ELENA Project Overview

C. Carli

ELENA Project Review, 14th October 2013

- Introduction
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  - Antiproton Decelerator AD
  - Motivation to add ELENA to the AD
- ELENA Overview
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- Summary and Aim of this Review

Introduction
Recap of CERN low energy Antiprotons rings

Low Energy Antiproton Ring LEAR

- p-bar availbale from accumulator AA constructed for $Sp\bar{p}S$ project
- Additional facility making use of the p-bars and
- Ultra-slow (and fast) ejection to experiments in south hall and internal targets
- Commissioning in 1982 with stochastic cooling
- First machine with electron cooler used for operation
- First observations of antihydrogen …

- First proposal to construct ELENA to decelerate to even lower energies (7.85 m circumference to reach 200 keV !!)

HH/fn
20/11/81

CERN/PSCC/82-3
PSCC/P52 Add.1
28 January, 1982

A Small Deceleration Ring for Extra Low Energy Antiprotons (ELENA)

H. Herr

INTRODUCTION

On completion of LEAR, experiments with low energy antiprotons may be carried out for the first time using well defined antiproton beams in the energy range from 1270 MeV down to 5 MeV. As some experiments demand antiprotons even below 5 MeV, several devices for deceleration have been

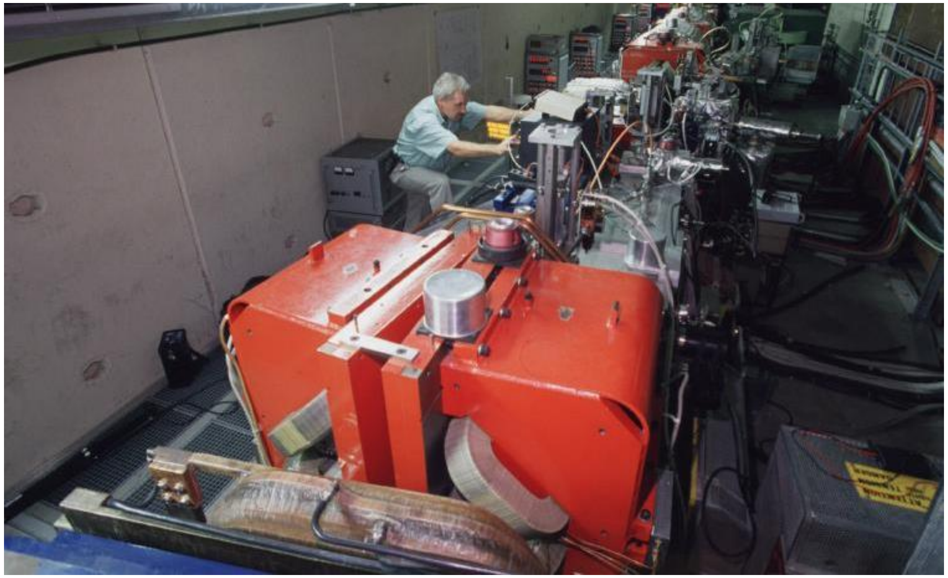
Introduction
Antiproton Decelerator AD

AD Construction and commissioning

- Around 1995:
  - No antiprotons needed for SPS since 1990
  - AC & AA running only for LEAR
  - Decision to discontinue p-bar physics with LEIR by the end of 1996 …
    … to free resources for LHC

