AD-ELENA, The Low Energy Antiproton Facility at CERN

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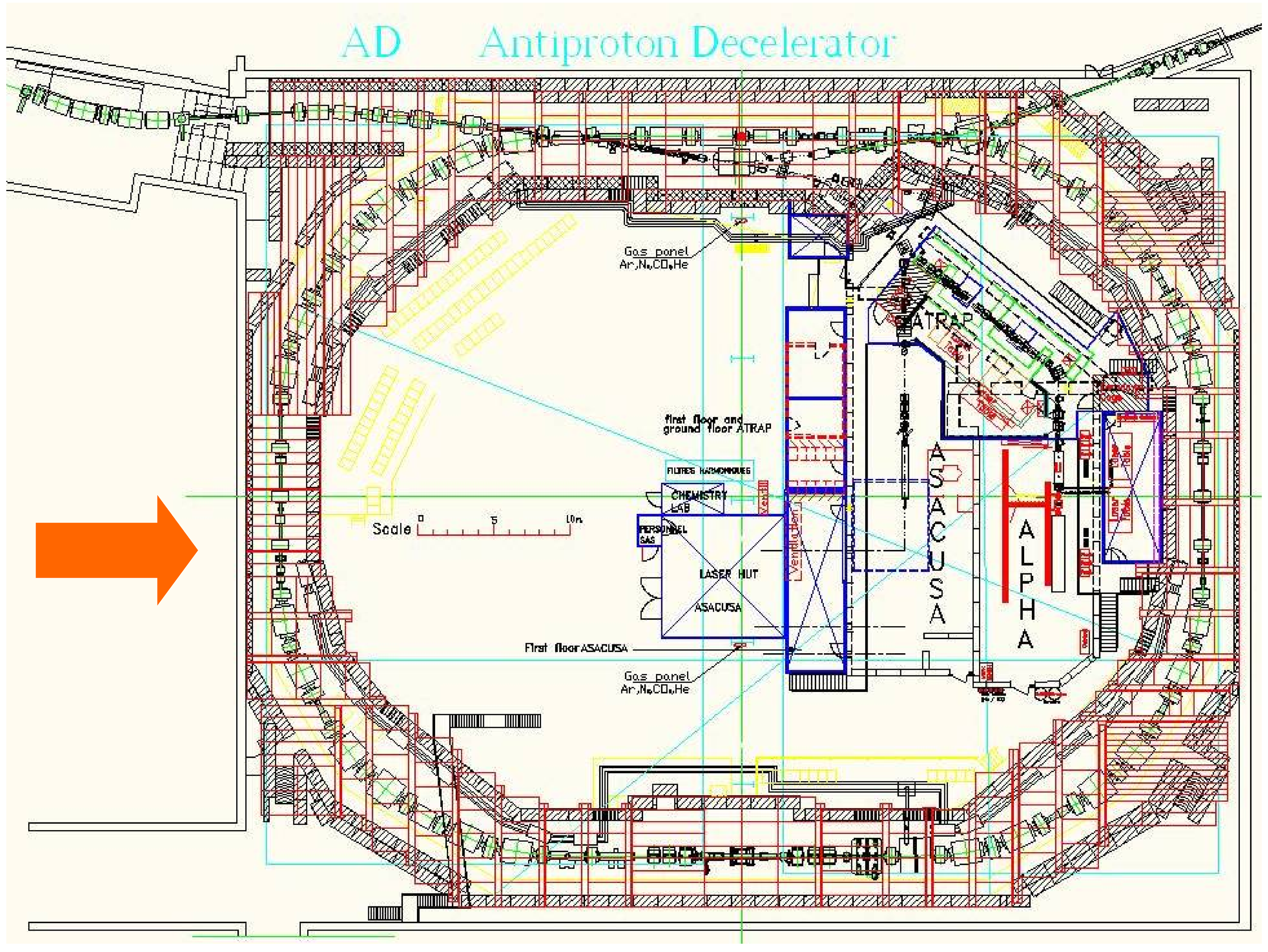
Abstract

During more than 10 years of regular operation, the AD has supplied the successful physics program with low-energy antiproton beams. For the long-term future, as well as for the extension of the physics program, it has been decided to enhance the performance of the facility with the construction of an additional decelerator ring, ELENA (Extra Low ENergy Antiproton ring), and to consolidate the existing AD.

