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Neutral pion number fluctuations at high multiplicity in pp-interactions at 50 GeV

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Abstract. The results of E-190 experiment (project Thermalization) with 50 GeV proton beam irradiation of SVD-2 setup are presented. MC simulation has shown the linear dependence of number of photons detected in electromagnetic calorimeter and the average number of neutral pions. Multiplicity distribution of neutral pion, N_0, for total number of particles in the event, $N_{tot} = N_{ch} + N_0$, are obtained with corrections on the setup acceptance, triggering and efficiency of the event reconstruction. The scaled variance of neutral pion fluctuations, $\omega = D/ < N_0 >$, versus total multiplicity is measured. The fluctuations increase at $N_{tot} > 18$. According to quantum statistics models this behavior can indicate a pion condensate formation in the high pion multiplicity system. This effect has been observed for the first time.

1 Introduction

Experiment E-190 is carried out at SVD-2 setup located at U-70 accelerator of IHEP, Protvino [1]. The basic elements of SVD-2 setup are: the liquid hydrogen target, microstrip silicon vertex detector (VD), straw tube chambers, magnetic spectrometer with proportional chambers, Cherenkov counter and electromagnetic calorimeter (ECal) . After the first publication of the evidence the rise of the neutral pion number fluctuations [2] the following upgrades of data analysis have been carried out:

– the data sample for analysis is increased two times;

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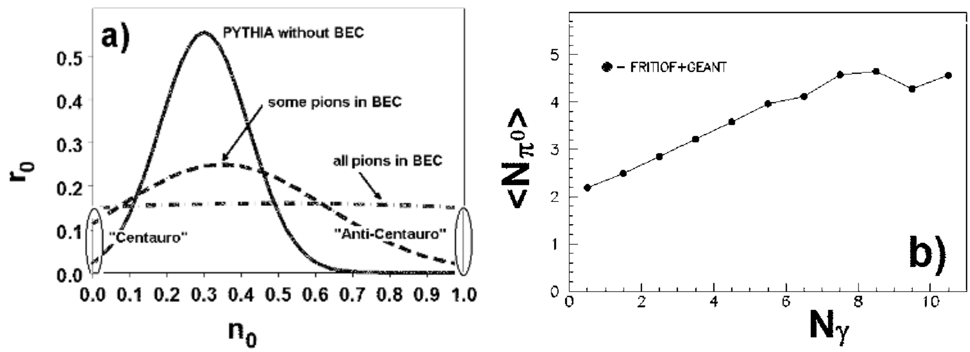

Fig. 1. a) Distributions r_0 for normalized multiplicity of neutral pions in QCD model and when the system approaches to BEC. b) The dependence of the average neutral pion number $< N_0 >$ on the photon number detected in ECal N_γ for MC events.

- more detail MC simulation of apparatus performance with program GEANT was made;
- the improvement of the photon reconstruction algorithm was achived;
- mean neutral pion multiplicity versus charged multiplicity was measured and compared with another experimental data [3].

The pions are copiously produced in *pp* -interactions at 50 GeV. They are the lightest hadrons with spin zero and obey the Bose-Einstein statistics. Mark Gorenstein and Viktor Begun have shown in statistical model of the ideal pion gas that the neutral pion number fluctuations begin to grow at the total multiplicity higher than certain threshold value, because in this case the pion system is approached to the Bose-Einstein Condensate (BEC) state [4][5]. This phase transition can be revealed by the scaled variance, ω, which is defined as the ratio of variance, D , of the neutral pion number distribution to their mean value $< N_0 >$,

$$\omega = D/ < N_0 >.$$

In accordance with [4][5] the function $\omega(N_{tot})$ depends on the temperature and energy density of pion system. Here $N_{tot} = N_{ch} + N_0$ is the sum of charged and neutral pions in the system. For the analysis of the data at different N_{tot} relative values are used: $n_0 = N_0/N_{tot}$ and scaled multiplicity $r_0 = N_{ev}(N_0, N_{tot})/N_{ev}(N_{tot})$. $N_{ev}(N_0, N_{tot})$ is number of events with N_0 at given N_{tot}. The number of events with N_{tot} is $N_{ev}(N_{tot})$. The variable n_0 changes in the range of $0\div1$ and the sum of all r_0 is equal to 1 for each N_{tot} (normalization condition). In Fig. 1a we give schematically the distributions r_0 obtained for the following cases: 1) MC simulation of events by PYTHIA, 2) in the pion system some pions drop out into condensate, 3) all pions are in the condensate. Each distribution is characterized by average, $< n_0 >$, and by standard deviation, σ.

