ELENA

Space Charge Collaboration Meeting 2014

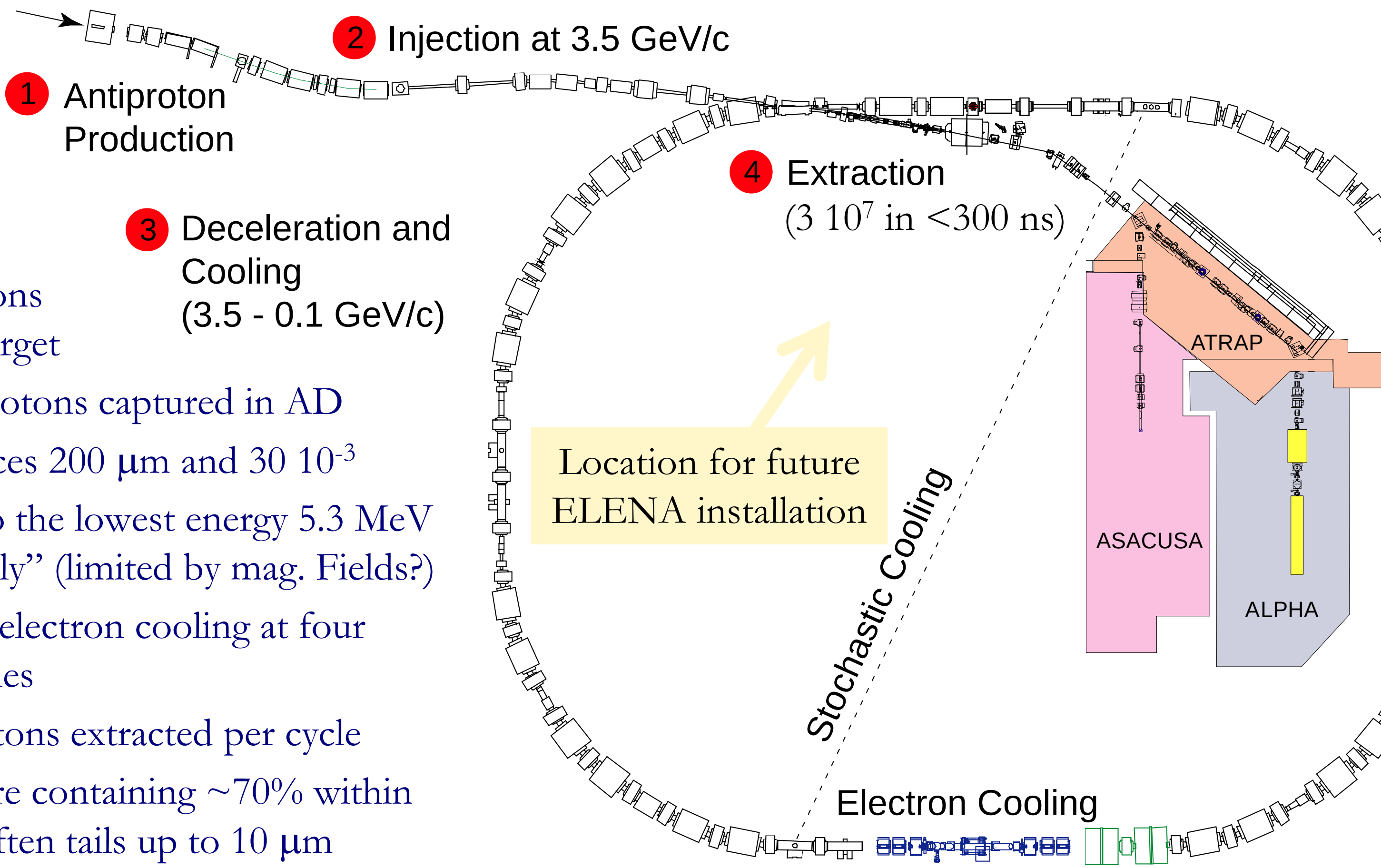
CERN, 20th May 2014

C.Carli on behalf of the AD/ELENA team(s)

- Introduction
- ELENA Overview and Layout
- Some of the Most Salient Features
- ELENA Lattice
- Conclusions, Status and Outlook

