A VERSATILE BEAM SPLITTING SYSTEM FOR SIMULTANEOUS DELIVERY OF THREE BEAMS TO INDUSTRIAL APPLICATIONS AT THE GANIL ACCELERATOR

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Abstract

The demand for heavy-ion irradiation in space applications has grown significantly in recent years, surpassing the available beam time at GANIL. To address this, we are developing an innovative beam splitting system combining stripper/degrader techniques with two large-aperture DC magnetic septa. The originality of this approach lies in generating and transporting three different charge states obtained through partial stripping (typically from a $^{129}Xe^{48+}$ beam at 50 MeV/u). These charge states are selected, separated from each other by the two septa and directed to three independent beamlines. These lines remain adjustable to accommodate various ion beams and magnetic rigidities. A key challenge is ensuring full operational independence of the beamlines, including control of beam intensity and access to experimental areas, which requires significant reconfiguration of the facility. Unlike time-sharing systems using fast switching magnets, our concept optimizes ion accelerator efficiency through a full parallel operation with a 100% duty cycle. This upgrade will enable simultaneous irradiations in three experimental areas, greatly enhancing GANIL's capacity to support high-demand, long-term irradiation programs. Moreover, this concept could be applied to other accelerator facilities desiring to feed multiple irradiations setup simultaneously without switching magnets.

MANUSCRIPTS

GANIL (Grand Accélérateur National d'Ions Lourds) [1] is one of the world's leading international laboratories dedicated to research using ion beams, ranging from ^{12}C to ^{238}U accelerated from 0.1 and 95 MeV/u. The facility house five cyclotrons and a superconducting LINAC. Equipped with high-performance detection instruments, the facility enables researchers from around the globe to conduct unique experiments across diverse fields, including nuclear physics, atomic physics, condensed matter physics, astrophysics, and radiobiology.

Alongside its scientific mission, GANIL also devotes a portion of its activities to industrial applications. In recent years, there has been a sharp increase in beam demand from the space applications for radiation testing of electronic equipment [2-6]. To meet this growing need and the other various demands of the scientific community, GANIL continually adapts and improves its beam production and guidance capabilities [7].

To significantly expand the beam time allocated to industry from 400 hours in 2023 to approximately 2,000 hours per year by 2030, several projects are being carried out simultaneously. One of these solutions is beam sharing.

Operating a complex accelerator requires substantial resources, including high initial investment, specialized personnel, and significant electricity consumption, all for a limited number of scientific experiments. Beam sharing, a strategy identified early in GANIL's development, aims to maximize the return on investment. The concept of conducting simultaneous experiments to enhance the accelerator's scientific impact has been successfully implemented at GANIL, notably on the medium-energy (SME, 1990) and low-energy (IRRSUD, 2003) beamlines.

Beam sharing has been employed at GANIL for several years by pulsing magnets to alternately direct the beam into two separate experimental caves at a frequency of every 10 seconds [8]. Similar multi-user platforms, relying on pulsed magnets, have also been implemented at other facilities worldwide [9].

To address these challenges, we propose to develop a new multi-users platform (shown on Fig. 1) for industrial applications at GANIL, designed to enable fully simultaneous experiments. Our approach involves splitting the high-energy $^{129}Xe^{48+}$ beam (50 MeV/u) into several distinct charge states via partial stripping. Three charge states are then selected and separated using large-aperture DC magnetic septa, whose design and integration require dedicated studies, and then guided in three different beamlines.

In this paper, we present a detailed design of this beam-splitting system, highlighting its potential to implement multi-user access at GANIL.

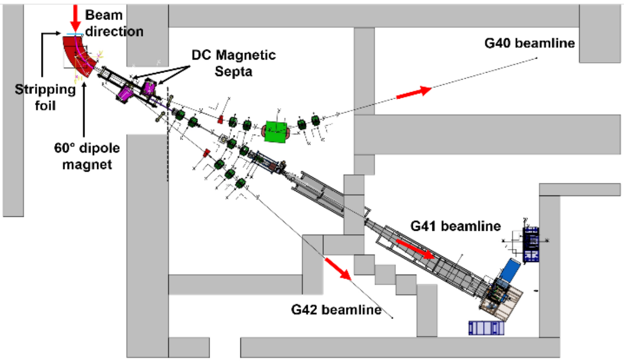

Figure 1: Schematic view of the three beamlines dedicated to the industrial applications at GANIL. The middle beamline is already in use, the others are in study.

