AD/ELENA
Status and Future

AD

- **Basic Parameters**

– 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	%

Extracted beam parameters

Parameters (at extraction)	Design	Operational 2010			
	100 MeV/c	100MeV/c	300MeV/c	500MeV/c	100MeV/c, multiej.
Transverse emittances H/V [μm]	1π	<1π	<2π	8π	<1π
Total energy spread [4σ] [10^{-3}]	1 – 0.1	0.8-0.4	0.5	2	>1
Bunch length [ns]	200-500	200	300	500	50
Number of antiprotons [107]	1.2	3.5	3.5	3.5	0.5*6
Cycle time [s]	60	100	90	85	112

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

2010

- 2010 startup:
  - Commissioning of new electron cooler power system (Faraday cage, HT transformer, converters, interlock system, safety installations, corrector dipole power converters and electronics/controls interface) ☺
  - Good performance established: 3-4 * 10^7 pbars/pulse decelerated, cooled and ejected ☺
  - Transverse emittances nominal but still problems with bunch length at ejection => 180 – 250 ns during the run ☹
- Studies:
  - Ring optics: Beam blow-up during deceleration ramps, orbit response measurements, transverse tail formation at low energies, beam-based alignment checks of the compensating solenoids and optics studies In the ASACUSA transfer line.
  - Blowup rates due to multiple gas scattering at low beam energies.
  - Tests of the new GEM detectors used for profile measurements in the ejection lines

Consolidation

- A limited consolidation program was launched in 2009 in view of continued AD operation until 2016/17

Item	Group	RS	RS after	Σmanpower	ΣM	M09	M10	M11	M12	M13
				MY	kSfr	kSfr	kSfr	kSfr	kSfr	kSfr
AD Magnets	TE-MSC	15	6	<2.4 (*)	325			125	200	
AD power converters	TE-EPC	10	3	<4.3 (*)	650		350	300		
AD controls	BE-CO	N.A	N.A	0	0		0	0		
AD vacuum ion pumps	TE-VSC	9	6	0.8	90		45	25	20	
AD vacuum ion pump power supplies&controls	TE-VSC	8	2	0.4	350		50	150	150	
AD Stochastic cooling p/u&kicker movement	BE-RF	9	2	1	50		50			
AD Stochastic cooling electronics	BE-RF	6..9	2	0.5	100		50	50		
AD C02 system	BE-RF	8	3	1	160		80	80		
AD target area ventilation & interlocks	EN-STI	8	3	1	100		20	80		
AD target water cooling + ctrls	EN-STI	6	4	0.1	50			50		
AD kicker oil system	TE-ABT	8	3	0.75	60		30	30		
AD kicker power supply/controls upgrade	TE-ABT	4	2	0.25	125			65	60	
AD ejection line power converters	TE-EPC	4	2	0.25	90			90		
AD C10 system	BE-RF	4	2	0.2	80		80			
AD power converter spares	TE-EPC	15	3	0.25	50		50			
Yearly total (kSfr)						**0**	**805**	**1045**	**430**	
Grand total (kSfr)					**2280**					

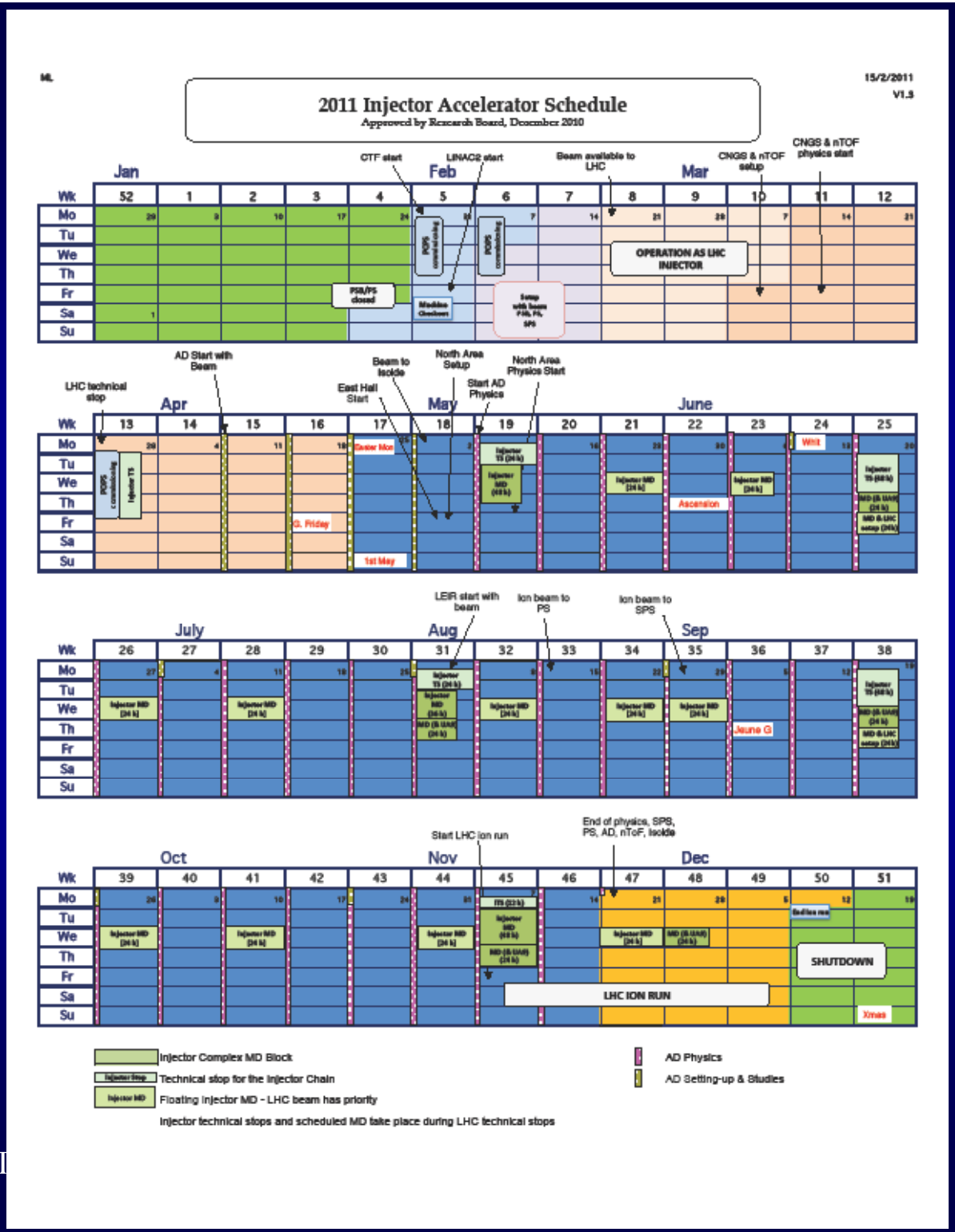
Other

- AEGIS experiment:
  - Beamline construction/installation completed
  - Magnets/power supplies/interlocks tests completed
  - Installation of experimental equipment during 2011
  - First pbar beams expected at end of 2011 run.

