ELENA project at CERN

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Abstract

- During more than 10 years of regular operation, CERN’s Antiproton Decelerator (AD) has supplied the successful physics program with low-energy antiproton beams at 5.3 MeV kinetic energy. For the medium and long-term future, several options exist for upgrades and consolidation of the facility as well as for extension of the physics program. One of these, the recently approved ELENA ring, is a small post-decelerator to be installed in the existing AD building. ELENA will bring the antiproton energy down to around 100keV and with the help of the built-in electron cooler greatly increase beam density and intensity thereby increasing the number of trapped antiprotons by up to two orders of magnitude.

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- Introduction
- ELENA
- New experiments
- AD status/consolidation

Pbars at CERN - timeline

- **1980-1986** **AA**
  - 3.57 GeV/c Antiproton Accumulator ring;
  - 10^12 pbars stored (peak). p/pbar collisions in SPS
  - + low energy experiments in LEAR
- **1986-1996** **AAC (AA+AC)**
  - Large acceptance Antiproton Collector ring added. Production rate increased 10-fold to 6*10^10 pbars/h
- **1998-2015** **AD**
  - AC converted from fixed energy storage ring to Decelerator. 5*10^7 pbars slowed down to 100 MeV/c (5.3MeV kinetic). Local experimental areas.
  - Many experiments: ASACUSA, ATHENA, ALPHA, ATRAP, ACE, AEGIS

AD

Basic Parameters

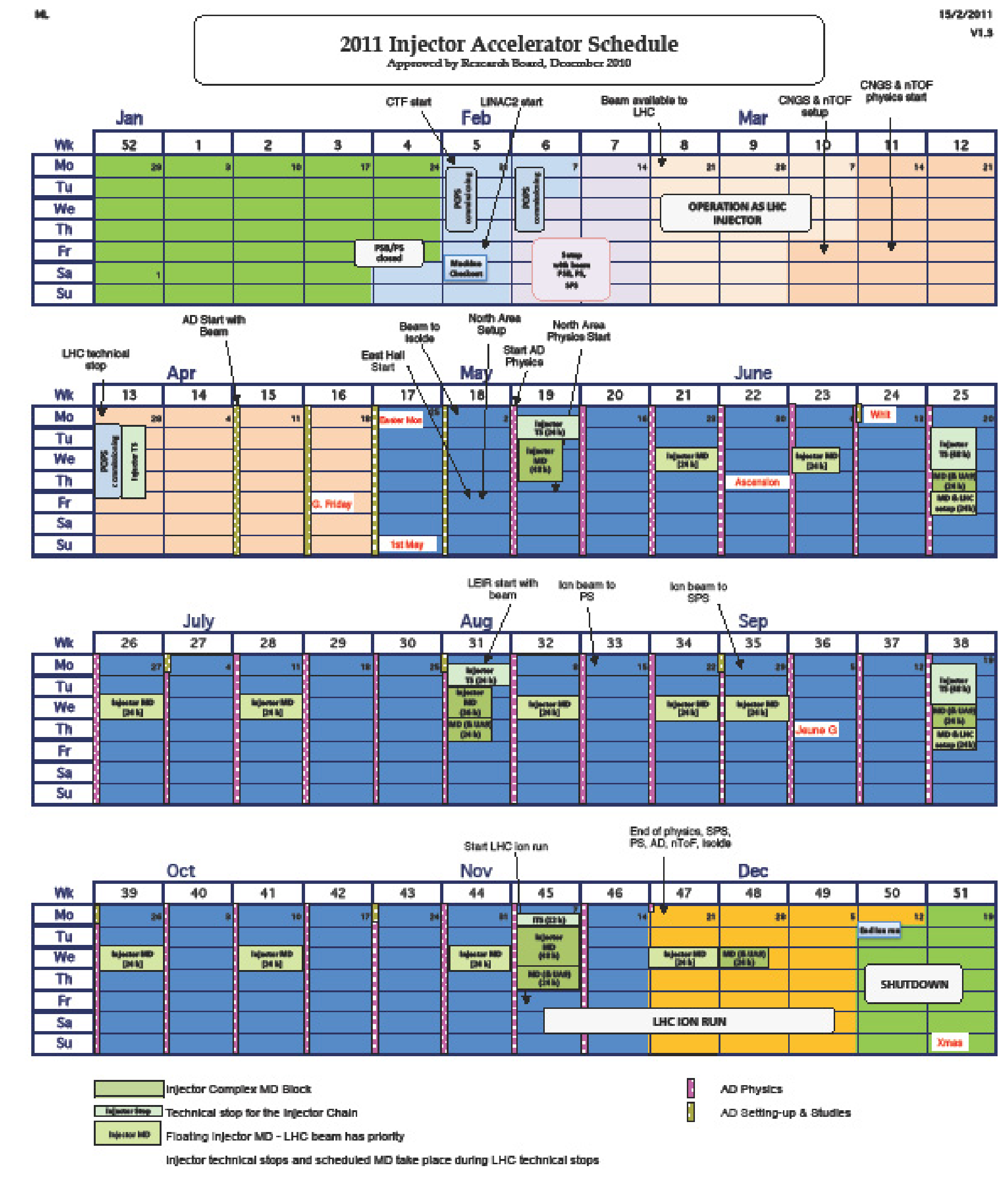
Parameter		Value	Unit
Circumference		182	m
Production beam		$1.5*10^{13}$	protons/cycle
Injected beam		$5*10^{7}$	pbars/cycle
Beam momenta max-min		3.57 – 0.1	GeV/c
Momenta for beam cooling			
– Stochastic		3.57 and 2.0	GeV/c
– Electron		0.3 and 0.1	GeV/c
Transverse emittances	h/v	200 – 1	π.mm.mrad
Momentum spread		$6*10^{-2}$ – $1*10^{-4}$	dp/p
Vacuum pressure, average		$4*10^{-10}$	Torr
Cycle length		100	s
Deceleration efficiency		85	%

AD Operation statistics

Run time (h)	2000	2001	2002	2003	2004	2006	2007	2008	2009	2010
Total	3600	3050	2800	2800	3400	2925	3800	3340	4600	4610
Physics	1550	2250	2100	2300	3090	2765	3760	3140	4460	4550
md	2050	800	700	500	310	160	40	200	140	60
Beam available for physics (%)	86	89	90	90	71	65	76	81	78	87
Uptime AD machine (%)					89	74	81	93	92	91

2011 AD run

- 28 weeks of physics
- ATRAP, ASACUSA, ALPHA: 8h periods
- ACE 1-2 weeks 24h/24
- AEgIS: 3weeks Oct/Nov
- 2012 run will be similar



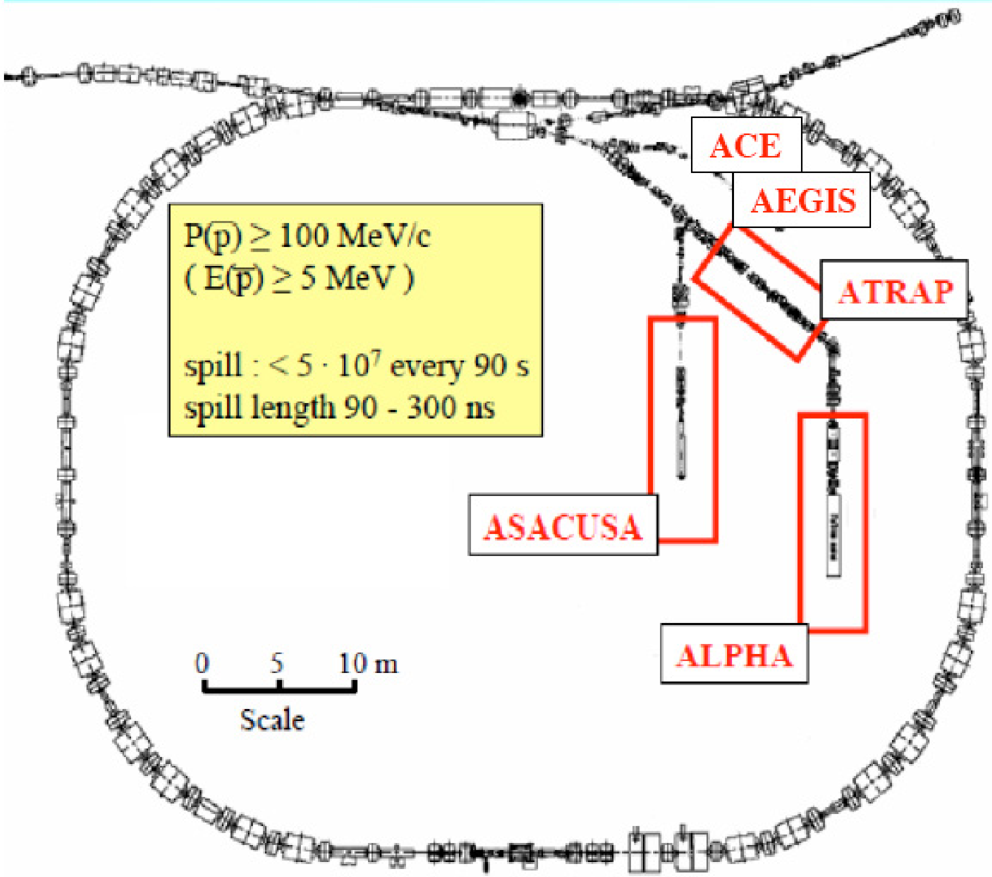
CERN/LHC run planning (provisional)

2013	LS1 - SPLICE CONSOLIDATION											
2014									RECOM	RECOM	1	2
2015	1	2	3	4	5	6	7	8	9	10	IONS	
2016		1	2	3	4	5	6	7	8	9	IONS	
2017		1	2	3	4	5	6	7	8	9	IONS	
2018	LS2											
2019		1	2	3	4	5	6	7	8	9	IONS	
2020		1	2	3	4	5	6	7	8	9	IONS	
2021		1	2	3	4	5	6	7	8	9	IONS	
2022	HL-LHC upgrade											

Tech. stop or shutdown
Proton physics
Ion Physics
Recommissioning

=> Affects LHC injectors and AD !

