RAPIDITY SPECTRA FOR NET PROTON PRODUCTION AT LHC

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Net proton rapidity distributions are calculated, reproduce very well data obtained at AGS, SPS, RHIC and predict results for the LHC experiment. Presence of non-ideal plasma effects due to strongly coupled plasma in the early stage of relativistic heavy-ion collisions is investigated in the framework of non-conventional statistical mechanics.

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In the presence of long–range forces or in irreversible processes related to microscopic long–time memory effects, the extensive thermodynamics, based on the conventional Boltzmann–Gibbs thermostatistics, is no longer correct. The Tsallis generalized thermostatistics is based upon the following generalization of the entropy

\[ S_q = \frac{1}{q-1} \sum p_i (1 - p_i^{q-1}) , \]

where \( p_k \) is the probability of a given microstate among \( W \) different ones and \( q \) is a fixed real parameter. The deformation parameter \( q \) measures the degree of nonextensivity of the theory.

The non-linear Fokker-Planck equation in the rapidity space \( y \) can be written as

\[ \frac{\partial}{\partial t} [f(y, m, t)] = \frac{\partial}{\partial y} \left[ J(y, m) [f(y, m, t)] + D \frac{\partial}{\partial y} [f(y, m, t)]^\mu \right] , \]

where \( D \) is diffusion and \( J \) is drift coefficient. For linear drift, the time dependent solution of the above equation is a Tsallis distribution with \( \mu = 2 - q \) and that a value of \( q \neq 1 \) implies anomalous diffusion. The choice of the diffusion and the drift coefficients plays a crucial role in the solution of the above non-linear Fokker-Planck equation and influences the time evolution of the system and its equilibrium distribution. Generalized to the relativistic case the standard expressions of diffusion and drift coefficients are \( D = \gamma T, \ J(y, m) = \gamma m \sinh(y) \equiv \gamma p_\parallel \), where \( \gamma \) is a common constant.

Out of equilibrium the rapidity distribution at fixed time can be obtained by numerical integration of Eq. (1). The net baryon rapidity distribution \( \frac{dN}{dy}(y, t) = \int \int m^2 \cosh(y) f(y, m, t) dm \), which depends on the “interaction” time \( \tau_{int} = \gamma t \) and \( q \).
In Fig. 1, the rapidity distribution for the net proton production \((p - \bar{p})\) is compared with the experimental data of RHIC (Au+Au at \(\sqrt{s_{NN}} = 200\) GeV),\(^3\) SPS (Pb+Pb at \(\sqrt{s_{NN}} = 17.3\) GeV)\(^4\) and AGS (Au+Au at \(\sqrt{s_{NN}} = 5\) GeV).\(^5\) The parameters employed for the three curves are: \(q = 1.485\) with \(\tau_{int} = 0.47\) for RHIC, \(q = 1.235\) with \(\tau_{int} = 0.84\) for SPS and \(q = 1.09\) with \(\tau_{int} = 0.95\) for AGS, respectively. Parameters \(q\) and \(\tau_{int}\) are not independent. Indeed, in the non-linear case \((q \neq 1)\) there exists one and only one time \(\tau_{int}\) for which the obtained rapidity spectrum well reproduces the broad experimental shape. On the contrary, for \(q = 1\), no value of \(\tau_{int}\) can be found, which allows to reproduce the data.

Strongly coupled non-ideal plasma is generated at energy densities corresponding to the order of the critical phase transition temperature and in such a regime, in this macroscopic approach, strong deviations from the standard thermostatistics is observed. At much higher energy, on the basis of a linear extrapolation of the \(q\)-value versus the beam rapidity, a suitable \(q\)-value for LHC is calculated \((q = 1.68)\). Fig. 2 shows the expected net proton distributions is evaluated at different \(\tau_{int} \leq 0.4\).

The rapidity spectra were studied from a macroscopic point of view by means of a non-linear kinetic equation which preserves the fluctuation-dissipation theorem by introducing an appropriate relativistic generalization of the drift and diffusion coefficients. Such a generalized evolution equation lies inside the framework of Tsallis’ non-extensive thermostatistics and contains anomalous diffusion effects which are strongly related to the presence of non-Markovian memory interactions and long-range color forces. The behavior of the \(q\)-parameter can be viewed as a phenomenological indication of a strongly coupled QGP plasma phase in the early stages of the collision.

References