ELENA project status

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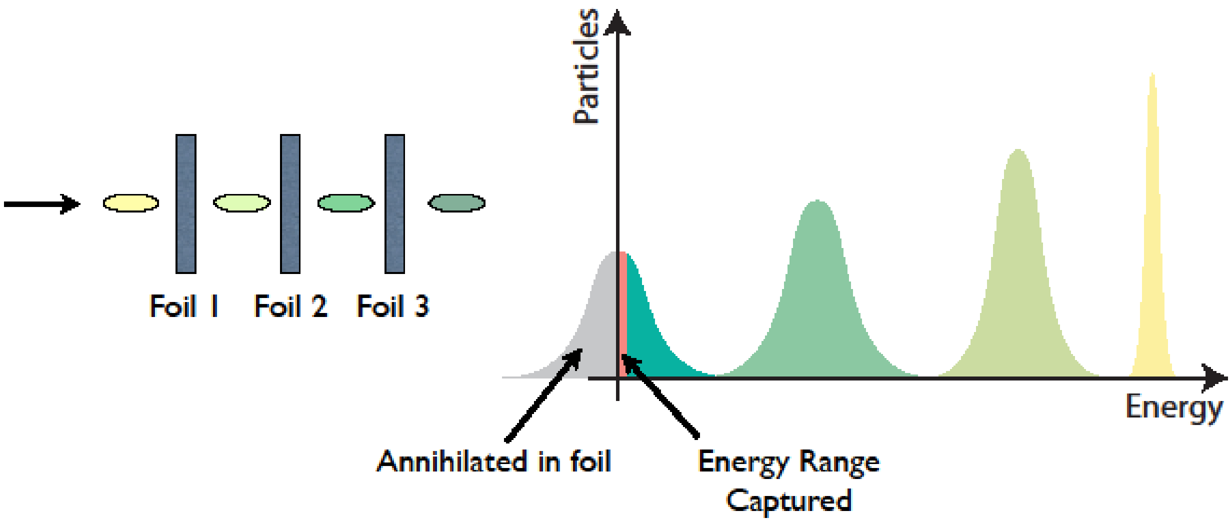
on behalf of ELENA team

Motivation to build ELENA

- Most of AD experiments need antiprotons of 3 keV to 5 keV kinetic energy,

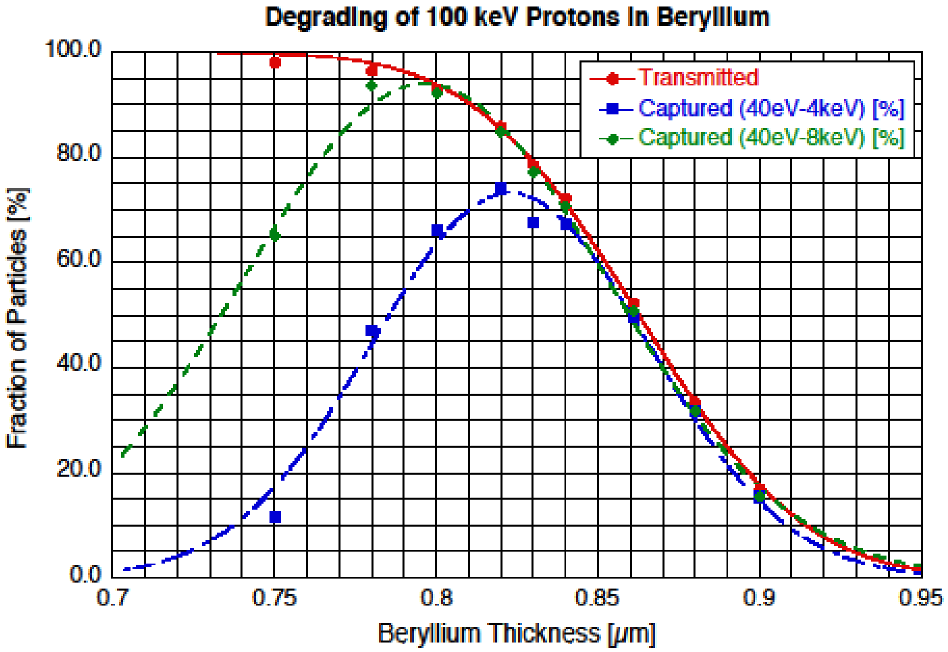
while AD produces them at 5.3 MeV.

