Status of the CERN Antiproton Decelerator (AD)

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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.
- **2016-2030+** **AD/ELENA**
  - Small post-decelerator ring to be added
  - Cooling and deceleration to 100 keV
  - Electrostatic beamlines and new experiments…

AD

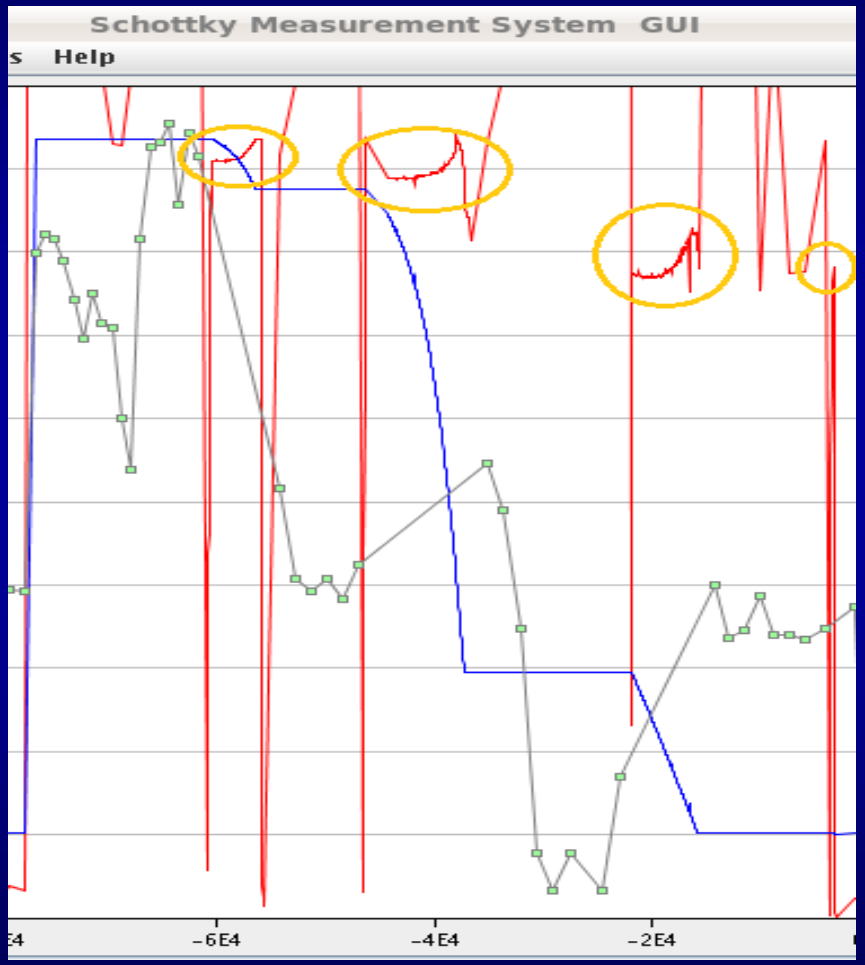
- **Basic Parameters**

– 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	%

AD operation statistics

Run time (h)	2000	2001	2002	2003	2004	2006	2007	2008	2009	2010	2011	2012
Total	3600	3050	2800	2800	3400	2925	3800	3340	4600	4610	4680	5480
Physics	1550	2250	2100	2300	3090	2765	3760	3140	4460	4550	4530	5360
md	2050	800	700	500	310	160	40	200	140	60	150	120
Beam available for physics (%)	86	89	90	90	71	65	76	81	78	87	84	90
Uptime AD machine (%)					89	74	81	93	92	91	90	95

AD performance 2012



Intensity and dp/p values

Np (3.5 GeV/c)	4.64 e7	100 %
Np (2 GeV/c)	4.53 e7	97 %
Np (300 MeV/c)	3.92 e7	84 %
Np (100 MeV/c ramp)	4.08 e7	87 %
Np (100 MeV/c end)	3.94 e7	84 %
DETFA7049	3.7 e7	79 %

dp/p (3.5 GeV/c)	16.152	24.652
dp/p (2GeV/c)	1.16	0.495
dp/p (300MeV/c)	1.5	0.041
dp/p (100 MeV/c)	0.395	0.224

