

# Status update from AD/ELENA and APOC WG

*D. Gamba, Y. Dutheil, L. Ponce for the AD/ELENA team*

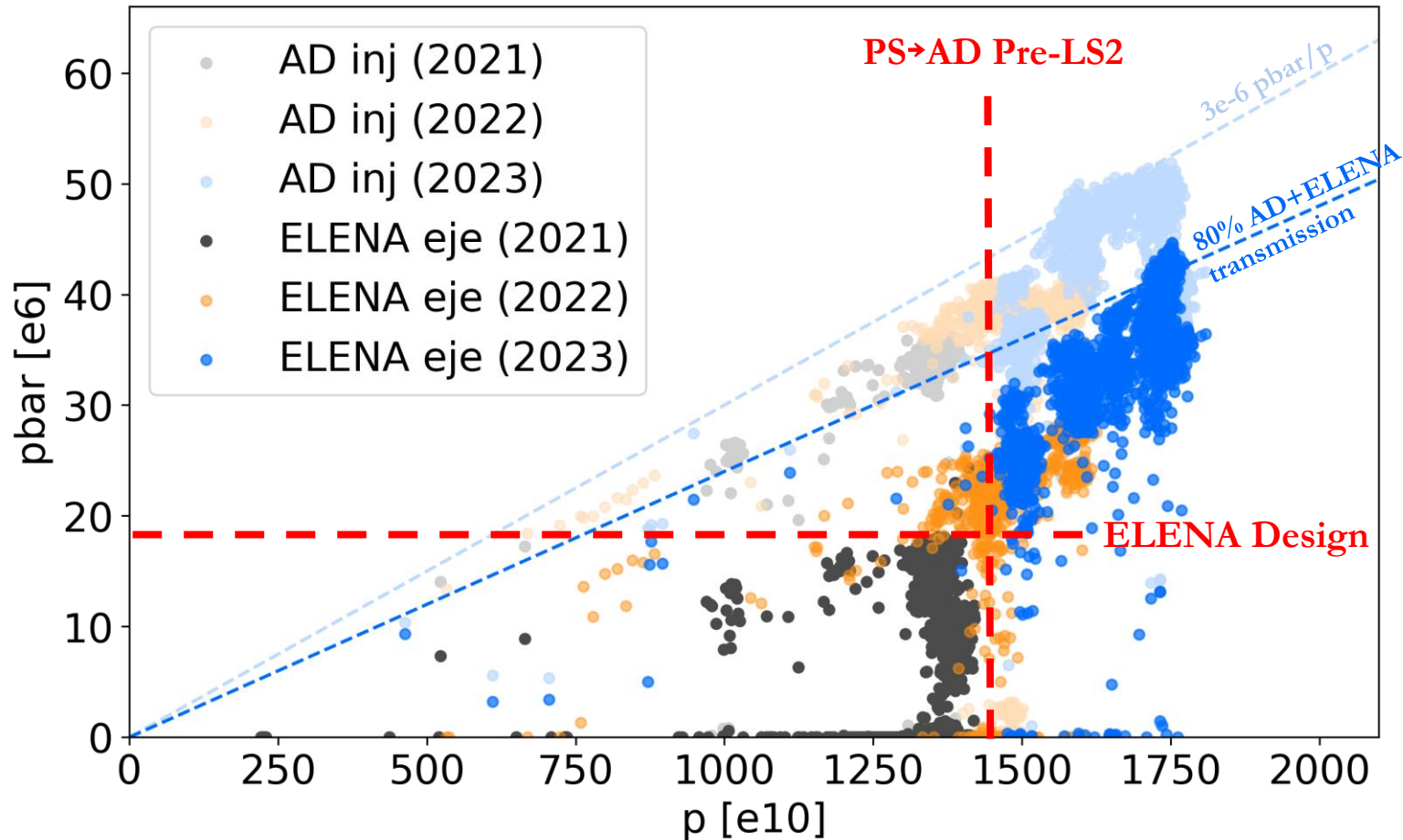
JAPW2023 – 07/12/2023



- **AD/ELENA Overall Performance**
- **User wishes and how we tackle them**
  1. **Intensity and its stability**
  2. **Repetition rate and availability**
  3. **Beam characteristics**
- **Long term sustainability**
- **Conclusions**

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- Overall performance can be expressed as pbars vs protons on target
  - Showing 1 cycle every 50 starting from 1st of July till end-of-physics in 2021, 2022 and 2023



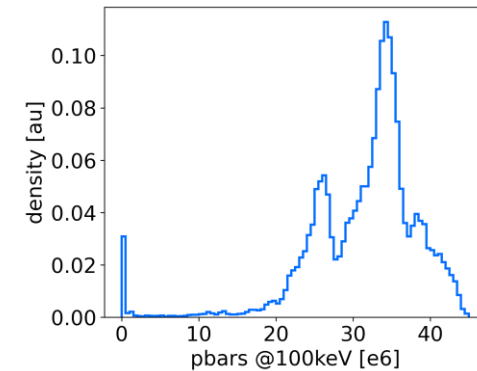
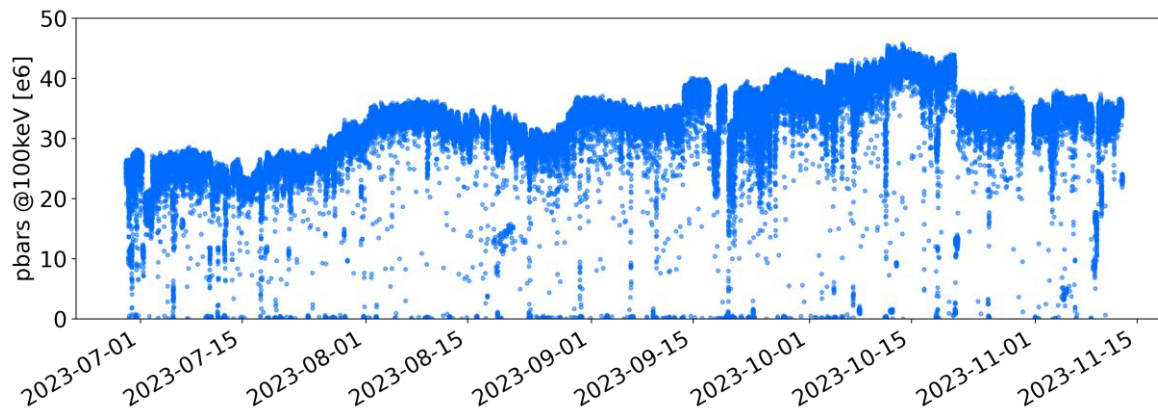
- Overall: another excellent year for AD/ELENA with performance improvements!

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# What our (typical) users want: stable intensity



- As part of follow up **action from JAPW2022**, the AD/ELENA mini-workshop was organised in **March 2023**
- A small **survey** was organized to ask for “**user wishes**” :
  1. **Request: stable intensity** of more than  $2.5e7$  pbar divided in 4 equal bunches
    - Typically, the more, the better....
    - **Acceptable to have slow drifts** over time scales of days/weeks



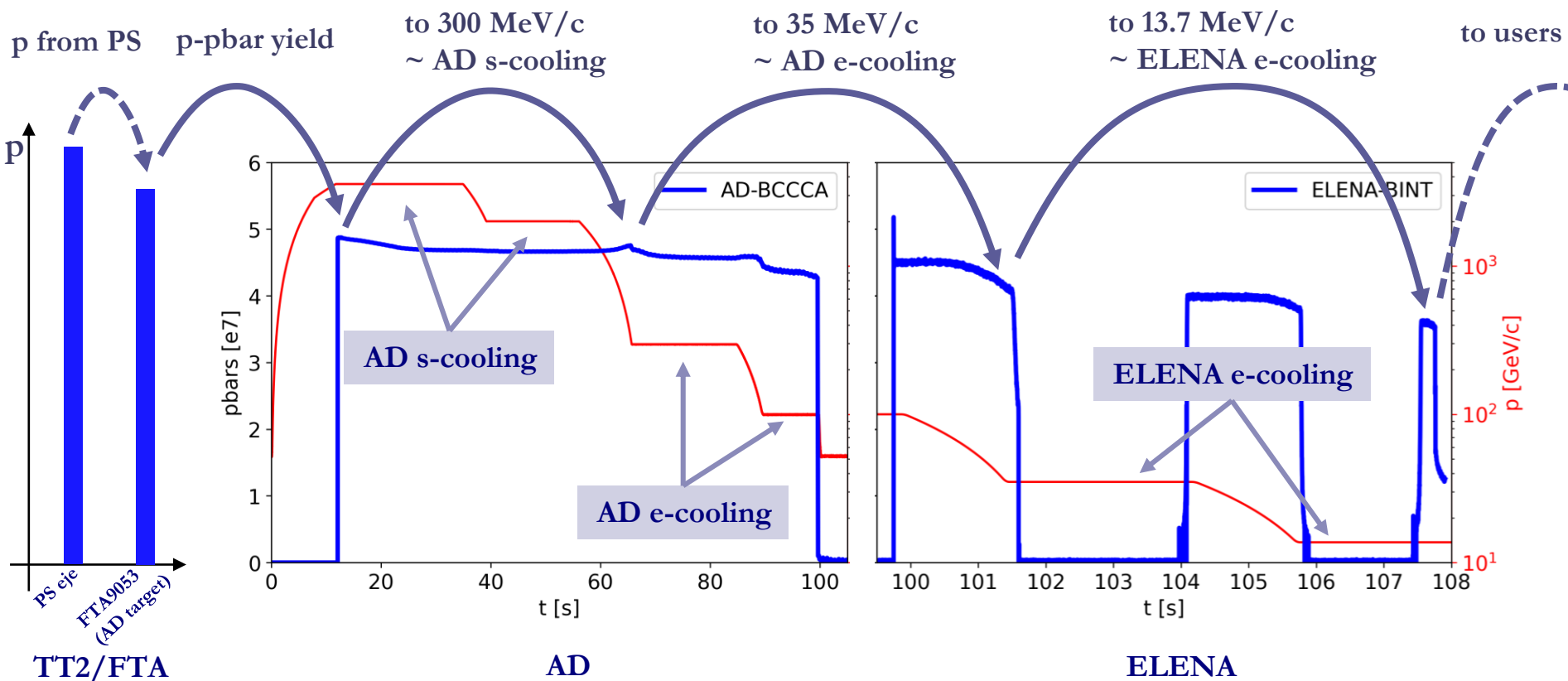
- In practice, quite some **intensity variation/fluctuation (>20%!)** over the year
  - **Slow improvements** thanks to motivated operation team
  - **Slow/fast degradations** due to **natural drifts** and **hardware faults/issues**
  - **Shot-to-shot fluctuations** due to **non-reproducibility** of several sub-systems

