Status of the Super Separator Spectrometer at GANIL

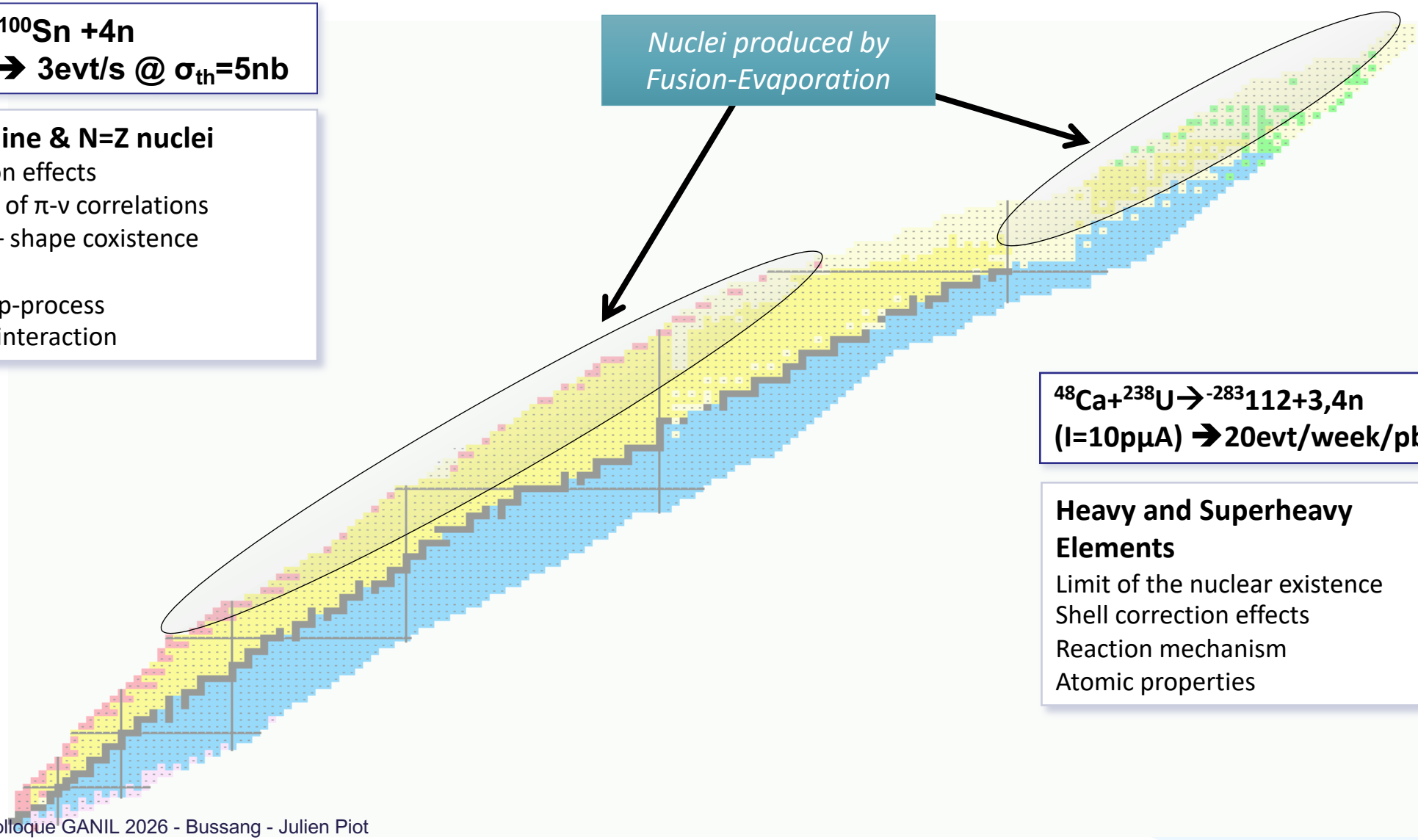
J.Piot *on behalf of the S³ project & collaboration*

Physics goals : Study of rare events in nuclear and atomic physics

$^{58}Ni+^{46}Ti \rightarrow ^{100}Sn +4n$
(I=10pμA) ➔ 3evt/s @ σ_{th}=5nb

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

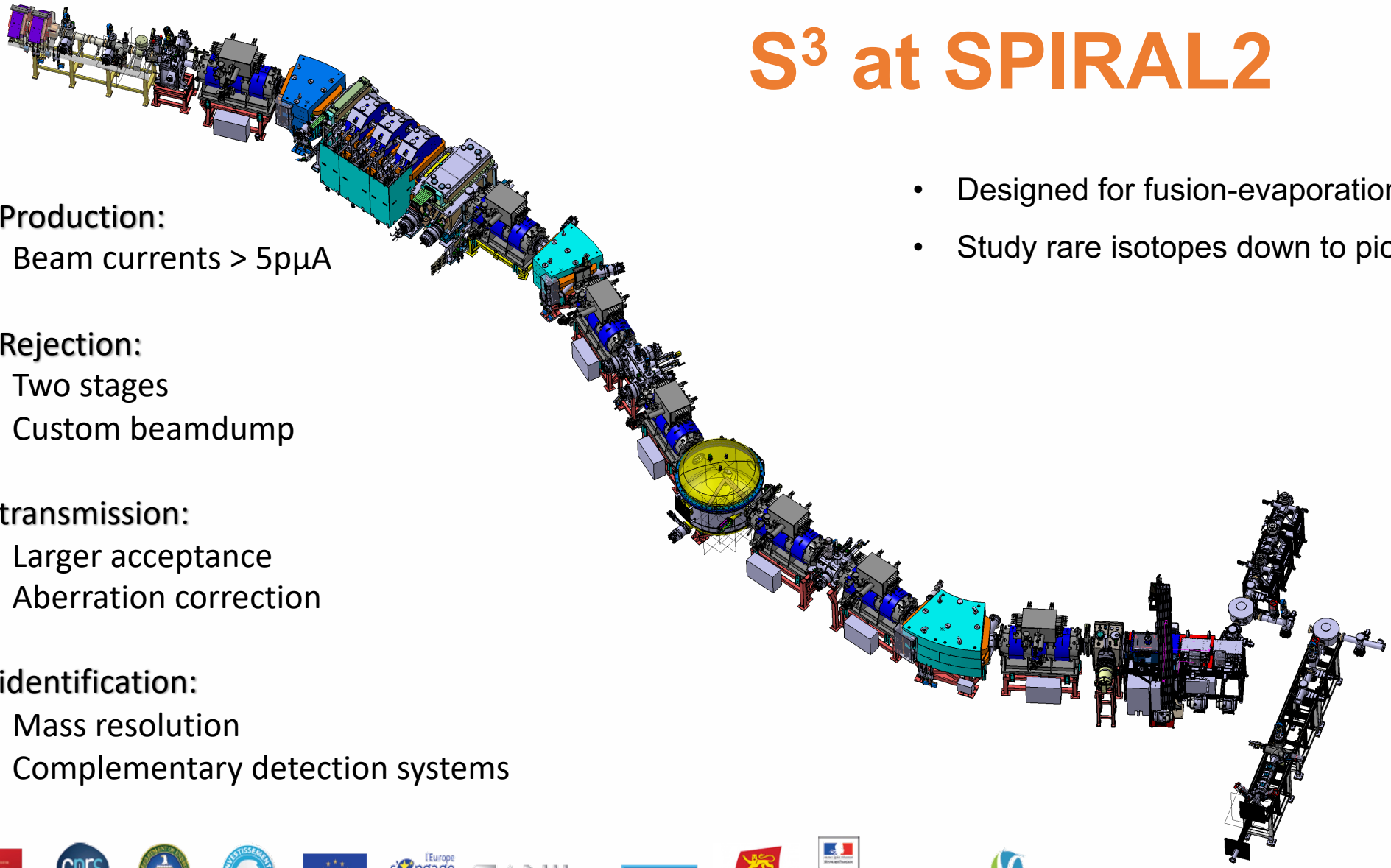
Nuclei produced by Fusion-Evaporation



$^{48}Ca+^{238}U \rightarrow ^{-283}112+3,4n$
(I=10pμA) ➔20evt/week/pb

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

S³ at SPIRAL2



- Designed for fusion-evaporation
- Study rare isotopes down to picobarns

Improve Production:

Beam currents > 5pμA

Improve Rejection:

Two stages

Custom beamdump

Improve transmission:

Larger acceptance

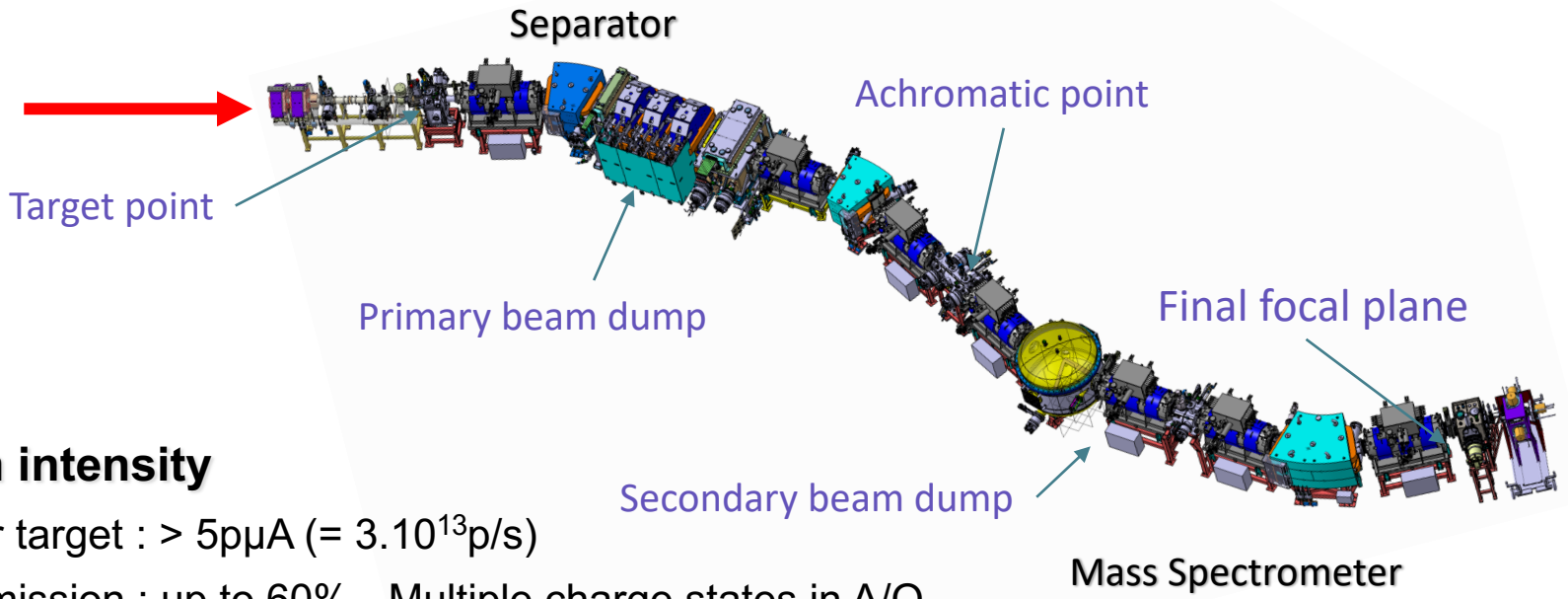
Aberration correction

Improve identification:

