Update of CERN X-Band activities

M. Boronat on behalf of X-Boxes team

15th Workshop on breakdowns science and high gradient accelerators technology, HG2022, May 16-19 2022.

X-Boxes News

X-Box 1

- Conditioning of VKX-8331 repaired klystron
- Phase stabilization test

The operation of these test stands has been limited by the availability of the 50 MW klystron

X-Box 2

- MgB_2 SC solenoid for VKX-8331 – Integration and optimization

X-Box 3

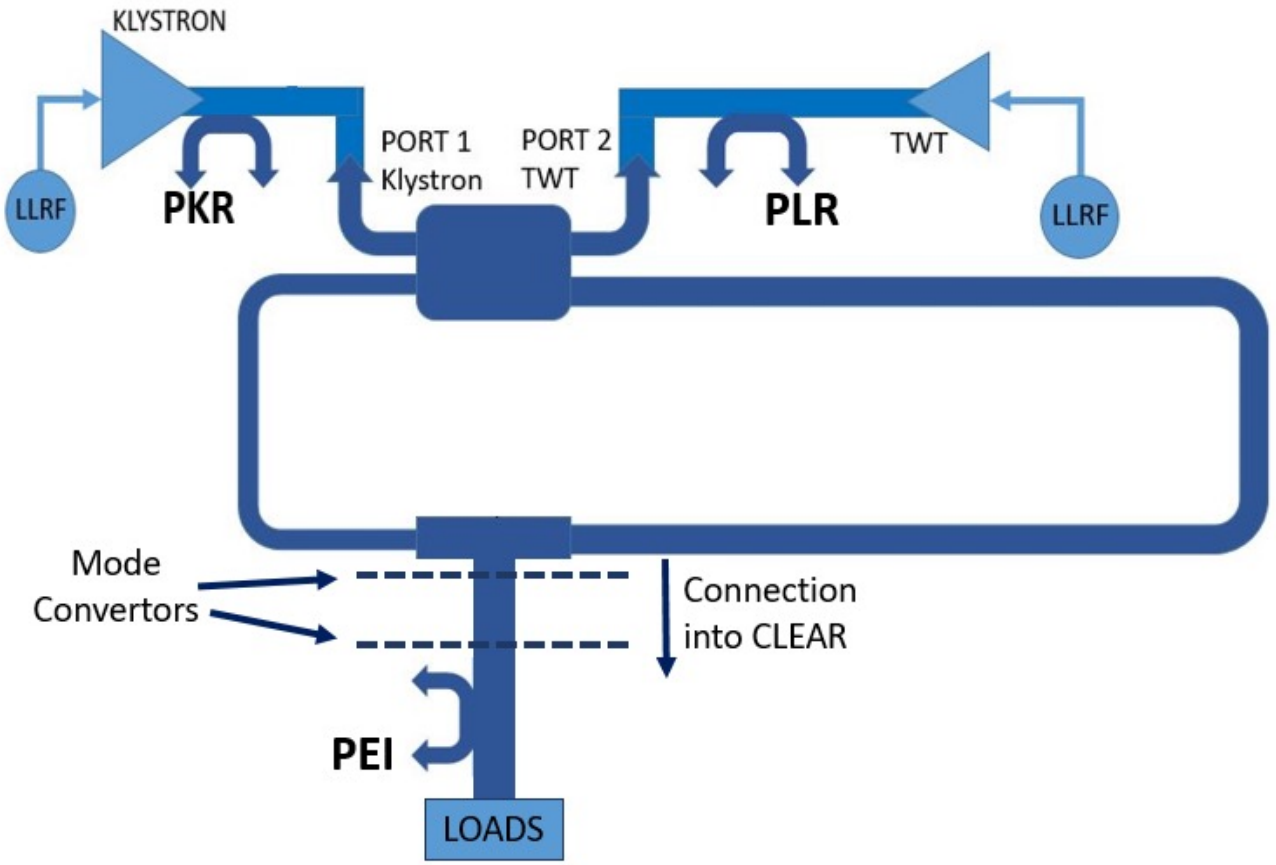
- "Single cell" test - post-morten
- HP RF Window tested
- CRAB cavity from Lancaster conditioned (TNA)
- Deflector SARI conditioned (TNA)

X-Box 1:

- Conditioning of VKX-8331 repaired klystron
- Phase stabilization test

X-Box 1 Phase stabilization test

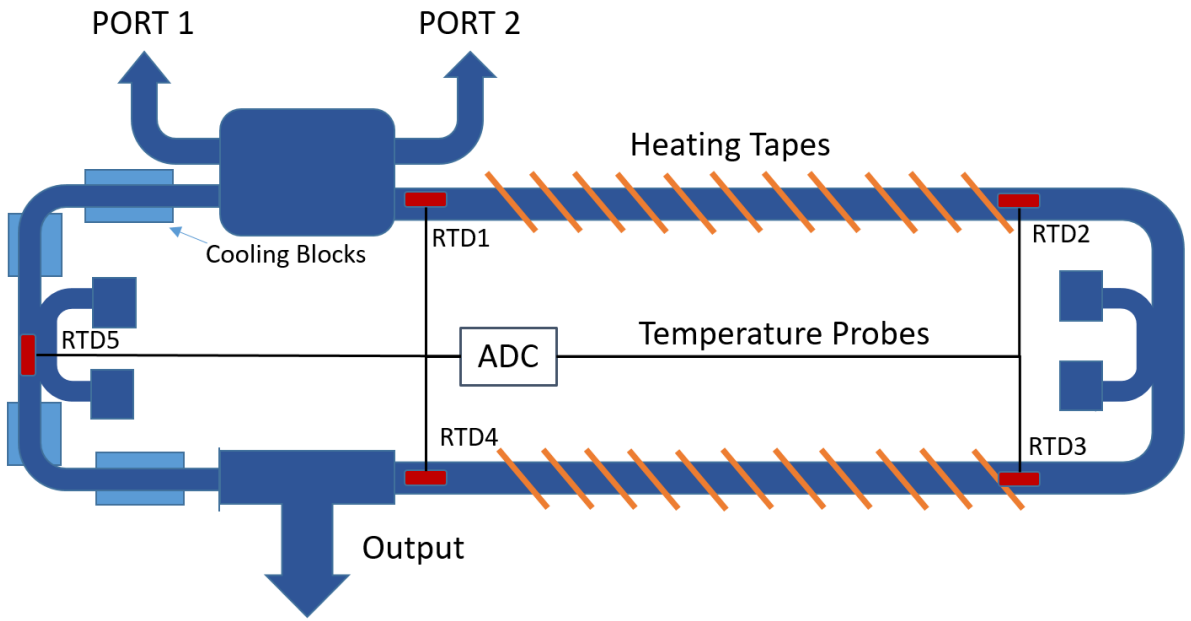
- Long waveguide networks are subject to changes on temperature, altering the phase of the RF arriving to the accelerating structure.
- To keep under control these changes the method proposed use a parasitic low power RF pulses that will be injected alongside with the high power pulses, using a different frequency.

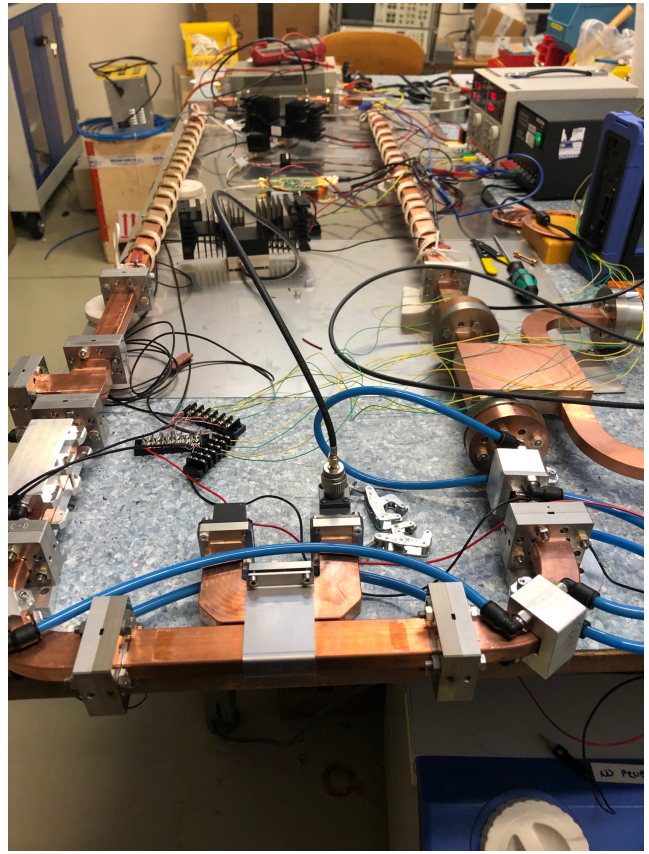


A.C. Dexter, S.J. Smith, B.J. Woolley, A. Grudiev, **Femto-second synchronisation with a waveguide interferometer**, https://doi.org/10.1016/j.nima.2017.11.046
Amelia Edwards et al. , **X-Band Interferometry at Xbox1 and Xbox Status**, CLIC Project Meeting 41

X-Box 1 Phase stabilization test

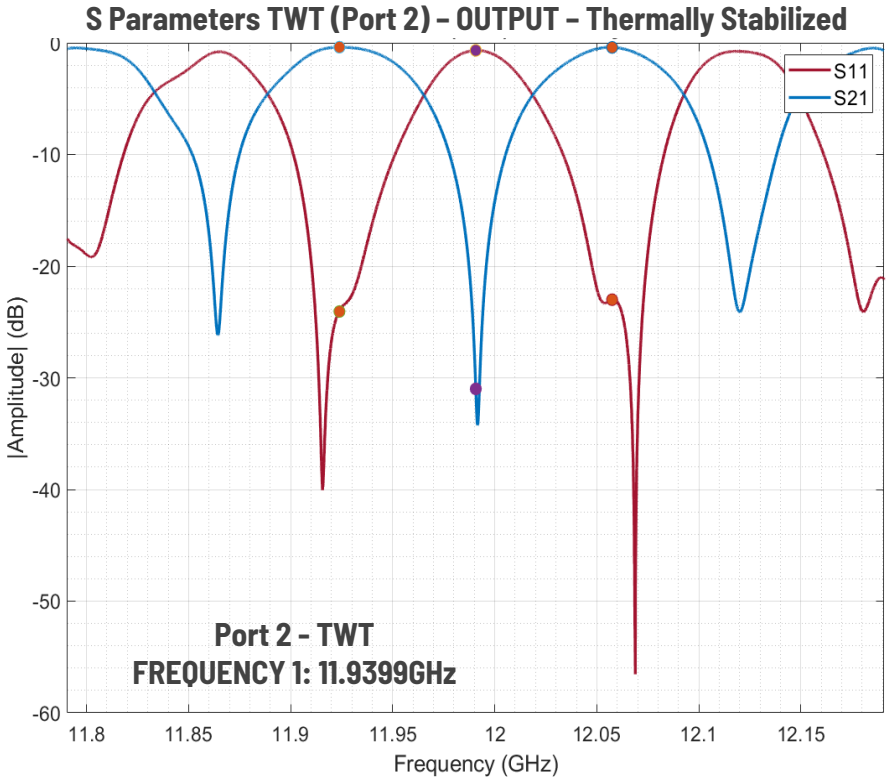
- The different of length between both arm need to be precisely determine and fixed
- Long arm temperature is controlled with heating tapes
- Short arm temperature is stabilized using water cooling

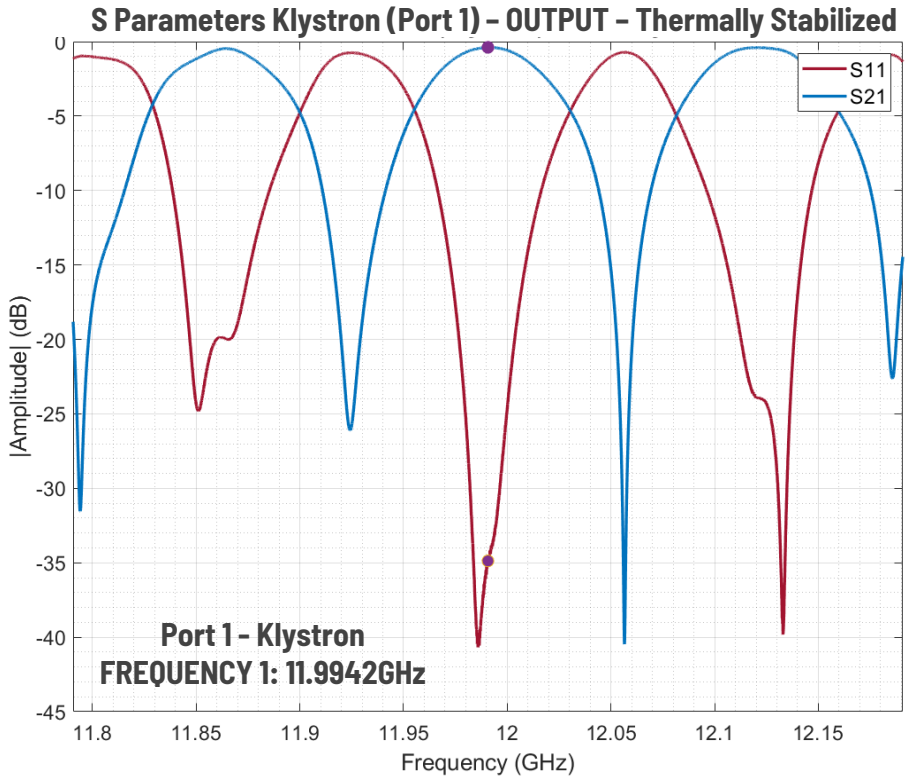




X-Box 1 Phase stabilization test

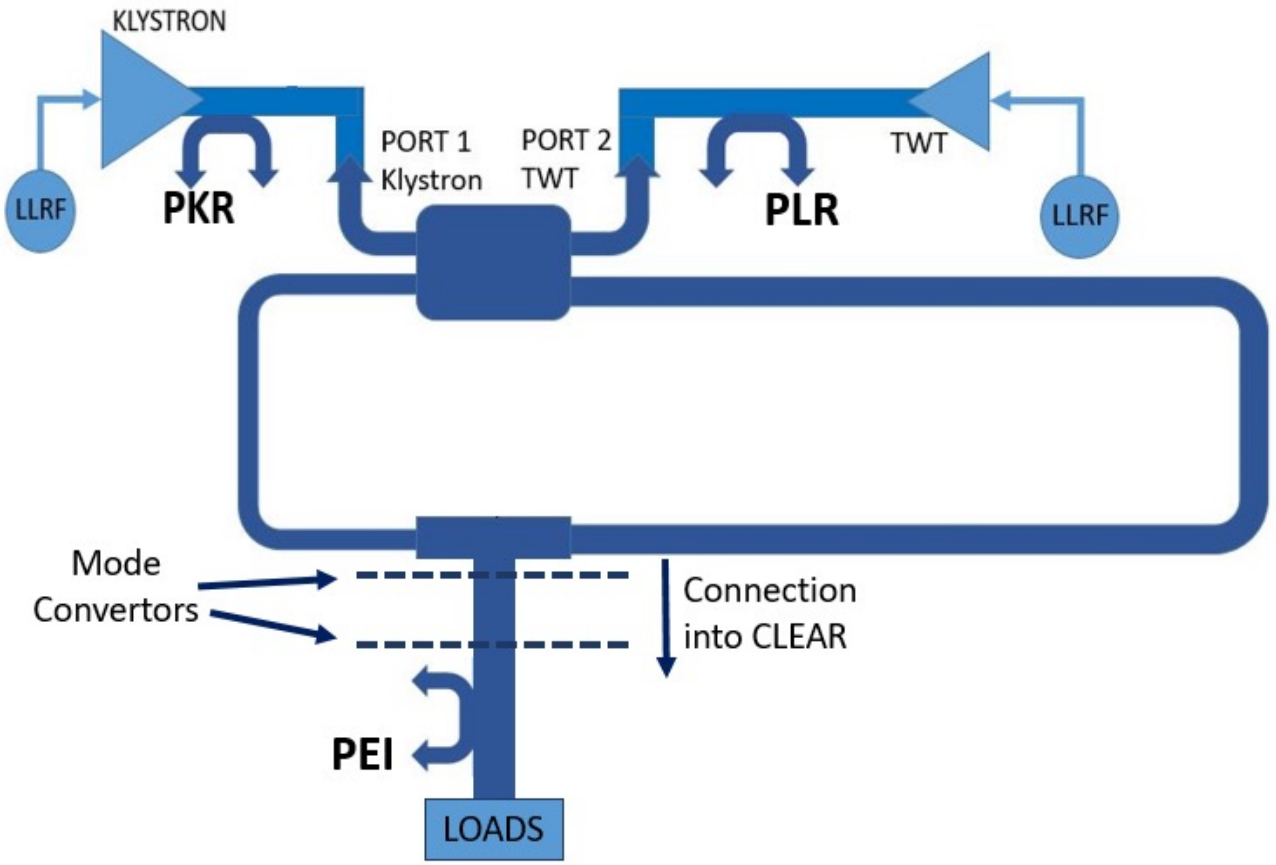
- The interferometer system should be ‘invisible' to high power klystron pulses entering into port 1





