

Abstract

The observation of a positive net hyperon yield in the mid-rapidity region of nuclear collisions at RHIC energies suggests that baryon number can be transported from the initial-state nucleons to hyperons across the rapidity gap—from beam rapidity to mid-rapidity. The dynamics for such baryon number transport are an interesting subject of theoretical and experimental investigations. Recently the gluon junction model, positing that the Y-shaped gluonic junction in proton and neutron may carry the baryon number, has attracted many interest, and the gluon junction interactions may be an effective mechanism of baryon number transport over a large rapidity gap. Given the conservation of strangeness in hyperon production, we utilize hyperon–kaon correlations as a sensitive probe for investigating baryon number transport dynamics. In this study, we present an analysis of hyperon–kaon correlations in p+Au collisions at $\sqrt{s_{NN}} = 39\text{ GeV}$ and 62 GeV , simulated using both AMPT and UrQMD models. Furthermore, we discuss implications of both the strangeness conservation and the baryon number transport dynamics on model predictions, and propose to use these results as a baseline reference for future experimental measurements.

1. Introduction

Recently, a positive net-baryon number was observed in the mid-rapidity region of heavy-ion collisions [1, 2], which implies that baryon number must be transported from beam rapidity to mid-rapidity, a process commonly referred to as baryon number transport (BNT). During the stopping process, with rapidity gap $\Delta y = y - y_{\text{beam}}$ (y is the final baryon rapidity and y_{beam} is the beam rapidity), quark–anti-quark pairs can be produced. Anti-quarks may combine with valence quarks from the incoming baryons to form mesons. As a result, the final-state baryons are naturally correlated with these mesons. If the pair-produced quarks are strange quarks, as illustrated in the left sub-plot in Fig. 1, the correlation between hyperons and kaons can be a sensitive observable for the baryon stopping process, since hyperons and kaons must originate from the collision dynamics, they provide a cleaner probe than protons/neutrons and pions.

There are two theoretical pictures commonly used to describe baryon stopping: the valence-quark picture and the baryon-junction model [3]. In the valence-quark picture, each valence quark carries one third of the baryon number, whereas in the baryon-junction picture, a Y-shaped gluonic structure connecting the three valence quarks carries the baryon number. Because valence quarks typically carry smaller momentum fraction x while gluon fields carry larger x , the gluon field has a longer

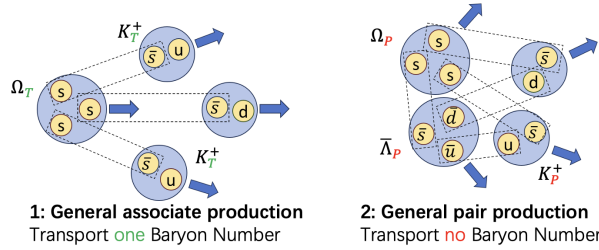


Fig 1: Two scenarios of Ω production. Left: associate production; Right: pair production. The circles inside the dashed box denote a pair-produced $s\bar{s}$ quark pair. The u and d quarks outside the box originate from the incoming baryons, indicating baryon number transport in scenario 1.

interaction time in the collision and is therefore more likely to be stopped at mid-rapidity. Therefore, the baryon-junction picture provides a more favorable explanation for the experimentally observed baryon stopping.

In this work, we propose a new method to investigate baryon stopping through kaon–hyperon correlations, which may provide an effective way to test the baryon junction picture. Our results may serve as a benchmark for future experimental analyses.

2. Correlation Function

To measure the kaon–hyperon correlation, we calculate the pair distributions P_{KH}^{same} in same events and P_{KH}^{mix} in mixed events, where P_{KH}^{mix} is normalized such that $\sum_{\text{pairs}} P_{KH}^{\text{mix}} = \sum_{\text{pairs}} P_{KH}^{\text{same}}$.