Extracted beam parameters

Parameters (at extraction)	Design	Operational 2012		
	100 MeV/c	100MeV/c	500MeV/c	100MeV/c, multiej.
Transverse emittances H/V [μm]	1π	<1π	8π	<1π
Total energy spread [4σ] [10^{-3}]	1 – 0.1	0.8-0.4	2	>1
Bunch length [ns]	200-500	~150	500	50
Number of antiprotons [10^{7}]	1.2	3.5	3.5	0.5*6
Cycle time [s]	60	100	85	112

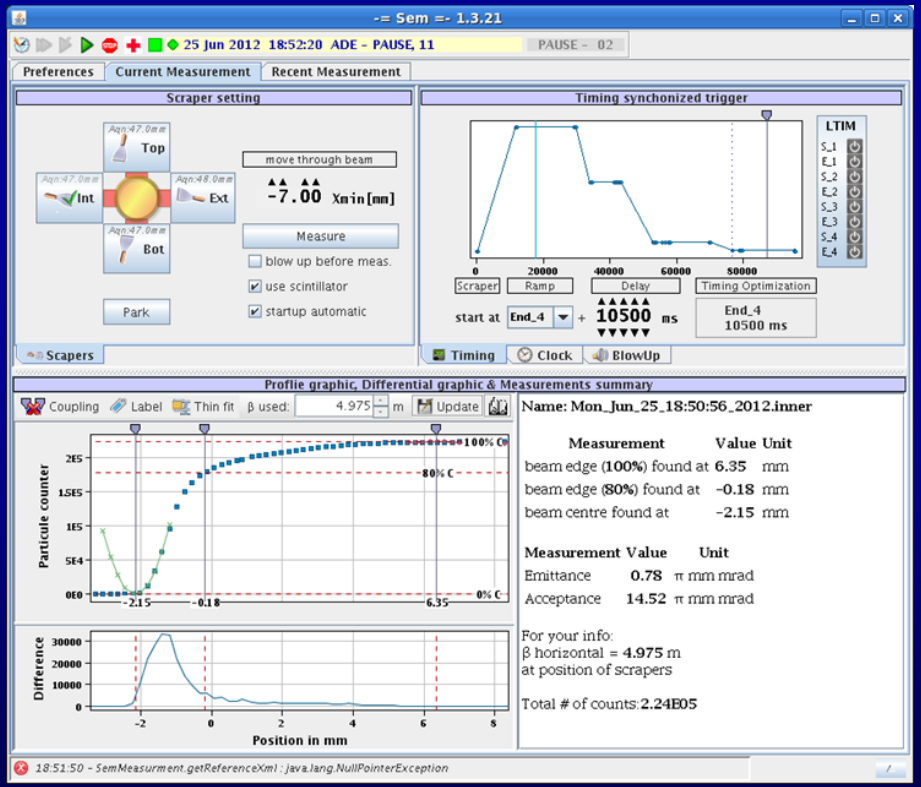
AD studies in 2012: beam profiles at 100 MeV/c

