XVI CPAN DAYS

Status and physics opportunities of the ISOLDE Superconducting Recoil Separator ISRS

Ismael Martel, MJG. Borge, I. Bustinduy, J. Cederkall, T. Kurtukian-Nieto, J. Resta, and O. Tengblad, for the ISRS collaboration

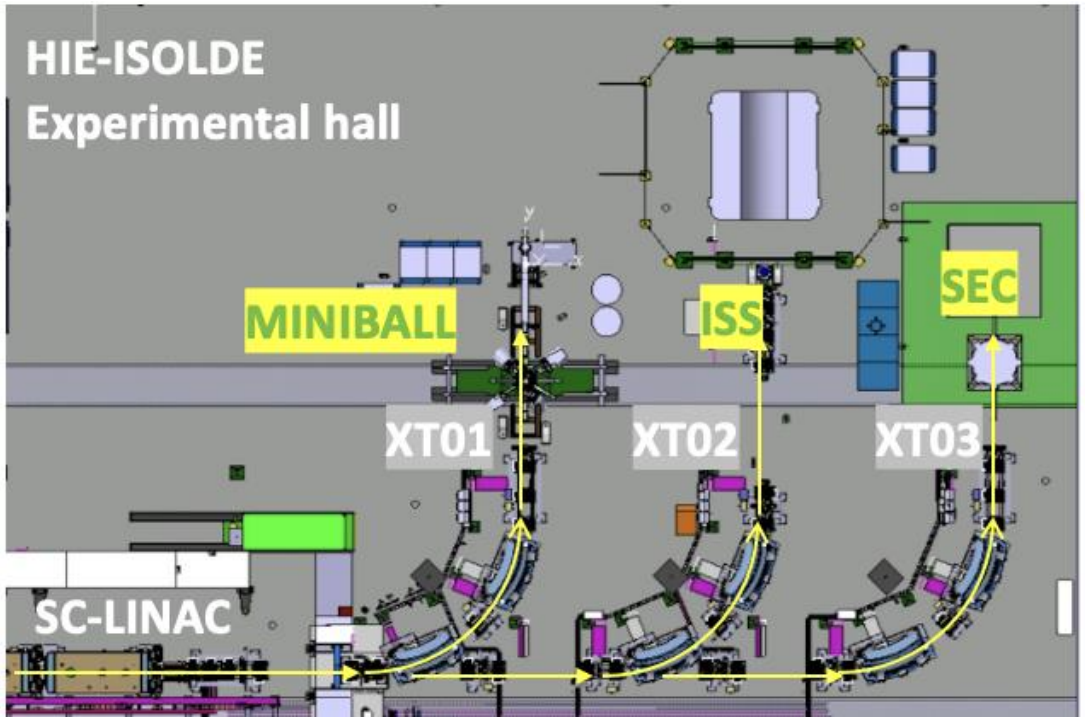
ISRS Web site
https://www.uhu.es/isrs/

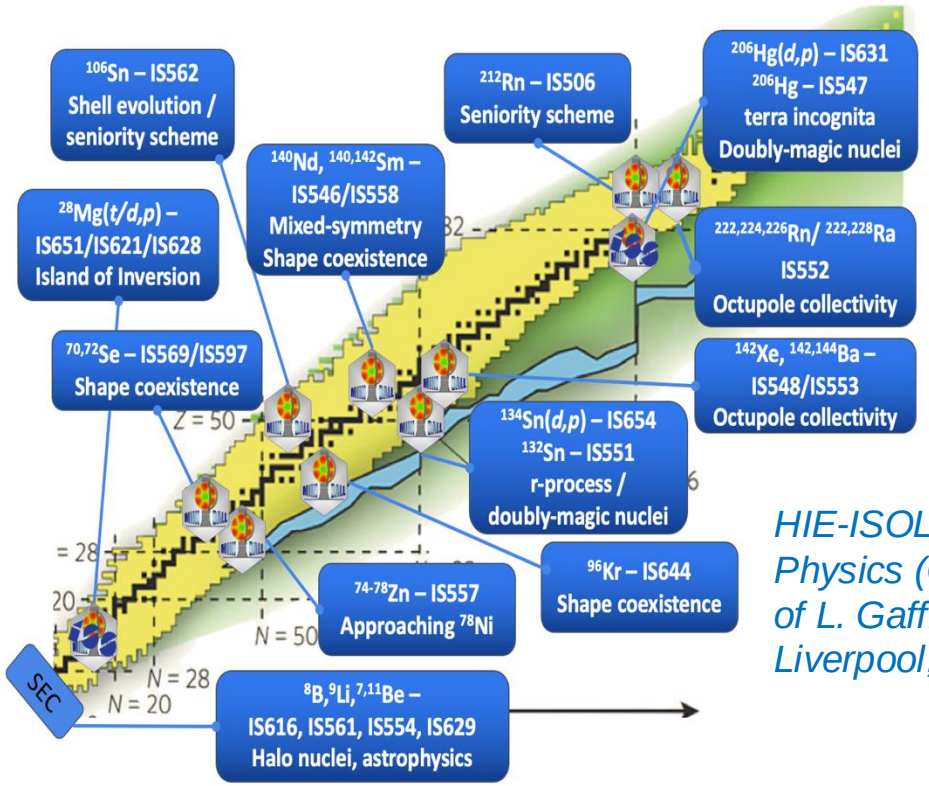
Universidad de Huelva
MINISTERIO DE CIENCIA E INNOVACIÓN
Plan de Recuperación, Transformación y Resiliencia
Financiado por la Unión Europea NextGenerationEU
CERN
ISOLDE

HIE-ISOLDE

The HIE-ISOLDE facility at CERN is a world leading radioactive beam facility that accelerates over 1300 isotopes from around 70 elements, up to approximately 10 MeV/A.

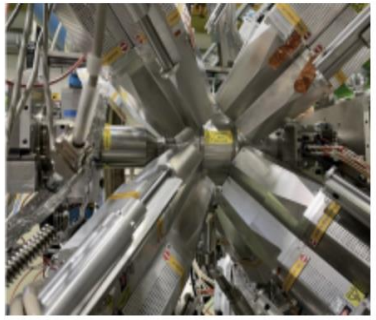
Mission: study of nuclear and atomic physics, astrophysics and fundamental interactions, by using optimal (N,Z) combinations provided by the radioactive beams.





HIE-ISOLDE Physics (Courtesy of L. Gaffney, Univ. Liverpool, UK).

MINIBALL

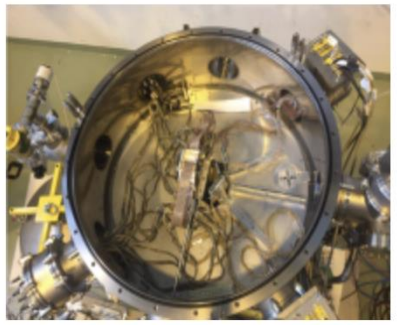


Coulomb-excitation and transfer-reactions with low multiplicity

ISS

Precision studies of inelastic scattering and transfer reactions

SEC



Reaction experiments such as elastic, inelastic, and transfer reactions

ISRS

The ISOLDE Superconducting Recoil Separator (ISRS) is a high-resolution separator that combines focal plane spectroscopy with particle and gamma detection at reaction target.

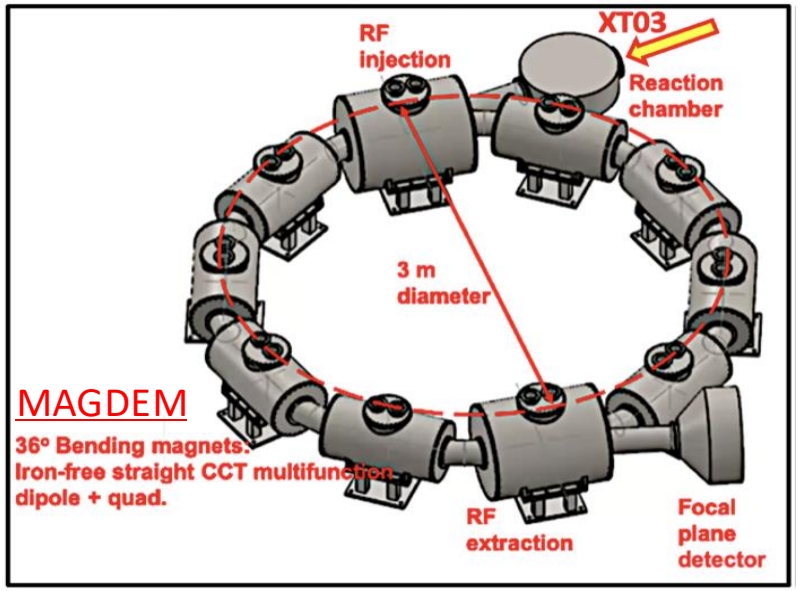
Mission: expand the HIE-ISOLDE physics program.

