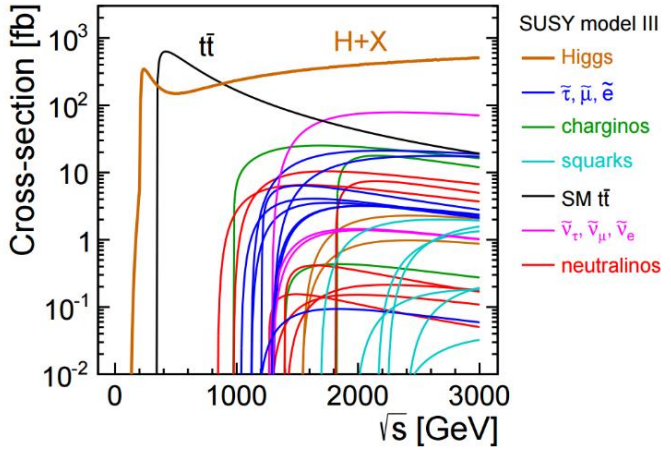
X-Band RF Test Stands at CERN

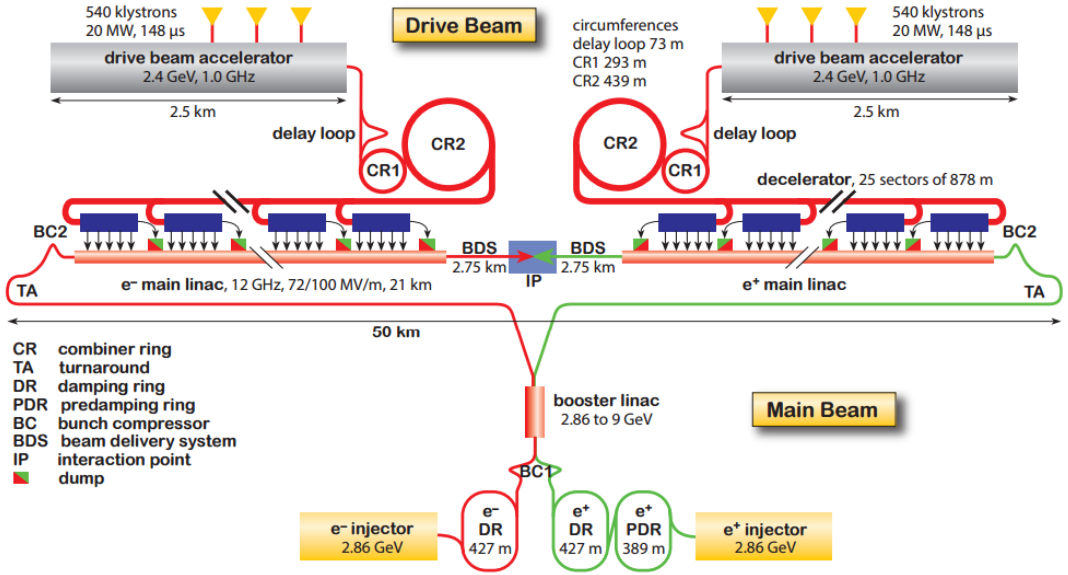
Jan Paszkiewicz on behalf of the Xbox group

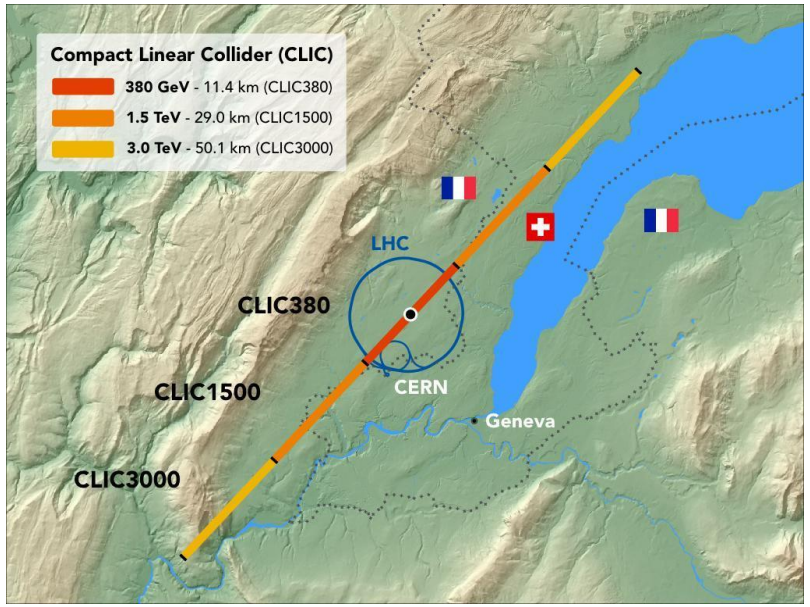
MeVArc, San Juan, 20-24 May 2018

Compact Linear Collider

- Linear e^+e^- collider for precision particle physics measurements.
- Staged implementation up to 3 TeV.
- Linear due to synchrotron losses.
- 100 MV/m accelerating gradient for high energy with reasonable machine length.

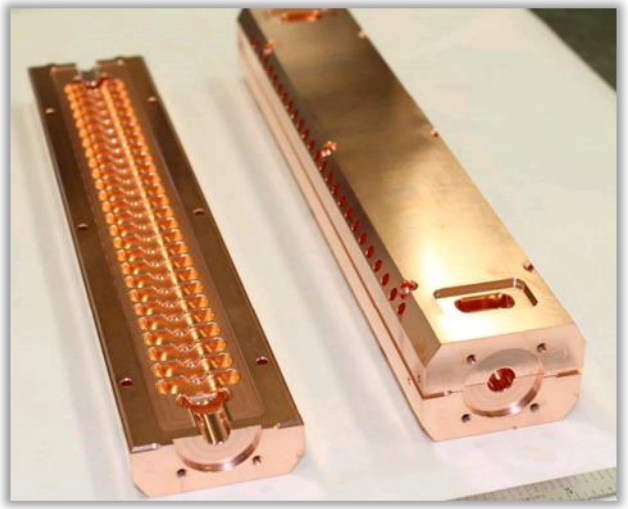


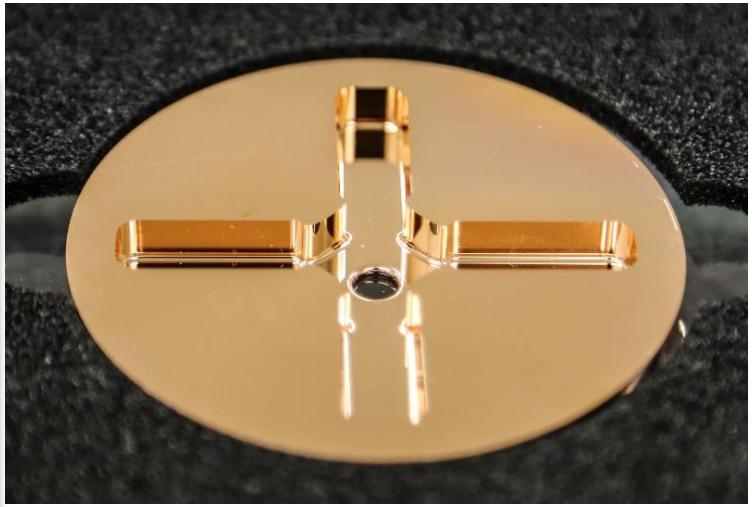


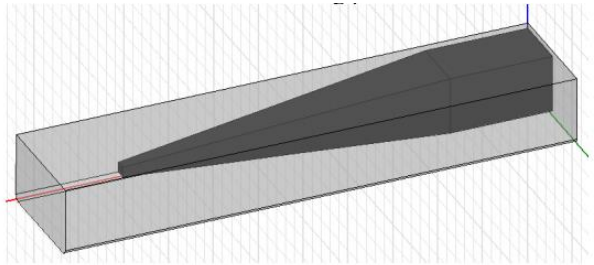


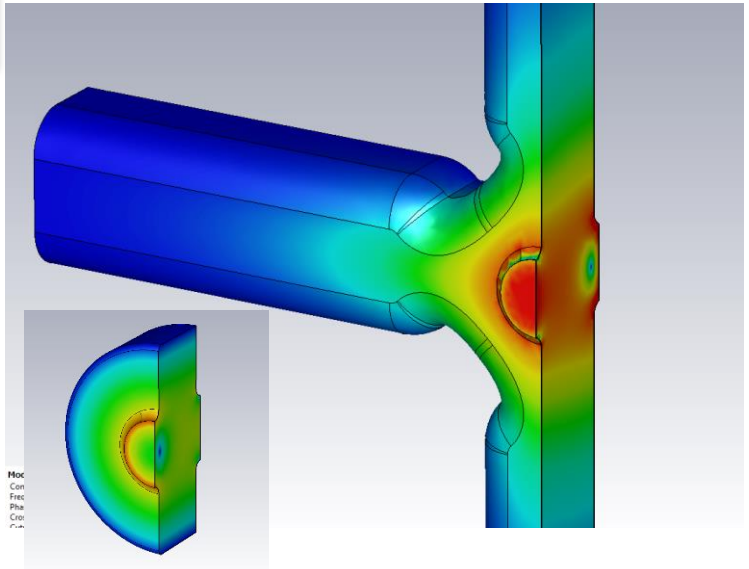
RF Accelerating Structures

- X-band (11.994 GHz RF)
- Traveling wave: RF pulse passes through the structure.
- Accelerating gradient (energy gain of particles) = 100 MV/m
- Peak surface field ≥ 200 MV/m, depends on design.
- High fields require high power: 40 - 50 MW without beam.
- CLIC BDR requirement: ≤ 3×10^{-7} bpp/m to limit losses of luminosity.
- Wakefield damping due to beam dynamics requirements.



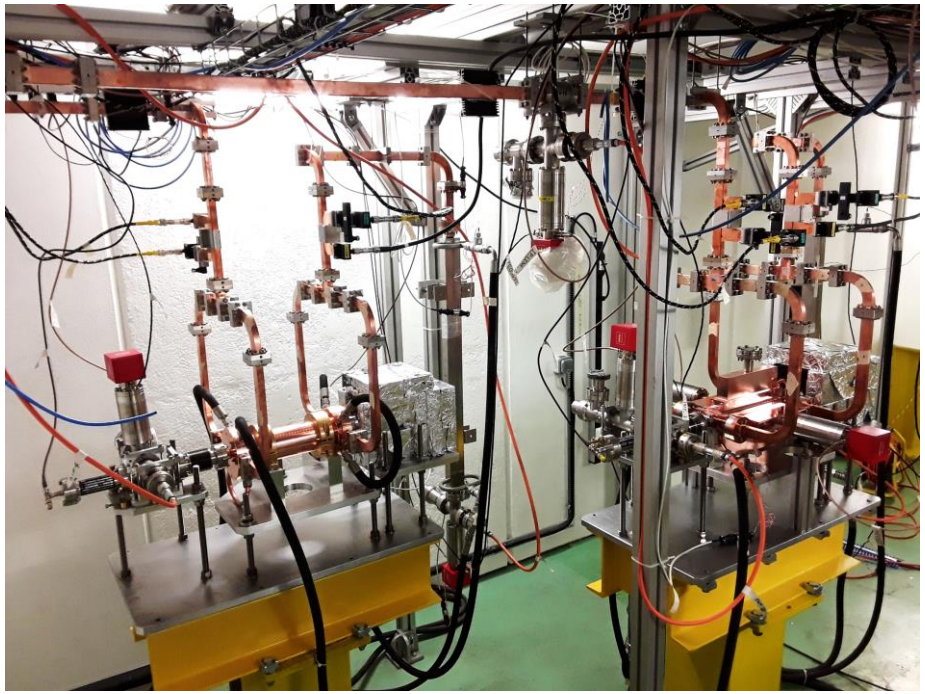






Test Stands at CERN

- Xbox 1: 50 MW klystron, 50 Hz, connection with CLEAR (e^- linac)
- Xbox 2: 50 MW klystron, 50 Hz
- Xbox 3: 4x6 MW klystrons, 400 Hz, 4 structure test slots
- Sbox: 45 MW klystron, 50Hz, S-band (3 GHz)

