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MEASUREMENTS OF THE Λ HYPERON LIFETIME IN HEAVY HYPERNUCLEI AT COSY-JÜLICH*

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At COSY-Jülich the lifetime of very heavy hypernuclei, produced in the reactions induced by protons, was measured for non-mesonic Λ decay by the recoil shadow method. The measurements were performed at proton energies of 1.5 and 1.9 GeV and the background was determined at 1.0 GeV. The Λ hyperon lifetime of (211 ± 30) ps was obtained in the p+U reactions and (160 ± 15) ps in the p+Bi reactions, respectively.

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1. Introduction

The free Λ hyperon decay is a mesonic one with a lifetime of (263.2 ± 2.0) ps [1]. On the contrary, the decay of hyperons bound in heavy hypernuclei is mainly non-mesonic, due to the Pauli blocking of emerging nucleons, and then can serve as a unique approach for studying this process. The measurements of the Λ lifetime performed with antiprotons on a bismuth target gave a value of [180 ±40(stat.) ±60(syst.)] ps and on a uranium target [130 ±30(stat.) ±30(syst.)] ps [2]. From the e^- + Bi reaction a lifetime of [2.7 ± 0.5] ns was obtained in Refs. [3,4]. We have measured in the COSY-13 experiment in Jülich a lifetime of the Λ hyperon by the observation of delayed fission of the heavy Λ hypernuclei using the recoil shadow method in the reactions induced by protons on U and Bi targets.

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2. Experimental method

Very thin targets were inserted in the circulating beam in the COSY-Jülich storage ring which was operating in a supercycle (different acceleration ramps combined in arbitrary order and repetition rate [5]). The use of this mode of operation eliminates the systematic errors, for example target deformation changes between the background and hypernucleus production runs, in the background subtraction.

The ribbon targets had a sandwich structure formed by three layers: the heavy material (U or Bi), carbon and again heavy material. The total thickness was 20-30 μg/cm^2 for the heavy material and 15-20 μg/cm^2 for the carbon backing. The heavy material had a dimension of 3 mm x 3 mm and a carbon backing length was between 12 and 17 mm.

The COSY-13 detection setup consists of two multiwire proportional chambers (MWPC) which are position sensitive in both directions (along and perpendicular to the COSY beam axis). This system allows measurements of energy losses (ΔE) and time of flight (TOF) of each detected fission fragments.

During all experiments the COSY beam (up to $\sim 10^{10}$ protons in the ring) was moved to a position below the target during injection and acceleration and then bumped onto the target where it was used up in almost constant rate.

Further details of the experiments are given in [5].

3. Lifetime determination

The experiments were performed at three energies of the proton beam: 1.0, 1.5 and 1.9 GeV. The background in all experiments was measured at 1.0 GeV. At this energy the hypernucleus production in reactions induced by protons on heavy targets is very small because the energy is far below the free NN threshold for the $K\Lambda$ production.

The only interesting events related to the Λ hypernucleus production are those connected with fission fragments. To reject other events the two dimensional TOF-ΔE spectra were analyzed. The track reconstruction has been performed to reject events not originating from the target [5].

Adopting the momentum distribution of hypernuclei from calculations done in the framework of a BUU plus Hauser–Feshbach model [6, 7], the lifetime of the Λ hyperon was obtained from a fit to the event distribution in the shadow region obtained by subtracting the background (at 1.0 GeV) from the data measured at higher energies. In the fit the maximum likelihood method was applied for the Poisson distribution. In Fig. 1 the measured and fitted distributions are shown for the reaction induced by 1.9 GeV protons on Bi.

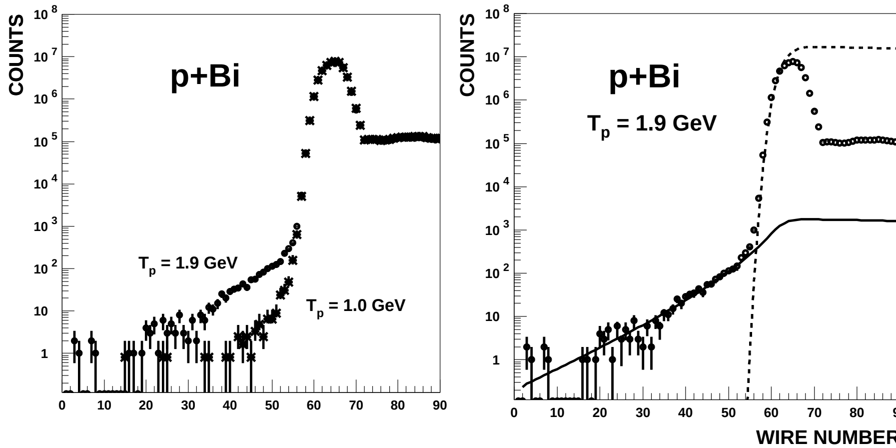

Fig. 1. Left: Position distributions obtained in the lower MWPC for collisions of 1.0 GeV and 1.9 GeV protons with a Bi target. Right: The experimental points shown for channels < 55 (the shadow region) were obtained by subtracting the background measured at 1.0 GeV. The full line presents the result of the fit of delayed fission fragments for a hypernucleus lifetime of 161 ps. The dashed line is the calculated distribution of prompt fission events. The plateau at wire numbers > 72 is caused by prompt fission fragments passing the narrow slit in the diaphragm which helps not to overload the detectors. The abscissa is the distance (in 1 mm wide channels) along the lower MWPC, parallel to the COSY beam direction.

