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# THE VACUUM SYSTEM OF THE EXTRA-LOW ENERGY ANTIPROTON DECELERATOR ELENA AT CERN

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*Abstract*

The Extra Low Energy Antiproton ring (ELENA) is a CERN project aiming at constructing a 30 m circumference synchrotron which will take antiprotons extracted at 5.3 MeV from the Antiproton Decelerator (AD), and further decelerate them down to 100 keV [1].

The ring will be equipped with two electrostatic (ES) pulsed extraction deflectors which will allow to deliver the low-energy, cooled antiproton beams to a number of experimental beamlines [2]. The total length of these transfer lines, equipped with ES optical elements is of the order of 100 m. From the vacuum point of view, machine physics issues related to rest-gas scattering and intra-beam scattering mandate a very low average pressure limit, calculated to be 4.0E-12 mbar [3,4]. The very compact ring and the beam-instrumentation installed on it, with many components placed inside of the vacuum system, and lack of space to install lumped pumps, has pushed us to design a pumping system based primarily on non-evaporable getter (NEG) coatings, and few lumped integrated NEG-ion pumps.

The vacuum requirements for the transfer lines are a bit more relaxed, in the 1.0E-10 mbar range, but still require state-of-the-art solutions in order to reduce the potentially large outgassing of the many electrodes, insulators, metal connections used for the ES components installed inside the vacuum system. NEG-coating and integrated NEG-ion pumps will therefore be used here too.

The entire vacuum system of ELENA, with the exception of a short, initial part of the injection line coming from the AD machine, has been specified to be bakeable at 250 ºC.


## MACHINE PHYSICS ISSUES AND VACUUM REQUIREMENTS

The low-energy of the antiproton beams, and the length of the deceleration and cooling cycles, mandate a very low average pressure along the ring, 4.0E-12 mbar [1,3-4]. This is not an unprecedented vacuum requirement at CERN, since the LEIR ring has, in the past, required the design of a vacuum system capable of reaching similar performances [5].

## OVERVIEW OF THE MACHINE AND TRANSFER LINES

In the following, the naming conventions adopted for the ELENA project will be used, for brevity:

- LNI: injection line from AD;
- LNR: ELENA ring;
- LNExx: transfer lines (total of 9 sections/segments);
- LNS: $H^+/H^-$ commissioning source

Figure 1 shows a bird's eye view of LNI, LNR, LNExx, and LNS. Figure 2 shows a busy intersection of vacuum lines, LNI, LNE, and LNS.

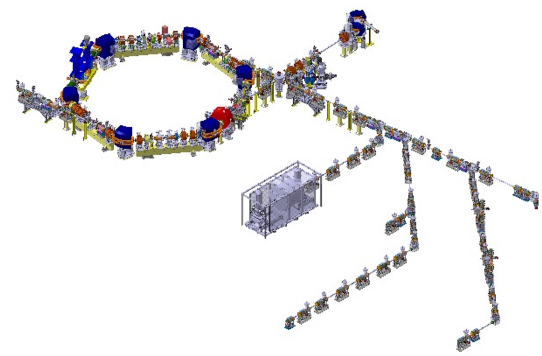

Figure 1: view of the whole ELENA complex, accelerators and beamlines.

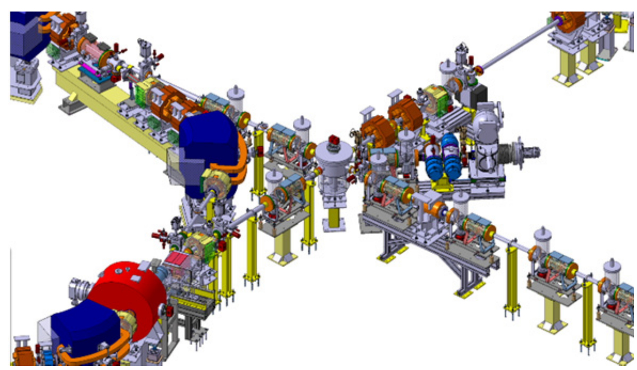

Figure 2: a busy crossing; the ion-switch (IS) chamber is in the middle, with its 5 connections to, clockwise from the 2-hour position: LNI from AD, LNS, LNE03, LNI going into LNR, and LNE00 coming out of the ring.

## VACUUM CHAMBER MATERIALS AND FLANGES

### Materials

The very low energy of the antiproton beam after the deceleration and cooling cycles mandate the choice of a very low magnetic permeability material. The choice has fallen on austenitic stainless steel, 316 LN grade, 3D-forged for all parts machined from blocks, and for flanges.