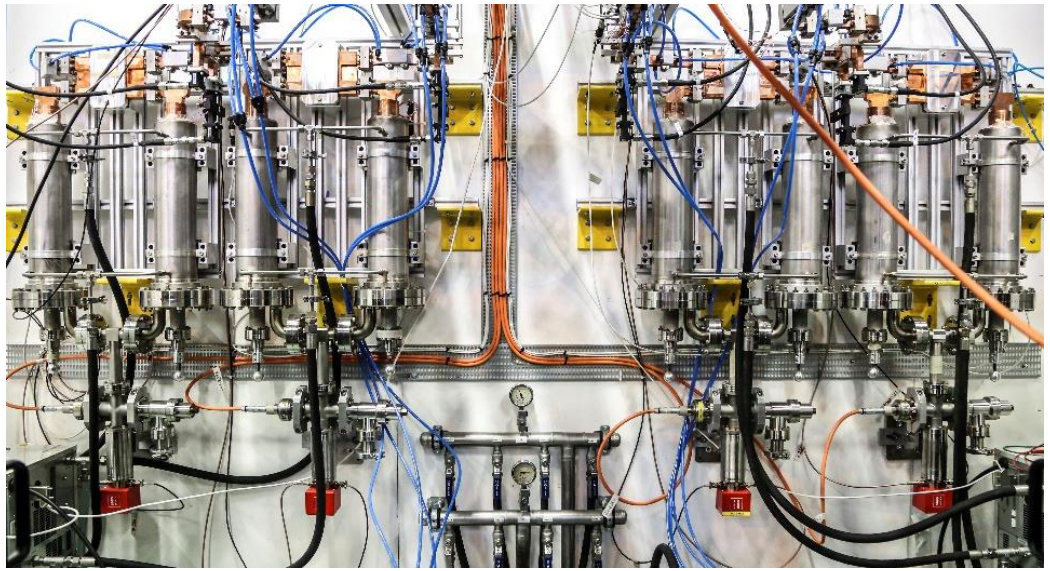


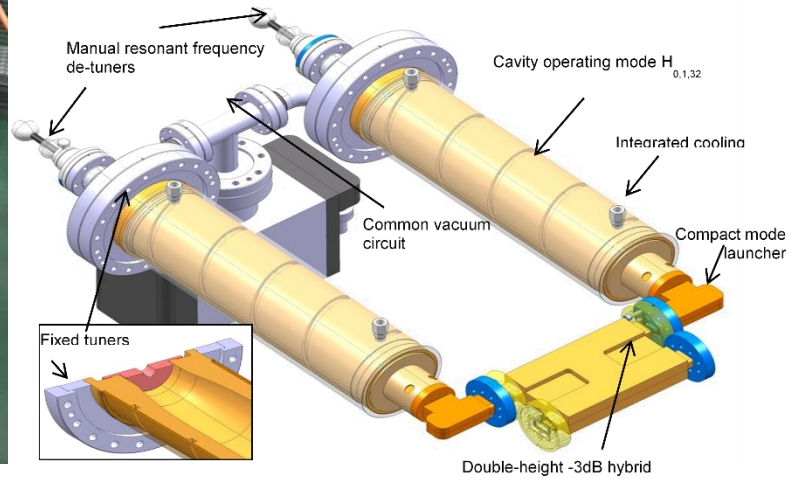
Generating High RF Power

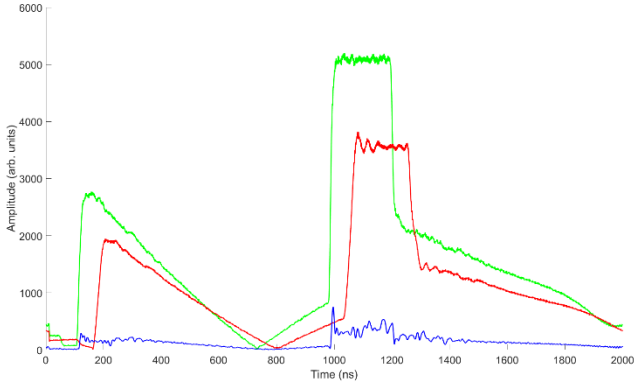
Modulators

Klystrons

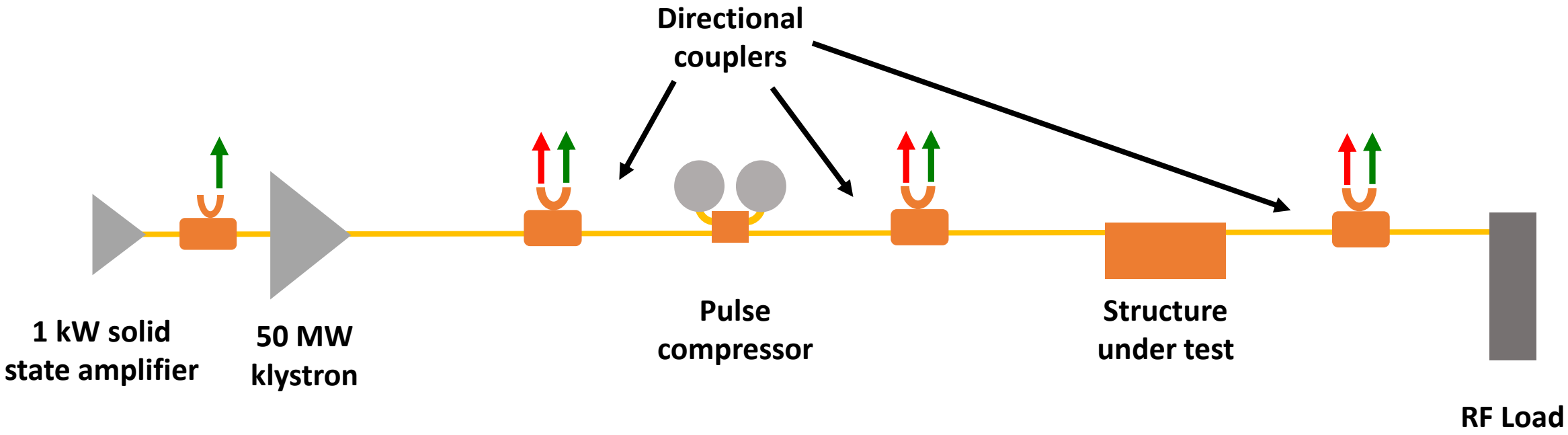
Pulse Compressors



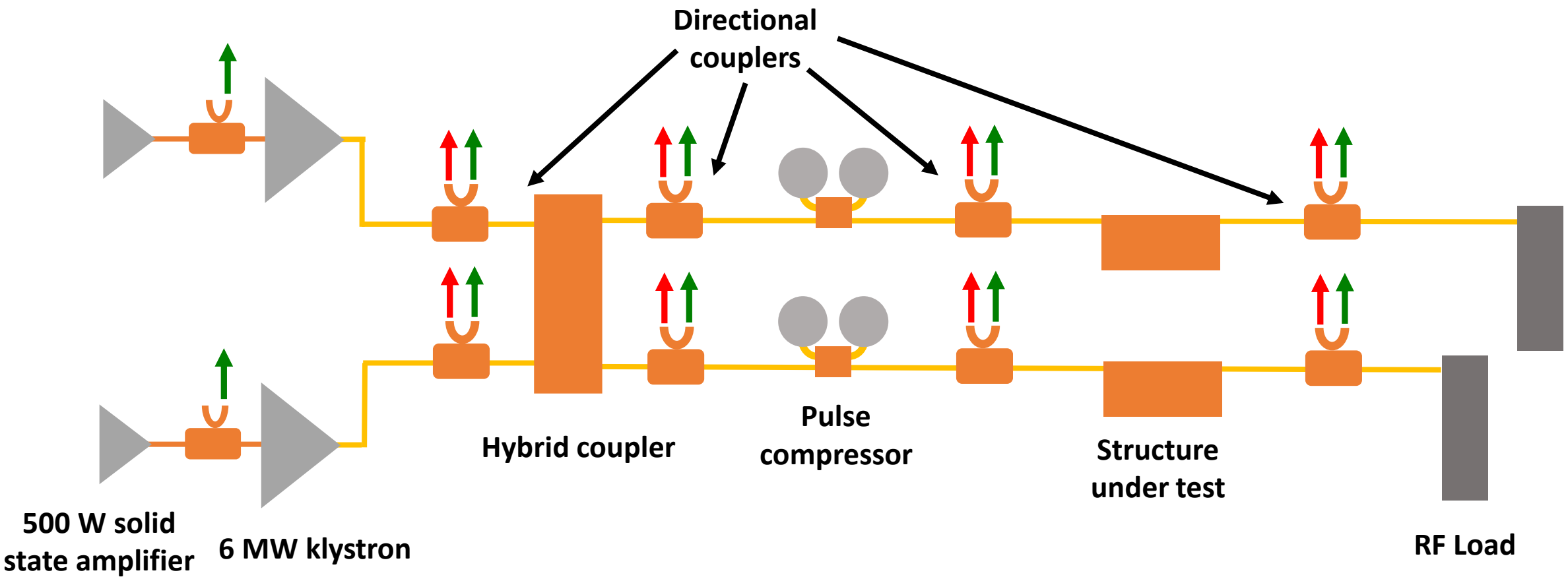




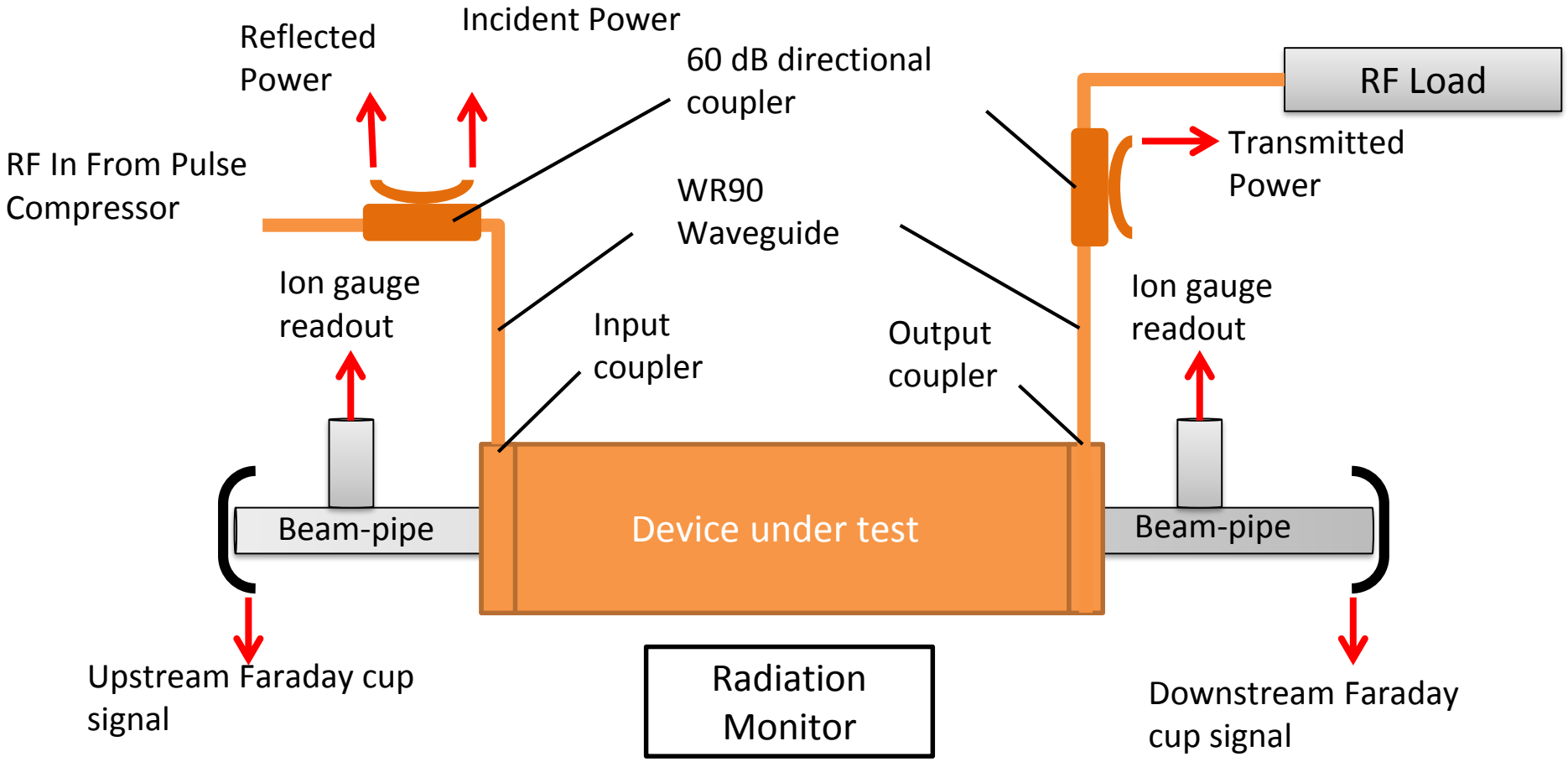
Xbox 2 Block Diagram



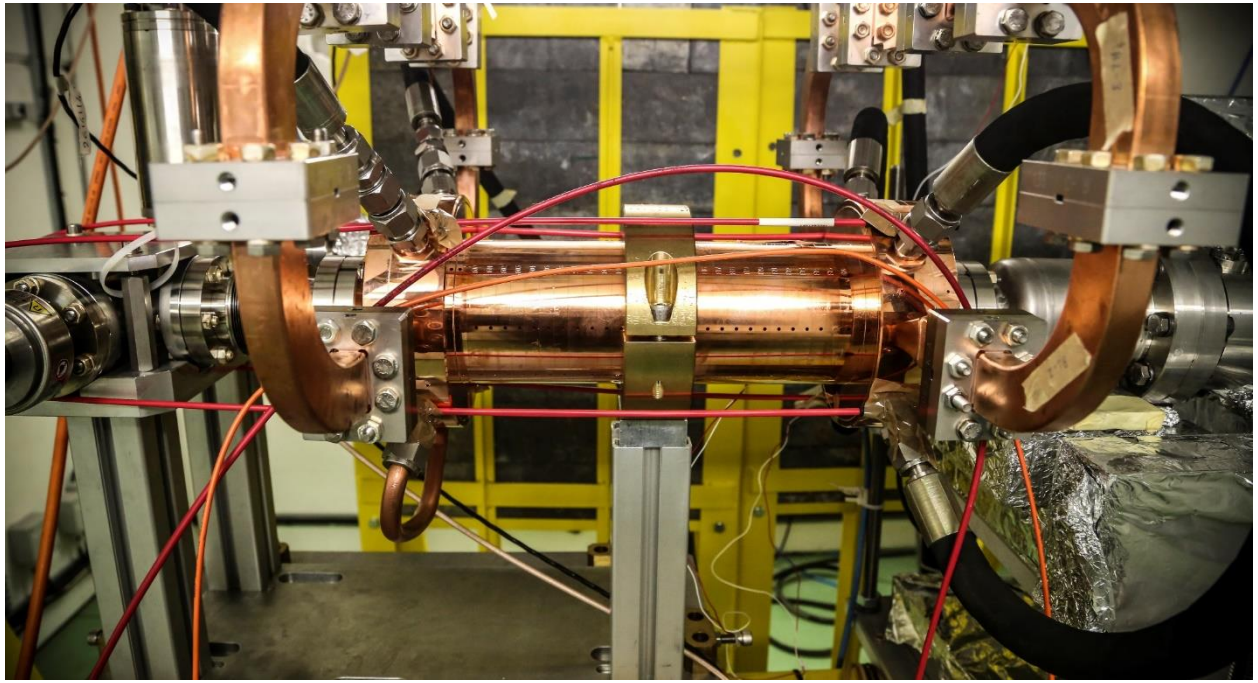
Xbox 3 Block Diagram

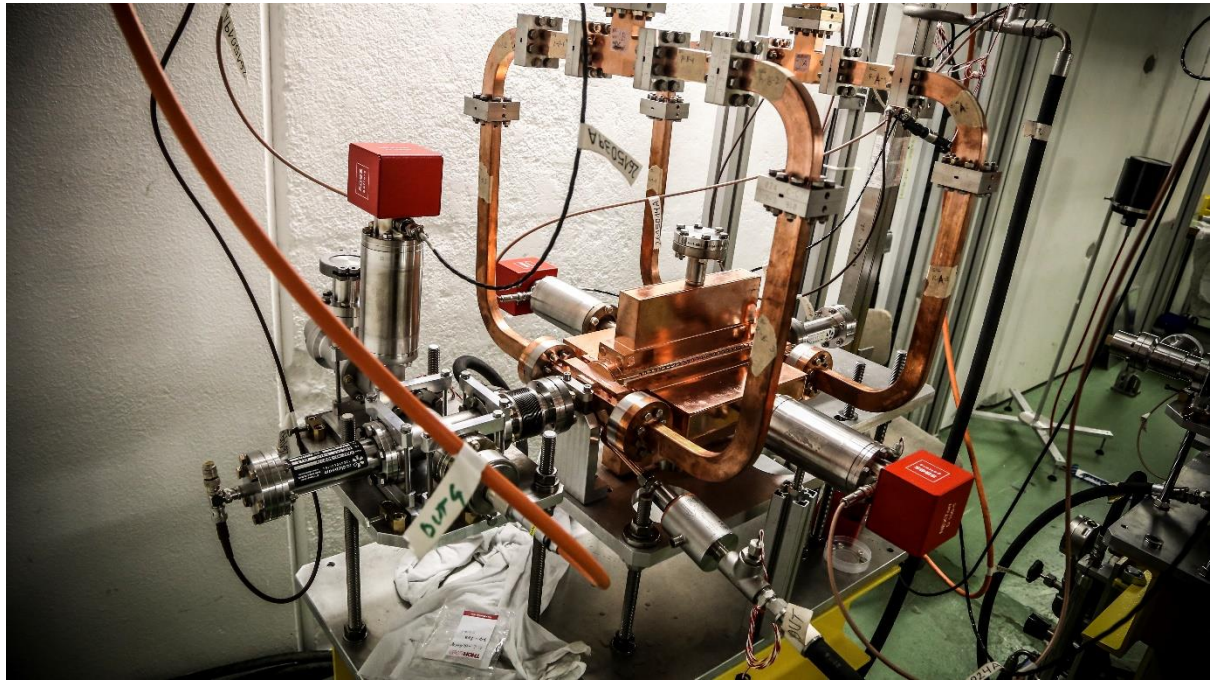


