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

Ground-state properties of K-isotopes from laser and β-NMR spectroscopy

IS484

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Abstract

Thanks to an improved and newly developed light collection region for the COLLAPS beam line, we have successfully measured the ground state magnetic moments and spins of the neutron-rich $^{48-49-50}$K isotopes. These nuclear observables provide information about the evolution of the proton sd-orbits as the neutron $p_{3/2}$ orbit is being filled towards N=32. Although not initially planned, we have also measured the isotope shifts from N=19 to N=31 (^{38,39,42,44,46,47,48,48,50}K), from which changes in the mean square charge radii are deduced. A clear shell effect is observed in the isotope shifts beyond N=28. In order to determine the ground state spin and magnetic moment of ^{51}K, for which an inversion from I=1/2 back to the normal I=3/2 is predicted, and to study the effect of a suggested N=32 shell gap in the isotope shifts, we apply for 12 shifts. As in the previous run, optical detection of the hyperfine structure using bunched-beam collinear laser spectroscopy in the COLLAPS beam line will be applied. To allow this measurement, a significant reduction in the detected photon background, related to the beam light from contaminating ions in the A=51 beam has been achieved.

Requested shifts: 12 shifts in 1 run.

Introduction

The proposal IS484 aimed at the study of the ground state spins and magnetic moments of the neutron rich $^{48-51}K$ isotopes. These isotopes with N=29 to N=32 neutrons have a ground state dominated by the gradual filling of the neutron $\nu 2p_{3/2}$ orbital. The odd-K isotopes (Z=19) have a proton-hole in the πsd-shell. Between N=20 and N=28, an inversion of the ground state spin from a normal I=3/2 (dominated by $\pi 1d_{3/2}$) to I=1/2 (dominated by $\pi 2s_{1/2}$) was observed in ^{47}K. This has been explained by the attractive $\pi 1d_{3/2}$-$\nu 1f_{7/2}$ tensor interaction, which makes the $\pi d_{3/2}$ orbital more bound when the $\nu f_{7/2}$ gets filled from N=21 to N=28, leading to a near-degeneracy of the $\pi d_{3/2}$- $\pi s_{1/2}$ orbits near N=28. Beyond N=28, little is known about the low-energy structure of the K-isotopes, and contradicting information was obtained from β-decay and in-beam γ-spectroscopy studies. Theoretically different effective shell model interactions predict different ground state properties for these isotopes (see original proposal for details and references). Thus direct measurements of the ground state spin and moments are needed to clarify the situation.

Therefore, we had requested 24 shifts to study the ground state spins and magnetic moments of the $^{48,49,50,51}K$ isotopes using bunched-beam collinear laser spectroscopy in combination with β-Nuclear Magnetic Resonance spectroscopy. 12 shifts had been approved, and a successful experiment was performed in November 2010.

(The combination with β-NMR was suggested in case it would not be possible to get an unambiguous spin assignment from the measured hyperfine structure only. The 12 shifts requested for this measurement were not yet approved.)

Improvements in the light-collection region at COLLAPS

An on-line commissioning run to test the bunched-beam collinear laser spectroscopy technique at ISOLDE, had been performed on the $^{46,48}K$ isotopes [1], prior to our proposal submission in 2008. During this experiment, the standard light collection region of the COLLAPS beam line was used, which has a peak response around 550 nm (using two Burle 8852 photomultiplier tubes). For the K-I D_1 and D_2 transitions, at 770 and 766 nm, the spectral response is about 50% lower than the peak value. With this set-up, a typical photon detection efficiency of 1 photon per 300.000 K-ions was observed. In order to allow bunched-beam laser spectroscopy studies on the neutron-rich K-isotopes, it became clear that an improvement of a factor of 10 would be needed in the detection efficiency, in order to allow measurements up to ^{51}K (with a predicted yield of 4500 ions/μC).

With this goal, a new light collection region has been designed and constructed [2]. The improvement in the detection efficiency comes mostly from a better lens geometry and by doubling the number of PMT's (see result from simulations in Figure 1, right). A schematic drawing of a horizontal cross section of the new set-up is shown in Figure 1, left. This new set-up provided a detection efficiency of 1/10.000 photons/ions, **yielding more than a factor 10 improvement in the detection efficiency** compared to the previous set-up. The yield of non-resonant background photons due to laser scatter also was somewhat reduced, from typically 1500 photons/s/mW of laser power to an average of 1000 photons/s/mW. This source of background photons is however not a major problem in the case of bunched-beam spectroscopy, as this technique reduces the non-resonant background counting by a factor of 10^4 (if this background is random in time, see e.g. [3]).