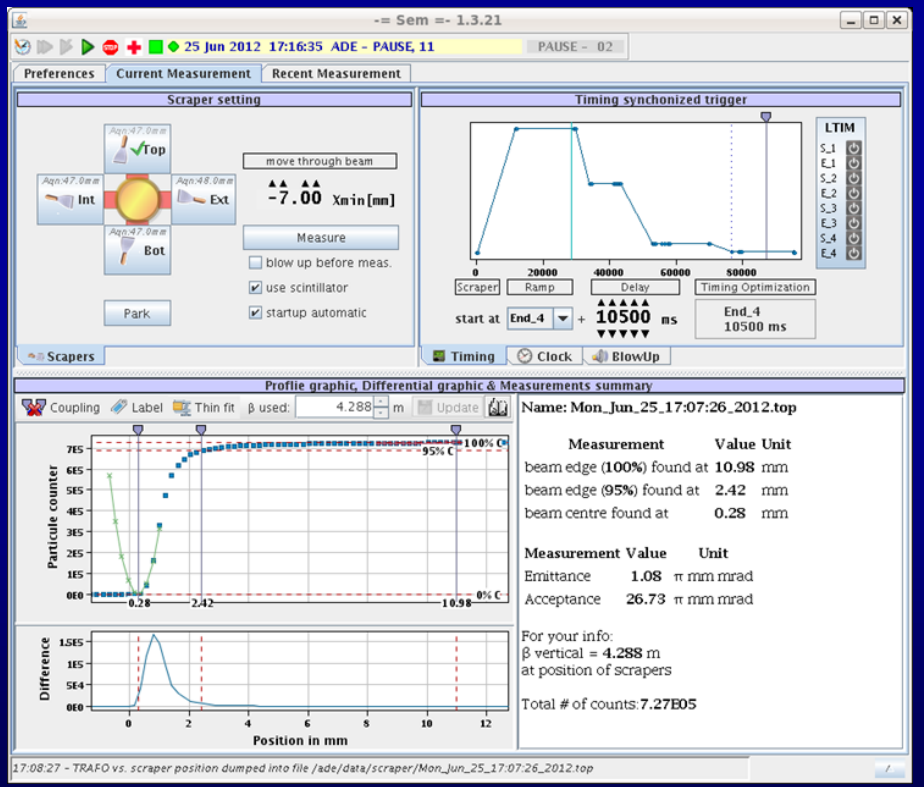
Essential for good deceleration through RFQD & trapping efficiency

Careful alignment of electron cooling e- and Pbar beams was done at startup

⇒ Reduced tails & “halo” effect

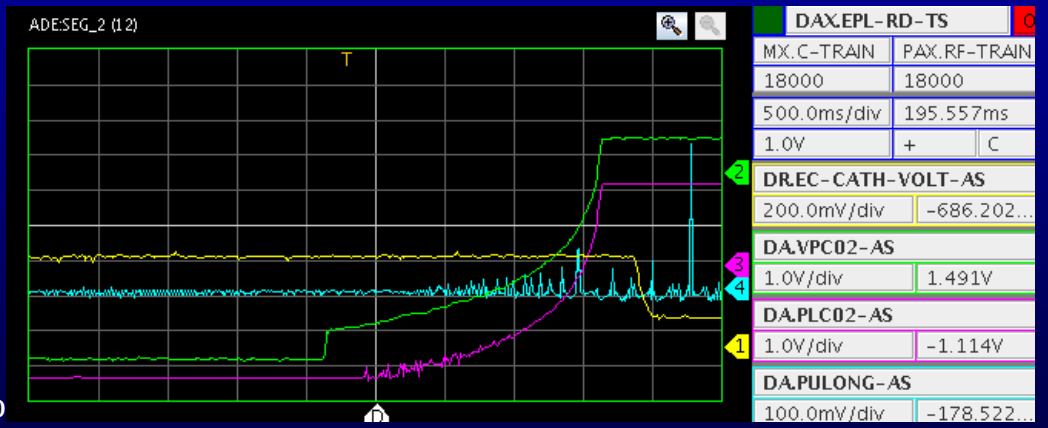
⇒ Less degradation of cooling performance over the year





AD studies in 2012 – longitudinal emittances

- Reduction of longitudinal emittances at ejection: essential for ELENA beam transfer and deceleration.
- Prior to ejection at 100 MeV/c the (operational) cooling rate is faster than the dp/p increase during bunching
- Tests with extended capture durations:
  - Nominal 500ms: (rms) dp/p = **$4.1*10^{-4}$**
  - 2000ms: (rms) dp/p = **$2.6*10^{-4}$**
  - 5000ms: (rms) dp/p = **$1.3*10^{-4}$**