Structure Diagnostics Overview

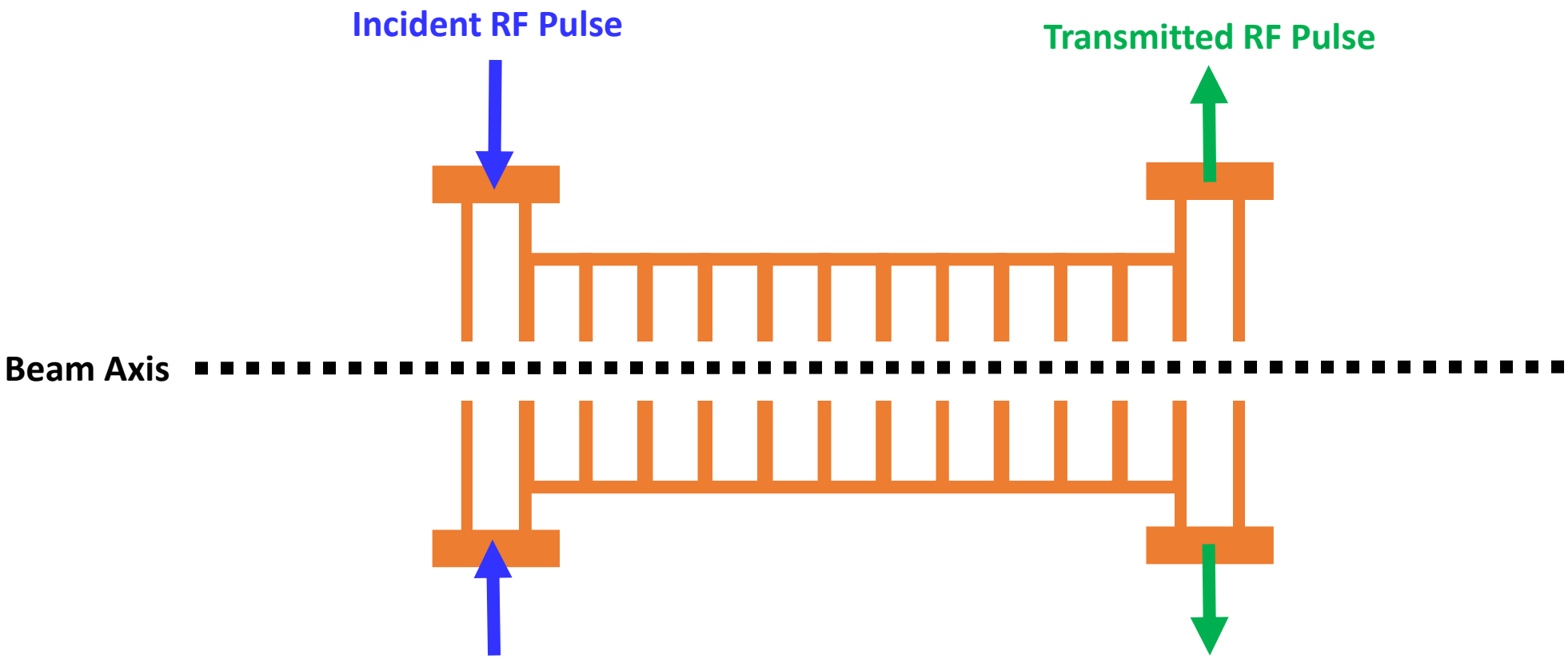


Structure Diagnostics Overview

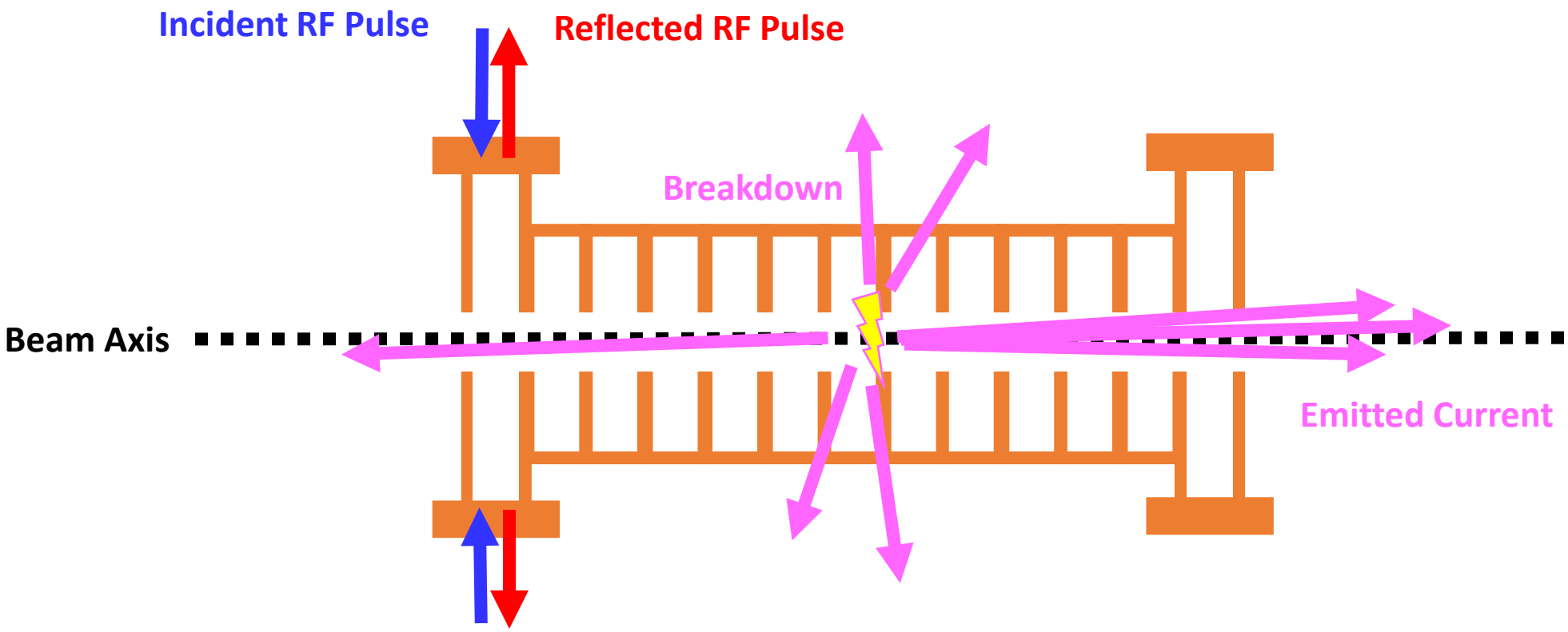




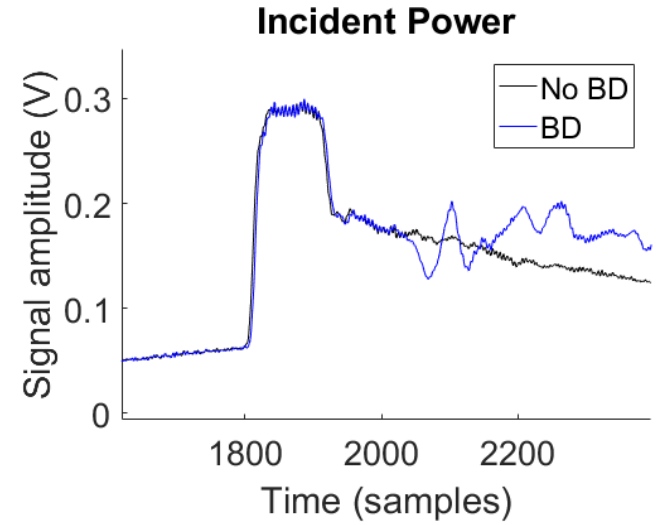
Breakdown

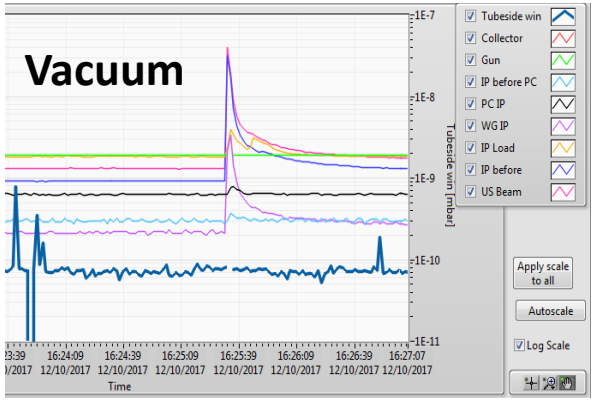


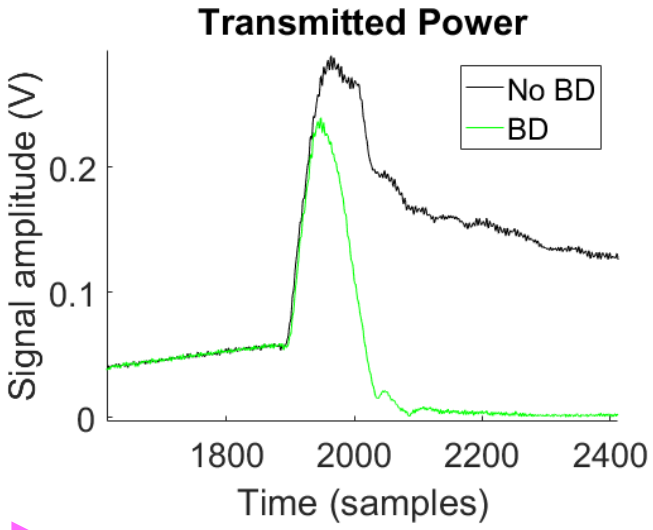
Breakdown

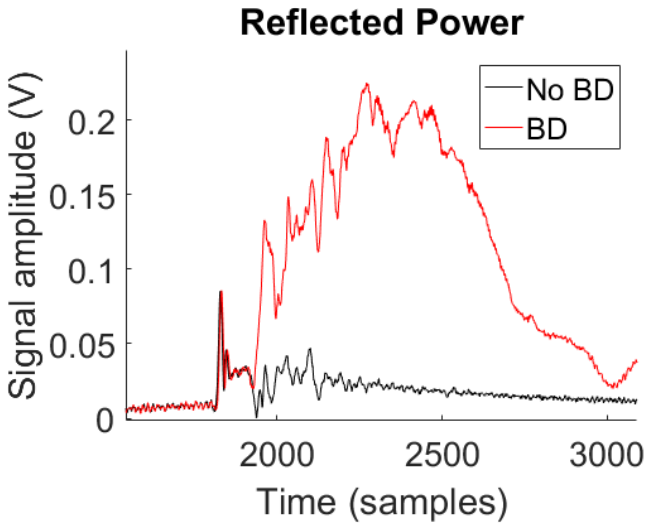

Incident RF Pulse
Reflected RF Pulse
Breakdown
Beam Axis
Emitted Current

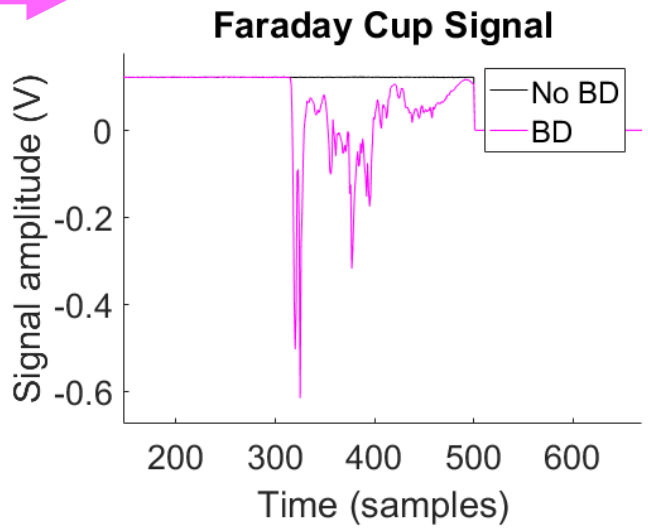