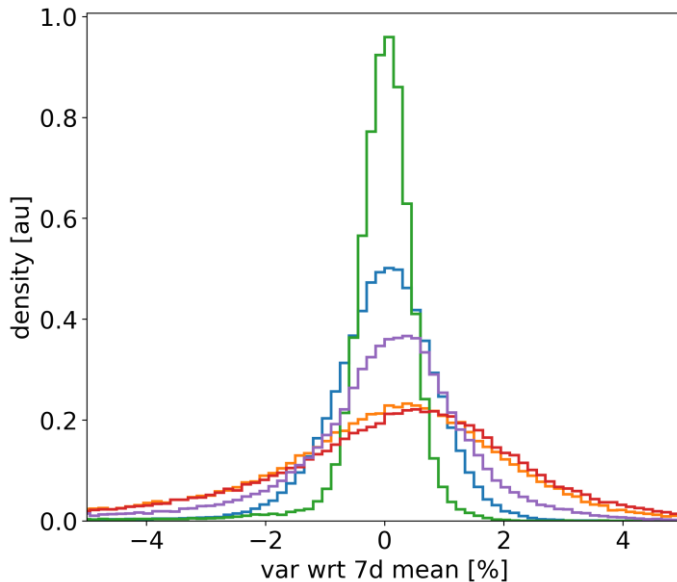
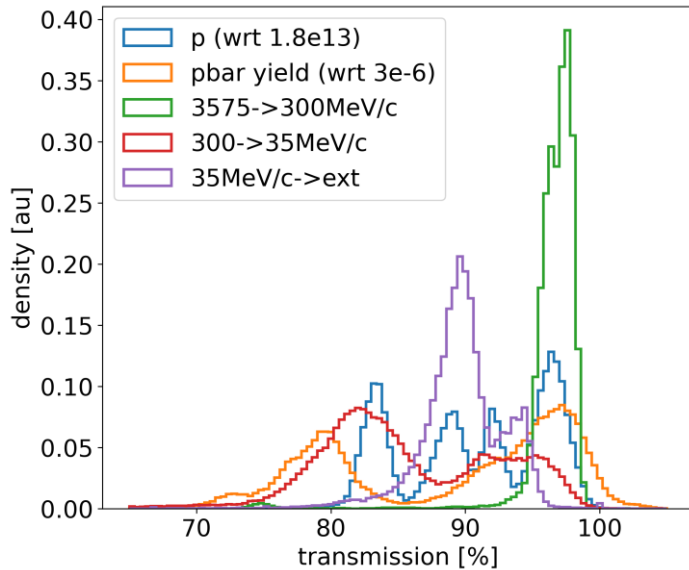
See also presentation by B. Holzer

# Note: AD/ELENA Cycles



- Magnetic cycles basically **un-changed in length since 2022**
- **To simplify**, the deceleration process can be divided (arbitrary choice) in **macro-steps linked to underlying “production” or “cooling” mechanisms**
  - **Disclaimer: transmission** along one step **might depend on beam quality** from previous one...





## ■ Proton intensity on target (BCT9053):

- Stepwise increase thanks to **5-bunch setup** by PS in 2022 and thanks to **improved shielding** of AEGIS area
- **Sizeable short-term variation** (see next slide)

## ■ “p-on-target to pbar-in-AD-ring yield:

- **Step** due to **horn flashovers** (being addressed during YETS)
- **Large short-term variation** subject of study of the **APOC WG** led by Y. Dutheil (ABT) (see following slides)

## ■ From AD injection to 300 MeV/c plateau:

- **Excellent performance** of s-cooling and AD at high  $p$

## ■ From AD@300 MeV/c to ELENA@35 MeV/c:

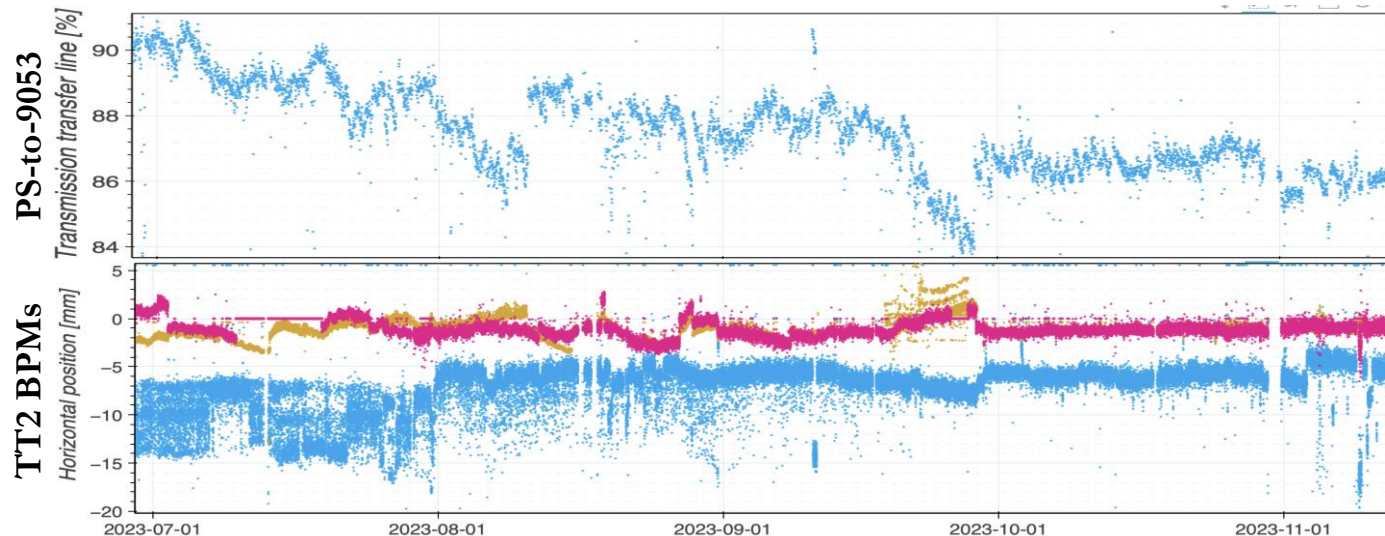
- **Large variation** of overall performance, linked to:
  - **AD e-cooler performance/stability**
    - Looking forward for a **new e-cooler** after LS3!
  - **AD ejection oscillation**
    - **Investigation ongoing** led by L. Bojtar (OP)

## ■ From ELENA@35 MeV/c to extraction:

- Low performance linked to **e-cooling** and **space-charge** effects
- Indication that **we need to spend some more time on ELENA**, and not only on keeping AD up and running...



- **Excellent stability** of proton production **up to PS last turn!** (see [T. Prebibaj](#))
- **~90% PS-to-AD-target transmission**, still below what it was (maybe) pre-LS2 :
  - **BCT's gating** not always accurate?
  - **BLMs not always consistent** with BCT readings?
  - **Tests with pencil beam planned**, if time allows, **in 2024** by Y. Dutheil
- Transmission **variation/drift** might also be linked to **steering** in TT2/FTA?!:
  - Possibility to **stabilize TT2/FTA already presented last year**, to be automatized
  - **No BPMs in FTA**: see request in presentation by [M. Van Dijk](#)
  - Some “**alarm-like**” **detection drift/degradation** would probably help operation?!



- Put in place as a **follow-up action from JAPW2022**

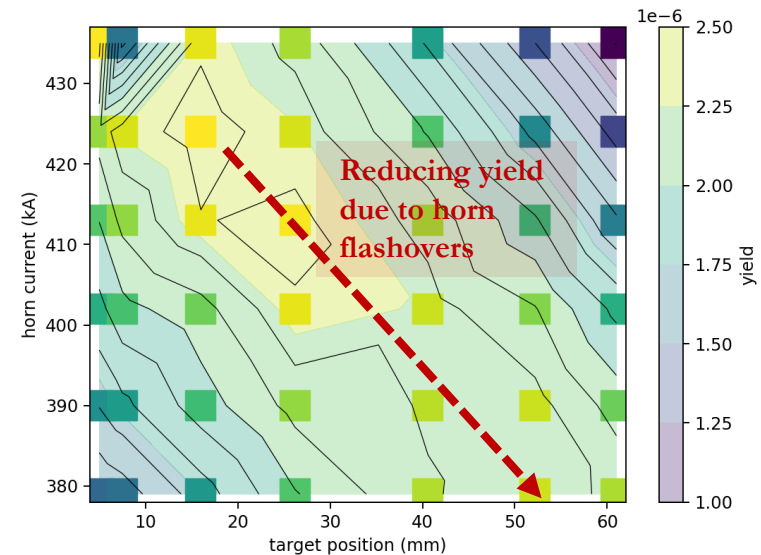
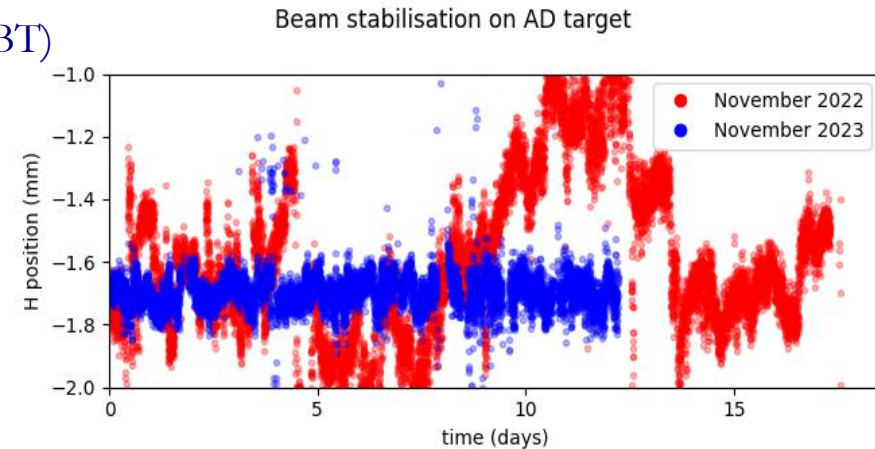
- General + topical zoom meeting since July
  - usually 2-5 participants (OP, ABP, STI and ABT)
- Indico category can be found [here](#)

