Study of strange non-strange hadron ratios in pp and p-Pb collisions at LHC energies

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Abstract

It has been observed that the yields of strange and multi-strange hadrons relative to pion increase significantly with the event charged-particle multiplicity. We notice from experimental data that yield ratios between non-strange hadrons, like $p/\pi$ or hadrons of same strange content, like $\Lambda/K^0_s$, show similar enhancement. We have studied this behavior within the ambit of a parton model (EPOS3) and A Multi-Phase Transport (AMPT) model in pp and p-Pb collisions at LHC energies. We investigate model predictions of yields and yield ratios of different identified hadron productions as a function of charged-particle multiplicity and compare them with published ALICE results. The string melting versions of AMPT and EPOS are found to establish enhancements in the particle yield ratios.

1 Introduction

The production of strange hadrons in the high energy hadronic interactions provides the effective tools to investigate the properties of Quark-Gluon Plasma (QGP). The strangeness is produced in hard partonic scattering processes by flavor creation, flavor excitation and gluon splitting. These productions dominate in high $p_T$ regions. The non-perturbative processes, like string fragmentation, dominate the productions at low $p_T$ regions. The relative yields of strange particles to $\pi$ in heavy ion collisions from top RHIC to LHC energies are found to be compatible with those of a hadron gas in thermal and chemical equilibria, and this behavior can be described using grand-canonical statistical models \cite{1, 2}. In peripheral collisions, the relative yields of strange particles to $\pi$ decrease and tend toward those observed in pp collisions. This behavior can be described by statistical mechanics approach. The statistical models, by implementing strangeness canonical suppression, can predict a suppression of strangeness production in small systems. It has been seen in ALICE for pp collisions at $\sqrt{s} = 7$ TeV that the $p_T$ integrated yields of strange and multi-strange particles relative to $\pi$ increase significantly with charged-particle multiplicity \cite{3}. The observed relative yield enhancements increase with the strange quark content in hadrons. Further, it will be interesting to study the behavior of ratios between same strange content particles. This study may open up a new possibility of particle production mechanism in hadron collisions at microscopic level.

In this paper, we present the comparison of yields and the respective normalized ratios of identified particles between ALICE data and the models like AMPT (A Multi-Phase Transport Model) \cite{4} and EPOS (3+1 Hydrodynamics Model) \cite{5, 6}. In section 2, we have described detail of the models. We discuss the results from models along with ALICE data in section 3 and the summary is given in section 4.

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2 Description of models

The AMPT model (version 1.26t7/2.26t7) mainly provides the initial conditions, partonic interactions, conversion from the partonic to hadronic matter, and hadronic interactions. The initial conditions, which include the spatial and momentum distributions of minijet partons and string excitations, are obtained from the HIJING Model [7, 8, 9, 10]. The partonic interactions or the scatterings among partons are modeled by Zhang’s parton cascade (ZPC) [11]. Here, we have studied both the versions of AMPT model, i.e., default version and string-melting (SM) version. In the default AMPT model, partons are recombined with their parent strings when they stop interacting, and the resulting strings are converted to hadrons using the Lund string fragmentation model [12, 13]. In the AMPT SM, a quark coalescence model is used instead to combine partons into hadrons. The dynamics of the subsequent hadronic matter is described by a relativistic transport (ART) model [14, 15] and extended to include additional reaction channels which are important in high energy processes, like formation and decay of resonances, baryon and antibaryon production from mesons and their inverse reactions of annihilation. Final results from the AMPT model are obtained after hadronic interactions are terminated at a cut off time ($t_{\text{cut}} = 40\text{fm}/c$) when observables under study are considered to be stable, i.e., when further hadronic interactions after $t_{\text{cut}}$ will not significantly affect these observables. As per model recommendation, default set of parameters are used for this study.

The model EPOS (version 3.107) is a parton model, with many binary parton-parton interactions, each one creating a parton ladder. EPOS describes the full evolution of a heavy-ion collisions. The initial stage is a multiple scattering approach based on pomerons and strings. The reaction volume is composed of two parts, i.e., core and corona. The core provides the initial condition for the QGP evolution, hence one employs viscous hydrodynamics. Hadrons from string decays simply form the corona part. After hadronization the core and corona hadrons are fed into UrQMD [16], which describe hadronic interactions in microscopic approach. The chemical and kinetic freeze-outs occur within this phase. EPOS is designed to be used for particle physics experimental analysis (SPS, RHIC, LHC) for pp or heavy ion from 100 GeV to 1000 TeV energies. Details of EPOS model can be found in Ref. [5, 6] and references therein.

In the ALICE experiment, multiplicity and centrality determination are done via the measurement of the charged-particle multiplicity using two forward detectors V0A and V0C [17], which span the pseudorapidity ranges $2.8 < \eta < 5.1$ and $-3.7 < \eta < -1.7$ in the ALICE frame of experiment, respectively. Charged-particle multiplicities in the pseudorapidity ranges of both the detectors are used to classify multiplicity classes in pp collisions. In p-Pb collisions, centrality selection is done via the measurement of charged-particle multiplicity in V0A acceptance, which is Pb going direction. The mean charged-particle multiplicity densities ($\langle dN_{ch}/d\eta \rangle$), corresponding to each multiplicity or centrality classes, are calculated in the pseudorapidity ranges $|\eta| < 0.5$. The above procedure is followed to adopt the steps pursued by ALICE [18].

