EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

Measurement of the super-allowed branching ratio of ^{22}Mg

B. Blank, M. Aouadi, P. Ascher, M. Gerbaux, J. Giovinazzo, T. Goigoux, S. Grévy, T. Kurtukian Nieto, C. Magron

CEN Bordeaux-Gradignan, France

A. de Roubin

MPIK Heidelberg, Germany and CEN Bordeaux-Gradignan, France

P. Delahaye, G.F. Grinyer, J. Grinyer, A. Laffoley, J.-C. Thomas

GANIL Caen, France

M.R. Dunlop, R. Dunlop, P.E. Garrett, C.E. Svensson

University of Guelph, Canada

G.C. Ball

TRIUMF, Vancouver, Canada

P. Finlay

K.U. Leuven, Belgium

Spokes-person: B. Blank (blank@cenbg.in2p3.fr)
Contact person: K. Johnston (karl.johnston@cern.ch)

Beam time requested: 10 shifts on LA1 and LA2

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Abstract

We propose to measure the super-allowed branching ratio and the half-life of ^{22}Mg, one of the least well measured 0+ → 0+ transitions of the 14 nuclei used to determine V_{ud} and to test the unitarity of the CKM matrix. We propose measurements which should allow to significantly improve the precision on the super-allowed branching ratio employing a precisely efficiency calibrated germanium detector and on the half-life. As no method exists to greatly (e.g. an order of magnitude) improve on previous results, the branching ratio and the half-life have to be measured with independent methods and in independent experiments several times.

1 Scientific background

Precision measurements of the ft values for super-allowed 0+ → 0+ Fermi decays between isobaric analogue states provide demanding tests of the Standard Model description of electroweak interactions. As the axial vector current does not contribute to 0+ → 0+ transitions in lowest order, the ft values for these decays can be directly related to the weak vector coupling constant G_V. According to the conserved vector current (CVC) hypothesis, G_V is not renormalized by strong interaction effects. Furthermore, the nuclear transition matrix elements for these decays are simply the expectation values of isospin ladder operators and are trivial isospin Clebsch-Gordon coefficients in the case of exact analogue states. The ft values for all super-allowed decays between states of a given isospin, once corrected for small radiative and isospin symmetry-breaking effects, are therefore expected to be equal, independent of the nuclei involved. In particular, for T = 1 multiplets, the CVC hypothesis can be expressed in the form [1]:

$$Ft = ft(1 + \delta'_R)(1 + \delta_{NS} - \delta'_c) = K / (M_F^2 * G_v^2 * (1+\Delta_R)) = \text{constant} \qquad (1)$$

where K is a known constant and M_F is the Fermi matrix element between analogue states. Radiative corrections δ'_R modify the decay rate by about 1.5% and structure-dependent corrections δ_{NS} - δ'_c modify the "pure" Fermi matrix element by about 0.5-1%. Δ_R is a radiative correction allying to all transitions.

To date, ft values have been determined to a precision of ±0.25% or better for the super-allowed decays of fourteen nuclei between ^{10}C and ^{74}Rb, with eight of these cases measured to better than ±0.10%. The consistency of the corrected Ft values for these transitions currently confirms the CVC hypothesis at the level of 1.2×10^{-4} and, under the assumption of a specific set of theoretical isospin symmetry-breaking corrections, yields a mean "corrected" ft value [1]:

$$Ft = [3072.27 \pm 0.62 \text{ (stat)} \pm 0.36 \ (\delta_R')] \text{ s} \qquad (2)$$

where the first uncertainty includes both the statistical uncertainties of the experimental ft values and the estimated theoretical uncertainties on the individual δ_{NS} and δ_C corrections within the adopted theoretical framework, while the second reflects a systematic uncertainty assigned to the δ_R' radiative corrections associated with truncation of their estimation at order $Z^2\alpha^3$ [1]. Substituting this mean value in Eq. 1 yields $G_V /(\hbar c)^3 = (1.13625\pm0.00025)\times10^{-5}$ GeV^{-2} for the vector coupling constant. Upon comparison with the Fermi coupling constant $G_F /(\hbar c)_3 = (1.1663787 \pm 0.0000006) \times 10^{-5}$ GeV^{-2} from muon decay, a value of

$$|V_{ud}| = G_V / G_F = 0.97417 \pm 0.00021 \qquad (3)$$

is obtained for the up-down element of the Cabibbo-Kobayashi-Maskawa (CKM) quark-mixing matrix. When combined with the 2014 Particle Data Group [2] recommended values of $|V_{us}| = 0.2253 \pm 0.0008$ and $|V_{ub}| = 0.00422 \pm 0.00042$, the above value of $|V_{ud}|$ deduced from the super-allowed Fermi decays provides a demanding test of the unitarity of the CKM matrix, a fundamental assumption of the Standard Model. The current result

