Review of event-by-event fluctuations in heavy ion collisions[1]

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The study and analysis of fluctuations are an essential method to characterize a physical system. In general, one can distinguish between several classes of fluctuations. On the most fundamental level there are quantum fluctuations, which arise if the specific observable does not commute with the Hamiltonian of the system under consideration. These fluctuations probably play less a role for the physics of heavy ion collisions. Second, there are "dynamical" fluctuations reflecting the dynamics and responses of the system. They help to characterize the properties of the bulk (semi-classical) description of the system. Examples are density fluctuations, which are controlled by the compressibility of the system. Finally, there are "trivial" fluctuations induced by the measurement process itself, such as finite number statistics etc. These need to be understood, controlled and subtracted in order to access the dynamical fluctuations which tell as about the properties of the system.

Fluctuations are also closely related to phase transitions. The well known phenomenon of critical opalescence is a result of fluctuations at all length scales due to a second order phase transition. First order transitions, on the other hand, give rise to bubble formation, i.e. density fluctuations at the extreme. Considering the richness of the QCD phase-diagram the study of fluctuations in heavy ions physics should lead to a rich set of phenomena.

The most efficient way to address fluctuations of a system created in a heavy ion collision is via the study of event-by-event (E-by-E) fluctuations, where a given observable is measured on an event-by-event basis and the fluctuations are studied over the ensemble of the events. In most cases (namely when the fluctuations are Gaussian) this analysis is equivalent to the measurement of two particle correlations over the same region of acceptance Consequently, fluctuations tell us about the 2-point functions of the system, which in turn determine the response of the system to external perturbations.

In the framework of statistical physics, which appears to describe the bulk properties of heavy ion collisions up to RHIC energies, fluctuations measure the susceptibilities of the system. These susceptibilities also determine the response of the system to external forces. For example, by measuring fluctuations of the net electric charge in a given rapidity interval, one obtains information on how this (sub)system would respond to applying an external (static) electric field. In other words, by measuring fluctuations one gains access to the same fundamental properties of the system as "table top" experiments dealing with macroscopic probes. In the later case, of course, fluctuation measurements would be impossible.

In addition, the study of fluctuations may reveal information beyond its thermodynamic properties. If the system expands, fluctuations may be frozen in early and thus tell us about the properties of the system prior to its thermal freeze out. A well known example is the fluctuations in the cosmic microwave background radiation, as first observed by COBE.

The field of event-by-event fluctuations is relatively new to heavy ion physics and ideas and approaches are just being developed. So far, most of the analysis has concentrated on transverse momentum and the net charge fluctuations.

Transverse momentum fluctuations should be sensitive to temperature/energy fluctuations. These in turn provide a measure of the heat capacity of the system Since the QCD phase transition is associated with a maximum of the specific heat, the temperature fluctuations should exhibit a minimum in the excitation function. It has also been argued that these fluctuations may provide a signal for the long range fluctuations associated with the tri-critical point of the QCD phase diagram. In the vicinity of the critical point the transverse momentum fluctuations should increase, leading to a maximum of the fluctuations in the excitation function.

Charge fluctuations on the other hand, are sensitive to the fractional charges carried by the quarks. Therefore, if an equilibrated partonic phase has been reached in these collisions, the charge fluctuations per entropy would be about a factor of 2 to 3 smaller than in an hadronic scenario.

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