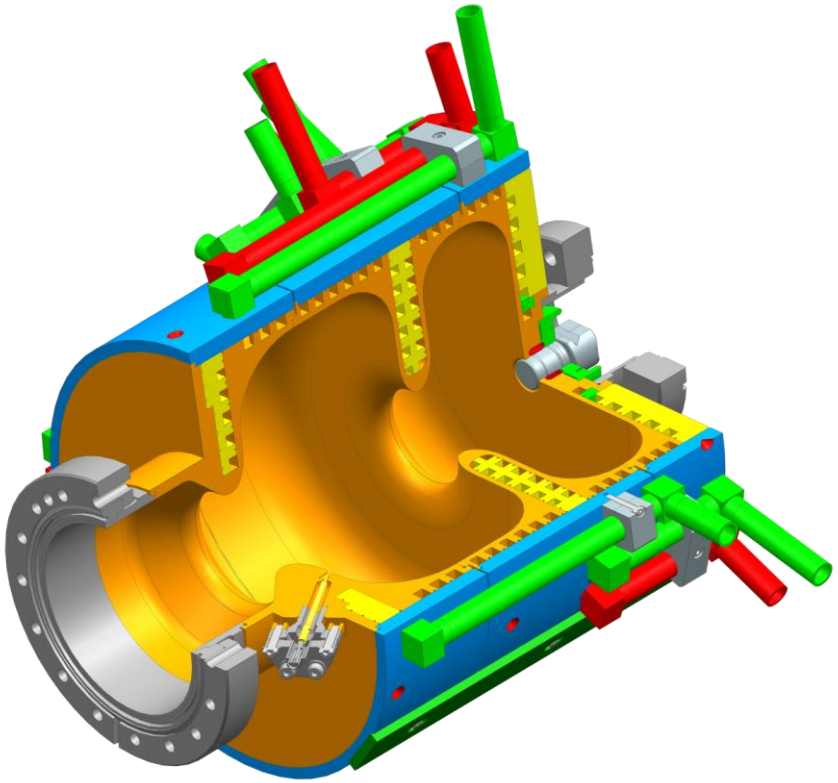
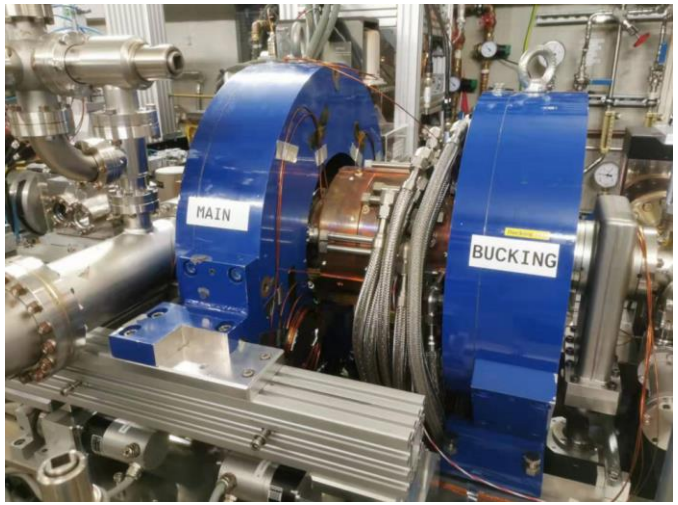
PITZ Experience with Gun5.1

Gun5 measurements and Status of L-Band conditioning facility



Mikhail Krasilnikov for the PITZ team
XFEL MAC, 08.11.2023



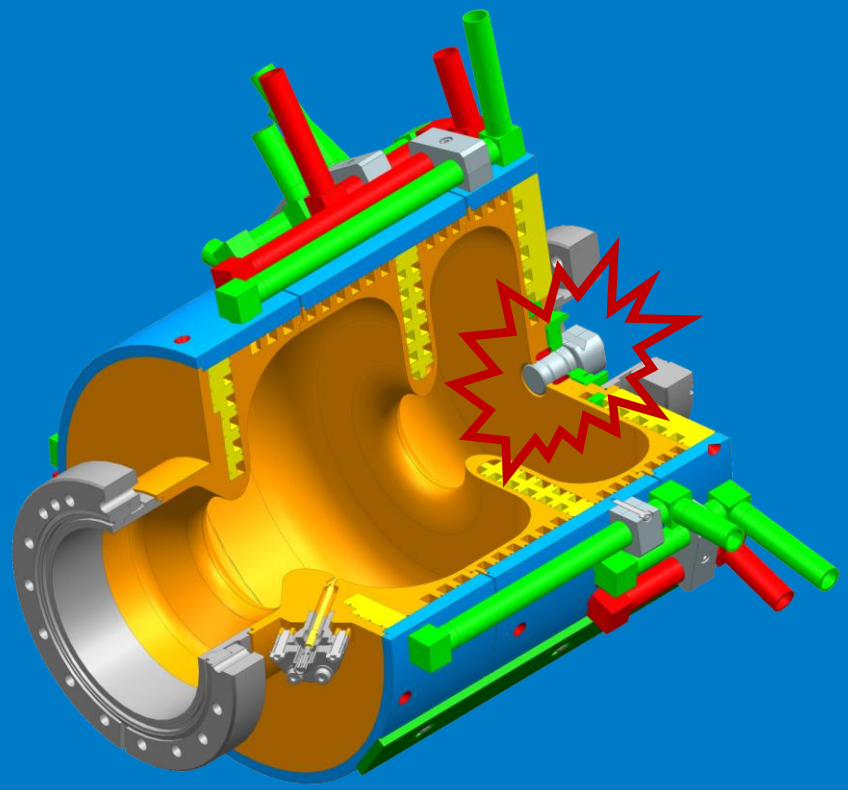
HELMHOLTZ

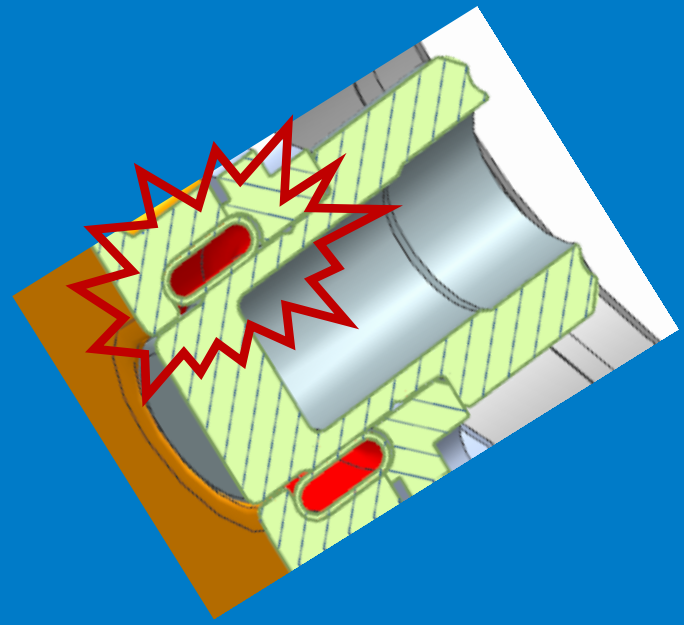
PITZ Photo Injector Test Facility Zeuthen

European XFEL

DESY.

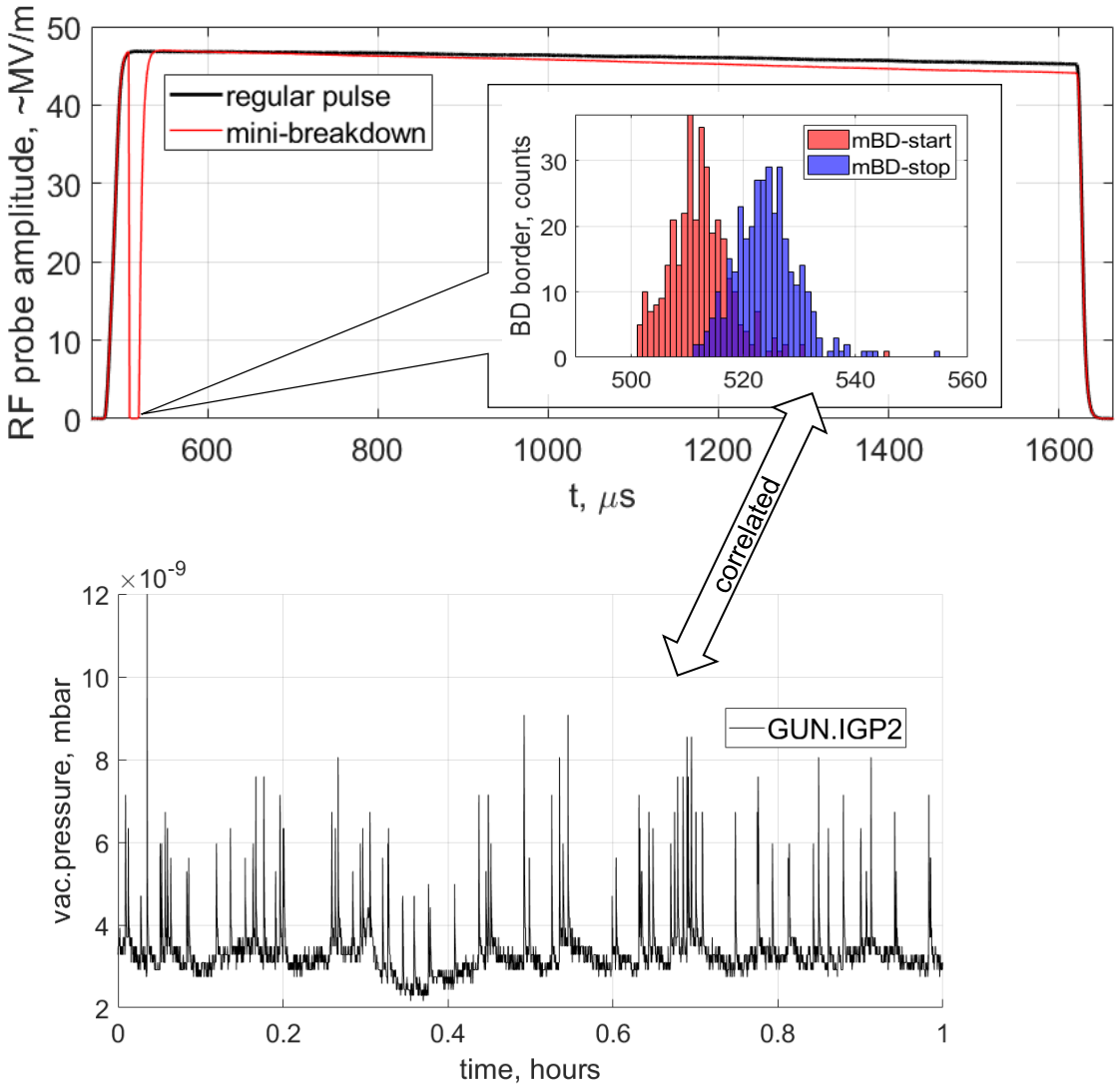
Gun5.1 at PITZ: Problems



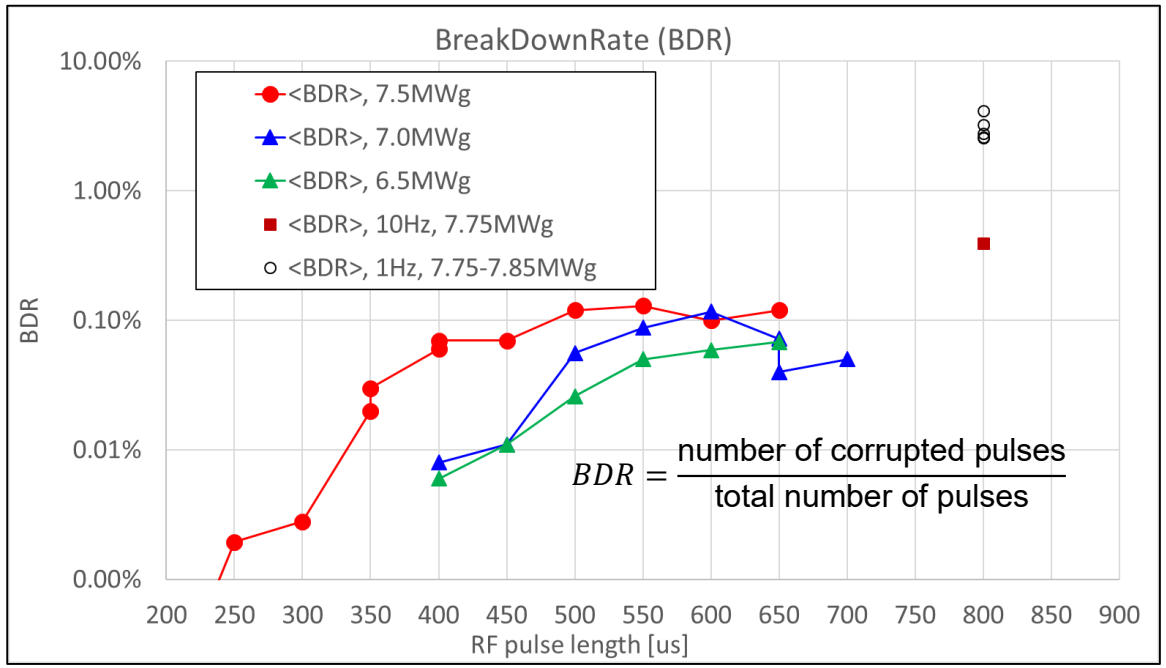


Gun5.1 at PITZ: Problems (1)

Mini-breakdown (mBD) events



- Short (~10μs) interruption in RF pulse (cavity pickup and reflected power signals) + recovery within the same pulse (with a typical 10..15μs cavity filling time)
- Majority of mBDs - in the first 30μs of the pulse, also (seldom) at middle to end of pulse, very seldom – multiple drops
- Independent on fill/rise time (2..50μs) of RF pulse (>300μs)
- Fast diode → typical "switching time" of an interruption <100ns
- Always accompanied by a vacuum mini-spike
- Also seen by IL sensors (VWV PMT + e-detector at the RF window, all under IL threshold)
- Source location is not clear (tests with permanent magnets ~0.4T around the coaxial coupler close to the gun cavity → no dependence observed)



Gun5.1 at PITZ: Problems (1)

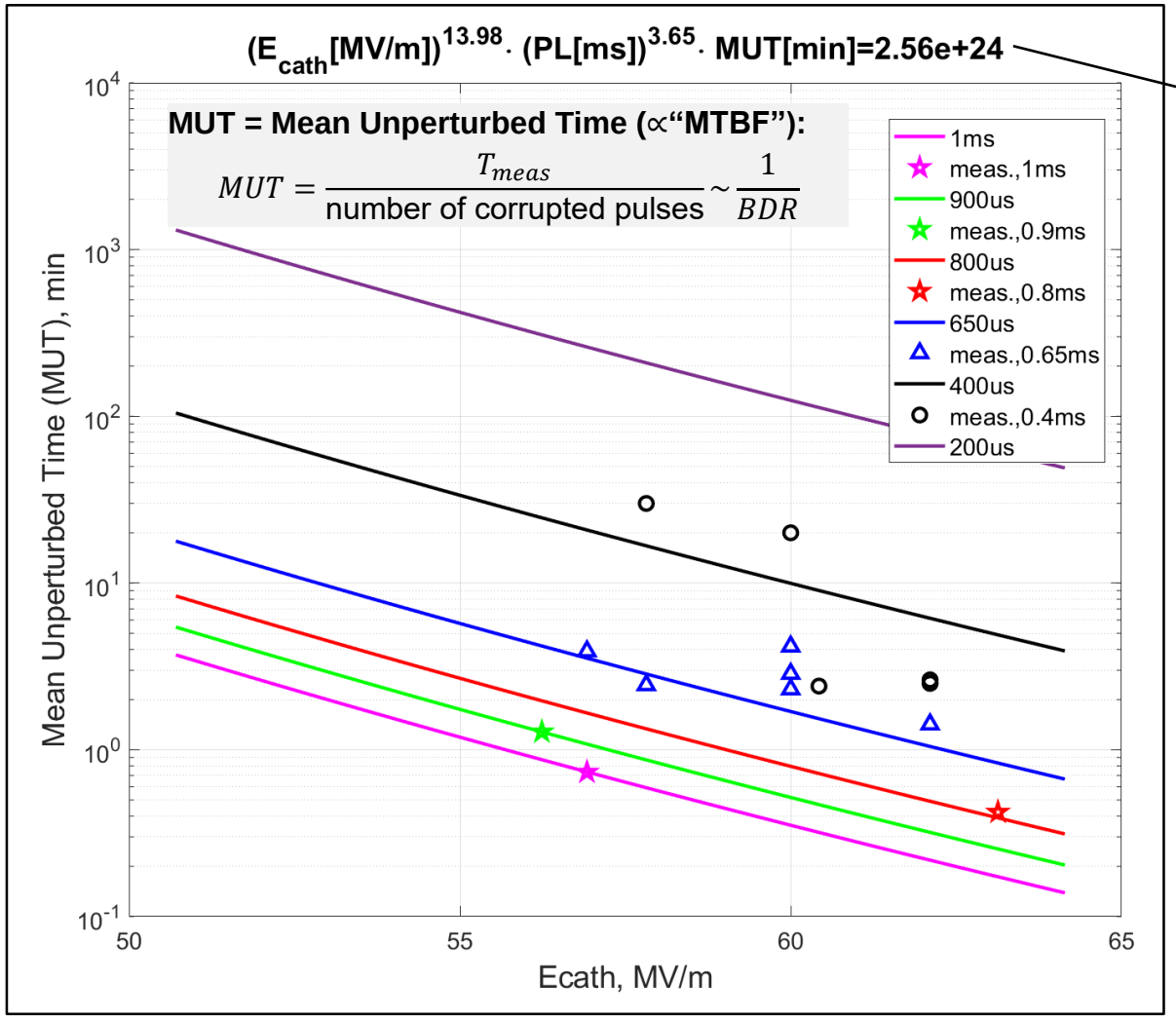
Mini-breakdown (mBD) events systematic studies

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **12**, 102001 (2009)

