Operation of the Valencia S-band high-power test stand and current activities

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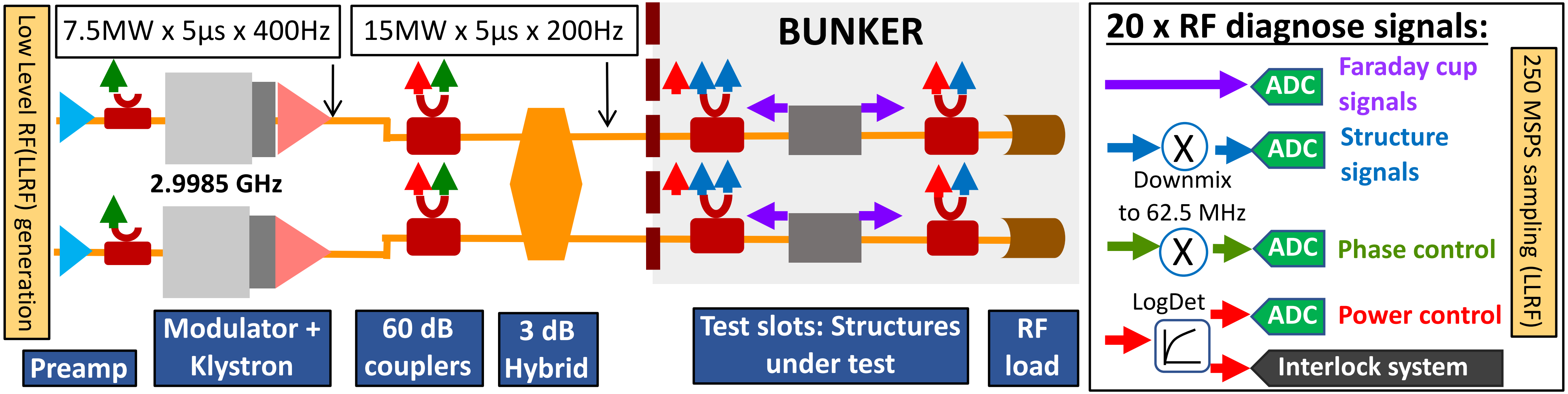
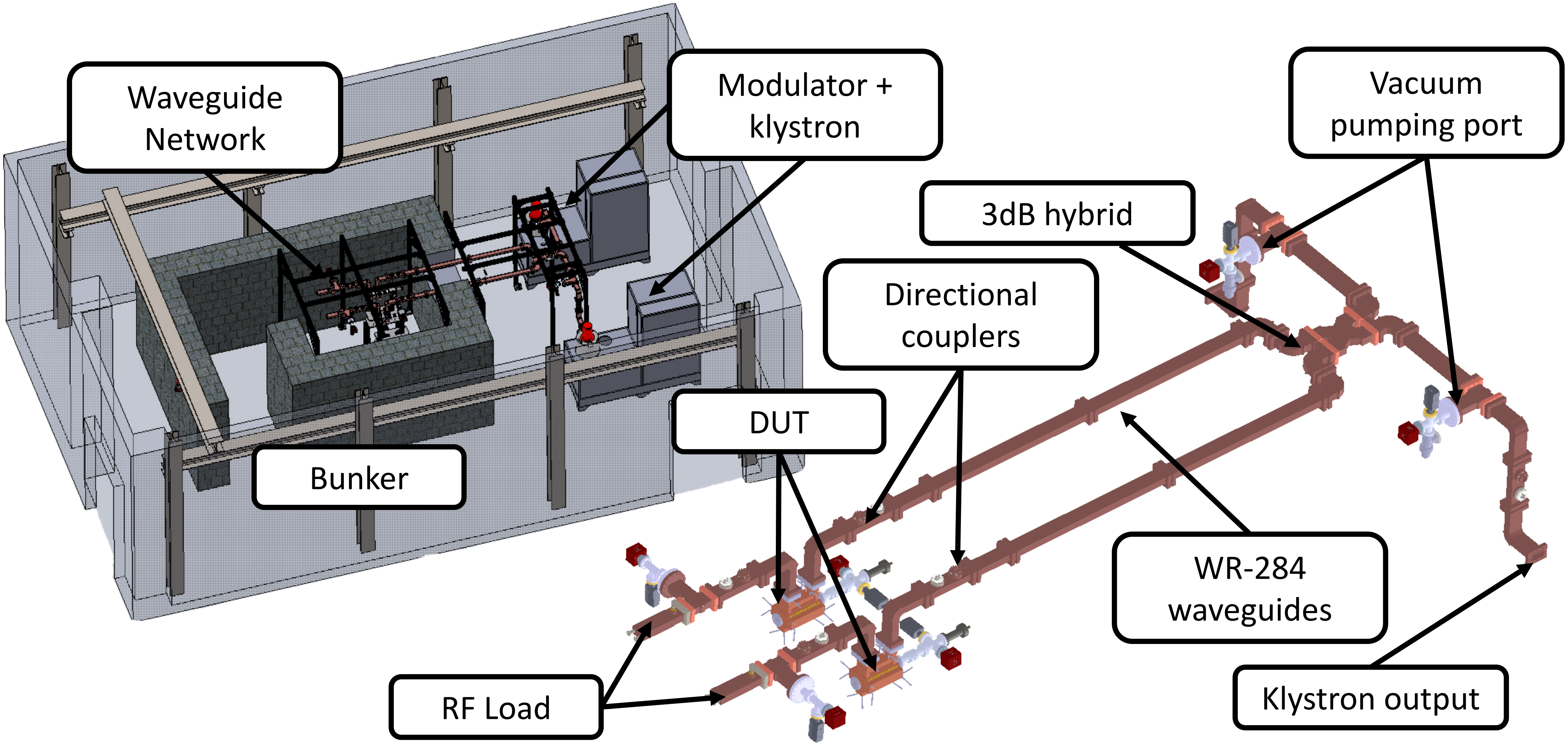
The IFIC – HGRF Laboratory: Overview

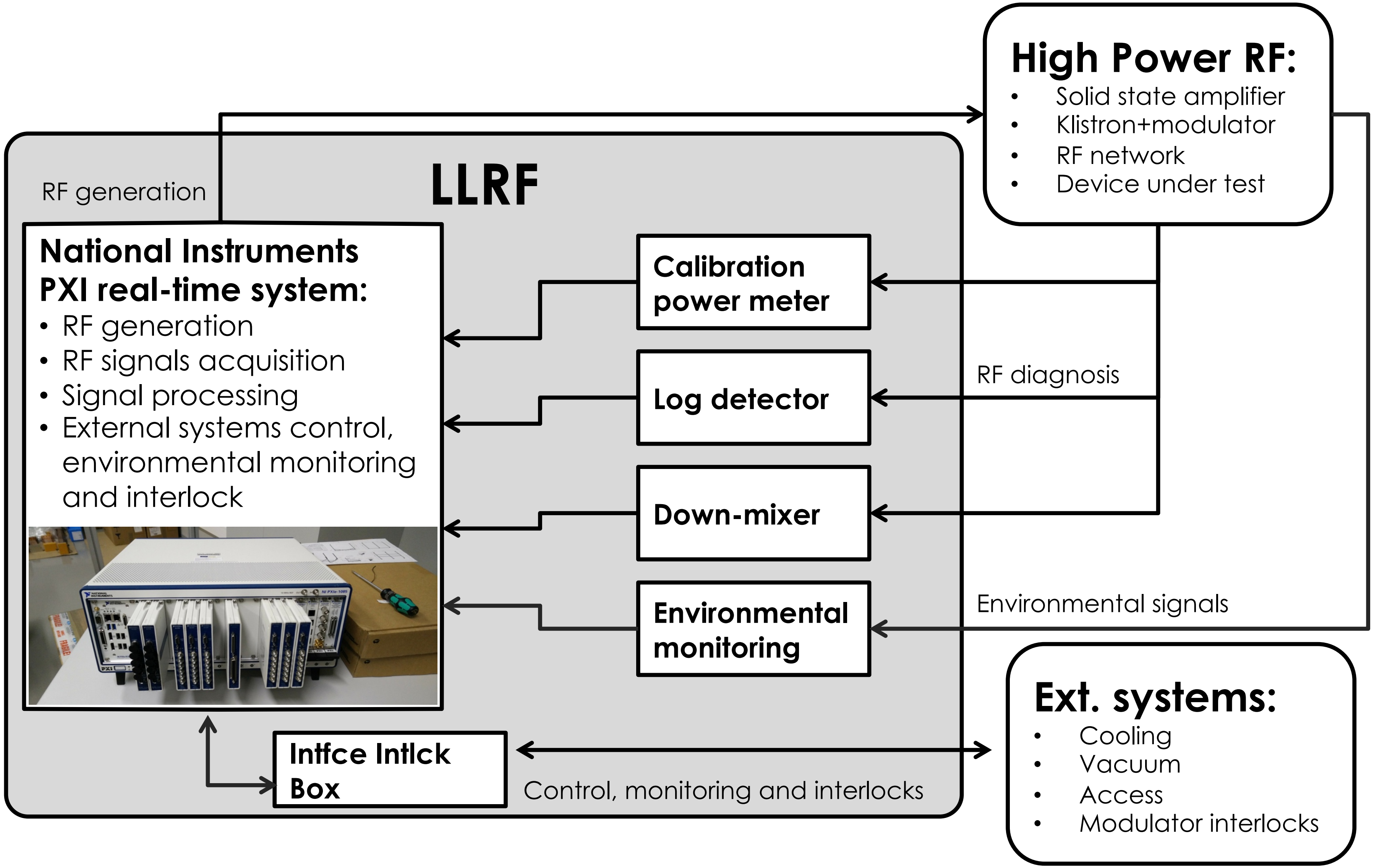


- Technical specifications:
  - S-Band (2.9985 GHz)
  - Pulsed High Power RF (HPRF):
    - 2 x pulsed power klystron: to 7.5 MW, 5 us pulse, 400 Hz
    - High power waveguide RF network that allows power combining: enables to test 2 structures at a time at up to 15 MW, 5 us pulse, 200 Hz repetition rate
  - Low level RF (LLRF): real-time control system with fast system interlock based on Ni-PXI acquisition system
  - Running on Ultra-High vacuum (10^{-9} mbar)

The IFIC – HGRF Laboratory: Overview



RF System Overview



The IFIC – HGRF Laboratory: Status

HPRF Sub-components:

- ☑ **Waveguide** components characterization.
- ☑ **Klystron** VKS8262G1 installation and test.
- ☑ **SSPA** (Solid-state Power Amplifier) installation and test.
- ☑ **Jema Modulation** installation and test.

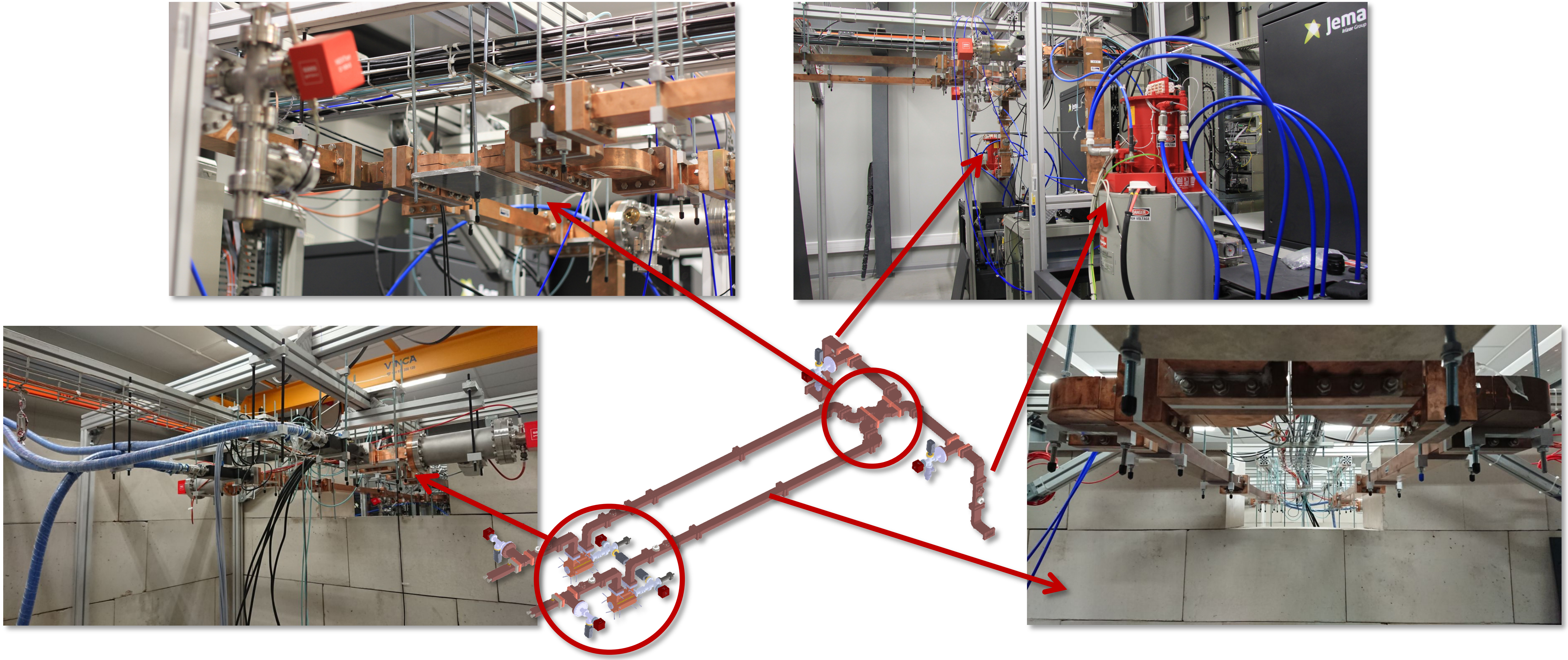
LLRF Sub-components:

- ☑ **Down-Mixer** assembly and test.
- ☑ **Log-Amplifier** assembly and test.
- ☑ **Interlock System** assembly and test.
- ☑ **Trigger Interlock Box** assembly and test.

