Λ Production at High Rapidity in d+Au Collisions at \( \sqrt{s_{NN}} = 200 \text{ GeV} \)

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We present first preliminary studies of Λ and \( \bar{\Lambda} \) production in the pseudorapidity region \( 2.5 < |\eta| < 4 \), covered by the forward radial-drift TPCs (FTPCs) in STAR. The FTPCs provide momentum and charge determination but no particle identification, making the use of combinatorial methods and background subtraction necessary for \( \Lambda \) identification.

The \( \Lambda/\bar{\Lambda} \) ratio measured at high rapidity is compared to the ratio obtained at mid-rapidity with the STAR TPC. Differences in the ratio at positive and negative rapidity point to an asymmetry in particle and antiparticle production in d+Au collisions.

These results have been presented as a poster at Quark Matter 2004 in Oakland, California.

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I. INTRODUCTION

In relativistic heavy ion collisions at the highest available RHIC energies, the ratio of yields of antiparticles to particles reaches the highest values yet observed. Even the baryon ratios \( p/p \) and \( \Lambda/\bar{\Lambda} \) reach values near unity, indicating an almost net baryon free environment at mid-rapidity. The antiparticle to particle ratios are observed to be flat as a function of rapidity \( (y) \) close to mid-rapidity [1, 2].

Away from mid-rapidity, the baryon content of the beam nuclei comes into play, and, in addition to particle–antiparticle pair production, other processes contribute significantly to the particle production. Measurements by the BRAHMS collaboration [1] show a significant drop of \( p/p \) in Au+Au collisions starting at \( y \sim 1 \). In asymmetric collision systems, measurements at lower energies by NA49 with p+Pb collisions show different contributions of baryon number transfer for projectile and target rapidity regions due to multiple collisions suffered by the projectile nucleon, but not by the target [3].

In the present paper, first preliminary measurements of \( \Lambda/\Lambda \) at \(|y| \sim 2.7\) in d+Au collisions are presented.

II. DETECTOR AND ANALYSIS TECHNIQUE

The two radial–drift forward time projection chambers (FTPCs) [4] of the STAR [5] experiment permit the study of charged hadrons at forward rapidity in heavy ion collisions. This extends the acceptance of the spectrometer towards the fragmentation region and gives access to phenomena away from mid–rapidity. However, the FTPCs measure a maximum of 10 hits per track, which makes particle identification via energy loss measurements impossible with the current state of detector calibrations.

The two FTPCs west (positive rapidity) and east (negative rapidity) of the interaction point in STAR are well located to study asymmetries in d+Au collisions. In the 2003 d+Au beam time, the deuterons were entering STAR from the east, gold from the west. Hence the particle multiplicity in FTPC east is higher than in west,
since particles produced from the gold nucleons preferentially continue towards the east.

Since the measurable decay mode of the Λ is $Λ \to p \pi$ (with a branching ratio of 64%), the lack of particle identification makes the use of all positive particles as $p$ candidates for the $Λ$ case or all negative particles as $\bar{p}$ for the $\bar{Λ}$ case necessary. This introduces a considerable background to the measurement. Strict geometric cuts on the assumed daughter tracks and the resulting Λ candidate help to reduce the background. The most important cuts were on the distance of closest approach (dca) to the primary vertex of the daughters, which should be relatively small for the $p$ candidate and large for the $π$ candidate, and cuts on the dca and the decay length of the resulting Λ candidate.

The major source of background remaining after these cuts is estimated to be from $K_0^0 \to π^+π^−$, where one of the two daughter pions is assumed to be a proton. For the current analysis a full GEANT detector simulation with a HIJING [6] generated $K_0^0$ distribution in $p_t$ and $y$ was used to predict this background produced by making the wrong mass assumption for one of the two daughters.

Although the analysis presented here does not correct the yields for acceptance and efficiency, simulation studies show that the corrections for $Λ$ and $\bar{Λ}$ are equal to first order. This permits the calculation of antiparticle to particle ratios without the knowledge of the absolute yield. The resulting ratios are not corrected for absorption or annihilation of the $Λ$ or its daughter particles in the detector material. Due to the high momentum of the particles in forward direction, absorption effects are small. Simulations show them to be less than 2%, which is of the same order as the statistical error of the study.

### III. ANALYSIS RESULTS

For the current analysis, a sample of 10.6 million d+Au minimum bias events with a reconstructed primary vertex within 50 cm of the nominal interaction point are used.

With the assumption that all candidates that pass the cuts are actually Λs, their rapidity can be calculated. This still includes all background that remains after the geometrical cuts. Figure 2 shows the total rapidity acceptance of the analysis for both detectors and the used range within ± 0.25 of the mean rapidity ($y$).

