Challenges in AD/ELENA Operation

Lessons learned during 20 years

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- Introduction to AD, ELENA and the experiments
- Lessons learned from ejection line instrumentation and beam delivery.
- Controls and human aspects of the machine to experiment interface
- Unusual machine faults

A brief introduction to the Antiproton Decelerator

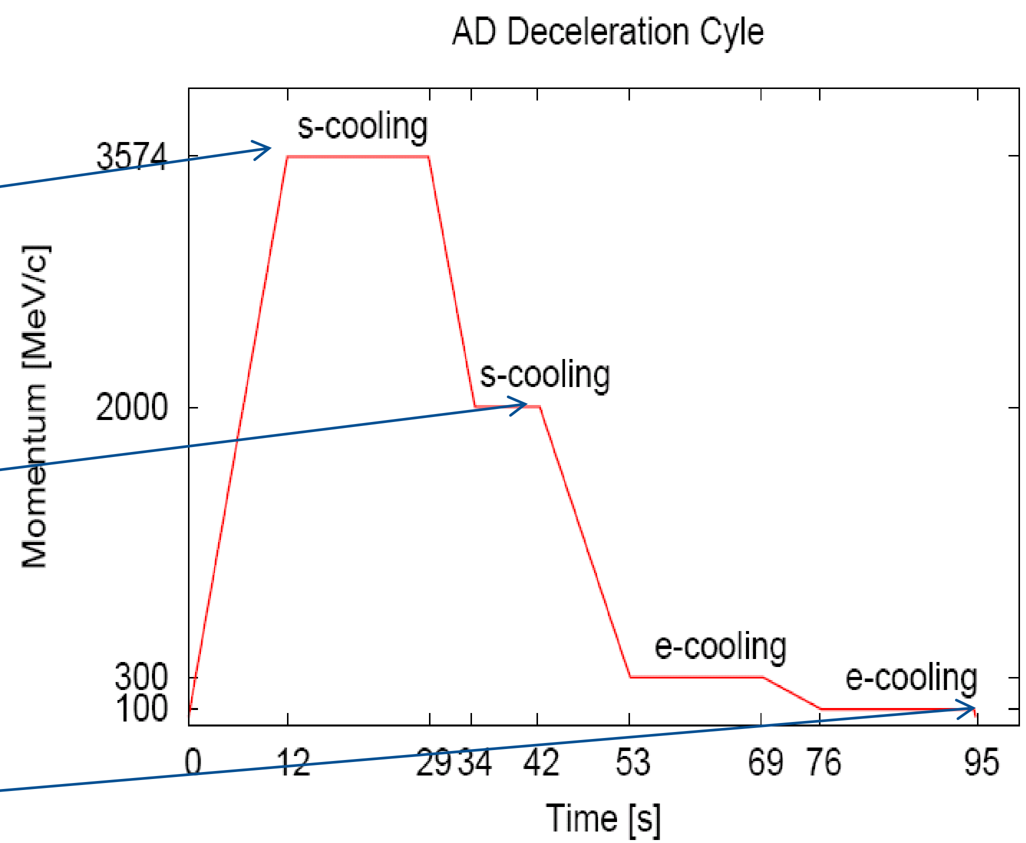
- The Antiproton Collector (AC, a storage ring) was converted to a decelerator in 1998.
- Regular operation since 2000.
- The aim of the AD is to decelerate antiprotons from 3.57 GeV/c to 100 MeV/c
- Stochastic cooling and electron cooling is essential for the AD.

AD cycle

Bunch rotation at injection reduces dp/p to fit better inside stoch. cooling acceptance.