3 Results and Discussion

We have simulated AMPT and EPOS events in pp collisions at $\sqrt{s} = 7$ TeV and in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. The Fig.1 shows the primary yields of hadrons, like $\pi$, $p$, $K^0_s$, $\Lambda$, $\Xi$, and $\Omega$ as a function of event charged-particle multiplicity density ($\langle dN_{ch}/d\eta \rangle$). For bravety, $\pi^+ + \pi^-$, $p + \bar{p}$, $\Lambda + \bar{\Lambda}$, $\Xi^- + \bar{\Xi}^+$ and $\Omega^- + \bar{\Omega}^+$ are denoted as $\pi$, $p$, $\Lambda$, $\Xi$, and $\Omega$, respectively. Here a primary particle is defined as a particle created in the collision, but not coming from a weak decay. The experimental data points are shown by markers in the figure and different model results are shown by respective colored lines. The statistical uncertainties from model results are shown by shaded bands. We note that the EPOS model describes quantitatively most of experimental data points within two standard deviations, but it highly overestimates the $\Omega$ yields. We further find that the AMPT default and AMPT SM models well describe the experimental data points
Figure 1: Yields of hadrons vs charged-particle multiplicity measured in pp collisions at $\sqrt{s} = 7$ TeV and p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. The markers show ALICE data [3] and the lines show results from models and their statistical uncertainties are shown by shaded bands.

Figure 2: Yield ratios of hadrons to $\pi$ in pp collisions at $\sqrt{s} = 7$ TeV and p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, normalized to the values measured in the inclusive INEL > 0 pp collisions at $\sqrt{s} = 7$ TeV. The solid and open star symbols show ALICE data [3] in pp and p-Pb collisions, respectively. The lines show results from models and shaded bands show their statistical uncertainties.
for mesons, but underestimate yields for strange baryons. The AMPT SM gives higher yield for baryons when compared to the AMPT default. The higher is the strange baryon mass, the lower is the AMPT model prediction from experimental data as a function of charged-particle multiplicity density. The Fig. 2 shows primary yield ratios of hadrons ($K_0^0$, $\Lambda$, $\Xi$, and $\Omega$) to $\pi$ yield (denoted as $\langle h/\pi \rangle$) divided by the same values measured in the inclusive inelastic pp collisions ($\langle h/\pi \rangle_{\text{inel}}^{pp}$) as a function of $\langle dN_{ch}/d\eta \rangle$, calculated from EPOS and AMPT models. The figure also shows same ratios from ALICE data. Here INEL > 0 represents events having at least one charged particle produced in the pseudorapidity interval $|\eta| < 1.0$. The measurements were performed at mid-rapidity $|y| < 0.5$ in pp collisions and within $-0.5 < y < 0$ in p-Pb collisions at the center of mass frame. A detailed information of the ALICE data can be found in Ref. [3] and references therein. From Fig. 2 it is clearly seen that EPOS qualitatively explains enhancements in the $\langle h/\pi \rangle$ ratios as a function of $\langle dN_{ch}/d\eta \rangle$ with an exception for $\Omega$. The EPOS gives a higher rate of production for $\pi$ as a function of $\langle dN_{ch}/d\eta \rangle$ compared to $\Omega$. AMPT SM describes the enhancement in the $\langle h/\pi \rangle$ ratios as a function of $\langle dN_{ch}/d\eta \rangle$. The enhancement in the $\Omega/\pi$ ratios in p-Pb collisions is noted to be well described by the AMPT model where Lund string fragmentation is incorporated for hadronization.

Figure 3: Yield ratios $p/\pi$ and $\Lambda/K_0^0$ in pp collisions at $\sqrt{s} = 7$ TeV and p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, normalized to the values measured in the inclusive INEL > 0 pp collisions at $\sqrt{s} = 7$ TeV. The solid and open star symbols show ALICE data [3] in pp and p-Pb collisions, respectively. The lines show results from models and shaded bands show their statistical uncertainties.

In Fig. 3 we have displayed the above said normalized ratios between non-strange hadrons, $p/\pi$ and single-strange hadrons, $\Lambda/K_0^0$, as a function of charged-particle multiplicity density. Here we notice from experimental data that the ratios between hadrons of same strange content show similar enhancement as a function $\langle dN_{ch}/d\eta \rangle$ like previously shown $\langle h/\pi \rangle$ ratios in Fig. 2. The AMPT SM and EPOS clearly depict a sign of enhancement in these hadron ratios as a function of $\langle dN_{ch}/d\eta \rangle$. In AMPT SM version, the model need to melt the strings into partons for energy density beyond a certain critical value. It may be difficult to achieve that critical energy density when one approaches to very low $\langle dN_{ch}/d\eta \rangle$. This could be a possible reason for AMPT SM to approach towards AMPT default version at low $\langle dN_{ch}/d\eta \rangle$. This behaviour can be seen for ratios like $\Lambda/\pi$, $p/\pi$, and $\Lambda/K_0^0$.

4 Summary

We have presented yields of strange and non-strange hadrons at mid-rapidity and their ratios in AMPT and EPOS models in pp collisions at $\sqrt{s} = 7$ TeV and in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$
TeV. We have compared model results with ALICE data. We observed that, like experimental data, models qualitatively described the enhancement in the yields of hadrons at mid-rapidity with event charged-particle multiplicity density. Both the versions of AMPT model are found to underestimate yields of strange baryons, whereas EPOS highly overestimates $\Omega$ yield. The AMPT SM and EPOS show multiplicity-dependent enhancement of the production of strange hadrons relative to $\pi$. The Lund string fragmentation implemented version of AMPT is found to be quite successful in describing the multiplicity-dependent enhancement in $\Omega/\pi$ ratios. The models predict multiplicity-dependent enhancement in the yield ratios between a heavier baryon and a lighter meson of same strange content, though there are quantitatively deviation from experimental data. This behaviour is completely independent of strangeness of hadrons. One needs more experimental data with improved uncertainties to figure out whether this is a mass-dependent phenomenon.

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