The shape of the drop-off around the shadow edge (wire numbers 55–63) is predominantly caused by absorption of fission fragments in the target and by small-angle scattering of fission fragments in a window foil at the bottom of the experimental chamber.

The following contributions were included to the systematic error of the lifetime (values are given for the 1.9 GeV p+Bi reaction [8]): target deformation: 2 ps, different wire ranges during analysis: 3 ps, small angle scattering described by the Gauss distribution: 5 ps, the error of measured lengths and distances in the experimental set up: 6 ps, uncertainty in the recoil momentum distribution and its modification caused by the absorption in the target: 8 ps, uncertainty in the target reaction point in vertical direction: 6 ps, different cuts in the event selection during the track reconstruction: 2 ps, normalizing and shifting of spectra from different (two hour) runs: 1 ps. Assuming independent contributions from different errors we get a total systematic error of 14 ps. In the wire range from 1 to 54 we have recorded 1604 events at 1.9 GeV and in the corresponding background at 1.0 GeV we measured 146 events. This gives a statistical error in the lifetime determination of 7 ps.

Altogether, four experiments with U and Bi targets were performed and the following Λ hyperon lifetimes were obtained [9]:

p +U: (194 ± 55) ps and (218 ± 35) ps,

p +Bi: (153 ± 50) ps and (161 ± 16) ps [10],

where the errors include both statistical and systematic uncertainties added in quadrature. In Ref. [11] slightly different numbers are quoted for the first p + U reaction because in the earlier analysis the least squares method was used for a Gaussian distribution.

Finally, the Λ hyperon lifetimes for the non-mesonic decay are:

(211 ± 30) ps in the p+U reactions,

(160 ± 15) ps in the p+Bi reactions.

4. Conclusions

The performed Λ hypernucleus experiments have shown that the reactions induced by protons on heavy targets are useful to look for details of strangeness production. The 1.9 GeV p + Bi reaction has lead to the most precise value of the lifetime of Λ hyperons in very heavy nuclei known up to now: (160 ± 15) ps. The measured Λ hyperon lifetimes agree well within the limits of errors with the lifetime obtained in antiproton experiments [2] but they differ significantly from the value obtained in electron + Bi studies [3,4].

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REFERENCES

[1] Particle Physics Booklet, July 1998, extracted from the Review of Particle Physics, C. Caso *et al.*, *Eur. Phys. J.* **C3**, 1 (1998).

[2] T.A. Armstrong, J.P. Bocquet, G. Ericsson *et al.*, *Phys. Rev.* **C47**, 1957 (1993).

[3] V.I. Noga, Yu.N. Ranyuk, N.Ya. Rutkevich *et al.*, *Yad. Fiz.* **43**, 1332 (1986).

[4] V.I. Noga, Yu.N. Ranyuk, N.Ya. Rutkevich *et al.*, *Yad. Fiz.* **46**, 1313 (1987).

[5] K. Pysz, I. Zychor, T. Hermes *et al.*, *Nucl. Instrum. Methods* **A420**, 356 (1999).

[6] Z. Rudy, W. Cassing, L. Jarczyk *et al.*, *Z. Phys.* **A354**, 445 (1996).

[7] W. Cassing, Z. Rudy, L. Jarczyk *et al.*, Proc. of the 8$^{\text{th}}$ Int. Conf. on Nuclear Reaction Mechanisms, Varenna, Italy, June 1997, ed. by E. Gadioli, p.142; nucl-th/9709032.

[8] I. Zychor, 1998 Annual Report of the Andrzej Soltan Institute for Nuclear Studies, Świerk, 1999, p.44.

[9] I. Zychor, K. Pysz, P. Kulessa *et al.*, Int. Sym. on Nuclear Electro-Weak Spectroscopy, NEWS 99, RCNP Osaka, Japan, March 9-12, 1999.

[10] P. Kulessa, Z. Rudy, M. Hartmann *et al.*, *Phys. Lett.* **B427**, 403 (1998).

[11] H. Ohm, T. Hermes, W. Borgs *et al.*, *Phys. Rev.* **C55**, 3062 (1997).