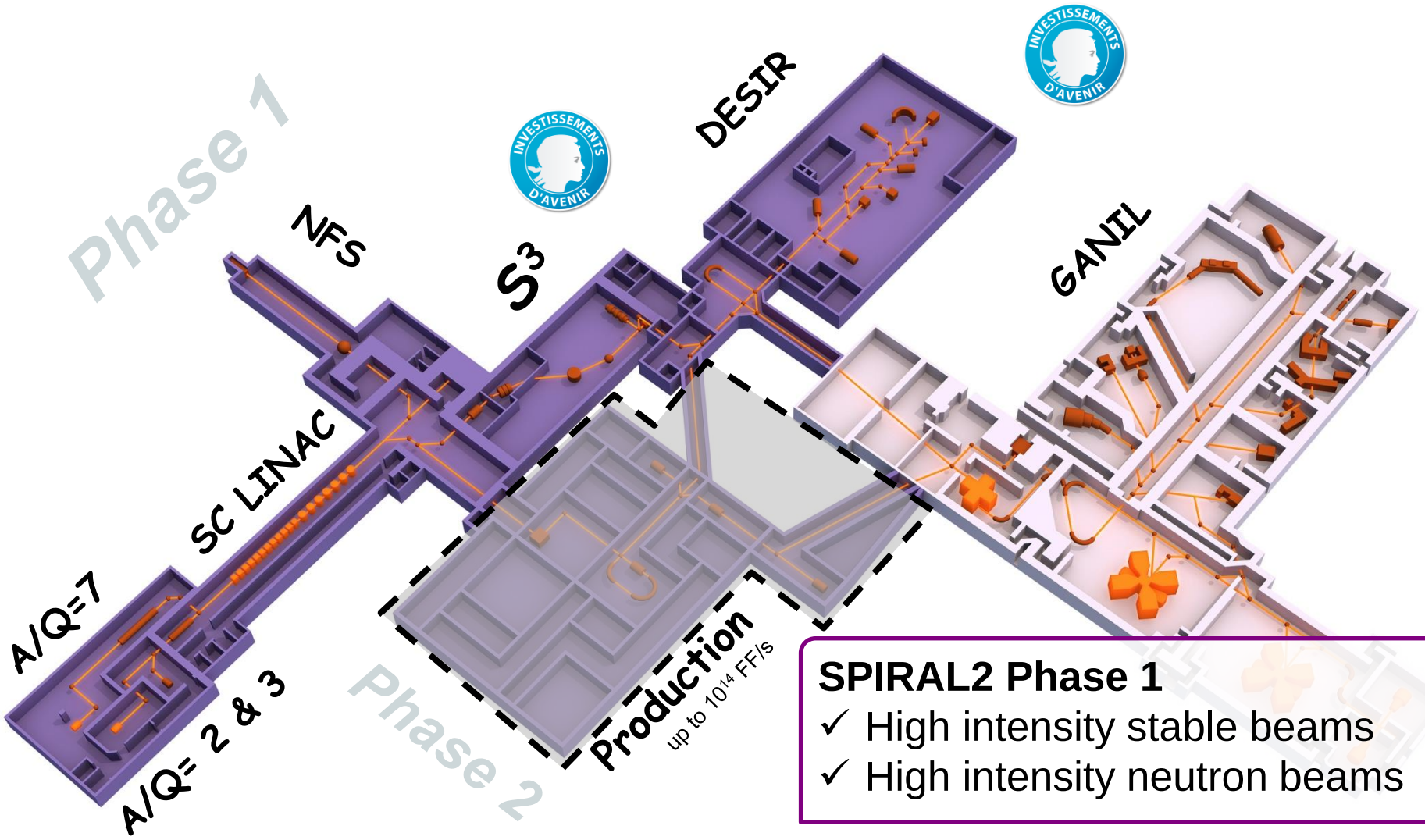
Super Separator Spectrometer

@ SPIRAL2

ISOLDE WORKSHOP 2017

H. Savajols (GANIL)

SPIRAL2 layout



SPIRAL2 Phase 1

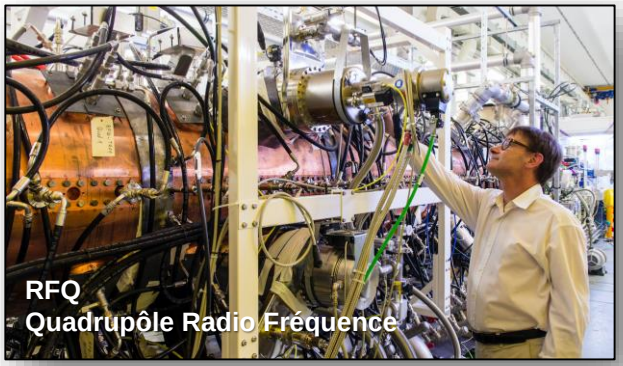
- ✓ High intensity stable beams
- ✓ High intensity neutron beams

◎ **A/Q = 3 : I ≤ 10^{15} pps, p-Ni, 0.75 MeV/n – 14.5 MeV/n**

◎ **A/Q = 7 : I ≤ 10^{15} pps, p-U, 0.75 MeV/n – 8.5 MeV/n**

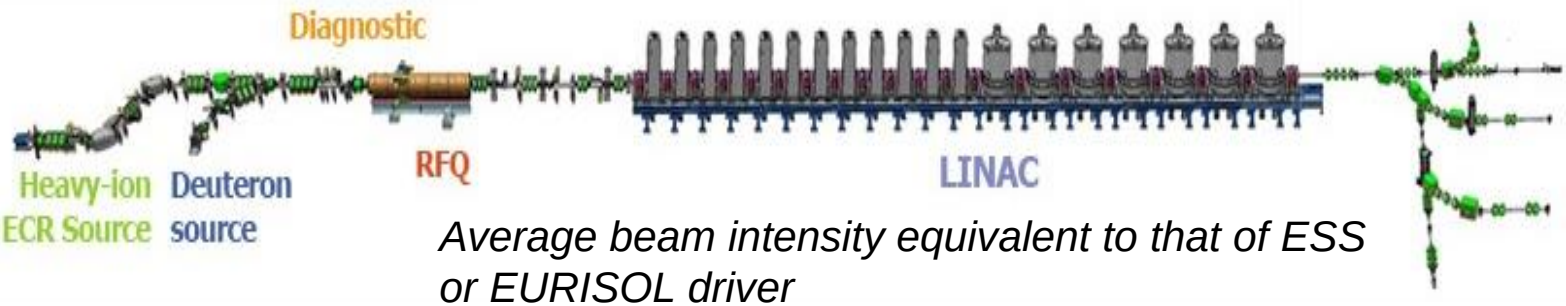
SPIRAL2 civil construction

SPIRAL2 accelerator


RFQ
Quadrupôle Radio Fréquence

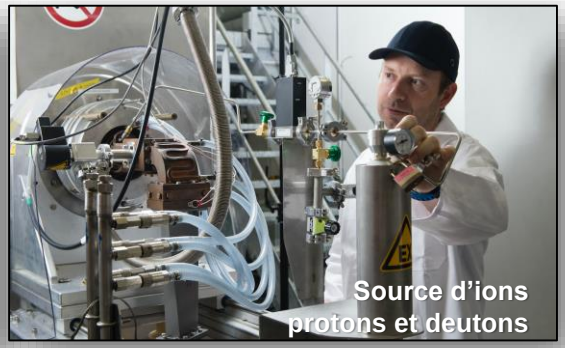
Cryomodules accélérateurs supraconducteurs A

