laboratoire commun CEA/DRF CNRS/IN2P3

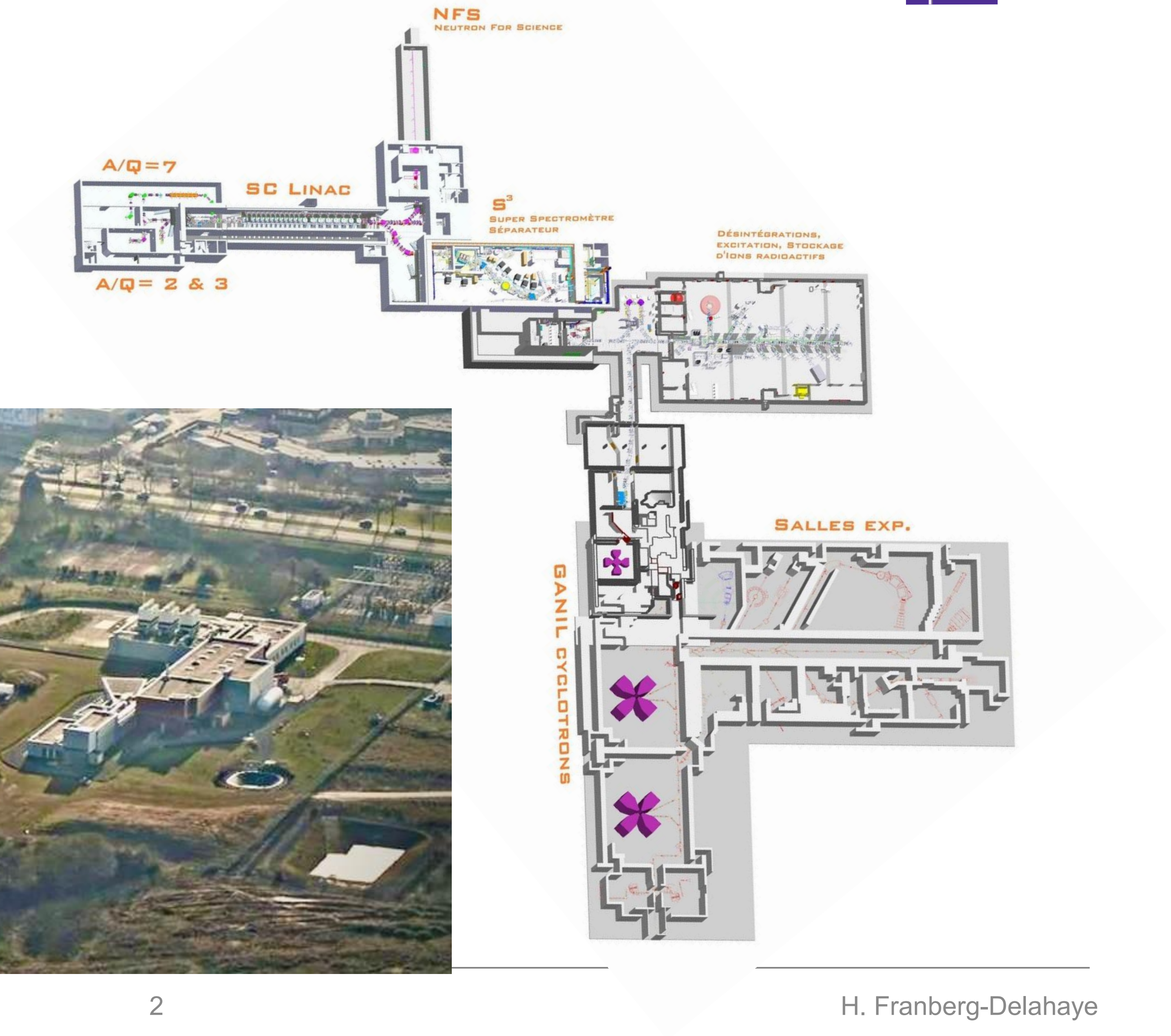
HIAT 2022 | Darmstadt

THE NEW GANIL BEAMS: COMMISSIONING OF SPIRAL2 ACCELERATOR AND RESENT DEVELOPMENTS

H. Franberg Delahaye
GANIL

Outline of my talk

- GANIL
- SC-LINAC
- CYCLOTRONS
- NEXT STEPS FOR GANIL



A brief history of GANIL

1976 Creation of GANIL (Grand Accélérateur national d'ions lourds)

1982 first extracted 40Ar16+ beam SSC

1983 First experiment

1990 Installation of Wien filter

1992 New 14 GHz ECR ion source 100 kV: High intensity adaptation of the beam lines THI : Beam diagnostics, Beam loss monitoring, beam strippers, supervision of our power supplies for the electric and magnet devices, thermal shielding, radiation protection, New rebunche between the two SSC.

2001 SPIRAL1 ISOL facility for exotic beams

2006 SPIRAL2 Project signature of convention for construction

2007 Upgade to high intensity framentation target LISE / CLIM ?

2016 SPIRAL2 ESFRI Landmark

2018 SPIRAL1 V2

2019 Start of the commissioning of SPIRAL2

2020 First neutron beams

2021 First NFS experiments (Neutron For Science)

2023 – S3

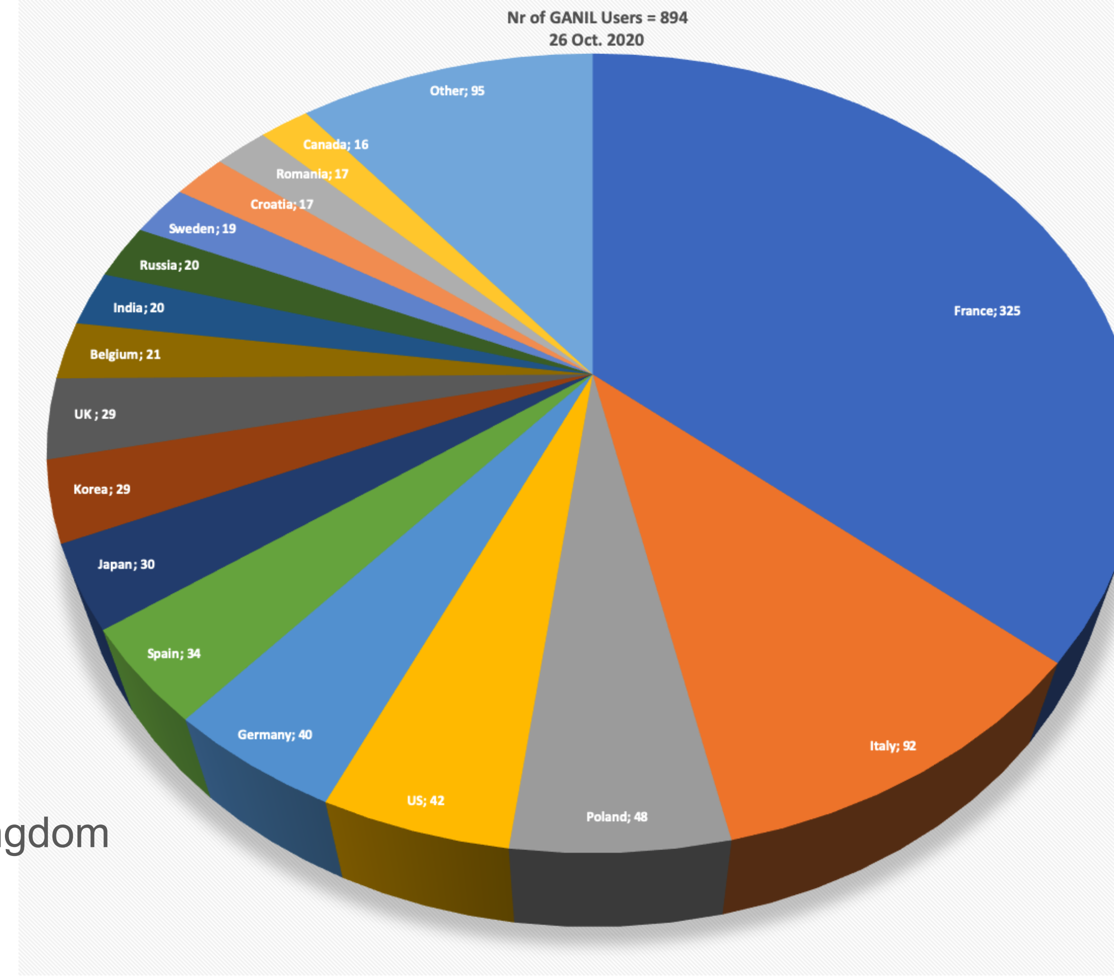
2026 – DESIR

2027 – Injector 3 A/Q=7 at SC LINAC

Some numbers

- 230 permanent staff members (CEA and CNRS researchers, engineers, technicians)
- 40 temporary staff (15 PhD, 5 postdocs)
- + CIMAP = 24 permanent staff + 15 PhD + 8 postdocs
- An international scientific community of ≈ 1000 members

France
Italie
Polonie
USA
Germany
Spain
Japan
Corea
United kingdom
Belgium
India
Russia
Sweden
Roumania
Canada

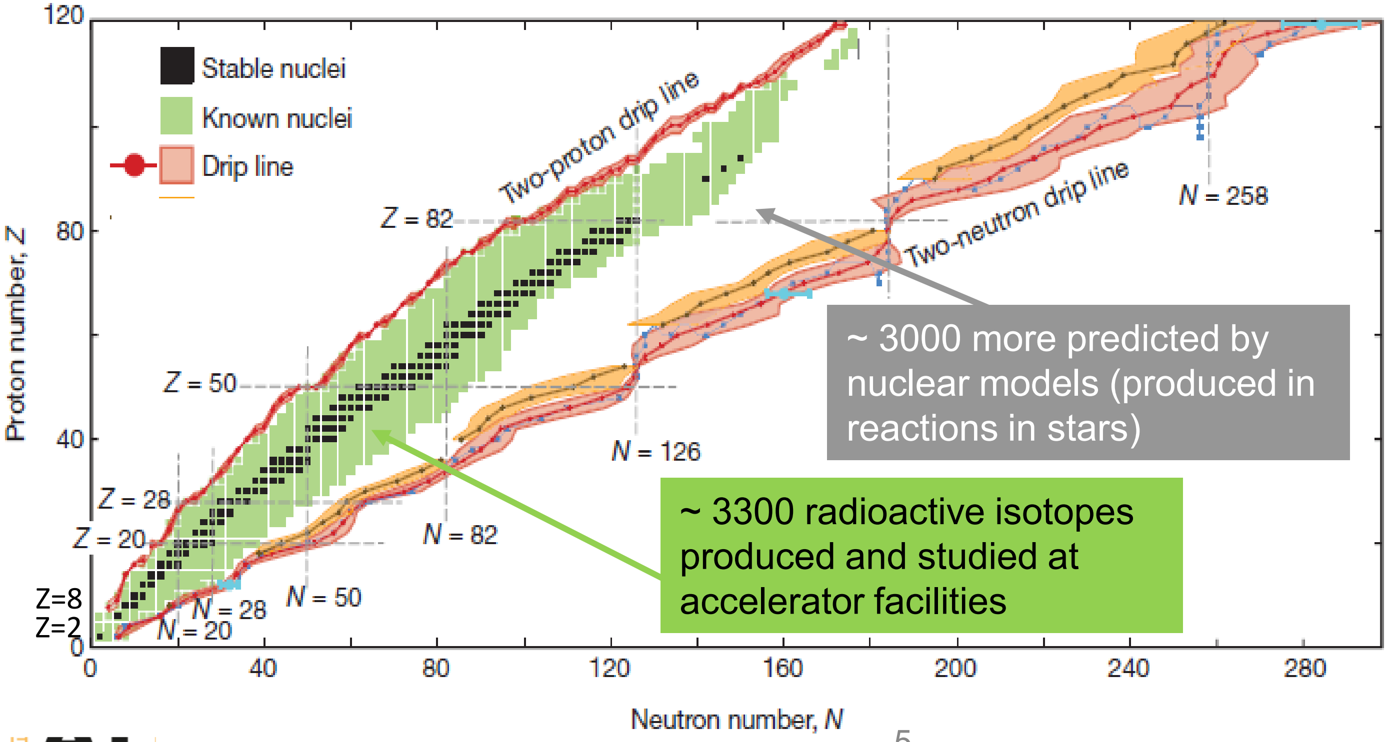


GANIL: a multidisciplinary and multi-users laboratory

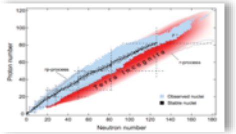
Nuclear Physics@GANIL: study of exotic nuclei

Main questions to be answered :

- What are the limits of existence of nuclei ?
- What are the underlying fundamental interactions ?
- How regular patterns emerge in the intrinsic structure of complex many body nuclei ?



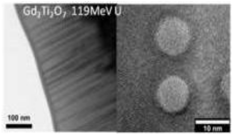
Nuclear Physics



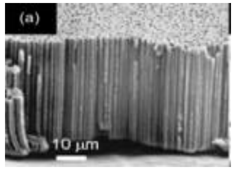
Nuclear Astrohysics

Astrochemistry

Materials under irradiation

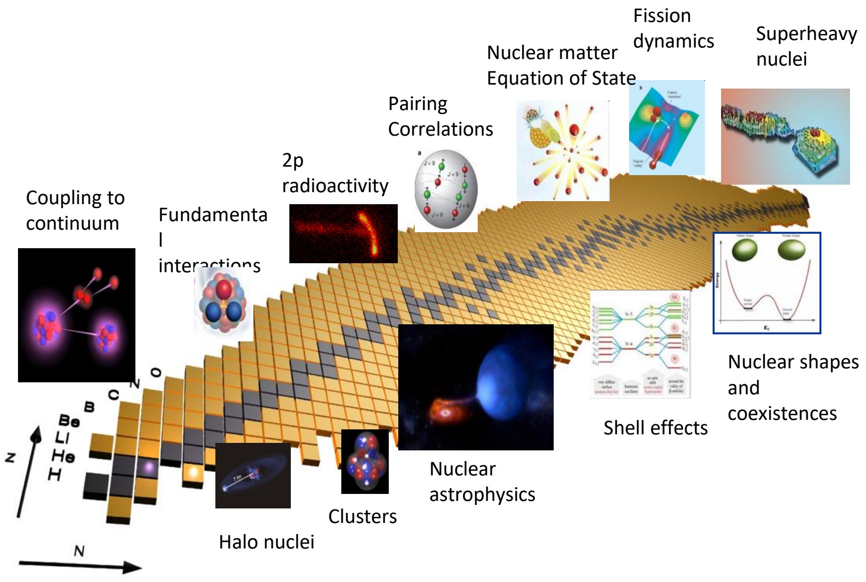


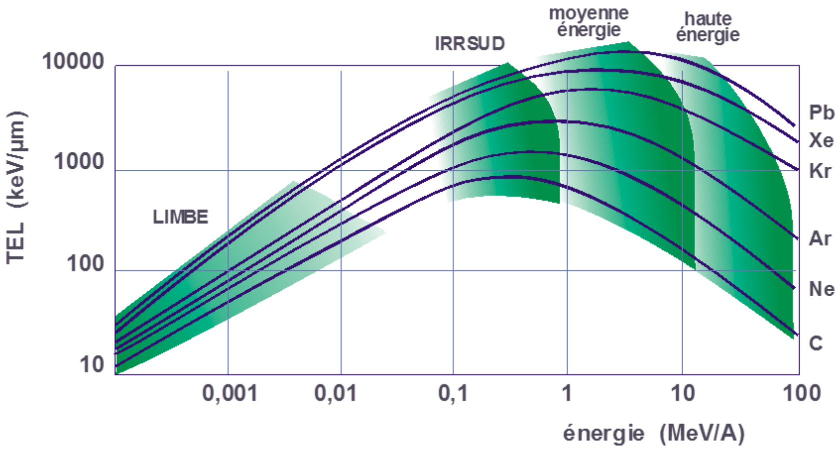
Nanostructuration



Radiobiology

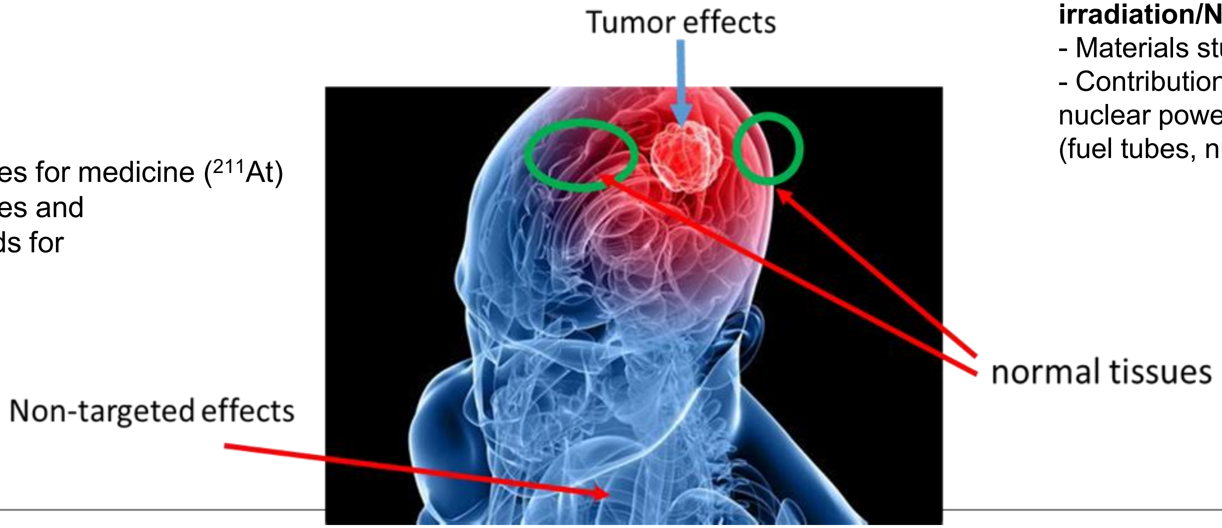
GANIL: a multidisciplinary and multi-users laboratory