Breakdown - Diagnostics











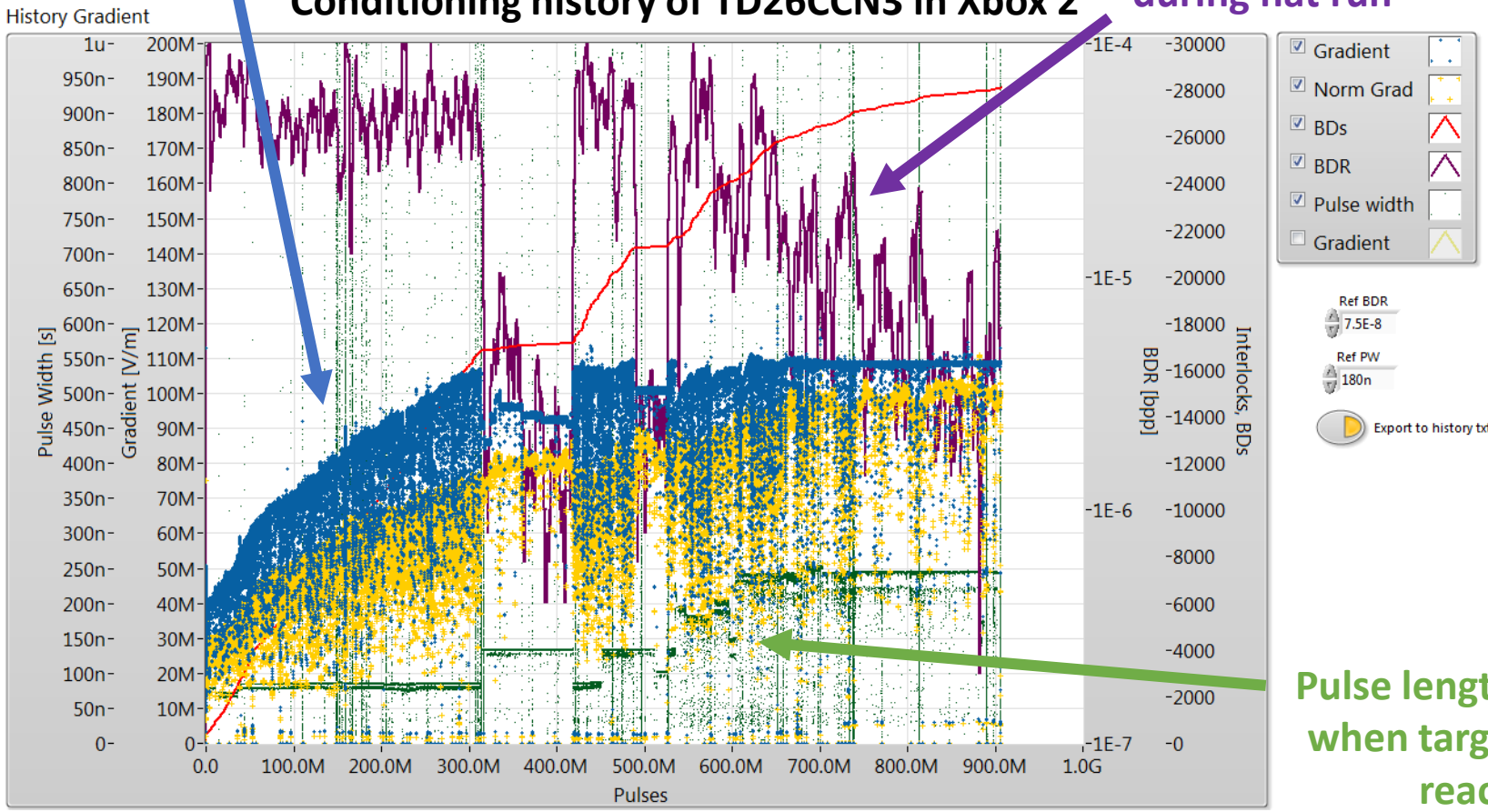
- BD position resolved using timing of RF pulses.
- Low group velocity (~0.02c), 65 ns filling time: very high time resolution not needed.

Conditioning Procedure

Ramping of gradient by algorithm

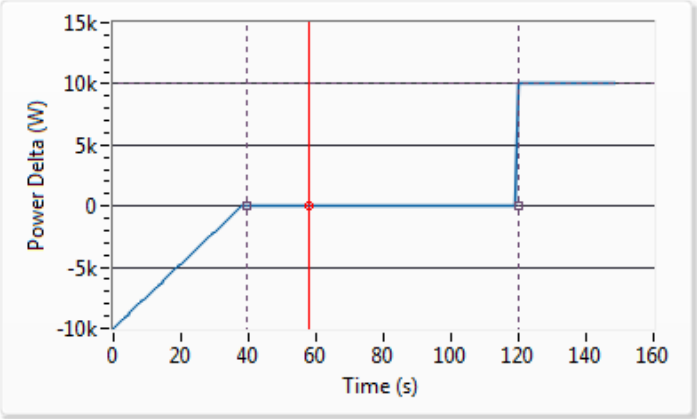
Reduction in BDR during flat run

Conditioning history of TD26CCN3 in Xbox 2



Pulse length increased when target gradient reached.

