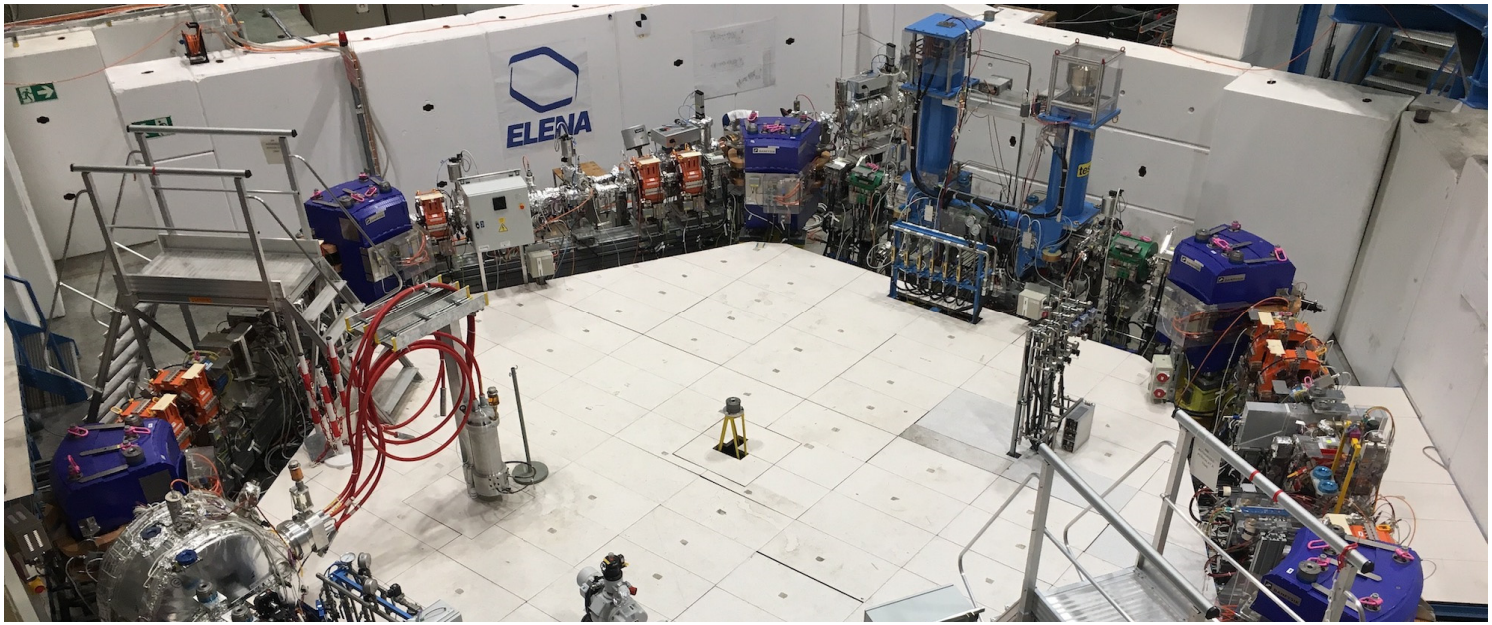
ELENA COMMISSIONING

D. Gamba* on behalf of the AD/ELENA collaboration

NAPAC2019 – 4th Sep 2019

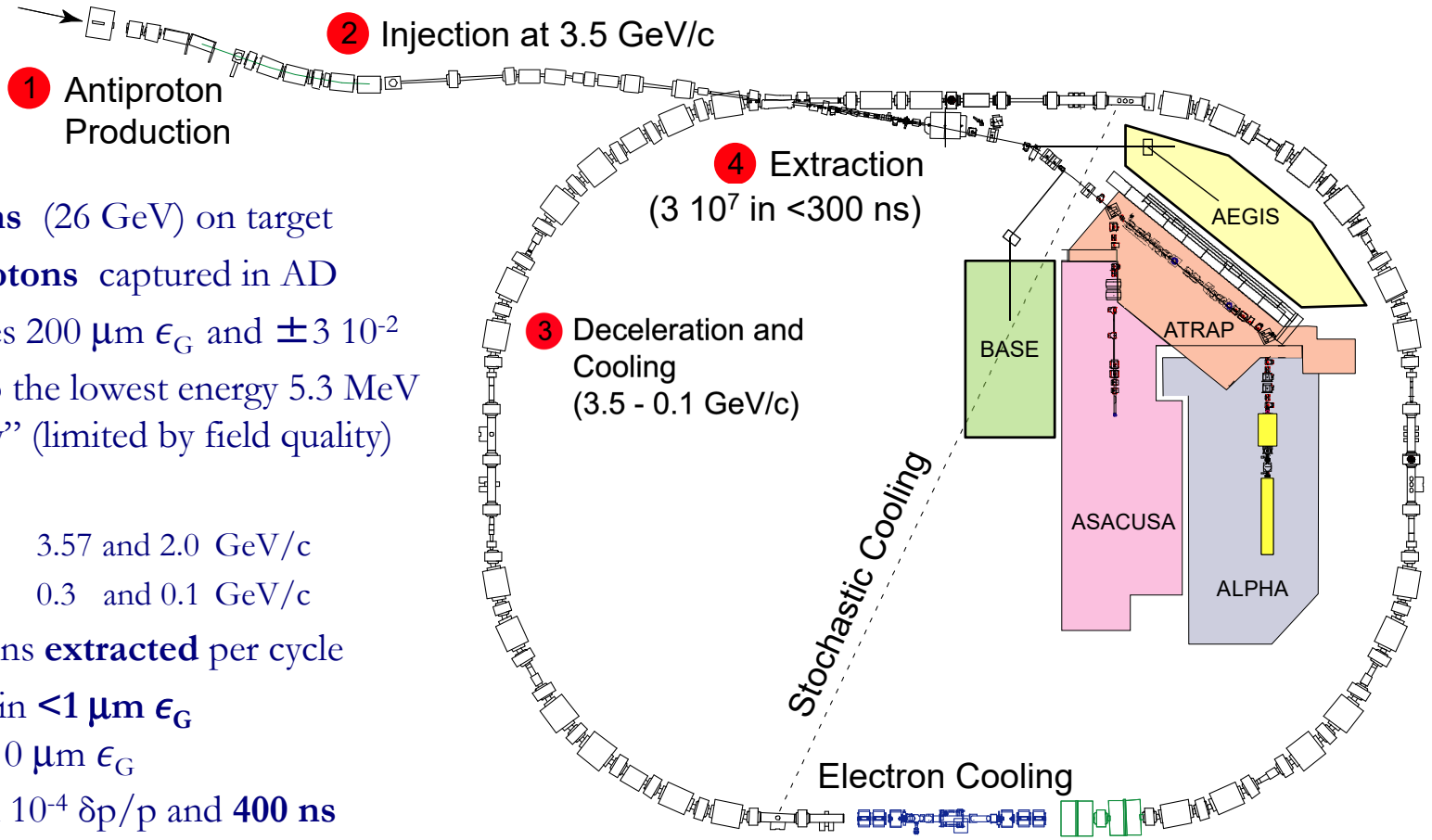


- From AD to ELENA: an **overview**
- Status of **H^-, pbar, electron cooler commissioning**
- **First beam extracted** to experiments (**GBAR**)
- **Current Activities and Plans** for **CERN Long Shutdown 2 (LS2)**

* davide.gamba@cern.ch

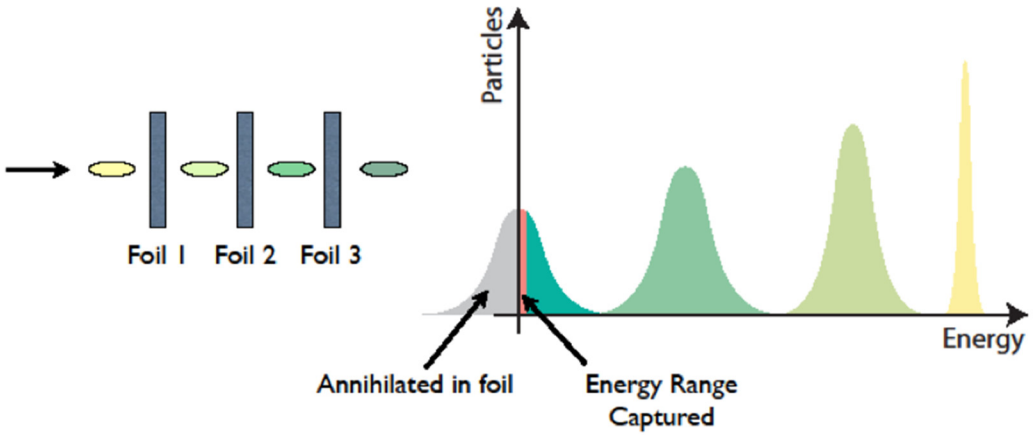
AD – a unique facility providing 5.3 MeV antiprotons

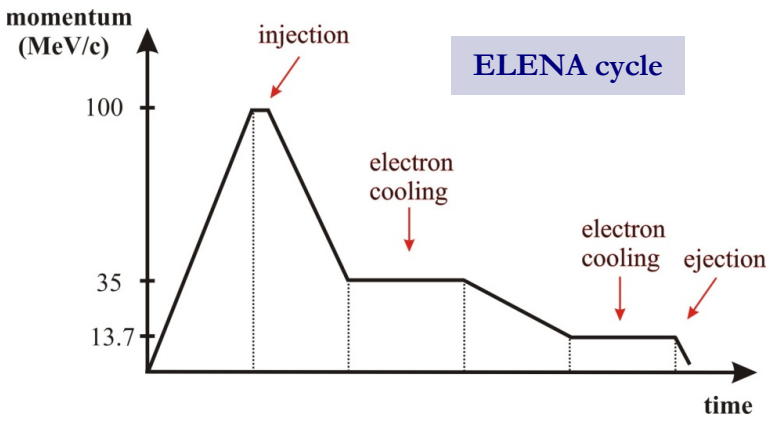
- **~1.5 10^{13} protons** (26 GeV) on target
- **~3.5 10^{7} antiprotons** captured in AD
  - Acceptances 200 μm ϵ_G and ±3 10^{-2}
- **Deceleration** to the lowest energy 5.3 MeV reachable "safely" (limited by field quality)
- **Beam cooling**
  - **Stochastic** 3.57 and 2.0 GeV/c
  - **Electron** 0.3 and 0.1 GeV/c
- **~3 10^{7}** antiprotons **extracted** per cycle
  - ~70% within **<1 μm ϵ_G** tails up to 10 μm ϵ_G
  - 95% within 10^{-4} δp/p and **400 ns** (before bunch rotation)
- **Vacuum pressure: ~10^{-10} mbar**
- **Cycle length ~100 s**