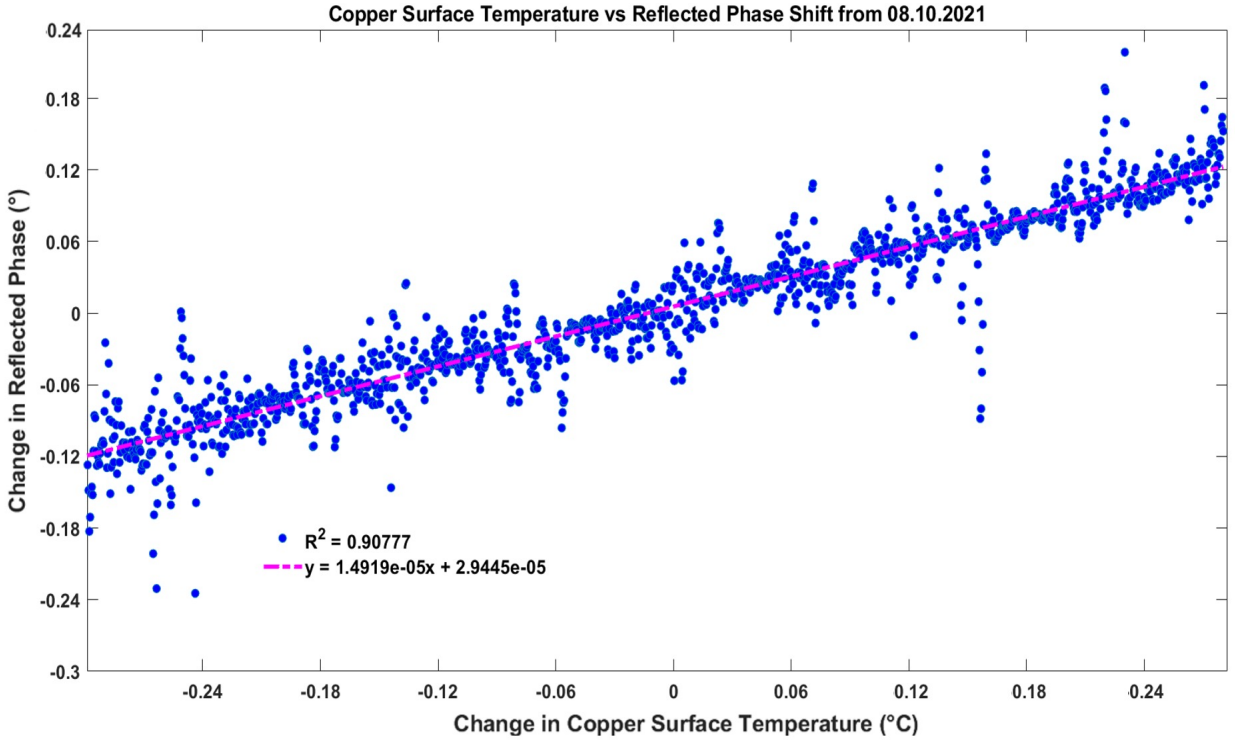
X-Box 1 Phase stabilization test

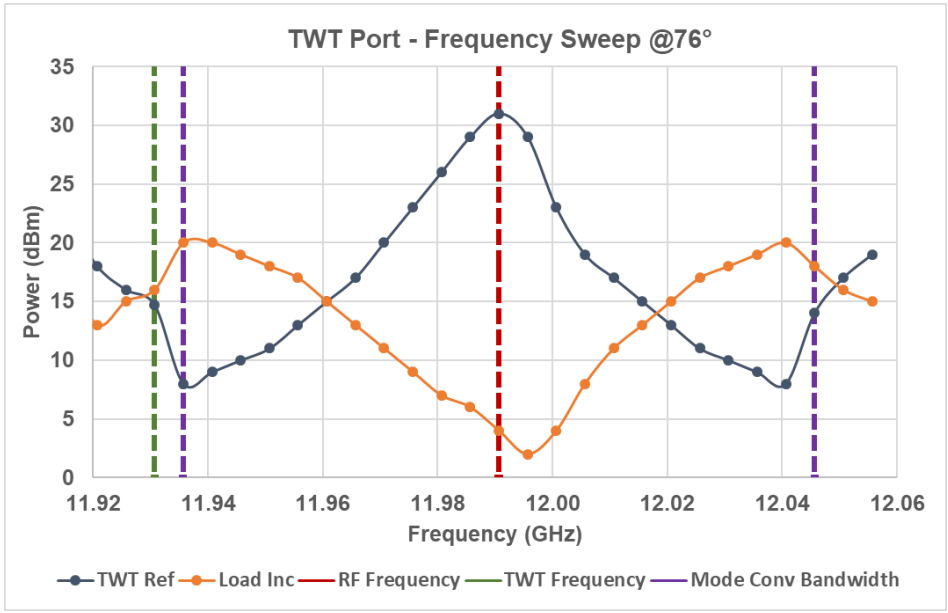
- The high power pulses, at 11,9942 GHz, will reach the loads.
- The low power pulse, at 11,9399 GHz will be partially reflected on the mode converter
- The reflected signal will be used to monitor the phase using the directional coupler connected to the TWT (PLR).



X-Box 1 Phase stabilization test

- The correlation between the reflected phase and copper surface temperature is shown
- Could be used to create a feedback system on the klystron output phase





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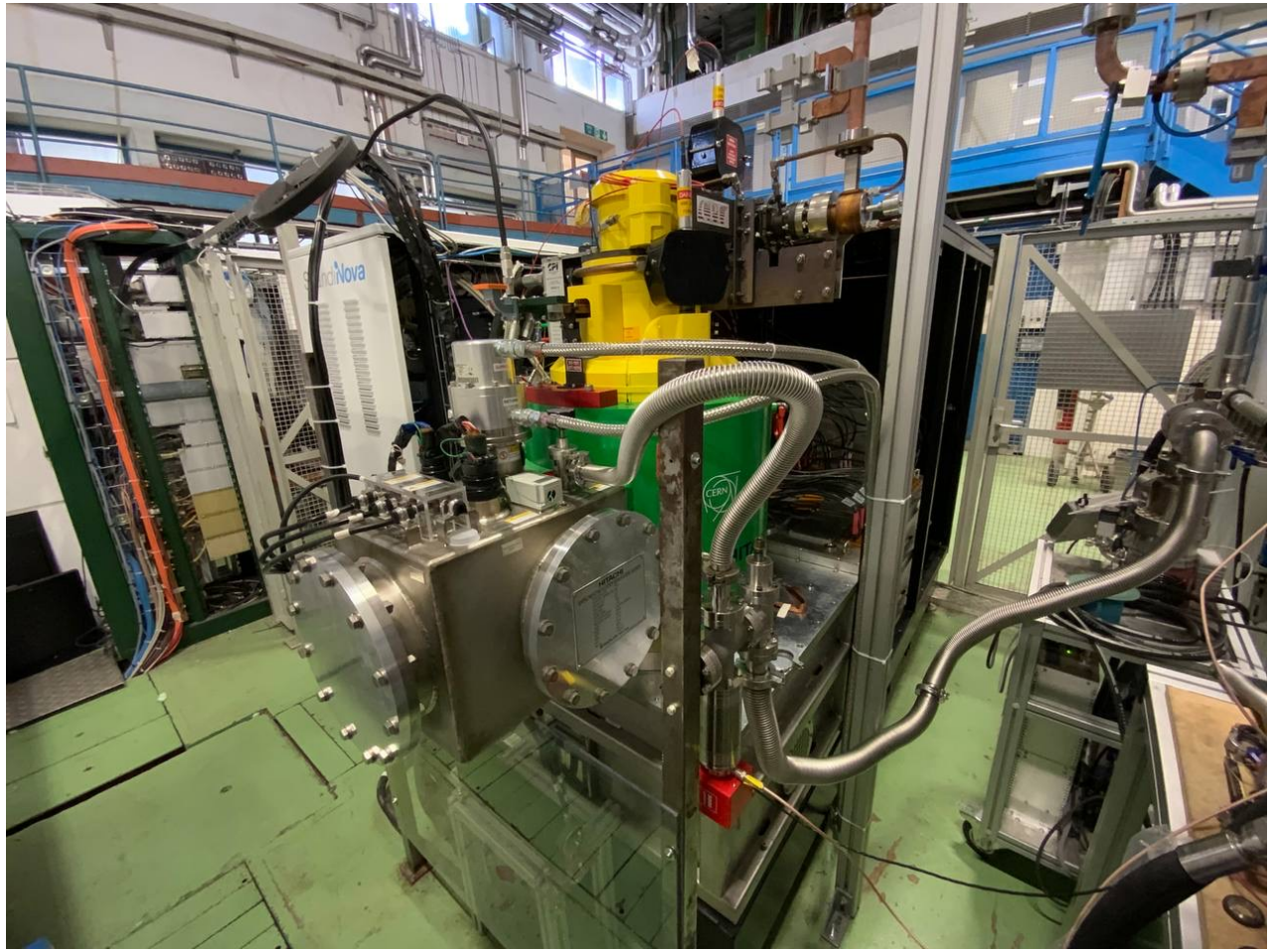
X-Box 1 Status and Plans

- Waiting for the 50 MW klystron to be repaired and shipped back
- Acceptance of the repaired klystron - Connected to the load, on CLEAR
- Can be use to test the super-structure on CLEAR
- Or, in CTF2, as a part of the AWAKE injector (X-Band PSI structure)

X-Box 2:

- MgB_2 SC solenoid for VKX-8331 – Integration and optimization

X-Box 2 MgB_2 Solenoid

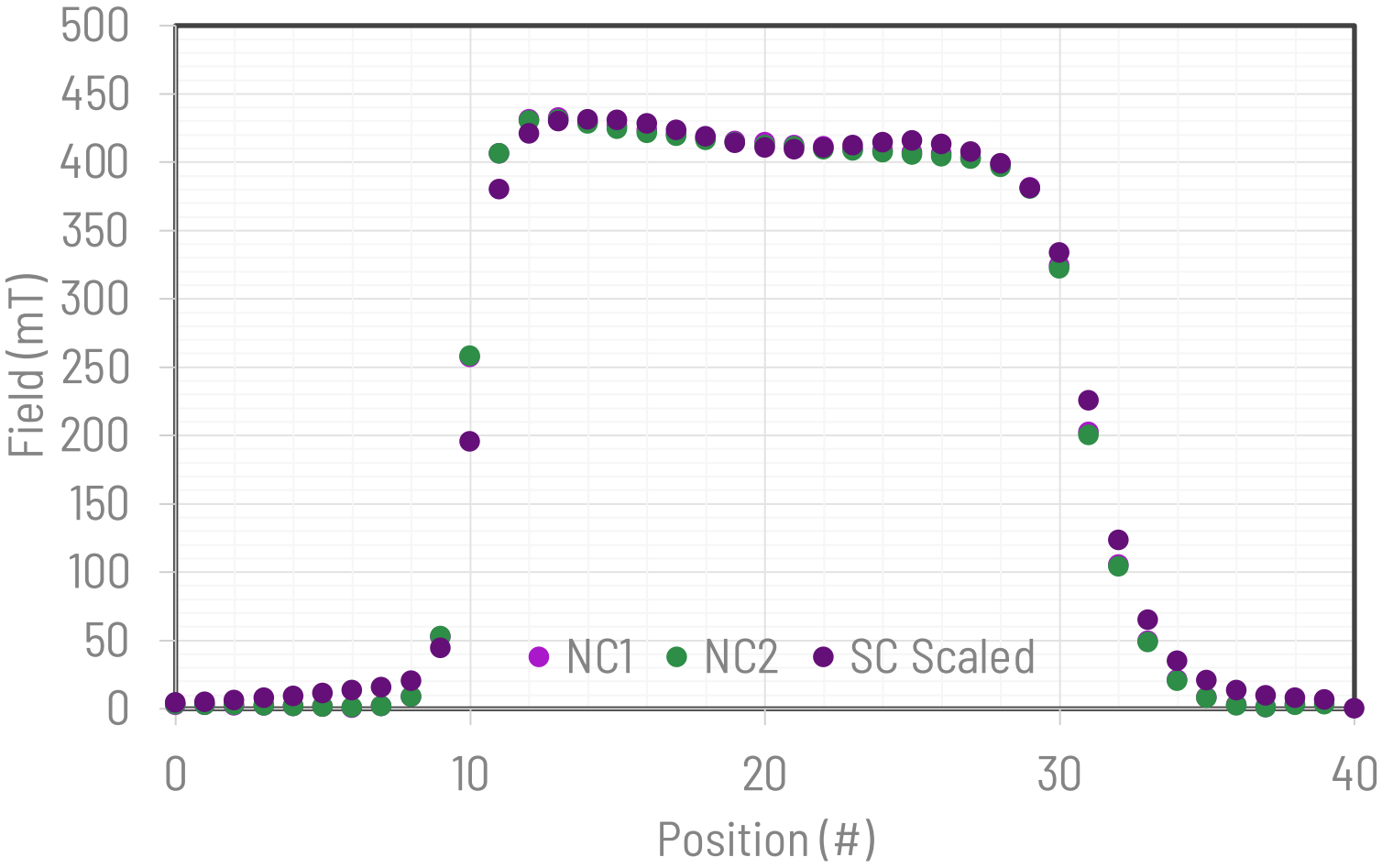


- Prototype compatible with 50 MW CPI klystron
- KEK-CERN collaboration and manufactured by Hitachi
- MgB_2 wire for the klystron magnet, with a unit length of 5.6 km. Diameter 0.67 mm
- Central field 0.8 T @ 57 A
- High efficiency: Reduce the power consumption form 20 kW to 3 kW
- Very safe and stable operation

HG2022

Applying Superconducting Magnet Technology for High-efficiency Klystrons in Particle Accelerator RF Systems; Yamamoto, Akira et al. CERN-ACC-2020-0020 ; CLIC-Note-1159. - 2020. - 6 p. (http://cds.cern.ch/record/2730571)

X-Box 2 MgB_2 Solenoid

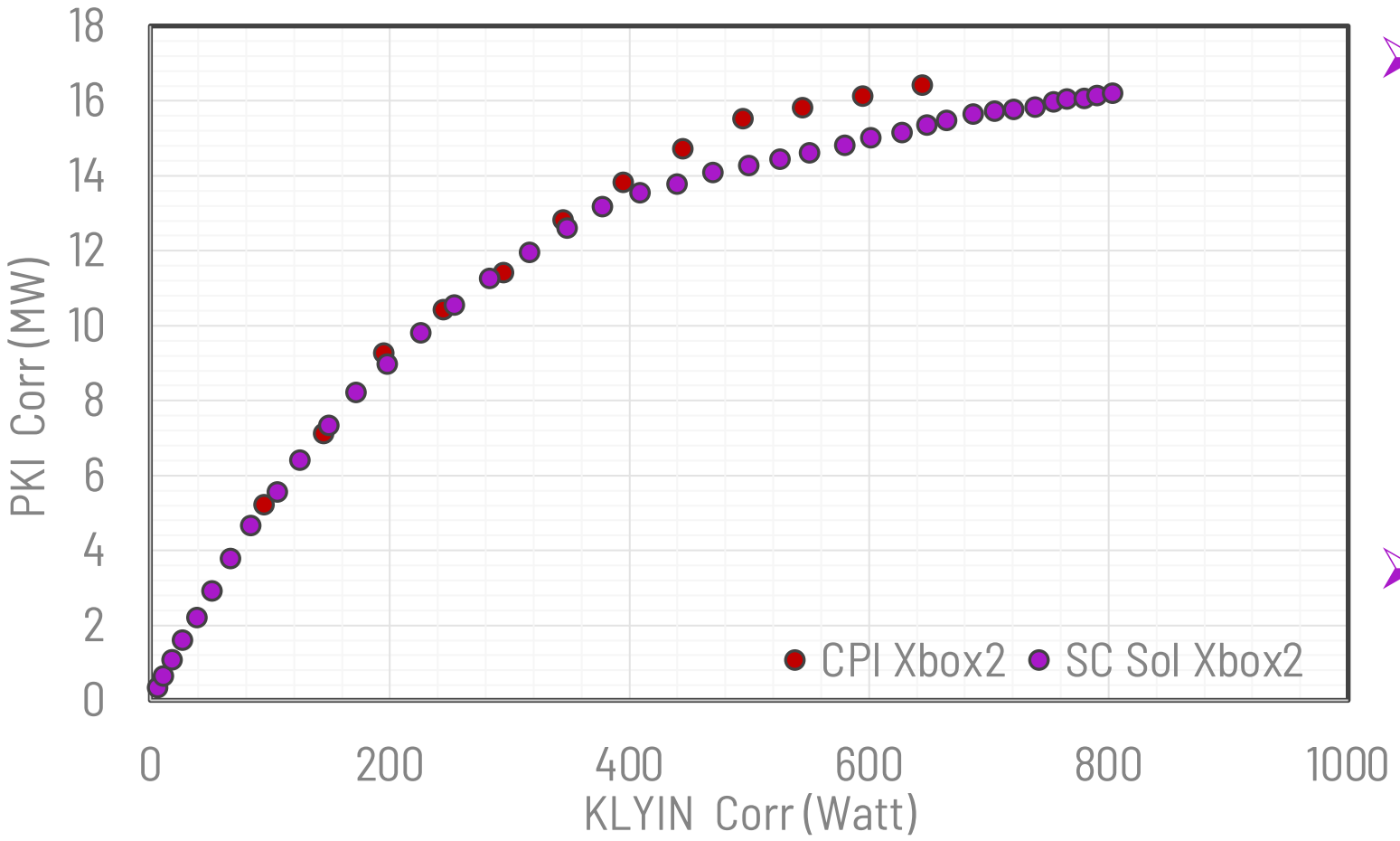


- Already made at CERN (Dec 2020)
  - Cooling and powering
  - Magnetic measurement
  - Interlocks integration and test
  - First Gain Curves
- To obtain the same magnetic profile than the normal conducting solenoid, the current applied was 29,86 A

HG2022

First klystron operation with the Mg2B superconducting solenoid; M. Boronat, N. Catalan-Lasheras, RF development meeting (https://indico.cern.ch/event/1004710/)

