THE ELENA ELECTRON COOLER

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Abstract

The ELENA (Extra Low ENergy Antiproton) ring will deliver antiprotons at an energy of just 100 keV to experiments aiming to precisely measure the properties of anti-hydrogen atoms. A crucial component of this decelerator ring is the electron cooler which will be used to counter the beam blow-up as the antiproton energy is reduced from 5.3 MeV to 100 keV. The electron cooler will operate at energies below 350 eV in a longitudinal guiding field of 100 G such that the perturbations to the ring can be easily corrected. We will present the design considerations as well as the production status of the cooler.

INTRODUCTION

Electron cooling will be central to the success of the ELENA project [1] which aims to increase by a factor of up to 100 the number of antiprotons available for the trap experiments.

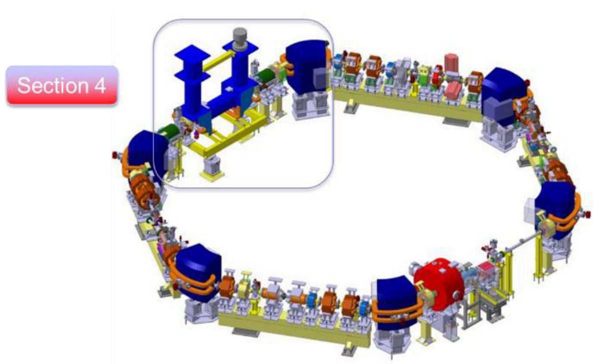

Figure 1: Location of the cooler in ELENA.

The cooler will be installed in long straight section 4 of ELENA (Fig. 1) and will take up almost half the available space. The rest of the section will accommodate the orbit correctors and the compensation solenoids of the cooler. Due to the size limitations of the straight sections in the ring, the space available for the electron cooler is only 2330 mm flange to flange. This leaves room for a drift solenoid with a length of 1000 mm. The electron cooler will have a beam height of 1200 mm as is the standard for the ELENA/AD complex.

For fast and efficient cooling special attention must be paid to the design of the electron gun and the quality of the magnetic field guiding the electrons from the gun to the collector. Another big challenge will be the generation of a cold and stable electron beam at an energy of just 55 eV in order to cool the 100 keV antiprotons. The main cooler parameters are summarised in Table 1.

Table 1: Main Electron Cooler Parameters

Momentum	35 MeV/c	13.7 MeV/c
Electron beam energy	355 eV	55 eV
Electron current	5 mA	1 mA
B_{exp}	1000 G	
B_{drift}	100 G	
Toroid bending radius	0.25m	
Cathode radius	8 mm	
Electron beam radius	25 mm	
Twiss parameters	β_h=2.103m, β_v=2.186m, D=1.498m	
Cooling (drift) length	1.0 m	
Total cooler length	2.33 m	

THE MAGNETIC SYSTEM

The magnet system consists of an expansion solenoid to increase the magnetic field around the electron gun which is needed for the adiabatic expansion of the electron beam, 3 main solenoids: the gun, drift and collector solenoids and two toroid sections each made up of 9 racetrack coils. The toroid coils come in 3 different sizes; two medium sized coils near the drift solenoid, three large coils to allow access by the antiproton beam as well as access for pumps etc. and finally four small coils near the gun and collector solenoids, respectively. In order to compensate for the larger size, the two outer large coils have 1 extra turn whilst the centre large coil has 2 extra turns.

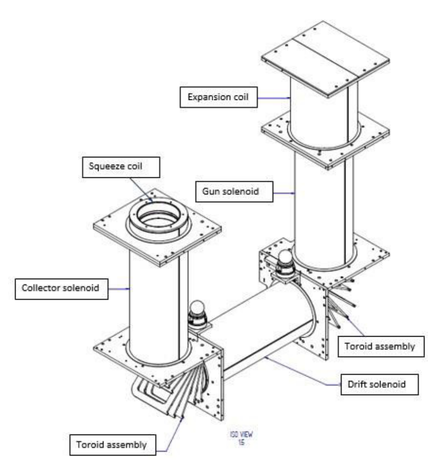

Figure 2: The ELENA cooler magnet system.

A squeeze coil is placed at the collector entrance to ensure that the electrons are focussed as they are decelerated by the repeller electrode. The complete setup of the main magnetic components can be seen in Fig. 2.

In order to reach the good field region requirement of $B_{\perp}/B_{\parallel} < 5\times10^{-4}$ over at least 65 cm in the drift solenoid, additional field correction and fine-tune coils are integrated in the solenoid design. A set of circular coils are placed close to the central region with the aim to ensure that $B_{\perp}/B_{\parallel} < 5\times10^{-3}$ over a maximum length. Saddle coils are installed at each end of the drift solenoid to compensate for the B field leaking into the drift solenoid from the toroids and the vertical solenoids. In addition, 24 fine-tune coils are inserted into the centre of the drift solenoid and can be powered individually to precisely reduce the transverse component of the magnetic field. Simulations of the effect of these coils have shown that the transverse field component can be reduced to well below 50 mG (Fig. 3).

