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Hypernuclear production cross section in the reaction of ^{6}Li + ^{12}C at 2 A GeV

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ABSTRACT

Hypernuclear production cross sections have been deduced for the first time with induced reaction of heavy ion beam on fixed target and by means of the invariant mass method by the HypHI Collaboration exploiting the reaction of ^{6}Li + ^{12}C at 2 A GeV or $\sqrt{s_{NN}} = 2.70$ GeV. A production cross section of 3.9 ± 1.4 μb for ${}^{3}_{\Lambda}$H and of 3.1 ± 1.0 μb for ${}^{4}_{\Lambda}$H respectively in the projectile rapidity region was inferred as well as the total production cross section of the Λ hyperon was measured and found to be equal to 1.7 ± 0.8 mb. A global fit based on a Bayesian approach was performed in order to include and propagate statistical and systematic uncertainties. Production ratios of ${}^{3}_{\Lambda}$H/${}^{4}_{\Lambda}$H, ${}^{3}_{\Lambda}$H/Λ and ${}^{4}_{\Lambda}$H/Λ were included in the inference procedure. The strangeness population factors S_3 and S_4 of ${}^{3}_{\Lambda}$H and ${}^{4}_{\Lambda}$H respectively were extracted. In addition, the multiplicities of the Λ hyperon, ${}^{3}_{\Lambda}$H, and ${}^{4}_{\Lambda}$H together with the rapidity and transversal momentum density distributions of the observed hypernuclei were extracted and reported.

1. Introduction

Reactions between complex nuclei have been a powerful tool to investigate subatomic structures as well as chemical properties of nuclear matter. In relativistic heavy ion collisions, the gen-

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eral feature of the reaction is well described by the participant-spectator concept [1]: the participant nucleons in the overlap region between the two colliding nuclei enter in collision, while the spectator nucleons in the non-overlapping regions pass by each other without interacting. Many hadrons are produced in the hot participant zone, and widely distributed between the target and projectile rapidities [2,3]. Hadrons from this hot participant zone may interact with the spectators and can be captured by the spectator fragments [4,5]. The spectator fragments or produced hadrons can be excited to unstable particles and later decay to their ground states by emitting particles and/or γ-rays.

Laying the nucleon–nucleon Λ threshold at 1.58 GeV [6,7], the wide rapidity distribution of produced Λ-hyperons can overlap with those of the projectile and the target spectators. Thus, the Λ-hyperon can be combined to a spectator fragment, and a Λ-hypernucleus can be produced in projectile or target rapidity regions [8]. The experimental viability of the hypernuclear spectroscopy is assessed by the order of magnitude of the production cross section. Additionally, their production cross section is a crucial physical observable which can provide more global understanding of the heavy ion collisions involving both participants and spectators at intermediate energies.

The first attempt to produce hypernuclei in the projectile rapidity regime was made with ^{16}O beams at 2.1 *A* GeV on a polyethylene target [9] estimating a hypernuclear cross section of the order of μb. Later, in the reaction of a beam of ^{4}He at 3.7 *A* GeV and ^{7}Li at 3.0 *A* GeV on a polyethylene target the cross section of $^{4}_{\Lambda}$H of 0.4 μb was estimated [10,11]. Those first experimental estimations of the production cross section do not agree on the magnitude of the cross sections, and a clear conclusion could not be stated due to the small number of light hypernuclei observed in both cases. Those rough estimations were then compared with the theoretical calculations within a simple coalescence model [8,12–14]. However, the identification of produced hypernuclei was ambiguous since the invariant mass of the final states was not measured. Subsequently, central collisions of platinum projectiles at 11.5 *A* GeV/c on a gold target were used to produce and identify $^{3}_{\Lambda}$H (hypertriton) and to estimate the upper limit for the observation of $^{4}_{\Lambda}$H hypernuclei [15]. Recently, the STAR Collaboration used gold–gold collisions at $\sqrt{s_{NN}} = 200$ GeV to study hypertriton and anti-hypertriton [16,17], followed by the observation of the ALICE Collaboration of those both hypernuclei in the lead–lead collisions at $\sqrt{s_{NN}} = 2.76$ TeV [18,19]. Those experiments observed hypernuclei in the mid-rapidity region and in ultra-relativistic heavy ion collisions, where the hypernuclei are formed by sudden hadronization at the chemical freeze-out. Therefore they provide information on the production mechanism in the hot participant zone that is described theoretically by statistical hadronization models [20,21].

