AD-ELENA Performance in 2021 and plans for 2022

L. Ponce on behalf of the AD/ELENA team

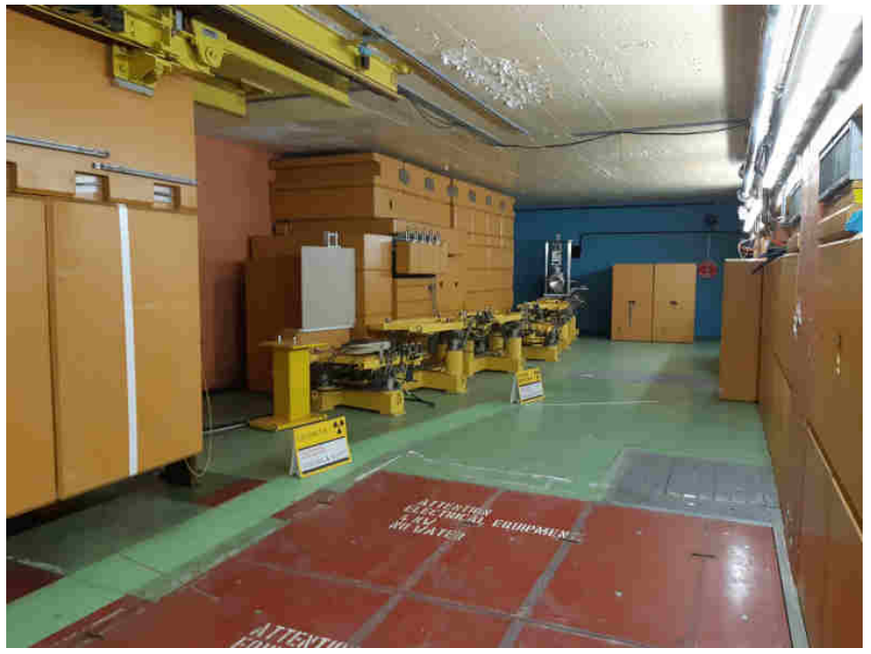
- Outline:
  - AD-ELENA start-up and performance
  - Machines issues
  - Run statistics
  - Outlook for 2022

Special thanks to Davide and Christian

Introduction

- Main objectives of AD and ELENA restart after LS2:
  - **Re-establish nominal 2018 performance for AD**
  - **Start physics production with ELENA**

- Summary of a long list of LS2 interventions:
  - AD target zone renovation:
    - New target system
    - Permanent quadrupoles replacing pulsed one
    - Mix of new and old PC controls system
  - AD ring:
    - Magnet refurbishment
    - New RF cavity, new LLRF
    - New synthetic B-train
    - Stochastic cooling completely dismantled and reassembled
    - Decabling campaign
  - ELENA:
    - ALL AD users connection to newly installed electrostatic transfer lines
    - 4 bunches distribution to 4 different users



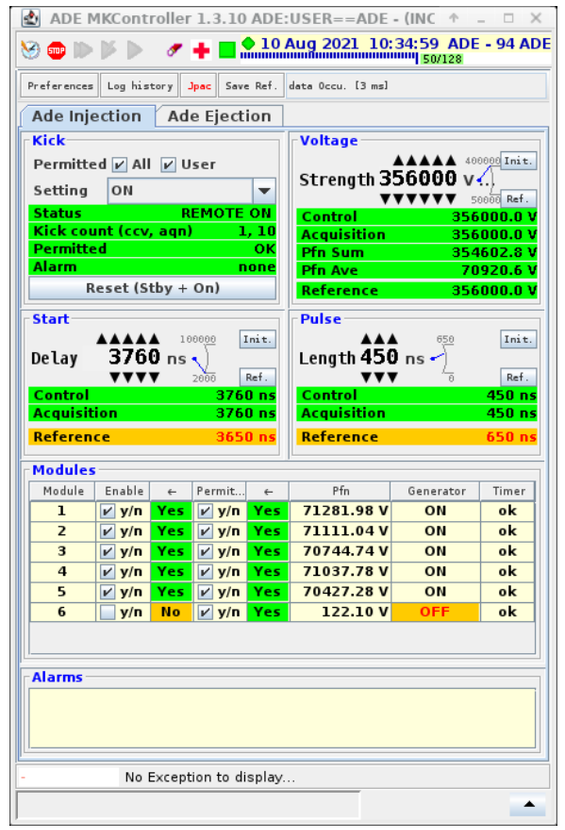
AD/ELENA at the end of LS2

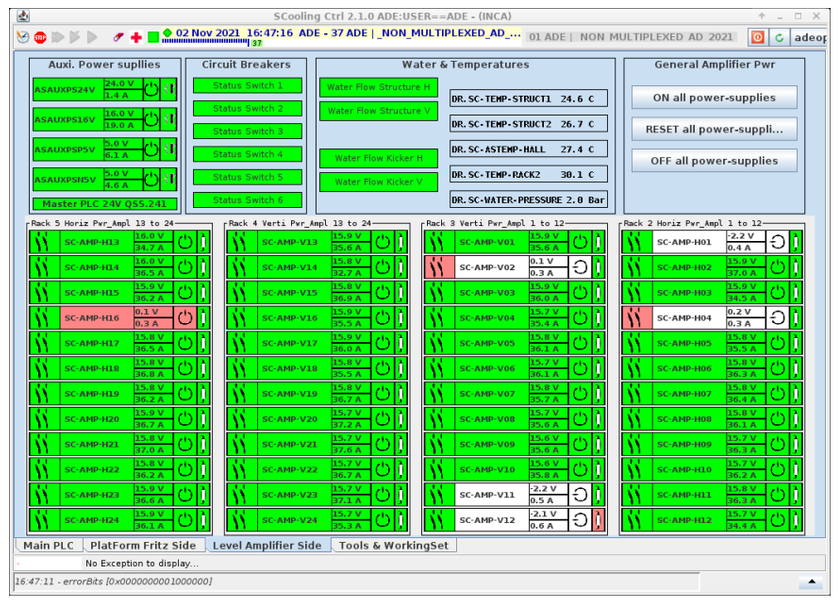
- Problems found too late during HW commissioning to be fixed:
  - Restart in “degraded” mode after a Long Shutdown

- In AD:
  - Short circuit in one module of the injection kicker:
    - No time to fix it without significant impact on planning
    - Operating with only 5 out of 6 tanks with nominal kick strength but no margin in case of trip (which did not happen!)
  - Couple of stochastic cooling amplifiers not operational
    - Same operating conditions as in 2018
    - Repair done only last week of run
  - New e-cooler collector not ready for installation in 2021:
    - gun performance OK for restart (No venting the sector)
    - Restart with same e-cooler as in 2018

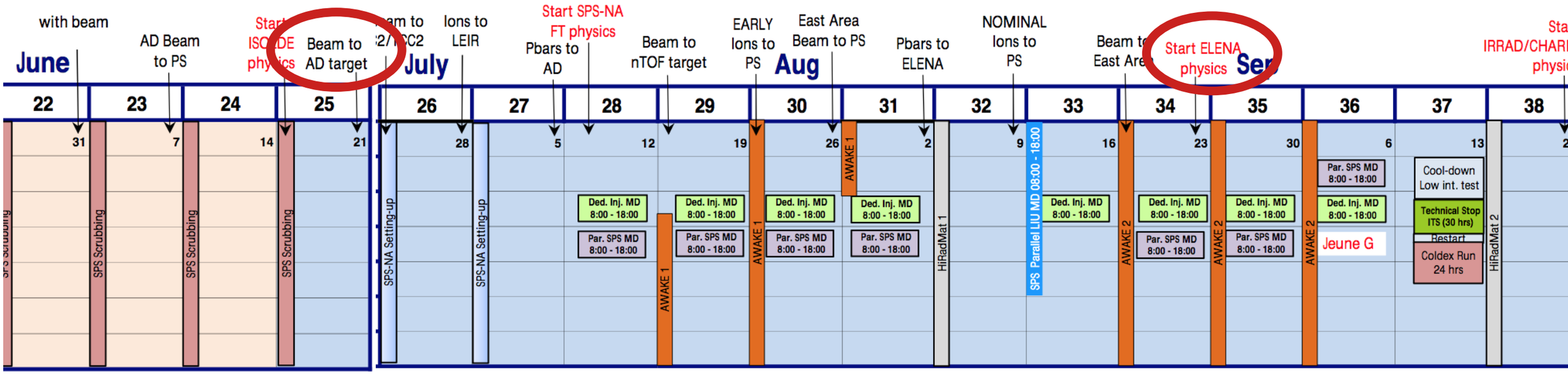
- In ELENA:
  - BTV screen in LNI not operational
    - Decided not to open vacuum in the kicker region because of known internal leak in kicker tank
    - Functionality replaced the grids in injection line

=> change of the BTV planned for this YETS





Beam commissioning initial planning



- Challenging plans for restart of complex during main vacation period:
  - Mainly AD target area re-installation affected by the COVID19 delays
- Foreseen schedule:
  - 2 weeks for target area:
    - FTA optics checks, target conditionning, DI optimizations
  - 4 weeks for AD:
    - 1 week for stochastic cooling
    - 2 weeks for all RF systems
    - 1 week for e-cooler, instrumentation, cycle optimization
  - 3 weeks for ELENA:
    - Injection and cycle optimization, e-cooler
    - transfer line commissioning with pbars

Reality

- Beam delivered on time from the PS to start AD target commissioning:
  - FTA optics ckecks, new target conditioning, first injection line optimization
  - Pulse shape problem on the new FGC_62 power supply

  => Beam on target 25th June as planned, but some activities postponed
- First injection in AD also on time, low intensity:
  - Bunch rotation setting-up, stochastic cooling at 3.5 GeV, deceleration…

  => Beam in AD 5th of July as planned, but...
- Problem to get nominal performance of stochastic cooling at 2 GeV:
  - 1 week lost to recover performance
- Problem of beam loss at arrival of 100 MeV plateau:
  - 1 week lost to identify a wrong setting on current limit of the main quad
- Beam sent to ELENA with more than 2 weeks delay
  - Commissioning of ELENA with pbars in a couple of days

- Physics delivered on time 23rd of August to the users, thanks to:
  - Very efficient setting-up of bunch rotation, deceleration, working points and e-cooler
  - Getting AD in good shape took one extra month during physics run (profitting of 1 day for MD per week and time without any users request)
  - Good preparation of the ELENA cycle and transfer lines with Hminus

