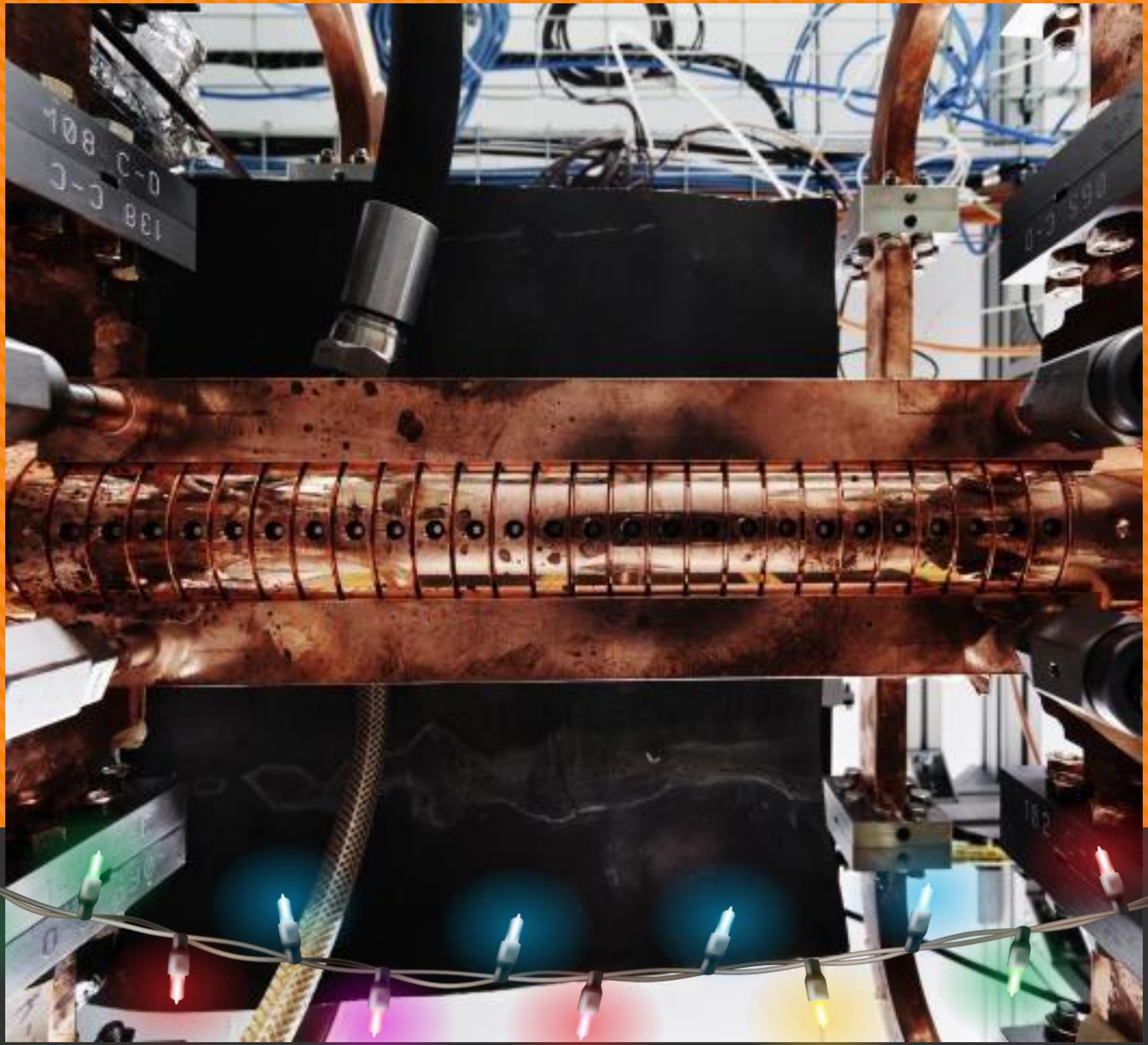
X-band INTERFEROMETRY and X-box STATUS

Amelia Edwards and the Xbox Team

CLIC project meeting #41

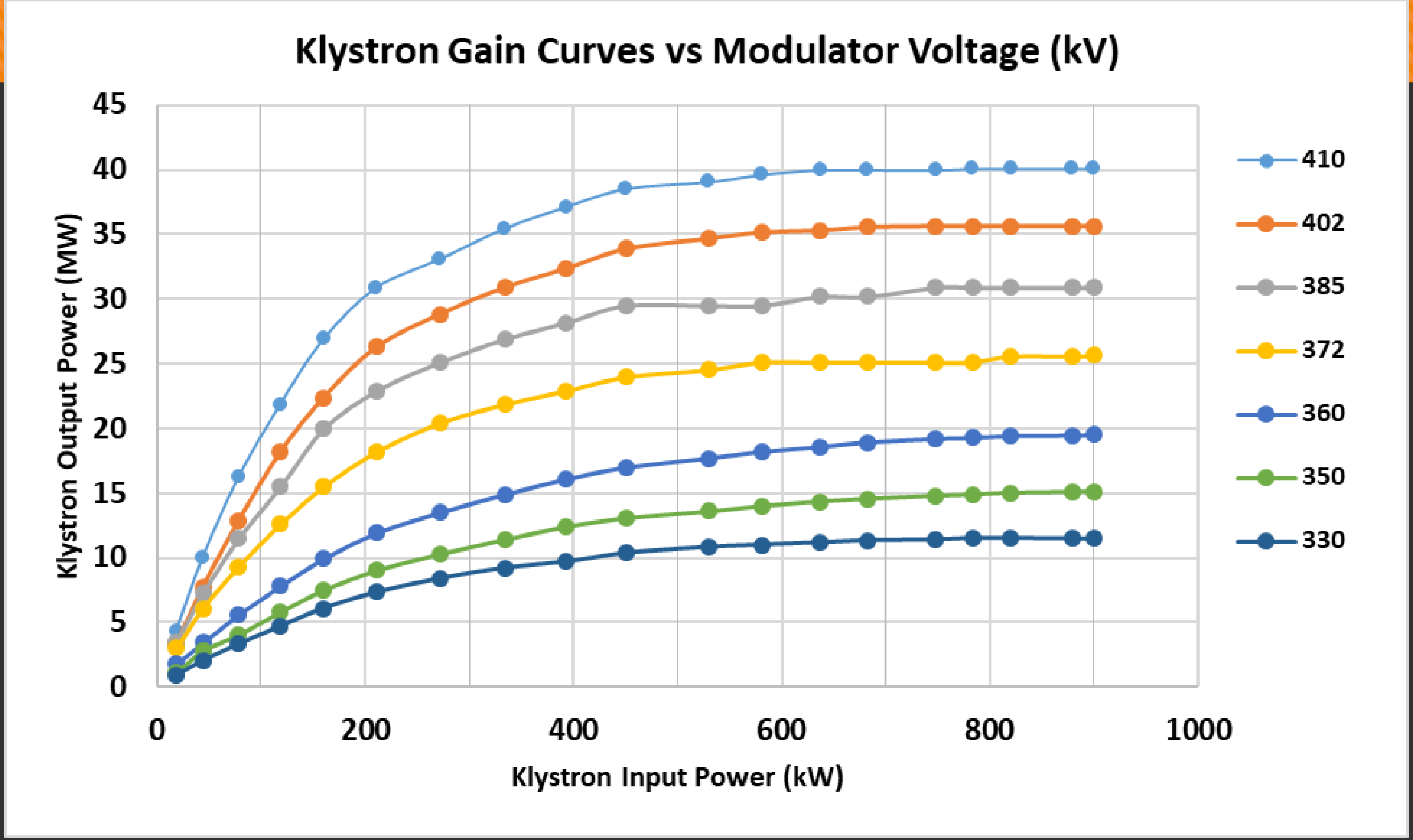
14.12.2021



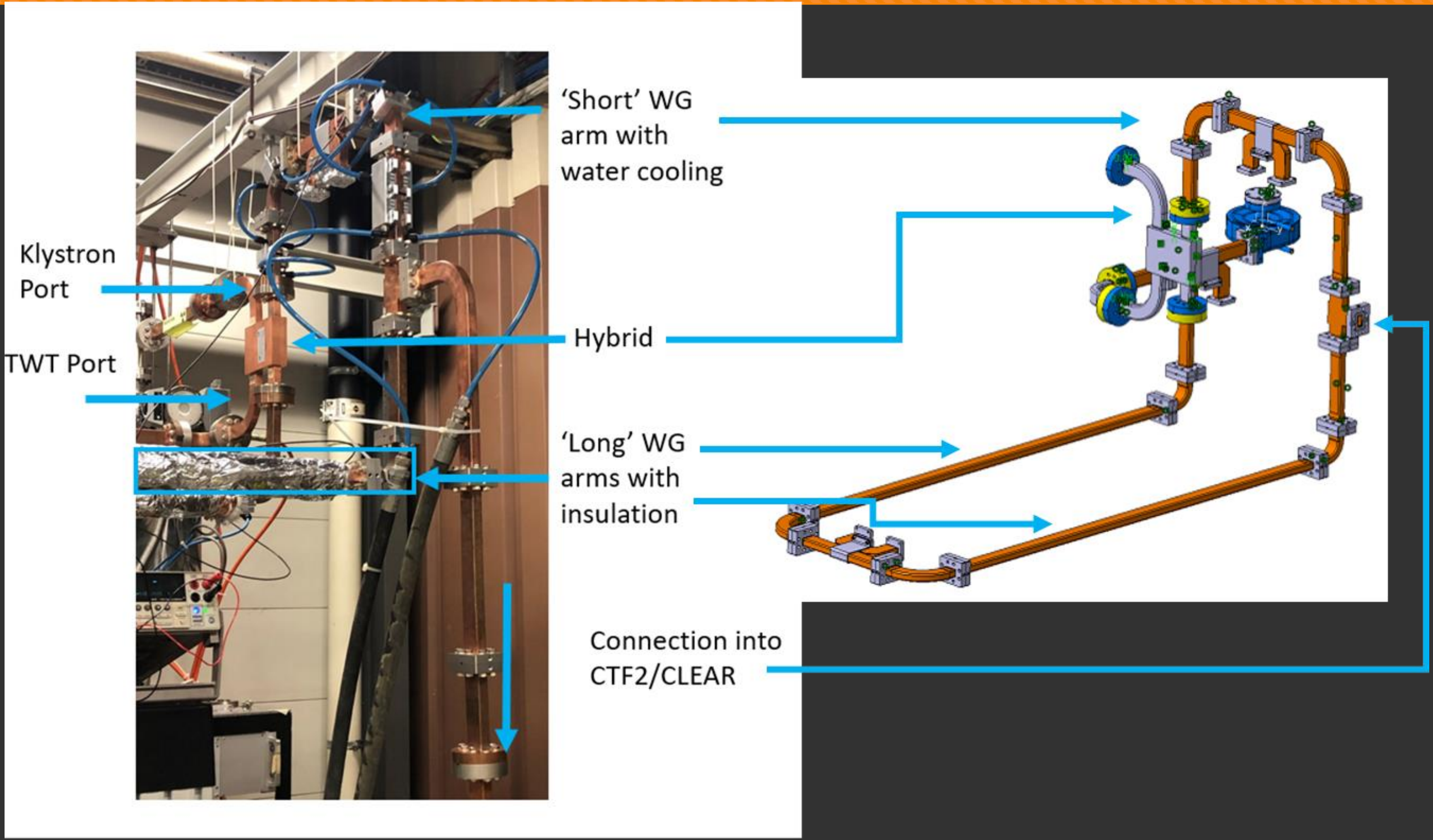
Xbox1

Conditioning of the 50MW repaired klystron

- Conditioning of the tube is the responsibility of CERN.
- Maximum RF power out of the klystron ever achieved
- **40MW Output for 50ns RF Pulse**
- No problems with new system (LLRF/software/klystron)
- Waiting for visit from ScandiNova in order to complete final gain curve

