Gluon dominance model and cluster production

Elena Kokoulina\textsuperscript{1,2}, Andrey Kutov\textsuperscript{2,3} and Vladimir Nikitin\textsuperscript{2}
\textsuperscript{1} GSTU, October Avenue, 48, Gomel, 246746, Belarus
\textsuperscript{2} JINR, Dubna, Moscow region, 141980, Russia
\textsuperscript{3} DM UrD RAS, Chernova, 3a, Syktyvkar, 167982, Russia

Gluon dominance model (GDM) studies multiparticle production in lepton and hadron processes. It is based on the QCD and phenomenological scheme of hadronization. The model describes well multiplicity distributions and their moments. It has revealed an active role of gluons in multiparticle production, it also has confirmed the fragmentation mechanism of hadronization in $e^+e^-$ annihilation and its change to recombination mechanism in hadron and nucleus interactions. The GDM explains the shoulder structure of multiplicity distributions. The agreement with Au+Au peripheral collisions data for hadron-pion ratio has been also obtained with this model. Development of GDM allows one to research the multiplicity behavior of $p\bar{p}$ annihilation at tens of GeV. The mechanism of soft photons production and estimates of their emission region have been offered.

The experimental data (project “Thermalization”, U-70, IHEP) have confirmed a cluster nature of multiparticle productions and their moments. It has revealed an active role of gluons in multiparticle production, it also has confirmed the fragmentation mechanism of hadronization in $e^+e^-$ annihilation and its change to recombination mechanism in hadron and nucleus interactions. The GDM explains the shoulder structure of multiplicity distributions. The agreement with Au+Au peripheral collisions data for hadron-pion ratio has been also obtained with this model. Development of GDM allows one to research the multiplicity behavior of $p\bar{p}$ annihilation at tens of GeV. The mechanism of soft photons production and estimates of their emission region have been offered.

Keywords: multiplicity distributions, quark-gluon system, hadronization, detectors, alignment.

I. INTRODUCTION

Heavy ions collisions (HIC) study at high energies reveal strong evidences of quark-gluon (QG) plasma production \cite{1}. The behavior of bulk variables at lower energies and also a detailed study of hadron interactions supply with understanding of the production mechanism of this new state. At present this analysis is realized at SPS (CERN) \cite{2}. The basic problem of HIC is to describe the systems, consisting of partons or hadrons. Experiments at RHIC have confirmed this collective behavior \cite{3}. The qualitative properties of the bulk matter may be represented with the phase diagram. The calculations at QCD and different models modify it. This diagram is made for long nuclear medium. It explains transition from the hadron phase to the QG one in HIC.

The question appears about the manifestation of this transition in hadron interactions at high energies. We can continue the analogy proposed in \cite{4} for water (boiling, condensing, ionization). In the case of the hadron interaction the new formed medium, named quark-gluon plasma (QGP), won’t have such a plenty of constituents. We consider that the evaporation of single partons from separate hot pots (cluster sources) in the system of collided hadrons, leads to the secondary particles production. This conception was taken as the basis of the Gluon Dominance Model (GDM) \cite{5,6,7,8}. Using of this model allows one to investigate the following problems for the researchers: multiparticle production (MP), hadronization and phase transitions. It is interesting to add that the analysis of MP in the framework of the other picture based on dissipating energy of participants \cite{9} describes the similarity of the bulk observable as the mean multiplicity in the hadron (nucleus) and $e^+e^-$ interactions.

II. $e^+e^-$ ANNIHILATION

The $e^+e^-$ annihilation is one of the most suitable processes for initial study of MP. According to the theory of strong interactions QCD, it is realized through the production of $\gamma$ or $Z^0$-boson into two pure quarks: $e^+e^- \rightarrow (Z^0/\gamma) \rightarrow q\bar{q}$. Perturbative QCD can describe the fission process of partons (quarks and gluons) at high energy, because the strong coupling $\alpha_s$ is small at high energy. This stage can be called as the stage of cascade. Towards the end of the fission partons have small virtuality and must change into hadrons, which we observe. At this stage we could not apply pQCD. Therefore phenomenological models are used to describe hadronization (transformation of quarks and gluons into hadrons). Before it was considered that the production of hadrons from partons is a universal process. Data obtained at RHIC are an evidence of the mechanism change in the nuclear medium in comparison with vacuum.