- Further deceleration is done with degrading foils where particles lose energy and straggle
- Only 0.3% of antiprotons are captured into trap



How we gain with ELENA in antiproton intensity

- With much lower extracted beam energy in ELENA compared with that in AD, the degrading foil still needed, but very thin. The capture efficiency is very high because straggling spread is of order of kV

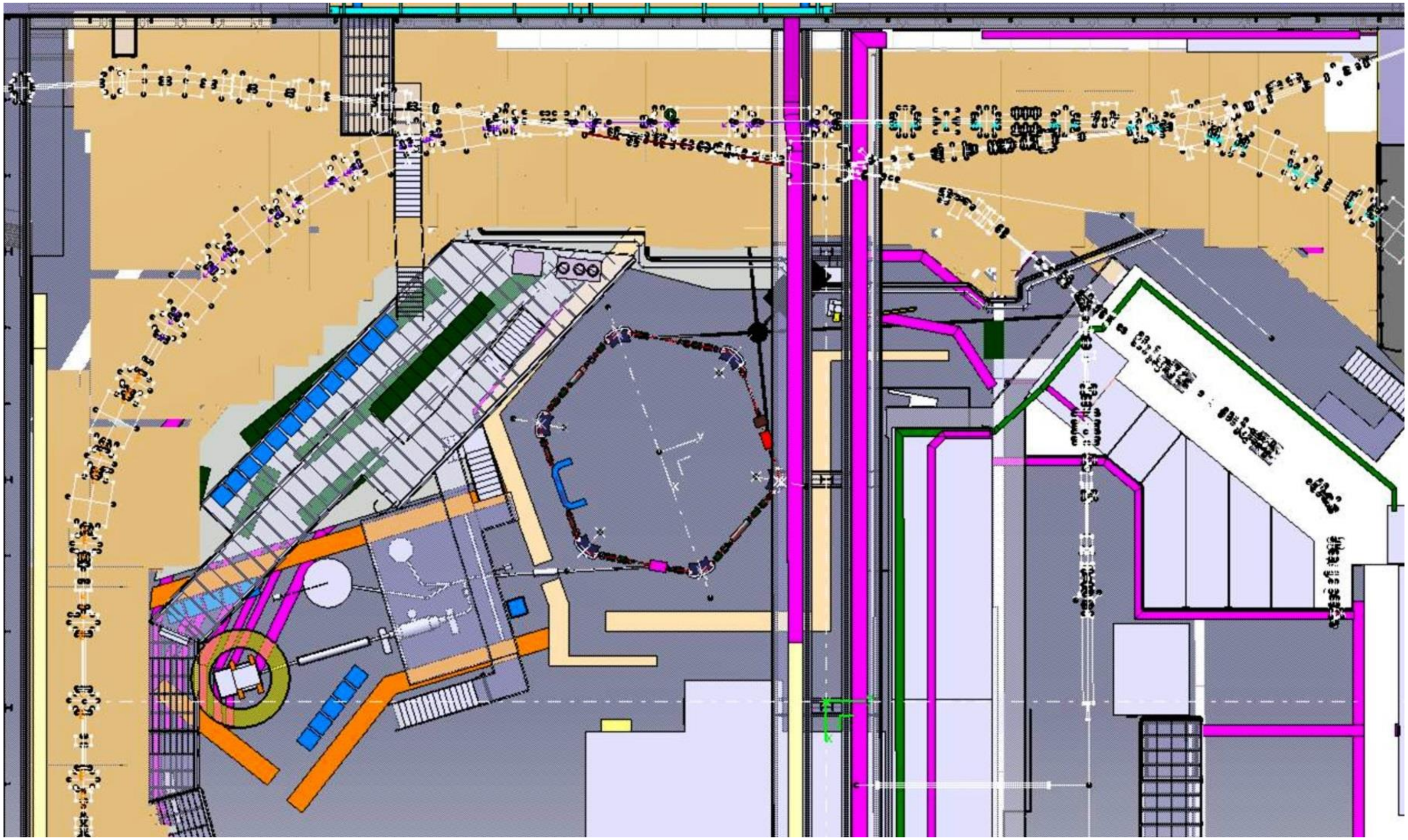


ELENA layout

Requirements:

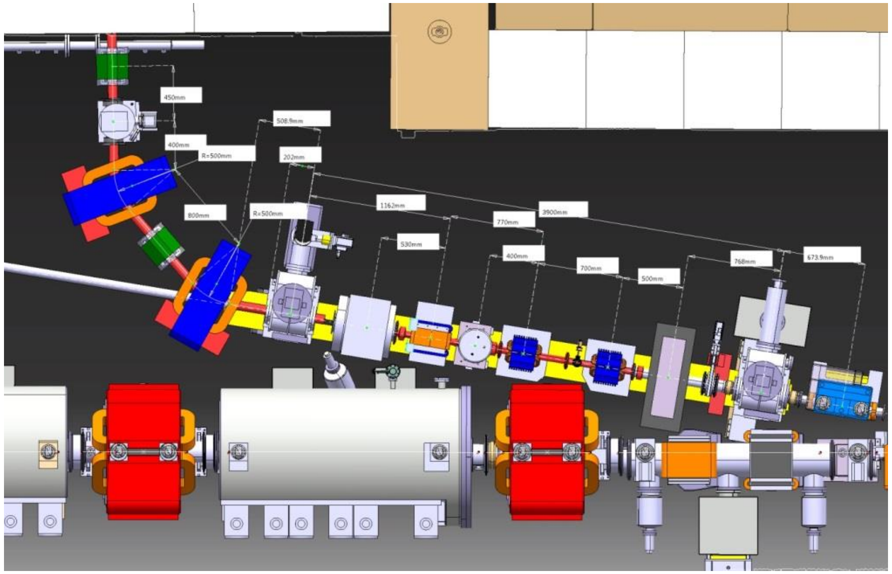
- Must be inside of AD hall (cheep solution)
- Must be compact, 1/6 of AD circumference fits just o.k., bigger value is more comfortable to place equipment, but needs more space in AD hall
- The initial part of existing AD injection line should be used, which put strong constraint on position and orientation of ELENA ring
- The existing experimental areas should stay in place (great savings)
- Placed in AD Hall in a way to minimize reshuffle of existing equipment in the area

ELENA layout in AD Hall



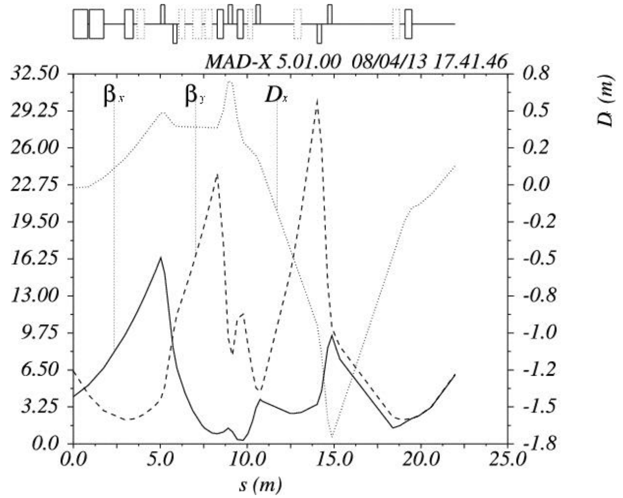
Beam transfer from AD to ELENA

- The initial part of existing AD injection line is used
- It is modified and reshuffled to make ELENA beam separation as soon as possible (layout constraint)
- Separation is made with 2 bending magnets 40° each
- The part of line which is close to ELENA will be bakeable



