

## THE ELENA PROJECT AT CERN\*

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We give an introduction to the exciting physics of the ELENA facility at CERN.

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CERN has a longstanding tradition of pursuing fundamental physics on extreme low- and high-energy scales. The present physics knowledge is successfully described by the Standard Model and the General Relativity. In the antimatter regime, many predictions of this established theory still remain experimentally unverified, and one of the most fundamental open problems in physics concerns the question of asymmetry between particles: why is the observable and visible universe apparently composed almost entirely of matter and not of antimatter? There is a huge interest in the very compelling scientific case for antihydrogen and low-energy antiproton physics, here to name especially the Workshop on “New Opportunities in the Physics Landscape at CERN” which was convened in May 2009 by the CERN Directorate and culminated in the decision for the final approval of the construction of the Extra Low ENergy Antiproton (ELENA) [1–3] ring by the Research Board in June 2011. 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 down to 100 keV. The layout of the ELENA ring with its main components is sketched in Fig. 1.

Controlled deceleration in a synchrotron equipped with an electron cooler to reduce the emittances in all three planes will allow the existing AD experiments to increase substantially their antiproton capture efficiencies and

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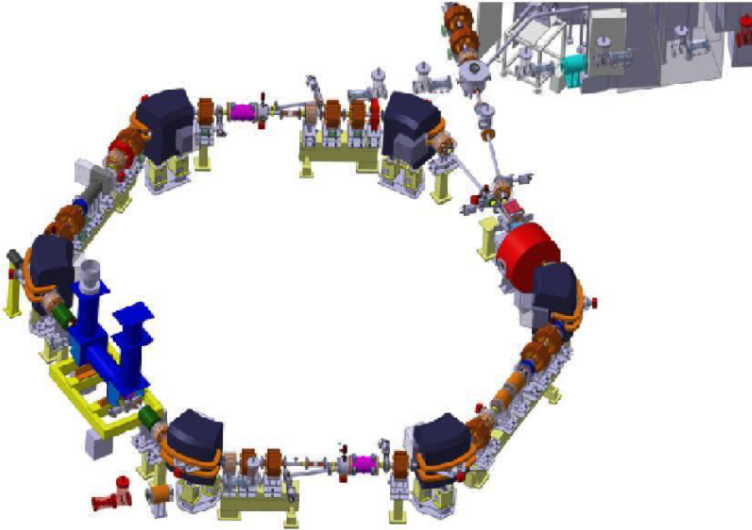


Fig. 1. Presentation of the ELENA ring and its components.

render new experiments possible. Unfortunately, this important piece of equipment is still missing due to delivery problems but is replaced by a straight section beam pipe for closing the ring and completing the vacuum and bake out of the system. Thus, the commissioning could start though without the electron cooler. Both  $H^-$  ions and protons are available from an external source and later — when promising for effective use — antiprotons might be delivered from the AD ring as well. ELENA is an upgrade of the Antiproton Decelerator (AD) at CERN and is devoted to experiments for physics using low-energy antiprotons. It will be located in the AD Hall as shown in Fig. 2.

The main topics are the antihydrogen production and consecutive studies of the features of this antimatter atom as well as the antiproton nucleon interaction by testing the QED to extremely high precision. ELENA will increase the number of useful antiprotons by one to two orders of magnitude and will allow serving up to four experiments simultaneously. Beam lines from ELENA to various experiments are shown in Fig. 3.

The motivation for ELENA was driven by the perspective to increase the efficiency of the antiproton facility with its compact and time consuming experiments, and by the steadily growing interest of additional research groups to share the available beam time. In particular, concrete motivations from the physics side arise in a number of theoretical approaches extending the established model framework including a consistent unified description of the corner stones of physics: Lorentz symmetry, quantum mechanics and

