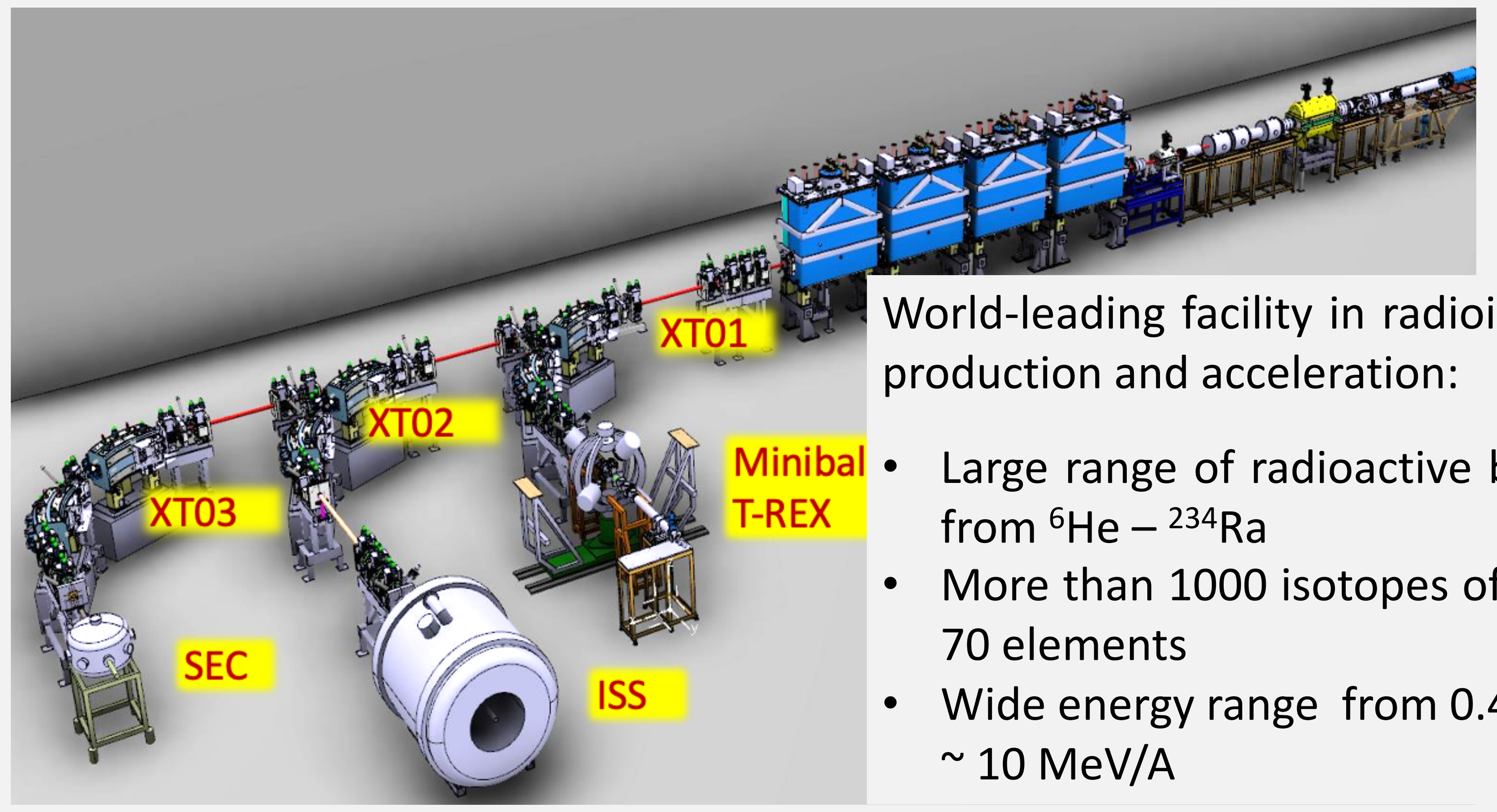
Recent developments in the design of the HIE-ISOLDE Superconducting Recoil Separator (ISRS)

I. Martel[1], G. Kirby[2], V. Rodin[3,4], O. Kirby[2], A. Foussat[2], J. Resta-López[5] for the ISRS Collaboration

[1]Univ. Huelva, Spain. [2]CERN, Geneva, Switzerland. [3]Univ. Liverpool, United Kingdom. [4]Cockcroft Institute, United Kingdom. [5]Univ. Valencia, Spain.

