The CERN Antimatter Facility

A status report - with input from many CERN equipment groups

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Outline

CERN antiprotons: timeline

AD: news & status 2015

AD consolidation

ELENA overview and status

Antiproton machines timeline

1980-1986 **AA** (Antiproton Accumulator)

- 3.57 GeV/c Antiproton Accumulator ring; 6 stochastic cooling systems
- 10^12 pbars stored (peak). p/pbar collisions in SPS + low energy experiments in LEAR

1986-1996 **AAC (AA+AC)** (Antiproton Accumulator Complex)

- Large acceptance Antiproton Collector ring added. 15 stochastic cooling systems
- Upgraded Target Area
- Production rate increased 10-fold to 6*10^10 pbars/h; 4,8 s repetition rate

1998-2015 **AD** (Antiproton Decelerator)

- AC converted from fixed energy storage ring to Decelerator. 3 stochastic coolingsystems + electron cooler (previously used in ICE and LEAR)
- 4*10^7 pbars decelerated to 100 MeV/c (5.3MeV kinetic). 100s cycle. Local experimental areas.

2016-2030+ **AD/ELENA** (AD/Extra Low ENergy Antiprotons)

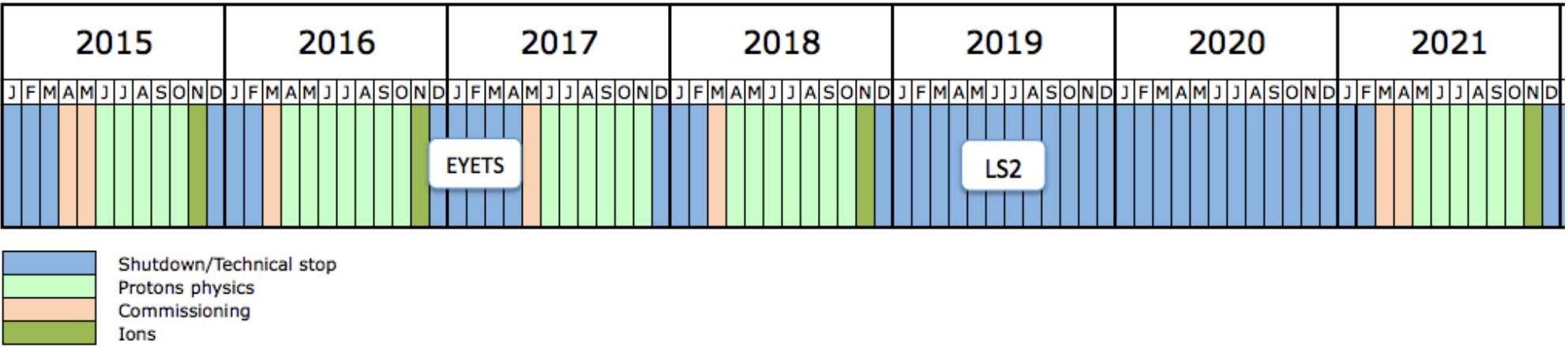
- Small post-decelerator ring with electron cooler to be added
- 1.8*10^7 pbars decelerated to 13.7 MeV/c (100 keV kinetic), 100 s repetition rate
- New ejection beamlines with electrostatic elements and extended experiment area

AD operation/planning

- Serving 5 active experiments: ALPHA, ASACUSA, ATRAP, AEGIS, BASE
- Running for physics since 2000, some 42000 physics hours realized, no machine runs in 2005 & 2013 (LS1):

AD statistics															
run time (h)	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Physics hours	1550	2250	2100	2300	3090	0	2765	3760	3140	4460	4550	4530	5360	0	2135
Beam available for physics (%)	86	89	90	90	71		65	76	81	78	87	84	90		85

- (not yet official) planning for the CERN accelerators with a 2-year stop 2019/20



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	p.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 extracted beam parameters

Parameters (at extraction)	Design	Operational		
	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	~130	500	50
Number of antiprotons [10^7]	1.2	4	4	0.5*6
Cycle time [s]	60	100	85	112

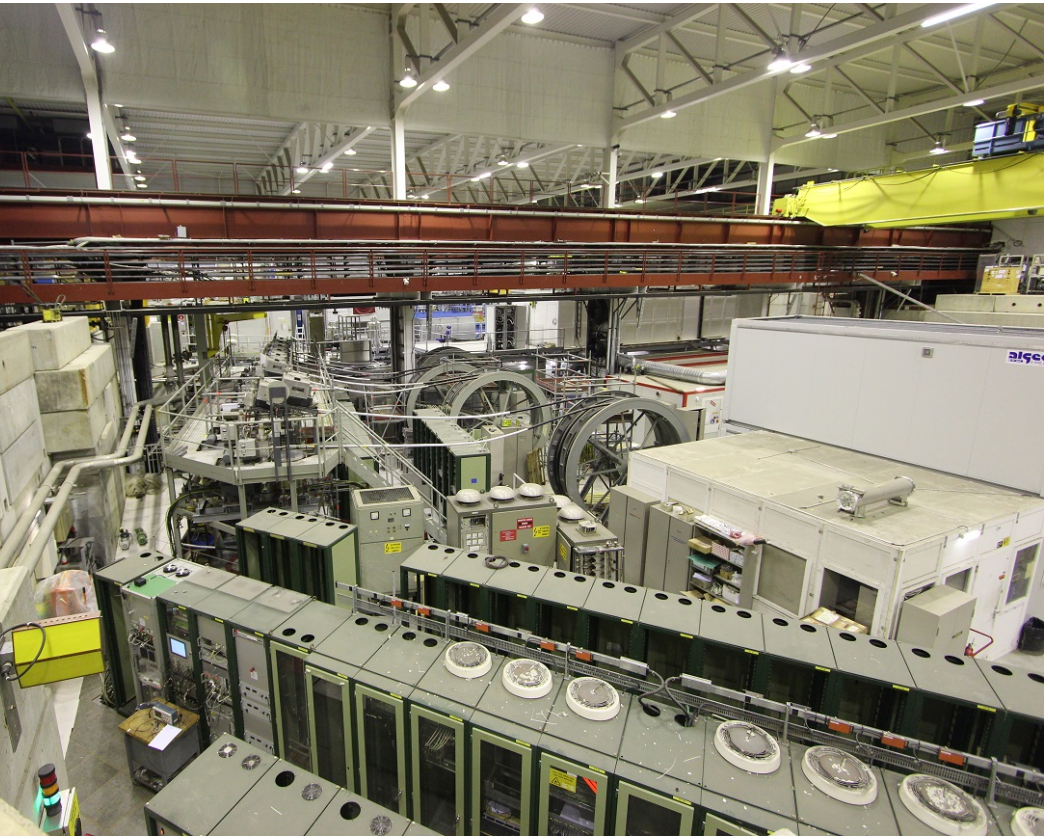
AD news & status 2015

AD physics run started July 6:th as planned

- Relatively smooth start-up
- Shutdown work 2014/15 – some examples:
  - Continued target area renovation – preparing for major items in LS2
  - Continued stochastic cooling renovation
  - Kicker pulse generator re-location
  - Magnet renovation
  - Cabling clean-up in view of ELENA installation
  - Cryogenic Current Comparator (CCC) construction/installation
  - Injection line instrumentation – renewal/addition of BCT:s

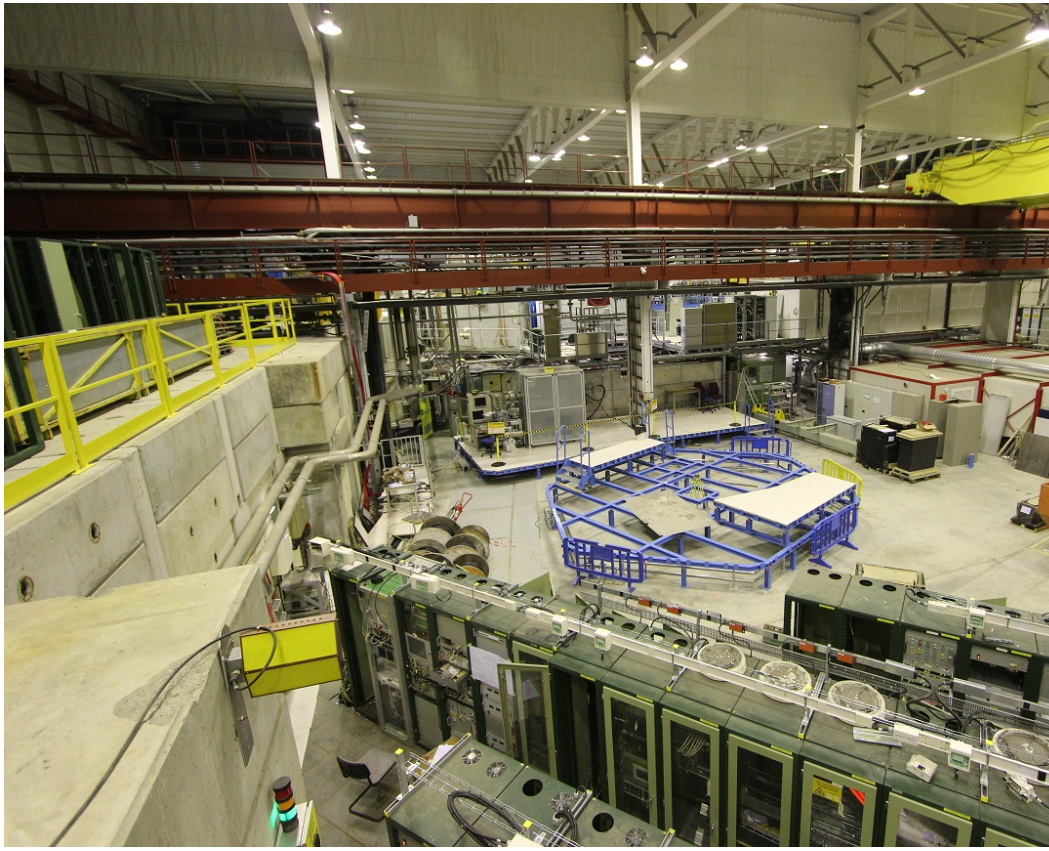
Injection/ejection kicker pulse generators for AD and ELENA

t end of run 2014



…have been removed to make place for ELENA

Situation in early Ju



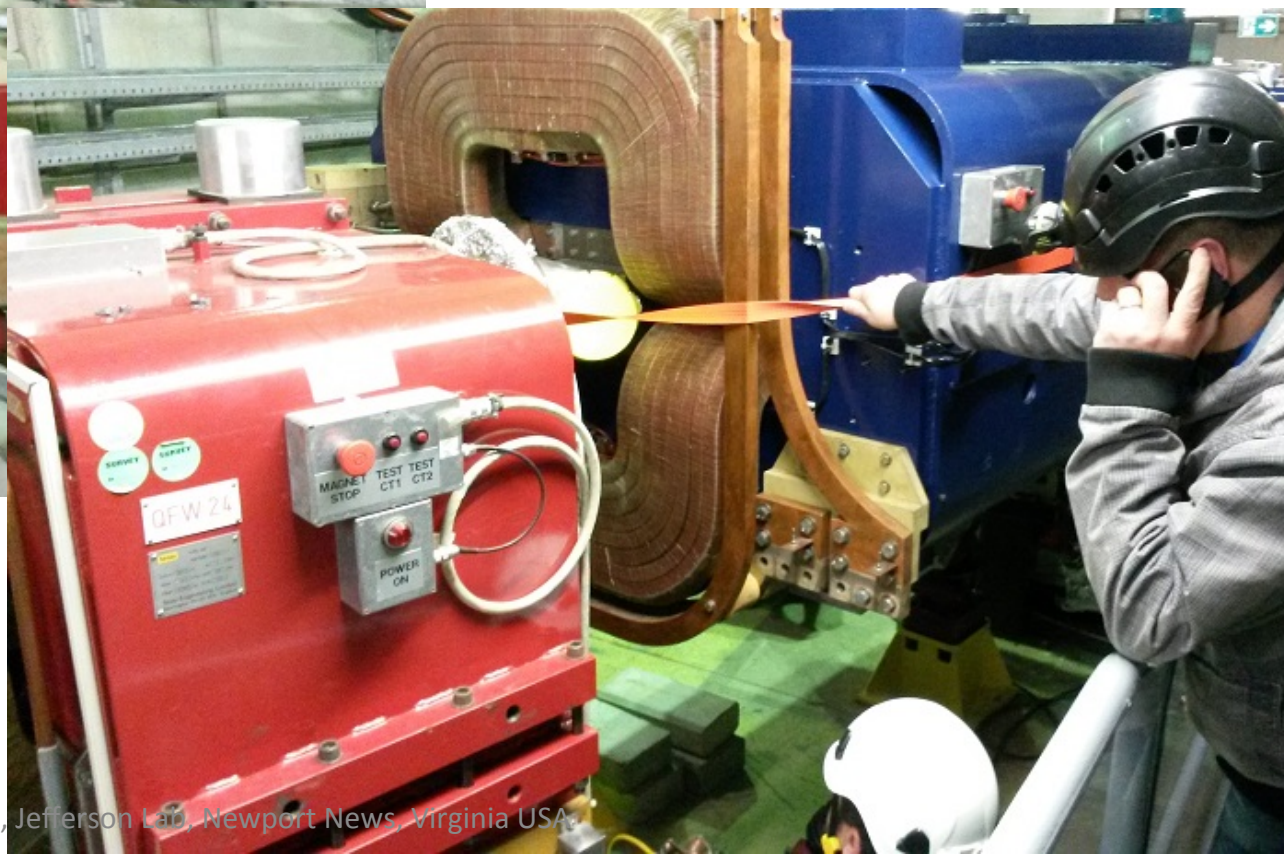
Kicker platform replacement

Pulse generators re-located to B393 including renewal of electronics/interlocks/controls interface etc.

pulse generators in the new building B393

Ring main dipole magnet refurbishment

BHZ23 & BHZ24 renovated, 21 more of these will be done over the next years.



e locations, AD equipment or
nental installations is installed on
he shielding above...