ELENA is a compact ring for cooling and further deceleration of the 5.3 MeV antiprotons delivered by the AD. A significant increase (between one and two orders of magnitude) in the antiproton trapping efficiency by the experiments is expected thanks to the efficient deceleration to 100 keV and adiabatic blowup compensation obtained by using an electron cooler. In addition, a second extraction channel is foreseen, opening the possibility for the installation of further experiments in the AD hall.

Antiprotons at CERN- timeline

- 1980 - 1986 AA & LEAR
  - 3.57 GeV/c Antiproton Accumulator ring
  - 10^{12} stored antiprotons
  - Proton/antiproton collisions in SPS
  - Low energy antiproton physics at LEAR
    - Ultra-slow extraction (>1hr) for experiments
- 1986 - 1996 AAC (AA+AC) & LEAR
  - Large acceptance Antiproton Collector ring
    - 10 fold increase in production rate. 6.10^{10} pbars/hr
  - Fast extraction for trap experiments
  - Production of first antihydrogen atoms
- 1998 - 2015 AD
  - AC converted from fixed energy storage ring to Decelerator
  - 5.10^{7} pbars slowed down to 100 MeV/c (5.3MeV kinetic)
  - Many experiments: ASACUSA, ATHENA, ALPHA, ATRAP, ACE, AEGIS
- 2016 - 2030? AD/ELENA
  - Small post-decelerator ring to be added
  - Beam cooling and deceleration to 100 keV
  - Electrostatic beam lines and new experiments…



- Basic Parameters
  - Circumference 182 m
  - Production beam $1.5*10^{13}$ protons/cycle
  - Injected beam $5*10^{7}$ pbars/cycle
  - Beam momenta max-min 3.57 – 0.1 GeV/c
  - Momenta for beam cooling
    - Stochastic 3.57 and 2.0 GeV/c
    - Electron 0.3 and 0.1 GeV/c
  - Transverse emittances h/v 200 – 1 π.mm.mrad
  - Momentum spread $6*10^{-2} – 1*10^{-4}$ dp/p
  - Vacuum pressure, average $4*10^{-10}$ Torr
  - Cycle length 100 s
  - Deceleration efficiency 85 %

AD Operation Statistics

Run time (h)	2000	2001	2002	2003	2004	2006	2007	2008	2009	2010	2011
Total	3600	3050	2800	2800	3400	2925	3800	3340	4600	4610	4680
Physics	1550	2250	2100	2300	3090	2765	3760	3140	4460	4550	4530
md	2050	800	700	500	310	160	40	200	140	60	150
Beam available for physics (%)	86	89	90	90	71	65	76	81	78	87	84
Uptime AD machine (%)					89	74	81	93	92	91	90

Motivation to Build ELENA

Most of AD experiments need antiprotons of 3kV to 5 keV kinetic energy, AD produces them at 5.3 MeV.

How antiprotons are decelerated further down today:

- experiments aimed to antihydrogen program (ALPHA and ATRAP) use set of degraders to slow 5.3 MeV beam from AD further down
- poor efficiency due to adiabatic blow up of beam emittances and due to scattering in degraders, less than 0.1 % of AD beam used. Similar efficiency is expected for AEgIS.

