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COMMISSIONING OF THE BEAM INSTRUMENTATION FOR THE HALF SECTOR TEST IN LINAC4 WITH 160 MeV H- BEAM

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Abstract

In the framework of the LHC Injector Upgrade (LIU) project, the Proton Synchrotron Booster (PSB) will be extensively modified during the Long Shutdown 2 (LS2, 2019-2020) at CERN [1]. This includes a new injector, Linac4, which will provide a 160 MeV H^- beam and a complete new injection section for the PSB composed essentially of a chicane and a stripping foil system. The equivalent of half of this new injection chicane, so-called Half-Sector Test (HST), was temporarily installed in the Linac4 transfer line to evaluate the performance of the novel beam instrumentation, such as, stripping foils, monitoring screens, beam current transformers, H^0/H^- monitor and dump, beam loss monitors, and beam position monitors. The results of the instrumentation commissioning of the HST are presented in this paper.

INTRODUCTION

The Half Sector Test project (HST) [2] aimed to test the new injection scheme of the PSB that will be installed during LS2. The beam instrumentation needed to commission the HST was temporarily installed in the Linac4 transfer line as shown in Fig. 1. In particular, the HST was composed by:

- The stripping foil system (TKSTR) and a beam imaging system based on a scintillating screen with radiation-hard camera (BTV1).
- Half of the injection chicane (BSW3 and BSW4 magnets).
- The monitor measuring the partially stripped and unstripped particles (H^0/H^- monitor) and the H^0/H^- dump integrated with BSW4.
- Beam Loss Monitors (BLMs) in the vicinity of the H^0/H^- dump, one ionisation chamber and one diamond detector for fast time-resolved measurements.
- One Beam Current Transformer upstream (BCT1) and one downstream (BCT2) of the HST for transfer efficiency measurements.
- A second beam imaging system (BTV2) for beam profile measurements and steering to the final (temporarily installed) dump.
- Beam Position Monitors (BPMs) installed along the Linac4 and the transfer line up to the HST.
- Vacuum equipment and services.

In the next section, the instrumentation will be described in more detail and their performance illustrated.

HST INSTRUMENTATION

Stripping oil and ptical eam Systems

The stripping foil system is composed by:

- A stripping foil loader holding up to six foils that can be remotely interchanged and fine-adjusted to reduce the time for machine intervention (e.g. foil substitution) and thus less dose absorbed by the personnel [3].
- A retractable optical beam observation system (BTV), consisting of a 1 mm thick Chromox (Al_2O_3 doped with Cr_2) scintillating screen that can be placed at a distance of 6 mm in front of the foil.

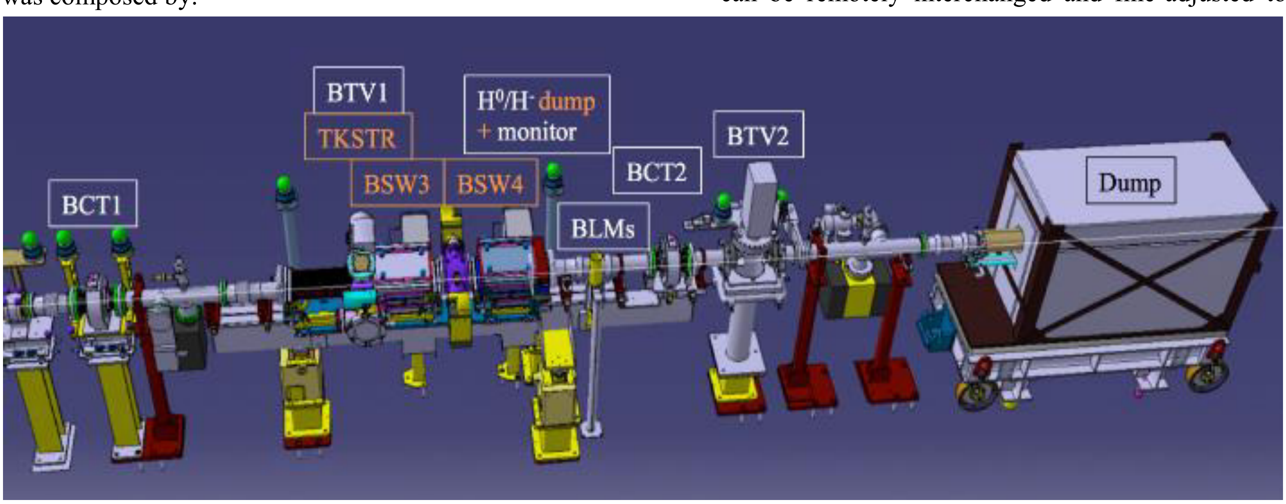

Figure 1: 3D drawing of the HST installation in the Linac4 transfer line (beam from left to right).

