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COMMISSIONING THE ELENA BEAM DIAGNOSTICS SYSTEMS AT CERN

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Abstract

The Extra Low ENergy Antiproton ring (ELENA) at CERN entered the commissioning phase in November 2016 using H^- ions and antiprotons to setup the machine at the different energy plateaus. The low intensities and energy of the ELENA beam generate very weak signals making beam diagnostics very challenging. With a circulating beam current of less than 1 µA and an energy where the beam annihilates in less than a few microns of matter, special care was taken during the design phase to ensure an optimal performance of these measurement devices once installed on the ring and transfer lines.

A year on we present the performance of the various devices that have been deployed to measure the beam parameters from the extraction point of the Antiproton Decelerator (AD), through the ELENA ring and in the experimental lines.

INTRODUCTION

ELENA was approved as a CERN project in June 2011 and construction began two years later [1]. Even though not all the ring components were ready, commissioning with beams of antiprotons and H^- ions started in 2017.

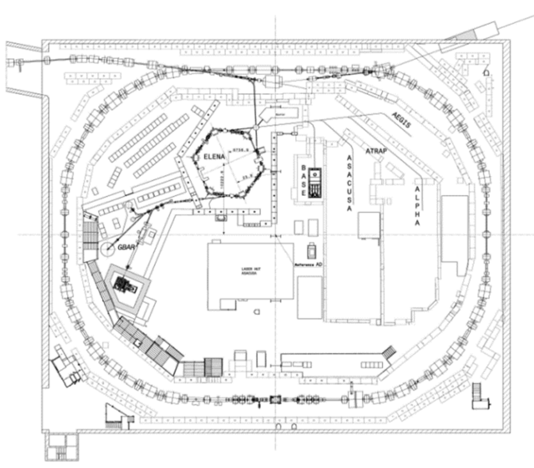

Figure 1: ELENA layout in the AD hall. The ELENA ring circumference is 30.4 m, exactly 1/6th of the AD ring.

The greatest challenge for the beam instrumentation is to measure all the parameters of a very low intensity beam in an energy range from 5.3 MeV to 100 keV. At such low energies the ELENA ring will operate with a dynamic vacuum of less than $4x10^{-12}$ Torr. Attention has been paid to the design of the elements that are installed in the ring as they are baked-out at 300°C and NEG coated [2]. The layout of the ELENA ring and the experimental zones is shown in Fig. 1.

BEAM POSITION

The orbit system consists of electrostatic pick-ups equipped with charge amplifiers, preamplifiers and VXS-DSP-FMC-Carriers [3]. The charge amplifiers send sum and difference signals from the pick-ups, via preamplifiers to ADCs placed on FMC boards. The ELENA RF system sends the actual revolution frequency as an integer value via an optical gigabit link, from which the orbit system will generate its own local oscillator frequency for digital down mixing of the sum and difference signals. Position calculations are performed in DSP modules and the results are sent to the real-time software that makes the data available to the control room. The orbit system also computes a real-time mean radial horizontal position for the RF radial feedback.

The closed orbit can be plotted for any time in the acceleration cycle (where position data is available i.e. when the beam is bunched). The orbit can then be adjusted using the standard CERN orbit correction application. Figure 2 shows one of the very first times this was successfully performed in ELENA; in pink the initial orbit, and in green the corrected orbit. Only horizontal correction was performed in this case, with the vertical measurement showing good reproducibility of both the machine and the measurement. The measurement to measurement standard deviation gives an upper limit of 0.1 mm on the resolution of the system.

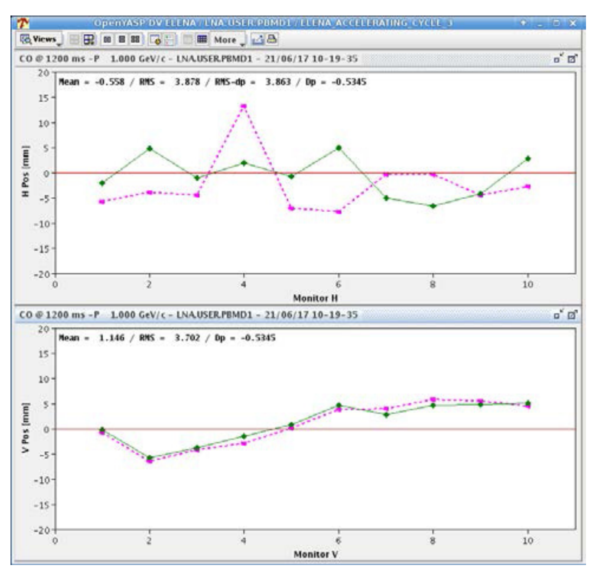

Figure 2: Orbit measurement (x-axis is the 10 pick-ups in each plane for which the position is given in mm) before (pink) and after (green) a horizontal orbit correction in ELENA.