Sketch of the "present" AD
circumference 182 m

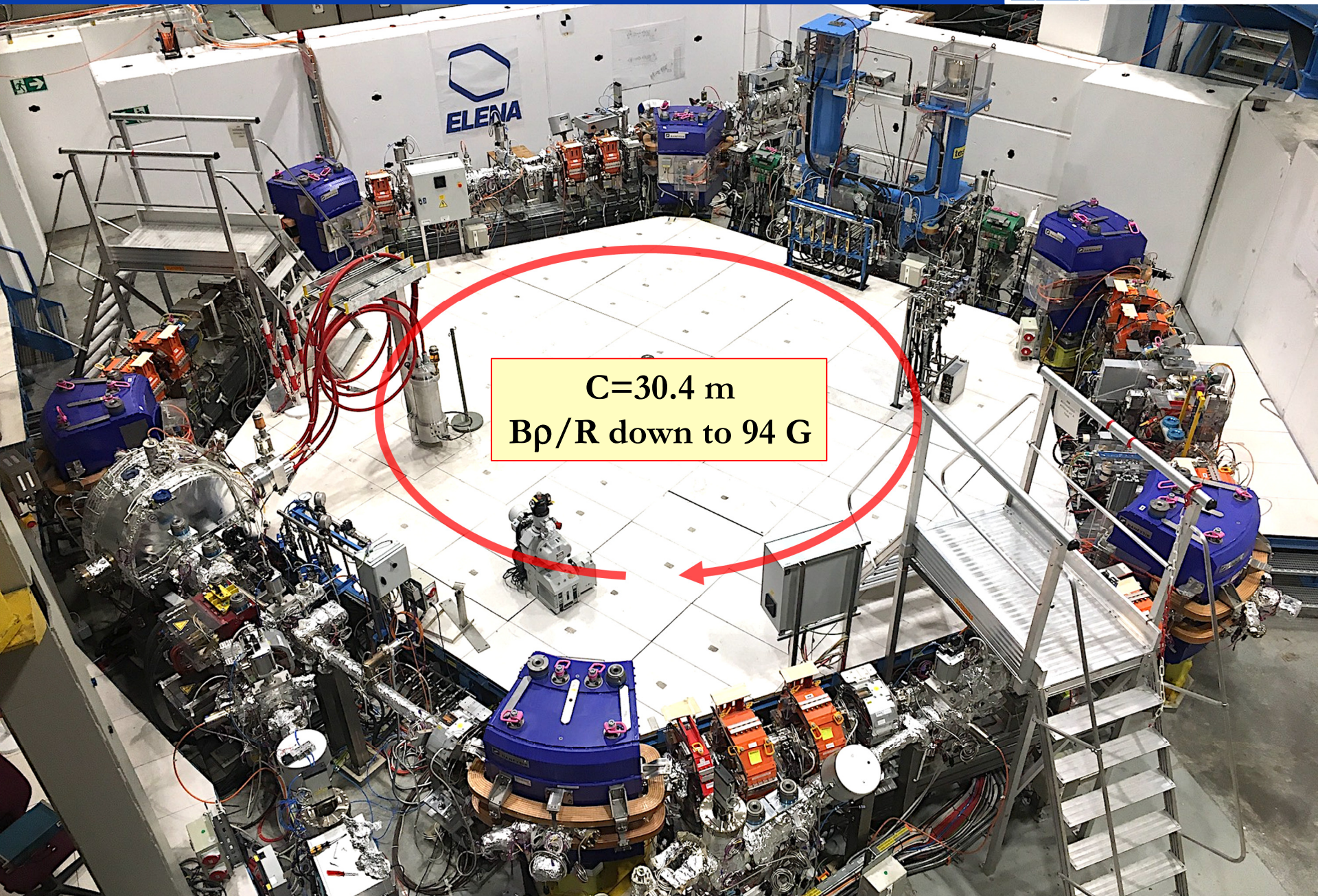
Why ELENA ?
= Extra Low ENergy Antiproton ring



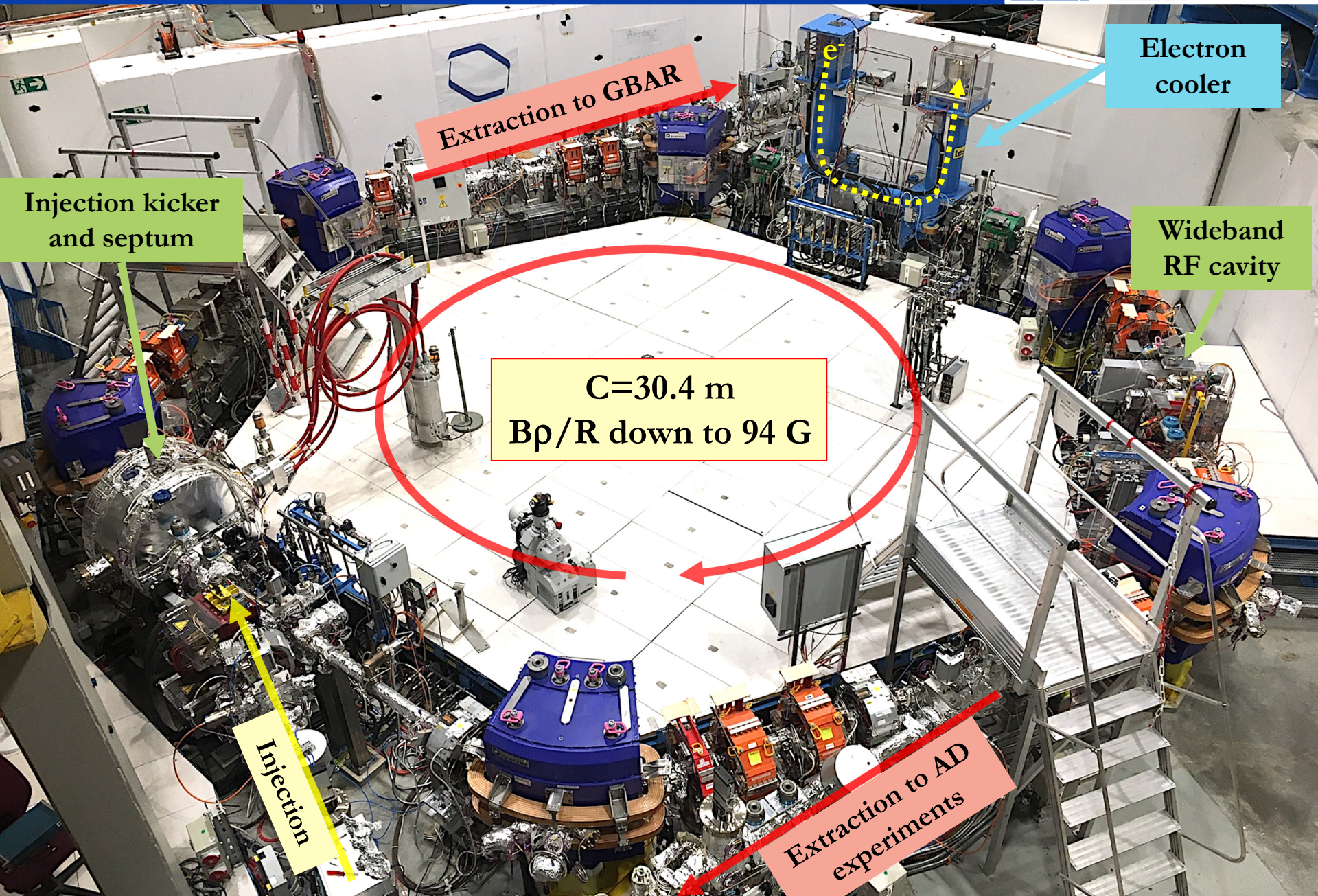


- To be able to **capture antiprotons in penning traps**, **most experiments use degrader foils** to further **decelerate** the **5.3 MeV** antiprotons coming from AD **to a few keV**.
- Energy straggling increases energy spread such that **only a few antiprotons can be captured (< 1%)**; even with optimized foil thickness
  - Almost **half of the incoming pbars** are **stopped in foil**, where they annihilate
  - Almost **half of the incoming pbars** are **too energetic** to be trapped
- **ASACUSA decelerates antiprotons** with an **RFQ**
  - they achieved about **one order of magnitude higher trapping efficiencies**
- **ELENA** will provide **100 keV antiprotons** (**over 4 bunches** => serving 4 experiments)
  - **Expected two order of magnitude higher trapping efficiency**
- Other **requirements from experiments:**
  - **Beam size** on foil small enough (rms size **<1 mm**); full **bunch length** less than **<300 ns**

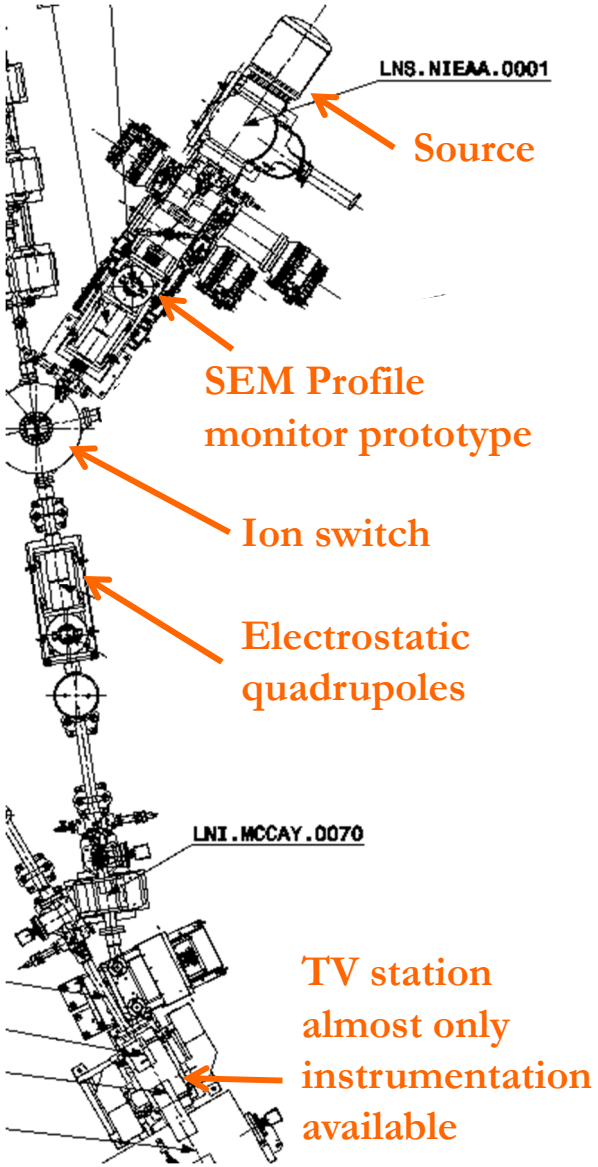
ELENA Ring – 2018



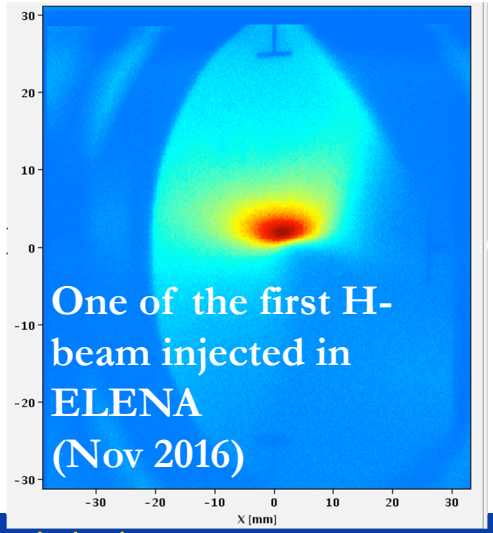
ELENA Ring – 2018



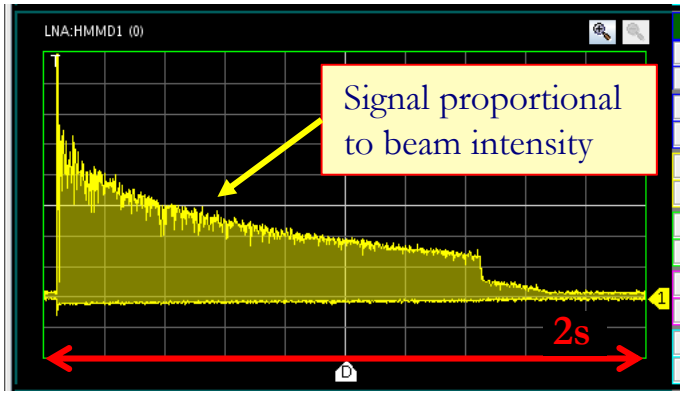
ELENA Commissioning – Ion Source and Line from Source to Ring