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- A radiation-hard camera, allowing either to check the beam position on the screen or the integrity of the foil. Indeed, the camera yielded the possibility to detect partial foil ruptures that did not affect the current measured at the foil nor the intensity transmission.

A schematic view of the stripping foil system is shown in Fig. 2. More details on the stripping foil efficiency measurements can be found in [4].

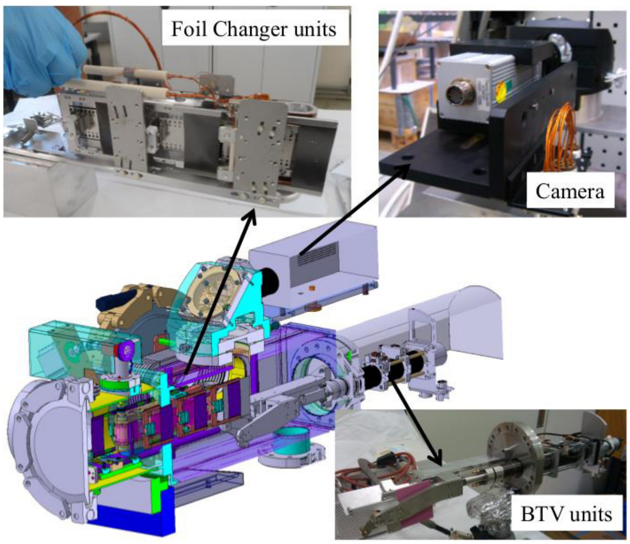

Figure 2: 3D drawing of the stripping foil system with a detailed view of the foil loader (top-left), the radiation-hard camera (top-right) and the retractable screen (bottom-right).

Beam Current Transformer (BCT)

The BCT consists of a magnetic core with a secondary winding (the beam replacing the primary winding) and a calibration winding. They are designed for the rather long Linac4 pulses of 400 – 600 µm with a droop that does not exceed 1%. In order to minimize the transformer sensitivity to external magnetic fields, 3 layers of mu-metal and 1 layer of ARMCO® magnetic shielding are employed. The signal is read out by a dedicated VME module (TRIC: TRansformer Integration Card).

The signal from the secondary winding is amplified by pre-amplifiers with two different gains and digitized in parallel into two 200 MHz ADC channels of the TRIC card. The samples are then averaged with a user-defined time resolution of between 10 ns (successfully used to measure the rise and fall times of the fast chopper) and several µs. The BCTs installed are regularly used to monitor the beam transmission along the different Linac4 sections up to the transfer line and trigger the interlock system ('watchdog') in case of poor transmission.

In particular, the two BCTs installed upstream and downstream the HST were cross-calibrated to provide precision measurements of the stripping foil efficiency at the percent level of accuracy. During the HST commissioning, a transmission higher than 100% between two subsequent BCTs was observed at the Linac4 dump and at the HST. This effect was finally attributed to the pre-amplifier saturation due to a strong 352 MHz RF component, which was well outside the presumed passband of the transformer. Once identified, this was successfully corrected by the addition of appropriate low pass filters.

H^0/H^- Monitor and ump

The H^0/H^- monitor consists of four Titanium plates located a few centimeters upstream of the in-vacuum Titanium beam dump, as shown in Fig. 3. It covers an area of 8 cm x 5.6 cm with 0.1 cm of thickness, enough to strip all the electrons and leave the resulting protons to reach the dump.

This system will serve two main functions:

- Monitor the efficiency of the stripping foil by detecting the amount of partially stripped (H^0) and unstripped (H^-) particles.
- Protect the dump from a high intensity beam impact by providing an interlock signal in case of stripping foil failure (integrated sum signal from the H^0/H^- plates).