How antiprotons are decelerated further down today at ASACUSA:

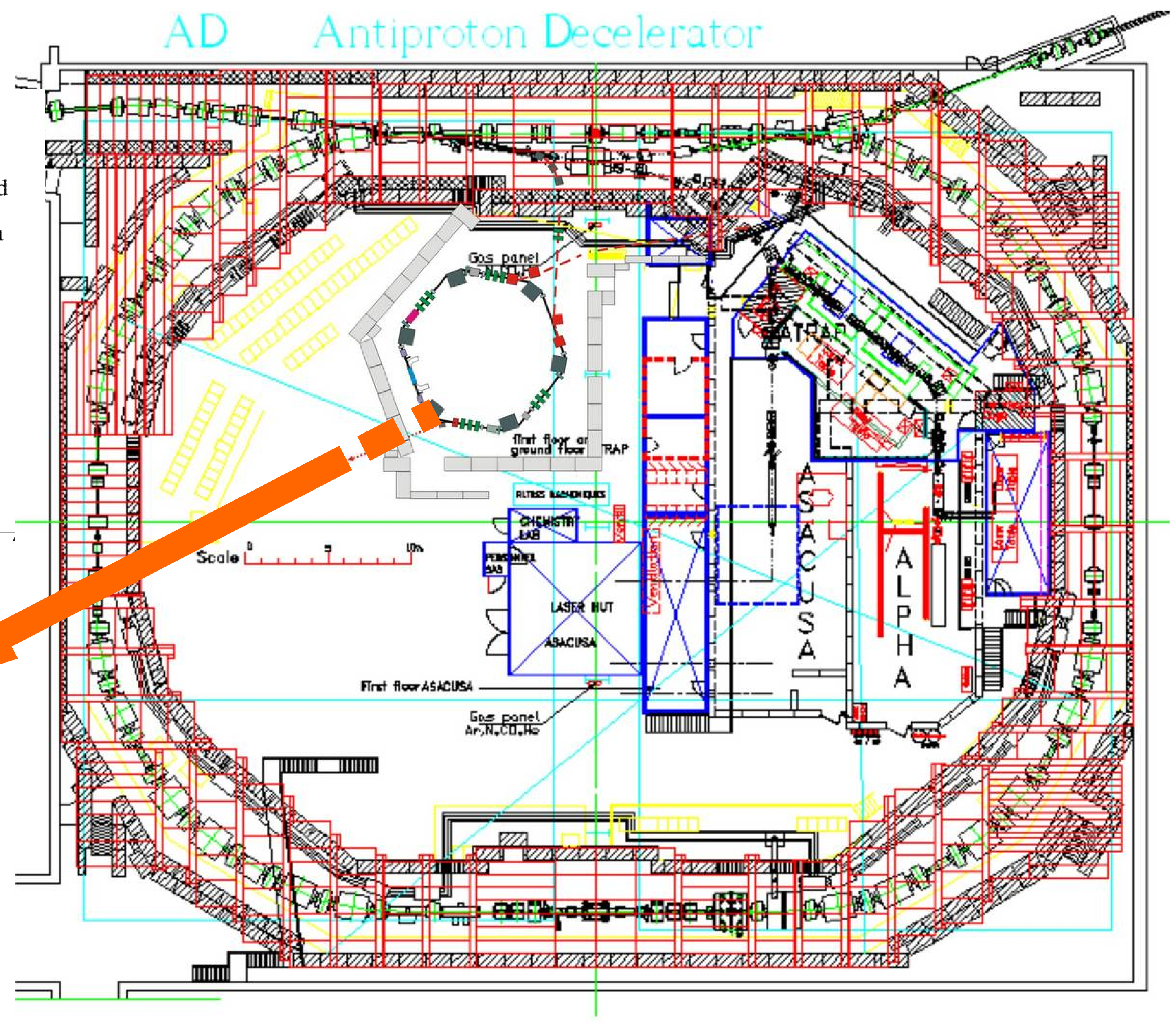
- RFQD is used for antiproton deceleration down to around 100 keV kinetic energy.
- deceleration in RFQD is accompanied by adiabatic blow up (factor 7 in each plane) which causes significant reduction in trapping efficiency.
- RFQD is very sensitive to trajectory and optics mismatch errors, difficult and time consuming tuning of transfer line from AD to RFQD needed.
- About 70% beam is lost after passing through RFQD, transverse beam size is very big (about 160mm), only short beam transport is possible after it (few meters)
- about 3-5% of antiprotons are captured after passing through degrader.