See extended version by C. Carli – 292nd IEFC

AD cycle in 2021

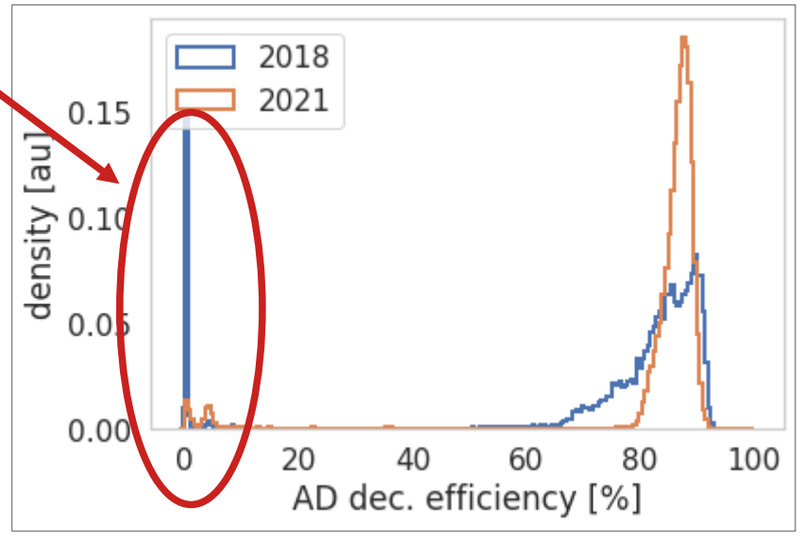
- Similar or better deceleration efficiency (~87%) than 2018
  - As well as better AD reliability (less shots with beam on target that had zero AD ej. Intensity)

CPS	BCT9012	BCT9053	3.5 GeV/c S	3.5 GeV/c E	2 GeV/c S
1552.5	1469.3271	1368.575	3.32E7 100%	3.15E7 94%	3.14E7 94%
2 GeV/c E	**300 MeV/c S**	**300 MeV/c E**	**100 MeV/c S**	**100 MeV/c E**	**BCT7049**
3.15E7 94%	3.12E7 93%	3.10E7 93%	2.92E7 87%	2.86E7 86%	2.95E7

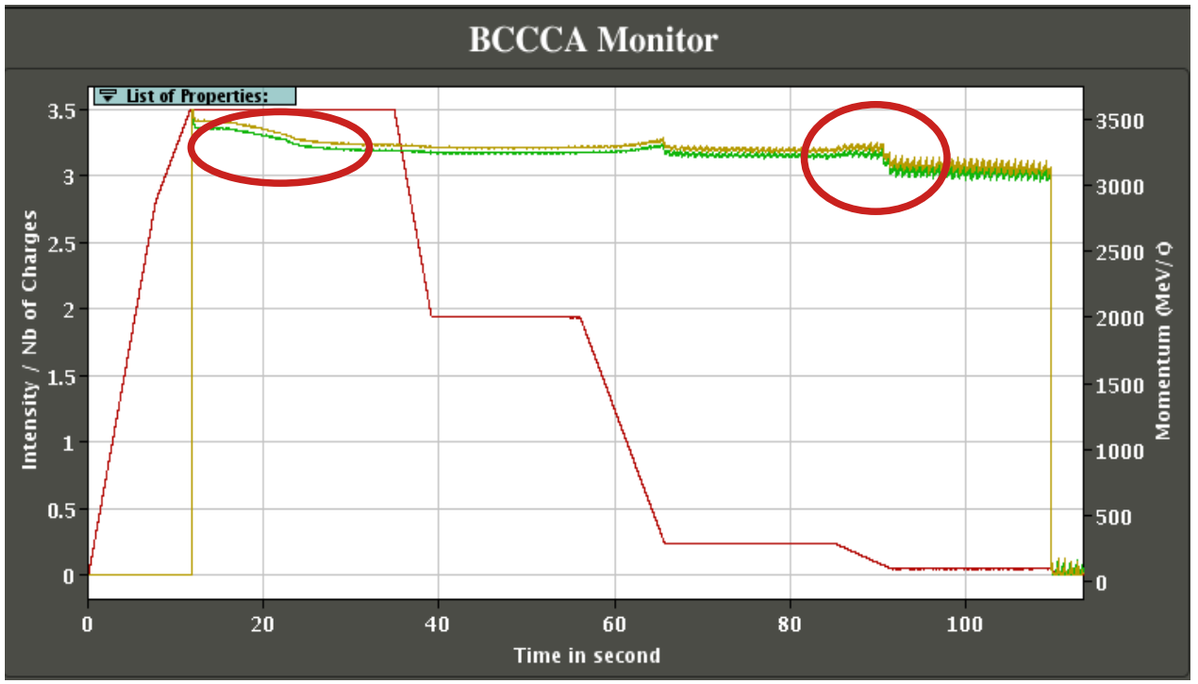
PBAR for ELENA

Comments (11-Nov-2021 12:02:00)

Day time: ACR 76688/76689 Nights and w.e. CCC 76677



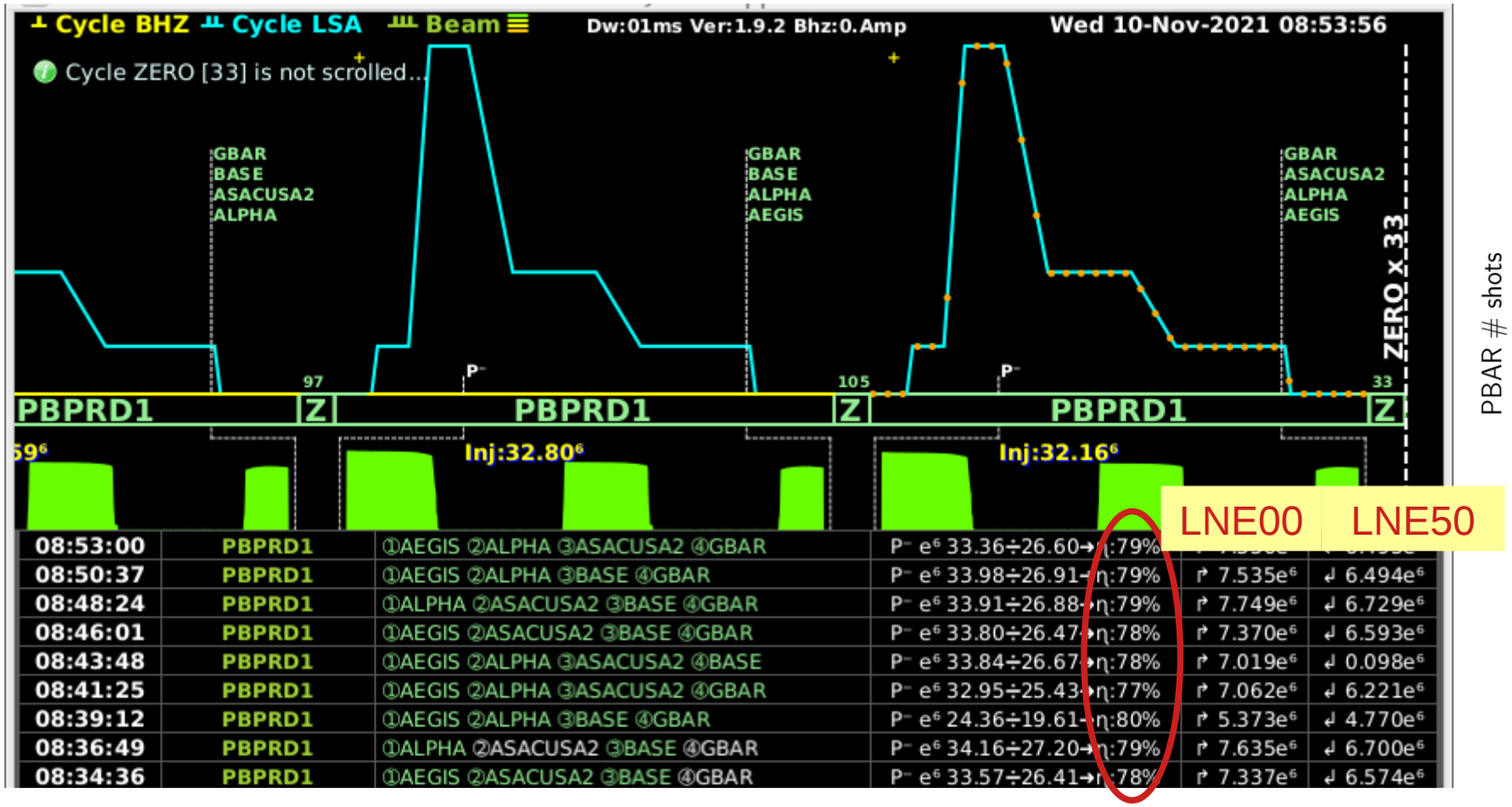
- Typical AD cycle end of 2021 about 5 s longer than in 2018:
  - Using h=1 for the whole cycle (h=3 for 300 → 100 MeV/c ramp pre-LS2)
  - Using bunched-beam cooling before extraction (was bunch rotation pre-LS2)
- Most losses still during injection plateau and on 300 → 100 MeV/c deceleration

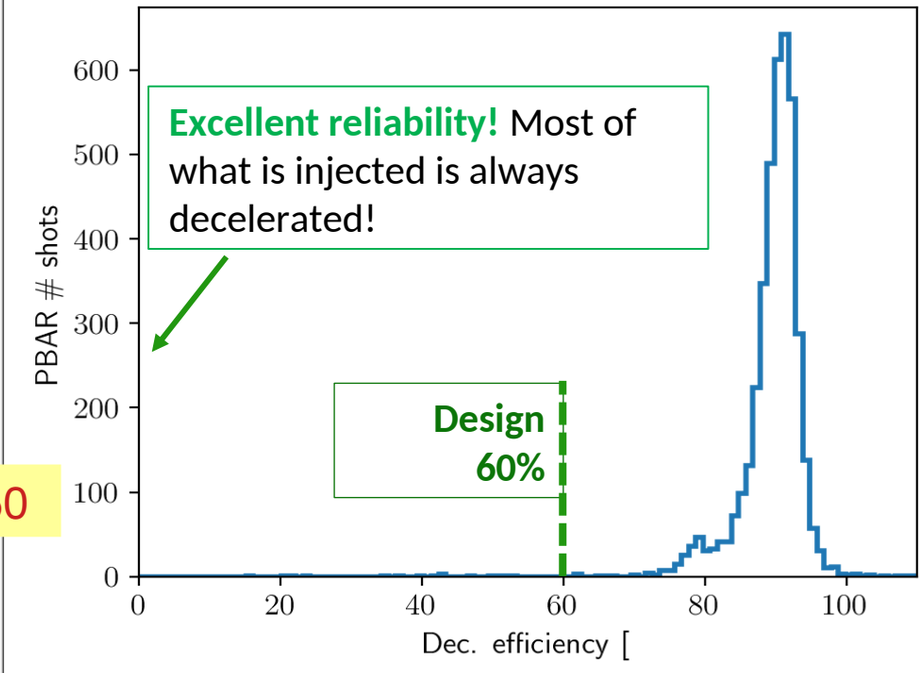


ELENA cycle

- ELENA deceleration efficiency ~ 80%, higher than design (60%):
  - Excellent reliability : what is injected is almost always delerated
  (Data over week 44 a reasonably quiet week at the end of the run)

