Novel Fragment Separators at CERN-ISOLDE: the ISRS and ISLS projects

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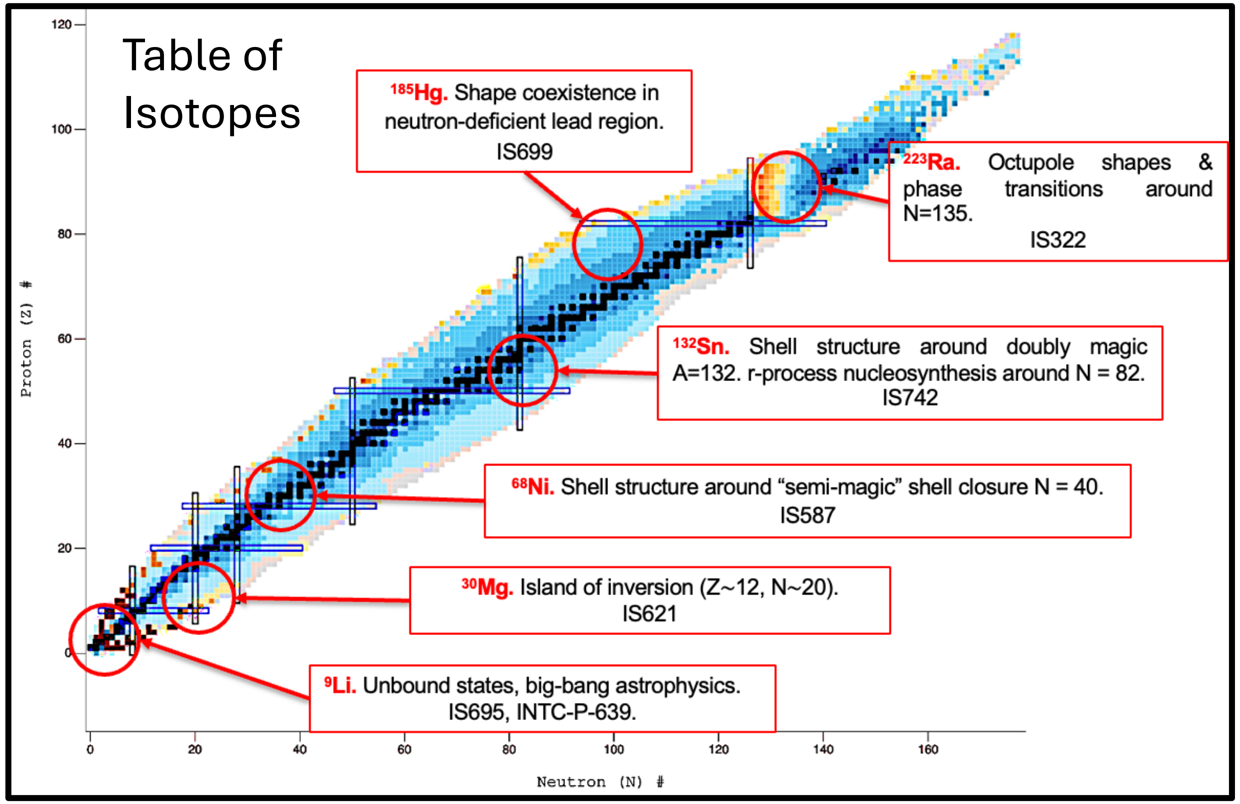
ISOLDE AND HIE-ISOLDE AT CERN

ISOLDE: acronym of "Isotope Separator On-Line DEvice", is the radioactive beam facility at CERN.

- Produces low-energy radioactive beams of more than *1000 isotopes of about 70 elements.*



Isotopes production

- Bombardment of thick targets (UOx, CaO, etc)
- Proton beam of the PS Booster (1.4 GeV)
- Spallation and fragmentation nuclear reactions.
- The targets are heated to release the radioisotopes
- Isotope selection using spectrometers and laser techniques.
- Typical energy ~ 60 keV

HIE-ISOLDE: a radioactive beam post-accelerator that accelerates radioisotopes up to ~ 10 MeV/u.

- Large range of species from ^{6}He to ^{232}Ra.
- Ideal energy range for nuclear studies: structure, reaction dynamics, and astrophysics.

Novel Fragment Separators

ISRS: ISOLDE Superconducting Recoil Separator

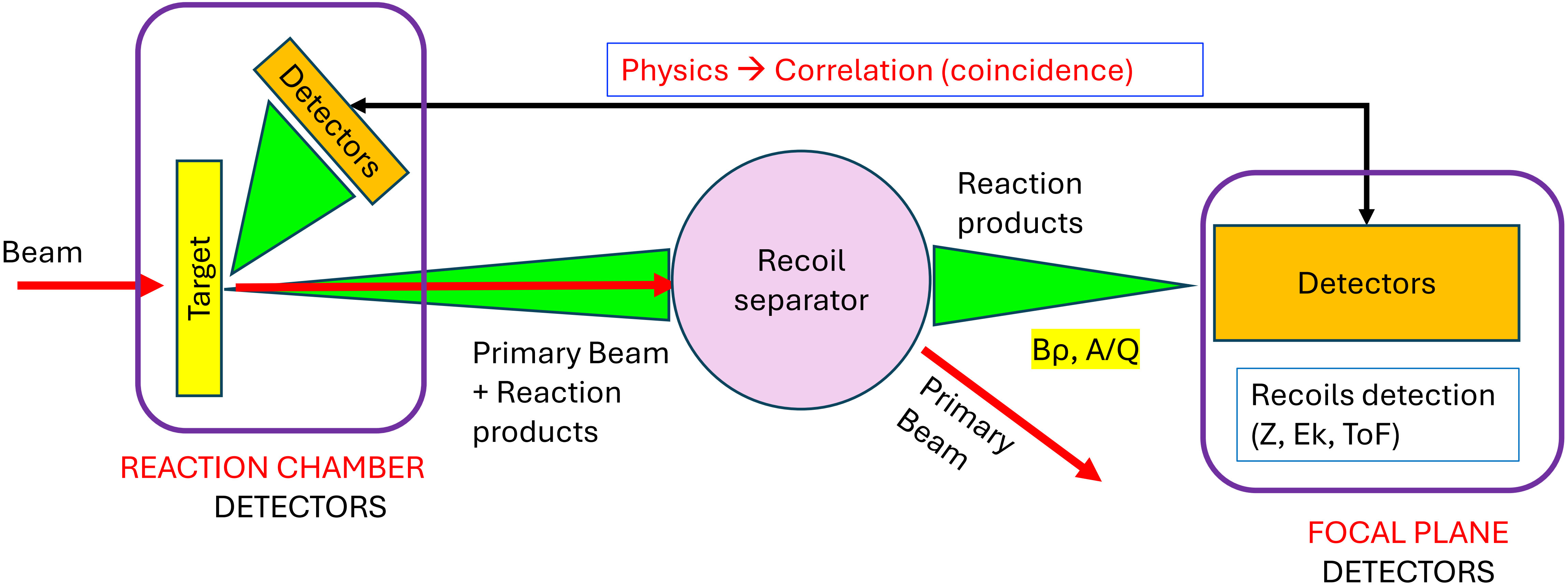
- Ring spectrometer

ISLS: ISOLDE Superconducting Linear Spectrometer

- "Classical" Linear spectrometer → ISRS prototypes

Recoil Separators

- Detection of forward-focussed reaction fragments; suppression of the primary beam.
- Correlate reaction fragments measured at focal plane and reaction target to improve experiment sensitivity.
- Direct reactions (cluster/nucleon transfer), Fusion-evaporation, Superheavy nuclei, Coulex, etc …



Standard fragment separators used in nuclear spectroscopy (5 - 10 MeV/u) usually require **large flight-path** to achieve a good resolution (> 10 m), **and large clean area** (~100 ^{2} m), for rotation to measure at various scattering angles.

