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Extreme multiplicity study: advancement and outlook

Elena Kokoulina* and Igor Roufanov†
Joint Institute for Nuclear Research, Dubna, Russia

Andrey Kutov‡
Department of Mathematics, Ural division of RAS, Syktyvkar, Russia

Vasiliy Ryadovikov§
Institute of High Energy Physics, Protvino, Russia

It is informed of the extreme multiplicity studies in proton and nuclear interactions at high energies. These investigations are carried out at U-70 accelerator (IHEP, Protvino) in the framework of the Thermalization project. It is expected the manifestation of the following collective phenomena: Bose-Einstein condensation, Cherenkov gluon radiation, excess of soft photon yield in this region and others. This project is aimed to the search for them.

Keywords:

1. Introduction

Multiparticle production is one of the fundamental problems of high energy physics and relativistic nuclear physics [1]. At present the significant attention is attracted to the study of the phase-transition of hadrons into quark-gluon plasma (QGP) [2]. The description of new phenomena in the multiparticle production processes by pQCD and phenomenological models is developed [3, 4]. In a number of theoretical models the assumption of the possible formation of quark gluon plasma (QGP) at low temperature (cold QGP) is suggested [5]. It may be manifested by the excess of the soft-photon yield [6].

The purpose of the proposed experiment Thermalization [7] is to investigate pp and pA interactions

$$pp \to n_\pi \pi + 2N \tag{1}$$

with the extreme high (more than average) multiplicity at the proton energy of $E_{lab} = 50 - 70\ GeV$. In the seventies the multiplicity distribution (MD) at these energies was measured up to the maximum number of charged particles $n_{ch} = 18$ [8]. We have registered the events with multiplicity $n_{ch} = 22$ and plan to reveal the events with still more multiplicity. In this region the main part of the center of mass energy $\sqrt{s} = 11.6\ GeV$ is transferred into mass of the produced particles. The density of the created hadron system may be rather high and the onset of cold QGP it is supposed.

The onset of QGP itself manifests via large intermittency in the phase space of rapidity - transverse momentum [9, 10] and an extra yield of the direct photons [11] and lepton pairs.

*Also at Gomel State Technical University, Belarus; E-mail: kokoulin@sunse.jinr.ru
†E-mail: ruf@sunse.jinr.ru
‡E-mail: kutov@dm.komisc,ru
§E-mail: Vasily.Ryadovikov@ihep.ru

This region is called as the high-multiplicity (HM) or the extreme multiplicity (ExMu) region. A number of collective phenomena is predicted at ExMu: the Bose-Einstein condensate (BEC) formation [12], ring events (gluon Cherenkov emission) [13], a certain grouping of secondaries (clusterization) [14, 15], and also high yield of soft-photon emission (in the comparison with the obtained in quantum electrodynamics estimations) [11].

2. Setup schematic

The study is carried out on the extracted 50 GeV proton beam at U-70 accelerator (IHEP, Protvino). The setup called the Spectrometer with the Vertex Detector (SVD) was created by SVD collaboration [16, 17]. Installation is capable to detect the events with high multiplicity of the charged particles $20 \div 40$ and γ quanta. Multiplicity of photons changes up to 100. The lower energy threshold of the photon registration is ~50 MeV. The trigger system is capable to select rare events with multiplicity $n_\pi = 20 \div 40$. The magnetic spectrometer has the momentum resolution $\delta p/p \approx 1,5\%$ in an interval $p = 0.3 \div 5.0$ GeV/c.