Tune change at the end of the 2 GeV/c plateau

Bunch rotation before ejection

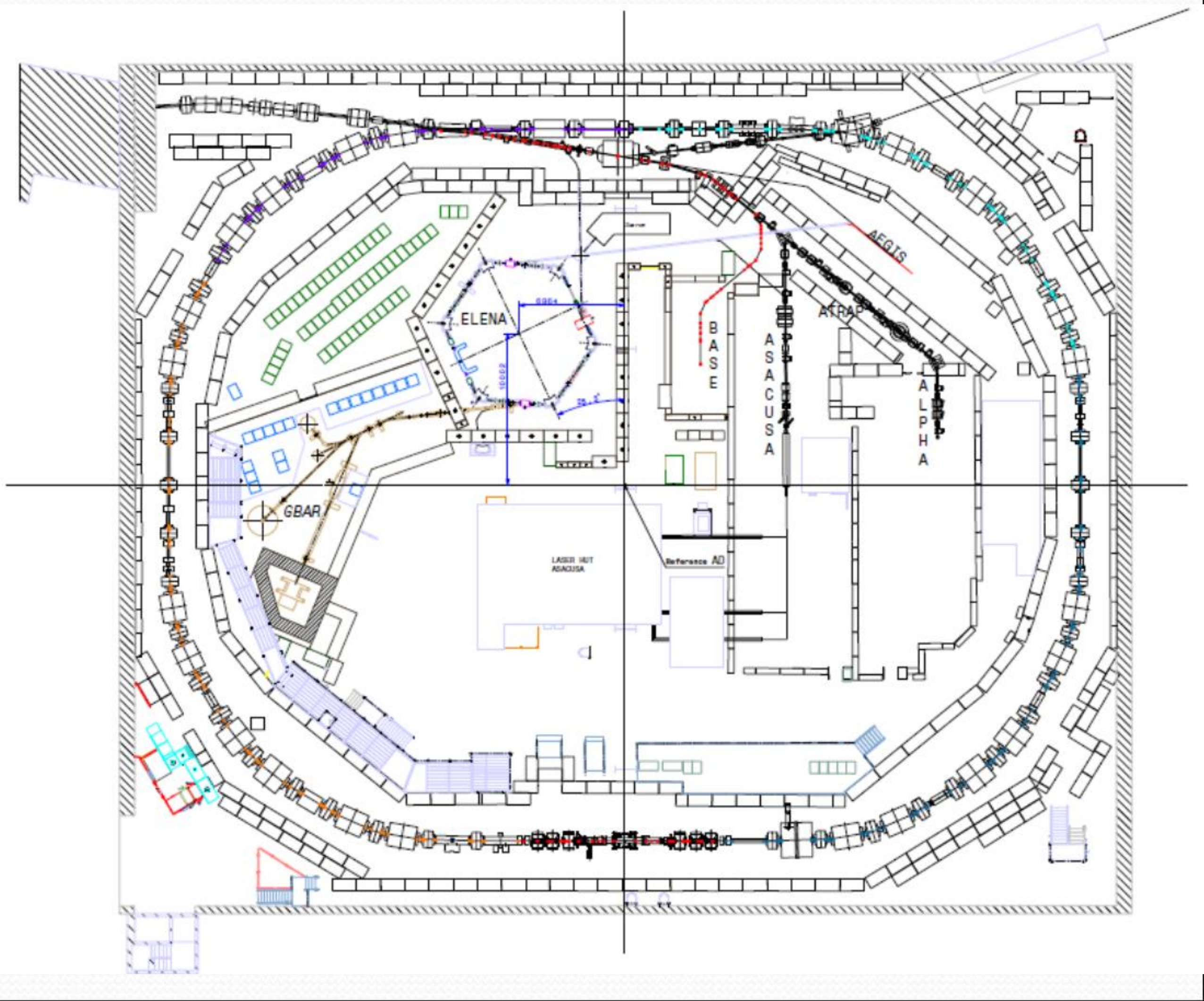


AD parameters

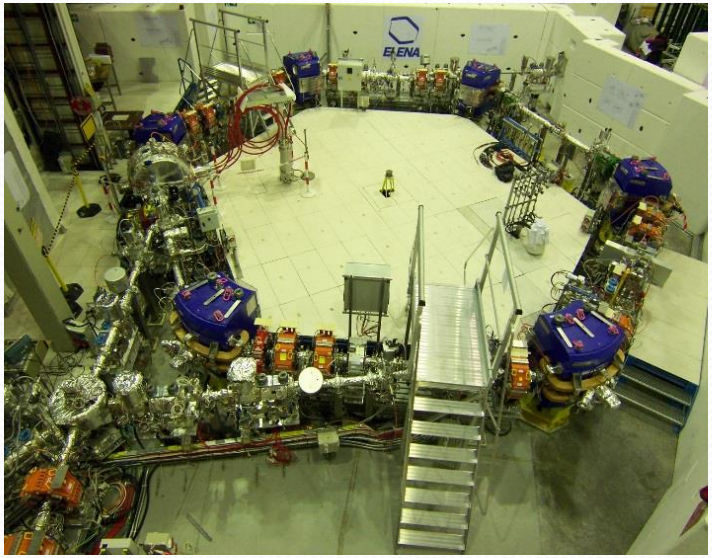
Circumference [m]	182
Prod. beam [protons/cycle]	1.3×10^{13}
Injected beam [pbars/cycle]	4×10^{7}
Momentum [GeV/c]	3.57-0.1
ϵ_{tr} $[\pi \times mm \times mrad]$	180-0.8
±dp/p	$3 \times 10^{-2} - 7 \times 10^{-5}$
Average vacuum [Torr]	4×10^{-10}
Cycle length [s]	96
Dec. efficiency [%]	85

