Description of pp-interactions with very high multiplicity at 70 GeV/c

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Abstract

The collective behavior of secondary particles in pp - interactions at 70 GeV/c is studied. A Two Stage Gluon Model is offered to describe processes with very high multiplicity. An active role of gluons is shown in multiparticle dynamics. The analysis of multiplicity distributions has revealed a possibility of a thermodynamic interpretation of these interactions. A mechanism of the soft photon production as a signature of the quark-gluon system is proposed.

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These investigations have been carried out in the framework of the project "Thermalization" (JINR). This project is aimed at studying the collective behaviour of secondary particles in proton interactions at 70 GeV/c. According to the present understanding of hadronic structure, based on quantum chromodynamics (QCD), protons consist of quarks and gluons. We have developed a Two Stage Gluon model to describe high energy multiparticle production (MP) in proton interactions. At the first stage of the model QCD and thermodynamical approaches are used. At the second stage (hadronization) a phenomenological description is applied.

After the inelastic collision of two protons a part of the energy of these moving particles is converted into the thermal one. Constituents of the proton, quarks and gluons, have enough energy to be described by pQCD, because the strong coupling reaches a small value. Quarks and gluons become liberated. Our model investigations have shown that the quark division of primary protons accompanied by hadron production in pp interactions at 70 GeV is absent. MP is realized by gluons. This study has confirmed the idea of P. Carruthers about a passive role of quarks.

We have used one of the most generally accepted methods to study multiparticle dynamics: the multiplicity distribution (MD) analysis. Two schemes of interactions are offered. They are distinguished only by the quark-gluon (QG) stage. If we want to study the gluon division inside the QG system (QGS), the scheme branch model is used. If we are not interested in what is going inside QGS the second scheme thermodynamic model should be applied. In the both schemes some of gluons (not all of them) leave QGS and convert to real hadrons. Using the thermodynamic interpretation we can say that active gluons are evaporated from hot QGS. After the evaporation they pass the stage of hadronization.
Processes of pp interactions at 70 GeV/c were investigated experimentally [5]. MD of charged particles were limited to 20 secondaries. Among them there are $n$ charged mesons ($\pi^+$ or $\pi^-$) and two leading protons: $p + p \rightarrow n\pi + 2N$. In Thermalization project it is planned to observe events with high multiplicities. The production of soft photons could give the information about the early stage of QG interactions [1, 6].

The choice of the MP scheme is based on comparison with experimental data [5]. Physicists from JINR (Dubna) used generator PYTHIA and obtained MD of charged hadrons [5]. It was shown that PYTHIA generator does not agree with the experimental data at high multiplicities and has a deviation two orders of the magnitude at $n_{ch} = 18$ equal to (Fig. 1). We have refused from the quark model [7] (Fig. 1) because of some specific features which we cannot accept and that is why we have built a scheme of hadron interactions for MD description by means of the modified Two Stage Model (TSM) [8]. We consider that at the early stage of pp interactions initial quarks and gluons take part in the formation of QGS. They develop branch processes [9]. Also as in TSM we have used the hypothesis of soft decoloration at the second stage

$$P_n = \sum_{m=0} P^n_P P^n_H(m),$$

where $P_n$ - resulting MD of hadrons, $P^n_P$ - MD of partons (quarks and gluons), $P^n_H(m)$ - MD of hadrons (the second stage) from $m$ partons.

At the beginning of this study we used the model where some of quarks from protons took part in the formation of hadron jets. But it turned out that parameters of that model had values which were differed a lot from the parameters obtained in $e^+e^-$ annihilation, and especially from the parameters of hadronization. It was one of the main reasons to give up the scheme with active quarks.

We dwell upon the model where quarks of protons do not take part in the jet production, but remain in the initial protons. All the remained hadrons are formed by gluons. We call these gluons the active ones. It is important to know how many active gluons are in QGS in the moment just after the impact. The simplest MD to describe this gluons is the Poisson distribution:

$$P_k = e^{-\bar{k}\bar{k}}/k!,$$

where $k$ and $\bar{k}$ are the number and mean multiplicity of the active gluons, accordingly.

