TRANSVERSE BEAM PROFILE MEASUREMENTS IN THE LINAC4 MEDIUM ENERGY BEAM TRANSPORT

M. Yarmohammadi Satri*, G. Bellodi, V. Dimov, J.B. Lallement, A. Lombardi, U. Raich, F. Roncarolo, F. Zocca, CERN, Geneva, Switzerland

Abstract

Linac4 is a 160 MeV H⁻ linear accelerator presently under construction at CERN. It will replace the present 50 MeV proton Linac2 as injector of the proton accelerator complex as part of a project to increase the LHC luminosity. The Linac4 front-end, composed of a 45 keV ion source, a Low Energy Beam Transport (LEBT), a 352.2 MHz Radio Frequency Quadrupole (RFQ) which accelerates the beam to 3 MeV and a Medium Energy Beam Transport (MEBT) housing a beam chopper, has been commissioned in the Linac4 tunnel. The MEBT is composed of three RF cavities and 11 quadrupole magnets to match the beam from the RFQ to the next accelerating structure (DTL) and it includes two wire scanners for beam profile measurement. In this paper we present the results of the profile measurements and we compare them with emittance measurements taken with a temporary slit-and-grid emittance measurement device located after the MEBT line.

INTRODUCTION

Linac4 is part of the CERN LHC injector upgrade [1], it accelerates H⁻ ions to 160 MeV in an 80 m long accelerator housed in a tunnel 12 m underground. It consists of a 45 keV RF volume source, a two-solenoid Low Energy Beam Transport (LEBT), a 352.2 MHz Radio Frequency Quadrupole (RFQ) accelerating the beam to 3 MeV, a Medium Energy Beam Transport (MEBT) line (Fig. 1), a 50 MeV Drift Tube Linac (DTL), a 100 MeV Cell-Coupled Drift Tube Linac and a Pi-Mode Structure bringing the beam to the final energy of 160 MeV. The ion source, the RFQ and the MEBT line have been commissioned in the Linac4 tunnel between October 2013 and March 2014, with a temporary diagnostic bench shown in Fig. 2.

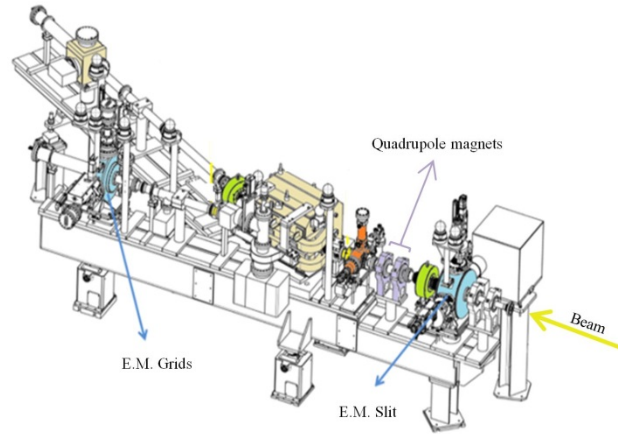

Figure 2: The 3 MeV temporary diagnostics bench.

The diagnostics permanently installed in the MEBT is minimal and consists of two beam current transformers and two wire scanners (WS), whereas a full suite of diagnostics, including a slit-and-grid emittance device (EM), a spectrometer, a Halo monitor, a Bunch Shape Monitor (BSM), and several position monitors are available on the temporary diagnostic bench [2].

The WSs are made of two 33µm carbon wires which travel through the beam in variable steps (0.07 mm minimum) and acquire the horizontal and vertical profiles over several pulses. The WSs measurements are time resolved in 4 µs slices, thus allowing observation of the profile along the beam pulse (100-400 µs). The emittance meter consists of a slit-and-grid system for a direct sampling of the horizontal and vertical phase space. The slits (with 300 µm aperture) are near the output plane of the MEBT and the grids are placed about 3 m downstream. A system of two quadrupoles allows changing the phase advance between the slits and the grids. In this paper we report the results of the transverse measurements in the MEBT and a comparison with the corresponding beam dynamics simulations.