Only 25 m^2 available at ISOLDE

ISOLDE Superconducting Recoil Separator (ISRS)

ISRS is a compact high-resolution recoil separator that combines focal plane spectroscopy with particle and gamma detection at the reaction target.

LOI-INTC-228 (2021): I. Martel, O. Tengblad, J. Cederkall

ISRS conceptual design:

- Compact particle storage ring ~3-4 m diameter → Space available
- Transport- Fixed Field Alternating Gradient → Momentum acceptance

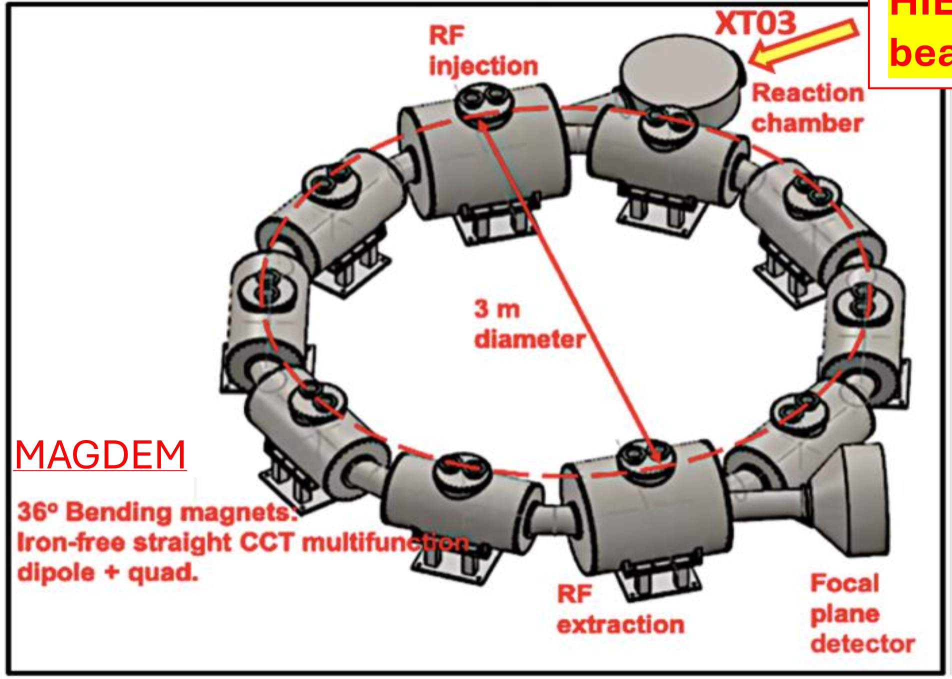
- Superconducting magnets → Bending strength
- Nested dipole + quadrupole functions → Compact
- Canted Cosine Theta (CCT) technology → field homogeneity
- Iron-free → Weight, Hysteresis, Thermal mass
- Cryocoolers technology (no LHe bath) → Portability / Rotation
  - → **Magnet demonstrator** MAGDEM
  - → L800mm x ϕ800 mm, opening ϕ200 mm

- Focal plane detector → Fragment ToF, Ek, Z
- Fragment Injection/extraction system → External target
- Multi-harmonic buncher → 10 MHz for optimum ring operation

ISRS WEB SITE https://www.uhu.es/isrs/

University of Huelva

HIE-ISOLDE beam



R&D FUNDING 2023-2026

Spanish Gov grant (RRF/EU): 3 M€.

- Univ. Huelva (Coordinator)
- ESS Bilbao
- Univ. Valencia
- IEM-CSIC-Madrid

2025-2028 NURISOL

- Univ. Huelva
- Univ. Valencia.

- ✓ Physics program
- ✓ Beam dynamics
- ✓ SC Magnets
- ✓ Focal plane detectors
- ✓ Multiharmonic buncher
- ✓ Ion Test Bench **- ISLS**

MULTIHARMONIC BUNCHER -MHB

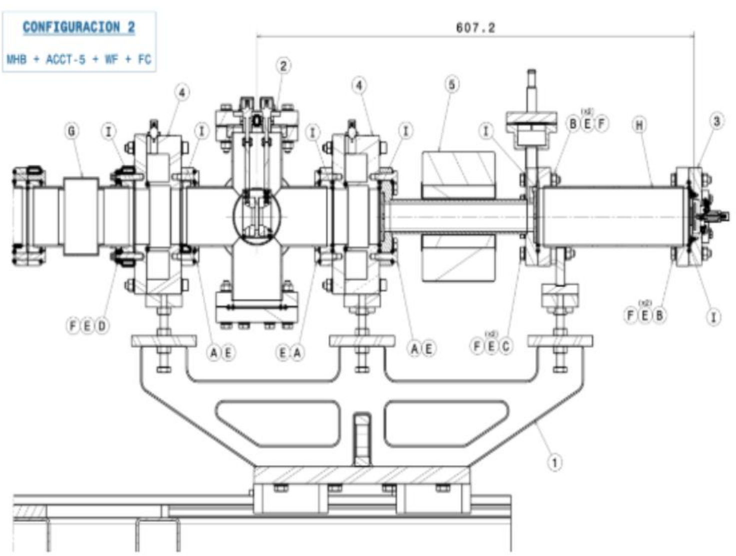
For optimal operation of ISRS, the present HIE-ISOLDE LINAC frequency of 101.28 MHz must be scaled down to 10 MHz. To achieve this goal, a multi-harmonic buncher (MHB) must be developed and installed at HIE-ISOLDE.

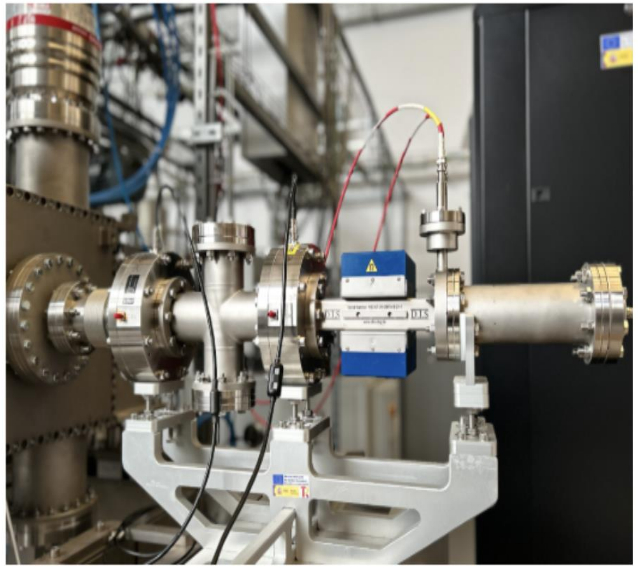
Parameters

- low energy dispersion (< 1%)
- high transmission (> 95%)
- bunch formation (< 5 m)
- Standard 4-way CF63 cross
- To be placed before the RFQ.

Ion Test Bench (ITB)

- ACCT for current measurements
- Fast Faraday Cup for the bunch-length measurements
- Wien filter for velocity selection
- Tests with H ions.





Ion test bench for MHB at ESS-Bilbao equipped with ACCT, Faraday Cup and Wien filter (10.09 keV H2+, ß=0.0328).