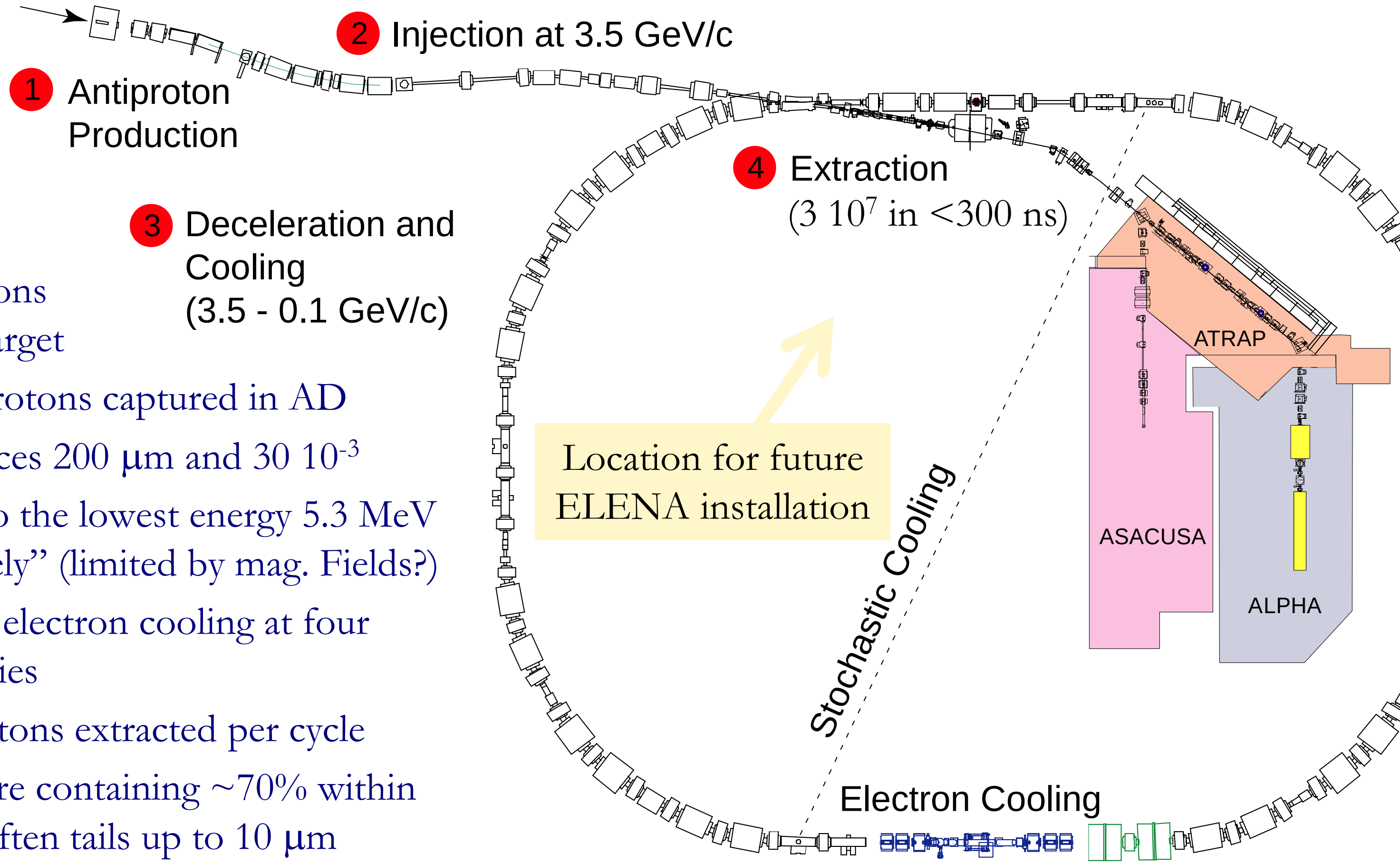
- Conversion of AC to AD proposed as simplified scheme for low energy p-bar physics
  - Only one p-bar machine
  - PS used only for p-bar production

- Start of AD Commissioning in Autumn 1998
- First physics run in summer 2000
- Successful program with an increasing number of experiments



Introduction
Antiproton Decelerator AD

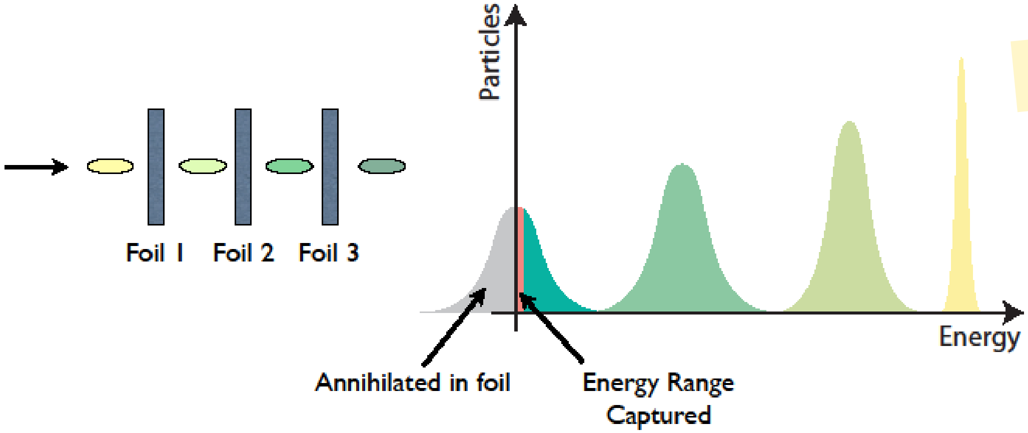
- ~1.5 10^{13} protons (26 GeV) on target
- ~3.5 10^7 antiprotons captured in AD
  - Acceptances 200 µm and 30 10^{-3}
- Deceleration to the lowest energy 5.3 MeV reachable "safely" (limited by mag. Fields?)
- Stochastic and electron cooling at four different energies
- ~3 10^7 antiprotons extracted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