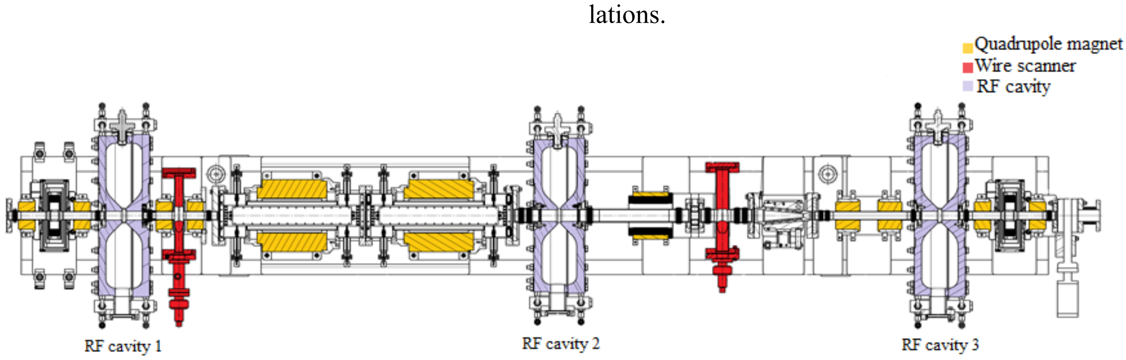

Figure 1: The 3 MeV MEBT line.

* Home Institute: IPM, Tehran, Iran

BEAM TRANSVERSE EMITTANCE

In this section we report on the measurements taken with the emittance meter at the end of the MEBT line. The measurements were taken over several days with a peak current of 10-12mA. Measurements were taken for varying optics settings (quadrupoles) and at different times along the pulse. In Fig. 3 we show a sample of these measurements.

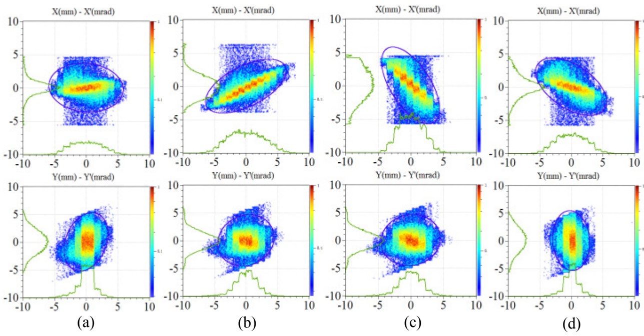

Figure 3: Horizontal (top) and vertical (bottom) phase spaces for different quadrupole settings (last 4 quadrupoles are varied), horizontal and vertical scales are the same for all the plots.

To cross-check consistency, the measured beams were back-tracked with the code PATH [3], to a location 1446 mm upstream where we expect the beam phase space to be unchanged by the variation of the optics. The result of the tracking is shown in Fig. 4: as expected the phase spaces are all identical in orientation.

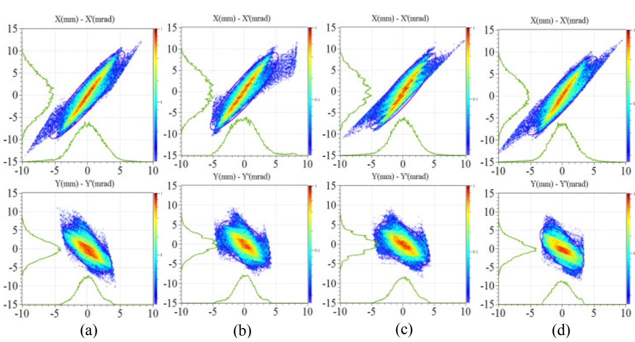

Figure 4: Horizontal (top) and vertical (bottom) beam phase space obtained by back-tracking 1446 mm upstream the emittance measurements on Fig. 3, horizontal and vertical scales are the same for all the plots.

The measured beams shown in Fig. 3 were further back-tracked to the output of the RFQ, 3.8m upstream the measurement location with the purpose of obtaining an empirical beam distribution for tuning the MEBT line and matching to the DTL. All further simulations were done using this input beam. This beam distribution compares favourably with what expected from simulations of the beam transport through the RFQ, see Fig. 5 and 6. Figure 5 shows a slightly smaller emittance, which could be partly explained by small losses in the MEBT transport during the measurement (about 5-10%).

