

# THE DESIR FACILITY AT GANIL-SPIRAL2: THE TRANSFER BEAM LINES

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## Abstract

The new ISOL facility SPIRAL2 is currently being built at GANIL, Caen France. The commissioning of the accelerator is in progress since 2015. SPIRAL2 will produce a large number of new radioactive ion beams (RIB) at high intensities. In 2019, the DESIR facility will receive beams from the upgraded SPIRAL1 facility of GANIL (stable beam and target fragmentation), from the S3 Low Energy Branch (fusion-evaporation and deep-inelastic reactions). In order to deliver the RIB to the experimental set-ups installed in the DESIR hall; 110 meters of beam line are studied since 2014. This paper will focus on the recent studies which have been done on these transfer lines: beam optics and errors calculations, quadrupoles, diagnostics and mechanical designs.

## THE DESIR FACILITY WITHIN THE SPIRAL2 PROJECT

SPIRAL2 is a major extension project of the GANIL facility in Caen, France dedicated to the production of heavy ion beams at high intensities and of very exotic nuclides. With SPIRAL2, the French and International communities will make decisive steps in the understanding of the atomic nucleus and of the nucleosynthesis processes occurring in astrophysics. The collection of nuclear data will help preparing the next generation of nuclear reactors and the production of new isotopes suitable to nuclear medicine will be investigated. In addition, a high intensity fast neutron source will open new research domains in material science [1]. The SPIRAL2 facility will produce a large number of new radioactive ion beams (RIB) at high intensity. These beams will be produced using a new linear accelerator that will deliver deuterons up to 40MeV at 5mA intensity, protons up to 33MeV at 5mA and ions with  $A/Q=3$  up to 14.5MeV/u at 1mA (see Fig. 1) [2].

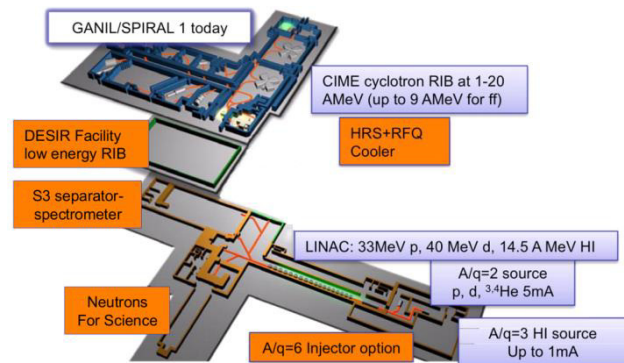


Figure 1: Scheme of the SPIRAL2 facility.

The DESIR (Decay, Excitation and Storage of Radioactive Ions) facility will receive beams delivered by the S3-LEB (Low Energy Branch of the new Super Separator Spectrometer) of SPIRAL2 [3]. Nuclides will be produced in fusion-evaporation, transfer and deep-inelastic reactions, and will notably consist in refractory elements. Finally, RIB produced in the fragmentation of high-intensity heavy ions and/or thick targets at the upgraded SPIRAL1 facility will also be available at DESIR [4]. The Steering comity of the SPIRAL2 project promote the phase 1+ witch include the DESIR facility with its transfer beam line coming from S3 and SPIRAL1.

Nuclear physics as well as fundamental weak-interaction physics and astrophysics questions will be addressed by means of laser spectroscopy, decay studies, mass spectrometry and complementary trap-assisted measurements. Experience at other ISOL facilities evidences that ion beams with a high degree of purity are required to push experiments towards the limits of nuclear stability [5, 6, 7].

## GENERAL PRINCIPLES FOR DESIGN

The DESIR facility consists to a 1500 m<sup>2</sup> experimental hall and 97m of upstream and interconnected beam lines. Along these lines, a RFQ-Cooler [8] and a High Resolution Separator (HRS) [9] will be in charge to provide a reduction of the emittance and high purification of the beams coming from S3-LEB and SPIRAL1 (see Fig. 2). The RFQ-Cooler will be located just before the HRS. Beam coming from S3-LEB or SPIRAL1 will can be injected in this branch or by-passed for direct injection up to the DESIR hall according physics experimental requirements. Experimental set-ups will be located in the large hall (see Fig. 2).