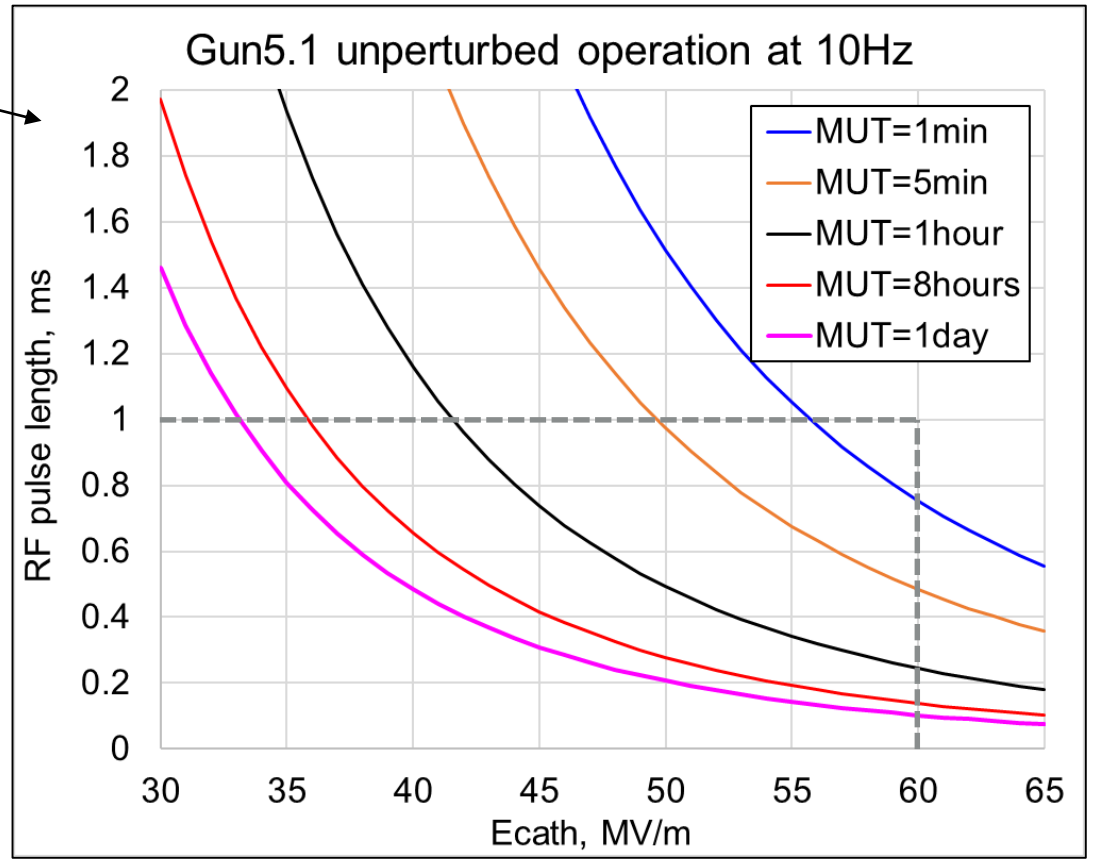
$$\frac{E_0^{30}\cdot\tau^5}{\mathrm{BDR}} = \text{const},$$

New local field quantity describing the high gradient limit of accelerating structures

A. Grudiev, S. Calatroni, and W. Wuensch
CERN, CH-1211 Geneva-23, Switzerland
(Received 28 January 2009; published 26 October 2009)



NB: E_{cath} → beam momentum based gun power calibration

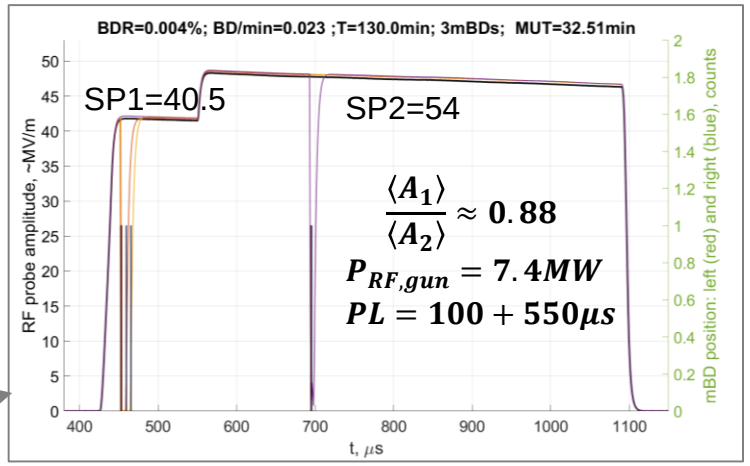


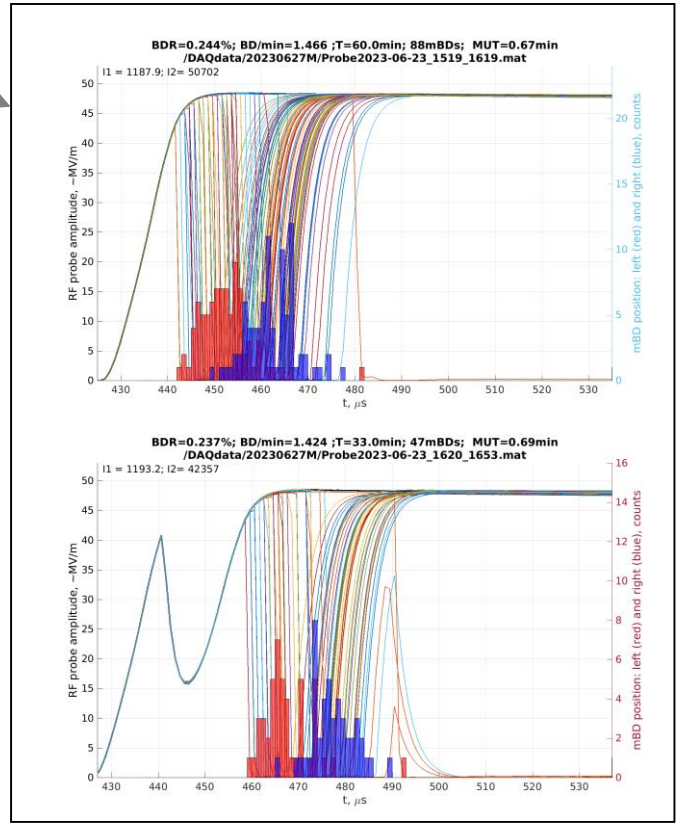
Mini-breakdown does not stop the operation, but with long RF pulses the gun RF feedback can lead to instability and even gun interlock (trip)!

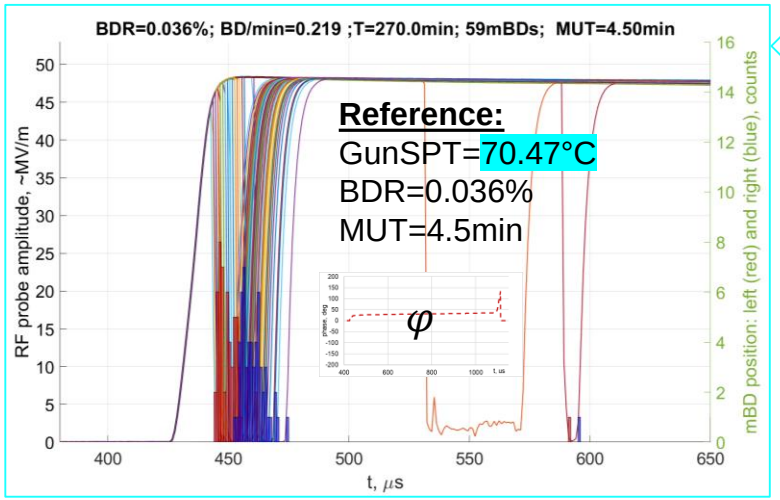
Gun5.1 at PITZ: Problems (1)

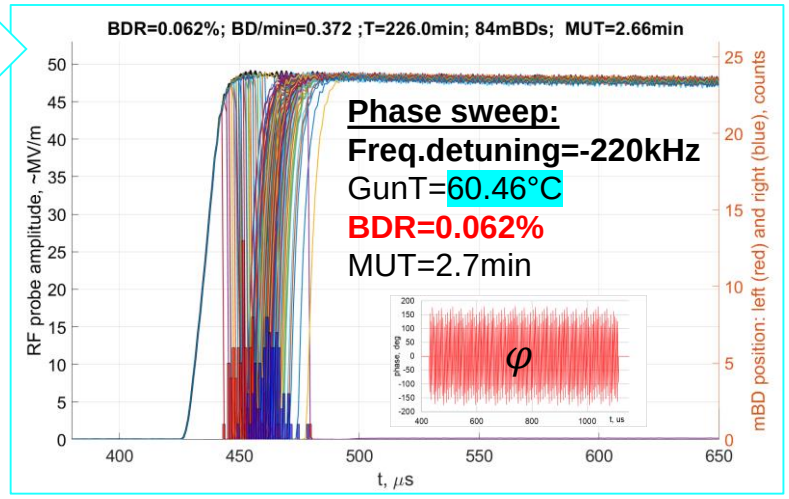
Mini-breakdown rate (mBDR) : summary + some specific studies

- Depends on peak power, RF pulse length, repetition rate mBDR(1Hz)>mBDR(10Hz)
- Does not seem to be significantly improved by conditioning
- Slightly reduced using "multi-flattop" option → by lowering the 1st 100us pulse amplitude still in the first 30μs, but applied modulation in the beginning of the pulse -> mBD location shifted
- DC voltage (±25V) applied to the RF pickup → mBDR remains the same
- No dependence on gun resonance (gun temperature →reflection) observed
- increases with lower gun water temperature (cavity detuning by a phase sweep, e.g., -10°C→cavity detuning by ~-220kHz➔ x2 higher mBDR)



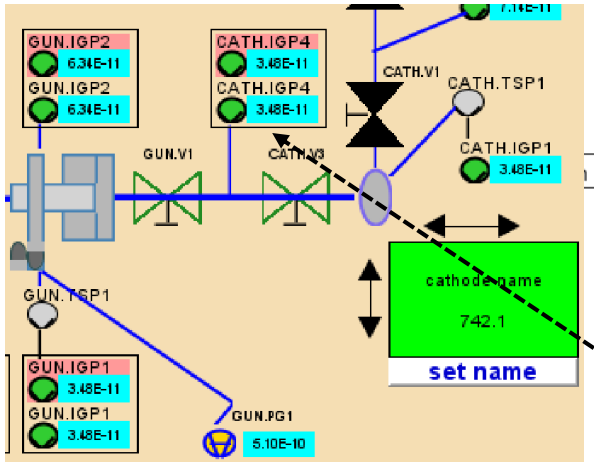


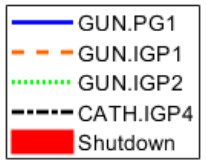


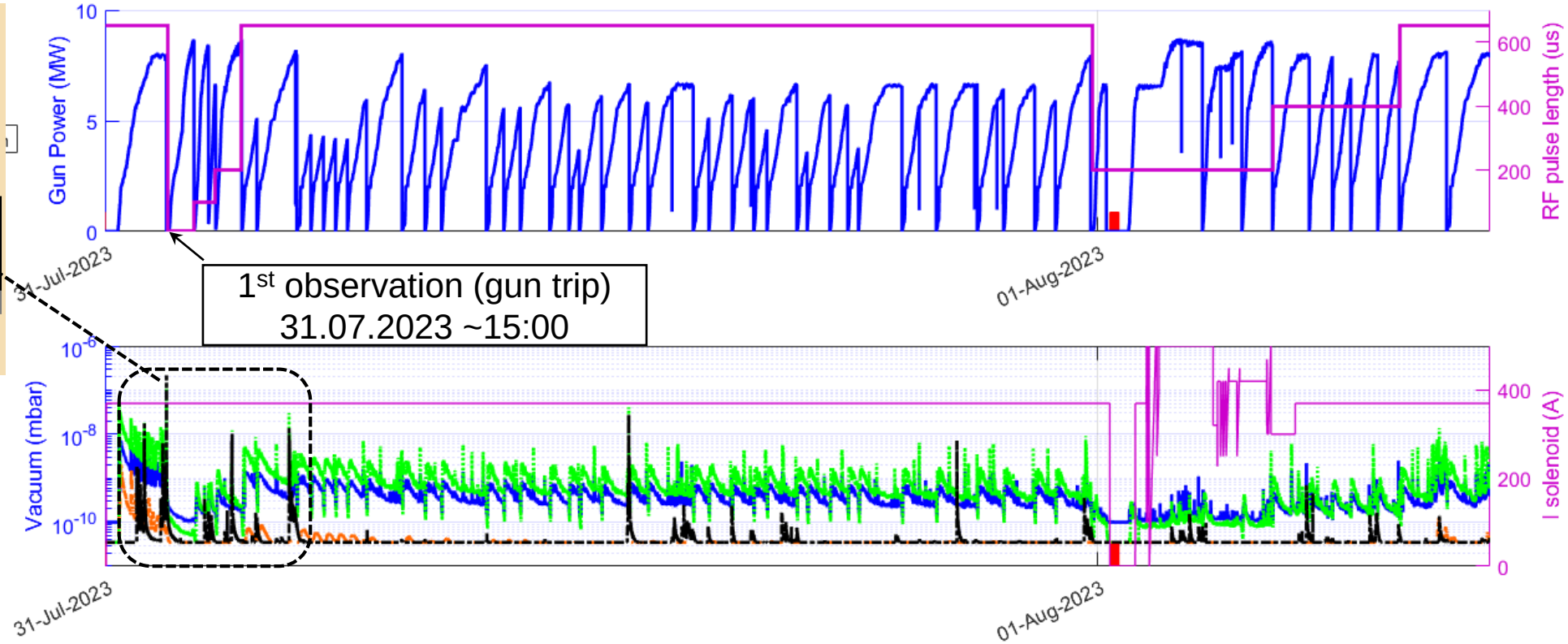


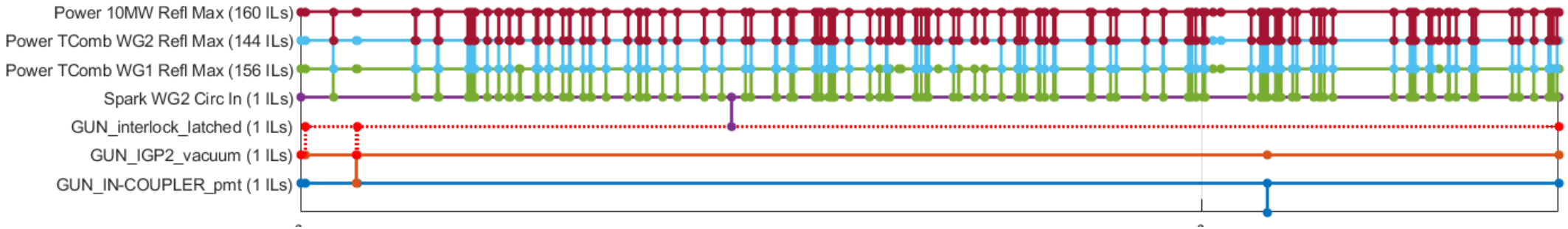
Gun5.1 at PITZ: Problems (2)

Cathode contact spring problem starting 31.07.2023





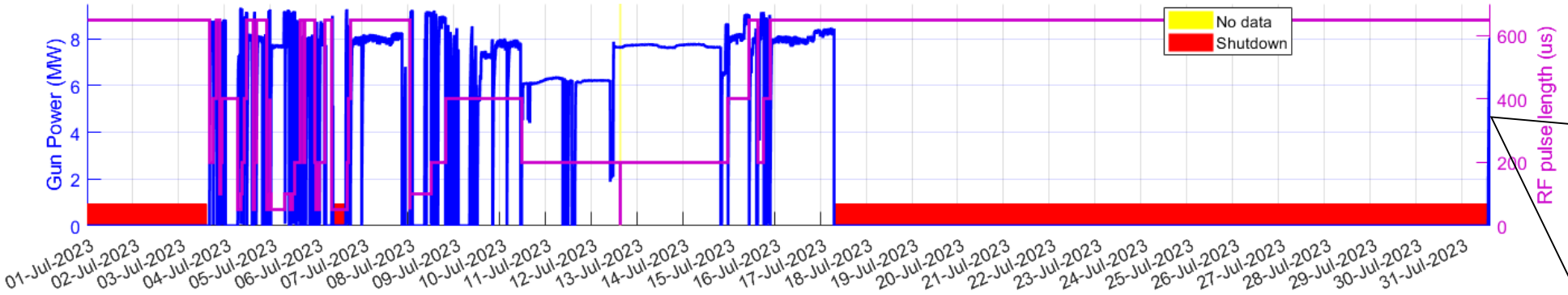


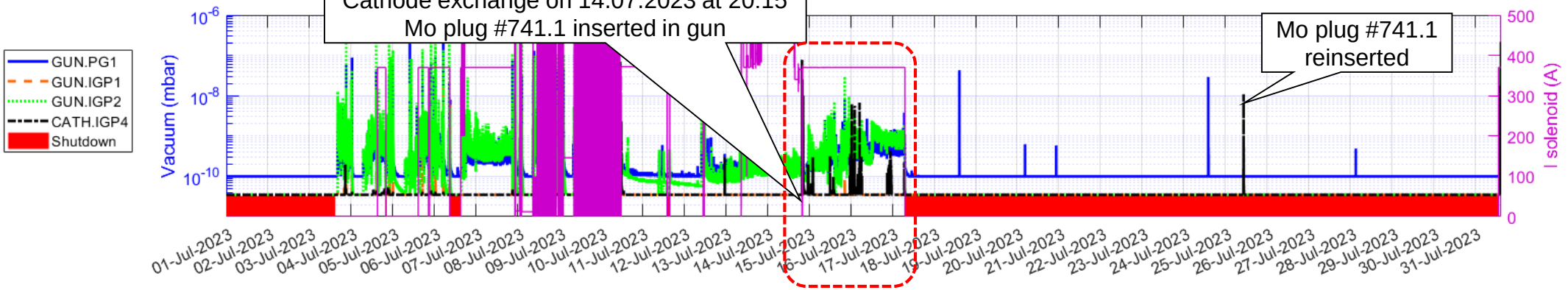


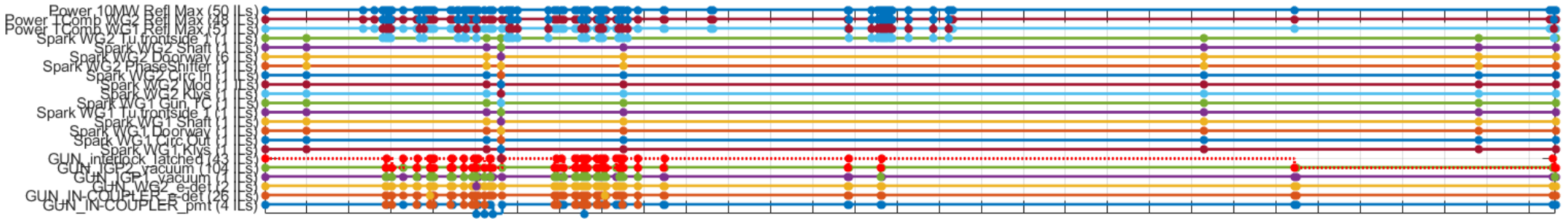
Gun5.1 at PITZ: Problems (2)

