Measurement of the Neutron to Proton Density Ratio at the Nuclear Periphery with Antiprotons

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The activity measurement of radioactive reaction products after antiproton annihilation is an elegant method to derive the neutron to proton density ratio at large nuclear distances:

For this method slow antiprotons were used, which are captured into high atomic orbits and cascade down towards the nuclear surface. This cascade terminates far above the lowest orbit, when the antiproton reacts with a nucleon on the nuclear surface and annihilates. This already takes place at nucleon densities of about one tenth of the maximum density. In 10% of the annihilations no produced pion reacts with the target nucleus due to the large annihilation distance from the nucleus. This leads to cold reaction products only one mass unit lighter than the target mass. Antiproton annihilation on a peripheral proton leads to products with one proton less than the target, whereas the annihilation on a neutron results in products with one neutron less. If both these products are radioactive their production yield, related to the peripheral proton and neutron density, can be easily determined using classical nuclear spectroscopy methods [1,2].

In September 1996 measurements were performed with the antiproton beam of the LEAR facility at CERN with a new transport system which was able to transfer the targets within two seconds after the end of the irradiation from the antiproton beam line to the measuring place. This allowed us to extend this method to short–lived isotopes with only a few seconds half–life. The measurement was done with a germanium detector inside a shielding of lead and paraffine.

Six new targets were investigated: ^{48}Ca with closed proton and neutron shells, ^{100}Mo with a strong E2–resonance effect, ^{112}Sn and ^{124}Sn with a closed proton shell and a large difference in the number of neutrons, ^{104}Ru and ^{116}Cd in addition to the already measured nuclei ^{96}Ru and ^{106}Cd.

The measurements for calcium lead to a value of the neutron density at the nuclear surface of ^{48}Ca which is about twice as high as that for the proton density. For ^{100}Mo and ^{104}Ru this ratio was found to be about four.

The result is in good agreement with the whole systematics, confirming a strong negative correlation of the neutron separation energy with the neutron halo in heavy nuclei.

In [2] the neutron halo factor f_h is defined as

$$f_{\mathrm{h}} = \frac{N_{N-1} \cdot Z}{N_{Z-1} \cdot N} \cdot \frac{1}{0.63},$$

Here N_{N-1} is the number of produced nuclei with one neutron less, N_{Z-1} the number of produced nuclei with one proton less. N and Z, respectively, are the neutron and proton number of the target nuclei. The ratio of the strengths of antiproton absorption on neutrons and protons is 0.63. In Fig. 1 f_h is plotted against the neutron separation energy of the target nuclei for ^{48}Ca and the nuclei investigated during previous runs [2].

In addition to these measurements antiprotonic X-rays from the targets were measured which also give information about the nuclear density in the periphery of the nuclei. The evaluation of these data is in progress.

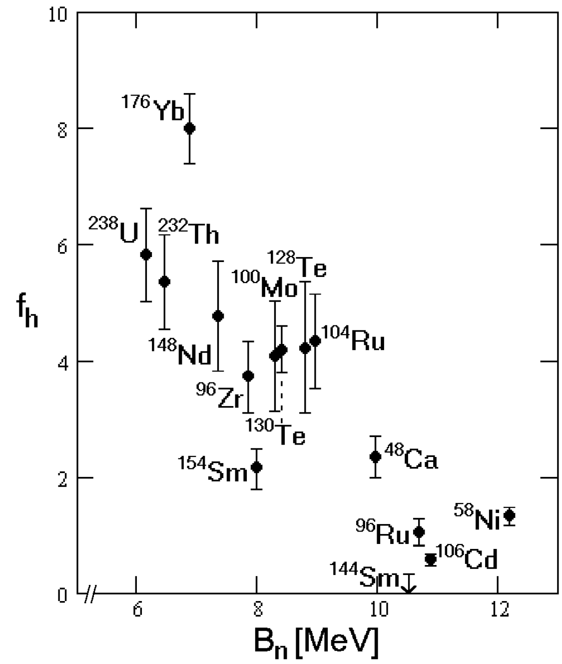

Fig. 1: Neutron halo factor f_h as a function of the target neutron separation energy B_n.

References

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