Commissioning plan of the S^3 project

GANIL Scientific Council – January 2024

1 Preamble

The S^3 project is now in its final phase of construction. The separator-spectrometer is expected to be ready to start the commissioning with beam in 2025.
The commissioning plan will take place in three phases.

- The first step is the “optical commissioning” with dedicated diagnostics along the spectrometer and at the focal plane. This phase, dealing with the spectrometer tuning for the beam transport, should last around 1-3 months. At this stage either SIRIUS or LEB can be connected at the focal plane but they will not be used for data taking.

- The second step concerns the “scientific commissioning” to optimize the rejection and the transmission for different relevant kinematics. This phase aims to reach the required performances in the Converging Mode (CM) for day1 experiments. In addition, even if the High-Resolution Mode (HRM) will not be used for the day1 campaign, some beam time will be devoted to test this optical tuning which is important for the SIRIUS scientific program and makes S^3 unique with respect to other facilities. The experience gained in this first HRM tuning will help to optimize this mode for the next beam time campaign.

- The third step is related to the commissioning of the two setups SIRIUS and LEB, which will take place in parallel with the second step. The goal is to have a full setup ready for the first experiments.

Given the complexity of S^3 the commissioning and the associated focal plane detection, two years will be necessary to reach adequate performances to start day1 campaigns with experiments selected by the PAC.

Following the discussions that took place within the S^3 User Collaboration Council (S^3UCC) in 2022 and 2023, a detailed commissioning scenario for the years 2025-2026 was elaborated and is presented in this report.

2 S^3 optical modes

The design of S^3 is highly versatile and allows the development of various optical modes dedicated to different experimental programs and detection systems. Two basic standard optical modes have been developed, and variations of these modes can be considered in future (see Figure 1):

- The converging mode (CM) allow a maximum transmission from the target point to the focal plane. In this mode, the beam rejection is moderate (performed at the momentum dispersive plane of the achromat and at the energy dispersive plane of the mass separator) and there is no mass resolution at the final focal plane.
- The high-resolution mode (HRM), or mass dispersive mode, that sacrifices part of the transmission in order to have a physical separation according to A/q at the final focal plane and thus a better rejection/identification.

For all optical modes a common tuning has been established for the Momentum Achromat (MA). Only the Mass Spectrometer (MS) has a different tuning between the Converging Mode (no high order corrections are required) and the High-Resolution Mode (high order corrections are needed).

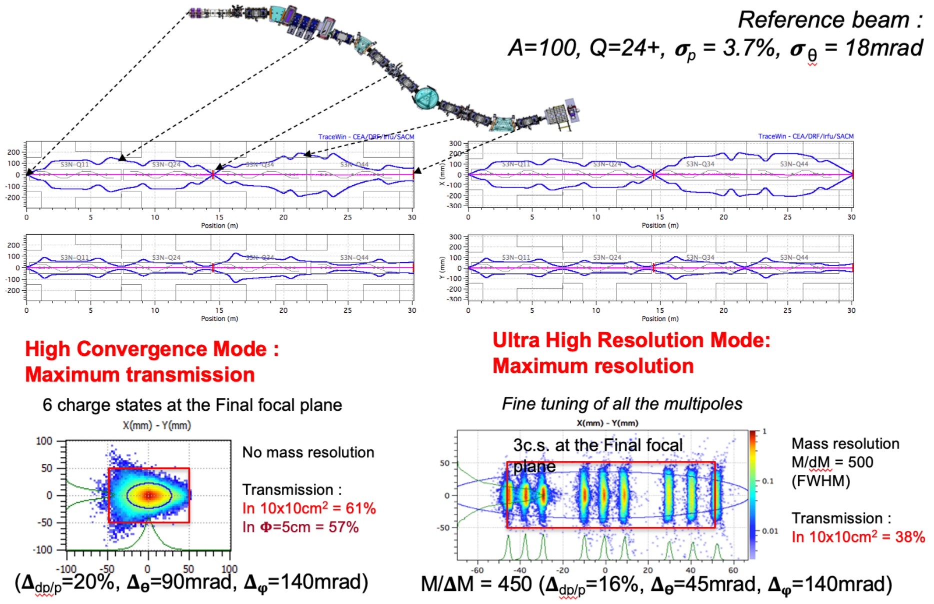

Figure 1: S^3 Optical mode description. Left: Converging mode (CV); Right : Mass dispersive mode (or High Resolution Mode HRM).

3 Prerequisites

3.1 Safety systems

For safety systems, SPIRAL2 project system engineering set up a specific reinforced process, to validate, at each step, all the requirements (technical, nuclear safety, quality, reliability, interfaces...) from the functional specifications to the final validation.

Since 2016, safety devices have been under construction and in test phase. These tests which are pre-requisites to deliver the first beam demonstrated that both functional and safety requirements are fulfilled. Currently, all of them are in operation for the LINAC and NFS.

The next step will consist of the validation (documentation/control/tests) of the specific systems needed to deliver the first beam at S^3.

Three main milestones have been defined using a phase approach for a gradual commissioning of S^3:

- Milestone J6a: LINAC beam delivery up to the S^3 target end 2024
    - LHS3N accelerator beam line test up to LHS3N-CF24
    - Beam spot optimization on the target (S3N-CF12) and beam synchronization
- Milestone J6b: spectrometer optical commissioning (see section 4)
- Milestone J6c: spectrometer scientific commissioning (see section 5)

A dedicated organization has been setup in 2023 with the list of the specific prerequisites identified for each milestone.

3.2 Spectrometer

Before the commissioning of the line per se, it is necessary to check, as much as possible, every equipment of the line, as well as the external inputs.
The magnets, power-supplies, diagnostics, beam intensity measurements, slits, control-command equipment, … must have been tested beforehand. Notably, must be checked:

- The alignments of magnets, centering of the fields
- The polarity of power-supplies
- The alignment and orientation of diagnostics
- The alignment and orientation of slits
- The consistency of the control-command equipment

3.3 LINAC

The commissioning of S^3 requires to increase progressively the beam intensity (from 10nA to tens of μA). This imply new developments to first reduce the intensity easily with pepper pots (1/100 to 1/1000000 reduction) in the LINAC and secondly to be able to measure low beam current with the design of a new AC Current Transformer to be installed at the entrance of the S^3 room. Those developments are ongoing and should be ready in 2024.

The beam on target must be carefully tuned (position, size, angle) and verified by the S^3 team with the help of a series of diagnostics located upstream of the target.

4 Spectrometer optical commissioning plan

In this section, we detail the different steps of the commissioning plan of the optical line, from the target point F0 up to the final focal point F4.

4.1 Principle

The principle of the commissioning is to test the elements progressively along the line by using the multiple diagnostics. At each step, the optical properties of the section will be tested at zero order (central trajectory), first order (dipole and quadrupoles) and higher order (correction of aberrations). Direct pencil beam is used for 0/1st orders, and scattered beam for 1st/Higher orders.

The momentum achromat (MA) optics are common to all modes (converging or mass dispersive) of the spectrometer. It can be tuned by the direct beam from the LINAC, or a moderately slowed beam. The mass spectrometer (MS), because of the electric dipole, must be tuned with a low energy beam (<1MeV/u). It could come either from the LINAC (if this energy regime can give a beam with correct optical properties) or by slowing it down at F0 and collimated in the MA.

Recently, oxygen and argon beams at an energy of 0.73 MeV/u were successfully accelerated up to the end of the LINAC with excellent beam properties. This setting will be preferentially used to tune the mass spectrometer.

Beam intensity will be adapted to the diagnostics (~10nA for emission profilers). Ne/Ar/Kr beams can be sued.

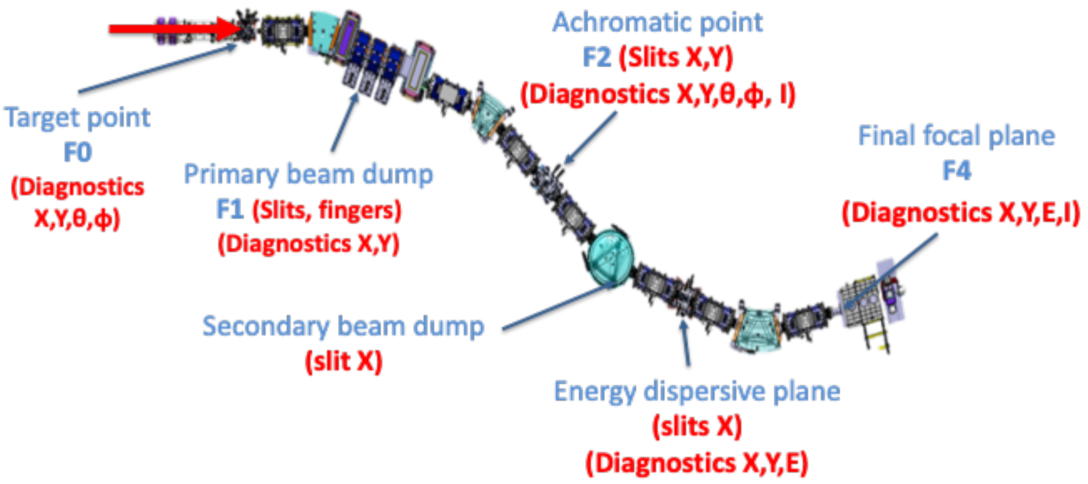

Figure 2: View of the S^3 line with the different focal points, diagnostics and slits location.

The table below summarizes all the beam diagnostics implemented on the S^3 line. They are divided into four categories to adapt different beam conditions:

1. Multi-wire X-Y profilers (EMS)
   Beam energy range: few keV/A to 100 MeV/A
   Beam intensity range: 1 nA to 100 µA
2. Secondary electron emission beam profile monitors (PFE)
   Very low energy limit ($E \approx 10$ keV/A)
   Beam intensity range: 10-10^{11} pps
3. Residual gas profile monitors (MIGR)
   Because this monitor will employ a residual gas detection strategy, it will not interfere with the beam. It can thus be used as a continuous position an intensity monitor.
   Beam energy range: 2-15 MeV/A
   Beam intensity range: 1 nA-100 mAe
4. Silicon strip detector (SSD)
   Intensity < 10^4pps

Location	**Distance**	**Type**	**Operational name**
Target F0	2,43m upstream	***EMS***	LHS3N-PR22
		PFE	LHS3N-PFE22
	1,5m upstream	***EMS***	LHS3N-PR23
		PFE	LHS3N-PFE23
	1,2m upstream	***MIGR***	LHS3N-PGR24-VE
		MIGR	LHS3N-PGR24-HO
	Target	***EMS***	S3N-PR12
Momentum dispersive plane F1	Dispersive plane	***EMS***	S3N-PR21
Acrhomatic point F2	0,5m upstream	***EMS***	S3N-PR31
		PFE	S3N-PFE31
	Acromatic point	***SSD***	S3N-SSD32
		EMS	S3N-PR32
		PFE	S3N-PFE32
	0,5m downstream	***EMS***	S3N-PR34
		PFE	S3N-PFE34
Energy dispersive plane F3	Dispersive plane	***PFE***	S3N-PFE41
		SSD	S3N-SSD41
Final focal plane F4	Focal plane	***SeD***	

Table 1: List of beam diagnostic detectors implemented on the S^3 line.

In the context of the optical commissioning, two additional multi-wire X-Y profilers and a dedicated faraday cup are installed at the focal plane (the SeD detector is not used).

4.2 Step 1: momentum achromat tuning

The beam is stopped in the faraday cup at F2 at LINAC energy.

Zero order

One can check all the alignment of the optic elements of line with beam (magnets, diagnostic, slits). The direct beam is sent along the central trajectory of the MA, checked at F1 and F2. One verifies that the magnets do not alter this central trajectory. Notable, the open sextupoles of the open triplet T2, produced by two compensating dipoles coils, must be carefully adjusted.

First order

Different optics are used to tests each triplet progressively:
- T1 only, focusing the beam on F1 diagnostics
- T1+T2, focusing on F1 diagnostics
- T1-T3, focusing on F2 diagnostics
- T1-T4, focusing on F2 diagnostics

Optical matrix elements are checked at F1 and F2: R11, R12, R33, R34, R16[1].
R16 corresponds to the momentum dispersion value at F1 and achromatism (R16 = 0) at F2.

Higher order

Some specific aberrations coefficients are measured, through the beam spot size on the diagnostics: T126 at F1, T122 and U1222 at F1 and F2.

4.3 Step 2: Mass spectrometer, converging mode (CM)

The beam is sent directly from the LINAC RFQ ($E \approx 0.73$MeV/u), as the accelerator operation in this energy regime gives correct optical properties. The need of low intensity beams requires the operation of pepper pots in the LINAC line. A thin degrader foil can also be used to get different charge states and larger momentum/angle distribution.
In a first stage, the MS is set in converging mode: only the dipoles and quadrupoles are used.

Zero order

This step is similar to the MA, with a special care for the electric dipole.

First order

This step is similar to the MA.

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[1] Standard ion-optical notations are used; numbers corresponding to the respective beam characteristics: x,θ, y, φ, s, dp/p: e.g. R12 is the linear dependence of x to θ at a given point.
T126 is the quadratic dependence of the x position to θ and dp/p. T122 is the dependence of x according to θ^2.
[1] U1222 is the third order dependence of x according to θ^3.