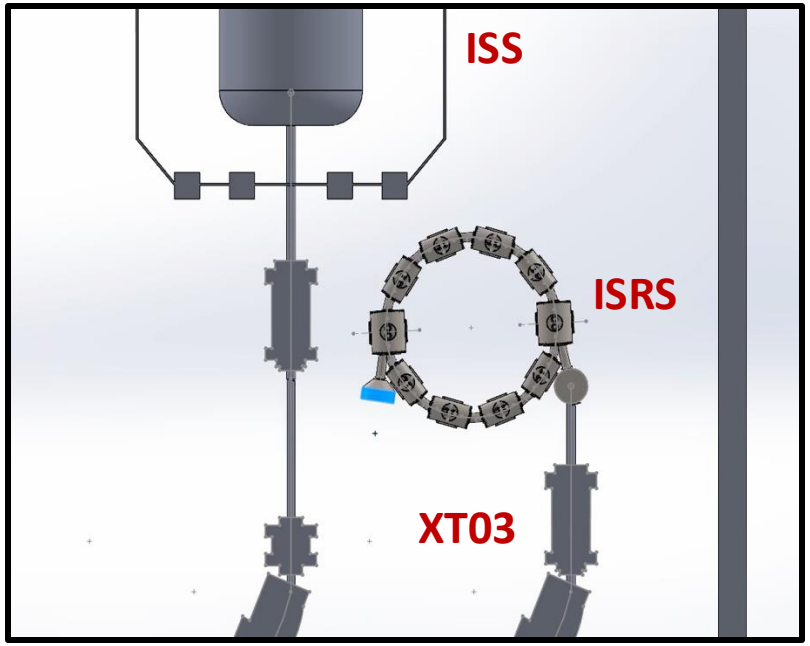
ISRS conceptual design:

- Compact particle storage ring
- NS Fixed Field Alternating Gradients
- Superconducting magnets
- Multifunction-nested (dipole + quadrupole)
- Canted Cosine Theta (CCT) technology
- Cryocoolers “dry” technology (no LHe bath)
- Injection/extraction (RF, Suchi, etc)

LOI-INTC-228 (2021): Design study of a Superconducting Recoil Separator for HIE-ISOLDE.

Spokespersons: I. Martel, O. Tengblad, J. Cederkall





Nuclear Instruments and Methods in Physics Research B 541 (2023) 176–179

The ISRS Collaboration

Mission: find resources to develop a Proof-of-Concept study as described in the LOI-INTC-228 (2021).

23 Research Institutions

Inst. de Física, UNAM, México.
Dpt. CC Integradas, Univ. Huelva, Spain.
IPNO, Univ. Paris-Sud, Orsay, France.
Dpt. of Physics, Univ. Liverpool, UK.
IEM, CSIC, Madrid, Spain.
ESS- BILBAO, Bilbao, Spain.
CERN, Geneva, Switzerland.
Dpt. of Physics, Univ. Surrey, UK.
Dpt. of Physics, Lund Univ., Sweden.
Univ. Edinburgh, UK.
LNL INFN, Italy.

Uppsala Univ., Sweden.
Dpt. of Physics and Astronomy, Aarhus Univ., Denmark.
Dpt. of Physics, Chalmers Univ. of Technology, Göteborg, Sweden.
CENGB, Gradignan, France.
Dpt. of Physics, Univ. York, UK.
School of Comp., Eng. & Phys. Sciences, Univ. West Scotland, UK.
ICMUV, Univ. de Valencia, Spain
Cockcroft Institute, Daresbury, UK.
APC, Paris, France.
Faculty of Mathematics and Science, Univ. Jyvaskyla, Finland..
IFIN-HH, Bucharest, Romania.

Denmark-France-Italy-Mexico-Romania-Spain-Sweden-Switzerland-UK

Funding

Spanish grant (RRF/EU): 3 MEuro. July 2023 – Dec. 2025. → Activity re-arranged; scope scaled to budget & timeline. → Univ. Huelva (Coordinator), ESS Bilbao, Univ. Valencia, IEM-CSIC-Madrid

WP/TASK	LEADER
WP1: STUDY OF BEAM DYNAMICS, INJECTION AND EXTRACTION	**UV**
T1.1. Selection of Physics cases	UHU
T1.2. Nuclear reaction calculation	UHU
T1.3. Study of beam dynamics	UV
T1.4 Selection of configuration	UV
T1.5. Study of Injection/Extraction	UV
T1.6. Study of prototype of non-interceptive beam diagnostics	UV
T1.7. High order corrections to beam dynamics	CSIC
WP2: CCT SOLENOIDS AND CRYOSTATS	**UHU**
T2.1. Prototype of solenoid	UHU
T2.2. Prototype of solenoid with cryostat (MAGDEM)	UHU
T2.3. Study of elements of the magnetic field mesurement system	UHU
T2.4. MAGDEM focussing system	CSIC
T2.5. Prototypes of critical elements of focal plane	CSIC
WP3: MULTI-HARMONIC BUNCHER	**ESSB**
T3.1. Revision of critical designs	ESSB
T3.2. Test acceptance of manufactured protoypes	ESSB
T3.3. Prototype of multiharmonic buncher	ESSB

Experiments ISRS

Configuration de ISRS

Supercond. magnets

Test benches

Focal plane

MH buncher

Physics cases and nuclear reactions calculations

- Coulomb breakup/dissociation
- Direct (single/2-nucleon) transfer reactions in inverse kinematics
- Multinucleon transfer reactions
- Fusion-evaporation reactions in inverse kinematics
- Low energy transfer, breakup and fusion reactions

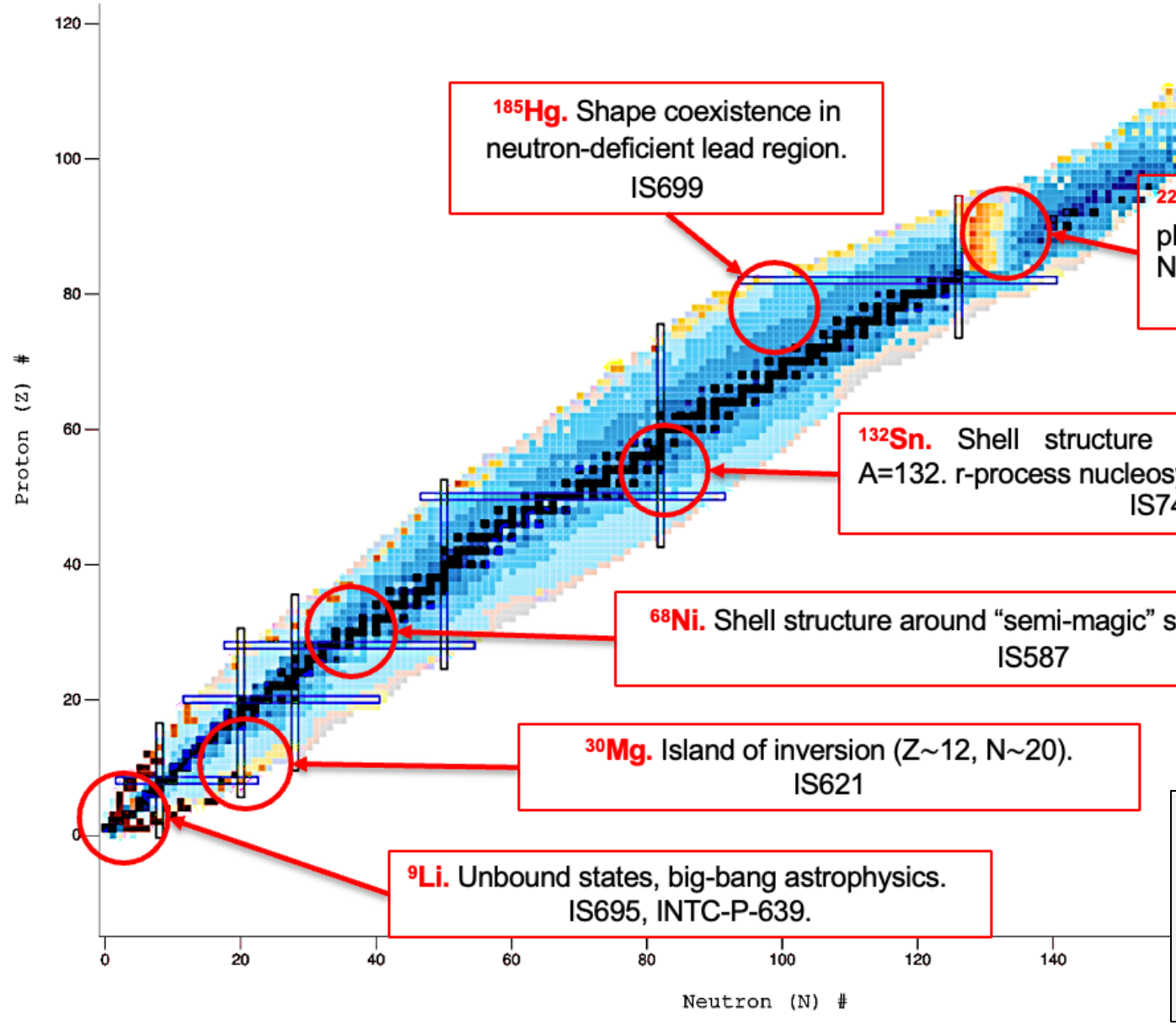
Minimum spectrometer requirements	
Parameters	Values
Momentum acceptance	±10%
Resolving power $p/\Delta p$	2000
Angular acceptance	±10°
Angular resolution	0.1°
Solid angle	100 msr
Charge resolution $\Delta Q/Q$	1/70 (FWHM)
Mass resolution $\Delta M/M$	1/250 (FWHM)
Rotation	0 – 70°

- ✓ Nuclear structure studies around N≈ 82, 126.
- ✓ Reactions relevant for the *s, p* and *rp* process nucleosynthesis around Z ≈ 50 and Z ≈ 82.
- ✓ Neutron-rich nuclei in Terra Incognita (^{78}Ni, r-nuclei ~N=126).
- ✓ Shell-quenching and the r-process.
- ✓ Reaction dynamics studies, collective phenomena, nucleon-nucleon correlations.