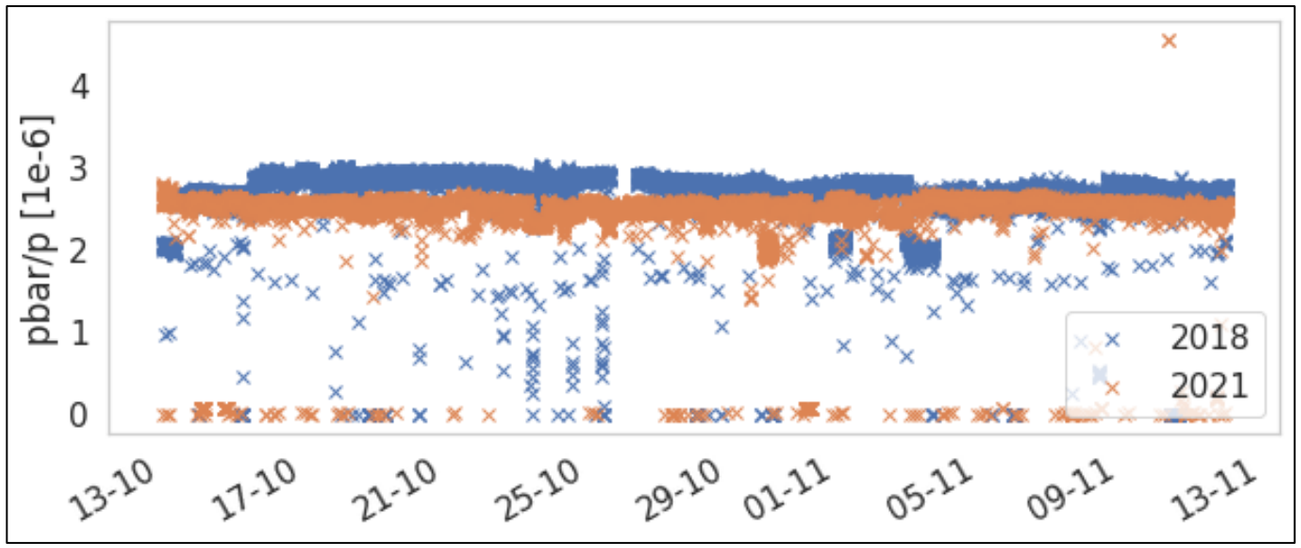
- New mode of operation: each user can place a request at any time
  - Up to 4 experiments can take one bunch each at each cycle
    - if request is placed, bunch is extracted whatever is the situation of the experimental zone
    - If more than 4 requests, one may need to wait 2 cycles

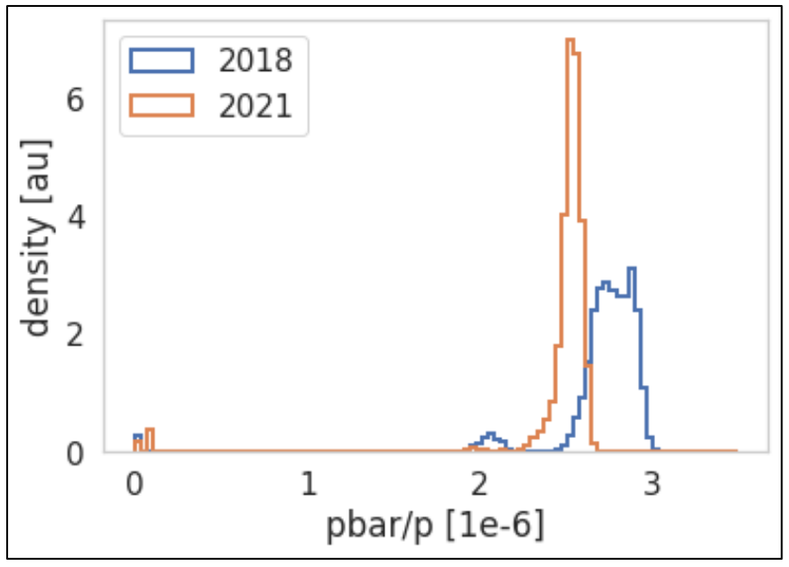




Pbar production in AD

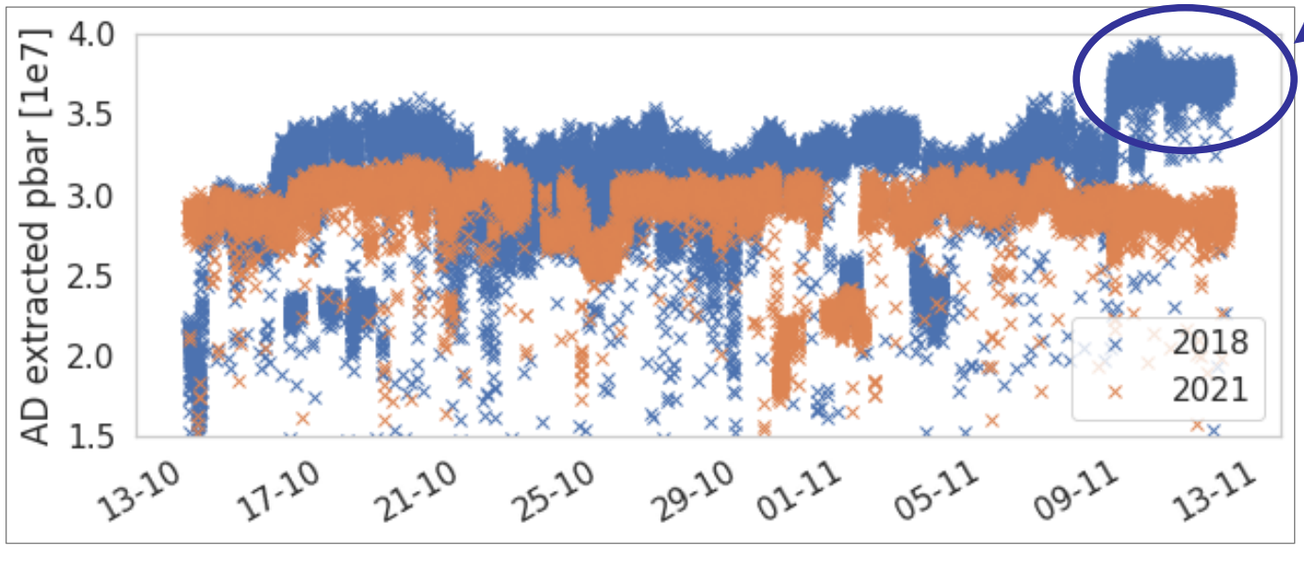
- Present target (+AD injection) yield below 2018:
  - Higher proton losses in FTA than in 2018 → more investigation required
  - Too little time to optimize and need improved instrumentation

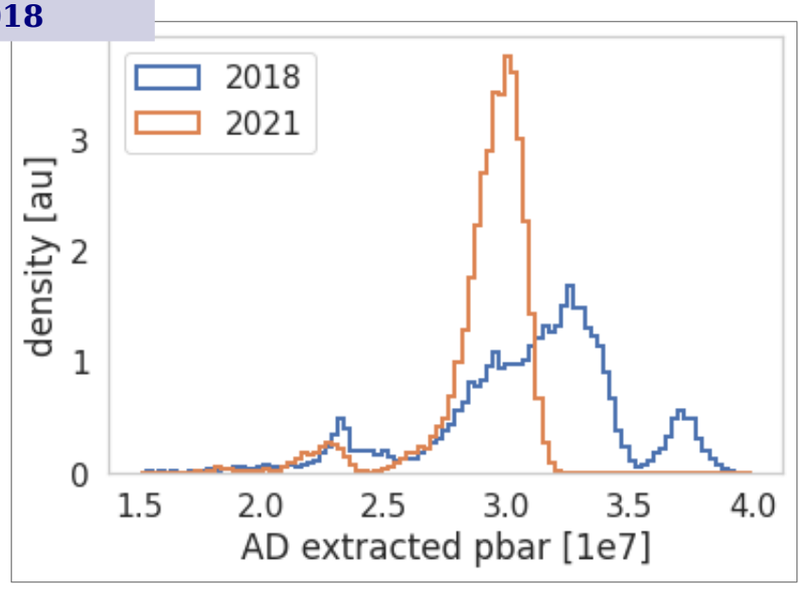




- Lower produced intensity than 2018:

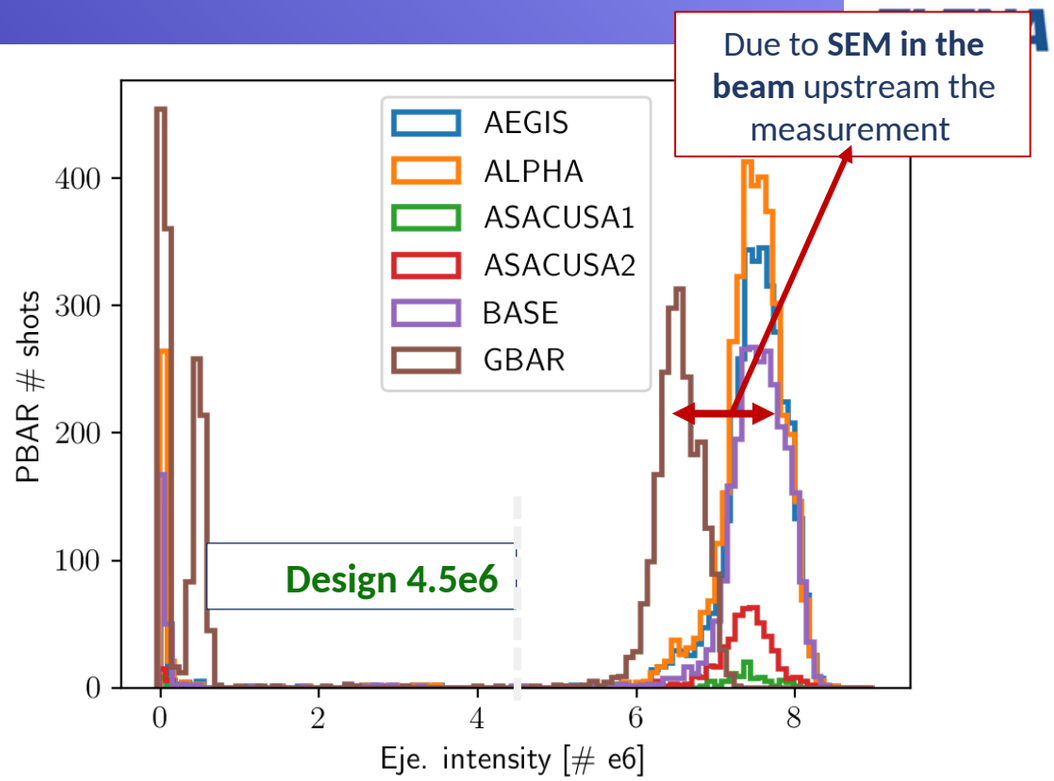
Higher proton intensity asked to PS end of 2018



