COMMISSONING OF THE S^3 SPECTROMETER: ADVANCES, CHALLENGES AND OUTLOOK

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Abstract

The linear accelerator of the SPIRAL2 facility at GANIL delivers both light ions to study nuclear reactions with neutrons in the Neutron for Science (NFS) experimental hall, and heavier ions to produce exotic nuclei, like heavy and super heavy nuclei, in the Super Separator Spectrometer (S^3). By combining electromagnetic components and thanks to their very large aperture, S3 is a powerful tool to purify most of the elements of interest produced in the target from the primary intense ion beam, and retrieving them up to the focal plane to analyse them. The search for very rare events in nuclear reactions requires advanced technics that are not standard in our laboratories, which in S3 are fulfilled by the 7 superconducting multipoles triplets, the large gap of the electric dipole, the high performance movable beam dump and the fully instrumented target station. This poster will generally give an overview of the on-going technical installation and commissioning of this new scientific facility at GANIL.

INTRODUCTION

The Super Separator Spectrometer (S^3) [1, 2] is being installed and commissioned at the SPIRAL2 [3, 4] facility in GANIL. It is designed to isolate and study rare isotopes produced by fusion-evaporation reaction using the high intensity stable beams provided by the LINAC accelerator of SPIRAL2. S^3 will tackle two main scientific cases: the study of superheavy nuclei and N=Z nuclei around 100Sn. Its two stages approach aims at reducing the background from the unreacted beam and light reaction products in the separator (first part) and at identifying the produced fusion-evaporation residues by A/Q in the mass spectrometer (second part). It will allow to access isotopes with production cross-sections down to the femtobarn region thanks to its high rejection and high transmission. In this contribution we report on the status of the installation and tests of the components of S^3.

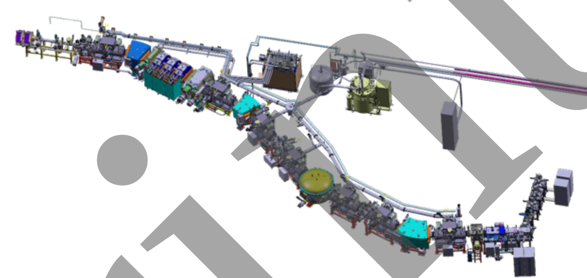

Figure 1: Layout of the Super Separator Spectrometer.

MAGNETS

The two stages of S3 are arranged symmetrically around an intermediate focal plane in order to cancel optical aberrations. The first stage is a momentum achromat composed of two magnetic dipoles (D_M) and four triplets of multipoles (M) in a $MMMD_MMMMMMMD_MMMM$ configuration. The second stage is a Mass separator composed of one electric dipole (D_E), a magnetic dipole and four triplets of multipoles in a $MMMD_EMMMMMMDMMMM$ configuration (Fig. 1).

Magnetic Dipoles

Three magnetic dipoles are installed in S^3. They provide a maximal magnetic field of 0.72 T and maximum Bρ of 1.82 Tm, with a bending radius of 4 m and a gap of 230 mm (Fig. 2). The power supply and cooling circuit have been tested in 2026.

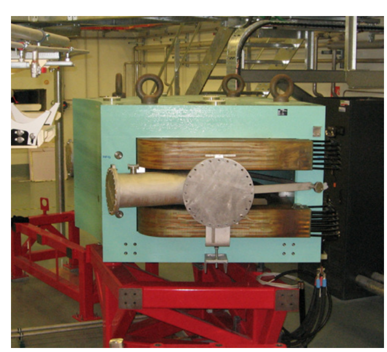

Figure 2: Magnetic dipole of the mass separator.

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Open Quadrupole

The high transmission of S^3 is based on the propagation of several charge states of the reaction products. This feature requires a large opening after the first magnetic dipole to transmit the required ions and deviate the background toward the beam dump. For this reason, the second triplet of quadrupoles of S^3 is open on the high rigidity side (Fig. 3). This triplet is composed of room temperature quadrupoles with sexutpole corrections. It has been fully commissioned offline in 2026.

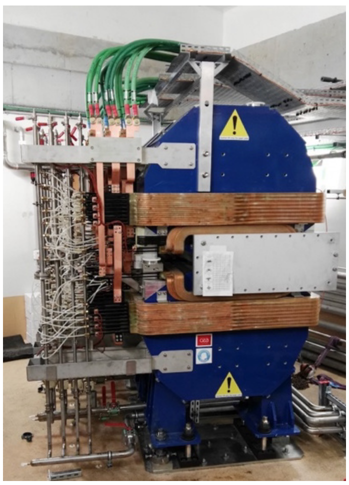

Figure 3: Open triplet of quadrupoles in the beamdump area.

Superconducting Multipole Triplets

The superconducting multipole triplets (SMT) are designed to focus and transmit the ions through S^3 (Fig. 4) They consist of triplets of superconducting coils placed inside a cryostat cooled by liquid helium (@4.5K), and liquid nitrogen (@77K) for thermally screening the cryostat. The coils host quadrupoles with sextupolar and octupolar corrections as well as dipole steerers.