The rapidity slice used for the analysis is limited to 0.5 units because HIJING simulations predict a strong rapidity dependence of $Λ/Λ$ in the region of interest, which would affect the measurement if a wide range of rapidities is included in one bin. In addition, the $p_t$ acceptance of the FTPCs is constant as a function of the pseudorapidity $η$, not as a function of $y$. In a wide analysis window in $y$ the covered $p_t$ changes considerably over the selected $y$ range, and a possible $p_t$ dependence of the ratio would make the interpretation of the results more difficult, especially if this dependence is different for the deuteron and the gold side of the collision.

Figure 2(a) shows in black the invariant mass distribution of all positive–negative pairs with $0.4 \text{ GeV/c} < p_t < 1.5 \text{ GeV/c}$ that fulfill the geometric cuts in FTPC west with the assumption that positive tracks are protons and negative tracks are pions. The red curve is the estimated background from wrongly identified Kaons, which is normalized to the integral of the invariant mass distribution in the range from 1.3 GeV/c$^2$ to 2.0 GeV/c$^2$.

This background is subtracted bin by bin and leads to the $Λ$ and $\bar{Λ}$ invariant mass distributions shown for both detectors in figure 2(b) and 2(c). The widths of the peaks are in agreement with simulations and due to the limited momentum resolution of the FTPCs, especially for tracks not originating from the primary vertex. From these invariant mass distributions the uncorrected yields and the statistical errors for $Λ$ and $\bar{Λ}$ at forward and backward rapidity are determined by summing all bins $1.08 \text{ GeV/c}^2 < M_{inv} < 1.18 \text{ GeV/c}^2$.

The systematic errors have not been investigated in detail yet. From a variation of cuts and background
estimations they are predicted to be 0.12 for this preliminary analysis. Since possible remaining background contributions tend to be equal for $\Lambda$ and $\bar{\Lambda}$, an asymmetry of the systematic errors towards lower values of the ratio appears likely, but has not yet been thoroughly investigated. The derived antiparticle to particle ratios are compared with the ratios given by the HIJING event generator.

The mean rapidity of $\Lambda$ and $\bar{\Lambda}$ candidates on the deuteron side (FTPC W) is $\langle y \rangle = 2.69$. The analysis yields a ratio of $\frac{\bar{\Lambda}}{\Lambda} = 0.58 \pm 0.02\text{(stat)} \pm 0.12\text{(syst)}$. On the gold side (FTPC E) $\langle y \rangle = -2.72$, with a ratio $\frac{\bar{\Lambda}}{\Lambda} = 0.71 \pm 0.02\text{(stat)} \pm 0.12\text{(syst)}$.

Figure 3 shows $\frac{\bar{\Lambda}}{\Lambda}$ from HIJING without taking detector effects into account. It has been shown by measurements in Au+Au collisions at $\sqrt{s_{NN}} = 130$ GeV that the pure HIJING model tends to understate the influence of baryon number transport, and thus overestimates the antibaryon/baryon ratio. Overlaid in red are the STAR points, the mid-rapidity value being 0.84, determined from a preliminary analysis of main TPC data. The data show good agreement with HIJING on the deuteron side, while on the gold side, HIJING appears to overestimate the ratio.

$\frac{\bar{\Lambda}}{\Lambda}$ shows a significant drop at high rapidity, probably due to baryon number conservation and fragmentation contributions to the $\Lambda$ production. The asymmetry of the ratio in the highly asymmetric collision system may be caused by different contributions of pair production and baryon number transport in the projectile and the target region. While the participating nucleons in the gold nucleus typically suffer only a single collision each, the nucleons from the deuteron participate in multiple collisions as they pass through the gold nucleus. This can lead to increased baryon number transport from the deuteron region towards mid-rapidity and thus results in a decrease of $\frac{\bar{\Lambda}}{\Lambda}$ in the studied rapidity range.

IV. CONCLUSION

First preliminary measurements of $\frac{\bar{\Lambda}}{\Lambda}$ at high rapidity in d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV using the forward TPCs of the STAR experiment have been presented. An asymmetry between the deuteron and the gold side of the collision is seen, indicating different contributions of antiparticle and particle production mechanisms and baryon number transport in the forward region. In general, the ratios at high rapidity are lower than at mid-rapidity.

Future studies will compare to a wider range of theoretical models and use a variety of background models and cut sets. A binning of the analysis in collision centrality, rapidity or $p_t$ might also be feasible.

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