Design and Beam Dynamics Studies of a Novel Compact Recoil Separator Ring for Nuclear Research with Radioactive Beams

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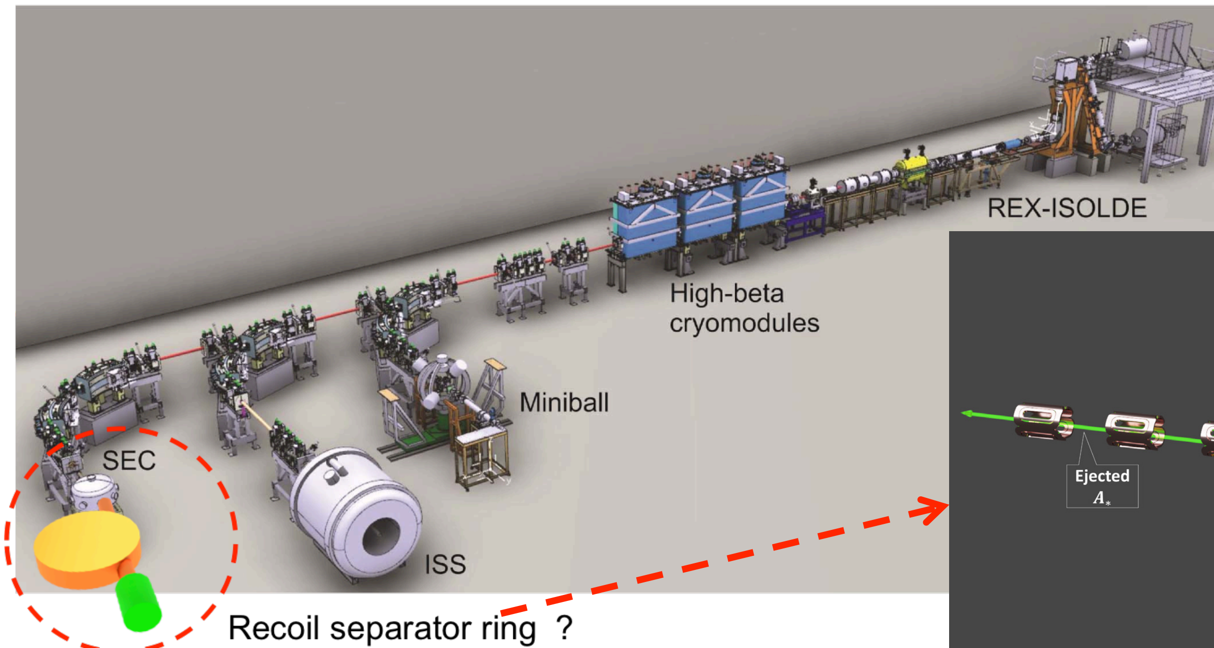
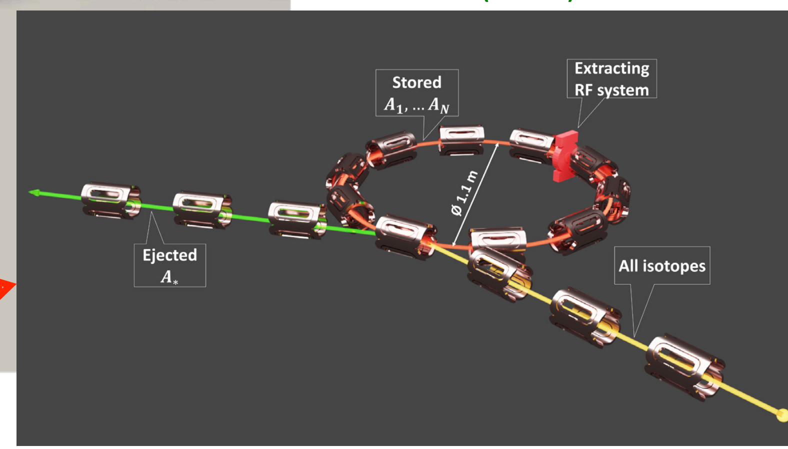
Introduction

The HIE-ISOLDE facility at CERN

- Very large range of radioactive beams from ^{6}He – ^{234}Ra
- 1000 isotopes, > 70 elements
- Wide energy range 0.45 – 10 MeV/u   (depending on A/Q)



