XBOX Operation and Performance

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on behalf of Xbox Team

High Gradient WORKSHOP 2018

SINAP, Shanghai, China

Outline

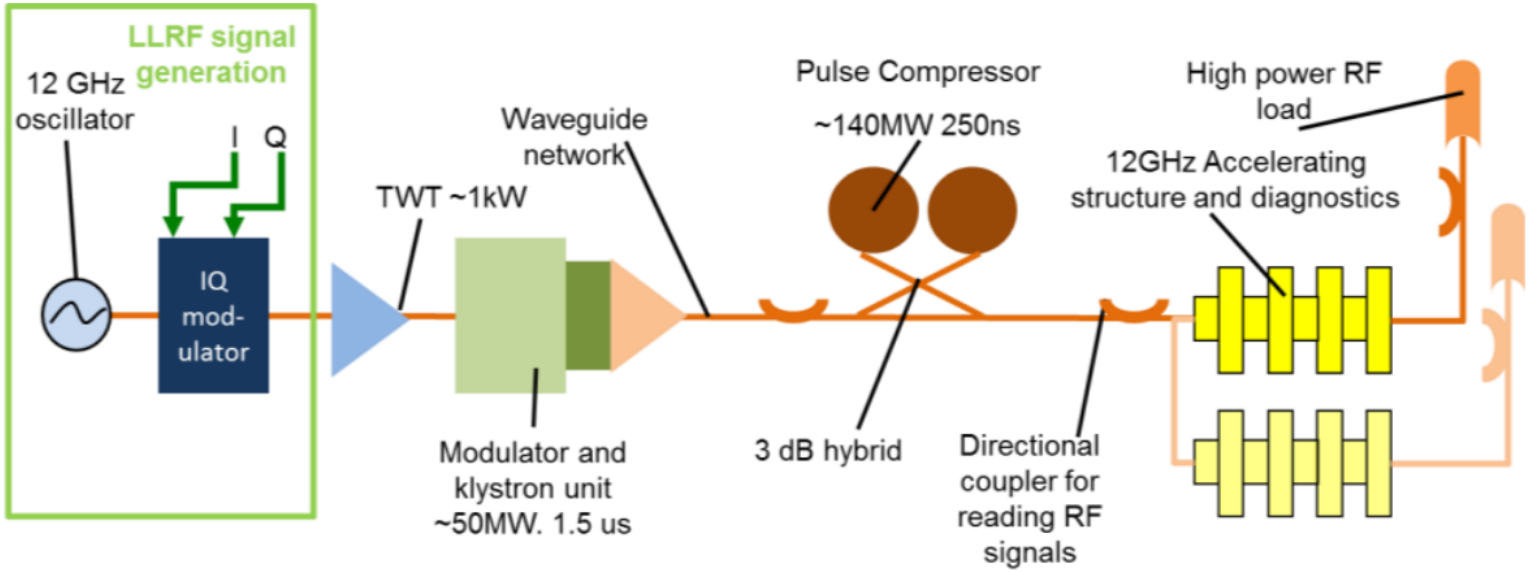
- Test stands specifications
- XBOX1
  - Challenges during last year
  - New Pulse Compressor tuning software
- Bunker optimization
- XBOX2
  - Performance
  - Future upgrade
- XBOX3
  - Components conditioning
  - Structure conditioning
  - Pulse Compressor conditioning
  - Frequency shift tool
- Conclusions
- Future plans

Test Stands specifications

- The required input power to commission CLIC structures is typically 40-60MW and a 250ns flat pulse
- The speed of conditioning depends on the number of pulses, therefore, high pulse repetition rates are preferred
- XBOX 1 and XBOX2 use a single 50MW klystron and pulse compressor to test one structure, although up to two structures could be tested
- Scandinova modulator, CPI klystron, pulse compressor factor ≈3

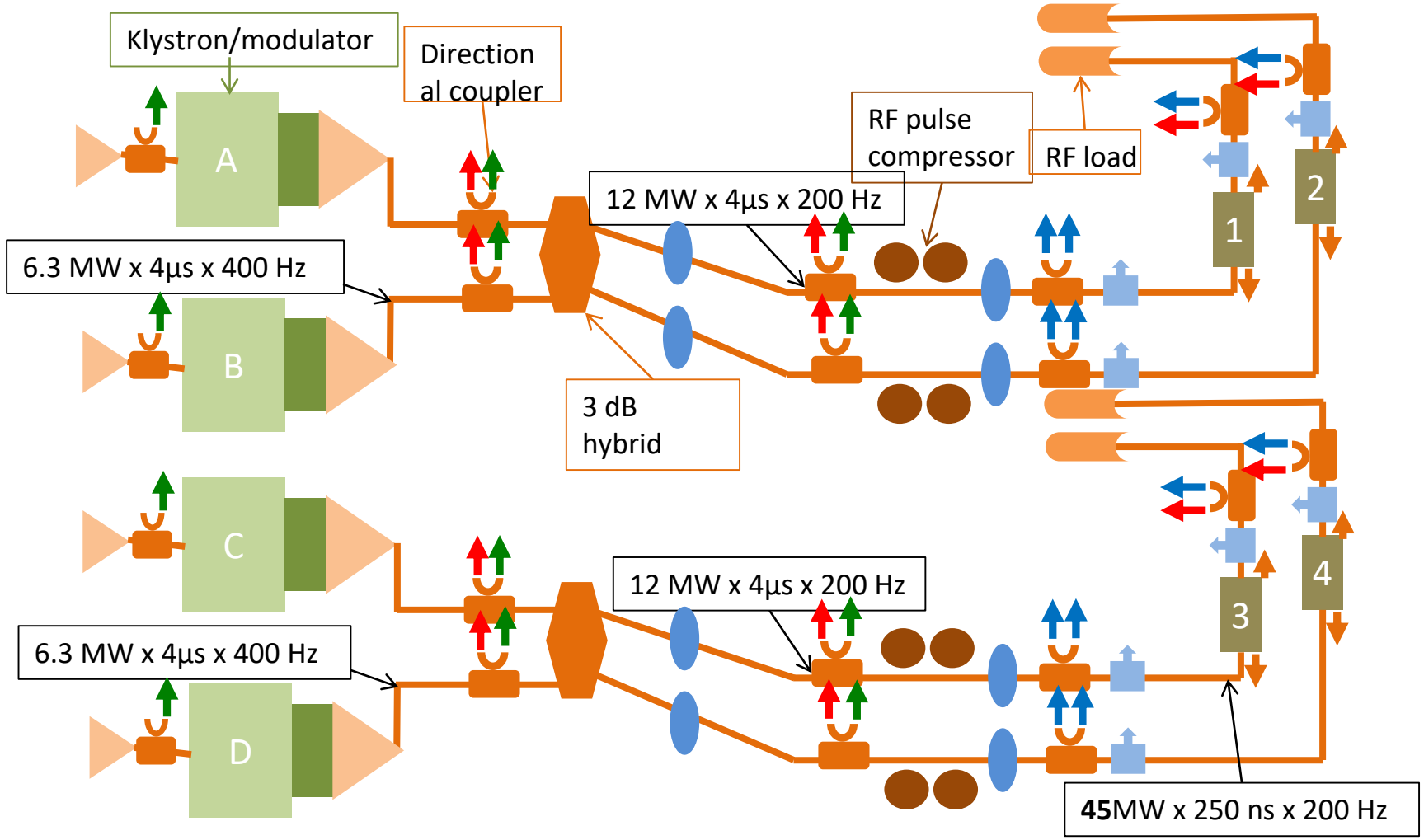
450kV, 350A, 1.5µs, 50Hz

50MW

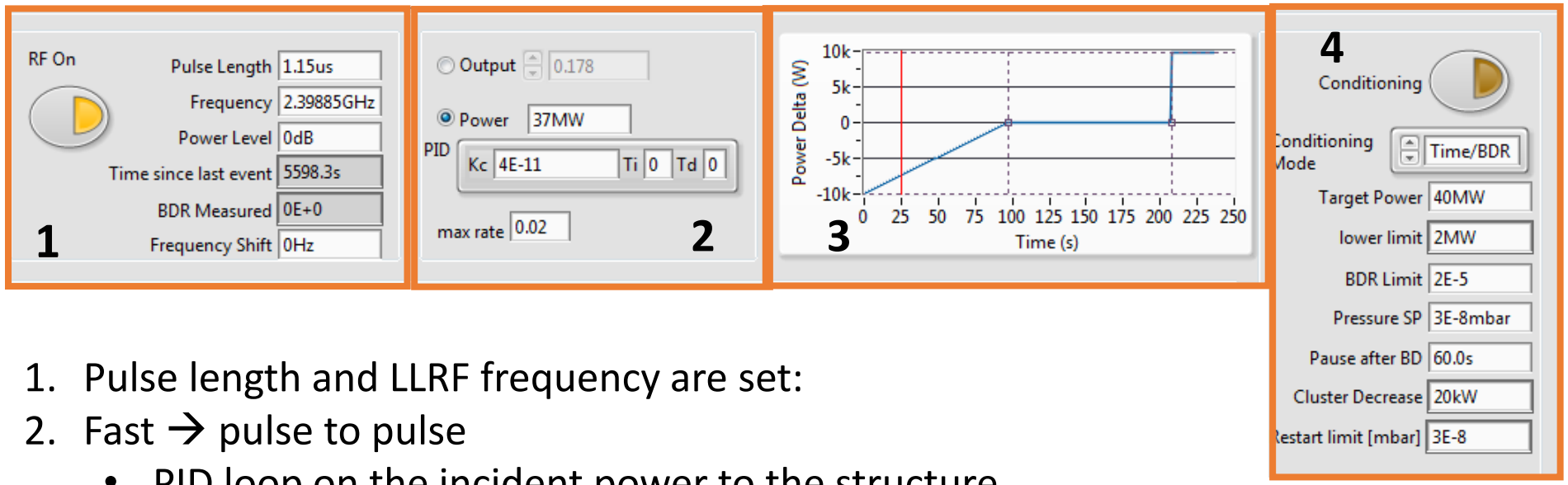


Test Stands specifications

- XBOX3 combines the power of two smaller klystrons with a higher rep. rate ≤400Hz to test two structures.
- Scandinova modulator, 6MW Toshiba klystron and pulse compression with a compression factor ~4



Conditioning algorithm

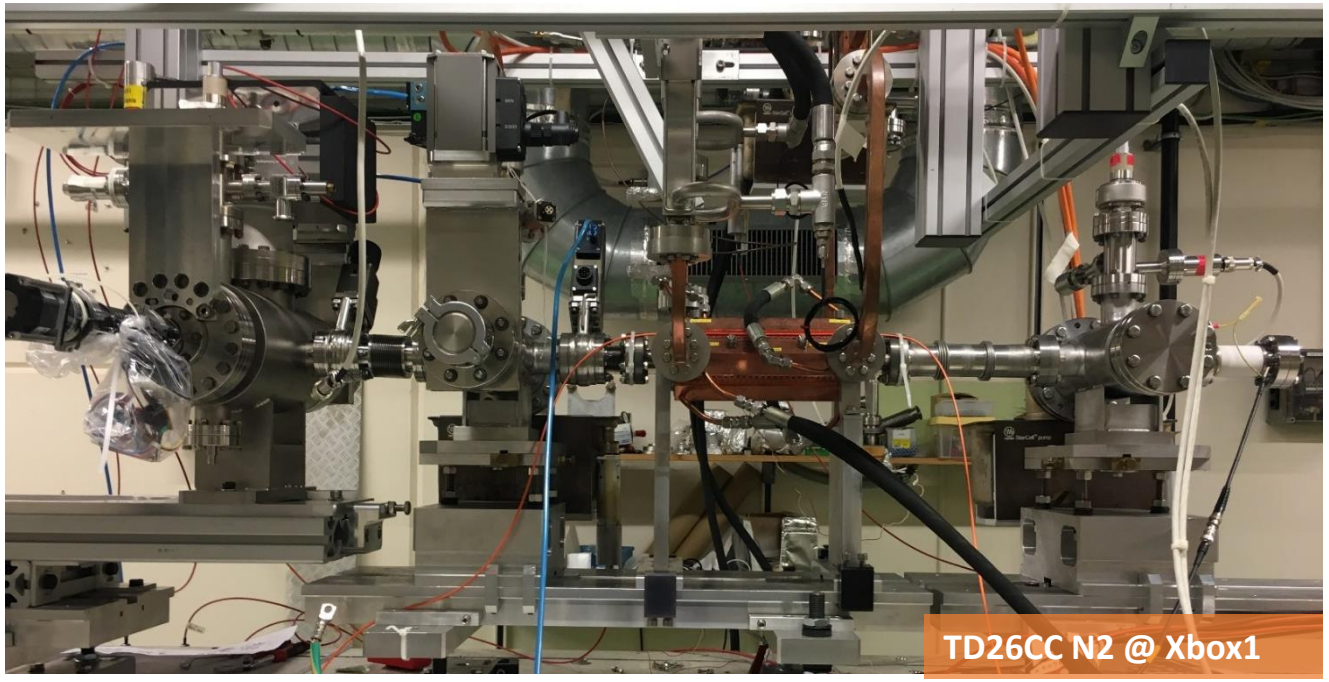


1. Pulse length and LLRF frequency are set:
2. Fast → pulse to pulse
   - PID loop on the incident power to the structure
3. Medium → seconds-minutes
   - increase power by 10kW every few minutes (**cycle loop**) if no BD
   - reduce power by 10kW if successive BDs too close in time
4. Slow → hours
   - **BDR measurement** performed across a moving window of approx. 1M pulses.
   - BDR measurement and stop power increase if it is too high

XBOX1 @ CTF2

June 2017

TD26CCN2



TD26CC N2 @ Xbox1

XBOX1 @ CTF2

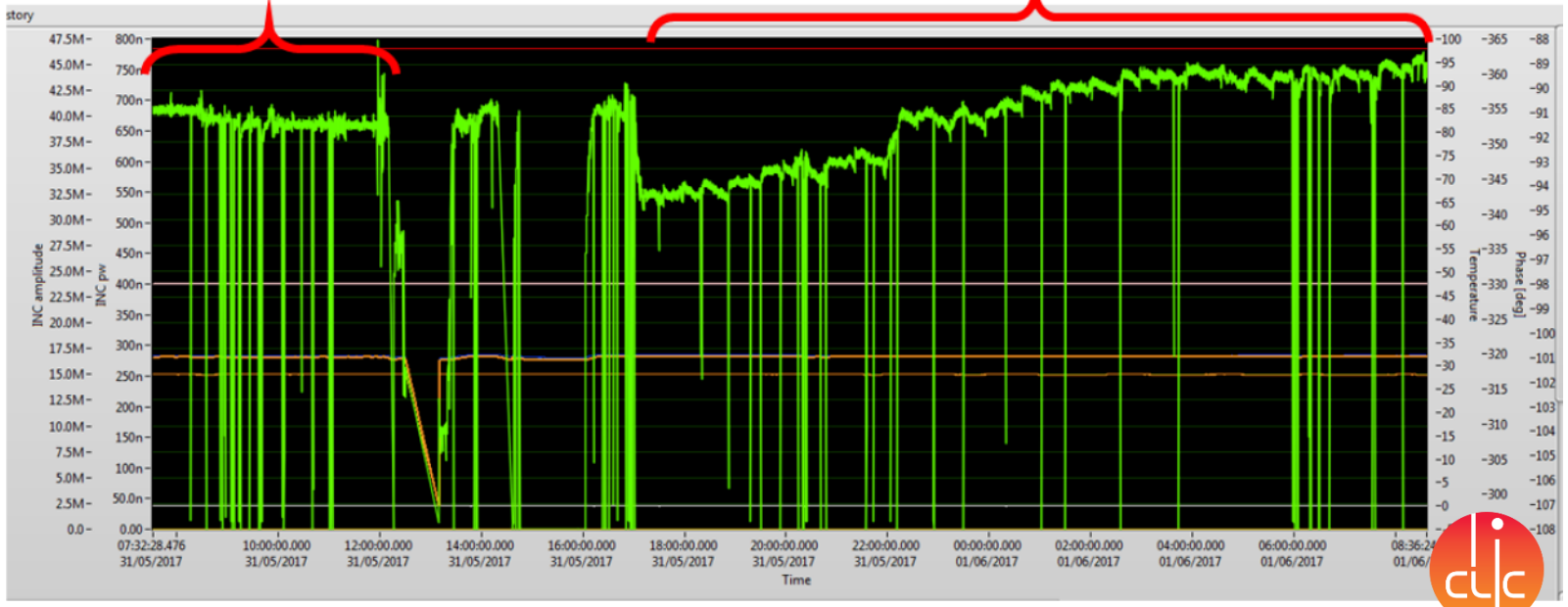
June 2017

TD26CCN2

Plot shows power as measured by log detector.

Feedback control stabilising log detector value.

Feedback control stabilising diode detector value.



- Feedback control of the incident power was modified to use the **diode detector** instead of the log detector.
- The power output is now much more stable.