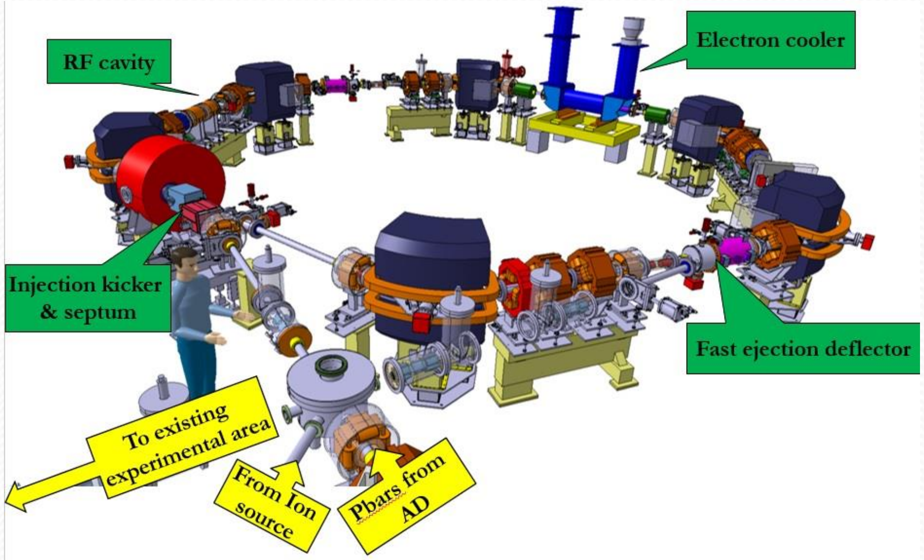
The AD hall layout 2018

- Between 2000-2018 beam was delivered to the experiments from the AD.
- ELENA ring is commissioned by end of 2018. There is still place for improvements.
- Electrostatic ejection lines from ELENA to the experiments is being installed during LS2 (2019-2021)



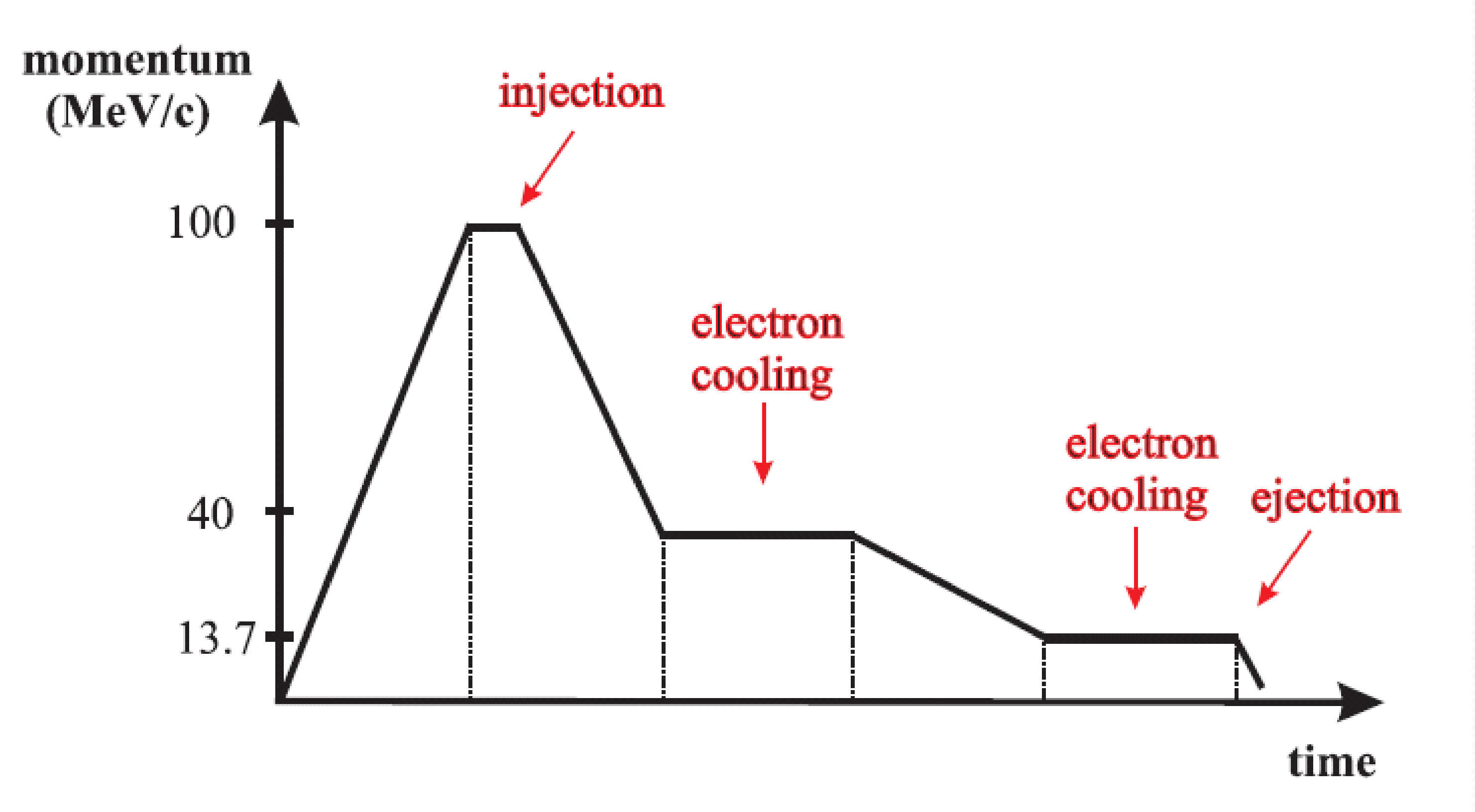
Elena ring and parameters





Momentum range, MeV/c	100–13.7
Energy range, MeV	5.3–0.1
Circumference, m	30.4055
Intensity of injected beam	3×10^7
Intensity of ejected beam	1.8×10^7
Number of extracted bunches	1–4
Emittances (h/v) at 100 keV, $h = 4\ \pi\cdot$mm$\cdot$mrad [95%]	4/4

