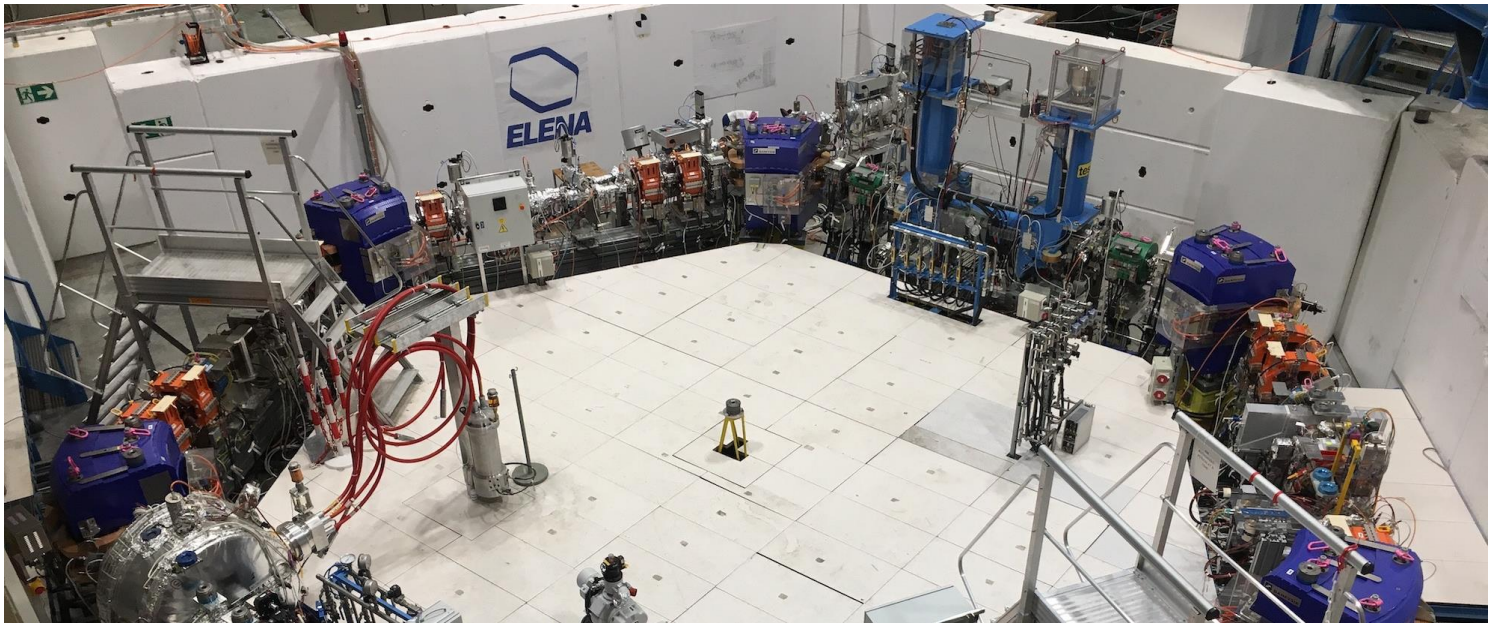
# AD/ELENA Beam Production and Delivery

Joint Accelerator Performance Workshop (JAPW) – 05-08/12/2022

*D. Gamba for the AD/ELENA team*




- Starting point: IEF Workshop 2021
- AD/ELENA Beam Performance Status
- Main successes and pitfalls of 2022
- Retrospective from 2021 to 2022 and wish list for 2023

**ACKNOWLEDGEMENTS: F. Asvesta, Y. Dutheil, L. Ponce, S. Albright, H. Damerau, A. Lasheen, B. Lefort, R. Ramjiawan, S. Rey and many more colleagues for the material provided!**

# Main conclusions from IEFW 2021

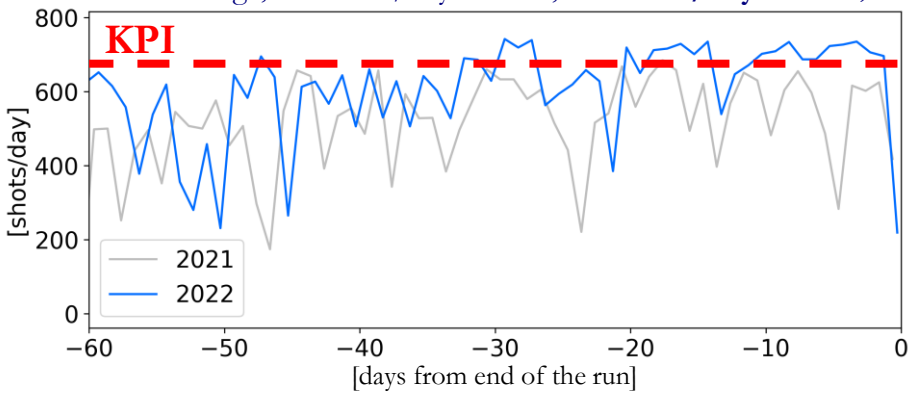
- **Beams close to design values were delivered to happy users!**
- Areas that **required improvement**:
  - **Consolidate/improve instrumentation:** availability and **accuracy** a generic issue from FTA to AD/ELENA to LNE, e.g. BPMs in FTA line? IPM in AD? Intensity in ELENA?
  - **Monitoring/logging:** for detecting and promptly acting on **degradation**, e.g. PS extraction
  - **Collect/use references:** for critical systems such as **s-cooling**
  - **Tooling:** e.g. for **transport** optimization or for following hardware drifts
  - Reduce **radiation levels:** e.g. p **losses** in FTA, **shielding** of AEgIS experimental area
  - **Recover pre-LS2 pbar/p yield**
- **Hunting** for even **higher performance**:
  - **Increase p intensity/quality in PS:** coupled bunch instability in PS limited the **p intensity** to about 1500e10 p/cycle. To check if p bunch length should be reduced (or not)
  - **Improve** AD/ELENA **deceleration efficiencies**
  - **Improve stability:** mainly at AD target and extraction, other sources to be found
  - **Improve repetition rate:** AD **cycle length**, improve PS **super-cycle composition**

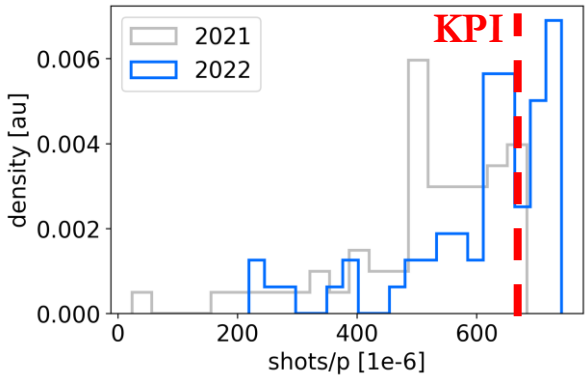
**For details, see presentation at IEF Workshop 2021**