- Algorithm controls power based on current BDR (based on last 360000 pulses).
- Typically reach 110 MV/m accelerating gradient.
- Increase pulse length in steps when gradient target reached. (50 , 100, 150, 200 ns)

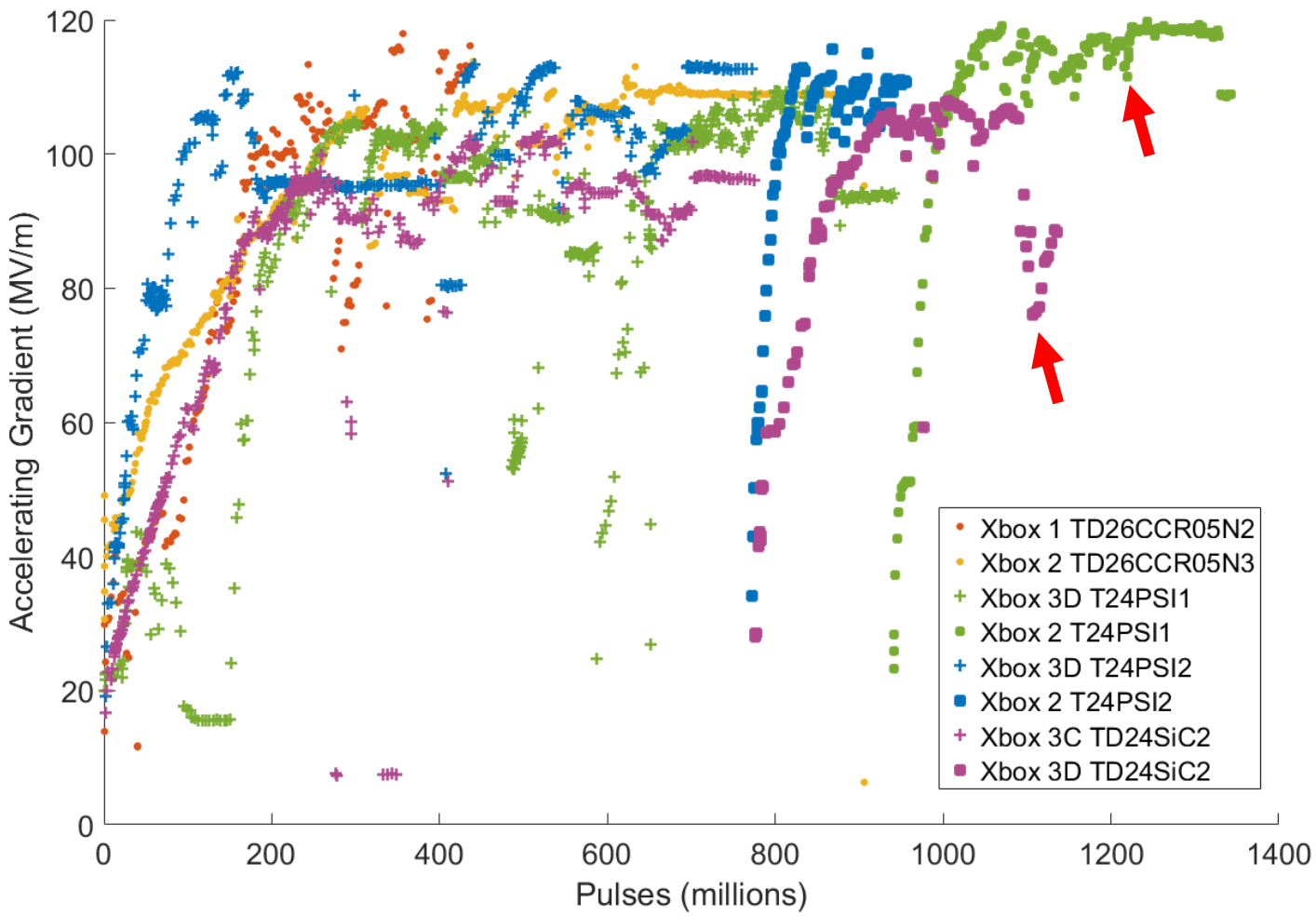


Conditioning algorithm

Conditioning of Different Structures

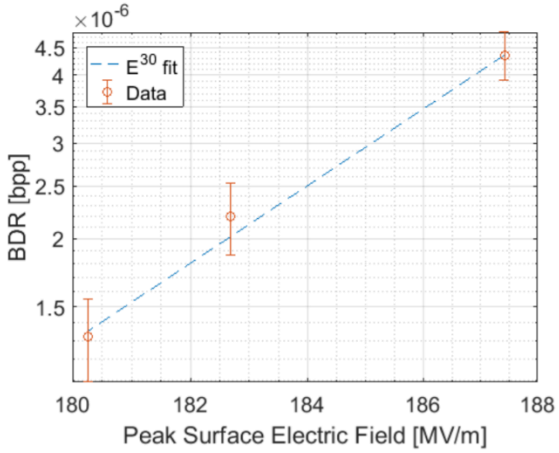
The conditioning curve can differ from the 'ideal' one due to constraints such as:

- Limited available power
- Vacuum level of other line
- Radiation limits
- Breakdowns in test stand itself (esp. pulse compressors)
- Large breakdown clusters



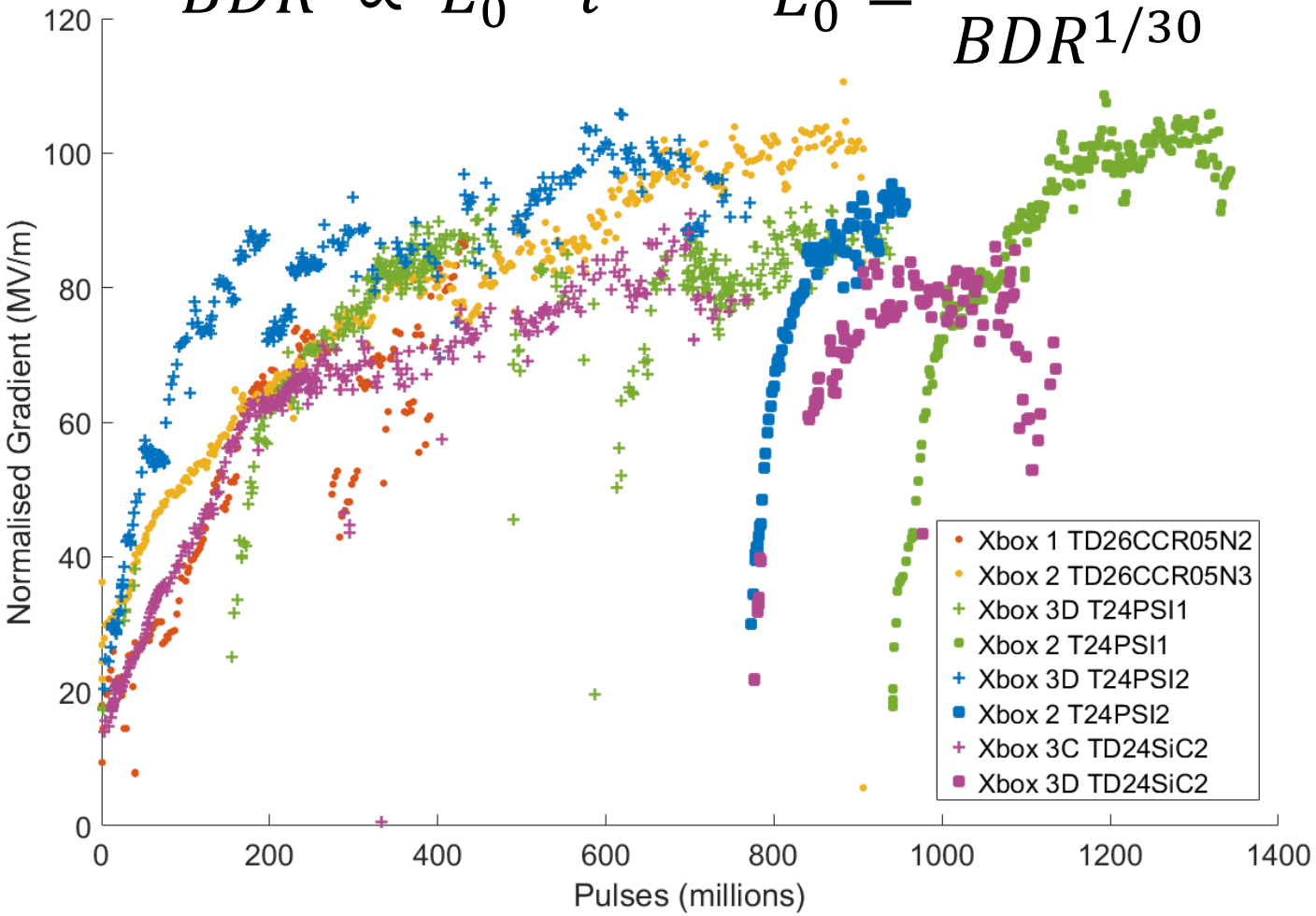
Conditioning Comparison – Normalised Gradient

- Gradient, BDR and pulse width summarised using normalised gradient.
- Based on empirical relationship between E, BDR and τ.
- Higher normalised gradient = low BDR at high field and long pulse length, ie. well-conditioned.



BDR dependence on field in TD26CCN3 structure in Xbox 2. (Thomas Lucas)

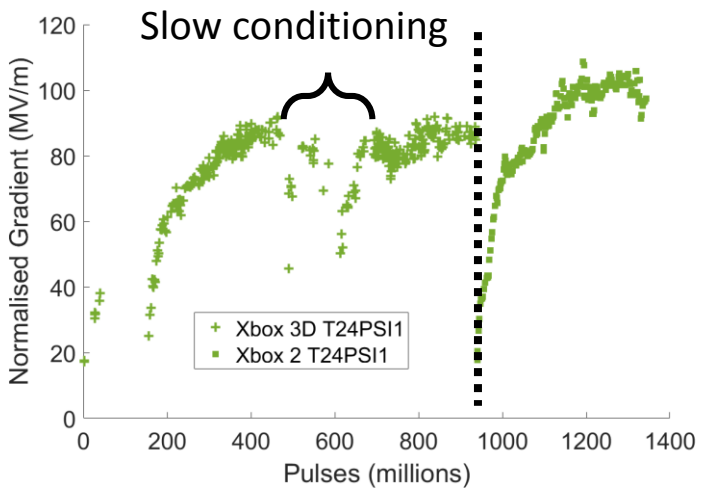
$$BDR \propto E_0{}^{30}\tau^5 \qquad E_0^* = \frac{E_0 \cdot \tau^{1/6}}{BDR^{1/30}}$$



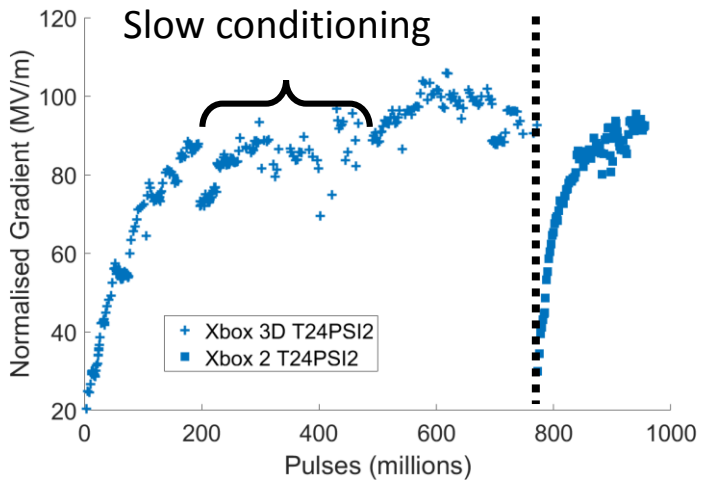
Persistence of Conditioning State

- 3 structures have been moved from one line to another so far to continue conditioning at higher power. During moving, the structures are exposed to air for several hours.
- In each case, the structure needs some time to re-condition but it is significantly faster than the first time.
- Both the PSI structures also spent some amount of time at reduced power due to external factors – normalised gradient did not increase significantly in this period.