Cryomodules accélérateurs supraconducteurs B



Average beam intensity equivalent to that of ESS or EURISOL driver

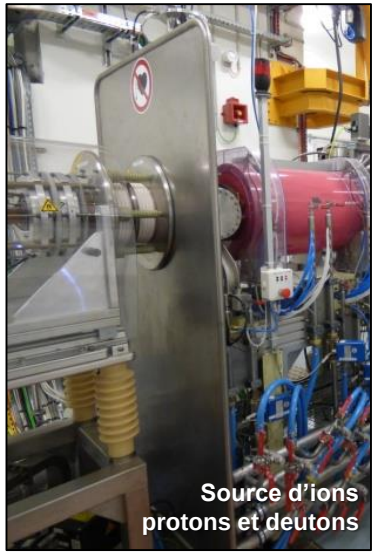

Source d'ions ions lourds

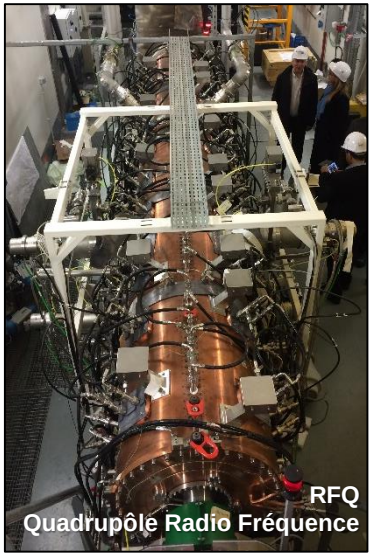

Source d'ions protons et deutons

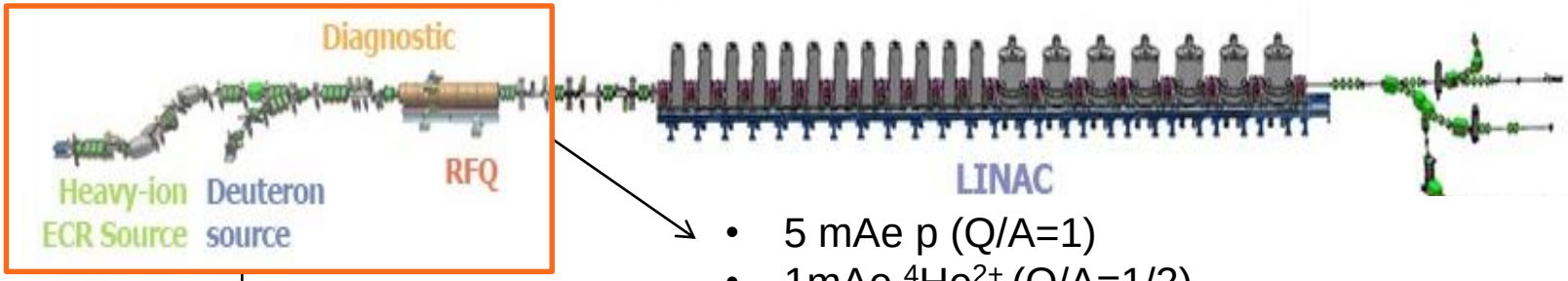

Lignes de faisceaux LHE

Installation is almost complete

First beams (Ions Sources & RFQ)





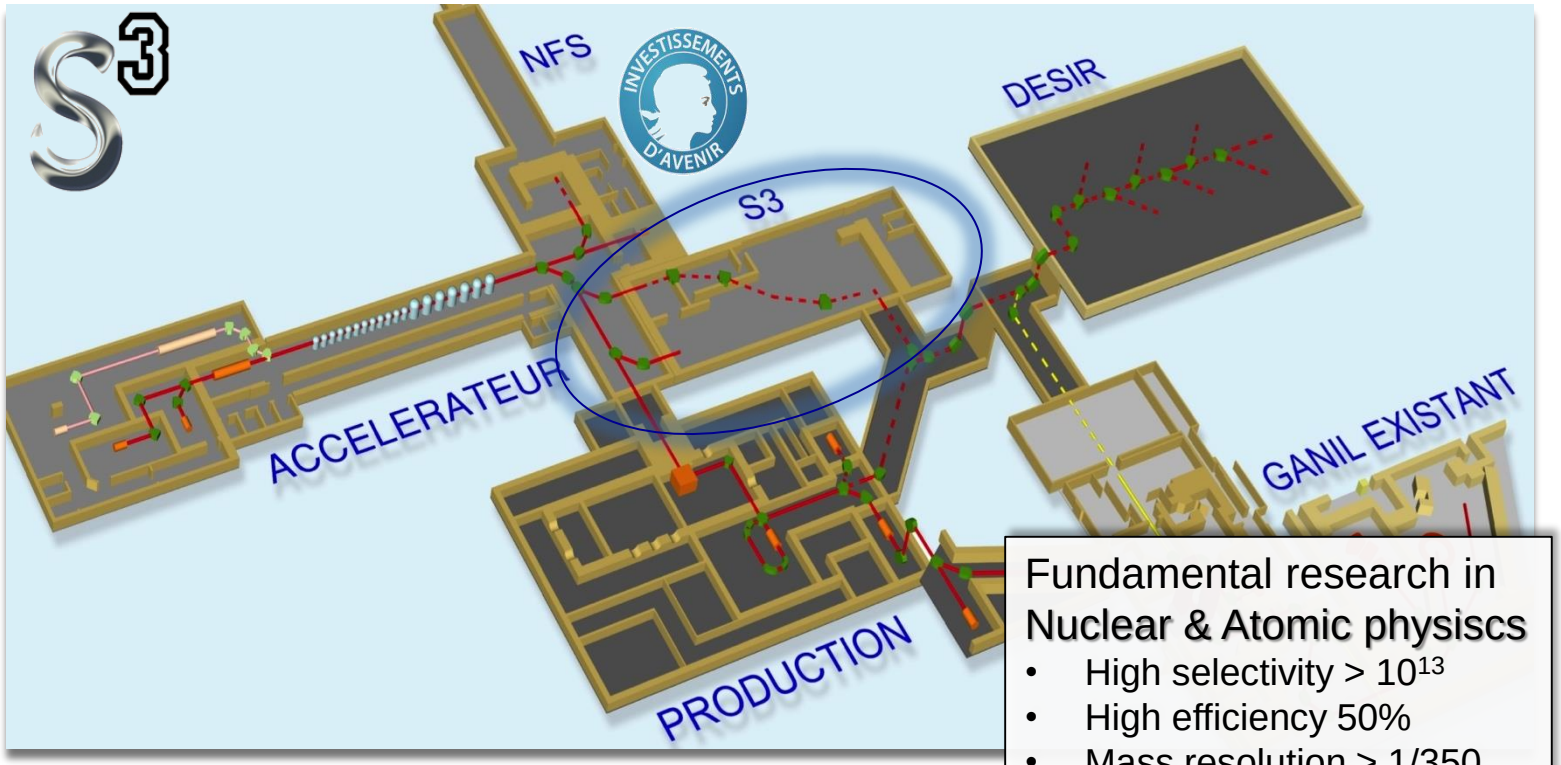


- 45 µAe $^{40}Ar^{14+}$ (60 kV)
- 2 mAe $^{4}He^{2+}$
- 1 mAe $^{18}O^{6+}$

- 5 mAe p (Q/A=1)
- 1mAe $^{4}He^{2+}$ (Q/A=1/2)
- $^{18}O^{6+}$ (Q/A=1/3)

- ➢ Partial commissioning ongoing
- ➢ Cooled down of the LINAC done (Nov 2017)
- ➢ Waiting for the safety authority clearance

Super Separator Spectrometer



Fundamental research in Nuclear & Atomic physiscs

- High selectivity > 10^{13}
- High efficiency 50%
- Mass resolution > 1/350
- Versatility

