Multiplicity, energy and event-shape dependence of freeze-out parameters at the LHC energies

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Introduction

Final-state particles produced in high energy collisions may carry the information about the space-time evolution and the dynamics of the produced system. In such collisions, the phase transition occurs from a deconfined state of quarks and gluons to a phase of hadrons. During the course of hadronization, the surface at which the inelastic collisions among the particles cease is known as chemical freeze-out (CFO) and after this, the surface at which the elastic processes stop and the transverse momentum ($p_{\rm T}$) spectra of final state hadrons are fixed, is known as kinetic freeze-out (KFO). Therefore, analysing the identified particle production in high energy collisions at Relativistic Heavy-ion Collider (RHIC) and the Large Hadron Collider (LHC) reveals the freeze-out information of the produced system. The information about the CFO can be obtained by analysing the hadron yields, whereas analysis of the $p_{\rm T}$-spectra reveals the information about KFO.

Statistical hadronization models are very successful in describing the $p_{\rm T}$-differential and integrated particle yields produced in high energy collisions with few parameters. However the applicability of statistical models for smaller systems can be verified by looking into the multiplicity dependence of particle production. Here, we analyse the $p_{\rm T}$-integrated hadron yields at LHC energies for various collision systems as well as collision energies as a function of charged particle multiplicity in canonical and grand canonical ensembles to get CFO information. Transverse spherocity is an event shape tool to distinguish the jetty events from isotropic ones. This is necessary as the production mechanisms for these two types are different - jetty is dominated by hard QCD, whereas isotropic events have dominant soft QCD contributions. An event-shape dependence of CFO parameters are then obtained for *pp* collisions using PYTHIA8 Monash tune.

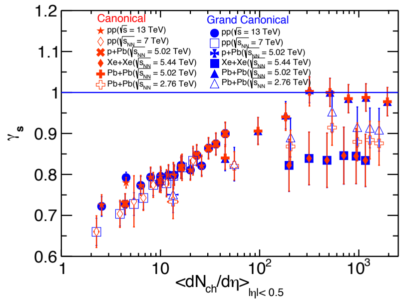

FIG. 1: (Color online) The strangeness saturation factor, γ_s as a function of charge particle multiplicity [1].

Results and Discussion

Fig. 1 shows the strangeness saturation factor (γ_s) for pp at $\sqrt{s}$ = 7 and 13 TeV, p+Pb at $\sqrt{s_{NN}}$ = 5.02 TeV, Xe+Xe at $\sqrt{s_{NN}}$ = 5.44 TeV and Pb+Pb at $\sqrt{s_{NN}}$ = 2.76 and 5.02 TeV obtained in canonical and grand-canonical ensembles using the particles ratios [1]. It shows a smooth evolution from *pp* to p+A and A+A collisions as a function of charged particle multiplicity, where it

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reaches the complete strangeness equilibrium for Pb+Pb at $\sqrt{s_{NN}}$ = 5.02 TeV. The values for γ_s show a fast rise for *pp* collisions towards one for high multiplicity, however full strangeness equilibrium is still to be achieved.

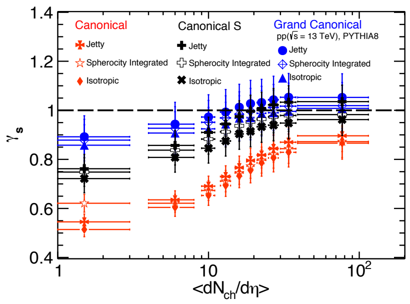

FIG. 2: (Color online) The γ_s as a function of charge particle multiplicity and event-shape classes [2].

Further, the event-shape dependence of γ_s as a function of charged particle multiplicity is shown in Fig. 2. A clear dependence of event class on γ_s is observed for *pp* collisions at $\sqrt{s}$ = 13 TeV [2]. The values obtained here are around one for high-multiplicity *pp* collisions in case of isotropic and spherocity integrated classes, whereas for jetty events it is below one. In order to understand the effect of final-state charged particle multiplicity ($dN_{\rm ch}/d\eta$) on CFO and KFO temperatures,

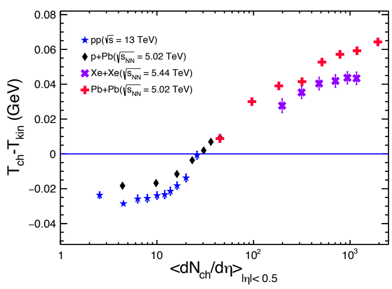

FIG. 3: (Color online) The difference between the chemical freeze-out (GC) and the kinetic freeze-out temperature as a function of charged particle multiplicity [1] .

we have shown the difference of these two temperatures as a function of $dN_{\rm ch}/d\eta$ in Fig. 3 for various collision systems at the LHC. One observes a threshold of $dN_{\rm ch}/d\eta \sim 20$, after which the CFO temperature becomes higher than the KFO temperature. This is a very important observation at the LHC, where the particle production seems to show a scaling in final state $dN_{\rm ch}/d\eta$.

Summary and Conclusion

Recently, high-multiplicity pp collisions at the LHC energies have drawn considerable attention, as they have shown heavy-ion like properties, for example, enhanced production of strange particles with respect to pions, degree of collectivity, hardening of particle spectra with multiplicity etc. Here, in this study an effort has been made to understand the freeze-out scenarios in small collision systems along with the larger collision system at the LHC energies. A clear evolution of the strangeness saturation factor γ_s, is seen as a function of charged particle multiplicity, where a complete strangeness equilibrium is achieved for the Pb+Pb at $\sqrt{s_{NN}}$ = 5.02 TeV. For *pp* collisions, the γ_s increases with event multiplicity but remains below one, which suggest a complete strangeness equilibrium is still to be achieved. Event-shape dependence study of γ_s, using PYTHIA8 MC generator, shows a complete strangeness equilibrium for isotropic and spherocity integrated classes, whereas for jetty events it is below one. The chemical freeze-out temperature is found to be weakly dependent on final state multiplicity and is close to the critical temperature for a deconfinement transition. The final state multiplicity has no role in the hadronization process, which seems to be very interesting. Details of these results are shown in [1], which will be discussed.

References

[1] R. Rath, A. Khuntia and R. Sahoo, arXiv:1905.07959 [hep-ph].
[2] R. Rath, A. Khuntia, S. Tripathy and R. Sahoo, arXiv:1906.04047 [hep-ph] and references therein.