ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-MOPAB177

ELENA COMMISSIONING AND STATUS

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Abstract

The Extra Low ENergy Antiproton ring ELENA is a small synchrotron recently constructed and commissioned to decelerate antiprotons injected from the Antiproton Decelerator AD with a kinetic energy of 5.3 MeV down to 100 keV. Controlled deceleration in the synchrotron, equipped with an electron cooler to reduce losses and generate dense bunches, allows the experiments, typically capturing the antiprotons in traps and manipulating them further, to improve the trapping efficiency by one to two orders of magnitude. During 2018, bunches with an energy of 100 keV with parameters close to nominal have been demonstrated, and first beams have been provided to an experiment in a new experimental zone. The magnetic transfer lines from the AD to the experiments have been replaced by electrostatic lines from ELENA. Commissioning of the new transfer lines and, in parallel, studies to better understand the ring with H^- beams from a dedicated source, have started in autumn 2020. The first 100 keV antiproton physics run using ELENA will start in late summer 2021.

INTRODUCTION

ELENA [1–4] is a small 30.4 m circumference synchrotron constructed recently at CERN and sketched in Fig. 1. The purpose of the machine is to decelerate antiprotons coming from the Antiproton Decelerator (AD) at 5.3 MeV down to 100 keV. In the past, experiments running traps received the antiprotons directly from the AD with lowest energy reachable with the given circumference, which allowed them to capture less than 1 % only of the beam. The aim of the project is to allow the experiments to increase the capture efficiency by one to two orders of magnitude.

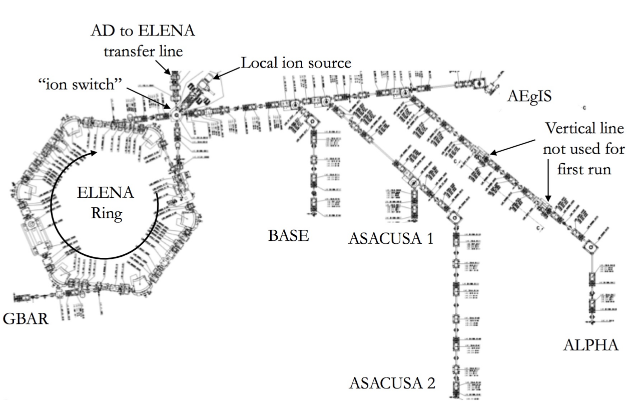

Figure 1: Layout of the ELENA ring and transfer lines.

In a first phase, the ELENA ring and short transfer lines (AD to ELENA transfer line, line from the source to the ring and extraction line towards the GBAR experiment shown in Fig. 1) required for the commissioning of the ring and a new experimental area have been installed. The ELENA ring has been successfully commissioned in 2018 mainly with antiprotons from the AD and not, as planned initially, with a simple ion source providing 100 keV H^- ions. The decision to dismantle the old magnetic transfer line from the AD and to replace them with new electro-static lines from ELENA has been agreed with the experiments, based on results obtained during ELENA ring commissioning. CERN Long Shutdown 2 (LS2), during which no antiproton production beam was available, was the perfect period to carry out these installation activities, followed by commissioning of the new lines with H^- beams from a local source. During this period, connection of ELENA to the old experimental area was possible without reducing availability of antiproton beams for experiments. In addition to transfer line commissioning, studies on the ELENA took place with H^- ions which will speed up the restart with antiprotons planned in August 2021. Improvements of the reliability of the ion source was essential to the very successful ELENA commissioning activities during the last months.

TRANSFER LINE COMMISSIONING

The main purpose of recent commissioning activities was to test the electrostatic transfer lines from ELENA to the experiments with 100 keV H^- beams from a local source, mimicking the antiproton beams. For this purpose, the beam pulse with a length of typically a few μs is transported from the source to the ring. The injection kicker with a plateau of only about 0.65 μs deflects only a part of the incoming beam pulse; most of the incoming beam is not injected and lost. The injection kicker is synchronized with the RF system such that the beam is injected at the center of the RF buckets. The beam circulates typically between a few 100 ms for extraction towards the GBAR experiment and a bit more than 1 s for extraction towards the old experimental area. This is necessary in order to ramp the potential of deflectors of the "ion switch", deflecting the beam coming from the the source towards the injection region, down to sufficiently small values not perturbing the beam extracted towards the old experimental zone.

