Design and Beam Dynamics Studies of the ISRS: Requirements for the magnets

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ISRS Workshop
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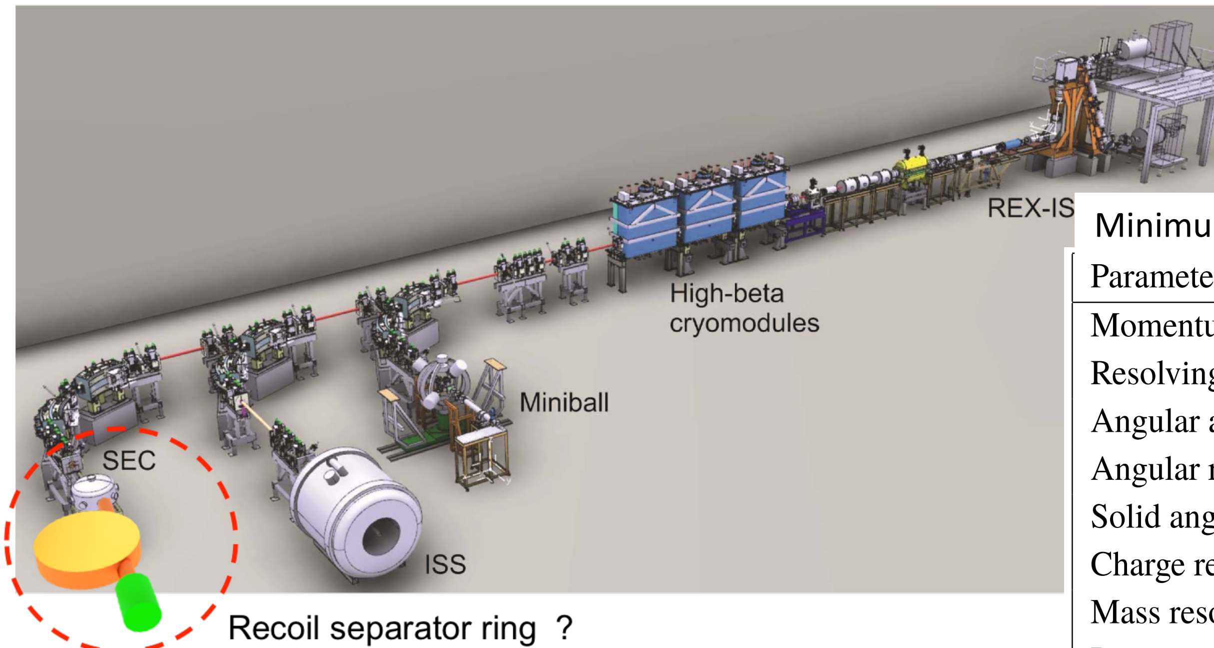
Introduction

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)



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°

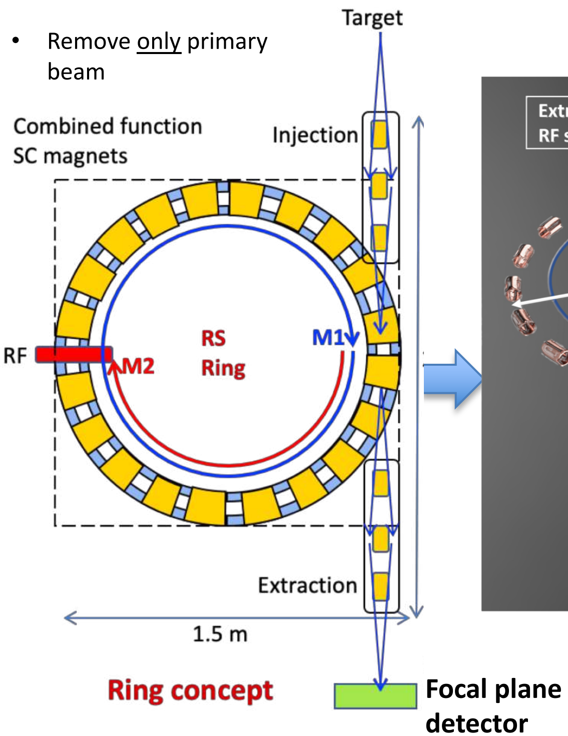
A compact recoil separator can bring new and exciting possibilities to the HIE-ISOLDE physics program

