EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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

Studies of exotic decays of light nuclei

January 15, 2014

IS476, IS507 and IS541 collaborations (as given in the original proposals).

Abstract

Status reports for three experiments on decays of exotic nuclei, ^{11}Be, ^{20}Mg and ^{31}Ar are given together with proposed plans for using the remaining shifts originally granted to these experiments.

Experiments and remaining shifts:

- IS476 – 5 shifts
- IS507 – 10.5 shifts
- IS541 – 5 shifts

CERN-INTC-2014-031 / INTC-SR-040
15/01/2014

Experimental setup/technique

The three experiments IS476, IS507 and IS541 have all been using the low energy (non post-accelerated) ISOLDE beams and the movable setup beam lines LA1 or LA2.

IS476 and IS507 employ similar types of experimental detection systems based on various types of detectors for both charged particles and gamma-rays, while is541 uses accelerator based mass spectroscopy to replace direct detection in order to search for a rare, low energy radiation and decay mode.

With the arrival of the new permanent decay setup, *The ISOLDE decay station*, IS476 and IS507 will move to there in order to benefit from the enhanced gamma-ray detection offered by that infrastructure.

All experiments have taken first data, and in two of the cases (IS476 and IS541) papers are already published or submitted. For IS507 the analysis is in progress with the results looking promising.

Status report for IS476

Title: Studies of of the β-delayed two-proton emission: The cases of ^{31}Ar and ^{35}Ca

Spokesperson: Hans Fynbo and Bertram Blank

Accepted isotopes: ^{31,33}Ar

Performed studies: Beam time from 2009 to 2012. Valuable data from the 2009 run, while several other beam time periods suffered from various technical problems from the ISOLDE side (not the experiment).

The motivation for IS476 focussed on two aspects:

- Elucidation of the mechanism of the two-proton emission from the decay of ^{31}Ar
- Exploration of the position and decay properties of resonances in ^{30}S of astro physical relevance.

These aspects were both studied already in earlier experiments at ISOLDE on this isotope (IS339 and earlier), but the re-measurement was triggered by increased yield numbers following work by the target group at ISOLDE on both ion-source and target material.

The first beam time was taken already in 2009 with a setup with much better coverage of both charged particle and gamma-ray detectors than previously employed at ISOLDE. Unfortunately the average yield delivered was only 1 atom/s, which is less than the yield in the previous measurement in 1997. Also, the experiment had some difficulty with electronic noise stemming from not fully compatible preamplifiers and amplifiers. Nevertheless, this beam time was successful in terms of most of the physics motivation originally pursued. Results on the ^{30}S resonances have already been published [1], and a new beta-delayed three-proton branch has been identified [2]. This decay mode has been identified earlier in two other isotopes, but due to the excellent conditions for spectroscopy coming from the ISOLDE low energy beams, IS476 provides the first spectroscopic look into this new decay mode. A third paper giving an updated view on the overall decay-pattern of this drip-line nucleus is basically ready for submission [3].

During 2012 our group came twice to ISOLDE to use the remaining shifts with focus on measuring very low-energy protons (not attempted in the earlier ^{31}Ar experiments and crucial for the astrophysics aim). Both times different difficulties with targets and the separators prevented any useful beam from being delivered to the experimental setup.

In 2013 we applied for further beam time to further be able to study the new 3p decay mode with enhanced statistics as well as also getting enhanced sensitivity in the determination of the decay mechanism of the ^{30}S resonances. This is also motivated by new, increased yield obtained from the target group in collaboration with some of us. 24 shifts were requested, but only 12 shifts granted because the 3p branch was considered more risky and therefore apparently 12 of the shifts were not granted for this reason. However, the 24 shifts we estimated based on *simultaneous* measurements of the two aspects, and hence with the reduction to 12 shifts the prospects for the study of the ^{30}S resonances will *also be significantly reduced*. We regret not having explained this clearly in the proposal.

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

(i) Envisaged measurements and requested isotopes

The remaining 5 shifts from IS476 we would like to use for the originally intended purpose of elucidating the properties of the ^{30}S resonances, with particular focus on measurement of the low energy protons from the charged particle decay of those resonances. This goal overlaps, as already explained, with one of the goals of the new experiment IS577, but we feel this is nevertheless justified in order to compensate for the reduction in shifts from 24 to 12 in the new experiment IS577.

The setup will be the new ISOLDE decay station together with our high efficiency charged particle detection system and a fully upgraded electronic and data acquisition system. This setup is also the same setup as intended for the new experiment IS577. By adding these shifts we will therefore partly be able to compensate for the reduction in shifts from 24 to 12.