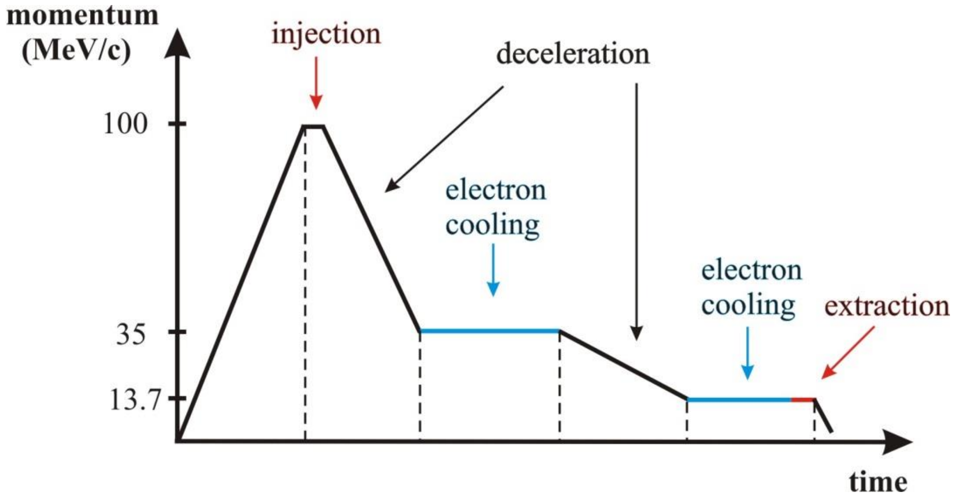
Transfer line optics

- Limited possibilities for matching to ELENA ring due to fixed positions of quads
- Matching of dispersion is impossible due to its zero value at the beginning of line and curved part with two 40° magnets. Yet the mismatch of dispersion and its derivative is minimized to reduce emittance blow up during injection into ELENA
- To reduce momentum spread of injected beam, electron cooling in AD will be applied during bunch compression right before beam extraction
- Special cares to reduce beam coherent oscillation after injection are under studies



ELENA cycle

- Injection of a bunched beam followed by deceleration
- Beam cooling at intermediate momentum to counteract beam emittances and momentum spread blow up
- Deceleration down to extraction energy, beam cooling, bunching at harmonic *h*=4, then compression to provide required bunch length and fast extraction
- The final goal is delivering to experiments beam 1.3m long with 1σ~1mm



Choice of extraction energy

- Extraction energy E_{kin}=100 keV allows to increase significantly an amount of captured antiprotons (~30%)
- If go to lower energy, one meets strong limitations imposed by:
  - IBS (Intra Beam Scattering)
  - transverse space charge limitations (incoherent tune shift)
  - very high vacuum required
  - difficult to manufacture foil thinner than 1μm
- If go to higher energy:
  - smaller number of antiprotons due to thicker degrader foil
  - difficult to equip extraction lines with electrostatic elements (high voltage)

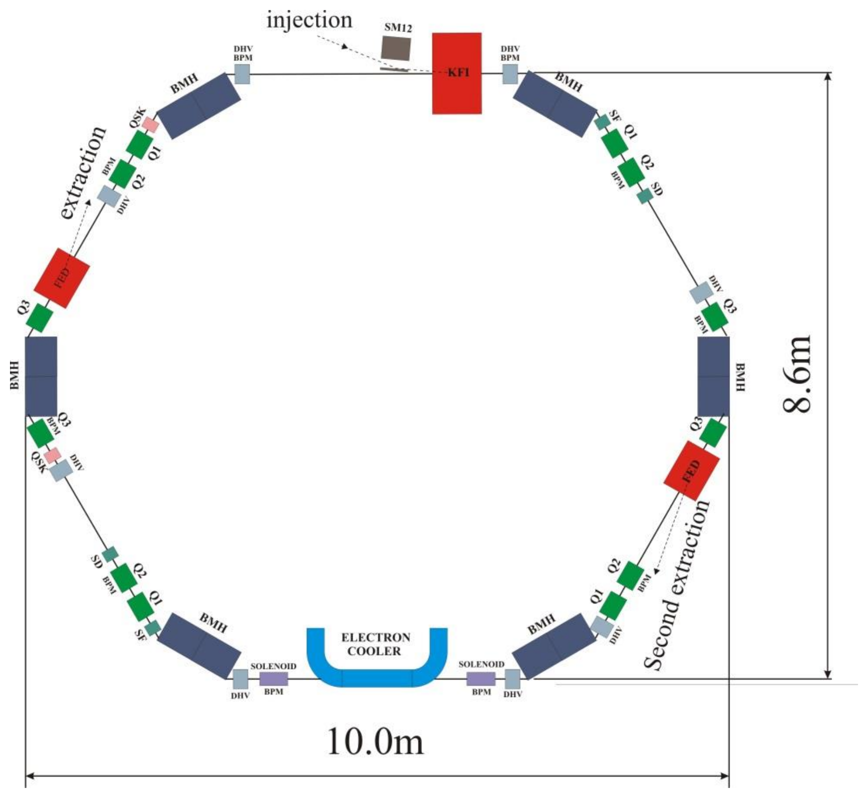
Choice of other parameters

- The bunch length must not exceed 300 nsec, which is about twice of trap length
- The transverse beam sizes must be around 1 mm ($\pm 1\sigma$). This comes to requirements on beam emittances after electron cooling at extraction plateau and beta function values at final focus point (usually at the entrance of solenoid of experiment). The emittances have to be small enough to provide good beam size but not too small to reduce space charge forces
- The momentum spread of extracted beam should be small enough to avoid problems with beam transport in electrostatic beam lines and give minimal contribution to beam size
- Circumference of 30.4m is 1/6 of AD. This is the minimal length to put required equipment in, and the maximal to fit properly inside of AD hall