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.99978 \pm 0.00055 \qquad (4)$$

satisfies the CKM unitarity condition of the Standard Model at the level of ±0.055% and places stringent limits [1] on various theories of physics beyond the Standard Model, such as right-handed currents, scalar currents, and additional quark generations [3].

While the results of the 2015 survey [1] of super-allowed Fermi decay data presented above appear to provide a strong confirmation of Standard Model expectations, we note that debate remains over the value of V_{us}. Recent lattice QCD calculations of the form factors for purely leptonic kaon and pion decays [5], for example, yield a value of V_{us} consistent with the 2014 Particle Data Group value, while those for semileptonic kaon decay [6] yield a smaller value of V_{us} that, when combined with the value of V_{ud} from Eq. 3, would lead to a violation of the CKM unitarity condition at the 2.1σ level. Furthermore, the value of V_{ud} given in Eq. 3 depends on the choice of a specific theoretical model for nuclear structure dependent isospin symmetry-breaking corrections in super-allowed decays. A re-evaluation of these δ_C corrections in 2008 [4] incorporating additional contributions of the core orbitals led to significant changes in their adopted values, in some cases exceeding 50% of their own values.

When compared directly to their previously adopted values [5], these new isospin symmetry-breaking corrections lower the world-average corrected super-allowed Ft value by more than 3σ and raise V_{ud} by 1.5 σ. Given the important implications of the super-allowed data for tests of the Standard Model, these significant changes in the adopted δ_C values motivated a wide range of new studies of the isospin symmetry-breaking effects in super-allowed decays by a variety of theoretical approaches [8, 9, 10, 13, 14, 15, 16, 17, 18], as well as semi-empirical analysis [19]. A summary of the δ_C values from these various models is presented in Fig. 1, and indicates the significant model dependence of the calculated values.

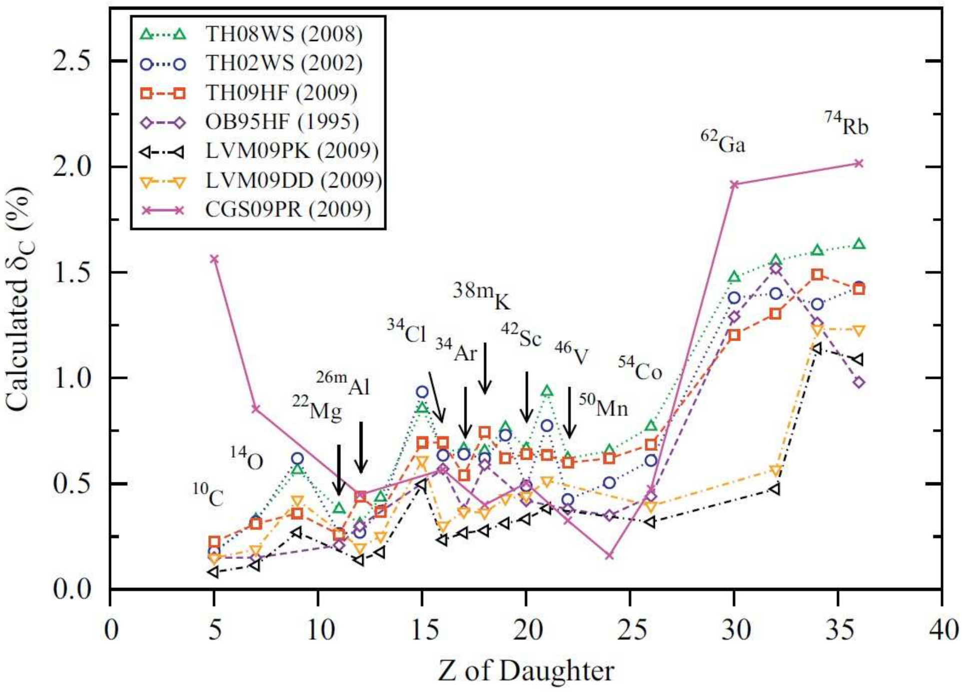

Figure 1: Calculated isospin symmetry-breaking corrections for super-allowed Fermi decays from various theoretical models. The results shown are from references: TH08WS [4], TH02WS [5], TH09HF [6], OB95HF [7], LVM09PK [8], LVM09DD [8], CGS09PR [9], and SAT12SV [10].