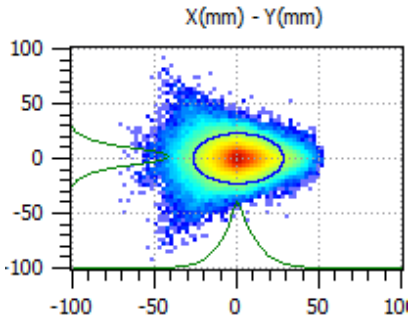
Mass resolution

Complementary detection systems

Super Separator Spectrometer



Convergent mode



✓ **High Beam intensity**

➔High power target : > 5pμA (= 3.10^{13}p/s)

➔High transmission : up to 60% - Multiple charge states in A/Q

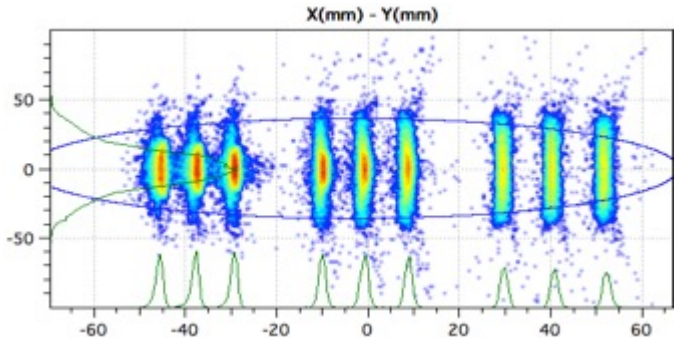
➔High Selectivity : > 10^{13} rejection

✓ **Versatility**

➔2 extreme optical modes defined

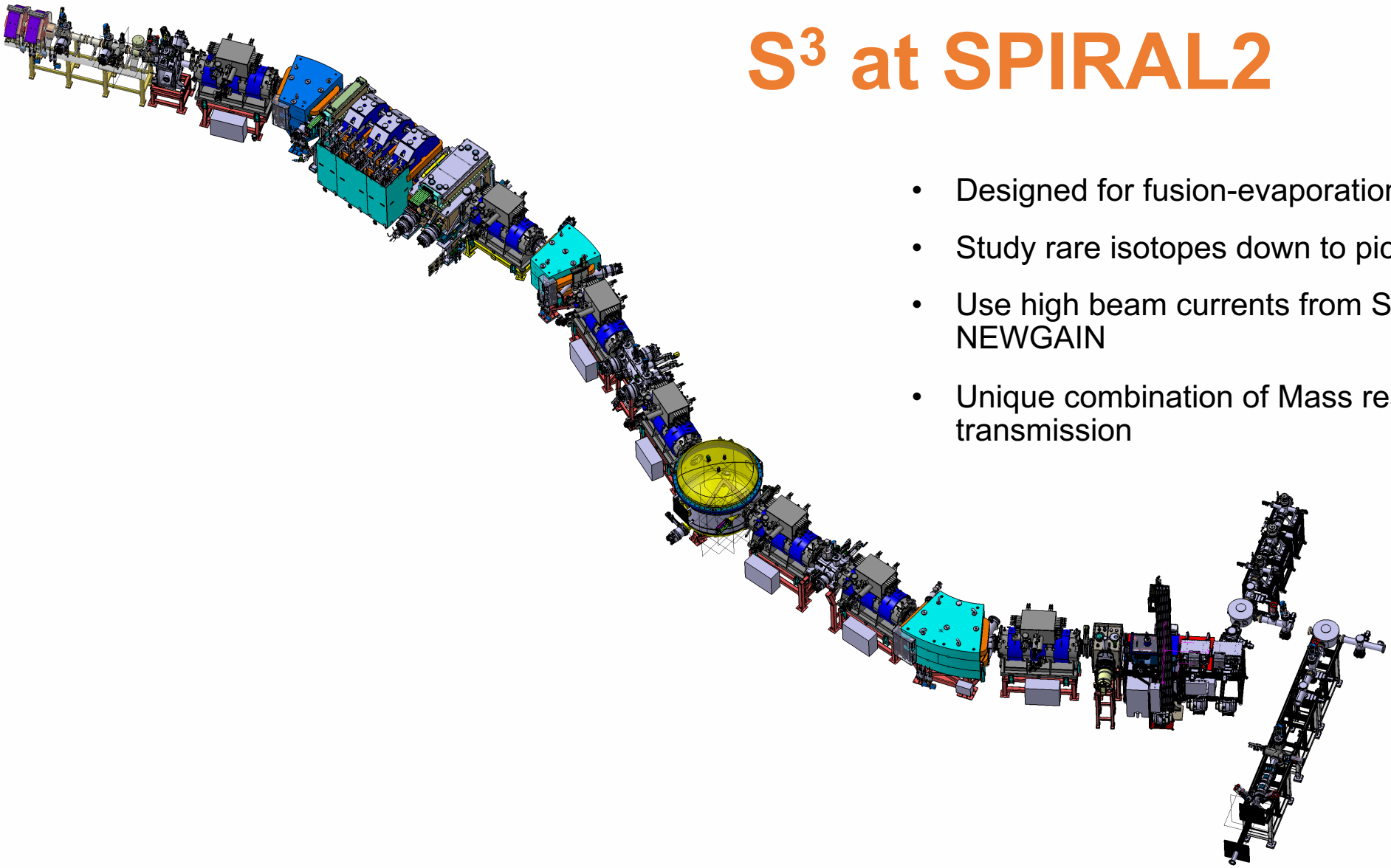
1. Convergent : Simplest mode for 1st expt ($\Delta_{dp/p}$=20%, Δ_{θ}=90mrad, Δ_{φ}=140mrad)
2. High mass resolution : M/ΔM = 400 ($\Delta_{dp/p}$=16%, Δ_{θ}=45mrad, Δ_{φ}=140mrad)

Mass Resolution mode



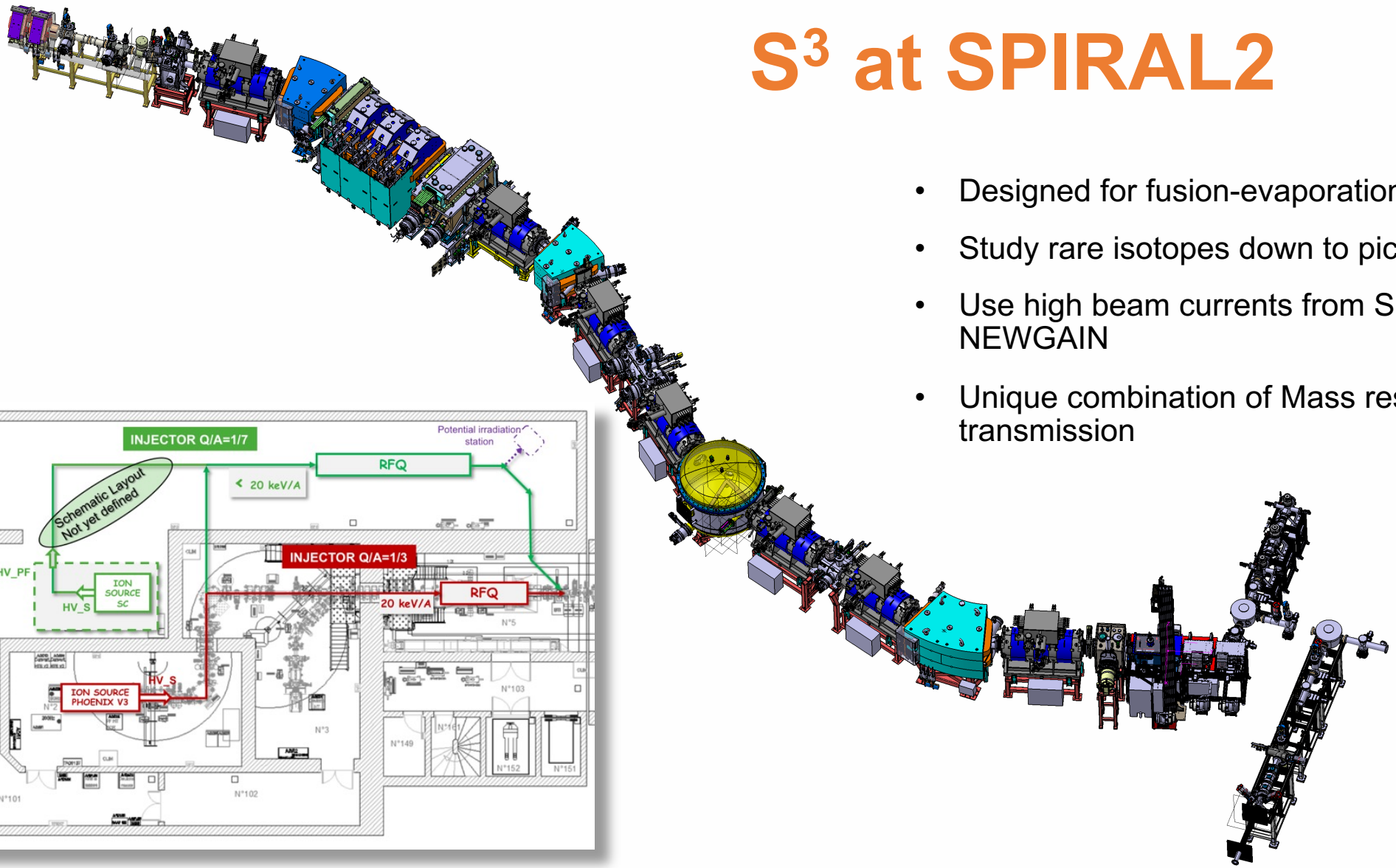
F. Déchery et al., NIMB **376** (2016) 125.
F. Déchery et al., Eur. Phys. J. A (2015) **51**: 66

S^3 at SPIRAL2



- Designed for fusion-evaporation
- Study rare isotopes down to picobarns
- Use high beam currents from SPIRAL 2 LINAC and NEWGAIN
- Unique combination of Mass resolution and high transmission