- **2023 progress:**

- **Beam stabilizer** to maintain the position of the **proton beam on the antiproton target**
  - Target is only 3mm in diameter while beam rms beam size  $\sim 1$ mm
  - Hundreds of manually adjustments in 2022, completely automatized since August 2023

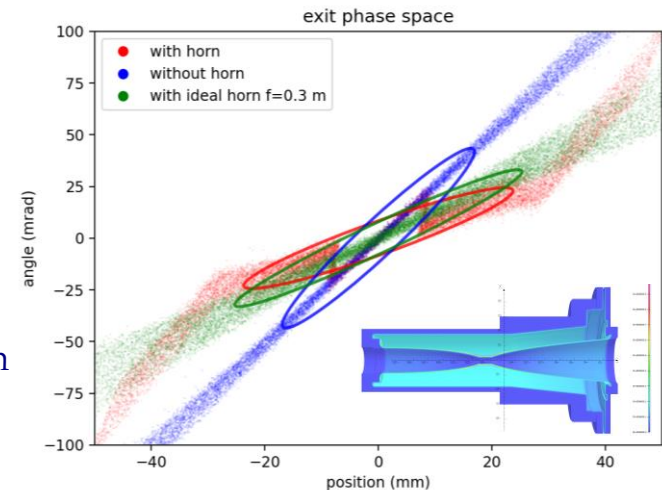
- **Antiproton yield mapping**

- Mapping of **horn-strength Vs target position** optimum: study started in 2022
- **Allowed to quickly compensate for degradation of horn hardware in Oct/Nov 2023!**
  - **Good example demonstrating the importance of this kind of studies!**



## ■ Progress on modelling of AD target and its horn:

- Horn magnetic finite element model and magnetic field map computed by ABT-PPE (J. Ruf, Y. Dutheil, see [#3](#))
- Antiproton distribution from STI using FLUKA
- **Toward model-guided setting up and optimization!**
  - Hopefully allowing to **study the expected yield** with various **target designs** and materials



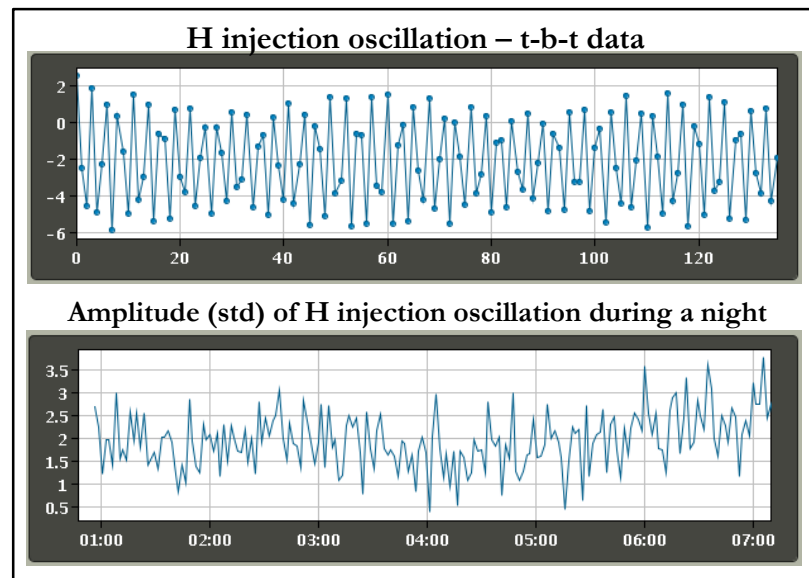
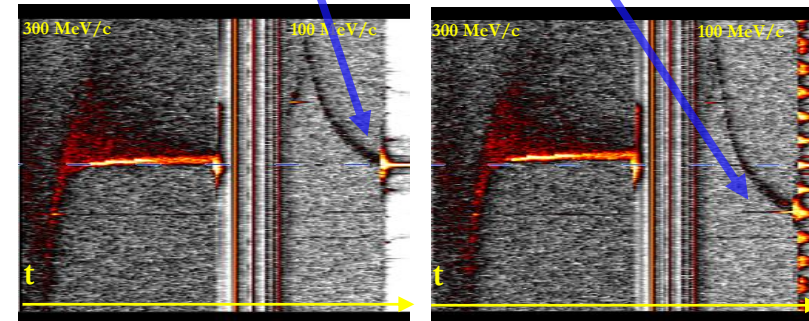
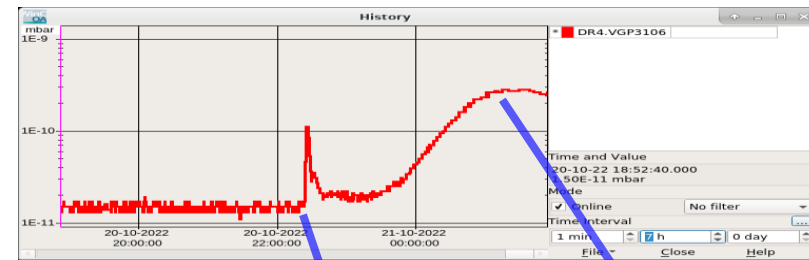
## ■ Reducing pulsing rate of DI magnets to extend equipment lifetime

- This turned out to have a **negative impact on pbar yield stability**
- **Measuring** the **DI.BHZ24&25 powering system** and **magnetic properties** during the YETS
  - Thanks to EPC and MSC colleagues! See also dedicated meetings [#1](#), [#2](#) & [#3](#)
- Working on **joint magnets+power converters consolidation** (See ECR [2953934](#))

## ■ Many other subjects being investigated, for example:

- Improved FTA control with magnets logicals and UCAP-hosted BTV screen fitting
- New methods for AD injection steering optimisation
  - Using ring BTV for injected and circulating beam position measurement (see [5<sup>th</sup> BIFT](#))
  - First turn trajectory measurement under investigation with BI

- Regular observation of **vacuum activity** that trigger **instability of AD e-cooler**
  - It might be possible to **develop software slow-feedback** to stabilise it...
  - ... hope in the **new AD e-cooler**
    - *See status at review in June2023 and presentation at COOL23*
  
- **Power converter/field instabilities**
  - E.g. **QUAD-TRIM3** suddenly providing only **half the current** despite normal acquisition...
    - ... consolidation “wanted”!
  
- **Trajectory instability at AD ejection**
  - Traced back to **AD ejection septa**
    - Investigations ongoing to cure it...
  - **Impact on AD-to-ELENA transport and deceleration to 35 MeV/c**
    - Developed on-demand **correction of ELENA injection oscillation to be converted in a (slow) feedback**



- **AD S-Cooling**
  - **Toward a clear understanding** of the **present implementation** and **efficient setup** strategy with modern tools: see S. Rey at [COOL2023](#)
  - **Must pursue this effort** to have a **solid consolidation/upgrade plan** of the system
- **HLRF + LLRF + C10**
  - Overall, **no major issues**, but **C10 in critical status**: consolidation plans being discussed...
    - **Need for better observables**: see presentation by [S. Albright](#)
  - **ObsBox online**, and **development/improvement** still **ongoing**
    - We need to start profiting of this system...
- **B-Train**
  - **Not ideal simulated b-train for AD**
  - **Still using LLRF test feature in ELENA...**
  - **Injector-wide strategy being discussed**. See for example [IPP in Oct. 2023](#)
- **Beam Instrumentation Characterization/Consolidation/Upgrade**
  - See, for example, work on **scraper measurement understanding** by [G. Russo](#) at [HBWS2023](#), and **presentation by [M. Van Dijk](#)**
  - Discussions ongoing at different forums about IPM, Intensity, Schottky Measurements, ...
    - **Need to draft a coherent plan** for better/new instrumentation
- **Radiation Levels Reduction**
  - **Thanks to additional shielding** installed during YETS22/23 and **better monitoring**

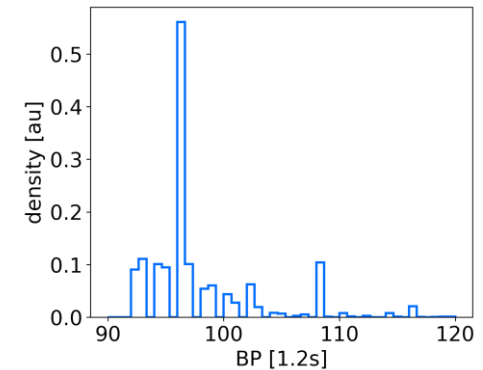
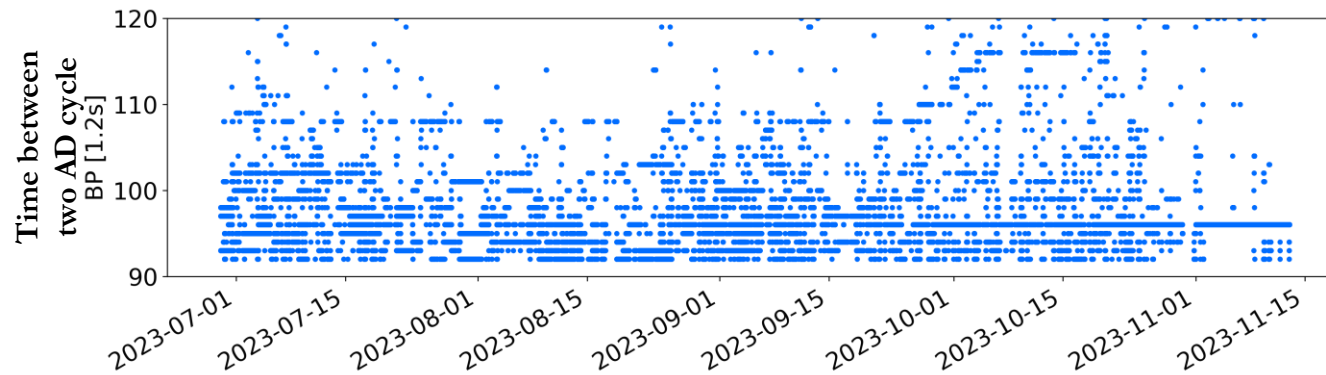
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# What our (typical) users wants: stable rep rate



