Gluon Dominance Model and Cluster Production

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Multiparticle production in lepton and hadron processes is studied by means of the Gluon Dominance Model (GDM) which is based on the Quantum Chromodynamics (QCD) and phenomenological scheme of hadronization. The model describes the multiplicity distributions and their moments very well. It has revealed an active role of gluons in multiparticle production and confirmed the fragmentation mechanism of hadronization in e^+e^- annihilation and its change to a recombination mechanism in hadron and nucleus interactions. The GDM explains the shoulder structure of multiplicity distributions. The hadron-pion ratio obtained by GDM has turned out to be in agreement with the experimental RHIC data of *Au*+*Au* peripheral collisions. Besides, development of GDM allows one to study the multiplicity behavior of $p\bar{p}$ annihilation at tens of GeV. The mechanism of soft-photon production and estimates of their emission region have been offered in the framework of this model. The experimental data (project "Thermalization", U-70, IHEP) indicated the cluster nature of multiparticle production revealed by using GDM.

Keywords: Multiplicity distributions; Quark-gluon system; Hadronization; Detectors; Alignment

I. INTRODUCTION

Heavy ion collisions at high energies reveal strong evidence of quark-gluon plasma (QGP) production [1]. The detailed study of bulk variables at lower energies and also of hadron interactions can bring a new understanding of the production mechanism of this state [2]. The main difficulty in dealing with heavy ion collisions is to describe the systems consisting of partons or hadrons [3]. The properties of the bulk matter may be represented with the phase diagram modified by Quantum Chromodynamics (QCD) and different models. This diagram is made for extended nuclear medium. It explains transition from the hadron phase to QGP in heavy-ion collisions.

There is a question concerning manifestation of this transition in hadron interactions at high energies. We can continue the analogy proposed in [4] for water (boiling, condensing). In case of the hadron interactions a new formed medium, named QGP, won't have such a plenty of constituents. It is possible to consider that the evaporation of single partons from separate hot spots in the system of collided hadrons, leads to the secondary particles production. This concept was taken as the basis of the gluon dominance model (GDM) [5–8]. This model enables one to investigate the multiparticle production (MP) problems. It is curious to note that the analysis of MP in the framework of the other picture based on dissipating energy of participants [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 the initial study of MP. According to the theory of strong interactions QCD, this annihilation is realized via production of γ or Z^0–boson into two pure quarks: $e^+e^- \to (Z^0/\gamma) \to q\bar{q}$. Perturbative QCD (pQCD) can describe the fission process of partons (quarks and gluons) at high energy, because the strong coupling α_s is small at high energy. This stage can be called "a cascade". At the end of the fission the partons have small virtuality and must change into hadrons, that has been observed. At this stage we can not apply pQCD. Therefore phenomenological models are used to describe hadronization (transformation of quarks and gluons into hadrons). Besides, the production of hadrons from partons is considered to be a universal process. The data obtained at RHIC have indicated the mechanism change in the nuclear medium in comparison with vacuum.

In 90-es we developed a scheme which unified the quark-gluon cascade and hadronization into a two stage model [5, 6]. According to it the multiplicity distributions (MD) in e^+e^- annihilation can be presented as

$$P_n(s) = \sum_m P_m^P(s) P_n^H(m), \tag{1}$$

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

$$P_m^P(s) = \frac{k(k+1)\dots(k+m-1)}{m!}\left(\frac{\overline{m}}{\overline{m}+k}\right)^m\left(\frac{k}{k+\overline{m}}\right)^k, \tag{2}$$

and $P_n^H(m)$ is a binomial distribution (BD) for hadrons produced from m partons at the stage of hadronization:

$$P_n^H = \binom{N_p}{n}\left(\frac{\overline{n}_p^h}{N_p}\right)^n\left(1-\frac{\overline{n}_p^h}{N_p}\right)^{N_p-n}, \tag{3}$$

where $\overline{n}_p^h$ and N_p ($p = q,g$) have the meaning of average multiplicity and the maximum possible number of secondary hadrons, respectively, formed from the parton at the stage of hadronization. Parameter $\alpha = N_g/N_q$ was introduced to distinguish hadrons produced from the quark and gluon at the second stage. The main result of the comparison (1) with the experimental data (10 – 200 GeV) was in almost full constancy of gluon hadronization parameteres: $N_g \sim 3$ and $\overline{n}_g^h \sim 1$

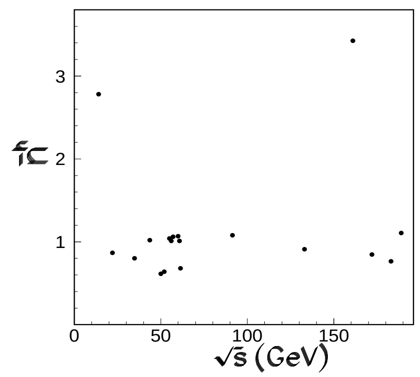

FIG. 1: The gluon hadronization parameter $\overline{n}^h$.

(Fig. 1) [5, 6]. This result has confirmed 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 differs from the quark one. We have used MD (1) to explain the sign changes as a function of the order for the ratio of factorial cumulative moments over the simply factorial ones. In the region lower Z^0 this ratio changes the sign with parity q. At higher energies the oscillation period increases up 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 two stage model and its application to study proton interactions has shown an active role of gluons in MP and confirmed the recombination mechanism of hadronization for them [6, 7]. That is why this scheme was named the Gluon Dominance Model. Our study at the energy range from 70 to 800 GeV/c and higher has shown that quarks of initial protons stay in leading particles. MP is performed 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 (dissipating) energy. One or several gluons become free and may give a cascade. At the second stage (hadronization) some of gluons (not all) leave the quark gluon system, i.e.– evaporate and convert into hadrons. Two schemes of MP have been offered in the framework of GDM.