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

Preliminary studies

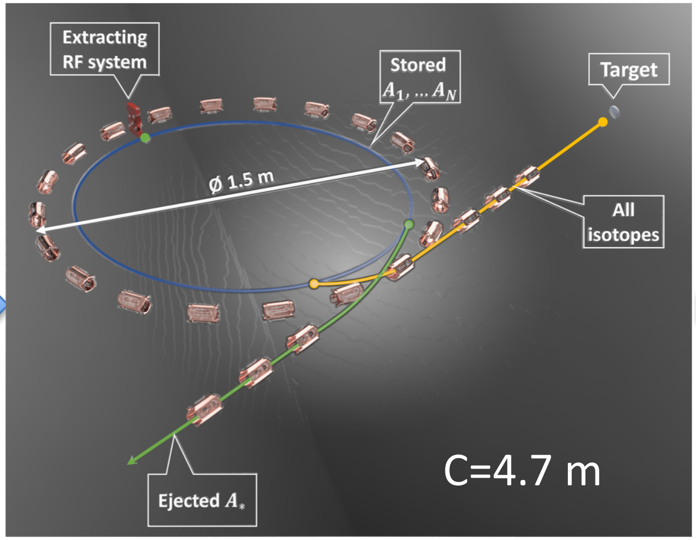
Conceptual design

I. Martel. 84th ICC meeting.
CERN, March 2019.



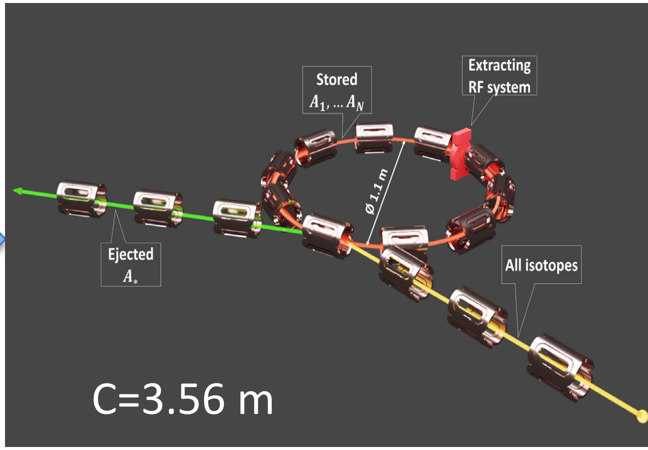
Ring concept

3D G4beamline model (20 multifunction magnets)



First optimization (10 multifunction magnets)

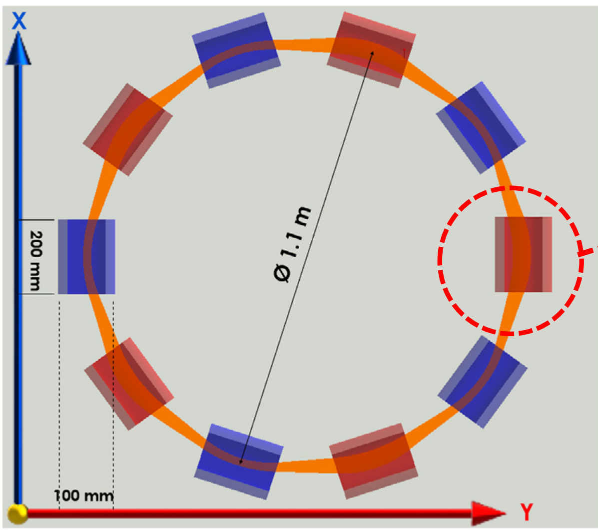
C. Bontoiu et al., NIMA 969 (2020) 164048

