PRAMANA — journal of physics
© Indian Academy of Sciences
Vol. 62, No. 3
March 2004
pp. 623–625

Fluctuations as a signal of quark-gluon plasma: Present experimental results

TAPAN K NAYAK (for the WA98 Collaboration)
Variable Energy Cyclotron Centre, 1/AF Bidhan Nagar, Kolkata 700 064, India

Keywords. Quark-gluon plasma; fluctuations, disoriented chiral condensates.

One of the spectacular predictions of quantum chromodynamics (QCD) is that at extremely high density and/or temperature the hadronic matter undergoes a phase transition to quark-gluon plasma (QGP). Heavy-ion collisions at relativistic energies offer a unique environment for the creation and study of the QGP phase in the laboratory. A characteristic feature of this process is that the system experiences large event-by-event fluctuations in thermodynamic quantities such as temperature and entropy. These can be studied by the experimentally observed quantities such as fluctuations of mean transverse momentum and multiplicity. Furthermore, study of the relative fluctuations of charged to neutral particles provides a measure of the formation of disoriented chiral condensates (DCC), which is a direct consequence of chiral phase transition. We give the current status of these results.

Multiplicities of photons and charged particles have been measured in 158·A GeV Pb+Pb reactions in the WA98 experimental set-up at the CERN-SPS. Photon measurement is performed by a pre-shower photon multiplicity detector (PMD) and the charged particles are measured by a silicon pad detector. The centrality of the interaction is determined by the total transverse energy (E_{T}) measured in the mid-rapidity calorimeter, and are expressed as fractions of the measured minimum bias cross-section. Multiplicity distributions of photons and charged particles show near-perfect Gaussian for narrow centrality bins (viz., 0–2%, 2–4% , . . . , 58–60%, etc.) over the full centrality range. The widths of these distributions contain information about the nuclear geometry (indicative of statistical fluctuation) and details of nuclear reaction mechanism (dynamical fluctuation).

For a variable, X, whose distribution is a Gaussian, the amount of fluctuation may be defined as: $\omega_X = \sigma_X^2/\langle X\rangle$, where σ_x and $\langle X\rangle$ denote the variance and mean value of X. Relative multiplicity fluctuations are expressed in terms of $\omega_X/N_{\mathrm{part}}$, where N_{part} is the number of participants. Figure 1 gives the experimental values of relative fluctuations for photons and charged particles. We consider a participant model [1] and compare the results of the calculations with those obtained from the data. A reasonable agreement of the data has been obtained with the participant model as well as VENUS event generator indicating the absence of any dynamical fluctuations [1].

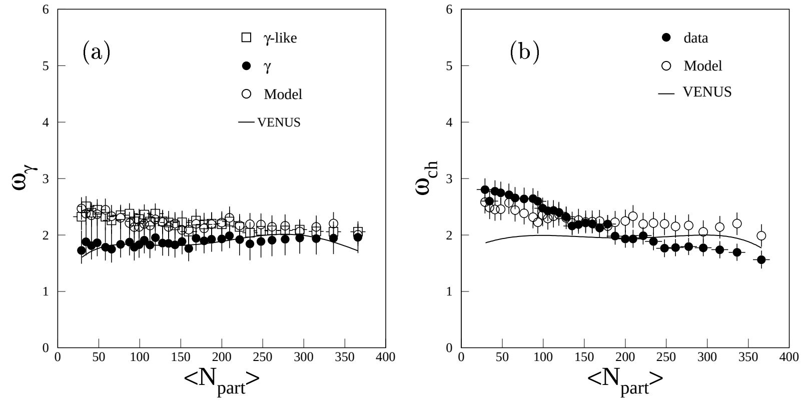

Figure 1. The relative fluctuations of (**a**) photons and (**b**) the charged particles compared to calculations from a participant model and VENUS.

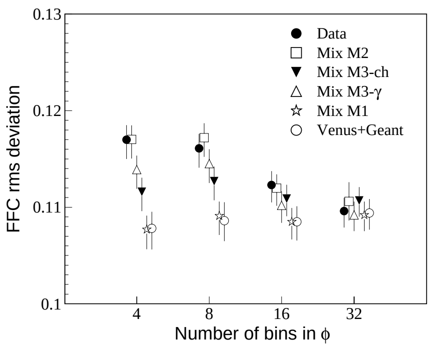

Figure 2. The root mean square (rms) deviations of the wavelet distribution for various divisions in the azimuthal angle. Errors are due to both statistical and systematic sources.