In 90-er we developed a scheme which joints the quark-gluon cascade and hadronization into a Two Stage Model (TSM) \cite{9,10,11}. According to it the multiplicity distributions (MD) in $e^+e^-$ annihilation are

$$P_n(s) = \sum_m P^p_m(s)P^H_n(m),$$  

(1)

where $P^p_m(Y)$ is NBD for partons

$$P^p_m(s) = \frac{k(k+1)\ldots(k+m-1)}{m!}(\frac{m}{m+k})^m(\frac{k}{k+m})^k,$$  

(2)

and $P^H_m(m)$ - binomial distribution (BD) for hadrons produced from $m$ partons at the stage of hadronization:

$$P^n_H = \left(\frac{N_p}{n}\right)\left(\frac{\bar{n}_p}{N_p}\right)^n (1-\frac{\bar{n}_p}{N_p})^{N_p-n},$$  

(3)

where $\bar{n}_p$ and $N_p (p=q,g)$ have the meaning of average multiplicity and a maximum possible number of secondary hadrons formed from the parton at the stage of hadronization. To distinguish hadrons produced from the quark and gluon at the second stage, parameter $\alpha = N_q/N_g$ was introduced. The main result of the comparison \cite{12,13,14,15} with the experimental data was in almost constancy of gluon hadronization parameters:
$N_g \sim 3$ and $\pi_g^0 \sim 1$ (Fig. 1). From this result we can confirm the universality and fragmentation character of the gluon hadronization [10] for $e^+e^-$ annihilation. The fact $\alpha < 1$ proves that hadronization of a gluon jet occurs softer than of the quark one. We have used MD [11] to explain the sign changes as a function of order for the ratio of factorial cumulative moments over the factorial ones. In the region lower $Z^0$ this ratio changes the sign with parity $q$. At higher energies the oscillation period increases to 4 and higher. It can be explained by the influence of the developed cascade and hadronization [5].

**III. HADRON INTERACTIONS**

Further development of the TSM scheme and its application to study proton interactions study has shown an active role of gluons in MP and confirmed a recombination mechanism of hadronization for them. That is why this scheme was named as GDM. Our study has shown that quarks of initial protons stay in leading particles (from 70 to 800 GeV/c and higher). MP is realized by gluons. We call them "active". In the framework of this model we have made the following basic assumptions. concerning the first stage we believe, that after the inelastic collision of two protons some part of energy is converted into the thermal (the dissipating energy) and one or few gluons become free, and they may give a cascade. At the second stage (hadronization) some of gluons (not all) leave the QG system – evaporate and convert to hadrons. Two schemes were offered.

The first scheme takes gluon branch into account. The final MD was determined as a convolution of three MD: 1) MD of active gluons at the moment of impact (Poisson), 2) MD of branch gluons (Furry) and 3) MD at the hadronization stage (BD). We have obtained a fraction of the remained free gluons equal to $0.47 \pm 0.01$ (the same in [11]). The remains of gluons from the QG system can become sources of soft photons (SP). Moreover, the value of $N_g \approx 40$ was very close to the number of partons in the glob of cold QGP [12], which explains the production of SP excess [13].