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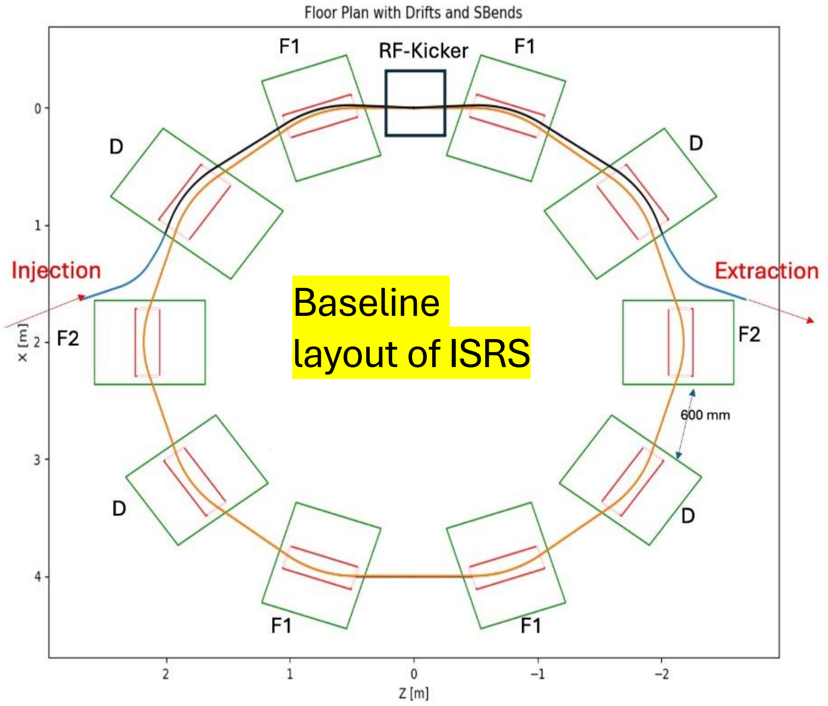
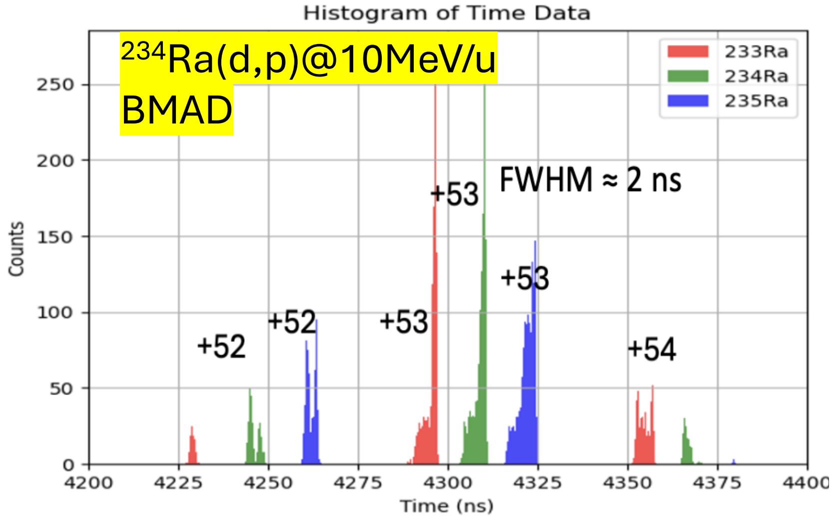
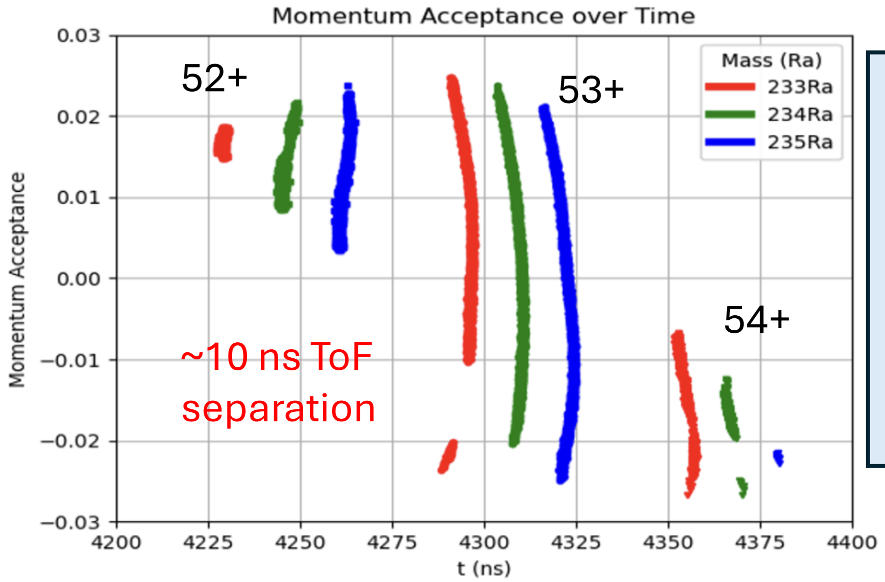
ISRS BEAM DYNAMICS



- Configuration optimization for 10 x MAGDEM units
- BMAD, Xsuite code, RF-Track for first order beam dynamics.
- GYCOSY + COSY INFINITY corrections up to third-order → small.
- Injection/extraction system
  - ✓ RF kicker
  - ✓ Standard + Truncated septum magnet (K. Sugita et al. (GSI), IPAC2018)
  - ✓ 2 ring CCTs

- Isochronous & quasi-isochronous operation ~ compromise on momentum acceptance $\delta P/P$ ~1% - 20%.
- Mass resolving power $\delta M/M$ (isochronous):
  - ✓ ISRS ~ 2100 (10 turns ~ 4.5 us)
  - ✓ S800/SNCL-MSU (2000), PRISMA/LNL (300)
  - ✓ Increases with storage time (→ 10^5!?), presently under study.





FOCAL PLANE DETECTORS

- Time resolution < 100ps
- Energy resolution < 100 keV.