XBOX1 @ CTF2

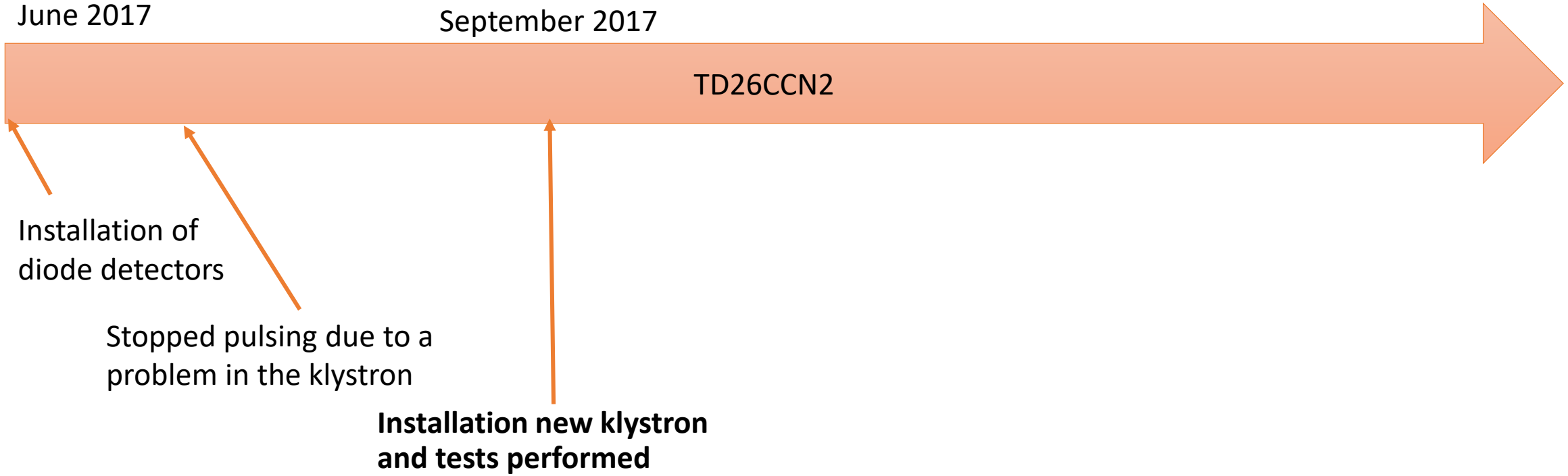
June 2017

TD26CCN2

Installation of diode detectors

Stopped pulsing due to a problem in the klystron

XBOX1 @ CTF2


June 2017
September 2017
TD26CCN2
Installation of diode detectors
Stopped pulsing due to a problem in the klystron
Installation new klystron and tests performed

XBOX1 @ CTF2

June 2017

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January 2018

TD26CCN2

Installation of diode detectors

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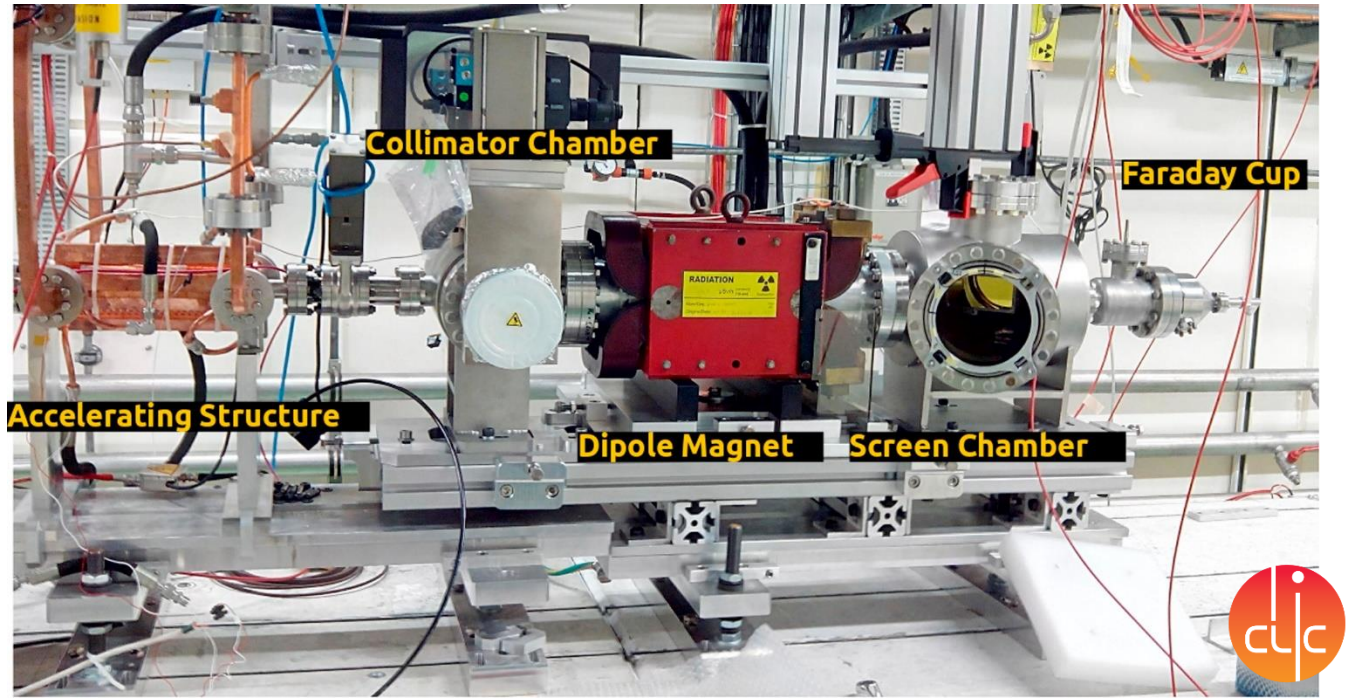
Installation new klystron and tests performed

Installation of the spectrometer from XBOX2



XBOX1 @ CTF2

June 2017

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TD26CCN2

Insta
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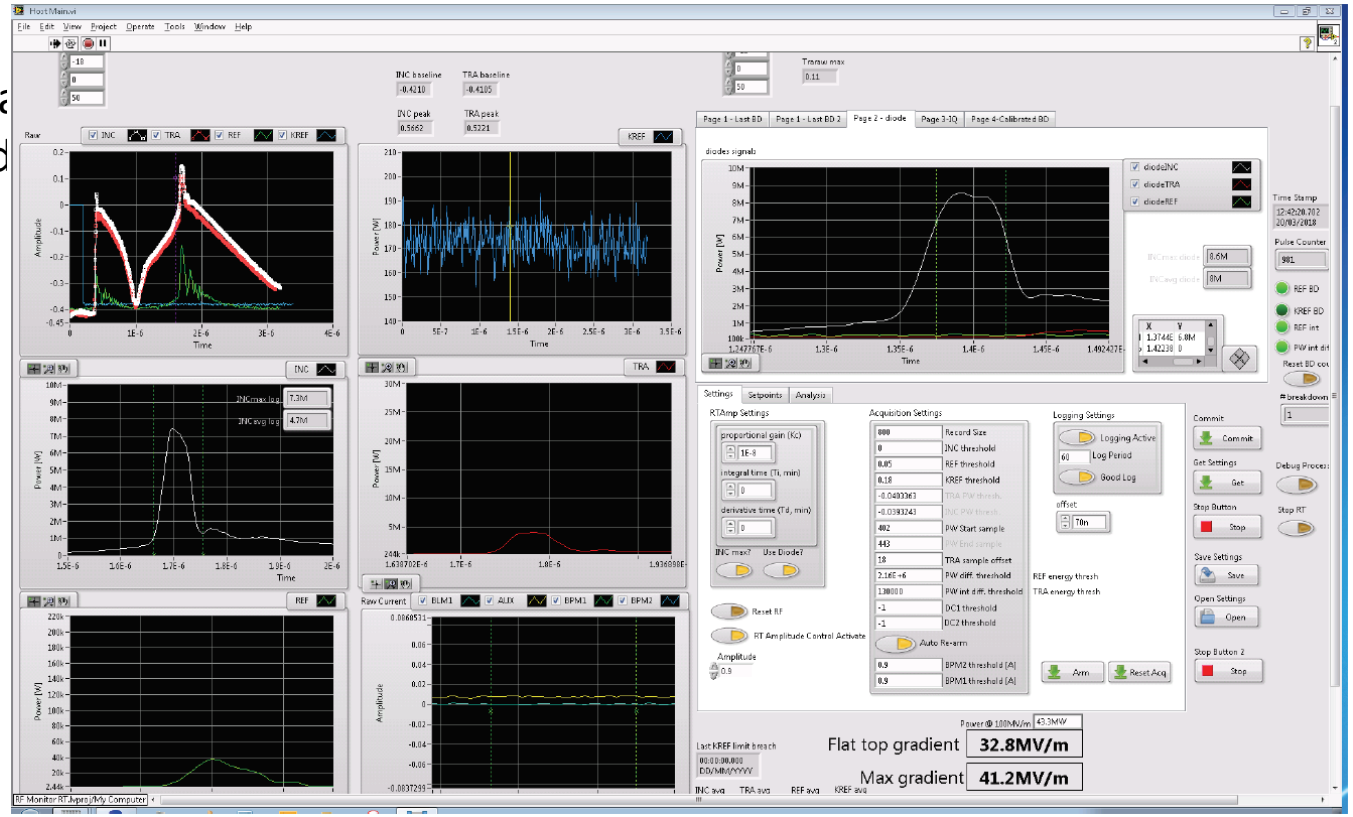
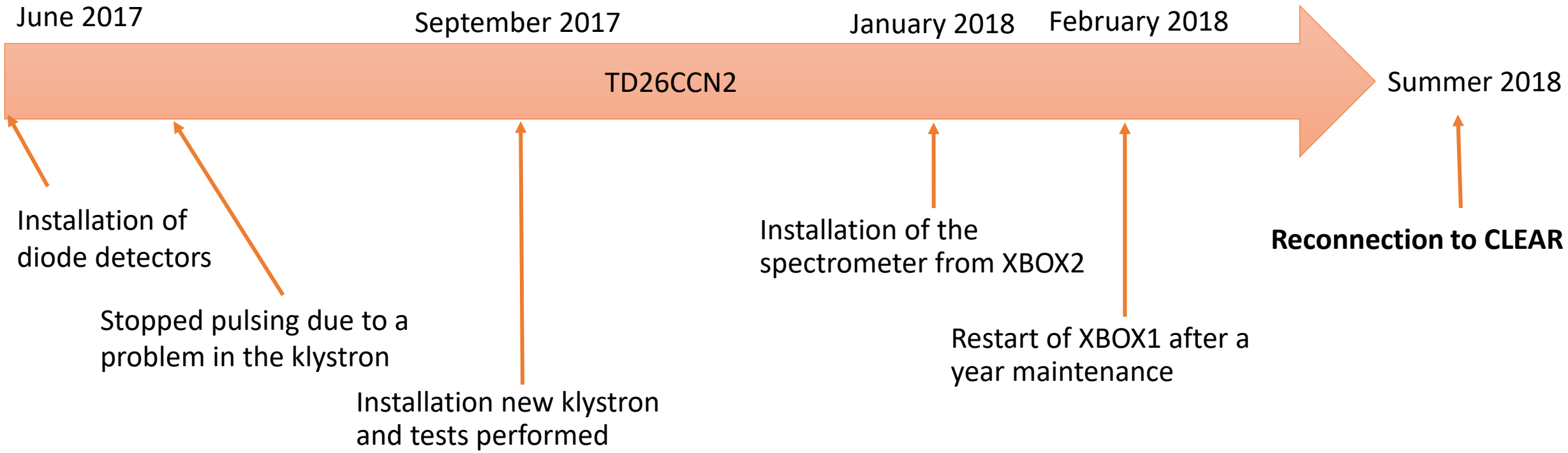


the
from XBOX2

Restart of XBOX1 after a year maintenance

XBOX1 @ CTF2


June 2017
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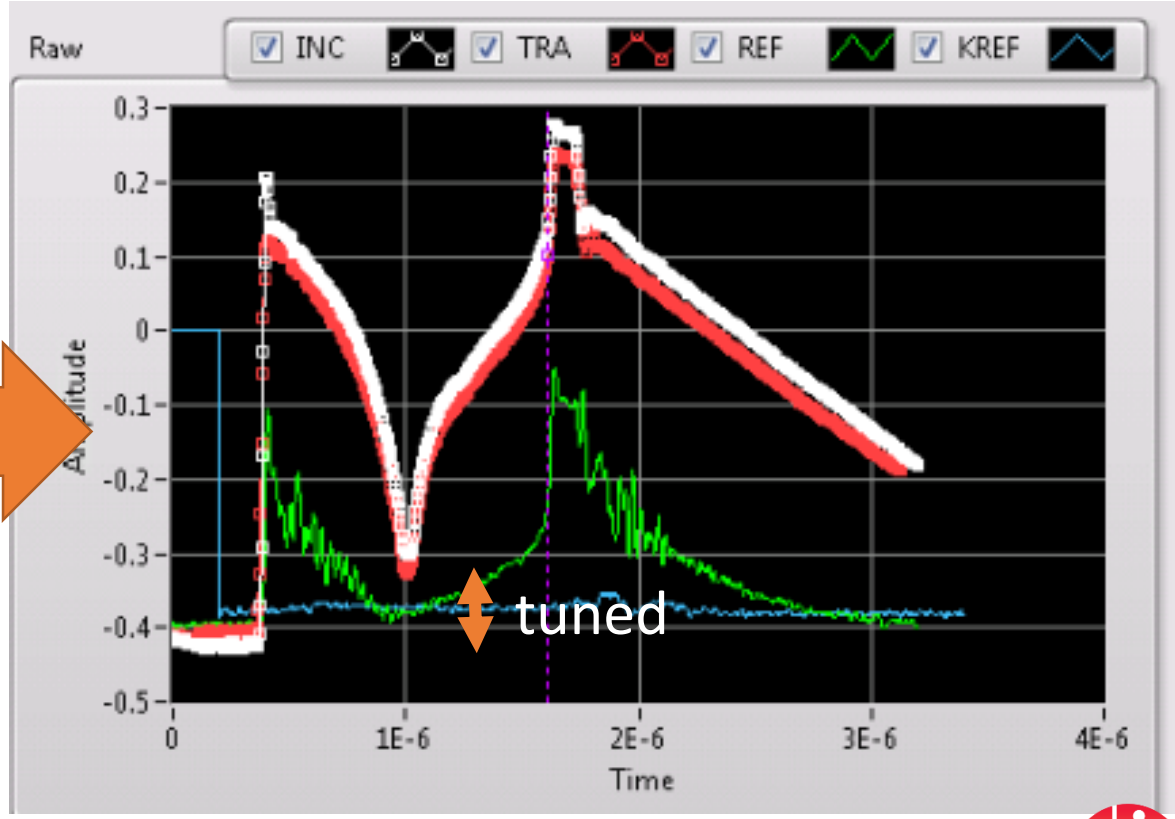
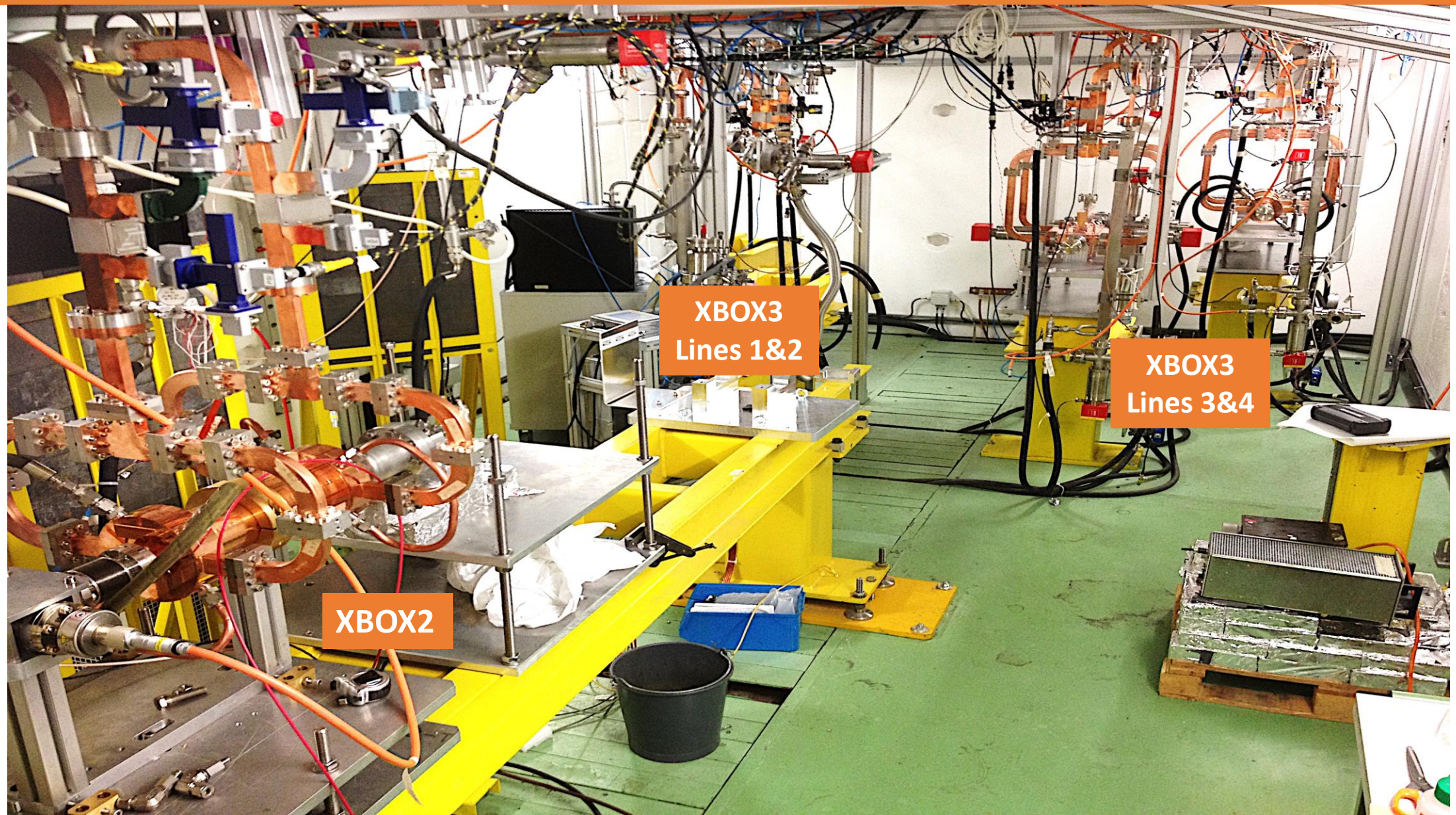
Installation of diode detectors
Stopped pulsing due to a problem in the klystron
Installation new klystron and tests performed
Installation of the spectrometer from XBOX2
Restart of XBOX1 after a year maintenance
Reconnection to CLEAR

XBOX1 @ Pulse Compressor Tuning

- New software for tuning pulse compressor by changing automatically the temperature of the chillers connected to each cavity of the pulse compressor



The Bunker



The Bunker

- Installation of a new waveguide cooling system for both XBOX2 and XBOX3


New cooling system

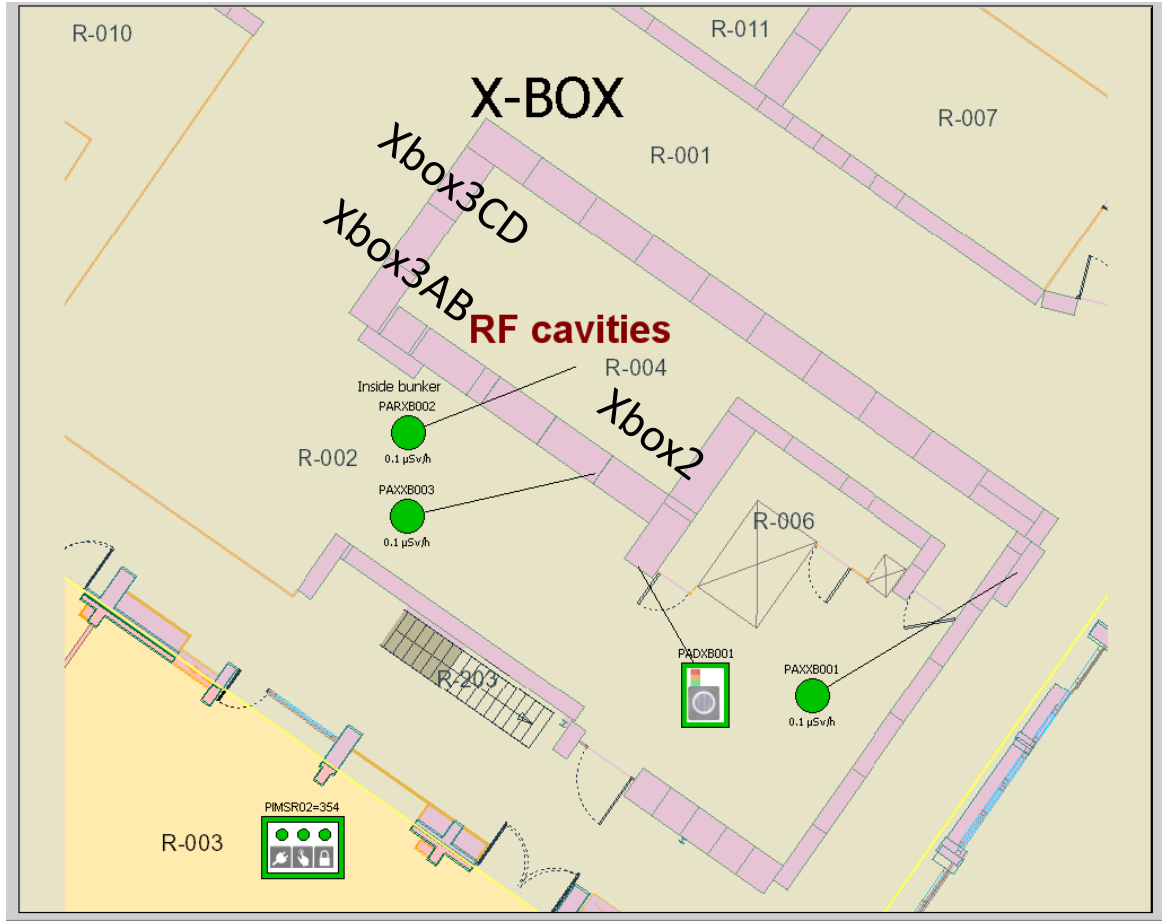
The Bunker

- Installation of a new waveguide cooling system for both XBOX2 and XBOX3
- New high power chillers in XBOX3 to maintain tuning temperature of the pulse compressor stable at a repetition rate of 400HZ (200Hz/line)


