CONSOLIDATION OF THE ANTIPROTON DECELERATOR ELECTRON COOLER

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Abstract

A new electron cooler, replacing the 40 year old one, will be installed starting in 2027, during Long Shutdown 3, in the CERN Antiproton Decelerator ring. The new electron cooler aims to improve reliability, cooling time and beam losses. The design of the new electron cooler, very similar in geometry, electron intensity and energies to the present device, will add electron beam magnetic expansion from the gun to the cooling section and enhance the field quality in the cooling section so to reduce electron transverse energy; approach the H/V orbit corrector magnets and improve relative position measurement of the antiproton and electron beams so to better centre the two beams; allow faster switching of the electron beam on/off at the gun so to ease operations. Ultimately, the testing strategy will ensure highly reliable operations. This paper presents an overview of the status of the project.

INTRODUCTION

The new electron cooler [1,2] for the Antiproton Decelerator (AD) ring, whose 3D assembly rendering is shown in Fig. 1, has been entirely designed at CERN and is currently under production. It is set to replace the existing cooler, illustrated in Fig. 2, which, although only operational in the AD since the year 2000, is over 40 years old, having originally been repurposed from the Low Energy Antiproton Ring (1982–1997) [3,4]. The new device aims at a high reliability, by design and robustness of the ancillary equipment.

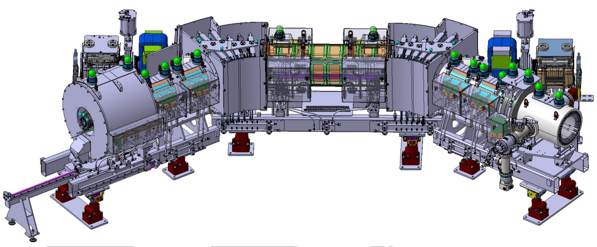

Figure 1: 3D rendering of the new AD electron cooler, with the supporting system, and, from left to right, the expansion solenoid, injection arm solenoid, toroid (pancake), drift solenoid, toroid (pancake), extraction arm, compression (squeeze) coil and collector. Behind the injection and extraction arms the H/V orbit compensators and sector valves.

Moreover, it is expected to have improved performance in terms of time of cooling, mainly obtained by limiting

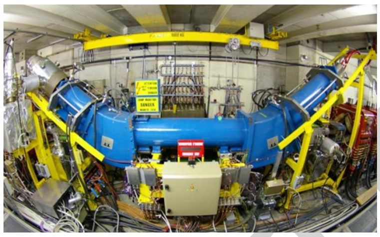

Figure 2: Photo of the 40 year old electron cooler currently installed and operating in the AD ring.

the electron transverse and longitudinal temperature and switching on/off the electron beam during the energy ramps [5], as described in the following. In this paper we give a status of production of the different components, details of the testing strategy and criteria for giving the green-light to deinstall the current device and start installation. A brief overview of planning for installation will also be given.

DESCRIPTION OF THE NEW AD ELECTRON COOLER AND COMPARISON WITH WHAT CURRENTLY INSTALLED

The new AD electron cooler design retains the geometry, electron beam intensity (up to 2.4 A), and energy (up to 27 keV) of the current system. Both designs share a drift solenoid length of 1505 mm and a magnetic field intensity of 60 mT [6], enabling electron beam cooling of antiprotons at beam momenta of 300 and 100 MeV/c [7]. The injection/extraction arms also maintain the same field intensity (60 mT) and axis angle (36°) relative to the drift solenoid. Conversely,

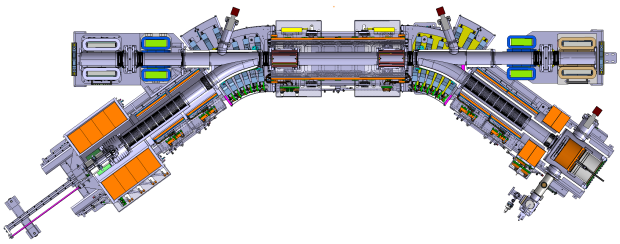

Figure 3: Top view drawing of new AD electron cooler.

compared to the existing electron cooler magnet system, the new magnet system gives a factor five improvement in field quality, $\left|\frac{B_\perp}{B_\parallel}\right|$, in the cooling region [1, 2, 6], thus limiting sources of electron beam heating. Furthermore, the new electron gun is immersed into a strong solenoid (nominal 0.24 T, called 'expansion solenoid') allowing the electron beam to expand transversely along the field line. Assuming adiabatic expansion and conservation of the magnetic mo-

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ment, this expansion occurs by a factor of $\sqrt{B_{gun}/B_{drift}} = 2$, and the transverse electron energy is reduced by a factor of $B_{gun}/B_{drift} = 4$, thereby accelerating the cooling process and lowering the final temperature of the circulating antiproton beam [1].