X-Box 2 MgB_2 Solenoid

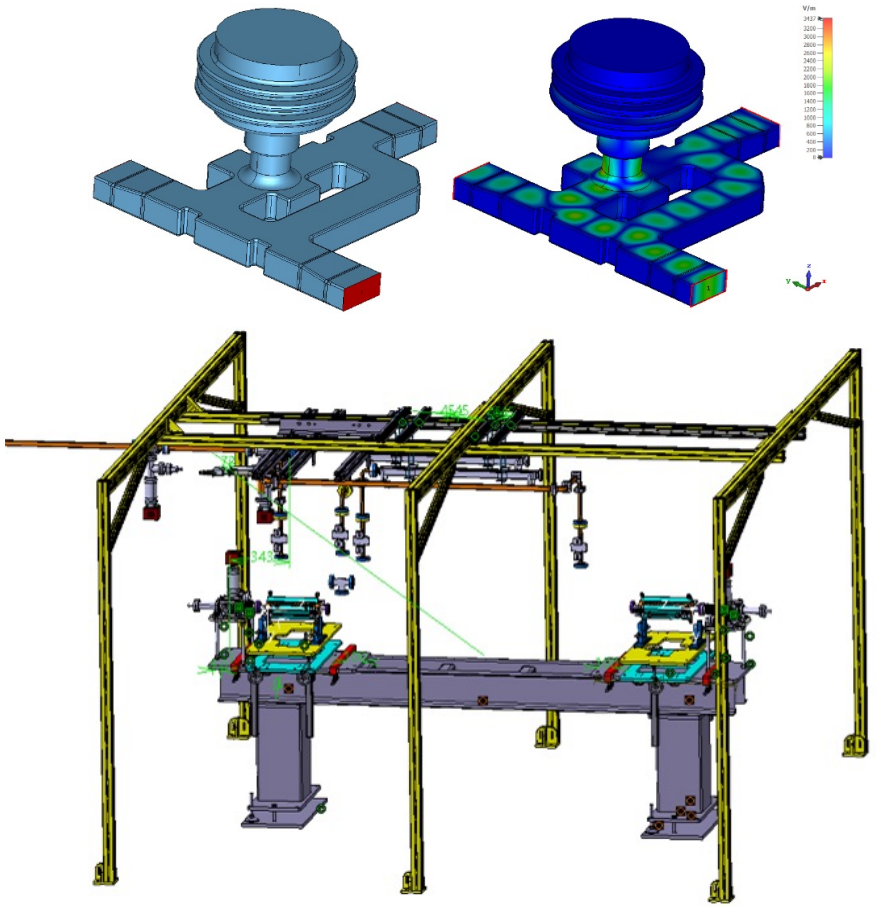


- Already made at CERN (Dec 2020)
  - Cooling and powering
  - Magnetic measurement
  - Interlocks integration and test
  - First Gain Curves
- Due the availability of the 50 MW klystron the testing was postponed

HG2022

Development of Prototype MgB_2 Superconducting Solenoid Magnet for High - efficiency Klystron Applications; Watanabe, H et al. CERN-ACC-2020-0022 ; CLIC-Note-1161. - 2020. - 7 p. (http://cds.cern.ch/record/2730621)

X-Box 2 – MgB_2 Solenoid & TD31



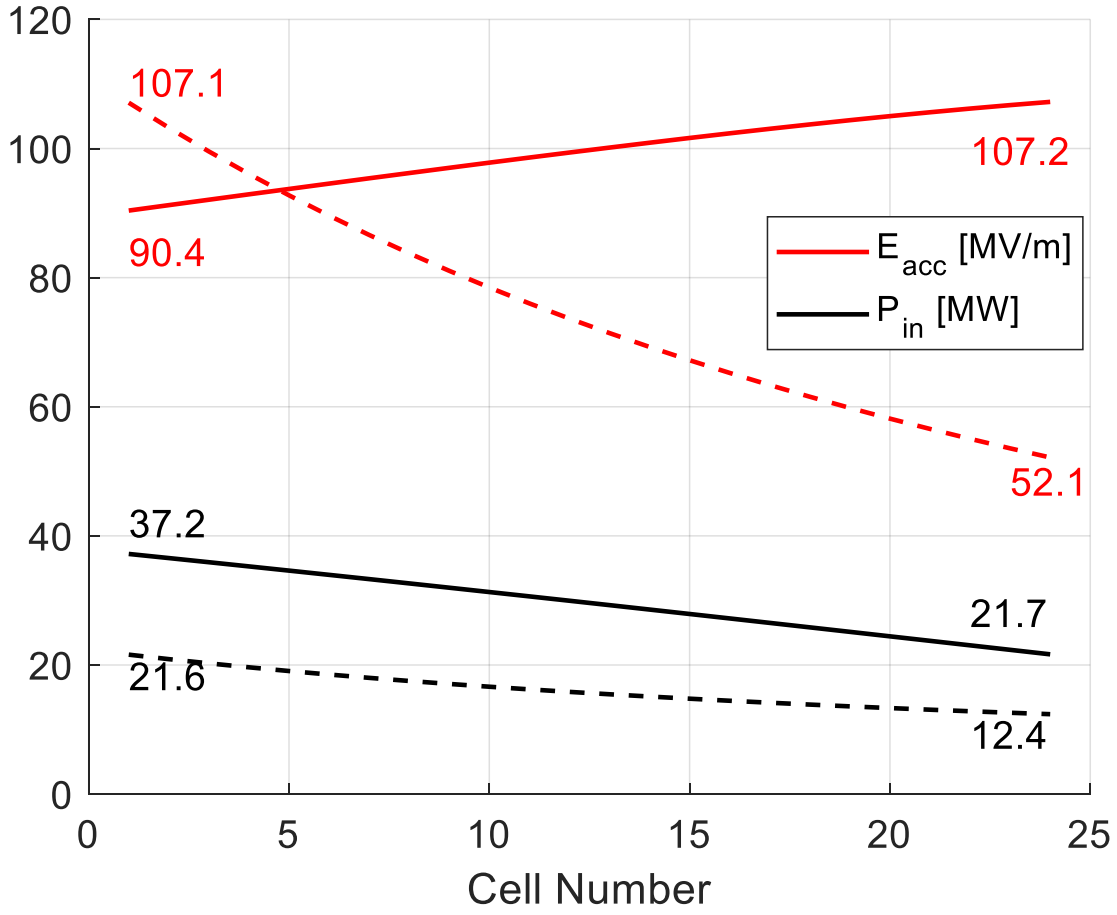
- The MgB_2 solenoid has been reinstalled in X-Box 2.
- Today the solenoid temperature was below 20k
- GOAL: Optimization of the klystron performance with MgB_2 solenoid
- Integration of the monitoring and interlock system for long term operation.
- Split the power in two test benches
- Install two TD31 structures

X-Box 3:

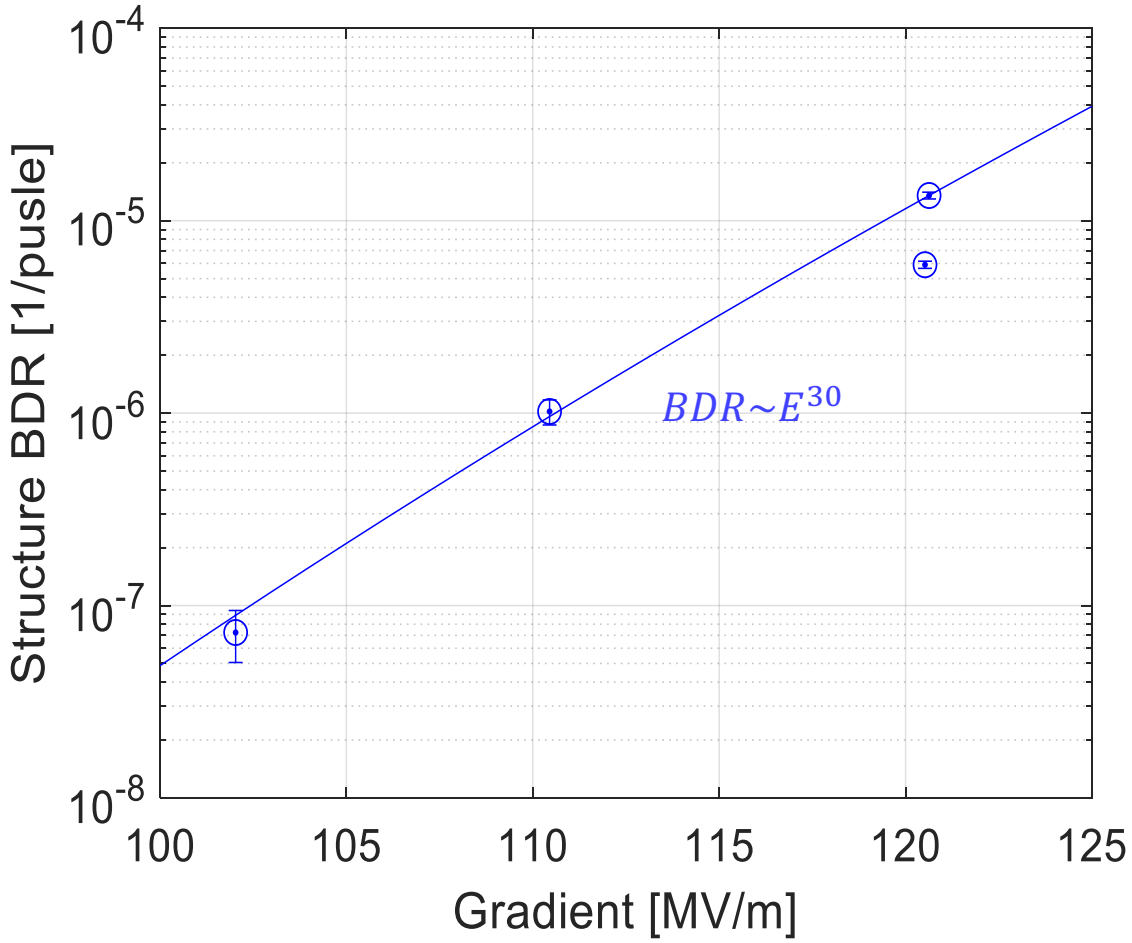
- "Single cell" test - post-morten
- HP RF Window tested
- CRAB cavity from Lancaster conditioned (TNA)
- Deflector SARI conditioned (TNA)

X-Box 3 – “Single cell” test

- Breakdowns concentrated in the front part of the structure.
- Less breakdowns in the end cells which have higher field
- Reach over 100 MV/m is limited due to the maximum power produce by X-box 3
- Flip the structure and retest it at high power
- Higher fields on the first cells



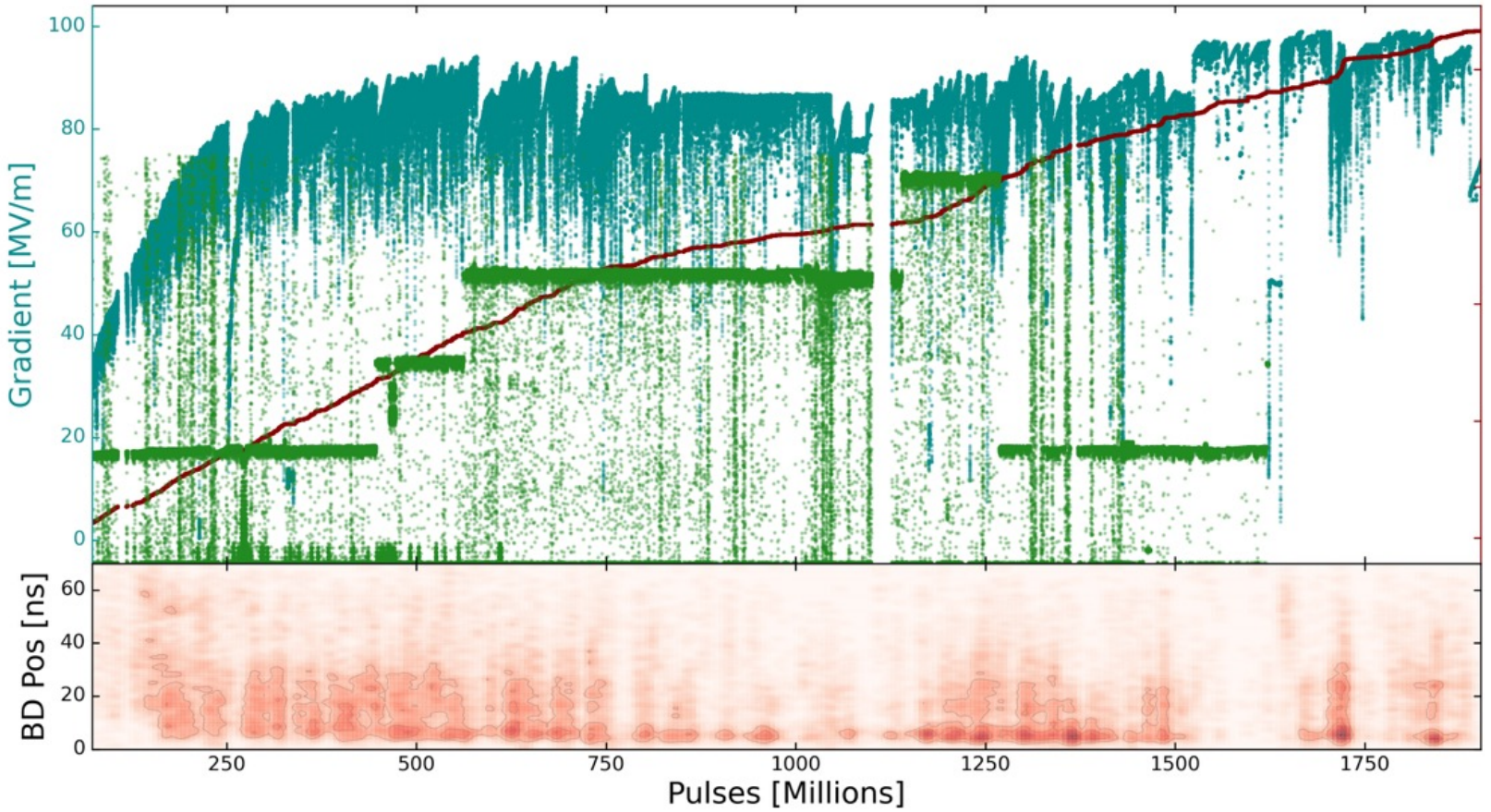
X-Box 3 – “Single cell” test



- Gradient of the first cell reached 120 MV/m (120.7 MV/m @ 27.4 MW input power)