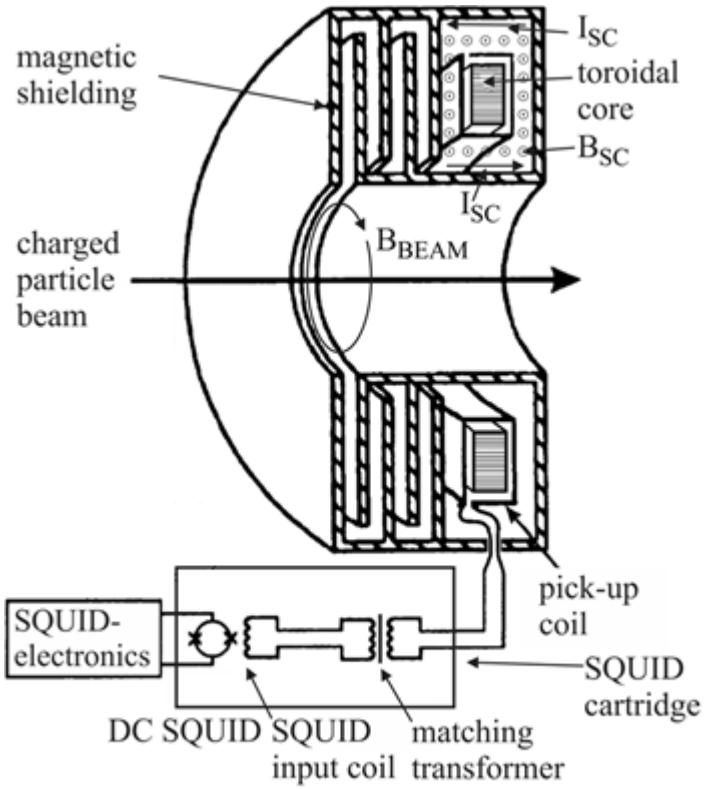
SQUID based Cryogenic current comparator

nents for a new current/
ensity monitor:

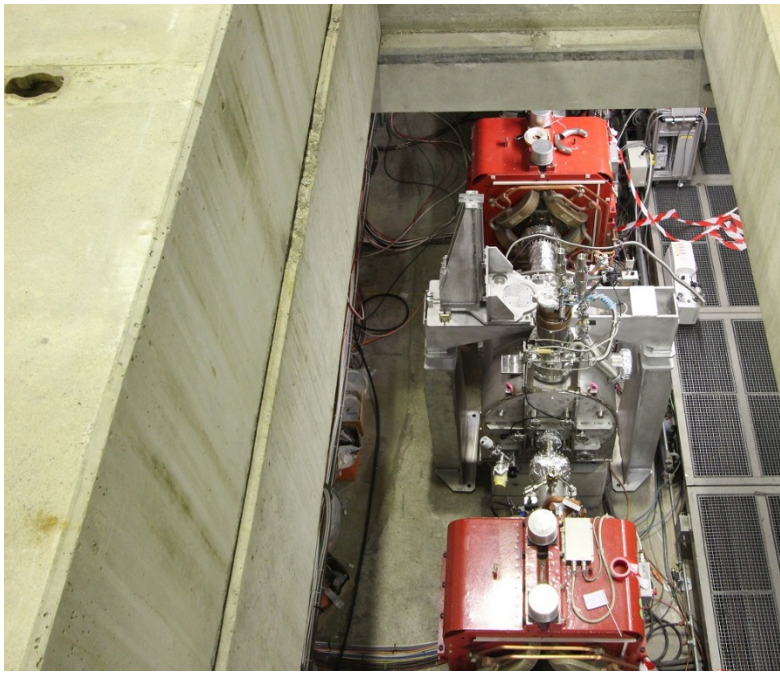
rent resolution: 10 nA
ensity resolution: 5 x 10^5 e
pends on β)
ndwidth: DC - 1 kHz

c

ro boil off" using a pulse
e refrigerator as
quefier unit
v vibration levels
g term operation
Installed in section 15
ing 2014/15 shutdown
l be upgraded next
tdown due to Cryo
blems.



- Would permit more precise intensit measurements in AD, especially dur beam cooling phases



Courtesy: Miguel

CCC results and Schottky comparison

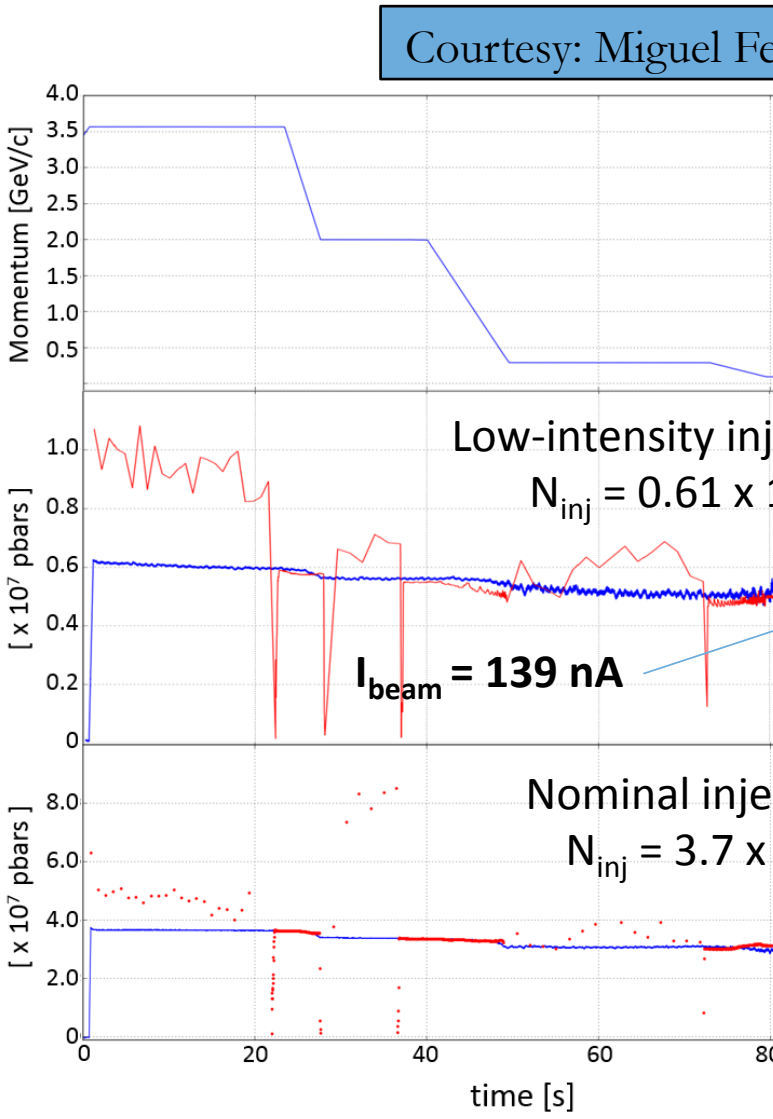
First ccc results are encouraging !

ky:
ed:
esolution of 200 *ms*
acy error > 10%

esolution of 20 *ms*
acy error of <10%
gth dependency
calibration process

t resolution (1µA)
w current regime

Ts:
bunched phases

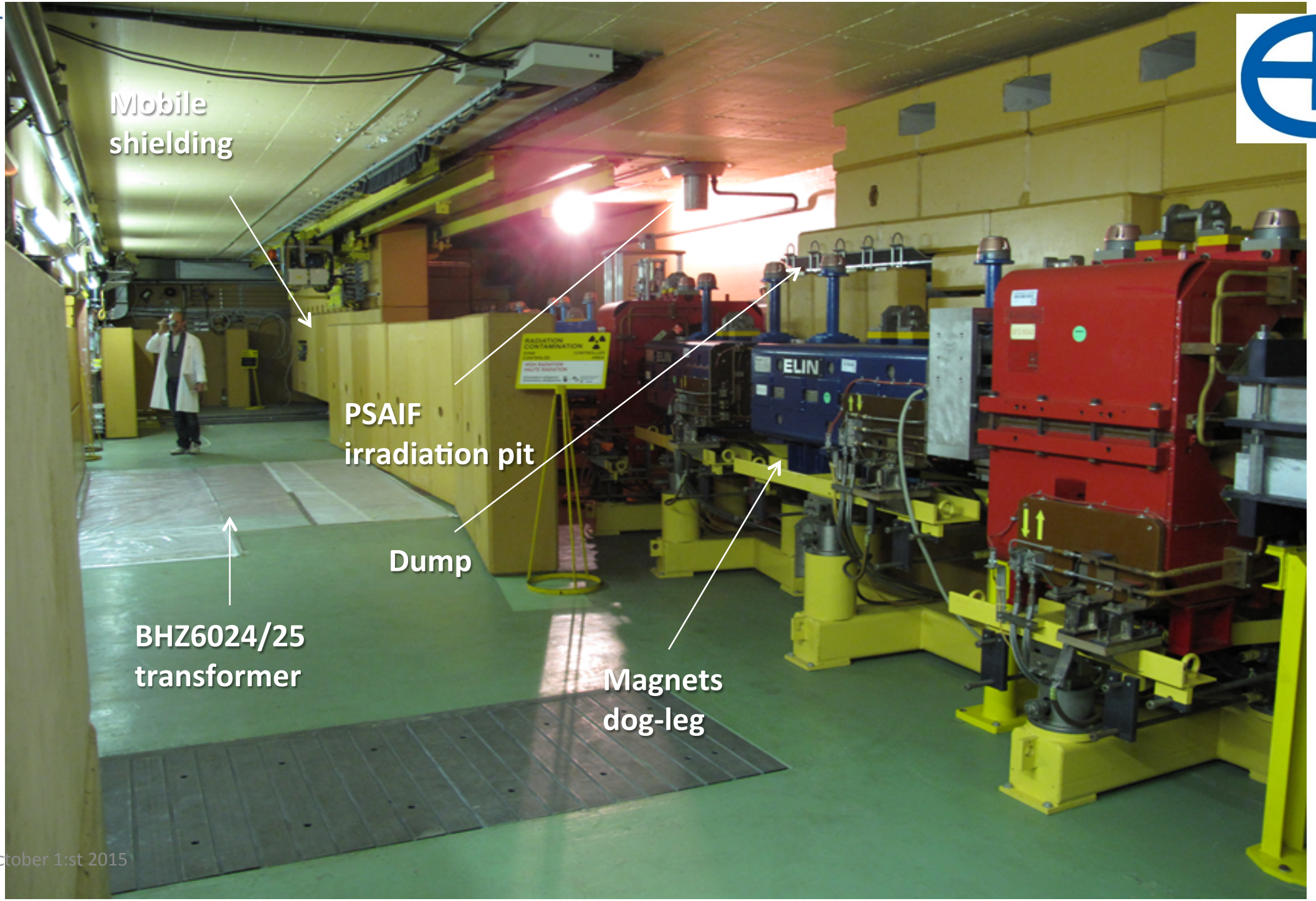


AD consolidation

- Most of AD dates from ~1980 => Main components are 30-35 years old….,
- CERN-wide standardisation also a motivation
- Due to other important CERN programs (LHC), only urgent issues were addressed for the first ~10 years of AD operation
- For many years, AD items were below the budget cut-off line due to LHC priorities
- A small consolidation program (~2.3 MCHF), independent of the LHC program, started in 2009 in view of running AD until 2016 or so
- After approval of the ELENA project, the scope of the consolidation increased and is aimed at continued operation of AD for at least 10-15 years after ELENA physics has started which means 2030 - 2035
- Concerned items are: Target area, magnets, power converters, vacuum system, beam cooling, instrumentation, RF, control system, Infrastructure etc.
- AD is at the moment in the middle of a major consolidation program with a budget plan of 23.8 MCHF allocated for the period 2014 – 2020

