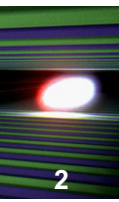


# XFEL-Gun Operator Training

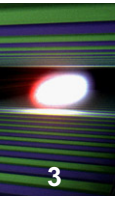
F.Brinker



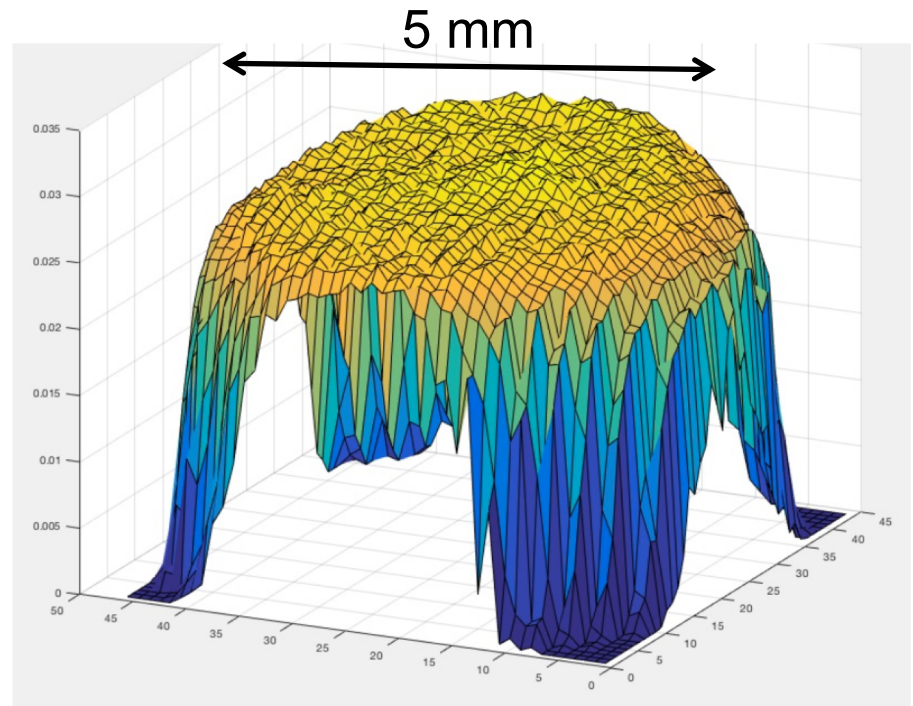
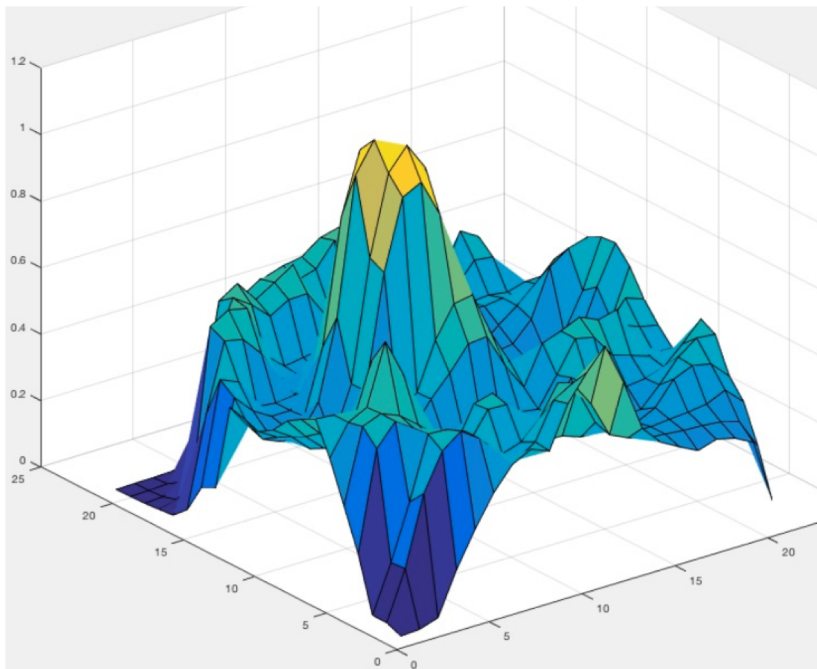
HELMHOLTZ  
| ASSOCIATION



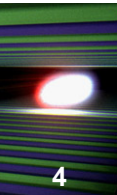
- Cathode
- Interlock systems
- Multi Pactoring
- Temperature regulation
- FSM and Ramp Up procedure



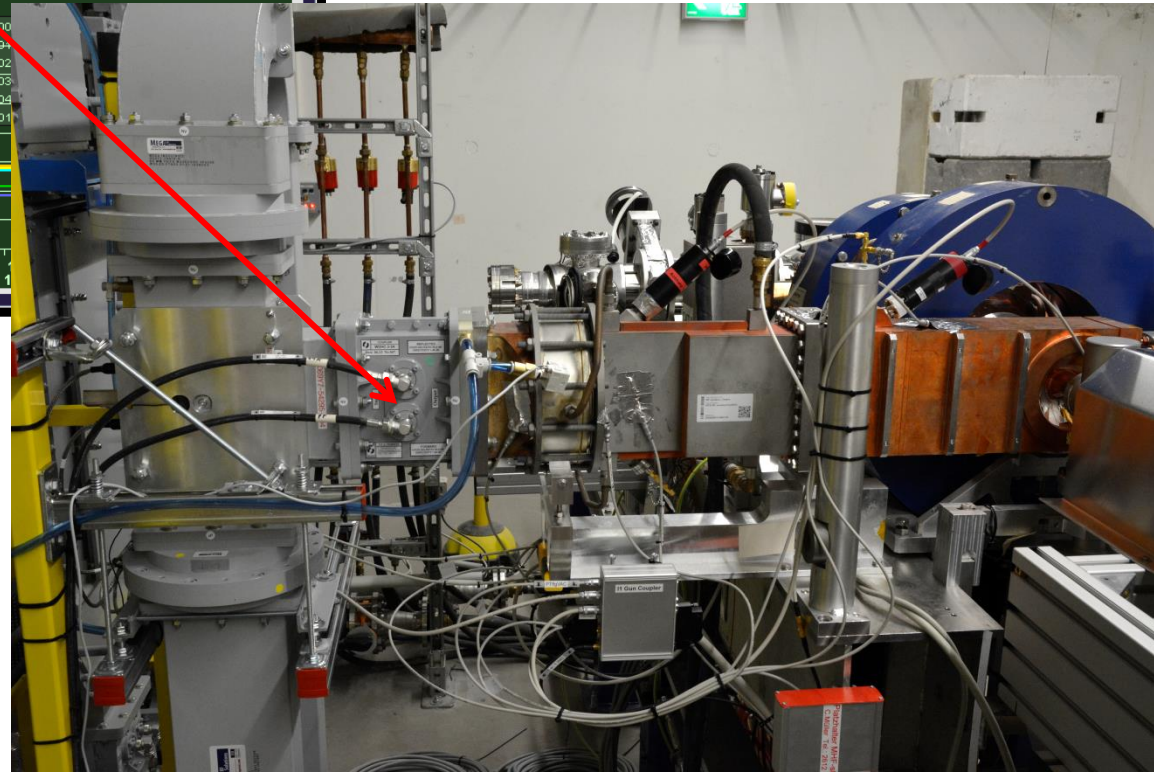
Messung der Quanteneffizient = wieviele Electrons werden pro Laser Photon freigesetzt



