The novel scaling of Tsallis parameters from the transverse momentum spectra of charged particles in heavy-ion collisions

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The transverse momentum (p_T) spectra of charged particles measured in Au + Au collisions from the beam energy scan (BES) program, Cu + Cu collisions at $\sqrt{s_{\rm NN}}$=62.4, 200 GeV at the RHIC and Pb + Pb, Xe + Xe collisions at the LHC are investigated in the framework of Tsallis thermodynamics [1]. The theory can describe the experimental data well for all the collision systems, energies and centralities investigated. The collision energy and centrality dependence of the Tsallis distribution parameters, i.e., the temperature T and the nonextensive parameter q, for the A + A collisions are also studied and discussed. A novel scaling between the temperature divided by the natural logarithm of collision energy ($\rm T/ln\sqrt{s}$) and the nonextensive parameter q is presented.

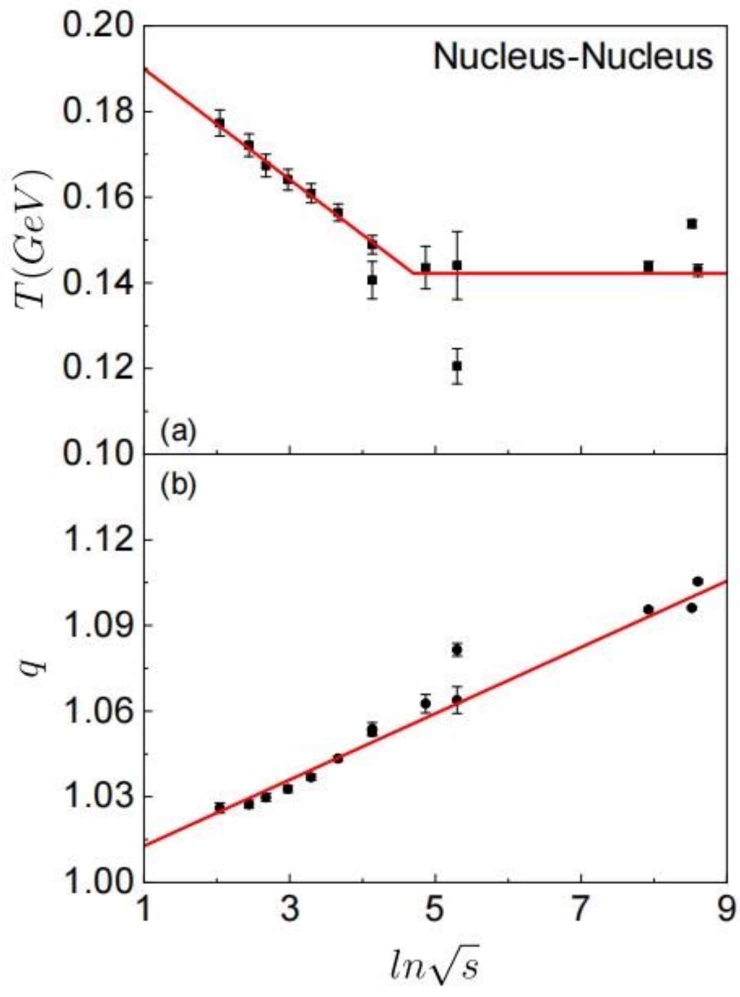

Fig. 1. (Color online) The collision energy dependence of the temperature T and nonextensive parameter q for the collision systems investigated at the most central collisions. See text for the lines.

In Fig. 1, the results of T and q versus collision energy from the RHIC to LHC for the most central collisions are shown. We use $\sqrt{s}$ to denote $\sqrt{s_{NN}}$ in units of GeV, i.e. $\sqrt{s}=\sqrt{s_{NN}}/1$ GeV. Thus, it is a dimensionless variable that is suitable used in an expression like $\ln\sqrt{s}$. For the temperature T, it is observed that a linear decrease from $\sqrt{s_{NN}}$=7.7 GeV to a certain collision energy and then it is approximately constant for the higher collision energies, which is the asymptotic value connected to the Hagedorn temperature, i.e., the pion mass. The lines are drawn to guide the eyes. Unlike the temperature T, the parameter q shows a linear monotonic increasing dependence on the collision energy in the whole energy region investigated. A linear fit gives $q=0.0116\ln\sqrt{s}+1.00116$ shown in the Fig. 1(b). This indicates that the higher the collision energy is, the less the collision system reaches thermal equilibrium during the evolution and the temperature fluctuation is larger. The parameters from the other centralities showing similar behaviors have been observed.