2 Simulation of neutral pion detection

Let us underline that to restore the neutral pion number we do not use "event by event" method. We are based on the statistical method. ECal detects photons from neutral pion decay. The registration of all π^0 in the every event is not possible because of limited ECal aperture and the threshold on the photon detection energy. But π^0 reconstruction efficiency can be estimated by means of simulation. Using FRITIOF7.02 codes *pp* inelastic interactions at 50 GeV are simulated. Fig. 1b shows the dependence of the average number of neutral pion, $< N_0 >$, on number of photons in ECal, N_γ, after GEANT. There is a linear correlation between average $< N_0 >$ and N_γ. So relation between the number of events $N_{ev}(N_\gamma, N_{ch})$ and $N_{ev}(N_0, N_{ch})$ can be found from this simulation. The FRITIOF7.02 code ($3.5*10^4$ events) shows also that 95% photons are the product of π^0 decay, $< N_{ch} >= 7.9$, $< N_0 >=2.9$, $< N_\gamma >=5.4$ in total and $< N_\gamma >=2.5$ in ECal. Values n and r were calculated for that MC events. Then

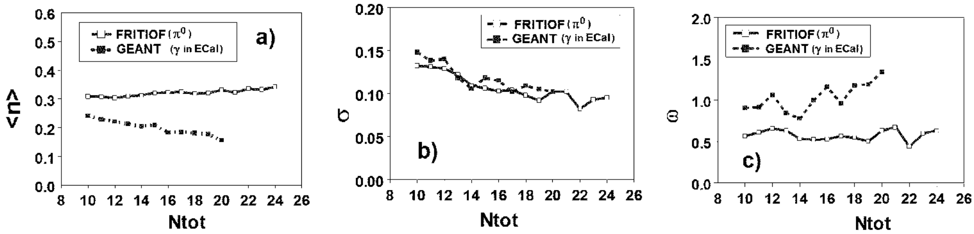

Fig. 2. a) Average $< n_0 >$, $< n_\gamma >$; b) standard deviation σ and c) scaled variance ω dependence on N_{tot} (see text) for MC events.

parameters $< n_0 >$, σ and ω are defined for distribution r on n. In Fig. 2a average $< n_0 >$ and $< n_\gamma >$ on N_{tot} dependences are presented, where $N_{tot} = N_{ch} + N_0$ for π^0 and $N_{tot} = N_{ch} + N_\gamma$ for photons. Standard deviations σ are presented in Fig. 2b, too. The scaled variance is shown in Fig. 2c. In our case it is defined as $\omega = \sigma^2 * N_{tot} / < n >$. The values ω increases slightly for photons, but remains near the constant for pions in the total range of N_{tot} changes. The similar results for PYTHIA code have been presented in our previous paper [2].

3 Photon and charged particles reconstruction

The present work comprises 956919 events of *pp* -interactions. Photon reconstruction consists in the searching for 5×5 signal clusters in ECal and analyzing of them with criteria for the photon. The measured values for photons are $< E_\gamma >$=2.8 GeV, $< N_\gamma >$=1.8. For the charged tracks reconstruction the data only from VD have been used. Because of various losses the corrections of charged particle number are essential for measurements of pion fluctuations. The correction for the setup acceptance and the particle reconstruction efficiency is made by means of GEANT program. The details of this procedure are presented in [6]. Second correction is needed because the present data are obtained with suppression of small charged multiplicity events with trigger conditions. It was made taking into account experimental data of topological cross sections. In Fig. 3a multiplicity distributions for N_{ch}, N_γ and N_{tot} are shown. We note that bin width for N_{ch} distribution equal 2, but it is 1 for N_{tot}. The change of the event number for N_{ch} after corrections ($< N_{ch} >= 6.7$) also leads to the change of the event number for N_γ in ECal ($< N_\gamma >= 2.3$). After corrections we have the table for event numbers with different total numbers particles (column) and numbers of charged particles (raw). The details of the analysis for this table are presented in [7].

