The HIE-ISOLDE recoil separator: present status and perspectives

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HIE-ISOLDE

International Nuclear Physics Conference 2010 (INPC2010) IOP Publishing
Journal of Physics: Conference Series **312** (2011) 052010 doi:10.1088/1742-6596/312/5/052010

The HIE-ISOLDE Project

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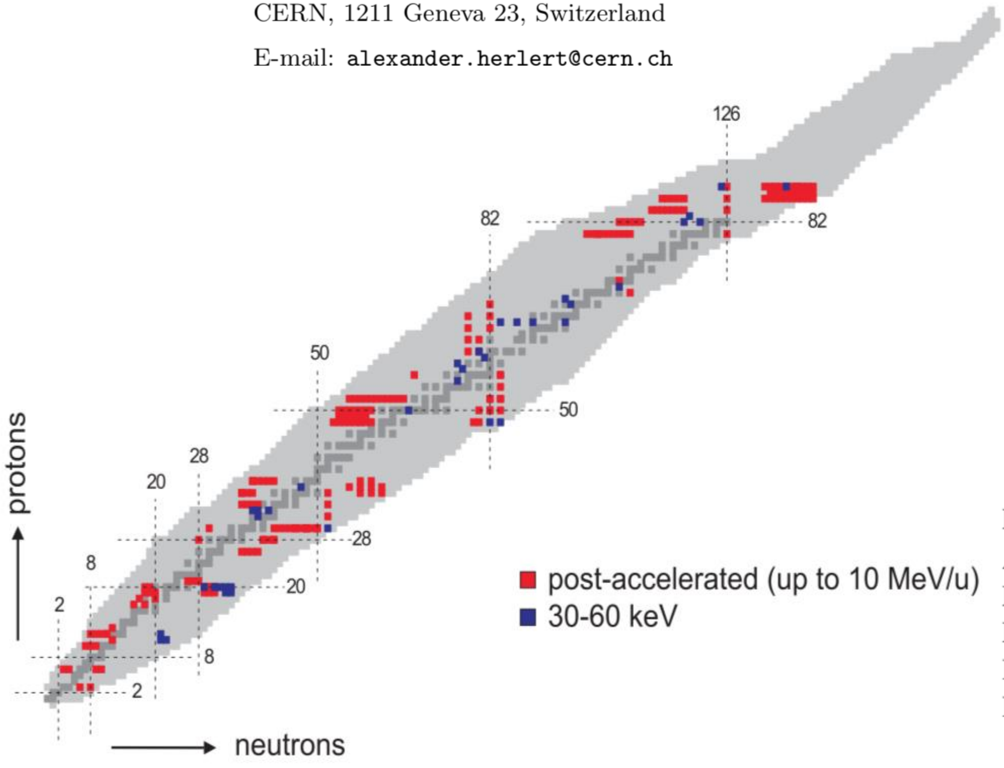
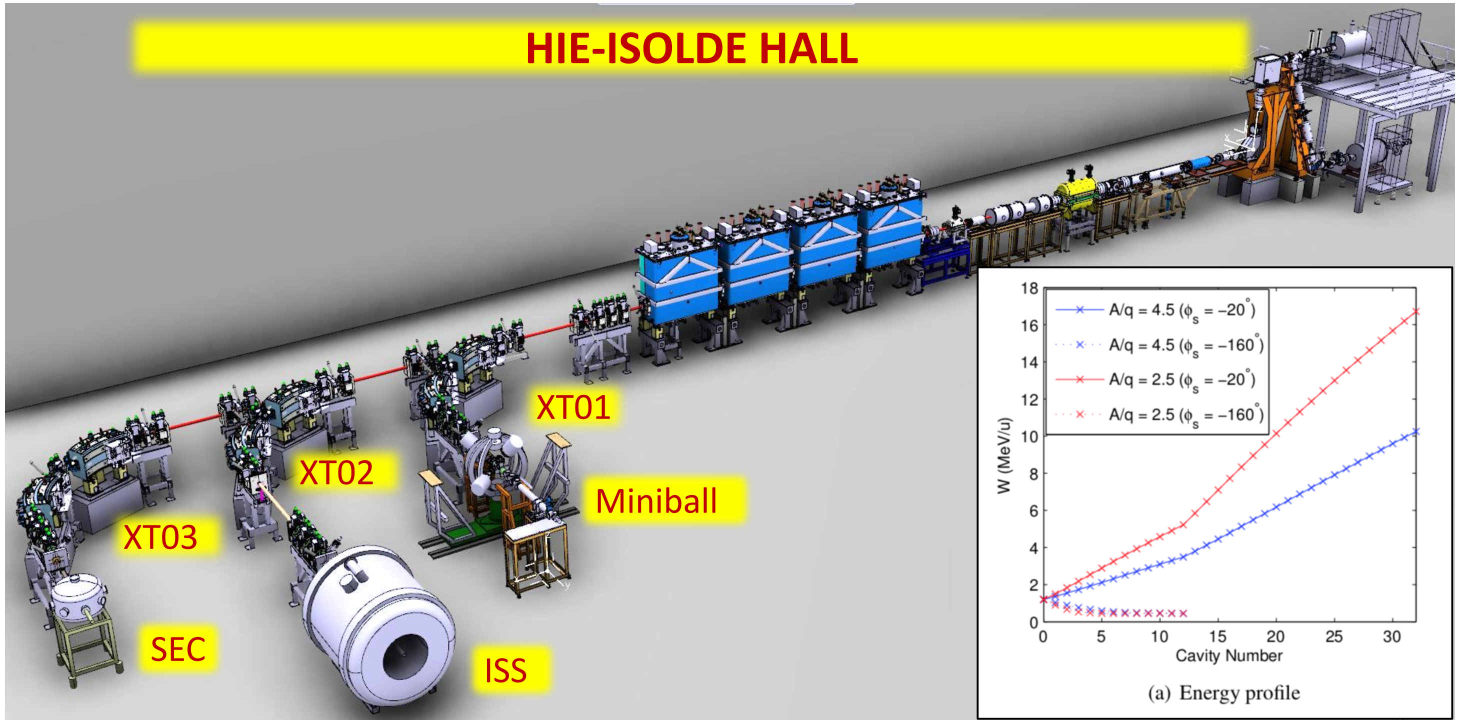
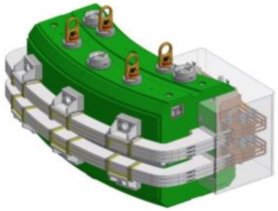


Figure 5. Isotopes requested by ISOLDE users for HIE-ISOLDE



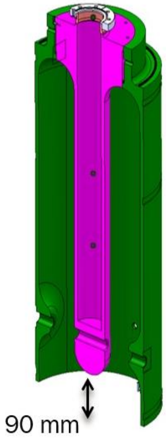
Peak field in centre [T]	1.2
Allowed integrated field error	$\pm 5 \cdot 10^{-4}$
Magnetic aperture [mm]	50
Magnetic length [mm]	1414
Bending radius [m]	1.8
Bending angle [deg]	45

Dipoles



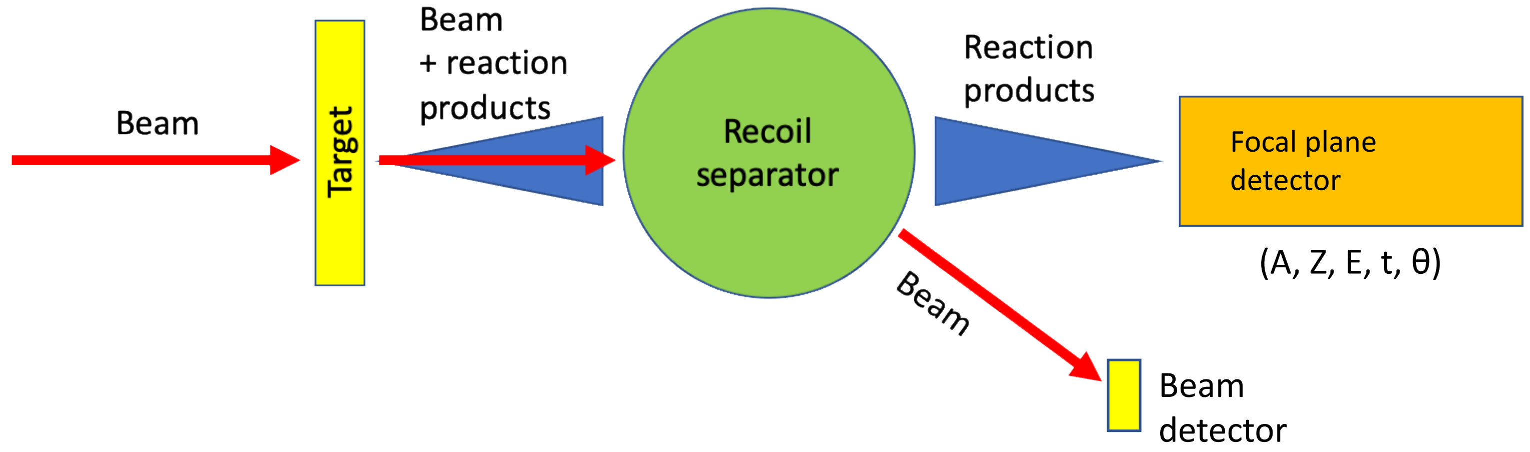
F_0 (MHz)	101.28
β_g (%)	10.3
E_{acc} (MV m^{-1}) $= V_0/L_a$	6
L_a (m)	0.3
Q_0 (at 6 MV m^{-1}, $P = 10$ W)	5×10^8
$\Gamma = R_s Q_0$ (Ω)	31
U/E^2_{acc} (mJ (MV m^{-1})$^{-2}$)	210
T (K)	4.5