ELENA Configuration and Placement

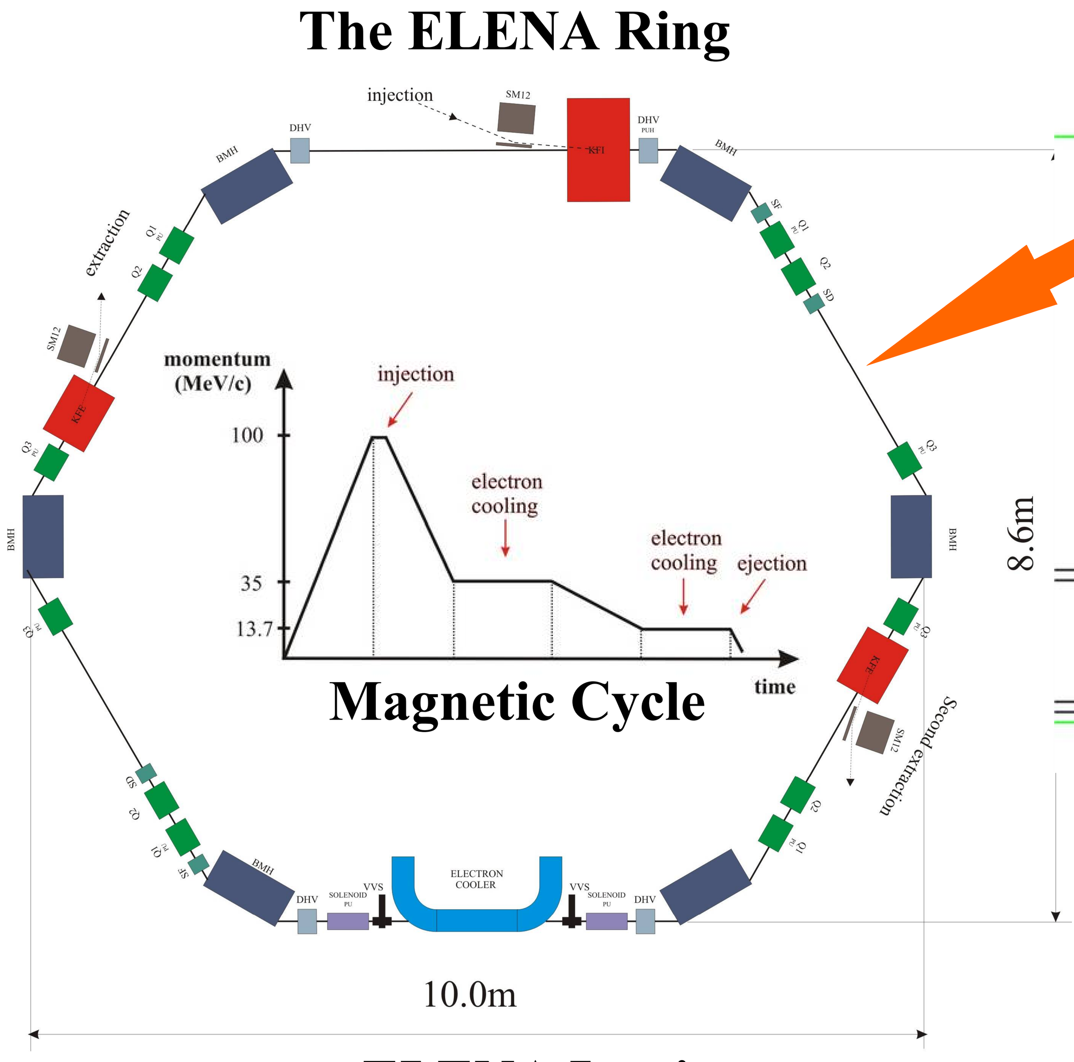
- Must be compact to fit in available space inside of AD Hall
- One long straight section for electron cooler needed
- Must be placed in AD Hall in an optimal way for transfer of antiprotons from AD and deliver them to existing and possible future experimental areas
- Placed in AD Hall in a way to minimize reshuffle of existing equipment in the area
- Placed inside the AD Hall allows the use of existing experimental areas (great saving!)
- The initial part of existing AD ejection line should be used => strong constraints on position and orientation of ELENA ring
- The extraction section of ELENA ring should be placed in a way to minimize the distance to experimental areas
- To make ELENA installation easier, the crane should be available to transport heavy units -> "dead zone" should be avoided
- Passing through AD shielding for ELENA transfer line should be done in concrete, avoid passing through the steel plates
- Space in AD Hall for new (extra) experimental areas has to be foreseen
- The Laser Hut of ASACUSA experiment should stay in place