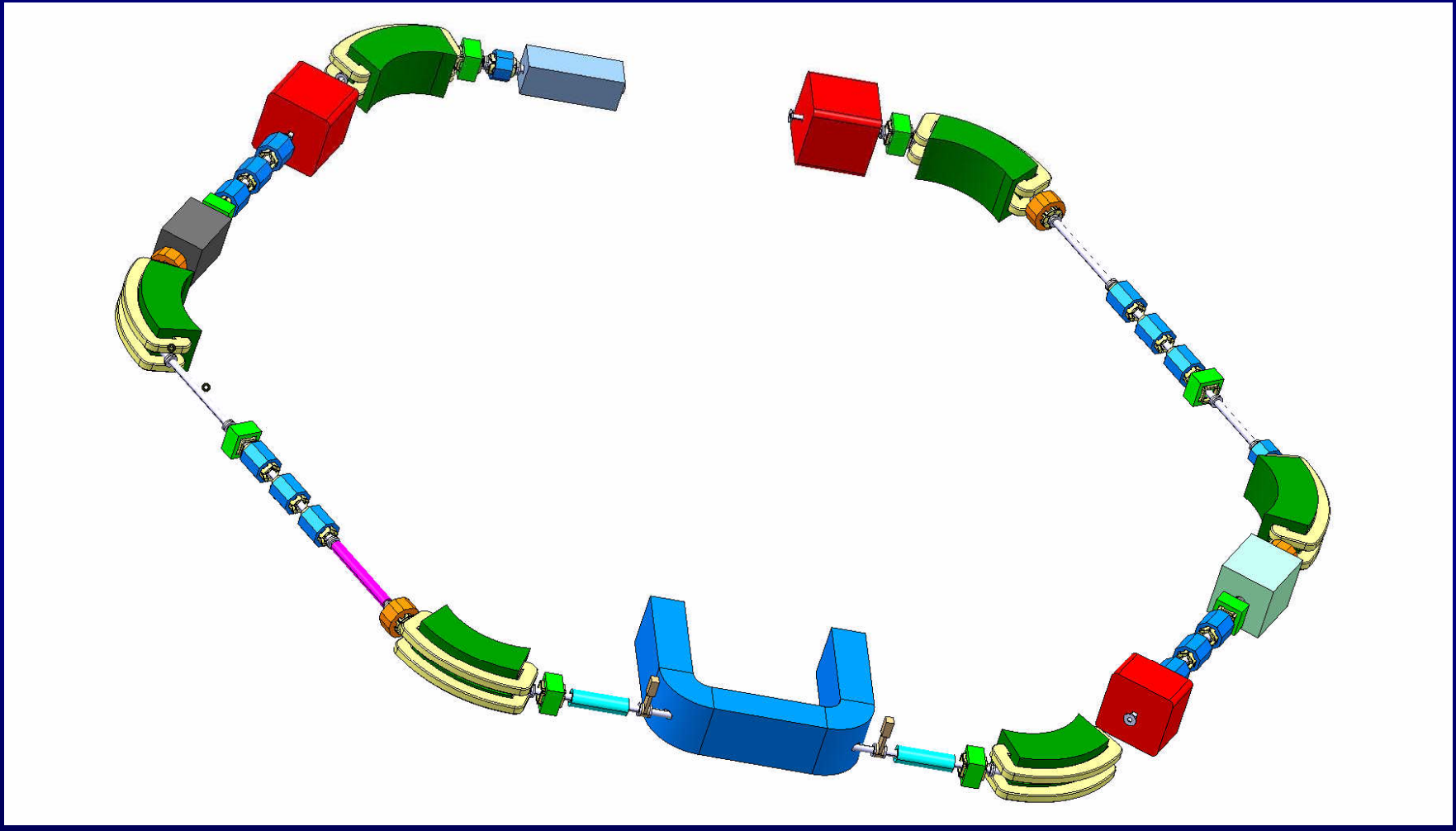
- Safety campaign - more stringent CERN safety rules
  - Visit itinerary modified, no ring visits for now
  - Cleanup/reorganisation of AD hall
  - Barracks to be built outside AD building for new users, rest/meeting area

2011 run

~ identical to 2010
- 28 weeks of physics
- ATRAP, ASACUSA, ALPHA 8h periods
- ACE 1-2 weeks 24h24
- AEGIS: towards the end



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



Motivation to build ELENA

How antiprotons are decelerated further down today:

- Experiments aimed to antihydrogen program (ALPHA and ATRAP) use set of degraders to slow 5.3 MeV beam from AD further down: poor efficiency due to adiabatic blow up and due to scattering in degraders, less than 0.1 % of AD beam used.
- ASACUSA uses RFQD for antiproton deceleration down to around 100 keV kinetic energy. Due to absence of cooling, beam 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, about 3-5% is captured after passing through degrader.

What do we gain in intensity with extra deceleration and cooling ?