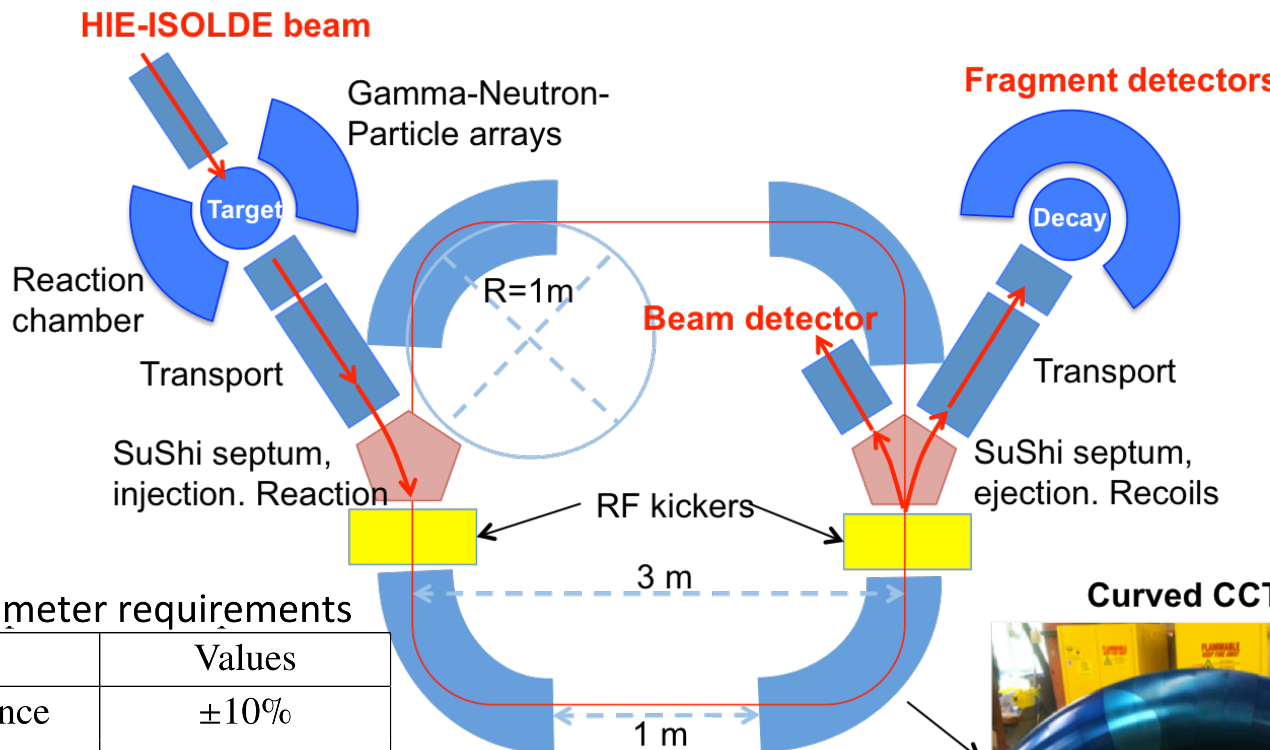
Very preliminary design:
C. Bontoiu, et al.,
NIMA **969** (2020) 164048



A compact recoil separator can bring new and exciting possibilities to the HIE-ISOLDE physics program

The ISOLDE Superconducting Recoil Separator (ISRS) – new initiative since 2019

ISRS conceptual design



Curved CCT magnet

Minimum spectrometer requirements

Parameters	Values
Momentum acceptance	±10%
Resolving power $p/\Delta p$	2000
Angular acceptance	±10°
Angular resolution	0.1°
Solid angle	100 msr
Charge resolution $\Delta Q/Q$	1/70 (FWHM)
Mass resolution $\Delta M/M$	1/250 (FWHM)
Rotation	0 – 70°