S³ at SPIRAL2



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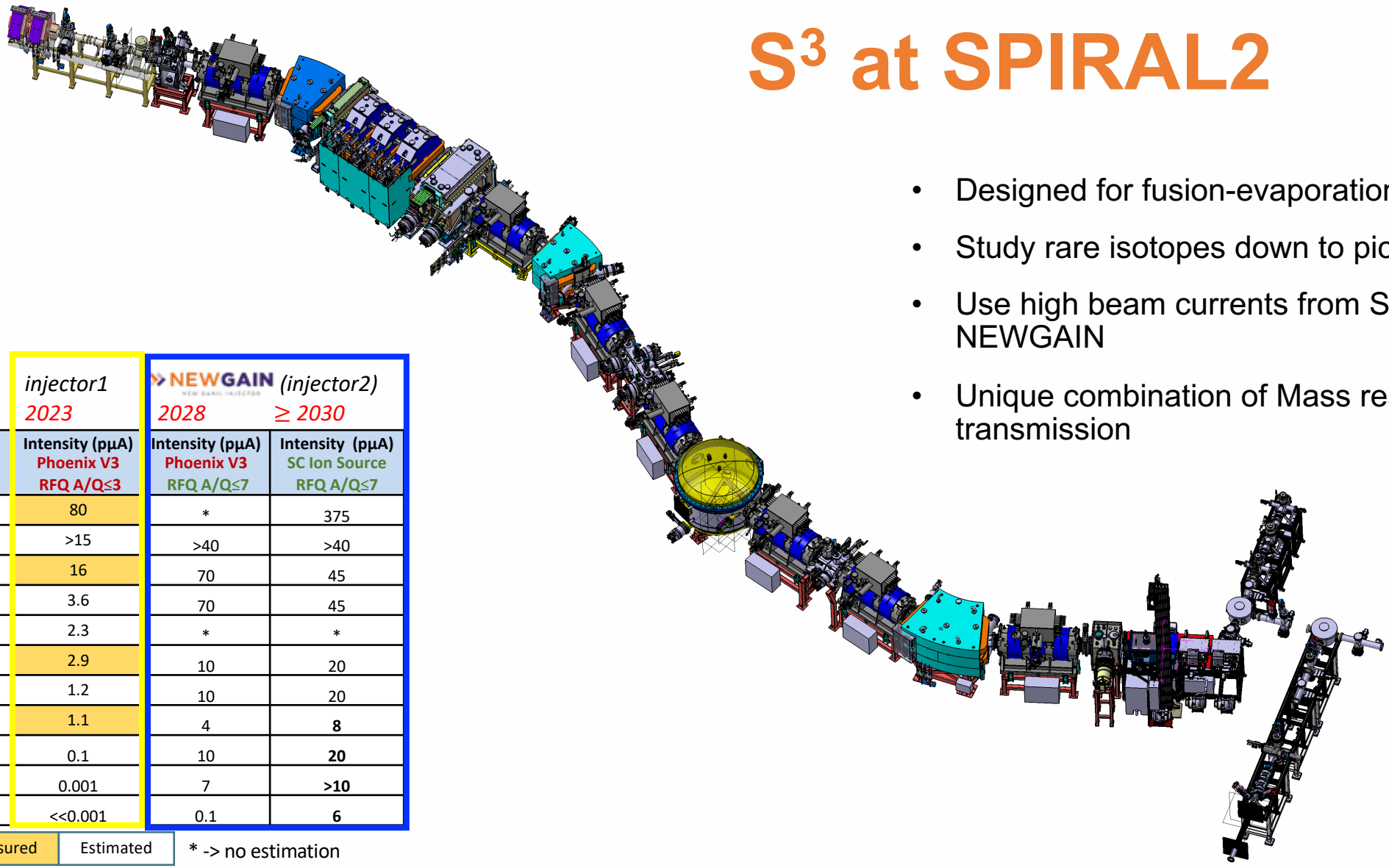

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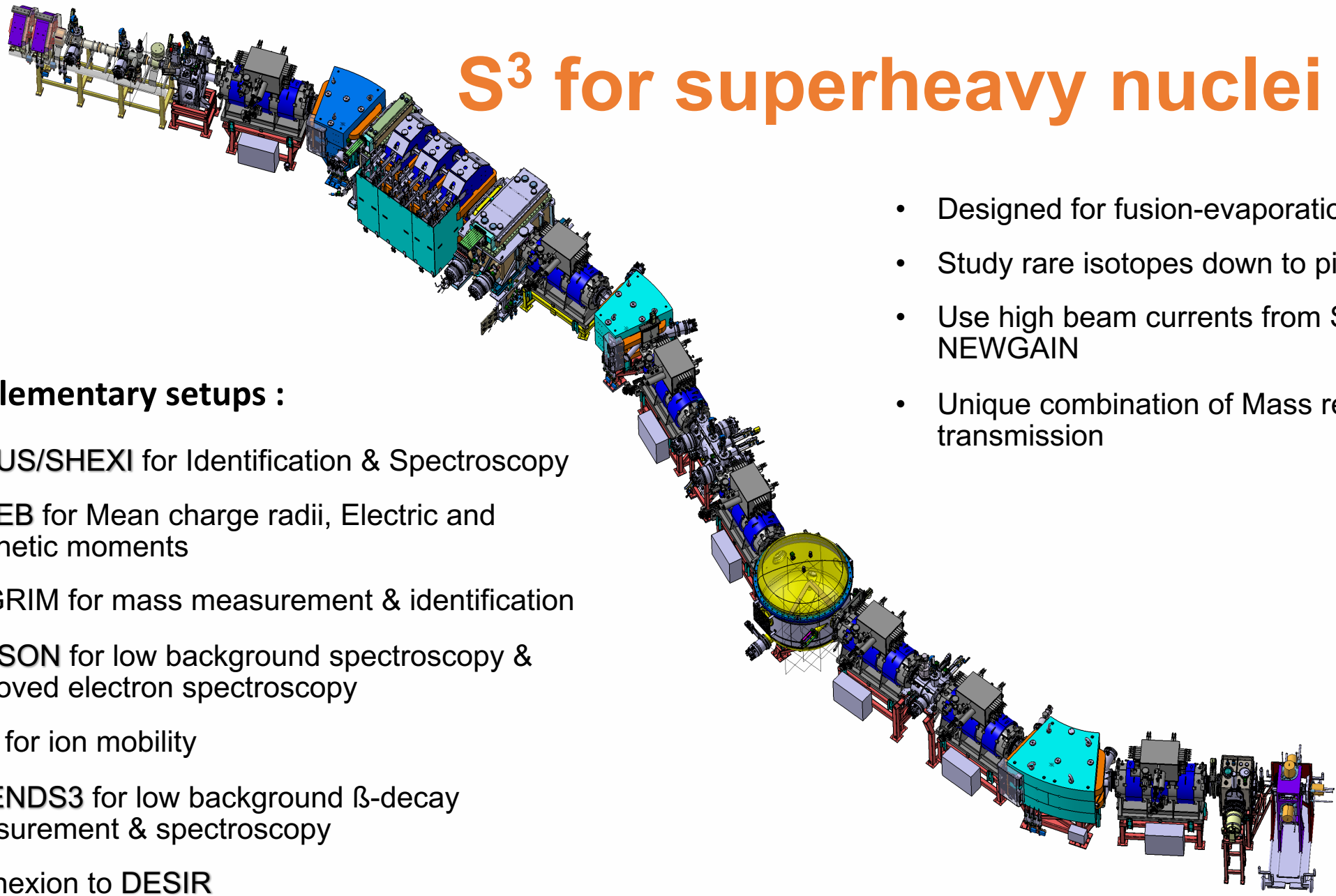
beam intensities	*injector1* *2023*	NEWGAIN *(injector2)* *2028*	*≥ 2030*
Ions	**Intensity (pμA)** **Phoenix V3** **RFQ A/Q≤3**	**Intensity (pμA)** **Phoenix V3** **RFQ A/Q≤7**	**Intensity (pμA)** **SC Ion Source** **RFQ A/Q≤7**
^{18}O	80	*	375
^{19}F	>15	>40	>40
^{36}Ar	16	70	45
^{40}Ar	3.6	70	45
^{36}S	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

S^3 for superheavy nuclei

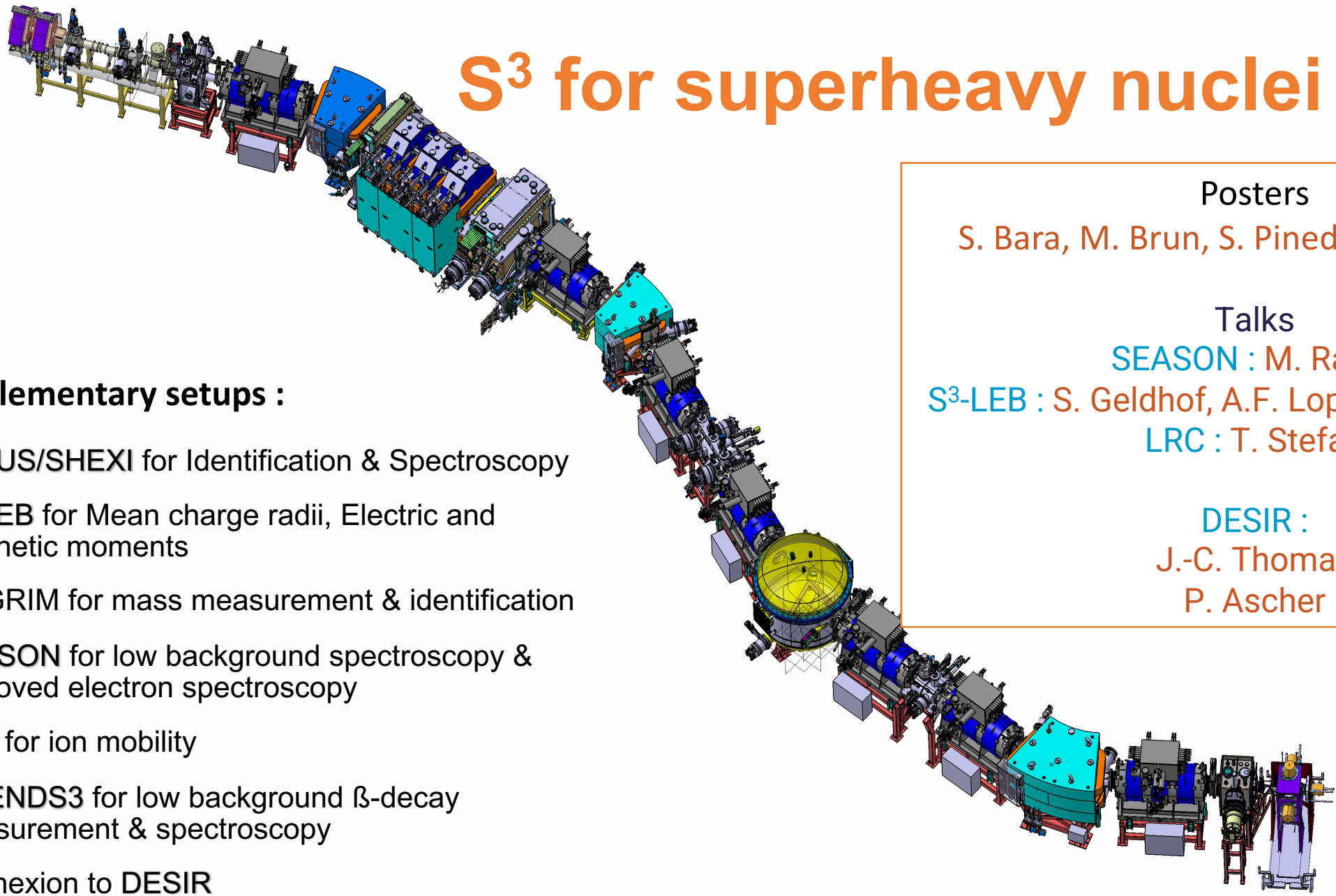


- Designed for fusion-evaporation
- Study rare isotopes down to picobarns
- Use high beam currents from SPIRAL 2 LINAC and NEWGAIN
- Unique combination of Mass resolution and high transmission

Complementary setups :

- SIRIUS/SHEXI for Identification & Spectroscopy
- S^3-LEB for Mean charge radii, Electric and Magnetic moments
- PILGRIM for mass measurement & identification
- SEASON for low background spectroscopy & improved electron spectroscopy
- LRC for ion mobility
- FRIENDS3 for low background ß-decay measurement & spectroscopy
- Connexion to DESIR