# Flash-forward: from end 2021 to end 2022

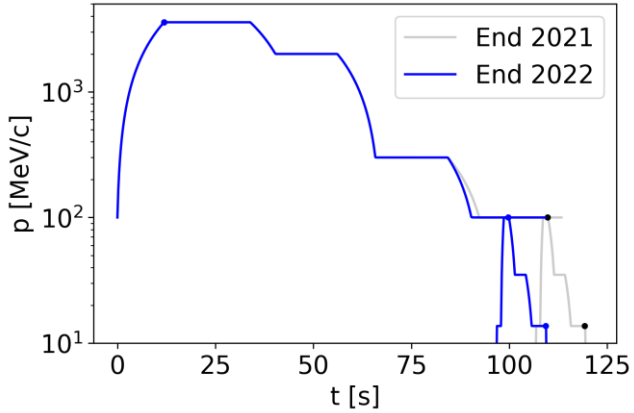
# AD/ELENA Repetition Rate

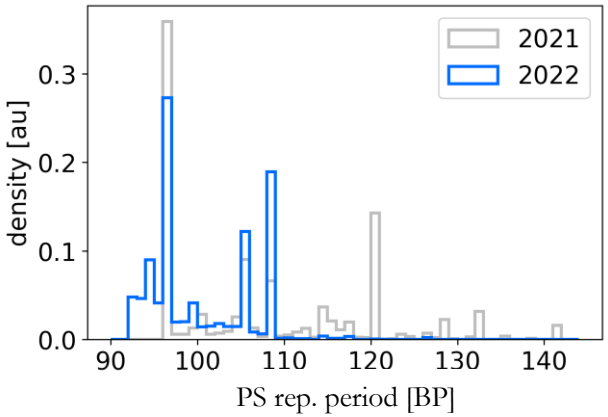
- **Number of daily good pbar shots (>10% than nominal intensity) per day extracted from ELENA**
  - On average, 514 shots/day in 2021, **606 shots/day in 2022**; to be compared to target of about 650 shots/day




- **AD extraction anticipated by 10 s! but AD cycle total length reduced by ~4 s**
  - Had to wait for ELENA ejection before new AD cycle: **experiments sensitive** to **AD magnetic field ramping up**!

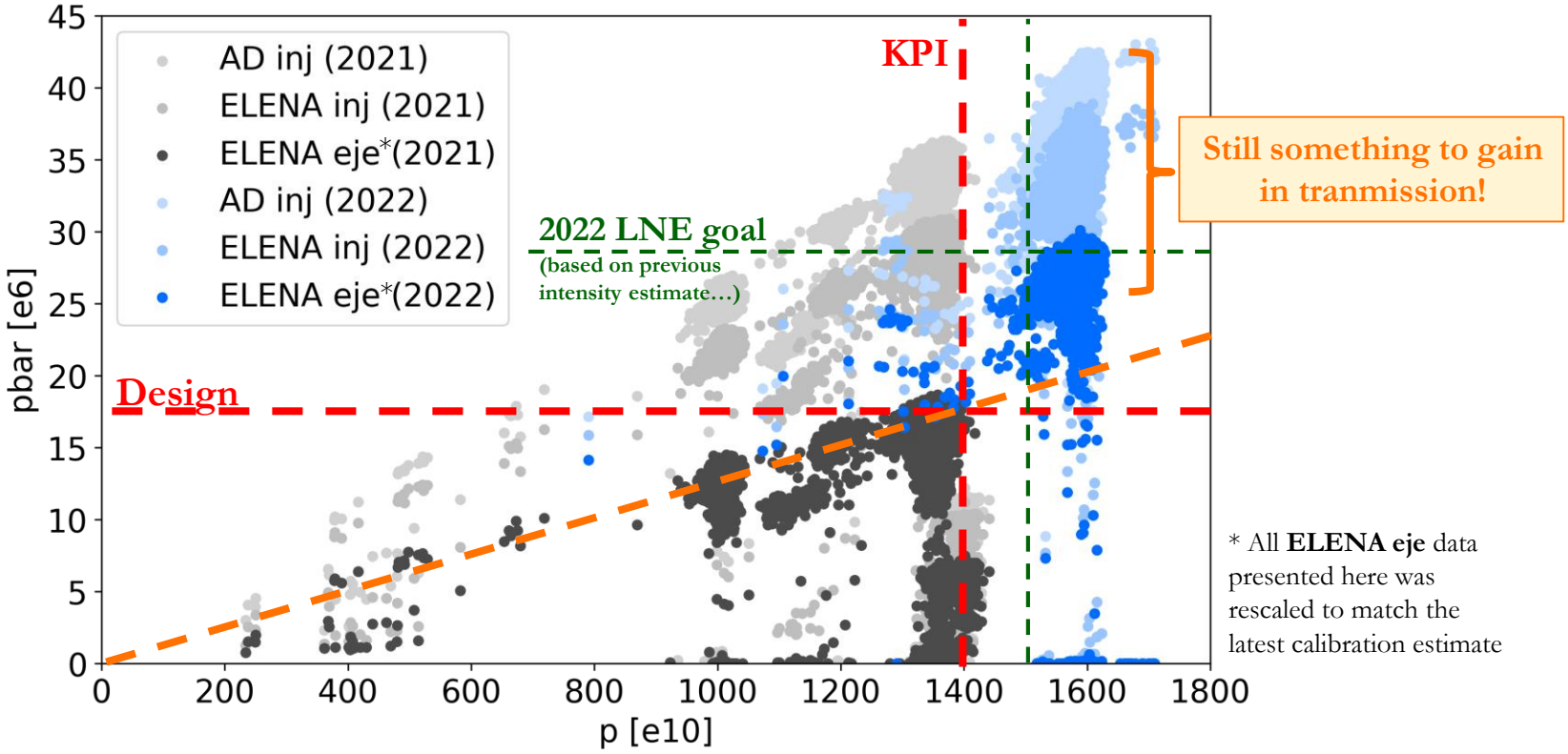



- **On the PS side, still some room for improvement:**
  - **~10% potential cycles lost in 2021**, and **~7% in 2022** (computed over the last 60 days of operation)
  - **Experiments ask** also for **regular repetition rate** (see also Stefan's talk)

# AD/ELENA Intensity/Transmission

- **Overall performance:** pbar per proton on target
  - Looking **last ~20 days** of operation for **2021** and **2022**




* All **ELENA eje** data presented here was rescaled to match the latest calibration estimate

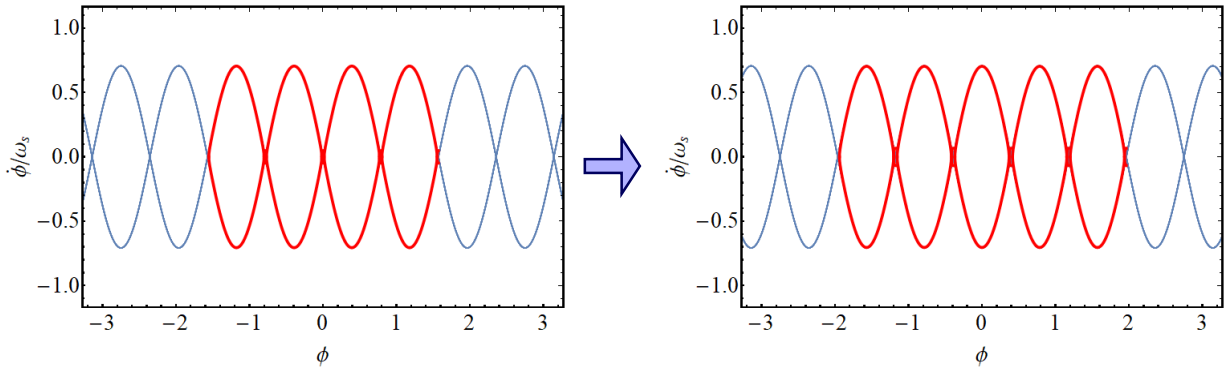
  - **Warning!** In **2021** (and most of 2022) we were **fooled by ~40% overestimate of beam intensity at ELENA ejection**! **Still uncertainties on pbar intensity measurement!**