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PROFILE MEASUREMENTS

BTV

The ELENA machine is equipped with two profile monitors based on scintillation screens and CCD cameras, so-called Beam TV Observation (BTV) stations. The principle of the BTV system is to insert a screen on the beam path and to collect the light, generated by the interaction of the particles with the screen, through an optical line (camera lens) with a camera. In ELENA, these monitors are used for beam steering and beam shape optimization.

The screen material is of Chromox type - AF995R from Ceraquest. It is held on a specific magnetically coupled bellows-less actuator from UHV Design. Some mechanical improvements were necessary to reach the UHV vacuum acceptance level. An illumination system is available mainly to perform calibration measurements on target marks made on the screens. The setup permits measurements with a resolution of 190µm/px and 215µm/px respectively in the horizontal and vertical planes. A set of optical density filters can be remotely positioned in front of the camera to avoid saturation and optimise the measurements as a function of the beam intensity.

Two BTVs are installed in a common vacuum chamber in the ELENA ring, as shown in Fig. 3. The first BTV (BTV1) monitors the injected beam (Fig. 4). It is the last element of the ELENA injection line, just between two active elements: injection septum and kicker. The second BTV (BTV2) monitors the 'first turn' beam.

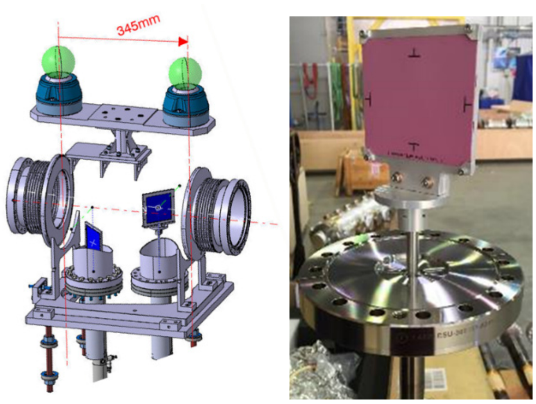

Figure 3: Drawing of the BTV vacuum tank (left) and the Chromox AF995R screen on the magnetically coupled actuator (right).

The two instruments are identical except for the default position of the screen. The BTV1 screen is retracted by default, whilst it is IN beam for BTV2. The reason is that the BTV2 screen is also part of the safety interlock chain and acts as a beam dump for any remaining beam in the machine during access mode.

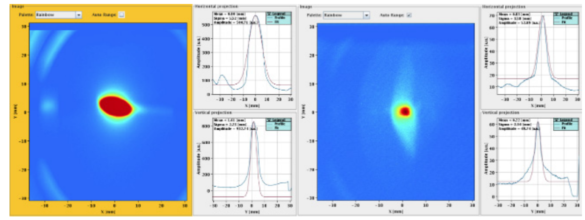

Figure 4: BTV measurements of pbars from the AD (left) and beam extracted from the H^- source (right).

Scraper system

The scraper device is a destructive diagnostic device using a motorised blade as a scraping tool [4]. It is moved into the circulating beam at constant speed. Secondary particles are emitted by the interaction of the beam with the blade. The flux of secondary particles detected is proportional to the beam density, and one can reconstruct the beam profile by plotting the flux as a function of the blade position.

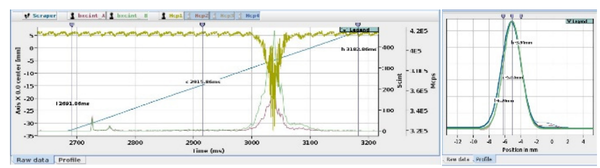

Figure 5: Signals measured on the scraper detectors (left) and reconstructed profile of pbars at 5.3 MeV (right).

Two detection systems have been implemented to cover the different particle types that are available in ELENA. For antiprotons two scintillator paddles outside the vacuum chamber capture the pions created by the annihilation of the particles with the blade. For protons and H^- ions, secondary electrons are measured on four micro-channel plates (MCP) installed inside the vacuum tank.

The signals obtained during the 2017 run (Fig. 5) do not correspond to what one would expect to measure from this type of monitor. As the blade moves through the beam the signal should increase and then suddenly drop to zero when the centre of the beam is reached. The continuous decreasing of the measured secondary shower indicates that not all the beam interacts with the blade during the scan. More work is needed to fully understand the factors that could influence the signals at these low energies.

Recombination monitor

Neutral hydrogen atoms, created either by the striping of the loosely bound electron of the H^- ion by the residual gas molecules or the recombination of protons with the electrons of the cooler device, can be detected in the extension of the downstream bending magnet. The monitor consists of a chevron mounted MgO coated MCP coupled to a P43 phosphor screen (Fig. 6). The image is acquired by a CMOS camera connected to a PC.