### Flanges

The already mentioned lack of space longitudinally along the ring has pushed us to choose a conical ConFlat flange design, with collars instead of the usual holes. This is a solution which is already employed and validated at CERN on several machines since a long time, both for un-

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baked and baked cases. LNExx will be equipped with standard CF flanges.

### *Bellows*

In order to allow proper chemical cleaning and NEG-coating of all vacuum surfaces, we have decided to adopt hydro-formed bellows everywhere possible. At the few locations where this is not allowed by space restrictions, welded-cup design will be adopted.

## THERMAL TREATMENTS, NON-EVAPORABLE GETTER THIN-FILM DEPOSITION, BAKE-OUT AND CONTROLS

### *NEG-coating*

The Low-Energy Ion-Ring (LEIR) machine at CERN is working reliably since many years. It has been designed for massive NEG-coating implementation, due to very stringent requirements on its vacuum pressure limits [5]. CERN has also an extensive experience on NEG-coated vacuum chambers installed along the > 6 km of room-temperature Long Straight Sections of the LHC. We are therefore confident that this is a reliable and stable solution for reducing the outgassing load and efficiently pumping all getterable species all at once.

Dedicated prototype mock-up chambers have been fabricated in-house for practicing and optimizing the NEG-coating procedure for the six 60-degree LNR dipole chambers, which have a challenging cross-section.

### *Surface Treatments*

Vacuum firing at 950 ºC for 2 h or 600 ºC for 24 h will be carried out on almost all vacuum chamber components, in our facility at CERN. Well known and tested procedures for cleaning and preparation of the surfaces to be NEG-coated will also be applied.

### *Bake-out*

For a number of reasons, it has been decided not to equip the vacuum chambers with dedicated insulating jackets. All chambers will be heated up using ribbon heaters wound around the chamber (either before sub-assembly into the magnets in the magnets' lab, or in-situ), and then thermally isolated using aluminium foils and kapton films, especially near the temperature-sensitive low-field dipole magnets [6].

### *Vacuum and Bake-out Controls*

All gauges and pumps will be cabled to dedicated crates which have already been partially populated with controllers and power supplies. Bake-out will be carried out sector-by-sector, using removable controllers shared with other CERN machines.

## VACUUM SECTORING, PUMPING AND GAUGES

LNR has been divided into 5 independent vacuum sectors. All-metal gate valves (GVs) have been chosen. The GVs do not need RF-bridges, since the low-intensity antiproton beam is not expected to be affected by beam impedance issues. Due to the very compact and dense installation of accelerator components, we have decided to install all gauges and manual valves (for pre-pumping) on the two side ports integrated on the body of the GVs see figure 3.

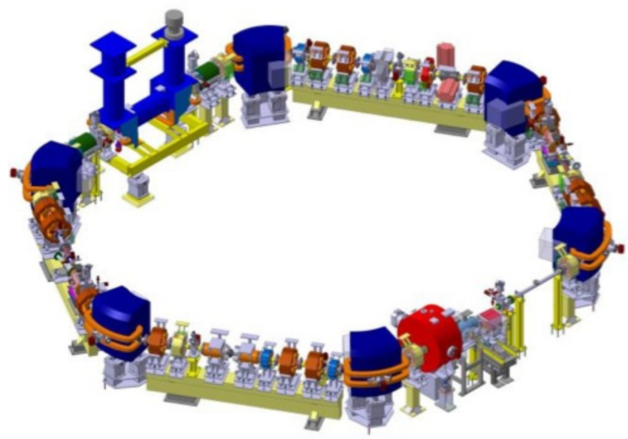

Figure 3: ELENA ring components, with "U"-shaped electron cooler (EC) visible on the left (in blue), and cylindrical injection kicker tank (in red), lower right.

Figures 4 show one ELENA dipole vacuum chamber.

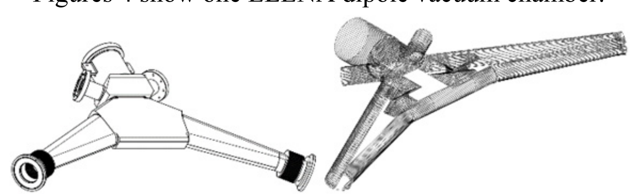

Figure 4: a) Top-view of the 60-degree dipole chamber; the present design has hydro-formed bellows at the two extremities. The cylindrical dome on the top will host a NEXTorr D2000 pump [7], while one of the two smaller flanges will be taken by an all-metal angle valve, for pumping during bake-out and NEG activation; the second flange will be used in one of the dipoles for installing a line-of-sight instrumentation for the EC; b) early 3D wireframe model made with the Molflow+ code, prior to adding bellows and pump.

