COMPLETE SIMULATION OF THE HEAVY ION LINAC PIAVE

A. Pisent, M. Comunian,
INFN- Laboratori Nazionali di Legnaro, Padova, Italy.

Abstract

PIAVE is the new injector under construction at LNL for the super conducting linac ALPI. The beam, generated by an ECR source, will be bunched by a three harmonic buncher and accelerated by a couple of super conducting RFQs, followed by eight QWR, for an equivalent voltage of 8 MV (U^{+28} beam). We present here the complete simulation of the injector, where the same ensemble of particles is transported from the buncher up to ALPI. The code used are PARMTEQM, PARMILA and specific software has been written to transport the particles in the field distribution (calculated by MAFIA) of the transition between the two RFQs and in the QWRs accelerating gaps. The performances of this design, especially for what longitudinal emittance is concerned, are discussed in this paper.

PARAMETERS OF THE LINAC

At LNL a new positive ion injector for the super conducting linac ALPI is under construction. The new linac, named PIAVE, will have an equivalent voltage of about 8 MV and will allow the acceleration of ions up to U above the nucleus-nucleus barrier. More details about the project status are given in the general paper [1].

In this paper, after a general overview of the beam parameters of PIAVE (Tab. I), we shall concentrate on the points that have been defined in this last period, namely the Low Energy Beam Transport Line (LEBT), the external bunching, the transition between the two super conducting RFQs. Moreover we show the simulations of the complete injector, where the same ensemble of particles is followed form the buncher up to ALPI.

Table 1
Injector parameters

Source and LEBT			
Ion source	ECR	14 GHz	
Mass to charge ratio	8.5÷1		
Platform voltage*	315	kV	
RMS Emittance	0.1	mm mrad	norm.
Bunching system	3H	40;80;120	MHz
$\Delta\varphi$	±6	deg	80 MHz
ΔW	±0.55	keV/u	
RFQ Accelerator			
Radio Frequency	80	MHz	
Input Energy	37.1	keV/u	β=.0089
Output Energy	586	keV/u	β=.0355
Max. Surface field*	25	MV/m	
Max. stored energy*	≤4	J	RFQ
Acceptance#	≥0.9	mm mrad	(norm.)
Output Emit. RMS	0.1	mm mrad	(norm.)
	≤0.14	ns keV/u	
	SRFQ1	SRFQ2	
Vanes length	137.8	74.61	cm
Output energy	341.7	586	keV/u
Voltage *	148	280	kV
Number of cells	42.6	12.4	
Average aperture R_0	0.8	1.53	cm
Modulation factor m	1.2-3	3	
Synchronous Phase	-40÷-18	-12	deg
QWR Section			
Number of resonators	8		
Output energy*	948	keV/u	β=.045
Radio Frequency	80	MHz	
Optimum β	0.05		
Accelerating Field	3	MV/m	
Shunt impedance	3.2	kΩ/m	
Synchronous Phase	-20	deg	
Matching Line to ALPI			
Number of bunchers	2	(room temperature)	
Buncher eff. Voltage VT	≤100	kV	

THE LEBT

The LEBT is now completely defined, magnets have been ordered to the industry and the construction of the bunchers has been launched.

The line, following the accelerating column, is composed by an achromatic bend, a couple of doublets that make a small waist at the buncher, followed by the second couple of doublets needed for the matching at the RFQ input.

After the analysis of different options we have selected a three harmonics buncher, with 40 MHz as fundamental frequency, at a distance of 3.51 m from the RFQ input. Indeed, since for each harmonic we use a two gaps configuration, the first and the third harmonics are applied in a first buncher, the second harmonic in a second buncher at a distance of 120 mm; all voltages are below 4 kV [2] [3].

The design efficiency of the bunching is such that 70% of the particles are captured by the RFQ with a final RMS longitudinal emittance of 0.13 ns keV/u with nominal focusing. Simpler configurations, like double drift double frequency bunchers, have not the same

* The values are referred to mass over charge ratio 8.5*($^{+28}U^{238}$)*.

We conventionally relate total and RMS values as $\varepsilon=5*\varepsilon_{rms}$

performances, due to the fixed distance between the two bunchers and the consequent difficulty of getting small beam waists in all gaps.