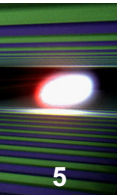
# Gun signals and interlocks



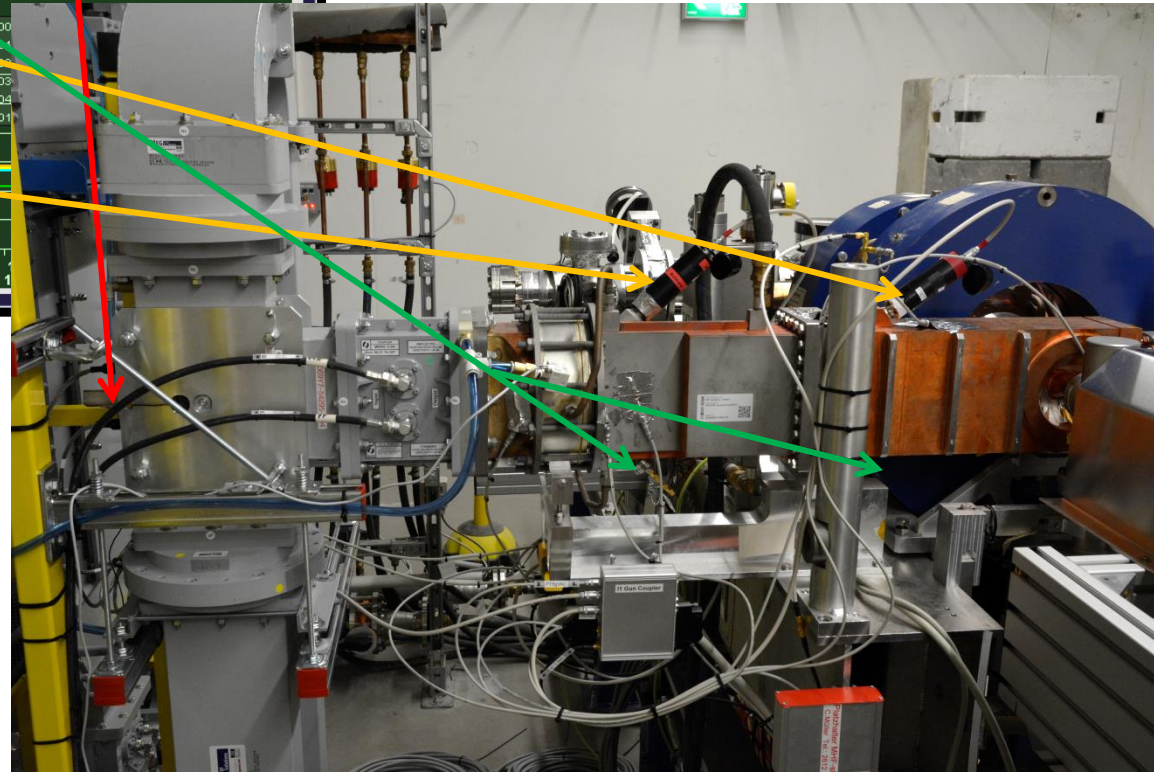
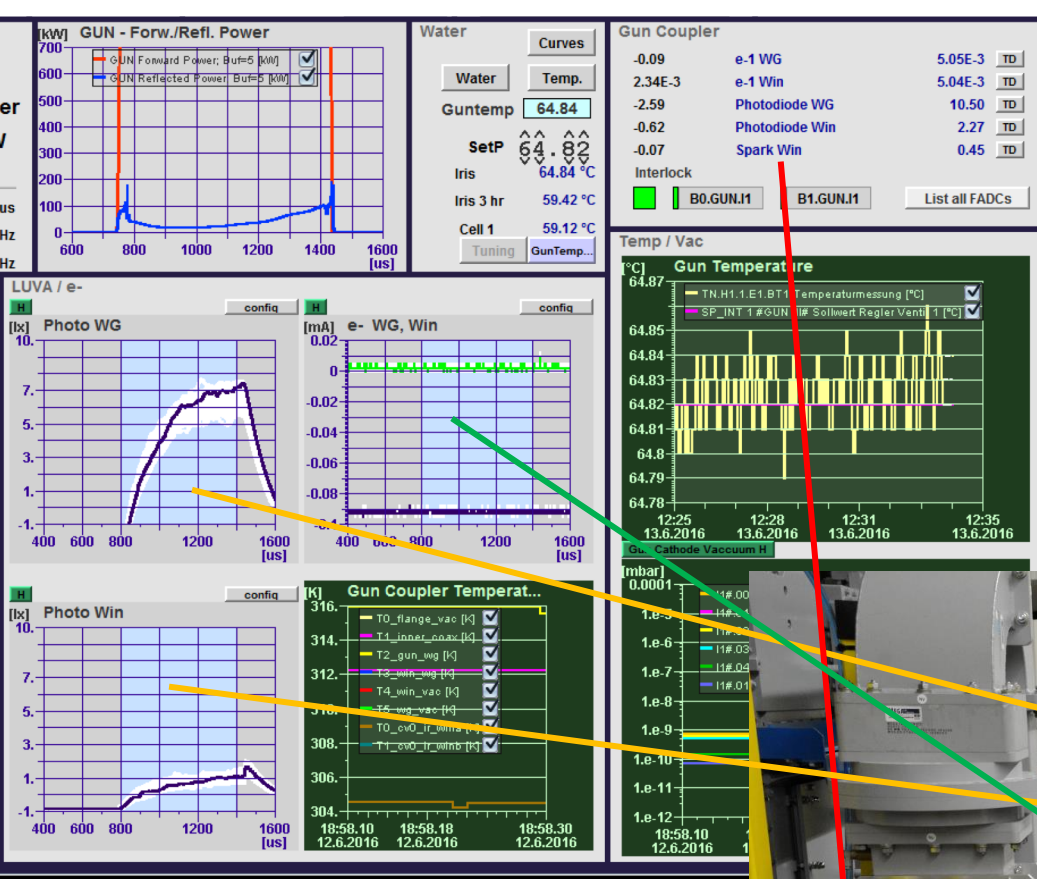
## RF measurement



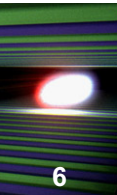
# Gun signals and interlocks



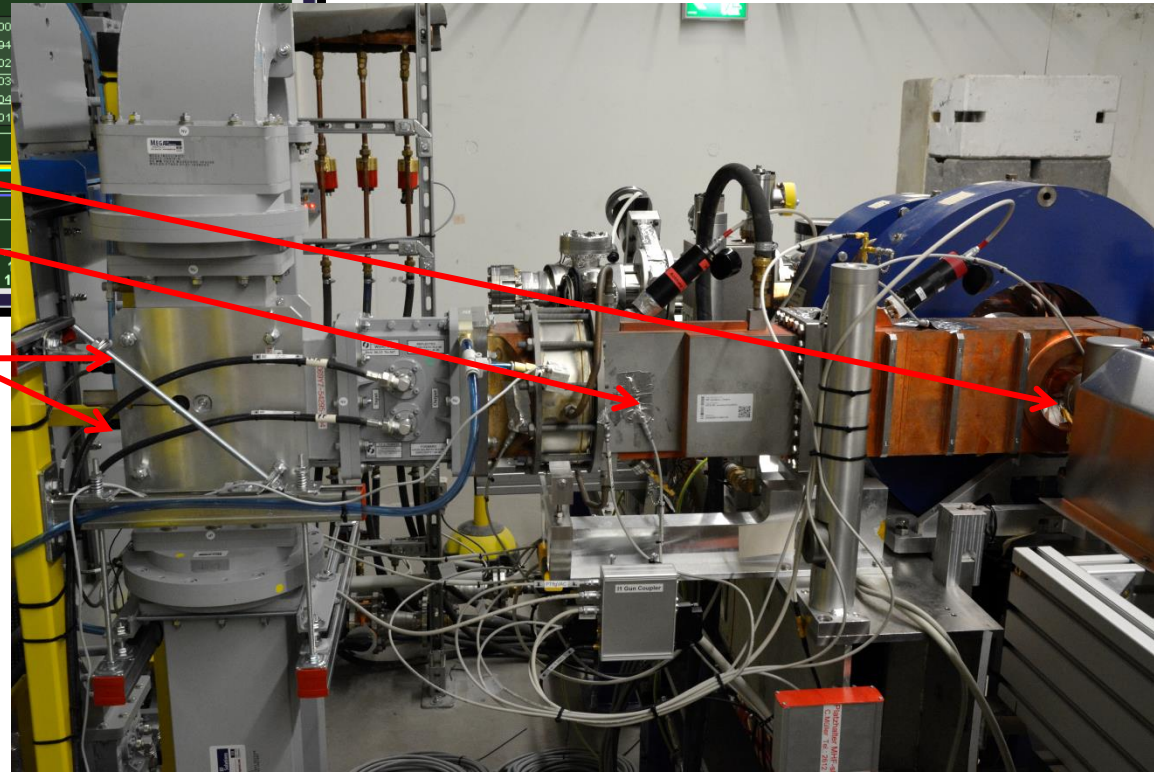
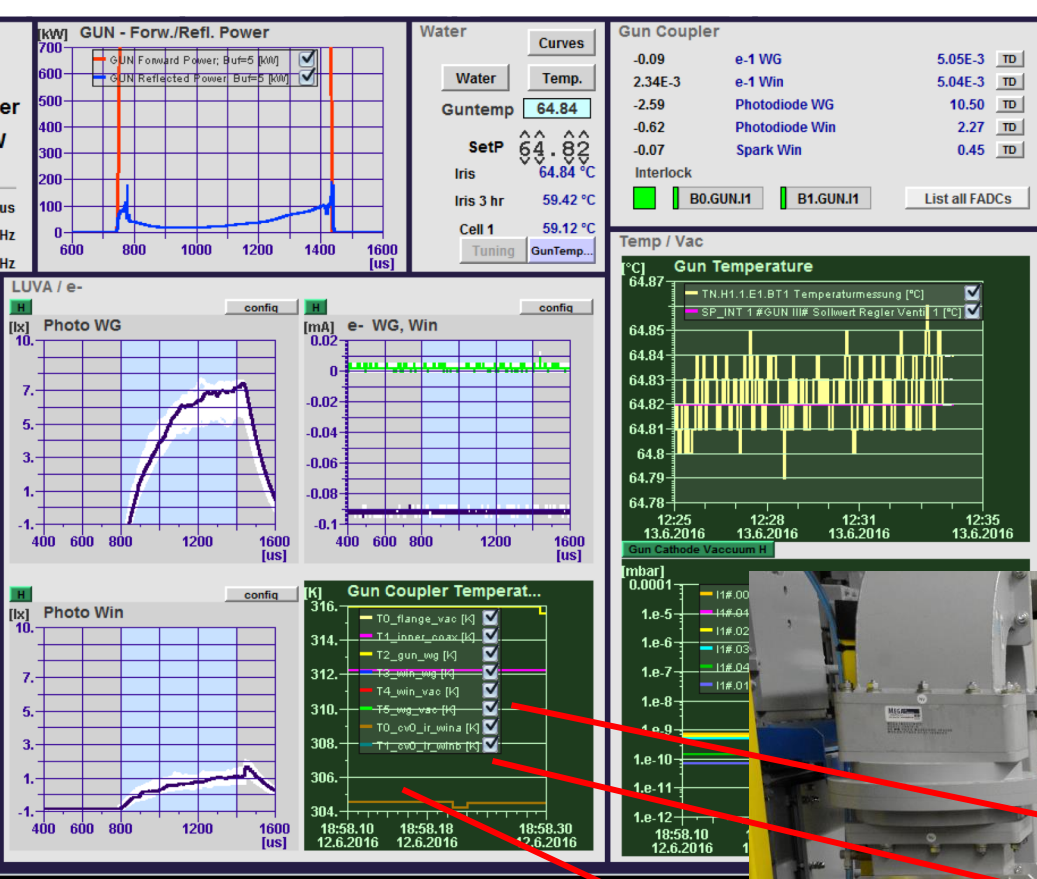
## Light and electron detection

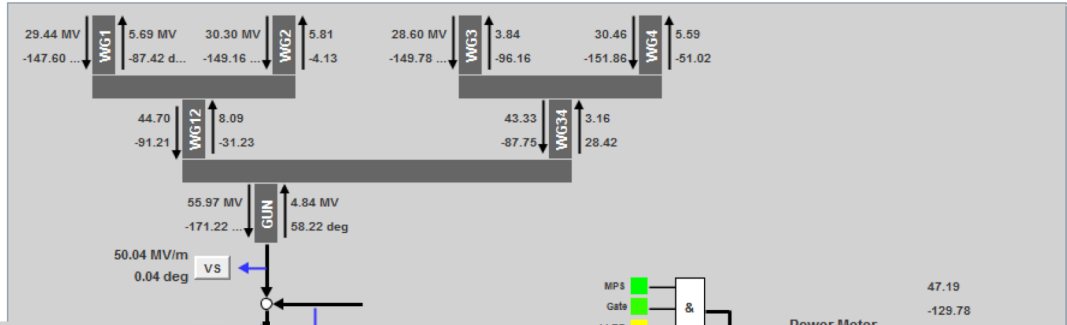
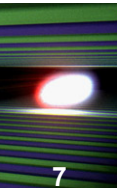