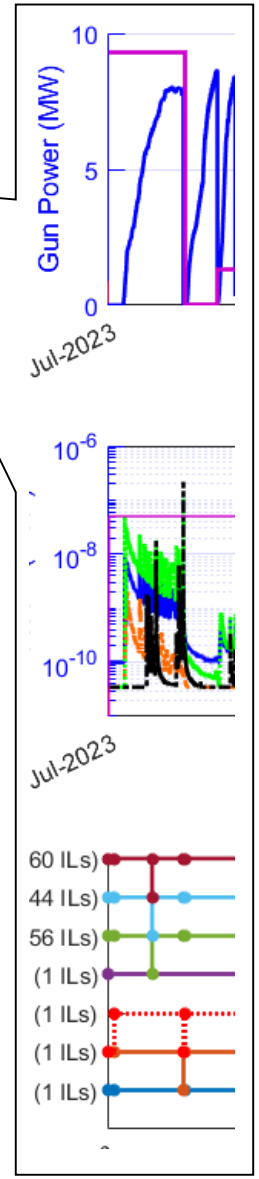
Pre-history 01.07-31.07.2023

31.07.2023



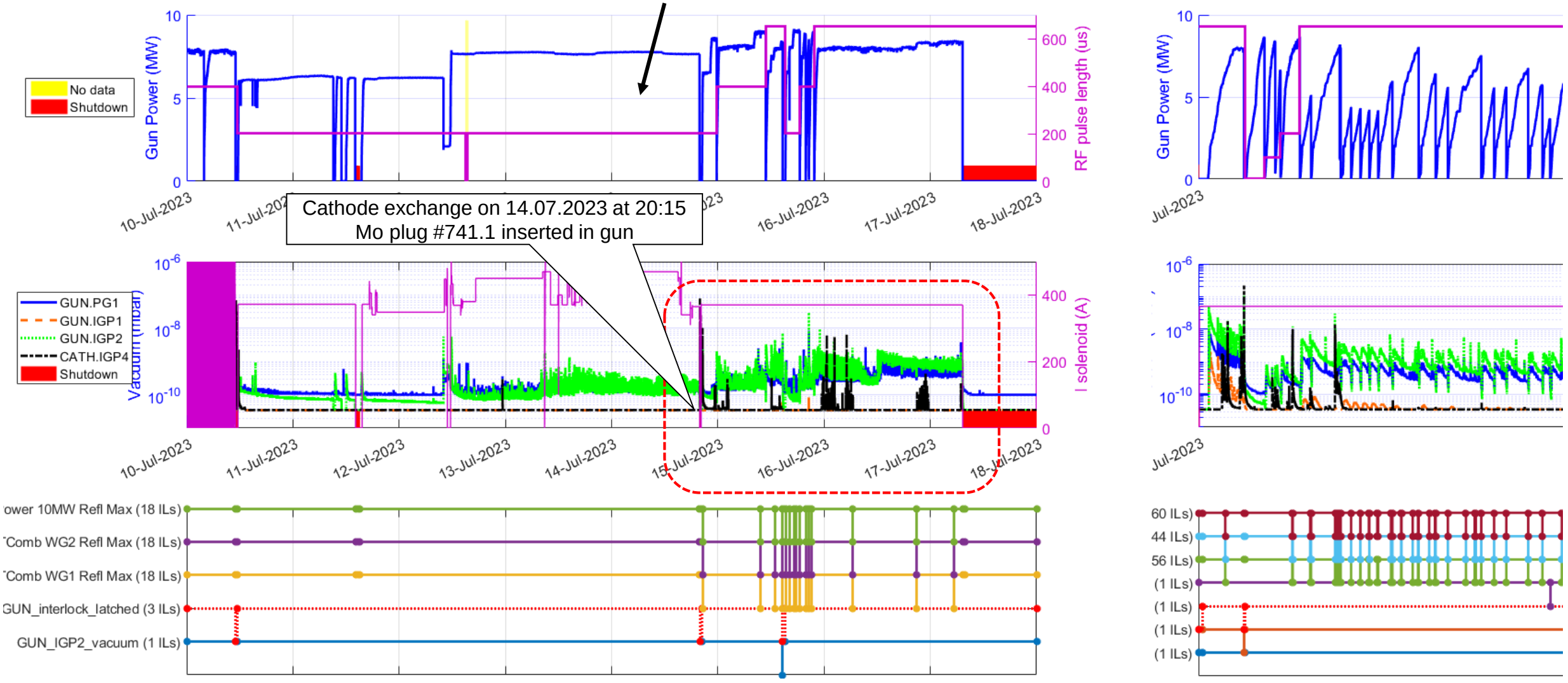






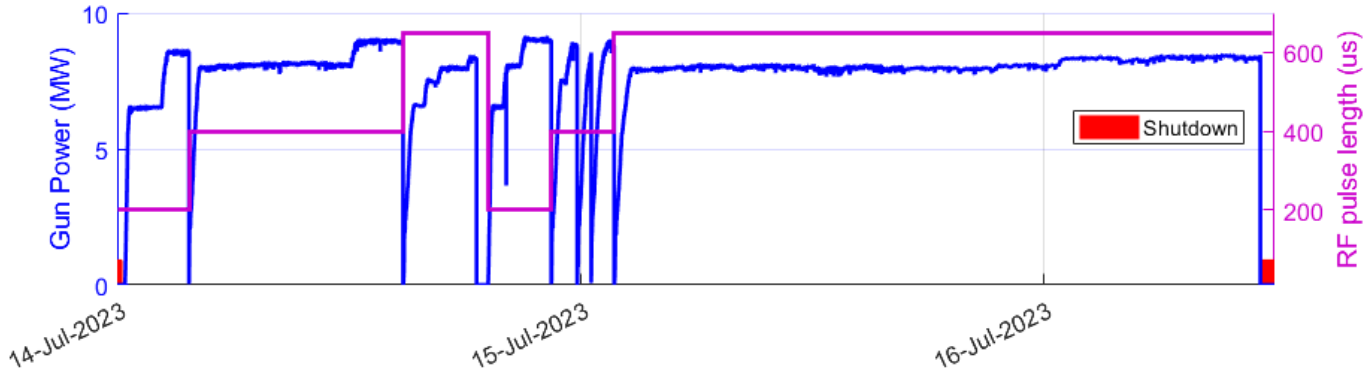
Gun5.1 at PITZ: Problems (2)

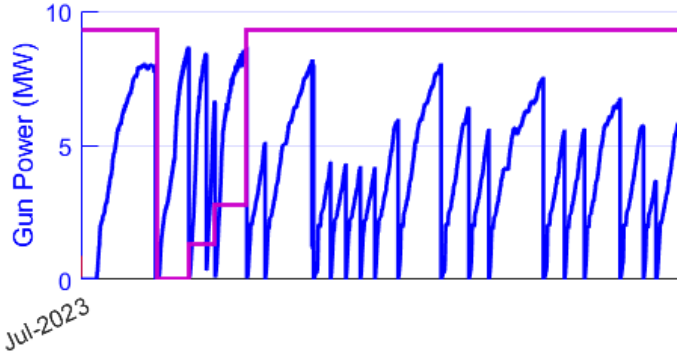
Pre-history 01.07-31.07.2023, zoomed – week 28

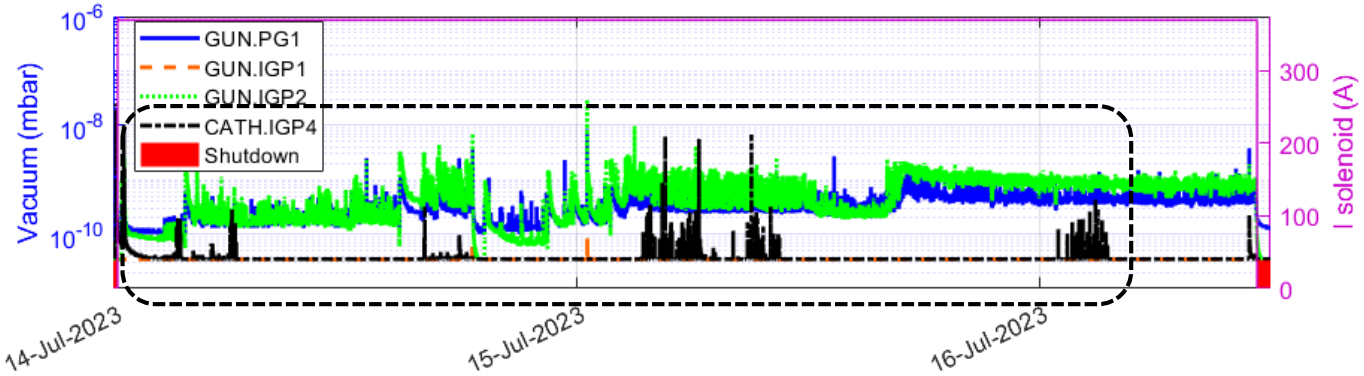


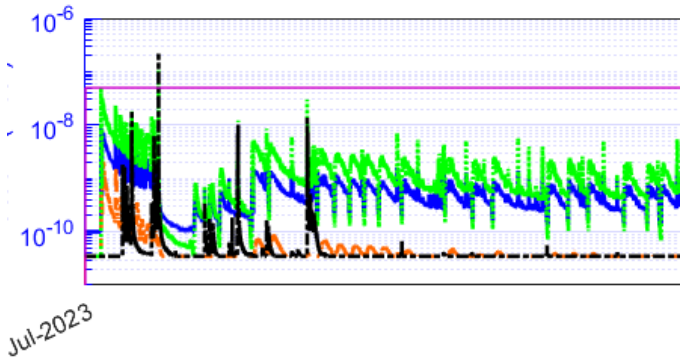
Gun5.1 at PITZ: Problems (2)

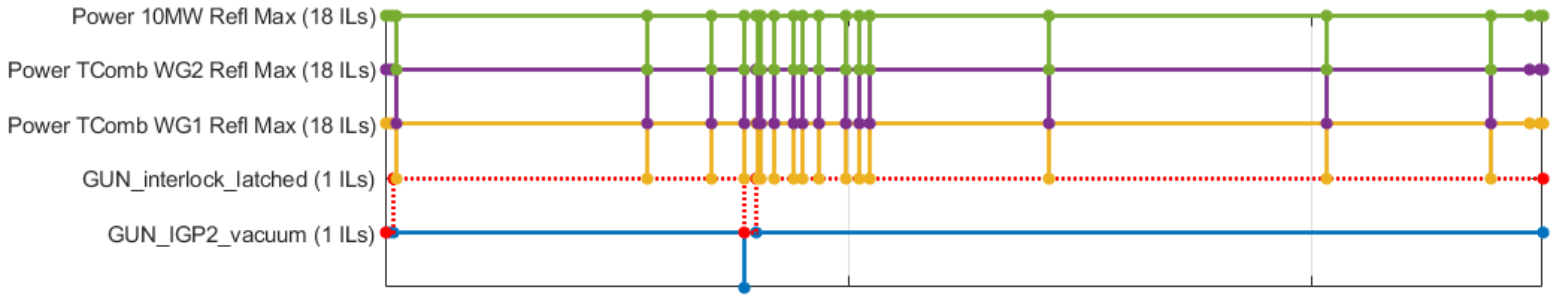
Pre-history 01.07-31.07.2023, more zoomed – weekend 14.07-17.07.2023 A.C.

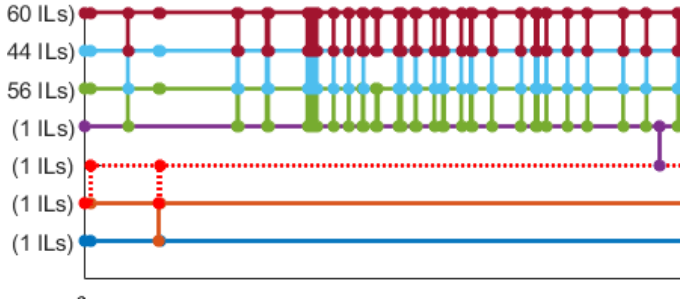






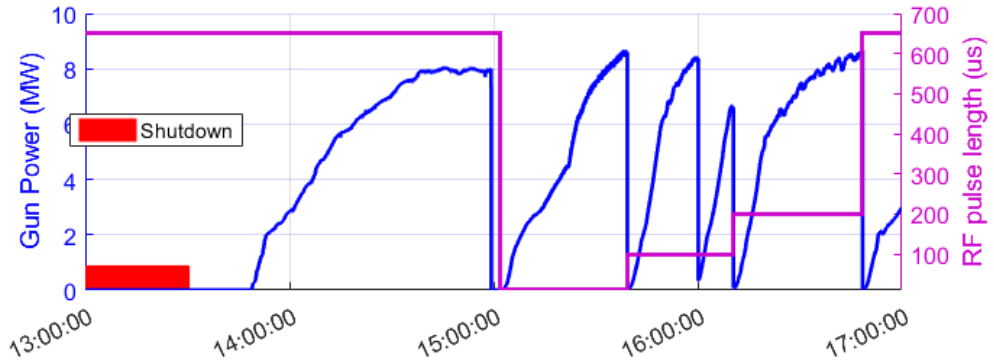


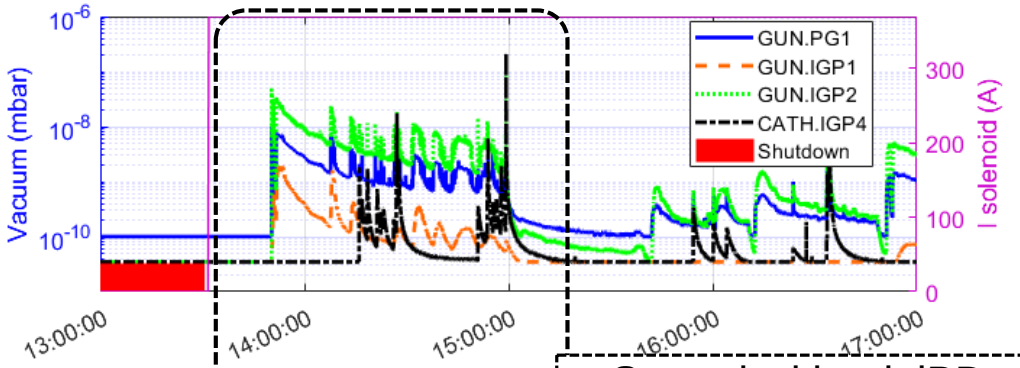




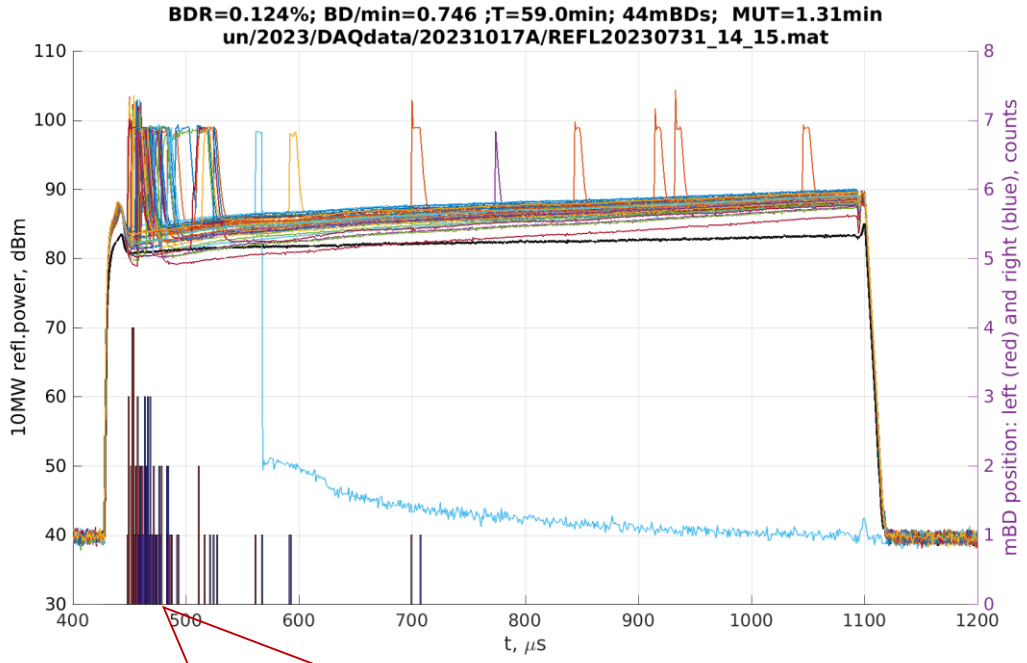
Gun5.1 at PITZ: Problems (2)