Higher order

In converging mode, the high order aberrations are not corrected. Only the quarupoles and dipoles are used. Sextupoles and octupoles are OFF. Only the full beam size is checked at F3 and F4.
At this stage, it is possible to perform reaction studies that do not require the nominal mass resolution.

4.4 Step 3: Mass spectrometer, dispersive mode (HRM)

The same conditions apply to the beam as in step 2.
Quadrupole tuning is different than in step 2 and the multipoles are used to optimize the mass resolution at F4.

Zero order

This step is similar to the MA, with a special care for the electric dipole.

First order

This step is similar to the MA, with the difference that the dispersion in F4 is non-zero.

Higher order

The multipoles are used to optimize the mass resolution at F4, *i.e.* the beam spot size is minimized for different A/q with the nominal dispersion.

5 Spectrometer scientific commissioning

Given the complexity of S^3, the commissioning will be made in two consecutive phases. The commissioning of the momentum achromat and the characterization of the rejection will be performed in a first stage using the “Convergent mode” of S^3. Following this step, the “High-Resolution mode” will be commissioned and the mass separation will be qualified.

5.1 Tools and detectors at the focal plane

5.1.1 SIRIUS

The diagnostic box with the SeD detector (Secondary electron gas Detector) in the SIRIUS configuration will be used.

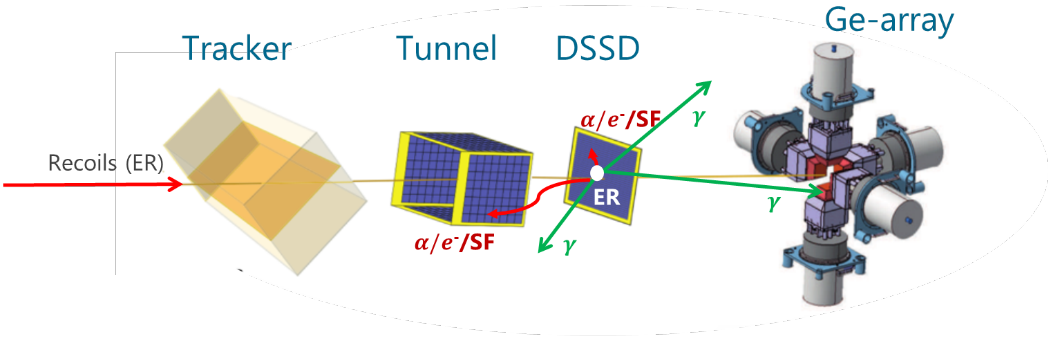


Figure 3: Schematics of the SIRIUS configuration

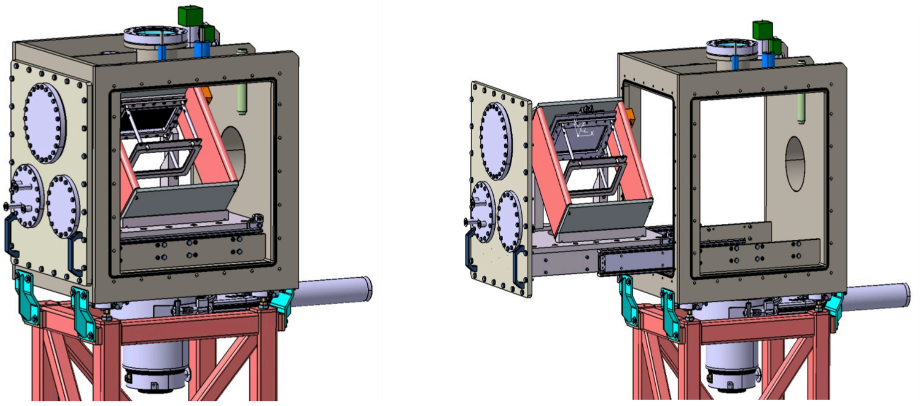


Figure 4: Diagnostic box with SeD detector in the SIRIUS configuration; Left: With the box closed, Right: with the box open, it can be seen the magnet surrounding the SeD detector (orange plates).

The SeD detector is equipped with magnets to reach the nominal position resolution with the tracker (1.4 mm FWHM) which is needed for the commissioning of the mass resolution of the spectrometer.

In addition, the veto detector placed behind the DSSD of SIRIUS will allow to discriminate the light charged particles from other events. This will provide a better understanding of the rejection of the spectrometer and of the production mechanisms at the target position.

5.1.2 LEB

In the LEB configuration, the diagnostic box is equipped with a time-of-flight SeD detector, tree DSSD detectors and a germanium detector, in order to perform basic identification of the nuclei (recoil energy, time of flight, decay particle identification and isomeric decay) and tuning optimization of the spectrometer before sending them to the S^3-LEB. All detectors can be removed from the beam line to let the nuclei reach the LEB gas cell.

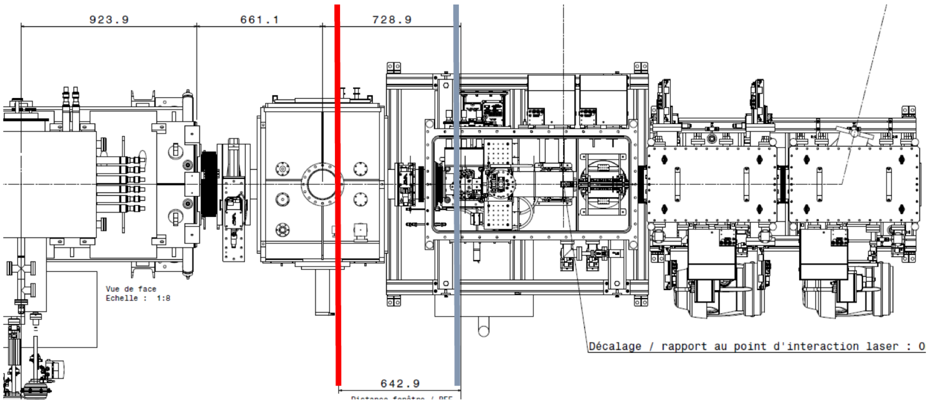


Figure 5: Mechanical study of the diagnostic box implementation in the S3 beam line. The figure shows the distance respect to the middle of the last triplet of S3. The red straight line indicates the plane final focal (PFF) defined as geometrical reference, and the blue straight line designs the position of the LEB entrance window.

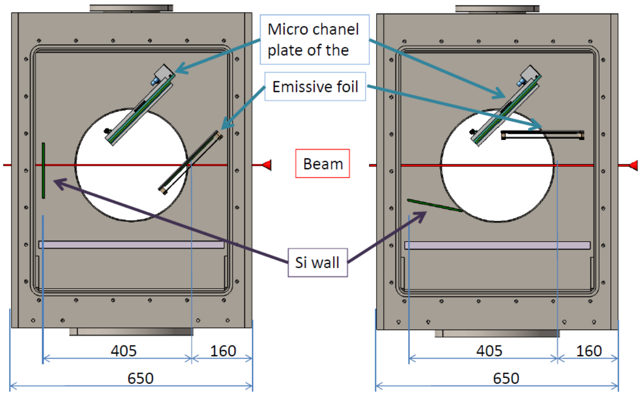


Figure 6: Slide cut of preliminary design of the diagnostic box for the LEB configuration performed by Patrice Gragnant. Left: The detectors are in the beam line. Right: the Si wall and the emissive foil are tilted 90 °, the wire chamber keeps in the same position.

The diagnostic box has lower gamma-ray efficiency (~ 0.1%) than in the SIRIUS configuration. The SeD without the magnet has a position resolution of the order of 4 mm (FWHM), which can give an estimation of the beam size. This configuration of the SeD detector without the magnet is not optimized for the high-resolution mode of the spectrometer (not required for the LEB experiments).

In addition, the LEB can also be used as a complementary tool to perform the spectrometer commissioning by doing mass analysis of the beam using the QMF and PILGRIM without lasers and without any voltage on the ion collector (non-neutralized beam).

Finally, additional detector may also help to assess the spectrometer performances (ex: Germanium detectors at the target position for absolute efficiency measurement).

5.2 Reactions

In the following, a number of reference reactions which could be used for the commissioning of the spectrometer are listed. In general, they employ “easy” beams and targets, and produce nuclei which are alpha emitters and easy to identify. Many cases have also been studied elsewhere (e.g. using the gas-filled separator RITU at JYFL, the VASSILISA at JINR DUBNA) allowing a direct comparison of spectrum quality and various other performances, such as primary beam suppression.

Such studies will help us to estimate important parameters crucial for future experimental campaigns: the transmission, rejection, mass resolving power and tuning in general of S^3 for different projectile-target combinations.

As stated during the S^3 steering Committee meeting in 2019, the GANIL management approved the possibility of scientific data taking during the so-called commissioning for SIRIUS and LEB.

The possible candidates for the reference reactions are detailed below.

Part 1: Asymmetric reaction

The ^{40}Ar + ^{116}Sn reaction to produce neutron deficient erbium nuclei. This reaction will be also use to perform the on-line commissioning of the S^3-LEB using a beam of ^{152}Er produced in the reaction ^{116}Sn(^{40}Ar – 180 MeV, 4n)^{152}Er.

Standard calibration reactions such as ^{40}Ar+^{174}Yb to produce known actinides with various alpha lines in the μbarn cross section range. This reaction is an ideal case to test also the performance of SIRIUS with transitions depopulating the different known isomeric states with gamma-ray transitions detected within µs range after the recoil implantation (isomers of 117 µs in ^{209}Ra and 2 µs in ^{210}Ra). It would also be interesting to vary the beam energies to make excitation functions for the 2-3n evaporation channels (^{211}Ra and ^{212}Ra - with isomers of ~ 9 µs) and the 6-7n evaporation channels with a longer isomer in ^{207}Ra of 55 ms.

In addition, the ^{40}Ar + ^{180}Hf reaction also produces a wide range of well-known alpha emitters with characteristic energies and several (tens of) micro barn cross sections (see section **Erreur ! Source du renvoi introuvable.**).

Beam	Target	CN	Isotope of interest	T1/2 (s)	Alpha branching (%)	Estimated XS (µb)
^{40}Ar	^{116}Sn	^{156}Er	^{152}Er (Z=68)	10.3	91	7000
^{40}Ar	^{174}Yb	^{214}Ra	^{209}Ra (Z=88)	4.8	90	1400
^{40}Ar	^{180}Hf	^{220}Th	^{216}Th (Z=90)	0.026	100	30

Part 2: Very Asymmetric reaction

Very asymmetric reactions using light projectiles like ^{20,22}Ne on heavy targets (^{197}Au, ^{208}Pb, ^{209}Bi) will be used to test the transmission of slow reaction products in S^3. Those reactions will help to estimate their implantation in SIRIUS and the capability to use thin entrance window with the S^3-LEB gas cell.

Beam	Target	CN	Isotope of interest	T1/2 (s)	Alpha branching (%)	Estimated XS (µb)
^{22}Ne	Pt	$^{216-220}$Ra	$^{210-214}$Ra (Z=88)	s to min	> 80	> 1000
^{20}Ne	^{197}Au	^{217}Ac	^{212}Ac (Z=89)	0.88	100	1000
^{22}Ne	^{208}Pb	^{230}U	^{226}U (Z=92)	0.35	100	6

The reaction ^{197}Au(^{20}Ne,xn)$^{217-x}$Ac is also interesting to study the nuclear structure evolution around N = 126 neutron shell closures in heavy actinide nuclei with the S^3-LEB.

Part 3: Symmetric reaction

Identification of reaction channels produced with symmetric fusion evaporation reactions below ^{100}Sn is a challenge since many reaction channels are open in a given compound nuclear reaction and all nuclei β-decay. In some case the contamination at the focal plane can be many orders of magnitude greater than the rate of the nucleus of interest.
For such kinematics, we can use similar reactions as used to test recoil mass separators at LNL (^{58}Ni + ^{64}Ni at 212 MeV with 300 mb cross-section) or at HRIBF (^{58}Ni + ^{28}Si at 212 MeV). In this case, S^3 is tune in the HRM and the efficiency is measured by the ration of the photopeak intensities of principal γ-lines accumulated at the target position with and without a coincidence condition with a single mass value selected in the mass spectrum at the focal plane (see section 5.4).
Another possibility to tag a reaction channel, is to rely in a well-known isomeric state identification at the focal plane which has a reasonable life time.

Each experiment should be interspersed with off-line tests of two or three weeks in order to optimize the whole set up.

5.3 Rejection

For beam rejection, the tuning is done at the nominal energy of the beam on the nominal target. The intensity is increased progressively in order to maximize its rejection. Again, this is done for the two stages of the spectrometer with different sets of slits and dumps, and notably:

For the momentum achromat

- at the dispersive plane F1 (dispersive according to the Bρ = mv/q ratio) fingers or slits have to be correctly placed to stop charge states of the beam. In this location, the roles of the various dump parts are to eliminate the major part (99.9%) of the primary beam according to the kinematic of the reaction, to contain the problems related to the activation and to the power deposition.

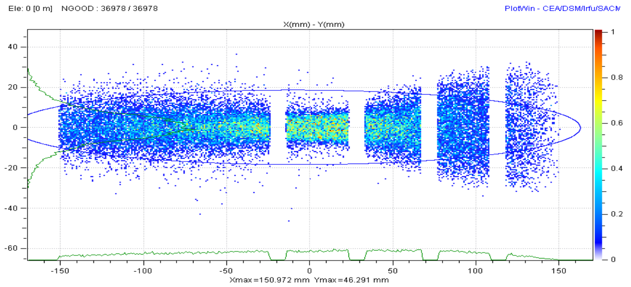


Figure 7: Spatial distribution of ^{100}Sn when 4 mobile fingers are positioned in F1.

