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Study of the $\Lambda(1116)$ interaction in cold nuclear matter

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Abstract. The interaction of Λ hyperons with baryonic nuclear matter at saturation density is expected to be attractive. The interaction strength was extracted from hypernuclei data. A different approach to obtain the potential depth of the Λ mean-field potential is to compare experimental data with transport simulations. We analyze experimental data of Λ hyperons measured with the HADES detector in p+^{93}Nb reactions with a kinetic beam energy of 3.5 GeV carried by the proton. The high statistic of measured Λ hyperons allows us to perform a double differential analysis in Lorentz-invariant observables of transverse momentum and rapidity. We present the analysis method and a comparison with simulations.

1 Introduction

The interaction of hyperons such as Λ, Σ, Ξ in a nuclear environment may have a strong overlap with astrophysics observables. There are models [1] predicting that because of energetically reasons it is favorable that a conversion of nucleons to hyperons via the weak interaction takes place in high density regions, like in the core of neutron stars. The appearance of additional degrees of freedom at high densities leads, eventually, to a softening of the nuclear equation of state. Such a softening implicates lower neutron star masses. Microscopic models with hyperon content can predict neutron star masses and be compared to a recent finding of a two solar mass neutron star [2]. These models use as an input and starting point the hyperon-nucleon interaction strength at saturation density and extrapolate to higher densities. For Λ hyperons the interaction strength was deduced from hypernuclei [3] measurements with a result of $U_{\Lambda N}(\rho = \rho_0)_{k=0} \approx -30$ MeV.

The in-medium modification of Λ hyperons should result in slightly different kinematics as compared to vacuum. To find such effects we compare our experimental kinematic observables with transport calculations.

The Λ hyperon was measured with the HADES setup [4]. We collected around $4 \cdot 10^9$ events for the p+^{93}Nb reaction at a beam kinetic energy of 3.5 GeV. Because of the large detector acceptance we were able to extract a high statistic Λ sample.

2 The method to analyze Λ hyperons

2.1 Λ identification

The Λ hyperon was reconstructed with the charged decay products p and π^- ($\Gamma_{p\pi^-}/\Gamma_{tot} = 63.9\%$), which were identified with graphical cuts in the energy-loss versus momentum spectrum which can be

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seen in Figure 1. To enlarge the Λ signal and reduce the combinatorial background of non Λ channels we applied the following three classes of secondary off-vertex cuts:
(1) distance between the Λ production vertex (PV) and the secondary decay vertex (SV) $d(|SV - PV|) >$ 43 mm,
(2) distance between the proton and the pion track $d(|p - \pi^-|) < 10$ mm,
(3) distance of closest approach of the proton and the pion track to the primary vertex $d(\pi^- - PV) >$ 10 mm and $d(p - PV) > 4$ mm. The resulting invariant mass spectrum is shown in Figure 2. With

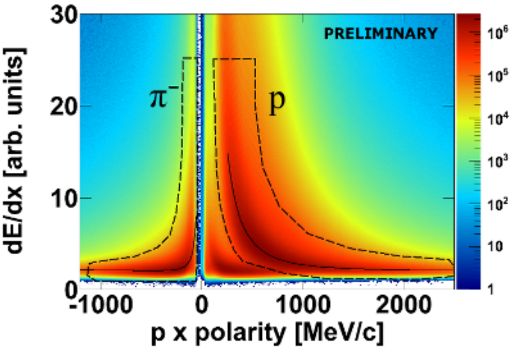

Figure 1. Particle identification of p and π^- with graphical cuts. Cuts were performed around theoretical Bethe-Bloch curves (solid lines).

the applied cuts we get about ~ 1.1M Λ's and a signal to background ratio of 0.85. The high statistic allows us to perform a double differential analysis in transverse momentum $p_t = (p_x^2 + p_y^2)^{1/2}$ ($0 < p_t < 975$ MeV/c, $\Delta p_t = 75$ MeV/c) and rapidity $y = \tanh^{-1}(p_z/E)$ in the nucleon-nucleon center of mass frame (CM) ($-1 < y_{CM} < 0.2$, $\Delta y_{CM} = 0.2$).

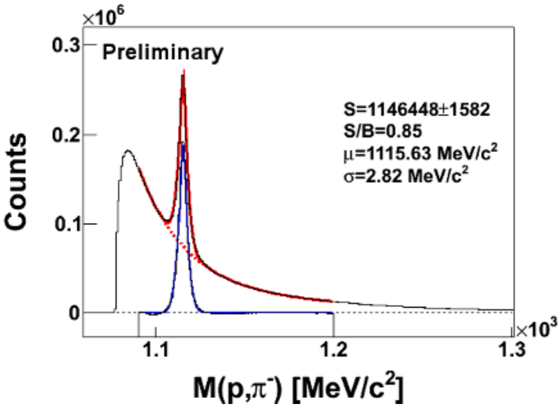

Figure 2. Invariant mass spectrum for p and π^- fitted with two Gaussian, a Landau, and a polynomial function.

