Performance of the AD Cryogenic Current Comparator

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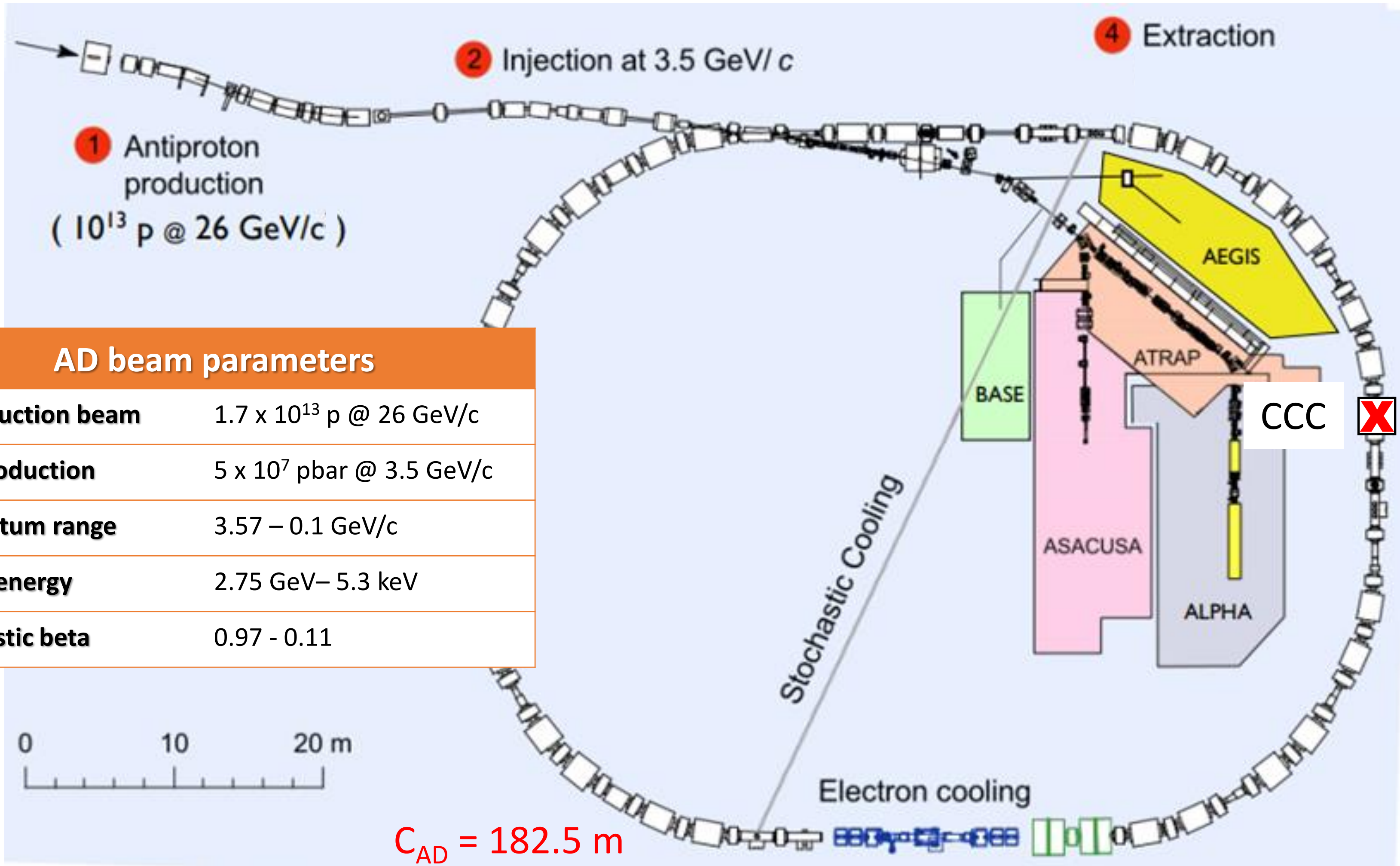
Outline

- **AD MACHINE**
- **THE CCC IN DETAIL**
- **THE CRYOSTAT**
- **OPERATION IN 2024**
- **ISSUES & MAINTENANCE**
- **CONCLUSION**

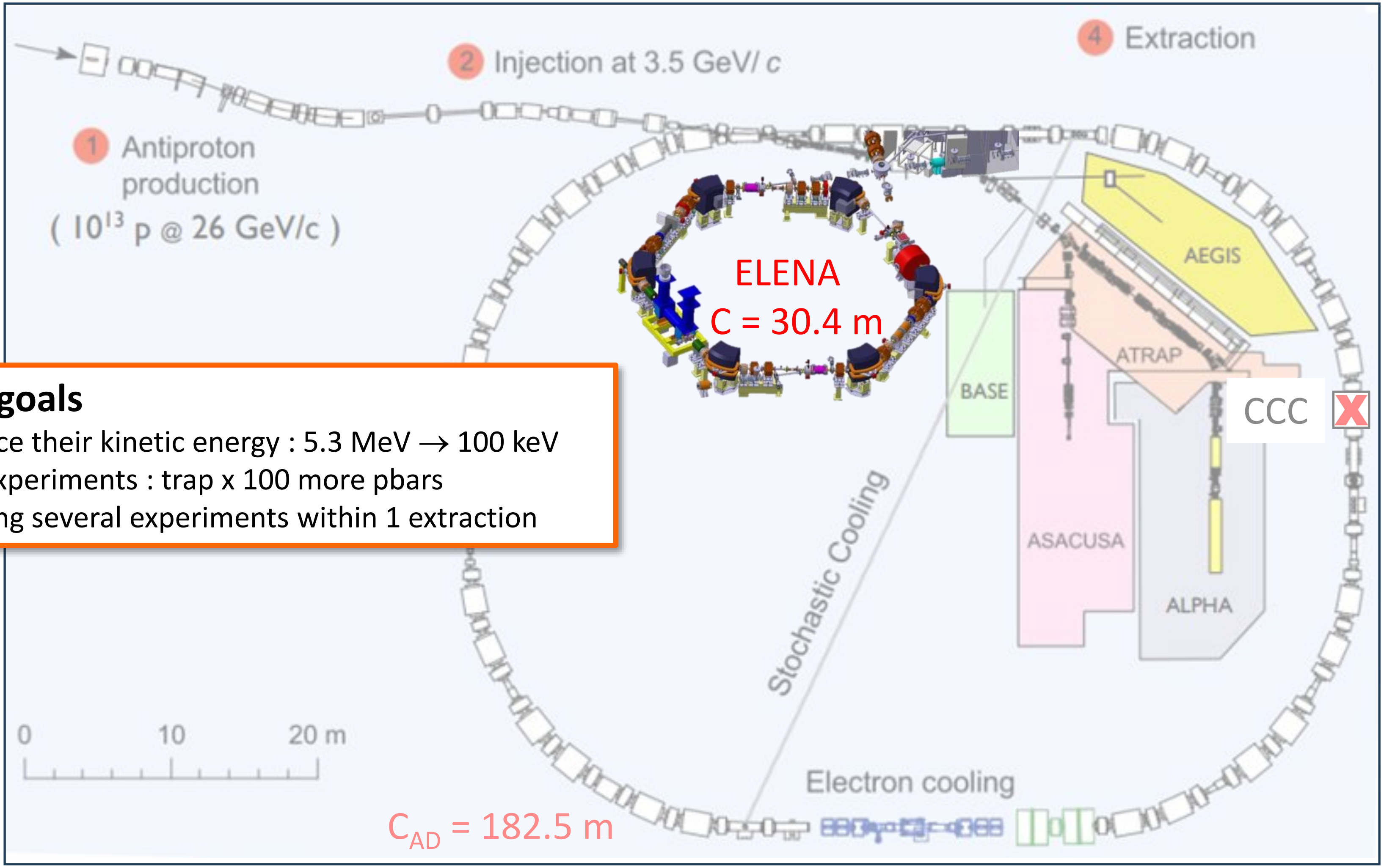
AD MACHINE

CERN pbar complex : AD



AD beam parameters	
PS production beam	1.7 x 10^{13} p @ 26 GeV/c
Pbar production	5 x 10^{7} pbar @ 3.5 GeV/c
Momentum range	3.57 – 0.1 GeV/c
Kinetic energy	2.75 GeV– 5.3 keV
Relativistic beta	0.97 - 0.11

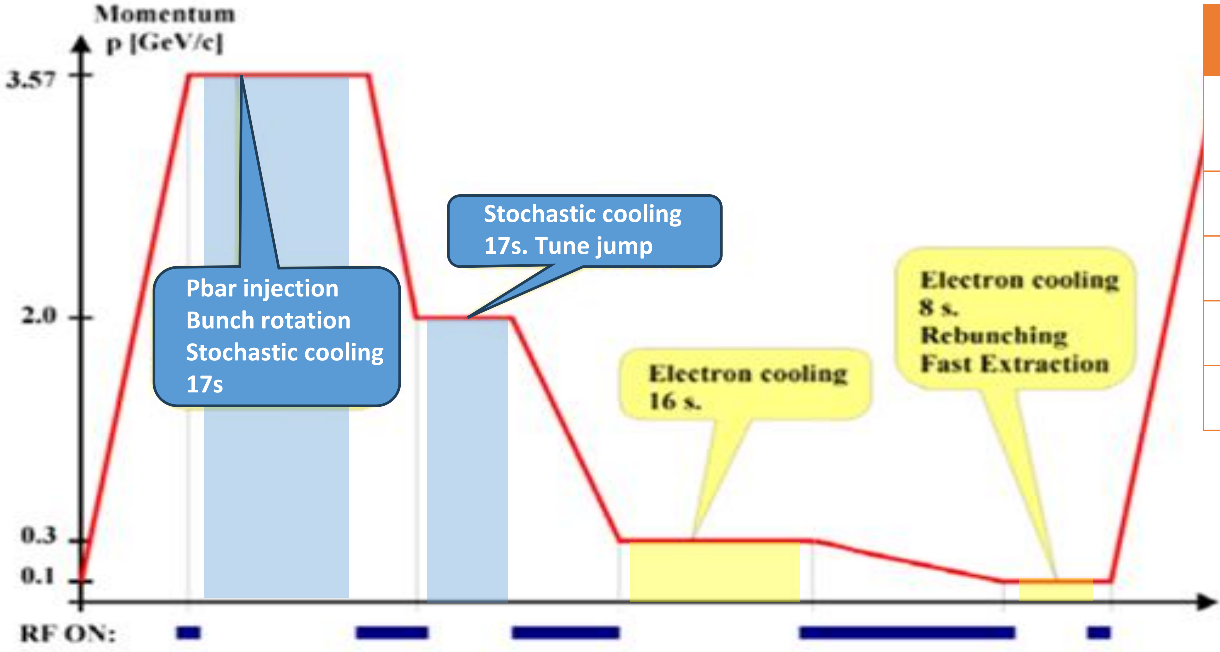
CERN pbar complex : ELENA



ELENA goals

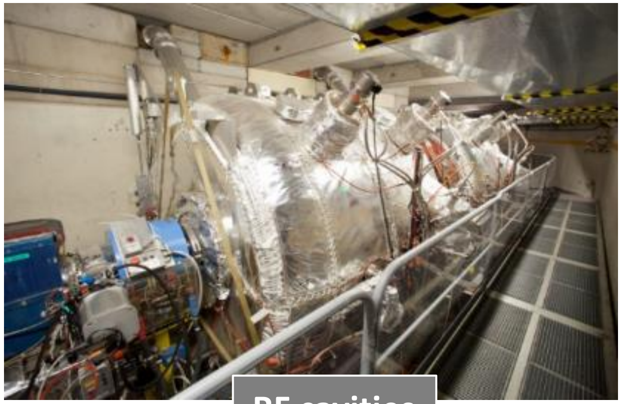
- Reduce their kinetic energy : 5.3 MeV → 100 keV
- For experiments : trap x 100 more pbars
- Serving several experiments within 1 extraction

