CERN's High Gradient X-Band Test Stands: Status and Update

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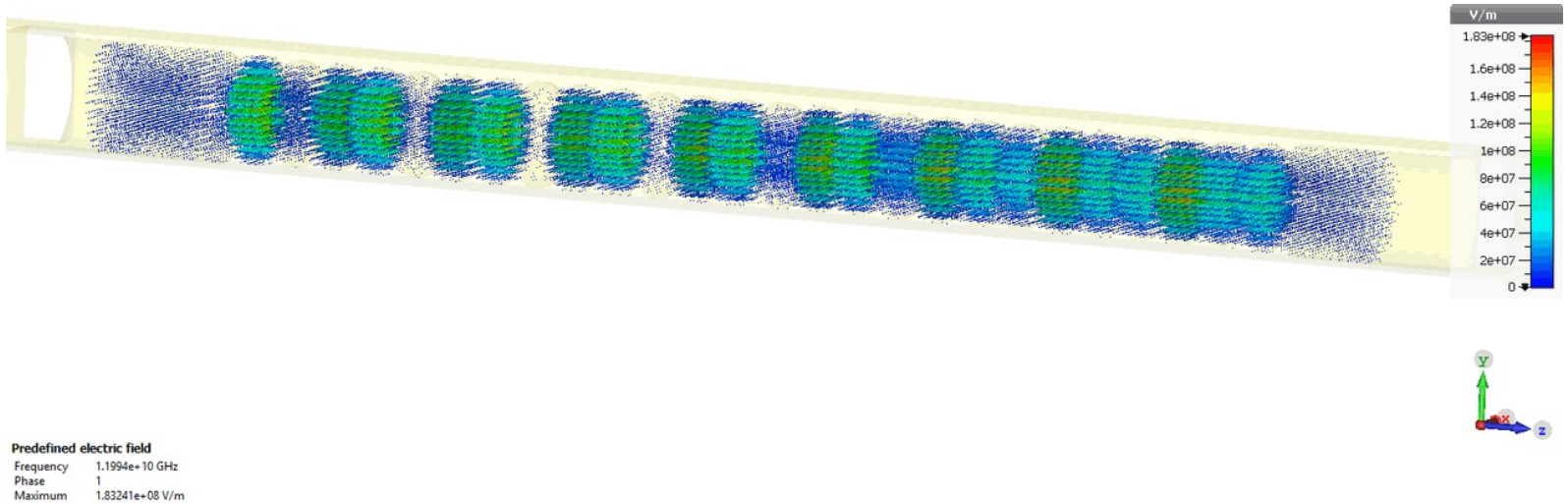
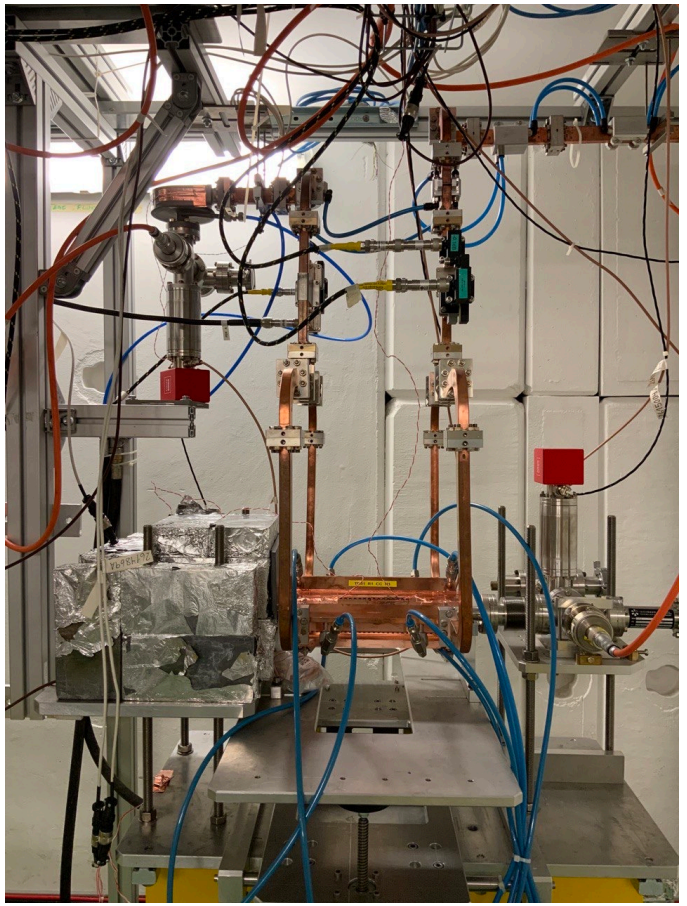
2023 International Workshop on Future Linear Colliders.

High Gradient X-Band Test Stands

High power test stands, producing RF pulses at 11.9942 GHz

- Power amplification based on SSAs, feeding the high power klystrons (up to 50 MW in Xbox 2)
- Real-time monitoring and RF production to ensure phase and amplitude stability (up to 400 Hz in Xbox 3): LLRF (Down-mixing, Up-mixing…), digitalization and processing, breakdown detection and interlocking.
- Test: Normal Conducting RF accelerating structures (CLIC …) and other components (pulse compressor, correction cavities, loads …)





The X-Boxes

- In recent years, enhancing the efficiency of our RF sources has been a priority, either by reducing energy consumption or increasing available power

X-Box 1 — KLYSTRON TO BE REPAIRED

- Waiting for the 50 MW CPI Klystron to be repaired.

X-Box 2 — OPERATIONAL

- SC Solenoid integration
- Two TD31 accelerator structures.

X-Box 3 — OPERATIONAL

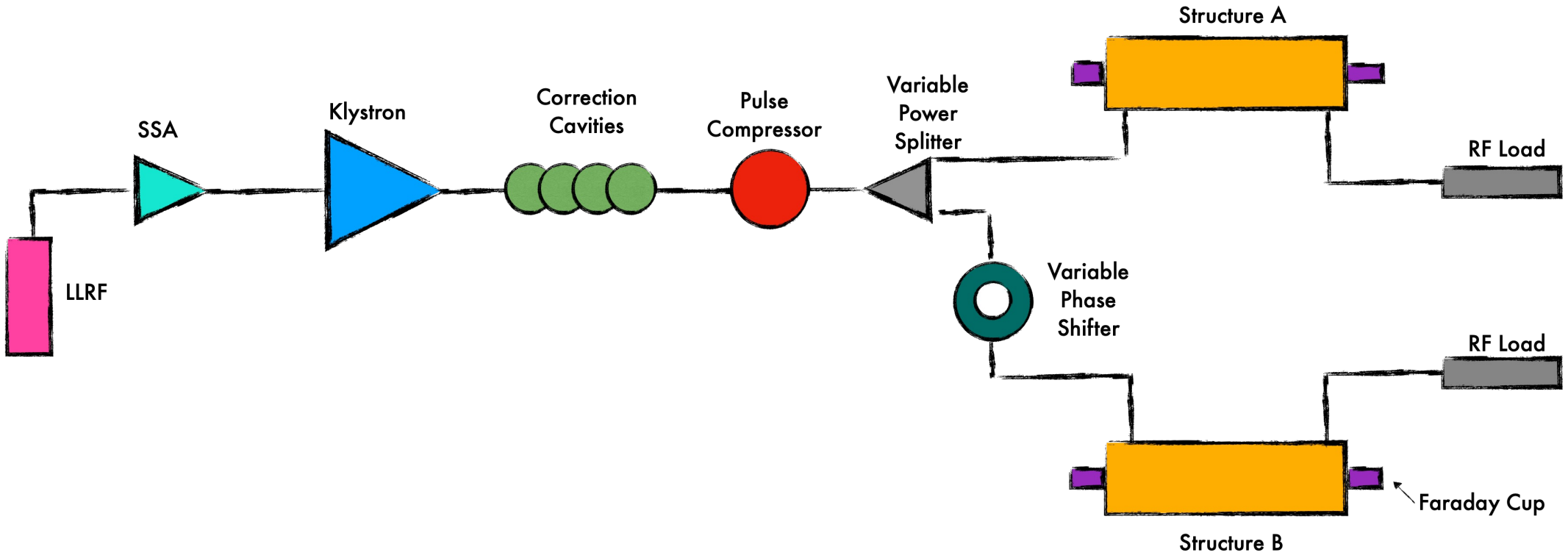
- CRAB cavity from Lancaster conditioned
- Deflector SARI conditioned
- 45 deg Spiral Loads
- Two TD31 accelerator structures.
- High Efficiency klystrons