High efficiency – Selectivity— Sensitivity

ISRS – coupled to detector arrays

- ISS
- MINIBALL
- SEC
- SAND
- AGATA
- ISR (old TSR)



At present:

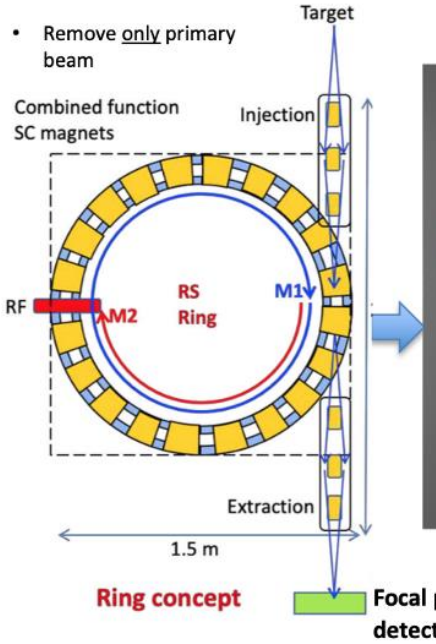
- Direct transfer reactions (d,p), (d,n)
- Coulex
- Compound nucleus

Beam dynamics

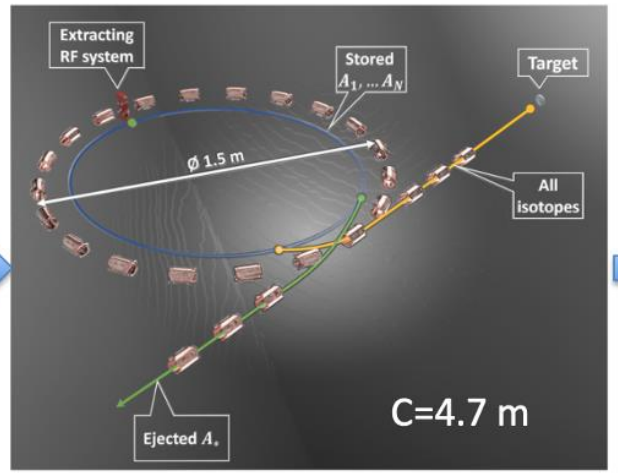
Based on *Design of a superconducting gantry for protons*, IPAC2015, TUPWI014
C. Bontoiu, J. Sánchez, R. Berjillos, J. Pérez, I. Martel → Fixed Field Alternating Gradient (FFAG) + Superconducting Multifunction Magnets

ISRS beam dynamics: *Conceptual design of a novel and compact superconducting recoil separator for radioactive isotopes*
C. Bontoiu, J. Resta, V. Rodin, I. Martel, C. Welsch, Nucl. Inst. Meth. A 969 (2020)164048

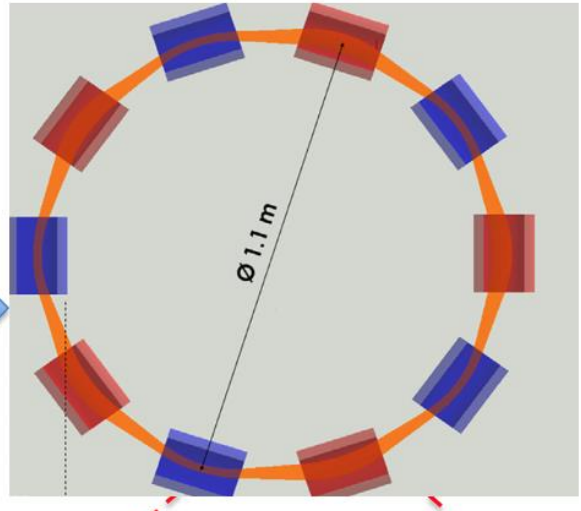
Conceptual design
I. Martel. 84th ICC meeting. CERN, March 2019.

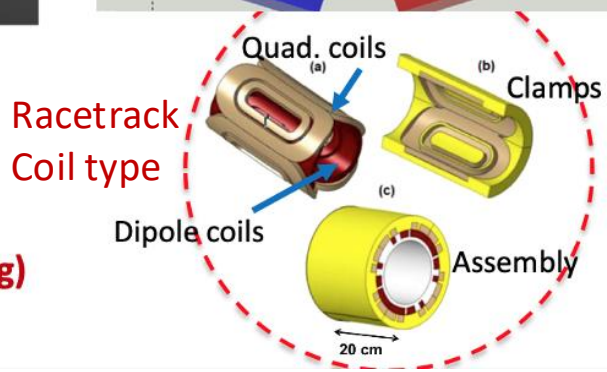


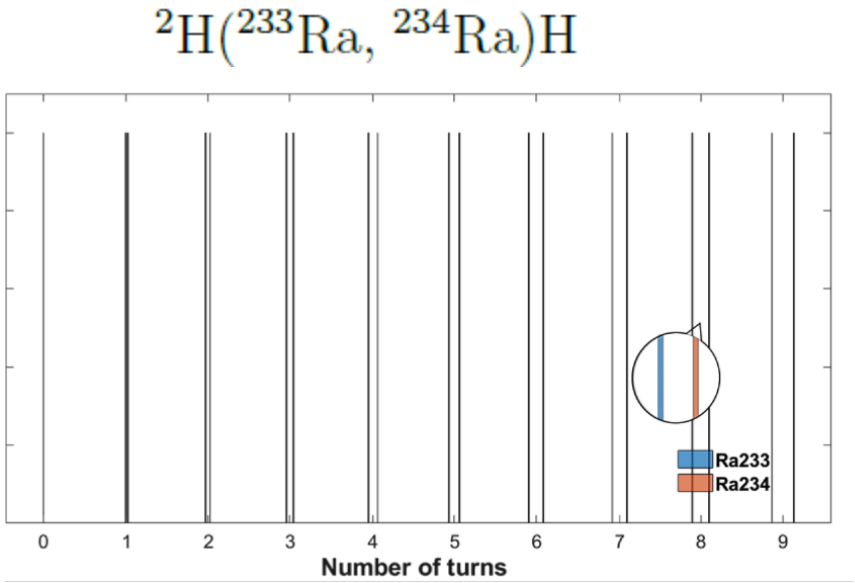
3D G4beamline model (20 multifunction magnets)



First optimization (10 multifunction magnets)
C. Bontoiu et al., NIMA 969 (2020) 164048



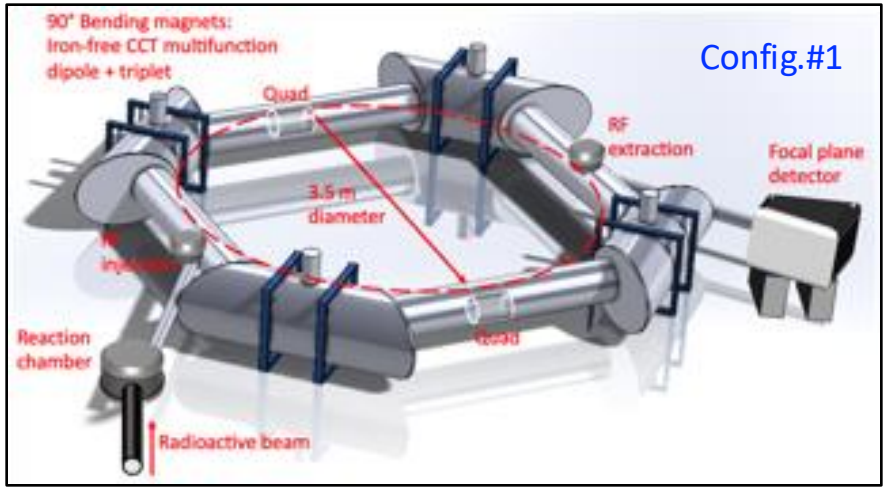


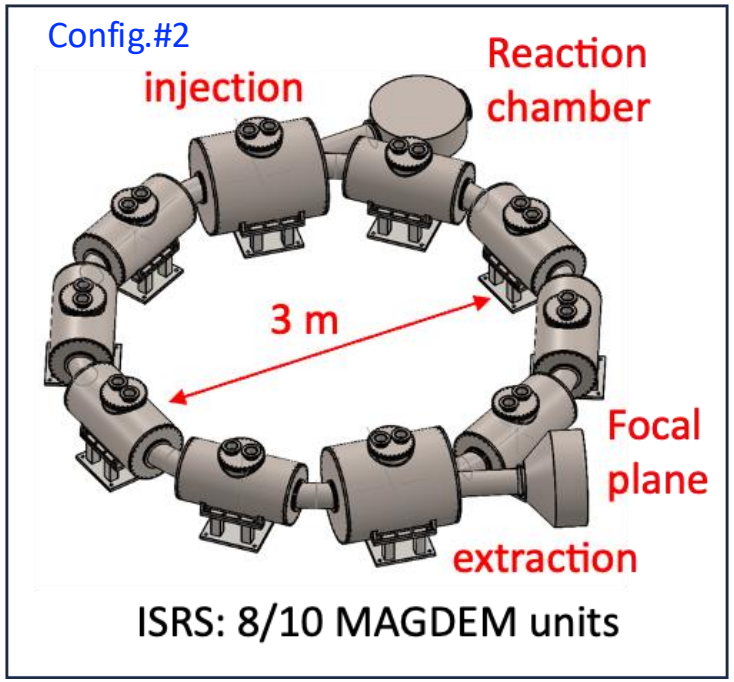


- Particle storage mini-ring
- Fixed Field Alternating Gradient (FFAG)
- Multifunction SC magnets (mini-LHC); D+Q (20 cm long)
- 1.5 meters diameter! – "Tabletop" spectrometer