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

Energy range of ELENA

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

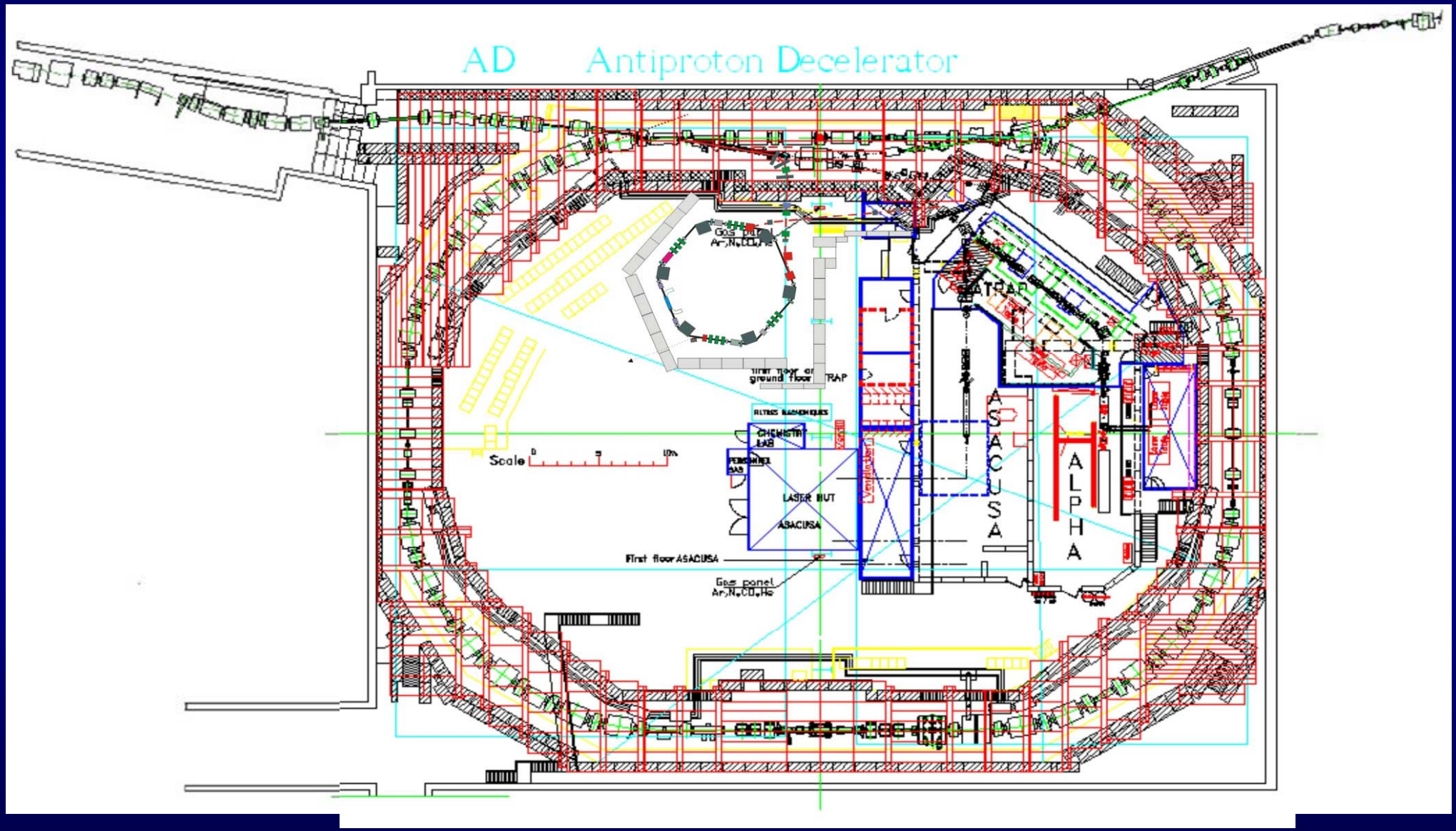
ELENA extraction energy 100 keV (13.7 MeV/c) defined by:

- space charge limit for antiproton 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 $3 \cdot 10^{-12}$
- foil thickness for separation of transfer line and trap vacuum