AD studies in 2012 – ejection line optics

- Optics never validated – need efficient deceleration in ASACUSA RFQD & matched transfer to ELENA
- MWPC:s are now replaced by GEM:s => better resolution
- Obvious mismatch in ASACUSA line
- Investigations with kick response measurements
- Unused dipole (BHZ8000): focussing effect from remanent field = > beamline shielding somewhat improved the situation
- 3D modelling (CST) of all dipoles: fringe field effects introduced as matrix elements in MAD-X => good fit with kick response measurements
- ……except for effects caused by ATRAP solenoid fields
- Slight (~4%) field errors in quadrupoles found by sliding matrix elements along z-axis until kick response measurments fit

AD studies in 2012 – ejection line optics

- Results:
  - ASACUSA: good fit with improved beam profiles after RFQD
    - Not implemented yet due to lengthy tuning @ ASACUSA
  - ATRAP: Good fit until entry into solenoids
    - Implemented with good results at ATRAP1, ATRAP2 not yet tested
  - ALPHA: fits well but beamline passes under both ATRAP solenoids
    - Old optics remain in use for now

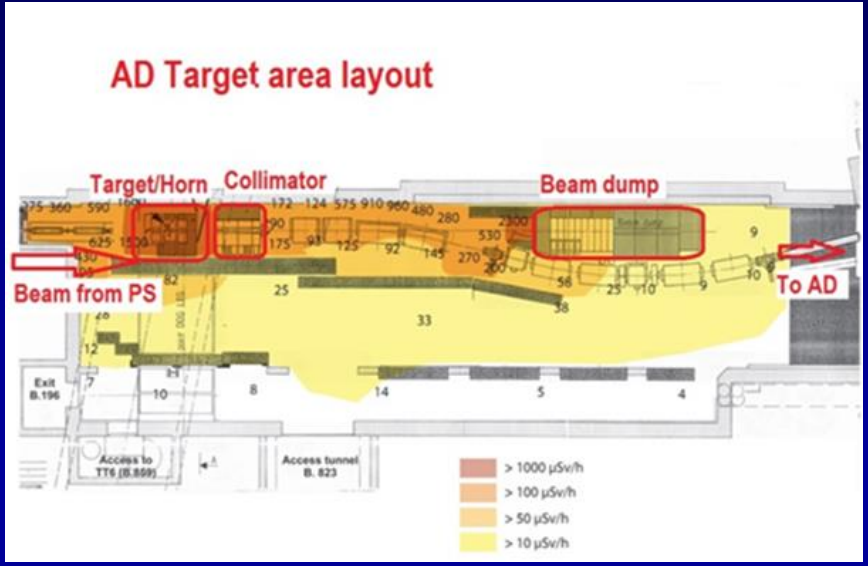
- Conclusion:
  - Fringe fields taken into account in MAD works well only for small bending angles
  - Very useful exercise for design and commissioning of AD to ELENA transfer line

AD consolidation

- Due to other important CERN programs, only urgent issues were addressed for the first ~10 years
- A small consolidation program started in 2009 and is now merged with a larger program aimed at continued operation of AD+ELENA for at least 10-15 years after ELENA physics has started
- A new review of all systems has been done and consolidation needs identified

- A budget of ~ 18 MCHF has been allocated for the period 2013 – 2020, this will cover most of the needs

