EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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

IS529: Spins, Moments and Charge Radii Beyond ^{48}Ca

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Abstract

In the evaluation of proposal P-313 submitted to the 41st meeting of the INTC it was recommended by the committee to begin measurements on $^{49-52}$Ca and subsequently develop *radioactive detection of optically pumped ions after state selective charge exchange* (ROC) during LS1. At this point in time we have successfully completed the measurements of $^{49-52}$Ca as outlined in the status report submitted with this addendum. In addition we have made significant progress in the development of the ROC technique as described in this document. Here we request the approval of the shifts required for the use of the ROC technique in the measurement of ^{53,54}Ca.

Requested shifts (in total): 17

The present Addendum follows the status report INTC-SR-033.

1. Motivation, experimental setup and technique

Whilst the physics case for performing collinear laser spectroscopy on ^{53,54}Ca was entirely endorsed by the 41st meeting of the INTC, the closed session concluded that we should first consider the possibility of using the CRIS beam line and technique, and secondly develop the ROC technique [1] during long shutdown 1. As the experimental resolution of the CRIS technique [2] is at present not sufficient to measure the small field shifts and hyperfine splitting we wish to study in Ca, we have pursued the development of the ROC technique.

Briefly the ROC technique employs an extended optical pumping region in which the ions may undergo multiple laser induced excitations and decays. In this process the Ca ions may be transferred from the $^2S_{1/2}$ ground state to the $^2D_{3/2}$ metastable state via the $^2P_{3/2}$ excited state only if the laser frequency corresponds to the Doppler shifted $^2S_{1/2} \rightarrow {}^2P_{3/2}$ transition frequency. A multi-step optical pumping scheme [3] will be employed for ^{53}Ca to avoid trapping of population in the $^2S_{1/2}$ hyperfine structure states. Subsequently the ions are decelerated to 5kV and passed into a Na charge exchange cell. At this beam energy the $^2D_{3/2}$ neutralisation cross section is 3 times larger than that of the $^2S_{1/2}$ [4]. Consequently the extent of neutralisation of the Ca beam will strongly depend on the excitation of the pumping transition. After the charge exchange cell the ion beam is electrostatically deflected away from the atom beam and both beams are sent to separate tape stations. By monitoring both the atom and ion beams not only is sensitivity improved but also the impact of a varying Ca beam intensity can be minimized. Thick plastic scintillators with 97% angular coverage are used at the implantation points of the tape stations in order to provide a degree of discrimination between β^- decay arising from ^{53,54}Ca ($Q_\beta \approx$10MeV) and the possible contaminants ^{53,54}Ti ($Q_\beta \approx$5MeV).

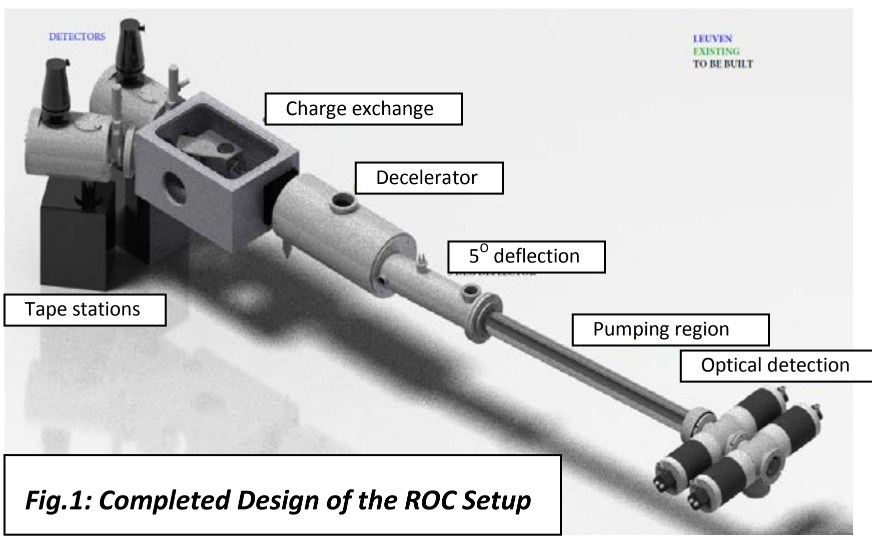

Fig.1: Completed Design of the ROC Setup

The design phase of the ROC beam line was separated into 3 interlinking tasks. Firstly the parameters required to achieve efficient high resolution optical pumping for both ^{53}Ca and ^{54}Ca were fully investigated via numerical solution of the atomic rate equations. Secondly the detection of the β^- decay of Ca isotopes and contaminant species using large volume plastic scintillators was studied in a series of GEANT4 simulations. The ability to supress contamination based on energy and time cuts and the residual Ca detection efficiency were established from these simulations. Finally full ion-optical simulations were performed to confirm the evolving design could work adequately with typical ISOLDE ion-beam parameters. The cumulative result of this design process can be summarised by the range of feasible production /contamination rates presented in section 2iii. As this range of feasibility was found to match well with the expected beams produced at ISOLDE we have subsequently submitted the full beam-line designs (Fig.1) for production and envisage all components will be installed by this summer.