ELENA cycle



momentum
(MeV/c)
injection
100
electron
cooling
electron
cooling
ejection
40
13.7
time

The experiments

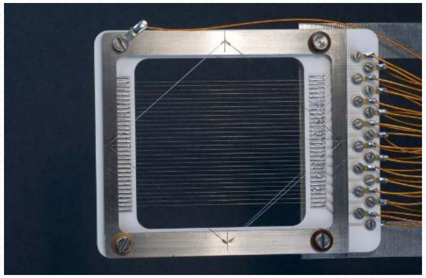
- AEGIS: Gravity measurement on antihydrogen
- ALPHA: Antihydrogen spectroscopy, CPT symmetry, gravity (from 2021)
- ASACUSA: Antiprotonic helium spectroscopy, CPT symmetry, hyperfine structure, collision cross section.
- ATRAP: Laser or microwave spectroscopy of antihydrogen, CPT symmetry.
- ACE (temporary mobile experiment): Biological effect of antiprotons, hadron therapy
- BASE: High precision measurements of magnetic moments of the proton and the antiproton
- GBAR : Antihydrogen spectroscopy, CPT symmetry, gravity.

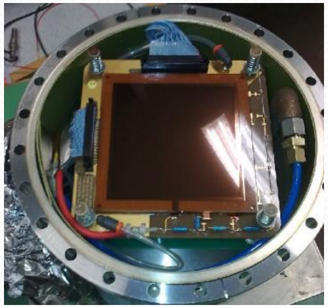
Stability issues during the early years

- Endless tuning due to jumps, drifts, slow and fast.
- Both on the machine side and the experimental side lots of time was lost due to beam steering.
- RFQD was extremely sensitive to steering.
- Part of the problem that the AD was not built for low energies. It was built from pieces we already had.
- Lot of work was done on power supplies improvements, cables re-routing, noise reduction, etc.

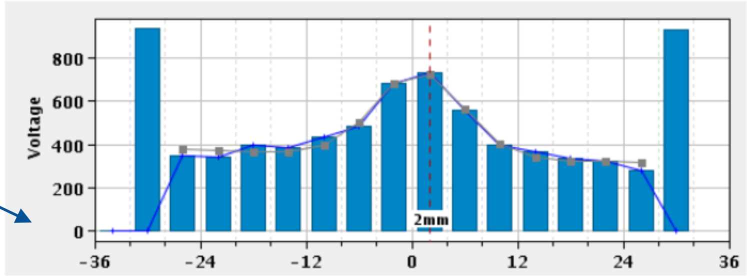
AD ejection line instrumentation

- AD had very limited instrumentation at the beginning.
- In the extraction line only secondary emission profile monitors (SEM) were available until 2011, later GEM profile monitors.
- SEM didn't allow precise studies of ejection line optics.
- Serious effort to understand the ejection line optics only from 2012.

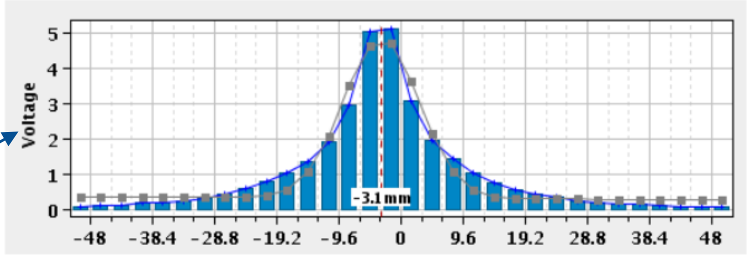




SEM profile



GEM profile



Optics studies by quadrupole scans

- Quadrupole scan procedure:

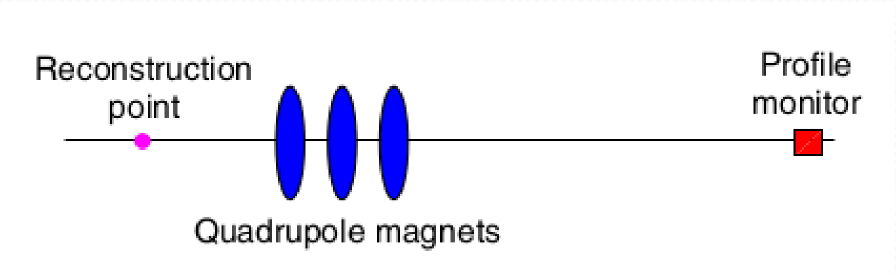
-Measure beam profile

-Change quadrupole currents

-Measure beam profile again

-Calculate optics parameters

A possible configuration for quadrupole scan



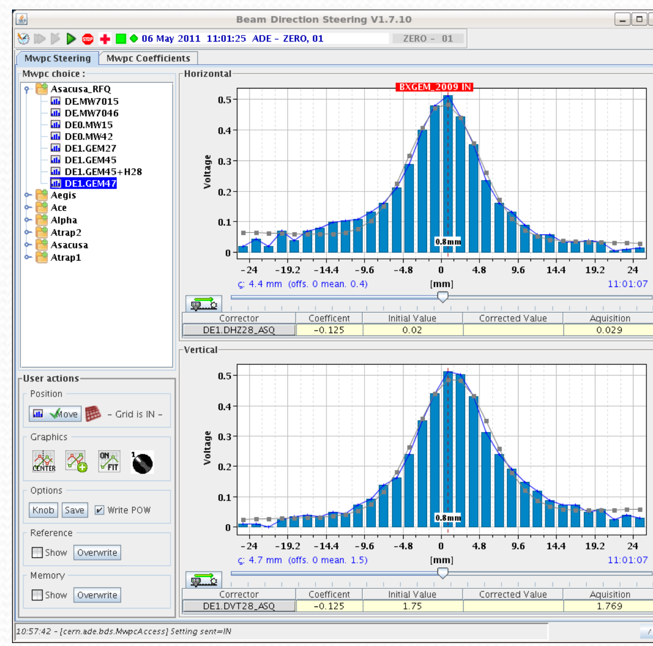
The procedure above gave something difficult to believe :

1 [pi mm mrad] emmitance in the ring and 40 [pi mm mrad] in the ejection line !!

Does the GEM works as expected for antiprotons?

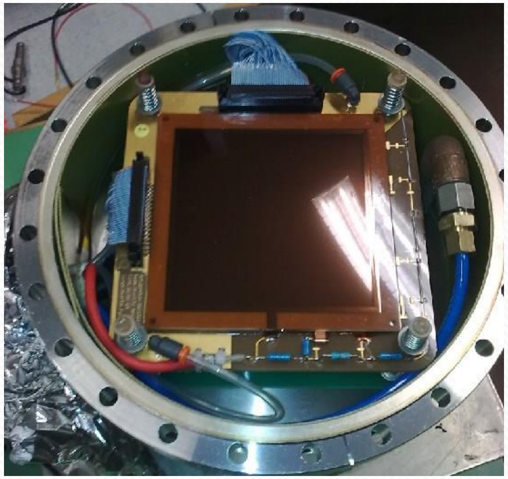
Testing a GEM with a collimator

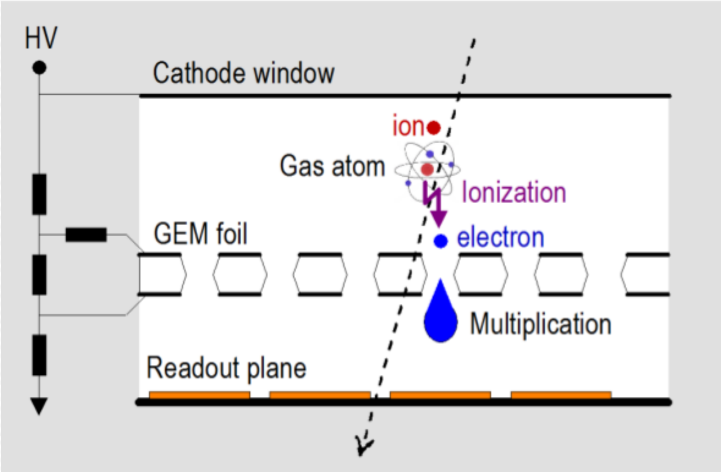
- A collimator with a 3 mm hole at the middle is placed into the beam line 30 cm front of a GEM.
- The measured profile was 4-5 times bigger than expected…



GEM and antiprotons

GEM has gas inside, so a thin window is needed to separate it from the vacuum. This window scatter and annihilate enough antiprotons to corrupt the profile. But it works well as a position monitor.