- E = 10 MeV/A, ΔP = 30%
- ToF separation ~ 40 ns (~10 turns/ 2.5 μs)
- ~ 100% transmission

Beam dynamics





IPAC 2023

14th International Particle Accelerator Conference, Venezia JACoW Publishing

450-231-8 ISSN: 2673-5490 doi: https://doi.org/10.18429/JACoW-IPAC-23-TUPA050

DESIGN OF A COMPACT SUPERCONDUCTING RECOIL SEPARATOR FOR HIE-ISOLDE*

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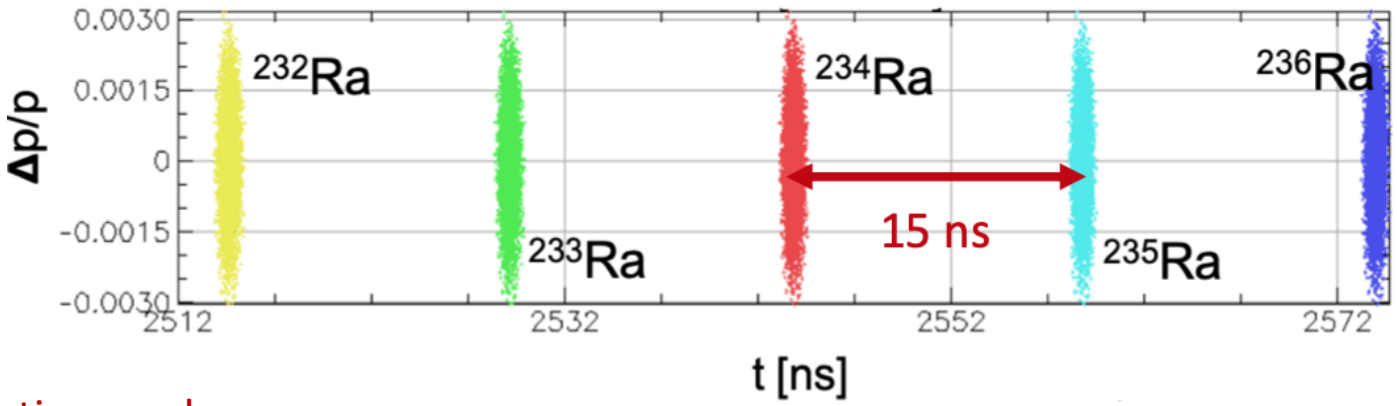
O. Kirby, Paul Scherrer Institute, Villigen, Switzerland
I. Martel, Universidad de Huelva, Huelva, Spain
C. P. Welsch, Cockcroft Institute and The University of Liverpool, United Kingdom

Isochronous



Operation modes

- High momentum acceptance ~ +/-30%
- Isochronous → ΔP acceptance ~ +/- 5%

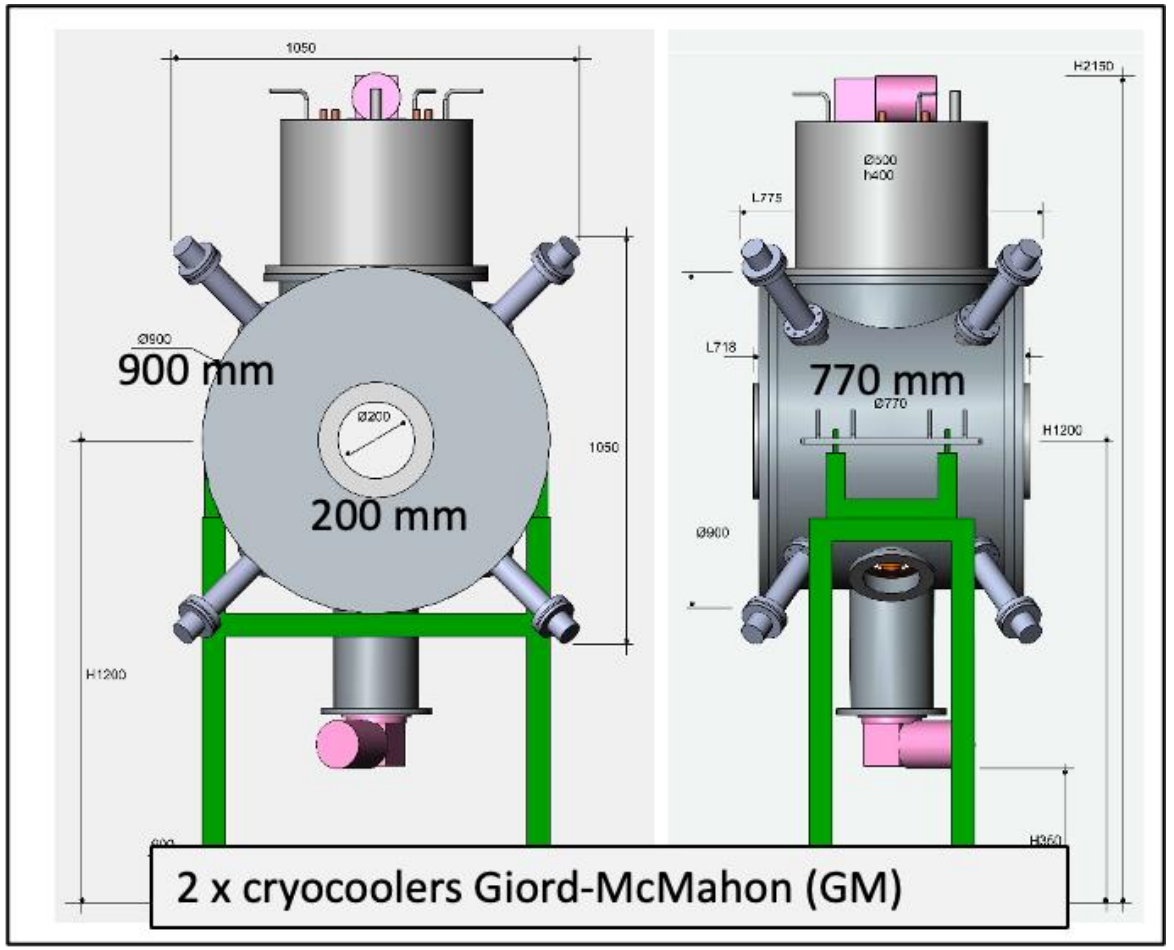
Courtesy of J. Resta, U. Valencia

MAGDEM (MAGnet DEMonstrator)

Study of the MAGDEM cryostat and its integration with the CCT solenoid developed in T2.1.

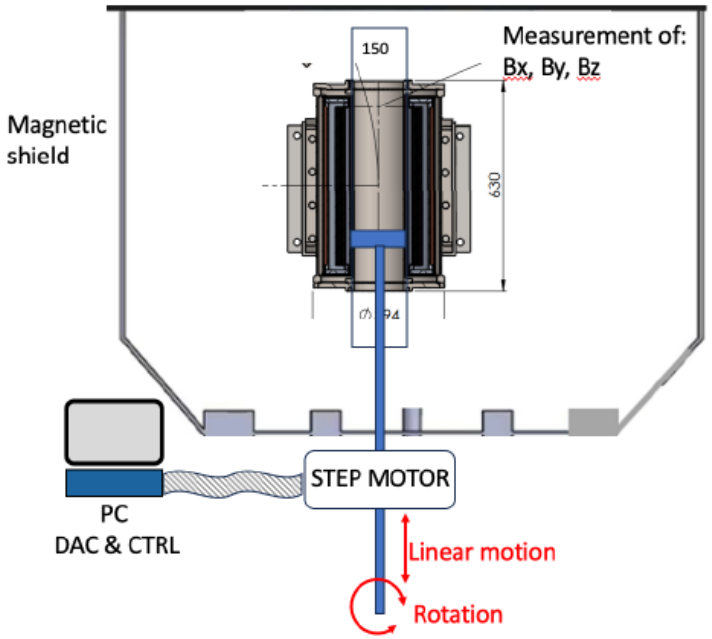
- Study of various options: (1) LHe bath, (2) hybrid LHe bath + cryocoolers, (3) Cryocoolers, (4) Pre-cooling with LN_2
- Minimum length and outer diameter, maximum aperture for beam circulation.
- 1 cryocoolers: cooling time 6 days. Including LN_2 precooling down to 2 days.