The HIE-ISOLDE facility at CERN



World-leading facility in radioisotope production and acceleration:

- Large range of radioactive beams: from ^{6}He – ^{234}Ra
- More than 1000 isotopes of about 70 elements
- Wide energy range from 0.45 to ~ 10 MeV/A

The HIE-ISOLDE Superconducting Recoil Separator (ISRS)

Measurement of reaction fragments for a range of radioactive beams ^{6}He – ^{234}Ra up to about 10 MeV/u. **R&D program** to study the design of a compact recoil separator using **innovative** concepts and technologies:

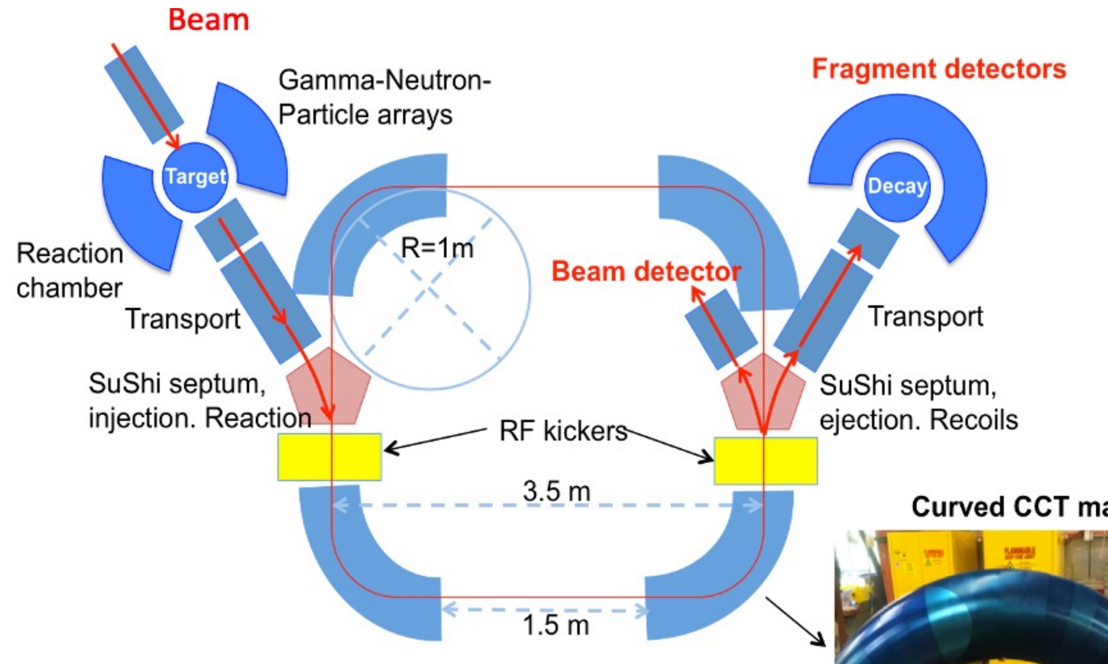
(1) Mini-Storage ring
(2) CCT-Multifunction Superconducting solenoids
(3) FFAG
(4) Iron free magnets
(5) cryocooling

- Unprecedent mass resolution, angular and momentum acceptance.
- Technological breakthrough for the construction of future spectrometers,
- R&D phase endorsed by the ISOLDE & NTOF Committee (CERN) -INTC66.

