CERN

HIE-ISOLDE superconducting recoil separator (HS-SRS) combined function magnet proposal

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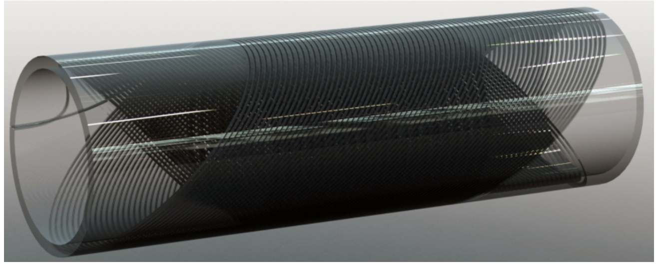
contribution for the INFRADEV call



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The HIE-ISOLDE Project

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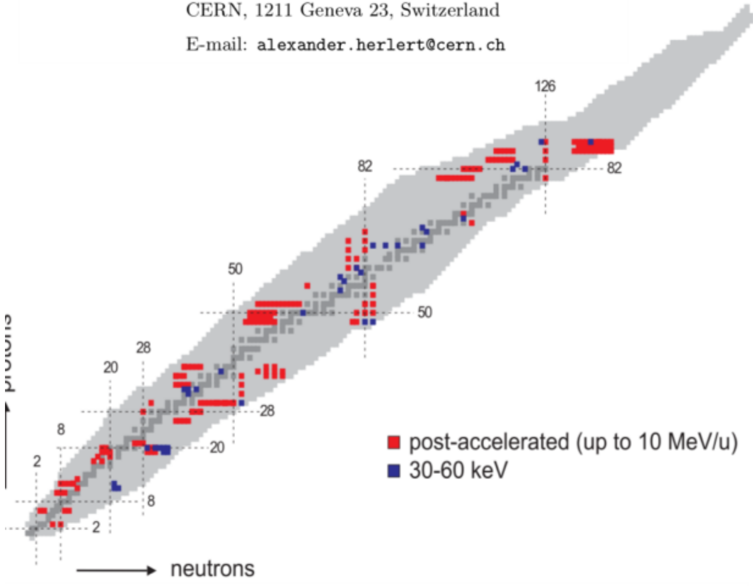
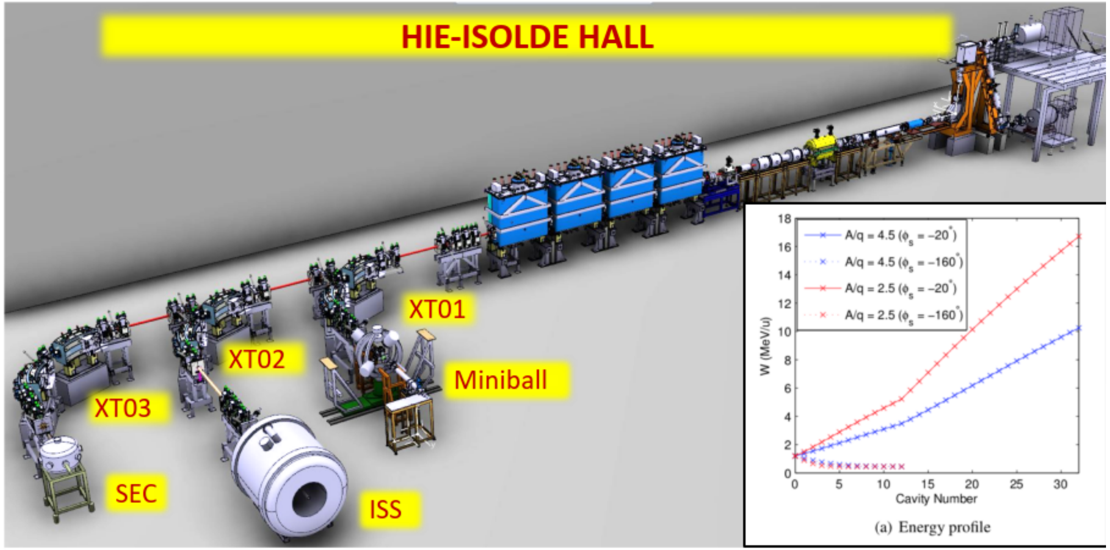


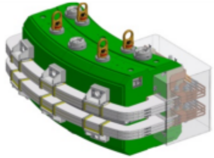
Figure 5. Isotopes requested by ISOLDE users for HIE-ISOLDE



(a) Energy profile

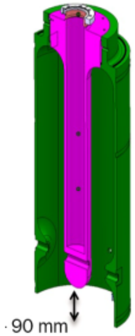
Peak field in centre [T]	1.2
Allowed integrated field error	$\pm 5 \cdot 10^{-4}$
Magnetic aperture [mm]	50
Magnetic length [mm]	1414
Bending radius [m]	1.8
Bending angle [deg]	45

