

# OPTICAL STUDIES FOR THE SUPER SEPARATOR SPECTROMETER S<sup>3</sup>

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## Abstract

S<sup>3</sup> (Super Separator Spectrometer) [1] is a future device designed for experiments with the high intensity heavy ion stable beams of SPIRAL2 [2] at GANIL (Caen, France). It will include a target resistant to these very high intensities, a first stage momentum achromat for primary beam extraction and suppression, a second stage mass spectrometer and a dedicated detection system. This spectrometer includes large aperture quadrupole triplets with embedded multipolar corrections. To enable the primary beam extraction one triplet has to be opened on one side, which requires an appropriate design of such a multipolar magnet.

The final mass separation power required for S<sup>3</sup> needs a careful design of the optics with a high level of aberration correction. Multiple symmetric lattices were studied for this purpose. A 4-fold symmetric lattice and the achieved results are described in this paper.

## INTRODUCTION

The S<sup>3</sup> spectrometer will use the high intensity stable ion beams (up to 50 kW) produced by the SPIRAL2 accelerator to investigate fusion-evaporation reactions. Such reactions allow to study super heavy element (SHE) synthesis, very heavy element (VHE) spectroscopy, mirror nuclides (N=Z) spectroscopy and transfer reactions of light nuclides.

The main characteristics needed for these studies are:

- A maximum magnetic rigidity of 1.8 Tm.
- A maximum electric rigidity of 12 MV.
- A mass resolution of 1/300.

As the reaction products have large angular, energy and charge-state distributions, the S<sup>3</sup> spectrometer must have:

- An angular acceptance of  $\pm 50$  mrad, horizontal and vertical.
- A magnetic rigidity acceptance of  $\pm 7$  %.
- A charge-state acceptance of  $\pm 10$  % (e.g.  $\pm 2$  charge-states around the reference charge-state).

The primary beam suppression must be up to  $10^{13}$  to allow easy nuclei identification. At last, the spectrometer must fit a 26 x 12 m<sup>2</sup> area, which is the allocated space inside the S<sup>3</sup> experimental hall.

The S<sup>3</sup> spectrometer (Fig. 1) is divided in two stages. The first one is a momentum achromat (MA) which will perform the separation between the reaction products and the primary beam. It must achieve a primary beam suppression of at least  $10^3$ . The second stage is a mass separator (MS) which must reach the final rejection and a 1/300 mass separation.

The MA has to operate with magnetic rigidities of recoil products up to 1.8 Tm. Depending on the type of reactions, a fraction of the primary beam is outside the spectrometer acceptance. The multipoles following the first dipole must have a vertical gap on one side to allow the primary beam extraction, and to prevent damages. A set of movable small beam stoppers, located at the dispersive focal plane, have to suppress the fraction of the projectile beam still in the momentum acceptance. Slits located at the MA image point have to reduce the residual projectile beam by at least a factor of  $10^3$ . A minimum free space of 1.6 m has to be preserved around the MA image point.

The MS needs a combination of an electrostatic dipole and a magnetic dipole to make a mass separation. To reach the mass separation at the MS image point (F4), the electrostatic dipole must have a length of at least 1.3 m, and an achievable field of 3 MV/m. The maximum electric rigidity leads to a limit of 1.2 Tm for the MS maximum magnetic rigidity. As the primary beam electric rigidity is different from the recoils products, the electrostatic dipole allows the final rejection of  $10^{13}$ .

The aperture diameter of all multipoles has to be 300 mm to obtain the large acceptances. To fit the allocated space, triplets of multipoles are used. A careful correction of aberrations is needed to achieve the required mass separation. Higher-order correctors, sextupole and octupoles, have to be superimposed to the main quadrupole component of the multipoles.

