

# Dependence of net-hyperon production at mid-rapidity on beam energy and its implication on baryon number carrier

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**Abstract.** The conventional picture of baryon number is that each valence quark inside a baryon carries  $1/3$  unit of baryon number. However, an alternative picture exists where the center of a Y-shaped topology of gluon fields, called the baryon junction, carries 1 unit of baryon number. Previous analysis suggests that the nature of the baryon number carrier is sensitive to net-proton yields at mid-rapidity in heavy-ion collisions, and experimental measurements potentially challenge the conventional picture. In this study, we analyzed published data from the BES-I program at RHIC, which performed Au+Au collisions at center-of-mass energies ranging from 7.7 to 200 GeV. We investigated the rapidity dependence of net-hyperon yields after correcting for strangeness production suppression, and found that the net-hyperon yields at mid-rapidity follow an exponential dependence on the beam rapidity. This behavior is consistent with Regge model predictions. Moreover, the exponential slopes for net- $\Lambda$ , net- $\Xi$ , and net- $\Omega$  are consistent with each other, suggesting that the baryon transport is flavor blind. Conventional models like PYTHIA, which use valence quarks as the baryon number carrier, have difficulty reproducing this transport behavior.

## 1 Introduction

The baryon number ( $B$ ) is a conserved quantity in quantum chromodynamics (QCD). While mesons, like pions and kaons, carry zero baryon number ( $B = 0$ ), baryons such as protons and neutrons carry one unit ( $B = 1$ ). The conventional quark model assigns  $1/3$  unit of the baryon number to each quark. However, an alternative theory proposes that the entire unit of the baryon number is carried by the baryon junction, a non-perturbative Y-shaped topology of gluons connected to all three valence quarks. Neither scenario has been verified experimentally. Recent proposals have outlined experimental approaches to distinguish these scenarios in high-energy hadronic and photon-induced collisions [1].

Here, we report the dependence of net-hyperon yields, after correcting for the strange quark production suppression, on  $\delta y$  by compiling published data on hyperon production at mid-rapidity in heavy-ion collisions. Here,  $\delta y = y_{beam} - y_{CM}$ , where  $y_{beam}$  is the beam rapidity and  $y_{CM} \sim 0$  denotes the rapidity where the net-hyperon yields are measured. Such a dependence is quantified by fitting the net-hyperon yields with  $f(\delta y) \sim e^{-\alpha_B \delta y}$ . Since baryon junction is flavor blind [1], one would expect the transport behavior of hyperons to resemble that of inclusive baryons. Specifically, we will inspect if the fitted  $\alpha_B$  for net- $\Lambda$ , net- $\Xi$  and net- $\Omega$  are consistent with each other and with that of net- $p$  at various centralities. Furthermore,

predictions of  $\alpha_B$  for net-hyperons from various versions and tunes of the PYTHIA event generator will be compared to our results.

## 2 Beam energy dependence of net-hyperon yields

Using published data from RHIC BES-I program, we compute net- $\Lambda$ , net- $\Xi$  and net- $\Omega$  yields,  $(dN/dy)_{\Lambda-\bar{\Lambda}}/\langle N_{\text{part}} \rangle$ ,  $(dN/dy)_{\Xi-\bar{\Xi}}/\langle N_{\text{part}} \rangle$ , and  $(dN/dy)_{\Omega-\bar{\Omega}}/\langle N_{\text{part}} \rangle$ , within the rapidity range of  $|y| < 0.5$  in Au+Au collisions at center-of-mass energies ( $\sqrt{s_{\text{NN}}}$ ) of 7.7, 11.5, 19.6, 27, 39, 62.4 and 200 GeV [2–5]. Here  $\langle N_{\text{part}} \rangle$  is the average number of participating nucleons in a given centrality class of Au+Au collisions.

