Proposal

β-asymmetry measurements in nuclear β-decay as a probe for non-Standard Model physics

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Abstract

We propose to perform a series of measurements of the beta asymmetry parameter in the decay of selected nuclei, in order to investigate the presence of possible time reversal invariant tensor contributions to the weak interaction. The measurements have the potential to improve by a factor of about four on the present limits for such non-Standard Model contributions in nuclear beta decay.

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Introduction

The Standard Model is generally considered to be only the low energy approximation of a more general theory describing particles and their interactions. The first unequivocal proof for the existence of new physics not included in the Standard Model was recently found with the discovery of neutrino oscillations (e.g. [1]). Most probably many more exiting new phenomena are still to be found. At the high energy frontier the new LHC collider can reveal many of these. Apart from increasing the energy that is available in particle collisions, the sensitivity to new physics can also be improved by increasing the precision of experiments at lower energies, viz. in muon decay and in neutron and nuclear β-decay.

At TRIUMF a new experiment (called TWIST - E614) is being set up to significantly improve the precision for the Michel parameters which describe the energy and angular dependence of positrons emitted in the decay of polarized positive muons [2]. In neutron decay continuous efforts are ongoing to improve the precision of the lifetime, of different correlation parameters and of searches for a neutron electric dipole moment [3]. Also in nuclear β-decay new experiments are continuously being set up in order to push precision and gain access to new observables [4-6].

In the past decade important progress was made in searches for non-Standard Model V,A interactions (i.e. searches for right-handed V,A currents) in nuclear β-decay. Whereas an overall analysis of data from neutron and nuclear β-decay available in 1991 indicated a possible deviation from the Standard Model at the 2.5 σ level [7], new measurements of the ν-asymmetry parameter B in neutron decay [8,9] and measurements of the longitudinal polarization of positrons emitted by polarized nuclei (the so-called polarization-asymmetry correlation; an observable that had never been addressed before) [10-12] have cleared this situation and pushed the lower limit from nuclear β-decay for the mass of a W boson with right-handed couplings to 320 GeV/c² (90% CL; in manifest left-right symmetric models). Although this is much less stringent than the lower limit of 720 GeV/c² from the D0 experiment at Fermilab [28], it is complementary to the D0 results if interpreted in more general left-right symmetric models (see e.g. refs. 5 and 11).

As for the more exotic scalar and tensor type weak interaction components, several new precision experiments in nuclear β-decay, which take advantage of a number of new developments in the field, are ongoing or being set up [13-19]. The first of these was the ISOLDE experiment IS334 that yielded improved limits for scalar currents from the Doppler broadening of β-delayed protons in the decay of 32Ar [13]. Several experiments use atom or ion traps to provide isotopically pure and backing-free samples that are free of scattering, e.g. the WITCH experiment that is being commissioned now at ISOLDE [14], but also the experiments at GANIL [15], at TRIUMF [16], at LBL Berkeley [17] and at Los Alamos National Laboratory [18]. All these are addressing either the βν-correlation coefficient $a_{\beta\nu}$ or the β-asymmetry parameter $A$. An overview is given in Table 1.

