# Extra Low ENergy Antiproton ring ELENA:
## From the Conception to the Implementation Phase

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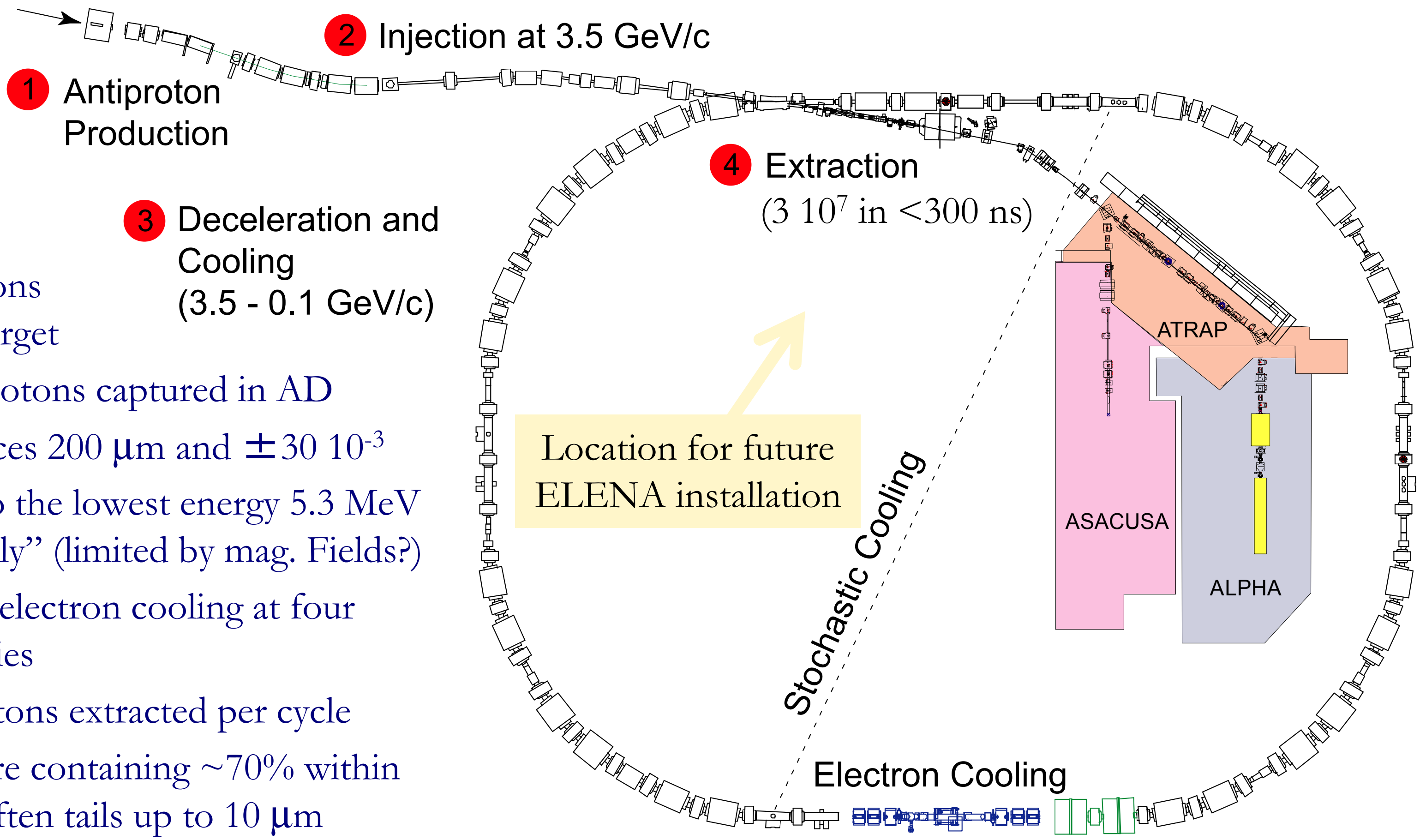
- Introduction
  - Antiproton Decelerator
  - Efficiency for experiments at present without ELENA and with ELENA
- ELENA Overview and Layout
- Selected Features and Issues
- Beam Parameter
- Conclusions, Status and Outlook

