ISBN: 978-3-95450-243-1 ISSN: 2226-0374 doi:10.18429/JACoW-COOL2021-S503

AD/ELENA ELECTRON COOLING EXPERIENCE DURING AND AFTER CERN LONG SHUTDOWN (LS2)

D. Gamba*, L. Bojtar, C. Carli, B. Dupuy, A. Frassier, L. V. Joergensen, L. Ponce, G. Tranquille,
CERN, 1211 Geneva, Switzerland

Abstract

Electron cooling is a key ingredient of the Antimatter Factory at CERN, now composed of the AD and ELENA rings, both featuring an electron cooler. After the successful commissioning of the ELENA ring and electron cooling with antiprotons in 2018, the facility was shutdown for the CERN long shutdown (LS2). In the meantime, ELENA has been operating with H^- ions generated from a local source and electron cooling of these H^- was demonstrated. The facility has restarted with antiproton operation during summer 2021, and it is now delivering 100 keV production beams through newly installed electro-static extraction lines to all the experiments for the very first time. We will give an overview of the experience gained and difficulties encountered during the restart of the AD and ELENA electron coolers. The experience with electron cooling of H^- beam in ELENA and the comparison with antiproton cooling will also be presented.

INTRODUCTION

The Antimatter Factory at CERN is a unique facility that provides antiproton beams to several experiments [1]. The facility, originally composed only by the Antiproton Decelerator (AD) [2], was complemented with the Extremely Low ENergy Antiproton (ELENA) ring [3] which was successfully commissioned in 2018 [4]. The AD provides about 3×10^7 antiprotons in a single bunch at 5.3 MeV kinetic energy approximately every two minutes. The ELENA ring allows to further decelerate the antiprotons down to 100 keV kinetic energy and produces 4 bunches of about 5×10^6 antiprotons per bunch, which are distributed to up to 4 experiments at the same time. The cycle length of ELENA, of about 15 seconds, falls in the shadow of the next AD cycle.

Stochastic cooling (in AD) and electron cooling (both in AD and ELENA) are used on several plateaus placed at injection (in AD), during the deceleration process, and before extraction in order to counteract the adiabatic emittance increase as well as possible heating effects.

Till the end of 2018, GBAR [5] was the only experiment connected to ELENA. During CERN Long Shutdown 2 (LS2), all AD experiments were connected to ELENA with the installation of electrostatic transfer lines. Despite the unavailability of antiprotons during LS2, the ELENA ring could still be operated with beams from of a local H^-/p source [6,7]. This allowed for progressing in the optimisation of beam performance in the ELENA ring, including e-cooling, as well as to commission the transfer line beam transport well before the arrival of the first antiproton beam after LS2.

The first proton beam for pbar production after LS2 was delivered at the end of June 2021. In the following weeks the AD operation was restored, including the setup of AD stochastic cooling [8] and electron cooling. The first pbar beam was delivered to ELENA mid August 2021 and 100 keV antiproton beams were available for users starting on August 23rd, as scheduled. During this short time, only minor adjustments of the previously prepared H^- cycle were necessary to decelerate and cool pbars, demonstrating that H^- beams can be used for optics and cooling studies in ELENA without the need of pbars.

In the following sections, the achieved beam performance of the facility will be outlined followed by observations of e-cooling related aspects during the restart in 2021.

BEAM PERFORMANCE IN 2021

During the run, further optimisation of both AD and ELENA cycles allowed to improve the overall performance of the facility. By construction, the characteristics of the beam delivered to experiments are defined by the e-cooling performance and heating effects (like Intra-Beam Scattering (IBS)) on the extraction plateau of ELENA, while the final intensity is driven by the efficiency of antiproton production and collection (in AD), and deceleration. For this, stochastic and electron cooling play a key role to at least counteract the adiabatic increase of the beam transverse and longitudinal emittances. The final AD and ELENA cycle deceleration efficiency are presented in Fig. 1 and Fig. 2, respectively. In AD the beam intensity is measured by a Cryogenic Current Comparator (CCC) [9], which allows to measure the beam current also while the beam is unbunched, while in ELENA the beam intensity is estimated by the Low Level Radio Frequency (LLRF) system which only works when the beam is bunched and does not take into account for longitudinal

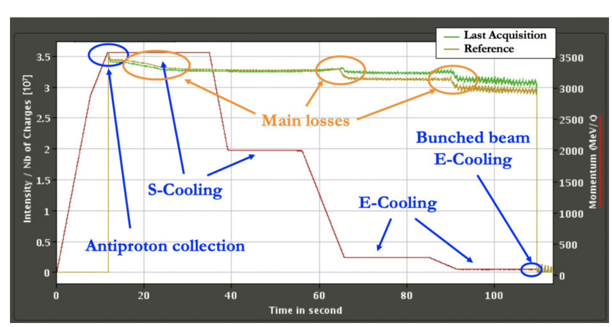

Figure 1: Beam intensity (in units of 10^7 charges) along a typical AD cycle. The main observations are highlighted.

* davide.gamba@cern.ch

ISBN: 978-3-95450-243-1 ISSN: 2226-0374 doi:10.18429/JACoW-COOL2021-S503

distribution variations and therefore has a lower accuracy than the AD CCC.