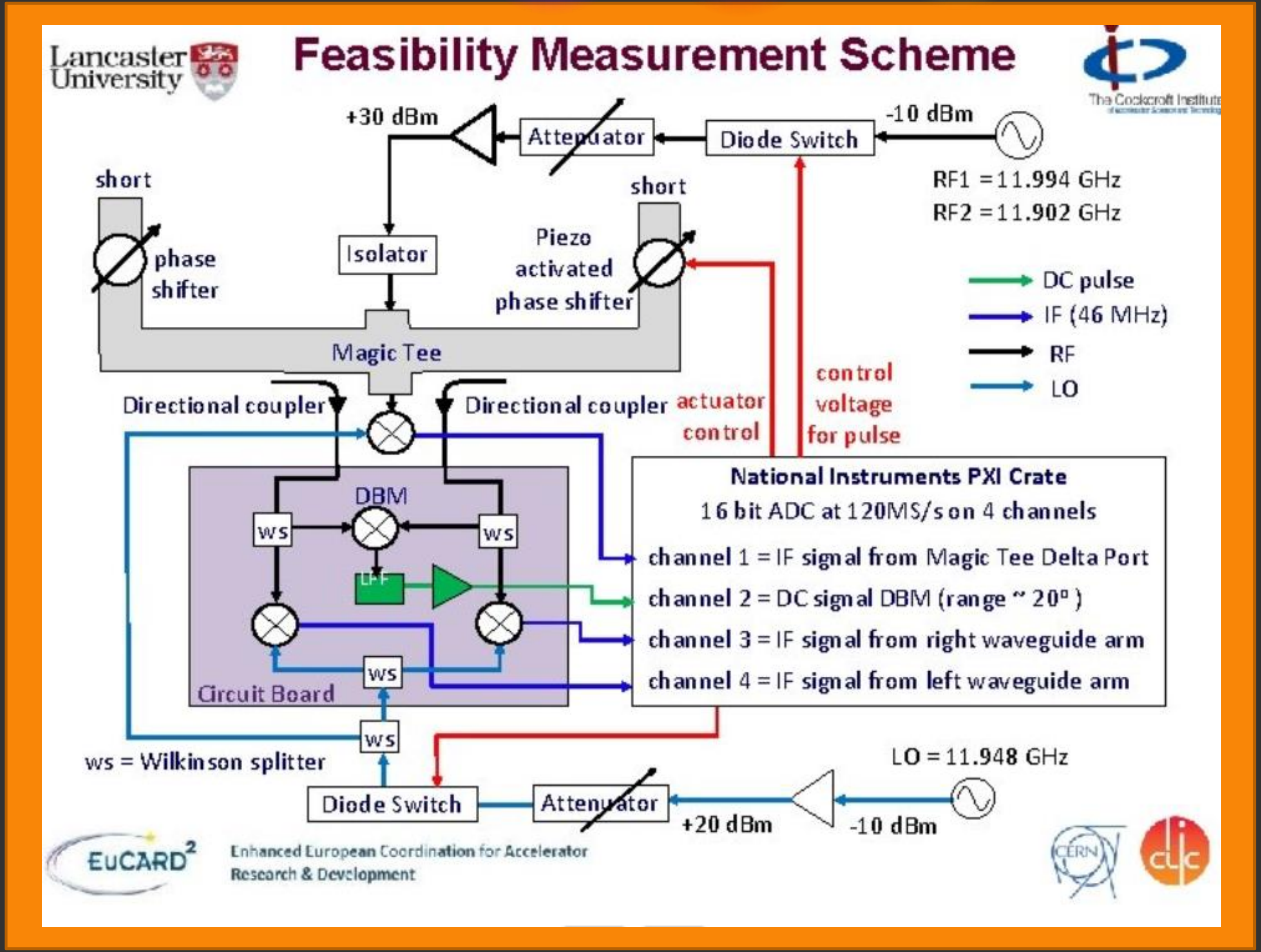


X-BAND WAVEGUIDE INTEFEROMETRY @ XBOX1



Xbox 1 Interferometry: Background

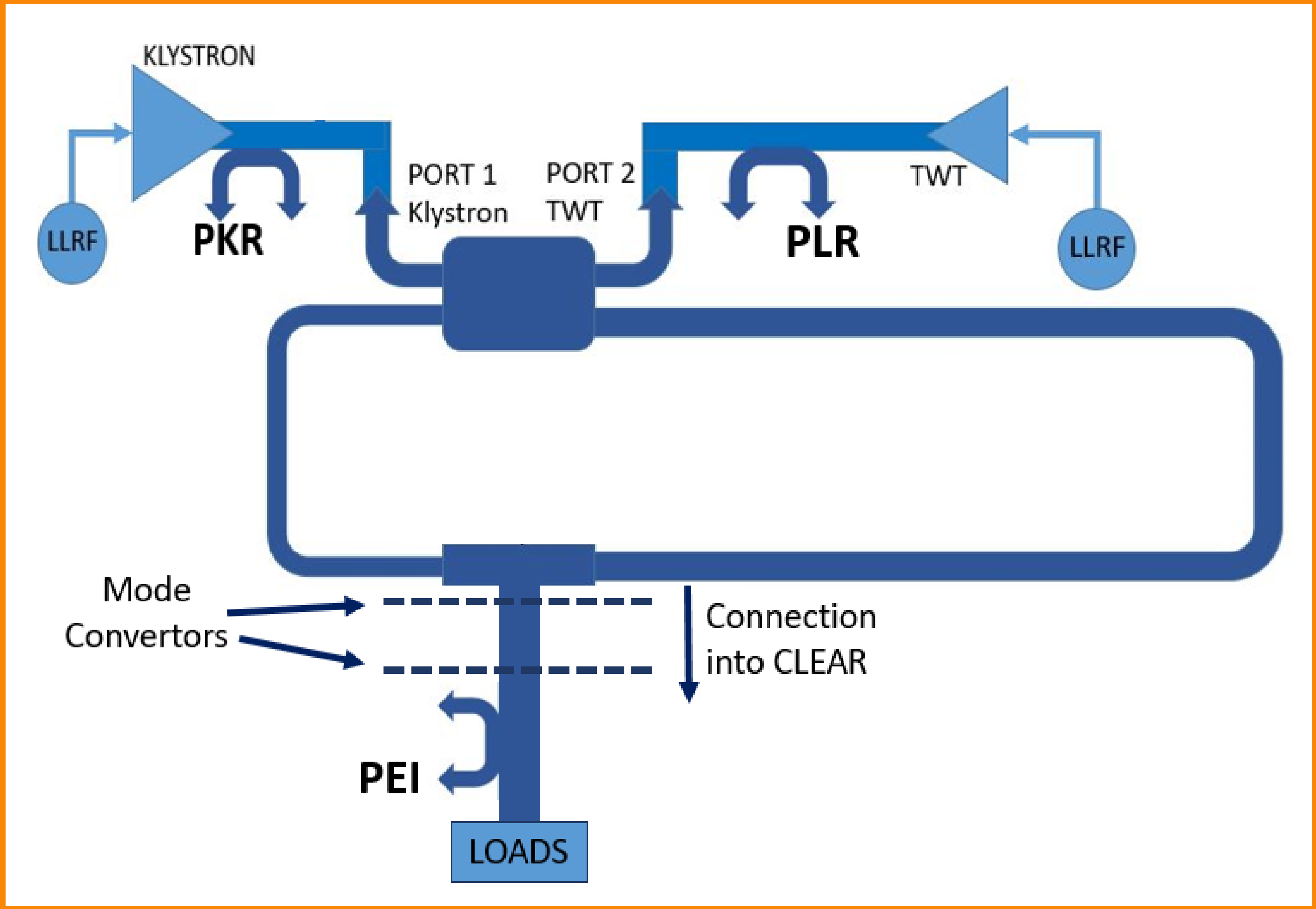
- Crab cavities are used for bunch alignment at the IP.
- These cavities are located approximately 25 metres either side of the CLIC IP.
- The luminosity target requires synchronisation of their RF phases on the order of fs rms
- Phase jitter is currently too large for the phase synchronisation target to be met
- The proposed solution is to split power from a single RF single source to drive both crab cavities
- **The length of the two waveguide paths needs to be precisely measured**
- Phase advance would be controlled with an active phase shifter operating in a feedback loop



A.C. Dexter, S.J. Smith, B.J. Woolley, A. Grudiev,
Femto-second synchronisation with a waveguide interferometer,
https://doi.org/10.1016/j.nima.2017.11.046.