- 4 Curved Canted-Cosine-Theta (CCT) magnets

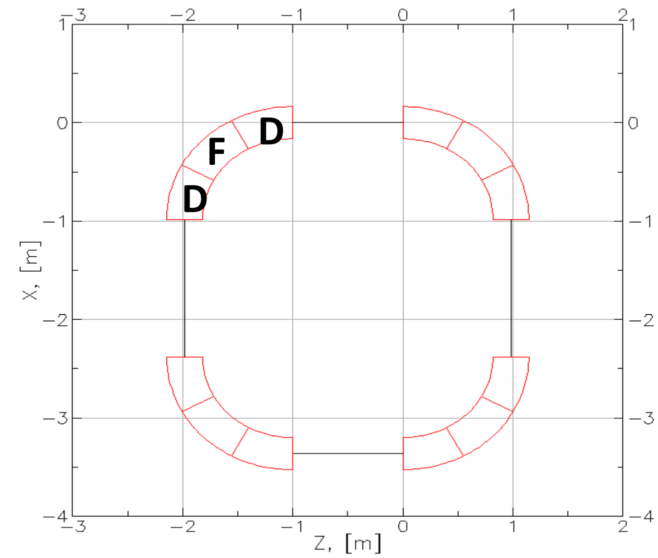
Optics layout

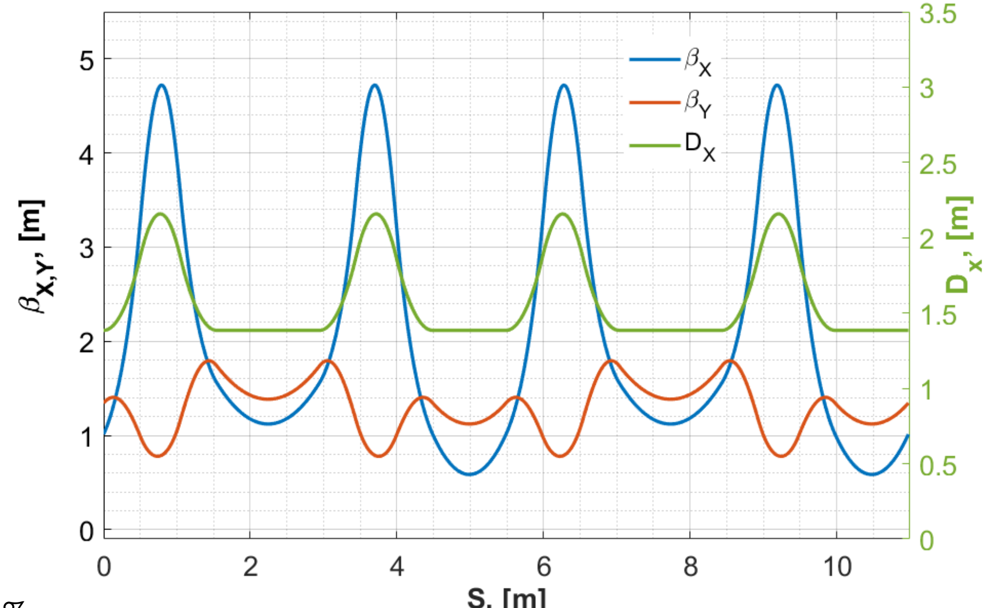
- DFD optics for non-scaling FFAG
- Lattice with sbend magnets

Isochronous mode: $\gamma \approx \gamma_t$

Beam	^{234}Ra
Kinetic energy	10 MeV/u
Rigidity, $B\rho$ [T m]	2
Maximum beta functions, $\beta_{x,y}$ [m]	4.8, 1.8
Maximum dispersion, D_x [m]	2.1
F magnet	
Effective length [m]	0.55
Dipole field [T]	2.11
Quadrupole gradient [T/m]	6.046
D magnet	
Effective length [m]	0.497
Dipole field [T]	2.0
Quadrupole gradient [T/m]	-6.046