- At the intermediate achromatic focus point F2, slits are tuned to limit the transmission of scattered products.

For the mass separator:

- At the electric dipole, the anode electrode is split to allow the extraction of the fastest ions (primary beam) to be stopped directly in a beam dump. This beam dump can be used for moderate intensity beams (up to 100W, e.g. 500 pnA of ^{40}Ar).
- At the energy dispersive plane F3 (dispersive according to the mv^2/q ratio), slits can be tuned to select the products of interest.

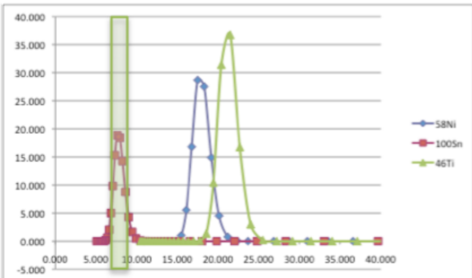


Figure 8: Electric rigidity [MV] distributions of the ^{100}Sn ions of interest (red), the ^{58}Ni primary beam and the ^{46}Ti target nuclei. The green window is the acceptance zone of S^3.

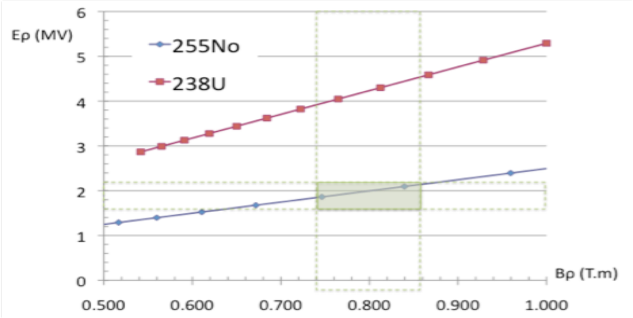


Figure 9: Electric rigidity versus magnetic rigidity for ^{255}No (blue) and ^{238}U target like recoils (red). The green window is the acceptance zone of S^3.

- At the final focal plane F4 when the mass spectrometer is in " ultra-high dispersion " mode in mass on charge.

5.4 Transmission

The absolute transmission efficiency is not a simple quantity to be measured because it is influenced by many factors.
At first, it will be evaluated using well known reactions with known cross sections.
One way is, for one isotope, to compare the counts observed in the γ-ray peaks recorded by germanium detectors at the target position to the counts in the same peaks recorded in coincidence with recoil decays observed at the focal plane. An example of absolute transition measurements with the gas-filled separator RITU is shown below.

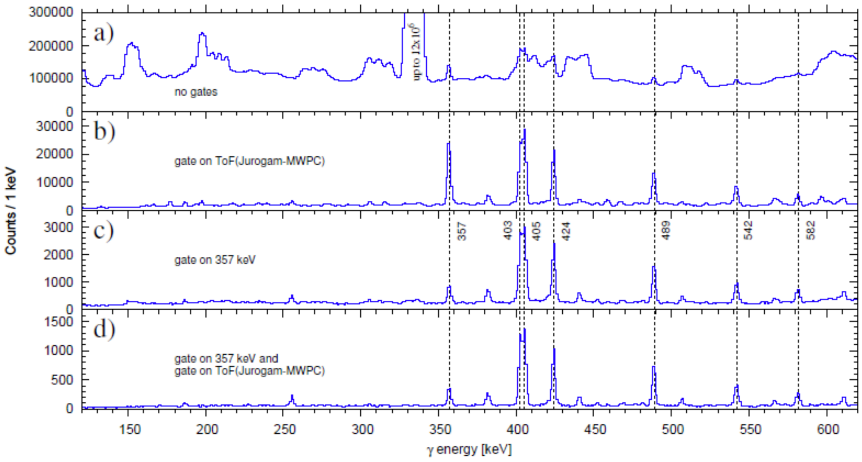


Figure 10: Prompt γ spectra at the target position from the reaction ^{150}SmF(^{40}Ar,4n)^{186}Hg. Most intense transition energies of ^{186}Hg are shown with vertical lines The panel a) shows singles γ spectrum while the panel b) shows singles spectrum of the events following the event in a MWPC of RITU at a time gate. Spectra in coincidence with 357 keV γ transition (mainly 6+ -> 4+) are shown with d) and without c) requiring MWPC coincidence.

One example of a test reaction (that has been used for the commissioning of the RMS at Legnaro), is ^{64}Ni(^{64}Ni,3-4n) fusion reaction to produce ^{124,125}Ba that allows single gamma identification at the target and at the focal plane to evaluate the transmission of the spectrometer.

6 Diagnostic box commissioning

The diagnostic box was first tested with beam in spring 2022. Two independent experiments were performed. The first test was focused on the study of the performance of the SED detector with the magnet (SIRIUS configuration) and the second test was focus on the study of the performance of the detectors for the LEB configuration. In the latter experiment, the performance required in the “Cahier de Charge” was successfully achieved. It was proven that the time and energy resolution of the systems was sufficient for the separation of the beam-like products (charge states primary beam among other) and the residues. The coupling between NUMEXO2 (DSSD) and GET (SED) electronics was achieved successfully as well, allowing to correlate the implantation signal with the position on the SED detector. The online analysis program was partially tested. During the experiment, there was no alpha emitter produced, therefore it was not possible to test the implantation-decay correlations.

The second in-beam test of the diagnostic box was performed with SIRIUS at the IRRSUD/GANIL in June 2023 with a ^{238}U beam below 1 MeV/u. A time-of-flight resolution between the SED and the DSSD of

2 ns (FWHM) was obtained which will able to separate the recoils from the target like fragments as shown in figure 11. There is still room for improvement and further off-line test will be performed with a ^{252}Cf source.

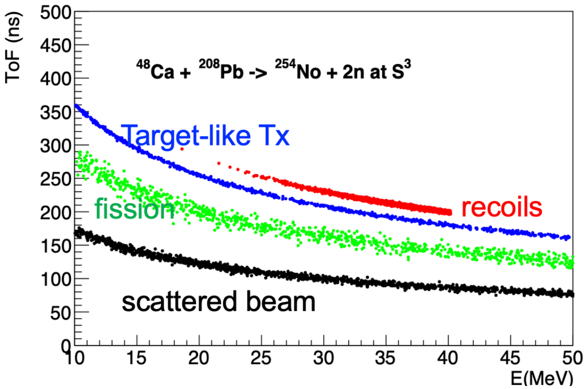


Figure 11: Simulated energy versus time-of-flight plot for ^{48}Ca + ^{208}Pb reaction with 2ns resolution.

During that beam time, a series of pepper-pot masks was used and the trajectory reconstruction between the DSSD and the SED was also successfully tested.

In the case of LEB type experiments at S^3, the diagnostic box will serve as a first identification device for the settings of the spectrometer. The setup cannot be used to identify the most exotic channels, but the settings of the spectrometer will be validated through the identification of stronger produced and transmitted reaction channels. It is noted, that for the LEB type experiments, the spectrometer will be set on converging mode.

7 SIRIUS status and commissioning

7.1 Off-line commissioning

SIRIUS has been installed and tested off-beam at GANIL since 2022. Such Source commissioning will already allow a qualification of most of the components of the setup like:

- Optimization of the filter parameters for the new detectors,
- Measurement of the energy resolutions with the new detectors,
- DSSD automatic gain switching: High gain (alpha, electron) resolution ≈ 20.9 keV FWHM, Low gain (implantation, fission) resolution ≈ 1% FWHM,
- Timing & synchronization tests,
- Evaluation of the Time-of-flight resolution with a ^{252}Cf source,
- Test of the DSSD/Germanium correlations with a ^{241}Am source.

Since September 2023, the diagnostic box and SIRIUS have been installed at the focal plane of S^3 (see figure 12) to validate their integration and for further optimizations (resolution, timing, firmware and pileup treatment). The final tests of the tunnel detectors and the merging of data from the EXOGAM clovers with the Silicon NUMEXO2 data have still to be done. The installation of the veto needs also to be checked.

In April 2024, SIRIUS will move to the cave 51 (adjacent to the spectrometer cave 48) to leave room for the installation of the LEB.

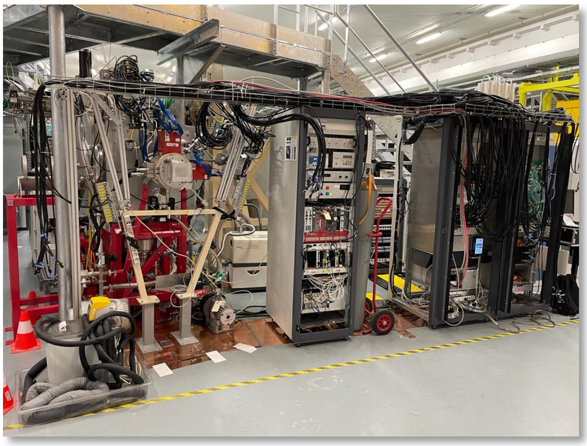


Figure 12: The diagnostic box and SIRIUS setups at the focal plane of S^3.

7.2 On-line commissioning

The in-beam commissioning test of the SIRIUS DSSD was done together with the diagnostic box at the IRRSUD/GANIL (see section 6). The full integration of all detectors/electronics has shown that in less than one week, the full setup can be dismounted and installed. The acquisition was stable during all the test period and has been validated up to 1kHz data rate.

It was also foreseen to test the full integration of all detectors in 2024 in a real decay experiment with FULIS/LISE. An experiment has been submitted to the GANIL PAC to study the nuclear structure of ^{217}Pa. This experiment that would allow to commission SIRIUS further on a long run with realistic conditions has unfortunately been rejected… The alpha-recoil correlations will have to be investigated online during the in-beam commissioning at S^3 in 2025.

The expected performances are:

- All Silicon detectors available (4 tunnels, 1 DSSD, 1 Veto),
- Acquisition stable and resilient,
- Merging of data from the tracker and the EXOGAM clovers with the Silicon NUMEXO2 data operational,
- Alpha energy resolution below 20 keV FWHM,
- Electron energy resolution below 15 keV FWHM,
- Time of flight resolution between 1-2 ns FWHM,
- Treatment of the gain switch capability on the DSSD available.

8 LEB status and commissioning

The installation of the S^3-LEB setup in the intended test configuration at LPC has been accomplished at the end of 2021. The setup includes the gas cell with a purified-gas injection line and baking regulator, the RFQ chain, the temporary transfer line to PILGRIM, and PILGRIM. The installation at LPC of the laser safety features and of the laser system required to perform broadband and narrowband laser spectroscopy has been accomplished at in 2022.

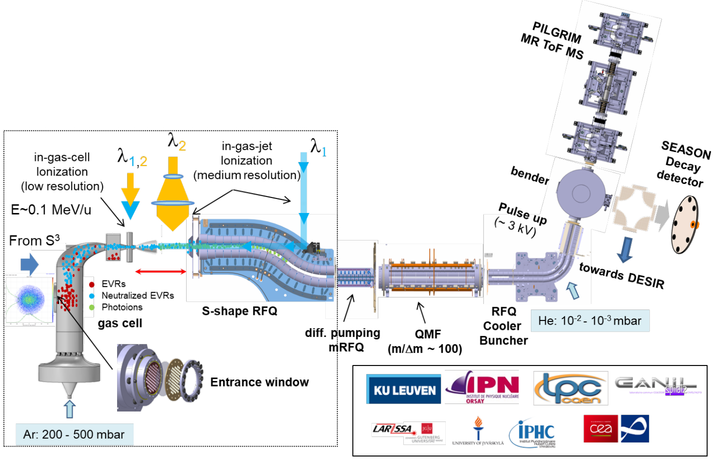


Figure 13: Schematics of the LEB configuration

8.1 Off line Commissioning

The planning of the years 2022-2023 was dedicated to finalize the off-line commissioning of the setup at LPC and the completion of the S^3 interface/installation studies. Here we report the main 2022-2023 landmarks:

- Validation of vacuum system with respect to gas-cell operation and pumping capacity,
- Laser ionization and spectroscopy of stable atoms of erbium in the gas cell, using broadband lasers,
- Laser ionization and spectroscopy of erbium atoms in the gas jet, using broadband and narrowband lasers (see figure 14),
- Proof of the required 200-300 MHz spectral resolution in the gas-jet laser spectroscopy, with a high Mach number at the nozzle,

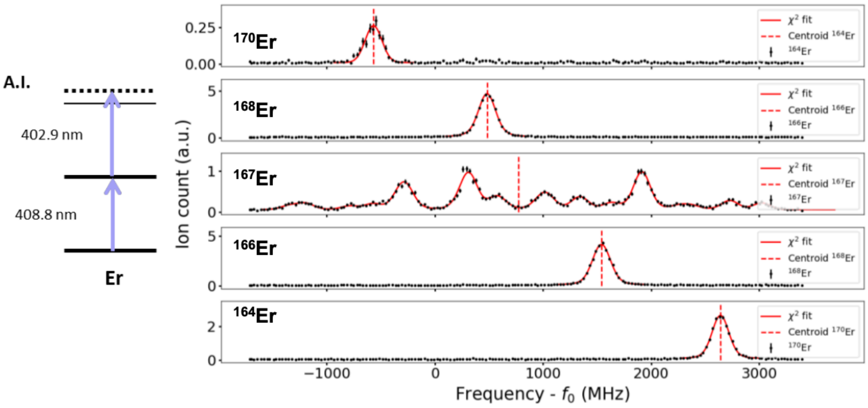


Figure 14: In gas jet laser spectroscopy of stable erbium isotopes.