Xbox 1 Interferometry: Theory of Operation

- The length of the high power waveguide network which connects Xbox1 and CLEAR is approximately 30m
- This waveguide network will be subject to vibrations, ground movement and temperature changes
- The disturbances alters phase of the RF arriving at the accelerating structure
- **The proposed measurement method requires low power RF pulses be injected into the waveguide alongside the high power pulses in a parasitic mode**
- **The low power measurements pulses operate at a different frequency hence the**
- Effectively a diplexer is needed



Xbox 1 Interferometry: Theory of Operation

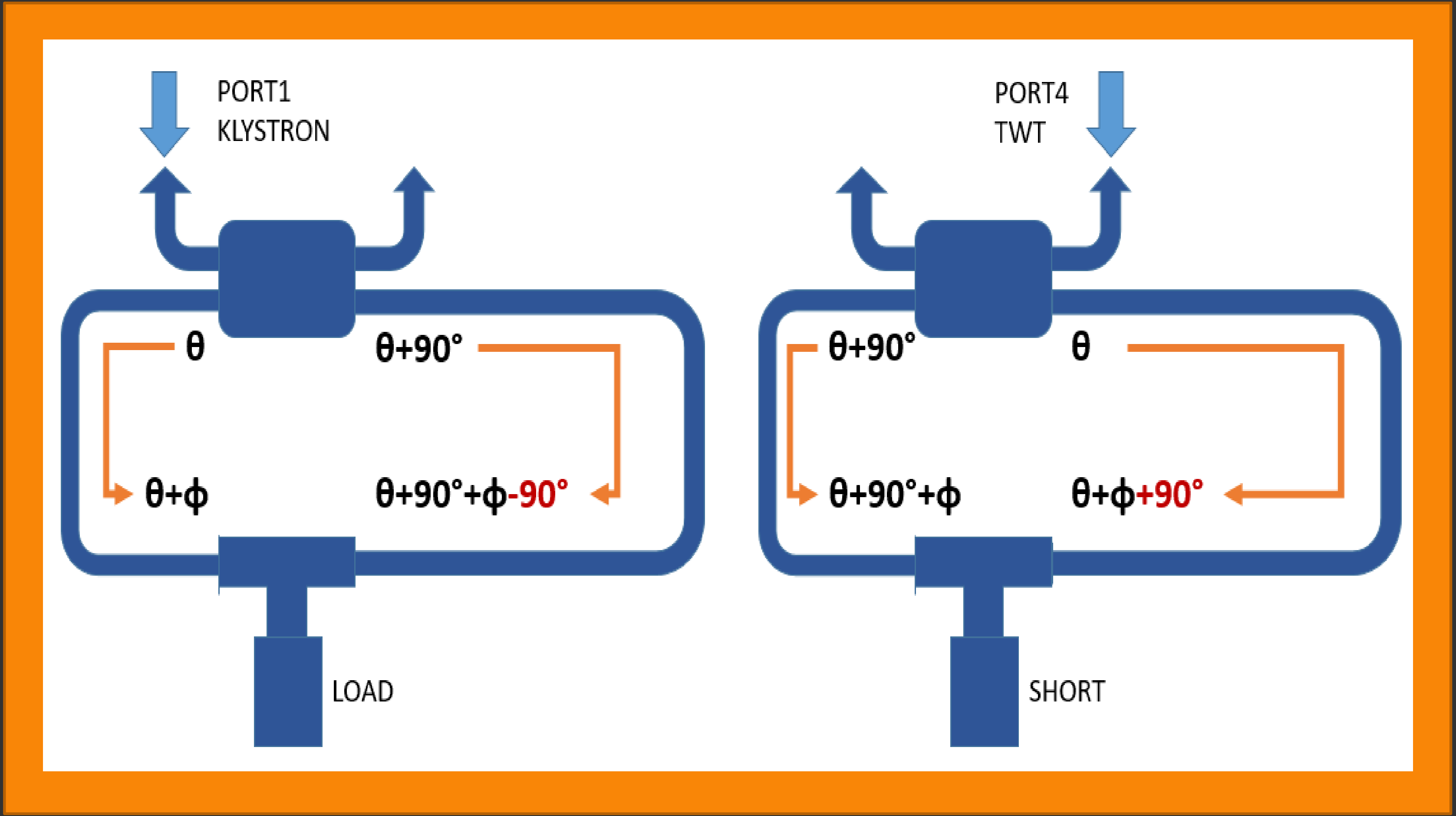
- Without a high power magic tee the only four-port component available for injection is a hybrid which will introduce a 90° phase shift depending on the input port.

- The two arms have a specific length which is calculated to allow correct recombination at the tee for both frequencies

- **We tune the length to be exact by heating the long arm of the loop**

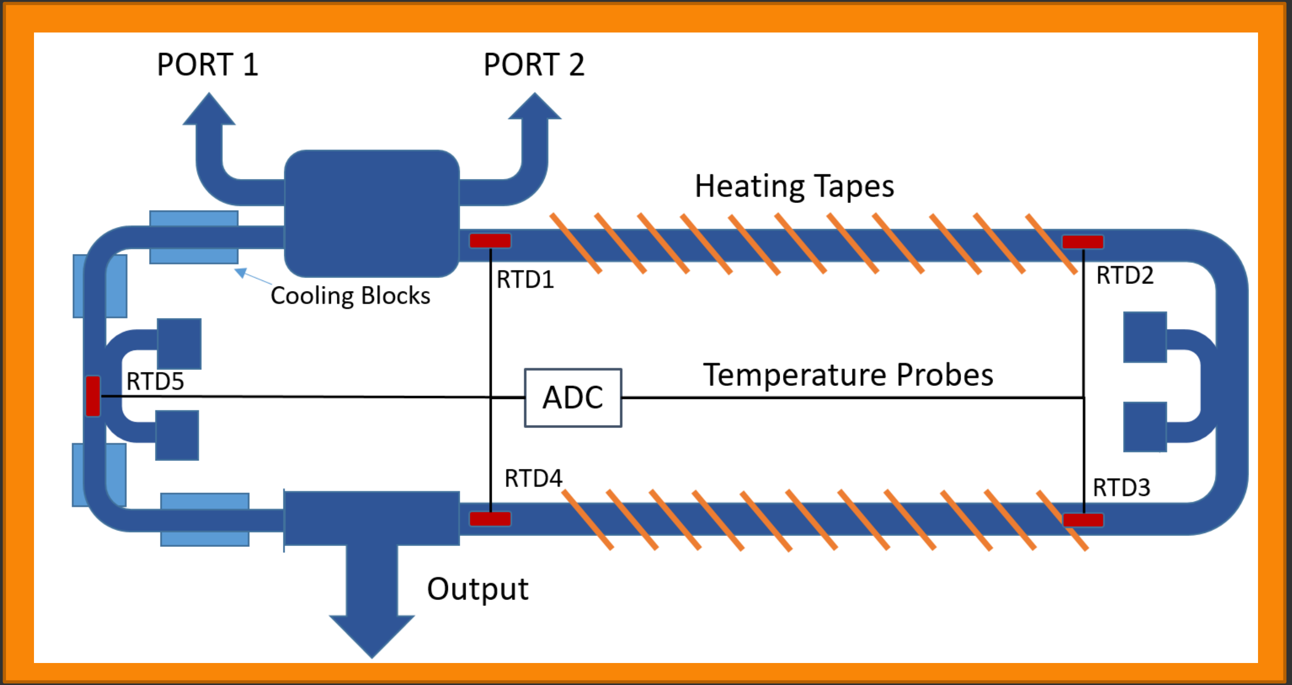
Port1 - Klystron
FREQUENCY 1:
11.9942GHz

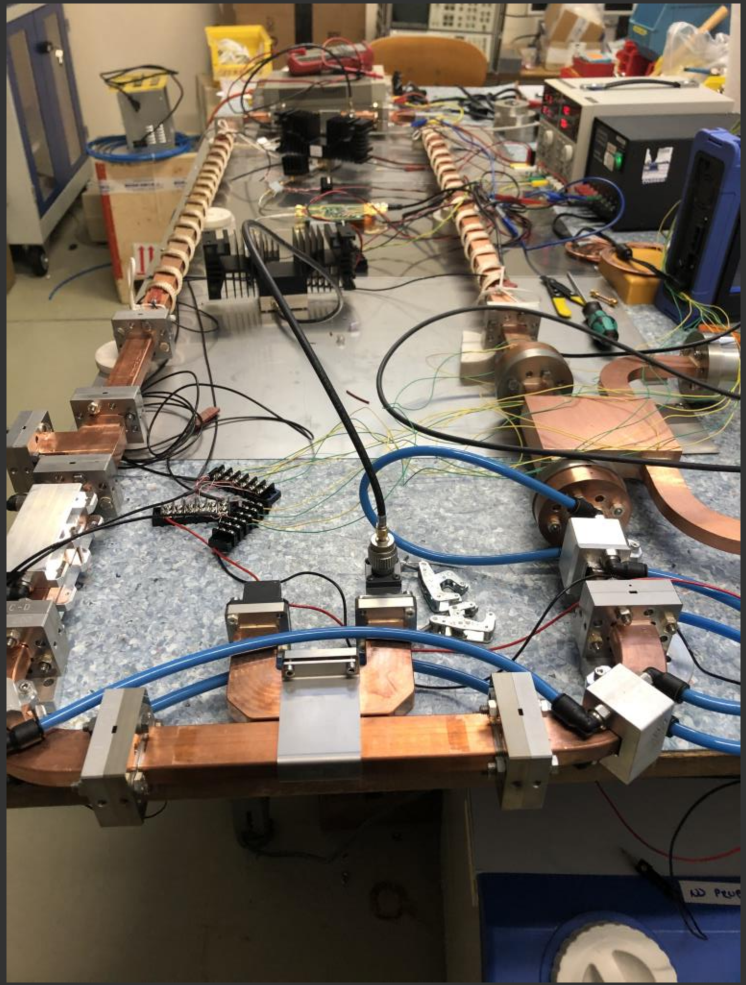
Port 2 - TWT
FREQUENCY 2:
11.9399GHz



Xbox 1 Interferometry: Thermal Stabilisation

- **Describe the heating tapes: We heat the long arm using heating tapes and the arms are insulated**
- The `short' arm is also held at a constant temperature using water cooling
- this ensures that the temperature different between the two arms (thus the difference in path length) is maintained