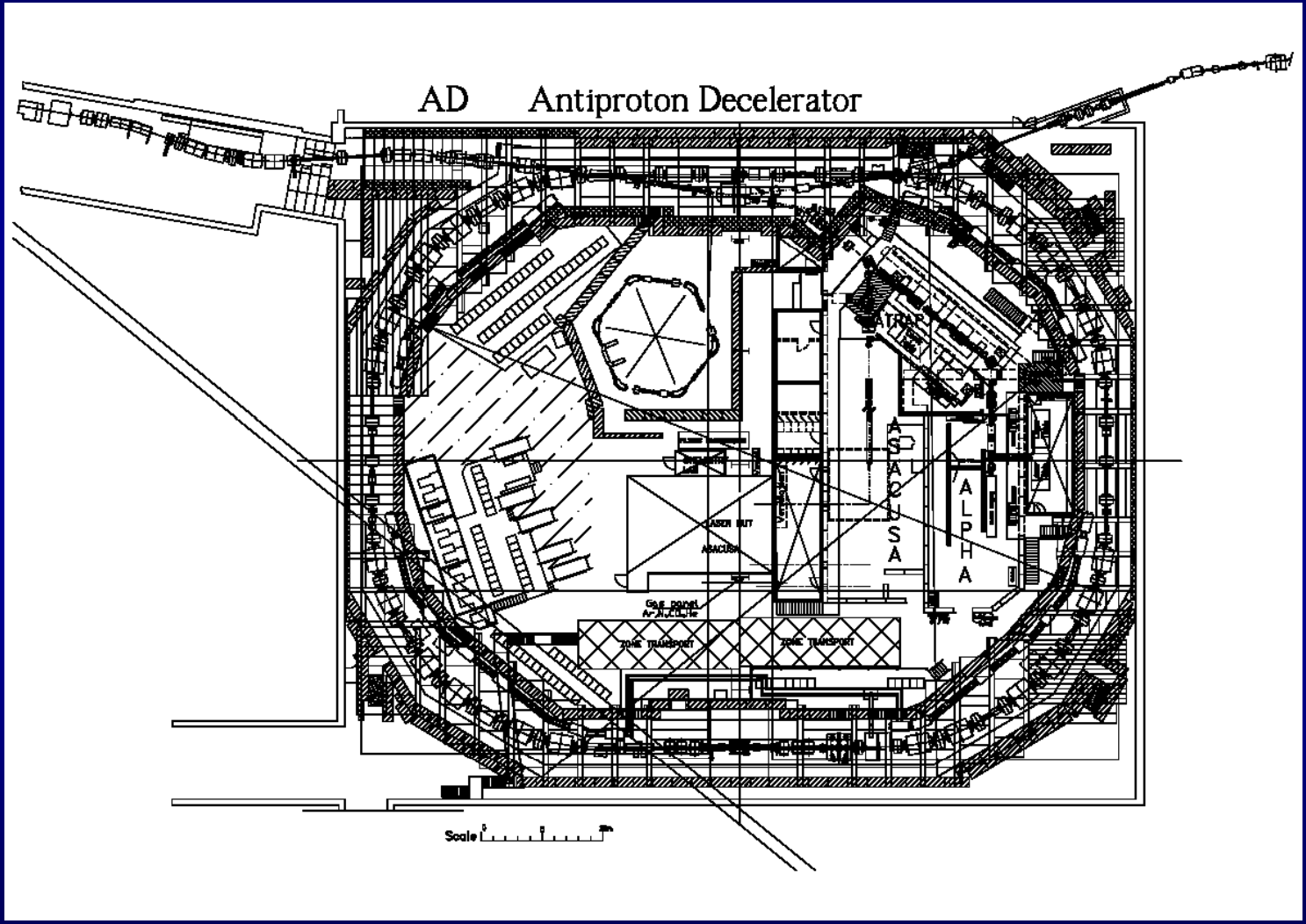
Requirements to ring configuration

- 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
- One long straight section for electron cooler needed
- Optional ejection line should be possible

ELENA layout in AD Hall



Integration in AD hall



Why did we change the layout?

Request from SPSC to provide additional experimental area and slow extraction as option (now eliminated) – not possible with old layout at “12 o’clock” position

Old layout advantages

- short experimental lines
- part of AD ejection line can be used for injection into ELENA
- no modifications in AD ring needed

Old layout disadvantages:

- Movement of the “kicker platform”
- modification and reduction of ASACUSA zone
- difficulties for installation (crane access)
- disturbance of experiments during installation
- limited area for the new experiments

Why did we change the layout? (continued)

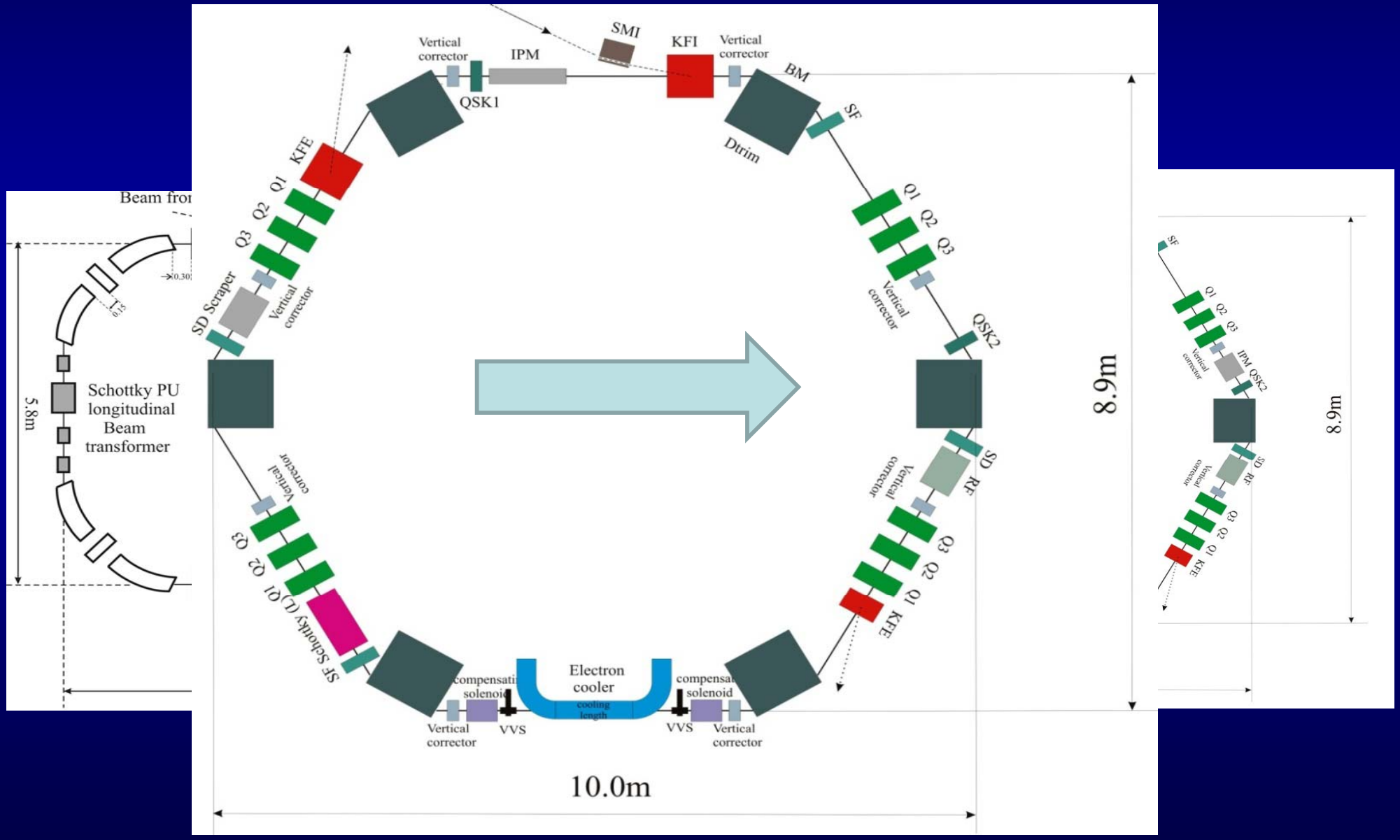
Advantages of today layout (“11 o’clock”)):

- use of part of existing AD extraction line (7000 line)
- easier access for installation (crane available)
- removal of empty racks only
- no perturbation of experiments
- space for shielding is available

Disadvantages:

- Kicker platform movement

ELENA before & now



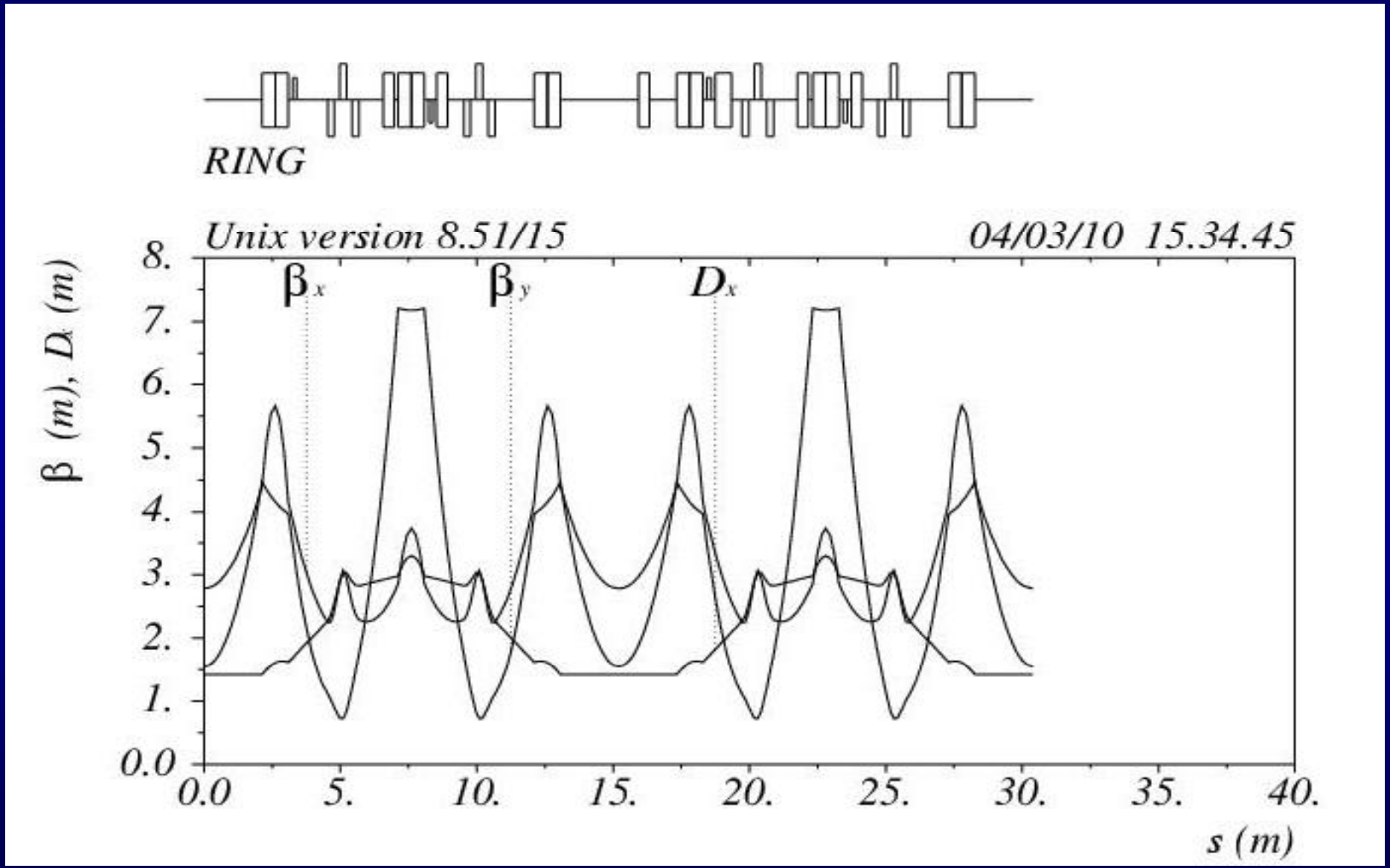
4-fold to ring to 6-fold ring

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:

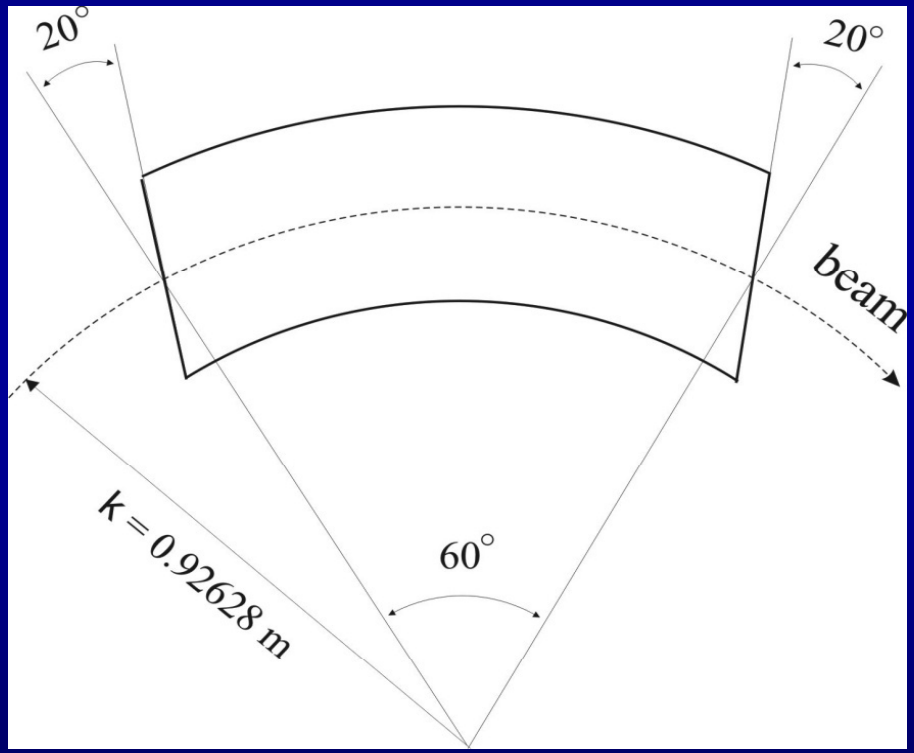
- More flexibility for injection and extraction with the new layout
- The total length of bending magnets is shorter for hexagonal lattice compared with rectangular lattice -> more space for other equipment
- Minimal magnetic field in bending magnets (at 100 keV) increased form 399 Gs to 493 Gs – essential!
- 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

