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H0 DIAGNOSTICS FOR THE ELENA ELECTRON COOLER

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Abstract

In addition to antiprotons, the ELENA ring at CERN can also inject protons and H^- ions from a dedicated ion source located close to the ring. These particles offer the possibility for extra diagnostics for detailed investigations into the cooling process at the very low energy of the ELENA ring. To this effect a monitor was installed downstream of the electron cooler to measure the recombination of protons with the cooling electrons. Although protons have never been used in ELENA, H^- ions are routinely used to setup and optimise the ring. The installed device is now used to monitor the stripping of the H^- ions on the residual gas and in the presence of electrons generated by the cooler, providing some insight on the evolution of the beam size during the deceleration cycle and the performance of the electron cooler on the two cooling plateaus.

INTRODUCTION

During the cooling process the centre of mass energy difference becomes very small and ions can capture an electron by radiative or di-electronic recombination. In the next bending magnet, their trajectory becomes very different from that of the circulating ions. For proton beams, neutral hydrogen atoms are formed and travel straight towards a detector.

The formation rate is related to the effective temperature of the electrons and is given by:

$$R_H = N_p \eta \alpha_r n_e \gamma^{-2}$$

where η is the ratio of cooling length to ring circumference, N_p the number of stored ions, n_e the electron current density and α_r the recombination coefficient [1]. Hence the measurement of this rate provides important information on the apparent temperature of the electron beam in the region defined by the overlap with the ions and the possible misalignment of both beams as the highest down-charge rate corresponds to the best matching of electron cooling. Direct measurement of the cooling time and the equilibrium emittances can also be estimated by observing the neutral beam profile.

In ELENA [2] a dedicated H^- linac, operating at an energy of 100 keV allows the machine to be operated with H^- ions or protons when it is not sending antiprotons to the experiments. Unfortunately, proton mode of operation has never been tested due to the complexity of changing the magnetic polarity of the ELENA ring resulting in a lengthy setting up. Moreover, after such a change, the machine performance in antiproton mode would need much time to recover because of the hysteresis of the magnets.

DETECTOR SETUP

To measure the neutral hydrogen beam profile a detector was installed in the vacuum extension of the 90° bending magnet approximately 6.3 m downstream from the electron cooler. The beam profiler consists of a chevron mounted micro-channel plate (MCP) coupled to a P43 phosphor screen. The H0 atoms that are created travel straight towards the monitor and as they hit the MCP surface, electrons are produced and are amplified in the MCP before they are accelerated onto the phosphor screen. The image of the phosphor screen is acquired by a Raspberry Pi4 computer using the Pi HQ camera mount with interchangeable lenses (see Fig. 1) [3].

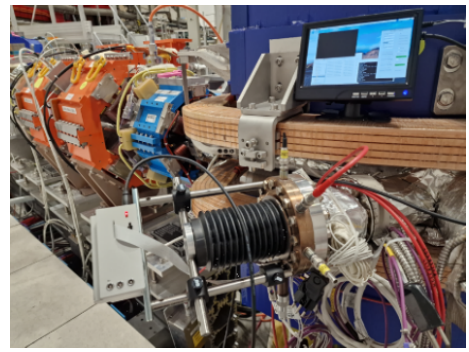

Figure 1: H0 beam monitor in the magnet extension.

Controls and Data Acquisition (DAQ)

The high voltage for the MCP and P43 screen is provided by an iSeg THQ dual channel power supply. A Python script controls the voltage ramp that is applied to the MCP and screen. Camera control is also performed via a Python script which enables the user to adjust the camera settings (resolution, exposure etc.) and to select the acquisition mode (see Fig. 2). Continuous, single/multi frame and video capture are available and can be triggered synchronously with events in the ELENA magnetic cycle.

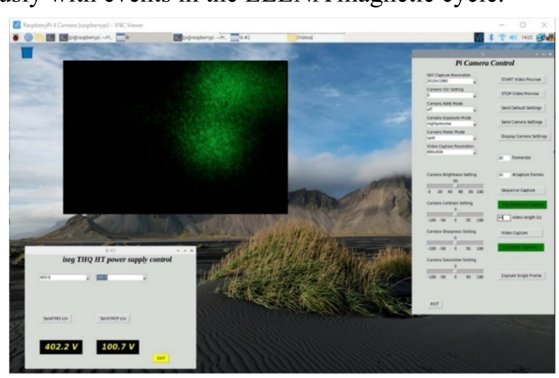

Figure 2: Raspberry Pi controls and DAQ setup.

Calibration

The 12.3-megapixel CCD camera allows single image capture resolutions up to 4056x3040 pixels and a maximum video resolution of 1920x1080 pixels (1080p). A transparent target was mounted on the window and the images at the available video resolutions were acquired to

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determine the spatial resolution for the different lens/resolution combinations (Table 1).

In video mode, the preferred acquisition mode, to keep an acquisition rate of 30 Hz, a lower resolution of 880x600 was chosen as the best compromise.

