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ELENA COMMISSIONING

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Abstract

The Extra Low Energy Antiproton storage ring (ELENA) is an upgrade project at the CERN Antiproton Decelerator (AD). ELENA will further decelerate the 5.3 MeV antiprotons coming from the AD down to 100 keV and allow the experiments typically operating traps to increase the capture efficiency. ELENA features electron cooling for emittance control during the deceleration and therefore preserve the beam intensity and to generate bright bunches extracted towards the experiments. The ring has been completed with the installation of the electron cooler at the beginning of 2018. The electron cooler is meant to operate at an electron energy of 355 eV and 54 eV, corresponding to a pbar momentum of 35 MeV/c and 13.7 MeV/c. First observations of cooling have been observed at both energies, and decelerated ion beams with characteristics close to the design values have been obtained before the start of CERN Long Shutdown 2 (LS2). The latest results of ELENA commissioning will be presented, together with an overview of the project and status and plans.

INTRODUCTION

The antimatter experiments at CERN presently take 5.3 MeV kinetic energy antiprotons beams from the AD decelerator. The recent installation of ELENA and its ability to further decelerate the antiprotons down to 100 keV will be a major breakthrough for the antimatter physics research, as it will allow to trap and study at least one order of magnitude more antiprotons per shot than what has typically been achieved before. A more detailed report on the ELENA Commissioning have been recently presented and described in [1]. In the following, only a short summary of [1] is reported.

ELENA OVERVIEW

The ELENA ring has a hexagonal shape and its circumference is about 30 m. Figure 1 shows a picture of the ring after its complete installation in 2018, with its main components highlighted.

For machine commissioning purposes, a standalone ion source able to provide 100 keV H^- or proton beams is installed next to the ELENA ring, between the ELENA injection and extraction beamlines shown in Fig. 2. An electrostatic ion switch installed at the intersection between injection and extraction lines allows for injecting H^- and proton beams in either directions in the ring. Unfortunately, the insulation transformer of the ion source High Voltage (HV) cabinet had several problems, and it eventually failed completely during the 2018 run, preventing further use of ion beams. Moreover, observed shot-to-shot H^- intensity variation limited the amount of studies that could be done while the source was operational. Despite several attempt to solve those problems, most of the ELENA commissioning had to be performed with limited pbar beam-time dedicated by AD to ELENA.

The typical pbar decelerating cycle is depicted in Fig. 3. The beam is injected as a single bunch from the AD at 100 MeV/c in a waiting RF bucket in ELENA. A first deceleration step brings the beam down to 35 MeV/c where the beam is debunched and the electron cooler is used to reduce the beam emittances to compensate for the adiabatic emittance blow-up (about a factor 3) induced by the deceleration. After being re-bunched, the beam is further decelerate down to 13.7 MeV/c where it is again debunched and cooled.

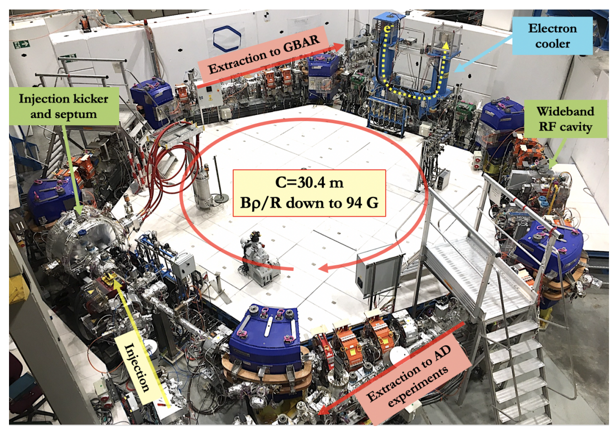

Figure 1: Picture of the ELENA Ring after installation. The main components, including the electron cooler, are highlighted.

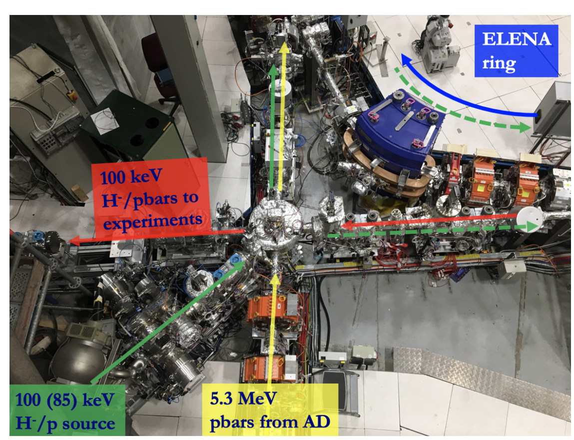

Figure 2: Injection and extraction lines toward main experiments. The ion source is partially visible in the bottom left corner. The possible beam paths are highlighted.