While not all of the theoretical models displayed in Fig. 1 have been constrained to the same extent by independent experimental data such as nuclear charge radii, separation energies, and coefficients of the isobaric mass multiplet equation, in previous surveys of the world super-allowed data [6] the model dependence of the calculated isospin symmetry breaking corrections has been accounted for by averaging the corrected Ft values obtained with two sets of theoretical calculations and assigning an additional systematic uncertainty to account for the different Ft values obtained with the two models. In both of the adopted models, the breaking of isospin symmetry by Coulomb and charge-dependent nuclear forces was described by dividing δ_C into two components, $\delta_C = \delta_{C1} + \delta_{C2}$, the first accounts for different degrees of configuration mixing in the parent and daughter states and the second reflects the imperfect overlap of radial wave functions arising from differences in the proton and neutron separation energies. The former, δ_{C1}, is calculated via a shell-model diagonalization, with isospin non-conserving interactions constrained to reproduce empirical isobaric mass multiplet equation coefficients. In the "Woods-Saxon" (WS) model [4, 5], the radial overlap correction δ_{C2} is computed with a full-parentage expansion in terms of single-particle wave functions in a Woods-Saxon plus Coulomb potential, while in the "Hartree-Fock" (HF) model [6, 7] single-particle wave functions are derived from a self-consistent Hartree-Fock calculation that includes the effects of an induced isovector interaction arising from differences in the proton and neutron density distributions.

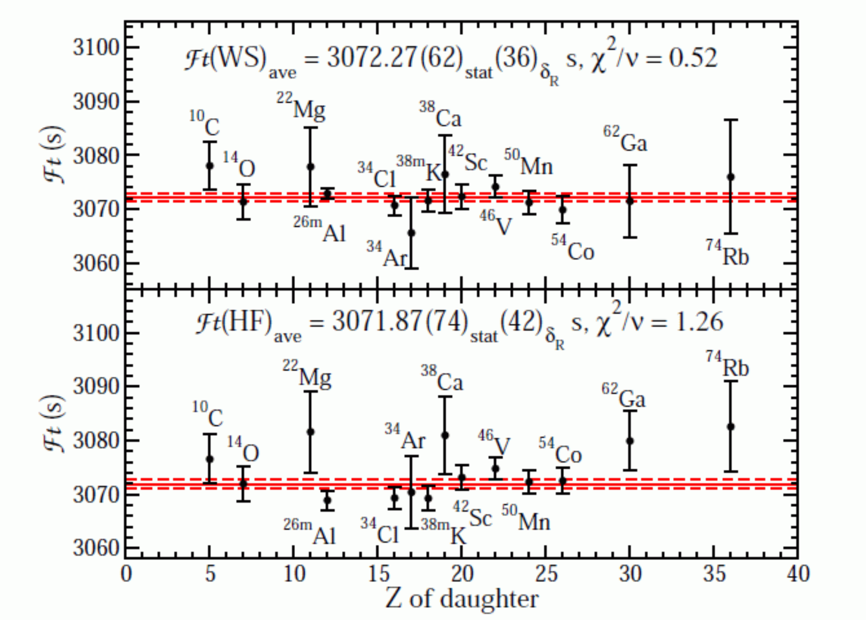

Figure 2: Ft values for the 14 precisely measured super-allowed Fermi decays using (upper) the Woods-Saxon δ_C corrections of Ref. [1], and (lower) the Hartree-Fock δ_C corrections of Ref. [6].