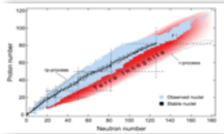


Materials under irradiation/Nanostructuration
- Materials study
- Contribution to improving the nuclear power plants safety (fuel tubes, nuclear packaging)

Radiobiology
- New radioisotopes for medicine (^{211}At)
- pre-clinical studies and innovative methods for hadrontherapy



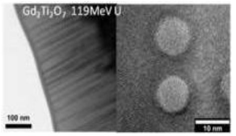
Nuclear Physics



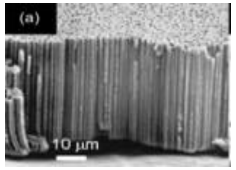
Nuclear Astrohysics

Astrochemistry

Materials under irradiation



Nanostructuration



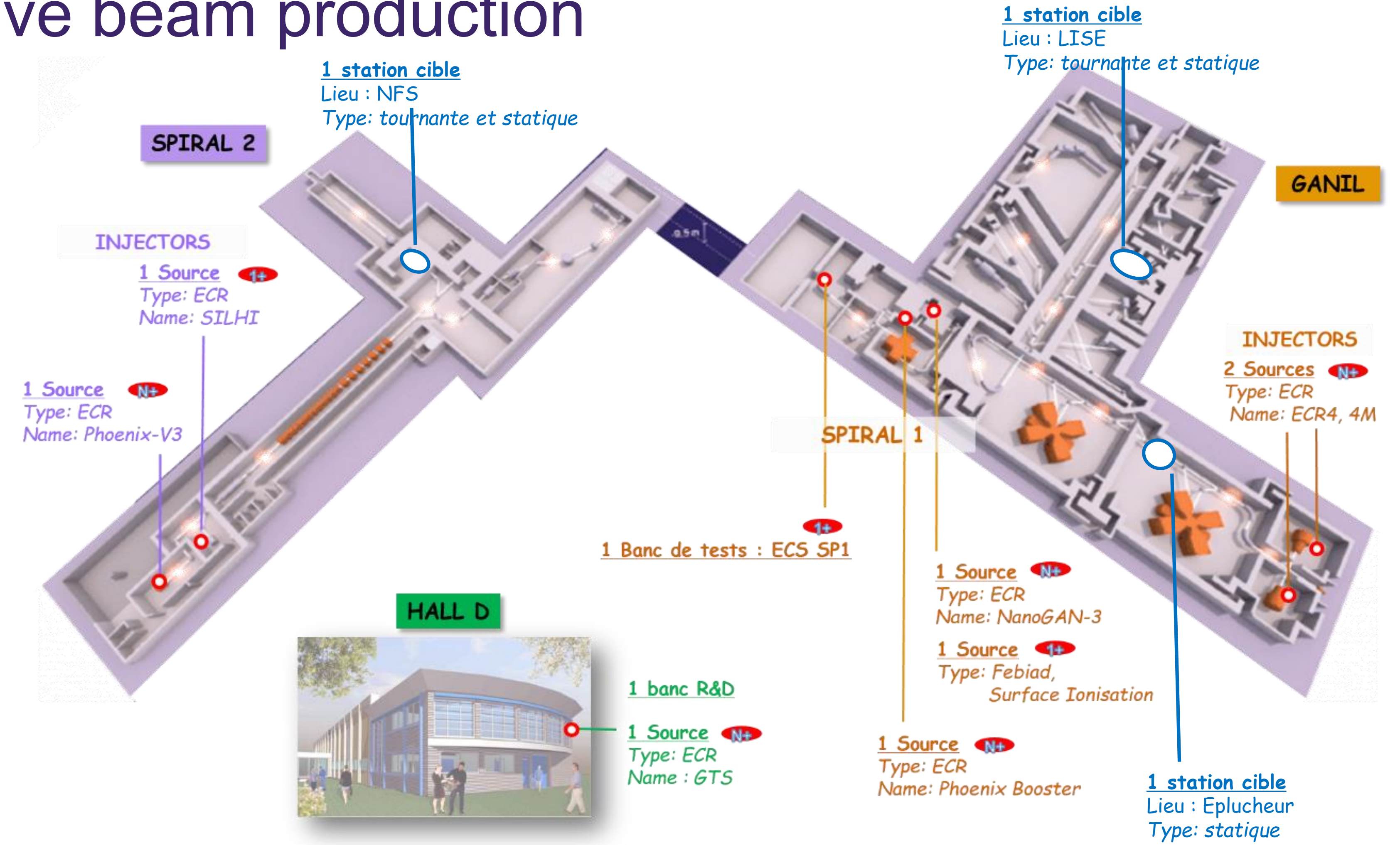
Radiobiology

Stable and radioactive beam production

- Injectors:
  - 2 ECR4-4M
  - Source Deutons/Protons
  - Source Phoenix V3

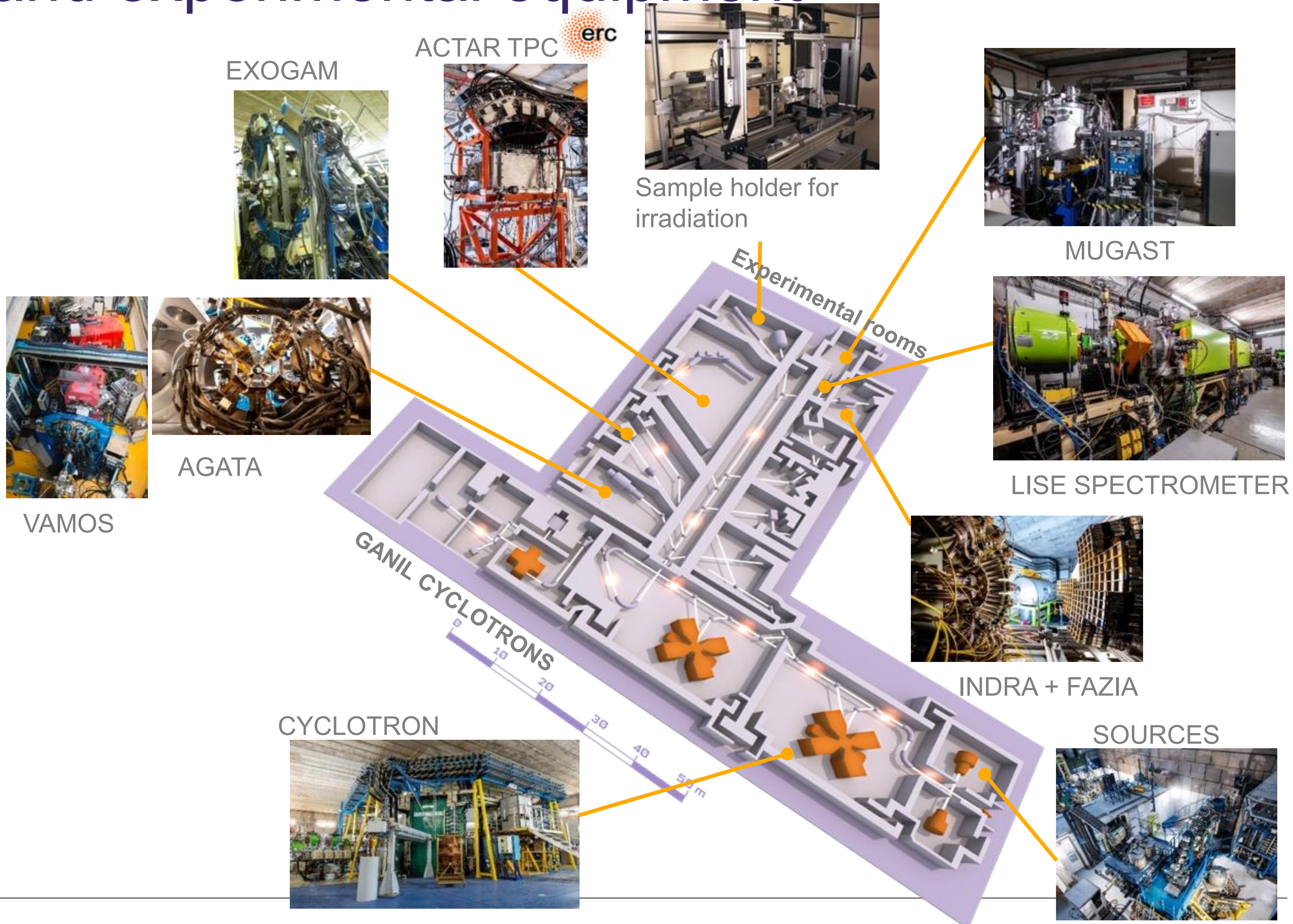
- Radioactive ion beams production
  - SPIRAL 1
    - FEBIAD ion source
    - NanoGAN ECR ion souce
    - Surface ion source
    - Thin targets
    - Thick targets
    - Charge breeder ECR
  - Fragmentation target LISE
  - Neutron converter

- Off line installation
  - GTS ECR ion source
  - Off-line target and ion souce + lasers
  - Off-line oven laboratory



GANIL Cyclotrons and experimental equipment

- Beams : ^{12}C to U
- Energy : from <1 MeV up to 95MeV/nucleon
- Up to 4 experiments in parallel

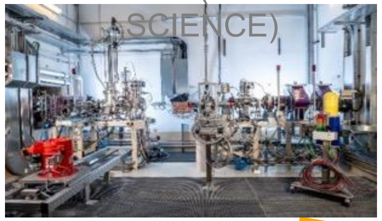


SPIRAL2 and the experimental equipment

33 MeV protons
40 MeV deutons
<14,5 MeV/A
heavy ions

- 1 experiment at the time

EXPERIMENTAL ROOM NFS (NEUTRONS FOR SCIENCE)

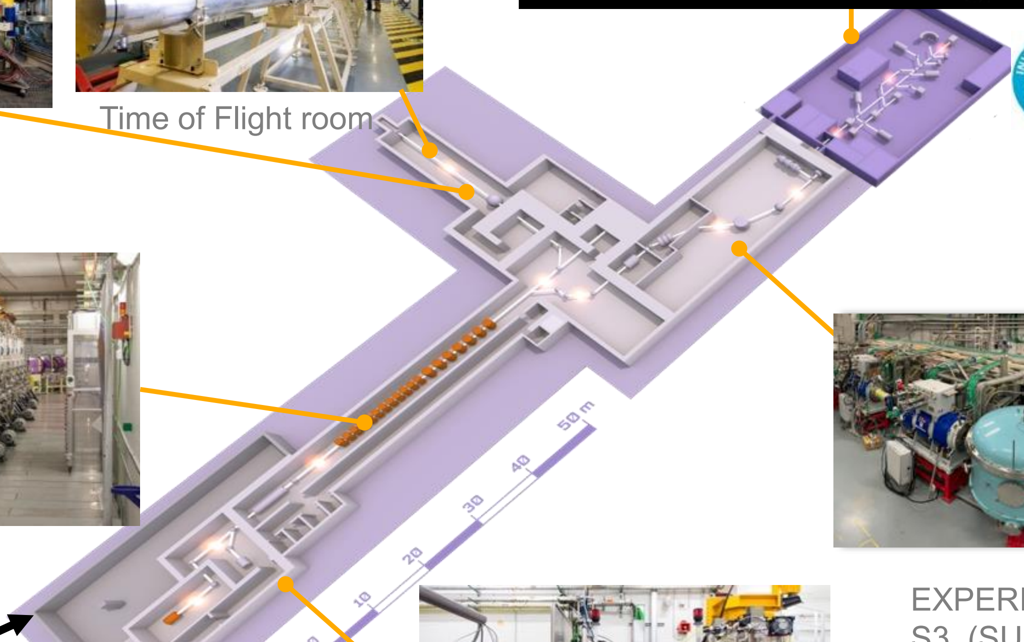


Convertor room

Time of Flight room

EXPERIMENTAL ROOM DESIR (Desintegration, Excitation and Storage of Radioactive Ions)

LINEAR accelerator (LINAC)



NEWGAIN
NEW GANIL INJECTOR

EXPERIMENTAL ROOM S3 (SUPER SEPARATOR SPECTROMETER)

ION SOURCE

Beams :
33 MeV protons
40 MeV deutons
<14,5 MeV/A heavy ions

SC-LINAC

GANIL-SPIRAL 2

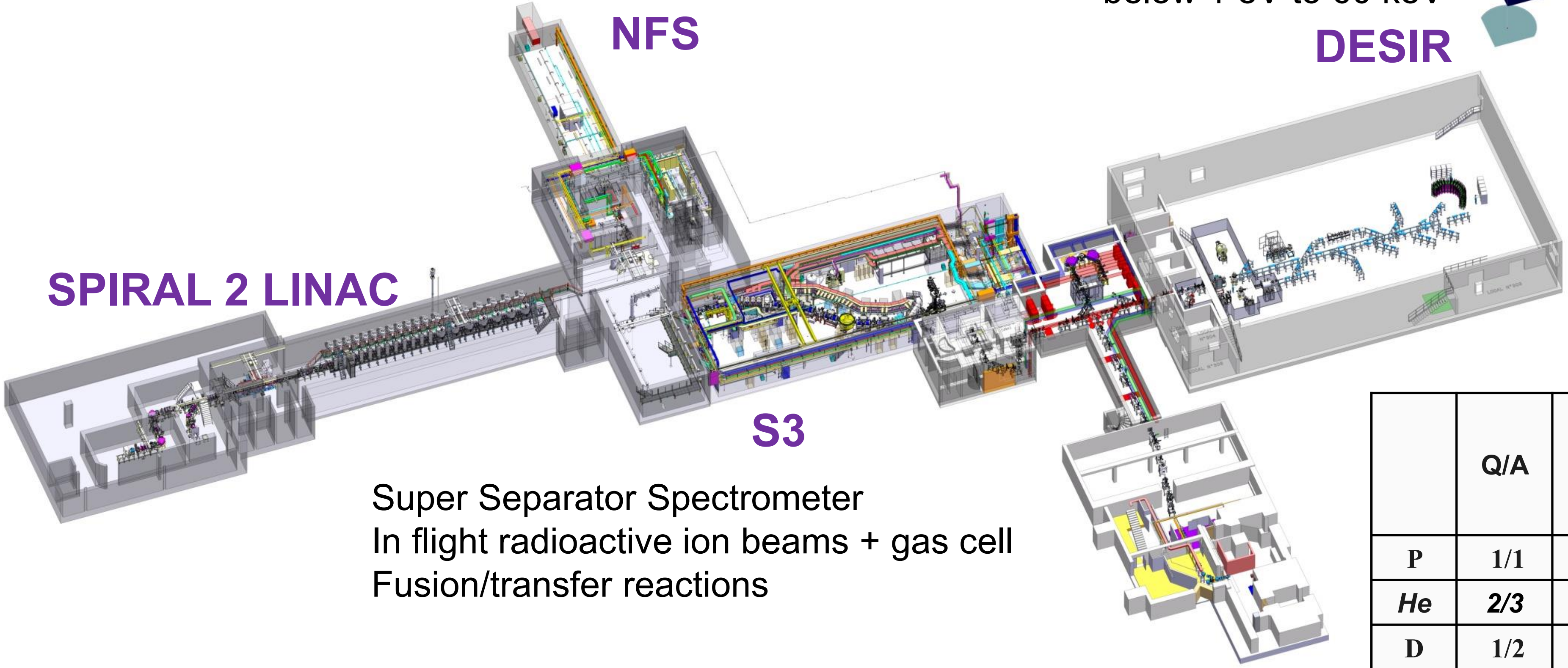
Neutron for Science
Neutrons up to 30 MeV

