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Thermalization of QGP through transverse momentum fluctuation in ultra-central Pb+Pb collision

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We report the first direct evidence of thermalization of the Quark-Gluon Plasma (QGP) formed in ultra-relativistic heavy-ion collision, by studying the fluctuation of mean transverse momentum per particle ($\langle p_t \rangle$) in ultra-central Pb+Pb collision. The recent experimental data from the ATLAS collaboration at the Large Hadron Collider (LHC), provides measurement of variance of $\langle p_t \rangle$ at fixed multiplicity (N_{ch}) and a steep fall of the variance is observed over a narrow range of N_{ch}, for most of the central collision events (Fig. 14 and 15, \href{https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/HION-2021-01/}{ATLAS : HION-2021-01}). Such a behaviour cannot be reproduced by previously existing models, such as HIJING which treats Pb+Pb collisions as a superposition of independent nucleon-nucleon collisions. However, our model results can accurately reproduce the peculiar pattern in the variance of $\langle p_t \rangle$ that is observed by ATLAS. To explain such a novel phenomenon, we argue that at a given multiplicity, the impact parameter (b) fluctuation plays an important role; the transverse momentum per particle increases with the increasing impact parameter. A larger b corresponds to a smaller collision volume resulting in a higher density. In relativistic thermodyanimcs, a higher density corresponds to a higher initial temperature which implies a larger energy per particle leading to a larger $\langle p_t \rangle$. Thus at a fixed N_{ch}, a higher $\langle p_t \rangle$ at a larger b is the effect of the thermalization of the system at a higher temperature. To illustrate this point further, we provide results for Pb+Pb collision from hydrodynamic simulation with TRENTO + MUSIC at b=0 and compare with corresponding HIJING results. From the hydro results, we find a very strong correlation between $\langle p_t \rangle$ and N_{ch} at fixed impact parameter, which is not observed in HIJING where there is no thermalization. The strong correlation is the consequence of the thermalization that is assumed in the hydro simulation.
(R. Samanta, S. Bhatta, J. Jia, M. Luzum and J-Y Ollitrault, \href{https://arxiv.org/pdf/2303.15323.pdf}{arXiv: 2303.15323})

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