# Gun signals and interlocks



## Temperatures





### Gun limiters and protection

Print

| Input Amplitude Limiter | WG      |           | WG1     |           | WG2     |           |
|-------------------------|---------|-----------|---------|-----------|---------|-----------|
|                         | Forward | Reflected | Forward | Reflected | Forward | Reflected |
| Pre Limiter [a.u.]      | 0.0000  | 0.0000    | 0.0000  | 0.0000    | 0.0000  | 0.0000    |
| Limiter                 | 0.0000  | 0.0000    | 0.0000  | 0.0000    | 0.0000  | 0.0000    |

Fast Protection

Limit: High 1.0000, Low 0.4000, Slope 0.00130, Threshold 17000

Timing: Start 27, Stop 0

Enable:

Table limits

Feed Forward: 44600, Setpoint: 44600

FF Correction: 8000, Controller: 10000

Output: 80.000, Ena:

SP signal

FF  FFC  LFF  DAC offset

OVC Gate

Power Meter: 94.96 dBm, 3.134221 MW

Klystron: 94.90 dBm, 3.123848 MW

Feedback:  FB,  MIMO

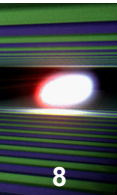
Output limiter:  Enable, 80.00

Pulse settings: Delay 740 us, Filling 30, Flatop 650

LLRF RF Gate Timing (x2timer): Start 586900, Length 86400, 732.35 us

Buttons: FF, SP, FB, LFF, ORC, Virtual Probe, Out, Limiter, Info, VM, Ref1, Ref2, ADC6, ADC4 (Klystron), ADC5 (SINCAV)

# LLRF fast protection – looking at the reflected power



XFEL\_GUN\_IIrf\_main.xml XFEL.RF/LLRF.CONTROLLER/GUN.II/SASE

## LLRF Control: MAIN.GUN.I1

**Main Control**

Voltage  $50.00$  H  
50.00 MV/m

Phase  $0.00$  H  
0.02 deg

FSM ON  RF On / Off

RF running

Feed-Forward  
 Output vector corre  
 Feedback  
 Feed-Forward corre  
 Learning FF

**Performance**

**Subsystems**

RF Gate  RF Gate

Klystron  
Modulator  
Timing  
MPS

Cpl Interlock  GUN.I1

Expert views  
REFER1  
REFER2  
WG Overview  
LLRF Expert  
LLRF Special

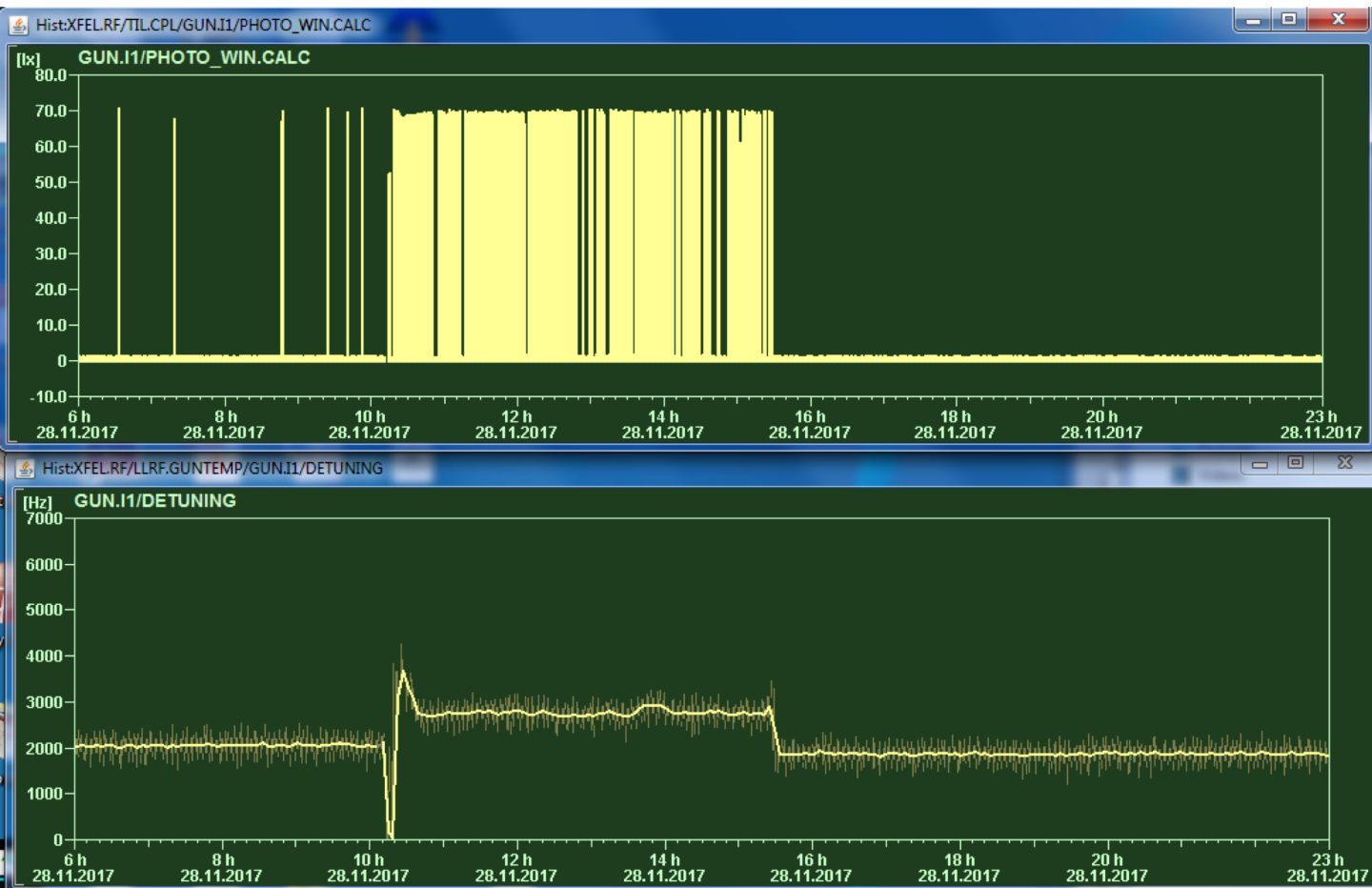
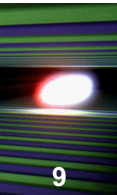
**Pulse Width Modulation**

Pulse Width Feedback

Activate when gun is stable!  
 Activate fast protection  
Protection  H

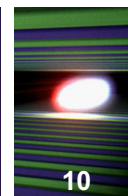


# Strong temperature ( detuning ) dependance of light emission

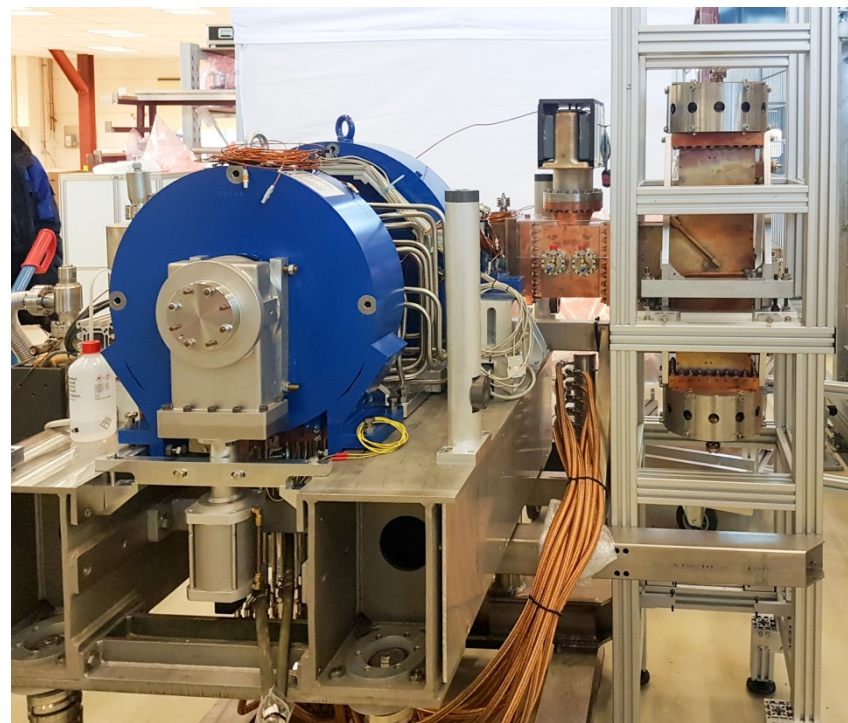


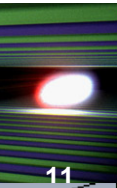
Below 2200 Hz  
Much less activity.