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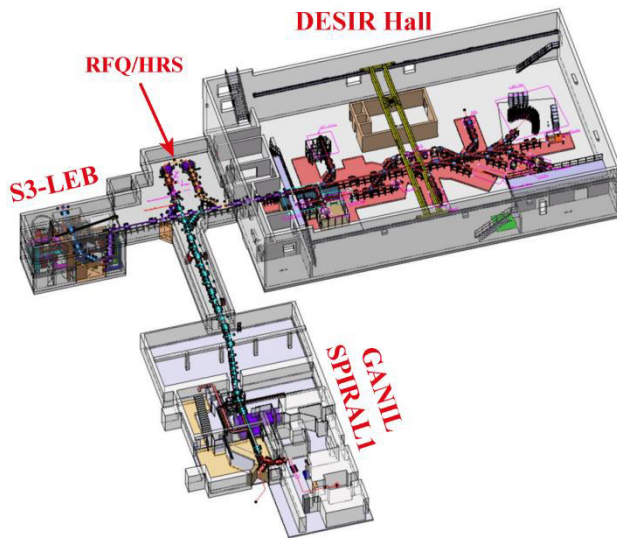


Figure 2: Scheme of the transfer beam line, S3-LEB and SPIRAL1 up to DESIR experimental hall. Designs of the building are not yet fully fixed.

Beam lines in DESIR experimental area, RFQ/HRS and SPIRAL1 lines will be at -1.75m underground. Beam line coming from S3-LEB will be at -8.5m ground. 3 various types of deviation must be designed: vertical ( $90^\circ$ ), and 2 in the horizontal plane ( $45^\circ$  and  $10^\circ$ ).

The building studies are actually under way. The final and optimal solution taking into account of all aspects will be delivered soon. The public enquiry will start in 2017, then building before making available for installation in 2019.

## OPTIC CONCEPTION OF THE TRANSFER LINES

### Nominal Beam Dynamic

Lines have been design in order to accept maximum beam energy to 60 keV and transverse geometric emittance to  $80 \pi \cdot \text{mm} \cdot \text{mrad}$ . Only singly-charged ions will be transported, for which electrostatic optical devices are better suited [10, 11].

Careful studies of the beam dynamics were performed using the CEA TraceWin code [12]. This code allows to run large and close to real condition simulations, to use field maps of optical elements, to perform diagnostics location optimizations, errors studies, corrections and feed-backs [13].

Making use of the knowledge and long experience on electrostatic devices [14, 15], we have studied and designed all optics elements with respect to the maximum beam emittance and energy. Electrostatics devices like quadrupoles, steerers and deflectors have been studied using the Opera-3D simulation tool [16]. Then, calculated field maps were used and compared directly in the TraceWin simulations of the entire transfer beam line.

Figure 3 shows the RMS transverse beam envelops along the transfer line linking the S3-LEB to the entrance of DESIR experimental hall. We can observe a good

agreement between the two calculations using pure and field maps for the optical elements.

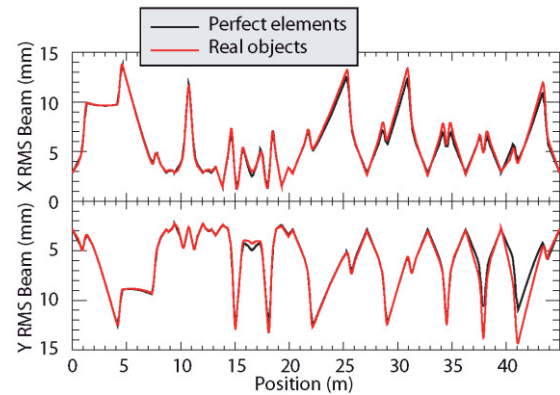


Figure 3: RMS transverse beam envelops along the 45m long transfer line linking the S3-LEB to the entrance of DESIR experimental hall. Black curves calculation using pure optical elements, red curves calculation using real field maps for optical elements.

Figure 4 shows the transverse beam distributions at the end of the line (the entrance of DESIR experimental hall). Calculated emittance growth is lower than 10% and transmission is better than 99.9%.