Beam Stripping

The first step of implementing a multi-user platform is to strip the high energy beam. As previously described, industrial applications at GANIL mostly use a $^{129}Xe^{48+}$ beam at 50 MeV/u. At this energy, heavy ions (from Ca to Xe) are only partially stripped to be accelerated.

By inserting a stripper foil inside the high energy beamline we can generate a charge states distribution from the primary beam, thus with lower magnetic rigidity. Mounting the foil on a precision translator enables real-time adjustment of its position, which modulates the partial stripping process and controls the charge states distribution intensities.

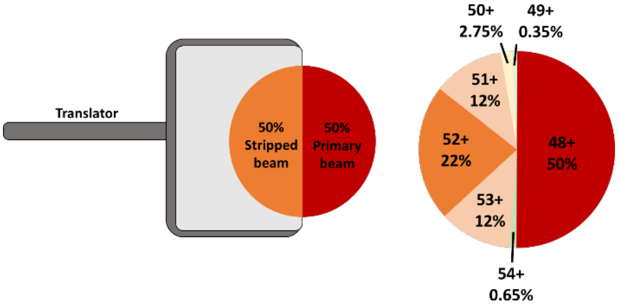

Figure 2: Left: partial stripping principle. Right: Charge states distribution of the Xe^{48+} high energy beam after 50% partial stripping with a 2.5 mg/cm² aluminium foil, showing the charge states proportions of the distribution.

Figure 2 illustrates an example of 50% beam stripping applied to the primary $^{129}Xe^{48+}$ beam. In this configuration, the aluminium stripper foil covers half of the beam spot, producing the charge states distribution shown in the right panel of the figure. This distribution can be further adjusted by varying the foil thickness or material composition. The relative intensities of the generated charge states compared to the primary 48+ beam are then fine-tuned by precisely positioning the stripper foil.

For lighter ions (from C to Ar), the process differs due to their fully stripped state required for acceleration. Since a stripper foil cannot be used in this case, a degrader could be employed instead. This slightly reduces the beam energy, thereby lowering its magnetic rigidity to achieve a similar effect.

Beam Splitting and Septa Magnet

The second step consists in separating the generated charge states and selecting those to be directed into the three beamlines. The charge states distribution first passes through a 60° dipole magnet, which deflects the beam toward the central beamline. Because higher charge states correspond to lower magnetic rigidity, they experience larger angular deviations, which facilitates their spatial separation. For example, using the $^{129}Xe^{48+}$ beam, the 51+ and 53+ charge states can be directed into the first two beamlines, while the primary 48+ beam is sent to the third beamline, as illustrated in Fig. 3.

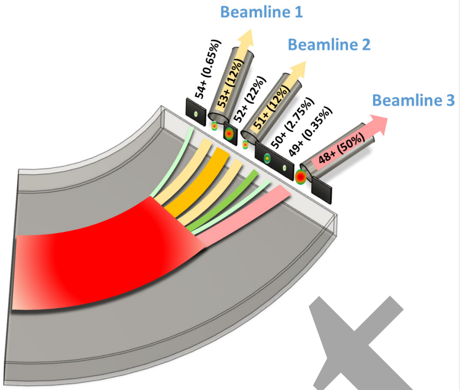

Figure 3: Separation of ^{129}Xe charge states in the 60° dipole magnet, illustrating their deflection angles and selection for the three beamlines.

However, two critical considerations must be taken into account during this separation process. First, it is essential to maintain the system's versatility, allowing adjustments to the characteristics of the beams (element, energy, charge state) delivered to users. This flexibility ensures that the system can adapt to a wide range of experimental requirements. Additionally, the small angular differences between the selected charge states, resulting from the high-energy stripping of the primary beam, present a significant challenge. These minimal angular separations require precise control to achieve clean and efficient beam separation.