Current 95% C.L. upper limits for scalar and tensor coupling constants in nuclear β-decay, relative to the vector, respectively axial vector coupling constants, are $|C_S^{(\prime)}/C_V| < 0.06$ and $|C_T^{(\prime)}/C_A| < 0.08$ [4] (primed and unprimed coupling constants refer to parity violating and parity conserving interactions). With this proposal we would like to investigate the presence of time reversal invariant tensor components in the weak interaction, and thus improve the limits for the corresponding $C_T^{(\prime)}$ coupling constants.
Table 1. Recent and current experiments in nuclear beta decay to search for scalar and tensor type contributions in the weak interaction.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Type of set-up</th>
<th>Isotope</th>
<th>Observable/new physics</th>
<th>Ref.</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>IS334 (ISOLDE)</td>
<td>Doppler broadening</td>
<td>$^{32}\text{Ar}$</td>
<td>$a_{\beta^+}$ / scalar</td>
<td>[13]</td>
<td>$a/a_{SM} = 0.9989(52)(39)$</td>
</tr>
<tr>
<td>TRINAT (TRIUMF)</td>
<td>atom trap</td>
<td>$^{38}\text{mK}$</td>
<td>$a_{\beta^+}$ / scalar</td>
<td>[16]</td>
<td>$a/a_{SM} = 0.9978(30)(45)$</td>
</tr>
<tr>
<td>LBL</td>
<td>atom trap</td>
<td>$^{21}\text{Na}$</td>
<td>$a_{\beta^+}$ / scalar</td>
<td>[17]</td>
<td>$a/a_{SM} = 0.940(17)$</td>
</tr>
<tr>
<td>WITCH (ISOLDE)</td>
<td>Penning ion trap</td>
<td>$^{35}\text{Ar}$</td>
<td>$a_{\beta^+}$ / scalar</td>
<td>[14]</td>
<td>preparation</td>
</tr>
<tr>
<td>LPC-Trap (GANIL)</td>
<td>Paul ion trap</td>
<td>$^{6}\text{He}$</td>
<td>$a_{\beta^+}$ / tensor</td>
<td>[15]</td>
<td>preparation</td>
</tr>
<tr>
<td>LANL</td>
<td>atom trap</td>
<td>$^{82}\text{Rb}$</td>
<td>$A$ / tensor</td>
<td>[18]</td>
<td>preparation</td>
</tr>
<tr>
<td>Leuven</td>
<td>nuclear orientation</td>
<td>$^{60}\text{Co}$, $^{133}\text{Xe}$</td>
<td>$A$ / tensor</td>
<td>[19]</td>
<td>preparation</td>
</tr>
</tbody>
</table>

1) The 3.5 $\sigma$ deviation from the Standard Model value is believed to be caused by an erroneous value of the branching ratio for the $\beta$-transition that was observed. Experiments are planned to determine this branching ratio again with better precision at both TRIUMF and at KVI-Groningen [20,21].

Proposal

This proposal concentrates on measurements of the $\beta$-asymmetry parameter $A$, which determines the correlation between the spin of a polarized nucleus and the momentum of the $\beta$-particle emitted by this nucleus [22]. We propose to measure this $\beta$-asymmetry parameter $A$ for a number of pure Gamow-Teller $\beta$-decays of polarized nuclei, using the NICOLE low temperature nuclear orientation set-up at ISOLDE. This will allow to investigate the possible presence of tensor type contributions to the weak interaction in nuclear $\beta$-decay. The radioactive nuclei from ISOLDE will be implanted in a pure Fe foil at a temperature of about 10 mK, and be polarized by the interaction between their nuclear magnetic moment and the magnetic hyperfine field which they feel in the Fe host. We have gained considerable experience in this type of measurements over the past few years in the framework of the experiment IS381 (“Isospin mixing in N $\approx$ Z nuclei” [23]).

Note that in Leuven we are pursuing similar goals with a different variant of the low temperature nuclear orientation method (cf. Table 1 and ref. 19). There the long-lived $^{60}\text{Co}$ and $^{133}\text{Xe}$ are/will be either diffused or implanted in a pure Cu foil, in which no hyperfine field is present, and then be ‘brute-force’ polarized in an external magnetic field of 15 T.
Those measurements will be absolute measurements of A. Measurements of A using external magnetic fields and those using hyperfine magnetic fields to polarize the nuclei have very different systematic errors, such that the results of both types of experiments will cross check and complement each other.