Target Area

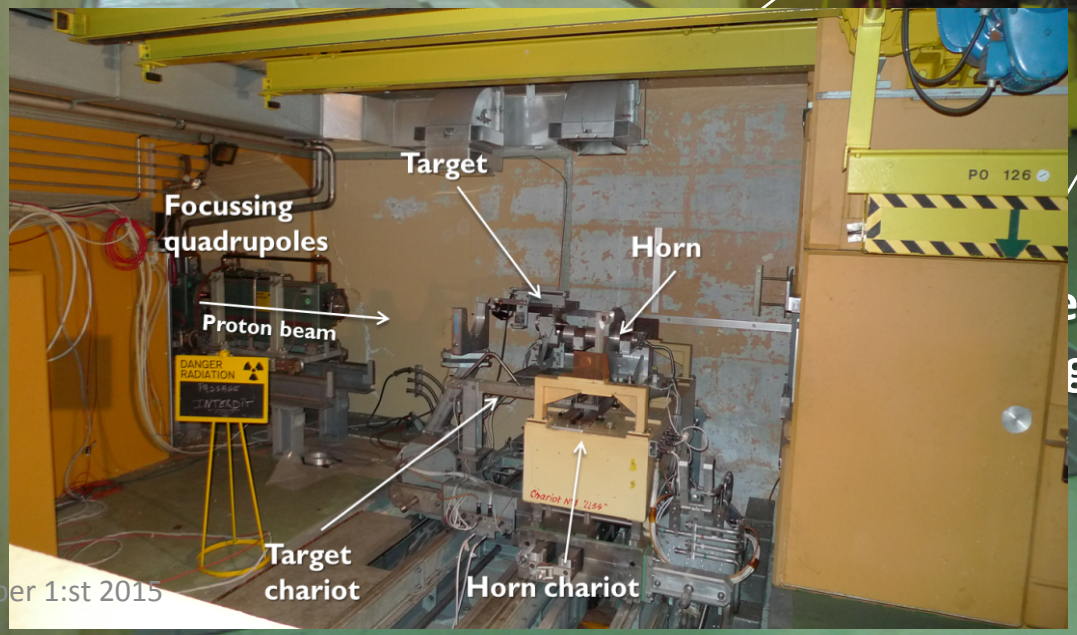
- During the SPS p$\bar{p}$ & LEAR programs (1980 – 1996) a full team was looking after design, operation and maintenance
  - Since the AD start-up only limited follow-up was done
  - Most of control equipment was conceived as prototypes
- Few problems occurred during 15 years of AD operation
  - Repetition rate is now ~ 100s, the target area was designed for 2,4 s
  - Very reduced maintenance over the year – loss of expertise
- Significant **impact on AD physics** in case of failure between LS2 and LS3
  - Know weak points (target, horn, magnets…)
  - Very long physics stops (**≥ year**)
- Increase **contamination levels and associated radiological risks**
- Horn assembly failure (stripline clamping system breakdown)discovered in LS1 is an indication that urgent consolidation is needed for the whole area

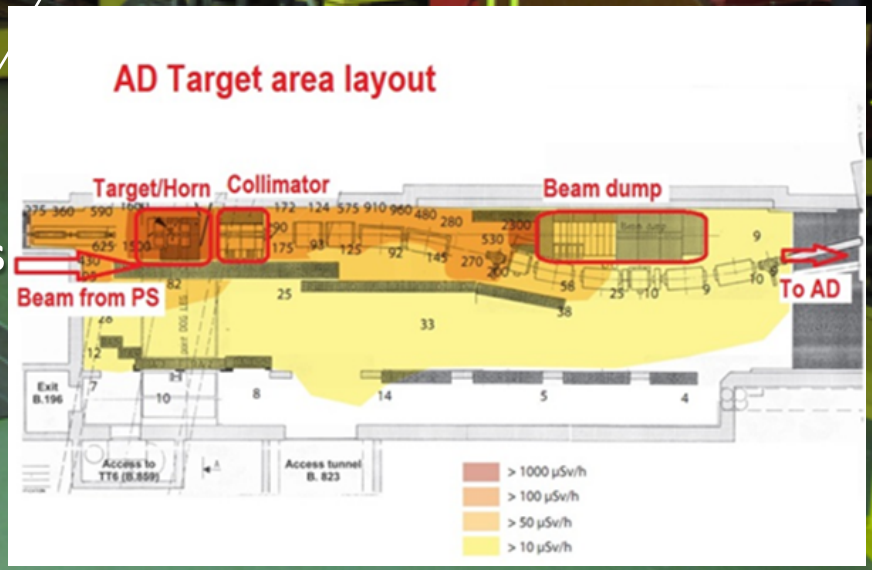

Mobile shielding
PSAIF irradiation pit
Dump
BHZ6024/25 transformer
Magnets dog-leg
ELIN


Mobile shielding
PSAIF irradiation pit
Focussing quadrupoles
Target
Horn
Proton beam
Target chariot
Horn chariot

Mobile shielding

PSAIF irradiation pit





Target Area, main items

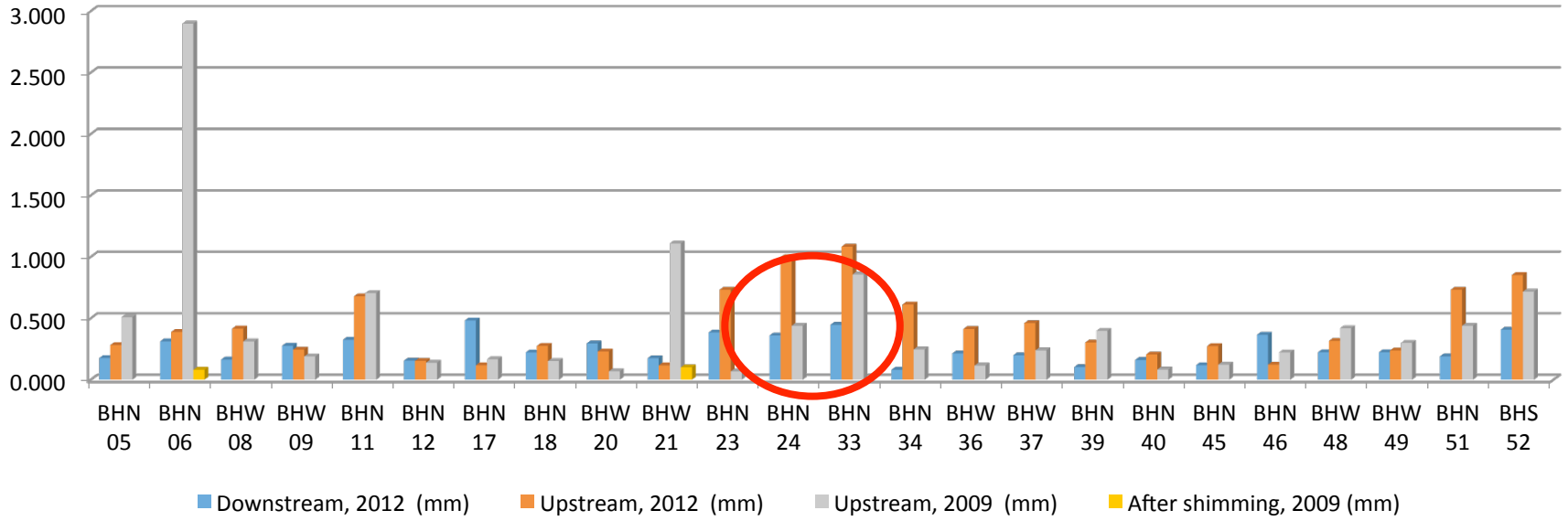
- Re-design of targets – air cooled targets instead of water cooled; heat loads under various future operational scenarios are being estimated.
- Magnetic Horn; production of new units (spare situation critical…)
- Target & Horn chariots + transport systems renewal
- Target area magnets:

  Quadrupoles upstream of target (9050 & 9052). Area is very hot,1 spare exists but lack of knowledge about state, manipulation & connections. Alternative designs are being considered including permanent magnets (SmCo). Radiation levels in the precise locations are being measured during this run.

  Remaining Bendings and quads: renovation of spare (irradiated) units
- Surface buildings renovation
- Ventilation & cooling system renewal
- Etc. etc.

Magnets, ring and transfer lines

- **Most urgent units renewed,** spare inventory almost complete.
- **Ejection line magnets** (except DEM-line) will be replaced by e-static units for ELENA ~2017
- **Main bendings** (24):
  - Renovation and re-shimming: Regular coil movement measurements on remaining units will determine which one(s) next.
  - 3 units will be renovated so far. 21 to go.



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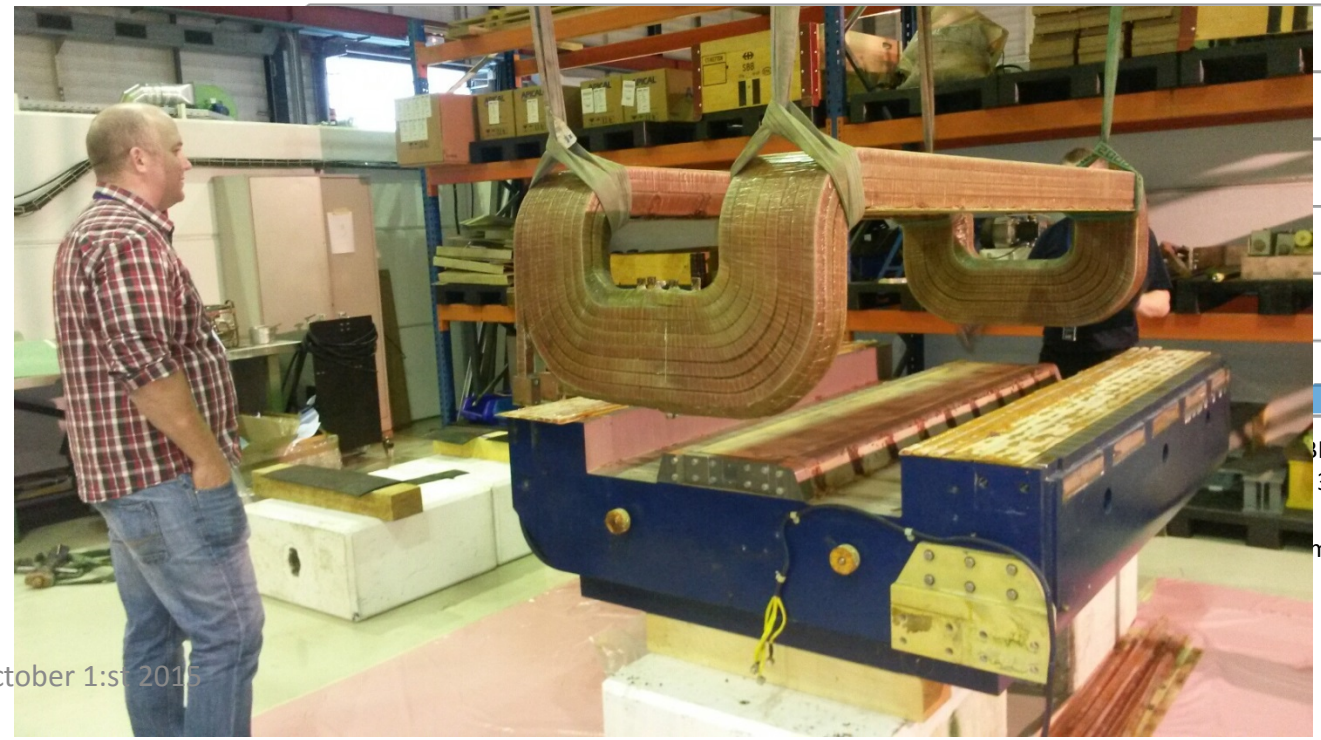

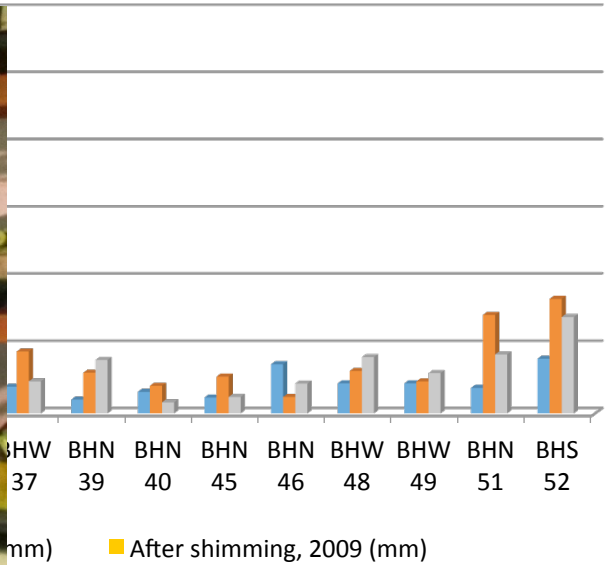

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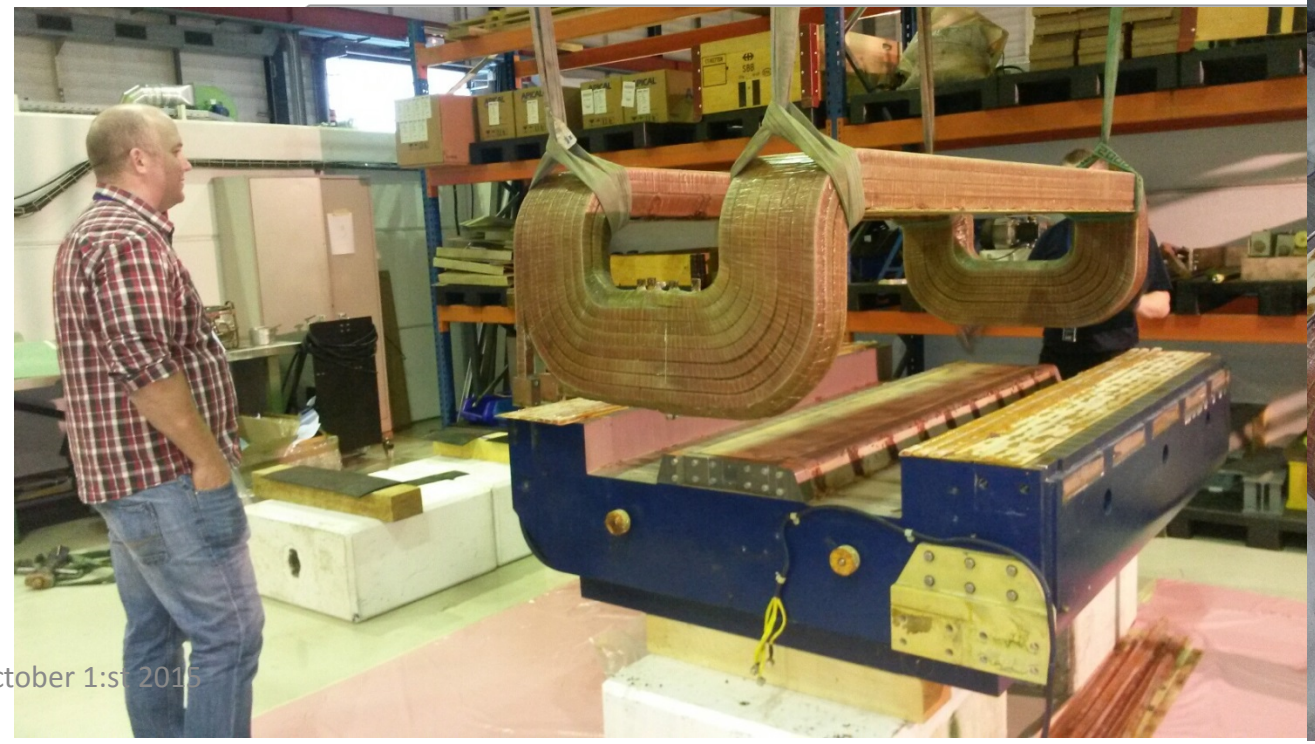

