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Partial restoration of chiral symmetry in the nuclear medium

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Study of pionic atom has been revisited by a recent discovery of deeply bound pionic states in the context of possible sensitivity to the partial chiral restoration in the nuclear medium. The chiral symmetry breaking in QCD is considered to be a driving mechanism of how hadrons acquire their masses. Exploring the QCD phase diagram towards high density regime is believed to experience highly non-trivial chiral phase transition. A quark condensate, $\langle \bar{q}q \rangle$, is an "order parameter" of this symmetry breaking and is expected to diminish as a consequence of chiral symmetry restoration. Efforts of detecting this precursor are being made intensively these days. The deeply bound pionic atom provides unique laboratory in this context. In the hadrons mass spectrum as quasi particle excitations of the condensate, pions are identified to be Nambu-Goldstone bosons, which are the lowest energy excitation modes. Isovector part of their s-wave interaction with nucleons is determined by the pion decay constant, f_π^2, which is directly connected to the magnitude of $\langle \bar{q}q \rangle$ through the Gell-Mann-Oaks-Renner relation. Since the pionic orbits of low-lying states have certain overlap with nucleus, a property of pion can be influenced by a nuclear medium. We performed a systematic measurement of 1s π^- states in ^{115,119,123}Sn by hiring ^{116,120,124}Sn(d,^{3}He) reactions at GSI SIS-FRS system, from which we determined the 1s binding energies and widths precisely. These are used to deduce the isovector s-wave interaction, $b_1 = 0.115 \pm 0.005 m_\pi^{-1}$. The observed magnitude is significantly enhanced over the free πN value, which is translated into a reduction of $\langle \bar{q}q \rangle$ by $\sim$35% at normal nuclear density.