RF cavity (QWR)

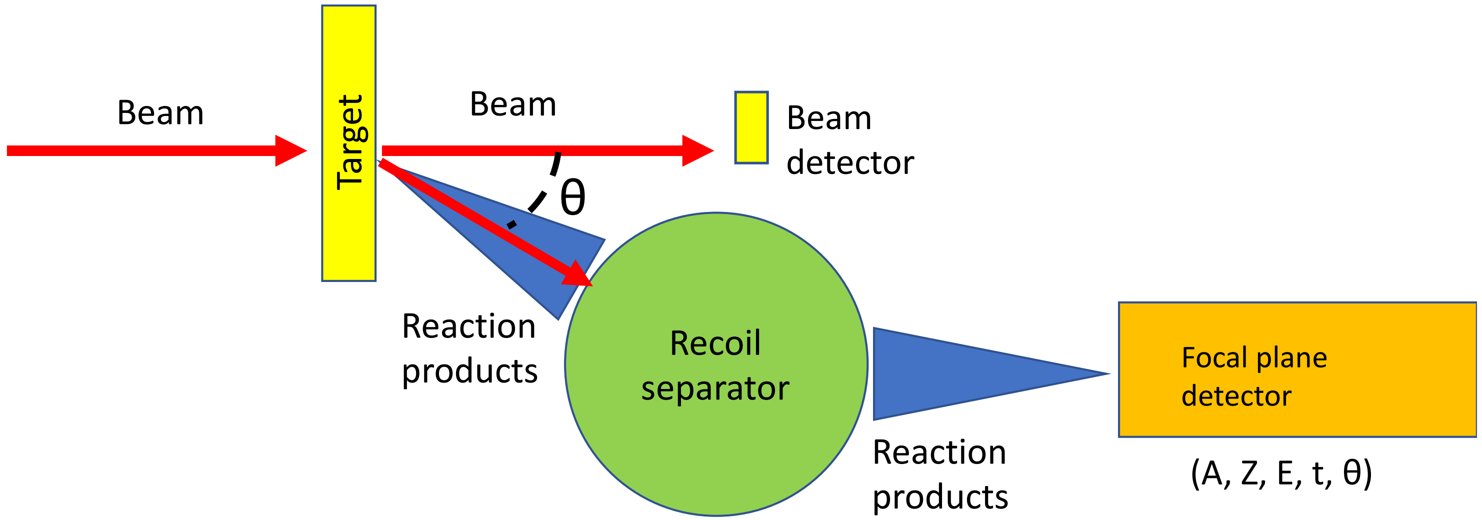


Recoil Separators

- Separate forward focussed reactions products (θ ~ 0°) from primary beam.



- Separate the reaction reaction products at selected angles (e.g. θ ~ grazing angle).



Principal elements

- Target and reaction chamber
- Injection and extraction system
- Separator
- Focal plane detector

Experiments

- Stand alone
- In coincidence with other systems

Advantages

- Simple experiments
- High efficiencies

Disadvantages

- Cost
- Size

The need of recoil separators at HIE-ISOLDE: the HIFI Project

March 10-11, 2011 | Spectrometer at HIE-ISOLDE, Workshop, Lund (Sweden)

Coordinators: Olof Tengblad, Wilton Catford, Joakim Cederkäll

Profit for proposals ~ 40%

- MINIBALL, SEC, ISS (fringe fields)

Other set-ups

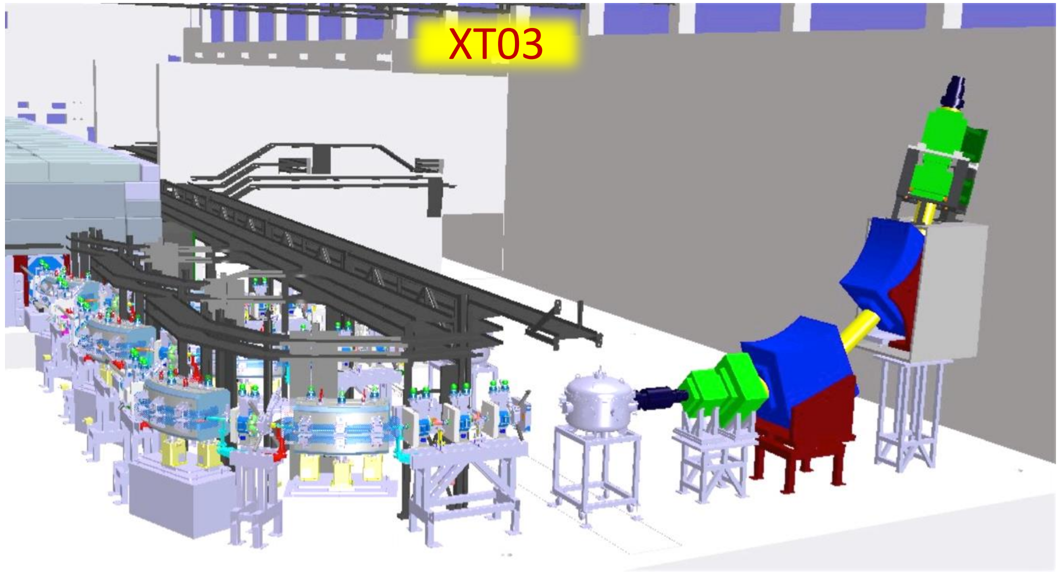
- GASPARD
- ACTAR

Physics cases

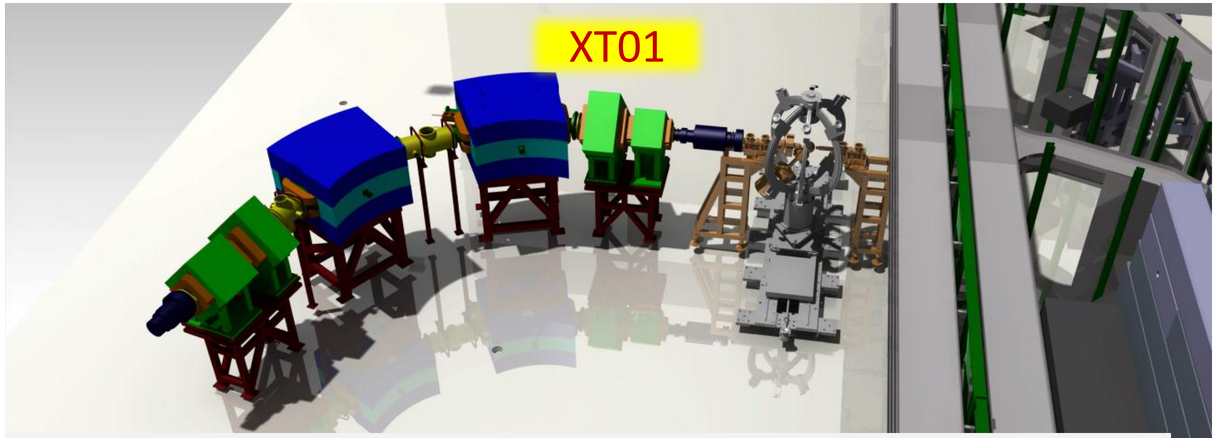
- *Direct reactions studies*
- *Transfer reactions*
- *Coulomb excitation*
- *Deep inelastic reactions*
- *Fusion-evaporation reactions*
- *Astrophysics*

HiFi→ Traditional system based on warm magnets

Layout for SEC



Layout for MINIBALL



- ToF – space limitations → poor mass resolution > 50.
- Not easy to move from one line to the other.

Approved HIE-ISOLDE experiments that could profit from a Recoil Separator (2018)

IS591 P377 ^{18}N: a challenge to the shell model and a part of the to r-process element production in Type II supernovae (**^{17}N(d,p)^{18}N).** Matta, A, Catford, W.

IS606 P440 Studies of unbound states in isotopes at the N = 8 shell closure **[^{11}Be(t,p)^{13}Be].** Tengblad O. / Mücher, D.

IS587 P398 Characterising excited states in and around the semi-magic nucleus ^{68}Ni using **Coulomb excitation** and one-neutron transfer. Gaffney, L. ; Flavigny, F. ; Zielinska M. ; Kolos, K.