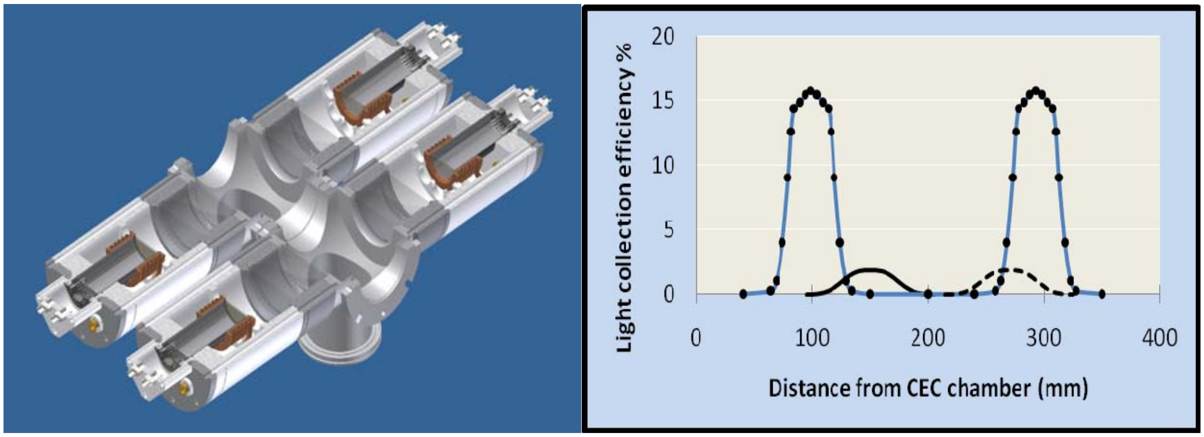

Figure 1: (left) Schematic view of the horizontal cross section of the new light collection region for COLLAPS. (right) Simulation of the expected light collection efficiency of the old (lowest) and new (highest) detection set-up, yielding a calculated improvement of a factor 14 in efficiency.

Preliminary results from the 2010 run

The K-isotopes have been produced on a UC_2 target using surface ionization, with yields about 3 times lower than quoted in the ISOLDE yield database. The experiment has been performed on K-atoms after charge exchange in the COLLAPS beam line, using the D1 transition at 770 nm. This transition is not sensitive to quadrupole moments, but only to the magnetic moments, the spins and the isotope shifts. To allow measurements on beams with intensities between 10^3-10^5 ions/μC, we used the bunched-beam collinear laser spectroscopy method (using ISCOOL + HRS) and the newly developed dedicated light collection region with a factor of 10 improved detection efficiency. This allowed us to achieve most of our goals, and to get even more results than initially aimed for. Unfortunately, due to a beam-induced photon background caused by a strong and unidentified beam contamination in the mass 51 as discussed below, it was not possible to measure the hyperfine structure and isotope shift of ^{51}K.

A very preliminary analysis allows following conclusions:

- Hyperfine spectra were measured for the first time for the isotopes of ^{48,49,50}K (N=29 to N=31). Additionally, hyperfine spectra of several isotopes between ^{38}K and ^{47}K were measured to verify the consistency with earlier measurements [4] and check the possibility for isotope shift determination.
- **Spins of ^{48,49,50}K can be unambiguously deduced** from the measured HFS. Spins for the other isotopes confirm the earlier assignments.
- The **magnetic moments of the ^{48,49,50}K ground states are measured** for the first time and for other isotopes an improved accuracy is achieved in some cases. Information about the single particle structure of these isotopes can be deduced.
- The **isotope shifts of ^{38,39,42,44,46,47,48,49,50}K have been measured**, extending the earlier measurements by Touchard et al. [4] towards the neutron-rich side beyond N=28. A clear effect is observed at the N=28 shell gap, with a flattening towards N=31 (figure

2). The measurement of isotope shifts was not put as a goal in our original proposal, because it was not clear at that time if isotope shifts can be measured using ISCOOL/HRS. The present measurement, and studies on the Cu and Ga isotopes performed in the mean time, have revealed the feasibility (and the limits) of this method.

