ELENA: INSTALLATIONS AND PREPARATIONS FOR COMMISSIONING

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Abstract

The Extra Low Energy Antiproton ring (ELENA) is a small synchrotron under construction at CERN to further decelerate antiprotons from the Antiproton Decelerator AD from 5.3 MeV to 100 keV. Controlled deceleration in a synchrotron equipped with an electron cooler to reduce emittances in all three planes will allow the existing AD experiments to increase substantially their antiproton capture efficiencies and render new experiments possible. Installation of the machine and lines needed for the commissioning of the ring are on-going and commissioning is expected to start around mid-2016. The aim is to complete ELENA ring commissioning in November followed by the installation of new electrostatic transfer lines to existing experiments until autumn 2017. Status of ELENA installations and preparations for commissioning will be reported.

INTRODUCTION

At present an active and growing users community receives antiproton bunches from the Antiproton Decelerator AD [1,2], at 5.3 MeV, the lowest energy, which can be safely reached in this machine. Most experiments capture the antiprotons in traps and, thus, have to further decelerate the beam using degrader foils or a decelerating Radio Frequency Quadrupole RFQD. In the case the beam is decelerated by a foil, many of the antiprotons are stopped in the foil or still have an energy too high for trapping and only up to 1% are captured. Matching to the RFQD is difficult, in particular in the longitudinal plane, and physical emittances increase during the deceleration resulting in a capture efficiency of several per cent.

ELENA [3-8] is a small 30.4 m circumference synchrotron under construction to decelerate the antiproton beams in a well-controlled manner and to reduce emittances with an electron cooler. This will allow existing experiments to increase their trapping efficiencies by one to two orders of magnitude and new types of experiments become feasible.

The antiprotons will be injected at 5.3 MeV, an energy reachable safely in the AD and then decelerated down to 100 keV, which is possible in such a small ring. Electron cooling will be applied at an intermediate plateau and at the final energy. The available intensity per cycle will be distributed into several (baseline four) bunches sent to different experiments, which can run simultaneously. Even though the initial motivation to generate several bunches had been to mitigate direct space charge effects becoming significant with the low energy and short bunch lengths, the resulting longer runs for the experiments are considered an advantage despite the lower intensity. ELENA main parameters are given in Tab. 1 and a sketch of the machine inside the AD hall is shown in Fig. 1.

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 [a)]	2.46/1.46
Circumference, m	30.4
Repetition rate, s [b)]	≈100
Injected beam population	$3 \cdot 10^{7}$
Ejected beam population (total of all bunches)	$1.8 \cdot 10^{7}$
Number of extracted bunches	4[c)]
$\Delta p/p$ of extracted bunches, (95%) [d)]	$2.5 \cdot 10^{-3}$
Bunch length at extraction, (95%), m /ns [d)]	1.3 / 300
Emittance (h/v) at extraction, π μm, (95%) [d)]	6/4
Nominal (dynamic) vacuum pressure, Torr	$3 \cdot 10^{-12}$

[a)] With sufficient tuning range e.g. to avoid resonances
[b)] Limited by the AD repetition rate; the expected ELENA cycle length is ≈25 s.
[c)] Less extracted bunches is an option leading to slightly larger emittances and momentum spreads
[d)] Present best guesses based on simulations

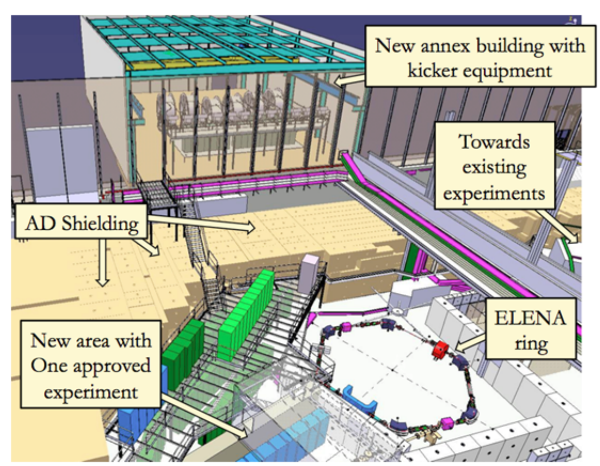

Figure 1: Sketch of the AD hall with ELENA, the new annex building and experimental areas.

ELENA LAYOUT AND MAIN FEATURES AND ISSUES

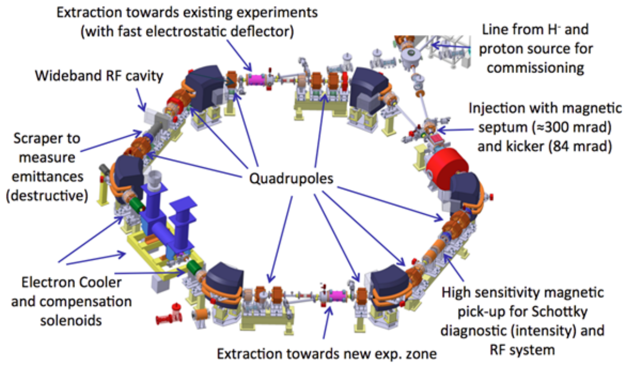

Figure 2: Sketch of the ELENA ring highlighting main features and particularities.