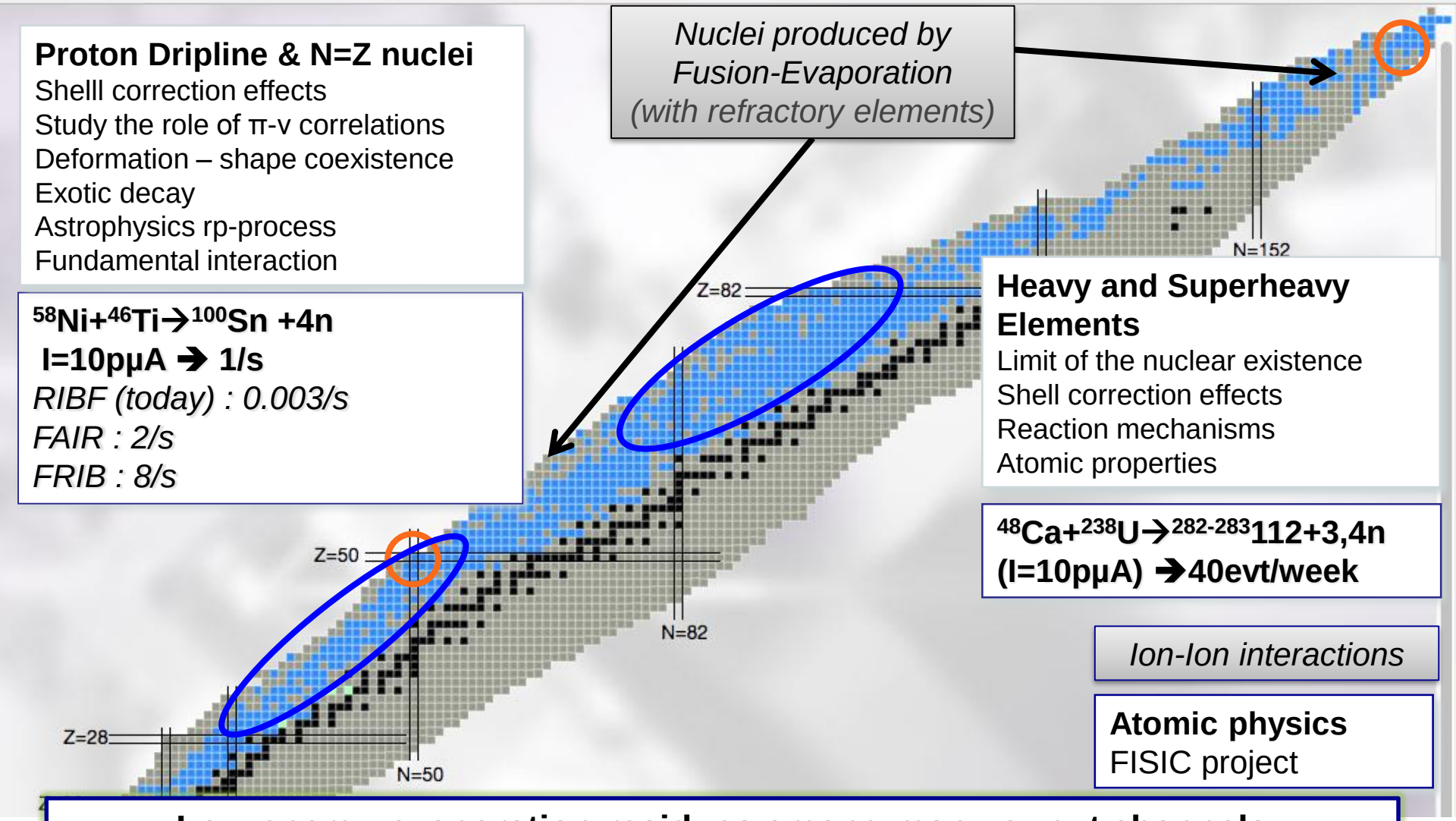
Physics goals

Study of rare events in nuclear and atomic physics

Proton Dripline & N=Z nuclei
Shelll correction effects
Study the role of π-ν correlations
Deformation – shape coexistence
Exotic decay
Astrophysics rp-process
Fundamental interaction

Nuclei produced by Fusion-Evaporation (with refractory elements)

^{58}Ni+^{46}Ti→^{100}Sn +4n
I=10pμA ➔ 1/s
RIBF (today) : 0.003/s
FAIR : 2/s
FRIB : 8/s



Heavy and Superheavy Elements
Limit of the nuclear existence
Shell correction effects
Reaction mechanisms
Atomic properties

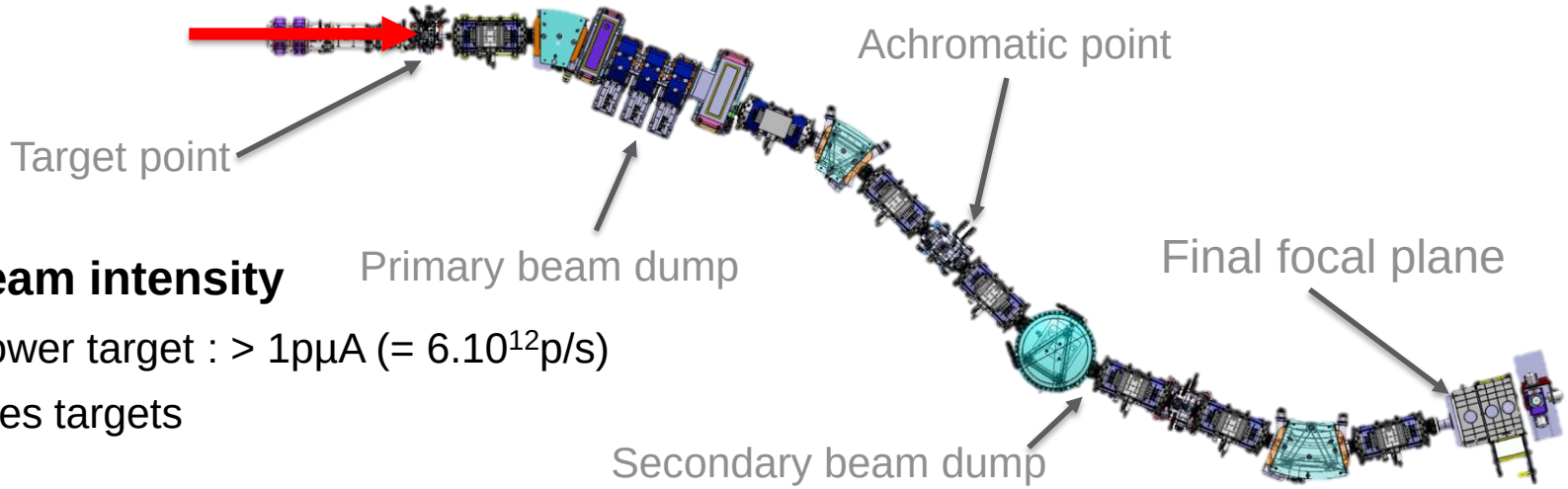
^{48}Ca+^{238}U→$^{282-283}$112+3,4n
(I=10pμA) ➔40evt/week

Ion-Ion interactions

Atomic physics
FISIC project

Low energy evaporation residues among many ouput channels
➔ High Selectivity and High Transmission Low energy separator

Performances



✓ **High Beam intensity**

➔High power target : > 1pμA (= 6.10^{12}p/s)

➔ Actinides targets

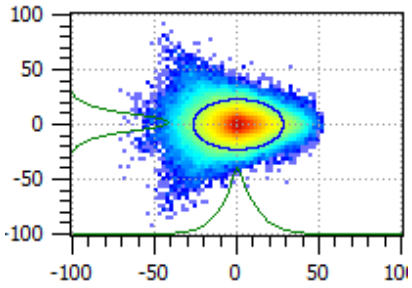
✓ **Versatility**

➔multistep separation

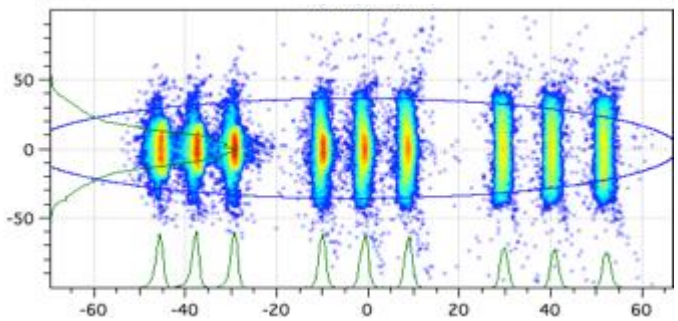
➔2 extreme optical modes defined

1. Convergent : Simplest mode for 1st expt ($\Delta_{dp/p}$=20%, Δ_{θ}=90mrad, Δ_{φ}=140mrad)
2. High mass res.: M/ΔM = 505 ($\Delta_{dp/p}$=16%, Δ_{θ}=45mrad, Δ_{φ}=140mrad)