NFS

Experimental areas for very low energy beams:
below 1 eV to 60 keV

DESIR

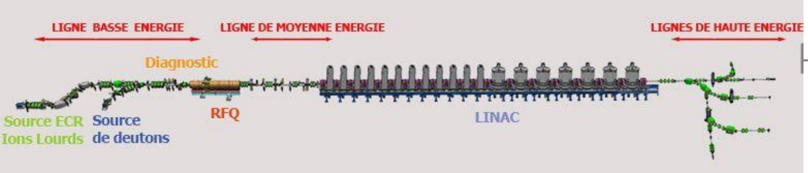
SPIRAL 2 LINAC



S3

Super Separator Spectrometer
In flight radioactive ion beams + gas cell
Fusion/transfer reactions

	Q/A	I max (mA)	Energy (MeV/n)	CW max beam power (kW)
P	1/1	5	2 - 33	165
He	*2/3*	*1*	*2-2 4*	*36*
D	1/2	5	2 - 20	200
Ions	1/3	1	2 - 14.5	45



Power up of SPIRAL 2

1. SPIRAL2 status
2. Main commissioning results
3. Linac validation
4. Conclusions

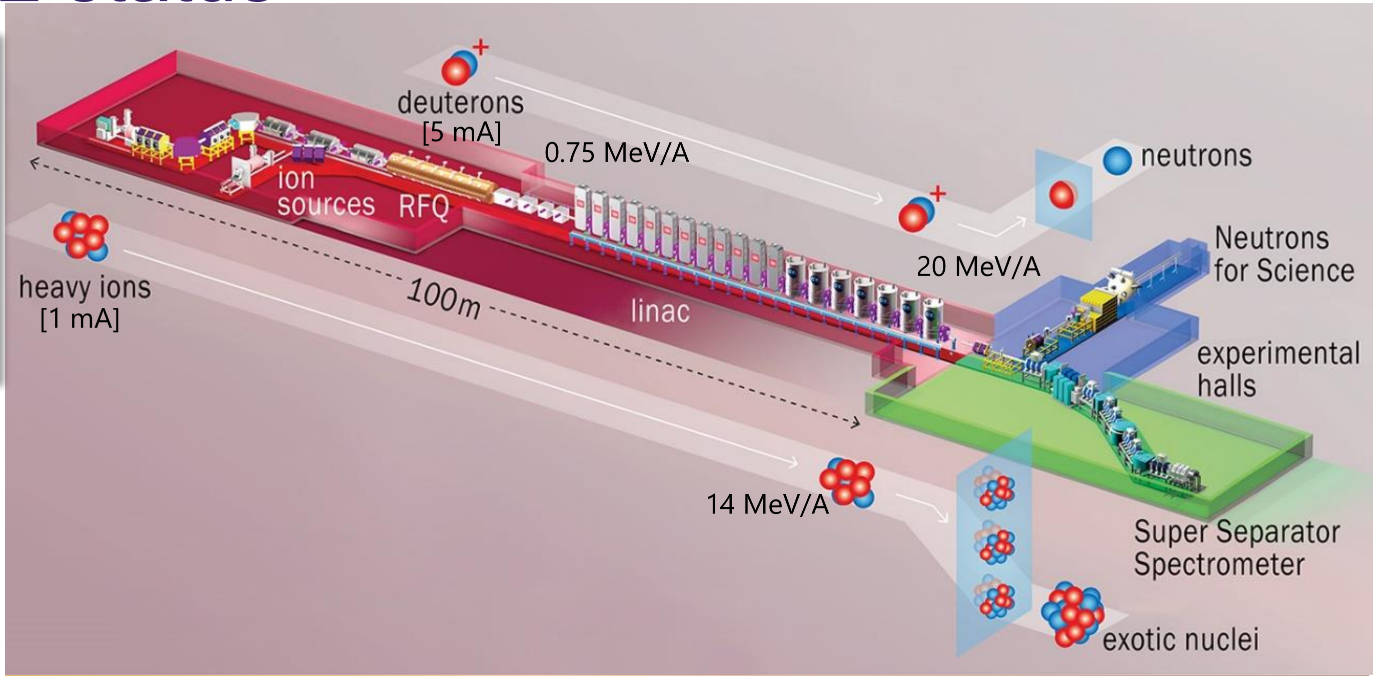
SPIRAL2 status

July 8th , 2019 : Administrative authorization to operate SPIRAL2

Built by several French Labs

Collaboration with International labs

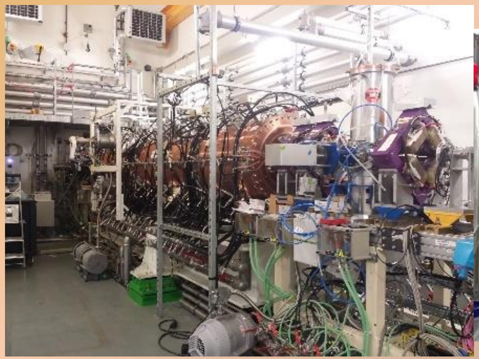
BARC (India), INFN (Italia)
IFIN-HH (Romania), IFJ-PAN (Poland)
SOREQ (Israel), INRNE-BAS (Bulgaria)



RFQ
88 MHz

Superconducting cryomodule A
[β=0.07]

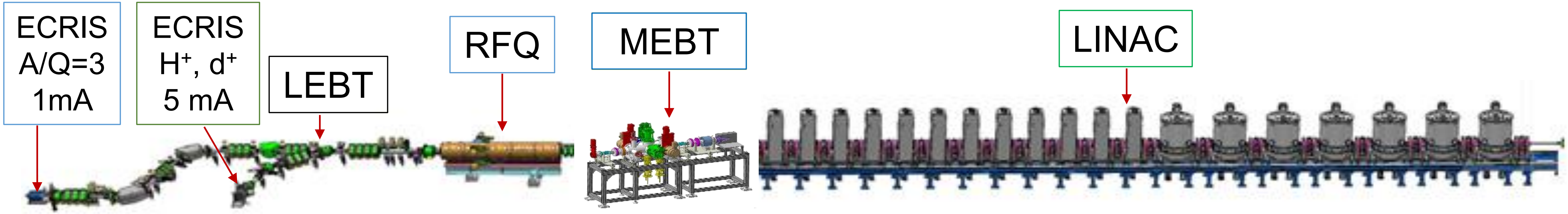
Superconducting cryomodule B
[β=0.12]



Particles	H^+	D^+	ions	Heavy ions
A/Q	1	2	3	7
Max I (mA)	5	5	1	1
Max energy (MeV/A)	33	20	14	8.5
Max beam power (kW)	165	200	44	51

A versatile machine to provide high intensity beams

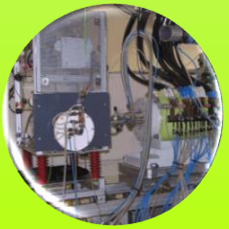
SPIRAL2 timeline



2014

P/D source: first beam 2 mA H^+.

December.



2015

Phoenix V2: first beam 230 µA Ar^{9+}.

July.

RFQ: first beam H^+. December.

2018

Diagnostic plate commissioning end.

April-November.

2019

MEBT @5 mA H^+.

SBS* @ 0.2 mA H^+

SC LINAC @ 0.2 mA H^+

33 MeV H^+

July-December

2020

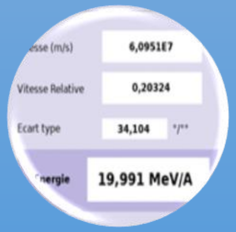
SBS @ 5 mA H^+. July

SBS* @1.3 mA $^4He^{2+}$

SC LINAC @ 5 mA H^+

16 kW H^+

July – December



2021

SC LIN@1.3 mA $^4He^{2+}$

SBS* @ 5 mA D^+

SC LINAC @ 5 mA D^+

40 MeV D^+

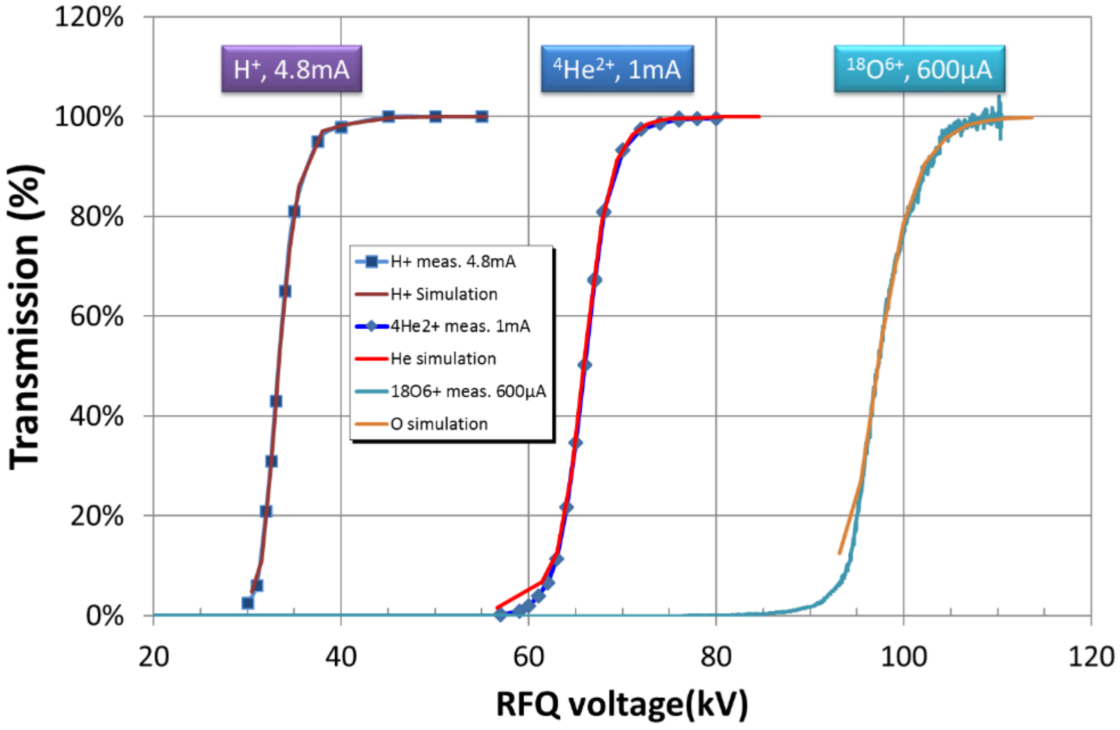
July-September

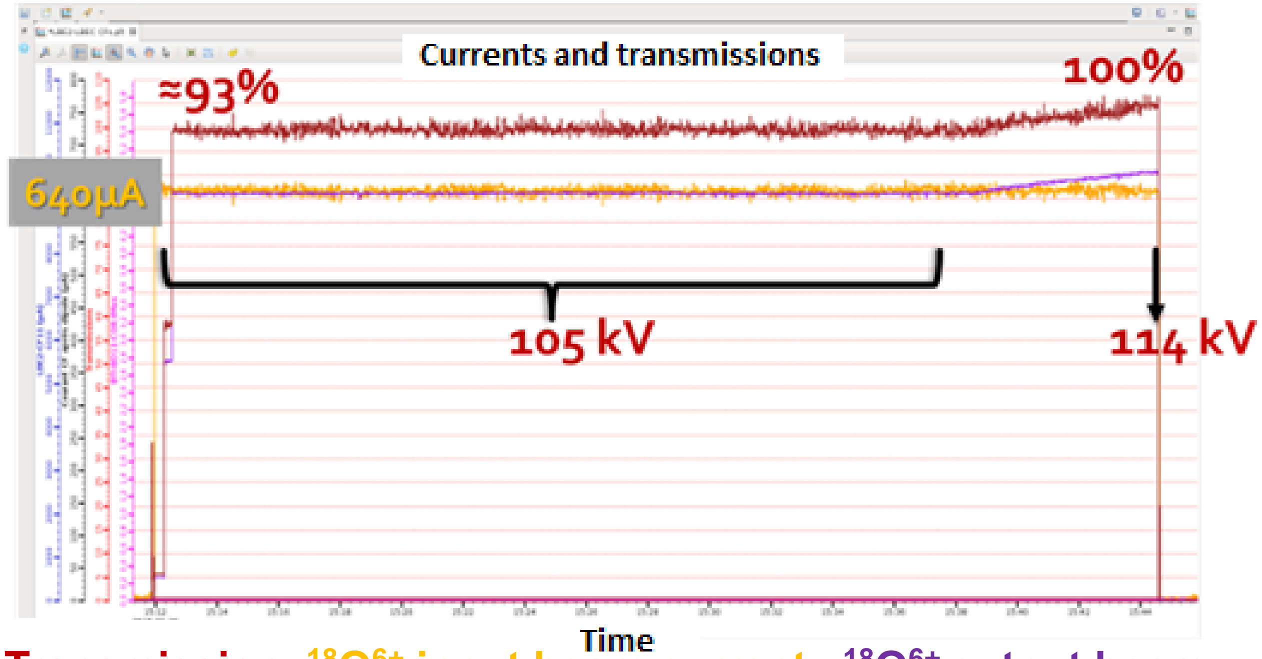
SBS*= Single Bunch Selector

Main commissioning results 1/5

RFQ transmission

- 100% transmission was obtained for 5 mA H^+, 1 mA $^4He^{2+}$ and 0.6 mA $^{18}O^{6+}$ pulsed beam and for a 25 µA $^{40}Ca^{14+}$ beam in CW mode.
- CW operation of the 640 µA $^{18}O^{6+}$ beam. Beginning with 105 kV and finishing with 114 kV





Transmission $^{18}O^{6+}$ input beam current $^{18}O^{6+}$ output beam current

R. Ferdinand et al,. IPAC19 -MOPTS006

Main commissioning results 2/5

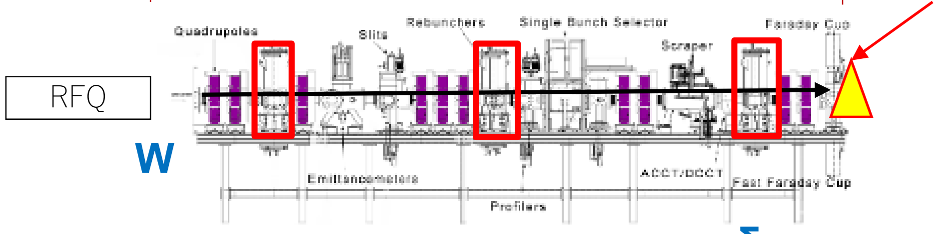
Rebuncher tuning method

1. Phase-scan in TraceWin
2. Manual phase-scan measurement

Tuning procedure

7.45 m

PC21
(1 pick up)