See: **Commissioning of the V-box Laboratory at IFIC (HG2018)** by Daniel Esperante

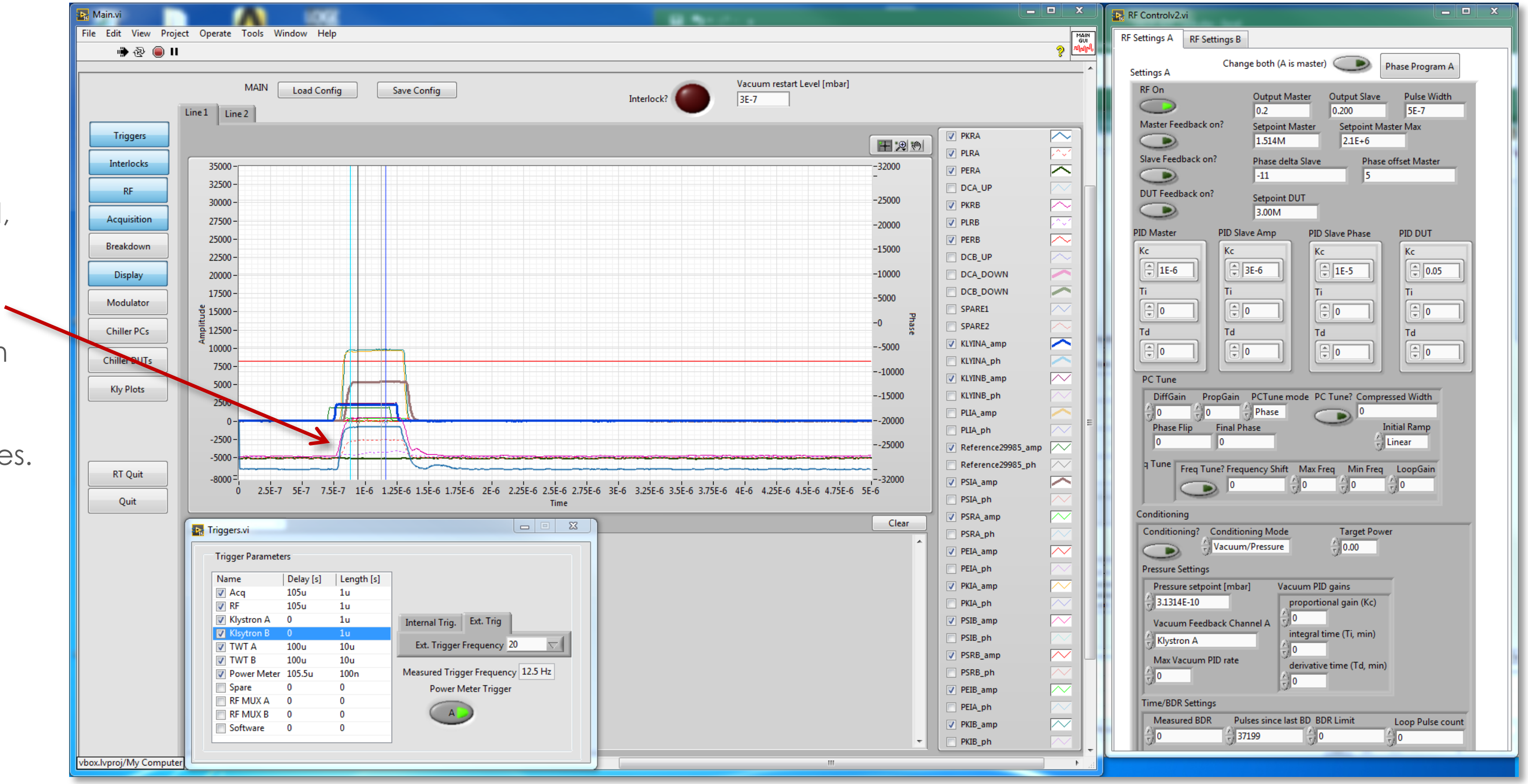
Laboratory Integration, Conditioning and Performance

HPRF Integration Status.



PXI and LabVIEW Integration Status.

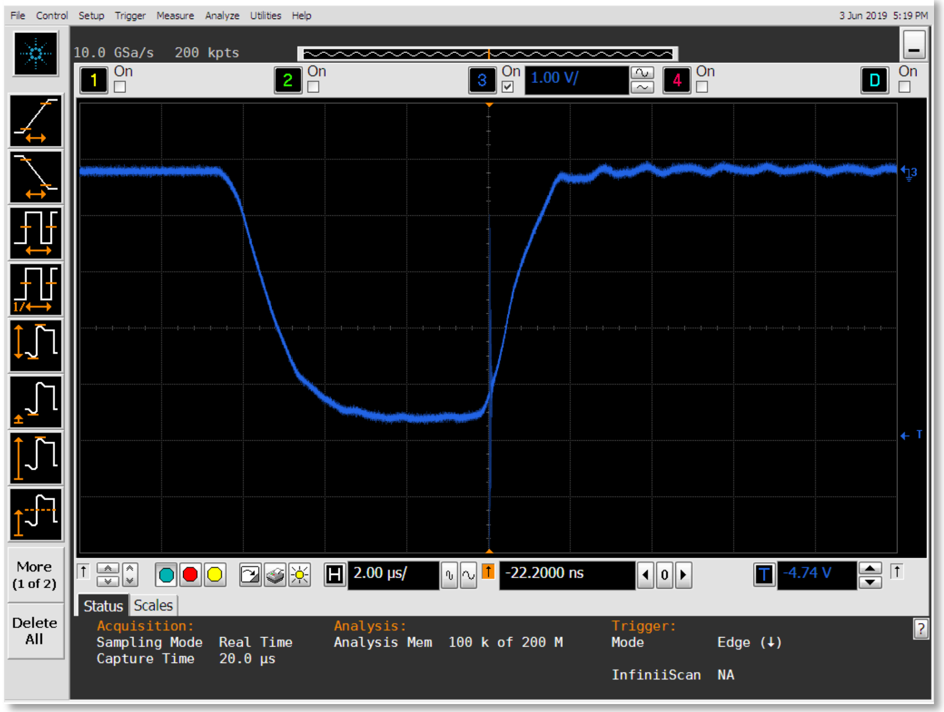
- Reflected signal measured, through the Log-Detector Crate, on the DC near to the Klystron windows.
- The measurement done on this DC, with the power meter, shows a -23.5 dB reflected signal, in both lines.



- LabVIEW Software adapted from the one for the XBOX3.
- First version of VBOX LabVIEW software has been released.
- All calibrations have been done.
- Power feedback loop and control displays working stably.

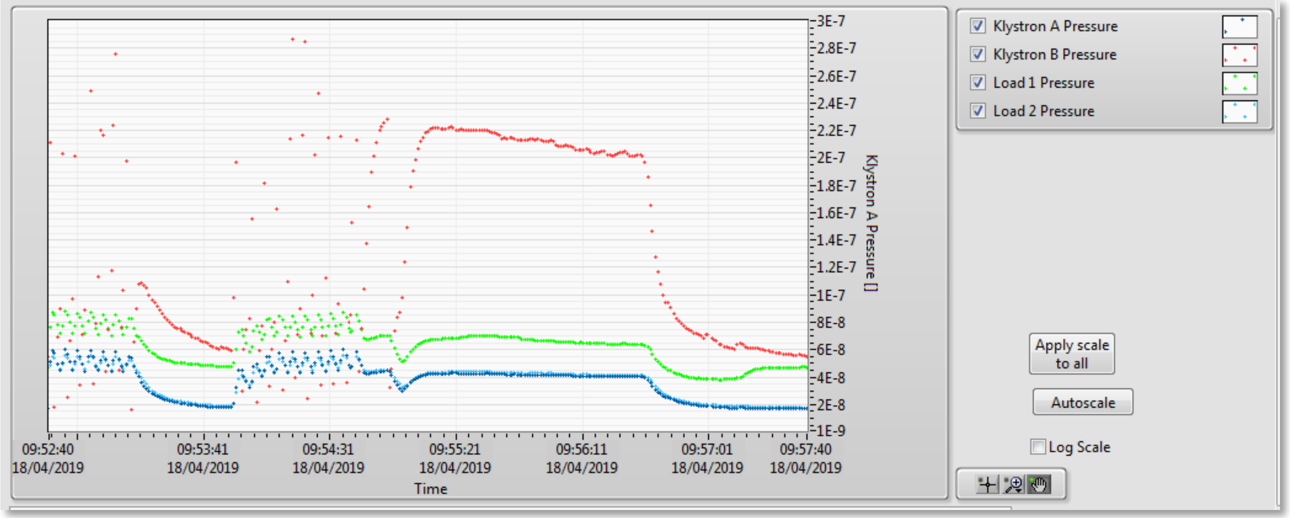
HPRF Conditioning Status

Klystrons Conditioning:



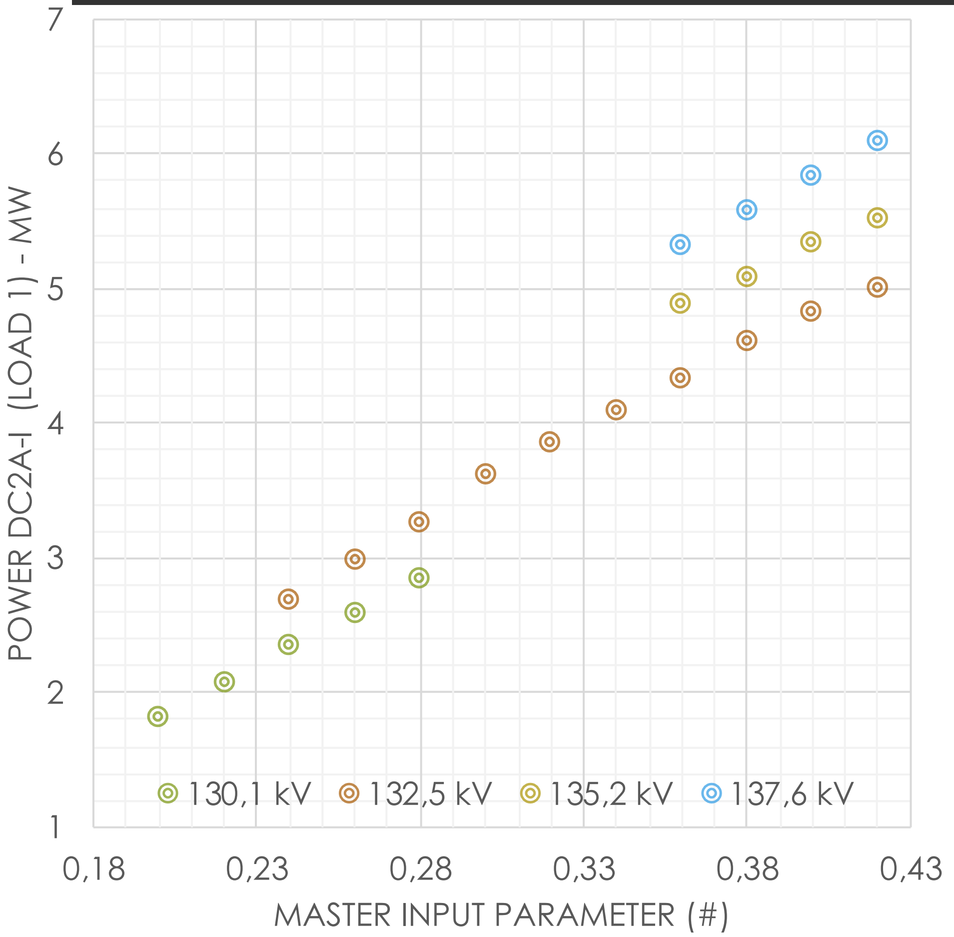
- Both klystrons have been conditioned in diode mode.
- Eventually, spikes appear on the cathode current, which limit the cathode voltage applied.
- These events disappear with the number of voltage pulses injected.