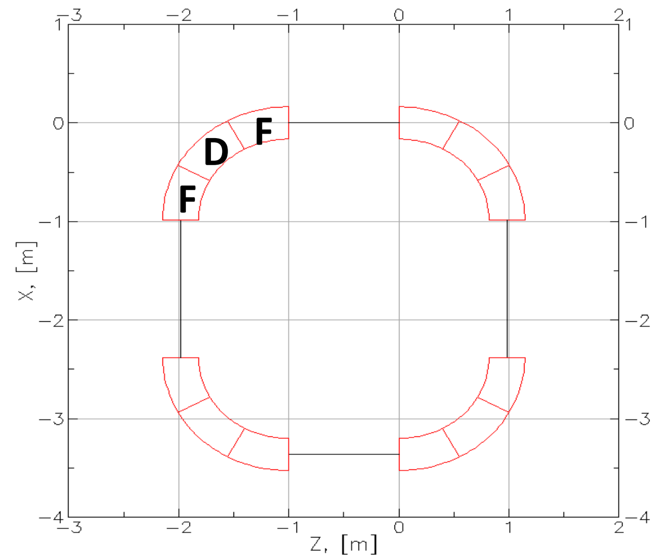
Expected max. momentum acceptance: $\Delta p/p = +/-5$ %