  → Diamonds

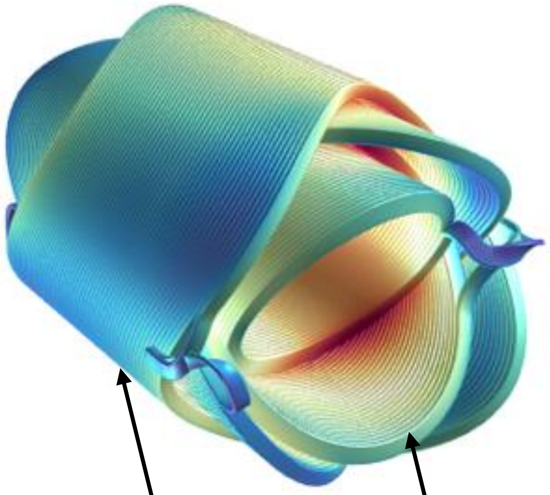
  → Silicon Carbide

ISRS MAGNET DEMONSTRATOR: MAG-DEM

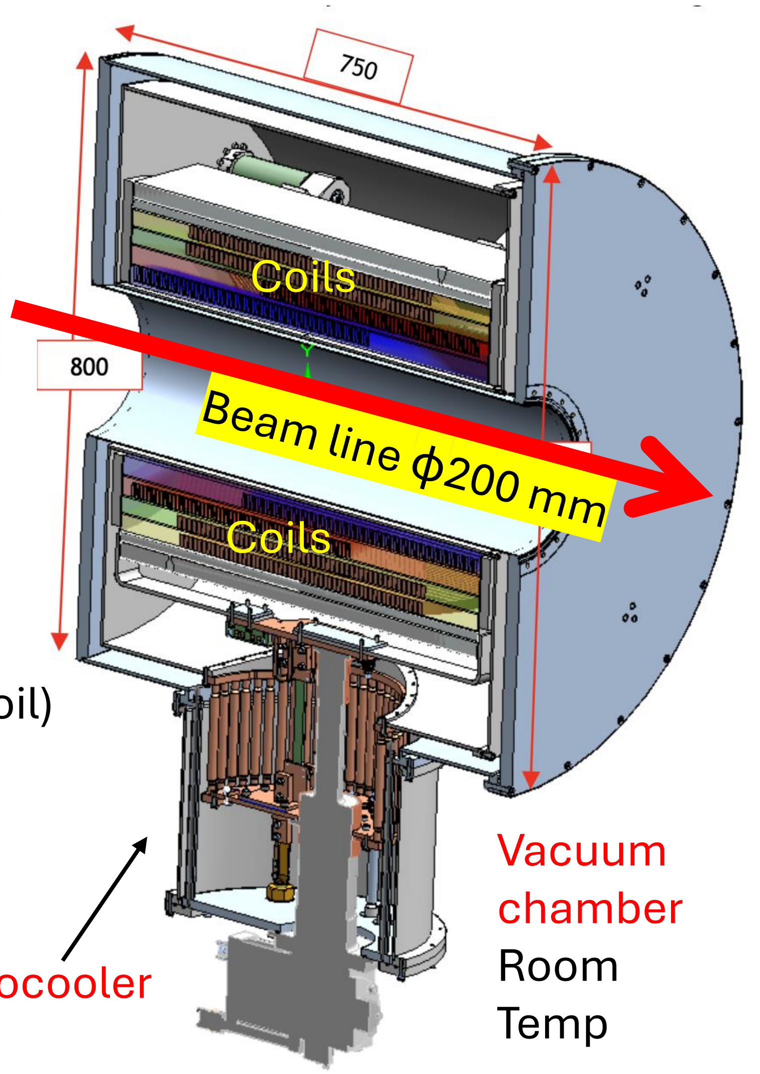
MAGDEM: Cryogen-free, iron-free, nested, dipole + quadrupole Canted Cosine Theta (CCT) superconducting magnet (NbTi) cooled by a cryocooler (GM).

- Already designed and expected delivery by external contractor @ Univ. Huelva (Spain) by Summer 2026.
- Dipole field 2 T, Quad gradient 9 T/m
- A week cooling time.
- Unique cryo-cooled CCT SC magnet for beam circulation with dipole and quad functions.

Aperture diameter	200 mm
Former length	606 mm
Magnetic bend	36 degrees
Magnetic length	1500 mm
Spiral pitch	5.7 mm
Peak dipole field at Inom	2.02 T
Dipole field integral at centre	0.75 Tm
Nominal dipole current	145 A
Peak Quadrupole field at r=100mm, Inom	0.92 T
Quadrupole integrated field at r=66.6mm	0.254 Tm
Nominal quadrupole current	141.6 A

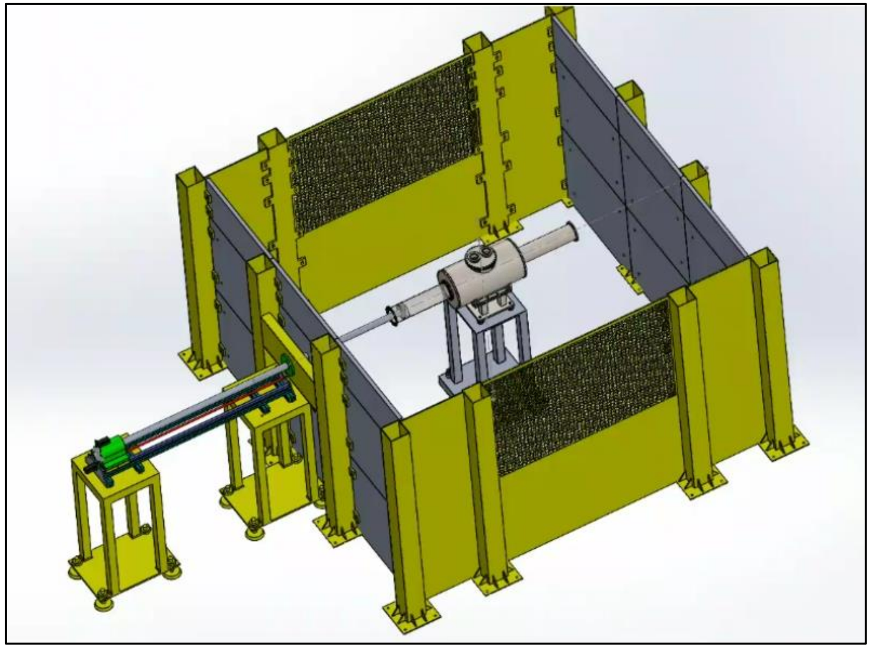


Coil design

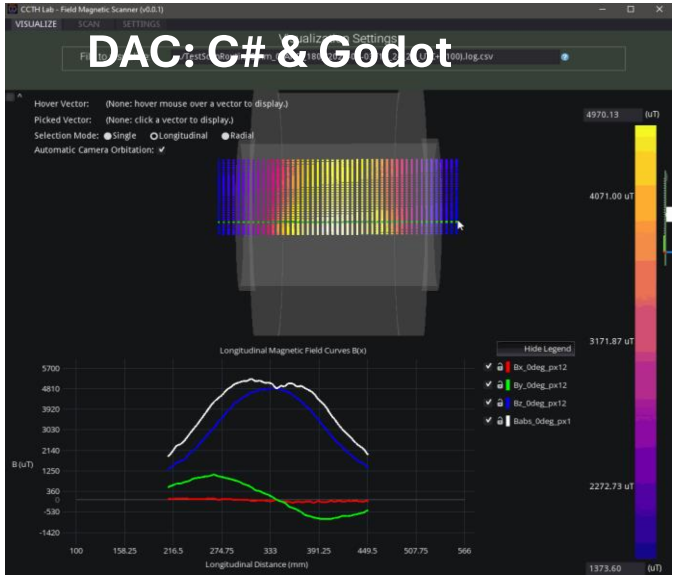


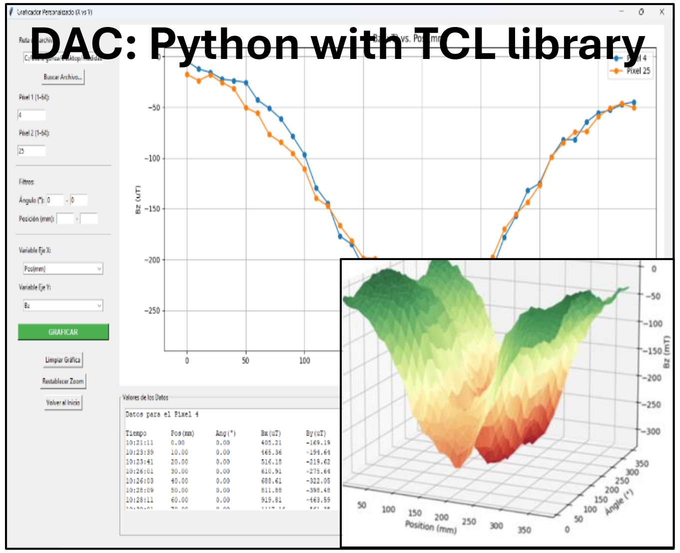
MAGDEM demonstrator

MAGNETIC FIELD SCANNER SYSTEM – MFSS



Commission of Magnetic Field Scanner at University of Huelva (Spain).