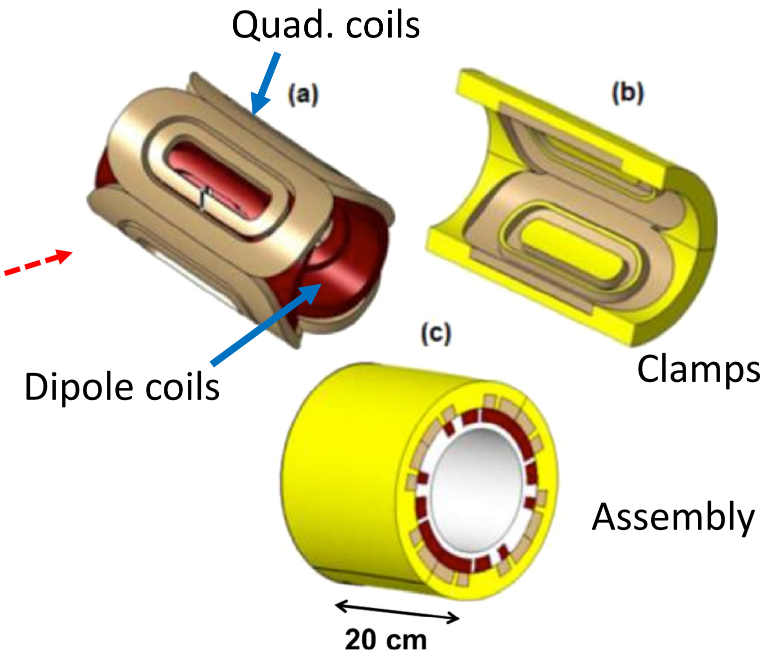


Based on combined function magnets: dipolar and quadrupolar components
Maximum magnetic field ~ 6 T

Preliminary studies

SC combined function magnets





Summary of magnet parameters for operation mode with light isotopes (e.g.^{11}Li) and heavy isotopes (e.g.^{118}Ag and ^{226,234}Ra nuclides).

Parameters	^{11}Li	^{118}Ag	^{226}Ra	^{234}Ra
Effective charge q_{eff}	2.999	35.457	52.883	52.879
Rigidity $B\rho$ [T m]	1.67	1.52	1.94	2.02
Deflection angle [deg]	36	36	36	36
Dipolar magnetic field B_y [T]	5.26	4.77	6.13	6.35
Quadrupolar strength KL [m^{-1}]	5	5	5	5
Quadrupolar gradient G [T/m]	41.86	37.98	48.77	50.5

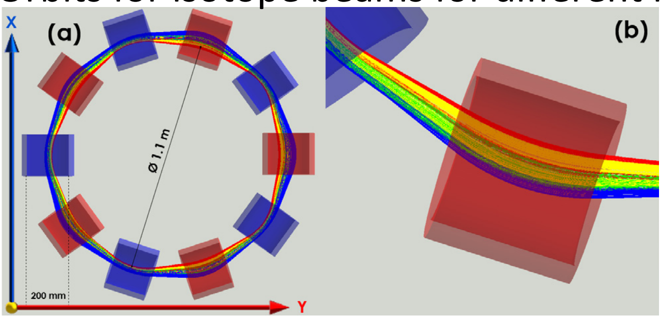
Magnets originally designed for a SC gantry for hadrontherapy

C. Bontoiu et al., IPAC2015, TUPWI014
C. Bontoiu et al., IPAC2015, WEPMN051
C. Bontoiu et al., NIMA 969 (2020) 164048

Preliminary studies

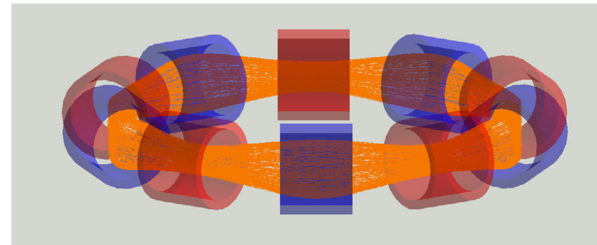
Beam dynamics.