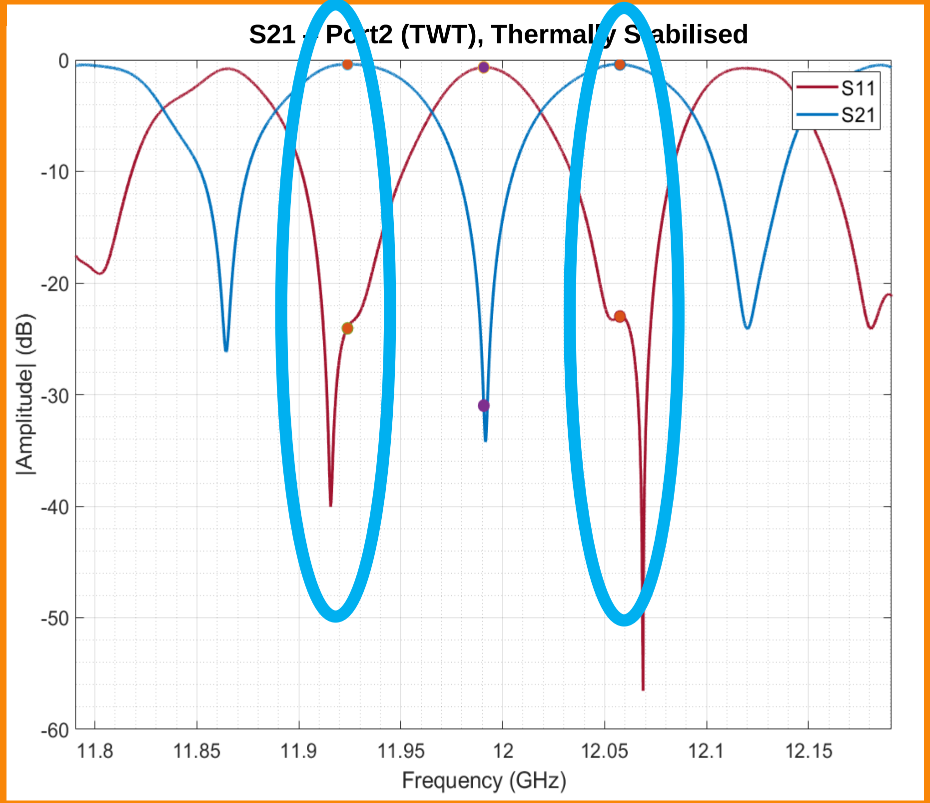


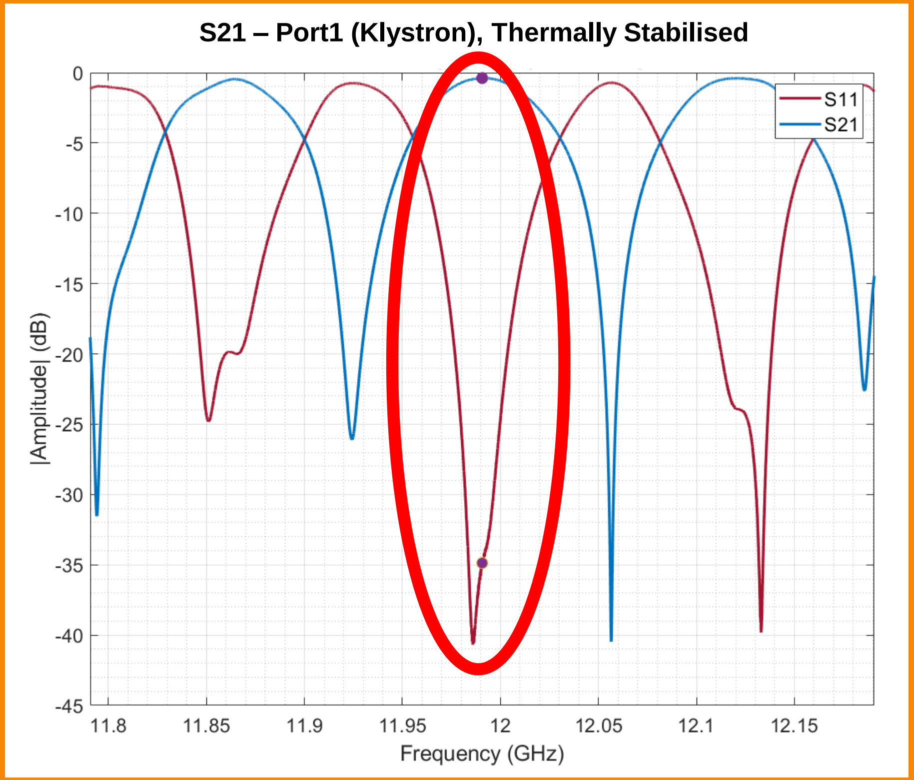


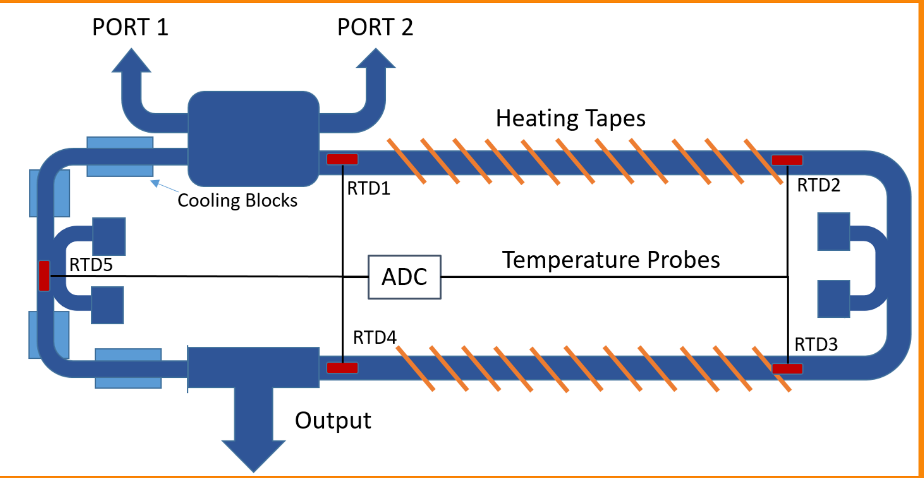
- **the reflected phase at port 2 (TWT) changes with the temperature of the heaters**

Xbox 1 Interferometry: Lab Tests

- The system is assembled and tested in the lab in air.
- The low power system is validated in two steps
- Firstly, a load is used on the output to replicate the long waveguide network.
- at the appropriate temperature, the pulses from both input ports must pass through the system with minimum reflection



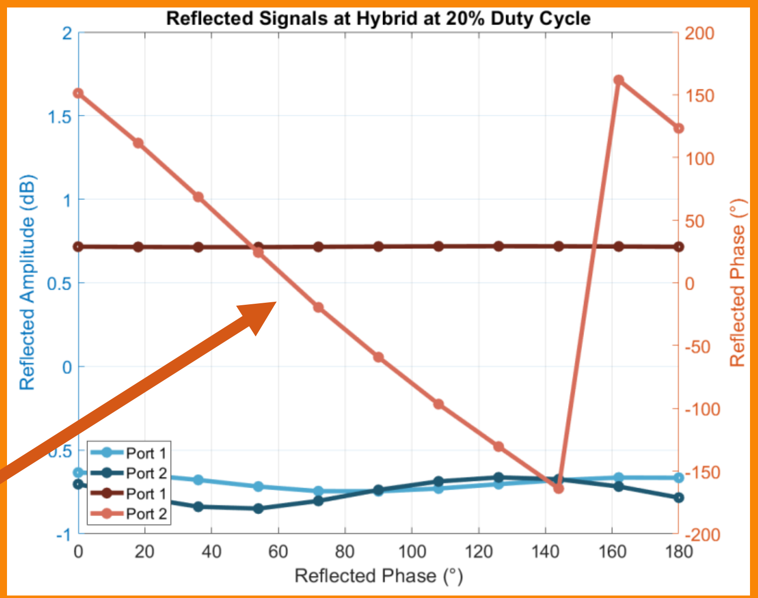




- The interferometer system should be 'invisible' to high power klystron pulses entering into port 1
- The reflections should be minimised for the TWT port and the TWT frequency

