Proton interactions with high multiplicity

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Project Thermalization is aimed to study the proton - proton interaction with high multiplicity of secondary particles. The region of high multiplicity is especially actual at present. We expect the manifestation of the secondary particle collective behavior at this region. The experimentally measured topological cross section was corrected for apparatus acceptance and detection efficiency. These data are in good agreement with gluon dominance model. The comparison with others models is also done and shows no essential deviations. There is evidence that Bose-Einstein condensation can formed at high total multiplicity region.

1. INTRODUCTION

he study of high multiplicity processes is closely connected with understanding of the nature of strong interactions. Our project Thermalization [1] is aimed to study of events with multiplicity significantly acceding the average one. We carry out the detection of these unique events at U-70 accelerator (IHEP, Protvino) at 50 GeV proton beams. The main aim of our project is to study the collective behavior of secondary particles at the extreme multiplicity region.

In seventies Collaboration Mirabelle had measured the multiplicity up to 16 charged particles in *pp* interactions at 50 GeV [2]. We continue the search for the events with multiplicity more than 20 both charged and neutral particles. To reach this goal, we have renewed SVD-2 setup on U-70 accelerator of IHEP (Protvino). Now it is equipped with a micro-strip silicon detector, a drift tube tracker, a magnetic spectrometer with proportional chambers, Cherenkov counter, electromagnetic calorimeter for registration of neutral particles and hydrogen target [3]. To suppress registration of the events with low multiplicity, we

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have implemented a trigger scintillation hodoscope. Using this device we have extended the multiplicity measurement from 16 (Mirabelle data) up to 24 charged particles. The achieved value of the partial cross section is less by three orders of magnitude in comparison with the Mirabelle results. Measured multiplicity distribution was corrected for apparatus acceptance and detection efficiency and compared with models predictions.

The collective behavior of secondary particles is expected to onset in the extreme multiplicity region. In particular, it may evidence for the Bose–Einstein condensation which has been predicted in this area [4]. The calculation by the MC PHYTHIA code has shown that the standard generator predicts a value of the partial cross section at 70 GeV (the energy of U-70) which is in a reasonably good agreement with the experimental data at small multiplicity ($n_{ch} < 10$) but it underestimates the value $\sigma(n_{ch})$ by two orders of magnitude at $n_{ch} = 18$ [1].

There are only few phenomenological models giving predictions on the multiplicity distributions at the extreme domain [5, 6]. That is why we have developed a gluon dominance model (GDM) [6–12]. It is based on the main essences of QCD and supplemented with the phenomenological mechanism of hadronization. This approach shows the activity of gluons and the passive role of the valent quarks in the multiparticle production mechanism. GDM confirms convincingly the recombination mechanism of hadronization in hadron and nuclear interactions and fragmentation in lepton processes.

The excess of the soft photon rate in comparison with the estimations obtained with quantum electrodynamics [13] was discovered. Evidently it is related with he quark–gluon nature of the multiparticle production mechanism. Now the prototype of the electromagnetic calorimeter is being manufactured to register soft photons on CsI crystal base. We hope the estimations of their yield as a function of charged and neutral multiplicities will be received and largely help to clerify the multiparticle dynamics.

2. SELECTION EVENTS, TRACK FITTING, AND CORRECTION PROCEDURE

The main element of SVD-2 setup is a micro-strip silicon vertex detector with 10 planes. It allows to reconstruct the interaction vertex and tracks. We have obtained the multiplicity distribution from vertex detector data. The 5.13 millions of events selected from 2008 run was analyzed. From this statistics 3.85 millions of events have been taken at trigger-level 8 (lower limit of the multiplicity set at trigger system). Out of them 2.1 millions of events have detected on hydrogen target. For final analysis 1.0 millions of events were remained. They were selected according of the criterion: a) the number of beam tracks simultaneously hitting the target is not exceed 2; b) the uncertainty of the vertex reconstruction on two projections is smaller than 5 mm. The reconstruction algorithm is followers. The coordinates of the hits are reconstructed accounting on one- and multi-strip clusters. The center of gravity method was applied: $\overline{X} = \sum_i A_i \times X_i / \sum_i A_i$, where X_i is strip coordinate and A_i — strip signal amplitude. Track approximated by straight line using separately the projections coordinates X and Y with 3 or 4 hits. For track reconstruction the Kalman filter is applied. It effectively rejects the random noise on strip planes. The length of the target is 70 mm. The initial location of primary vertex is assigned in a half of the target closest to the vertex detector. This is done to minimize apparatus acceptance correction. At least the presence of the one hit is required on first two planes. Among a few tracks candidates the candidate with best least chi-square is selected. If one the candidates with four hits has worse chi-square than candidates with three hits then the candidates with four hits is chosen. In our method two tracks can pass through common (one or two) hits.