Introduction

Present Antiproton operation with the AD

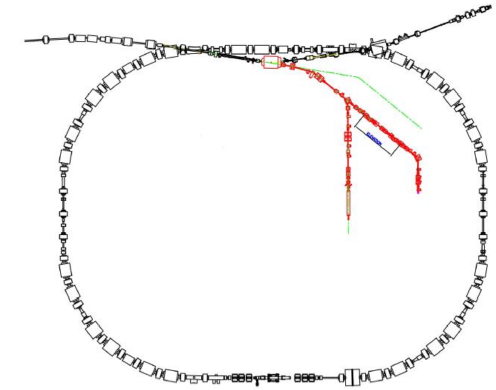


- ~1.5 10^{13} protons (26 GeV) on target
- ~3.5 10^{7} antiprotons captured in AD
  - Acceptances 200 µm and 30 10^{-3}
- Deceleration to the lowest energy 5.3 MeV reachable "safely" (limited by mag. Fields?)
- Stochastic and electron cooling at four different energies
- ~3 10^{7} antiprotons extracted 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

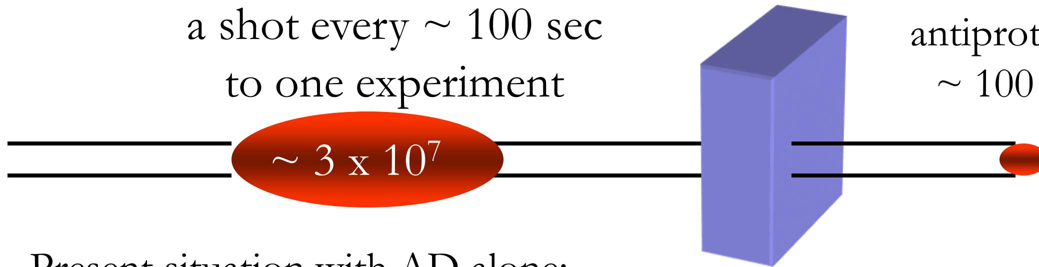
Sketch of the present AD – circumference 182 m
- In addition experiment AEGIS installed
- Experiment BASE being installed
- Gbar approved to receive beam from ELENA

