# BEAM DYNAMICS SIMULATIONS OF THE PIAVE-ALPI LINAC

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*Abstract*

At the Legnaro National Laboratories it is operating a Super Conducting linac for nuclear studies. 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. The main part of the linac (at the present 64 cavities for a total voltage up to 48 MV) is build up in two branches connected by an achromatic and isochronous U-bend. The PIAVE-ALPI complex is able to accelerate beams up to A/q = 7. The layout of the linac ALPI is, from the point of beam dynamics, quite complex due the presence of RFQs, cavities, dipoles, magnets, etc. These elements behaviours are entirely not linear, so a small change on the settings can induce a big change in the Linac beam dynamics. An automatic tuning procedure and a full field maps description are mandatory to handle a so high number of active components. The program used at this scope is TraceWin that is able to do an envelope simulation and a full multiparticles simulation.

## INTRODUCTION

The ALPI ( Acceleratore Lineare Per Ioni ) accelerator is a flexible structure for nuclear physics study with heavy ions. ALPI is able to delivering ions in the mass range between Si and U, with a final beam energy range from 6 up to 20 MeV/u. Its flexibility is mainly due to the presence of a variety of elements (RFQs, QWR cavities, dipoles and quadrupoles magnets, etc) which can be independently set. However, the best machine setting for a optimized beam transport should be find among a large number of possible solutions.

The usual ALPI operation requires a careful preparation of the machine setting for each single beam which is analyzed with a full multiparticles simulation program. The program used at this scope is TraceWin [1] which has the advantages of using the QWR fields' maps with a wide-ranging matching criteria and a full Graphics Output.

Some operational cases are here reported, namely a delivery of $^{76}Ge^{11+}$ with final energy of 164 MeV in the configuration of XTU Tandem-ALPI in February 2010, a delivery of $^{136}Xe^{26+}$ with 870 MeV using PIAVE-ALPI in May 2010 – both beams were delivered for the AGATA detector. For the Tandem-ALPI configuration here are shown the cases of the shift $^{16}O^{6+}$ at 192 MeV delivered to the III experimental hall, and the shift $^{82}Se^{11+}$ at 515 MeV delivered to the I-II halls. Both these beams were accelerated in May 2009.

These run are made with the full QWRs RF field maps. All the cavities used in ALPI have been simulated with both HFSS and COMSOL, to generate the electric and magnetic fields for TraceWIN [2]. The calculated accelerator model does not take into account any statistical errors due to misalignments of the elements or amplitudes of the fields.

## BEAM DYNAMIC SIMULATIONS

The preparation of the input file for the simulating program is simplified by using a spreadsheet program [3]. In facts many input parameters, such as the initial kinetic energy W, the RMS beam emittance $\varepsilon_{RMS,n}$ and the relative energy spread of the beam ΔW/W, change as soon as the mass A and charge Q of the ion are changing. Furthermore the maximum field performance of all the 71 QWRs should be provided as input, and last but not least, the magnet setting is rescaled from a reference setup scaled with the rigidity of the beam.

The input conditions after the SRFQ in PIAVE are a bunched beam perfect matched with the ALPI input with a quite large transverse $\varepsilon_{RMS,n}$ of 0.1 mm-mrad (actually measured), and a longitudinal $\varepsilon_{RMS}$ of 0.89 deg-keV/u. When the beam comes from XTU Tandem a continuous beam with ΔW/W of 0.3% is used, under the assumption of transverse $\varepsilon_{RMS,n}$ of 0.1 mm-mrad. The values of emittance and energy spread used for the XTU Tandem are only assumptions since they have never been measured.