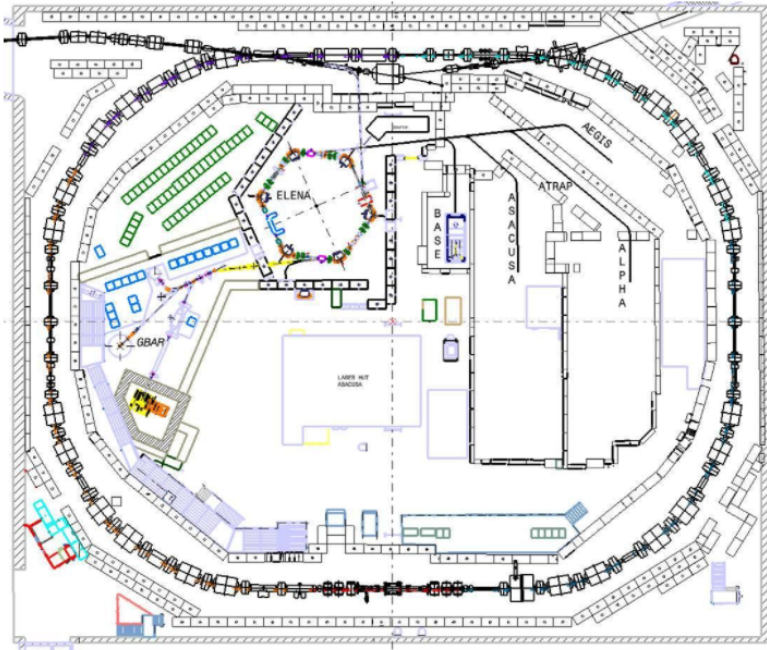


Fig. 2. ELENA in the AD Hall, where in the inner part of the AD Ring the experiments are hosted as well.

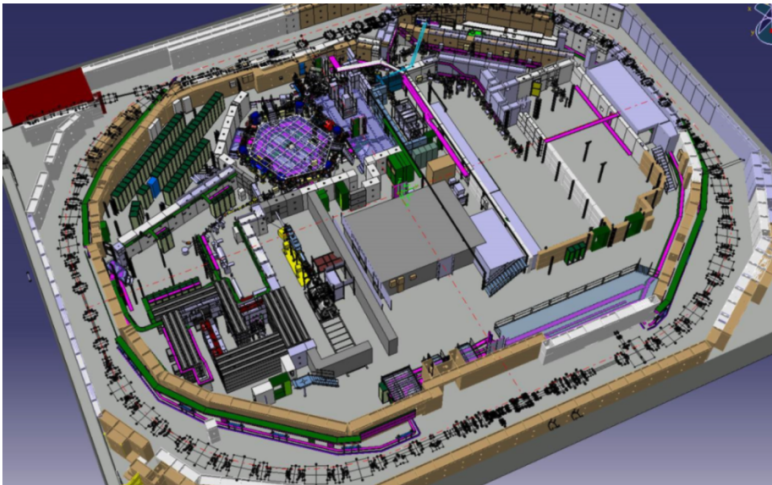


Fig. 3. ELENA and the beam lines to the different experiments in the AD Hall.

gravity [4]. Experiments with antiprotons will substantially increase the knowledge of atomic, nuclear and particle physics by testing precisely familiar interactions and fundamental constants, by studying discrete symmetries and by searching for new interactions.

These days antihydrogen atoms are produced frequently by three collaborations at the AD: ATRAP [5], ALPHA [6], and ASACUSA [7] employing essentially similar methods. Whereas ATRAP and ALPHA produce antihydrogen at rest, ASACUSA produces a beam of these atoms for hyperfine transition studies in low magnetic fields. In 2002, first the ATHENA Collaboration and shortly thereafter the ATRAP group announced the creation of the first “cold” antihydrogen. Still, since the neutral antihydrogen atom is unaffected by the electric fields used to trap its charged components, the antihydrogen hits the trap walls and annihilates very soon after its creation. High-precision tests of the properties of antihydrogen in magnetic minimum traps can only be performed if the antihydrogen atoms are cold enough to be hold in place for a relatively long time. The antihydrogen atoms have a magnetic moment which interacts with an inhomogeneous magnetic field; low field seeking antihydrogen atoms can be trapped in a magnetic minimum. In fall 2010, the ALPHA Collaboration as first reported the success of 38 trapped antihydrogen atoms. A year later life times of more than 15 minutes of the antihydrogen atoms were observed by both collaborations ALPHA and ATRAP. ALPHA reported on the very first spectroscopy of an antimatter atom demonstrating the observation of resonant quantum transitions in antihydrogen by manipulating the internal spin state. Finally, they published late 2016 the observation of the 1S–2S transition in trapped antihydrogen consistent with a CPT relative accuracy of about  $2 \times 10^{-10}$ . In addition, new supplementary experiments at the AD, as AEGIS [8] and Gbar [9] are presently preparing for precise measurements of the gravitational interaction between matter and antimatter. Further, the BASE Collaboration [10] suggested a measurement of the magnetic moment of the antiproton increasing the precision by a factor of 1000 as compared to the successful recent result of the ATRAP group at the AD.

