Multiplicity distributions of neutral pions in hadron interactions (part 3)

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The SVD-2 (Spectrometer with Vertex Detector) setup, which is irradiated by the extracted proton beam of the IHEP U-70 accelerator, is used to carry out the SERP-E-190 experiment, the Thermalization project at JINR. The SVD-2 setup includes a liquid hydrogen target, a microstrip silicon vertex detector (MVD), a system of Mini drift tubes, a magnetic spectrometer, a threshold Cherenkov counter, and an electromagnetic calorimeter [1]. The goal of the Thermalization project is to study the multiple production of particles in pp interactions at a proton beam energy of 50 GeV.

Multiparticle processes are one of the fundamental areas of research in hadron physics. They cannot be described hadronization stage in QCD using perturbation theory. The theory gives only a qualitative picture of the process. The particle multiplicity distribution at an energy of 50 GeV was measured earlier [2] up to the number of charged particles N_{ch}=16. The average number of charged particles at this energy is $<N_{ch}>=5.3$. The kinematic limit for the total number of charged and neutral particles is N_{tot}=59 (all kinetic energy of initial protons transforms in new pions).

In the Thermalization project, events in the range of $N_{ch}=4\div22$ and $N_{tot}=4\div31$ were registered. At high multiplicity significantly (more than average), collective effects may manifest themselves: large fluctuations in the number of charged and neutral pions as a result of the formation of a pion condensate, the formation of jets of identical pions, the so-called many-particle Bose-Einstein effect, the formation of events with a ring topology as a result of the hadronization of gluons emitted by partons in the nuclear medium (analogous to Cherenkov radiation), and others. The data obtained at the SVD-2 facility allow us to test and develop various models of multiple production in the region of $N_{tot} > <N_{tot}>$.

In the works of M.I. Gorenshteyn and V.V. Begoun [3, 4] it was shown that in the model, based on quantum statistics, as the pion system approaches the conditions of the formation of the Bose-Einstein condensate (BEC), fluctuations in the number of neutral pions in the system increase. These fluctuations can be detected by the growth of the normalized variance, determined by the ratio of the variance D of the distribution of the number of neutral pions N_0 to the average value $<N_0>$, $\omega = D/<N_0>$. The degree of growth of ω with an increase in the total number of neutral and charged particles $N_{tot}=N_{ch}+N_0$ depends on the temperature and energy density of the pion system.

To search for neutral pion fluctuations, we used a portion of the data obtained in the experiment. The setup registered the number of charged particles N_{ch} and the number of γ-quanta N_γ in each event. Using modeling, these values are corrected for the registration efficiency and the acceptance of the equipment. Modeling also allows us to reconstruct the number of π^0 -mesons N_0. To analyze the data for different values of the total multiplicity N_{tot}, we used the relative values $n0=N_0/N_{tot}$ and $r_0=Nev(N_0, N_{tot})/Nev(N_{tot})$. Here, $Nev(N_0, N_{tot})$ is the number of events with a given number of π^0 and the total number of particles N_{tot}, $Nev(N_{tot})$ is the number of events with the total multiplicity N_{tot}. The value r0 expresses the proportion of events with the number of neutral pions N_0 from the total number of events at a fixed value of N_{tot}. In this case, n0 varies in the interval [0,1] and the sum of all r0 is equal to 1 for each N_{tot}.

Fig. 1 qualitatively illustrates the distributions by relative multiplicity n_0: when simulating events using the PYTHIA5.6 program for a pion system in the absence of condensate; for a pion system in which some of the particles fall into the condensate; for the case when all particles are in the BEC state. Each distribution is characterized by the mean $\langle n_0 \rangle$ and the standard deviation σ when parameterized by a Gaussian function.

1. SIMULATION OF NEUTRAL-PION DETECTION

The presence of a photon detector (DEGA, which stands for DEtector of GAmmas) in the SVD-2 setup makes it possible to record events where the production of neutral pions is followed by their decay to two photons. Since DEGA has a finite aperture and since there is a lower limit on the photon-detection energy, it is impossible to record all neutral pions in an event, but, via a simulation, one can determine the efficiency of neutral-pion detection. For the problem of measuring fluctuations of the number of neutral pions, the existence of a linear relation between the number of detected photons and the number of neutral pions in an event is of importance.