Since strange quarks must be pair-produced, we need to account for the effects associated with the strange quark production to isolate the effect of baryon transport. We gauge the difficulty of strange quark production using the  $K^-/\pi^-$  ( $d\bar{u}$ ) yield ratio in Au+Au collisions. The correction for the strangeness production suppression is performed by dividing the net-hyperon yields by  $(K^-/\pi^-)^n$ , where  $n$  is the number of valence strange quarks in the hyperon. Figure 1 shows that net-hyperon yields follow exponential dependence on  $\delta y$  as the Regge theory predicted. The fitted  $\alpha_B$  values are shown in Fig. 2a, and they agree with each other within  $2\sigma$  for all hyperons and net-protons. There is a mild centrality dependence for peripheral collisions, but it disappears if we use  $K^-/\pi^-$  from 0-10% centrality for all centralities instead as Fig. 2b shows. It indicates that this centrality dependence is a result of changes in  $K^-/\pi^-$  ratio in peripheral collisions, rather than a change in baryon transport mechanism.

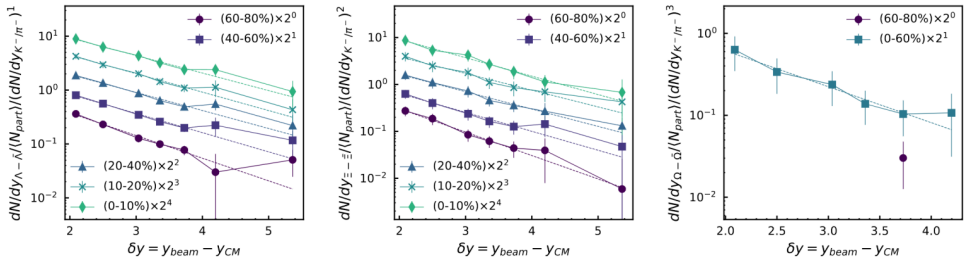


Figure 1: Net- $\Lambda$  (left), net- $\Xi$  (central) and net- $\Omega$  (right) yields within  $|y| < 0.5$  as a function of  $\delta y$  in Au+Au collisions. These yields are scaled by  $(K^-/\pi^-)^n$  in Au+Au collisions, where  $n$  is the number of valence strange quarks in the hyperon.

The independence of  $\alpha_B$  on centrality shows that  $\alpha_B$  is not affected by superfluous processes such as multiple scattering and reflects the inherent properties of baryon stopping mechanism, and therefore Au+Au results should be comparable to results from systems of other sizes. When other published data for Pb+Pb collisions at CERN SPS [6, 7] and by ALICE [8, 9], for 200 GeV Cu+Cu collisions by STAR [3], and for 200 GeV and 900 GeV  $p+p$  collisions by STAR [10] and ALICE [11] are included in the fit for central collisions,  $\alpha_B$  values remain unchanged with combined fits show  $\alpha_B(\Lambda) = 0.72 \pm 0.06$ ,  $\alpha_B(\Xi) = 0.93 \pm 0.12$  and  $\alpha_B(\Omega) = 1.02 \pm 0.32$ . Values for Au+Au only fit can be found in Table 1.

## 3 Comparison between data and PYTHIA

Here, we compare slope parameters in  $p+p$  collisions predicted by the PYTHIA event generator, which employs valence quarks as the baryon number carriers, to those in Au+Au