AD beam and cycle parameters

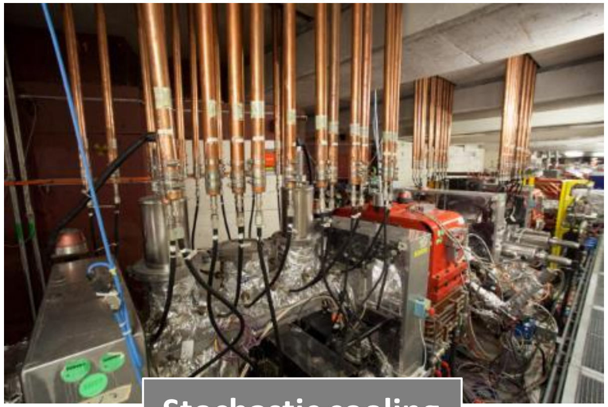


AD beam parameters	
Longitudinal structure	DC and Bunched
Frev	1.59 - 0.174 MHz
Cycle length	~110 s
Beam intensity	(5 – 0.1) x 10^7 pbars
Beam current	(12 - 0.1) μA

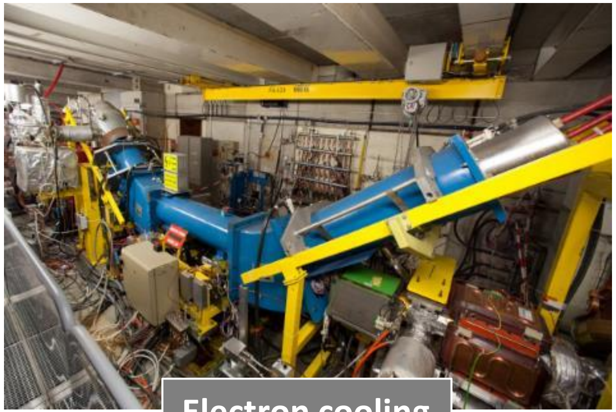
For OP and the experiments, monitoring the number of pbars is of paramount importance !



RF cavities



Stochastic cooling



Electron cooling

THE CCC IN DETAIL

Specifications of a new ring current monitor

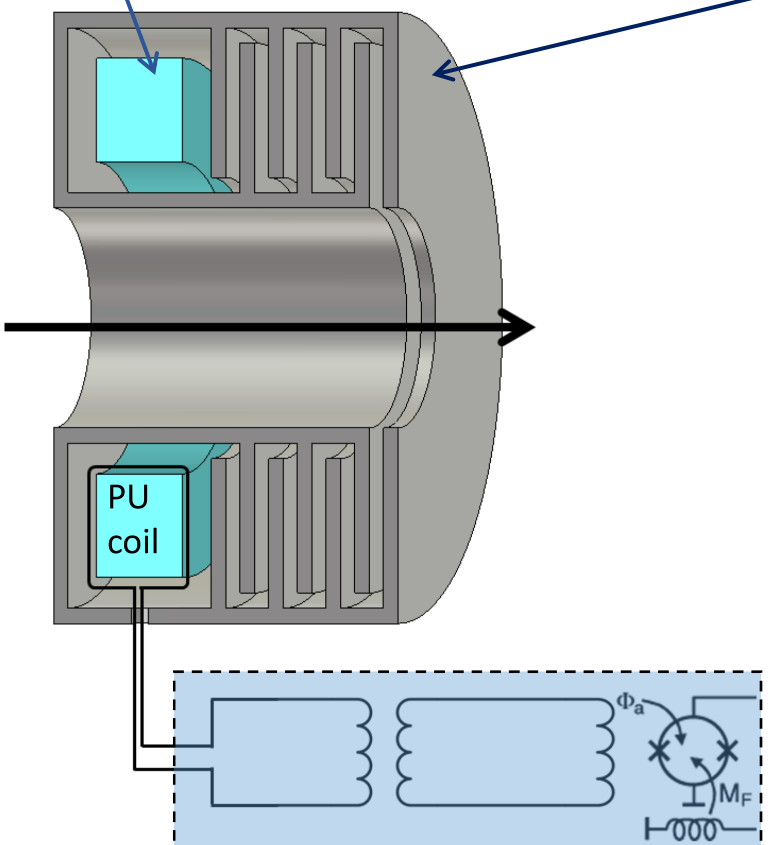
Current/intensity measurement:

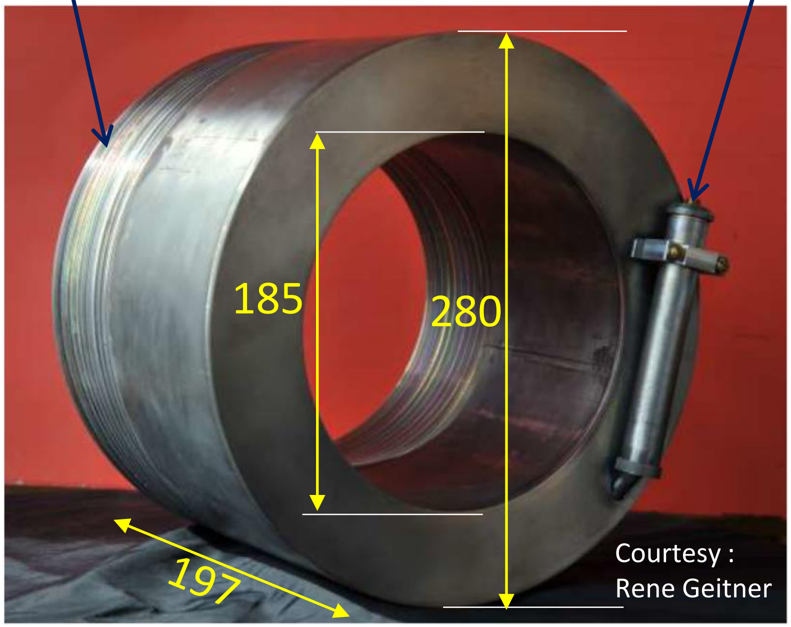
- Method: Non-destructive
- Beam structure: Bunched and debunched
- Current resolution: < 10 nA
- Intensity resolution: < 5 x 10^5 charges (1%)
- Absolute measurement: Calibrated monitor, accuracy ~1%
- Bandwidth: DC - 1 kHz

Operations ready:

- Integrated acquisition: FESA-based
- Automatic operation: synchronized with AD cycle

CCC components



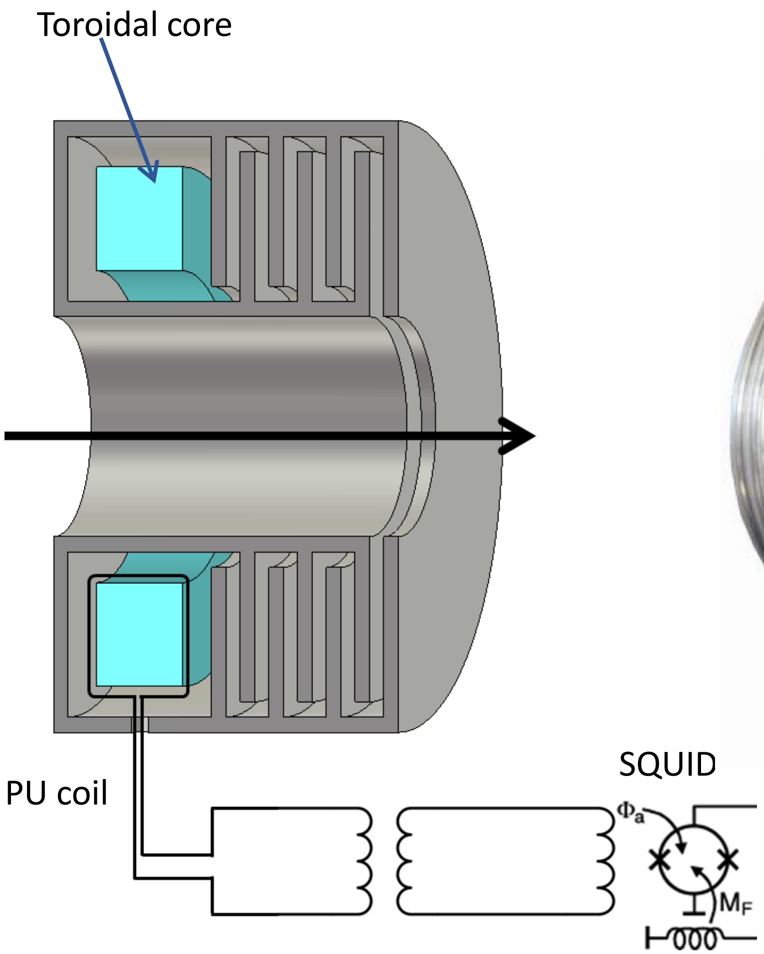


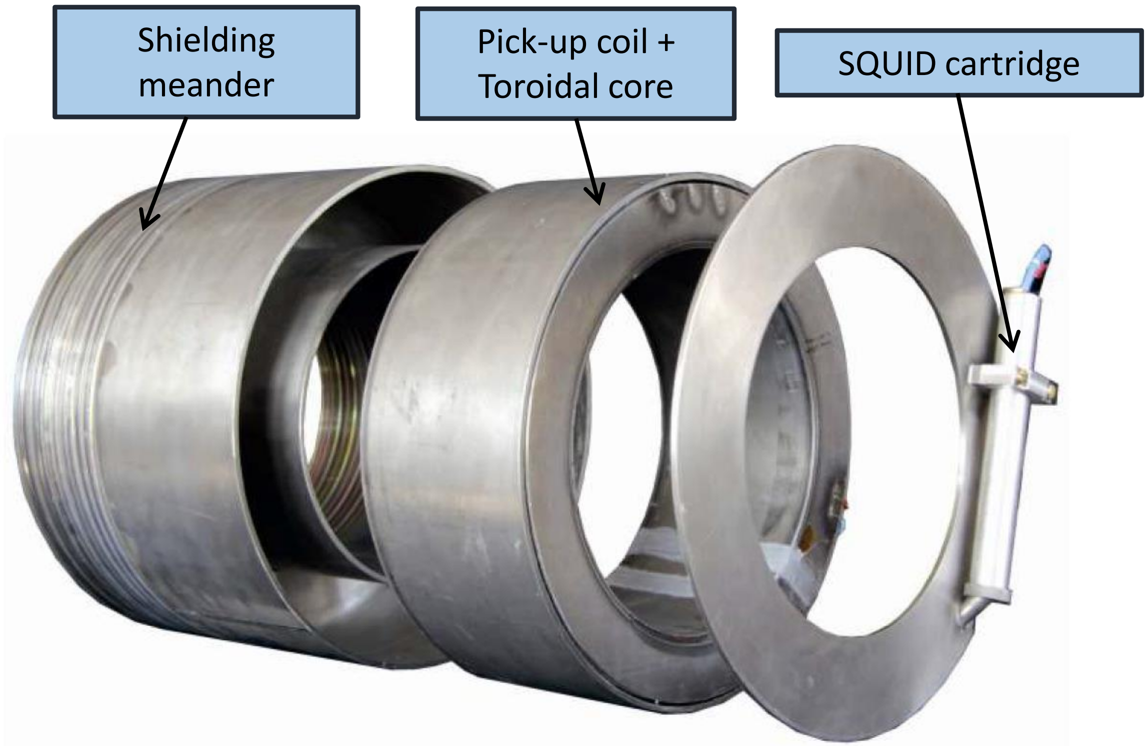
Basic idea of CCC:

Precise measurement of azimuthal magnetic field (fT-range) using **DC-SQUIDS**

Superconducting QUantum Interference Device

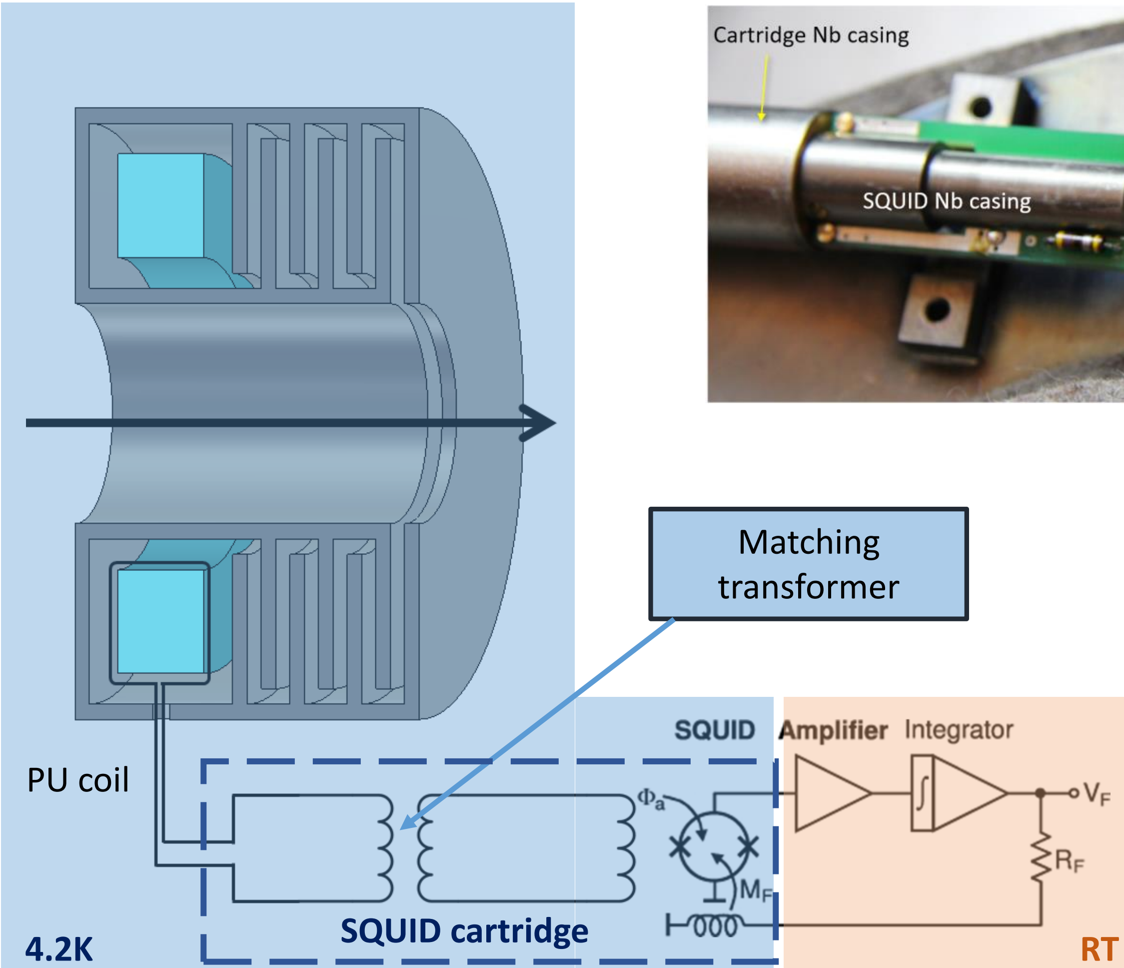
Magnetic shielding and PU coil

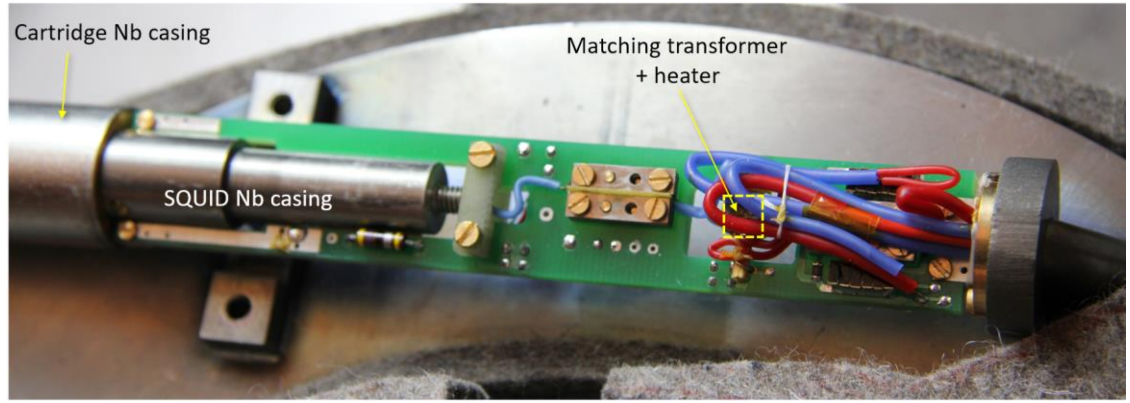




Superconducting material : Niobium
Core material : Nanoperm
SQUID manufacturer: Magnicon GmbH

SQUID cartridge and FLL

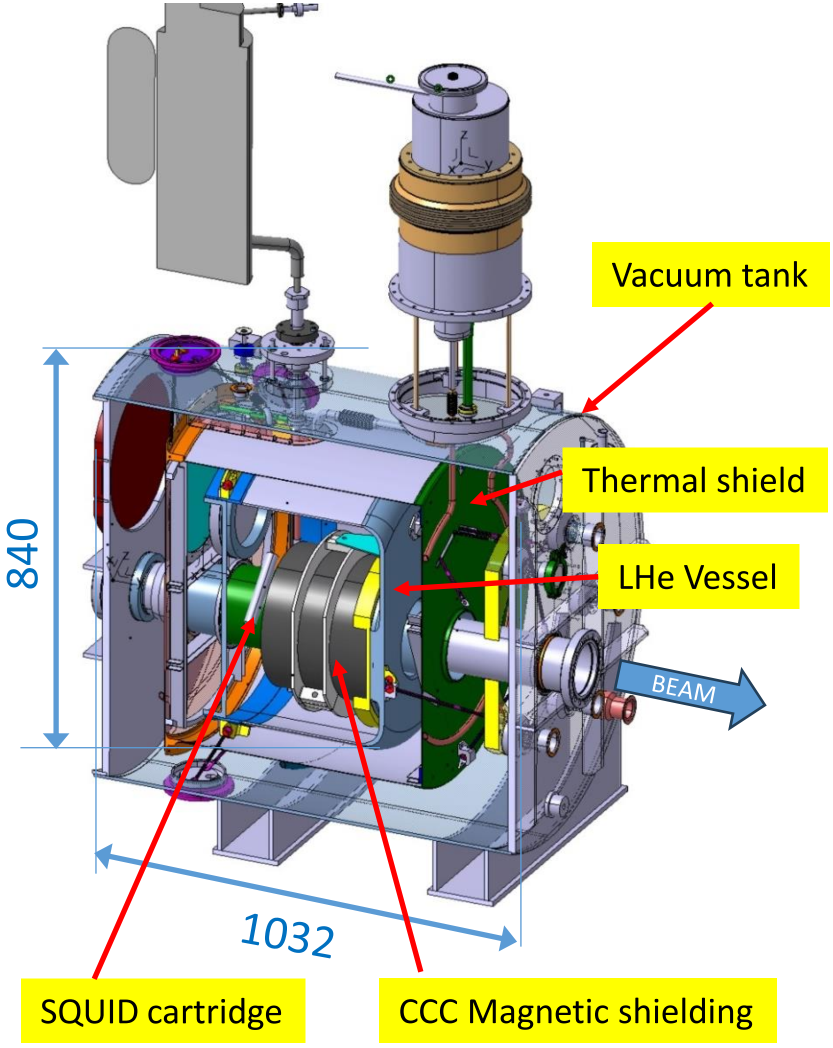




Flux Locked Loop electronics

THE CRYOSTAT

Hollow cryostat



Specifications

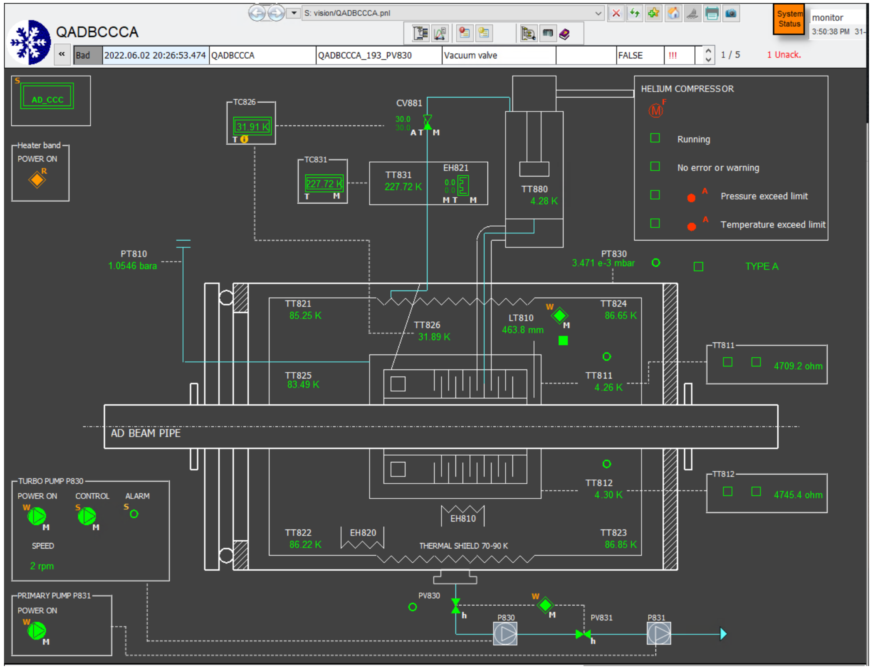
- New custom "hollow" cryostat to host the CCC
- Inner beam pipe is at room temperature
- Standalone operation
- "Zero boil off"
- Use a pulse tube refrigerator as reliquefier unit
- Damping vibration supports
- Non-magnetic parts