Dipole



F_0 (MHz)	101.28
β_g (%)	10.3
E_{acc} (MV m^{-1}) $= V_0/L_a$	6
L_a (m)	0.3
Q_0 (at 6 MV m^{-1}, $P = 10$ W)	5×10^8
$\Gamma = R_s Q_0$ (Ω)	31
U/E^2_{acc} (mJ (MV m^{-1})$^{-2}$)	210
T (K)	4.5

RF cavity (QWR)

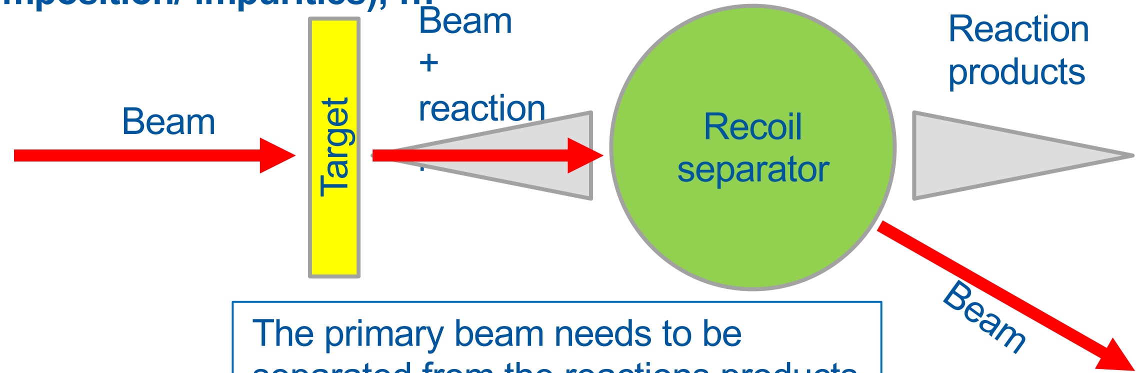


Recoil Separators

Courtesy Ismael Martel Bravo

Measurement of reactions products → main advantage when forward focussing recoils.

- **Direct reactions, nucleon transfer in inverse kinematics, fusion-evaporation, Coulex (beam composition/ impurities), …**



The primary beam needs to be separated from the reactions products (recoils).

The recoils need to be measured (A, Z, E, t) in a dedicated detector system.

Stand alone
In coincidence with other systems
HIE-ISOLDE low-energy beams ($\beta \sim 0.05$-0.15).

Simple experiments
High efficiencies

High cost of separator
Moderate cost of detectors

Operation range

- Energy range from 0.45 MeV to 10 MeV

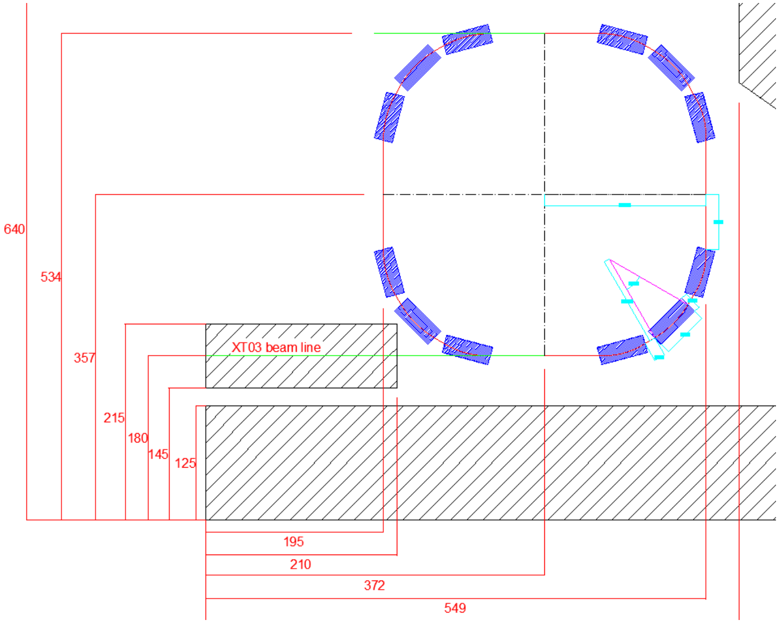
Parameters	^{11}**Li**	^{118}**Ag**	^{234}**Ra**
Effective charge	2.999	35.457	52.88
Rigidity $B\rho$ [T·m]	5.02	53.87	106.82
Deflection angle [deg]	36	36	36
Dipolar magnetic field B_y[T]	5.26	4.77	6.35
Quadrupolar strength KL [m^{-1}]	6	6	6
Quadrupolar gradient G [T/m]	50.23	45.58	60

Physics		
E [MeV/u]	0.45	10
A	7	234
A/Q	2.5	4.5
P [MeV/c]	1	30
Bρ [Tm]	0.25	2.16

- Objective to build a recirculating accelerator ring with overall integrated dipole field of 13.6 T.m along the ring.