We begin our MD analysis with the branch scheme of gluons. To describe the MD of k gluons, we have used the Farry distribution [9]

$$P^B_k = \frac{1}{m^k} \left(1 - \frac{1}{m}\right)^{m-k} \cdot \frac{(m-1)(m-2)\cdots(m-k+1)}{(k-1)!}, k > 1,$$

where $m$ and $\bar{m}$ are the number of secondary gluons and their mean multiplicites.

At the second stage some of the active gluons may leave QGS and transform to real hadrons. We call such gluons the evaporated ones. Let us introduce parameter $\alpha$ as the ratio of the evaporated gluons, leaving QGS, to all the active gluons, which may be
transformed to hadrons. We use binomial distributions for MD of the hadrons from the evaporated gluons at the stage of hadronization

\[ P_n^H = C_{amN}^{m-2} \left( \frac{n^h}{N} \right)^{n-2} \left( 1 - \frac{n^h}{N} \right)^{amN-(n-2)}, \]  

(4)

where \( n^h \) and \( N \) are parameters of hadronization. They mean the average value and maximal possible multiplicities of the hadrons from one active gluon at the second stage.

The hadron MD in the process of pp scattering in the Two Stage Gluon Model with branch(TSMB), is:

\[ P_n = \sum_{k=0}^{m} \frac{e^{-\overline{k}}}{k!} \sum_{m=k}^{\infty} \frac{1}{m^k} \frac{(m-1)(m-2)\ldots(m-k+1)}{(k-1)!} \] 
\[ \cdot \left( 1 - \frac{1}{m} \right)^{m-k} C_{amN}^{m-2} \left( \frac{n^h}{N} \right)^{n-2} \left( 1 - \frac{n^h}{N} \right)^{amN-(n-2)}. \]  

(5)

The parameters are determined from the comparison with experimental data [5]. They are \( N = 40(\text{fix}), \overline{m} = 2.61 \pm .08, \alpha = .47 \pm .01, \overline{k} = 2.53 \pm .05, n^h = 2.50 \pm .29 \). We can conclude that branch processes are absent, since parameters \( \overline{m} \) and \( \overline{k} \) are equal to the errors. The fraction of the evaporated gluons is equal to .47. A maximal possible number of hadrons from the gluon looks very much like the number of partons in the glob of cold QG plasma of L.Van Hove [10]. At the fixed parameter of hadronization \( n^h \) equal to 1.63 (see below the thermodynamic model) the fraction of the evaporated gluons is about .73 (Fig. 1).

In the thermodynamic model without branches the active gluons which appeared in the moment of the impact, may leave QGS and fragment to hadron jets. We assume that the active gluons the evaporated from QGS have the Poisson MD as in [2]. Using the binomial distribution for hadrons [11] and the idea of convolution of two stages [1], we obtain MD of hadrons in pp-collisions in the framework of the Two Stage Thermodynamic Model (TSTM)

\[ P_n = \sum_{m=0}^{M} \frac{e^{-\overline{m}}}{m!} C_{mN}^{m-2} \left( \frac{n^h}{N} \right)^{n-2} \left( 1 - \frac{n^h}{N} \right)^{mN-(n-2)} \]  

(6)

\( P_2 = e^{-\overline{m}} \). The comparison [3] with experimental data [12] (see Fig. 2), gives the following parameter values: \( N = 4.24 \pm .13, \overline{m} = 2.48 \pm .20, \overline{n^h} = 1.63 \pm .12 \). In sum [6] we constrain the maximal possible number of the evaporated gluons equal to \( M = 6 \). At the description of experimental data of \( e^+e^- \) annihilation the hadronization parameter \( N \) was found equal to \( \sim 4 - 5 \) [8]. We can see that our parameter \( N \) obtained in TSTM coincides with this value. Both TSMB and TSTM describe the data equally well.