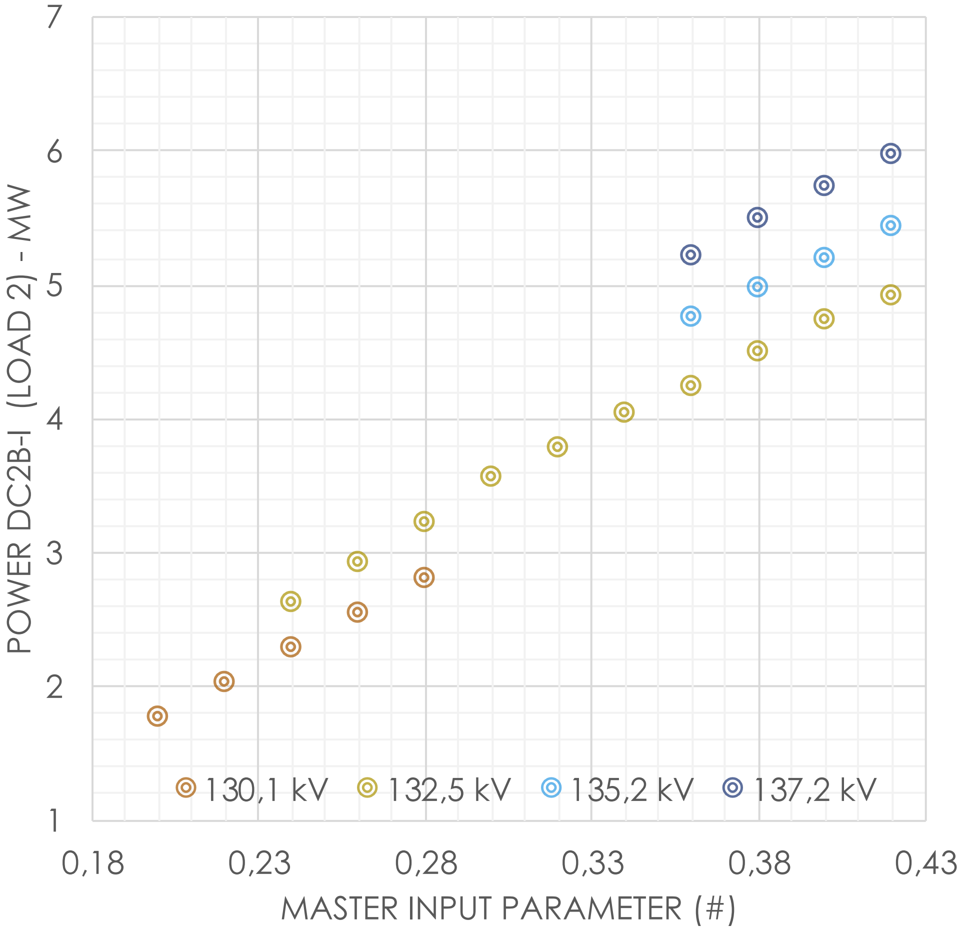
HP Components Conditioning:



- The new HP components installed produce outgassing once RF pulses are injected.
- The outgassing limits the maximum power that can be applied to the components.
- Measurements have been done with the NexTorr pumps though the PXI interface.
- Load 1 and Klystron B WG branches are the most active, since they were recently installed.
- This effect is reduced with the number of RF pulses injected.

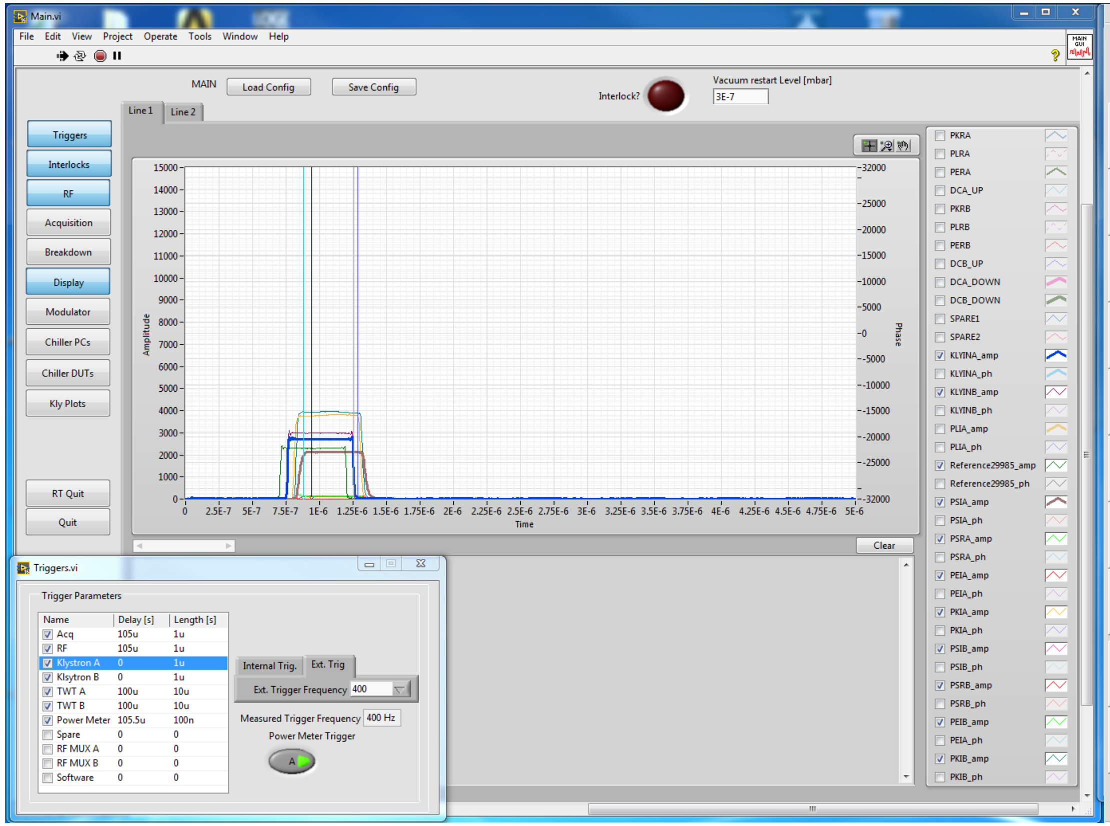
HPRF Conditioning Status





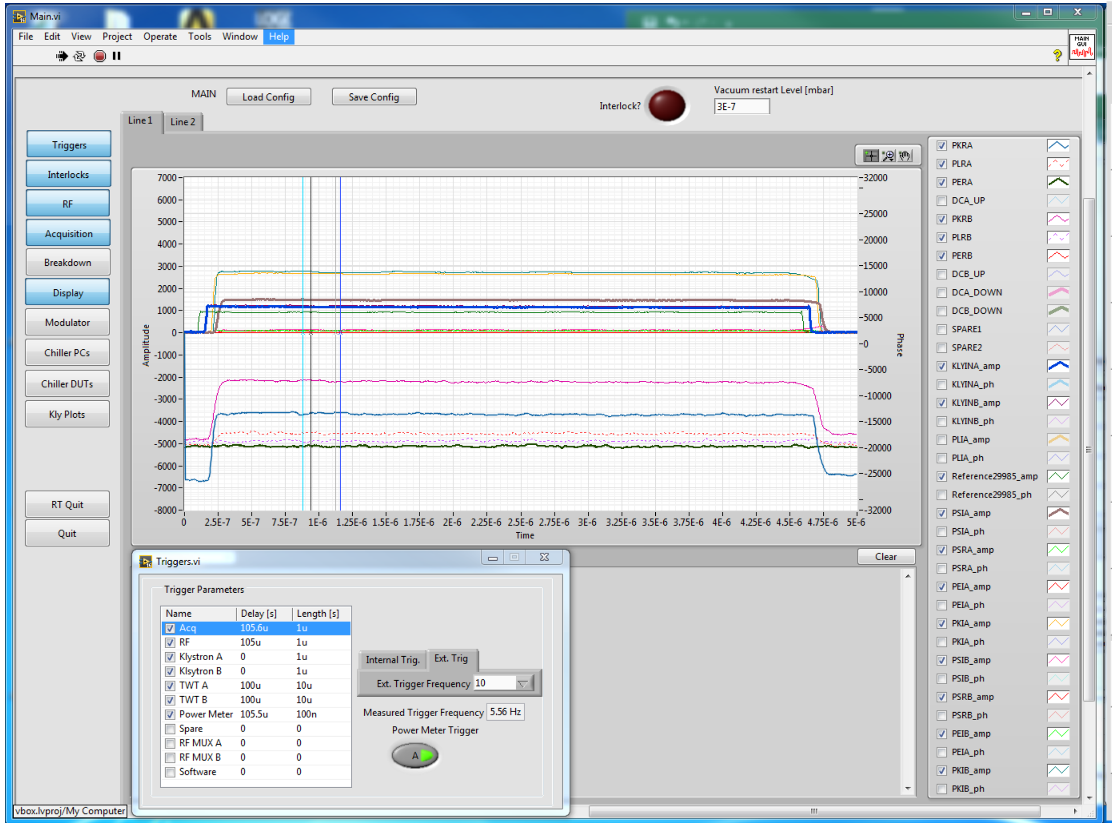
- In the current conditioning status, the maximum power achieved was over 6 MW, in both lines (DC before the LOADs).
- Using a pulse length of 1.2 μs and 50 Hz (25 Hz per line) repetition rate.

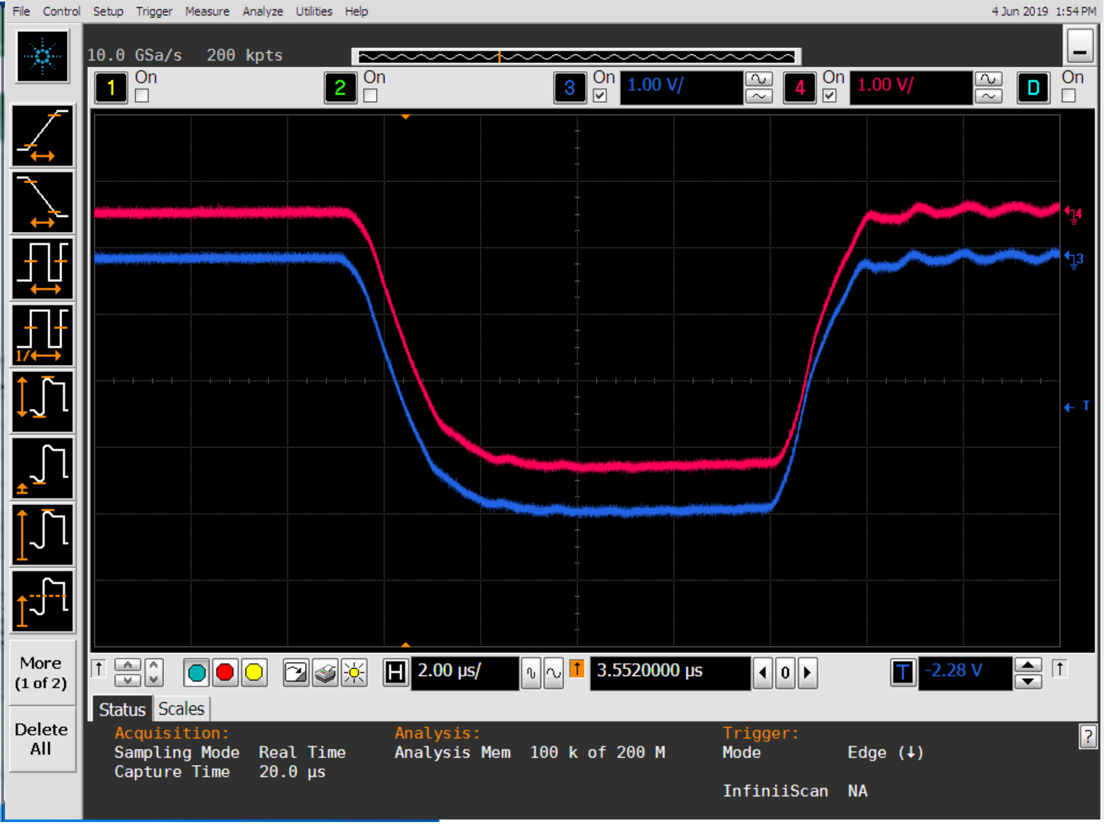
Performance: High repetition rate.



- The facility is capable of working at 400 Hz repetition rate with only one line in operation, or 200 Hz, with both lines operating simultaneously. Test at high repetition rate have been performed, proving a good pulse stability in both scenarios.

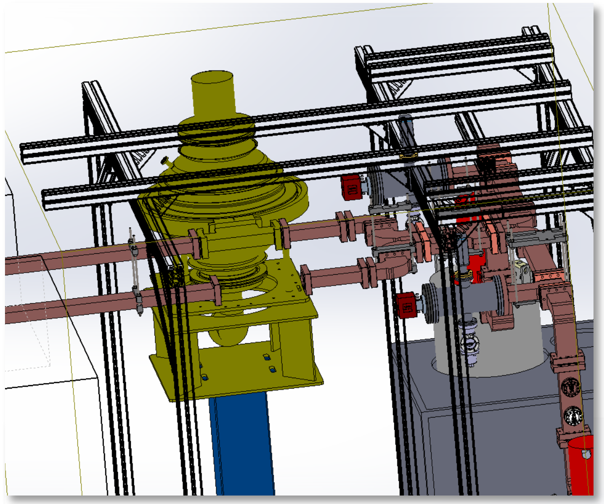
Performance: Very long pulses.



