Multiplicity and Rapidity Dependent Study of (Multi-)strange hadrons in small collision system using the STAR Detector

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Abstract. Strangeness enhancement has long been considered as a signature of the quark-gluon plasma formation in heavy-ion collisions. Strangeness enhancement has also been observed in small systems at the Large Hadron Collider (LHC), but the underlying physics still needs to be fully understood. This motivates us to study the strange hadron production in small systems at RHIC. We present new measurements of (multi-)strange hadrons (K^0_S, Λ, Ξ and Ω) in d+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV, collected by STAR in 2016. We report the multiplicity and rapidity dependence of strange hadron transverse momentum (p_T) spectra, p_T-integrated yields dN/dy, average transverse momentum ($\langle p_T \rangle$), yield ratios of these strange hadrons to pions, nuclear modification factors and rapidity asymmetry in d+Au collisions.

Keywords: Heavy-ion collisions, Quark Gluon Plasma, RHIC, STAR

1 Introduction

The production of strange hadrons in high-energy hadronic interactions provides a way to investigate the properties of quantum chromodynamics (QCD), the theory of strongly interacting matter. Strangeness enhancement in heavy-ion collisions with respect to p+p collisions has been suggested as a signature of quark-gluon plasma (QGP) formation [1]. However, the creation of QGP in small systems is still under intense debate.

Small collision systems like proton-nucleus (p–A) and deuteron-nucleus (d–A) can be considered as control experiments where the formation of an extended QGP phase is not expected. These collision systems are used for baseline measurements to study the possible effects of cold nuclear matter and to disentangle them from hot dense matter effects signifying the QGP formation in heavy-ion collisions. The process of generating hadrons can be affected by various factors that include modifications in parton distribution functions within nuclei, the possibility of parton saturation, multiple scatterings of the partons traversing the nucleus, and the radial flow [2, 3]. It is anticipated that the magnitude of these effects may vary with the rapidity of the produced particles.

Nuclear effects can be quantified using variables such as nuclear modification factor and rapidity asymmetry. The nuclear modification factor is defined as the ratio of the yield of a particle in heavy-ion collisions to its yield in p+p collisions, scaled by the number of binary nucleon-nucleon inelastic collisions [4].

$$\mathrm{R_{AB}(p_T)} = \frac{\mathrm{Yield_{AB}(p_T)}}{\langle \mathrm{N_{bin}} \rangle \mathrm{Yield_{pp}(p_T)}} \tag{1}$$

where $\langle \mathrm{N_{bin}} \rangle$ is the average number of binary nucleon-nucleon collisions. A comparative study of particle production in forward and backward rapidity regions uses rapidity asymmetry ($\mathrm{Y_{Asym}}$) [4]. $\mathrm{Y_{Asym}}$ is defined as

$$\mathrm{Y_{Asym}(p_T)} = \frac{\mathrm{Y_B(p_T)}}{\mathrm{Y_F(p_T)}} \tag{2}$$

where $\mathrm{Y_B}$ and $\mathrm{Y_F}$ are particle yields in backward and forward rapidity regions, respectively.

2 Analysis Details

A successful run of d+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV was carried out in 2016 at RHIC. In this analysis utilizing the d+Au dataset, we focus on $\mathrm{K^0_s}$, $\Lambda(\bar{\Lambda})$, $\Xi(\bar{\Xi})$, $\Omega(\bar{\Omega})$ that are weakly decaying particles that travel a certain distance before decaying into daughter particles ($\mathrm{K^0_S} \rightarrow \pi^+ + \pi^-$, $\Lambda(\bar{\Lambda}) \rightarrow \mathrm{p(\bar{p})} + \pi^-(\pi^+)$, $\Xi^-(\bar{\Xi}^+) \rightarrow \Lambda(\bar{\Lambda}) + \pi^-(\pi^+)$, $\Omega^-(\bar{\Omega}^+) \rightarrow \Lambda(\bar{\Lambda}) + \mathrm{K^-(K^+)}$).

The $\mathrm{K^0_s}$, $\Lambda(\bar{\Lambda})$, $\Xi(\bar{\Xi})$, $\Omega(\bar{\Omega})$ signals are extracted using the invariant mass method. The decay topology can be used to enhance the signal and suppress the background. We have used double Gaussian and second order polynomial functions to describe the signal and background invariant mass distributions, respectively. The signal mean and the width are extracted from the functional fitting. Raw yield is determined within the mass window of $\mathrm{M_0} \pm 3\sigma$, where $\mathrm{M_0}$ and σ is the fitted mean and fitted width of $\mathrm{K^0_S}$ (or $\Lambda/\Xi/\Omega$) respectively. The raw yield for each $\mathrm{p_T}$ interval is corrected for branching ratio, acceptance and efficiency to obtain corrected $\mathrm{p_T}$ spectra. Weak decay contributions from Ξ are subtracted from the yields.

