Extra Low Energy Antiproton Ring (ELENA) for antiproton deceleration after the AD

Motivation to build ELENA

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

How antiprotons are decelerated further down today by experiments:

- 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.

Motivation to build ELENA (continued)

How antiprotons are decelerated further down today by ASACUSA experiment:

- 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 (more than100 mm), only short beam transport is possible after it (few meters)
- about 3-5% of antiprotons are captured after passing through degrader

How do we gain in intensity with extra deceleration and cooling ?

- 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 increases significantly

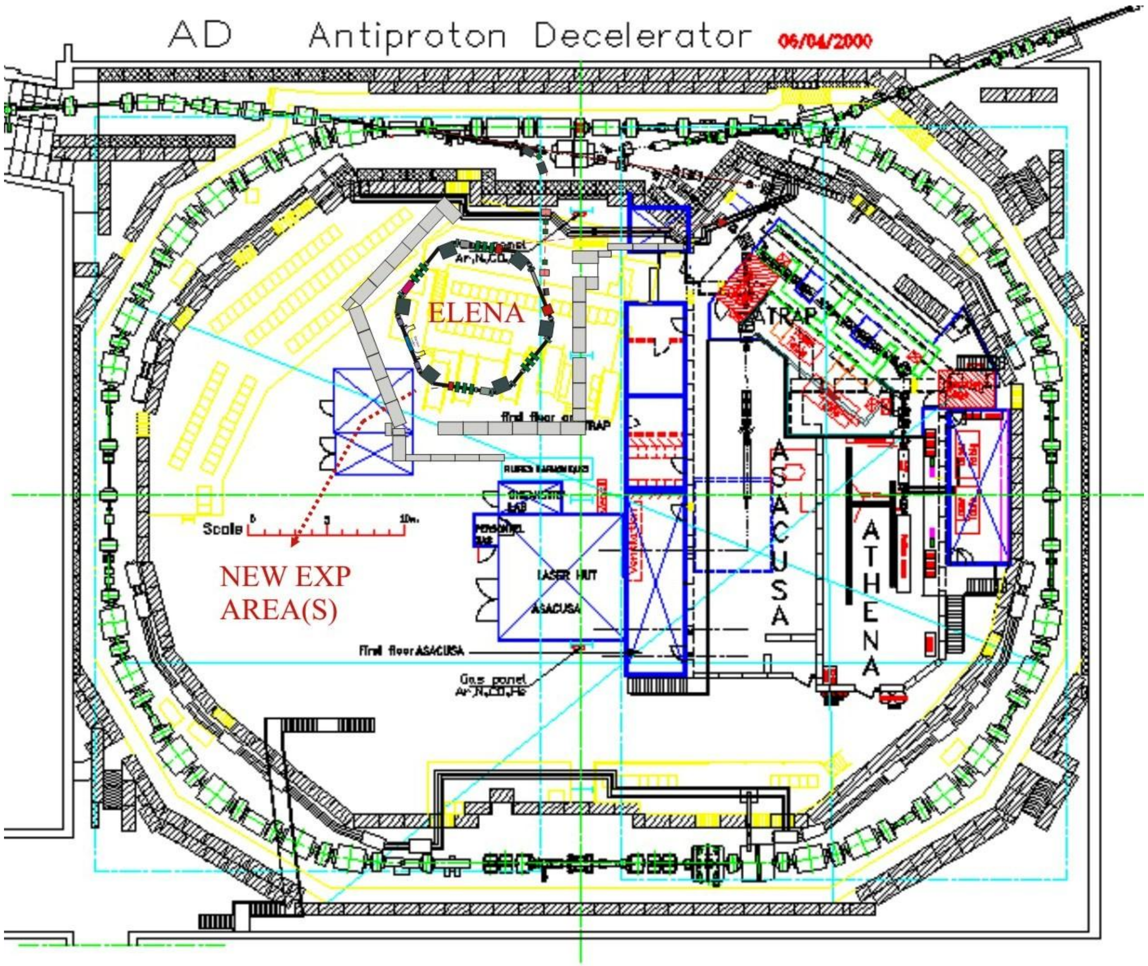
Energy range of ELENA

ELENA injection energy is 5.3 keV (100 MeV/c) = AD ejection energy

ELENA extraction energy 100 keV (13.7 MeV/c) defined by:

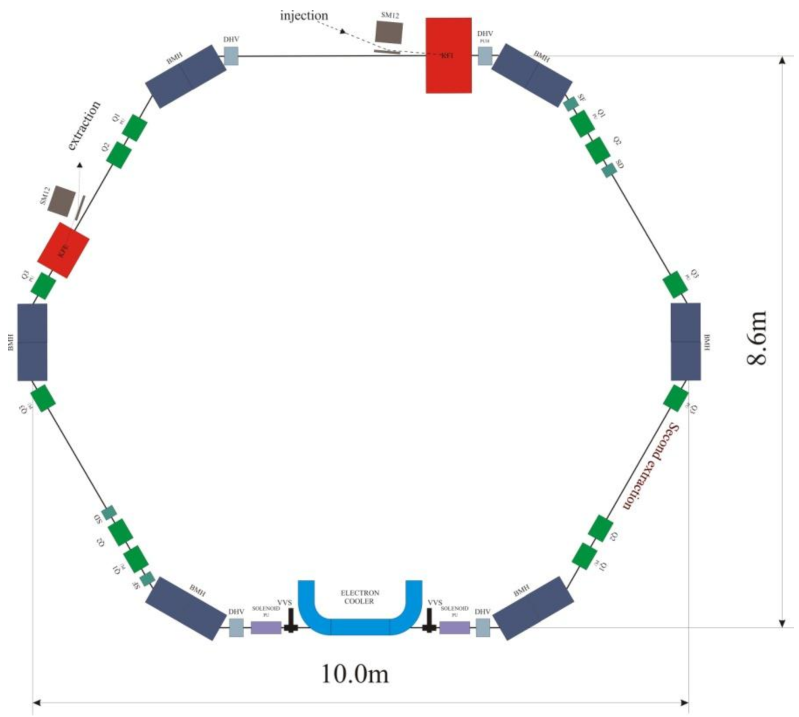
- space charge limit for antiproton beam
- good quality of electron beam for cooling (limited by space charge of electron beam)
- beam lifetime: residual gas scattering and IBS at extraction energy
- strong requirements to high vacuum in machine $3 \cdot 10^{-12}$ Torr
- foil thickness for separation of transfer line and trap vacuum

ELENA layout in AD Hall

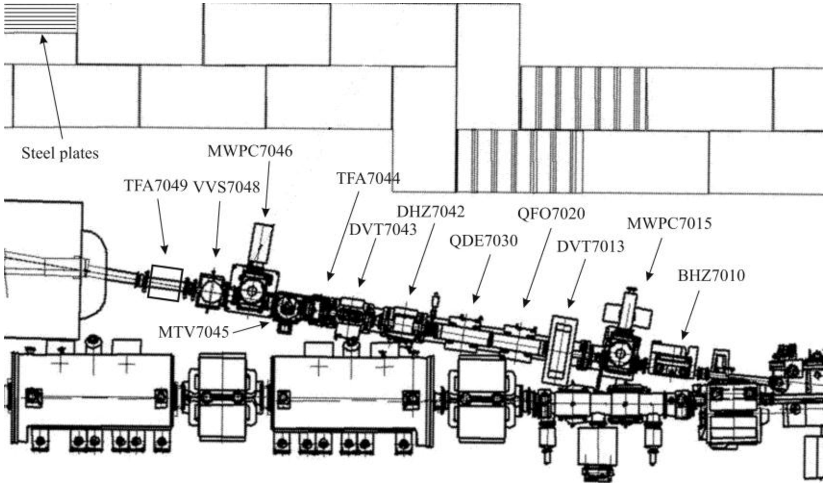


ELENA ring configuration

- Two straight sections without quadrupoles, for injection and for electron cooling
- Four straight sections, each includes 3 quadrupoles for beam focusing
- Injection and extraction made in a different section to facilitate beam transfer from AD to ELENA and from ELENA to experimental area
- Second extraction is foreseen for future experiments (Gbar experiment is approved by SPSC)