Addendum

Future plans with all <u>requested</u> shifts (including available shifts):

(i) Envisaged measurements and requested isotopes

Here we aim to perform high resolution measurements of the hyperfine structure and isotope shifts of ^{53,54}Ca. In addition to these two isotopes we will require access to a selection of the $^{40\text{-}52}$Ca isotopes for calibration of the charge radii. In order to provide a clear insight into the influence of N=32,34 the uncertainty on the charge radii should be somewhat smaller than the typical scale of the odd even staggering in the $^{48\text{-}52}$Ca region. Due to the extended time required to measure such exotic isotopes systematic variations due to a varying beam energy can be problematic. For this reason we estimate a successful run will require in the region of 5 individual scans of ^{53,54}Ca, each with a peak height of $\approx 5\sigma$ above background.

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

As noted in the closed session of the 41st meeting of the INTC a similar proposal has been submitted to TRIUMF. To date we understand that no measurements have been performed on any Ca isotope in relation to this competitive proposal.

These specific isotopes have been the subject of substantial scientific interest in the last 2 years. Mass measurements at ISOLTRAP [5] have demonstrated a prominent shell closure at N=32 and highlighted the significance of 3-body forces. Additionally the measurement of the first 2^+ excited state energy in ^{54}Ca [6] has given evidence for a new 'magic number' N=34. Whilst these investigations have significantly enhanced our understanding of the region we feel that the unique sensitivity of the charge radii to cross-shell pairing correlations [7,8] would provide a complementary view of the magic nature of N=32,34.

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

In the recent measurement of the masses of ^{53,54}Ca at ISOLTRAP using a UC_x target with RILIS it was found that these isotopes were produced with rates of 100 ions/s and 10 ions/s respectively. In addition it was observed that beyond stable Cr the major radioactive contaminant is ^{54}Ti, which was collected at a rate of 30 ions/s. As we are not able to use the HRS for the measurements proposed here the ^{54}Ti contamination could be significantly larger. It should also be noted that in our previous $^{49\text{-}52}$Ca measurements the yields obtained were approximately 1 order of magnitude lower that those seen in the ISOLTRAP run.

To form the shift request below we have considered the time required to obtain a similar uncertainty on the isotope shifts as in our previous $^{49\text{-}52}$Ca measurements. Specifically using the simulated optical pumping efficiencies and scintillation detector resolution we have evaluated a range of production/contamination scenarios. At the low yield end of the feasibility range we find the shifts requested below would allow successful measurements with a ^{54}Ca yield of 0.5 ions/s and a ^{54}Ti contamination equal to that observed by ISOLTRAP. Considering the high contamination end of the line of feasibility, with a ^{54}Ti contamination 500 times that observed by ISOLTRAP, measurements could be performed if the ^{54}Ca yield was equal to that observed by ISOLTRAP. Measurements of ^{53}Ca will take somewhat longer than the corresponding ^{54}Ca scans, despite the order of magnitude higher production. This is simply connected to the spread of ionic population over Hyperfine structure states and the larger scanning region required to cover all components. We feel that given the potential variation in production and contamination of these extremely exotic isotopes and the difficulties in determining these parameters, the following shifts are required to enable a successful measurement campaign.

isotope	Yield (/uC)	Max Ti contamination(/uC)	target – ion source	Shifts (8h)
53Ca	6 to 60	60 to ≈ 10^4	UC_x# - RILIS	9
54Ca	0.3 to 6	20 to ≈ 10^4	UC_x# - RILIS	5
40-52Ca†	Not Critical	-	UC_x# - RILIS	2
54Ca‡	6 to 60	60 to ≈ 10^4	UC_x# - RILIS	1

Total shifts: 17

† Calibration Scans to be performed between individual ^{53,54}Ca measurements.

‡ Scintillation detectors setup and optimisation.

#As noted by T. Stora a nanostructured UC_x produced with nanoparticles of UO_2 and carbon nanotubes was tested under IS540 (UC498) in 2012 and could provide further improvements in the yield of these isotopes. Whilst the present yields appear sufficient to complete these measurements this target would be of interest if the results of further testing envisaged at the start of the next running period are positive.

References:

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