S^3 for superheavy nuclei



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Posters

S. Bara, M. Brun, S. Pineda, M.Y. Merrer

Talks

SEASON : M. Ragot

S^3-LEB : S. Geldhof, A.F. Lopez, V. Marchand

LRC : T. Stefan

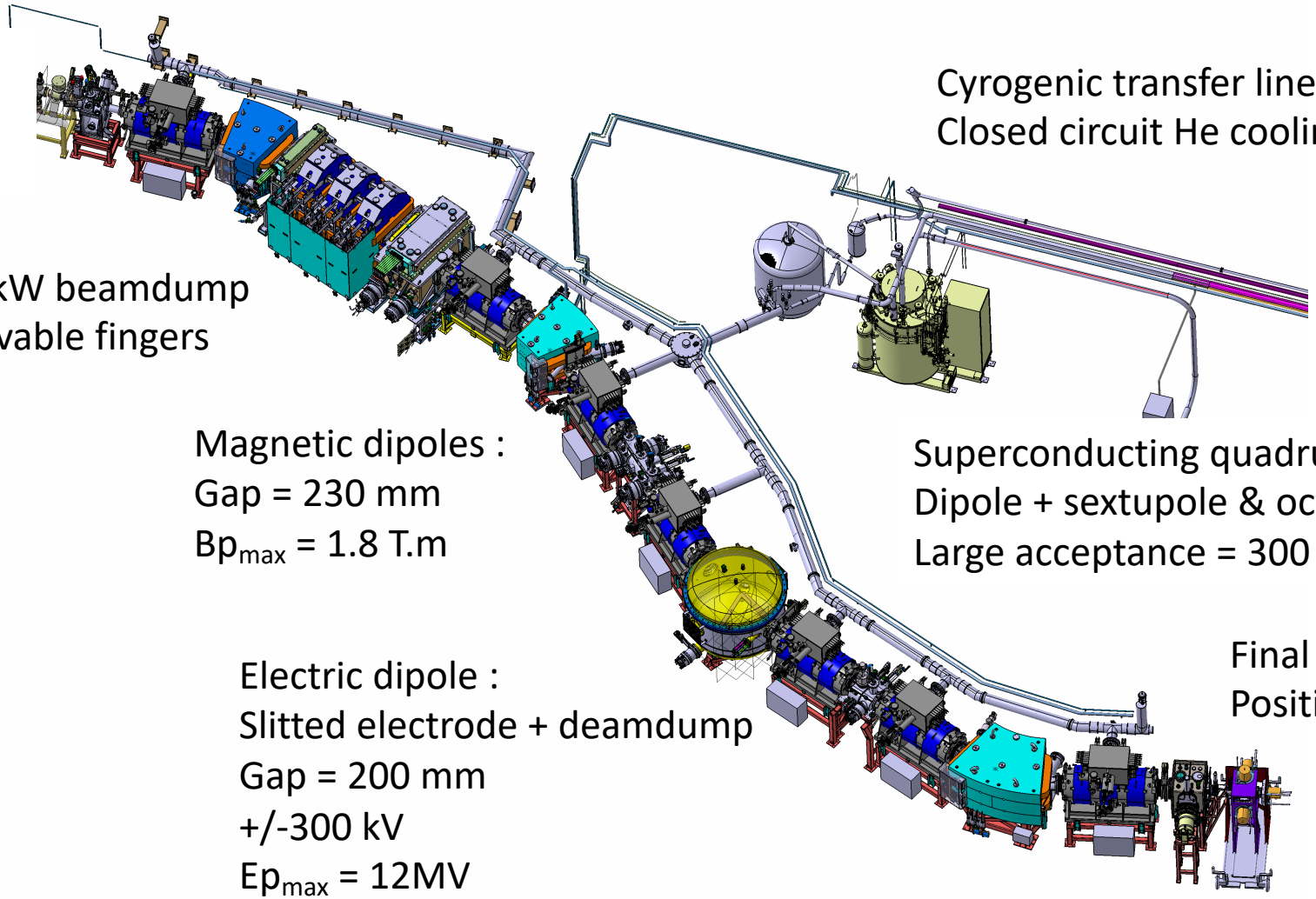
DESIR :

J.-C. Thomas

P. Ascher

Super Separator Spectrometer

High power target station:
Beam intensity > 5pμA
Online target monitoring



10 kW beamdump
Movable fingers

Cyrogenic transfer line
Closed circuit He cooling

Magnetic dipoles :
Gap = 230 mm
Bp_{max} = 1.8 T.m

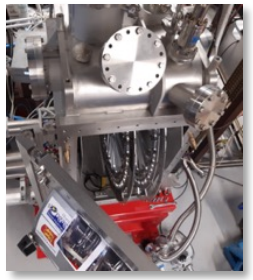
Superconducting quadrupole triplets
Dipole + sextupole & octupole corrections
Large acceptance = 300 mm

Electric dipole :
Slitted electrode + deamdump
Gap = 200 mm
+/-300 kV
Ep_{max} = 12MV