TE-CRG : engineering, simulations, commissioning & support

EN-MME : cryostat production, assembling, EN13445 standards

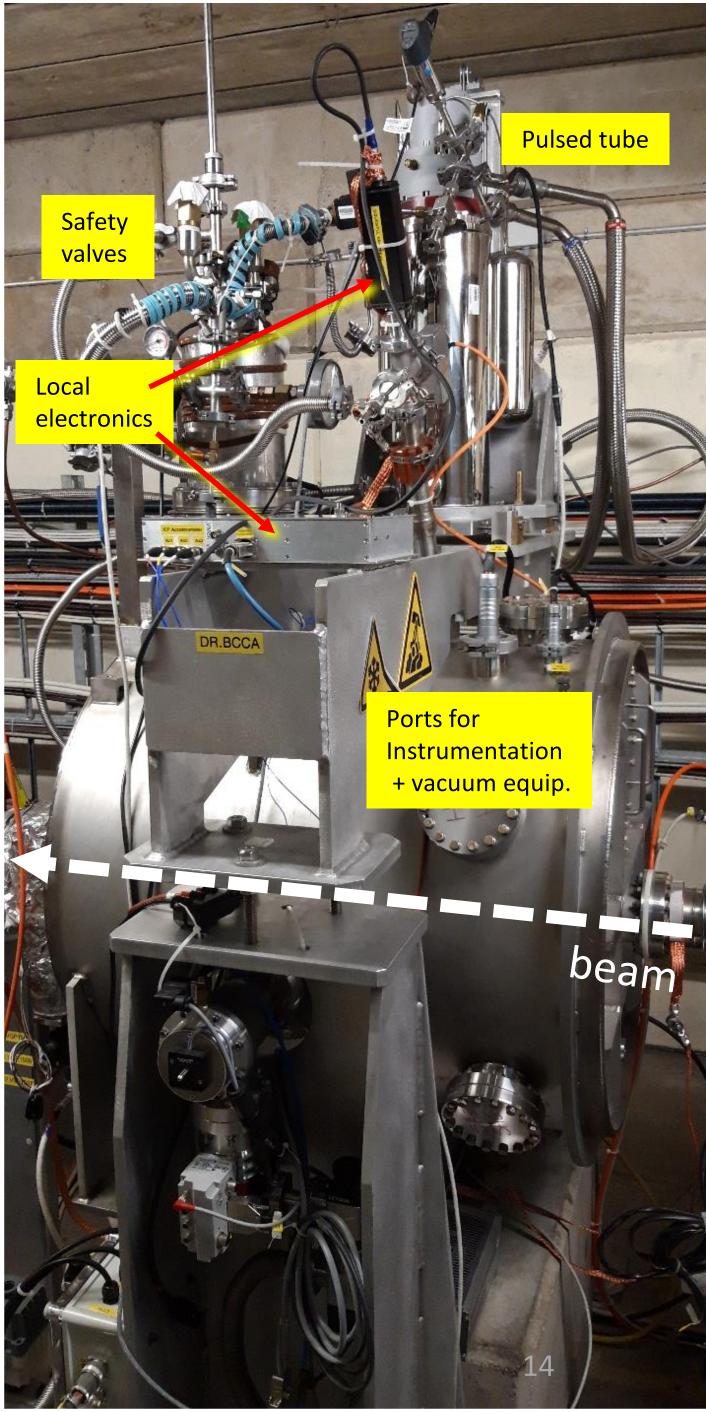
BE-ICS : PLC-based cryogenic instrumentation

Cryogenics PID

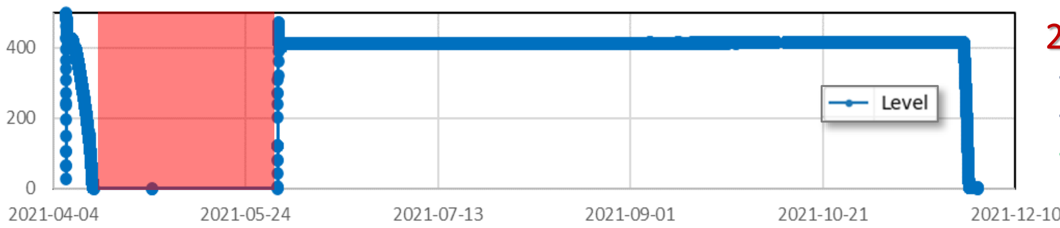


PLC-based system

- Temperature transducers
- Pressure : GHe and insulation vac.
- Level transducers
- Heater : inner resistors, outer bands
- Primary + turbo Pumps
- Valves, flow-metre

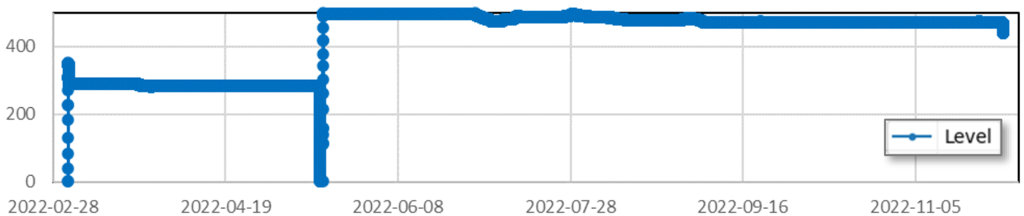


Restart after Long Shutdown 2



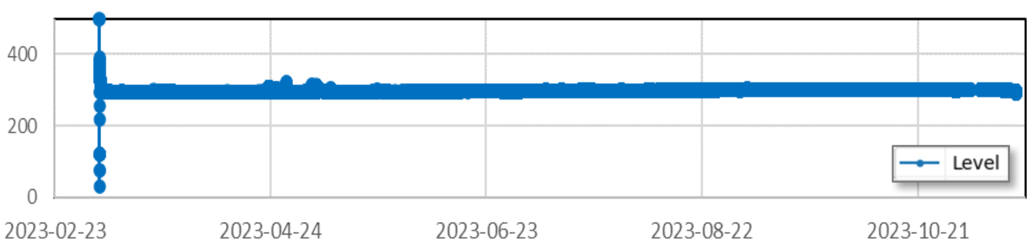
2021

- ~2 months unavailable : Ice blocking He flux
- Replaced metal SV from Cryomech by O-ring sealed
- standalone operation

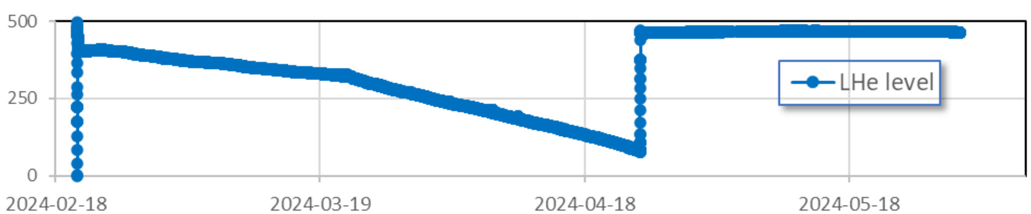


2022 : standalone operation

- Negative output signal saturated : Trapped flux ?
- TS1 : Warm up to release trapped flux in the SC trafo
- Shutdown: Cryostat opening to check connections



2023 : standalone operation

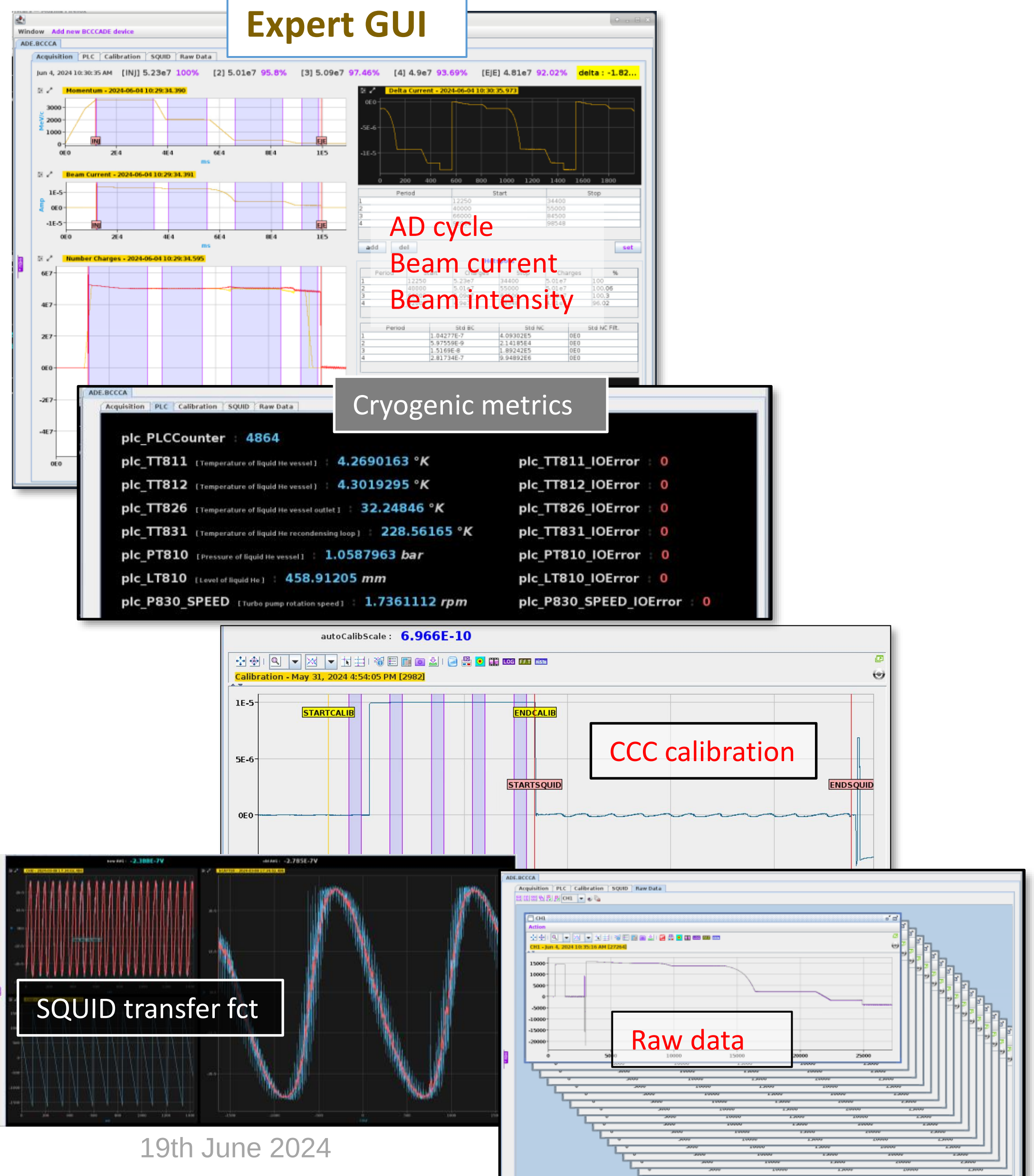


2024

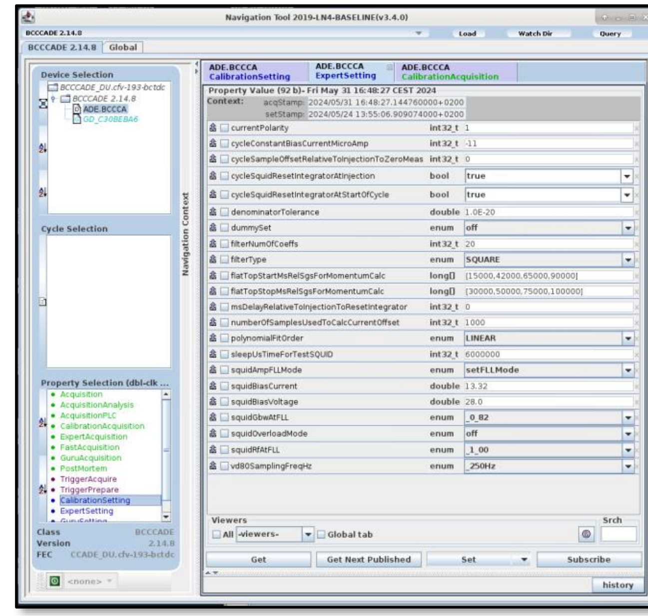
- 1 week after cool down: He level started to decrease
- He pressure in the compressor was too low
- 24/04 Access for He refill: compressor & cryostat
- standalone operation