Multiple scattering in vertex detector causes the track deviation from straight line. In our case this deviation in position of last plane does not exceed the coordinate measurement precision of the detector. The vertex of interaction is determined by least-squares method. The tracks with high deviation from vertex are not included in the event. The vertex reconstruction precision amounts 17–50 mcm on X, Y axes, 230–450 mcm on Z axis without taking into alignment uncertainty. The detectors misalignment deteriorates the coordinate precision determination on factor 2 or 3. The simulation shows that the number of tracks which deviate from the vertex more then 1 mm amounts 0.1%. In our experiment the number of such tracks is equal to 15%. These tracks come from secondary vertex or are fakes. Tracks in the space are reconstructed by means of two oblique planes U and V located at the end of vertex detector.

The correction procedure of charged multiplicity distributions is carried out taking into account an influence of the multiplicity trigger conditions and inefficiency of track reconstruction algorithm in vertex detector. To make these corrections we used tables of spread coefficients on reconstructed multiplicity, $a_{ij} = N_i/N_j$, where a_{ij} is the probability to reconstruct successfully i charged tracks for event with j charged tracks, N_j — the number of simulated events with j charged tracks, from which N_i events were reconstructed as events with i charged tracks. The index i changes from 1 up to 24, the index j takes only even values from 2 up to 24. The table of coefficients is calculated using Monte-Carlo simulation of events (GEANT3) and following the events treatment by the reconstruction program accounting for all apparatus parameters including the trigger condition.

We get the overdetermined system of linear equations, in general case 24 equations with 12 unknown quantities x_j: $\sum_{j=2}^{24} a_{ij}x_j = b_i$, where b_i is the experimental number of events with reconstructed multiplicity i. This system can be solved by the ordinary Gauss-Zaidel method or by the least-squares method. It is difficult to account the trigger inefficiency below it threshold (8 minimum ionizing particles) so we publish here corrected topological cross section for $n_{ch} \geq 10$ where trigger efficiency is close to 1 and its influences is insignificant. The event simulation is carried out in accordance with some physical models (Boltzmann, Bose and others). The differences in coefficients a_{ij} obtained for these models were used for the estimation of the error of the correction coefficients. To Mirabelle data we have added 7 new points from 10 up to 24. The last point cross section is three order of magnitude lower than previously known cross section at $n_{ch} = 16$. We normalized our data to Mirabelle one [2]. This allows us to get inelastic cross section, $\sigma(n_{ch}) = 31.5$ mb and the mean charged multiplicity, $\overline{n}(s) = 5.45$. We also calculated the variance — 7.21 and second correlative moment, $f_2 = 1.75$.

3. COMPARISONS WITH MODELS

Available experimental data at proton energy 50 GeV are shown in Fig 1. Corrected data are shown in Fig. 2. We compare corrected data with three models. First one is the gluon dominance model [6]. The essence of the GDM is the convolution of the parton (gluon) cascade with phenomenological scheme of hadronization. The active gluons play dominant role in multiparticle process. Hadronization parameters obtained in present analysis are similar to those obtained for proton energy 70 GeV. Exclusion is the maximal number of hadrons formed in one gluonic source. The account of events with large multiplicity led to increase of role of the gluonic source.

An analytical expression for multiplicity distribution was obtained by a theoretical group from IHEP [14]. This model has combined the inelastic and elastic processes. The negative binomial distribution (NBD) [15] is the commonly utilized formula for multiplicity distributions . Unfortunately it describes the data only in the high multiplicity region and does not describe region of small multiplicity. These three curves are shown in Fig. 2.

In hadron interactions mainly the lightest particles, pions, are formed. They are bosons. The more secondary particles are produced the smaller energy of the relative motion they have. V. Begun and M. Gorenstein [4] have suggested to search for Bose–Einstein condensation (BEC) of π mesons in the extreme multiplicity events. They have shown that at the thermodynamic limit the pion number fluctuations strongly increase and may give a prominent signal at approaching the BEC condition. It was noted [4] that the pion number fluctuations could be studied in high-energy hadron and/or nuclei collisions. To search for the BEC fluctuation signals, one needs to carry out the event-by-event identifications of the both charge and neutral pions. Unfortunately, in most event-by-event studies only charged pions have been detected. In this case the global conservation laws lead to a strong suppression of the particle-number fluctuations [4] and no anomalous BEC fluctuations would be seen.

