BEAM DYNAMICS OF THE LINAC ALPI-PIAVE IN VIEW OF POSSIBLE UPGRADES SCENARIO FOR THE SPES PROJECT

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Abstract

At the Legnaro National Laboratories it is operating a Super Conducting linac for nuclear studies named ALPI. The ALPI linac is injected either by a XTU tandem, up to 14 MV, or by the s-c PIAVE injector, made with 2 SC-RFQ. In this article will be report the beam dynamics simulations for some possible scenario upgrade of the linac operate by a new injector, made with a new RFQ.

INTRODUCTION

The SPES strategy is to develop a facility for Nuclear Physics research together with a facility for applied Physics based on the same technology and infrastructure.

SPES [1] is designed to provide neutron-rich radioactive nuclear beams (RIB) of final energies in the order of 10 MeV/A for nuclei in the A= 9-160 mass region. The radioactive ions will be produced with the ISOL technique using the proton induced fission on a Direct Target of UCx [2] and subsequently reaccelerated using the PIAVE-ALPI accelerator complex. A Uranium fission rate of 10^13 fission/s is foreseen.

Fig. 1 shows schematically the SPES main elements located at underground level, a second floor at ground level hosting laboratories and services is not shown.

The driver is the proton cyclotron delivering beam on different targets. Two production ISOL targets are planned to be installed. The production target and the first mass selection element will be housed in a high radiation bunker. Before the High Resolution Mass Spectrometer (HRMS) a cryopanel will be installed to prevent the beam line to be contaminated by radioactive gasses and a RFQ cooler to reduce the input emittance of the HRMS. After passing through the HRMS, the selected isotopes will be stopped inside the Charge Breeder and extracted with increased charge (n+). A final mass selector will be installed before reaching the PIAVE-ALPI accelerator, to clean the beam from the contaminations introduced by the Charge Breeder itself.

THE NEW RFQ INJECTOR

The injection to the ALPI Linac is based on the use of a new Radio Frequency Quadrupole, with the adiabatic bunching inside. In this way a high voltage platform can be avoided, and a higher overall transmission could be achieved.

The new RFQ will operate in a CW mode (100% duty factor) at a resonant frequency of 80MHz. This frequency is the same as that of the lowest energy ALPI superconducting structures. The injection energy of ions was set to 5.7 keV/u. This choice is a compromise between the desire to reduce the ion energy to simplify the LEBT and RFQ bunching section design and the need to increase the injection energy to reduce space charge effects. The extraction energy was set to 727 keV/u, higher than the output of PIAVE RFQ, to optimize the beam dynamics of the SRF linac. Table 1 summarizes main new RFQ parameters [3].

