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Offline 2, ISOLDE's target, laser and beams development facility

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ABSTRACT

Offline 2 is an entirely new research and development mass separator laboratory for the ISOLDE facility located on the Meyrin site of CERN. It closely resembles beam production (for non-radioactive beams) of the on-line (radioactive) systems at ISOLDE with machine versatility and flexibility at the core of its design. The beam optics and down stream beam preparation can deliver bunched beams or continuous beams of negative or positive ions with kinetic energies up to 60 keV. The mass resolving power of the separator operating with a typical ISOLDE ion source is $R \sim 500$. All of this is housed within a highly accessible 125 m^2 work area with multiple beam optics instruments to determine the beam quality, quantify modifications, develop new technologies and create alternate beam tunes, with the purpose of improving the beams and targets used during on-line operations.

1. Introduction

Nuclear physics has been a very productive field in recent decades and as the number of Radioactive Ion Beam (RIB) facilities has increased, so have the beam requirements [1]. Experiments are demanding higher quality beams with greater intensity, smaller transverse beam emittance and lower contaminants. Throughout this the Isotope Separator On-Line DEvice (commonly know as ISOLDE) located at CERN has continued to advance technologies in target and beam manipulation with use of new target designs to satisfy these needs. Many of the new targets and systems are in need of a dedicated testing platform to allow the development required to utilise their full potential. The FEBIAD ion source [2] and the Radio-Frequency Quadrupole cooler and buncher (RFQcb) [3] are just two of the many very promising emerging technologies that such a facility is necessary for. In the past many of the developments have come from an off-line testing station (Offline 1) and very basic tests with the on-line system, this invokes strong limitations on the development process. The lack of available time to test on-line at ISOLDE and the difficulties associated with the environment at the target area prevent serious on-line development. The limitations of the existing off-line separator (Offline 1), a basic target coupling table, Einzel lens and separator magnet setup, share little similarity to the on-line systems. Predominantly, Offline 1 is used for target production and beam composition characterisation, it is not an adequate development facility for thorough and precise studies of future ISOL technologies.

2. New facility

The new off-line ion beam separator facility, Offline 2, has been commissioned specifically for the purpose of testing and developing technologies directly applicable to ISOLDE and other RIB facilities. The facility has 125 m^2 of laboratory floor space with an ion beam line installed within a 40 m^2 Faraday cage (see Fig. 2).

The new facility (Figs. 1 and 2) has been designed with maximum versatility in mind. All the beam equipment has been positioned for ease of access and modifiable positioning with additional space for future equipment installations. Some of the key features of the Offline 2 facility are: The RFQcb (a clone of ISCOOL), the beam production (ion source) and handling that mimics the on-line systems without the radioactivity, the identical beam optical elements found on-line and identical ion beam energies used at ISOLDE.

3. Offline 2

Here the key aspects of the facility and the beam optics are discussed.

3.1. Front End (FE) ion source

The ion source is a standard ISOLDE target (which is interchangeable with any current ISOLDE targets) and is coupled to the Front End (FE).

The FE is the 8th target handling and beam preparation system for ISOLDE (see Fig. 3) and replicates the on-line beam optics and ion

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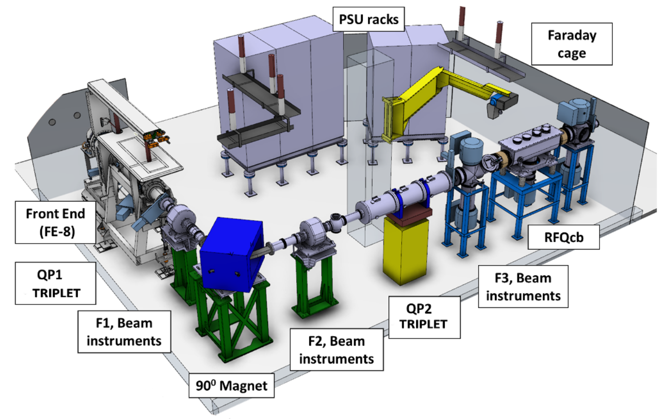

Fig. 1. The layout of the Offline 2 beam line imaged in the CATIA V5 design suite. The ion source is located on the Front End (FE-8) assembly along with the first quadrupole triplet (QP1). The Beam-Scanner and Faraday-Cup (SC & FC, labeled Beam instruments) boxes are located at selected points near or at focal points (F1 and F2) along the beam line for diagnostic purposes. The RFQcb is located after the second quadrupole triplet (QP2) at the end of the beam line, the last permanent piece of equipment on this beam line.