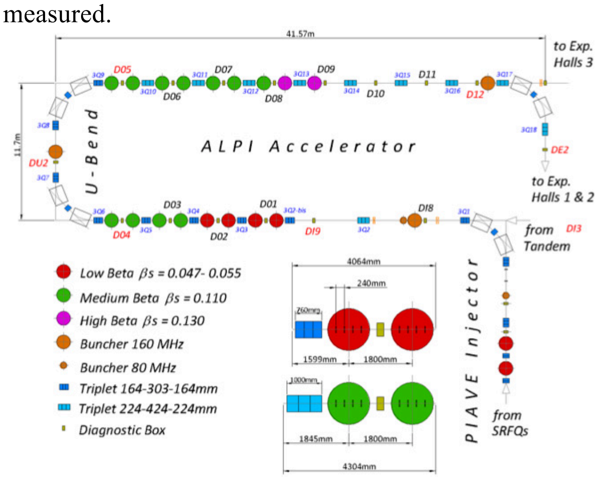


Figure 1: Layout of the PIAVE injector and the ALPI Linac. The three different beta sections of the accelerator are shown in different colours. The change of the lattice length before and after the U-bend is also exposed in the bottom right part of the picture. The names in red for the beam diagnostic box are where the beam current can be measured by a Faraday Cup.

The simulation starting points are shown in Fig. 1, with zero dispersion in both cases. The ends of the simulations is the FC7 for the experimental halls I and II and DT5 for hall III.

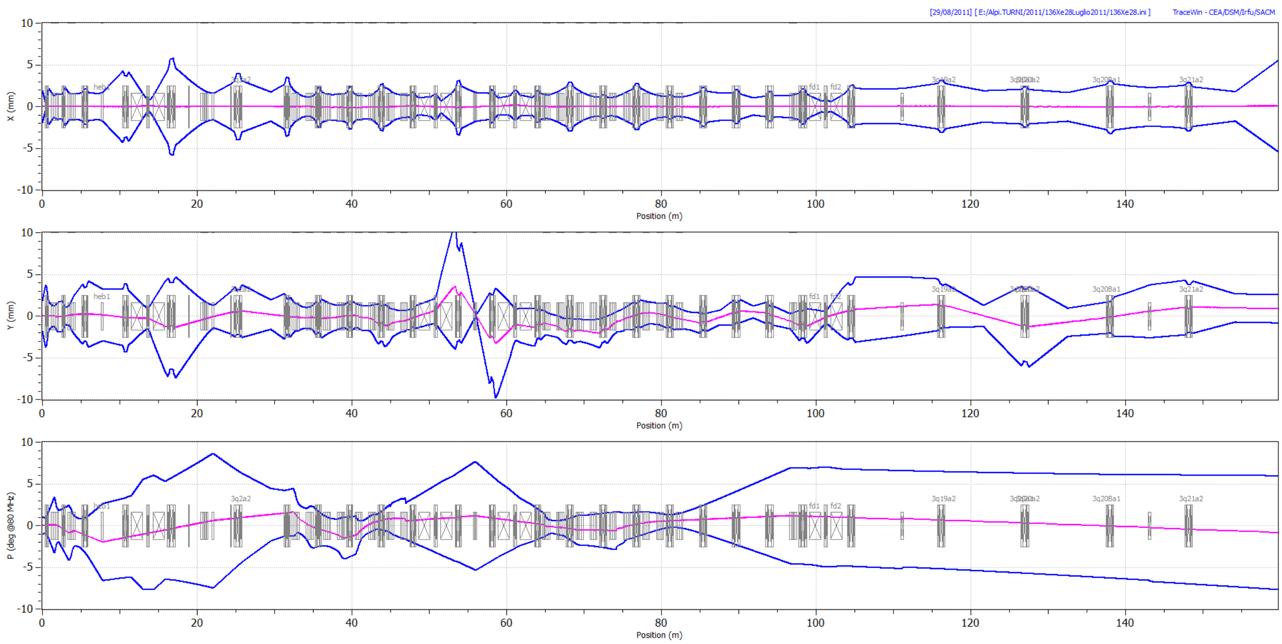


Figure 2: Multiparticles RMS envelopes on X,Y and Phase, in the case of PIAVE-ALPI $^{136}Xe^{28+}$ in July 2011, from the Exit of SRFQ to the 2° Experimental Hall.