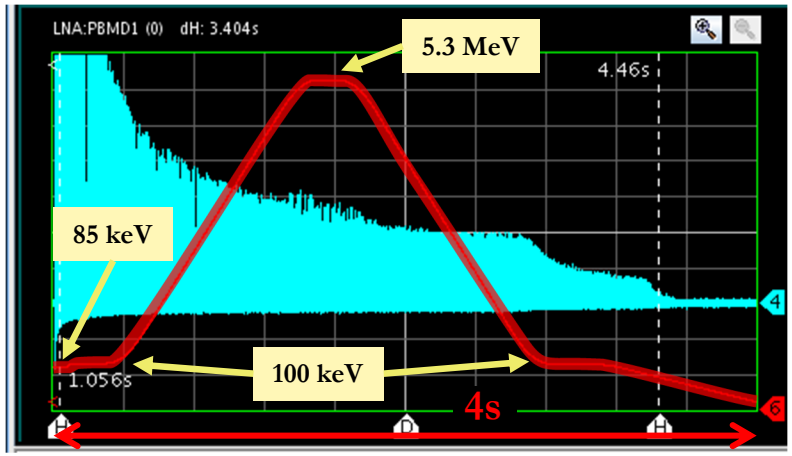
- **Aim**: progress as much as possible without taking precious antiprotons
- **Source available and tested well in advance**
  - **100 keV** (post-acceleration), source a few meters from Faraday cage with HV cables in between
  - First tests with source mounted in Faraday cage
- **Empirical adjustments** led to unexpected quadrupole settings in injection line
- **Limited beam diagnostics due to delays with SEM**
  - **Only one profile monitors with temporary electronics**

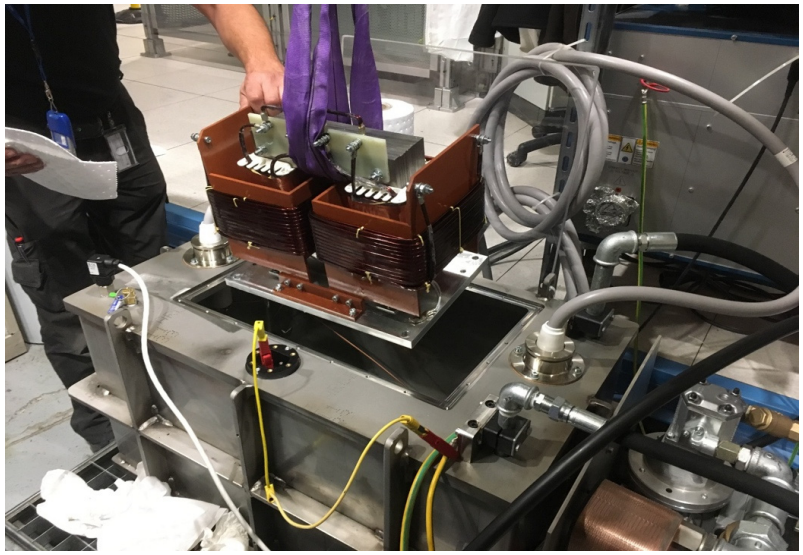


Circulating H^- beam; lifetimes > 1 s



H- Status: a "full cycle"





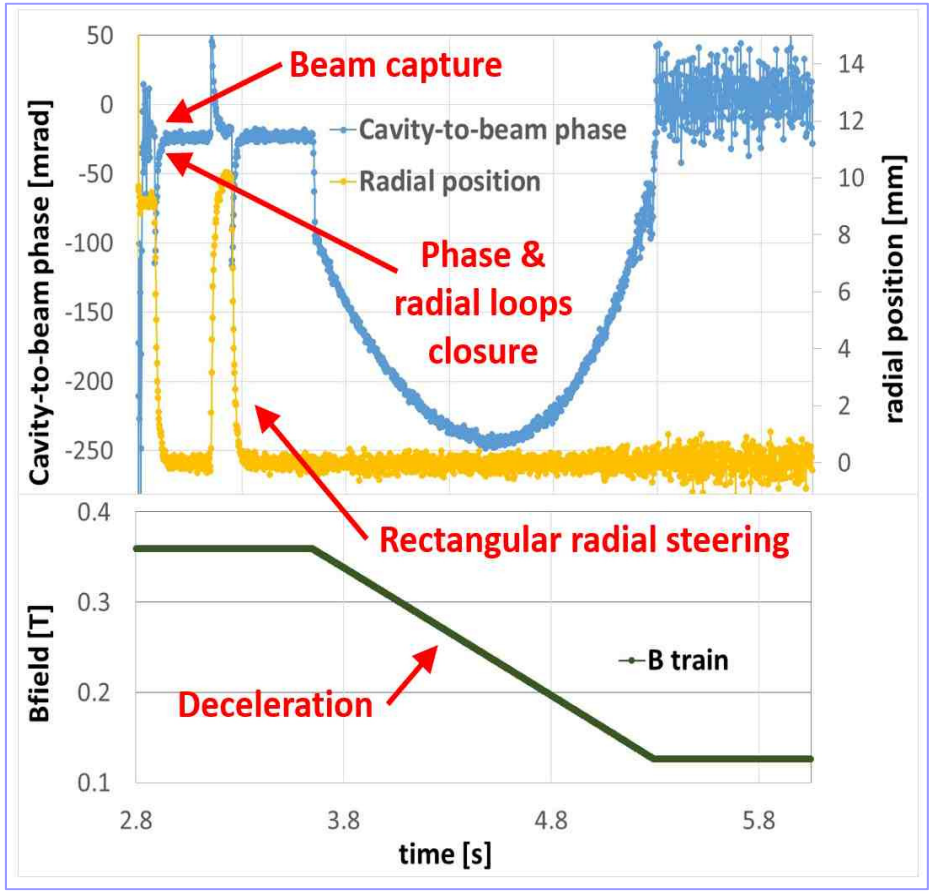
- **Accelerating cycle:**
  - From 85 keV to 100 keV
  - From 100 keV to 5.3 MeV
  - Back to 100 keV.
- Possible to have beam even for energies lower than 85 keV after deceleration
- **H^-** beam also used for **GBAR commissioning**
  - **First experiment taking ELENA beam**
- **H^- lifetime main limitation** for long cycles, and/or e-cooling studies

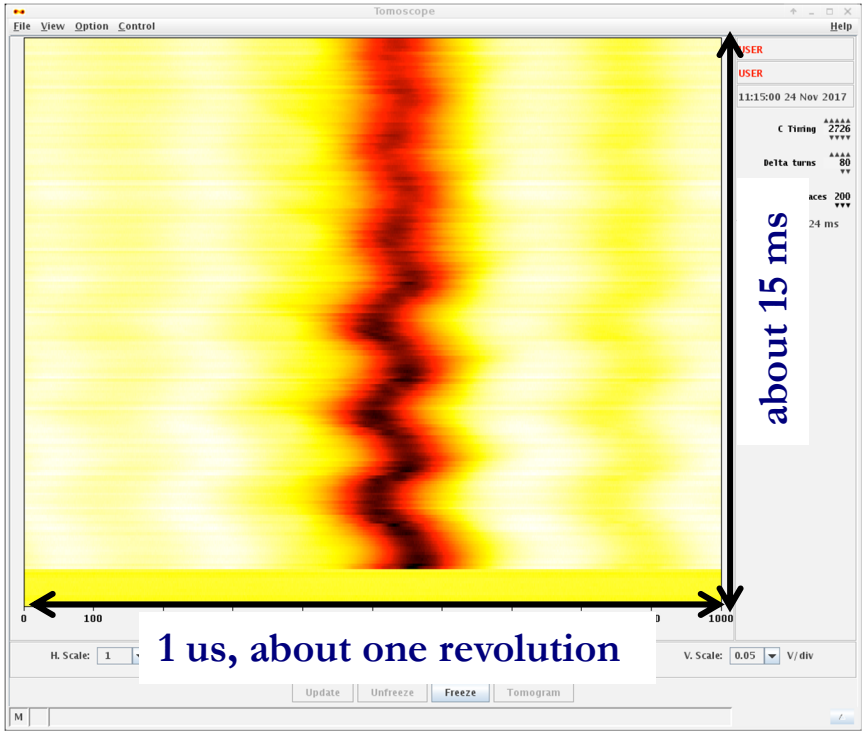
- Unfortunately we had many **issues** with **HV insulation transformer**
- **Only a few month operations in 2018 at 85 keV instead of nominal 100 keV**

- **H^- could only be used for a few sub-system (e.g. RF, timing) and partially to commission transfer line to GBAR experiment.**

Commissioning with Antiprotons from the AD

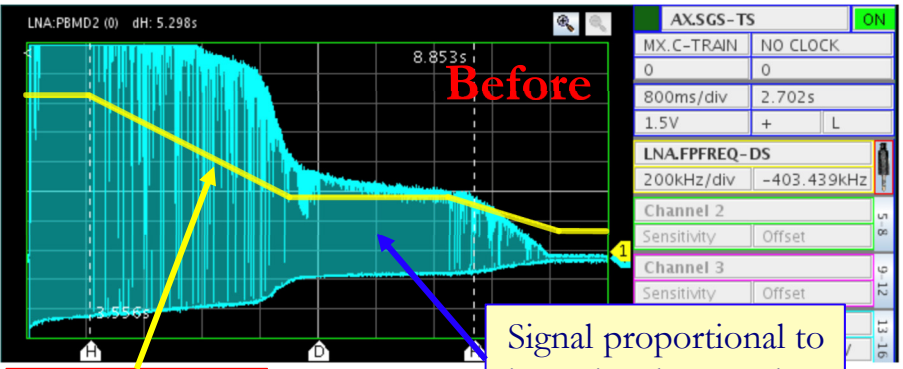
- **Bunch to bucket** transfer between **AD** and **ELENA** (~ 3.2E7 pbars) and deceleration with **phase** and **radial loops**





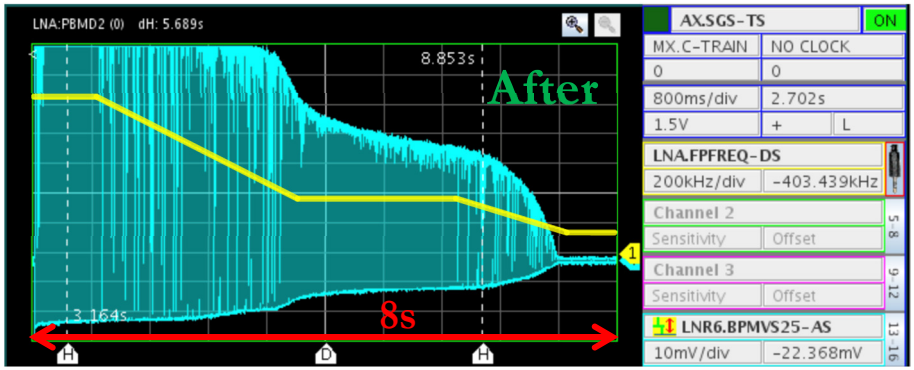
Bunch transferred into ELENA waiting bucket - Phase loop damps synchrotron oscillations