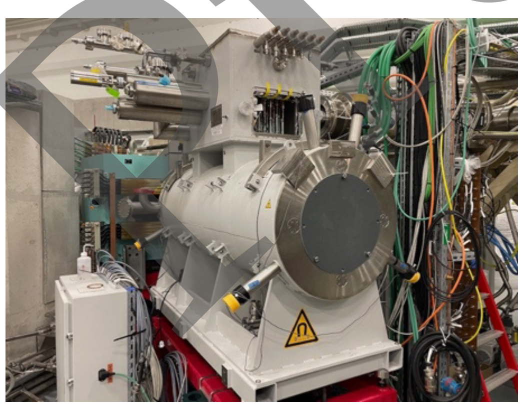

Figure 4: Superconducting Multipole Triplet.

All seven SMTs have been received and installed at S^3. At the moment of writing, one SMT has been tested under cooling and its magnetic field mapped. Five SMTs have been or are undergoing repairs for faulty electrical contacts or helium leaks inside the vacuum chamber.

Electric Dipole

The electric dipole consists of two curved electric plates separated by a 20 cm gap for a bending radius of 4 m, and it is designed for a maximum polarization of ±400 kV with a maximum rigidity of 12 MV (Fig. 5). The presently installed power supplies provide up to ±300 kV. The in-beam direction right plate (see figure) has a slit at the center to let the high rigidity ions pass towards the secondary beam dump designed for 200 W. The electric dipole has been conditioned and tested up to ±200 kV in 2025.

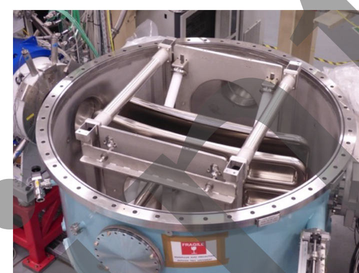

Figure 5: Electrostatic plates of the electric dipole of the mass separator.

TARGET SYSTEM

S^3 is planned to use heavy-ion beams from 12C to 70Zn with intensities up to 10 pμA (6×1013 pps). The impact of the beam can deposit up to 3.5 kW in the target material, leading to temperatures that can exceed its melting point. For this reason, S^3 is equipped with a rotating target system [5] where the target material is placed at the periphery of a 70 cm wheel rotated up to 3000 rpm to allow the dissipation of the deposited heat over a larger surface (Fig. 6). The beam pulses of the LINAC are synchronized with a timing signal from the wheel in order to irradiate only the target material, avoiding the target frames.

Several diagnostic devices are installed in and outside of the vacuum chamber to monitor the targets.

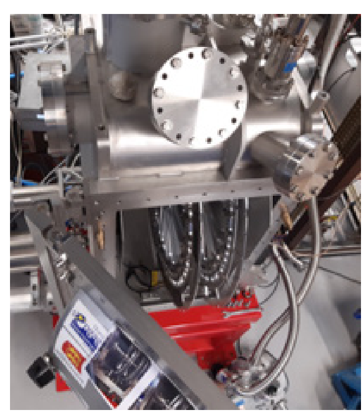

Figure 6: Vacuum chamber and wheels of the target station for stable isotopes.

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The target system has been commissioned at S^3 with an ^{40}Ar beam provided by the LINAC in November 2024 [6]. The synchronization of the LINAC beam with the rotation of the target wheel was successfully accomplished. The different diagnostic devices have been extensively tested online and offline prior to installation at S^3.

BEAM DUMP

The beam dump will receive the unreacted beam separated from the reaction products by the first magnetic dipole of S^3. It consists of five movable fingers, four movable shutters and two fixed plates dispatched in an upstream and a downstream section. The beam dump is cooled to withstand a 10 kW power deposition on fixed plates, and between 2 and 5 kW on mobile parts.

The vacuum chambers and the cooling system are installed and have been qualified. The beam stopping elements are under construction and will be installed in 2027.

CRYOGENIC SYSTEM

The SMTs of S^3 require a two-stage cooling system comprising a 77 K liquid nitrogen circuit — serving as the thermal screen of the cryostat and cooling the high-Tc superconducting current leads — and a 4.5 K liquid helium circuit dedicated to the superconducting coils. The liquid helium is produced by a liquefier consisting of a Cold Box, a 1000 L Dewar, and a 12 bar compressor, designed to dissipate a heat load of 100 W at 4.5 K. The system is supplied with helium gas from the SPIRAL2 LINAC installation. The cryogenic system was completed and started in 2018. Several technical and administrative challenges have hindered its operation since 2024 with several technical failures of the compressor which have been solved. The cryogenic system is now scheduled to be recommissioned in 2027 for the cooldown of the SMTs. The reliability of this system is essential to the proper operation of S^3.

BEAM DIAGNOSTICS

The tunning of S^3 requires beam diagnostics adapted to the beam current and energies used in the experiments. Three different technologies are used depending on the position in the spectrometer and therefore the ion masses, kinetic energies and flux. Six emissive foil profilers, seven secondary electron emission profilers and two residual gas profilers are used to tune S^3.

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CONCLUSION

S^3 is in the final stage of its construction with several components already commissioned. The final mounting steps, tests and magnetic alignment operations are scheduled in 2026, and the beginning of the optical commissioning should start at the end of 2027, for a physics commissioning in 2028.

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