HiThor@Spectrap - A Penning Trap to faciliate a Thorium Nuclear Clock

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Synopsis We will present the basic idea of the thorium nuclear clock and describe the used Penning trap to capture the ions from an accelerator and prepare them for laser-ion interaction.

Highly-ionized-thorium clocks are ideal for tests of fundamental interactions since the ions are elementary quantum systems composed of only a few building blocks. Two cases of $^{229}Th^{q+}$ clocks excel. On the one hand, one-electron $^{229}Th^{89+}$ that combines two nuclear-clock transitions in the VUV with hyperfine IR atomic-clock transitions, and on the other hand fully ionized $^{229}Th^{90+}$ which constitutes the prototype of a nuclear clock, one without any electrons. [1] In the first state, the effect of nuclear hyperfine mixing is present which facilitates the excitation of the one electron from the ground state to the first isomeric state. One step to investigate the feasability of a nuclear clock is the storage of such ions in a Penning trap and measure the transition energy and lifetime of the isomeric state. Here, the transition energy is about 8.36 eV which can be driven by a UV-laser. To prepare the ions in a defined position, we have developed a Penning trap optimised to capture ions from an accelerator. This a accomplished by a set of deceleration stages and by a well-designed electronically compensated trap.

The transition energy and the lifetime are measured with laser excitation of the stored ions with subsequent measurement of the emitted photons from the relaxation process. To cover a large opening angle, we have decided to eliminate the ring electrode from our design and placed 16 silicon photo multipliers (SiPM) in the central plane of the trap. This design has been verified to allow a good harmonicity of the trap but comes along with no orthogonality. Upon ion capture, the ions will be cooled fast using resistive cooling [2]. In this context, we have calculated the axial frequency dependence of stored ions depending on their kinetic energy. We have found the ion frequency spread to be less than the typical width of a normal conducting resonant circuit which is hence suitable to cool all captured ions fast and at once. This will allow efficient ion confinmement in the trap centre.

We will present the thorium nuclear clock experiment (ERC Advanced Research Grant "HiThor") and the Penning trap as a part of this project. We will give some insight into the envisaged ion storage techniques and laser measurements.

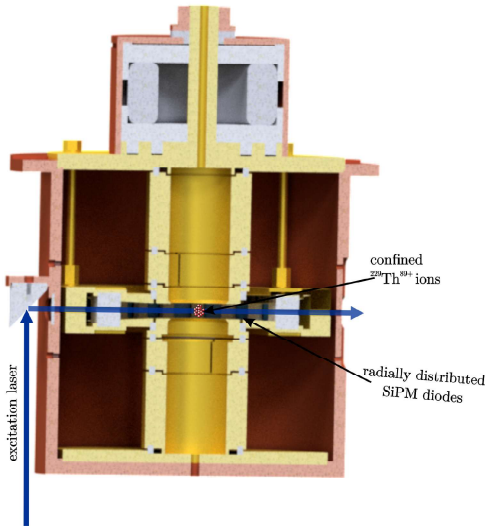

Figure 1. HiThor Penning trap consisting of six electrodes for electronic compensation. The eliminated ring electrode is replaced with a set of 16 SiPM to measure emmitted photons.

References

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