EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Status Report to the ISOLDE and Neutron Time-of-Flight Committee

IS483: Measurement of the magnetic moment of the 2^+ state in neutron-rich radioactive ^{72,74}Zn using the transient field technique in inverse kinematics

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A. Illana[1,2], A. Blazhev[3], J.A. Briz[4], R. Gernhäuser[5], P.T. Greenlees[1,2], C. Henrich[6], P.R. John[6], Th. Kröll[6], M.L. Lozano Benito[7], D. Müncher[8], E. Nacher[4], J. Ojala[1,2], R. Orlandi[9], J. Pakarinen[1,2], A. Perea[4], N. Pietralla[6], M.M. Rajabali[10], P. Reiter[3], J.A. Rodriguez[7], T.R. Rodríguez[11], M. Seidlitz[3], B. Siebeck[3], E. Siesling[7], J.J. Valiente-Dobón[12], M. J. Vermeulen[13], D. Voulot[7], N. Warr[3], F. Wenander[7], H. De Witte[14], the MINIBALL collaboration and the HIE-ISOLDE collaboration.

[1] *Department of Physics, University of Jyväskylä, Jyväskylä, Finland.*
[2] *Helsinki Institute of Physics, University of Helsinki, Finland.*
[3] *Institut für Kernphysik, Universität zu Köln, Köln, Germany*
[4] *Instituto de Estructura de la Materia, CSIC, Madrid, Spain*
[5] *Physik Department E12, Technische Universität München, Garching, Germany*
[6] *Institut für Kernphysik, Technische Universität Darmstadt, Darmstadt, Germany*
[7] *ISOLDE, CERN, Switzerland*
[8] *Department of Physics, University of Guelph, Toronto, Canada*
[9] *Advanced Science Research Center, Japan Atomic Energy Agency, Tokai, Ibaraki, Japan*
[10] *Department of Physics, Tennessee Technological University, Cookeville, USA*
[11] *Departamento de Física Teórica, Universidad Autónoma de Madrid, Madrid, Spain*
[12] *INFN Laboratori Nazionali di Legnaro, Legnaro, Italy*
[13] *Department of Physics, University of York, United Kingdom*
[14] *KU Leuven, Instituut voor Kern-en Stralingsfysica, Leuven, Belgium.*

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Spokesperson: A. Illana [andres.a.illana@jyu.fi]
Contact person: J. Konki [joonas.konki@cern.ch]

Remaining shifts: 11 shifts
Installation: [MINIBALL + g-factor chamber.]

Abstract: This report presents the status update of the g-factor experiment IS483, which aimed to measure the magnetic moment of the first excited state in $^{72.74}$Zn using the Transient Field (TF) technique via coulomb excitation in inverse kinematic. Magnetic moments of excited states constitute a stringent test of different theories describing the interplay between collectivity and single particle structure. In particular, it allows to probe the $\nu g_{9/2}$ component of the wave function of first excite 2^+ states around the N = 40 isotones.

In 2011 the first part of this experiment was successfuly performed employing for the first time a new target chamber especially designed and constructed for g-factor measurements with MINIBALL detectors at REX/HIE-ISOLDE. The value of g(2^+) in ^{72}Zn was measured as described in detail in Ref. [1]. The remaining 11 shifts will then be dedicated to measure the value of $g(2_1^+)$ in ^{74}Zn.

1 Motivation, experimental setup/technique

A detailed discussion of the motivation, the method and the experimental set-up with all references can be found in the original proposal [2], the first status report submitted in 2015 [3] and in the articles published as a result of the first part of this proposal [1, 4]. Hence a summary of the scientific motivation and the experimental set-up will be briefly presented here.

The nickel isotopes (Z = 28) is an excellent testing ground for nuclear models, in particular the influence of the $\nu g_{9/2}$ orbital has in this region and to study the evolution of the single-particle and collective phenomena between non-conventional harmonic-oscillator sub-shell closure N = 40 and the sub-shell closure N = 50. In this region, ^{68}Ni has been the subject of numerous experimental and theoretical studies in recent years. The spherical neutron shell gap at N = 40 is not strong enough to stabilize the nuclei in a spherical shape as soon as protons are added to or removed from the ^{68}Ni core [5–9]. Moreover, no discontinuity at N = 40 has been observed in Fe, Zn, Ge, or Se isotopes for any of the standard observables, i. e., the energy of first excited 2^+ state, $E(2_1^+)$, the transition probability, $B(E2;\, 2_1^+ \rightarrow 0_{g.s.}^+)$, or the quadrupole moment $Q(2_1^+)$.