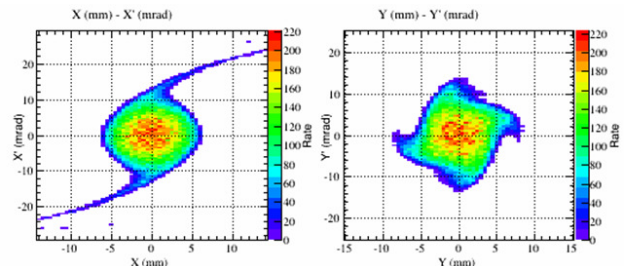


Figure 4: Calculated transverse beam emittances at the end of the line (the entrance of DESIR experimental hall) using field-maps for the optical elements.

Same calculations and methodology were taken for each beam lines. Nominal parameters are already defined. For a 60keV mono-energetic beam, maximum potential in the quadrupoles will be 3200V and 7880V in deflectors. We will use quadrupoles with aperture to  $D=100\text{mm}$ , length to 175mm with a circular shaping with  $R=57.5\text{mm}$  (reduce cost compare to hyperbolic shape). Two grounded rings will be 2mm thick, 100mm in aperture located at 27.5mm to the electrodes. Deflector radius will be  $\rho=400\text{mm}$ , aperture  $a=50\text{mm}$ , electrode height  $h=100\text{mm}$ , Pole face will be toroidal shape with radius to 335mm in order to have an optimized focus.  $45^\circ$  bending is obtained with  $37^\circ$  angular aperture and  $90^\circ$  bending is obtained with  $83^\circ$  angular aperture. Horizontal and vertical orbit correctors will be located at the same longitudinal position. Electrodes will be set at maximum potential to  $\pm 300\text{Volts}$  (see next section for explanation). Electrodes gap will be 100mm, Length to 100mm and width to 80mm with additional longitudinal shimming.

### Errors Calculation

Quadrupoles, steerers and deflectors alignments have to be better than 0.1mm, field stability precision better to 1%, rotation better to  $\pm 0.1^\circ$ . Diagnostics position must be better than  $\pm 0.5\text{mm}$  and beam sizes measurements precision must be lower than  $\pm 0.5\text{mm}$ .

With these real conditions, we make errors calculations on beam lines in order to ensure that our structures are stables and adjustable. It can be also use to define working range and precisions of the electric alimentionation for optical elements.

For each line, we made 500 errors calculation by apply random and homogeneous errors to each element and primary beam. New lines parameters are recalculated for each case. Therefore, we obtain value set for each individual optical elements (see Figs. 5 and 6).

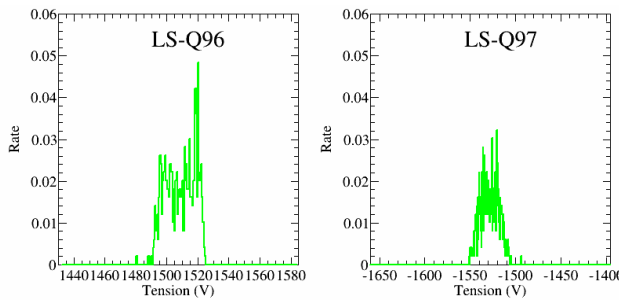


Figure 5: Examples of potentials distribution obtain for two quadrupoles for the 500 calculations.

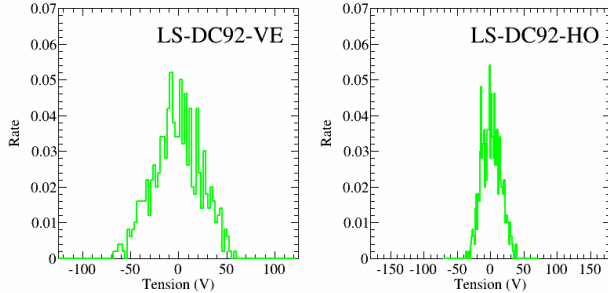


Figure 6: Examples of potentials distribution obtain for two steerers for the 500 calculations.

For each optical element, we determine the mean, the RMS, maximum and minimum values. A general criterion of the beam optic correction scheme can be the mean of the difference between the maximum and the minimum value divided by the average value for each quadruple. More this mean is small; more the beam line is stable. In our case, this value is close to 15%. For the beam alignment, our criterion is the mean of the difference between the maximum and minimum steerer by steerer. In our case, this value is close or lower than 150V. Therefore, we see that we have sufficient margin for the  $\pm 300\text{Volts}$  steerer alimentionations.

