EXTRA LOW ENERGY ANTIPROTON RING ELENA: FROM THE CONCEPTION TO THE IMPLEMENTATION PHASE

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Abstract

The Extra Low Energy Antiproton ring (ELENA) is a CERN project aiming at constructing a small 30 m circumference synchrotron 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. The ELENA design is now well advanced and the project is moving to the implementation phase. Component design and construction are taking place at present for installation foreseen during the second half of 2015 and beginning of 2016 followed by ring commissioning until the end of 2016. New electrostatic transfer lines to the experiments will be installed and commissioned during the first half of 2017 followed by the first physics operation with ELENA. Basic limitations like Intra Beam Scattering limiting the emittances obtained under electron cooling and direct space charge effects are reviewed and the status of the project is reported.

INTRODUCTION

The Antiproton Decelerator AD [1,2], is a unique facility constructed after the completion of the exploitation of the Low Energy Antiproton Ring LEAR [3,4] and providing low 5.3 MeV energy antiprotons to experiments. Most experiments further decelerate the beam using degrader foils or a decelerating Radio Frequency Quadrupole RFQD and then capture the beam in traps. Both processes to decelerate are not perfect and lead to significant antiproton losses. Deceleration with a degrader foil is limited by energy straggling such that, even with optimized thickness, many antiprotons are stopped in the foil and annihilate there and many still have a too high energy to be trapped; this results in a trapping efficiency well below 1%. Matching to the RFQD is difficult, in particular in the longitudinal plane, and physical emittances increase during the deceleration resulting in losses.

The ELENA project aims at constructing a small 30.4 m circumference synchrotron to improve the trapping efficiencies of existing experiments by one to two orders of magnitude by controlled deceleration in a small synchrotron and reduction of the emittances with an electron cooler [5-8]. New types of experiments will 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

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)	2.3/1.3
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)
Δp/p of extracted bunches, (95%) d)	$2.5 \cdot 10^{-3}$
Bunch length at extraction, 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

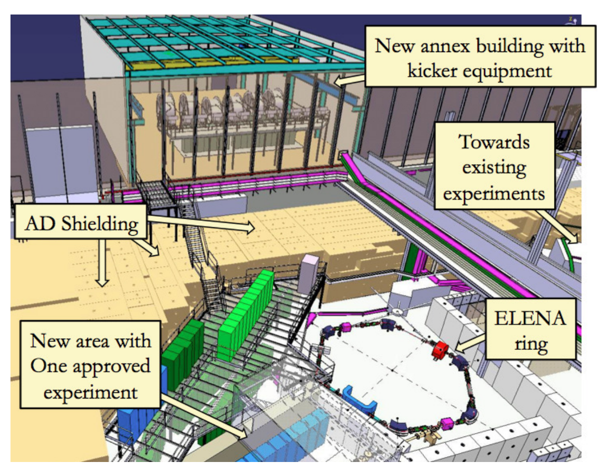

Figure 1: Sketch of the AD hall with ELENA, the new annex building and experimental areas.

small ring. Electron cooling will be applied at an intermediate plateau and at the final energy. Moreover, ELENA will not send the full available intensity in one bunch to one experiment, but send several (baseline four) bunches with lower intensity to several experiments. 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.

ELENA LAYOUT AND MAIN FEATURES AND ISSUES

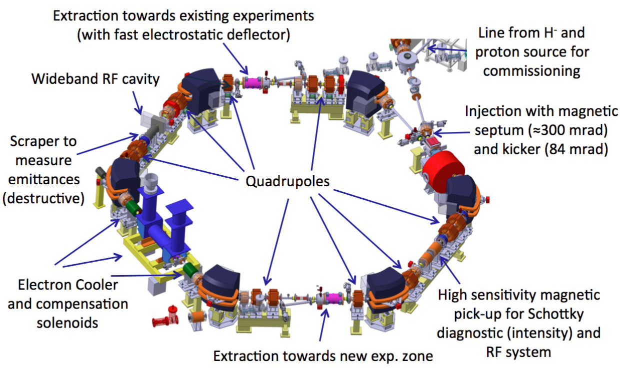

Figure 2: Sketch of the ELENA ring highlighting main features and particularities.

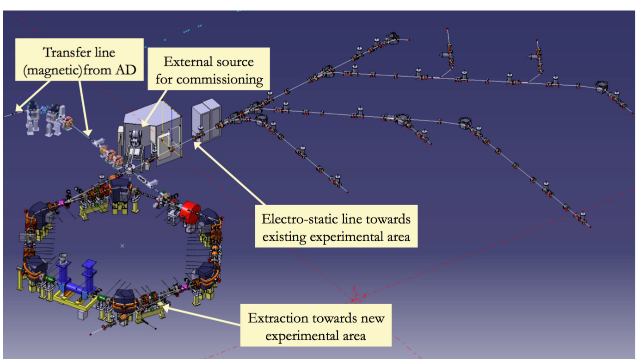

Figure 3: ELENA ring and transfer lines.

