Simulations of experiments on the Chopper-line at CERN

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Abstract

Linac4, the new accelerator under construction at CERN, is designed to accelerate H- ions to 160 MeV for injection into the existing Proton Synchrotron Booster. The low energy section, comprising an H- ion source, a LEBT, a 352.2 MHz Radio Frequency Quadrupole and a 3 MeV chopper line will be assembled at CERN in the next year.
Linac 4 is also designed as an injector for the SPL, a high power proton driver delivering 5MW at 4 GeV. In this case the beam losses must be limited to 1 W/m and therefore the formation of transverse and longitudinal halo at low energy becomes a critical issue which has to be measured and controlled.
The chopper-line is composed of 11 quadrupoles, 3 bunchers and the chopper itself. Its beam dynamics will be characterized with specific detectors and diagnostic lines. In particular the transverse and longitudinal halo will be measured by a Beam Shape and Halo Monitor (BSHM) with a sensitivity of 10.000 particles per bunch and a time resolution of 2ns.
In this paper we present the simulation work in preparation for the measurement campaign scheduled in 2009.

This paper is in support of deliverable CARE-HIPPI-2007-37. The deliverables included the results of a measurement campaign on the 3 MeV test stand at CERN, that turned out to be impossible during the HIPPI time frame. The IPHI-RFQ, which was initially foreseen to be operational in 2007, is not anymore the baseline RFQ for the CERN Linac4. The RFQ has gone through a phase of redesign and will be delivered only in 2010.

Introduction

Linac4 is composed of a source, a LEBT, an RFQ, a chopper-line, a DTL, a CCDTL and a PIMS. The source delivers a 45keV H- beam accelerated by the RFQ up to 3 MeV at 352.2 MHz frequency. At 3 MeV, the chopper-line, composed of 11 quadrupoles, 3 bunchers, two sets of electrostatic chopper plates and a dump, is dedicated to the removal of 3 over 8 micro bunches coming from the RFQ. It has also to match the beam to the following accelerating structure and perform a collimation of the transmitted beam. Then, the Drift Tube Linac, equipped with 111(???) permanent quadrupoles, accelerates the beam to 50 MeV. The next stage of acceleration is done by a Cell-Coupled Drift Tube Linac to 100 MeV. The final accelerating structure is a Pi Mode Structure which brings the beam to 160 MeV. The total length of Linac4 is around 80 m. The Linac4 duty cycle is respectively 0.1% and 3-4%, if used as the PS booster injector or SPL injector.

Project advance overview

An End-to-End simulation was performed from the source to the PIMS [2]. Beam dynamics in the RFQ was simulated with Toutatis [3] and Parmteqm [4] codes. For the following structures, from chopper-line to PIMS, simulations were performed with two different codes: PathManager [5] from CERN and TraceWin [6] from CEA. The results of both codes agree, and show that main beam dynamics perturbations arise before the beam reaches 3 MeV. In fact, most of the losses, emittance increase and halo formation is located in the chopper-line (cf. Table1). For this reason it has been decided to lead a 3 MeV line measurement campaign.

Table1 : Results from End-to-End simulation

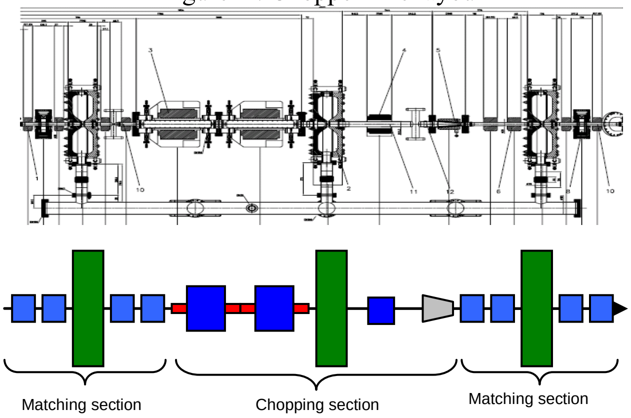
	RFQ input 45keV	DTL input 3MeV	PIMS output 160MeV
Transverse emittance. Norm RMS in mm.mrad	0.25	0.31	0.35
Longitudinal emittance Norm RMS in deg.MeV	###	0.16	0.20
Transmission	###	90%	90%

The RFQ is now under construction and the chopper-line is assembled. The 3MeV test stand [7], where the source, the LEBT, the RFQ and the chopper-line will be assembled together and their operational characteristics measured, is scheduled to operate in 2009.