Final focal plane
Position sensitive detector

S3 Super Separator Spectrometer

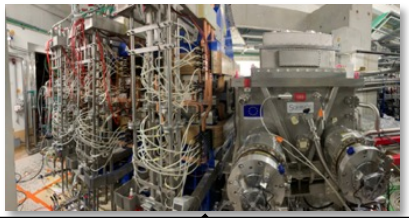
Target system

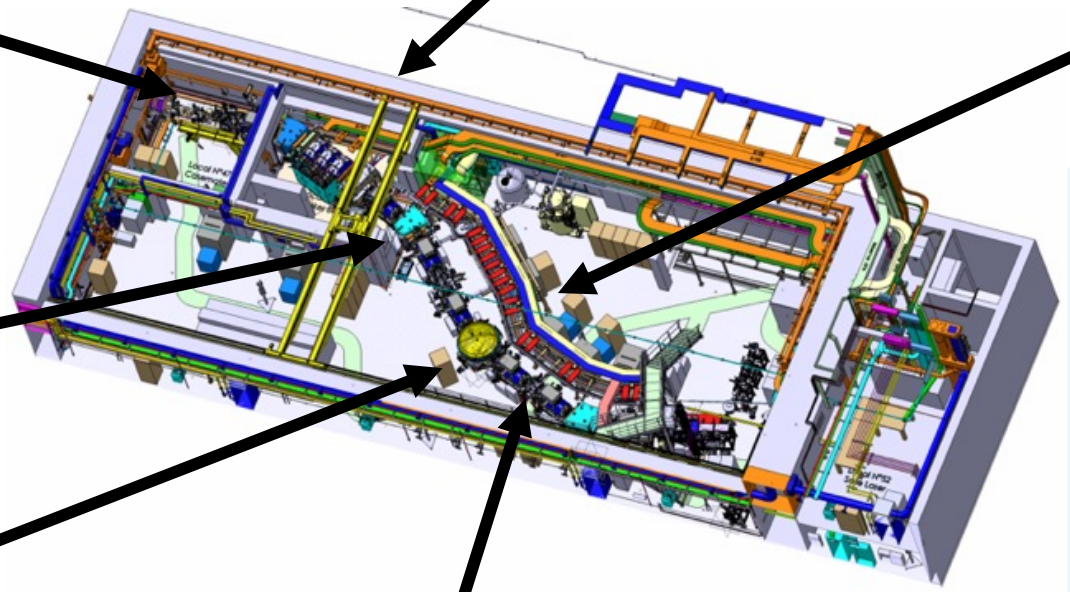


High power rotating targets

Dispersive zone

Open RT magnet & beam dump & Movable fingers





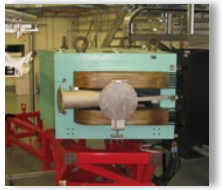
Infra / Interface

Lot C68, Cooling system, Laser room …

LEB

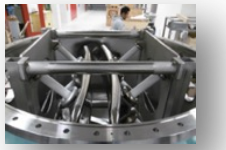
LEB @ LPC & GISELE Laser Lab

3 × M-dipoles



Large H & V gaps

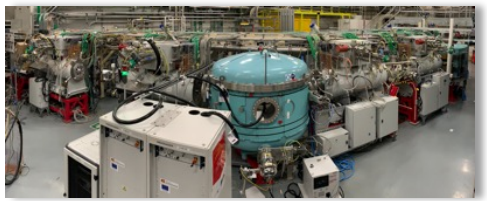
E-Dipole



20 cm gap & +/- 300 kV
Open slit in the anode

SC Multipoles

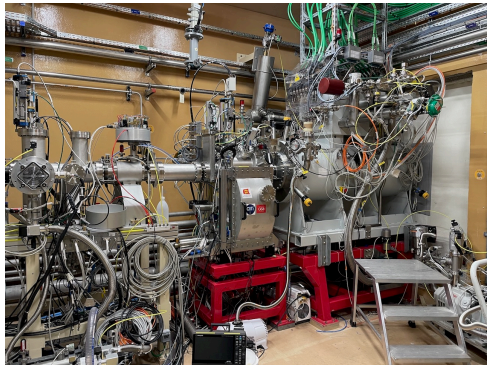
SMT, PSS, Coldbox & LTC

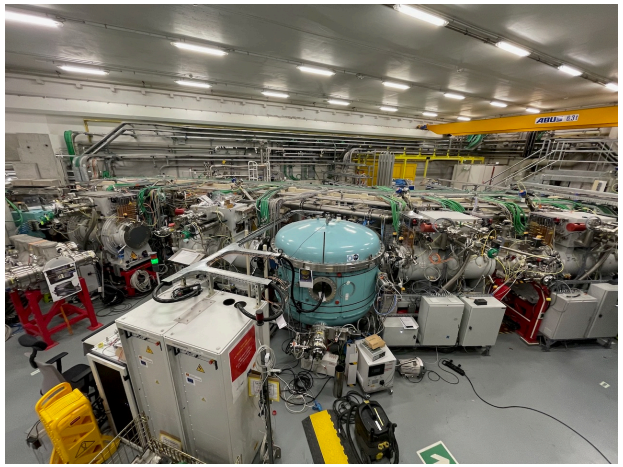


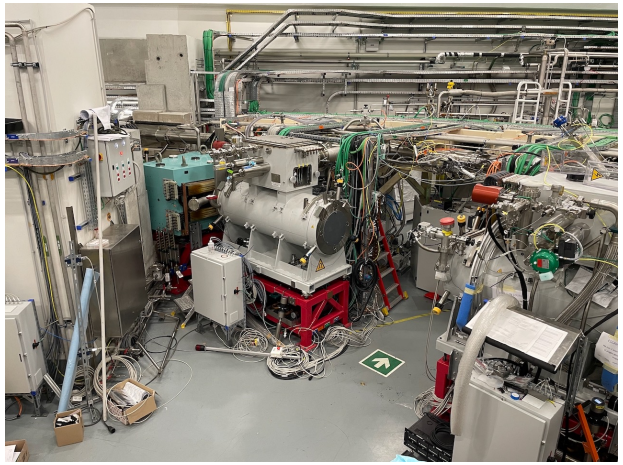
SIRIUS

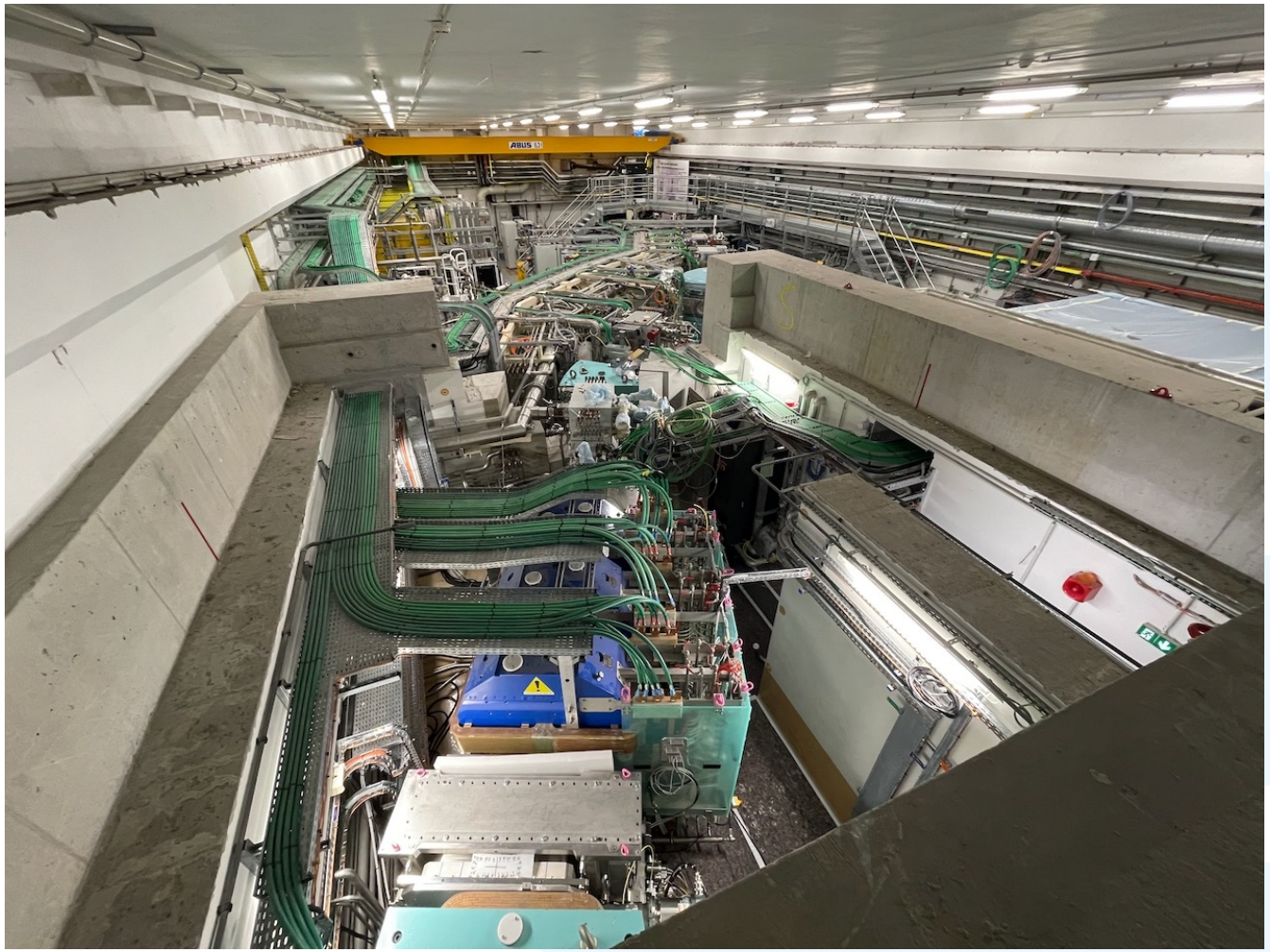
DSSD, SSD, FEE/BEE, DAQ & Diagbox

Status of S^3



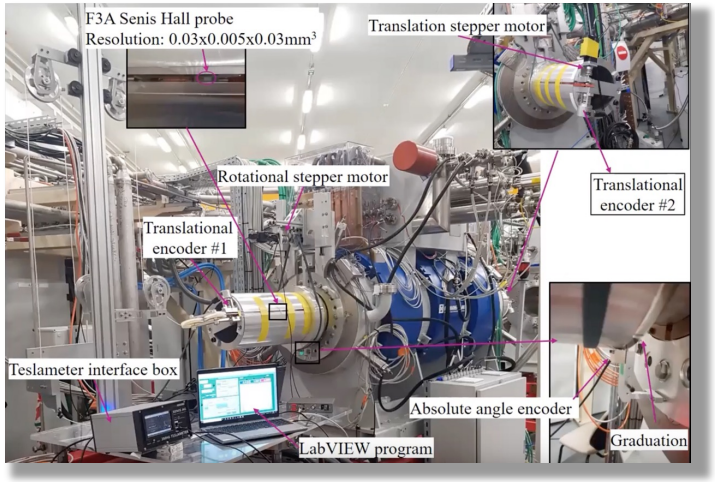


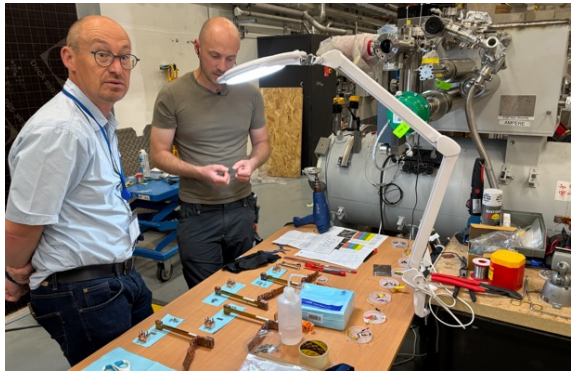


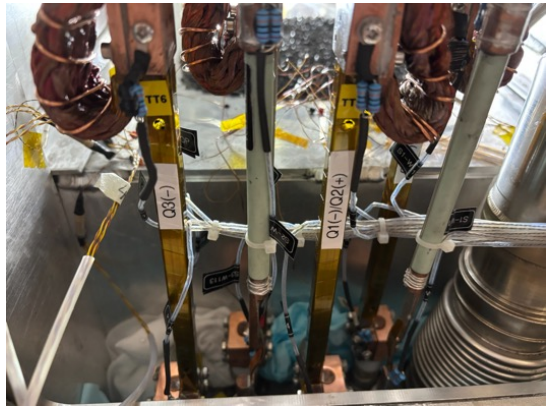


Status of S³

- All Equipement installed except Beamdumps
- Control of accelerator by target validated.
- Electrical Dipole conditionned at +/- 200kV
  Voltage sufficient for first experiments
- SMTs P1,2,3,4 repaired
- SMT P7 dismounted for repair
- Field mapping done on 2 SMT - Alignement of cold mass in the dewar done
- Cold box authorized – tests ongoing







Cold Box situation

➔ Nuclear Safety authority (ASNR) stopped operation due to non conformity in a pressure vessel – Nov 25

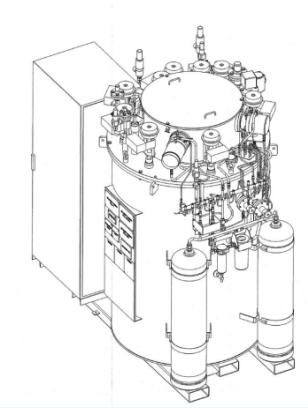
➔ Exemption request sent to ASNR mid July:
- ➢ Risk analysis from Manufacturer (Air Liquide)
- ➢ Economical analysis of replacement/repair (Air-Liquide)
- ➢ Proposed safeguards :
  - ▪ Limit of pressure in Cold box with lower value on discharge valve -> New calculations provided by Air-Liquide mid July ;
  - ▪ Automation of the Helium inlet valve

➔ Restart authorized by ASNR July 21st.

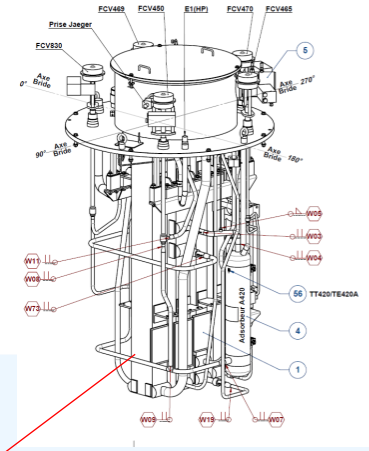
➔ Validation of new safeguards on Sept. 19th.

➔ **A lot of work managed by Pierre-Emmanuel Bernaudin (DOD-GVC) and Vincent Cingal (DQSN-DIR) for the exemption file , and GVC & G2CA groups to install & test the safeguards**

➔ **Impact: One year lost in the tests of the equipments**



Cold Box S3



Pressure vessel

Repairs SMT

Nitrogen leak on SMT Positions 1, 3, 4 & 7:

➔ Nitrogen leaks due to corrosion on HTS (High temperature Superconducting) current leads installed by the manufacturer

➔ All current leads have been replaced

Progress:

➔ SMT3 Done & online (2025)

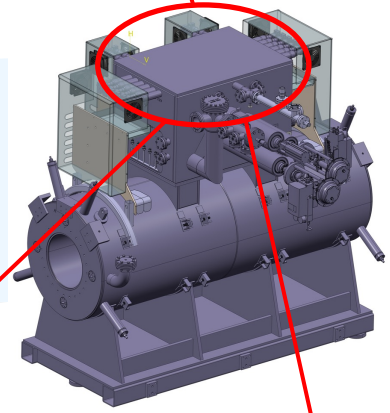
➔ SMT4 Done & online (2025-2026)

➔ SMT1 Done & online (Sept. 2026)

➔ SMT7 Dismounted to be repaired beginning 2027

HTS

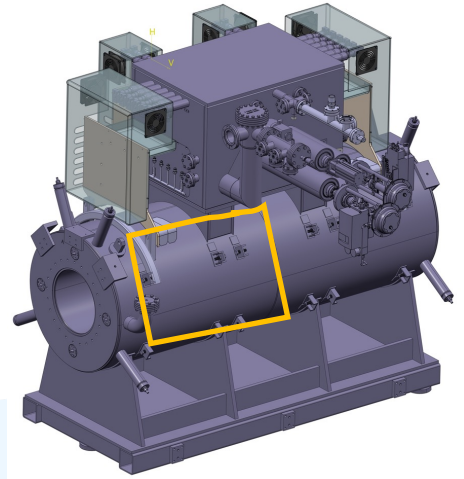
SMT open



before

after

Repair SMT



Borken current connexion SMT Position 2:

➔ Cable damaged by heat probably due to a compression from the insulator
➔ Cryostat & He tank opened at GANIL following expert review in 2024
➔ Cable repaired, tanks closed, but leaks in the He tank at cooldown in Nov 25

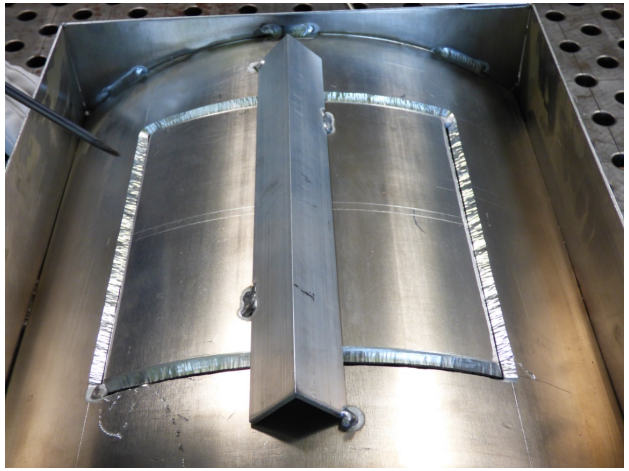
➔ Cryostat opened again T4-2025 with following actions:
- ➔ Expertise from IRFU and institut de soudure (institute of Soldering)
- ➔ Request for technical support on Aluminu soldering from Technitub
- ➔ Soldering controlled by Foucault currents & ultrasound
- ➔ Offline cooldown with liquid N_2 to validated resistance of the soldering