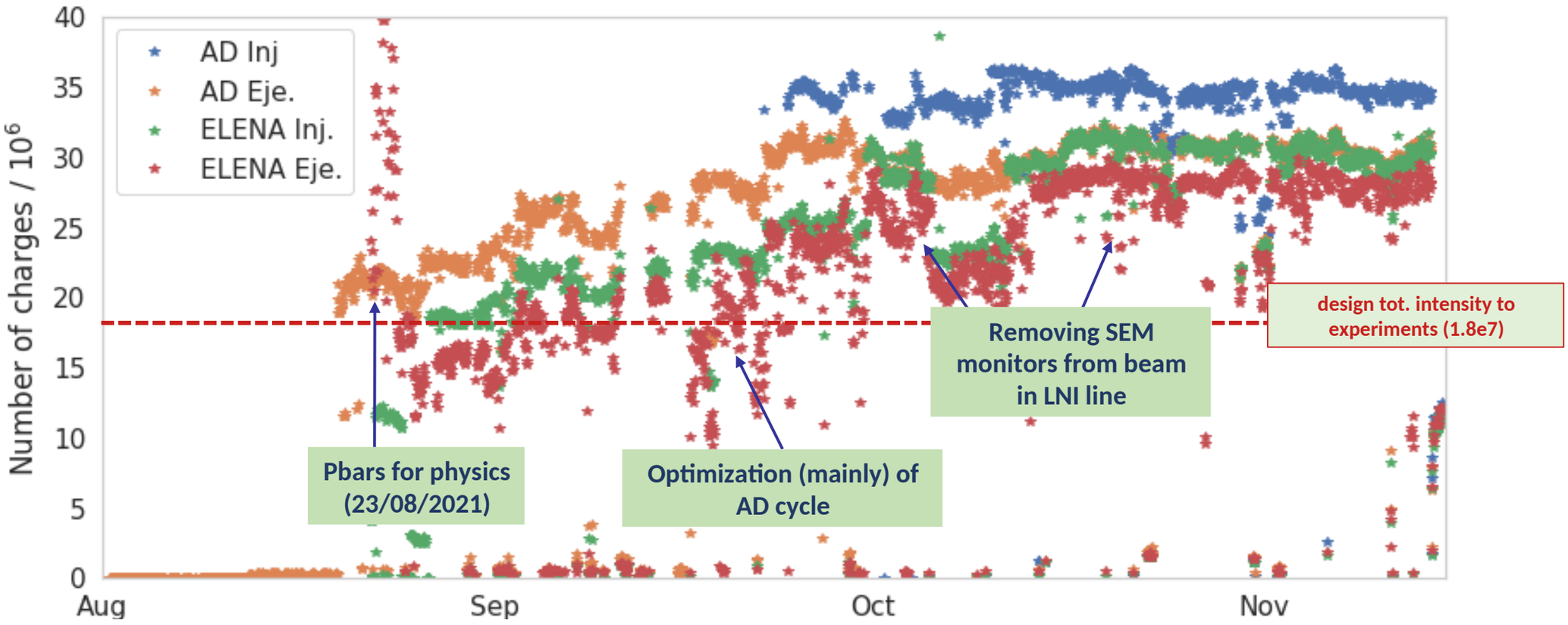


Typical delivered pbar intensity

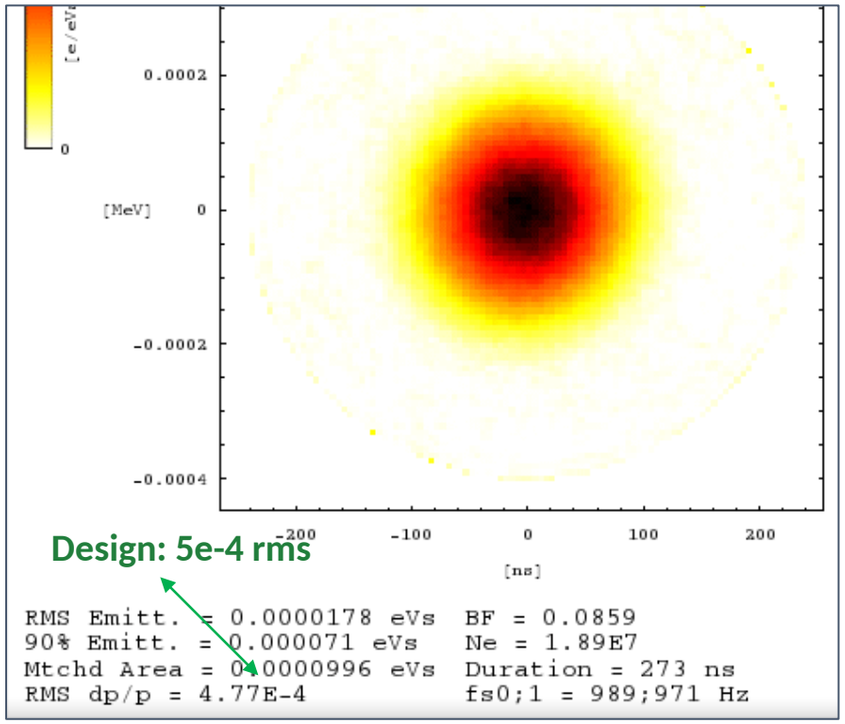
- ELENA delivered bunch intensities well above design value despite lower intensity from AD than 2018:
  - Uncertainty (say 10-15%) on calibration/signal treatment of instruments
  - SEM are semi-interceptive device (about 10 % beam loss per monitor)

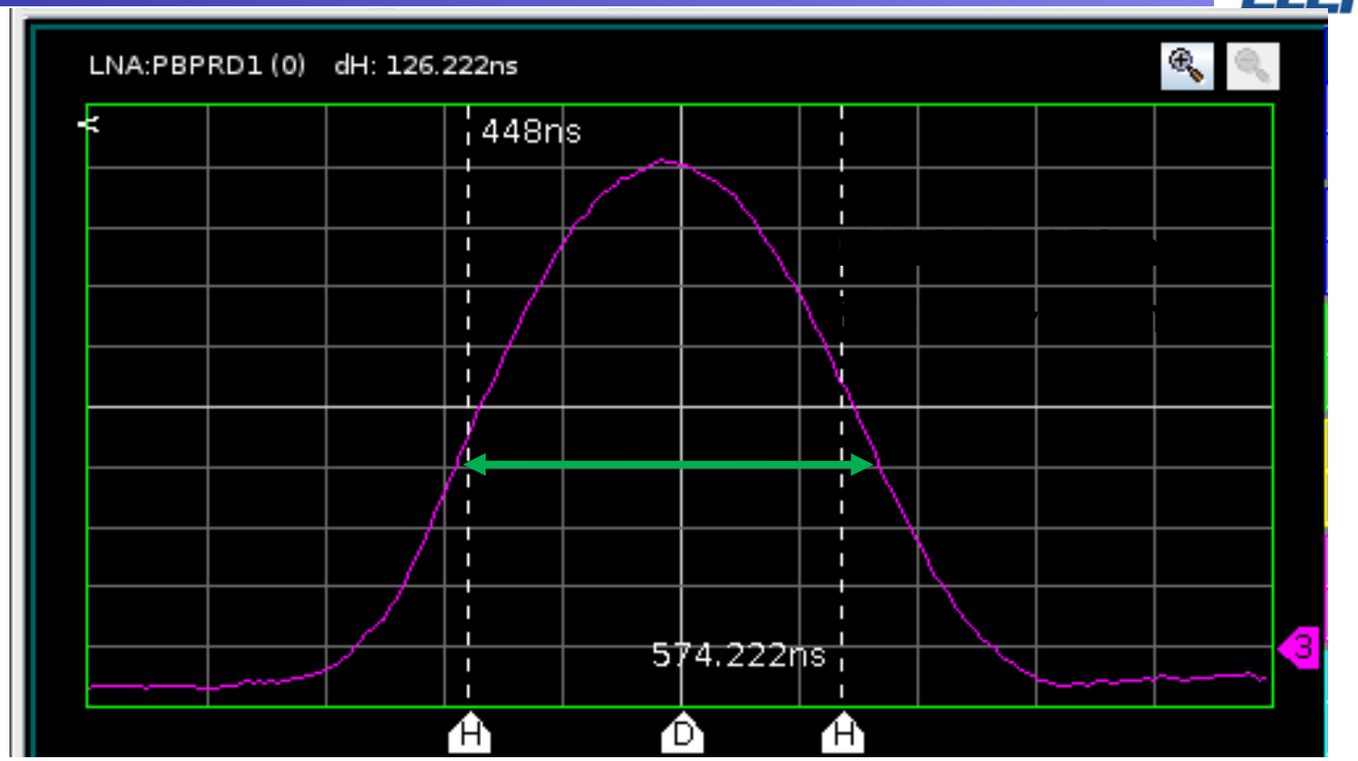


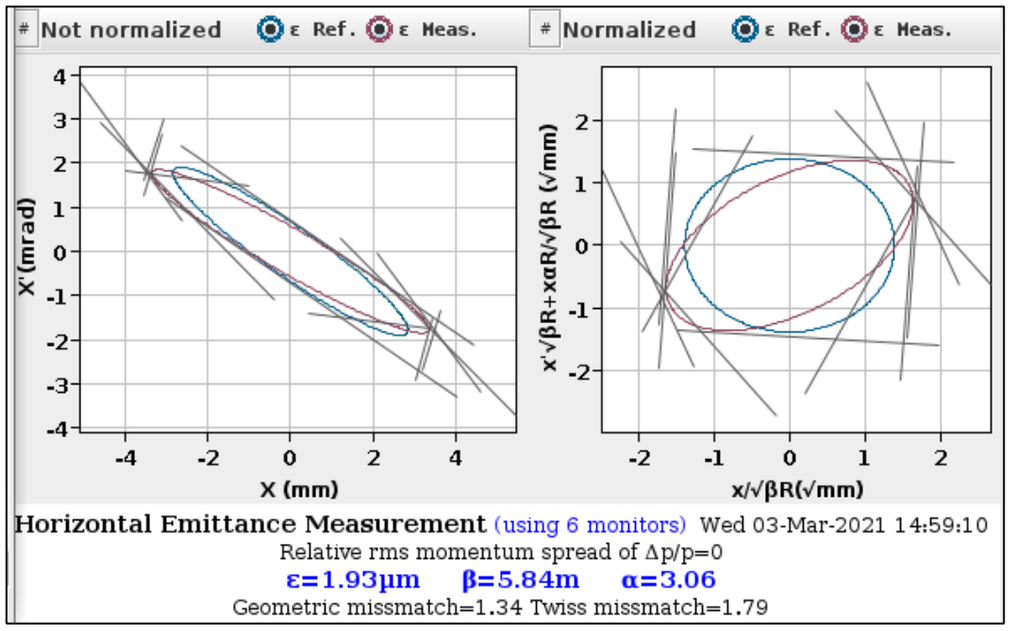
- Max pbar intensity over 1 hour periods since 1st of August