3 Results and Discussions

In Fig. 1, dN/dy scaled by the average number of nucleon participants ($\langle \mathrm{N_{part}} \rangle$) for $\mathrm{K^0_s}$, $\Lambda(\bar{\Lambda})$, $\Xi^-(\bar{\Xi}^+)$ and $\Omega^- + \bar{\Omega}^+$ as a function of $\langle \mathrm{N_{part}} \rangle$ is d+Au collisions is shown. d+Au collisions fill the gap between p+p collisions and peripheral Au+Au and Cu+Cu collisions. The yields of strange hadrons in d+Au collisions lie in trend with peripheral Cu+Cu and Au+Au collisions. Strangeness enhancement is observed for $\mathrm{K^0_s}$, $\Lambda(\bar{\Lambda})$, $\Xi^-(\bar{\Xi}^+)$ and $\Omega^- + \bar{\Omega}^+$ in 0-20% and 20-50% d+Au collisions at 200 GeV.

Figure 2 (left) shows the ratio of integrated $\mathrm{K^0_S}$, Λ, Ξ and Ω yields to pion yields as a function of mid-rapidity multiplicity for d+Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV. A smooth transition of these ratios from p+p to heavy-ion collisions is observed. Data from different collision systems are consistent with each other at similar multiplicities and yields of particles with more strangeness content decrease faster as we move from high to low multiplicities. Similar trends have been observed at the LHC.

In Fig. 2 (right), nuclear modification factors for $\mathrm{K^0_S}$, Λ and Ξ at mid-rapidity ($|y| < 0.5$) for d+Au collision is presented. Cronin-like enhancement [8] is observed at intermediate $\mathrm{p_T}$, which is stronger for baryons (Ξ, Λ, p) as compared to mesons ($\mathrm{K^0_S}, \pi$).

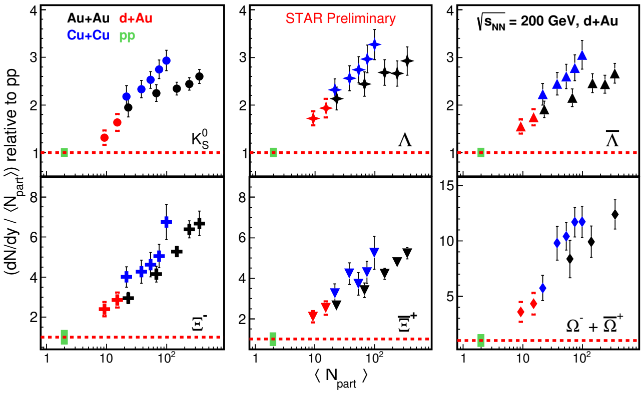

Fig. 1: (dN/dy / $\langle N_{part} \rangle$) relative to $p+p$ as a function of $\langle N_{part} \rangle$ of (K^0_S, $\Lambda(\bar{\Lambda})$, $\Xi^-(\bar{\Xi}^+)$ and $\Omega^- + \bar{\Omega}^+$) in d+Au, Cu+Cu and Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV at $|y| < 0.5$.

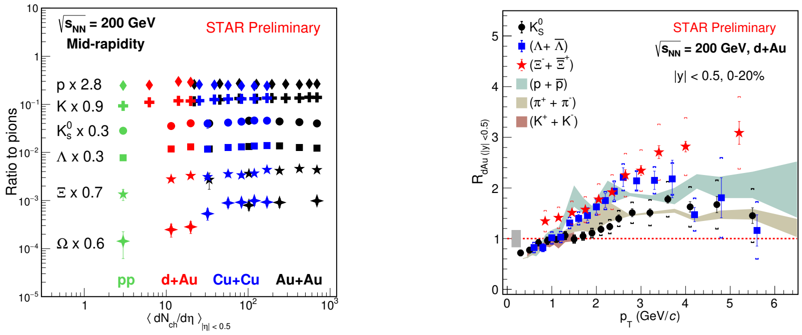

Fig. 2: Left: Integrated yield particle-to-pion ratio (left) for strange particles (K^0_S, Λ, Ξ and Ω) as a function of multiplicity for $p+p$, d+Au, Cu+Cu and Au+Au collisions. Right: Nuclear modification factors (R_{dAu}) for strange particles (K^0_S, Λ and Ξ) in d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

In Fig. 3 (Left), integrated yield and $\langle p_T \rangle$ for $\pi^+(\pi^-)$, $K^+(K^-)$, $p(\bar{p})$, K^0_s, $\Lambda(\bar{\Lambda})$, $\Xi^-(\bar{\Xi}^+)$ and $\Omega^- + \bar{\Omega}^+$ is shown as function of multiplicity [5-7] . We observed increase of dN/dy and a hint of increase of $\langle p_T \rangle$ as a function of multiplicity. $\langle p_T \rangle$ is larger for heavier mass particles which strongly supports the picture of collective evolution, specially radial flow. We observed smooth transition of particle production from $p+p$ to A+A collisions.