We have also study the beam characteristics at the end of the lines. For each errors calculations, transverses positions and sizes are known and can be compared with the nominal properties. As an example we give in Table 1

the characteristics obtained at the end of the 45m long transfer line between S3-LEB and the DESIR hall.

Table 1: Calculated errors of the positions and sizes for the 60keV mono-energetic beam at the end of the 45m long transfer line from S3-LEB up to DESIR hall.

		Mean	RMS
Orbits or Positions	X (mm)	0.0	0.2
	X' (mrad)	0.0	0.3
	Y (mm)	0.0	0.3
	Y' (mrad)	0.0	0.3
RMS Sizes	X (mm)	2.9	0.7
	X' (mrad)	4.7	0.2
	Y (mm)	2.9	0.1
	Y' (mrad)	4.7	0.2

Using these errors conditions, the beam stability in the lines is estimated to be less than 1mm at 3RMS (orbit and size) and 2.1mrad for the transverses divergences sizes which is satisfying for our case.

### MECHANICAL CONCEPTION

According beam process specifications we have already done the full transfer beam line integration. Coordination system and mechanical standards definition is done by the SPIRAL2 Phase1+ system group. IPN Orsay is in charge to make the complete mechanical conception up to 2D detail drawings of optics devices, diagnostics boxes, bellows, pipes, supports, frames.

Figure 7 shows the mechanical design of the electrostatic quadrupole, steerer vertical and horizontal.

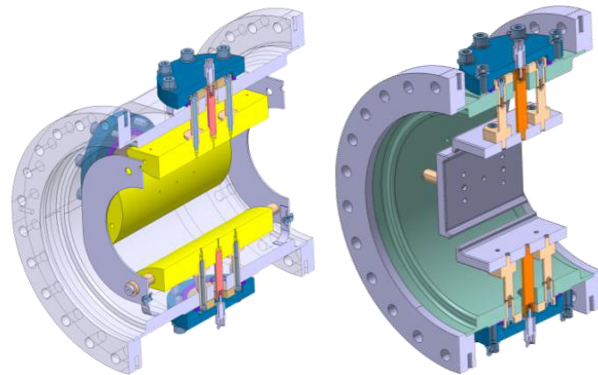


Figure 7: 3D design of the electrostatic quadrupole (left picture) and steerer (right picture) inside the vacuum chambers.

Vacuum chamber of quadrupole and steerer will be identical and machining with the same technic. Blocks will be assembling in order to form quadrupole doublet or triplet with a vertical and horizontal steerer. The mounting procedure has already been validated in through a prototype made in 2014. The prototype is in operation at CEN Bordeaux-Gradignan laboratory and connect to a R&D experimental device dedicated to DESIR.

Figure 8 shows the mechanical design of the electrostatic beam deflectors to 45° and 90° bending angles.

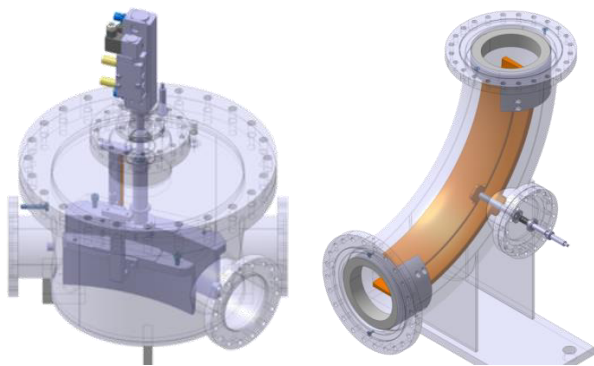


Figure 8: 3D design of the electrostatic beam deflectors 45° (left picture) and 90° (right picture) bending angles.

According to the various paths of the beam in the transfer lines, we have designed the 45° deflector in order to have the possibility to remove the electrodes to the line. Design is carefully studied in order to obtain an excellent reproducibility of positioning.

Figure 9 shows an example of a diagnostic box conception with 3 diagnostics which can be inserted in the beam line.