Chopper-line beam dynamics

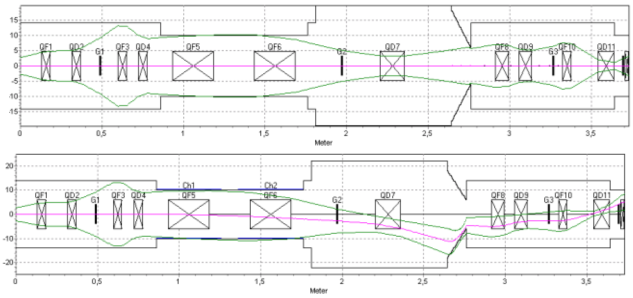
The chopper-line is composed of 11 quadrupoles, 3 bunchers, the chopper itself and the dump dedicated to collect the chopped bunches. From the beam dynamics point of view, we can divide it into 3 parts. The first section, 2 FODOs and one buncher, provides matching from the fast phase advance in the RFQ to the slow phase advance in the chopper. The second section with the chopper, 2 focusing quads, 1 defocusing quad and the dump, ensures the chopping. A voltage of 800 V is applied between the two chopper plates separated by 20 mm. It gives 5.4 mrad angular kick to the beam. The 2 focusing quadrupoles keep the beam size small so that the beam does not hit the chopper plates. The angular kick given by the chopper field is then amplified by a defocusing quadrupole situated between the chopper and the dump and by the RF defocusing effect of the buncher. The dump, whose final radius is 6mm collects the chopped bunches and serves as a rudimentary collimator for the transmitted ones. The last section, 2 FODOs and one buncher, matches the beam to the DTL. The chopper-line layout is shown in Figure 2 (quadrupoles in blue, bunchers in green, chopper in red and dump in grey).

Figure 2 : Chopper-line layout



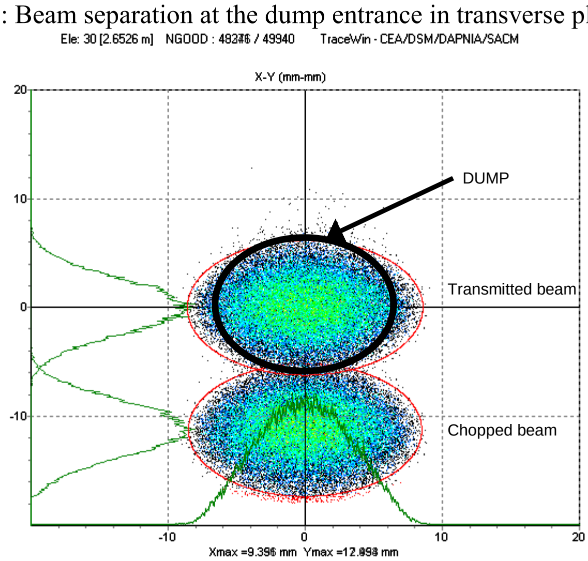
The results from the simulations obtained with the two codes TraceWin and PathManager are very encouraging. They show a 99.9% chopper efficiency for the chopped beam and a 96% transmission for the transmitted beam to the DTL. Figure 3 represents the envelope of the beam in the vertical plane (the chopping plane) in both cases: transmitted and chopped.

Figure 3 : Vertical envelopes in the chopper-line



On Figure 4 we clearly see that the separation of the two beams at the dump entrance is almost complete, but a small overlap (less than 1% of the beam) still remains. We can also see on Figure 4 that the dump, which collects the main part of the chopped bunches (99.9%), is also used to collimate the transmitted bunches (4% of the transmitted beam is collected in the dump).

Figure 4 : Beam separation at the dump entrance in transverse plane.



BSHM

The Beam Shape and Halo Monitor

For hands-on maintenance, we have to keep the losses in the high energy part below 1W/m. Note that 1 W at 4 GeV corresponds to 10^2-10^3 particles per bunch depending on the duty cycle. As we saw before, all halo formation happens in the RFQ and the chopper-line. This is why we plan to measure the transverse halo downstream the chopper-line. The second issue, arises from the remaining particles of the incompletely chopped bunches. These particles are efficiently transmitted in the Linac4 and will be lost in the booster or in the superconducting part of the SPL. They constitute the longitudinal halo. The BSHM [8], developed at CERN will be able to provide measurement of these two types of halo. Its aim is twofold:

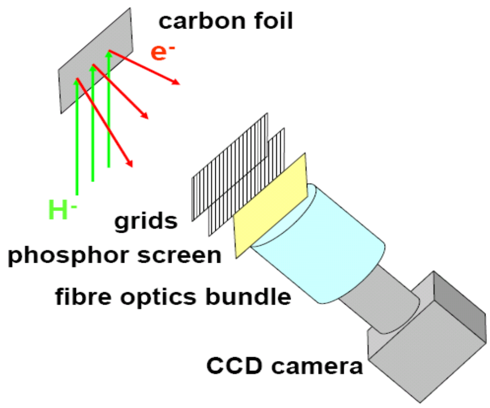
- Measure the transverse halo generated in the RFQ and the chopper-line
- Detect and measure the incompletely chopped bunches. The “longitudinal halo”

BSHM Hardware

The principle of operation of the BSHM is as follows. The H- ions hit a carbon foil and generate secondary electron emission with the same current and spatial distribution. These electrons are accelerated toward a phosphor screen by an electric field applied between accelerating grids. In order to avoid space charge effect in the electrons cloud, a pre-accelerating grid with 1kV has been added just 2 mm after the carbon foil. It helps to achieve the spatial (1 mm) and time resolution (2ns). Once the electrons reach the phosphor screen, they generate light, which is transmitted to a CCD camera via optic fibers.