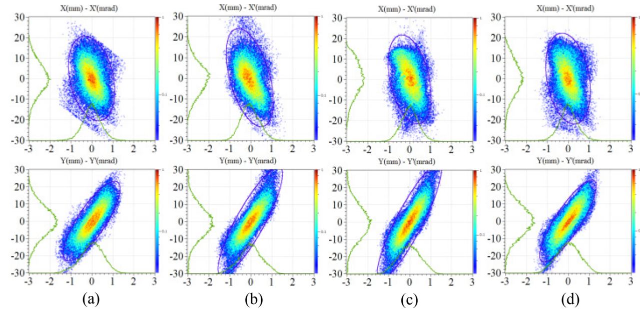

Figure 5: Horizontal (top) and vertical (bottom) beam phase space obtained by back-tracking the emittance measurements on Fig. 3 to the location of the RFQ output plane, horizontal and vertical scales are the same for all the plots.

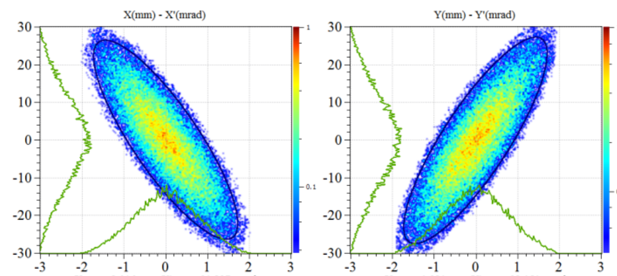

Figure 6: Horizontal (left) and vertical (right) beam phase space expected at the RFQ output for 10mA beam output current.

BEAM TRANSVERSE PROFILES

Transverse beam profiles were measured with the WSs at two locations in the MEBT line. These measurements are non-destructive and will be the sole transverse measurements available at 3 MeV during further commissioning stages. It is therefore very important to cross-calibrate these measurements with the emittance measurements.

Figure 7 shows beam profiles measured with WS2, which is located 1446 mm upstream the emittance meter slits, at the location of the beam distributions shown in Fig. 4. The projections of these in real space are compared with the measured beam profiles: the consistency between wire scanner and emittance measurements is proved, an important result for the next stage of commissioning.

In addition to this check, the transverse beam sizes were measured at the two locations of the WSs and compared to the expected values from the simulations.

The results are shown in Figs. 8-9 for the WS1 located 588mm downstream of the RFQ and Fig. 10-11 for the WS2 located 1286mm upstream of the DTL. In all cases we obtained a fair agreement with the simulations.

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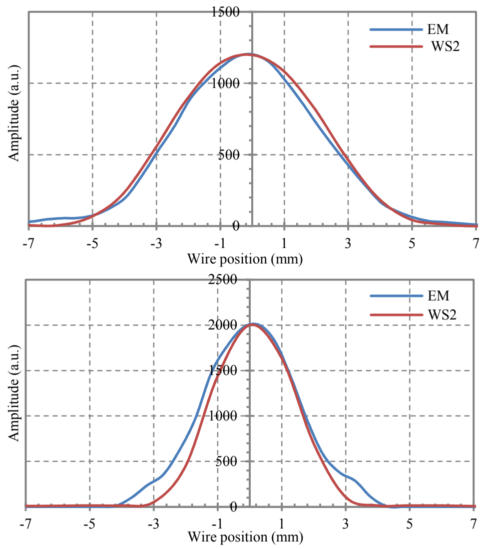

Figure 7: Horizontal (top) and vertical (bottom) beam profile measured by WS2 (red) and obtained from emittance measurements (blue) back-tracked to the same location.

