Some remarks on the statistical model of heavy ion collisions[1]

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The statistical (thermal) model works very well in describing/predicting measured ratios of particle abundances in ultra-relativistic heavy ion collisions. But even more remarkably, it works also for particle ratios measured in high energy proton-proton and even e^+e^- collisions. In this contribution we will take the success of the statistical model as given and rather ask ourselves what can be learned from that.

In general a statistical description of a physical system is appropriate if the system has many degrees of freedom but is characterized only by few observables/measurements. This is e.g. the case in a thermal system, which is characterized only by the constants of motion, namely the energy (and momentum), volume and all the conserved particle numbers. (Of course in a canonical or grand canonical formulation, the energy and/or particles number are replaced by the conjugate variables temperature and chemical potential).

But not only a thermal system meets the requirements for a statistical description. Let us consider a high energy collision which produces many particles in the final state. If we are only interested in the number of pions produced, we constrain the final state very little, and thus statistical methods should be applicable. This is the idea of the statistical theory of particle production first invented by Fermi.

Now suppose the statistical model of Fermi applies for particle production in high energy collisions. Does that mean that we are dealing with a thermal system in the sense of Boltzmann, where particle collisions keep the system in a state of equilibrium? This is very unlikely in case of e^+e^- collisions, where the produced particles hardly have a chance to re-interact. And actually explicit measurements show no indication for interaction among the partons from different jets in e^+e^- collisions. Therefore, “statistical” does not always mean “thermodynamic” in the sense that one is dealing with matter in thermal equilibrium, and that one can define a pressure and an equation of state. Statistical may simply mean phase-space dominance and the ”temperatures” and ”chemical” potentials are nothing but Lagrange multipliers characterizing the phase-space integral.

This, however, may be different in a heavy ion collision. There one would naively expect (this is actually the main motivation for such complicated experiments) that the initially produced particles do re-interact on the partonic and/or hadronic level. The question then is, how to experimentally establish that a sufficient amount of re-interaction has taken place and that matter in the Boltzmann sense has been formed. One possibility is to investigate the diffusion of conserved charges, i.e. to which extent the local conservation of any charge, such as strangeness is still required in order to describe the data.

Finally, the most important question, is what the statistical variables extracted from particle ratios can tell us about the phase structure of QCD. Even if they resemble more than just Lagrange multipliers, can they tell us about a phase boundary. How is this possible, if they are extracted using free hadronic properties.

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