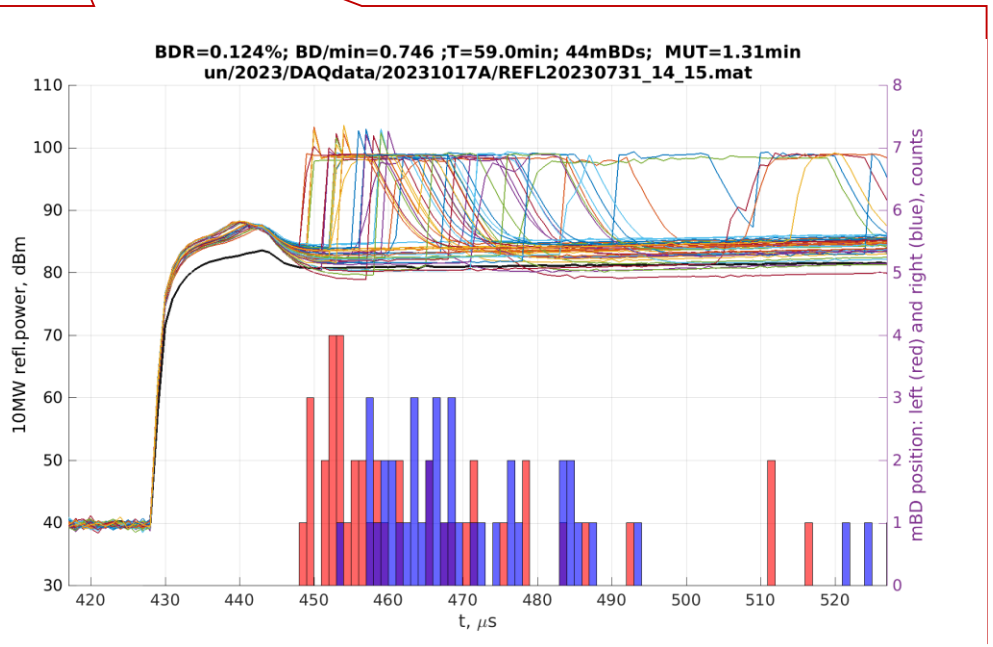
First hours run on 31.07.2023





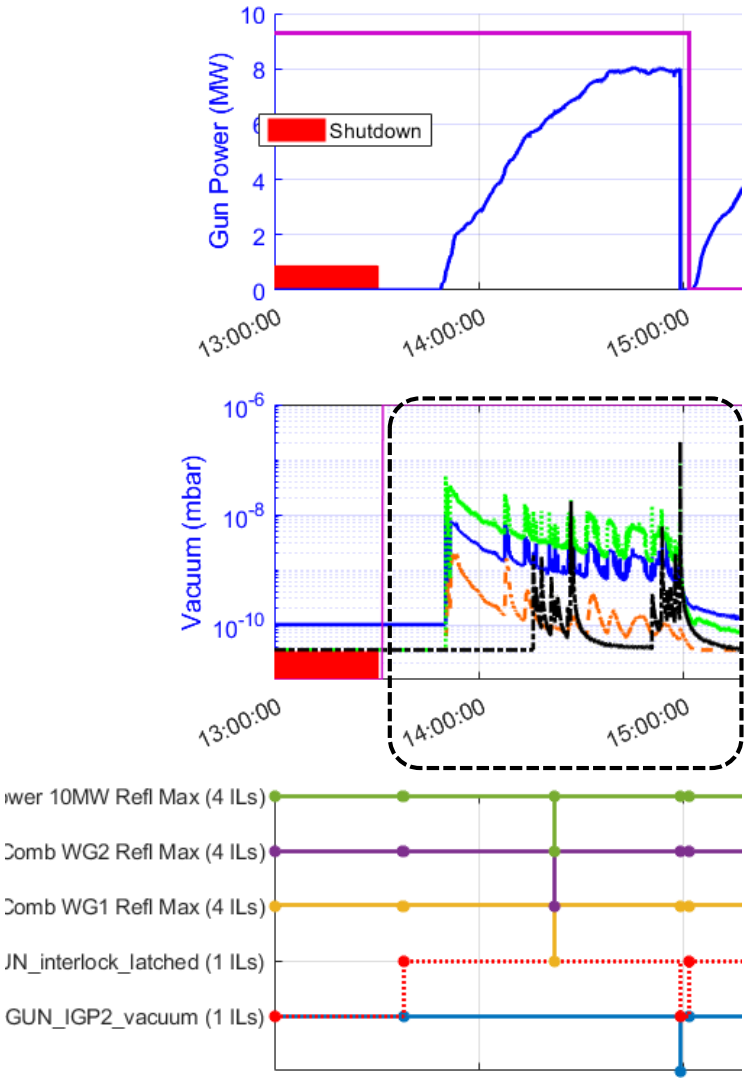
Started with miniBDs, then…

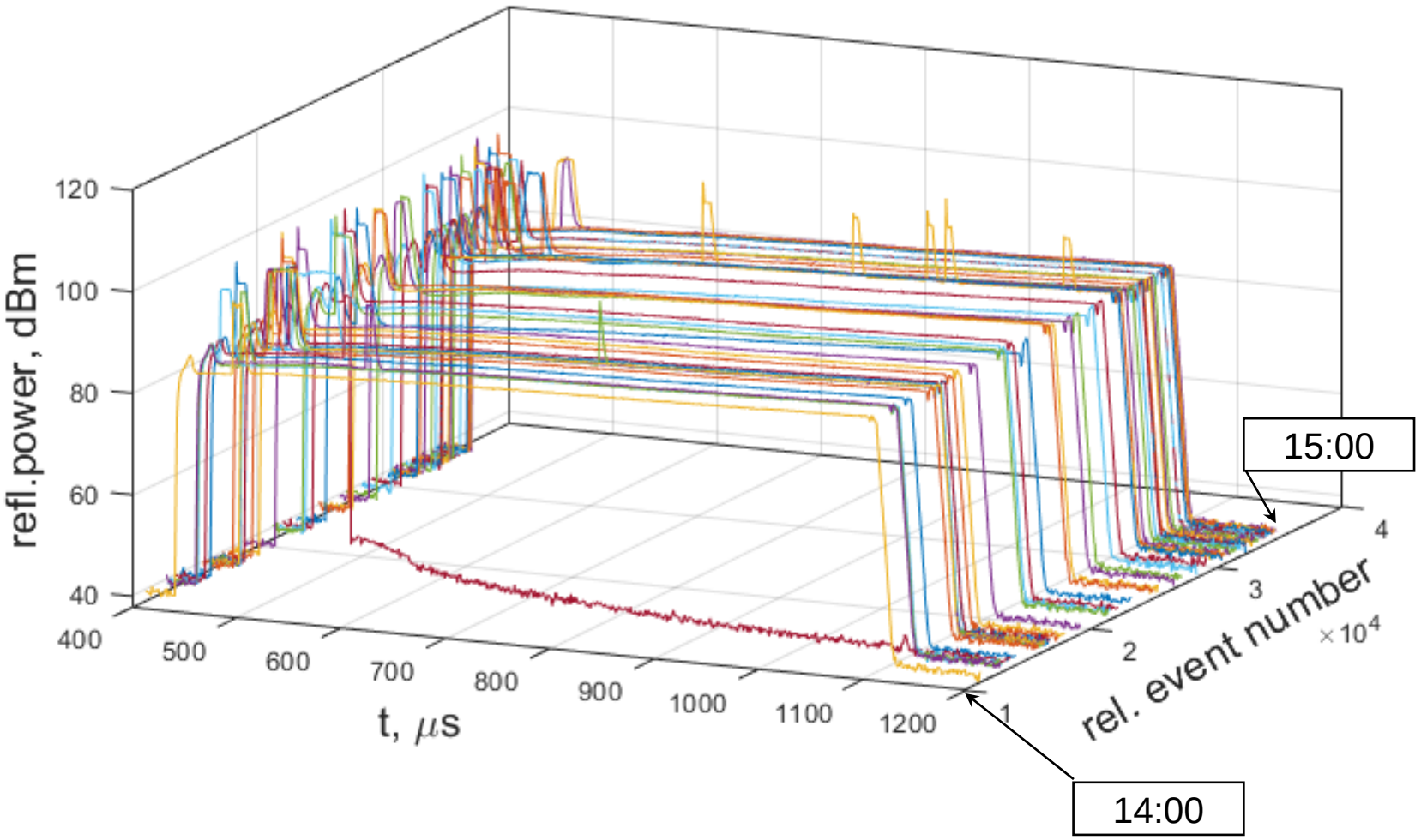




Gun5.1 at PITZ: Problems (2)

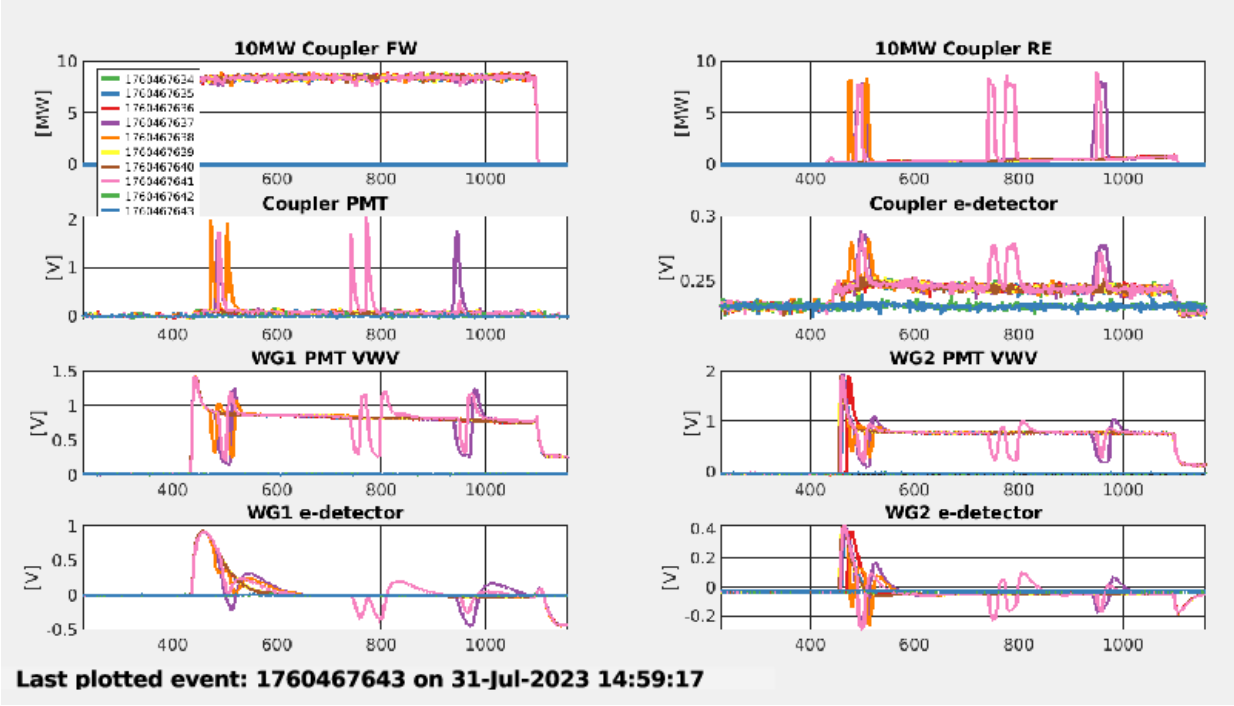
First hours run on 31.07.2023

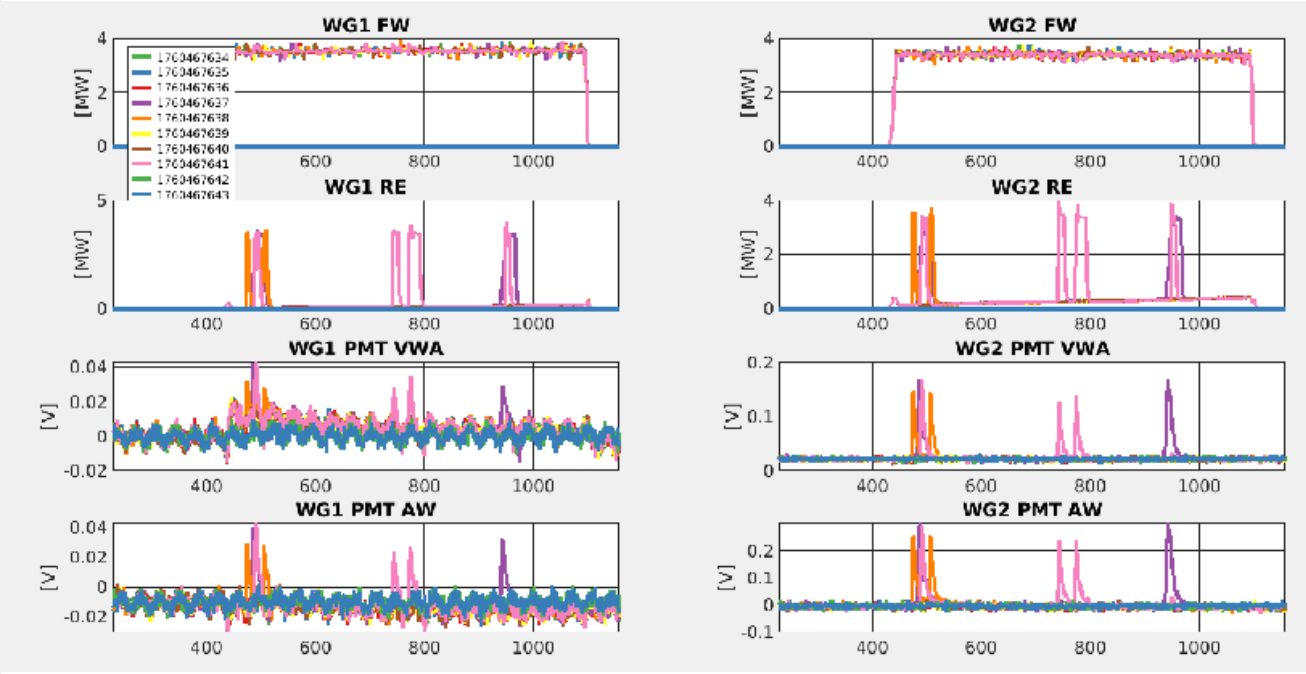




Gun5.1 at PITZ: Problems (2)

1st Gun trip investigation with LILI

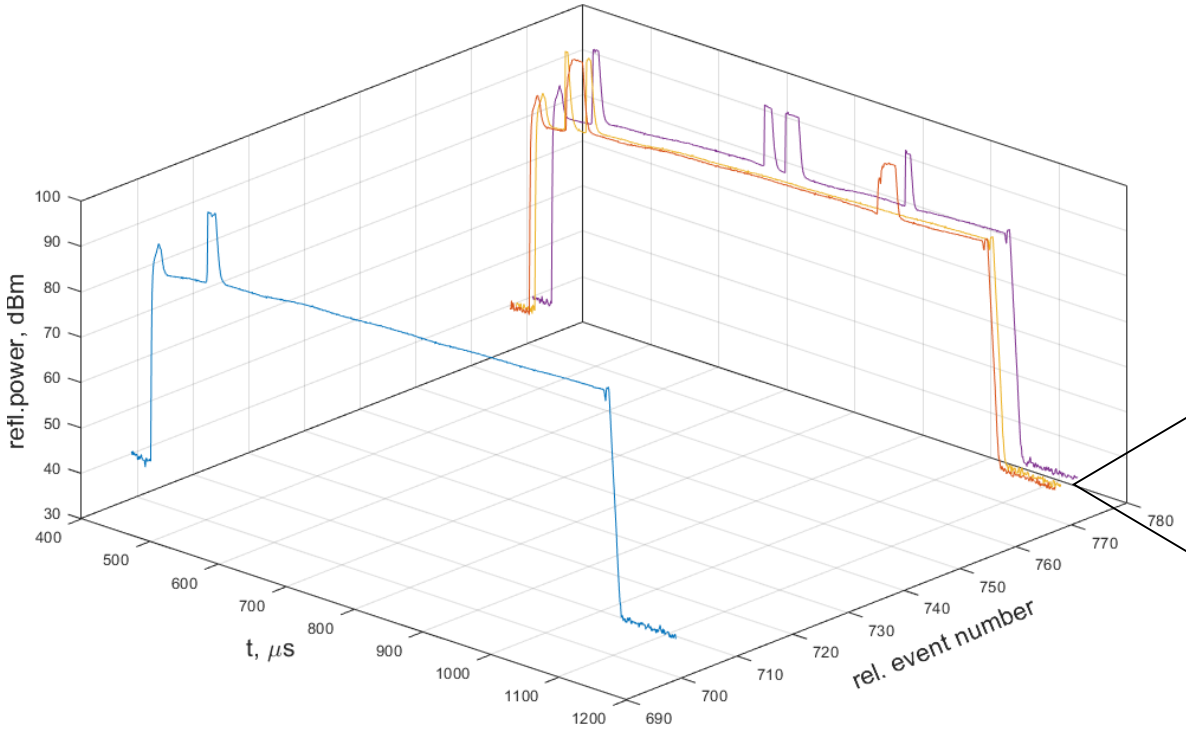


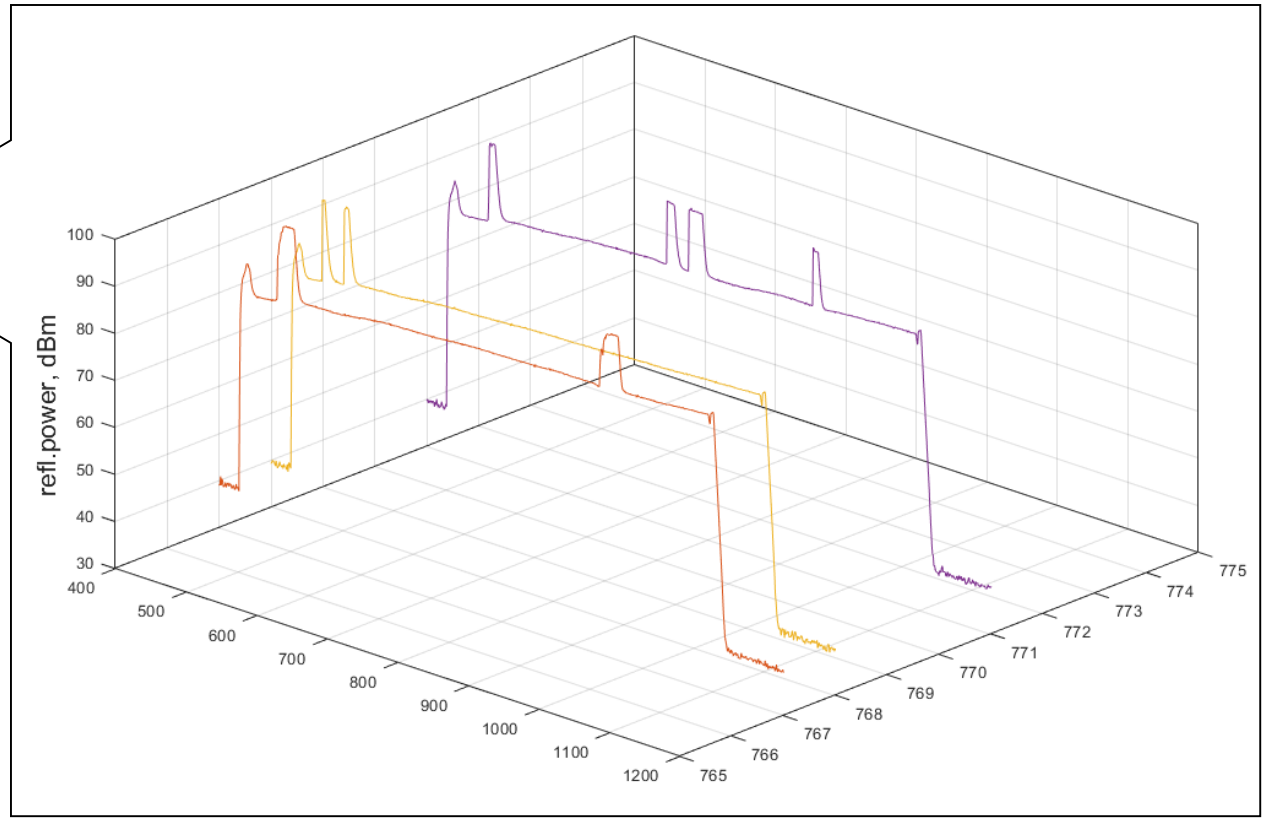


NB: The RF probe was disconnected from measurements at this time for bias voltage tests