Convergent mode



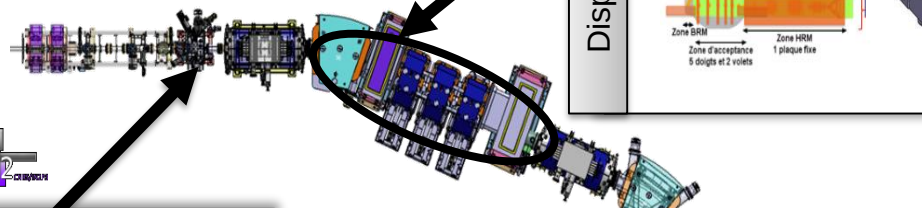
Mass resolution mode



Main equipments

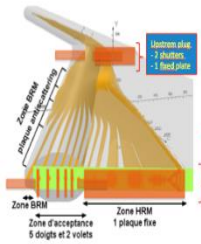
F. Dechery et al., Eur. Phys. J. A (2015) 51: 66
F. Dechery et al., in press NIMB

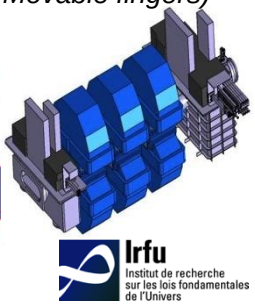
- Multistep separation
- Large acceptance
- Variable modes
- Mass resolution



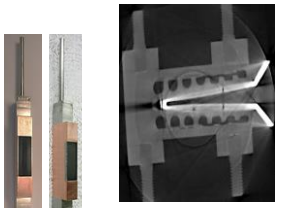
Dispersive zone

(beam dump & Movable fingers)



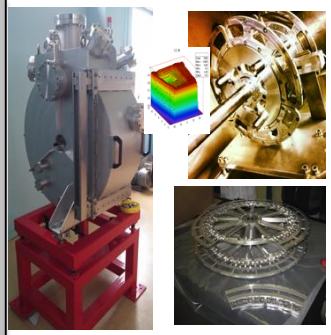


Irfu
Institut de recherche sur les lois fondamentales de l'Univers



tested for 5kW/cm²

Target system



High power rotating targets (3000-5000 rpm)
Stable & Actinide systems

3 × M-dipoles

Large H & V gaps

E-Dipole

20 cm gap & +/- 350 kV
Epmax : 12-14 MeV
Open slit in the anode

IPN
INSTITUT DE PHYSIQUE NUCLÉAIRE
ORSAY

SC Multipoles

Q+S+O fields

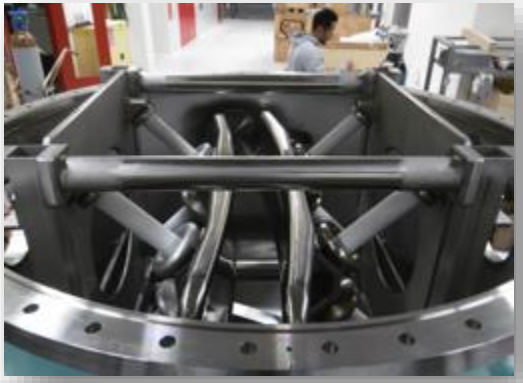
PSS

Cold Box

(L=26m)

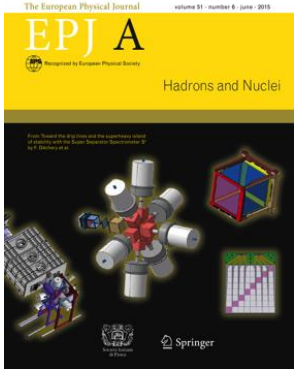
Argonne NATIONAL LABORATORY

Full assembly & tests with beam planned in 2020

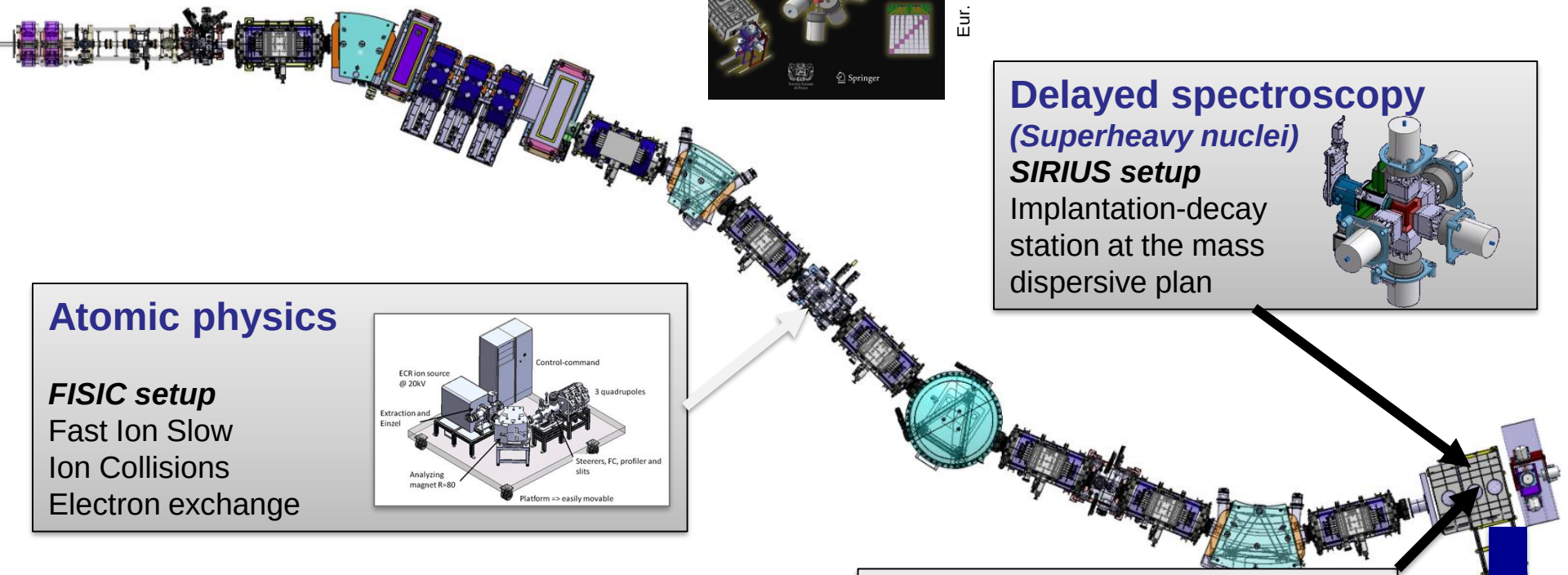


Experimental techniques

S3 Physics case (26 LoIs)
- VHE-SHE nuclei
- Proton drip-line & N=Z
- Nuclear Astrophysics
- Atomic physics



Eur. Phys. J. A (2015) 51: 66



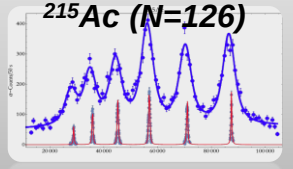
Delayed spectroscopy
(Superheavy nuclei)
SIRIUS setup
Implantation-decay station at the mass dispersive plan