In the 2015 survey [1], the Woods-Saxon isospin symmetry-breaking corrections, with slightly updated values [1] resulting from new experimental constraints, are adopted and a systematic uncertainty associated with the model dependence of these isospin symmetry-breaking corrections is no longer assigned to the world-average Ft value given in Eq. 2. This choice was motivated by: i) a greater consistency of the corrected Ft values, and thus a smaller χ^2/ν for the CVC test, obtained with the WS δ_C corrections, and ii) a recent determination [21] of the ^{38}Ca super-allowed ft value with sufficient precision to compare the A = 38 mirror super-allowed transitions ^{38}Ca → ^{38m}K and ^{38m}K → ^{38}Ar, which favoured the WS δ_C calculation over the HF value at the 1.7σ level. We note, however, that the other pair of mirror super-allowed decays measured with comparable precision, ^{34}Ar → ^{34}Cl and ^{34}Cl → ^{34}S, actually favours the HF δ_C correction over the WS value. When treated in the same manner as the WS corrections that result in the value of Ft_{WS} = 3072.27 $(62)_{stat}$ $(36)_{\delta R'}$ s with χ^2/ν = 0.52 given in Eq. 2 and shown in the top panel of Fig. 2, including the estimated theoretical uncertainties for the δ_C values within each model, the HF corrections shown in the lower panel of Fig. 2 yield Ft_{HF} = 3071.87 $(74)_{stat}(42)_{\delta R'}$ s with χ^2/ν = 1.26. While, the χ^2/ν for the CVC test is certainly better for the case of the WS δ_C corrections, with 13 degrees of freedom a value of χ^2/ν as large as the 1.26 obtained with the HF corrections has a probability of approximately 23% for statistically independent data. Furthermore, as can clearly be seen in the lower panel of Fig. 2, the fact that the χ^2/ν for the CVC test exceeds unity for the HF δ_C corrections is associated entirely with four of the least precisely measured Ft values, for the cases of ^{22}Mg, ^{38}Ca, ^{62}Ga, and ^{74}Rb, each of which has an uncertainty exceeding 0.22%. If only the 9 transitions with Ft precision of 0.15% or better are retained, one obtains for the two sets of calculations, Ft_{WS} = 3072.20 $(63)_{stat}(36)_{\delta R'}$ s with χ^2/ν = 0.67 and Ft_{HF} = 3071.43$(76)_{stat}(42)_{\delta R'}$ s with χ^2/ν = 1.00. These results are both fully consistent with the CVC hypothesis, but differ in their central values by 0.77 s, equivalent to the entire statistical uncertainty of the world super-allowed data set.

In light of the above observations, and the importance of the world-average super-allowed Ft value in establishing V_{ud} and constraining models of new physics beyond the Standard Model, removal of a systematic uncertainty associated with the model dependence of the isospin symmetry-breaking corrections would not appear to be justified at this time. In particular, careful scrutiny of those decays that discriminate between the different theoretical approaches is essential, and improved precision for these Ft values is highly desirable.

Of the four cases mentioned above, ^{22}Mg, ^{38}Ca, ^{62}Ga, and ^{74}Rb, the latter two cases with A≥62 have Ft uncertainties that are currently dominated by theoretical uncertainties in the isospin symmetry-breaking corrections. While experiments can provide important guidance for improving these calculations, it would appear that further progress in understanding isospin symmetry-breaking in these high-Z nuclei will require significantly larger shell model spaces than have been employed to date [21, 22]. For the cases of ^{22}Mg and ^{38}Ca, however, the Ft uncertainties are currently dominated by uncertainties in the experimental ft values and, unlike most of the super-allowed decays that have been measured multiple times by independent groups, the ^{22}Mg super-allowed ft value presented in the 2015 survey [1] is dominated by a single high-precision half-life measurement and a single high-precision branching ratio measurement [26]. Presently, the half-life value is (3875.2±2.4) ms (0.6‰) and the super-allowed branching ratio is (53.16 ± 0.12) % (2.3 ‰). The Q value is known with a precision of 0.07 ‰ (4124.53±0.28 keV).

The intensities available at ISOLDE are sufficient for the measurements proposed here. For the branching ratio measurement, the intensity is limited by the acceptable rates of the germanium detector (see below), whereas the half-life measurement will be limited by the dead-time correction. We intend to improve the ^{22}Mg branching-ratio and the half-life precision by more than a factor of 2 and 3, respectively. These measurements, combined with the precisely known Q-value for ^{22}Mg decay [23, 24], will improve the precision of the Ft value of this nucleus by more than a factor of 2. As can be seen from Fig. 2, such an improvement in the ^{22}Mg Ft will play a major role in discriminating between different theoretical approaches to the isospin symmetry-breaking corrections in super-allowed decays and their influence on the determination of V_{ud} and tests of the Standard Model.