$$200\text{Hz} = 0.01^\circ \text{ C!}$$

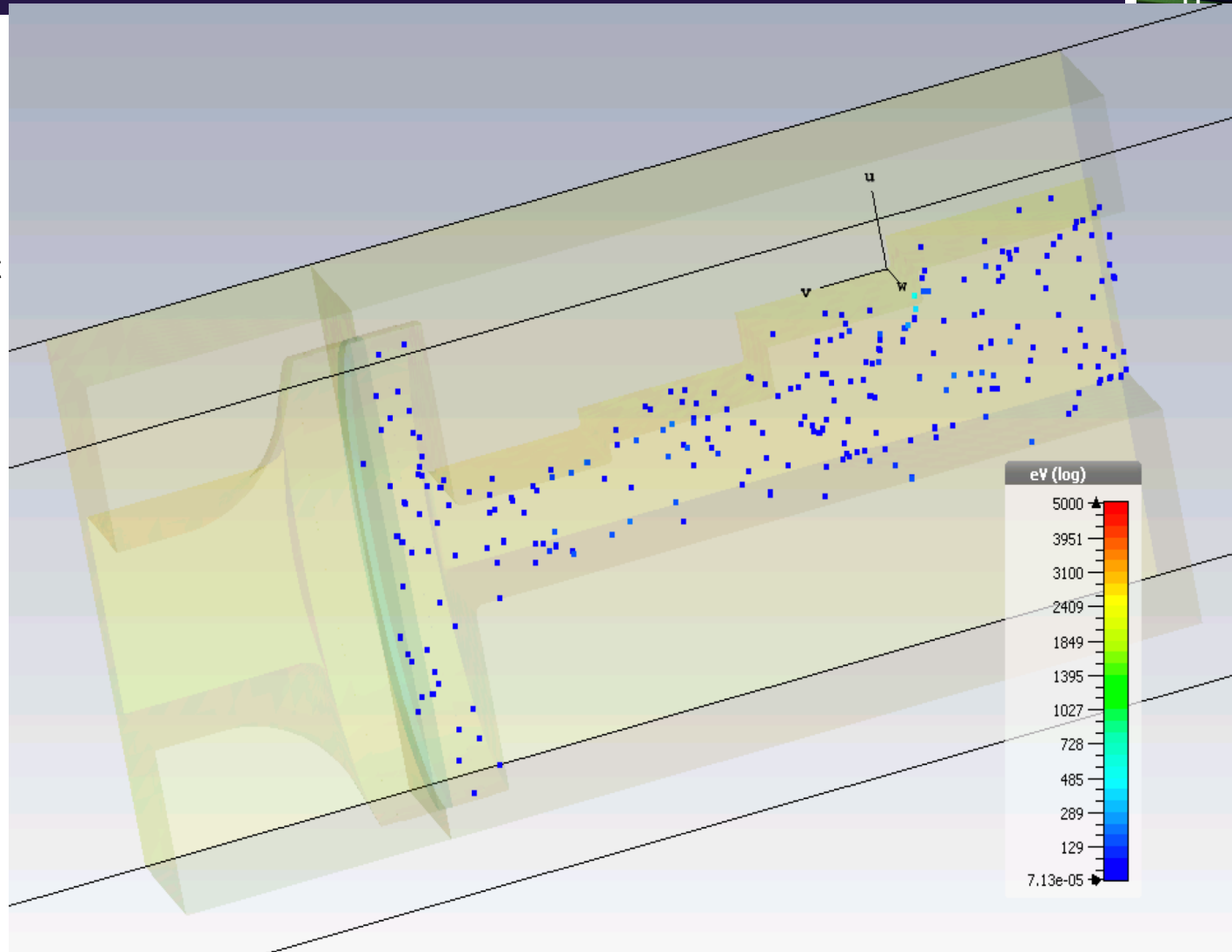


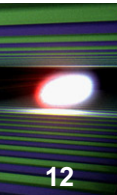
- December 2017 the gun has been exchanged with the Gun 4.6, which has been conditioned at PITZ
- The two guns are identical beside a different cathode spring design ( watchband reloaded at 4.6 )
- The goal is to have two identical guns available which proved to deliver beams for SASE
- It turned out that the Thales window easily produced multi pactoring with rapid raise of vacuum pressure
- Could not get rid of this also after longer conditioning



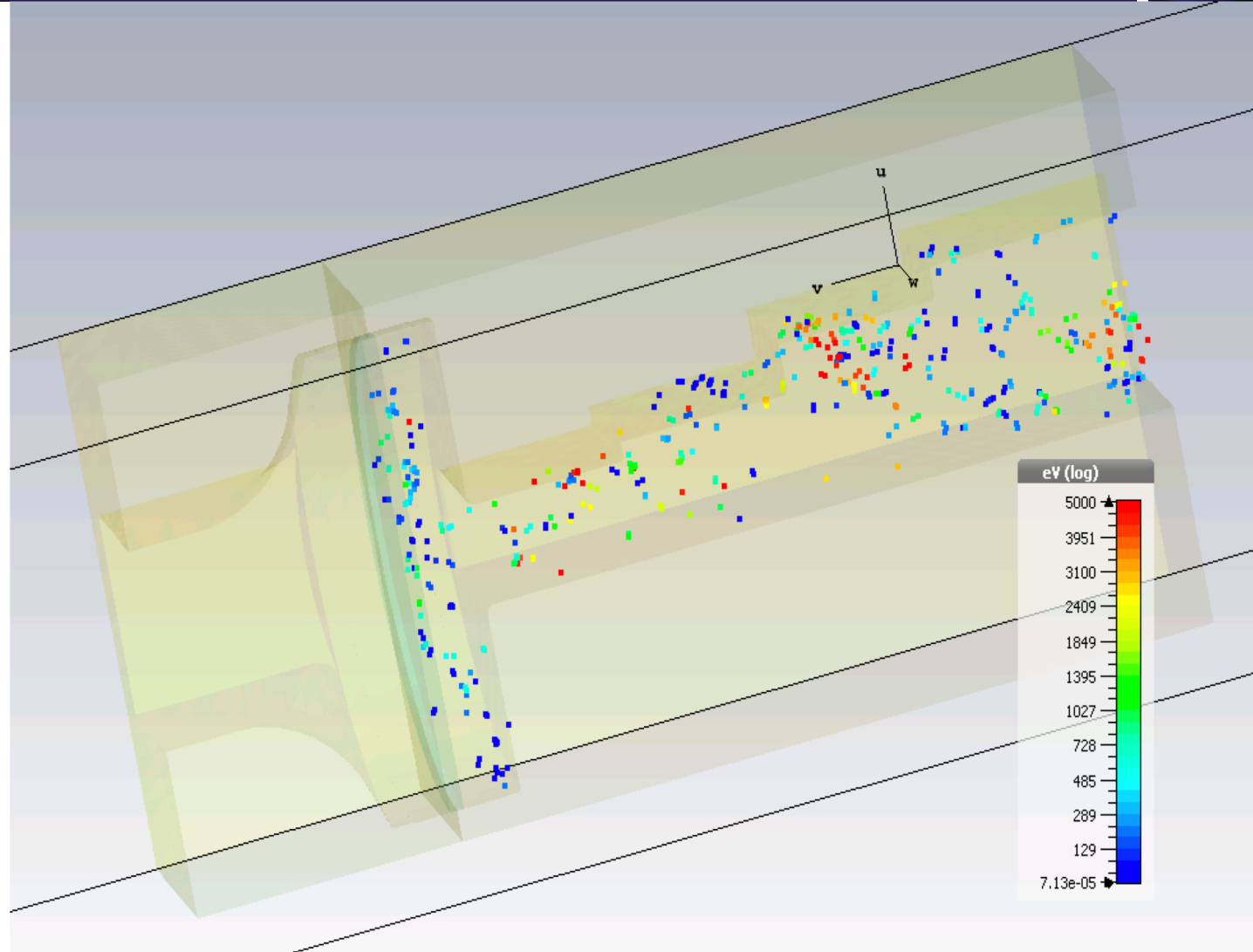


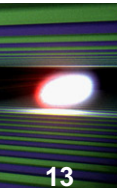
- $t = 0.05 \text{ ns}$
- $n = 1,000$
- The electrons are distributed pseudo randomly in space at the beginning



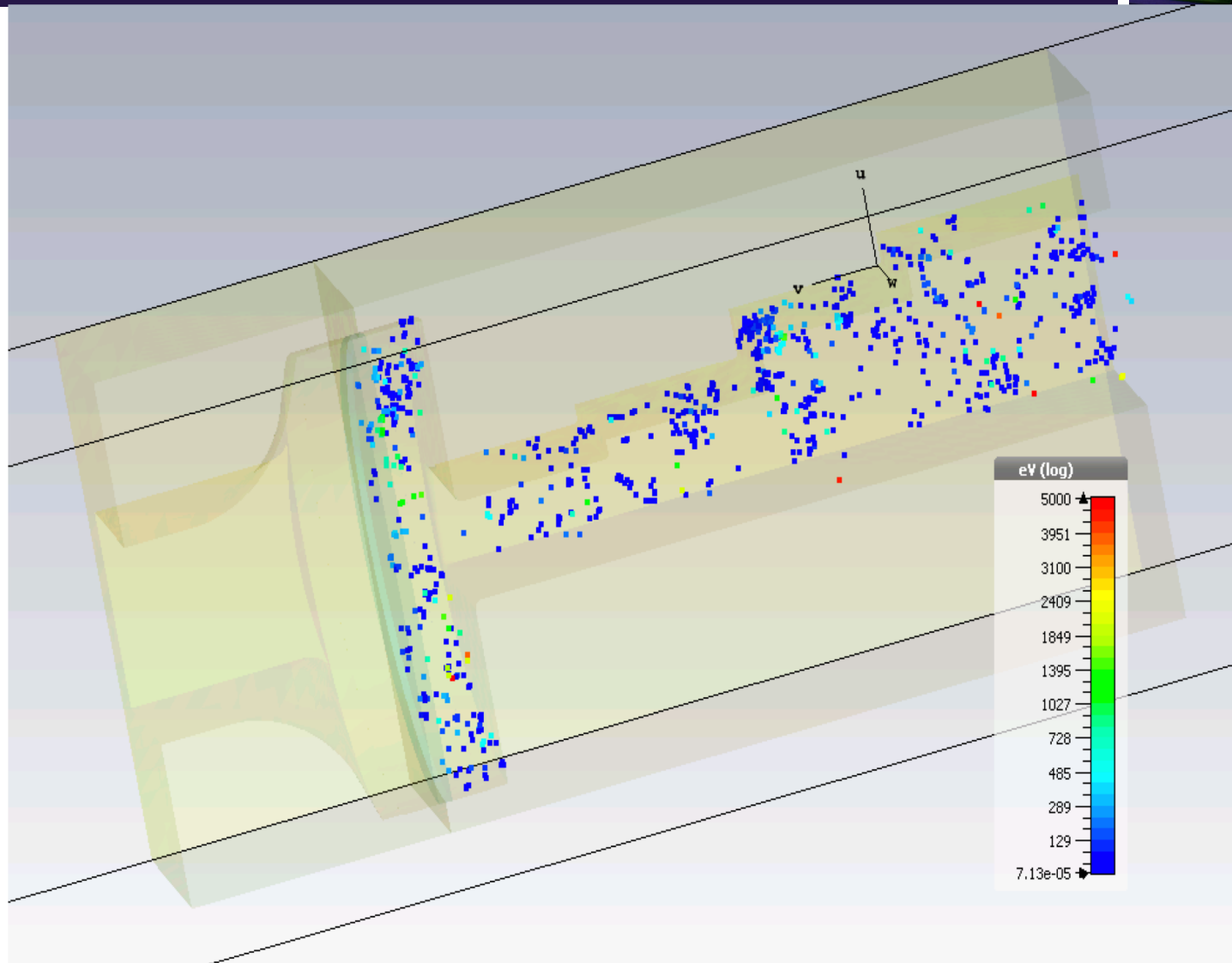


- $t = 2 \text{ ns}$
- $n = 1,008$
- Electric field accelerate the electrons
- Power = 6.98 MW