New cooling system

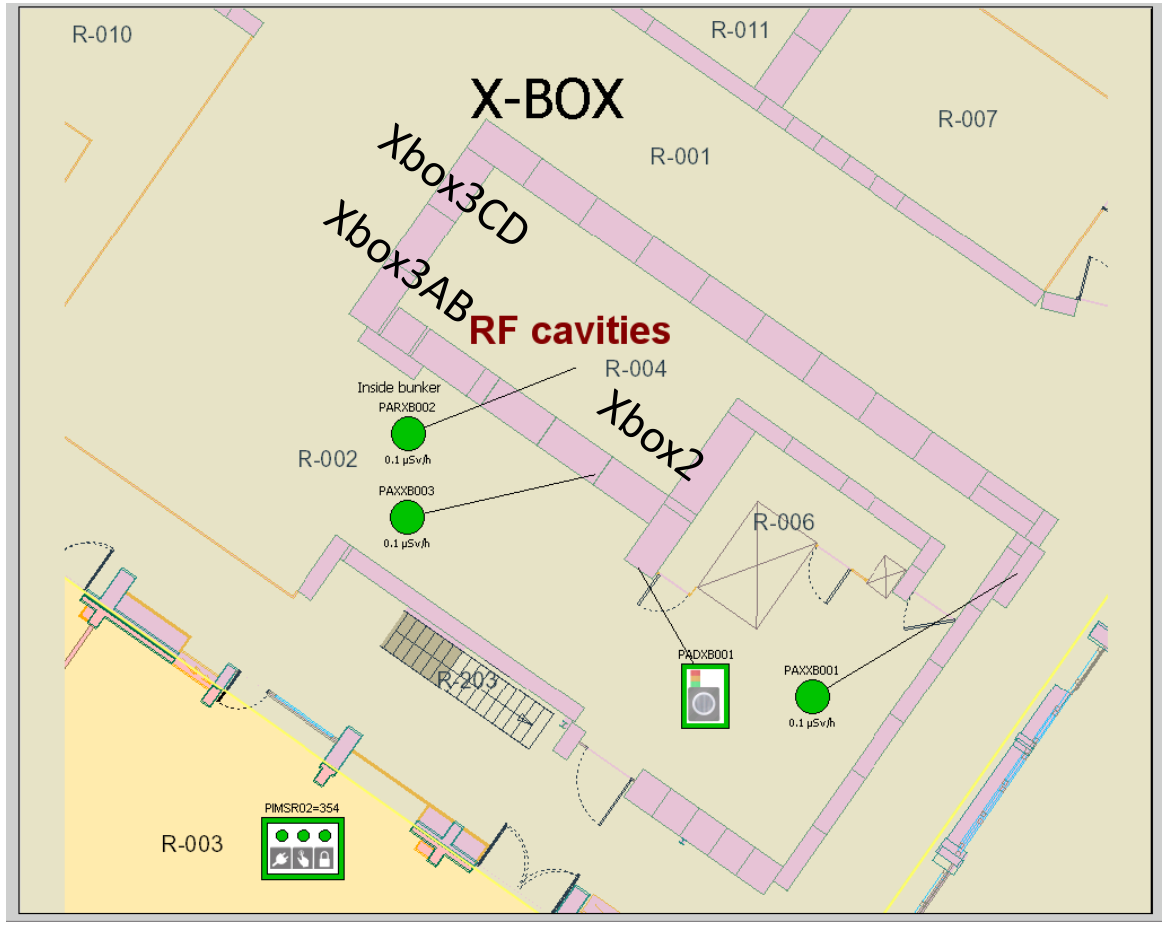
Radiation

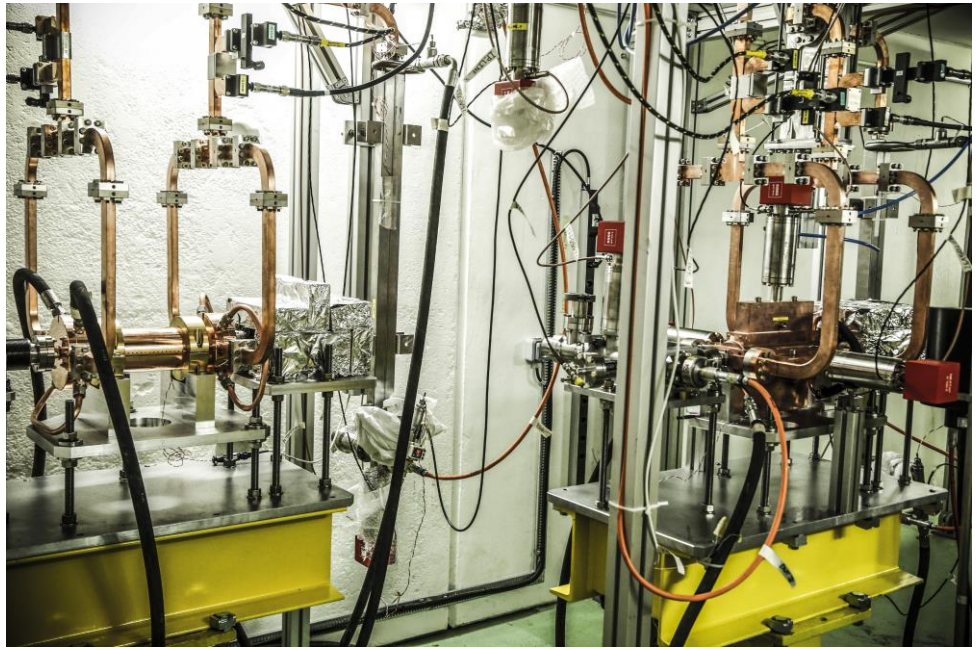
- Exceeding the radiation limits interlocked the system



Radiation

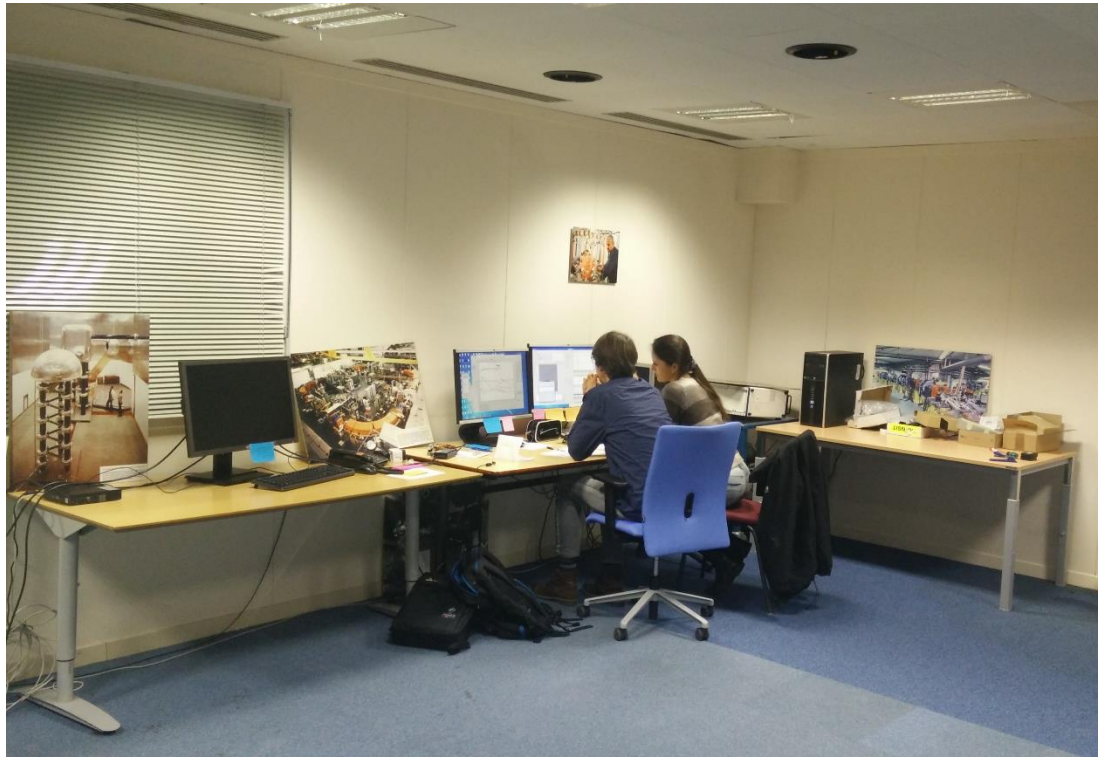
- Exceeding the radiation limits interlocked the system
- We solved the problem by removing the spectrometer from XBOX2 and shielding the downstream faraday cups with 500Kg of lead





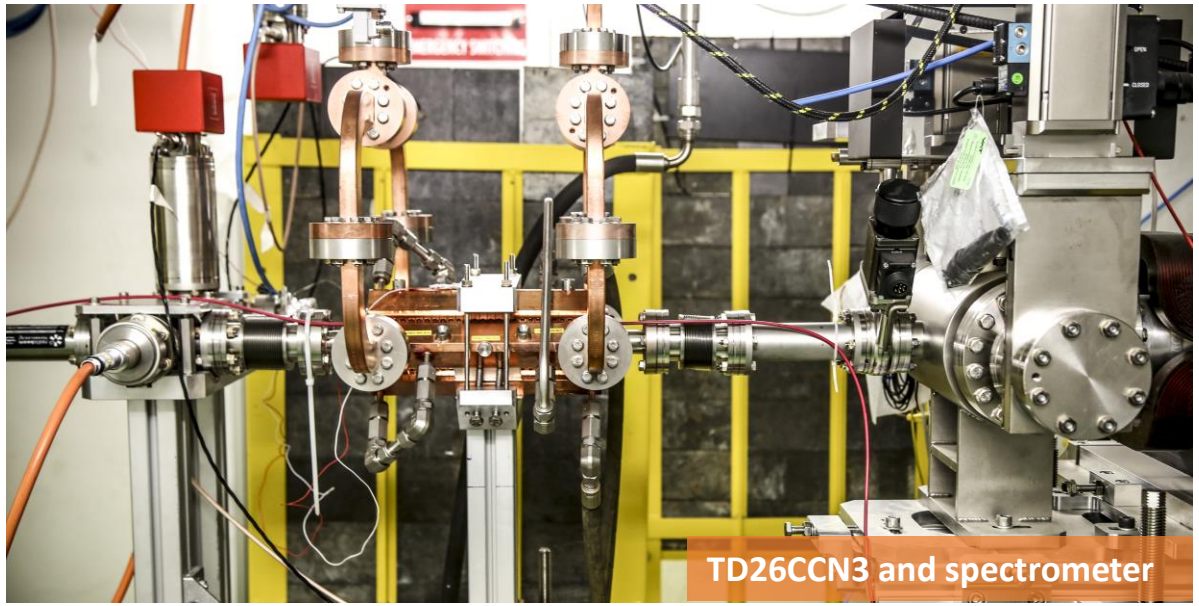
New Control room

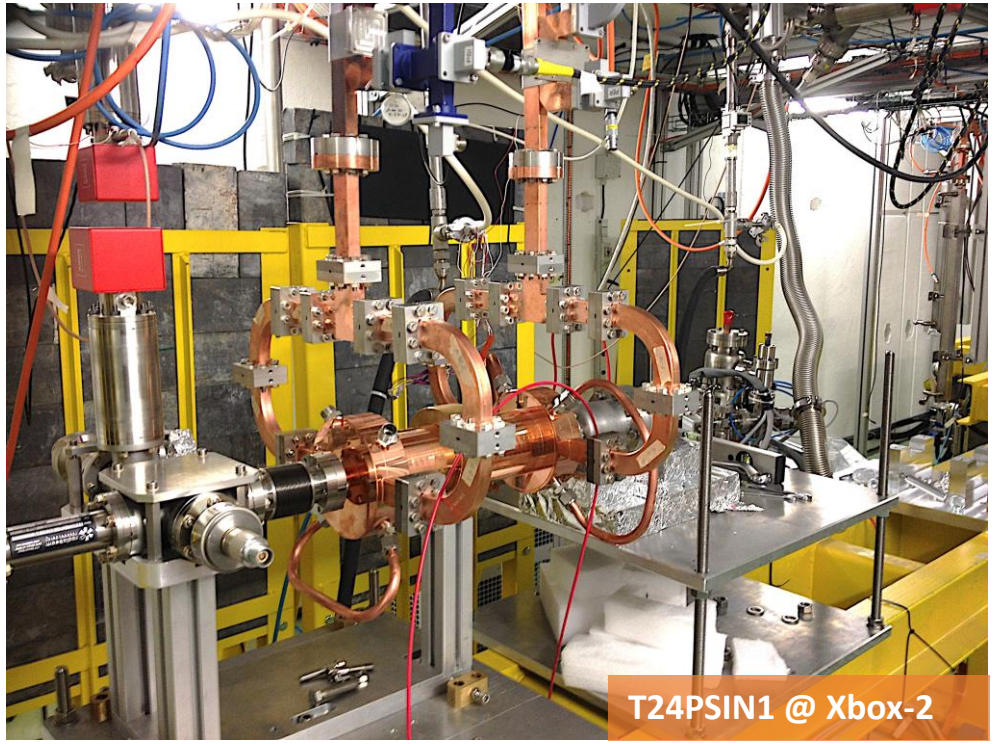
- Since summer 2017, located in front of the testing facilities
- All XBOXes can be operated from the control room, including XBOX1@CTF2
- Meeting room



XBOX2

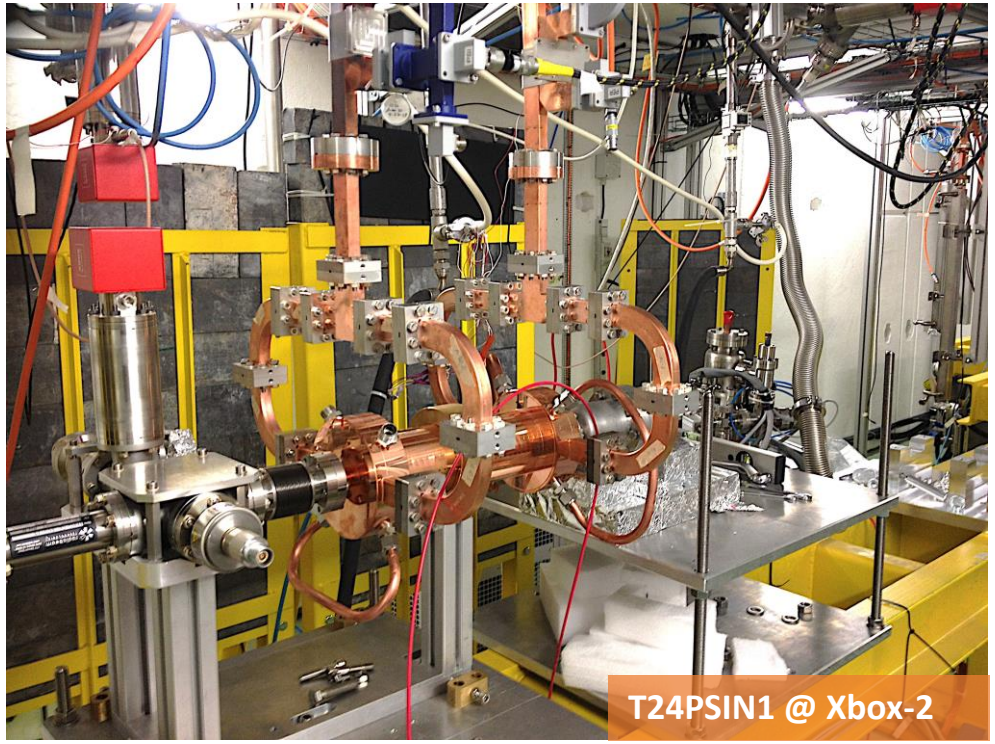
- Three different structures since last year
- Most robust test stand


TD26CCN3 and spectrometer


T24PSIN1 @ Xbox-2

XBOX2

- Three different structures since last year
- Most robust test stand
- **4M pulses per day**
- **80% availability**



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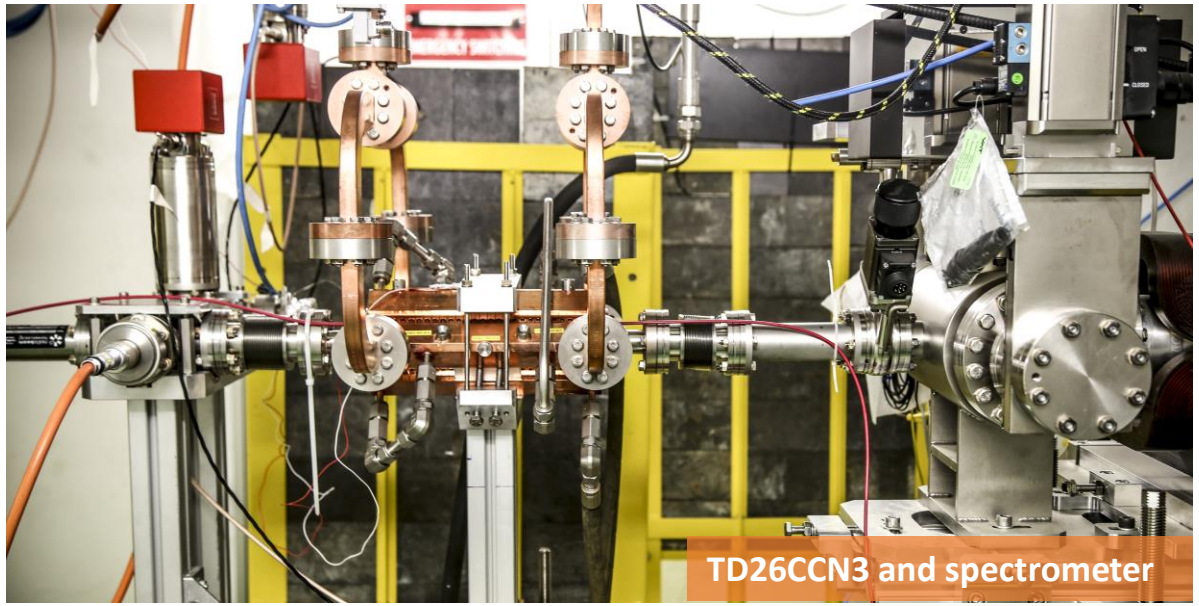