SVD-2 installation consists of the liquid hydrogen target, the precision vertex detector (PVD), the drift tube tracker (DTT), the magnetic spectrometer (MS), Cherenkov counter (CC), electromagnetic calorimeter or detector of gamma-quantum (DeGa), the scintilator hodoscope or the trigger system to select events with high multiplicity. The drift tubes tracker locates between the precision vertex detector (PVD) and the magnetic spectrometer consisted of the proportional chambers

The main element of SVD-2 setup is PVD. It allows one to reconstruct the interaction vertex to a high degree of accuracy. It was created on the basis of strip silicon sensors with a step of 25 and 50 μm. It has a plane set at the following angles: 0, $\pi/2$ and $\pm 10.5°$. We distinguish coordinates x, y, u (+10.5°) and v (-10.5°), respectively. The oblique planes U and V are necessary to disentangle tracks in space.

In the physical run (2007) two oblique planes U and V was included in PVD. Unfortunately, one of them has burned down. The track reconstruction in a space by using one oblique plane causes difficulties. That is why MDs in the PVD data were obtained on two (X and Y) projections.

The design and manufacture of the liquid hydrogen target is under a full JINR responsibility. The team under the leadership of Golovanov L.B. has a unique experience to develop a very reliable, easy maintained and low helium consuming target. The liquid hydrogen target characteristics are: thickness h=0.5 g/cm^2, at the instant luminosity $L = 3.0 \times 10^{30} cm^{-2} s^{-1}$ the fraction of the beam interaction in the target $r = 1.0 \times 10^{-2}$, the instant and average rate of events, are accordingly, $N_{int} = 1.0 \times 10^5$ s^{-1} and $\bar{N}_{int} = 1.6 \times 10^4$ s^{-1}. In the 2007 run the automation control of the liquid helium consumption and temperature regime, have been established.

A straw tube chamber or drift tube tracker (DTT) is a new addition to SVD-2 setup. This detector has been designed in the department of headed by Peshehonov (LPHE, JINR). This chamber is completed with front end boards leaving preamplifiers produced in Minsk (NC PHEP BSU) and TDC modules produced in Protvino (IHEP) which allow to detect several pulses, subsequently coming from the anode on each trigger signal. The system consists of 3 modules, each module consists of 3 chambers measuring particle coordinates U, X and V. The chambers of each module are identical, but U and V detectors are turned relative Y axes on angle $\pm 10.5°$. The middle-plane dimension is 70×70 cm^2. Each chamber contains 2 layers thin-wall drift tubes with diameter d=6 mm. The information is read out from the anode wires, which are independent registration channels.

The calibration of every drift tube is carried out (Fig. 1). The coordinate measurement accuracy

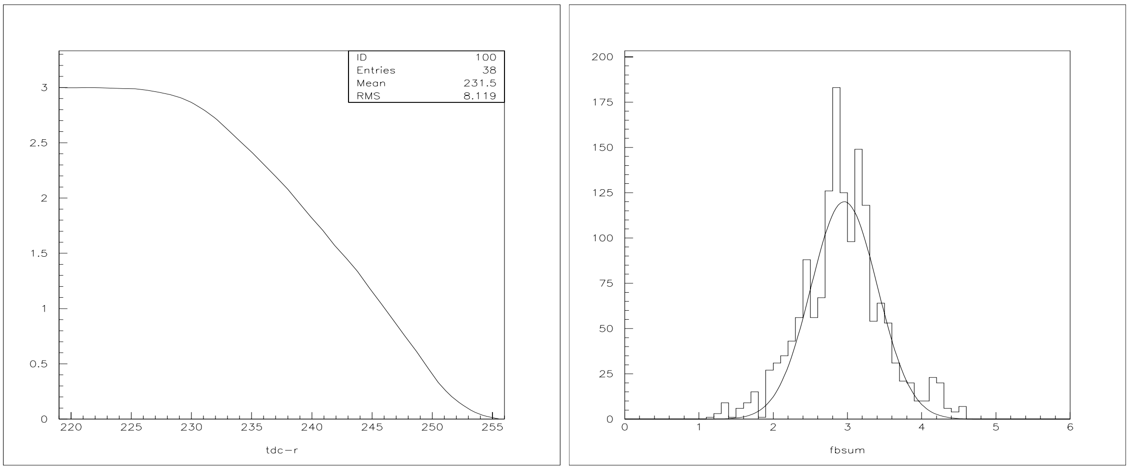

FIG. 1. Calibration function for single drift tube (from above) and the resolution of DTT (below).

by means of drift time of the single tube was found about 250–300 μm (2006-2007 runs). The software for the track reconstruction in this tracker was designed and used for the coordinate measurement. The drift tube chamber efficiency was not lower than 99.9% at the operation of two adjoining tubes. The two-track resolution was found about 1.5 mm [18].