Before the simulation TraceWin changes automatically the magnets setting and the accelerating fields of the buncher for matching some criteria. Some of them are:

- Beam size waist between the cryostats of 3 mm rms.
- Longitudinal waist at the entrance of the CR07 or CR03 cryostats.
- Maximum beam size of 10 mm radius.
- Keep the vertical centre of the beam on the beam axe.

## ANALYSIS OF THE RESULTS

In the following graph are reported the simulations losses results along the LINAC (line) and the losses reported in the Faraday Cups diagnostics in the experimental shift (cross points).

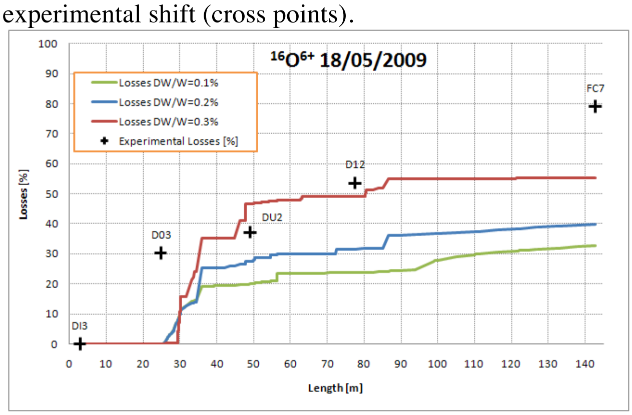


Figure 3: The beam current measurement in D03 and DT5 is not optimized because particles are passing out of the centre of the diagnostic box and not all of them are intercepted by the Faraday Cup. The discrepancy in DT5 is also reasonable with a misalignment of the transport line.

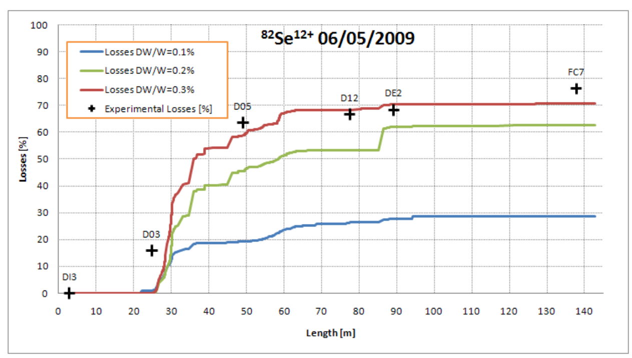


Figure 4:Three theoretical losses curves are plotted with different assumption of energy spread for the input beam. It is visible a good agreement between simulation and measurements with the hypothesis of a tandem energy spread of 0.3%.

The LINAC ALPI turned out to be properly descripted by nonlinear accelerating elements. The TraceWin simulating tool seems to give a realistic picture of the complexity of the actual beam dynamics in some cases, although the predictions are depending on some parameters that cannot be promptly measured with the diagnostics actually installed on the accelerator line.

It should be pointed out that all the experimental data presented here were not optimized for the study of the machine, but they are just the values reported on the logbook for preparing the correct condition for the nuclear experiment without delay.

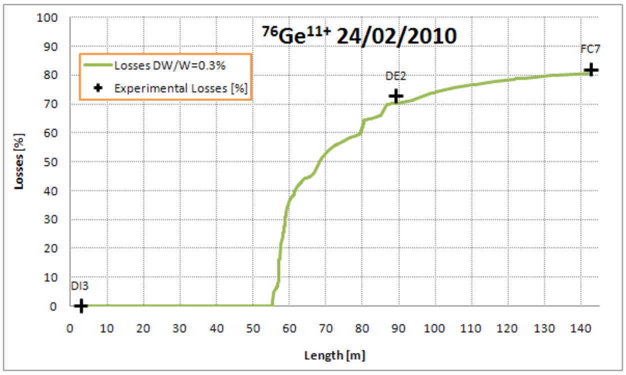


Figure 5:The simulation well predicts the losses also in case of anomalous transport. The bunching was done in the high energy ALPI branch.