(I. Martel et al., LoI INTC-I-228, 2020)

Conceptual layout of the separator

The ring consists of curved CCT magnets, straight sections, injection/extraction systems and beam diagnostics.

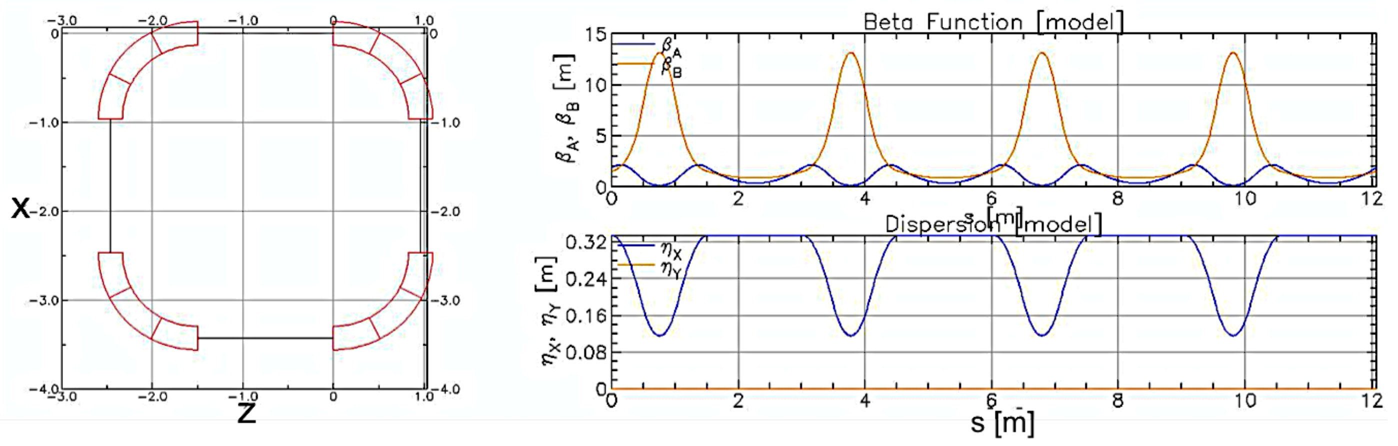


Ring diameter: 3.5 m.

A prototype of an assembled curved CCT magnet (NIM A (2020) 163414)

Beam dynamics

The ring will operate as an isochronous non-scaling fixed-field alternating-gradient (FFAG) system based on Canted-Cosine-Theta (CCT) magnets Preliminary FFAG optics calculations predict large solid angles > 100 msr and momentum acceptances $\Delta p/p$ > 20% from ^{11}Li to ^{234}Ra @ 10 MeV/u, mass resolution better than 1/2000. Storage efficiency ~ 100%.