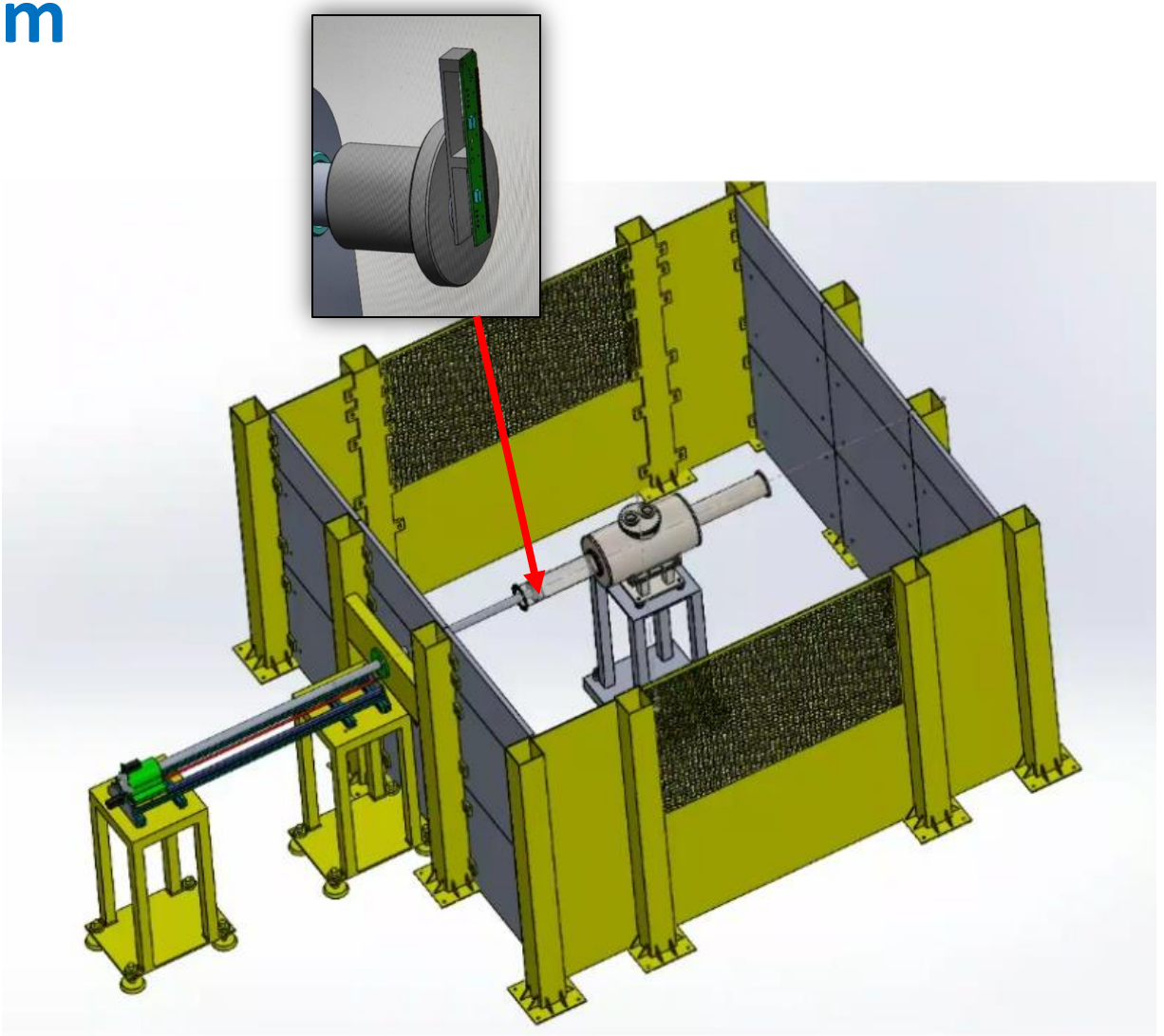
- Very compact design achieved with 220 mm aperture, 900 mm diameter, 775 mm length.
- 2 x 2 stage Giord-McMahon (GM) cryocooler, top and bottom. Cooling power > 1.5W at 4K, 40W at 40K-50K.
- 8 tie beams of Ti-6Al-4V. Forces between magnets ~ 2 Tons
- LN2 precooling improve cooling time.



Magnetic field measuring system

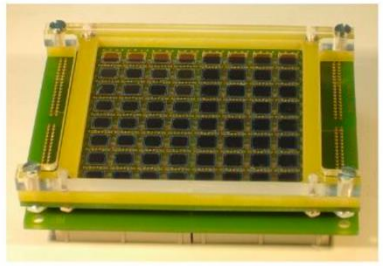
- ✓ Precision 3D Mapping of MAGDEM fields
- ✓ Multi-axis positioning system
- ✓ 1 mm step size along z-axis (1.700 mm), +/-0.05 mm
- ✓ 1° step rotation up to 360° (+/-0.01°)
- ✓ HallinSight® 32x2 pixels sensor array
- ✓ Max field 2.5 T, resolution of 4 uT.



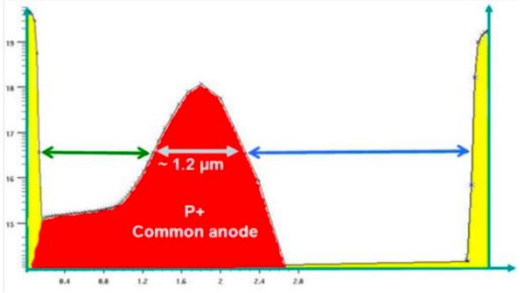


Focal plane detector

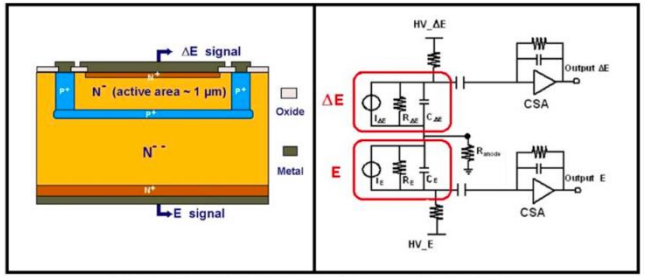
Monolithic Si Detector



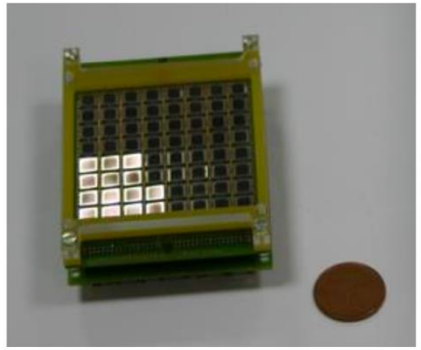
a) Photo of the monolithic detector.

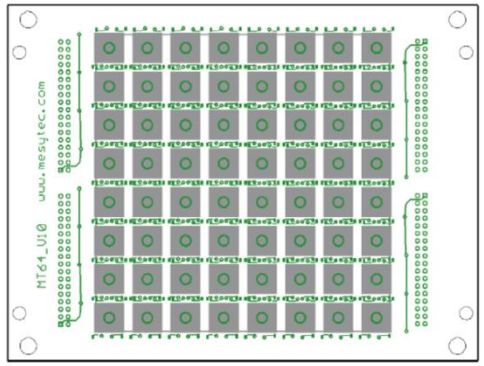


b) Doping structure of the Si wafer.