Table 1: Lens / Video Resolution Combinations

Resolution	FUJINON 25mm	RPI 6mm
640x480	39 µm/px	110 µm/px
880x600	22 µm/px	64 µm/px
1280x720	18 µm/px	
1600x900	15 µm/px	
1920x1080	12 µm/px	

The MCP gain was calibrated by recording the integral of the H0 signal at the end of the first injection plateau as a function of the MCP voltage. To avoid signal saturation, a voltage of 1400 V was selected, giving a gain of approximately 10^5.

DATA ANALYSIS

Image Analysis

Single images captured by the camera system can be analysed to measure the neutral beam size at a particular time in the ELENA cycle. The raw data is first smoothed using a Savitzky-Golay filter which calculates a polynomial fit of successive data windows based on polynomial degree and window size. A Gaussian fit is then applied to the filtered data and the beam parameters are calculated and displayed with the fitted curve (see Fig. 3). One can also "zoom" into a zone of interest for a selective fitting if the image consists of multiple beams as shown in Fig. 4.

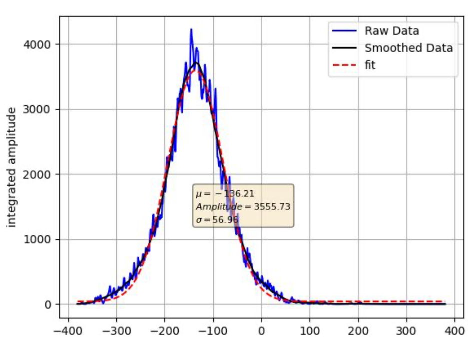

Figure 3: Example of a fitted vertical beam profile.

Frame-by-Frame Analysis

To measure properties of the beam profiles acquired by the video capture, a python script was developed to perform a frame-by-frame analysis. For each selected frame the beam parameters are evaluated using the same methods described above. The data is stored in a text file for further post-processing.

Full Video Signal Analysis

In addition to the frame-by-frame method, the complete video can be analysed to display the H0 formation rate and the estimated beam sizes for the full acquisition time. The drawback with this method is that the measured beam sizes are influenced by the distortions to the beam spots seen during the cycle as the "zoom" option is not implemented in this analysis method.

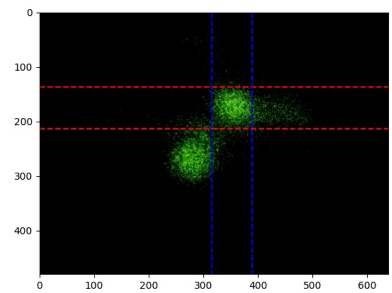

Figure 4: Selective fitting of the beam profile.

RESULTS

H0 Formation With and Without Electrons

The first series of measurements consisted in observing the effect of the electron beam of the cooler on the stripping of the circulating H^- beam. From Fig. 5 it is clearly seen that the H0 formation rate, due to the stripping of the loosely bound H^- electron, is greatly enhanced in the presence of the cooler electron beam. The blue trace shows the H0 rate when the electrons are present only on the lower cooling plateau (100 keV, after 8.6 s). With electrons also present on the first cooling plateau (red trace) one sees a significant increase in the H0 rate. However, without a measurement of the circulating beam intensity one cannot confirm that the beam lifetime [4] is affected by the increase in the stripping rate. Bunched beam intensity measurements at the start and end of each cooling plateau are available but do not have the required accuracy to determine the beam lifetime.

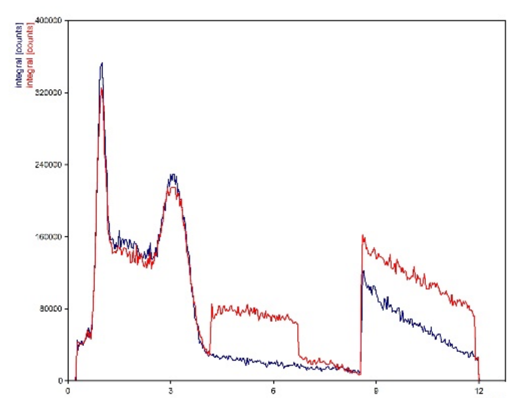

Figure 5: Total H0 signal measured for a full ELENA cycle with electrons (red) and without electrons (blue).

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Beam Size Measurements at 648 keV

Using the frame-by-frame method we were able to plot the evolution of the neutral beam size with the electron cooler switched on and off. At 648 keV the analysis is somewhat difficult due to the presence of two beams after deceleration from 5.3 MeV. First indications from the video seem to indicate that only the upper right beamlet sees the cooler electrons. However, if both beamlets are analysed separately one sees that they both behave in a similar way when electrons are present.