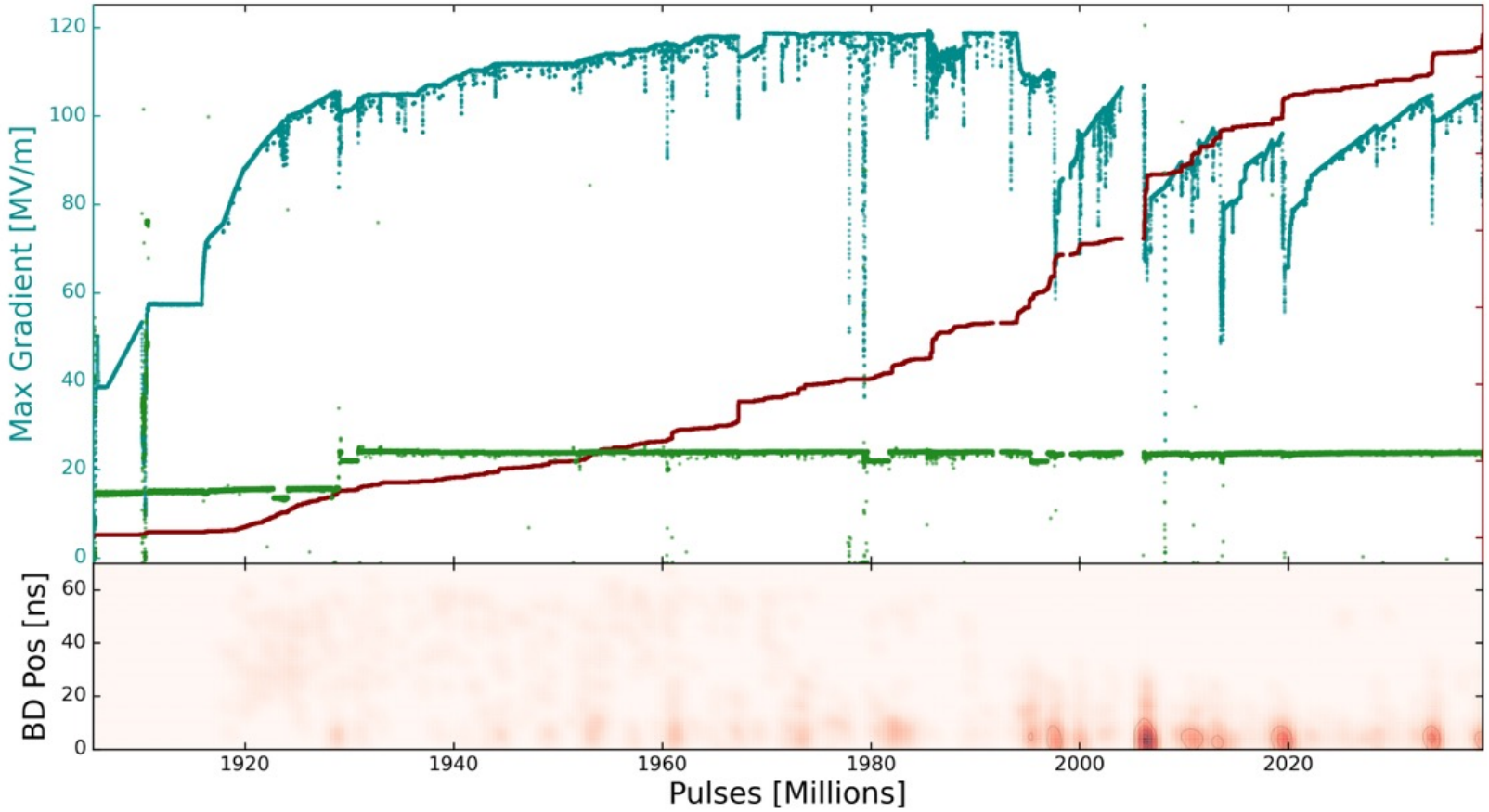
X-Box 3 – Line 1 T24 Post Morten

- Fordward History



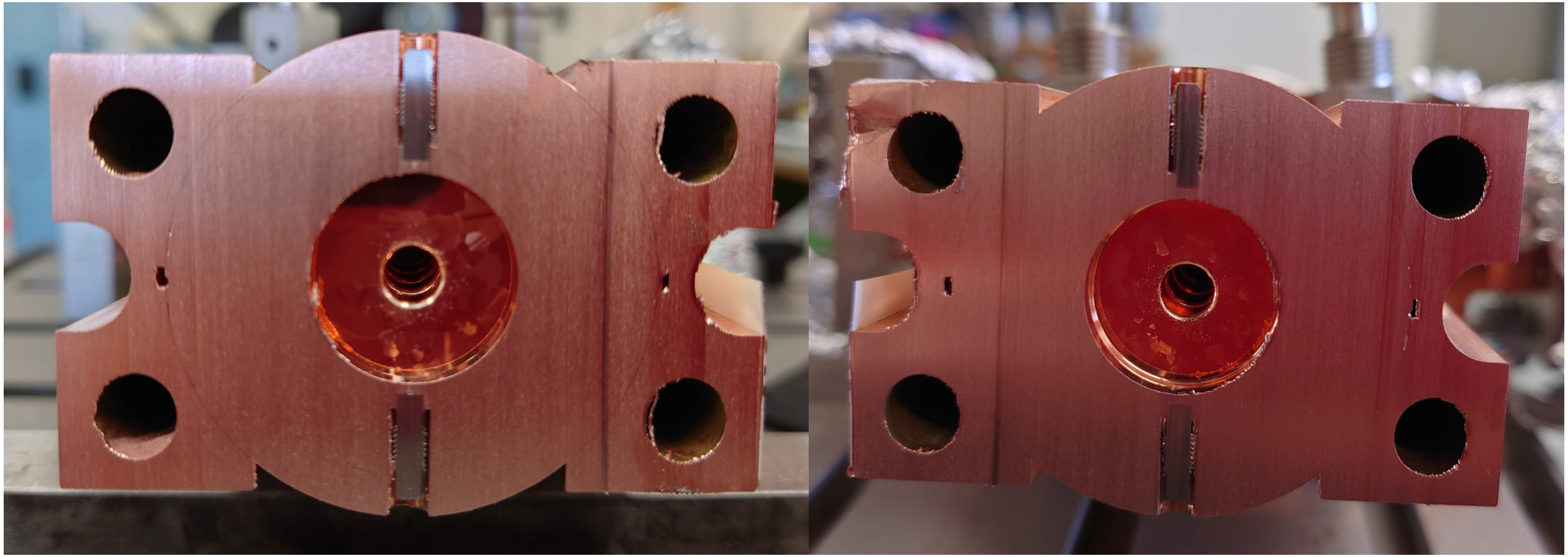
X-Box 3 – Line 1 T24 Post Morten

- Backward History



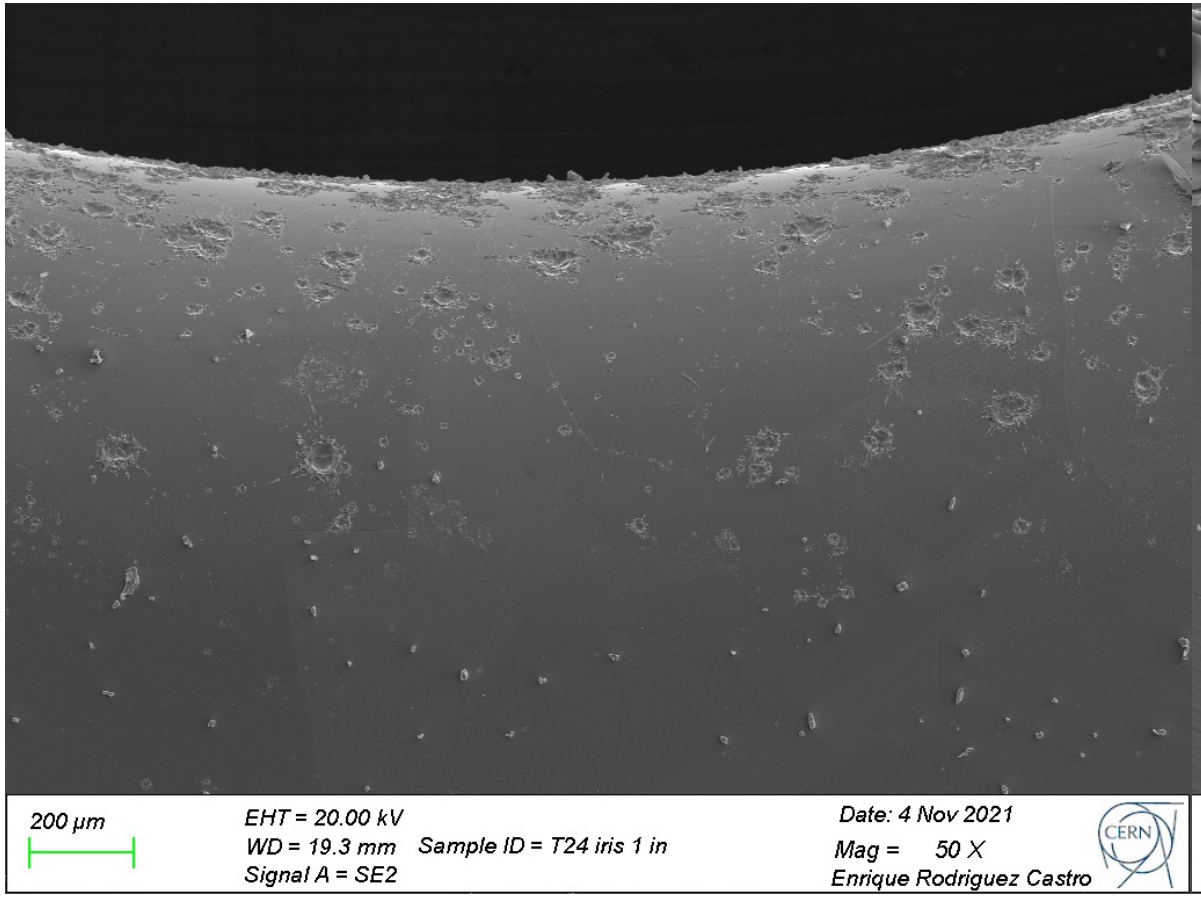
X-Box 3 – Line 1 T24 Post Morten

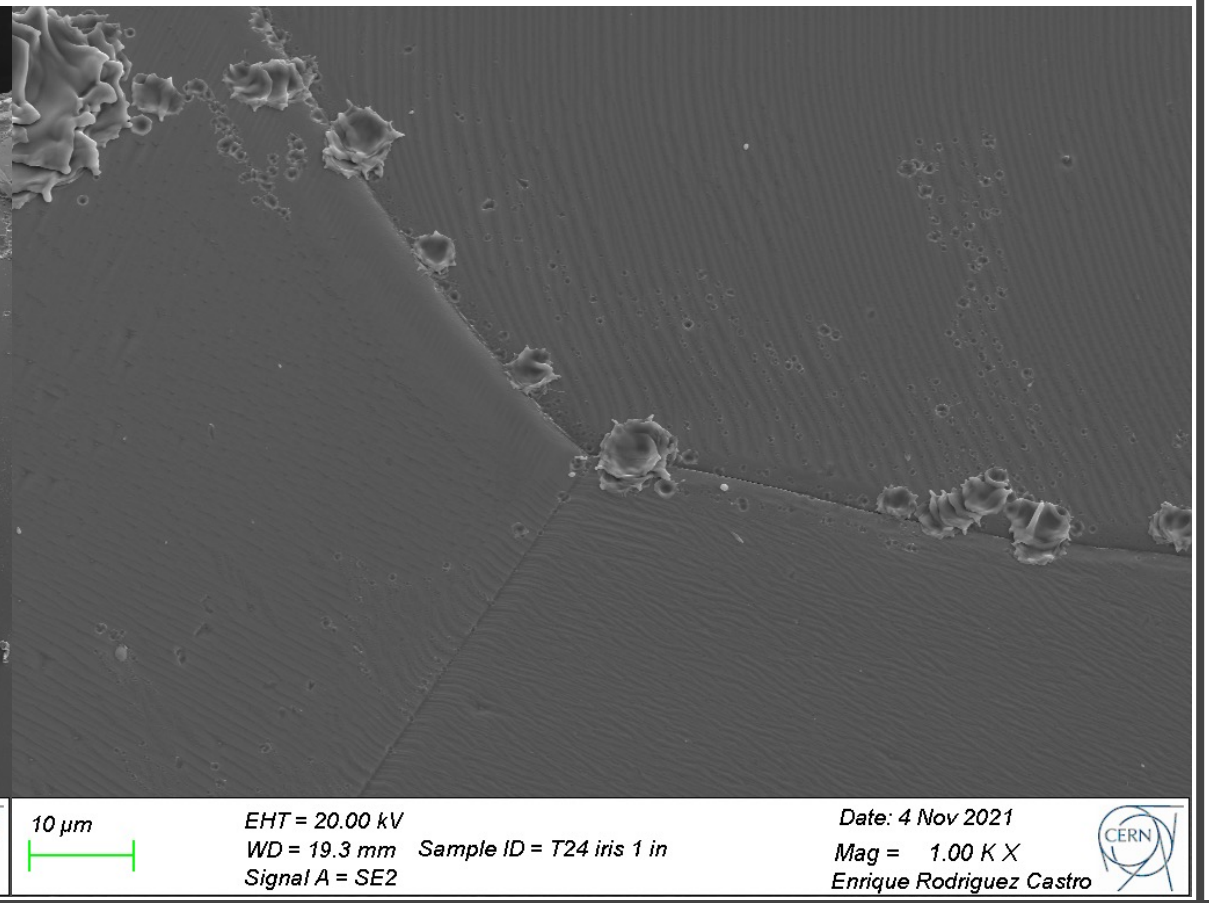
- First structure dry cut with diamond wire at CERN