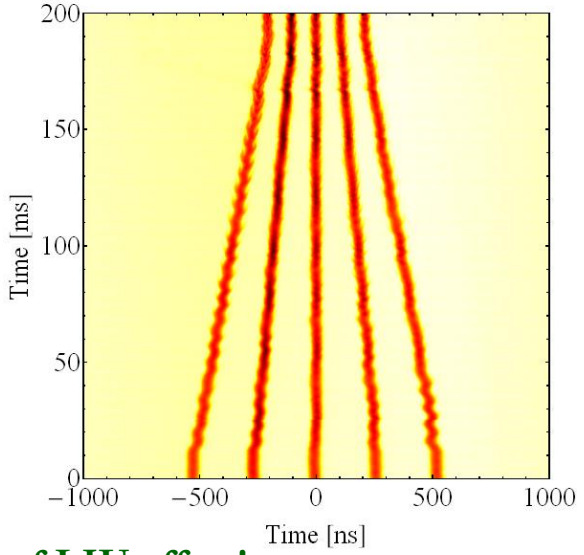
- **Overall: another excellent year for AD/ELENA with performance improvements!**
  - **Still need to work on stability, repetition rate, and transmission…**

# How did we get there:
# main successes and pitfalls of 2022 run

# 5 bunches operation in PSB and PS

- 5 p bunches **were available at AC times**, but **not for AD** due to conversion of PS complex for LHC
  - **Limitations removed** after LS2 with LIU **high brightness capabilities of PSB**
- Studies ignited by C. Lombard to make 5 bunches back in operation for AD
  - In **PSB,** it required to implement **bunch splitting in R3**
    - Needed to **increase longitudinal blow-up** to equalise emittance (as for SFTPRO)
    - Since R3 has twice the intensity, had to compensate for **higher space charge** effects by staying at **higher injection tunes** (4.43 instead of 4.34) and for much longer to equalise emittances (as for LHC)
      - Needed to **make sure** that the **resonances overlapped are compensated**
  - In **PS**:
    - Optimisation of the cycle to **reduce losses** by OP team
    - **New sequence of harmonic numbers** for up to 5 bunches during batch compression
      - It **allows** to have **any number of bunches from 1 to 5** for AD
      - see H. Damerau et al. for details



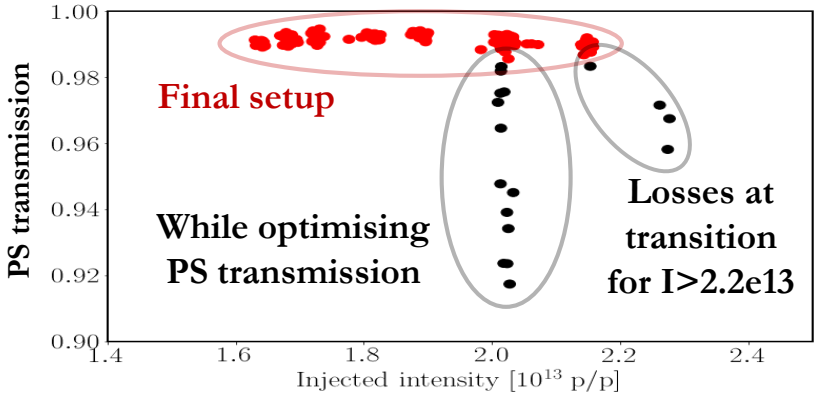



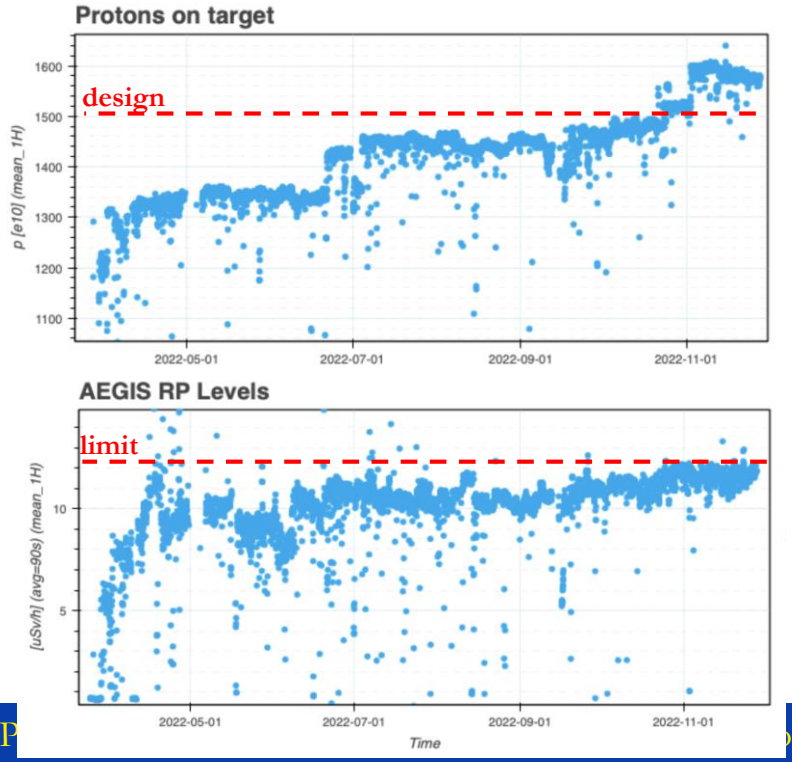

**Excellent work by PSB and PS colleagues, also profiting of LIU effort!**

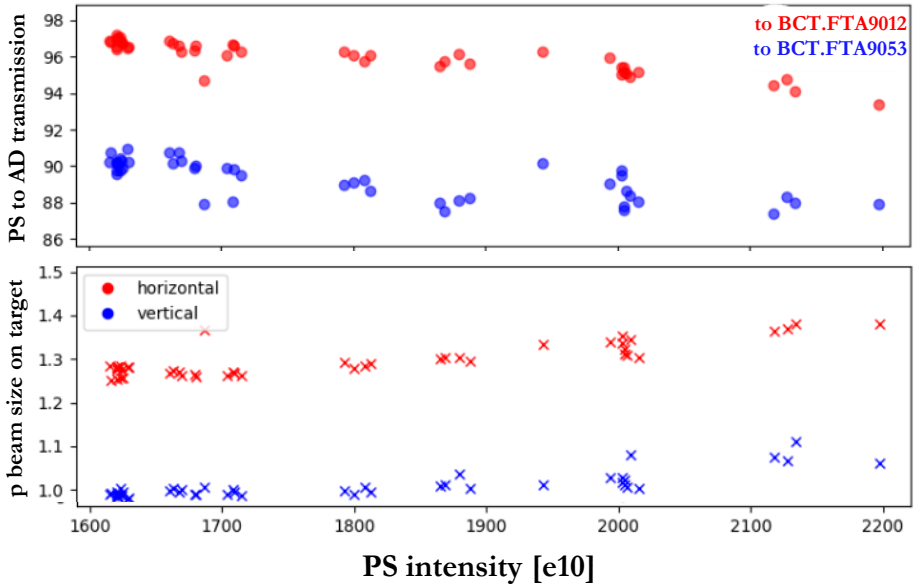
# High intensity proton generation and transport