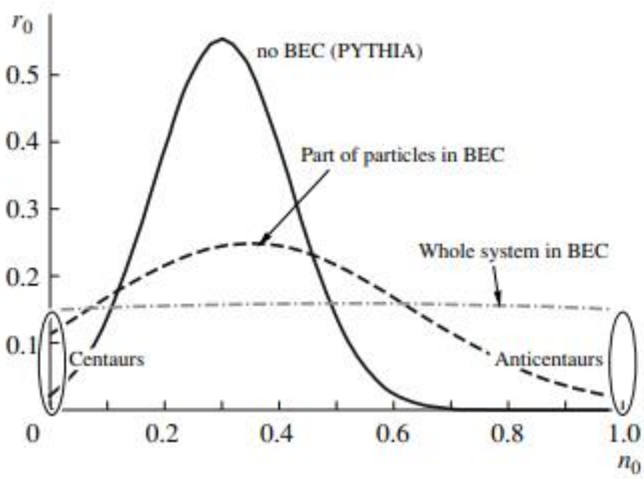

Fig. 1. Neutral-pion multiplicity as a fraction of Ntot in QCD and in the case where the pion system approaches the state of a Bose–Einstein condensate (BEC).

With the aid of the PYTHIA5.6 code, we generated about 106 inelastic pp → X events at 50 GeV. The efficiency of photon detection in DEGA was taken to be unity if a photon finds its way to the calorimeter aperture (a rectangle 160 × 122 cm in area at a distance of 1070 cm from the target) and if its energy is in excess of 100 MeV. We analyzed only events in which Nch ≥ 4. Among them, the number of events featuring one or more neutral pions was 83%. The mean multiplicity of charged particles in an event was $\langle Nch \rangle = 6.0$. The mean multiplicity of neutral pions was $\langle N_0 \rangle = 2.3$. The mean multiplicity of all photons was $\langle N\gamma \rangle = 4.3$, their fraction from neutral pion decays being 95%—that is, almost all photons in an event originated from neutral-pion decays. Our simulation revealed that the laboratory energy of a neutral pion must be higher than 1 GeV for both photons from its decay to find their way to the DEGA aperture. Only 37% of all pions generate a signal in DEGA; for half of them, both photons from neutral pion decay hit the detector, while, for the other half, only one does this.

Fig. 2 illustrates the behavior of the number of neutral pions as a function of Nγ in DEGA. One can see that, in an individual event, it is impossible to determine precisely the total number of neutral pions (Fig. 2a). One can only find the probability with which some number N0 corresponds to the number Nγ of photons that hit DEGA. From our analysis, we derived coefficients that relate the numbers of events Nev(Nγ,Nch) and Nev(N0,Nch) and which we use in the following to find fluctuations of the number of neutral pions. It is important that the mean value $<N_0>$ depends linearly on the number Nγ (see Fig. 2b).

Figure 2c shows the multiplicity distribution of all neutral pions and photons in DEGA. Fig. 3 illustrates the results obtained from our Monte Carlo (MC) simulation of the dependence of the mean values $<n_0>$ and $<n_\gamma>$, the respective standard deviations σ, and the parameter ω ($\omega = \sigma_2 N_{tot}/<n>$) on the total number of particles, N_{tot}, for MC events. Over the entire range of Ntot, the parameter ω decreases for photons, but it remains virtually invariant for pions. (i) A cluster (3 × 3) should contain not less than two channels in which the signal is above the threshold equal to ten counts of the analog-to-digital converter (ADC) used. In the absence of signals in channels neighboring the central one because to the presence of uninvolved channels or because of a signal below the threshold, one corrects the total shower energy. It should not exceed 50 GeV.