Beam position and profiles in the extraction lines are determined using wire grids, placed at regular intervals. However not all could be installed for the start of the commissioning in autumn 2020. Priority had been given to the ALPHA line and the BASE line, but since then all lines have been equipped with monitors. Based on experience with the commissioning of lines becoming available earlier, the second but last profile monitor position of the ASACUSA 2 line was

12th Int. Particle Acc. Conf. IPAC2021, Campinas, SP, Brazil JACoW Publishing
ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-MOPAB177

left empty in order to make the line available earlier. In all cases, once a transfer line became available, it was fast to bring the beam up to the last monitor before the handover with the experiment.

Figure 2 shows profiles acquired along a straight part of the transfer line starting at the extraction towards the old experimental area. One notes that, despite the low intensities of a few 10^6 H^- ions, the beam can be well characterised. Despite some of the monitors featuring several missing channels, the beam position and size can be determined with appropriate accuracy. As beam particles hitting a wire of a monitor are stopped, the intensity is reduced by about 10 % for each monitor inserted. Even for the longest transfer lines, the beam can be observed on all monitors with one and the same bunch. This is a major improvement with respect to AD operation, where the beam could be observed only on the first monitor inserted intercepting the whole beam. Phase space ellipses at the ELENA extraction reconstructed from the profiles shown in Fig. 2 are plotted in Fig. 3. One notes good agreement between the measured (blue) and expected (green) phase space ellipses.

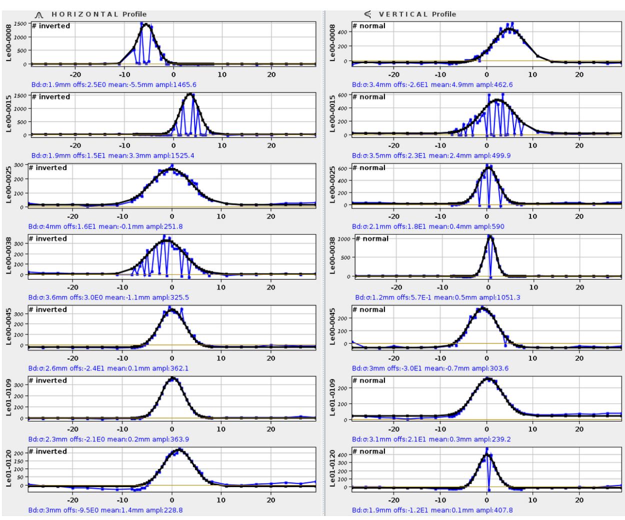

Figure 2: Profile measured with subsequent profile monitors along a straight transfer line from the extraction towards the old experimental area.

Beam properties have been extensively measured using quadrupole scans. Figure 4 shows typical examples of quadrupole scans towards the end of the ASACUSA 1 line measuring the beam size with the last monitor of the line for the horizontal plane and the second but last monitor of the line for the vertical plane and varying the strengths of the two quadrupoles upstream from the second but last monitor. The reference location for the re-constructed Twiss parameters is the ELENA extraction (entrance of fast deflectors). In Fig. 5 the measured phase space ellipses are compared to the ones obtained with design Twiss parameters and the measured emittances. One notes excellent agreement between measured and expected Twiss parameters. Thus, re-matching of the lines to bring the optics closer to the theoretical one

