New Results of Extreme Multiplicity Studies

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Extreme multiplicity studies at 50 GeV in pp interactions are discussed. Preliminary multiplicity distributions at U-70 (IHEP, Protvino) energy have been obtained for more than 20 charged particles. A new elaborated algorithm for the track reconstruction in a drift tube tracker and magnetic spectrometer, has been checked. The collective behavior of secondary particles is manifested in these interactions in the extreme multiplicity region. For the first time the ring events in pp interactions have been observed in this region. A possibility of detecting the Bose-Einstein condensation detection is discussed.

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I. INTRODUCTION

At present the phase transition signal search for hadrons and nuclei into quark-gluon plasma [1, 2, 3] and back to hadronization, is in progress. These studies are carried out at high and low energies [4]. The data obtained at working accelerators are checked whether these transitions are possible. The search for the phase transitions is closely connected with a high (extreme) multiplicity region exceeding considerably the mean multiplicity [5].

We suggest that the transition to the quark-gluon phase happens in this region, and this phase can be revealed by means of the collective behavior of secondary particles in the proton and nuclear interactions at accelerator U-70 (IHEP, Protvino). The search is realized in the extreme multiplicity region because the Bose-Einstein condensation has been predicted in this very region [6]. Also the indications were obtained on the formation of ring events (analogy of Cherenkov emission gluons from quarks) [7] and on the grouping of secondary particles – clusterization [8].

Now the experimental and theoretical studies are in progress to check the assumption about the increased soft photon (less than 50 MeV) yield in comparison with the estimations obtained in quantum electrodynamics. The existing theoretical models and Monte-Carlo event generators differ very much in their estimations and multiplicity behavior predictions in the high multiplicity region.

We have developed a Gluon Dominance Model (GDM) [9] to describe the extreme multiplicity and mechanism of hadronization. This model predicts the maximal number of charged and neutral particles at 70 GeV which does not exceed 26 and 16, correspondingly.

The investigations are carried out on the modern experimental setup SVD-2 [10] (Spectrometer with Vertex Detector) equipped with a strip silicon detector, a drift tube tracker, a magnetic spectrometer with proportional chambers, Cherenkov counter and an electromagnetic calorimeter. We have designed and manufactured a scintillator hodoscope (high multiplicity trigger) producing a signal to register events with multiplicity not less than the given level – the so called trigger level. The realization of this project will enable the community to move ahead towards the deeper understanding of the strong interaction nature in the extreme multiplicity region.
II. THE SVD-2 SETUP AND DATA PROCESSING

Since 2005 we have been working with the 50 GeV proton beam. Our experimental studies are carried out at SVD-2 (Spectrometer with Vertex Detector) setup on U-70 accelerator of IHEP (Protvino, Russia).

This installation consists of the following basic elements: a hydrogen or nuclear target, a precise vertex detector (PVD), a straw tube chamber or a drift tube tracker (DT), a magnetic spectrometer (MS) with proportional chambers (PC), Cherenkov counter and an electromagnetic calorimeter or gamma-quantum detector (DeGa). We manufactured a scintillation hodoscope or high multiplicity trigger which produces a signal to record the events with not lower than the specified multiplicity level.

The main element of SVD-2 setup is PVD. It allows one to reconstruct the interaction vertex with a high degree of accuracy. It was manufactured on the basis of strip silicon sensors with a step of 25 and 50 µm. It has a set of planes at the following angles: 0, π/2 and ±10.5°. We distinguish coordinates x, y, u (+10.5°) and v (-10.5°), respectively. The oblique planes U and V necessary for disentangling of tracks in space, were installed in November 2008. In the previous 2006 and 2007 runs we obtained double multiplicity distributions on each from two projections: XOZ and YOZ, where axis Z is the beam direction.

After the 2008 run we performed data processing with two oblique planes and got preliminary single multiplicity distributions using the PVD data (high multiplicity trigger level was equal to 8) and compared it with Mirabel data and GDM. Fig. 1 illustrates four multiplicity distributions for comparison: Mirabel results at 70 GeV (empty square) and 50 GeV (full square), the last distribution is consistent with SVD distribution (full circle) and with the gluon dominance model (the solid curve).

The suppression of distributions in the small multiplicity region (n ≤ 8) is stipulated by the scintillation hodoscope rejections. This element regulates the high multiplicity event selection. We have taken into account the efficiency of registration of the high multiplicity events by the PVD.

The Monte Carlo simulation has demonstrated that the subsequent data processing from DT and MS does not significantly change these distributions. These detectors can improve, in principle, the registration efficiency for high multiplicity events.

The Monte-Carlo simulation and comparison with the Mirabel data have given the estimations of these losses caused by the limited PVD acceptance as about two charged particles on the average. These losses have been taken into account in Fig. 1.

Now we have designed and debugged new software for track reconstruction by using these additional detectors based on Kalman Filter technique. This algorithm can use the tracks reconstructed in PVD and propagate them in DT and MS for a more precise track parameter estimation (especially momentum) and then it also finds additional tracks in DT and MS with the hits which were not used in the previous step. It means that we can find tracks which are invisible at PVD (because of the restricted acceptance) and determine the momentum of these particles.

It is also possible to work without PVD information for track reconstruction but only in DT and MS. The examples of the track recon-
New results of the extreme multiplicity studies

FIG. 2: Example of MC simulated event and its reconstructed tracks at DT and MS by using a new algorithm.

FIG. 3: Example of MC simulated event and its reconstructed tracks at DT and MS by using a new algorithm.

