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The Collinear Resonance Ionization Spectroscopy (CRIS) experimental setup at CERN-ISOLDE ☆

T.E. Cocolios [a,b,*], H.H. Al Suradi [c], J. Billowes [a], I. Budinčević [d], R.P. de Groote [d], S. De Schepper [d], V.N. Fedosseev [e], K.T. Flanagan [a], S. Franchoo [f], R.F. Garcia Ruiz [d], H. Heylen [d], F. Le Blanc [f,1], K.M. Lynch [a,b], B.A. Marsh [e], P.J.R. Mason [g,2], G. Neyens [d], J. Papuga [d], T.J. Procter [a], M.M. Rajabali [d,3], R.E. Rossel [e,h], S. Rothe [e,h], G.S. Simpson [i], A.J. Smith [a], I. Strashnov [a], H.H. Stroke [j], D. Verney [f], P.M. Walker [g], K.D.A. Wendt [h], R.T. Wood [g]

[a] School of Physics and Astronomy, University of Manchester, Manchester M13 9PL, United Kingdom
[b] ISOLDE, PH Department, CERN, CH-1211 Geneva-23, Switzerland
[c] University of Sharja, Sharja, United Arab Emirates
[d] Instituut voor Kern- en Stralingsfysika, KU Leuven, B-3001 Leuven, Belgium
[e] EN Department, CERN, CH-1211 Geneva-23, Switzerland
[f] Institut de Physique Nucléaire d'Orsay, F-91406 Orsay, France
[g] Centre for Nuclear and Radiation Physics, University of Surrey, Guilford GU2 7XH, United Kingdom
[h] Institut für Physik, Johannes Gutenberg Universität, D-55099 Mainz, Germany
[i] LPSC, F-38026 Grenoble Cedex, France
[j] New York University, New York, NY 10003, United States

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ABSTRACT

The CRIS setup at CERN-ISOLDE is a laser spectroscopy experiment dedicated to the high-resolution study of the spin, hyperfine structure and isotope shift of radioactive nuclei with low production rates (a few per second). It combines the Doppler-free resolution of the in-flight collinear geometry with the high detection efficiency of resonant ionisation. A recent commissioning campaign has demonstrated a 1% experimental efficiency, and as low as a 0.001% non-resonant ionisation. The current status of the experiment and its recent achievements with beams of francium isotopes are reported. The first identified systematic effects are discussed.

1. Introduction

Laser spectroscopy of radioactive atoms provides ground-state nuclear properties without any nuclear model assumptions [1,2]. It has therefore attracted a lot of interest in the recent years [3,4] and the techniques are being pushed to their limits to study the most exotic systems.

In general, the collinear laser spectroscopy technique uses beams produced at on-line facilities where the ions are mass separated and delivered either continuously or alternatively in bunches to the experimental setup. The beam may be neutralised in an alkali vapour upon entering the atom/laser interaction region where the atom beam is overlapped by a co-propagating laser beam. The excited atoms decay and the resonantly scattered photons are detected with photomultipliers. The acceleration of the beam provides a reduction of the velocity distribution of the ions, resulting in a Doppler compression of the resolution down to the natural line width. This technique has benefited, in recent years, from the use of bunched beams [5,6] and has reached a sensitivity down to 100 ions per second under optimum conditions [7], though a more typical required rate is 10,000 ions per second [3].

In-source laser spectroscopy is an alternative to the collinear laser spectroscopy technique and has gained particular interest in the last decade [8]. The isotopes of interest are resonantly ionised within the ion source with a series of resonant transitions, one of

* Corresponding author at: School of Physics and Astronomy, University of Manchester, Manchester M13 9PL, United Kingdom. Tel.: +44 1612754281; fax: +44 1612755509.
E-mail address: Thomas.Elias.Cocolios@cern.ch (T.E. Cocolios).
[1] Present address: IPHC, Strasbourg, France.
[2] Present address: STFC Daresbury Laboratory, Daresbury, United Kingdom.
[3] Present address: TRIUMF, Vancouver, BC, Canada.

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which is scanned across the resonance, mass separated and delivered to a counting station. The high efficiency of ion counting and the possibility of decay tagging has made this technique very powerful and has allowed the study of isotopes with production rates below 1 atom per second [9–12]. The spectroscopic resolution is dependent upon the ion source conditions (temperature, pressure, divergence) and is typically 100–1000 times lower than in collinear laser spectroscopy, although continuous improvements are ongoing [13].

The Collinear Resonance Ionisation Spectroscopy (CRIS) technique was proposed as a means of benefiting from both techniques [14]. The ion beam is prepared and delivered to the experiment as in collinear laser spectroscopy. The atom beam is then overlapped with additional laser beams for efficient ionisation. The ionised beam is finally deflected towards a high-efficiency counting station.