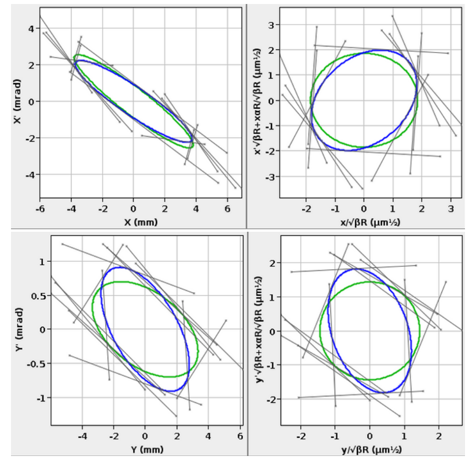

Figure 3: Transverse phase space reconstruction using the measured beam sizes from Fig. 2.

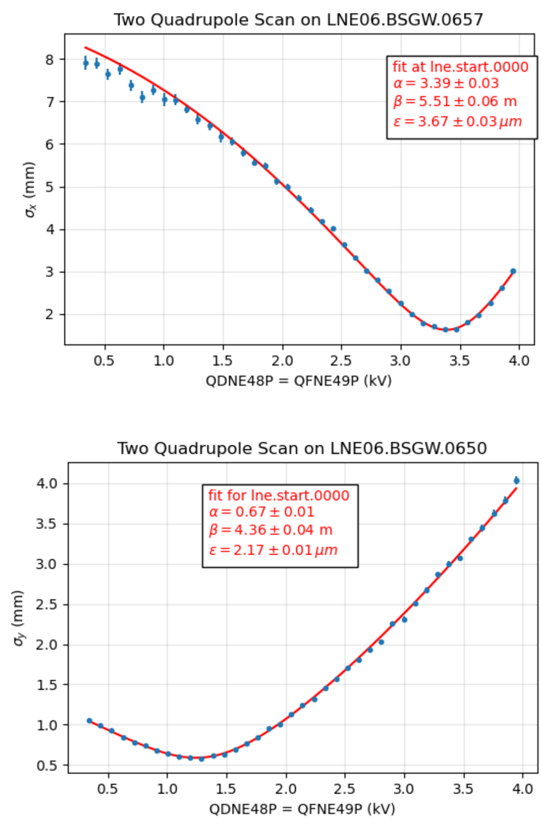

Figure 4: Typical quadrupole scans to characterise the beam done towards the end of the ASACUSA 1 line.

is deemed not necessary. The discrepancies between the measured and expected dispersion was found small as well.

Furthermore successful tests of the automatic beam distribution system, sending up to four bunches available at extraction to different experiments with the help of fast deflectors raising during the gap between bunches, have taken place.

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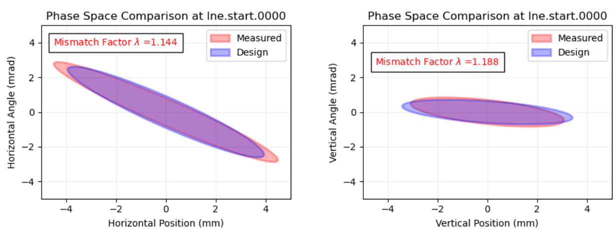

Figure 5: Comparison of phase space ellipses from the quadrupole scan shown in Fig. 4 with theoretical ones.

TESTS WITH THE ELENA RING

In addition to transfer line commissioning, various investigations on the ELENA ring have taken place to improve the understanding of the machine and to prepare already for the first nominal 100 keV antiproton physics run. Typical examples are investigations on hysteresis and remanence, which are relevant for operation with very low magnetic field. Tests of the Low Level RF system (LLRF) [5] aim at ensuring that the required cycle with periods with RF on for deceleration or before extraction and periods without RF for electron cooling and different harmonics can be set up.

