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THE DESCRIPTION OF *pp*-INTERACTIONS WITH VERY HIGH MULTIPLICITY AT 70 GeV/c*

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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 Thermalization project (JINR). This project is aimed at studying the collective behavior of secondary particles in proton interactions at 70 GeV/c [1].

According to the present understanding of hadronic structure, based on quantum chromodynamics (QCD) [2], protons consist of quarks and gluons. We have developed a Two Stage Gluon model [3] to describe high energy multiparticle production (MP) in proton interactions. At first stage of the model QCD and thermodynamical approaches are used. At second stage (hadronization) a phenomenological description is applied.

After inelastic collision of two protons a part of the energy of these moving particles is converted into the thermal one. Constituents of proton, quarks and gluons, have large energies, and they can be described by pQCD, because the strong coupling reaches a small value. Quarks and gluons become liberated. Our model investigations had shown that interaction of quarks with initial protons are irrelevant for the hadrons in *pp*-interactions at 70 GeV. MP is realized by gluons. This study had confirmed the idea of Carruthers about a passive role of quarks [4].

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We have used one of the most generally accepted methods to study multiparticle dynamics: the multiplicity distribution (MD) analysis. Two schemes of interactions are proposed. They are distinguished only by the quark–gluon (QG) stage. If we want to study gluon division inside the QG system (QGS) we use the first scheme branch model. If we are not interested in what is going inside the QGS we use the second scheme thermodynamic model. In both schemes some of gluons (not all) leave QGS and convert to real hadrons. Using the thermodynamic interpretation we say that active gluons are evaporated from hot QGS. After the evaporation they pass 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 (π^+ or π^-) and two leading nucleons: $p + p \to n\pi + 2N$. In Thermalization project it is planed to observe events with high multiplicities. The production of soft photons could give the information about early stage of QG interactions [1, 6].

The choice of 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 do not agree with experimental data at high multiplicities and has the deviation at $n_{\rm ch} = 18$ equal to two orders of magnitude (Fig. 1). We had rejected the quark model [7] because it has some drawbacks (Fig. 1) and had built scheme of hadron interactions for MD description by modification of a Two Stage Model (TSM) [8]. We assume 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 use hypothesis of soft decoloration on the second stage

$$P_n = \sum_{m=0} P_m^P P_n^H(m) \,, \tag{1}$$

where P_n — resulting MD of hadrons, P_m^P — MD of partons (quarks and gluons), $P_n^H(m)$ — MD of hadrons (second stage) from m partons.

At the beginning of this study we took a model where some of quarks from protons take part in the formation of hadron jets. However, it turned out that parameters of that model had values which differed a lot from parameters obtained in e^+e^--annihilation, especially parameters of hadronization. It was one of the main cause for our rejecting the scheme with active quarks.

We consider the model where quarks of protons do not take part in the creation of jets, but stayed in initial protons. All remaining hadrons are formed by gluons. We call these gluons active ones. It is important to know how many active gluons there are in QGS at the instant after the impact.

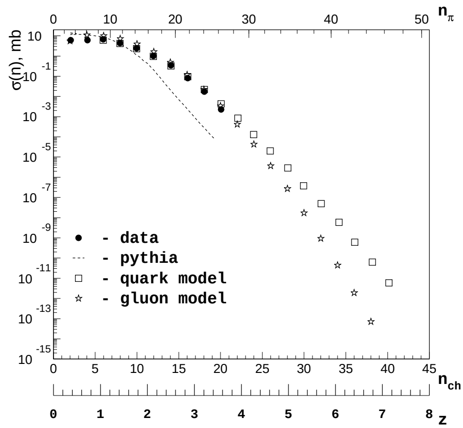

Fig. 1. $\sigma(n_{\rm ch})$ in different models (see text).