2022: A total of 8 RF components have been installed, 6 test programs completed

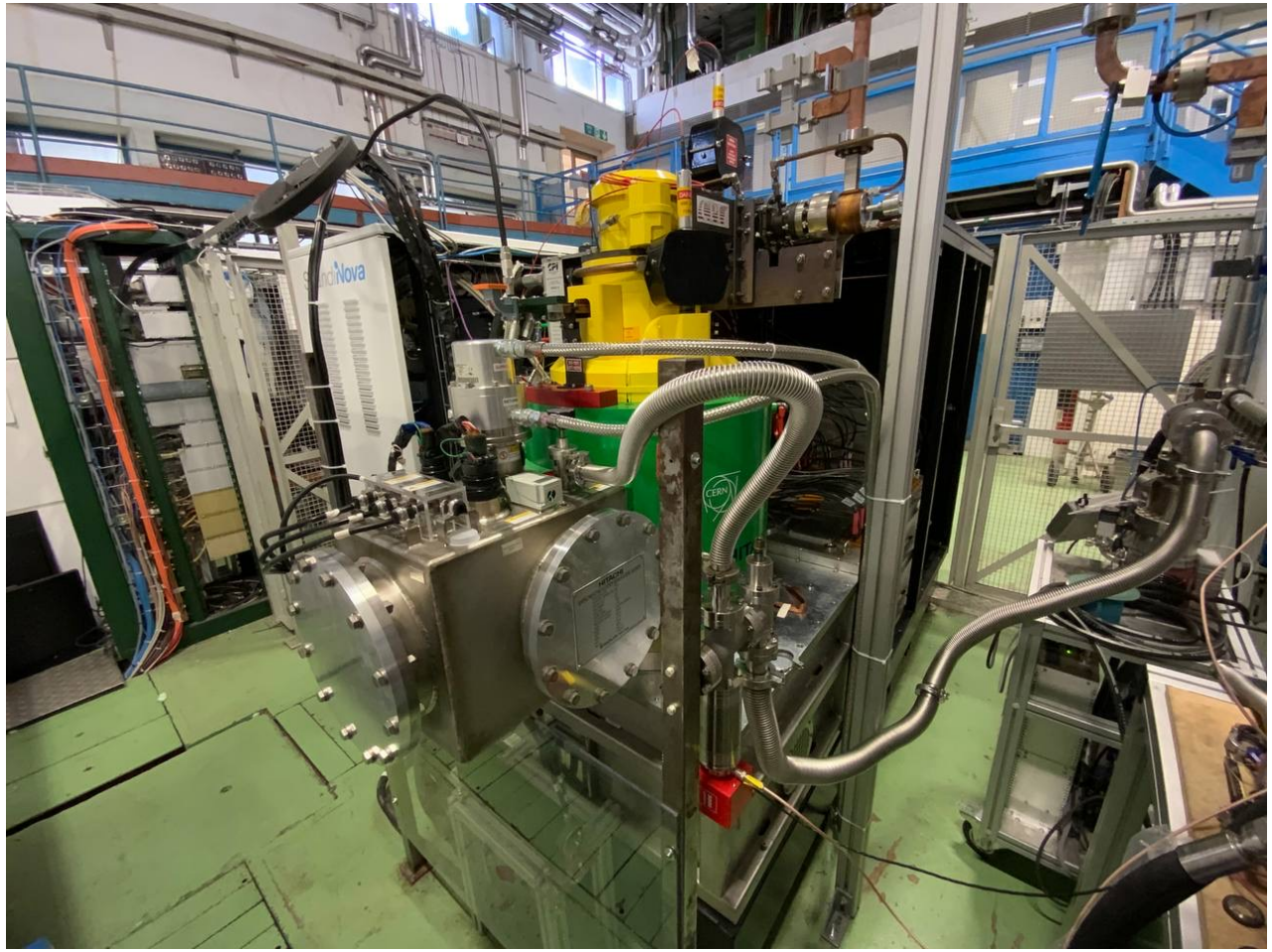
X-Box 2:

- MgB_2 SC solenoid for VKX-8331
- TD31 structures

X-Box 2 Layout



X-Box 2 MgB_2 Solenoid

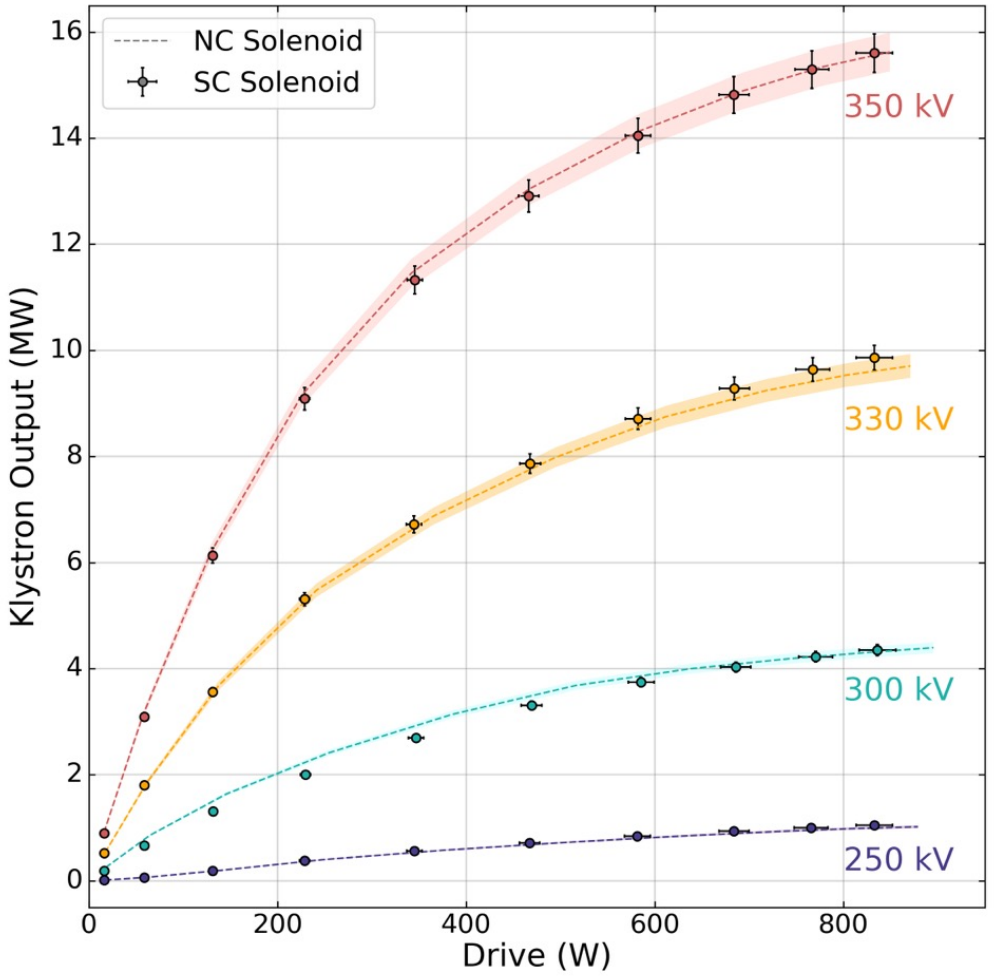


- Prototype compatible with 50 MW CPI klystron
- KEK-CERN collaboration and manufactured by Hitachi
- MgB_2 wire for the klystron magnet, with a unit length of 5.6 km. Diameter 0.67 mm
- Central field 0.8 T @ 57 A
- High efficiency: Reduce the power consumption form 20 kW to 2 kW
- Very safe and stable operation