Tensor $d \rightarrow u e \nu_e$ interactions can come from contact terms or from spin-zero leptoquark exchange. Tensor interactions from leptoquark exchange are accompanied by pseudoscalar type interactions of equal strength. Since for pseudoscalar interactions the ratio $R_\pi = \Gamma(\pi \rightarrow e\nu_e) / \Gamma(\pi \rightarrow \mu\nu_\mu)$ limits the coupling constants to the $10^{-4}$ region [5], this limit thus also applies to tensor interactions from leptoquark exchange. For contact interactions this is not the case. Since tensor interactions contribute to $R_\pi$ only through electromagnetic radiative corrections the constraints for tensor interactions from $R_\pi$ are weaker than those for pseudoscalar interactions. As a consequence, improvements of the beta decay limits on tensor coupling constants would give new information on contact interactions [5].

In the Standard Model one has for a $J \rightarrow J'$ pure Gamow Teller transition $A_{GT}^\beta \equiv \lambda_{jj}$ with $\lambda_{jj} = 1$ for $J \rightarrow J-1$ and $\lambda_{jj} = -J/J+1$ for $J \rightarrow J+1$. Note that $J \rightarrow J$ transitions are not considered here as they can contain small but non-negligible Fermi contributions due to isospin impurities (which we studied in the ISOLDE experiment IS381 [23]) that would mask non-Standard Model contributions. Allowing for a tensor component in the weak interaction and assuming Standard Model V,A interactions, the $\beta$-asymmetry parameter $A_{GT}^\beta$ becomes [22]:

\[
A_{GT}^\beta \equiv \lambda_{jj} \left[ 1 + \frac{\alpha Z m}{p} \text{Im} \left( \frac{C_T + C'_T}{C_A} \right) + \frac{\gamma m}{E} \text{Re} \left( \frac{C_T + C'_T}{C_A} \right) \right]
\]

(1)

with $C_T$ and $C'_T$ the coupling constants for a parity conserving/violating tensor type interaction and $C_A = -1.27 C_V$ the axial vector coupling constant obtained from neutron decay. Further, $\alpha$ is the fine structure constant, $Z$ is the charge of the daughter nucleus, $m$ is the rest mass of the electron, $p$ and $E$ are the momentum, respectively the total energy of the $\beta$-particle and $\gamma = \sqrt{1-(\alpha Z)^2}$. For simplicity recoil terms have been neglected in the above equation, but they will be discussed in detail in the next section. For the fast transitions that were selected for this proposal, i.e. with log $ft \approx 5$ to 6 (see Table 2), recoil effects on the $\beta$-asymmetry parameter can be calculated (using [24]) with a precision of about 0.5% or better (see below), which is comparable or a factor of two below our precision goal of 0.5% to 1%. Radiative corrections are one to two orders of magnitude smaller [25] and can therefore be neglected.

Recently, a very stringent limit was obtained for a time reversal violating tensor type interaction, i.e. $-0.008 < \text{Im}(C_T+C'_T / C_A) < 0.014$ (90% C.L.), from a precise determination of the so-called $R$-correlation in the decay of polarized $^8\text{Li}$ at the Paul Scherrer Institute [26]. We will focus here on a time reversal invariant tensor type interaction, i.e. on the last term in Eq.1 (i.e. $\text{Re}(C_T+C'_T/C_A)$), which enters the expression for $A$ via the so-called Fierz interference term [22]. In order to assure a good sensitivity to this combination of coupling constants $\beta$-transitions with low endpoint energy should preferably be used.
Experiment

The experiments will be carried out with the NICOLE low temperature nuclear orientation set-up. The radioactive nuclei are on-line implanted into a pure (99.99 %) Fe host foil mounted on a Cu sample holder at a temperature of about 10 mK inside the NICOLE ³He-⁴He dilution refrigerator. The nuclei are polarized by the combination of this low temperature and the large magnetic hyperfine field (order of 10 T to 100 T) they feel in the magnetized Fe foil. The β-particles emitted in the decay of the polarized nuclei are observed with two thin HPGe detectors installed at angles of 20° and 160° with respect to the polarizing magnetic field (quantization axis). The detectors will be installed 20° out of the plane of the Fe host foil in order to minimize the effect of scattering of the β-particles in this foil. The sample temperature will be determined with a calibrated nuclear orientation thermometer (e.g. ⁵⁷CoFe or ⁵⁴MnNi) attached to the back side of the sample holder, which will be observed with three large volume HPGe detectors outside the refrigerator.