The first scheme takes the gluon branch into account. The final MD is 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 free gluons equal to 0.47 ± 0.01 (the same in [11]). The remains of gluons from the quark gluon system can turn out to be sources of soft photons. Moreover, the value of $N_g \approx 40$ is very close to the number of partons in the glob of cold QGP [12] which explains the production of soft photons excess [13].

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

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

This expression describes the data in the energy range from 70 to 800 GeV/c (Fig. 2). The gluon hadronization parameter $\overline{n}^h$ in pp interactions is comparable with the values obtained in e^+e^- annihilation though a weak growth from 1.63 to 2.66 is observed in this region. This behavior is an evidence of

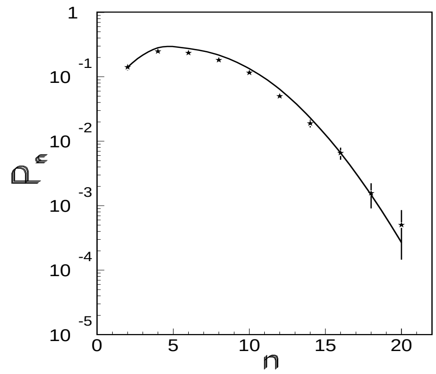

FIG. 2: MD in pp at 102 GeV/c [14], GDM - solid.

the influence of the parton medium on hadronization in pp interactions, that agrees with the recombination mechanism when several gluons break up simultaneously into $q\overline{q}$ pairs and form real hadrons at their random walking in the quark gluon 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 have been also obtained as well as for the total multiplicity in GDM [7]. The comparison of these distributions with the data [15], has shown that the maximum number of π^0 at the charged multiplicity smaller than the mean one, can not be bigger than the total number of the charged particles. The upper limits of the neutral and total multiplicity have been 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. Since the active gluons at higher energies may give fission, the above should be taken 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 MD at these energies rather well 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 π^0-mesons has been obtained in GDM [8]. It is equal to ≈ 1.6 and agrees with the experimental data [17].

We have used the black body emission spectrum at the assumption that the quark gluon system or excited new produced hadrons are in almost an equilibrium state during a short period of time. The obtained size of the soft photons emission region ranges from 4 to 6 fm [7, 18] that is known as the hadronization region.

To describe the experimental differences between $p\overline{p}$ and pp inelastic topological cross sections and second correlation moment behavior at few GeV/c [19], it is possible to modify GDM by including the intermediate quark topologies into this model. The tail of high multiplicity in this process originates from "4" or "6"-topologies.

IV. PROJECT "THERMALIZATION"

Project "Thermalization" [20] is aimed at studying MP in pp and pA interactions at the beam proton energy E_{lab}=70 GeV. The emphasis is made on high multiplicity (HM) events, $n_{ch} > 20$. The experiment is carried out at IHEP accelerator(Protvino) on the liquid hydrogen target and a spectrometer with the vertex detector supplied with the trigger system to register these rare events. It is purposed to suppress interactions with track multiplicity below 10. Besides, the trigger is thin enough not to distort the angular and momentum resolutions of the setup. In the region of HM the following is expected [20]: formation of a high density thermalized hadronic system, transition to pion condensate or cold QGP, enhanced rate of soft photons. We search for new phenomena: Bose-Einstein condensate, events with ring topology (Cherenkov gluon radiation). The available MP models and Monte Carlo codes (PYTHIA) diverge considerably in the HM region. In 2005 the first technical run was performed at U-70 accelerator with a hydrogen target. The alignment task of detectors had to be solved to reconstruct the tracks. The quality check of each detector was estimated by χ^2 and residual distributions. For the alignment procedure we used a robust, efficient and high precision V.Blobel [21] method based on the Linear Least Squares fit. It allows one to resolve the problem with a lot of parameters and define misalignment parameters with good precision (Fig. 3). The data of the 2002 run for $p+A$ (A = Si, C and Pb) are studied in the HM region, too. MD for these targets were obtained by using the silicon vertex detector. An interesting phenomenon had been preliminary revealed: the indication of grouping of secondaries in some certain directions. Cluster production was seen rather well – consisted of few charged particles (2-4). The sharp peak is observed for distribution on the absolute values of the differences of angles $\Delta\theta$ between the particles (Fig. 4). We are planing to continue the new phenomena study in the HM region.

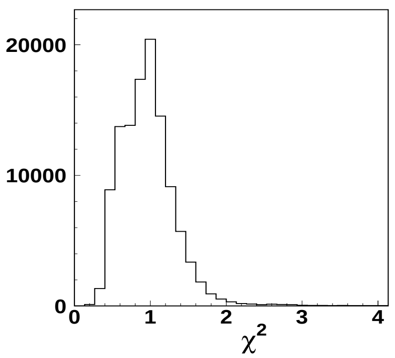

FIG. 3: χ^2/n_{df} for tracks in magnetic spectrometer after alignment.

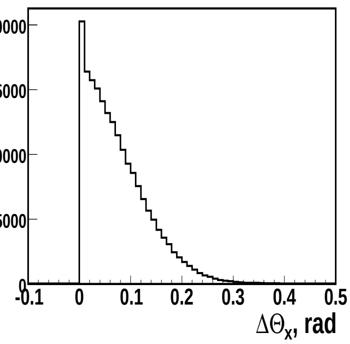

FIG. 4: $\Delta\theta-$ distribution (see text).

Acknowledgements

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