THE RFQS

The major constraints for the RFQ design, dictated by the superconducting nature of the cavities, are the maximum electric surface field E_s (25 MV/m) and the maximum stored energy per resonator U (4 J). This last value is imposed by the RF power needed to keep the resonator locked within the required frequency window of ±10 Hz.

Due to the high costs of a super conducting structure and associated cryostat in the design of the RFQ modulation big emphasis was given to the maximization of the average acceleration; this was pursued with the external bunching, and keeping the modulation factor m, kR_0 (average aperture over modulation wavelength) and intervane voltage V relatively large [4][5]. Moreover the specification for U imposed the use of two electromagnetically decoupled RFQs.

The drift space of 200 mm between the two RFQs electrode terminations determines a certain beam mismatch in SRFQ2 and a consequent problem in keeping the specified acceptance. Cutting the electrodes where the beam envelopes have a waist can minimize the problem [6][7]. This corresponds to a length of

$$\frac{\beta\lambda}{2}\left(\frac{1}{2}-\frac{\phi_s}{\pi}\right)$$

for the last cell of SRFQ1 and correspondingly for the first cell of SRFQ2 (almost *half-cell*).

This *half-cell* has been simulated using MAFIA Electrostatic solver, so to have an accurate description of both the focusing and the accelerating field components. In doing this it is important to take into consideration the (local) electrode voltage relative to ground, determined by the resonator supports geometry. In our resonator the modulation is such that, in first approximation, this special cell has the focussing effect of half-cell (minimum mismatch) and the acceleration of a full cell (maximum acceleration) [8].

SIMULATIONS

Multi-particle simulations have been done using the LANL programs PARMTEQM, in the RFQs, and PARMILA, for the transfer lines and the QWRs section. The same ensemble of 10000 particles is transported from the bunchers up to the end of the accelerator. The space charge can be completely neglected up to 5 μA, while we do not aspect more than 1 μA from the source. In the transition between the two RFQs particle trajectories are calculated with a dedicated code using the MAFIA fields.

In fig. 1 we summarized the result of simulations as function of the initial transverse emittance; namely the RFQ transmission, the total PIAVE transmission (including bunching efficiency), and the longitudinal emittance after the RFQs and after the QWRs are plotted. In the QWR section there is an emittance growth due to the change of longitudinal and transverse focusing structure. Nevertheless correspondingly to the ECR nominal RMS emittance (0.1 mmmrad) 70% of the particles are transmitted with a final longitudinal emittance within the specifications.

In fig. 2 we show the transverse and longitudinal phase space in critical locations for the nominal beam. In particular it is possible to appreciate the longitudinal phase space evolution all over PIAVE and the residual mismatch at the transition between the two RFQs.

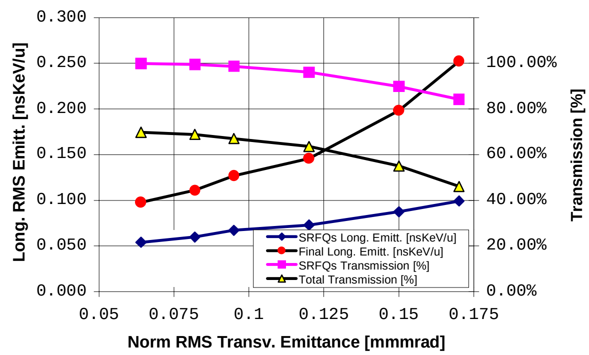

Fig. 1 Long. Emittance and Transmission as function of Transverse Initial Emittance.

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REFERENCES

[1] Lombardi et al., “The new positive ion injector PIAVE at LNL” This Conference Proceedings.
[2] M. Comunian, A. Pisent, “LEBT and Three Harmonics Buncher Design for PIAVE” LNL Annual Report, 1996.
[3] Facco, F. Scarpa, “The new triple harmonic buncher for the PIAVE project” ibid.
[4] BenZvi, A. Lombardi and P. Paul, Particle Accelerators 35 (1991) 177
[5] Pisent, “Beam Dynamics of the new LNL Injector” LNL-INFN (REP) 107/96.
[6] Y. Iwashita, H. Fujisawa, Linac Conference Ottawa, 1992, pg. 698-700.
[7] Kolomiets, LNL Internal note.
[8] Pisent, M. Comunian, in preparation.