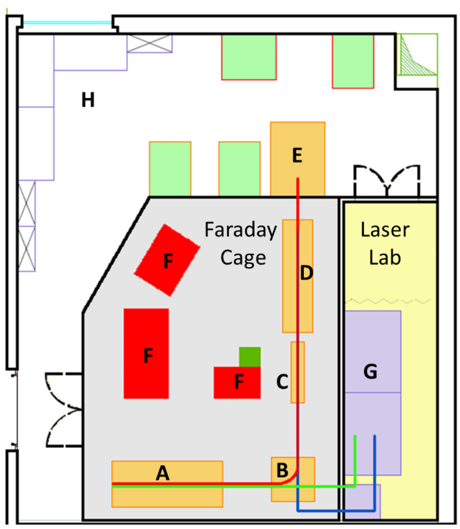

Fig. 2. The Offline 2 laboratory layout. A) Front End (FE-8), ion source and first QP triplet, B) Separator magnet, C) Second QP triplet, D) RFQcb and pumping sector, E) Non-permanent beam instrumentation, F) Floating power converters, G) Laser optics tables and H) control stations for operating beam line. The red line is the ion beam path, the green line is the laser path to target and the blue line shows laser paths to the RFQcb. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

production for stable isotopes. Atoms are generated from an evaporated material within the target chamber and diffuse out of the target through the transfer line, after which they are thermally ionised in the ion source. Alternative ion sources can be used (such as FEBIAD [2], LIST [4] or other plasma based ion sources [5]) and space for new designs is available. The transfer line and target are heated via resistive heating from independent power converters capable of providing 6 kW at high current loads (800 A). Mass markers (an isotopically pure sample of a given isotope) in tantalum tubes (ovens) are remotely controlled to independently inject atoms into the ion source in addition to a gas injection and mixing system. At the end of the target line (ion source aperture) a strong electrostatic field gradient, up to $\overline{E} = 9$ kV/cm, between the ions source (at 60 kV) and the grounded extendable

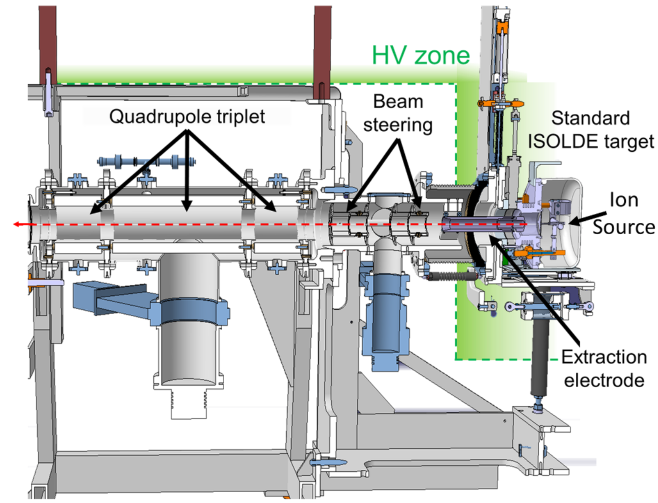

Fig. 3. Front End 8 (FE) CATIA generated image of a section plane of the beam path showing the layout of the optical instruments, beam steerers, extraction electrode and the first quadrupole triplet (QP1). The beam path is shown in red. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

extraction electrode exists to establish the ion acceleration region (see Fig. 3). After acceleration, the beam can be steered both horizontally and vertically to compensate for minor beam offsets in ion production, to re-centre the beam before the first quadrupole triplet and prevent unnecessary beam distortions.

3.2. Beam transport

The ion beam is produced and centralised to the reference axis along the first quadrupole triplet (QP1, see Fig. 4) and focused in the horizontal plane at a beam instrumentation box (FP1, see Fig. 4).

The first focal point in the horizontal plane (FP1) is before the magnet aperture and has beam instrumentation to determine the total beam current and the XY profile. The magnet is a 90° bending dipole magnet with a 374 mm bending radius and a maximum field of 1.2 T. A Hall sensor with a dedicated Siemens PLC controller maintains the field with a PID controller to compensate for hysteresis within the magnet. A second focal point (FP2) is situated after the magnet with an additional beam instrumentation box dedicated to provide information on the quality of the mass separation and will contain insertable slits to ‘cut’ the unwanted masses before entering the second quadrupole triplet (QP2). The second electrostatic quadrupole triplet, QP2, has additional field offset paired to the final quadrupole and gives beam steering capabilities into the RFQcb. The RFQcb alters the major beam properties, emittance in transverse and longitudinal planes, and beam energy spread. It effectively ‘resets’ the beam into a virtual ion source after RFQcb extraction.

The beam transport properties up to the RFQcb injection aperture have been computed with COSY infinity V9.0 software [6] for various beam energies and types. This was combined with the spatial restrictions of the room to give the optimum drift lengths (DL) between the beam line elements. The solutions of the 5th order transport matrix, *M*, were extracted from COSY. From *M* the acceptance and the neighbouring mass contaminants were calculated at the RFQcb aperture using Monte-Carlo techniques.