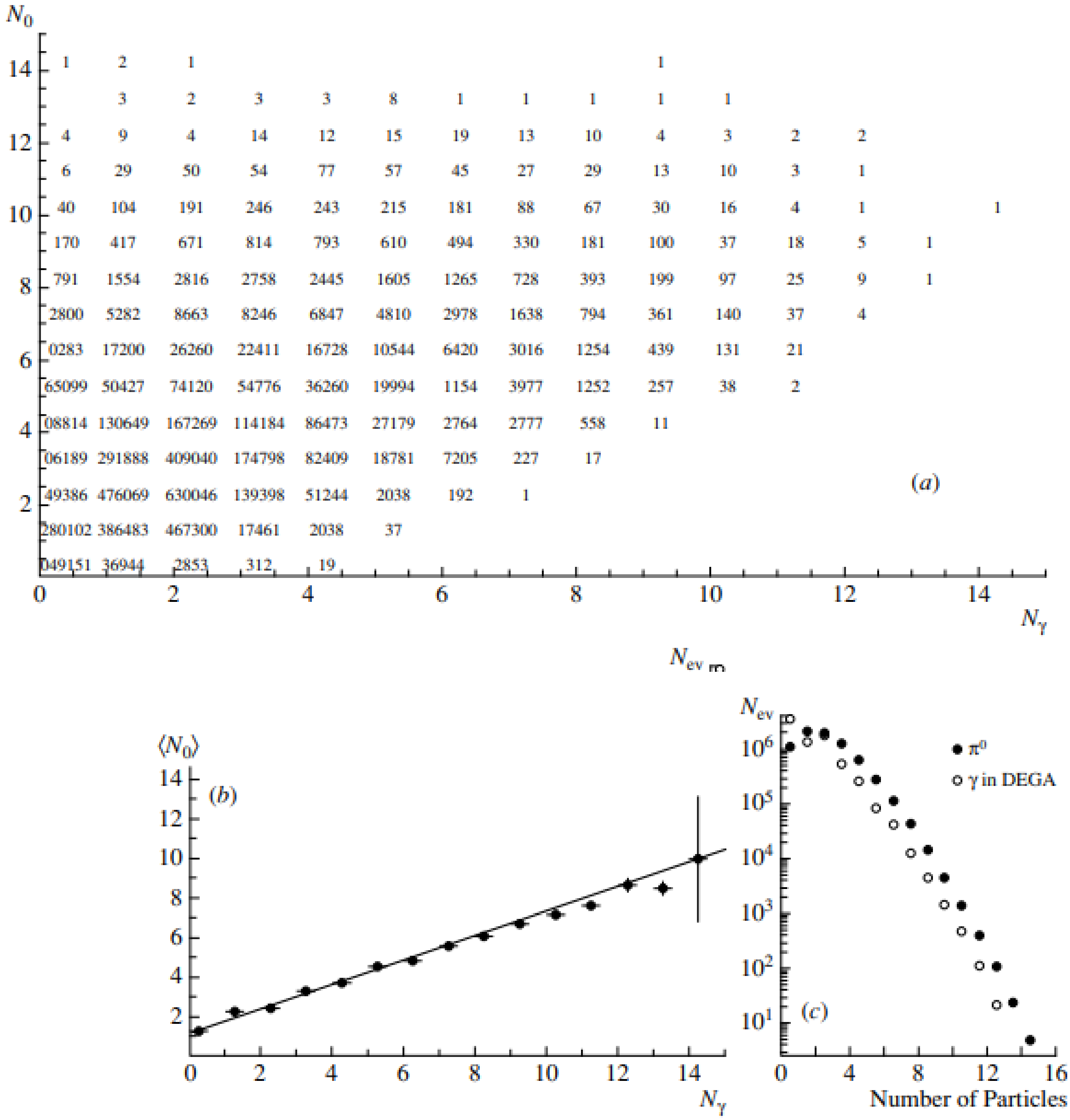

Fig. 2. (a) Number of π^0-mesons, N_0, in an event as a function of the number of photons, N_γ, in the photon detector (DEGA— that is, DEtector of GAmmas); (b) $<N_0>$ as a function N_γ; and (c) multiplicity distribution for all π0 and γ in DEGA.