Antiproton Decelerator (AD) @ CERN



- **Started operation** July 6, **2000**

  Antiproton capture, deceleration, cooling
- **Pulsed extraction**
- **Many Experiments**
  - ASACUSA
  - ATRAP
  - ALPHA
  - AEGIS
  - Free Fall
  - PAX
  - ACE
  - .....
- **Request for more and better antiproton beams**
  - To speed up progress
  - To boost accuracy

$\Rightarrow$ **ELENA**

CERN COURIER

CERN COURIER

Aug 26, 2011

ELENA prepares a bright future for antimatter research

At its recent session in June, the CERN Council approved the construction of the Extra Low ENergy Antiproton ring (ELENA) - an upgrade of the existing Antiproton Decelerator (AD). ELENA will allow the further deceleration of antiprotons, resulting in an increased number of particles trapped downstream in the experiments. This will give an important boost to antimatter research in the years to come.

The recent successes of the AD experiments are just the latest in a long list of important scientific results with low-energy antiprotons at CERN that started in the 1990s with the Low Energy Antiproton Ring. Over the years, the scientific demand for antiprotons at the AD has continued to grow. There are now four experiments running there (ATRAP, ALPHA, ASACUSA and ACE). A fifth, AEGIS, has been approved and will take beam for the first time at the end of the year; further proposals are also under consideration. The AD is approaching the stage where it can no longer provide the number of antiprotons needed. As antihydrogen studies evolve into antihydrogen spectroscopy and gravitational measurements, the shortage will become even more acute.

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- **2016-2026+** **AD/ELENA**
  - Small post-decelerator ring to be added
  - Cooling and deceleration to 100 keV
  - Electrostatic beamlines and new experiments…

A SMALL DECELERATION RING FOR EXTRA LOW ENERGY ANTIPROTONS (ELENA)

H. Herr

CERN, Gene

Workshop on Physics
with Low Energy
protons
– 16, 1982

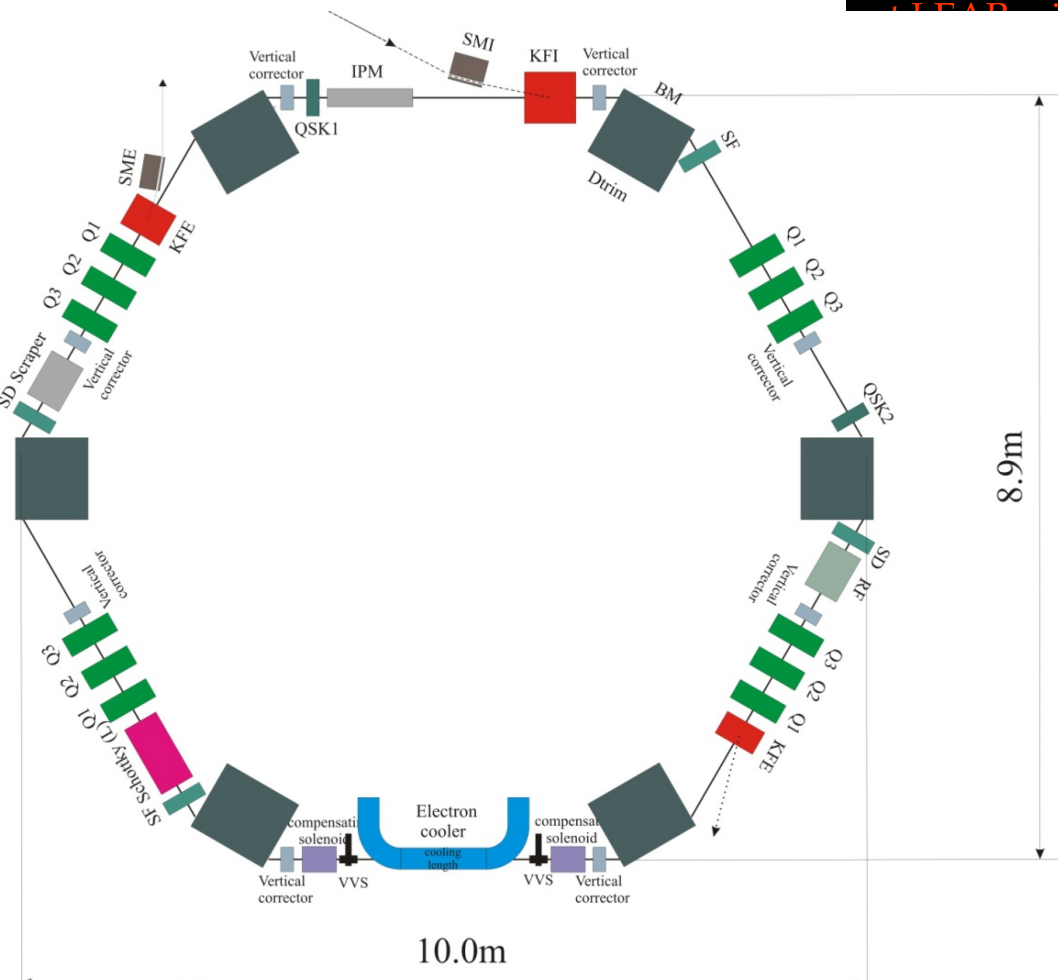
ABSTRACT

A small ring whi
from LEAR down to 20(
during deceleration i
dimensions are limite
number of decelerated
have at least the san
LEAR beam.

INTRODUCTION

Studying the req
mass difference betwe
cision of ∿ 10^{-9} by m
that, owing to the re
be achieved with part
few hundred keV. Thi
which will be of the
tion, such as degrade

However, owing t
deceleration and the
number of particles p
small for a reasonabl
overcome by a deceler
sate the increase of
and relatively inexpe
cooling[2,3] is presented; it can decelerate antiprotons coming



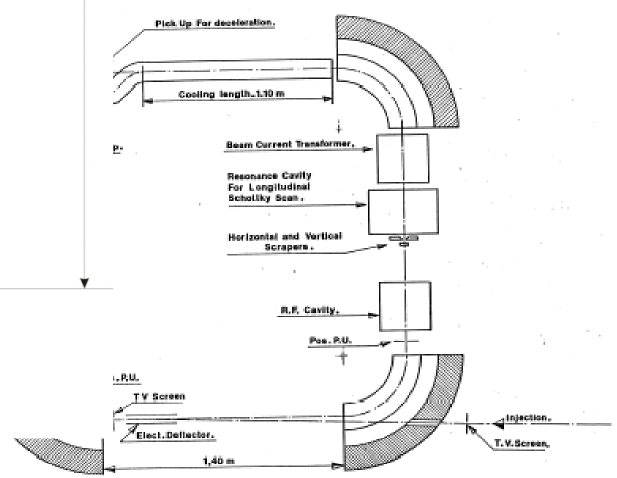


Fig.1

Motivation to build ELENA

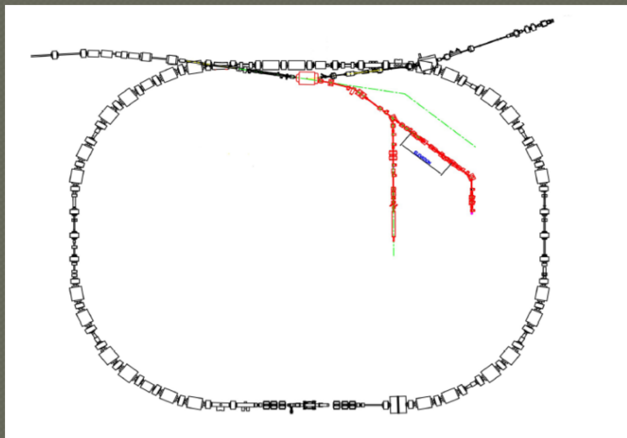
How antiprotons are decelerated further down today:

- Two experiments (ALPHA and ATRAP) use a set of degraders to slow 5.3 MeV beam from AD to ~ 4 keV:
  - poor efficiency due to adiabatic blow up,
  - to scattering in degraders and
  - to annililation
  - less than 0.5 % of AD beam used.

- ASACUSA uses RFQD 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. Difficult and time consuming tuning of transfer line from AD to RFQD.
  - About 70% beam is lost after passing through RFQD,
  - transverse beam size is very big (about 160mm), only short beam transport is possible after it (few meters)
  - about 3-5% is captured after passing through degrader.