The angular distribution of the β-particles is obtained as

\[ W(\theta) = \frac{N(\theta)_{\text{pol}}}{N(\theta)_{\text{unpol}}} = 1 + k A_{GT}^{\beta^+} P \frac{v}{c} \cos \theta \]

(2)

with \( N(\theta)_{\text{pol}} / N(\theta)_{\text{unpol}} \) the count rate in the detector at angle \( \theta \) with respect to the magnetization axis when the nuclei are polarized, respectively unpolarized. An unpolarized ensemble is obtained by heating the sample to a temperature of about 4K. Further, \( k \) is a factor determining the implantation quality, \( v/c \) is the velocity of the β-particles relative to the speed of light, \( P \) is the degree of nuclear polarization and \( Q \) is a solid angle correction factor that takes into account the finite dimensions of the source and the detector but also the effects of scattering and of the magnetic field. The Fe host foil is taken sufficiently thick to avoid scattering of the β-particles on the relatively high-Z Woods solder with which the foil is attached to the Cu sample holder. In order to limit the effect of the magnetic field on the β-particles trajectories, the field is kept at 0.1 T during the measurements. This low field is sufficient to maintain the magnetization of the Fe foil (thus guaranteeing a large degree of polarization) once it has been magnetized in a field of 0.5 T prior to the measurements. The values for the factor \( Q(v/c)\cos \theta \) are calculated with the Geant 4 code (see below).

Since the change in \( A_{GT}^{\beta^+} \) due to tensor type contributions is in opposite directions for \( \beta^+ \) and \( \beta^- \) transitions (see Eq. 1) and as these terms are moreover small with respect to unity, one can increase the sensitivity by performing a relative measurement using both a \( \beta^+ \) and a \( \beta^- \) transition. Neglecting time reversal violating tensor contributions one then has

\[ \frac{A_{GT}^{\beta^-}}{A_{GT}^{\beta^+}} \approx -\frac{\lambda_{JT}^{\beta^-}}{\lambda_{JT}^{\beta^+}} \left\{ 1 - \left[ \left( \frac{\gamma m}{E} \right)_{\beta^-} + \left( \frac{\gamma m}{E} \right)_{\beta^+} \right] \Re \left( \frac{C_T + C_T}{A_A} \right) \right\} \]

(3)

This is possible for the Kr isotopes we want to address (see Table 2). For these \( \lambda_{JT}^{\beta^-}/\lambda_{JT}^{\beta^+} = 1 \). Performing relative measurements in addition has the advantage that one becomes independent of the factor \( k \) (which gives the fraction of the nuclei that feel the full polarizing hyperfine interaction and which depends on the surface quality of the particular Fe foil that is
used) if one chooses for this relative measurement two isotopes of the same element and measures these in the same Fe foil in a single experimental run. One then has

\[
\frac{[W(\theta)-1]_\beta}{[W(\theta)-1]_{\beta'}} = \left[ \frac{A P Q \frac{v}{c} \cos \theta}{A P Q \frac{v}{c} \cos \theta} \right]_{\beta'}
\]

(4)

which is independent of \( k \). If the ratio of the nuclear polarizations of the two isotopes (i.e. \( P_\beta / P_{\beta'} \)) can be determined with a precision of the order of 0.001 this will not significantly contribute to the final error account either. This requires that the nuclear magnetic moments \( \mu \) and the magnetic hyperfine field \( B_{hf} \) are known with good precision. Note that in this case each individual detector yields a value for \( A_{GT}^{\beta} / A_{GT}^{\beta'} \).