4 Neutral pion fluctuation measurements

Thus we have corrected experimental event numbers with N_γ (= i) in ECal and N_{ch}. Then two-dimensional distributions for MC events (PYTHIA5.6, 10^7 events) with N_γ and N_0 (= j) are used to recover event numbers with N_0 and N_{ch}. The coefficients matrix $c_{ij} = N_{ev}(i, j)/N_{ev}(i)$ is calculated for this. So c_{ij} factors depend on N_0 for various N_γ and N_{ch}. The form of these distributions slightly depends on N_γ and N_{ch}, but their average $< N_0 >$ increases with N_γ. The simulation allows obtain c_{ij} for $N_\gamma \leq 10$ and $N_{ch} \leq 14$ only because of limitation of the MC events statistics. Regularities of factors c_{ij} are used to extrapolate them to $N_\gamma > 10$ and $N_{ch} > 14$ region and the full sample of $N_{ev}(N_{tot}, N_{ch}, N_0)$ is obtained, which is used then to determine pion fluctuation. Then with coefficients from the simulation we can reconstruct the table of experimental events for neutral pions. The average number of neutral pions $< N_0 >$ after their reconstruction (Fig.4a) is in agreement with Mirabelle data at 70 GeV [3]. This fact confirms the procedure of this reconstruction is correct. As mention before we have used scaled variables n_0 and r_0 (see Introduction): $n_0 = N_0/N_{tot}$ and $r_0(n_0) = N_{ev}(N_0, N_{tot})/N_{ev}(N_{tot})$, where $N_{tot} = N_0 + N_{ch}$. Distributions $r_0(n_0)$ are shown in Fig. 4b for $N_{tot} \geq 10$. These distributions allow calculate the mean, variance and scaled variance of neutral pion number distribution. The data in the

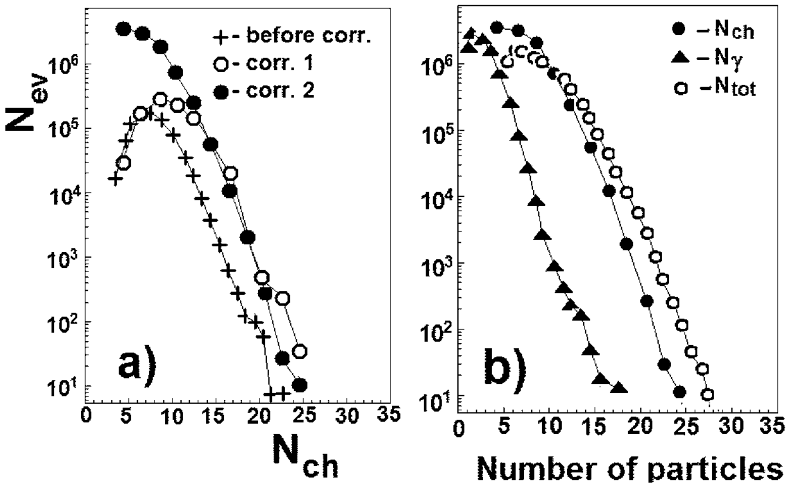

Fig. 3. Multiplicity distributions: a) N_{ch} before and after corrections; b) corrected N_{ch}, N_γ and $N_{tot} = N_{ch} + N_\gamma$.