LCWS 2023

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



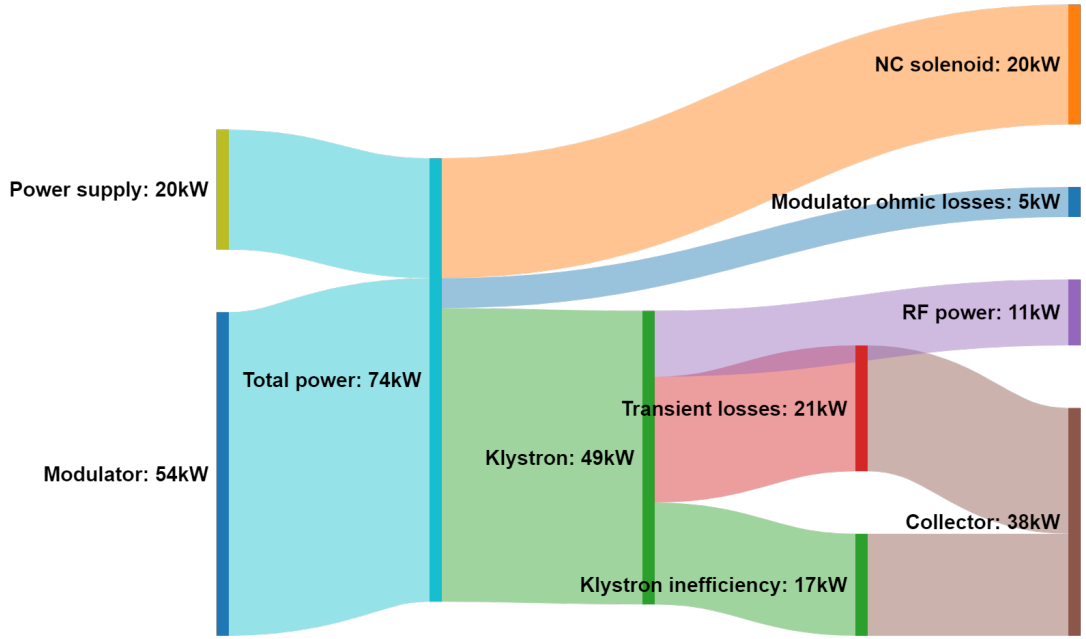
- SC technology can be applied to klystron solenoid
- Energy consumption reduced by 90 % 20 ->2 kW. Further reductions still possible
- Magnetic field very similar to the conventional magnet
- No interception
- Some adjustments needed to recover performance inside the tuning range of the power supply – 20% Counter-coil current adjustment, for smaller beam and match original gain
- Large operational margin makes it very stable and robust against failures

LCWS 2023

First klystron operation with the Mg2B superconducting solenoid; Nuria Catalan Lasheras; Anisullah Baig; Marçà Boronat;Alejandro Castilla;T akuji Kimura; Peter Kolda; Gerard McMonagle; Shinichiro Michizono; Igor Syratchev; Akira Yamamoto JACoW. IPAC2022, pp. 3138 - 3140. 2022. Available on-line at: <doi:10.18429/JACoW-IPAC2022-FROXSP3>

X-Box 2 MgB_2 Solenoid

- With a high efficiency klystron, modulator AND a SC solenoid we will save >50% of the power for the same output RF power!