The factor \( Q (v/c) \cos \theta = Q^\theta \) for different \( \beta \)-transitions and/or detectors will be calculated with the Geant 4 code. Off line measurements with collected samples of \(^{82}\text{Rb}\) and \(^{118}\text{Sb}\) will be performed to test and optimize the Geant calculations. This will be done by comparing experimental quantities which depend only on \( Q^\theta \), such as e.g.

\[
\frac{[W(20\text{ })-1]_{\beta'}}{[W(160\text{ })-1]_{\beta'}} = \frac{Q^{20}}{Q^{160}}
\]

(5)

with the results obtained from Geant. The isotopes \(^{82}\text{Rb}\) and \(^{118}\text{Sb}\) were chosen for this as they can be obtained from the decay of collected long-lived \(^{82}\text{Sr}\) (\( t_{1/2} = 25.4 \text{ d} \)) and \(^{118}\text{Te}\) (\( t_{1/2} = 6.0 \text{ d} \)), such that statistics can be collected during a measurement period of several weeks, in off-line conditions.

The isotopes and \( \beta \)-transitions selected for these measurements are listed in Table 2, together with their main properties. As can be seen, all isotopes have rather low endpoint energy leading to rather good sensitivity factors \( \gamma m/E = 0.34 \) to 0.52. In a relative measurement with \(^{79}\text{Kr}\) and \(^{85}\text{Kr}\) the total sensitivity (i.e. summed \( \gamma m/E \)-factor) is even 0.80. A measurement of \( A_{GT}^{\beta} / A_{GT}^{\beta'} \) for these two isotopes with a precision of 1% (resp. 0.5%), which is our precision aim for these measurements, then yields a 90% C.L. upper limit of 0.021 (resp. 0.010) for \( \text{Re}(C_T+C'_T/C_\lambda) \). This is comparable to the present limits for time reversal violating tensor currents obtained in the decay of \(^{8}\text{Li}\) that were mentioned already [26]. As the magnetic hyperfine field of Kr in Fe is not sufficiently well known yet [27], we will determine this in a nuclear magnetic resonance (NMR/ON) experiment on the oriented \(^{79}\text{Kr}\). As \(^{79}\text{Kr}\) has a half-life of about 35 h this can be done in off-line conditions with a collected sample. Further, since both Kr isotopes have spin \( J=1/2 \), the emission of the \( \gamma \)-rays in their decay will be fully isotropic such that the intensities of these will allow for an internal normalization of the W(0) for beam intensity fluctuations and isotope half-life. For the Kr isotopes we can thus use Eq. (4) such that each \( \beta \)-detector will yield an independent value for \( A_{GT}^{\beta} / A_{GT}^{\beta'} \).
For the isotopes $^{67}$Cu and $^{82g,83}$Br, absolute measurements will be performed as no suitable $\beta^+$-emitting Cu and Br isotopes for our purposes are available. The sensitivity factor $\gamma m/E$ then ranges from 0.34 to 0.52. Even though no relative measurements can be performed for these nuclei, they have the advantage that their asymmetry parameter is two or three times larger compared to the Kr isotopes while also a larger degree of nuclear polarization can be achieved (see Table 2), resulting in a three to four times larger asymmetry effect (i.e. the value for $AP(v/c)Q \cos \theta$). Further, with respect to recoil effects $\beta^-$-emitters have the advantage that the contribution from weak magnetism is partially cancelled by the one from the induced tensor form factor which has opposite sign. The implantation quality factor $k$ that is needed in the case of absolute measurements (see Eq. 2) will be determined from the $\gamma$ ray anisotropies in the decay of respectively $^{68}$Cu ($t_{1/2} = 31.1$ s) and $^{83}$Br.

### Table 2. Main properties of the isotopes and $\beta$-transitions that will be investigated. In the case of $^{79}$Kr and $^{85m}$Kr a relative measurement and for $^{67}$Cu, $^{82g}$Br and $^{83}$Br absolute measurements of the $\beta$-asymmetry parameter will be performed. The isotopes $^{82}$Rb and $^{118}$Sb will be used to test and optimize the Geant calculations for the factors $Q^0 \equiv Q(v/c) \cos \theta$.