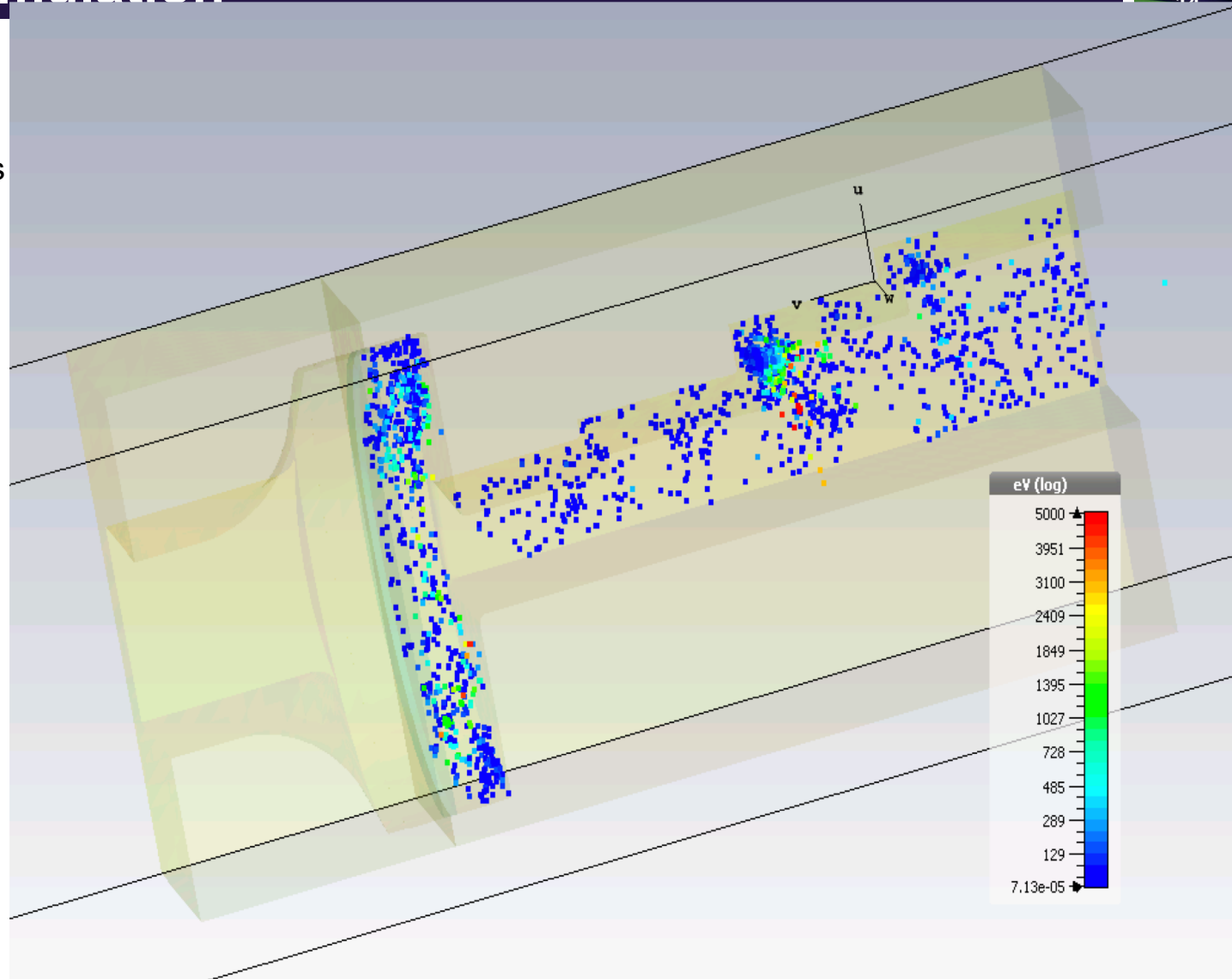




- $t = 10 \text{ ns}$
- $n = 1,942$
- Number of electrons doubles

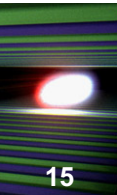
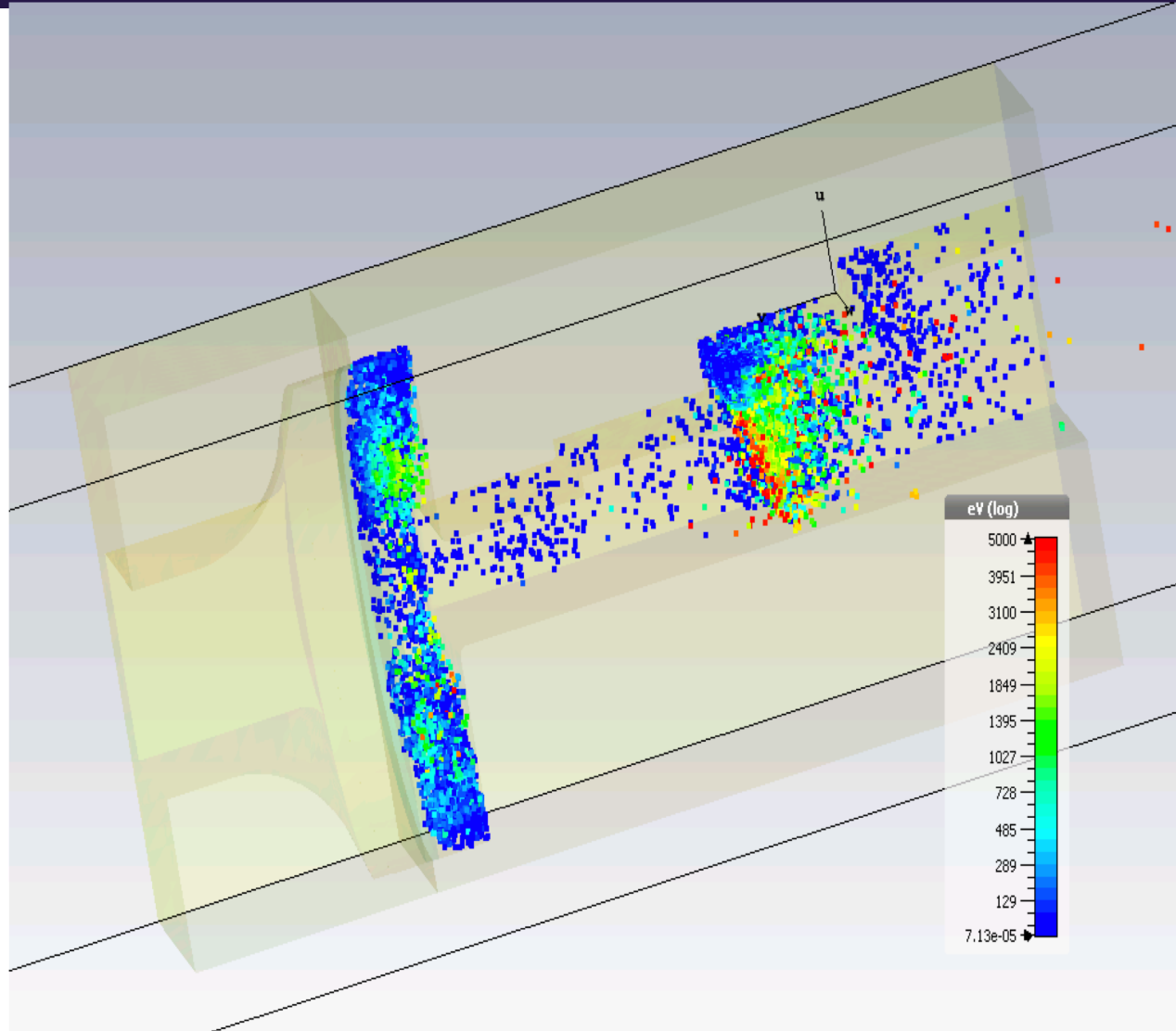


- $t = 20 \text{ ns}$
- $n = 3,983$
- Number of electrons doubles again

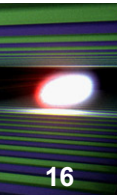


# European XFEL Run Simulation

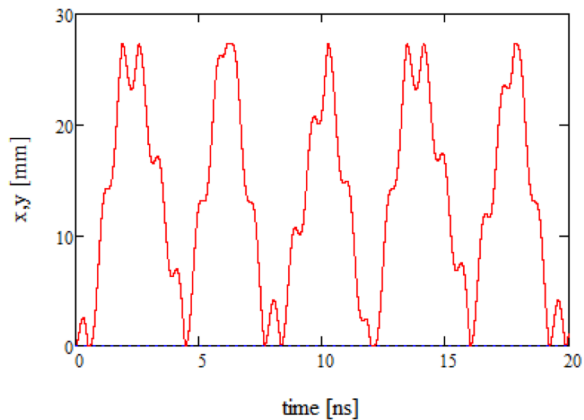
- $t = 40 \text{ ns}$
- $n = 56,413$
- Number of electrons increase faster
- Electrons are concentrate in some parts
- Important: were the electrons are concentrate depends on the applied power



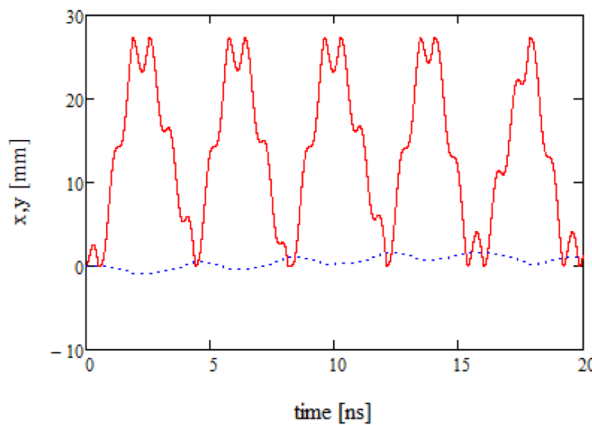
# Qualitative calculation of multipacting between copper and ceramic with magnetic field