Introduction

Efficiency for users without and with ELENA

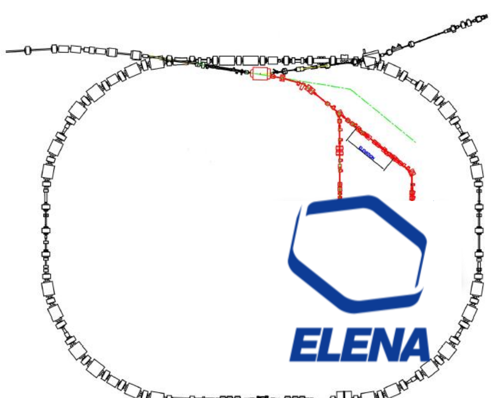


5.3 MeV antiprotons
a shot every ~ 100 sec
to one experiment

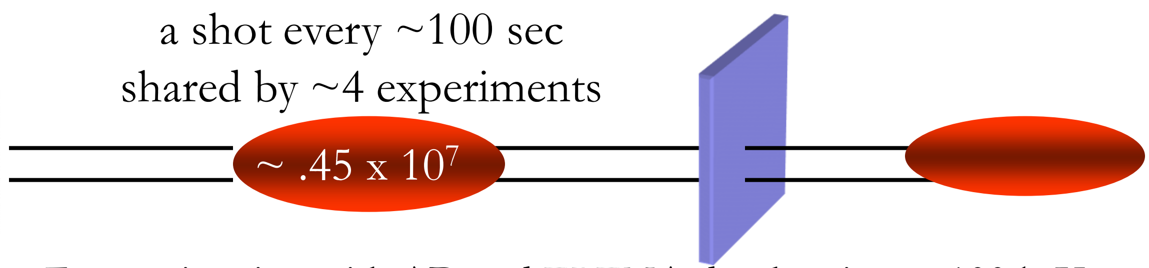


~4 keV
antiprotons/
~ 100 sec

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

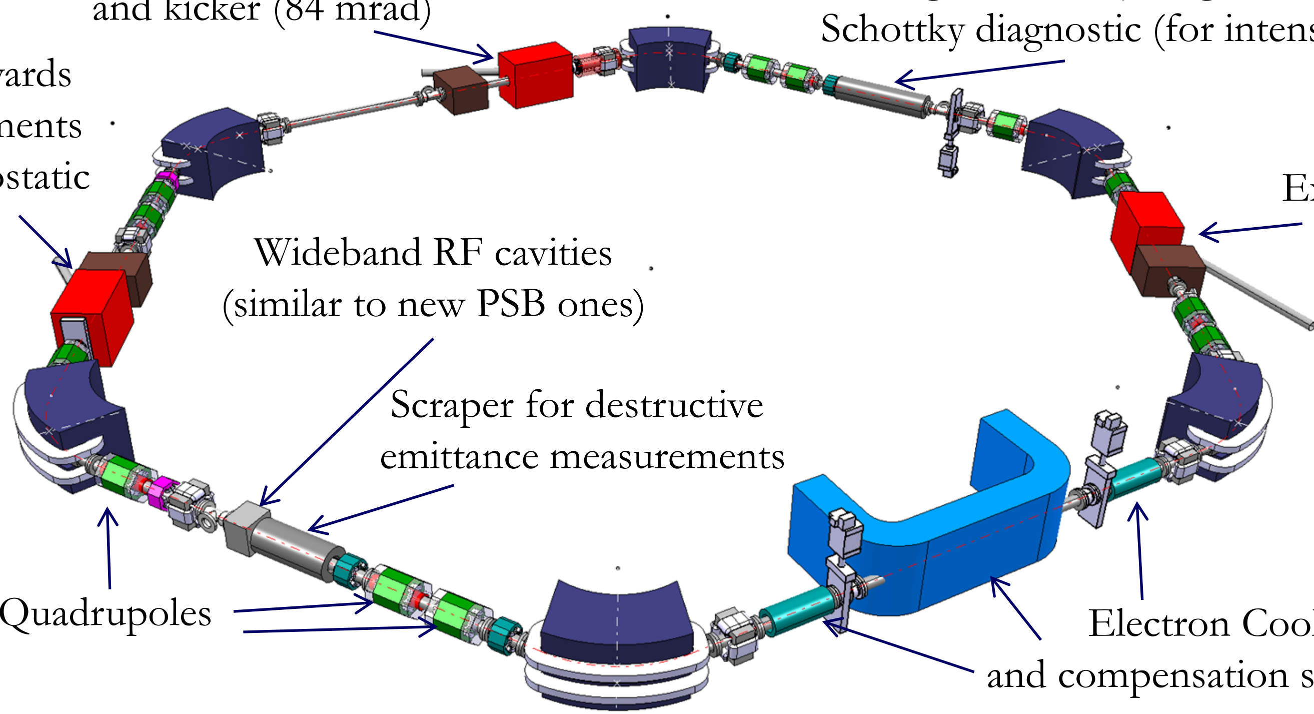


