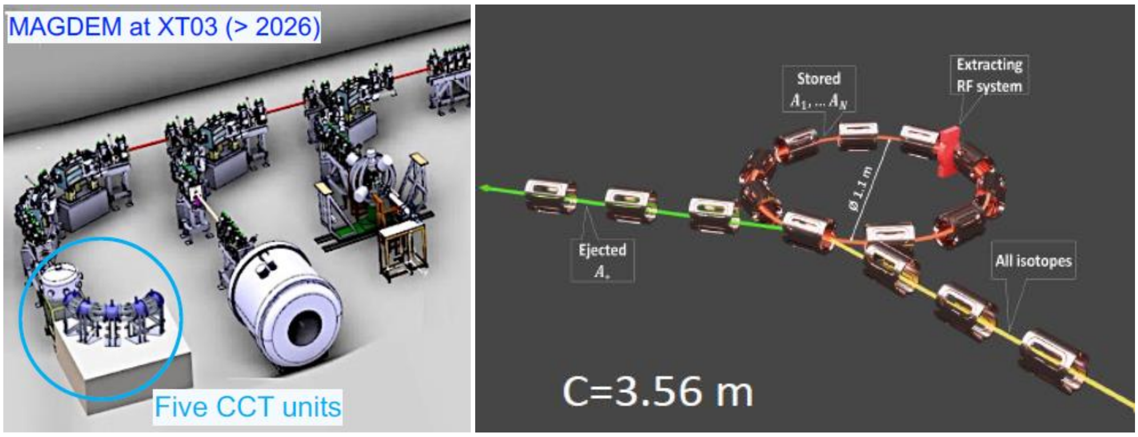
PHD THESIS IEM-CSIC-IN2P3-CNRS:

Study of high-order harmonics and development of a cryostat for the MAGDEM prototype of the CERN ISOLDE Recoil Separator

Context

The ISOLDE experiment at CERN aims to study the structure and dynamics of radioactive nuclei and their applications. The high-energy scientific program developed with the HIE-ISOLDE post-accelerator requires a high-resolution equipment to analyze the reaction fragments. The Spectrometer described in the Letter of Intent LoI-INTC-I-228 aiming to developing a detailed design study of the so-called “ISOLDE Superconducting Recoil Separator” (ISRS) was approved in 2021 by the ISOLDE and Neutron Time-of-Flight Experiments Committee (INTC) of CERN.

ISRS consists of a storage ring that enables fragment mass identification using Fixed Field Alternating Gradient (FFAG) beam dynamics and multi-function superconducting solenoids that deflect the beam without an iron core. The solenoids are of the CCT (Canted Cosine Theta) type, whose winding is inclined with respect to the axis of circulation of the beam and generates the multipole components of the magnetic field necessary to optimize the transport of the beam. The solenoids are installed in cryostats adapted to the circulation of the ion beam. Analysis of the reaction fragments is performed by coupling the storage ring to a multi-harmonic ion packer (buncher) and a focal plane that identifies the energy and charge of the reaction fragments.



Left: MAGDEM prototype consisting into five units, covering half of ISRS ring. Right ISRS rings consisting of 10 units and 1.1m of diameter.

As compared to present state-of-the-art particle storage systems, ISRS project allows for a drastic reduction in size, weight, and complexity, as well as a reduction in energy consumption and overall environmental impact. The design concept consists of the combination of Fixed-Field Alternating Gradient optics (FFAG) and Superconducting (SC) Multifunction magnets (SCMFM) into a small storage ring. In the FFAG-SCMRs spectrometer, selected fragments can be separated by an RF system and ToF using their characteristic cyclotron frequency. With only 1.1 m diameter and 10 units of 20 cm length low-field SCMFMs (< 5 T) the spectrometer will be able to recirculate with 100% efficiency a cocktail of radium isotopes of 10 MeV/u kinetic energy and 20% momentum spread and to fully separate single unit masses as studied in our previous works.

In SCMF magnets, multipolar fields are produced by superimposing the corresponding SC coils (dipole, quadrupole, hexapole, etc.) in the same coil in a nested configuration, leading to very compact devices. The use of SC magnets avoids energy losses of equivalent conventional warm magnets down to a few watts, reaching 30 times higher fields with 10 times smaller size and 1000 times reduced weight.

This Ph.D. Thesis will be part of the ISRS Spanish project that foresees the construction of the MAGDEM demonstrator, a technological prototype composed of an iron-free multi-function CCT magnet and cryostat.

In order to test MAGDEM, a test bench will be implemented in Madrid that includes a set of quadrupole magnets to focus the beam into a reaction chamber where solid and jet-type targets will be implanted. The beams will be focused into spots of 1cm as well as millimetric and sub-millimetric sizes. The Ph.D. candidate will work on the implantation of a **cryogenic jet target** devoted for the sub-millimetric beams.

Full ion optical studies including the influence on the multipolar fields should be studied by the Ph.D. Candidate. **The complete beam dynamics simulation of the beam through MAGDEM making use of the 3D magnetic fields** are also foreseen during this Ph.D. Thesis.

The second part of the PhD thesis will consist in the design of the **cryostat** unit to house and thermally insulate the superconducting FUSILLO prototype, a 90° CCT solenoid with dipole function being built at CERN while providing interfaces for ion-beam circulation with reliable and safe operation.

Two methods of cooling using cryocoolers will be evaluated, the first consists of cooling by conduction, the second uses liquid helium. The cooling by conduction is compact and economical and could be well suited for iron-free CCT magnets operating at temperatures close to 4K, but special attention must be focused on the use of the cooling power available in the two stages (40K, 4K) of the cryocoolers in order to reduce the coils cooling time as much as possible. The main interest of this approach is to **eliminate the need for liquid helium and all the associated safety and maintenance constraints**. The second cooling method is to use **liquid helium as a cooling fluid and use cryocoolers to produce the required cryogenic power**, this solution has the advantage of providing homogeneous cooling of the coils with low thermal gradients. For both cooling methods, one of critical aspect is the available cryogenic power at nominal temperature, and the technical feasibility of the equipment to allow the cooling and the operation of the magnet. **These two options will be investigated during this PhD. Thesis.**

Research program

Main research axes are described below:

• Complete beam dynamics simulation using 3D field maps and study of the influence of high-order harmonics on the ion optics.

- ✓ Commissioning of the cryogenic jet target by using silicon detectors and the available gases to produce a proof-target.
- ✓ Performing of the differential vacuum system and the jet vacuum system using turbo pumps, roots pumps and scroll pumps.

• Design definition of a cryostat for FUSILO using cryocoolers considering two options, cooling by conduction, and liquid helium.

Profile of candidates

Master or equivalent (Engineer) requested with good knowledge on physics and fluid mechanics. As cryogenics is key, experience in experimental methods/techniques on this field will be appreciated. The candidate should also be able to work in a very multi-functional and international team (Current exchanges in English. Spanish and/or French will be appreciated).

General information

- **Field:** Physics of Accelerators, Fluid Mechanics and Cryogenics.
- **Location:** Location at Instituto de Estructura de la Materia, CSIC, Madrid Spain & APC-CNRS-IN2P3, Paris France).
- **Duration:** 3 years
- **Salary:** CSIC Madrid first 18 months and CNRS-IN2P3APC Paris last 18 months

Supervisors

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- **APC-CNRS-IN2P3:** Jean-Pierre Thermeau thermeau@apc.in2p3.fr

To apply

- **Interested candidates should apply by sending the following papers to the aforementioned supervisors:**
  - your most recent CV
  - academic reports for the last 3 years