- Bunching of laser ions (E = 13(1) ev and ΔT_{tof} = 179(8) ns), transport to PILGRIM and trapping,
- Proof of principle of mass resolving power with laser ions on the order of 10^5 and mass accuracy on the order of low 10^{-7},
- Proof of principle of laser scans using detection of mass-separated Er ions after PILGRIM,
- Proof of principle of removing contaminants with PILGRIM at low number of revolutions,
- An excellent global transport efficiency on the order of 70% from the first RFQ until the end of PILGRIM (S-RFQ + miniRFQ: $\epsilon \sim$ 95(5)%, QMF: $\epsilon \sim$ 95(5)%, RFQ-CB: $\epsilon\text{bunched} \sim$ 95(5)%, RFQ-CB – PILGRIM: $\epsilon >$ 80%).

In parallel, some developments have been performed in the GISELE laboratory at GANIL:

- Development of laser spectrometry methods with system of different linewidths
  - New injection-locked Ti:sa cavity in collaboration with JGU Mainz
  - New continuous wave Ti:sa laser in collaboration with Uni. Nagoya
- Laser scheme development (Er, Sn, Pd) with the Atomic Beam Unit (ABU)

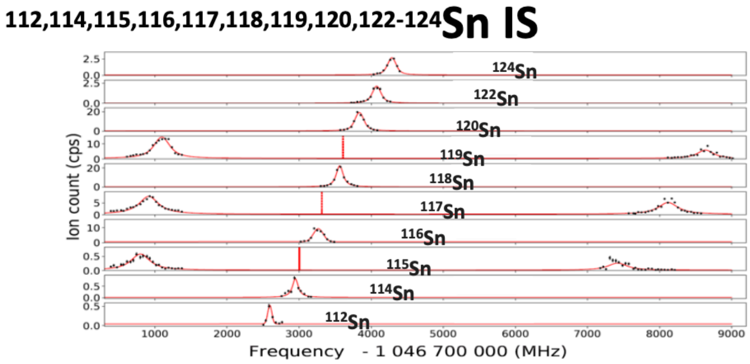


Figure 15: Isotope shifts of stable thin isotopes measured at GISELE with the ABU.

In January-February 2024, an EPICS control system and EPICS-compatible FASTER communication for PILGRIM will be implemented together with new cables C1SH to comply with SPIRAL2 regulation.

In March 2024, the off-line commissioning at LPC will be complete and the setup will be dismantled and transported to the S^3 cave for installation at the focal plane. This process is complex with a lot a lot of interfaces (decay delay line, laser beam transport, laser room, …) and has to be done prior the on-line commissioning of the spectrometer.

The program of tests for the next years will be shared between proof-of-principle measurements and technical stops for a series of upgrades and tests.
The planning of proof-of-principle measurements will be aimed at the following objectives:

- Steady state operation of the new diode-pumped continuous-wave Ti:sa acting as seed laser for the narrowband cavity,
- The in-gas jet laser spectroscopy of isotopes required for Day1 experiments and test of another laser scheme for Er, allowing a larger isotope shift (already validated at GISELE Lab),
- Improvement of the gas jet flow to reach Mach 8,
- A test of the efficiency and extraction time of the gas cell either using a recoil ^{223}Ra source or an in-gas-cell alkali-ion source,
- Validation with respect to resistance and leak rate of the 5 µm and 3 µm Ti foils for the entrance windows and the 1-3 µm Mylar windows, using an off-line test bench constructed in 2022,
- A series of systematic mass measurements using the PILGRIM mass spectrometer.

Following the accomplishment of these objectives, the S^3-LEB setup will be ready for on line commissioning.

8.2 On line Commissioning

The on-line commissioning of S^3LEB will be performed using a beam of ^{152}Er produced in the reaction ^{116}Sn(^{40}Ar – 180 MeV, 4n)^{152}Er in convergent mode.

With an estimated production rate of ^{152}Er > 10^4/s at the S^3 final focal plane, this case would allow a successful experiment to be performed even with a global efficiency of the setup ≈ 0.01%.

A schematic planning of the commissioning experiment would be:

- Delivery of ^{152}Er beam and contaminants to the gas cell. Optimization of tuning with the diagnostic box.
- Study of beam resulting from the gas cell without lasers and without any voltage on the ion collector (non-neutralized beam). Mass analysis of the beam using the QMF and PILGRIM. Ions are counted on MCPs and MagneToF detectors.
- Optimization of the collector voltage for suppressing non-neutralized beam. Repetition of mass analysis for observation of collector effect.
- In-gas-cell laser ionization and spectroscopy of ^{152}Er using broadband lasers, with detection after PILGRIM on the MagneToF detector.
- In-gas-jet laser ionization and spectroscopy of ^{152}Er using narrowband laser.
- Optimization of ^{152}Er injection and focusing in the gas cell using S^3 optics, in order to maximize the ^{152}Er ion rate obtained in the gas jet. Comparison to diagnostic box result.
- Repetition of measurements after optimization.
- Repetition of laser spectroscopy measurements using Si detectors and alpha selectivity.
- Mass measurements of Er isotopes and contaminants available in the beam cocktail using PILGRIM.

In-gas-jet laser ionization of other isotopes available in the beam cocktail, without changing production and S^3 settings.

<u>Required performance of S^3-LEB for day 1 campaign:</u>

- Availability of laser schemes for selected cases,
- Availability of entrance window for selected cases,
- Gas-cell neutralization + extraction efficiency: 10 to 25%,
- Transport efficiency of ion optics until end of PILGRIM: 30% to 80%,
- Mass resolving power of PILGRIM > 100 000,
- SEASON if needed (not mandatory).

9 Commissioning scenario timetable

The commissioning scenario is based on the beam time plan proposed by the GANIL management for the next years (august 2023 hypothesis).

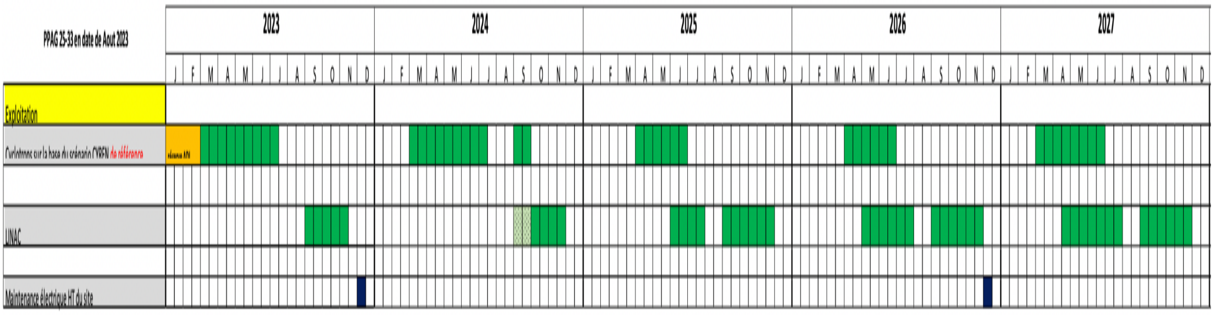
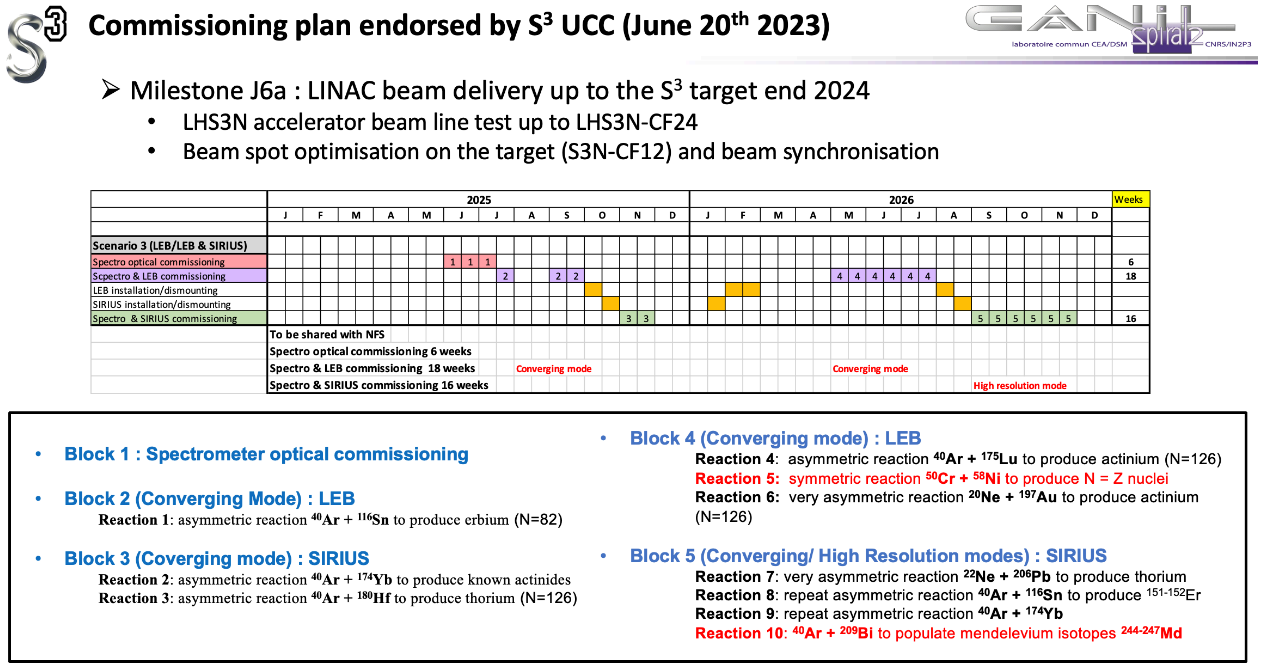


Figure 16: Beam time plan for the next years.

The goal is to gradually increase the beam time with parallel operation of cyclotrons and LINAC.

Given the complexity of S^3 the commissioning and the associated focal plane detection, two years will be necessary to reach adequate performances to start day1 campaigns with experiments selected by the PAC.

Following the discussions that took place within the S^3 User Collaboration Council (S^{3}UCC) in 2022 and 2023, a detailed commissioning scenario for the years 2025-2026 was elaborated and is presented below (figure 17).


Commissioning plan endorsed by S^3 UCC (June 20th 2023)

- Milestone J6a : LINAC beam delivery up to the S^3 target end 2024
  - LHS3N accelerator beam line test up to LHS3N-CF24
  - Beam spot optimisation on the target (S3N-CF12) and beam synchronisation

	2025																								2026																								Weeks
	J		F		M		A		M		J		J		A		S		O		N		D		J		F		M		A		M		J		J		A		S		O		N		D		
Scenario 3 (LEB/LEB & SIRIUS)																																																	
Spectro optical commissioning											1	1	1																																				6
Scpectro & LEB commissioning														2			2	2															4	4	4	4	4	4											18
LEB installation/dismounting																			▨								▨	▨											▨										
SIRIUS installation/dismounting																				▨						▨														▨									
Spectro & SIRIUS commissioning																					3	3																			5	5	5	5	5	5			16
	To be shared with NFS																																																
	Spectro optical commissioning 6 weeks																																																
	Spectro & LEB commissioning 18 weeks														Converging mode																		Converging mode																
	Spectro & SIRIUS commissioning 16 weeks																																								High resolution mode								

- **Block 1 : Spectrometer optical commissioning**
- **Block 2 (Converging Mode) : LEB**
  - **Reaction 1**: asymmetric reaction ^{40}**Ar** + ^{116}**Sn** to produce erbium (N=82)
- **Block 3 (Coverging mode) : SIRIUS**
  - **Reaction 2**: asymmetric reaction ^{40}**Ar** + ^{174}**Yb** to produce known actinides
  - **Reaction 3**: asymmetric reaction ^{40}**Ar** + ^{180}**Hf** to produce thorium (N=126)
- **Block 4 (Converging mode) : LEB**
  - **Reaction 4**: asymmetric reaction ^{40}**Ar +** ^{175}**Lu** to produce actinium (N=126)
  - **Reaction 5:** symmetric reaction ^{50}**Cr +** ^{58}**Ni** to produce N = Z nuclei
  - **Reaction 6:** very asymmetric reaction ^{20}**Ne +** ^{197}**Au** to produce actinium (N=126)
- **Block 5 (Converging/ High Resolution modes) : SIRIUS**
  - **Reaction 7**: very asymmetric reaction ^{22}**Ne +** ^{206}**Pb** to produce thorium
  - **Reaction 8**: repeat asymmetric reaction ^{40}**Ar +** ^{116}**Sn** to produce $^{151-152}$Er
  - **Reaction 9**: repeat asymmetric reaction ^{40}**Ar +** ^{174}**Yb**
  - **Reaction 10**: ^{40}**Ar +** ^{209}**Bi** to populate mendelevium isotopes $^{244-247}$**Md**

Figure 17: Commissioning plan endorsed by the S^3 UCC.