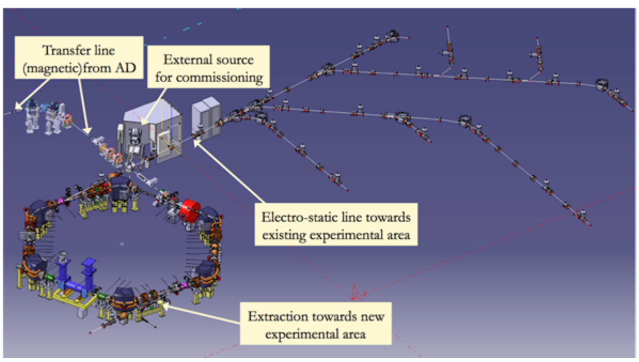

Figure 3: ELENA ring and transfer lines.

Main features and possible issues of the ELENA ring sketched in Fig. 2 and its extraction lines shown in Fig. 3 are:

- ELENA is operated at an unusually low energy for a synchrotron with a magnetic focusing structure. Thus, any possible performance limitation has to be evaluated with particular attention to the low beam energy. Many of the features listed below are the consequence of this unusual energy range.
- The lattice design has to cope with typical difficulties for small machines such as few quadrupole families to adjust optics parameters, constraints on lattice parameters to be fulfilled and to deal with strong focusing due to the bending magnets. Three quadrupole families allow adjusting the lattice.
- A good magnetic field quality is a challenge due to the very low magnetic fields required and remanence and hysteresis effects. Initially "thinning", i.e. mixing laminations made of magnetic steel with larger non-magnetic laminations, of the yoke had been foreseen for the bending magnets [9] and envisaged for the other magnets. Careful measurements with prototypes showed that this does not improve field quality; the underlying reasons are well understood now [10]. Finally most magnets will be constructed with conventional laminated yokes without "thinning". Orbit correctors will be constructed without magnetic cores to avoid any effects related to hysteresis.
- The electron cooler [11, 12] is an essential ingredient to the project and will cool the beam at an intermediate energy of around 650 keV to reduce emittances before further deceleration and avoid losses, and at the final energy of 100 keV. In order to reduce the energy spread of bunches sent to the experiment, bunched beam electron cooling will be applied by keeping the cooler switched on during the capture process.
- Emittance blow-up due to Intra Beam Scattering (IBS) is expected to be the main performance limitation and to determine, together with the performance of electron cooling, the characteristics of the beams extracted and sent to the experiment.
- Beam diagnostics is challenging due to the low intensity and velocity.
- With the challenging nominal pressure of 3 10^{-12} Torr in the ring, obtained with a carefully designed vacuum system making use of NEG coatings wherever possible, interactions with rest gas molecules are not the dominant performance imitations [13].
- Extraction and transfer to the experiments is based on electrostatic elements [14] as this is an efficient and flexible low-cost solution at these low energies.

INSTALLATIONS AND PREPARATIONS FOR COMMISSIONING

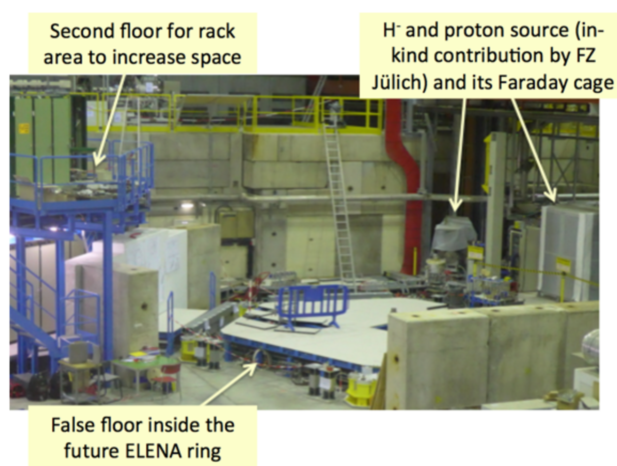

Fig. 4: ELENA Location by the end of 2015.

The first ELENA project phase aims at installing and commissioning the ring and all lines required for this step.