Orbits for isotope beams for different momentum ranges



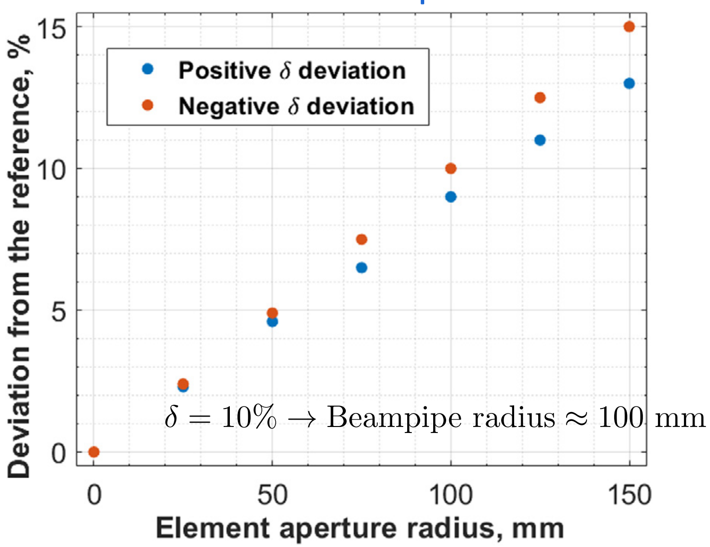
Angular acceptance

Tracking of Ra226 for 300 turns



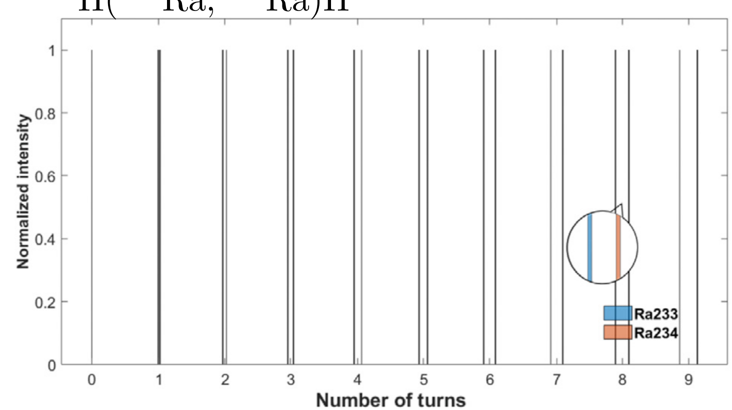
$\mathrm{Max}(x', y') \approx (115, 160)$ mrad

Momentum acceptance



Mass resolving power

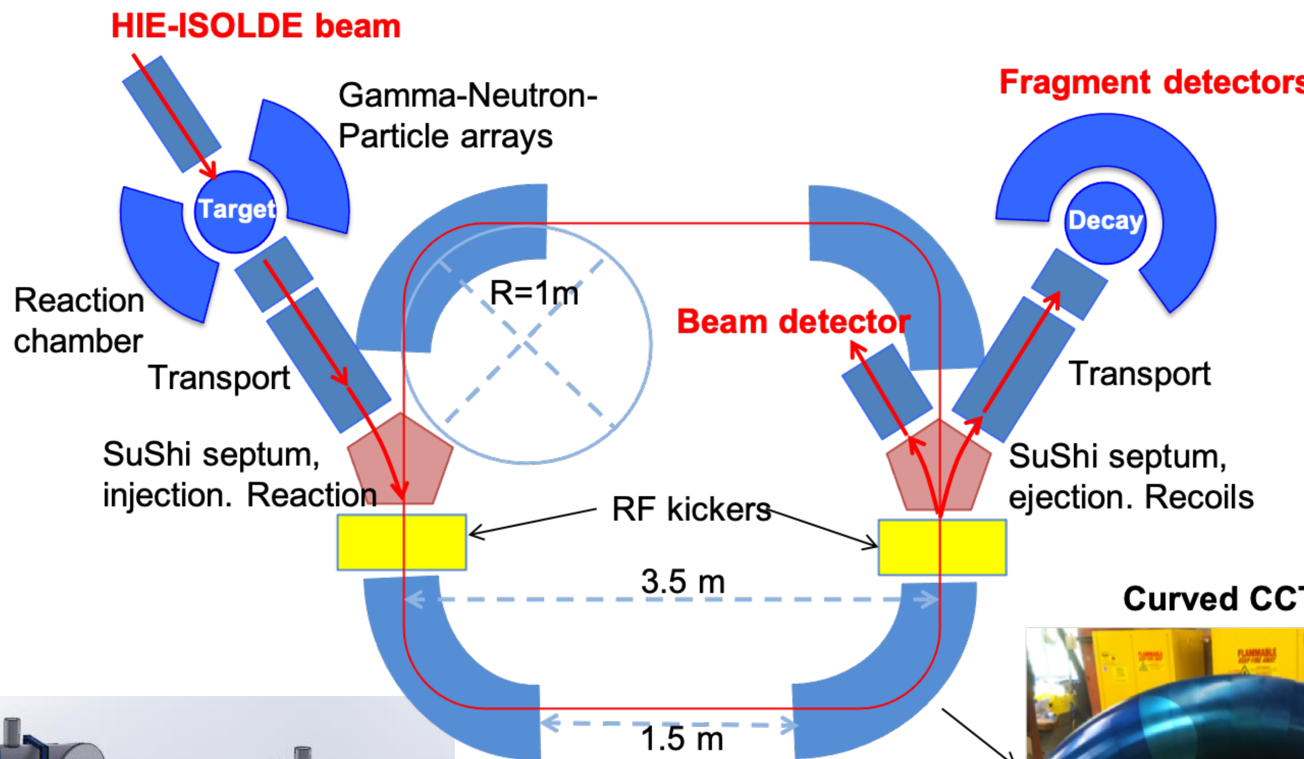
$^{2}\mathrm{H}(^{233}\mathrm{Ra},^{234}\mathrm{Ra})\mathrm{H}$