DAQ & Ctrl systems

- Scanner for cylindrical volumes
- ϕ_{max} 300 mm, L_{max} 1500 mm
- Linear and rotary step motors (PLC ctrl)
- Mechanical pres. 0.05 mm (L), 2 mrad (θ)
- 64 Hall 3D sensors in 2 rows x 32
- Resolution ~ 50 μT
- Remote ctrl (PC), monitoring, DAQ
  - C# & Godot
  - Python + TCL

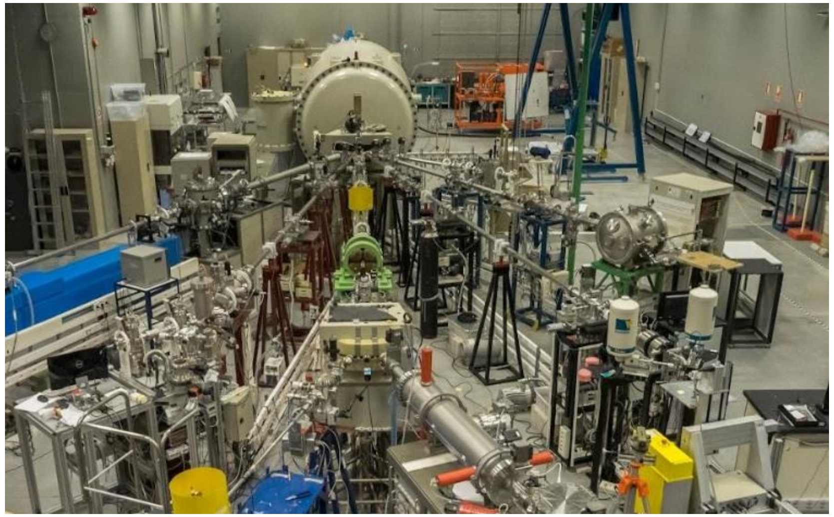
METROLAB probe HallinSight® 32×2

FOCAL PLANE DETECTOR

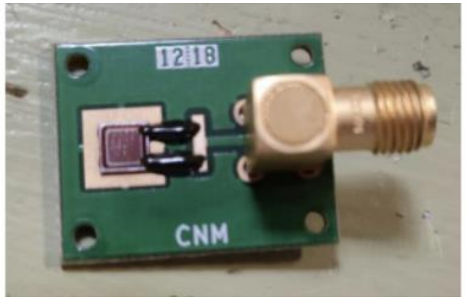
ISRS ring → A/Q selectivity

- Focal plane: ToF, Z, Ek
- Reaction chamber: M, Z, Time, Ek
- Coincidence Target – Focal plane
- Neutron (Plastic, Liquid)
- Gamma (LaBr, BGO, HPGe, NaI(Tl))
- Particle (Ioniz. Chamb., SS detectors)
  - ➢ Si-DSSD, Si-monolitic
  - ➢ SiC, Diamond

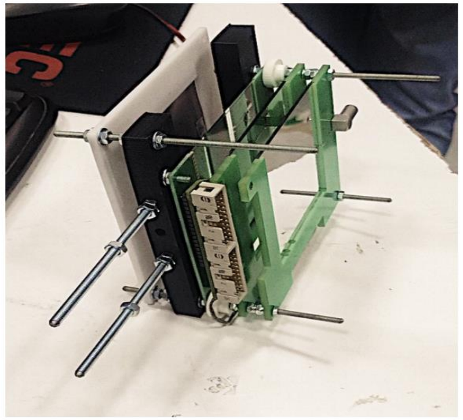
3MV Tandem at CNA (Seville, Spain)



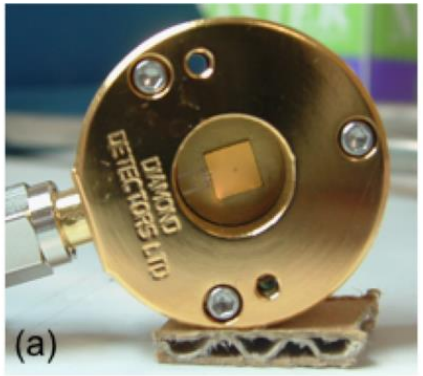
5MV Tandetron at CMAM (Madrid, Spain)



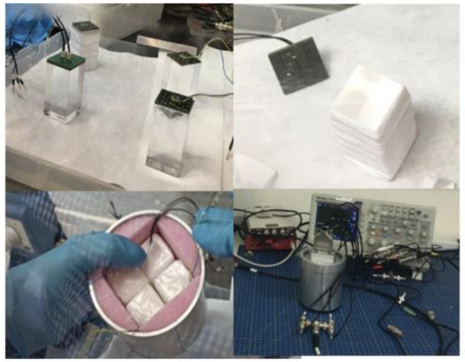
CNM - Barcelona & IEM/CSIC-Madrid SiC detectors of 50 and 100μm



Si DSSD telescope BB7 Micronsemiconductors Ltd



50 um sc-CVD diamond detector. Diamond Detectors Ltd



LaBr3 clover detectors developed at UWS

ISOLDE SUPERCONDUCTING LINEAR SPECTROMETER – ISLS

Ion Test Bench for MAGDEM characterisation that can operate as a linear spectrometer → the ISOLDE Superconducting Linear Spectrometer

- Installation at ISOLDE during CERN LS3 (2026-2028).
- CERN LoI INTC-I-283 (2025). Spokespersons I. Martel (Univ. Huelva), T. Kurtukian-Nieto (IEM-CSIC, Madrid), I. Bustinduy (ESS-Bilbao), J. Resta (Univ. Valencia).

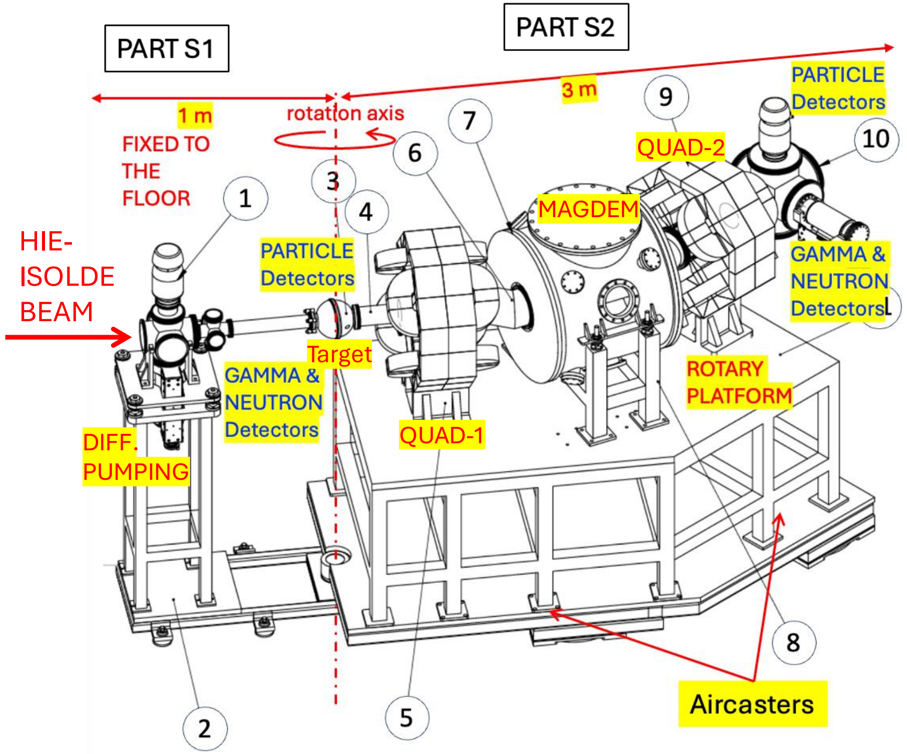
-**Optimize beam transport** (BMAD and GCOSY).

→Dispersion ~ 0.6 cm/%, +/-50 mrad acceptance.