First decelerating cycles:
Impact and correction of injection orbit

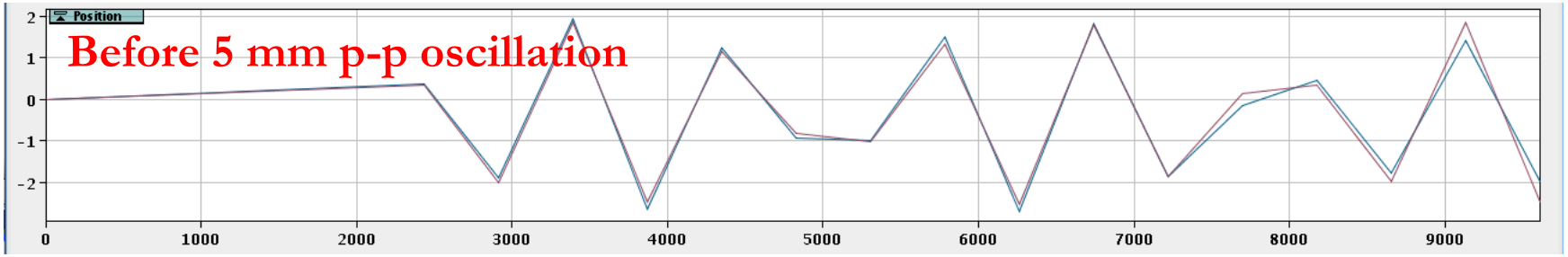


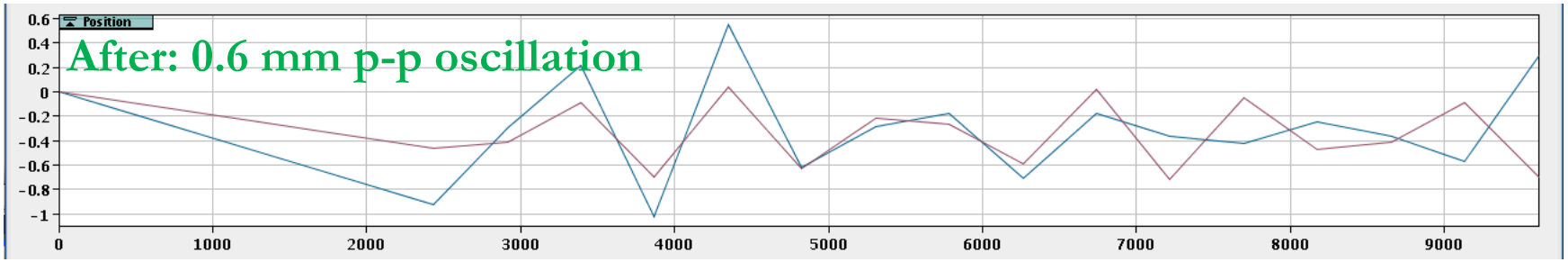
Magnetic cycle

Signal proportional to intensity along cycle



- **Orbit correction** in injection transfer line to **match** ELENA **closed orbit**

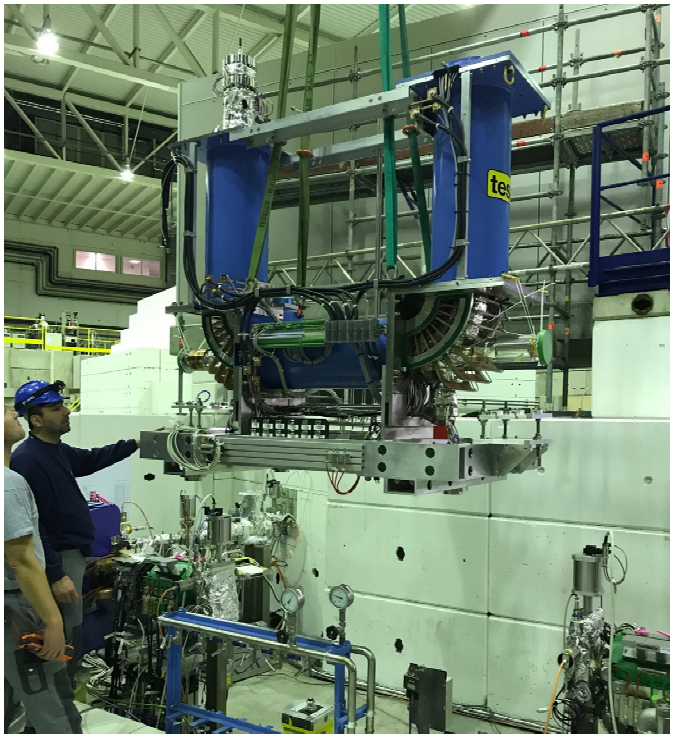




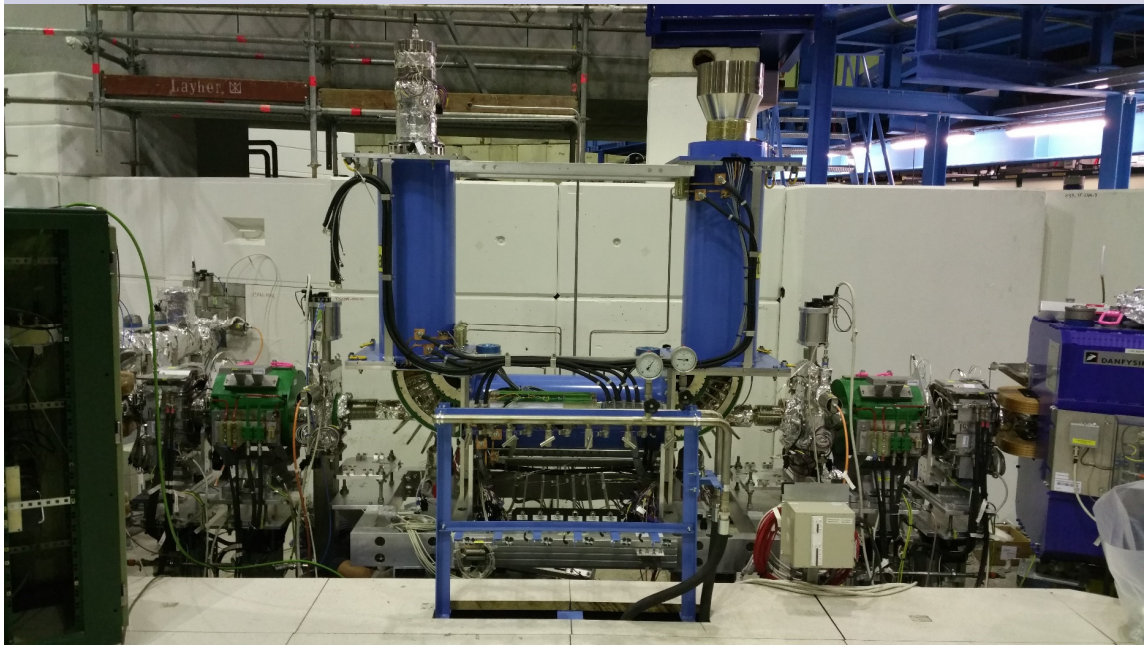
From B. Lefort (link)

ELENA Electron Cooler

- Design based on L-LSR e-cooler (Kyoto)
- Cooler **installed** beginning of **December 2017**
  - Unfortunately, a **vacuum leak** developed after first bake-out
- Cooler taken out for dismounting and repair
  - **ELENA restarted delayed to April 2018**

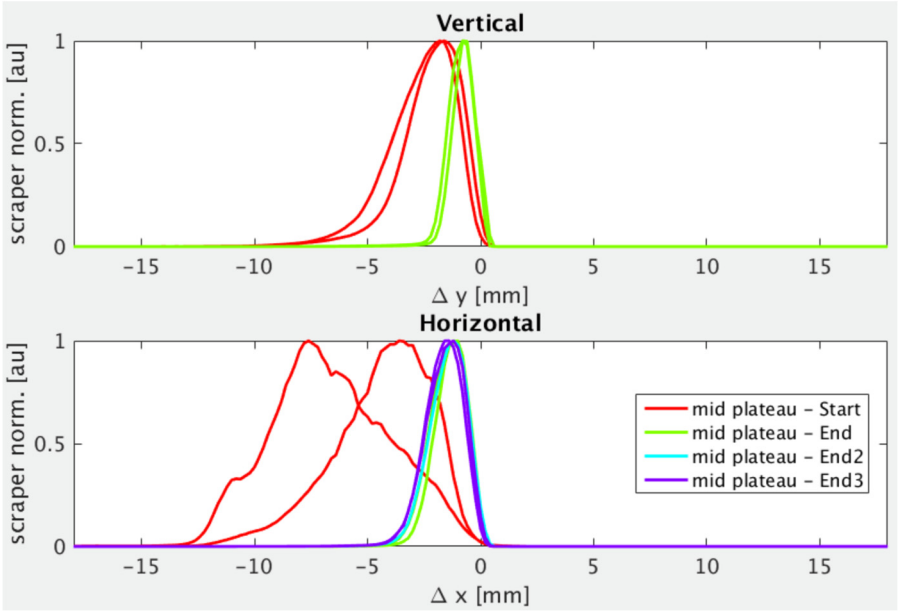


e-cooler fully available in July 2018

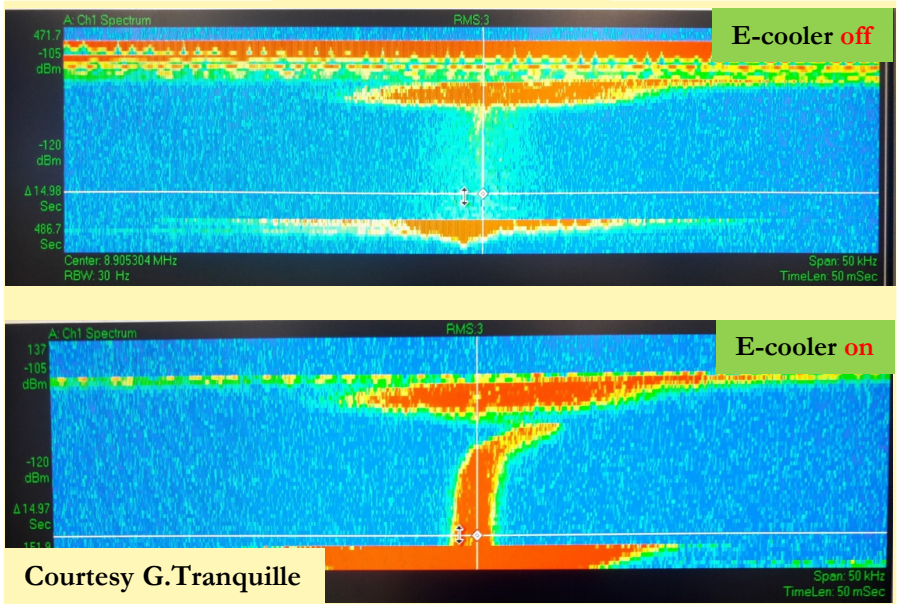


E-cooler in action (35 MeV/c plateau)

~half profile measured with "**scraper**"