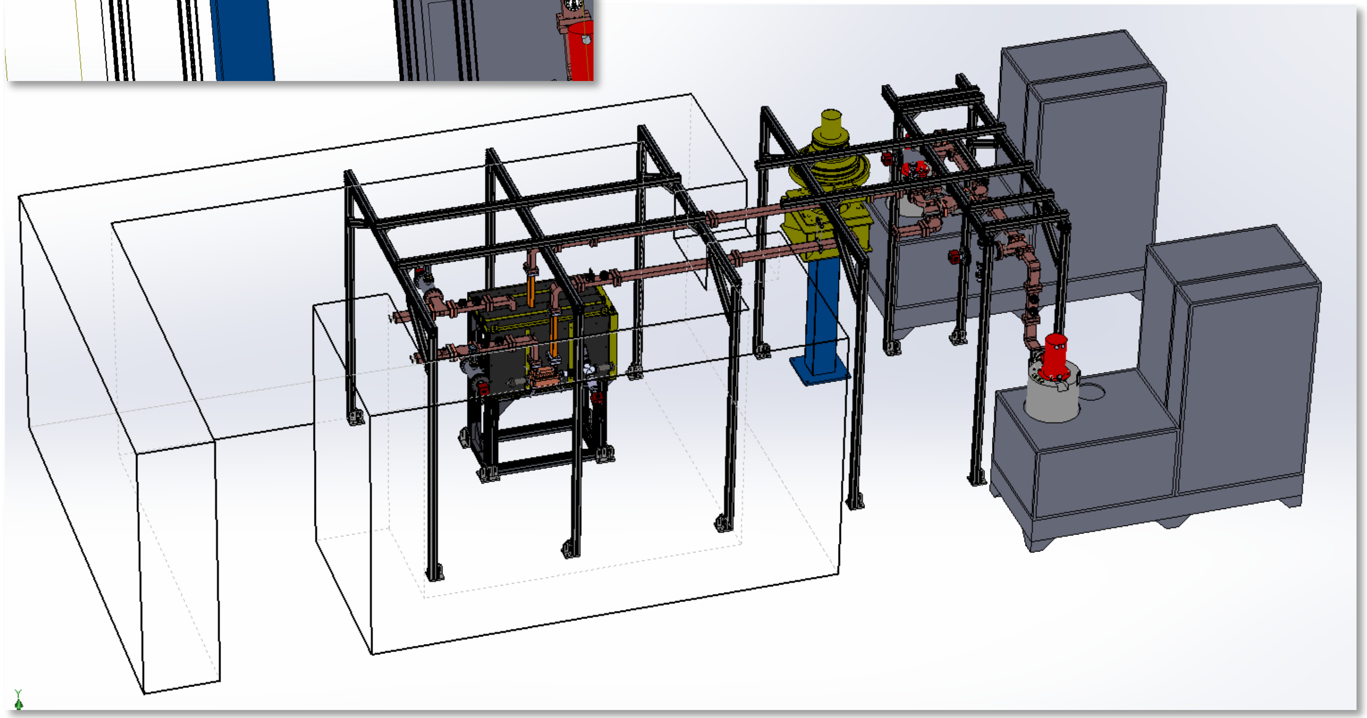


- Long voltage pulses have been used to test the pulse stability and check the available amplification region (6 µs available for the maximum pulse length accepted by the klystron - 10 µs).
- 5 µs RF pulse have been injected to test the stability and the planarity of the pulse, these long pulses are required to operate a BOC Pulse Compressor.
- The 6 µs amplification region gives enough time to implement a double pulse generation, on the same voltage pulse (2 pulses with 2 µs max length), raising the max repetition rate to 800 Hz in a individual operation(400 Hz dual operation).

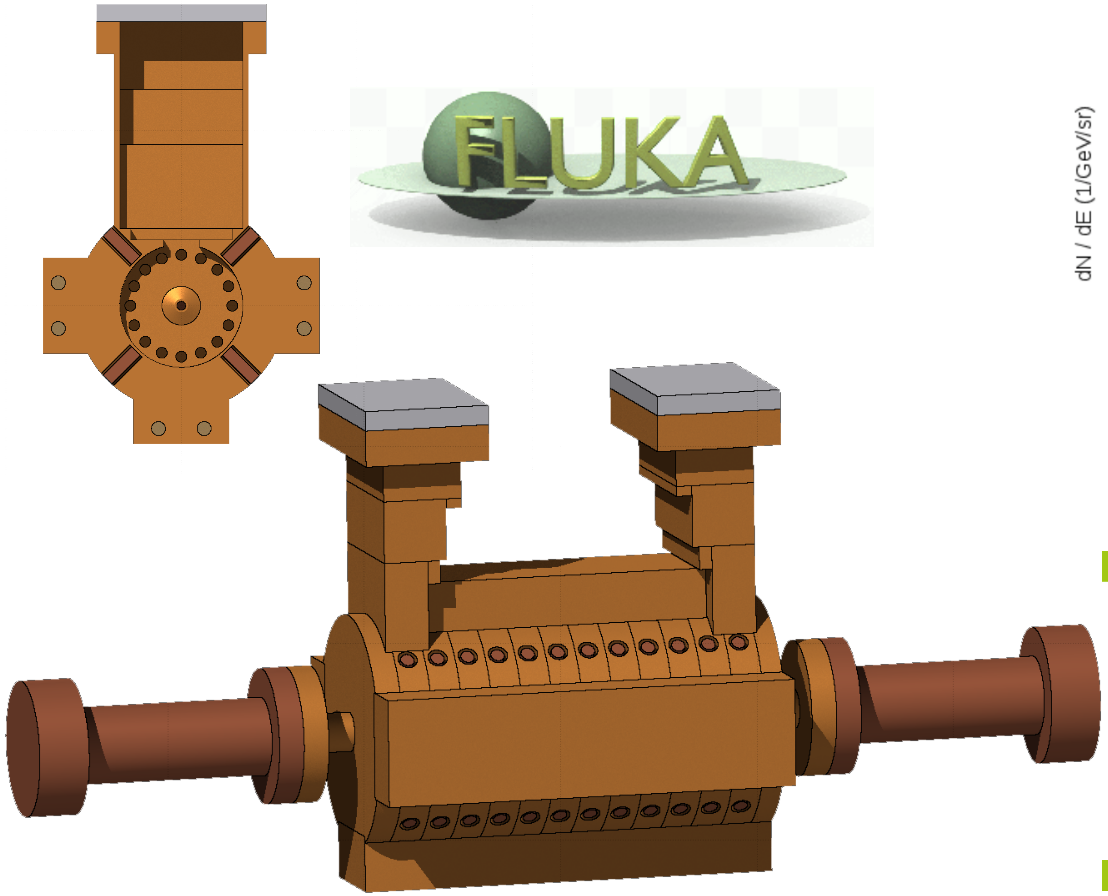
Pulse Compressor Integration

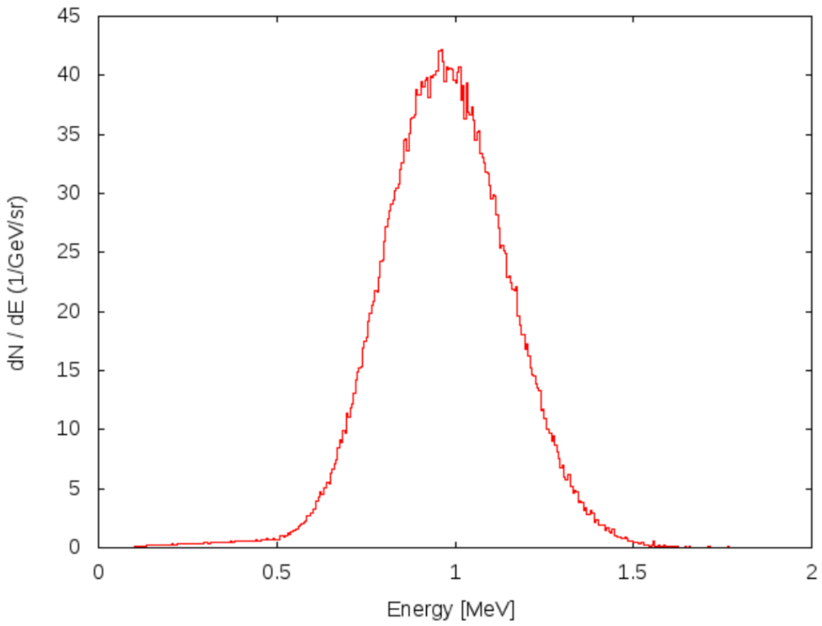


- The BOC pulse compressor have been received in Valencia.
- It will be installed in line A, outside the bunker, increasing the available power up to 30 MW (compressed pulses)
- Line B will be able to reach up to 15 MW and will remain as a testing line for very high repetition rate a long length pulses.



Environmental Radiation Simulation



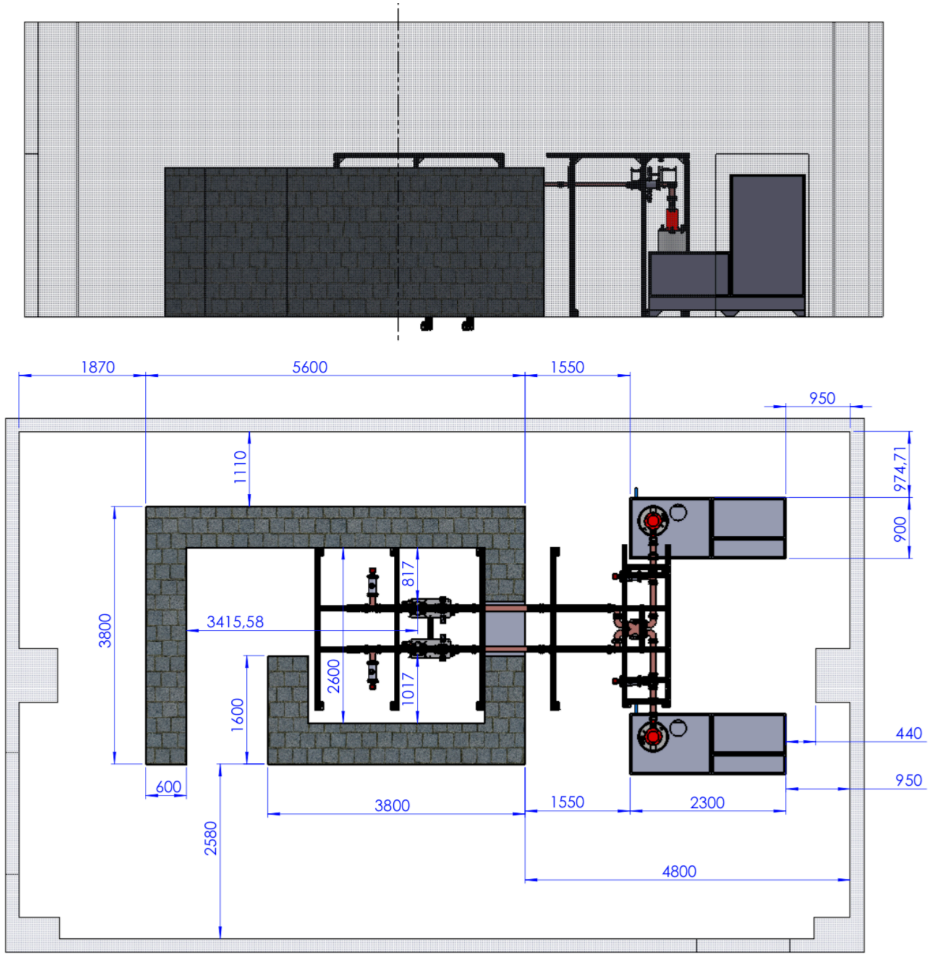


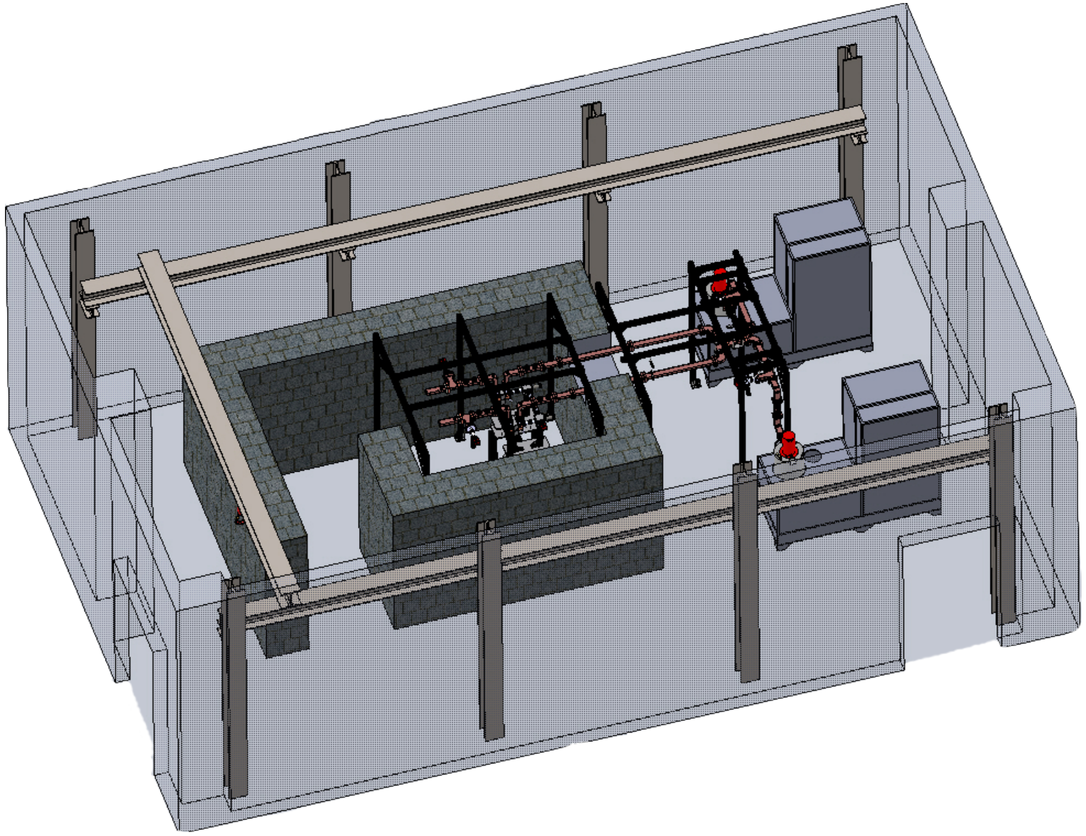
Electrons energy distribution inside structure

- The simulations have been performed using FLUKA and FLAIR framework. The goal was to simulate, approximately, the energy profile of the dark current electrons and calculate the equivalent dose on the laboratory zones.

- Simulations of the dark currents in a S-Band structure (for $\beta=0.38$) showed that the maximum energy of the dark current electrons would be around ~1.4 MeV.