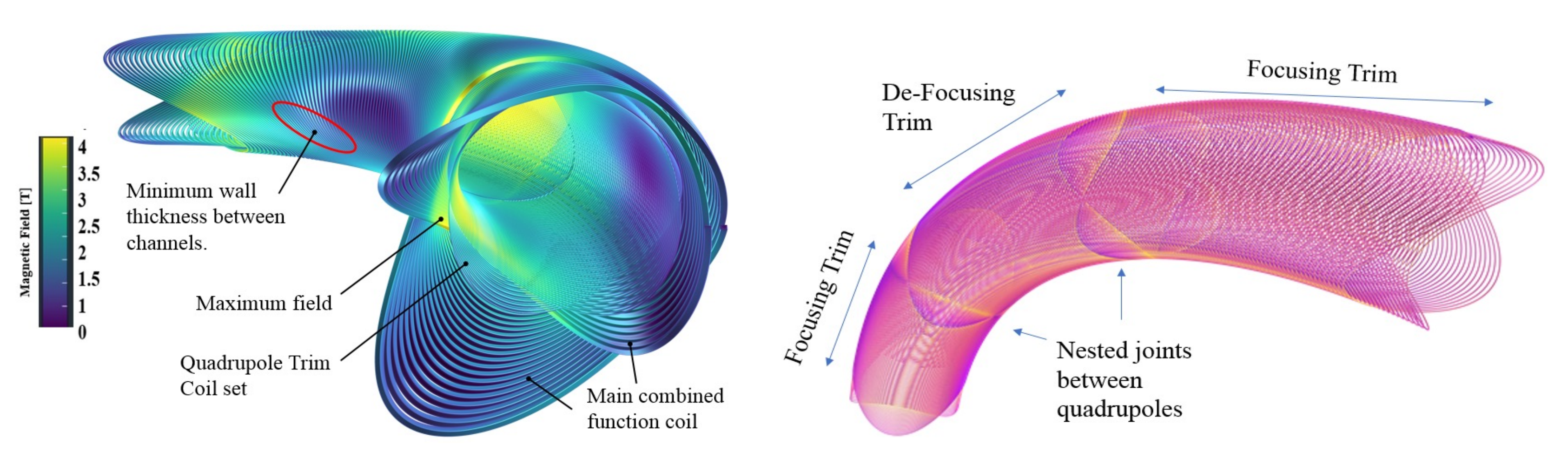


Footprint of the optics, betatron functions and first order dispersion for a FDF optics configuration (C. Bonotiu et al., NIM A 969 (2020)164048).

Technological challenges involved

1. Beam dynamics: FFAG optimisation for ring configuration and operation.
2. Multifunction SC magnets, with **straight** and **curved configurations,** iron free option.
3. SC magnet test bench for the above configurations.
4. In-ring beam diagnostic systems.
5. Injection/extraction system.
6. Multi-harmonic buncher system (MHB).
7. Re-buncher system (RBS).
8. Focal plane detectors and particle trajectory reconstruction.
9. Detailed study of the charge breeder operation (EBIS, ISOLDE case).
10. Cryocoolers vs LHe cooling.

Superconducting Curved Canted-Cosine-Theta (CCT)



The multifunction CCT magnets have two alternating-gradient quadrupoles nested inside an outer dipole. Orbit stability is achieved for dipole maximum fields of 2.2 T and quadrupole gradients of 14 T/m for heavy ions @ 10 MeV/u. *(G. Kirby et al., MT25, 2021)*

