Search for collective phenomena in hadron interactions

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Experimental studies of collective phenomena are carried out on U-70 accelerator in Protvino. These phenomena can be discovered since the high parton density can form in the high multiplicity region. The collective behavior of secondary particles can manifest in the Bose-Einstein condensation of pions, Vavilov-Cherenkov gluon radiation, excess of soft photon yield and other unique phenomena. The revealed peaks in the angular distribution are interpreted as the gluon radiation. The search for Bose-Einstein condensation is continued. The gluon dominance model has shown a good agreement with the multiplicity distribution at high multiplicity and confirmed the guark-gluon medium formation.

1 Introduction

The participants of ISMD 2010 were strongly surprised when they knew the news of CMS Collaboration [1] on two-particle angular correlations for charged particles emitted in proton-proton collisions at center-of-mass energies of 0.9, 2.36, and 7 TeV. It was informed that a pronounced structure emerges in the two-dimensional correlation function for particle pairs with $1 < p_T < 3$ GeV/c, $2.0 < |\Delta\eta| < 4.8$ and $\Delta\phi \approx 0$ in high multiplicity events with more than 70 (85) tracks at 2.36 (7) TeV. The observed structure resembles similar features in heavy ion experiments [2, 3]. These data obtained by STAR Collaboration for Au+Au central collisions were not aimed at aimed selecting high multiplicity events [4].

It is significant that the ridge-like behavior in proton-proton has been revealed at the high multiplicity event region. The SVD-Collaboration has been studying this region in the framework of Thermalization project [5] since 2005. Our experiment is carried out at U–70 acceleration in IHEP, Protvino, Russia, with the 50–GeV proton beam. We investigate the multiparticle production both proton-proton and proton-nuclei interactions with the high multiplicity.

The mean number of secondary particles for pp interactions at 50 GeV counts about 5 charged and 2 neutral particles, basically, it is pions [6]. We have registered and studied events with the multiplicity more than mean multiplicity. We have assumed that the conjecture the observable number of secondary particles is restricted, has the upper limit which is much less then the kinematical one and can be reached in our experiment. It is known that this region

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is not enough studied. These events are very rare. The first experiments in this field were performed in the project Thermalization. In spite of the fact that we work at not too high energy, we have observed unusual behavior of the both — the charged and neutral particles at their extreme multiplicities. Monte Carlo event generators do not give correct predictions in this region [5]. The latest results obtained at LHC by ATLAS [7], ALICE [8] and CMS [9] Collaborations have found significant discrepancies between the data and available generators.

We have used a gluon dominance model [10] to describe the multiplicity distribution of the charged and neutral particles at the extreme high multiplicity. This model has been derived from the two stage model [11]. The parton cascade description in it is based on essentials of QCD. For the hadronization stage the phenomenological approach is applied. The two stage model could describe multiplicity distributions in e^+e^- annihilation in a wide region from 10 up to 200 GeV [11]. The gluon dominance model has predicted the upper limits on the charged and neutral multiplicities and their behavior. It has also confirmed recombination mechanism of hadronization for the hadron and nuclei interactions and fragmentation mechanism for lepton processes. THe behavior of hadronization parameters in these interactions shows an active role of gluons in multiparticle production.

In accordance with this model the proton is macroscopic enough, since it consists of some number of active gluons. These gluons are sources of new produced particles, the valent quarks are staying passive spectators. The same ideas were expressed by E. Shuryak in his comments on the CMS discovery [12]. We have also used a number of such gluons to determine the impact parameter. Now we see that high multiplicity is closely related with the central impact parameter [13].

Obviously the dense nuclear matter may be produced at U–70 energy at the parton stage in high multiplicity events. The phase transition of the hadrons and nuclei into quark-gluon matter can onset in this case. The observable collective phenomena will indicate their hadron or parton nature. At present the phase transition signal search [14] is in progress. These studies are carried out at high and low energies [15]. RHIC and SPS began and LHC will continue to study properties of the matter formed under extreme conditions (high density and temperature).

