Identified hadron spectra and baryon stopping in $\gamma + \text{Au}$ collisions at STAR*

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Photonuclear collisions are one of the simplest processes possible in a heavy-ion collision. They occur when one nucleus emits a quasi-real photon which interacts with the other colliding nucleus, similar to an $e+A$ collision except that the photon tends to have a much smaller virtuality. Results are presented for identified $\pi^{\pm}$, $K^{\pm}$, and $p(\bar{p})$ spectra in photonuclear collisions at STAR for Au+Au collisions at $\sqrt{s_{NN}} = 54.4$ GeV. Significant baryon stopping and rapidity asymmetry are observed at low transverse momentum, which could indicate the existence of a baryon junction within the nucleon, a nonperturbative Y-shaped configuration of gluons which carries the baryon number and is attached to all three valence quarks. Measurements of identified particle spectra and their rapidity dependence in $\gamma + A$ events will give insights into the origin of baryon stopping and also inform future measurements of identified particles at the Electron-Ion Collider.

1. Introduction

Baryon stopping is a well-documented phenomenon in heavy-ion physics where more baryons than antibaryons are observed even at midrapidity [1]. Because the baryon number is strictly conserved, the excess baryons must come from the colliding nuclei and their lost kinetic energy allows for the large multiplicity of particles produced in heavy-ion collisions. The net baryon yield is often estimated through the net proton yield, which includes contributions from the decays of heavier baryons. One of the proposed mechanisms for inducing baryon stopping is the baryon junction: a nonperturbative Y-shaped configuration of gluons connected to all three valence quarks. In this model, the baryon junction, rather than the valence quarks, carries the baryon number. It is theorized to be an effective mechanism to stop baryons in both proton-proton and heavy-ion collisions [2], but this has yet to be confirmed experimentally.

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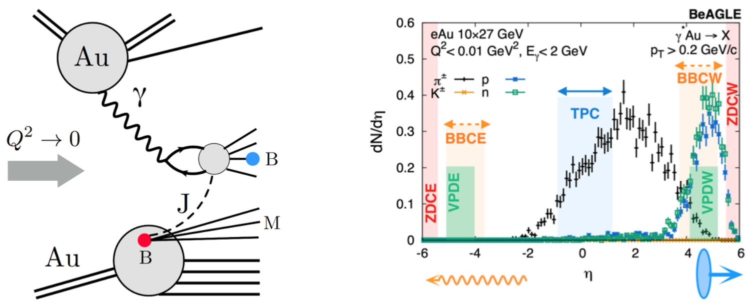

Fig. 1: (Left) A cartoon of a resolved photonuclear event [4], see text for details. (Right) The expected pseudorapidity distributions of particles in $\gamma + \mathrm{Au}$ events simulated using the BeAGLE event generator [5, 6].

Heavy ions traveling at ultrarelativistic speeds produce a large flux of quasi-real photons. In a photonuclear collision, a photon from one ion collides with the other ion causing it to break up. As depicted in Fig.1 (Left) [4], in the majority of cases the photon fluctuates into a $q\bar{q}$ pair that scatters off of the partons in the target nucleus, also known as the resolved process [3]. If the baryon number were carried by the three valence quarks, then this $q\bar{q}$ pair would not be able to stop the incoming target baryon (B) (pictured as the red dot). But if instead the junction (J) carried the baryon number, then the $q\bar{q}$ pair could slow the junction down and pull it to midrapidity. Because the junction is flavor blind, when it acquires new quarks from the vacuum this can result in a midrapidity baryon (B) (drawn as the blue dot) of a different flavor. The quarks of the initial target baryon then fragment into mesons (M), filling up the gap between midrapidity and the beam.

2. Selecting Photonuclear Events

This measurement uses data from Au+Au collisions with $\sqrt{s_{NN}} = 54.4$ GeV which was taken at STAR in 2017. Figure 1 (Right) shows simulated $e + A$ collisions generated by BeAGLE [5, 6] where the photon virtually ($Q^2 < 0.01$ GeV/c^2) and energy ($E_\gamma < 2$ GeV) are restricted and the ion energy is set to 27 GeV in order to reproduce the kinematics of photonuclear events in this data set. Photonuclear events are selected using the minimum bias trigger, which yielded a total of 700 million events and crucially did not require events to be symmetric across the forward detectors since the $\gamma + A$ collisions are highly asymmetric. The Zero Degree Calorimeters (ZDCs) select for events in which one neutron travels in the photon-going direction and multiple neutrons travel in the ion-going direction. The Beam-Beam Counters (BBCs) and Vertex Plain Detectors (VPDs) require no event activity on the photon-going side and some activity on the ion-going side.

