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RIB TRANSPORT AND SELECTION FOR THE SPES PROJECT

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Abstract

At LNL INFN is under construction a Rare Isotope Facility (SPES) based on a 35-70 MeV proton cyclotron, able to deliver two beams with a total current up to 0.5 mA, an ISOL fission target station and an existing ALPI superconducting accelerator as a post accelerator (up to 10 MeV/u for A/q=7). In this paper, some highlights are presented: the high resolution mass separator, the 5 MHz buncher performances and the voltage profile errors of the CW RFQ (80 MHz, 727 keV/u, internal bunching). The problems that have been solved during the design phase are partly common to all RIB facilities, like the necessity to have an high selectivity and high transmission for a beam of a very low intensity, plus the specific challenges related to the use of ALPI (with a reduced longitudinal acceptance) and related to the specific lay out. At present the design phase has been finalised, and the procurement procedure for the charge breeder, the transfer lines and the RFQ are in an advanced state.

INTRODUCTION

SPES, acronym of Selective Production of Exotic Species, is a CW radioactive ion beam facility under construction at LNL INFN in Italy. It will produce and accelerate neutron-rich radioactive ions, in order to perform nuclear physics experiments, which will require beams above Coulomb barrier.

The main functional steps of the facility are shown in Fig. 1: the primary beam delivered by the cyclotron, the beam from the fission target (as an example, up to 10^{10} particle/s of ^{132}Sn), the beam cooler, the separators, the charge breeder and the accelerator, the existing ALPI with a new RFQ injector. The use of the continuous beam from the +1 source, which can be of LIS, PIS, SIS type, maximizes the RNB efficiency but need a CW post accelerator (RFQ and ALPI); the charge breeder is chosen to be an ECR that woks in continuous. The energy on the transfer lines are determined by the chosen RFQ input energy (wRFQ=5.7 keV/u); for this reason, all the devices where the beam is approximately stopped (production target, charge breeder and RFQ cooler) lay at a voltage:

$$eV = (A/q)w_{rfq} \quad (1)$$

The charge state range (3.5<A/q<7) is bounded by the RFQ field level for the upper limit and by the minimum voltage on q=1 transport line. A full facility layout is shown on Fig. 2.

The beam preparation scheme satisfies various requirements:

- the zone with worst radiation protection issues is reduced by the first isobar selection (resolution R=1/200).
- after that an RFQ cooler reduces the beam energy spread and transverse emittance both for the isobar separation and to cope with the charge breeder acceptance (about 5 eV and 2 mm mrad rms normalized emittance).
- HRMS and MRMS (high and medium resolution mass separators, R=1/20000 and R=1/1000 respectively) are used to select the RNB (with good transmission) and to suppress the contaminants from the charge breeder source.
- both the HRMS and the MRMS are installed on a negative voltage platform, to decrease the beam geometrical emittance and the relative energy spread.
- the 7 m long RFQ is designed with an internal bunching and relatively high output energy; this easies the setting and allows 90% transmission into ALPI longitudinal acceptance.
- an external 5 MHz buncher placed 9 m before the RFQ will provide order of 100 ns beam length for specific experiments.
- the dispersion function is carefully managed in the various transport lines; where possible the transport is achromatic, otherwise the dispersion is kept low (in particular at RFQ input D=0).

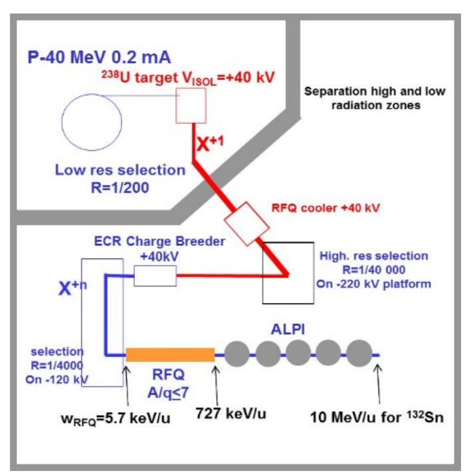

Figure 1: Functional scheme of the SPES facility. There are two main areas: the 1+ line and the n+ line, where 1+ and n+ indicates the beam charge state.

