Measurement of Λ_c baryon production in Au+Au collisions at $\sqrt{s_{NN}} = 200\,\mathrm{GeV}$ with the STAR experiment

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In ultra-relativistic heavy-ion collisions, such as the ones carried out at Relativistic Heavy Ion Collider (RHIC), a new state of matter the so-called strongly-coupled quark-gluon plasma (sQGP) can be created [1]. Charm quarks are mainly produced in hard processes during the early stages of such collisions, since the charm quark mass is much larger than the temperature of the QGP which makes the thermal production improbable. Therefore, charm quarks experience the whole evolution of the medium and can be used to probe the properties of the hot and dense nuclear matter [2]. The Λ_c baryon [3] contains valence quarks u, d, and c, and is the lightest baryon containing a charm quark. As such, it presents a unique tool to study the charm quark hadronization in the medium. However, the extremely short proper life time ($\sim 60\,\mu\mathrm{m}/c$) of the Λ_c baryon makes the measurements experimentally challenging, especially in heavy-ion collisions where the background is large.

An enhancement of baryon-to-meson ratio has been observed for light hadrons in intermediate transverse momentum (p_T) range in central heavy-ion collisions at RHIC [4] and LHC [5]. This is illustrated in the left and middle panels of Fig. 2 where measurements of the p/π and Λ/K_s ratios at RHIC are shown and clear enhancements are seen for $2 < p_T < 4\,\mathrm{GeV}/c$. This phenomenon can be explained by the coalescence hadronization mechanism in which quarks combine with each other to form hadrons, as opposed to the fragmenation hadronization. If charm quarks also participate in the coalescence hadronization, an enhancement is expected for the Λ_c/D^0 ratio in heavy-ion collisions, and the right panel of Fig. 2 shows several theoretical estimates of such an enhancement [6–11].

Experimental setup

The Solenoidal Tracker at RHIC (STAR) [12] is a multi-purpose experiment with excellent particle identification capabilities at midrapidity. In particular, the Λ_c measurement was enabled by the Heavy Flavor Tracker (HFT) [13] upgrade that took data in the years 2014–2016. HFT is a vertex tracker that consists of 4 layers of silicon detectors with a track pointing resolution in the transverse plane about $20\,\mu\mathrm{m}$ for high-p_T particles. This was achieved using the MAPS technology in the two innermost layers of HFT.

Λ_c measurement in Au+Au collisions at STAR

The STAR experiment has measured the Λ_c baryon for the first time in heavy-ion collisions through the hadronic decay channel $\Lambda_c^\pm \to \pi^\pm K^\mp p^\pm$ with 2014 data. The topological cuts were optimized utilizing the Toolkit for Multivariate Analysis Package [14] with

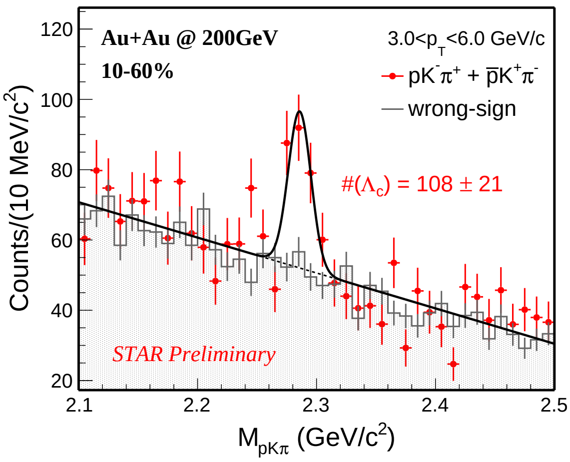

Fig. 1. Invariant mass spectrum of the p+K+π triplets in 10–60% central Au+Au collisions at $\sqrt{s_{NN}} = 200\,\mathrm{GeV}$ for $3\,\mathrm{GeV}/c < p_T < 6\,\mathrm{GeV}/c$.

training samples of signals produced from simulation and background from data. The invariant mass spectrum is shown in Fig. 1. The yield of the combinatorial background (shaded histogram) was calculated using π, K, and p triplets with wrong combinations of the charge sign.

A novel data-driven approach to evaluate HFT performance was developed. Λ_c were reconstructed in the p_T region of 3–6 GeV/c in 10–60% centrality bin. In this analysis, the efficiency correction of the yield was assessed using the data-driven simulations and the systematic uncertainties were obtained by varying the cuts simultaneously in the data analysis and efficiency estimation. The resulting ratio of $N(\Lambda_c^+ + \overline{\Lambda_c}^-)/N(D^0 + \overline{D^0}) = 1.31 \pm 0.26(\mathrm{stat.}) \pm 0.42(\mathrm{sys.})$, where the D^0 spectrum was measured in the same data sample.