We have selected events with the charged multiplicity up to 24 and determined the number of neutral particles for every of these events. One assumes 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 of middle multiplicity. 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. The neutral particles are reconstructed by using the electromagnetic calorimeter data. The variance of the number of particle fluctuations of the both neutral and charged pions will give a signal on the BEC formation or its absence.

The anomalous formation of soft photons in hadron multiparticle production has not been enough studied yet. The data analysis of a number of experiments at the SPS and LEP accelerators was carried out in CERN [13]. Such formation of soft photons is observed at hadron channels. The rate of such photons exceeds the theoretical predictions by 4–7 times. We hope to continue these investigation at SVD-2.

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Table 1. The corrected cross sections at 50 GeV beam in pp interactions.

n_{ch}	10	12	14	16	18	20	22	24
$\sigma(n_{ch})$	1.685	0.789	0.234	0.0526	0.0104	0.00169	0.000326	0.000054
$\Delta\sigma(n_{ch})$	0.0047	0.016	0.022	0.018	0.012	0.0066	0.0029	0.0012

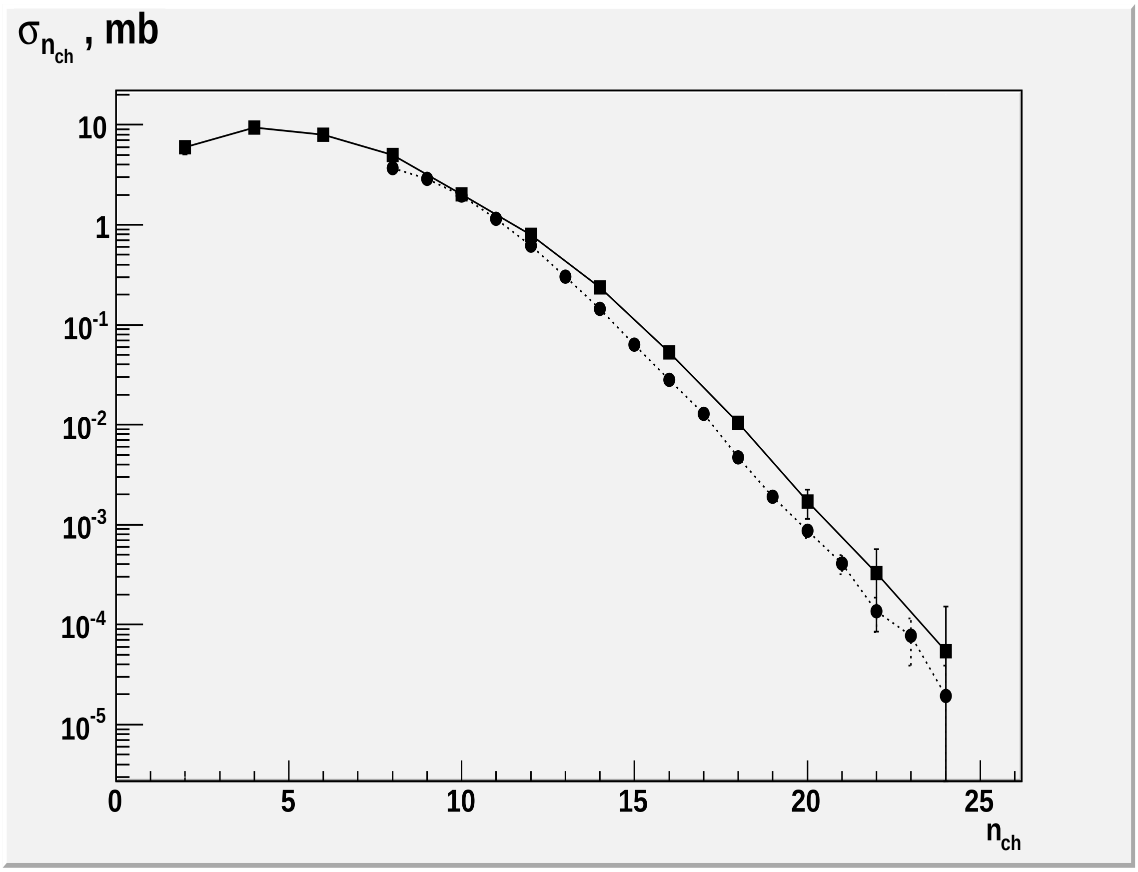

Figure 1. Experimental topological cross sections for pp interactions before (dotted curve) and after (solid curve) corrections with inclusion of Mirabelle data.