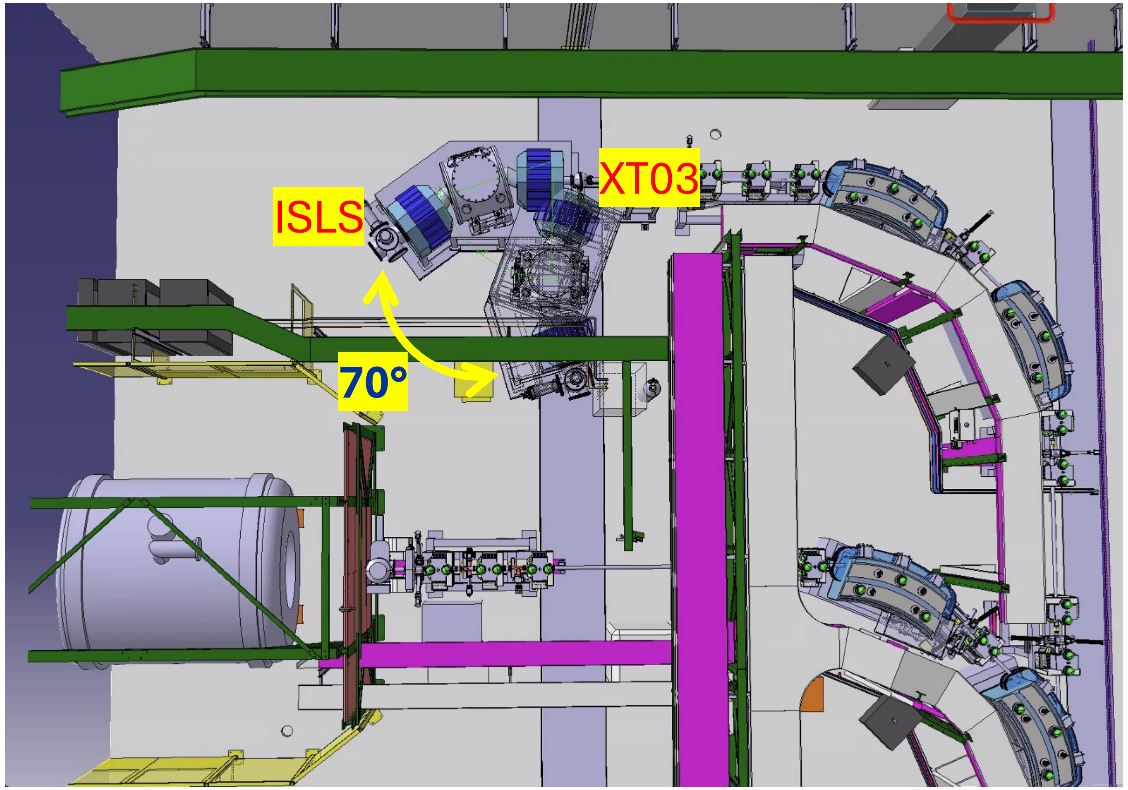
→PRISMA (LNL-INFN Italy), 1.4 cm/%/ & 200 mrad

→ Physics studies for light masses up to ~ Mg isotopes

- Physics program and performance simulations are in progress.



Layout of the ISLS spectrometer at the XT03 beam line



Integration of ILS spectrometer in XT03 beam line

SUMMARY AND CONCLUSIONS

ISOLDE Superconducting Recoil Separator (ISRS)

- The ISRS is a high-resolution ring spectrometer designed to combine focal plane spectroscopy with particle and gamma detection at the reaction target.
- Present layout consists of a compact storage ring of only ~4 m diameter with superconducting, iron-free CCT magnet technology, allowing for isochronous and quasi-isochronous operation.
- The system achieves an excellent mass resolving power of ~ 2100 with only 10 turns, requiring focal plane detectors with a TOF resolution of < 100 ps and energy resolution of ~100 keV.
- Prototypes of buncher, MAGDEM, Magnetic Field Scanner system, and Focal plane detectors are under construction.

ISOLDE Superconducting Linear Spectrometer (ISLS)

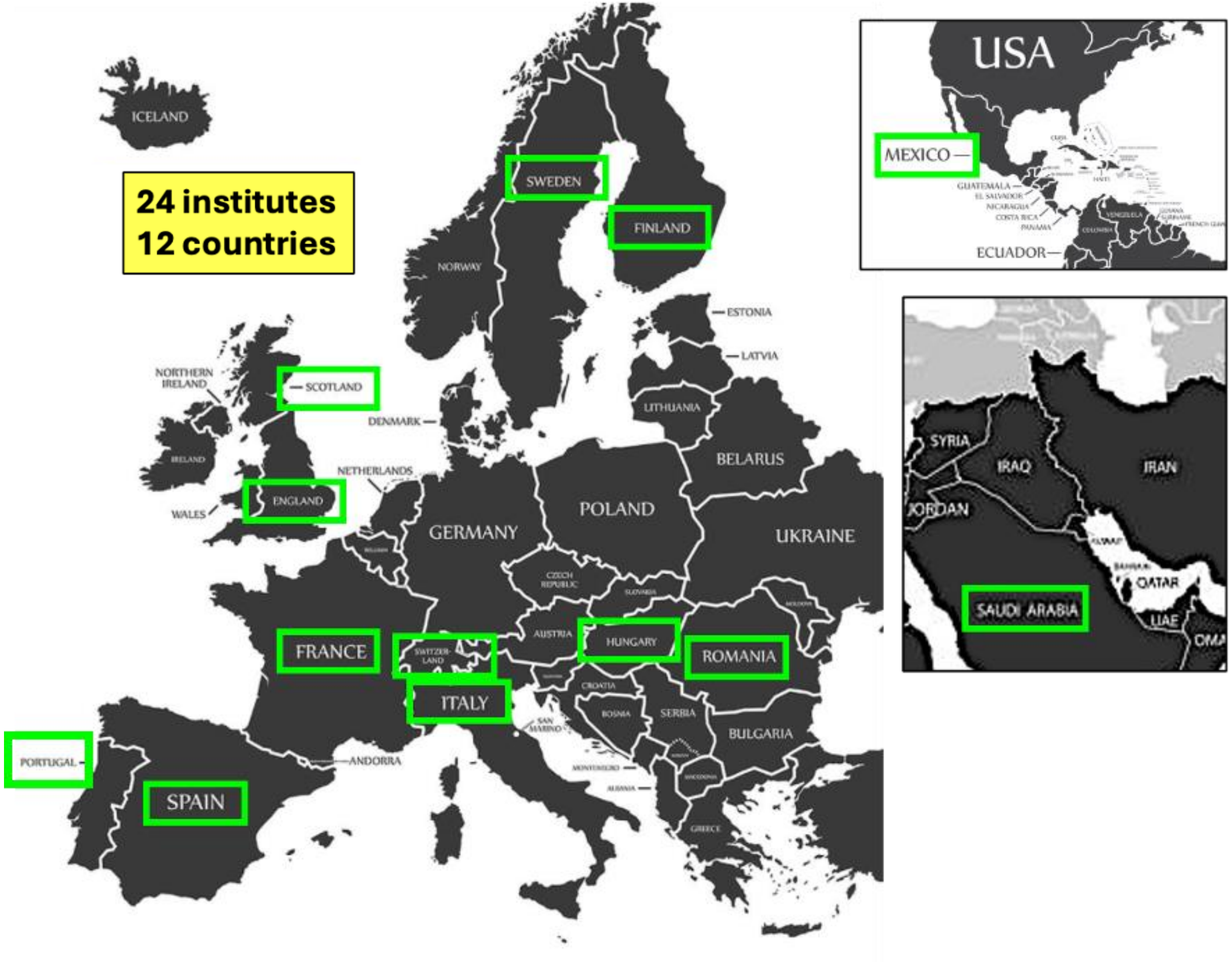
- ISLS is a "classical" linear spectrometer based on the MAGDEM demonstrator, providing highest possible performance with the available footprint.
- Limited mass dispersion of ~0.6 cm/% and +/- 50 mrad acceptance; Physics focused on light to medium mass isotopes.
- Installation is foreseen during CERN LS3 (2026-2028).

THANKS!!

