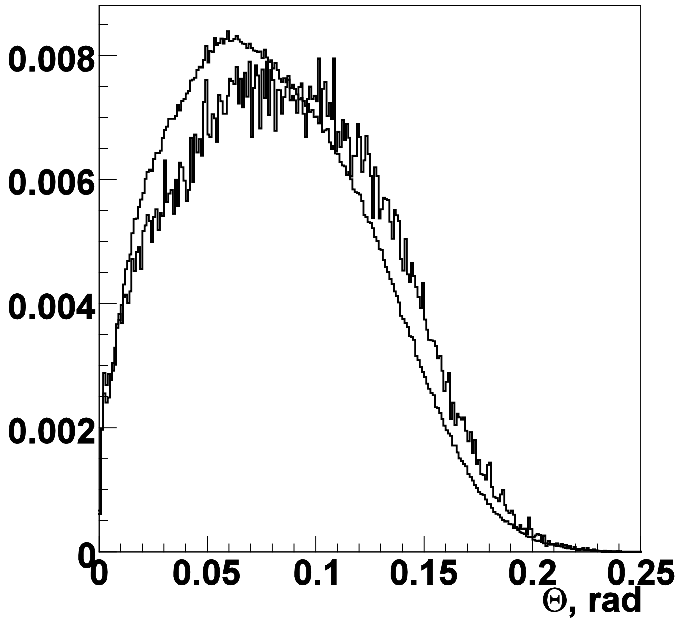

Fig. 4. Θ - distributions on the number of tracks (N) for events with small multiplicity not more than 8 of charged particles (left curve) and with high multiplicity n > 9 (right curve).

In hadron interactions mainly the lightest particles, pions, are formed. They are bosons. The more secondary particles are produced the smaller energy they have. V. Begun and M. Gorenstein have proposed to search for Bose—Einstein condensation (BEC) of π-mesons in the high multiplicity events. They have shown that the pion number fluctuations strongly increase and may give a prominent signal at approaching the BEC. To reveal these signals, one needs to carry out the event-by-event identifications of the both - charge and neutral π. An abrupt and anomalous increase of the scaled variance $\omega = <(n_0-<n_0>)^2>/<n_0>$, of neutral ($n_0$) and charged pion number fluctuations will be the signal of BEC.

We detect the numbers of charged particles, N_{ch}, and photons, N_γ, in each event. These values are corrected on the setup acceptance and reconstruction efficiency by means of modeling. Simulation has allowed getting the neutral pion number, N_0, in each event. Numbers of events, $N_{ev}(N_0, N_{tot})$, are measured here and corrected on various losses. For the analysis of the data at different total multiplicity, N_{tot}, relative values of $n_0=N_0/N_{tot}$ and $r_0=N_{ev}(N_0, N_{tot})/N_{ev}(N_{tot})$ are used. Thus n_0 changes in the range of 0÷1 and the sum of all r_0 is equal to 1 for each N_{tot} (normalization condition). Fig. 5

qualitatively illustrates the behaviour of value r_0 for three cases: a) the generation of events with PYTHIA5.6 program, b) the pion system in which some pions drop out into condensate, c) all pions are in the BEC condition. Each distribution is characterized by average, $<n_0>$, and by standard deviation, σ, for a Gaussian fit.

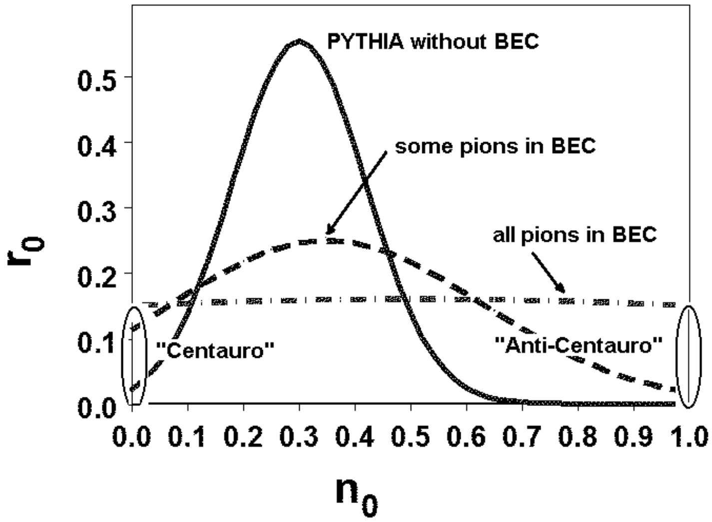

Fig. 5. Normalized multiplicity distributions, r_0, of scaled neutral pion multiplicity, n_0 , in PYTHIA without BEC, with some pions in BEC and with all pions in BEC.