IS566 P370 Probing intruder configurations in ^{186,188}Pb using **Coulomb excitation.** Pakarinen, J.

IS562 P362 **Transfer Reactions** and Multiple **Coulomb Excitation** in the ^{100}Sn Region. Cederkäll, J.

IS561 P361 **Transfer reactions** at the neutron dripline with triton target. Riisager, K., Mücher, D.

IS556 P352 Spectroscopy of low-lying single-particle states in ^{81}Zn populated in the **^{80}Zn(d,p) reaction.** Orlandi, R., Raabe, R.

IS554 P350 Search for higher excited states of ^{8}Be* to study the cosmological ^{7}Li problem ^{7}Be(d,p),(d,d). Gupta, D.

IS553 P348 Determination of the B(E3,0+->3-) strength in the in the octupole correlated nuclei ^{142,144}Ba using **Coulomb excitation**. Scheck, M., Joss, D.

IS551 P345 **Coulomb excitation** of doubly magic 132Sn with MINIBALL at HIE-ISOLDE. Reiter, P.

IS549 P343 **Coulomb Excitation** of Neutron-rich $^{134;136}$Sn isotopes. Kröll, T., Simpson, G.

IS548 P342 Evolution of quadrupole and octupole collectivity north-east of ^{132}Sn: the even Te and Xe isotopes. Kröll, T., Simpson, G.

IS547 P340 **Coulomb excitation** of the two proton-hole nucleus ^{206}Hg. Podolyak, Z.

IS555 P351 Study of shell evolution in the Ni isotopes via one-neutron **transfer reaction** in ^{70}Ni Valiente Dobon, J., Orlandi, R., Mengoni, D.

5 Transfer (35%), 7 Coulex (50%), 2 Astrophysics (15%)

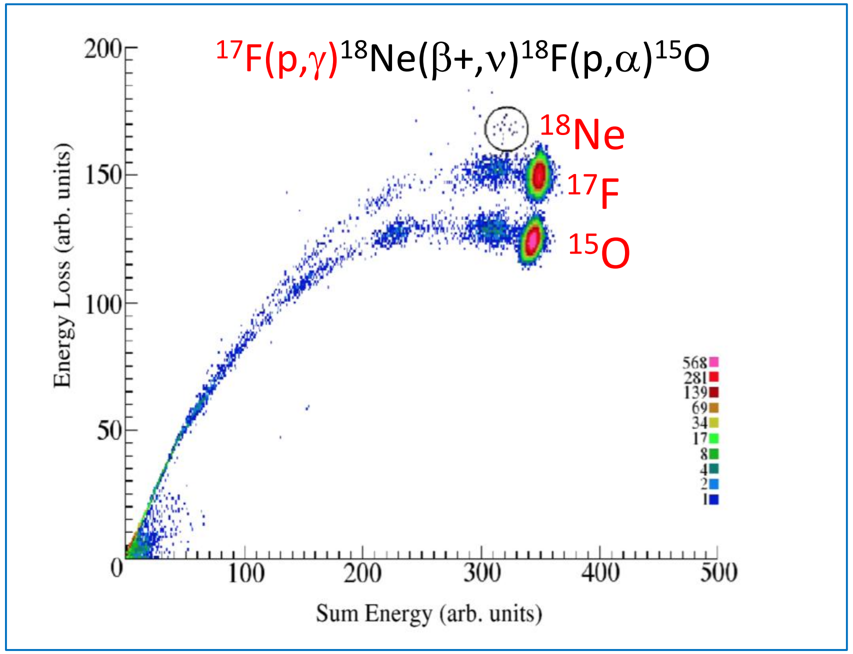
Courtesy of Olof Tengblad

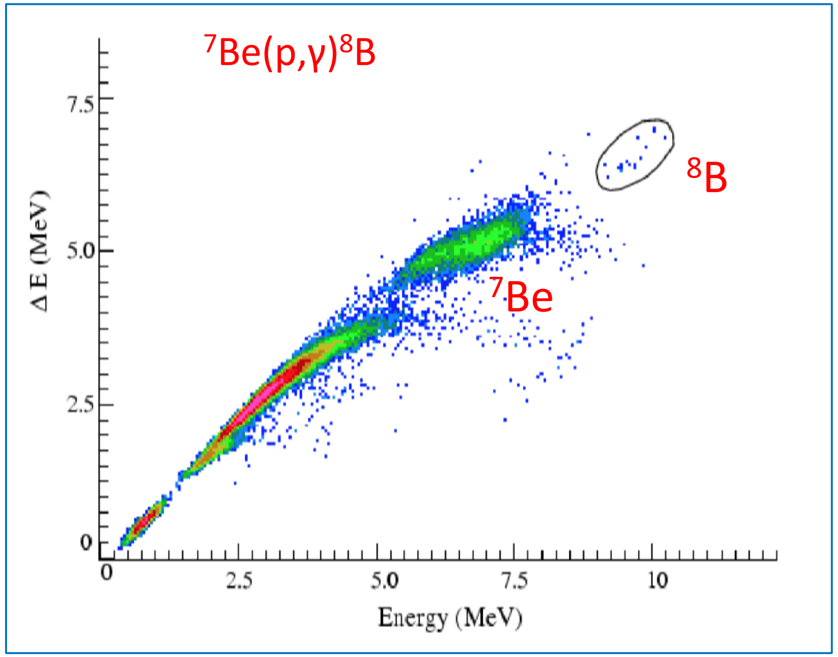
Astrophysics: Direct measurements of (*p*,γ) cross sections

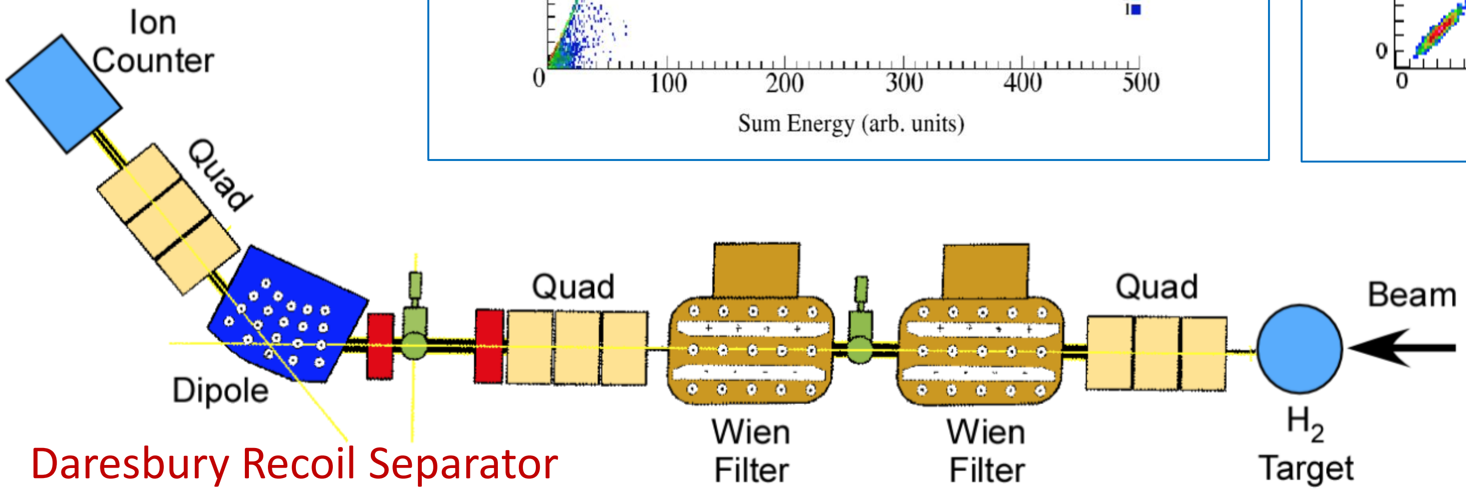
D. W. Bardayan, *et al*. European Physical Journal A, 2009.