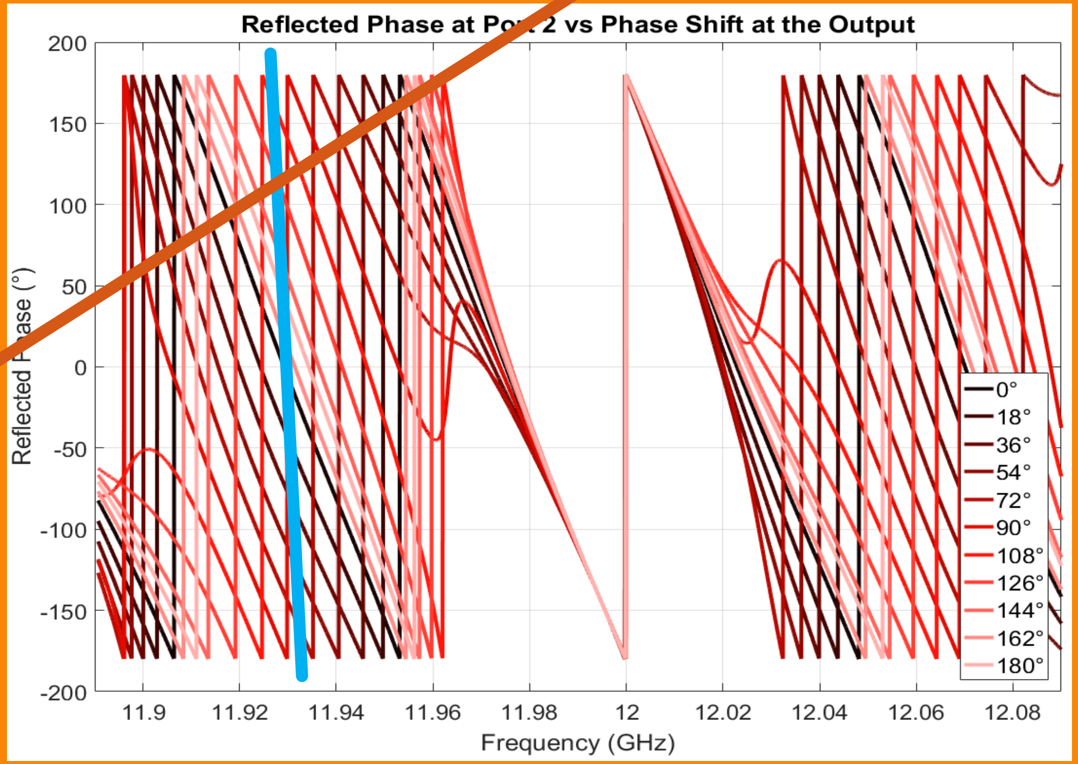
Xbox 1 Interferometry: Lab Tests

Port1 = Klystron Port
Port 2 = TWT Port



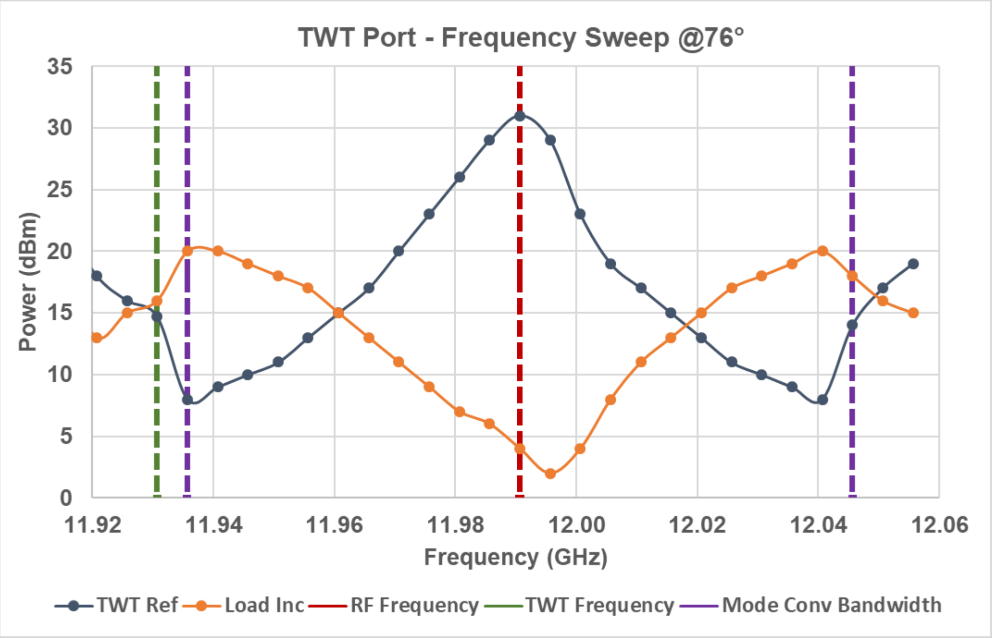
- After the system was stabilised, a short is used on the output to replicate the reflected TWT signal
- In this case the power is reflected back to the TWT port and the phase response is sensitive to phase changes from the load. The low power test is also used to characterise the thermal stability of the interferometer.
- When the reflected phase is rotated through 180° using a variable short, only the phase at port 2 responds proportionally
- The reflected amplitudes and the reflected phase at port 1 remain relatively unchanged

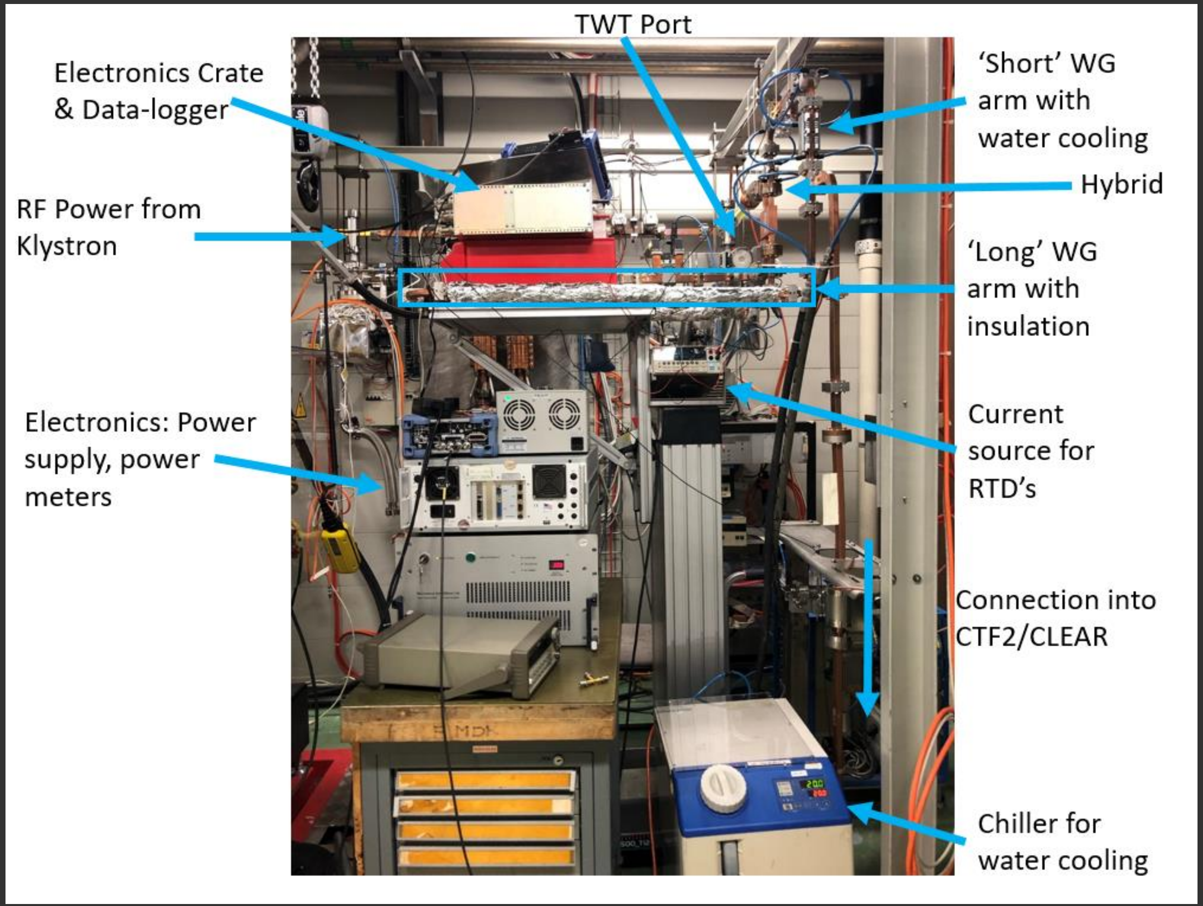
TWT
Frequency

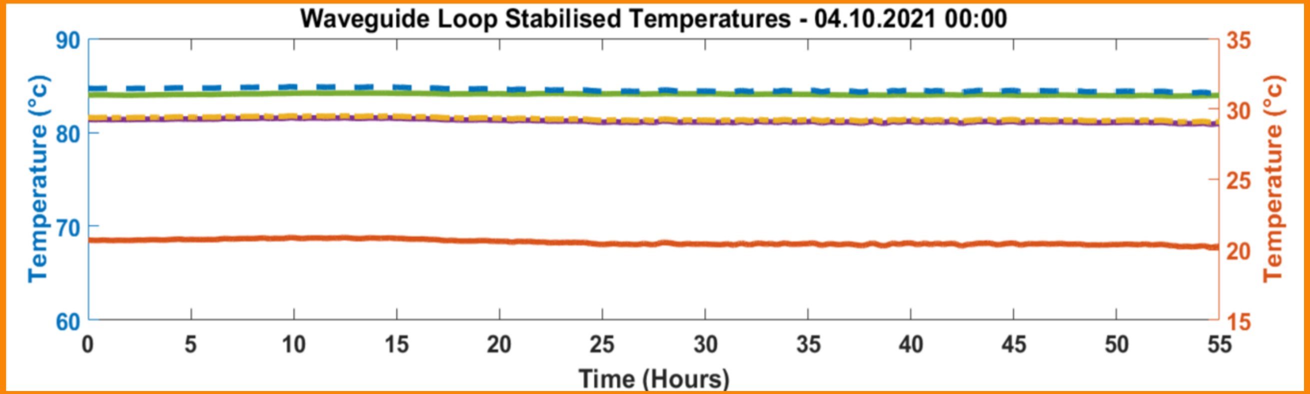


Xbox 1 Interferometry: High Power Installation

- The interferometer was transferred from the lab to Xbox1 and assembled in the CTF2 klystron gallery
- The pulse compressor was removed and the klystron port connected
- After installation the process was repeated to find the stable operating point