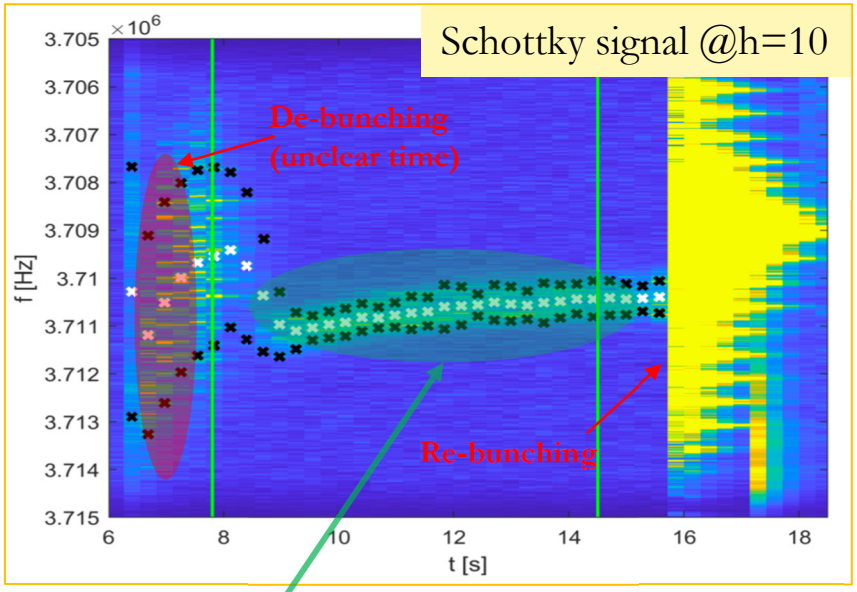


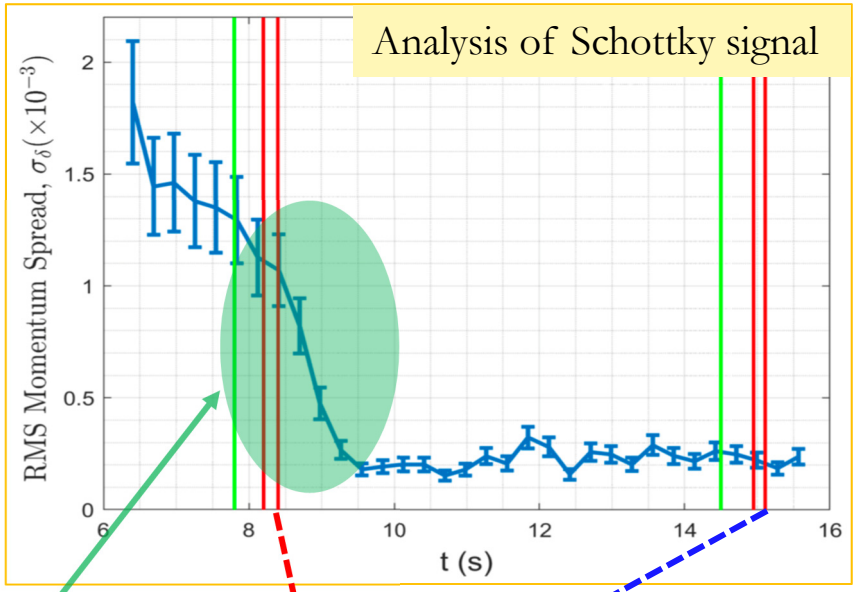
Schottky signal



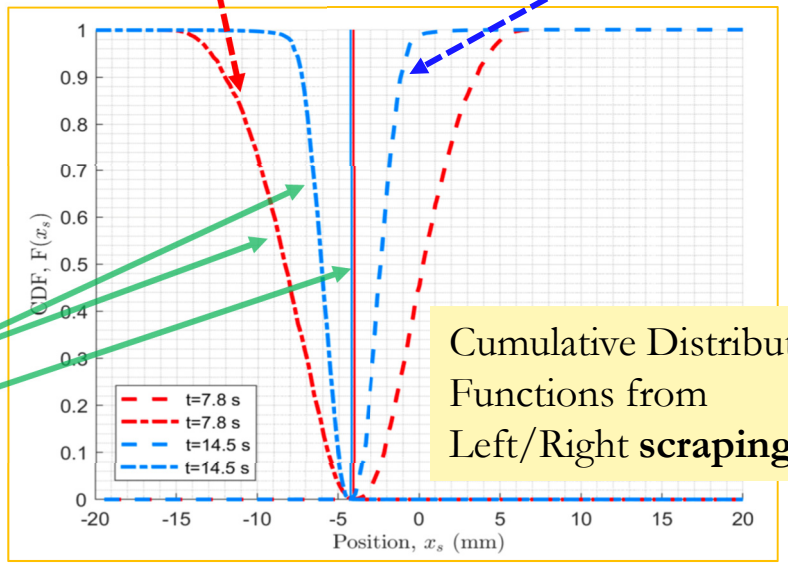
- **Clear transverse and longitudinal emittances reduction observed**
- **Only limited amount of time** on systematic optimization of cooling (**lack of time**)
  - **Some optimisation with orbit bumps/angles in e-cooler**
  - **Surely(?) margin** for improvements

Some details (35 MeV/c plateau)





- Some **drift** of **mean energy**
  - e- beam energy drift?
- **Longit. cooling time** of the order of **1 s**
  - Momentum spread (~2.5e-4) and cooling time compatible with expectations
- Clear **reduction** of transverse **beam size**
- No sizable variation of beam mean transverse position



Cumulative Distribution Functions from Left/Right **scrapings**

From J.Hunt Ph.D thesis

Transverse performance

TABLE 6.8: Intermediate plateau summary table. Note: changes in emittance are expressed as percentages of initial emittance.

	begin t=7.8	Error	end t=14.5	Error	Change	Error
ϵ_y(mm mrad)	1.59	0.02	1.15	0.02	28%	2%
y_0 (mm)	-2.88	0.03	-2.89	0.03	-0.01	0.06
ϵ_x (mm mrad)	3.6	0.27	0.70	0.05	81%	10%
x_0 (mm)	-4.05	0.04	-4.22	0.04	-0.17	0.08

TABLE 6.9: Ejection plateau summary table. "e$^-$C. Off" and "e$^-$C. On" refer to the status of the electron cooler. Note: changes in emittance are expressed as percentages of initial emittance.

	begin e$^-$C. Off	Error	end e$^-$C. On	Error	Change	Error
ϵ_y (mm mrad)	2.55	0.03	0.53	0.01	79%	2%
y_0 (mm)	-2.08	0.03	-2.03	0.03	0.05	0.06
ϵ_x (mm mrad)	2.5	0.20	0.55	0.04	78%	10%
x_0 (mm)	-3.67	0.04	-3.91	0.04	-0.24	0.08

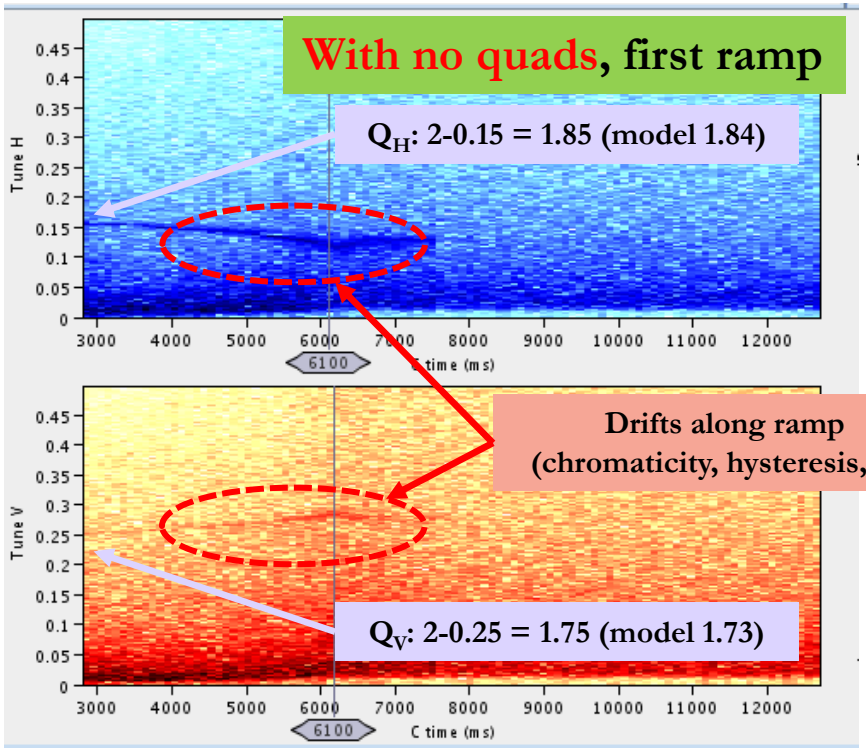
still, about **x2 worst than design** values
(0.3/0.2 μm ϵ_G for **coasting beam** with cooling on)

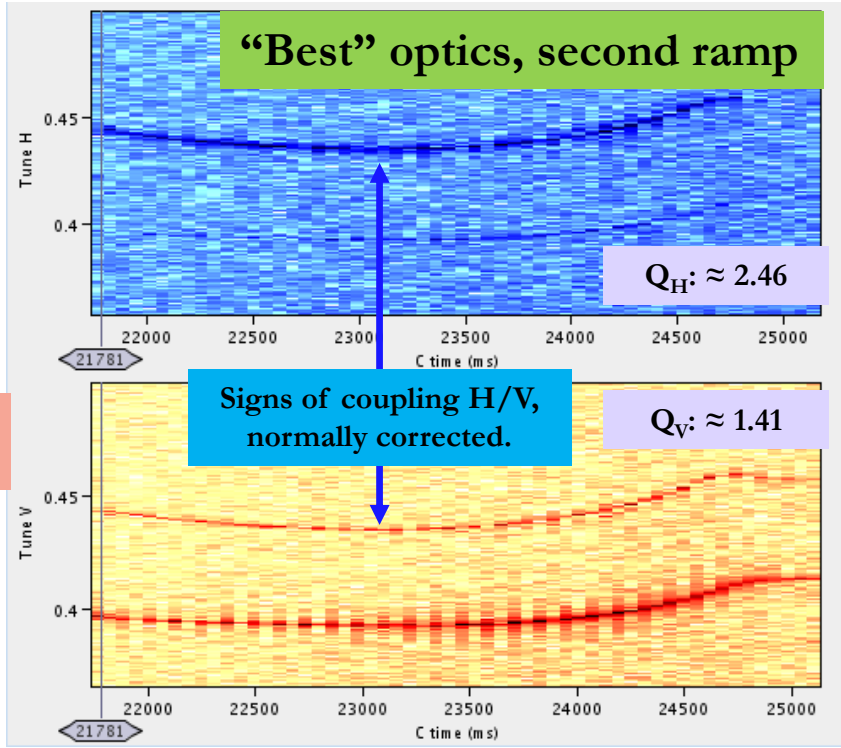
Great emittance reduction

From J.Hunt Ph.D thesis

Tune optimization

- Machine was **designed** to allow for a **broad range of tunes** (around **2.3/1.3**)
- Several **tune measurements** taken at different time with **different optics**
  - Mainly **empirical adjustments** / **trial-and-error** approach
  - The main observable for **optimization** was the **transmission** along cycle

