Deeply Bound π^- States and the Pion-Nucleus Potential

H. Gilg, P. Kienle, M. Münch , W. Schott, A. Gillitzer [a], H. Geissel [b], G. Münzenberg [b], H. Weick [c], S. Hirenzaki [d], R. S. Hayano [e], K. Suzuki [e], K. Itahashi [f], M. Iwasaki [f], D. Tomono [f], T. Yoneyama [f], and T. Yamazaki [g]

[a] Institut für Kernphysik, Forschungszentrum Jülich [b] GSI Darmstadt [c] Universität Gießen
[d] Nara Women's University
[e] Department of Physics, University of Tokyo [f] Department of Physics, Tokyo Institute of Technology
[g] Institute of Particle and Nuclear Studies, High Energy Accelerator Research Organization and JSPS

A series of experiments at the GSI Fragment Separator (FRS) uses deeply bound pionic atoms to investigate the pion-nucleus interaction.

In a first experiment on the ^{208}Pb(d,^{3}He) reaction at $T_d = 600\,$MeV the deeply bound $(1s)_\pi$ and $(2p)_\pi$ states in lead were discovered [1]. The analysis of this experiment is now completed. In the measured excitation energy spectrum the population of these states causes a prominent peak. In the analysis the peak was decomposed into 2p and 1s components coupled to the low lying neutron hole states in ^{207}Pb, and thus the binding energy and width of the $(2p)_\pi$ state were determined [2,3]. Both quantities depend very sensitively on the s-wave part of the pion-nucleus interaction and could therefore be used to deduce the corresponding real and imaginary optical potential parameters b_0 and ImB_0 [4]. The real part of the s-wave potential can be translated into a shift of the effective π^- mass in the center of the ^{207}Pb nucleus $\Delta m_\pi^{eff}(r=0) = 20 \sim 24\,$MeV [2,4].

The results from B_{2p} and Γ_{2p} are consistent with the constraints obtained from B_{1s} and Γ_{1s}. Due to the larger overlap of the pionic 1s wave function with the nuclear density distribution the width and the binding energy of the $(1s)_\pi$ state are even more sensitive to the local part of the optical potential than B_{2p} and Γ_{2p}. However, since the $(1s)_\pi$ state was observed only as a bump on the tail of the dominant $(2p)_\pi$ peak, B_{1s} and Γ_{1s} were determined with comparatively large errors and the corresponding constraints on the pion-nucleus potential are weaker than for the $(2p)_\pi$ state.

Therefore a recent experiment used the ^{206}Pb(d,^{3}He) reaction to populate deeply bound pionic states [3]. Due to an improved energy resolution and due to the better suited neutron shell structure of ^{206}Pb it was possible to observe the $(1s)_\pi$ state in lead as a distinct peak in the excitation energy spectrum (Fig. 1) for the first time. In the region of the deeply bound states the experimental spectrum is fitted well by the theoretical function which is composed of $(1s)_\pi$ and $(2p)_\pi$ components coupled to the neutron hole states in ^{205}Pb (mainly to $(3p_{3/2}, 2f_{5/2})_n^{-1}$), as shown in figure 2. The analysis of this experiment is still in progress. Together with further experimental improvements, the clear separation of $(1s)_\pi$ and $(2p)_\pi$ states will allow to determine B_{1s} and Γ_{1s} (as well as B_{2p} and Γ_{2p}) with a significantly higher precision.

In a future experiment the population of substitutional $(1s)_\pi \otimes (s_{1/2})_n^{-1}$ states in various tin isotopes (^{115,119,123}Sn) will be investigated. The isotope shift of their binding energies and widths can provide valuable information on the local isovector part of the pion-nucleus interaction, which is closely related to the pion decay constant f_π.

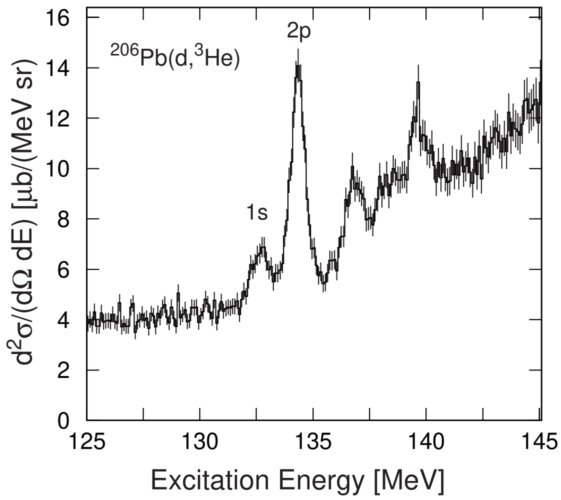

Fig. 1: Excitation energy spectrum for the ^{206}Pb(d,^{3}He) reaction at $T_d = 600\,$MeV

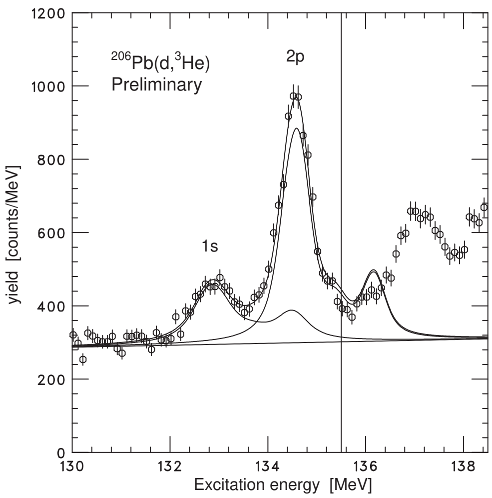

Fig. 2: Decomposition of the excitation energy spectrum into $(1s)_\pi$ and $(2p)_\pi$ components.

References

[1] T. Yamazaki *et al.*, Z. Phys. **A355** (1996) 219;
H. Gilg *et al.*, Jahresbericht 1996, p. 48
[2] T. Yamazaki *et al.*, Phys. Lett. **B418** (1998) 246
[3] H. Gilg *et al.*, Jahresbericht 1998, p. 4
[4] H. Gilg *et al.*, to be published in Phys. Rev. **C** (2000) ;
K. Itahashi *et al.*, to be published in Phys. Rev. **C** (2000)