Requirements to ELENA optics (layout)

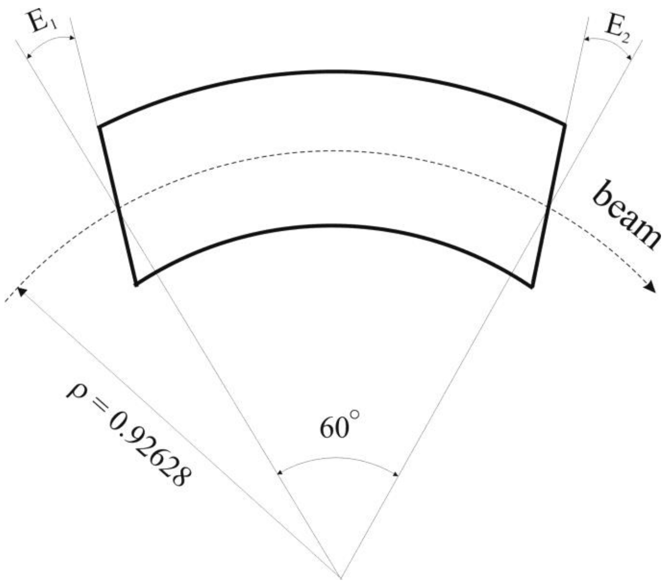
The 6-fold optics for ELENA ring:

- allows making beam injection into the ring and two beam extractions from it in the most efficient way, with minimal strength of kickers and septum
- Provide two free-quadrupoles straight sections for beam injection and electron cooling and



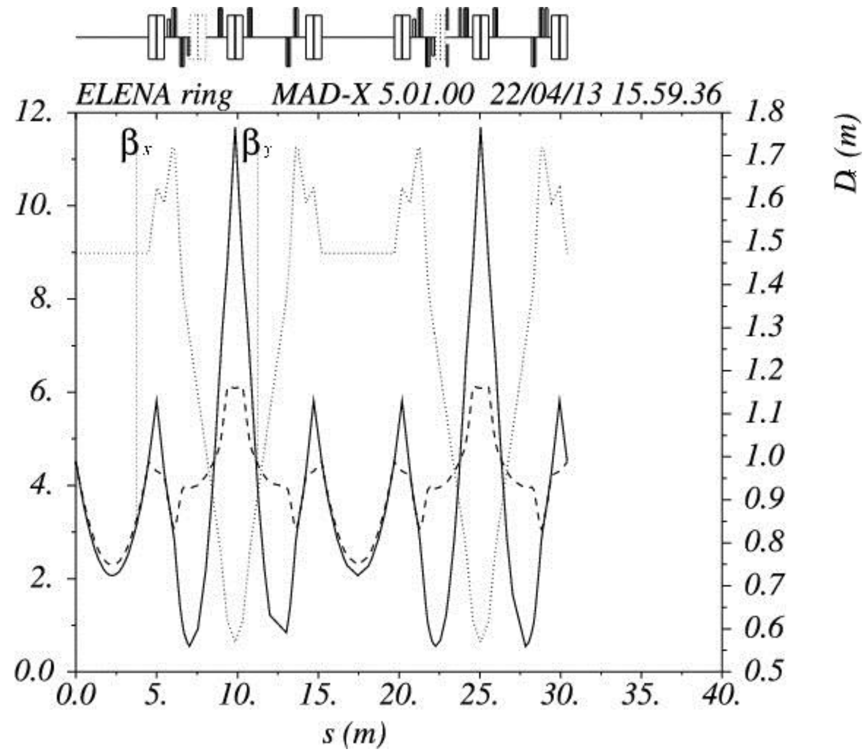
ELENA optics: choice of the bending magnet length

- Longer magnet makes smaller contribution to the beam focusing and easy optics adjustment.
- Shorter magnet allows operating at extraction energy with magnetic field not too small.
- Shorter magnets provide more space for other equipment placement, which is very critical for ELENA ring
- Compromised value of bending length 0.97 m and magnetic field in ELENA at extraction energy 493 G have been chosen.
- By varying the edge angle at the entrance and exit of bending magnet one can make this focusing stronger in one or another plane.