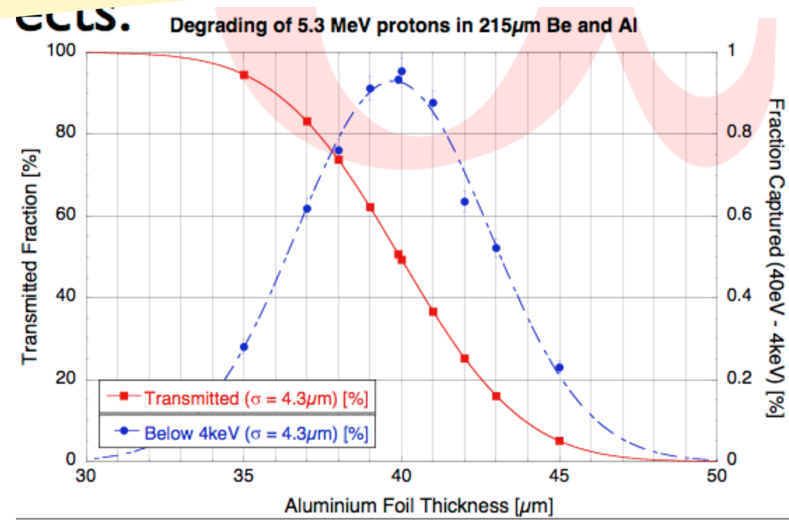
Sketch of the present AD – circumference 182 m
- In addition experiment AEGIS installed
- Experiment BASE being installed

Introduction

Motivation to add ELENA to the AD



BPPC Presentation by N.Madsen, from ALPHA

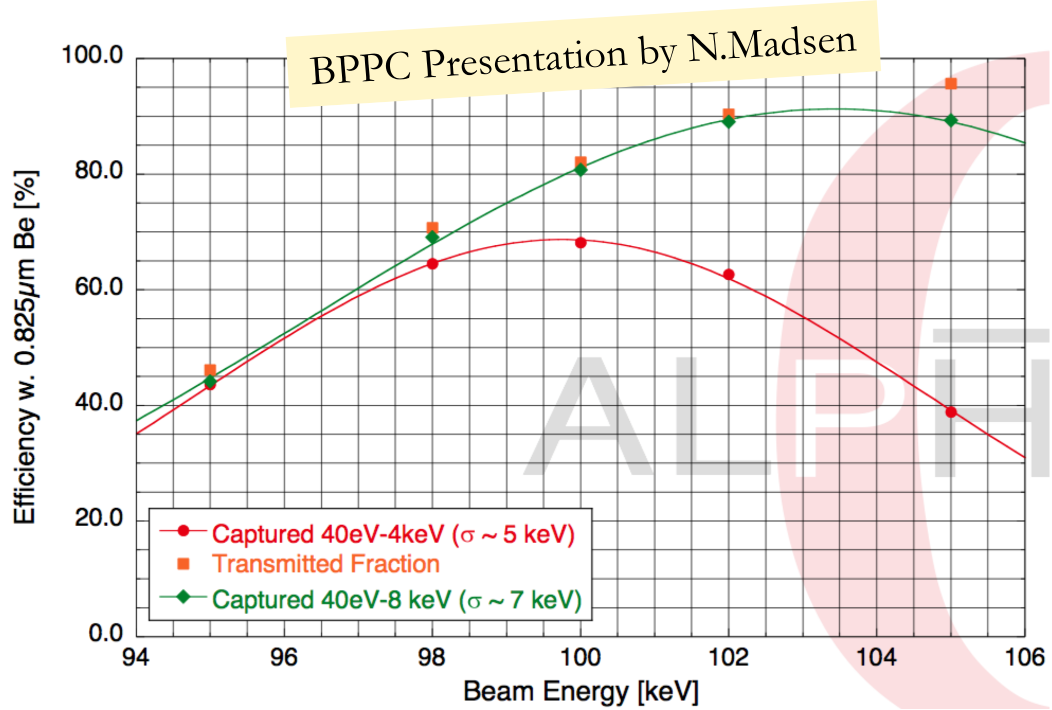


- Most experiments further slow down antiprotons coming from AD now at 5.3 MeV down by "foils" to a few keV and then capture them in traps
- Energy straggling increases energy spread such that only few antiprotons can be captured; even with optimized foil thickness
  - Almost half of the incoming pbars stopped in foil, where they annihilate
  - Almost half of the incoming pbars to energetic to be trapped
- (Note: there are AD experiments not using degraders as e.g. ASACUSA decelerating antiprotons with an RFQ – they achieve about one order of magnitude higher trapping efficiencies)
- Transverse: beam size on foil small enough for pbars to be cooled in trap