HRIBF (Oak Ridge)

Daresbury
Recoil Separator







Daresbury Recoil Separator

Dedicated experiments with **γ, n** at exit channel

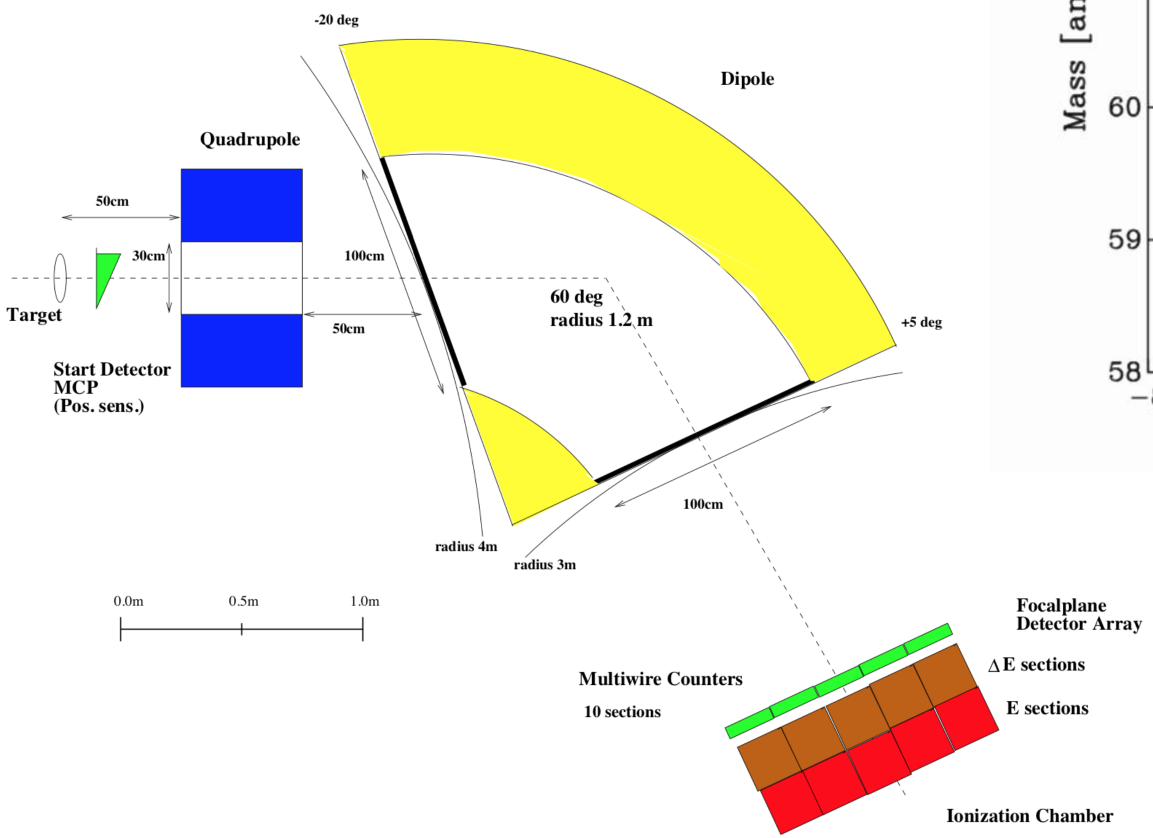
Pairing interaction: Multi-neutron transfer reactions

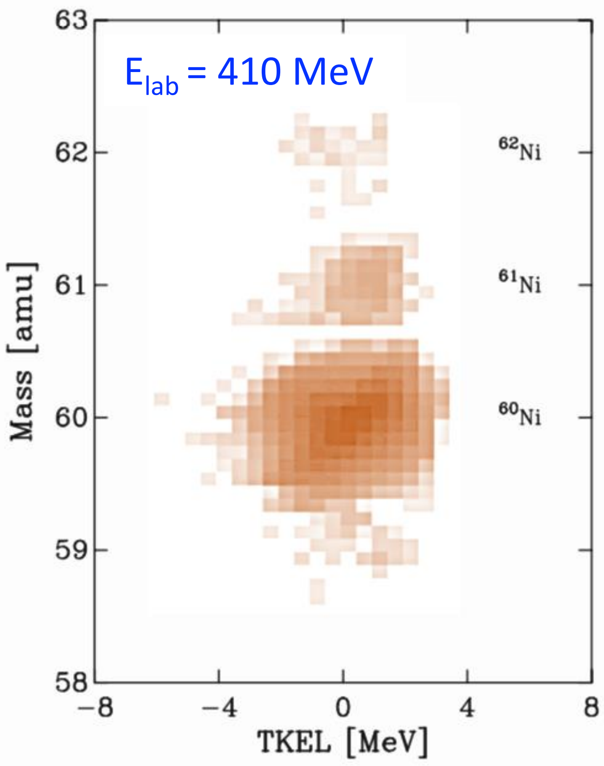
D. Montanari *et al.*, PRL 113, 052501 (2014)

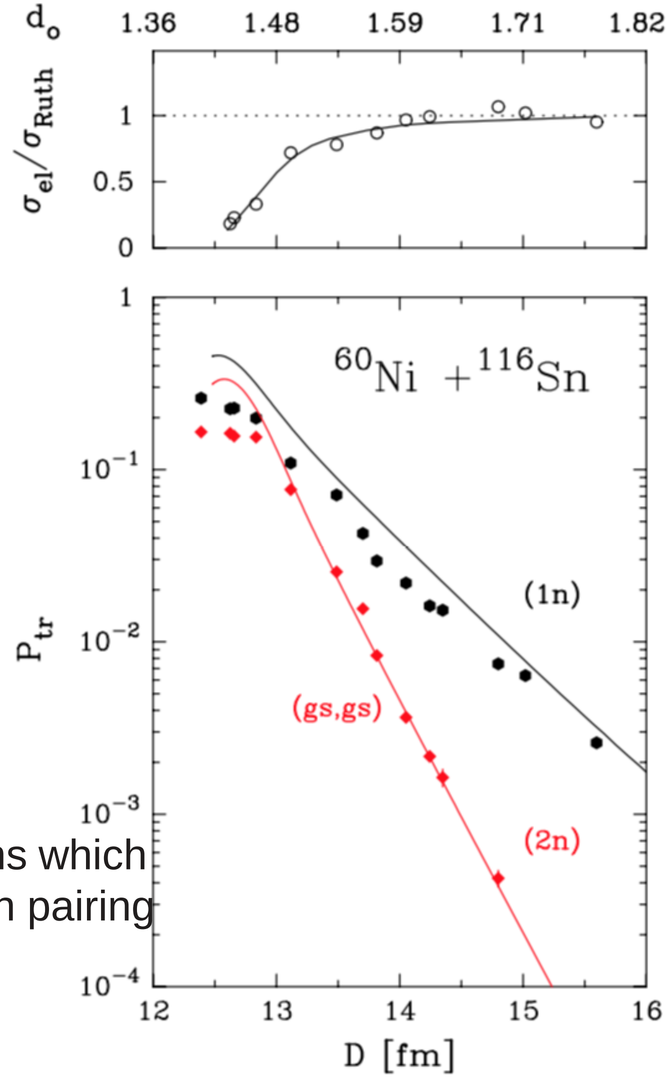
LNL (Italy), ^{116}Sn + ^{60}Ni @ E= 4.3-3.4 MeV/u

PRISMA spectrometer; θlab = 20°

Coulomb Barrier energies







Test microscopic calculations which incorporate nucleon-nucleon pairing correlations (BCS).

- Pairing gap
- 2n - SF

Dedicated multinucleon Transfer experiments

Shell evolution: Study of ^{25}Ne using ^{24}Ne(d, pγ)^{25}Ne

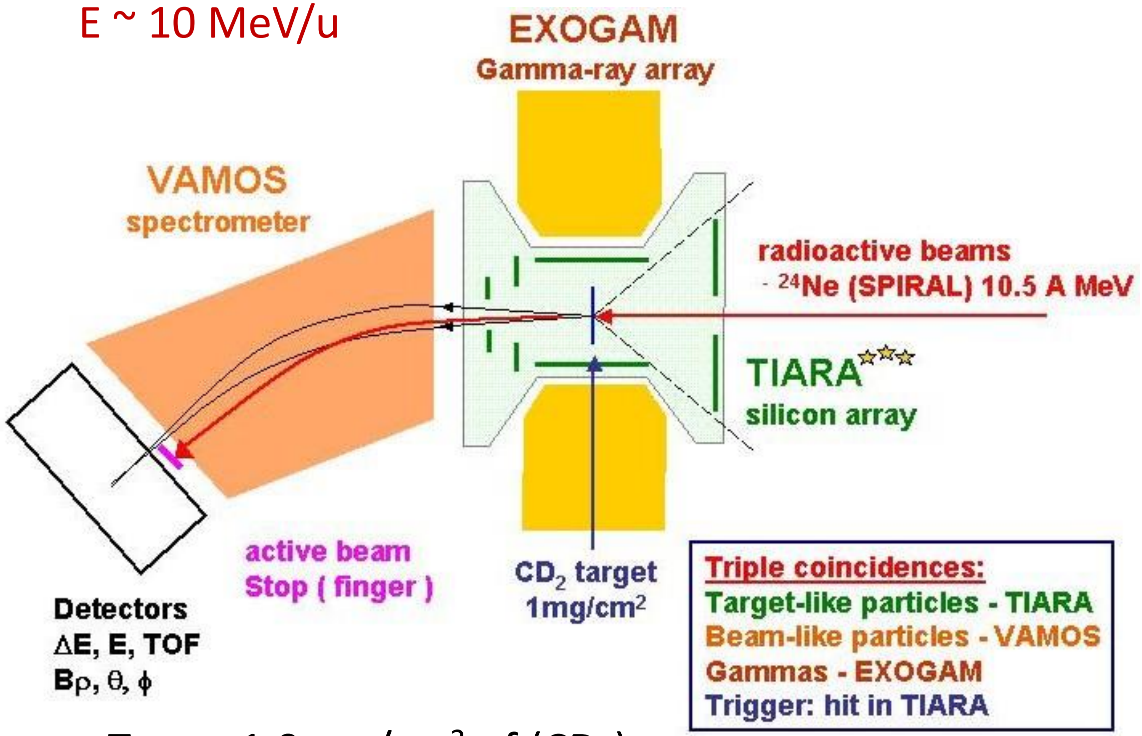
W.N. Catford *et al.*, Eur. Phys. J. **A25**, Suppl. 1, 245 (2005).