This scenario is based on the fact that:

- Both optical tunings are tested with a priority to reach the required performances in the Converging Mode (CM) for day1 experiments and to allocate some beam time for the High-Resolution Mode (HRM) tuning. The experience gained in this first HRM tuning will help to optimize this mode for the next beam time campaign,
- Both setups (LEB and SIRIUS) will get appropriate beam time for their commissioning before experiments selected by the PAC,
- Time is given in 2024 prior the beam commissioning phase to debug the complex installation of LEB.

The order of the setup sequence (LEB as the first setup) is motivated by:

- Diagnostic box in LEB mode is a rather simple device well suited to perform basic identification of the nuclei to optimize for the first time the spectrometer transmission and rejection,
- Time needed for the first installation and tests of LEB (and possibly SEASON) at the focal plane. This process is complex with a lot a lot of interfaces (decay delay line, laser beam transport, laser room, …) and has to be done prior the on-line commissioning of the spectrometer. This initial installation phase will enable us to gain experience when we need to change configuration between LEB and SIRIUS,
- The on-line commissioning of LEB is more complex than the one of SIRIUS to assess the overall performances and will require significantly more beam time. Contrary to SIRIUS, the performances will also depend on the reactions and elements to be studied. The experience gained in the first beam run will help to optimize the setup for the next beam period,

- The on-line commissioning of LEB does not require to reach nominal spectrometer performances (transmission as good as possible and a beam intensity in the gas cell up to 10^9pps). Improvement of the spectrometer performance can be done in parallel with the LEB commissioning,
- The on-line commissioning of LEB will be performed using a beam of ^{152}Er produced in the reaction ^{116}Sn(^{40}Ar – 180 MeV, 4n)^{152}Er in convergent mode. With an estimated production rate of ^{152}Er > 10^4/s at the S^3 final focal plane, this case would allow a successful experiment to be performed even with a global efficiency of the setup ≈ 0.01%.

9.1 Block 1: Spectrometer optical commissioning

This phase consists of a progressive tuning of the elements with direct and scattering/stripped beams (see section 4). Some part of the beam time will be also devoted to debug all the functionalities of the spectrometer (CC, diagnostics …).

In the context of the optical commissioning, all diagnostics along the spectrometer are used together with two additional multi-wire X-Y profilers and a dedicated faraday cup at the focal plane.

In addition, a strong alpha source may also be used to calibrate both the momentum achromat and the mass separator as both the magnetic and electric rigidities matched S^3 characteristics:

- E= 5.155 MeV; $B\rho = 0.327$ Tm and $E\rho = 5.15$ MV
- E= 5.486 MeV; $B\rho = 0.337$ Tm and $E\rho = 5.49$ MV
- E= 5.806 MeV; $B\rho = 0.347$ Tm and $E\rho = 5.81$ MV

In this case only the secondary electron emission beam profile monitors (PFE) are sensitive to detect alpha particles which will limit the number of measurements to be performed.

For this phase, we estimated 3/4 sequences of 3-5 days beam time with allocated time in between to analyze the measurements and to be able to modify some software or hardware parts if needed.

9.2 Block 2

- Beam time: 1.5 months in total to share with NFS
- Spectrometer optical mode: Converging Mode (CM)
- Focal plane set-ups: diagnostic box (LEB Mode) + S^3-LEB

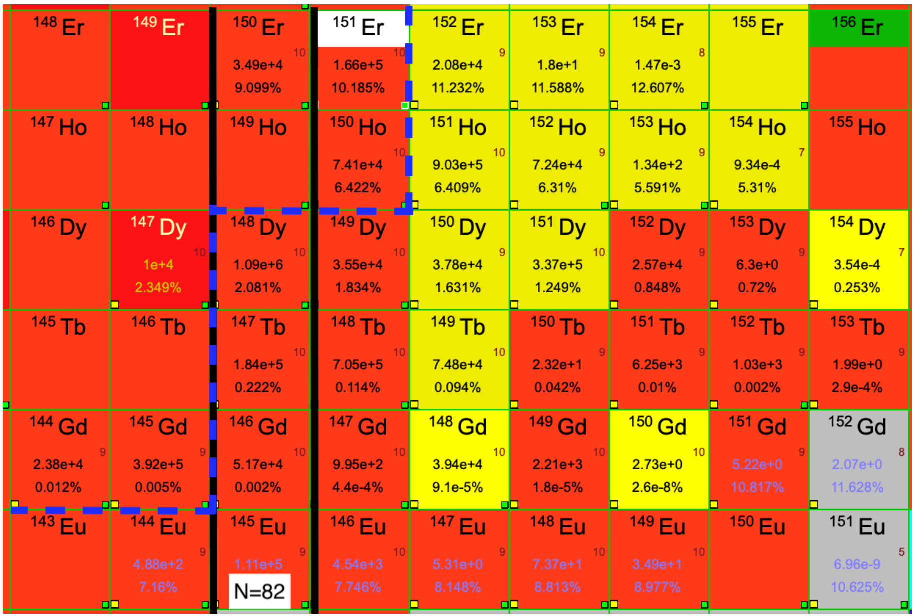
Reaction 1: asymmetric reaction **^{40}Ar + ^{116}Sn** to produce erbium for the commissioning of the spectrometer in CM and the S^3-LEB (for more detail see section 8.2).

Possible data taking by producing the more neutron-deficient isotopes plus neighboring lighter

→ The development of Er RIS at S^3-LEB was performed in order to simultaneously perform novel laser spectroscopy measurements of ^{151,151m}Er. This measurement would bring the laser spectroscopy experimental observations of erbium closer to a complete picture of the nuclear structure development with another step taken closer to the N = 82 shell closure. The ^{151}Er and ^{151m}Er isotopes have a half-life value of 23.5 s and 580 ms, respectively. Considering the necessary ion transportation time of ~ 500 ms in the S^3-LEB gas cell as the major time-consuming process during the IGLIS and mass measurements, both cases are accessible with the current setup.

→ In gas jet laser ionization and spectroscopy of other isotopes available in the cocktail beam. Evolution of the nuclear charge distribution of the n-deficient rare earths (Eu, Gd, Dy and Tb) around N = 82 at the edge of the known data: laser spectroscopy + mass measurements.

The figure below shows the LISE++ simulation for nuclei produced at the focal plane of S^3. The reaction is ^{40}Ar on ^{116}Sn target (0.5 mg/cm2) at an energy of 4.3 MeV/u and an intensity of 2pμA. The production cross-sections for the isotopes that will be studied in these experiments are from the LISEfus model (ex: 19 mb for the 5n channel). The dash blue line shows the limit of known laser spectroscopy data. By changing the beam energy, more neutron deficient ^{148,149}Ho, ^{146}Dy, ^{146}Tb and ^{143}Gd will be also accessible.



^{148}Er	^{149}Er	^{150}Er 10 3.49e+4 9.099%	^{151}Er 10 1.66e+5 10.185%	^{152}Er 9 2.08e+4 11.232%	^{153}Er 9 1.8e+1 11.588%	^{154}Er 8 1.47e-3 12.607%	^{155}Er	^{156}Er
^{147}Ho	^{148}Ho	^{149}Ho	^{150}Ho 10 7.41e+4 6.422%	^{151}Ho 10 9.03e+5 6.409%	^{152}Ho 9 7.24e+4 6.31%	^{153}Ho 9 1.34e+2 5.591%	^{154}Ho 7 9.34e-4 5.31%	^{155}Ho
^{146}Dy	^{147}Dy 10 1e+4 2.349%	^{148}Dy 10 1.09e+6 2.081%	^{149}Dy 10 3.55e+4 1.834%	^{150}Dy 9 3.78e+4 1.631%	^{151}Dy 10 3.37e+5 1.249%	^{152}Dy 9 2.57e+4 0.848%	^{153}Dy 9 6.3e+0 0.72%	^{154}Dy 7 3.54e-4 0.253%
^{145}Tb	^{146}Tb	^{147}Tb 10 1.84e+5 0.222%	^{148}Tb 10 7.05e+5 0.114%	^{149}Tb 10 7.48e+4 0.094%	^{150}Tb 9 2.32e+1 0.042%	^{151}Tb 9 6.25e+3 0.01%	^{152}Tb 9 1.03e+3 0.002%	^{153}Tb 9 1.99e+0 2.9e-4%
^{144}Gd 9 2.38e+4 0.012%	^{145}Gd 9 3.92e+5 0.005%	^{146}Gd 10 5.17e+4 0.002%	^{147}Gd 10 9.95e+2 4.4e-4%	^{148}Gd 10 3.94e+4 9.1e-5%	^{149}Gd 10 2.21e+3 1.8e-5%	^{150}Gd 10 2.73e+0 2.6e-8%	^{151}Gd 9 5.22e+0 10.817%	^{152}Gd 8 2.07e+0 11.628%
^{143}Eu	^{144}Eu 9 4.88e+2 7.16%	^{145}Eu 9 1.11e+5 N=82	^{146}Eu 10 4.54e+3 7.746%	^{147}Eu 9 5.31e+0 8.148%	^{148}Eu 10 7.37e+1 8.813%	^{149}Eu 10 3.49e+1 8.977%	^{150}Eu	^{151}Eu 5 6.96e-9 10.625%

Figure 18: LISE++ rate estimate for ^{40}Ar + ^{116}Sn reaction.

9.3 Block 3

- ○ Beam time: 1 months in total to share with NFS
- ○ Spectrometer mode: Converging Mode (CM)
- ○ Focal plane set-ups: diagnostic box + S^3-SIRIUS

Reaction 2: asymmetric reaction **^{40}Ar + ^{174}Yb** to produce known actinides with various alpha lines. This reaction is the ideal case to test the performance of S^3-SIRIUS with different known isomeric states within µs range. Excitation functions can be performed to populate 2-3n channels (^{211}Ra and ^{212}Ra - with isomers of ~ 9 µs) and 6-7n channels with a longer isomer in ^{207}Ra of 55 ms.

The figure 19 shows the Log_2 of the time difference between the detection of a recoil and its subsequent alpha decay as a function of the energy of the alpha particle, measured at the focal plane of SHELS.

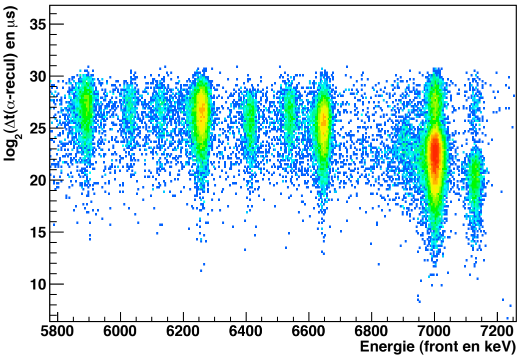


Figure 19: Log$_2$ the time difference between the detection of a recoil and its subsequent alpha decay as a function of the energy of the alpha particle in ^{40}Ar + ^{174}Yb reaction.

Reaction 3: asymmetric reaction **^{40}Ar + ^{180}Hf -> ^{220}Th (CN)** at 174 MeV. This reaction with cross section greater than 1 μb results in a complex decay spectrum which is a consequence of a large number of different evaporation channels (3n, 4n, α3n, α4n and α-α4n) with many α-active daughter nuclei in a subsequent α-decay cascades (α energies up to 10 MeV). In addition, the transitions exhibit a large difference in lifetimes (200ns to 2μs).

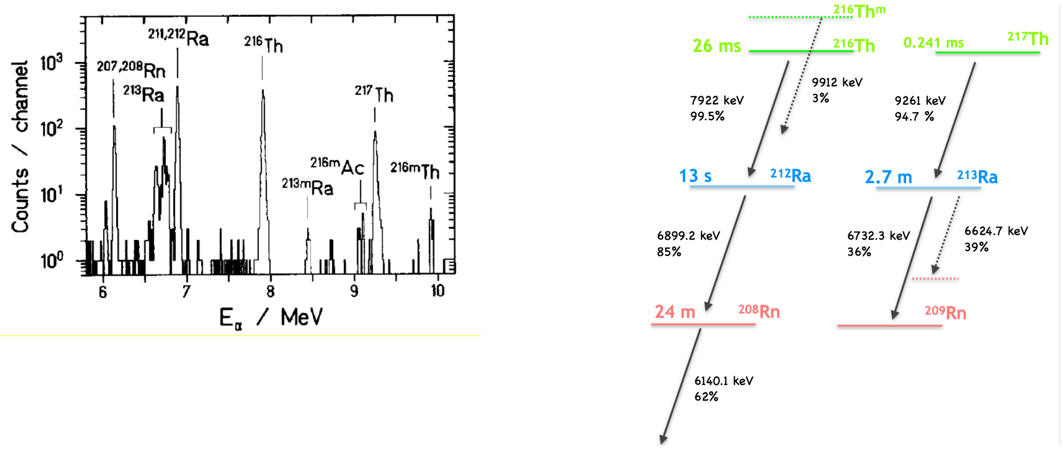


Figure 20: (Right) α spectrum of evaporation residues produced in the reaction ^{40}Ar + ^{180}Hf at 174 MeV [Zeitschrift fur Physic, A318 (1984) 157-169], (Left) decay pattern.

To produce the various reaction channels, we plan to vary the beam energies which give around 10000 detected recoil-α correlations in two hours beam time with 1pμA beam intensity.