TD26CCN3 and spectrometer

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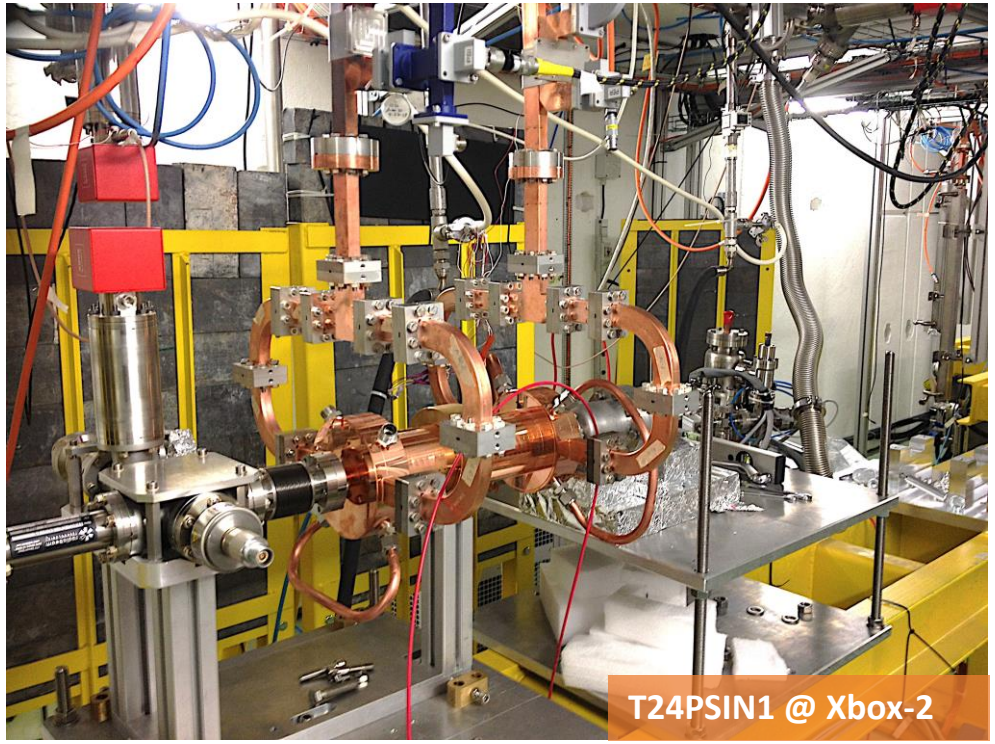
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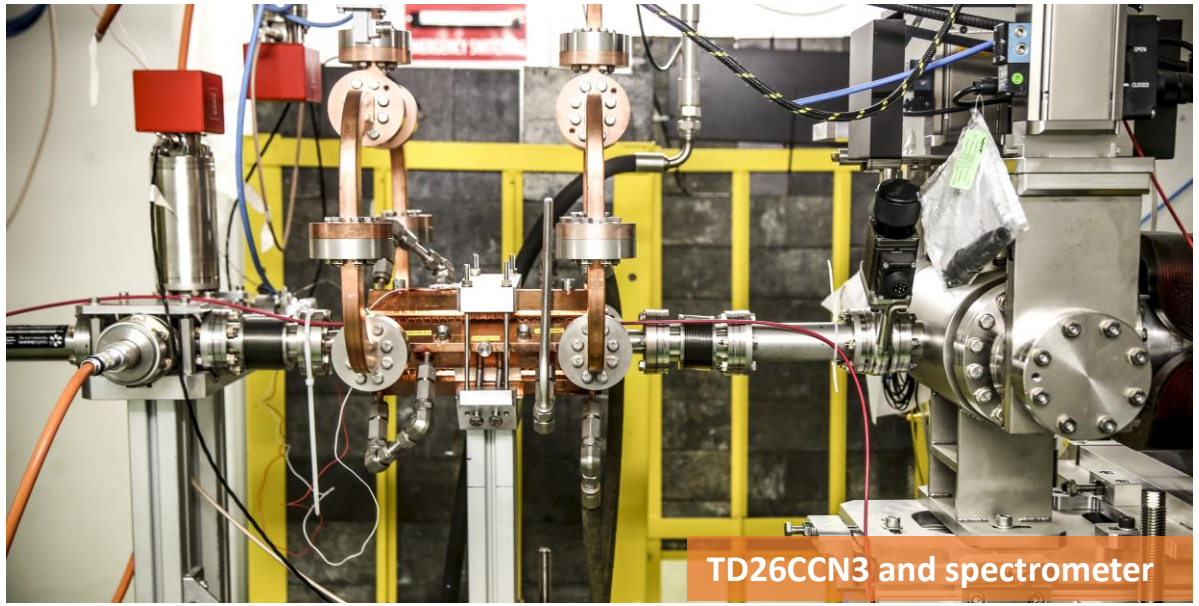
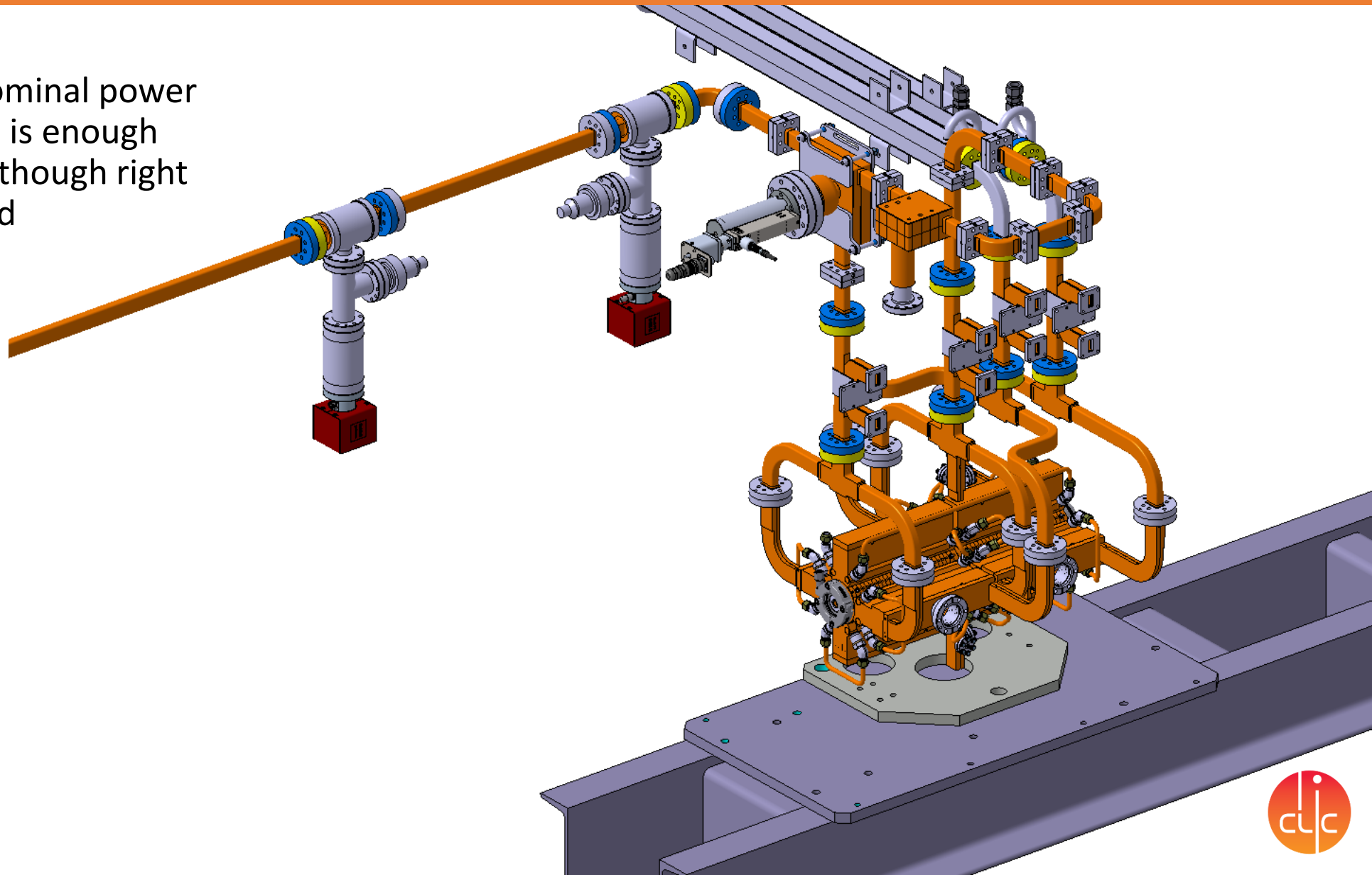

TD26CCN3 and spectrometer

- XBOX2 upgrade with the goal to split the line after the pulse compressor to feed two structures (**Superstructure**)

XBOX2 upgrade

- XBOX2 can provide a nominal power of about 130MW which is enough to feed two structures, though right now only one is installed



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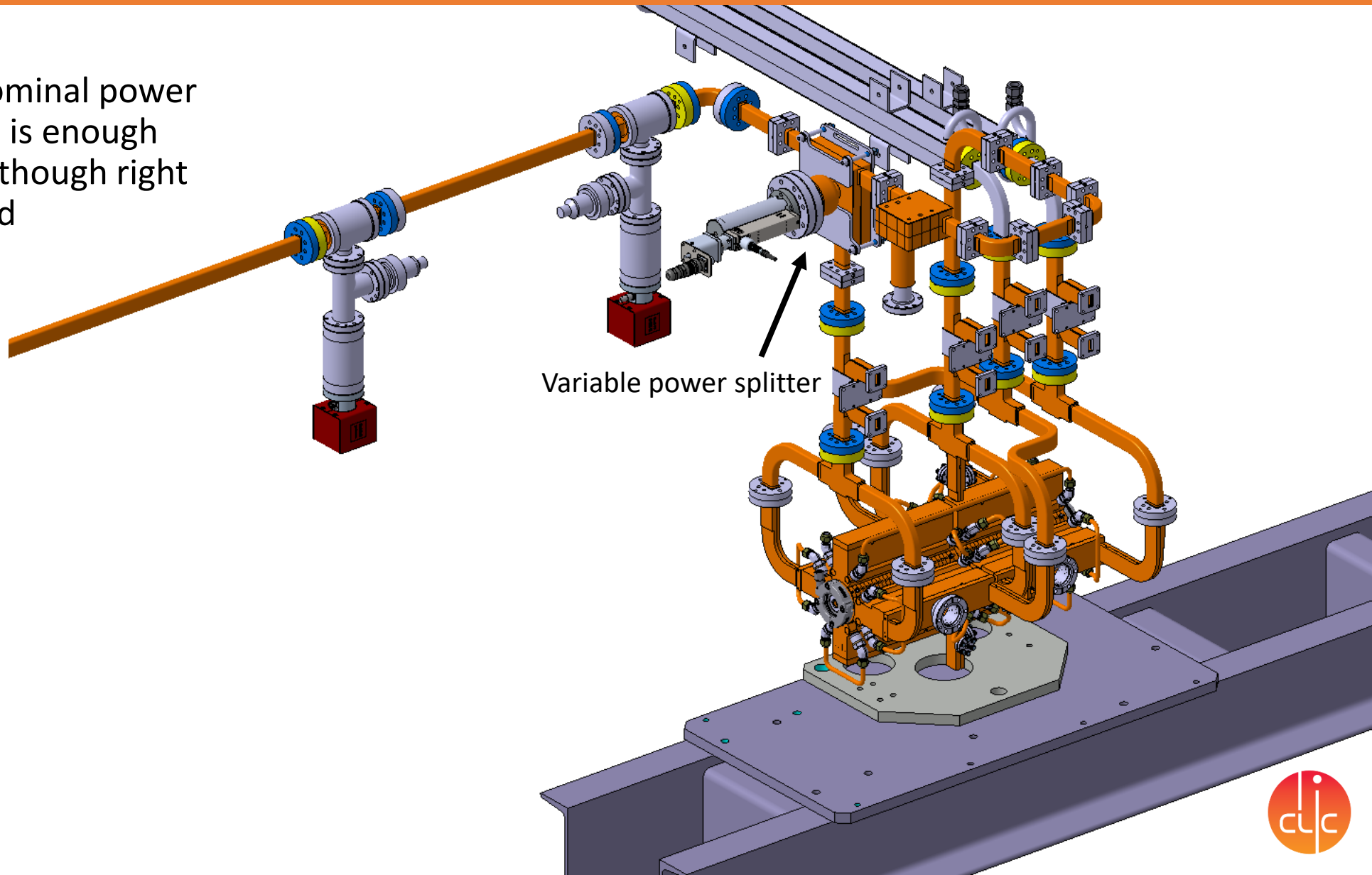

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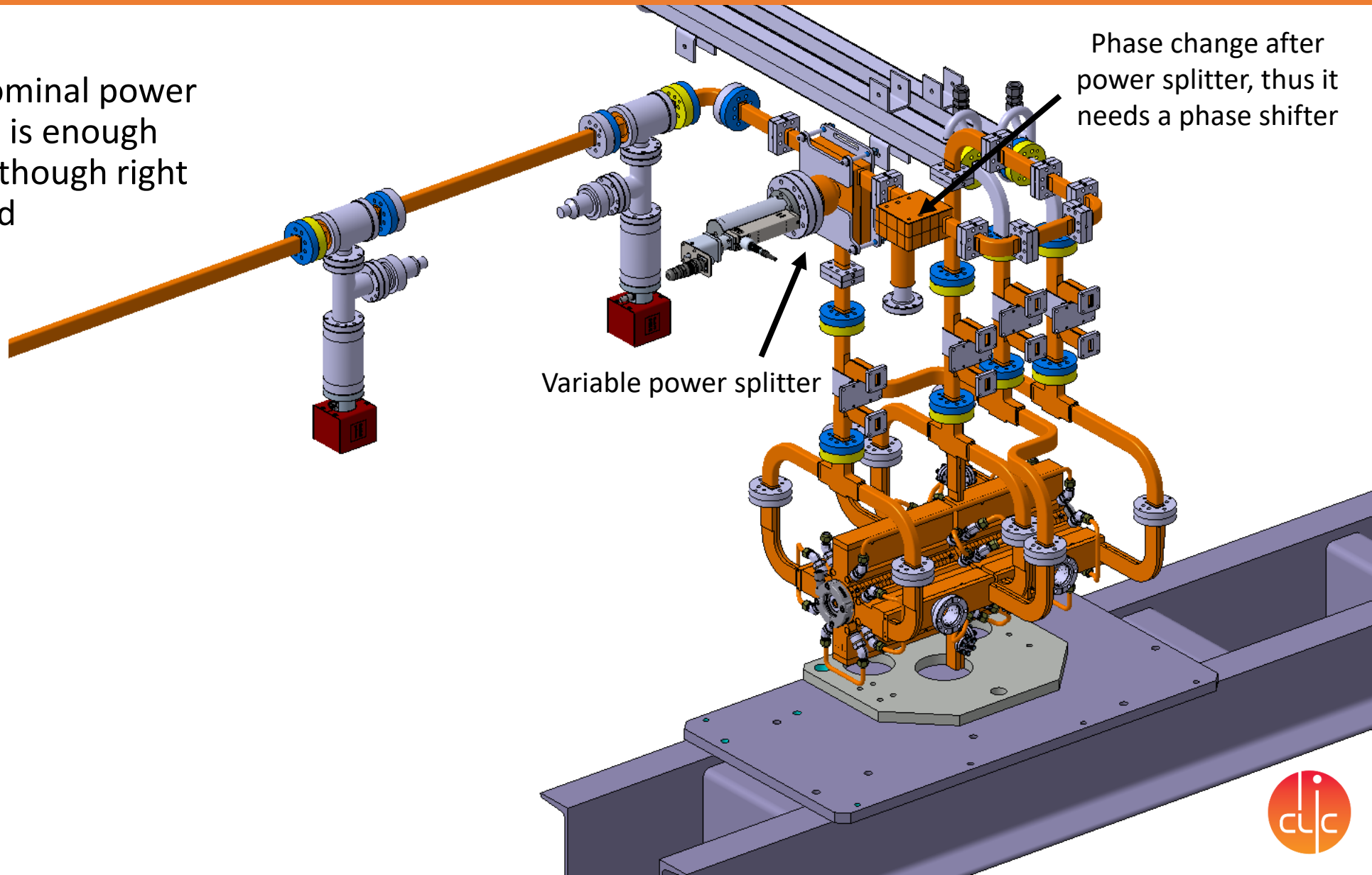
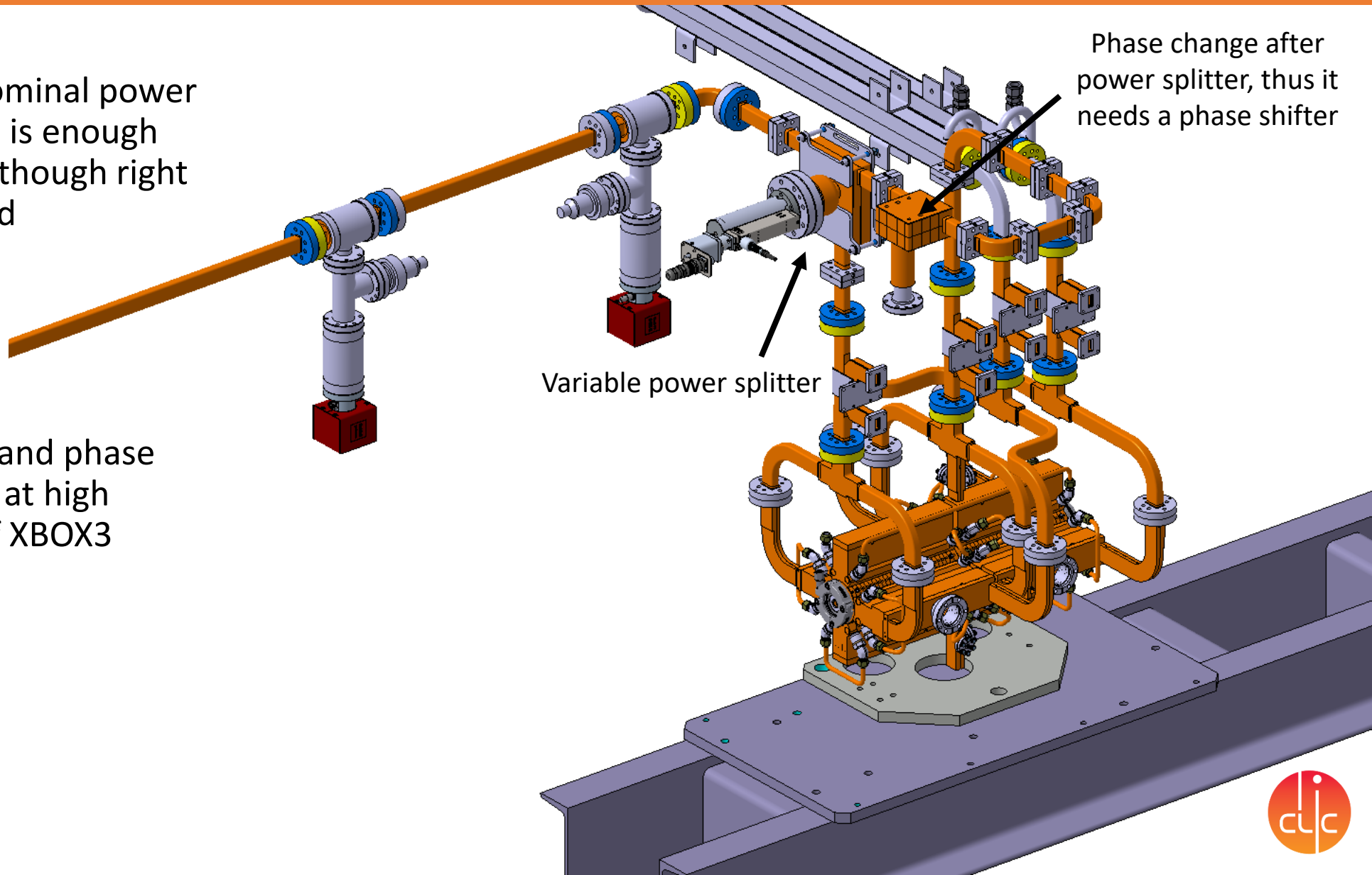