OPERATION in 2024

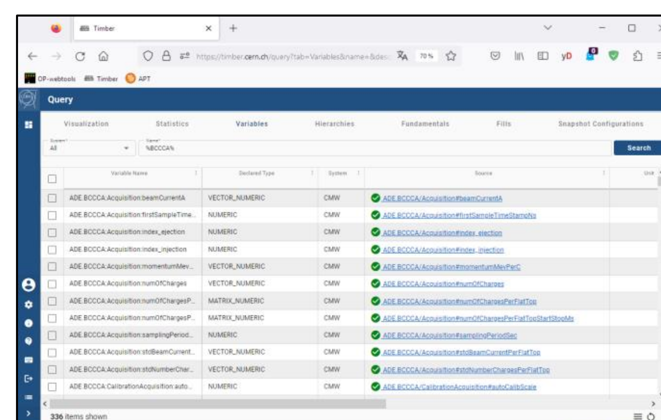
Apps. for controls and settings



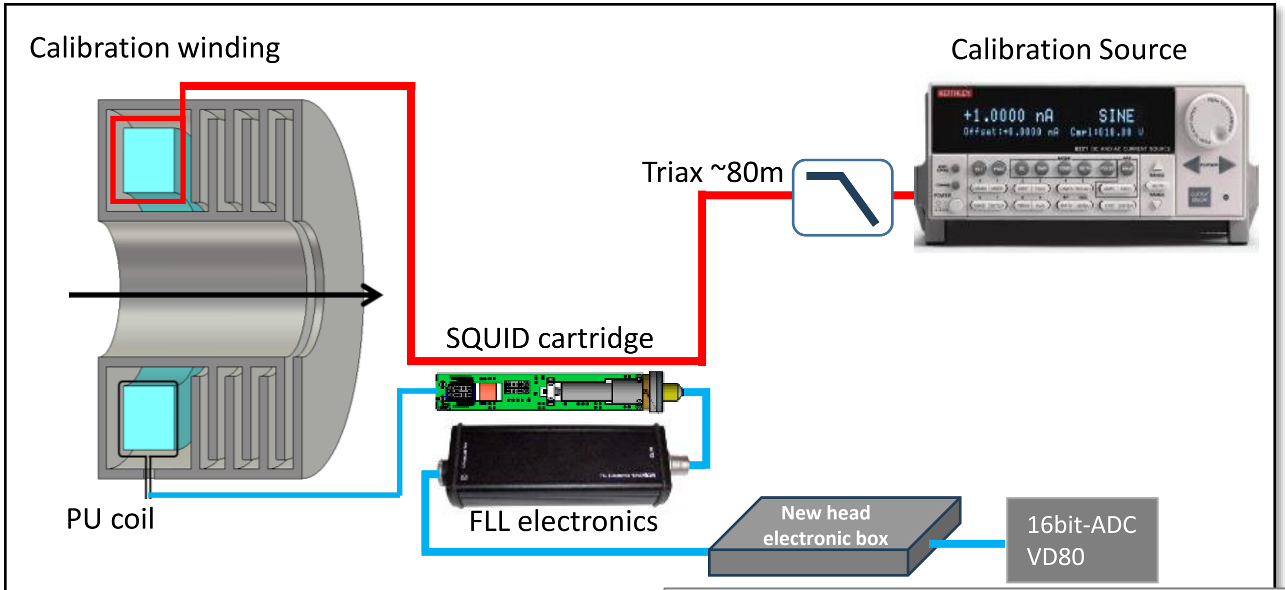
FESA class

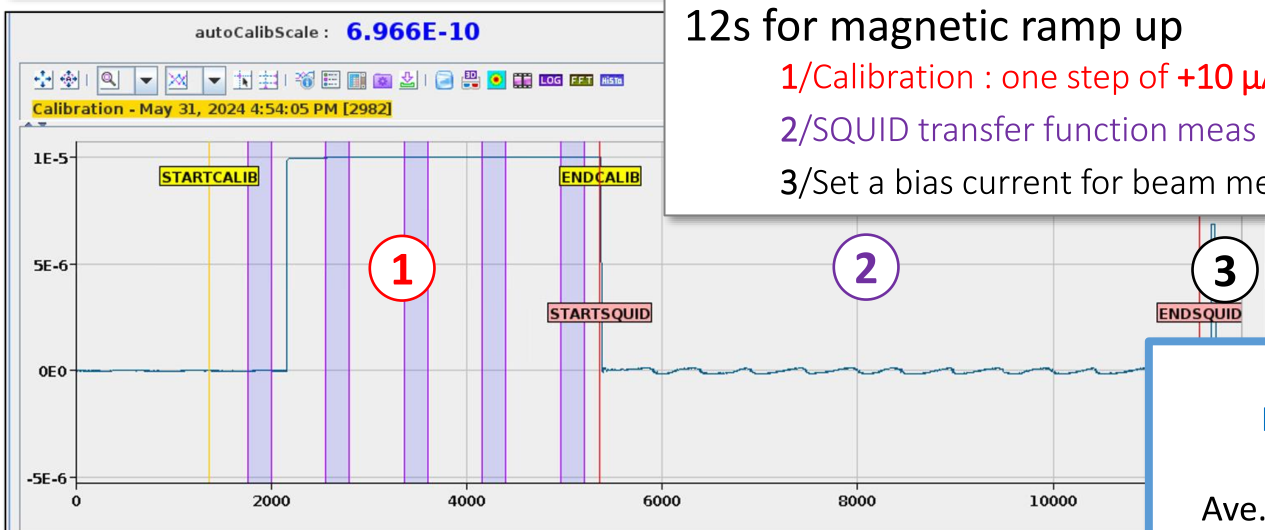


Logged in DB : Raw data, Beam, SQUID and cryostat var.



Calibration every AD cycle





12s for magnetic ramp up

1/Calibration : one step of **+10 µA for 3.2s**

2/SQUID transfer function meas

3/Set a bias current for beam meas.