➔ **Helium tank repaired and controlled end July**
➔ **Validation of the repair during cooldown Nov 2026**

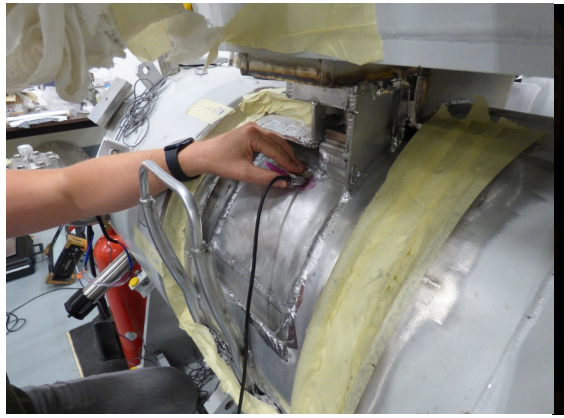
A lot of time lost, but expertise gained in understanding and repair of the SMTs

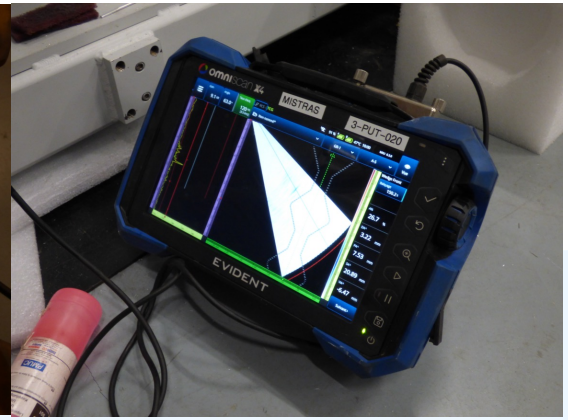
Open He tank

Réparation SMTs

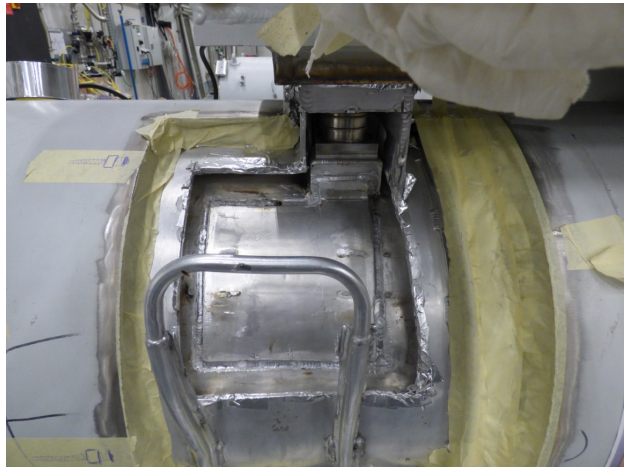


Several tests of the soldering procedure

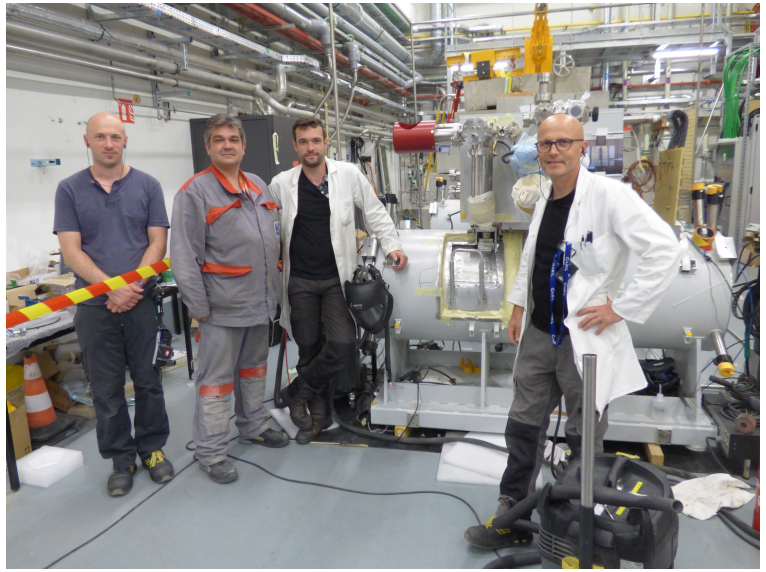




Foucault current & ultrasound tests



Closed He tank



Ganil repair team with Technitub soldering staff

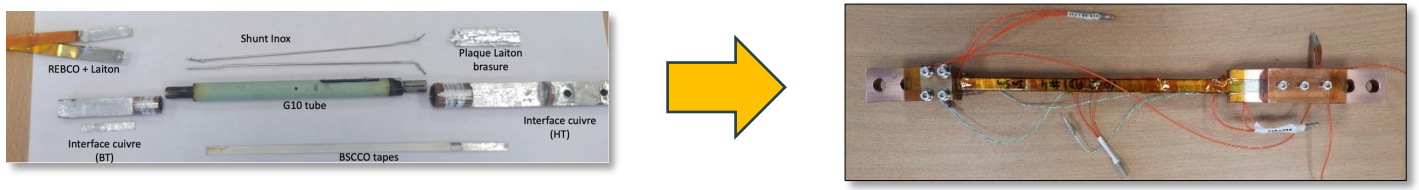
Soldering

New HTS Development (IRFU/GANIL)

New design HTS of SMT / fiabilisation:

➔ HTS design showed weaknesses over time

➔ New design decided with Irfu



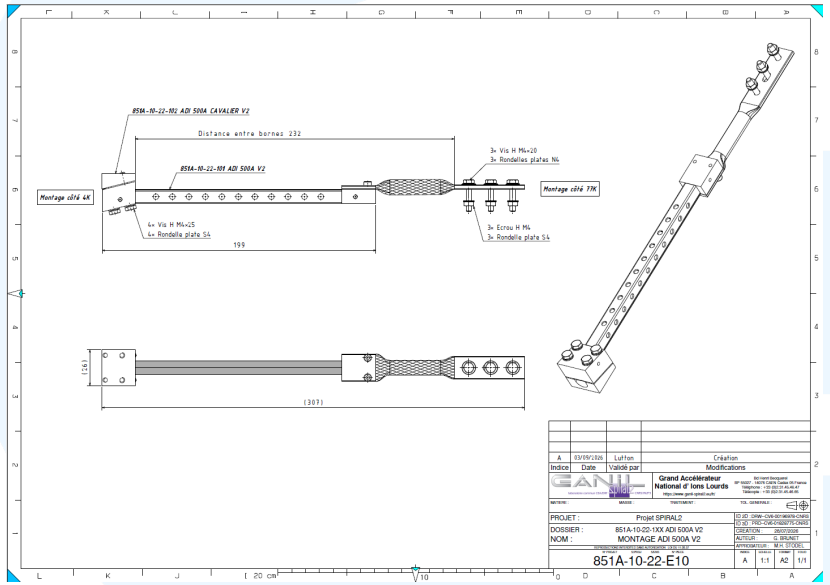
Intégration Proto V1

➔ 4 HTS prototypes V1 installed in SMT P3

➔ Test in November at cooldown

➔ Design V2 finalized mid-2026 to reduce size

➔ 3 units under production for tests on SMT P7 in 2027



Design Proto V2

SMT Tests

November 26 :

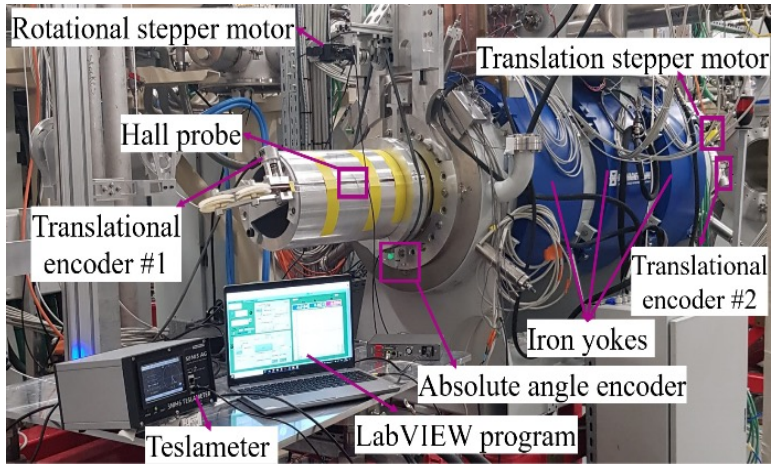
- SMT P1,2,3 to be retested pair with their own PSS (final position in the spectro line – All PSS ready)

April – Octobre 2027

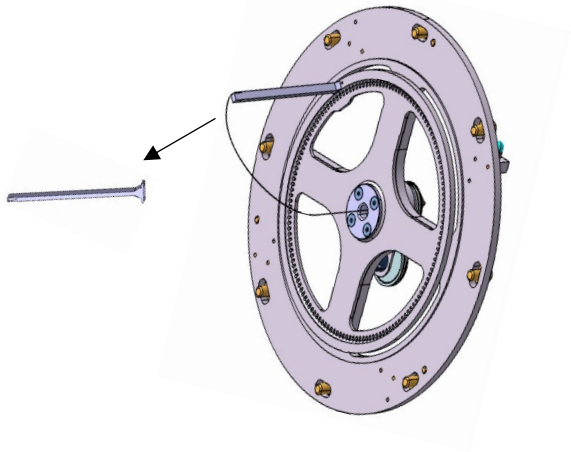
- Coil mass alignment of SMT P1-2-3-5-6-7 (difficult task as various alignment tools are required)

(SMT P4 aligned in September 2025 with the thin mapper)