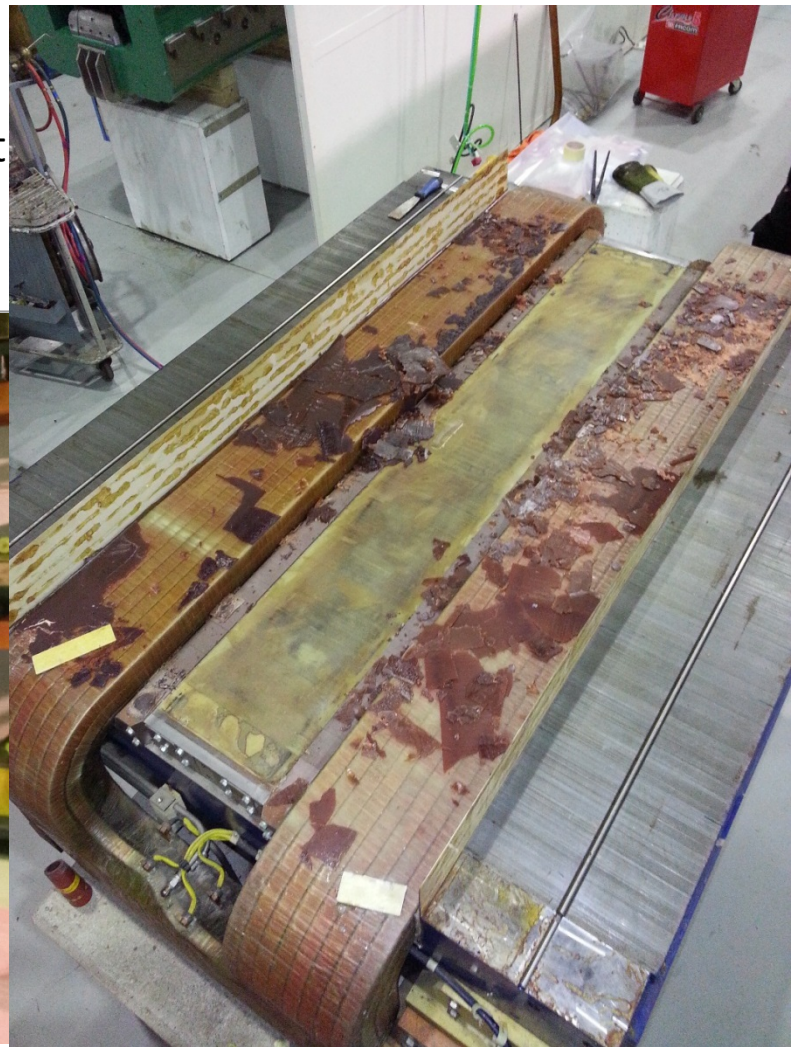

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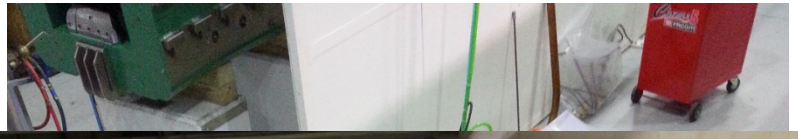

Stochastic cooling

- **Controls, electronics, delay/attenuator platform installation, individual u-wave amplifier power supplies and p/u & kicker movement motors/electronics all renovated or replaced during LS1.**
- **Notch filters**: Replacement of large cable-box with optical filter system. 2015. Glassfiber notch filter (to replace coax line filters) obtained from GSI and lab tests underway..
- **0.8 – 1.6 GHz power amplifiers** (48): Obsolete semi-conductors, increased failure rate. Prototyping for new design (if old amplifiers become unrepairable or too unreliable).
- **Vacuum tanks:** Life expectancy and mechanical integrity of pickup and kicker vacuum tanks & s-cooling equipment inside. ***Possible consolidation not yet addressed.***

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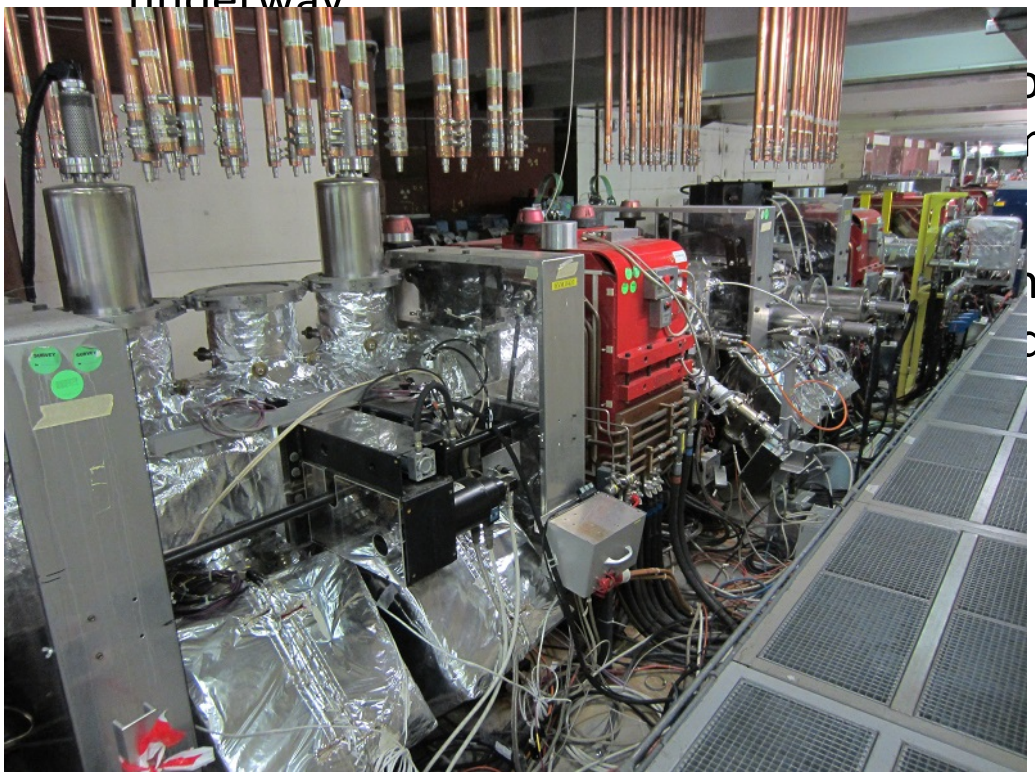

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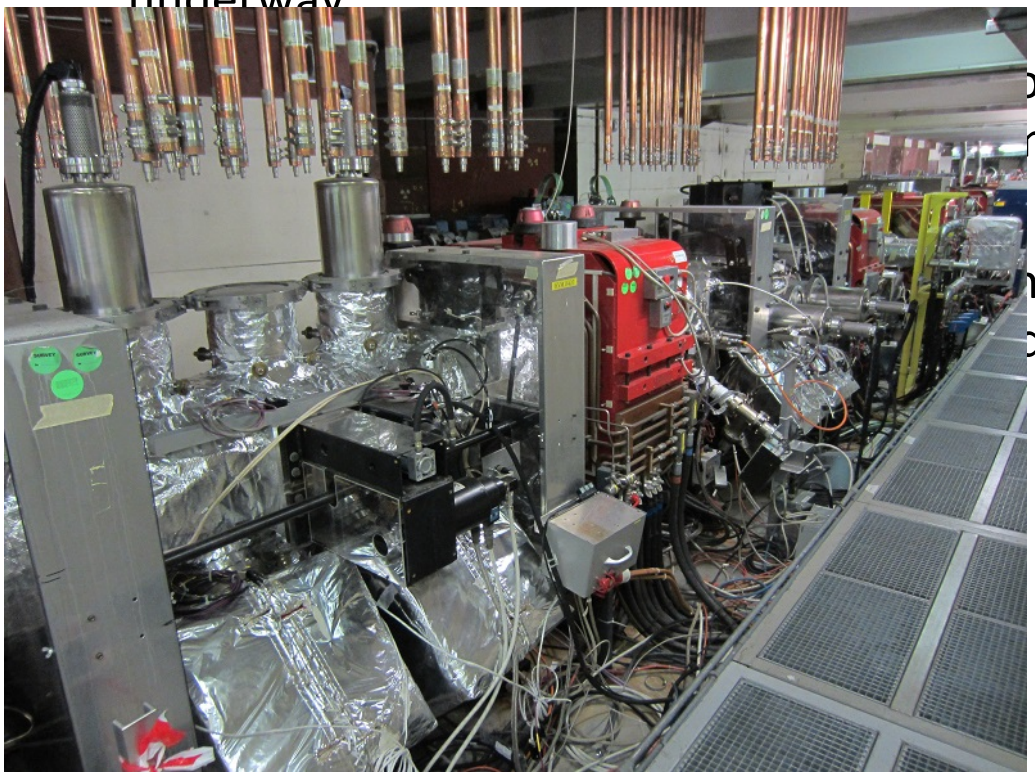

Electron cooling consolidation

- **Renewal of electron cooler**:
  - Build a new state-of-the-art cooler
  - 2015 – 2018. Aim for installation in LS2.
  - Existing cooler:
    - Is >35 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

Momentum pbar	300 MeV/c	100 MeV/c
Electron energy	30 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 (π × mm × mrad)	0.8 / 0.5 (π × mm × mrad)
dp/p	10^{-4}	$< 7 \times 10^{-5}$

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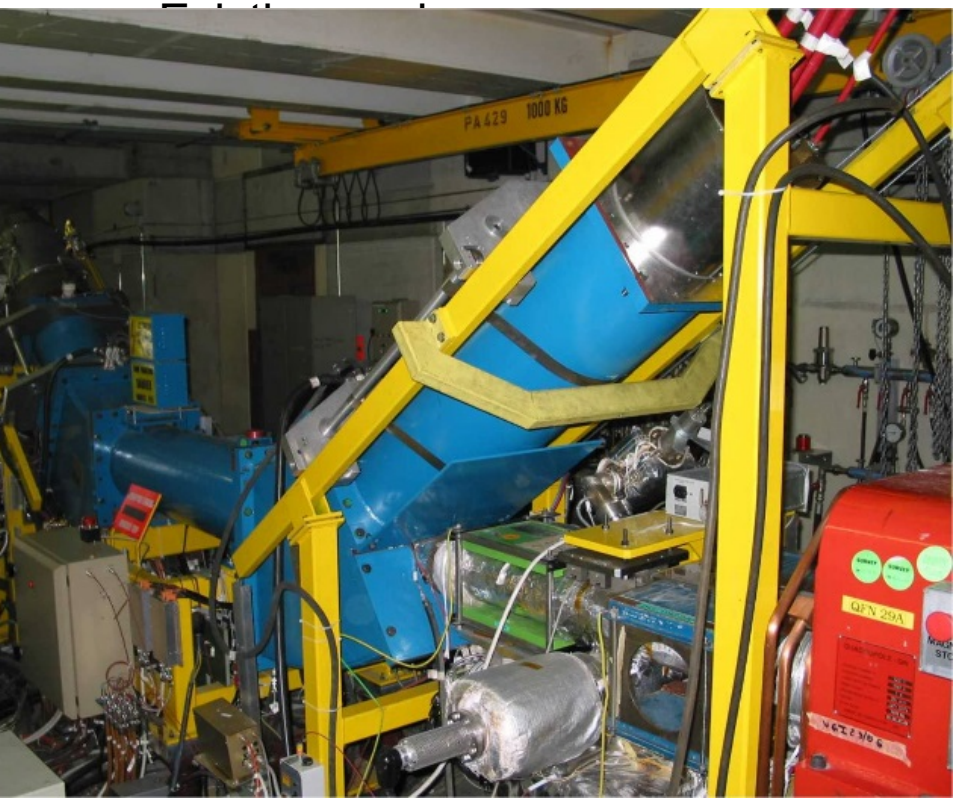