Intensity gains with ELENA

- 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
- Additional gain for experiments: due to extraction in 4 bunches number of hours/day with available beam increase significantly



5.3 MeV antiprotons/ ~ 100 sec

~ 3 x 10^7

~4 keV antiprotons/ ~ 100 sec

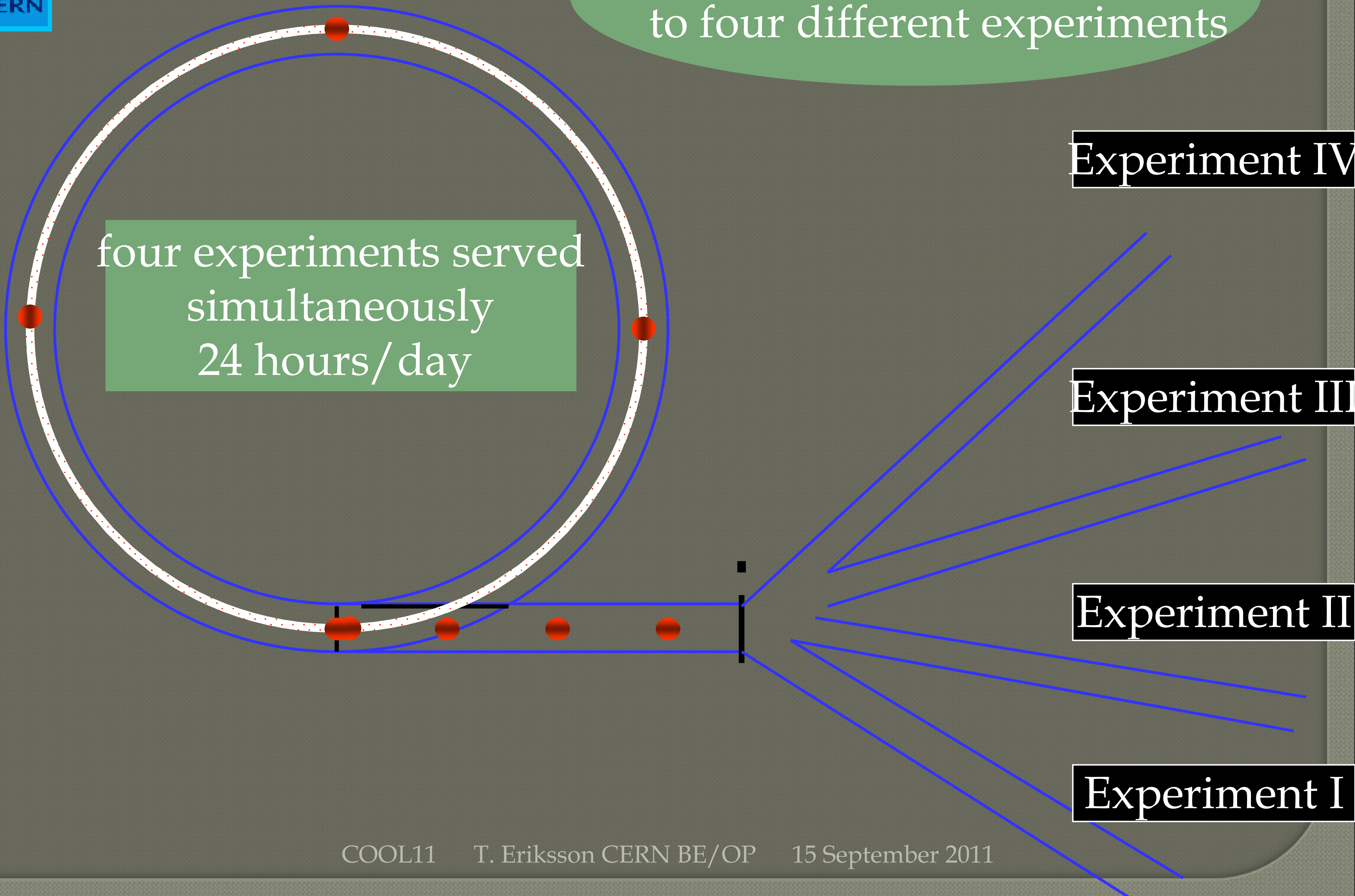
~ 1 x 10^5

ATRAP`s very best value: 1.3x10^5

2.99 x 10^7 antiprotons lost

→ efficiency 3 x 10^{-3}

$0.625 \times 10^7 \bar{p}$´s
to four different experiments



ELENA energy range

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

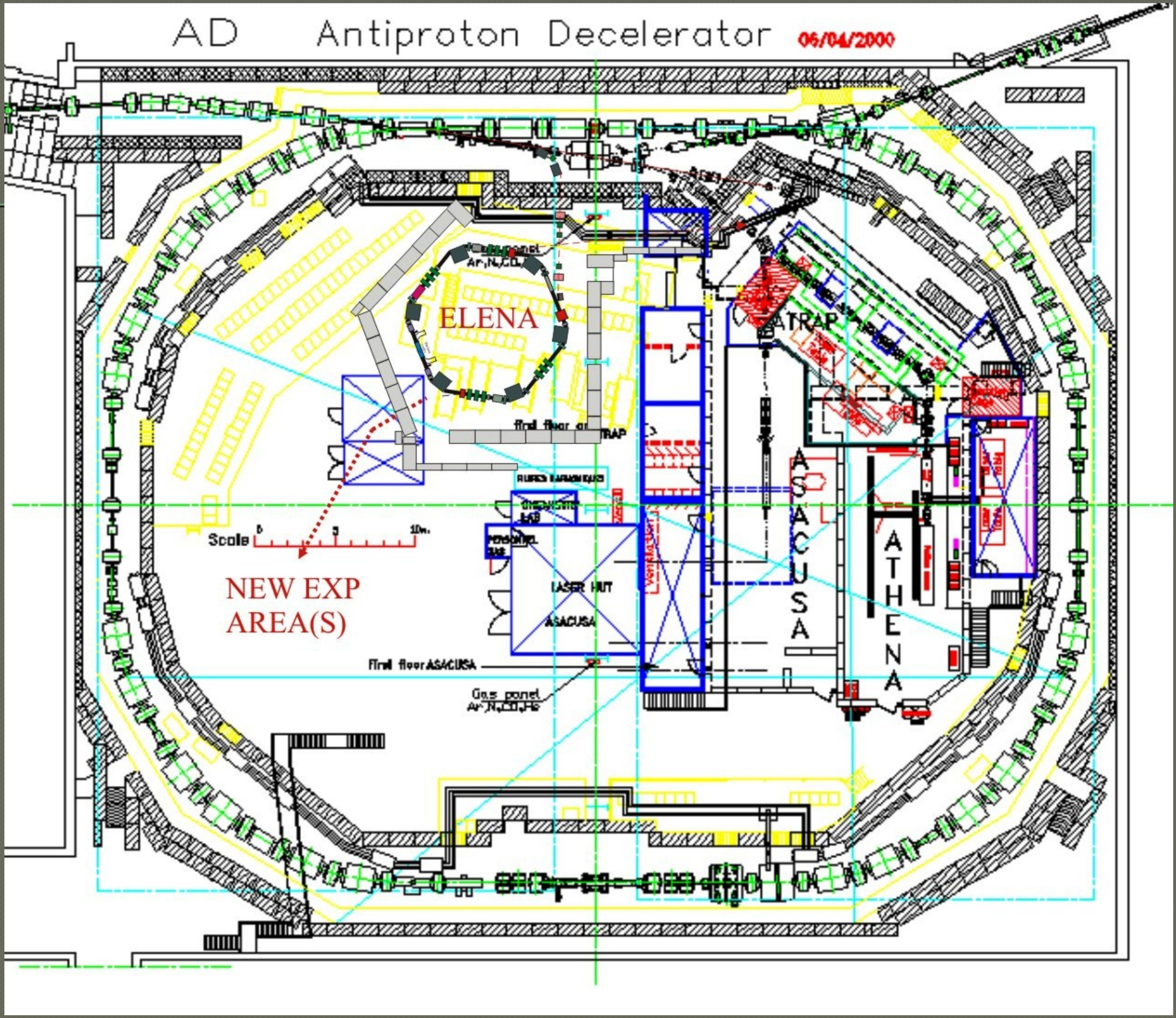
ELENA extraction energy 100 keV (13.7 MeV/c) defined by:

- space charge limit for pbar beam
- good quality of electron beam for cooling (limited by space charge of electron beam)
- beam lifetime: residual gas, IBS at extraction energy(relaxed with extraction in 4 bunches)
- strong requirements to high vacuum in machine $3 \cdot 10^{-12}$ Torr
- foil thickness for separation of transfer line and trap vacuum

ELENA configuration and placement

- Must be compact to fit in available space inside of AD Hall
- Circumference 1/n (integer) of AD ring (bucket to bucket beam transfer to avoid longitudinal blow up of the beam)
- Placed in AD Hall in an optimal way for injection from AD and extraction to existing experimental areas
- Placed in AD Hall in an optimal way to minimize reshuffle expenses of existing equipment in the area
- The first section of existing AD ejection line should be used => strong constraints on position and orientation of ELENA ring
- One long straight section for electron cooler needed
- Optional ejection line for the new experimental area should be foreseen (but no slow extraction)

ELENA layout in AD Hall



ELENA ring design

- Circumference:
  - Must be as small as possible due to limited space in AD Hall
  - Should be 1/n (integer) of AD ring (bucket to bucket beam transfer to avoid longitudinal blow up of the beam at injection plateau)

  Evolution in time:
  - 22.8m, 4-fold ring in 2004 (presented to SPSC in Villars)
  - 26.1m , 4-fold ring in 2007 (ELENA cost study…)
  - 30.4m, 6-fold ring since 2010
- 6-fold ring configuration:

Initial ring circumference was 26.2m (1/7 of AD ring) -> not enough space to place all required equipment, not possible to prepare extra experimental area (SPSC request) -> new circumference is 30.4 (1/6 of AD ring)

Advantages of the new rings:

- More flexibility for injection and extraction with the new layout
- The total length of bending magnets is shorter for hexagonal lattice compared with rectangular lattice -> more space for other equipment
- Minimal magnetic field in bending magnets (at 100 keV) increased form 399 Gs to 493 Gs
- Optics for 4 fold ring of 30 m long has unfavorable tunes (too much focusing in magnets), wide choice of tunes in 6 fold ring
- Smaller beta function values -> smaller aperture required by beam, relaxed requirement for vacuum

Space charge limit in ELENA

The extracted bunch parameters are limited by tune shift due to space charge forces

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

For bunch length l_b=1.3 (300ns) , beam emittance ε_x=4π mm mrad, ring circumference C=30.4m and Gaussian distribution (F=2) the bunch intensity is N=0.75·10^7.

With 83% of deceleration efficiency based on AD experience and accepted for ELENA and 3·10^7 ejected antiprotons from AD 2.5·10^7 antipronons decelerated in ELENA down to 100 keV. To avoid space charge problems, the beam will be bunched at harmonic h=4 before extraction. Fast electrostatic switching magnets will be used to define destination of the beam to one of the experiments (ATRAP, ALPHA , ASACUSA, AEGIS, etc.)