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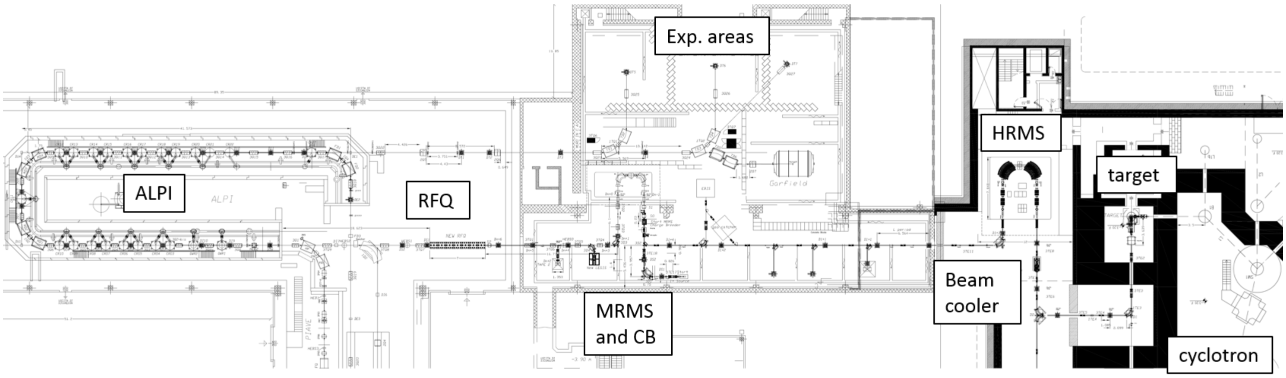

Figure 2: Full SPES layout with main areas.

METHOD FOR SIMULATIONS

The main software used for the simulation is TraceWin [1] a 3D multiparticle tracker, capable of field map usage. Thus, it is possible to take into account all the non-linear effects of the device such as the Wien Filter.

It can also perform static or dynamic errors for all beam line devices, in order to take into account a more realistic scenario.

The made simulations will be benchmarked with different programs such as GIOS and COS-INFINITY.

The TraceWin software proved capable to set all beam line for the runs of the LNL installed accelerators: this kind of commissioning was demonstrated successful for the setting of linac ALPI cavities [2].

HIGHLIGHTS

In this paper some highlights are presented: the HRMS high resolution mass separator, the 5 MHz buncher in the MRMS line and the RFQ voltage profile errors.

The HRMS

The high resolution mass separator is used to obtain the ions of interest because it removes isobars coming from the source. It is composed by six quadrupole lens, two exapole lens, two dipoles and an electrostatic multipole.

Table 1: Dipole Main Parameters

Parameter	Value
ρ	1500 mm
H/2	350 mm
V	100 mm
Edges	21.3° entry 31.0° exit

The multipole and the curvature edges will be used to fix the higher order aberration (up to 12° order). Table 1 shows the dipole main parameters. The radius and the edges may be further modified in order to boost its performances.

The reference beam used for the study is the following: $^{132}Sn^{1+}$ at 260 keV, with a normalized rms emittance of 0.0014 mm mrad, 10 times the beam cooler input emittance [3]. The beam takes into account an energy spread of $\Delta W = \pm$ 1 eV [4], which means an overall $\Delta W / W = 1/260000$. The beam is Gaussian distributed in the transverse phase space, while it is uniform distributed in the longitudinal space between ± 180°.

The dispersion at the image point is 90 m, while the beam transverse dimensions at the image point is 0.6 mm. We can calculate the linear resolving power, which is shown below:

$$\frac{D_x}{2 \cdot r_{beam}} = 75000 \tag{2}$$

The curvature aberrations are included in the multiparticle routine of TraceWin. After a first optimisation the emittance growth is reduced down to 7%, which allows a fully separation of two beams of 1/20000 in mass, as shown in Fig. 3.

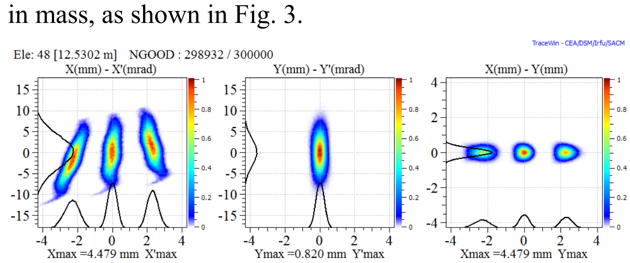

Figure 3: Phase space at the HRMS image point. The three beams are separated of 1/20000 with ± 1eV energy spread.