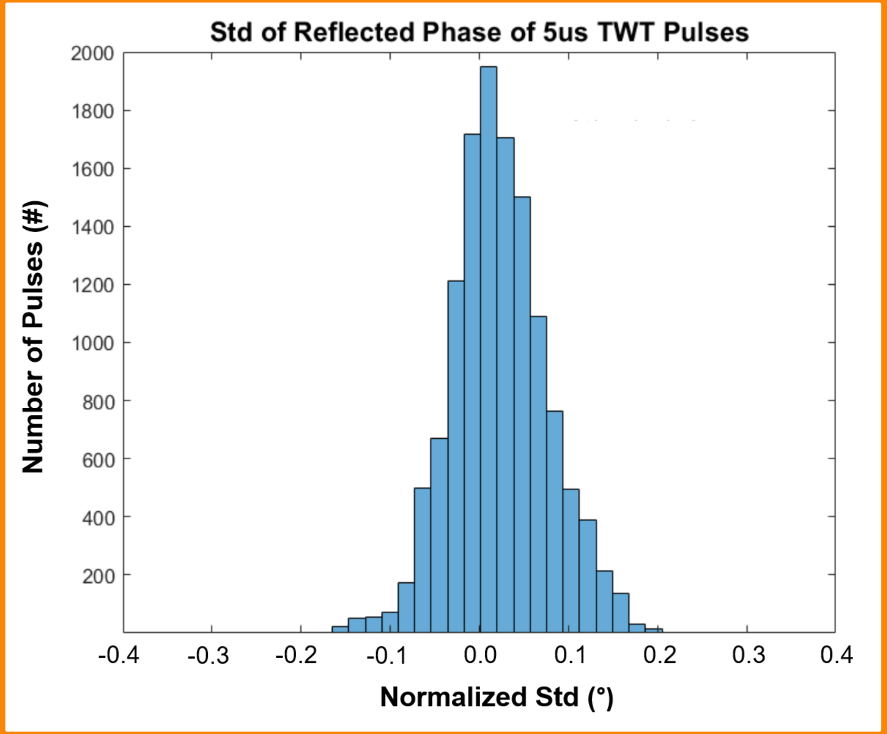


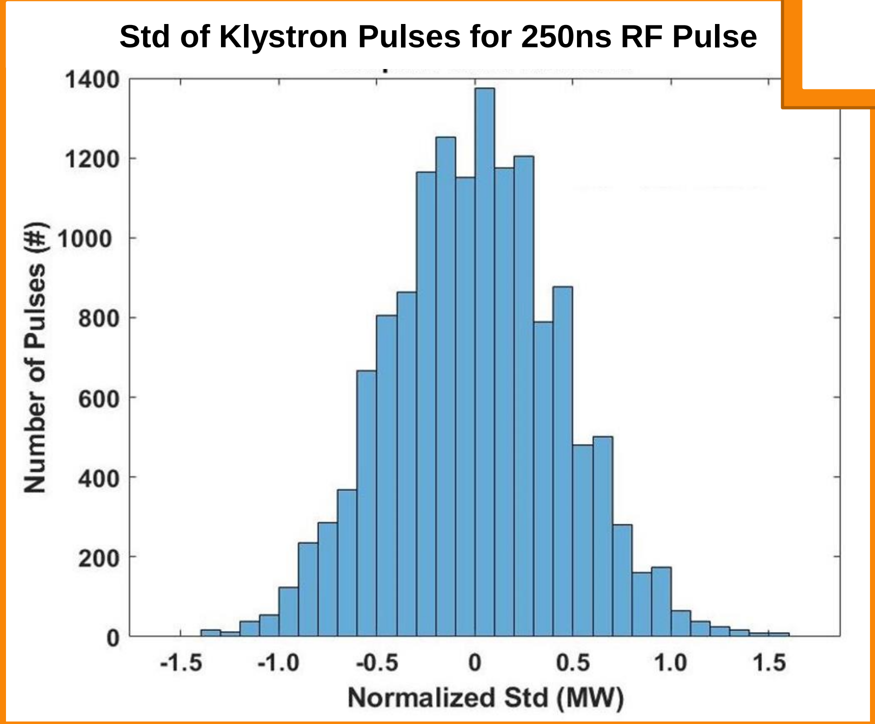




Xbox 1 Interferometry: High Power Installation

- The TWT pulses have much less phase jitter with respect to the klystron pulses
- There are two reasons for the reduction in phase jitter. Firstly, the klystron is the most significant contributor to the phase jitter which is not included in this signal chain
- Secondly the TWT pulses are much longer, 5us, so averaging across a much longer pulse significantly reduced the phase jitter.

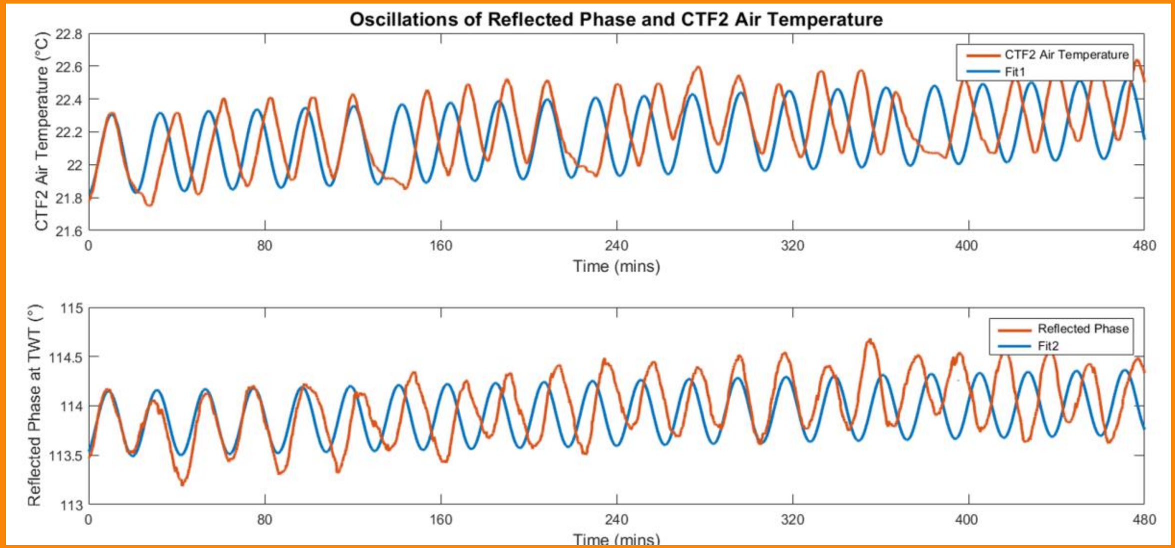


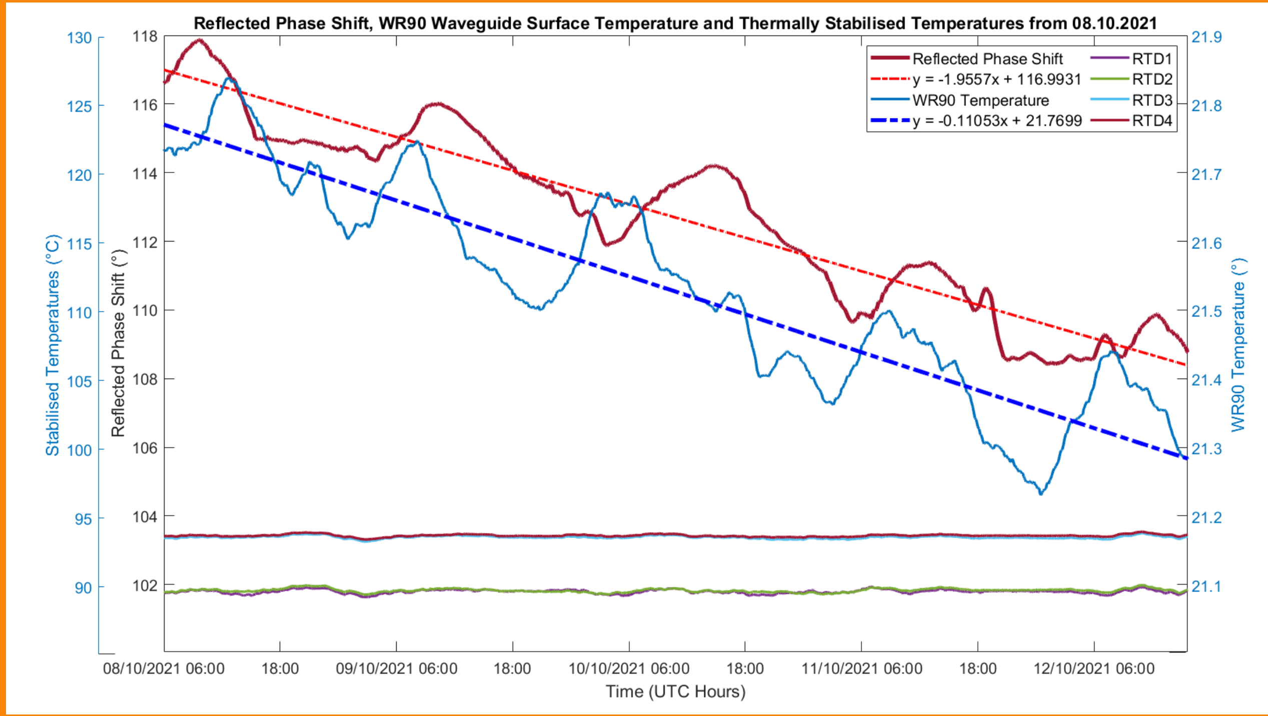


CLIC PM #37
Xbox1 new LLRF and acquisition system

Xbox 1 Interferometry: Results

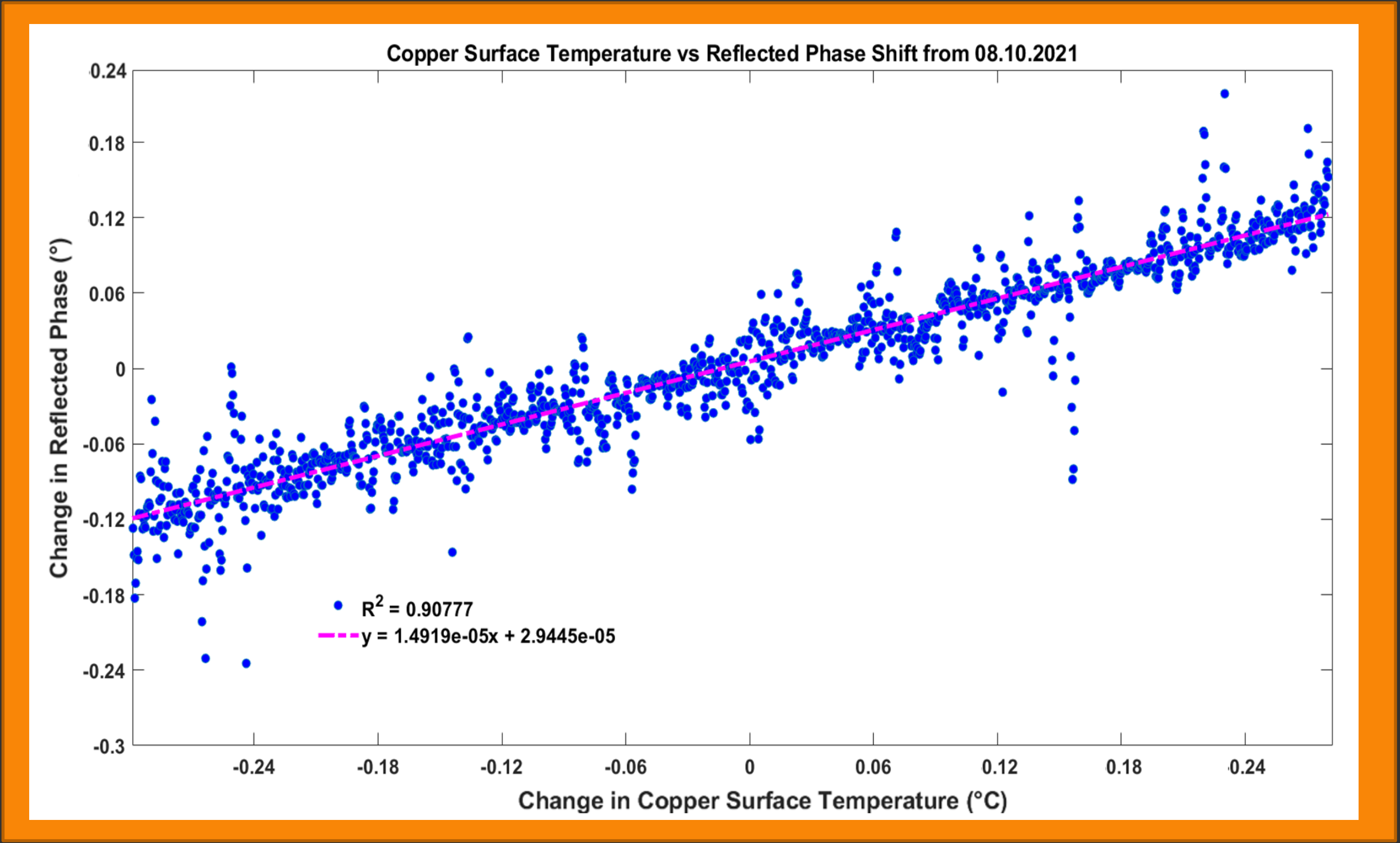
- The reflected phase at the TWT exhibits phase changed over two distinct timescales
- There are 'fast' oscillations which are on the order of 20 minutes. These are attributed to temperature changes due to the air conditioning in the CTF2 klystron gallery
- Secondly, the reflected phase from the TWT also exhibits 'slow' phase changes which take place over the course of the day





