Addendum to proposal P242 to the ISOLDE and Neutron Time-of-Flight Committee

SEARCH FOR NEW CANDIDATES FOR THE NEUTRINO-ORIENTED MASS DETERMINATION BY ELECTRON-CAPTURE

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Requested shifts: 5 shifts (1 run)
Introduction:

The determination of the neutrino mass from nuclear electron capture (EC) is an exciting alternative to $\beta$-decay experiments with $^{187}$Re and tritium [1,2]. Unlike the $\beta$-decay experiments, in which nuclides with the smallest $Q_\beta$-value are preferred, the determination of the neutrino mass from EC nuclides requires the smallest total energy of the emitted neutrino. To date, the best candidate is $^{163}$Ho with a decay energy of $Q_{EC} = 2.56(2)$ keV [3]. However, there is a variety of other potential candidates with $Q_{EC}$ below 100 keV and with expected very small total energy of the emitted neutrino [4,5]. The choice of the best candidate among them is hampered by imprecise knowledge of their $Q_{EC}$-values.

With the proposal P242 and the experiment IS473 we have initiated a search for potential candidates (besides $^{163}$Ho) for a determination of the neutrino mass from EC by a determination of the $Q_{EC}$-values of the nuclides of interest [4]. The first two candidates we addressed were $^{194}$Hg and $^{202}$Pb.

Status report 2011:

The $Q_{EC}$-values of EC in $^{194}$Hg and $^{202}$Pb were proposed [4] to be determined by high precision Penning trap mass measurements of $^{194}$Hg, $^{194}$Au and $^{202}$Pb, $^{202}$Tl with ISOLTRAP. Within the beam-time allocated to the experiment IS473 we have successfully completed three quarters of the program by having measured the masses of $^{194}$Hg, $^{194}$Au and $^{202}$Pb with an accuracy of a few keV. An overview of ISOLTRAP beam times that were scheduled and performed in the framework of proposal P242 is given in Table 1.

<table>
<thead>
<tr>
<th>Beam time</th>
<th>Dedicated for</th>
<th>Target/ion source</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>May 2008</td>
<td>$^{202}$Pb, $^{202}$Tl</td>
<td>UC$_x$/Hot plasma</td>
<td>canceled due to power failure</td>
</tr>
<tr>
<td>July 2008</td>
<td>$^{194}$Au</td>
<td>UC$_x$/RILIS</td>
<td>successful</td>
</tr>
<tr>
<td>August 2008</td>
<td>$^{194}$Hg</td>
<td>UC$_x$/Hot plasma</td>
<td>by-product of experiment IS461</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>successful</td>
</tr>
<tr>
<td>October 2008</td>
<td>$^{202}$Pb</td>
<td>UC$_x$/Hot plasma</td>
<td></td>
</tr>
<tr>
<td>April 2009</td>
<td>$^{194}$Hg</td>
<td>UC$_x$/Hot plasma</td>
<td>unsuccessful</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>no $^{194}$Hg was seen</td>
</tr>
<tr>
<td>June 2011</td>
<td>$^{202}$Pb, $^{202}$Tl</td>
<td>UC$_x$/RILIS, Surface ionization</td>
<td>Direct measurement of the $Q_{EC}$-value. The $Q_{EC}$-value is measured with insufficient accuracy</td>
</tr>
</tbody>
</table>

Table 1: ISOLTRAP beam times scheduled for proposal P242.
The successful runs in July and August 2008 have enabled us to determine the $Q_{EC}$-value of $^{194}$Hg. The resulting new $Q_{EC}$-value is 29(4) keV and substantially deviates from the AME2003 evaluated $Q_{EC}$-value of 69(14) keV. A thorough consideration of the data available in the literature on mass measurements of $^{194}$Hg and $^{194}$Au has led us to the conclusion that such a strong discrepancy between the AME2003 and our $Q_{EC}$-values originates in inaccurate experimental data for the $^{194}$Au mass taken by AME2003 for the evaluation. The total energy of the neutrino emitted in EC in $^{194}$Hg has thus been calculated to be 15(4) keV.

With the new value for the neutrino energy one can presently in principle determine the neutrino mass from EC in $^{194}$Hg with an uncertainty of approximately 20 eV, which would be a tenfold improvement of the present limit. Nevertheless, it would still be much worse than the present limit on the antineutrino mass of 2 eV from the tritium experiments. Thus, it can be concluded that $^{194}$Hg is not a suitable nuclide for the determination of the neutrino mass on the level of a few eV.

The new $Q_{EC}$-value of $^{194}$Hg and all details associated with the measurement have been published in Physics Letters B 693 (2010) 426.

**Addendum to proposal:**

In June 2011 we attempted to perform a direct measurement of the $Q_{EC}$-value of EC in $^{202}$Pb by measuring the cyclotron frequency ratio of $^{202}$Pb/$^{202}$Tl by alternating between the parent and daughter nuclide in the same run. The RILIS ion source was used to create $^{202}$Pb ions, whereas $^{202}$Tl ions were expected to come out of RILIS due to surface ionization on the hot surfaces in RILIS. Unfortunately, the ionization rate of $^{202}$Tl has turned out to be much lower than expected. This has resulted in the determination of the $Q_{EC}$-value of 51(20) keV with by far insufficient accuracy to draw a definite conclusion on the suitability of $^{202}$Pb for the determination of the neutrino mass.

Since the mass of $^{202}$Pb was successfully measured in October 2008 with an uncertainty of approximately 3 keV, it remains to only measure the mass of $^{202}$Tl, which has not been measured in the meantime.

**Beam time request:**

Based on the experience acquired during the above-mentioned runs, we ask for 5 more shifts of on-line beam at ISOLDE to measure the mass of $^{202}$Tl. We would like to perform the experiment in 2012 with the RILIS ion source and UCx target. We expect the $^{202}$Tl- yield of $10^5$ ions/μC, which is sufficient for our experiment. It is sufficient to determine the Q-value of EC in $^{202}$Pb with an uncertainty of approximately 3 keV in order to unambiguously state whether $^{202}$Pb falls into the group of the good candidates. Thus, the mass of $^{202}$Tl has
to be measured with an uncertainty of 2 keV. The measurement is planned to be performed by alternating between the measurements of the cyclotron frequency of reference $^{133}$Cs-ions and the measurements of the cyclotron frequency of $^{202}$Tl. More than 20 such alternating one-hour measurements of the cyclotron frequencies of $^{202}$Tl and $^{133}$Cs are needed to acquire sufficient statistics. This corresponds to about 3 shifts of a pure measurement time. The mass measurements of $^{194}$Hg, $^{194}$Au and $^{202}$Pb have shown that the pure measurement time constitutes at most two-thirds of the total beam-time. Thus, five shifts and the Ramsey scheme [6-8] for fast measurements appear to be realistic to measure the mass of $^{202}$Tl with an uncertainty of few keV.

References:

Appendix

**DESCRIPTION OF THE PROPOSED EXPERIMENT**

The experimental setup comprises: *ISOLDE* and *ISOLTRAP*

<table>
<thead>
<tr>
<th>Part of the Choose an item.</th>
<th>Availability</th>
<th>Design and manufacturing</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISOLTRAP</td>
<td>✚ Existing</td>
<td>✚ To be used without any modification</td>
</tr>
</tbody>
</table>