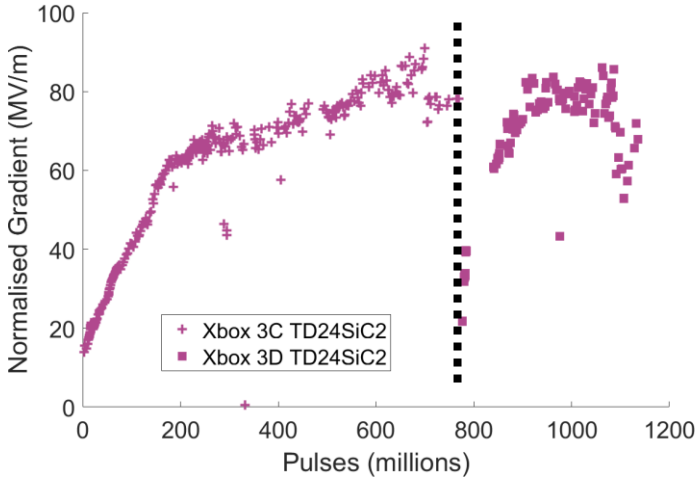
T24 PSI 1



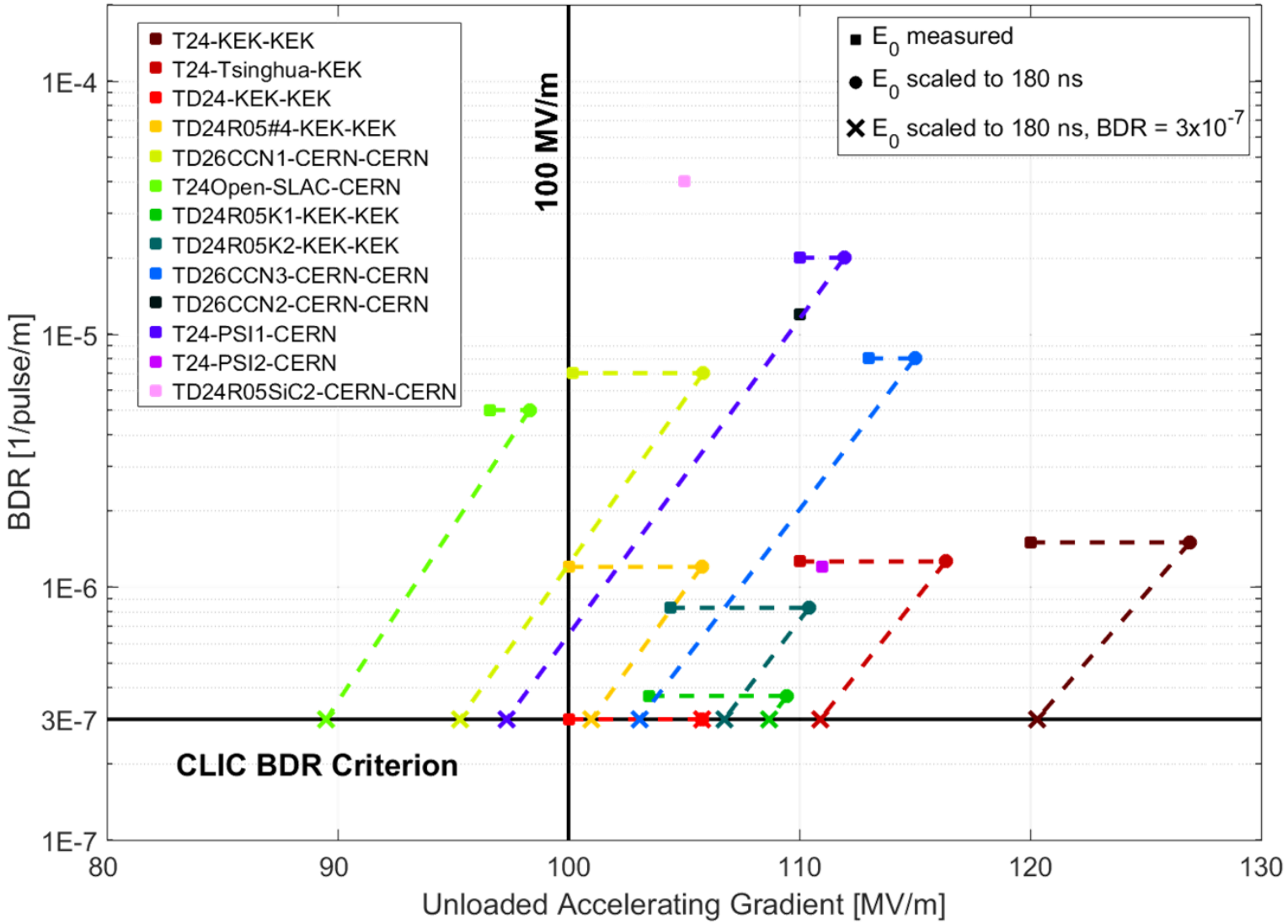
T24 PSI 2



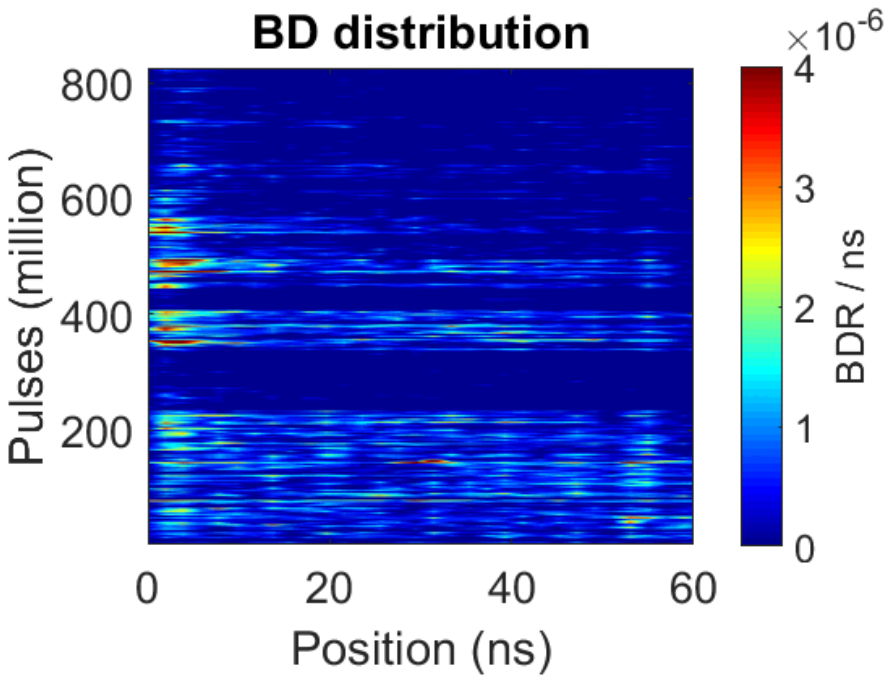
TD24 SiC 2

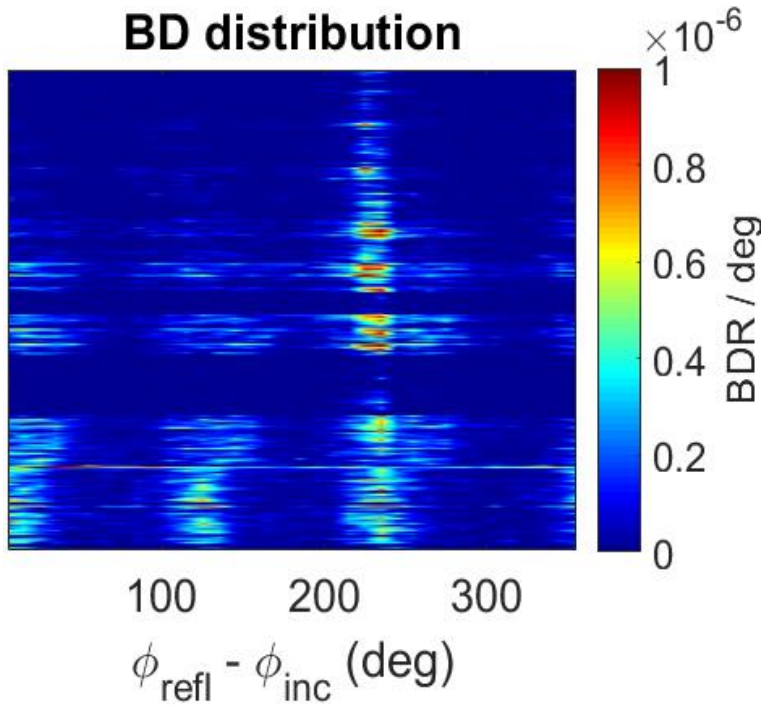


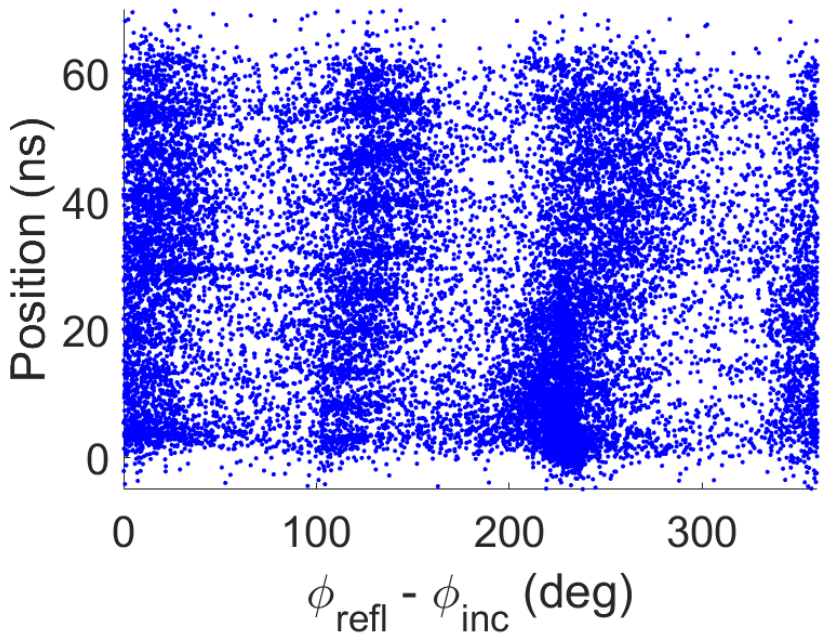
Structure Final Performance



Breakdown Locations (TD26CCN3)