And now? The safety door is closed. Beam can be send to the area behind, where the mechanical construction of ELENA was finished early November 2016 (see the short video [11]). In fact, the following image (Fig. 4) shows the spot of the very first proton beam on the “BTV” instrument located between the injection septum and the kicker. Already three days after starting the commissioning, a first coasting beam was observed for one and shortly after for three turns. It took only a few more days to observe the beam over several 10 s of turns. A very first success.

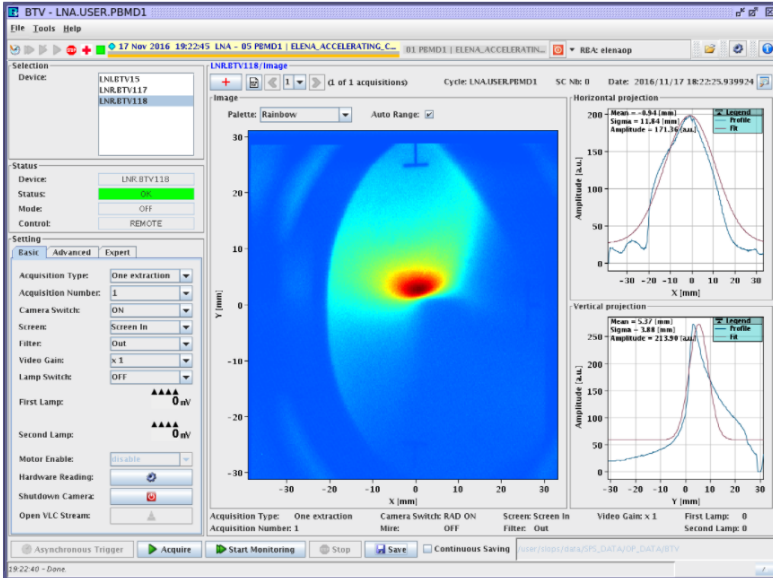


Fig. 4. Beam spot on a BTV located between injection septum and kicker.

Now, in Fig. 5, I would like to present with some proudness the mechanically finished ring with nearly all its main components enclosed in the concrete shielding wall for radiation protection, all located within the AD Hall. Here, is not the place to name all the different main activities, milestones and indicative planning for the commissioning which was scheduled to take place from November 14<sup>th</sup> to Christmas break 2016. Unfortunately, on November 26, the transformer of the source failed which will need a repair of four weeks and, therefore, the commissioning could only continue in early 2017 still without the electron cooler, which would be installed and tested depending on what has been achieved and on the availability of the device sometime in summer 2017. It should culminate in late summer this year with  $H^-$  or  $p$  beams delivered to new experiment Gbar and somewhat later in 2017 with antiproton operation for this experiment, in parallel with continuous improvements of the commissioning conditions. In 2018, ELENA will serve exclusively Gbar, whereas the other experiments will get their antiprotons still from the AD, since the time-consuming procedure for dismantling the present magnetic beam lines and installing new electrostatic beam lines to the existing experiments (see Fig. 3) was shifted to be done during the long shut down (LS2) lasting from 2019 to 2020. Thus, the solely operation of ELENA for all experiments will most likely start in 2021. ELENA will then be able to deliver beams almost simultaneously to all experiments (within one cycle up to four experiments) resulting in an essential gain in





Fig. 5. The ELENNA ring and its components installed in the AD Hall.

the total beam time for each collaboration. Very visible to the outside people at CERN is the construction of the new building 393. This “Antimatter Factory” hall is hosting the kickers for the AD operation which had to be moved out of the AD Hall in order to make place for the ELENNA ring itself. In addition, it houses storage places for the experiments and a rather small workshop for fast repairs for the experiments when needed. Figure 6 depicts the outside view and a look inside.



Fig. 6. Outside and inside the new building 393 — the Antimatter Factory — housing the kickers and storage place for the experiments.