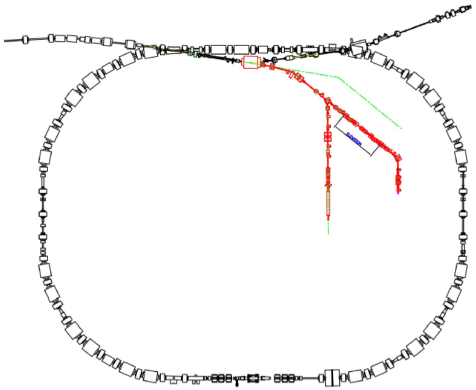
# Introduction: Antiproton Decelerator AD – a unique facility providing 5.3 MeV antiprotons



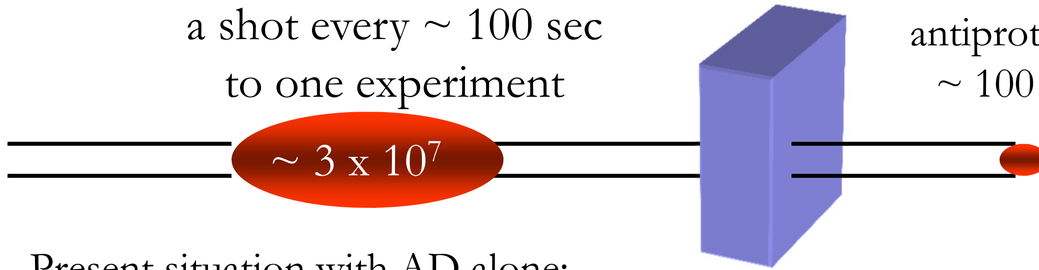

- ~1.5 $10^{13}$ protons (26 GeV) on target
- ~3.5 $10^{7}$ antiprotons captured in AD
  - Acceptances 200 µm and ±30 $10^{-3}$
- Deceleration to the lowest energy 5.3 MeV reachable "safely" (limited by mag. Fields?)
- Stochastic and electron cooling at four different energies
- ~3 $10^{7}$ antiprotons extracted per cycle
  - Dense core containing ~70% within <1 µm, often tails up to 10 µm
  - Longitudinal before bunch rotation 95% within $10^{-4}$ and 400 ns
- Cycle length about 100 s

Sketch of the present AD – circumference 182 m
- In addition experiment AEGIS installed
- Experiment BASE being installed
- Gbar approved to receive beam from ELENA

# Introduction: Efficiency for capturing antiprotons in traps without and with ELENA

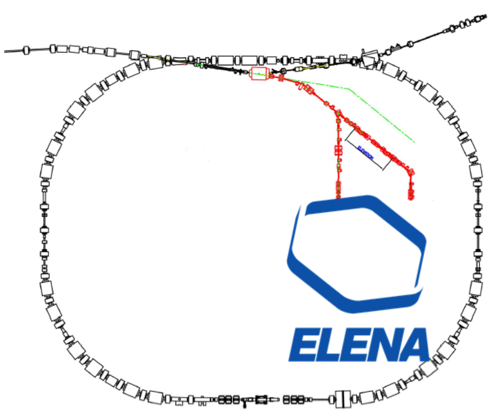


5.3 MeV antiprotons
a shot every ~ 100 sec
to one experiment

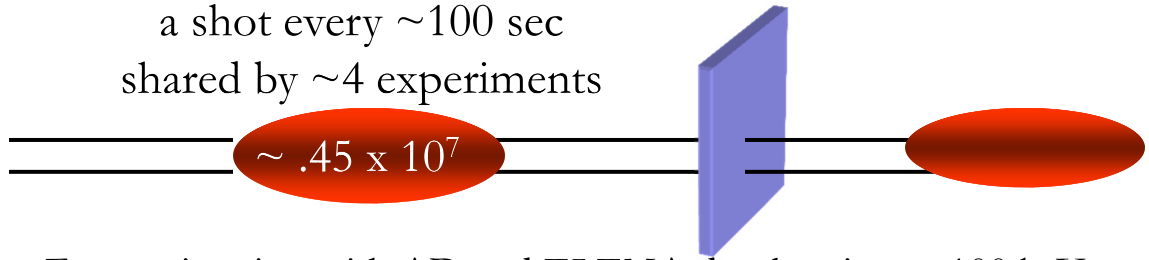



~4 keV
antiprotons/
~ 100 sec

Present situation with AD alone:
- Most experiments slow antiprotons down by “degrader”
  => very inefficient – most (>99%) antiprotons lost
  (one experiment uses an RFQ for deceleration with higher efficiency)