ELENA optics



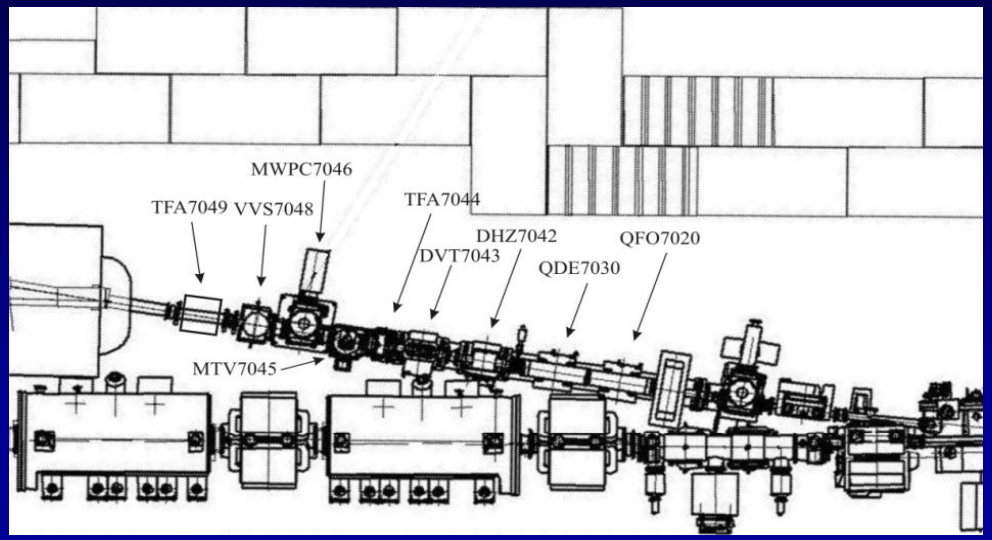
ELENA magnet system

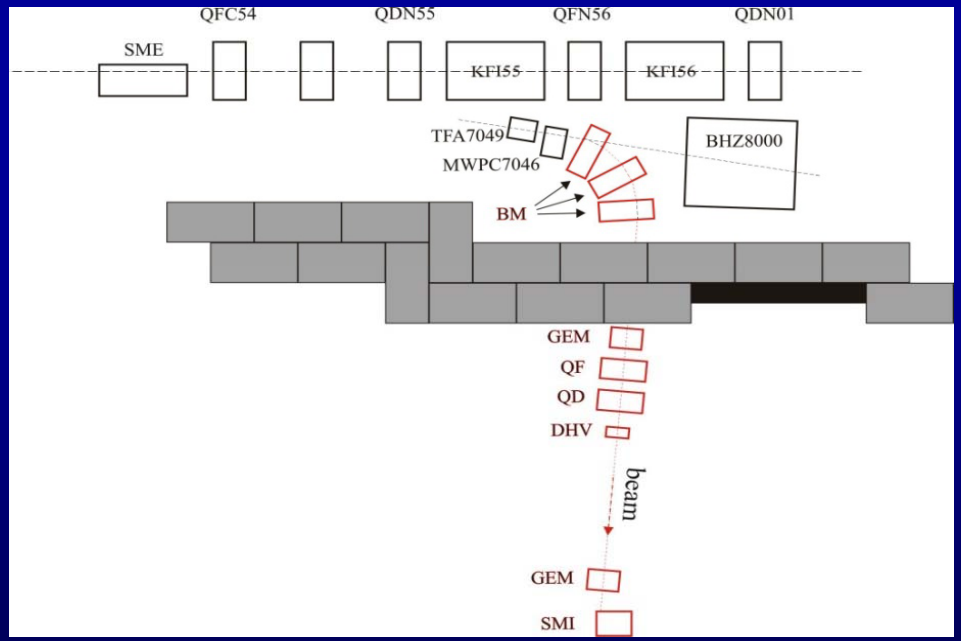
- 6 C-type bending magnets, curved, 60º each, with edge angles 20º each, magnetic length 0.97m, field range 3.60 kGs to 0.493 kGs
- 12 quadrupoles, 0.25 m long, with maximal gradient about 1.3 T/m
- 4 sextupoles, 0.2m long, weak
- 8 combined horizontal/vertical dipole correctors, short, about 60 Gm.
- Bakeable machine



Beam transfer from AD to ELENA

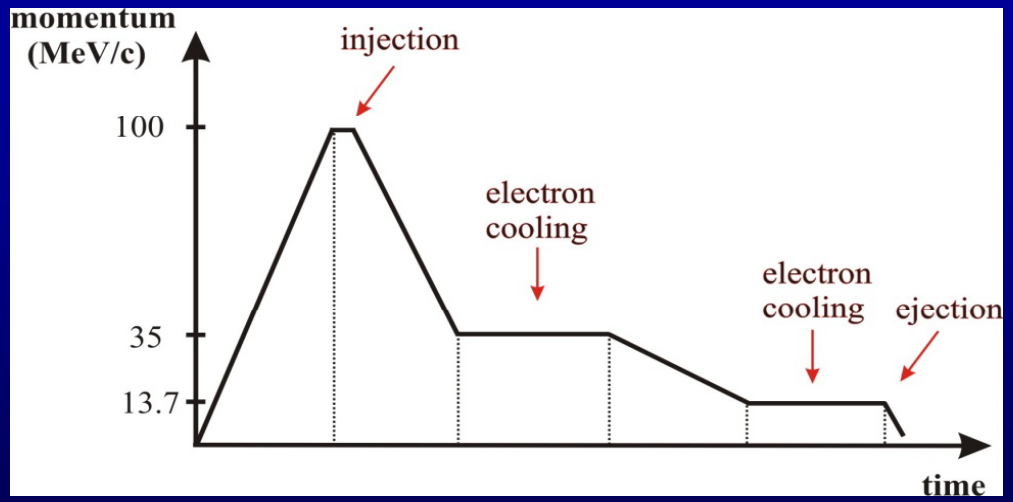
- The first separating magnet has to be placed downstream to 2 quads of 7000 line (used for matching), H and V correctors, TFA7049, VVF and MWPC7046
- To make the 85° bend, two or three magnets will be placed inside the shielding (AD ring zone)
- A hole in shielding should be made preferably in concrete, avoiding passing through steel plates
- TFA7044 and MTV7045 will be dismantled (no protons via loop anymore)