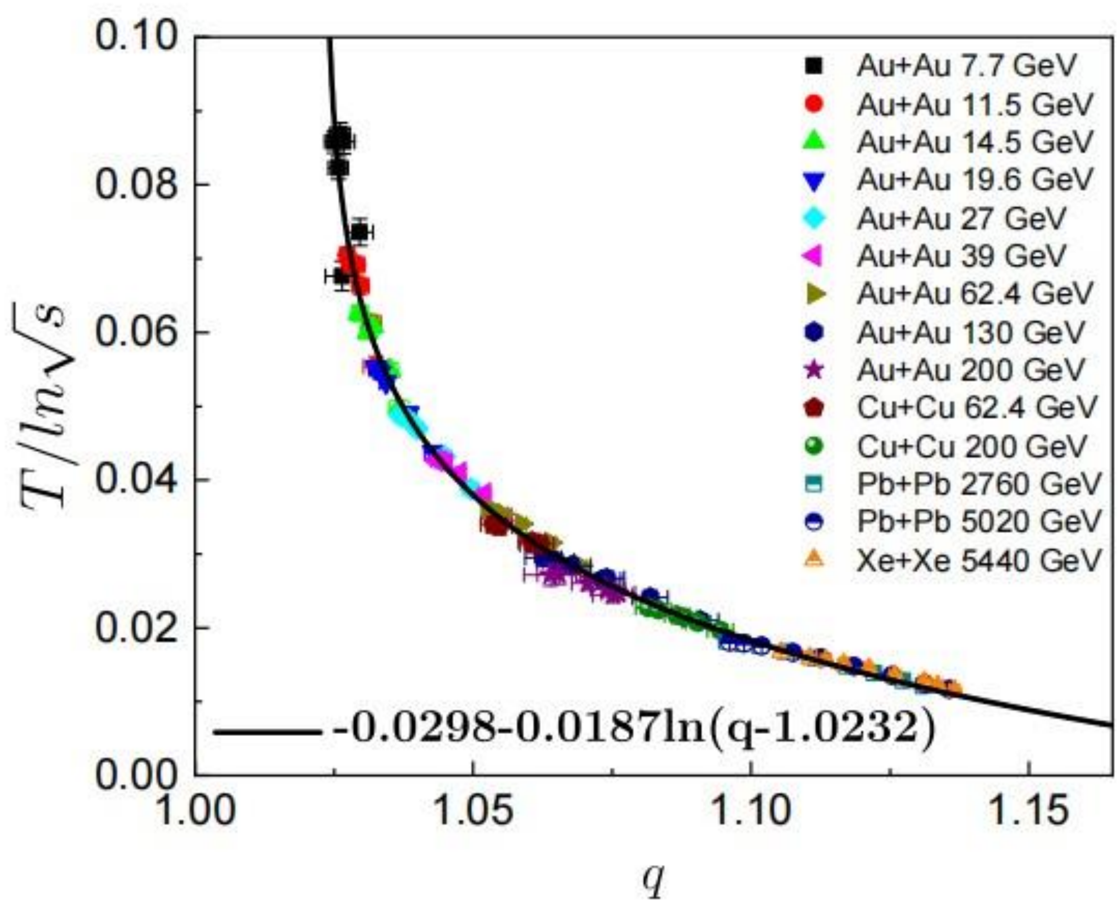

Fig. 2. (Color online) Nonextensive parameter q dependence of the temperature divided by the natural logarithm of collision energy $\mathbf{T/\ln\sqrt{s}}$ in A + A collisions with different centrality. The curve is the fit results and the fit function is indicated in the legend.

In Fig. 2, the results of the novel scaling discovered between the temperature divided by the natural logarithm of collision energy $\mathrm{T}/\ln\sqrt{s}$ and nonextensive parameter q for all the A + A collision systems and centralities investigated is shown. It is clear that all the data points are scaled into one curve.

We are able to fit it with the function indicated in the legend of Figure2. This observed strong scaling indicates that the parameters of Tsallis distribution obtained from the charged particle transverse momentum spectra are not independent of each other but are anticorrelated. It also suggests that further fundamental characteristics of the nonextensive statistics are yet to be studied. The emergence of this scaling maybe attributed to hydrodynamical scaling but further investigations are needed.

[1] J.Q. Tao, W.H. Wu, M. Wang, H. Zheng, W.C. Zhang, L.L. Zhu, and A. Bonasera, Particles **1**, (2022).