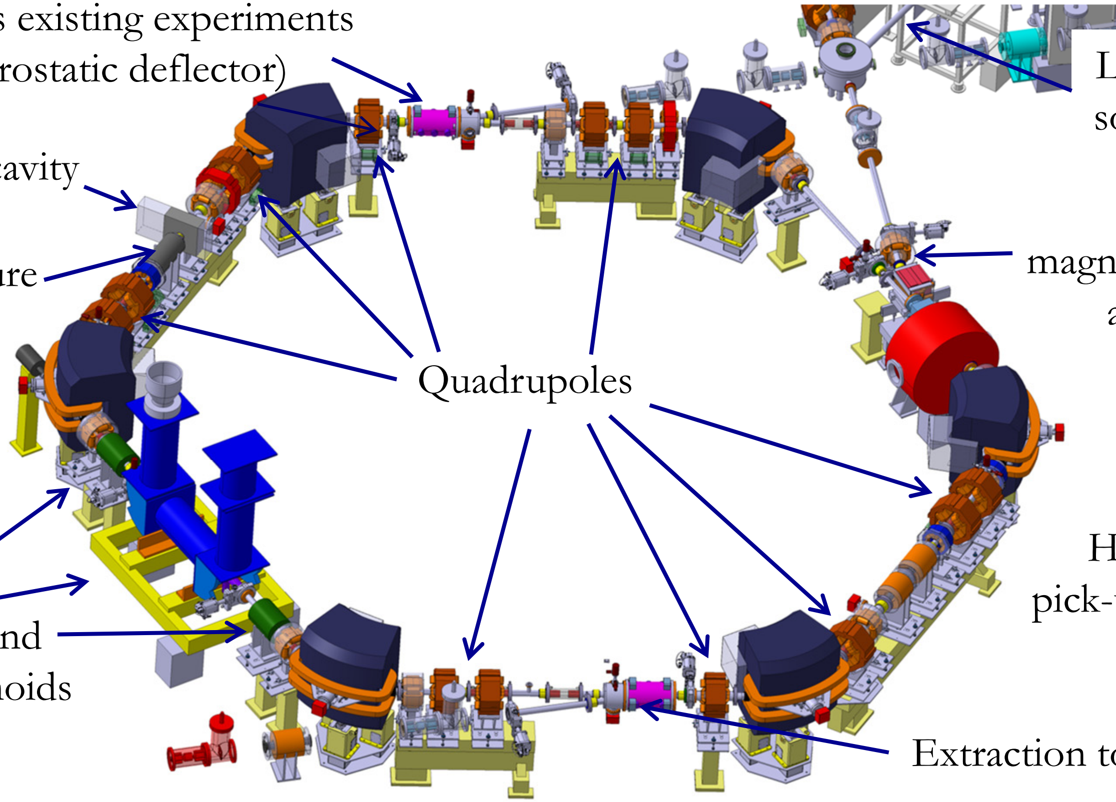



100 keV antiprotons
a shot every ~100 sec
shared by ~4 experiments



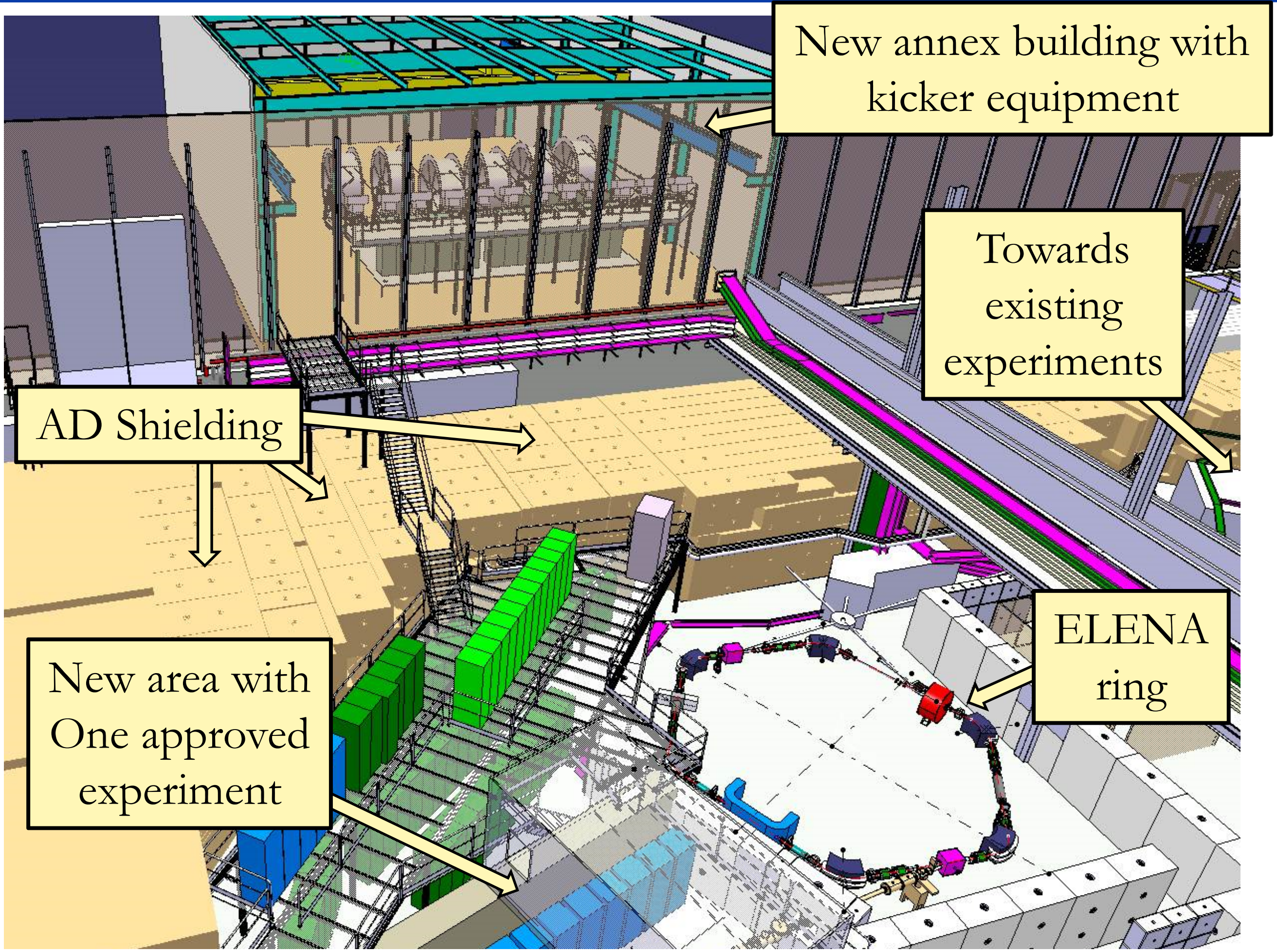

Future situation with AD and ELENA decelerating to 100 keV:
- thinner “degrader” and increased trapping efficiency
  (some experiments use other means to decelerate the beam)
- Intensity shared by four exp’s allows longer periods with beam