2. MEASUREMENT OF NEUTRAL-PION FLUCTUATIONS

It was shown by simulation that the number of photons detected in DEGA depends linearly on the mean multiplicity of neutral pions in an event (see Fig. 2b). In order to reconstruct the number of events involving neutral pions, we employ the $Nev(N_\gamma,N_0)$ two□dimensional distributions for Monte Carlo events (see Fig. 2a). For the sake of convenience, we introduced the notation $i = N_\gamma$ and $j = N_0$. From the $Nev(N_\gamma,N_0) = Nev(i,j)$ two-dimensional distri□bution, we can obtain, for each value of N_{ch}, the matrix of coefficients $c_{ij} = Nev(i,j)/Nev(i)$, where $Nev(i) = \sum j\ Nev(i,j)$. Further, the numbers of events $Nev(N_\gamma,N_{ch})$ are decomposed into the sum of events in which N_0,$Nev(i,j) = c_{ij}Nev(i)$ takes different values at N_{ch} = const. For c_{ij} , the following normalization condition holds: $\sum c_{ij} = 1$. The resulting sum $Nev(j) = \sum i\ Nev(i,j)$ is the number of events that is similar to the number $Nev(N_\gamma,N_{tot})$ at N_{ch} = fix, but, now, for neutral pions. A simulation with the aid of the PYTHIA5.6 code makes it possible to obtain the coefficients only for values satisfying the conditions $N_\gamma \leq 10$ and $N_{ch} \leq 14$. In order to continue reconstructing the numbers of events, the regularities that are observed for the coefficients c_{ij} were used for values in the regions of $N_\gamma > 10$ and $N_{ch} > 14$.