X-Box 3 – Line 1 T24 Post Morten

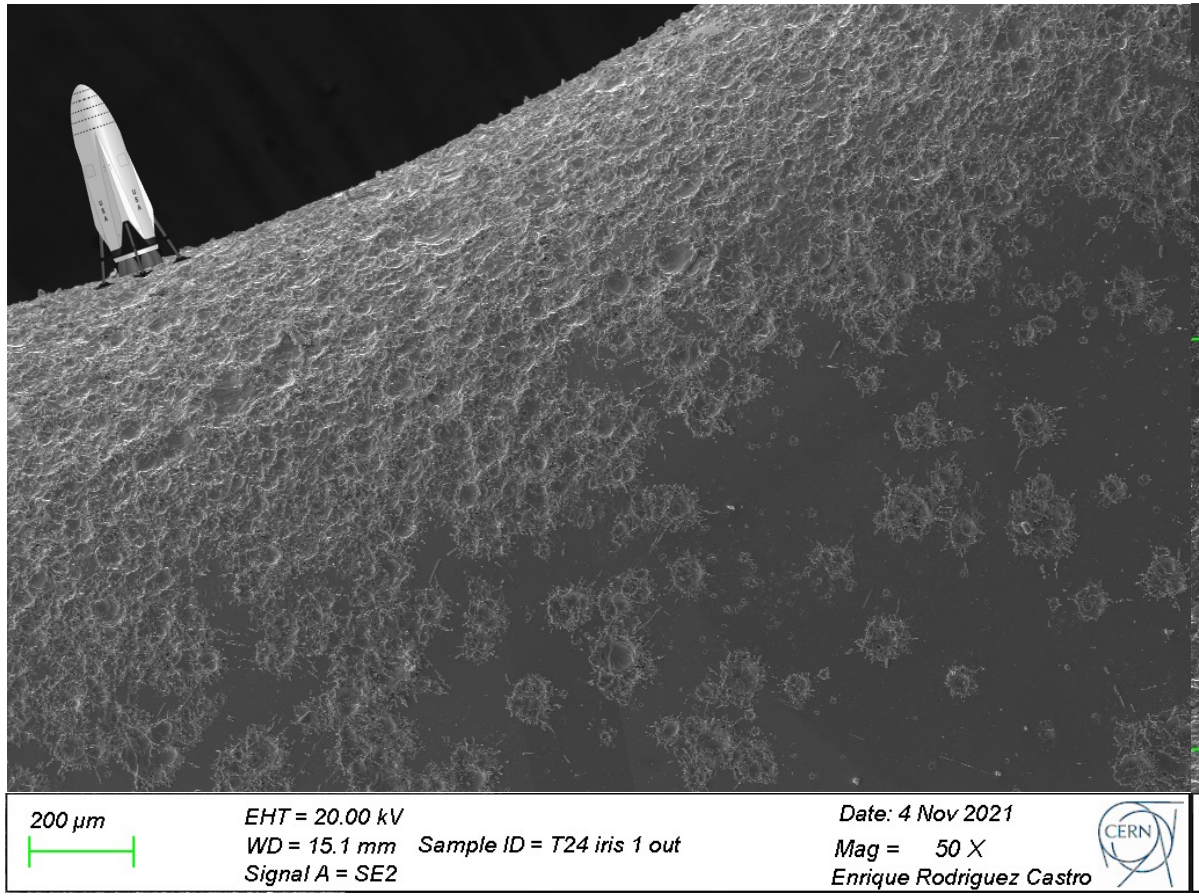
- Iris 1 - Input

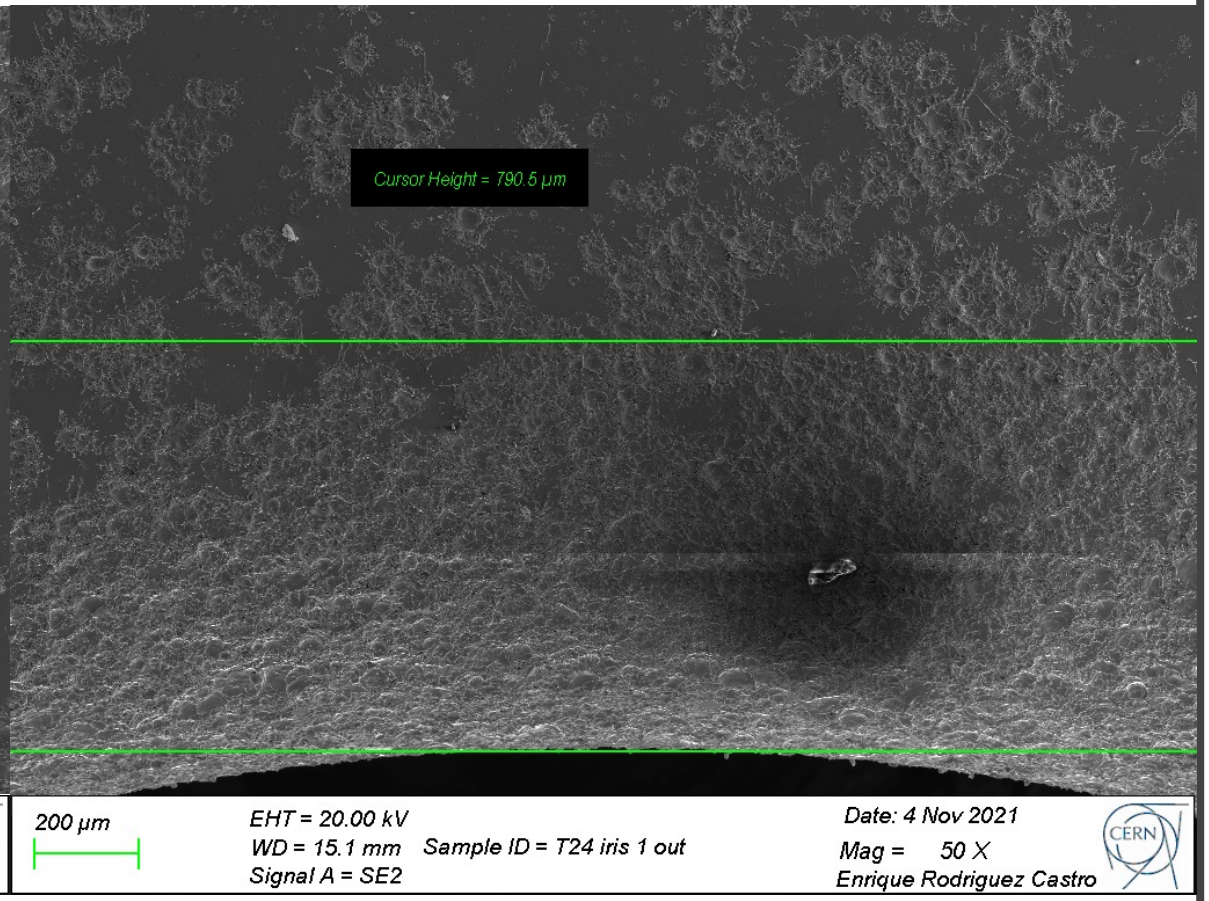




X-Box 3 – Line 1 T24 Post Morten

- Iris 1 - Output





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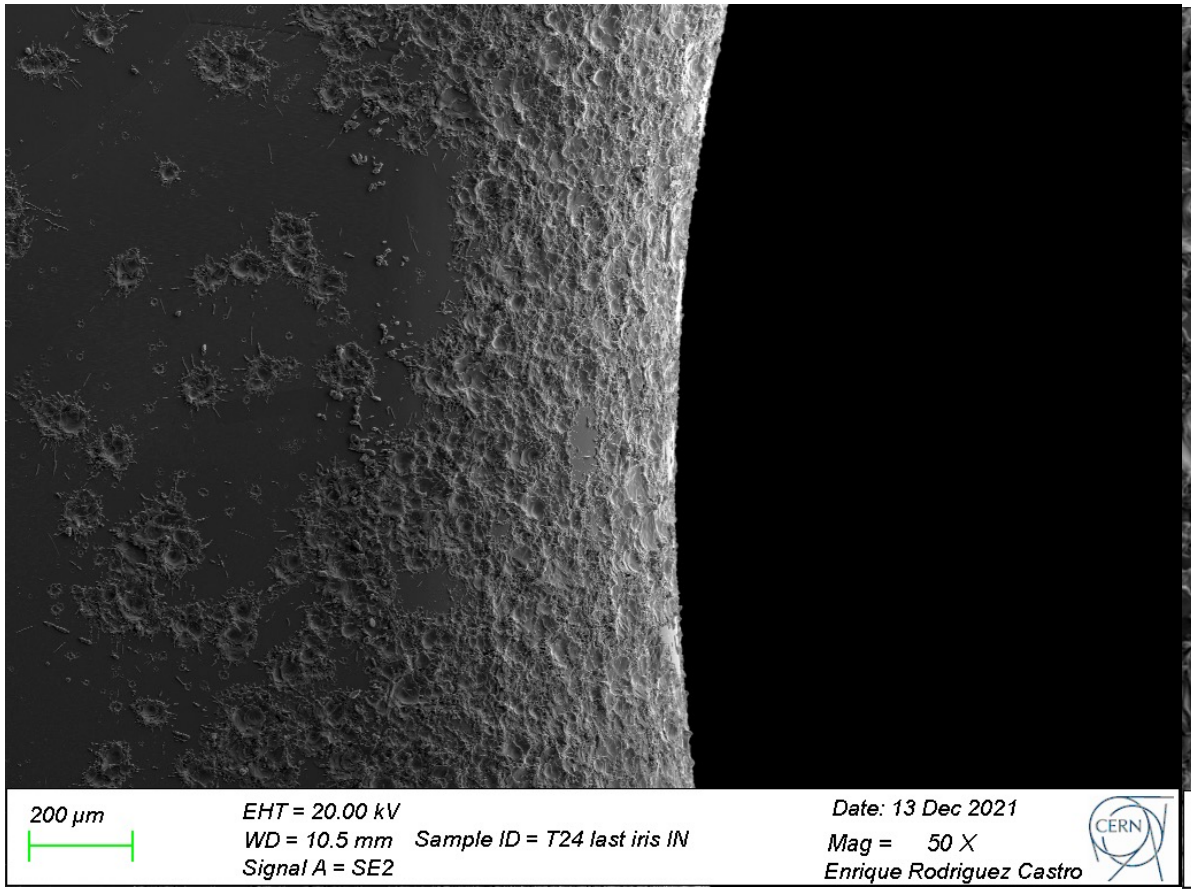
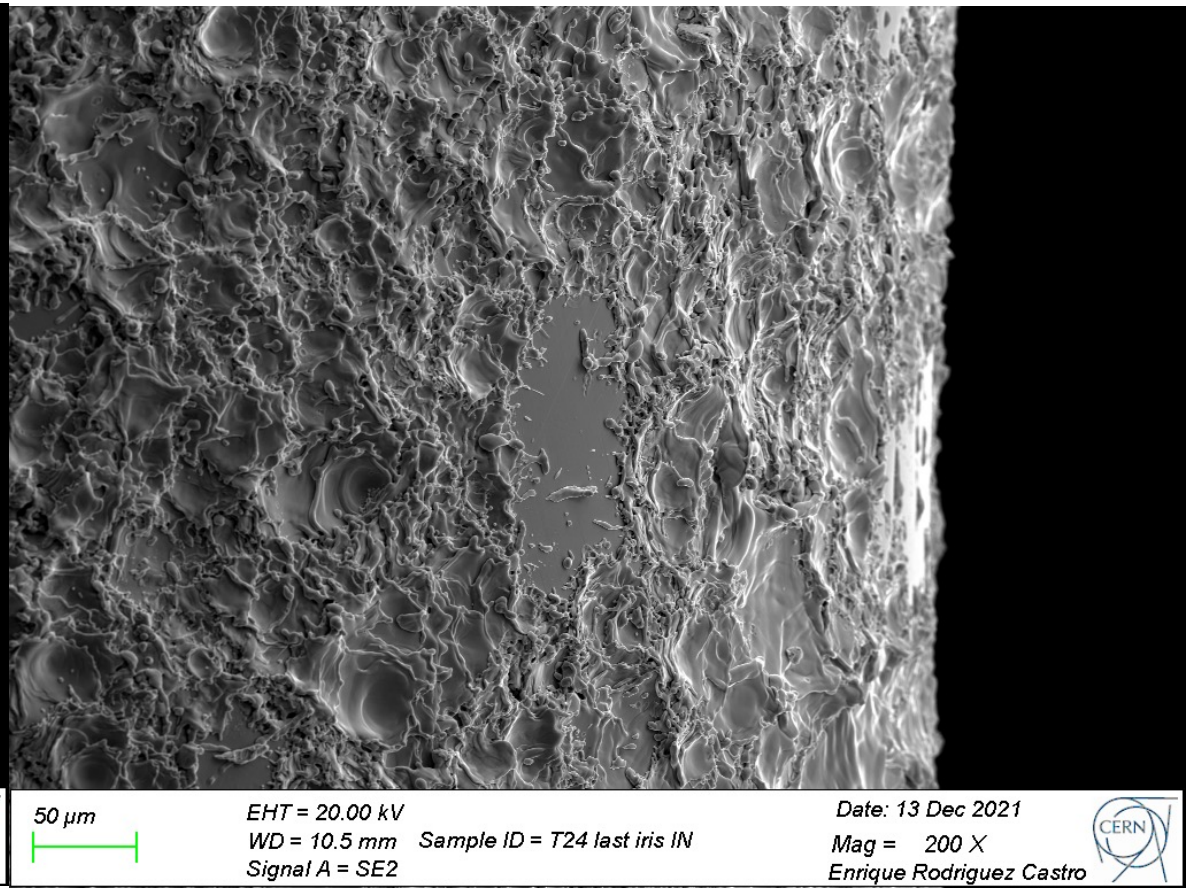
X-Box 3 – Line 1 T24 Post Morten

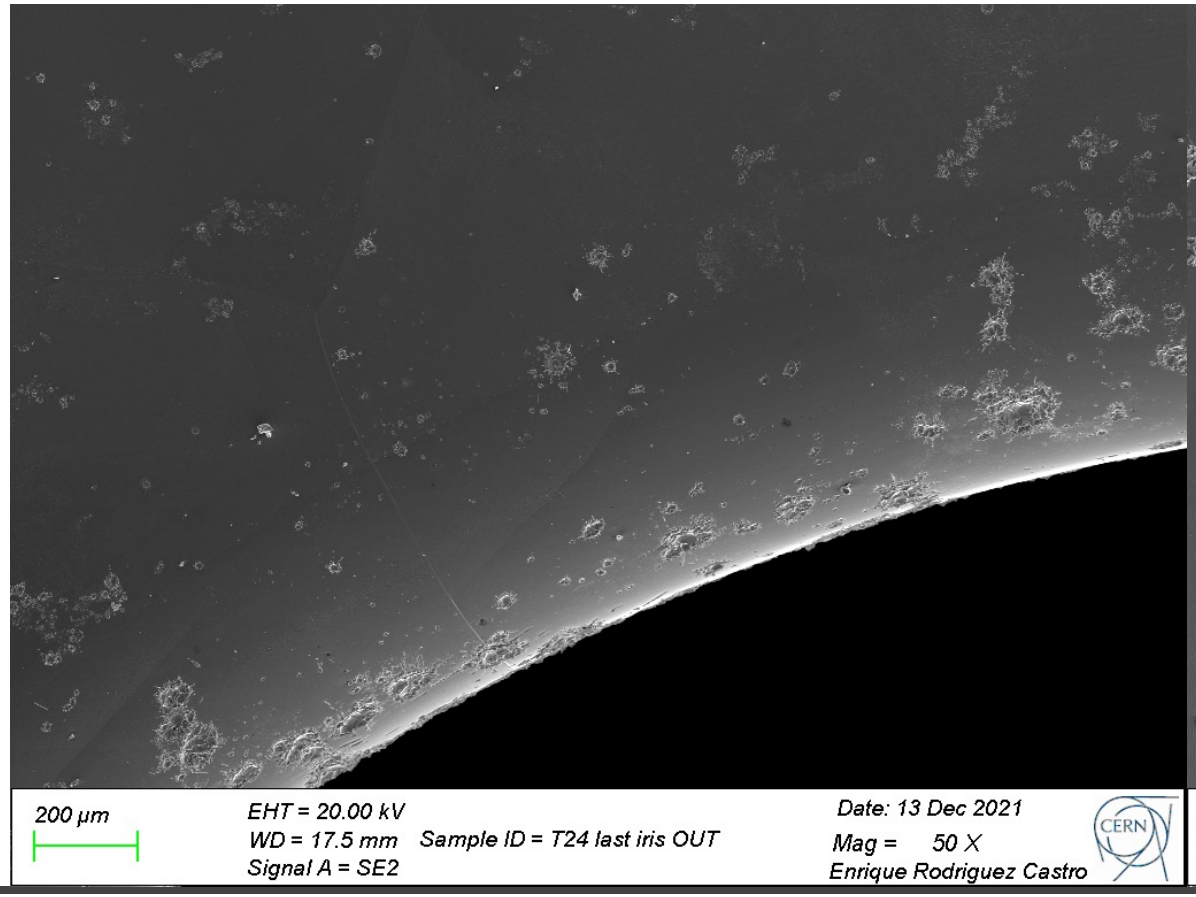
- Iris 26 - Input

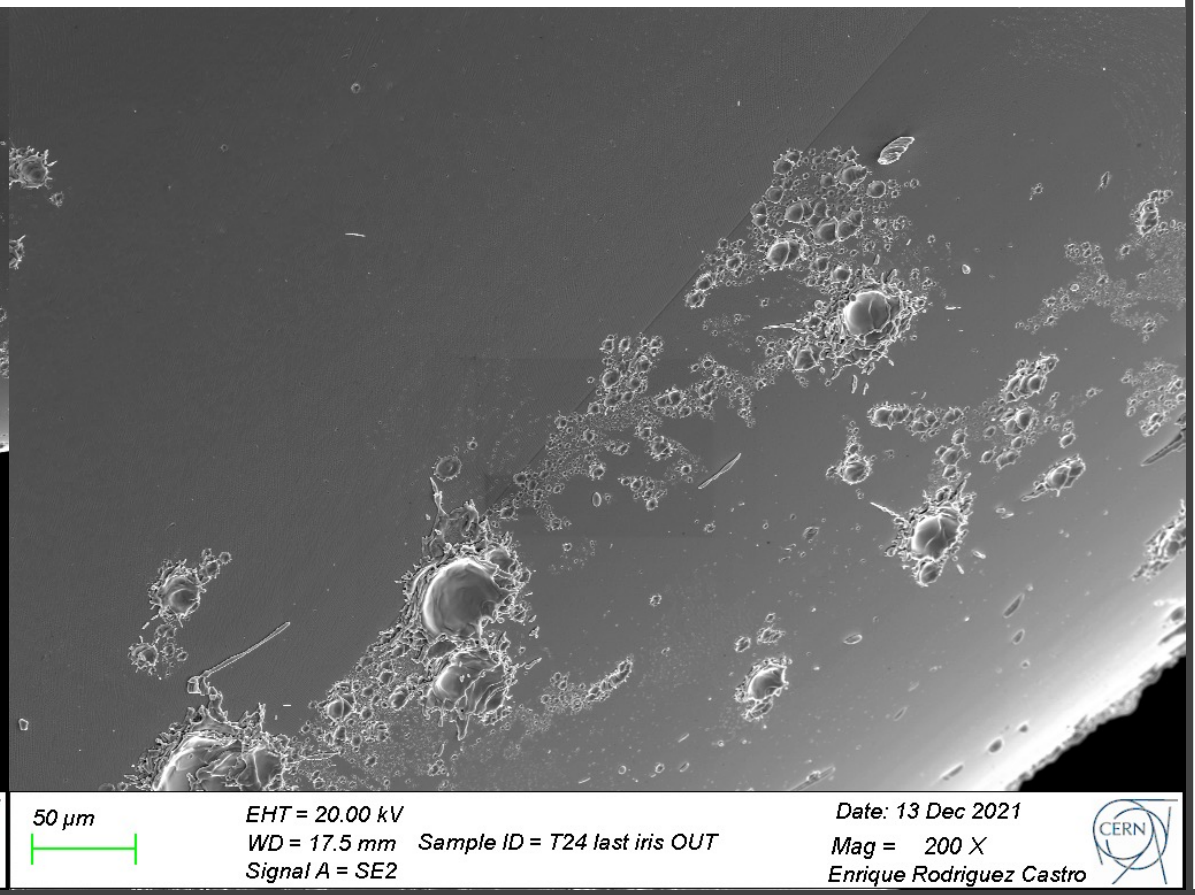




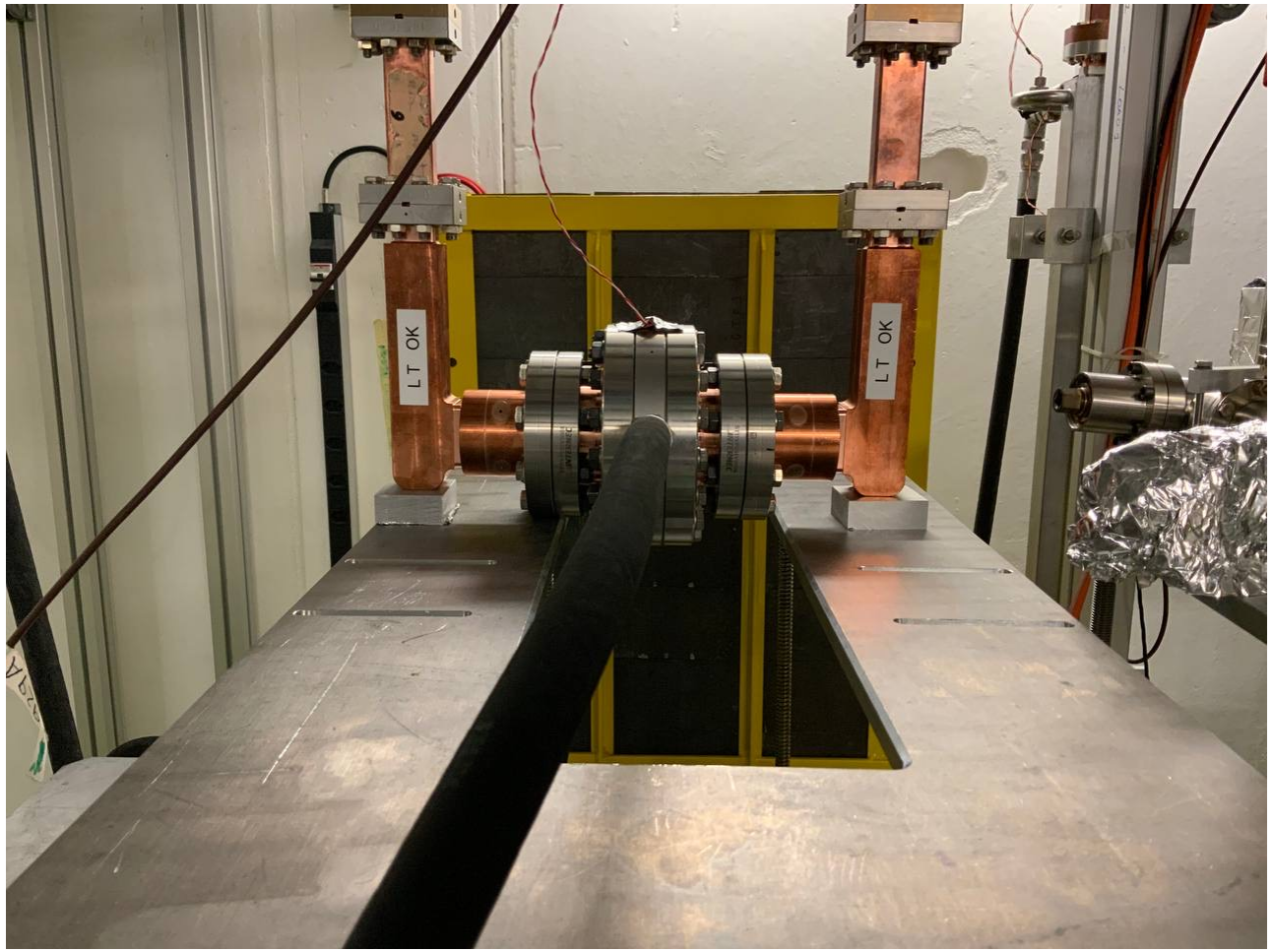
X-Box 3 – Line 1 T24 Post Morten

- Iris 26 - Output



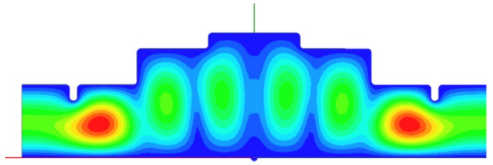


X-Box 3 HP RF Window

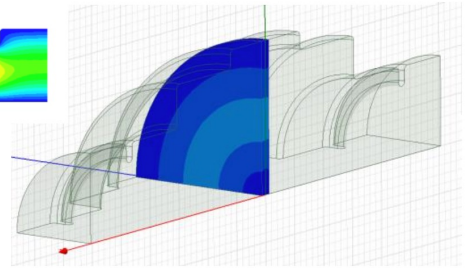


- High power RF window tested on X – Box 3 up to 40 MW
- Frequency 11.9942 GHz
- Designed up to 75 MW
- E_{max} Ceramic 3.4 MV/m
- Integrated Power Flow : 2.4 kW

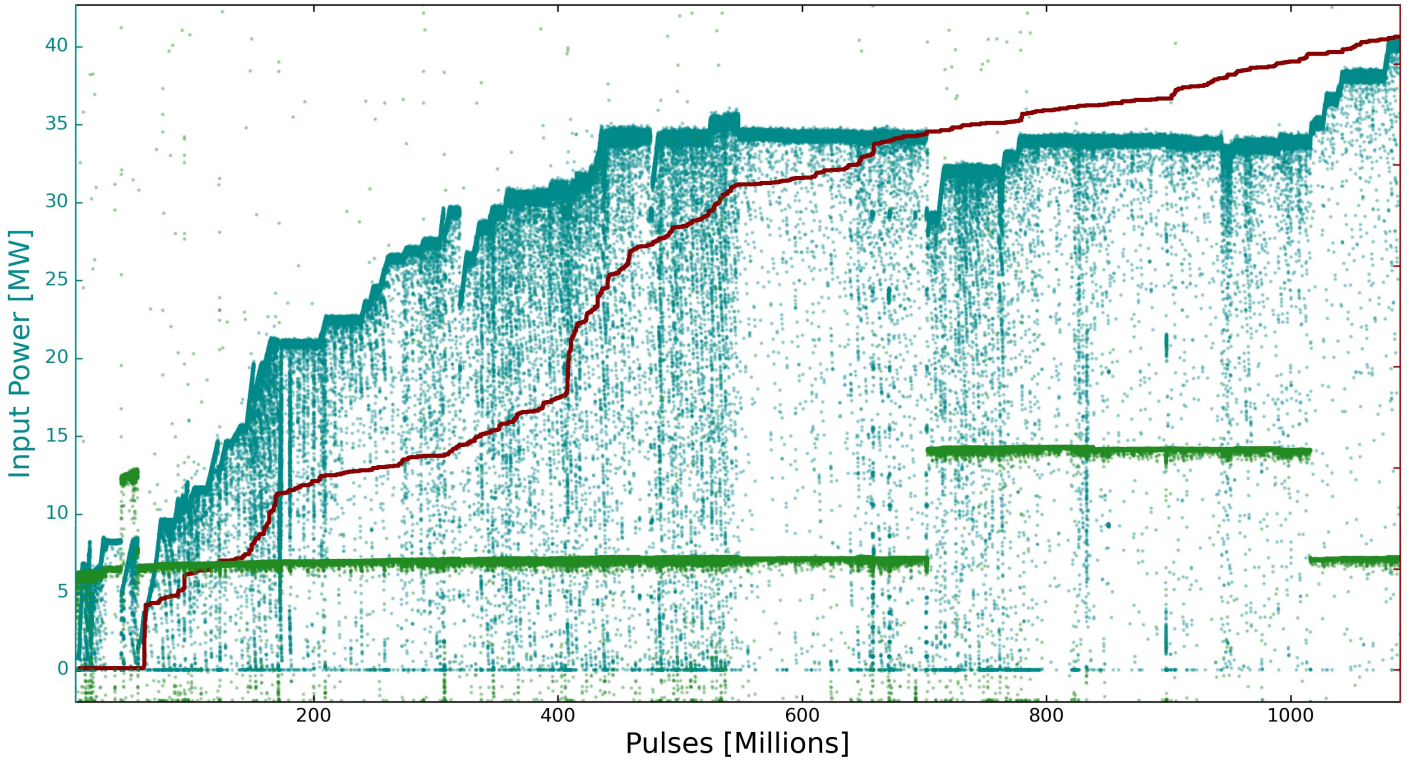
E-field



E-field on Ceramic



X-Box 3 HP Window



- High power RF Window tested up to 40 MW
- Ramping speed limited by the conditioning of the structure on the other line
- 3 months installed