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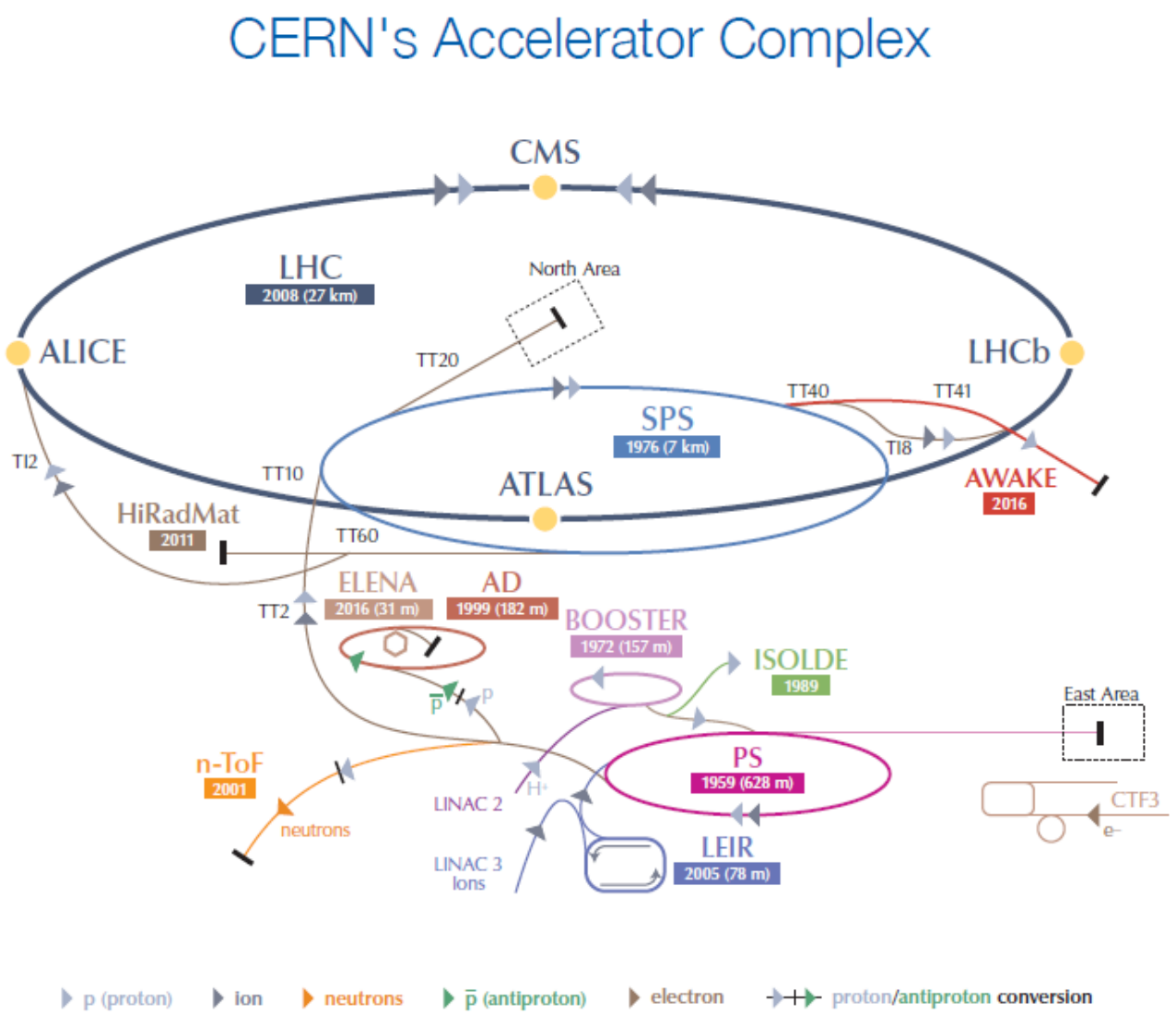
And also…..

- **Instrumentation:**
  - **Orbit system**: solution with individual ADC:s, similar to planned ELENA system. Will permit measurements during ramps. Standard analysis/correction SW operational in AD.
  - **BBQ-tune measurement**: Using existing pickup, commissioned but not yet in regular operation.
  - **Schottky analysis** (longitudinal): integrate ageing DSP equipment into new C02 LL beam control system + new system for visual monitoring. 2016 – 2018
- **RF:**
  - **C02 HV & tuning power supplies.** New, smaller systems. Re-located to make space for ELENA.
  - **C02 Low-Level:** Migration to PSB/ELENA-like DSP based system (including Schottky analysis).
  - **C02/C10 interlock system renewal;** PLC-based standard CERN implementation
  - **C10 Low-Level & High-Level renewal:**
    - C10 final stage (obsolete TH116 valves): New power amplifier/control/interlock systems to be developed.
    - Re-build existing stock of used TH116 – being investigated
- **Controls/software:**
  - **Major LS1 renovation:**
  - Front-end upgrade (ACCOR): ~complete (80-90%) renewal in LS1
  - Central Timing: re-design for de-coupling AD from the LHC injector complex
  - Cycle Generation: adaptation to comply with new central timing system
  - New Beam Request Server
  - Similar CT, CG and BRS systems will be implemented in ELENA
  - Obsolete SW has been eradicated; complies with present CERN standards
  - Some implications:
    - Major debugging effort during 2014 start-up !

ELENA


CERN's Accelerator Complex
CMS
LHC
2008 (27 km)
North Area
ALICE
LHCb
TT20
TT40
TT41
SPS
1976 (7 km)
TI8
TI2
TT10
ATLAS
AWAKE
2016
HiRadMat
2011
TT60
ELENA
2016 (31 m)
AD
1999 (182 m)
TT2
BOOSTER
1972 (157 m)
ISOLDE
1989
East Area
n-ToF
2001
PS
1959 (628 m)
LINAC 2
LINAC 3
Ions
neutrons
LEIR
2005 (78 m)
CTF3
p (proton)
ion
neutrons
p̄ (antiproton)
electron
proton/antiproton conversion

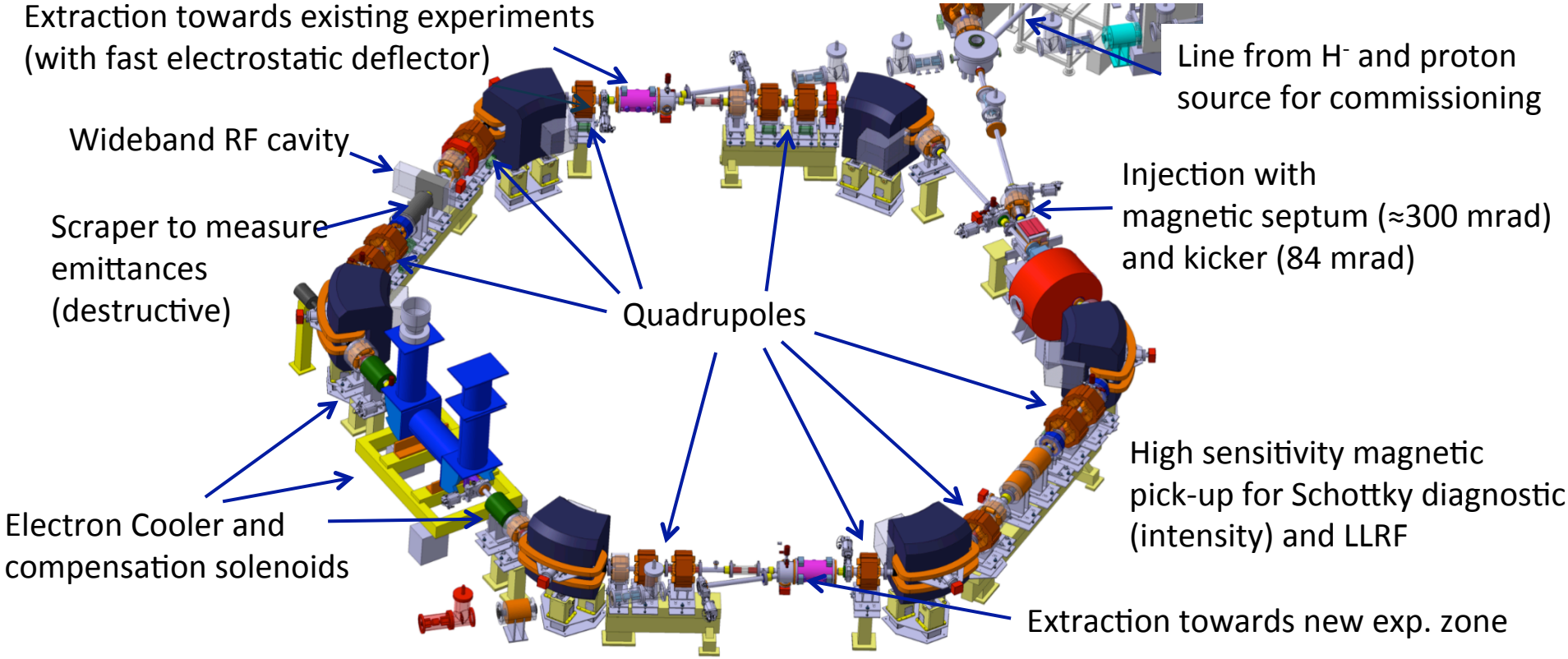
ELENA

- Motivation:
  - Build a smaller version of AD for further deceleration
  - Electron cooling at 2 energy levels will permit efficient deceleration and higher beam densities
  - Final deceleration at experimental traps will be reduced to 100 => 5 keV (vs. 5.3 MeV => 5 keV)
  - => use of much thinner degrader foils
  - => less losses and blow-up
  - Pbar trapping efficiency at the experiments expected to increase by up to 2 orders of magnitude
  - Several experiments can be served simultaneously by using fast kickers and deflectors

  - Concept (and name!) was proposed first in 1981 by H.Herr as an addition to LEAR
  - Approved by CERN research board in 2011 as an addition to AD

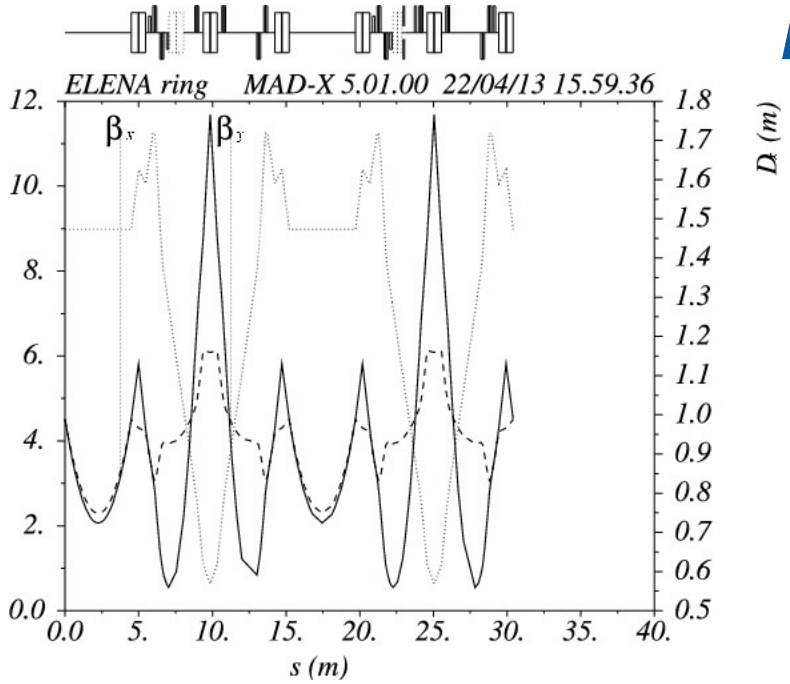
ELENA Overview

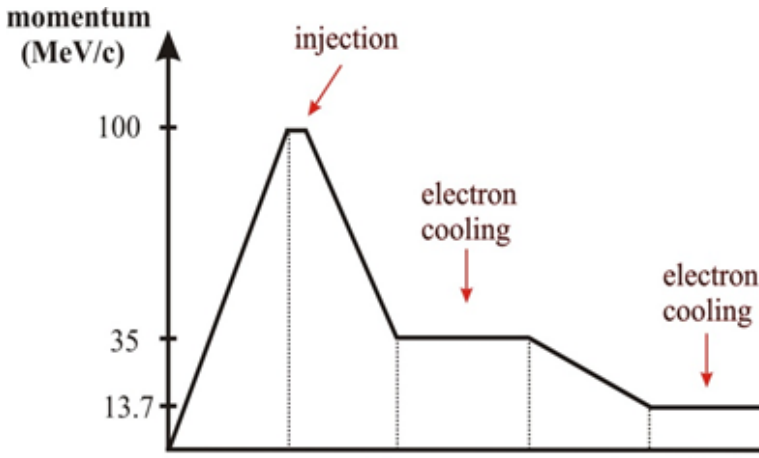
- Deceleration of antiprotons from 5.3 MeV to 100 keV to improve efficiency of experiments
- Circumference 30.4 m (1/6 the size of the AD)
  - Fits in available space in AD hall and allows installing all equipment without particular efforts
  - Lowest average field (beam rigidity over average radius) Br/R = 94 G (smaller than for AD 115 G)