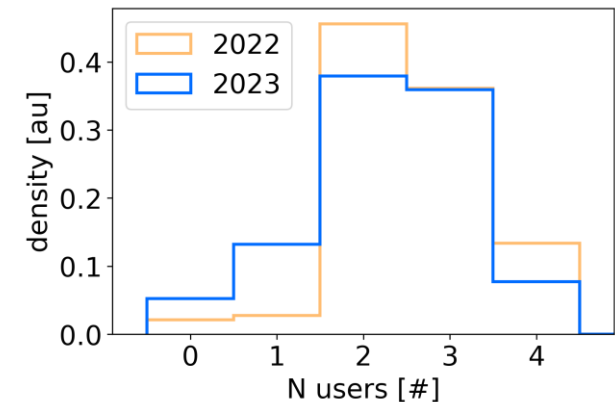
User request: **stable** (order of 5% over  $\sim 1$  week) **repetition period** ( $\sim 110$  s)

- Usual **repetition rate variation** driven by **PS supercycle** composition and strategy
  - Some punctual improvement, but **not much we can do** (but cycle the injectors only for AD...)



## ■ Beam request handling not always optimal

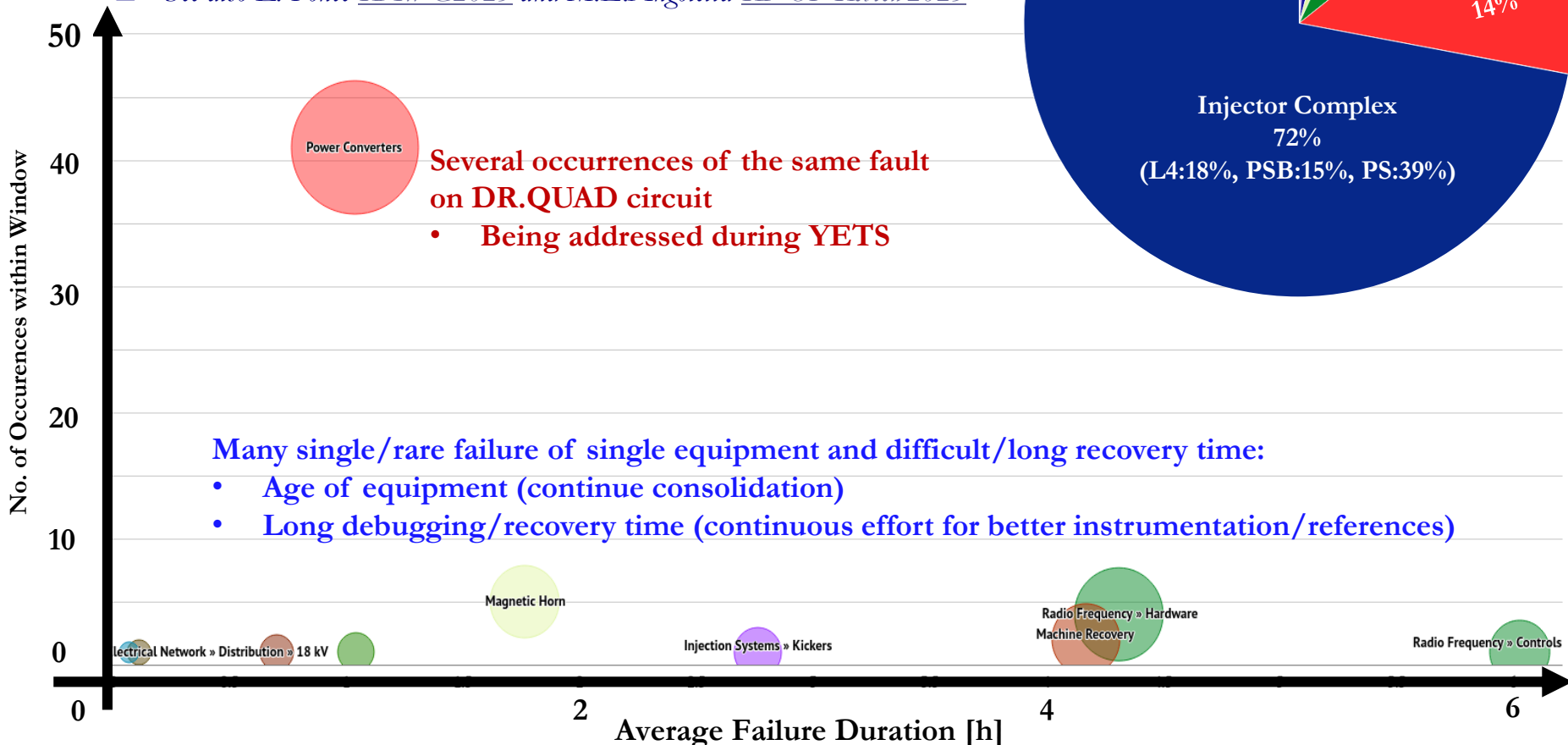
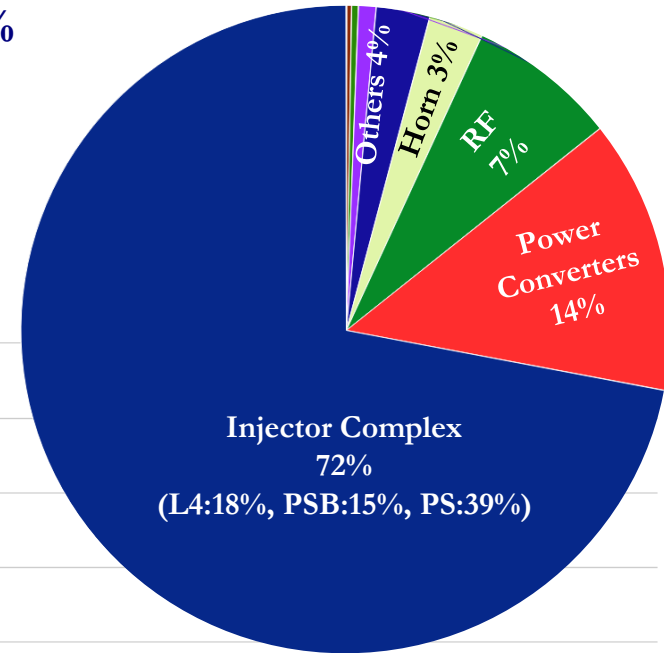
- E.g. some users (e.g. ALPHA) would benefit of **being certain to receive one bunch every N cycles**
- Only **less than 10% of the time with 4 users** taking beam simultaneously :
  - One could think of **reducing the number of bunches to 3**, but **complex problem...**
- **...to be discussed with the users!**



# Hardware Faults During Physics – any Trend?

■ **AD average availability** (without injector faults) is **97.5%**

- **With injector faults**, this would drop to about **90%!**
- **ELENA not considered** here, but **no big issues to report**
- Initial issue with **QFC54 not considered**: this alone corresponds to about **10% loss of physics time with respect to initial plan**
- See also *L. Ponce-RAWG2023* and *M.E. Angoletta-RF OP Review2023*

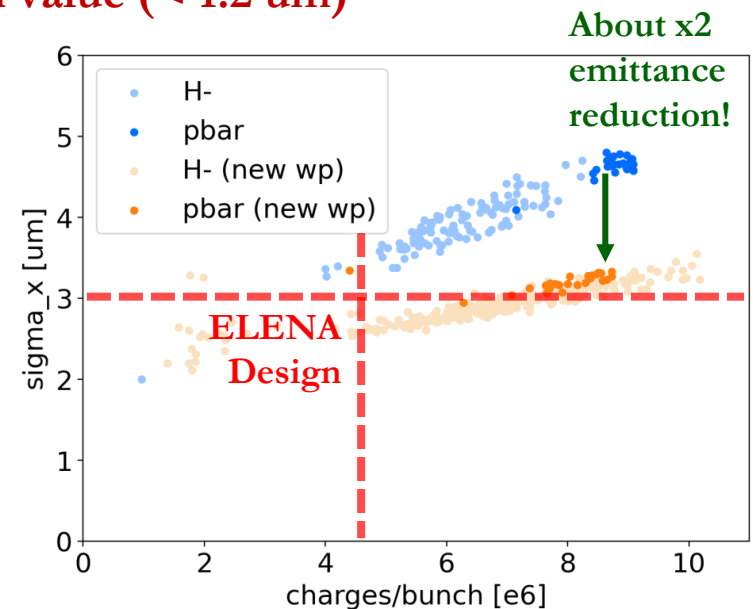




- **AD/ELENA Overall Performance**
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## User request: keep present beam characteristics

- Extraction energy of **100 keV**:
  - Present user hardware designed for this energy
- bunch-length **<150 ns FWHM**
  - GBAR asking for <100 ns FWHM, routinely achieved with bunch rotation
- Emittance **< 2 $\mu\text{m}$** 
  - **only parameter not meeting ELENA design value (< 1.2  $\mu\text{m}$ )**
  - This might be a **limitation for some user like GBAR**
  - **Investigation with  $\text{H}^-$  showed that using a different working point could be beneficial**
    - Observation **confirmed with a few pbar cycles!**
    - Another example of the **importance of keeping the ELENA  $\text{H}^-$  source operational!**
  - **Plan to start 2024 run with the new working point**



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- **AD is aging! ... and soon ELENA will as well...**
  - *Example:* issue with **QFC54** at startup: **important to finalize magnets consolidation**
  - *Example:* long term strategy for **SEM** in **ELENA** transfer lines being discussed
  - Plans to **establish a test facility for low-intensity, low-energy (pbar/H<sup>-</sup>) beam instrumentation and components testing** (see **TELMAX** proposal, EDMS [2975107](#))
  - Usual concerns for **liquid helium distribution, water cooling, cranes, powering during YETS, ...**

...many hardware/infrastructure topics not discussed here...