In the second scheme the gluons leave the QG system (evaporation) and fragment to hadrons without taking this branch into account. In this case the final MD are determined by the Poisson (first stage) and BD (hadronization) convolution

$$P_n = \sum_m e^{-\pi_m^0} \frac{mN}{m!} m^{n-2} \left( \frac{\pi_m^0}{N} \right)^{n-2} \left( 1 - \frac{\pi_m^0}{N} \right)^{mN-n+2}. \quad (4)$$

This expression describes the data from 70 to 800 GeV/c (Fig. 2) and gives the gluon hadronization parameters [6]: $N_g = 4.24 \pm 0.13$, $\pi_g^0 = 1.63 \pm 0.12$ at 70 GeV/c. The gluon hadronization parameter $\pi_g^0$ in pp interactions is comparable with the values obtained in $e^+e^-$ annihilation but has weak growth from 1.63 to 2.66. This behavior is an evidence of the influence of parton medium on hadronization in pp interactions, that agrees with the recombination mechanism when simultaneously few gluons fragment into $q\bar{q}$ pairs and form real hadrons at their random walking in the QG system. Moreover, the maximum number of active gluons $M$ grows from 6 to 10 in this energy region. This value allows one to estimate the upper limit of multiplicity of the charged hadrons as 26 at 70 GeV/c. MD for neutral mesons and for the total multiplicity were also obtained in GDM [6]. Using these distributions and compare them with the data [15], it was shown that the maximum number of $\pi^0$ at the charged multiplicity smaller than the mean one could not be bigger than total number of the charged particles. The upper limits of neutral and total multiplicity were defined as well. The shoulder structure of MD shows up in the region of ISR energies [16] and higher. It can be explained by GDM. As the active gluons at higher energies may fission, we should take this into account. The independent evaporation of gluon sources consists not only of single gluons but groups from two and more fission gluons as "superposition" with the hadronization following. This superposition describes well MD at these energies and gives understanding of soft and (semi)hard components as clusters with single or few fission gluons, respectively [8]. The ratio of charged hadron pairs to $\pi^0$-mesons was obtained in GDM [5]. It is equal to $\sim 1.6$ and agrees with the experimental data [17].

We have used the black body emission spectrum at the assumption that the QG system or excited new formed hadrons are in almost equilibrium state during a short period of time. The obtained linear size of SP emission region changes from 4 to 6 fm [7, 18]. It is known that hadronization occurs in this region.

At modification GDM by the inclusion of intermediate quark topologies we can describe the experimental differences between $p\bar{p}$ and $pp$ inelastic topological cross sections and second correlation moment behavior at few GeV/c [19]. The tail of high multiplicity in this process originates from "4" or "6"-topologies.

**IV. PROJECT "THERMALIZATION"**

Project "Thermalization" [20] is aimed at MP studying the interaction of the beam energy protons $E_{lab}=70$ GeV of IHEP (Protvino) with the hydrogen and nucleus targets in the region of high multiplicity: $n > 20$. The experiment is carried out on the set-up SVD - the Spectrometer with the Vertex Detector.
supplied with the trigger system to register rare high multiplicity events. Our collaboration has designed and manufactured a scintillation hodoscope or the HM trigger. It should suppress interactions with track multiplicity below 20. Beyond this it should be thin enough not to distort the angular and momentum resolutions of the setup to any kind of the fake signal. The scintillator counter array may operate at higher counting rate and is more resistant to many kinds of noise.

In the region of high multiplicity (HM) $n_{ch} > 20$ we expect [20]: formation a high density thermalized hadronic system, transition to pion condensate or cold QGP, enhanced rate of SP. We search for new phenomena: Bose-Einstein condensate (BEC), events with ring topology (Cherenkov gluon radiation), hadronization, pentaquarks. The available MP models and MC codes (PYTHIA) are distinguished considerably in the HM region. In 2005 one technical run was performed at 102 and 405 GeV/c with the trigger system.

