EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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

IS411: Coulomb Excitation of neutron-rich A~140 Nuclei

14.01.2015

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CERN-INTC-2015-010 / INTC-SR-047
14/01/2015

Abstract

We propose to study as conclusion of the approved IS411 programme the very neutron-rich isotope ^{144}Xe (N=90) at HIE-ISOLDE in "safe" Coulomb excitation at 3 MeV/u with the MINIBALL & CD set-up aiming for the determination of the B(E2) values and quadrupole moments of the first 2^+ and 4^+ states. Shell model calculations with empirical interactions predict a new shell closure at N=90 in Sn which may extend also towards Xe, two protons above. The results will be also the necessary prerequisite for the future study at higher beam energies where multiple Coulomb excitation is much more prominent investigating the evolution of octupole collectivity beyond the "magic octupole number" N=88.

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Remaining shifts: 15.5

1. Motivation, experimental setup/technique

For medium and heavy mass nuclei with A > 100, only the two regions around doubly magic nuclei are experimentally accessible: the stable ^{208}Pb and the radioactive ^{132}Sn. IS411 aims for the determination of B(E2) values and quadrupole moments in even-even isotopes around ^{132}Sn. Near to a double shell closure a regular behaviour is expected, but many anomalies occur in this region which have been understood only partially so far. Several theories have been applied to describe the structure in this region like the shell model or (beyond) mean field approaches and experimental data serve as benchmarks for the predictions. Further interest comes from the vicinity to the path the astrophysical r-process.

We employ the "safe" Coulomb excitation in inverse kinematics. The γ-rays are detected by MINIBALL and both the scattered projectiles and the recoiling targets are detected by a DSSSD, the so called CD detector [War13]. If installed, the T-REX array in Coulex configuration can be used as well. The data sets are divided in different sub-sets covering smaller angular ranges in the CM system and a maximum likelihood analysis is performed to extract the transition and diagonal matrix elements. In order to minimise the systematic errors, the analysis is preferably done relatively to the excitation of the target whose electromagnetic properties are well known.

The analyses of ^{122,124,126}Cd [Beh09, Thü12, Ili14] and ^{140}Ba [Bau10, Bau12] are completed and the results are published. All nuclei have been studied at around 3 MeV/u and only the first 2^+ state has been excited. The lifetimes of the first 2^+ states in ^{140}Ba [Bau10, Bau12] and ^{126}Cd [Thü12, Ili14] have been studied by DSAM measurements with the same set-up as well and entered as additional information the maximum likelihood analysis. Two "spin-off experiments" of the IS411 programme investigating ^{123}Cd (IS524) [Har14] and ^{128}Cd (IS477) [Bön14, Bön15] have been performed successfully too. The final steps of the reanalysis of ^{138,140,142}Xe are on the way (see the Status Report in Sec. 2).

The very neutron-rich isotope ^{144}Xe is interesting because recent shell model calculations employing empirical interactions predict a new shell closure at N=90 in Sn, see IS549 (CERN-INTC-2012-042; INTC-P-343). The decrease of the excitation energies along the Xe isotopic chain seems not to give evidence that this appears also in Xe, however the B(E2) values would give an additional proof.

It is planned in future to study this nucleus also at a higher beam energy, see IS548 (CERN-INTC-2012-041; INTC-P-342), to follow the evolution of octupole collectivity across N=88. Since at HIE-ISOLDE multiple Coulomb excitation is much more important, as starting point for the analysis the knowledge of the B(E2) values and quadrupole moments of the first 2^+ and 4^+ states is mandatory.

The very high interest in Coulomb excitation of nuclei around ^{132}Sn and the evolution of the nuclear structure north-east of the double shell closure is documented by several new proposals for HIE-ISOLDE already approved by the INTC: ^{132}Sn (IS551), ^{134,136}Sn (IS549), ^{136}Te (CERN-INTC-2014-055; INTC-P-421), ^{142}Xe (IS548) and ^{144}Ba (IS553). More proposals, e.g. the continuation of the study of the neutron-rich Cd isotopes, are under preparation.

2. Status Report

For the isotopes ^{138,140,142,144}Xe preliminary results have been obtained [Beh09]. The Xe ions were produced by the cold plasma source and no surface ionised contaminations from ISOLDE have been observed. Recently a complete reanalysis has been performed including the reorientation effect in a maximum likelihood analysis [Hen14]. Because of the high beam intensity, in these runs the innermost part of the CD particle detector had to be covered in order to avoid radiation damage and high dead time, but resulting in a considerably reduced angular range in the CM system. In ^{140,142,144}Xe already multiple Coulomb excitation occurred and the 4^+ states were observed too resulting in a larger set of matrix elements to be considered in the analysis. The reanalysis of ^{138,140,142}Xe benefitted very much from new, still preliminary, lifetimes measured with EXILL&FATIMA at ILL [Ili14a]. As soon as this analysis is completed also the results from the combined analysis of both data sets will be published. The preliminary results follow the modified Grodzins' systematics as well as are in agreement with recent theory calculations.