100 keV antiprotons/
a shot every ~100 sec
shared by ~4 experiments



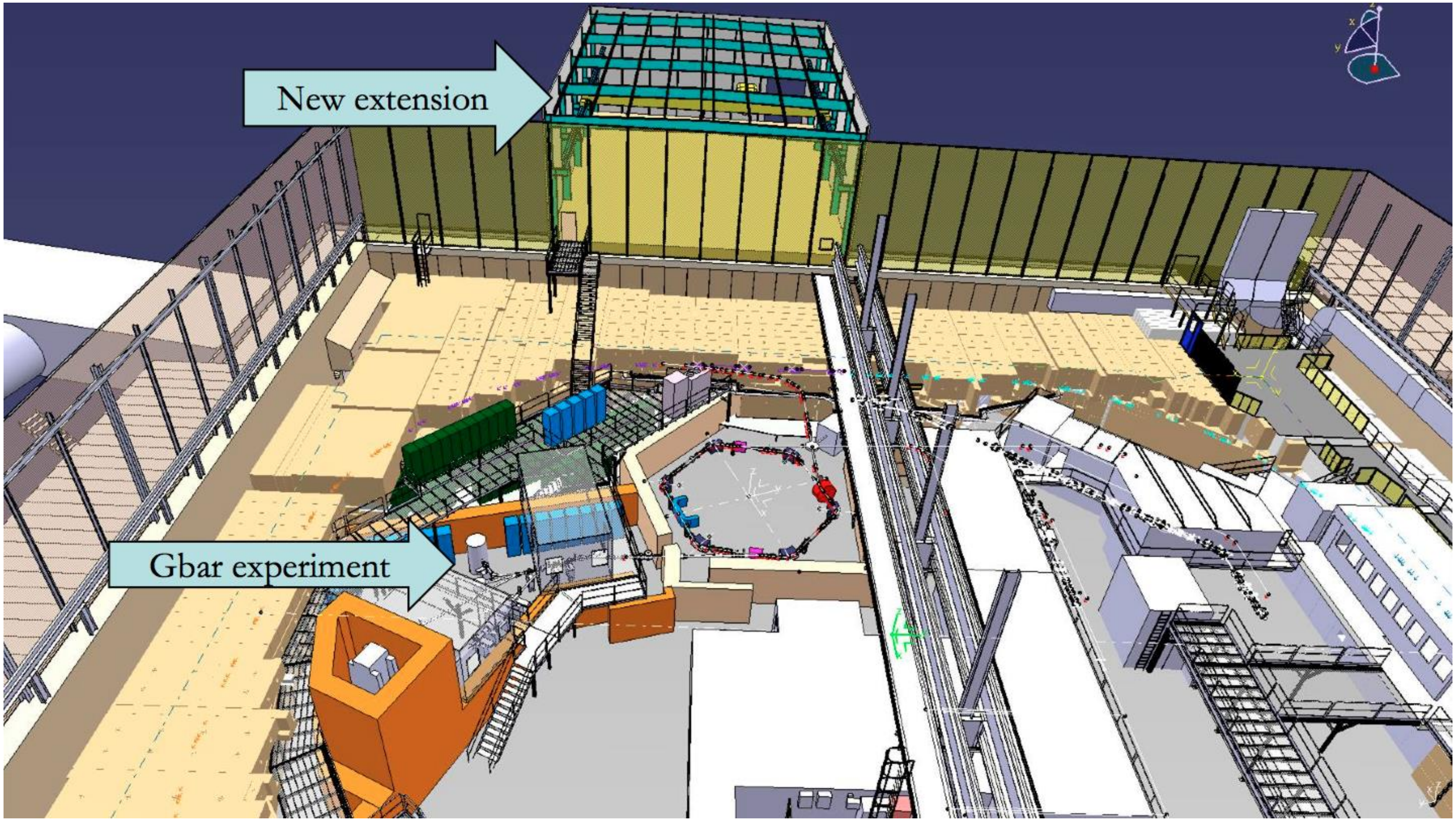
Future situation with AD and ELENA decelerating to 100 keV:
- thinner "degrader" and increased trapping efficiency
  (some experiments use other means to decelerate the beam)
- Intensity shared by four exp's allows longer periods with beam