Beam lifetime and vacuum requirements

The main limiting factor is multiple Coulomb scattering -> beam emittance blow up

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

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 $\Delta\varepsilon$=0.6 π mm mrad/s.

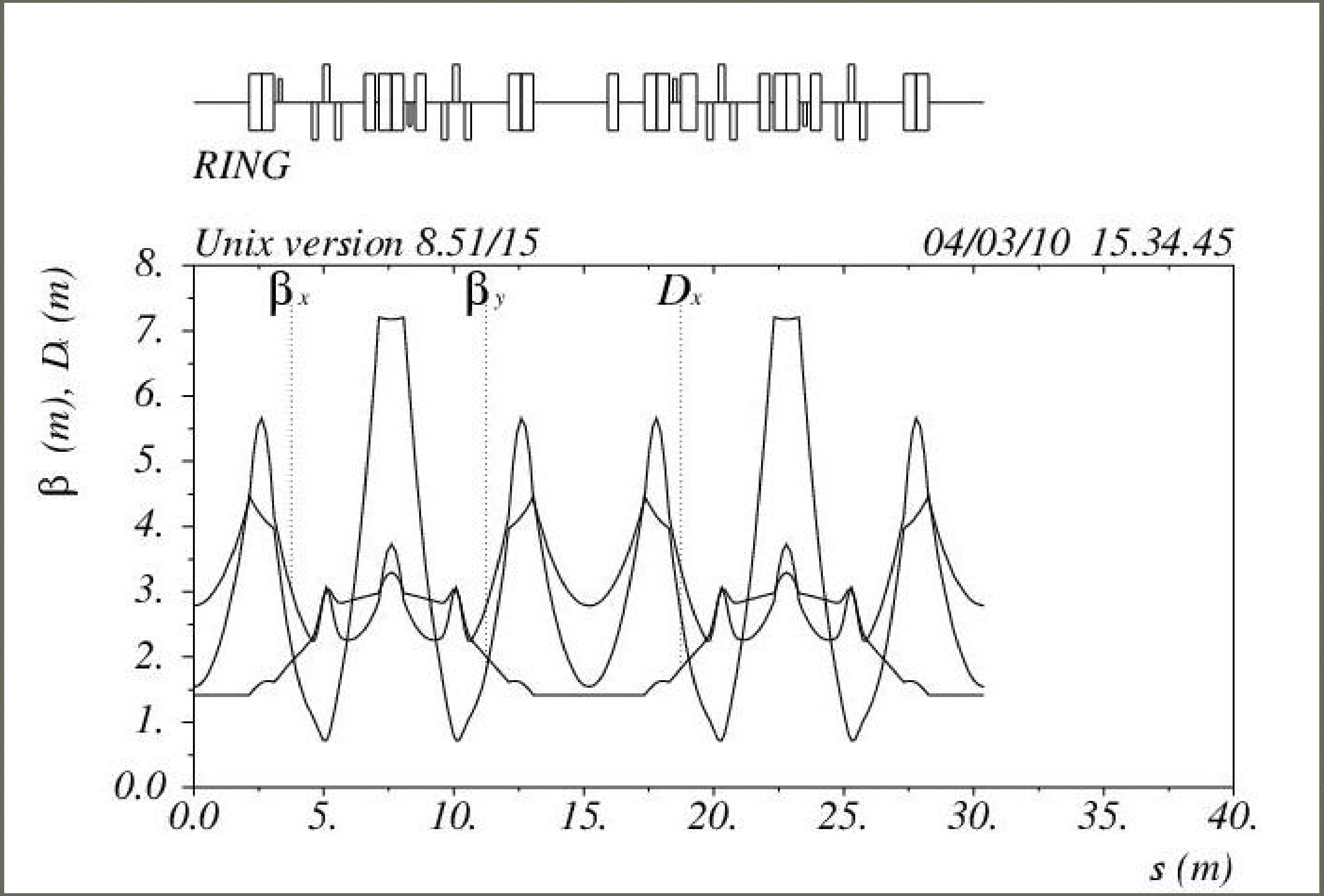
The required cooling rate for emittance equilibrium is

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

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	2.5×10^{7}
Number of extracted bunches	4
Emittances (h/v) at 100 KeV, $\pi \cdot$mm$\cdot$mrad, [95%]	4 / 4
$\Delta p/p$ after cooling, [95%]	10^{-4}
Bunch length at 100 keV, m / ns	1.3 / 300
Required (dynamic) vacuum, Torr	3×10^{-12}

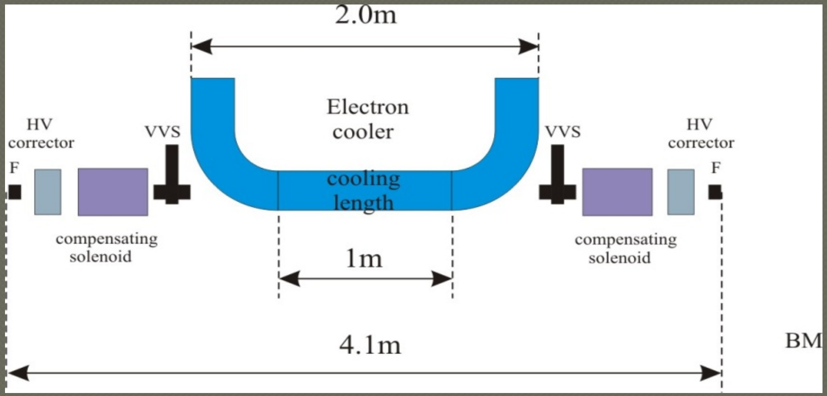
ELENA ring optics

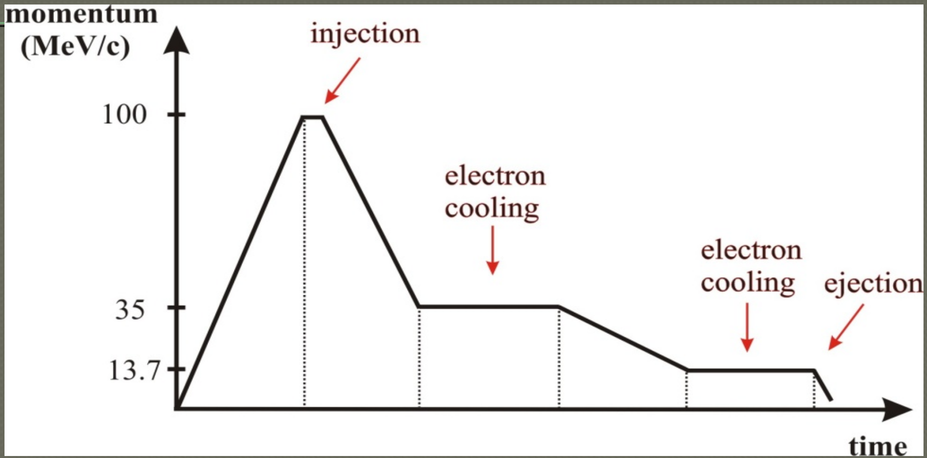


ELENA electron cooler

- The cooler will be installed in one of the long straight sections of the machine and will take up almost half the available space. The rest of the section will accommodate the orbit correctors and the compensation solenoids of the cooler.
- Cooling will be needed at two momenta during the ELENA deceleration cycle. At the intermediate momentum of 35 MeV/c the antiproton beam will need to be cooled in order to guarantee that it can be decelerated further to 13.7 MeV/c without any excessive blowup and losses. At the lower momentum the cooling will ensure that the phase-space characteristics of the extracted antiproton beam fit the requirements of the experiments.
- Special attention must be paid to the design of the electron gun and the quality of the longitudinal magnetic field guiding the electrons form the gun to the collector.
- The complete magnetic guiding system will consist of a series of small solenoid "pancakes" which can be individually adjusted. => small transverse components ($B_\perp/B_\parallel < 10^{-4}$)

The ELENA Electron Cooler





- Compact cooler for cooling at 35 MeV/c and 13.7 MeV/c
- Corresponding electron beam energies of 355 eV and 55 eV
- Conventional thermionic cathode ($n_e \approx 3x10^{12}$ cm^{-3})
- Effective cooling length ~ 0.8m
- 100 G magnetic field in toroids and main solenoid to reduce perturbations to the ring
- Placed flat for ease of maintenance (vertical orbit distortion)
- Challenges :
  - Generation of a cold low energy electron beam ($T_\perp < 0.1$ eV, $T_\parallel < 1$meV)
  - Electron beam energy stability
  - Reliable electron cooling diagnostics
  - Dynamic vacuum 10^{-12} torr

The ELENA Electron Cooler

Momentum (MeV/c)	35	13.7
b	0.037	0.015
Electron energy (eV)	355	55
Electron current (mA)	15	2
Expected cooling time (mS)	150	20
Bgun (G)	400	
Bcooling section (G)	100	
Cathode radius (mm)	12.7	
Electron beam radius (mm)	25.4	

Beam diagnostics

- 8 combined HV BPMs for orbit measurements. Performance similar to AD expected (reliable orbit measurement with $5 \div 10 \cdot 10^6$ antiprotons)
- Longitudinal Schottky PU for intensity measurement and cooling control
- IPM (for commissioning and MDs)
- Scrapers for beam profile/emittance measurements
- Transverse BTF DSP system+dedicated kicker for tune measurements

2010 ELENA cost estimate

- Several institutes are interested to contribute to the ELENA project (up to 50% of costs) with manpower and/or money
- CERN meeting 28-29 September 2011:
  - Press release
  - Initiate collaboration with external institutes.