Calibration stability

Figures of 2024 run: ~30k cycles

Ave. Scaling Factor: **0.6946 nA/ADC bin**

Std Dev: **0.455 per mille**

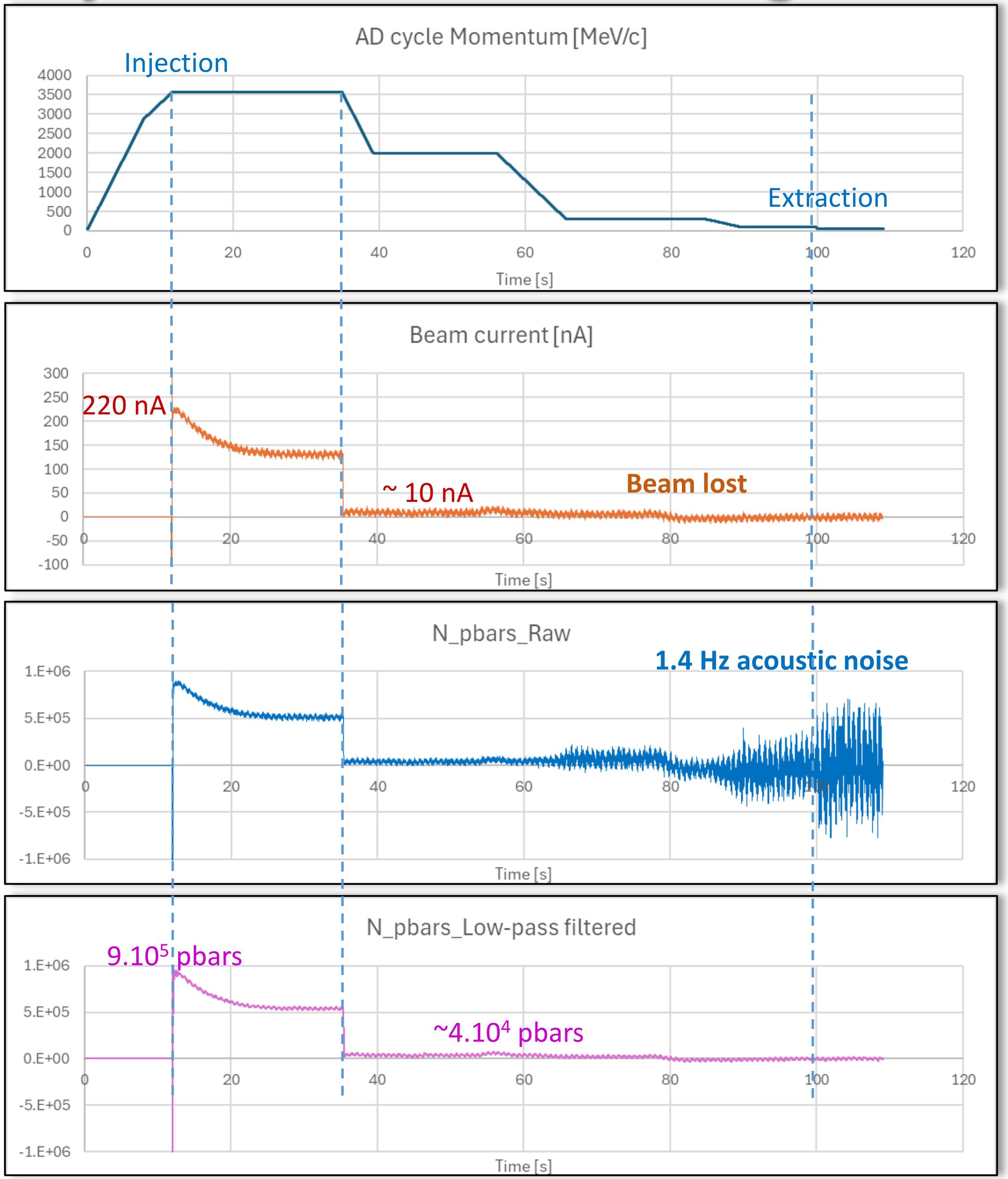
2024 Day1: commissioning with beam

March 8th, 14:41 UTC

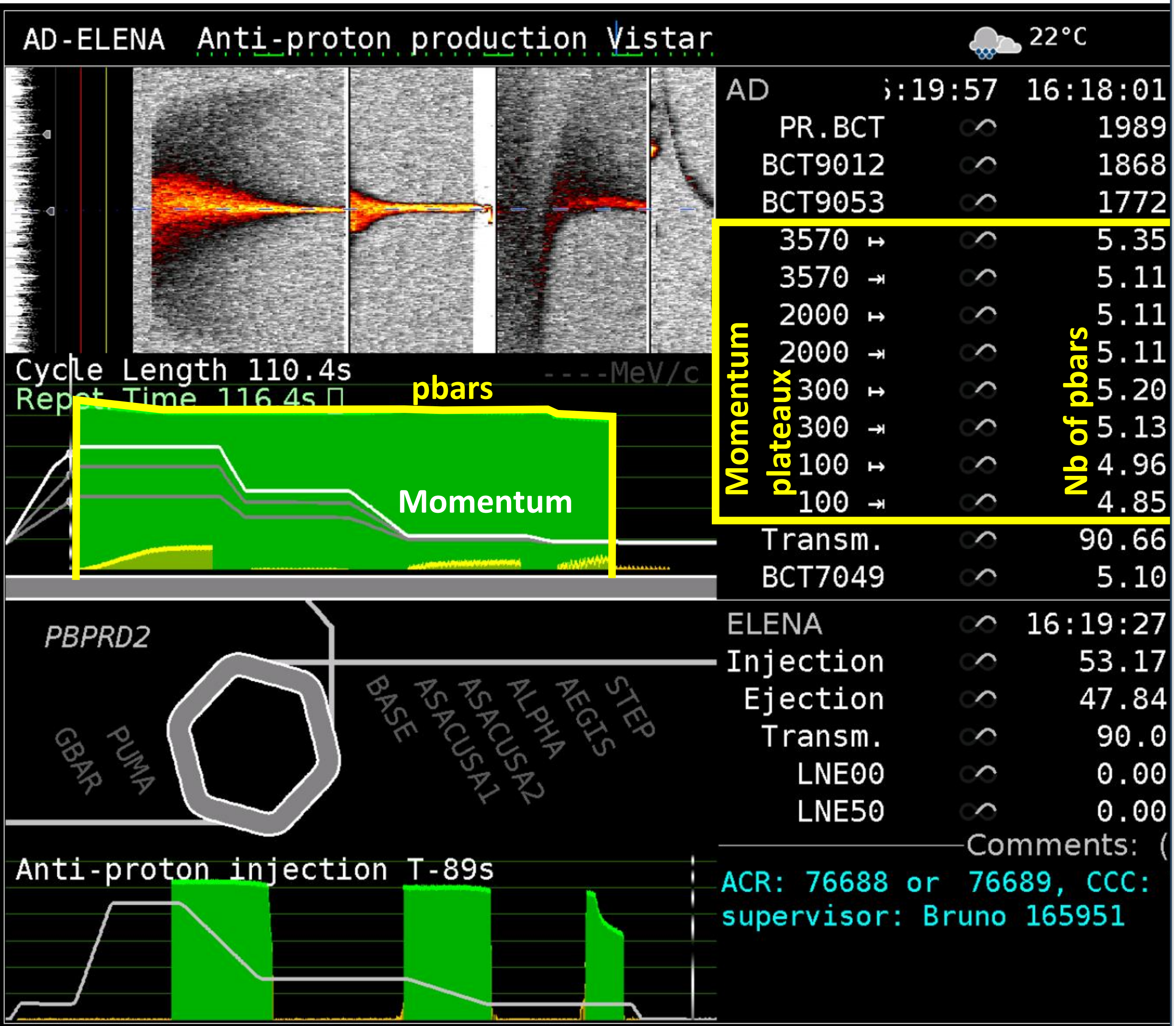
Raw data

Normalised Raw data

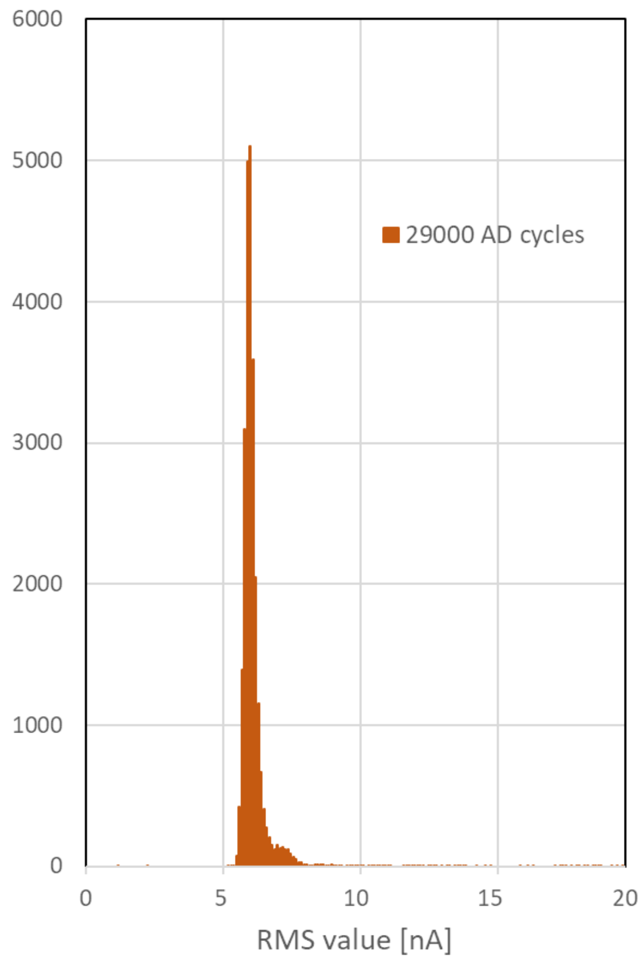
Normalised & filtered data



An operational monitor



Distribution of CCC RMS beam current along stochastic cooling. April-June 2024

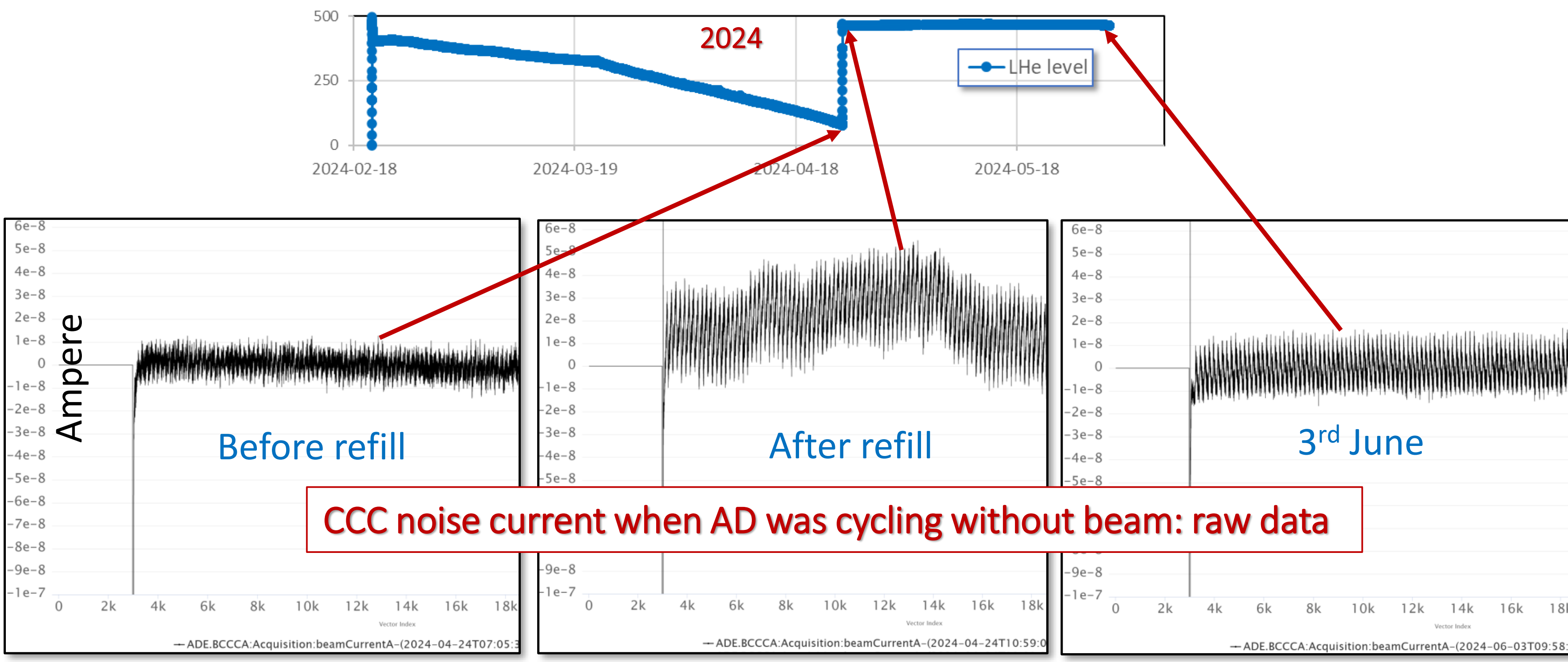


ISSUES & MAINTENANCE

There is room for improvement (1)

SQUID sensitivity to acoustic noise

- 1.4 Hz noise induced by pulsed tube on beam current signal
- Acoustic noise amplified by LHe level
- Numerical filtering techniques exist: but **OP wants raw data** !!



There is room for improvement (2)

Artefacts : slow increase of N_{part} at end of the deceleration ramps!!

- $eN_{pbars} = I_{beam} \cdot dt$ where ***dt* = *f*(synthetic Btrain)**
- Using *f(synthetic Btrain)* : it is implicitely assumed that the beam follows an ideal orbit
- Beam trajectory is affected by RF capture and transverse feedback loop.
- Artefacts after normalising with synthetic Btrain or LLRF signal.
- New trial by OP : normalize with **direct Btrain field** input
- Next step: **add frequency correction**

There is room for improvement (3)

Flux jump at injection

- Short bunched pbars at injection yield a flux rate of 400 $M\Phi_0/s$: FLL electronics can't follow !!
- Add a 1 kHz low pass filter at the SC transformer input: reduced to ~ 5 $M\Phi_0/s$
- Difficult to get rid of the perturbation if it is transported through image current.