One can see that the measured average $<n_0>$ (Fig. 6, left) coincides with the same values for the neutral pions from MC events at $N_{tot}>12$. In the gluon dominance model (MGD) the dependence of mean multiplicity for neutral pions on N_{tot} has been received by analytical way. This dependence is also presented in Fig. 6, left and illustrates quite good agreement with the experimental data at $N_{tot}>14$. The average $<n_\gamma>$ is also shown. The measured standard deviations, σ (Gaussian), (Fig. 6, right) have shown the qualitative agreement with MC model only for $N_{tot}<22$. The measured values σ increase at higher N_{tot}.

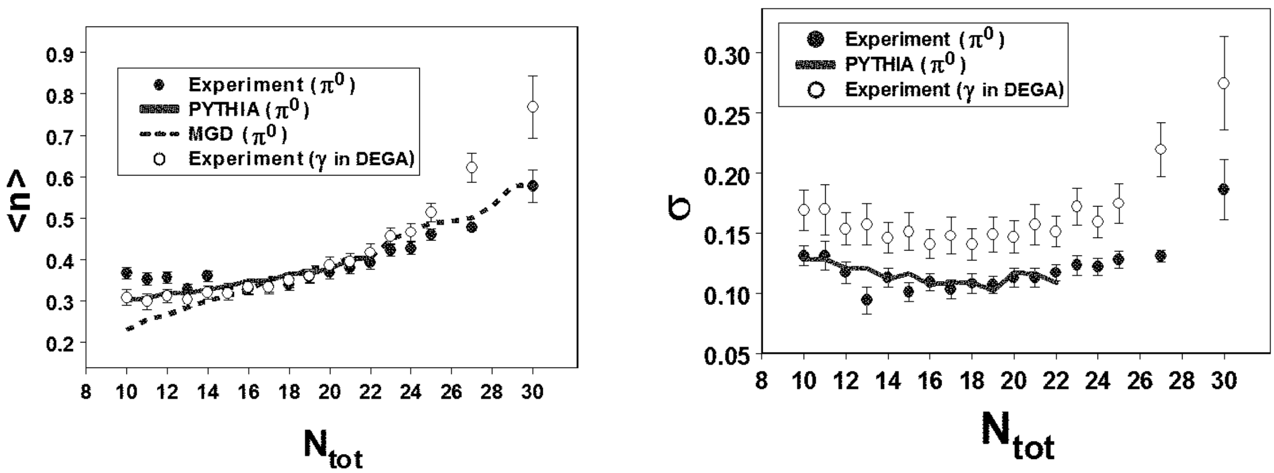

Fig. 6. Fitted parameters of neutral pions number and photons number distributions for experimental data and MC events as function of N_{tot}. For neutral pions $N_{tot}=N_{ch}+N_0$, for photons $N_{tot}=N_{ch}+N_\gamma$.

The theoretical prediction of scaled variance ω behavior (in our case $\omega=D(N_0)/<N_0>=\sigma^2*N_{tot}/<n_0>$) was obtained by Gorenstein. The analysis has been done for three energy densities of the pion system at the approach to the Bose-Einstein condensate condition (pion condensate) (Fig. 7a). Our experimental data (Fig. 7b) have confirmed assumption about the BEC formation in pion system at $N_{tot}>22$ in pp-interactions at 50 GeV.