Beam transfer from AD to ELENA

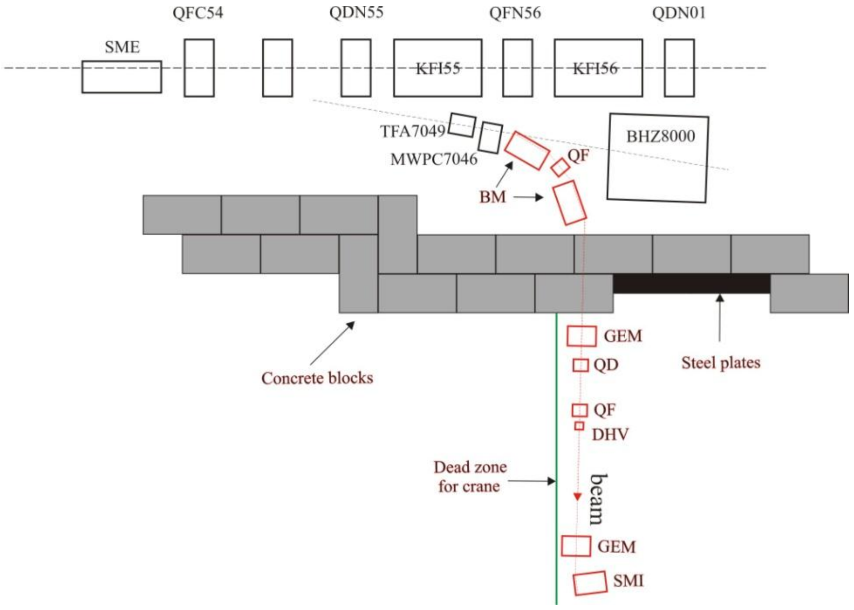


What should we modify in AD ejection line (7000 line):

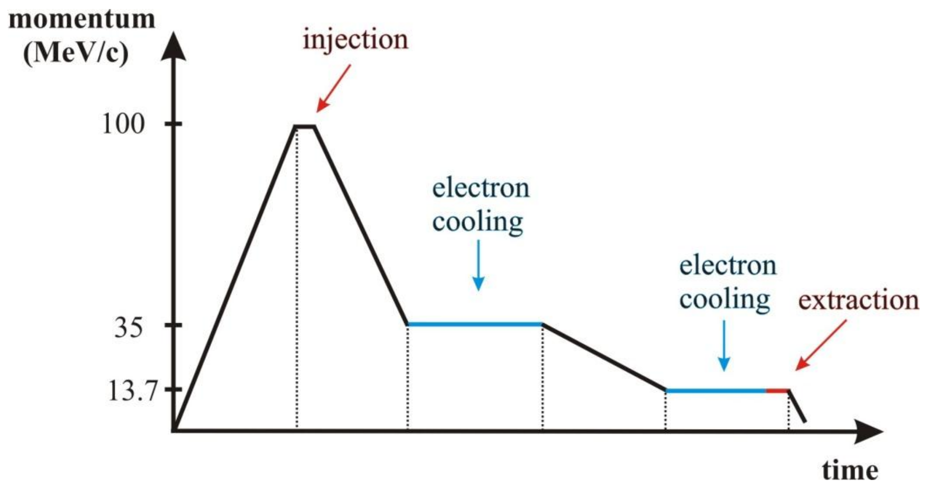
- place sector valve VVS32 between MWPC7015 and DVT7013
- move dipole correctors 7042 and 7043 upstream
- remove proton transformer TFA7044 and MTV7045
- To place current transformer TFA7049 before MWPC7046
- To make small modification in vacuum equipment in this area