- **Working on a long-term Consolidation/Upgrade plan** for the facility
  - Will need to include power supplies, s-cooling, instrumentation, infrastructure, ...
  - **It requires input from physics community** (maybe at SPSC in 2024 or 2025?)
  - **Main aim: provide inputs to CERN management such to obtain a clear statement on the long-term (beyond LS4) lifetime of the complex**
  - See also [IEFC of 7th July 2023](#) and [ADTC of 14th Sep. 2023](#)

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- Generally, **yet another excellent year for AD/ELENA!**
  - Despite several **reliability issues** and **bad surprises**
  - Thanks to **determined** and **motivated AD/ELENA teams** with **invaluable support** from **uncountable colleagues...**
  - **In 2023**, we probably **reached the peak performance** of the facility **with present hardware** (and manpower)
  - **Investments** into new tools and machine understanding **have paid off** on several occasions!
  
- **Projections for 2024 and beyond:**
  - Work on **performance stabilisation** and **faster recovery** time, e.g.:
    - Stabilise **proton reproducibility** and **pbar yield**
    - Cure sources of **fluctuations** observed in **DI line** and **AD ejection**
    - Continue to **collect references** and **procedures**
  - **Invest more time on ELENA pbar performance**
    - E.g., close the chapter of **higher emittances than design...**
  - Work on a **coherent plan for a bright long-term future of the facility**

as in JAPW2022!

2023

2024+++





# Thanks!

C. Ahdida, S. Albright, M.E. Angoletta, L. Bojtár, F. Butin, C. Carli, F.S. Carlier, J. Cenede, B. Dupuy, Y. Dutheil, A. Frassier, P. Freyermuth, T. Giles, W. Hofle, S. Jensen, L.V. Joergensen, G. Khatri, Be. Lefort, C. Machado, O. Marqversen, B. Ninet, S. Pasinelli, L. Ponce, S.F. Rey, S. Reignier, G. Russo, G. Tranquille...

... and the many more colleagues to whom I apologise for not mentioning their name, but without whom AD/ELENA would not give us so much satisfaction (i.e. troubles) and anti-physics!

## ■ Repetition time and stability:

- ~110s (mainly driven by BASE: shorter cycles can be a problem for them!)
- Ideally requiring **back-to-back cycles** (optimum for stability and intensity flux).
  - If not (as today) we should **aim for 5% rep-rate stability**

## ■ Delivered bunch properties:

- >7.5e6 pbars/bunch (driven by AEgIS design)
- Rms emittance <2um. No strong desire for lower (but GBAR, short term)
- Rms dp/p <1e-3. No strong desire for lower
- Trajectory stability <0.1 mm
- 100 ns FWHM bunch length
  - Today's 150 ns FWHM without bunch rotation sufficient for most experiments, but GBAR.
- 100 keV fixed extraction energy
  - But keep open the possibility to explore 50-500 keV (up to 5.3 MeV for ASACUSA1)

## ■ Beam availability:

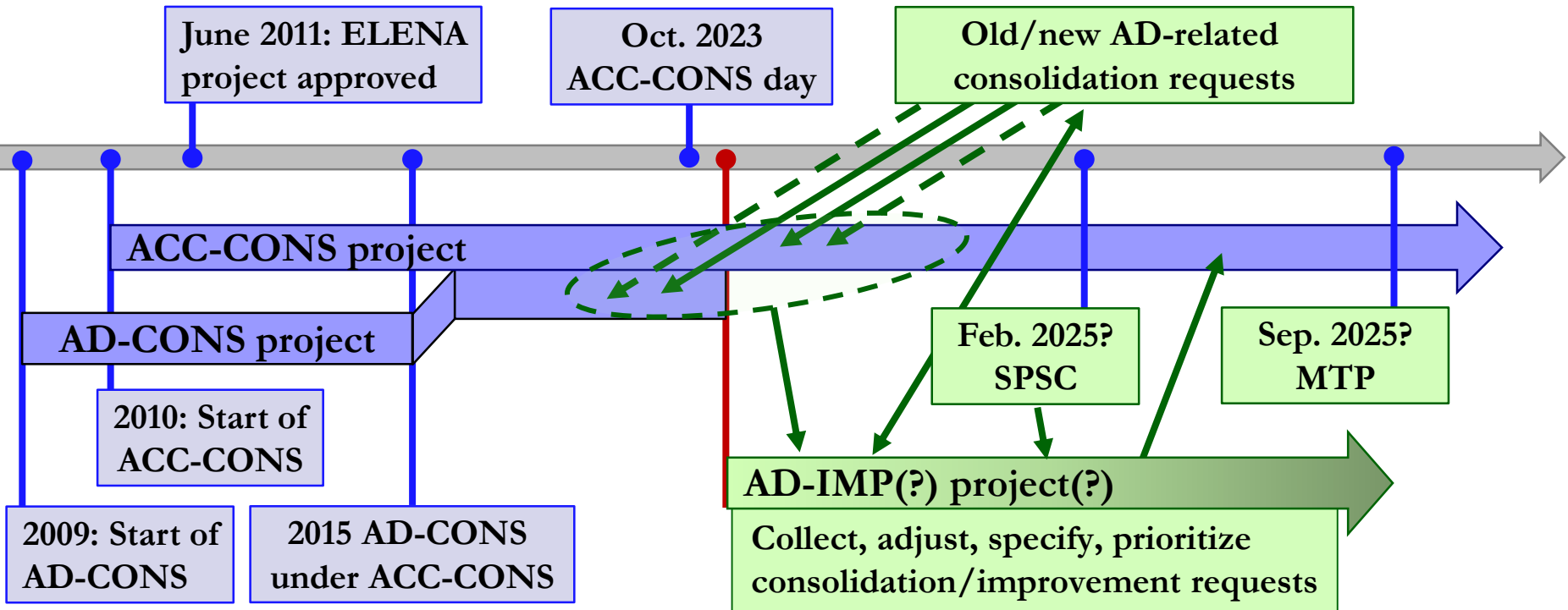
- Present **yearly schedule (days of pbar physics)** and **injectors availability** typically good enough
  - Both could be improved with **equal importance**
- 4 bunches extracted from ELENA all the time** seems to satisfy most use cases
  - More **dynamic scenarios don't seem to be interesting**





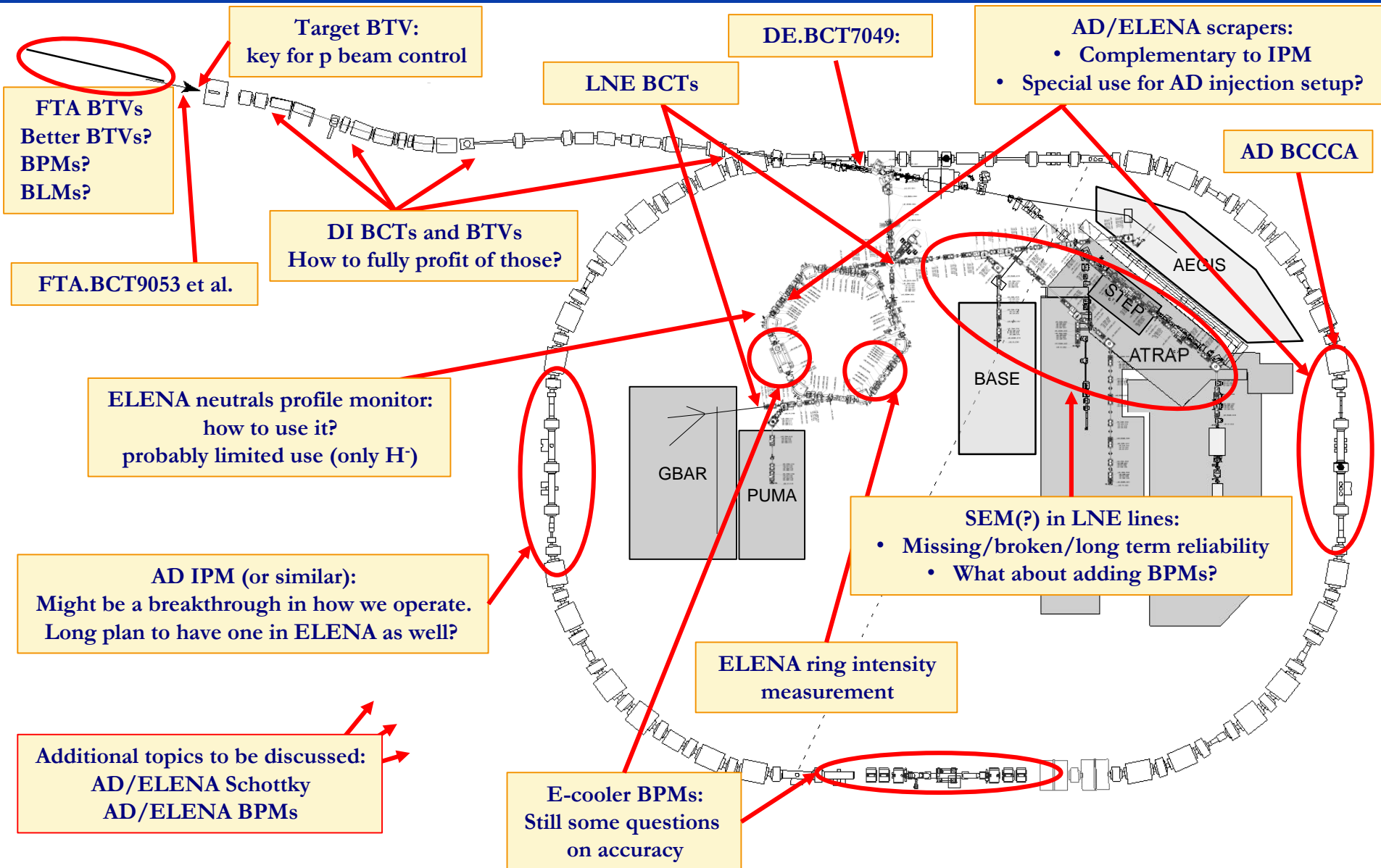
- Optimise for **quality/stability** of delivered pbar bunches
  - **100 ns FWHM** bunch length, **1e-3 rms dp/p**,
  - Try to solve the “large emittance issue”, aiming at **~1 um rms emittances**
  - Work on **intensity measurement accuracy** and beam **trajectory stabilisation**
  - Work on “**performance recovery**” procedures (e.g. e-cooler drifts, trajectory drifts due to stray fields, ...), including **ring optics studies**
- Aim at **~100s-long, regular cycles**
  - Insist on more **careful super-cycle composition** (short term) and/or “**on demand**” **beam request** from PS (long term) – (worth up to 10% higher pbar flux at fixed rep-rate)
  - Insist on **higher availability from injectors** – (worth up to 10% higher pbar flux)
  - Reduce AD cycle length where possible, but no need to insist too much (already close to 100s)
- Aim at 4 x **1e7 bunches** extracted from ELENA
  - **Exploit maximum AD target capabilities**
    - highest **proton intensity** (toward  $2e^{13}$  p/pulse)
    - Pbar **yield optimisation** (including studying of DI optics and AD injection)
  - Aim at **80% transmission** from AD injection to ELENA ejection
  - Test of **h=3 instead of h=4** at ELENA ejection? (to be discussed)
- **long term/nice to have (to be discussed):**
  - Open the possibility for **higher-energy** and **lower-energy extraction** from ELENA?
  - Possibility to inject/decelerate **antideuteron** in AD?