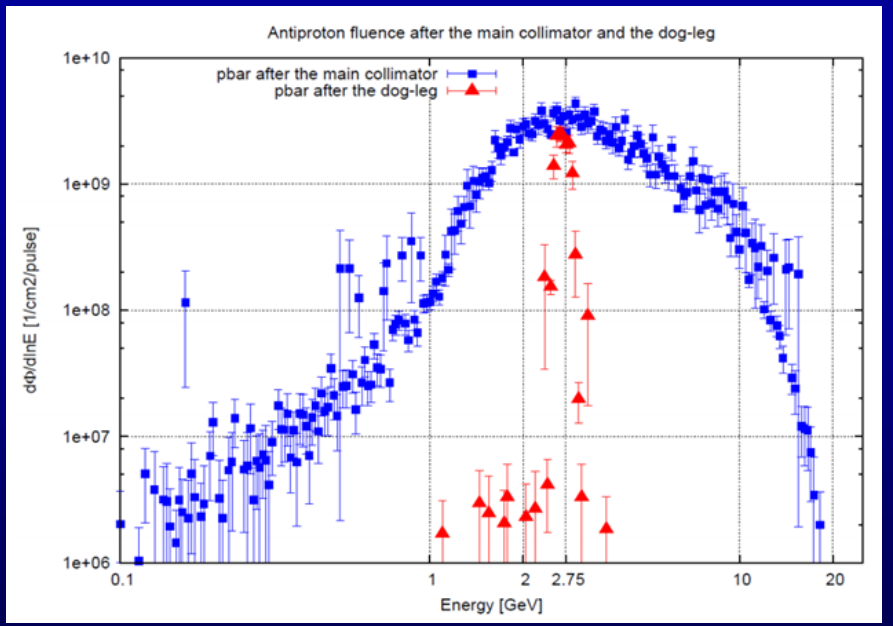
Target area consolidation



Overview of AD target area

FLUKA simulations cross-checked by in-situ radiation and particle fluence measurements:
- confirms the effect of the magnetic spectrometer
- estimation of energy deposition in area elements (cooling needs)
- horn/target mis-alignment loss estimations

(Blue: fluence downstream of horn, Red: fluence at end of spectrometer)



Target area consolidation

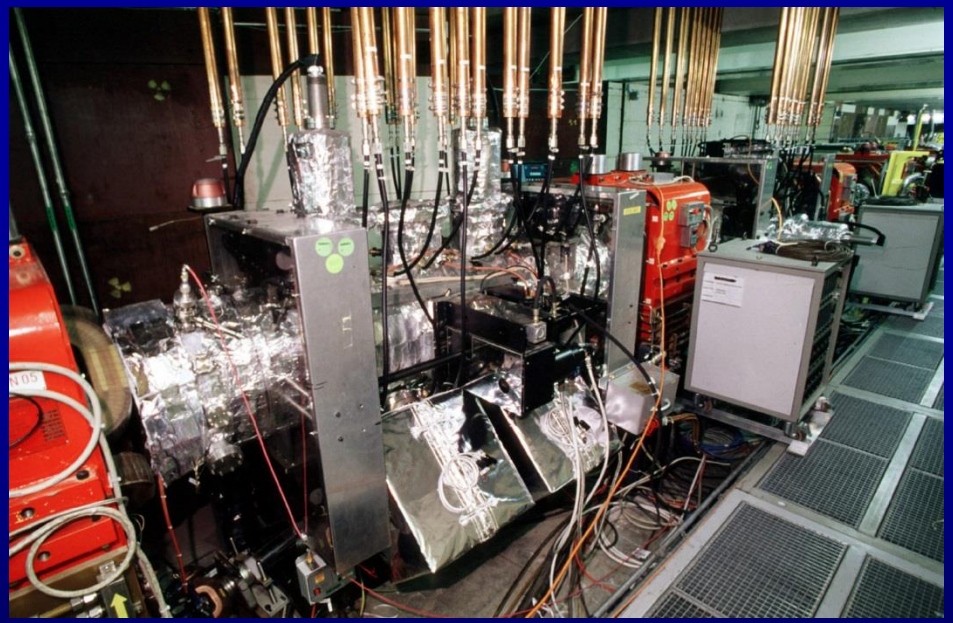
- Ongoing/LS1:
  - Transport system (lifting/manipulation vehicle) renovation – urgent!
  - Target/Horn control system for lateral movement: renewal
  - Remote survey equipment renewal
- Long-term:
  - General consolidation plan established
    - Cooling/ventilation controls
    - Communication and other equipment in the buildings
    - Spare Horn/stripline assembly
    - RAMSES
  - Indicative for LS2 (costs more uncertain):
    - Target + Horn chariots renewal
    - New target design and spares
    - Water cooling system renewal
    - Ventilation system renewal