# ELENA Overview and Layout



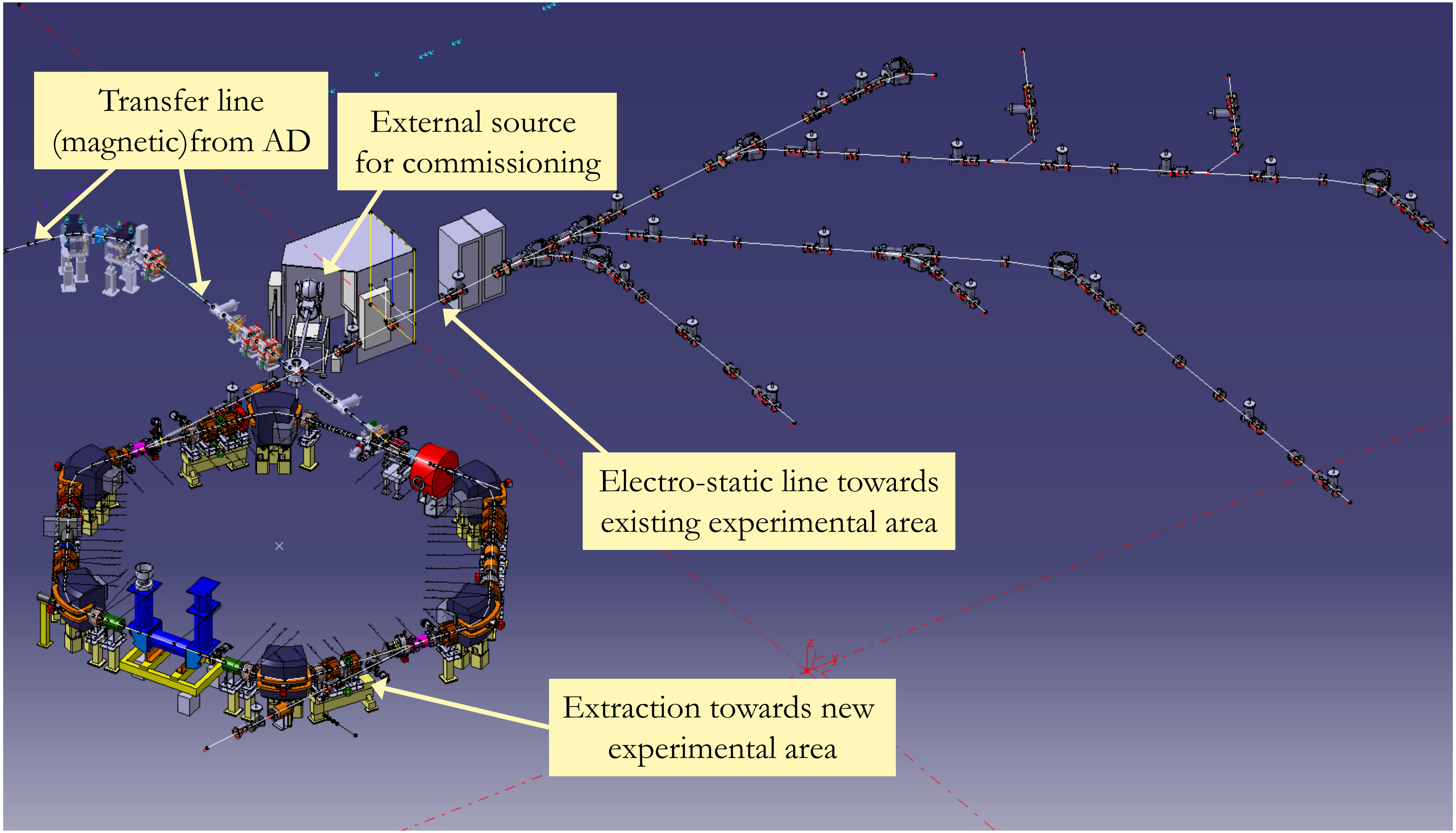

- Deceleration of antiprotons from 5.3 MeV to 100 keV to improve efficiency of experiments
- Circumference 30.4 m (1/6 the size of the AD)
  - Fits in available space in AD hall and allows installing all equipment without particular efforts
  - Lowest average field (beam rigidity over average radius) $B\rho/R$ = 94 G (smaller than for AD 115 G)