Reduced SQUID dynamic range

- Already reported by Miguel in Sept. 2016, but it was not understood !
- Actions during shutdown 2022-23
  - ✓ cryostat opening to check cables connections,
  - ✓ EMI & grounding loops hunt,
  - ✓ Used embedded heater to free trapped flux
- **Both issues are coupled**: the cal. source shows the full dynamic range is immediately recovered when AD is cycling without beam
- **Mitigation action with beam** : apply a bias current to correct for it. Dynamic range 25μA

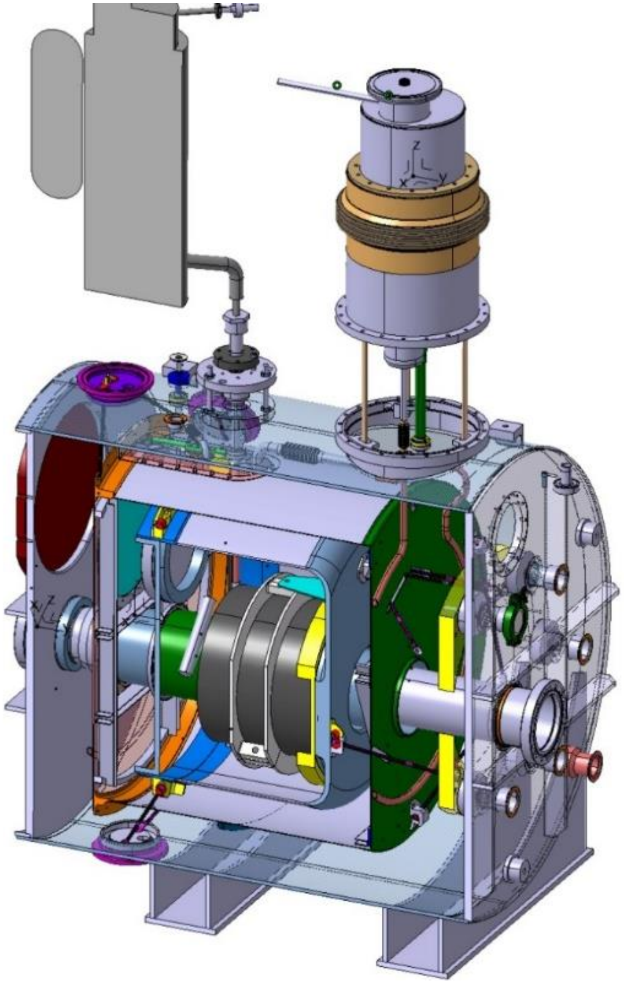
Maintenance and spare situation

Cryogenics

- Charcoal filter replacement after 20,000 h of operation
- Purge of He circuit
- **New 2024**: Refill the compressor unit with GHe.

Available spares

- FLL electronics with cryo-cables
- One SQUID
- One blank PCB
- Nb-Ti wires
- A set ceramic breaks
- Next YETS : build a spare amplifier box with FLL electronics



Conclusion

CCC : An operational current transformer for DC and bunched beams

- Absolute current monitor with ~ 6 nA resolution
- Cryostat fully operating in standalone mode since June 2021
- Automatic system control with FESA class and expert GUI
- “***A must***” for OP : Saves commissioning time and eases daily operation

Not a turn-key system

- Acoustic noise, Flux jump, SQUID dynamic range reduction, Artefact…
- Keep documentation up to date and ensure knowledge transfer
- 2025: last run AD before Long Shutdown 3

GSI-FSU-HI-CERN collaboration

- 2013: We started from scratch, and joined the bandwagon
- The CCC monitor is the result of **a great and fruitful collaboration**

CCC collaboration

CERN

SY-BI
- Jocelyn TAN
- Gunn Khatri
- Mark McLean
- Stephane BART PERDERSEN

TE-CRG
- Torsten KOETTIG
- Laetitia DUFAY-CHANAT
- Agostino VACCA

BE-ICS
- Marc QUILICHINI

GSI Darmstadt
- Thomas SIEBER
- Marcus SCHWICKERT
- Lorenzo CRESCIMBENI

FSU, Helmholtz-Institut Jena
- Thomas STÖHLKER
- Frank SCHMIDL
- Volker TYMPEL

IPHT Leibniz
- Ronny STOLZ
- Vyacheslav ZAKOSARENKO

Technische Hochschule Mittelhessen
- Andreas PENIRSCHKE
- Stephan KLAPROTH

Past PhD students

Miguel FERNANDES
Febin KURIAN
Rene GEITNER
Max Stapelfeld
Jessica GOLM
David HAIDER
Nicolas MARSIC

Magnicon

Henry J. BARTHELMESS

Thank you for your attention

SPARE SLIDES

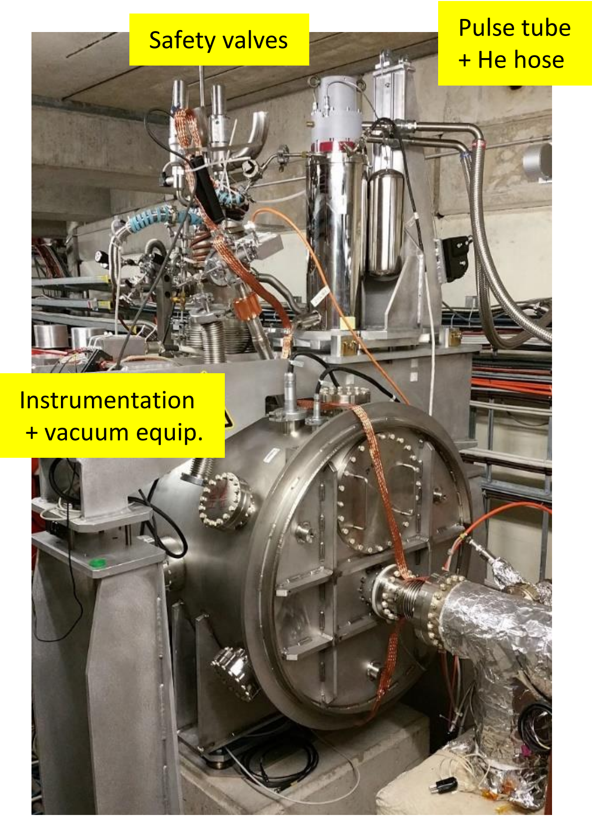
Teething issues

Assembling issues

- The Feed through was larger than the space provided
- Damaged instrumentation during assembly of MLI and Thermal Shield
- Gap required to cut electrical path through MLI was forgotten
- Helium Vessel SQUID Feed through Length Clash

First cooldown : LHe all gone after 3 days !

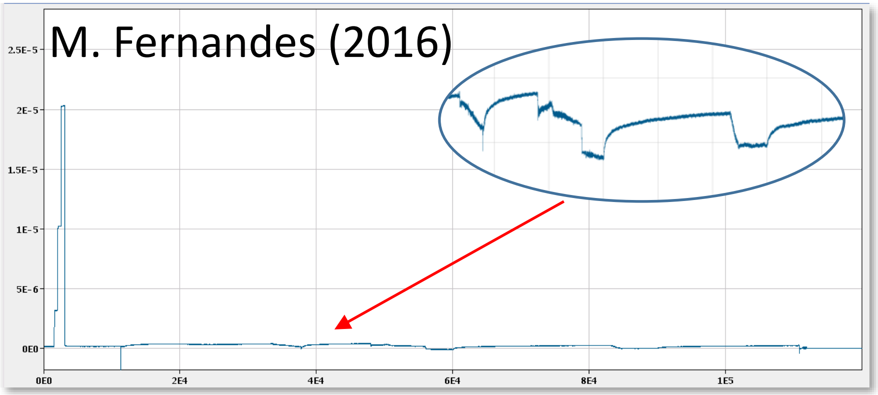
- Broken valve : N_2 ice inside brought extra heat load
- Heat load measurement shows 16 W on thermal shield
- MLI : 25 layers insufficient, missing insulation in extraction tower piping
- Strain gauge cabling was not realized with Manganin wires
- Too much strain gauge instrumentation
- Possible oil contamination on reliquefier unit
- Too large cross section of Ti rod supports
- Re-open the cryostat...

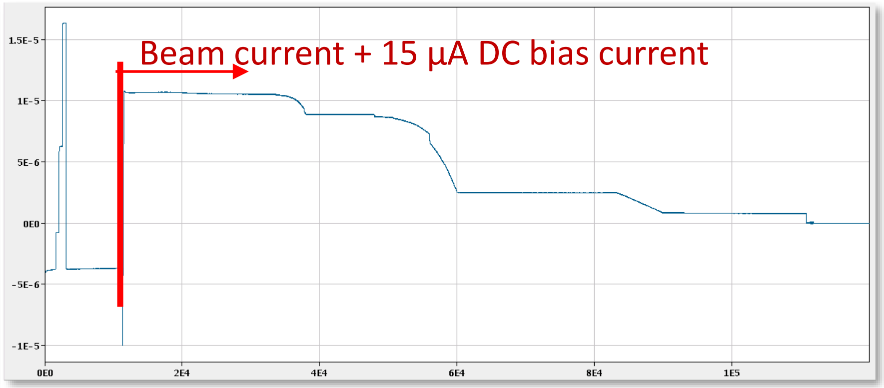


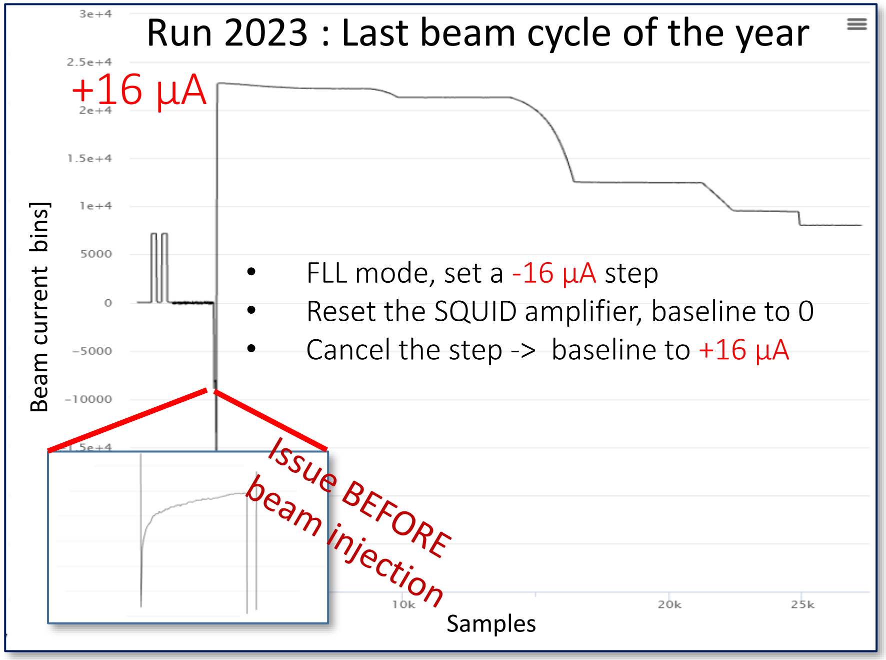
Before LS2

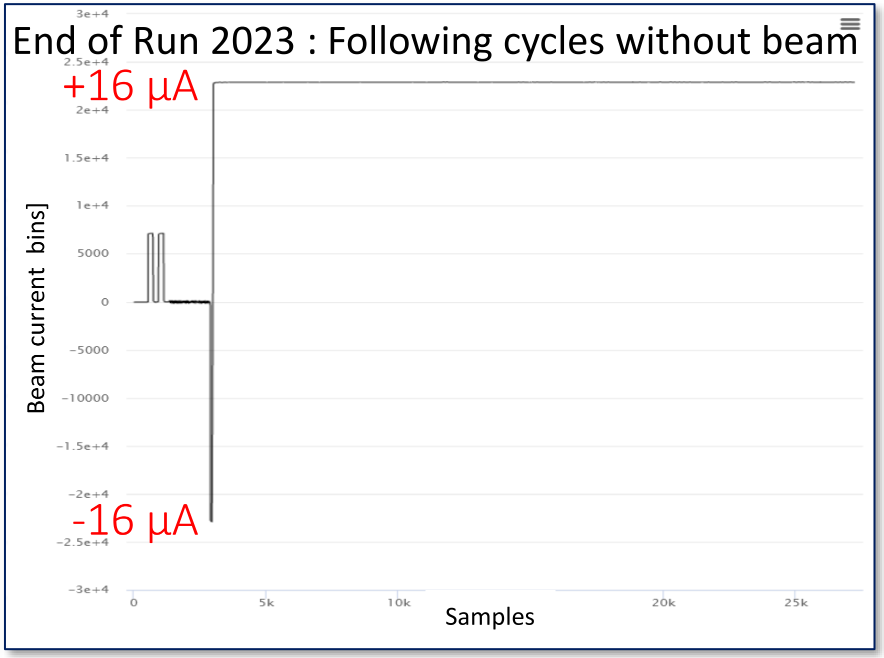
- Refill LHe every 2.5 months

There is room for improvement (3)