The optics improvement is still ongoing but is shows a fully resolving capability of isobars separated of 1/20000 in mass. It is important to take into account that its performance depend on the beam cooler efficiency.

The 5 MHz Buncher

A 5 MHz buncher is provided in the MRMS for those experiments, which require order of 10^2 ns beam length.

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This system proved to increase the beam transmission compared to a "pure" chopping device (see Table 2).

The number of harmonics studied are up to three. The input beam comes from the MRMS separator: $^{132}Sn^{19+}$ at 760 keV with a normalised rms emittance of 0.1 mm mrad and an energy spread of ±15 eV.

The buncher is placed at 9 m from the RFQ, where the phase focus is set; the E_0TL for the single harmonic cavity is set 657.9 V.

The following table shows the longitudinal rms emittances and the transmissions varying the number of harmonic of the buncher.

Table 2: Buncher Performances Varying the Harmonics

n. of harmonics	**transmission**	**Emittances (keV deg/u)**
No buncher	3%	5.1
1°	50%	2.3
2°	60%	3.4
3°	70%	4.5

The values shown in the Table 2 take into account the chopper effect. However, it is still possible to see the improvement in transmission and longitudinal emittance at the exit of the RFQ (simulated via TOUTATIS) even if a single harmonic buncher is used.

RFQ Errors and Tuning Range

Two main studies were performed regarding the voltage profile: the tilt and the one harmonic contamination (see eq. 3).

The nominal voltage V_n was perturbed following Eq. 3:

$$V(z) = V_n(z) + V_{error} \cdot V_n(z_0)\cos\left(\frac{\pi}{L}z\right), \quad (3)$$

where V_{error} is the error applied, V is the voltage applied at each vane, L is the length of the RFQ, and z_0 its starting point. The modulation is introduced by the cosine function.

The beam input for the RFQ belongs to the MRMS matching line, in such a way to take into account all the remaining aberrations.

Figures 4 and 5 show the relative emittance growth and transmission. From these plots, it is possible to choose the tuning range, which is set between ±3% [5].

The chosen tuning range ensures a maximum longitudinal emittance growth of 2.25%, and maximum relative losses of 0.28% respect to the nominal case.

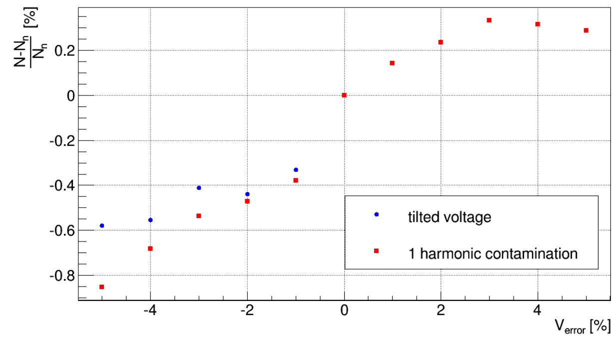

Figure 4: relative transmission vs voltage error. Tilt and one harmonic contamination are shown.

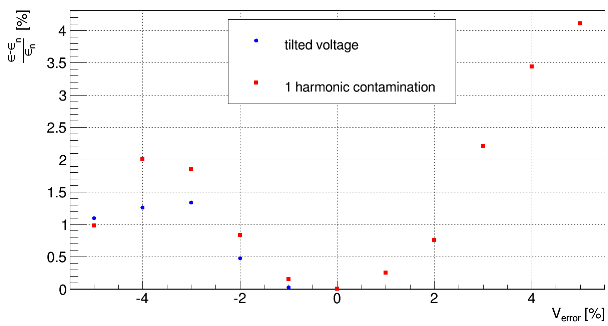

Figure 5: relative longitudinal rms emittance growth vs voltage error. Tilt and one harmonic contamination is shown.

CONCLUSIONS

Several highlights of the SPES project were shown [6]. The high resolution mass separator first optimisation shows its capability of fully resolve 1/20000 separated in mass ions with ±1 eV. Moreover, there is possibility for a further optimisation to keep into account several type of different errors.

The beam dynamics simulation for a 5 MHz buncher resulted in an efficient bunching system capable to improve beam longitudinal emittance and transmission compared to a "pure" chopping system. The possibility to use more harmonics was also studied.

The RFQ voltage profile errors supplied the needed information for the tuning range. The chosen range ±3% ensures low emittance growth and 0.28% relative losses.

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