Item	Material (kCHF)	Manpower FSU or charged (kCHF)	CERN Manpower FTE (MY)	Needed manpower contribution FTE (MY)
Magnets (ring+inj. line)	1590(*)	135	2.5	2.8
Power converters	955		3.8	
Injection/ejection septa	75		0.3	0.7
Injection/ejection kickers	1706		6.3	2.8
Electron cooler	1300		5.0	1.0
Vacuum, ring+inj.line	1475	50	3.0	2.0
RF + Schottky diagnostics	303	30	3.8	0.4
B-trains	80		0.7	
Diagnostics	655	85	1.2	1.3
Controls	804		1.0	
H- source	400		0.5	
Experimental area:lines, vacuum, monitors	4235		6.3	6.5
Mech. Design/Drawings		347kCHF/4 MY (**)		13.0
Div.	290		5.0	2.0
Total (MCHF/MY)	13.868	.647	39.4	32.5
Grand Total (MCHF/MY)	14.515		71.9	

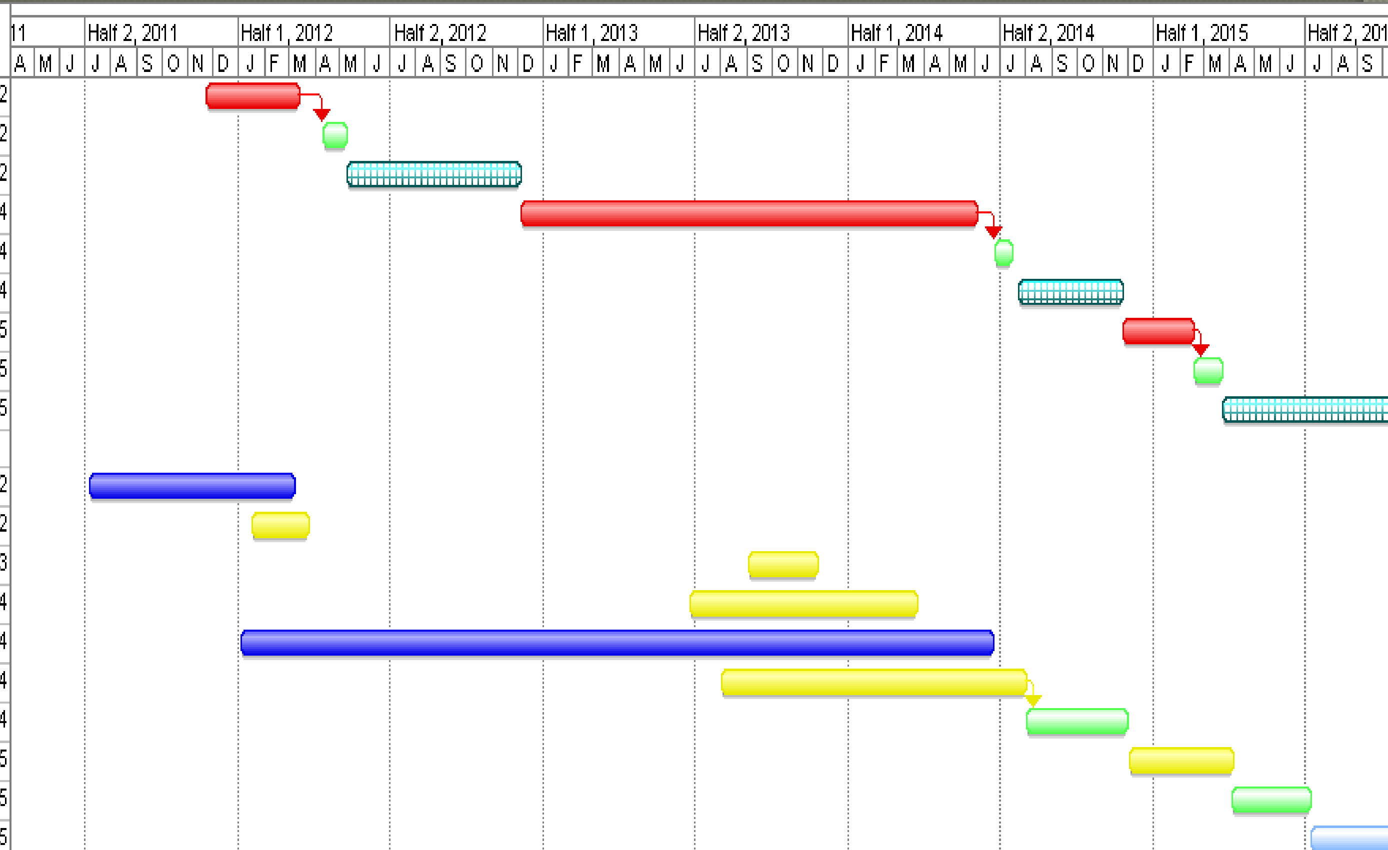
Planning

- Planning stretched in order to minimize impact on physics program
  1. Design, fabrication, installation of ELENA whilst using the existing ejection lines for physics @ 5.3 MeV => ~ 3 years
  2. Commissioning of ELENA in parallel with physics => ~ 6 months
  3. Installation and commissioning of new 100 keV ejection lines (physics stopped) => 0.5 to 1 year

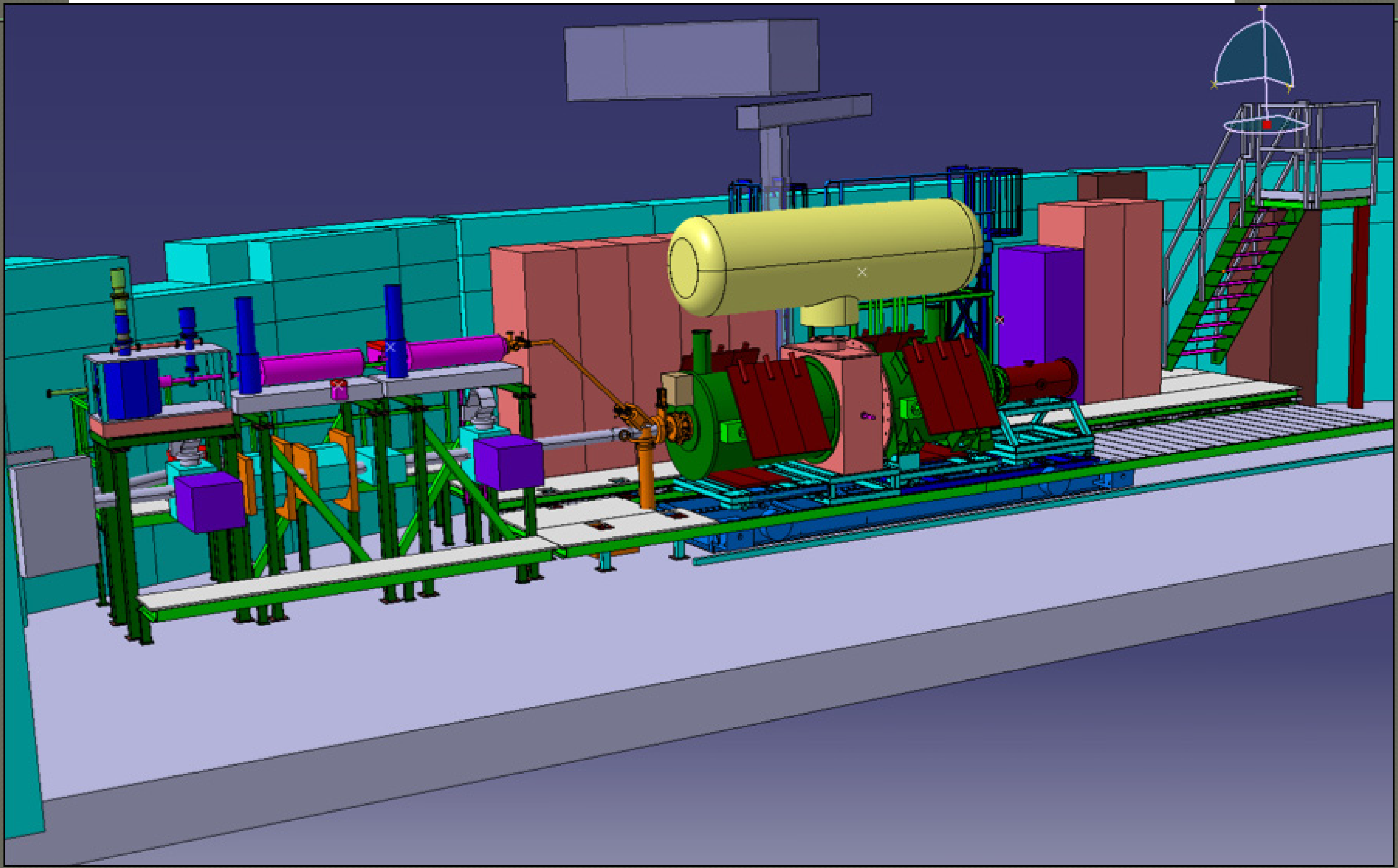
=>Total duration 4 to 4.5 yrs

ELENA planning

Task Name	Duration	Start	Finish
2011-2012 shutdown	80 days?	Mon 21/11/11	Sun 11/03/12
Setup for physics	20 days	Mon 09/04/12	Sun 06/05/12
AD physics run 2012	150 days	Mon 07/05/12	Sun 02/12/12
1st long shutdown	390 days?	Mon 03/12/12	Sun 01/06/14
Setup for physics	15 days	Mon 23/06/14	Sun 13/07/14
AD physics run 2014	90 days	Tue 22/07/14	Sun 23/11/14
2014-2015 shutdown	60 days?	Mon 24/11/14	Sun 15/02/15
Machine startup	25 days	Mon 16/02/15	Sun 22/03/15
AD run 2015	180 days	Mon 23/03/15	Sun 29/11/15
ELENA TDR	176 days?	Mon 04/07/11	Mon 05/03/12
Move kicker platform	50 days	Mon 16/01/12	Fri 23/03/12
Modification of 7000 line	60 days	Mon 02/09/13	Fri 22/11/13
Modification of AD hall	195 days	Mon 24/06/13	Fri 21/03/14
Design & procurement of ELENA par	645 days	Mon 02/01/12	Fri 20/06/14
ELENA installation	261 days	Thu 01/08/13	Thu 31/07/14
ELENA commissioning	87 days	Fri 01/08/14	Fri 28/11/14
Install electrostatic beamlines	90 days	Mon 01/12/14	Fri 03/04/15
ELENA & beamline commissioning	67 days	Fri 03/04/15	Mon 06/07/15
ELENA physics run 2015	104 days	Tue 07/07/15	Sun 29/11/15