With **5th bunch** unlocked the **possibility to increase proton intensity** (and potentially pbar) **by 25%**

- **Tests in the PS** ensured to be able to reach **up to 2.1e13**
- **No issues observed during p transport test to AD**
  - No major losses in FTA line
  - Minor beam size degradation on the target
- In agreement with STI colleagues**, proposed to increase smoothly proton intensity above target design**
  - **Plan endorsed by IEFC** 7th Oct 2022 (EDMS 2783690)
  - **Limited by AEgIS radiation levels!**
  - **Target degradation also to be expected at some point!**

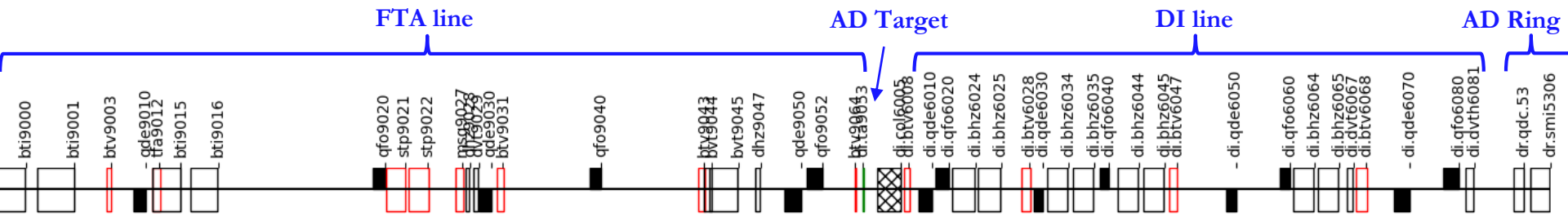


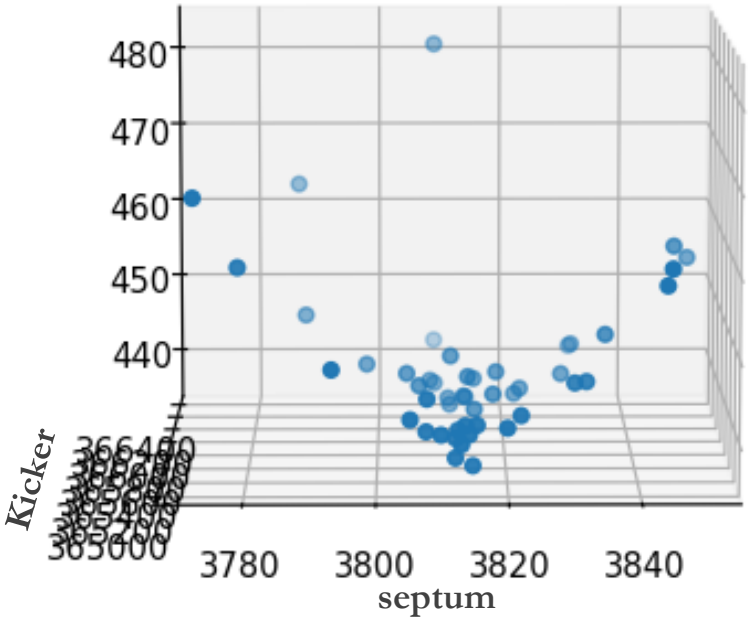




**Excellent work by PS and ABT colleagues!**

# Proton transport and pbar production optimisation



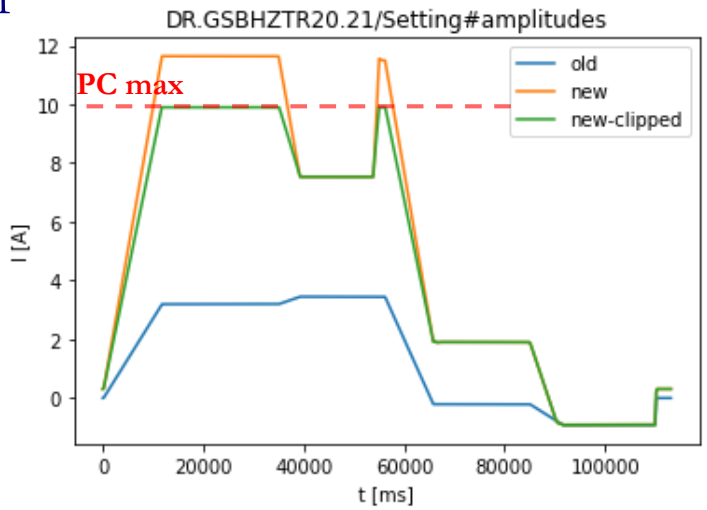

- **Studies** on **FTA** optics and transport:
  - see **Rebecca's talk** on Wednesday afternoon
- **Optimisation** of **AD Target** region:
  - see **Tim's talk** on Wednesday morning
- **Optimisation** of **DI line** (Target to AD Ring):
  - Some tests done using **optimiser** algorithm;
    - But only **marginal success** due to **limited** number of **shots/hour** available and limited **instrumentation**
  - Still mainly work for **experienced/patient operators**:
    - We **must find a way to setup this line** in a way that is not based on "try and error"




- **Plans** by STI and ABT colleagues to **work on modelling** the **pbar production** and DI **line optics/aperture** (see Tim's talk)
- **Must plan a discussion with BI** to see if **new/different instrumentation** could be useful. See also Athanasios's talk on Wednesday afternoon
- **Concerns about magnets/PC aging!** see Anthony's and Francois's talks

# Power Converter Reliability

- **AD Dipole Trim** (BHZ-Trim) **PC failure** end of April
  - EPC did **not manage to get it back online**
    - **Old equipment**, difficult to diagnose
    - See details at IEFC meeting #306
  - Found a **patch using all orbit correctors**
    - **Managed to conclude the run** in this state, **but we should get back to the nominal setup!**

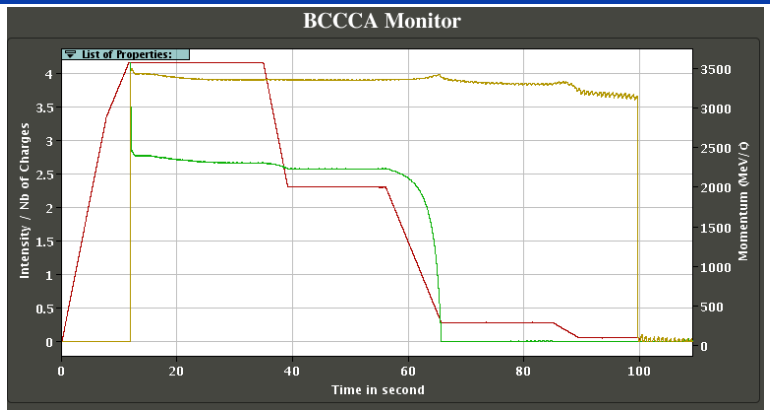



- **Main Quadrupoles** (QMAIN)
  - **Several trips especially during summer time**
  - **Interventions to improve reliability often resulted in different machine**
    - (typically, different tune): not straightforward to debug
- **Horn power converters** not able to sustaining max voltage (**sparks**!)
  - Weakness in the design identified, but probably just a single bad cubicle.
  - Issues with communication/trips being investigated

