X-Box High Power Test Facility

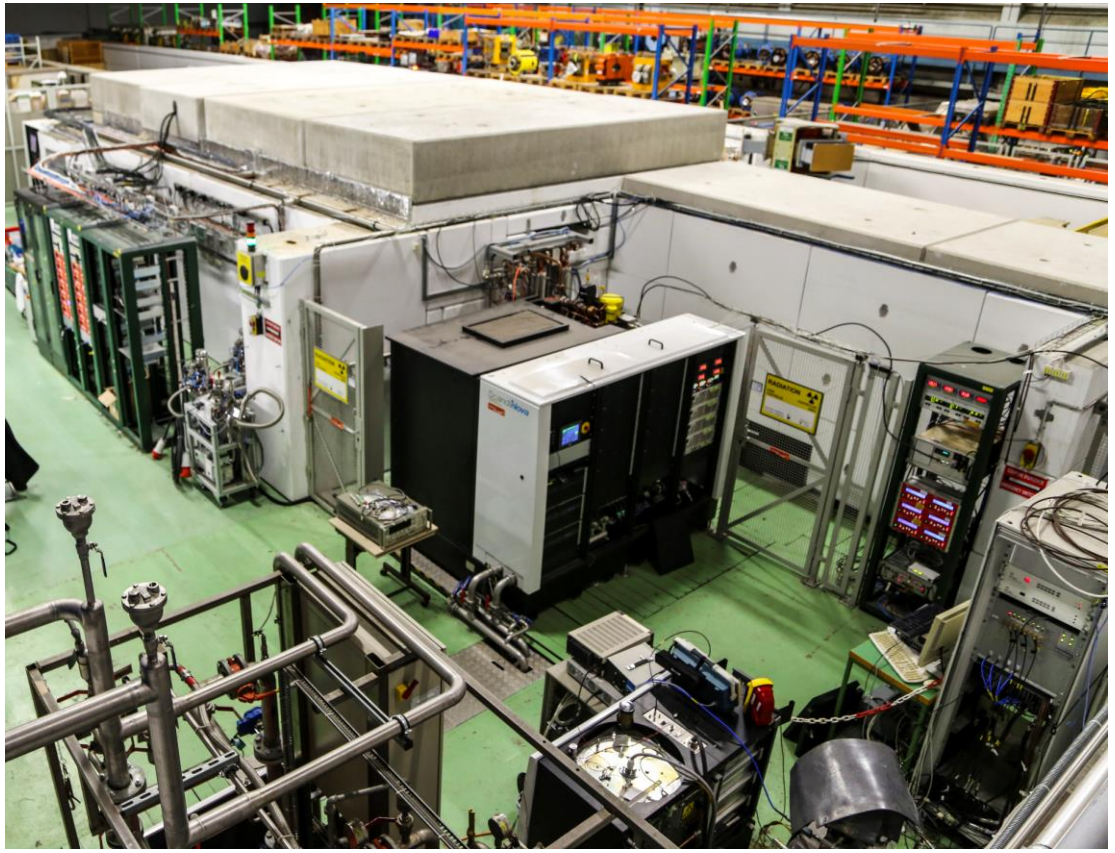
SAM PITMAN ON BEHALF OF THE X-BOX TEAM

CLIC PROJECT MEETING

22 OCTOBER 2018

Introduction to X-Boxes

- Test area for high gradient structure development and prototype operation.
- Close to RF systems needed for klystron based CLIC and other high gradient applications.
- 4 x 12GHz & 1 x 3GHz test bench
- 2 x 50 MW 1.5µs CPI Klystrons.
- 4 x 6 MW 5µs Toshiba Klystrons.
- 6 x Scandinova modulators.
- Fully implemented diagnostics for high-gradient measurements.
- National Instruments PXI/Labview based control and data acquisition.



X-band facilities at CERN

CPI 50MW 1.5us klystron
Scandinova Modulator
Rep Rate 50Hz
Beam test capabilities - CLEAR

CPI 50MW 1.5us klystron
Scandinova Modulator
Rep Rate 50Hz
Full Klystron Capacity

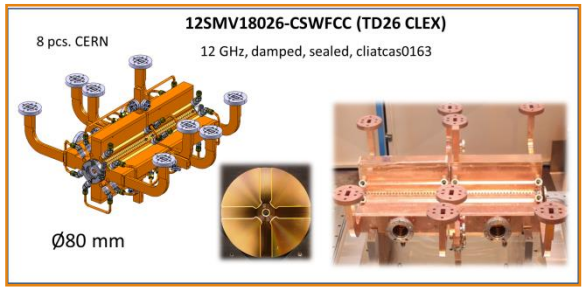
4x Toshiba 6MW 5us klystron
4x Scandinova Modulators
Rep Rate 400Hz
High Throughput Testing

Current Status

Line	DUT	Power (MW)	Status
Xbox 1	TD26CCR05N2	130 max	Preparing for CLEAR Connection
Xbox 2	Phase Shifter Power Splitter	~20MW	Running
Xbox 3A	T24N4	~5MW	Running
Xbox 3B	T24N5	~5MW	Running
Xbox 3C	TD24 Baked out	39 MW	Running
Xbox 3D	TD24 Not Baked out	39 MW	Running
Sbox	BTW1	43 max	Preparing for second medical structure.

X-Box 1 → CLEAR

- ‘The one with beam’
- X-Box 1 was the prototype test bench.
- Single structure tests @50Hz.
- Spectrometer for dark current analysis.
- Previous connection to ‘dogleg’ experiment.
- 3 structures conditioned successfully. 2 tested with beam after initial conditioning.
- Upgrade to connect to CLEAR.