Summarizing, ELENA is an upgrade of the Antiproton Decelerator (AD) at CERN and is devoted to experiments for physics using low energy antiprotons. At last, Fig. 7 (prepared by Stefan Ulmer for the workshop “Physics Beyond Colliders”, CERN September 2016) conglomerates the possibilities of fundamental physics in the low-energy regime of high precision experiments and gives at the upper right and left corner the logos of the six collaborations working or being just installed at the AD/ELENA complex. The six experiments are named: ATRAP, ALPHA, ASACUSA, AEGIS, Gbar and BASE. Their specific properties and features might be observed in CERN’s Grey Book. For instance, the BASE experiment approved in 2013, reported in 2015 an improved high precision comparison of the charge/mass ratio for the antiproton–proton system with a fractional precision of 69 parts in a trillion. Moreover, the collaboration has invented a novel reservoir trap technique and very recently demonstrated trapping of antiprotons for more than 1 year. Happy birthday to these exotic antiparticles! Once low-energy antiprotons are available — as provided now at the AD and even lower energy by ELENA in the future — they might be used either as free particles for studying the fundamental properties as charge/mass ratios and magnetic moment or investigated in bound systems.

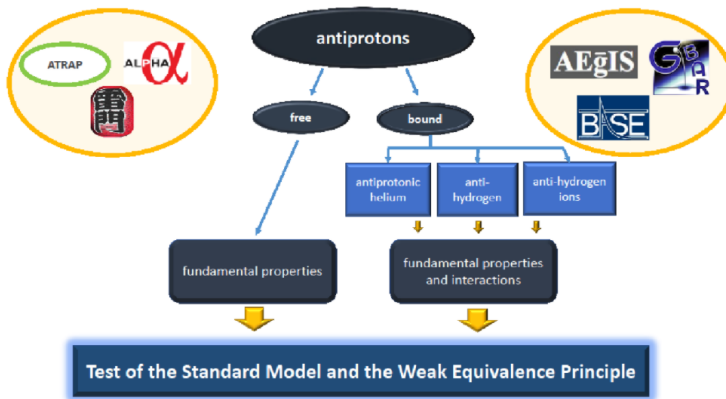


Fig. 7. Possibilities of fundamental research with low-energy antiprotons.

Bound states are:

1. a normal matter atom (*e.g.* He) with a bound antiproton replacing an electron *e.g.* antiprotonic helium,
2. the exotic antihydrogen atom with an antiproton core surrounded by a positron, and
3. antihydrogen ions.

In all these cases, high precision measurements in the spectroscopic and the gravitational sector investigate fundamental properties and exact interactions eventually in comparison to normal matter. Thus, we might understand why there is much more matter rather than antimatter. With ELENA there is a brilliant future to come for basic antimatter physics to be studied.

## REFERENCES

- [1] CERN Document: CERN-SPSC-2009-026(SPSC-P-338)  
<https://espace.cern.ch/elena-project/SitePages/Home.aspx>
- [2] CERN Document: CERN-BE-2010-029 OP.
- [3] CERN Document: Design Report CERN-2014-002.
- [4] D. Colladay, V. Kostelecky, *Phys. Rev. D* **58**, 116002 (1998); N. Russell, *AIP Conf. Proc.* **796**, 21 (2005).
- [5] J. DiSciaccia *et al.*, *Phys. Rev. Lett.* **110**, 130801 (2013);  
<http://gabrielse.physics.harvard.edu/gabrielse/overviews/Antihydrogen/Antihydrogen.html>
- [6] M. Ahmadi *et al.*, *Nature* **548**, 66 (2017); <http://alpha.web.cern.ch/>
- [7] M. Hori *et al.*, *Science* **354**, 610 (2016);  
<http://asacusa.web.cern.ch/ASACUSA/asacusaweb/main/main.shtml>
- [8] P. Scampoli, J. Storey, *Mod. Phys. Lett. A* **29**, 1430017 (2014);  
<http://aegis.web.cern.ch/aegis/home.html>
- [9] P. Indelicato *et al.*, *Hyperfine Interact.* **228**, 141 (2014);  
<http://gbar.web.cern.ch/GBAR/>
- [10] S. Ulmer *et al.*, *Nature* **524**, 196 (2015); <http://base.web.cern.ch/>
- [11] Link to video:  
[http://home.cern/about/updates/2016/11/new-ring-slow-down-antimatterutm\\_source=Facebook&utm\\_medium=Social&utm\\_campaign=cernsm](http://home.cern/about/updates/2016/11/new-ring-slow-down-antimatterutm_source=Facebook&utm_medium=Social&utm_campaign=cernsm)