The first demonstration of this technique suffered however from a low duty cycle associated with overlapping a continuous ion beam with a pulsed laser system [15], resulting in an efficiency of 0.001%. Subsequent tests performed at the University of Jyväskylä with bunched beams and synchronised pulsed lasers achieved a high efficiency but suffered from bad vacuum conditions resulting in a high background rate from non-resonant collisional re-ionisation [6,16–18].

2. The CRIS setup at ISOLDE

The new CRIS setup at CERN ISOLDE has been designed to overcome the shortcomings of the previous applications of this technique. The three components of the setup are the ion beam line, the laser system, and the detection chamber.

2.1. The CRIS beam line

The radioactive beam is produced upon the impact of the CERN PSBooster proton beam onto the ISOLDE target [19]. The nuclear-reaction products diffuse and effuse to an ion source, the ions are accelerated to 30–50 keV, mass separated in the high-resolution separator magnets HRS [20], cooled and bunched in a gas-filled radio-frequency quadrupole linear Paul trap (ISCOOL) [21] and delivered to the experimental setup.

A detailed description of the CRIS beam line can be found in Ref. [22]. Its most important features and characteristics are presented in this section and can be seen in Fig. 1. The ion bunch is deflected to the laser axis to be overlapped. It is then neutralised in a potassium-filled charge-exchange cell. The charge-exchange cell chamber may be biased to Doppler tune the bunch onto resonance. The potassium vapour is maintained at a temperature near 150 °C and produces a background pressure of the order of 10^{-6} mbar.

The neutral atom bunch is then directed through a differential pumping region while the non-neutralised component is deflected within the differential pumping region. The atom bunch is temporally overlapped with the laser pulse in the interaction region, where the pressure is maintained under 10^{-8} mbar, in order to minimise non-resonant collisional ionisation. The axial overlap is adjusted with ion optic electrodes upstream of the charge-exchange cell, while the longitudinal overlap is adjusted by synchronising the laser pulses with the bunch release from ISCOOL. In the study of the francium isotopes, the atom bunch width was found to be ~ 2 μs, which is well contained within the length of the interaction region (1.5 m).

At the end of the interaction region, the re-ionised atoms are deflected to the decay-spectroscopy station (DSS) to be counted with either a micro-channel plate (MCP) detector or an α-decay spectroscopy setup.

2.2. The laser system

The francium atoms are ionised in a two-step process, with a resonant transition from the $7s^2S_{1/2}$ atomic ground state to the $8p^2P_{3/2}$ state at 23,658.306 cm^{-1}, and a non-resonant excitation across the ionisation potential with a 1064 nm laser pulse.

The full laser system can be seen on Fig. 2. The 422.7 nm laser light is provided by one of the RILIS tunable Ti:Sapphire (Ti:Sa) laser [23], which was operated in narrow line-width mode [24]. The Ti:Sa laser is pumped with a frequency doubled Nd:YAG laser, operating at 10 kHz pulse repetition rate. The fundamental output of the Ti:Sa laser is frequency doubled in a BBO crystal. The laser light is delivered to the CRIS experimental setup via a 35 m-long optical fibre. The ability to scan this laser system has been improved recently by the implementation of a remote control system with a built-in stability control system [25]. The bandwidth of the fundamental laser light was typically 1 GHz.

The second step used the fundamental output of a Nd:YAG laser at 30 Hz repetition rate. The two lasers are synchronised temporally and the time overlap is monitored with a photodiode placed downstream of the interaction region. The 10 kHz signal was used as the master trigger for the experiment.

The two laser pulses are merged spatially on a launch platform in front of the beam line and overlapped with the ion/atom beam

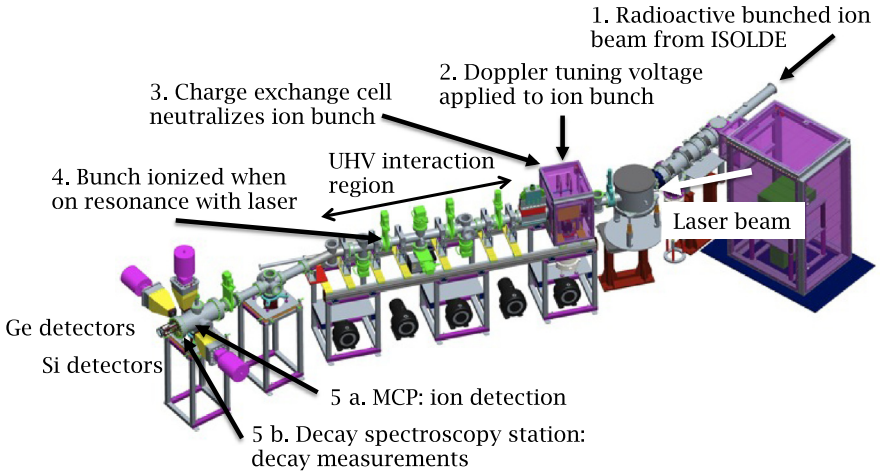

Fig. 1. Layout of the CRIS beam line. The ion and laser beams travel from right to left through the charge exchange cell, the interaction region, and finally to the DSS.