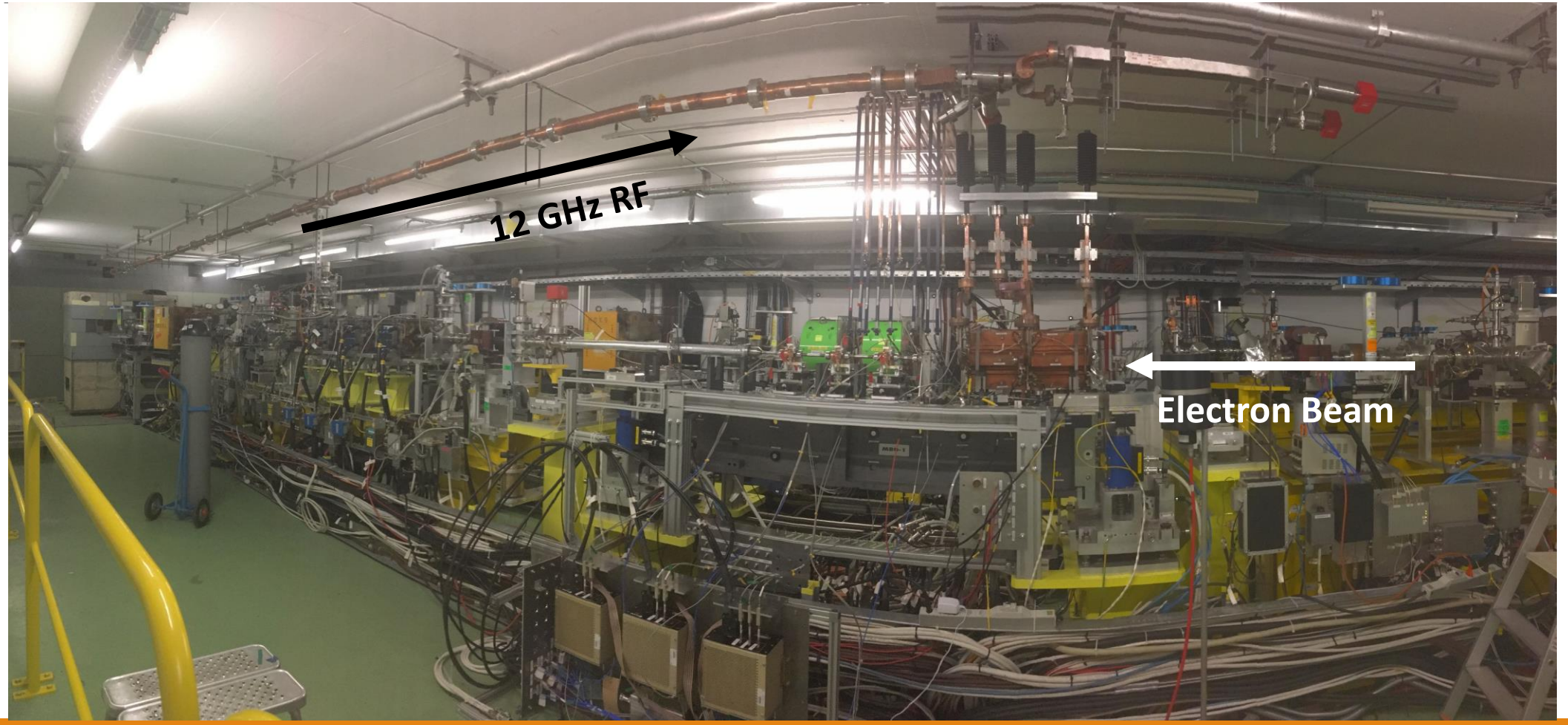


TD26 CLEX

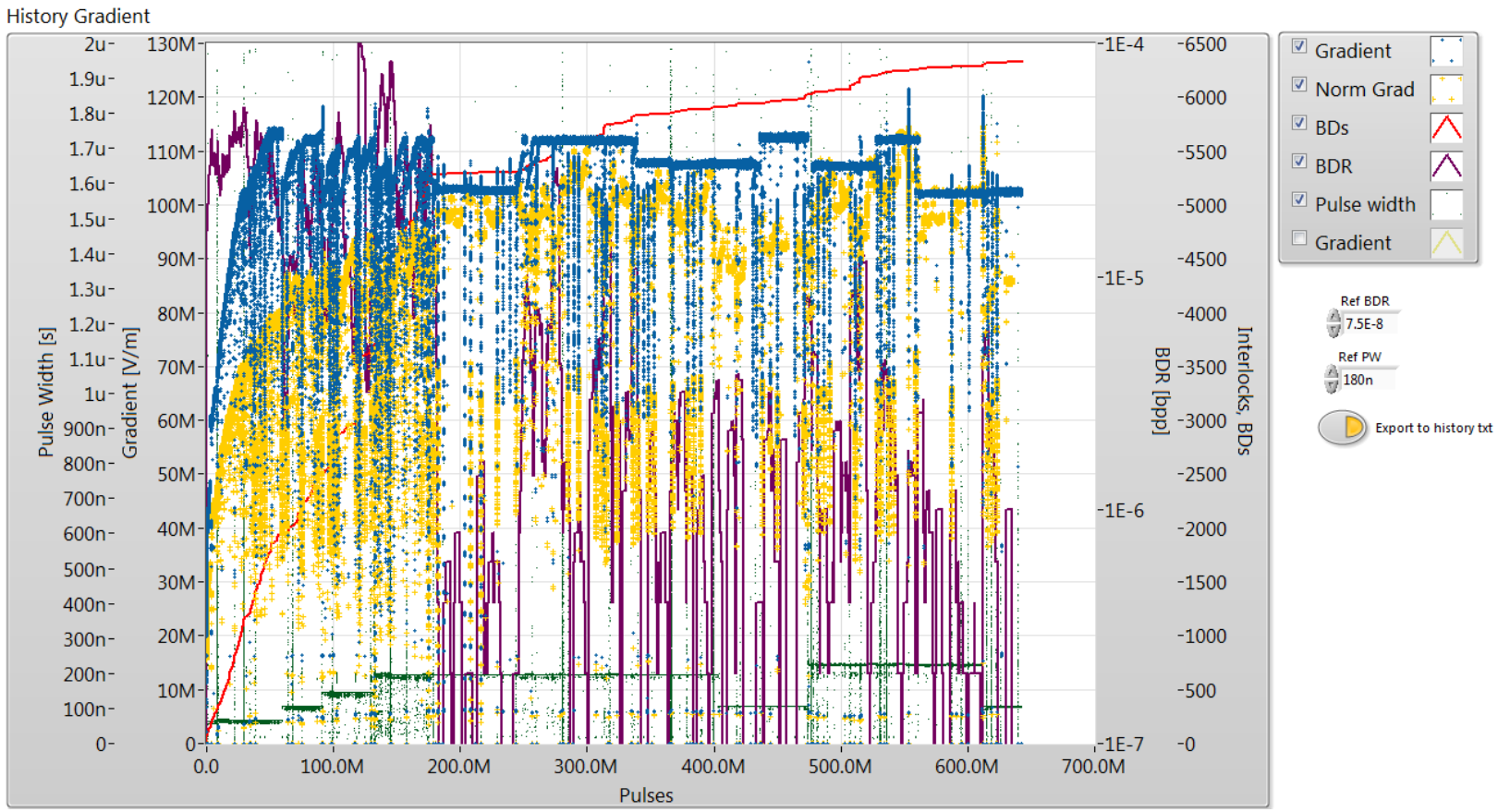
Upgrade:

- LLRF
  - RF Generation – modulate using PXI card rather than multiple existing steps in PFN.
  - Data Acquisition – down mix to 200 MHz matching X-Box 2 & 3.
  - IQ sampling to obtain phase and amplitude information.
  - Keeping triggers and 3GHz master oscillator from CTF3
  - Signals split and analysed by CLEAR and X-Boxes.
- Software to be upgraded and brought in line with X-Box 2 & 3.