Magnet MC-7A has length of 3 m along the beam in the spectrometer. The magnetic field in the center is 1.1 Tl at a current of 4000 A. The detection system of the spectrometer includes 18 planes of proportional chambers (PC). The data analysis gives the following characteristics of the spectrometer: average PC efficiency is 80 %; coordinate accuracy on the reconstructed tracks is 1 mm; the momentum resolution on beam tracks (=70 GeV) is 3 %; the momentum resolution on the secondary tracks is ~ 1 %. Magnetic spectrometer electronics allows one to register up to 1.5 thousand events per 1 accelerator cycle. In the 2007 run some of MS amplifiers have fallen out. In 2008 new amplifiers were designed by NC PHEP (Minsk) and will be installed to the future run.

The threshold Cherenkov counter has 32 channels of the signal registration from photomultiplier (PMT). PMT are supplied with active magnetic field protection. The efficiency of pions registration in the momentum interval of 3÷30 GeV is 70 %. Low efficiency is due to insufficient magnetic field compensation and possible leak of air in the radiator filled up with freon.

The gamma - detector or electromagnetic calorimeter (EMC) consists of 1536 full absorption Cherenkov counters. Radiators from the lead glass have the size of $38 \times 38 \times 505$ 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 the γ quantum coordinate reconstruction is ~ 2 mm.

At the technical 2006 run the calibration of the gamma-detector at specially formed electron beam was carried out. The recording of the full information was accomplished from all detectors including DeGa. At present the reconstruction procedure of photons and neutral mezons is executed. Our participants from IHEP plan to renovate partially EMC. It permits to take data from the total system of detectors in future physical run in December 2008.

In our experiment 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 at LPHE, JINR. It produces a signal which permits to register events with multiplicity not lower than the specified level (for example, 8). Beyond this it is thin enough not to distort the angular and momentum resolutions of the setup. This hodoscope is manufactured from plastic

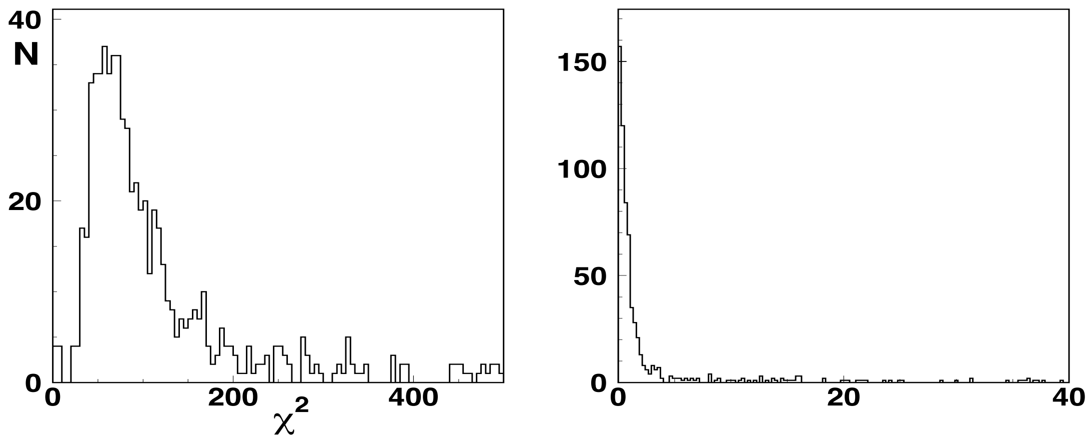

FIG. 2. χ^2/n_{dof} for tracks: (top) before and (bottom) after alignment procedure.