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The beam is finally re-bunched and extracted toward the experiments. By design, the final re-bunching is performed at harmonic four and the electron cooler is kept ON for "bunched beam cooling" in order to obtain short bunches with sufficiently low momentum spread.

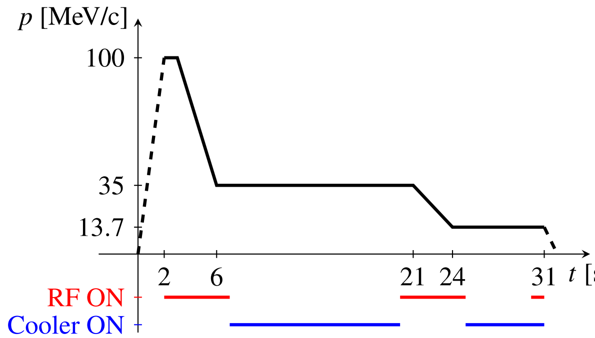

Figure 3: Typical ELENA pbar cycle. A solid black line indicates the period with circulating beam. RF and electron cooler are ON during the periods highlighted in red and blue, respectively. The time scale is an approximation of what was being used by the end of 2018.

ELECTRON COOLER SETUP

The electron cooler was installed in the ELENA ring at the beginning of 2018, and it was made fully operational by July 2018. Due to the limited beam time availability, only the minimum necessary studies on cooling efficiency were performed with the main purpose to commission a full decelerating cycle. The electron beam velocity was adjusted for each plateau to match the circulating beam velocity by looking at longitudinal Schottky signal, which was taken from a single Beam Position Monitor (BPM) sum signal. Alignment and overlap of the electron and ion beams were empirically adjusted with orbit bumps on the circulating beam while minimising the final emittance measured with the scraper. After all adjustments, the effect of cooling was clearly visible in both the transverse (e. g. Fig. 4) and longitudinal (e. g. Fig. 5) planes. The measured longitudinal cooling time of the order of a second, as well as the obtained beam size reduction are compatible with expectations, despite more studies are needed to verify the actual cooling dynamics.

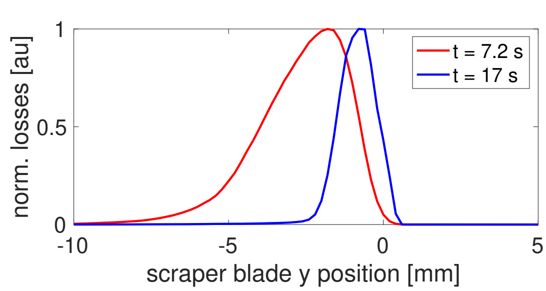

Figure 4: Normalised beam losses as a function of the vertical scraper position before (red) and after (blue) cooling. The width of the signal corresponds to half the beam size.

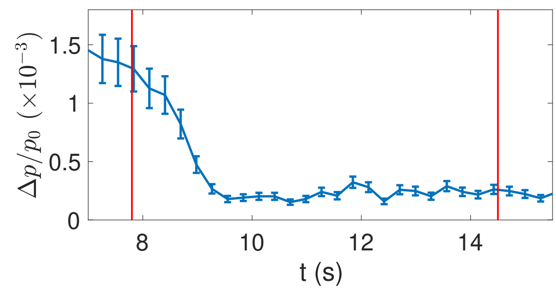

Figure 5: RMS momentum spread obtained from the longitudinal Schottky signal during the intermediate plateau with e-cooling. The start times of the scraper measurements in Fig. 4 are indicated in red.