X-Box 1 → CLEAR



X-Box 2 – Most recent test



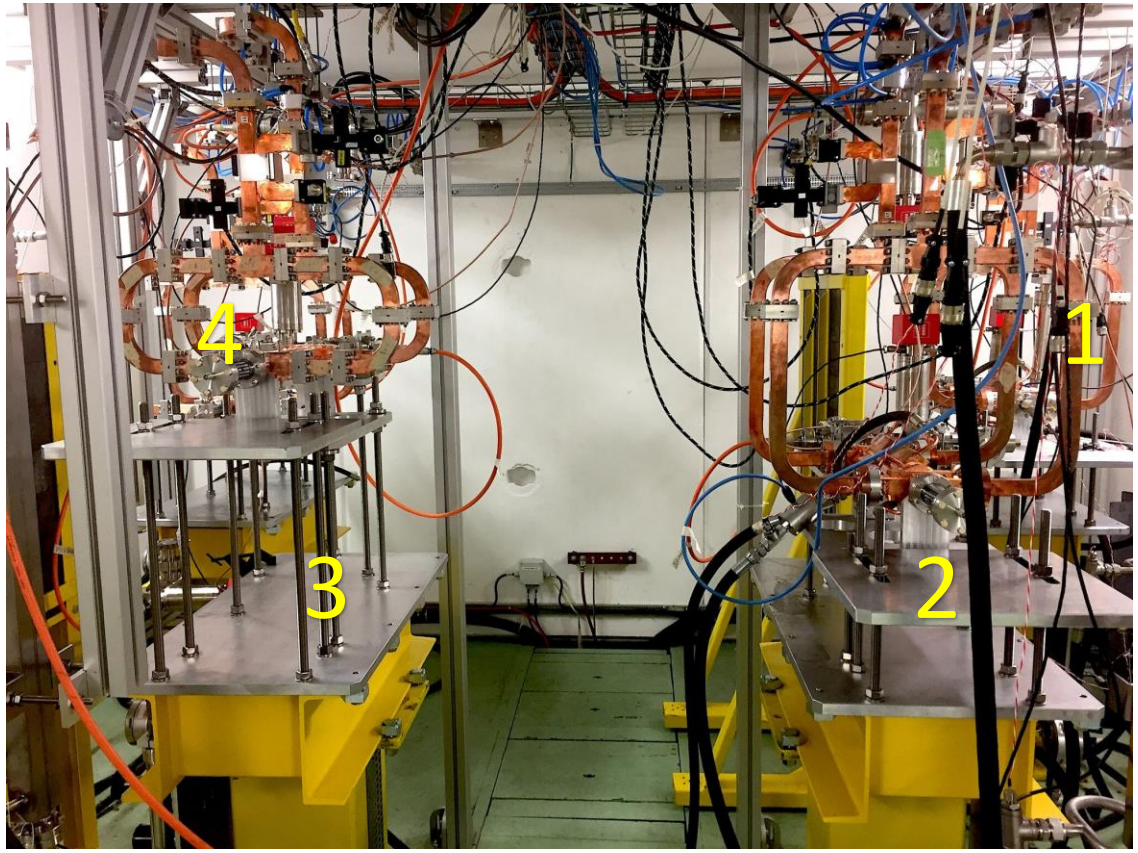
- ‘The high power one’
- High power testing of single structures.
- 130 MW – 50 Hz.
- ~4M pulses per day.
- Most recent test PSI2 structure.
- Previously conditioned in X-Box 3 then moved to X-Box 2 for more power.
- Upgrade to test 2 structures at full klystron capacity.
- 5 structures conditioned and tested.

X-Box 2 - Upgrade

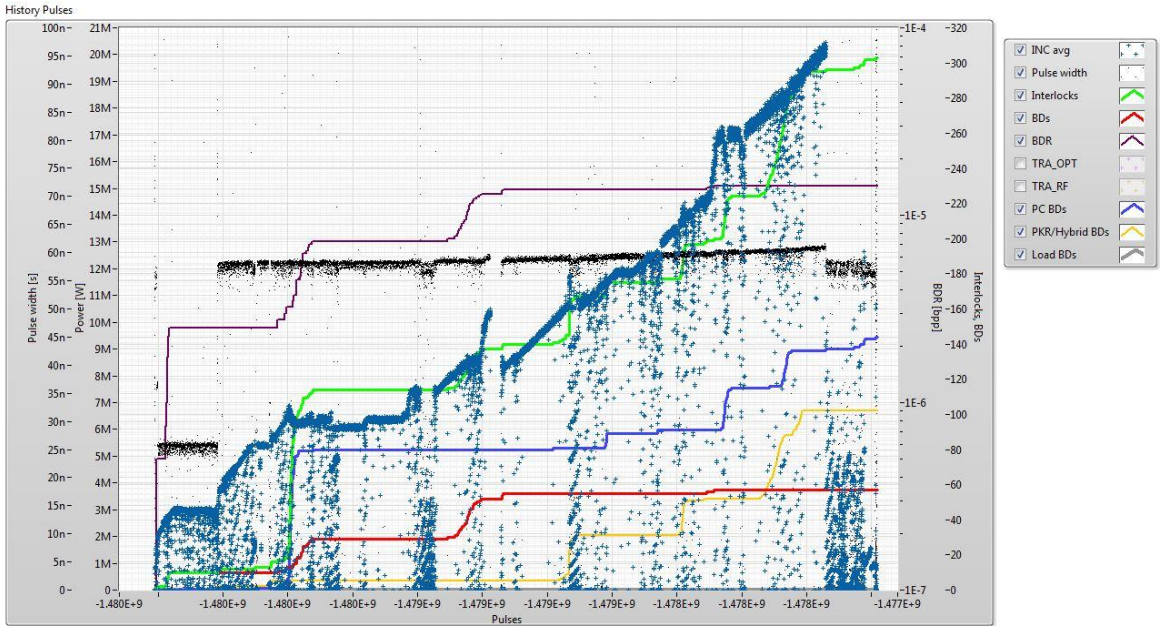
- Upgrade to test two single structures or ‘superstructure’.
- alongside high power RF components.
- Close to nominal version of linac.
- Phase shifter and power splitter installed and under vacuum.
- Interested in breakdowns travelling through the structure.
- Interested in dark current captures with varying phase advance between structures.
- Software + LLRF upgrade in progress.
- New pulse compressor with corrector cavity.
- 5 more structures lined up for testing.

X-Box 3 - Introduction

- ‘The high rep rate one’
- 4 x 6 MW 5µs Toshiba Klystrons High rep rate units – 400hz conditioning at 200hz.
- Historically 2 testing structures 2 testing components.
- Capable of ~17M pulses per day!
- 6 high power components conditioned and tested.
- 4 structures conditioned and tested.