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 machine will be located inside the existing AD hall. This is an economic solution as no large additional building is needed to house the new ring and experiments and this allows keeping existing experiments at their present location. A smaller new building has been completed recently in order to free space in the AD hall for the ELENA ring and a second experimental area.
- The lattice design has to cope with typical difficulties for small machines 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. An important condition was to find a layout suitable for installation in the AD hall and compatible with the position of the injection and the two extractions towards the foreseen experimental areas. The ELENA ring has hexagonal shape and two-fold periodicity (neglecting the perturbation of the lattice due to the cooler). Two slightly longer straight sections without quadrupoles house the electron cooler with associated equipment and the injection line. Three quadrupole families (one magnet of each family in each of the remaining four sections) 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; measures to guarantee the required field quality are summarized in [9]. From the beginning of the project, it had been foreseen to apply “thinning”, i.e. mixing of non-magnetic stainless steel laminations with magnetic laminations, for the main bending magnets; this increases the magnetic flux density in the magnetic laminations and reduces hysteresis effects. Quadrupole prototypes are constructed to test whether “thinning” is appropriate for quadrupoles and, possibly, sextupoles as well. Orbit correctors will be constructed without magnetic cores to avoid any effects related to hysteresis.
- Electron cooling will be applied 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. The design of the ELENA cooler [10] is based on the one constructed for the L-LSR ring in Kyoto, but with parameters optimised for our case. First simulations of electron cooling at 100 keV predicted final energy spreads of the coasting beam by about one order of magnitude larger than expected initially. With adiabatic bunching without electron cooling, this would have led to energy spreads at the limit of the acceptance of the transfer lines and inacceptable for some experiments. 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. For example, the lowest beam currents are well below 1 μA, which is well below the capabilities of standard slow beam current transformers. Thus, the intensity of coasting beams during electron cooling will be determined by Schottky diagnostics using optimised pick-ups.

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Further diagnostics in the ring are low noise position pick-ups (precision better than 0.1 mm), a tune measurement BBQ system, a scraper to determine destructively emittances and possibly a ionization profile monitor (feasibility under study). Diagnostics in the lines comprises TV stations, GEM monitors and "micro-wire" profile monitors.

- Cross sections for interactions with rest gas molecules as scattering out of the acceptance or emittance blow-up become large at low energies. These effects have to be evaluated with care, paying attention to the very low energy in order not to overestimate emittance blow-up [11]. The machine will be fully bakeable and equipped with NEG coatings wherever possible in order to reach the challenging nominal pressure of 3 10^{-12} Torr and to guarantee that interactions with rest gas is not the main performance limitation.
- An RF system with a rather modest RF voltage of less than 500 V is sufficient for deceleration and to create short bunches at extraction. However, the system has to cover a large dynamic range.
- Direct space charge detuning is a significant effect despite the low intensity due the low energy and short bunches required for the experiment and would result in tune shift of almost -0.4 with only one extracted bunch. As mitigation measure, the available intensity will be split into several bunches to serve several experiments almost simultaneously.
- Extraction and transfer to the experiments is based on electrostatic elements [12] as this is an efficient and flexible low-cost solution at these low energies.
- Commissioning of the ELENA ring will be done mainly with an external source providing H^- ions or protons in parallel to AD operation for experiments. This allows injecting beam with a higher repetition rate than would be possible with antiprotons and a bunch every ≈100 s from the AD and is expected to speed up commissioning despite the fact that this implies starting at the lowest energy

STATUS

The basic conception of the ELENA ring and transfer lines is completed. A general project review in October 2013 has endorsed the principle of adding a small synchrotron equipped with electron cooling to increase the number of antiprotons useful for the experiments. Many suggestions for further improvements and studies are followed up. The machine to be constructed has evolved significantly since the approval of the project [5], but is well known now. The machine to be constructed is the one presented at the review and described in the Technical Design Report (TDR) [13] published in-between.

A new building adjacent to the AD hall required to house kicker hardware now installed in the AD hall at the location, where ELENA will be installed, and to serve as storage space for the experiments has been completed recently with infrastructure installation taking place at present.

The design and integration of components is almost completed for the ELENA ring and advancing well for the extraction lines. First contracts for construction of large components are being placed in industry.

OUTLOOK

The place inside the AD hall, where ELENA will be installed, will be freed from kicker equipment during the first part of 2015. After installation during the second half of 2015 and beginning of 2016, ELENA ring commissioning is planned in parallel to AD operation mainly with the help of a dedicated source delivering 100 keV protons or H^- ions. Dismantling of the existing magnetic transfer lines from the AD to the experiments will and installation and commissioning of new electrostatic lines from ELENA is planned for the first half of 2017. First 100 keV antiproton beams from ELENA for physics are expected in autumn 2017.

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