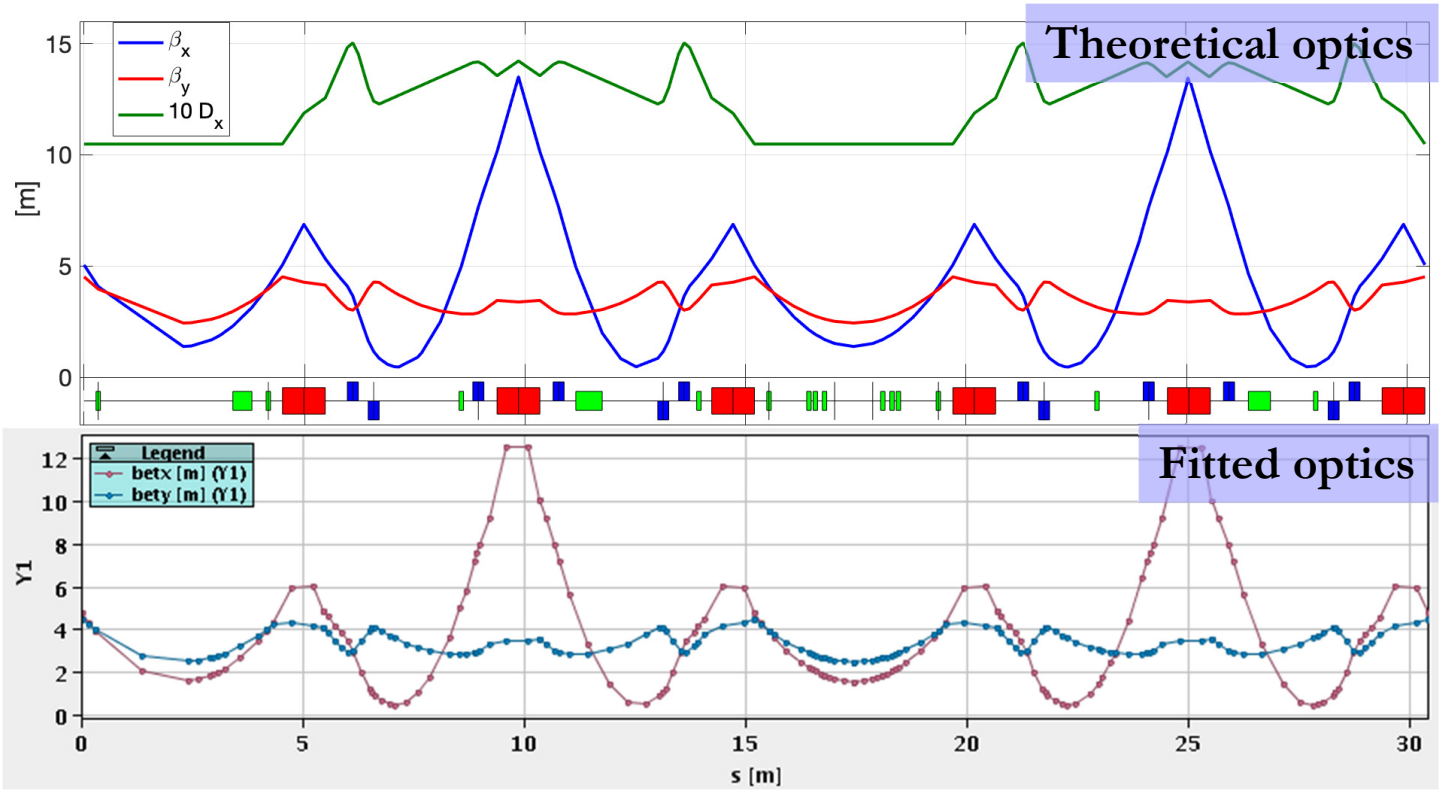




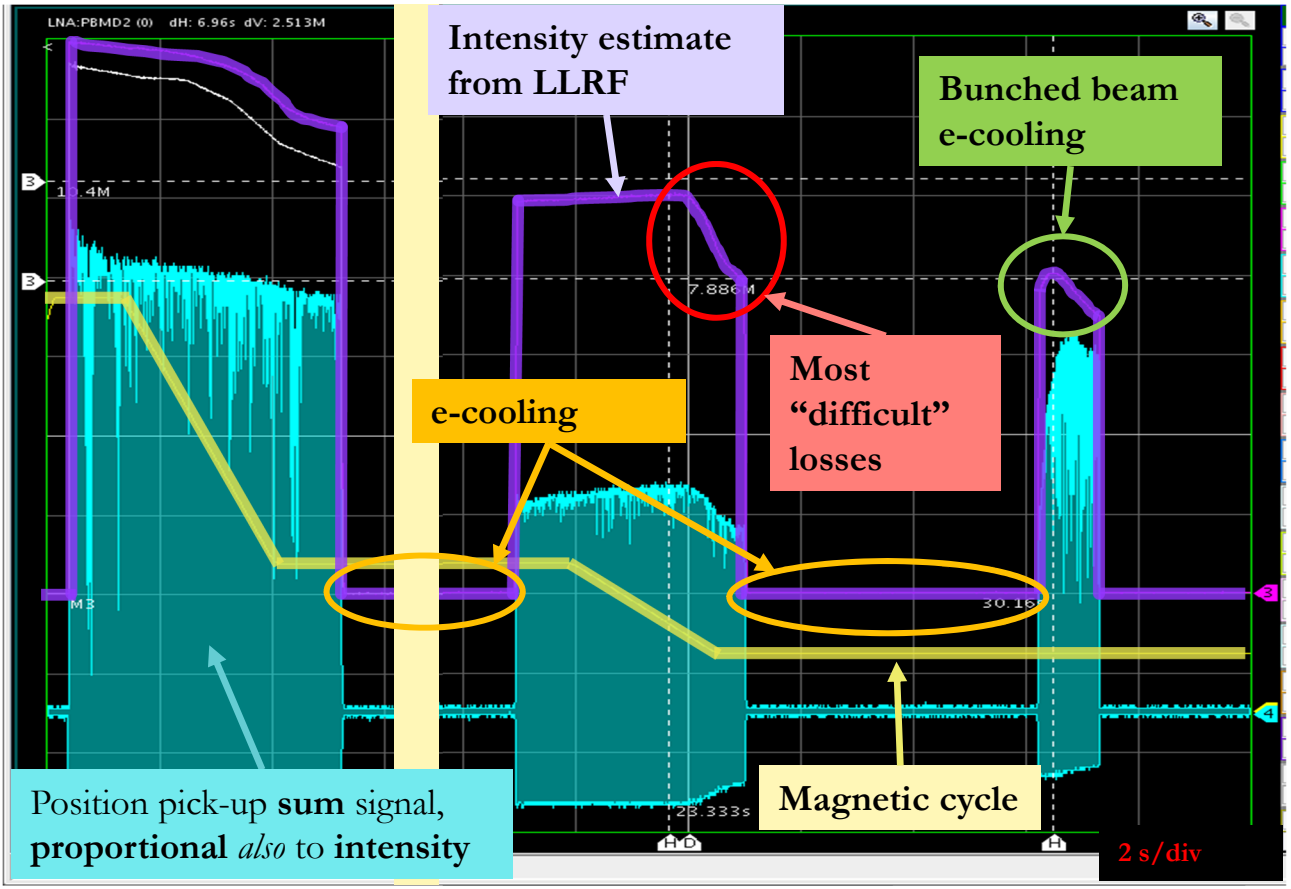
- **Finally able to control tune better than $\Delta Q < 0.02$**
  - Mainly **limited by beam time** and **control system** restrictions (being solved)

Kick response matrix analysis

- **Discrepancies** between **machine model** and **measurements** have been observed
  - Discrepancy **varies along** magnetic **cycle**, pointing to possible **hysteresis effects**
- A possible way to investigate is via **kick response matrix analysis**
  - **(Preliminary) Overall agreement between theoretical optics and fitted optics**



Status End of Run 2018



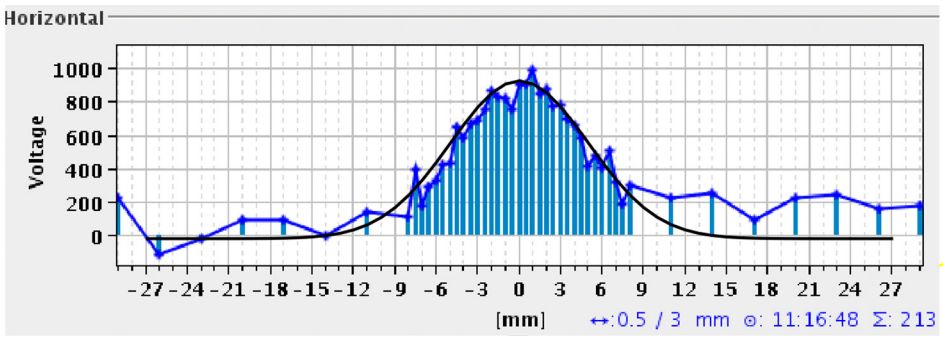
- Almost nominal cycle:
  - Injection 100 MeV/c
  - Deceleration to 35 MeV/c (**h = 1**)
  - De-bunching and **e-cooling**
  - Deceleration to 13.7 MeV/c (**h=4**)
  - De-bunching and **e-cooling**
  - Re-bunching (**with e-cooler on**) on **h=4** and **extraction to experiment**
    - GBAR only user so far.
- If we trust LLRF intensity estimate we have **about 50% deceleration efficiency**
- Still quite some **losses** at the end of **second ramp**
  - **Still to be understood…**

Not far from design parameters

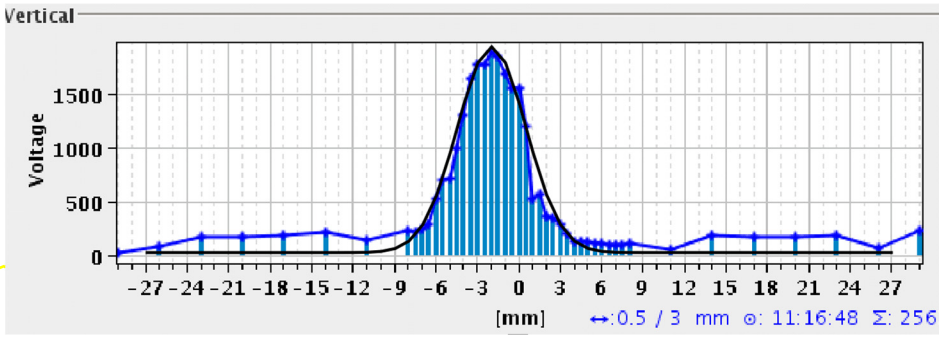
Connection of ELENA to AD experiments approved at the end of 2018