Gun5.1 at PITZ: Problems (2)

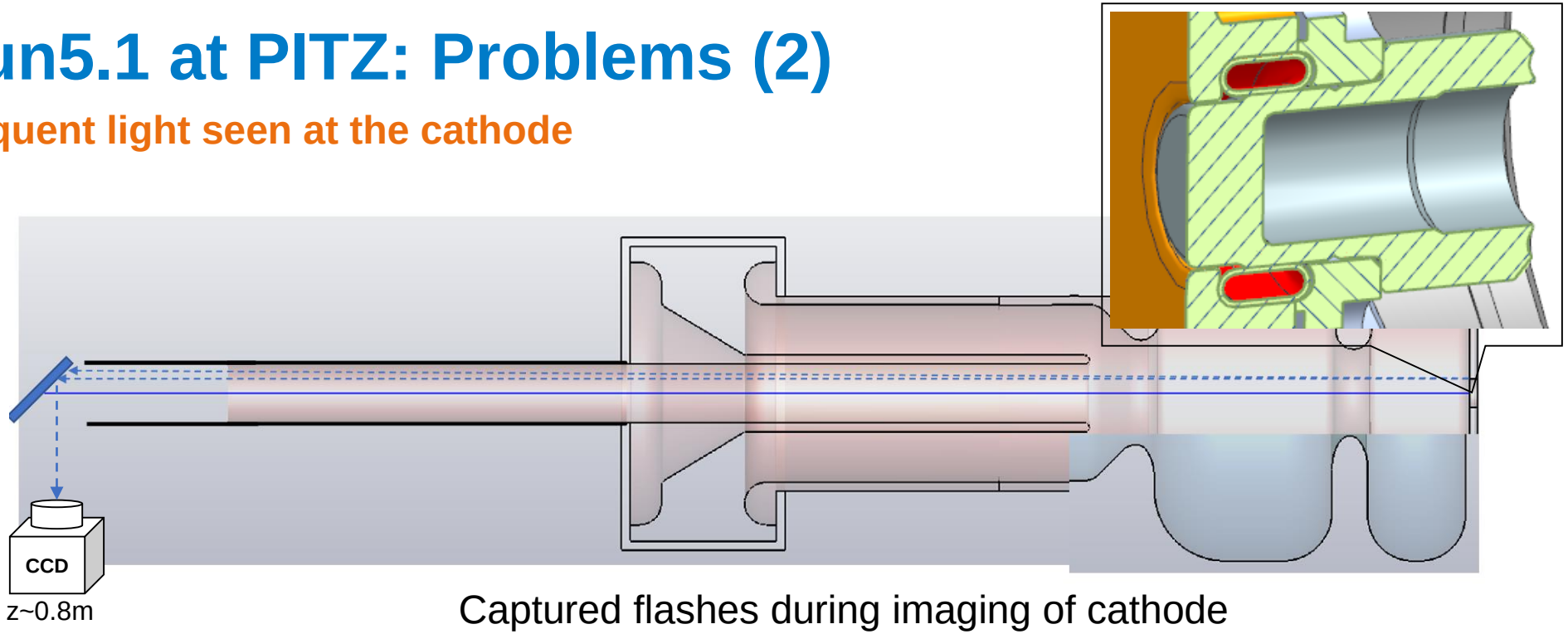
1st Gun trip investigation: reflected power



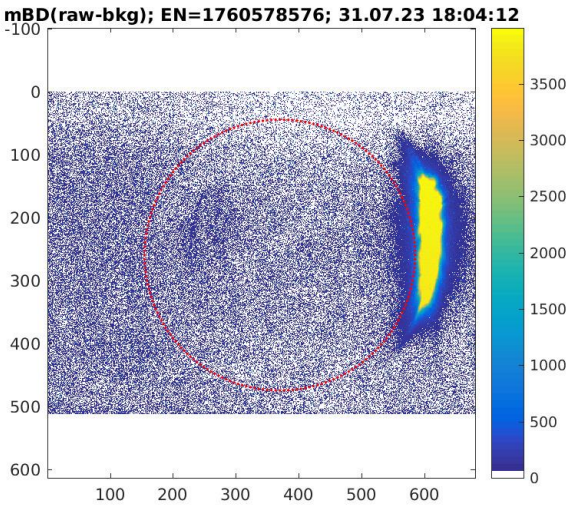


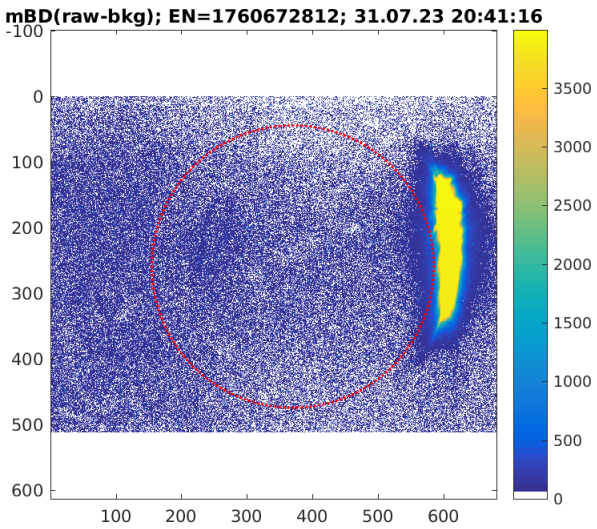
Gun5.1 at PITZ: Problems (2)

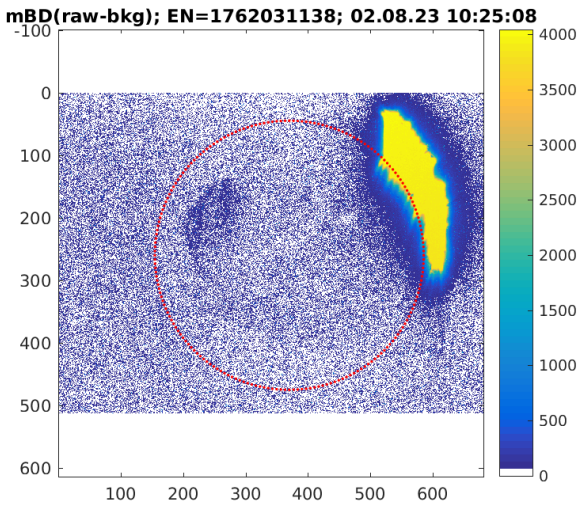
Frequent light seen at the cathode

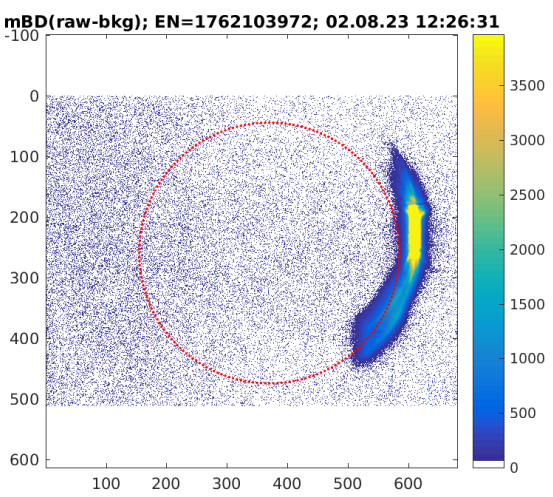


Captured flashes during imaging of cathode



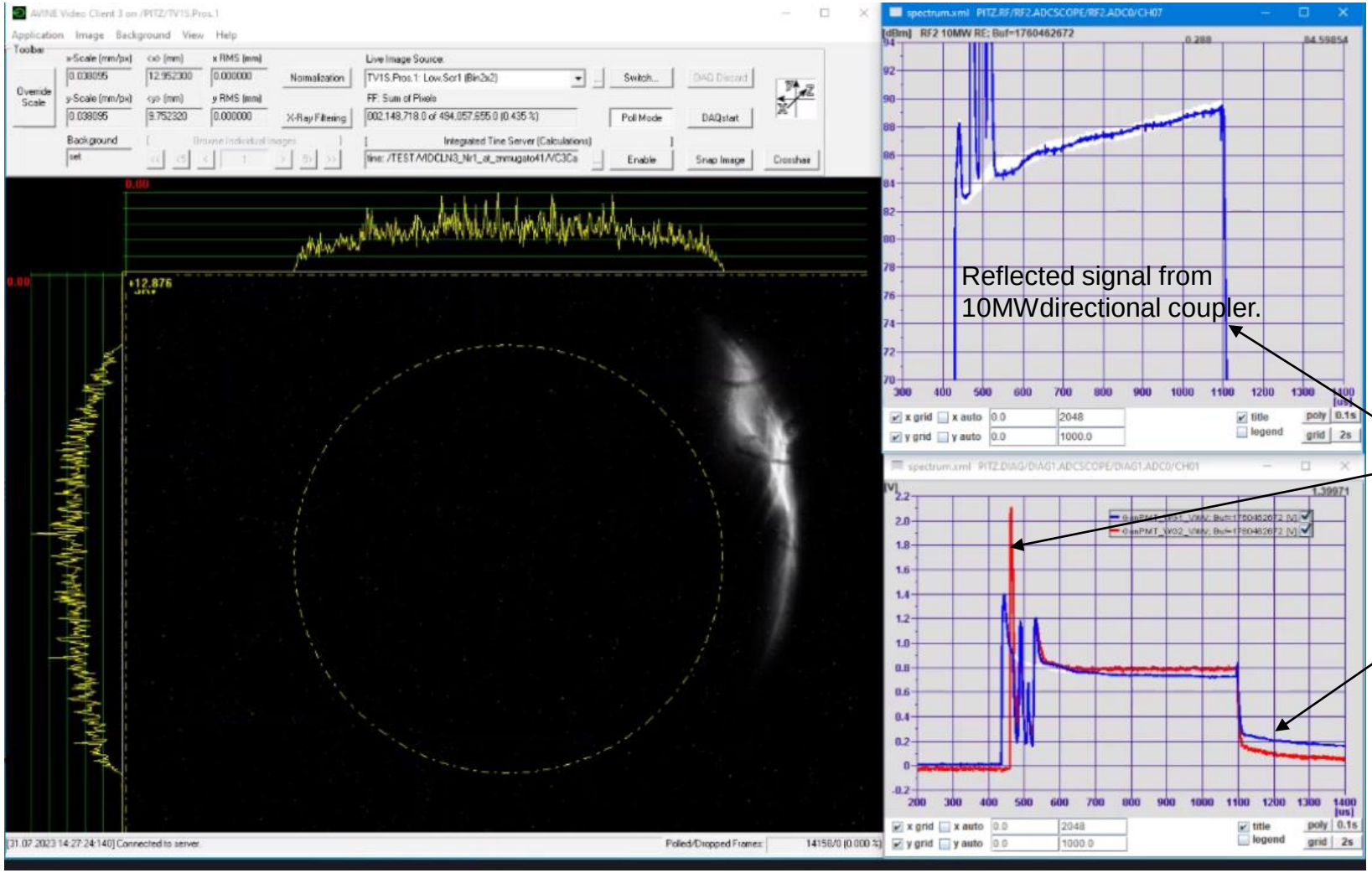


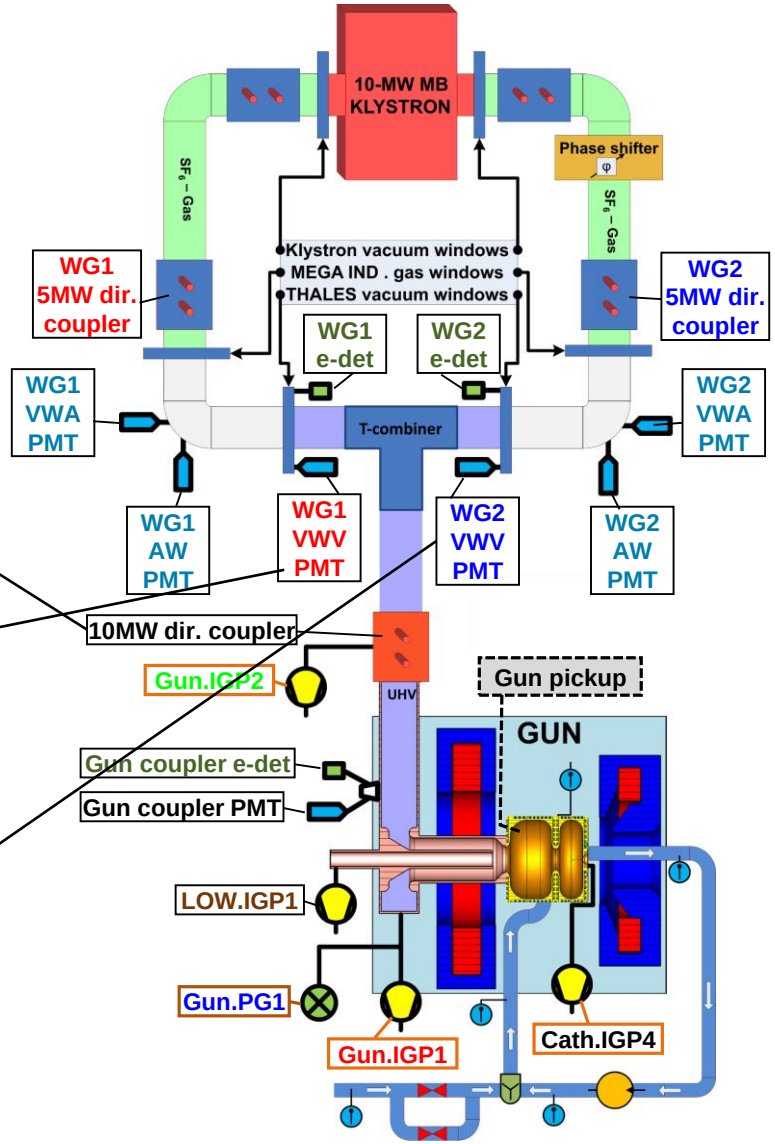




Gun5.1 at PITZ: Problems (2)

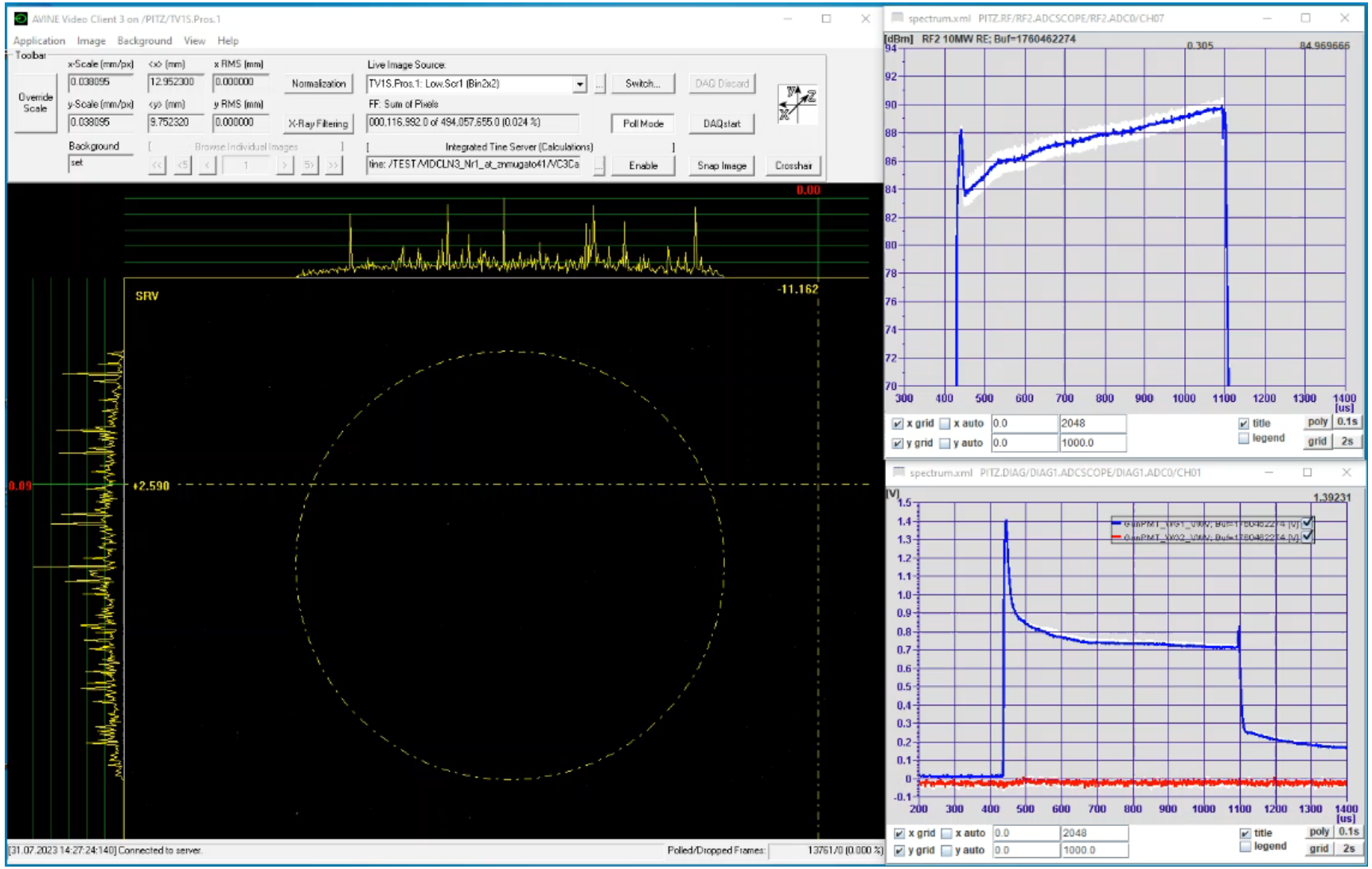
Flashes are correlated with RF signals distortion





