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Σ^0 production in proton nucleus collisions near threshold

HADES Collaboration

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The production of Σ^0 baryons in the nuclear reaction p (3.5 GeV) + Nb (corresponding to $\sqrt{s_{NN}} = 3.18$ GeV) is studied with the detector set-up HADES at GSI, Darmstadt. Σ^0s were identified via the decay $\Sigma^0 \to \Lambda\gamma$ with subsequent decays $\Lambda \to p\pi^-$ in coincidence with a e^+e^- pair from either external ($\gamma \to e^+e^-$) or internal (Dalitz decay $\gamma^* \to e^+e^-$) gamma conversions. The differential Σ^0 cross section integrated over the detector acceptance, i.e. the rapidity interval $0.5 < y < 1.1$, has been extracted as $\Delta\sigma_{\Sigma^0} = 2.3 \pm (0.2)^{stat} \pm \left(^{+0.6}_{-0.6}\right)^{sys} \pm (0.2)^{norm}$ mb, yielding the inclusive production cross section in full phase space $\sigma^{total}_{\Sigma^0} = 5.8 \pm (0.5)^{stat} \pm \left(^{+1.4}_{-1.4}\right)^{sys} \pm (0.6)^{norm} \pm (1.7)^{extrapol}$ mb by averaging over different extrapolation methods. The Λ_{all}/Σ^0 ratio within the HADES acceptance is equal to $2.3 \pm (0.2)^{stat} \pm (^{+0.6}_{-0.6})^{sys}$. The obtained rapidity and momentum distributions are compared to transport model calculations. The Σ^0 yield agrees with the statistical model of particle production in nuclear reactions.

1. Introduction

The study of hyperon production in proton-induced collisions at beam energies of a few GeV is important for many open questions in the field of hadron physics. While several experimental results exist for Λ hyperons in p+p and p+A reactions [1–6], measurements of Σ^0 production are scarce [4–6]. The dominant electromagnetic decay $\Sigma^0 \to \Lambda + \gamma$ (BR $\approx$ 100%) requires the identification of photons with $E_\gamma \simeq 80$ MeV coincident to the detection of pπ^- pairs from Λ decays. Our measurement is the first step towards gaining access to the hyperon electromagnetic form factors [7]. Once the measurement of virtual photons in the Dalitz decay $\Sigma^0 \to \Lambda e^+e^-$ (BR $<$ 1%) is performed it can be separated from the decays involving a real photon and therefore provide complementary information on the nucleon and Δ baryon form factors [8].

Hadron collisions at energies of a few GeV with hyperons in the final state are also suited to study the role played by intermediate hadronic resonances in the strangeness production process. Indeed, non-strange resonances like N* and Δ have been found to contribute significantly [9–13] via the channels $N^* \to \Lambda + K^+$ and $\Delta^{++} \to \Sigma(1385)^+ + K^+$. In case of N*, up to seven resonances with similar masses and widths have been identified including the occurrence of interference effects among them [2,14]. In this context, the simultaneous measurement of Λ and Σ hyperons becomes important to understand the interplay between the spin 1/2 and 3/2 states occurring in the strong conversion process $\Sigma + N \to \Lambda + N$. This process manifests itself as a peak structure on top of the smooth $\Lambda + p$ invariant-mass distribution close to the Σ–N threshold and is known to be responsible for cusp effects [15]. Hyperon production in nuclear reactions gives also access to details of the hyperon–nucleon interaction. The existence of Λ hypernuclei is argued as evidence for an attractive potential at rather large inter-baryon distances [16,17]. Theoretical models [18] trying to describe scattering data [19,20] with hyperon beams postulate the presence of a repulsive core for the Λ–N interaction. Σ^0 hypernuclei, on the other hand, have not been observed so far due to difficulties implied by the electromagnetic Σ^0 decays and the requirement of large acceptance and high resolution electromagnetic calorimeters. Since also scattering data for Σ hyperon beams are scarce, constraints on the Σ–N interaction are missing so far and new measurements of Σ^0 production in nuclear targets are essential.

Medium-energy heavy-ion collisions producing hyperons allow to study their properties within a dense baryonic environment (up to $\rho \approx 2-3\rho_0$) [21–24]. One question of interest is whether the attractive Λ–N interaction in vacuum or at nuclear saturation might change due to the postulated appearance of a more dominant repulsive core at increased densities and short distances [25]. The quest for detailed information on such aspects requires the knowledge of Λ feed down effects from Σ^0 production and its corresponding behaviour in baryonic or even cold nuclear matter.

Experimental data for simultaneous Σ^0 and Λ production are available for proton–proton collisions either close to the free NN production threshold ($E_{th} = 2.518$ GeV for Λ and $E_{th} = 2.623$ GeV for Σ^0) [4,5] or at excess energies of $\simeq 5$ GeV and above [26]. So far, no data are available for Σ^0 hyperons emerging from proton + nucleus collision systems at few GeV incident beam energy. In this work we present the first measurement of Σ^0 production in p + Nb collisions at an incident kinetic beam energy of $E_p = 3.5$ GeV. Our paper is organised as follows. In section 2, we describe the experimental set-up. Section 3 is devoted to Σ^0 identification and background subtraction. In section 4 the method for efficiency correction and differential analysis is shown. In section 6 the extracted cross sections and yields are compared to different models. In sections 6 we give a summary and short outlook.

2. The HADES experiment

The High-Acceptance Di-Electron Spectrometer (HADES) [27] located at the GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt (Germany) is an experimental facility for fixed target nuclear reaction studies in the few GeV energy region. The spectrometer is dedicated to measure low-mass dielectrons originating from the decay of vector mesons in the invariant-mass range up to the ϕ mass and offers excellent identification by means of charged hadrons such as pions, kaons and protons. The detector setup covers polar angles between 18° to 85° over almost the full azimuthal range designed to match the mid-rapidity region of symmetric heavy ion collisions at E = 1–2 AGeV. A set of multi-wire drift chamber (MDC) planes arranged in a sixfold segmented trapezoidal type structure, two layers in front and two behind a toroidal magnetic field, is used for charged-particle tracking and momentum reconstruction with a typical resolution of $\Delta p/p \simeq 3\%$. An electromagnetic shower detector (Pre-Shower) and a Time-Of-Flight scintillator wall (TOF and TOFINO) build the Multiplicity and Electron Trigger Array (META) detector system used for event trigger purposes. The energy loss (dE/dx) signals measured in the TOF and MDC detectors are used for charged particle identification. In addition, electrons and positrons are identified over a large range of momenta with a Ring Imaging Cherenkov (RICH) detector surrounding the target in a nearly field-free region.

In the present experiment, a proton beam accelerated by the SIS18 synchrotron to a kinetic energy of $E_p = 3.5$ GeV has been

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