Bunches extracted to GBAR

- Beam profiles in measured on **Microwire monitors** installed in **GBAR line**



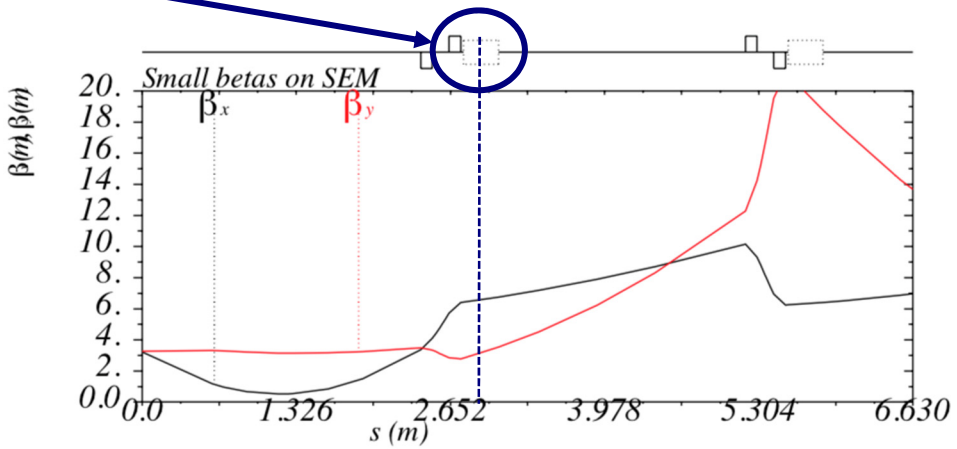
Gaussian fit by hand with σ_H = 5 mm



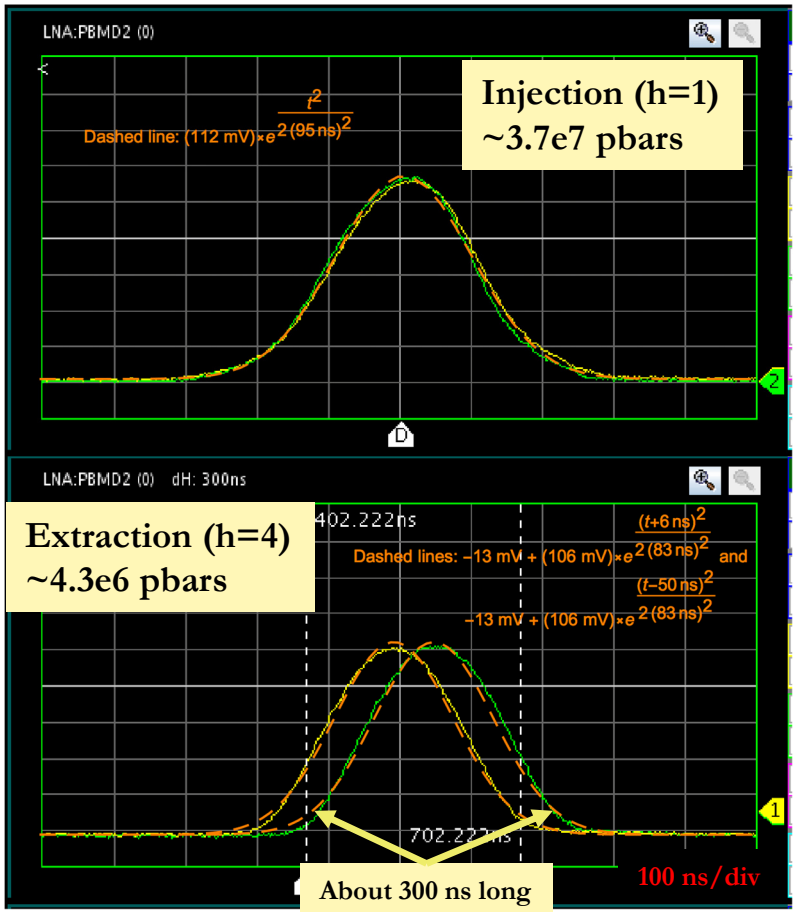
Gaussian fit by hand with σ_V = 2.5 mm

- Acquisitions with second monitor LNE.BSGWA.5020 in GBAR line

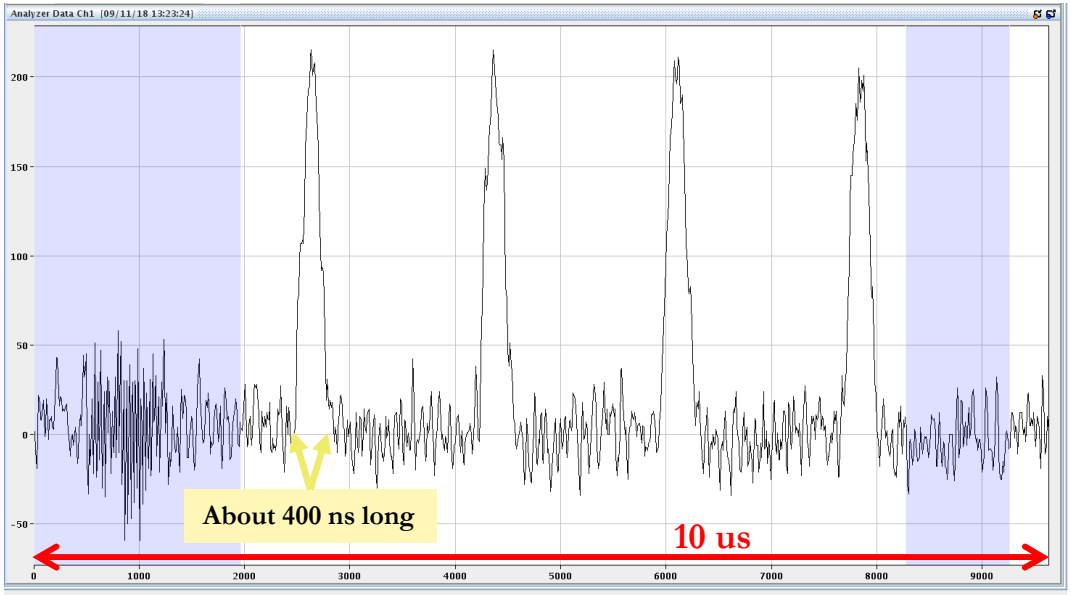
- Beam sizes with voltages of first two quads of line set to zero
  - β_H = 6 m gives rms emittance:
    ε_H = 4.1 µm (without taking dispersion into account)
    (design 1.2 µm)
  - β_V = 4 m gives rms emittance:
    ε_V = 1.5 µm (design 0.75 µm)



Bunches extracted to GBAR

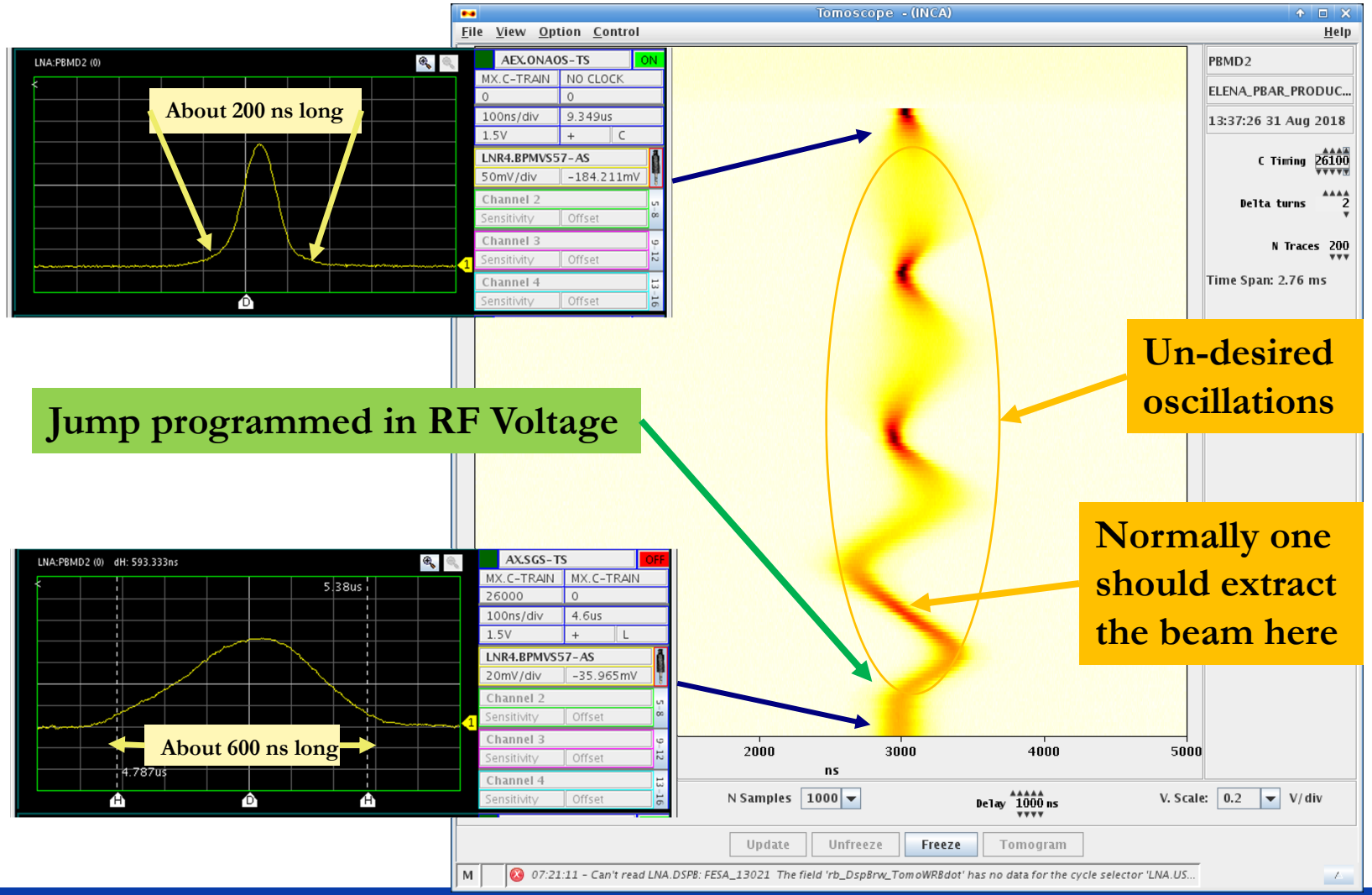


- According to Transverse Pickup signals:
  - After injection 3.7e7 pbars
  - Before extraction 4x4.3e6 = 1.7e7 pbars
- According to Magnetic Pickup in extraction line we see about 1e7 pbars extracted (over all 4 bunches)
  - Unrealistic to think we are loosing 0.7e7 pars at extraction… Probable some calibration error!



“Bunch rotation” (h=1)

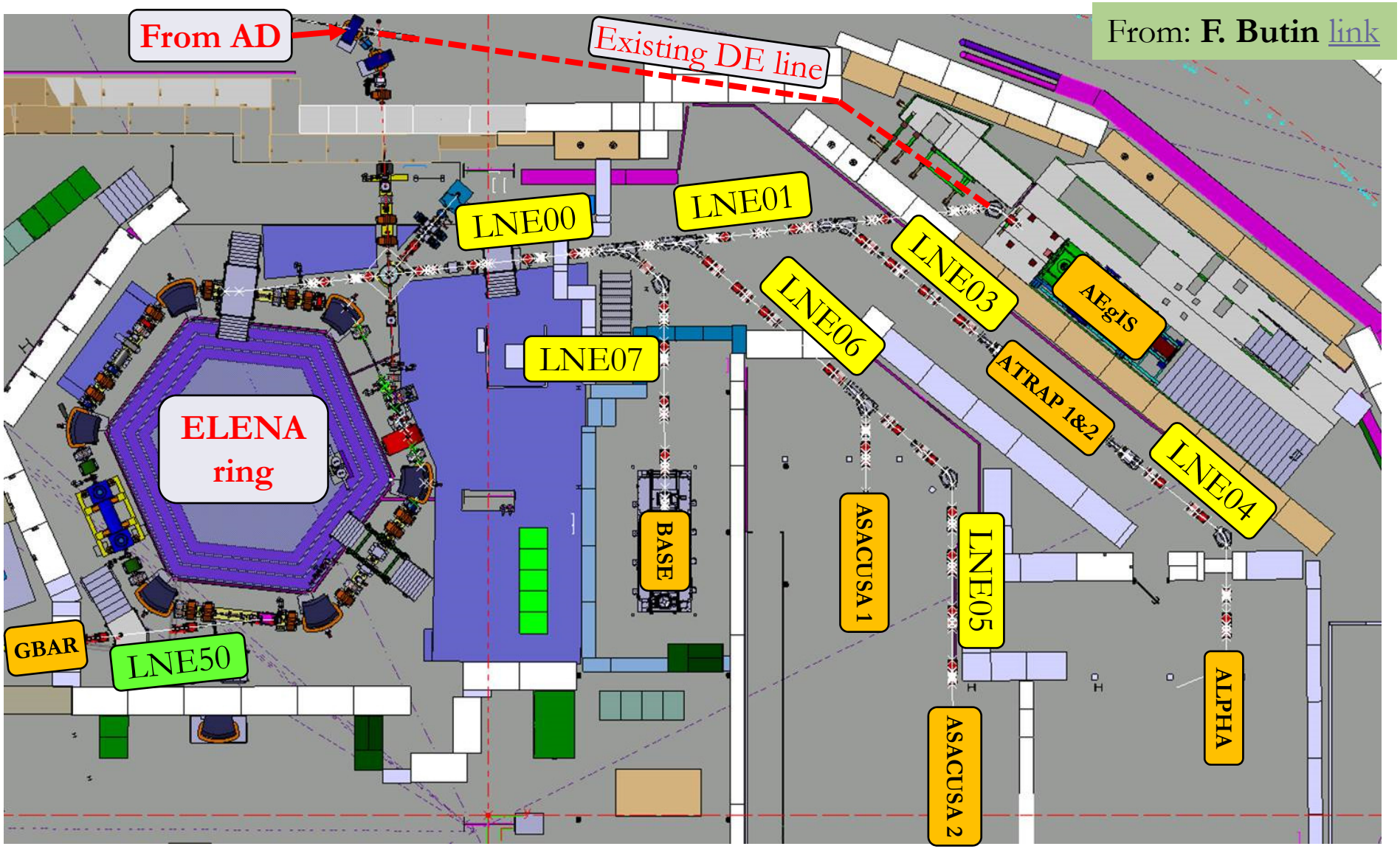
- **Possible** to shorten the bunches (but higher energy spread) with bunch rotation (not baseline) for **h=1** operation.