Gun5.1 at PITZ: Problems (2)

Flashes are correlated with RF signals distortion

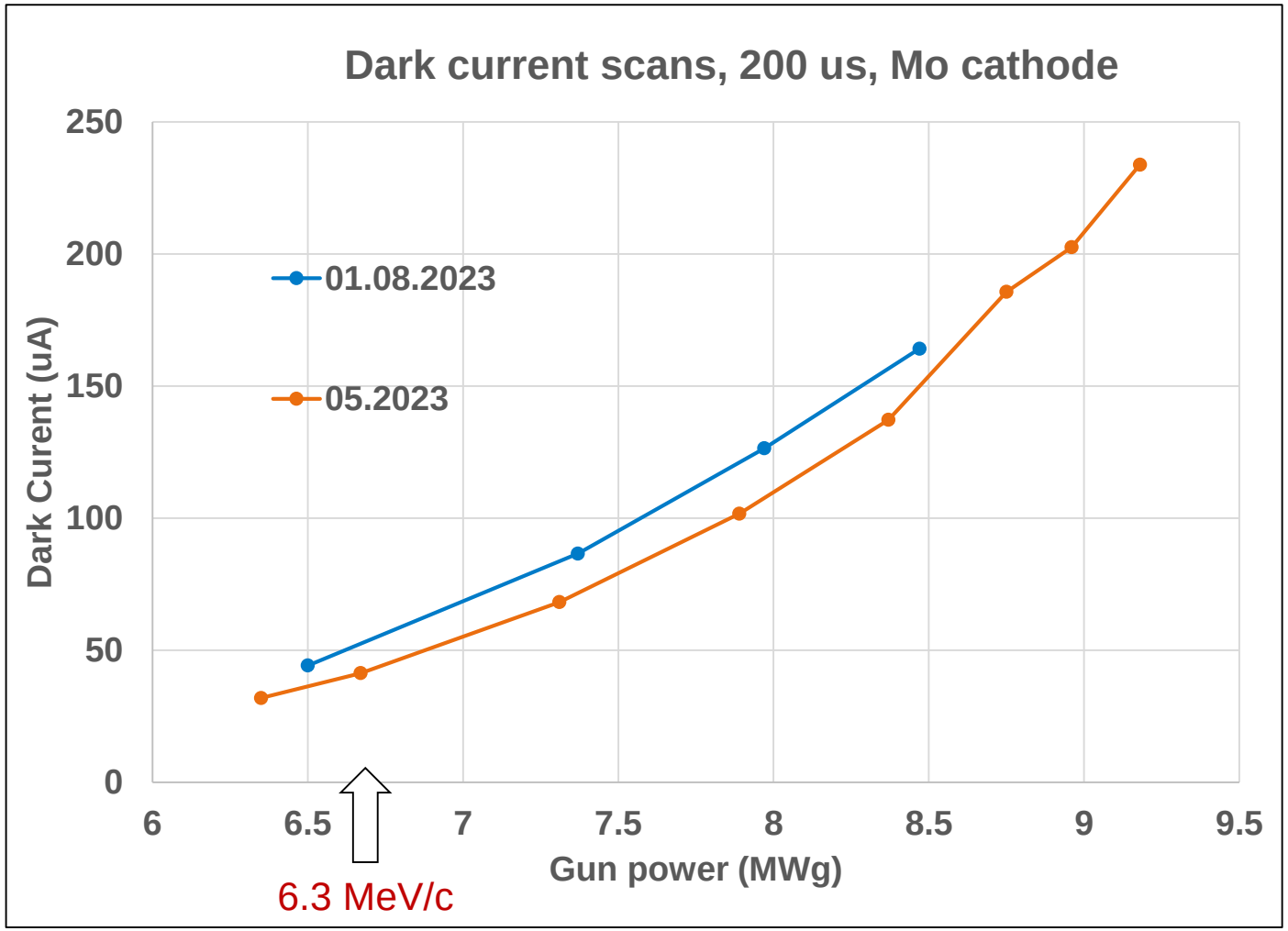


These distortions are seen by other detectors as well:

→“gamma-bursts” related to RF pulse interruptions are observed by many detectors (e.g. booster spark PDs)!

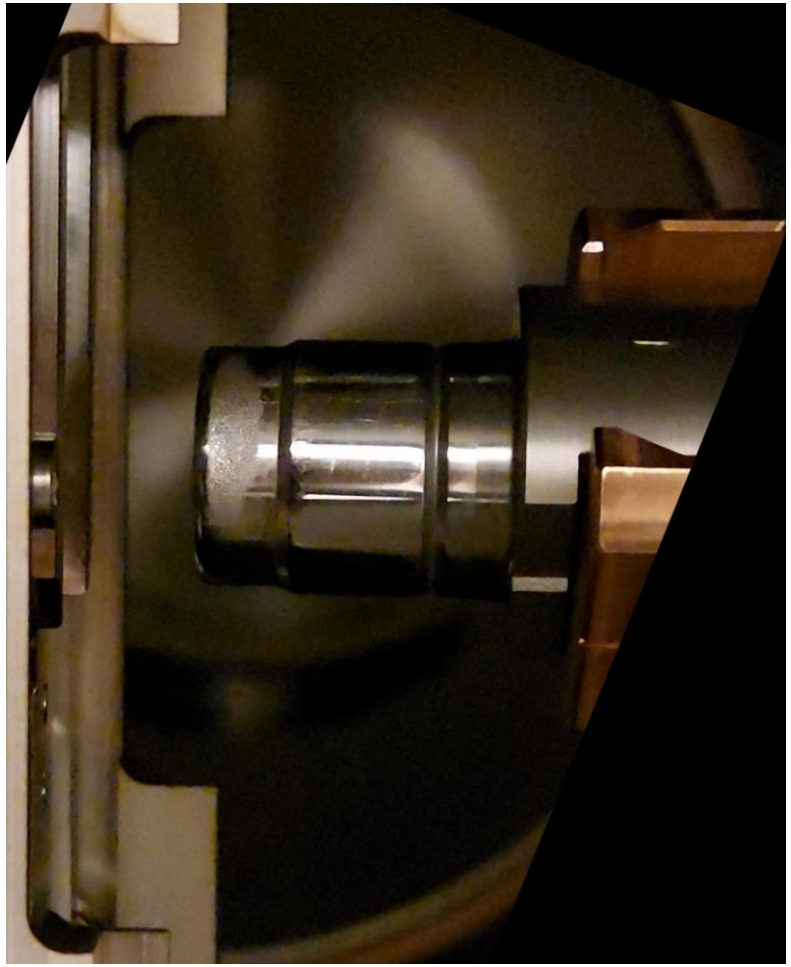
Dark current

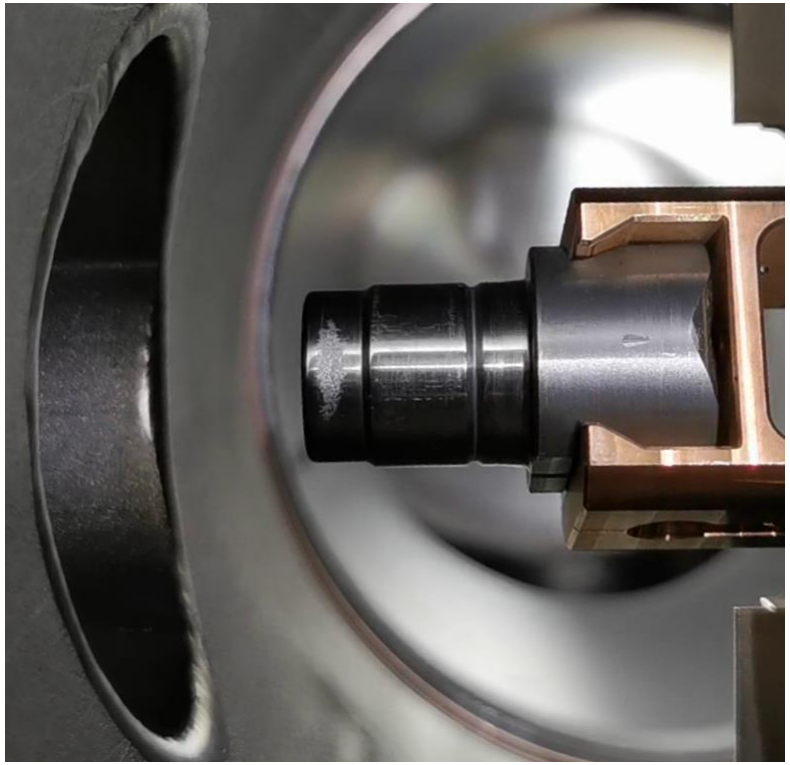
Even after problems started – no significant increase!



Gun5.1 at PITZ: Problems (2)

Damage observed on the side surface of extracted cathodes (Mo#741.1 and Cs2Te#693.1)

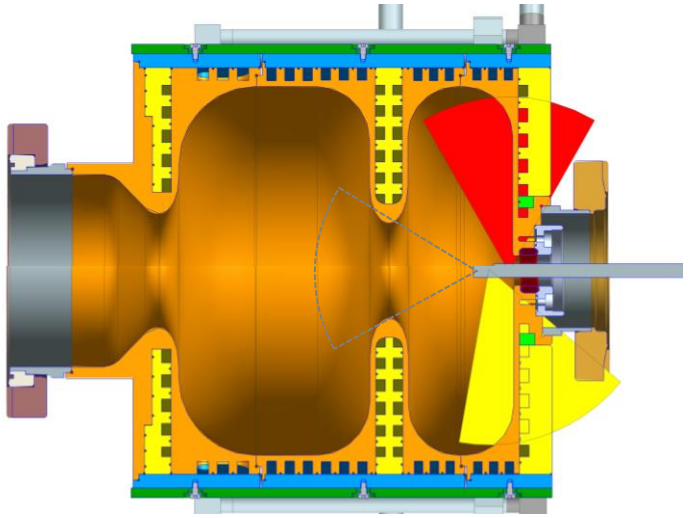


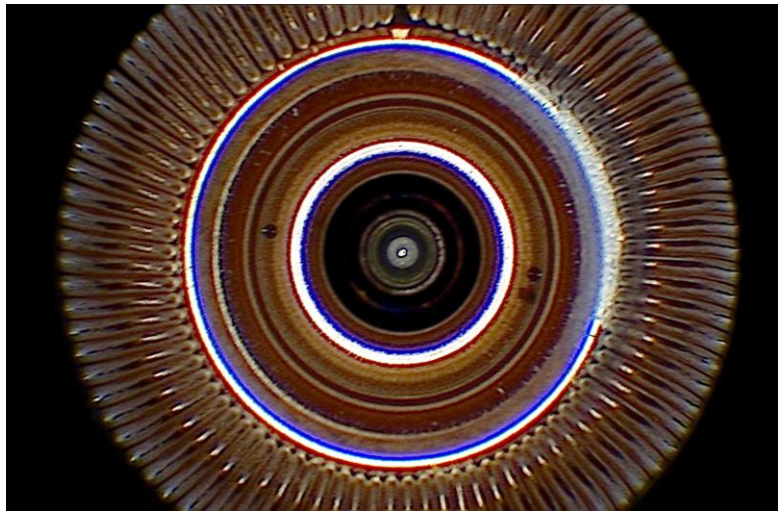


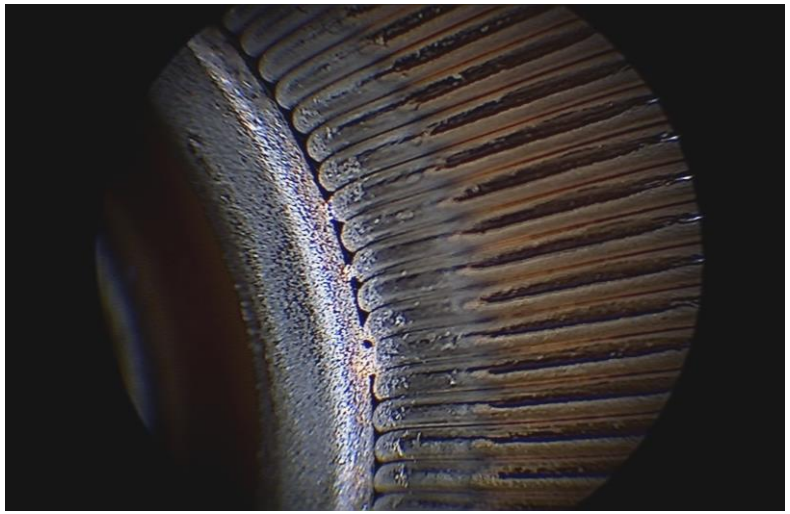
Courtesy Frieder Müller

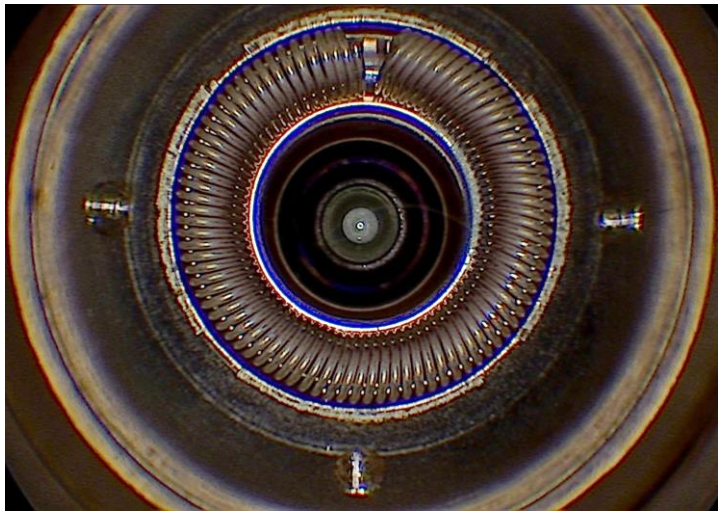
Gun5.1 at PITZ: Problems (2)

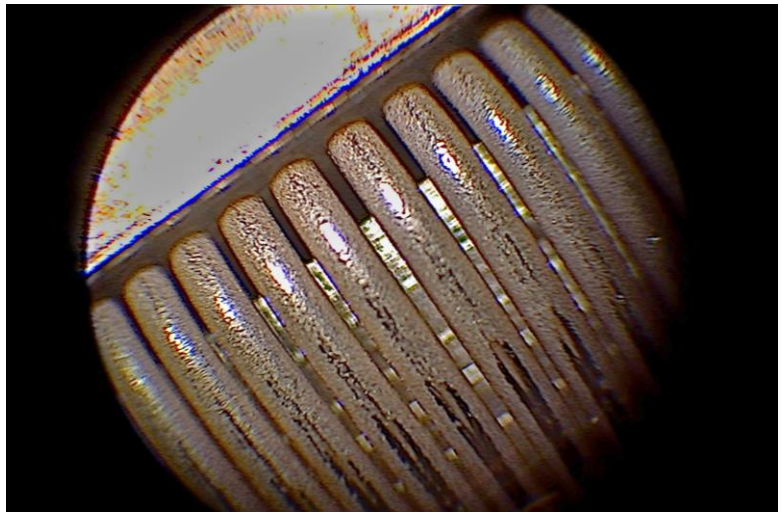
Gun opened from the back (cathode) side, visual inspections on 18.08.2023 and on 23.08.2023