Extracted pbars beam parameters





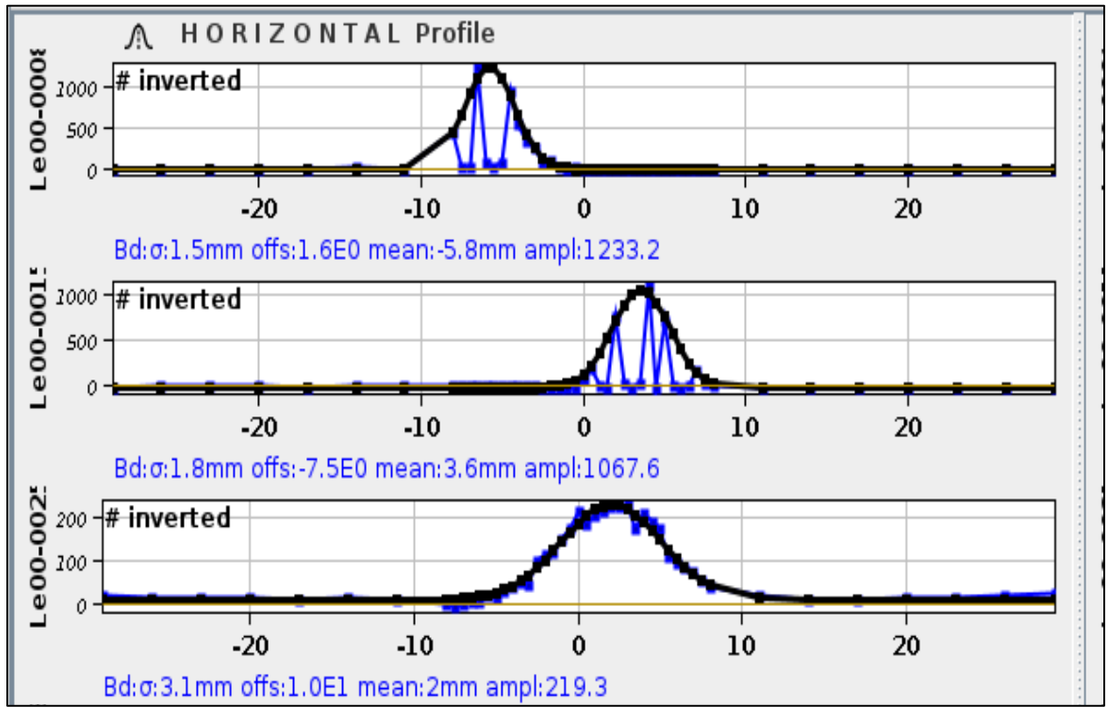


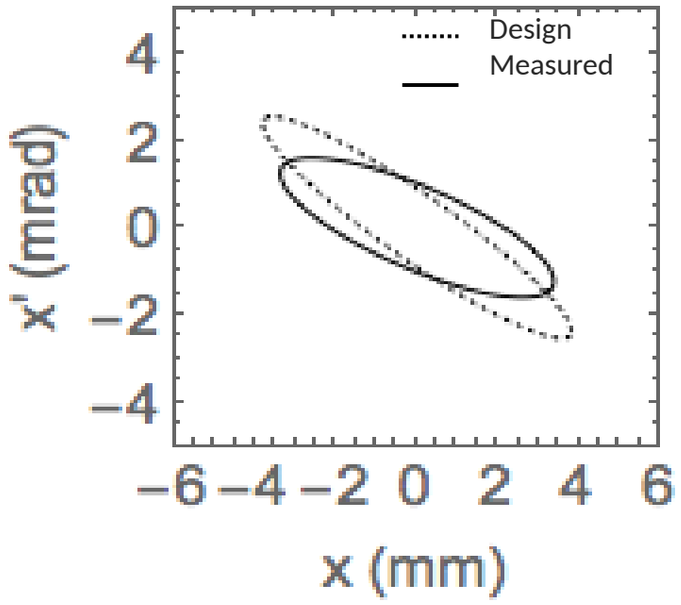
- Energy spread and bunch length typically within or better than design
  - Bunch length could be further reduced to 90 ns FWHM at expense of energy spread
- Typical emittances of 2 um rms are about factor 2 worst than design, but factor ~2 better than 2018 estimate:

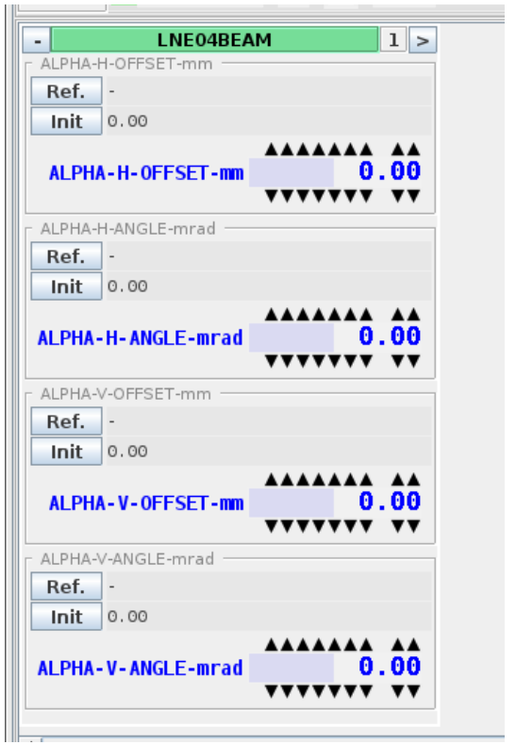
=> Overall reached close to nominal beam characteristics:

We might profit from further inputs from experiments to understand what to improve first

Transfer line setup and control





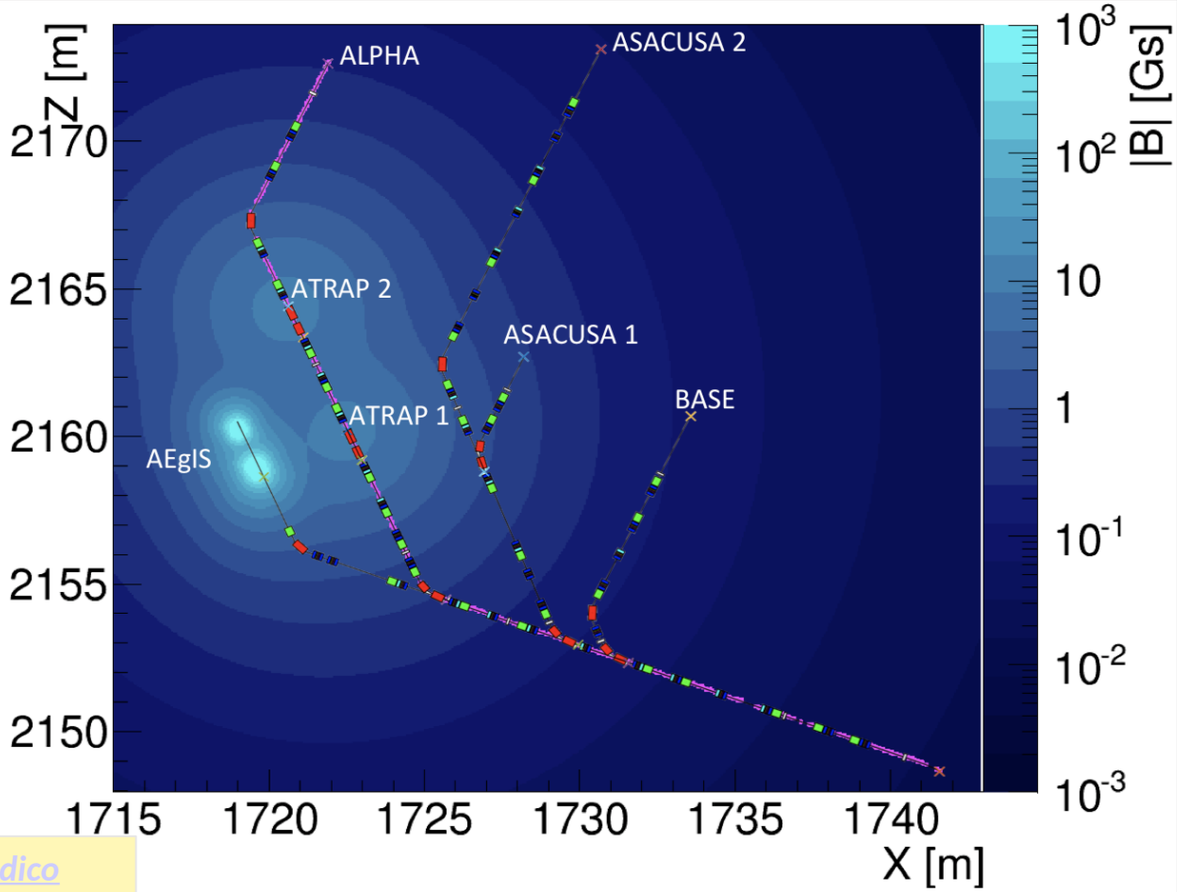


- Earlier worries about **profile monitor availability** and **data quality** were efficiently addressed before pbar arrival:
  - **Extensive studies** by ABT using **H^- beams only**
    - Basically no need re-matching/ corrections with respect to design optics! (change for ASACUSA optics on their request)
  - Only **minor steering** of the full line **with pbars** during the run
    - Calibrated knob (mm and mrad) available fo steering at hand-over point
- **High level parameters** (quadrupole and correctors strength) implemented in the transfer lines:
  - Allow steering with CERN-wide tools in 2 cycles

The “AEgIS effect »

- As « expected » **AEgIS solenoid** does perturb orbit in nearby transfer lines (mainly to ALPHA, but also ASACUSA)
  - Profile monitors not inserted in ASACUSA line during magnet ramp-up, need to check the effect

- |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

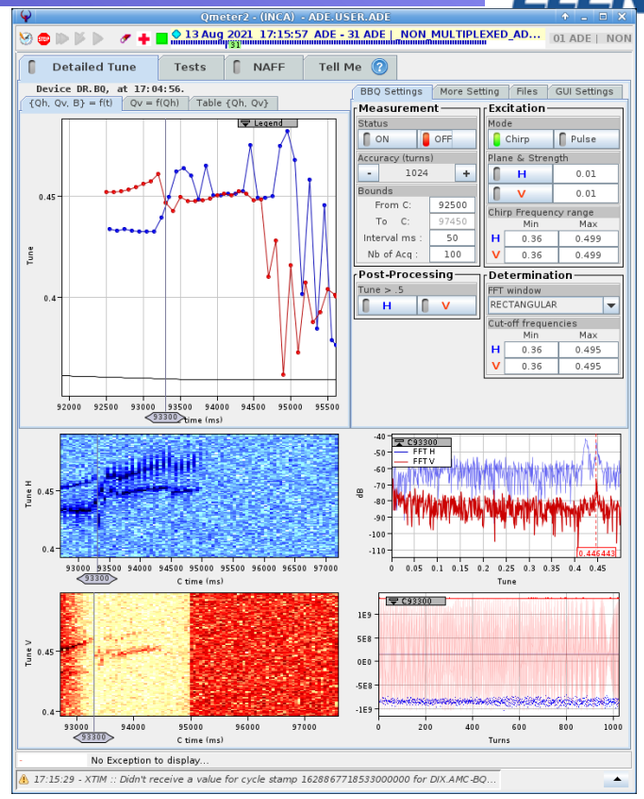


Courtesy J. Jentzsch - indico

- Found steering settings for « solenoid ON » and « solenoid OFF »
  - Reaching some correctors current limit, so needed to re-work the trajectory
  - Reference trajectory and settings in both configuration, easy to reload
  - Still beam not coming back exactly at the same postion, so **fine tuning might be needed**
  - Need AEgIS magnet status flag to load corresponding settings

