Final result from precision study of deeply bound pionic 1s states of Sn nuclei

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Within the experimental program on deeply bound pionic states at GSI [1] the most recent beamtime was devoted to a systematic study of the $(d,^3\mathrm{He})$ reaction on Sn isotopes, which was considered to be promising for two reasons:
i) The existence of $3s_{1/2}$-neutrons in one of the last bound orbitals dramatically enhances the population of the pionic 1*s* state, being quasi-substitutional at the recoil-free condition.
ii) The long chain of stable isotopes of Sn allows to observe for the first time the isotope effect in deeply bound pionic states and thus to seperately deduce the isoscalar and the isovector part of the pion-nucleus potential. The isovector strength parameter $b_1^\star$ is of fundamental interest due to its direct relation to the pion decay constant and chiral order parameter f_π.

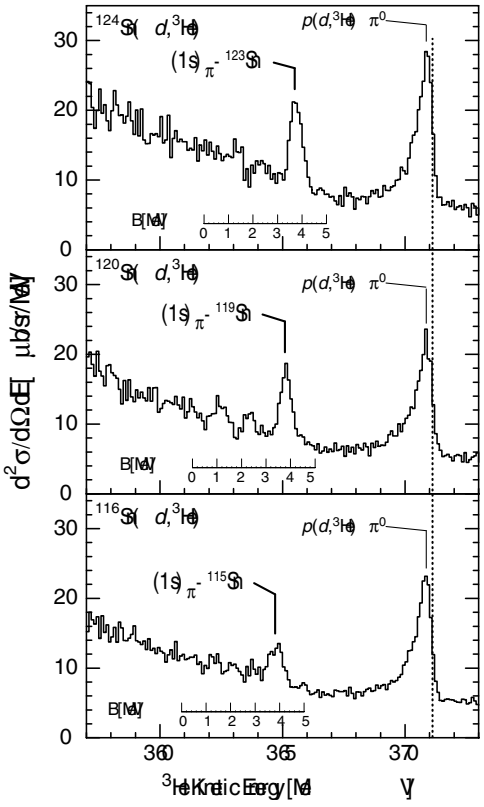

Fig. 1: Double differential cross sections of the ^{124,120,116}Sn$(d,^3$He$)$ reactions at measured at incident deuteron energy $T_d = 503.388\,$MeV versus the ^{3}He kinetic energy. The scales of the π^- binding energies are also indicated.

Information on the experimental method and the relevant instrumental parameters is given in Refs. [2, 3]. The data analysis has now been completed and binding energies and widths of the pionic 1*s* state in ^{115,119,123}Sn were determined [3]. The measured double differential $(d,^3\mathrm{He})$ cross sections $d^2\sigma/dEd\Omega$ with ^{124,120,116}Sn targets are shown in Fig.1. The thin mylar backing attached on purpose to the targets gives rise to a prominent peak due to the $p(d,^3\mathrm{He})\pi^0$ reaction, whose higher-energy edge serves as an absolute calibration point with an accuracy of ± 7 keV. The observed 1*s* binding energies (B_{1s}) for the Sn isotopes 115, 119 and 123 are 3.906 ± 0.024 MeV, 3.820 ± 0.018 MeV, and 3.744 ± 0.018 MeV, the 1*s* widths (Γ_{1s}) are 0.441 ± 0.087 MeV, 0.326 ± 0.080 MeV, and 0.341 ± 0.072 MeV, respectively.
The binding energies and widths of pionic 1*s* states of heavy nuclei are almost exclusively determined by the *s*-wave part of the pion-nucleus interaction, whereas the contribution of the *p*-wave part is nearly negligible. Using *p*-wave parameters fixed from global fits of pionic atom data the measurement of deeply bound pionic 1*s* states reliably determines the *s*-wave potential. Its isovector and isoscalar parts can then be determined by a precise measurement of the isotope shift, as indicated above. However, due to the smallness of the isotope shift a more accurate determination of the isovector strength is obtained if the isoscalar part is deduced from the known pionic 1*s* states of light symmetric nuclei. The values of the isovector effective scattering length $b_1^\star$ obtained individually in this way for each of the Sn isotopes is shown in Fig.2, together with the $b_1^\star$ value deduced from the previous ^{205}Pb data [1]. For the weighted average we obtain $b_1^\star = -0.115 \pm 0.005\, m_\pi^{-1}$, considerably enhanced as compared to the vacuuum value b_1^{free}, resulting in the ratio $b_1^{\mathrm{free}}/b_1^\star = f_\pi^\star(\rho_{\mathrm{eff}})^2/f_\pi^2 = 0.78 \pm 0.03$. Since the pion effectively probes a density of $0.6\,\rho_0$ this corresponds to a reduction of 37% for the chiral order parameter f_π^2 at normal nuclear density.

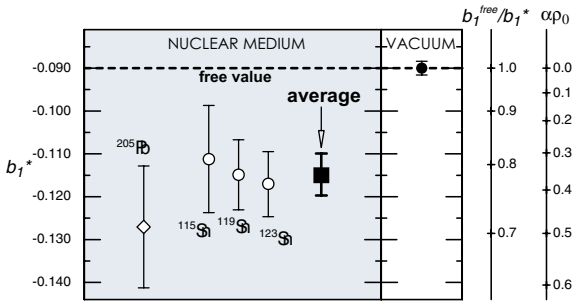

Fig. 2: Values of the in-medium isovector effective scattering length parameter $b_1^\star$ (in m_π^{-1}) deduced from the 1*s* binding energies B_{1s} in ^{115,119,123}Sn.

References:

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