2 Experimental setups and experiment

The branching ratio will be measured by means of our precisely calibrated germanium detector [25]. The germanium detector has been calibrated in efficiency with a relative precision of 0.1% in the region down to 100 keV at a fixed distance of 15 cm. Additional off-line measurements with calibration sources will be performed before the on-line experiment to improve the precision at low energies as required for the present measurement (γ ray at 74 keV where the precision given for the moment is 0.5%).

The activity will be accumulated on a tape facing the germanium detector at 0°. As the 583 keV γ ray collects close to 100% of the decay strength, all other γ rays can be measured with respect to this γ ray and thus only relative branching ratios need to be measured (see Fig. 3). Therefore, the measurements will be performed in continuous mode. Each time a proton pulse is available, we will take it. The experiment trigger would thus be the trigger of the germanium detector and we “simply” need to perform a γ singles measurement. However, as we will measure only γ singles, we need to make absolutely sure that no activity is deposited elsewhere in the vicinity of the set-up than on the catcher. In a recent ^{10}C experiment at ISOLDE performed in a similar way, we installed a DSSSD detector directly behind the catcher to get, via the β particles, the profile of the implantation in the catcher. We will perform a similar measurement with an independent data acquisition.

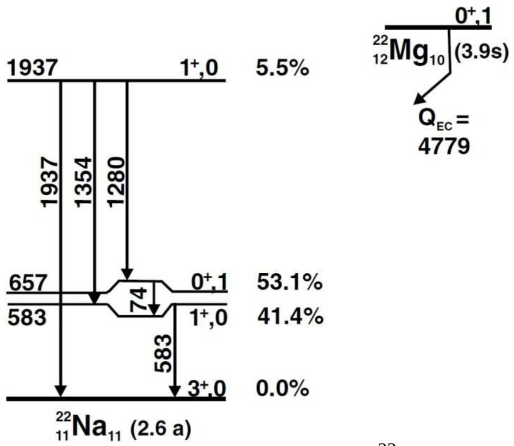

Figure 3: Decay scheme for the decay of ^{22}Mg from Ref. [26].

The half-life will be measured with an independent set-up optimized on the half-life. It will consist of a tape transport system, of two plastic scintillators, "sandwiching" the tape thus yielding close to 100% detection efficiency, to detect β particles and of a fast and simple data acquisition time-stamping the events and collecting the events in cycles. We will not measure the data in listmode acquisition mode, but only as cycles. The cycles will consist in an accumulation phase, the transport of the activity from the collection point to the decay station and the decay measurement for 20 half-lives. After such a cycle, the data from this cycle will be stored, the tape will be moved to remove any remaining activity and a new cycle will start.

The production rate for ^{22}Mg is given on the ISOLDE web page as high as $8*10^6$ per μC. The prime contaminant will be ^{22}Na with possibly a factor of 100 higher rate. However, its half-life is 2.6 years and it will therefore hardly contribute to the decay. LIST will suppress ^{22}Na by a factor of 10^4 while reducing ^{22}Mg by a factor of 30. This is still enough as compared to the production rate needed. According to the target – ion-source specialists it can not be completely excluded that there will not be any ^{22}F produced (T1/2 = 4.23(4) s). This is not a problem for the branching ratio measurement, however, due to its similar half-life with respect to ^{22}Mg a significant production of ^{22}F (let us say more than 1% as compared to ^{22}Mg) would put into danger the half-life measurement. Such a production of ^{22}F is not expected, but could be detected with the set-up used for the branching ratio measurement. If detected and quantified, it can be included in the half-life fit. ^{22}O has probably a too small production rate to be a worry.

3 Statistics and measurement times

Branching ratio measurement on LA1
We aim at reaching approximately 2×10^9 decays in the setup, yielding approximately 1.2×10^7, 6×10^6, and 2.2×10^5 counts in the 74 (1% peak efficiency), 583 (0.3%), and 1280 keV (0.2%) photopeaks, respectively. With a ±0.1 % relative efficiency calibration between 74 and 583 keV, as achieved in Ref. [25] above 100 keV, we would obtain a ^{22}Mg super-allowed branching with a precision limited by the detector efficiency calibration.