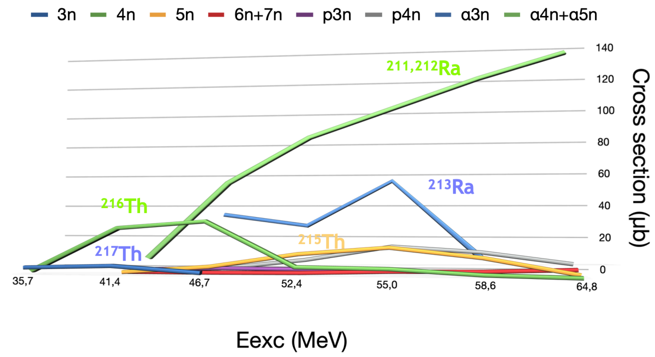


Figure 21: Cross sections of the reaction ^{40}Ar + ^{180}Hf for different compound nucleus excitation energies [Zeitschrift fur Physic, A318 (1984) 157-169], (Left) decay pattern.

9.4 Block 4

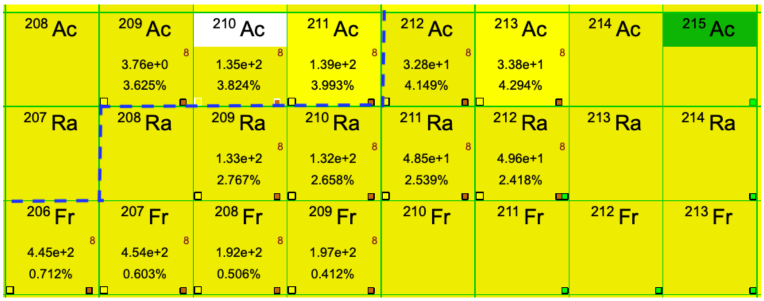
- Beam time: 3 months in total to share with NFS
- Spectrometer mode: Converging Mode (CM)
- Focal plane set-ups: diagnostic box (LEB Mode) + S^3-LEB

Reaction 4: asymmetric reaction **^{40}Ar + ^{175}Lu** to produce actinium to test the capability of S^3-LEB in the heavy mass region.

Possible data taking: follow up of the $^{212\text{-}215}$Ac studies at LISOL [Nat. Commun. 8 (2017)]

→ This reaction is interesting to study the nuclear structure evolution along and away from the N = 126 neutron shell closures in heavy actinide nuclei. This experiment will partially follow up the measurements at the LISOL facility on the $^{212\text{-}215}$Ac isotopes. Unlike the latter, in this experiment we will apply the in-gas jet laser spectroscopy method to study the actinium with a high spectral resolution that will enable a firm spin assignment and will provide their spectroscopic quadrupole moments as well as the dipole moments and mean-squared charge radii. The data will be compared to large-scale shell model calculations and models based on modern energy density functional.

The figure 22 shows LISE++ simulation for nuclei produced at the focal plane of S^3. The reaction is ^{40}Ar on ^{175}Lu target (0.5 mg/cm2) at an energy of 3.75 MeV/u and an intensity of 2pμA. The production cross-sections for the isotopes that will be studied in these experiments have been measured to be 69 mb for the 4n+5n channel and 42 mb for the 2n+3n channel [Zeitsch fier Physik A 318, 157 (1984)].



^{208}Ac	^{209}Ac 3.76e+0 3.625%	^{210}Ac 1.35e+2 3.824%	^{211}Ac 1.39e+2 3.993%	^{212}Ac 3.28e+1 4.149%	^{213}Ac 3.38e+1 4.294%	^{214}Ac	^{215}Ac
^{207}Ra	^{208}Ra	^{209}Ra 1.33e+2 2.767%	^{210}Ra 1.32e+2 2.658%	^{211}Ra 4.85e+1 2.539%	^{212}Ra 4.96e+1 2.418%	^{213}Ra	^{214}Ra
^{206}Fr 4.45e+2 0.712%	^{207}Fr 4.54e+2 0.603%	^{208}Fr 1.92e+2 0.506%	^{209}Fr 1.97e+2 0.412%	^{210}Fr	^{211}Fr	^{212}Fr	^{213}Fr

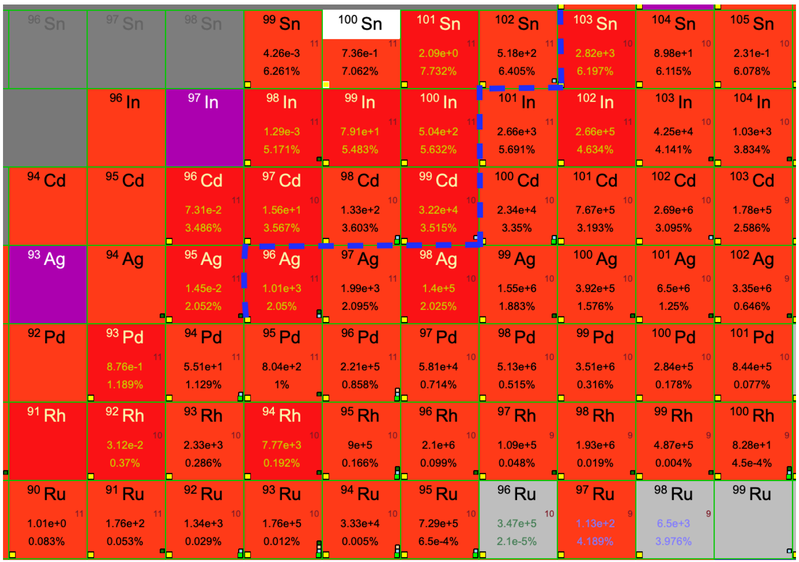
Figure 22: LISE++ rate estimate for ^{40}Ar + ^{175}Lu reaction.

The complementarity reactions ^{178,180}Hf(^{40}Ar,5n)^{213,215}Th (reaction 2 bis) might also be considered to extend those studies to the thorium neutron deficient nuclei (LoI S^3).

Reaction 5: symmetric reaction **^{50}Cr + ^{58}Ni** to produce nuclei approaching N = Z line to test the spectrometer and the S^3-LEB capabilities in this region. Identification of the reaction products will rely on isomeric detection at the focal plane combined the S^3-LEB measurements.

→ Possible data taking: physics around N = Z, laser spectroscopy + mass measurements (several LoI S^3). One milestone of the S^3-LEB physics cases is the exotic odd-even ^{101}Sn and self-conjugate doubly-magic ^{100}Sn isotopes. In the case of ^{101,100}Sn isotopes no laser spectroscopy measurements have been performed, which would provide a vital information of the nuclear structure observables along the neutron-deficient tin isotope chain. The ^{101,100}Sn isotopes have a half-life of 1.7 s and 1.16 s, which as for the erbium case is large enough to perform IGLIS and mass measurements with the current setup.
For the ^{100}Sn case, the ^{50}Cr on ^{58}Ni nuclear reaction will be used with 5.1 MeV/u energy. The estimated cross section for 255 MeV corresponding to the maximum for the (α,4n) reaction channel populating ^{100}Sn is of the order of 4×10^{-5} mb.

The figure 23 shows LISE++ simulation for nuclei produced at the focal plane of S^3. The reaction is ^{50}Cr on ^{58}Ni target (1.2 mg/cm2) at an energy of 5.11 MeV/u and an intensity of 2pμA. The cross-section model used is from LISEfussion (cross section for ^{100}Sn is 1.75×10^{-5} mb in LISE++ as compared to 40 nb measured at GANIL with the CSS2 mass measurement).



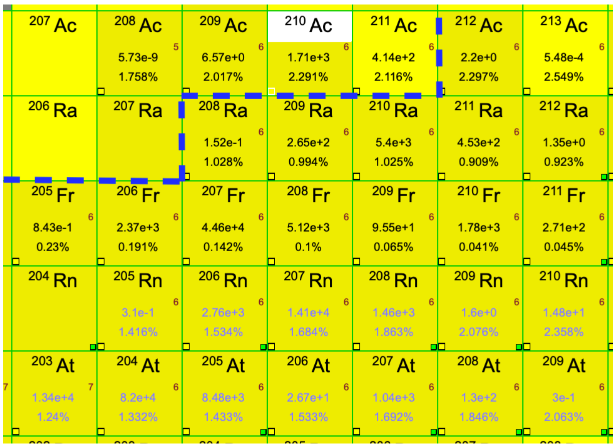
^{96}Sn	^{97}Sn	^{98}Sn	^{99}Sn 11 4.26e-3 6.261%	^{100}Sn 11 7.36e-1 7.062%	^{101}Sn 11 2.09e+0 7.732%	^{102}Sn 11 5.18e+2 6.405%	^{103}Sn 10 2.82e+3 6.197%	^{104}Sn 10 8.98e+1 6.115%	^{105}Sn 10 2.31e-1 6.078%
	^{96}In	^{97}In	^{98}In 11 1.29e-3 5.171%	^{99}In 11 7.91e+1 5.483%	^{100}In 11 5.04e+2 5.632%	^{101}In 11 2.66e+3 5.691%	^{102}In 11 2.66e+5 4.634%	^{103}In 10 4.25e+4 4.141%	^{104}In 10 1.03e+3 3.834%
^{94}Cd	^{95}Cd	^{96}Cd 11 7.31e-2 3.486%	^{97}Cd 10 1.56e+1 3.567%	^{98}Cd 10 1.33e+2 3.603%	^{99}Cd 10 3.22e+4 3.515%	^{100}Cd 10 2.34e+4 3.35%	^{101}Cd 10 7.67e+5 3.193%	^{102}Cd 10 2.69e+6 3.095%	^{103}Cd 9 1.78e+5 2.586%
^{93}Ag	^{94}Ag	^{95}Ag 11 1.45e-2 2.052%	^{96}Ag 11 1.01e+3 2.05%	^{97}Ag 11 1.99e+3 2.095%	^{98}Ag 10 1.4e+5 2.025%	^{99}Ag 10 1.55e+6 1.883%	^{100}Ag 10 3.92e+5 1.576%	^{101}Ag 10 6.5e+6 1.25%	^{102}Ag 9 3.35e+6 0.646%
^{92}Pd	^{93}Pd 11 8.76e-1 1.189%	^{94}Pd 11 5.51e+1 1.129%	^{95}Pd 11 8.04e+2 1%	^{96}Pd 11 2.21e+5 0.858%	^{97}Pd 10 5.81e+4 0.714%	^{98}Pd 10 5.13e+6 0.515%	^{99}Pd 10 3.51e+6 0.316%	^{100}Pd 10 2.84e+5 0.178%	^{101}Pd 10 8.44e+5 0.077%
^{91}Rh	^{92}Rh 10 3.12e-2 0.37%	^{93}Rh 10 2.33e+3 0.286%	^{94}Rh 10 7.77e+3 0.192%	^{95}Rh 10 9e+5 0.166%	^{96}Rh 10 2.1e+6 0.099%	^{97}Rh 9 1.09e+5 0.048%	^{98}Rh 9 1.93e+6 0.019%	^{99}Rh 9 4.87e+5 0.004%	^{100}Rh 9 8.28e+1 4.5e-4%
^{90}Ru 11 1.01e+0 0.083%	^{91}Ru 11 1.76e+2 0.053%	^{92}Ru 10 1.34e+3 0.029%	^{93}Ru 10 1.76e+5 0.012%	^{94}Ru 10 3.33e+4 0.005%	^{95}Ru 10 7.29e+5 6.5e-4%	^{96}Ru 10 3.47e+5 2.1e-5%	^{97}Ru 9 1.13e+2 4.189%	^{98}Ru 9 6.5e+3 3.976%	^{99}Ru

Figure 23: LISE++ rate estimate for ^{50}Cr + ^{58}Ni reaction.

Reaction 6 (option): very asymmetric reaction **^{20}Ne + ^{197}Au** to produce actinium to test the transmission of the slow reaction products and to test the capability of S^3-LEB in the heavy mass region with the use of thin entrance window and low-pressure working regime.

→ This reaction can serve as a test to compare the performance of the spectrometer coupled to S^3-LEB for very low energy reaction products (around 0.05 MeV/u) requiring the use of a thin entrance gas cell window and a working function at low pressure.
A direct comparison can be made with the ^{40}Ar + ^{175}Lu reaction that will produce nuclei in the same mass region.

The figure 24 shows LISE++ simulation for nuclei produced at the focal plane of S^3. The reaction is ^{20}Ne on ^{197}Au target (0.25 mg/cm2) at an energy of 7 MeV/u and an intensity of 2pμA. The production cross-sections for the isotopes that will be studied in these experiments are from the LISEfus model (ex: 4 mb for ^{210}Ac as compared to 250mb reported in Nuclear Physics A568 (1994) 1323-332).