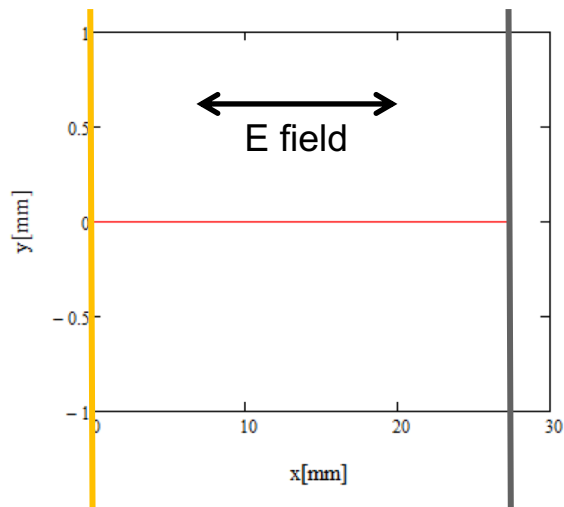
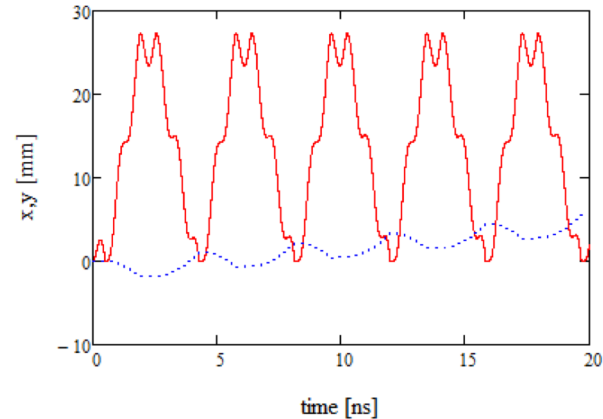
$E_0 = 0.86 \frac{MV}{m}$   $B_z = 0 \text{ mT}$



$E_0 = 0.86 \frac{MV}{m}$   $B_z = 0.3 \text{ mT}$

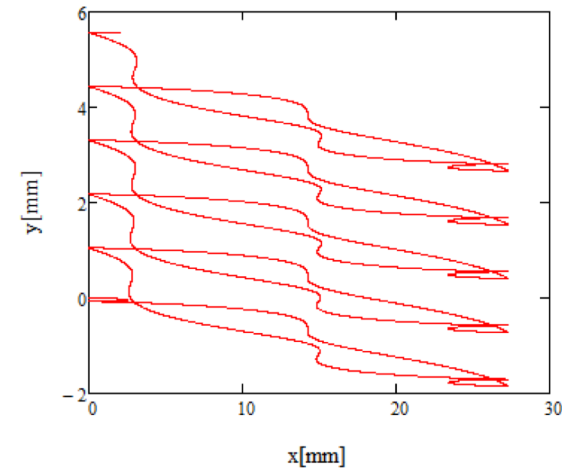
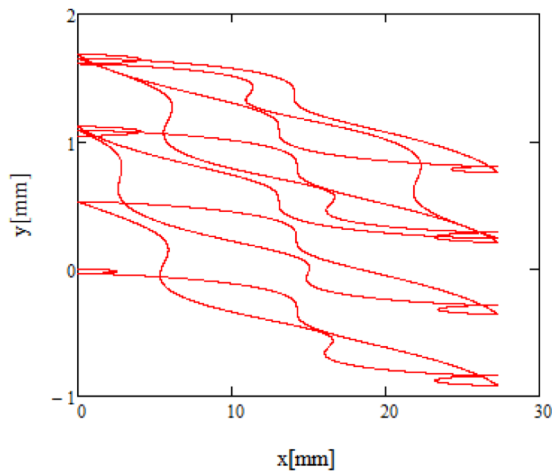


$E_0 = 0.86 \frac{MV}{m}$   $B_z = 0.6 \text{ mT}$



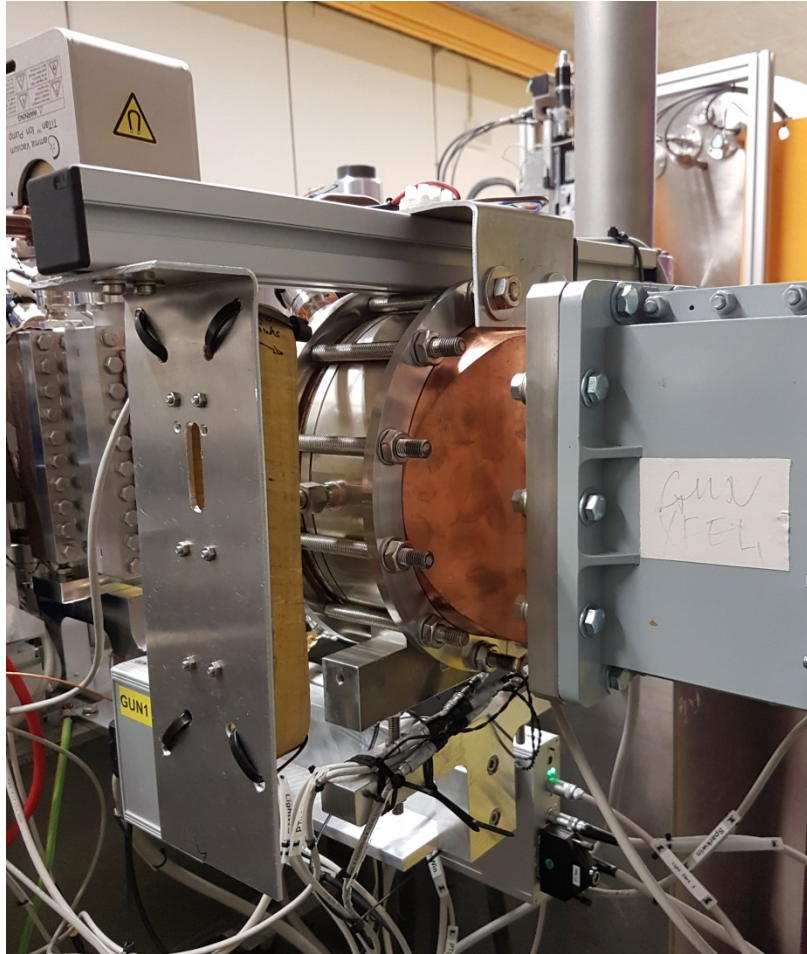
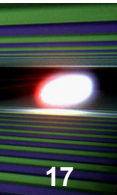
copper

ceramic



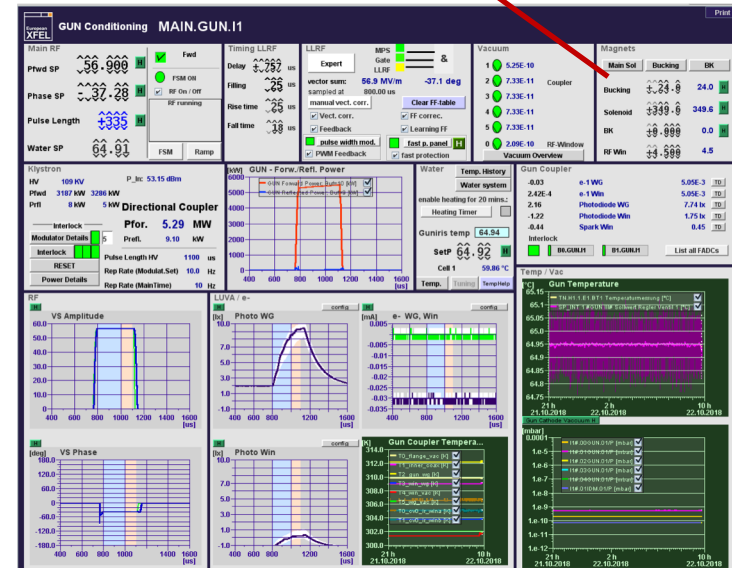


# Preliminary installation of air coils at the gun vacuum window – successful suppression of MP



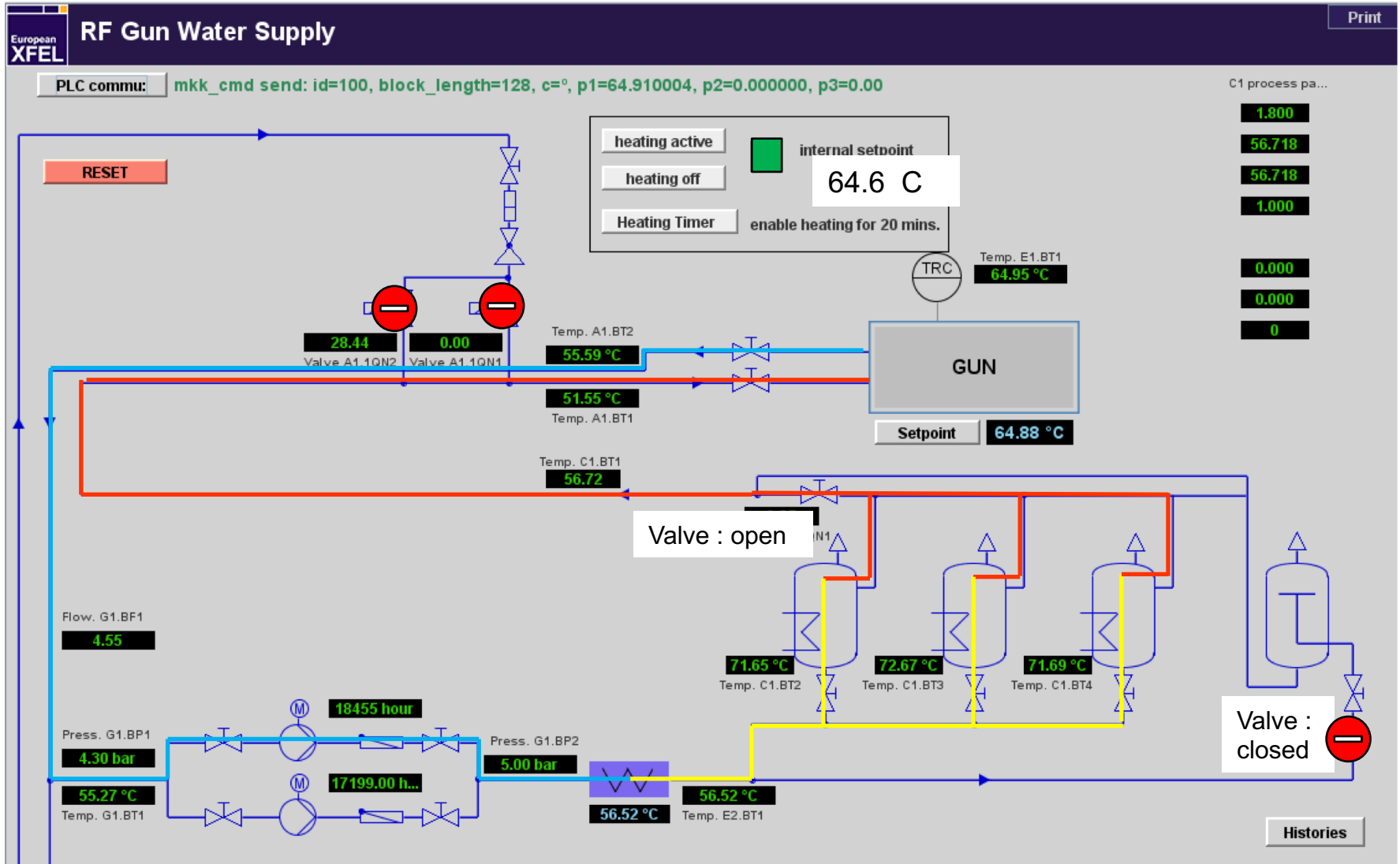
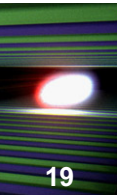
| Magnets  |             |         |
|----------|-------------|---------|
| Main Sol | Bucking     | BK      |
| Bucking  | $\pm 24.0$  | 24.0 H  |
| Solenoid | $\pm 349.6$ | 349.6 H |
| BK       | $\pm 0.000$ | 0.0 H   |
| RF Win   | $\pm 4.500$ | 4.5 H   |