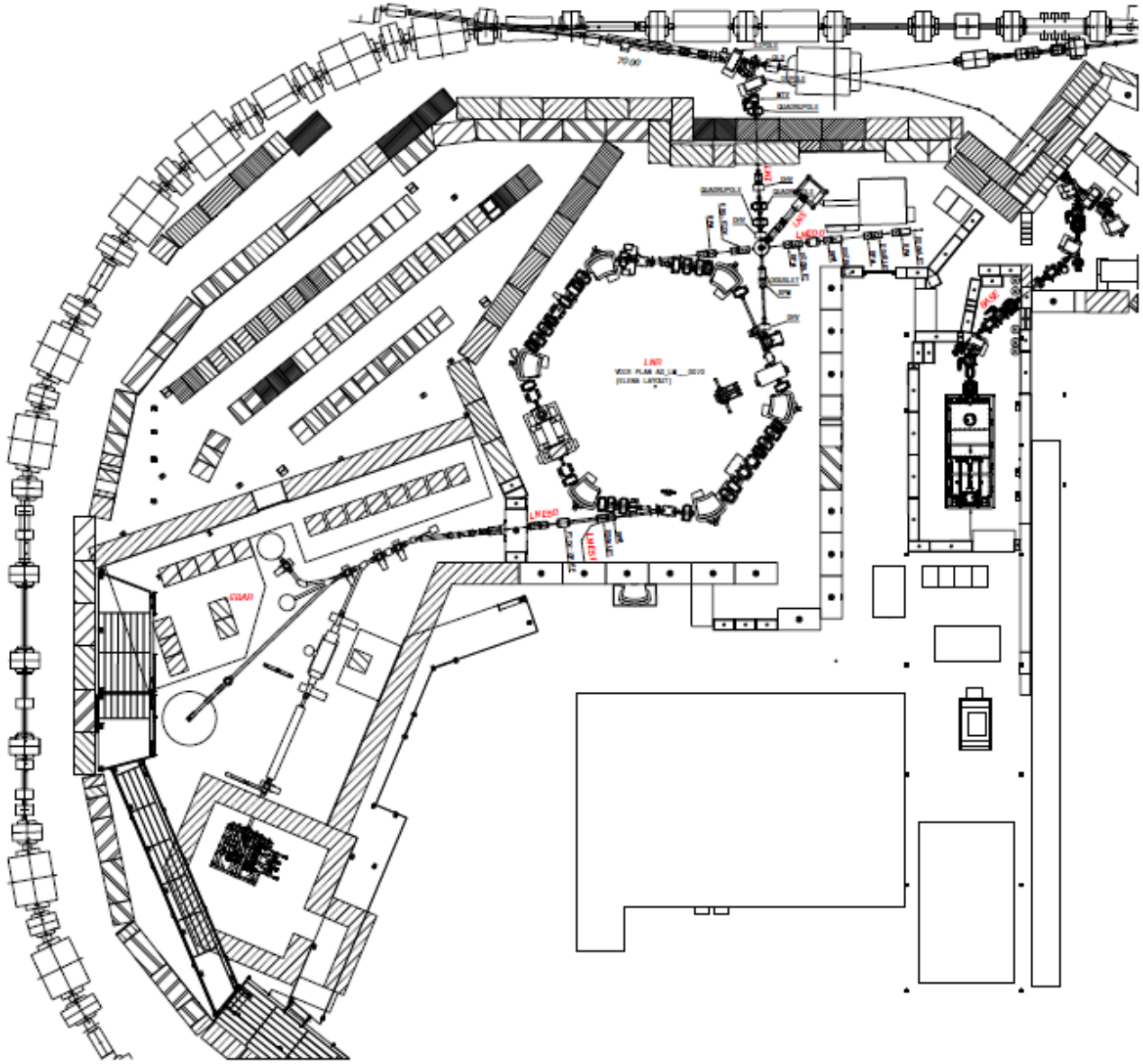
ELENA basic parameters

omentum range, MeV/c	100 - 13.7
ergy range, MeV	5.3 - 0.1
rcumference, m	30.4
ensity of injected beam	3×10^7
ensity of ejected beam	1.8×10^7
umber of extracted bunches	1 to 4
nittances (h/v) at 100 KeV, π·mm·mrad, [95%]	4 / 4
/p after cooling, [95%]	10^{-3}
nch length at 100 keV, m / ns	1.3 / 300
quired vacuum pressure, pTorr	3





ELENA Overview and Layout - 2016



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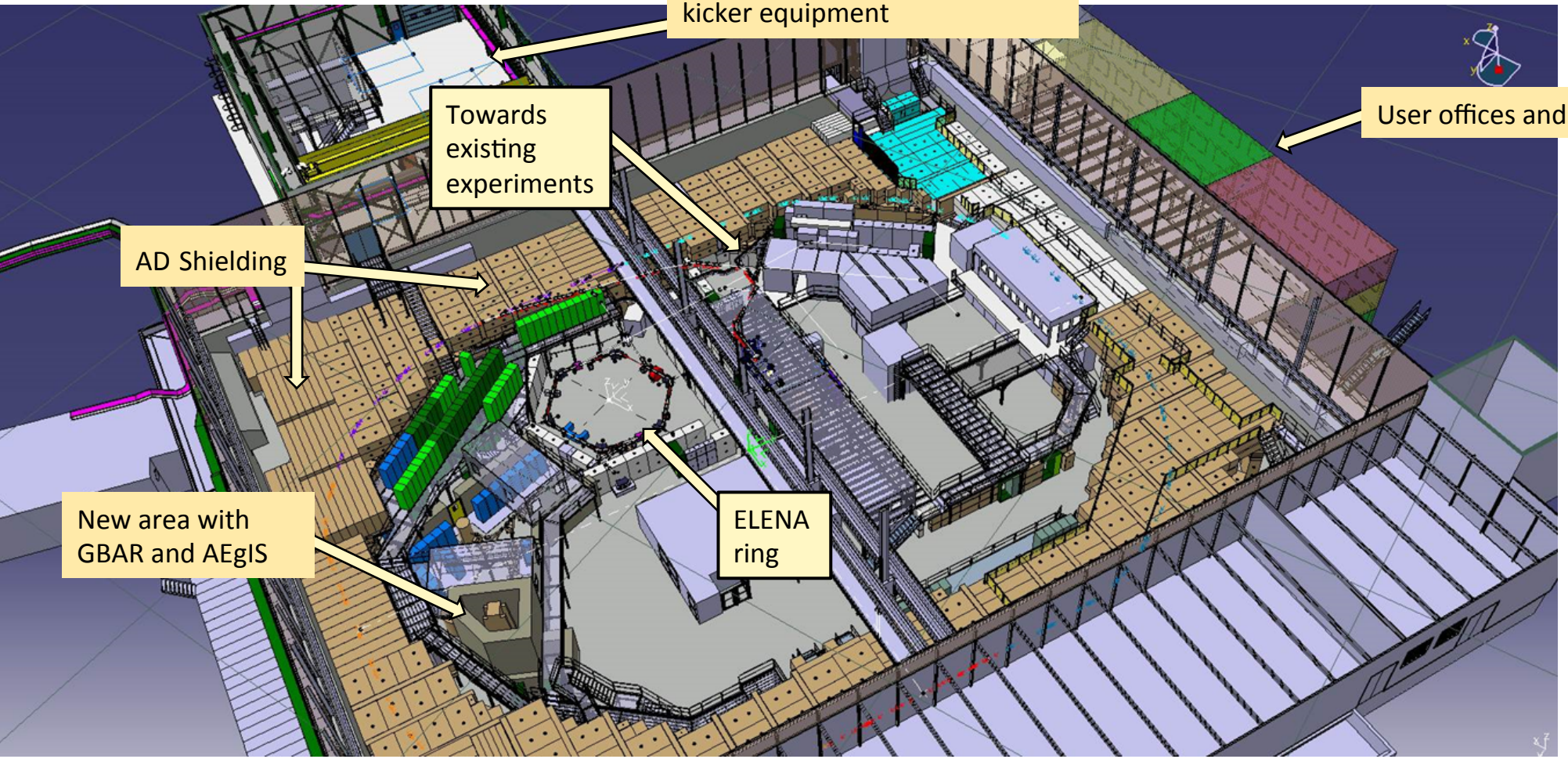

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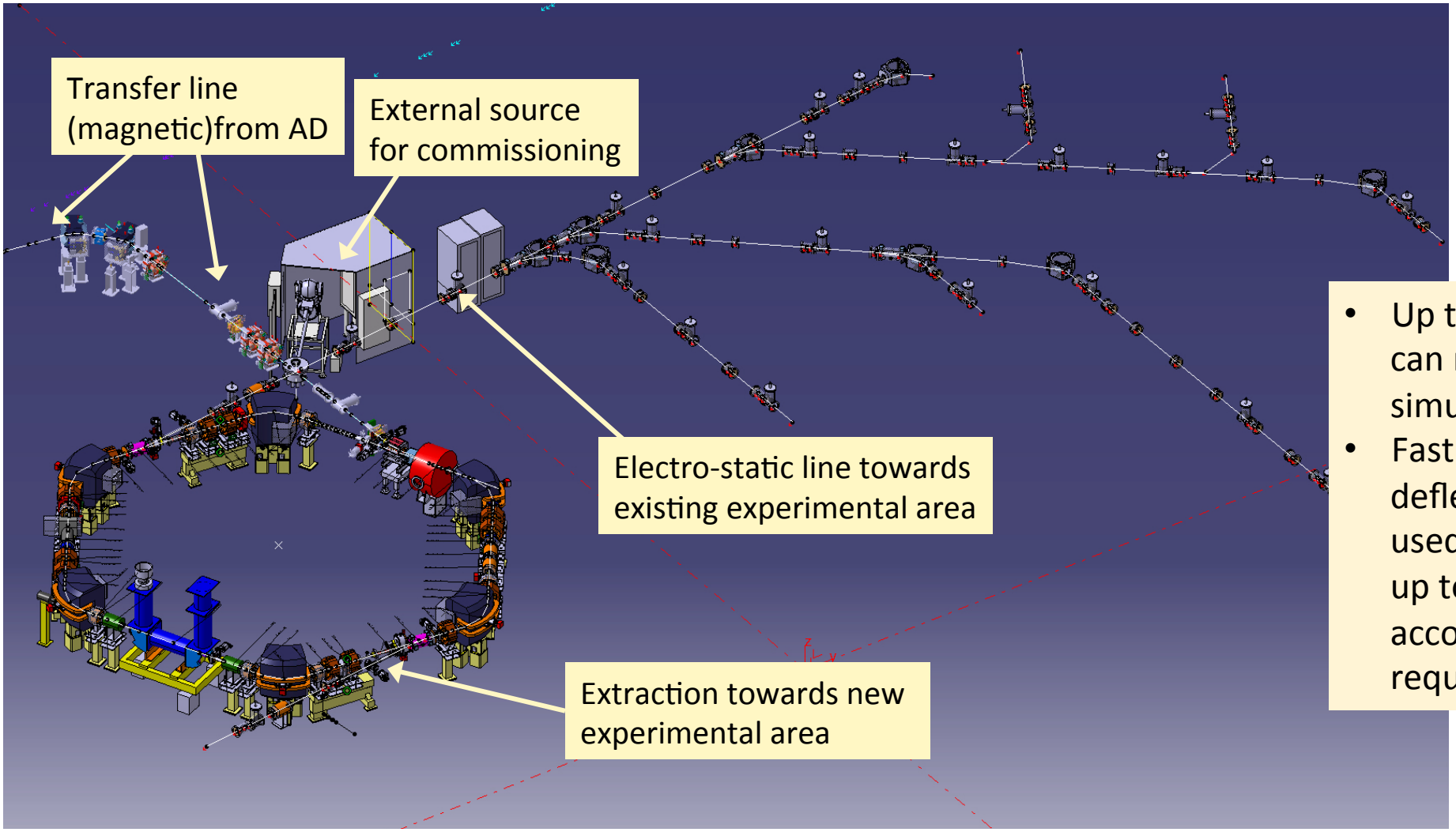


- Up to 4 expe can receive simultaneou
- Fast kickers deflectors w used to distr up to 4 bunc according to requests

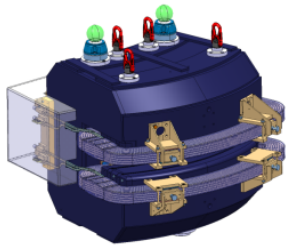
Selected Features and Challenges

- Energy Range
  - Machine operated at an unusually low energy for a synchrotron (down to 100 keV!)
- Lattice and geometry
  - Many Constraints (Long straight Section with small Dispersion for Electron Cooling, Geometry in AD hall, Beta Functions and resulting Beam Sizes, Working Point ...)
  - Hexagonal shape and optics with periodicity two (two long Straights without Quadrupole Magnets)
- Electron cooling
  - Applied at two plateaus to mitigate losses and generate dense bunches
  - Very low energy electrons at bottom plateau
  - Bunched Beam Cooling at 100 keV extraction Energy to generate dense Bunches for Experiments
  - Effect (perturbation) of magnetic field of cooler on circulating antiprotons: delicate study started, continuation under discussion
- Expected main performance limitation: Intra Beam Scattering
  - Determines beam parameters with cooling (equilibrium between the two processes)
- Vacuum System: fully baked with NEGs where possible to reach 3 10^{-12} Torr

  ➠ Interactions with rest gas (Blow-up, Losses) not the dominant limitation despite the low energy
- Beam Diagnostics with very low Intensities and at low Energy
  - E.g.: Beam currents down to well below 1 mA far beyond reach standard slow BCTs

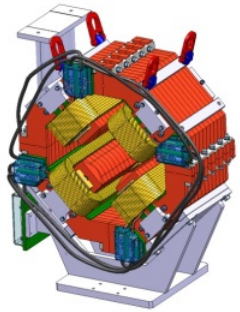
  ➠ Intensity of coasting beam measured with Schottky diagnostics or ccc