In the extreme multiplicity case the high density matter can be formed at not very high temperature. The phase transition studies are also planned at GSI: Compress Baryon Matter (CBM) project [16] and at JINR: NICA/MPD project [17] for heavy ion interactions. We are sure that the understanding of multiparticle production nature will be found while stadying the unique high multiplicity region. Our preliminary experimental and theoretical studies have already shown unusual behavior of the charged and neutral particles.

2 SVD-2 setup

The experimental studies of the high multiplicity events are carried out at U-70 accelerator in Protvino, Russia. One of the main elements of our setup, Spectrometer with Vertex Detector (SVD-2) [5], is a micro-strip silicon vertex detector. It consists of silicon planes and allows one to determine the vertex of the interaction and tracks of secondary charged particles with high precision. We have a unique hydrogen target in this expeiment. Our drift tube tracker has bigger acceptance than the vertex detector. The magnetic spectrometer consists of a large magnet and proportional chambers. We have also a Cherenkov counter and an electromagnetic calorimeter to register neutral particles.

To suppress registration of the events with low multiplicity, we have designed and manufactured a trigger, a scintillation hodoscope. This trigger was used ourselves for the first time to select high multiplicity events. It makes a signal to select the events with the multiplicity higher than the specified level. We have registered events at the trigger level from 2×MIP up to 12×MIP. In the left panel of Fig. 1 multiplicity distributions are presented at three trigger–levels 8×MIP, 10×MIP and 12×MIP.

Using the scintillation hodoscope we have forwarded the multiplicity distribution from 16 (Mirabelle data) up to 24 charged particles (our experiment). The achieved value of the partial cross section is less by three orders of magnitude in comparison with the Mirabelle results. The obtained distribution agrees well with the gluon dominance model (in the right panel of Fig. 1).

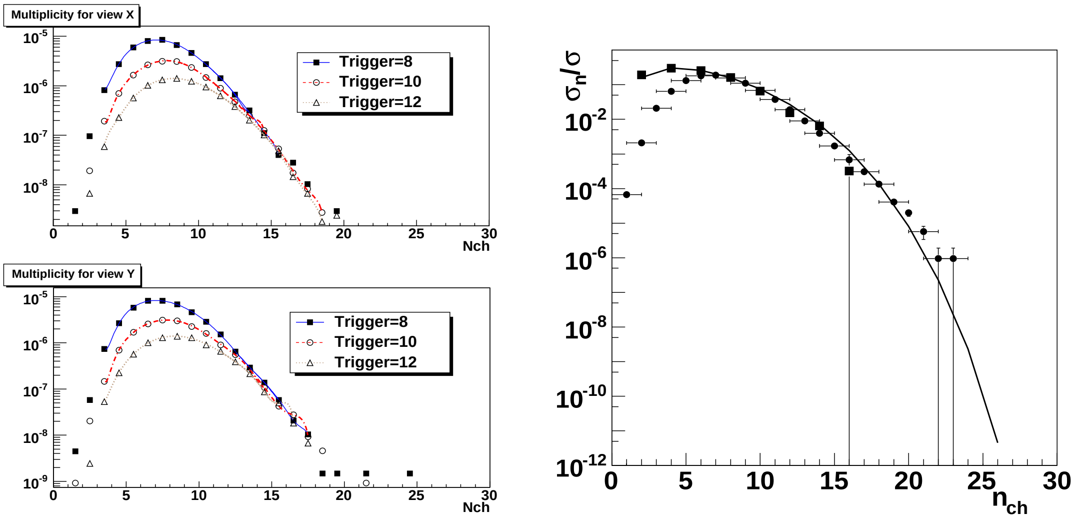

Figure 1: Left panel: The relative yield of events as the function of the registered charged multiplicity. The normalization is carried out by the primary track number at trigger-levels 8, 10 and 12 (×MIP) on two projections X (top) and Y (bottom). Right panel: Multiplicity Distributions obtained at $E_p = 50$ GeV at Mirabelle (■) [6] and SVD-2 (•) and the GDM prediction (the solid curve).