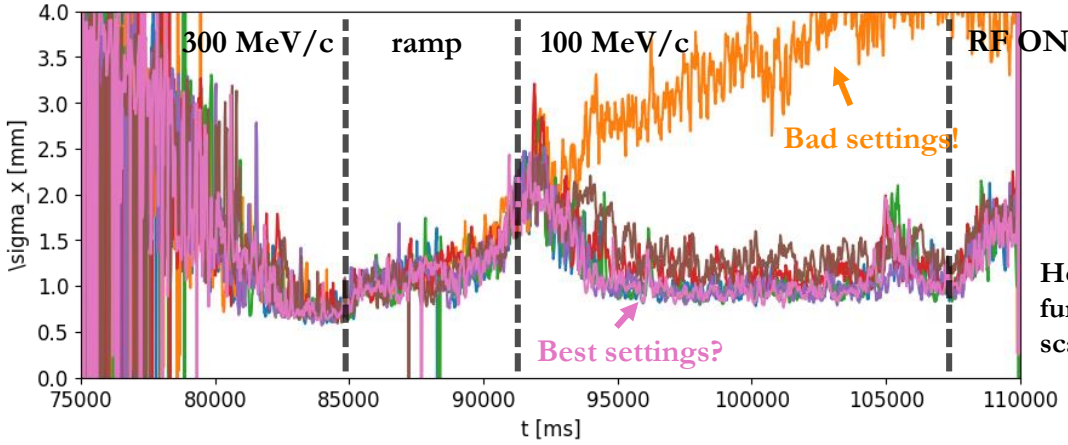
- **More and more urgent to think about anticipating(?) the powering consolidation?**

See Francois' talk on Thursday afternoon

# Instrumentation Reliability and Accuracy



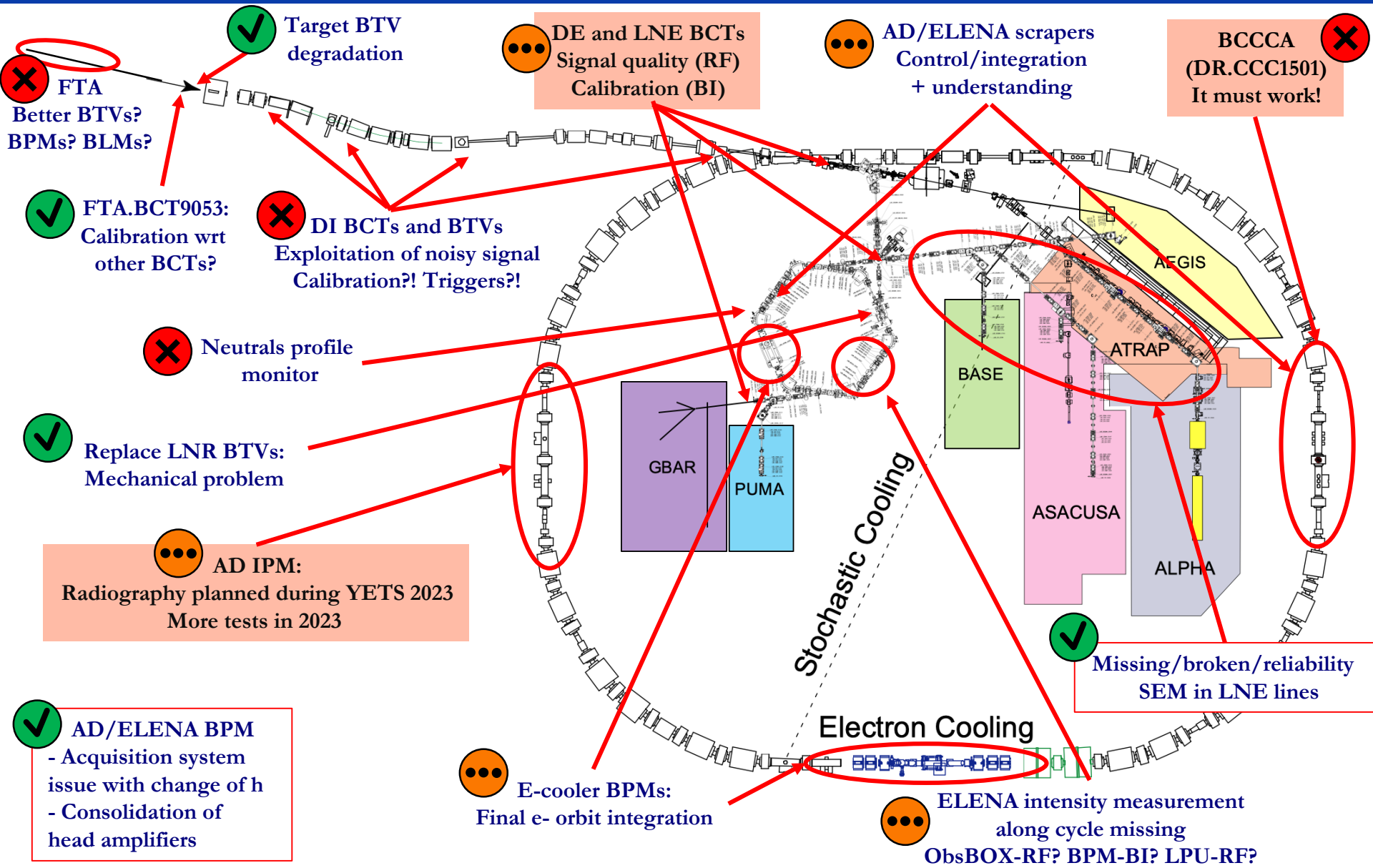

- **AD BCCCA stopped working**
  - **Started** the year in **degrated** mode
    - Had to find a workaround to make it work
  - Finally **unusable in October**
    - **Cross-calibrated** an **RF signal** using historical data as temporary replacement
      - **Only** works for **bunched beam**, and is **not self-calibrated**
- **Intensity monitor** in ELENA **ejection line** turned out to be **wrong by ~40%!**
  - **We must improve! This is the primary information we provide to our users.**
- **AD IPM** only **partially operational**
  - Still, it allowed us to see that **transverse cooling at 100 MeV/c** is **done in 5 s instead of 15 s**
  - **We should get this instrument fully operational: it will be a game changer! (see also Francois' talk)**




Horizontal beam size as a function of time while scanning on e-pbar alignment

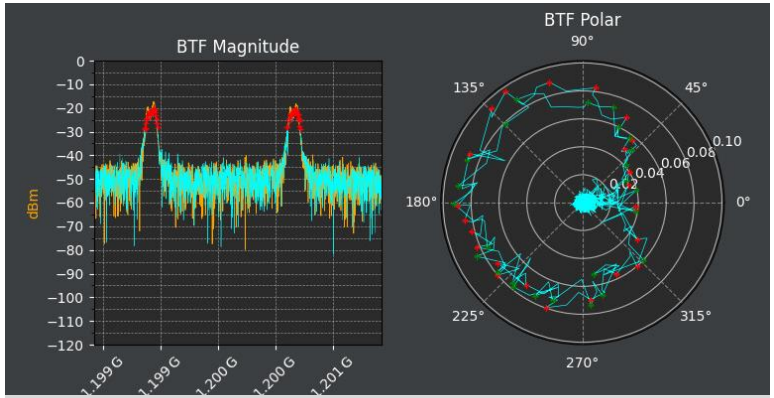
# Overview of Beam Instrumentation Improvements wrt 2021

(see also Athanasios', Rebecca's and Francois' talks)