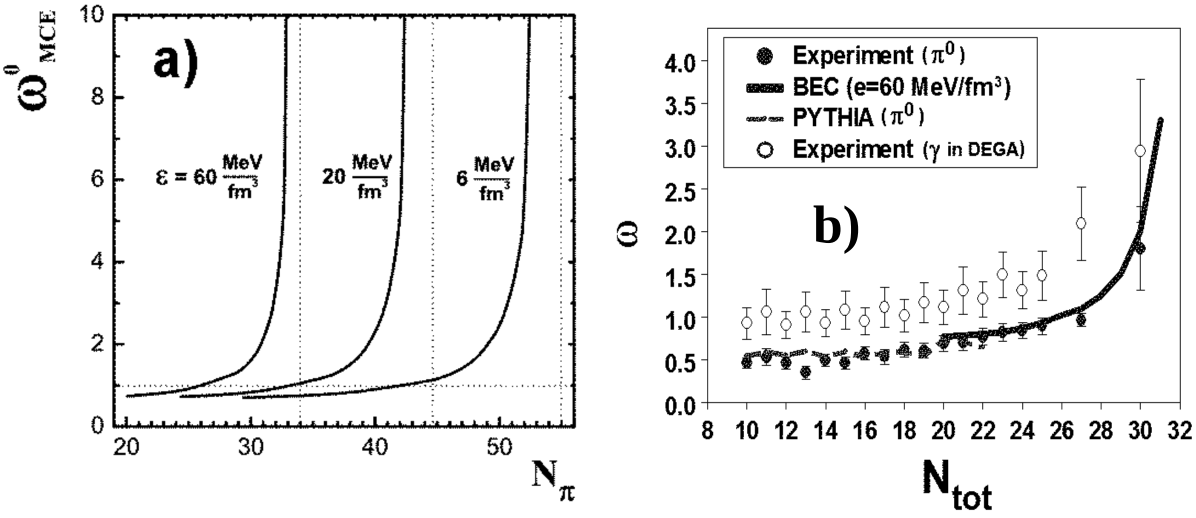

Fig. 7. a) Scaled variance ω as function of N_{tot} [3] and b) the result of the present measured of ω for neutral pions and photons. $N_{tot}=N_{ch}+N_0$ for neutral pions, $N_{tot}=N_{ch}+N_\gamma$ for photons.

Pion number fluctuations increase at $N_{tot}>22$, can indicate to approaching to pion condensate conditions for the high multiplicity pion system according to GCE, CE, MCE models.

Gluon dominance model

We have developed a gluon dominance model (GDM). It is based on the main essences of QCD and supplemented with the phenomenological mechanism of hadronization. This approach shows the activity of gluons and the passive role of the valent quarks in the multiparticle production mechanism. GDM confirms convincingly the recombination mechanism of hadronization in hadron and nuclear interactions and fragmentation in lepton processes. The unexpected conclusion is originated from GDM about the maximum possible number of secondary particles. At present beam -energy (50 GeV) this limit is equal to 26 for charged and 16 for neutral pions (note, that kinematical limit is 56 pions). This model describes well multiplicity distributions at high multiplicity tail.

Research program.

Good knowledge of C++ programming language and the ROOT software (http://root.cern.ch) is greeted. Students it is proposed to take part to carry out at the following themes of project:

- <u>Multiplicity distributions for neutral and charged particles at high energies in lepton, hadron and nuclei interactions in framework of gluon dominance model.</u>

- Getting acquainted with the work of the main detectors of SVD-2 setup: vertex detector, drift tube tracker, magnetic spectrometer, electromagnetic calorimeter and scintillator hodoscope.
- Acquiring skill for track reconstruction algorithm based on Filter Kalman.
- Alignment task.
- Drift tube calibration procedure.
- The BEC formation at proton nucleus interaction with high multiplicity.

References: **Introductory books on multiparticle production**

1. V.S. Murzin and L.I. Sarycheva. *Interactions of high energy hadrons*. (Russian edition). 288 pp. 1983.
2. R. Hagedorn. *Statistical thermodynamics of strong interactions at high-energies*. Nuovo Cim.Suppl.3:147-186, 1965.
3. Yu. L. Dokshitzer et al. *Basics of Perturbative QCD*. Editions Frontieres. 1991.
4. Z. Koba, H. B. Nielsen and P. Olesen. Phys. B. 1972. V. 40. P. 317.

General papers

1. A. Giovannini and R. Ugocioni. *Clan structure analysis and QCD parton showers in multiparticle dynamics: an intriguing dialog between theory and experiment*. Int.J.Mod.Phys. A20, 3897-4000 (2005).
2. A. Aleev et al. *Project "Thermalization"*, Nonlinear Dynamics and Applications: Proceedings of the 13th annual seminar "Nonlinear Phenomena in Complex Systems", Minsk, May 16-19, 2006/ Joint Institute for Power and Nuclear Research-Sosny, National Academy of Sciences of Belarus; edited by L.F. Babichev, V.I. Kuvshinov. - Minsk, 2006. - p. 83-93.
3. V. Blobel, Proc. Conf. Advanced Statistical Techniques in Particle Physics. Durham, March, 2002. DESY, Hamburg.
4. V. V. Begun and M. I. Gorenstein, Phys. Lett. B 653, 190 (2007).
5. http://www.slac.stanford.edu/spires/find/hep/www?rawcmd=a+Kokoulina,+ …

The number of participating students is 1÷ 4.

The project supervisors: Prof. Vladimir Nikitin, Dr. Elena Kokoulina (Head of group of High Multiplicty). Baldin and Veksler Laboratory of High Energy Physics, tel: 65329, e-mail: nikitin@sunse.jinr.ru, kokoulin@sunse.jinr.ru