A description of the gun used in the existing AD cooler can be found in [8]. The conceptual design of the new electron gun, detailed in [9], does not fundamentally change for its external body. The geometry of the electrodes [9, 10], on the other hand, count a new gun cathode radius of 12.5 mm against 25 mm, to allow for expansion; new mechanical design of Pierce, grid and anode electrodes to guarantee a gun perveance of 2.2 μP against the current 0.51 μP (smaller cathode but same target value for the emission current) and tight tolerances to ensure as low a transverse energy as possible at nominal operational parameters. Specifications for the High Voltage (HV) system [1] include faster change in the cathode voltage and switching on/off the electron beam during the antiproton energy ramps, to avoid mismatch between electron and antiproton longitudinal beam speed which causes beam losses.

The new collector design [11] was developed for the present cooler, with cooling water circuit outside the vacuum to avoid risks of water leaks in-vacuum, and adapted to the new cooler vacuum geometry, modifying the external vacuum chamber and improving the decelerator and repeller electrodes to increase capture efficiency.

The new electron cooler is equipped with two Beam Position Monitors (BPMs) [12], positioned at the entrance and at the exit of the electron beam into the drift region. These BPMs use have cylindrical geometry with electrode (see Fig. 10 in [2]) dimensions optimized for large beams. They can measure the position of both beams, though only one beam type (either bunched antiproton or modulated electron) can be measured at a time, with the electron beam intensity modulated at a harmonic of the antiproton revolution frequency [13].

The new electron cooler will be horizontal rather than vertical, requiring new orbit compensators (shown in blue/green in Figs. 1 and 3). These compensators are designed to improve performance by enabling more precise, local control of the antiproton beam orbit (both horizontally and vertically) as it enters and exits the cooling section, thereby minimizing distortions.

STATUS OF PRODUCTION AND TESTING STRATEGY

The design of the new AD electron cooler began several years ago [14], evolving from a pancake-only magnetic system to the current design [6]. In this version, to enhance field quality and reduce installation time, pancakes are used exclusively in the toroidal section. Concurrently, the gun's design transitioned from a compact, cost-optimised approach to one closely inspired by the present model [9], following limitations identified during measurements. Additionally, a squeeze coil was added in front of the collector [11]—mirroring the present installation—to compress the electron beam at the collector entrance and improve the collector efficiency. Consequently, the support system was modified to accommodate these changes and evolutions. Procurement started only in 2024 for the magnets and 2025 for the gun.

The limited timescales available between the delivery of its sub-components and final installation will not allow testing of the fully assembled electron cooler. Furthermore, such a test would require a complete installation outside the AD ring, which would be costly both in terms of time, resources and space required. The new electron cooler's electron closely resemble the current system in terms of drift length, bending angles, magnet strength, and maximum electron current and energy—with the main differences being the addition of the expansion solenoid and the plane change of the toroids. This similarity gives us confidence to proceed with dismounting the present cooler and installing the new one, as long as we ensure that the electron beam production at the gun, the magnetic system, and the collector each meet their specifications through individual testing and allocate sufficient time during commissioning for fine-tuning. Our approach will involve testing both gun and collector, with expansion of the electron beam; accurately measure each magnet and the full magnetic system (including the H/V orbit compensators) in its final configuration to tune steerer to best field quality in the drift. The toroid plane change, which affects the residual magnetic field plane for both the electron and antiproton beams, will be handled by the dipole V steerers in the toroid section and the new adjacent orbit compensators.

In the following we give the state of production and describe in more details the ongoing tests and the criteria used for the GO/No-GO to mechanical de-installation of the present cooler.

Magnetic System and Supporting Structure

The magnetic system for the new AD electron cooler, with one spare per type of magnet, is currently in production by external suppliers, with pre-series magnets already being delivered. The full set of magnets for one complete assembly is expected to be received by August 2026. At CERN, acceptance tests will verify the geometry, fiducialisation, thermal performance, and magnetic functions of each magnet, including field mapping using a Translating-Coil Magnetometer [15][1] A comprehensive measurement campaign will then characterize the entire system in its final configuration, accounting for interactions between adjacent magnets. This includes: testing all magnets, including H/V orbit compensators; determining current settings for drift correctors and V steerers to achieve the required magnetic field map [1, 6], with final tuning to occur after installation using the electron beam; and characterizing spare magnets to enable installation without full re-measurement. To ensure accuracy, support girders will be mounted and aligned in Q2

[1] Please note that Fig. 1 in this article refers to the previous design for the AD electron cooler [14], for which the Translating-Coil Magnetometer was initially developed.