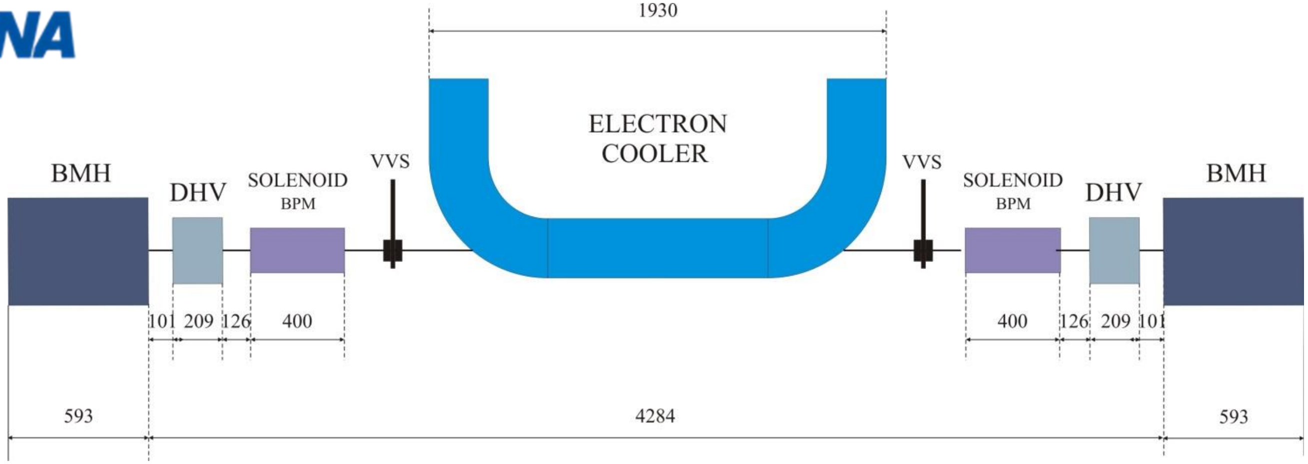


ELENA optics (continued)

- Three quadrupole families are used to control tunes
- The tunes have to chosen to operate with big incoherent tune shift due to space charge-> Q_x=2.3, Q_y=1.3
- The beta function values in cooling section should be suitable for fast electron cooling of antiproton beam, the dispersion in electron cooler
- The vertical beta function value in bending magnet must be modest
- The maximal beta function values throughout the ring must be modest to have reasonable large acceptance