Fig. 3 shows comparison of the measured ratio to several theoretical calculations. The scenario with no coalescence, shown as the green line obtained from PYTHIA [6]. The data are significantly above this scenario. The Statistical Hadronization Model (SHM), demonstrated by the gray rectangle [7, 16], underpredicts the data as well. The dashed lines show the Ko model with two coalescence scenarios [8]: one where the charm quark coalesces with a light di-quark structure and the other where all three quarks coalesce. No rescattering in the hadron gas is considered in these two scenarios. The data are consistent with both the di-quark and three-quark coalescence scenarios calculated for 0–5% centrality bin, which is different from that used in data. The Greco model, shown as the darker gray band, employs the three-quark coalescence mechanism, and calculates the diffusions of Λ_c and D^0 via an effective T-matrix approach [9–11]. Note that the denominator for this calculation is the sum of all

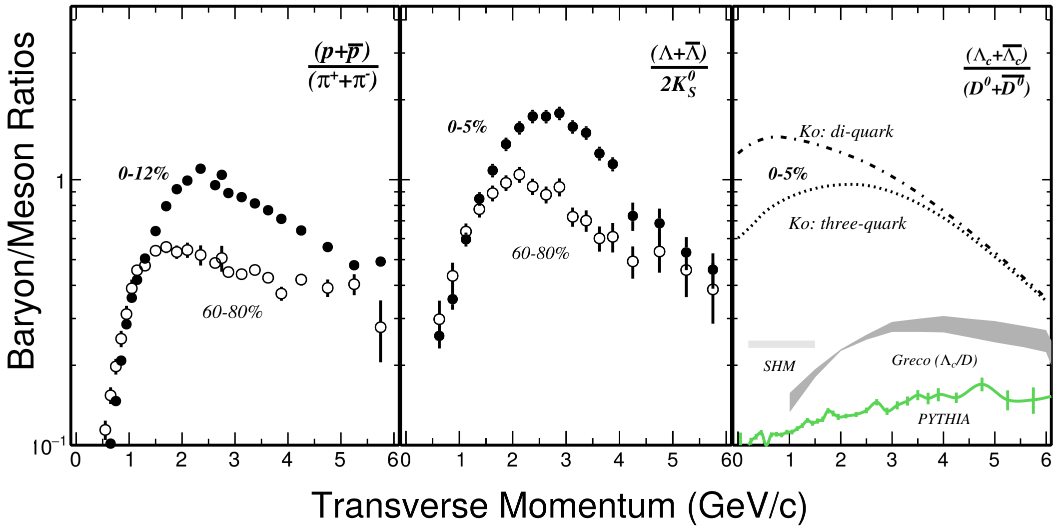

Fig. 2. Baryon-to-meson ratios vs. p_T in Au+Au collisions at $\sqrt{s_{NN}} = 200\,\mathrm{GeV}$ at STAR. Left: Ratio of the invariant yields of $(\mathrm{p}+\bar{\mathrm{p}})$ over $(\pi^+ + \pi^-)$ for the centralities 0–12% and 60–80% [4]. Middle: ratio of the yields of Λ over K^0_s for central (0–5%) and peripheral (60–80%) collisions. Right: Models of the ratio of Λ_c over D^0 [7, 8, 11].

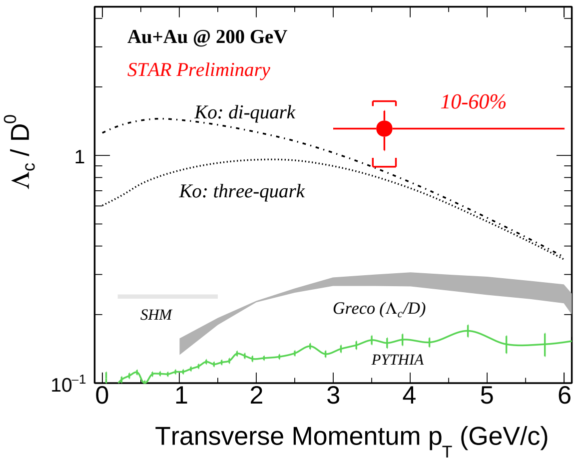

Fig. 3. Ratio of the yield of Λ_c over D^0 vs. p_T measured by STAR in 10–60% central Au+Au collisions, compared to various models [7, 8, 11].

D meson species rather than only D^0, and one expects it to increase if only D^0 meson was used as in data.

Conclusion and outlook

STAR has measured the Λ_c baryon for the first time in 10–60% central Au+Au collisions for $p_T = 3$–$6\,\mathrm{GeV}/c$ thanks to the addition of HFT. The Ko model, including coalescence of thermalized charm quarks, is consistent with data within uncertainties.

STAR recorded approximately twice more data in 2016 compared to 2014 with better performance of HFT. This will allow to measure the ratio of Λ_c to D^0 in more centrality and p_T intervals to place more stringent constraints on theoretical calculations.

Acknowledgements

This work has been supported by the Czech Technical University in Prague grant no. SGS16/238/OHK4/3T/14 and by the grant LG15001 of the Ministry of Education of the Czech Republic.

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