ELENA – FROM INSTALLATION TO COMMISSIONING

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Abstract

ELENA (Extra Low ENergy Antiproton ring) is an upgrade project at the CERN AD (Antiproton Decelerator). The smaller ELENA ring will further decelerate 5.3 MeV antiprotons from the AD ring down to 100 keV using electron cooling to obtain good deceleration efficiency and dense beams. An increase of up to two orders of magnitude in trapping efficiency is expected at the AD experiments. This paper will report on the current status of ELENA where beam commissioning of the ring is now taking place. Phase one of the project installation has been completed with ring and injection lines in place, while phase two will finalize the project with installation of 100 keV transfer lines connecting the experiments to ELENA and is planned to take place in 2019/2020.

INTRODUCTION

Since the start-up of the AD physics program in 2000 [1,2], experiments receive antiprotons directly from the AD ring at 5.3 MeV and then decelerate them to energy levels suitable for capture in Penning traps. Using degrader foils for deceleration results in large emittance blow-up and losses, only up to 1% can be captured in this way. At one of the experiments, a Radio Frequency Quadrupole Decelerator is used which reduces losses but due to emittance blow-up and imperfect longitudinal matching, capture efficiency remains low.

To increase efficiency and accommodate for the growing number of AD experiments, the ELENA [3] project was launched in 2011. ELENA is a compact synchrotron for deceleration of 5.3 MeV antiprotons down to 100 keV. An increase of up to two orders of magnitude in the antiproton trapping efficiency at the experiments is expected. This will be obtained by controlled deceleration and by cooling the beam at two energy levels using electron cooling, resulting in limited deceleration losses and increased phase-space density in all three planes. Furthermore, the available antiproton intensity will be distributed in up to four bunches serving up to four experiments thanks to fast deflectors in the beam transfer lines. An added advantage of this multi-bunch scheme is the mitigation of undesired space-charge effects with short bunch lengths at these low energies. ELENA basic parameters are given in Table 1. A layout of ELENA, the AD ring and the experimental areas for ALPHA, ASACUSA, ATRAP, AEGIS, BASE and GBAR collaborations can be seen in Fig.1, Fig. 2 shows an overview with main components.

Table 1: ELENA Machine and Beam Parameters

Momentum range, MeV/c	100 – 13.7
Kinetic Energy range, MeV	5.3 – 0.1
Machine tunes h/v	2.3/1.3
Circumference, m	30.4
Deceleration cycle length, s	≈25
Injected beam population	$3 \cdot 10^{7}$
Ejected beam population (total of all bunches)	$1.8 \cdot 10^{7}$
Number of extracted bunches	4[a)]
Δp/p of extracted bunches, (95%) [b)]	$2.5\cdot 10^{-3}$
Bunch length at extraction, (95%), m /ns [b)]	1.3 / 300
Emittance (h/v) at extraction, π µm, (95%) [b)]	6/4
Nominal (dynamic) vacuum pressure, Torr	$3 \cdot 10^{-12}$

[a)] Fewer extracted bunches is an option leading to slightly larger emittances and momentum spreads

[b)] Present best guesses based on simulations

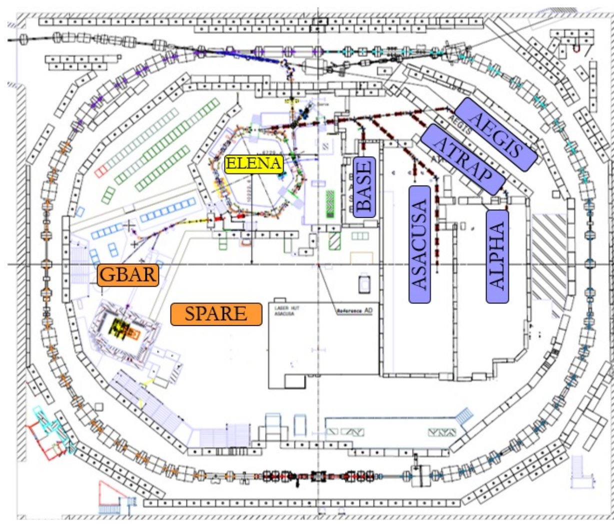

Figure 1: Layout of the AD ring, ELENA and the experimental areas.

