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Production of exotic hypernuclei from excited nuclear systems

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Abstract

Hybrid approaches including dynamical and statistical stages, which were previously developed for description of fragmentation of conventional nuclei, can explain production of hypernuclei emitted from projectile residues in relativistic ion collisions. These reactions proceed via formation of intermediate moderately-excited hypernuclear systems, which decay into conventional nuclei and hyperfragments. With a similar reaction mechanism one can also obtain weakly-bound exotic hypernuclei (such as Λn and H-dibaryons), which may not be easily accessible in other processes.

Keywords: Hypernuclei; Peripheral relativistic collisions; Hypernuclear matter

In nuclear reactions at high energies strange hadrons (baryons and mesons) are produced abundantly, and they are important for the reaction process. When hyperons are captured by nuclei, hypernuclei are formed, which can live long enough in comparison with nuclear reaction times. Single hypernuclei, containing only one Λ-hyperon, were mostly under experimental investigation [1]. Production of these nuclei can be explained by direct processes in reactions initiated by hadrons and leptons of high energy. However, it is difficult to obtain in such reactions some exotic species, since the target selection is usually limited by stable nuclei. Also, in addition to single hypernuclei, double- and multi-strange nuclei are also very interesting, because they can provide information about the hyperon–hyperon interaction and hyper-matter properties. For

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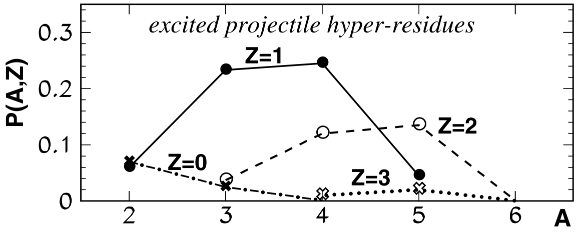

Fig. 1. Ensemble of the projectile spectators with one absorbed Λ hyperon as predicted by DCM calculations for ^{6}Li (2 A GeV) + ^{12}C reaction: $P(A,Z)$ is relative probability to produce specific excited hyper-residues with mass A and charge Z. The dot-dashed, solid, dashed, and dotted lines correspond to residues with $Z = 0, 1, 2$, and 3, respectively.

these reasons it is necessary to suggest new reactions, which could be used to achieve new hypernuclear systems.

Historically, the very first experimental identification of a hypernucleus was performed in the photo-emulsion exposed to high energy cosmic rays [2]. This event was observed in a multi-fragmentation reaction induced by an energetic proton or ion. Multifragmentation reactions in conventional nuclear matter were under intensive investigation during last 20 years. It was established that the fragment production in such reactions takes place via formation of a thermal-like intermediate hot nuclear system and disintegration of this system into cold fragments afterwards. The hybrid theoretical approaches, which include a dynamical stage describing excitation of the system and a statistical stage for description of its disintegration were very effective in reproduction of experimental data [3–5]. Within this reaction picture the hypernuclei have to be produced as a result of break-up of excited hypernuclear systems too [6].

The basic mechanisms of such hadron- and ion-induced reactions are established: The hadrons and nucleons in the overlapping zone between the projectile and the target interact intensively with each other and produce many new particles including strange ones. These particles can re-scatter and propagate further towards the non-interacting parts of colliding nuclei (spectator residues), and they can be captured there, if their relative kinetic energy is smaller than their potential in nuclear matter. This mechanism leads to formation of excited hyper-spectators, which disintegrate into ordinary and hyper-fragments later on [6–9]. Such processes may give access to heavy and exotic hypernuclei, as well as to multi-strange nuclei [7]. It was also predicted that the relative yields of hypernuclei produced in these reactions can reveal important information about their properties and reaction mechanisms [6]. We emphasize an essential difference of this mechanism from the coalescence prescription which was previously assumed as a possible mechanism for production of hyper-spectators in relativistic ion collisions [10]: The coalescence capture of hyperons assumes a formation of fragments in final-states without subsequent decay which can change their baryon content.

Recently the HypHI Collaboration at GSI Darmstadt has reported first results on the production of light hypernuclei in the disintegration of 2 GeV per nucleon ^{6}Li projectiles impinging on a ^{12}C target [11]. The observed production of $^{3}_{\Lambda}$H is by about a factor of three larger than the production of $^{4}_{\Lambda}$H. In a preliminary analysis also indications for a bump in the π^{-}-deuteron invariant mass distribution were found [12]. This observation could be interpreted as the formation of a slightly bound Λ-neutron system (Λn), and its yield is significantly larger than yields of other hypernuclei [12].

As suggested [7], the first dynamical stage of this collision process is described within the transport Dubna cascade model (DCM), which can calculate production of Λ hyperons and