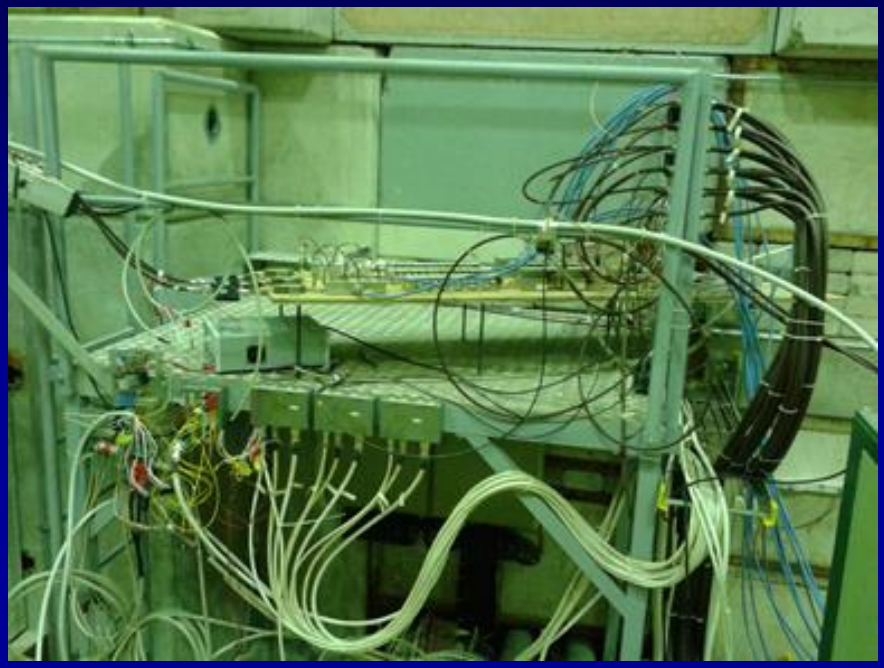
Stochastic cooling consolidation

- Ongoing/LS1:
  - Electronics for system parameter control (delays/attenuators): Installation/comissioning tests done with beam in 2012. Old system to be dismantled in LS1.
  - Controls/acquisition upgrade
  - u-wave amplifier power supplies: replace existing large units with 48 individual supplies + renewed PLC-based controls. Installation in LS1
  - Pickup/kicker movement: Update of obsolete system with modern digital servo motor controller. Lab tests underway, installation during LS1
  - p/u & kicker vacuum tanks: 4 tanks (band 2) returned from GSI in 2012 => Used as test-bench in the lab
  - Pickup tanks cryo-system renovation, tanks removed from ring
- Long-term:
  - Renewal of u-wave amplifiers: request for ~1MCHF in 2015, detailed specs to follow
  - Vacuum tanks including pickup and kicker equipment: can existing tanks be used for 20 years? (see above)
  - Optical filters to replace large filter box presently limiting space around ELENA

Stochastic cooling consolidation

Horizontal and vertical kicker tanks as installed in the AD ring.





“Platform Fritz”: signal transmission circuitry with dynamic and static parameter control (system attenuation and delay), switching between different beam energies etc.
In need of consolidation !