AC/RF efficiency = 15.2%

+ SC Solenoid

AC/RF efficiency = 20 %

+ HE Klystron

AC/RF efficiency = 31.7%

LCWS 2023

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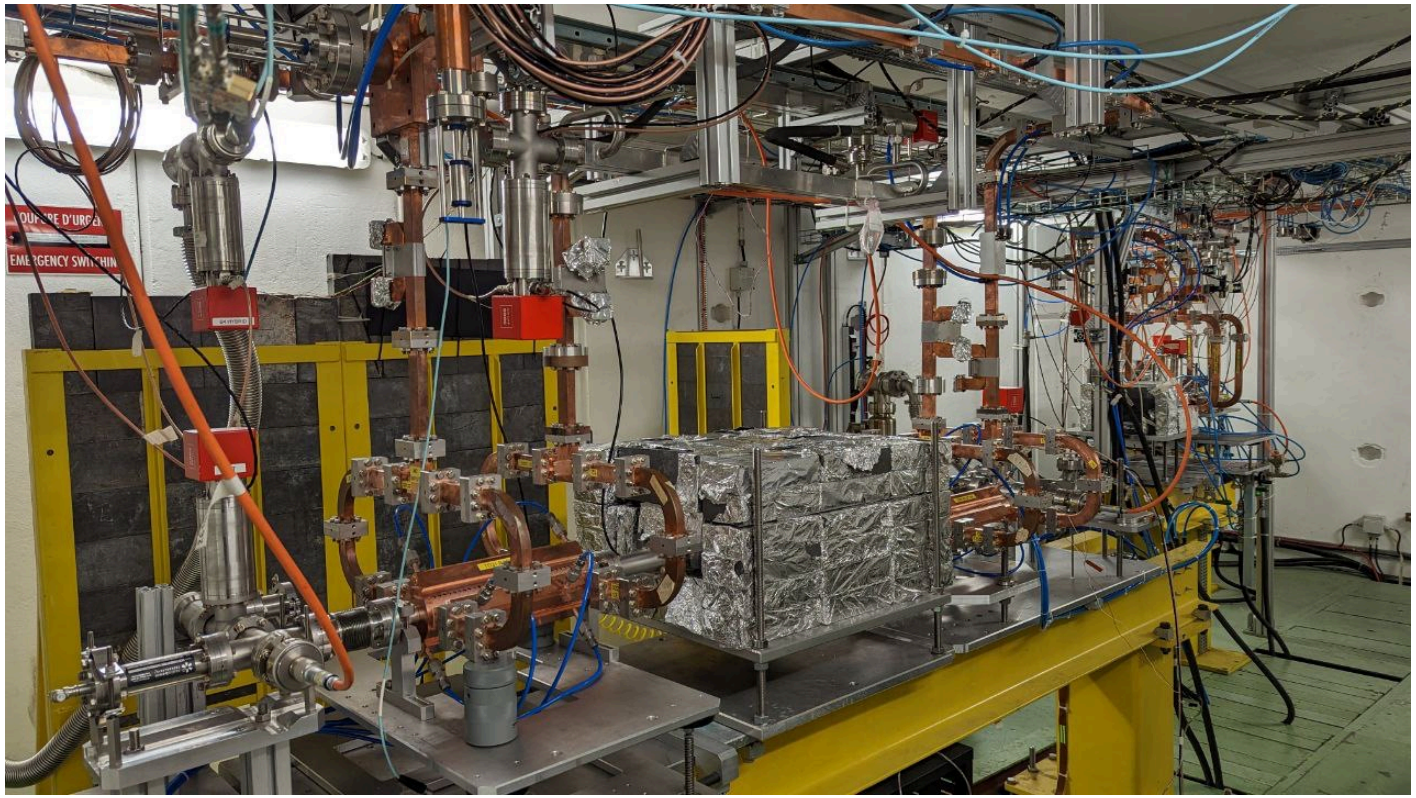
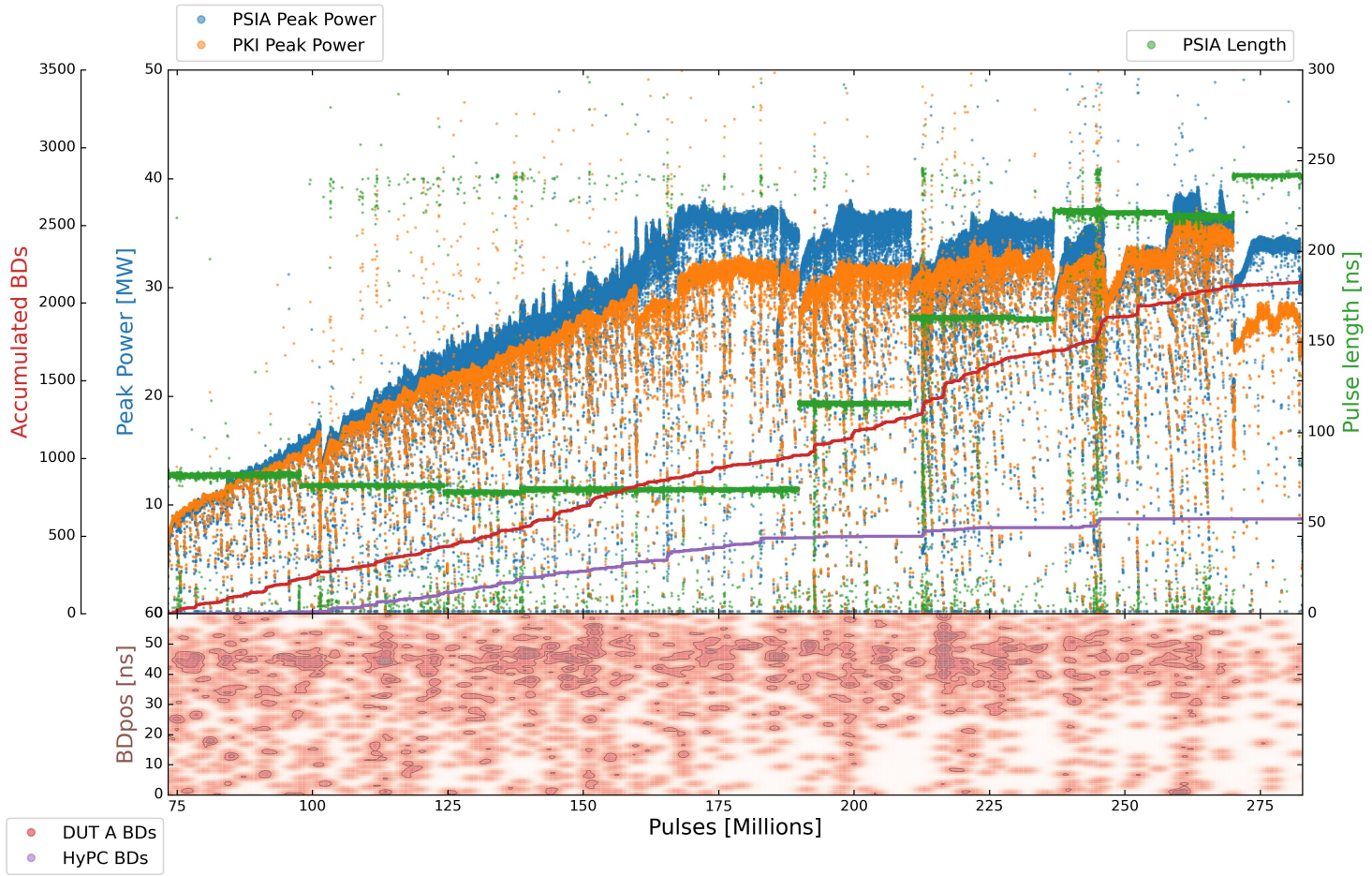
X-Box 2 –TD31s



TD31 for CLIC 380:

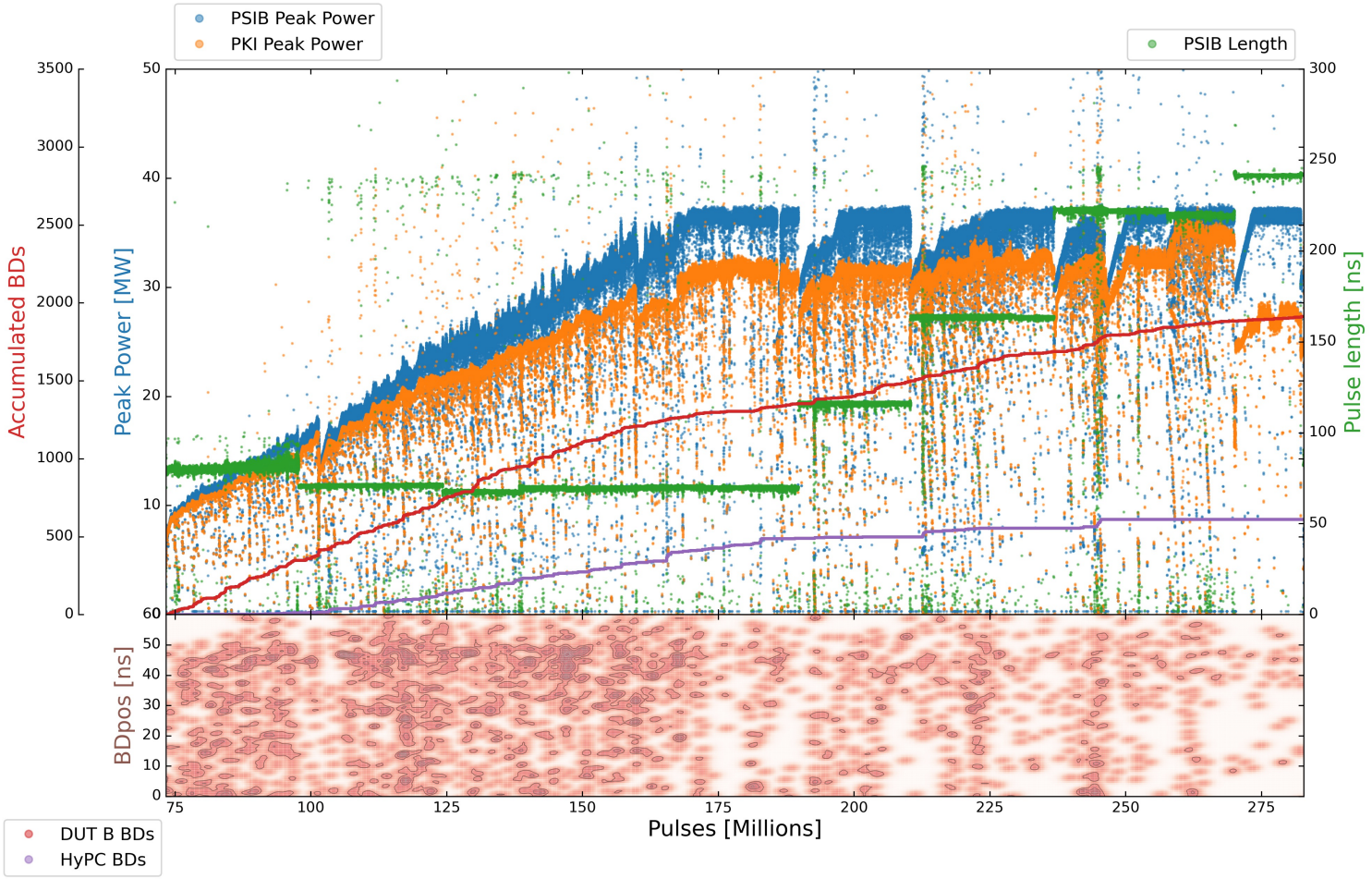
- P_{in} [MW] for <G=72MV/m>
  Unloaded = 36.1 MW
- P_{in} [MW] for <G=92MV/m>
  Loaded = 59.2 MW
- Four structures manufactured and ready to test, N3 and N4 installed in Xbox 2