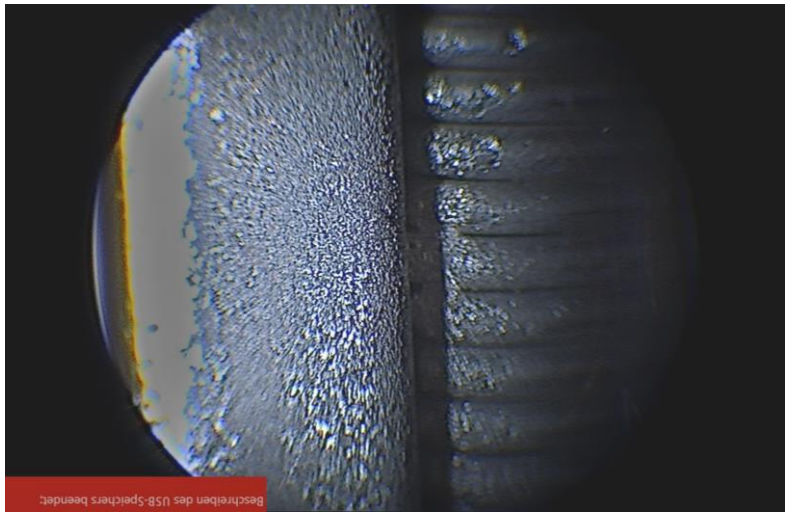








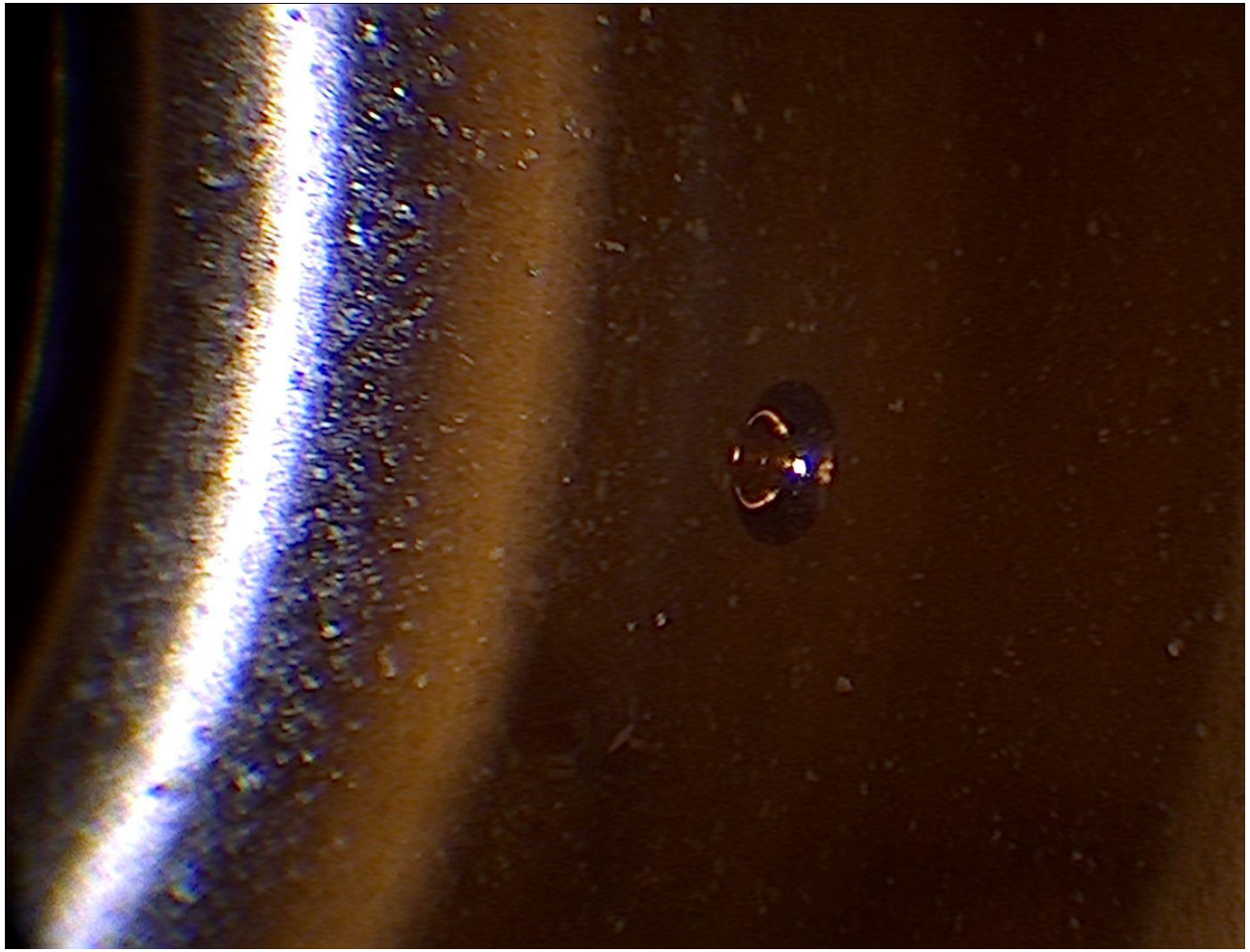


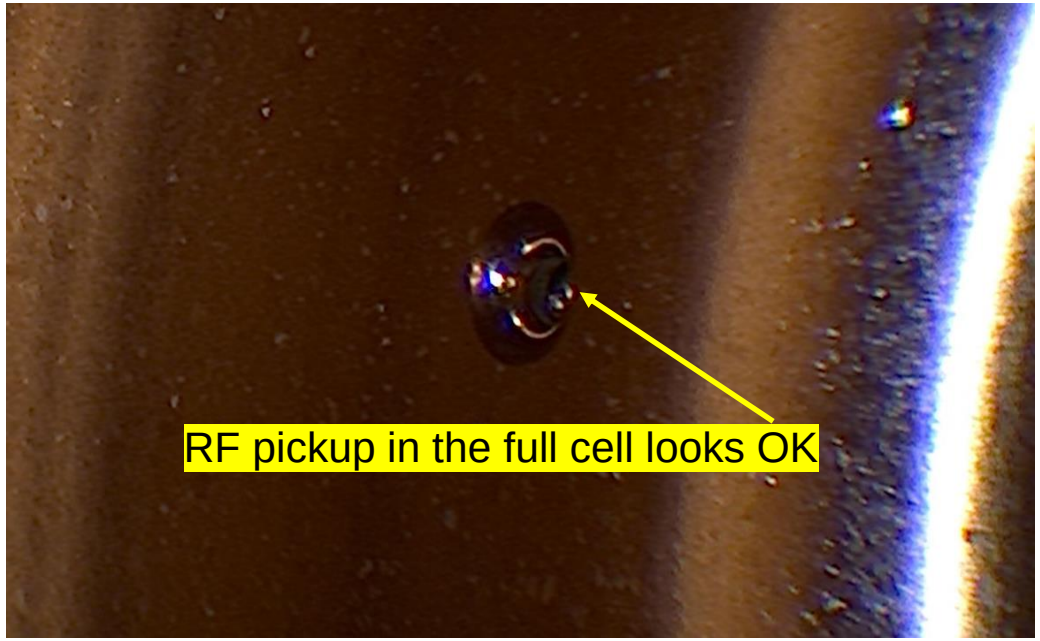


Courtesy Frieder Müller

Gun5.1 at PITZ: Problems (2)

Gun video inspection on 23.08.2023: positive message – no damage observed on the RF pickup

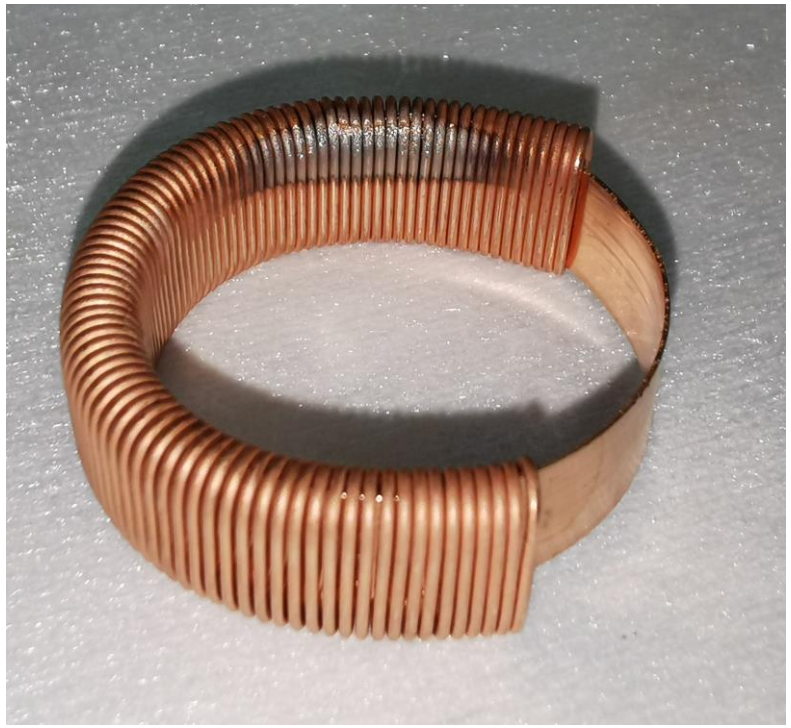




Courtesy Frieder Müller

Gun5.1 at PITZ: Problems (2)

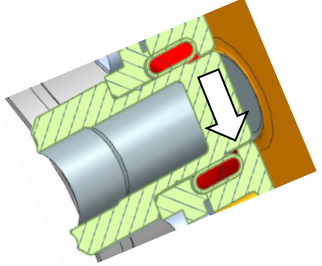
Damages contact spring removed



Courtesy Frieder Müller

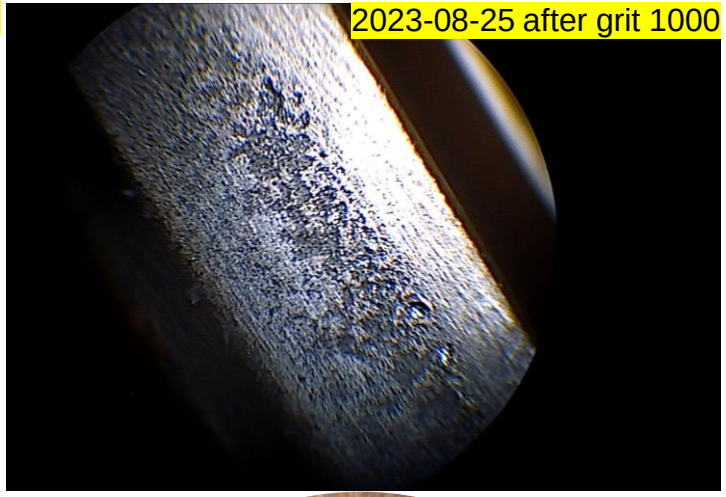
Gun5.1 at PITZ: Problems (2)

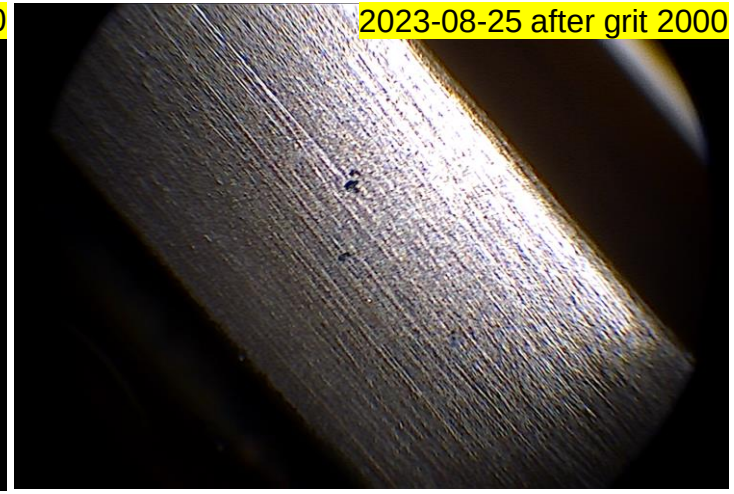
Cathode area repair



Polishing

- 6x Grit 1000
- 1x Grit 1500
- 1x Grit 2000





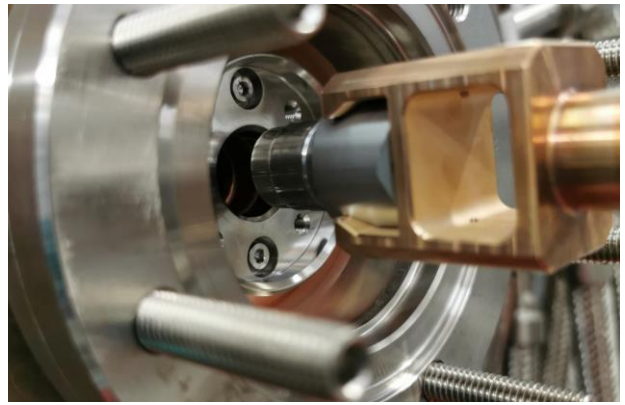
NB: no dry ice cleaning!

New contact spring inserted:

- Approx 2 windings longer than old one
- 1st and 2nd try

Windings never will flip in one and the same direction!

Z-actuator re-aligned



Courtesy Frieder Müller

Gun5.1 at PITZ: Problems (2)

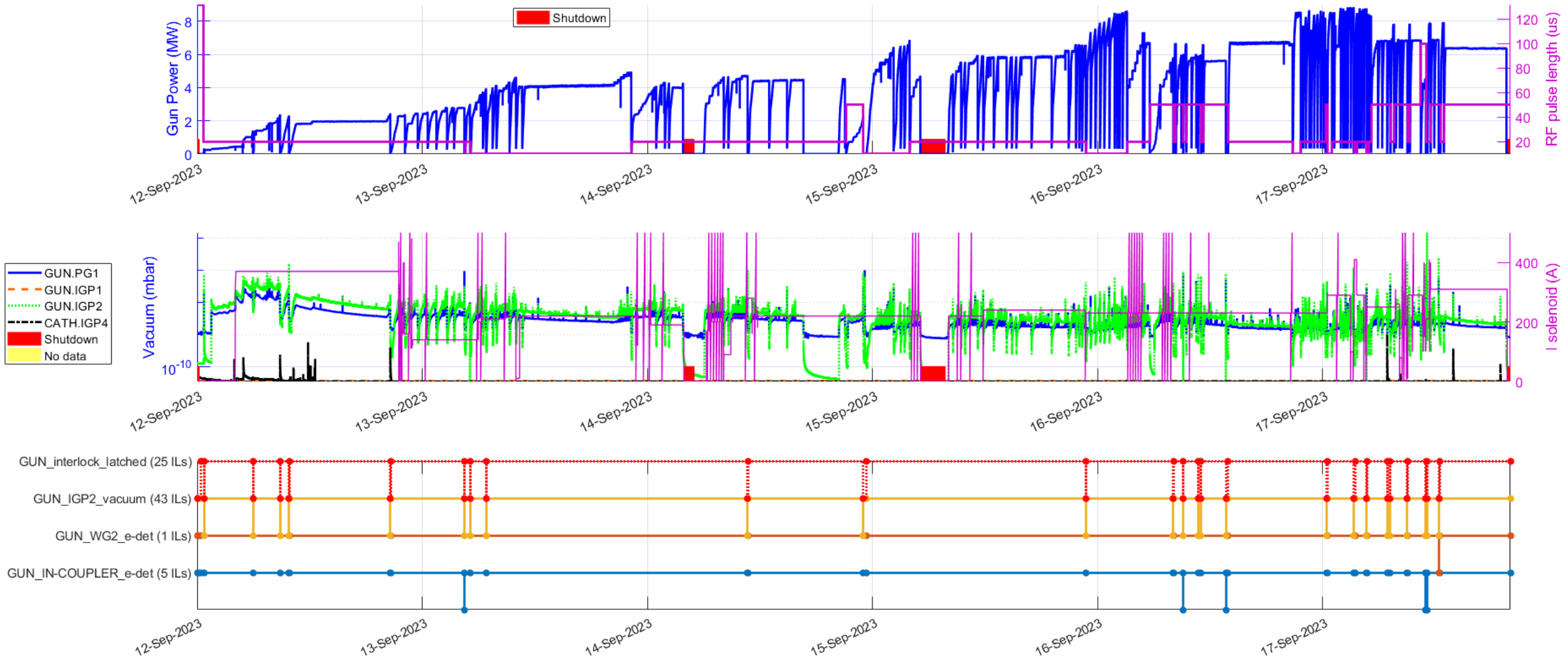
After mechanical repair

After mechanical repair of the cathode area:

- vacuum was closed
- pumping down
- baking
  - using gun cooling water at max, i.e. 85ºC,
  - IGPs and TSP heated as well
  - cathode system ~150ºC

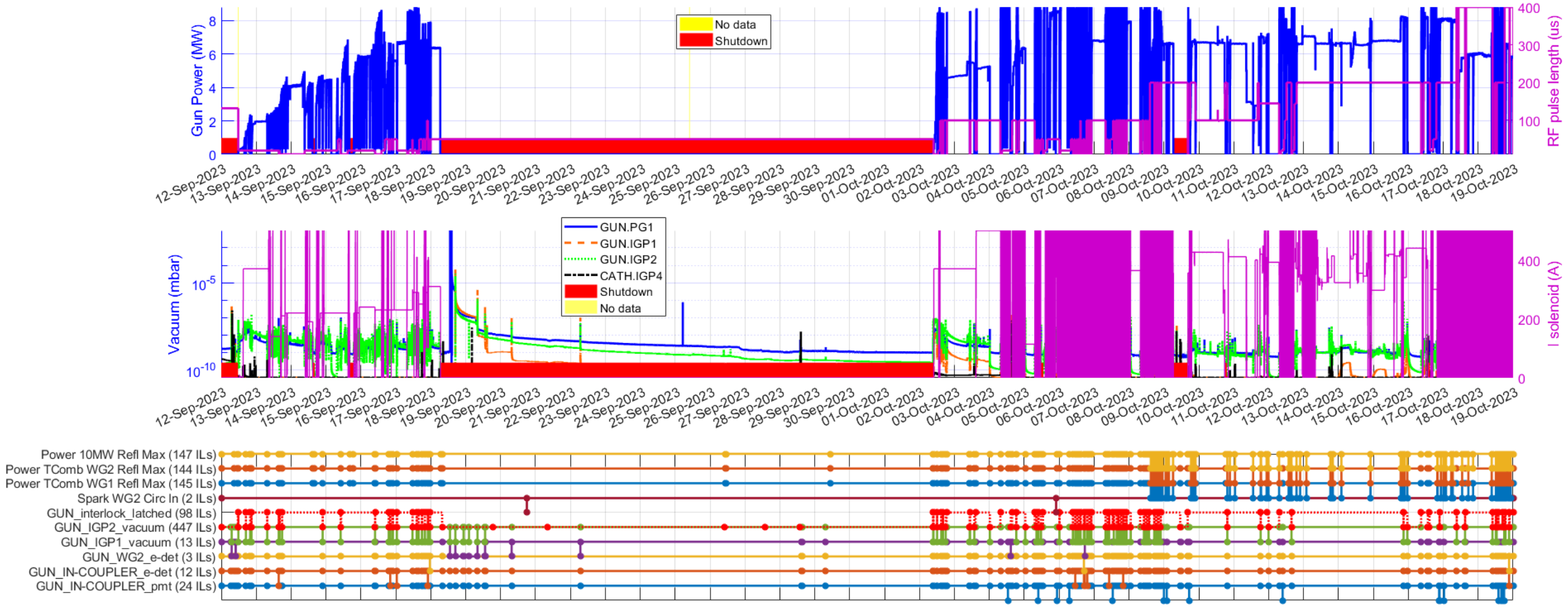
Gun5.1 at PITZ: Problems (2)