# ELENA Overview and Layout



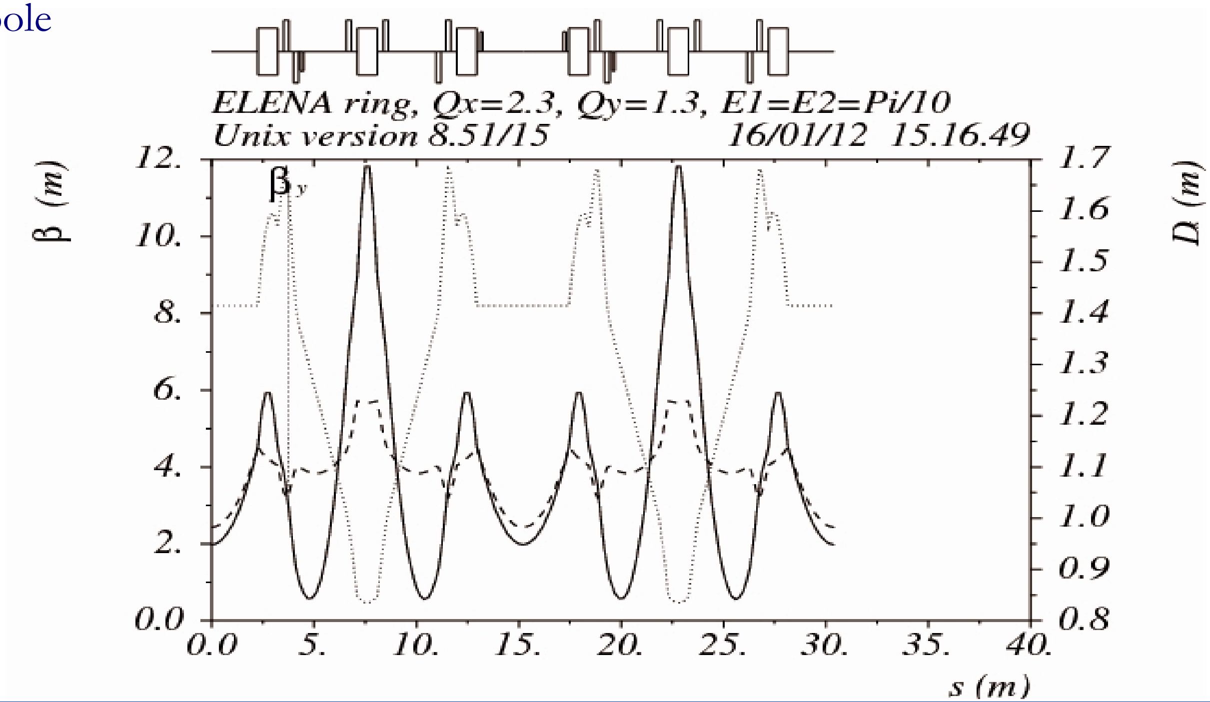

- ELENA in AD hall with existing (AD experiments) and new experimental area
  - Cost effective with short transfer line from AD and no relocation of existing experiments
  - New (small) building to house equipment now at location, where ELENA will be installed

# ELENA Overview and Layout



# Selected Features and Issues

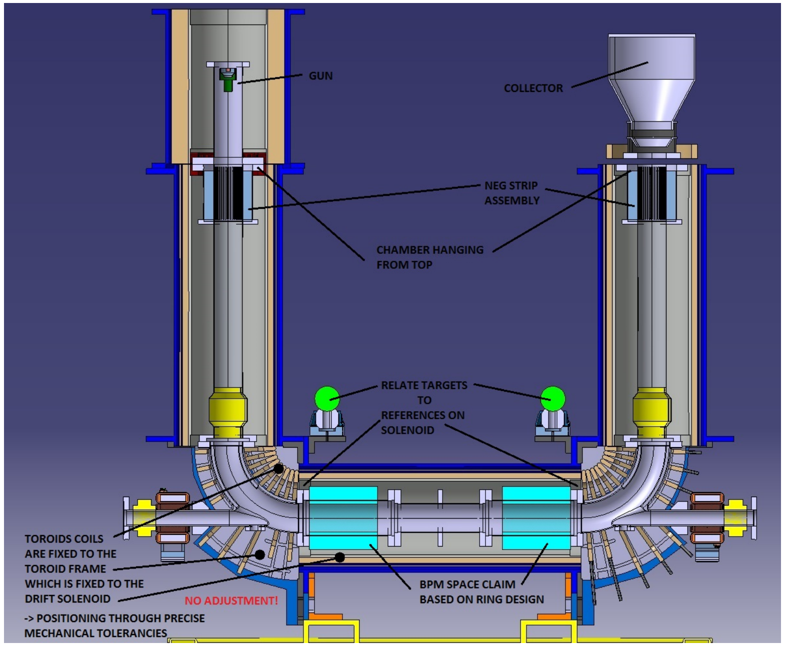
- Energy Range
  - Machine operated at an unusually low energy for a synchrotron (down to 100 keV!)
  - Many points below a consequence of the low energy
- Lattice
  - Constraints
    - Long straight section with small dispersion for electron cooling
    - Geometry in AD hall (location of injection and two extractions)
  - Many geometries and quadrupole locations investigated
  - Hexagonal shape and optics with periodicity two
  - Tunes: $Q_X \approx 2.3$, $Q_Y \approx 1.3$ (e.g. $Q_X = 2.23$, $Q_Y = 1.23$)
  - Acceptances: about 75 μm (depends on working point)



# Selected Features and Issues

- Electron cooling
  - Applied at
    an intermediate plateau at 35 MeV/c
    and the final energy 100 keV
  - To reduce losses during deceleration after 1st cooling plateau and generate bright bunches for experiments
  - Electron beam expansion by factor 10 to reduce its temperature
  - Bunched beam cooling at 100 keV
    to reduce momentum spread of
    short bunches requested by experiments
  - Perturbations of magnetic system on circulating beam under study
- Expected main performance limitation:
  Intra Beam Scattering IBS
  - Determines beam parameters with cooling (equilibrium between the two processes)