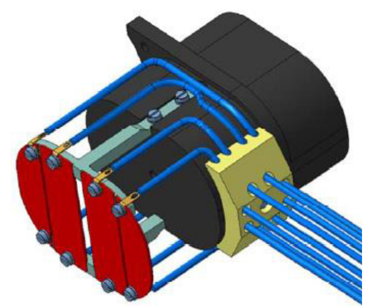

Figure 3: 3D design of the H^0/H^- monitor plates (in red) fixed in fort of the dump.

During the HST phase, a series of measurements was carried out in order to commission this new device. The four plates were first calibrated sending a low intensity H^- beam directly onto the monitor (i.e. no stripping foil inserted). The horizontal beam size was reduced as much as possible so that the entire beam spot could fit onto a single plate. An example of the transverse beam profile on the BTV1 (in front of the stripping foil) is presented in Fig. 4, for a pulse of 1.8 mA and 31 µs length. The beam

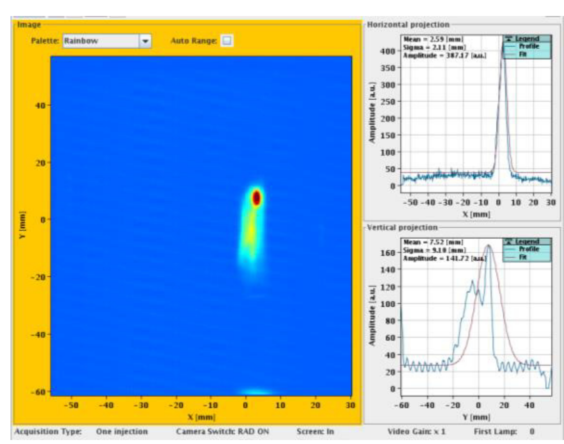

Figure 4: Beam spot on the BTV in front of the stripping foil, generated by a pulse of 1.8 mA and 31 µs.

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spot is clearly visible in the centre of the BTV and on the right side of the application window the horizontal and vertical fits to the projected profiles can be seen. With this setup, each plate response to the impinging beam was measured for different beam intensities and fixed pulse length of 5 μs, allowing the extraction of the calibration factors to calculate the stripping foil efficiency [5].

Using the same beam setup, it was possible to observe the structure of the H^0/H^- monitor. The beam was moved from left (H^0L plate) to right (H^-R) by changing the current of the first chicane magnet (BSW3) while keeping the BSW4 constant (to guarantee the same magnetic field at the monitor/dump for the emitted secondary charged particles). An example is reported in Fig. 5, which shows the case of 1.8 mA beam current with 31 μs pulse length. On the y-axis there is the sum signal of the 4 plates normalized with the beam current measured at the BCT1. The zero on the x-axis corresponds to the centre of the H^0L plate. The first "hole" at about 8 cm, corresponds to the gap between the H^0 plates. The second one is deeper (this gap is twice as large as the first one) and corresponds to the space between H^0R and H^-L plates. The measurement in Fig.5 shows a distance between the gap centres of ~2 cm, in good agreement with the 2.3 cm of the mechanical drawing, taking into account the errors introduced by a beam entering the plates with an angle.

It was not possible to reach the H^-R plate without increasing the BSW4 current and using a steering magnet upstream the HST; for this reason the H^-R plate is not visible in Fig. 5.

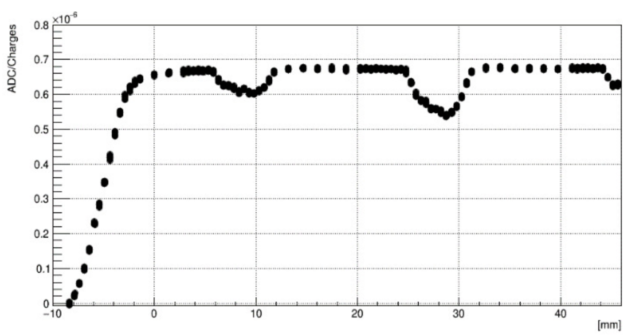

Figure 5: Sum of the four plate signals normalized over the beam current of BCT1 as a function of the beam position on the H^0/H^- monitor. The zero corresponds to the centre of the H^0L plate. The two "holes" correspond to the gaps between the plates.