<table>
<thead>
<tr>
<th>Isotope</th>
<th>$t_{1/2}$</th>
<th>$\beta$-transition</th>
<th>$E_{\text{endpoint}}$ [keV]; log $f$</th>
<th>$I_\beta$ [%]</th>
<th>$A$ (Standard Model)</th>
<th>$\gamma m/E$ @ endpoint</th>
<th>$\mu$ [$\mu_N$]</th>
<th>$B_{\text{ref}}$ [T]</th>
<th>$P$ [%] at 10 mK</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{79}$Kr</td>
<td>35.04(10)h</td>
<td>$\beta^+$, $1/2^-\rightarrow 3/2^-$</td>
<td>604; 5.62(12)</td>
<td>7</td>
<td>-0.333</td>
<td>0.44</td>
<td>0.536(2)</td>
<td>-31</td>
<td>54</td>
</tr>
<tr>
<td>$^{85m}$Kr</td>
<td>4.480(8)h</td>
<td>$\beta^-$, $1/2^-\rightarrow 3/2^-$</td>
<td>840; 5.252(6)</td>
<td>78</td>
<td>+0.333</td>
<td>0.36</td>
<td>0.633(2)</td>
<td>-31</td>
<td>61</td>
</tr>
<tr>
<td>$^{67}$Cu</td>
<td>61.83(12)h</td>
<td>$\beta^-$, $3^-\rightarrow 5/2^-$</td>
<td>576; 6.3</td>
<td>22</td>
<td>0.60</td>
<td>0.43</td>
<td>+2.54(2)</td>
<td>-21.8(1)</td>
<td>76</td>
</tr>
<tr>
<td>$^{82g}$Br</td>
<td>35.282(7)h</td>
<td>$\beta^-$, $5^-\rightarrow 4^-$</td>
<td>444; 5.048(8)</td>
<td>99</td>
<td>-1</td>
<td>0.52</td>
<td>+1.6270(5)</td>
<td>+81.38(6)</td>
<td>87</td>
</tr>
<tr>
<td>$^{83}$Br</td>
<td>2.40(2)h</td>
<td>$\beta^-$, $3/2^-\rightarrow 1/2^-$</td>
<td>931; 5.03(4)</td>
<td>99</td>
<td>-1</td>
<td>0.34</td>
<td>-</td>
<td>+81.38(6)</td>
<td>98</td>
</tr>
<tr>
<td>$^{82}$Rb</td>
<td>1.273(2) m</td>
<td>$\beta^+$, $1^-\rightarrow 0^+$</td>
<td>3379; 4.580(5)</td>
<td>82</td>
<td>+1</td>
<td>0.13</td>
<td>0.554508(1)</td>
<td>≈10</td>
<td>13</td>
</tr>
<tr>
<td>$^{118}$Sb</td>
<td>3.6(1) m</td>
<td>$\beta^+$, $1^-\rightarrow 0^+$</td>
<td>2635; 4.525(13)</td>
<td>73</td>
<td>+1</td>
<td>0.15</td>
<td>2.47(7)</td>
<td>+23.387(10)</td>
<td>87</td>
</tr>
</tbody>
</table>
Finally, we now come back to the effect of the recoil terms on $A_{GT}^\beta$ for the isotopes selected here. Including recoil terms (see e.g. [24]) Eq. 1 becomes (for $J \rightarrow J \pm 1$ beta transitions):

$$A_{GT}^\beta \approx \lambda_{yJ} \left[ 1 + \frac{\gamma_m}{E} \left( \frac{C_T + C'_T}{C_A} \right) - \frac{E + 2m^2 / E}{3M_n} b - \frac{-E + m^2 / E}{3M_n} d \right] \frac{\lambda_{Jy'}}{J + 1} \frac{5E}{M_n} f$$