5A ~ 1mT

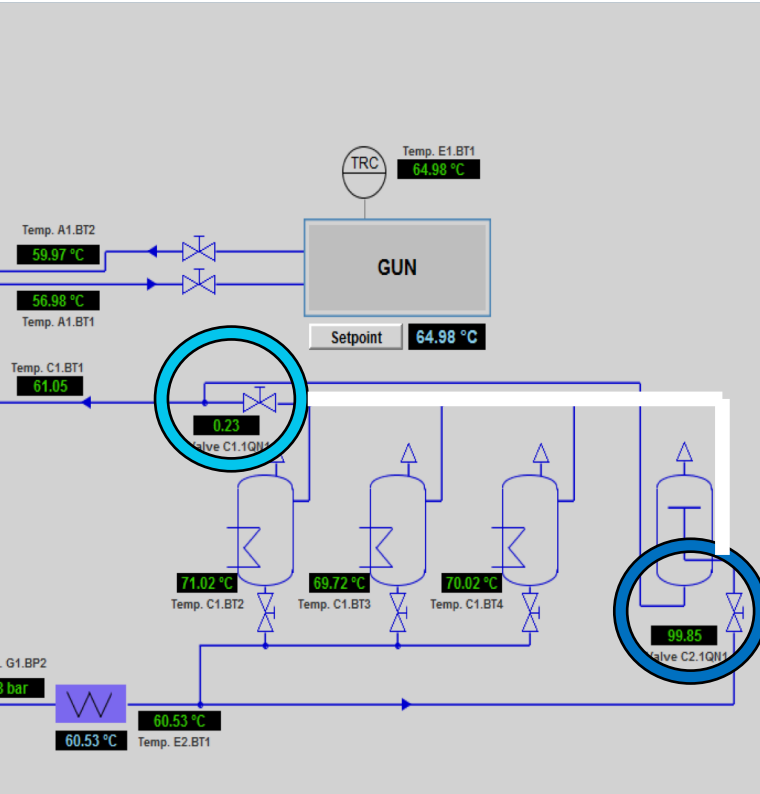
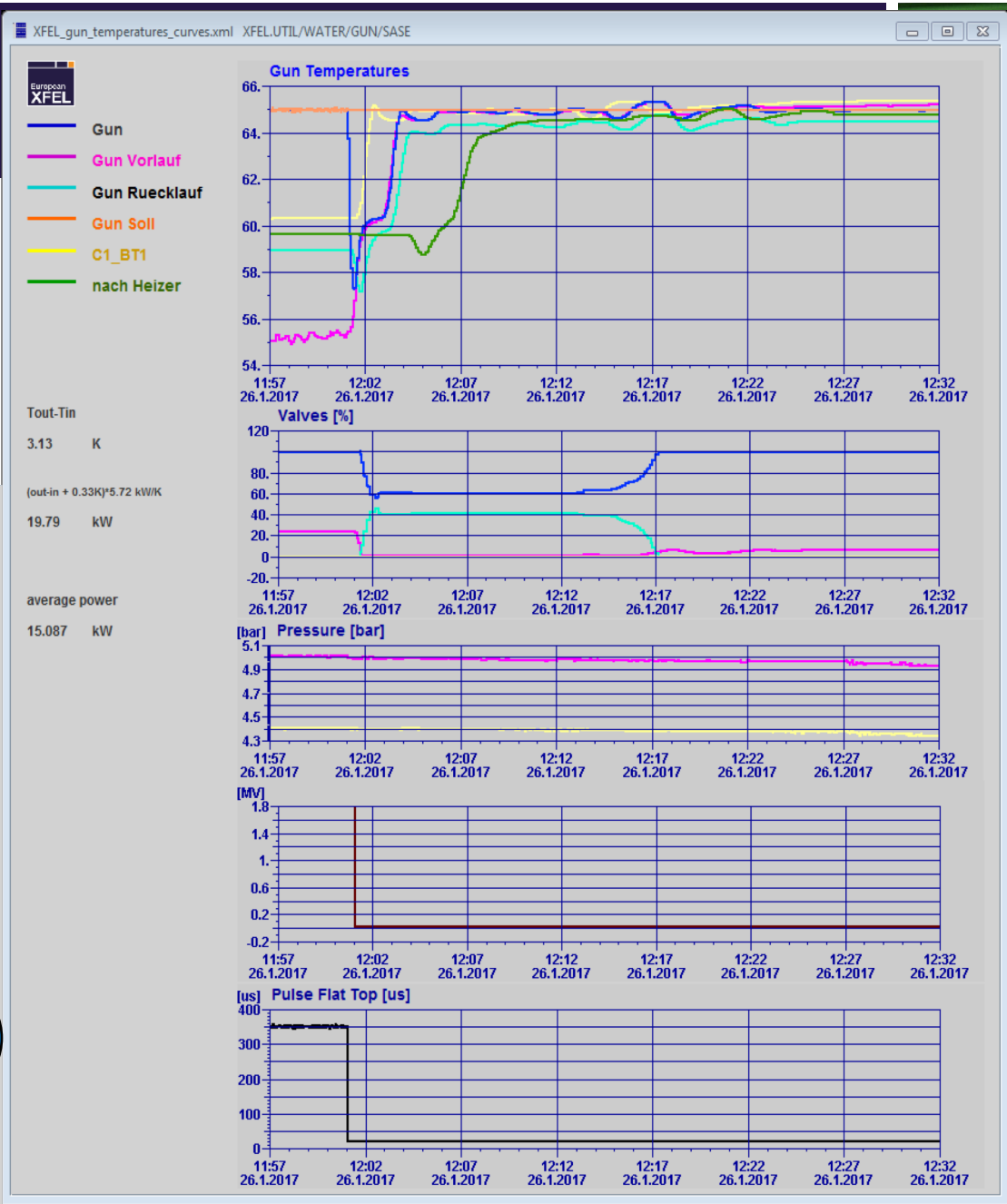




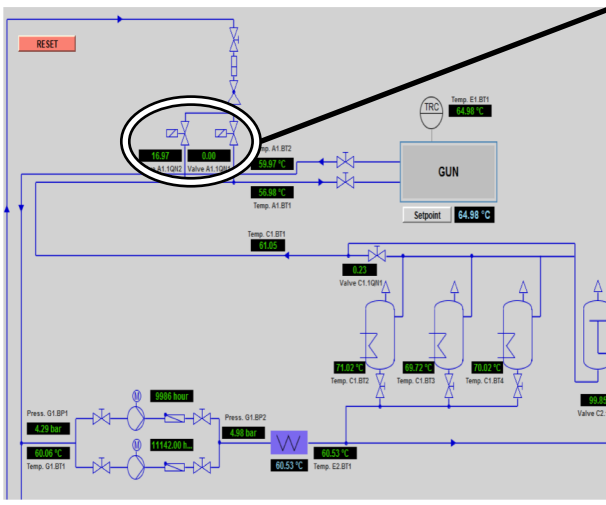
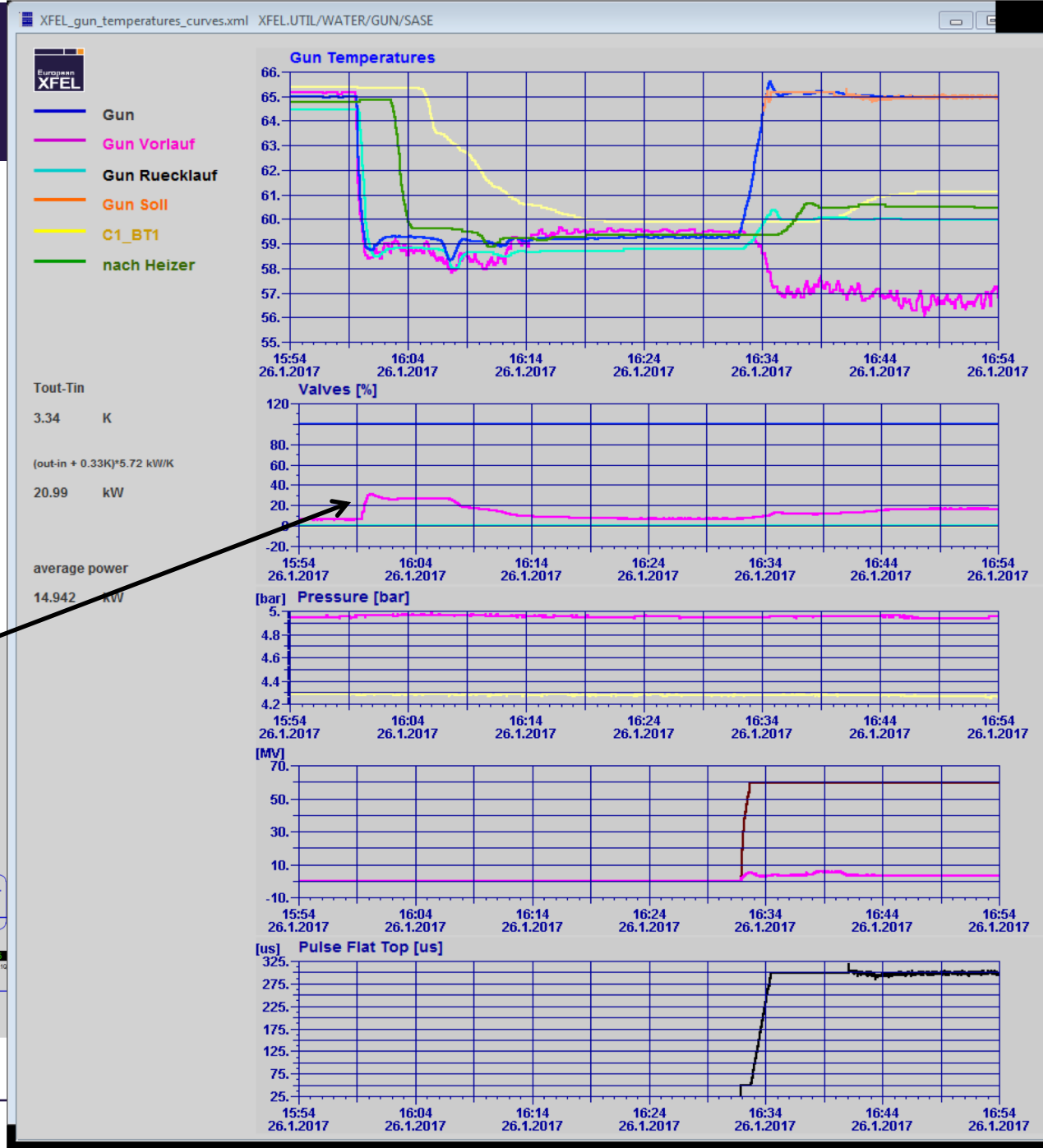
# Water temperature regulation – heating up for some time