INSTALLATION

Installation in the AD building is done in 2 phases. The first phase which started in 2015 includes the ELENA ring, the 100 keV Ion source and all beam lines necessary for H-/H+ injection from the Ion source, antiproton transfer from AD to ELENA and antiproton transfer from ELENA towards the Gbar zone. Phase 2 will be done once commissioning of the ring with Ions and antiprotons

ISBN 978-3-95450-182-3

is completed. Planned to start in December 2018 and lasting approximately 1 year, it includes replacing the existing, magnetic beam transfer lines to all experimental areas with new, low-energy lines employing electrostatic deflectors and focussing devices as well as sensitive beam profile monitors. A re-location of the AEGIS experiment to the spare area is also proposed.

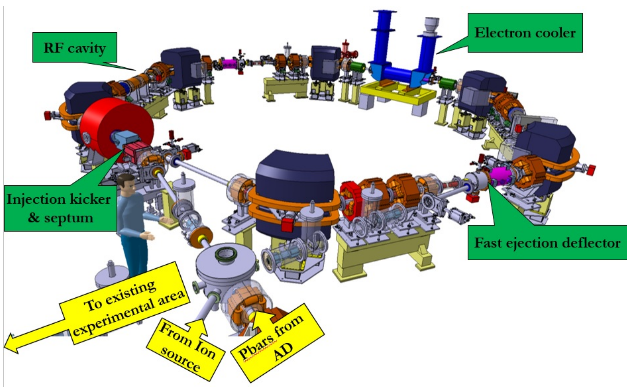

Figure 2: ELENA ring overview.

Installation Status

At present, most of the phase 1 installation work is completed. Main remaining items are: the electron cooler, injection/ejection line longitudinal pick-ups and beam profile monitors as well as completion of the GBAR beam line. Phase 1 completion is foreseen during the summer of 2017, beam commissioning will then be paused for a few weeks to allow for this. Fig. 3 shows the ELENA ring area in its current state.

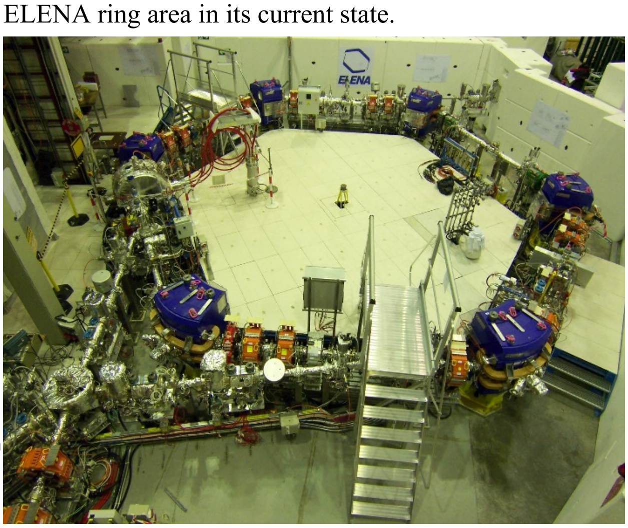

Figure 3: Installed ELENA ring with injection/ejection lines at bottom left and GBAR ejection line at top right.

COMMISSIONING

Hardware Commissioning

After a period with alternating equipment tests and installation activities, the hardware commissioning program could start mid-October 2016. Extensive tests were carried out on all installed systems with particular attention given to safety systems, machine interlocks, magnet circuits including thermal tests, HV circuits and establishing nominal vacuum pressure.