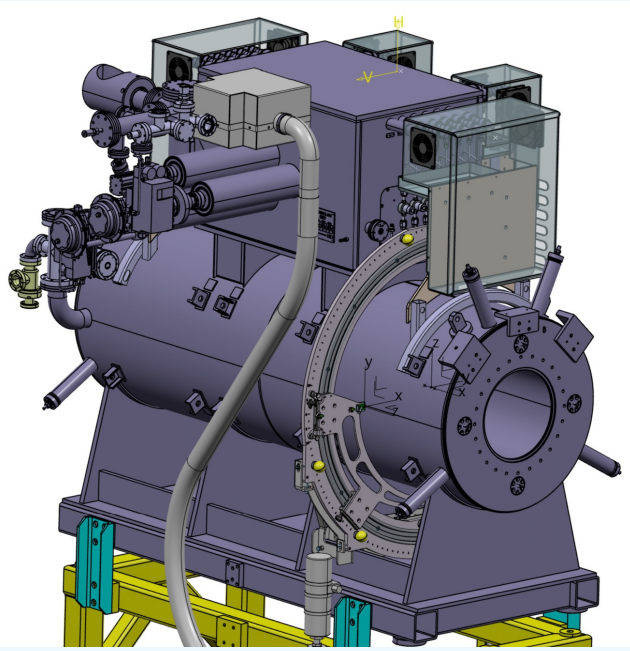
3D mapper



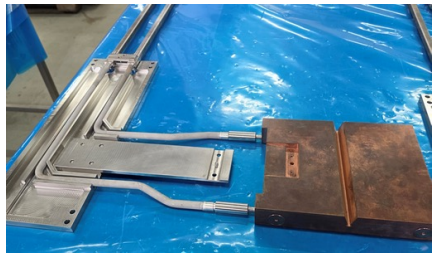
Thin mapper

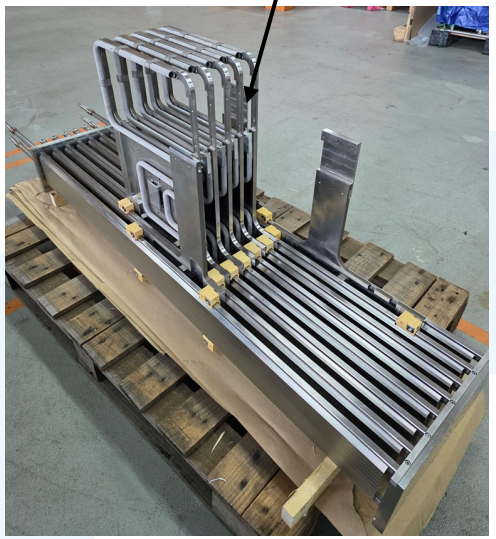


External mapper (GANIL/Irfu)



Beam Dump





Downstream cradle with guides

Production :

➔ All parts save one received and validated

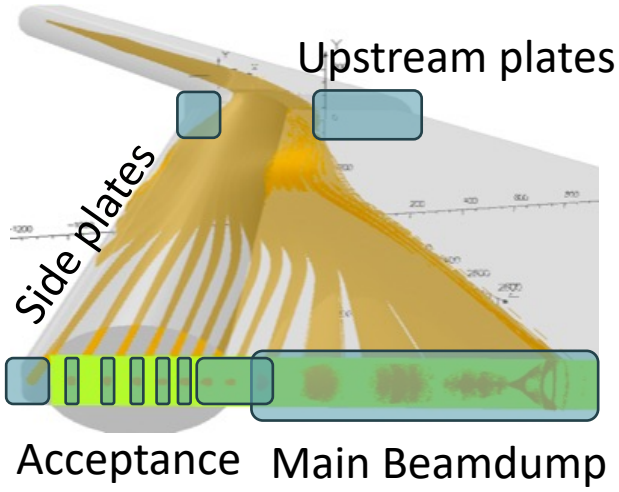
➔ Assembly & tighness test almost done for last part

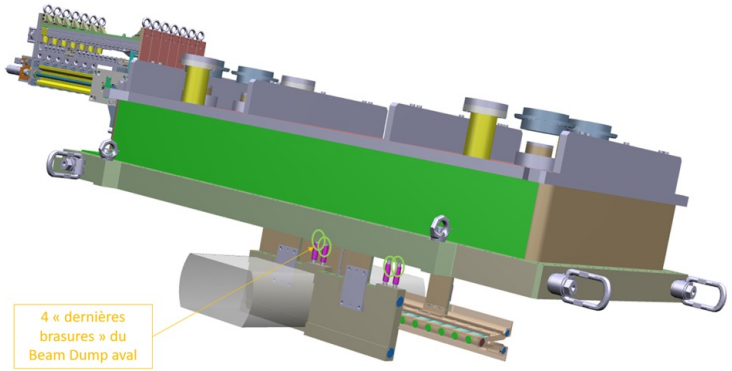
➔ **Delivery to Irfu beginning of October**

Assembly & tests at Irfu planned until feb. 27

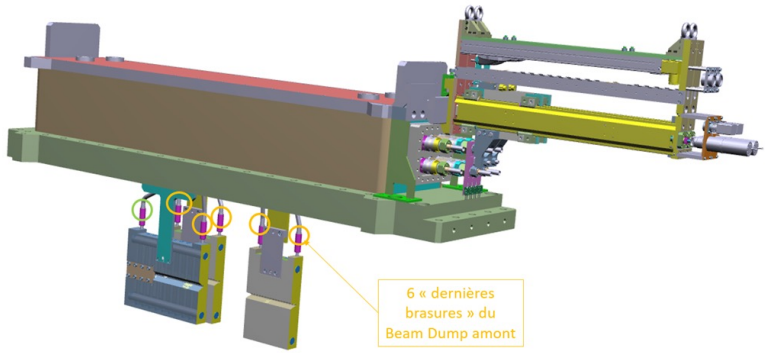
Delivery to GANIL planned feb 27

Beamdump ready for test online by april 27



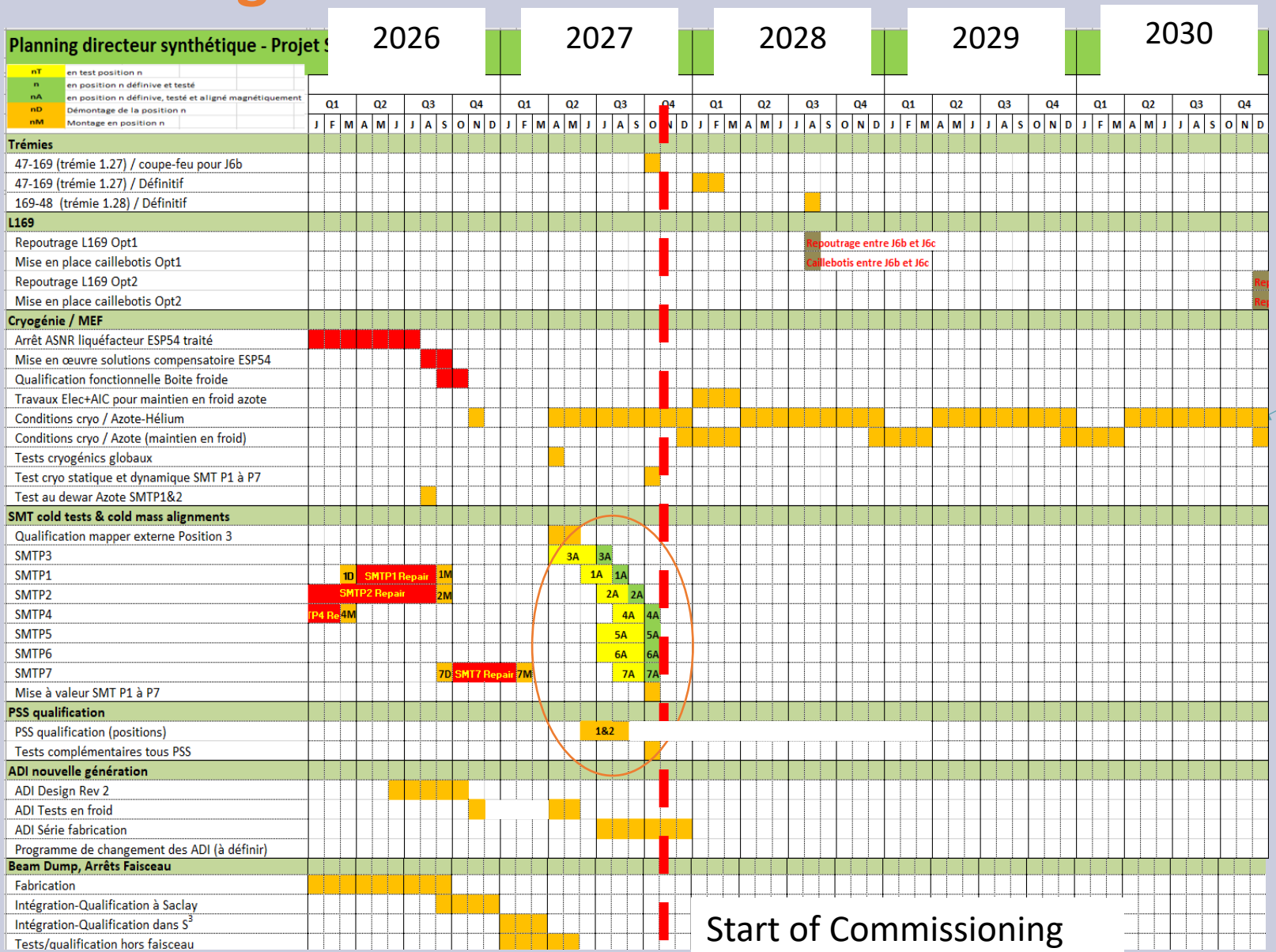


Downstream beamdump



Upstream beamdump

Planning



S^3 cold at 4K

S^3 maintained at Nitrogen cooling

Tests, qualification & Field mapping

J6x : commissioning milestones

J6A — Accelerator & beam line tuning up to the target

Done in Nov 2024

J6B — Spectrometer optical commissioning with direct beam

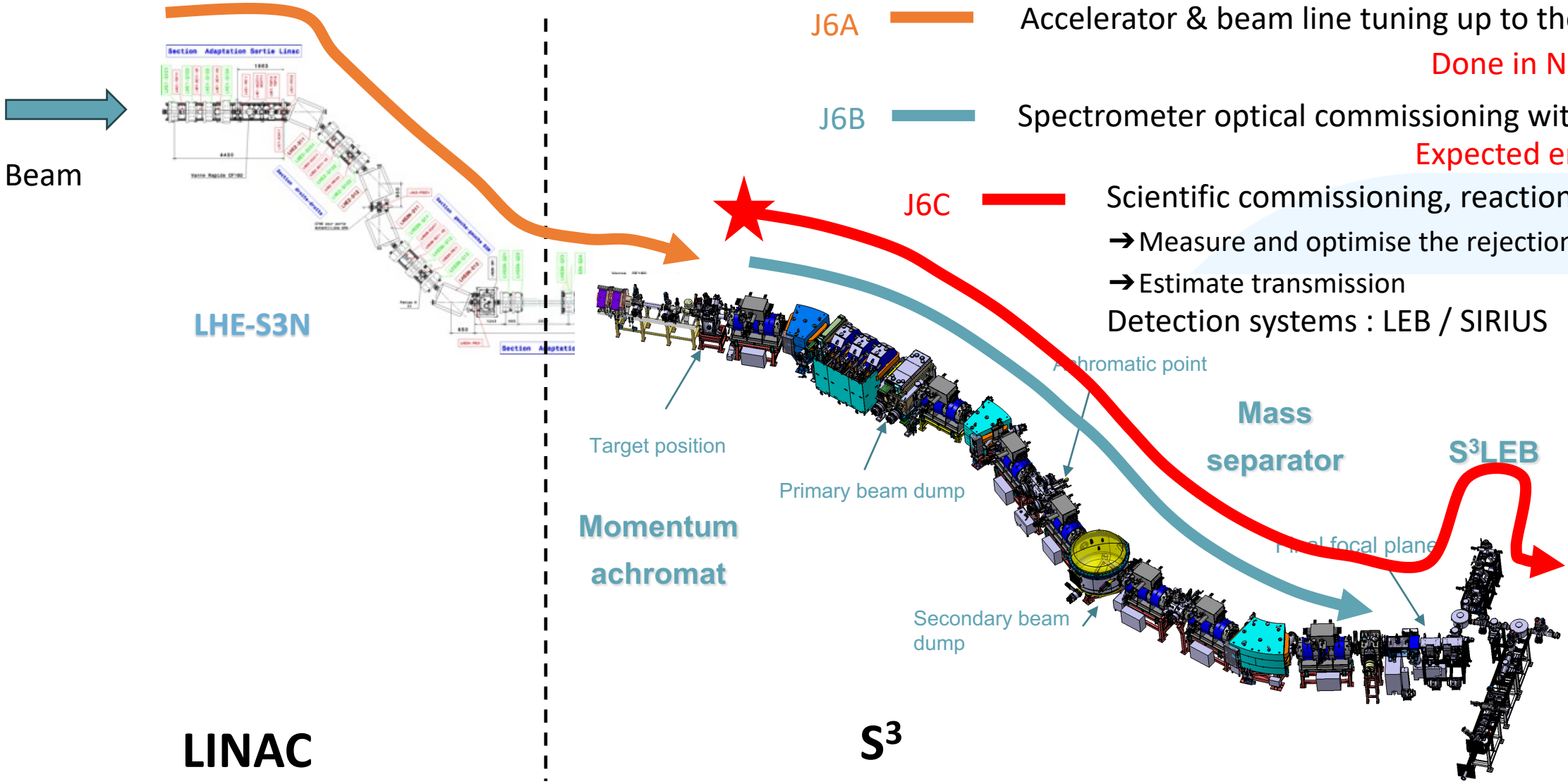
Expected end fall 2027

J6C — Scientific commissioning, reactions at the target

➔Measure and optimise the rejection (case by case)

