Direct observation of the bound-state beta-decay of fully-stripped ^{207}Tl

D.Boutin[a], L.Maier[b], F.Bosch[a], C.Scheidenberger[a], T.Yamaguchi[a,d], K.Beckert[a], P.Beller[a], T.Faestermann[b], B.Franczak[a], B.Franzke[a], H.Geissel[a,c], E.Kaza[a], P.Kienle[b], O.Klepper[a], C.Kozhuharov[a], Yu.Litvinov[a], M.Matoš[a], G.Münzenberg[a,e], F.Nolden[a], Yu.Novikov[f], T.Ohtsubo[g], W.Plass[c], M.Portillo[a], J.Stadlmann[a], M.Steck[a], K.Takahashi[a], H.Weick[a], and M.Winkler[a]

[a]GSI; [b]TU München; [c]JLU Gießen; [d]Saitama University; [e]JGU Mainz; [f]NPI St Petersburg; [g]Niigata University

Bound-state β-decay [1] is a special type of β-decay, where the created electron occupies a previously vacant orbit of the daughter atom. This process being weak in the terrestrial decays of neutral atoms, plays a significant role in stellar nucleosynthesis, where the extreme temperature and pressure lead to an intensive stripping of the electrons. In the latter case drastic changes in nuclear decay rates can occur.

This exotic decay mode was first observed in a pioneering experiment at the GSI facility with fully-stripped ^{163}Dy [2]. Subsequently also ^{187}Re [3], ^{206}Tl and ^{207}Tl [4] were investigated experimentally.

^{207}Tl was studied with the combination of the fragment separator FRS [5] and the storage ring ESR [6]. After fragmentation of a 832 MeV/u ^{208}Pb beam in a 4 g/cm^2 Be target, fully-ionized $^{207}Tl^{81+}$ ions were selected, separated with the FRS, and finally injected into the ESR. Stochastic precooling [7], and thereafter electron cooling were applied to the stored ions, reducing the overall cooling time to 8 s.

The Schottky-noise signal induced by the circulating ions was continuously recorded via capacitive pickups. After application of a FFT algorithm to this signal, frequency spectra were produced, in which the areas of the peaks are proportional to the number of particles. Figure 1 shows the evolution of $^{207}Tl^{81+}$ and its bound-state β-decay daughter, $^{207}Pb^{81+}$, with a typical measurement time of 32 min.

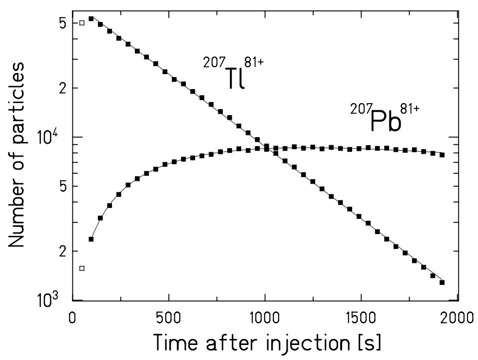

Figure 1: Evolution of the number of $^{207}Tl^{81+}$ and $^{207}Pb^{81+}$ ions in the ESR. Each data point corresponds to 48 s of observation. The fits from equations 1 and 2 are shown as solid lines.

The decay constants were derived from the following equations:

$$N_{Tl}(t) = N_{Tl}(0)e^{-\lambda_{tot}t} \quad (1)$$

$$N_{Pb}(t) = \frac{\lambda_b(e^{-\lambda_l t} - e^{-\lambda_{tot}t})N_{Tl}(0)}{\lambda_{tot} - \lambda_l} + N_{Pb}(0)e^{-\lambda_l t} \quad (2)$$

where $N_{Tl}(t)$ and $N_{Pb}(t)$ are the number of Tl and Pb ions at the time t, respectively; λ_{tot} the total decay constant of $^{207}Tl^{81+}$; λ_b, λ_c and λ_l describe the bound-state, continuous-state β-decay constants and the losses in the storage ring due to non-nuclear effects respectively; with $\lambda_{tot} = \lambda_b + \lambda_c + \lambda_l$.

The fit results are very sensitive to the feeding of Pb ions in the beginning of the injection, thus these measurements are complementary to those presented in [4]. ¿From equations 1 and 2 preliminary results give a nuclear decay constant of $(2.62 \pm 0.10)\times10^{-3}$ s^{-1} (rest frame), yielding a half-life $T_{1/2} = (265 \pm 10)$ s. This corresponds to a reduction of 7 % compared to the neutral half-life [8]. The branching ratio of the bound-state to the total nuclear decay constant could be evaluated as (17.7 ± 2.6) %.

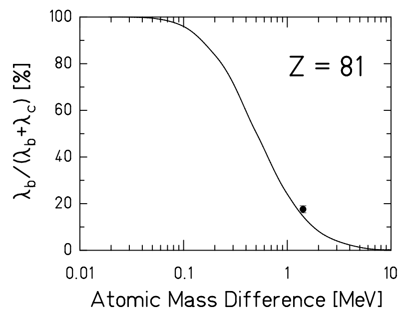

Figure 2: Branching ratio of bound-state to total β-decay rate calculated for Z=81 (solid curve) as function of the Q-value compared to our experimental result (full circle).

Calculations of the decay constants of $^{207}Tl^{81+}$ were performed using a code based on a self-consistent relativistic mean-field approximation ([9]). Results of the calculations for the bound-state to the nuclear ratio are shown in figure 2. The calculated half-life $T_{1/2} = 250$ s, as well as the ratio $\lambda_b/(\lambda_b + \lambda_c) = 0.146$, are in good agreement with the experimental results presented above, considering that in the calculation an allowed spectrum has been assumed (e.g. [8]). The analysis is still in progress.

References

[1] J.N.Bahcall, Phys. Rev. **124** (1961) 495
[2] M.Jung *et al.*, Phys. Rev. Lett. **69** (1992) 2164
[3] F.Bosch *et al.*, Phys. Rev. Lett. **77** (1996) 5190
[4] T.Ohtsubo *et al.*, GSI Report **2001-1** (2001) 15; T.Ohtsubo *et al.*, in preparation
[5] B.Franzke *et al.*, Nucl. Instr. Meth. **24/25** (1987) 18
[6] H.Geissel *et al.*, Nucl. Instr. Meth. **70** (1992) 286
[7] F.Nolden, Nucl. Instr. Meth. **A441** (2000) 219
[8] J.M.Trischuk, E.Kankeleit, Nucl. Phys. **A90** (1967)33
[9] K.Takahashi, K.Yokoi, Nucl. Phys. **A404** (1983) 578