A 30 keV ion source with $\varepsilon_{rms} = 15\,\pi$ mm mrad emittance has been computed and shown in Fig. 5. The acceptance of the beam into the RFQcb is 86.6% for mass $m_0 = 100$ AMU and contaminated with 0.8% from $m_{\pm 1}$ for 4 mm slits. It is possible to improve the matching up to 95.6% but at the expense of neighboring mass contaminants. The

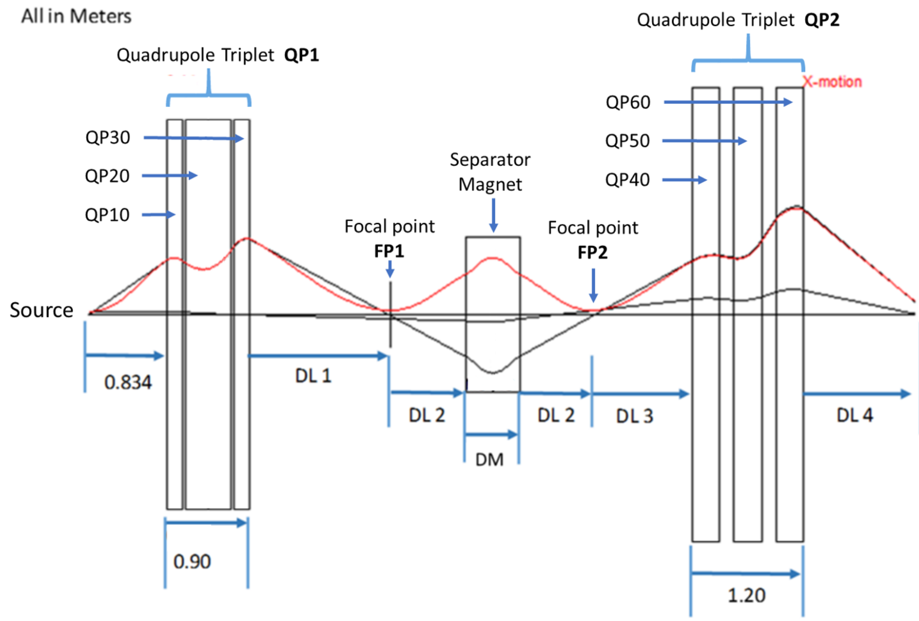

Fig. 4. The optical path of the horizontal beam profile from the COSY infinity beam optics software with key components labeled. The black lines show ray traces and the red the beam envelope. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).