Expected Intensity Gains with ELENA

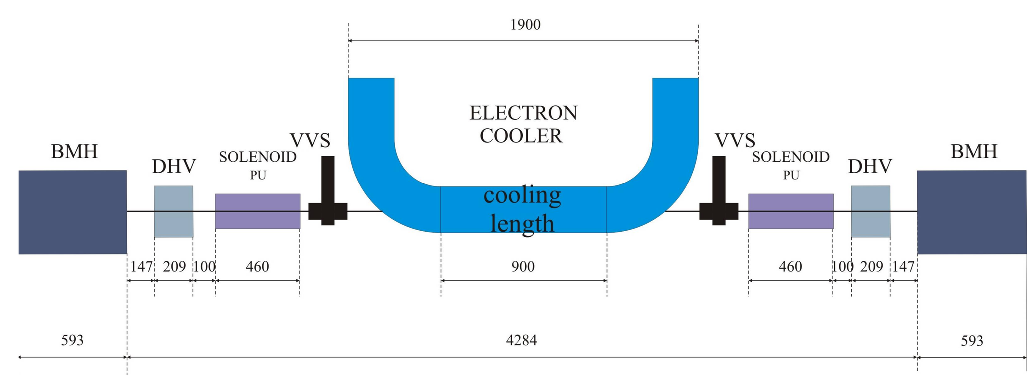
- Deceleration of the antiproton beam in a small ring down to 100 keV and its cooling by electron beam to high density
- Emittances of beam passing through a degrader will be much smaller than now due to electron cooling and due to use of much thinner degrader (100 keV beam instead of 5.3 MeV) => two orders of magnitude gain in intensity is expected for ALPHA, ATRAP and AEGIS.
- Due to cooling, beam emittances after deceleration in ELENA will be much smaller than after RFQD => one order of magnitude gain in intensity is expected for ASACUSA
- Extra gain for experiments: due to extraction in 4 bunches number of hours/day with available beam increase significantly