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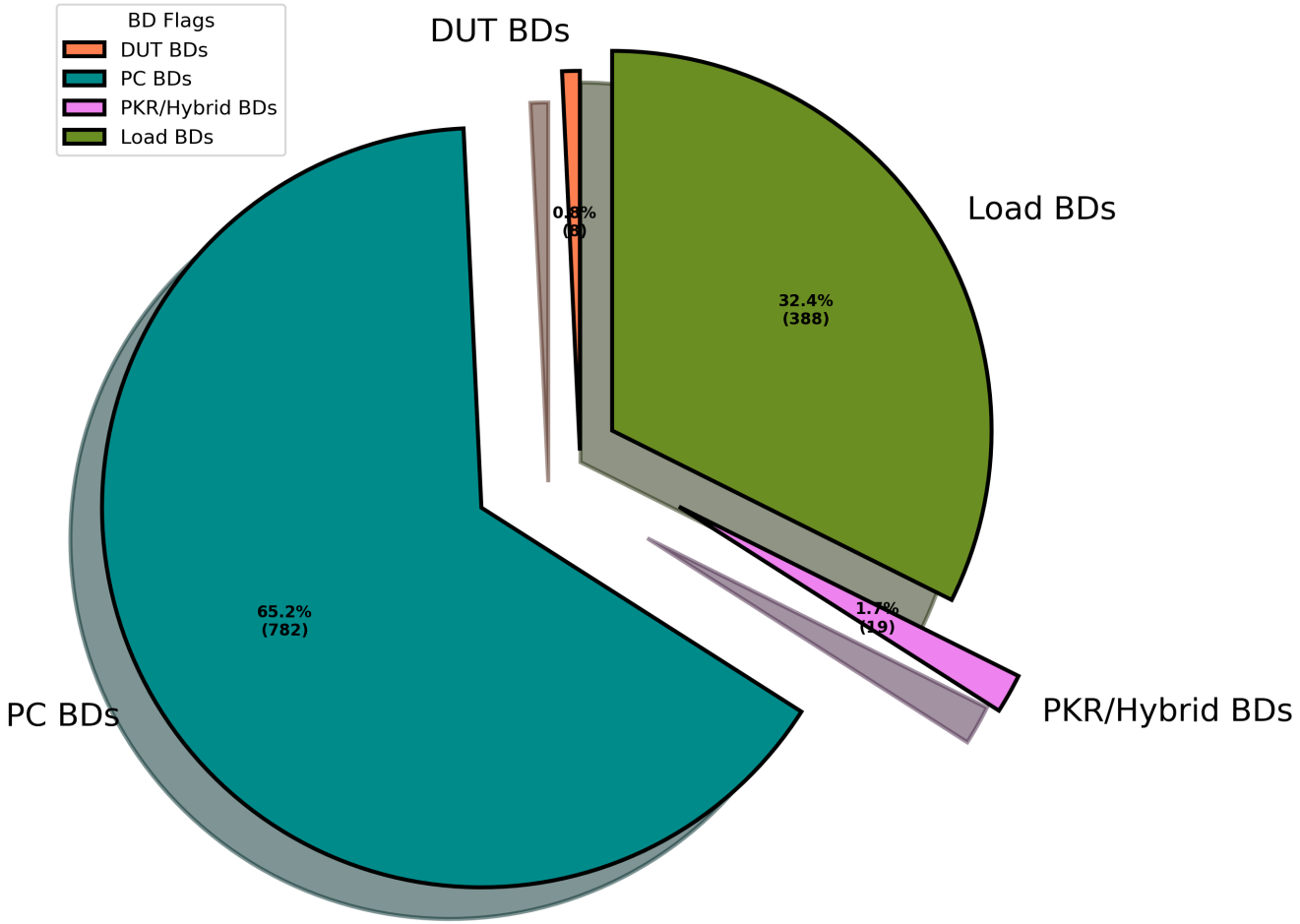
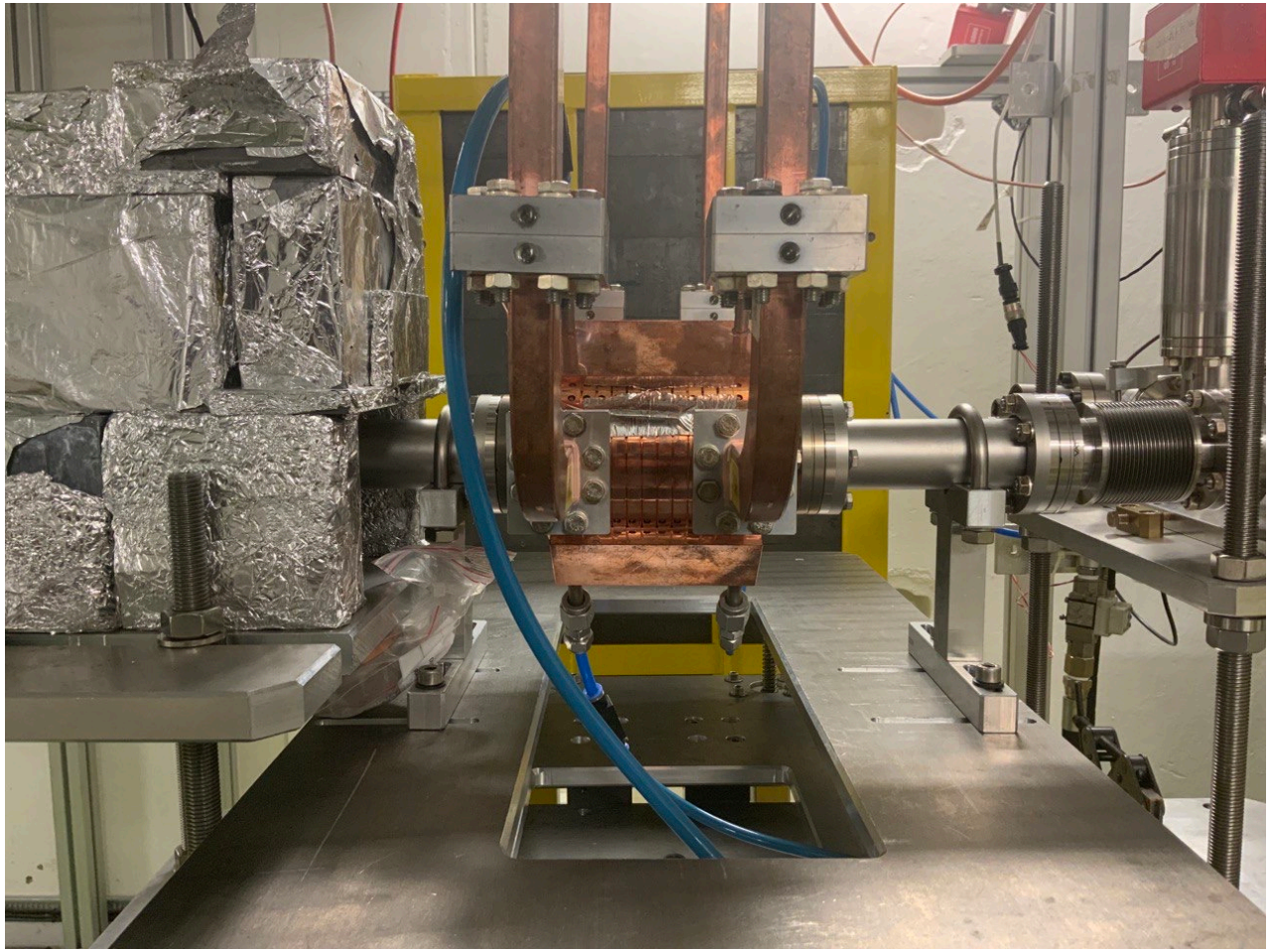
X-Box 3 HP RF Window



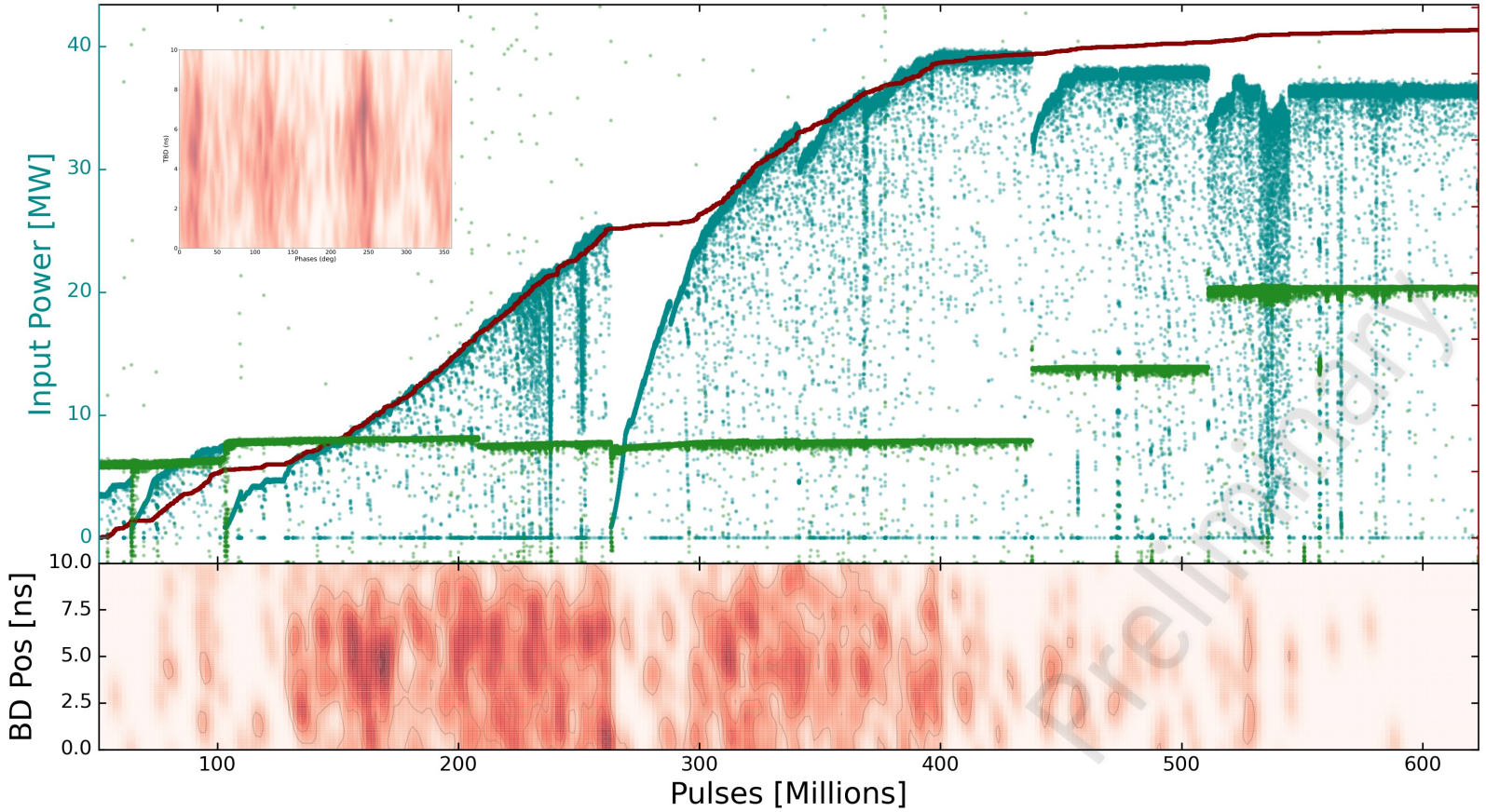
- High power RF Window tested up to 40 MW
- Ramping speed limited by the conditioning of the structure on the other line
- 3 months operation
- Most of the BDs detected on other components of the test benches

X-Box 3 Lancaster Deflector

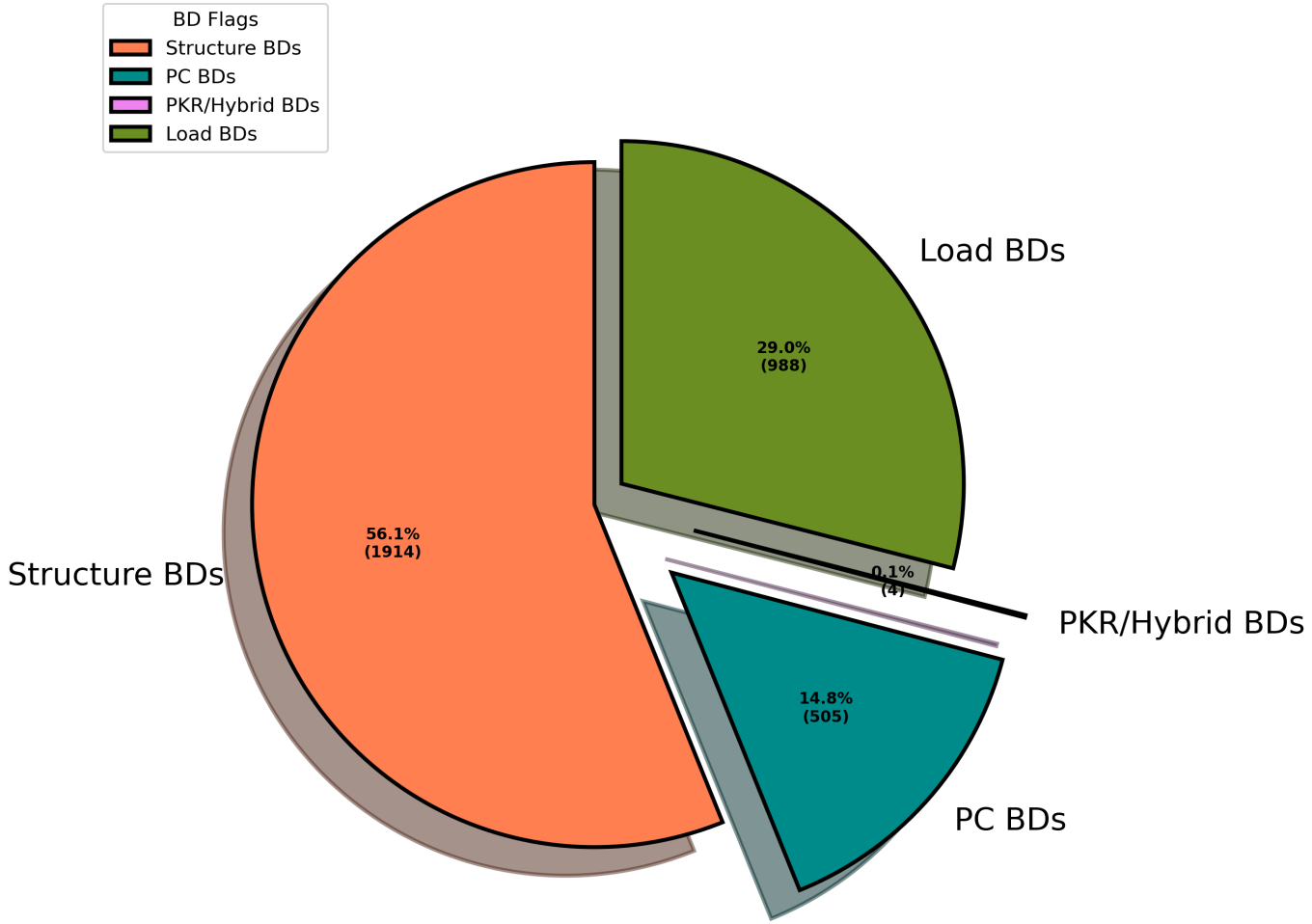


- CRAB Deflector:
  - Frequency - 11.9942 GHz@34 deg
  - Phase Adv - 120 deg
  - Fill time - 11.2 ns
  - Num cells – 12
- Conditioned up to 40 MW with pulse length 50 ns, 100 ns 150 ns
- 5 month installed