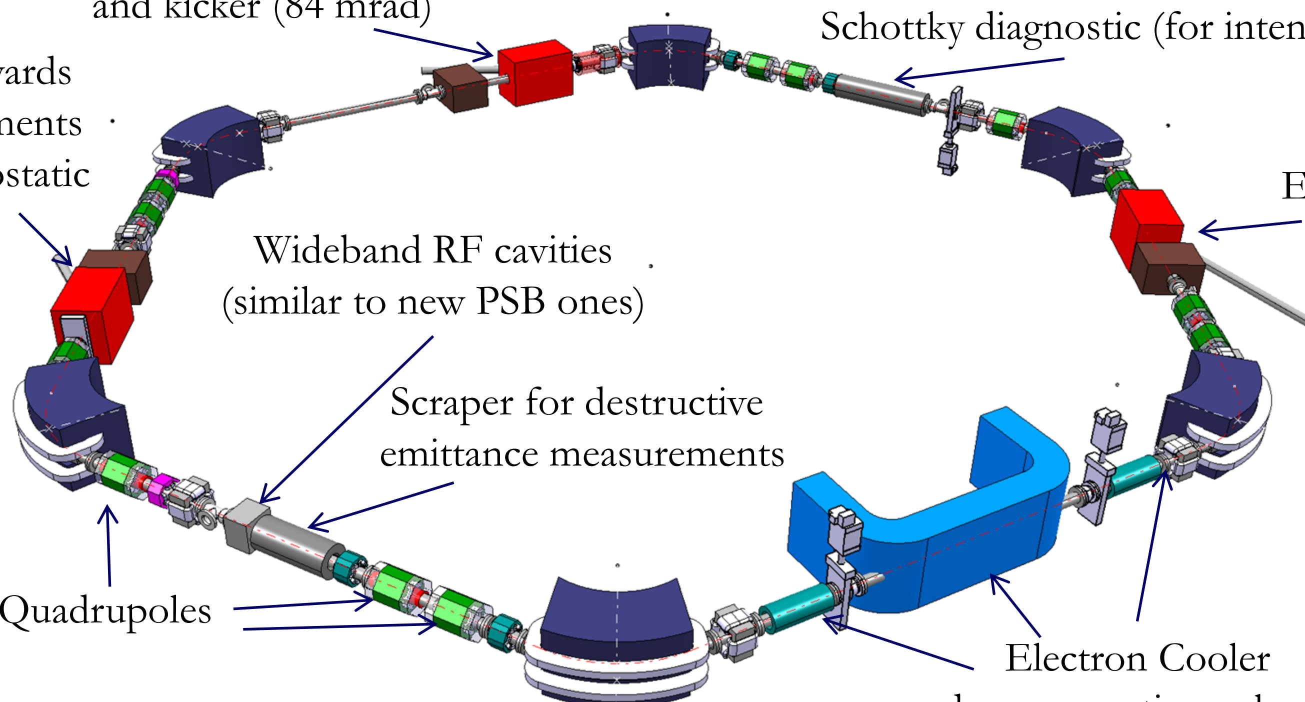
Introduction

Motivation to add ELENA to the AD

- ELENA with further decelerate antiprotons to 100 keV
  - Still foil to decelerate to a few keV, but reduced thickness
  - Reduced energy straggling and increase of capture efficiency by about two orders of magnitude (about one order of magnitude for ASACUSA using RFQ)
    - Energy spread of extracted beam up to a few % does not lead to significant reduction of capture
  - New types of experiments (gravitation of antihydrogen) become possible
- Electron cooling at intermediate and final energy to reduce emittances
- Available intensity per shot distribute in several (baseline: four) bunches for several experiments; longer running periods for experiments
- Other requirements from experiments
  - Beam size on foil small enough (rms size <1 mm)
  - Full bunch length less than 300 ns