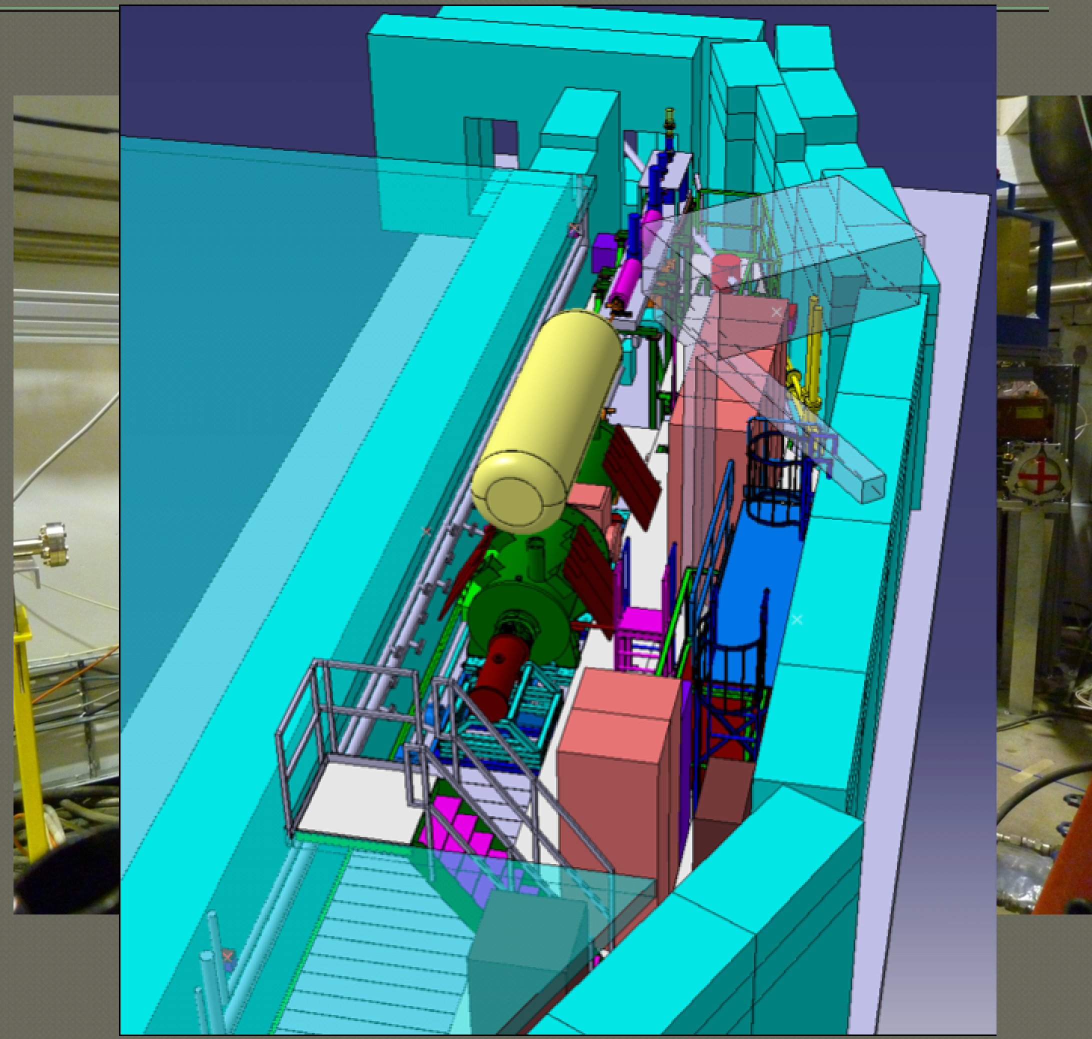


New experiments: AEGIS



AEGIS – present status

- Infrastructure modifications finished
- Access system operational
- Pbar beamline from AD installed
- Beamline tests + optics checks with 100MeV/c pbars finished => beam focused on last monitor
- Experimental installations in progress



AEGIS planning

- 2011:
  - June - September: installation of positron accumulator, 5 T magnet, transfer section and traps
  - October: cryogenics installation/commissioning
  - November: commissioning of trapping of antiprotons with 5.3 MeV AD beam
- 2012:
  - January/February/March: installation of the 1T magnet + lasers
  - April/May: commissioning
  - June-November: commissioning of the different physics processes

2013: work with protons

2014-2016: work with antiprotons, antihydrogen, antihydrogen beam

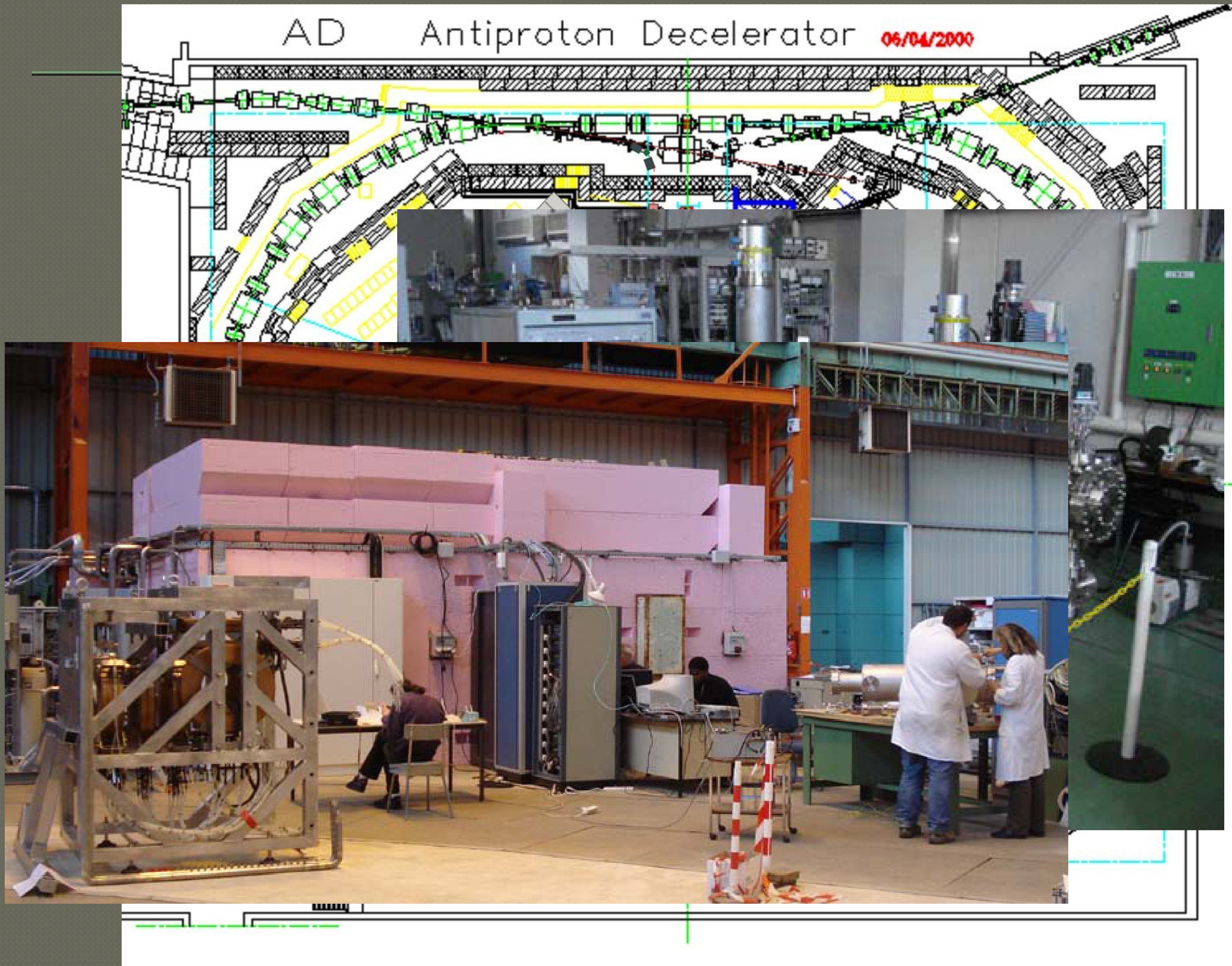
2016: 100 keV beam from ELENA

New experiments: Gbar

Gravitational Behaviour of Antihydrogen at Rest

- Saclay project – continuation of SOPHI R&D (Irfu)
- Similar goals as AEgIS
- Proposal being prepared
- Trap tested at Riken
- High intensity Positron source (need space in AD hall)
- To be installed in the new part of the AD experimental area => re-location of AD kicker platform considered

Gbar



New experiments: recycler

- New ASACUSA experiment proposal (SPSC in 2011?)
- Internal gas-jet target
- Explore atomic cross-sections
- Requires circulating beam at 40keV
- Need only a few thousand turns
- Initially planned as new e-static ring in ASACUSA zone
- Could it be done in ELENA by deceleration down to 40keV ?
  - Deceleration with e-cooler => avoid beam blow-up
  - Main B field 500 => 300 G;   stability?
  - No vacuum improvement needed
- Alternatively: installation of new ring in the new experimental zone