2026, replicating the final installation setup. Orbit steerers will be characterized during this campaign, though their exact operational currents will be finalized post-installation. A GO/No-GO decision for de-installing the old electron cooler is set for July 2026, once enough coils have been magnetically measured as standalone units and accepted. Full system measurements and adjustments will continue until December 2026, with spare coil delivery and testing remaining non-critical to the project timeline. The DC powering for the magnets has already been procured.

Vacuum System and BPM

The vacuum system (visible in Fig. 3) comprises the following main components: two arm vacuum chambers (with NEG strips and a liner for a smooth electron beam envelope), toroid chambers, and a drift chamber—including one BPM per side [2]. Manufacturing and NEG coating are performed at CERN. Currently, the toroid chambers (the most complex for both manufacturing and NEG coating) and the BPMs are complete, while the remaining components are in production, with delivery expected in June 2026 and NEG coating later in the year. Standard procurement for pumps, NEG strips, gauges, and valves is complete, pending NEG strip delivery. All elements—including the electron gun, collector, BPMs, and chambers—must undergo vacuum acceptance tests [16] and mechanical validation. The BPMs, described in [2], have already been produced and tested at CERN, with prototype tests confirming expected performance. Acceptance tests, including mechanical verification and vacuum tests, are scheduled for Q2 2026. The GO/No-GO milestone for the vacuum system is scheduled for August 2026.

Electron Gun and Collector

The new electron collector, including both the series and spare units, has been produced by the CERN main workshop. One unit is currently mounted on the Electron Cooler Test Stand (ECTS) for testing. The collector pot, a critical component of the design, has already been validated at the ECTS in both pulsed and DC operation modes [11, 17]. The collector will be considered fully functional after successfully dumping a DC electron beam power of 10 kW for at least 24 h while maintaining electron losses below 10^{-4}. After these tests, the collector will undergo vacuum acceptance tests as specified in [16]. The GO/No-GO milestone for the collector is scheduled for August 2026.

The new electron gun, including both the series and spare units, is currently being produced by the CERN main workshop. Its design prioritizes efficient thermal management, ensuring the cathode operates at a uniform temperature of 1000 °C while keeping the insulation ceramics sufficiently cool to maintain electrical resistance. Excess heat is extracted via a cooling water circuit brazed to the air side of the gun's vacuum chamber. Testing will be conducted at the ECTS [9, 11, 17]. Due to the limited bore size of the test expansion solenoid (0.24 T), the gun will be tested in a vacuum chamber without the cooling water circuit, with compressed air cooling used as an alternative. The gun will be validated upon demonstrating a stable electron beam of 2.4 A at 27 keV (with a current stability of $\Delta I / I_{e^-\text{beam}} \sim 1 \times 10^{-4}$ at constant cathode heating, i.e., filament voltage between 10 and 15 V and ripple of 2 $\mathrm{mV_{RMS}}$ / 8 $\mathrm{mV_{PP}}$) for at least 24 h. Vacuum acceptance tests will follow these validation tests. To be noted that the gun's perveance has already been measured (using the same electrode geometry) up to 5 kV between the cathode and grid in a solenoid field of 90 mT, achieving 700 mA with a perveance of 2.15 $\mu\mathrm{AV}^{3/2}$ [11]. Moreover, the HV powering for gun and collector has already been purchased. The GO/No-GO milestone for the electron gun is set for December 2026.

INSTALLATION AND COMMISSIONING

Once the vacuum and magnet acceptance tests, as well as the full magnet assembly characterization, are completed, the electron cooler will undergo a staged pre-assembly process, foreseen from January to April 2027 and in parallel to the present electron cooler dismantling, before being transported to the AD ring. This pre-assembly approach ensures that any interface non-conformities can be identified and addressed in a more accessible environment before final installation. Connection of the gun and collector will be carried out directly in the AD ring. Installation should progressively start from March 2026 and end around October 2026. This will give several months for the commissioning of each component as well as the full beam transport, before the start of the AD machine operation.

A risk inherent to the nature of the electron cooler (only one type per accelerator) is that each of its components–whether industrially produced or manufactured at CERN–is one-of-a-kind. Potential risks, such as late deliveries, test facility unavailability, or resource conflicts with other activities, have been identified, and mitigation strategies have been proposed. The current schedule includes sufficient buffer time to absorb delays of a few months. However, any delays beyond this margin will result in a postponement of the electron cooler's operation. To prepare for such contingencies, the operation team is already preparing a cycle to for beam commissioning without the electron cooler.

CONCLUSION

The production of the new electron cooler for the AD ring is well underway. Once all sub-components are tested according to specifications, the magnet system is measured and characterised as a whole before installation, mechanical parts are pre-assembled to verify the absence of non-conformities, and alignment (for magnets) is pre-performed in the lab to establish installation references, then–taking into account the similarities with previous equipment, the experience gained, and the improvements made–the new equipment can be installed with confidence. We expect the final decision to be made at the end of year 2026, to give enough time for installation and commissioning of the full device.

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