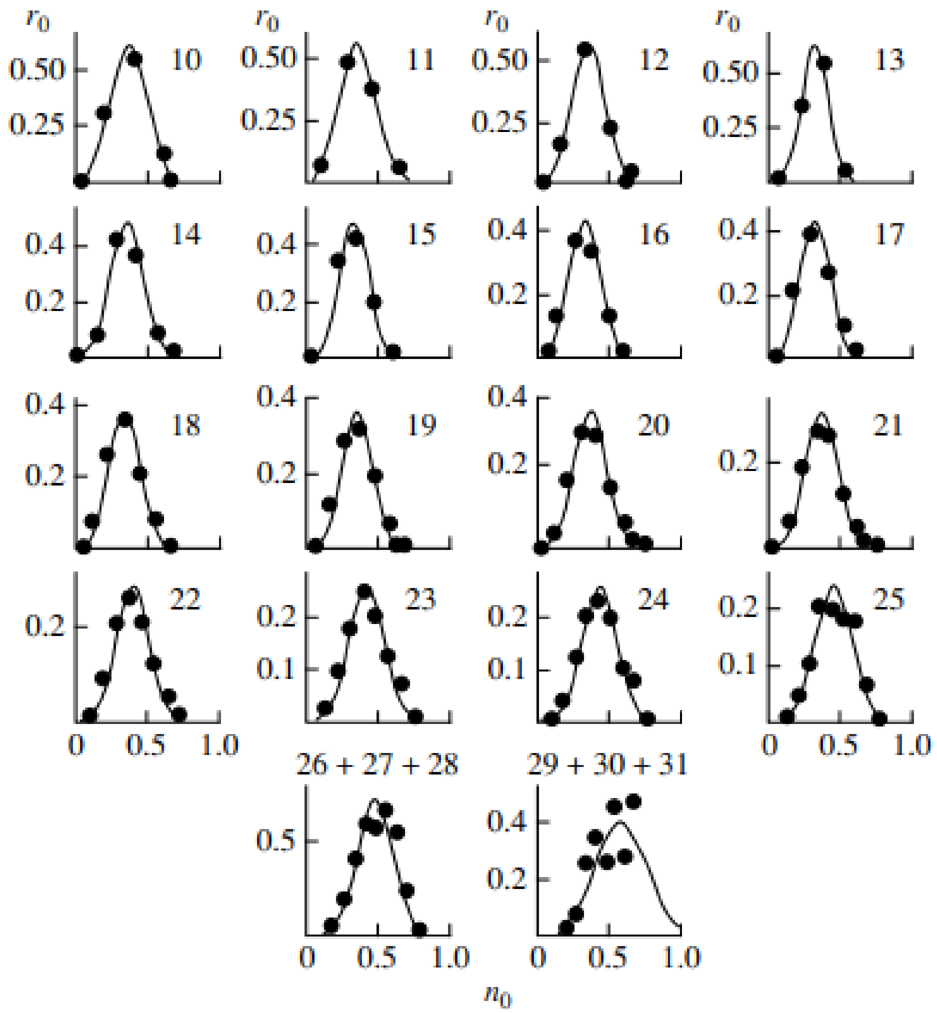

Fig.3 Distribution of the number of neutral pions for various values of Ntot (indicated in the figure)

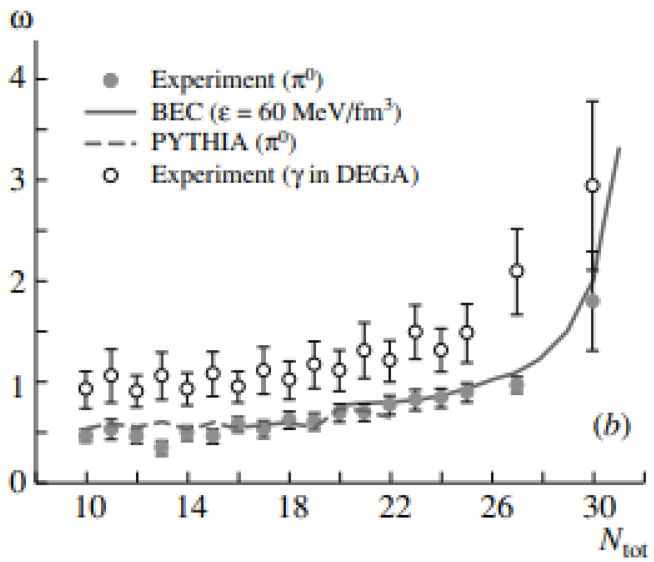

Fig. 4 ω measured for neutral pions and photons in DEGA. For neutral pions, $N_{tot} = N_{ch} + N_0$, while, for photons, $N_{tot} = N_{ch} + N_\gamma$.

Required skills

Good knowledge of C++ programming language and the ROOT software

(http://root.cern.ch) is greeted. Students it is proposed to take part to carry out at the

Based on the first and second parts of the previous practices Students it is proposed to take part to carry out the following themes of project:

1. Getting of multiplicity distributions of neutral pions from SVD-data. The description of multiplicity distribution for pi-mesons and calculation of their digital characteristics (mean value, variance, second correlative moment).

2. The calculation of the scaled variance from SVD-Data.

3. Application of the model to the description another available data from bubble chambers.

4. The inclusion in the model of the gluonic branching and comparison with data.

References:

1. **Begun V.V. and Gorenstein M.I. Bose-Einstein condensation of pions in high multiplicity events. Phys. Lett. B 653, N2-4, 190-195, 2007.**

2. **Begun V.V. and Gorenstein M.I. Bose-Einstein condensation in the relativ-istic pion gas: Thermodynamic limit and finite size effects. Phys.Rev. C77 N6 (2008) 064903.**
3. **Csorgo T. and Zimany J. Analytic Solution of the pion-Laser model. Phys.Rev.Lett.80, N5, 916-919, 1998. 117 Lednicky R. et al. Multiboson effects in multiparticle production. Phys.Rev.C61, 034901, 2000 (19p.). Kokoulina, Elena. Neutral Pion Fluctuations in pp Collisions at 50 GeV by SVD-2, Progress of Theoretical Physics Supplement. 193, 306-309, 2012.**
4. **Kokoulina, Elena, Kutov Andrey, Kalyada Andrey, Salyanko Ruslan. The evidence for the pion condensate formation in pp interactions at U-70, Proceedings of Science, Изд:SISSA, 1-8, 2013.**

The number of participating students is 1-4.

The project supervisors: Prof. Elena Kokoulina (Head of the hadron interaction group). Baldin and Veksler Laboratory of High Energy Physics.

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