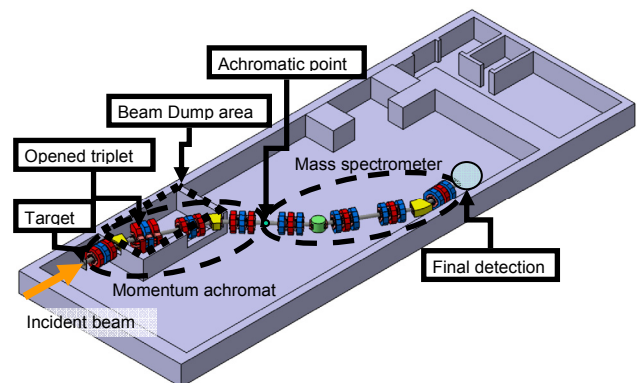


Figure 1: S<sup>3</sup> implantation in the experimental hall.

## S<sup>3</sup> OPTICS DESCRIPTION

The main guideline is to conceive the most possibly symmetric structure. A 4-fold symmetric lattice [3] is presented below. The basic cell of this lattice is composed of a fixed drift, a quadrupole triplet and a half-dipole. The quadrupole strengths and the drift between the triplet and

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the dipole are adjusted in order to give a first-order matrix with null diagonal elements. This cell is repeated by mirror symmetry and combined. The first-order matrix of two cells is then minus identity (-I). By combination of two groups one obtains a separator stage of the spectrometer with identity (I) first-order matrix (Fig. 2). Each separator stage is achromatic separately. Such optical design insures the cancellation of the geometrical second-order matrix elements [3]. In the MS, the two dipoles are not the same nature so the symmetry and the 2<sup>nd</sup> order terms cancellation is not perfect.

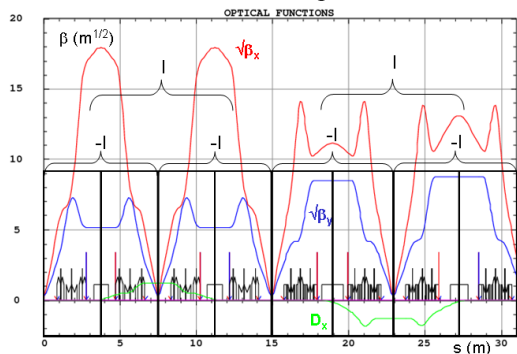


Figure 2: Optical functions of the spectrometer, horizontal beta function (red line), vertical beta function (blue line), and dispersion function (green line). The basic cells defined in the first-order optics are indicated with square black boxes, as well as the combinations making unitary transfer matrices.

For each stage, the initial drift is repeated 4 times for symmetry reasons, leading to unnecessary space as each drift is not adjusted independently to the experimental needs. This is a disadvantage of such configuration.

Sextupoles components are inserted in each multipole for the correction of higher-order aberrations. Octupole components could improve this correction, and the effects of their insertion in each separation stage will be studied.

### MAGNET DESIGNS

The classical iron dominated magnet and the superconducting (SC) magnet technologies have been envisaged for the closed multipoles and for the open multipoles (2<sup>nd</sup> triplet) as well. Octupoles were considered only in the SC technology case.

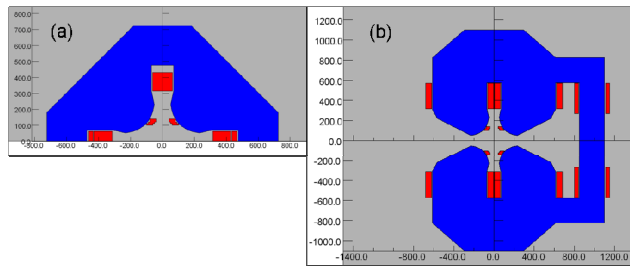


Figure 3: 2D views of closed (a) and open (b) iron dominated multipoles. The dimensions are in mm.

### Room Temperature Iron Dominated Multipoles

The magnet shapes are shown in Figure 3. The pole geometry was optimized in order to reduce the iron saturation down to 1.55 T. For the open magnets, the sextupolar component is obtained by subtraction of two dipolar fields; this allows a vertical gap around the horizontal axis, but a residual dipolar component remains. For closed magnets, the sextupolar component is achieved with a set of coils placed around the beam pipe in a sextupolar arrangement, as proposed by GANIL [4].