The hypernuclear production at intermediate energy has also been studied theoretically in addition to the statistical models of the ultra-relativistic energy, by employing a phase space coalescence model [22,23] and Fermi-break up of excited hypernuclear spectators [24]. Yet the extremely scarce experimental data currently available do not restrain those models. One has to also notice that first theoretical work from [8,12–14] and updated calculations [22–24] differ by order of magnitude on the prediction of the hypernuclear production cross sections.

Recently, the HypHI Collaboration has observed the production of light hypernuclei, $^{3}_{\Lambda}$H and $^{4}_{\Lambda}$H in a reaction with ^{6}Li projectiles impinging on a graphite (^{nat}C) target [25]. The production cross section of $^{3}_{\Lambda}$H and $^{4}_{\Lambda}$H should provide information on the production mechanism of hypernuclear spectators since hypernuclear matter is expected to stem from the participant and spectator regions. Performing hypernuclear spectroscopy in the spectator region has also an advantage of a better observation efficiency

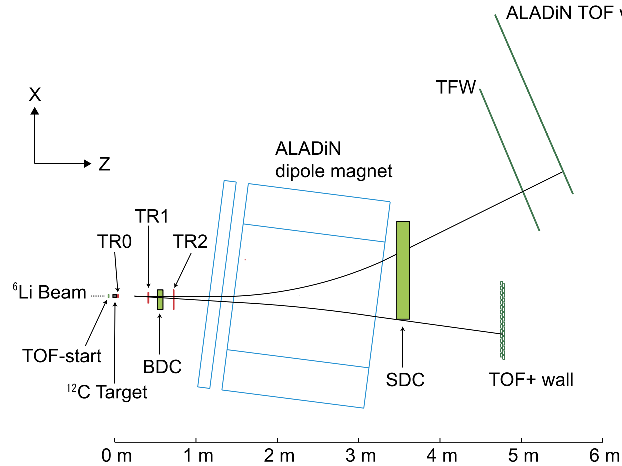

Fig. 1. Layout of the experimental setup.

compared to the heavy ion experiment studying the mid-rapidity region. During the data collection, over 3.5 integrated days, the final estimation of the integrated luminosity is 0.054 pb^{-1}, in which several hundreds of hypernuclei were observed. We have deduced the cross section of $^{3}_{\Lambda}$H and $^{4}_{\Lambda}$H for the first time with unique identification of those hypernuclei produced by ^{6}Li projectiles.

In this Letter, we provide the information on the cross section of these hypernuclei, together with the Λ production cross section and the yield ratio of the different species. The *strangeness population factors* S_3 and S_4 are reported. The multiplicity per collision of those species and the observed hypernuclear rapidity in the center-of-mass system, $y0 = y/y_{CM} - 1$, and transversal momentum, Pt, density distribution are also presented.

2. Experimental apparatus

The experiment was performed with ^{6}Li projectiles at 2 *A* GeV with an intensity of 3×10^{6} ions per second bombarding on a graphite (^{nat}C) target with a thickness of 8.84 g/cm^{2}. As discussed in [25], the experimental apparatus, shown in Fig. 1, consisted of three tracking stations of scintillating fiber detector arrays (*TR0, TR1, TR2*) and two drift chambers (*BDC, SDC*) for the displaced vertex measurement. As well, three scintillating hodoscope walls (*TOF+, TFW, ALADiN TOF*) were appended to the tracking systems for tracking, energy loss and time-of-flight measurements of charged particles across a large acceptance dipole magnet. The tracking system for vertexing was placed in front of the dipole magnet around the expected decay volume of hypernuclei, while the *SDC* drift chamber was mounted behind the magnet. Two detached detection branches consisting of *TOF+* and *TFW & ALADiN TOF* hodoscope walls were situated behind the magnet as such to measure separately positively and negatively charged particles, respectively.

At the trigger level, the event topology was selected in order to record potential events containing a Helium isotope and a π^- stemming from a displaced vertex. The displaced vertex trigger used the information of *TR0*, *TR1* and *TR2* fiber detector arrays that were placed around the decay volume of hypernuclei and Λ hyperons. The Helium isotope trigger used the time-over-threshold measurement of the energy loss from the *TOF+* hodoscope wall dedicated solely for the positively-charge particles and fragments. The π^- trigger involved the hit detection on the *TFW* hodoscope wall dedicated exclusively for π^- detection behind the dipole magnet. This topological combination at hardware level was exploited in order to cope with the large difference of magnitude between the hypernuclear production cross section and the total reaction cross section. During the trigger design, a difference of