Deeply bound 1s and 2p pionic states in ^{205}Pb and effective pion mass in nuclear matter

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Recently we have succeeded in observing the 1s and 2p bound pionic states in ^{205}Pb nucleus as well separated peaks in the excitation spectrum of the ^{206}Pb(d, ^{3}He) reaction. The observed spectrum agreed quite well with the theoretical prediction where the formation cross section was calculated for the deeply bound pionic states (1s and 2p) [1]. These states are accommodated in proximity to the nuclear surface as halo states in a potential provided by the attractive Coulomb and the repulsive core. The binding energies and the widths were precisely measured as shown below, and the values were used to determine the unknown s-wave part of the π–nucleus interaction and to deduce the effective pion mass in the nuclear matter which turned out to be 26 MeV larger than in vacuum.

The experiment was performed at GSI, Darmstadt, employing the $T_d = 604.3$ MeV deuteron beam on the enriched ^{206}Pb target. We measured the excitation energy of the ^{206}Pb(d, ^{3}He) reaction by analyzing the ^{3}He momentum in the FRS spectrometer [2,3]. The measured spectrum is shown in Fig. 1. The π^- production threshold at $E_x = 139.570$ MeV is shown by the vertical broken line. The continuum due to the quasi-free pion production appears above the threshold. The largest peak at the center is $(2p)_\pi$ and the small peak at its side is $(1s)_\pi$.

We decomposed the region of interest of the spectrum into each component of pionic states and deduced the binding energies and the widths to be $B_{1s} = 6.768 \pm 0.044 \pm 0.041$ MeV, $\Gamma_{1s} = 0.778^{+0.150}_{-0.130} \pm 0.055$ MeV, $B_{2p} = 5.110 \pm 0.015 \pm 0.042$ MeV, and $\Gamma_{2p} = 0.371 \pm 0.037 \pm 0.048$ MeV including the statistical and systematic errors [4].

The above obtained values are very precise and we extracted information on the π–nucleus strong interaction. Since the 1s pionic state is entirely dominated by the s-wave (local) part interaction, we focused on this domain and deduced the real ($= V_0$) and imaginary ($= W_0$) potential depths at the center of ^{205}Pb. According to the results, V_0 and W_0 were determined to be $26.1^{+1.7}_{-1.5}$ MeV and $-13.8^{+3.4}_{-3.5}$ MeV, respectively. The real part depth is significantly larger than the $V_0 \sim 16$ MeV expected from free πN scattering length after double scattering correction [5].

The deviation between the present value of 26 MeV and above value of 16 MeV can be explained by the increase of the isovector strength ($|b_1|$) expected from the chiral symmetry restoration of the quark condensate. We will make an experiment to directly deduce the b_1 part dependence of the π–Nucleus interaction using long chain of tin isotopes. The described approach will also be applied to the in-medium mass measurement of other hadrons.

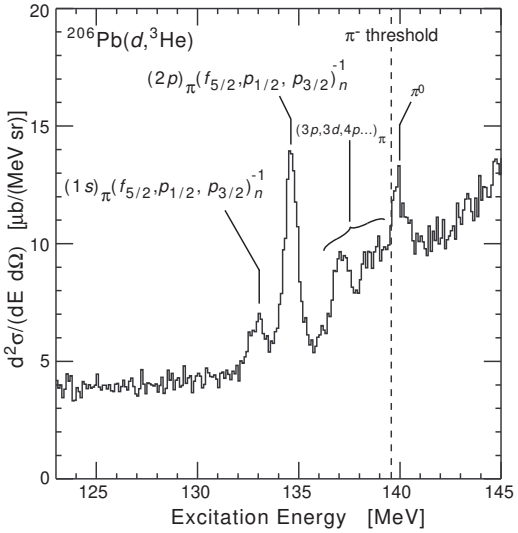

Figure 1: Double differential cross section versus excitation energy of the ^{206}Pb(d, ^{3}He) reaction measured at the incident deuteron energy (T_d) of 604.3 MeV.

References

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