(Eq. 6) with $M_n$ the nucleon mass and $A$ the mass number. Further, $b$, $c$, $d$ and $f$ are respectively the weak magnetism, Gamow-Teller, induced tensor and the $f$-form factors. The dominant contribution is the one from weak magnetism, while the induced tensor term is typically a factor of two to three smaller and the term from the $f$-form factor is again a factor of about two smaller. Eq. 3 then becomes:

$$\frac{A_{GT}^\beta}{A_{GT}^\beta} \approx -\frac{\lambda_{yJ}'}{\lambda_{yJ}} \left\{ 1 - \left[ \left( \frac{\gamma_m}{E} \right)_{\beta^-} + \left( \frac{\gamma_m}{E} \right)_{\beta^+} \right] \left( \frac{C_T + C'_T}{C_A} \right) - \left[ (d - d') + (f - f') \right] \right\}$$

(Eq. 7), where $b'$, $d'$ and $f'$ are the contributions from the weak magnetism ($b$), the induced tensor ($d$) and the $f$-form factor in Eq. 6. The dominant contribution is again the one from weak magnetism. For the induced tensor form factor only the difference of two nearly identical terms now contributes, while the contribution from the $f$-form factor is typically a factor of four or more smaller than the one from weak magnetism.

Based on information about the different form factors in the literature [29, 30], conservative estimates were made for all three form factors (see Table 3). For the relative measurement with the two Kr isotopes one then calculates a recoil order correction of $-0.015(5)$ for the ratio $A_{GT}^\beta / A_{GT}^\beta$, which equals $-1$ in the absence of tensor contributions or recoil terms. For the absolute measurements with $^{67}$Cu and $^{82g,83}$Br, the recoil corrections are about $\pm 0.004(3)$ (see Table 3).

Assuming a 1% error on our experimental result for $A_{GT}^\beta / A_{GT}^\beta$ with the Kr isotopes and using the above mentioned value for the recoil correction, our measurement will be sensitive (at 90% C.L.) to $\text{Re} (C_T + C'_T/C_A) = 0.023$, which is only about 10% larger than when recoil terms are neglected (see above). Thus, recoil effects when taken into account, do not significantly affect the sensitivity of this type of measurements. For $^{67}$Cu and $^{82g,83}$Br a 1% (resp. 0.5%) experimental error corresponds to a sensitivity (90% C.L.) of about 0.040 (resp. 0.020) if recoil effects are included.

**Experimental apparatus to be used**

NICOLE

**Data handling requirements**

We will provide our own data handling equipment.
Table 3. Calculation of the recoil contributions to $A_{GT}^\beta$ and $A_{GT}^\beta/A_{GT}^{\beta_r}$, with Eqs. 6 and 7.

<table>
<thead>
<tr>
<th>Isotope</th>
<th>$A_{GT}^\beta$ or $A_{GT}^\beta/A_{GT}^{\beta_r}$ (no recoil)</th>
<th>log ft</th>
<th>b/Ac</th>
<th>d/Ac</th>
<th>f/Ac</th>
<th>$A_{GT}^\beta$ or $A_{GT}^\beta/A_{GT}^{\beta_r}$ (including recoil)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{79}$Kr</td>
<td>-0.333</td>
<td>5.62(12)</td>
<td>10(5)</td>
<td>5(3)</td>
<td>0.15(15)</td>
<td></td>
</tr>
<tr>
<td>$^{85m}$Kr</td>
<td>+0.333</td>
<td>5.252(6)</td>
<td>10(5)</td>
<td>5(3)</td>
<td>0.15(15)</td>
<td></td>
</tr>
<tr>
<td>$^{79}$Kr/$^{85m}$Kr</td>
<td>$A_{GT}^\beta/A_{GT}^{\beta_r} = -1$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{67}$Cu</td>
<td>0.600</td>
<td>6.3</td>
<td>20(8)</td>
<td>10(4)</td>
<td>0.15(15)</td>
<td>0.604(3)</td>
</tr>
<tr>
<td>$^{82}$Br</td>
<td>-1.000</td>
<td>5.048(8)</td>
<td>8(4)</td>
<td>4(2)</td>
<td>0.15(15)</td>
<td>-1.004(2)</td>
</tr>
<tr>
<td>$^{83}$Br</td>
<td>-1.000</td>
<td>5.03(4)</td>
<td>8(4)</td>
<td>4(2)</td>
<td>0.15(15)</td>
<td>-1.005(3)</td>
</tr>
</tbody>
</table>

**Beam time request**

We plan three experimental runs in this proposal:

1. one for the relative measurement with $^{79}$Kr (collection) and $^{85m}$Kr (on-line),
2. a second one for the measurement with $^{67}$Cu (collection) and $^{68}$Cu (on-line), and
3. a third one for the measurements with $^{82}$Br (collection) and $^{83}$Br (on-line).