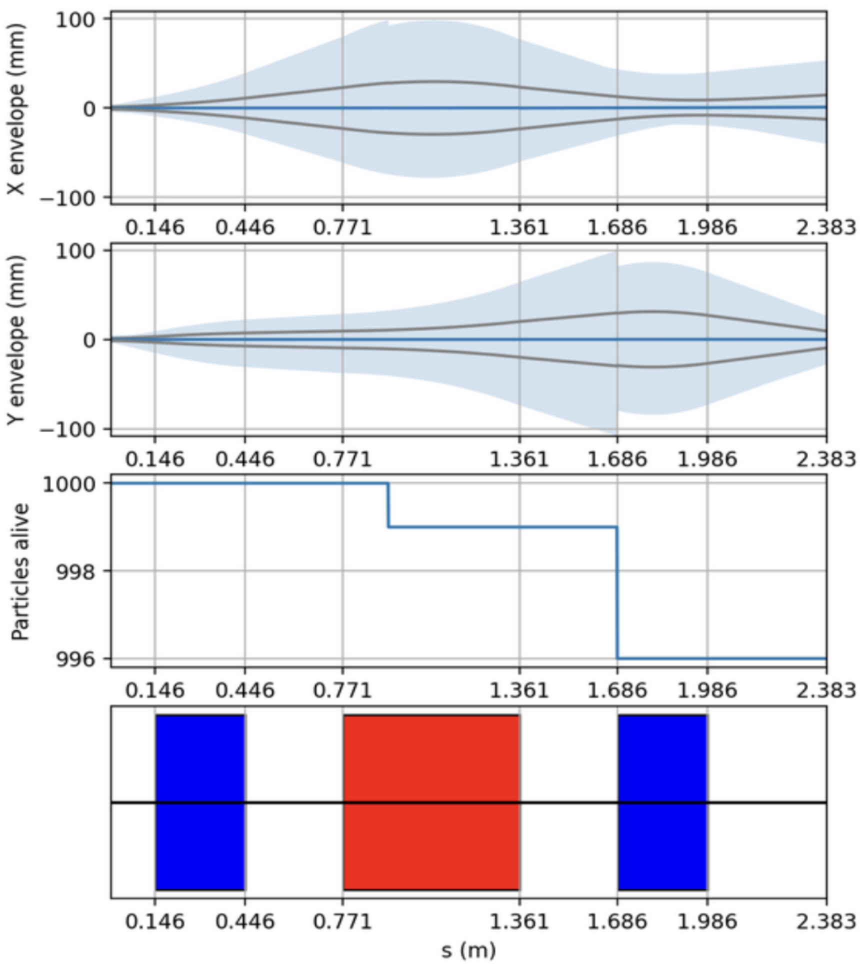
Universidad de Huelva · Vniversitat de València · ESS Bilbao · CSIC Consejo Superior de Investigaciones Científicas · ISOLDE · CERN · Ministerio de Ciencia e Innovación · Plan de Recuperación, Transformación y Resiliencia · Financiado por la Unión Europea NextGenerationEU

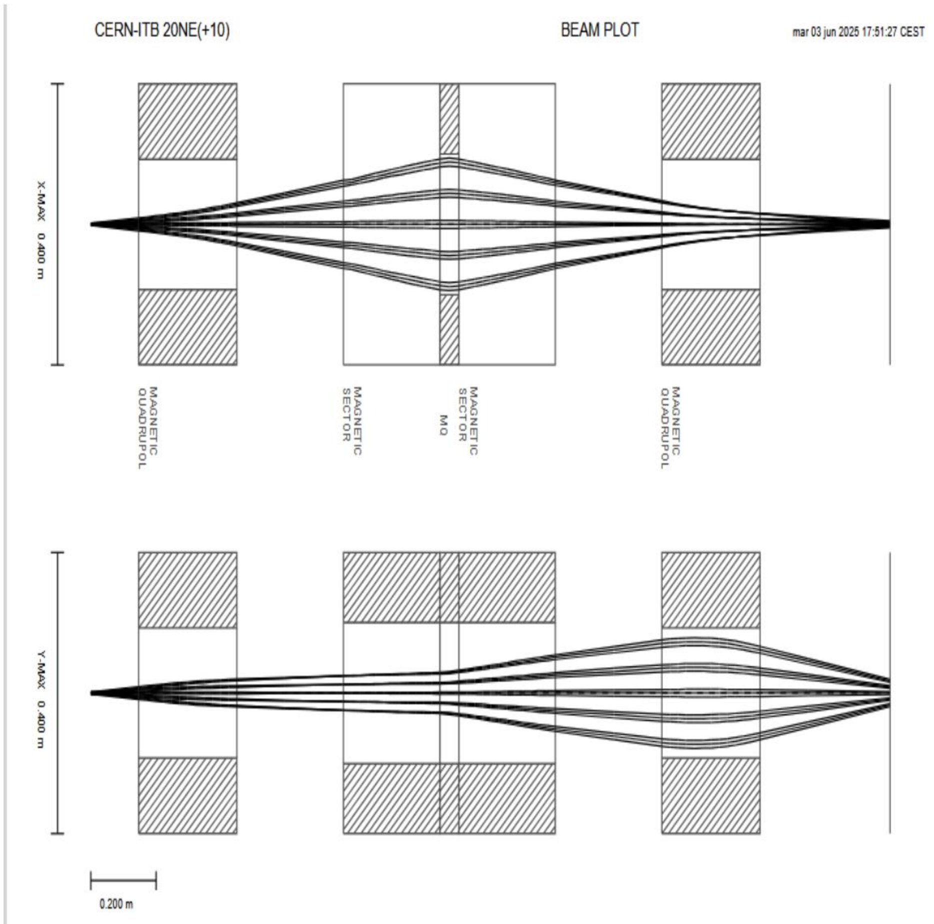
ISRS Collaboration

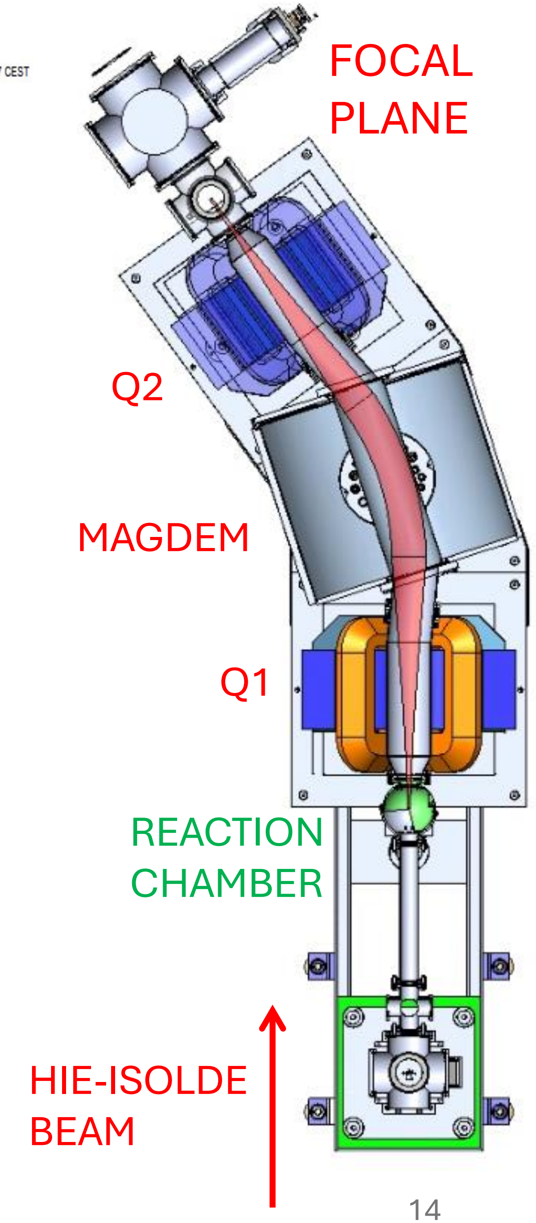
- Astroparticule et Cosmologie, Univ. Paris Diderot, Paris, France.
- CERN, Geneva, Switzerland.
- CENGB, Gradignan, France.
- Cockcroft Institute, Daresbury, UK.
- Dpt. Ciencias Integradas, Univ. Huelva, Spain.
- Dpt. of Physics and Astronomy, Aarhus Univ., Denmark.
- Dpt. of Physics, Chalmers Univ. of Technology, Göteborg, Sweden.
- Dpt. of Physics, Lund Univ., Sweden.
- Dpt. of Physics, Univ. Liverpool, UK.
- Dpt. of Physics, Univ. Surrey, UK.
- Dpt. of Physics, Univ. York, UK.
- ESS-BILBAO, Bilbao, Spain.
- Faculty of Mathematics and Science, Univ. Jyvaskyla, Finland.
- ICMUV, Univ. de Valencia, Spain.
- IFIN-HH, Bucharest, Romania.
- IPNO, Univ. Paris-Sud, Orsay, France.
- Inst. de Estructura de la Materia, CSIC, Madrid, Spain.
- Inst. de Física, UNAM, México.
- IMIS Univ. Riyadh, Saudi Arabia.
- LIP - Laboratório de Instrumentação e Partículas
- LNL INFN, Italy.
- Univ. of West Scotland, UK.
- Univ. Edinburgh, UK.
- Uppsala Univ., Sweden.
- Wigner Research Centre for Physics, Budapest, Hungary.