According to the hyperon production mechanisms, there are two scenarios [4], as shown in Fig. 1, with Ω used as an example. There are three categories of K^+ : K_T^+ , K_P^+ , and K_U^+ , denoting kaons produced via scenario 1, scenario 2, and uncorrelated sources, respectively. There are two types of hyperons: H_T and H_P , representing hyperons produced with and without BNT. Clearly, only $P_{K_T^+ H_T}^{\text{same}}$ contains correlation information related to baryon stopping. Assuming that the spectra satisfy $K_P^+ = K^-$, $H_P = \bar{H}$, and $K_U^+ = K_U^-$, one can extract the genuine interaction term as

$$P_{K_T^+ H_T}^{\text{same}} = P_{K^+ H}^{\text{same}} - P_{K^- \bar{H}}^{\text{same}} - P_{K^- H}^{\text{same}} - P_{K^+ \bar{H}}^{\text{same}} + 2P_{K^- \bar{H}}^{\text{mix}}, \quad (1)$$

$$P_{K_T^+ H_T}^{\text{mix}} = P_{K^+ H}^{\text{mix}} + P_{K^- \bar{H}}^{\text{mix}} - P_{K^- H}^{\text{mix}} - P_{K^+ \bar{H}}^{\text{mix}}. \quad (2)$$

Here we focus on p+Au collisions, where initial protons are defined at positive rapidity and Au nuclei at negative rapidity. Since the valence quarks of the proton tend to form leading mesons, the gluon fields are

more likely to be stopped, producing faster kaons and slower hyperons in correlated pairs. Thus, we compare the kaon–hyperon correlations for hyperons with different rapidity signs. Hyperons at positive rapidity are more likely to inherit the proton’s baryon number and thus exhibit stronger stopping effects.

To compare correlations regardless of emission direction, we define the relative rapidity as

$$\Delta y = \theta(y_H)(y_K - y_H) + \theta(y_K)(y_H - y_K), \quad (3)$$

where $\theta(x)$ is the step function, and y_K and y_H are the rapidities of kaons and hyperons, respectively. Thus, $\Delta y > 0$ ($\Delta y < 0$) indicates that the kaon is emitted with a larger (smaller) rapidity than the hyperon.

After calculating $P_{K_T^+ H_T}^{\text{same}}(\Delta y)$ and $P_{K_T^+ H_T}^{\text{mix}}(\Delta y)$, their difference removes the background contribution and reflects the physical correlation. Thus, we define the correlation function:

$$C_{KH}^{\text{CBS}}(\Delta y) = \frac{1}{N} \left[P_{K_T^+ H_T}^{\text{same}}(\Delta y) - P_{K_T^+ H_T}^{\text{mix}}(\Delta y) \right], \quad (4)$$

where the normalization factor N is chosen such that the sum of positive bins of $C_{KH}^{\text{CBS}}(\Delta y)$ equals unity.

3. Analysis Result

We perform model simulations using A Multi-Phase Transport (AMPT) model [5] (Version 2.25t7cu with String Melting) for both $K-\Lambda$ and $K-\Xi$, and Ultra-relativistic Quantum Molecular Dynamics (UrQMD) [6] for $K-\Lambda$. A detector acceptance cut $|\eta| < 1.5$ is applied to both kaons and hyperons to mimic realistic experimental conditions.

Both $C_{K\Lambda}^{\text{CBS}}(\Delta y)$ and $C_{K\Xi}^{\text{CBS}}(\Delta y)$ at 39 and 62 GeV exhibit similar patterns, as shown in Fig. 2. The peak appears in the region $\Delta y \simeq -1.5 \sim 0.5$, indicating that the correlated kaons tend to be emitted slightly slower than the corresponding hyperons that carry baryon number.

For hyperons emitted with positive (negative) rapidity, the correlation functions $C_{KH_{y>0}}^{\text{CBS}}(\Delta y)$ and $C_{KH_{y<0}}^{\text{CBS}}(\Delta y)$ are shown as blue and red markers, respectively, in Fig. 2. Their difference $C_{KH_{y>0}}^{\text{CBS}}(\Delta y) - C_{KH_{y<0}}^{\text{CBS}}(\Delta y)$ is plotted as black points, where peaks and nearby points are connected by red lines to highlight the contrast.