ELENA Overview and Layout



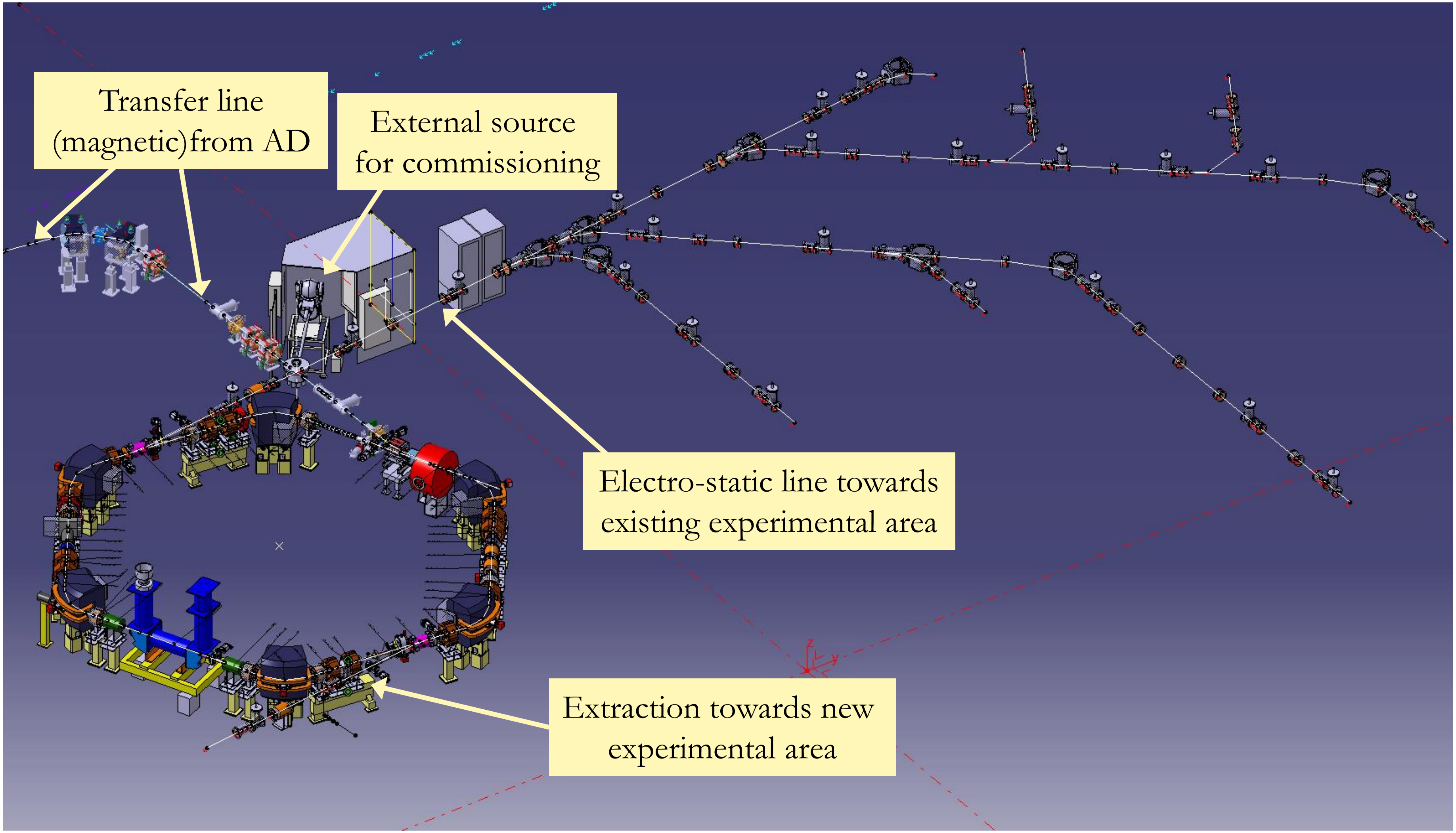
- Deceleration of antiprotons from 5.3 MeV to 100 keV to improve efficiency of experiments
- Size a factor ~10^3 smaller than LHC, kinetic energy of beams for physics factor ~10^8 lower than LHC
  Circumference 30.4 m or 1/6 the one of the AD (.. 4 times the size of the first proposal in 1982!)
  - Allows installing all equipment required without particular efforts to gain space
  - Fits in the available space inside the AD hall
  - 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 new experimental area for Gbar and, possibly, another experiment:
  - 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