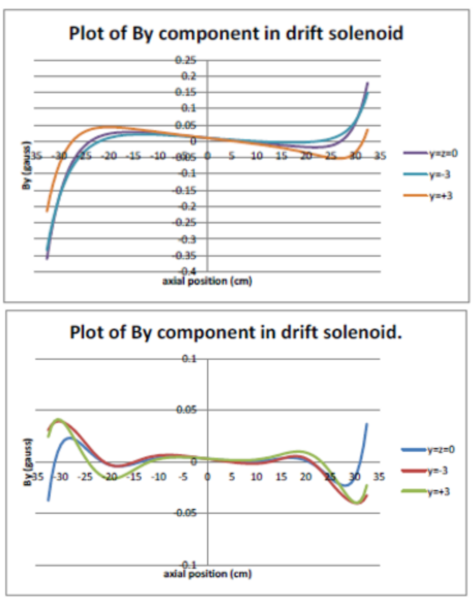

Figure 3: Plot of B_y along the drift solenoid without any correction (top) and with the fine-tune coils (bottom).

To guide the electron beam through the solenoid magnets and toroids, steering coils have also been integrated into the magnets. These will provide a small deflection such that the electrons can be aligned to the circulating ion beam and steered correctly into the collector.

The horizontal kick experienced by the circulating beam in the toroids is compensated by two orbit correctors at the cooler entrance and exit.

MECHANICS AND VACUUM

Figure 4 shows the mechanical layout of the electron cooling device. The magnets, incorporating the vacuum system, are mounted on a base frame which is placed on three jacks for the vertical and tilt alignment. The supporting frame will also hold two standard machine orbit correctors.

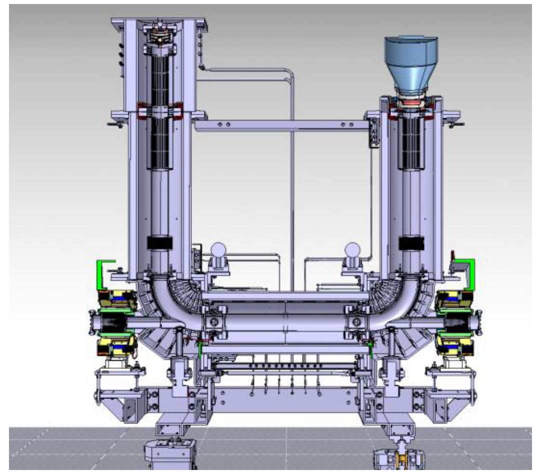

Figure. 4: Mechanical layout.

The device will be mounted in a well-defined sequence alternating between magnet and vacuum elements. In particular, the toroid section needs special care due to the shape of the vacuum chamber. After the nine coils have been installed they must be individually moved to a parking position to leave space for the chamber to be connected to the drift chamber. When this has been performed the coils are put back into position and fixed. A 1:1 3D print model was made in order to validate the mounting sequence of this section (Fig. 5).

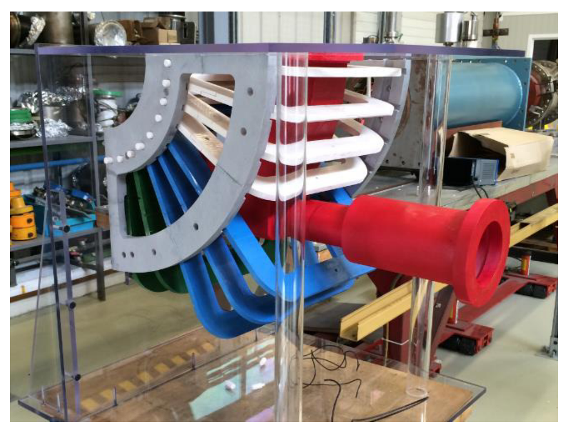

Figure 5: 3D print model of the toroid section.

The vacuum level in the cooler must be the same as for the rest of the ring: 3×10^{-12} Torr [2]. All the chambers are made of 316LN stainless steel and NEG coated where it is possible. At the gun and collector, special chambers incorporating NEG strips have been designed. This will increase the pumping speed by a factor of 10 in these regions where the gas load is the highest.

Two vacuum ports below the cooler will be used to install NEXTorr ion pumps and vacuum diagnostics equipment.

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The electron cooler is regarded as a separate vacuum sector and is connected to the ELENA ring by two sector valves (Fig. 6). The primary vacuum pumping will be made through these valves which will also allow for the easy installation and removal of the device without having to bake-out a large proportion of the ring.