AD status/consolidation: Long-term AD future

- PS2/SPL conceptual designs completed =>
  will be kept "in the cupboard" for the future
- Instead, existing injectors will be refurbished
  - Linac4 under construction; (connection to PSB earliest in 2014.)
  - Studies for PSB renovation or replacement by new RCS =>PSB to be kept
  - PS: only the main magnet yokes + 50% of coils left from 1950:s

AD operation beyond 2016:

- Production beam for AD will be available as it is today
- ELENA now has project status

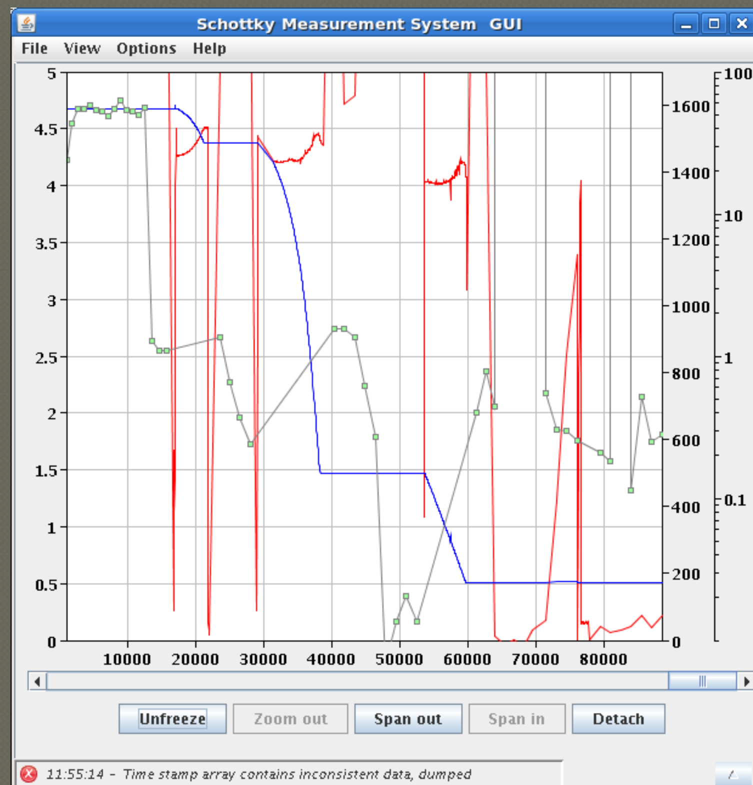
➔ AD consolidation for 10+ more years of operation

AD status: machine consolidation

- A limited consolidation program was launched in 2009 in view of continued AD operation until 2016/17
- Out of some 40 items needing attention, 1/3 was prioritized with a total budget of 2.3 MCHF
  - E-cooler power supplies, HV equipment and controls interface - done
  - Ring/transfer line magnets – in progress
  - Ring/transfer line power converters – in progress
  - Vacuum system – in progress
  - RF (C02/C10) – in progress
  - Stochastic cooling – to be started
  - Kickers – to be started
  - Target area – to be started
- With the ELENA approval a new consolidation program is being worked out assuming AD /ELENA will run at least 10 - 15 more years

AD status:deceleration

- Good intensity
- Deceleration efficiency >90%
- Bunch length at extraction 160 – 220 ns



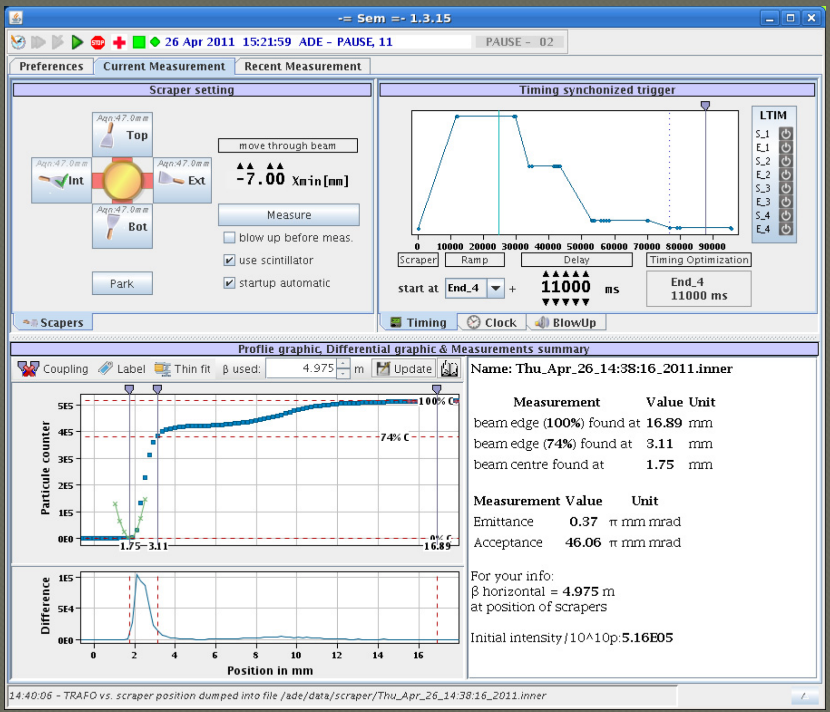
Intensity and dp/p values

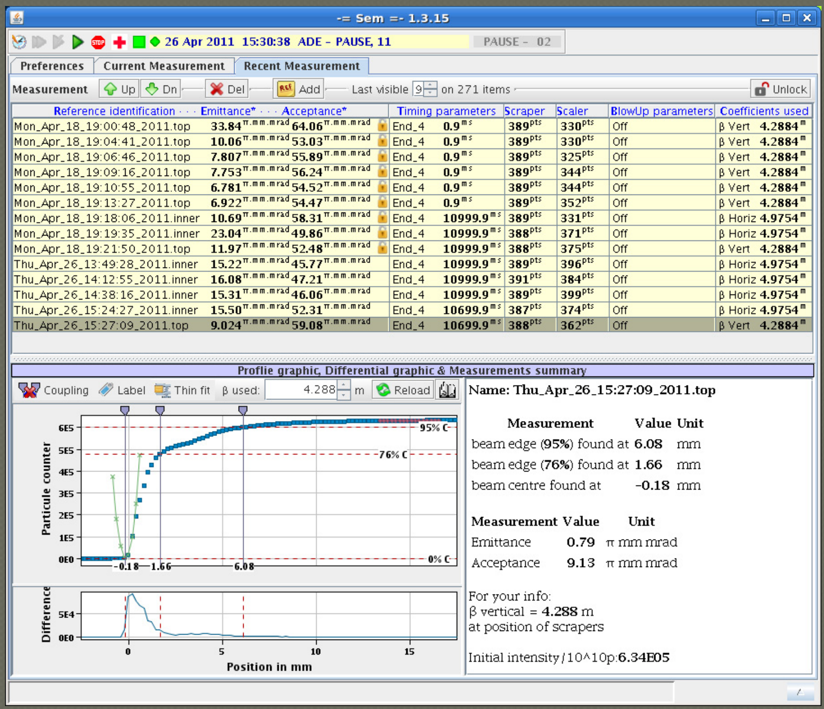
Np (3.5 GeV/c)	4.28 e7	100 %
Np (2 GeV/c)	4.2 e7	98 %
Np (300 MeV/c)	4.02 e7	93 %
Np (100 MeV/c ramp)	4.08 e7	95 %
Np (100 MeV/c end)	3.94 e7	92 %
DE.TFA7049	3.64 e7	85 %

dp/p (3.5 GeV/c)	23.943	1.098
dp/p (2GeV/c)	1.363	0.242
dp/p (300MeV/c)	1.554	0.014
dp/p (100 MeV/c)	0.399	0

AD status: Beam profiles at 100MeV/c

- ~70% of beam within 1 pi.mm.mrad
- Tail or halo formation, reasons not well understood