XBOX2 upgrade

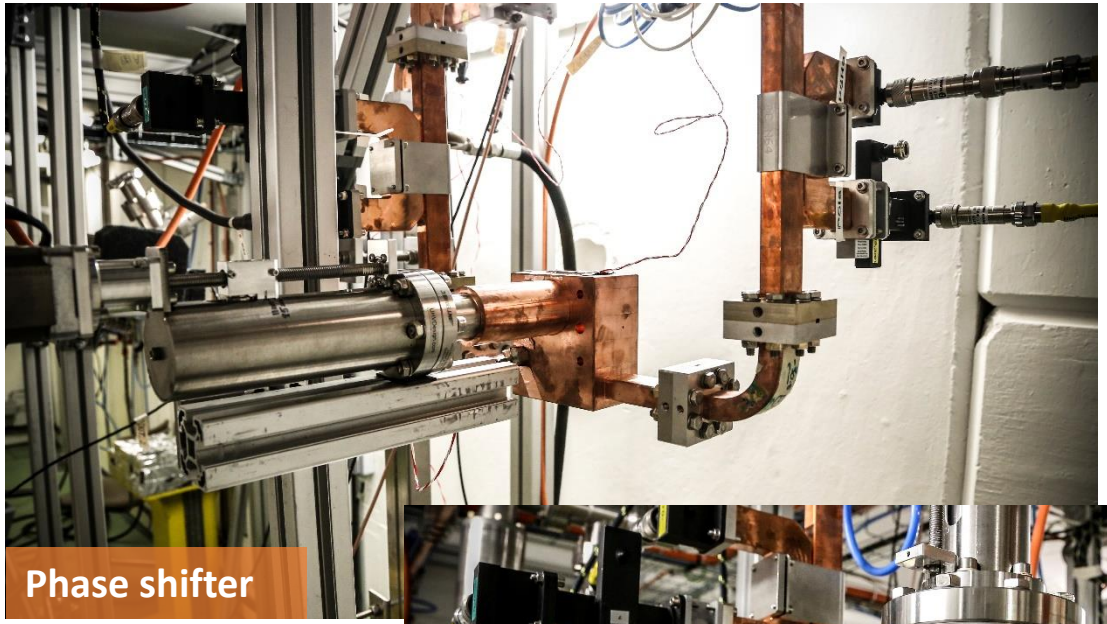
- XBOX2 can provide a nominal power of about 130MW which is enough to feed two structures, though right now only one is installed

- Variable power splitter and phase shifter are being tested at high power in line 1 and 2 of XBOX3

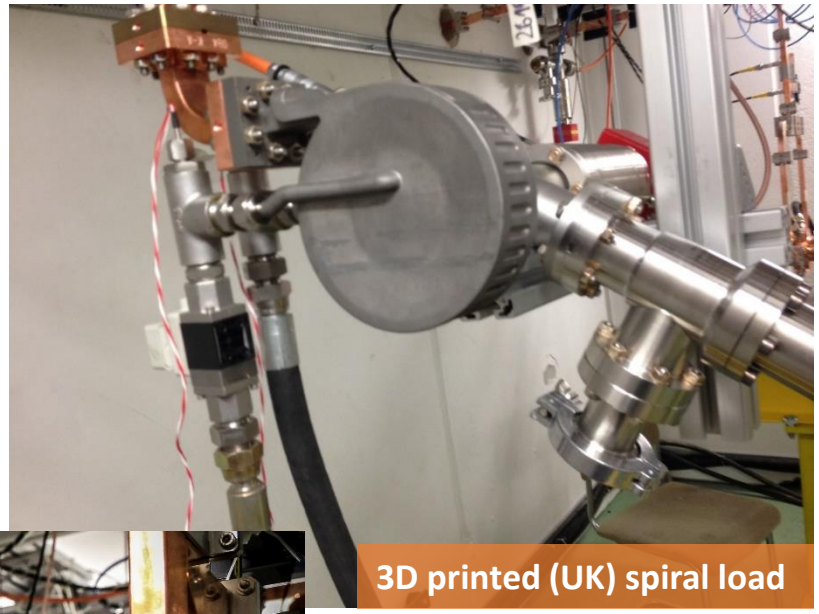


XBOX3 – Components conditioning

- Two 3D printed loads, phase shifter and power splitter were tested last year in lines 1 and 2 of XBOX3



Phase shifter



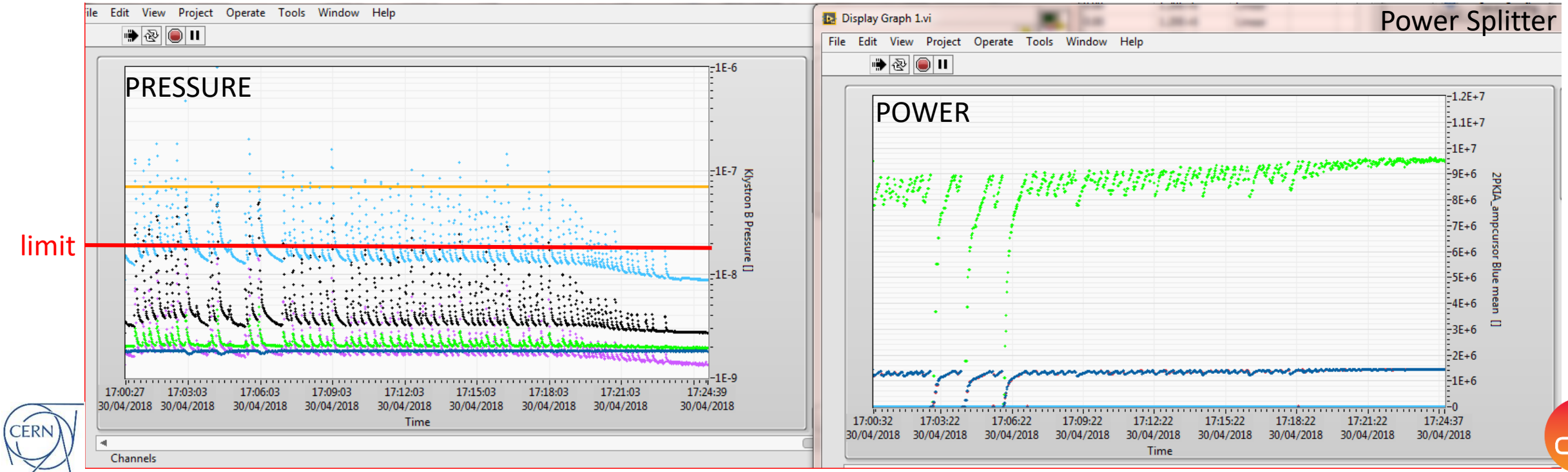
3D printed (UK) spiral load

Power splitter

3D printed (CERN) compact load

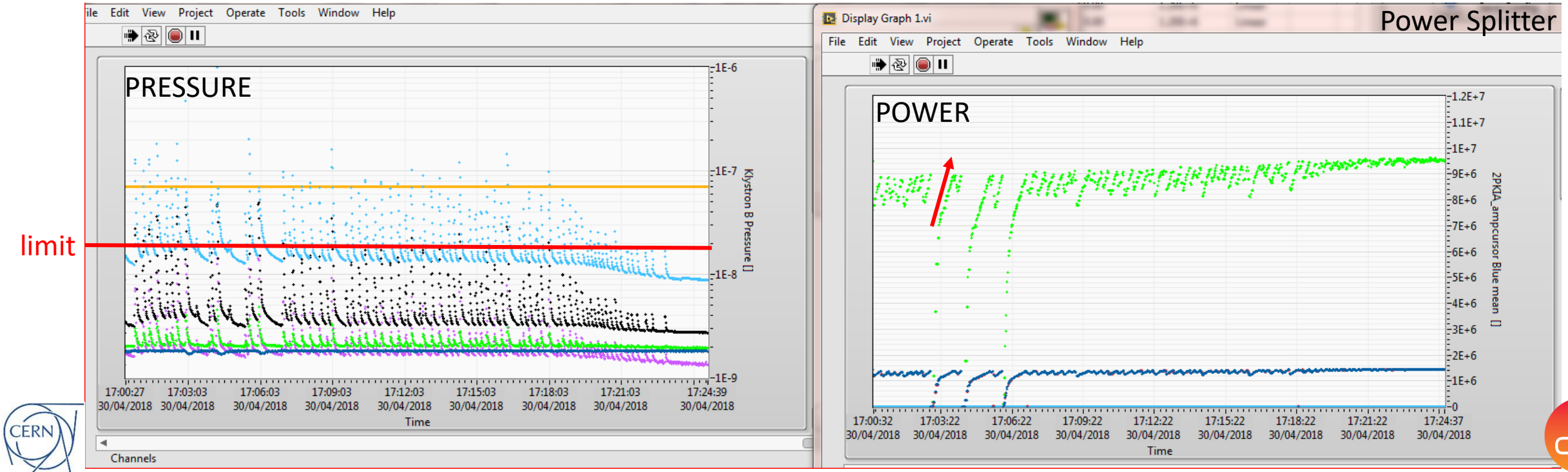
XBOX3 – Components conditioning

- Conditioning with an algorithm based on vacuum pressure calculations instead of BDR.
  - Set a pressure limit



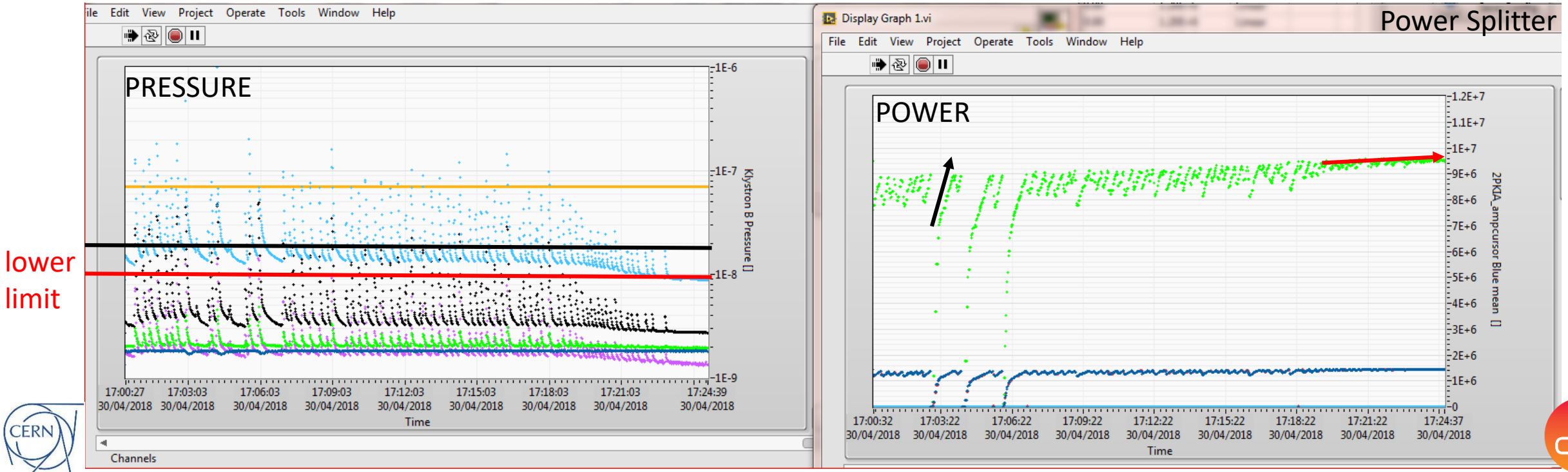
XBOX3 – Components conditioning

- Conditioning with an algorithm based on vacuum pressure calculations instead of BDR.
  - Set a pressure limit
  - Power increase based on the difference between actual pressure and limit pressure



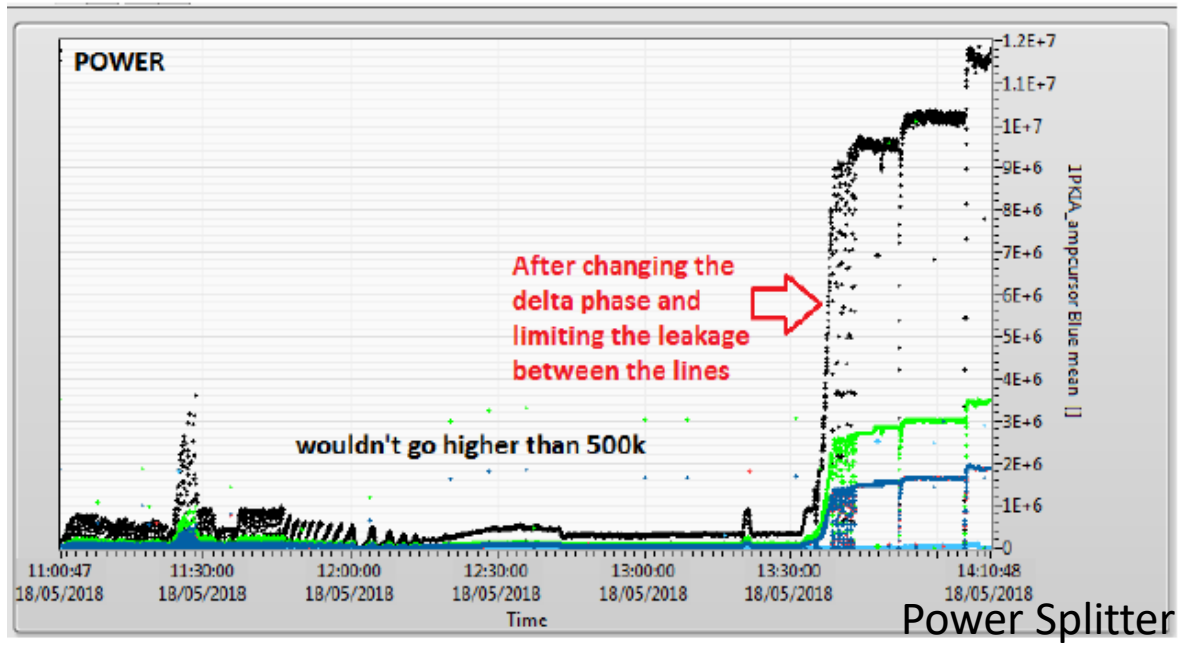
XBOX3 – Components conditioning

- Conditioning with an algorithm based on vacuum pressure calculations instead of BDR.
  - Set a pressure limit
  - Power increase based on the difference between actual pressure and limit pressure
  - Pressure limit has to be set close to baseline pressure to avoid a fast increase on the power that will lead to vacuum spikes



XBOX3 – Components conditioning

- Conditioning with an algorithm based on vacuum pressure calculations instead of BDR.
  - Set a pressure limit
  - Power increase based on the difference between actual pressure and limit pressure
  - Pressure limit has to be set close to baseline pressure to avoid a fast increase on the power that will lead to vacuum spikes
  - At low power leakage between lines is critical, needs manual adjustment of the phase between lines and keeping a similar power in both lines

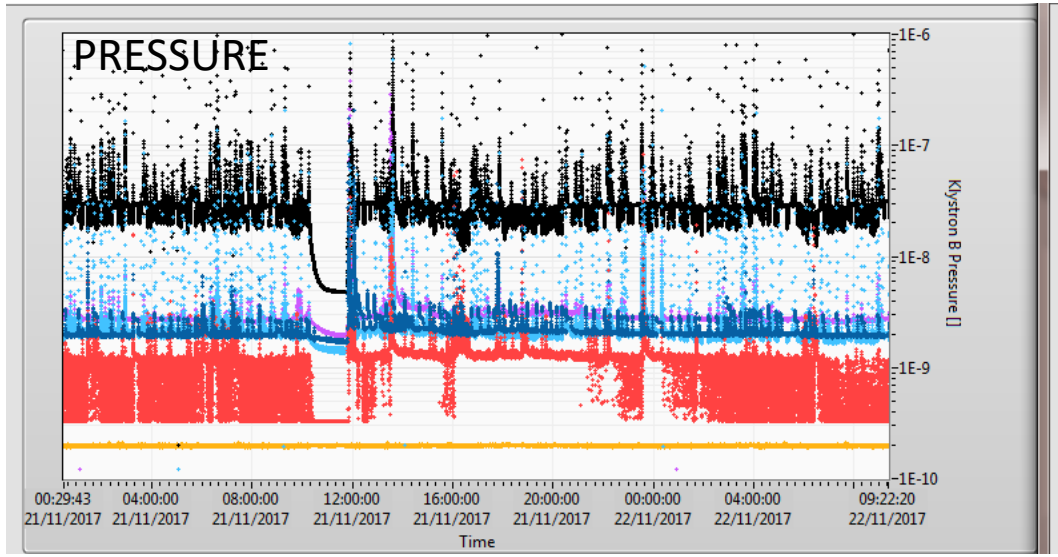


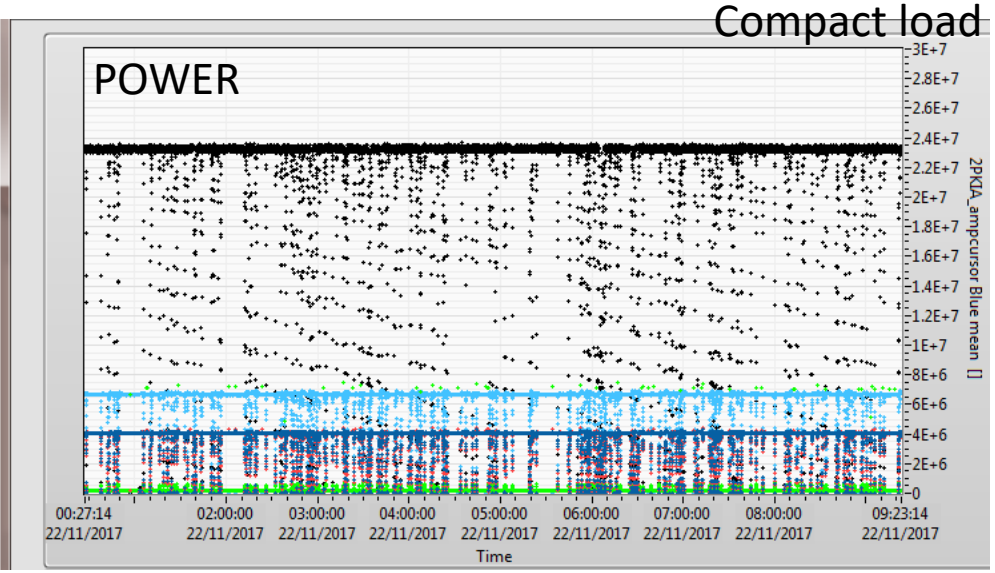
Power Splitter

XBOX3 – Components conditioning

- Conditioning with an algorithm based on vacuum pressure calculations instead of BDR.
  - Set a pressure limit
  - Power increase based on the difference between actual pressure and limit pressure
  - Pressure limit has to be set close to baseline pressure to avoid a fast increase on the power that will lead to vacuum spikes
  - At low power leakage between lines is critical, thus keep similar power level in both lines
  - Requires a lot of human monitoring
  - Set to constant power during unattended periods