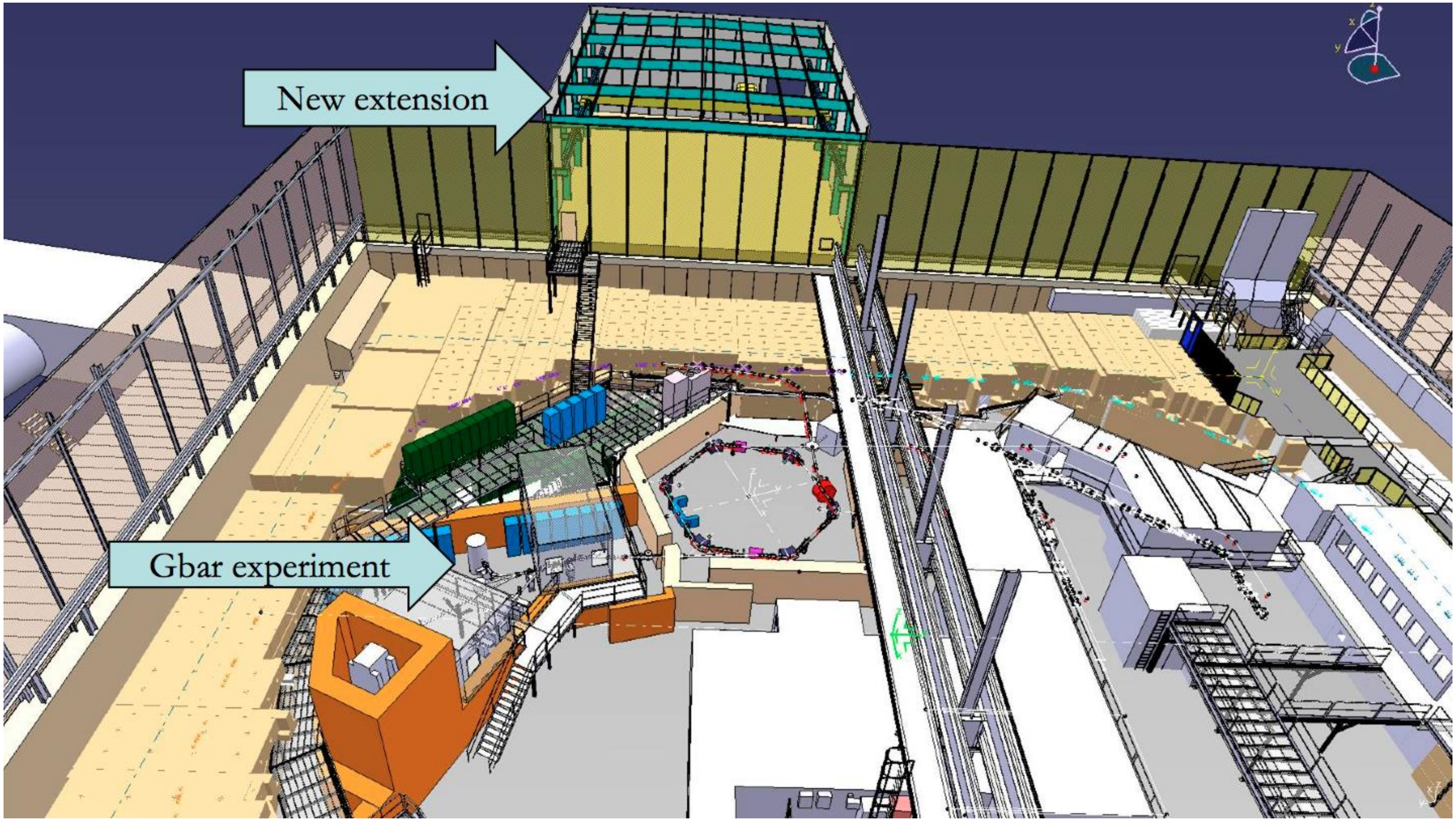


ELENA Overview - Layout



- Improve capture efficiency of experiments (traps) by (i) decelerating antiprotons coming from the AD at 5.3 MeV down to 100 keV and (ii) reducing emittances using an electron cooler
- Circumference 30.4 m or 1/6 the one of the AD (.. 4 times the size of the first proposal in 1982!)
  - Ample space to allocate space for all equipment required or foreseen
  - 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 – Layout



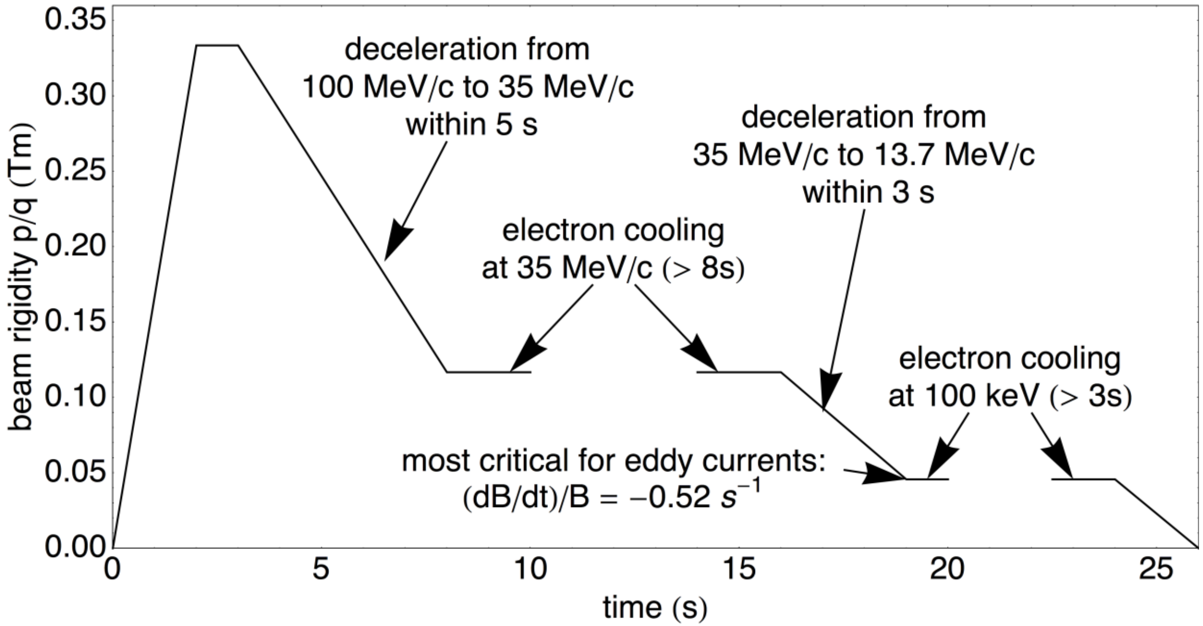
- ELENA Installation in AD hall:
  - Cost effective with short transfer line from AD and no relocation of existing experiments
  - New (small) building to house equipment now at location, where ELENA will be installed