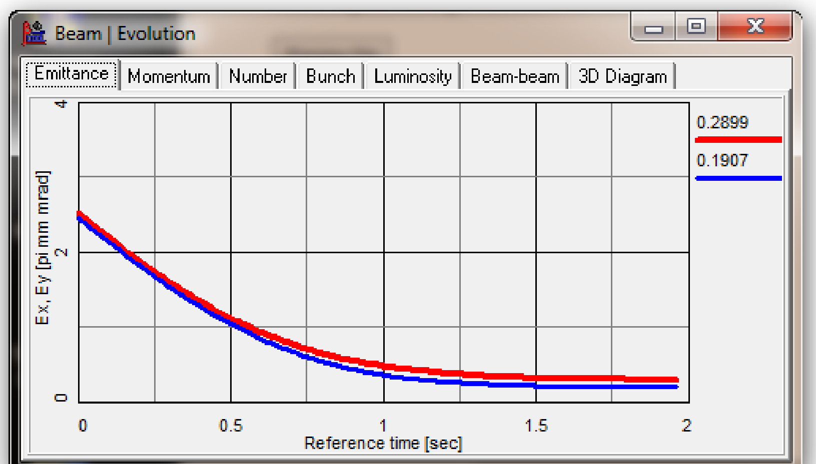
Electron cooler

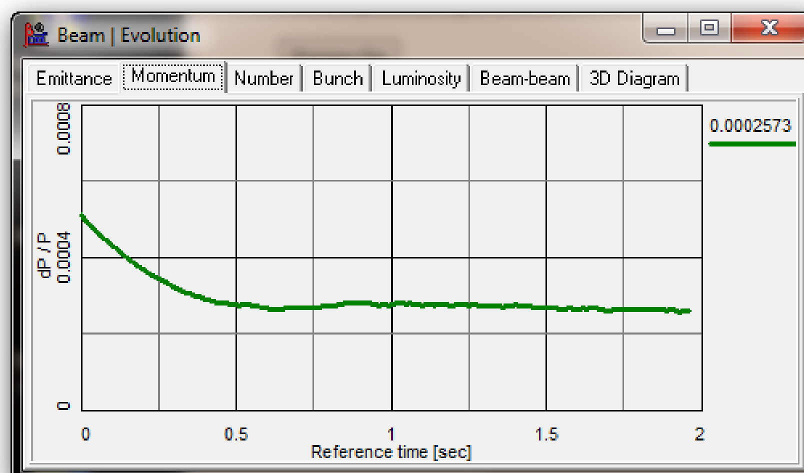


Drift section length l_c, m	1.0
Beam cooled at momentum, MeV/c	35 & 13.7
Electron beam current I_e, mA	5 & 2
Cathode voltage at 35 MeV/c and 13.7 MeV/c, V	355 & 55
Nominal/maximal magnetic field in solenoid, G	100/500
Electron beam radius at 35 MeV/c and 13.7 MeV/c, mm	25

Cooling at 13.7 MeV/c (simulations with BETACOOL)

- Initial parameters: $\varepsilon_{x,y}$=15π mm mrad, Δp/p=±1·10^{-3}, look at emittances (95% of beam) after 2 seconds of cooling, intra beam scattering is included
- Transverse emittances are overcooled (in view of tune shift due to space charge of beam), beam blow up will be applied
- Longitudinal cooling stop early, cooled not enough in view of bunch compression and transport through electrostatic beam lines





Intensity limit due to space charge

- important for bunched beam only, especially right before extraction

$$\Delta Q = -\frac{G_T r_p N_b}{2\pi\varepsilon_x \beta^2 \gamma^3}\frac{G_L C}{l_b}$$

- Here r_p =1.54·10^{-18} m, the ring circumference C=30.4m , factors G_T=1÷2 and G_L=1÷2 depend on transverse and longitudinal beam distributions,
- With 60% of deceleration efficiency (3·10^7 antiprotons injected into ELENA, 1.8·10^7 antiprotons decelerated down to 100 keV) and basic scenario with 4 bunches extracted the bunch intensity is N_b=0.45·10^7
- At extraction energy β =1.46·10^{-2}, the bunch length l_b=1.3m (300ns) , beam emittances $\varepsilon_{x,y}$=4π mm mrad, G_T=G_L=2 the tune shift is ΔQ=-0.12
- Can be reduced by factor 2 with flattened longitudinal beam distribution by superimposing RF voltage harmonics 4 and 8
- With improved deceleration efficiency up to 80% and using two RF harmonics the tune shift is on the safe side ΔQ=-0.08

Extension of cooling on beam bunching process

- Might be useful in case if equilibrium momentum spread at the end of coasting beam cooling will be too high for efficient beam transfer via electrostatic beam lines to experiments
- Becomes more useful in case of increased number of particles in a bunch (bigger IBS rates)
- Requires much slower bunch compression (a second or more instead of ~100 msecs) to use effectively electron cooling to keep momentum spread on acceptable level

Vacuum system

- average pressure of around $3 \cdot 10^{-12}$ Torr is defined by acceptable rate of residual gas scattering
- gas composition mainly given by hydrogen and low-Z gas species, meaning extreme high-vacuum regime
- Massive NEG-coating is applied everywhere possible
- Additional pumping is installed on each dipole magnet and on each straight section, by using integrated NEG and ion-pump combinations
- Additional pumping is foreseen on the injection and on the two extraction elements and on the electron cooler
- The vacuum system is designed for a 300 C bakeout and NEG-coating activation
- low net outgassing rate is particularly important in the area near the ELENA ring, as backstreaming of gas species from the experimental beamlines to the ring should be minimized