Atomic physics

FISIC setup
Fast Ion Slow Ion Collisions
Electron exchange

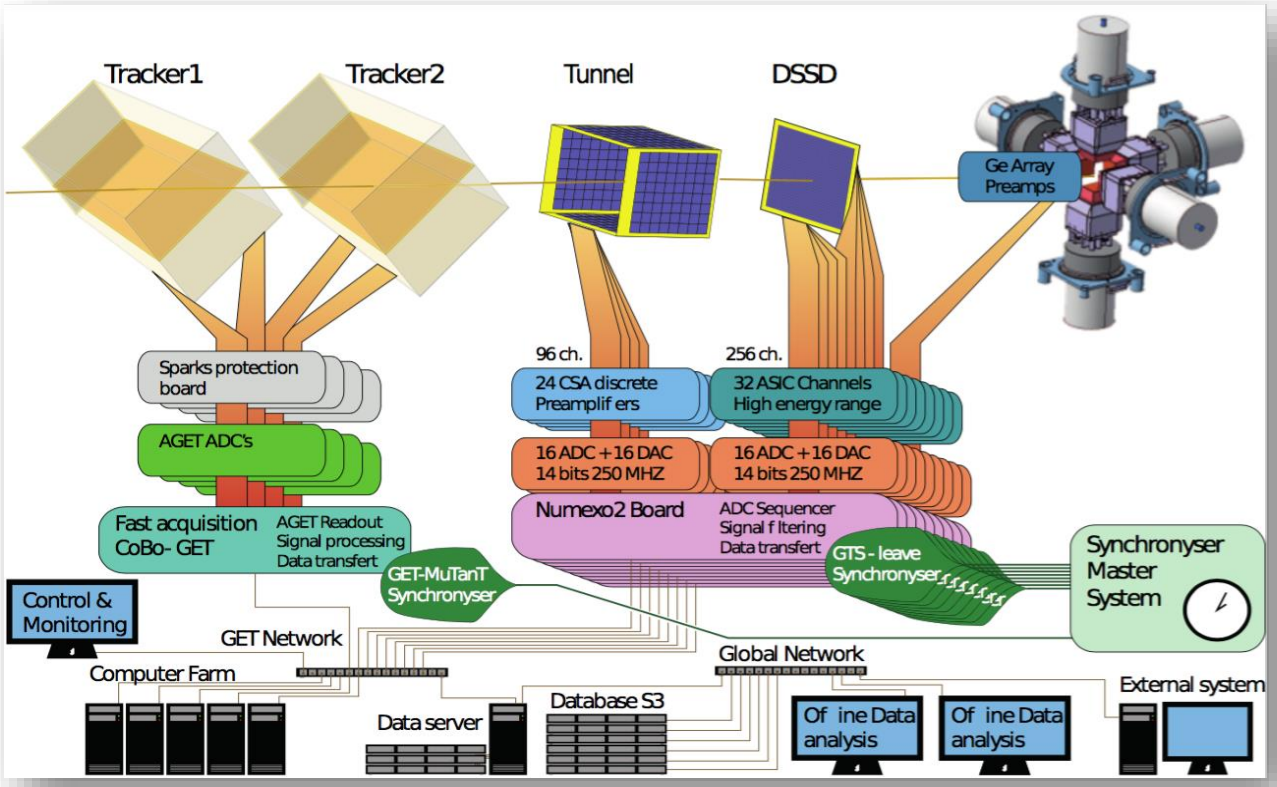
Ground state properties
(mass, size, moments, spins)

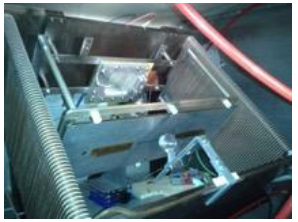
S3-LEB setup
IGLIS + Mr-ToF

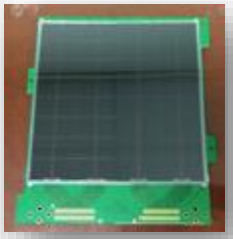


DESIR

SIRIUS (Spectroscopy & Indentification of Rare Ions Using S^3)







F. Dechery et al., Eur. Phys. J. A (2015) 51: 66

Alpha, electron, gamma decay spectropy

- Time of flight ($\sigma(t) < 1ns$) and tracking ($\sigma(x) < 0.5mm$) of (super)heavy ions
- Implantation decay correlation (10x10cm^2, 128x128ch DSSD)
- Digital electronics for fast decays (low gain/high gain switching) $\sigma(E_{alpha}) < 20keV$

Commissioning with sources and beams 2019

VHE/SHE day 1 Science opportunities

nuclide	feature	X-section [nb]	rate [h^{-1}]	21UT integral	
				day 1	phase 1++
^{254}No	ER	2000	60.000	**6×10^{7}**	1×10^{7}
^{256}Rf	ER	17	550	**90.000**	5.4×10^{5}
^{266}Hs	ER	15 (^{270}Ds)	0.34	**57**	285
^{266m}Hs	K-isomer	15 (^{270}Ds)	0.01	**2.5**	12.5
^{270}Ds	ER	15	0.45	**76**	380
^{270m}Ds	K-isomer	15 (^{270}Ds)	0.22	**38**	190
^{262}Sg	α-decay	15 (^{270}Ds)	0.02	**5**	25
^{276}Cn	ER	0.5 (^{277}Cn)	0.01	*2.5*	*12.5*
^{288}115	ER	10	0.3	*50*	*300*
^{288}115	L X-rays	10	1,8	*300*	*1800*

Rate summary vs GSI UNILAC

- ✕ 2-4 [A/Q=3]
- ✕ **15-20 [A/Q=7]**

◎ Nuclear structure

Quasi-particle excitations ➔ deformation/K-isomers

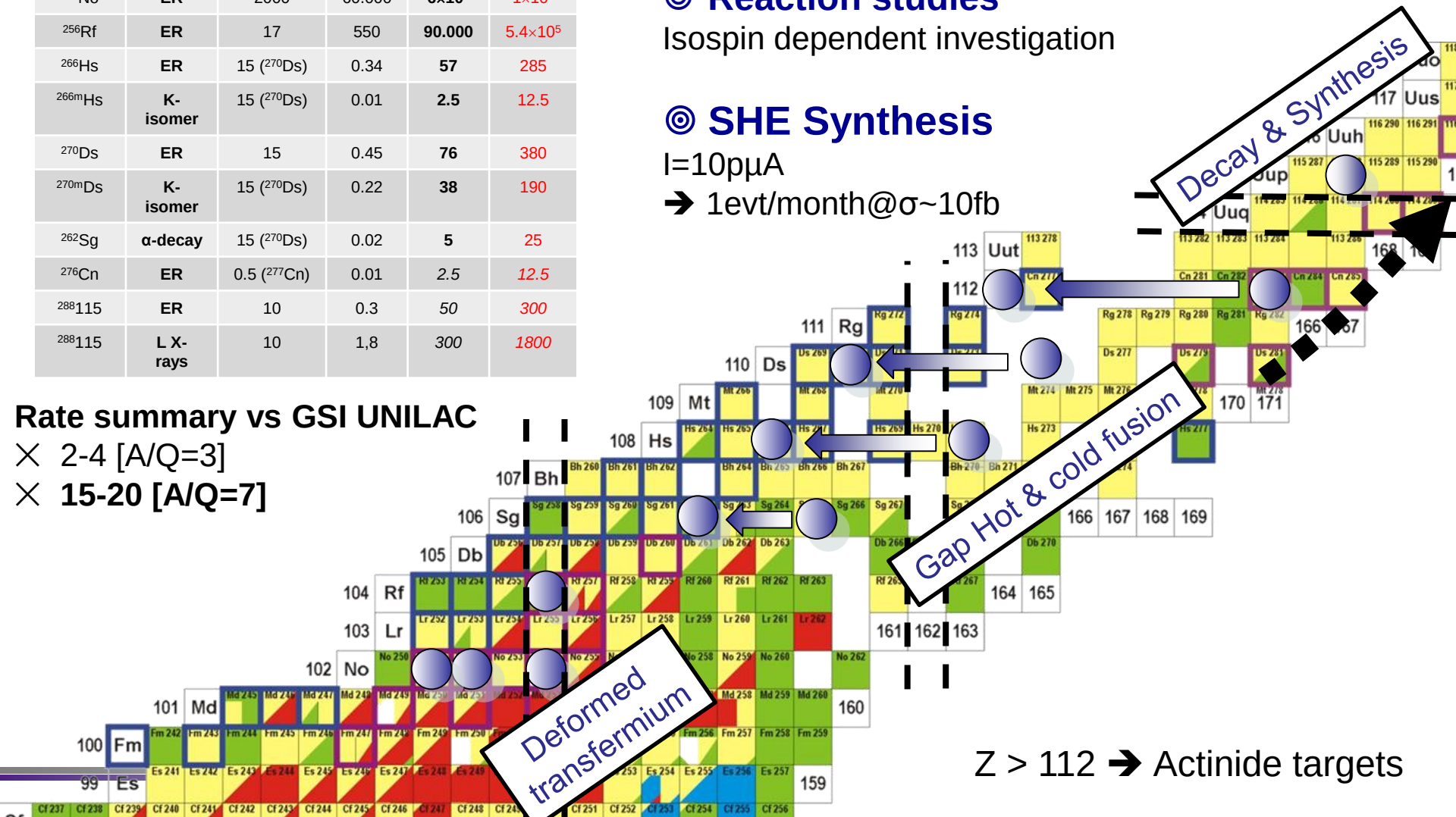
◎ Reaction studies

Isospin dependent investigation

◎ SHE Synthesis

I=10pμA

➔ 1evt/month@σ~10fb

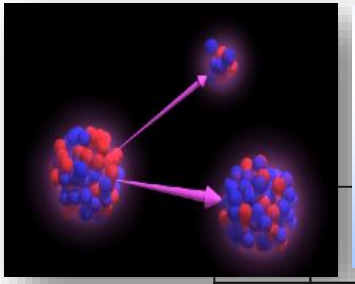


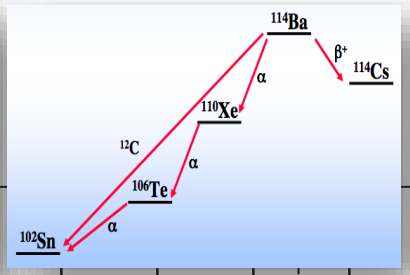
Z > 112 ➔ Actinide targets

N=Z day 1 Science opportunities

^{100}Sn region experimental status

- ^{112}Ba-^{108}Xe -^{104}Te super-allowed α decay and search for cluster radioactivity