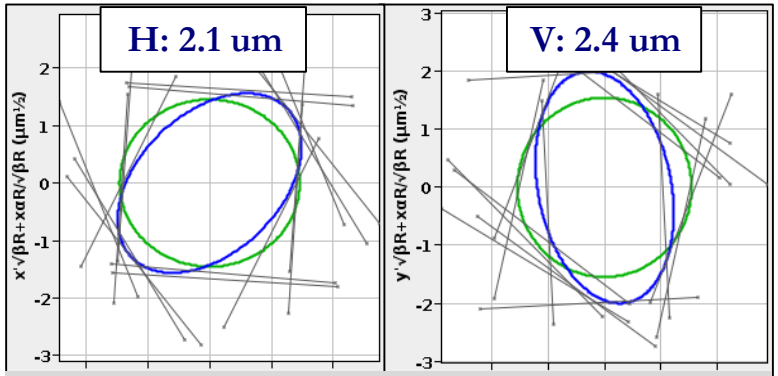
# Work on Machine Understanding and Documentation

- **Weekly MDs** with biweekly discussions (see wikis)
  - Investigate **hardware issues/limitations**
    - E.g. **AD bunch rotation**
  - **LSA tools debugging**
    - E.g. LLRF **makerules, cycle setting** management
  - **Setup of new beamlines**
    - **Successfully sent beam to PUMA and STEP!**
  - Take **machine references**
    - E.g. **s-cooling**
  - **Improve perfomance**
    - … still, **mainly to follow hardware drifts**
- **Improve logging** of machine performance
  - **Setup of BPT page for AD/ELENA**
- **Still missing** (among others)
  - **Improve emittance at ELENA extraction**
    - **Still x2 bigger than design values**
    - **Very limited time invested on this**
  - **ELENA B-Train** (operational, but not used):
    - No time, but also **doesn't seem to be a limitation**




S-cooling automatic BTF measurements

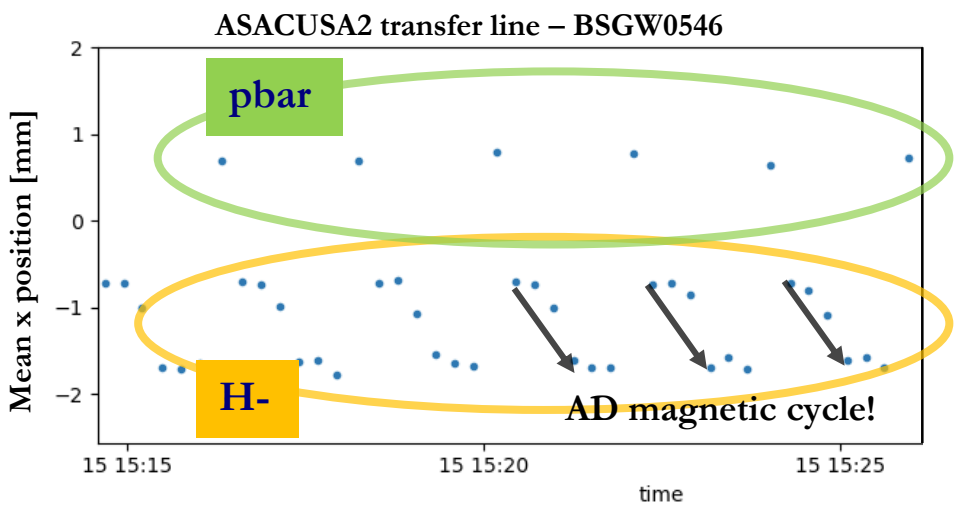
Trombone disconnection during scans

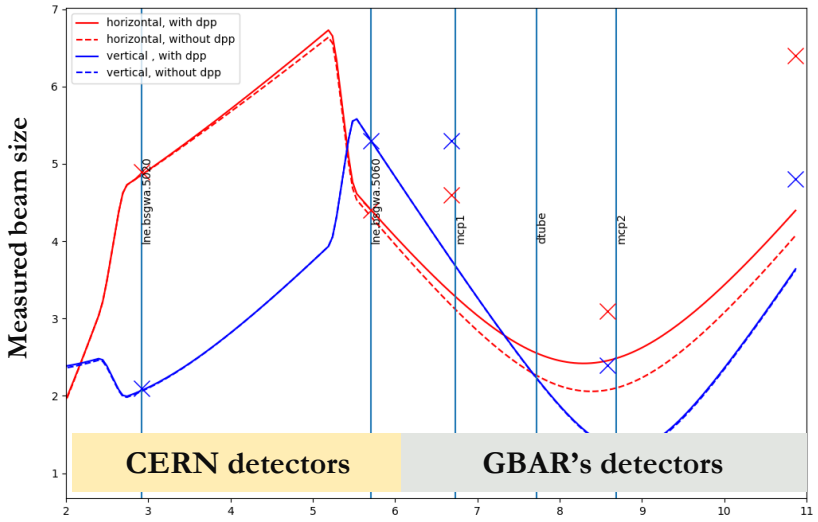



Emittance measurement in LNE lines

# Beam Delivery to Users

- **Transport** through the LNE lines is very **stable and reproducible**
  - **Only minor cabling mistakes** on new lines commissioned this year: once fixed, using design optics
- **Impact of stray magnetic fields**:
  - From **other experiments**:
    - We **would benefit** from **magnetic shielding** of transfer lines (see Francois's talk)
    - **ABT effort** on the **modelling** and **possibly automatic correction** (see IPAC2022)
  - From **AD**:
    - **"wasting" ~5% of AD cycling time** to wait for ELENA ejection before starting a new cycle, such as **to ensure reproducible transport**
- **Close collaboration with our users to respond to their needs**
  - **Experiments benefit from support by CERN expertise beyond the delivery point!**



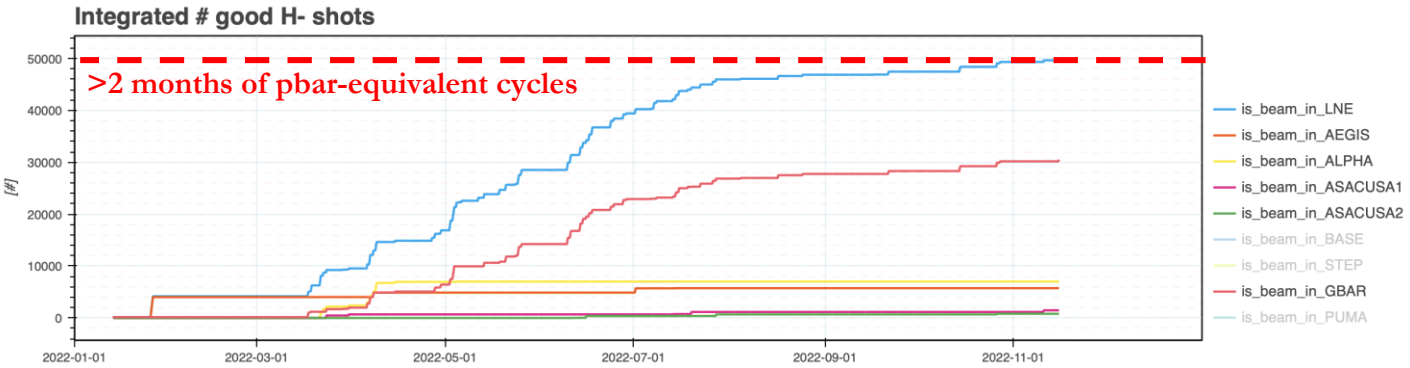
# Conclusions: what we still need to work on