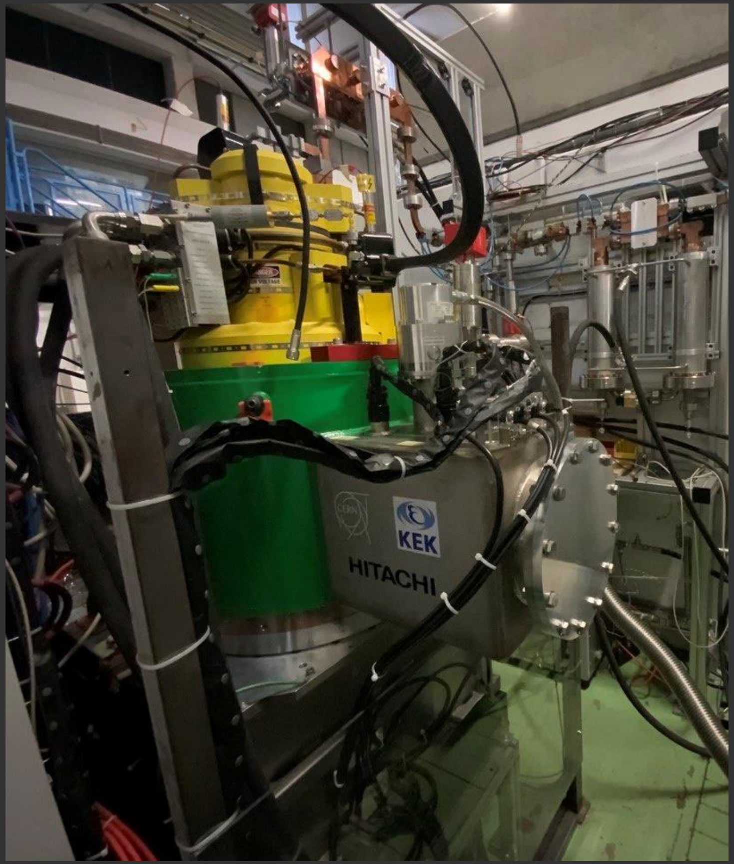
Xbox 1 Interferometry: Results

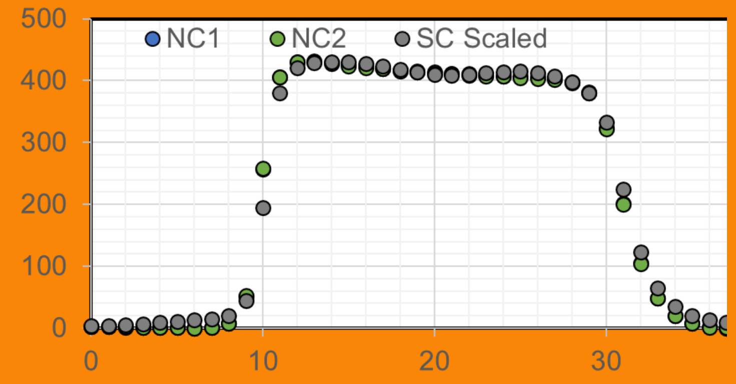
- The relationship between the reflected phase and copper surface temperature is shown
- This is calculated by comparing the gradient of the phase and temperature using a sliding window
- The window for the temperature can be larger than the phase window as the temperature is a much slower changing property
- The correlation is very high
- The linear fit shows that a change in phase of 1°c corresponds to a change in surface temperature of 1.4919°c
- Could be used to create a feedback system on the klystron output phase

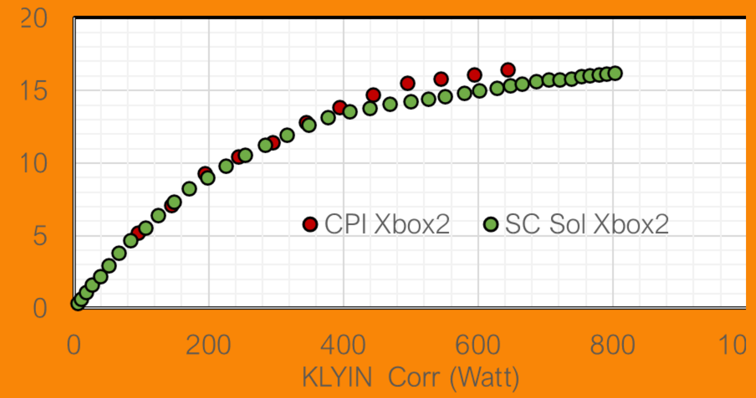


XBOX2 PLANS – KLYSTRON, SC SOLENOID & TD31

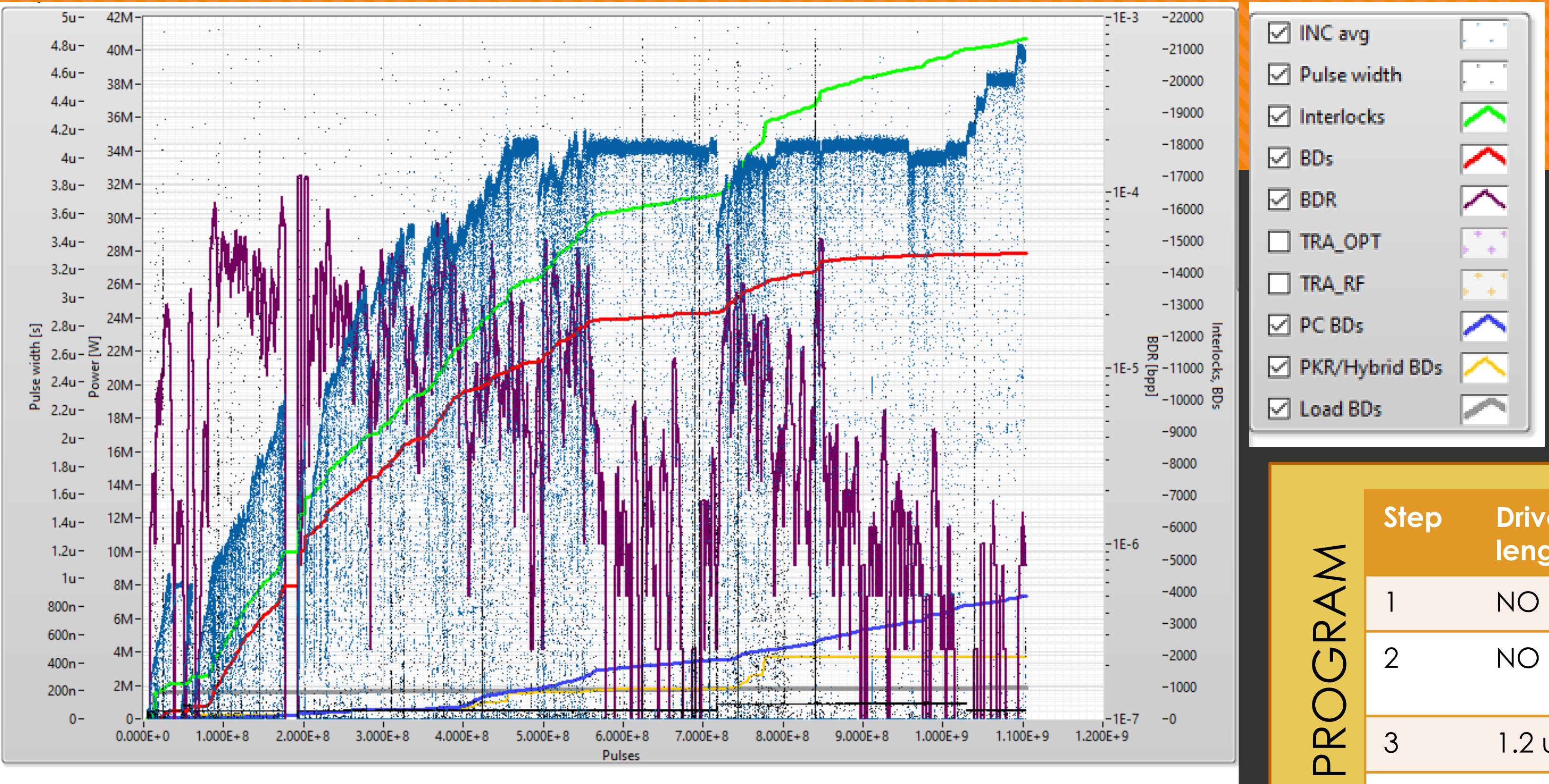
- Relocating the 50MW klystron from Xbox1 to Xbox2
- Finishing fully testing the SC solenoid
- Plan to install two TD31 structures – designed for 380GeV CLIC
- Two structures are ready for installation, two ore will arrive at CERN later this week