Magnet specifications

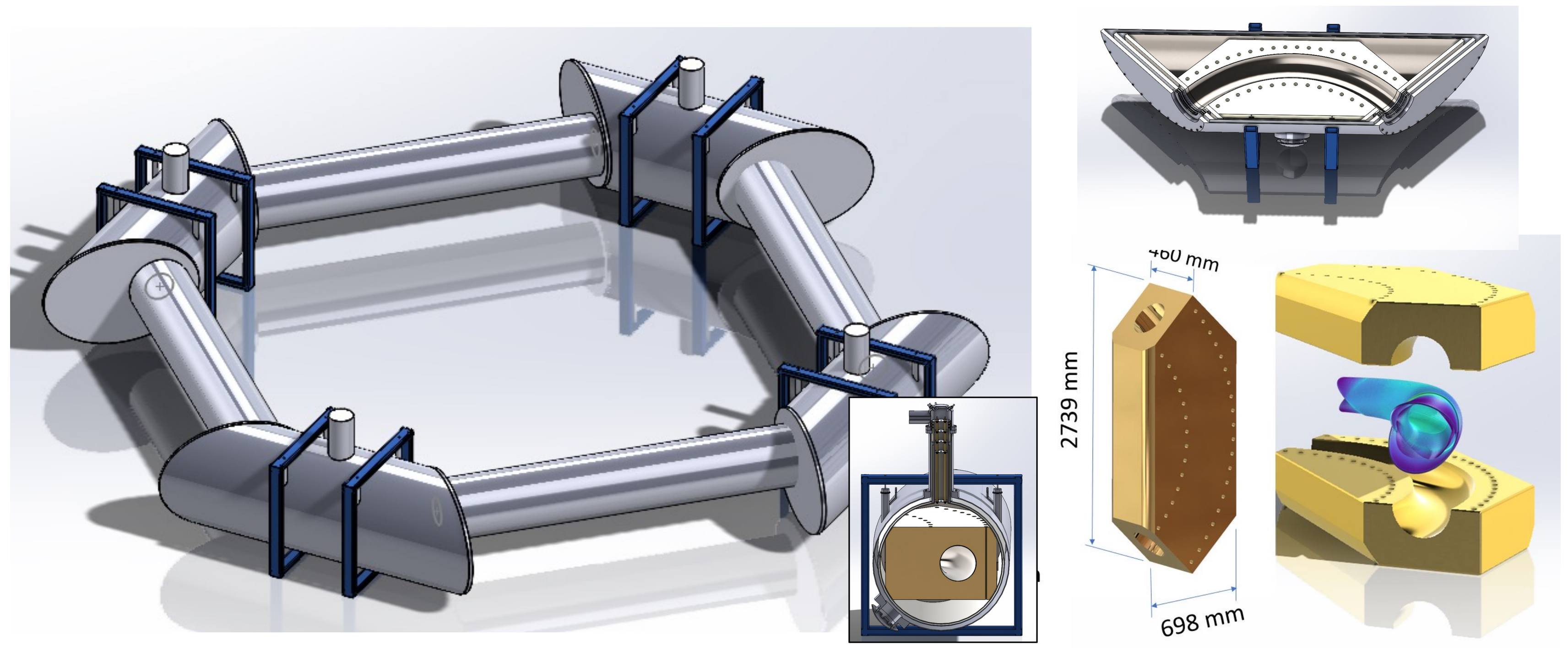
Magnet aperture	200 mm
Curvature radius	1000 mm
Magnetic Bend	90 deg
Total Matix Inductance	3322.4 mH
Total Energy	228.065 kJ
Superconductor	
Bare Strand Diameter	0.825 mm
Insulated Polyimed Strand Diameter	1 mm
Superconducting material	Nb-Ti
Cu:Su ratio	1.9 to 1.2:1
RRR	> 100 to 250
Total wire length: Main CF + Trims Q's	11.64 km *
Main Magnet Combined function coil	
Dipole field aperture	2.2 Tesla
Qaudrupole field	15 T/m
Noninal Current	365 A
Max field with all coils powered (max in magnet)	4.127 T
Max field with just Main coil powered	4.006 T
Short Sample at Nominal currents in all coils	73.3 %
Number of wires in channel	20

Main Magnet Combined function coil (Cont.)		
Number of layers/formers		2
Channel turns in formers		108
Coil Conductor lengh		10.25 km
Main Coil Inductance		3307.112 mH
Total number of joints in coil		19
Trim Quadrupole Coils	**Center Coil**	**End Coils**
Max Quadrupole Gradient	2.29	± 2.27 T/m
Noninal Current	(±) -300	(±) + 300 A
Max field with all coils powered	4.086	3.738 T
Short sample at Nominal Currents 4.5K	73	71.4 %
Number of wires in channel	2	2
Number of layers	2	2
Channel turns in formers	81	69
Magnetic Bend	33.1	28.2 Deg
Coil Conductor lengh	514.7	775.1 m
Coil Inductance	9.06	7.68 mH
Total number of joints in coil	5	5

* Coil is still subject to fine tuning so lenth may vary

Mechanical integration

Mechanical study of curved magnet cryostat and integration into a ring: LHe vessel, gas cooled radiation shields. Separate beam and cryostat vacuum.



Summary and conclusions

The R&D program for the design study of the Isolde Superconducting Recoil Separator is rapidly developing. Major advances include the beam dynamics and the design study of a curved multifunction coil with nested trim coils according to the specifications. First studies of cryostating and mechanical integration concepts into a compact storage ring have been carried out.

Acknowledgements

Work partially supported by the Grant PGC2018-095640-B-I00 (2018-21) of the Spanish Ministry of Science and Innovation.