Main components production status

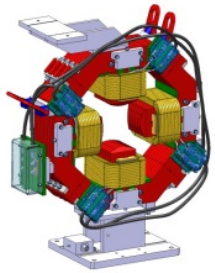


8 dipoles

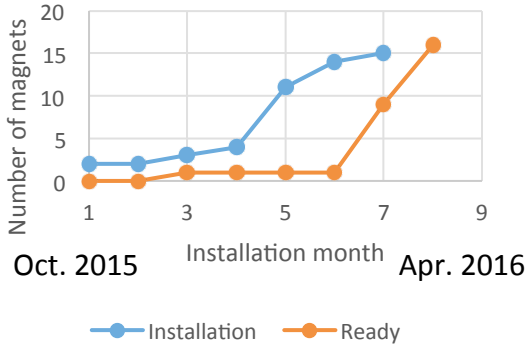
Magnet	Ready
Sector 2	18/02/2016
Sector 3	18/02/2016
Sector 4	16/03/2016
Sector 5	16/03/2016
Sector 6	13/04/2016
Sector 1	13/04/2016



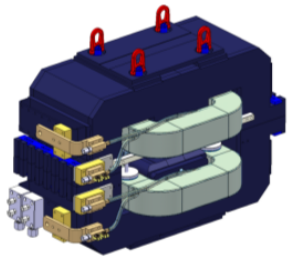
16 quadrupoles

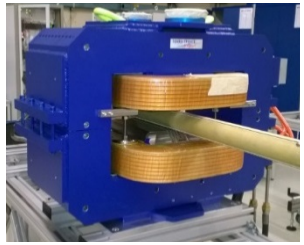


3 skew quadrupoles



Oct. 2015 Apr. 2016



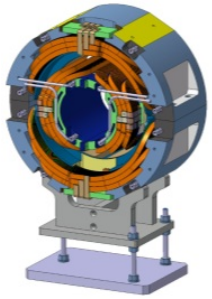


3 TL dipoles

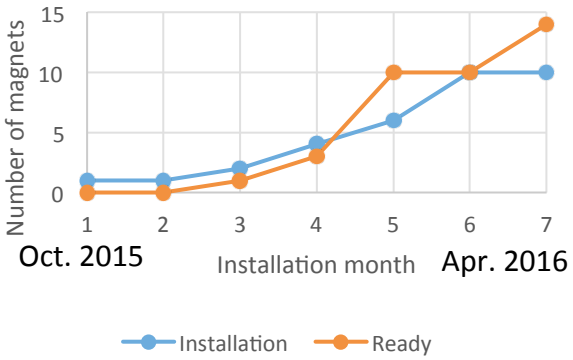
Magnet	Ready
3 magnets	1 available 2 in October 15

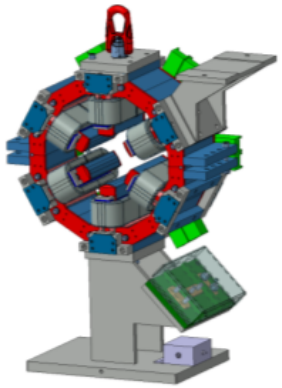
Courtesy: D. Schoerling

Main components production status (2)



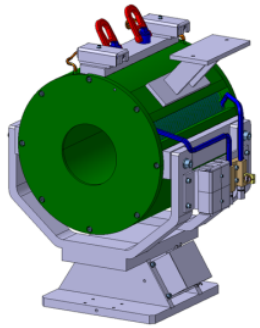
14 H/V correctors





5 sextupoles

Magnet	Ready
Pre-series	10/2015
Series	12/2015



3 solenoids

Magnet	Ready
2 magnets	01/2016

Courtesy: D. Schoerling

Main components production status

ic measurements on ELENA MBR pre-series

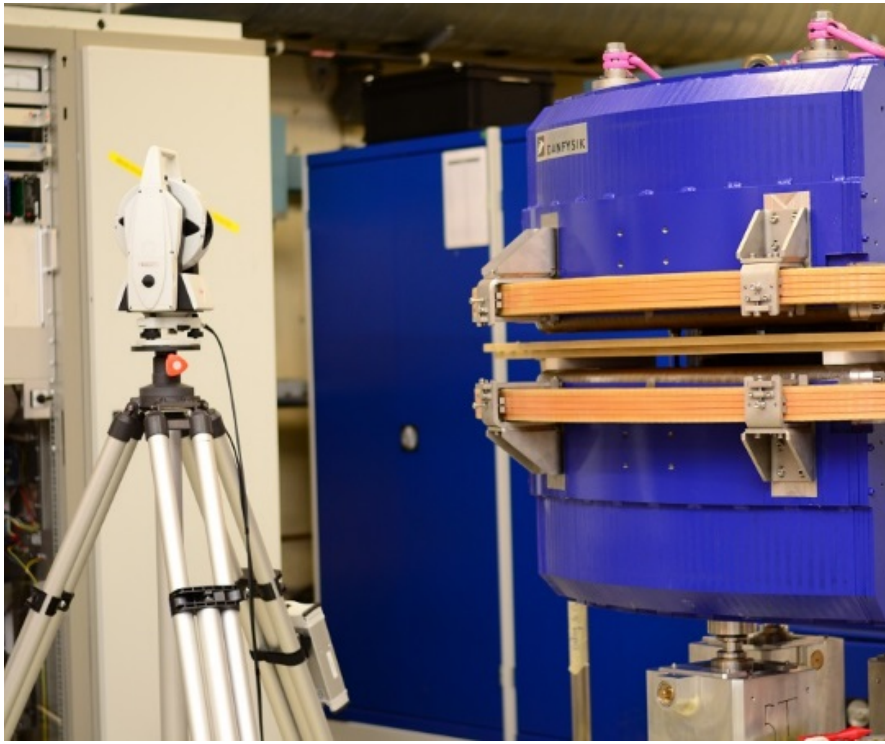
ntense measurement campaign has been carried out.
nstrumentation and methods:

- Fluxmeter
- Hall-probe mapper
- Stretched wire

mplete characterization of the magnet:

- Central field — B_0 = 0.42881 T at 326 A
- Integral field — Bdl = 0.4179 T m at 326 A
- Magnetic length — L_m = 974 mm
- Remnant field — $Bdl_{remnant}$ = 0.78 mT m
- Field homogeneity — within ±2 units
- Eddy currents — within 10 units at 200 A s^{-1}

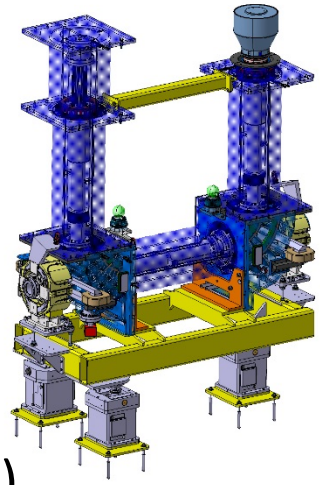
gnet is within specifications.



Courtesy: D. Schoerling

Main components production status (3)

Electron cooler:



Critical for ELENA!

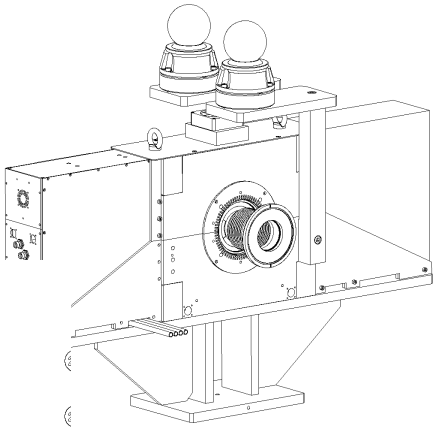
- Operate at very low electron energies (down to 55 eV).
- Operate at very low magnetic field to minimize disturbance to circulating low energy antiprotons – we have chosen 100 Gauss in the cooler.
- Have extremely good vacuum.
- Adiabatic expansion to reduce transverse temperatures.
- Very good field quality – especially in the cooler solenoid ($B_{\perp}/B_{\parallel} < 5 \times 10^{-4}$).
- Orbit correctors and solenoid compensators.

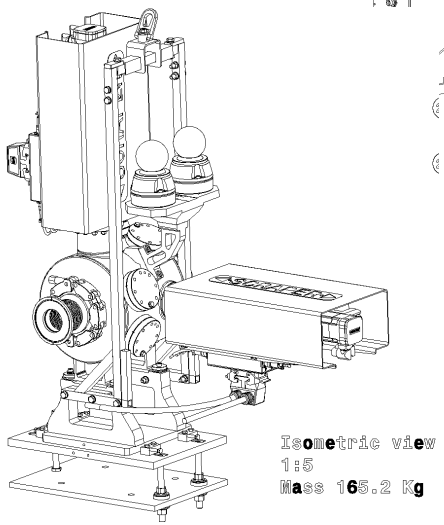
Magnetic system in production at TESLA, vacuum system designed and to be produced at CERN, Delivery expected first half of 2016

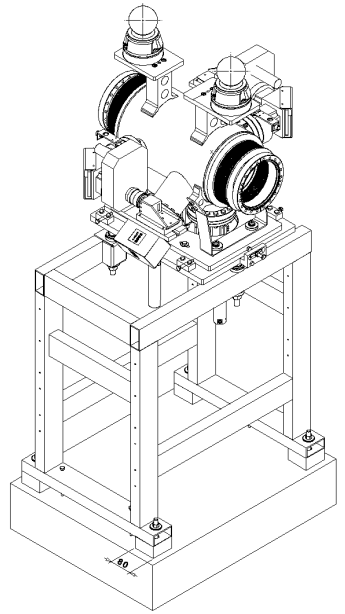
Main components production status (4)

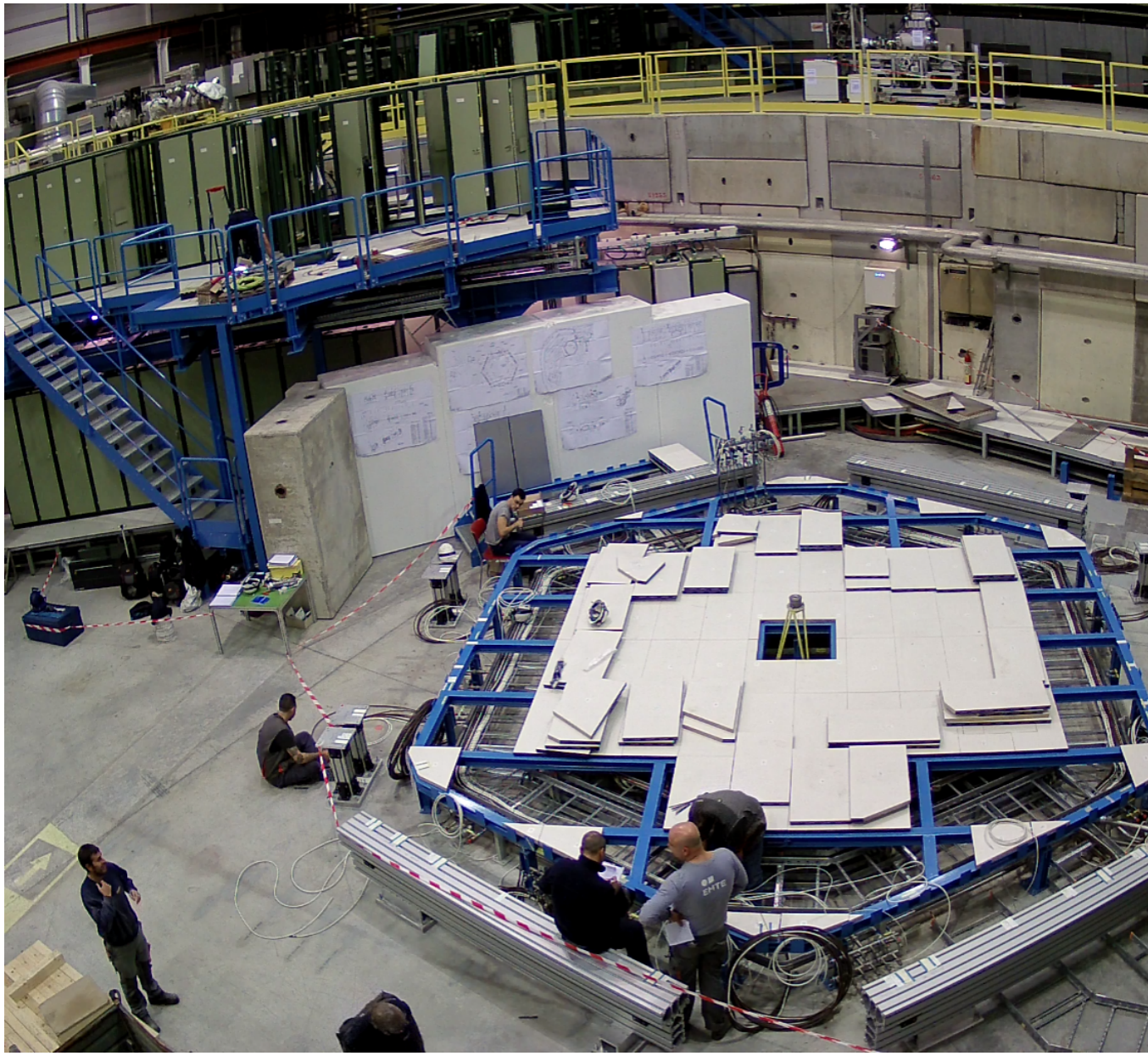
ther components: All in production – on time (!)