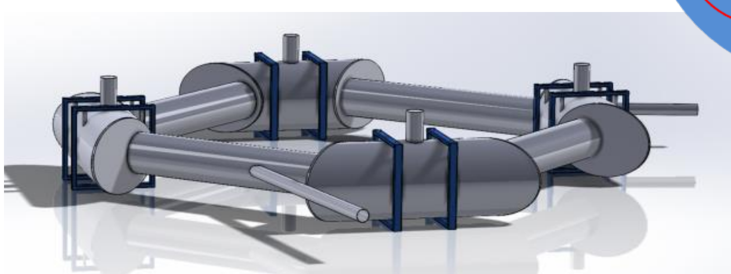


The detected intensity peaks of both Ra233 and Ra234 separate longitudinally as the number of turns increases.

C. Bontoiu et al., NIMA 969 (2020) 164048

ISRS conceptual design. Recent studies



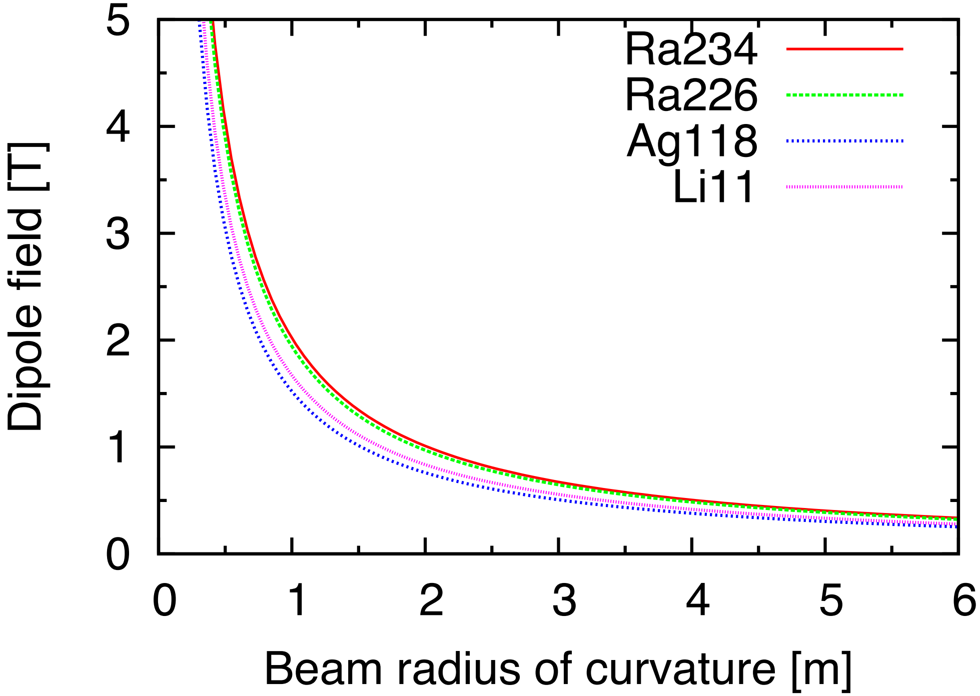


Curved CCT magnet

LBNL design

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

Dipole field



