The Super Separator Spectrometer (S^3) for SPIRAL2 stable beams

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S^3 (Super Separator Spectrometer) is a device designed for experiments with the very high intensity stable beams of LINAG, the superconducting linear accelerator of GANIL, which will be built in the framework of SPIRAL2. These beams can reach intensities exceeding 100pμA for lighter ions. These unprecedented intensities open new opportunities in several physics domains, e.g. super-heavy and very-heavy element properties, spectroscopy at and beyond the dripline, isomer and ground state properties, and the products of multi-nucleon transfer and deep-inelastic reactions. An international collaboration has been formed for proposing physics experiments and developing technical solutions for this new instrument. We present here the optical layout of the spectrometer and the studies of its multipole magnets.

1. Introduction

Starting in 2012, the SPIRAL2 facility at GANIL will be able to produce stable heavy ion beams (from carbon to uranium) of unprecedented currents, up to 1mA for light ions, with energies from 2 to 14MeV/u. They will enable the production of radioactive nuclei with low cross section reactions and us to study them: super heavy elements (SHE) or neutron-deficient nuclei produced with fusion-evaporation reactions, or neutron rich nuclei produced by multi-nucleon transfers. Then delayed or secondary reaction studies of these rare nuclei can be performed. These physics cases have been presented in a previous document [1], and can be found in the SPIRAL2 Letters of Intent [2]. It is necessary to separate the interesting nuclei (with a production rate down to one per month!) from any primary beam ions (in some cases over 10^{14} particles per second) that are transmitted after the thin production target. Thus the basic design of S^3 includes:

- a rotating production target, able to sustain high beam currents
- a two-part electromagnetic separator which rejects a large fraction of the primary beam ions in the first half —to prevent them from reaching the electric dipole or

the final detection system— and selects the desired products from the remaining recoils by M/Q separation.

- a focal plane system well adapted to the study of the nuclei of interest, possibly including gas cell with subsequent reacceleration on a "low energy" branch for high precision measurements [6,7].

To take full advantage of the opportunities offered by the system, the electromagnetic separator should have large angular and charge state acceptances, ± 50 mrad in both the horizontal and vertical planes and ± 10% respectively, as well as a large magnetic rigidity acceptance of ± 10%. Magnetic and electric rigidities of Bρ_{max}=1.8 Tm and Eρ_{max}=12 MV will be needed. A mass resolution of 1/300 (FWHM) is required. We will present here the latest technical developments in the design of the spectrometer and magnets. Details about the other apsects may be found on the S^3 website [3].

2. Optical Design - MAMS

The S^3 design, composed of a Momentum Achromat followed by a Mass Separator (MAMS), is shown in figure 1.

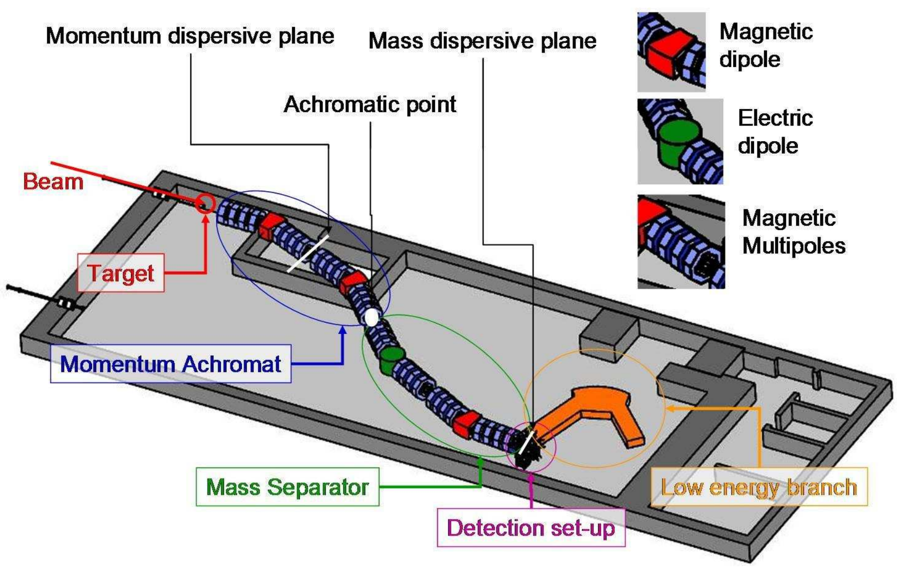

Figure 1. Basic design of the Super Separator Spectrometer.