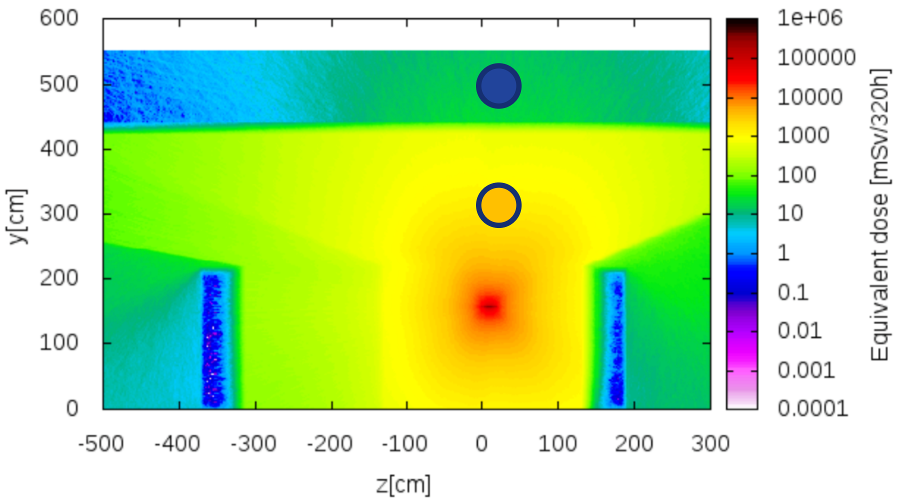
Current Laboratory Layout

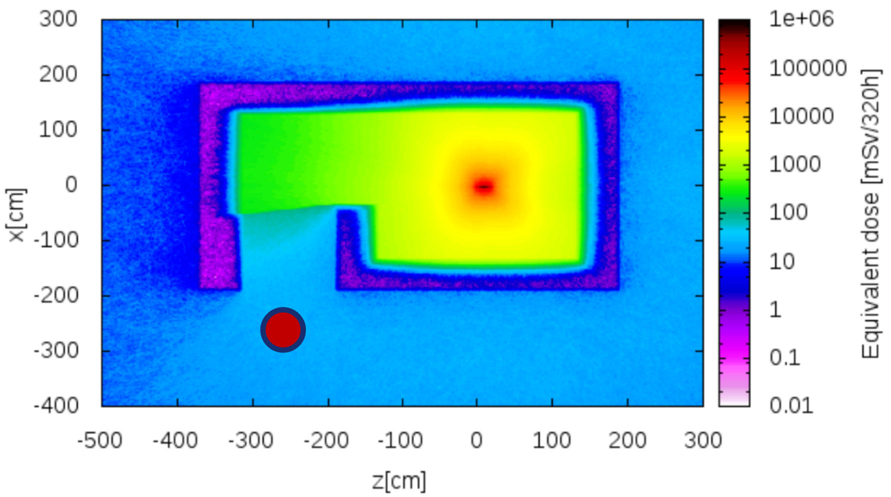




- First bunker proposal: no ceiling, no door, 60 cm concrete wall and 20 cm concrete layer on the laboratory roof.

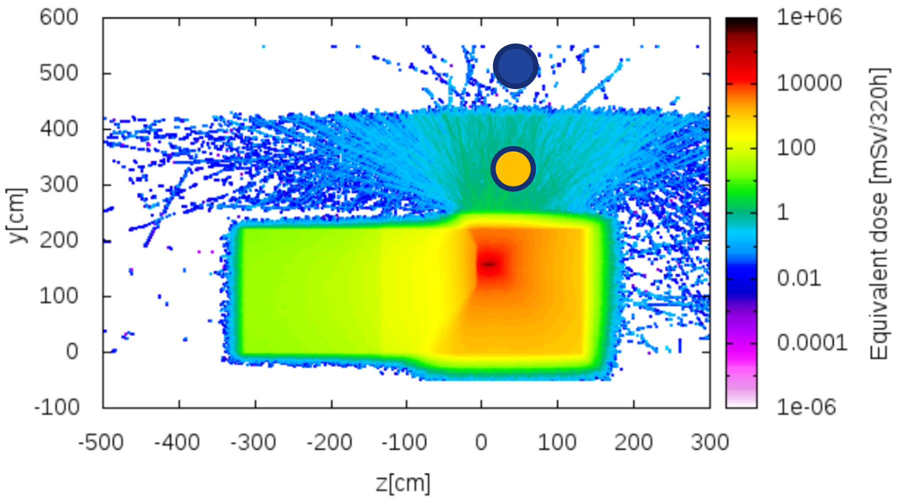
Environmental Radiation Simulation

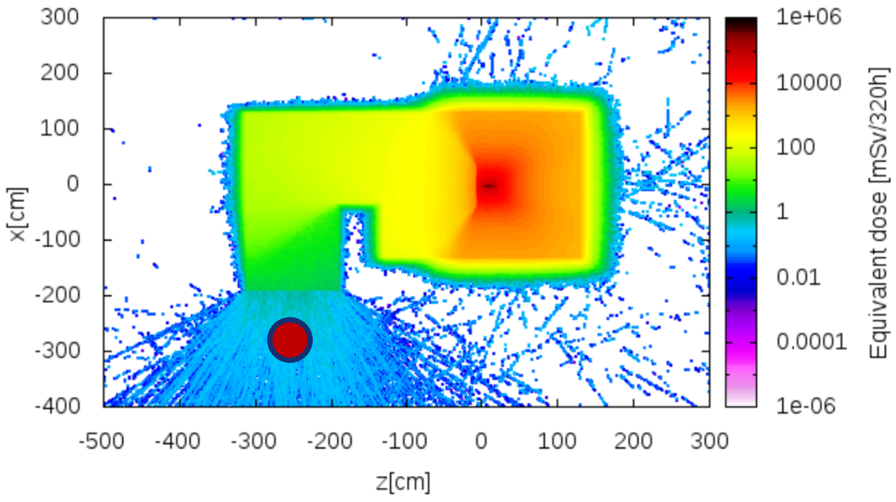




- Room above:
  12 ± 5 mSv/y
- Entrance:
  17 ± 2 mSv/y
- Over bunker:
  1200 ± 100 mSv/y

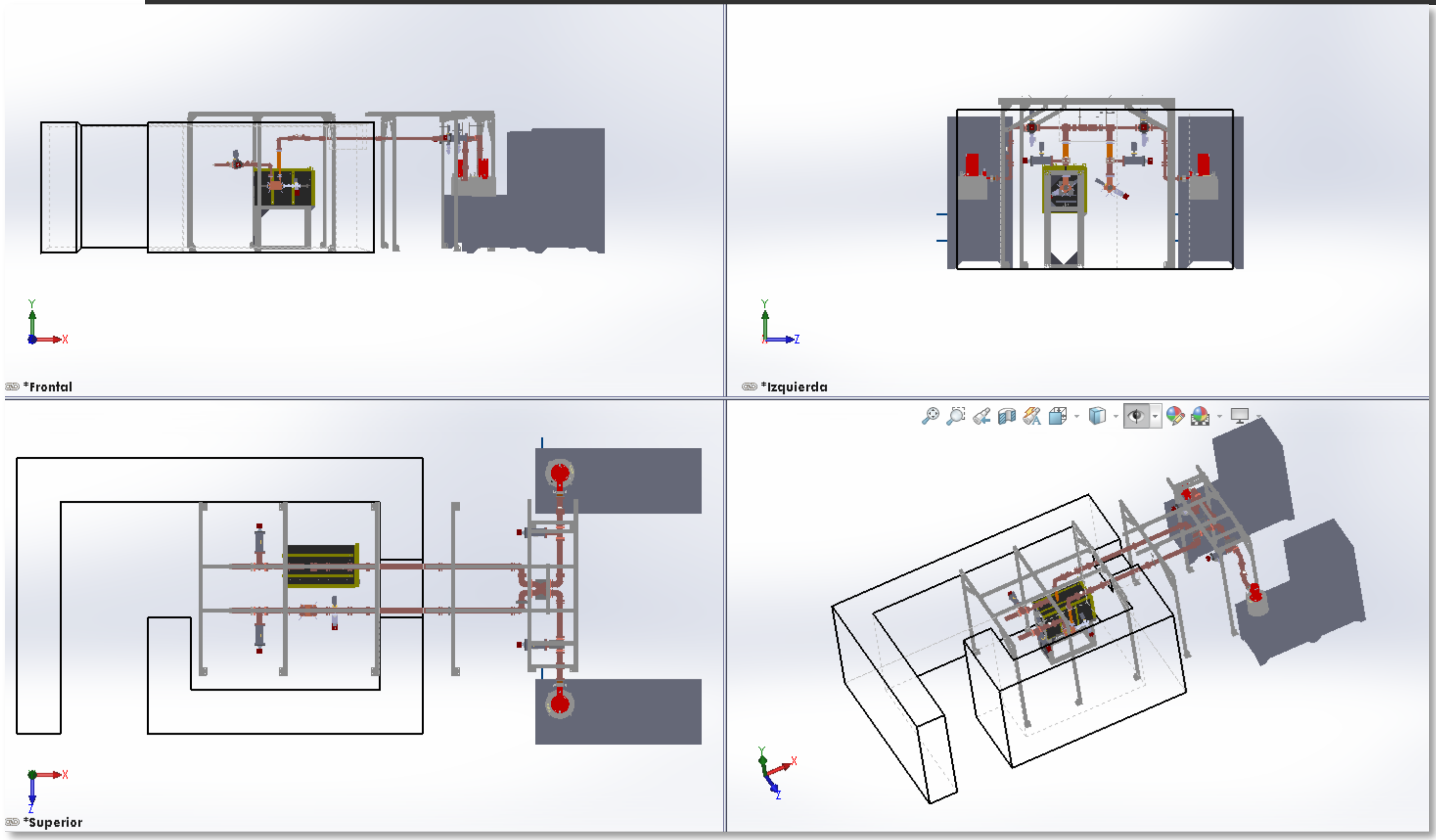
- Bunker roof: 40 cm of concrete or equivalent. Bunker door: 3 mm of Iron. 5 cm lead panel, in front of the structure, covering the entrance region

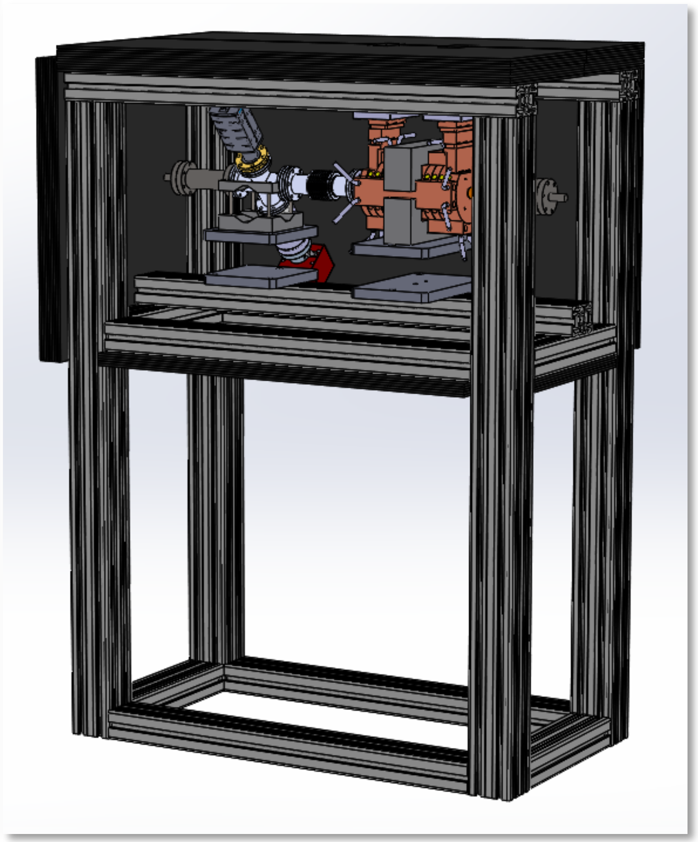




- Room above:
  0.02 ± 0.04 mSv/y
- Entrance:
  0.22 ± 0.08 mSv/y
- Over bunker:
  0.76 ± 0.32 mSv/y