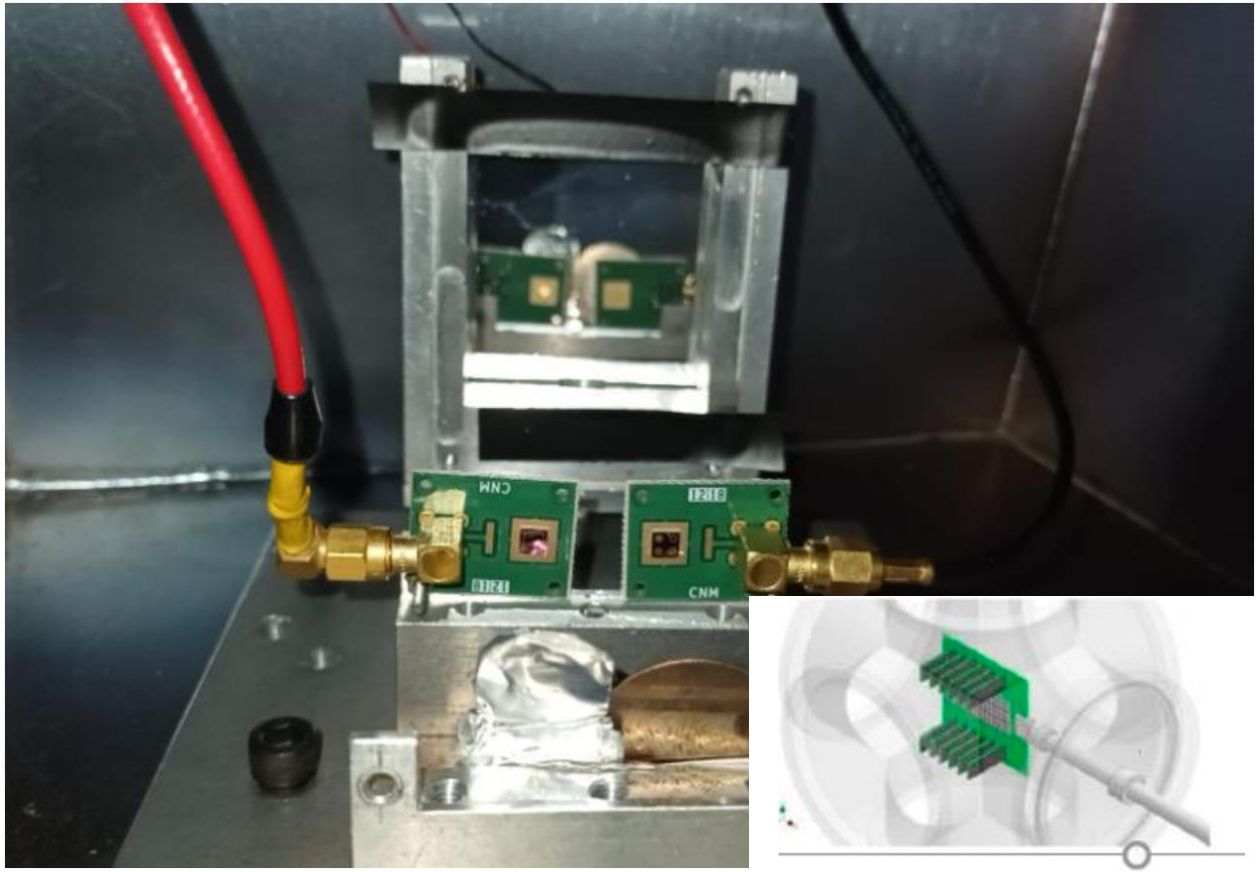


c) Electronic equivalent circuit of the monolithic detector.





SiC developed at IMB-CSIC

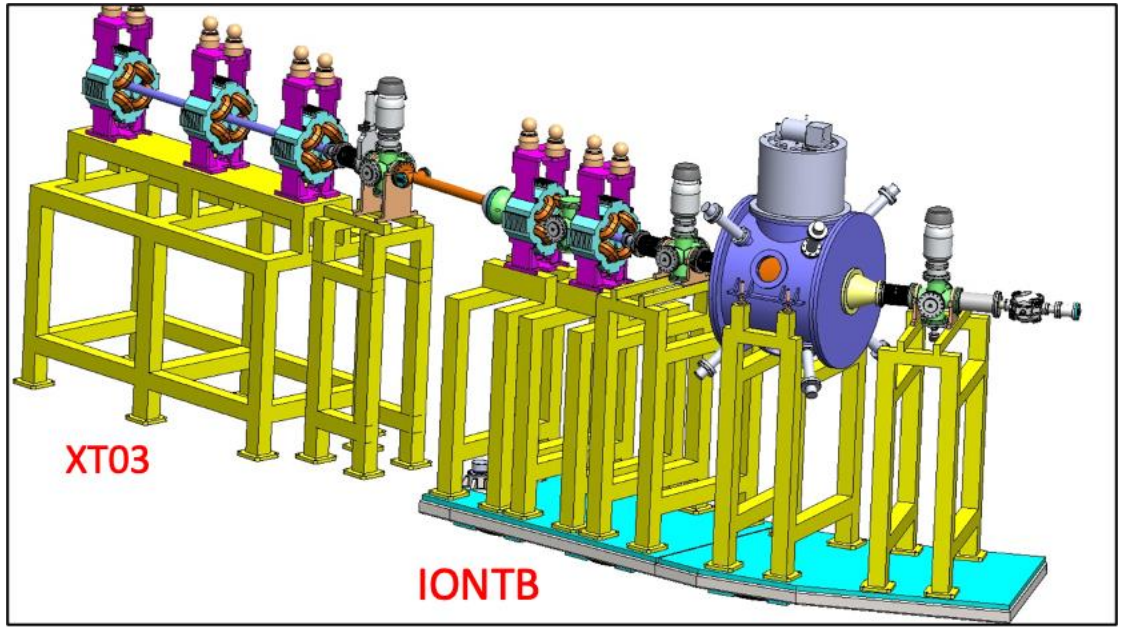


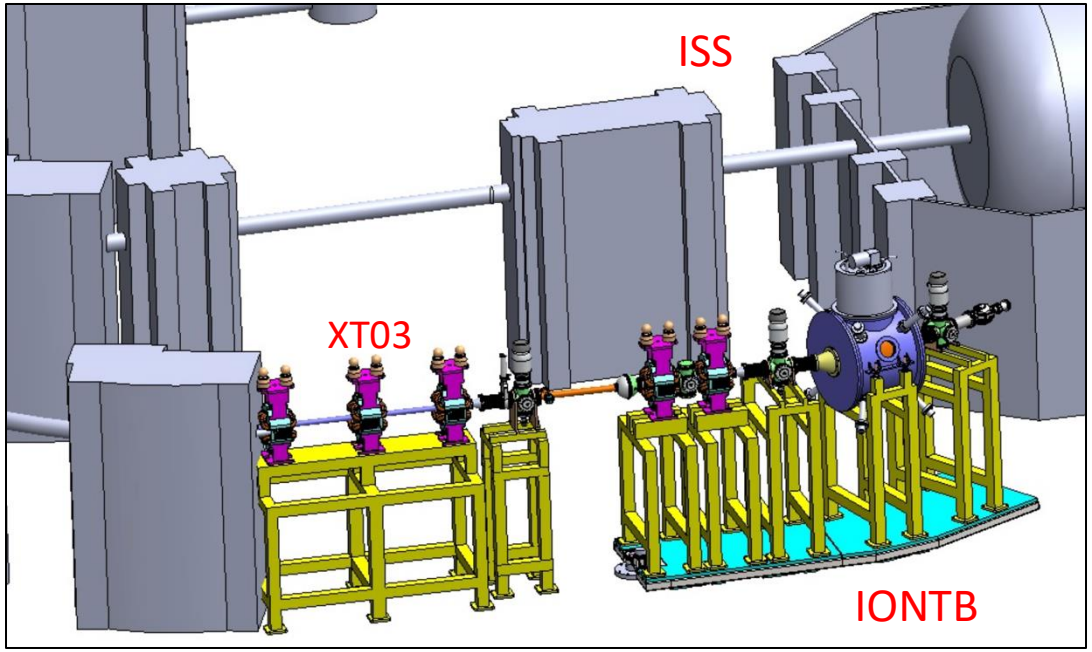
Courtesy of T. Kurtukian-Nieto IEM-CSIC-Madrid

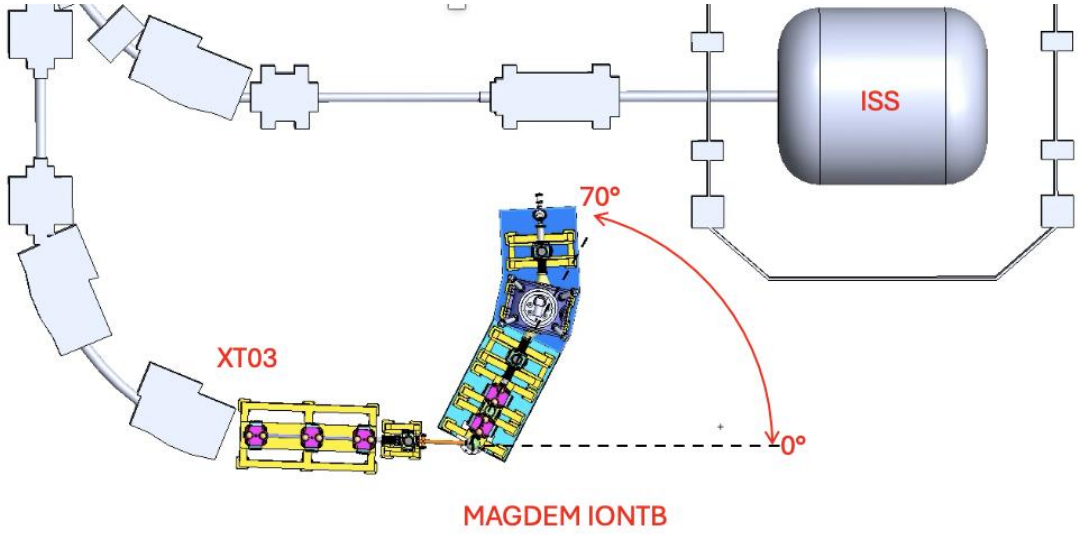
MAGDEM ion test bench (IONTB)

