EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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

Collinear laser spectroscopy with the COLLAPS setup

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IS529

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With*: *IS519

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With*: *IS508

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Abstract

At the beginning of long shutdown 1, three collinear laser spectroscopy experiments using the COLLAPS setup remained open. IS519 (Zn) has yet to be scheduled, IS508 (Mn) was able to take 11 of the 18 shifts approved and IS529 (Ca) successfully completed all measurements for which shifts were allocated. In this document we demonstrate that the physics cases originally endorsed by the INTC remain significant and that substantial technical developments have been undertaken in order to fully address the remaining unmeasured isotopes.

Experiments and remaining shifts: IS508 - 7 shifts, IS519 - 21 shifts, IS529 - 0 shifts.

Experimental setup/technique

Bunched beam collinear laser spectroscopy (BBCLS) has been extensively described in a wide range of publications arising from work at COLLAPS over the last 6 years [1-11].

Briefly ions are accumulated in the linear Paul trap ISCOOL for a period ~100ms and subsequently released as an ion "bunch" with a typical time spread of 5μs. The ions are transported to the COLLAPS beamline where they are collinearly overlapped with a beam of cw laser light. Optionally the ions can be neutralised by collisions with alkaline vapour producing a fast atomic beam (used in IS508 and IS519). By varying the energy of the beam whilst maintaining a fixed laser frequency one may "Doppler tune" the laser frequency across the relevant atomic/ionic hyperfine transitions. This approach provides accurate high resolution spectra. If the laser frequency matches the Doppler shifted hyperfine transition frequency the atom/ion will be excited and subsequently decay emitting photons. These photons are imaged onto 4 photomultiplier tubes (PMT's). As the ion/atom bunch has a temporal width of only 5μs the continuous background from scattered laser light can be supressed by a factor $>10^4$ by only accepting counts when the bunch is in front of the PMT's.

All measurements performed to date in IS508 and IS529 have used BBCLS and it will also be employed in the IS519 campaign. Although this approach can be thought of as one of the most generally applicable, sensitivity is limited to ion rates greater than a few 10^2 or 10^3 per second. Additionally only transitions from states populated in the production or neutralisation can be used. Beyond this "workhorse" technique two additional approaches are under development for the future measurements in IS508 and IS529.

Firstly a substantial realignment of ISCOOL has been undertaken to allow optical pumping in the cooler. This technique [12] will be used to populate an ionic metastable state in Mn giving access to an efficient and sensitive transition for the completion of the approved IS508 measurements. The successful implementation of this approach will provide advantages not only for the BBCLS measurement of Mn but also for a range of future cases as outlined in INTC-P-286.

Secondly for the completion of IS529 the 41st meeting of the INTC encouraged the development of radioactive detection of optically pumped ions after state selective charge exchange (ROC) [13] during LS1. To this end a full systematic design study was undertaken and a new beamline is now in production. In this technique the sensitivity limits of BBCLS can be surpassed by removing the requirement to detect photons. A full description of the technique, the beamline under construction and its sensitivity are presented in the separate addendum submitted with this status report.

Status report for IS529

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

Spokesperson: M. L. Bissell

Accepted isotopes: $^{49-54}$Ca

Performed studies: $^{49-52}$Ca

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. In the separate addendum submitted with this status report the development of the ROC technique is fully described. At this point beamtime for the measurement of the remaining isotopes ^{53,54}Ca is requested.

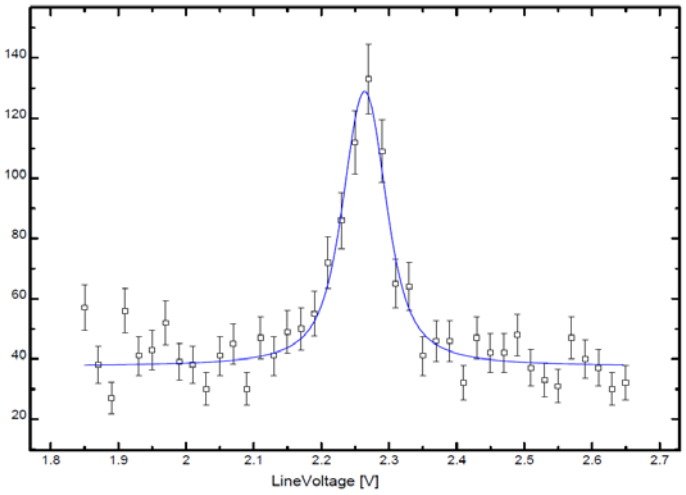

Fig.1: *Spectrum of 52Ca in the 396.8 nm 2S1/2 → 2P3/2 transition acquired in 4 hours.*

In the measurements of the $^{49-52}$Ca isotopes for which shifts were granted all scientific objectives were met. Specifically the charge radii, spins, magnetic moments and electrostatic quadrupole moments were all obtained successfully. In this experiment the new optical detection station was used for the first time on an ionic beam with ground-breaking results. The spectroscopy of ^{52}Ca was achieved with a production yield of only ~300 ions/s, a new sensitivity record for BBCLS at COLLAPS. The quality of data obtained can be seen in figure 1.

The observed magnetic moments and charge radii provide a detailed view of single particle like and pairing correlations across *N*=32.
The preliminary charge radii are presented in figure 2. We are now working with a number of nuclear theory colleagues on the full interpretation of these observations. Two papers are in preparation in which these results will be presented [14,15].