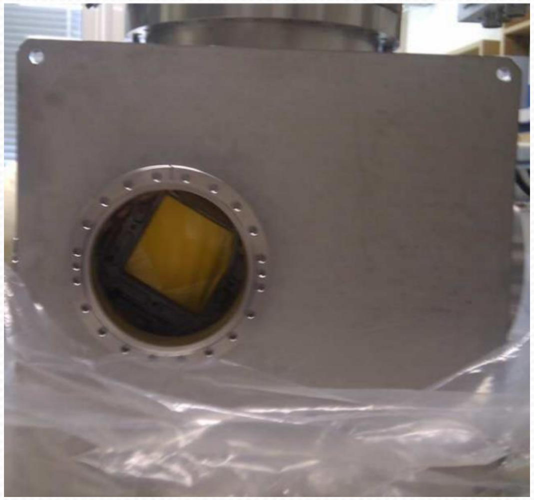


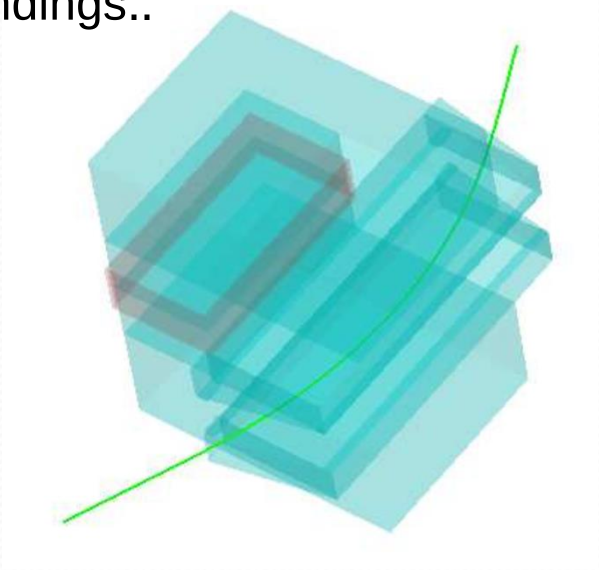


Debugging the ejection line with kick response measurements

- Apply a kick for a corrector dipole and measure the response on all position monitors after.
- Compare it with the expected values from the MAD-X model.
- Find out the reason for the deviations.
- Communication is not always easy !

Some of the findings..





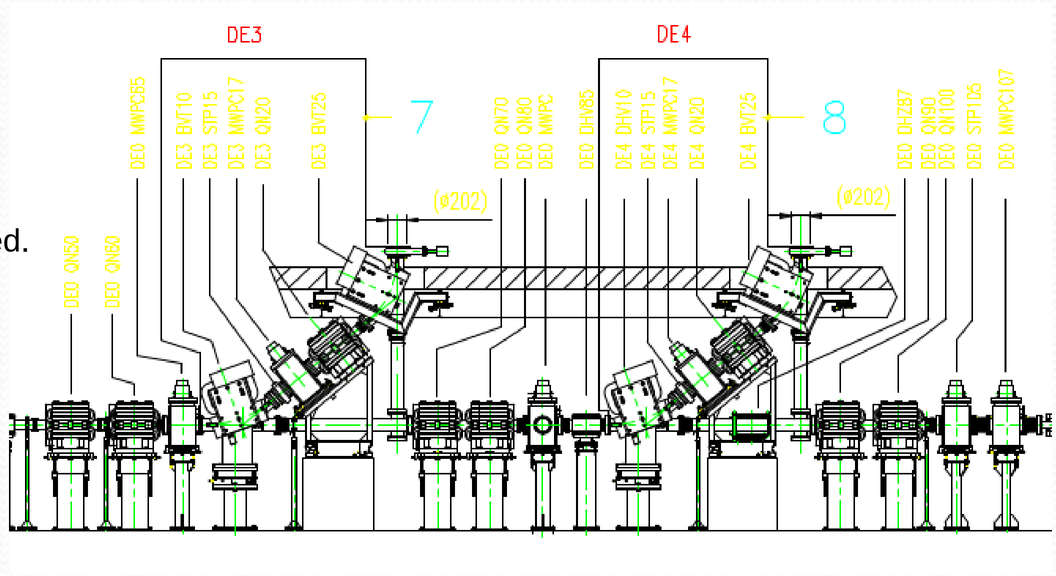
Magnetic interference between the experiments and the ejection line

- Experiments have strong superconducting solenoids. Some of has a strong effect on the line. Every time an experiment changes the current of their solenoid, the steering of the line has to be corrected. Fortunately, this does not happen often.

- Electrostatic lines are foreseen without shielding. for ELENA

- The momentum is 7 times lower, 7 times more disturbance .

- *New non-destructive* position monitors will be used. This should make the steering of the lines much faster.



Control aspects

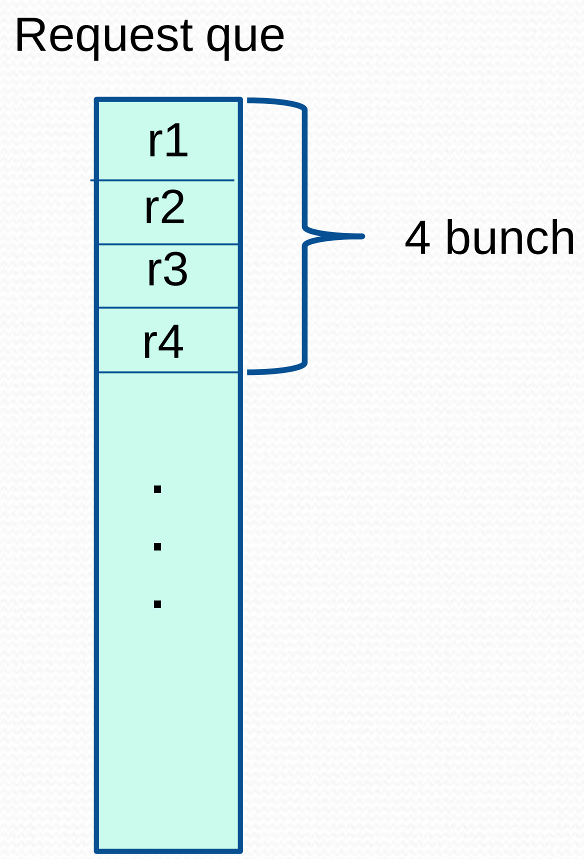
- The control system of the AD from the experiments is well separated. There are very few connections between the two, like timing cables.
- The experiments have a limited subset of the AD control system. It allows a fine-tuning of the end of their ejection line.
- Some acquisition data in the machine control system is exposed to the experiments, like beam intensity.
- The access system of the experimental zones however must be connected to the control system of the machines.