The ELENA Ring



Electron Cooling



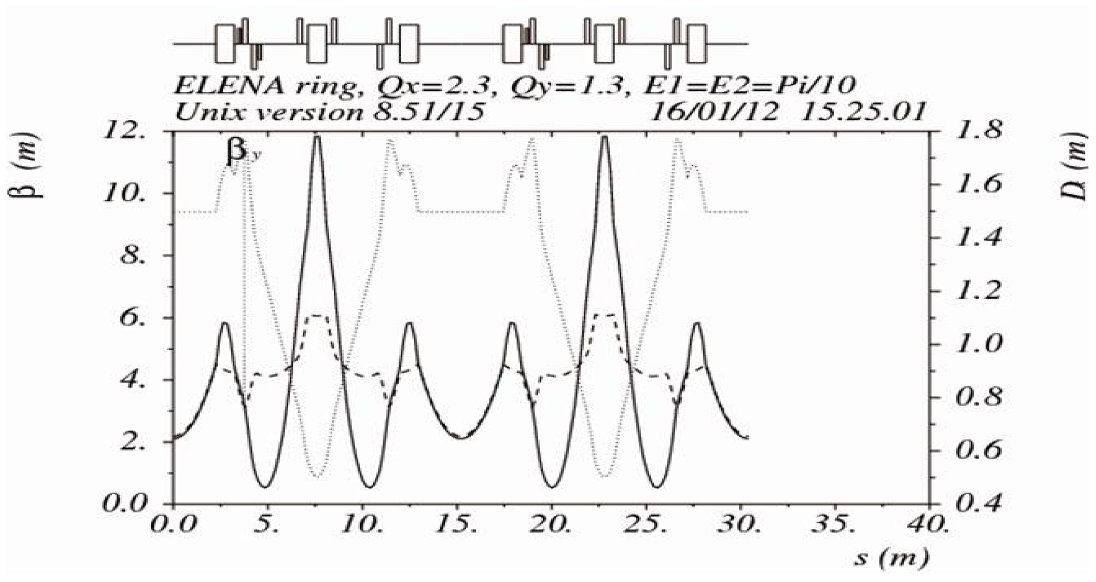
Electron Cooler Parameters

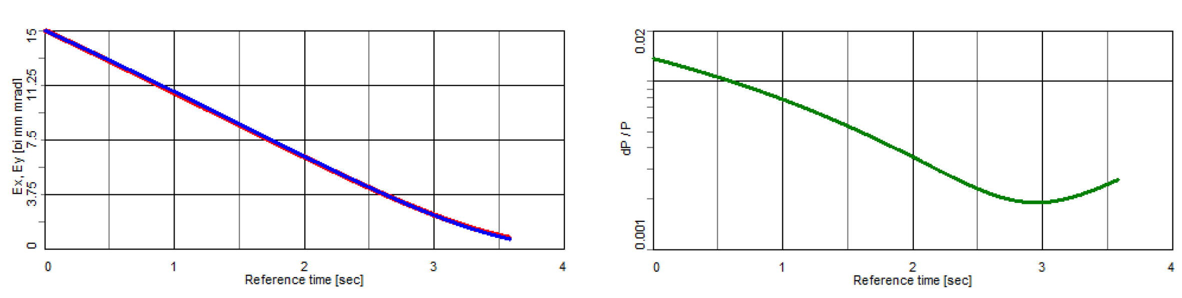
Effective Cooling length l_c, *m*	0.8
Beam cooled at momentum, MeV/c	35 & 13.7
Electron beam current I_e, *mA*	20 & 1
Cathode voltages, V	354 & 55
Maximal magnetic field in solenoid B_0, *Gs*	100
Electron beam radius *a, cm*	2.5

ELENA Ring Basic Parameters

Momentum range	100 - 13.7 MeV/c
Energy range	5.3 - 0.1 MeV
Circumference C	30.4 m
Tunes horizontal/vertical	~2.3 / ~1.3
Electron cooling	100 keV and ~650 keV
Intensity of injected beam	3×10^{7}
Intensity of ejected beam	1.8×10^{7}
Efficiency	60 %
Number of extracted bunches	1 to 4
Transverse emittances (95%) at ejection at 100 keV	4 / 4 µm
Δp/p after cooling, [95%]	10^{-4}
Bunch length L_b at 100 keV	1.3 *m (300 ns)*
Required (dynamic) vacuum, Torr	3×10^{-12} *Torr*

ELENA Lattice





First Simulations of Cooling with BETAcool

Left: transverse cooling for a beam with emittances of 15 π mm mrad in each plane
Right: longitudinal cooling for a beam with a momentum spread of 13.7 keV/c (1 ‰)