Reconditioning starting 12.09.2023



Gun5.1 at PITZ: Problems (2)

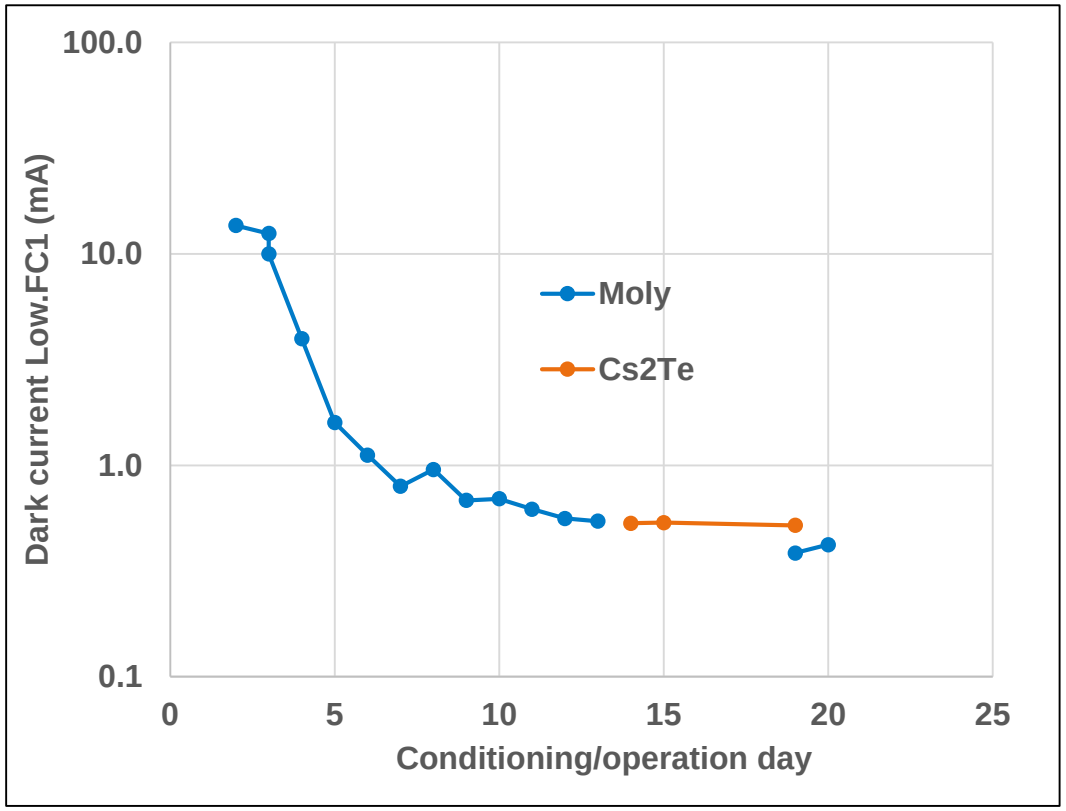
Reconditioning 12.09.2023-19.10.2023

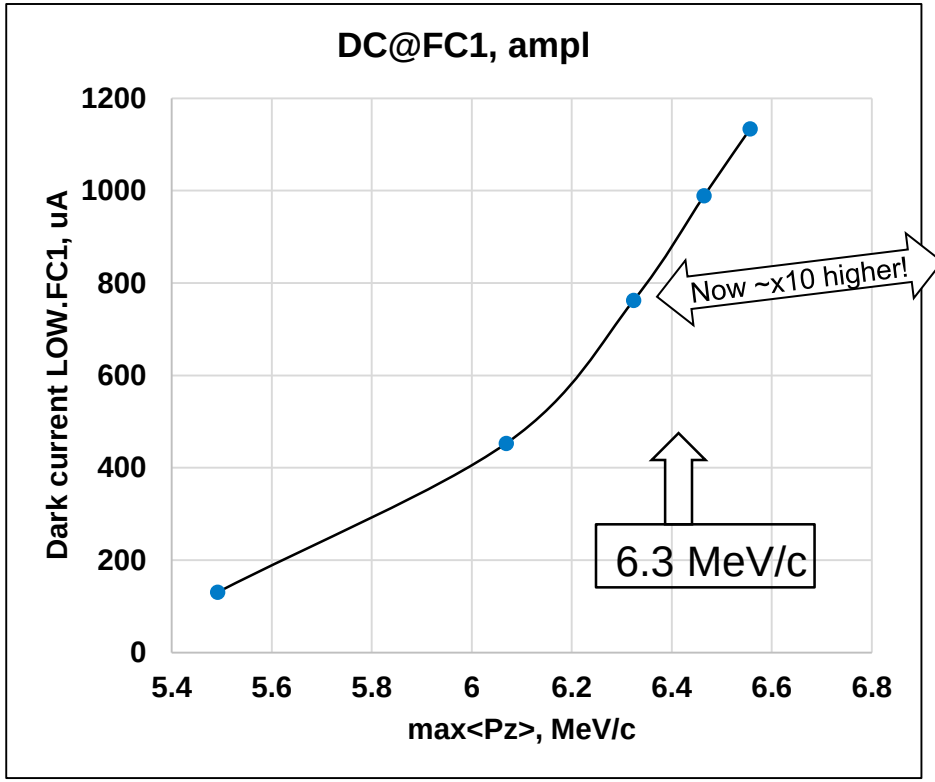


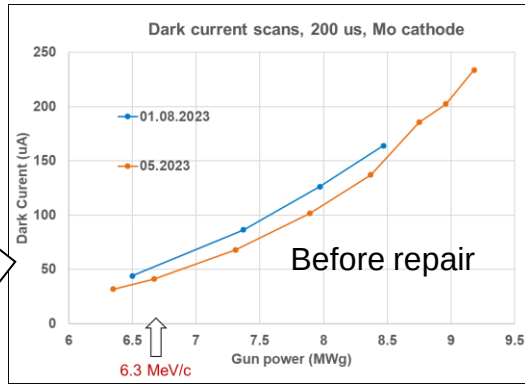
Gun5.1 at PITZ: Problems (2)

Observations during reconditioning

- Extremely high dark current (~mA at 6.7MWg), but reduced with conditioning
- Strong multipacting (MP) observed after main RF pulse → looks like conditioned out now
- No damage of cathode Mo plug after several weeks of conditioning



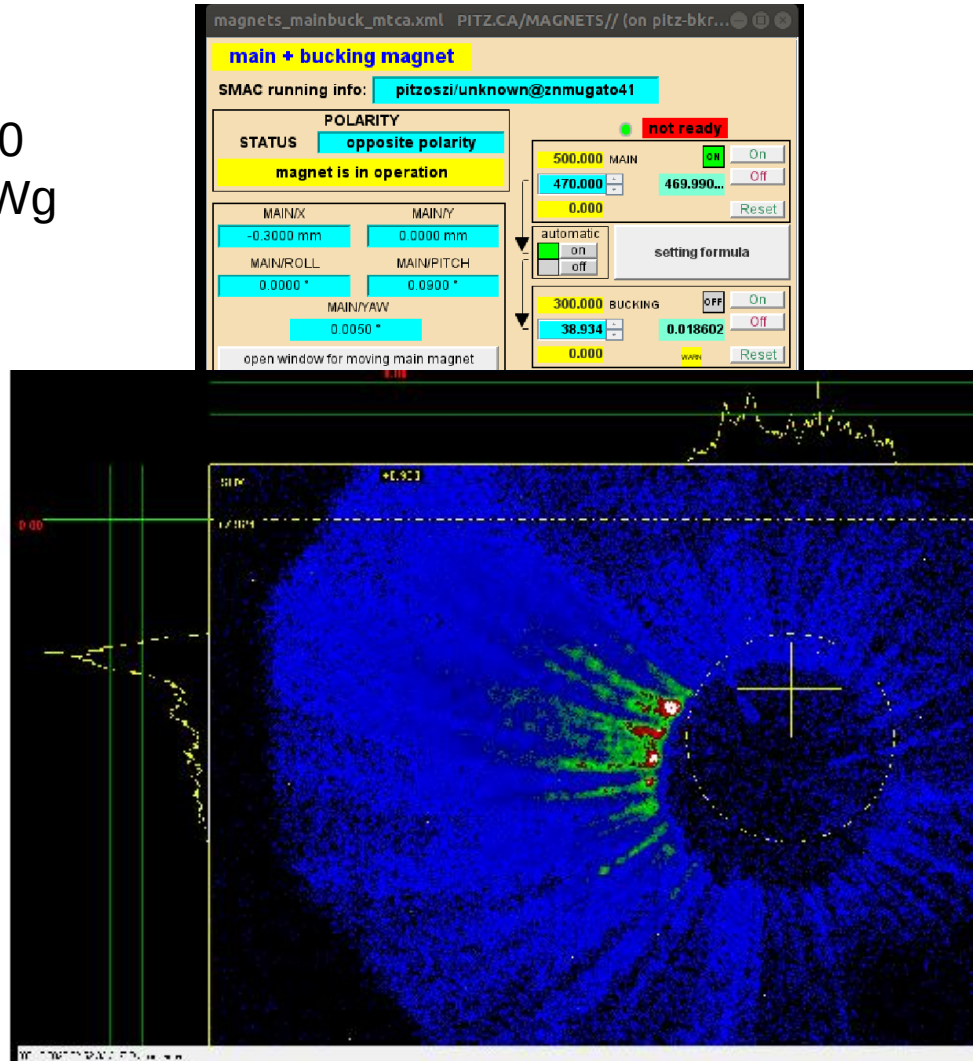


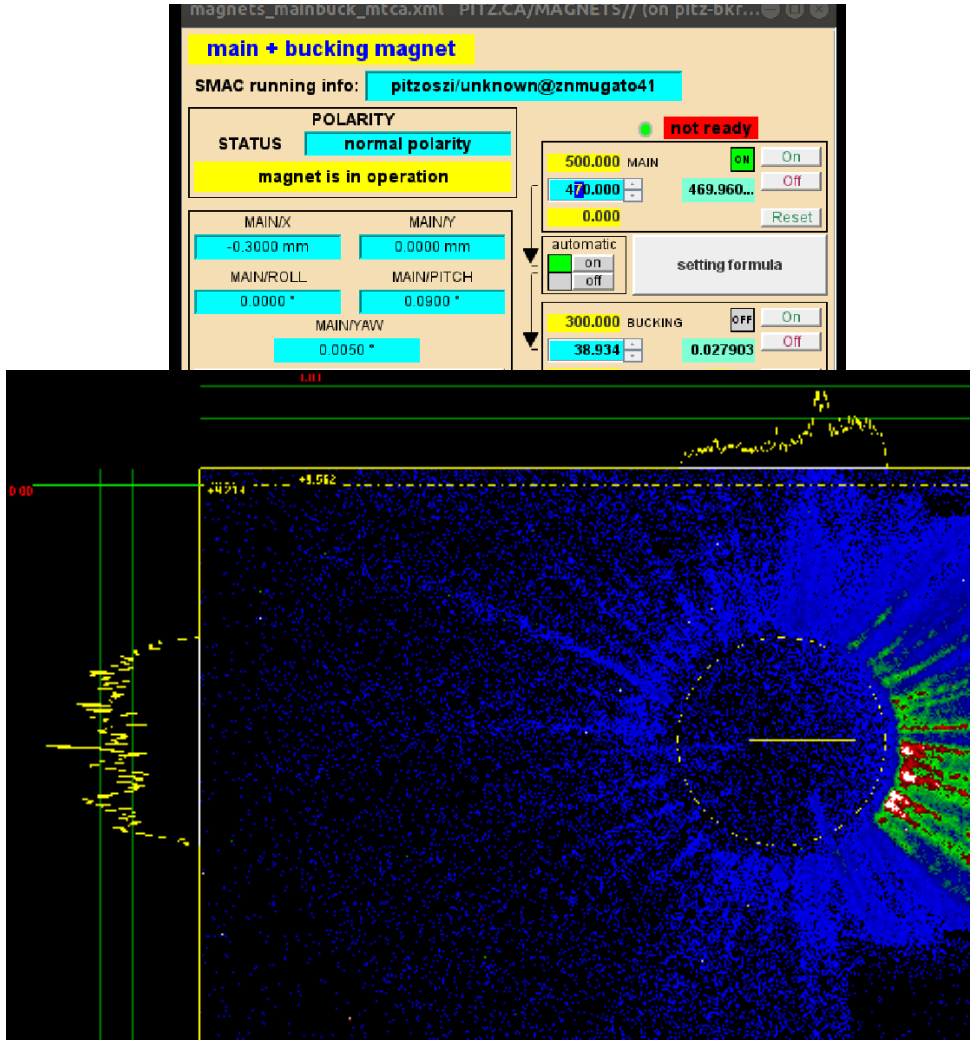


Gun5.1 at PITZ: Problems (2)

Dark current imaging

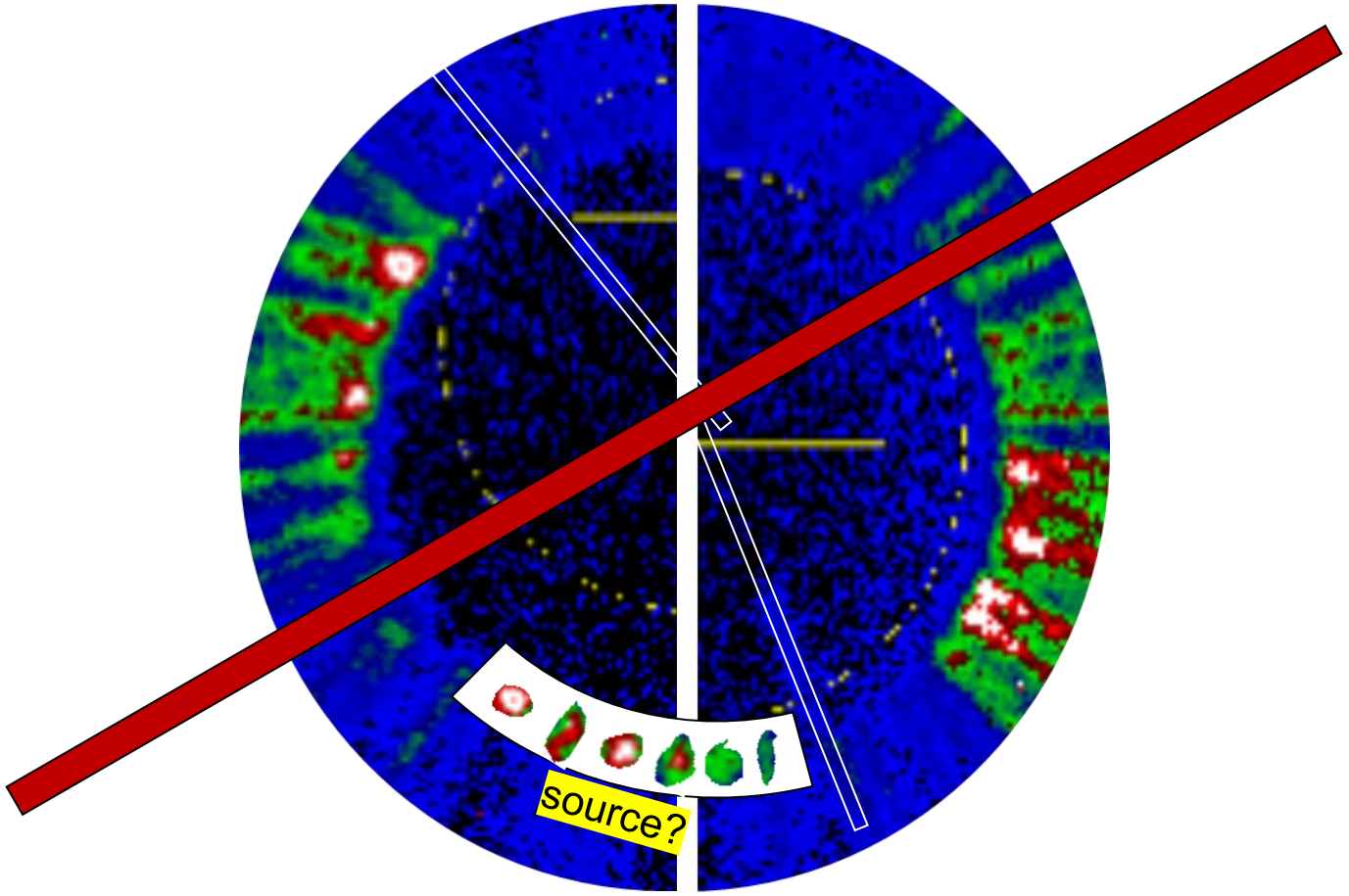
50us
SP=60
8.5MWg





Gun5.1 at PITZ: Problems (2)

Dark current imaging: looking for a FE source



Gun5.1 at PITZ: Problems

Summary

- Mini-breakdown events observed from the very beginning
  - Short RF pulse interruptions mostly in the first 30us, recovered with a same pulse
  - Many studies performed, but still not clear location of the problem found
- Starting 31.07.2023 – severe problems:
  - Numerous gun interlocks and trips
  - Distortions are seen by other detectors as well: “gamma-bursts” related to RF pulse interruptions are observed by many detectors (e.g. booster spark PDs)!
- Cathode side surface damage observed
- Upon opening the gun:
  - severe damage to the cathode contact spring and surrounding area observed
  - but RF pickup in the full cell looks OK
- Repair:
  - multi-step polishing, but no dry ice cleaning (significant efforts – very long shutdown)
  - new cathode contact spring (2 windings more)
  - z-actuator re-aligned
- Re-conditioning started on 12.09.2023:
  - No cathode side surface damage observed
  - Significant dark current:
    - x10 higher than before
    - Source is most probably – still contact spring area
    - reduced by conditioning but progress is now slowed down