Status report for IS508

Title: Collinear laser spectroscopy of manganese isotopes using optical pumping in ISCOOL

Spokesperson: Bradley Cheal

Accepted isotopes: 51,53,54,55,56,57,58,59,60,61,62,63,64

Performed studies:

Collinear laser spectroscopy was performed on neutron-rich isotopes of manganese up to ^{64}Mn. ISCOOL was used to provide bunched ion beams, which allows the photon background to be critically supressed. The spectroscopy also included isomeric states in ^{58,60,62}Mn. For these mass numbers, an additional gate could be applied to the photon counting, whereby a window initiated by the proton trigger defined a 'useful time', corresponding to a number of half-lives. For data collected in this way, the hyperfine structure of the shorter-lived state was enhanced relative to that of the longer-lived state. This enabled not only better resolving power but also a means of state identification – linking the observed structure with the known half-life.

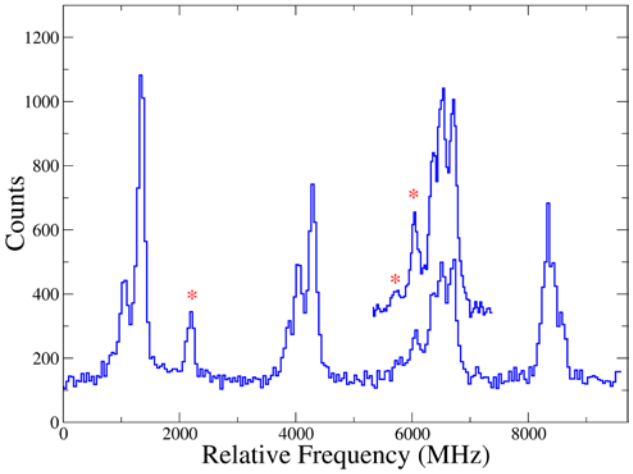

Fig.2: *Full hyperfine structure of the ^{60}Mn ground state and isomer. For illustration, asterisks indicate only those peaks of the low-spin state which are fully resolved by eye.*

In this initial study, spectroscopy was performed on an atomic transition from the ground state. This enabled measurements to be performed up to N=39, in a region where an onset of collectivity is predicted to occur, described as a new "island of inversion". In all cases, direct measurements of the nuclear spin have been performed. The expected migration of single-particle levels is now being studied by comparing the measured magnetic moments, which are particularly sensitive to the precise construction of the nuclear wave function, with state-of-the-art shell model interactions. The mean-square charge radii extracted from our data will indicate subshell effects (if they occur) at N=32 and N=34, by exhibiting a characteristic upward 'kink'.

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

(i) Envisaged measurements and requested isotopes

While the measurements performed in November 2012 recorded the full hyperfine structure for a range of manganese isotopes, the studies stopped tantalisingly short of N=40. Collinear laser spectroscopy of atomic manganese has been shown to suffer from efficiency losses introduced during the charge exchange process. When the ion beam is neutralised via passage through an alkali vapour cell, the high electronic level density leads to the population being spread over several atomic levels other than the (ground) state being spectroscopically probed. For the manganese ion, the transition from the ionic ground state is at 230nm and spectroscopically weak. Both of these factors also present difficulties for high-resolution collinear fast-beam spectroscopy. However, optical pumping in ISCOOL will transfer the electronic population from the ground state to the 9473cm^{-1} level, from which an efficient and accessible transition at 295nm can be used. The resulting increase in efficiency will permit measurements to cross N=40. Additionally, the 295nm transition will show far higher sensitivity to the quadrupole moments than the previously studied atomic transition, enabling these to be extracted precisely from the hyperfine structure.

Work is currently underway during the shutdown to improve the alignment of ISCOOL and to facilitate the transport of the pumping laser beam (provided by RILIS) to the trapping region. These developments, and the physics obtained, is forming the basis of two PhD theses.

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

These studies have not been carried out elsewhere. The physics case remains unaltered.

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

isotope	yield (/uC)	target – ion source	Shifts (8h)
53 - 66	500	UCx	7

Total shifts: 7

Status report for IS519

Title: Shell structure and level migrations in zinc studied using collinear laser spectroscopy

Spokesperson: Bradley Cheal

Accepted isotopes: N/A

Performed studies: N/A – experiment has not been scheduled so far

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

A total of 21 shifts were awarded by the INTC in 2011, but due to time constraints and the long shutdown, it has not been possible to schedule any shifts so far. It is hoped that the first experiment will proceed in 2014.

(i) Envisaged measurements and requested isotopes

It is anticipated that the yields will permit laser spectroscopic measurements of a long chain of Zn isotopes, from mass number 60 to 81. Of particular interest are the neutron rich isotopes where the phenomenon of monopole migration has been of recent intense interest (eg. IS439, IS457). In reaching N=51, the measurements will also cross the shell closure, enabling the neutron shell gap in the vicinity of ^{78}Ni to be studied. Unlike the copper (IS439) and gallium (IS457) isotopes, the mean-square charge radii, obtainable from the optical isotope shifts, have a reliable calibration. Meanwhile, a series of ground and isomeric state nuclear spins will be unambiguously measured in this work. These values are invaluable for interpreting the data from nuclear spectroscopic experiments.

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

These studies have not been performed by any other group. The physics case outlined in the proposal remains the same.

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

isotope	yield (/uC)	target – ion source	Shifts (8h)
60 - 81	2000	UCx	21

Total shifts: 21

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