ISOLDE Linear Spectrometer ILSL– Beam optics studies







Beam transport simulations using BMAD and GCOSY. Maximum mass dispersion for MAGDEM ~ 1 cm%. For the final configuration: dispersion ~ 0.6 cm/%, +/-50 mrad angular acceptance. → PRISMA (LNL-INFN Legnaro, Italy), 1.4 cm/% and 150-200 mrad

ISOLDE Linear Spectrometer – First test experiment

^{19}Ne + d → ^{20}Na + n (1p capture)

$^{20}Ne + p\ (1n\ transfer)$ q= 6$^+$

$^{19}Ne + d\ (elastic)$ q= 6$^+$

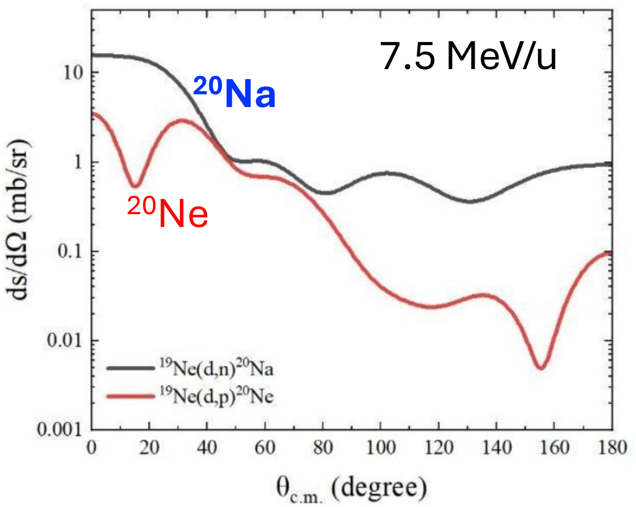
$^{19}Ne\ (beam\ )$ q= 6$^+$

$^{20}Na\ (recoil)$ q= 7$^+$

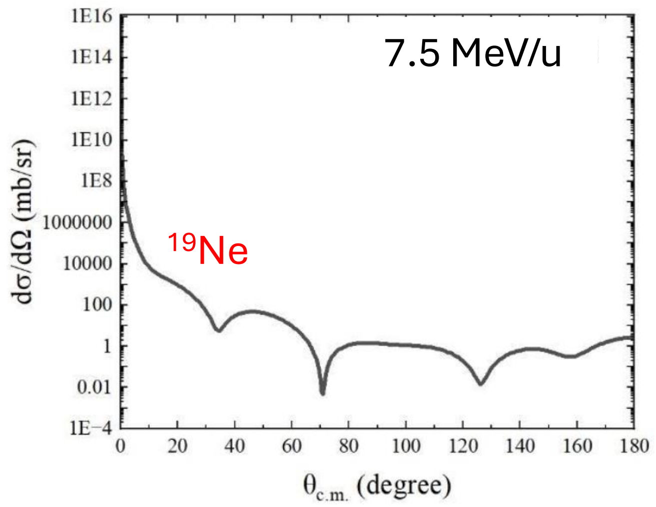
FRESCO

IJ. Thompson, CPR. 7(1988)167.

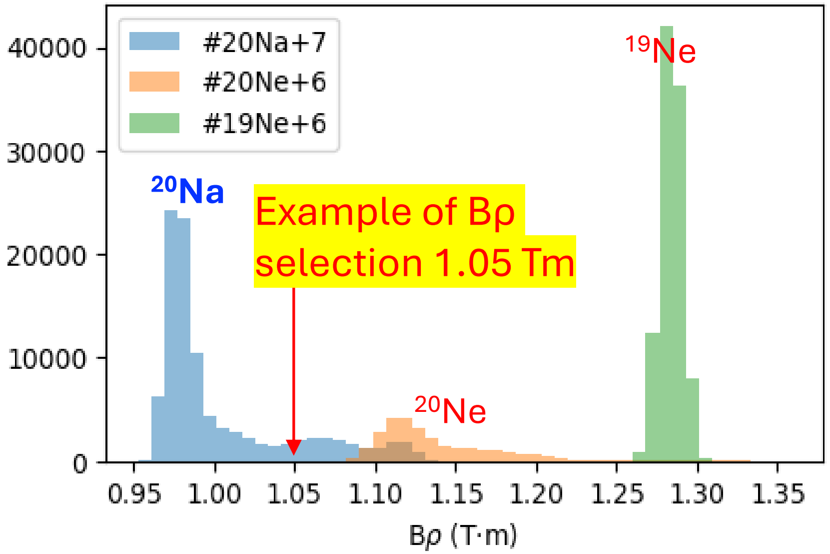
Proton and neutron capture



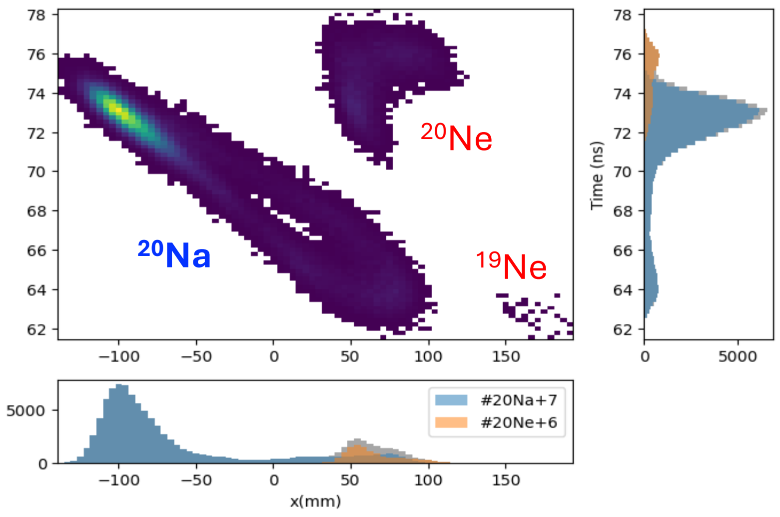
Elastic scattering



MAGDEM Bρ scan plot



TOF (ns) – Focal Plane position (mm)



Scattering angle selection

θLab = **0** ±0.2 deg