An innovative Superconducting Recoil Separator for HIE-ISOLDE

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Abstract

The ISOLDE Scientific Infrastructure at CERN offers a unique range of post-accelerated radioactive beams. The scientific program can be improved with the "Isolde Superconducting Recoil Separator" (ISRS) an innovative spectrometer able to deliver unprecedent (A, Z) resolution. In this paper we present an overview of the physics and ongoing technical developments.

1. The ISRS recoil separator

The HIE-ISOLDE facility at CERN can accelerate more than 1000 isotopes of about 70 elements at collision energies up to ~ 10 MeV/A, making an ideal testbench to probe nuclear theories by selecting optimum (N, Z) combinations. The ISRS collaboration has recently proposed the construction of a novel high-resolution recoil separator, the "ISOLDE Superconducting Recoil Separator" (ISRS) [2]. The aim is to extend the physics programme [1] to more exotic isotopes produced in the secondary target by combining focal plane spectroscopy with particle and photon detection using HIE-ISOLDE detectors [3- 7].

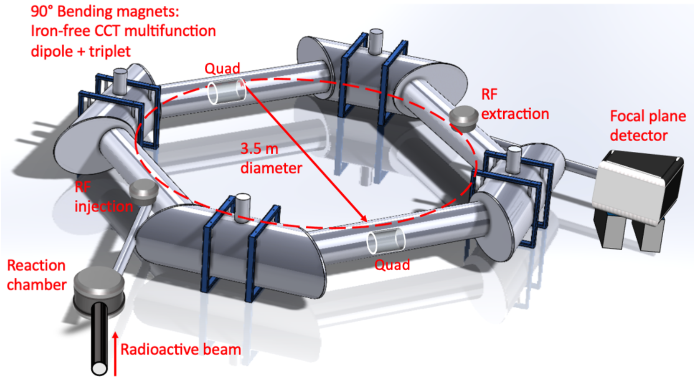

Figure 1. A conceptual design of the ISRS ring showing the main subsystems.

Transfer reactions in inverse kinematics exhibit very high cross sections at HIE-ISOLDE beam energies. Fragment angular distributions are very sensitive to the details of the nuclear wave-functions, such as energies, angular momentums, and spectroscopic factors. They can be used for example to study the evolution of nuclear structure and reactions relevant for nucleosynthesis around closed shells $N \approx 82$ and $N \approx 126$ [8,9]. Multinucleon transfer processes via deep inelastic, quasi-elastic and quasi-fission reactions [10-12] can produce many exotic nuclei in the energy levels of interest, including the drip line 78Ni and closed-shell region N=126 [13] which are crucial for studying shell-quenching and r-process. Charge-exchange reactions allows to investigate the dynamics of spin and isospin excitations, the structure of particle-hole states and the scalar and isovector components of nuclear matrix elements relevant for nuclear beta decay, thus connecting strong and weak interactions [14, 15]. Fusion-evaporation reactions can produce very exotic residues [16] for which the ISRS spectrometer brings the opportunity of performing lifetime measurements with plungers [17]. Direct or inverse kinematics with light or heavy targets will be used, and therefore spectrometer should be able to rotate to cover from zero to the typical heavy-ion grazing angles (~ 50 - 70 degrees). Some ISRS requirements are: Energy range: $4 \leqslant E/A \leqslant 10$ MeV; Angular acceptance (> 15 degrees, > 100 msr); Energy resolution < 100 keV; Time resolution < 100 ns; Angular resolution < 0.1 degrees; $\Delta Q/Q < 1/70$ (FWHM); $\Delta M/M < 1/250$ (FWHM) $\Delta Z/Z < 1/60$ (FWHM).

2. ISRS design studies

State-of-the-art spectrometers [18-21] are linear arrays of magnets with performance limited by the length of drifts and dispersive planes. Spectrometer operation suffers also from iron nonlinearities, hysteresis, remnant magnetization and ohmic losses (cooper wiring), which demands efficient cooling systems. Precision rotation of such structure to accommodate experiment requirements requires complex mechanical systems due to the relatively high weight. The design of the ISRS spectrometer follows a different conceptual approach, see Fig. 1. Instead of using dispersive planes, particle separation is obtained by injecting the reaction fragments into a particle storage system composed by an array of iron- free superconducting multifunction magnets (SCMF) cooled by cryocoolers, integrated into a compact storage mini-ring using Fixed Field Alternating Gradient focussing (FFAG). In a recent paper [22] we have studied a very compact configuration having only 1.5 m diameter and relatively low magnetic field (< 5 T), can recirculate with 100% efficiency a cocktail of radium isotopes at 10 MeV/u and 20% momentum spread, and fully separate single unit masses.