X-Box 2 TD31 N3



- Maximum available power reached 36,1 MW at 50, 100, 150, 200 ns and 250 ns CP length, in 14 weeks conditioning.
- Nominal unload P_{in} reached at all pulse CP lengths

X-Box 2 TD31 N4

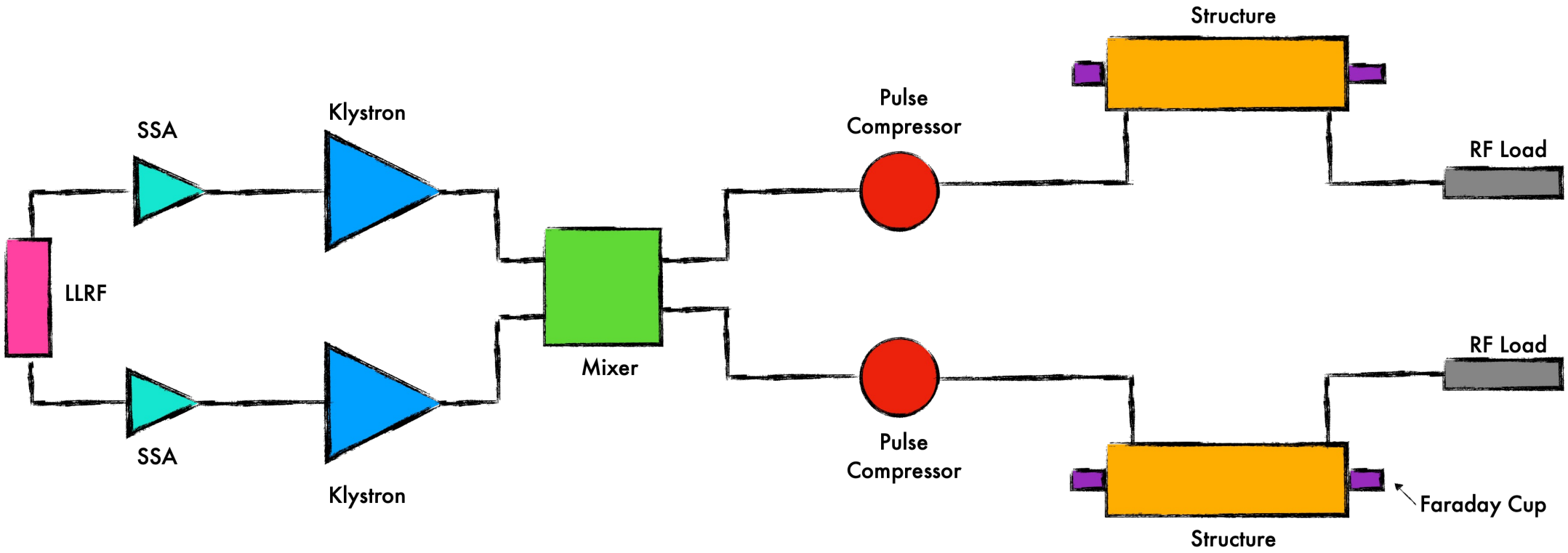


- Maximum available power reached 36,1 MW at 50, 100, 150, 200 ns and 250 ns CP length, in 14 weeks conditioning.
- Nominal unload P_{in} reached at all pulse CP lengths

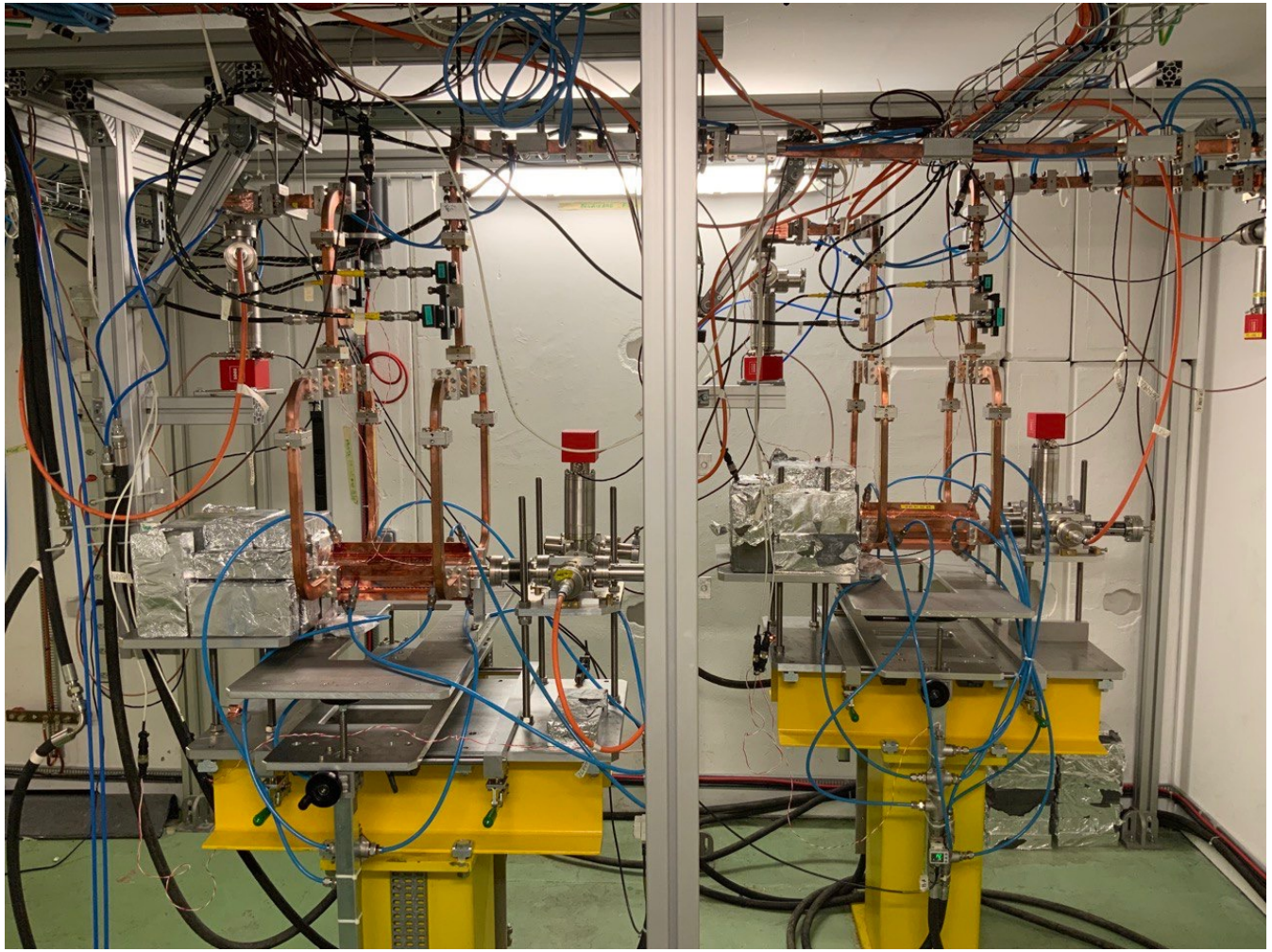
X-Box 3:

- TD31 structures
- Canon HE Klystrons

X-Box 3 Layout



X-Box 3 –TD31s



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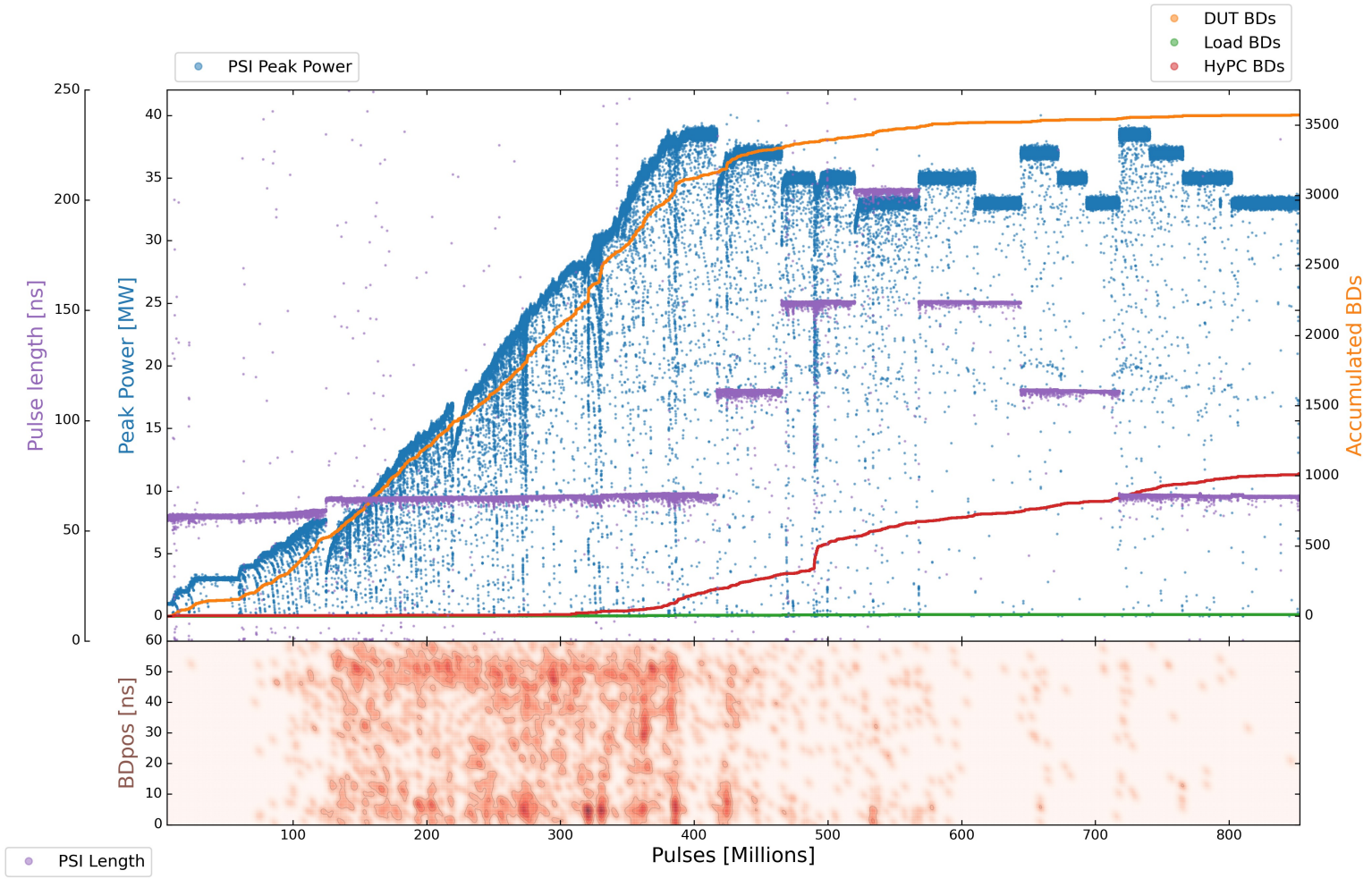
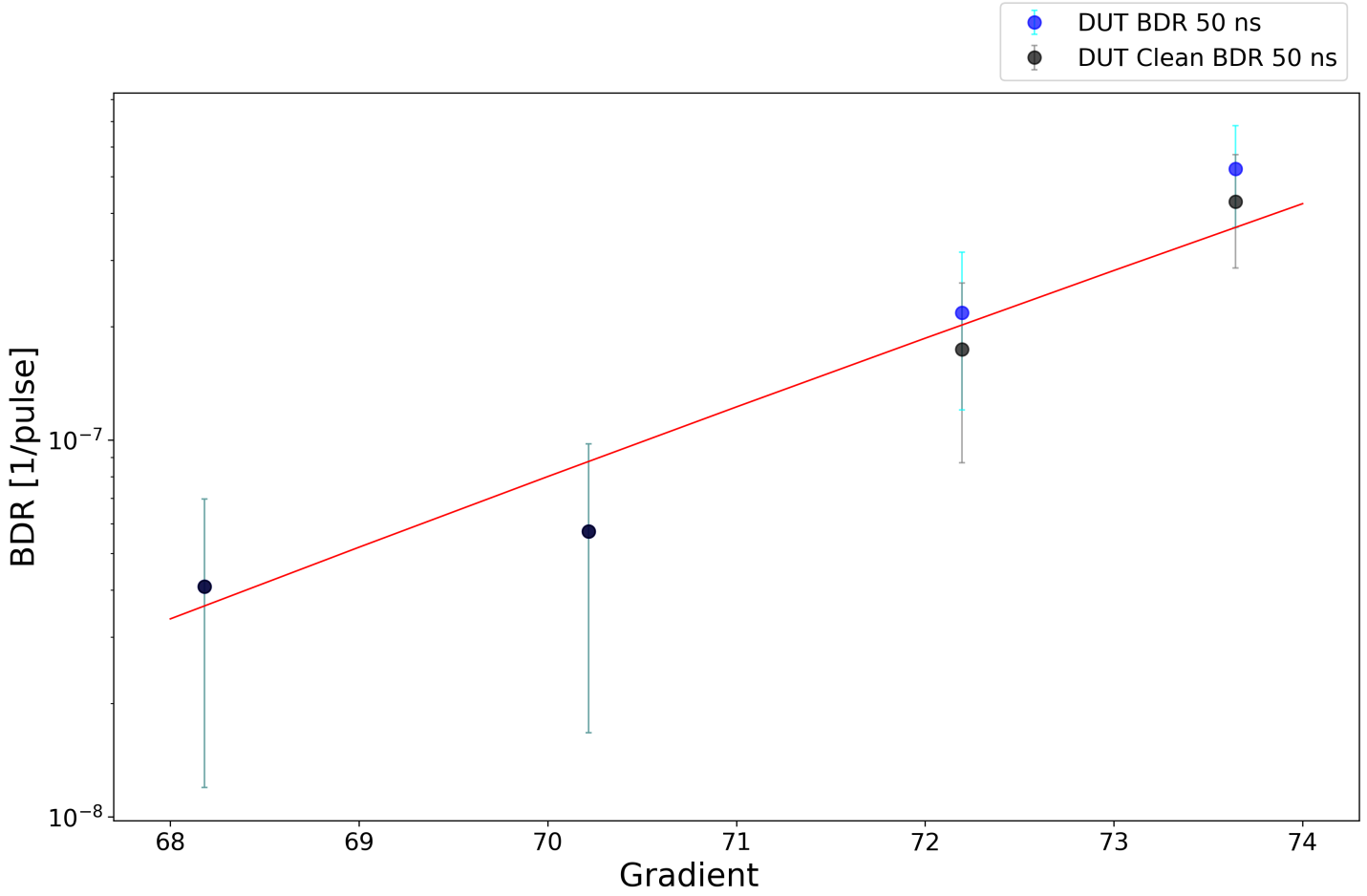
  Loaded = 59.2 MW
- Four structures manufactured and ready to test, N1 and N2 installed in Xbox 3