GANIL - SPIRAL

VAMOS, θlab = 0°

E ~ 10 MeV/u

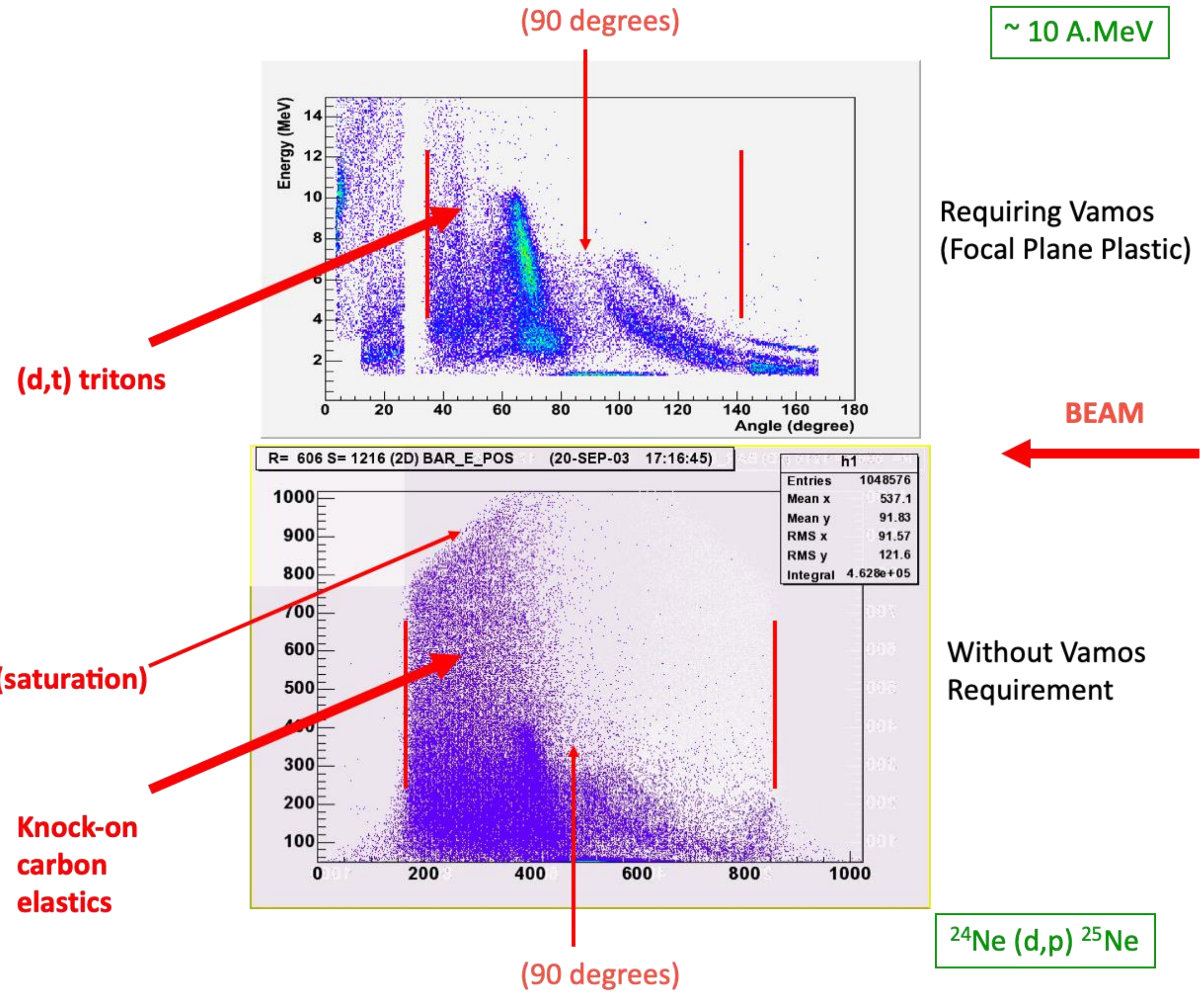
N=16 replaces broken N=20



Target 1.0 mg/cm^2 of $(CD_2)_n$

Courtesy of Wilton Catford

Recoil Separator as ancillary detector



HIE-ISOLDE: Preliminary specifications of the SC recoil separator

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

Timing

Slow extraction from EBIS useful for TOF

Linac f = 101.28 MHz → buncher down to ~ 10 MHz (or lower).

Multi-harmonic buncher (M. Fraiser et al. LINAC2014, THPP030)

Intensity

10^5/s for heavy beams, but 10^9/s instantaneous rate.

→ debuncher

Size of the HIE-ISOLDE hall

Separator

- Primary beam suppression < ~10^{-12}
- 100 % transport efficiency
- Mass resolution > 1/300
- Large acceptance ~ 100 mrad
- Gas-filled mode

Focal plane detector

- Position sensitivity ~ 1 mrad (scattering angle)
- Particle identification (A, Z)
- Eloss, Time of Flight, Pulse shape
- Time resolution ~ ns
- Energy resolution < 100 keV
- 100% efficiency

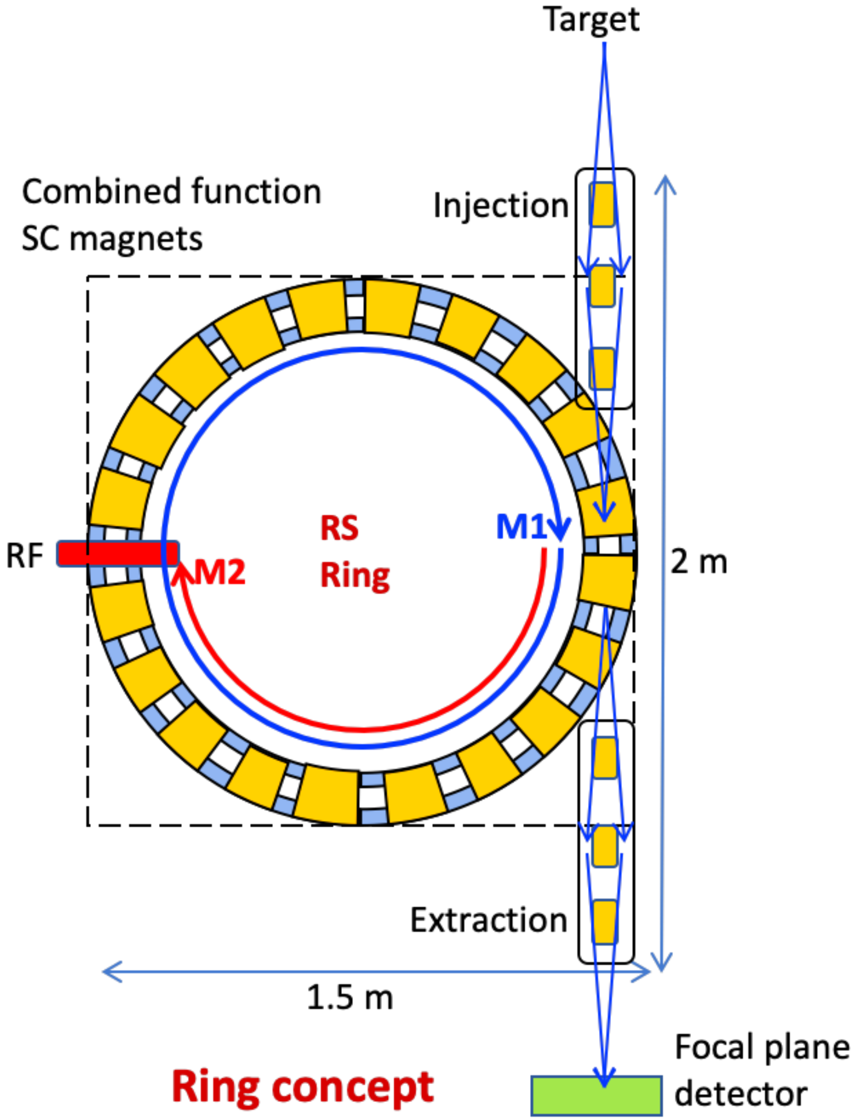
Simulations (HiFi)

EMMA, MARA, PRISMA

- $^{9}Li(d,n)^{10}Be$
- $^{22}Mg(d,n)^{23}Al$
- $^{68}Ni(d,n)^{69}Ni$
- $^{132}Sn(d,p)^{133}Sn$
- $^{184}Hg(^{3}He,n)^{186}Pb$

Proposal for a design study: superconducting mini-storage ring

Design concept using SC coils and RF cavities to produce a compact high-selectivity recoil separator.