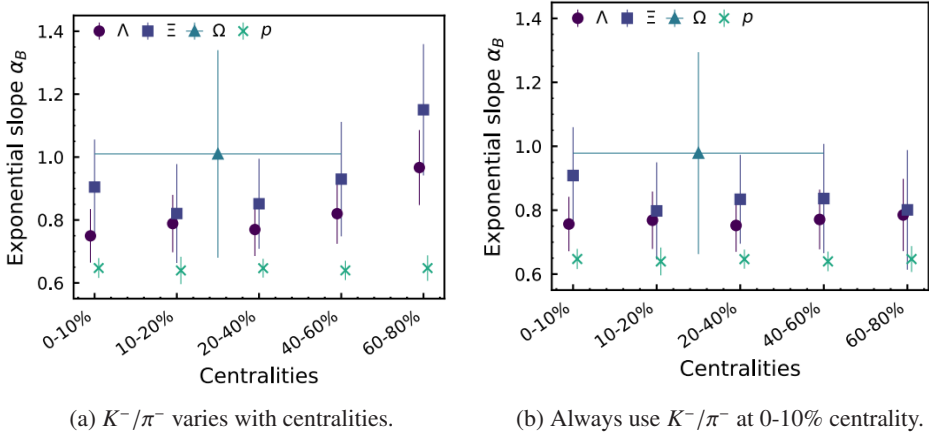


Figure 2: Comparison of slope parameters for net- $\Lambda$ , net- $\Xi$ , net- $\Omega$  and net- $p$  as a function of centrality from Au+Au collisions at  $\sqrt{s_{NN}} = 7.7 - 200$  GeV. (a) used  $K^-/\pi^-$  at varying centralities, while (b) only used  $K^-/\pi^-$  at 0-10% centrality for net-hyperon of different centralities.

Table 1:  $\alpha_B$  values from measurements and PYTHIA.

	Data (0-60%)	Ver. 6.4	Ver. 6.4 (P0)	Ver. 6.4 (P12)	Ver. 8.3	Ver. 8.3 CR
$\Lambda$	$0.72 \pm 0.07$	$2.58 \pm 0.03$	$1.15 \pm 0.01$	$0.81 \pm 0.01$	$1.18 \pm 0.01$	$0.88 \pm 0.01$
$\Xi$	$0.85 \pm 0.13$	N.A.	$0.73 \pm 0.05$	$0.52 \pm 0.05$	$0.62 \pm 0.08$	$0.55 \pm 0.06$
$\Omega$	$0.98 \pm 0.32$	N.A.	$0.25 \pm 0.10$	$0.04 \pm 0.15$	N.A.	N.A.
$p$	$0.65 \pm 0.07$	$0.74 \pm 0.05$	$0.72 \pm 0.02$	$0.35 \pm 0.01$	$0.98 \pm 0.02$	$0.69 \pm 0.02$

collisions. The fitted  $\alpha_B$  values from PYTHIA are compared to measurements in Table 1. Values for some configurations of PYTHIA are marked as "N.A.", corresponding to cases where the PYTHIA distribution was not fitted due to presence of negative net-hyperon yield at any beam energy.

Not only does PYTHIA fail to reproduce the measured  $\alpha_B$ , it also shows strong variations across hyperon species. PYTHIA 8.3 CR, which includes a partial implementation of the baryon junction picture, performs better than its non-CR counterpart as its predicted  $\alpha_B$  values are closer to the measured values for both net-proton and net- $\Lambda$ . This underscores the potential of implementing the baryon junction mechanism. However, it still fails to reproduce the slope parameter for net- $\Xi$  and net- $\Omega$ , and does not eliminate the flavor dependence, as  $\alpha_B$  values change significantly between net- $\Lambda$ , and net- $\Xi$ . This calls for a genuine inclusion of the baryon junction mechanism in event generators for a more rigorous test.

## 4 Summary

We investigated the validity of the baryon junction picture by analyzing net-hyperon yields in Au+Au collisions from RHIC BES-I program. After accounting for the difficulty associated with the strange quark production by dividing net-hyperon yield with  $(K^-/\pi^-)^n$ , net-hyperon yields at mid-rapidity ( $|y| < 0.5$ ) exhibit the expected exponential dependence on beam rapidity. The extracted exponential slopes ( $\alpha_B$ ) for net- $\Lambda$ , net- $\Xi$ , and net- $\Omega$  are consistent with

each other within uncertainty, which suggests a common transport mechanism for different hyperons and supports a flavor-blind baryon junction scenario. Predictions from different versions and tunes of PYTHIA event generator, which assigns baryon number to valence quarks in the incoming protons, are unable to replicate the transport behaviors for all the baryons examined.

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