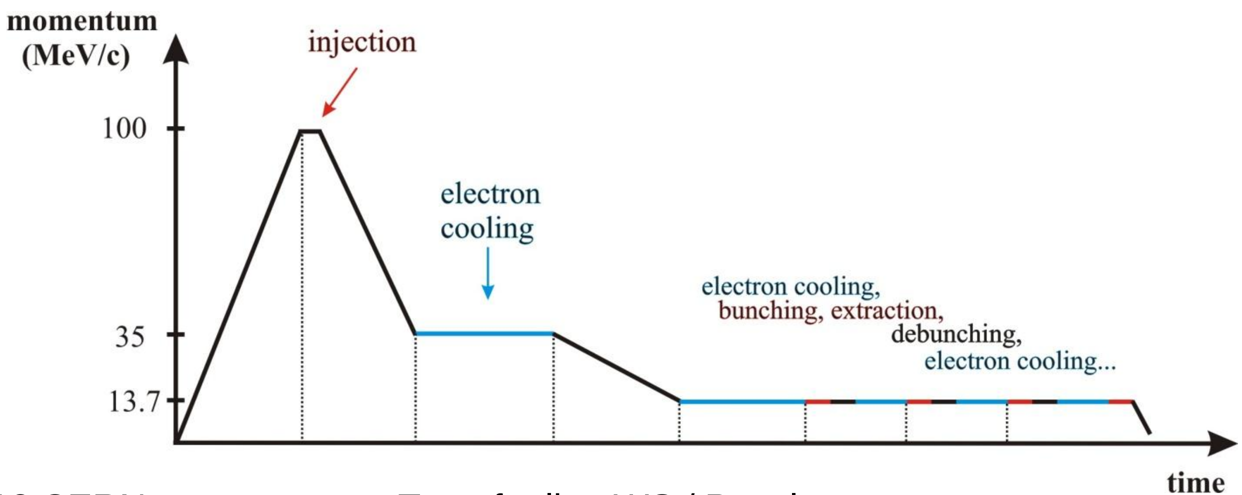
AD to ELENA transfer line

- To make 82˚ bend, two magnets will be placed upstream to the shielding of AD Hall
- 5 or 6 quads used for matching of the Twiss functions. Matching of dispersion is not possible, a small mismatch and the horizontal emittance blow up expected
- The line layout and length are fixed by layout (unfortunately!)
- Special care should be given to a crossing of injection and extraction lines

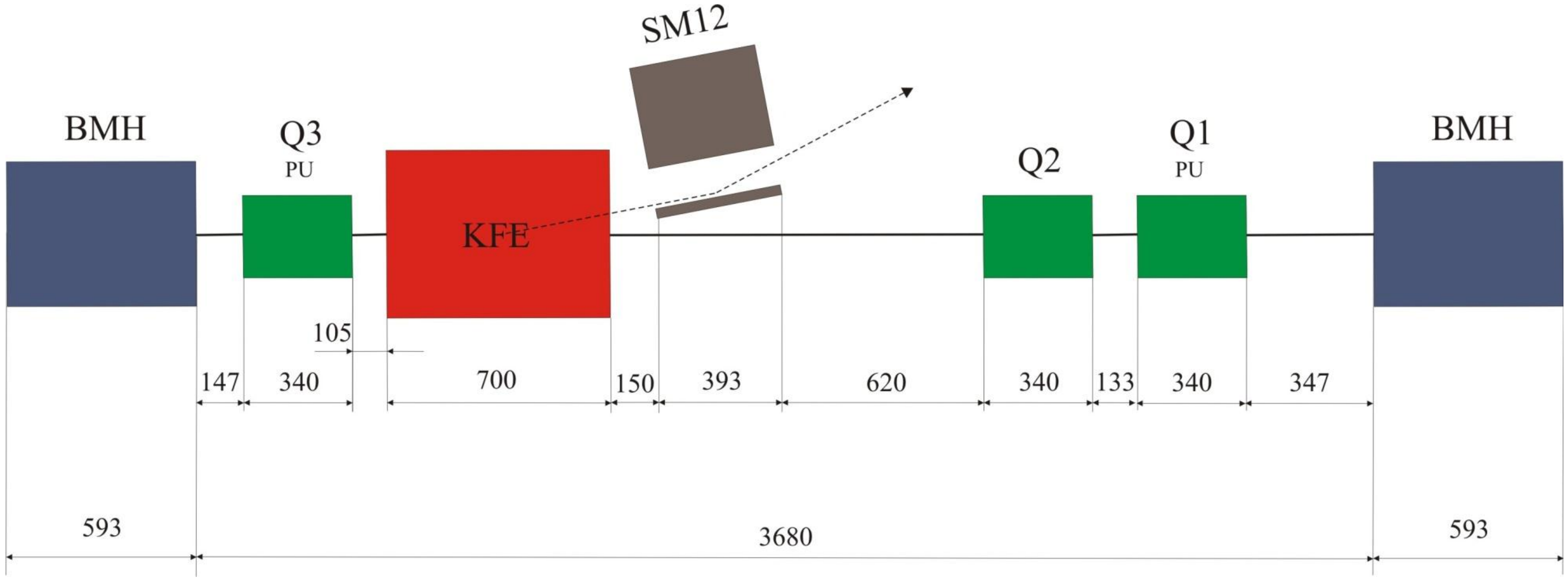


Schematic view of ELENA cycle





Extraction from ELENA in a short straight section



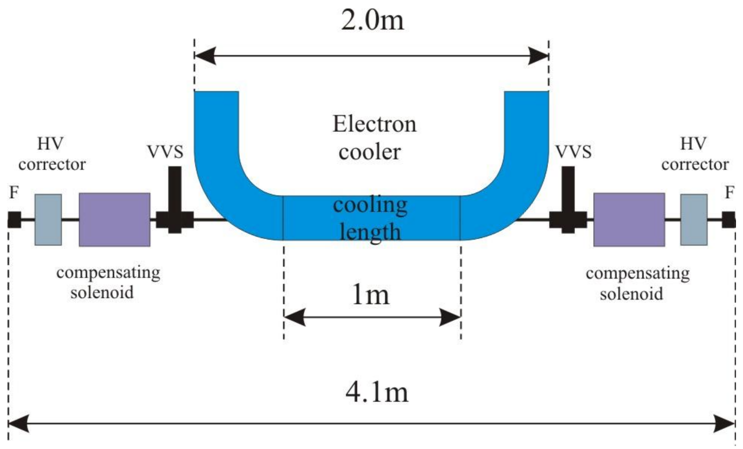
Space charge limit in ELENA

- important for bunched beam only (right before extraction)