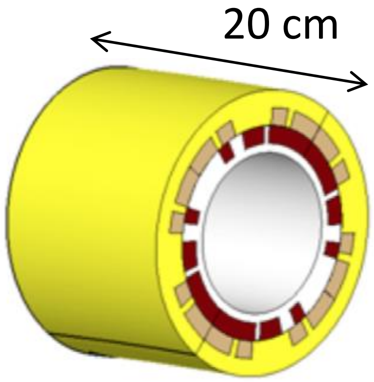
Ring concept

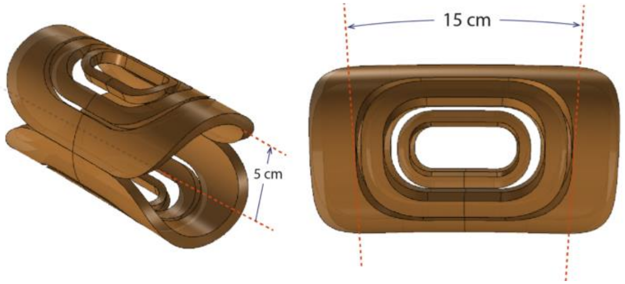
Combined function magnets

R&D Project with Industry - Spanish Government
"Design of a superconducting Gantry for cancer treatment using proton therapy" (GASP: ITC-20131073, 2014)

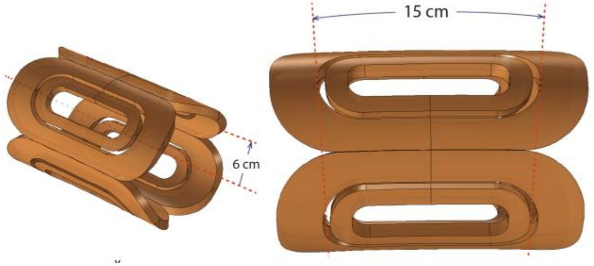
C. Bontoiu, et al., IPAC2015, doi:10.18429/JACoW-IPAC2015-WEPMN051

- Protons of 175 MeV
- Large momentum acceptance (± 20%)
- R= 2.5 m
- Bmax = 2 T
- Dipoles Bρ = 5.47 Tm (HIE-ISOLDE ~ 2 Tm)
- Quads gradient = 90 T/m
- Small magnets ~ 20 cm x 15 cm
- 36 magnets, FFAG





SC Dipole



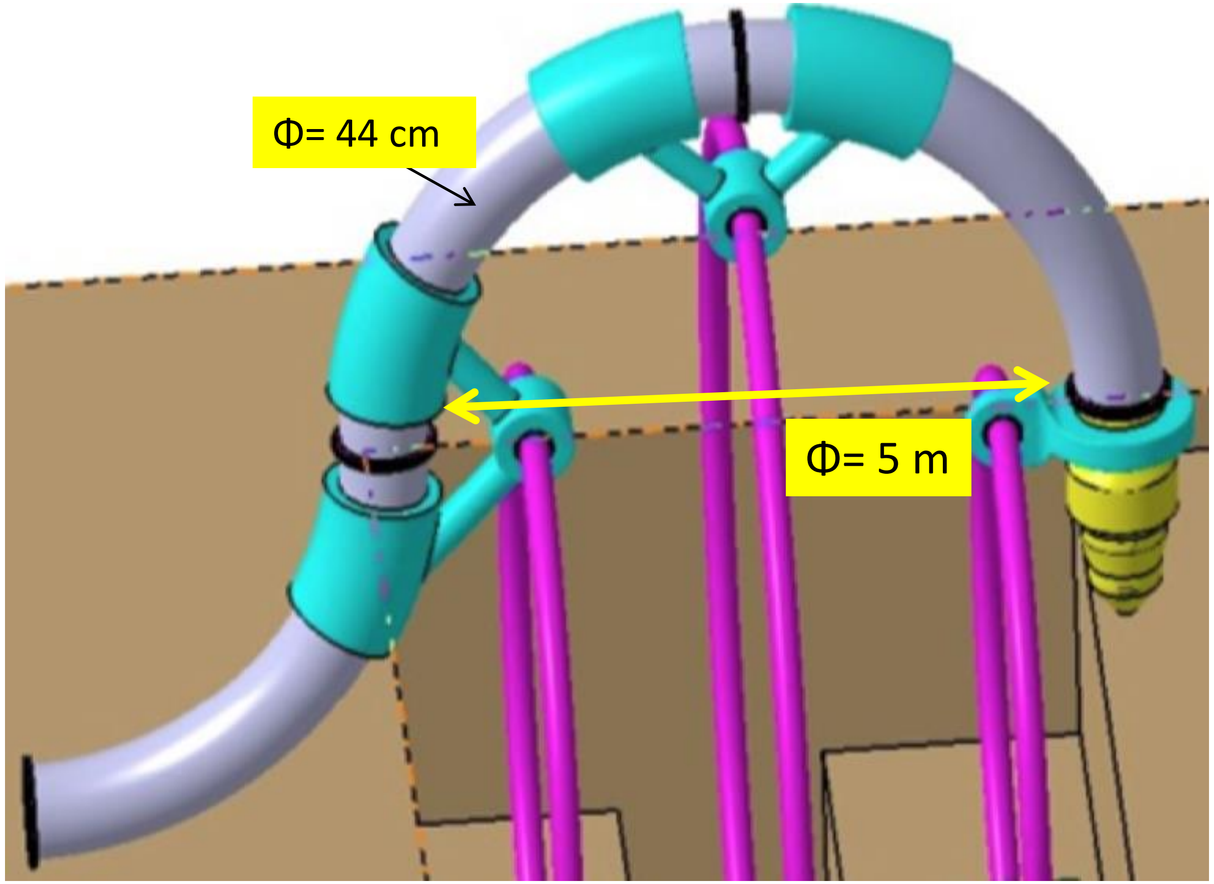
SC quadrupole

SC solenoids

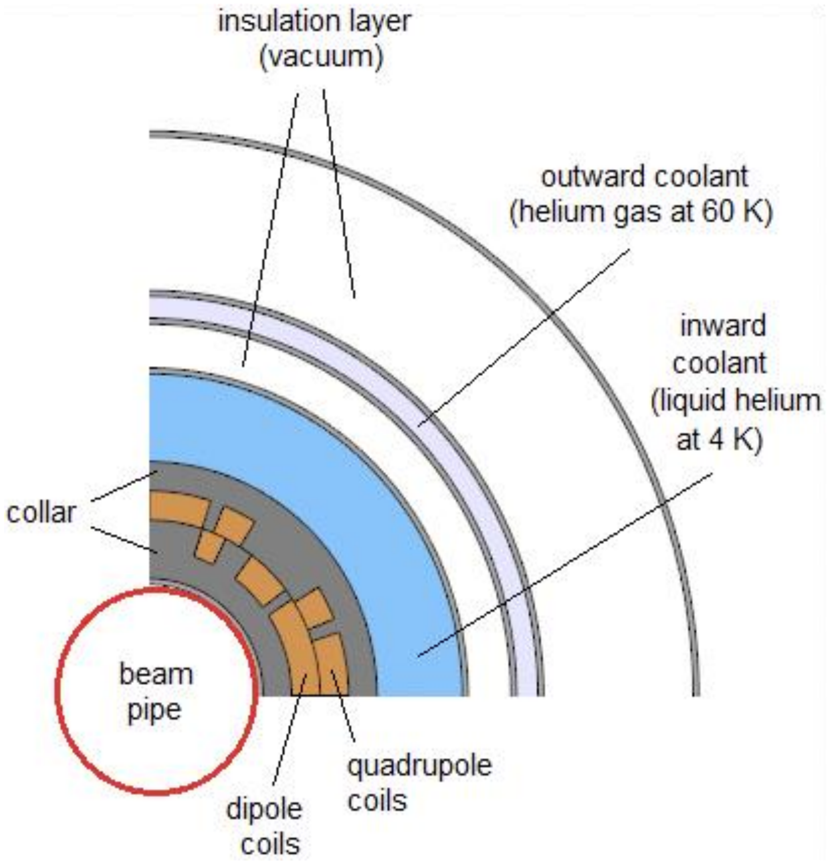
- Combined function magnets for bending and focussing ~ 8 T
- SC RF cavities ~ 10 MV/m
- Non Scaling-Fixed Field AG (NS-FFAG)
- Buncher < 10 MHz

"Design of a superconducting Gantry cryostat"