III. THE COLLECTIVE PHENOMENA

The search for the collective phenomena in the high multiplicity region is in progress. We consider that they can be observed in this region. The indications on the ring events were obtained in pA interactions at high (more than 18) multiplicity [8]. It is interesting to analyze pp interactions and compare them with nuclear interactions. Let us determine $\theta$ as an angle between tracks of the primary and secondary particles. Using the PVD data for different multiplicity intervals (small and high) which can be considered as a certain value of the impact parameter, we have discovered a two-hump structure. It was revealed in the extreme multiplicity region. In Fig. 4 we give the $\theta$ distribution for the events with more than 8 charged particles. The solid line is the result of the polynomial approximation of the seventh order. We see two different picks. These picks are absent in the case of small multiplicity - not more than 8 charged particles (Fig. 5). In this picture we compare these $\theta$-distributions. The Monte-Carlo simulation was carried out and high multiplicity events were selected. The reconstruction of these events has shown the absence of the two-hump structure for the $\theta$-distributions (Fig. 6). If we assume that this two-hump structure is caused by Cherenkov gluon radiation, then it is possible to use the formula by Dremin [12] for the index of refraction. The value of $\theta_C$ determines angle $\theta$ between the
direction one of the maximal humps and the primary track: $\theta_C = 0.065 \pm 0.005$ rad. According to the Dremin theory for gluon rings \[12\],

\[ \cos \theta_C = 1/\beta n, \]

where $\beta = p/\sqrt{p^2 + m_p^2}$ and $n$ is the index of refraction. At beam momentum $p=50$ GeV and proton mass $m_p=0.938$ GeV from (1) we obtain the experimental value of the index of refraction at 50 GeV:

\[ n = 1.0023 \pm 0.0003. \] (2)

Using the formula by Dremin we obtain the following:

\[ n = 1 + \Delta n(p) = 1 + 3m_{pr}^2\nu_h\sigma(p)\rho(p)/8\pi E_{pr}, \] (3)

where $m_{pr}$ - mass of the parton, $\nu_h$ - the number of scatterers within a single nucleon (conventional number is equal to 7), $\rho = ReF/ImF$ is the ratio of real and imaginal parts of the scattering amplitude of partons, $E_{pr}$ - energy of the parton. The parton mass and its momentum is replaced by the values for proton: $m_{pr} \rightarrow m_p/\nu_h$ and $p_{pr} \rightarrow p/\nu_h$. After that we get

\[ \Delta n(p) = 3m_p^2ReF/2p^2 = 0.0005ReF. \] (4)

We can reach the agreement with our experimental result $\Delta n = 0.0023$ if $ReF = 4.6$ GeV$^{-1}$ or 0.92 fm for parton scatters.

A possibility of of forming Bose-Einstein condensation (BEC) formation in the extreme multiplicity region, has been shown in \[6\] by Begun and Gorenstein. It is known that pions (charged and neutral) are copiously formed at U-70 energies. They are bosons. Their momenta are approaching to zero at high multiplicity and the BEC can form. The pion number fluctuations will be a prominent signal in the BEC-point. They predict that the scaled variance of neutral and charged pion-number fluctuations

\[ \omega_0 = \langle (\Delta N)^2 \rangle / \langle N \rangle \]

in the vicinity of BEC-line, have an abrupt and anomalous increase. Our project is aimed at checking this prediction in the experiment.

Our Collaboration is preparing to check this prediction experimentally. For this purpose we have selected the high multiplicity events to determine the number of $\pi^0$ (photon) for every of

![FIG. 5: $\theta$ The $\theta$ distribution for events with small, no more than 8 of charged particles (solid curve) and with high multiplicity (the same two-hump curve like in Fig. 4).](image1)

![FIG. 6: $\theta$ The $\theta$ distribution for Monte-Carlo simulation for events with high multiplicity (more than 8): before (top) and after (bottom) reconstruction.](image2)
them. Then the variance of the number of particle fluctuations of the both neutral and charged pions may give a signal about the BEC formation or its absence.

We are sure that the extreme multiplicity studies are very interesting and useful. The recovering of the two-hump structure, BEC formation, search for the turbulence and different collective phenomena will be carried out at LHC and other centers.

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[1] Andronic A Braun-Munzinger P and Stachel J (2006) Nucl Phys A772:167-199.
[2] Cleymans J and Redlich K (1999) Phys Rev C 60:054908.
[3] Becattini F, Manninen J and Gazdzicki M (2006) Phys Rev C 73:044905.
[4] Oeschler H Ritter H and Nu Xu (2009) arXiv:0908.1771[nucl-ex].
[5] V.V. Avdeichikov et al., Proposal “Termalization” (2005) JINR-P1-2004-190.
[6] V.V. Begun and M.I. Gorenstein (2007) Phys Lett B 653:190-195.
[7] Kokoulina E and Kutov A (2008) Phys Atom Nucl 71:1543-1551.
[8] Kokoulina E Kutov A and Nikitin V (2007) Braz J Phys 37:785-787.
[9] Kokoulina E and Nikitin V (2005) in Proceedings of 17th ISHEPP, JINR, Dubna 319-326, 327-336; The 7th International School - Seminar on Actual Problems of High-Energy Physics, Gomel, Belarus, Jul 28- Aug 8 2003, arXiv:0308139[hep-ph]; Kokoulina E AIP Conf Proc (2006) 828:81-86.
[10] Aleev A et al SVD-2 Collaboration Nonlinear Dynamics and Applications (2006) 13:83-93.
[11] Kokoulina E, Kutov A and Ruidovikov V (2009) Phys of Atom Nucl 72:184-188.
[12] Dremin I (1981) Phys Lett B 102:40-42; Dremin I (2007) Rom Rep Phys 59:977-985; Dremin I (2008) Acta Phys Polon Supp 1:641-646; Dremin I M (2009) arXiv:0903.2941v2[hep-ph].