Fluctuations of Voids in pp Collisions at LHC Energies

Shakeel Ahmad, Shaista Khan and Anisa Khatun
Department of Physics, Aligarh Muslim University, Aligarh-202002, INDIA

Studying the particle production in pp collisions at 7.0 TeV in the frame work of EPOS, it has been pointed out[1] that QGP formation is possible in pp collisions if the collision energy is high enough. Measurement and analysis of the pp data at LHC energies have been advocated to test the QGP formation experimentally. A system undergoing 2^{nd} order phase transition is envisaged to exhibit large fluctuations and long-range correlations. If the quark-hadron phase transition is of 2^{nd} order then large fluctuations are expected in the hadron multiplicity not only from event-to-event but also from one region to the other in the geometrical space in which emission of hadrons occurs. Such local hadron density fluctuations would give rise to the formation of spatial patterns involving clusters of hadrons and regions of no hadrons between clusters[2, 3]. These non-hadronic regions, often referred to as the 'voids', may, therefore, provide a significant insight into the fluctuations associated with the critical behavior of QGP phase transition. Hwa and Zhang have suggested a method to study the fluctuations in terms of voids. It is, therefore, considered worthwhile to undertake a systematic study of fluctuations of voids in pp collisions at LHC energies by analyzing the data simulated using Monte Carlo generator PYTHIA. Event samples (each with 10^6 events) corresponding to 0.9, 2.76, 7.0 and 13.0 TeV are simulated using the code PYTHIA-8212.

The fluctuations of spatial pattern using voids are studied in terms of the distributions of normalized G_q moments calculated on ebe basis as $G_q = g_q/g_1^q$, where $g_q(=\frac{1}{m}\sum_{k=1}^{m} {x_k}^q)$ is the moment of order q for each configuration; x_k is the fraction of bins that a k^{th} void occupies. A detailed description of the method of analysis may be found in refs.3,4. Pseudorapidity, (η) space is divided into M bins of equal width $\delta(= 1/\mathrm{M})$. The occurrence of voids are looked into and the size of voids are determined. Void fractions, x_k, moments, g_q and normalized moments G_q are calculated for q = 2-5 by varying M from 16 to 96. Variations of $\ln\langle Gq\rangle$ with lnM for pp data at 13.0 TeV are displayed in Fig.1. It is observed that $\ln\langle Gq\rangle$ increases with lnM. The lines in the figure are due to the best fits to the data of the form: $\ln\langle Gq\rangle = a_1 + b_1M + c_1M^2$. Similar trends of variations of $\ln\langle Gq\rangle$ with lnM are observed for the data at other energies. These observations reveal that variations of $\ln\langle Gq\rangle$ with lnM are quadratic in nature. A linear increase of $\ln\langle Gq\rangle$ with lnM for 340 GeV/c π^--AgBr and 200A GeV/c S-AgBr collisions has, however been observed by Mondal et al.[5]. Hwa and Zhang[4] have also suggested such dependence to be linear. Data points shown in Fig.1 for M=32 and above also indicate a linear increase of $\ln\langle Gq\rangle$ with lnM and suggest a power law behaviour of the form $\langle Gq\rangle \sim M^{\gamma_q}$. Such a scaling behaviour may be interpreted as an indication for the presence of voids of all sizes. The values of the parameter γ_q estimated from the best fits to the data (for M > 32). Since G_q moments of various order are highly correlated γ_q should depend on q in some simple way. A linear increase of γ_q with q is clearly reflected from Fig.2. It may also be noted from the figure that for a given value of q, γ_q are almost energy independent. The lines in the figure represent the best fits to the data of the form, $\gamma_q = c_0 + cq$. The values of slope parameter 'c' is presented in Table 1; the parameter c is regarded as the numeric description of the scaling behaviour of voids.

The shape of G_q distribution would characterize the nature of ebe fluctuations in the distribution. A moment which quantifies the degree of these fluctuations is expressed as $C_{p,q} = \frac{1}{N}\sum_{e=1}^{N}(G_q^{(e)})^p$. The derivative of $C_{p,q}$ at $p = 1$, $S_q = \frac{d}{dp}C_{p,q}\Big|_{p=1} = < G_q ln G_q >$ is envisaged to yield maximum information regarding the ebe fluctuations. Variations of

S_q with lnM are examined which, like $\ln\langle Gq\rangle$ vs lnM plots, indicates the presence of a power law behaviour of the type $S_q \sim M^{\sigma_q}$ for M≥32 (not shown).

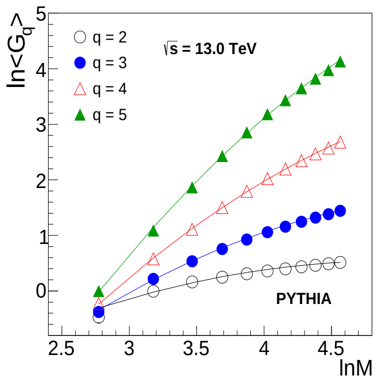

FIG. 1: Dependence of $\ln\langle Gq\rangle$ on lnM for the PYTHIA events at 13.0 TeV energy.

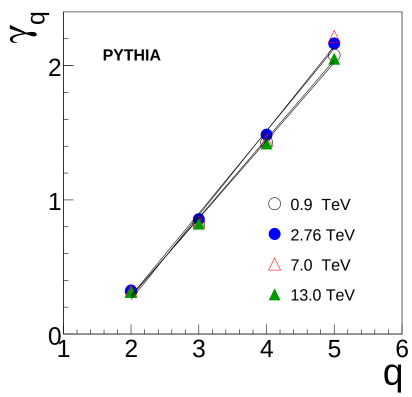

FIG. 2: Variations of γ_q with q for the PYTHIA events at $\sqrt{s} = 0.9$, 2.76, 7.0 and 13.0 TeV energies.

Values of $\sigma_q$for various data sets are estimated and dependence of σ_q on q are looked into. It is observed that variations of σ_q with q are of the form $\sigma_q = s_0 + sq$. The values of s evaluated for all the data sets are presented in Table 1. As a qualitative signature of 2^{nd} order quark-hadron phase transition, the values of c and s are predicted[4] to lie in the ranges 0.73-0.96 and 0.7-0.9 respectively. However, the values of these parameters obtained in the present study are much smaller suggesting that no such phase transition occurs at the energies considered in the present study.

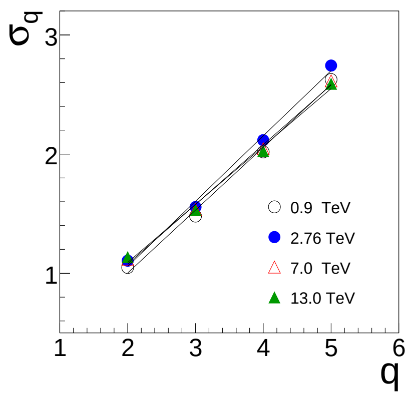

FIG. 3: Variations of σ_q with q at $\sqrt{s} = 0.9$, 2.76, 7.0 and 13.0 TeV energies.

Table 1: Values of parameters c and s.

	$\sqrt{s}$ (TeV)			
	0.9	2.76	7.0	13.0
c	0.536±0.001	0.573±0.001	0.580±0.001	0.545±0.001
s	0.494±0.002	0.511±0.002	0.473±0.002	0.456±0.002

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