Nuclear magnetic moments are very sensitive probes of the contributions of the valence protons and/or neutrons to the wave function of the state of interest, especially in the vicinity of shell closures. And thus, it is possible to study the importance of particular single-particle orbitals in its formation. Magnetic moments of excited states are known to provide complementary structure information to the interpretation of the aforementioned experimental observables.

g factors of short-lived excited states (picosecond regime) can be measured employing two different techniques: Recoil In Vacuum (RIV) and Transient Field (TF) method. TF is subdivided in two depending on the velocity of the beam: Low-Velocity TF (LVTF) for ISOL facilities and High-Velocity TF (HVTF) for the case of in-flight facilities. It should be noted that the sign and magnitude of the magnetic moment can only be extracted employing the TF technique. This technique has been successfully applied in a large number of stable ion beam experiments in the past [10], however, the advent of intense

radioactive ion beams has allowed for extending the LVTF technique to rare nuclei.
The new reaction chamber for g-factor measurements was born with this aim. In order to fulfil the especial requirements of this measurements, the design of the new chamber must include a magnetic circuit to polarize the ferromagnetic layer of the target, a system of flowing liquid nitrogen for keeping the target at a temperature well below the Curie temperature of Gd and segmented Si detectors for particle detection.
These measurements require a polarized ferromagnetic target. This can be achieved by cooling of e.g. Gd below the Curie temperature. A new target chamber to house a segmented Si silicon detector for particle detection and the circulation of liquid nitrogen for target cooling was designed. The new equipment was successfully used for the first time in 2011 at REX-ISOLDE in the first part of experiment IS483. More details about the chamber are given in Ref. [4].

2 Status Report

Accepted Isotopes: ^{72,74}Zn.
Performed Isotopes: ^{72}Zn, in October-November 2011.

The first part of the experiment was carried out at the MINIBALL spectrometer (the current XT01 beam line) before the HIE-ISOLDE upgrade. In the previous status report we presented the new reaction chamber for g-factor measurements at MINIBALL and the results of the measurements for ^{72}Zn. The final result obtained for $g(2^+)$ was +0.47 (14). This value was compared with different theoretical models and previous experiments, see Fig. 1. The obtained value is close to the collective value and confirms the non-existence of a structural change between ^{70}Zn (N = 40) and ^{74}Zn (N = 44) isotopes.
We would like to remark that it was the first successful g-factor experiment of excited states performed at ISOLDE using the TF technique with radioactive beams ($T_{1/2}$ (^{72}Zn) = 46.5 h), and the third in the world. This is due to the complexity of dealing with thick targets and radioactive beam. The experience gained during this experiment was invaluable and nowadays we have a reliable set-up for this kind of measurements. This knowledge was not only essential for g-factor experiments, but also essential in further experiments such us the IS572 experiment devoted to in-beam gamma spectroscopy employing the Multi-Nucleon Transfer reaction, see Ref. [17, 18]. In this case, a 13 mg/cm^2 thick ^{208}Pb target was bombarded by a high intensity beam of ^{94}Rb at 6.2 MeV/u. In both cases, dealing with the accumulation of activity close to the target due to the straggling of the beam was the key of the experiments. In summary, the experience acquired up to now will allow us to choose the right parameters, e.g. the optimal thickness of the Gd layer in the target, for the successful application of the TF technique in future experiments.

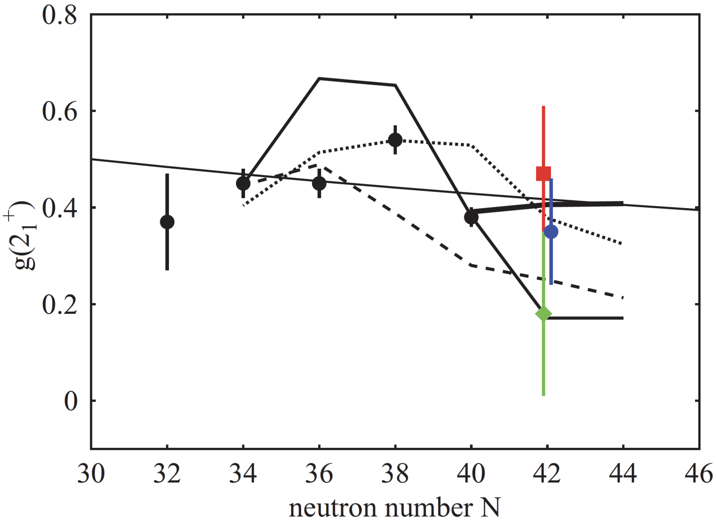

Figure 1: Comparison between experimental and theoretical g factors for the first excited 2^+ state in even-even Zn isotopes. Experimental results for the stable isotopes are shown as black dots [11], the HVTF result for ^{72}Zn [12] as a green diamond, the IS483 result as a red square, and the average value of the IS483 and HVTF as a blue dot. Shell-model calculations using the LNPS [13] (solid black line), JUN45 [14] (dotted line), and JJ4B [15] (dashed line) interactions are included. The beyond-mean-field calculations [16] are shown as a thick black line and the collective value Z/A expected for nuclei in the middle of a major shell is shown as a thin black line. Extracted from Ref. [1].