X-Box 3 – Line 1: TD31 N1



- Maximum available power reached at 50 (39 MW), 100 (37 MW), 150 (35 MW) and 200 ns (33 MW) CP length, in 6 weeks conditioning.
- Nominal unload P_{in} reached at 50 and 100 ns
- 4 weeks of data points.

X-Box 3 – Line 1: TD31 N1



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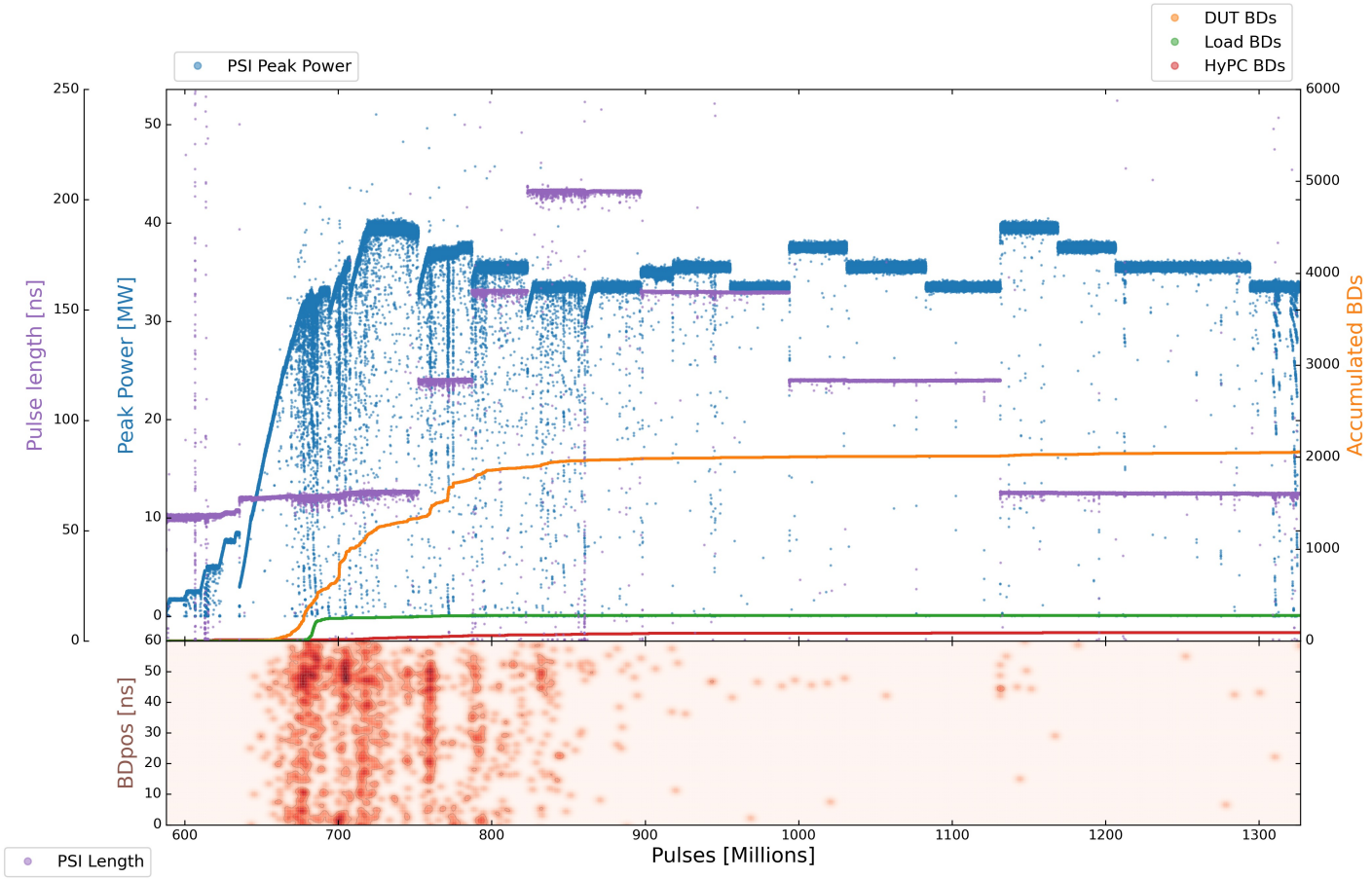
- Nominal unload P_{in} reached at 50 and 100 ns
- 4 weeks of data points.

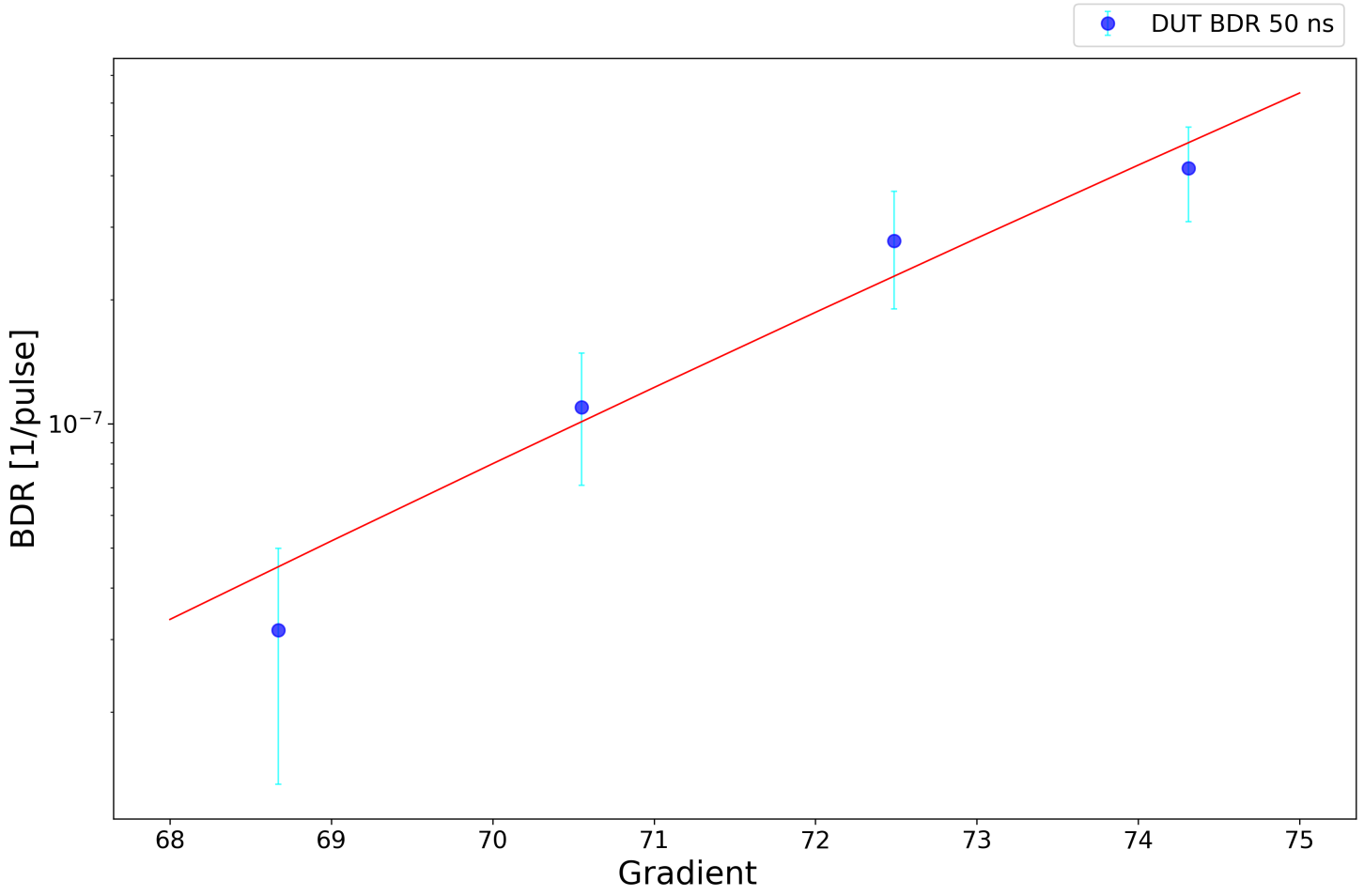
$$\frac{BDR}{E_{acc}^{30} \times \tau^5} = cnt$$

