Discovery of Deeply Bound π^- States in the ^{208}Pb(d,^{3}He) Reaction

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Due to absorption low lying states (e.g 1s or 2p) in pionic atoms with medium heavy and heavy nuclei are not populated in electromagnetic cascades, and these states had so far not been observed experimentally. Toki and Yamazaki [1] realized that nevertheless the deeply bound states should exist even for the heaviest atoms like lead, since the short range s-wave repulsion in the π^--nucleus optical potential reduces the widths of the lowest states to values considerably smaller than the level distance. They proposed [1] to search for their direct population in transfer reactions.

Following the arguments of ref. [2] we studied the ^{208}Pb(d,^{3}He) reaction at 0^o at an incident deuteron energy of 300 MeV/u [3], which due to the low momentum transfer populates dominantly states with small angular momentum. As a forward spectrometer with high resolving power and good background suppression capability we used the GSI Fragment Separator which consists of four bending sections and four focal planes. At the central dispersive focal plane the momentum of the ejectiles is measured by two sets of high-rate drift chambers, whereas the ^{3}He ions are identified downstream by the measurement of time of flight and energy loss in three plastic scintillation counters. A 2 mm wide ^{208}Pb strip target with 45 mg/cm^2 thickness was bombarded with up to 10^{11} deuterons/spill at 2.8 s cycle time. The beam momentum spread $\delta p/p \sim 5 \cdot 10^{-4}$ and the energy loss in the target allowed for a Q value resolution of 0.5 MeV. The momentum on the focal plane was calibrated at different Bρ settings of the separator by using the p(d,^{3}He)π^0 reaction, which creates monoenergetic ^{3}He at 1678.7 MeV/c momentum.

In order to exclude instrumental effects as origin of any observed structure in the ^{3}He momentum spectrum, the spectrum was measured for three different Bρ settings. The momentum bite $\Delta p/p \sim \pm 1\%$ corresponds to a 25 MeV interval of the reaction Q value. An acceptance corrected Q value sum spectrum for the three settings for the ^{208}Pb(d,^{3}He) reaction is shown in fig. 1a in comparison to the theoretical prediction [2] in fig. 1b. The threshold for free π^- production with ^{207}Pb in its 3p$_{1/2}$ ground state corresponds to $Q = -140.147$ MeV. At less negative Q values in the bound π^- region we observe a structure with a pronounced peak at $Q = -135.6$ MeV above a flat continuum. In a comparative run with an ^{27}Al target only the rise of the yield for the quasifree π^- production without any structure was seen (fig. 1c).

The dominant peak in fig. 1a was assigned to the $(2p)_\pi(3p_{1/2},3p_{3/2})_n^{-1}$ configuration in ^{207}Pb. The binding energy of the $(2p)_\pi$ orbital was deduced to be $B_\pi(2p) = (5.4 \pm 0.2)$ MeV with an intrinsic width below 0.8 MeV.

These two quantities are directly related to the real and the imaginary part of the pion-nucleus optical potential at short distance, so far not accessible to experimental study. Since there is a considerable overlap of the π^- wavefunction in deeply bound states with the nucleus the experimental determination of the π^- binding energy sets more reliable constraints on the medium modification of the pion mass in nuclear matter.

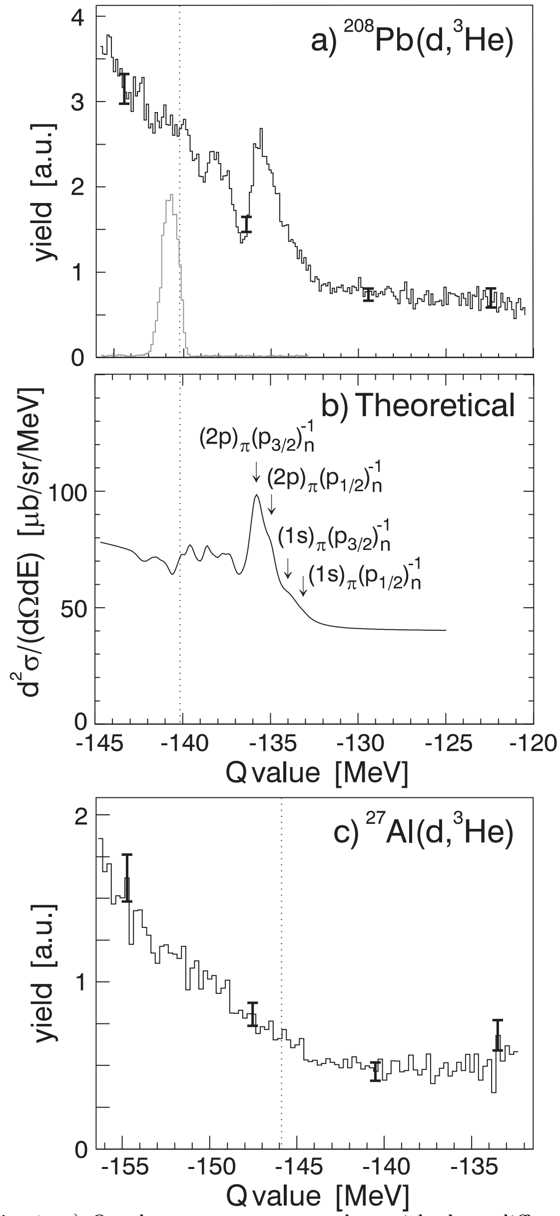

Fig. 1: a) Q value sum spectrum taken with three different Bρ settings. The free π^- production threshold is shown by the dotted line. The dotted spectrum is for the p(d,^{3}He)π^0 reaction in the equivalent Q value scale. b) Theoretical prediction [2] with 0.5 MeV resolution. c) A reference spectrum of the ^{27}Al(d,^{3}He) reaction in the scale of the Q value of this reaction.

References

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