This required beams of ^{31}Ar and ^{33}Ar, the latter for calibration.

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

No.

(iii) Number of shifts (based on newest yields) required for each isotope

isotope	yield (/uC)	target – ion source	Shifts (8h)
^{31}Ar	10	CaO, Vadis source	4.9
^{33}Ar	1000	-“-	0.1

Total shifts: 5

Status report for IS507

Title: Study of the β-decay of ^{20}Mg

Spokesperson: Hans Fynbo

Accepted isotopes: ^{20}Mg

Performed studies: 1 beam time completed using 7.5 shifts

The motivation for IS507 is three-fold:

1. Exploration of the position and decay properties of resonances in ^{20}Na of astro physical relevance. In particular the determination of the spin of a known level at ca. 2650keV.
2. Studying the mirror-symmetry between the decays of ^{20}O and ^{20}F. Presently the mirror asymmetry observed is among the largest observed for all nuclei, which could be due to the previous measurements of ^{20}Mg decay at RIKEN, GANIL and MSU.
3. Detailed study of the beta-decay pattern of ^{20}Mg to enable a comparison to modern (shell-model) calculations for his N=8 system.

The first beam time was completed in 2011 with a setup focussed on the first objective. This consisted of a single double-sided Si-strip detector, and a "sandwich" detector (telescope) built from a Gas detector in front of two small Si-detectors. The latter allowed the separation of different charged particles (in this case beta-particles, protons and alpha-particles).

In 2012 results from an experiment performed at Texas A&M [4] were published, which to some extend corresponded to our motivation 1. A new improved lower limit on the log-ft value of the relevant resonance strongly suggests that the feeding is forbidden and the spin therefore not 1^+, but 3^+. The setup used in that experiment did not permit to address the two other questions (thin detectors and significant beta-summing hindered this).

In the data from our 2011 beam time we will be able to place a limit similar to that from Texas A&M, but not improve it. However, this will most likely be possible in the 2nd part of the intended programme. The 2011 beam time did provide a proton spectrum much improved compared to all previous measurements, which will go into motivation 2 and 3. The 2011 beam time also gave an unexpected result in that we found an unknown delayed alpha-decay channel in the decay of ^{21}Mg, which was used as a calibration source. See Figure 1.

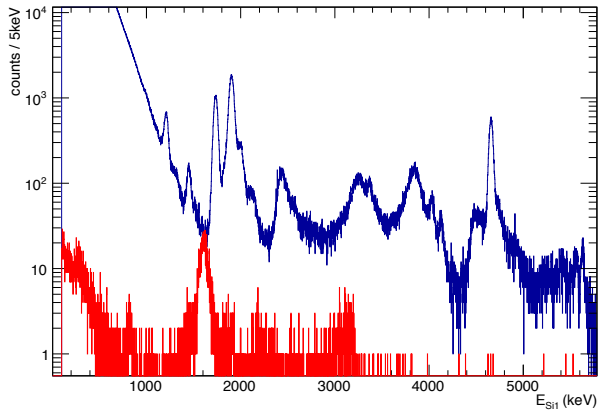

Figure 1 Proton (blue) and alpha (red) spectrum from the decay of ^{21}Mg as measured by Gas-Si-Si telescope. The alpha-particles have not been previously identified in this decay, and the protons are here measured with significantly improved quality.

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

(i) Envisaged measurements and requested isotopes

We plan to use the remaining shifts, as explained in the original proposal, with a high coverage setup of both charged particle and gamma-ray detectors – the same as already mentioned for IS476 (including the ISOLDE decay station). This will provide us with a much higher statistics data set for motivation 2 and 3, and may also allow us to improve the limit on the population of the 2650keV state by using the coincidence detection technique developed by some of us, and first used in the recently published work on the decay of ^{20}Na [5].

Possibly this experiment could benefit from the use of the new laser ion source trap design to suppress the contamination from Na isobars [6]. That would allow to further improve the limit on the feeding of the 2650keV resonance.

This will require beam of ^{20,21}Mg, the latter for calibration.

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

Partly, as already mentioned in [4]. There could be competition coming from Triumf as well since they now also have a strong ^{20}Mg beam.

(iii) Number of shifts (based on newest yields) required for each isotope

10.5

Isotope	yield (/uC)	target – ion source	Shifts (8h)
^{20}Mg	50	SiC, RILIS (possibly LIST).	10
^{21}Mg	1000	-“-	0.5

Total shifts: 10.5

Status report for IS541

Title: Search for beta-delayed protons from ^{11}Be

Spokesperson: Karsten Riisager

Accepted isotopes: ^{11}Be

Performed studies: Two beam times: July 2012 and December 2012.