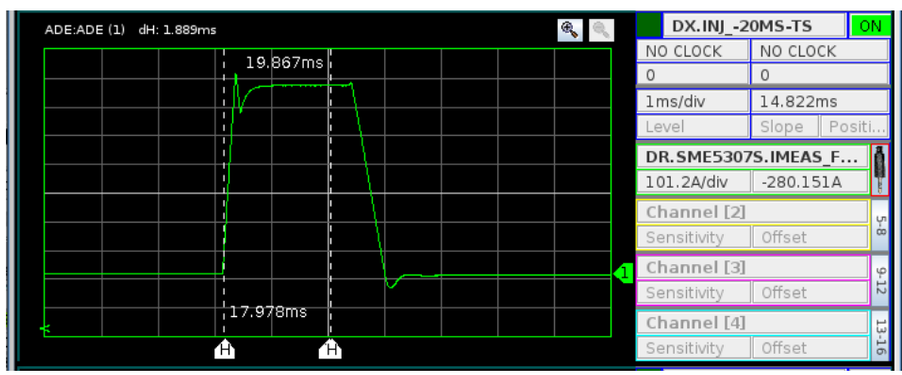
Main issues during beam commissioning

- Wrong minimum current limit set by mistake on the Main quadrupole:
  - 1 week lost on investigating beam loss at the arrival of 100 MeV/c plateau
    - Gained a good control of the working point!
  - Lack of diagnostics on the old power converter type



- New DI.QDE6020 power converter allowing lower pulse rate broke after couple of days of operation:
  - No spare parts to repair so switch back to spare
  - But spare Pow1553 PC not operational: 2 days of beam commissionning lost
  - New system not back operational at the end of the run: not a problem till water leak…

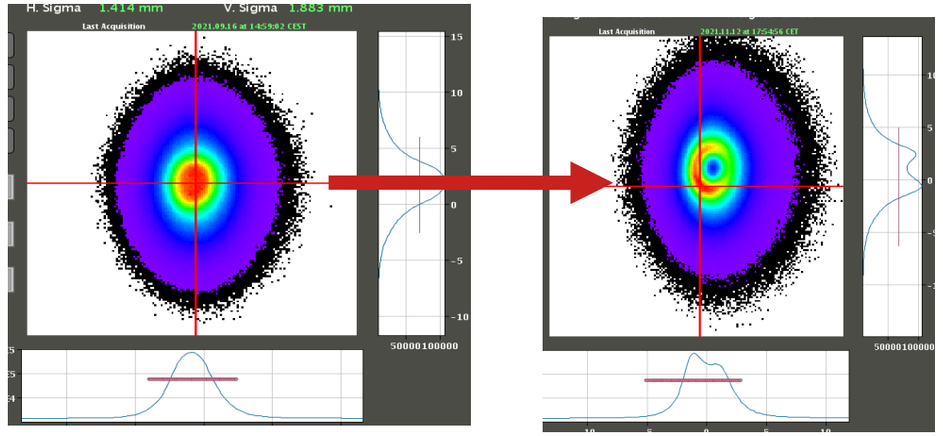
- Current shape of the AD ejection septum inducing shot to shot orbit jitter in LNI:
  - Suspect issue of interference in cable tray between rise edge of the septum and orbit correctors
  - Known (but forgotten!) problem since 2014, fixed by adjusting the ramp rate



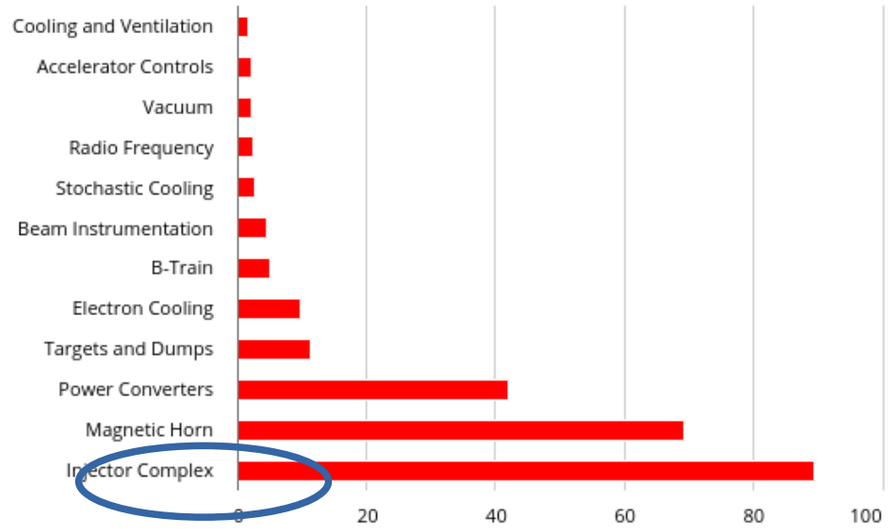
Main HW issues during the run

- AD Target BTV oxydation:
  - Rapid degradation of the BTV surface
    - Old BTV used to have a hole
  - Proposal to test different type at 2022 restart

After few days



- AD magnetic horn:
  - Problem with PLC to be resetted (expert action)
  - No piquet, only best effort intervention

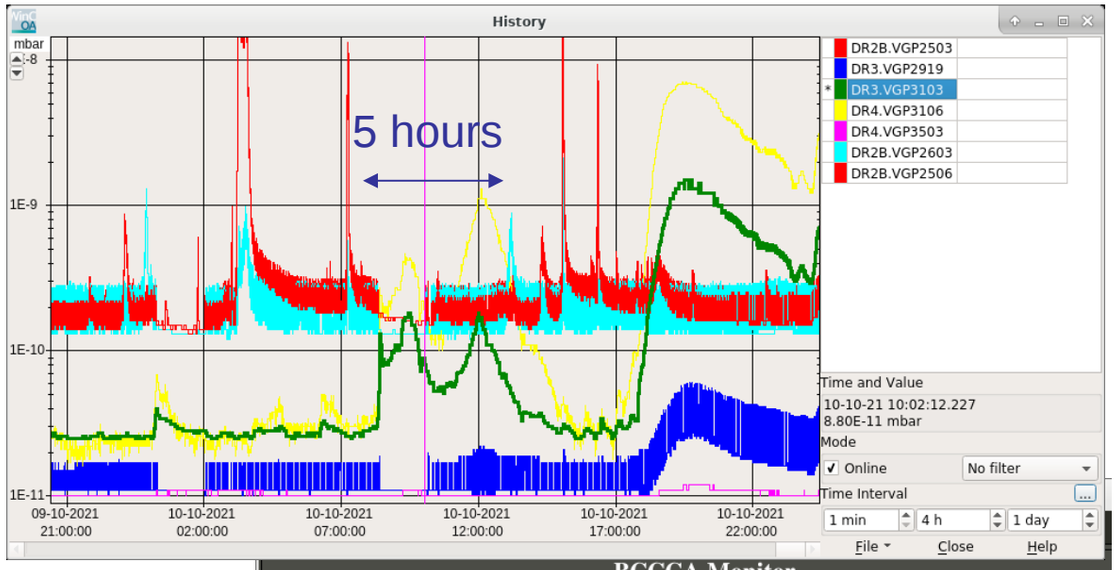


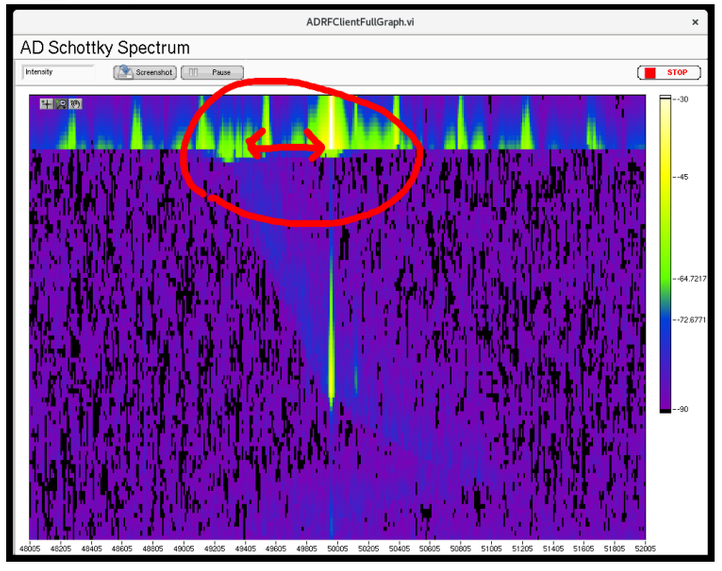
- Water leak on quadrupole DI.QDE6020 few days before end of run:
  - No time to exchange magnet so tried to run without water or without quadrupole
  - 1/3 of intensity injected without the magnet (no time to optimize)
  - Could not try to operate the quad without cooling because FGC_62 not available

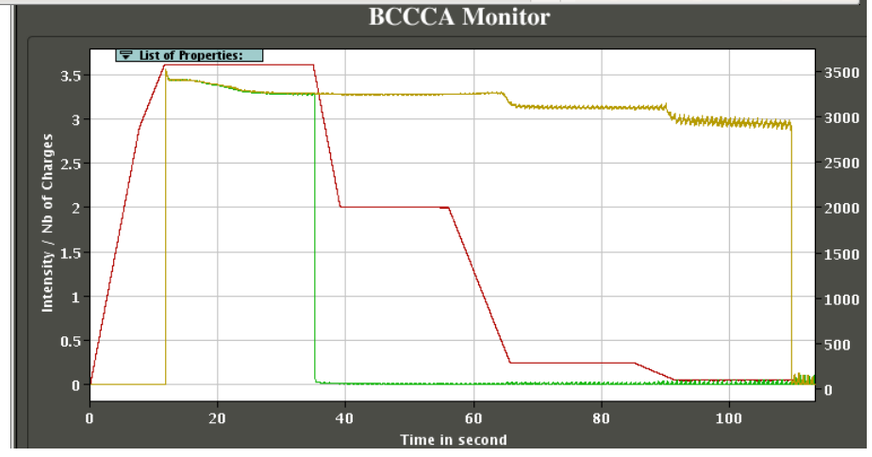
=> Feasibility study of operating DI magnets without cooling to be considered?