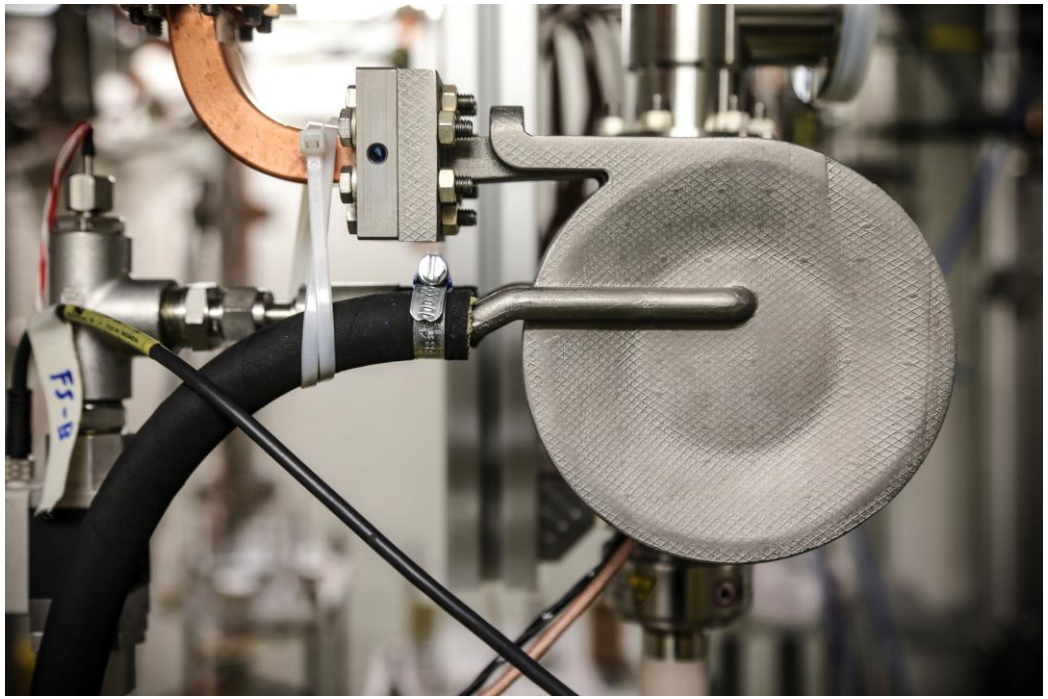


X-Box 3 line 1 – Terminator N1

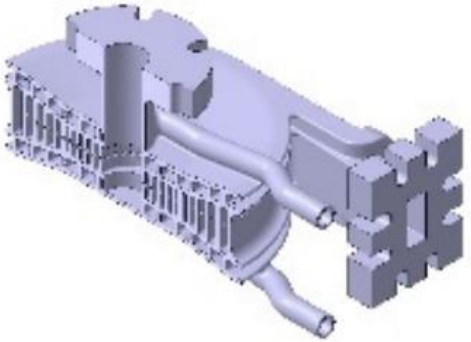


- Terminations designed for hybrid 4th port.
- Breakdowns could cause spurious reflections in fourth port of hybrid.
- Needs to withstand single high power pulses – low average power
- Reached 20.5MW.
- 5Hz Repetition rate.
- 50ns pulse.

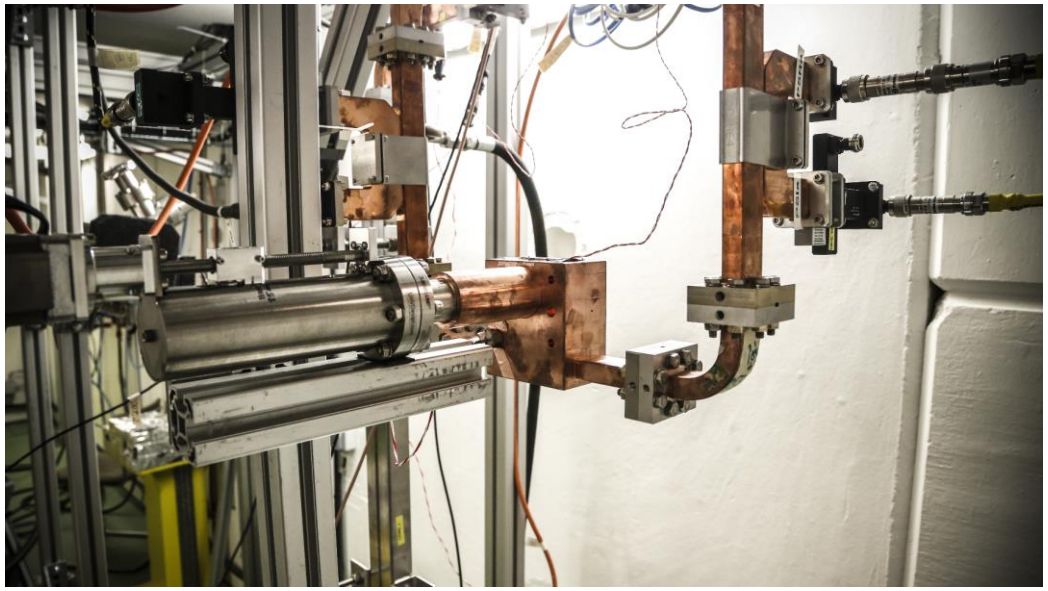
X-Box 3 line 1 – Spiral Load



- 3D printed titanium load.
- Tapered waveguide spiraling inwards for compactness.
- Breakdowns visible through reflected power.
- 50ns – 35.5 MW peak power
- 200ns – 25 MW peak power
- Average power = 2.1 kW
- Tested to maximum capability of test stand.