- Exotic decays from the 21$^+$ isomer in ^{94}Ag

Low Energy Branch (LEB)

R. Ferrer et al., NIM B 317 (2013) 570–581

KU LEUVEN (Gas cell, laser system)

IPN INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY (Gas cell)

lpc caen (RFQs)

GANIL spiral2 laboratoire commun CEA/DSM CNRS/IN2P3 (mr-TOF-ms, laser system infractructure, safety, RFQsdetectors)

LARISSA JGU JOHANNES GUTENBERG UNIVERSITÄT MAINZ; UNIVERSITY OF JYVÄSKYLÄ (narrow band-width laser pre-studies at MARA)

MCP

MR ToF MS ($m/\Delta m \sim 10^5$)

200 - 500 mbar Ar

R. Ferrer et al., NIM B 317 (2013) 570
Yu. Kudryavtsev et al., NIM B 297 (2013) 7

gas cell

S-shape RFQ

diff. pumping RFQ

QMF ($m/\Delta m \sim 100$)

buncher

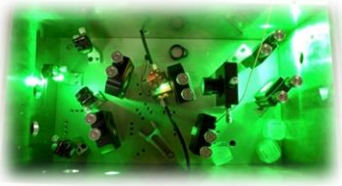
bender

EVRs
Neutralized EVRs
Photoions

from S^3

towards Multi Purpose Room - Identification/detection

Two lasers systems: TiSa and dye



10^{-8} mbar

towards DESIR

$\lambda_{1,2}$

λ_2

λ_1

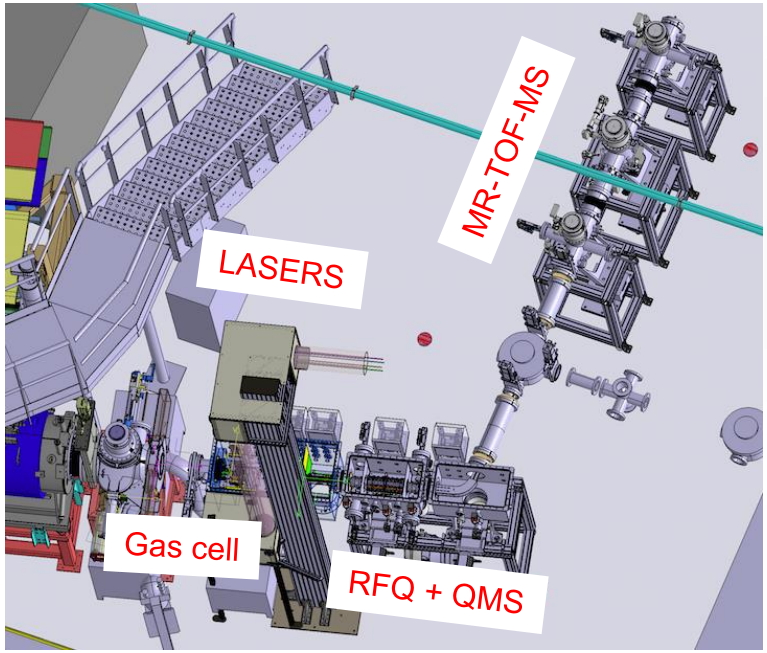
in-gas-cell ionization

in-gas-jet ionization

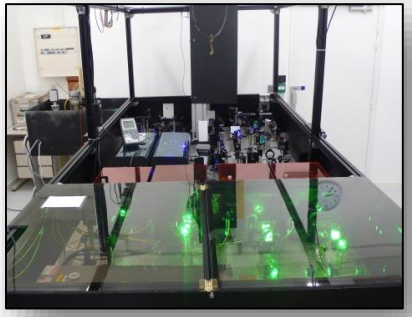
10^{-2} mbar

- Provide pure & low energy beams from S^3
- Perform medium resolution laser spectroscopy
  ➔100 MHz & Eff > 10%
  (charge radii, spin, magnetic dipole moment, electric quadrupole moment)

LEB equipment

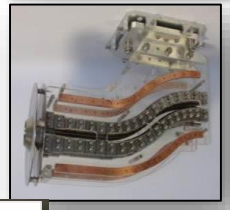


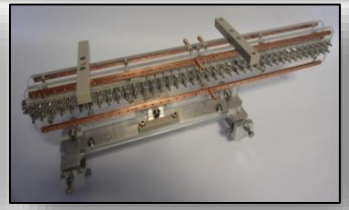
TiSa Lasers

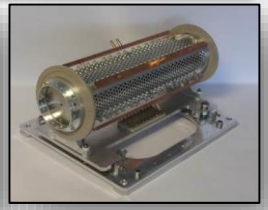


MR-TOF-MS (PILGRIM)