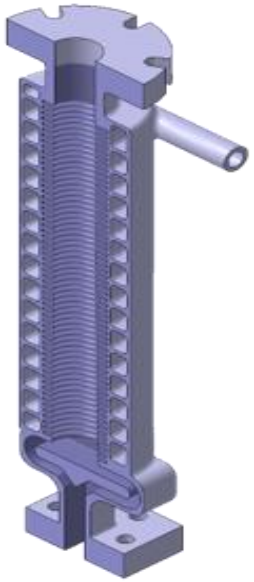
Compact load

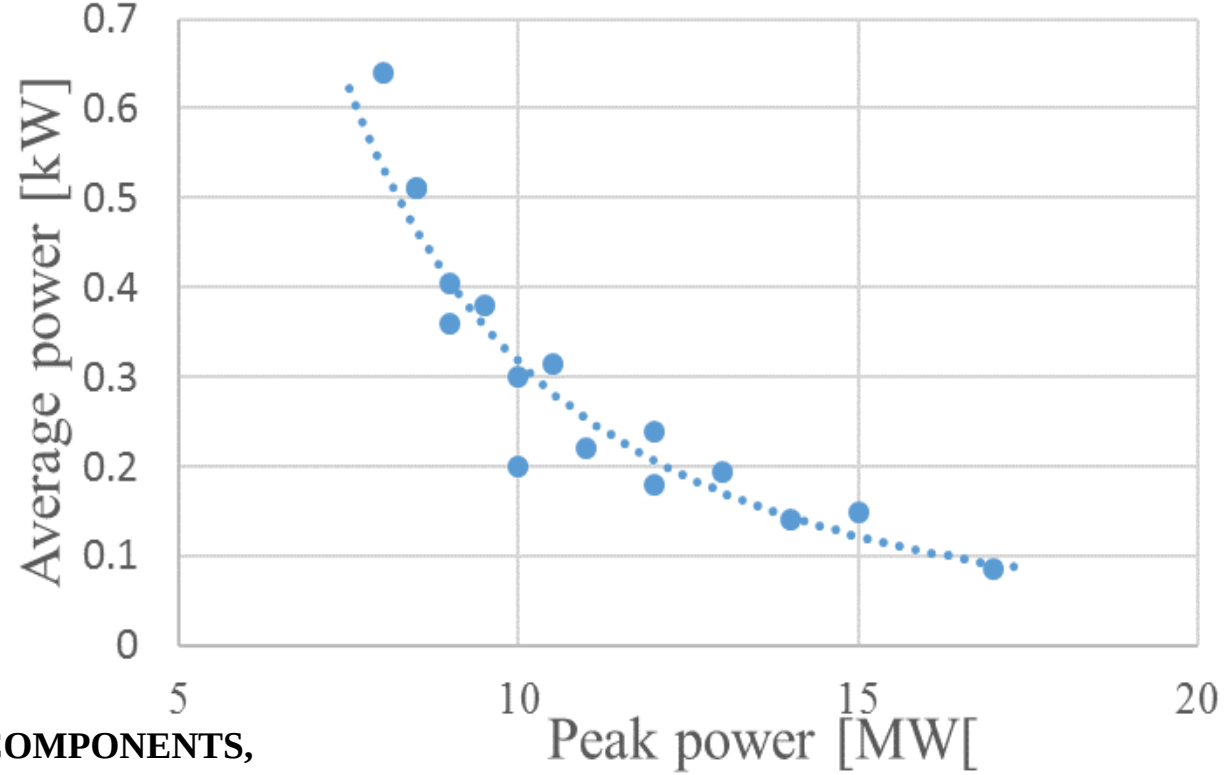




Compact Load

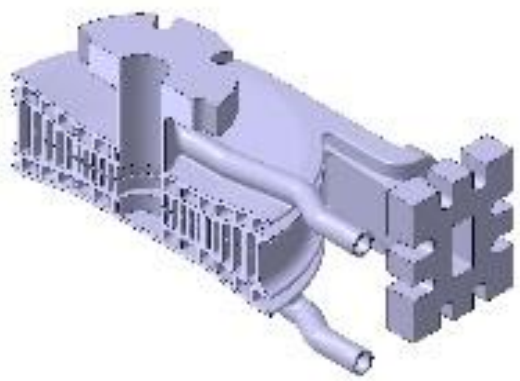
- Only vacuum conditioned as there was not significant reflected power to be measured
- Not limited exclusively by peak power or average power but by a combination of both
- Reached 17MW@50ns and 1E-8mbar pressure
- Pressure in the load will not improve with further conditioning at constant power

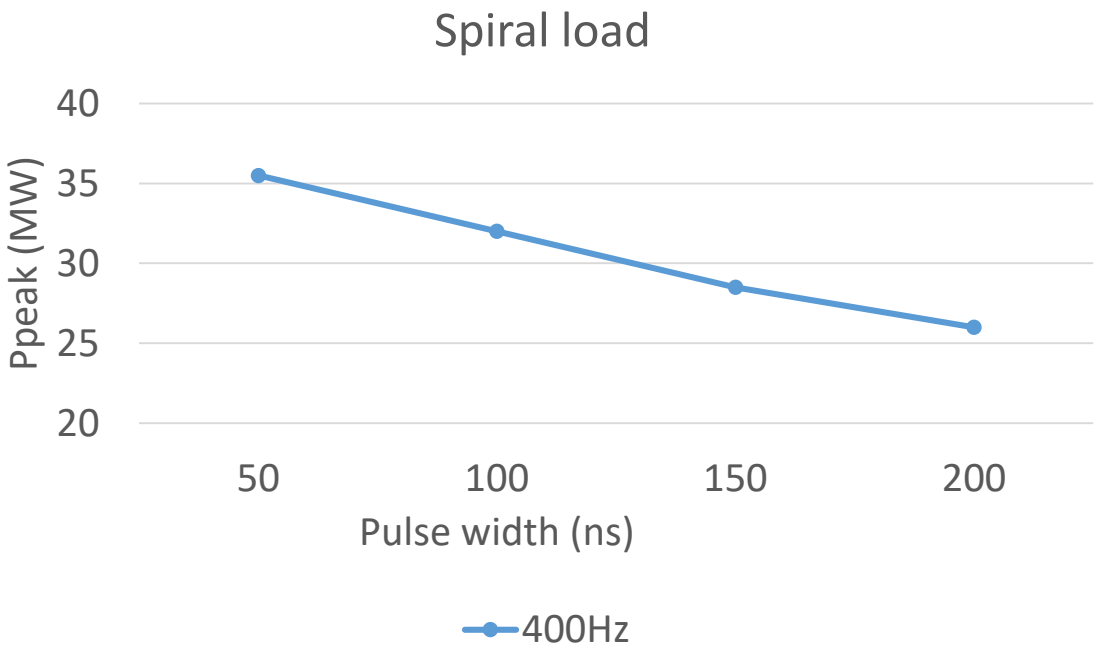




Spiral load

- The load does not seem to have an intrinsic limitation
- Tested up to the maximum available power in the line which was 35.5MW peak power for 50ns and 25MW for 200ns pulses always at 200 Hz/line.
- The maximum aver-age power put into the load was 2.1 kW

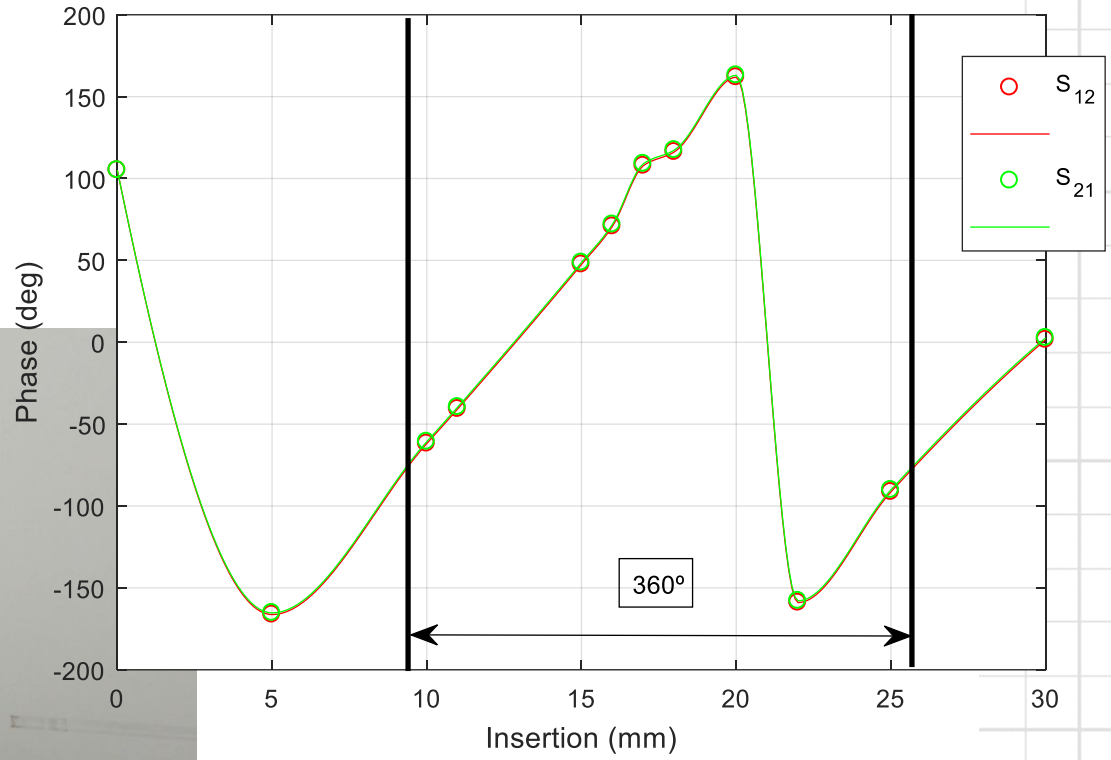


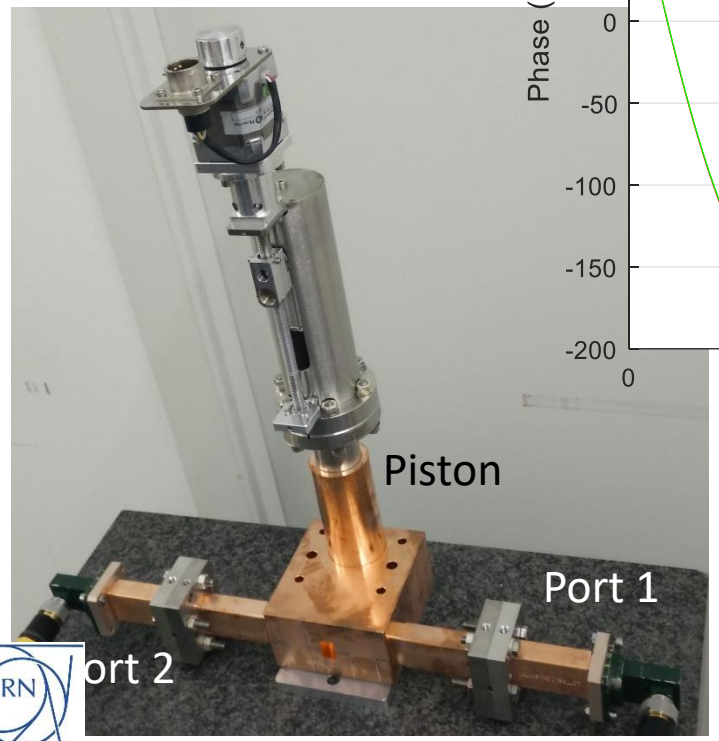


HIGH POWER CONDITIONING OF X-BAND RF COMPONENTS,
N. Catalan-Lasheras et al., IPAC2018

Phase Shifter

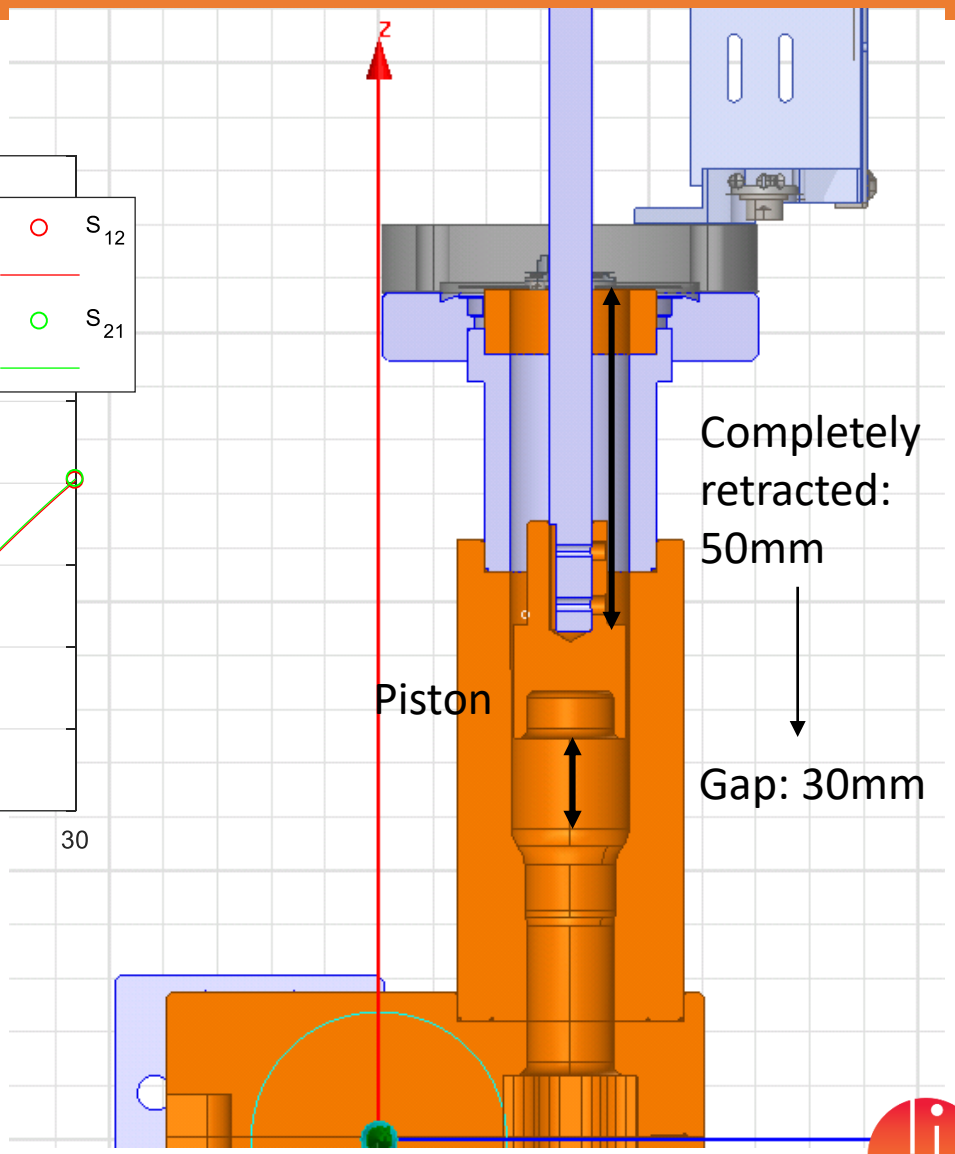
- VNA measurements done to variable phase shifter