In order to have good measurement of the transverse halo, the dynamic range reached during the development of this detector is 10^5. For the measurement of the longitudinal halo, it can be switched ON or OFF within 1ns. In fact, as the RFQ frequency is 352MHz, the spacing between two consecutive bunches is 2.8 ns.

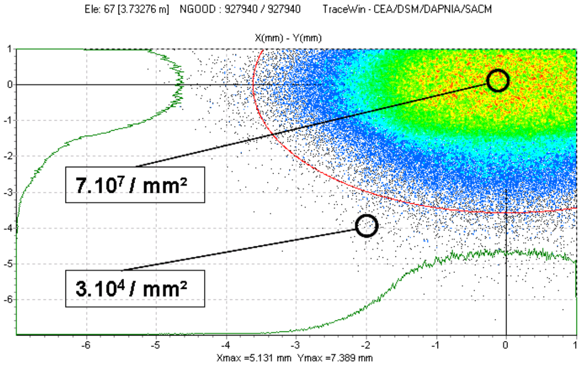
Figure 5 : BSHM hardware



1st Objective: Transverse Halo Measurement

A 1 million particles simulation performed with Toutatis for the RFQ and TraceWin for the chopper-line, has given us a good idea of what could be the density in the halo and in the centre of the beam (cf. Figure 6).

Figure 6 : Beam density after the chopper-line
(Transverse plane X-Y)



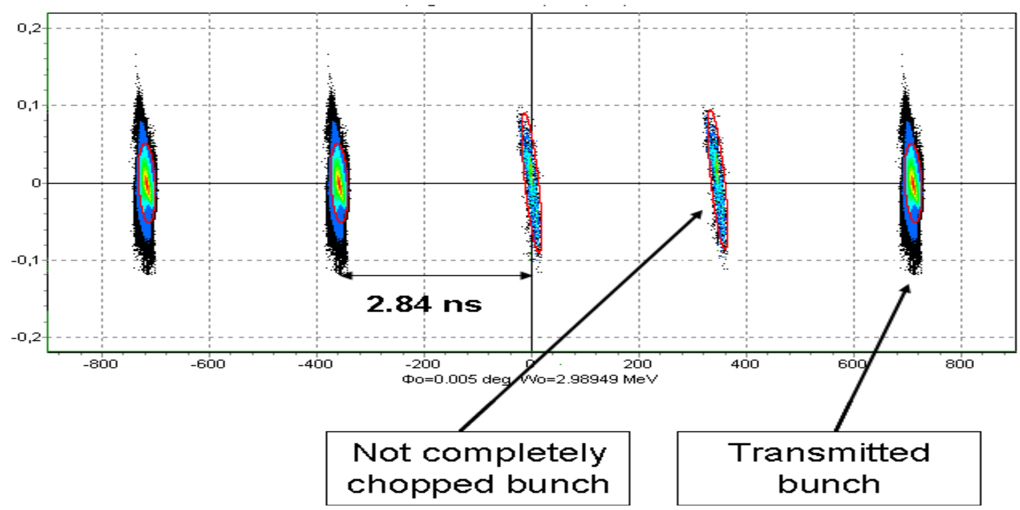
The dynamic range provided by the BSHM will give us sufficient precision in order to characterize the transverse halo. Depending on the results we will observe during the Linac4 exploitation, we will be able to take the decision whether we need to collimate the beam or not in order to limit losses below the 1W/m limit.

2nd Objective: Longitudinal Halo Measurement

Incompletely chopped bunches (0.1% of the main beam), are transmitted through the dump. It appears that they are efficiently accelerated in the following structures (DTL-CCDTL-PIMS). These “residual” particles will be lost during the injection into the CERN booster or into the superconducting part of the SPL. The BSHM is also designed to detect these undesired micro-bunches.

Its capability to be turn on/off within 1ns and to detected residual H- ions with a sensitivity of 10^4 ions in a vicinity of full bunches (10^9) makes it a very useful detector perfectly adapted to the Linac4 chopper-line and for the next high energy SPL project.

Figure 7 : View of transmitted and chopped bunches
(Phase (°) - Energy (MeV))



Conclusion

The transverse halo formation in the first part of Linac4 is unavoidable. Simulations show that it is very well transmitted all along Linac4 up to 160MeV. The BSHM will be able to provide us a good description of this halo. And the decision to collimate or not the beam after the MEBT for the SPL project in order to limit losses to 1W/m, depends on this detector.

Concerning the longitudinal halo, which is also a critical issue for the SPL, it is directly linked to the chopper efficiency. The BSHM will also be able to characterize it with a good precision (up to 0.001% of remaining beam), and will aid us in setting up the chopper.

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Acknowledgements

We acknowledge the support of the European Community-Research Infrastructure Activity under the FP6 “Structuring the European Research Area” programme (CARE, contract number RII3-CT-2003-506395)