Background level reduction

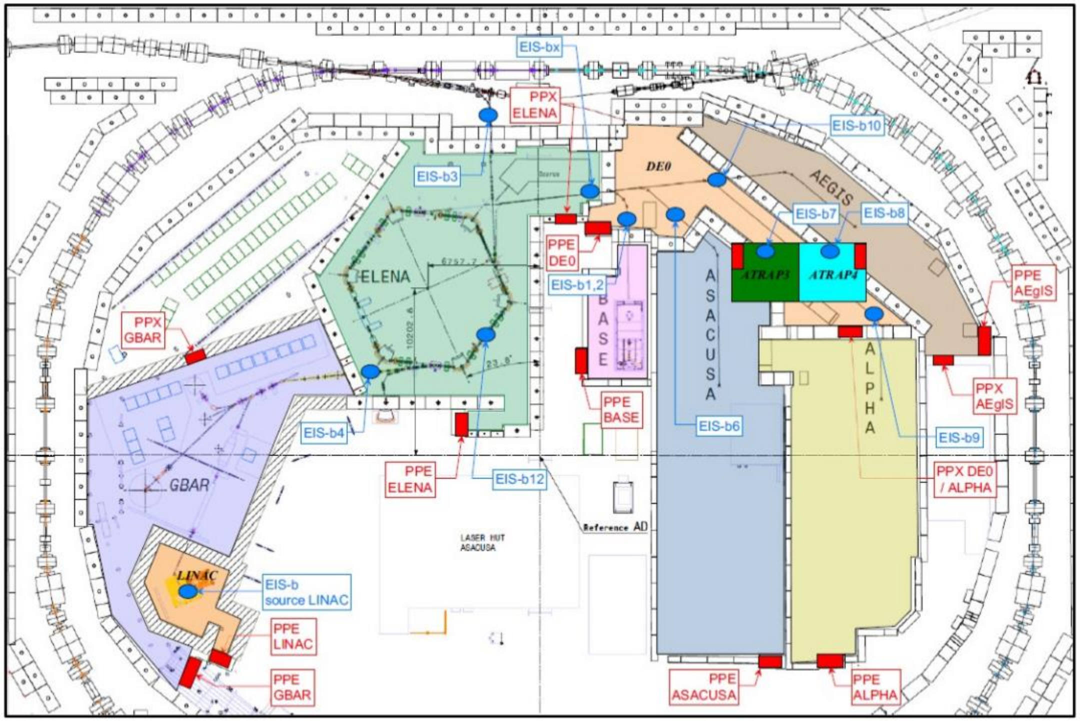
- We want to cycle the AD regularly due to thermal effects.
- The ALPHA experiment is sensitive to background caused by beam dumped to the beam stopper nearby.
- Sometimes they don't want the kicker to be pulsed, so the beam is lost during those cycles in the ring within the shielding blocks.
- They were given a small application, so they can disable the ejection kicker when they want.

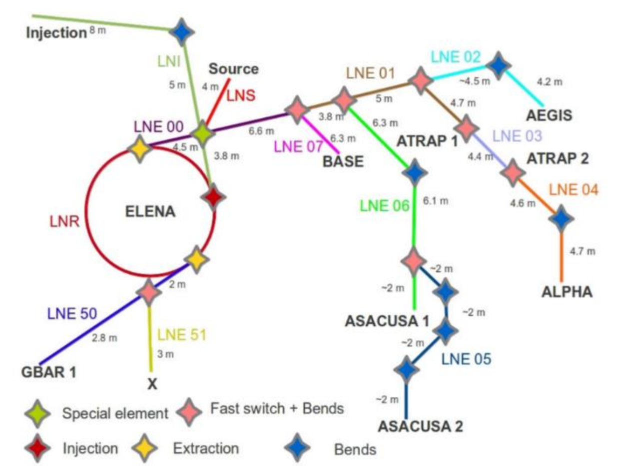
Future beam distribution from ELENA

- The AD ejection line can deliver the beam only to one experiment at a time. Usually, thee are 3 times 8 hours shifts/day.
- The ejection line of ELENA will be more flexible. Can serve up to 4 experiments at the same time
- Up to 4 bunches are ejected.
- A beam request server will distribute the beam between the experiments.