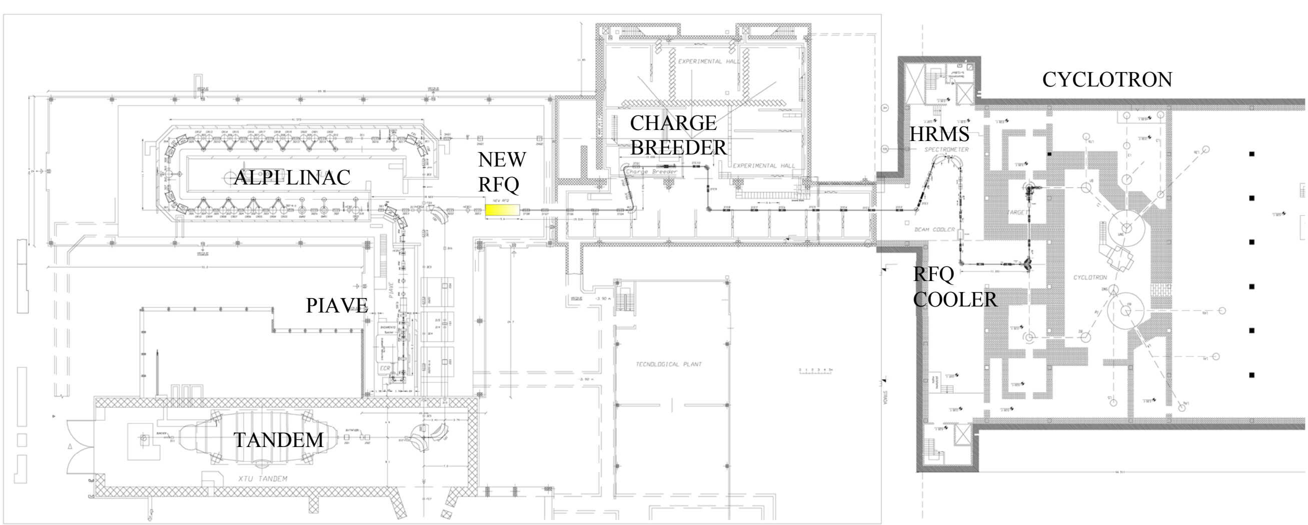

Figure 1: Layout of the SPES and ALPI facility; the dark black part on right is the new Cyclotron area. In yellow the new RFQ as ALPI injector.

Table 1: Principal RFQ parameters

Operational mode	CW
Frequency (MHz)	80.
Injection Energy (keV/u)	5.7 (β=0.0035)
Extraction Energy (keV/u)	727 (β=0.0395)
Accelerated beam current (μA)	100
Ratio Charge over Mass (Q/A)	7 – 3
Internal bunching section	Yes

The design goals were to minimize the longitudinal and transverse emittances and to optimize the RF losses and transmission of the RFQ structure.

A comparison with the PIAVE injector, show the advantage of the new RFQ: it has better transmission with a lower total longitudinal emittance, see table 2. The PIAVE SRFQ is with a lower RMS longitudinal emittance due to the external 3 Harmonic buncher.

Table 2: Comparison PIAVE-new RFQ

Parameter [units]	PIAVE SRFQ	NEW RFQ
A/q	8.5	7.0
Input Tr. Norm. RMS emittance [mmmrad]	0.071	0.1
Output Energy [keV/u]	587 (β=0.0355)	727 (β=0.0395)
Output RMS Long. emittance [degkeV/u]	2.2	4.3
Output 90% Long. emittance [degkeV/u]	62	16
Transmission [%]	72	95
QWR 0.047 TTF	0.85	0.95
QWR 0047 DY' [mrad]	-0.48	-0.32

THE ALPI LINAC UPGRADE

The present configuration of the Legnaro superconducting accelerator complex (PIAVE injector and ALPI main accelerator) fits the requirements for SPES post acceleration too. Nevertheless an upgrade of its performances both in overall transmission and final energy is needed and a solution which minimizes the impact on the present structures [4].

The super-conducting linac ALPI is injected either by a XTU tandem or by the s-c PIAVE injector, see Fig. 2. The linac (at the present 64 cavities and a total voltage of 48 MV) is build up in two branches connected by an achromatic and isochronous U-bend. ALPI period consists in one triplet and 2 cryostats (4 cavities in each cryostat), and a diagnostic box (profile monitor and Faraday cup) in between.

The PIAVE-ALPI complex is able to accelerate beams up to A/q = 7. Higher A/q ions suffer from too low injection energy to the medium-β cryostats, where the RF defocusing is too strong and the beam gets easily lost onto the cavity beam ports. In the last years the average cavity accelerating field has been enhanced by more than a factor of two with respect to the original design value. The strength of the focusing lenses on the other hand, has remained the same, 20 T/m, therefore, even for 6 < A/q < 7 it is hard to design a proper longitudinal beam dynamics such that it will not cause problems on the transverse plane. To fully exploit the available acceleration gradient, some improvements are required in the layout of ALPI.

In this framework, it has been proposed to promote the presently "bunching" cryostats CRB2 and CRB4 (at the beginning and end of ALPI) to the role of "accelerating" cryostats CR21 and CR22, equipping them with 8 additional Nb-sputtered QWRs.

The role of the 160 MHz buncher CRB2 can be taken by the already existing 80 MHz NC buncher HEB2 for relatively light beams injected by the Tandem directly into the 160 MHz medium β_{opt} section, with negligible beam loss.