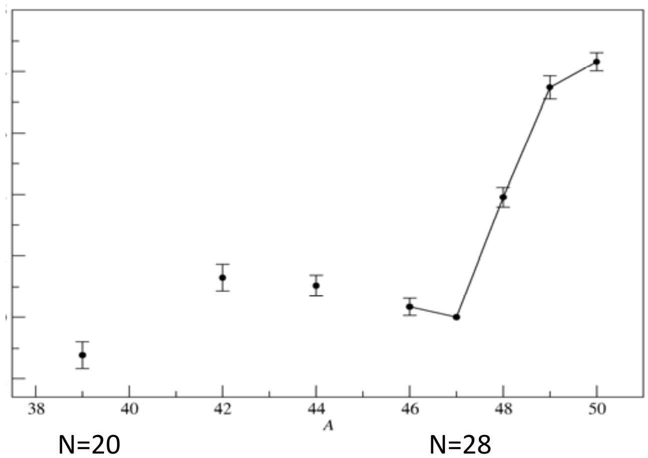

Figure 2: Preliminary result from measured isotope shifts in the ^{39}K-^{50}K isotopes: changes in mean square charge radii show a steep increase beyond N=28 (in ^{48}K), with a flattening towards ^{50}K (N=31). The goal of the present proposal addendum is to see if a hint of a shell effect can be seen in ^{51}K at the prediced new magic number N=32.

Motivation for new beam time.

The very preliminary and rough analysis of the mean square charge radii deduced from our measured isotope shifts (Fig. 2) is based on the calculated field factor from Martensson-Pendrill [5]. The results for $^{39-47}$K agree well with the earlier measurements from Touchard et al. [4] and the reanalysis from [5], showing that it is possible to deduce changes in the mean square charge radii from the measured isotope shifts, using bunched-beam collinear laser spectroscopy. A more detailed analysis will reduce the error bars, but already now it is clear that a rich structure is observed beyond N=28. It is our goal to extend this measurement towards ^{51}K, to see if an effect of the newly predicted magicity at N=32 can be seen in the charge radii.

A second goal of our measurement is to establish the ground state spin and structure of ^{51}K, by determining the magnetic moment and spin through its hyperfine structure. For ^{49}K, we have established that the ground state spin is I=1/2, like in ^{47}K. That follows directly from the fact that only three transitions are seen in the HFS, while four transitions occur for isotopes with I>1/2. Its measured magnetic moment is not very well reproduced by the shell model calculations (figure 3), and further studies are needed to investigate the reason for this. In the large scale shell model calculations, the ½ and 3/2 levels are nearly degenerate for ^{49}K, with either ½ or 3/2 as the ground state, depending on the used effective interaction. For ^{51}K however, the ground state is predicted to have spin I=3/2 in all cases, with the first excited state (I=1/2) above 400 keV. It would be interesting to see if the spin of ^{51}K is indeed I=3/2 as predicted, and to investigate the dominating component in its wave function by determining μ.

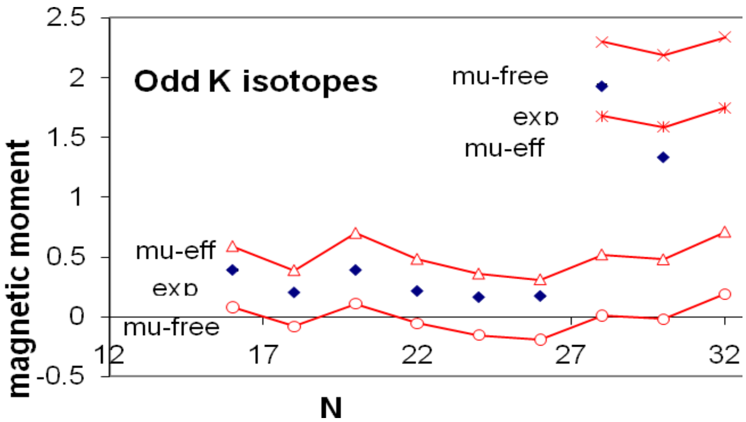

Figure 3: Experimental and calculated magnetic moments of the odd-K isotopes from ^{37}K to ^{51}K. Calculations are performed with the sdpf-U interaction of Nowacki and Poves. [6]

Finally, in case time would remain available, we would also try to measure the quadrupole moments of some of the K-isotopes. Till now, only the quadrupole moments of the stable ^{39}K [7] and the short-lived ^{37}K [8,9] have been measured. The value of ^{37}K is found to be significantly larger than the value for the semi-magic ^{39}K, suggesting a strong core polarization when removing neutrons from the ^{40}Ca core. This is not reproduced by current shell model calculations. Our aim is to investigate if a similar core-polarizing effect is observed on the spectroscopic quadrupole moments of stable and neutron-rich K-isotopes beyond N=20, where the interaction with the negative parity $f_{7/2}$ and $p_{3/2}$ neutrons is dominating. A measurement on the D_2 line for ^{44,46}K has shown that the HFS lines are not fully resolved in this transition [1]. However, quadrupole moments can be deduced because all magnetic moments are known from measurements on the D1 line, as well as the isotope shifts and spins, leaving Q the only parameter to fit the observed HFS.