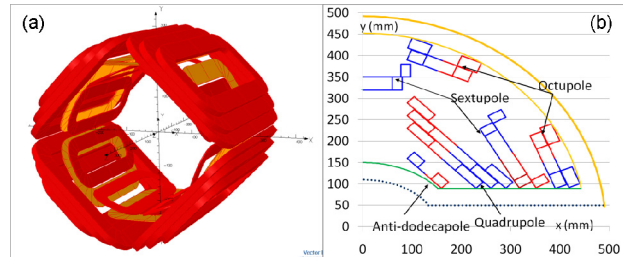


Figure 4: (a) 3D view of a SC closed magnet, (b) coil layout of a SC open magnet.

### Superconducting Multipoles

Flat racetrack coil configurations were proposed by Irfu/SACM [5] for the closed and open SC multipoles (Fig. 4). The flat racetrack coils leads to a simplification of the coil winding, which has an impact on the magnet cost. Quadrupole, sextupole, and octupole components can be inserted in the same multipole. Originally, the sextupole design for the open multipoles use the same concept than to the open room temperature case. A new symmetric coil configuration has been proposed for the sextupole without the residual dipolar component. It can include an octupole component as well.

## HIGHER-ORDER OPTIMIZATIONS

### Optimization Strategy

The higher-order optimizations were performed with the tracking code TraceWin [6]. The code transports a cloud of particles through a beam line, taking into account all orders. The simulated beam has the same kinematic distribution than the recoil products after the target. The <sup>100</sup>Sn reaction products were chosen for the optimization because this nuclide has distributions similar to the nominal acceptance of the spectrometer ( $\sigma(x)=0.5\text{mm}$ ,  $\sigma(x')=\sigma(y')=17.8\text{mrad}$ ,  $\Delta y=\pm 5\text{mm}$  (uniform distribution),  $\sigma(\delta p/p)=3.7\%$ ). The retained optimization method uses as variables all the sextupoles, all the octupoles whether they are inserted, and the last quadrupole triplet. The goal is to maximize the mass separation of 3 different beams transported to the focal plane F4. This is achieved by a global minimization of all higher-order aberrations.

The TraceWin code tracks successively 3 charge-states of the same particle distribution, which cover the useful final focal plane area ( $\pm 50\text{ mm}$  in the horizontal plane). Once the optimization has converged, the magnet setting is adapted to the <sup>292</sup>116 super-heavy element reaction case

( $^{48}\text{Ca} + ^{248}\text{Cm} \rightarrow 4n + ^{292}\text{116}$ ). The spectrometer mass separation power is then calculated from the beam FWHM sizes and positions at F4 between neighboring nuclei (Fig. 5). The same first-order lattice is employed for all the optimizations, in order to compare the different magnet technologies for each combination of multipoles.

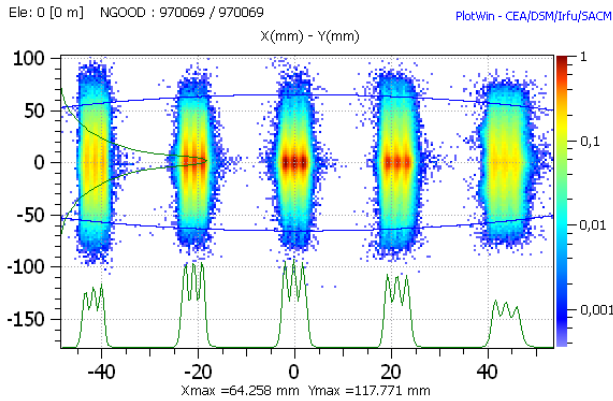


Figure 5: Distribution of the  $^{292}\text{116}$  reaction products at F4. Five charge-states of three isotopes around  $^{292}\text{116}$  are displayed.