X-Box 3 – Line 2: TD31 N2



- Maximum available power reached at 50 (39 MW), 100 (37 MW), 150 (35 MW) and 200 ns (33 MW) CP length, in 6 weeks conditioning.
- Nominal unload P_{in} reached at 50 and 100 ns
- 5 weeks of data points.

X-Box 3 – Line 2: TD31 N2



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- Nominal unload P_{in} reached at 50 and 100 ns
- 5 weeks of data points.

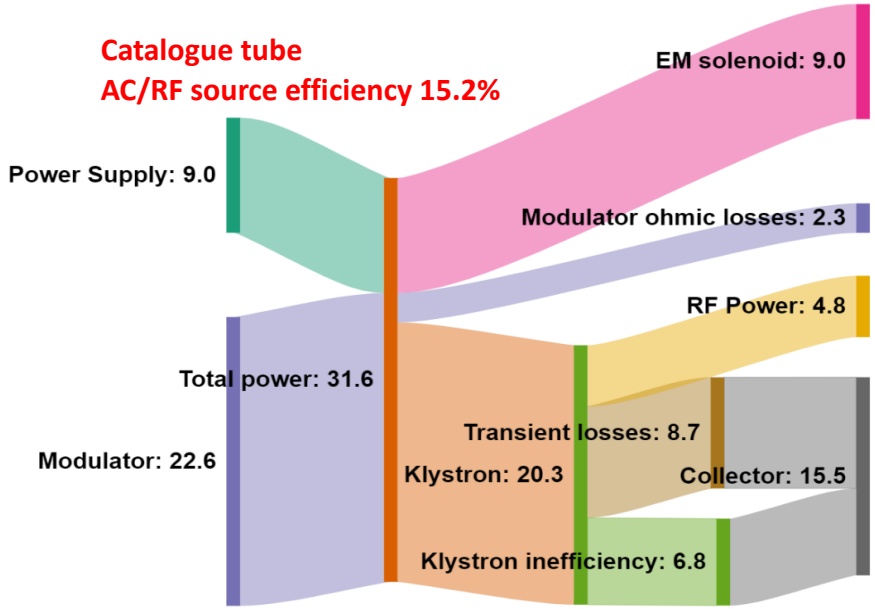
$$\frac{BDR}{E_{acc}^{30} \times \tau^5} = cnt$$

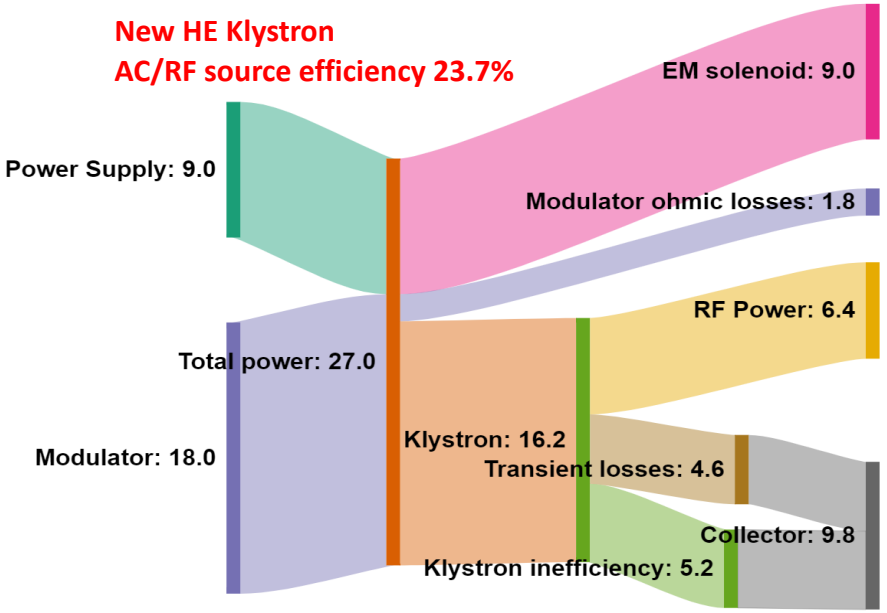
X-Box 3: HE Klystrons

	E37117 design
Voltage, kV	154
Current, A	94
Frequency, GHz	11.994
Peak power, MW	8.16
Sat. gain, dB	58
Efficiency, %	57/ FCI
Life time, hours	30 000
Solenoidal magnetic field, T	0.4
RF circuit length, m	0.127

- June 2023, the klystrons in X-Box 3 will be replaced by E37117 high-efficiency klystrons from Canon, providing up to 10 MW.
- It will allow to continue the conditioning of the TD31 structures towards P_{in} loaded (59,2 MW)

X-Box 3: HE Klystrons





- We want to design and build a permanent magnet solenoid for an available HE klystron, to increase up to 35.5% efficiency in the global RF system

Conclusions

- High Gradient X-Band Test Stands at CERN have been operational for almost 10 years. In this period, plenty accelerating structures and RF components have been successfully tested.
  - Currently, 4 TD31s accelerating structures for CLIC 380, are being conditioned, in parallel. Unloaded target power have been achieve for all of them (36,1 MW). Next goal: Loaded target power (60 MW)
- In recent years, we have been directing our efforts towards enhancing the efficiency of our RF sources, either by reducing energy consumption or increasing available power.
  - Xbox 2: A SC Solenoid has been integrated with the 50 MW CPI klystron, operating stably for more than a year. Reduction of 25% in power consumption
  - Xbox 3: HE Klystrons will be installed this month, increasing the available power from 6 MW to 10 MW per klystron.

Thanks

... S. Gonzalez Antón, N. Catalan Lasheras, A. Baig, R. Brouns, A.M. Chauchet, A Fontenla, A. Grudiev, L. Millar, P. Morales, I. Syratchev, M. Volpi, W. Wuensch, P. Wang, M. Wendelmuth ...