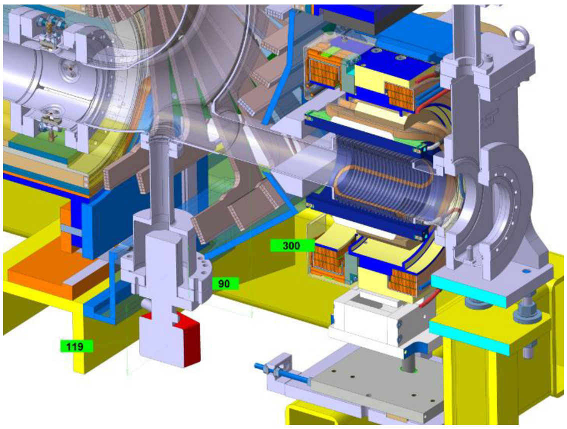

Figure 6: Integration of the vacuum pumping elements in the electron cooler.

ELECTRON GUN DESIGN

The electron gun must produce a cold ($T_\perp < 0.1$eV, $T_\parallel <$ 1meV) and relatively intense electron beam ($n_e \approx 1.5\text{x}10^{12}$ m^{-3}). A conventional 16 mm diameter thermionic cathode will be used and the electrodes have been designed to minimize the transverse temperature after acceleration to the desired energy. The gun is immersed in a longitudinal field of 1000 G which is adiabatically reduced to a field of 100 G in the transition between the expansion and gun solenoids. In this manner the transverse temperature is reduced by a factor of 10 through an adiabatic beam expansion. The electron beam dimension is also increased as to completely overlap the circulating ion beam.

The complete gun assembly consisting of the cathode, Pierce electrode, grid and anode is shown in Fig. 7. The modular design of the gun means that modifications to any electrode can be made by simply replacing only that element with the new design.

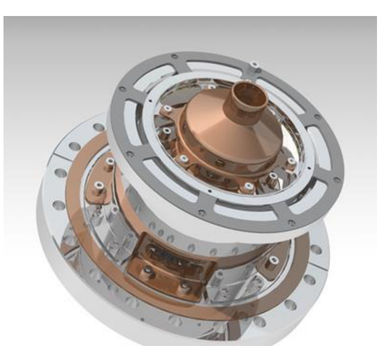

Figure 7: The electron gun.

The design was made using the EGUN code and the COMSOL multi-physics package [3]. A more detailed description can be found in reference [4].

THE ELECTRON BEAM COLLECTOR

After the cooling section, the electrons are separated from the circulating ion beam in the second toroid and are transported and dumped in the collector. At the collector entrance the electrons are decelerated by the repeller electrode and are then given a small acceleration on to the collector surface. The longitudinal field is also decreased such that the electrons are spread out over the whole collector surface (Fig. 8). For ELENA, the collected electrons are of relatively low power and hence there is no need to cool the collector as is normally done on other electron coolers.

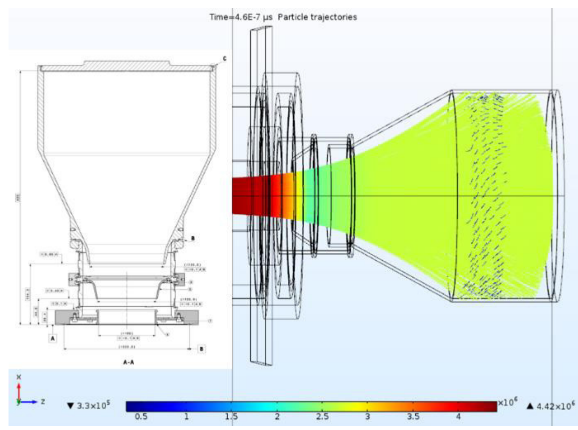

Figure 8: The collector: mechanical drawing (left), electron trajectories in the collector (right).

STATUS AND OUTLOOK

The ELENA electron cooler construction is well under way with the magnet system produced in industry and the vacuum system, including the gun and collector, made at CERN. A careful co-ordination was necessary in order to avoid any integration issues between the magnet and vacuum systems. Many small problems encountered during the production have resulted in a delay in the delivery of the complete system until September 2016. In the meantime, we will commission and optimise the electron gun on our test stand.

REFERENCES

[1] C. Carli *et al.*, “ELENA: Installations and Preparations for Commissioning”, MOPOY009, IPAC’16.
[2] W. Bartmann *et al.*, “Progress in ELENA Design”, WEPEA062, IPAC’13.
[3] G. Tranquille, “Modelling the ELENA Electron Cooler with COMSOL Multiphysics Software”, COMSOL Conference 2014, Cambridge, UK.
[4] G. Tranquille, “Design and Optimisation of the ELENA Electron Cooler Gun and Collector”, THPMB048, IPAC’16.