## PRESSURE PROFILE MODELLING

In order to guarantee that the average pressure specification is met, 4.0E-12 mbar, extensive and detailed 3D modelling using the Molflow+ test-particle montecarlo code has been carried out [8].

For lack of space it is impossible to review here all of the models and simulations made, and therefore only one particular example is discussed, the LNS line with its

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custom-designed differential pumping system (LNS-DPS), depicted in figure 5.

Under the LNS-DPS girder 3 ACP turbo backing pumps are visible. Total length (without IS and source) is 2,503 mm.

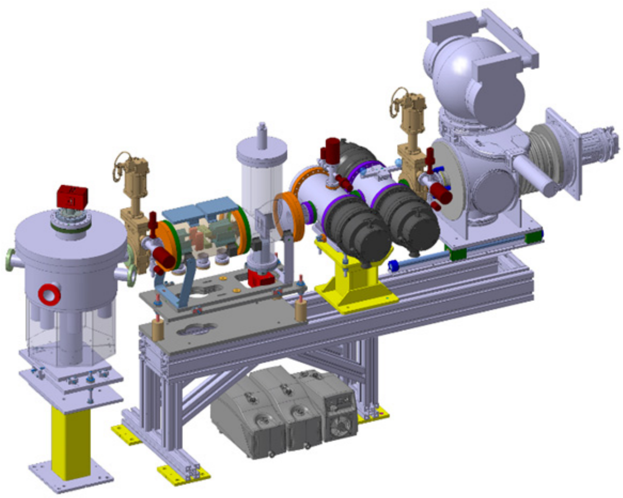

Figure 5: LNS vacuum components; right to left: $H^+/H^-$ source; turbo pump for stand-alone source operation (mounted vertically); sector GV with side-port gauges; LNS-DPS (3x 1,200 l/s turbo pumps (dark grey) and 1x 1,400 l/s ZAO-NEG pump (not visible); see-through micro-wire BPM (in-kind contribution) with NEXTorr D1000 pump; see-through ES FODO element (2 quadrupoles, 1 combined HxV corrector; second sector GV with gauges; IS vacuum chamber with NEXTorr D1000 pump on top flange.

Figure 6 shows a Molflow+ screen-shot showing the 3D model created for the LNS-DPS.

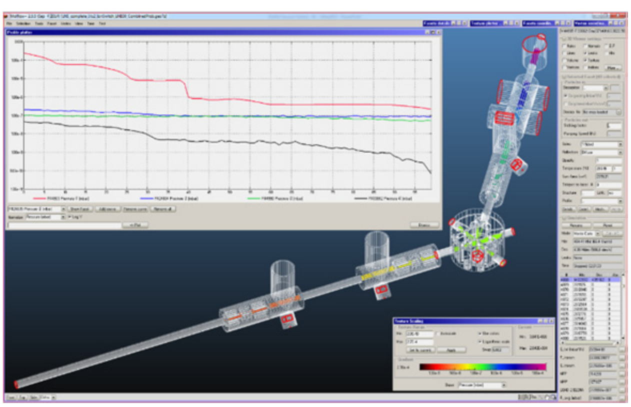

Figure 6: 3D Molflow+ model of the LNS-DPS: the source's flange is on the top-right corner; the facets highlighted in red indicate the pumping surfaces (NEXTorr D1000 pumps on the 3 micro-wire BPMs, and the IS. ZAO-NEG pump on the DPS. The red circles simulate the entrance flange of the 4 large-capacity turbo pumps; the curves on the inset show the pressure profiles along several segments of the beam path (red: source to IS; blue: IS in; green: IS: out; black: IS to ring). The lower left end of the model is attached to the exit of the ES deflector taking the beam out of LNR. The transmission probability from source to ring has been computed to be equal to 0.00024.

## ELECTRON COOLER [9,10]

The vacuum system for the EC is presently under advanced design in collaboration with CERN/BE-BI. It will be 100% NEG-coated, and will have two NEXTorr-D500 pumps at the two extremities, and a custom-made differential pumping system in front of the electron gun filament, based on St707 NEG strips, similar to what is reliably working since many years on the AD EC.

## PRESENT STATUS AND LOOK AHEAD

The ELENA area in the AD hall is practically ready for start of installation of the machine's components.

Fabrication of the vacuum chambers for the ring has started; while the design of the transfer lines is being completed, fabrication has also started.

The first vacuum components to be tested are parts of the line used for the commissioning $H^+/H^-$ source (IS chamber), which is provided as in-kind contribution by a laboratory member of the ELENA collaboration. This is expected to take place in mid 2015. Installation of the ring's vacuum system in the AD hall is scheduled to take place between the second half of 2015 and first half on 2016, with finalization of the transfer line in early 2017.

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