3 Future plans

Since the run in 2011 several improvements in the set-up and the beam production have been achieved. The most relevant for this proposal are the following:

- The beam intensity for ^{74}Zn is slightly better. During the first HIE-ISOLDE experiment, IS557 [19, 20], the value was 5×10^6 pps.
- The beam energy is a crucial parameter for this experiment. In 2011 the beam energy was on the limits of the previous REX-ISOLDE accelerator. This experiment can be benefited from higher beam energy provided by HIE-ISOLDE for the second part of the experiment. This will depend on what it is better for the machine point of view without compromising the aim of the experiment.
- During the long shutdown 2, the MINIBALL collaboration is performing a full upgrade of the electronic. The new DAQ system based on FEBEX. This new system will allow us to handle high count rates experiment without very low deadtime, like g-factors.

Future plans with remaining shifts:

(i) Envisaged measurements, beam energy, and requested isotopes.
The second part of the experiment IS483 will be devoted to study the magnetic

moment of the first excited 2^+ state in ^{74}Zn (11 shifts). This measurement requires the standard UC_x target source in conjunction with the laser ionization source (RILIS). The desirable beam energy should be similar than the first part of the experiment, 2.94 MeV/u. However, HIE-ISOLDE beam energy can be used if it is easier for the machine.

(ii) Have these studies been performed in the meantime by another group?
No and it cannot be performed anywhere else. Pure ^{74}Zn beams of high intensity and requested energy are only available at HIE-ISOLDE.

(iii) Number of shifts (based on newest yields and latest REX-EBIs and REX-trap efficiencies) required for each isotope

Isotope	Yield (/μC)	Target – ion source	Shifts (8h)
^{74}Zn	6.9$\times$ 10^7	UC_x + RILIS	11

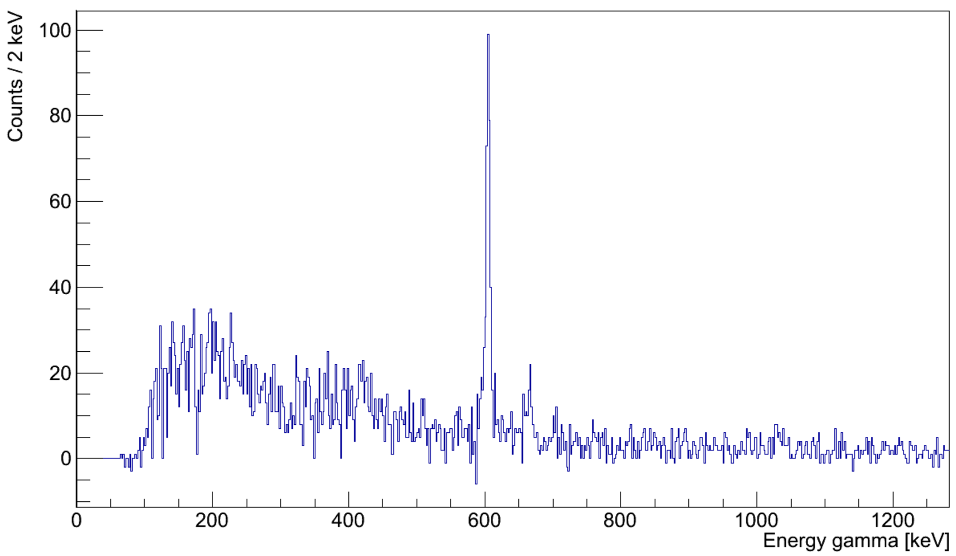

Figure 2: Spectrum of γ-rays obtained during four hours of ^{74}Zn beam on target.

During the run in 2011 we measured effectively about four hours of ^{74}Zn beam on the thinner target, 3 layers with a total thickness of 8 mg/cm^2). It was successfully prove of the capabilities of our setup for performing g-factor measurement with radioactive beams with very short half-lifes. $T_{1/2}$ (^{74}Zn) is 96 s and the daughter, ^{74}Ga, is 8.1 min, as a consequence after a few tens of min, the activity in the chamber already reached the equilibrium with a beam intensity around 3×10^6 pps at the target position. From this data we obtained the γ-ray spectrum shown in Fig. 2 with about 400 counts in the 606 keV line corresponding to the $2^+ \rightarrow 0^+$ transition in ^{74}Zn. We can therefore expect that a beam with an intensity of 6×10^6 pps can be accepted during a full run of 11 shifts, leading to the estimate of a total of 14.600 counts in the 606 keV line summing all four MINIBALL cluster detectors. While for the $2^+ \rightarrow 0^+$ transition in ^{72}Zn, 11.500 count were measured with the same target. Therefore, we expect that $g(2^+)$ in ^{74}Zn can be determined with a precision of about 20%. This results will allow us to understand much better the shell evolution in the Zn isotope chain between N = 40 and N = 50.

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