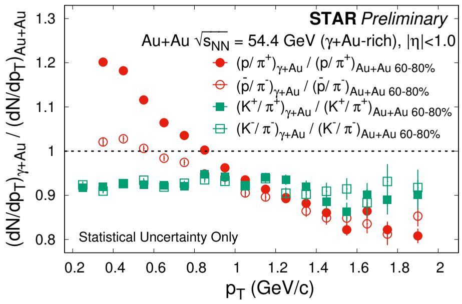

Fig. 2: Double ratios of K/π and p/π in $\gamma + A$ enriched events divided by the same ratio in peripheral $A + A$ events for $|\eta| < 1.0$.

Once these cuts are applied, the distribution of charged particle tracks in the Time Projection Chamber (TPC) is highly asymmetric similar to that shown in Fig. 1 (Right). As expected, the photonuclear events have very low multiplicity and so for a baseline comparison we study the particle spectra in peripheral events with a centrality of 60-80%.

3. Results

The identification of pions, kaons, and protons is done with the TPC and Time of Flight (TOF) detectors. Figure 2 shows the double ratios of K/π and p/π in the photonuclear enriched event sample divided by the same ratio in peripheral Au+Au events. This double ratio is constructed such that the tracking efficiency cancels out. The K/π double ratios are less than 1, which is consistent with there being less access to strangeness in photonuclear collisions compared to hadronic events. The p/π double ratios having a steeper slope in p_T compared to K/π is consistent with there being more radial flow in peripheral hadronic events. The striking feature of this plot is that the p/π^+ ratio is larger than the $\bar{p}/\pi^-$ ratio for $p_T < 1$ GeV/c, indicting the presence of soft baryon stopping in photonuclear events.

Figure 3 shows the double ratios of antiparticles to particles in photonuclear events divided by the same ratio in peripheral events. The pion and kaon ratios are flat with p_T and consistent with 1, while the $\bar{p}/p$ double ratio decreases at $p_T < 1$ GeV/c. As a function of rapidity, $\bar{p}/p$ double ratio is slightly bigger than 1 in the backward or photon-going direction, and less than 1 and progessively smaller with increasing rapidity at low p_T. It means that not only is there soft baryon stopping present in $\gamma + A$ events, it is a stronger effect than in hadronic collisions with similar multiplicities. This is possible evidence of a baryon junction existing within the nucleon.

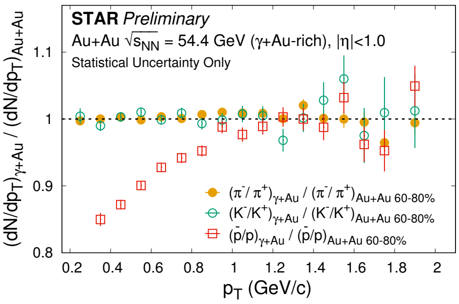

Fig. 3: The antiparticle to particle double ratio in $\gamma + A$ enriched events divided by the same ratio in peripheral $A + A$ events for $|\eta| < 1.0$.

4. Summary

Identified particle spectra are measured in photonuclear collisions at the STAR experiment using Au+Au collisions at $\sqrt{s_{NN}} = 54.4$ GeV. These photonuclear events are selected by a combination of cutting on the number of neutrons in the ZDC and the event activity close to the beam line. Significant baryon stopping is measured at low p_T, indicating the existence of a baryon junction within the nucleon. These results can inform future measurements of baryon stopping in electron-ion collisions at the upcoming Electron-Ion Collider, assuming the ability to cleanly identify protons and antiprotons at low momentum.

REFERENCES

[1] I.C. Arsene (BRAHMS Collaboration), Nuclear stopping and rapidity loss in Au+Au collisions at $\sqrt{s_{NN}} = 62.4$ GeV, Phys. Lett. B **677**, 267 (2009).

[2] D. Kharzeev, Can gluons trace baryon number?, Phys. Lett. B **378**, 238 (1996).

[3] C. A. Bertulani, S. R. Klein, and J Nystrand, Physics of ultra-peripheral nuclear collisions, Ann. Rev. Nucl. Part. Sci. **55**, 271 (2005)

[4] J. D. Brandenburg *et al*, Search for baryon junctions in photonuclear processes and isobar collisions at RHIC, arXiv 2205.05685

[5] BeAGLE: a Tool to Refine Detector Requirements for *eA* Collisions EIC R&D; Project eRD17 E. Aschenauer, M. Baker, W. Chang, J. Lee, Z. Tu et al. https://wiki.bnl.gov/eic/index.php/BeAGLE.

[6] Z. Tu, Probing short-range correlations in the deuteron via incoherent diffractive J/ψ production with spectator tagging at the EIC, Phys. Lett. B **811**, 135877 (2020)