φ_{RN} $\delta\varphi$

φ_{R1} U_{R1}	φ_{R2} U_{R2}	φ_{R3} (Scan) U_{R3}

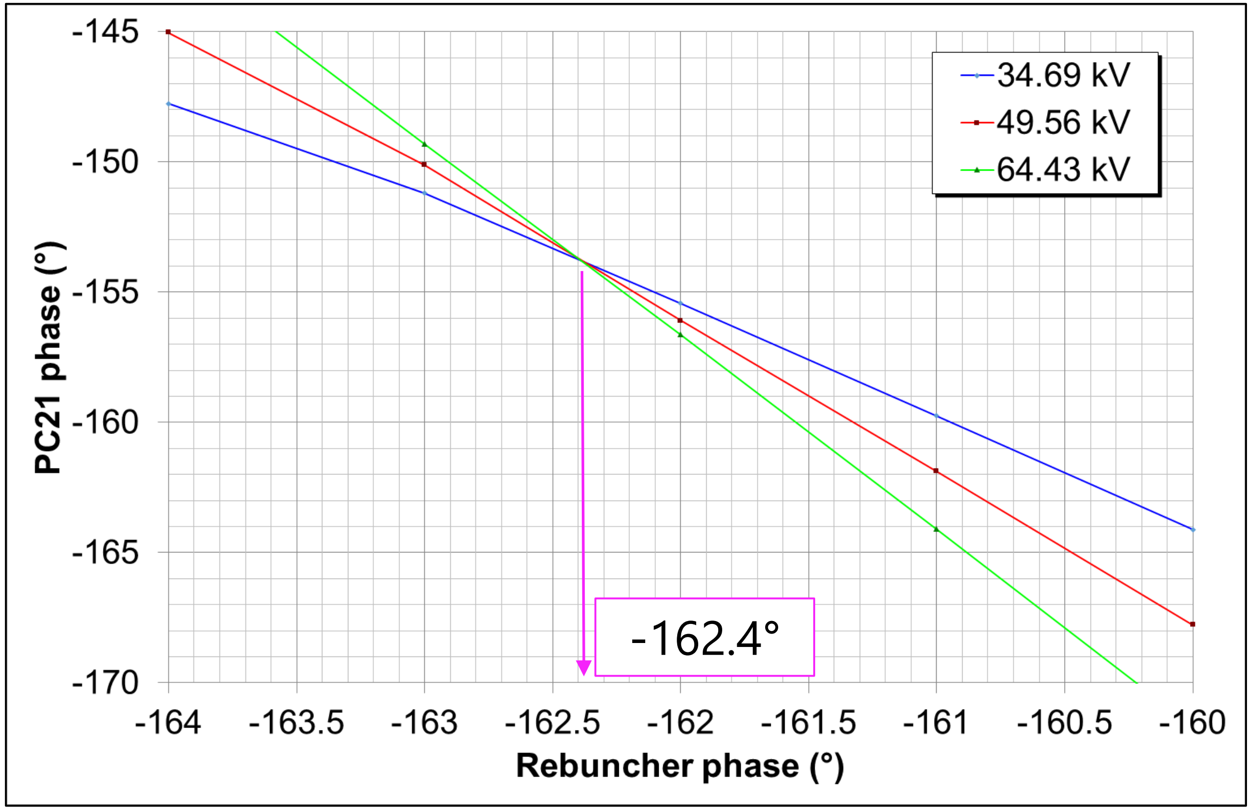
Measurements

$\delta\varphi = 0$ in rebuncher mode

$\delta\varphi = \varphi_{RN}OFF - \varphi_{RN}ON$

Phase scan $\delta\varphi = f(\varphi_R)$

Rebuncher 1

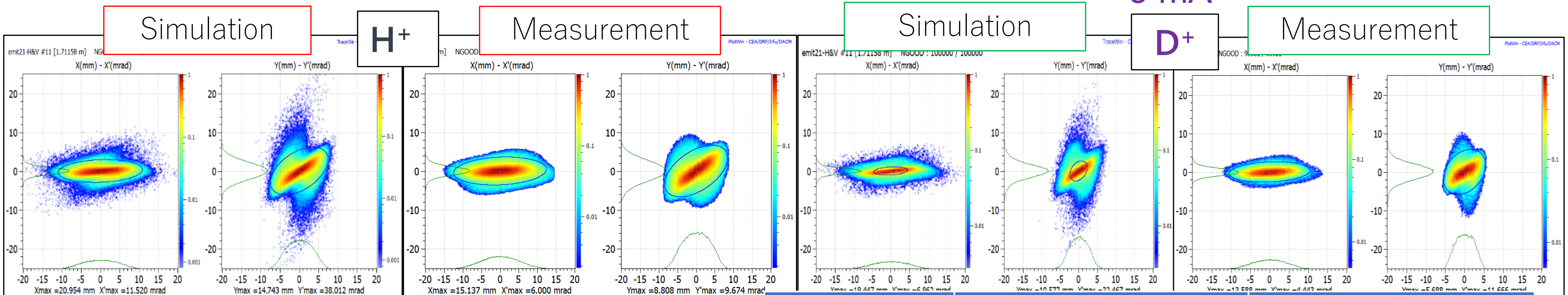


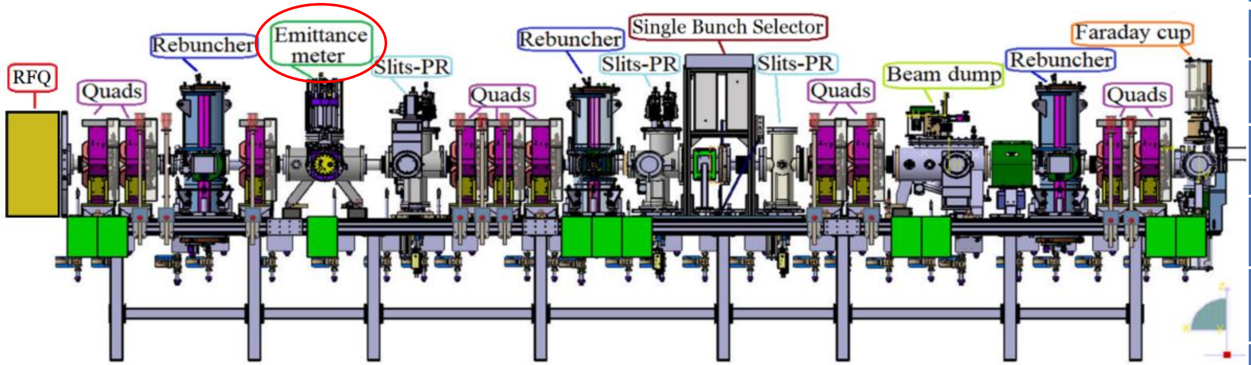
Advanced method 2021

Good agreement between simulations and measurements

Main commissioning results 3/5

MEBT transverse emittance





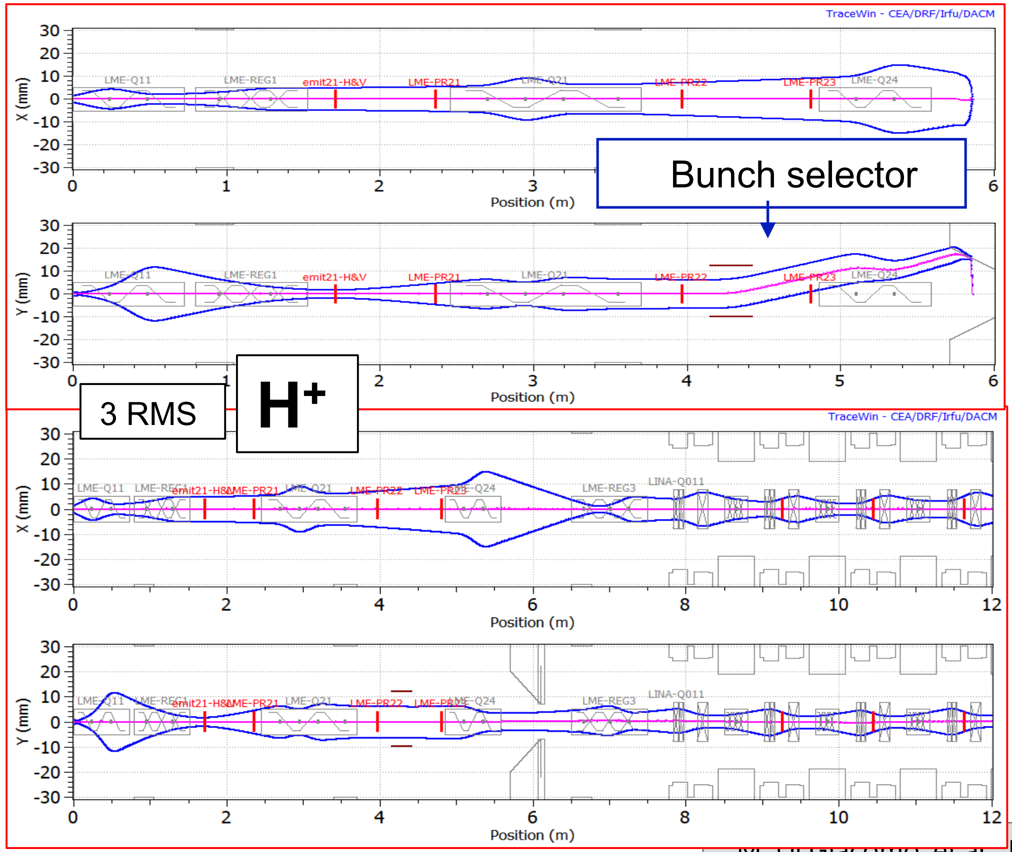
	5 mA H^+		5 mA D^+	
	Simulation	Measurement	Simulation	Measurement
Emit-xx' (rms)	0.20	0.19	0.19	0.17
Beta-xx'	3.75	3.48	4.26	4.02
Alpha-xx'	-0.12	-0.13	-0.23	-0.16
Emit-yy' (rms)	0.26	0.21	0.21	0.20
Beta-yy'	1.38	1.47	0.98	0.98
Alpha-yy'	-0.55	-0.59	-0.33	-0.31

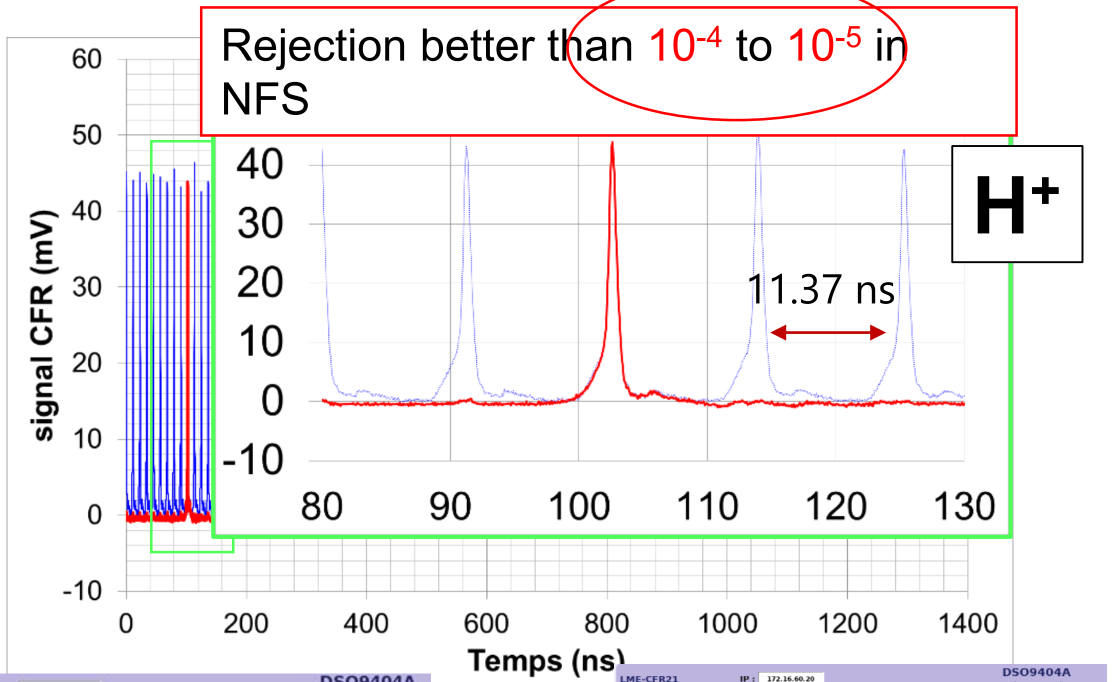
Transverse emittance **presents good agreement** between the simulations and measurements

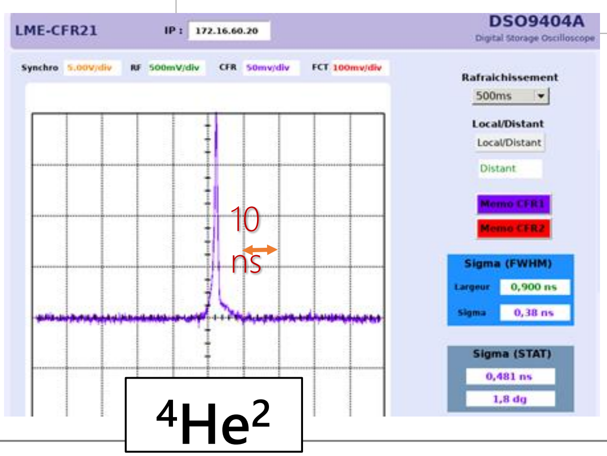
Main commissioning results 4/5

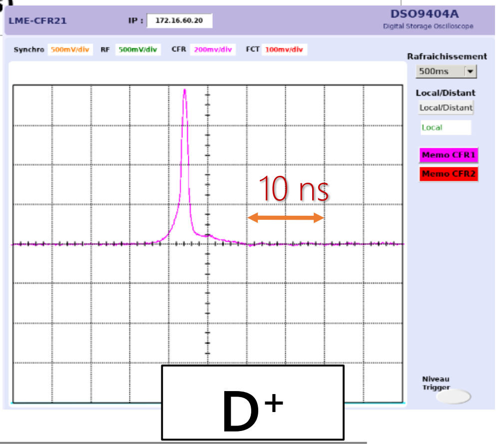
Single bunch selector

- Required for Physics (Time of Flight), and HEBT tuning (limitation of power deposition) => From 1/100 to 1/10000 bunch selection.
- Separation and injection and transport have been validated at all intensities (5mA, 1mA, 0.2mA) in pulsed and CW mode.