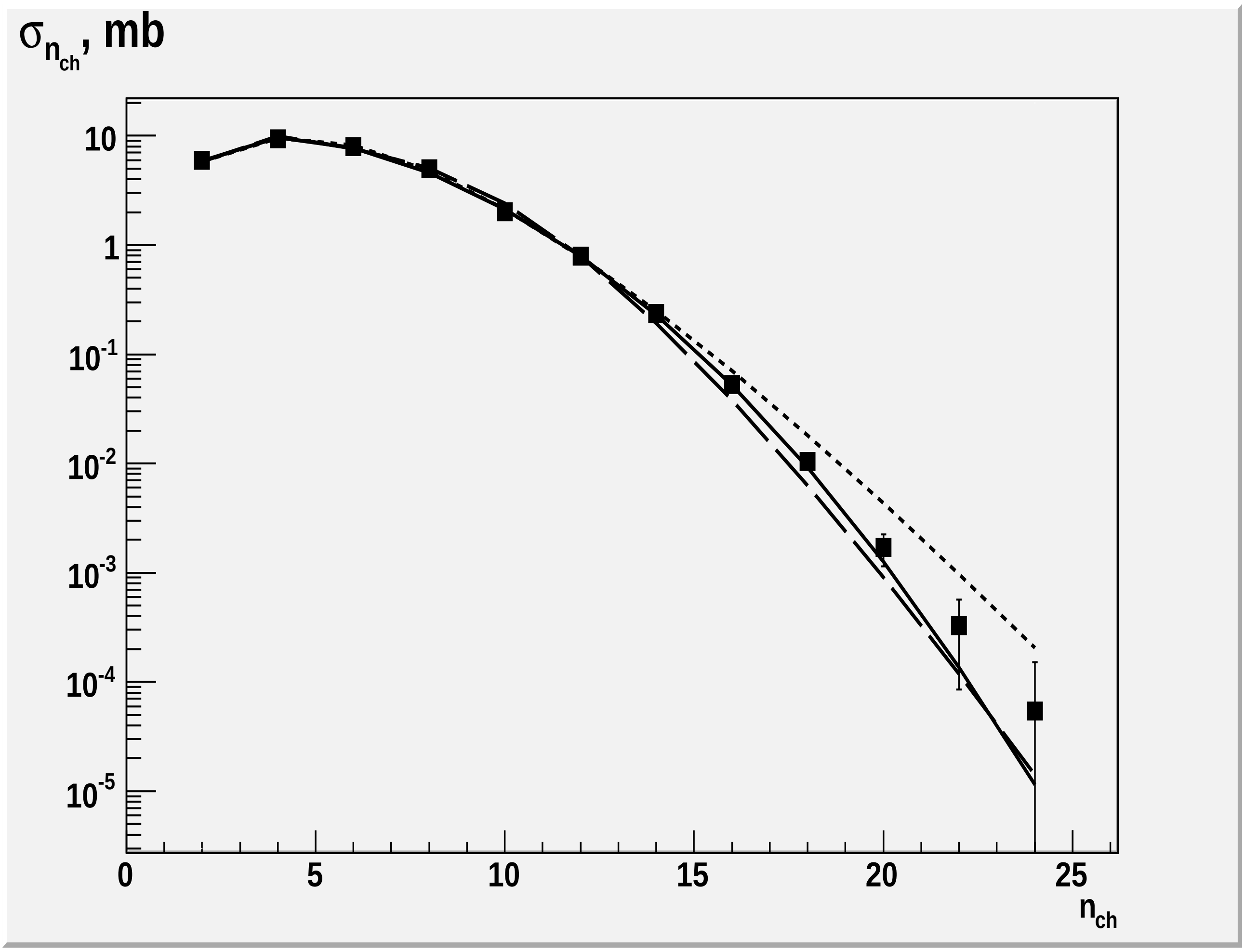

Figure 2. Comparisons data with GDM (solid curve), IHEP model (dotted curve), and NBD distribution (dashed curve).

FIGURE CAPTIONS

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Fig. 2: Comparisons data with GDM (solid curve), IHEP model (dotted curve) and NBD distribution (dashed curve).