For SPES, the Radioactive Ion Beam at 727 keV/A will be injected into ALPI by means of the QWRs actual present into PIAVE, that will be moved in at the begin of ALPI, with a different period: QWR1, triplet, QWR2, triplet, to reduce the longitudinal phase advance, see figure 2 and figure 3 and the envelopes in figure 4, the other parts of ALPI remain unchanged.

In this scenario the ALPI configuration is with qwr1-2 at 4 MV/m, CR03-CR18 at 4.5 MV/m and CR19-CR22 at 6.5 MV/m.

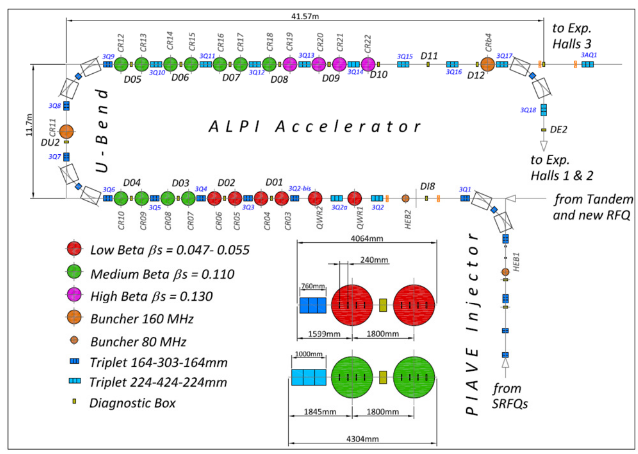

Figure 2: New ALPI Layout: the low Beta, red circles, begins with a shorted period.

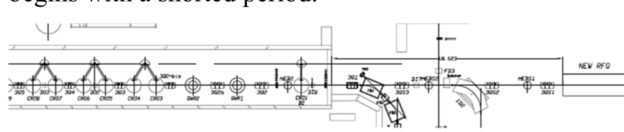

Figure 3: Layout of ALPI with the new RFQ as Injector.

THE ALPI BEAM DYNAMICS

By using this new ALPI layout and with the help of the new RFQ the losses in the ALPI linac are reduced at about 6%: 3% in the first branch of the linac and the other 3% in the high energy branch of the ALPI linac see figure 5. The input distribution is assumed gaussian at 3σ, with a longitudinal cut on +/-50° on phase. The transverse emittance is below in the case of PIAVE, because it has been measured, in the case of the new injector it has been assumed a larger margin on the emittance, probably by a factor 2.

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The beam is focused between the cryostat with a spot size of about 0.3 mm RMS. In the first half of ALPI the synchronous phase is set +/- 20° as needed to focalize/steerer the beam and to reduce the longitudinal phase advance. After the U bend of ALPI, the cavities phase is set to -20°.

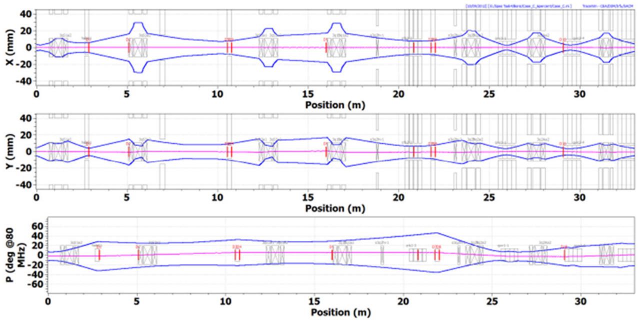

Figure 4: Multiparticles beam envelopes from the new RFQ to CR03, from left to right.

CONCLUSIONS

In table 3 is reported the comparison on performance between the PIAVE and the new RFQ as injectors of ALPI, the main advantage of the new RFQ is in term of global transmission, i.e. taking into account the performance of the internal bunching section of the new RFQ. The low longitudinal emittance, produce by the new RFQ, play an important role to permit a good transport through ALPI, but at linac end this high transmission can induce a larger beam emittance on the longitudinal plane. An upgrade of the triplets of ALPI are not been take into account due to the high cost, in this scenario this is the principal limit, i.e. the maximum gradient force of 20 T/m do not permit to reduce the losses at zero on any injectors. The actual limit on energy is also connected to the dipoles maximum rigidity and with the problems/costs connected with the installation of new cryostats.