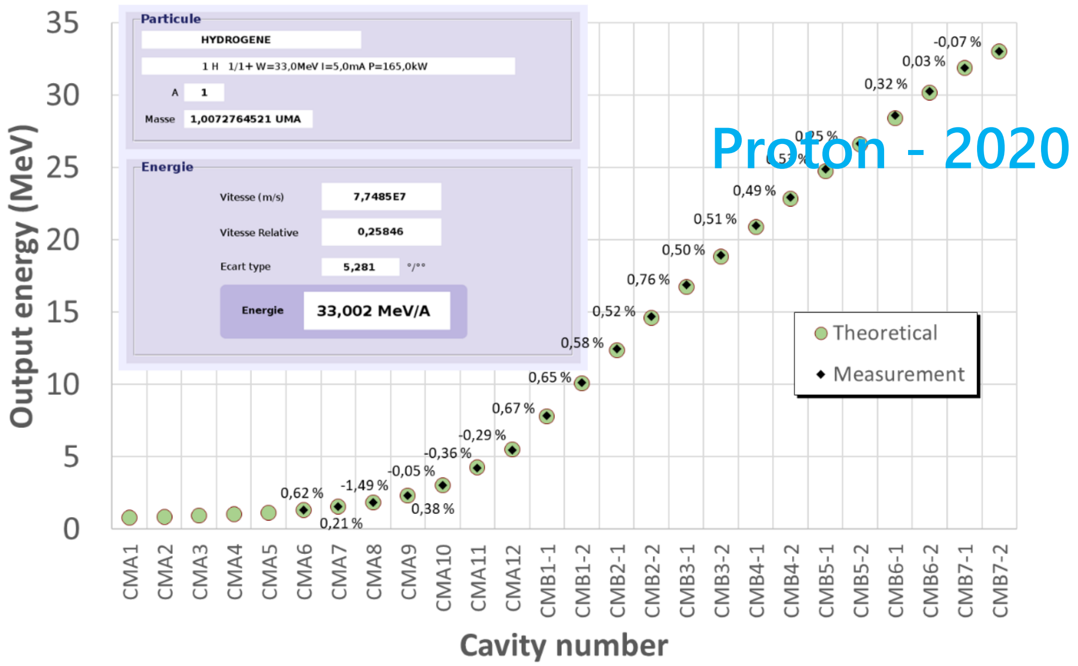
M. Di Giacomo, et al,. Journal of Instrumentation (2020)

Main commissioning results 5/5

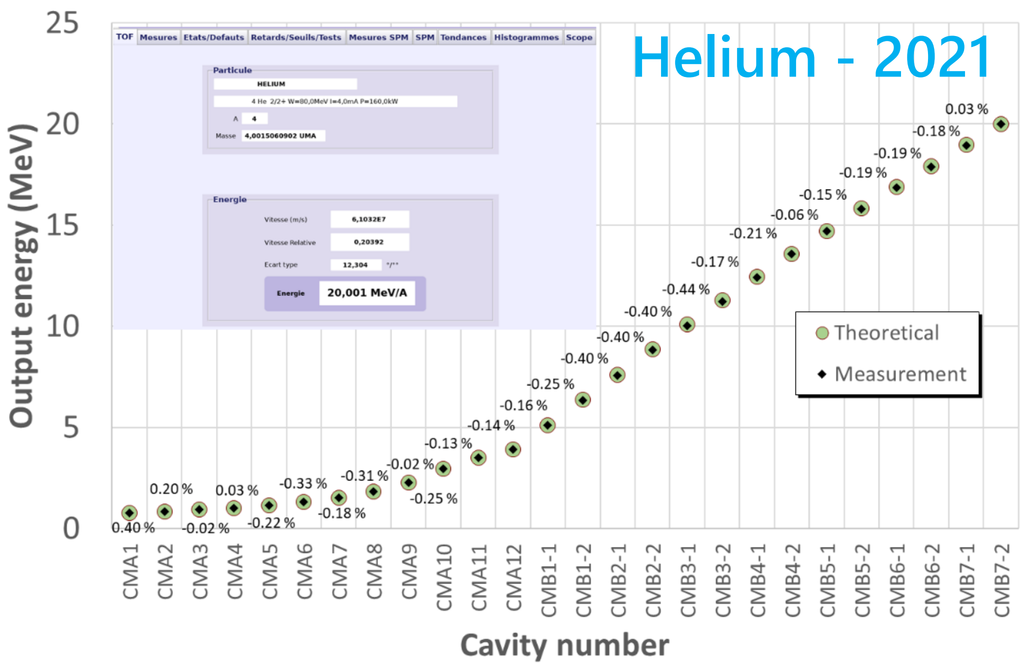
Energy measurement

- The tuning to any energy in the range 10-33 MeV for proton or 10-40MeV for helium/deuteron takes about 2h.
- The final energy shows a very small error.

Tuning with signature matching method



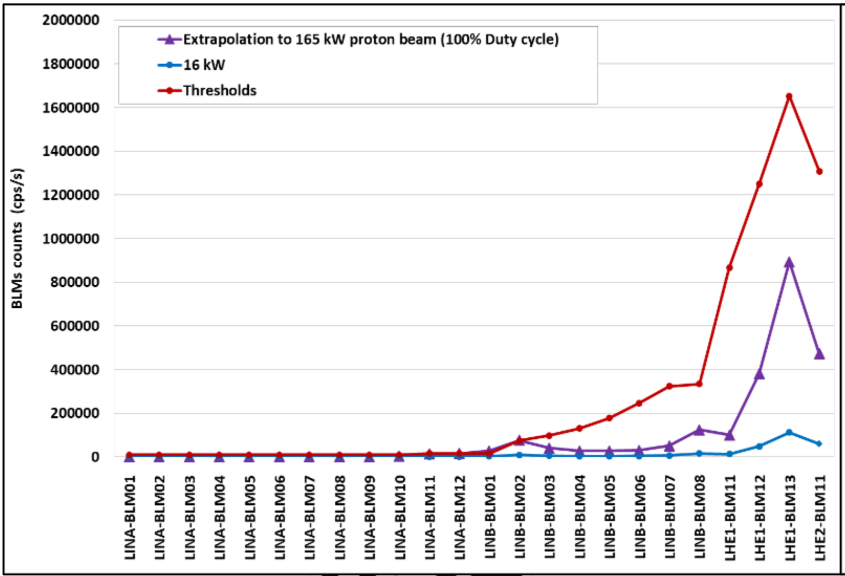
Tuning with advanced method

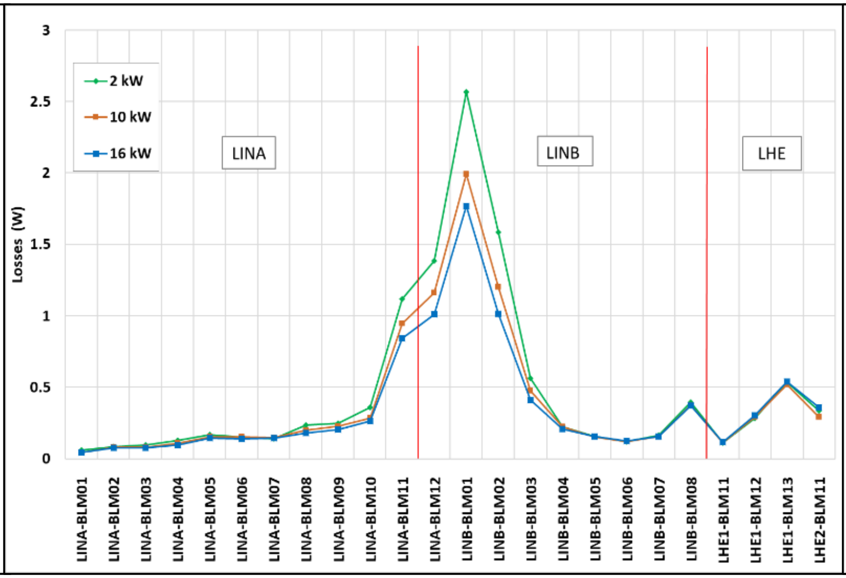


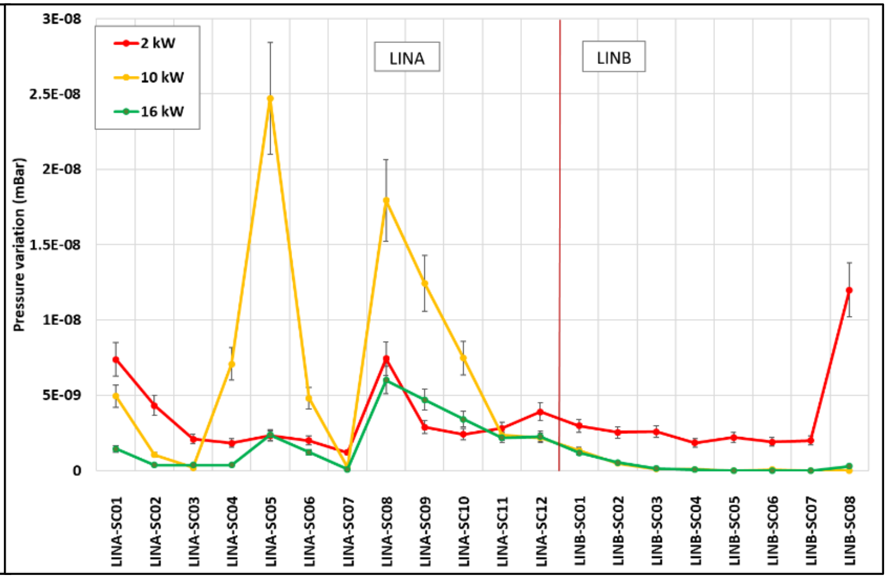
LINAC validation

- SC LINAC proton beam transmission @16 kW.
  Demonstration of 165 kW
- BLMs measurement confirm losses below 1W/m.
- Pressure variation measurement is a good probe for the low energy section of the linac.
- Linac transmission is 100% within diagnostic precision.
- Good agreement between simulations and measurements.
- Actions taken to reduce losses were validated.

Main results





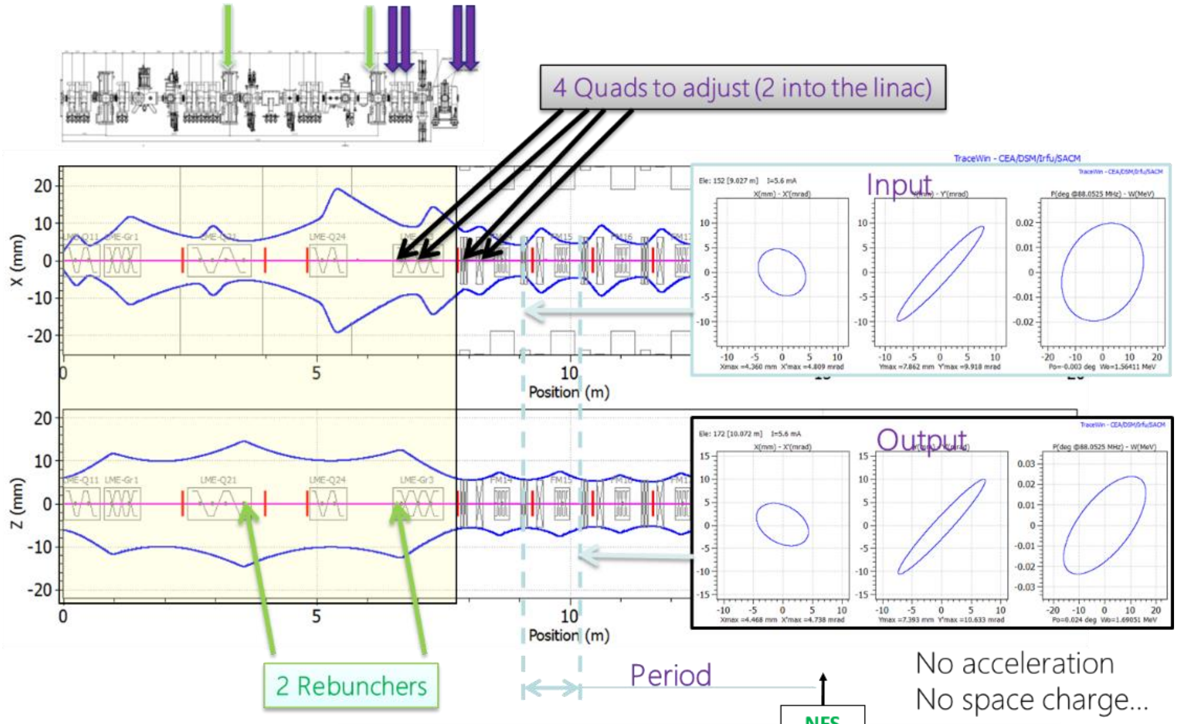


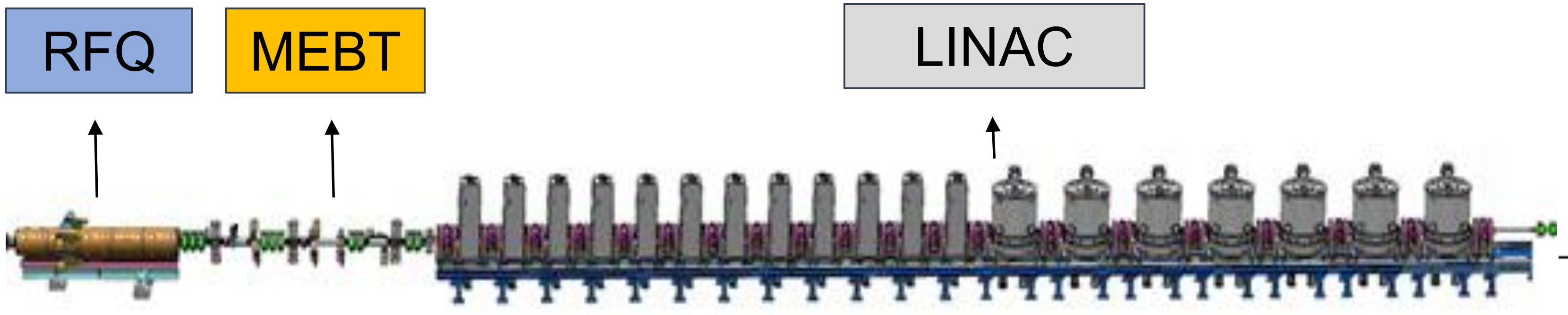
Power increase

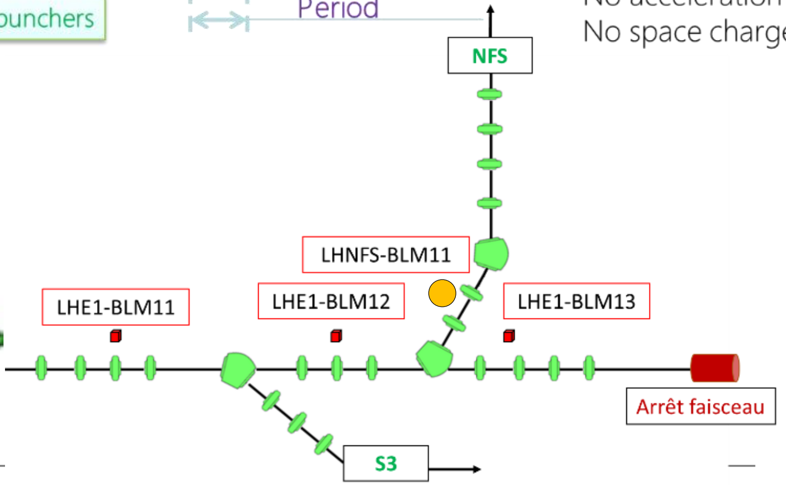
MEBT-LINAC matching

- Match the MEBT beam to the linac to reduce the observed beam losses.
  - Transmission ●
  - BPMs ●
  - BLMs ●
  - Vacuum pressure ●
- Slowly increase the beam power (first beam current, then DC).

How to match the beam if LINAC is a continuous focusing channel in x,y,z :







Power increase to 16kW

LLRF PIDs improvement in all cavities. 05/10/2020.

Increase rebuncher (N° 3) voltage from 29.6 kV to 35.6 kV. 06/11/2020

2 kW
10/11/2020

31.9 MeV
4.35 mA
1 Hz
14.5 ms
DC = 1.45 %

Transmission study in function of the last MEBT quadrupoles. 12/11/2020.

Study of longitudinal dynamics as a rebunchers function 16/11/2020.

Feedforward study 16/11/2020

10 kW
12/11/2020

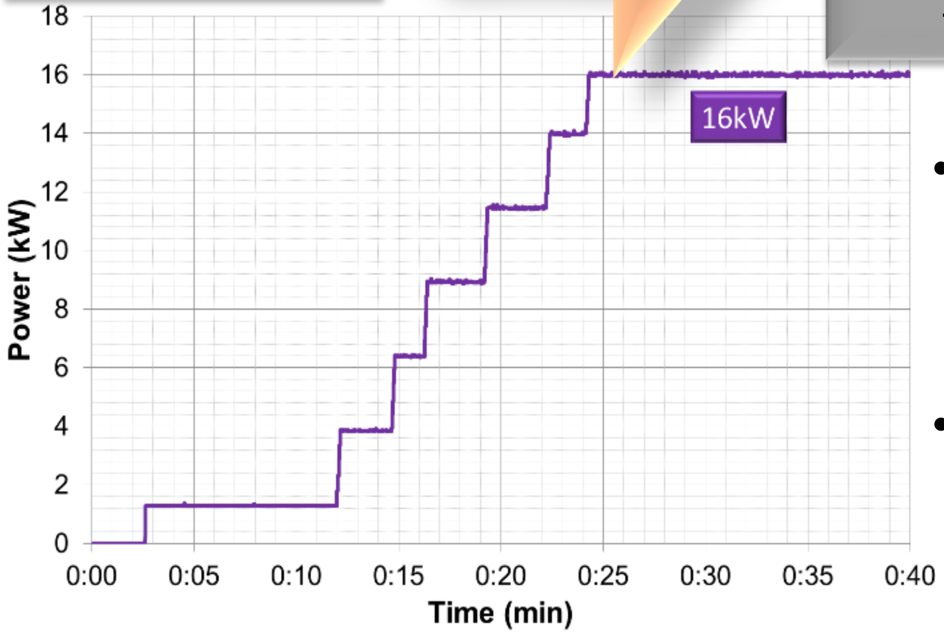
31.9 MeV
4.10 mA
10 Hz
7.66 ms
DC = 7.66 %

Alignment of the HEBT line.

