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Design study of a pre-separator for the LINAG super separator spectrometer

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Abstract

The super separator spectrometer (S^3) is a device being 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, which will be provided in the first phase of SPIRAL2, ions with $A/q = 3$ can reach intensities exceeding 100 p μA for lighter ones $A < 40 - 50$ depending on the final choice of the ECR (electron cyclotron resonance) ion source. These unprecedented intensities open new opportunities in several physics domains, e.g.: super-heavy and very-heavy nuclei, spectroscopy at and beyond the dripline, multi-nucleon transfer and deep-inelastic reactions, isomers, ground state properties and molecular resonances. An international collaboration has been formed for proposing physics experiments and developing technical solutions for this new instrument. All of the experiments mentioned have the common feature of requiring the separation of very rare events from intense backgrounds. Hence, the present study is aimed at finding an appropriate technical solution for a pre-separator stage of S^3. In this paper we propose some possible approaches and discuss the challenges in addressing the ion optical issues of this device. Three different layouts have been considered to date. Further studies are in progress.

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1. Introduction

SPIRAL2 is a project to expand the capabilities of the GANIL facility in nuclear physics research with exotic beams [1]. One of the new instruments envisioned is the super separator spectrometer (S^3) for high intensity stable heavy ion beams [2,3]. The physics that is proposed to be studied with the instrument includes super-heavy elements synthesis and spectroscopy, fusion and evaporation reactions, nucleon transfers, deep inelastic reactions, production of rare isotopes via secondary reactions, astrophysics at very low energy, and plasma studies [1]. A working group was formed to establish the design objectives and find innovative solutions for the S^3 device [2]. This paper summarizes the current status of some preliminary design studies of the separator stage.

2. Design objectives

It is envisioned that S^3 will be a two stage device with a separator stage and a spectrometer stage. The schematic idea for the layout is shown in Fig. 1. The purpose of the separator stage is to reject the primary beam and perform

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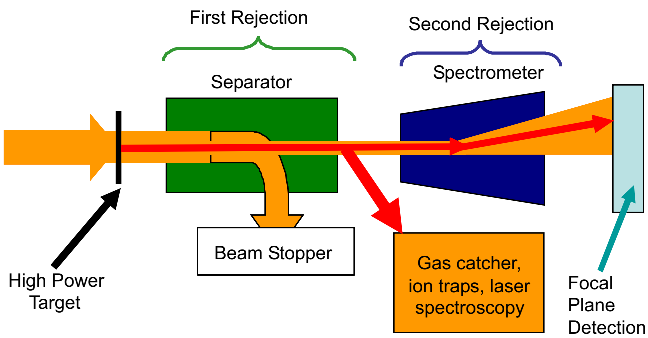

Fig. 1. Schematic idea for S^3 showing the two stage separator.

m/q selection of the recoil particles. The spectrometer stage following the separator stage will be used for secondary reaction studies.

It is a design goal for S^3 to work for symmetric, inverse kinematics and direct kinematics reactions. It will use high power targets, large beam spots, ± 0.5 mm $\times$ 10 mm and gas targets. 1–100 p μA stable beams will be used. Very high primary beam suppression is required ($\geqslant 10^{13}$) for the operation of S^3. The recoil beam will have large angular spread, ± 80 mrad in X and Y, magnetic rigidity $B\rho$ spread of $\pm 10\%$, and electric rigidity $E\rho \leqslant 30$ MV. Due to large angular and rigidity acceptance, the aberration corrections to fifth order will be required. Another design goal is high selectivity for weak reaction channels, requiring a high mass resolving power ($\approx$1:350). The spectrometer stage is envisioned to have large acceptance for secondary reaction studies. The device will have different operation modes in which the separator/spectrometer are turned on and off independently from each other.

In addition, there are also a few non optical design requirements. It is essential to keep the requirements for the individual electric and magnetic elements within practically achievable limits. Electrostatic fields of 3 MV/m with gaps of 30 cm represent practical limits in existing devices, which usually puts the limitation on the resolving power achieved. Also, when a high intensity primary beam hits electrostatic devices there is a possibility of sparking and damage to electrodes. Care must be taken to avoid this scenario while designing the lattice. This requirement limits the dispersion in these devices if the primary beam is not rejected prior to the use of electric sectors or Wien filters.

No existing devices can presently achieve all the above objectives. Due to the high intensity and the low energy of the primary beam, conventional absorber techniques cannot be used for the separation of the primary and recoil beam. The design of S^3 will be unique and challenging in this respect.

3. Proposed layout

Since the energies of the primary beams and the reaction products are low ($\leqslant$10 Mev/nucleon) both the electric and magnetic elements, and devices such as Wien filters, comprising of crossed electric and magnetic field, can be used for separation of the primary beam and recoil beam. The electric and magnetic elements provide separation based on rigidity difference, whereas the Wien filter provides separation based on the velocity difference between the primary beam and the recoil particles. The separation of particles with specific m/q ratio requires use of both electric and magnetic elements.

For ion optics design purposes, three reaction types, (a) symmetric reaction, (b) inverse kinematics and (c) direct kinematics, were identified to cover the gamut of nuclear reactions under consideration for experiments at S^3. One representative example was considered for each of the reaction types. Beam parameters necessary for the ion optics simulations, like the energy, mass and charge of the reference particle and the spot size, momentum, charge and mass spread for the incident and recoil beam were determined for all three examples. Codes such as HIVAP [4] to determine reaction cross sections were used to identify nuclear physics specific constraints. The parameters are listed in Table 1.

The ion optics design studies for S^3 have so far focused on the separator stage, and three different ion optics layouts have been proposed. Some of the designs use the Wien filter in a non standard mode for rejecting the primary beam, see Appendix A for details. First order design studies have been performed for the proposed design layouts using beam optics codes COSY Infinity [5] and Zgoubi [6]. The findings are summarized below.

Table 1
Parameters for the examples chosen for the three reaction types

	$B\rho$ (Tm)	$E\rho$ (V)	Q	β_{rel}	KE (Mev/nucleon)	x (mm)	θ (mrad)	y (mm)	ϕ (mrad)	$\delta p/p$(%)	δQ
Symmetric reaction $^{40}Ca+^{40}Ca \rightarrow ^{78}Zr+2n$											
Beam parameters ^{40}Ca	0. 602	1.394×10^7	+16	0. 077	2. 793	1	7	5	7	0	±1
Recoil parameters ^{78}Zr	0. 507	0.603×10^7	+19	0. 039	0. 735	0. 5	50	5	50	5	±1
Inverse kinematics: $^{208}Pb+^{48}Ca \rightarrow ^{254}No+2n$											
Beam parameters ^{208}Pb	1. 197	3.702×10^7	+56	0. 103	4. 996	2	5	10	5	0	±1
Recoil parameters ^{254}No	1. 132	2.861×10^7	+59	0. 084	3. 329	0. 5	7	10	7	1	±1
Direct kinematics: $^{48}Ca+^{238}U \rightarrow 114^*$											
Beam parameters ^{48}Ca	0. 947	3.046×10^7	+17	0. 107	5. 411	2	5	10	5	0	±1
Recoil parameters 114^*	0. 534	0.250×10^7	+26	0. 015	0. 113	0. 5	30	10	30	5	±1