AD status/consolidation: stochastic cooling

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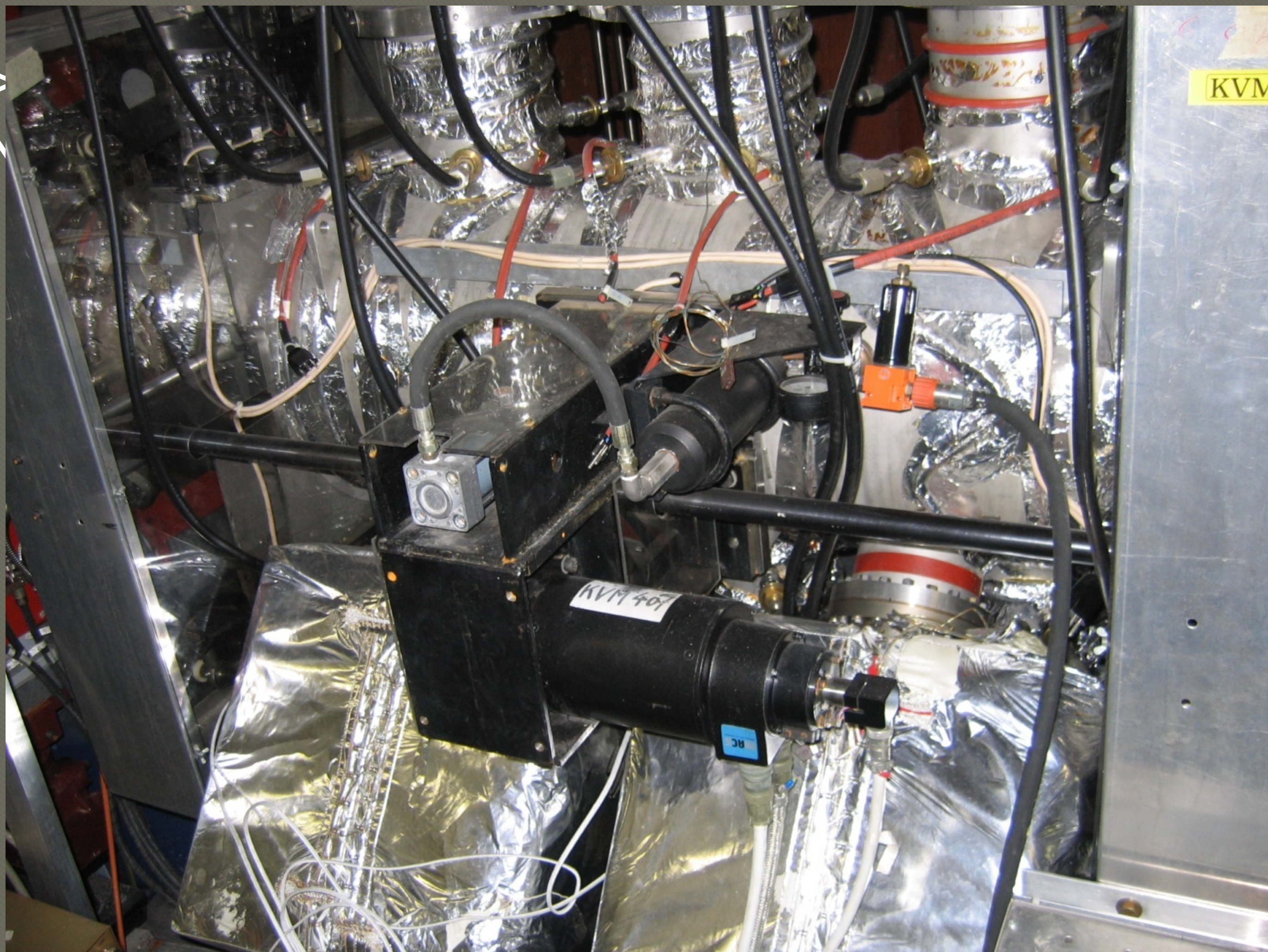
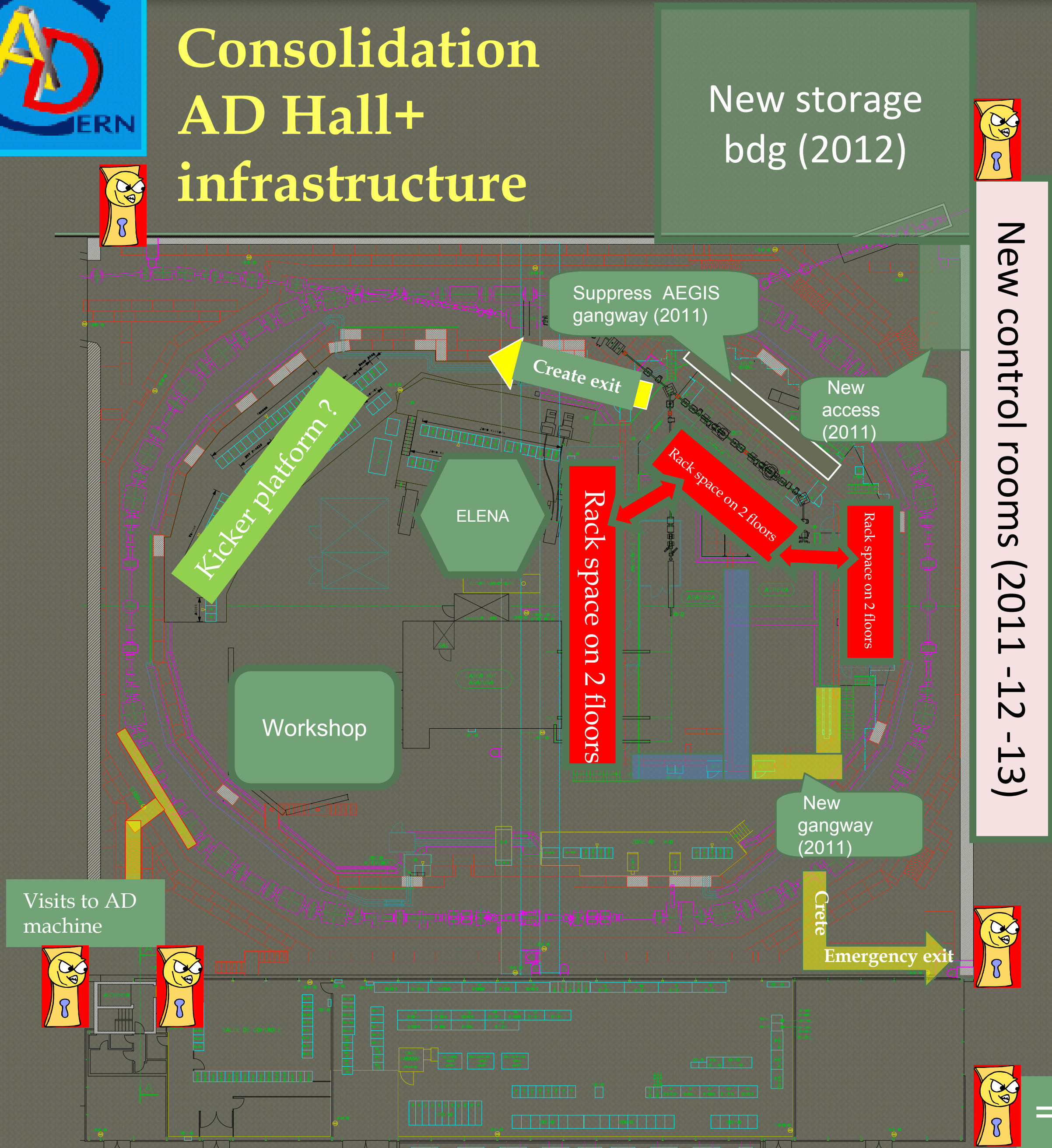


AD status: electron cooling

Consolidation AD Hall+ infrastructure

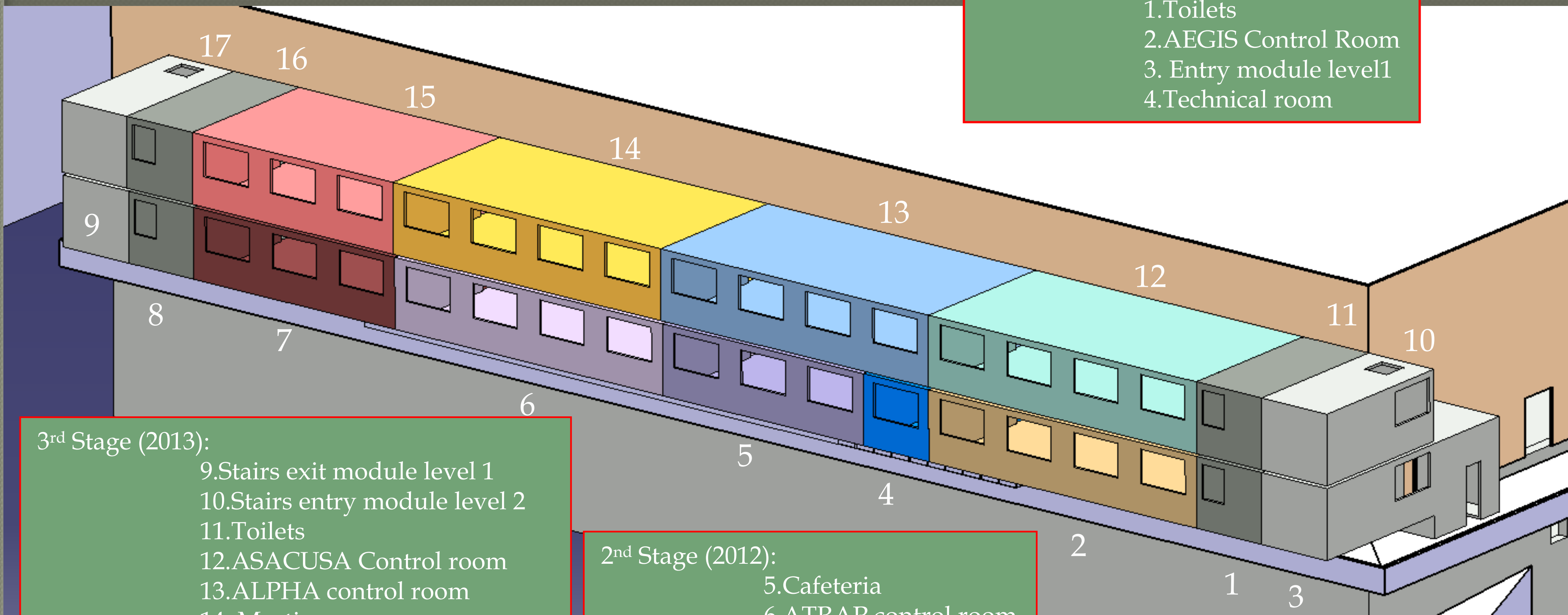


Infrastructure consolidation:

- Access control upgade
- RP shields upgrade
- New gangways for circulation and evacuation improvement
- New control rooms for ALARA respect and racks/ storage space increase
- Cranes upgrade for more efficient and safer handling
- Cryogens distribution audit
- Ventilation system audit
- Review needs for smoke/ODH detection
- Provide long term (bdg 133) and short term (new building) storage facilities
- New cafeteria/ toilets / meeting room / parking
- New visit itineraries and procedures

=new access control (5)

New control rooms for AD experiments



1st Stage (2011):
1.Toilets
2.AEGIS Control Room
3. Entry module level1
4.Technical room

2nd Stage (2012):
5.Cafeteria
6.ATRAP control room
7.ACE Ccontrol room
8.Toilets

3rd Stage (2013):
9.Stairs exit module level 1
10.Stairs entry module level 2
11.Toilets
12.ASACUSA Control room
13.ALPHA control room
14. Meeting room
15.ELENA related control room
16.Toilets
17.Stairs exit module level 2

Extra Low ENergy Antiproton ring (ELENA) for antiproton deceleration after the AD

Thanks for your attention !