# Status wrt conclusions of IEFW 2021

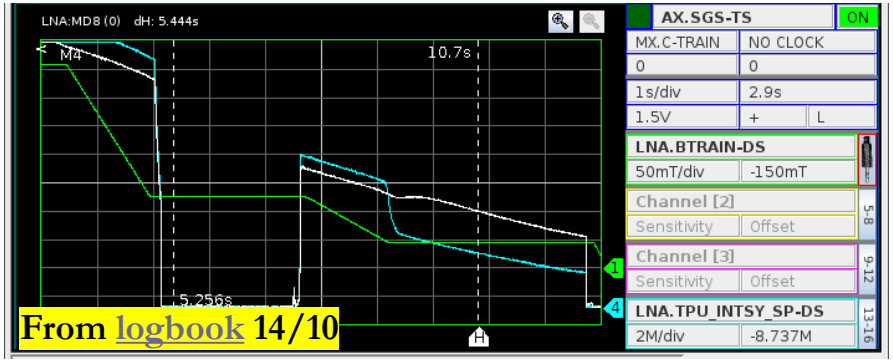
- Areas that **required improvement:**
  - **Consolidate/improve instrumentation: Many steps done, still work to do, +BCCCA reliability must be addressed!**
  - **Monitoring/logging: BPT** put in place, opening the room for **easier performance analysis**
  - **Collect/use references: work on s-cooling ongoing**, several **references taken** for efficient 2023 restart?!
  - **Tooling: mainly concentrating on status/diagnostics** (new Vistar, Live Schottky, Inspector panels,…), still **need to spend more time on "correction" (eventually feedback) tools**
  - Reduce **radiation levels:** plans to improve **RP shielding around AEgIS**
  - **Recover pre-LS2 pbar/p yield: some improvement,** probably **not yet there: see Tim's talk**
  - **+Hardware Reliability!: Powering!, Instrumentation!**
- **Hunting** for even **higher performance:**
  - **Increase p intensity/quality in PS: limited by radiation levels in AEgIS**
  - **Improve** AD/ELENA **deceleration efficiencies: >80% reached, but difficult to maintain it!**
  - **Improve stability: too little time available to work on this**
  - **Improve repetition rate (+stability):**
    - **10% AD cycle length reduction**!
    - Ideally, **better matching with PS super-cycle** could be improved, or at least **stabilized**!

# IEFC pending actions

- **FTA line optimisation/upgrade plans** to meet beam size requirements and reduce losses
  - See **Rebecca's presentation** on Wednesday afternoon
- Make **formal** decision for **keeping ELENA H$^-$ source operational**
  - **GBAR interested in H$^-$ beam also for complementary physics program**
  - **Informal-agreement** to maintain the source as is **for the next 2-3 years** with shared responsibility ABP/OP
    - Several **actions already taken** to **consolidate spare parts** and **documentation**




- **Investigate** the possibility for ELENA to **eject pbar beams at 80 keV**
  - **Preliminary test** by OP to verify that ELENA can decelerate (H$^-$) in ring to at least **85 keV**
  - **No time** for dedicated studies with pbar ejecting at 80 keV in the transfer lines
    - **Not a high priority from experiments** (optimised for 100 keV already)



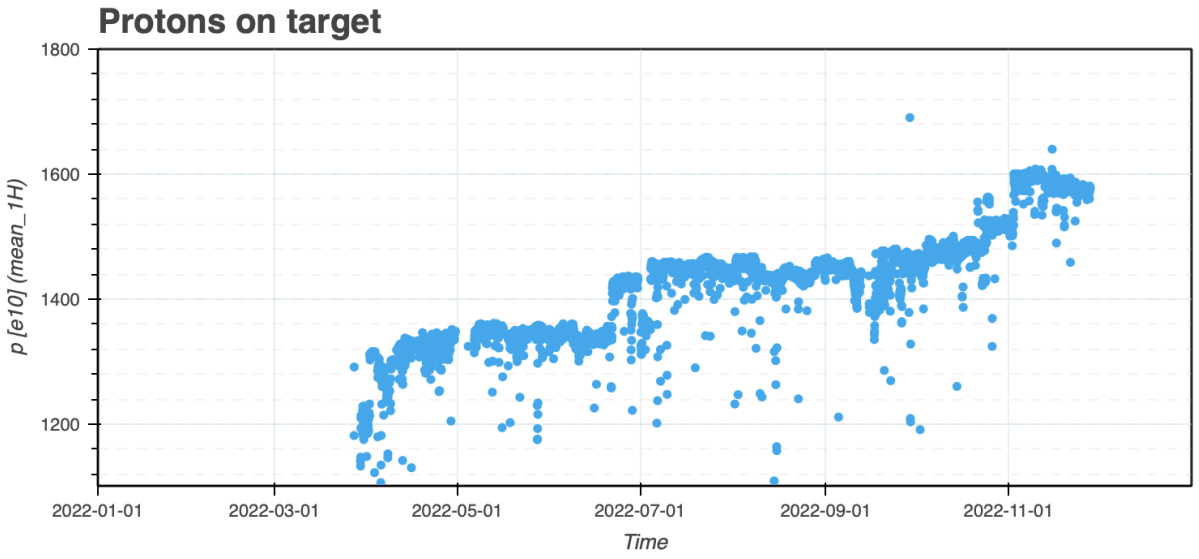
# Conclusions and top 3 desiderata

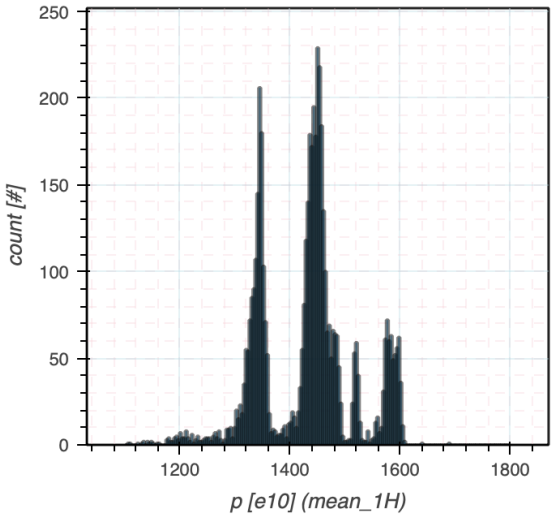
- Generally, **another excellent year for AD/ELENA!**
  - Despite several **reliability issues** and **bad surprises**
  - Thanks to **determined** and **motivated AD/ELENA teams** with **invaluable support** from **uncountable colleagues** from the **PS-crew, BI, RF, EPC, MSC, …**
- **Short term top 3 desiderata**:
  - **Reliability:**
    - Need to (or aim to) **avoid working in degraded condition**
      - **key ingredient** if we want to profit of **feedback/automation tools**
    - **Advancing consolidation plans**? **More support/time allocated** from equipment owners to **improve availability** (e.g. PC, instrumentation, …)
  - **Stability:**
    - Studying **transmission drifts** and find ways to **compensate/stabilize**
    - It **includes rep-rate**, mainly from **PS super-cycle composition**
  - **Understanding target/injection area:**
    - Must be a **joint effort STI-OP-ABT-ABP-BI**