![FIG. 2: GDM MD in pp (solid) (left) at 102 and (right) 405 GeV/c [14].](image)

![FIG. 3: $\chi^2/n_{df}$ for 114769 tracks in magnetic spectrometer. Left: before alignment, right: after alignment.](image)

We are planning to continue this work to make programme packets for tracking tasks and study new phenomena in the region of high multiplicity. The alignment task of detectors had to be solved for the track reconstruction. The quality check of each detector was estimated through $\chi^2$ on it and residual distributions. For the alignment procedure we have used a more robust, efficient and high precision method based on the Linear Least Squares (LLS) with a linear model: $\mathbf{u} = \mathbf{A} \mathbf{a} + \mathbf{r}$, where $\mathbf{u}$ is a vector of the measured data, $\mathbf{A}$ - matrix, $\mathbf{a}$ - vector parameters and $\mathbf{r}$ - vector residuals. The solution of it $\mathbf{a} = C^{-1}A^T Wy$ requires the inversion of symmetric matrix $C = A^T W A$. V. Blobel [21] designed and applied LLS to the calibration and alignment tasks. His approach allows one to resolve the problem with a lot of parameters. Their number may reach thousands and hundred thousands. V. Blobel had solved this mathematical puzzle and put into a general program package MILLEPEDE [21] for the efficient solution into practice. We have developed programme packets based on MILLEPEDE to define misalignment parameters with good precision (Fig. 3). The reconstruction of tracks is realized by sequential histogramming and Hough methods. The data of the 2002 run for $p + A$ (A = Si, C and Pb) were studied in the HM region, $n_{ch} > 20$ charged. MD for these targets were obtained (Fig. 4, left) by using VD. Interesting phenomenon was revealed: the indication of grouping of secondary in some certain direction. Cluster production is seen well – consists of few charged (2-4). This is the peak in the differences of the absolute value of angle $\Delta \theta$ between particles distribution (Fig. 4, right).

We are planing to continue this work to make programme packets for tracking tasks and study new phenomena in the region of high multiplicity.

**Acknowledgements**

The implemented study of MP in the framework of project “Thermalization” is partially supported by RFBR grant 06 – 02 – 81010 – Bel.\(\alpha\).

[1] C.A. Salgado, Plenary talk at the Conference Physics at LHC, Cracow (Poland), July 2006, hep-ph/0609177
[2] C. Blume, to be published in Nucl. Phys. A, nucl-ex/060922.
[3] I. Arsene et al. BRAMS collaboration, nucl-ex/0610021
[4] B. Tomasic, Proceedings of 15 Conference of Slovak Physicists.
[5] V.I. Kuvshinov and E.S. Kokoulina, Acta Phys.Polon. B13, 553 (1982); E.S. Kokoulina. XI NPCS, Minsk, Belarus, (2002); E.S. Kokoulina, XXXII ISMD, 340 (2002).
[6] E.S. Kokoulina and V.A.Nikitin, 17th ISHEPP, Dubna, JINR, (2005).
[7] P.F. Ermolov et al., 17th ISHEPP. Dubna, JINR, (2005).
[8] E.S. Kokoulina, AIP Conf.Proc. 828, 81 (2006).
[9] E.K.G. Sarkisyan and A.S. Sakharov, AIP Conf.Proc. 828, 35 (2006).
[10] B.Müller. Contribution to RBRC Scientific Articles Proceedings Series "New Discoveries at RHIC" (2004).
[11] A. Muller, Nucl.Phys. B715, 20 (2003).
[12] P. Lichard and L. Van Hove, Phys. Let. B245, 605 (1990).
[13] P.V. Chliapnikov et al., Phys. Let., 141B, 276 (1984).
[14] C. Bromberg et al., Phys. Rev. Lett. 31, 1563 (1973).
[15] K. Jager et al., Phys. Rev. D11, 2405 (1975).
[16] A. Breakstoune et al., Phys. Rev., D30, 528 (1984).
[17] K. Adcox et al., Nucl. Phys. A757, 184 (2005).
[18] M. K. Volkov et al., Particles and Nuclei, Letters, 1, 16 (2004).
[19] J. G. Rushbrooke and B. R. Webber, Phys. Rep. C44, 1 (1978).
[20] V. V. Avdeichikov et al. Proposal "Termalization". (In Russian) JINR-P1-2004-190, 45pp (2005).
[21] V. Blobel, Proceed. Conf. Advanced Statistical Techniques in Particle Physics. Durham, March, 2002. DESY, Hamburg.