# AD/ELENA Improvement Project Timeline



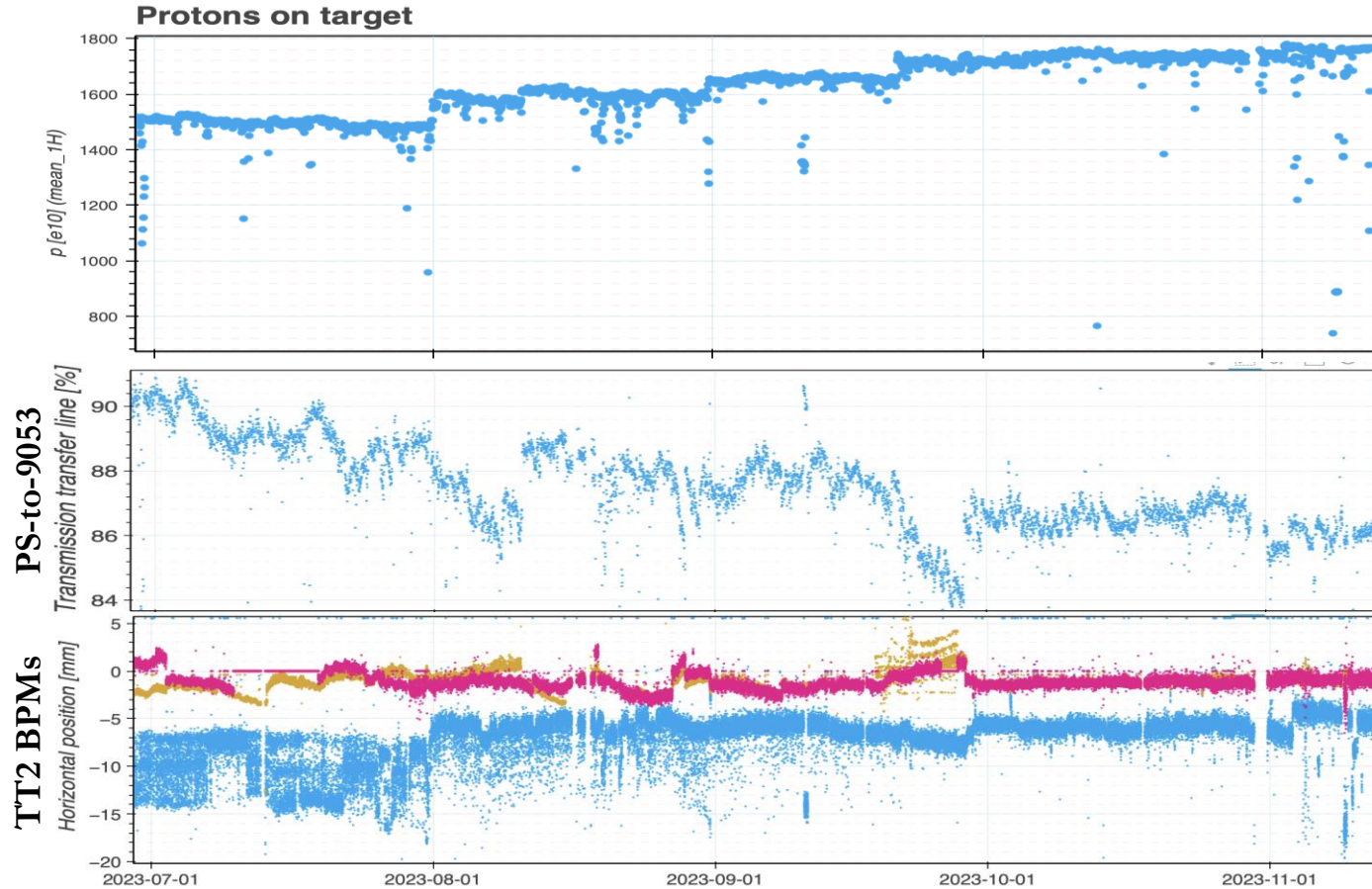
- The SPSC has recommend the Research Board for a call for proposal for new experiments (probably in 2024 or more likely in 2025)
- On our side, drafting a document to describe how the facility could be “improved”
  - **Main aim:** we need to provide inputs to CERN management such to obtain a clear statement on the long-term (beyond LS4) lifetime of the complex

# Overview of Beam Instrumentation Needs

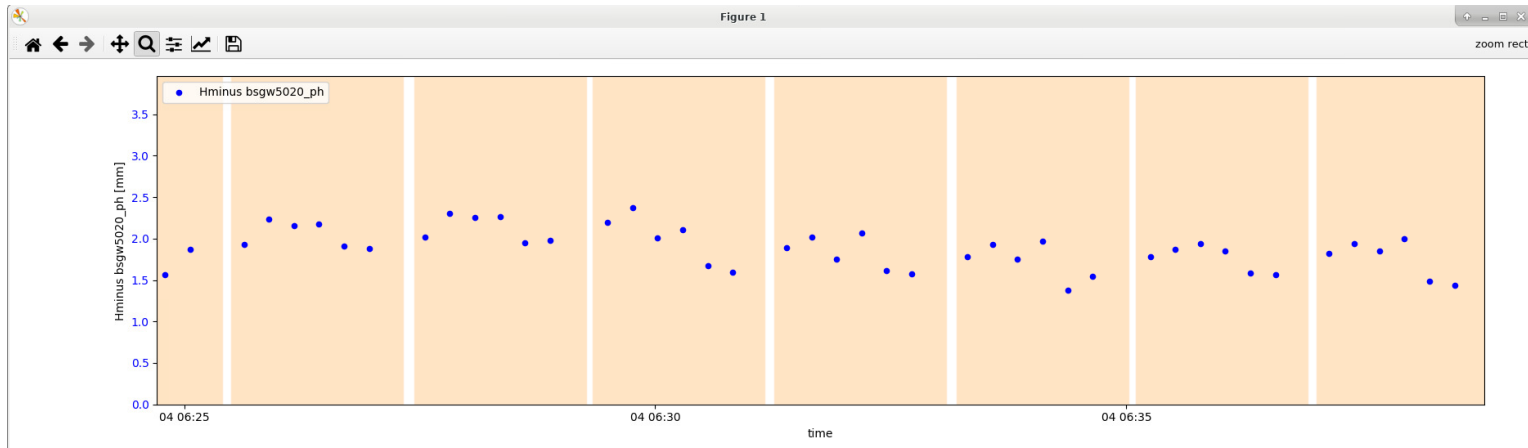
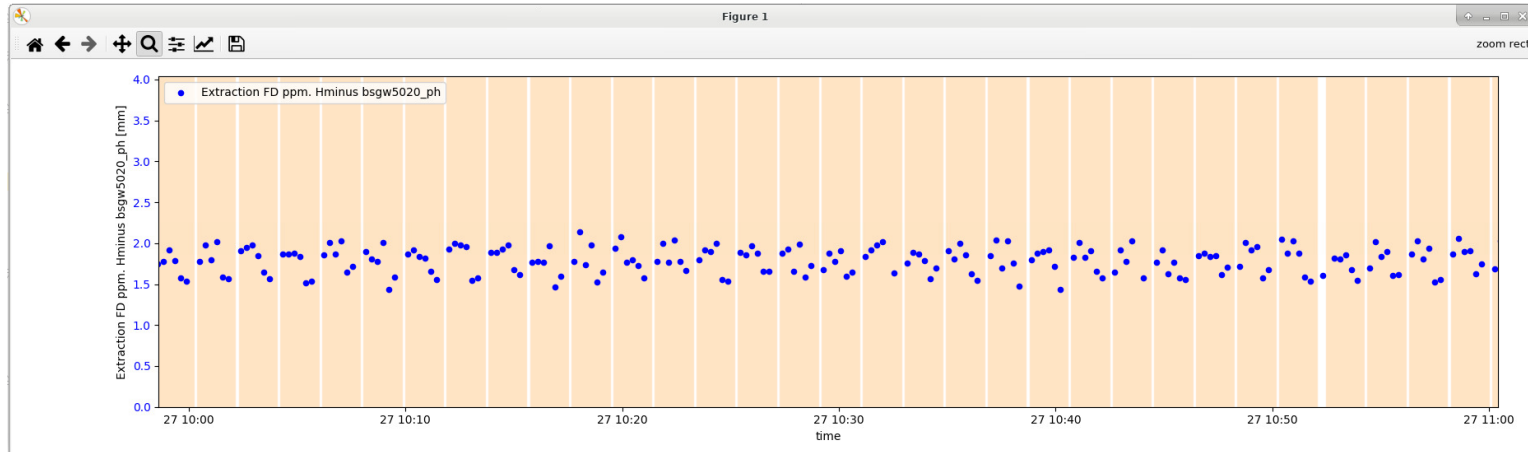


## ■ Linked to proton intensity increase?

- Not so sticking... Surely not the whole picture...