Beam instrumentation

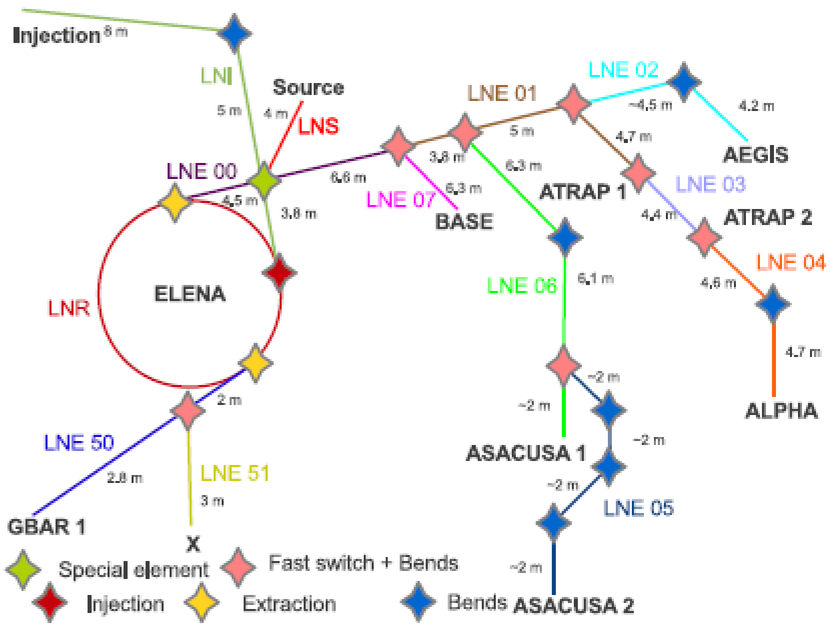
- 10 electrostatic beam position monitors will be installed inside of 6 ring quadrupoles and 4 orbit correctors to measure the closed orbit during the deceleration cycle. Expected resolution is 0.1 mm with an accuracy of 0.3 to 0.5 mm. The sum of all 20 PU’s will be used as well for Schottky-based intensity and momentum spread measurements
- The tune measurement system is based on the base-band tune BBQ systems will use one pick-up to provide the tune evolution throughout the cycle
- As in the AD, it is planned to use a high sensitivity longitudinal Schottky pick-up to measure the beam intensity
- Scrapers will be used to destructively measure the transverse profile (and hence emittance) of the circulating
- GEM monitors will be used in transfer lines to detect beam centre position and its profile

ELENA main parameters

Momentum range, MeV/c	100 - 13.7
Energy range, MeV	5.3 - 0.1
Circumference, m	30.4
Working point, Q_x/Q_y	2.3 / 1.3
Ring acceptances, π mm mrad	75
Intensity of injected / ejected beam	$3.0 / 1.8 \times 10^7$
Number of extracted bunches	4
Emittances (h/v) of extracted beam, π·mm·mrad, [95%]	4 / 4
$\Delta p/p$ of extracted beam, [95%]	$2.5 \cdot 10^{-3}$
Bunch length at 100 keV, m / ns	1.3 / 300
Required (dynamic) vacuum, Torr	3×10^{-12}

Electrostatic transfer lines

- 5 existing and 3 new experiments, the upper extraction delivers beam to existing experimental zone, the lower to the new one
- Totally 100 m transfer lines having 7 fast separators are used to distribute beam to the different experiments



Electrostatic transfer lines (continued)

- The beam line layout is constrained by existing experiments and shielding walls
- H^-/p source will be used for ELENA commissioning at 100 keV
- Installation of source imposes extra constraints on injection and extraction transfer lines
- An electrostatic switchyard will be installed at the crossing of injection and upper extraction transfer lines. The protons and H^- ions will be deflected there by ±53.75°.
- Protons can be injected either via ejection channel with normal polarity of ELENA ring, or via the injection line with inverted polarity of the ring, which is useful for the lattice studies and for tests of electron cooling (if lifetime of H^- ions will be poor)

Planning for ELENA project

- The Technical Design Report under preparation and expected by Summer 2013
- Expected time-line:
  - ➢ Construction of annexed building (April 2014), moving kicker platform there (January 2015), kickers commissioning (May 2015), beam back to AD (June 2015)
  - ➢ ELENA installation in 2015, connection to AD in January 2016
  - ➢ Commissioning with external source and a few antiproton transfers from AD in 2016
  - ➢ Installation of new electrostatic lines from ELENA to experiments during 2016/2017 shutdown
  - ➢ Commissioning of new lines in summer 2017
  - ➢ First physics run with ELENA during second half of 2017

Thanks for your attention!