To estimate the beam time required, we start from the fact that we want to limit the number of counts detected by the germanium detector to less than 1000 events per second. All calibration measurements have been performed with this limitation. In the decay of ^{22}Mg, an average of 1.6 γ rays is produced per decay. In addition, two 511 keV γ rays come from the positron annihilation. To take into account background radiation, we assume that we have 5 γ rays per ^{22}Mg decay. Therefore, we can detect 200 ^{22}Mg decays per second. An overall average total detection efficiency of our detector is 1% at 15 cm, so we can accept 20000 decays per second in the set-up. In order to reach 2 x 10^9 decays in the setup, we need 10^5 s of measurement time, i.e. with breaks 4 shifts.

Half-life measurement on LA2

We aim at detecting 10^8 decays in different measurements where we modify experimental parameters like fixed dead times, detector high-voltages, and trigger thresholds. If we want to limit the dead time correction in all channels of the time spectrum (and in particular in the first channel having the highest rate) to less than 20%, we have to limit the number of implanted ^{22}Mg per cycle to 10^5. In such a scenario, the first 15ms channel would have 250 counts which yields a dead-time correction of 1 / (1-R*DT) = 1 / (1- 250/0.015 1/s * 8e-6s) = 1.15, which means for a fixed dead time of 8μs we would have a correction of 15%. With 2 s of accumulation, 0.5 s of transport, 77.2 s of measurement (20 half-lives), and a final tape transport of 0.5 s, we would arrive at a cycle duration of about 80 seconds. This means we need 1000 cycles and thus about 3 shifts of measurement, i.e. with down times, we estimate 4 shifts.

Tuning times

In addition, we believe that the tuning of the target ion source and the beam lines will take another 2 shifts.

4 Summary of beam time request

In total, we request 10 shifts:

- 4 shifts for the branching ratio measurement
- 4 shifts for the half-life measurement
- 2 shifts for tuning and optimizing

Note:

There is an accepted proposal at TRIUMF to perform similar measurements (half-life with a 4π gas proportional counter and branching ratios with the multi-detector array GRIFFIN) by basically the same collaboration although with different responsibilities. We underline here again that there is no way to improve in particular the branching ratio significantly in one measurement. This precision can only be improved from different measurements at different places having different limitations and uncertainties.

References

1. J.C. Hardy and I.S. Towner, Phys. Rev. C 91, 025501 (2015).
2. K. Olive et al., Chin. Phys. C 38, 090001 (2014).
3. I.S. Towner and J.C. Hardy, Rep. Prog. Phys. 73, 046301 (2010).
4. I.S. Towner and J.C. Hardy, Phys. Rev. C 77, 025501 (2008).
5. I.S. Towner and J.C. Hardy, Phys. Rev. C 66, 035501 (2002).
6. J.C. Hardy and I.S. Towner, Phys. Rev. C 79, 055502 (2009).

7. W.E. Ormand and B.A. Brown, Phys. Rev. C 52, 2455 (1995).
8. H. Liang et al., Phys. Rev. C 79, 064316 (2009).
9. A.E. Calik et al., Z. Naturforsch 64a, 865 (2009).
10. W. Satula et al., Phys. Rev. C 86, 054316 (2012).
11. A. Bazavov et al., Phys. Rev. D 90, 074509 (2014).
12. A. Bazavov et al., Phys. Rev. Lett. 112, 112001 (2014).
13. G.A. Miller and A. Schwenk, Phys. Rev. C 78, 035501 (2008)
14. G.A. Miller and A. Schwenk, Phys. Rev. C 80, 064319 (2009).
15. N. Auerbach, Phys. Rev. C 79, 035502 (2009).
16. W. Satula et al., Phys. Rev. Lett 103, 012502 (2009).
17. I.S. Towner and J.C. Hardy, Phys. Rev. C 82, 065501 (2010).
18. W. Satula et al., Phys. Rev. Lett 106, 132502 (2011).
19. G.F. Grinyer, C.E. Svensson, and B.A. Brown, Nucl. Instrum. Meth. A 622, 236 (2010).
20. H.I. Park et al., Phys. Rev. Lett. 112, 102502 (2014).
21. P. Finlay et al., Phys. Rev. C 78, 025502 (2008).
22. R. Dunlop et al., Phys. Rev. C 88, 045501 (2013).
23. G. Savard et al., Phys. Rev. C 70, 042501(R) (2004).
24. M. Mukherjee et al., Phys. Rev. Lett. 93 (2004) 150801
25. B. Blank et al., Nucl. Instrum. Meth. Phys. Res. A 776, 34 (2015).
26. J.C. Hardy et al., Phys. Rev. Lett. 91, 082501 (2003).