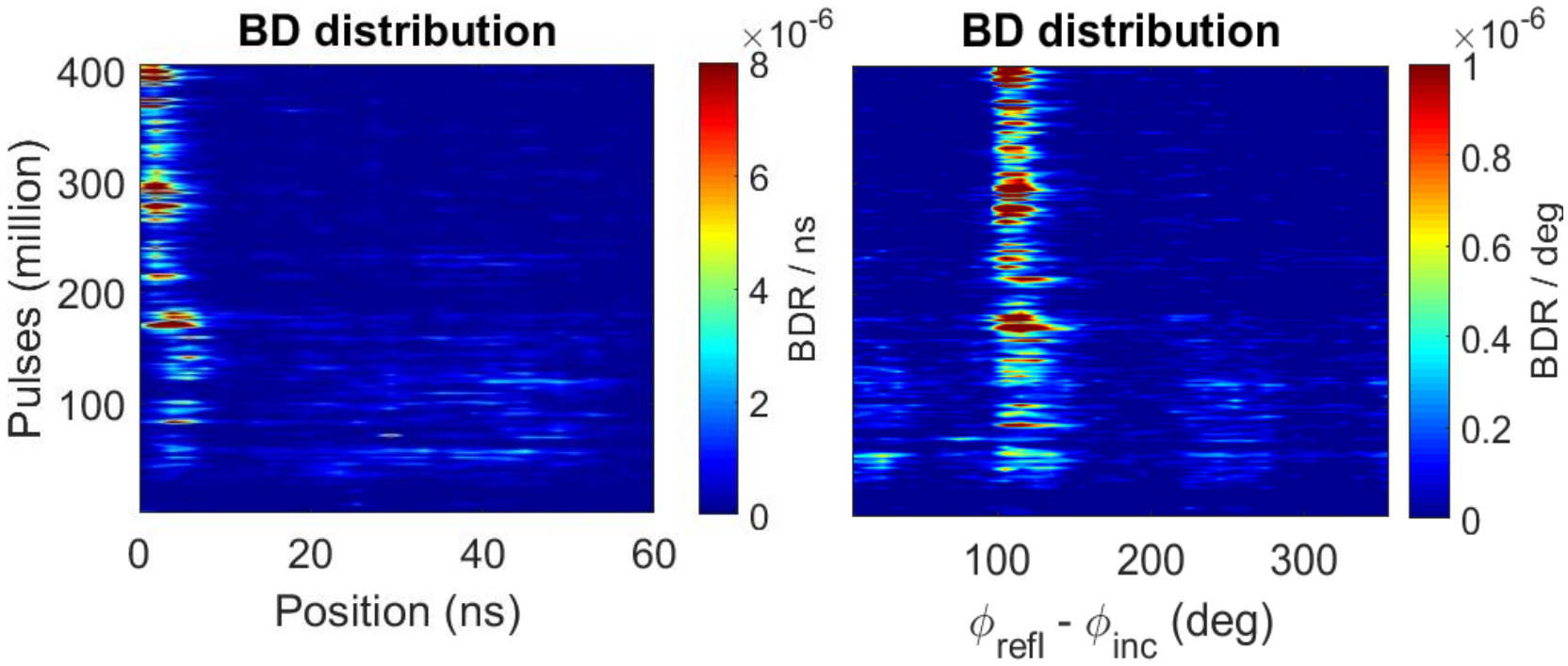


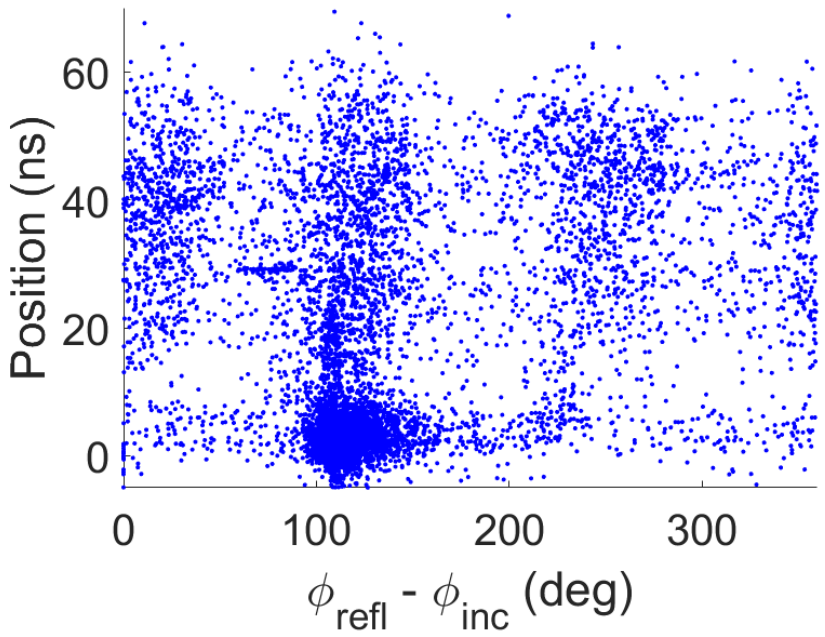




120° nominal phase advance per cell:
BDs in adjacent cells are 120° apart.
Detuning changes this value.

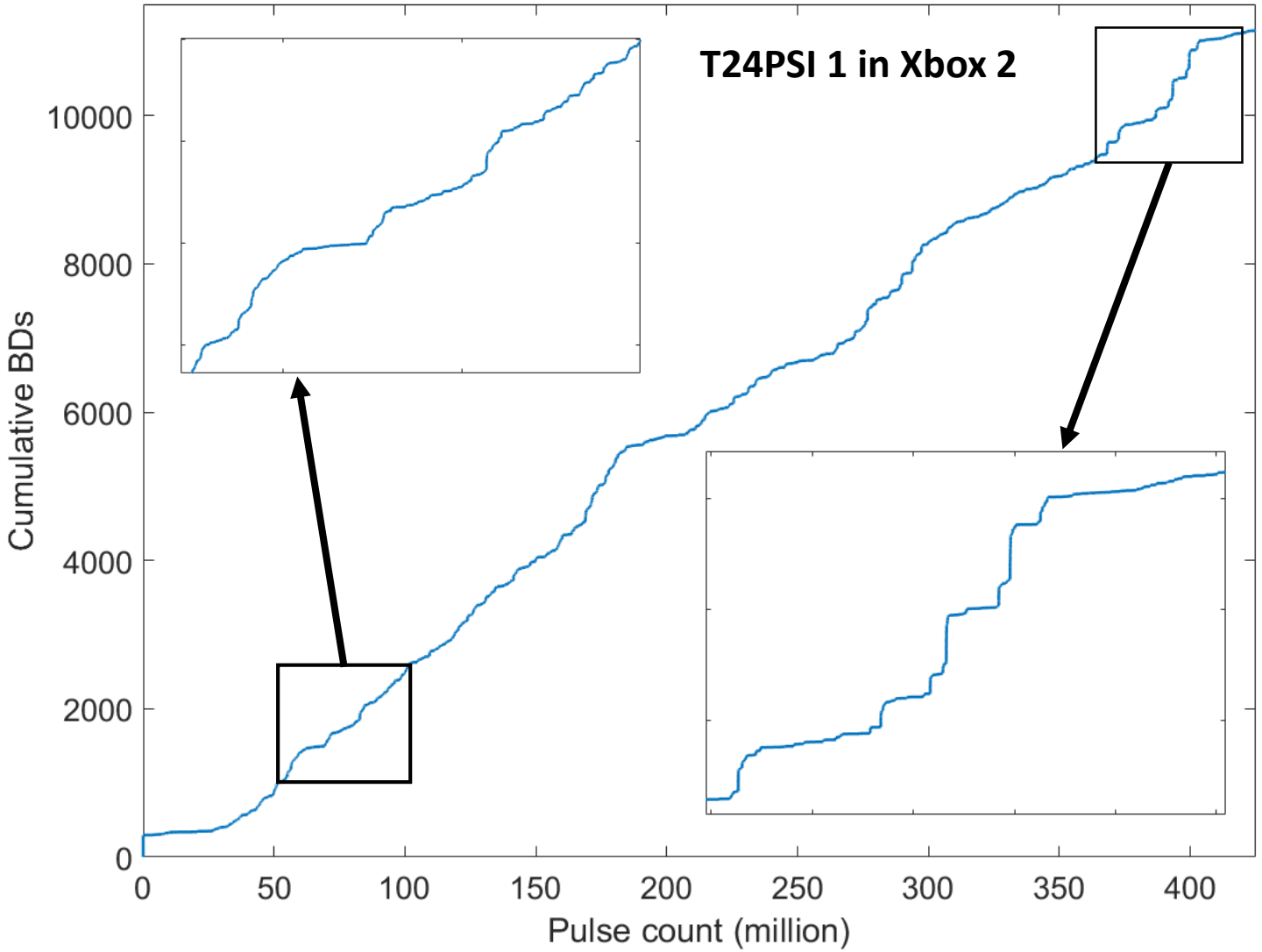
Another Example (T24PSI1)





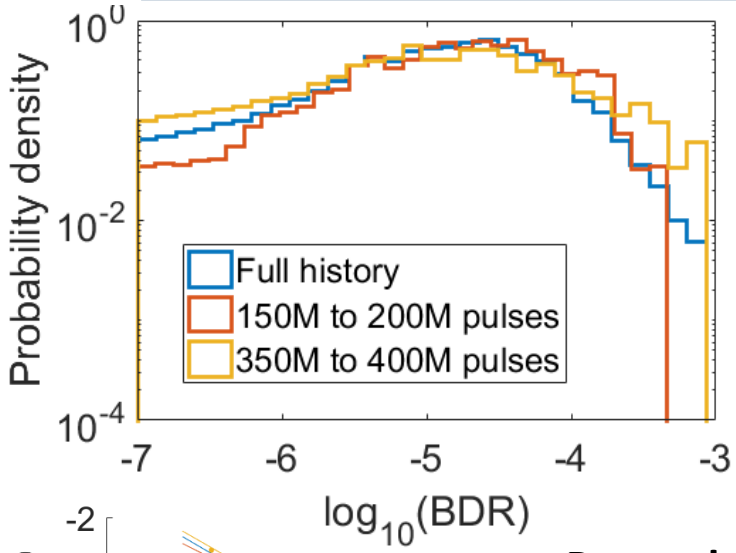
This structure was already partially conditioned in another line before being installed in Xbox 2 – concentration of BDs in start of structure already apparent from the beginning of the test.

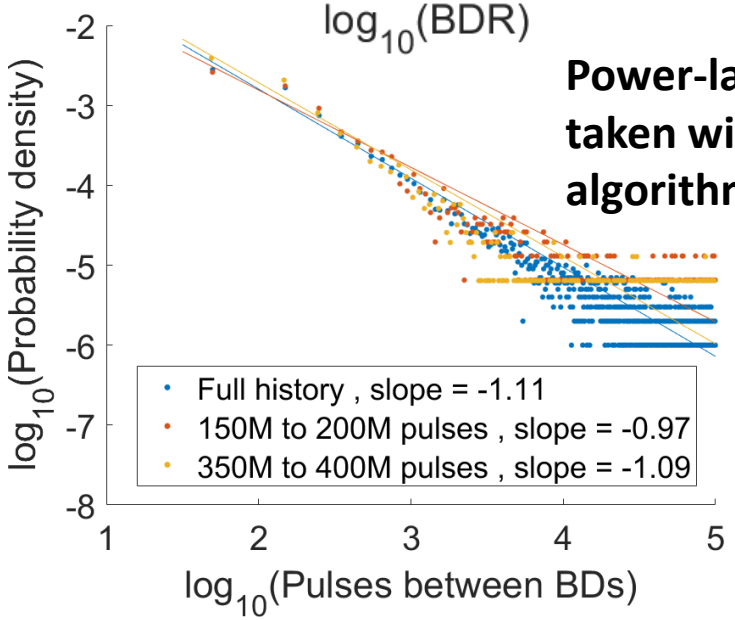
Breakdown Clustering



Similar average slope (breakdown rate) but instantaneous BDR is either very high or very low.