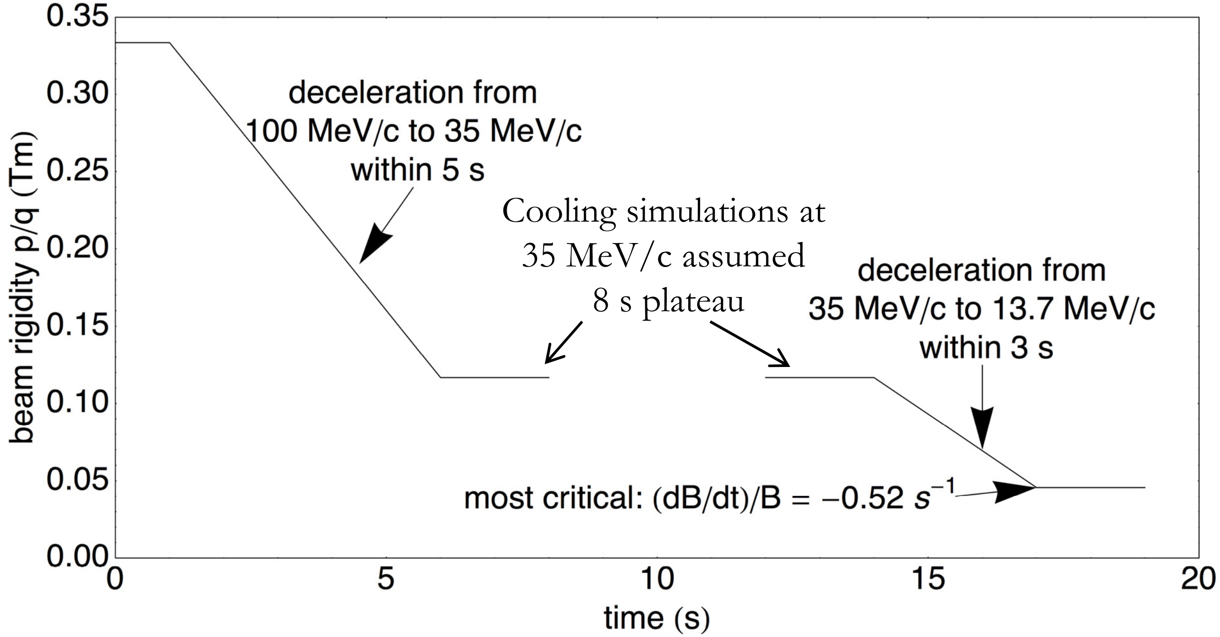
| | | |
|---|---|---|
| Momentum (MeV/c) | 35 | 13.7 |
| Relativistic β | 0.037 | 0.015 |
| Electron beam energy (eV) | 355 | 55 |
| Electron current (mA) | 10 | 2 |
| Electron beam density ($10^{12}$ $m^{-3}$) | 2.8 | 1.4 |
| Field at gun (Gauss) | 1000 | |
| Field at cooling section (Gauss) | 100 | |
| Expansion factor | 10 | |
| Cathode radius (mm) | 7.9 | |
| Electron beam radius (mm) | 25 | |



# Selected Features and Issues

- Rest gas interactions and vacuum system
  - 3 $10^{-12}$ Torr nominal pressure - fully baked machine with NEGs wherever possible
  - Interactions of beam with rest gas to be evaluated with care (see TUPRI028, MOPRO036) and not a dominant performance limitation
- Beam diagnostics with very low intensities and energy
  - E.g.: Beam currents down to well below 1 μA far beyond reach standard slow BCTs
  - ➠ Intensity of coasting beam measured with Schottky diagnostics
- Magnets with very low fields (see TUPRO106)
  - "Thinning" (mixing of stainless steel and magnetic laminations) for bending magnets and possibly for other small magnets, steerers without magnetic yoke
  - Careful magnetic measurement with pre-series magnets
- Electrostatic transfer lines to experiments (see MOPRI101)
  - Cost effective at very low energies, easier for shielding against magnetic stray fields
- RF system with modest voltages, but very large dynamic range
- Direct space charge defocusing a possible limitation despite very low intensity (and 300 ns long bunches)
  - Split available intensity to several (baseline four) bunches to mitigate
- Commissioning with external $H^-$ and proton source (and electrostatic acceleration to 100 keV)
  - Higher repetition rate but start commissioning at the difficult low energy part of the cycle

# Expected Magnetic Cycle




- Ramps
  - Blow-up due to IBS must remain acceptable (fast ramp)
  - Perturbation of optics due to Eddy currents must remain acceptable (slow ramp)
- Plateaus with electron cooling
  - Duration taken from simulations of cooling
- ELENA cycle expected to last about 25 s, but repetition rate slower (beam from AD about every 100 s)