Beam Commissioning

By mid-November, the first H- beams could be extracted from the Ion source, transferred through the injection line and injected into the ring, where on the 18th of November the first few turns could be observed. On the 23rd of November, beam survival of a few ms was obtained after further steering and initial adjustments of transfer line focussing devices and ring quadrupoles. At this stage, the only way to monitor beam position and profiles in the injection line was via a scintillating screen positioned at the end of the line near the injection septum. A typical measurement is seen in Fig. 4. To facilitate monitoring and studies, several secondary emission profile monitors will be installed in both injection and ejection lines and the unit already installed directly downstream of the Ion source has to be made fully operational.

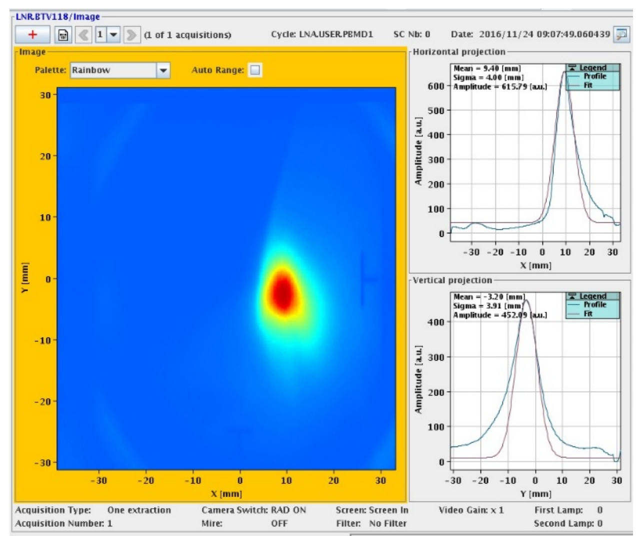

Figure 4: H- beam profiles as seen on BTV118.

Pulses with a length of a few us and reasonably well defined leading and trailing edges were injected on the first plateau of a special acceleration cycle, which was created for setting up the cycle with 100 keV H^- Ions from the source. Signals from the position pick-ups could be observed for up to a few ms. As the RF system had not yet been commissioned and, thus, the beam could not be bunched, it was unclear, whether the beam was lost after these few ms or if it continued to circulate without longitudinal structure.

ELENA can be operated with interleaved machine cycles of different kinds permitting simultaneous machine studies and running for physics. A system dealing with cycle generation, timing and synchronisation of the different ELENA cycles and beam transfers was installed and quickly brought into operation. An example of an ELENA super-cycle, including one nominal deceleration cycle and several shorter acceleration cycles can be seen in Fig. 5.

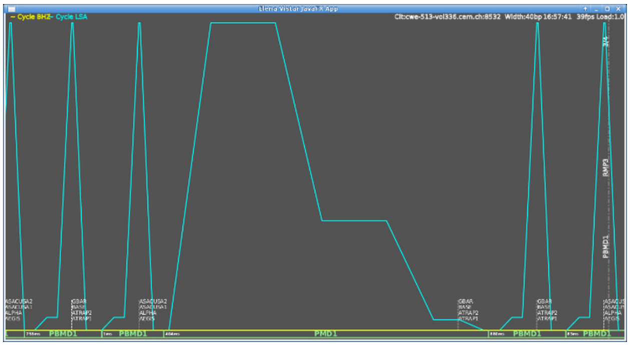

Figure 5: ELENA super-cycle.

After the winter shut-down, beam commissioning resumed in March 2017. Due to technical problems with the Ion source, the beam energy was reduced to 85keV to minimise the risk of further breakdowns and repairs. Thanks to careful preparation (B-train calibration, initial RF LL/HL set-up, tune optimisation, ring position pick-ups and signal observation system availability etc.), initial commissioning of the low-level RF system [4] quickly permitted bunching on the injection plateau and first rough estimations of minimum beam life-time at 85 keV. The yellow trace in Fig. 6 shows a bpm sum-signal of a bunched H- beam surviving throughout the injection plateau of 400ms and then being lost during the acceleration ramp. A life-time in the range of a second or more looks achievable at this energy which is below the nominal 100 keV.