Beam distribution from ELENA





Experimental areas access system

- Experimental area access doors are operated with strict logic due to security reasons.
- They are connected to the AD/ELENA security chains and can trip the machine if not properly used.
- It can happen for example when an emergency exit handle is used.
- The operator has to come to unblock the security chain.
- Newcomers should be trained on how to use the access system properly.

Communication problems I.

- AD/ELENA is operated during working hours by the supervisor in charge.
- Outside working hours the PS (Proton-Synchrotron)

operation team is ”babysitting” it from CCC, which is far. This is usually limited to simple problems, like resetting power supplies, etc.

- When they can’t resolve an issue, the AD supervisor is called.
- Funny situations can happen when not everybody is informed that the AD supervisor is working on the problem.

Communication problems II.

- It happens sometimes that newcomers don't know or remember who to call and when.
- When the AD supervisor is waked up in the middle of the night because of a request like "Could you please switch the beam to us ?", we know that somebody new arrived at the experiment. This can be handled with 1 click by the PS operators.
- Newcomers should be trained at arrival at least on 3 important things:

  - Security
  - Proper use of the zone access system
  - Who to call during working hours and outside working hours.

The advantage of physical proximity

- The experiments of big machines like LHC, SPS, are far from the control room (CERN Control Centre, CCC) and there is not much personal contact with the physicists.
- The AD/ELENA control room is located in the same building as the experiments. We have daily contact with the physicists.
- When they need something from us they just come to the control room and explain it. This is often the case when an experiment is starting, like ACE, Aegis, Gbar.
- Problems are easier to solve when we looking at the same screen next to each other than trying to explain things on the phone.

Experiments can help us

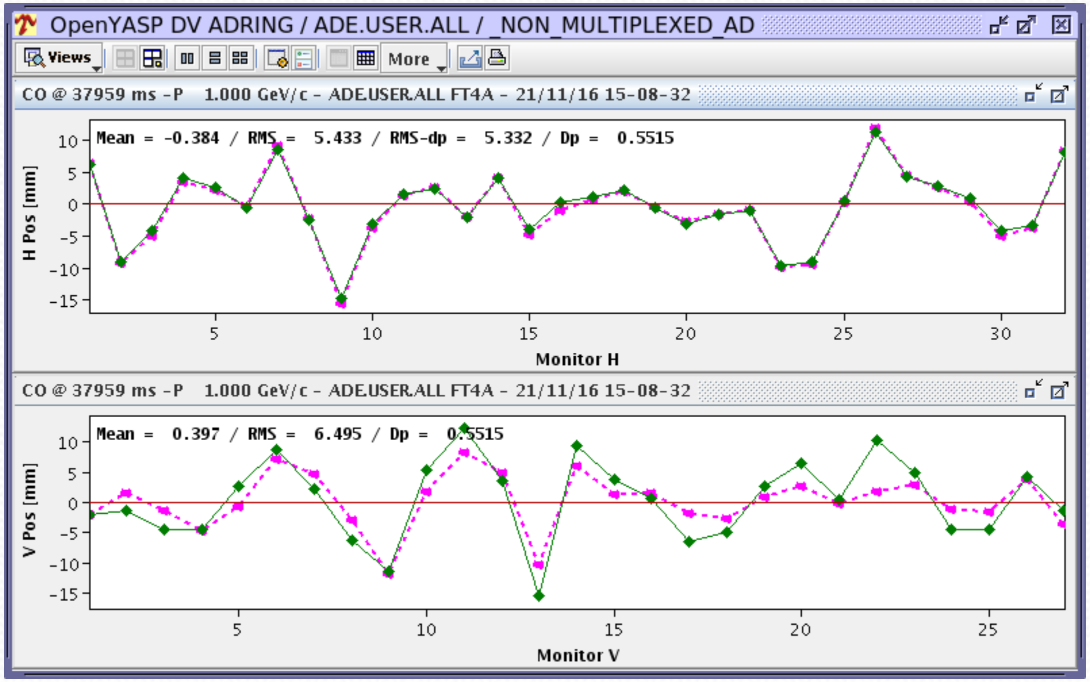
- During the BASE beamline commissioning the beam was lost between two BTV screens and we didn't understand why.
- Physicist from BASE put two scintillator detectors near the beamline. We could locate where the beam was lost and how the position of the loss was changing with the magnet settings in the line.
- It turned out that one bending magnet in the transfer line is different from all the others, its coil has one turn less.

Unusual machine faults I.

- Symptom: Sever losses during deceleration at a specific energy.
- Cause: Quadrupole coil moving due to missing shimming and touching the bake out foil on the vacuum chamber.

Unusual machine faults II.

- Symptom: Orbit jumps after the electron cooler tripped.
- Likely cause: Cables for orbit correctors running parallel to high current cables of the e-cooler. When it trips, the corrector magnet is saturated due to the induced current. The corrector ends up on a different point in the hysteresis curve.



Thank you !

Questions ?