Study of ring size layout

- Based on the HIE ISOLDE hall layout largest some footprint without major reconfiguration of the beam lines and equipment in the hall has been pre analysed.
- Injection line in the ring using the XT03 line.
- The dashed area in the picture represents the last portion of the line (a triplet of normal conducting quads, steerers and beam instrumentation). This part of the beam line could be adapted to the needs of the ring.
- Limited space by a safety passage, the XT02 beam line and the ISS experimental setup.
- Ring with width 3.4 m, bending sector 1 m radius
- Maximum beam rigidity of the beams will be 2 T.m (10 MeV/u for beams with A/q = 4.5). If possible with a ~10% of margin (2.2 T.m)



Courtesy Jose alberto Rodriguez, CERN BE

Fig 1. Overall 90 deg sector Recoil separator ring

SC combined function magnet

- The baseline study option magnet layout is based on LTS superconductor (Nb-Ti) in He-II supercritical bath in-cryostat.
- The magnet layout is based on the so called econominal Modulated Double Helical Coils technology with layout of canted coil co-theta which allows compactness and is suitable for medium field range (2-5T).

- The optic layout is chosen with a 90 deg sector of 3.3 T.m integrated field composed of three straight coils segments each 0.5 m long.
- Proposal to use a first double layer Canted coil structure to achieve dipole field and up to four layer canted quadrupole;

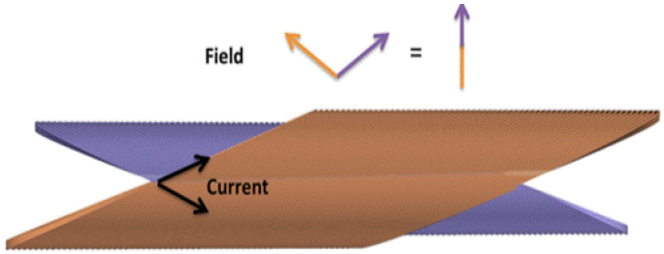
- An extended study could be to develop a curved version of the combined magnet which requires further development steps.

Design options

- Assessment considers the use of LTS NbTi SC strand (LHC type) for the construction of a demonstrator made of 3 CCT-like combined magnet coil segments (about 550 mm long each).
- The peak field of combined magnet section on conductor is 5T (1 T dipole peak field contribution), with and integrated field of 0.3 T.m (excluding the magnetic iron).
- The quadrupole magnet section could have a gradient of up to about 40 T/m across an aperture of 150 mm.
- The expected stored energy of one magnet section would be 120 kJ.

Pre-design study case of CCT-helical magnet parameters

- Number of dipoles in ring: 12
- Bending sector radius: ~ 1 m
- Bending angle: 30 deg
- Investigated aperture: 150 - 200 mm
- Overall length: ~ 550 mm
- Integrated field per segment coil: 1.1 T.m
- Straight section between quarters: about 100
- LHC type NbTi strand, Current density of 400-500 A/mm2
- Achieved peak magnetic field of 5 T in quad., achieved gradients of 40 T/m over a 150 mm aperture (45T/m over 200 mm). Temperature margin of 0.9 K.



Modulated Double Helical Coils concept
C. Goodzeit, et al. IPAC2007. 2007.