We have also measured the transverse momentum dependence of Y_{Asym} for K^0_s, Λ and Ξ for different rapidity intervals (backward rapidity intervals: $-0.8 < y < -0.4$, $-0.4 < y < 0$ and forward rapidity intervals: $0 < y < 0.4$, $0.4 < y < 0.8$) in 0-20% d+Au collision at $\sqrt{s_{NN}} = 200$ GeV. Y_{Asym} values deviate from unity at low p_T (< 3 GeV/c), as shown

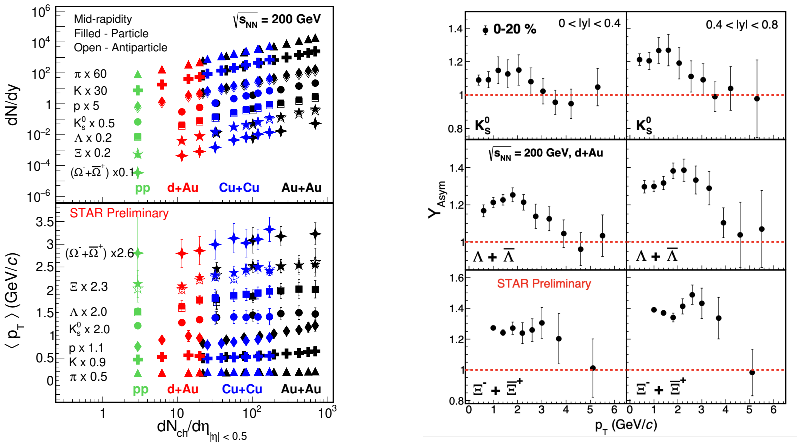

Fig. 3: Left: Integrated yield (dN/dy) and mean transverse momentum $\langle p_T \rangle$ for $\pi^+(\pi^-)$, $K^+(K^-)$, p($\bar{p}$) strange particles (K^0_S, Λ, Ξ and Ω) as a function of multiplicity for *p*+*p*, *d*+Au, Cu+Cu and Au+Au collisions. Right: Rapidity asymmetry (Y_{Asym}) as a function of p_T (right) for strange particles (K^0_S, Λ and Ξ) in *d*+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV.

in Fig. 3 (right), suggesting the presence of a rapidity dependence in the nuclear effects. Y_{Asym} is consistent with unity at high p_T, hinting that nuclear effects become weaker at high p_T. The asymmetry is more prominent for larger rapidity interval and heavier particles.

4 Summary

In these proceedings, we present measurements of multiplicity and rapidity dependence of (multi-)strange hadron (K^0_S, $\Lambda(\bar{\Lambda})$, $\Xi(\bar{\Xi})$ and $\Omega(\bar{\Omega})$) production in *d*+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV with the STAR experiment. Results suggest that strange particle production at 200 GeV is mainly driven by multiplicity. The observed enhancement of integrated yield ratio to pion increases with increasing strange content. Hint of Cronin-like enhancement is observed for 0-20% centrality for K^0_S, Λ and Ξ. Y_{Asym} larger than one at low p_T indicates the presence of the nuclear effects. The Y_{Asym} is more prominent for larger-mass particles and higher rapidity interval.

References

1. J Rafelski, B Muller, Phys. Rev. Lett. **48**, 1066 (1982).
2. M. Hirai et al. Phys. Rev. C. **70**, 044905 (2004).
3. R. Baier et al. Nucl. Phys. B **484**, 265 (1997).
4. J. Adam et al. (ALICE Collaboration) Nature Phys **13**, 535–539 (2017).
5. B. I. Abelev et al. (STAR Collaboration) Phys. Rev. C **79**, 034909 (2009).
6. B. I. Abelev et al. (STAR Collaboration) Phys. Rev. C **75**, 064901 (2007).
7. G. Agakishiev et al. (STAR Collaboration) Phys. Rev. Lett. **108**, 072301 (2012).
8. J. W. Cronin et al. Phys. Rev. D. **11**, 3105 (1975).