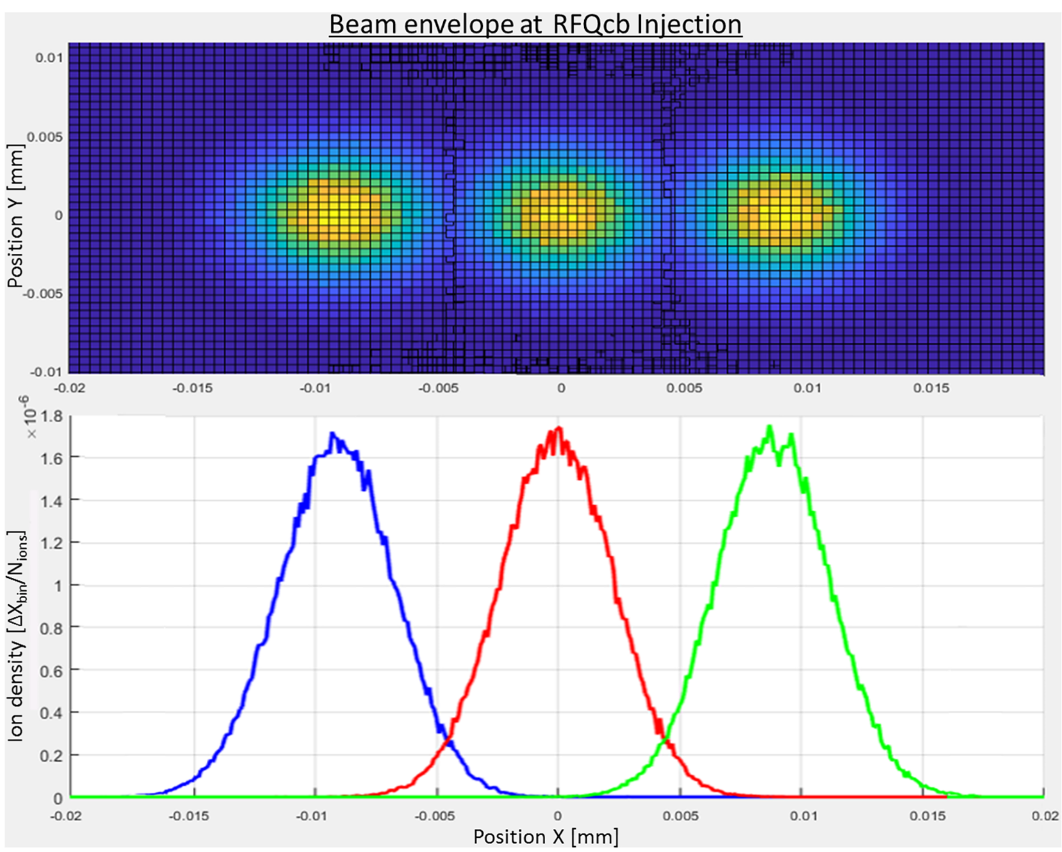

Fig. 5. The beam envelope at injection to the RFQcb post transport and mass separation for a beam with emittance $\varepsilon_{rms} = 15\,\pi$ mm mrad. The density of ions in the x-axis provides the mass distributions with the central line (red) of mass $m_0 = 100$ AMU and the adjacent lines (blue and green) having masses m_{-1} and m_{+1} respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

computed mass resolving power for the Offline 2 separator, $R = \frac{(X\,|\,\delta m)}{2x_{00}(X\,|\,X) + \Delta}$ is ~ 500, where $(X|\delta m)$ is the mass dispersion term, x_{00} is half the initial beam width (FWHM), $(X|X)$ is the magnification and Δ is the width increase due to aberrations [7].

3.3. RFQcb

The RFQcb at Offline 2 is a replica of the ISolde COOLer (ISCOOL) RFQcb on the HRS line of ISOLDE [8]. The RFQcb improves the beam quality downstream by reducing both beam energy spread ($\Delta E < 1$ eV) and transverse emittance ($\varepsilon_{90\%} < 3\,\pi$ mm mrad, for 90% of the total beam) and also converts a DC ion beam into pulsed beams with repetition rate of 1 kHz for up to 10^8 ions per bunch [3,8]. Whilst it is not identical, it can replicate the conditions of ISCOOL (operational pressures, AC and DC potentials and beam energy). However, the RFQcb at Offline 2 has been designed with the following extra features.

- Buffer gas pressure: On-line operation is restricted by the pumping capacity of the upstream and down stream equipment. Offline 2 has double the pumping capacity and greater dynamic range of operational pressures.
- Radio frequency: The RF system has 10 times more power and an extra 2 decades of frequency range. It is capable of generating an arbitrary waveform with linear response over 0.1 to 10 MHz with peak amplitude of 1 kV.
- DC offsets: The RFQcb platform potential offsets are identical to ISCOOL. This allows for the same beam energies (60 keV) with upgraded controls to a LabVIEW PXI systems for the axial electrodes and RF controls. This gives the potential for considerably more exotic tunes using the LabVIEW interface (e.g. traveling wave axial off-sets, ramping RF cycles, etc.).

Development and study of this device will dramatically improve the quality of beam delivered at ISOLDE and help towards the understanding of ion behaviour during collisional cooling.

3.4. Laser laboratory

A dedicated laser room is situated adjacent to the Offline 2 Faraday cage (see Fig. 2). The laser room will contain two industrial Nd:YAG laser systems; a Photonics Industries DM60-532 (60 W, 200 ns) and an Edgewave INNOSLAB (60 W, 8 ns). Both will operate with a repetition rate of 10 kHz and with a wavelength of 532 nm. The DM60-532 will be used to pump two Z-cavity Ti:Sa lasers capable of producing up to 2.5 W of fundamental light between 700 and 940 nm. The INNOSLAB will be used to pump a Sirah Credo dye laser (up to 3 W fundamental output between 550 and 700 nm) and/or for non-resonant ionization of excited atoms in the hot-cavity ion source, where the spectral range of these tuneable lasers can be extended using non-linear crystals (BBO and BiBO). The light produced from these systems can be sent down the two optical paths, to the hot-cavity ion source for ionization scheme development or into the RFQcb for optical pumping and molecular breakup tests.

4. Commissioning

Commissioning of the facility started in Jan 2018 and will continue until mid 2019 as each section of the beam line is completed and fully characterized. The Front End commissioning has been completed along with the magnet sector marking a large milestone in the project. The RFQcb sector is expected to be completed in the beginning of 2019 along with the laser system, final commissioning is expected mid 2019. This will mark the start of an unprecedented target, RFQcb, laser schemes and beam manipulations development campaign finally allowing the study of: longitudinal emittance of the cooler (trade-off between low-energy spread, space charge, and pulse width), laser excitation of trapped ions, exotic ion sources, exotic laser schemes and new alternative target testing. These are just a few of the high impact investigations planned with the new Offline 2 testing facility at ISOLDE.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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