- Test concepts with ion beams
- works also as a low/resolution linear spectrometer
- Three versions being studied (~ A, Q, ΔP)
  - High resolution: RC-QQ(MG)QQ-FPD
  - Medium resolution:RC-QQ(MG)-FPD
  - Low resolution: RC-Q(MG)-FPD

Medium resolution IONTB: RC-QQ(MG)-FPD



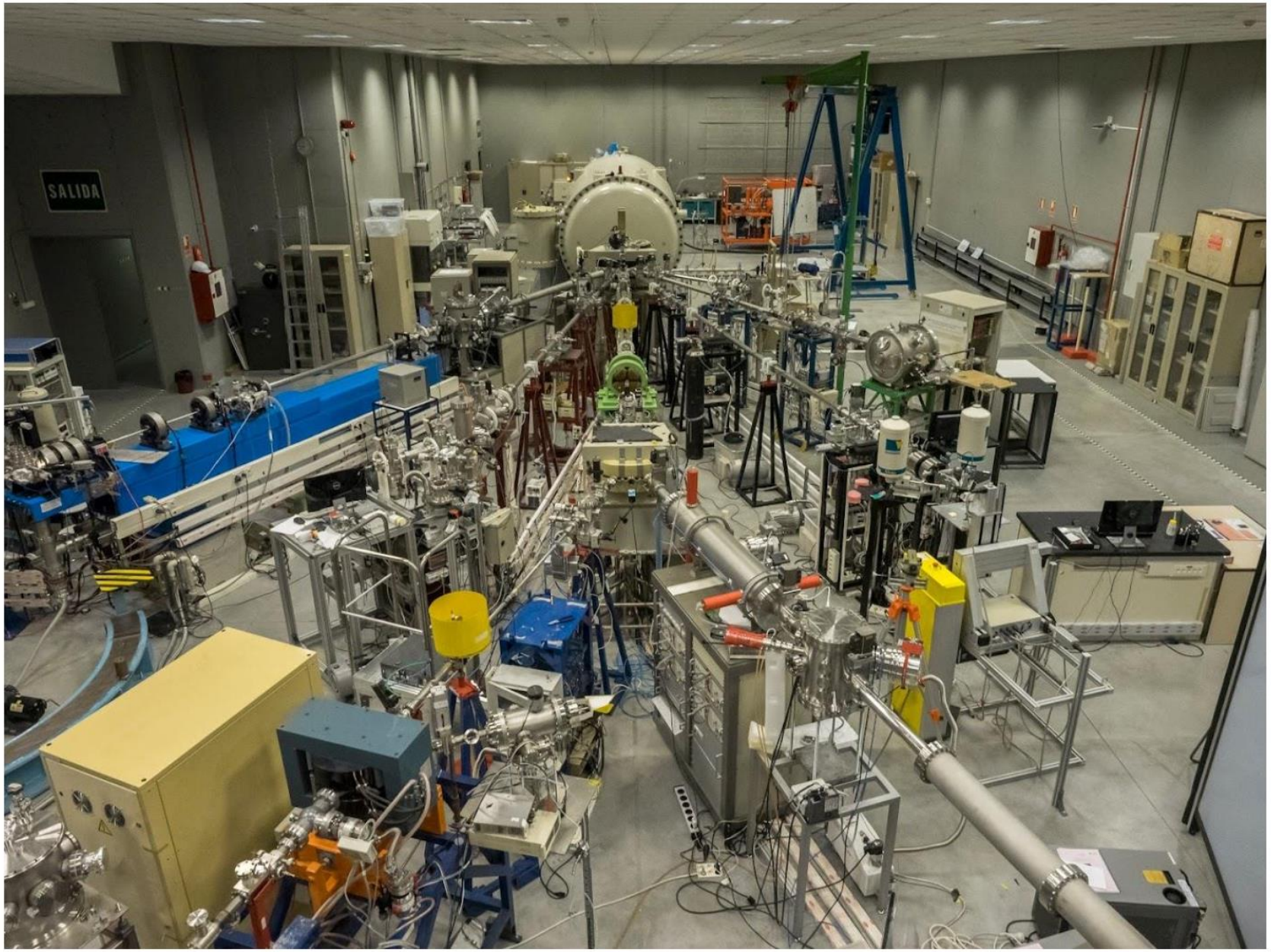




CMAM Madrid

Commissioning

- Focal plane
- Ion test bench

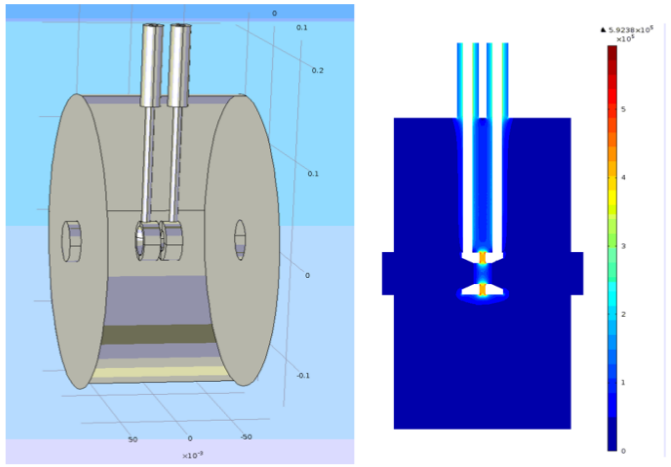


Multiharmonic buncher

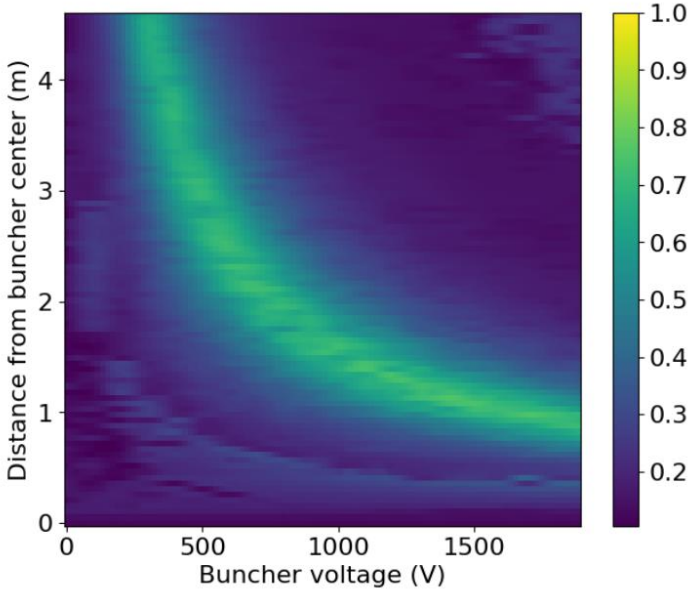
Objectives:

- Design and build prototype of multi-harmonic bucher for the operation of ISRS at HIE-ISOLDE.
  - ✓ low energy dispersion (< 1%)
  - ✓ high transmission (> 95%)
  - ✓ reduced space for bunch formation (< 5 m).
- RF power signal generation
- Test at ESS-Bilbao injector

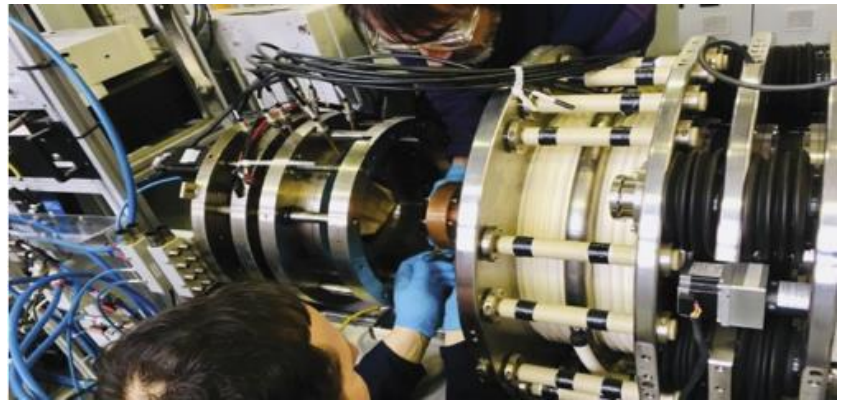
	ESS-BILBAO INJECTOR
RF Frequency	10.128 MHz
Macro-Pulse	1-50 Hz, 50 - 3000 μs
Beam Energy	5-45 keV/q
Ion Species	H+ / He+ / N+
Beam Current	0.1-40 mA
Vacuum Flange Interface	DN63CF
Maximum longitudinal space	4.0 m



EM model of the MHB with wedge electrodes. Frequency 10.128 MHz



Bunching efficiency as a function of distance and electrode voltage.