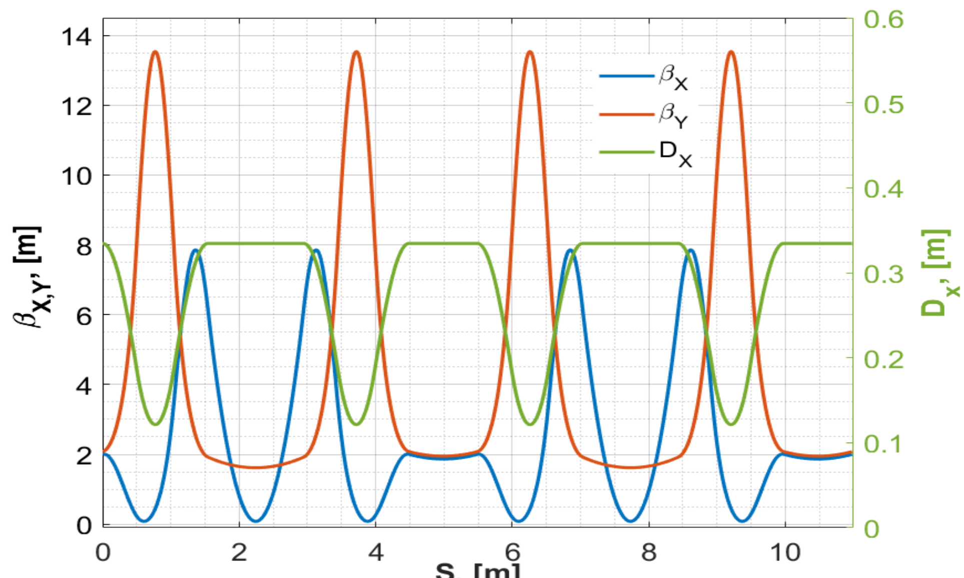
Optics layout

- FDF optics for non-scaling FFAG
- Lattice with sbend magnets



High momentum acceptance mode

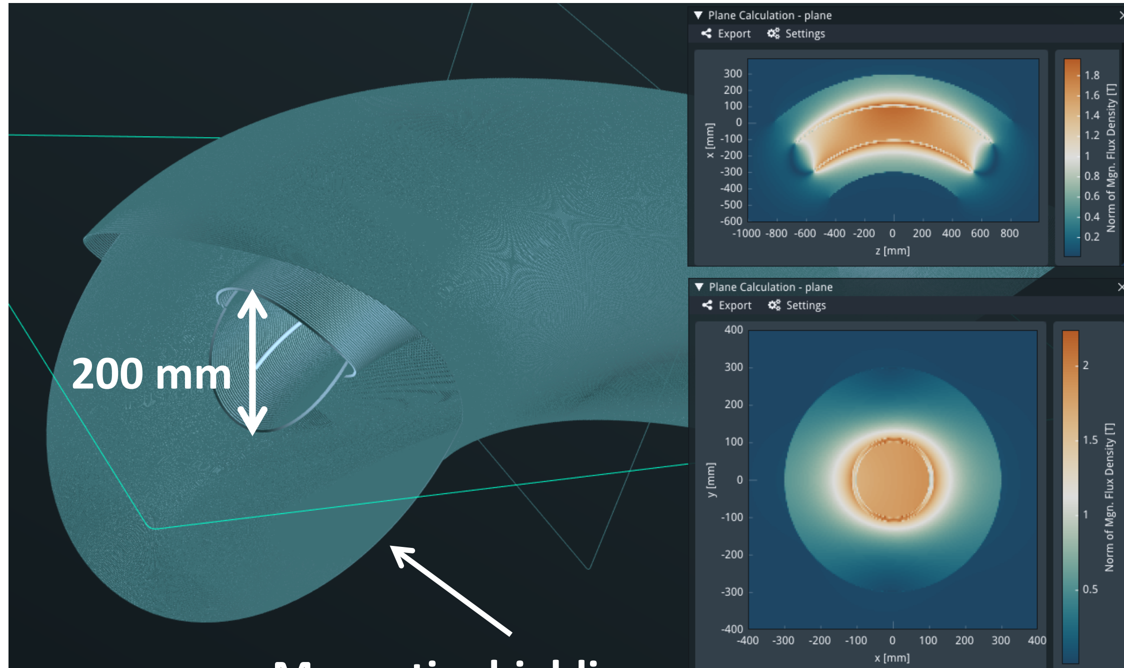
Beam	^{234}Ra
Kinetic energy	10 MeV/u
Rigidity, $B\rho$ [T m]	2
Maximum beta functions, $\beta_{x,y}$ [m]	7.8, 13.5
Maximum dispersion, D_x [m]	0.32
F magnet	
Effective length [m]	0.497
Dipole field [T]	2.0
Quadrupole gradient [T/m]	12.3
D magnet	
Effective length [m]	0.55
Dipole field [T]	2.11
Quadrupole gradient [T/m]	-13.1

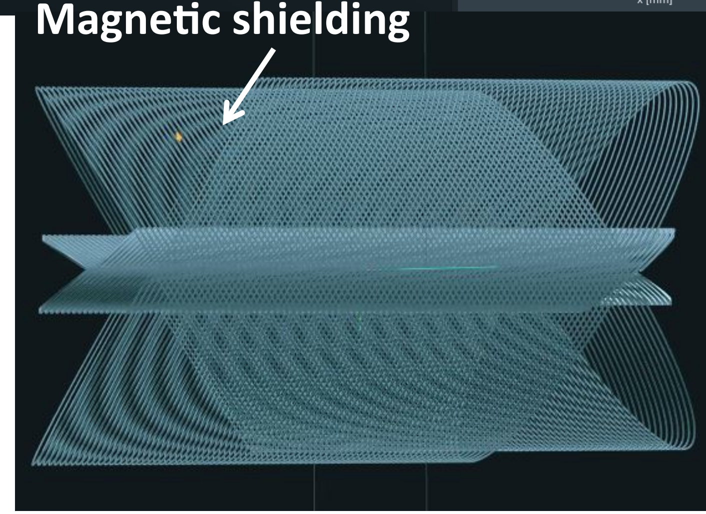


Expected max. momentum acceptance: $\Delta p/p$=+/-31.25 %

Magnets

- **Bent CCT nested dipole and quad. magnet**
- Synergy with CCT magnets for gantries
- 200 mm beam aperture
- Curvature of 1 m
- 90 deg. bend
- Two layer coil has both 2.2 T dipole and 13 T/m (maximum) quad. in a single conductor pack
- The quad. consists of three sections rotated by +/- 45 deg. to make a FDF (DFD) triplet focusing/defocusing configuration
- Stray field shield that replaces the classic iron yoke