### Optimization Results

The first simulations were performed with a theoretical modelling of the multipoles. They have shown that sextupole correctors are needed in all multipoles, including the open multipoles.

Afterwards, this modelling was replaced by closed magnet 3D field maps. It has to be noted that TraceWin doesn't implement dipole field maps yet. To reach the wanted mass separation, a correction with octupolar components in the multipoles is needed (Fig. 6). Such correction could be achieved in the MA also with dipole edge curvatures. In the MS, this type of correction cannot be done with an electrostatic dipole, so only octupole components are possible. This conducts to the use of the SC technology for the MS multipoles.

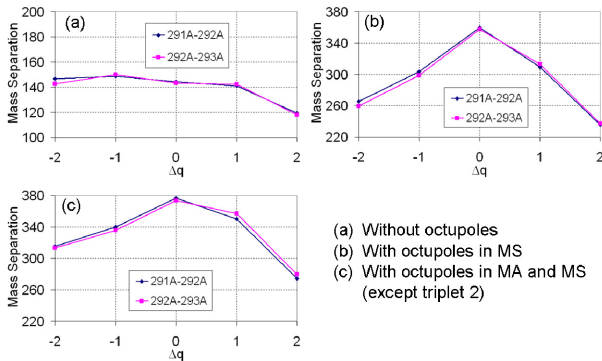


Figure 6: Mass separation power with closed multipoles.  $\Delta q = 0$  corresponds to the charge-state  $q=26$ .

At last, open multipole field maps were introduced in the 2<sup>nd</sup> triplet. The best results on average have been obtained with the SC symmetric coil configuration (Fig.

7). In addition, this design authorizes the insertion of octupole components.

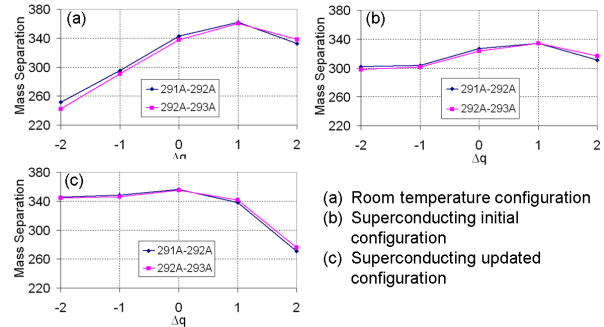


Figure 7: Mass separation power with open multipoles.  $\Delta q = 0$  corresponds to the charge-state  $q=26$ .

The overall transmission for the five charge-states of the  $^{292}\text{116}$  reaction products has been calculated. The results, between 52% and 57%, are comparable for all cases. One example of SHE transmission with SC open multipole insertion is presented in Figure 8.

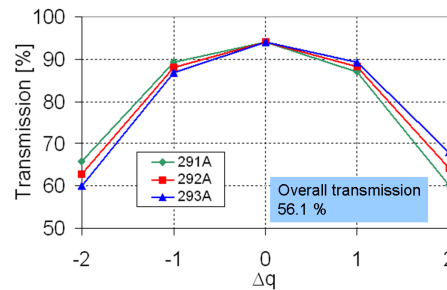


Figure 8: Example of SHE transmission with open multipoles.  $\Delta q = 0$  corresponds to the charge-state  $q=26$ .

## CONCLUSION

We have studied a 4-fold symmetric lattice for the  $S^3$  spectrometer. The separation goal is reached for 4 charge-states out of 5, for the best results. The sextupolar chromatic correctors are needed everywhere in the dispersive regions. Octupolar corrections in the MS and the MA improve significantly the mass separation. This means that superconducting technology must be envisaged for the MS. An octupolar correction can be done in the MA also with dipole edge curvatures but without flexibility. Superconducting open multipoles give better results than conventional ones. The definitive spectrometer structure is still on development.

## REFERENCES

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