From Fig. 2a and Fig. 2c, one observes that at 39 GeV, $\Lambda_{y>0}$ preferentially correlates with slower kaons compared to $\Lambda_{y<0}$, while an opposite trend emerges at 62 GeV. This indicates that hyperons carrying the initial proton baryon number tend to correlate with faster kaons at higher energies, possibly because the initial protons experience more collisions

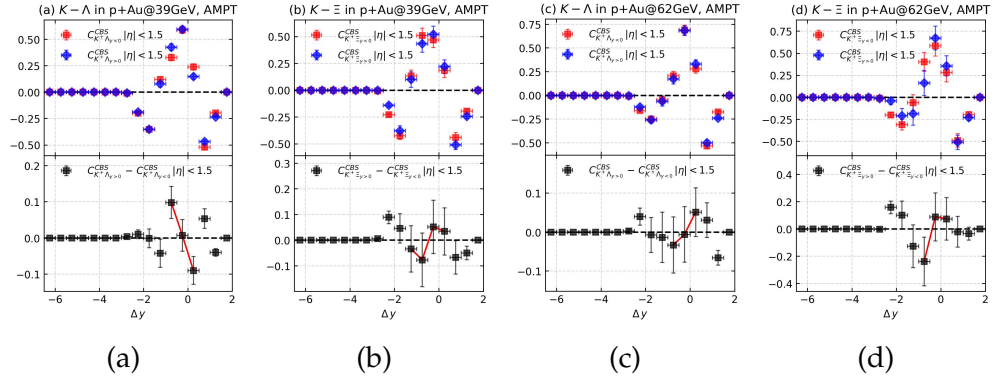


Fig 2: AMPT calculations of $K-\Lambda$ and $K-\Xi$ at 39 and 62 GeV.

than Au nucleons on average, resulting in stronger baryon stopping at higher energies. A similar trend is observed in UrQMD simulations, as shown in Fig. 3.

For Ξ , the behavior differs: in both energies, $\Xi_{y>0}$ correlates with faster kaons than $\Xi_{y<0}$, as seen in Fig. 2b and Fig. 2d. This suggests that hyperons containing more initial valence quarks (i.e., fewer valence s quarks) tend to correlate with slower kaons when carrying proton baryon number. This behavior is consistent with the valence-quark picture, since u and d quarks from the proton carry larger momentum and thus undergo less stopping, leading to a smaller rapidity gap between the final baryon and meson.

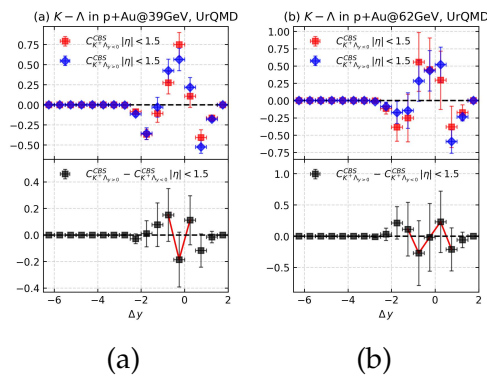


Fig 3: UrQMD calculations of $K-\Lambda$ at 39 and 62 GeV.

4. Conclusion and Outlook

Because $s\bar{s}$ quark pairs are produced during hadronization, kaon-hyperon correlations provide a sensitive probe of both hadronization dynamics

and baryon stopping. By comparing same-event and mixed-event distributions, we extract the correlation on relative rapidity using a new method based on $C_{KH}^{CBS}(\Delta y)$. In p+Au collisions, hyperons with positive rapidity are more likely to carry the initial proton baryon number, resulting in stronger baryon stopping, as demonstrated for $K-\Lambda$ and $K-\Xi$ at 39 and 62 GeV in both AMPT and UrQMD. We also observe that hyperons with fewer valence s quarks show weaker stopping, consistent with the valence-quark picture. These results serve as a useful baseline for future experimental studies and may help discriminate the baryon-junction mechanism. We therefore plan to apply this analysis to experimental data in upcoming work.

References

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