Deeply Bound States in Pionic ^{207}Pb and the Effective Pion Mass in the Nuclear Medium

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Recently, deeply bound pionic states in lead were observed for the first time in a (d,^{3}He) transfer reaction at the GSI Fragment Separator [1,2] using high resolution momentum analysis of the ^{3}He ejectiles emitted at 0^0. In comparison to a DWIA calculation [3] the dominant peak in the Q value spectrum was assigned to the population of the $2p$ state of the π^- coupled to the $(p_{1/2})_n^{-1}$ ground state and the $(p_{3/2})_n^{-1}$ 897 keV excited state in the ^{207}Pb nucleus. Some strength observed in the tail of the peak around Q = -133.5 MeV indicated the population of the pionic $1s$ state.

In the course of the data analysis, the Q value resolution could be considerably improved by eliminating some of the instrumental contributions to the energy smearing, namely the time dependence of the beam momentum within the extracted SIS spill, ion optical aberrations of the FRS due to finite ^{3}He angles, and long term shifts of the FRS magnetic field. With the improved energy resolution the $(p_{1/2})_n^{-1}$ and $(p_{3/2})_n^{-1}$ sub-peaks of the pionic $2p$ configuration are almost separated and the shoulder due to the $1s$ peak is clearly seen as shown in fig. 1. After a decomposition of the spectrum into $2p$ and $1s$ components coupled to the low lying neutron hole states in ^{207}Pb the pionic binding energies $B_{2p} = (5.28 \pm 0.11)$ MeV and $B_{1s} = (7.04 \pm 0.32)$ MeV are obtained. Since the instrumental resolution is not accurately known and since it may be the dominant contribution to the observed width, only upper limits can be given for the widths: $\Gamma_{2p} < 0.51$ MeV and $\Gamma_{1s} < 1.79$ MeV.

In the $1s$ and the $2p$ state the pion forms a halo state around the *Pb* nucleus with considerably larger overlap of the pionic wave function than in the more shallow states that have been studied with capture and electromagnetic deexcitation of stopped π^-. The binding energies and widths of these states yield therefore constraints on the local s-wave pion-nucleus potential which was poorly known so far, while the non-local p-wave part of the potential is well established by level shifts measured for many shallow states in pionic atoms. In the present study [4], the local potential $V_{\rm local}(r) = V_0 \frac{\rho(r)}{\rho(0)}$ was assumed to be proportional to the nuclear density, neglecting different shapes of the proton and neutron density distributions and effects quadratic in the density.

For the imaginary and the non-local part of the potential the potential parameters as given by Seki and Masutani [5] were used. By solving the Klein-Gordon equation with artificially varied values of V_0 and comparing the calculated pionic binding energies to the measured values, we obtain the constraint $V_0 = (20.2 \pm 4)$ MeV from the pionic $2p$ state. This value is also consistent with the constraints resulting from B_{1s}, Γ_{2p} and Γ_{1s}. The real part of the local potential can be directly translated to a mass shift as shown in fig. 2, resulting in $m_\pi^{\rm eff} \approx 160$ MeV in the center of the ^{207}Pb nucleus.

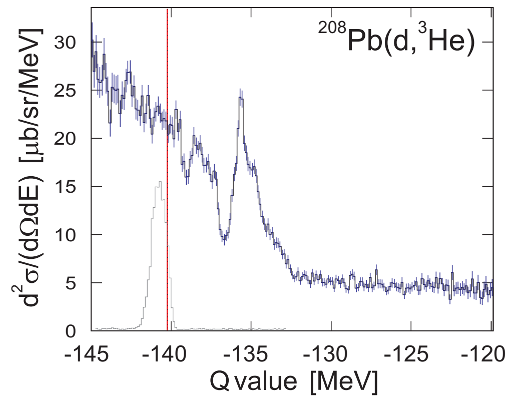

Fig. 1: Experimental Q value spectrum corrected for various instrumental contributions to the energy resolution. The vertical line at Q = -140.15 MeV is for the free π^- production threshold on ^{207}Pb$_{\rm g.s.}$ and the dotted peak is for the energy calibration with the p(d,^{3}He)π^0 reaction.

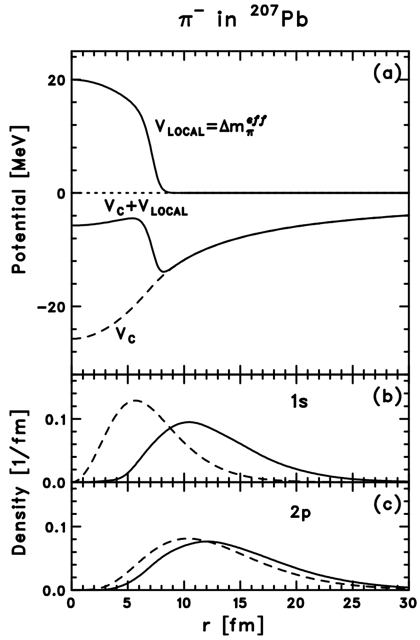

Fig. 2: The π^- mass shift and local potential (top) and the π^- densities in the $1s$ and $2p$ state (bottom) as a function of the radius. The dashed curves are obtained for a pure Coulomb potential.

References

[1] H. Gilg *et al.*, Jahresbericht 1996, p. 48
[2] T. Yamazaki *et al.*, Z. Phys. **A355** (1996) 2006
[3] S. Hirenzaki, H. Toki and T. Yamazaki, Phys. Rev. **C44** (1991) 2472
[4] T. Yamazaki *et al.*, to be published in Phys. Lett. **B** (1998)
[5] R. Seki, K. Masutani, Phys. Rev. **C27** (1983) 2799