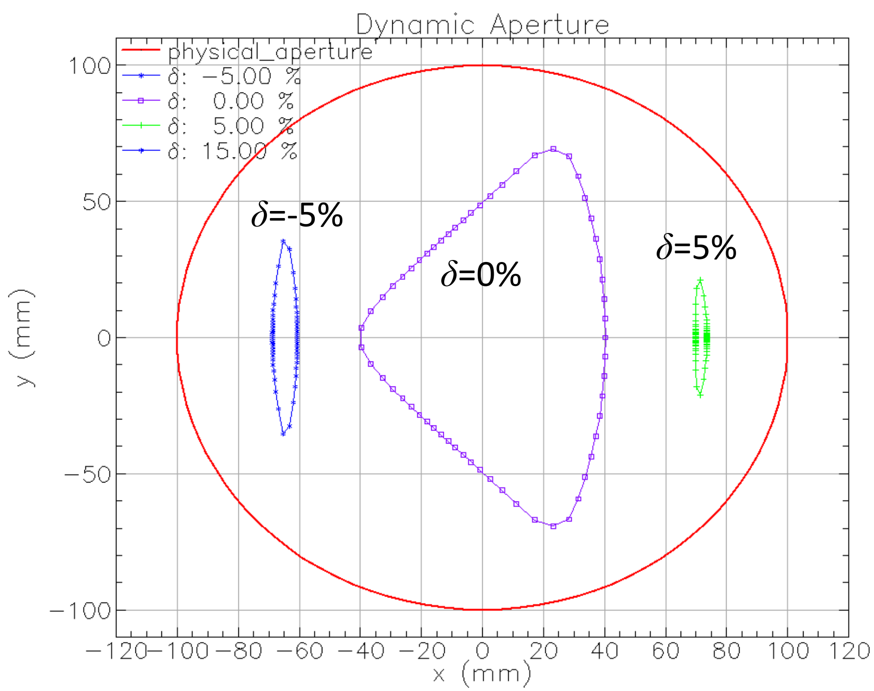
Rat program (thanks to Little Beast Engineering)

Beam dynamics

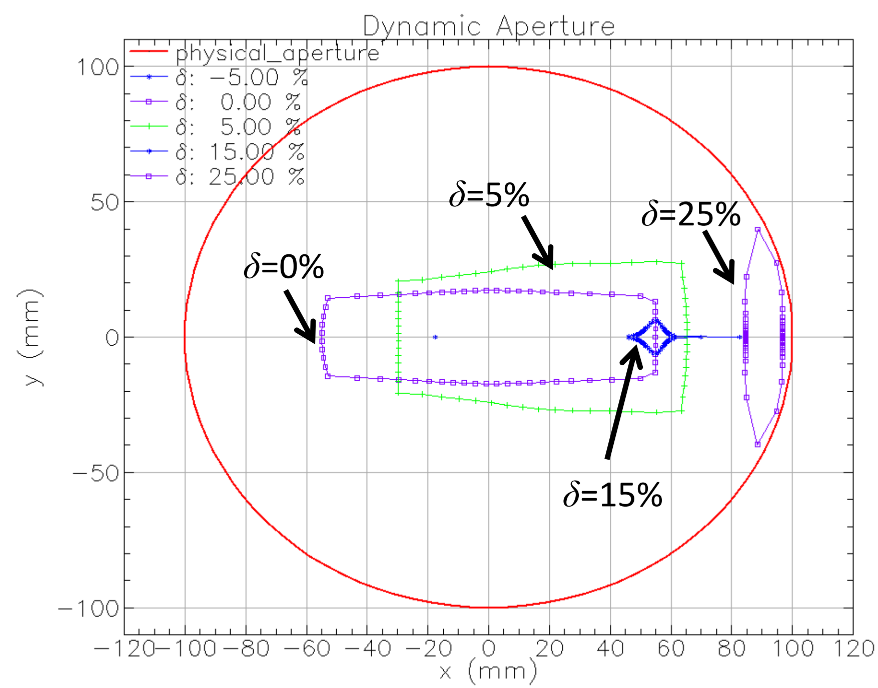
Dynamic aperture studies for different operation modes

- Tracking performed with ^{234}Ra for 500 turns using the code BMAD

Isochronous mode



High momentum acceptance mode



- Asymmetric
- Minimum acceptance for negative $\Delta p/p$

Outlook

- A new concept of compact recoil separator is proposed: The Isolde Superconducting Recoil Separator (ISRS)
- It will significantly increase the number of accessible exotic nuclei for critical studies with sufficient precision using the beam intensities and energies available at the HIE-ISOLDE
- Optics layout based on innovative CCT curved magnets (strong synergies with medical gantries); non-scaling FFAG ring
- Versatile optics, different operation modes: isochronous, high momentum acceptance, etc.
- Fine tuning of the magnets and the FFAG optics will provide very large solid angles > 100 msr and momentum acceptances $\Delta p/p > 20\%$.
- Consolidated collaboration for the design, optimization and proof-of-concept of the different subsystems and elements of the ISRS.