



## A dedicated decay-spectroscopy station for the collinear resonance ionization experiment at ISOLDE

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### ABSTRACT

A new decay-spectroscopy station (DSS) has been developed to be coupled to the collinear resonance ionization spectroscopy (CRIS) beam line at CERN-ISOLDE. The system uses a rotatable wheel with ten  $20 \mu\text{g}/\text{cm}^2$  carbon foils as beam implantation sites for the efficient measurement of charged decay products. Silicon detectors are placed on either side of the carbon foil in an optimal geometry to cover a large solid angle for detecting these charged particles. In addition to the silicon detectors at the on-beam axis position, a second pair of off-beam axis detectors are placed at the wheel position  $108^\circ$  away, allowing longer-lived species to be studied. Up to three high purity germanium detectors can be placed around the chamber for particle-gamma correlated measurement. The radioactive beam is transported through the CRIS beam line before implantation into a carbon foil at the DSS. All materials used in the DSS are UHV-compatible to maintain high vacuum conditions required by the CRIS beam line. This paper describes the DSS and presents the first data collected at the setup during the commissioning run with  $^{221}\text{Fr}$ .

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### 1. Introduction

Experiments developed for the study of nuclear properties of rare isotopes produced using ISOL targets are often hindered by the presence of large isobaric contaminants in the beam. This has driven the development of several beam purification techniques of which the laser ion source (LIS) has proved to be very successful [1–4]. Further steps can be taken to reduce the isobaric contamination from surface ionization as described in Refs. [5,6]. Despite these efforts, experiments designed to study rare isotopes that are produced with lower yields may require even further purification of the beam so as to obtain precise decay branching ratios or for the purpose of total absorption spectrometry.

A compelling problem is that of low-lying isomers that cannot easily be distinguished from their ground state using conventional decay spectroscopy or mass separation techniques.

To study cases where additional beam purification becomes essential, a different but complementary method is needed. In-source laser spectroscopy has previously been used for isomer selection and identification [7,8]. Following this selection, experiments such as Coulomb excitation [9] and mass measurements [10] have been performed on isomeric beams. These experiments did suffer from the presence of isobaric contamination, as well as significant ground-state contamination due to the overlap of the Doppler-broadened hyperfine resonances of each isomer [11].

A new experimental set-up has been constructed at ISOLDE-CERN for performing collinear resonance ionization spectroscopy (CRIS) measurements [12,13]. This method combines the high efficiency and selectivity, commonly achieved in a LIS resonant ionization spectroscopy (RIS) experiment [1] with the high resolution of a collinear laser spectroscopy experiment [11].

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While initially developed for hyperfine structure studies, this set-up will provide ultra-pure beams of rare isotopes and isomers for decay spectroscopy.

A UHV compatible decay spectroscopy station (DSS) has been developed, dedicated to conduct laser assisted decay spectroscopy at the end of the CRIS beam line. The technique utilizes the selectivity of RIS to perform decay measurements on rare isotopes with the ability to distinguish states that are isomeric ( $> 1$  ms) from the ground state. This paper reports on the technical aspect of the DSS where  $^{221}\text{Fr}$  was used as part of the commissioning process.

## 2. DSS design

The experimental constraints imposed by the CRIS technique require the DSS to operate at a pressure below  $1 \times 10^{-9}$  mbar. This vacuum requirement makes it essential to have components that do not outgas and that can sustain baking temperatures. For this reason, the cables and detectors used in the DSS are of UHV grade material and all the components are made of either stainless steel or polyether ether ketone (PEEK) to reduce outgassing.

### 2.1. Windmill design for $\alpha$ -decay spectroscopy

The decay spectroscopy station consists of a rotatable wheel implantation system as shown in Fig. 1(a) and (b). It is based on the design from KU Leuven [14–17] shown in Fig. 1 of Ref. [17], which has provided results in a number of successful experiments [8,17,18]. The wheel holds 10 carbon foils, which were produced at the GSI target laboratory [19], with a thickness of  $20 \mu\text{g}/\text{cm}^2 \pm 5\%$  (90 nm) into which the ion beam is implanted. The carbon foils and the wheel system are favored over a Mylar tape system for the compact size and, more importantly, the better detection efficiency resulting from the improved transmission of  $\alpha$  particles, following the decay of implanted ions in the carbon foils.

A stepper motor (17HS-240E, 2.3 A/phase) is used to rotate the wheel. The controller for the motor is operated via a programmable computer software package. The rotation of the wheel can be controlled using optical switches or by predefining the number of steps that the motor should turn. In order to maintain UHV, the motor is situated externally and connected to the internal windmill system via a magnetic coupling supplied by UHV Design. This coupling has negligible influence on the noise introduced to the signal between the detector and the preamplifier.