- For the Kr isotopes we ask for 2 shifts to collect $^{79}$Kr (one for the measurement of the $\beta$-asymmetry parameter and one for the NMR/ON experiment to determine the hyperfine magnetic field $B_{hf}$ for Kr in Fe) and 8 shifts to measure the $\beta$-asymmetry parameter with $^{85m}$Kr.
- For the measurement of the $\beta$-asymmetry parameter of $^{67}$Cu we ask for 1 shift to collect this isotope and 4 shifts for the measurement with $^{68}$Cu to determine the implantation quality factor $k$.
- For the Br isotopes we also ask for 1 shift to collect $^{82}$Br and 10 shifts for the experiment with $^{83}$Br. Of these 10 shifts, 8 will be used for the measurement of the $\beta$-asymmetry parameter, and the two others to perform a NMR/ON measurement to determine the nuclear magnetic moment of this isotope.
- For $^{82}$Rb and $^{118}$Sb we ask 1 shift for each isotope for collecting the $^{82}$Sr and $^{118}$Xe precursors.
## Table 4. Detailed beam time request.

<table>
<thead>
<tr>
<th>Beam</th>
<th>Min. intensity</th>
<th>Target material</th>
<th>Ion source</th>
<th>Shifts</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{79}$Kr</td>
<td>$1 \times 10^7$</td>
<td>Nb foil, ZrO$_2$ or UCx</td>
<td>plasma cooled transfer line</td>
<td>2</td>
</tr>
<tr>
<td>$^{85m}$Kr</td>
<td>$1 \times 10^6$</td>
<td>Nb foil, ZrO$_2$ or UCx</td>
<td>plasma cooled transfer line</td>
<td>8</td>
</tr>
<tr>
<td>$^{67}$Cu</td>
<td>$1 \times 10^6$</td>
<td>U Carbide or ZrO$_2$</td>
<td>RILIS</td>
<td>1</td>
</tr>
<tr>
<td>$^{68}$Cu</td>
<td>$1 \times 10^6$</td>
<td>Ta foil, U Carbide or ZrO$_2$</td>
<td>RILIS</td>
<td>4</td>
</tr>
<tr>
<td>$^{82}$Br</td>
<td>$1 \times 10^6$</td>
<td>Nb foil, ZrO$_2$, UCx or ThO$_2$</td>
<td>LaB$_6$ source</td>
<td>1</td>
</tr>
<tr>
<td>$^{83}$Br</td>
<td>$1 \times 10^6$</td>
<td>Nb foil, ZrO$_2$, UCx or ThO$_2$</td>
<td>LaB$_6$ source</td>
<td>10</td>
</tr>
<tr>
<td>$^{82}$Sr</td>
<td>$5 \times 10^6$</td>
<td>Nb foil or powder, Zr foil</td>
<td>W surface</td>
<td>1</td>
</tr>
<tr>
<td>$^{119}$Te (or $^{118}$Xe )</td>
<td>$5 \times 10^6$</td>
<td>CeO$_2$, BaO, La$_2$O$_3$</td>
<td>hot plasma (or cooled transfer line)</td>
<td>1</td>
</tr>
</tbody>
</table>

1) To determine the implantation quality factor $k$ for the measurement with $^{67}$Cu.
2) To produce a sample of $^{82}$Rb, resp. $^{118}$Sb to testing and optimize the calculation of $Q^0$ with Geant.

### References