Stochastic cooling consolidation

New individual Power supplies for the 0.8—1.6 GHz stochastic cooling amplifiers.
To be used as of 2014 start-up

Electron cooling consolidation

- Ongoing/LS1:
  - HV power supply renewal (TE/EPC)
- Long-term:
  - Build a new state-of-the-art cooler ~ 2.5 MCHF 2014 – 2018. Aim for installation in LS2.
  - Including adiabatic expansion, variable density electron beam and electrostatic deflector plates for efficient collection of the electron beam
  - Existing cooler:
    - Is >30 years old
    - We have no spare magnets; very long down time if failure, significant cost for new spares
    - Performance issues
    - e- bpm:s not operational
    - Contains unused equipment

Momentum pbar	300 MeV/c	100 MeV/c
Electron energy	35 keV	2.8 keV
Electron current	2.5 A	100 mA
Cooling length	1.5 m	
Drift magnet field	590 Gauss	
Electron beam radius	25 mm	
Cooling time	16 s	15 s
$\varepsilon_x / \varepsilon_y$	3 / 3 ($\pi \times$ mm $\times$ mrad)	0.8 / 0.5 ($\pi \times$ mm $\times$ mrad)
dp/p	10^{-4}	$< 7 \times 10^{-5}$

AD systems consolidation

- **RF:**
  - C02 tuning system and HV-supplies renewal, re-location of RFQD racks/supplies: necessary to make space for ELENA and BASE
  - C10 final stage (obsolete TH116 valves): New power amplifier/control/interlock systems to be developed: 4MCHF 2016-2018 (but search for TH116 not completely abandoned yet…)
  - C02 electronics and interlock systems renewal 2016 - 2018
  - C02 Beam control: migration to standard (Similar to ELENA) DSP-based system (including Schottky analysis) – planning to be finalised.
- Magnets:
  - Main bends: DR.BHN06 dismantling/inspection/refurbishment + evolution of coil movement will determine further actions. Renovation of some or all magnets ?
  - Main quadrupoles: in better condition, coil shimming re-done, no action planned now
  - Replacement of various magnets with CERN-standard units in progress
  - All ejection line magnets will be replaced by e-static units for ELENA ~2016/17

AD systems consolidation

- Diagnostics:
  - IPM renovation + merging H and V systems into 1 tank (sect.14)
  - Schottky analysis (longitudinal): integrate ageing DSP equipment into new LL beam control system + new system for visual monitoring => BE/RF
  - Orbit system: solution with individual ADC:s in 2015, similar to ELENA system. Will permit measurements during ramps.
  - BCT (TFA6006 and 5302) renewal: mechanical redesign + electronics/software update
  - Tune measurement => initial studies done make measurements on ramps possible