The data set for ^{144}Xe was measured with the full CD detector, but effectively only for approximately 12 hours under very unstable beam conditions (see Fig. 1). Because of the low statistics no analysis relative to the target excitation was possible. Therefore, the analysis was performed with respect to the elastic scattering (Rutherford scattering) resulting in much larger systematic errors, e.g. for the absolute efficiency of MINIBALL. Unfortunately, ^{144}Xe was not populated in the ILL experiment and no additional lifetime information could be included in the maximum likelihood analysis. In order to determine the beam composition - the short-lived ^{144}Xe ($T_{1/2}$=388 ms) already decays partially on the way to MINIBALL (mainly during breeding in the EBIS) - the characteristic γ-decay following the β-decay of ^{144}Xe is needed. No information is found in literature and the small statistics obtained in a very short measurement with MINIBALL during the run of IS411 did not allow for conclusive results [Mül12].

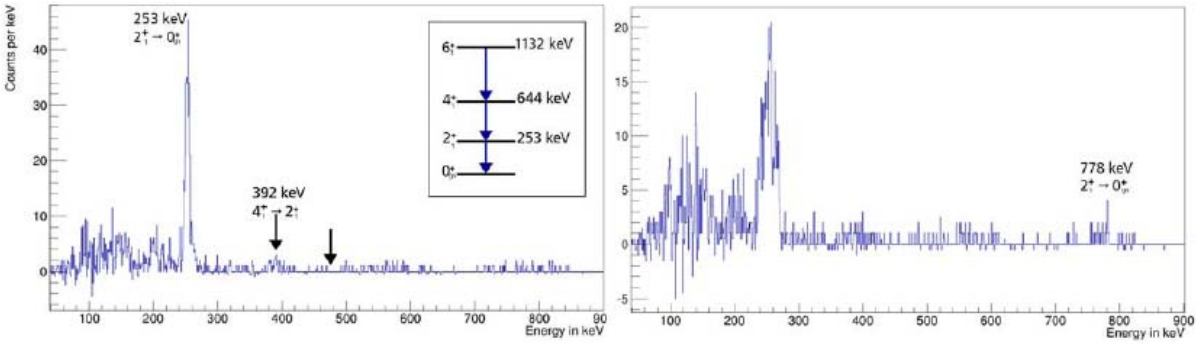

Fig. 1: Spectrum for ^{144}Xe on ^{96}Mo: Doppler correction with respect to the projectile (left) and target (right) (Corinna Henrich, TU Darmstadt)

Accepted isotopes: **^{122,124,126}Cd, $^{(140,)148,150}$Ba, ^{138,140,142,144}Xe**

Performed studies: **Coulomb excitation of all accepted isotopes except ^{148,150}Ba (production/extraction failed) at around 3MeV/u**

Future plans

Future plans with <u>available</u> shifts:

(i) Envisaged measurements, beam energy, and requested isotopes

We want to use the remaining 15.5 shifts of IS411 to investigate the very neutron-rich isotope ^{144}Xe in Coulomb excitation at 3 MeV/u. Assuming a beam intensity of 3000/s as before, this beam time would, at least, increase the statistics for target excitation by a factor of 10 resulting in statistics comparable to the other Xe isotopes (measured with the same target). This would enable to perform the more precise relative analysis with respect to the target excitation. The low beam energy restricts the excitation to the 2^+ and 4^+ state (the 6^+ state may have to be regarded in the analysis). One shift, distributed in shorter runs along the whole run, will be dedicated to stop the beam inside of MINIBALL to (a) establish the level scheme of ^{144}Cs populated by the β-decay of ^{144}Xe and (b) determine the beam composition needed for normalisation. The first task could be done with a separate run at the IDS too, the latter, of course, not.

(ii) Have these studies been performed in the meantime by another group?

No, low-energy beams of neutron-rich Xe are available at ISOLDE only. Even if our fast timing experiment at ILL would have been successful for ^{144}Xe too, the quadrupole moments are accessible only by low-energy Coulomb excitation.

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

The remaining shifts have been already requested twice in 2011/12, but the experiment could not be scheduled. The required yield is estimated assuming conservatively an efficiency of 3% for HIE-ISOLDE as it was for REX-ISOLDE.

isotope	yield (/uC)	target – ion source	Shifts (8h)
144Xe	5E4	UCx - cold plasma source	15.5

Total shifts: 15.5

References:

[War13] N. Warr et al., Eur. Phys. J. A 49, 40 (2013)

[Ili14a] e.g. S. Ilieva et al., Proceedings of ARIS2014

3. Appendix

[Beh09] T. Behrens, PhD thesis (TU München, 2009)
[Thü12] M. Thürauf, Master thesis (TU Darmstadt, 2012)
[Ili14] S. Ilieva et al., Phys. Rev. C 89, 014313 (2014)
[Bau10] C. Bauer, Master thesis (TU Darmstadt, 2010)
[Bau12] C. Bauer et al., Phys. Rev. C 86, 034310 (2012)
[Har14] A.-L. Hartig, Master thesis (TU Darmstadt, 2014)
[Bön14] S. Bönig, PhD thesis (TU Darmstadt, 2014)
[Bön15] S. Bönig et al., submitted to Phys, Rev. Lett.
[Hen14] C. Henrich, Master thesis (TU Darmstadt, 2014)
[Mül12] O. Müller, Bachelor thesis (TU Darmstadt, 2012)