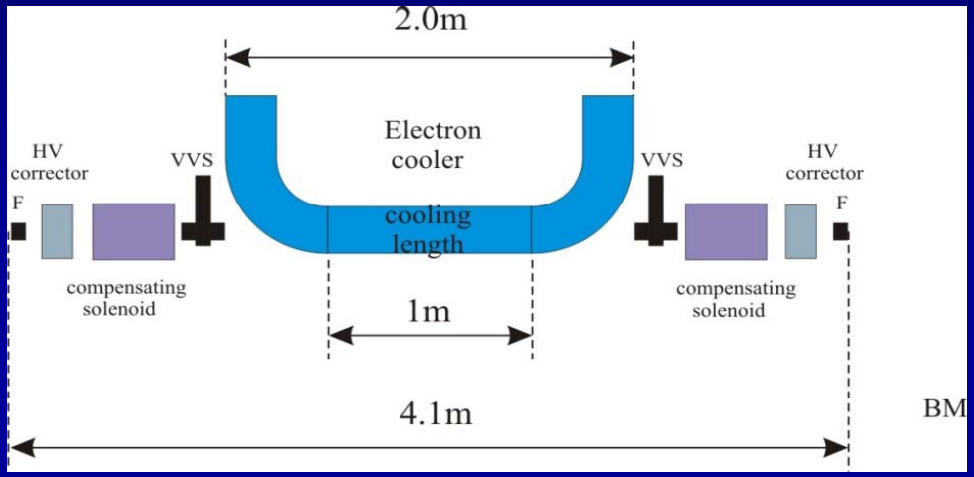


ELENA cycle

- No electron cooling is performed at injection energy: beam is cooled already in AD. After single bunch injection the beam is decelerated immediately.
- One intermediate cooling at 35 MeV/c is needed to avoid beam losses
- The cycle duration is much shorter than in AD and will be defined during commissioning



Electron cooler for ELENA



Cooling length l_c, m	1
Beam cooled at momentum, MeV/c	35 & 13.7
Electron beam current I_e, mA	15 & 2
Cathode voltage at 100 keV, V	55
Maximal magnetic field in solenoid B_0, Gs	100
Electron beam radius a, cm	2.5

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

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, π·mm·mrad, [95%]	4 / 4
Δp/p after cooling, [95%]	10^{-4}
Bunch length at 100 keV, m / ns	1.3 / 300
Required (dynamic) vacuum, Torr	3×10^{-12}

2010 cost estimate - updated

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

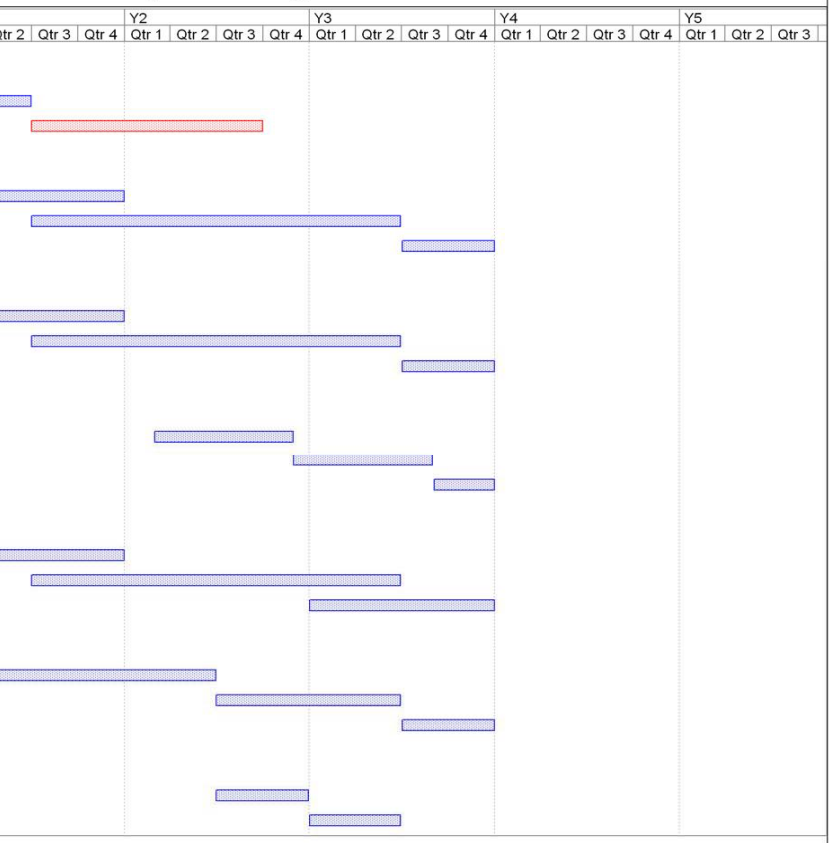
  =>Total duration 4 to 4.5 yrs

Coordinator : Tommy Eriksson

ELENA - Project Planning

19.11.10

ID	Task Name
1	**General Infrastructure and services**
2	Design, specification and tender
3	Production & testing
4	Preparation, Installation tests
5	
6	**Magnets**
7	Design, specification and tender
8	Production & testing
9	Preparation, Installation tests
10	
11	**Converter**
12	Design, specification and tender
13	Production & testing
14	Preparation, Installation tests
15	
16	**Septa magnectic and electrostatic**
17	Design, specification and tender
18	Production & testing
19	Preparation, Installation tests
20	
21	**Kickers**
22	Design, specification and tender
23	Production & testing
24	Preparation, Installation tests
25	
26	**Electron Cooler**
27	Design, specification and tender
28	Production & testing
29	Preparation, Installation tests
30	
31	**Vaccum**
32	Design, specification and tender
33	Production & testing



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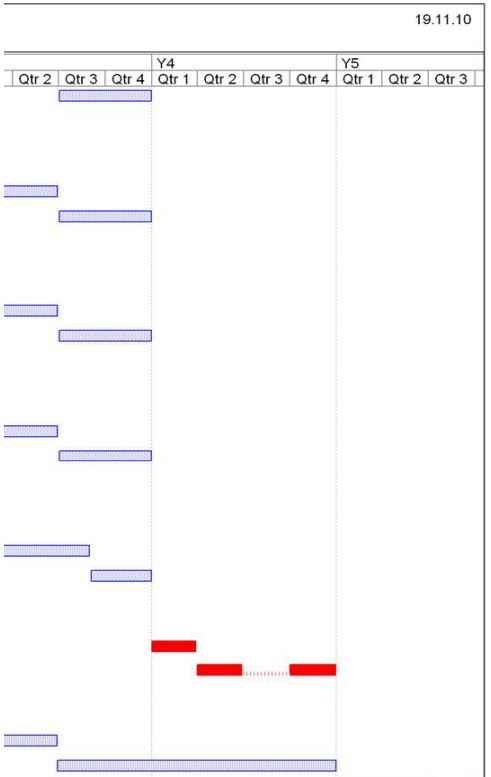


	Production & testing
63	Preparation, Installationand commissioning

Project_Elena_v2 Page 2

Where are we today?