- RF Finemet cavity
- Scraper
- BTV
- Longitudinal pick-ups
- Beam Position Monitors
- Septum
- Injection kicker magnet
- Electrostatic elements
- Ejection line u-wire SEM grids
- Vacuum equipment
- Supports









ent situation of ELENA llation in AD hall:

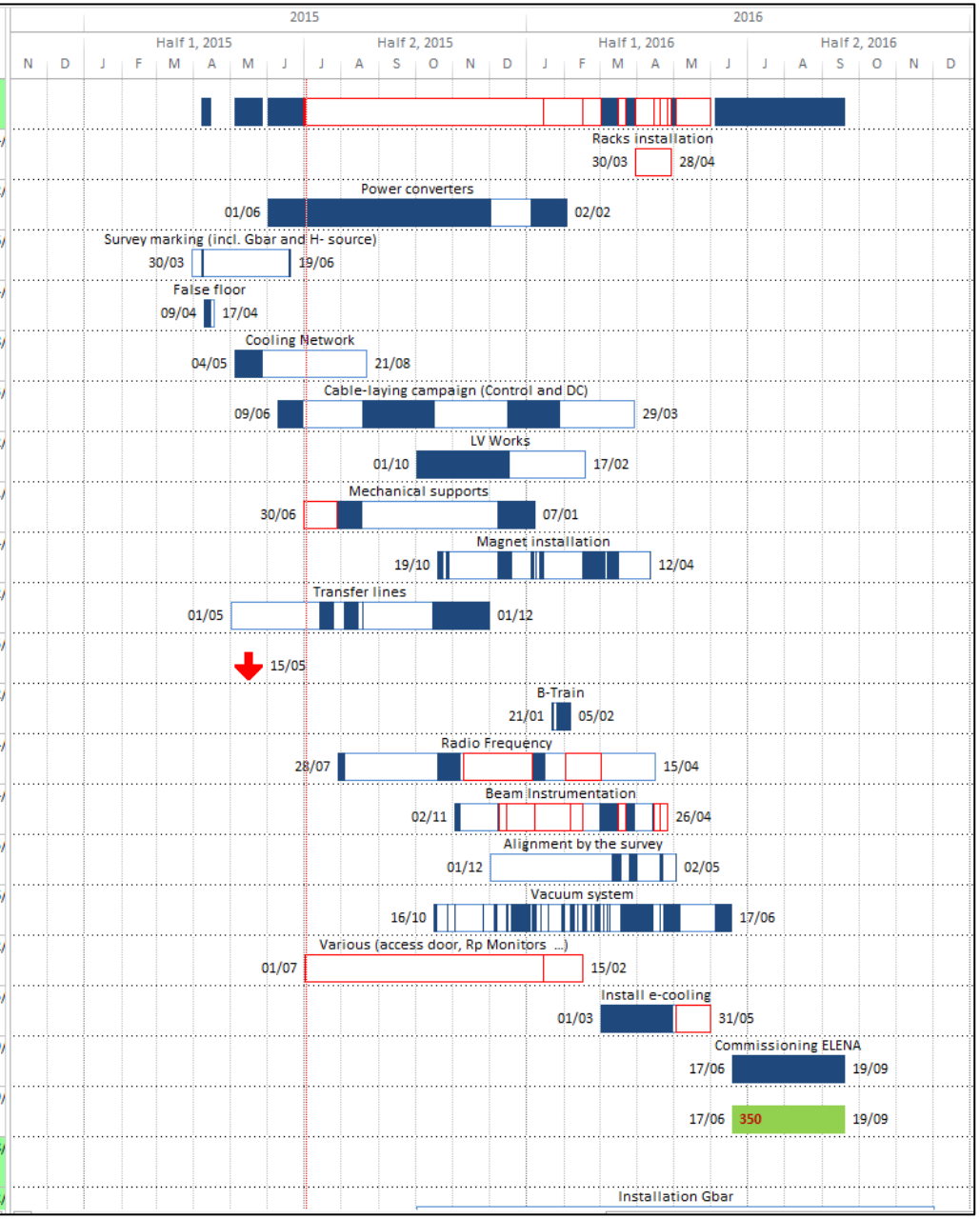
led: false floor, water bution, straight section rs, Ion source (final location), ion septum, 2:nd level ment racks, cable trays, AD on line modifications

ing: Cabling, shielding, aring experimental area etc.

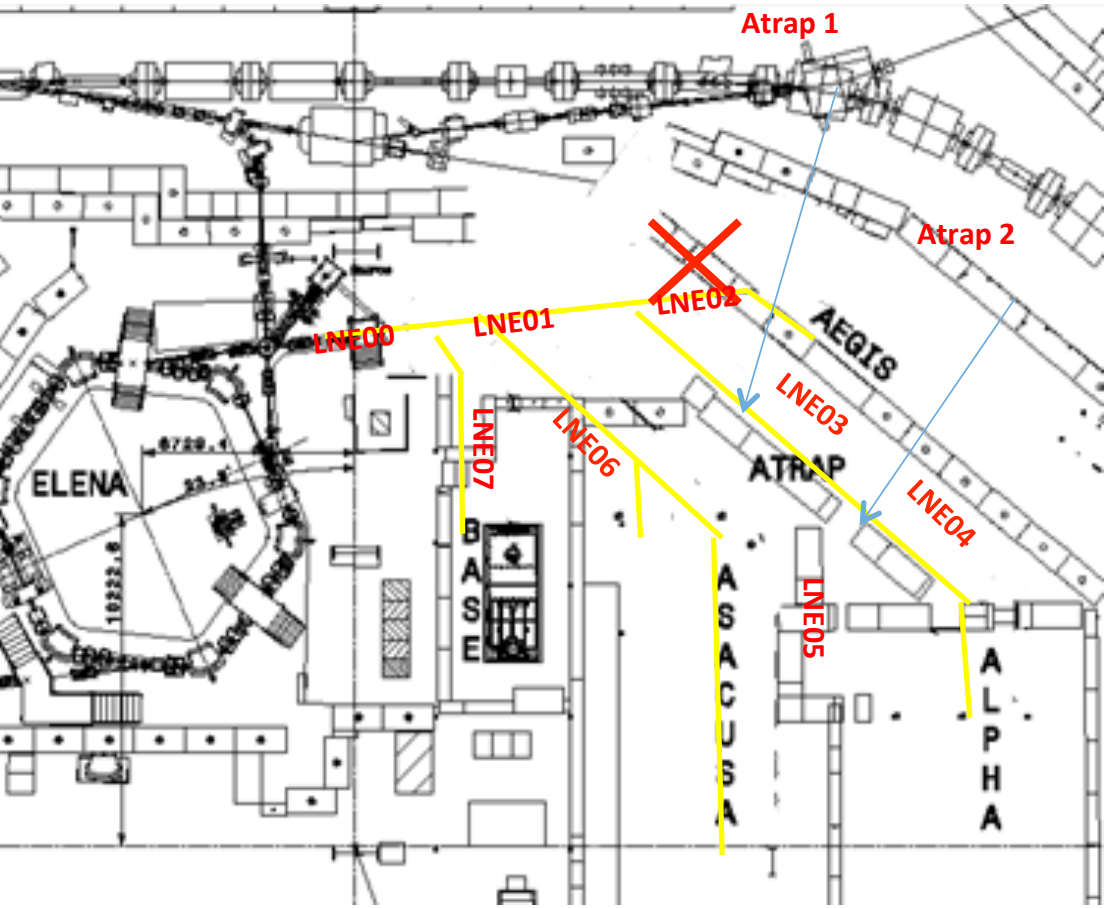
tion on 22 Sept. =>

General installation schedule

Task Name	Duration	Start	Finish
Elena machine installation		Wed 01/02/12	
Racks installation	22 days	Wed 30/03/16	Thu 28/04/
Power converters	167 days	Mon 01/06/15	Tue 02/02/
Survey marking (incl. Gbar and H- source)	60 days	Mon 30/03/15	Fri 19/06/
False floor	7 days	Thu 09/04/15	Fri 17/04/
Cooling Network	80 days	Mon 04/05/15	Fri 21/08/
Cable-laying campaign (Control and DC)	201 days	Tue 09/06/15	Tue 29/03/
LV Works	90 days	Thu 01/10/15	Wed 17/02/
Mechanical supports	128 days	Tue 30/06/15	Thu 07/01/
Magnet installation	116,5 days	Mon 19/10/15	Tue 12/04/
Transfer lines	152 days	Fri 01/05/15	Tue 01/12/
AD closing / restart	0 days	Mon 06/01/14	Fri 15/05/
B-Train	12 days	Thu 21/01/16	Fri 05/02/
Radio Frequency	178,9 days	Tue 28/07/15	Fri 15/04/
Beam Instrumentation	116,5 days	Mon 02/11/15	Tue 26/04/
Alignment by the survey	100 days	Tue 01/12/15	Mon 02/05/
Vacuum system	165,5 days	Fri 16/10/15	Fri 17/06/
Various (access door, Rp Monitors ...)	154 days	Wed 01/07/15	Mon 15/02/
Install e-cooling	66 days	Tue 01/03/16	Tue 31/05/
Commissioning ELENA	66 days	Fri 17/06/16	Mon 19/09/
Commissioning ELENA (H-) (100 keV -> 5.3 Mev)	3 mons	Fri 17/06/16	Mon 19/09/
Redevelopment TL towards experiments	317,5 days	Fri 01/06/18	Tue 20/08/
Installation Gbar	296 days?	Thu 01/10/15	Thu 01/12/

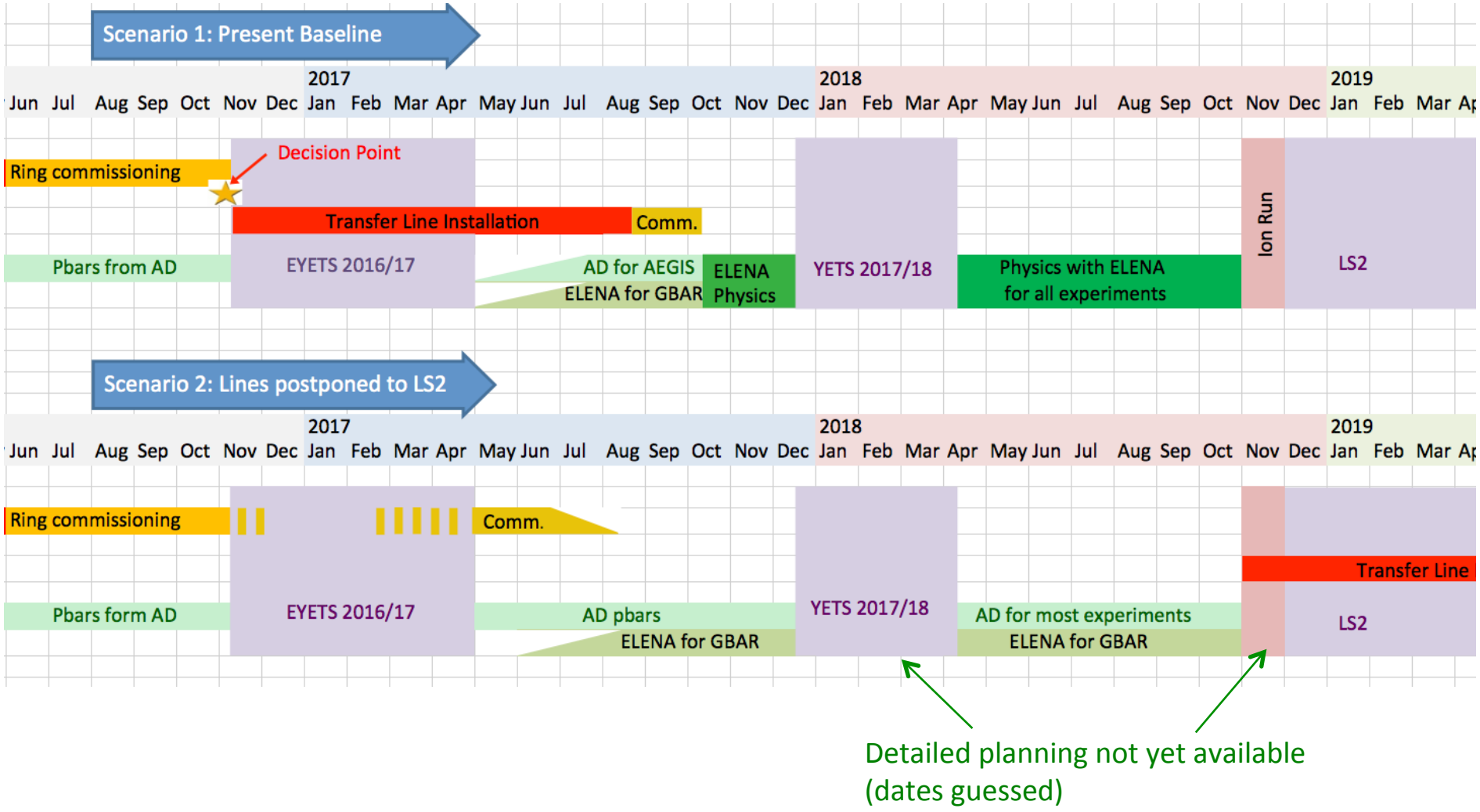


Replacing the magnetic lines from the AD by electrostatic lines from ELENA



ELENA ring will be commissioned in 2016 during the physics run. Once completed, the current magnetic ejection lines will be replaced with the new electrostatic lines which will take about 9 months!! + commissioning ~ 6 weeks!

Possible scenarios for 2017 and 2018 with LS2 starting around end 2018



Summary and Outlook

AD off to a good start 2015…..after a somewhat troublesome post-LS1 start-up 2014
Major upgrade work underway at the AD
ELENA design finished – production underway
ELENA installation has started and is progressing according to plan
Outlook: > 20 more years of low-energy Pbar physics !! (?)

Thanks!