ELENA Overview –
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)
  - Determines equilibrium emittances together with electron cooling (see presentations on performance limitations and electron cooling)
- 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 (see presentations on RF and Instrumentation)
- Electron cooling at very low energies
  - Stringent requirements on field quality and, in addition, low fields, anything
  - Bunched beam cooling to obtain acceptable momentum spread of short extracted bunches
- Magnets with very low fields (see dedicated presentation on magnets)
  - "Thinning" (mixing of stainless steel and magnetic laminations) for bending magnets
  - Significant 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 (see dedicated presentation on transfer lines)
  - Cost effective at very low energies, easier for shielding against magnetic stray fields
- RF system with modest voltages, but very large dynamic range (see dedicated presentation on RF)
- Commissioning with external H^- and proton source (and electrostatic acceleration to 100 keV) (see dedicated presentations on transfer lines and commissioning and operation)

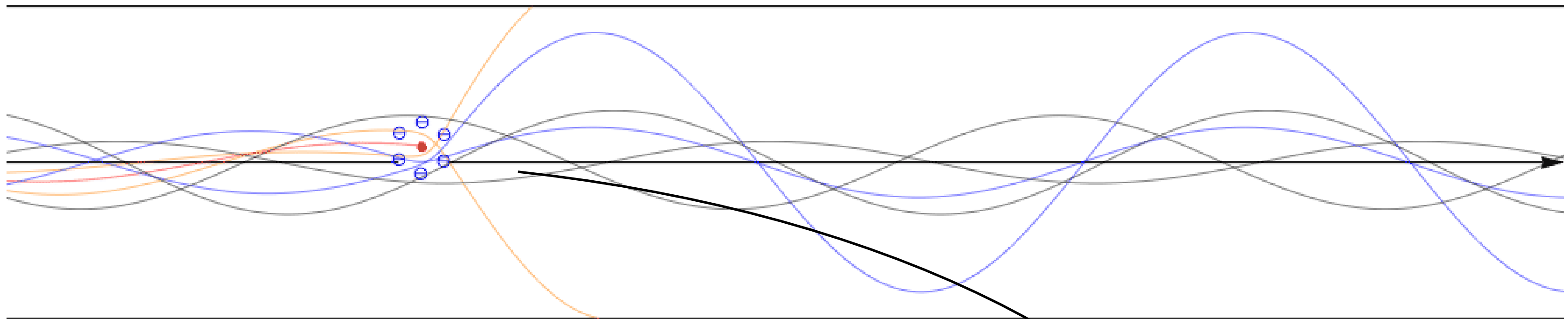
ELENA Overview – Magnetic Cycle

- Present Ideas on Magnetic Cycle of Ring
- Ramp up within one up to a few seconds (not critical)
- Total duration not critical if longer than ~100 s AD cycle