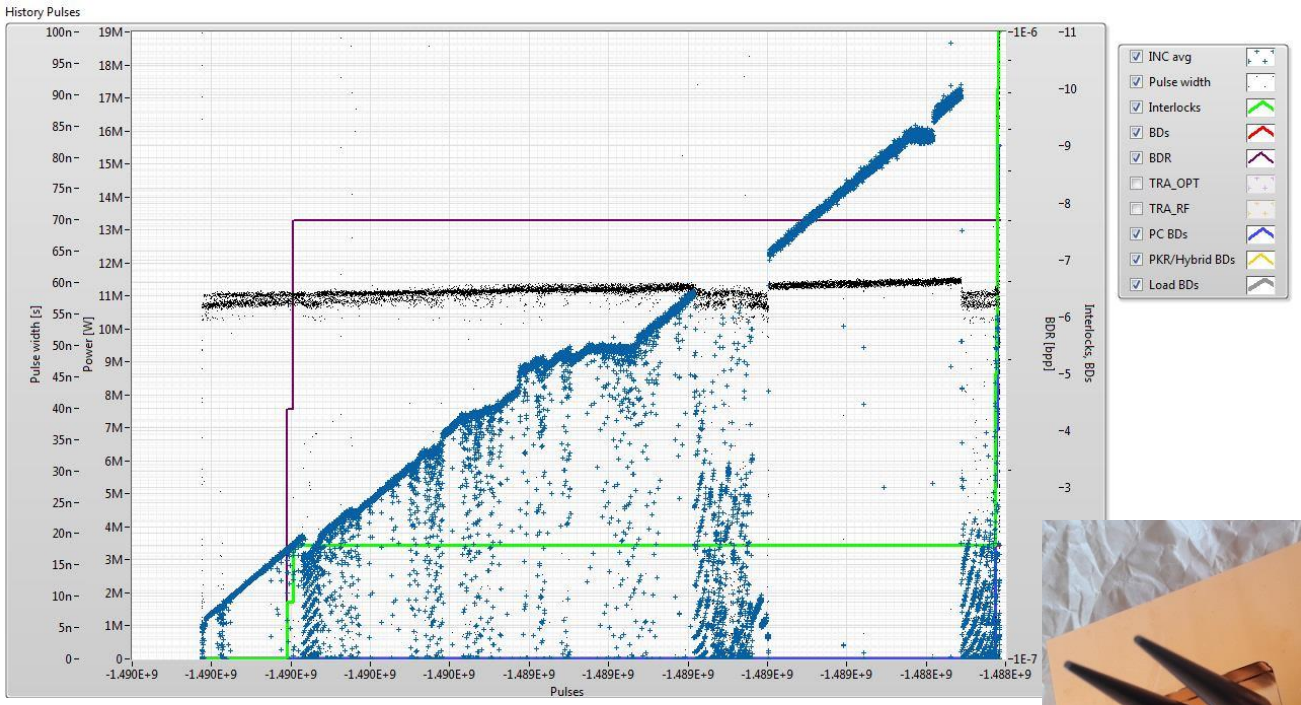


X-Box 3 line 1 – Phase Shifter



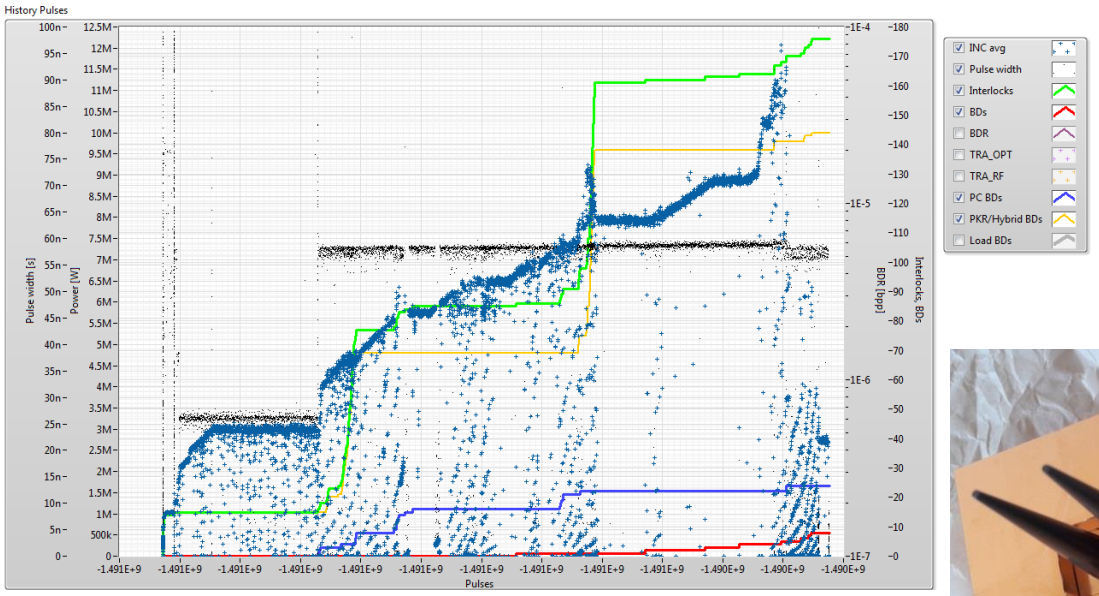
- Designed to shift phase at high power.
- Motorised remotely controlled piston varies the phase shift.
- Reached 37 MW peak power.
- 25Hz repetition rate.
- 100ns pulse length.
- Structure now installed in X-box 2 where there is more power available.
- Structure will shift phase between two devices under test.

X-Box 3 line 2 – Terminator N2



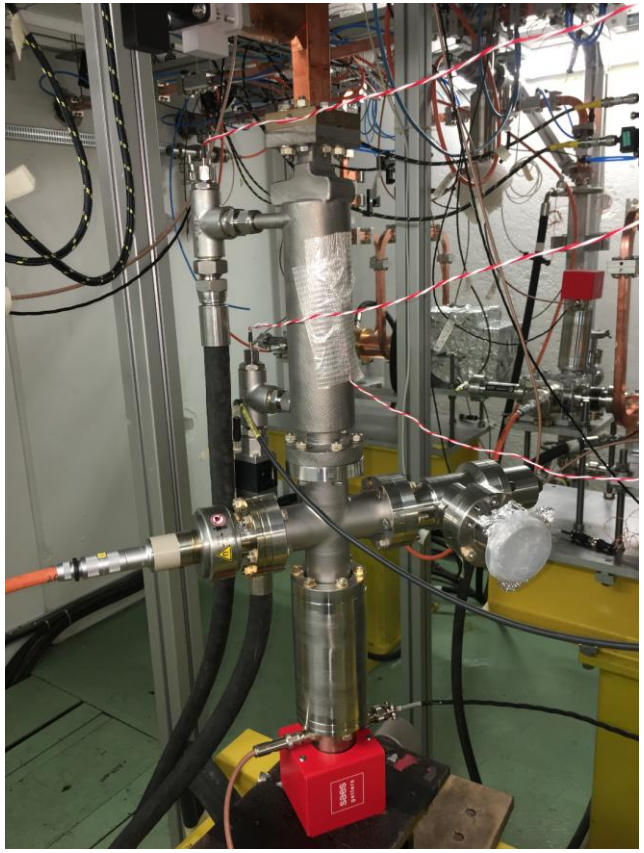
- Tested to 17.5MW.
- Analysis ongoing.

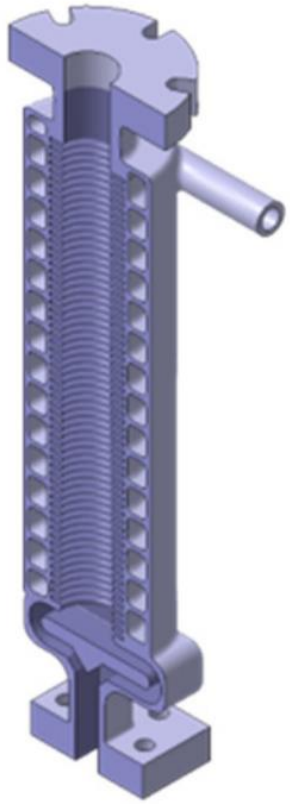
X-Box 3 line 2 – Terminator N4



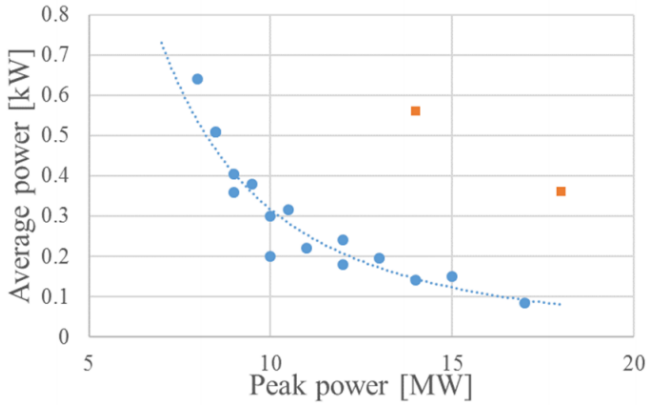
- Tested to 12MW.
- Will install N1 on forth port of hybrid in CLEAR.