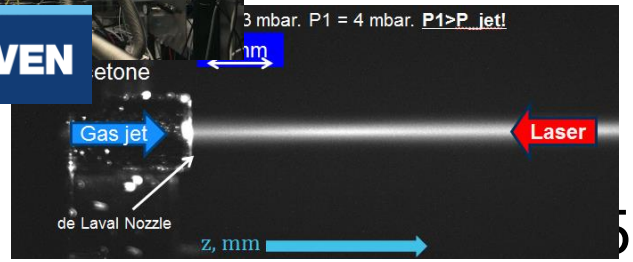
RFQ + QMS







Leuven test bench
In-Jet Laser spec system



Full assembly & tests at LPC Caen in 2017-2019
Installation at S3 in 2019-2020

LEB day 1 science opportunities

◎ **Heavy (and Super Heavy) element region**

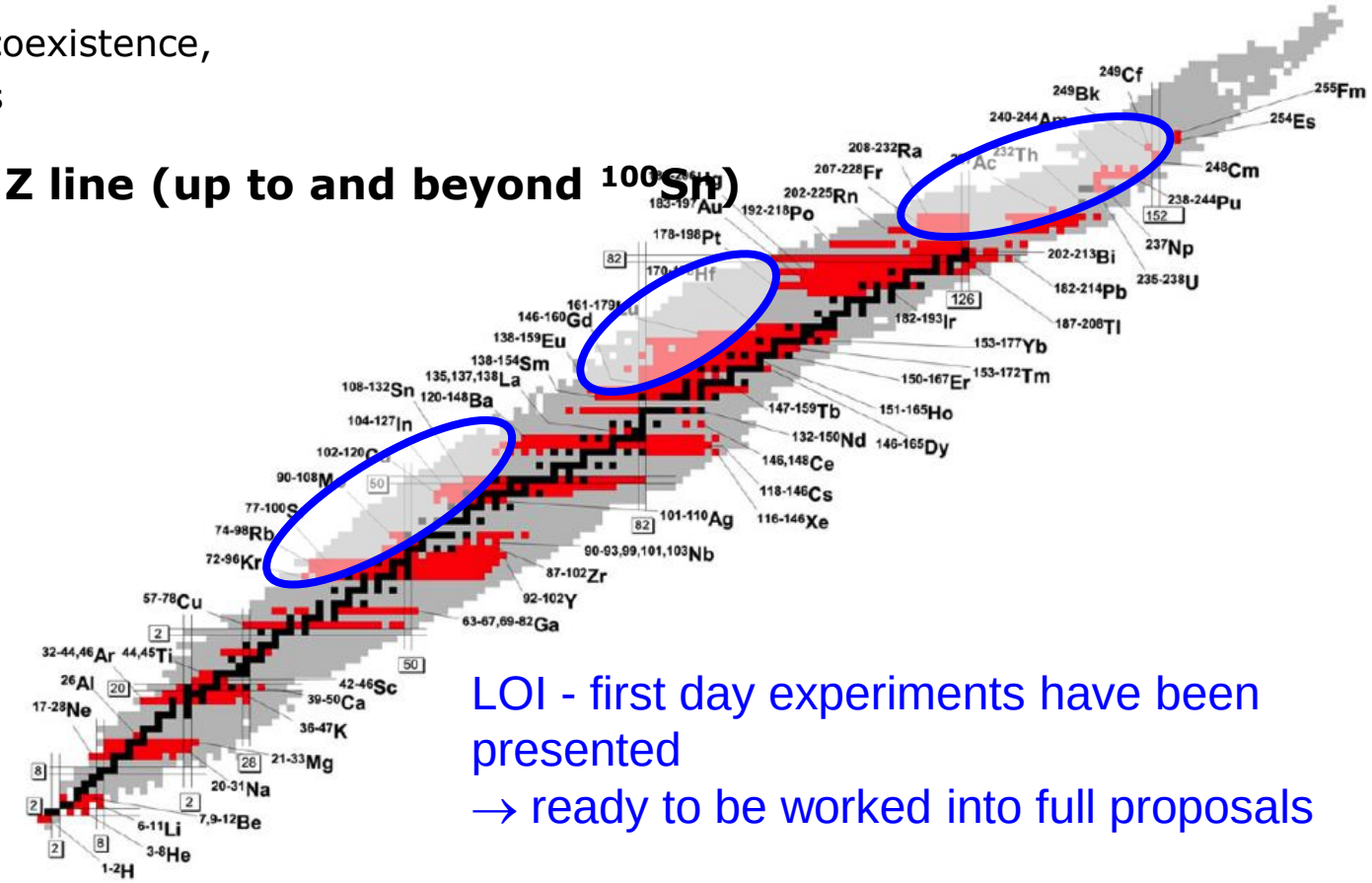
- single-particle versus deformation,
- atomic physics

◎ **Heavy neutron-deficient refractory element region and trans lead region**

- shapes and shape coexistence,
- exotic decay modes

◎ **Close to the N=Z line (up to and beyond ^{100}Sn)**

- shell evolution,
- nuclosynthesis,
- symmetries



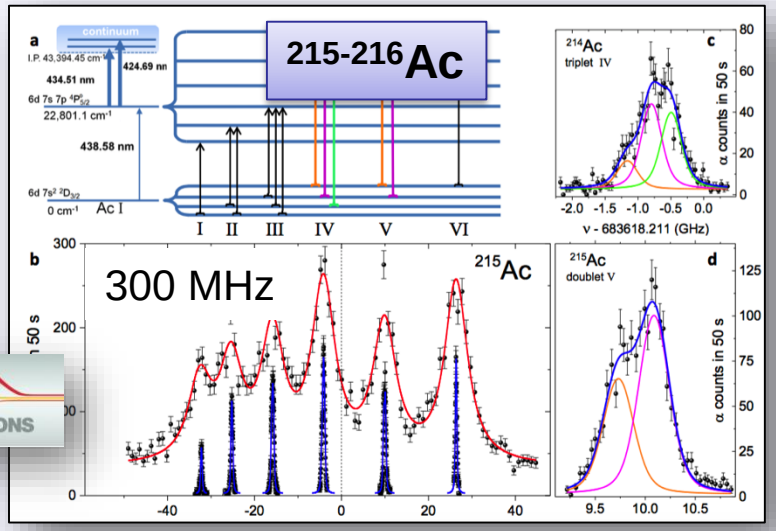
LOI - first day experiments have been presented
→ ready to be worked into full proposals

Blaum K., Dilling J., Nörtershäuser W. Phys. Scr. T152 (2013) 014017

Laser Spectroscopy SHE

◎ High-resolution laser ionisation spectroscopy of the heaviest elements in S³ like experiment

Nuclear spins, magnetic- dipole and electric-quadrupole moments, and differences in mean-square charge radii of neutron- deficient actinium isotopes around the N = 126.



nature COMMUNICATIONS

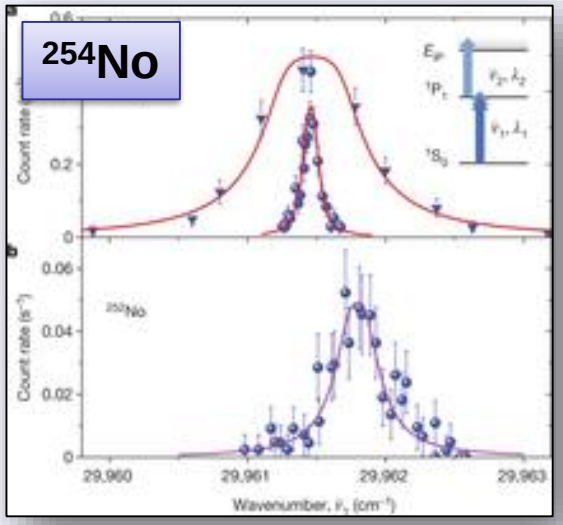
Nat. Commun. 8, 14520 doi:10.1038/ncomms14520 (2017).

◎ Atom-at-a-time laser resonance ionization spectroscopy of nobelium (GSI)

Ionization potential of nobelium.

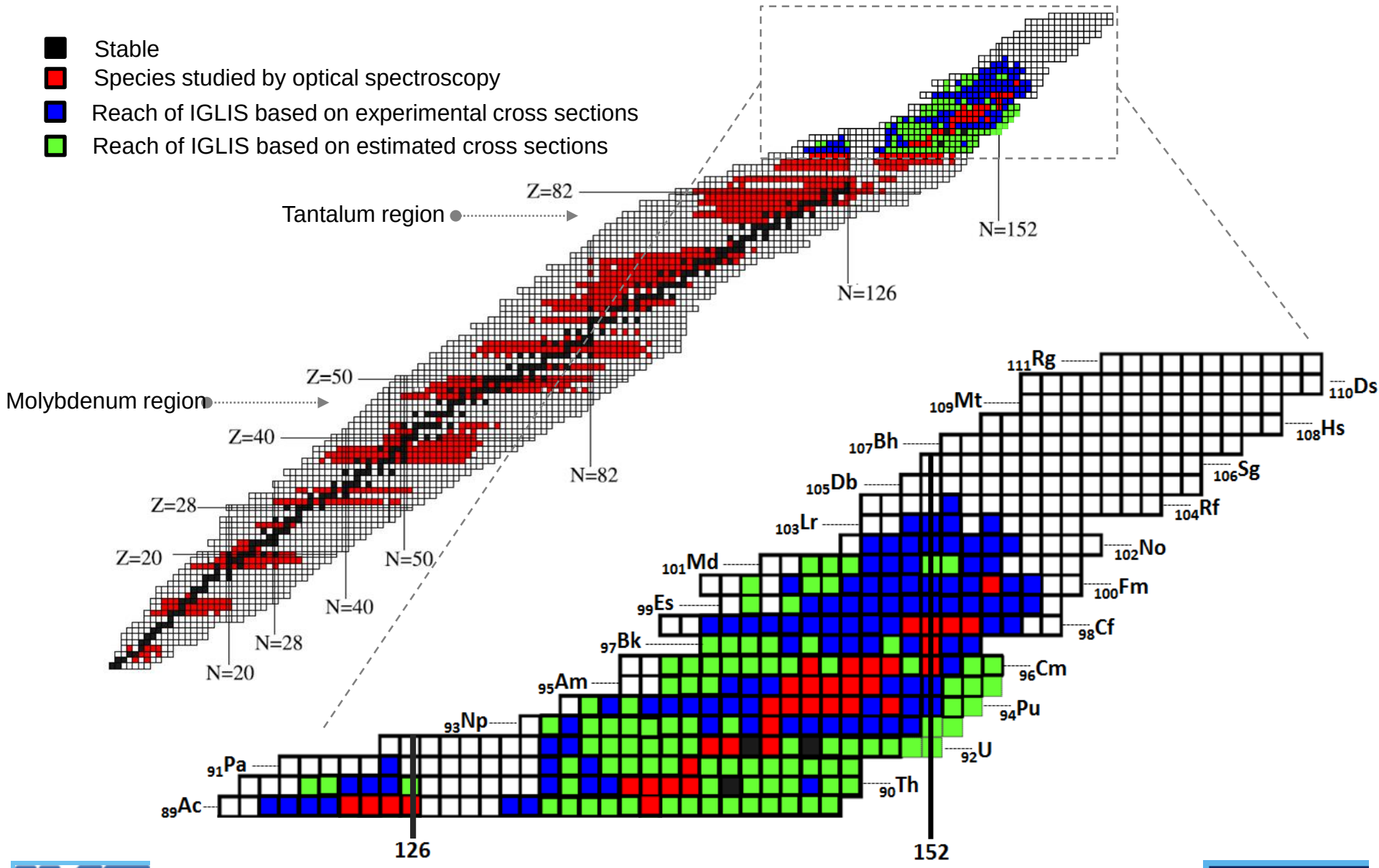
Nature 538, 495–498 (27 October 2016)