Table 1: Design [4] and Obtained [5] Beam Parameters Before LS2 for the pbar Cycle

Parameter	Design	Obtained
Q_x/Q_y	$\approx 2.3/\approx 1.3$	2.46/1.41
Cycle duration [s]	20	30
Injected intensity [pbars]	3e7	3.7e7
Efficiency [%]	60	50
Extracted bunches [#]	4	4
Bunch population [pbars]	0.45e7	0.43e7
$\Delta p/p_0$	5e-4	7e-4
Bunch length [ns]	75	85
ϵ_{phys} x/y [μm]	1.2/0.75	4.1/1.5

Due to several failure and instability issues of the H^- source, very limited attempts of cooling H^- has been performed. However, during the limited experience, no evident degradation of the H^- lifetime due to the possible interaction with cooler electrons have been observed.

More details on the ELENA electron cooler commissioning can be found in [3].

OBTAINED BEAM PERFORMANCES

Despite the little beam time availability and the issues with the ion source, and thanks to several empirical optimisations, by the end of 2018 it was possible to achieve beam parameters for the bunches before extraction which are reasonably close to the design values. Both achieved and design values are summarised in Table 1. Note that most measured values have a rather high uncertainty as very little statistics could be accumulated and not all diagnostics could be fully calibrated.

Figure 6 shows the typical beam transmission obtained along the deceleration cycle toward the end of the 2018 run. Note that the blue trace is affected by the bunch intensity but also by bunch length and number of bunches. The small signal during the second ramp is due to the use of the fourth RF harmonic ($h = 4$) instead of $h = 1$ as for the first ramp.

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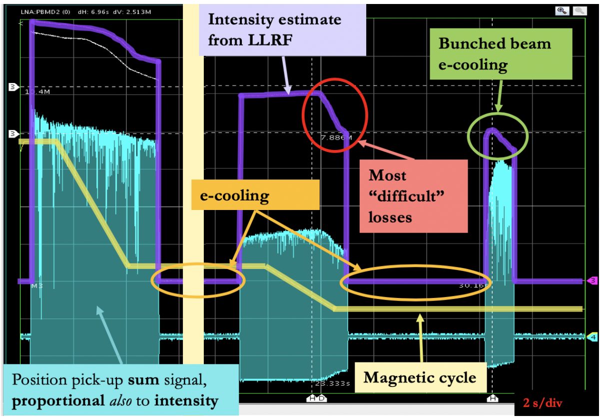

Figure 6: Beam intensity (purple) and magnetic cycle (yellow) as a function of time. The blue trace is the peak line density of the beam seen by one BPM.

Also during the final bunched beam cooling the RF was set to $h = 4$ and one can see the increase of the line density corresponding to the shortening of the bunches due to bunched beam cooling. The use of $h = 4$ during the second ramp was not the baseline option, but it seemed to have a beneficial impact on transmission, even though considerable losses are still present toward the end of this ramp. Those losses were the most difficult to reduce for reasons which are still unclear, and will require further measurements and studies during the next run.

CONCLUSIONS

2018 was a very fruitful year for ELENA commissioning. The finally obtained beam parameters at extraction were close to the design values, despite the limited available beam time. Transverse emittance reduction up to about 80 % was achieved even at the lowest plateau at 100 keV [2]. The final machine settings were obtained after several steps of systematic and empirical tuning of the available machine knobs, which surely left room for improvements.

During the present CERN Long Shutdown 2 (LS2) the main activity is the installation and commissioning with H^- of all electrostatic transfer lines toward the "old" AD experimental zone. Figure 7 shows a layout of the experimental areas next to the ELENA ring with all transfer lines being installed. Moreover, several consolidation works are also ongoing to ensure a restart of operation with H^- in mid 2020 and with pbars in mid 2021.

More details on ELENA and its electron cooler commissioning can be found in [1, 3].

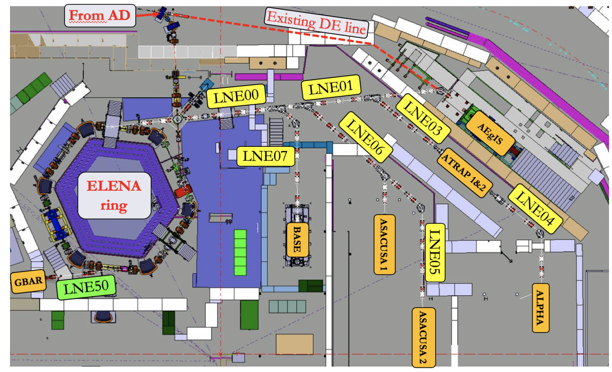

Figure 7: Layout of ELENA extraction lines. The lines being built during LS2 are highlighted in yellow.

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