3 Search for collective phenomena

In the extreme multiplicity region we search for of the new collective phenomena. They are hadron nature as well as quark–gluon nature. We have analyzed the events with the trigger-level equal to 8 × MIP and higher. The experimental angular distributions were obtained at two domains of multiplicity by using the vertex detector data without taking into account the acceptance corrections and efficiency of the setup (at present this work is in progress). These distributions are shown in the left panel of Fig. 2 (with the multiplicity more than 9 and with multiplicity less than 9 charged particles).

We have revealed the unusual shape of the angular distribution in the case of high multiplicity: two noticeable peaks, especially in the left at $\theta \approx 0.1$ rad. This distribution was described by the sum of the third order polynomial and two Gaussian functions, the right panel of Fig. 2. The significance of the both peaks is equal to $3.5 \div 4$. In case of the low multiplicity we have not observed any peaks.

If we assume that this peak structure is stipulated by Vavilov–Cherenkov gluon radiation, then it is possible to estimate the refraction index of the hadronic matter [18]: $cos\theta_{\rm Ch} = 1/\beta n$, where $\theta_{\rm Ch}$ is Cherenkov angle, $\beta = p/\sqrt{p^2 + m_p^2}$, m_p is proton mass and n is the refraction index. At beam momentum p=50 GeV the experimental value of the refraction index obtained in project Thermalization is equal to $n = 1.0023 \pm 0.0003$. This value is very close to 1. Dremin [18] relates this behavior with the dilute parton system (quark-gluon gas). The opposite case $n \geq 3$ at RHIC experiment corresponds to a more density system (quark-gluon liquid).

In pp 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 [19] have proposed to search for Bose–Einstein condensation (BEC) of π mesons in high multiplicity events. They have shown that the pion number fluctuations strongly increase and may give a prominent signal while approaching the BEC.

To reveal these signals, one needs to carry out the event-by-event identification of the both — charged and neutral pions. An abrupt and anomalous increase of the scaled variance, $\omega_0 =< (n_0 - < n_0 >)^2 > / < n_0 >$, of neutral ($n_0$) and charged pion number fluctuations will be the signal of BEC. The value of ω_0 should be found at the fixed total multiplicity (a sum of charged and neutral pions).

To analyze ω_0, we have selected events with the charged multiplicity up to 24 and determined the number of neutral particles for every of these events. We assumed that the number of neutrals would be roughly proportional to the charged multiplicity. But we have observed the maximum number of neutrals in the interval $n_{ch} = 8 \div 14$ (up to 16 neutrals in this region). We plan to increase the number of selected events in this region to reveal the events with high multiplicity of neutrals. This analysis is in progress.

In accordance with the recombination mechanism in the gluon dominance model of hadronization $q\bar{q}$ pairs of light flavors, up and down, are produced simultaneously. After that they recombine to neutral and/or charged pions. The neutral pion production is carried out through the combination of the same flavor quarks ($u\bar{u}$ or $d\bar{d}$). The charged pions consist of quark-antiquark pairs of different flavors. The production of neutrals requires smaller energy than of the charged pions (small discrepancy in their masses confirmed this statement). Besides, the process of the multiparticle production goes in a confined volume. At case of the central collision (high multiplicity event) there is a bulk of $q\bar{q}$ pairs, and the production of neutral pions is sure to be preferable.