Event-by-event charged to neutral fluctuations have been studied in terms of global event characterisation and in localised $(\eta - \phi)$ domains. No event with large charged-neutral fluctuations have been observed in the global analysis [2]. Theoretical calculations indicate that the DCC domains would be localised in $(\eta - \phi)$ phase space. We have studied this by using the correlation method and a more sophisticated wavelet analysis. In both the cases the available phase space is divided into smaller azimuthal bins and the derived quantities, such as correlation coefficients and wavelet coefficients, are plotted for varying number of bins in the azimuth. The rms deviations of these coefficients are compared to those obtained from mixed events. Figure 2 shows these distributions for the case of wavelet coefficients. Mixed events provide the most unambiguous means to probe any new physics. Four different kinds of mixed events are generated from the data, and their behaviours are understood using DCC model. Comparison of data to mixed events provides model-independent evidence for non-statistical fluctuations at the 3σ level for ϕ intervals greater than $45°$. The origin of the non-statistical fluctuations is

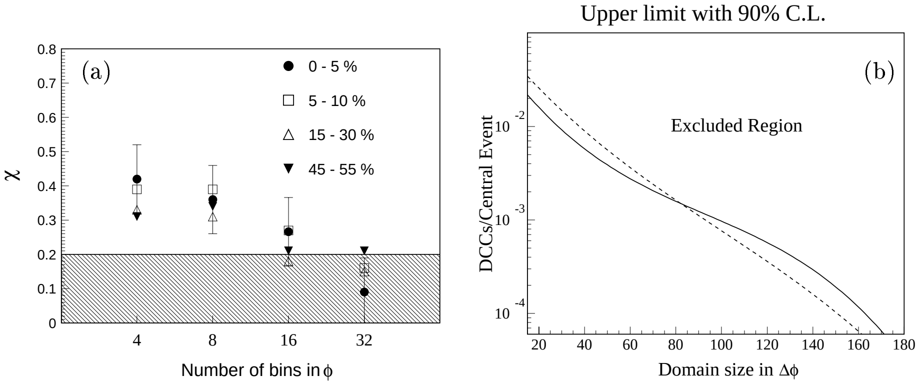

Figure 3. (**a**) The fluctuation strength parameter for the four centrality classes. (**b**) The 90% confidence level upper limit on DCC production for central Pb+Pb collision at 158 A·GeV/c as a function of the DCC domain size in azimuthal angle.

attributed to the individual fluctuations in photons and charged particles, but not due to any correlation fluctuation.

Centrality dependence of N_γ vs. $N_{\rm ch}$ fluctuations has been studied for four centrality classes [3]. The results are quantified using a strength parameter, defined by, $\chi = \sqrt{(s^2 - s_1^2)}/s_1$, where s_1 and s correspond to the rms deviations of the wavelet distributions of the M1 mixed events and real data, respectively. This is plotted in figure 3a as a function of the number of bins in azimuth for the four centrality bins. The shaded region gives the limit of detection. The result shows that the strength of the fluctuation decreases as the number of bins in ϕ increases, and the strength of the signal decreases with decreasing centrality.

Finally, upper limits on the probability of DCC-like fluctuations at the 90% confidence level have been calculated and shown in figure 3b for two most central event classes in terms of DCC domain size and DCC probability. The solid line in the figure corresponds to data from the top 5% and dashed line to top 5–10% of the minimum bias cross-section.

In summary, a detailed study of centrality and rapidity acceptance dependence of multiplicity fluctuations, carried out at the CERN-SPS energies, shows absence of any significant non-statistical multiplicity fluctuations. A model independent study of event-by-event correlated fluctuations (DCC-type) using a robust mixed event technique reveals the absence of significant DCC-like fluctuations. Using the results from the data, mixed events, and a DCC model, an upper limit on DCC production at SPS energies has been set. We are looking forward to results from RHIC which are expected within the next few years.

References

[1] WA98 Collaborations: M M Aggarwal *et al*, *Phys. Rev.* **C65**, 054912 (2002)
[2] WA98 Collaborations: M M Aggarwal *et al*, *Phys. Lett.* **B420**, 169 (1998)
[3] WA98 Collaborations: M M Aggarwal *et al*, *Phys. Rev.* **C67**, 044901 (2003)