Magnetic rigidity

$$B\rho[\mathrm{T\,m}] = \left(\frac{3.3356}{q_{\mathrm{eff}}}\right) \cdot A \cdot P[\mathrm{GeV/c}]$$

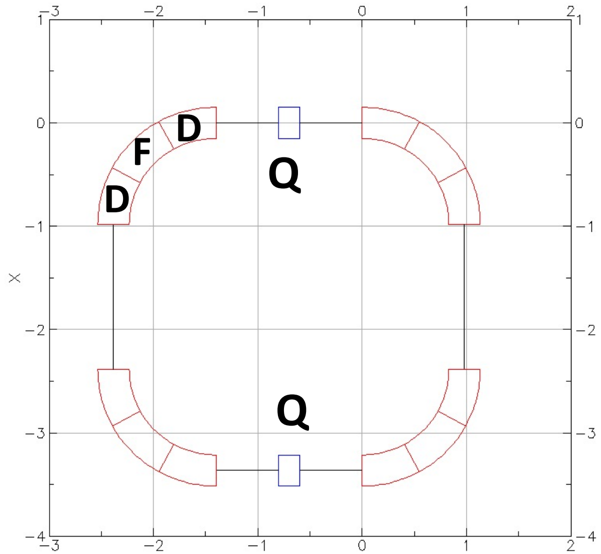
Example for different ions at 10 MeV/u kinetic energy

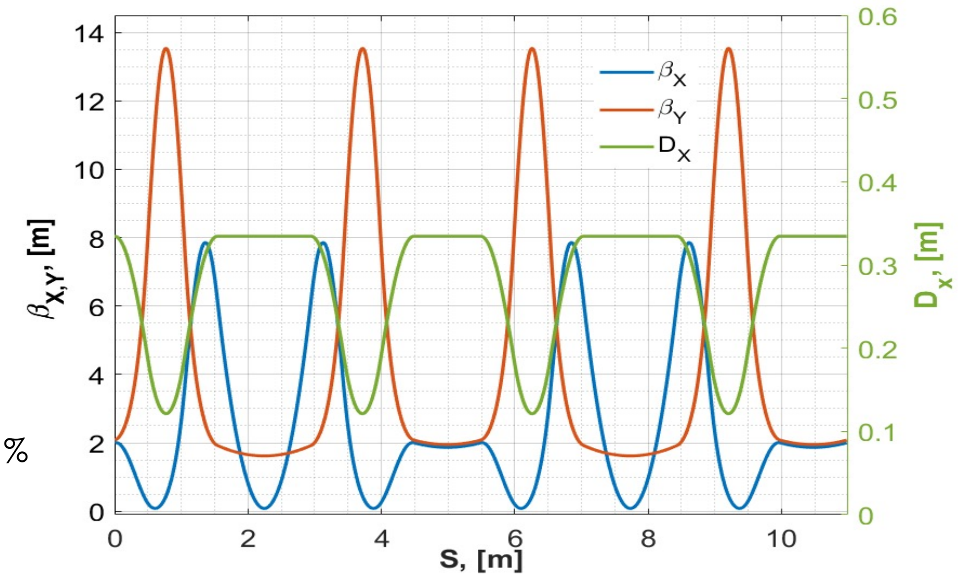
Parameters	^{11}Li	^{118}Ag	^{226}Ra	^{234}Ra
Effective charge q_{eff}	2.999	35.457	52.883	52.879
Rigidity $B\rho$ [T m]	1.67	1.52	1.94	2.02