Combined function magnet

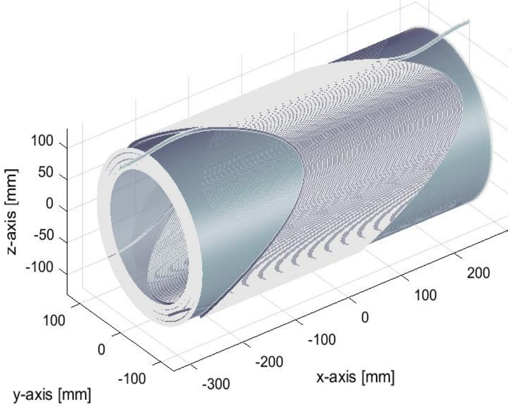


Fig 1. Canted coil cos theta combined Dipole and quadrupole demonstrator magnet

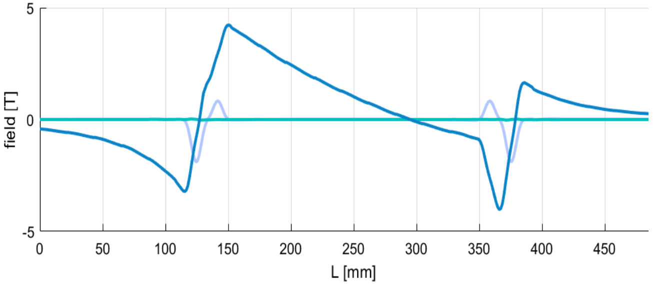


Fig 2. Transverse magnetic field profile on mid plane in combined function mode

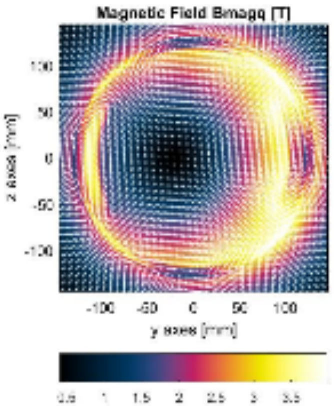
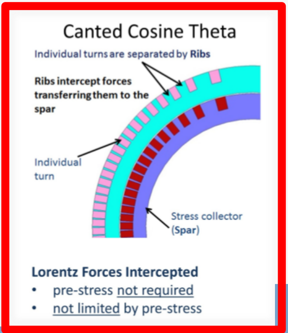


Fig 4. Combined function magnetic field contour

Fig 5. HL-LHC CCT Dipole, TE MSC G Kirby



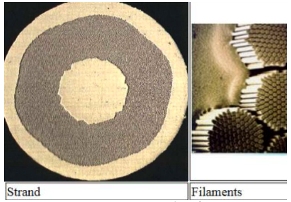
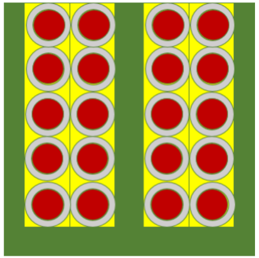


Fig 3. SC Strands layers in former grooves (spars)



WBS possible

- The work breakdown structure proposed summarises the detailed costing of the conceptual, detailed design of the combined function magnet including the cryogenics and protection circuit.
- The hardware procurement includes the magnet parts, the cryogenic auxiliaries, the dedicated tooling and the test bench preparation.
- Indirect cost not included, nor matching funds.

PHASE	SCOPE	ES HA
WBS 1.0 : CONCEPTUAL SC MAGNET DESIGN	SC Magnet, structure cryogenics design	
WBS 2.0 : DETAILED DESIGN	-	
WBS 3.0 : CRYOGENICS	Cryostat, CL, thermal shields, safety device	
WBS 4.0 : LTS CABLE	NbTi strands, insulation system	
WBS 5.0 : MAGNET CONSTRUCTION	3 combined CCT-Quad modules, 0.5 m long	
	Iron yoke	
WBS 6.0 : PROTECTION SYSTEM	Extraction energy system (excl. P.S)	
WBS 7.0 : TEST BENCH	Test integration, mech. supports	
Total (p.m)		
Total (kEur)		
Grand total		

Feedback on pre-evaluation, prospects

- A **HTS superconductor technology** based on Rebco tape conductor was considered as alternative with cryo-free system solution on similar basis magnet design.
  - The evaluation shown a increase on total project cost by about 60% due to the raw conductor price and R&D phasing
- The **cryogen-free cooling option** solution for the NbTi (LTS) conductor at 4.5K should be evaluated and impact on the magnet design, temperature margin.
- Some interesting CCT related features **like modulation of field harmonics on quadrupole layers ends**, incl complete alternating Gradient (FFAG) structure could be assessed.
- Active shielding versus **iron yoke** layout to be assessed

Next, to be adressed…

- To confirm the **project magnet specification** wrt. Recoil separator Ring layout, optics parameters
- Reorganise **WPs related to magnets and services** to define a clear flow of deliverables and stepped approach
- Set **formal CERN resources on collaboration agreement**, as in Institutes to cover the work packages tasks 3 and 5,
  - set up the *design packages and hardware procurement route, deliverables and test strategy*.
- **Schedule the activities** of the Magnet design and prototype production
- **Consolidate and secure budget of the packages**, resources, including matching funds.
- Assess the **possibility to further developed a curved CCT** based magnet geometry, combined with alternating fixed field gradient allowing higher momentum acceptance as benefits for the optics. – Common **interest with other EU R&D** programs ?
- Dimension and perform first detailed conceptual design assessment on selected magnet technology

Summary

- A CCT-based LTS cabled combined function magnet is been evaluated as a demonstrator prototype of the manufacture route option for the future HIE ISOLDE Recoil separator (HS-SRS).
- Would the technology be considered, it would benefit form recent HL LHC CCT dipole development
- Some first short model would be required followed by real size prototype cryostated magnet shall be constructed and tested
- Next, further definition and formalisation of SC combined function Magnet Demo project collaboration to be set.

THANK YOU
for your attention

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