To meet these two requirements, two magnetic septa must be implemented on the first and third beamlines to enhance charge states separation. A septum features a specific design that enables the deflection of one beam without perturbing nearby ones, even when their trajectories are extremely close. Its geometry is specifically optimized to minimize the gap between the magnetic field region and the field-free region, typically just a few centimeters, as illustrated in Fig. 4. Another key characteristic of these dipoles is their large field region, which allows the collection of charge states separated by a wide range of angles.

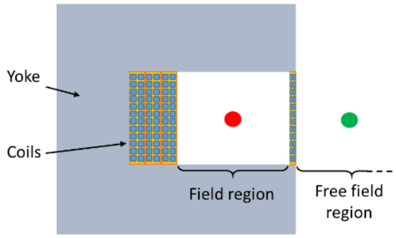

Figure 4: Schematic of a septum geometry. The red spot represent the deflected beam inside the septum, and the green spot represent the beam not deflected.

The ultimate goal of these septa is to collect charge states regardless of their angular separation (within the accepted range) and the magnetic field is adjust to deflect them onto the optical axis of their respective beamlines. These two DC magnetic septa represent the primary technical challenge of the project. Their role is critical to the feasibility of the multi-user platform, yet their highly specialized geometry demands a comprehensive design study. We are currently analysing the performance of an existing septum on GANIL's SME beamline, while also exploring the possibility of developing an entirely new geometry to meet our specific needs.

Infrastructure Modifications

One of the key requirements imposed by the space industry users is the independent control of beam intensity for each beamline. This means that each beamline must operate autonomously, with its own dedicated equipment, and that users must be able to interrupt the beam on their specific beamline to enter in the dedicated experimental cave without affecting beam delivery to the others. This requirement necessitates significant structural and operational changes at GANIL, including a revision of the historical methods used to stop and control the beam.

The middle beamline, shown in Fig. 1, is already operational for space industry applications. However, the two additional beamlines along with their dedicated experimental caves must be constructed by relocating concrete walls to accommodate the new layout.

Beyond physical separation of the experimental caves, this independence also requires modifications to the so-called *fishbone* beamline, which distributes the beam to the different experimental caves. We propose to extend the fishbone to incorporate the initial section of the three beamlines, where the beams are in close proximity. This extension will house all critical components, including the stripper foil, the 60° dipole magnet, two DC magnetic septa, and essential equipment for each beamlines such as faraday cups, slits, diagnostics, and scanning magnets.

These modifications will ensure full operational independence for each beamline, meeting the strong demands of multi-user industrial applications.

CONCLUSION

The development of a versatile beam-splitting system at GANIL represents a major advancement in addressing the growing demand for heavy-ion irradiation from the space industry. By combining selective charge states stripping with large-aperture DC magnetic septa, this system enables simultaneous, independent beam delivery to three experimental areas, which is a significant improvement over traditional time-sharing methods. The proposed design not only triples GANIL's irradiation capacity dedicated to industrial applications but also ensures full operational flexibility, allowing users to adjust beam parameters (element, energy, intensity) without disrupting other experiments.

The technical challenges, particularly the design of the septa, are currently under study. This involves analyzing existing GANIL systems while exploring innovative geometries to meet the project's requirements. The independence of each beamline, coupled with the ability to interrupt beams separately, meets the strong requirements of industrial applications, particularly for radiation hardness testing of electronic components.

Beyond GANIL, this concept demonstrates scalability and adaptability to other accelerator facilities seeking to optimize multi-user access. Future work will focus on finalizing the septa design and the beam optics, validating the system through experimental tests, and extending the platform to lighter ions using degrader techniques. In summary, this upgrade will transform GANIL's capabilities for simultaneous heavy-ion irradiation, enabling high-efficiency, multi-user operations that address the needs of both scientific research and industrial applications.

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