- Updated project and cost estimate has been presented to various CERN committees
  - IEFC, SPSC, SPC
  - recommendation made at RB in December:

"An updated cost and feasibility study has been finalized for the ELENA upgrade of the AD facility [8], validated by the IEFC committee.

The SPSC re-iterated its strong support to the project.

The motivation has been strengthened by recent breakthrough at the AD with the successful trapping of antihydrogen.

The Research Board endorsed the strong scientific case for ELENA.

All efforts are encouraged to ensure that the required resources are found, within the collaboration or elsewhere, so that ELENA can go ahead, securing the long-term future of the AD programme."

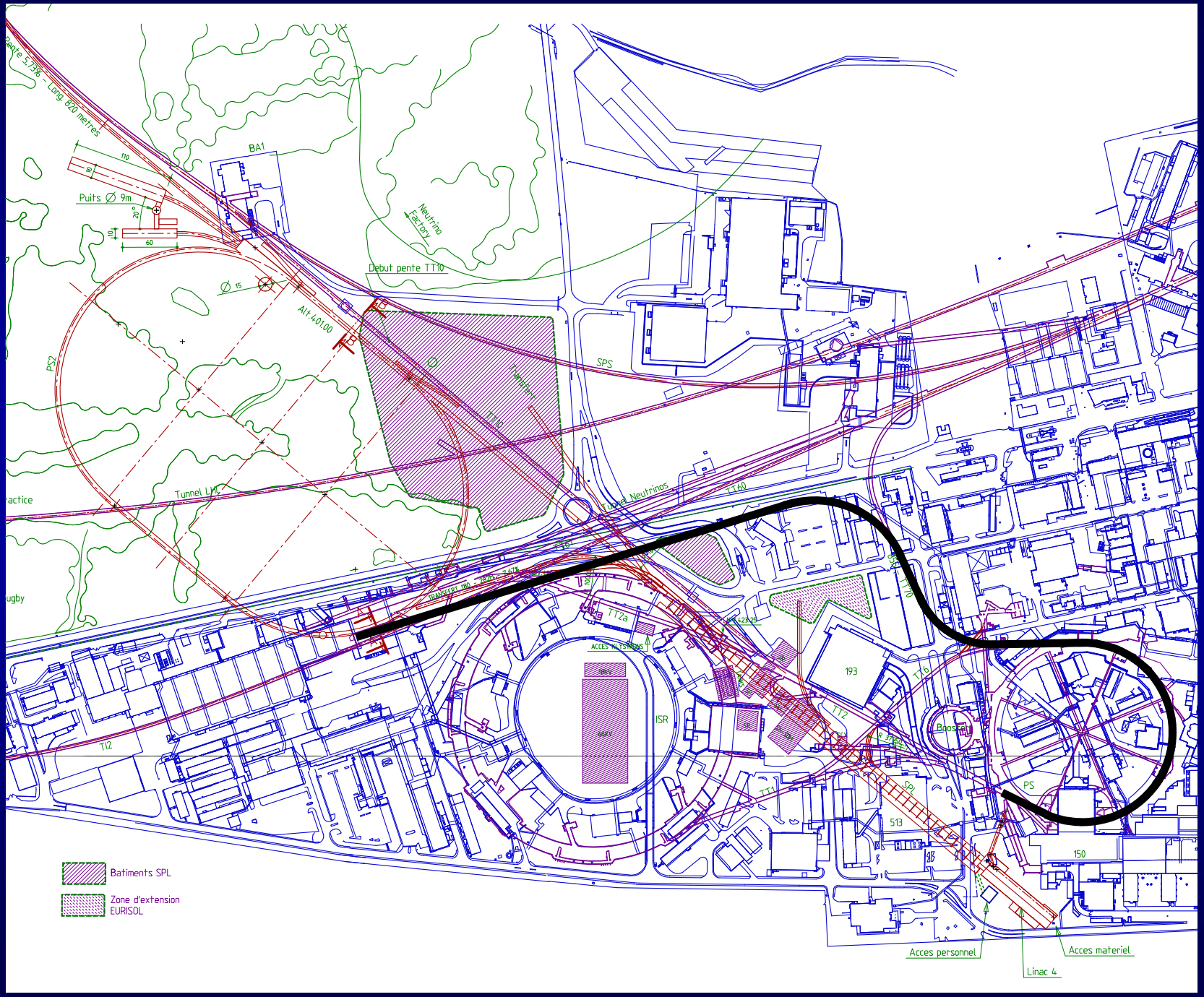
Further AD experiments

- PAX (proposal): Decision pending, expected in 2011
- One more new experiment might be proposed: Internal target in ELENA ring
  - 40 KeV kinetic energy antiproton beam, circulating a few thousand turns in ELENA. Need approximately 1 m longitudinal space in the ELENA ring.
  - Could be considered within the possibility of additional experiments mentioned in the ELENA feasibility study, with commissioning (or, at least trial of commissioning) after 100keV physics is established in ELENA. => we have to foresee certain features in ELENA design.
  - The most natural way to decelerate antiprotons further down to 40 keV is to do this with electron beam of cooler. This will allow avoiding extension of RF system parameters. The cooler has to have a feedback system which allow to adjust voltage and maintain synchronization with main magnetic field. Permanent beam cooling during deceleration makes longitudinal Schottky diagnostics easier during deceleration.
  - The low energy limit for magnetic field goes down from 500 Gs to 300 Gs. The stability of power supplies in extended range (factor 11 instead of factor 7) needed. The influence of remanent fields should taken into account as well.
  - No extra vacuum requirements are imposed due to the short beam lifetime (a few thousand turns) needed for experiment.

Long-term AD future: 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 area.
- **2015?-2025+** **AD/ELENA?**
  - Small post-decelerator ring to be added
  - Cooling and deceleratoin to 100 keV
  - Electrostatic beamlines and new experiments…

- Plans for construction of 50 GeV/c PS2 and SPL abandoned !
- PS1 did already celebrate it's 50:th birthday
- ….good news for AD !



21 February 2011

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 ongoing for PSB renovation or replacement by new RCS
  - PS: only the main magnet yokes + 50% of coils left from 1950:s

AD operation beyond 2016:

- ELENA descision soon !

➔ AD consolidation for 10+ more years of operation