Our observations have checked this assumption. At present we have observed the maximum of total multiplicity which is close to 30 particles. Here the number of charged particles is in the interval of $8 \div 14$, i.e. the number of neutrals considerably exceeds the charged multiplicity (two times more). At the same time in the high multiplicity tail ($n_{ch} > 18$) we have observed small number of neutrals. We can consider these events as peripheral collisions with the smaller number of the produced quark pairs in comparison with the central collisions. Both of these processes take place in the same volume. At the peripheral collisions the predominance of neutral pions should be a rare events. Our preliminary Monte Carlo event simulations significantly differ from the obtained experimental results.

Very interesting and unexpected results of the manifestation of the collective behavior of secondaries were observed by DELPHI Collaboration at SPS in the Z^0 boson region [20]. The anomalous production of soft photons was revealed in hadron channels. The rate of these photons exceeds the theoretical predictions by 4–7 times for the charged hadron channels and by 17–20 times — for the neutral hadron channels.

We are planning to carry out investigations of the soft photon yield at SVD-2 setup. Our group is developing an electromagnetic calorimeter for their registration. We carry out Monte Carlo simulation to manufacture a prototype of this calorimeter. We are planning to investigate the soft photon yield as function of the number charged and neutral hadrons at the high multiplicity region. We expect that the yield of soft photons will increase at high total multiplicity and believe that the solution of the soft photon puzzle is closely related with the this region.

According to the gluon dominance model, the production of soft photons happens at the hadronization stage [21, 22]. It may be assumed that this distinction in the yield of photons is stipulated by a different way of their productiontion. The neutral mesons consisting of the quark pair of the same flavor, spend less gluon matter while their production, and charged pions are formed from different flavor quarks. In case of the neutral pions there is more the unused gluon material remained than at the charged pions. In both cases this excess of the gluon matter is reradiated through soft photons. This behavior confirms the recombination mechanism of hadronization.

Our plans concerning future experimental studies are related with the new IHEP program to accelerate the carbon beams. We assume to carry out the search for collective phenomena in carbon-nuclei interactions.

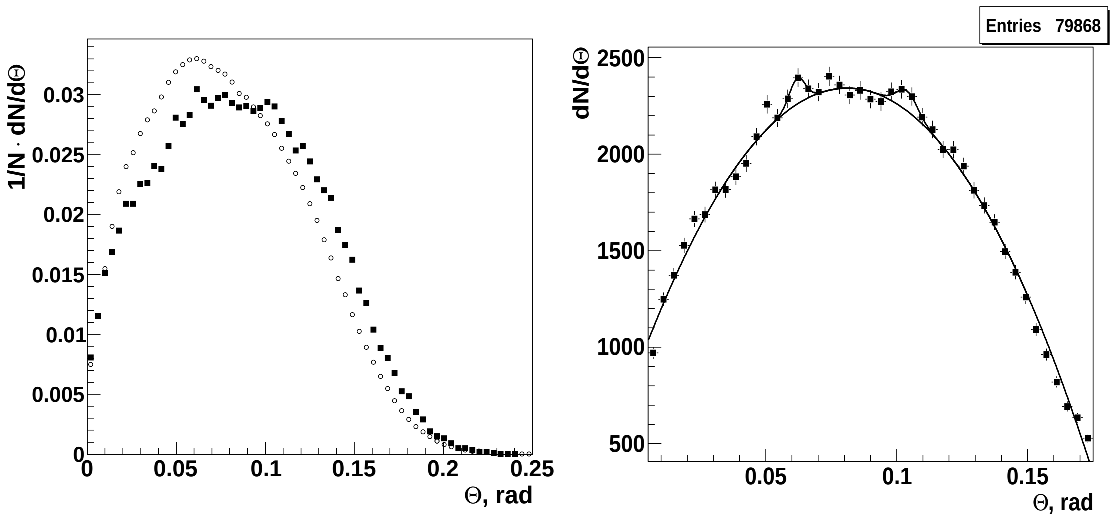

Figure 2: Left panel: The θ-distributions on the number of tracks (N) for events with small multiplicity, $n_{ch} < 9$ ($\circ$), and with high multiplicity, $n_{ch} > 9$ ($\blacksquare$). Right panel: The description of the θ-distribution for the central region on the number of tracks (N) for events with $n_{ch} > 9$ by the three order polynomial of background and two Gaussians of two peaks (the same two-hump curve like in the left panel.)