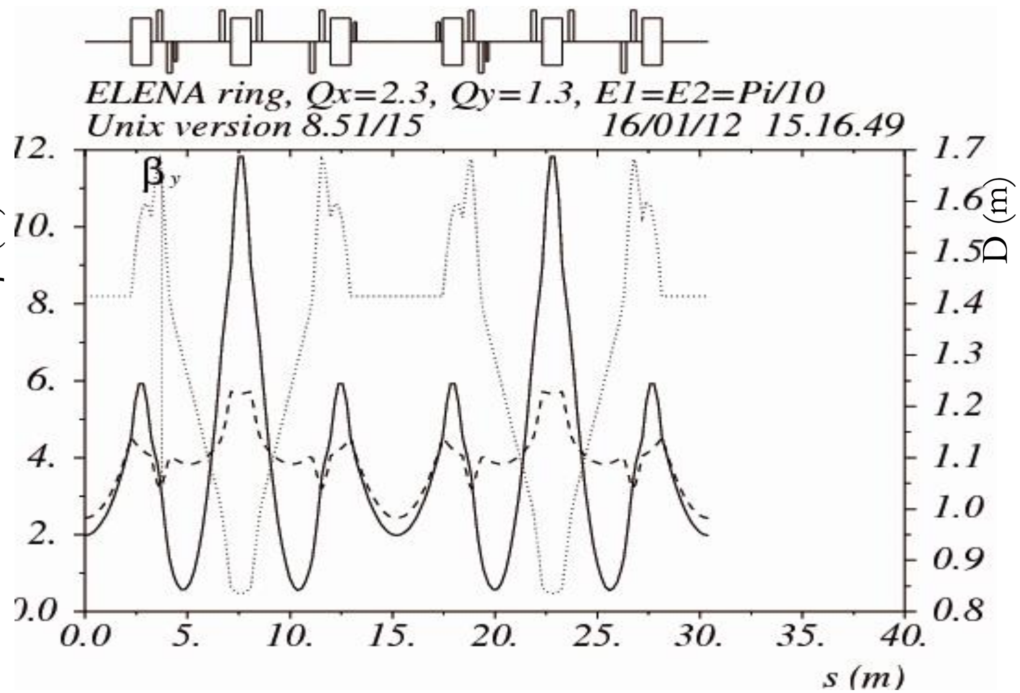


Some of the most Salient Features

- Machine operated at an unusually low energy for a synchrotron (down to 100 keV!)
- Expected main performance limitation: Intra Beam Scattering (IBS, see later)
  - Determines equilibrium emittances together with electron cooling
- Rest gas interactions: stringent requirements - 3 10^{-12} Torr nominal pressure
- Beam diagnostics with very low intensities and energy
  - Beam currents down to well below 1 μA (far beyond reach standard slow BCTs)
  - Intensity of coasting beam measured with Schottky diagnostics
- Electron cooling at very low energies .. essential ingredient for concept
  - Bunched beam cooling to obtain acceptable momentum spread of short extracted bunches
- Magnets with very low fields
  - "Thinning" (mixing of stainless steel and magnetic laminations) for bending magnets and probably for other small magnets
    - Mitigate remanence effects and impact on field quality for quadrupoles, sextupoles … ?
    - Careful magnetic measurement with pre-series magnets ("thinning" as well for other magnets?)
- Electrostatic transfer lines to experiments
  - 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
- Commissioning with external H^- and proton source (and electrostatic acceleration to 100 keV)

ELENA Lattice and Space Charge

- Challenges (usual for low small rings) for lattice design and optics
  - Many constraints and few "free parameters" (quadrupole strengths)
    - Suitable tunes, acceptances, beam transfers, long straight with small dispersion for cooler ..
    - Geometry in AD hall - many geometries and quadrupole locations investigated
- Baseline lattice: hexagonal shape with two periods and two long straights (for cooler and injection)
  - 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 depending on working point (Maximum expected emittances plus some margin for reserve)
- Space Charge
  - One short (rms length 75 ns requested by experiments) bright (rms emittance ~1 μm) bunch would give $\Delta Q \approx -0.4$
  - Mitigation: several (baseline four) bunches sent to different experiments
  - Resulting longer beam periods considered an advantage despite lower intensity
  - No plans for simulations studies so far (will not impact design, may-be later)



Conclusions, Status and Outlook

- ELENA will be a small ring to further decelerate antiprotons from the AD
  - Electron cooler to reduce beam emittances and, thus, sizes and energy spread
  - Improvement for existing experiments and new types of experiments (e.g. gravitation)
  - Space charge significant despite low intensity (few 10^7) with short dense bunches
    - Mitigated by splitting (well received) into several bunches sent to several experiments
    - So far no plans for simulation studies, but possibly later
- ELENA Machine to be built well known now
  - General Project Review on 14th and 15th October
    - Concept of decelerator with electron cooling endorsed, no showstoppers identified
    - Many proposals to improve (Tunability for working point, "thinning" of small magnets ..)
  - Technical Design Report TDR describing machine published
- Outlook
  - Adjacent building 393 completed, infrastructure installation going on
  - First call for tenders for equipments (magnets …) ongoing
  - ELENA installation in 2nd half of 2015 and beginning 2016 followed by commissioning
  - Transfer line installation followed by commissioning during 1st half 2017
  - First physics run with 100 keV antiprotons from ELENA planned for 2nd 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

Basic ELENA Parameters

Present best Guess for beam parameters combining different Sources

Step in cycle	ε_L (meVs)	σ_p/p (10^{-3})	σ_E (keV)	σ_T (ns)	$\varepsilon_{H,rms}$ (μm)	$\varepsilon_{V,rms}$ (μm)
Injection[+,a)]	3.5	0.25	2.8	98	0.5	0.3
Start 1^{st} ramp[+,b)]	3.5	0.49	5	53	0.5	0.3
End 1^{st} 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 2^{nd} ramp[d)]	2.5	0.84	1.1	180	0.45	0.42
End 2^{nd} 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 σ_β the rms betatron beam size and β_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