# Heating up by adding hot water from the tanks

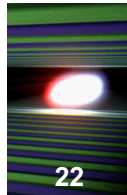
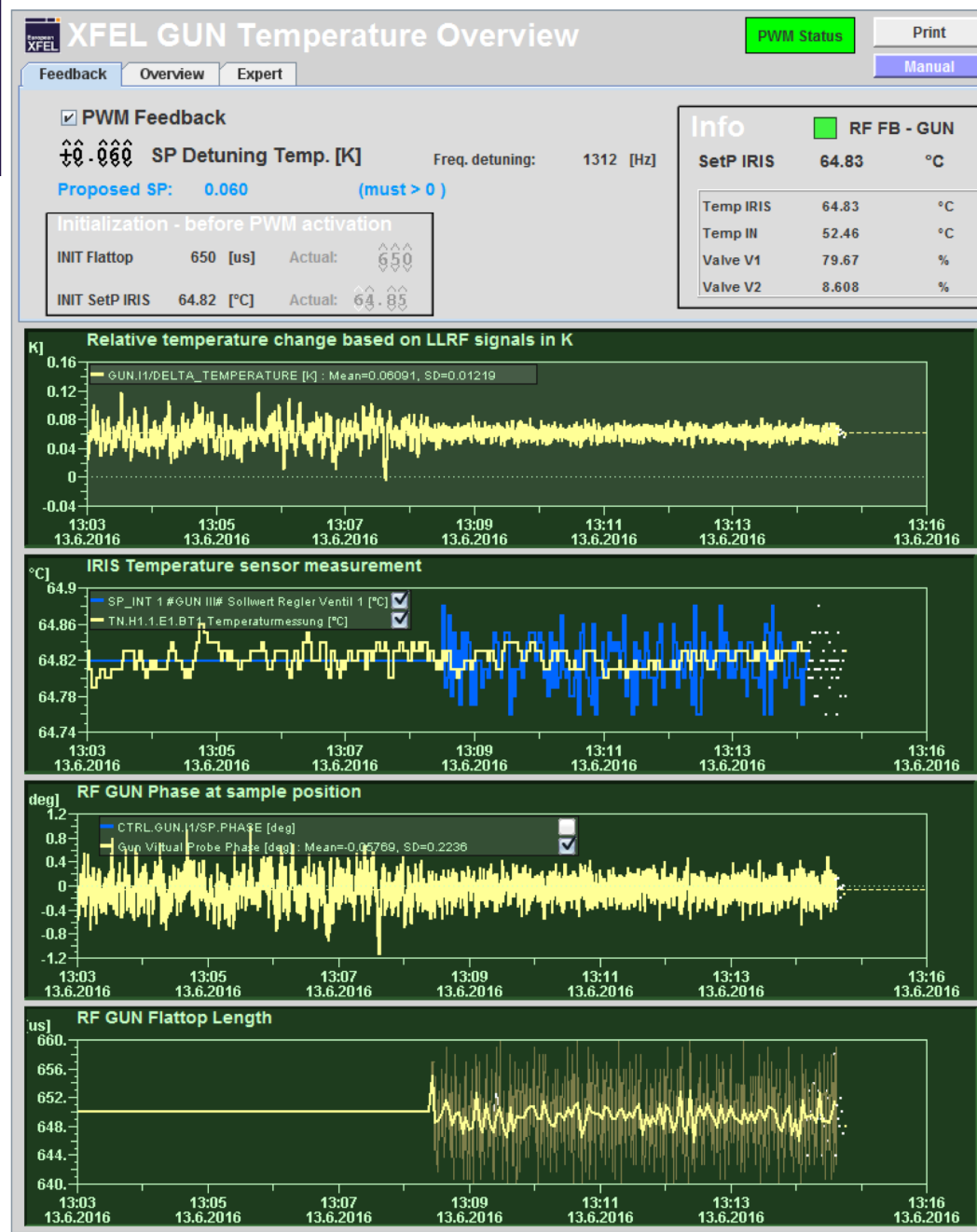


# Cooling down with cold water



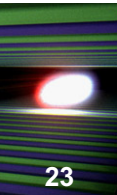
# Pulse width modulation

- Fast measurement of gun temperature/detuning (0.1sec vs. 7 sec)
- compensate temperature deviations with the RF pulse width
- Compensate for cooling water drifts after ramp



# Fast Gun Ramp Up – by FSM

Typically the parameters are taken from the last run!



XFEL\_gun\_conditioning.xml XFEL\_DIAG/TIMER.CENTRAL/MASTER/SASE

### GUN Conditioning MAIN.GUN.I1

Main RF

Pfwd SP: 0.020  
Phase SP: 27.00  
Pulse Length: 20  
Water SP: 59.21

Fwd  
FSM ON  
RF On / Off  
RF is switched off

Timing LLRF  
Delay: 740 us  
Filling: 30 us  
Rise time: 30 us  
Fall time: 16 us

Klystron  
HV: 0 kV  
P\_Inc: 2.20 dBm dBm  
P\_Pwd: 0 kW  
P\_Prt: 0 kW

Directional Coupler  
Pfor: 0.00 MW  
Modulator Details  
Interlock: 0  
Pulse Length HV: 1000 us  
Rep Rate (Modulat.Set): 10.0 Hz  
Rep Rate (MainTime): 10 Hz

RF  
WG Sound  
VS Amplitude

### FSM : Gun Ramp Up

FSM On

Target values

VS setpoint  
Pulse width [us]  
Resonance Temp. [°C]

Average power:  
now: 12.42kW target: 12.26 kW

Water  
Start temperature: 64.92 °C  
Water Setpoint: 65.07 °C

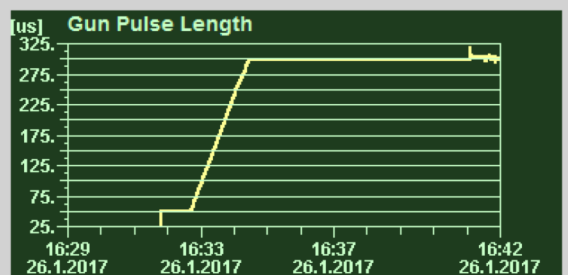
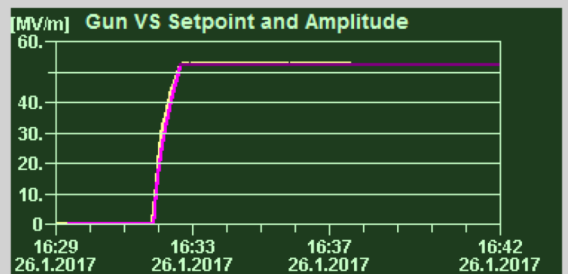
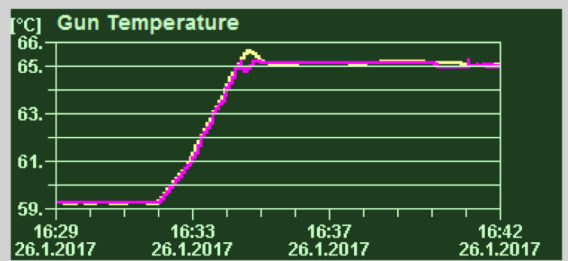
Start Ramp  
Switch off RF

FSM RF On:   
FSM RF Off:

RF running

FSM

Print Help



1) FSM On

2) Choose targets: gradient and pulse width

Estimation for the start temperature

3) Set start temperature and wait until it's reached (~0.2 C)

4) Start ramp by switching FSM RF On

FSM messages

Only for new parameters!

1. The FSM **sets the Gun frequency** on the actual resonance frequency defined by the temperature
2. Gradient and pulse length are ramped up
  - The temperature set point tracks the actual temperature which rises with RF power
  - The frequency is kept on resonance to avoid reflections
3. After reaching the target values, the FSM is waiting for the temperature to stabilize before setting the frequency to nominal.
4. The pulse width modulation is started to compensate for temperature drifts
5. When Set points for amplitude and phase are close to the measured values the feedback and learning feed forward are started. From now on the gun parameters can be changed by hand as usual
6. “RF off “ switches the gun off – the temperature setpoint follows the actual temperature, therefore we end up already with the correct starting point to come back with the same parameters