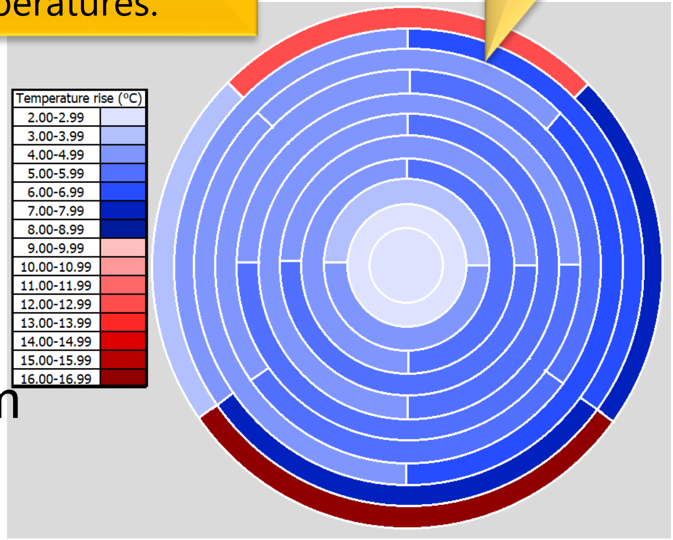
Optimisation of the last quadrupoles in the HEBT line by controlling the amount of correlating segmented loss ring and SAFARI temperatures.

16 kW
18/11/2020

31.9 MeV
4.00 mA
10 Hz
12.6 ms
DC = 12.6 %



- Main losses improvement due to LLRF regulation improvement and use of feed forward.
- 16 minutes at 16 kW limited by beam dump “SAFARI” activation.



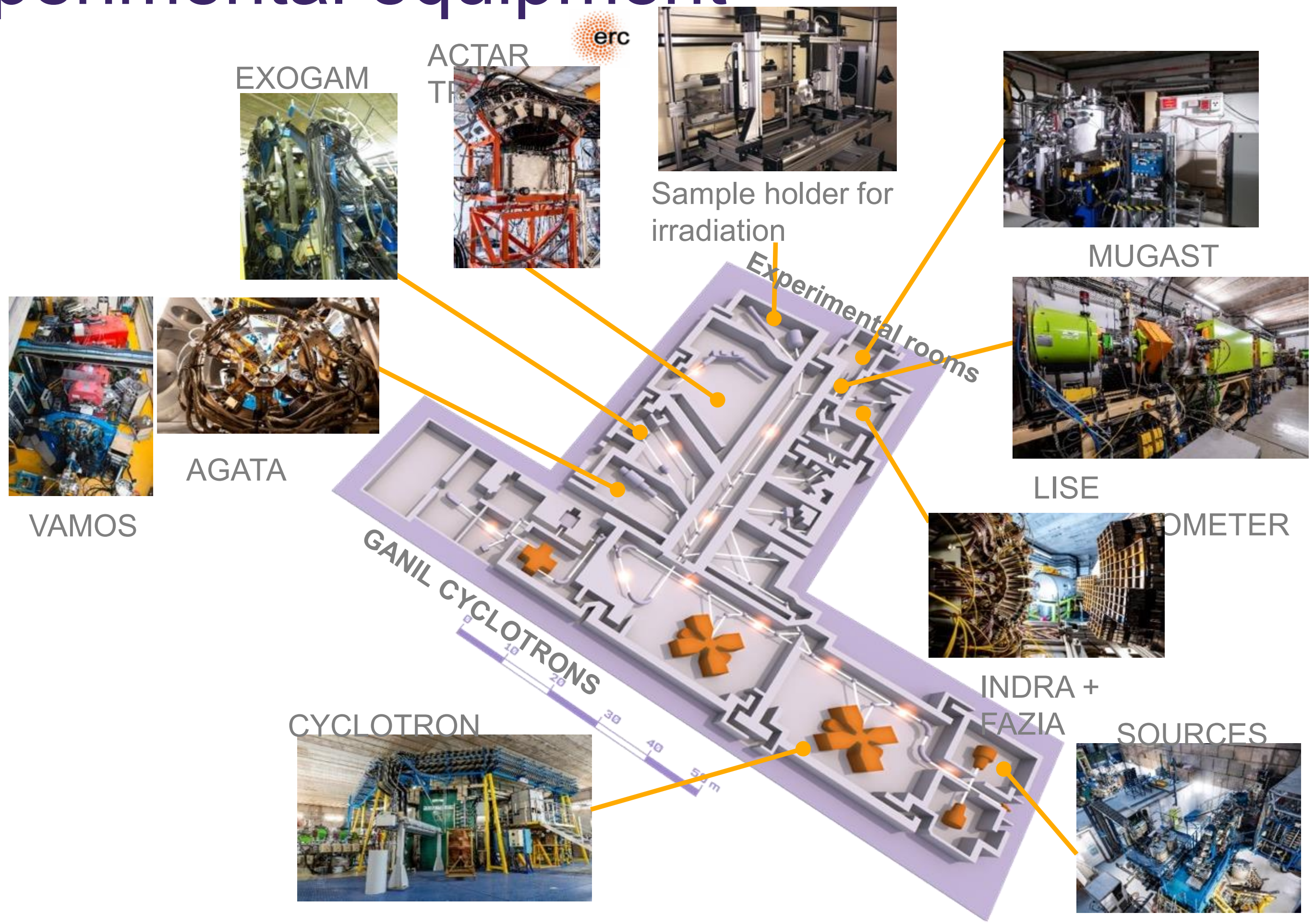
CYCLOTRONS

GANIL Cyclotrons and experimental equipment

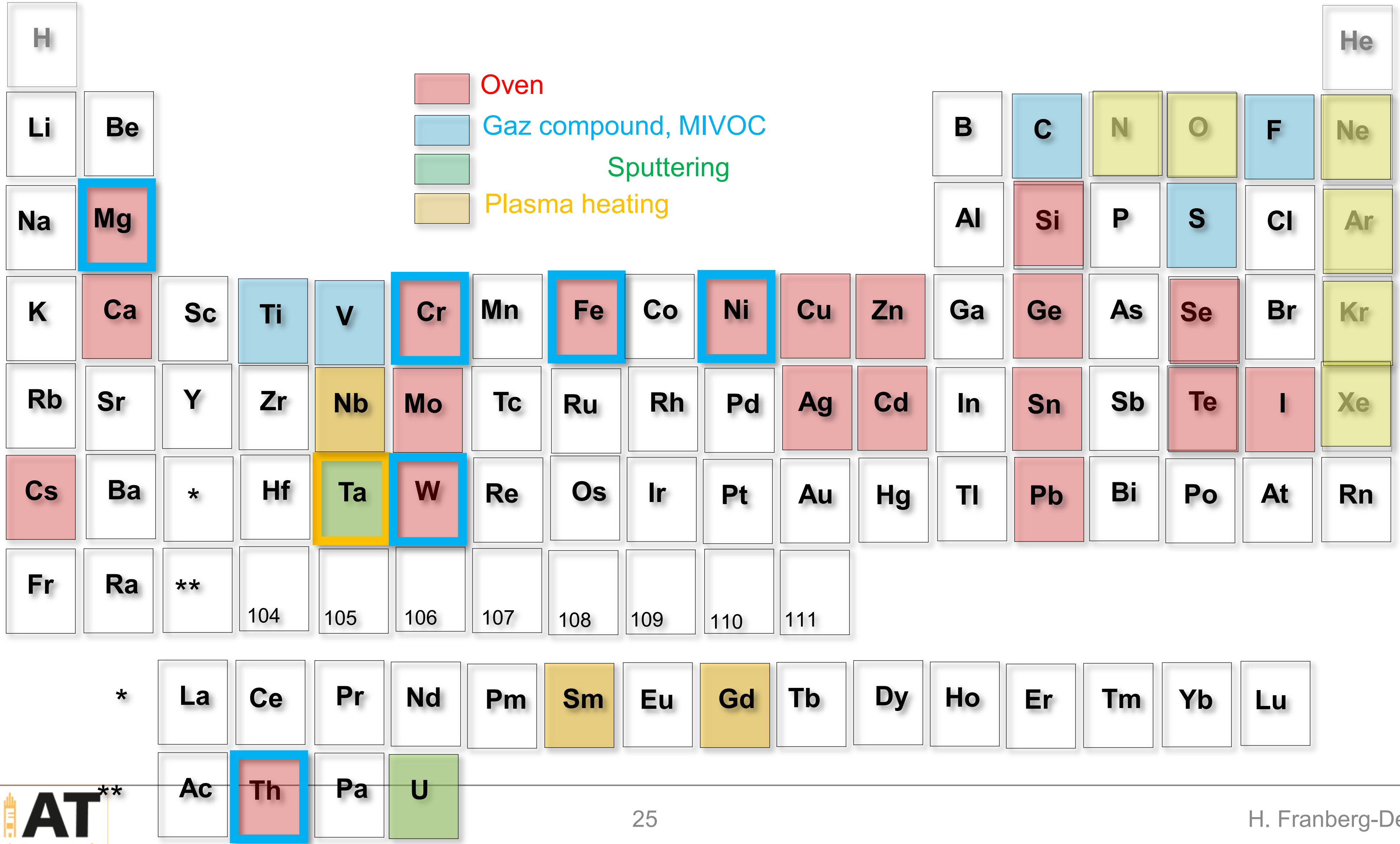
- Beams : 12C to U
- Energy : from <1 MeV up to 95MeV/nucleon
- Up to 4 experiments in parallel

<u>Stable ions:</u>
2 sources d'ions ECR stables : $^{12}C^{4+}$ à $^{238}U^{34+}$, I < 10^{13} pps
2 cyclotron (K=30) : 1 per injecotr
2 cyclotrons in cascade (K=380)
1 spectrometre (α, $\Delta E/E = 2.10^{-3}$)
I : 2. 10^{13} pps max ; 6 kW max

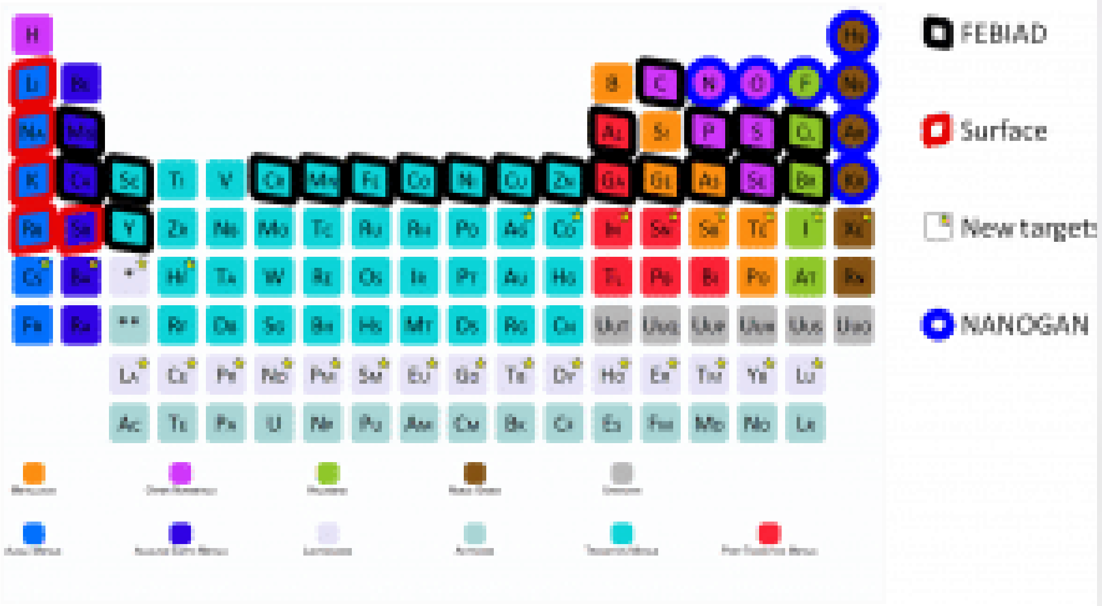
<u>SPIRAL1 : 2001 – ISOL (ions radioactives)</u>
C – Nb target,
ECR, febiad and surface ion source
Charge breeder
Post-acceleration and : CIME (2-25 MeV/u,
separation : $\Delta E/E = 5.10^{-4}$) (K=265)
Intensités : 5 10^{11} pps   @ 25 MeV/u max