High momentum acceptance mode

- FDF optics for non-scaling FFAG
- Lattice with sbend magnets. BMAD code

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 %

Isochronous condition

Revolution period deviation

$$\frac{dT}{T} = -\frac{df}{f} = \frac{1}{\gamma_t^2}\frac{d(m/q)}{m/q} - \left(1 - \frac{\gamma}{\gamma_t^2}\right)\frac{dv}{v}$$

$\gamma_t = 1/\sqrt{\alpha_c}$ Transition point

$$\alpha_c = \frac{dC/C}{d(B\rho)/(B\rho)} = \frac{1}{C}\oint \frac{D_x(s)}{\rho(s)} ds$$ Momentum compaction factor

The revolution frequency becomes velocity independent if $\gamma \rightarrow \gamma_t$

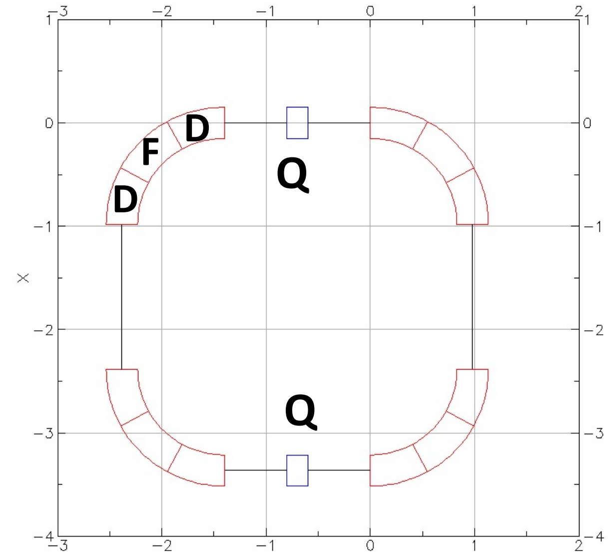
Isochronous mode

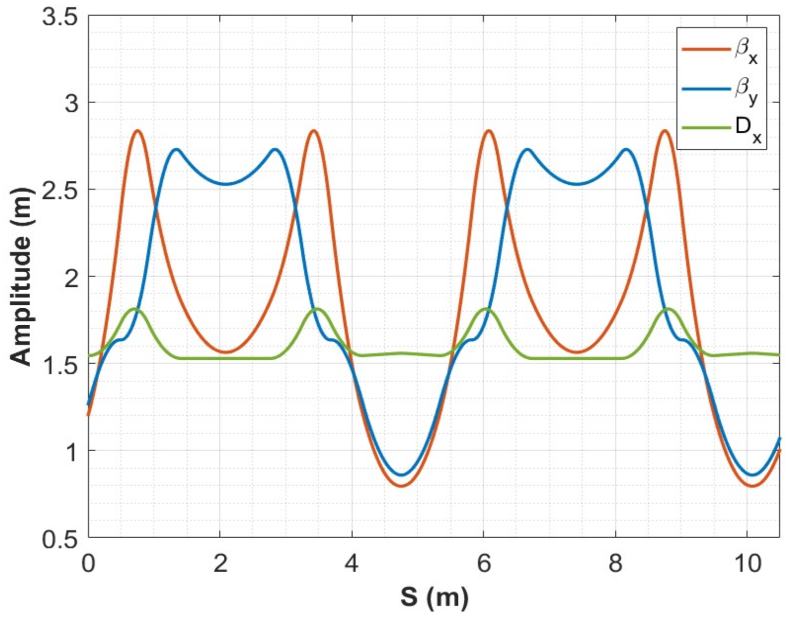
- DFD optics for non-scaling FFAG
- Matching with two additional quads. (Q). BMAD

$$\alpha_c = 0.98 \quad \gamma_t = 1.0102$$

$$\gamma = 1.0107 \; (^{234}\mathrm{Ra\ at\ 10\ MeV/u})$$

Beam	^{234}Ra
Kinetic energy	10 MeV/u
Rigidity, $B\rho$ [T m]	2
Maximum beta functions, $\beta_{x,y}$ [m]	2.85, 2.72
Maximum dispersion, D_x [m]	1.8
F magnet	
Effective length [m]	0.55
Dipole field [T]	2.45
Quadrupole gradient [T/m]	2.531
D magnet	
Effective length [m]	0.497
Dipole field [T]	2.133
Quadrupole gradient [T/m]	-2.967
Additional quads. Q	
Quadrupole gradient [T/m]	0.423