Feasibility and beam time request.

The ground state properties of ^{51}K could not be measured during the November run, because of an unexpected contaminating ion in the A=51 beam selected by the HRS. This contamination seemed to be present at the beginning of the experiment (after day 1), but not at the end (day 4). This is illustrated clearly in the release curves measured by detecting the mass 51 ions in the COLLAPS beam line with a secondary electron multiplier as a function of time (Figure 4). At the beginning of the run, instead of a release curve (decrease of ions in time), a build up of contaminating ions is observed. This made us decide not to attempt a measurement on ^{51}K, because a huge beam-related non-resonant photon background was observed in our photomultiplier spectra (Figure 5, left) for the mass 51 beam. This beam light originates from the de-excitation of contaminating ions that are excited in the charge exchange cell via collisional excitation or charge exchange into excited levels. With such a beam-related photon background, which cannot be cut out by time gating, we estimated that it would require at least 6 shifts to get an acceptable signal-to-noise ratio in the ^{51}K HFS spectrum. Only if that background can be removed a measurement on ^{51}K is possible. Luckily, the wavelength of this beam light is in a different range than the IR fluorescence light from the K-beam, and thus it can be filtered out by placing a RG715 filter in front of the lens. That is seen by comparing the spectra taken with and without filter (Figure 5, right), for a short time during the CRIS beam time (IS471), immediately after or experiment.

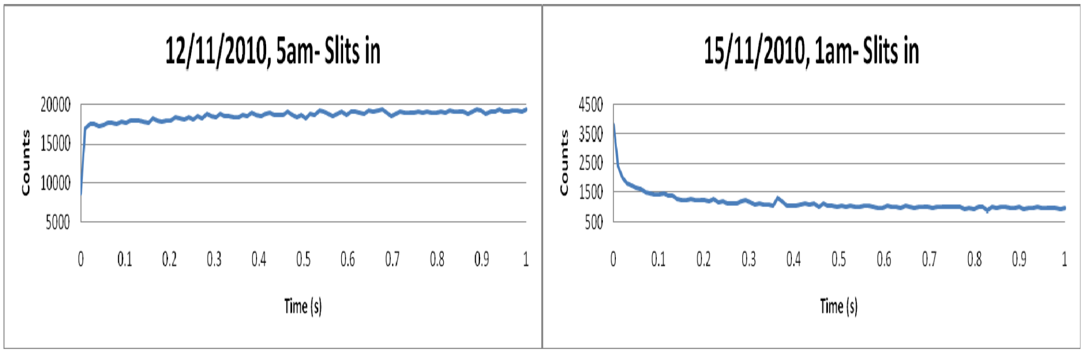

Figure 4: Detected ion counts as a function of time in the COLLAPS beam line, after selection of a ^{51}K beam. In the beginning of the experiment, a build-up of ion background counts is observed, while at the end of the experiment, a normal K-release curve is visible (typical K-release time from the ion source is 100 ms).