^{207}Ac	^{208}Ac 5 5.73e-9 1.758%	^{209}Ac 6 6.57e+0 2.017%	^{210}Ac 6 1.71e+3 2.291%	^{211}Ac 6 4.14e+2 2.116%	^{212}Ac 6 2.2e+0 2.297%	^{213}Ac 6 5.48e-4 2.549%
^{206}Ra	^{207}Ra	^{208}Ra 6 1.52e-1 1.028%	^{209}Ra 6 2.65e+2 0.994%	^{210}Ra 6 5.4e+3 1.025%	^{211}Ra 6 4.53e+2 0.909%	^{212}Ra 6 1.35e+0 0.923%
^{205}Fr 6 8.43e-1 0.23%	^{206}Fr 6 2.37e+3 0.191%	^{207}Fr 6 4.46e+4 0.142%	^{208}Fr 6 5.12e+3 0.1%	^{209}Fr 6 9.55e+1 0.065%	^{210}Fr 6 1.78e+3 0.041%	^{211}Fr 6 2.71e+2 0.045%
^{204}Rn	^{205}Rn 6 3.1e-1 1.416%	^{206}Rn 6 2.76e+3 1.534%	^{207}Rn 6 1.41e+4 1.684%	^{208}Rn 6 1.46e+3 1.863%	^{209}Rn 6 1.6e+0 2.076%	^{210}Rn 6 1.48e+1 2.358%
^{203}At 7 1.34e+4 1.24%	^{204}At 6 8.2e+4 1.332%	^{205}At 6 8.48e+3 1.433%	^{206}At 6 2.67e+1 1.533%	^{207}At 6 1.04e+3 1.692%	^{208}At 6 1.3e+2 1.846%	^{209}At 6 3e-1 2.063%

Figure 24: LISE++ rate estimate for ^{20}Ne + ^{197}Au reaction.

9.5 Block 5

- Beam time: 3 months in total to share with NFS
- Spectrometer optical mode: Converging Mode (CM)
- Focal plane set-ups: diagnostic box) + S^3-SIRIUS

Reaction 7: very asymmetric reaction **^{22}Ne + ^{206}Pb** at 119 MeV [Eur. Phys. J. A (2014) 50: 132] to produce thorium isotopes with short half-life (200 ns – 2 μs) to test the implantation in the DSSD for slow reaction products and the capability to manage "pile-up".
The ideal case is to study the $^{220-221}$Th decay chains with half-life transitions around 200 ns and 2 μs. The α-decay chains of interest are shown in figure 25.

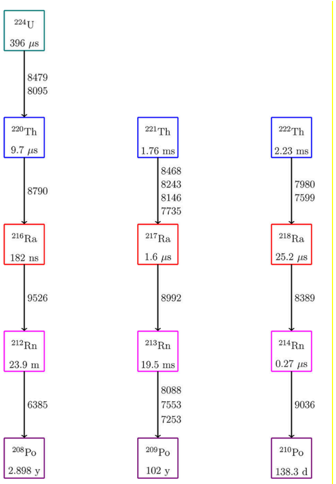


Figure 25: Diagram showing the α-decay chains of interest.

The use of a reaction that leads to spontaneous fission would also allow us to check the gain switching mechanism of the Si-detector electronics on line. As an option, we can also plan to do **^{40}Ar + ^{208}Pb** reaction to produce ^{246}Fm in the 2n channel (~ 25 nb) that has a ~ 7% fission branch.

- Spectrometer mode: High Resolution Mode (HRM)

Reaction 8: repeat asymmetric reaction **^{40}Ar + ^{116}Sn** to produce $^{151-152}$Er (nuclei decaying only by one α) leading to unambiguous identification at the focal plane (Identification matrix: $E_{recoi\ l}$- $E_{\alpha 1}$ and Position X - $E_{\alpha 1}$) to optimize the mass resolution.

Reaction 9: repeat asymmetric reaction **^{40}Ar + ^{174}Yb.** This reaction is the ideal case to demonstrate the performances of S^3 with mass separation of nuclei decaying with similar α energies (ex: doublet in Ra isotopes).

Reaction 10: reactions in the nbarn to sub-nbarn regime **^{40}Ar + ^{209}Bi** to populate mendelevium isotopes **$^{247-244}$Md** to test the high-resolution mode and mass (A) determination capabilities for these nuclides exhibiting competing decay modes ($\propto$, β, SF), isomers and an unsolved mass assignment controversy. *Possible data taking/discovery potential $^{244-455}$Md A-assignment. Literature: J. L. Pore et al., PRL 124, 252502 (2020); J. Khuyagbaatar et al., PRL 125, 142504 (2020); F. P. Heßberger et al., PRL 126, 182501 (2021).*

→ *^{245}Md was first observed in 1996 at the velocity filter SHIP of GSI, Darmstadt, Germany [V. Ninov et al., Z. Phys. A 356, 11 (1996)], and ^{244}Md was reported recently for the first time in 2020, almost* *contemporaneously detected in experiments at the Berkeley Gas-filled separator (BGS) of LBNL, Berkley, CA, U.S.A. [J. L. Pore et al., PRL 124, 252502 (2020)] and the gas-filled separator TASCA of GSI [J. Khuyagbaatar et al., PRL 125, 142504 (2020)]. These two independent studies presented conflicting assignments, initiating an intense and yet unresolved debate.*

For the first one [J. L. Pore et al., PRL 124, 252502 (2020)] the decay properties of the claimed isotope were measurement at the BGS focal plane by means of a retractable 32×32 double-sided silicon strip detector (DSSD), while a mass assignment was obtained in a separate measurement using the FIONA set-up, a mass spectrometer consisting of a gas- stopping cell, re-acceleration, a trochoid spectrometer and particle detection. Pore et al. reported for the reaction ^{40}Ar+^{209}Bi at a beam energy of 220 MeV six decay chains which were all assigned to the α-decay chain ^{244}Md→^{240}Es→^{236}Bk. The proposed scenario included two α transitions for ^{244}Md, with α-decay energies and half-lives of E=8663(23) keV and $T_{1/2}=0.4^{+0.4}_{-0.1}$ s, and E=8306(223) keV and α 1/20.1α $T_{1/2}\approx 6$ s, respectively, suggesting the longer-lived state to be an isomer.

The second measurement was performed at the gas-filled separator TASCA of GSI, Darmstadt, Germany [J. Khuyagbaatar et al., PRL 125, 142504 (2020)] employing the reaction ^{50}Ti+^{197}Au at two excitation energies E^* of 26.2 MeV and 32.7 MeV, expected to lead to the 2- and 3-neutron evaporation channels ^{245,244}Md, respectively. They observed three decay chains at the lower beam energy and attributed them to the 2n-evaporation channel ^{245}Md which agrees with literature data [V. Ninov et al., Z. Phys. A 356, 11 (1996)]. At the higher beam energy, a total of ten α-decay sequences were extracted. Three of them were again in agreement with an assignment to ^{245}Md while the seven others showed similar decay times as the ones assigned to ^{245}Md but higher α-decay energies of 8.73 MeV to 8.86 MeV. With $T_{1/2}=0.3^{+0.1}_{-0.09}$ s they were attributed to the new isotope ^{244}Md.

In a comment to these contradicting findings, Heßberger et al. discussed the decay properties of both experiments in the context of the 25 years old literature values [F. P. Heßberger et al., PRL 126, 182501 (2021)] and proposed a re-assignment of the BGS decay chains to ^{245}Md putting the A assignment by FIONA in doubt.

It is interesting to point out that for ^{247}M and ^{246}Md, the α decay properties measured at the BGS correspond to what is known from literature, while those of ^{244}Md and ^{245}Md are very different from the data measured at GSI. So, the situation is quite puzzling and calls for more statistics, but definitely, instead of the two-step procedure as applied in the case of FIONA, for a simultaneous measurement of A, E_α and decay times it would be possibly with S^3 in high-resolution mode.

In the figure 26 a comparison of the experimental cross sections with HIVAP [W. Reisdorf, Z. Phys. A 300, 227 (1981)] calculations provided by Heßberger et al. [F. P. Heßberger et al., PRL 126, 182501 (2021)] summarizes the present knowledge for $^{244-247}$Md, where the literature references are [1: J. L. Pore et al., PRL 124, 252502 (2020)], [4: F. P. Heßberger et al., EPJ A 26, 233 (2005)] and [7: M. Wang et al., Chin. Phys. C 41, 030003 (2016)]:

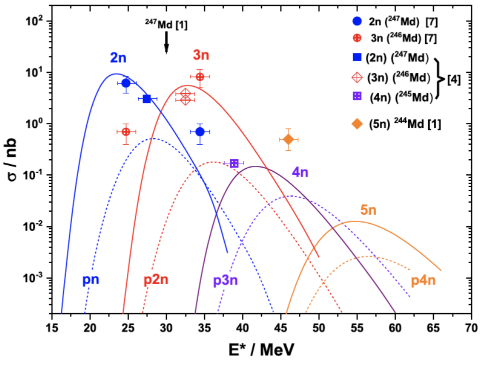
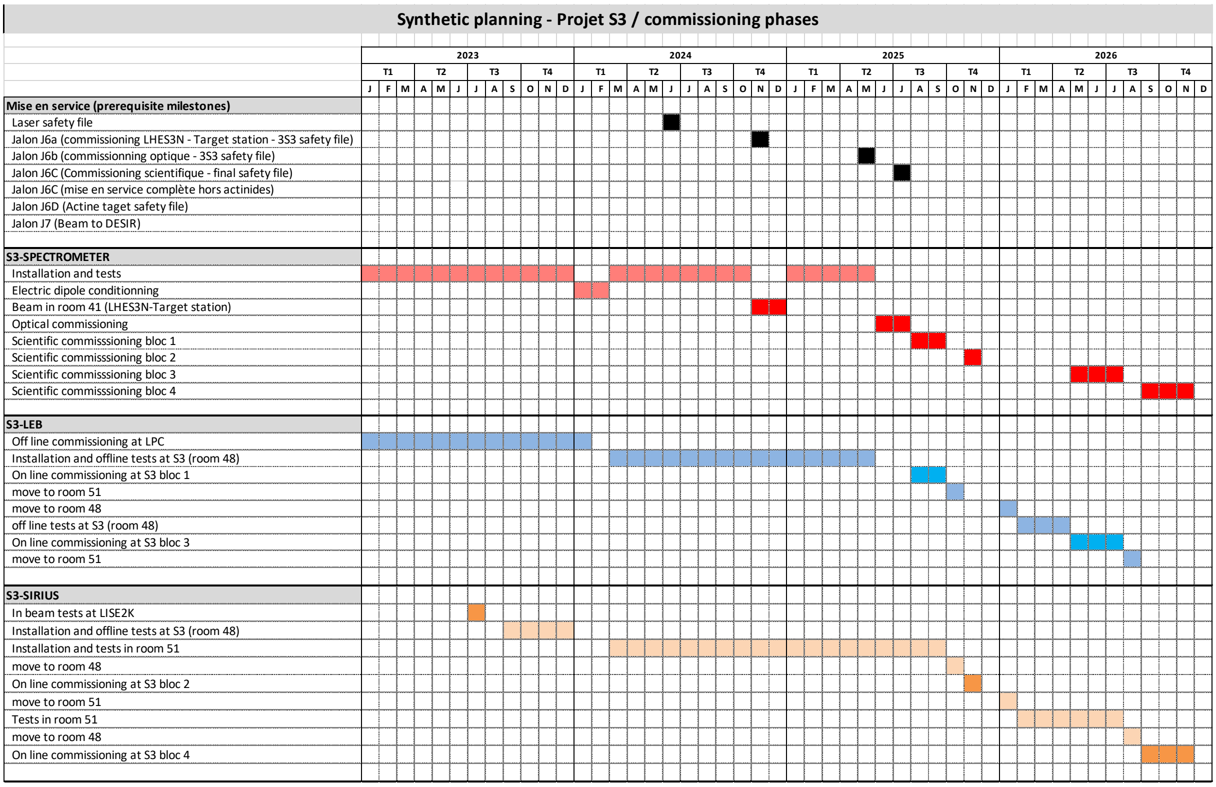


Figure 26: Comparison of the experimental cross sections with HIVAP.

The count rate estimates are (target 400 µg/cm2, 2 pµA, transmission 20%):

- *^{247}Md and ^{246}Md -> measured cross sections 10 nb: 2500 nuclei implanted/day*
- *^{245}Md -> according to the cross section given in PRL 126 (2021)> 0.1 nb: 25 nuclei implanted/day*
- *^{244}Md -> cross section > 0.01 nb: 2.5 nuclei implanted/day*

10 Projected planning of the commissioning phases



Synthetic planning - Projet S3 / commissioning phases

	2023												2024												2025												2026											
	T1			T2			T3			T4			T1			T2			T3			T4			T1			T2			T3			T4			T1			T2			T3			T4		
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Mise en service (prerequisite milestones)																																																
Laser safety file																		■																														
Jalon J6a (commissioning LHES3N - Target station - 3S3 safety file)																						■																										
Jalon J6b (commissionning optique - 3S3 safety file)																													■																			
Jalon J6C (Commissioning scientifique - final safety file)																															■																	
Jalon J6C (mise en service complète hors actinides)																																																
Jalon J6D (Actine taget safety file)																																																
Jalon J7 (Beam to DESIR)																																																
S3-SPECTROMETER																																																
Installation and tests	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥			🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥			🟥	🟥	🟥	🟥	🟥																			
Electric dipole conditionning													🟥	🟥																																		
Beam in room 41 (LHES3N-Target station)																						🟥	🟥																									
Optical commissioning																														🟥	🟥																	
Scientific commisssioning bloc 1																																🟥	🟥															
Scientific commisssioning bloc 2																																			🟥													
Scientific commisssioning bloc 3																																									🟥	🟥	🟥					
Scientific commisssioning bloc 4																																													🟥	🟥	🟥	
S3-LEB																																																
Off line commissioning at LPC	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦																																			
Installation and offline tests at S3 (room 48)															🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦																			
On line commissioning at S3 bloc 1																																🟦	🟦															
move to room 51																																		🟦														
move to room 48																																					🟦											
off line tests at S3 (room 48)																																						🟦	🟦	🟦								
On line commissioning at S3 bloc 3																																									🟦	🟦	🟦					
move to room 51																																												🟦				
S3-SIRIUS																																																
In beam tests at LISE2K							🟧																																									
Installation and offline tests at S3 (room 48)									🟧	🟧	🟧	🟧																																				
Installation and tests in room 51															🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧															
move to room 48																																		🟧														
On line commissioning at S3 bloc 2																																			🟧													
move to room 51																																					🟧											
Tests in room 51																																						🟧	🟧	🟧	🟧	🟧	🟧					
move to room 48																																												🟧				
On line commissioning at S3 bloc 4																																													🟧	🟧	🟧	

11 Collaboration/team

11.1 External experts

Before starting to send beam in the spectrometer a review will be organized with external experts (ANL, MSU, JYFL and TRIUMF) to assess the commissioning plan proposed by the project and the collaboration. The members of this committee have a long expertise in spectrometer like FMA at ANL, RITU/MARA at JYFL and EMMA at TRIUMF. We will also invite Daniel Bazin (MSU) who participated as an international expert to the S^3 project review organized in 2018 by the CEA/Irfu and the CNRS/IN2P3.