The layout of ISRS is shown in Fig. 1. When the radioactive beam hits the reaction target reaction recoils and transmitted primary beam are injected into the spectrometer. After recirculating for a few microseconds, neighbouring masses are separated by its cyclotron frequency and selected using a suitable RF system synchronized to the duty cycle. When operating in the isochronous mode, the time-of-flight is a direct measurement of the M/Q ratio. The ring features a ~ 3.5 m diameter, four SCMF iron-free 90-degree Cosine Canted Coil (CCT) [23] bending magnets of 1 m radius, which include dipole and triplet focusing quadrupoles, two additional quadrupoles in the straight sections to complete the FFAG cell, an injection/extraction system inspired in the SuShi magnet system developed for the HiLumi project [24], and a focal plane detector. The complete assembly is presently being under studied to maximise transmission efficiency and mass resolution.

The FFAG optical lattice allows efficient recirculation of an ion beam with large energy and momentum spread, whereas the CCT SCMF coils reduce aperture and radius of the ring leading to a very compact configuration. The suppression of the iron joke eliminates iron non-linearities and hysteresis and reduces magnet weight. In comparison to a standard spectrometer with comparable resolving power and efficiency, the ISRS will be an order of magnitude smaller, three orders of magnitude lighter, and small energy losses down to a few watts per meter. The reduced thermal mass opens the possibility to use cryocoolers instead of the liquid Helium bath. Avoiding the need of complex LHe system, simplifying the mechanical structure needed for rotation as well. The results of beam dynamics calculations for this layout are shown in Fig. 2 (Left panel) for an isochronous optics solution.

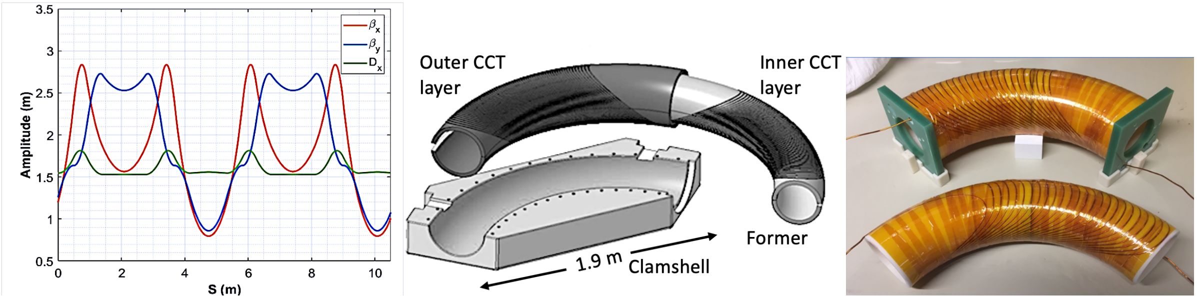

Figure 2. Left: Betatron functions. Centre: FUSILLO assembly. Right: pulsed-resistive models of the CCT coils.

The collaboration is developing a prototype of a 90° bending magnet (MAGDEM) composed of a CCT solenoid (FUSILLO) with a pure dipole central field of 3.5 T, and a dedicated cryostat (PENTOLA). First reduced scale pulsed-resistive models have been developed and tested with current pulses at CERN, and the magnetic measuring system to produce the field maps. The study of the low frequency multi-harmonic buncher system has started (Fig. 3) based on the previous work of the HIE-ISOLDE buncher [23].

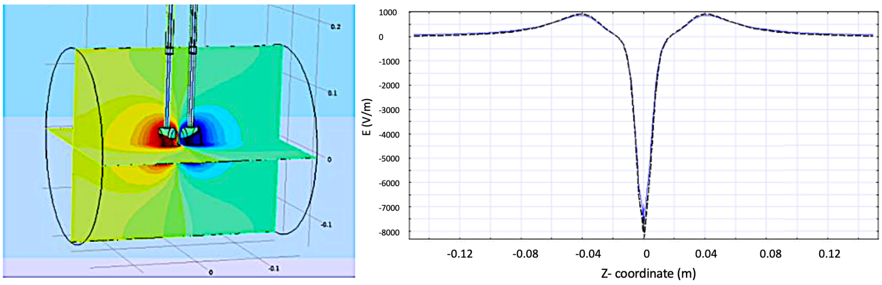

Figure 3. Left: Electromagnetic 3D model of the MHB. Right: Field profile along the beam axis (right).

3. Summary and conclusions

The R&D program for the design of the Isolde Superconducting Recoil Separator is under development. Major advances include the beam dynamics and the design study of a curved multifunction coil with nested trim coils. First resistive models of CCT coils have been successfully developed and tested. Studies of the cryostats and the multi-harmonic buncher are ongoing.

Acknowledgements

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