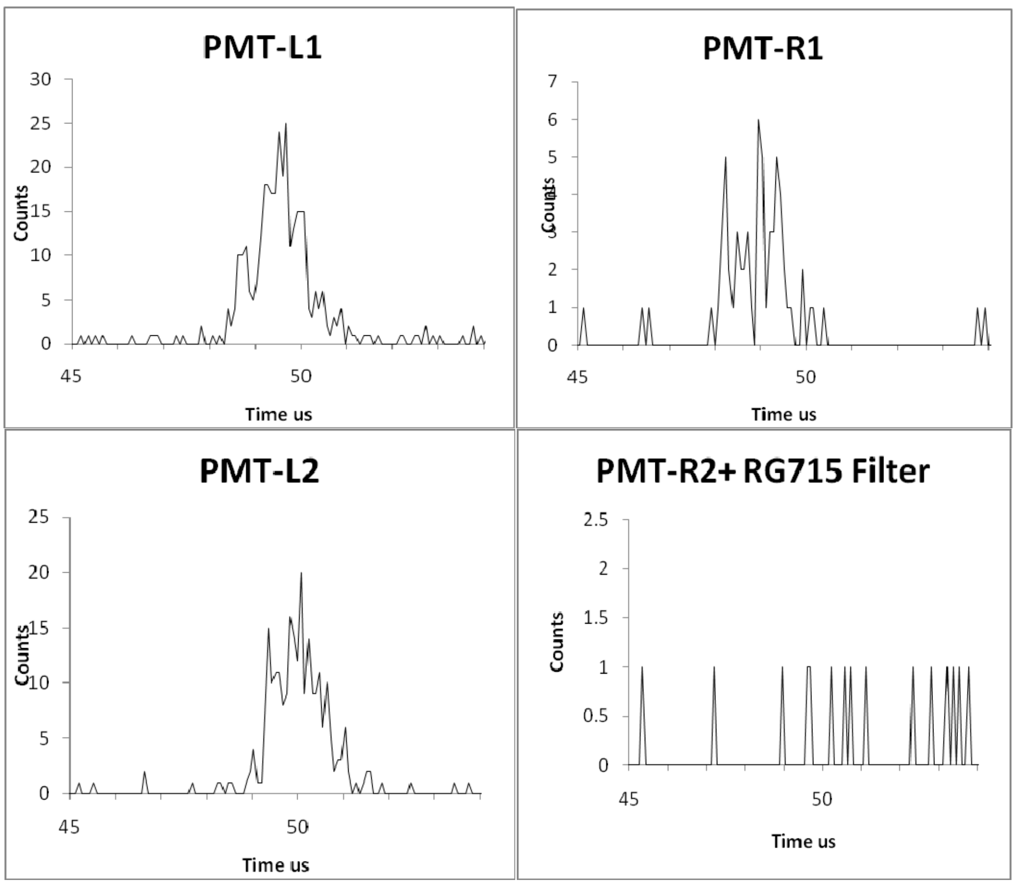

Figure 5: (left) Non-resonant beam-related photons detected in the PMT's as the mass-51 beam-pulse passes in front of the PMT detectors. (right) These beam-related non-resonant photons can be eliminated by placing a filter in front of the PMT: spectrum PMT-R1 is without filter and PMT-R2 is with a filter. As the remaining background photons are now random in time, they can be eliminated from detection by placing a 3 μs time gate on the scaler.

In conclusion, by eliminating the beam-related non-resonant photons in our PMT's by using filters, as illustrated in Fig. 5, a measurement of the HFS of ^{51}K is feasible in about 3 shifts. For this time estimate, a rate of 1500 ions/μC is assumed, based on the yield measured on the ISOLDE tape station before our run. A signal-to noise ratio of 8:1 in the ^{51}K HFS spectrum can be achieved, which is needed to resolve all peaks (including the smaller ones).

Summary of requested shifts:

We ask for **12 shifts, using protons on a UCx target for producing K-isotopes through surface ionization**, to study the isotope shift and the ground state spin and magnetic moment of ^{51}K, relative to some other K-isotopes. For one HFS scan on ^{51}K we need about 3 shifts. We want to reproduce this measurement at least 3 times relative to a few other K-isotopes to get a reliable isotope shift determination.

References:

[1] E. Mané, Ph.D. Thesis, University of Manchester, 2009 and E. Mané et al., Eur. Phys. J. A **42**, 503–507 (2009)

[2] M.L. Bissell et al., in preparation for NIM

[3] P. Vingerhoets et al., Phys. Rev. C 82, 064311 (2010)

[4] F. Touchard et al., PLB 108B, 169 (1982)

[5] A-M Martensson-Pendrill et al., J. Phys. B: At. Mol. Opt. Phys. **23** (1990) 1749-1761.

[6] F. Nowacki and A. Poves, Phys. Rev. C **79**, 014310 (2009)

[7] E. Arimondo, et al., Rev. Mod. Phys. 49 (1977) 31.

[8] J.A. Behr, et al., Phys. Rev. Lett. 79 (1997) 375.

[9] K. Minamisono et al., Phys. Lett. B 662, (2008) 389.

Appendix

DESCRIPTION OF THE PROPOSED EXPERIMENT

The experimental setup comprises: *(name the fixed-ISOLDE installations, as well as flexible elements of the experiment)*

Part of the Choose an item.	Availability	Design and manufacturing
COLLAPS	☒ Existing	☒ To be used without any modification

HAZARDS GENERATED BY THE EXPERIMENT

Hazards named in the document relevant for the fixed [COLLAPS] installation.

3.2 Average electrical power requirements (excluding fixed ISOLDE-installation mentioned above): *(make a rough estimate of the total power consumption of the additional equipment used in the experiment)*