The maximal possible number of the charged particles from TSTM is 26. It is interesting to get MD for neutral mesons. For this purpose we have taken the \( 
\) mean multiplicity in pp-interactions at 69 GeV/c and used it for normalization. It is equal to 2.57 \pm .13 [13].
We have determined the parameter of hadronization $\pi_0^h$ for neutral mesons. It is equal to $1.036 \pm 0.041$. We are based on TSM [3] to estimate the probability of the different hadron production from one active gluon.

MD for neutral mesons is shown in Fig. 3. From this distribution we see that the maximal possible number of $\pi^0$'s from TSTM is equal to 16. MD for total multiplicity is shown on Fig. 4. We see that the maximal possible number of total number of particles in this case is equal to 42.

The dependence of the mean multiplicities of neutral mesons versus the number of the charged particles may be obtained by means of MD for total multiplicity $P_{n_{tot}}$:

$$\pi_0(n_{ch}) = \sum_{n=n_1}^{n_2} P_{n_{tot}} \cdot (n - n_{ch}) / \sum_{n=n_1}^{n_2} P_{n_{tot}},$$

we take the Bayes theorem into account, $n_1$ and $n_2$ are determined only by conservation laws. Fig. 5 shows a difference with the data at small multiplicities. The noticeable improvement will be reached if we decrease the top limit at low multiplicities ($n_{ch} \leq 10$) to $n_2 = 2n_{ch}$ (Fig. 6). We don’t know what is happening in the region of VHMP. This behavior of $n_1$ and $n_2$ in (7) indicates that Centauro events with a large number of charged particles and practically no accompanying neutrals, may be realized in the region of VHMP. AntiCentauro events with a large number of neutral particles and with very small number charged ones must be absent.

In Two Stage Model with gluon branch it was established that several of active gluons are staying inside of hot QGS and don’t give hadron jets. New formed hadrons are catching up small energetic gluons which were free before this time. These hadrons are excited because they have additional energy at the expense of absorbed gluons. This energy may be thrown down by means of the photon radiation.

In project "Thermalization" it is planned to investigate of soft photons (SP) [1]. It was shown that measured cross sections of such photons are several times larger than expected from QED. For the explanation of the SP excess the phenomenological glob model [10] and the modified soft annihilation model Lichard and Thomson [12] are used.

We want to estimate the number of them. We consider that at certain moment QGS or exited hadrons may be in almost equilibrium state on. That’s why we try to use for the description of the massless bosons (gluons and photons) the black body emission spectrum [13]

$$\frac{d\rho(\nu)}{d\nu} = \frac{8\pi \nu^2}{c^3 e^{\hbar \nu/T} - 1},$$

where $\nu$ is the energy of photon. These spectra help us to calculate the number of SP [14].

The gluon density at the deconfinement temperature $T_c \approx 160 - 200$ MeV can be estimated by comparison with relic one: $\rho_{gl}(160) = 0.13(fm)^{-3}$ and $\rho_{gl}(200) = 0.25(fm)^{-3}$. The number of gluons $N_{gl}$ in the hot QGS of size $\sim L^3$, where $L = 2fm$, will be: $N_{gl}(160) \sim 1$, $N_{gl}(200) \sim 2$. 
Using the spectral spatial density of relic photons it is possible to get the number of SP $N_{\gamma}$ in the region of size of our system (new formed hadrons). This size must be bigger than one in the gluon case. If the size of our system about 2 fm and average energy of photons 15-20 MeV/c the number of such SP will be the order of $10^{-3}$.

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Figure 1: $\sigma(n_{ch})$ in different models (see text).

Figure 2: MD $P(n_{ch})$ in TSTM.

Figure 3: MD $P(n_o)$ in TSTM.

Figure 4: MD $P(n_{tot})$ in TSTM

Figure 5: $\bar{n}_\pi$ versus $n_{ch}$ without of restrictions.

Figure 6: $\bar{n}_\pi$ versus $n_{ch}$ with restrictions.