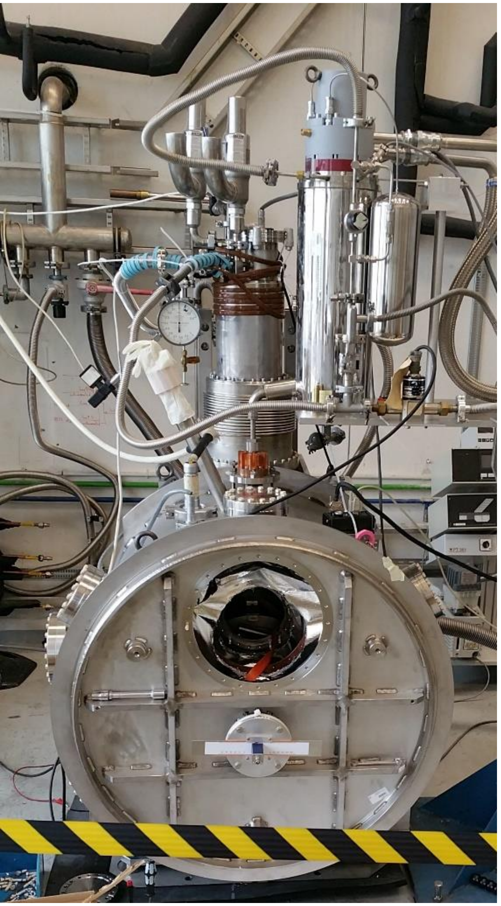




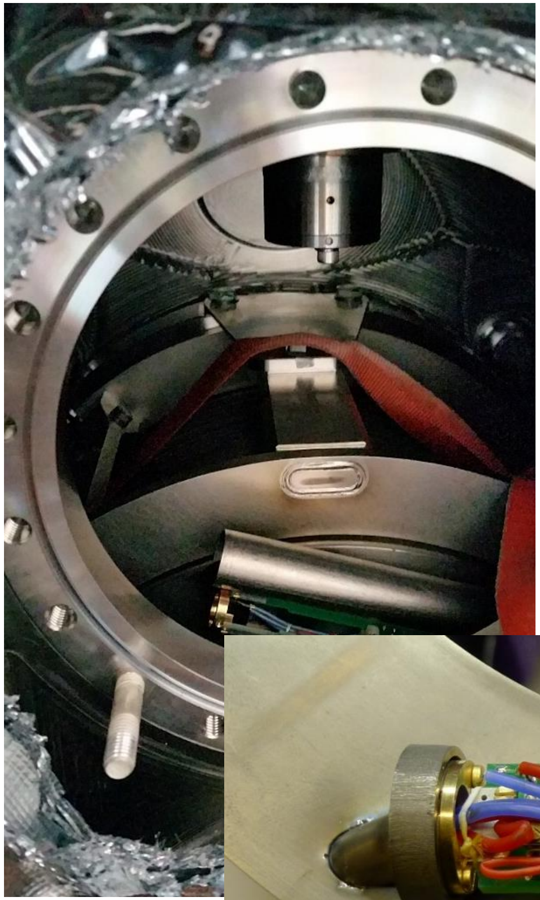


SQUID issues during cold tests (2)

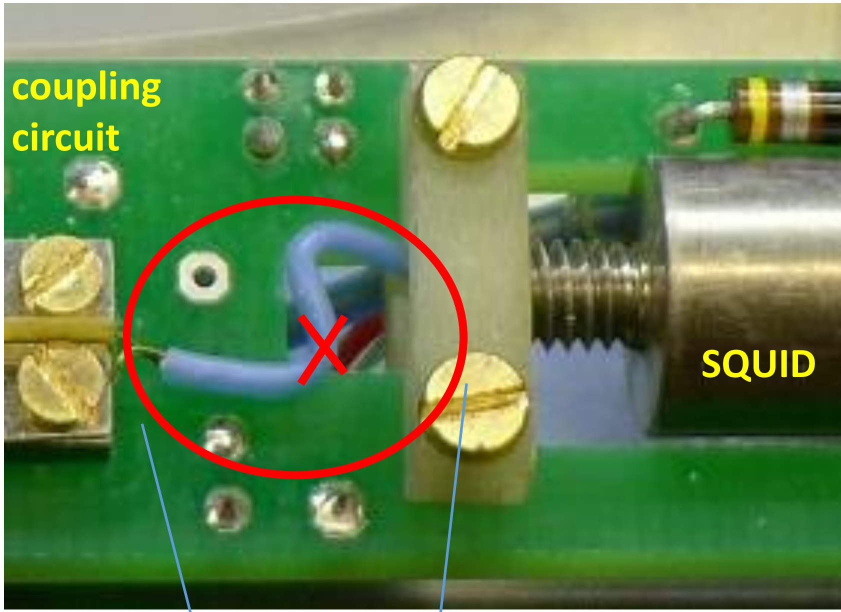
Open the cryostat, MLI

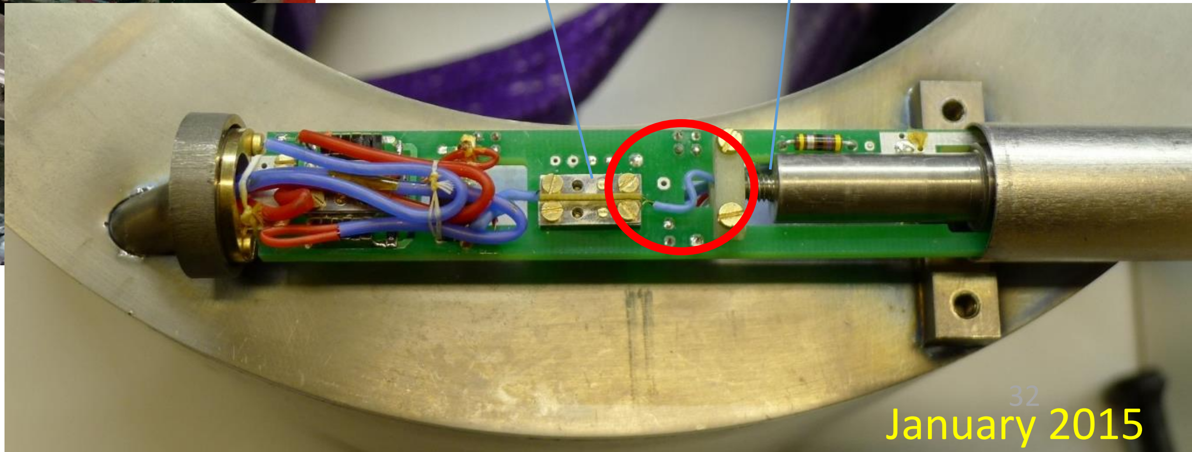


Remove the SQUID cartridge via access hatches



- Fatigue-like damage on silicon insulation tubing
- Niobium wire broken

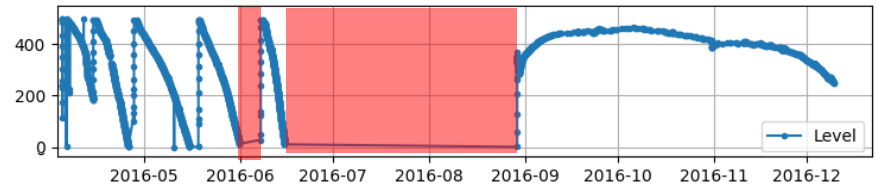




Mitigation actions

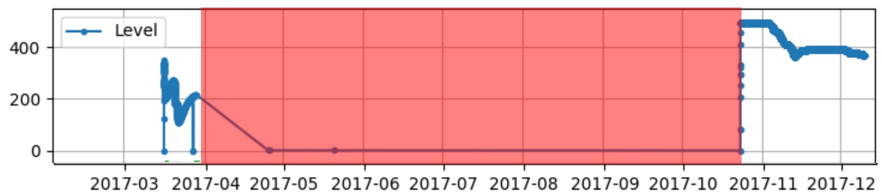
- Redundant NbTi wires added to Nb ones
- Special insulation tubing used by cryolab
- Replace the SQUID by its spare
- Visual inspection of other wires
- Cold test before installation
- Next monitor
  - new PCB design
  - implement 2 SQUIDs instead of one
  - Replace Nb wires by NbTi.

A long way to “standalone” mode



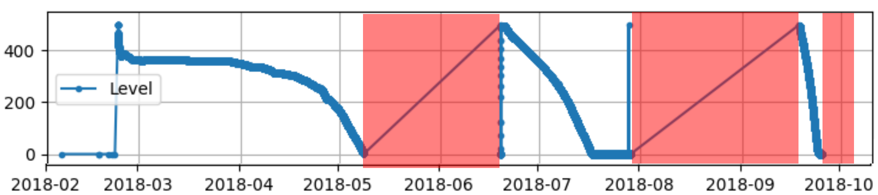
2016

- Started actively pumping the insulation vacuum
- Air contamination at end of year



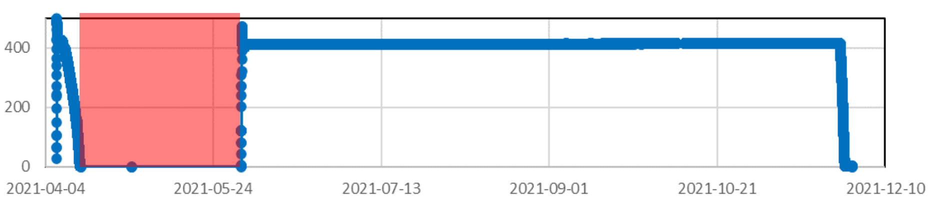
2017

- Turbo pump off by power glitch : compromised vacum
- Still possible to work with gas



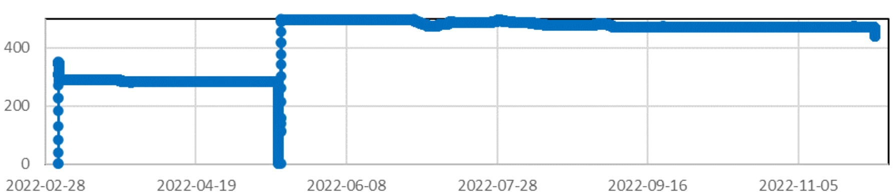
2018

- New controls for vacuum pumps and vacuum valves
- New remotely controlled gas flow-valve was installed
- ~2 months unavailable



2021

- ~2 months unavailable : Ice blocking He flux
- Replaced original safety valves from Cryomech by O-ring sealed
- standalone operation



2022 : standalone operation

- TS1 : Warm up to release trapped flux in the SC trafo
- Cryostat opening to check heater and cables

Beam current acquisition