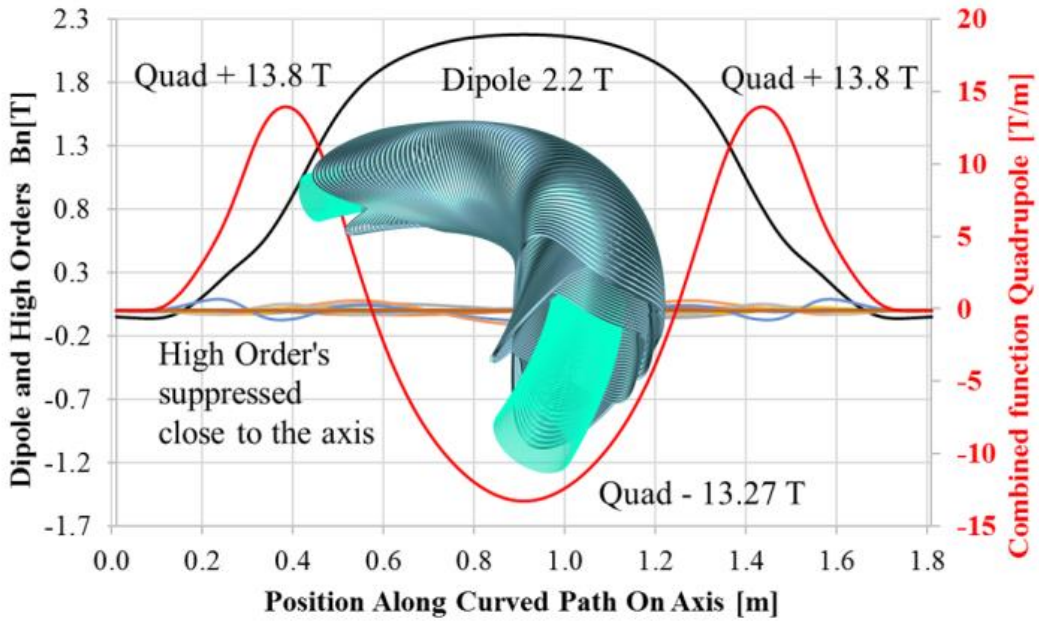


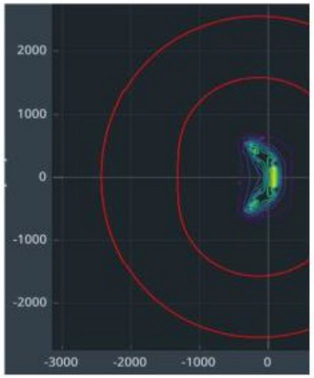
Expected max. momentum acceptance: Δp/p=+/-5.5 %

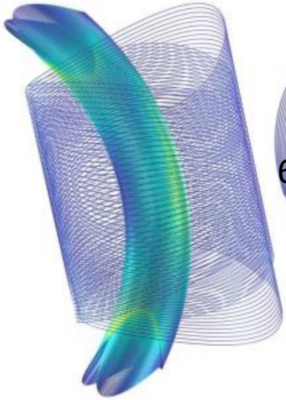
Magnets

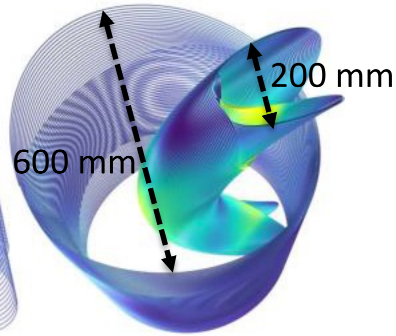
G. Kirby, MT27 Conference, 2021
G. Kirby, This Workshop

- **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 ~ 14 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









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 $\Delta p/p > 20\%$ (high momentum acceptance mode).
- Ongoing studies to get a better balance between isochronicity and momentum acceptance.
- Injection/extraction are very challenging for heavy isotopes in such a compact lattice. Under investigation.