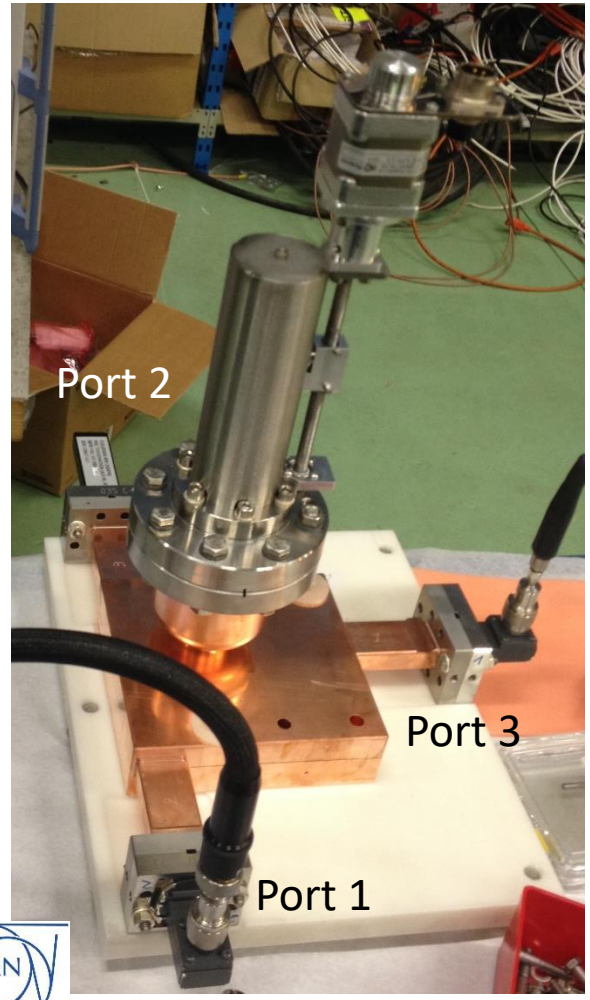
1mm insertion ~ 21º phase shift

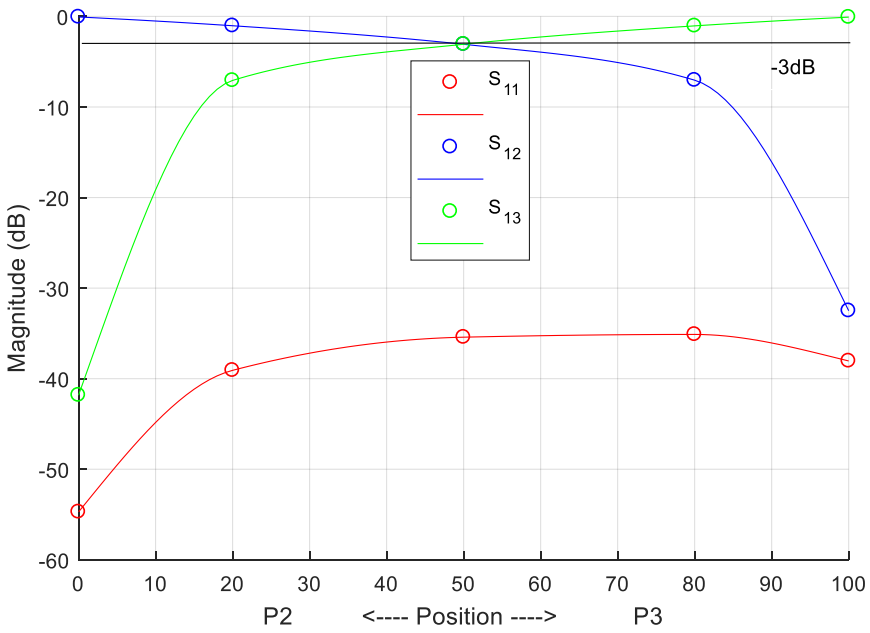
17mm insertion ~ 360º phase shift



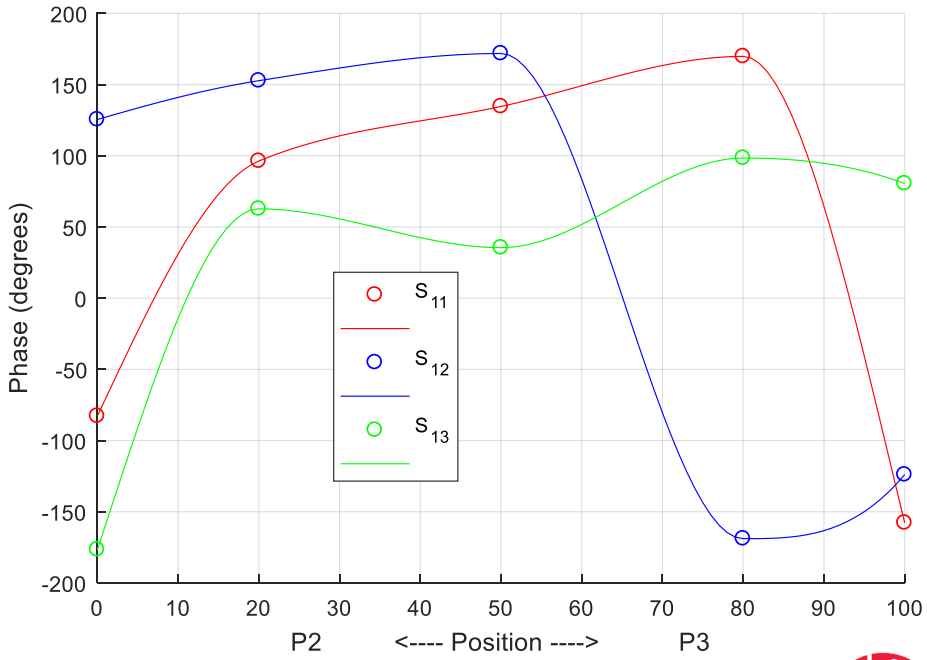
Power Splitter

- VNA measurements done to variable power splitter



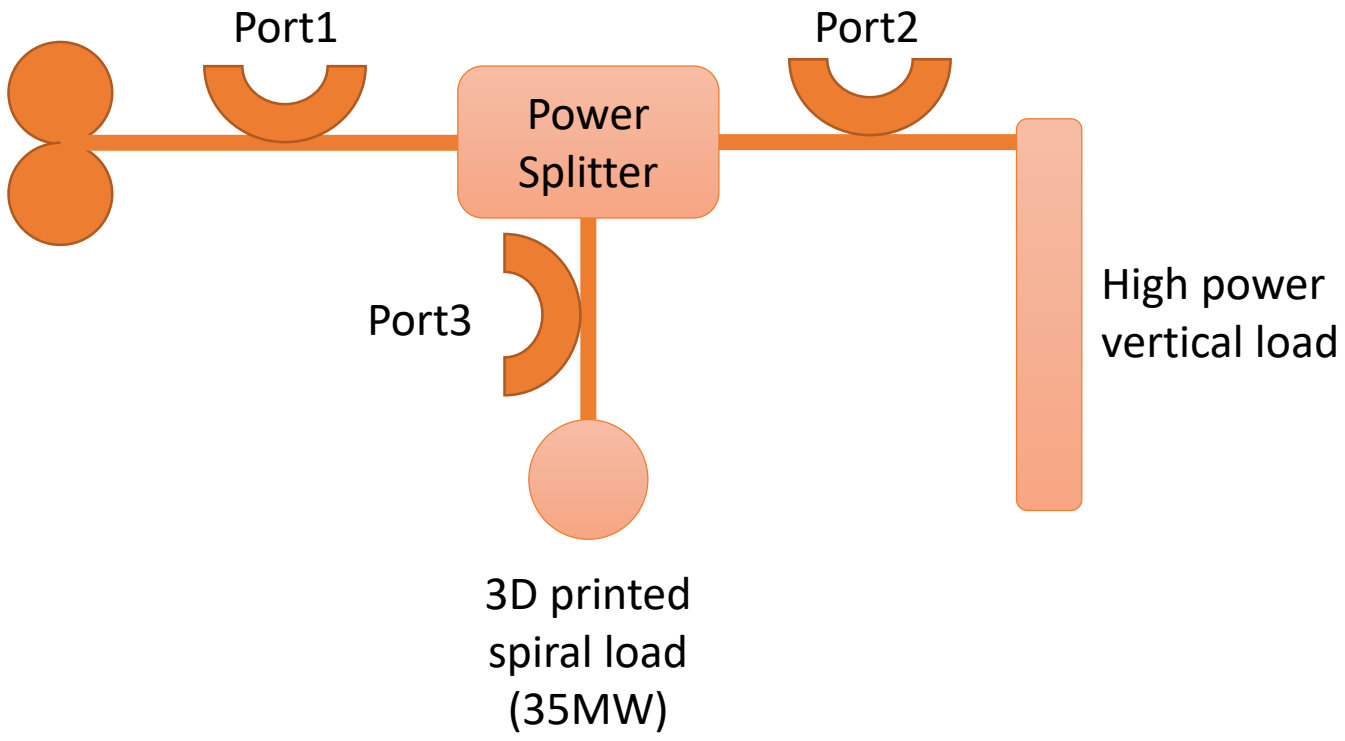


Phase changes when moving the piston



High power conditioning

- Tested in XBOX3
- Power splitter conditioned one output port at a time
- Phase shifter conditioned with the piston at the middle of the shifting-range



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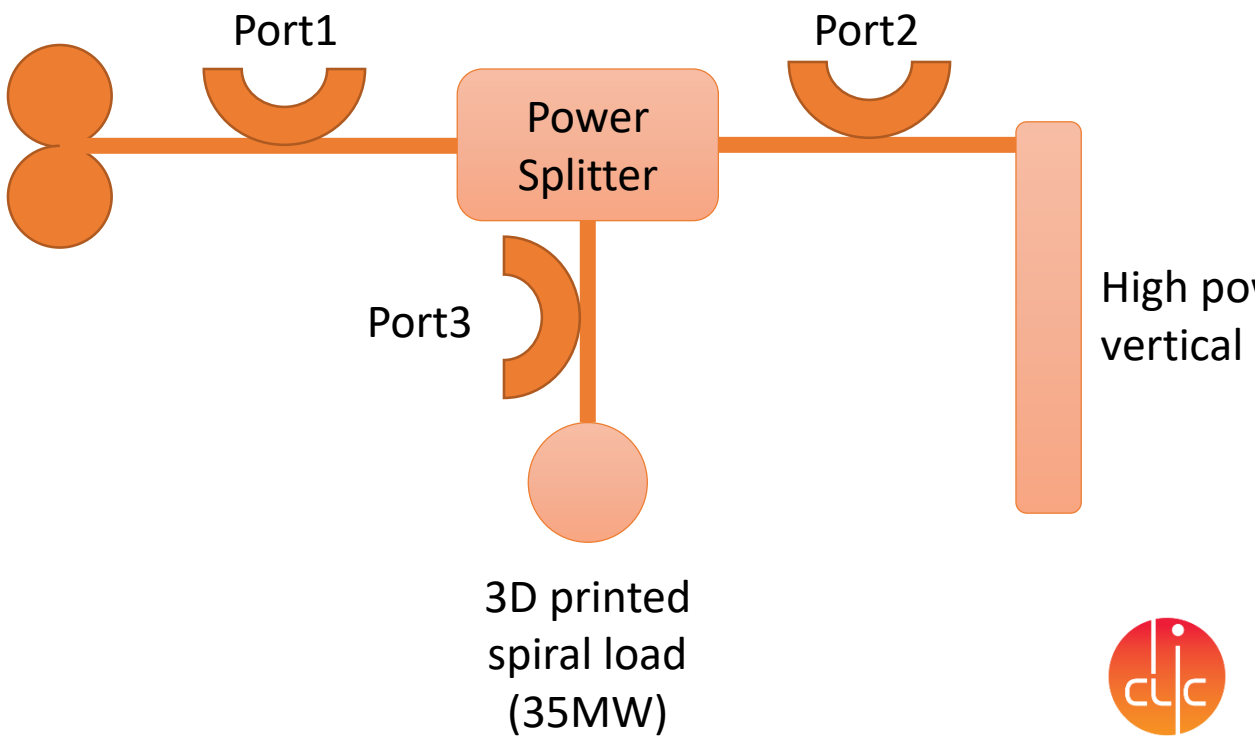
- Power splitter conditioned faster than phase shifter in line 1 and we had to lower the power due to line-to-line leakage



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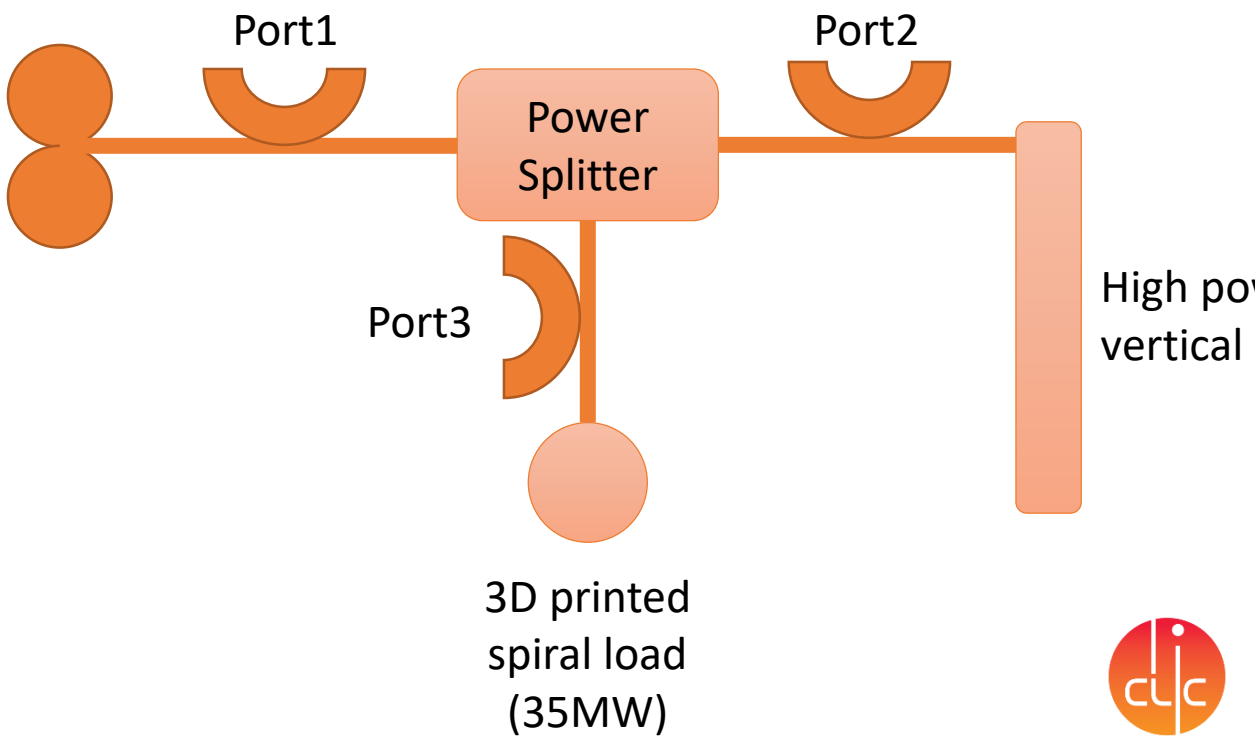
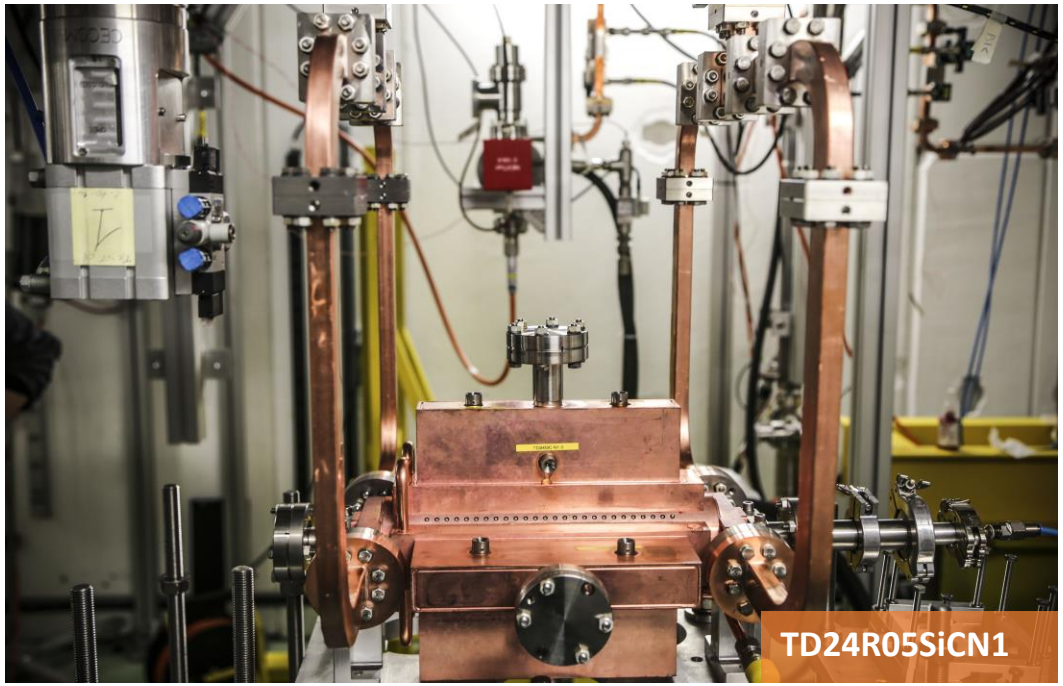
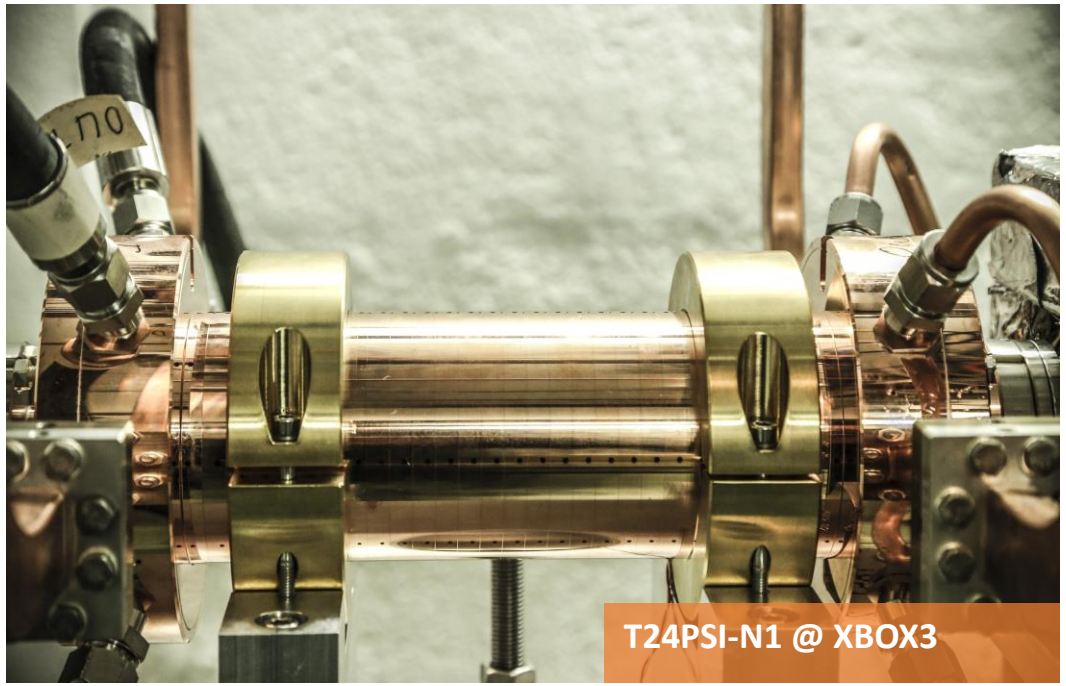
- Tested in XBOX3
- Power splitter conditioned one output port at a time
- Phase shifter conditioned with the piston at the middle of the shifting-range
- Power splitter conditioned faster than phase shifter in line 1 and we had to lower the power due to line-to-line leakage
- Both have reached 42MW@50ns



XBOX3 – Structures conditioning

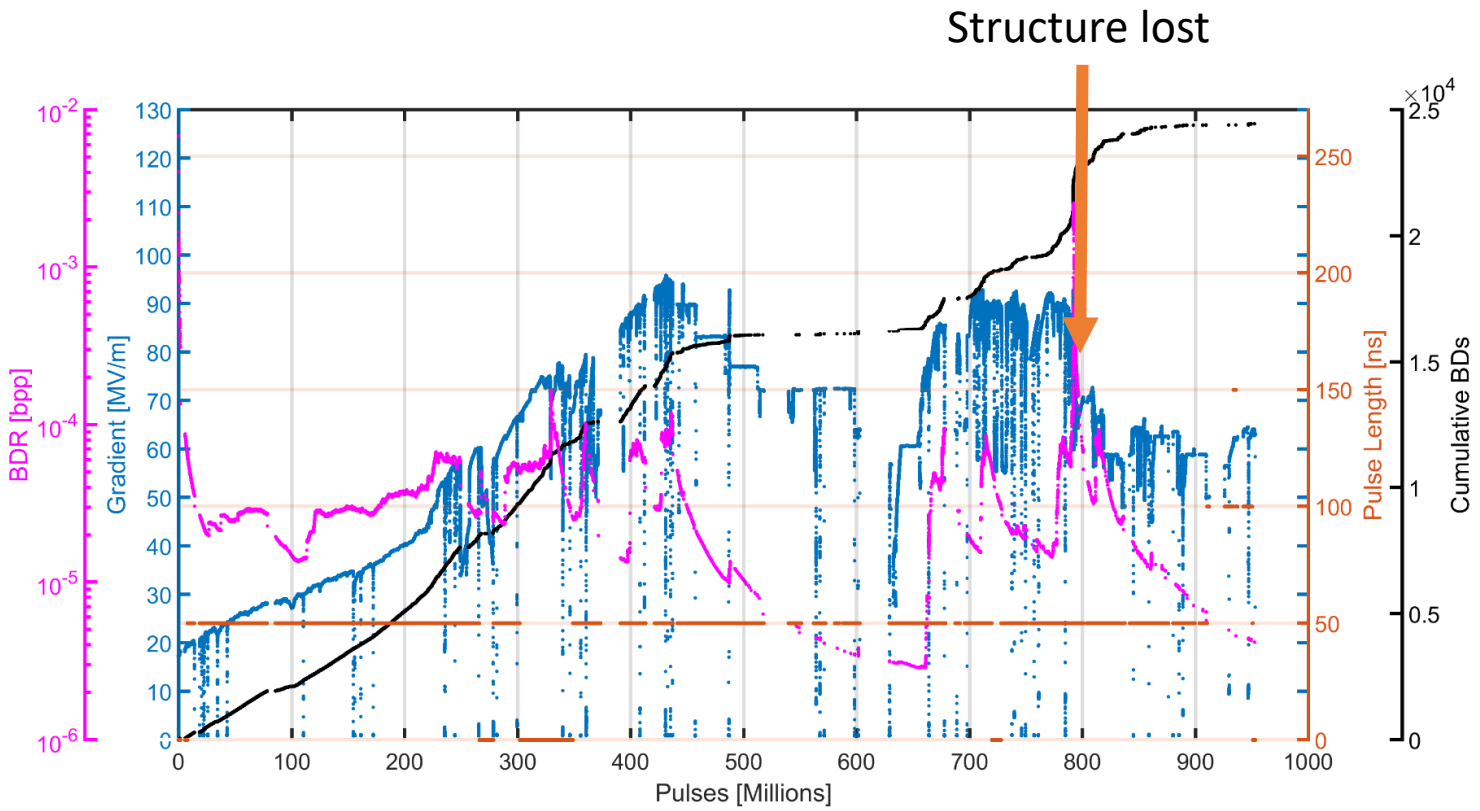
- Two TD24SiC and two T24PSI structures were tested last year in lines 3 and 4 of XBOX3
- ~ 1400M pulses in each line