X-Box 3 line 2 – Compact Load

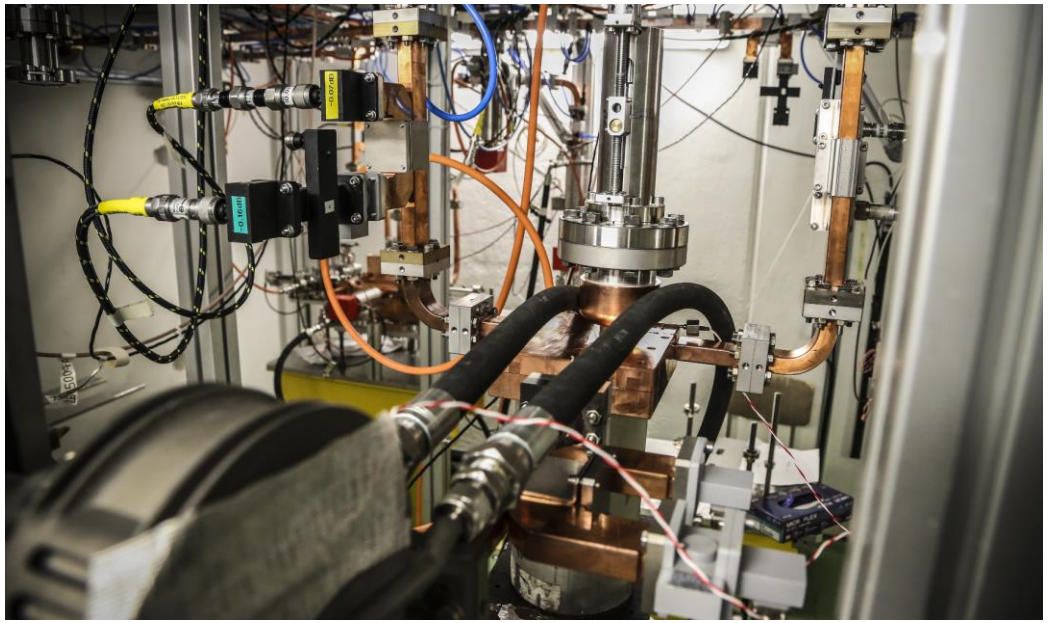




- Titanium printed at CERN.
- Based on corrugated waveguide.
- Breakdown only visible through vacuum activity.
- Power limited by combination of peak and average power.