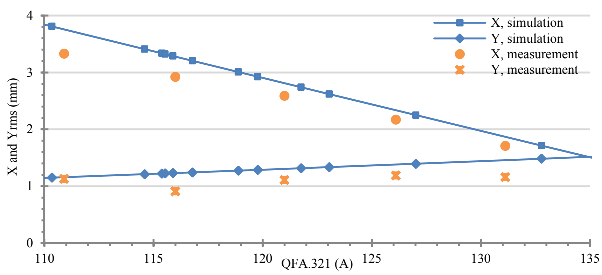

Figure 8: Transverse beam sizes measured on WS1 when varying the second quadrupole magnet strength.

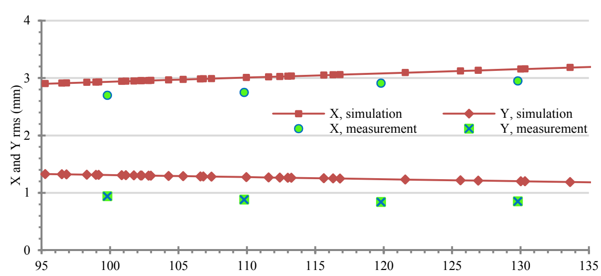

Figure 9: Transverse beam sizes measured on WS1 when varying the third quadrupole magnet strength.

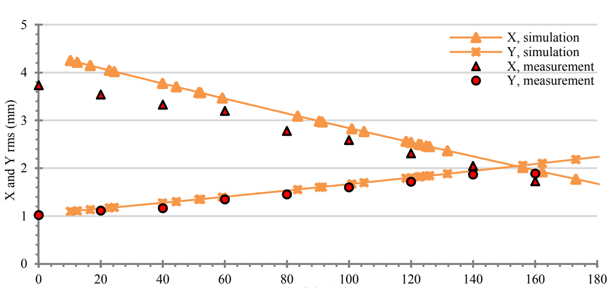

Figure 10: Transverse beam sizes measured on WS2 when varying the 7th MEBT quadrupole magnet strength, RF cavities on.

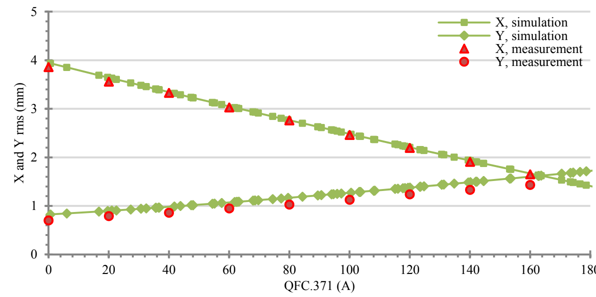

Figure 11: Transverse beam sizes measured on WS2 when varying the 7th MEBT quadrupole magnet strength, RF cavities off.

An interesting measurement on the WS2 showed the effect of the transverse RF defocusing of the RF cavities: we observed the effect of changing the RF phase by 180° on the transverse beam size 556 mm downstream, see Fig. 12. Although this measurement is only qualitative; it clearly shows the effects and could be used in the future to discriminate between opposite RF phases.

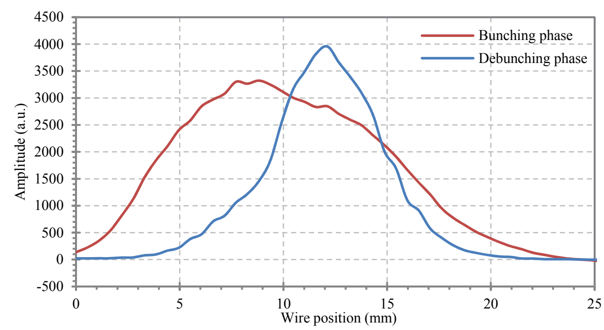

Figure 12: Transverse beam size on WS2 for two different phase settings of the MEBT RF cavity.

CONCLUSIONS

The 3MeV beam emittance and transverse profiles have been measured under different optics conditions at Linac4. The measurements taken on the permanent wire scanner are in agreement to what is obtained with the temporary slit-and-grid emittance device. In addition a beam distribution based on the slit-and-grid emittance measurements was prepared for further simulations through the next stages of acceleration.

REFERENCES

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[3] A. Perrin, J.F. Amand, "Travel v 4.06 user manual", CERN 2003.