ESSB plasma ion source

Courtesy of I. Bustinduy, ESS-Bilbao

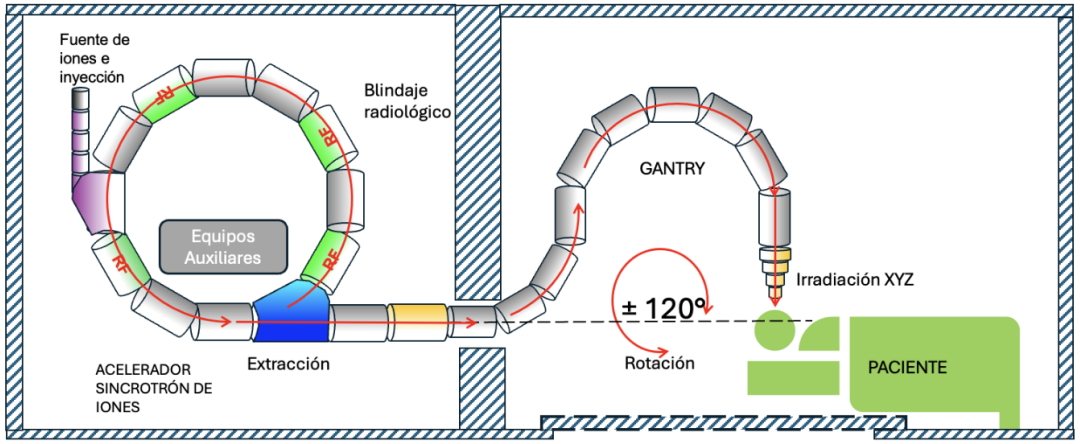
Applications of ISRS developments

MAGDEM

- compact, light weight magnet ~ Bρ 2.5 Tm
- Nested Dipole + quadrupole → FFAG
- Ideal for compact particle storage rings/acceleration

Hadron-therapy

- Superconducting hadron-therapy system", SUPERHATS
- Funding aplication -- Junta de Andalucía (Huelva-Madrid -Valencia



ISOLDE Storage ring-> ISR

- TSR – K. Blaum et al- INTC-O-014 (2012)
- Max-Planck Institute for Nuclear Physics in Heidelberg
- New project foreseen - ISRS

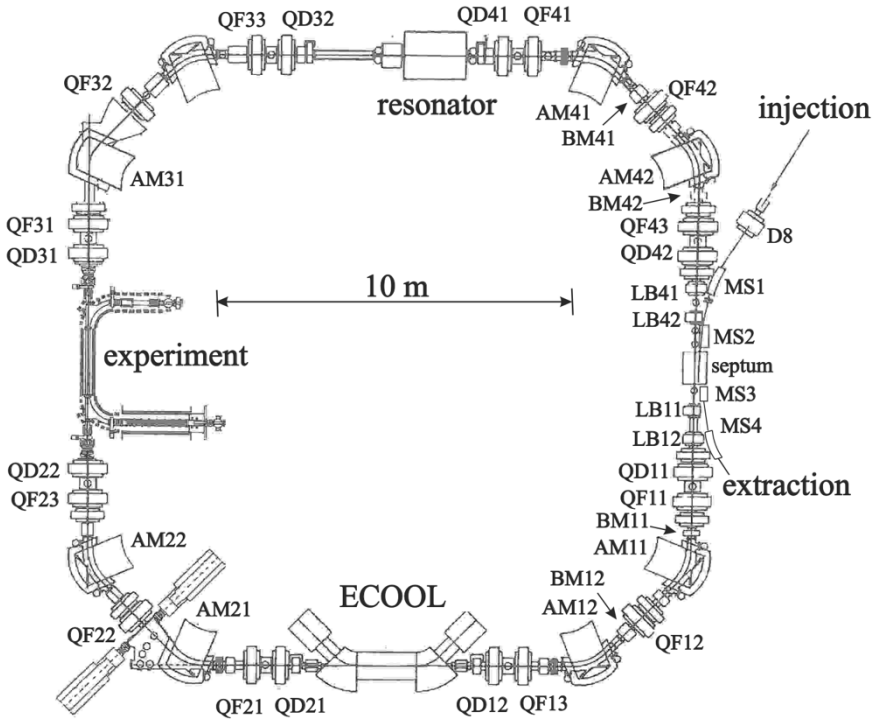


Figure 33: The lattice of the TSR.

ISRS Collaboration meeting & Physics Workshop

- November 25- 26 at CERN
- Remote participation (ZOOM)
- Technical aspects November 25
- Physics program November 26

ISRS Collaboration meeting, Nov 25

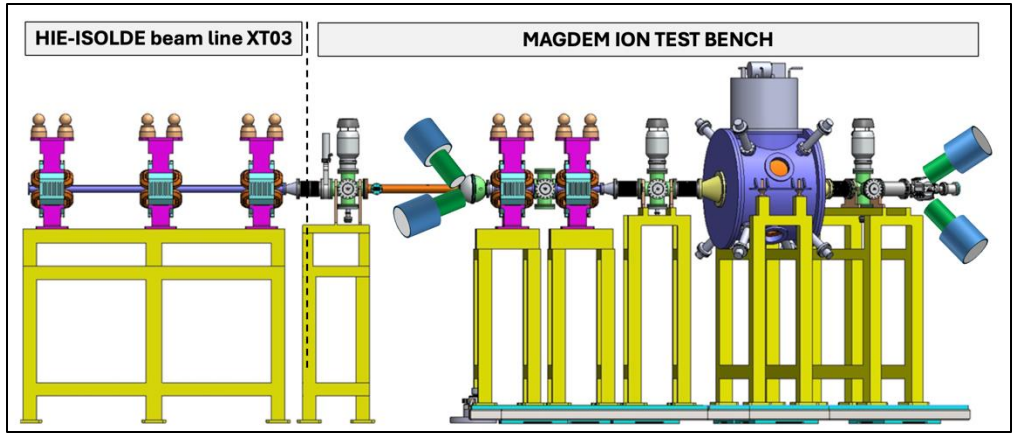
Speaker/Convener	Topic	Time	
I. Martel/ T.Kurtukian-Nieto	Welcome & Status	09:00:00	09:10:00
F. Torabi	Physics cases & Reaction calculations	09:12:00	09:22:00
I. Bustinduy	Multiharmonic buncher	09:24:00	09:34:00
J. Resta	Beam dynamics	09:36:00	09:46:00
T. Kurtukian-Nieto	High order corrections	09:48:00	09:58:00
Cofee break		10:00:00	10:20:00
R. Berjillos/I. Martel	Magnet demonstrator (MAGDEM)	10:20:00	10:30:00
R. Berjillos	Magnetic Flux Scanner System	10:32:00	10:42:00
T. Kurtukian-Nieto/O. Tengblad	Focal plane detector	10:44:00	10:54:00
T. Kurtukian-Nieto/O. Tengblad	MAGDEM focussing system	10:56:00	11:06:00
S. Sánchez (High resolution)	Ion test bench (IOTB)	10:56:00	11:06:00
F. Taft (Low and medium mass resolution)		11:08:00	11:18:00
D. Gómez (Integration and control systems)		11:20:00	11:30:00
S. Freeman	SAC meeting	11:32:00	12:30:00
Lunch		12:30:00	14:00:00
I. Martel/T. Kurtukian-Nieto	Discussion	14:00:00	15:00:00

Physics workshop, Nov 26

Speaker/Convener		Time	
T.Kurtukian-Nieto (Madrid)/I. Martel (Huelva)	Welcome	08:50:00	09:00:00
Annika Lennarz, TRIUMF, Vancouver, Canada	The EMMA recoil mass spectrometer for ISAC-II at TRIUMF	09:00:00	09:25:00
Nishio Katsuhisa, ASRC,Tokai, Japan	Superheavy element research using FFAG ion storage ring	09:30:00	09:55:00
Lucio Gialanella, Univ. Campania, Italy	Nuclear Astrophysics with the RMS ERNA	10:00:00	10:25:00
Cofee break		10:30:00	10:55:00
Suzana Szilner, IRB, Zagreb, Croatia	Population of heavy-neutron rich nuclei in multinucleon transfer reactions	11:00:00	11:25:00
Francesco Cappuzzello, LNS, Catania, Italy	New results from the NUMEN project at the INFN LNS MAGNEX facility	11:30:00	11:55:00
Emanuele Vardaci, INFN Naples, Italy	HIE-ISOLDE Superheavy studies	12:00:00	12:25:00
Manfred Grieser, MPI Heidelberg, Germany	A new HIE-ISOLDE Storage Ring	12:30:00	12:55:00
Lunch		13:00:00	14:00:00
F. Torabi, Univ. Huelva, Spain	Probing residual nuclei production to optimize ISRS performance	14:05:00	14:30:00
J.E. García Ramos, Univ. Huelva, Spain	SRS as a new tool to disentangle the nuclear shapes	14:35:00	15:00:00
F. Torabi/J.E. García Ramos	Discussion	15:05:00	16:05:00

Summary and conclusions

- ISRS will provides BIG opportunities to expand the HIE-ISOLDE physics program with a modern high resolution spectrometer
- R&D project ISRS - Spain
  - ✓ Physics whitebook
  - ✓ Beam dynamics
  - ✓ Multiharmonic buncher
  - ✓ Magnetic field scanner system
  - ✓ Ion test bench --> linear spectrometer
- Several applications are envisaged: hadrontherapy, storage rings (ISR),...
- Synergies between research institutes and industry



THANKS!

Universidad de Huelva
MINISTERIO DE CIENCIA E INNOVACIÓN
Plan de Recuperación, Transformación y Resiliencia
Financiado por la Unión Europea NextGenerationEU
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