$$\Delta Q = -\frac{F r_p N C}{2\pi \varepsilon_x \beta^2 \gamma^3 l_b}$$

- example: ΔQ=0.1, the bunch length l_b=1.3m (300ns) , beam emittance $\varepsilon_{x,y}=4\pi$ mm mrad, β =1.46·10^{-2} ring circumference C=30.4m , Gaussian distribution (F=2) -> the bunch intensity is limited at N=0.625·10^7.
- Can be increased by factor 2 with flattened longitudinal beam distribution with superimposing RF voltage with harmonics 1 and 3
- With 60% of deceleration efficiency (3·10^7 antiprotons injected into ELENA, 1.8·10^7 antiprotons decelerated down to 100 keV) at least 3 bunches has to be prepared for extraction to avoid space charge problems
- To deliver at the same time beam up to 4 experiment, RF system should be able to operate at harmonics h=1,2,3,4.

Electron cooler for ELENA



Cooling length l_c, m	1
Beam cooled at momentum, MeV/c	35 & 13.7
Electron beam current I_e, mA	15 & 2
Cathode voltage at 100 keV, V	55
Maximal magnetic field in solenoid B_0, G	100
Electron beam radius a, cm	2.5

Beam lifetime and vacuum requirements

The main limiting factor at the low energy is multiple Coulomb scattering -> beam emittance blow up

$$\Delta\varepsilon_{x,k\sigma} \approx 0.14k^2 \frac{q_p^2}{A_p^2} \bar{\beta}_x \frac{Pt}{\beta_p^3 \gamma_p^2} \qquad \left(P\{Torr\}, \beta_x[m], t[\sec]\right)$$

For ELENA at extraction energy (*pc*=13.7 MeV/c, *β*=0.0146, *P*=$3\cdot10^{-12}$, averaged *β*=3.5m, *k*=2) emittance blow up *Δε*=0.6 π mm mrad/s.

The required cooling rate for emittance equilibrium is

$$\tau_{cool} = \frac{\varepsilon_{x,eq}}{\Delta\varepsilon_{xq}/\Delta t} = \frac{4}{0.6} = 6.7\sec$$

ELENA main parameters

Momentum range, MeV/c	100 - 13.7
Energy range, MeV	5.3 - 0.1
Circumference, m	30.4
Intensity of injected beam	3×10^7
Intensity of ejected beam	1.8×10^7
Number of extracted bunches	1 to 4
Emittances (h/v) at 100 KeV, π·mm·mrad, [95%]	4 / 4
Δp/p after cooling, [95%]	10^{-4}
Bunch length at 100 keV, m / ns	1.3 / 300
Required (dynamic) vacuum, Torr	3×10^{-12}

Possible scenarios of beam extraction from ELENA

With $1.8 \cdot 10^7$ antiprotons in the ring (60% of deceleration efficiency):

- Extraction in 4 bunches to 4 experiments with nominal emittances and reduced bunch length 220 nsec. The fast switch between destinations will be provided by electrostatic bending magnet(s). Timing for extraction of each bunch at given turn by kicker can be adjusted to relax (if necessary) requirements to switcher. Extraction to new experimental area can be arranged with proper timing as well.
- Extraction in 3 bunches to 3 experiments with nominal parameters
- Extraction in 2 bunches to 2 experiments with nominal parameters (RF system works with harmonics h=2 and h=6)
- Extraction in 1 bunch to 1 experiment with emittances 2 times bigger than nominal

Important steps

- Ring optics and layout: Spring/2012
- Transfer lines: Mai/2012 (?)
- TDR: October/2012
- Manpower/budget profiles and schedule: March/2012
- Magnets design: December/2012 (?)
- AD Hall preparations: 01/2013-03/2014
- ELENA Installation: 01/2014-03/2015
- ELENA commissioning: from 04/2015
- p or H- or no source: 2/2012
- Design of the new building: 10/2011-04/2012 (Discussions started !)
- Delivery of the new building: 10/2013
- Moving the kicker platform: 10/2013-03/2014
- AD Start-up: 05/2014

Thanks for your attention!