The simplest MD for the description of such gluons is Poisson distribution

$$P_k = \frac{\mathrm{e}^{-\overline{k}}\overline{k}^k}{k!}\,, \tag{2}$$

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

We begin our MD analysis with branch scheme of gluons. For the description of MD of k gluons we use Furry distribution [9]

$$P_m^B = \frac{1}{\overline{m}^k}\left(1-\frac{1}{\overline{m}}\right)^{m-k}\frac{(m-1)(m-2)\cdots(m-k+1)}{(k-1)!}\,, \quad k>1\,, \tag{3}$$

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

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

$$P_n^H = C_{\alpha m N}^{n-2}\left(\frac{\overline{n}^h}{N}\right)^{n-2}\left(1-\frac{\overline{n}^h}{N}\right)^{\alpha m N-(n-2)}\,, \tag{4}$$

where $\overline{n}^h$ and N are parameters of hadronization. They have the meaning of the mean and maximal possible multiplicities of hadrons from one active gluon on the second stage. The hadron MD in the process of pp-scattering in a Two Stage Gluon Model with branch (TSMB) is:

$$P_n = \sum_{k=0} \frac{e^{-\overline{k}}\overline{k}^k}{k!} \sum_{m=k} \frac{1}{\overline{m}^k} \frac{(m-1)(m-2)\dots(m-k+1)}{(k-1)!}$$
$$\times \left(1-\frac{1}{\overline{m}}\right)^{m-k} C^{n-2}_{\alpha m N} \left(\frac{\overline{n}^h}{N}\right)^{n-2} \left(1-\frac{\overline{n}^h}{N}\right)^{\alpha m N-(n-2)} . \quad (5)$$

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

In the thermodynamic model without branches active gluons appearing in the moment of the impact may leave QGS and fragment to hadron jets. We assume that evaporated from QGS active gluons have Poisson MD as (2). Using binomial distribution for hadrons (4) and the idea convolution of two stages (1) we obtain MD of hadrons in pp-collisions in framework of Two Stage Thermodynamic Model (TSTM)

$$P_n = \sum_{m=0}^{M} \frac{e^{-\overline{m}}\overline{m}^m}{m!} C^{n-2}_{mN} \left(\frac{\overline{n}^h}{N}\right)^{n-2} \left(1-\frac{\overline{n}^h}{N}\right)^{mN-(n-2)} \quad (n > 2) \qquad (6)$$

($P_2 = e^{-\overline{m}}$). The comparison of (6) with experimental data [5] (see Fig. 2), gives next 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 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. TSMB and TSTM describe data equally well.

From TSTM the maximal possible of charged particle number is 26. It is interesting to get MD for neutral mesons. For this purpose we take π^0's mean multiplicity in pp-interactions at 69 GeV$/c$ and use it for normalization. It is equal to $2.57 \pm .13$ [11]. We determine parameter of hadronization $\overline{n}^h_0$ for neutral mesons. It is equal to $1.036 \pm .041$. We relay on TSM [3] for probabilities of the creation of different hadrons from one active gluon.

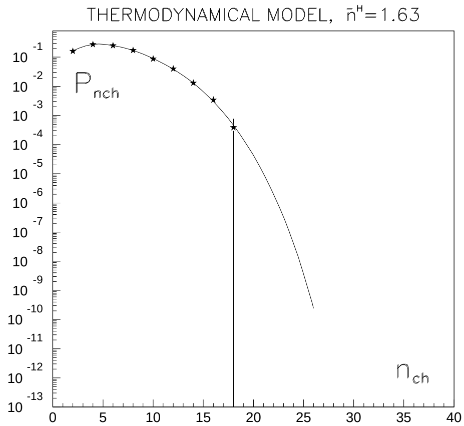

Fig. 2. MD $P(n_{\mathrm{ch}})$ in TSTM.

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

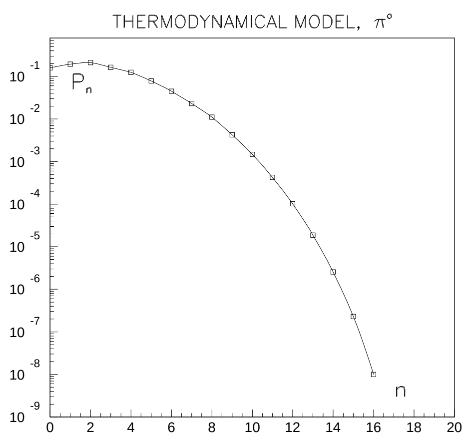

Fig. 3. MD $P(n_0)$ in TSTM.