2.2 Acceptance and efficiency correction

The extracted Λ yield was measured with the HADES detector, which has a certain geometrical acceptance and reconstruction efficiency including tracking efficiency, secondary off-vertex cuts and particle identification. To correct our data for such effects we generated Λ's with the UrQMD transport code [5] [6]. The simulated data was processed through the full analysis chain to model the HADES detector performance. This procedure allows us to obtain losses for every phase-space bin $\mathrm{d}N/\mathrm{d}p_t\mathrm{d}y_{CM}$ and correct for it.

3 Preliminary results

After acceptance and efficiency correction we compared our data with GiBUU (v1.5.0) [7] and UrQMD (v3.3p1) transport model calculations in 13 transverse momentum and 6 rapidity bins (an example of one specific rapidity bin in $-0.8 < y_{CM} < -0.6$ is given in Figure 3). The data was absolutely normalized to the total cross section, which is in the experimental case $\sigma_{tot} = 848$ mb for p+Nb reactions at 3.5 GeV. The GiBUU model clearly underestimates the experimental Λ yield whereas the UrQMD model predicts a too large Λ contribution.
The experimental data points were fitted with a Boltzmann-like function, to extrapolate to the low p_t region where we have in some phase space regions no data points due to the finite HADES polar acceptance of $\Theta > 15°$. With the summation of our data points and integration of the function in low p_t for every rapidity bin, we extract the rapidity-density distribution illustrated in Figure 4. One can see that the Λ yield increases continuously by going from large rapidities $y_{CM} \sim 0.5$ to lower ones $y_{CM} \sim -1$. In comparison to symmetric heavy ion collisions A+A, where the rapidity-density distribution is centered symmetrically around $y_{CM} = 0$, the experimental Λ yield is shifted to lower rapidities in comparison to the nucleon-nucleon mid-rapidity $y_{CM} = 0$, which is a sign for rescattering and stopping processes in the asymmetric p+Nb system. Transport models should reproduce such effects. By comparing the transport predictions with our data, we see that the GiBUU model predicts a nearly flat yield for lower rapidities. The UrQMD model is able to describe the trend of our data, but overshoots the experimental yield.

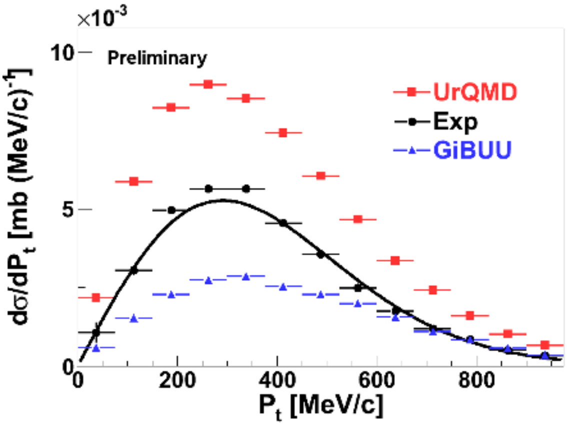

Figure 3. Transverse momentum distribution of Lambdas compared to model predictions of GiBUU and UrQMD in the rapidity range $-0.8 < y_{CM} < -0.6$.

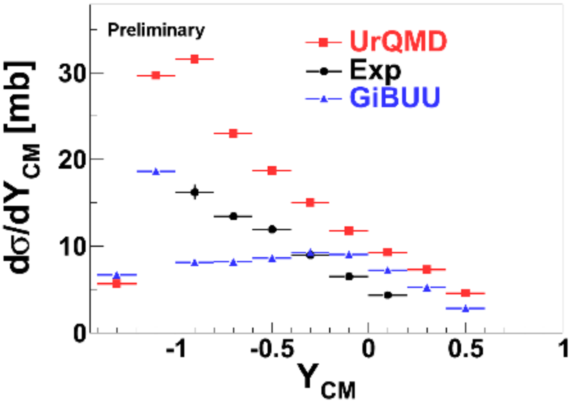

Figure 4. Rapidity-density distribution for experimental data and comparison to UrQMD and GiBUU predictions.

4 Summary and Outlook

We presented a study of an inclusive experimental Λ analysis performed in a p+^{93}Nb reaction, at a beam energy of 3.5 GeV measured with the HADES detector. The identification of charged particles and the reconstruction of Λ hyperons was shown. The data was corrected for acceptance and efficiency with help of the UrQMD model, and compared to predictions of transport models. The models showing discrepancies in describing our data.

The next step in our analysis is to understand this discrepancies and tune the models such that they match our data. The final goal is then to study in-medium modifications of the Λ hyperon in the Nb-system with help of tuned models.

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