Strangeness Nuclear Physics at $\overline{\mathrm{P}}$ANDA

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$\overline{\mathrm{P}}$ANDA at FAIR will address the physics of strangeness in nuclei by several novel measurements. These studies are only made possible by the one-of-a-kind combination of the stored antiproton beam at FAIR and the modular $\overline{\mathrm{P}}$ANDA detector which will be complemented by a carbon filament target for hyperon production and a secondary target, in which low-momentum hyperons can be stopped. An additional germanium detector array for high-resolution γ-spectroscopy offers the unique possibility to search for X-rays from very heavy hyperatoms. It will also allow to extend the studies on $\Lambda\Lambda$ hypernuclei by determining excited states of these nuclei for the first time. Furthermore, the exclusive production of hyperon–antihyperon pairs close to their threshold in antiproton–nucleus collisions offers a so-far unexplored opportunity to elucidate the behaviour of antihyperons in cold nuclei.

Keywords: Single and double Λ hypernuclei; Hyperatoms; Hyperons and antihyperons; Nucleon–hyperon interactions; γ-spectroscopy.

1. The $\overline{\mathrm{P}}$ANDA Experiment at FAIR

$\overline{\mathrm{P}}$ANDA at FAIR will address the physics of strangeness in nuclei by several novel measurements. These studies will only be made possible by the one-of-a-kind combination of the stored antiproton beam at FAIR and the modular $\overline{\mathrm{P}}$ANDA detector. The large cross sections for the production of associated hyperon–antihyperon pairs[1] combined with the high luminosities that can be achieved even with very thin primary targets will lead to the formation of utilizable numbers of hyperon–antihyperon pairs, Ξ^- hyperatoms, and single and double Λ hypernuclei[2,3]. In this contribution we focus on the setup and the physics potential of the Ξ^- hyperatom study.

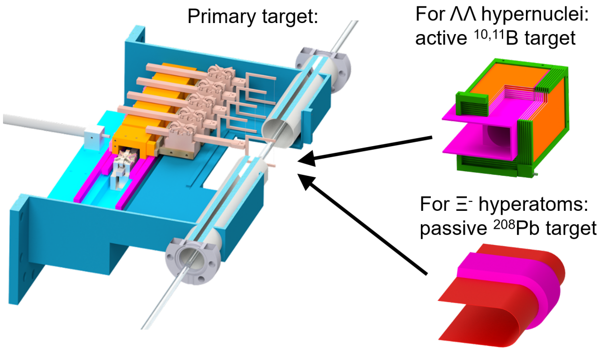

Fig. 1. Left: Details of the primary target station which will house several μm-sized carbon filaments in holding frames (beige) that can be precisely positioned in the halo of the antiproton beam and remotely replaced by spare targets to secure long-term reliability. The vacuum chamber (blue) has an opening in which the secondary targets can be inserted. Right: Secondary targets made from silicon detectors (orange) and boron layers (pink) for $\Lambda\Lambda$ hypernuclei studies (top) or alternatively from a passive sheet of lead (pink) for Ξ^- hyperatom studies (bottom). The secondary targets will be an integral part of the vacuum system[3].

2. Dedicated Setup for Hyperatoms and Hypernuclei

In addition to the general purpose $\overline{\text{P}}$ANDA setup, the hyperatom and hypernuclear studies require i) dedicated primary targets to produce Ξ^- hyperons, ii) secondary targets for stopping a low-momentum fraction of these Ξ^- hyperons, and iii) a high purity germanium (HPGe) array for high-resolution γ-spectroscopy. The secondary targets will be mounted close to the beam line and will cover a large solid angle to reach maximum stopping probability for the short-lived hyperons. Figure 1 shows details of the primary target and two different secondary targets optimized for either hyperatom or hypernuclear studies. The so-called PANGEA hodoscope of HPGe triple detectors[4] will be placed at backward angles with respect to the antiproton beam.

3. X-rays from Heavy Ξ^- Hyperatoms

Strongly interacting, negatively charged particles such as Ξ^- hyperons could occupy atomic orbits in which their wavefunctions have significant overlap with the nuclear wavefunction, so that they are influenced by the strong interaction and can be captured by the nucleus. This leads to energy levels that are shifted and broadened with respect to the pure elec-

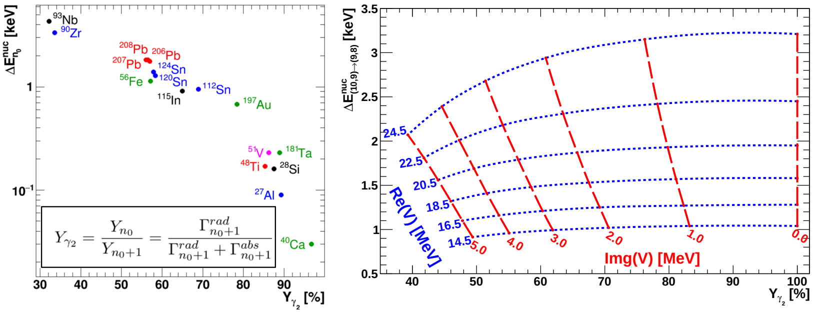

Fig. 2. Left: Overview of X-ray energy shifts and relative yields for possible target materials in a hyperatom experiment. Elements with small energy shifts or low relative yields are difficult to study experimentally. Right: Mapping of the real and imaginary parts of the $\Xi^-{-}^{208}$Pb optical potential on the energy shift of the $(10,9) \rightarrow (9,8)$ transition and the relative yield Y_{γ_2} of this transition with respect to the $(11,10) \rightarrow (10,9)$ transition. The calculations were performed by M. Steinen[2] with a program provided by E. Friedman[5,6].

tromagnetic situation. In Ξ^- hyperatoms the electric dipole transition ($\Delta n = \Delta l = 1$) leading to the lowest atomic state (n_0, l_0) not fully absorbed by the strong interaction with the nucleus is the last transition which could be observed with a reasonable X-ray branching ratio. This level is shifted by the energy $\Delta E^{\mathrm{nuc}}_{n_0}$ and broadened by the nuclear absorptive width $\Gamma^{\mathrm{abs}}_{n_0}$ due to the strong interaction. The shifts, widths, and relative yields of the transition lines may be expressed in terms of real and imaginary parts of the nuclear optical potential. To probe the nuclear periphery of Ξ^- hyperatoms firstly the two X-ray energies E_{γ_1} and E_{γ_2} of the unshifted $(n_0+2, l_0+2) \rightarrow (n_0+1, l_0+1)$ and the shifted $(n_0+1, l_0+1) \rightarrow (n_0, l_0)$ transition could be measured. Secondly, the intensity of the last X-ray transitions will be reduced by the strong interaction and the relative yield Y_{γ_2} of the last X-ray to the second to last X-ray transition could be measured, which is dependent on the radiative and nuclear absorptive widths of the (n_0+1, l_0+1) state. Figure 2 shows these strong interaction effects in different possible target elements and a quantitive study of such effects in dependence of the optical potential for $\Xi^-{-}^{208}$Pb hyperatoms. It can be demonstrated that the Ξ^- hyperatom X-ray spectroscopy at $\overline{\mathrm{P}}$ANDA will, e.g., allow to constrain the neutron skin of lead nuclei[7].

4. Conclusions

$\overline{\mathrm{P}}$ANDA is a versatile experiment with a broad and unique physics program. Hypernuclei and hyperatoms are unique femto-laboratories for strong interaction studies. Furthermore, strangeness nuclear physics is embedded in the quest for the determination of the equation-of-state of nuclei with a direct link to dense stellar systems such as neutron stars.

Acknowledgments

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