CORRELATIONS AND FLUCTUATIONS OF PIONS AT THE LHC*

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The intriguing possibility of Bose–Einstein condensation of pions at the LHC is examined with the use of higher order moments of the multiplicity distribution. The scaled variance, skewness and kurtosis are calculated for the pion system. The obtained results show that the normalized kurtosis has a significant increase for the case of the pion condensation.

1. Introduction

The LHC data on mean particle multiplicities [1] demand that the temperature at the freeze-out is surprisingly small [2, 3]. The best fit in the standard hadron gas model still gives three sigma deviation for protons [3]. The experimentally measured pion spectra at the LHC are about 25–50% higher at low transverse momenta, $p_{\mathrm{T}} < 200$ MeV, than the prediction of the existing models [1, 4], which worked very well at RHIC. There are several ways to explain these deviations [2, 5, 6], which one may group to the equilibrium and the non-equilibrium scenarios, see [7]. The chemical non-equilibrium allows to reproduce not only the mean multiplicities, but also the spectra of pions, protons and light strange particles, including short-living K^* and long-living ϕ mesons [6]. The source of the non-equilibrium could be the overcooling of the fireball [8], or gluon and then pion condensation at the LHC [9]. The ALICE Collaboration reports a large coherent emission of pions from multi-pion correlation studies [10]. The non-equilibrium parameters obtained in our analysis require that about 5% of pions are in the Bose–Einstein condensate (BEC) [11]. The spectra are not sensitive enough

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to judge about the existence of BEC, see Fig. 1, left, from Ref. [11]. However, multiplicity fluctuations are infinite at BEC in an infinite system [12]. The fireball, that is created in Pb+Pb at the LHC, may be large enough to produce the fluctuations that can be detected.
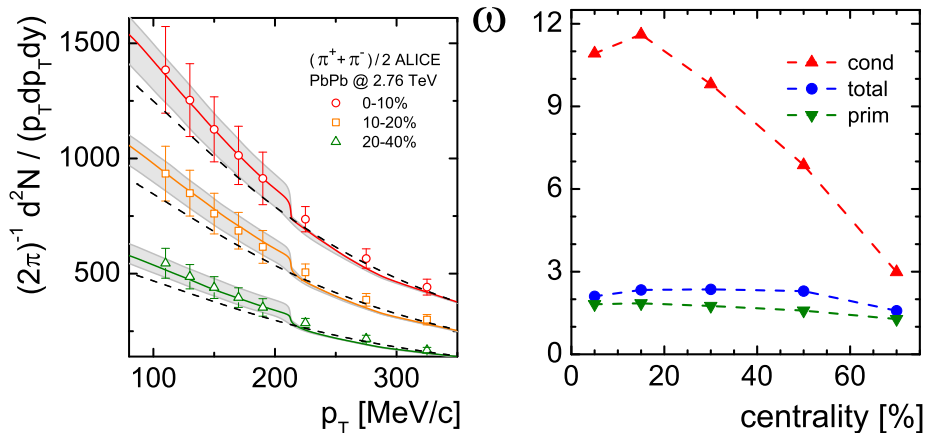

Fig. 1. Left: The p_T spectra of charged pions in Pb+Pb collisions with different centralities at the LHC. The dots correspond to the data, the dashed line — to the equilibrium, solid line — non-equilibrium with the condensate, the grey area — to the 10% deviation from the best fit, see [11] for details. Right: Scaled variance for positively or negatively charged pions as the function of centrality for the particles only from the condensate with $p = 0$, cond., for non-condensate primary particles $p \neq 0$, prim., and for the total number of primary particles, $p \geq 0$, total.

2. Pion fluctuations

The fluctuations of primary pions can be calculated analytically, using the thermodynamic parameters obtained in [11, 13]. Fluctuations of any order of $\langle (\Delta N)^k \rangle = \langle (N - \langle N \rangle)^k \rangle$ can be expressed as the sum over the momentum levels $\sum_p$ of the fluctuations on the individual levels $\langle n_p \rangle$

$$\left\langle (\Delta N)^k \right\rangle = \sum_p \left(c_1 \langle n_p \rangle^1 + c_2 \langle n_p \rangle^2 + \ldots + c_k \langle n_p \rangle^k \right) , \qquad (1)$$

where the coefficients c_i can be straightforwardly calculated for any order of k for primary pions [7]. The sum $\sum_p$ can be replaced by the integral $(2\pi^2)^{-1} V \int_0^\infty p^2 dp$ in the infinite volume limit, $V \to \infty$, only if there is no BEC. Otherwise, at least the condensate level should be taken into account [14]. As a thought experiment, one can separately calculate fluctuations on the $p = 0$ level, on $p \neq 0$ levels, and the fluctuations from all $p \geq 0$

levels. These cases are correspondingly labelled as cond., prim., and total in Figs. 1 and 2. One can see that the signal can be very large[1], and it is larger for higher order fluctuations. The fluctuations on the $p = 0$ level are the order of magnitude larger than the fluctuations on the $p \neq 0$ levels. The total fluctuations of primary pions are in between, closer to the $p \neq 0$ case.
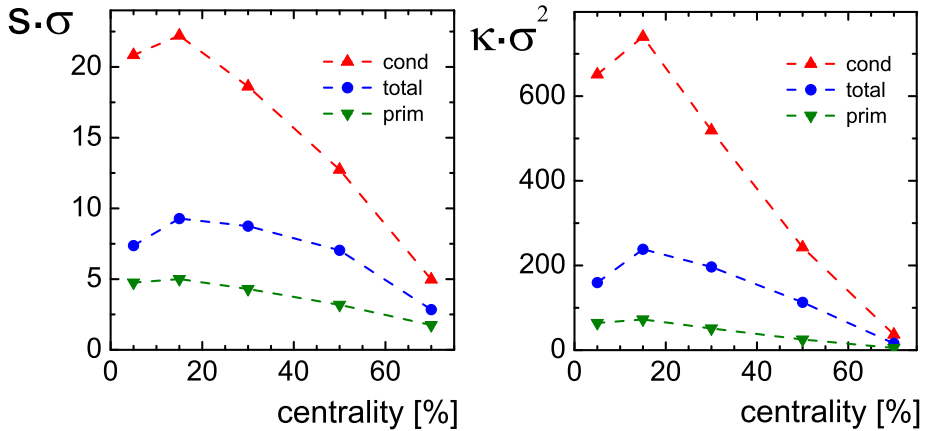

Fig. 2. The same as Fig. 1, right, for normalized skewness (left) and normalized kurtosis (right).

3. Conclusions

In order to increase the possible signal of BEC, one may try to find a way to select more particles from the condensate. The easiest way to do it, is to impose a momentum cut, because pions from the condensate receive a finite momentum boost due to movement with the hypersurface[2] [11]. A realistic estimate should also include the contribution from resonance decays, see [7].

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[1] For random emission of particles, one has Poisson distribution for which $\omega = S\,\sigma = \kappa\,\sigma^2 = 1$. For large number of particles, Poisson is often replaced by Gauss distribution, which similarly has $\omega = 1$, but $S\,\sigma = \kappa\,\sigma^2 = 0$.

[2] The maximal allowed momentum for particles from the condensate is shown as the step in Fig. 1, left. The step itself is the artefact of the approximation that we have no excited levels above the condensate. An inclusion of a few of them would produce a few steps and a smoother line.

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