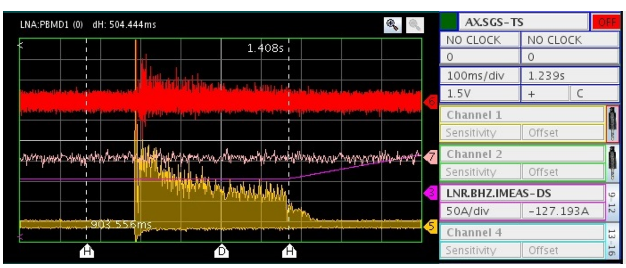

Figure 6: bpm signals of circulating H- beam at 85keV.

First capturing tests of the 85keV beam were done on harmonic h=2 as the revolution frequency of 130.7 kHz at 85 keV is outside the range of the RF-system. A waterfall plot from reconstructed bpm data on the left is presented in Fig. 7. Radial position data from the bpm's could also be used to calculate the synchrotron frequency which was found at ~1.5 kHz.

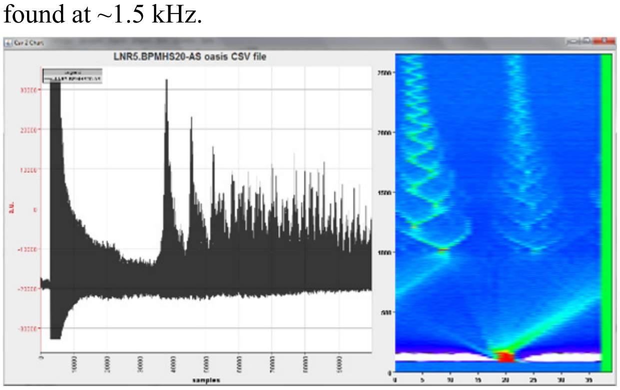

Figure 7: first RF capture tests on h=2.

Further beam commissioning activities focussed mainly on calibration of the magnetic measurement system (B-train) and setting-up of the scraper/MCP detector system for beam profile measurements in the ring [5].

Next Steps

Beam commissioning will continue during 2017 with the aim of delivering first beams (initially H^- or protons, possibly later as well antiprotons) to the GBAR experiment during the second half of the year. In the RF system, the radial and beam phase loops will be brought into operation and the system will be prepared for bunch to bucket transfers from AD. The associated longitudinal pickup will also be used for intensity measurements using a Schottky analysis system integrated in the LL RF [6]. Orbit and tune measurement/correction systems need to be operational before acceleration/deceleration tests and setting-up can be done. Studies to better understand the signals from the SEM profile monitor near the Ion source will be done as all channels/wires give some output (positive or negative) regardless of beam position. Another issue slowing down progress, and in particular further commissioning of instrumentation and the RF system, during initial beam commissioning has been severe shot to shot variations of the injected beam intensity. Investigations will take place to try to identify whether this lies within the Ion source itself or with the injection line or ring.

SUMMARY AND OUTLOOK

It has been shown that H- Ions seem to have sufficient lifetime even at energies below the nominal lowest operational value of 100keV. This validates several points in the design as well as correct function of many machine systems. Next major milestones will be further commissioning of instrumentation and the RF system and acceleration tests with beam from the source and then antiproton injection and deceleration. This will be followed by installation and commissioning of the electron cooler, which could be challenging at electron beam energies as low as 55eV. Installation of the missing SEM profile monitors in the injection/ejection lines will be done at the same time and will help for better understanding and setting-up.

ELENA will provide beam to the GBAR experiment located in a new experimental area from 2017 on. AD experiments in the old experimental area will be connected to ELENA to receive beams at 100 keV only during CERN Long Shutdown 2, scheduled in 2019 and 2020 for upgrades of the LHC and its injector chain.

ACKNOWLEDGEMENTS

Many colleagues from inside and outside CERN have contributed to the project and made the ring commissioning possible.

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