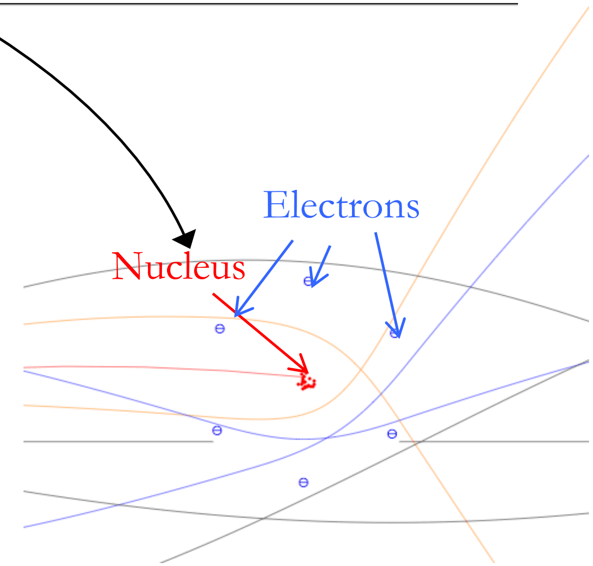


- Duration of ramps compromise between
  - Short enough to keep blow-up due to Intro Beam Scattering well acceptable
  - Long enough too avoid perturbations of optics due to Eddy currents in bending magnet chamber (net current along not isolated chamber in C-magnet created gradient)
- Length of cooling plateaus from simulations with BETACOOL (large "error bar" – longer cooling times than predicted seen for other machines)
- Significant remanence effects to be expected due to low fields for quadrupole, sextupoles…
  - Repeat always the same hysteresis cycles (good understanding of remanence from measurements)

Topics not covered elsewhere - Interactions with Rest Gas

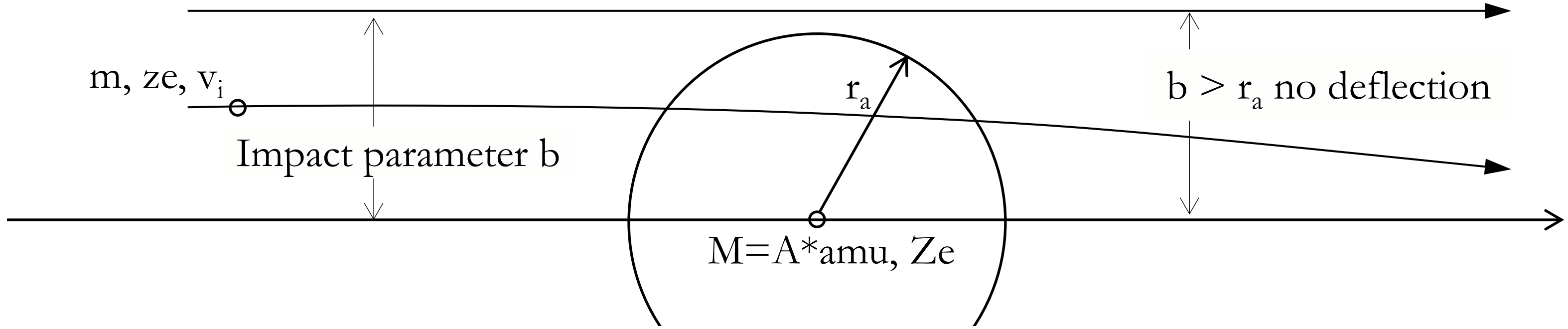


- Special situation with low pressure and velocity
  - Most p-bars do not interact with rest gas molecules (black) at all: in average ~40 s between interactions at 100 keV!
  - Nuclear interactions (red): very rare and negligible
  - Large angle scattering outside acceptance (orange): rather large cross section due to low energy (but few encounters)
  - Small angle scattering (blue):
    - several deflections of one p-bar at 100 keV very unlikely blow-up not a multiple scattering phenomenon
    - "Small" ratio between minimum and maximum impact parameter leading to blow-up
    - "Coulomb" logarithm and blow-up rates much smaller than using standard multiple scattering formulas