Appendix

DESCRIPTION OF THE PROPOSED EXPERIMENT

The experimental setup comprises: *(name the fixed-ISOLDE installations, as well as flexible elements of the experiment):* LA1 and LA2

Part of the Choose an item.	Availability	Design and manufacturing
[if relevant, name fixed ISOLDE installation: COLLAPS, CRIS, ISOLTRAP, MINIBALL + only CD, MINIBALL + T-REX, NICOLE, SSP-GLM chamber, SSP-GHM chamber, or WITCH]	☒ Existing	☒ To be used without any modification
[Part 1 of experiment/ equipment]	☒ Existing	☒ To be used without any modification ☐ To be modified
	☐ New	☐ Standard equipment supplied by a manufacturer ☐ CERN/collaboration responsible for the design and/or manufacturing
[Part 2 experiment/ equipment]	☒ Existing	☒ To be used without any modification ☐ To be modified
	☐ New	☐ Standard equipment supplied by a manufacturer ☐ CERN/collaboration responsible for the design and/or manufacturing
[insert lines if needed]		

HAZARDS GENERATED BY THE EXPERIMENT

(if using fixed installation) Hazards named in the document relevant for the fixed [COLLAPS, CRIS, ISOLTRAP, MINIBALL + only CD, MINIBALL + T-REX, NICOLE, SSP-GLM chamber, SSP-GHM chamber, or WITCH] installation.

Additional hazards:

Hazards	*[Part 1 of the experiment/equipment]*	*[Part 2 of the experiment/equipment]*	*[Part 3 of the experiment/equipment]*
Thermodynamic and fluidic			
Pressure	[pressure][Bar], [volume][l]		
Vacuum	chamber of about 1l	chamber of about 1l	
Temperature	[temperature] [K]		
Heat transfer			
Thermal properties of materials			
Cryogenic fluid		LN2 for Ge cooling	
Electrical and electromagnetic			
Electricity	Detector HV (2000V)	Detector HV(4500V)	
Static electricity			
Magnetic field	[magnetic field] [T]		
Batteries	☐		
Capacitors	☐		

Ionizing radiation			
Target material	[material]		
Beam particle type (e, p, ions, etc)	22Mg	22Mg	
Beam intensity	10**5	10**5	
Beam energy	30 keV	30 keV	
Cooling liquids	[liquid]		
Gases	[gas]		
Calibration sources:	☒		
• Open source	☐		
• Sealed source	☒ [ISO standard]		
• Isotope	137Cs, 60Co, 133Ba, 152Eu		
• Activity	qq KBq		
Use of activated material:			
• Description	☐		
• Dose rate on contact and in 10 cm distance	[dose][mSV]		
• Isotope			
• Activity			
Non-ionizing radiation			
Laser			
UV light			
Microwaves (300MHz-30 GHz)			
Radiofrequency (1-300MHz)			
Chemical			
Toxic	[chemical agent], [quantity]		
Harmful	[chemical agent], [quantity]		
CMR (carcinogens, mutagens and substances toxic to reproduction)	[chemical agent], [quantity]		
Corrosive	[chemical agent], [quantity]		
Irritant	[chemical agent], [quantity]		
Flammable	[chemical agent], [quantity]		
Oxidizing	[chemical agent], [quantity]		
Explosiveness	[chemical agent], [quantity]		
Asphyxiant	[chemical agent], [quantity]		
Dangerous for the environment	[chemical agent], [quantity]		
Mechanical			
Physical impact or mechanical energy (moving parts)	[location]		
Mechanical properties (Sharp, rough, slippery)	[location]		
Vibration	[location]		
Vehicles and Means of Transport	[location]		
Noise			
Frequency	[frequency],[Hz]		
Intensity			
Physical			
Confined spaces	[location]		
High workplaces	[location]		
Access to high workplaces	[location]		
Obstructions in passageways	[location]		

Manual handling	[location]		
Poor ergonomics	[location]		

0.1 Hazard identification

3.2 Average electrical power requirements (excluding fixed ISOLDE-installation mentioned above): *(make a rough estimate of the total power consumption of the additional equipment used in the experiment)*

The total power consumption will be a few kW for the experiment electronics (data acquisitions racks and crates).