Table 3: PIAVE-ALPI versus new RFQ-ALPI

Parameter [units]	PIAVE-ALPI	new RFQ-ALPI
A/q	7.0	7.0
Output Energy [MeV/u]	10.1	10.3
Output RMS Long. emittance [degkeV/u]	18	32
Alpi Transmission [%]	88	94
Total Transmission [%]	62	90

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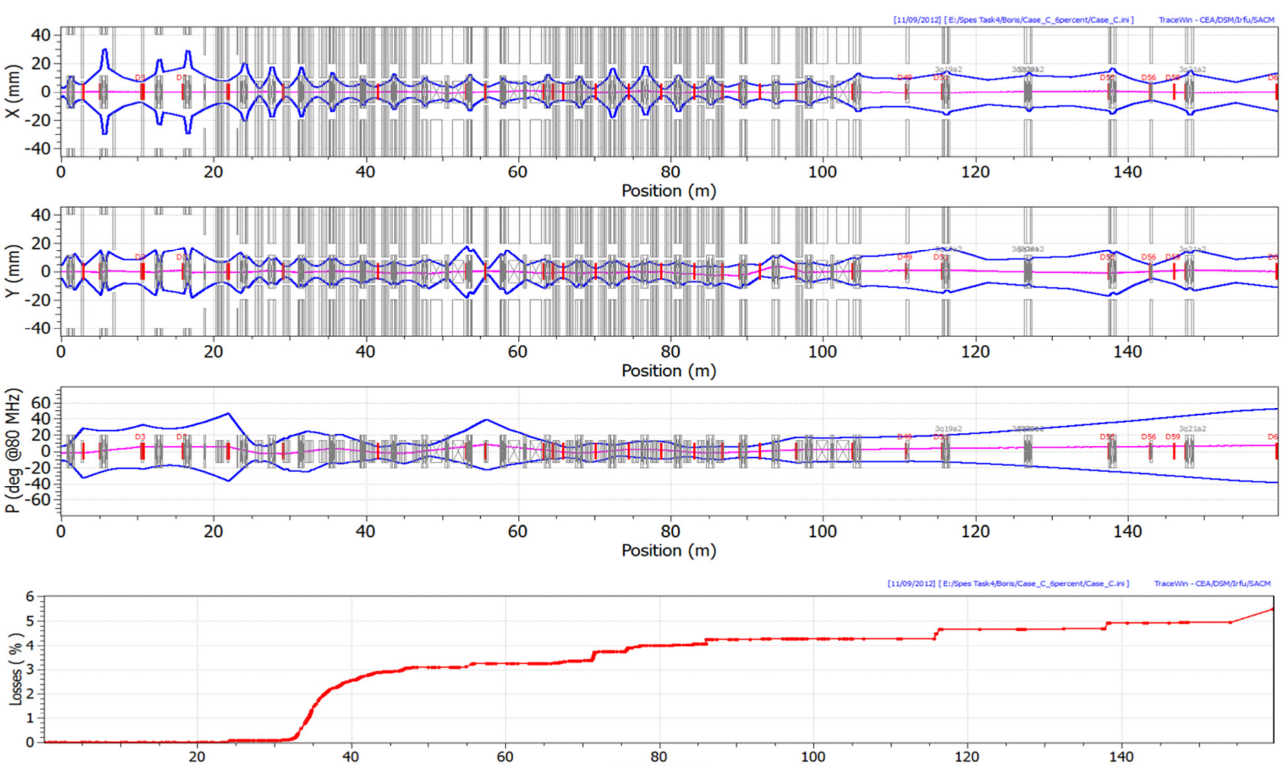

Figure 5: Multiparticles beam envelopes of the ALPI and losses, with the beam coming out from the new RFQ, from left to right.