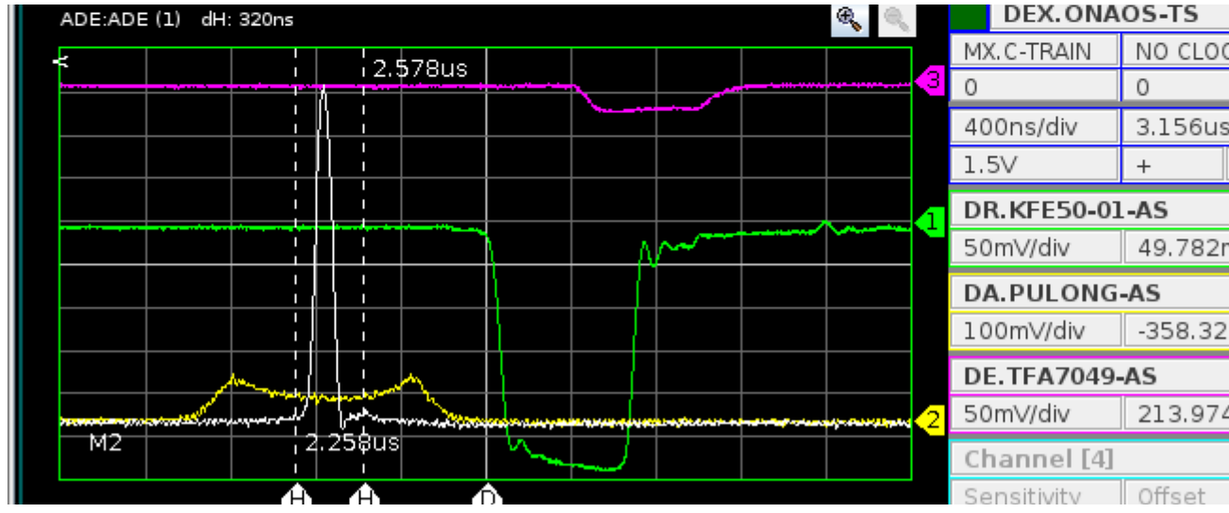
Vaccum issue in AD ring

- Cryo pump in AD:
  - Period of strong outgazing in the C10 – Stochastic cooling pick-up region inducing e-cooler or stochastic cooling performance degradation
    - Beam lost on the first deceleration (few shots) or only partially extracted
    - Found a “pre-warning” on SC temp sensor but solution was to try adjusting e-cooler energy during the storm
  - Problem fixed during the maintenance planned during YETS



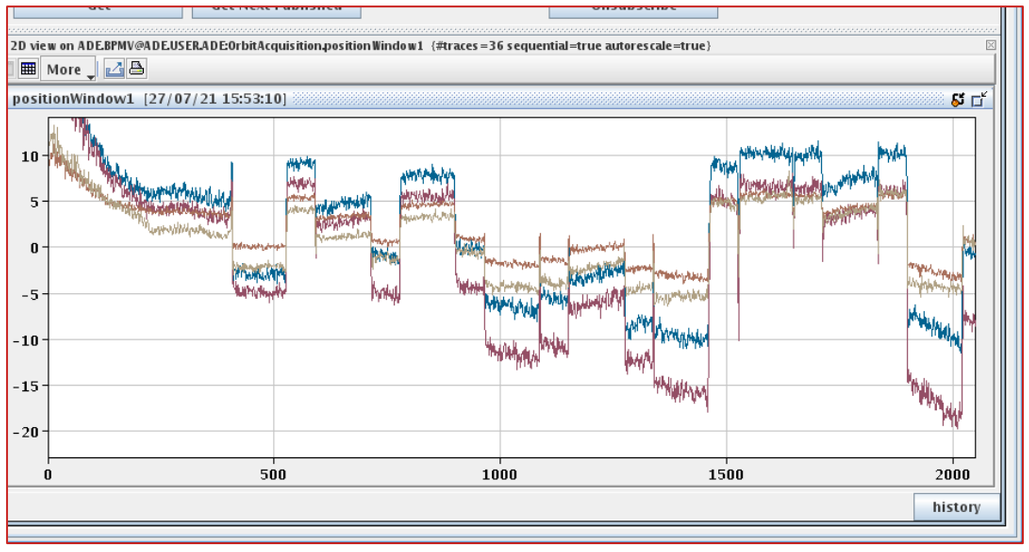


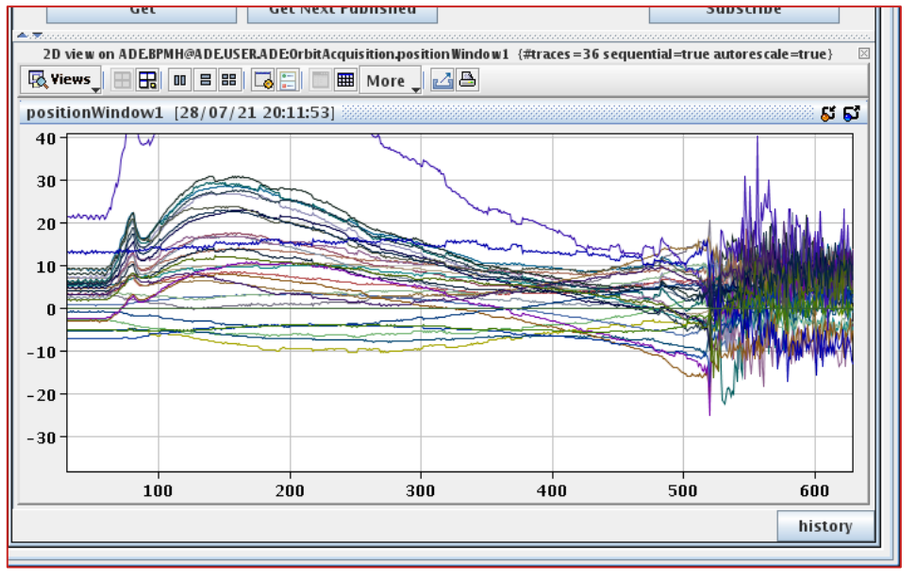




diagnostics/measurements issues

- orbit system:
  - Wrong gain initially set (summer period!) in AD
  - Not stable reading when change of harmonic in the cycle in both machines:
    - change of operational mode in AD, not possible in ELENA so no reliable orbit reading in ELENA for the rest of the run





- Problem with the data of the scraper (interfaces between different groups):
  - No reliable emittance measurement, vertical measurement not avaialble for several weeks during summer period
  - Complex integration of the timings, RT tasks of different equipment (motor and scintillator)
  - Very lenghty (and destructive) to debug started after summer period

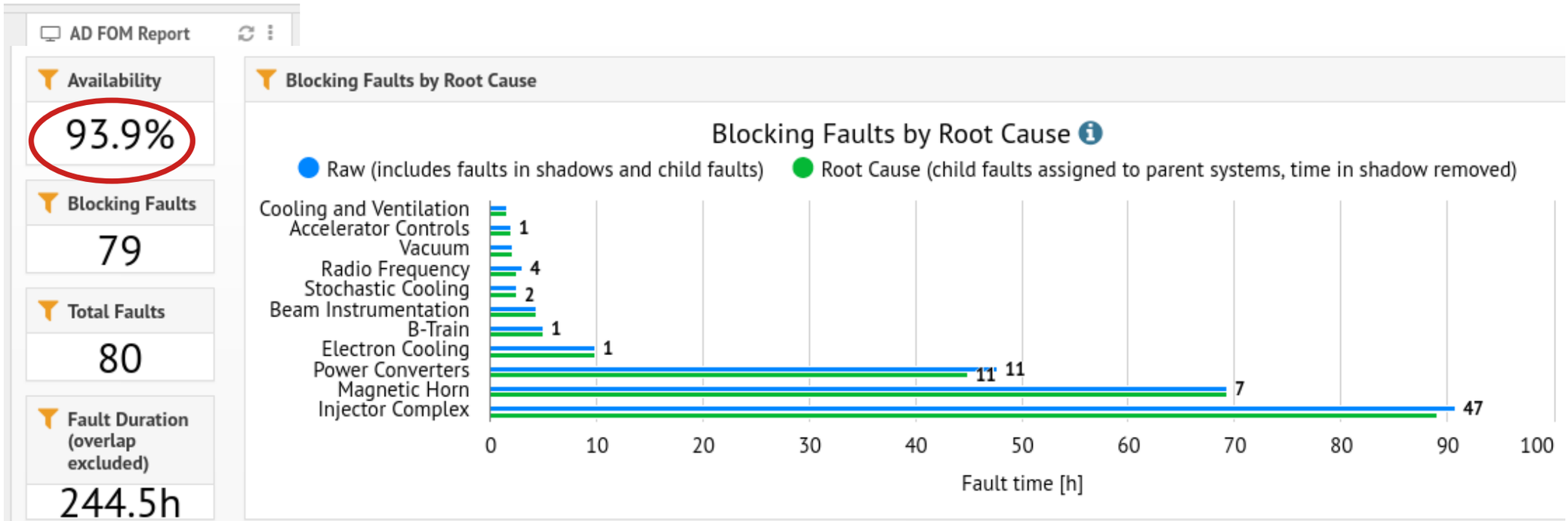
ELENA commissioning with H^-

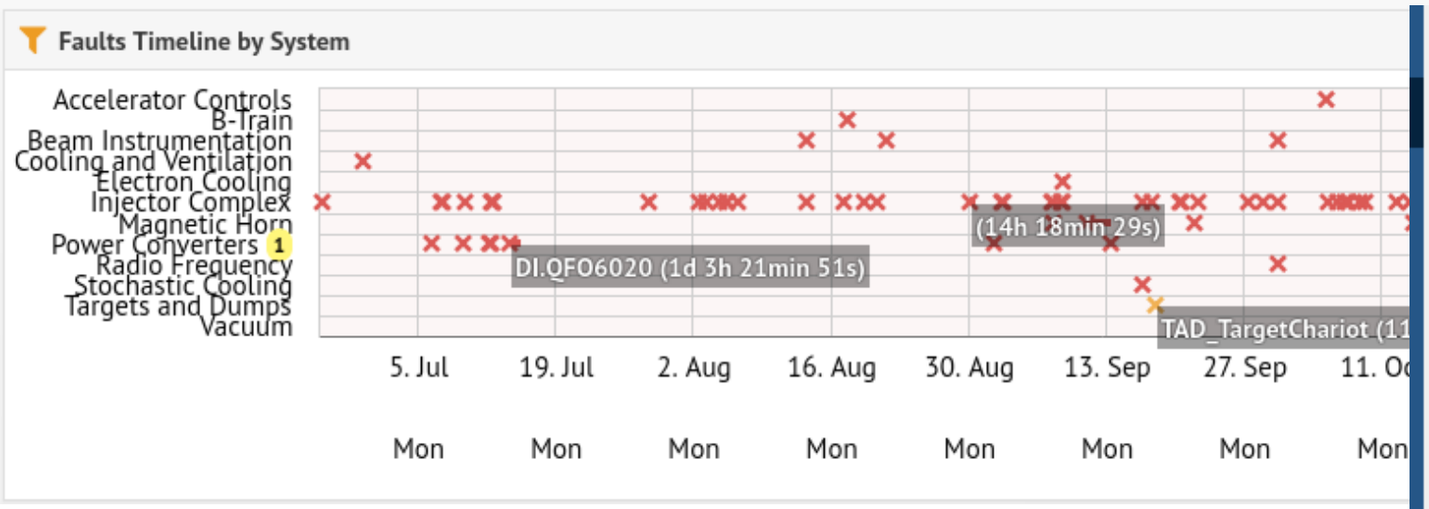
- Good progress since in **end of 2020** with **more reliable H^- source operation**
  - Still **limited by source intensity stability**, being **hopefully addressed during YETS**
- **H^- have been instrumental for the learning and setup** of:
  - **Magnetic cycle** and **LLRF** control
    - **Cycle editor** and general **control** issues **debugging**
    - **LLRF experience efficiently reused in AD**!
    - Investigations on **measured b-train reliability**
      - **Finally operated in 2021 without measured b-train: to be further investigated**
  - **E-cooling**
    - **Demonstrated that we can cool H-**, and therefore **setup e-cooling** with those.
  - **Tune** and **orbit measurement** and **correction**
    - **Solved most transmission losses** observed in 2018 (**quantification/studies to be continued**!)
  - **Instrumentation testing** (tune meters, orbit system, Schottky, scraper)
  - ELENA extraction **transfer lines commissioning**:
    - **More than 100 power supplies** to check and control
    - **Orchestration of timing** for beam delivery to up to 4 experiments at the same time
    - **SEM characterization**
      - Found **several wires in several not working**, but overall **quality sufficient for commissioning and operation**