C. Bontoiu, I. Martel, et al., IPAC-2015, doi:10.18429/JACoW-IPAC2015-WEPMN051



Gantry layout

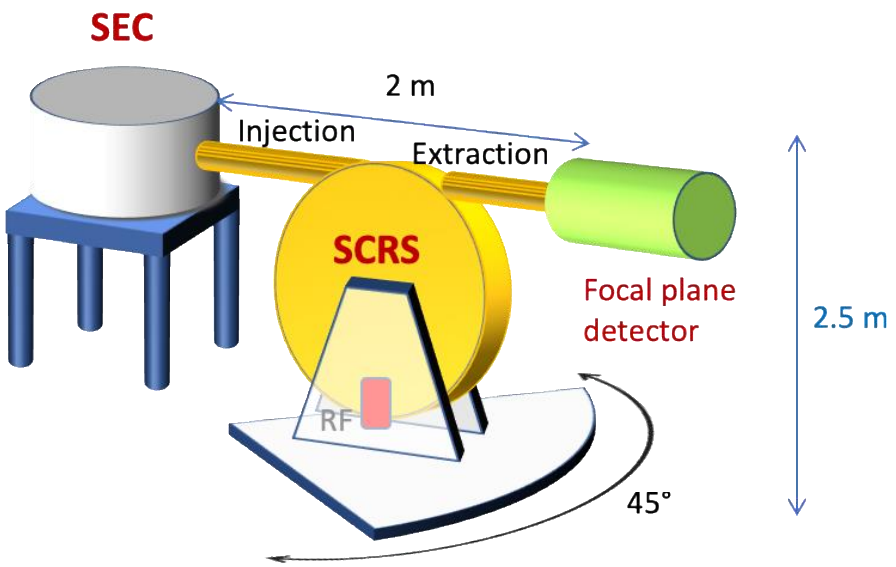


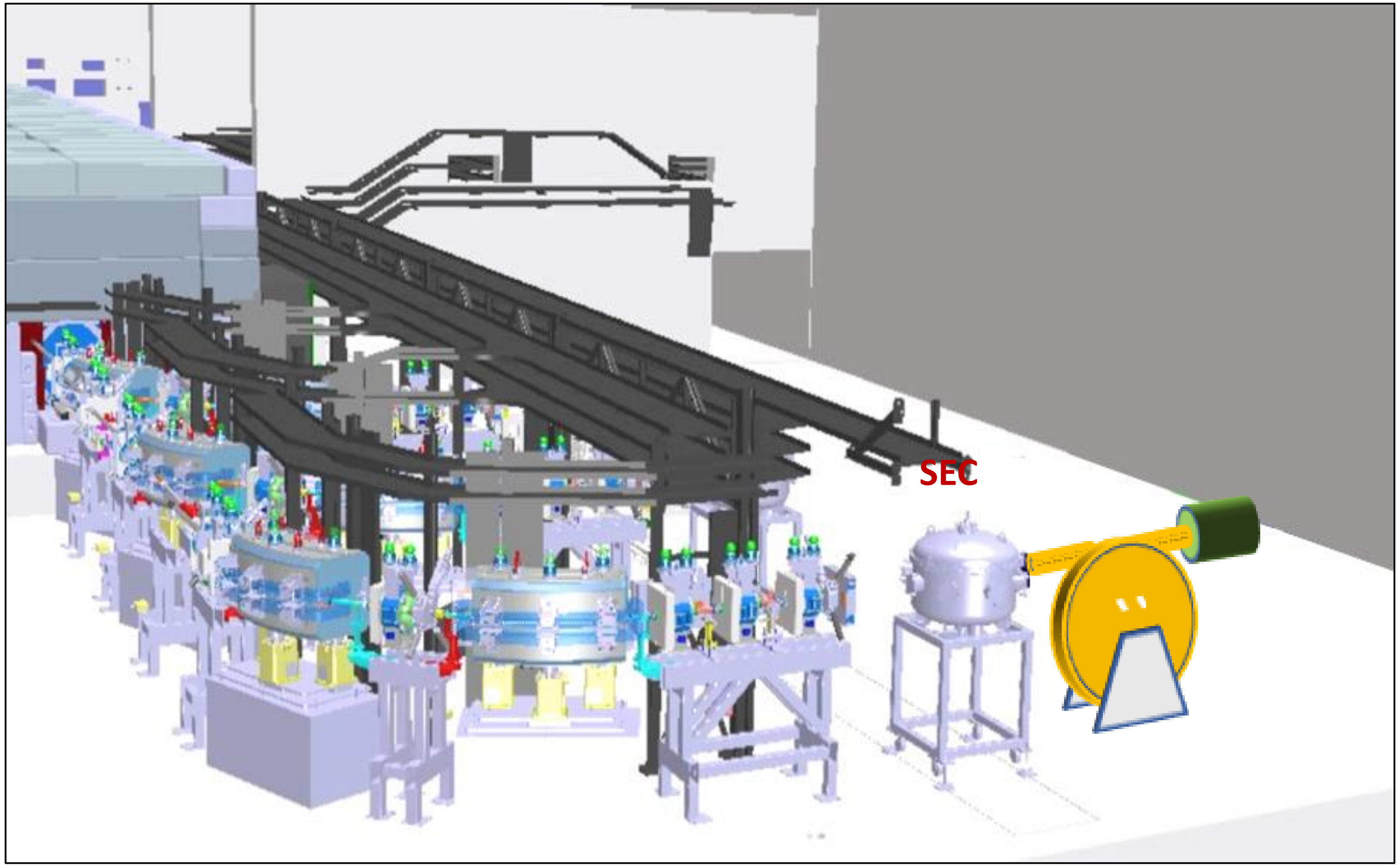
Superconducting Recoil Separator

R [m]	0.5 - 1
B [T]	2 - 6
f_0 [MHz]	10 - 40
f_k [kHz]	100 - 3000
Storage t [μs]	0.5 - 10

Using RF → Extract primary beam and selected isotopes

Vertical layout





FFGA lattice design

J. Resta, V. Rodin, C. Welsch – Cockcroft Institute (UK) & U. Liverpool

BMAD model

Example for **^{234}Ra** @ 10 MeV/u
Rigidity *Bρ* =1.2 T m
Ring circumference: 6 m
FFAG
20 magnets

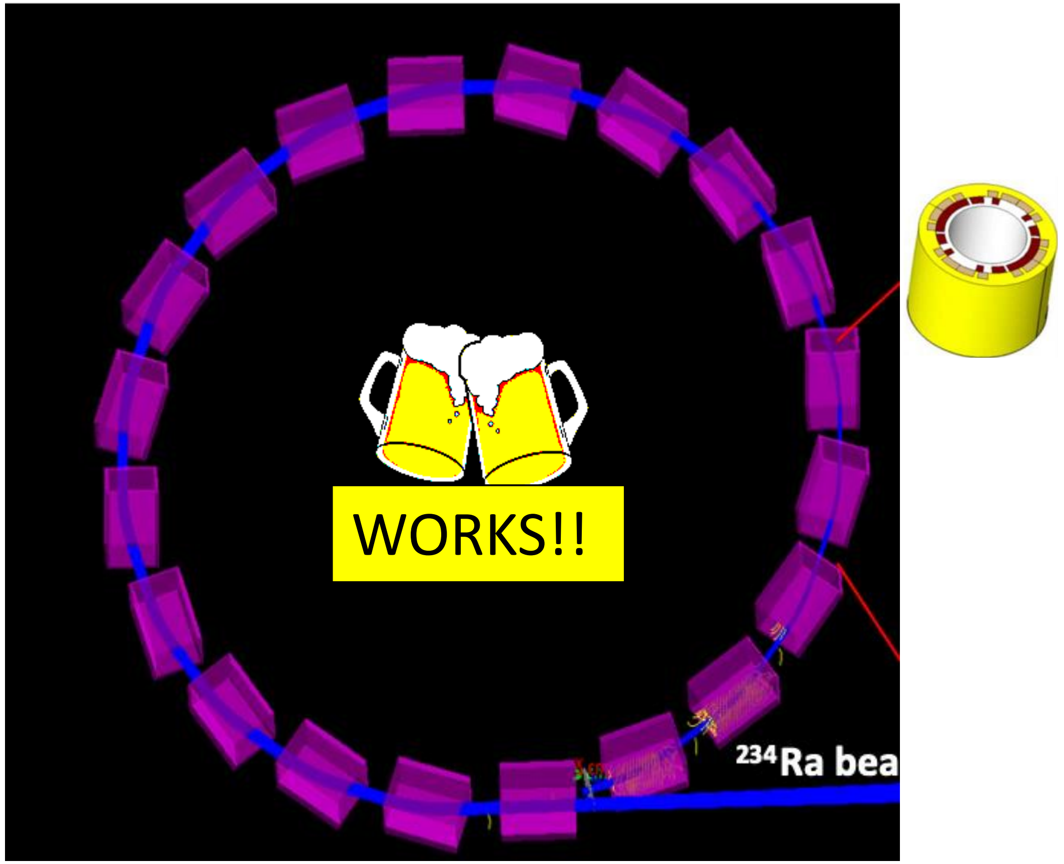
Dipolar magnetic field *B*=1.9 T

Bending angle *ϑ*=0.3 rad

Integrated quadrupolar strength *KL*=1.0 m^{-1}

G4beamline "toy" model

Scaling the EM fields of multifunction magnets designed in the context of a superconducting Gantry cryostat [C. Bontoiu, et al., IPAC2015, doi:10.18429/JACoW-IPAC2015-WEPMN051]



- Closed stable orbit for a ^{234}Ra beam at 10 MeV/u.
- Still need to fully characterise the optics and study the beam dynamics of both the main beam and the reaction products.
- The work is ongoing.