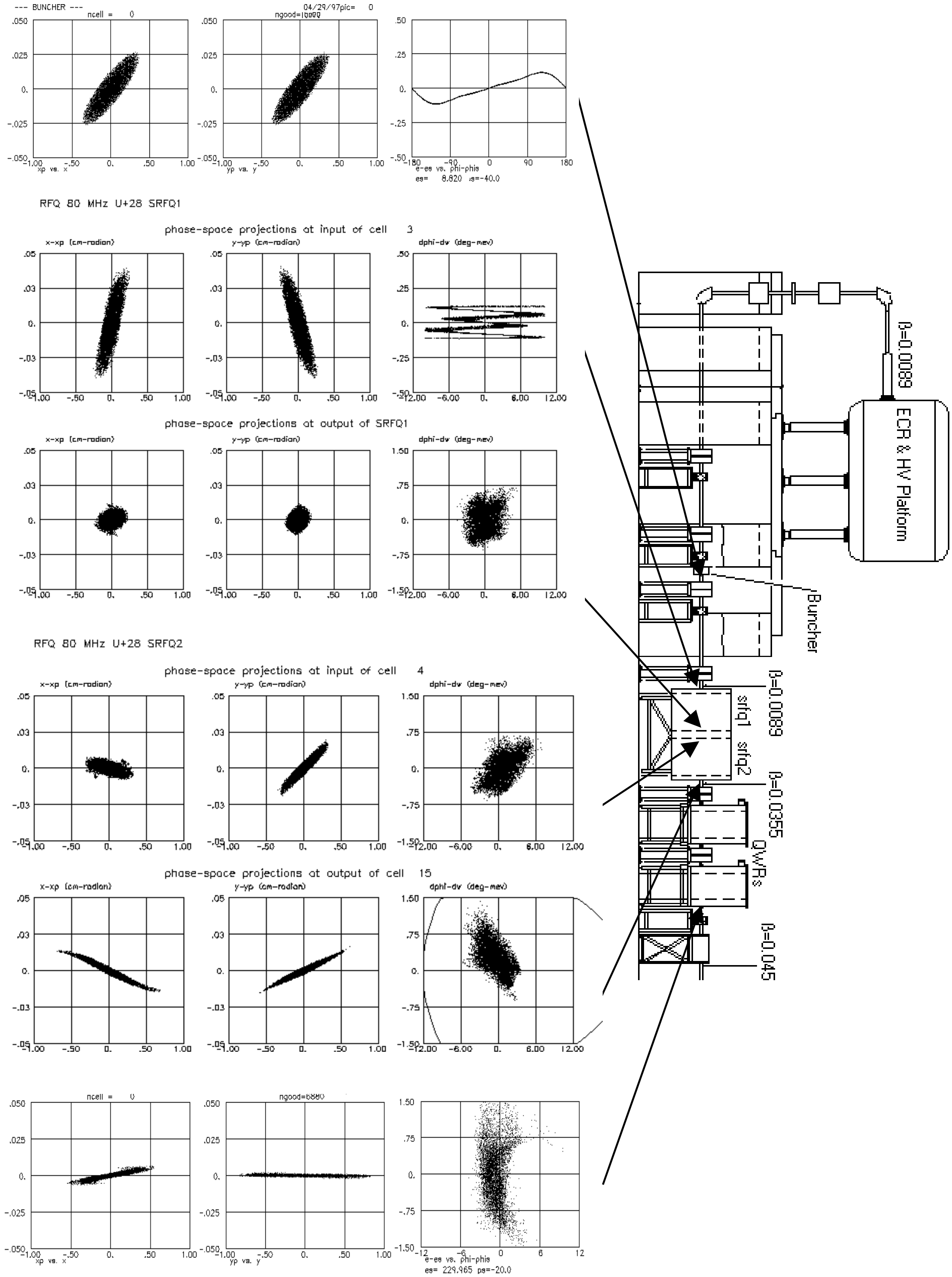

Fig. 2 PIAVE layout and transverse and longitudinal phase space in various locations.