After the calibration phase, the H^0/H^- monitor was used to measure the stripping foil efficiency in comparison with the beam transmission at the HST. For the stripping foils 1, 2, 3 (position on the foil loader), there was no signal on the H^0/H^- monitor, in agreement with the expected 100% stripping efficiency for that type of foil (XCF-200, arc evaporated amorphous Carbon, collodion coated), but 1% beam transmission inefficiency was detected at the HST BCTs. More interesting is the case of the stripping foils 5 and 6 (the number 4 was broken) where a stripping inefficiency was detected at the H^0/H^- monitor of ~0.25% and ~0.35% respectively, while a beam transmission inefficiency of ~1.25% and 1.35% was detected at the BCTs, as shown in Fig. 6.

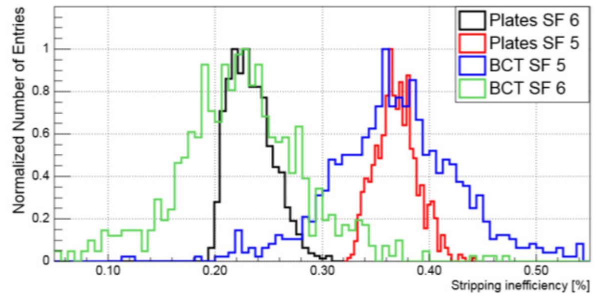

Figure 6: The comparison of the inefficiencies of the stripping foils 5 and 6 (green and blue curves) with the signals measured at the H^0/H^- monitor (black and red lines) shows an excellent agreement.

There are two important observations about this result: There is a systematic 1% of transmission inefficiency measured at the HST BCTs for all the stripping foils, which might come from either a measurement error of the BCTs, or not detected beam losses before the BCT2, or a combination of both. But subtracting the systematic 1%, the measured stripping inefficiencies at the H^0/H^- monitor for the stripping foils 4 and 5 agree perfectly with the transmission inefficiencies at the HST BCTs, validating the correct functionality of this device.

The H^0/H^- monitor electronics also provides the integrated sum of all particles on the four plates. This will be used in the PSB as an interlock in case of stripping foil degradation. For this acquisition chain, the limited HST beam time allowed only commissioning the system linearity, validated over a large intensity range from 20 to $140 \cdot 10^{10}$ charges per pulse.

Beam Loss Monitor (BLM)

The BLMs are essential machine protection elements that were installed in Linac4 to assure keeping operational losses below 1 W/m.

At the HST there were two types of BLMs installed:

- Ionization Chamber (IC), which is the same used for the LHC [6], but with a readout system adapted to the Linac4 requirements.
- Diamond BLM for a fast time-resolved readout (turn-by-turn losses in the PSB).

The IC BLM system has a very high dynamic range, being able to detect currents ranging from 10 pA to 200 mA. Processing is carried out with several integration windows ranging from 2 μs to 1.2 s. This type of BLM is installed along the Linac4 and its transfer line. For the moment they have been used only to qualitatively monitor local beam losses. The study of their calibration at different beam energies and the definitions of the thresholds that will interlock the beam permit will be a milestone of the Linac4 reliability run during this year.

On the other hand, the measurements with the diamond BLM were dominated by noise, which requires an im-

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provement of the signal transmission for the final system deployment.

Beam Position Monitor (BPM)

The BPM sensor consists of shorted strip-line pick-ups that offer the versatility to fit into the limited space available, while ensuring good linearity and sensitivity. They were designed to monitor the beam position with 100 µm resolution and to provide the relative beam intensity between two monitors with 200 µA resolution.

As well as being extensively used to monitor and optimize the beam trajectory, they have also provided a useful cross-check of the beam transmission to identify the BCT pre-amplifier problem mentioned before. In addition, they have been essential to set up and tune the RF structures (from 12 to 160MeV) of Linac4 by using the Time of Flight (ToF) measurements to infer the beam energy at the exit of each cavity.

CONCLUSIONS

Beam diagnostics were essential for the successful commissioning of the HST with a 160 MeV H^- beam. During this period it was possible to verify the functionality of all instruments, debug software and, where necessary, to identify and correct issues, such as the saturation of the BCT pre-amplifiers.

More time would have been needed to fully establish the absolute accuracy of the H^0/H^- monitor, to study in details the interlock functionality and test the final version of the acquisition electronics. Ways to complete these studies during the Linac4 reliability run are now being investigated, together with threshold definition for different beam currents of the BLM system.

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