The collection of ^{11}Be samples for this experiment was originally scheduled for July 2012, but several problems with the ISOLDE facility caused the yield to be several orders of magnitude below the expected one. Luckily it was possible to reschedule the experiment at the end of the running period in 2012 and several samples could be taken, although smaller problems prevented full use of the allocated beam time so that several samples (for cross checks and test of systematic uncertainties) could not be collected.

Still, the three collected samples – combined with reanalysis of the systematics of yields from similar targets in earlier experiments – has allowed to identify the beta-delayed proton decay from ^{11}Be and determine a value for its branching ratio through comparison of the ^{10}Be intensity measured in the sample via accelerator mass spectrometry (at VERA in Vienna) with the ^{11}Be intensity measured on-line during collection via the gamma-line from the decay of ^{11}Be. The result has been presented at the INPC last year [7] and a letter describing the results is in preparation.

The deduced branching ratio of 8.4(6) 10^{-6} is unexpectedly large: more than two orders of magnitude above the value 3 10^{-8} expected before the experiment [8]. Although more recent calculations [9] may be able to explain this high intensity, we believe it is imperative to carry out the missing checks in order to exclude fully any experimental systematic effect. This would at the same time allow us to reduce the uncertainty on the extracted branching ratio. The found significantly higher branching ratio will allow the experiment to be done within the remaining shifts, since we are now not statistics limited. We shall aim for taking several samples at different mass positions as well as a sample on the ^{11}Be mass position with the RILIS lasers blocked in order to check for the (unlikely) presence of the BeH molecule. The latter sample could not be collected in December 2012 and we at the moment exclude a BeH component based on results from earlier targets. It will clearly close a small logical loophole if measurements could be performed explicitly on the same target and in the same running conditions as the sample showing the beta-delayed proton branch.

The high branching ratio will allow us to collect all samples within 5 shifts, but the time needed for sample change (and for mass position changes) precludes cutting the beamtime further.

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

(iv) Envisaged measurements and requested isotopes

Confirmation of the decay branch by a measurement on the ^{11}Be mass position. Test of BeH molecular contamination through a sample taken with RILIS lasers blocked. Test of the ISOLDE mass profile by samples collected at mass positions slightly off the ^{11}Be one. Crosscheck with calibrated ^{10}Be samples produced via ^{11}Li decay (sample taken on the ^{11}Li mass position).

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

No.

(vi) Number of shifts (based on newest yields) required for each isotope

isotope	yield (/uC)	target – ion source	Shifts (8h)
^{11}Be	10^7	Ta	4
^{11}Li	10^3	Ta	1

Total shifts: 5

References:

[1] G. Koldste et al., Phys. Rev. C87, 055808 (2013).

[2] G. Koldste et al., in preparation (paper intended for Phys. Lett. B. on beta-delayed 3p branch)

[3] G. Koldste et al., in preparation (paper intended for Phys. Rev. C, on overall decay properties)

[4] J.P. Wallace et al., Phys. Lett. B 712, 59 (2012).

[5] K. L. Laursen et al., Eur.Phys.J. A49, 7 (2013).

[6] D.A. Fink et al., Nucl. Inst. Meth. B317, 417 (2013).

[7] K. Riisager and the IS541 collaboration, EPJ Web of Conferences, in press (Proc. INPC 2013).

[8] D. Baye and E.M. Tursonov, Phys. Lett. B696, 464 (2011).

[9] K. Riisager, submitted to Nucl. Phys. A / arXiv:1312.0479.

Appendix

IS476:

Publications

- **Paper 1,2,3 in list of references**

Theses :

- **Jeppe Kusk (master, 2011)**
- **Gunvor Koldste (master, 2012) and PhD to be submitted ultimo 2014.**
- **V. Pesudo (master, 2011)**

IS507:

Publications

- **None yet. First manuscript will be prepared on delayed alpha-particle branch from the decay of ^{21}Mg. After 2nd beamtime we will publish a detailed paper on the decay of ^{20}Mg.**

Theses

- **Malin Klintefjord (master, 2012)**
- **Morten Lund (master, 2014) and PhD to be submitted ultimo 2015.**

IS541:

Publications

- **Paper submitted to Nature Physics**

Theses

- **Morten Lund (master, 2014) and PhD to be submitted ultimo 2015.**