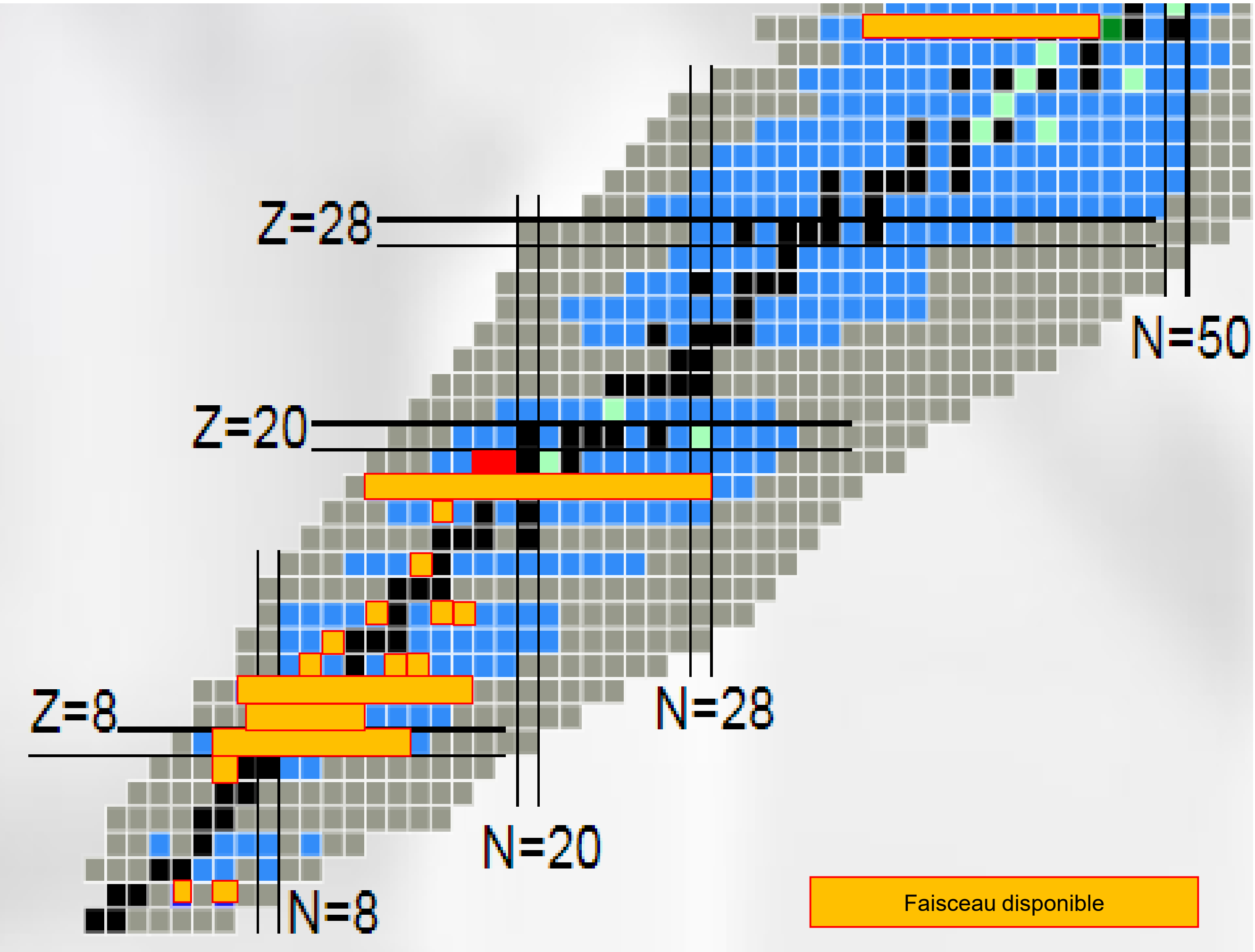


The stable ion beams

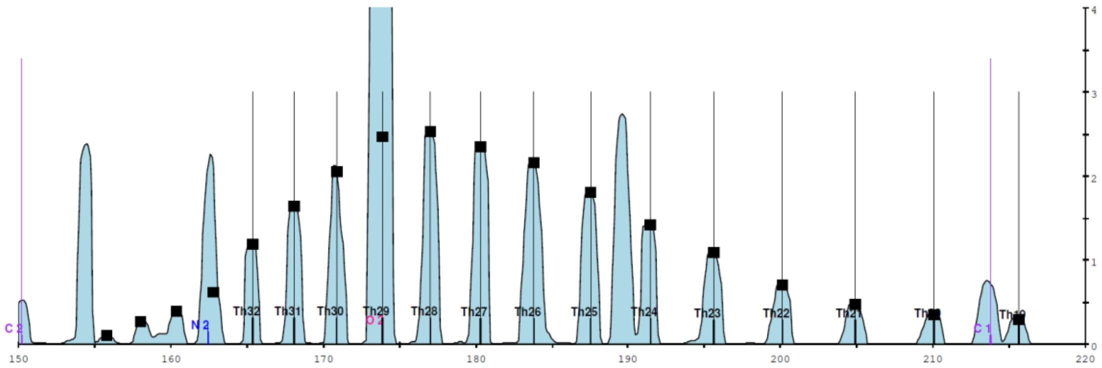


Radioactive ion beams that can be post-accelerated





New beam stable beam in 2021 ^{232}Th



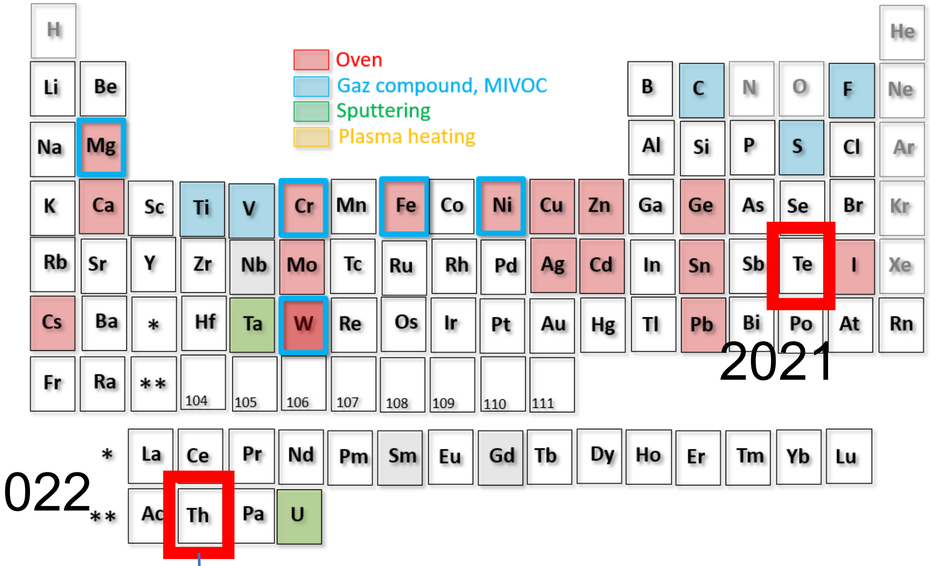
New beams are developed on request:

2021: ^{232}Th beam

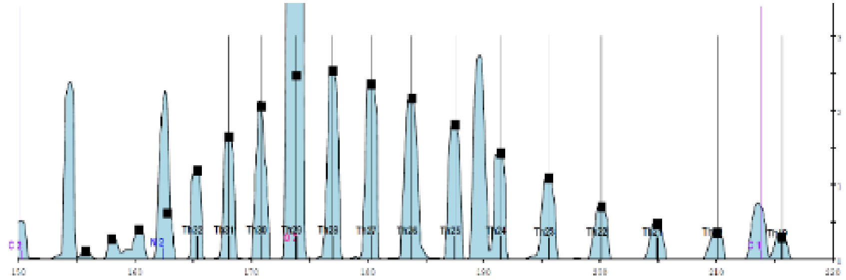
This beam is produce from a compound of $^{232}ThF_4$,

The characterization of the compound and the tests carried out on the ECR4 ion source allow to validate this new beam, in terms of intensity, stability and charge state required for an acceleration to 6.1MeV/A.

R&D Stable beam development

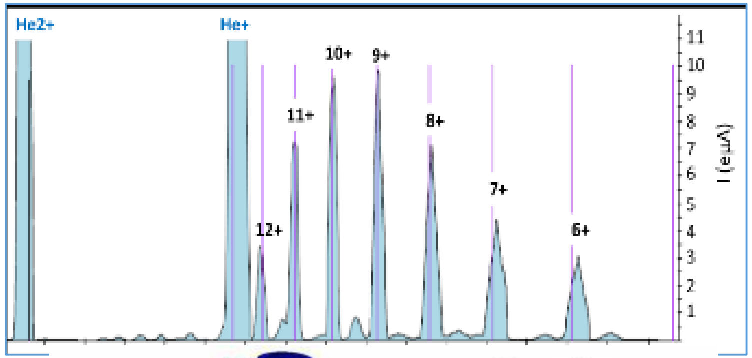


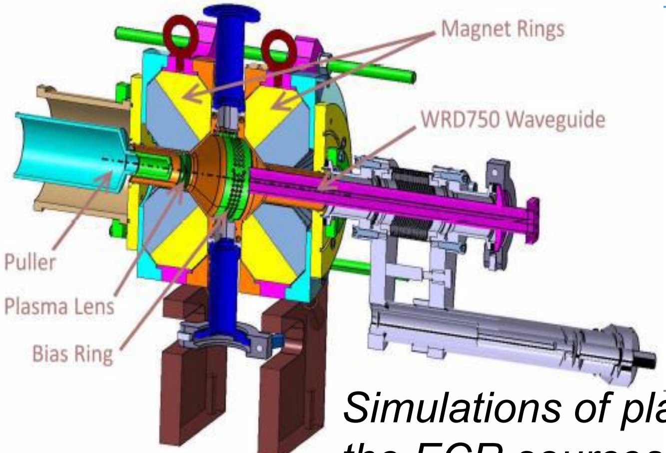
^{232}Th

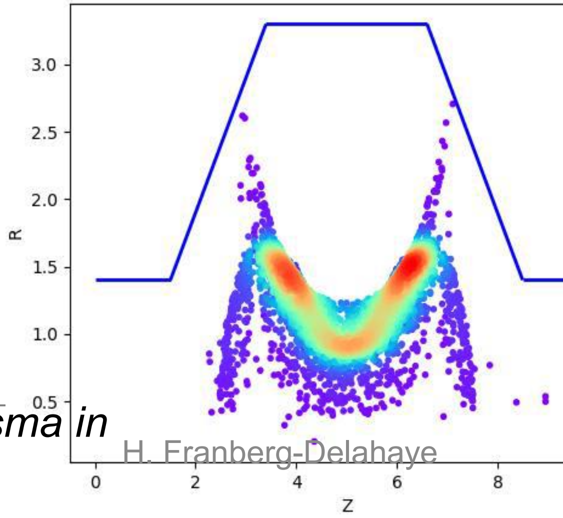


High temperature oven

MIVOC development

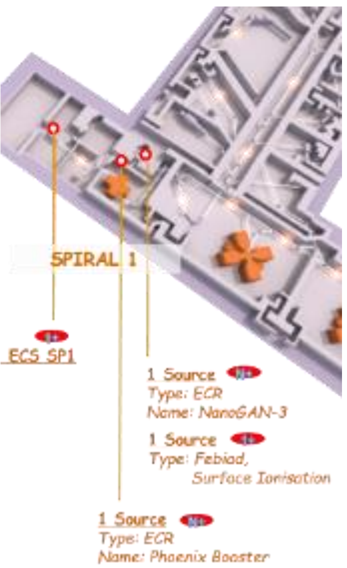




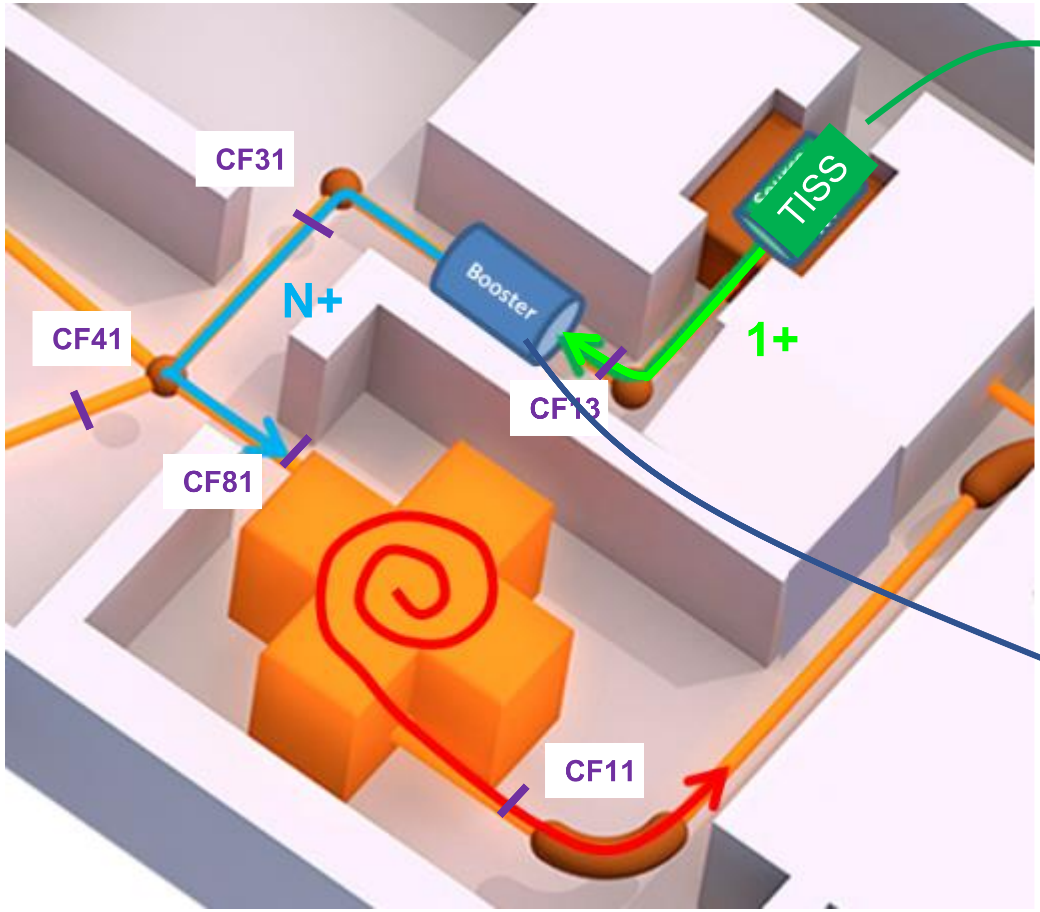


Simulations of plasma in the ECR sources

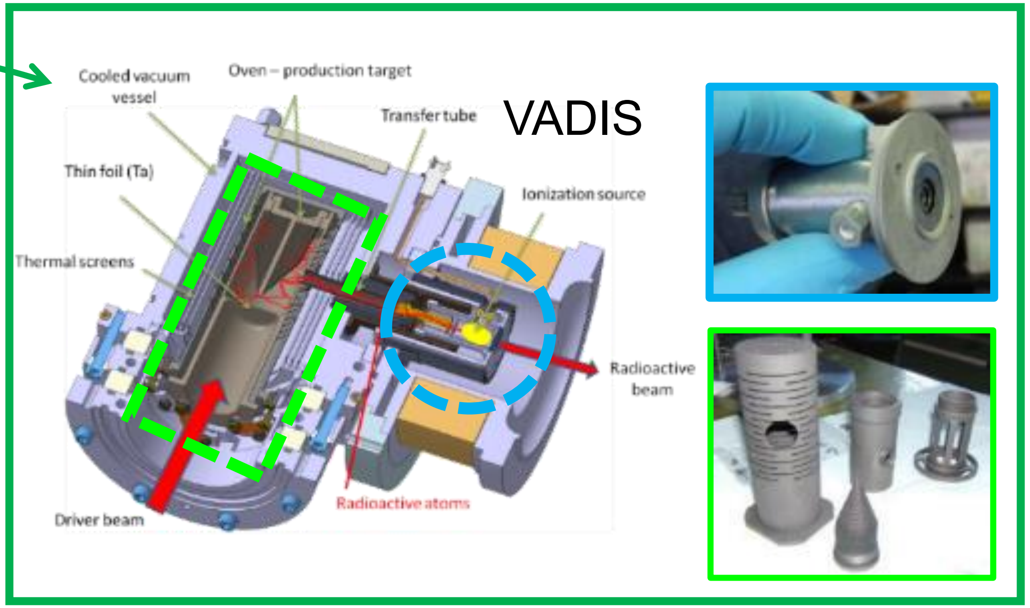
R&D RIBs



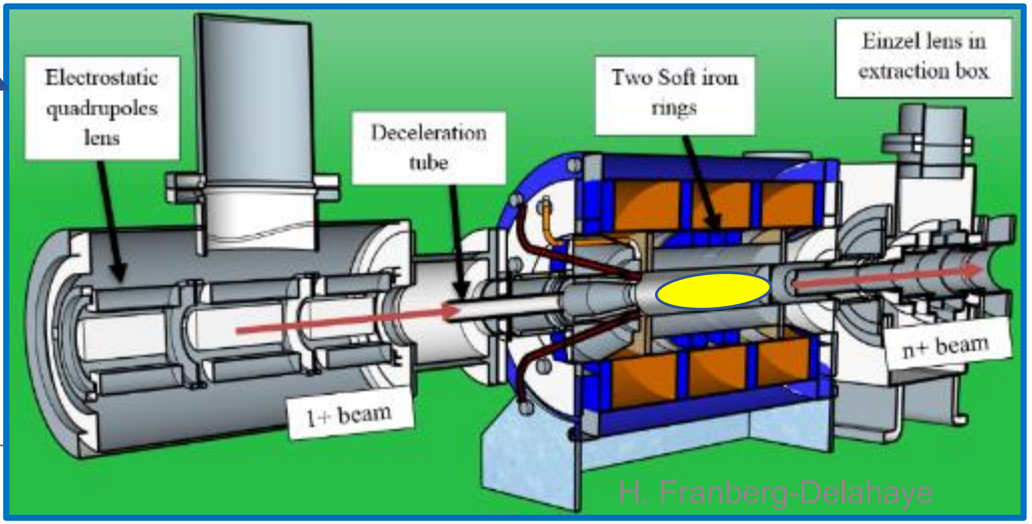
SPIRAL 1
ECS SP1
1 Source
Type: ECR
Name: NanoGAN-3
1 Source
Type: Febiad,
Surface Ionisation
1 Source
Type: ECR
Name: Phoenix Booster



CF31
CF41
CF13
CF81
CF11
N+
1+
Booster
TISS



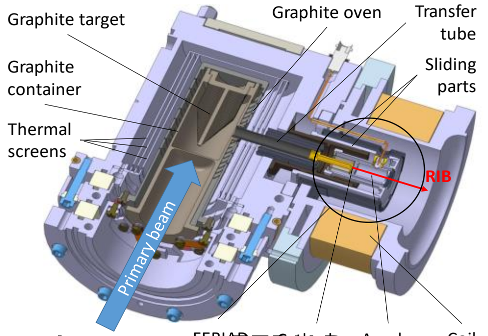
VADIS
Cooled vacuum vessel
Oven – production target
Transfer tube
Thin foil (Ta)
Ionization source
Thermal screens
Radioactive beam
Driver beam
Radioactive atoms



Electrostatic quadrupoles lens
Deceleration tube
Two Soft iron rings
Einzel lens in extraction box
1+ beam
n+ beam
H. Franberg-Delahaye