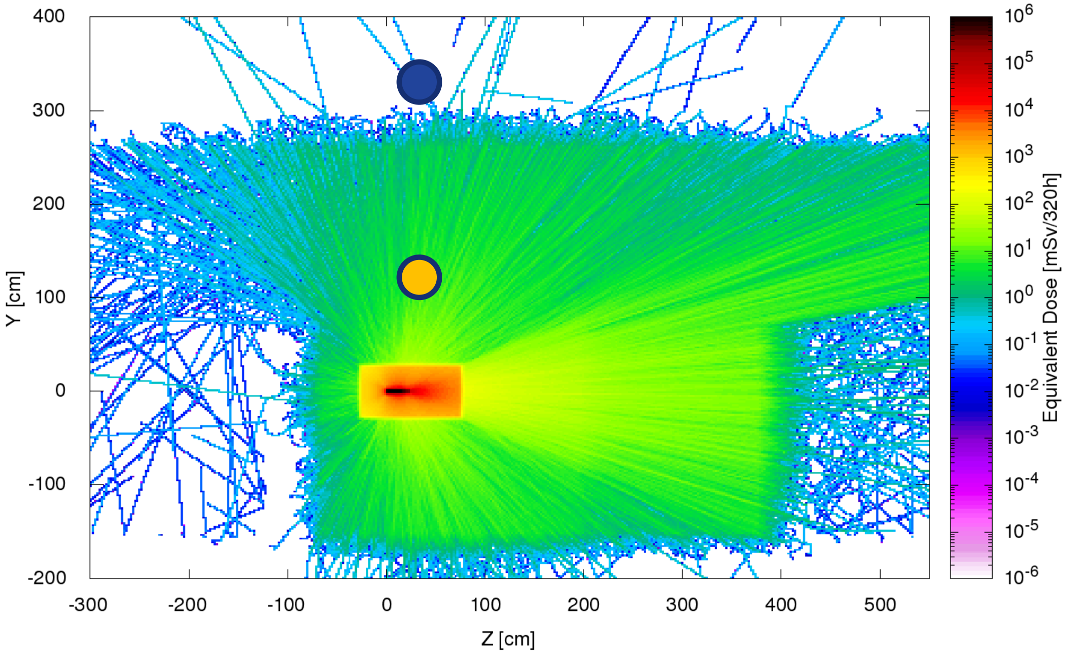
The Sarcophagus

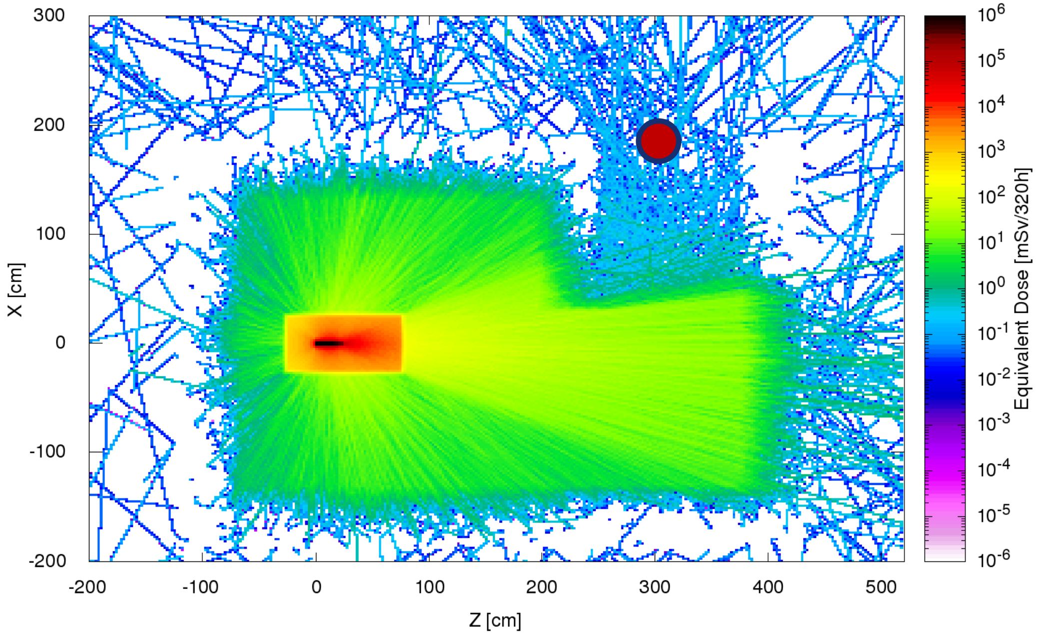




- As a feasible solution, on the short term, a box with 5 cm lead walls have been designed and manufactured (it will be installed this week).
- As a measure of safety, an ionization chamber will be installed near the box and integrated to the master interlock.

The Sarcophagus Simulation





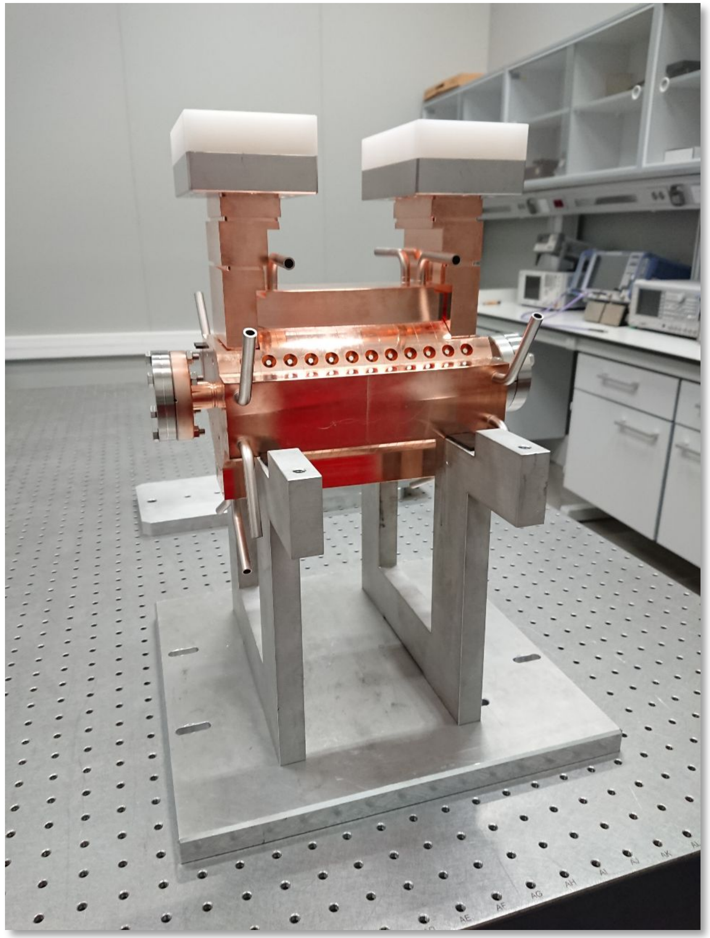
- The simulation shows that operate the structure inside the lead box will be enough to protect the surrounding laboratories.
- This protection measure will be valid only for the low power stages and always monitored by the radiation detector.
- In the final layout, with the roof and the shielded door, the lead box will remain, as an extra safety measure, on the line with higher power(with compressed pulses).

Room above:
0.03 ± 0.05 mSv/y

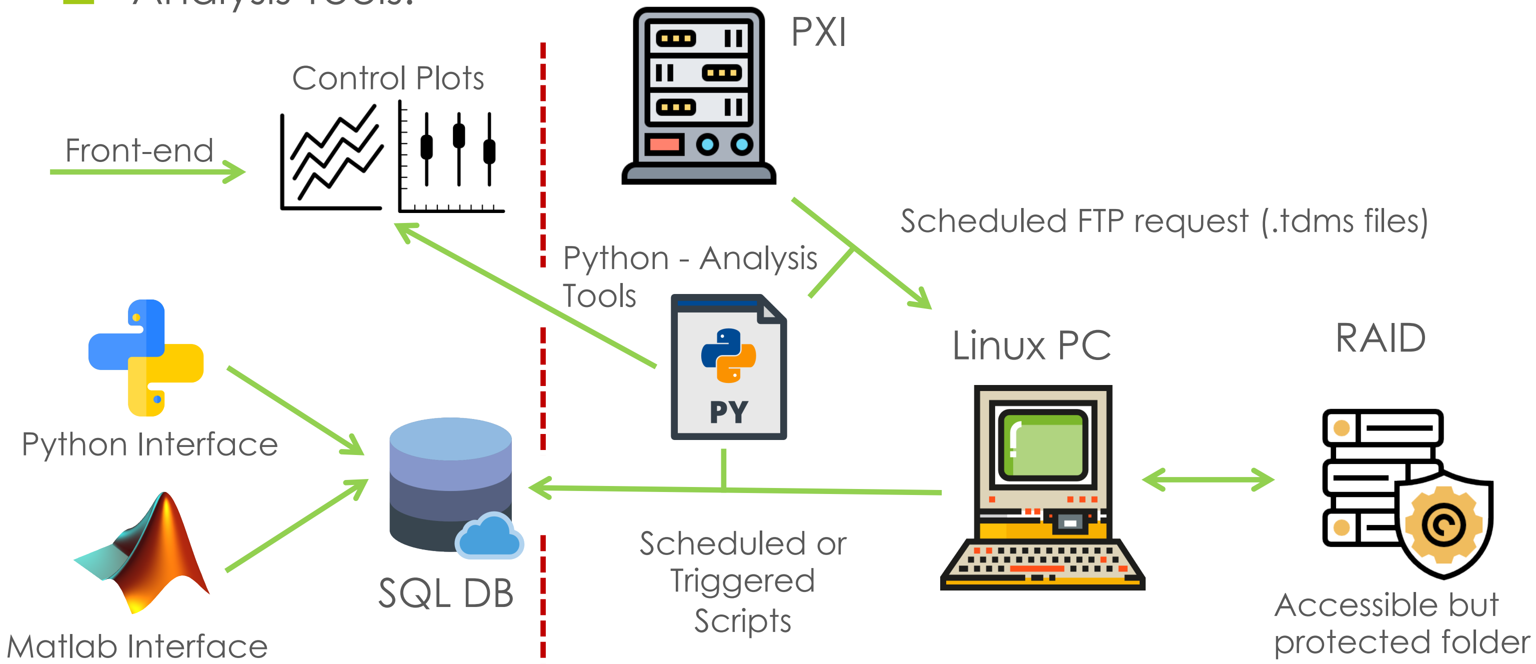
Entrance:
0.18 ± 0.12 mSv/y

Over bunker:
9.5 ± 1.3 mSv/y

Work in progress…

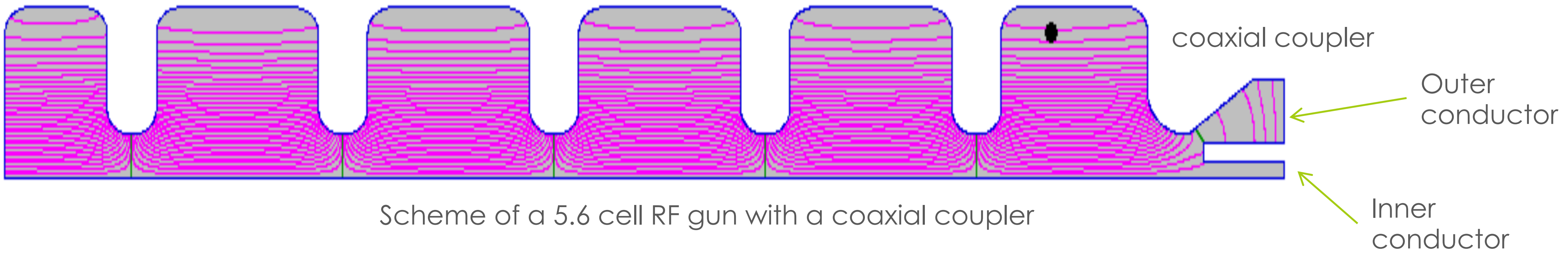


- The KT structure will be measured with the VNA and installed in the following month to start the conditioning process.
- LabVIEW Control Software Modifications:
  - Optimization of the conditioning algorithms
  - Double pulse implementation
- Analysis Tools:



CompactLight Project: X-band RF photoinjector

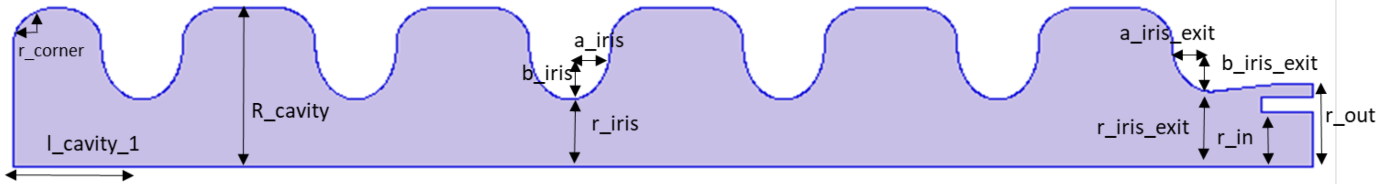
- The European XLS-CompactLight Project is aimed to improve the latest generation of light sources: the Free Electron Lasers (FELs). The first stage of a FEL consists of an RF electron gun
- The main task of our work package is to design an X-band RF photoinjector based on a 5.6 cell standing wave structure that operates in the TM010 π–mode and it is fed by a coaxial coupler
- Since the entire device (RF gun + coupler) is rotationally symmetric, this task will be carried out using SUPERFISH, which is much faster than HFSS or CST
- This design is focused on the optimization of three parameters: the resonant frequency, the coupling factor, and the uniformity of the maximum RF axial electric field values in all the gun cavities:



Scheme of a 5.6 cell RF gun with a coaxial coupler

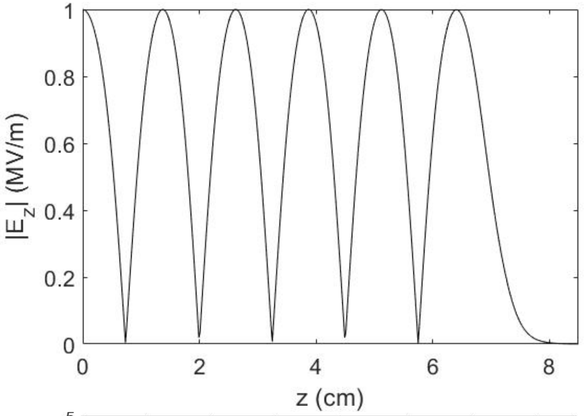
Final RF gun design

- The main characteristics of the final RF gun design are:

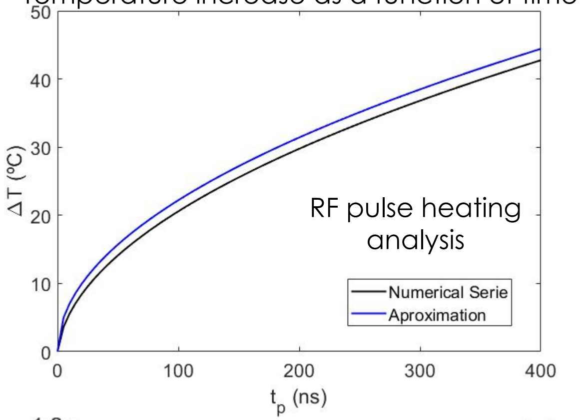


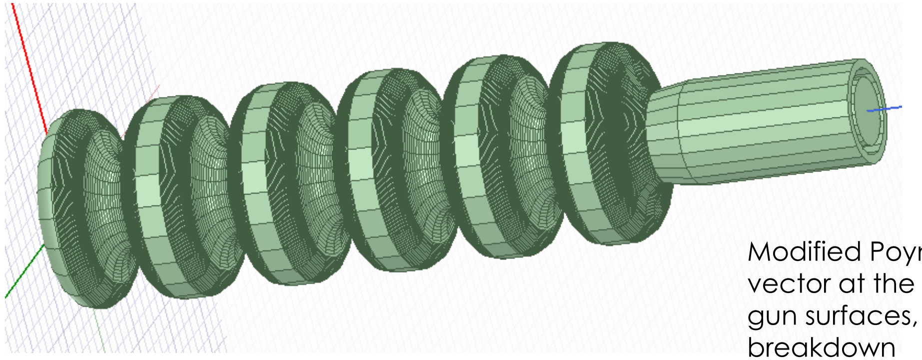
$$f = 11.993996\ GHz$$
$$\beta = 1.005$$
$$\Delta f = 27.1\ MHz$$
$$\max(E_{sup}) = 0.988\ \frac{MV}{m}$$
(for 1 MV/m at cathode axis)

Modulus of the RF electric field along the gun axis - RF electric field maximum flatness is better than 99%



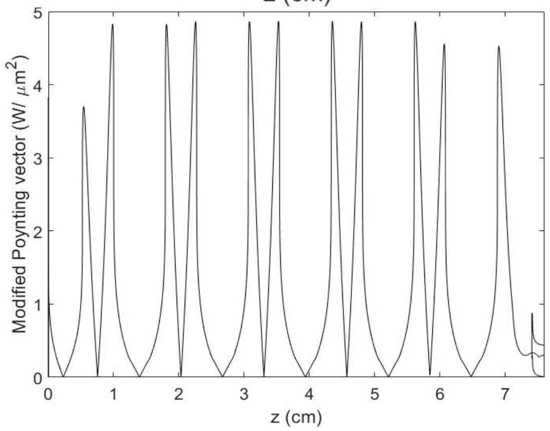
Temperature increase as a function of time

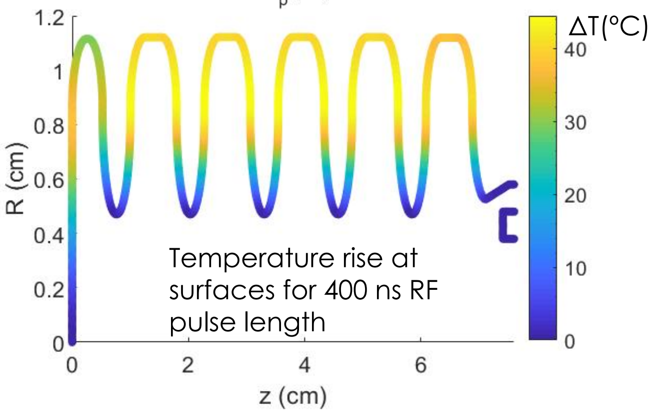




3D view of the RF gun

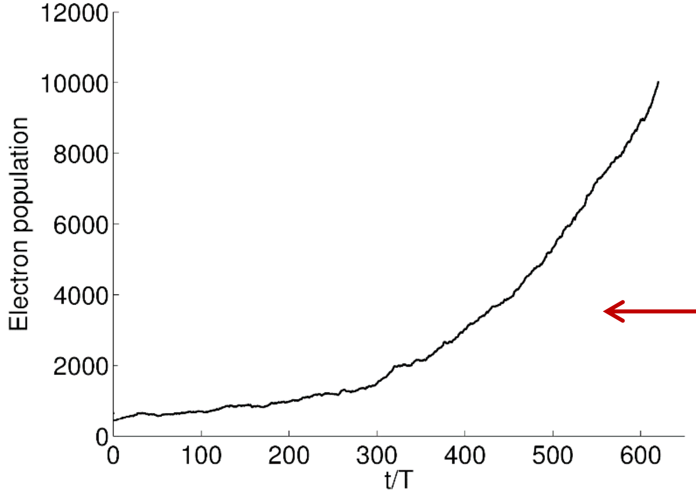
Modified Poynting vector at the RF gun surfaces, RF breakdown risk assessment





Multipactor analysis in the coaxial coupling

- Multipactor risk at the coaxial coupler was assessed by means of numerical simulations using our in-house developed code.
- Numerical simulations were launched in order to analyze the presence of multipactor phenomenon at several RF voltage values up to the maximum RF voltage reached at the coaxial coupler.



Capture of the output results for the multipactor code

Multipactor zones

Multipactor window	P (MW)	V(kV)
1	0.035-0.56	0.891-3.565
2	1.20-3.10	5.219-8.388

Multipactor discharge is expected for such RF voltage amplitude since an exponential increase in the electron population is found

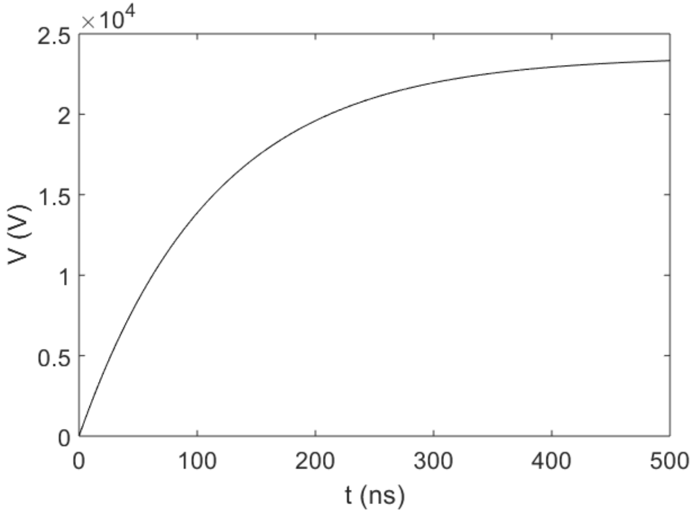
Thus, the coaxial does not suffer multipactor at the steady operating voltage (13.226 kV), however it is likely to appear during the filling of the RF gun cavity

$$V(t) = V_0\left(1 - e^{-\frac{t}{\tau_F}}\right)$$

$$t_F = \frac{2Q_L}{\omega_0} \quad t_F = 112.5\,ns \quad t_F/T = 1349$$

First window → $\Delta t = 15\,ns,\ \Delta t/T = 180$

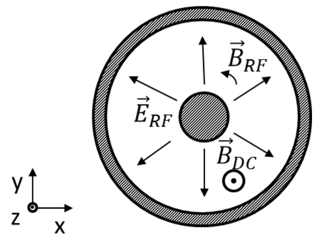
Second window → $\Delta t = 23\,ns,\ \Delta t/T = 276$



Coaxial voltage amplitude during the cavity filling

Multipactor analysis in the coaxial coupling

- Despite the multipactor risk appearance at the coupler has been evidenced, it is not a crucial problem since it can be suppressed by means of an external magnetic field.
- This fact was both theoretically and experimentally demonstrated for a coaxial line[1],thus the following conclusions arise:
  - Multipactor can be suppressed provided that a strong enough magnetic field is applied along the coaxial axis.
  - As an approximate rule, the minimum magnetic field to mitigate the discharge is given by:



coaxial line transverse cross section

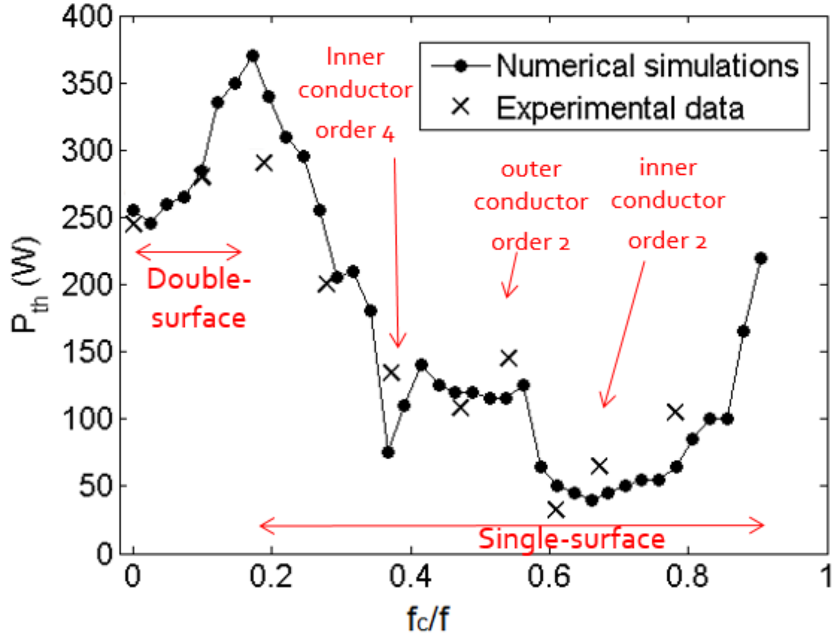
$$f_c \approx f$$

f is the RF frequency B_{dc} is the external magnetic field m is the electron mass

$$f_c = \frac{1}{2\pi}\frac{e}{m}B_{dc}$$

fc is the cyclotron frequency $-$ e is the electron charge

In our case, the above condition gives: $B_{dc} = 428.5\ mT$



Multipactor RF power threshold as a function of the ratio between the cyclotron frequency and the RF frequency. For a coaxial line at f = 1.145 GHz

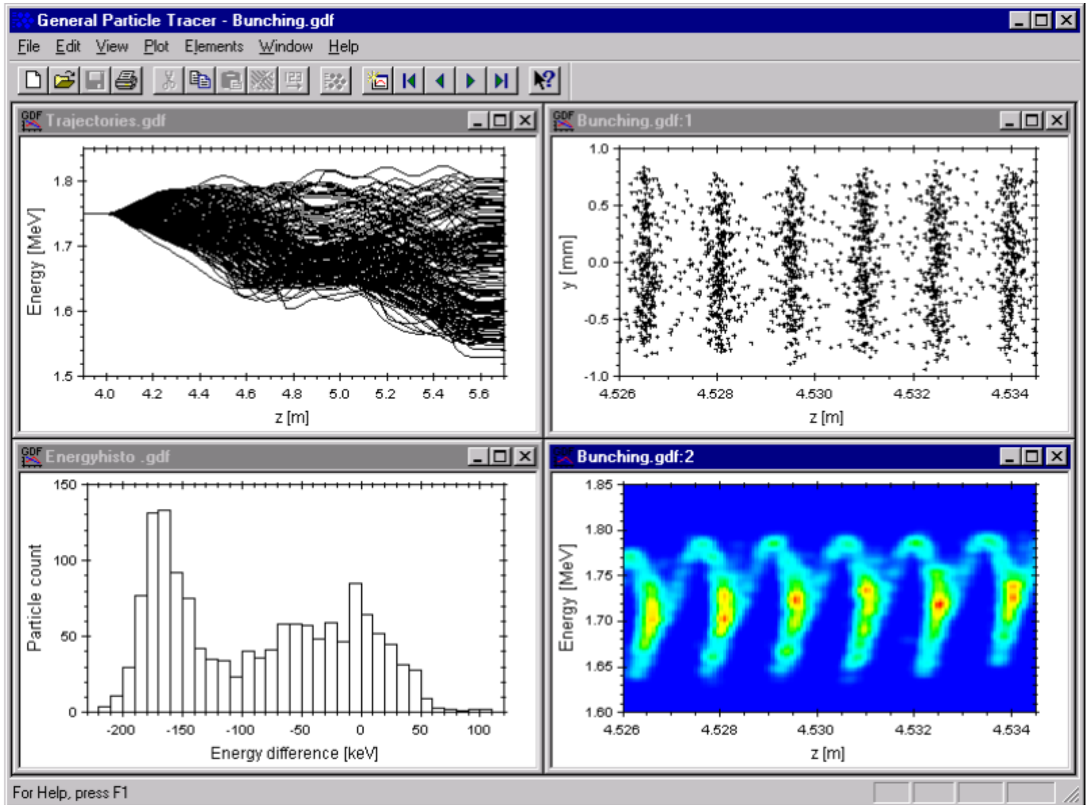
- Numerical simulations support that no multipactor discharge is expected with such external magnetic field.
- In fact, it is found that a $B_{dc} = 360\ mT$ is enough to suppress the discharge, according to the numerical simulations.

[1]D. González-Iglesias et al., "Multipactor Mitigation in Coaxial Lines by Means of Permanent Magnets", IEEE Transactions on Electron Devices, vol. 61, no. 12, pp. 4224-4231, Dec. 2014.

Work in progress…

- Beam dynamics simulations will be performed using the General Particle Tracer (GPT) software in order to obtain the beam performance parameters: emittance, rms size, brightness, etc.