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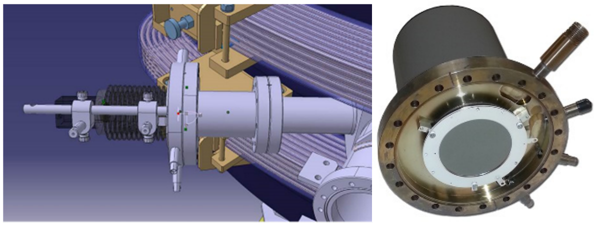

Figure 6: The recombination monitor on LNR.BHN40.

The signal is a direct image of the circulating beam from which the transverse profiles can be inferred. An example is shown in Fig. 7. During beam cooling, the integral of the signal is proportional to the recombination rate from which the transverse energy of the electron beam can be evaluated. It will be a good means to correct any angular deviations between the electron and ion beams.

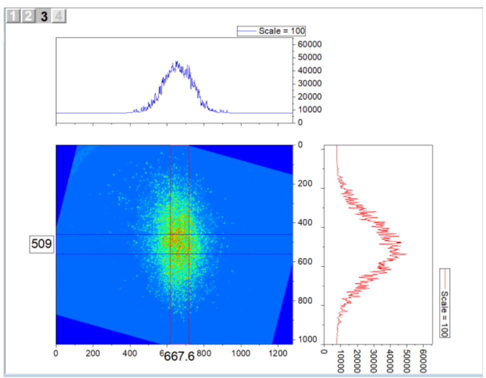

Figure 7: H^- beam profile at 85 keV measured with the recombination monitor.

TUNE MEASUREMENT

The tune measurement system uses two identical pick-ups (PUs) with four 340 mm electrodes. One PU is used to capture beam signals and the second for beam harmonic excitation.

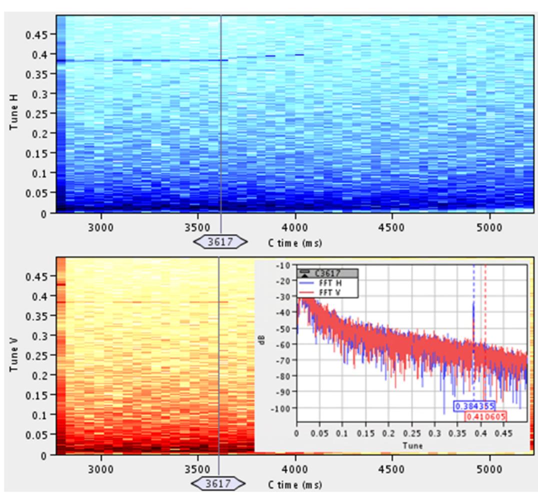

Figure 8: Beam spectra evolution during a commissioning cycle with no excitation and an important coupling. An example of the magnitude spectra is shown for cycle time 3.617 s.

Beam signals from the four electrodes of the capture PU are amplified with four low noise amplifiers installed directly on the PU ports. The amplifiers have high input impedance to assure good PU response for relatively long ELENA bunches. The amplified signals are sent to the tune signal processing electronics based on diode detectors, a so called Base Band Tune (BBQ) front-end [5]. The amplified and filtered base-band horizontal and vertical tune signals are then digitized with two 16-bit ADCs sampling at the 8th harmonic of the machine revolution frequency (1.045 MHz to 144 kHz). The ADCs are accommodated on a mezzanine of an FPGA VME board, performing signal processing and beam spectra computation. The system is sensitive enough to measure tunes in favorable conditions even without beam excitation. An example of such a measurement is shown in Fig. 8.

Chirped beam excitation signals are produced by two 12-bit DACs clocked with the same 8th harmonic of the revolution frequency. The DACs are accommodated on the second mezzanine of the FPGA board. The DAC output signals are amplified to provide currents in the order of 100 mA passing through the electrodes of the excitation PU.

EXTRACTED BEAM MEASUREMENTS

The position and profile of the low energy beams extracted from ELENA will be measured by micro-wire monitors installed along the beam lines [6]. This semi-non-destructive monitor allows most of the antiprotons to pass through without any degradation, while the small portion (1-3%) intercepted by the wires produces the signal. It consists of two position-sensitive photocathode grids providing the X and Y projections of the beam, sandwiched between three anode grids with a distance of l-2 mm between them.

A few monitors were installed at various locations in the ELENA transfer lines but unfortunately the read-out electronics was not available during the 2017 run.

STATUS AND OUTLOOK

The ELENA beam diagnostics systems have performed satisfactorily during the 2017 commissioning run but progress has been hindered by the lack of stable beam time. Measurements on the deceleration ramps still need to be performed, and now that the electron cooler is installed, cooled beam profiles will be available using the scraper and recombination monitor.

This year should see the completion of the commissioning of all the diagnostics systems, including the experimental beam line monitors which are being equipped with their full control and data acquisition electronics.

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