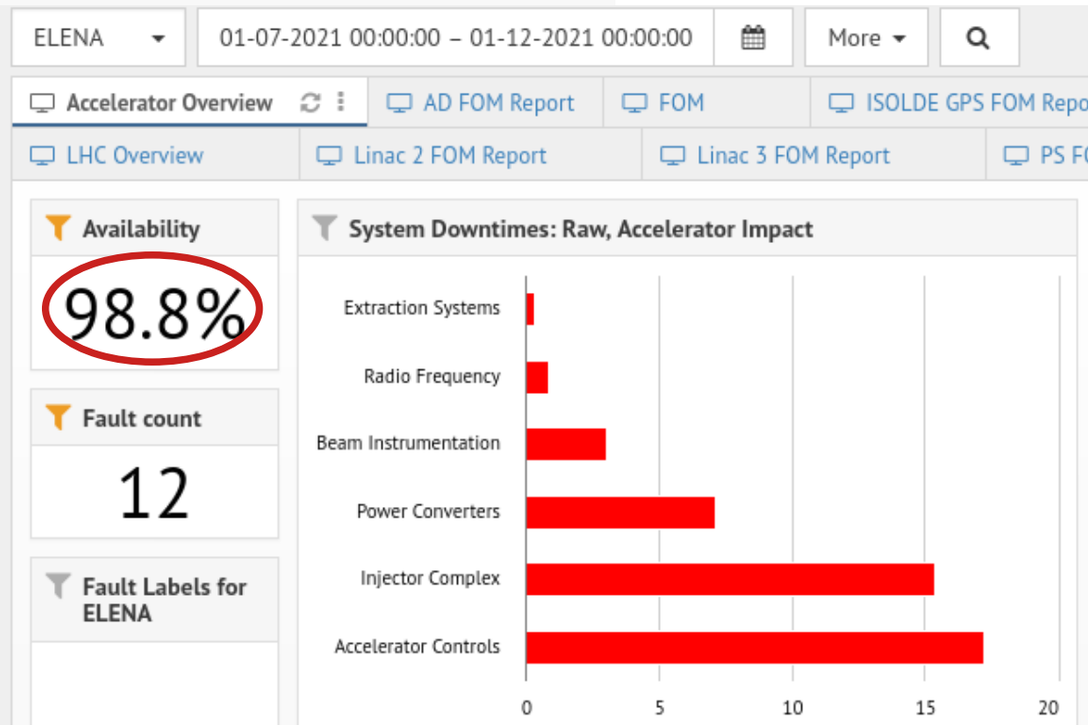
Courtesy D.Gamba

Run statistics

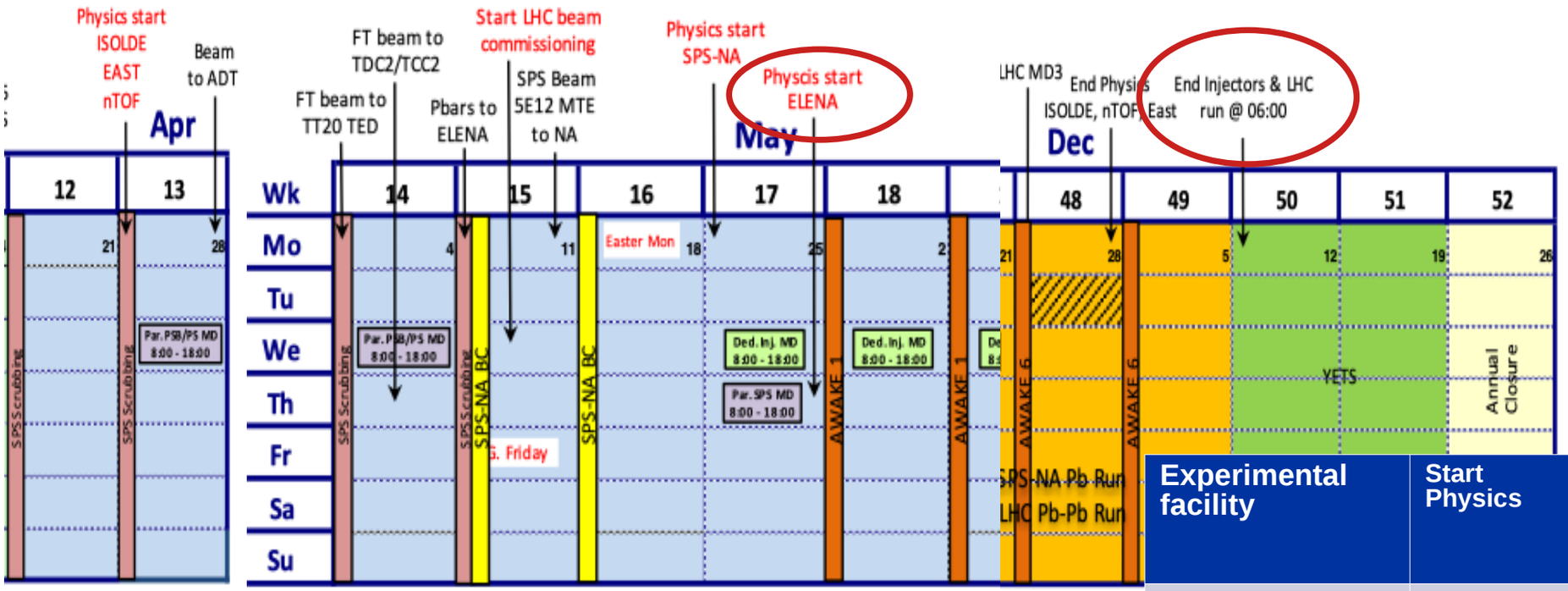
- Very good availability for both machine (close to 2017 for AD, 2018 was a bad year!)
  - Note: need to consolidate the faults capture:
    - Faults not automatically registered, double counting of injectors faults...







Draft injector schedule for 2022



Experimental facility	Start Physics	End Physics	Duration 2022 [days]*	Duration 2018 [days]*
ISOLDE	28.03.2022	28.11.2022	**245**	217
nTOF	28.03.2022	28.11.2022	**245**	224
PS East Area	28.03.2022	28.11.2022	**245**	224
SPS North Area p^+	25.04.2022	14.11.2022	**203**	217
ELENA (AD)	28.04.2022	12.12.2022	**228**	196
SPS North area Pb ions	14.11.2022	12.12.2022	**28**	28
AWAKE	02.05.2022	12.12.2022	**105**	91
HiRadMat	16.05.2022	31.10.2022	**35**	25

- Key dates for 2022 pbars operation:
  - First beam on AD target on 28th of March
  - Start of physics on 28th of April
    - Commissioning during Easter period
  - End of pbar operation 12th of December
    - 228 days for physics run (MD not inc.)

- Restart of Hminus source operation mid February:
  - After BTV in LNI exchange
  - Mainly for ELENA cycle setting-up and new line commissioning
    - Could be delivered to users if beam permit signed

Areas for improvement

- Recover AD ejected intensities pre-LS2
  - Improve transport to in transfer lines (FTA, DI and AD to ELENA)
    - Time comsuming activity
  - Optimize target production
    - Need improved instrumentation

- Reduce transverse emittances in ELENA transfer lines to deliver nominal parameters
  - Need users input to define optimum between transverse and longitudinal
  - Optimization on e-cooling, study of intensity dependance

- Improve repetition rate:
  - Reduce AD cycle length
    - Work on both cooling
    - Study ramp rate reduction
    - Work on cycle structure definition
  - Better adapt to PS supercycle

=> OP team will request again 1 day per week for Machine developement

Summary

- **AD** and **ELENA** have been **successfully** (re-)**commissioned** during summer period
  - **New era for antimatter physics**: 100 keV pbar beams delivered to all experiments

- **Beam characteristics very close to design values**:
  - Easy to get **shorter bunches** than design, but **emittances still a factor 2 bigger than nominal**
  - **Higher intensities than design** in ELENA despite lower intensities than 2018 in AD
    - Some margin to gain in the future? (but emittance…)

- **Extremely usefull run** for both **operation and users** to learn about advantages and pitfall of the new AD+ELENA combo:
  - Experience gained on operation with **4 bunches available** on demand **at any time** to any experiments:
    - But **if more than 4 users**, then **additional waiting time** for some users
    - **Beam request server could/should be further optimized** to allow « last second » change of destination (e.g. one user cannot suddenly take beam)
  - Pretty **good orbit stability** of beam delivery in transfer lines
    - Still **strong impact of experiment magnetic fields** when swicthing **on/off**
      - We **can compensate** for it but we **need to know the status of the magnets!**
  - **H^- source operation very usefull** for **ELENA** and transfer line set-up, but also for **experiment** setup/optimization (higher repetition rate)

We are ready for a long exiting physics production run

Summary Key Performance Indicators

	Target (IPP #40)	Achieved 2021	How to measure
p at PS extraction	**n.a.**	**1.5e13**	
Requested p on target (compatible with Nov 2018)	**(1.3e13)**	**1.3e13 - 1.4e13**	BCT before target
p beam-size/orbit stability on target	**??**	**1.5 mm rms**	BTV before target?
p bunch length on target (4σ)	**n.a.**	**28 ns?**	To be checked
AD target → injection efficiency	**2.75x10^{-6}**	**2.5x10^{-6}**	Target BCT + Schottky on inj plateau or CCC ?
AD deceleration efficiency	**85%**	**85%**	Schottky on inj plateau or CCC ?
AD extracted pbars	**3e7**	**2.9e7**	BCT on DE line
AD cycle length	**110 s**	**115s**	FGCs…
AD uptime/for physics	**90%/84%**	**???**	BCT after extraction(?)
ELENA injection efficiency	**95%?**	**???**	BCT in the ELENA ring? BPM? LLRF?
ELENA deceleration efficiency	**60%**	**90%**	BCT in the ELENA ring? BPM? LLRF?
ELENA extracted pbars	**4x 4.3e6**	**4x ~7e6**	BCTs in transfer lines
ELENA uptime/for physics	**95%?/90%?**	**???**	BCTs in transfer lines(?)
AD+ELENA for physics	**84%*90%=76%?**	**???**	BCTs in transfer lines(?)
Cycles/day for physics	**n.a.**	**???**	BCTs in transfer lines(?)
Geometric emittance ϵ_{rms}	**<4 mm mrad H/V ?**	**2 mm mrad**	A few SEM in from time to time? Always?
Orbit stability at experiment	**<< 1 mm?**	**???**	A few SEM in from time to time? Always?
Bunch length σ_{rms}	**75 ns?**	**<65 ns**	BCTs in transfer lines? BPM in the ring?
Momentum spread δ_{rms}	**0.7e-3?**	**0.5e-3**	Tomoscope in the ring from to time?

Courtesy D.Gamba