Trajectories out side atom
=> no deflection

Topics not covered elsewhere - Interactions with Rest Gas



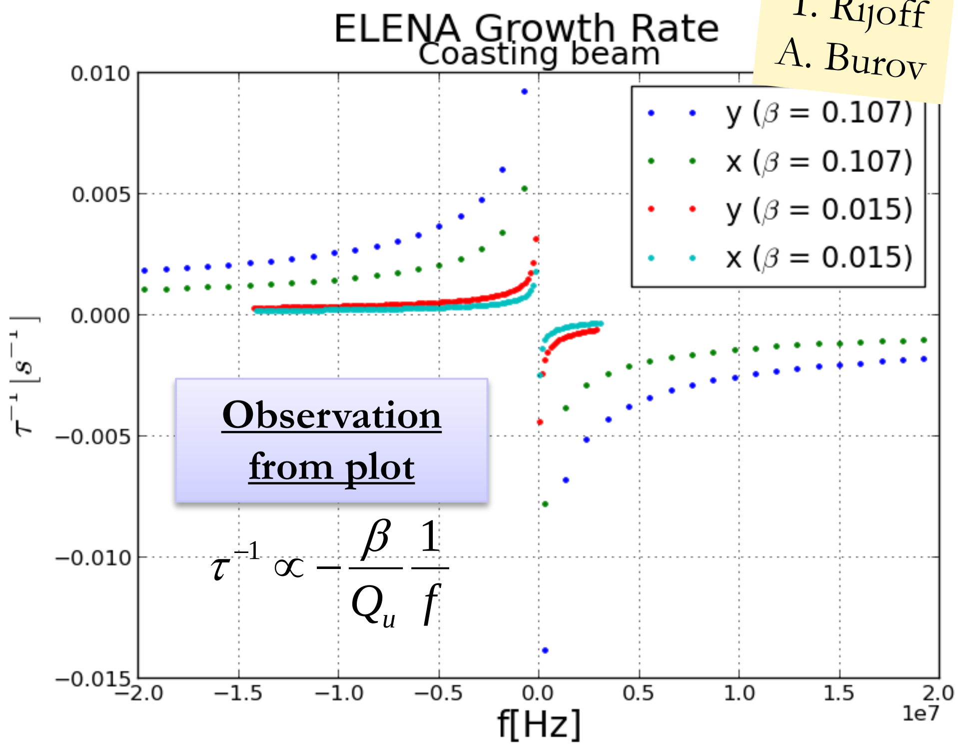
- Adaptation of similar study for AD
  - Separation of different cases for different impact parameters b
- Assume (pessimistically) N_2 with pressure 3 10^{-12} Torr at room temperature
  - Residual gas density n = 9.6 10^{10} m^{-3}, Z = 7, A = 14
- At ejection (0.1 MeV) energy
  - Total interaction rate: 2 $\sigma_{sc} n \beta_e c$ = 0.024 s = 1/41 s … most p-bars are not scattered at all!!
  - Impact parameter for loss and loss cross section
    - For β_T = 3 m and A_T = 50 μm: b_{loss}=2.5 10^{-11} m, σ_{loss} = 1.9 10^{-21} m^2, 2 n σ_{loss} $\beta_e c$ = 1/622 s
  - Blow-up (of transverse rms emittances) rates:
    - For β_T = 3 m and A_T = 50 μm: σ_{bu} = 9.6 10^{-20} m^2 (μm/s), 2 n σ_{bu} $\beta_e c$ = 0.081 μm/s

- With 3 10^{-12} Torr for ELENA ring: significant effects, but not the dominant limitation
- Significantly higher pressures > 10^{-8} Torr acceptable lines, except close to some experiments

Topics not covered elsewhere – Impedances and Instabilities

- Can collective instabilities be a limitation despite the low intensity due to the very low energy?
- First studies on resistive wall (coasting beam) instabilities
  - Growth times long enough not to be an issue
  - Even longer rise times for lower energies (is there a simple explanation?)
  - Comparison of different models to compute resistive wall impedance
- Status
  - Estimations of impedances of other equipment
  - At present position pick-ups optimized to maximize signal at head amplifier and, thus, potentials and fields in vacuum chambers
  - Kicker (injection) will follow soon
- Presently, no damper foreseen, but space could be made available

T. Rijoff
A. Burov



$$\tau^{-1} \propto -\frac{\beta}{Q_u}\frac{1}{f}$$

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[a)]		For Baseline with four bunches
Number of bunches	4	
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)	$\varepsilon_{H,r.s}$ (μm)	$\varepsilon_{V,r.s}$ (μm)
Injection[+,a)]	6.3	0.38	4	125	0.5	0.3
Start 1st ramp[+,b)]	6.3	0.65	7	72	0.5	0.3
End 1st ramp[c)]	6.1	1.8	2.4	200	1.8	1.1
Start plateau 35 MeV/c[d)]	9.1	0.8	1.05	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 0.1	0.50	.100	75	1.2	0.75

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

a) AD measurements about a year ago – smaller values obtained in 2012, in particular with bunched cooling

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

c) Simulations of IBS on ramp – Slides sent on 14th November

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) BPPC presentation by G.Tranquille

f) From BPPC presentation by P. Beloshitsky on 2nd August 2012 – case for four bunches and 2.4 10^7 pbars

Summary and Aim of this Review

- Aim of ELENA
  - Small synchrotron with electron cooler to further decelerate antiprotons from the AD from 5.3 MeV to 100 keV
  - Improved efficiency of experiments trapping antiprotons by 1 to 2 orders of magnitude and allow for new types of experiments (gravitation with antihydrogen)
  - Will provide beam to several experiments simultaneously (lower intensities)
  - First antiproton physics with ELENA planned in 2017 (2^{nd} half)
- Aim of this review
  - Present our ideas for the construction of ELENA to experts in the field and give them a good understanding of how the machine should look like
  - Emphasize areas and topics, which we believe to be critical
  - Get feedback from the review panel on our plans
    - Is the technical design sound and likely to meet the expected performance?
    - Are possible limitations and performance to be expected properly analyzed and adequately addressed?
    - Have any possibly overlooked issues or showstoppers been identified?


Thanks for your attention !