- Investigation on trajectory stability and impact of AD cycle
  - Some correlation with AD cycle, but not very clear (at least in LNE50 at this time)

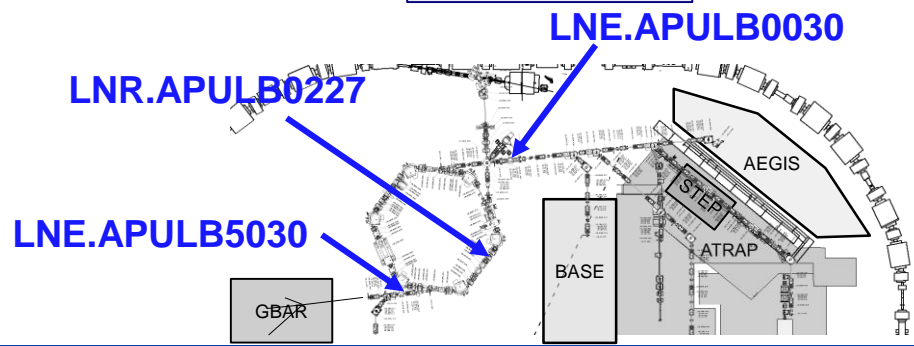
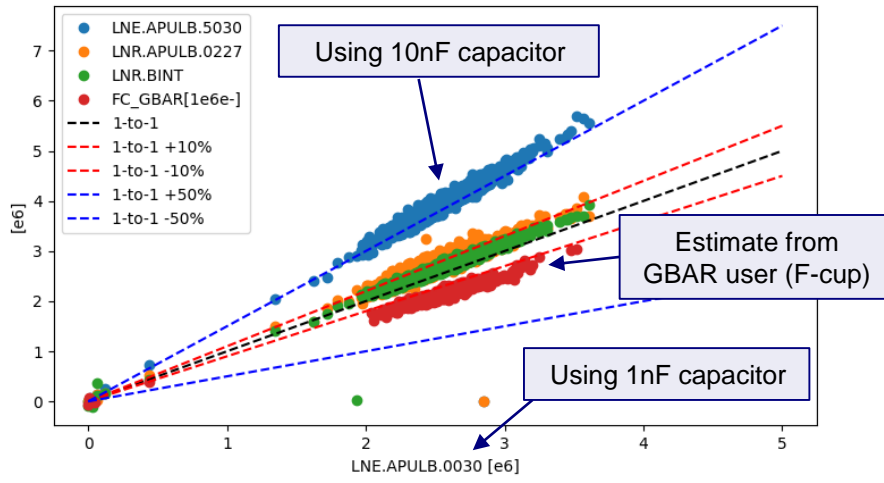
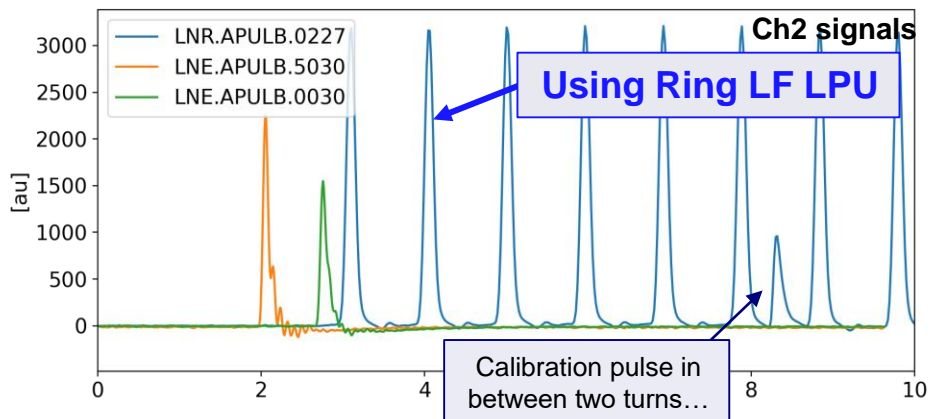
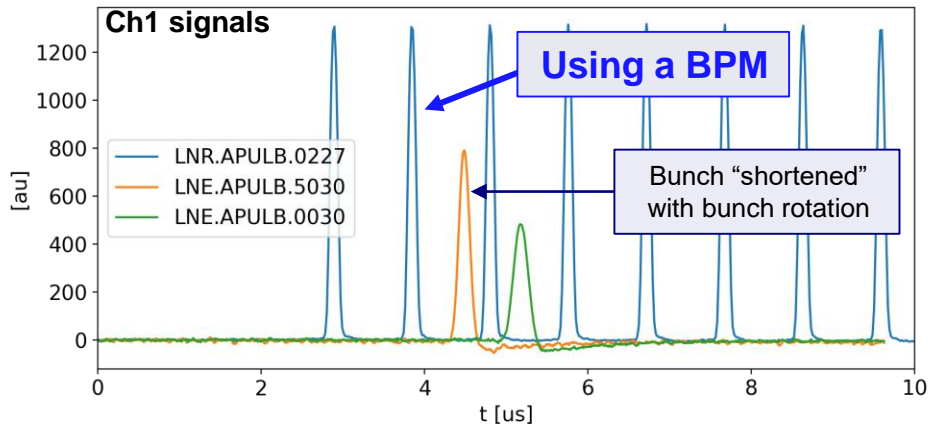


*By S. Pasinelli*

# ELENA Single Pass Intensity



- Based on BI-TRIC system on LF LPU design of ELENA ring
- Till early 2023, several doubts about calibration
  - Long lasting investigation by BI and RF teams, including adding a not-foreseen TRIC system + surface amplifiers for Ring LF LPU
  - “Solved” by using a 1 nF calibration capacitor in TRIC (as in DE.BCT7049)



□ Details in [BIQ-548](#)

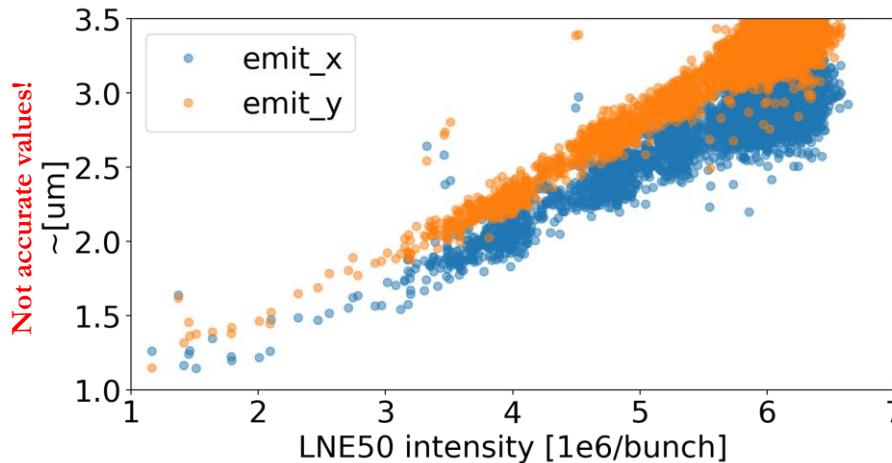
# Properties of beams delivered to users



- In longitudinal, normally meeting user needs
  - Thanks to flexibility provided by bunched beam cooling, and bunch rotation

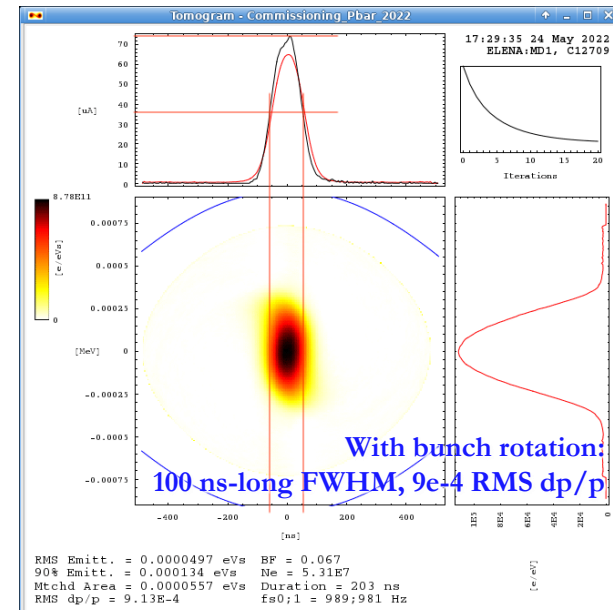
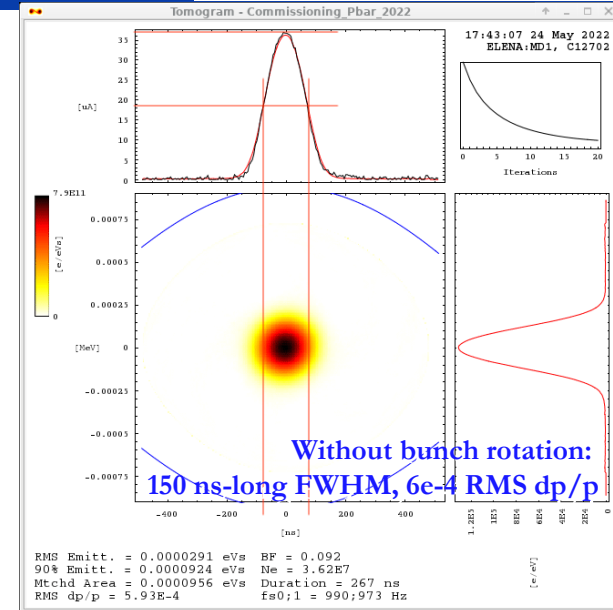
- **Transverse emittances too large** (Typically  $\sim 2.5 \mu\text{m}$ )!