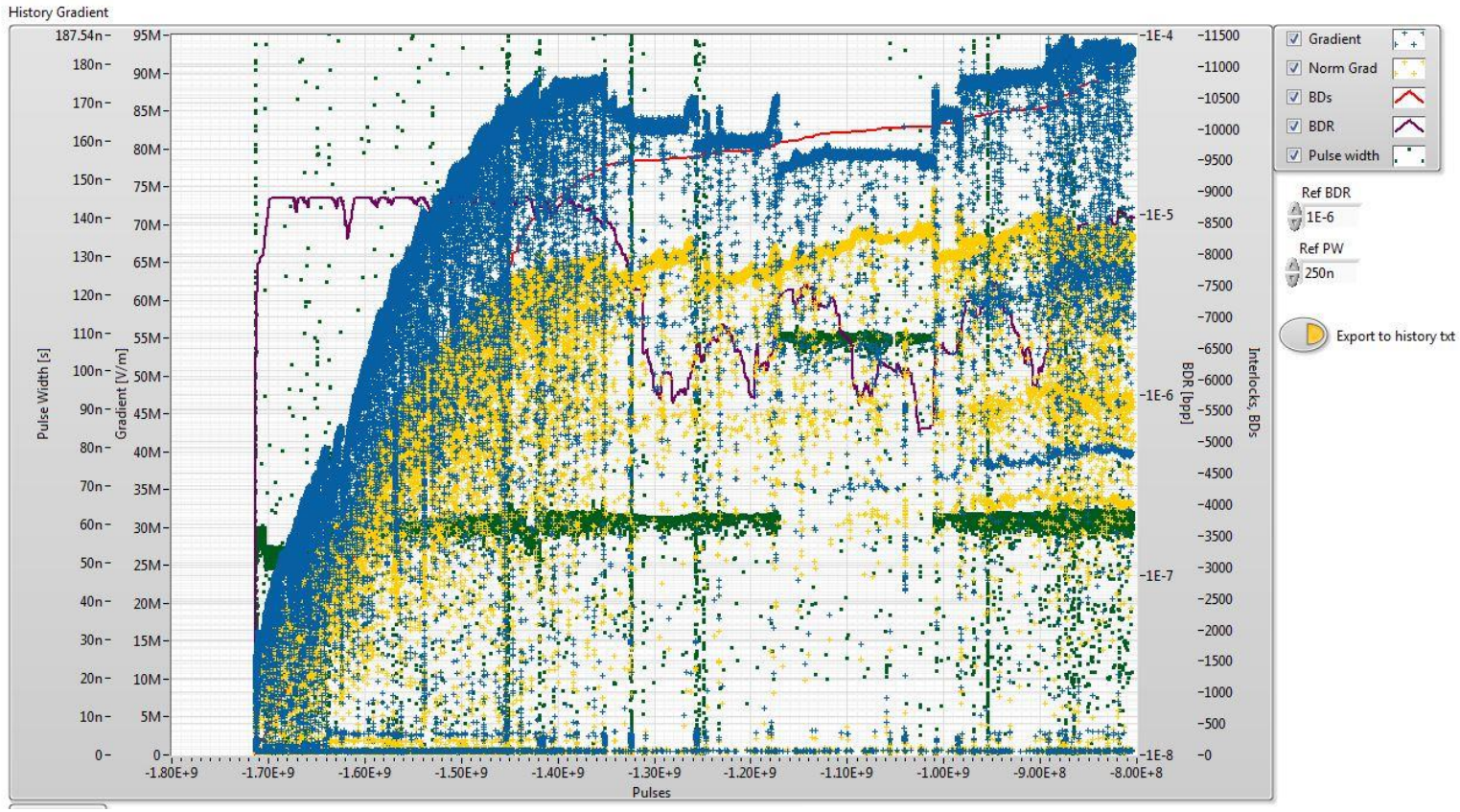


X-Box 3 line 2 – Power Splitter



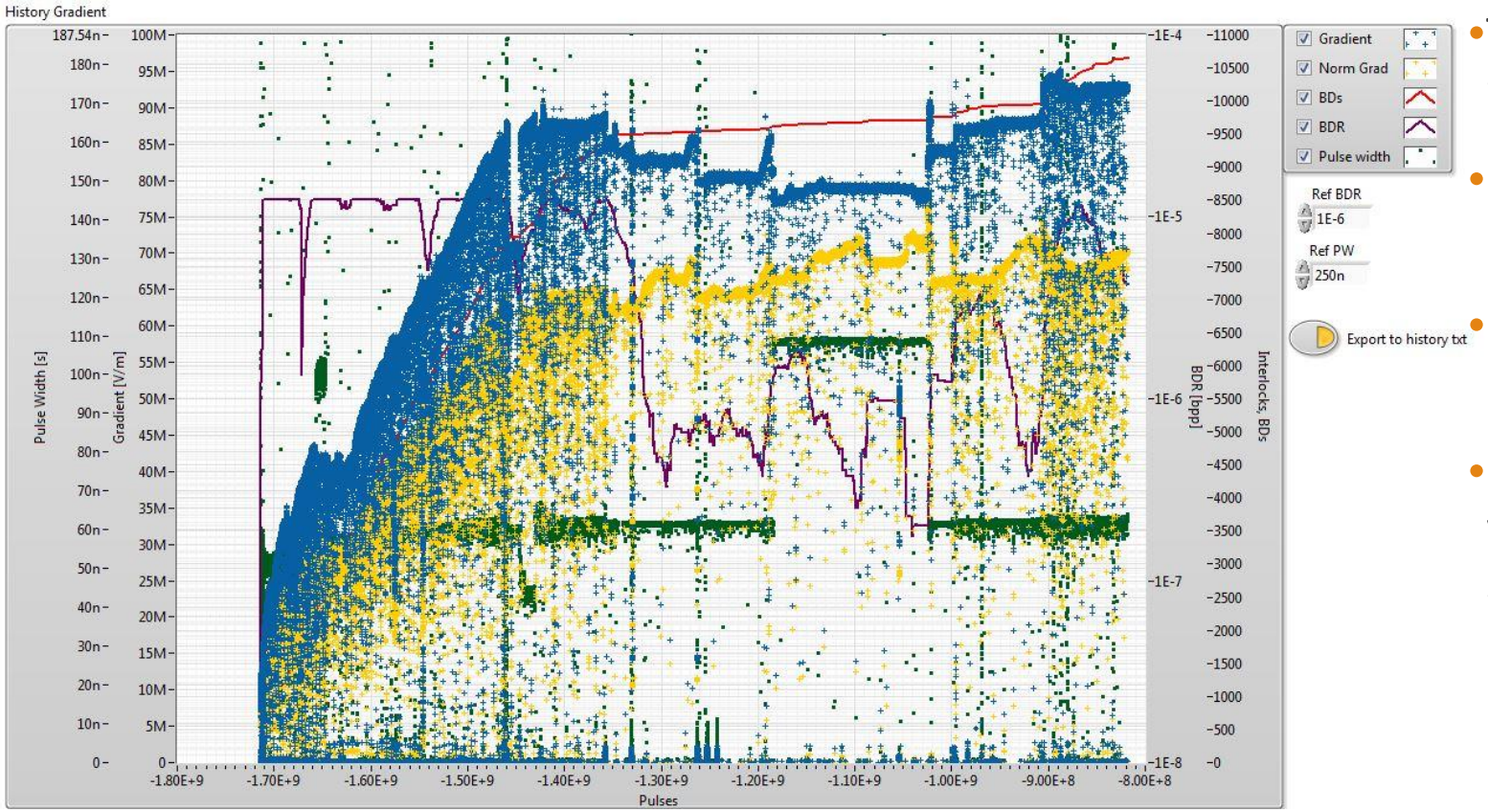
- Designed to split power between structures.
- Motorised remotely controlled piston varies the power balance between the two output ports.
- Reached 44 MW peak power.
- 25Hz repetition rate.
- 100ns pulse length.
- Structure now installed in X-box 2 where there is more power available.
- Structure will split power between two devices under test.

X-Box 3 line 3 – HG Structure



- TD24 baked out– 95MV/m
- Stored under nitrogen for >5years
- Recent bake-out
- Producing significantly more dark current.
- Limited by radiation interlocks
- New pulse compressor conditioning.

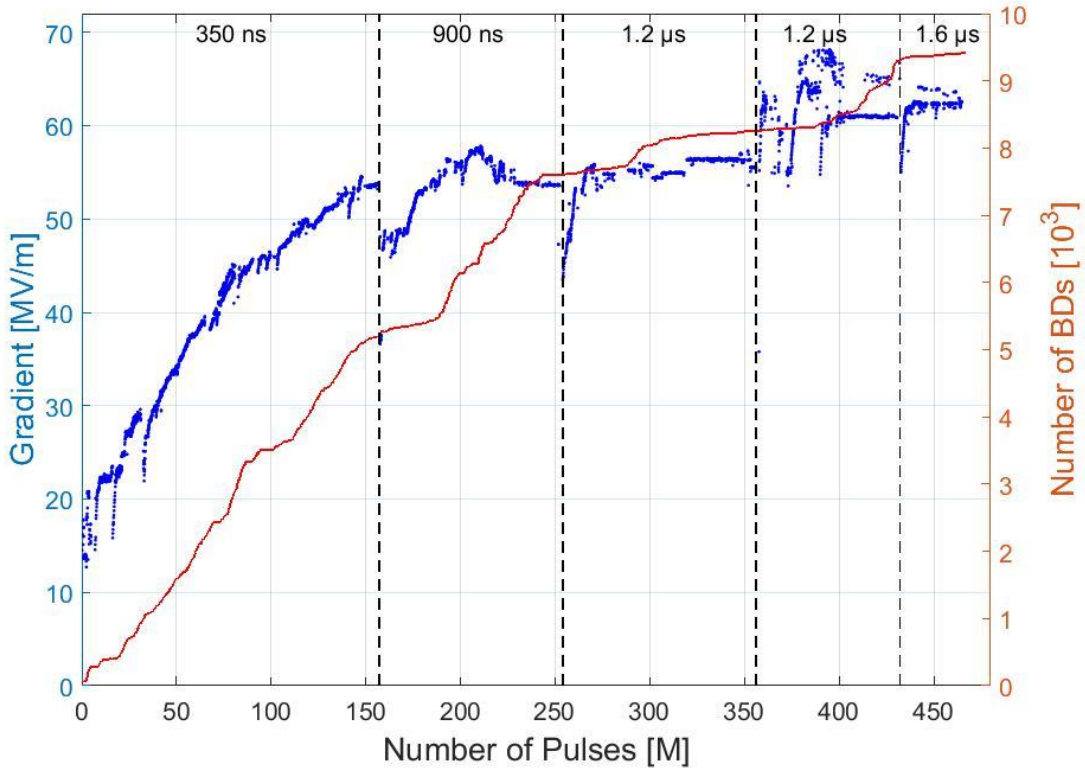
X-Box 3 line 4 – HG structures



- TD24 not baked out – 95MV/m
- Reaching same power as baked out.
- RGA installed to analyse outgassing.
- Empirical measurement with RP to improve shielding inside.

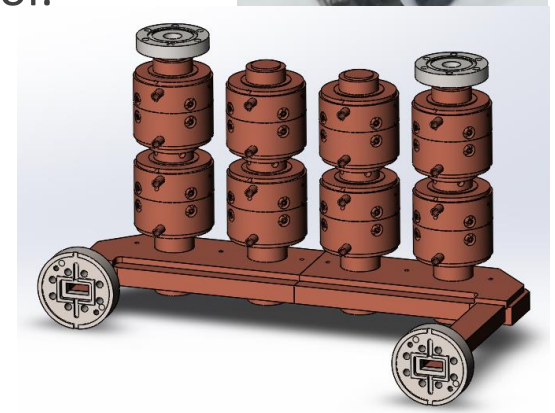
S-Box – 3 GHz Test Stand

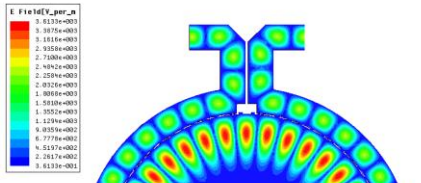
- Test completed 31MW - ~60MV/m beta-0.38
- Second backwards travelling structure to be installed for testing.
- ProBE high gradient SW structure to be tested.