# ELENA Beam Parameters

## Present best guess combining different Sources

| Step in cycle | $\varepsilon_L$ (meVs) | $\sigma_p/p$ ($10^{-3}$) | $\sigma_E$ (keV) | $\sigma_T$ (ns) | $\varepsilon_{H,rms}$ (μm) | $\varepsilon_{V,rms}$ (μm) |
|---|---|---|---|---|---|---|
| Injection[+,a)] | 3.5 | 0.25 | 2.8 | 98 | 0.5 | 0.3 |
| Start 1st ramp[+,b)] | 3.5 | 0.49 | 5 | 53 | 0.5 | 0.3 |
| End 1st ramp[c)] | 3.5 | 1.4 | 1.8 | 150 | 1.8 | 1.1 |
| Start plateau 35 MeV/c[d)] | 5.2 | 0.46 | 0.6 | coasting | 1.8 | 1.1 |
| End plateau 35 MeV/c[e)] | 1.7 | 0.15 | 0.20 | coasting | 0.45 | 0.42 |
| Start 2nd ramp[d)] | 2.5 | 0.84 | 1.1 | 180 | 0.45 | 0.42 |
| End 2nd ramp[c)] | 2.4 | 2.1 | 0.42 | 455 | 2.2 | 2.5 |
| Start plateau 100 keV[d)] | 3.2 | 0.46 | .092 | coasting | 2.2 | 2.5 |
| Cooled coasting 100 keV[e)] | 1.1 | 0.25 | .050 | coasting | 0.3 | 0.2 |
| Cooled bunched 100 keV[f)] | 4 x 0.12 | 0.60 | .120 | 75 | 1.2 | 0.75 |

$\varepsilon_{rms} = \sigma_\beta^2/\beta_T$ with $\sigma_\beta$ the rms betatron beam size and $\beta_T$ the Twiss betatron function

+) difficult to determine due to (i) dense core and long tails, (ii) variations with time

a) Typical values measured with AD – some reduction of long. Emittance with bunched beam cooling

b) Increase of voltage from 16 V at transfer to 100 V on ramp

c) Simulations of IBS on ramp

d) Debunching/bunching with 50% blow-up (bunched with LHC def. $\varepsilon_L = 4\pi\, \sigma_E\, \sigma_T$, coasting $\varepsilon_L = 4\,(2/\pi)^{1/2}\, \sigma_E\, T_{rev}$)

e) From ELENA technical meetings with presentations by G.Tranquille and P. Beloshitsky

# New building adjacent to the AD hall

- New Building 393 completed in February ahead of schedule
  - Will house electronics (PFL) for AD and ELENA injection kicker
  - Storage space .. for experiments
- Infrastructure installation ongoing

# Conclusions, Status and Outlook

- ELENA will be a small ring to further decelerate antiprotons from the AD
  - Electron coolimg to reduce beam emittances and energy spread
  - Improvement for existing experiments and new types of experiments (e.g. gravitation)

- ELENA Machine to be built well known now
  - General Project Review last autumn
    - Concept of decelerator with electron cooling endorsed, no showstoppers identified
    - Many proposals for further studies and improvements
  - Technical Design Report TDR describing machine published

- Status and outlook
  - Moving from the conception to implementation phase
  - First contracts for equipment (magnets …) being signed
  - ELENA installation in $2^{nd}$ half of 2015 and beginning 2016 followed by commissioning
  - Transfer line installation followed by commissioning during $1^{st}$ half 2017
  - First physics run with 100 keV antiprotons from ELENA planned for $2^{nd}$ half of 2017

# Thanks for your attention !

# Basic ELENA Parameters

| Parameter | Value | Comment |
|---|---|---|
| Basic shape | Hexagonal | two long straights for injection and cooling |
| Periodicity | Two periods | neglecting the electron cooler |
| Circumference | 30.4055 m | 1/6 the AD |
| Max. beta functions $\beta_{H,max}$/ $\beta_{V,max}$ | ≈12 m/≈ 6m | |
| Working point $Q_H/Q_V$ | ≈2.3/≈1.3 | some tuning range to choose working point |
| Relativistic gamma at transition | ≈2 | |
| Energy range | 5.3 MeV – 100 keV | |
| Momentum range | 100 MeV/c – 13.7 MeV/c | |
| Transverse acceptances | 75 μm | |
| Cycle length | >25 s | deceleration and cooling |
| Repetition rate for pbar operation | ≈100 s | limited by AD operation |
| Injected intensity | 3 $10^7$ antiprotons | |
| Efficiency | 60% | conservative guess |
| Parameter at ejection | | with bunched beam cooling |
| Number of bunches | 4 | baseline with four bunches |
| Bunch population | 0.45 $10^7$ pbars | |
| Rel. mom. spread | 0.5 $10^{-3}$ | Rms value |
| Bunch length | 75 ns | Rms value |
| Hor. emittance | 1.2 μm | Rms, physical |
| Vert. emittance | 0.75 μm | Rms, physical |