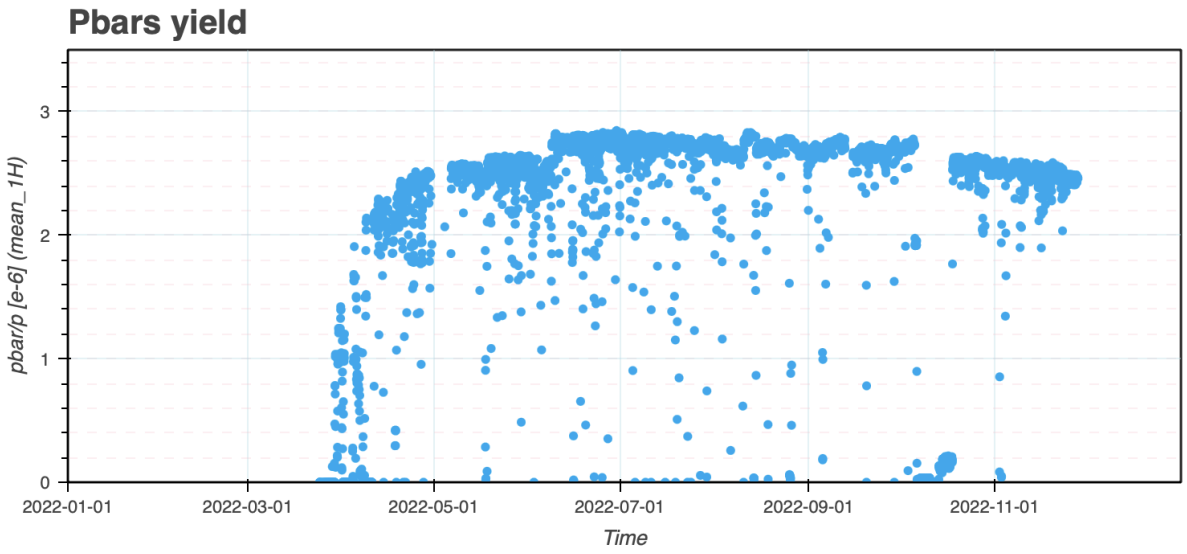
**Thank you for your and attention and support!!!**

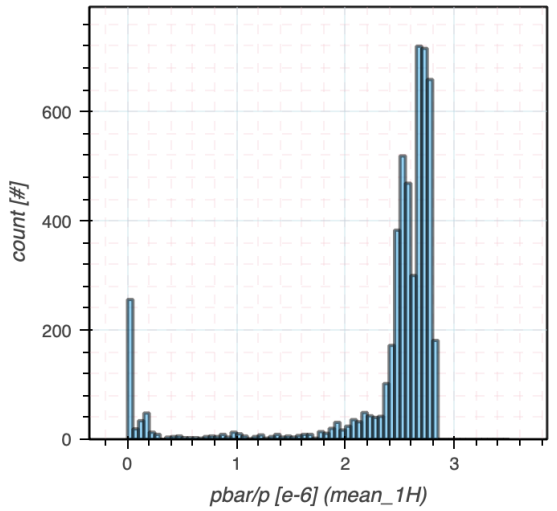
# Appendix

# BPT Plots Selection (2022 target)

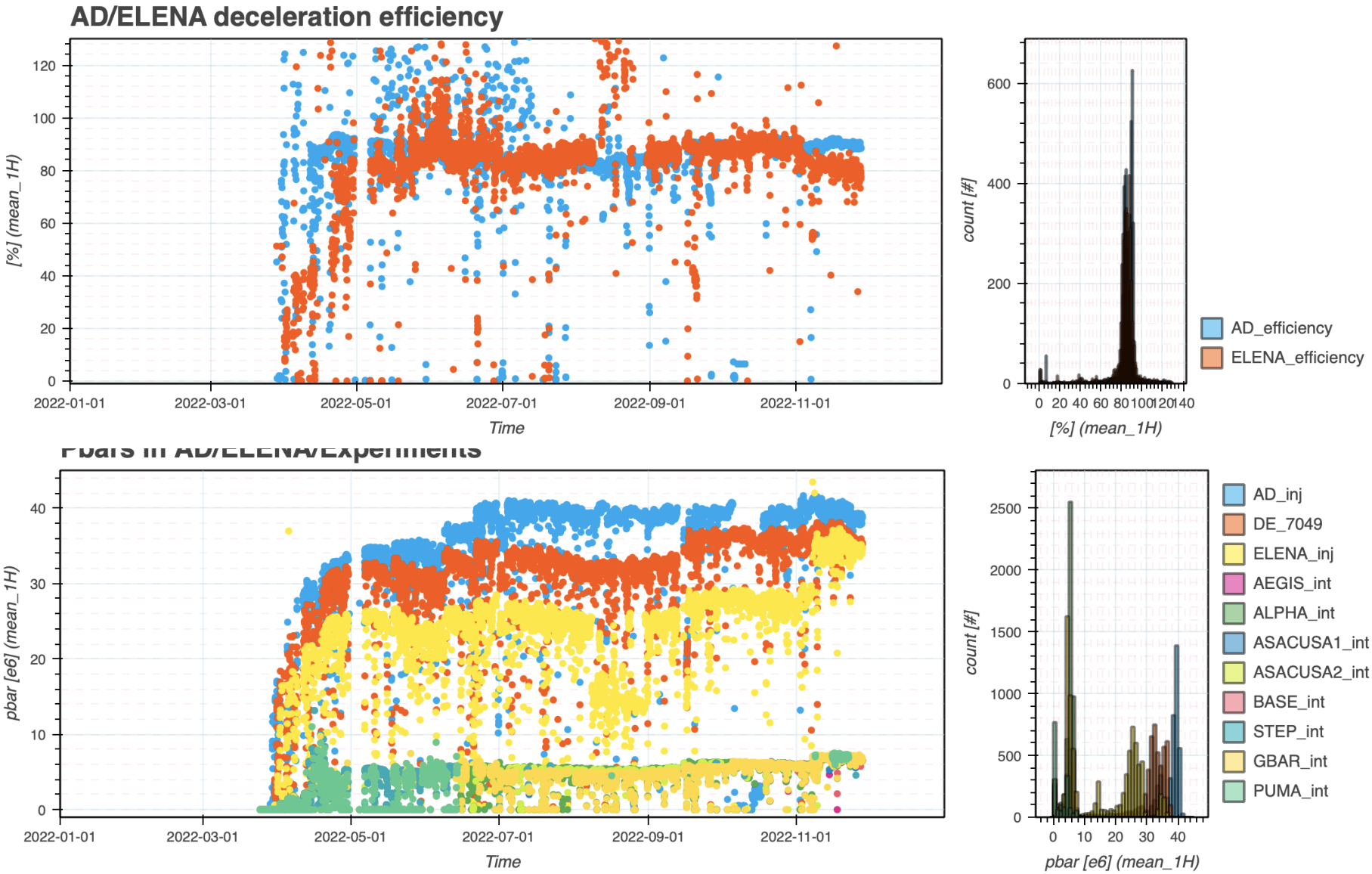


# BPT Plots Selection (2022 pbar)



# Some other issues not covered…

- Orbit drifts on AD target: considerable drifts observed
- Beam size and proton bunch length on AD target: not studies yet
- AD ejection orbit oscillation by septa (and/or other effect?)
- Compensation of field lag in AD
- Saturation of BPMs at 100 MeV/c in AD
- Issues with AD bunch rotation control
- AD e-cooler drifts due to vacuum condition and HV sparks
- AD e-cooler HV switches problem
- Water leaks problems (DI magnets, AD e-cooler)
- AD FINEMET cavity issues
- …