The dependence of the mean multiplicities of neutral mesons *versus* the number of charged particles may be obtained with the help of MD for total multiplicity $P_{n_{\mathrm{tot}}}$

$$\overline{n}_0(n_{\mathrm{ch}}) = \frac{\sum\limits_{n=n_1}^{n_2} P_{n_{\mathrm{tot}}}(n - n_{\mathrm{ch}})}{\sum\limits_{n=n_1}^{n_2} P_{n_{\mathrm{tot}}}}\,, \tag{7}$$

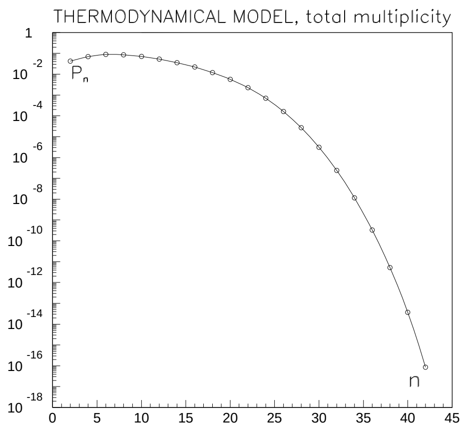

Fig. 4. MD $P(n_{\text{tot}})$ in TSTM

we take into account Bayes theorem, n_1 and n_2 are determined only by conservation laws. In Fig. 5 we see the big deviation from data at small multiplicities. The marked improvement will be reached if we decrease the top limit at low multiplicities ($n_{\text{ch}} \leq 10$) to $n_2 = 2n_{\text{ch}}$ (Fig. 6). We do not know what is happening at the region of VHMP. Such behavior of n_1 and n_2 in (7) indicates that Centauro events with a large number of charged 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 of charged particles must be absent.

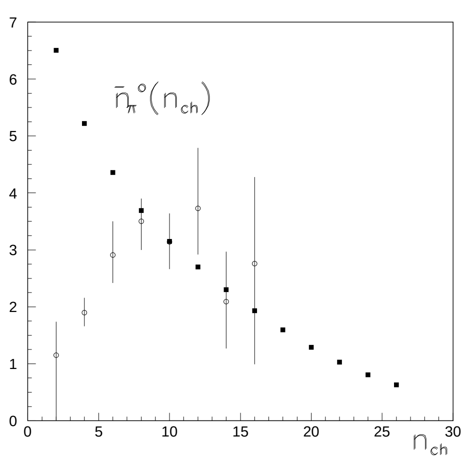

Fig. 5. $\overline{n}_{\pi^0}$ *versus* n_{ch} (see text).

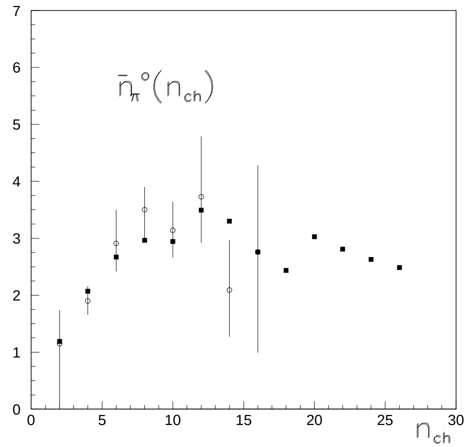

Fig. 6. $\overline{n}_{\pi^0}$ *versus* $n_{\rm ch}$ (see text).

In Two Stage Model with gluon branch it was established that several of active gluons are staying inside of hot QGS and do not 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 Thermalization project it is planned to investigate the 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 [6] are used.

We want to estimate their number. We consider that at certain moment QGS or excited hadrons may be in an almost equilibrium state. That is why we try to use for the description of the massless bosons (gluons and photons) the black body emission spectrum [12]

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

where ν is the energy of photon. These spectra help us to calculate the number of SP [13]. The gluon density at the deconfinement temperature $T_{\rm c} \approx$160–200 MeV can be estimated by comparison with relic one: $\rho_{\rm gl}(160) = 0.13({\rm fm})^{-3}$ and $\rho_{\rm gl}(200) = 0.25({\rm fm})^{-3}$. The number of gluons $N_{\rm gl}$ in the hot QGS of size $\sim L^3$, where $L = 2$fm, will be: $N_{\rm gl}(160) \sim 1$, $N_{\rm gl}(200) \sim 2$.

Using the spectral spatial density of relic photons (8) it is possible to get the number of SP N_γ in the region of size of our system (new formed hadrons). This size must be bigger than the one in the gluon case. If the size of our system is about 2 fm and average energy of photons is 15-20 MeV/c the number of such SP will be of the order of 10^{-3}.

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