- $\sim$ linear dependence with beam intensity
  - i.e. higher intensity will bring even larger emittances...



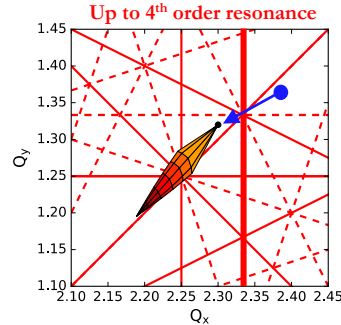
- Some hints for improvement looking at electron temperature and/or vacuum levels and/or e- energy control... or pbar optics **to be investigated**

- **Note: users do not seem to have strong requirements on emittance and/or energy spread** (but GBAR, at least on the short term)



# Exploring a New Working Point for Smaller $\epsilon$

- Present tune spread intercept third order resonance....

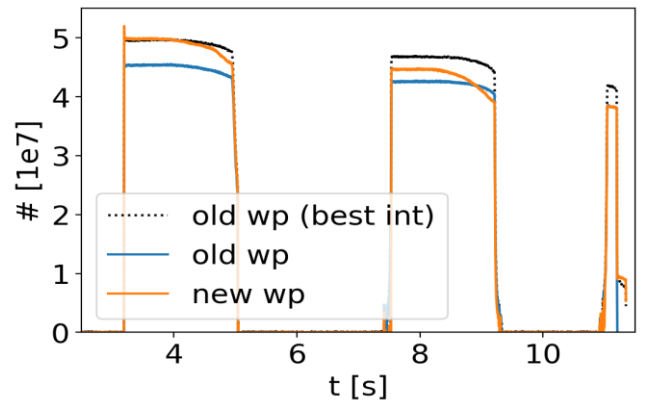
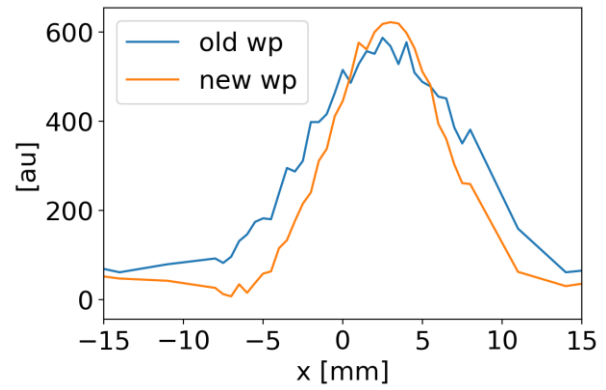
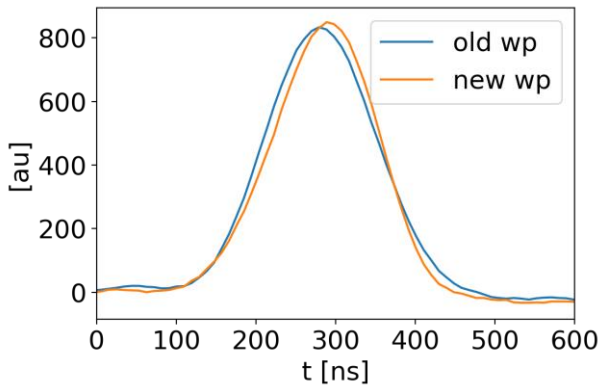
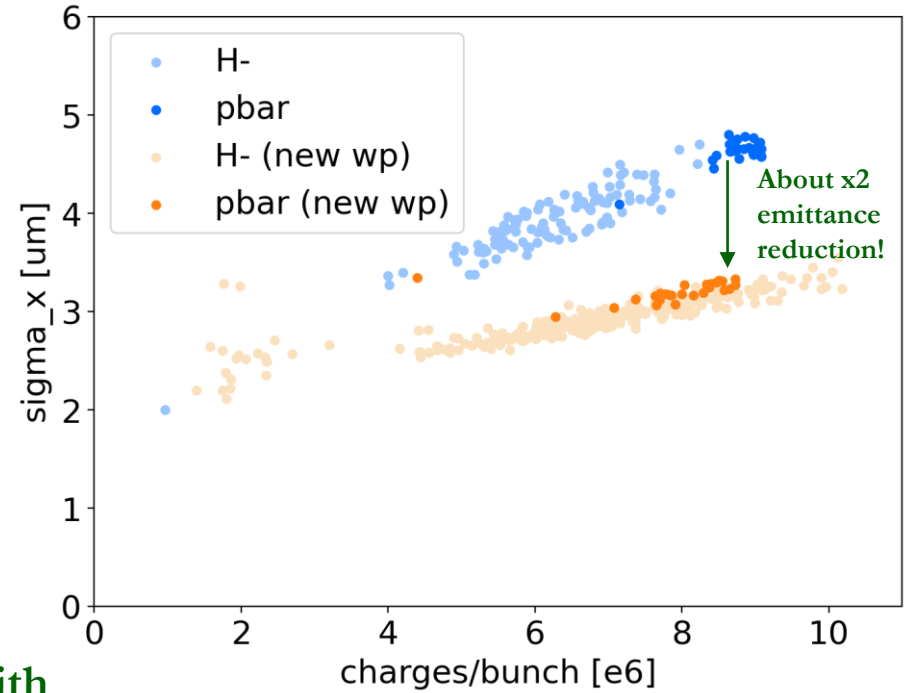


- Moving below third order resonance requires to change whole ELENA cycle...

- Tested first with H-

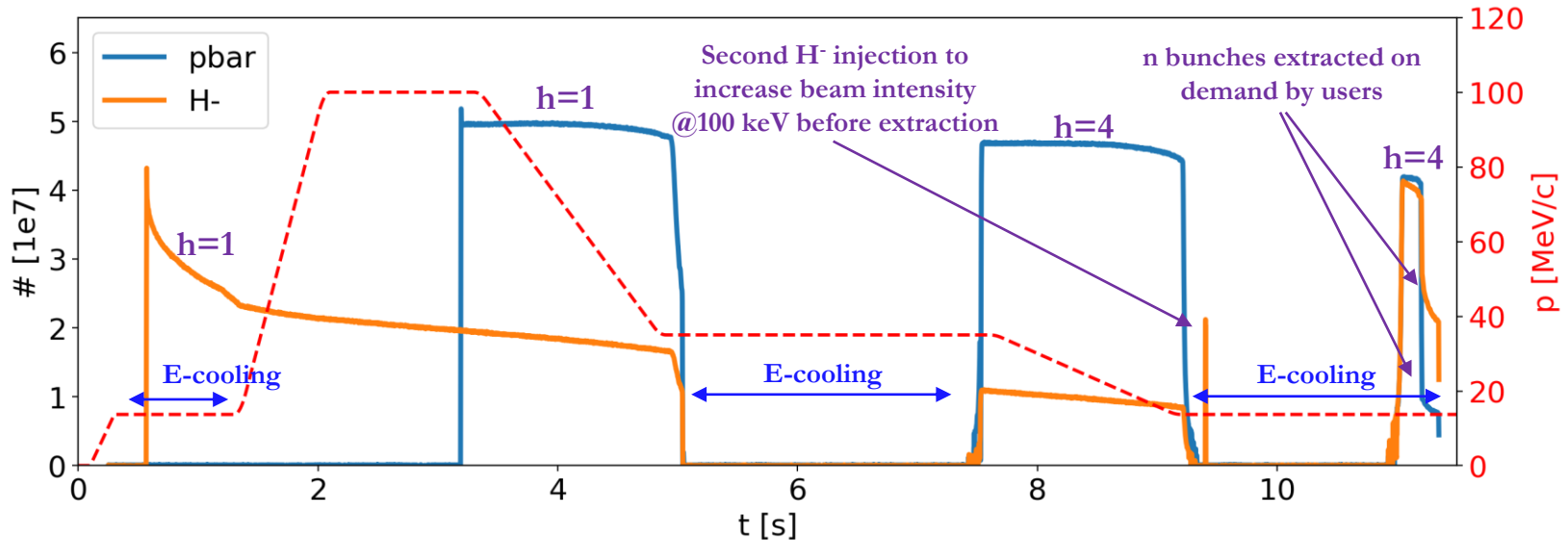
- Clear reduction of beam size observed for equivalent bunch length
- (Another example of the importance of keeping the ELENA H<sup>-</sup> source operational...)

- Promising preliminary results confirmed with pbar (but losses along the cycle to be cured)





- Running with two (magnetically-equal) **~15-second-long pbar/H-** cycles



- We are providing 4 equal bunches to serve 4 experiments in contemporary
- Margin of improvement:
  - Transmission: today up to **~20% losses**,
  - Cycle length: not important if we run in the shadow of AD (baseline), but **relevant if we wait for ELENA extraction before restart AD** (as **today!**)
- Repetition rate is very **slow** for any study/setup **with pbar**
  - Good news: No H- lifetime degradation observed with e-cooling! **We can use H- for most studies!**
  - Bad news: **H- source reliability** questionable, known to be prone to hardware faults...
  - Bad news: **H- lifetime** strongly affected by vacuum levels in the ring (typically  $10^{-11}$  mbar)