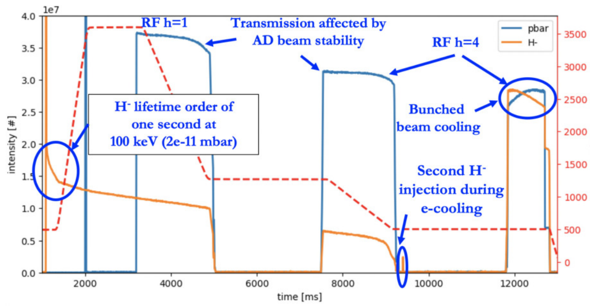

Figure 2: H^- (orange) and pbar (blue) beam intensity along a typical ELENA cycle (dashed red). The main observations are highlighted.

During the 2021 run it was not possible to re-establish the same pbar production and/or AD injection efficiency that was achieved in 2018, which was as high as 5e7 pbars injected, while the final AD deceleration efficiency of about 85% is close or better than what was achieved in the past. In AD, the main losses appear on the injection plateau, likely due to the limited longitudinal acceptance of the stochastic cooling system, and during the 2 GeV/c to 300 MeV/c, and 300 MeV/c to 100 MeV/c ramps, likely due to poor cooling performance on the tails of the beam distribution. In ELENA, the achieved transmission was of the order of 80%, which is much higher than the 60% from the design [3] and the 50% achieved in 2018 [4].

The typical distribution of single bunch intensities over 7 days of operation is shown in Fig. 3. In this case, the bunch intensity is measured by two beam current transformers [3] installed on the two extraction lines, named LNE50 and LNE00. GBAR is presently the only experiment in the LNE50 line. The discrepancy in the average beam intensity between GBAR and the other experiments is due to the presence of a partially-intercepting beam profile monitor upstream the intensity monitor but also due to systematic calibration and measurement issues on the two LNE50 and LNE00 pickups, which are being investigated.

Other main beam characteristics at ELENA extraction are summarised in Table 1 together with design values.

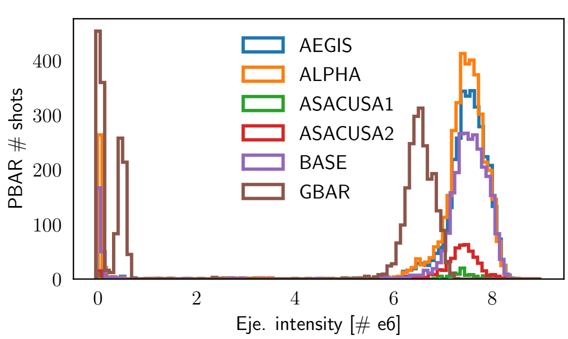

Figure 3: Typical distribution of ELENA extracted bunch intensities per experiment over one week of operation.

Table 1: Design [3] and estimated beam parameters at ELENA extraction at the end of 2021 run for the pbar cycle.

Parameter	Design	Obtained
Q_x/Q_y	$\approx 2.3/\approx 1.3^a$	2.38/1.39
Cycle duration [s]	20	<15
Injected intensity [pbars]	3e7	≈3e7
Efficiency [%]	60	≈80
Extracted bunches [#]	4	4
Bunch population [pbars]	4.5e6	≈7e6
$\Delta p/p_0$	5e-4	≈4.5e-4
Bunch length (rms) [ns]	75	<75
ϵ_{phys} x/y [μm]	1.2/0.75	≈2/≈2

[a] With sufficient tuning range to choose working point in vicinity.

E-COOLERS AND INSTRUMENTATION

The main parameters of the AD and ELENA e-coolers are summarised in Table 2.

The AD e-cooler is the oldest built at CERN: it was used in the Initial Cooling Experiment (ICE) in 1977-80, then used in LEAR (1982-97) and finally moved to the AD where is being used since 1999. Due to the critical spare parts situation, a new e-cooler for AD is being designed [10]. During LS2, it was planned to already replace the present electron collector with one compatible with the new e-cooler design. Unfortunately, the pandemic situation, and high-voltage issues discovered during testing of the first prototype did not allow to perform this exchange. This would have been the occasion to also replace the thermionic cathode in the electron gun, which is now being operated for several years. However, the unavailability of the new collector and the overall good performance of the present cathode did not justify to break the vacuum, which is always considered to be a risky operation for the long baking time needed to recover good vacuum (typically of the order of 10^{-11} mbar).

The ELENA e-cooler [11–13] was commissioned in 2018 [14], and did not require any special modification. Therefore, no modifications nor major maintenance was done in either AD and ELENA e-cooler during LS2.

The key instrument for the setup and optimisation of cooling is the longitudinal Schottky system. In AD this is realised by looking at the second (300 MeV/c) or eighth (100 MeV/c)

Table 2: AD and ELENA E-Cooler Main Parameters

Parameter	AD		ELENA	
Ion p [MeV/c]	300	100	35	13.7
Ion E_k [MeV]	46.8	5.3	0.635	0.1
e^- E_k [keV]	25.5	2.9	0.355	0.055
β_{rel}	0.305	0.106	0.037	0.015
I_{e^-} [mA]	2.5e3	100	5	1
Cooler L [m]	1.5		1	
Ring L [m]	182.43		30.41	
Gun B [G]	590		up to 1000	
Drift B [G]	590		100	
e^- beam r [mm]	25		8 to 25	