R&D RIBs

Fragmentation
TISS FEBIAD

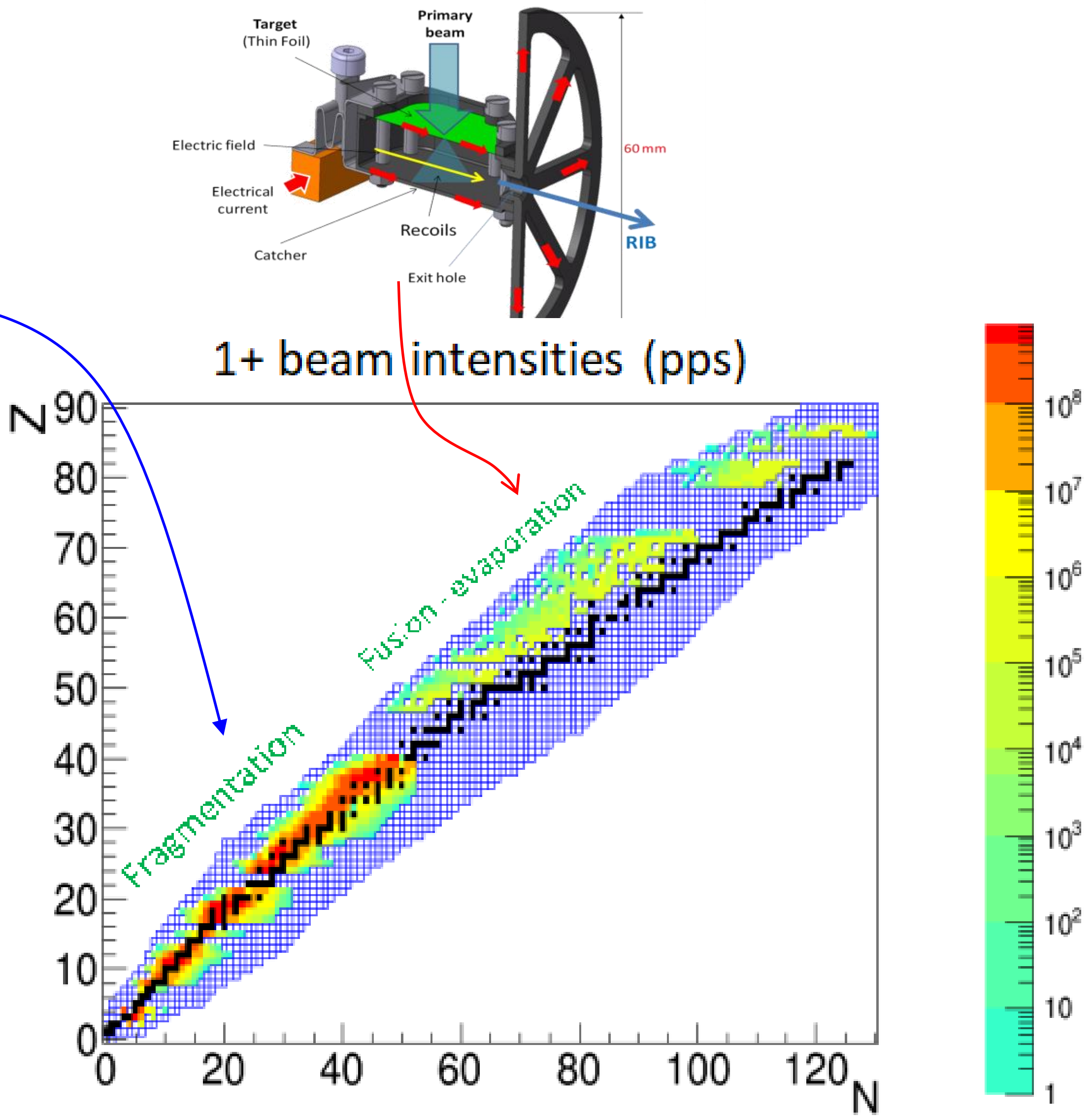


Ions source FEBIAD

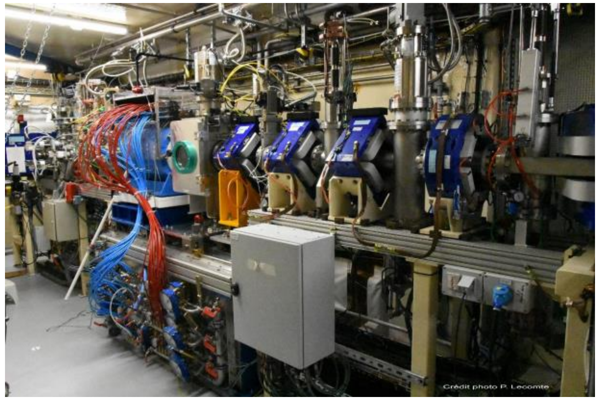
New target material and shapes (A>93)

C

Nb



Fusion evaporation targets



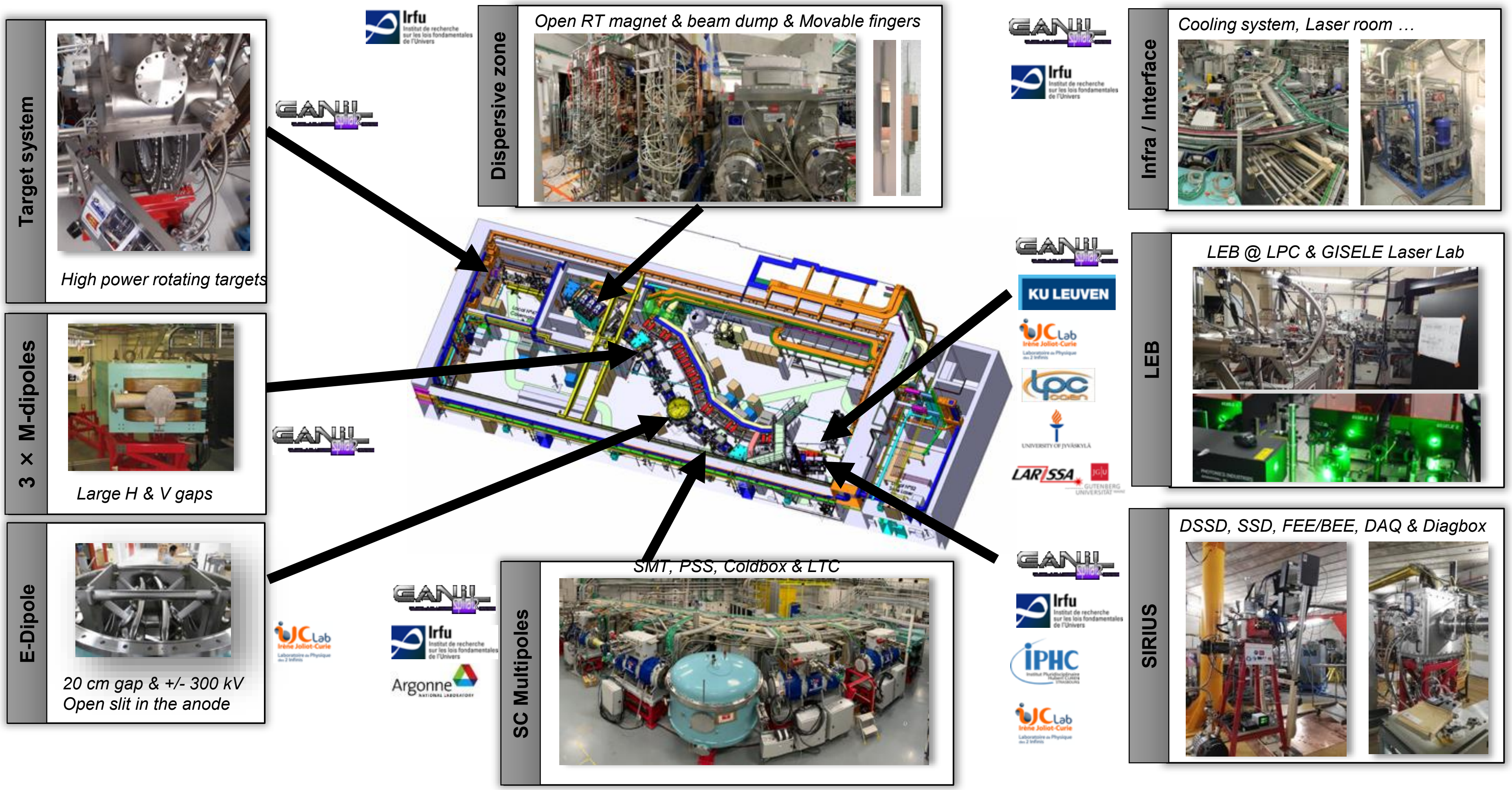
Optimisation booster de charge

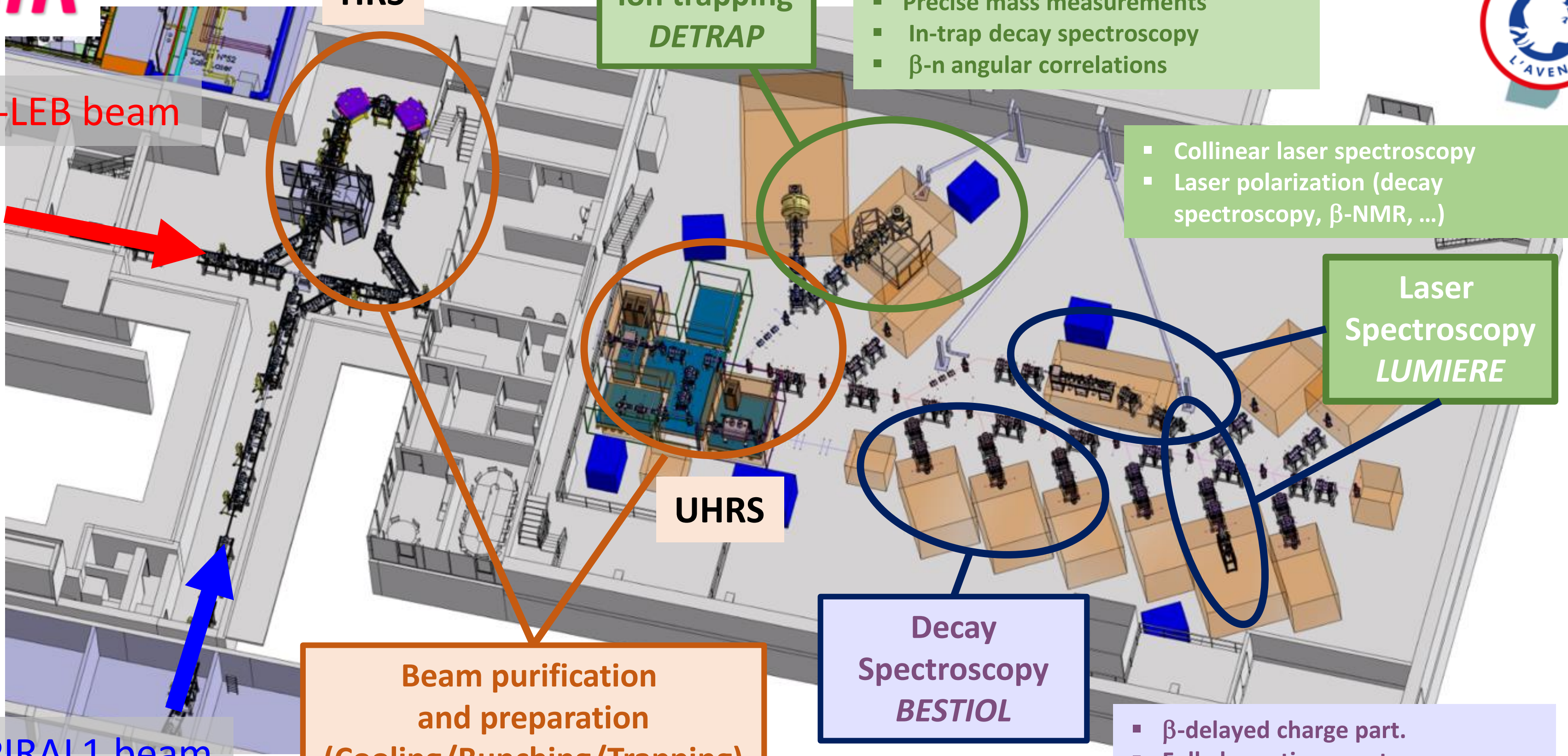
Futur at GANIL

S3 : the Super Separator Spectrometer

Fundamental research in
Nuclear & Atomic physics

- High selectivity > 10^{13} beam rejection
- High efficiency 50%
- Mass resolution > 350
- Versatility : high resolution, high transmission, high beam rejection modes…
- Unique instrumentation : SIRIUS for p, a, electron and g spectroscopy, and S3-LEB with gas catcher, RFQ and MR-ToF-MS



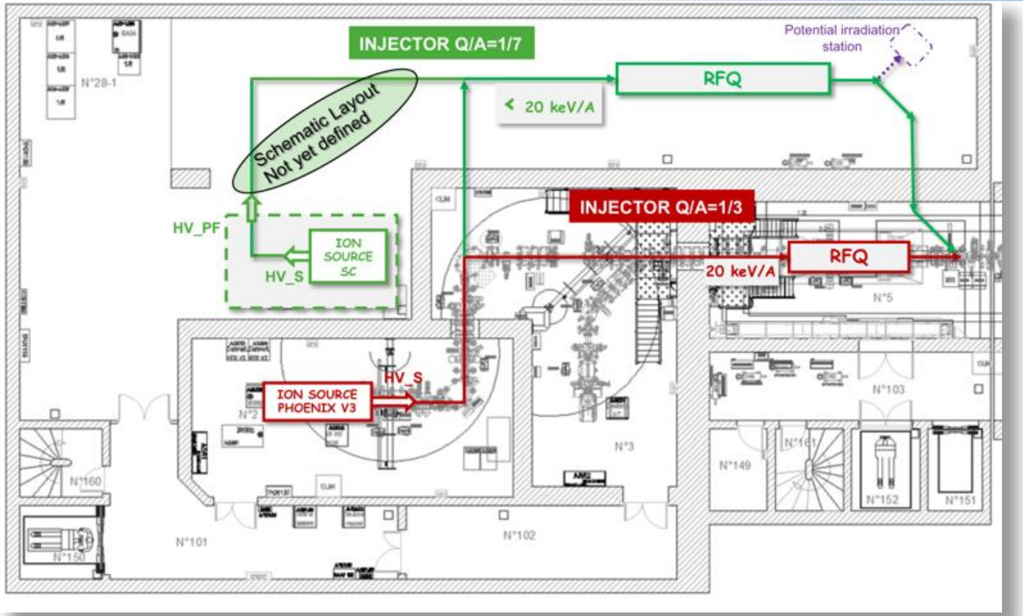


Low-energy radioactive-ion-beam facility

- Beams from SPIRAL1 and S^3
- Important beam preparation and purification capabilities
- High resolution/precision experiments

3rd injector for SC LINAC : NewGAIN project

NEWGAIN
NEW GANIL INJECTOR



beam intensities

Ions	*injector1* *2023* Intensity (pμA) Phoenix V3 RFQ A/Q≤3	NEWGAIN *2028* Intensity (pμA) Phoenix V3 RFQ A/Q≤7	*≥ 2030* *(injector2)* Intensity (pμA) SC Ion Source RFQ A/Q≤7
^{18}O	80	*	375
^{19}F	>15	>40	>40
^{36}Ar	16	70	45
^{40}Ar	3.6	70	45
^{36}S	2.3	*	*
^{40}Ca	2.9	10	20
^{48}Ca	1.2	10	20
^{58}Ni	1.1	4	**8**
^{84}Kr	0.1	10	**20**
^{139}Xe	0.001	7	**>10**
^{238}U	<<0.001	0.1	**6**

Measured | Estimated

* -> no estimation

NEWGAIN *White Book*

https://www.ganil-spiral2.eu/scientists/ganil-spiral-2-facilities/accelerators/newgain/

NEWGAIN *time line*

2020	2021	2022	2023	2024	2025	2026	2027	2028

Study Phase → Construction Phase → *first beam*

Acknowledgments

Thanks to A. Orduz, M. Dubois, G. Normand for slides

Thank you to the organizers to invite me for this talk and the organisation of the conference

Thank you for listening