Proposed expert committee:

- Daniel Bazin (MSU) TBC
- Juha Uusitalo (JYFL) TBC
- Darek Seweriniak (ANL) TBC
- Barry Davids (TRIUMF) TBC

The member of this committee may also be solicited during the commissioning phases.

11.2 Beam optic team

The beam optic team in charge of the tuning of the S^3 spectrometer during the commissioning is composed accelerator/spectrometer physicists from the “Physique des accélérateurs” group at GANIL, one research engineer from the “service des accélérateurs” at IPHC, physicists from GANIL and CEA/Irfu and dedicated postdocs.

Proposed beam optic team:

- Bertrand Jacquot (GANIL)
- Omar Kamalou (GANIL) / part-time
- Mathieu Lalande (GANIL)
- Emil Trykov (IPHC)
- Antoine Drouart (CEA/Irfu)
- Hervé Savajols (GANIL)
- Jean Charles Thomas (GANIL) / part-time
- Guillem Tocabens (Irfu posdoc)
- New GANIL postdoc (2025-2027)
- Matt Amthor (Uni. Bucknell) GANIL visiting scientist

It is also of very important to rely on GANIL expert referents (cryogenic, magnets, power supplies, PLC, control/command, diagnostics, …) who have to make themselves available on demand.

The commissioning coordinators for the spectrometer are Bertrand Jacquot /optical commissioning/ and Antoine Drouart (CEA/Irfu)/Hervé Savajols (GANIL) /scientific commissioning/.

11.3 SIRIUS and LEB

- The commissioning coordinators for the diagnostic box are Lucia Caceres (GANIL) and Julien Pancin (GANIL).
- The commissioning coordinators for the SIRIUS commissioning are Julien Piot (GANIL) and Karl Hauschild (IJCLAB).
- The commissioning coordinators of the LEB commissioning are Vladimir Manea (IJCLab) and Nathalie Lecesne (GANIL).

All the scientific collaboration and the project team will be also involved.

12 Day1 preliminary risk analysis

In the following, we have compiled a risk analysis based on our knowledge beginning 2023. Some information might be updated in 2024.

This analysis is based on 7 major risks:
- LINAC beam availabilities
- Target availabilities
- SIRIUS/LEB readiness
- Spectrometer commissioning and qualified performances
- Scientific program feasibility (spectrometer performances)
- Scientific competition
- Scientific impact

12.1.1 LINAC beam availabilities

Beams	**SIRIUS**	**LEB**
LINAC	Heavy ion beam developments ongoing 2022-2024 The recent acceleration of ^{18}O and ^{40}Ar at 7 MeV/u have shown no show stopper for the LINAC tuning	
Beam acceleration Available/need tests (no developments) Required development Not available (Day1)	Very intense: ^{18}O, ^{22}Ne, ^{26}Mg, $^{28-30}$Si, $^{32-36}$S, $^{36-40}$Ar, with intensities > 1pµA Intense ^{40,48}Ca, $^{48-50}$Ti, ^{51}V, ^{54}Cr with beam intensities of 1pµA or more Energies between 4.5-7MeV/A	Very Intense $^{36-40}$Ar, ^{22}Ne ^{24}Mg and ^{18}O; with intensities > 1pµA Intense $^{40-48}$Ca, ^{50}Cr, ^{58}Ni; with beam intensities of 1pµA or more Energies between 3.3-7.9MeV/A
Rare isotope availabilities have to be workout	^{48}Ca not secured ^{50}Ti 1 year operation ^{50}Cr 14000$/g ^{36}S & ^{54}Cr isotopes? SiO/SiO2 isotopic to be investigated	^{48}Ca not secured ^{50}Cr 14000$/g
Comments	The absence of ^{48}Ca modifies the program given in 2018. In particular, the letter of intent on the limits of stability of No isotopes will not be feasible. One letter of intent is partially affected by the ^{48}Ca shortage (Alpha-decay spectroscopy of odd-Z isotopes in fermium region)	The absence of ^{48}Ca modifies marginally the program given in 2018
Risks	Beam unavailability	

12.1.2 Target availabilities

Targets	**SIRIUS**	**LEB**
Target station readiness	In beam test @ GANIL LISE 2K scheduled in July 2023	
Target requirements Available Required development Not available (Day1)	Stables : ^{164}Dy, ^{170}Er, ^{174,176}Yb, ^{180}Hf, ^{181}Ta, ^{182}W, ^{197}Au, ^{204,208}Pb, ^{204,208}PbS, ^{209}Bi, ^{209}Bi$_2$O$_3$, ^{238}U	Stables : ^{118}Sn, ^{50}Cr, ^{58}Ni, ^{46}Ti, ^{175}Lu, ^{178,180}Hf, ^{208}Pb
Comments	• PbS isotopic supply to be investigated • ^{182}W, ^{181}Ta to be investigated with e-gun	• ^{50}Cr to be investigated with e-gun

	• Lanthanides: Know-hows at GSI… under development at GANIL • ^{181}Ta: magnetron sputtering to be developed at GANIL (Approach with LMA Lyon) • ^{238}U: Know-how at GSI, under collaboration with ORANO and possible development in future at GANIL	• Lanthanides: Know-hows at GSI… under development at GANIL
Risks	Target unavailability	

12.1.3 SIRIUS/LEB readiness

Detection Setups	**SIRIUS**	**LEB**
Readiness Ready Need development Difficult	Ready • Radioactive source commissioning (2023) • In beam commissioning at LISE (2024)	Ready • Laser development @ GISESLE • Off-line commissioning at LPC
Setup installation Rather simple Complex Difficult	Rather simple Tested last May moving from G3 to G2. Disconnection, dismounting and moving takes two days. Installation and cabling take a week with the necessary staff available.	Complex To change the configuration of the diagnostic box from SIRIUS to LEB mode will take 4 days. To dismount S^{3}LEB and transport everything into room 51, it should take less than one week. To mount, connect and test S3LEB: one month
Setup on-line commissioning Rather simple Complex Difficult	Rather simple Online commissioning planned for March 2024 on FULIS. Twice 4 UTs of beamtime requested. An experiment has been submitted to the GANIL PAC to study the nuclear structure of ^{217}Pa. This experiment will allow to commission SIRIUS further on a long run with realistic conditions.	Complex Online commissioning is needed to assess the LEB overall performances. Contrary to SIRIUS the performances will also depends on the reactions and elements to be studied.
Comments		The on-line commissioning will be performed using a beam of ^{152}Er produced in the reaction ^{116}Sn(^{40}Ar – 180 MeV, 4n)^{152}Er in convergent mode. With an estimated production rate of ^{152}Er > 10^4/s at the S^3 final focal plane, this case would allow a successful experiment to be performed even with a global efficiency of the setup ≈ 0.01%.
Risks	Scientific program feasibility	

12.1.4 Spectrometer commissioning and qualified performances

Spectrometer commissioning	**SIRIUS**	**LEB**
Optical commissioning	Dedicated diagnostics at the focal plane. SIRIUS and LEB can be partially installed during this phase	

Optical modes	• Optimize the rejection and the transmission for relevant kinematics to reach the required performances in the Converging Mode (CM) for day1 experiments • Test the High-Resolution Mode (HRM) important for the SIRIUS scientific program (*The experience gained in this first HRM tuning will help to optimize this mode for next beam time campaigns). SIRIUS is required for the final stage of the HRM commissioning.*	
Scientific commissioning setups	Diagnostic box (Tracker with magnet) + SIRIUS	Diagnostic box in LEB mode (Tracker without magnet + DSSD + one Germanium) + LEB
Scientific commissioning reactions	VHE-SHE ^{40}Ar+^{116}Sn (High XS) ^{40}Ar+^{174}Yb (High XS) ^{40}Ar + ^{182}W (Low XS) Ne + Pb,Bi,Th,U	VHE & N=Z ^{40}Ar +^{116}Sn-> ^{152}Er
Setup performances to perform the spectrometer commissioning High Medium Low	High • Unique recoil, alpha, electron, gamma, beta, fission efficiencies • Nominal position resolution with the tracker (1,4mm FWHM, important for the HRM commissioning) • Cannot handle high counting rate	Medium • Good recoil, alpha, electron, beta, fission efficiencies • Poor gamma-ray efficiency • Poor position resolution with the tracker (4mm FWHM, no magnet) • N=Z identification without HRM will rely on gamma-rays/isomer decays + LEB measurements (PILGRIM)
Commissioning data taking Scientific impact High Medium Low	• ^{50}Ti+^{208}Pb->^{256}Rf, ^{257}Rf • ^{40}Ar+^{209}Bi --> ^{247}Md • ^{18}O+^{238}U->^{252}Fm • ^{22}Ne+^{238}U -> ^{256}No • ^{26}Mg+^{197}Au->^{217}Pa	• ^{40}Ar + ^{116}Sn -> ^{151}Er and the area around, to test with the same set up as the commissioning with ^{152}Er the capabilities of S^{3}LEB, Physics around N=82, Ho, Dy… laser spectroscopy + mass measurement • ^{40}Ar + ^{175}Lu -> $^{210\text{-}215}$Ac and the area around, to test the capabilities of S^{3}LEB in the heavy mass region, Physics around N=126, laser spectroscopy + mass measurement • ^{50}Cr + ^{58}Ni -> $^{100\text{-}105}$Sn and the area around, to test the capabilities of S^{3}LEB in the N=Z region
Risks	Commissioning feasibility and first data taking impact	

12.1.5 Scientific program feasibility (spectrometer performances)

Spectrometer performance requirements	**SIRIUS**	**LEB**
Optical modes	Converging and High-Resolution Modes	Converging Mode
Rejection Not required Partially required Essential	Essential Rejection higher than 10-^{12} for beam-like transfer products, higher than 10$^{11\text{-}12}$ for direct beam	Partially required Good rejection is required (gas cell can work with 10^{8}pps)
Transmission Not required Partially required Essential	Partially required Higher than 40% for ^{48}Ca type kinematics. Higher than 10% for O/Ne type kinematics	Partially required The higher the better, but some day1 physics cases can accommodate a spectrometer not at 100% of its performances.

		The converging mode has the higher transmission efficiency
Mass resolution Not required Partially required Essential	Partially required Mass resolution around 300 with high-intensity beam on target	Not required Not relevant
Risks	• High rejection not reach after the first commissioning phase • Optimised mass resolution not available after the first commissioning phase	

12.1.6 Scientific competition

Scientific Competition	**SIRIUS**	**LEB**
Topics	VHE-SHE decay spectroscopy	
Competing facilities High Medium Low	Medium • No beam planned in GSI for 2023. • SHIP has deserted the decay spectroscopy field • A program for decay spectroscopy is starting at TASCA with a detector designed to measure electrons independently (ANSWERS) • The SHE factory is running, SHELS+GABRIELA++ as well • RIKEN is focusing on Z=119, but testing its equipment on the other GARISes • ANL has started a program on AGFA for in-beam spectroscopy. Beam intensity is lower than the capabilities of S^3	Medium - MARA-LEB at JYU: 2024-2025, lower intensities - JetRIS at GSI: 2024. ^{251}No already done at high resolution, even so at low statistic - KISS at RIKEN
Risks	Experiments done elsewhere	

12.1.7 Scientific impact

Scientific impact	**SIRIUS**	**LEB**
Topics	Decay and isomer spectroscopy of Transfermiums (N=152), Detailed study of the K isomers in 256Rf, odd Z/N nuclei in the fermium region, reaction mechanism studies	Medium-mass nuclides along the N = Z line from Z = 40 (Zr) to Z = 56 (Ba), doubly magic ^{100}Sn, the heavy actinide region (Ac and U) and the super heavy element region (around No Z=102).
Revised S3 LoIs 2018 World leading Important contribution Marginally competitive (or not feasible)	Some of the experiments have been performed but have open new questions / some of the program are still relevant (K-isomers, XS, fission, alpha-decay) / ^{48}Ca shortage is an issue HRM of S^3 is unique for SIRIUS.	Scientific program is still relevant in 2022 with high scientific impact (mass measurement, laser spectroscopy and decay studies)