scintillator 1.8-mm thick. It consists of 20 elements in a form of triangles of $h = 18$ mm coupled with PMT FEU-137-3. This equipment gives out an exit signal of 250-mV for MIP (minimum ionization particle) at 25-mV noise level. The full signal width is shorter than 20 ns. It is impossible to get such perfect characteristics in any silicon system. the 2006 run had corroborated these opportunities. The technical run 2006 and physical run 2007 have confirmed the reasonable work of the HM-trigger [19].

The important task of any experimental project is the alignment procedure. It is necessary to provide the correcting geometry of setup for reconstruction of tracks in space and the finding of their characteristics. For these purposes we have designed program packets based on ideas of Millepede–program of Blobel [20] to find linear and nonlinear parameters in our alignment task. In Fig. 2 it is shown χ^2/n_{df} for tracks before and after alignment procedure.

3. Physical program

Our physical program is directed to searching for collective phenomena in ExMu region. At the beginning of this study we have analyzed the existing experimental data and theoretical models of hadron and nuclear interactions. We have found Monte Carlo event generators underestimate MD at 16 charged particles about two orders. Phenomenological models differ considerably in this region [21, 22]. That is why we have developed the gluon dominance model (GDM) [22–28]. It is based on the main essences of QCD and supplemented with the phenomenological mechanism of hadronization. This approach sets the activity of gluons and the passive role of the valent quarks in multiparticle production mechanism. GDM confirms convincingly the recombination mechanism of hadronization in hadron and nuclear interactions and fragmentation in lepton processes.

At last years after RHIC data were obtained the multiparticle production mechanism was significantly revised. The theory of CGC (Colour Glass Condensat) and Glasma (gluon condensat) is developed and relativistic nuclear physics gets new concept. Our GDM agrees with this theory and permits to understand nature of strong interactions.

The basic collective phenomena which we study in our project are: (∗) Bose-Einstein condensation (BEC) of pions, (∗) the ring events (analogy of Cherenkov radiation), (∗) the excess of soft photon yield, (∗) the clusterization [14, 15].

The possibility of BEC formation in the ExMu region have shown in [12] by Begun and Gorenstein. It is known pions (charged and neutral) are copiously formed at U-70 energies. They are bosons. Their momenta are approaching to zero at ExMu and the BEC may form. The pion number fluctuation will be a prominent signal in the BEC-point. They predict that the scaled variance of neutral and charged pion-number fluctuations, $\omega^0 =< (\Delta N)^2 > / < N >$, in the vicinity of BEC-line have an abrupt and anomalous increase. Our project permits to check this prediction by the experiment.

The ring-like structures were revealed at the angular distributions in nuclear collisions at some experiments in the same energies [29, 30]. Our preliminary analysis of data points out the existing of two picks in the pseudorapidity distribution for ExMu ($n_{ch} > 18$) in pA - interactions (A = Si, C, Pb) [19, 23]. In distribution on total multiplicity these peaks absent. This is indication to the appearance of the ring events at ExMu.

The puzzle of soft photons is our investigation too. We have got the estimation of the emission region of soft photons in GDM. It is equal about $4 - 6$ fm [31]. In this region hadronization process is finished and the kinematical freeze-out is realized. Today we are planning to design and manufacture a prototype of new electromagnetic calorimeter to register very soft photons.

We also expect to reveal in ExMu region groups of particles which fly under small angles (point to clusterization). Leader of our team V. Nikitin have made the unexpected proposal. He considers that the appearance of turbulence phenomena at ExMu in hadron nuclear interactions may find by groups of particles lying in one plane. We believe the realization of our scientific program will be successful and unique for multiparticle dynamics study.

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