X-box3 Lancaster Deflector



X-Box 3 Lancaster Deflector



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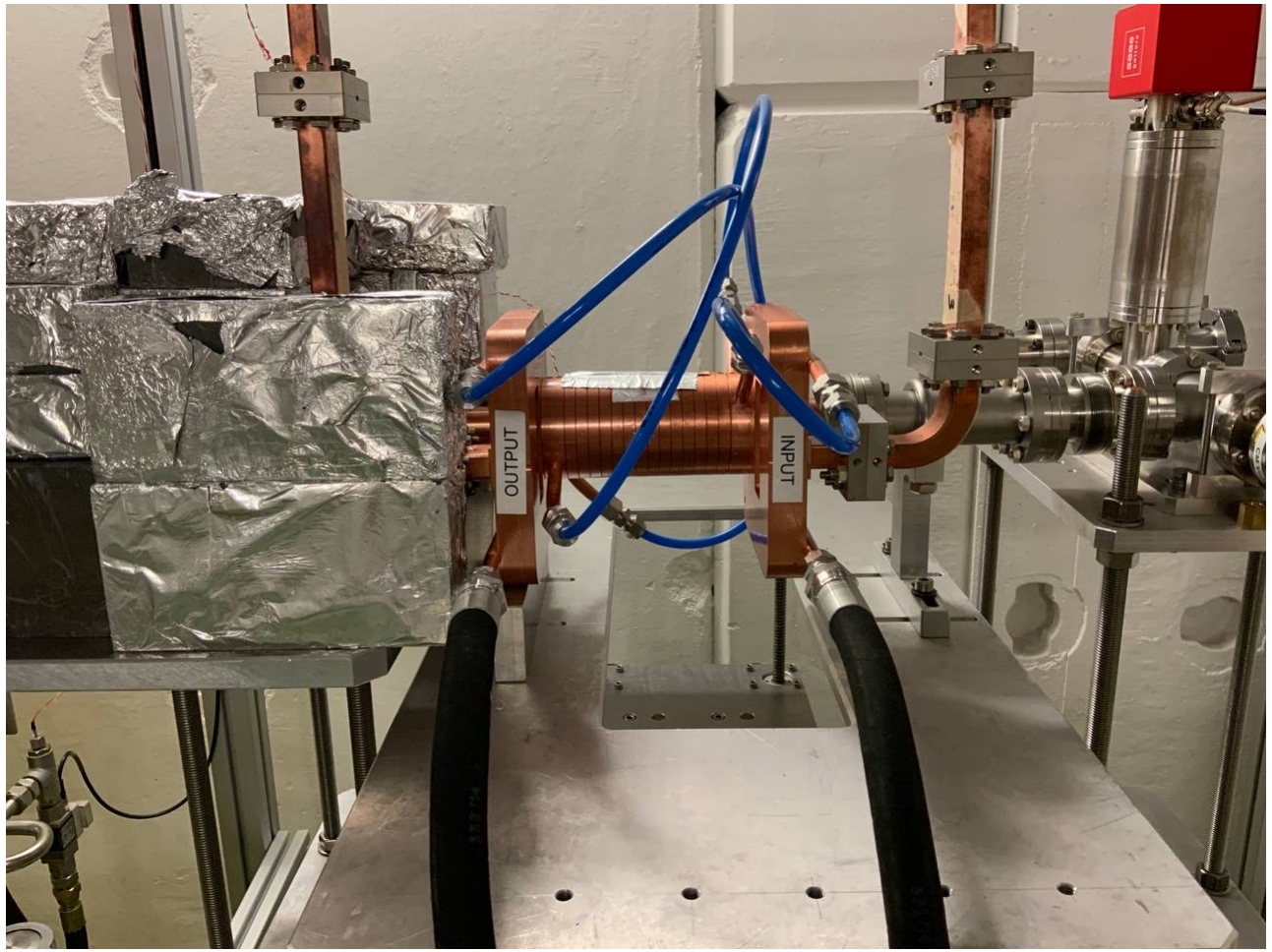
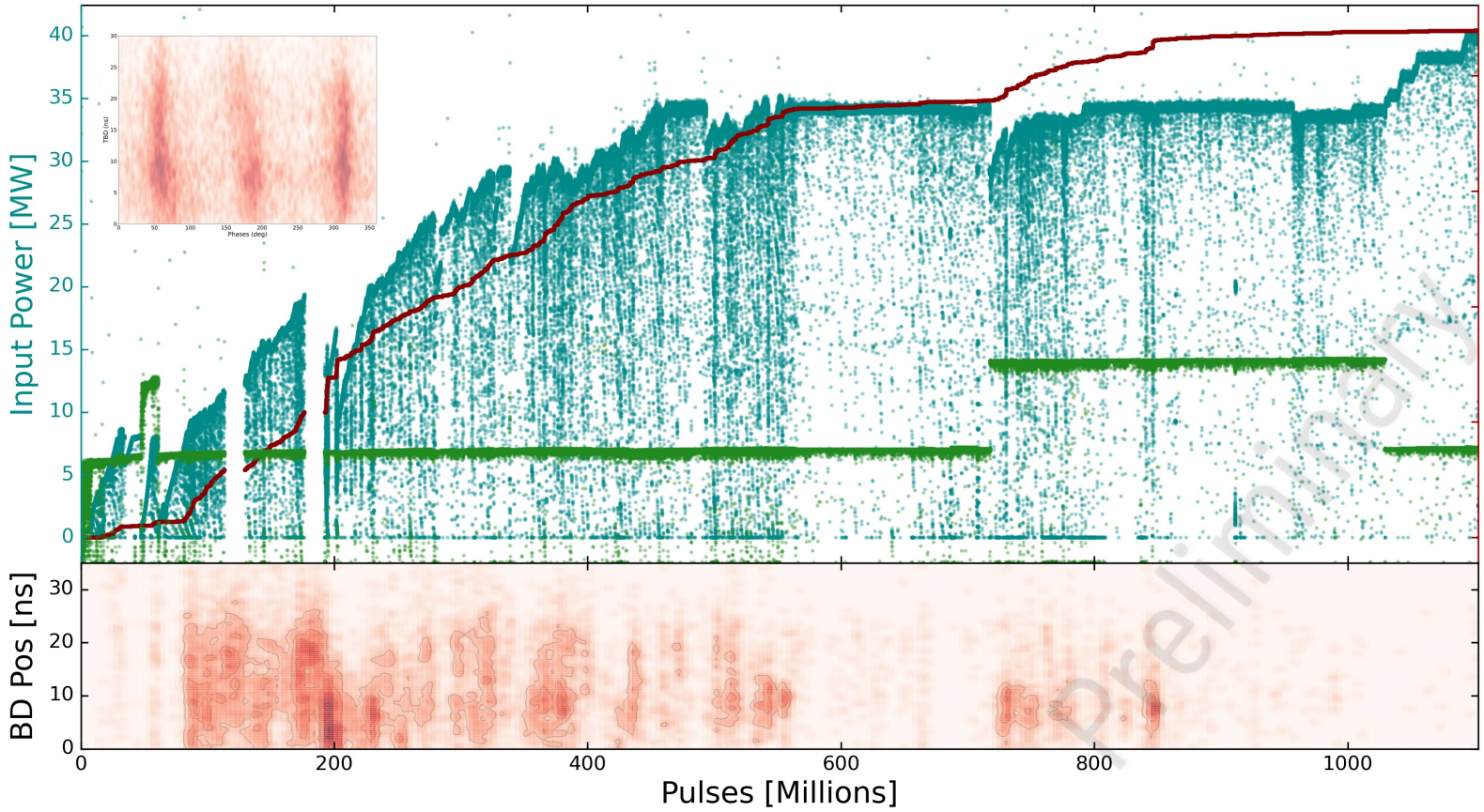
X-Box 3 Shanghai Deflector



- SARI Deflector:
  - Frequency - 11.9942 GHz@26 deg
  - Phase Adv - 120 deg
  - Fill time - 21 ns
  - Num. cells – 20
- Conditioned up to 40 MW with pulse length 50 ns, 100 ns 150 ns
- 11 month installed