XBOX3 RESULTS – SARI STRUCTURE

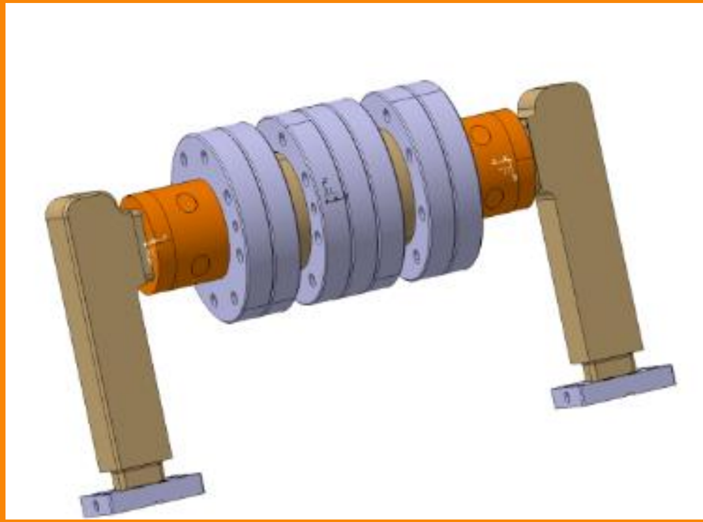


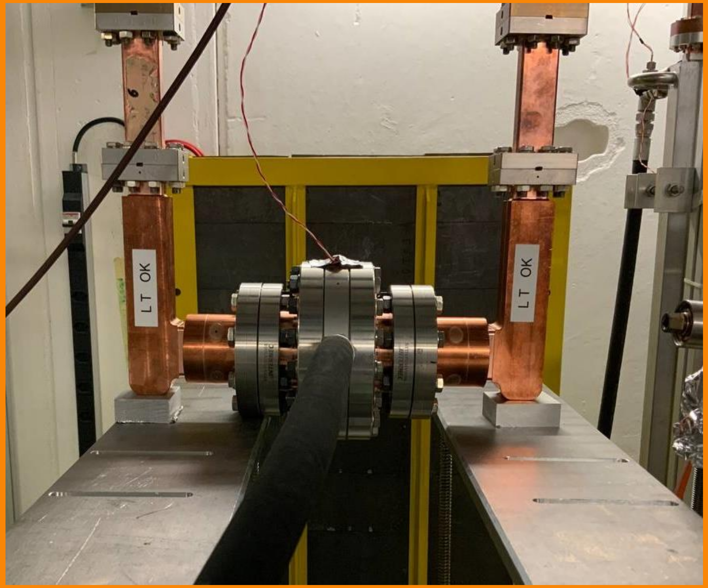
- X-band deflector from Shanghai (TNA)
- 11.9942GHz @ 26°C
- Conditioned up to 35MW for 100ns RF Pulse
- Max Power 41MW @ 50ns RF Pulse length
- Planning to go up to 150ns pulse

SARI TESTING PROGRAM

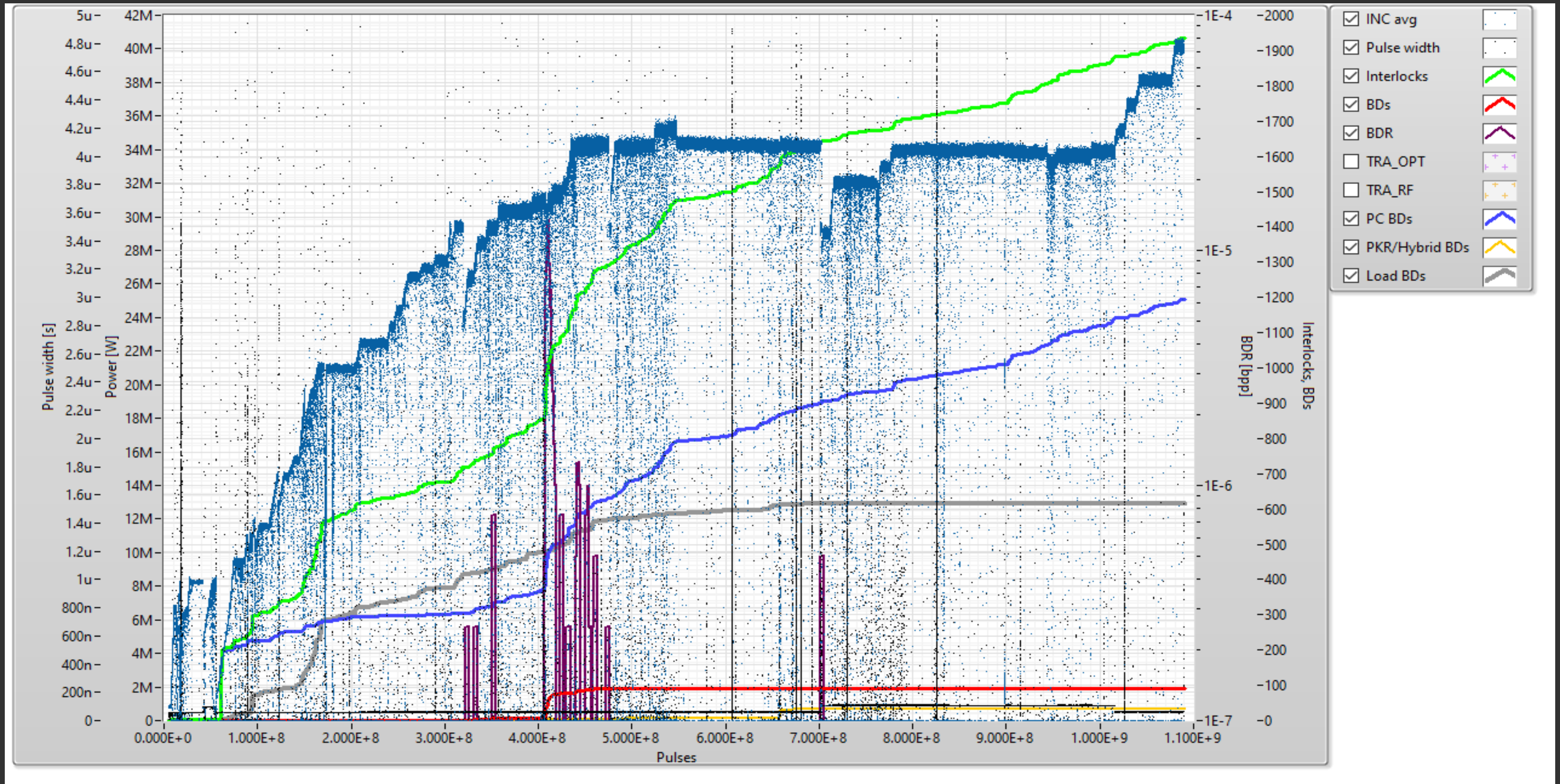
Step	Drive length	Pulse length	MAX Power	Comment
1	NO	50 ns	9 MW	No PC
2	NO	100 ns	9 MW	No PC (Mainly 200Hz per line)
3	1.2 us	50 ns	30 MW	Compressed Pulse
4	1.9 us	50 ns	35 MW	Compressed Pulse
5	2.2 us	50 ns	35.5 MW	
6	1.9 us	50 ns	35 MW	Flat run
7	1.9 us	100 ns	35 MW	
8	1.9 us	100 ns	35 MW	Flat run
9	1.9 us	50 ns	41 MW	

XBOX3 RESULTS – RF WINDOW



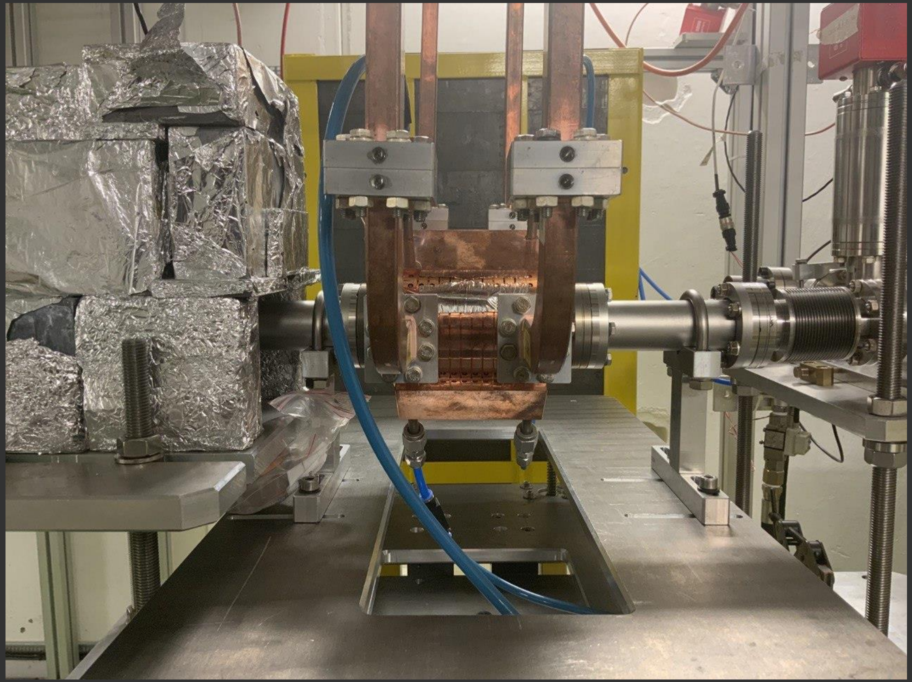


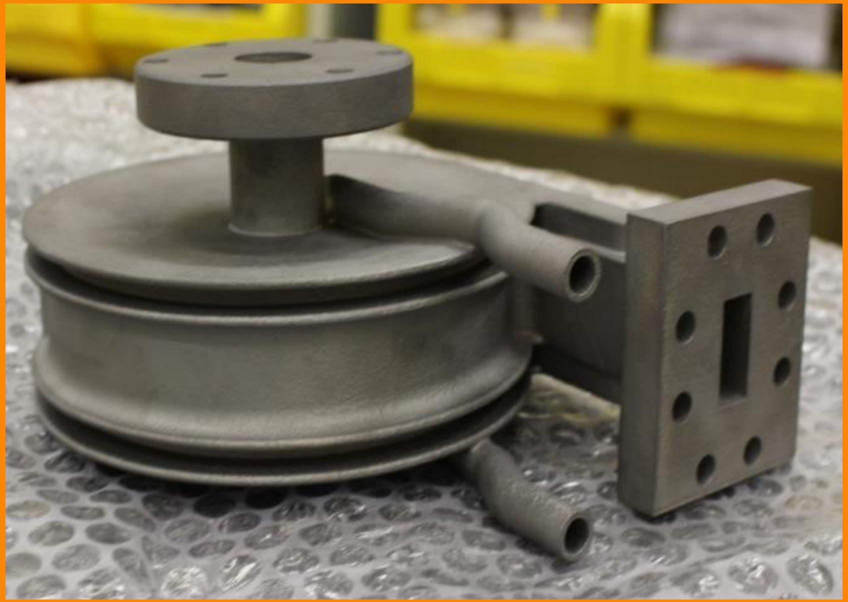
- Three have been manufactured
- One was assembled and tested in Xbox
- Conditioned up to 41MW
- Window will be installed in CTF2



XBOX3 PLANS – CRAB CAVITY & SPIRAL LOADS

- Newly improved spiral load design to avoid supports and allow stacking
- Two spiral loads installed
- Crab cavity installed and vacuum conditioning has started
- The previous crab cavity reached an input power level in excess of 40MW, with a measured breakdown rate of better than 10-5 breakdowns per pulse





MERRY CHRISTMAS
THANKS FOR LISTENING!

On behalf of: Nuria, Marçà, Lee, Xiaowei, Walter, Igor, Alexej, Gerry, Matteo, Alejandro, Alan, Stephane, Pedro, Serge, Ruben, Ben…