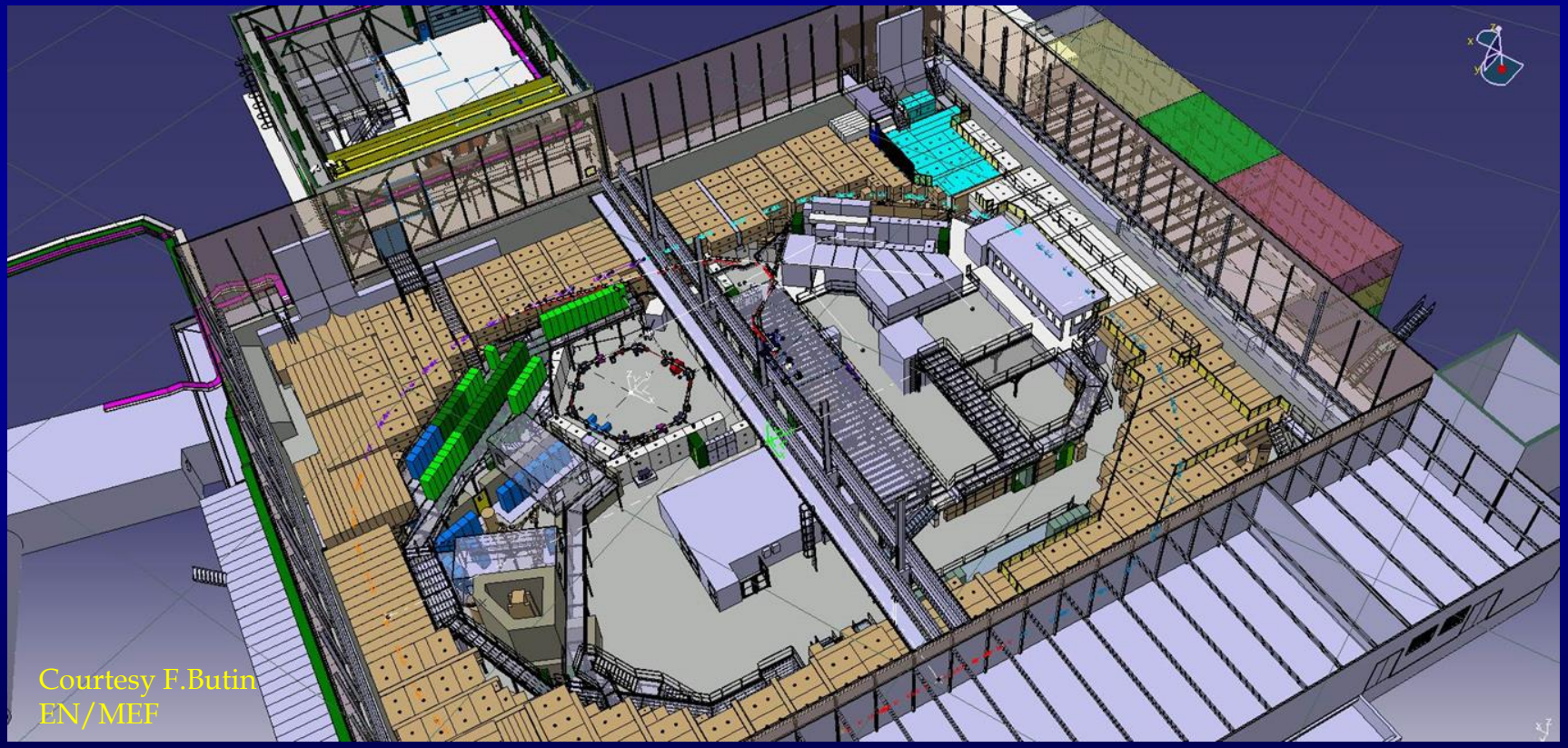
- Beam transfer:
  - Structural improvement of KFI55/56 vacuum tanks (vacuum/weld problems) in progress
  - Magnetic Horn HV power supply renewal
  - Kicker electronics/controls renewal: included in the ELENA planning since the platform needs to be displaced to B393
  - Septa electronics/controls renewal
  - Magnetic Horn: replace Mercury ignitrons with solid state switches, renew capacitor chargers, build new test stand (space reserved in new AD/ELENA building)

AD systems consolidation

- Vacuum:
  - General program 2013 – 2018 has been started(~2,5MCHF) including:
    - Cryo system renovation, Bakeout system upgrade, General controls upgrade, Ion pump HV feedthrough improvement (refurbishing + heating system), Ion pump replacement, Turbo pumps + power supplies + gauges, Turbo pump controls, Gas injection system, Transfer line components
- Control system:
  - Front-end upgrade (ACCOR): ~complete (80-90%) renewal in LS1, separate BE/CO budget
  - Timing/cycle generation: re-design for de-coupled AD/injector complex & ELENA functionality etc.: definitions underway, to be operational at 2014 re-start.
  - GM => FESA, Java migration, InCA: majority will be completed
- + Power converters, Infrastructure, etc. etc.

Infrastructure/ experimental areas

- Relocation of kicker pulse generators into new building
- Relocation of racks/cabling etc.
- Reduction of user space inside the hall => new barracks adjacent to AD building
- New experiment (BASE) will be installed in 2014



Conclusion

- LS1: extremely busy time @ AD
- Upgrades to most systems
- 2014 start-up will be more of a re-commissioning than a regular start-up…without extra beam-time

- AD/ELENA future is now known, for the first time !
- => Into the 30:ies ? (2030…)