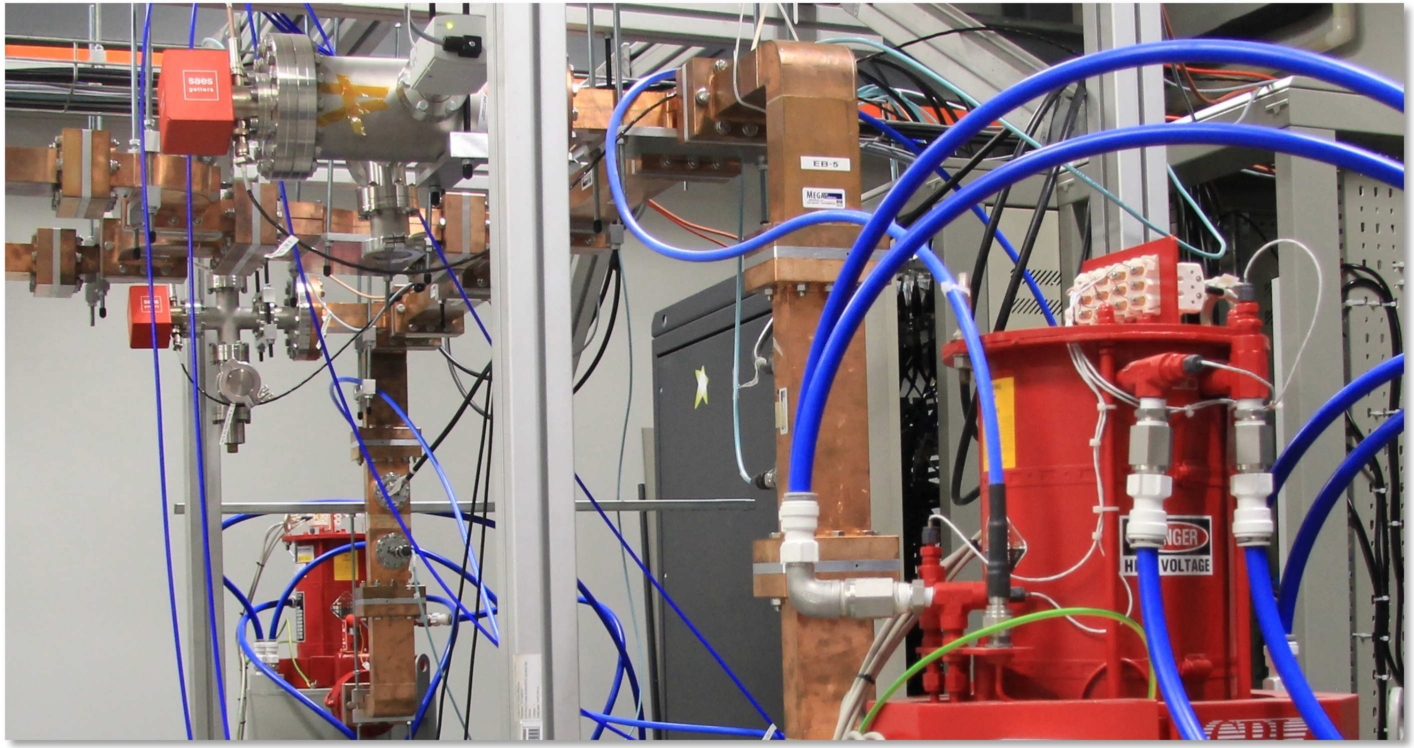
- A solenoid for both beam emittance compensation and multipactor suppression purposes will be designed.



Some GPT Screenshots

Summary

The IFIC HG-RF laboratory is ready to offer a testing facility for whoever wants/needs to use it.



Kick-Off Meeting of the Radio-Frequency Laboratory of the Medical Physics Facility (IFIMED) at IFIC

25th – June at IFIC (Valencia)

Event Information and Registration:
https://indico.ific.uv.es/event/3751/

Acknowledgements

- Former and present team group members and students**: A. Faus-Golfe, J. Giner, C. Blanch, T. Argyropoulos, J. Fuster, A. Vnuchenko, V. Sanchez, E. Baader, A. Catalá, Jose R. Rausell**

- XBOX team: **W. Wuensch, W. Wolley, G. McMonagle, N. Catalán-Lasheras, M. Volpi, I. Syratchev, A. Grudiev**

- This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 750871

Backup

Performance: Pulse Planarity Adjustment.

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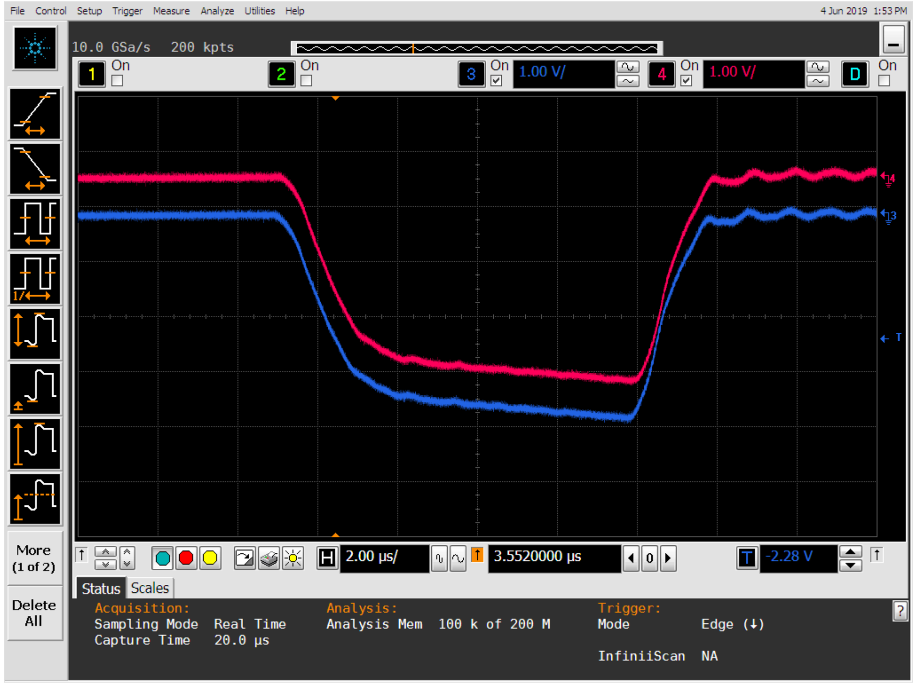

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Analog Memory Depth automatic 200.003 kpts, Digital 40.002 kpts
Analog Sampling Rate automatic 10.0 GSa/s, Digital automatic 2.00 GSa/s
Analog Averaging off, Interpolation on

Channel 3: Scale 1.00 V/, Offset -1.88 V, Skew 0.0 s
Coupling DC, Impedance 50 Ω

Channel 4: Scale 1.00 V/, Offset -2.56 V, Skew 0.0 s
Coupling DC, Impedance 50 Ω

Horizontal: Scale 2.00 µs/, Position 3.5520000 µs, Reference center

Trigger: Mode edge, Source Channel 3, Level -2.28 V, Slope falling
Sweep triggered, Sensitivity normal, Holdoff Time 100 ns

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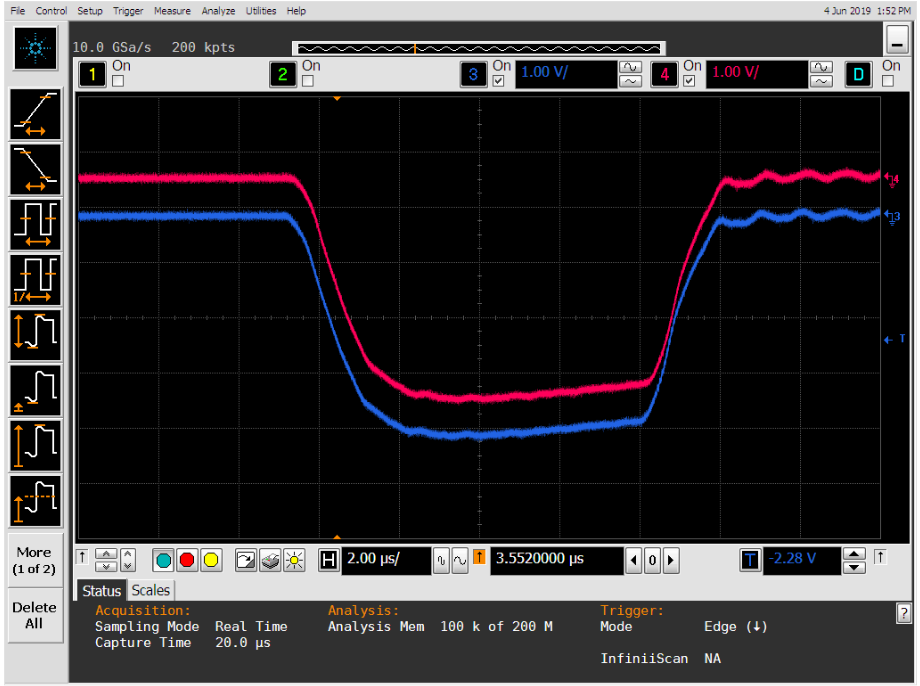


Acquisition: Sampling Mode real time, Normal
Analog Memory Depth automatic 200.003 kpts, Digital 40.002 kpts
Analog Sampling Rate automatic 10.0 GSa/s, Digital automatic 2.00 GSa/s
Analog Averaging off, Interpolation on

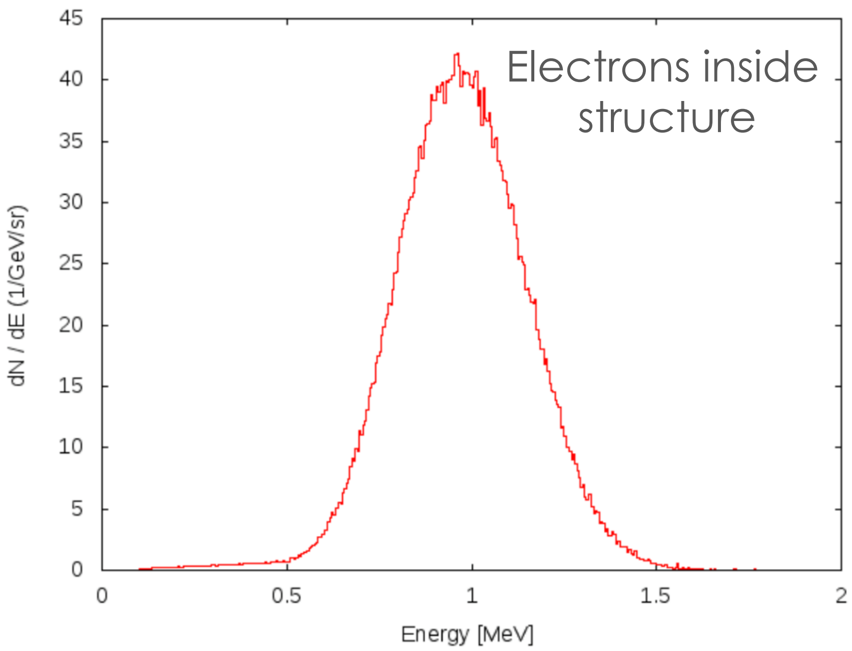
Channel 3: Scale 1.00 V/, Offset -1.88 V, Skew 0.0 s
Coupling DC, Impedance 50 Ω

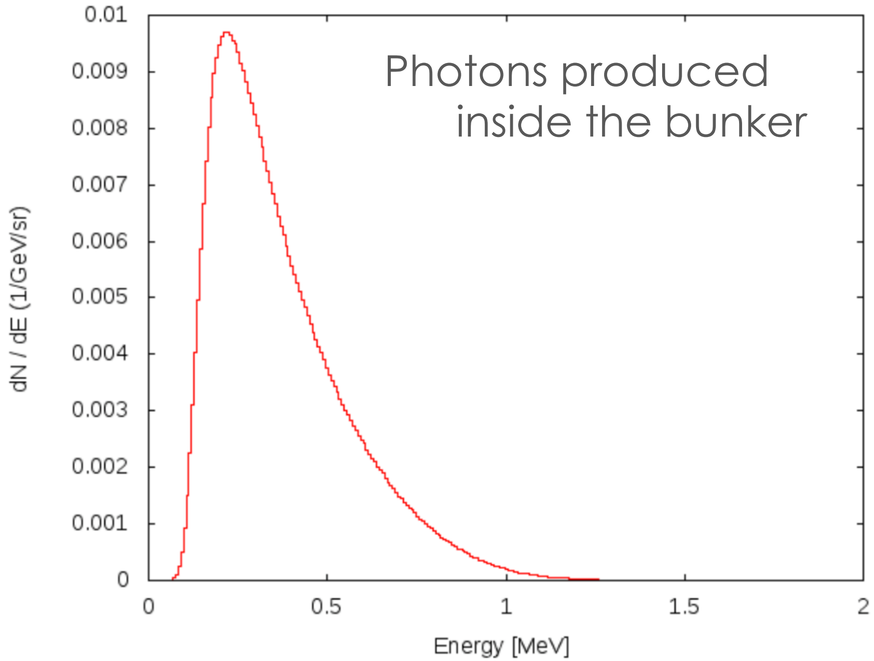
Channel 4: Scale 1.00 V/, Offset -2.56 V, Skew 0.0 s
Coupling DC, Impedance 50 Ω

Horizontal: Scale 2.00 µs/, Position 3.5520000 µs, Reference center

Trigger: Mode edge, Source Channel 3, Level -2.28 V, Slope falling
Sweep triggered, Sensitivity normal, Holdoff Time 100 ns

Motivation





- Simulations of the dark currents in a S-Band structure (for β=0,38) showed that the maximum energy of the dark current electrons would be around ~1.4 MeV.
- Considering these limitations and overestimating the number of electrons is this range of energies, the energy profile has been defined as a Gaussian cantered on 1 MeV and σ=0,2 MeV (left).