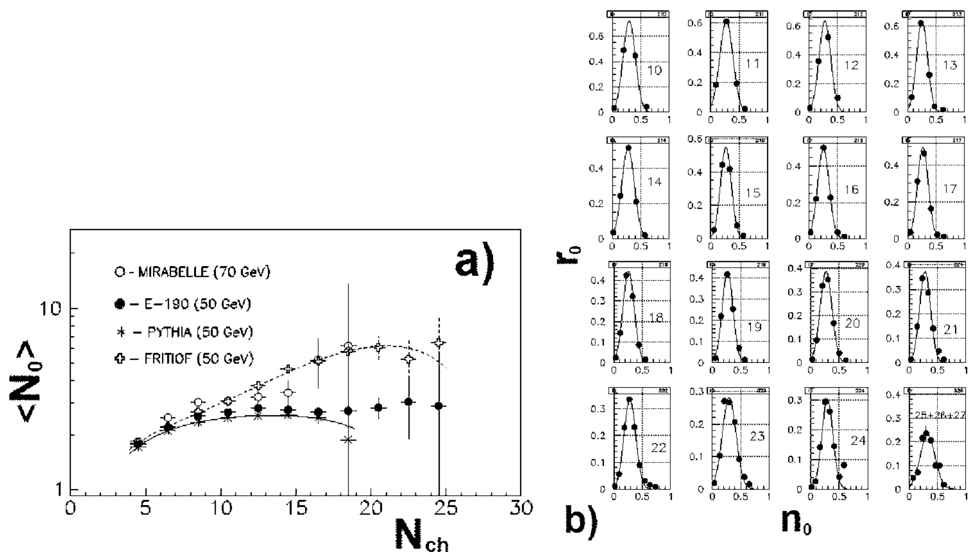

Fig. 4. a) The dependence of average number of neutral pions $< N_0 >$ on charge multiplicity. b) Scaled neutral pions number n_0 distributions for various N_{tot} (are specified by number).

intervals (25, 26, and 27) are combined due to small statistics. These values are presented in Fig. 5. In Fig. 5a one can see that the measured average $< n_0 >$ has the same behavior as MC simulation. The average $< n_\gamma >$ is also given. The measured standard deviations σ in Fig. 5b) shows the qualitative agreement to MC model only for $N_{tot} < 18$. The experimental value σ is increasing at higher N_{tot}.

The theoretical prediction of the scaled variance ω behavior is given in [4]. This analysis has been done for three energy densities at the approach the BEC condition (pion condensate) in the unrestricted and restricted volumes of pion systems. The growth of scaled variance at $N_{tot} > 18$ (Fig. 5c) evidences for the possibility of the BEC formation in pion system in pp -interactions at 50 GeV. We estimate this signal for π^0 by the significance on the level of 7 standard deviations (Fig. 5d).

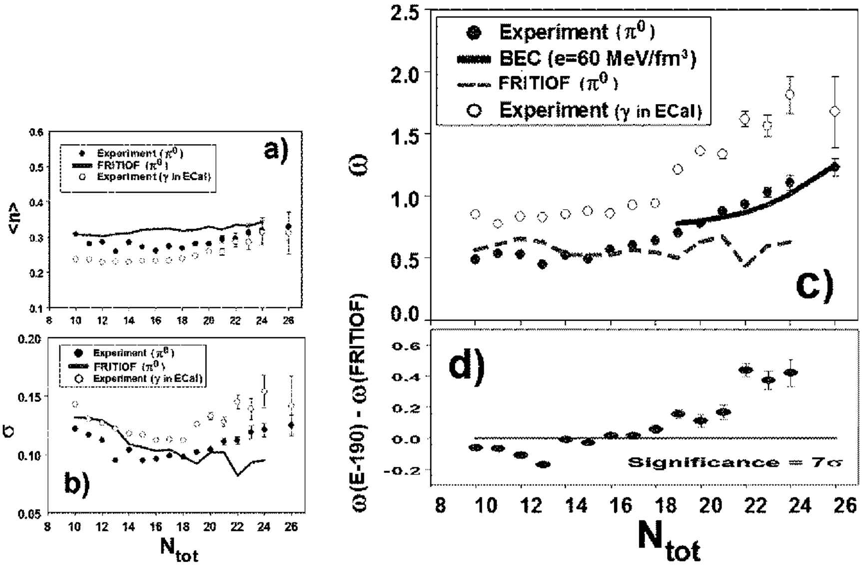

Fig. 5. a, b) Parameters of neutral pions number and photons number distributions for experimental data and MC events as function of N_{tot}. c) The result of the present measured of ω for neutral pions and photons. $N_{tot} = N_{ch} + N_0$ for π^0 and $N_{tot} = N_{ch} + N_\gamma$ for photons. d) The difference of omega experimental and simulated one for π^0.

5 Conclusion

Measurements of the charged and neutral pions number in the events with high multiplicity in *pp* -interactions at 50 GeV together with MC analysis led to the following results:

– The multiplicities of produced neutral pions and the detected photons are linearly connected that allows one to calculate neutral pion fluctuations from photon fluctuations.
– The reconstructed average number of neutral pions $< N_0 >$ is in agreement with another experimental data [3].
– Observable neutral pion number fluctuations increase at $N_{tot} > 18$, that is the evidence for approaching the pion condensate formation at the pion system with high total multiplicity according to statistical models [4][5]. **This effect has been observed for the first time.**

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