Figure 6 shows the time evolution of a coasting H^- beam under the action of the electron cooler. Contrary to initial expectations, the electron beam from the cooler did not result in a significant reduction of the life-time of the circulating H^- beam due to stripping of the second loosely bound electron. One clearly observes that the average revolution frequency of the coasting beam increases, a behaviour not observed with the electron cooler switched off. This implies that studies on and empirical optimization of electron cooling can be carried out with H^- beams. Thus, it is unlikely that ELENA will be, as envisaged, be operated with proton beams from the source and with inverted polarity. The acquisition system uses the sum signal from all electro-static position pick-ups in order to enhance the ratio between Schottky noise and background noise from the head amplifiers, and is still under development.

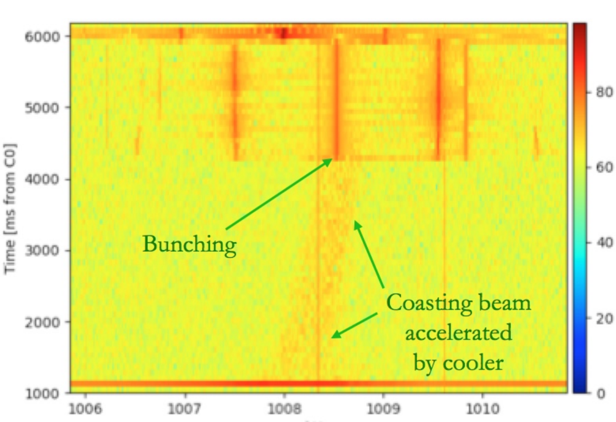

Figure 6: Longitudinal Schottky spectra of a coasting H^- beam under electron cooling.

Figure 7 shows a machine cycle set up to prepare for antiproton operation expected to start in August 2021. The H^- beam is injected at a first 100 keV plateau followed by acceleration to the nominal antiproton injection energy of 5.3 MeV. Then the beam is decelerated with two ramps as required for antiproton operation and plateaus at the two energies, where electron cooling will be applied, which are shorter. This allows to optimize the ramps with careful adjustments of the working point and the closed orbit. Setting-up of these machine cycles profits from improvements, implemented after the commissioning period with antiprotons in 2018, of the tools to program the machine cycle. The signals shown in Fig. 7 do not indicate a fast loss close to the end of the second ramp down as observed often with antiprotons in 2018 despite careful empirical adjustments. One observes a slow loss probably dominated by stripping of the second electron of the H^- ions interacting with rest gas molecules.

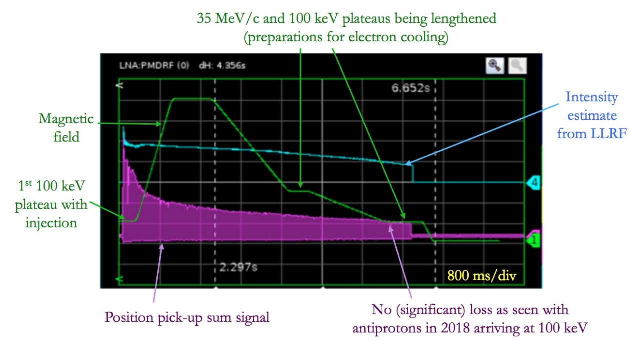

Figure 7: Cycle with H^- acceleration followed by deceleration to prepare antiproton operation.

Different versions of this cycle accelerating and decelerating exist, in particular with longer plateaus to start setting-up of electron cooling.

SUMMARY AND OUTLOOK

During the CERN Long Shutdown 2, the magnetic transfer line from the AD to experiments in the old experimental zone have been replaced by electro-static ones from ELENA. Commissioning of these new transfer lines is almost completed with beam having reached the last monitor in front of the hand-over to all experiments taking beam during the first nominal 100 keV antiproton run starting in August 2021. No major issues have been encountered and the optics along the line has been found sufficiently close to the design, such that no re-matching is foreseen.

Perturbations of the beam transfer due to stray fields from the AD or equipment belonging to experiments have not yet been possible and will be carried only a few weeks before the first 100 keV antiproton run.

In addition, many tests to better understand the ELENA ring could be carried out with even preparations for the setting-up of the antiproton decelerating cycle. In consequence, ELENA is well prepared for the first nominal run.

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