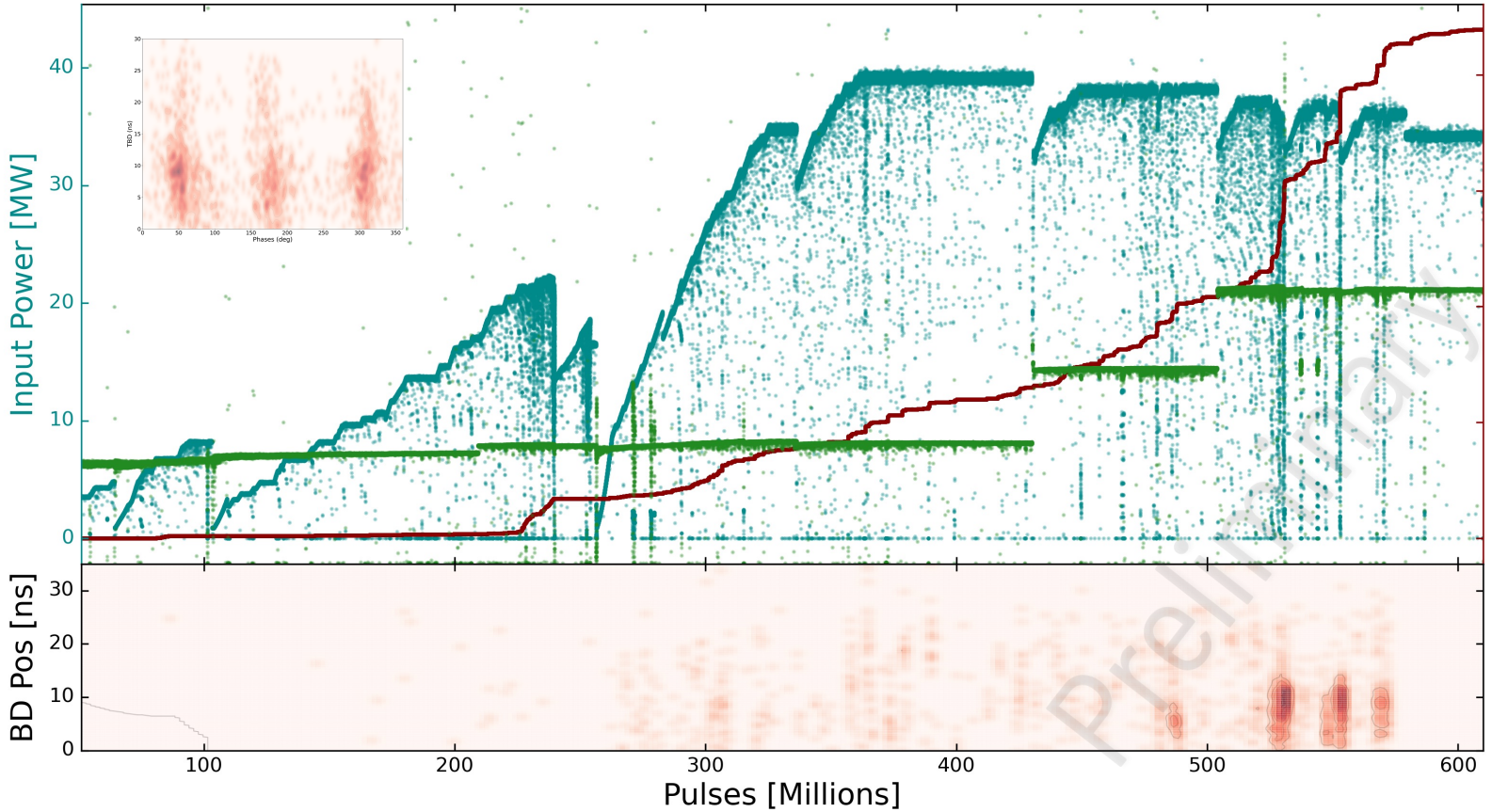
X-Box 3 Shanghai Deflector

- Fist Round



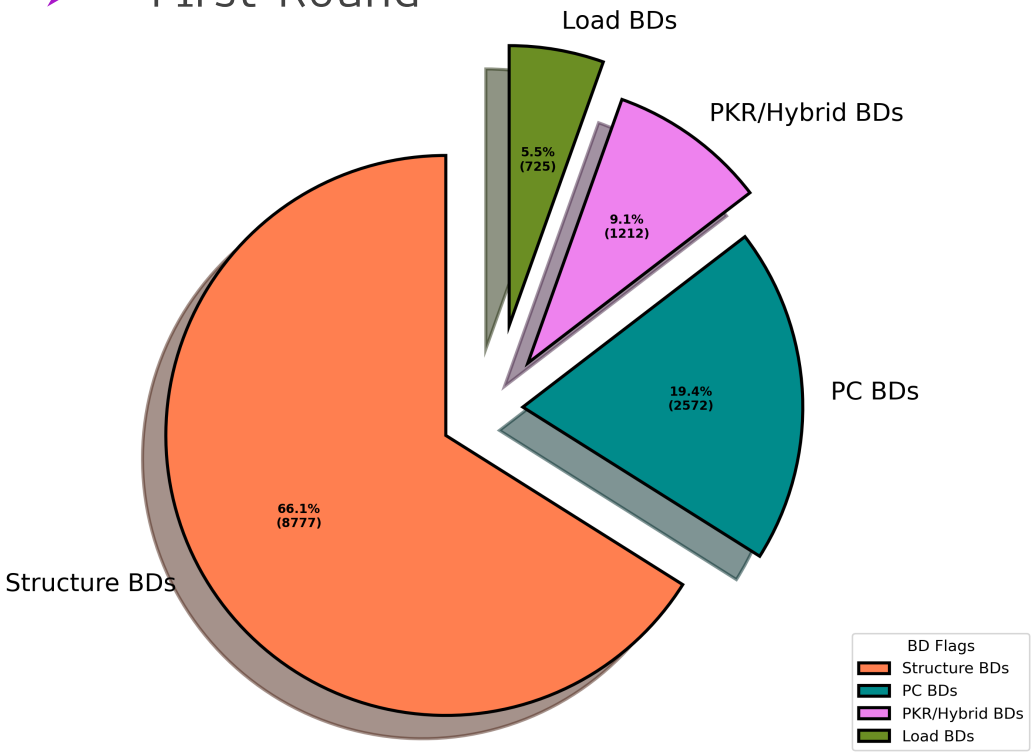
X-Box 3 Shanghai Deflector

- Second Round

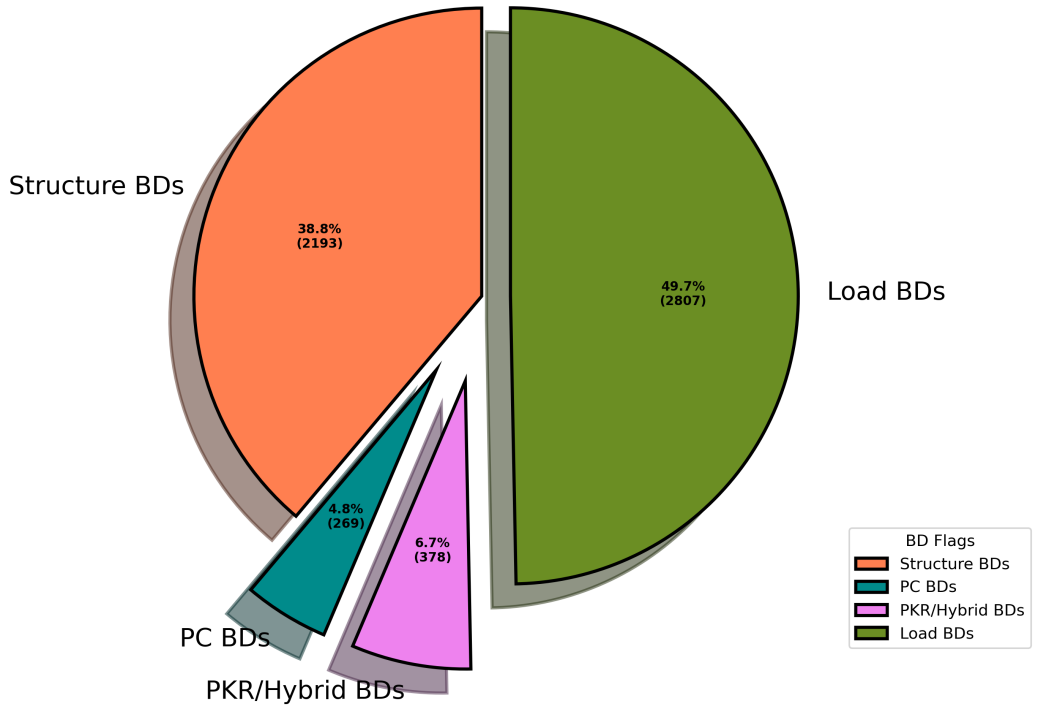


X-Box 3 Shanghai Deflector

First Round



Second Round



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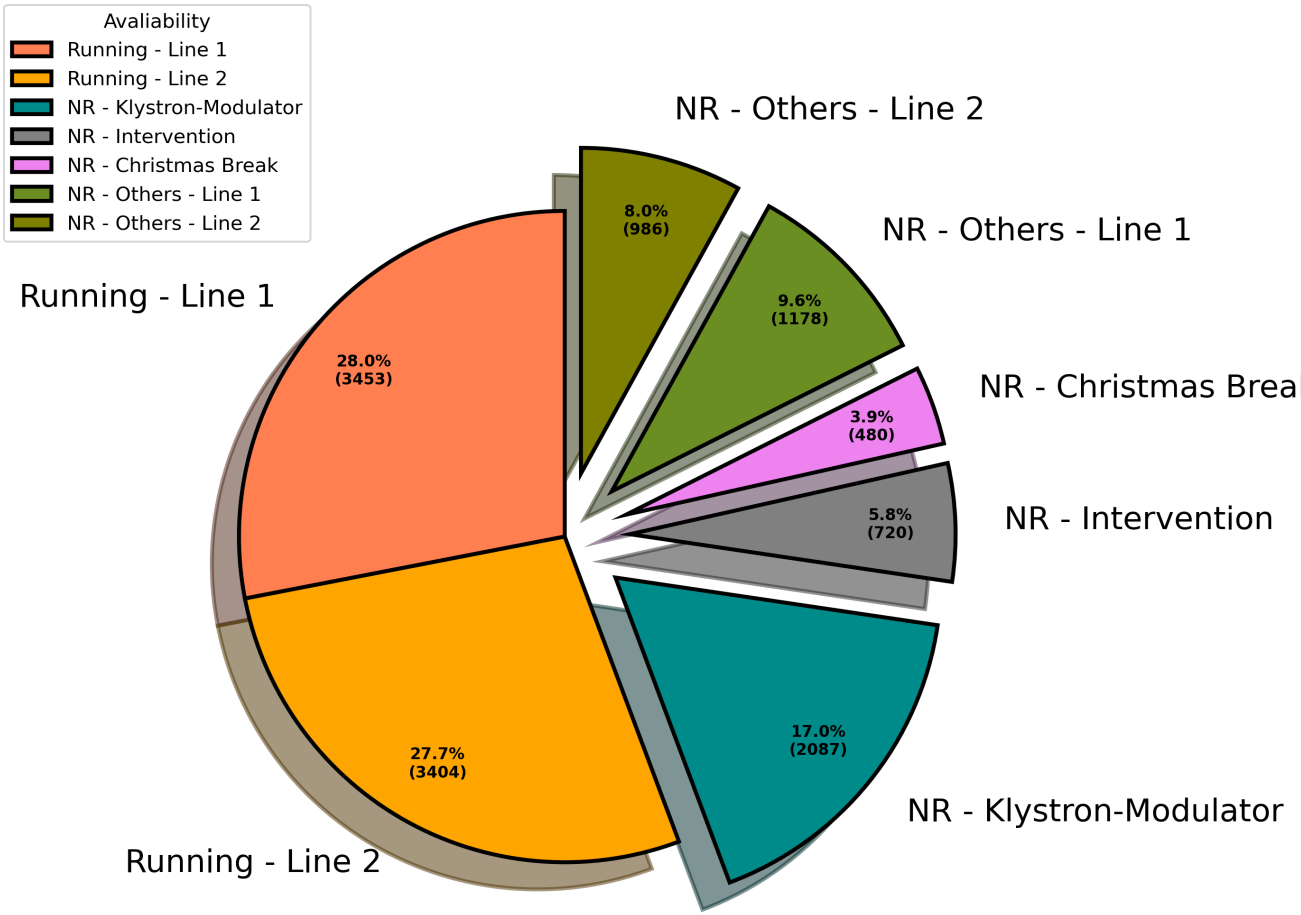
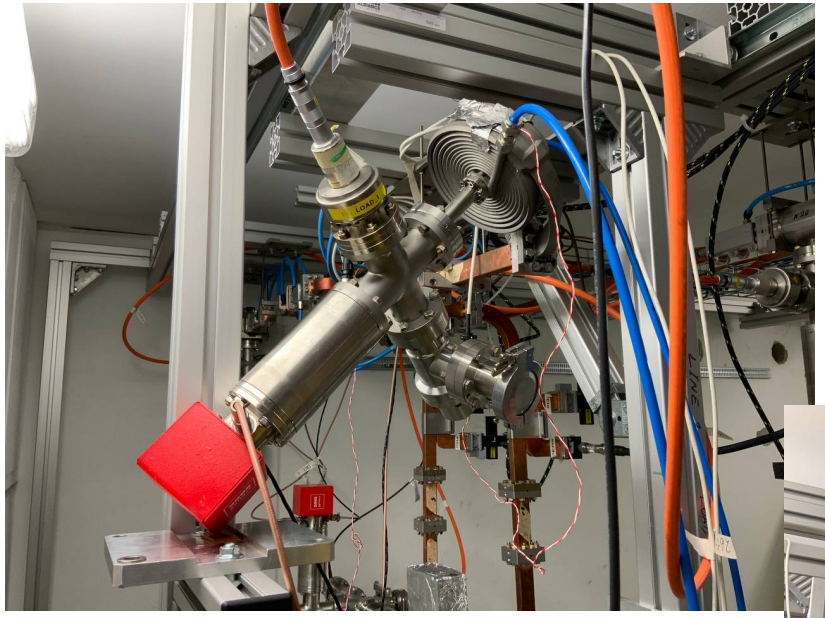
X-Box 3 Availability time

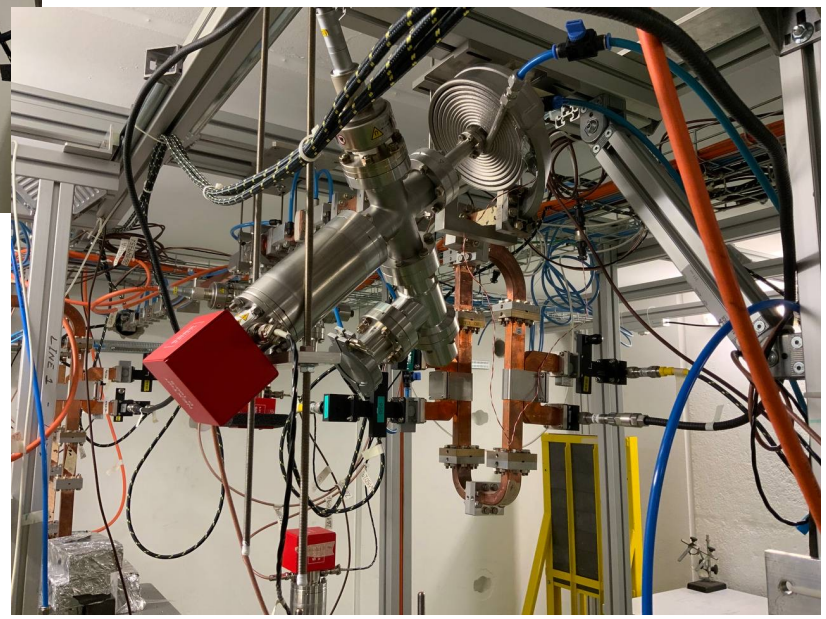


- Availability in the las 11 month.
- Two klystron broken (windows problem, heater ploblem)
- New klystron installed CANON E37113 with a new improved window
  - Efficiency 42% to 56%
  - Peak power 6MW to 8.2MW

X-Box 3 Spiral Loads and TD31



- Currently installed 2 spiral loads with 45 deg geometry to perform a standalone test and conditioning.
- Install two TD31 structures



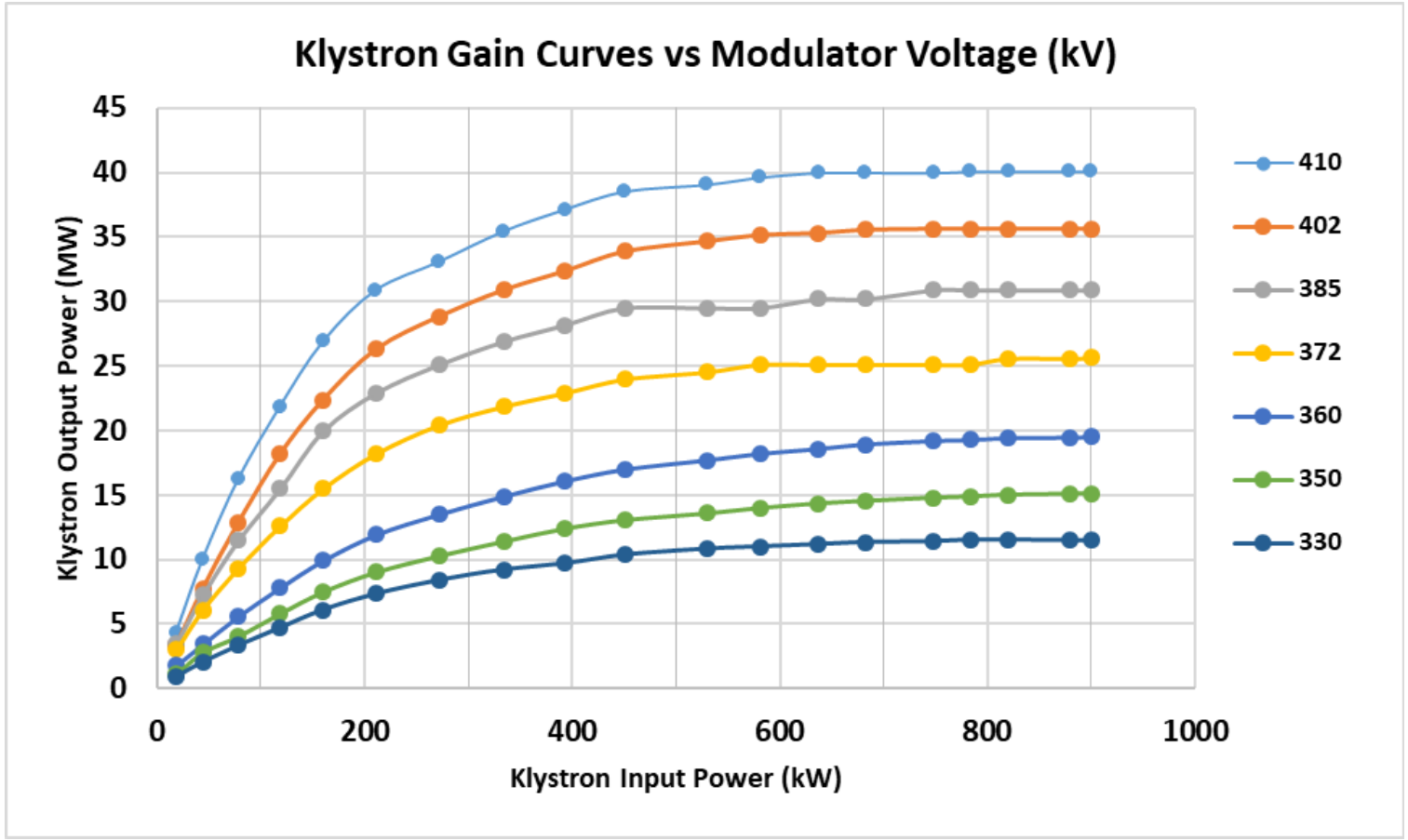
Thanks

...N. Catalan Lasheras, A. Baig, R. Brouns, A.M. Chauchet, S. Curts, E. Rodrigez, H. Bursali, J. Cai, M. Capstick, A. Edwards, A Fontenla, A. Grudiev, S. Lebet, G. Mcmonagle, L. Millar, P. Morales, J. Sauza Bedolla, C. Serpico, A. Solodko, I. Syratchev, M. Volpi, X. Wu, W. Wuensch...

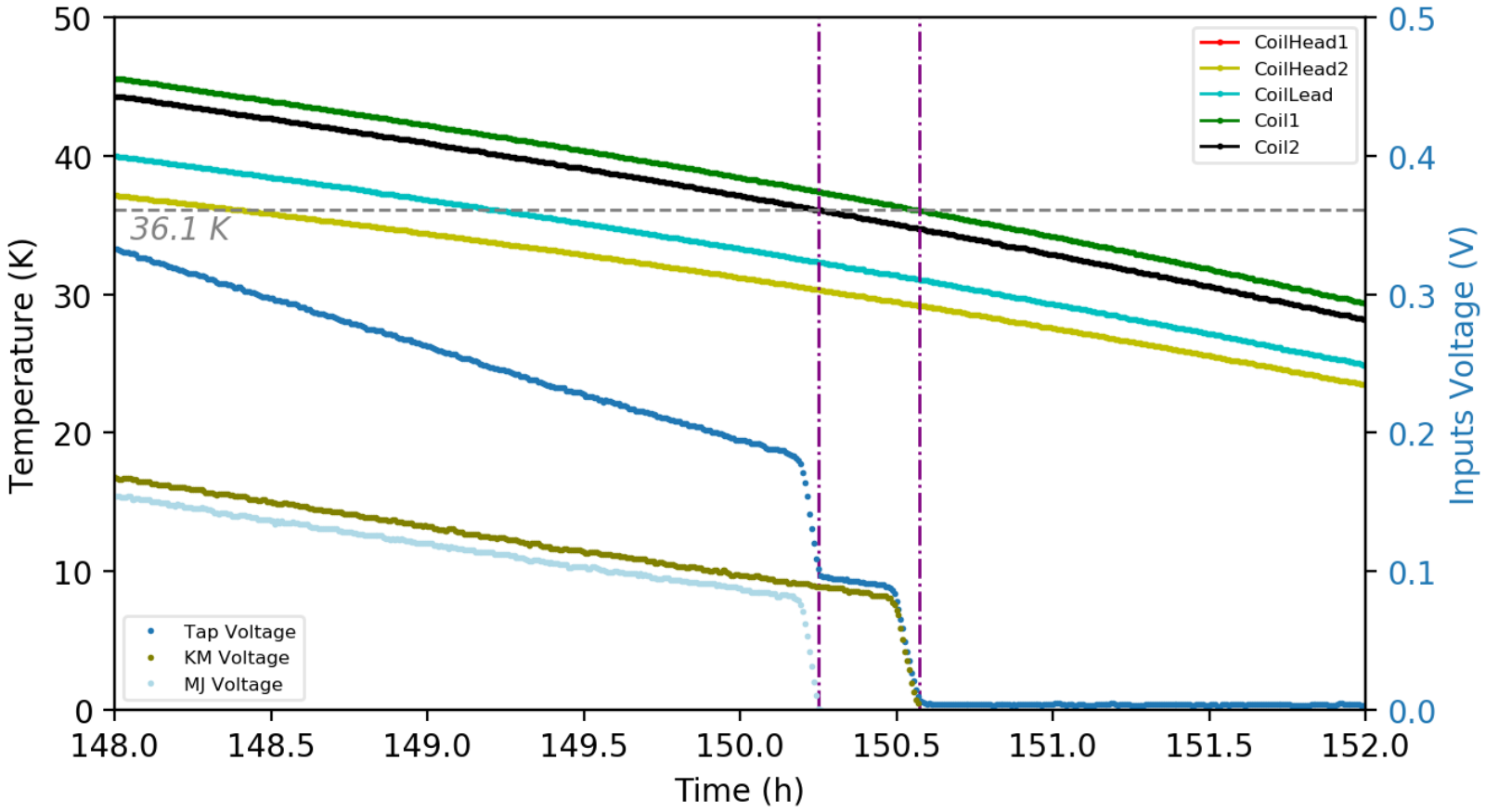
Backup

X-Box 1 – VKX8331 Conditioning

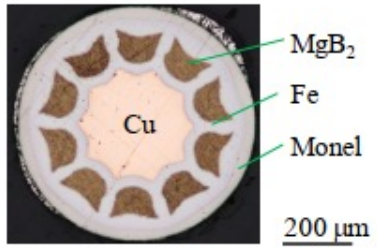
- Basic check made at the factory
- Installed in X-Box 1 and connected to two loads inside CLEAR facility
- The conditioning was done at CERN
- The upgraded signal generation and acquisition systems was tested
- Using a 50 ns RF pulses, the output power reached was 40 MW

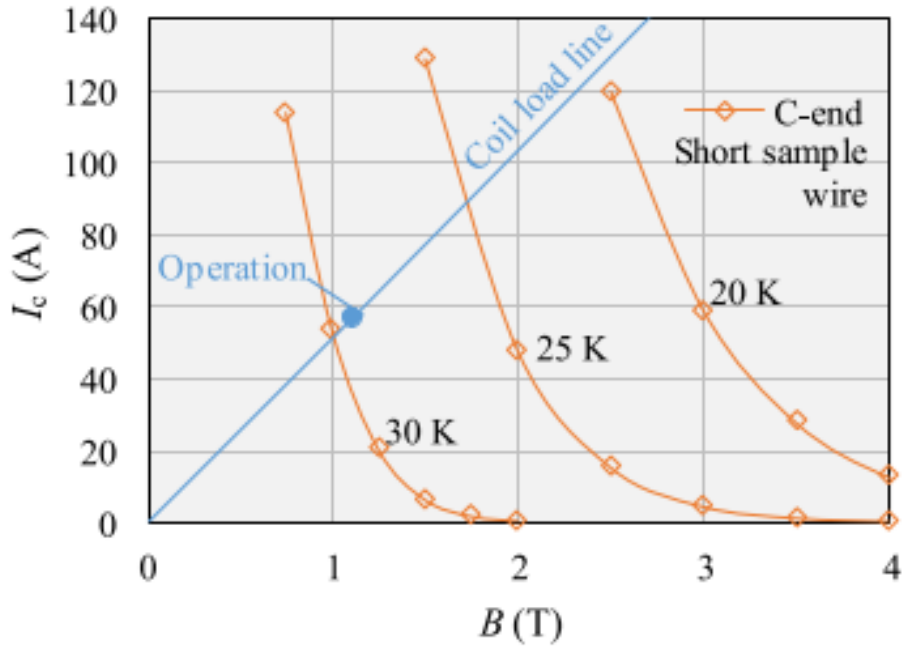


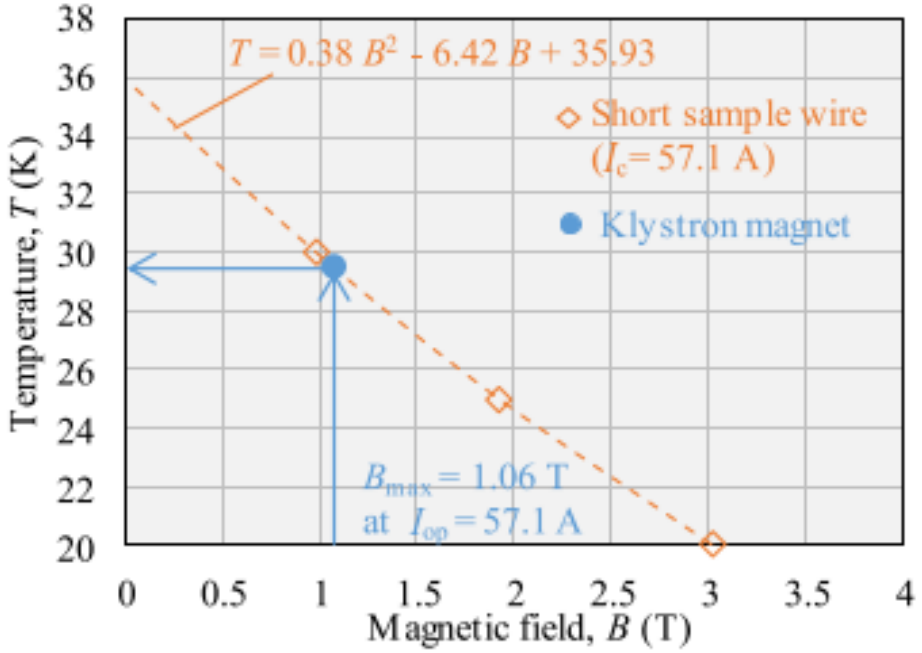
X-Box 2 MgB_2 Solenoid



X-Box 2 MgB_2 Solenoid







X-Box2 MgB_2 Solenoid

- MgB2 wire for the klystron magnet, with a unit length of 8 km. Diameter 0.67 mm.
- 5.6 km used for the solenoid coil.
- It consists of 152 turns and 16 layers per coil.
- I_{cs} of the magnet at I_{op} = 57.1 A is 29 K.
- The coil design parameters are optimized to realize a self-protected coil without requiring an active quench protection system.
- Thin, 0.2 mm thick Cu sheets (half cylinder shells) are embedded between coil layers to enhance conducting cooling power and quench propagation velocity along the coil axial direction.
- *Operation temperature ~15K*
- A cryocooler is applied for conduction cooling of the coil via Cu thermal link.
- Cooldown ~150 h
- *The energy consumption per magnet was less than 3 kW.*
- Two magnets in a series, energy consumption per magnet less than 1.5 kW.

X-box3 – “Single cell” test