The MAMS design for S^3 is composed of one basic "cell", a multiplet and a half dipole, which is symmetrically reproduced eight times, with the noted exception that the third dipole, of the four in the system, is an electric bending element. The first half of S^3 behaves as a momentum achromat, and the second half separates the nuclei according to mass-to-charge ratio. At the middle of S^3 is an achromatic focal point, which can be used as a secondary target point. The high level of symmetry of this layout cancels second order aberrations [4]: most of the second order aberrations are canceled by the symmetry of the quadrupoles, then superimposed sextupoles fields can be used to cancel the remaining second order aberrations. The primary beam rejection and recoil purification is achieved in several steps. A preliminary rejection occurs at the momentum dispersive plane. All the beam ions outside the Bρ acceptance (in most cases with higher Bρ) are stopped in an external beam dump. In order to reduce scattering inside the beamline and activation of the pipe and surrounding multipoles, the magnetic multipoles following the first dipole are of an open-yoke design. This allows primary beam charge states which pass the beam dump in the first dipole to be stopped in a dedicated system outside the magnetic focusing elements (see next section). A rejection factor of 10^3 is expected to be achieved by the end of the momentum achromat. A small collimator is placed at the intermediate achromatic focus at this point that will stop most of the ions scattered within the achromat. The second stage of S^3 makes an additional selection, with velocity selection and a final slit system blocking all the ions except for the selected ratio of M/Q. Simulation studies, using different ion optical codes, show that the performance of this device is very good. All order simulations for a super heavy elements production reaction (^{48}Ca+^{248}Cm $\rightarrow$ ^{292}116 + 4n) gives global transmission of 57% with a mass resolution (FWHM) calculated to be better than 1/300.

3. Magnetic Elements

In order to have a good mass resolution combined with a high acceptance, it is required that optical aberrations are corrected. As mentioned previously, the multipoles combine quadrupole and sextupole fields for that purpose. We show here two models of multipoles that are currently being studied. Both use standard room temperature technology. The need for octupole corrections, which would require superconducting multipoles, is currently being evaluated. The first design (see figure 2, right) is using two compensated dipole fields in order to produce a sextupole field [5]. This design is completely open on one side and enables the beam to pass through this opening after the deflection by the first dipole. The drawback is that the resulting fields are not symmetric outside the central zone and may bring specific aberrations for outer trajectories.

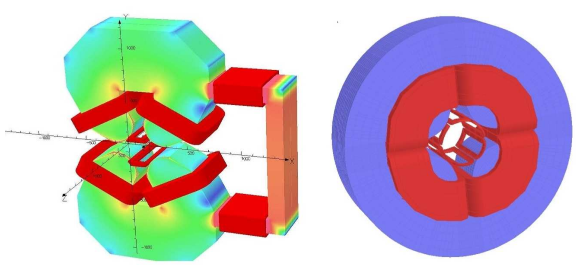

Figure 2. Left: Opened yoke multipole [CEA Saclay Irfu/SACM] and Right: Closed yoke multipole [GANIL]

The second type uses sextupole coils placed on the outside of the beam pipe. The design of these magnets is presented in figure 2, left. We are currently studying the full 3D field maps of these magnets to include them in the optical simulations.

As an alternative solution to these magnets, we are also studying the use of superconducting multipoles. While technologically more complex, this solution remains cost effective since it substantially reduces the number of power supplies needed (due to the high power consumption of room-temperature magnets) and could provide further savings through reduced power consumption in the long term. Superconducting elements also have the advantage of enabling the addition of octupole fields that could be used to further correct higher order aberrations. Figure 3 shows the preliminary design with and without iron shell enclosure. Other options based on double helix magnet design [1] are also being considered.

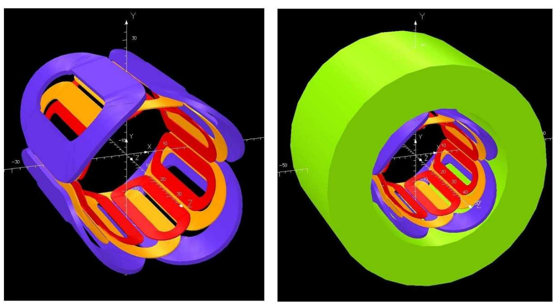

Figure 3. Superconducting multipole [Argonne National Lab.]

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