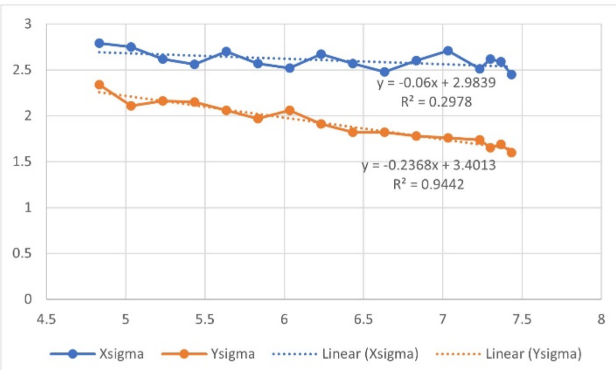

Figure 6: Horizontal (blue) and vertical (orange) beam size evolution with cooling on the first cooling plateau.

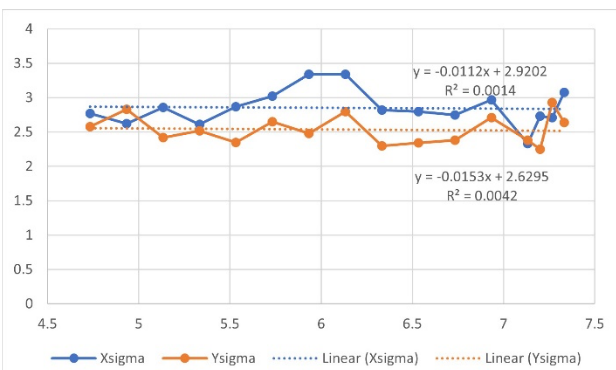

Figure 7: Horizontal (blue) and vertical (orange) beam size evolution without cooling on the first cooling plateau.

Figure 6 shows the horizontal (blue) and vertical (orange) beam size (1σ) evolution under electron cooling as a function of time. Figure 7 shows the same but this time without any cooling electrons. In the horizontal plane no cooling is observed whilst in the vertical plane the beam size reduction is only marginal. Another indication that the beam is not cooled is the variation of the profile amplitude which decreases over time in the same manner, with or without cooling.

Beam Size Measurements at 100 keV

At the low energy plateau of 100 keV the situation is somewhat different as can be seen in Figs. 8 and 9. On this plateau a new beam is injected as the intensity of the decelerated beam is too low to be of any use. The amplitude of the fitted profiles (orange) indicates an increase in particle beam density, but the change in beam size (blue) seems to indicate the contrary. The sudden decrease of the horizontal beam size after injection is probably due to particle loss and not cooling. Throughout the plateau the beam size remains constant, again indicating that the circulating beam is not cooled.

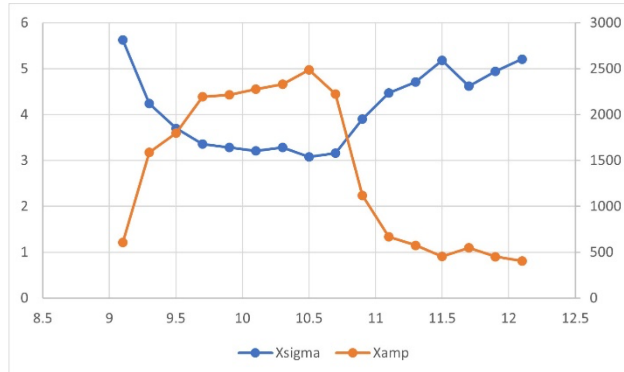

Figure 8: Horizontal beam size (blue) and Gaussian fit amplitude during the second cooling plateau.

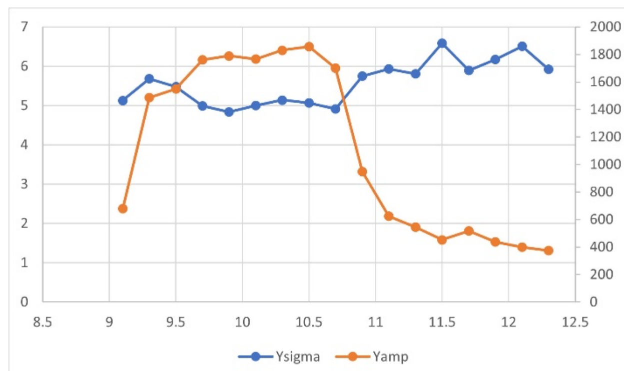

Figure 9: Verticalal beam size (blue) and Gaussian fit amplitude during the second cooling plateau.

CONCLUSION AND OUTLOOK

The neutral beam profile monitor in ELENA has been optimised to capture the effect of H^- beam stripping due to residual gas interactions or the presence of electrons from the cooler.

The measurements so far do not show clear signs of beam cooling but there is a need to disentangle the effect of residual gas stripping, which occurs over the full length of the straight section, from the stripping from the cooler electrons, which takes place over only 1 metre. Moreover, the two-beam structure that is observed over most of the cycle also hinders the proper evaluation of the beam size and the source of this perturbation needs to be fully understood.

For future measurements we will investigate the effect of the circulating beam position and intensity as well as the electron beam current on the H0 profile. A correlation with the profile measured with the beam scrapers will also be necessary to confirm the observed two-beam structure.

The use of protons in ELENA should also be envisaged as a wealth of information can be obtained and will allow us to optimise the cooling of antiprotons more efficiently.

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