Current Activities and Plans for LS2

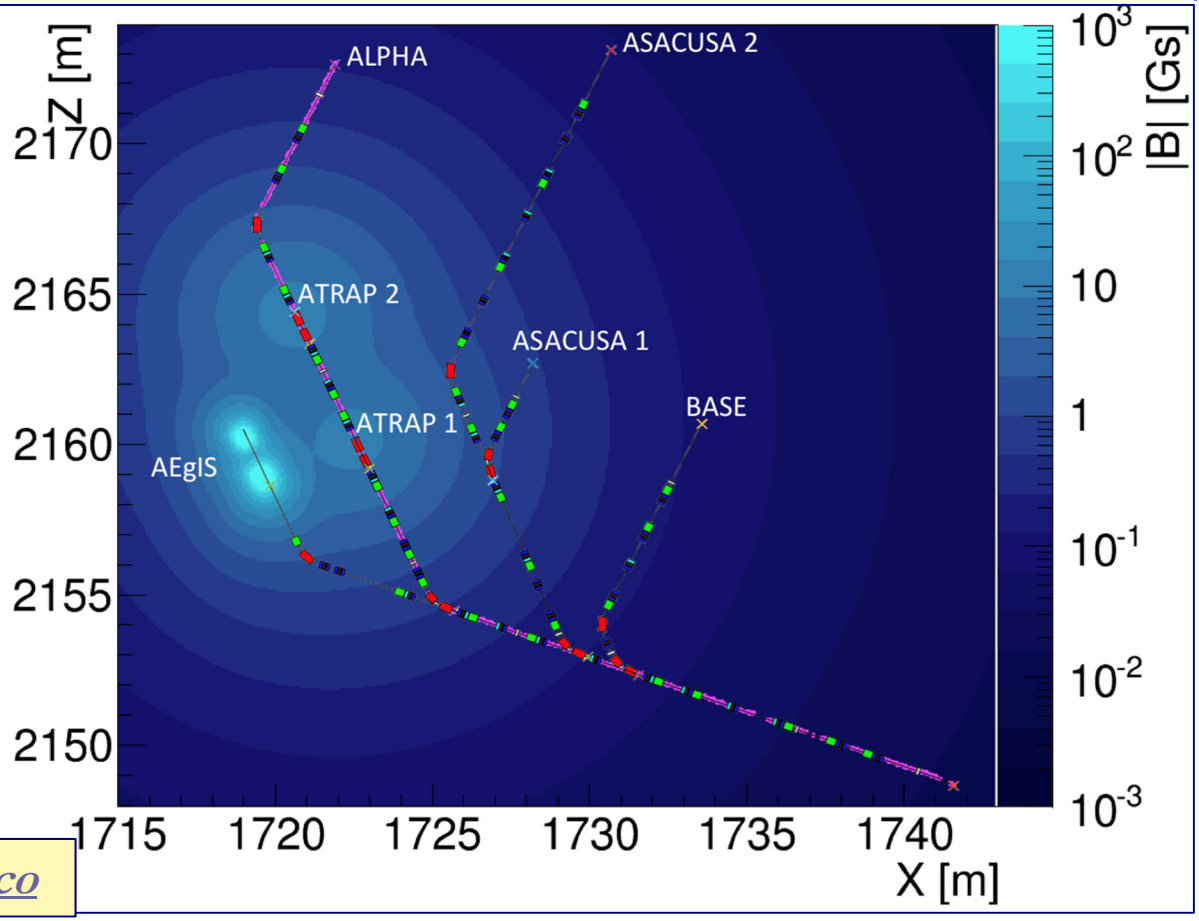
LS2: Electrostatic lines being installed

From: **F. Butin** link



Some concern:
stray fields from experiment magnets

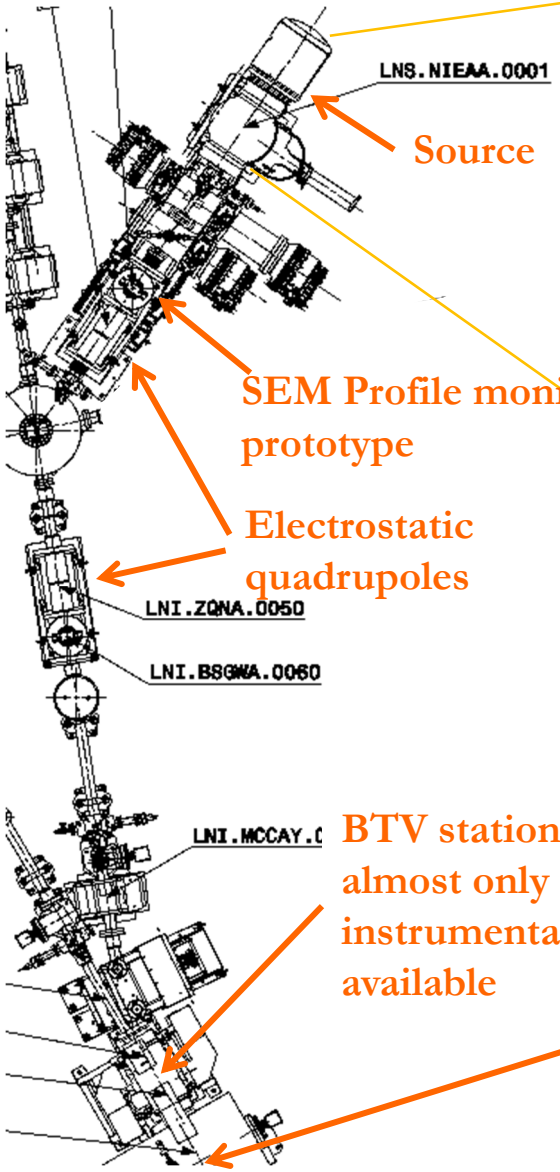
- |B| @ common beam level
- 5 exp. magnets simulated:
  - AEgIS (1T)
  - AEgIS (4.46T)
  - ATRAP 1 (5T)
  - ATRAP 2 (1T)
  - ATRAP 2 PBAR (2T)
- Based on analytical calculations and numerical field maps inside the magnets

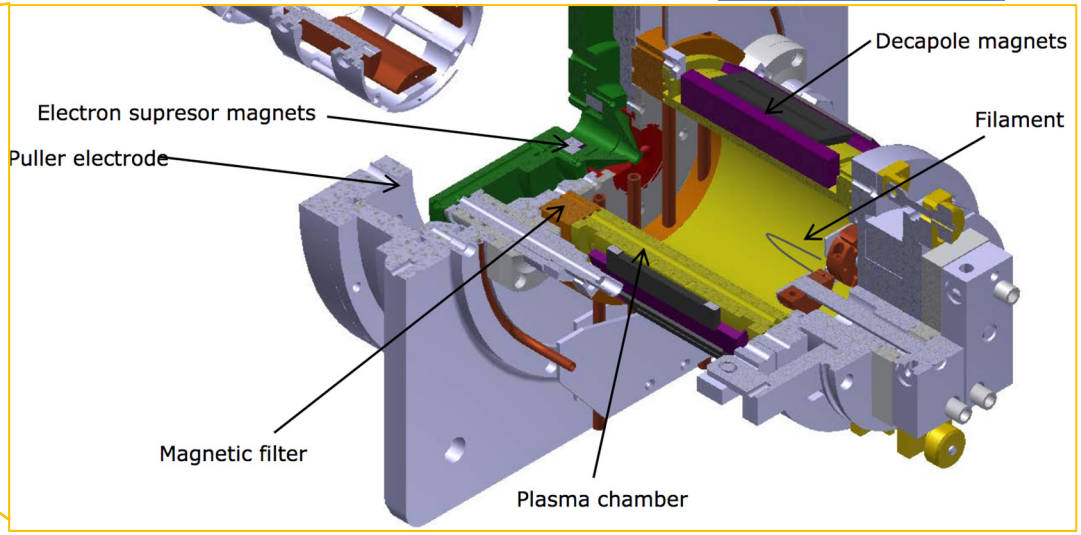


Courtesy J. Jentzsch - indico

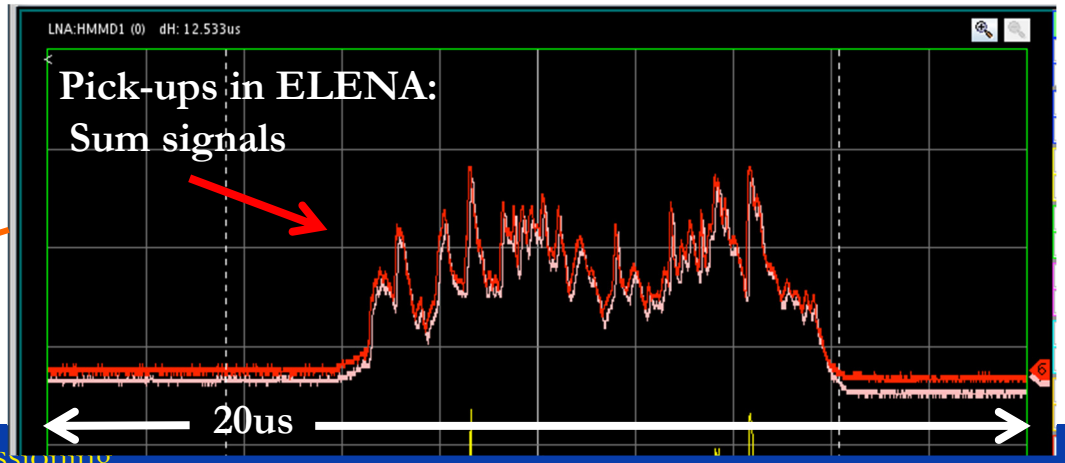
- From preliminary studies, **transfer line design should be able to cope with static fields**
  - **How to cope** with **experiments going on/off** while others are taking beam?
    - Additional **shielding** and/or **"online" orbit correction** knobs **possible**
  - **Plan** is to **start sending beam** to **first assess** the actual **impact on** the **beam**

Some concern:
Ion source instability under investigation





- Experienced **poor beam intensity stability**
- **Lack** of **nearby instrumentation** for debugging
- **Possible** to **see** source **instability** on ELENA **pick-up**



Summary

- **2018** a very **fruitful year** for **ELENA** commissioning
  - Many **sub-systems** (RF, BI, e-cooler) (almost) fully **commissioned**
  - Nominal **beam performance** (almost) **established**
- **E-cooling** is doing what it has promised
  - **Emittance reductions of ~80% at 100 keV**
  - **Longitudinal** beam **specifications** met with **bunched beam cooling**
  - **Results obtained with limited/empirical studies → room for improvement!**
- **Could not** fully **profit** of the **H^-/p source => being fixed**
  - Use of ***p*** **beam envisaged for e-cooling studies (higher rep rate)**
- **Plans for LS2**
  - **Installation** of the **ELENA transfer lines** to the "old" experimental zone
  - **Fix damaged tune kicker** in ELENA Ring
  - **Fix ion source** and **Improve** its **reliability** and **stability**
  - **Resume commissioning activities** with **H^-/p in 2019/2020**
  - **Commissioning** of **electrostatic transfer lines** in **2020**

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