nature

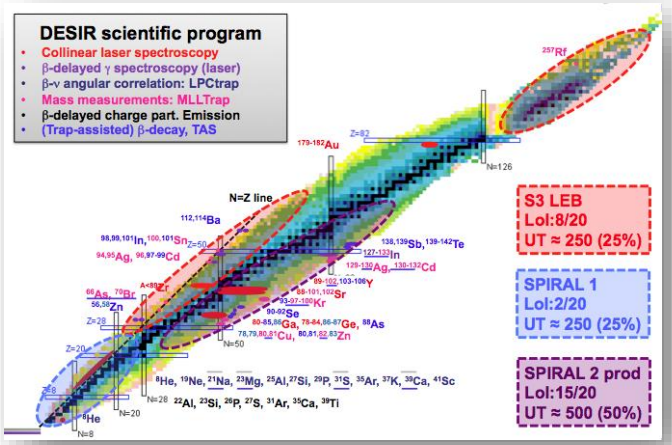


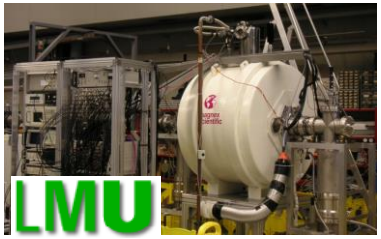
Open the door to high-precision measurements for SHE
➔ Hyperfine splitting measurement with S³ !!!

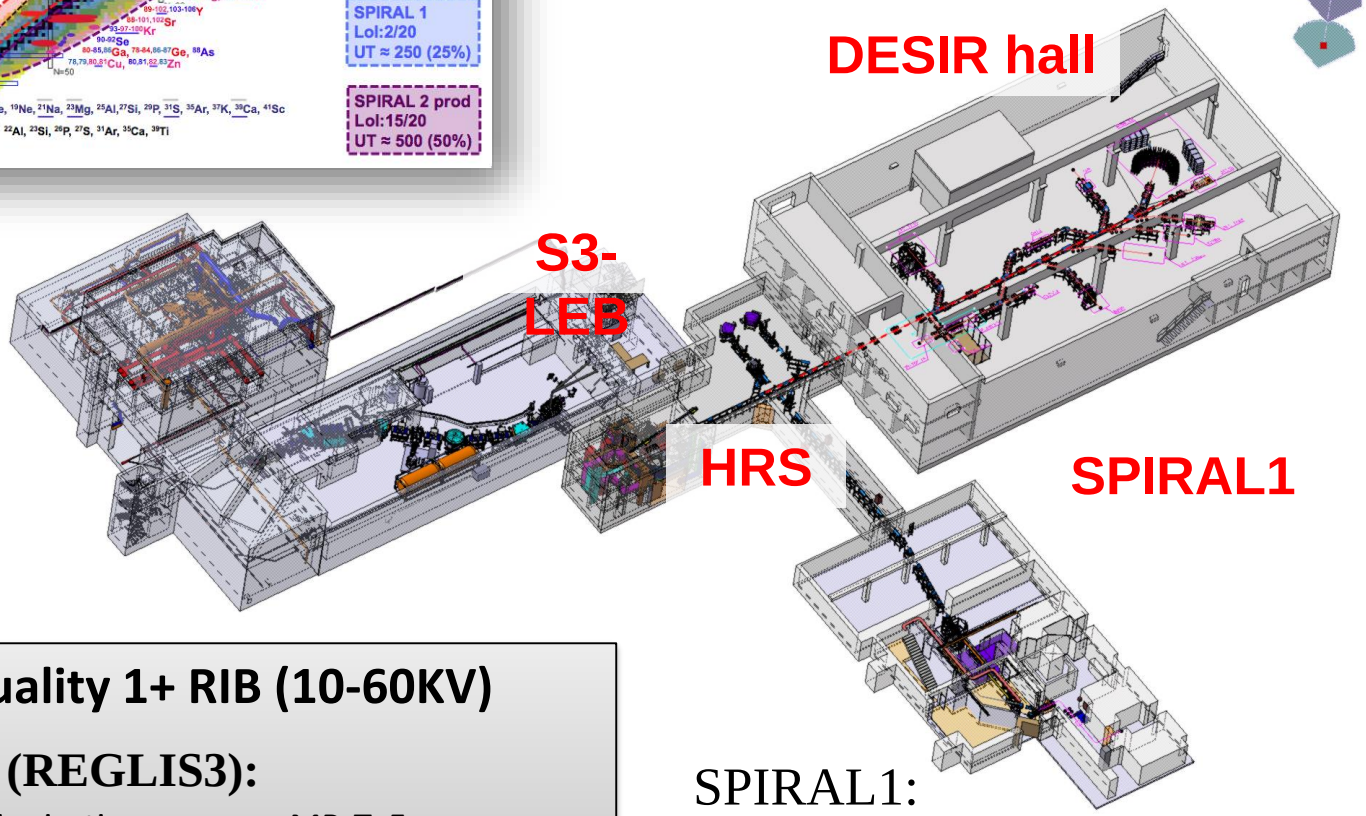
Outlook: IGLIS on Actinides at S^3

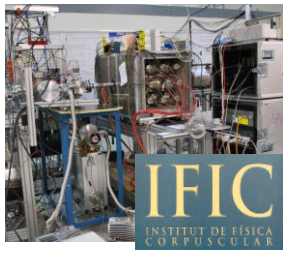


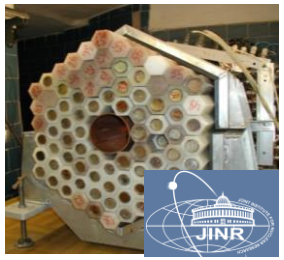
Construction planned mid 2020











High quality 1+ RIB (10-60KV)

S^3 LEB (REGLIS3):

- laser ionization source + MR-ToF
- refractory elements
- n-deficient nuclei & very heavy nuclei

SPIRAL1:

- beam + target fragmentation
- ECR + FEBIAD + Surface ionization
- light nuclei

Conclusions

- **Start the scientific program with SPIRAL2 in 2019**
  - Commissioning of SPIRAL2 Phase 1 ongoing
  - First experiment with NFS planned in 2019

- **S^3 is a low energy in-flight separator for the Spiral2 stable beams**
  - Fusion-evaporation, two-step reactions, rare channels, electron exchange…
- **Designed for the selection and identification of rare events**
  - 2 steps rejection and >350 Mass resolution
  - High transmission of evaporation residues
  - High versatility
- **Two basic detection set-ups**
  - Implantation-decay spectroscopy station (SIRIUS)
  - In gas cell laser ionization & spec. + MR ToF (LEB)

  ➔ **Full assembly & tests with beam planned in 2020**

You are welcome to join the collaboration; first campaign to be discussed in 2018 at next S^3 collaboration meeting (June 2018)

Conclusions