INFRADEV-01 call: Design study of the Isolde Superconducting Recoil Separator

European Commission

Funding & tender opportunities

Single Electronic Data Interchange Area (SEDIA)

English EN

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select programme

Horizon 2020 Framework Programme (H2020)

clear filter

Oct 27, 2017

Design Studies

ID: INFRADEV-01-2019-2020

The Commission considers that proposals requesting a contribution from the EU of between EUR 1 and 3 million would allow this specific challenge to be addressed appropriately. Nonetheless, this does not preclude submission and selection of proposals requesting other amounts.

Type of action:

- RIA Research and Innovation action

Deadline Model : single-stage

Opening: **25 July 2019**

Deadline: **12 November 2019 17:00:00 Brussels time**

Open

Work Plan → under discussion

WP1	**Project Coordination and Management**

WP2	**System specifications and selection of technologies**
T2.1	State of the art
T2.2	**Physics case/White book**
T2.3	Conceptual design and critical components

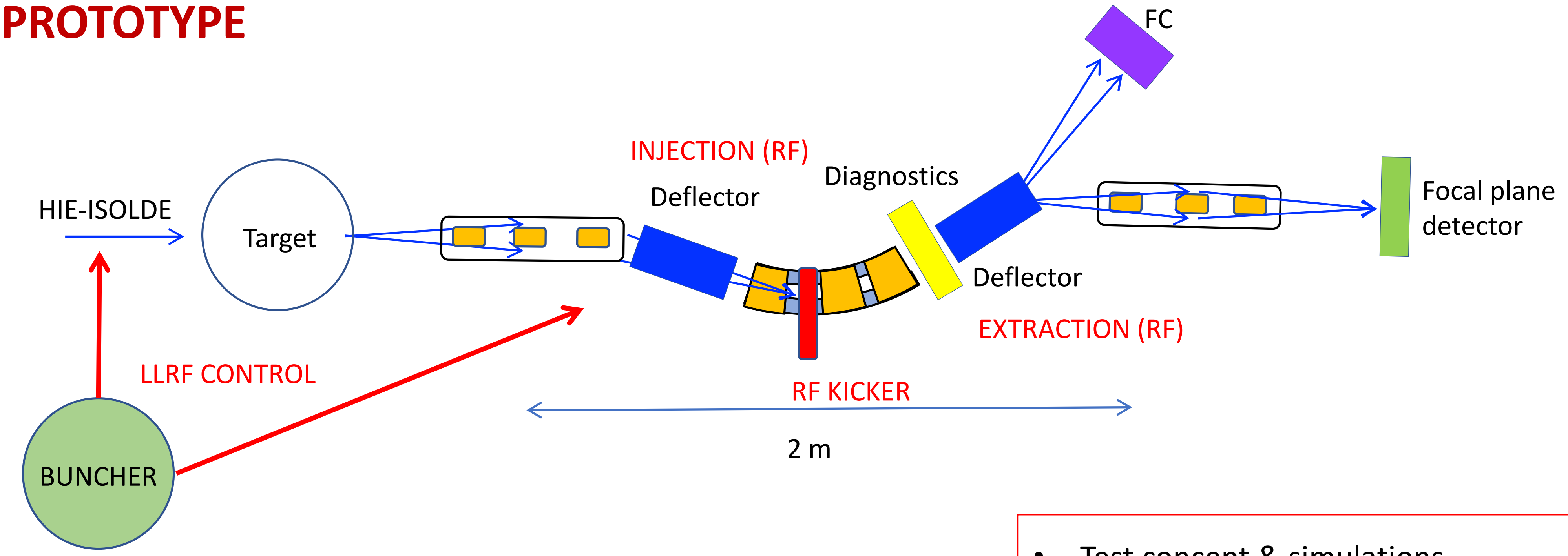
WP3	**Design study**
T3.1	Beam dynamics FFAG
T3.2	Beam transport (SEC, MINIBALL and ISS)
T3.3	Buncher
T3.4	Re-buncher system
T3.5	Superconducting multifunction magnets
T3.6	Magnetic probes and magnet test bench
T3.7	Injection/extraction system
T3.8	Ring cryomodule design, cryogenic system, control
T3.9	RF and LLRF systems
T3.10	Beam diagnostic systems
T3.11	Focal plane detectors
T3.12	Ancillary detectors and special equipment
T3.13	Machine and personal safety
T3.14	Budget and timeline

WP4	**Construction of prototypes**
T4.1	Beam transport
T4.2	Buncher
T4.3	Debuncher
T4.4	Injecction/extraction
T4.5	Multifunction magnets
T4.6	Magnetic probes
T4.7	Magnet test bench
T4.8	Ring cryomodules, cryogenic system, control
T4.9	Beam diagnostics
T4.10	Focal plane detector

WP5	**Prototype evaluation and test**
T5.1	Prototype testing plan
T5.2	Off-line test and data analysis
T5.3	System integration
T5.4	Commissioning at HIE-ISOLDE
T5.5	Off-line test and data analysis
T5.6	In-beam test and data analysis

WP6	**Exploitation and dissemination**

PROTOTYPE



- Target chamber
- 3 x Combined function SC magnets
- 2 X Deflectors for injection/extraction
- RF cavity
- Diagnostics
- Focal plane detector

- Test concept & simulations
- Magnet production
- Injection/extraction
- Storage/transmission
- LLRF control/ HIE-ISOLDE LINAC
- Beam diagnostics
- etc

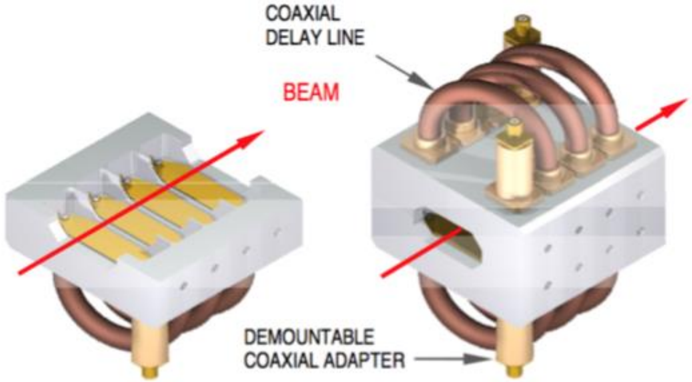
KICKERS/INJECTION/EXTRACTION

HIPPI

HIPPI Work Package 4 (WP4): The RAL[†] Fast Beam Chopper Development Programme
Progress Report for the period: January 2007 – June 2008

M. A. Clarke-Gayther[†]

[†] STFC Rutherford Appleton Laboratory, Didcot, Oxfordshire, UK

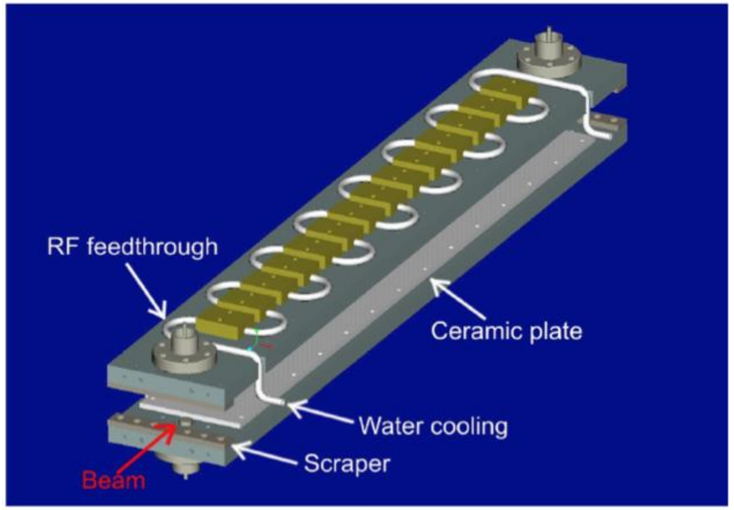


EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/PS/2002-056 (RF

DESIGN OF A CHOPPER LINE FOR THE CERN SPL

F. Caspers, K. Hanke, A. Lombardi, A. Millich, A. Mostacci[1] , M. Paoluzzi, M. Vretenar



Summary and conclusions

- Existing physics programs would benefit from a Recoil Separator.
- Specific Physics Program for a Recoil Separator.
- Specific ancillary detectors and equipment to complement the Recoil Separator.
- Design study of a mini-storage ring using SC coils and RF cavities to produce a compact, efficient instrument.
- Full support of ISOLDE Collaboration Committee
- First beam dynamics calculations started.
- Proposal for funding design study to EU INFRADEV-01 call by international collaboration.

  ✓ HIE-ISOLDE Recoil Separator White Book

  ✓ Prototype: Test concept of SC magnets and RF cavities in ring configuration