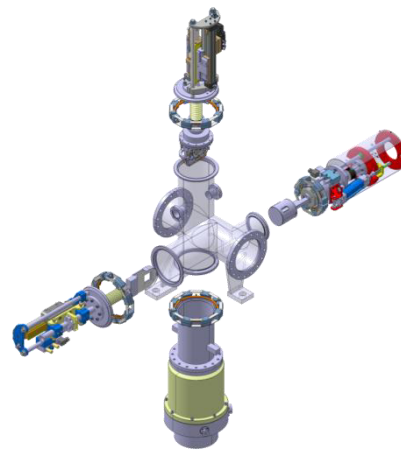


Figure 9: Diagnostic box conception with 3 diagnostics insertion (secondary emission profiler, low intensity profiler, faraday cup) and turbo-molecular pump.

The full integration takes into account various parameters like building constraints, implantation of crate and electronics in the frame, GANIL mechanical standards, vacuum systems, installation and maintenance methodology, free space under the line, safety and security rules (see Fig. 10).

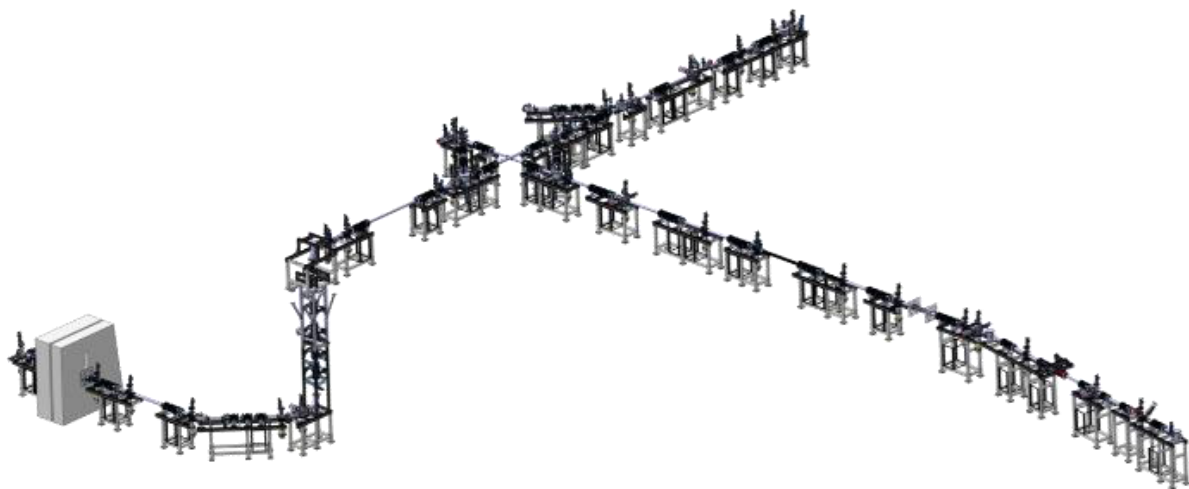


Figure 10: 3D view of the transfer line for the DESIR project.

## CONCLUSION

We have presented here an introduction of the DESIR project. DESIR will be a new and extended experimental area dedicated to the study of the fundamental properties of new exotic radioactive nuclides to be produced at SPIRAL2-GANIL. This paper is focused on the long beam transfer lines which will connect the different production sites to the DESIR experimental hall. Low energy beams will be delivered by the Low Energy Branch of the new Super Separator Spectrometer (S3-LEB) and the upgraded SPIRAL1 facility.

Special care must be taken about focalization devices, deflectors, kicker benders and orbit correctors in combination with beam diagnostic measurements in order to minimize the overall cost of the beam lines and to optimize their tuning. This process has started in 2013. A prototype quadrupole structure has been manufactured. The set-up already operates properly at CENBG since 2015. It will offer the possibility to validate the machining choices and to have feed-backs with the beam dynamic calculations. We have already done some modifications which have been illustrated. All systems of the lines are integrated in the transfer line. The preliminary design review points few small modifications. Details studies are under way. According to the collaboration between GANIL

and FAIR, building of series will start at the beginning of 2017.

Same methodology of studies will be taken in the DESIR experimental hall. Physics requirements for each experimental set-ups are not yet well defined. Installation of the sub-section beam line up to experimental set-ups will be phase in time.

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