4 Conclusion

Preliminary studies of collective phenomena of multiparticle production in *pp* interactions have carried out. There are indications on unusual behavior of the angular distributions in the high multiplicity region for charged particles. The yield of neutral mesons as function of charged multiplicity is also unusual. We have observed the maximum total multiplicity at the high number of neutral pions. In the high charged multiplicity region we have observed small multiplicity of neutrals. We are planning to investigate the collective phenomena and penetrate deeper in the understanding the nature of multiparticle production.

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References

[1] V. Khachatryan [CMS Collaboration], arXiv:hep-ph/0411040.

[2] B. Alver [PHOBOS Collaboration], Phys. Rev. C **81** (2010) 024904 [arXiv:nucl-ex/0812.1172].

[3] A. I. Abelev [STAR Collaboration], Phys. Rev. Lett. C **105** (2010) 0222301 [arXiv:hep-ex/0912.3977].

[4] J. Adams [STAR Collaboration], Phys. Rev. C **73** (2006) 034906.

[5] V. V. Avdeichikov [SVD Collaboration]. Proposal "Termalization" (in Russian), JINR-P1-2004-190. 2005.

[6] V. V. Ammosov [Mirabelle Collaboration], Phys. Lett. B **42** (1972) 519.

[7] G. Aad [ATLAS Collaboration] Phys. Lett. B **688** (2010) 21.

[8] K. Aamodt [ALICE Collaboration] Eur. Phys. J. C **68** (2010) 89.

[9] R. Field, [arXiv:hep-ph/1010.3558].

[10] E. S. Kokoulina and V. A. Nikitin. 7th International School-Seminar The Actual Problems of Microworld Physics, Gomel, Belarus, Dubna. (2004) 221 [arXiv:hep-ph/0308.139].

[11] E. S. Kokoulina. XI Annual Seminar NPCS, Minsk, Belarus, (2002) [arXiv:hep-ph/0209.334].

[12] E. Shuryak, [arXiv:hep-ph/1009.4635].

[13] A. Dumitru et al., [arXiv:hep-ph/1009.5295].

[14] J. Cleymans, H. Oeschler, K. Redlich, and S. Wheaton, Phys. Rev. C **73** (2006) 034905 [arXiv:hep-ph/0511094].

[15] B. I. Abelev [STAR Collaboration], Phys. Rev. C **81** (2010) 024911[arXiv:nucl-ex/0909.4131].

[16] P. Senger, J. Phys. G **30**, (2004) 1087.

[17] V. Toneev, [arXiv:nucl-ex/0709.1459]; NICA Conceptual Design Report, JINR, January 2008, http://www.jinr.ru/.

[18] I. Dremin, Rom. Rep. Phys. **59** (2007) 977; I. Dremin, Acta Phys. Polon. Supp. **1** (2008) 641; I. M. Dremin [arXiv:hep-by/0903.2941v2].

[19] V. V. Begun and M. I. Gorenstein, Phys. Lett. B **653** (2007) 190; V. V. Begun and M. I. Gorenstein, Phys. Rev. C **77** (2008) 064903.

[20] J. Abdallah [DELPHI Collaboration], Eur. Phys. J. C **47** (2006) 273; J. Abdallah [DELPHI Collaboration] Eur. Phys. J. C **57** (2008) 499.

[21] E. S. Kokoulina, AIP Conf. Proc. **828** (2006) 81.

[22] E. S. Kokoulina and A. Ya. Kutov, Phys. Atom. Nucl. **71** (2008) 1543; E. Kokoulina, A. Ya. Kutov and V. N. Riadovikov, Phys. Atom. Nucl. **72** (2009) 189.