Installation during 2015

After reinstallation of the AD kicker generators, which used to be at the location of the ELENA ring, in an adjacent annex building constructed mainly for this purpose, the area has been become available in spring 2015 and was cleaned and prepared for the new machine. This has been followed by installations of mainly infrastructure until the end of 2015 as shown in Fig. 4. A second floor of the rack area allows providing sufficient

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space for racks on a smaller surface due to nearby areas for an experiment (GBAR) and ELENA. A false floor inside the future ELENA ring and in some locations outside, with cooling water and compressed air distributions and cables pulled in a first cabling campaign, as well as the support structures have been installed.

An external H^- and proton source for commissioning has been provided, upgraded to allow the generation of 100 keV beam and tested as in-kind contribution by the FZ Jülich. This source has already been used for a successful first tests of electro-static beam transfer elements including an "ion switch" [12] deflecting the beam from the source to the two possible injection points.

Completion of ELENA Ring Installations

After a second cabling campaign and installation of further support structures, infrastructure needed for ELENA ring commissioning is now almost completed.

The first part of the transfer line from the AD to ELENA located inside the AD tunnel has been completed before the AD restart with the installation of two bending magnets, two quadrupoles, beam instrumentation and is under vacuum now.

Only few machine elements of the ELENA ring, as fast electro-static deflectors to extract the beam and a first bending magnet, have been installed during the first months of the year 2016. However, preparations of machine hardware are in full swing now. Although the installation schedule, updated regularly to take so far small delays of various components into account, is dense and challenging, no show-stopper ruling out start of commissioning in July 2016 has been identified.

Plans for Commissioning

The ELENA ring will be commissioned mainly using the external 100 keV H^- and proton source in parallel to AD operation for the physics program. The advantages are minimum perturbation to the low energy antiproton experiments and an increased repetition rate for ELENA (pulses from the source spaced by a few seconds instead of an antiproton bunch from the AD every 100 s). The disadvantage of commissioning with an external source is that first tests will be done at very low energy, which is more delicate. Antiprotons from the AD will be required to complete ELENA ring commissioning and to demonstrate a successful cycle comprising injection, deceleration, electron cooling and extraction.

The first phase of ELENA ring commissioning without the electron cooler installed is expected to start in July 2016 After a brief hardware test period, beam will be injected for the first time. The polarity of the magnets will be the nominal one allowing injecting protons with inversed sense of rotation or H^- with the nominal sense of rotation. The only diagnostics available in the ring until circulating beam is obtained are electro-static beam position monitors. The source will provide a beam with a well-defined raising edge of the pulse to ease interpretation of the signals measured with the pick-ups. Circulating beam will be detected with Schottky diagnostics based on optimized magnetic pick-ups and/or the sum signal from one position pick-up. Next steps will be commissioning of the RF system followed by orbit corrections and machine optics studies based on orbit response measurements. This first phase of ELENA ring commissioning will be completed by acceleration and, possibly, deceleration tests.

The second phase of ELENA ring commissioning will take place after installation of the electron cooler and aim at commissioning and optimizing cooling and setting-up of a complete machine cycle. First electron cooling tests will probably take place with nominal magnet polarity and H^- ions from the source. In (the likely) case, that the beam H^- life-time drops to inacceptable short durations due to stripping by electrons from the cooler, the polarity of the ring will be inversed and the source switched to protons to commission the cooler. Pick-ups installed in the cooler allow measuring the positions of the electron beam and the circulating beam making it faster to re-optimize electron cooling after switching to antiprotons by steering to beam to the optimum positions in the cooler.

A full antiproton cycle consisting of transfer from the AD, deceleration, electron cooling and extraction has to be set-up and demonstrated to complete ELENA ring commissioning.

SUMMARY AND OUTLOOK

Completion of installations and preparations for ELENA ring commissioning by July 2016 is very tight, although so far not ruled out by any show-stopper. From July on hardware tests and ring commissioning are foreseen. The very ambitious aim is to sufficiently advance ring commissioning by September to be confident that the machine functions properly and allows generating the beams expected by the users, despite the fact that cooling tests will not yet have been possible.

During installation and commissioning of the new electro-static 100 keV beam lines to the existing experimental area (see Fig. 3), an activity lasting about 11 months, no beam will be available for users in this area. Thus, the scheduling for these new lines has to be coordinated with users and take into account general CERN planning with the Long Shutdown 2 (LS2), driven by LHC plans, in 2019 and 2020 and no beams available during this period. The present baseline scenario, assuming that ELENA commissioning progresses well and the users endorse this plan, is to decide in September 2016 to install the new lines from November 2016 to autumn 2017 with a rather brief 100 keV antiproton run for all experiments in 2017 and a normal run in 2018 followed by LS2.

If ELENA ring commissioning is not sufficiently advanced by September 2016, the installation of the lines to the existing experimental area will be postponed to LS2. In any case, 100 keV antiproton beams from ELENA are expected for the new experimental area with one experiment being installed, from 2017 on.

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