TD24R05SiCN1


T24PSI-N1 @ XBOX3

XBOX3 – Structures conditioning

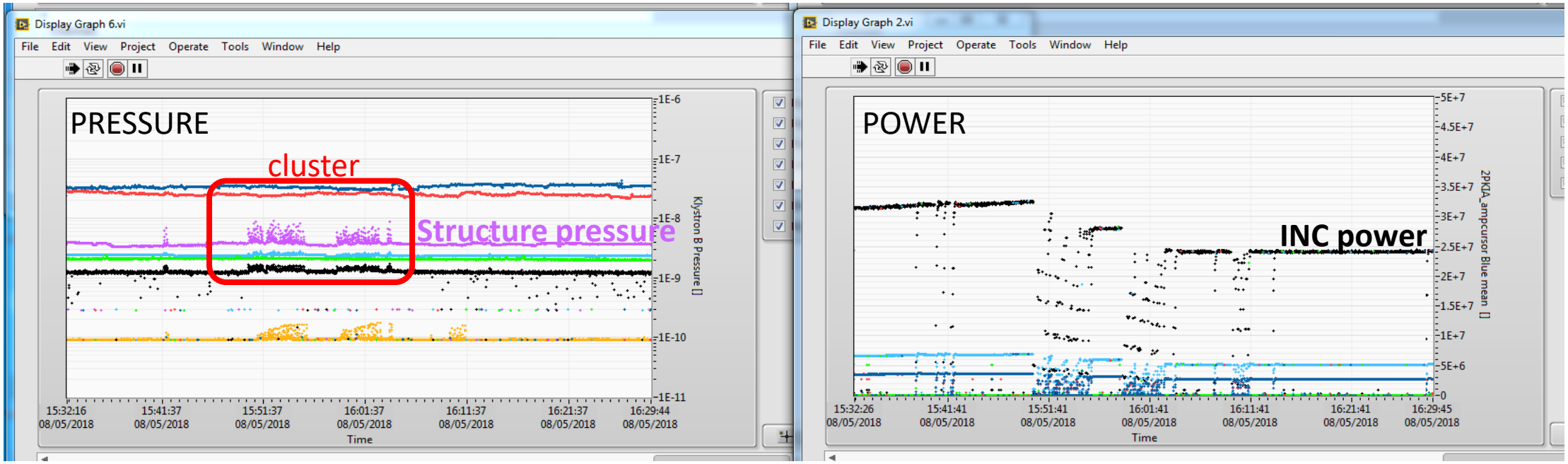
- Many operational lessons learned.
- First SiC structure lost due to a hot-cell which developed and drove down the power as a consequence of a bug in the code when running a high rep. rate that switched the power between the two lines



See J. Paszkiewicz talk

XBOX3 – Structures conditioning

- Many operational lessons learned.
- First SiC structure lost due to a hot-cell which developed and drove down the power as a consequence of a bug in the code when running a high rep. rate that switched the power between the two lines
- Second SiC structure suffered from a BDs cluster that lasted ~30min due to a bug in the software that didn't reduce the power.



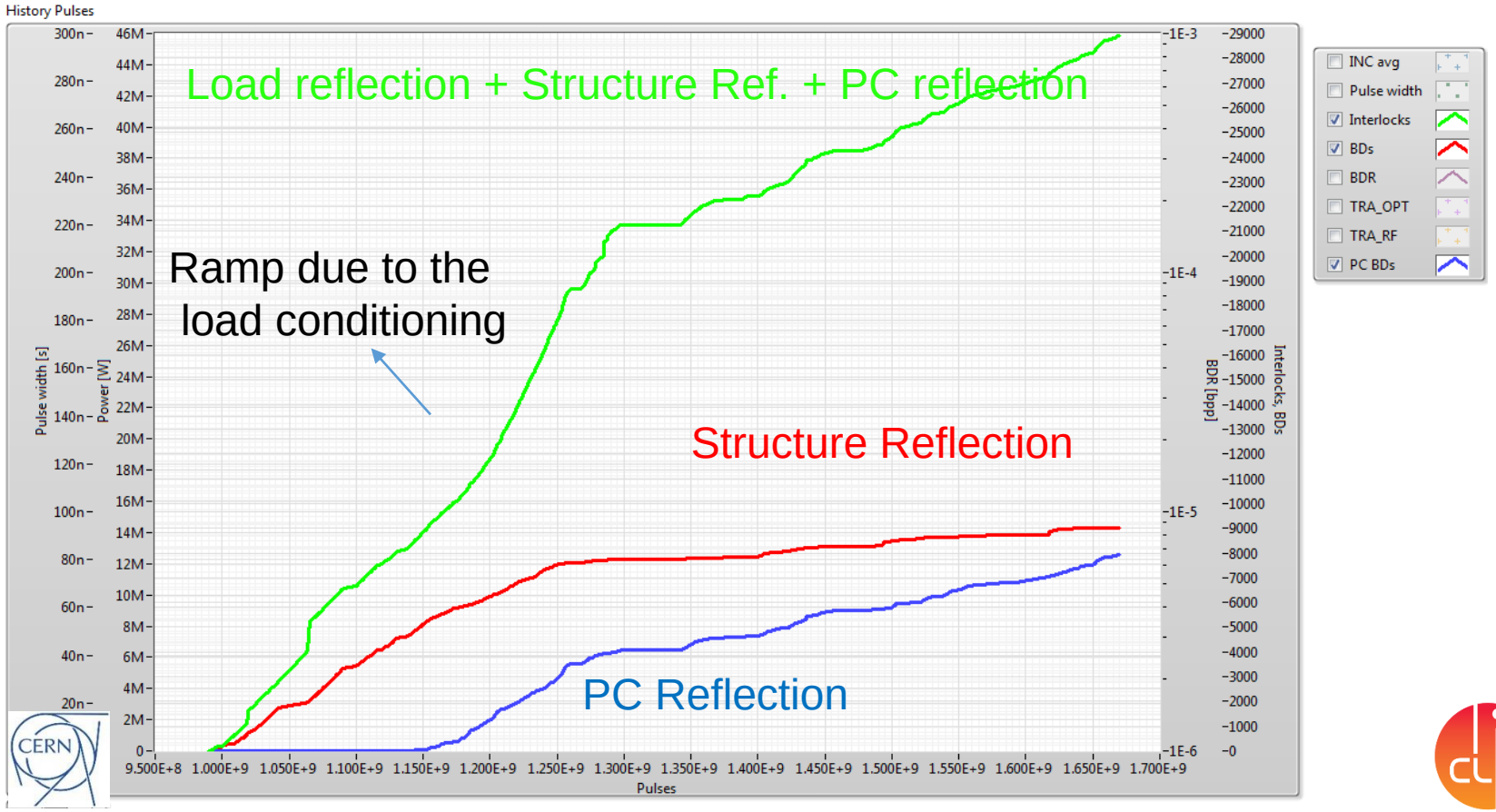
Example of how it should work….but didn't

XBOX3 – Structures conditioning

- Many operational lessons learned.
- First SiC structure lost due to a hot-cell which developed and drove down the power as a consequence of a bug in the code when running a high rep. rate that switched the power between the two lines
- Second SiC structure suffered from a BDs cluster that lasted ~30min due to a bug in the software that didn't reduce the power.
- Pulse compressor in line 3 wouldn't condition any further and had to be changed for a new one

Pulse Compressor line 3

- PC in line 3 of XBOX3 wasn't conditioned before installing the structures
- First SiC structure got lost after 35MW and the second one couldn't go more than 40MW because the PC wouldn't stop breaking-down



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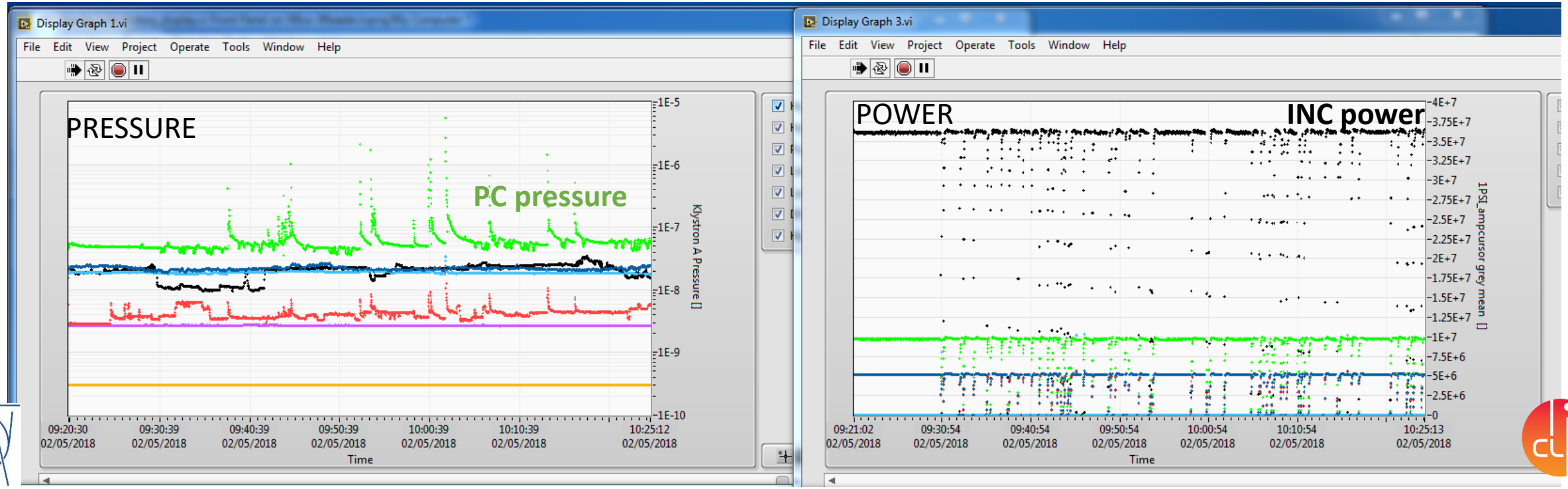

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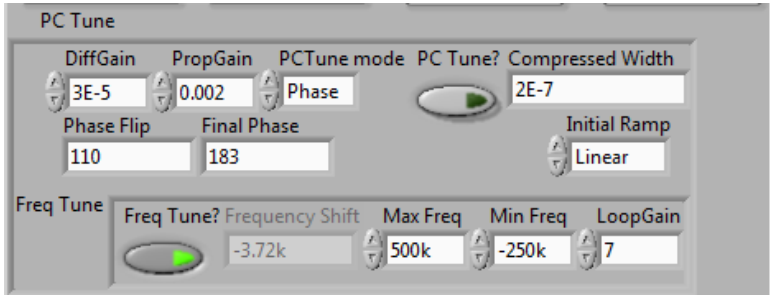
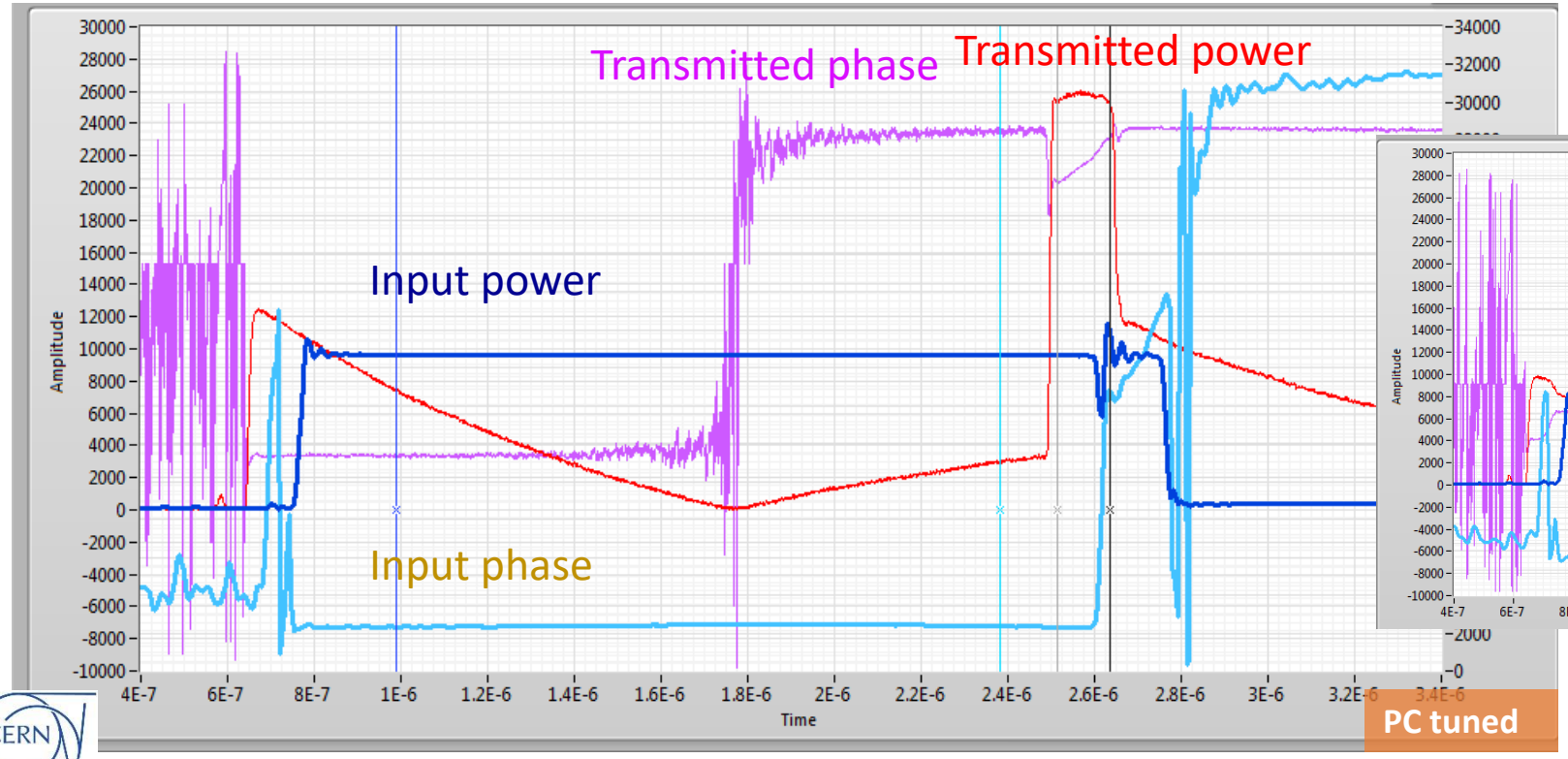
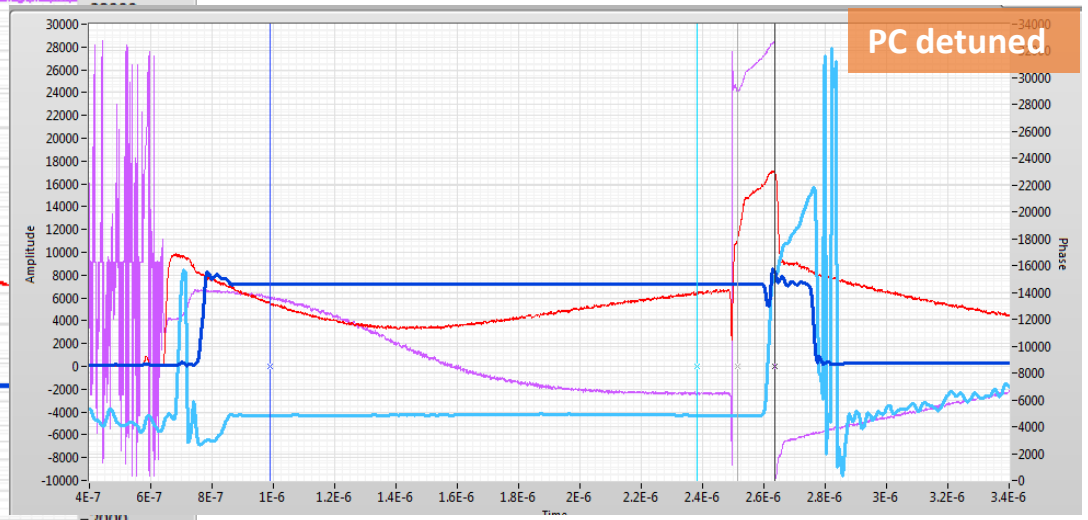
- PC changed in the last installation and have since then being conditioned up to 40MW with a high power load
- Next structure conditioning will not be limited by conditioning of the PC or the load

Frequency shift tool

- New frequency shift tool for rapid tuning of the pulse compressor after a power lost (BD).
  - Before the tuning frequency was achieved by changing the temperature on the chillers connected to the cavities of the PC, which is slower.
  - Calculates de correct transmitted phase and corrects the frequency.
  - Up to 1MHz shift







Conclusions

- **Six** operational lines, 24h operation
- XBOX3 pulsing at 200Hz/line
  - New high power chillers
  - More radiation protection
- First time we do conditioning based on vacuum level not BDR
  - Suitable for components where there is not enough reflected power
  - Needs constant human monitoring
- PC automatic tuning
  - XBOX1: based on temperature change, slow
  - XBOX3: based on frequency shift, fast
- Software bugs fixed
- PC line 3 conditioned and ready for testing new structures

Future plans

	Ongoing test	Next tests
Xbox 1	TD26CC N2	Test with beam from CLEAR
Xbox 2	T24 PSI N2	TD26_SiC superstructure
Xbox 3 Line 1	Power Splitter	Both lines will be moved to Melbourne University
Line 2	Phase Shifter	
Line 3	New pulse compressor	Unbaked/Baked TD24
Line 4	TD24 R05 SIC N2	

See N. Catalan Lasheras talk

Credits

Thanks to everyone in the XBOX Team…

… and thanks for your attention