➔Estimate transmission

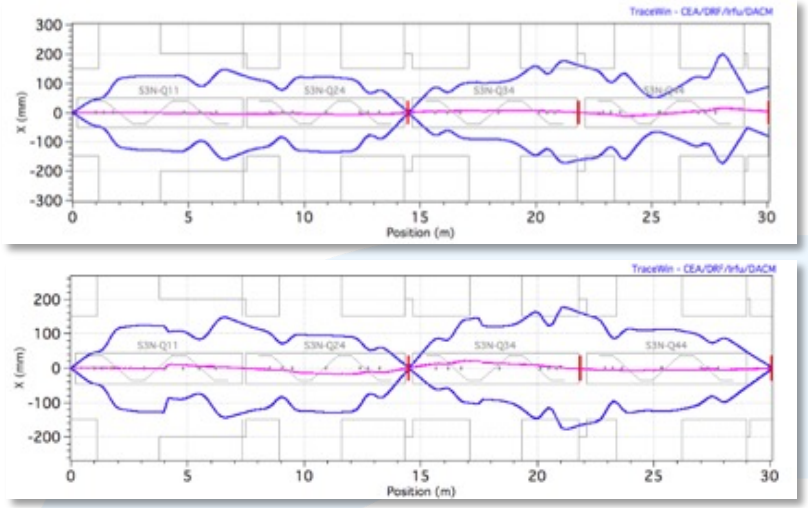
Detection systems : LEB / SIRIUS

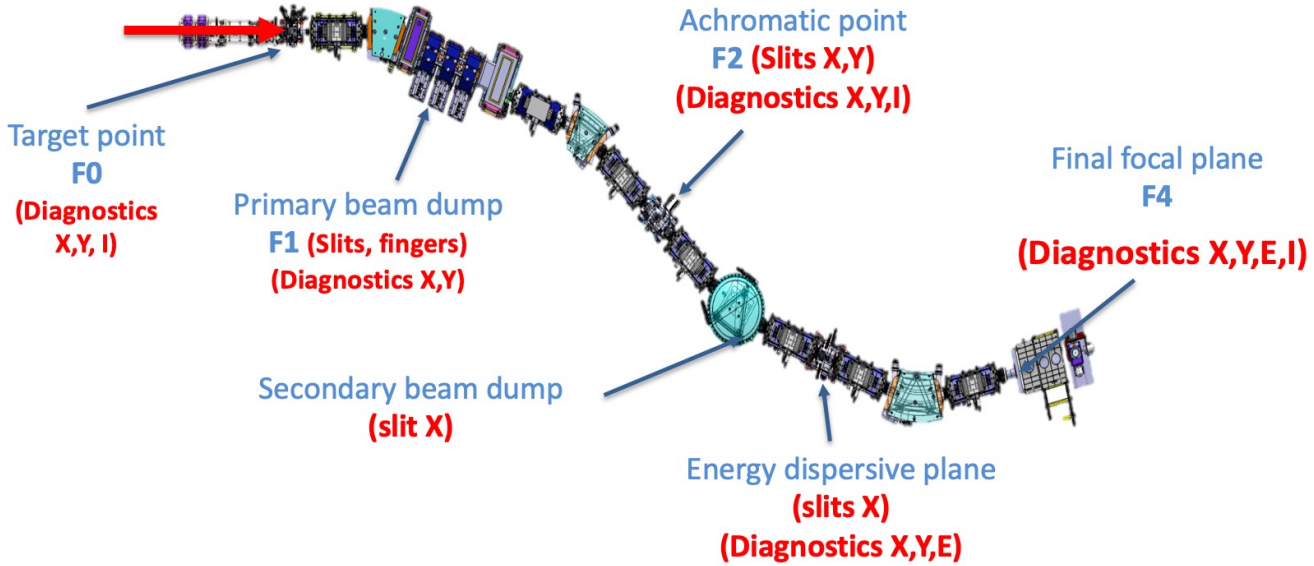


Spectrometer optical commissioning

- Direct and stripped beam up to the focal plane
- Progressive tuning of the elements (MA+ MS)
- Tools : diagnostics along the spectrometer + additional diagnostics at the focal plane (SIRIUS & LEB can be connected but not used)

➔ Beam ^{40}Ar ; E = 0.73 - 5 MeV/u and intensity of 30 W





Prerequisites

- Beam on target : commissioning de of LHE-S^3 with validation of the beam characteristics at the target point (Done J6A)
- Commissioning of individual elements (magnets, power supplies, control-command, diagnostics…)
- Alignments of magnets, slits and diagnostics Safety systems must be operational

Planning Commissionning

1. Optical commisioning	End 2027 to mid 2028
2. Commissioning Convergent mode	Mid 2027 to fall 2028
3. Commissioning S3-LEB	Fall 2028 to Mid 2029
4. Commissioning SIRIUS	Mid 2029 to mid 2030
5. Commissioning High resolution mode	Mid 2023 to en 2030

Conclusions

- S^3 designed to study low cross-section isotopes with mass identification
- Construction ongoing : All elements except Beamdump installed
- A lot of experience on Superconducting magnets (hard) earned
- Tests of SMTs planned to start November 26 until fall 27
- Optical commissioning starting October 27
- S^3-LEB commissioning ongoing
- SIRIUS ready for operation
- LRC under construction

Workshop announcement

Physics of Super Heavy Nuclei: status and prospects with S3

3–4 nov. 2026
IJClab
Fuseau horaire Europe/Paris

Entrer le texte à rechercher

- Accueil
- Ordre du jour
- Registration

The aim of the meeting is to review the open questions on the physics of super heavy nuclei (both in experiment and theory), present the experiments that are foreseen at S3 and discuss beam and target needs and strategies as well as current problems and possible mitigation.

The sessions on tuesday and the first session on wednesday with review talks and technical presentations are public. The last discussion session on the wednesday is closed.

The meeting will be in hybrid mode and is sponsored by the GDR RESANET.

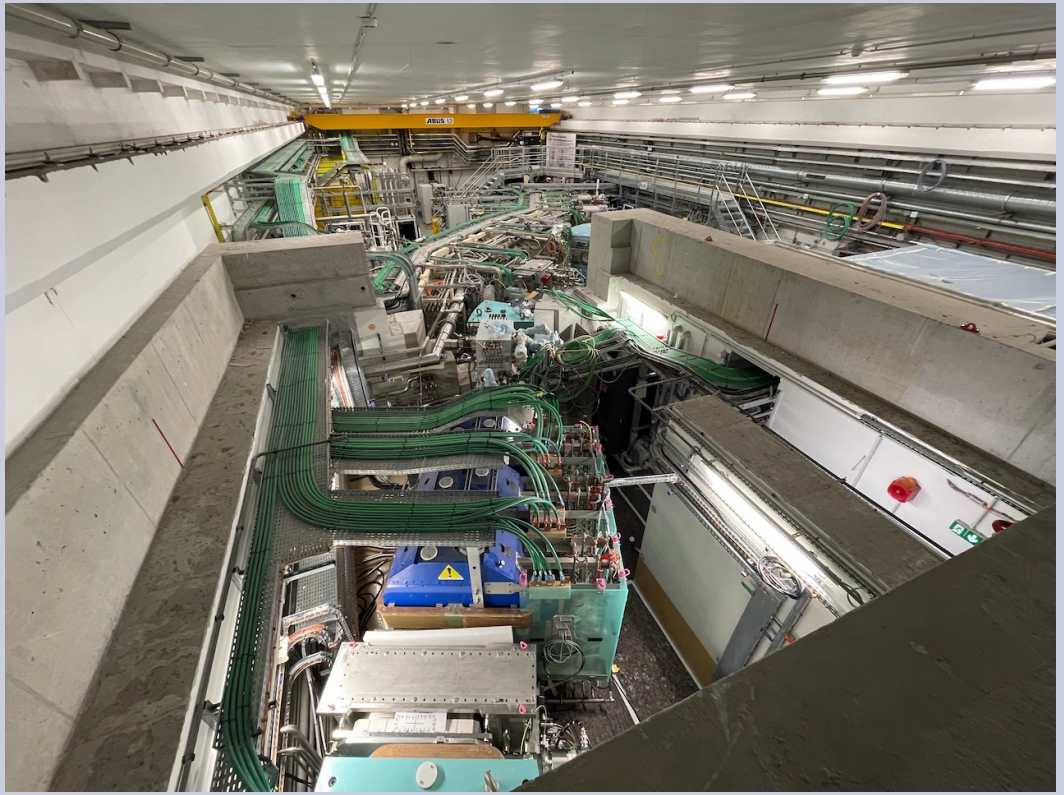
Commence le 3 nov. 2026, 09:00
Finit le 4 nov. 2026, 13:00
Europe/Paris

IJClab
Salle des Conseils (3/11) and room A018 (4/11)

Thank you for your attention

S^3 Collaboration - Letters of intent proposed by 18 laboratories:
ANL (U.S.A.), CENBG, IJCLab, JINR-FLNR, (Russia), GANIL, GSI (Germany), INFN Legnaro (Italy), IPHC, IPNL, Irfu CEA Saclay, JYFL (Finland), K.U. Leuven (Belgium), University of Liverpool (U.K.), LNS (Italy), LPSC, MSU (U.S.A.), LMU (Germany), Nanjing University (China), Northern Illinois University (U.S.A.), SAS Bratislava, (Slovaquia), IFJ PAN Cracovie (Poland), Smoluchowski Institute (Poland), CEA-DAM, SUBATECH, TAMU (U.S.A.), University of Mainz (Germany), University of York (U.K.), Vinca Institute (Serbia)

Construction partners :
GANIL, Irfu, IJClab, ANL, KU LEUVEN, IPHC, INSP/UPMC, CIMAP, University of Mainz, University of Jyväskylä, University of JENA, GSI



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