Two Canberra passivated implanted planar silicon (PIPS) detectors for particle detection ( $\alpha$ , electron, fission fragments) are situated on either side of the implantation carbon foil, as shown in Fig. 1(a). One PIPS detector (Model: BKA 300-17 AM, thickness 300  $\mu\text{m}$ ) sits behind the carbon foil and another annular PIPS (APIPS) (Model: BKANPD 300-18 RM, thickness 300  $\mu\text{m}$ , with an aperture of 4 mm) is placed in front of the carbon foil. The detectors are connected to charge sensitive preamplifiers (Canberra model 2003BT) via custom-made Kapton cables and a UHV type-C sub-miniature electrical feed-through. The ion beam is directed through the 4 mm aperture of the annular detector and implanted into the carbon foil. Decay products from the carbon foil can be measured in either the PIPS or APIPS detectors. In addition to the on-axis detectors, two PIPS detectors can be placed off-axis. Rotating the implanted foil from the on-axis to off-axis detector position allows the measurement of unperturbed decay curves on longer-lived decay products. For  $\gamma$ -ray detection, up to three high-purity germanium (HPGe) detectors can be placed around the implantation site. In addition to the silicon

and germanium detectors, the spectroscopy chamber also houses a microchannel plate (MCP) detector (Hamamatsu F4655-13) for hyperfine structure measurements with the CRIS experiment [13]. The MCP is set up as a negative ion counter. In this configuration, the beam strikes the surface of a copper plate (Fig. 1(c)) and emits secondary electrons which are then electrostatically guided to the MCP resulting in the observed signal.

### 2.2. Beam tuning to the carbon foil

Resonantly ionized bunched beams from the interaction region in the CRIS beam line are deflected to the decay spectroscopy station by applying voltage to a pair of vertical electrostatic plates. The deflected ion beam is transported along the length of a 1.93 m long beam line before being implanted into a carbon foil in the windmill. In the process, the beam has to be directed through a 64.9 mm spacing between the copper plate and MCP (see Fig. 1(c)) in addition to being focused through a 4 mm aperture of the annular detector. To achieve this, ion optics components have been added to the beam line as shown in Fig. 1(c). After the  $20^\circ$  deflection, the beam is first directed through a quadrupole doublet which corrects for astigmatism introduced earlier in the beam line. It is then passed through a final pair of vertical and horizontal steering plates (see Fig. 1(c)) which along with the quadrupole doublet allow the focus and position of the beam to be optimized for either the copper plate or the carbon foil.

Two sets of collimators are installed in the detection chamber. The first is attached to a manual linear actuator with a series of 3, 6 and 10 mm apertures and is housed in the same region as the MCP detector. The second is a fixed aluminum disk placed in front of the APIPS detector (see Fig. 1(b)) to protect against direct ion implantation into the silicon wafer. The PEEK holder (see Fig. 1(c)) electrically isolates this disk from the grounded support structure as well as the APIPS detector. An electrical contact is made to read the current when an ion beam strikes this collimator enabling its use as a beam tuning device. The beam focus can be monitored during implantation into one of the carbon foils by measuring how much of the beam is lost on the aluminum disk. When it is not in use as a Faraday cup, the collimator is grounded to avoid charge build-up.

To further improve the beam tuning capability to the ion-implantation site, a copper plate (thickness 0.5 mm, diameter 10 mm) is installed at the position of one of the carbon foils in the steel wheel of the DSS. The plate is electrically isolated from the steel wheel by two PEEK rings and connected by a spot-welded Kapton cable to a freely rotatable BNC connection installed at the center of the wheel.

### 2.3. Shielding and efficiency

Measurements of the  $\gamma$ -ray attenuation by the stainless steel body of the chamber and the steel windmill were carried out using a 70% high purity germanium detector (Model: GC7020). The results are presented in Fig. 2. Known  $\gamma$ -ray sources of  $^{241}\text{Am}$ ,  $^{152}\text{Eu}$  and  $^{60}\text{Co}$  were positioned 65 mm from the detector, with and without the chamber present. More than 92% of the 59 keV  $\gamma$ -rays and 52% of the 123 keV  $\gamma$ -rays were attenuated (see Fig. 2) by the 3 mm thick steel walls. At energies above 591 keV, fewer than 18% of the  $\gamma$ -rays were affected by the steel wall.

The attenuation of the  $\gamma$ -rays by the steel wheel of the rotatable windmill system was also investigated. Two sources,  $^{60}\text{Co}$  (2.156 kBq) and  $^{152}\text{Eu}$  (1.249 kBq), were attached to the wheel separated by  $108^\circ$ . Measurements were taken with one source placed in front of the detector while the other was  $108^\circ$  away. The  $\gamma$ -ray energy spectra obtained are shown in Fig. 3.

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