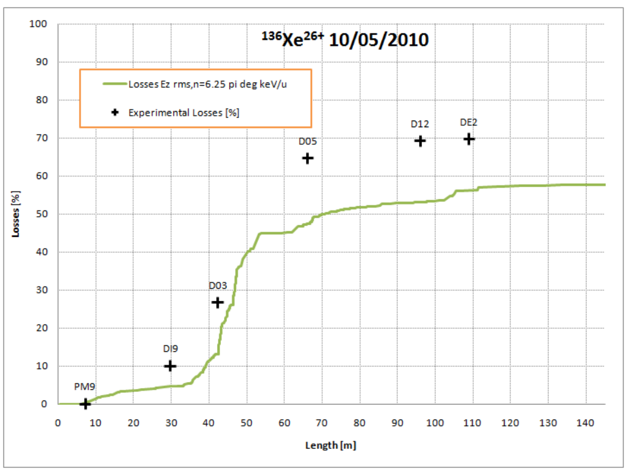


Figure 6:The real injection from PIAVE is affected from problems of misalignment with the ALPI input, and the effects of vertical steering of ±2 mm induce a lot of losses after D03.

Nevertheless one has to keep in minds that the complete optimization of machine can be realized on one hand if the misalignment of the elements are minimized or simply known, and on the other hand if diagnostics can provide more accurate and more detailed information of the actual shape of the beam.

As soon as the precision of the calculations increases, and therefore the machine is better understood, better solutions can be found and the proper selection of the machine setting can increase also the overall transmission.

## FURTHER INVESTIGATION

Some test has been made to check the response to the transmission of some of the injector parameters. Both RFQs voltages appear very sensitive to the global transmission, and this can be explained by checking the surviving longitudinal particles. The acceptance simulation, made with a very small transverse emittance, shows a narrow "good" area, see fig. 6, in the longitudinal phase plane. The calculation is done for the actual set up of the accelerator for the shift of $^{136}Xe^{28+}$ of June 2011, with 2 complete cryostats missing. More in general is necessary to introduce a longitudinal larger stable zone by choosing at beginning some larger value of cavities RF phases. Also the injector PIAVE is suffering of 1 cavity missing, this reduce the Transit Time Factor of the low beta cavities at the begin of ALPI.

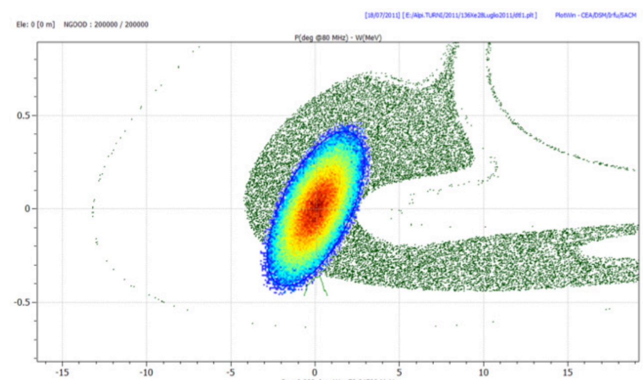

Figure 7: Longitudinal acceptance on the complex PIAVE-ALPI, with the beam injected from the RFQ, for the shit of $^{136}Xe^{28+}$ of June 2011.

## CONCLUSION

The comparison between simulated and measured transmission data shows that the above described method predicts the losses along the linac. The enhanced reliability of the simulations permits "virtual" experiments in order to evaluate the use of a larger number of ion beams and new machine setups, for an overall improvement of performances of the TANDEM-PIAVE-ALPI complex.

## REFERENCES

[1] D. Uriot et al., PAC03 Conf., FPAD012.
[2] M. Comunian et al., this Conference, MOPC089.
[3] M. Comunian et al., LINAC10 Conf., THP082.