Pulse Compressors

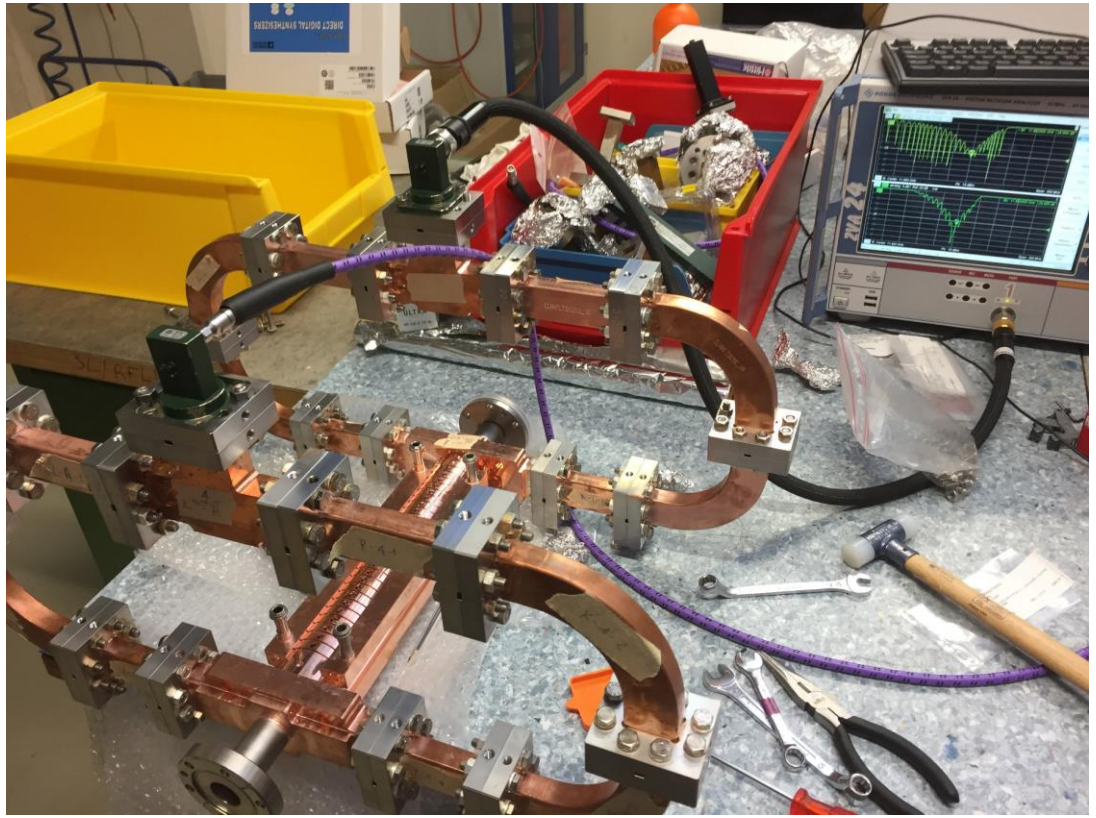
- 6 +2 SLED I pulse compressors.
  - 7 tested at high power.
- Preparing to install and test the PSI ‘BOC’ Barrel Open Cavity pulse compressor.
- ‘Whispering Gallery’ mode – intrinsically high quality factor.
- Correction cavity chain to be used to flatten the compressed pulse.





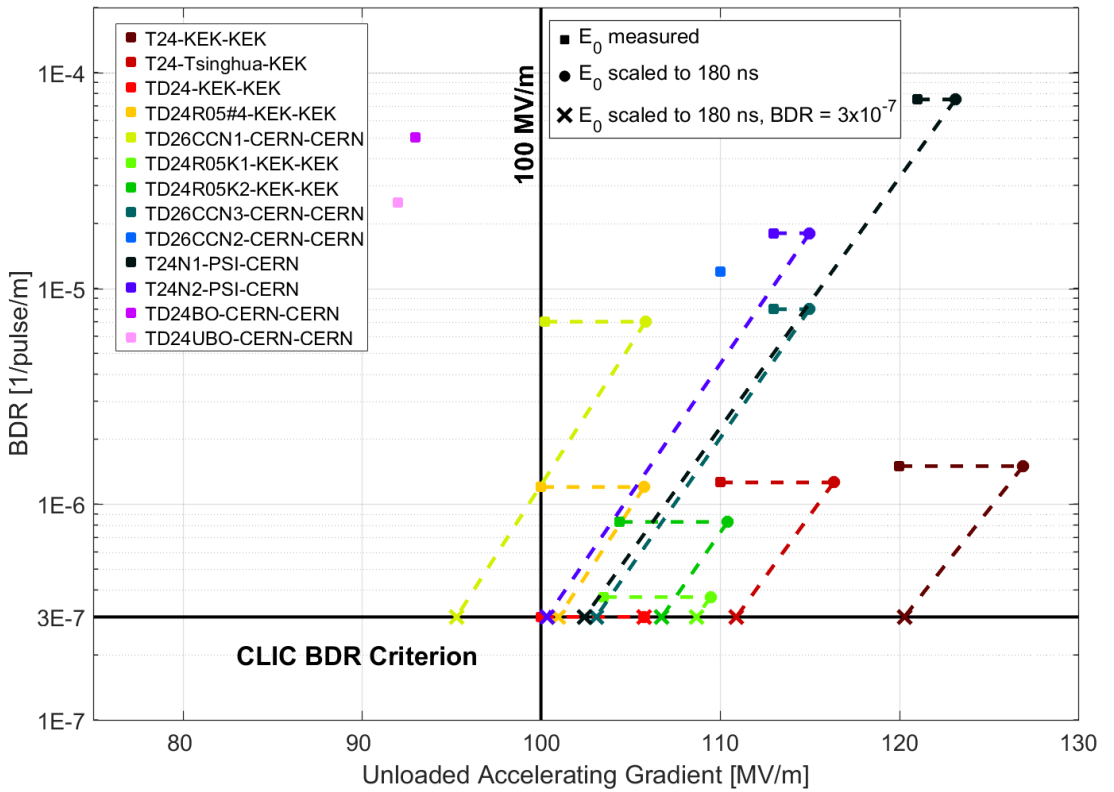
Summary

- X-Box 1: Beam & High Gradient.
  - Connect to superstructure at CLEAR, upgrade LLRF & software.
- X-Box 2: Klystron full capacity running.
  - Upgrade to superstructure, upgrade LLRF & software.
  - 4 structures in line for test slot.
- X-Box 3: high throughput conditioning and testing.
  - 4 components in line for testing.
  - 7 structures in line for testing.
- S-Box: 2 high gradient medical structures in line for testing.



Summary

- Exceeded the 32-bit integer limit on our pulse counters.
- That's > 2 147 483 647 pulses!
- So far we have conditioned and tested dozens of structures.
- 8 high power components tested and some now installed and operational.
- Full lines including pulse compressors ar high power loads have also been conditioned and run reliably as high power test benches.
- Estimated over 10 Billion pulses and counting!



Thank you!

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