BDR Statistics – T24PSI1

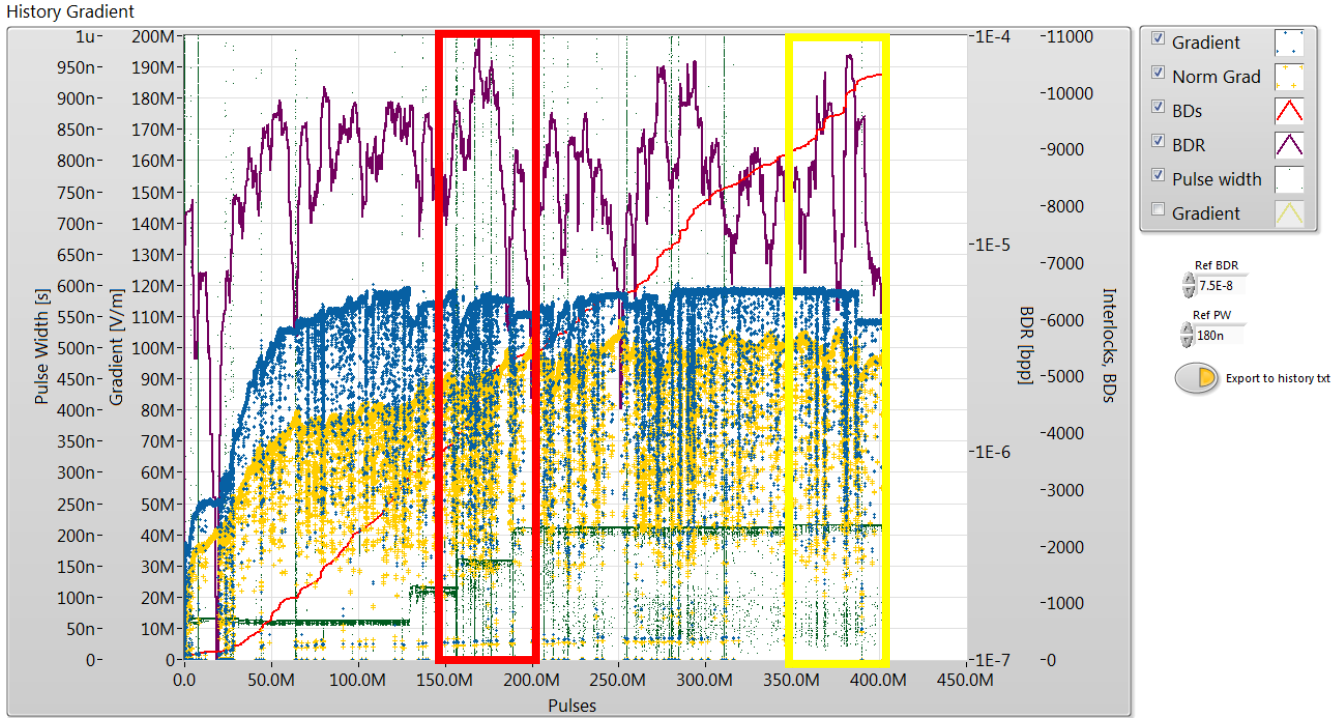




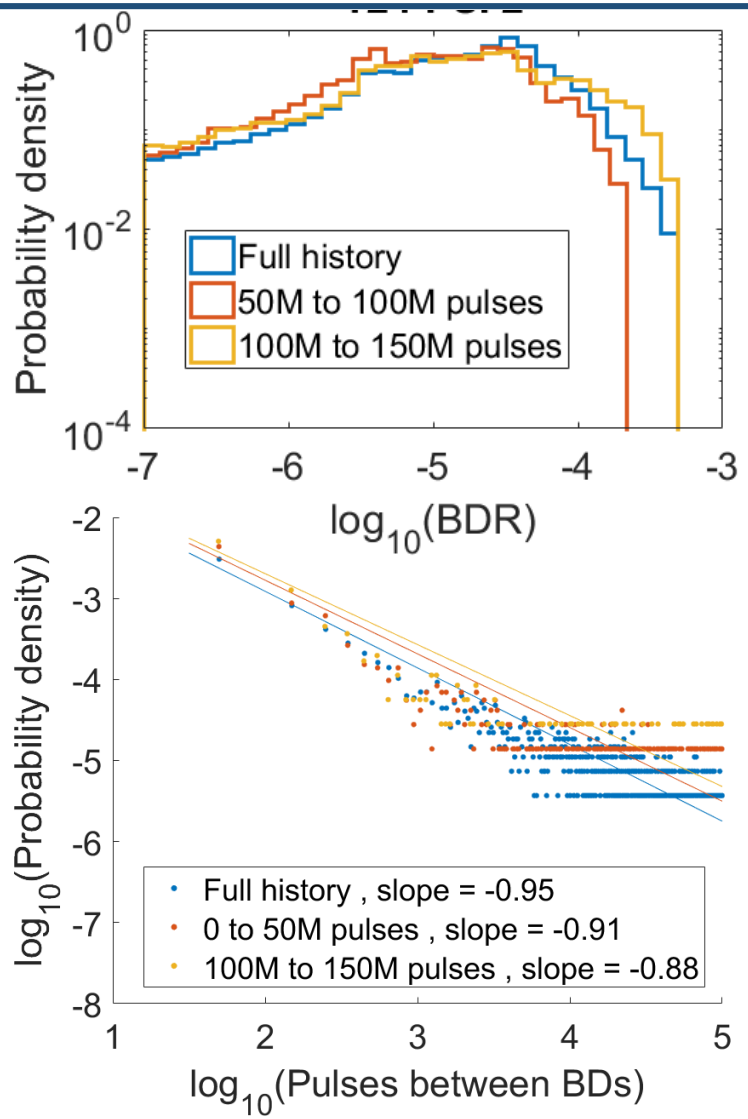
Power-law fit; data taken with conditioning algorithm ON.

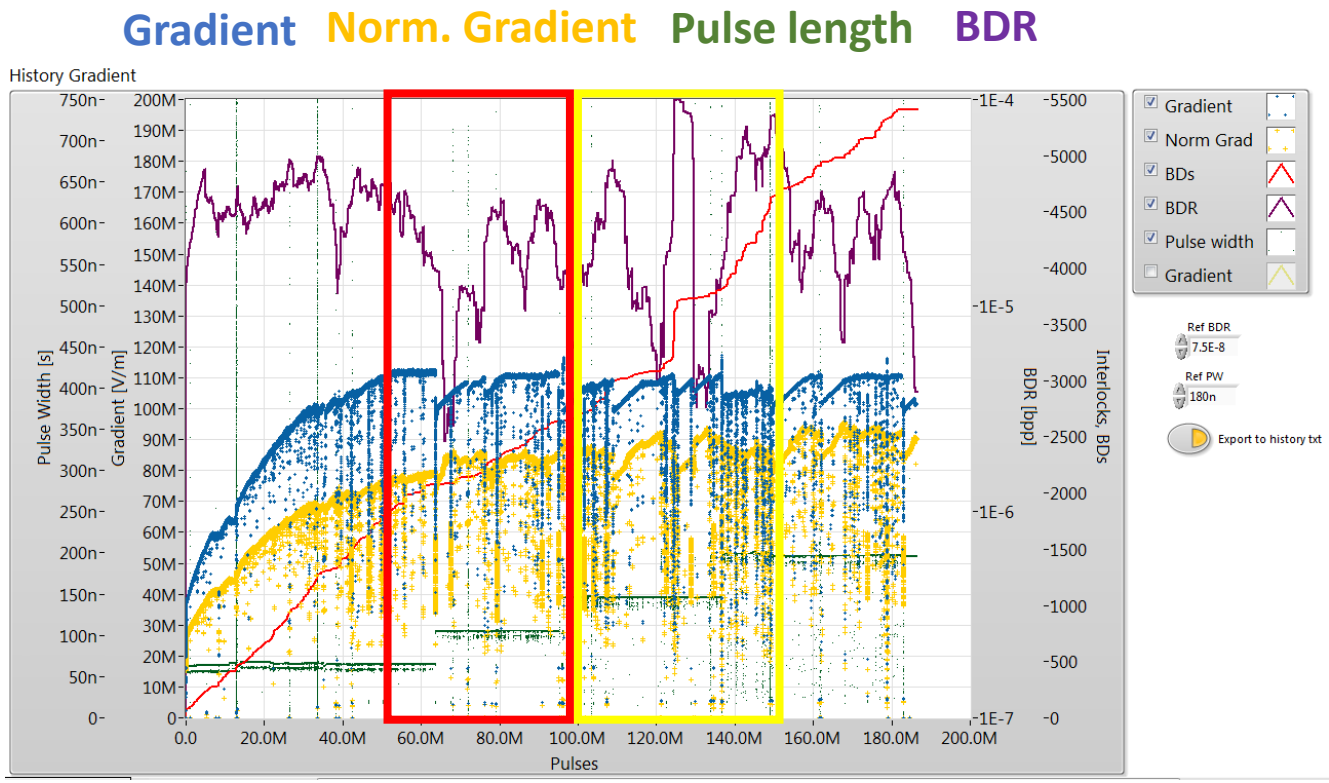
BDR in histogram obtained using a Gaussian window with σ = 50000 pulses. BDR window for conditioning algorithm is 360000 pulses. An IIR window is essential for high dynamic range.

Gradient **Norm. Gradient** **Pulse length** **BDR**

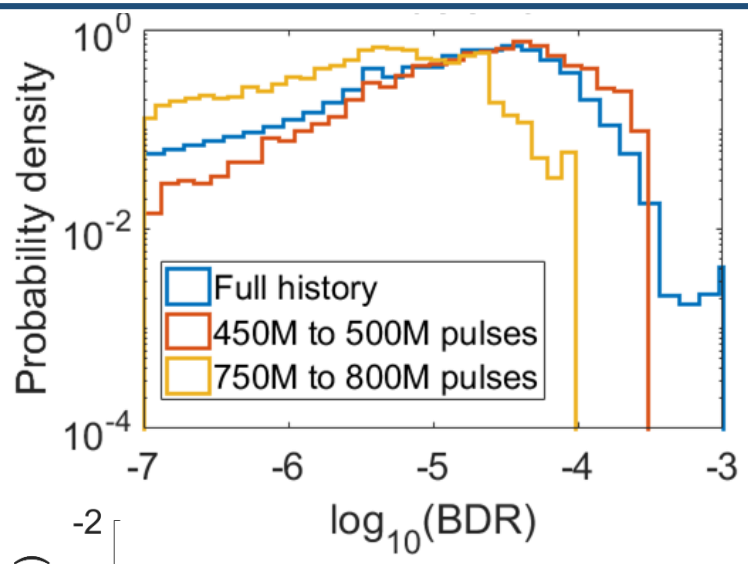


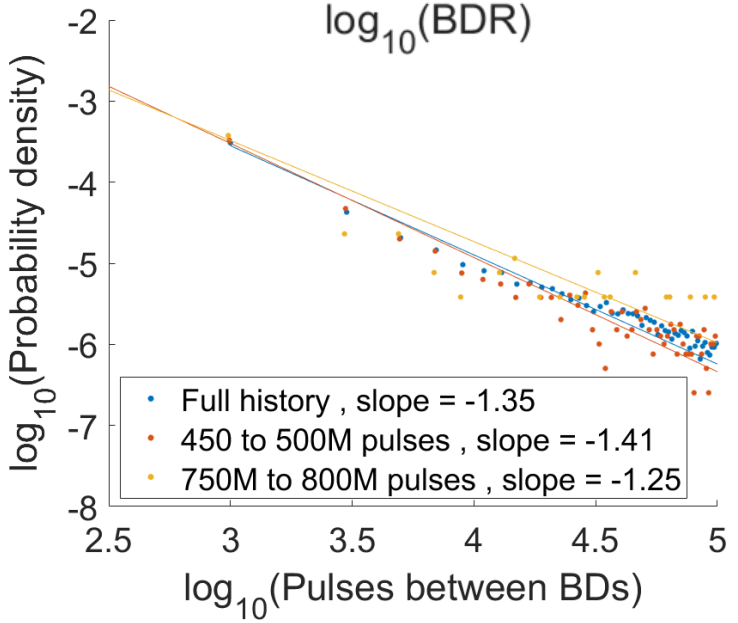
BDR Statistics – T24PSI2



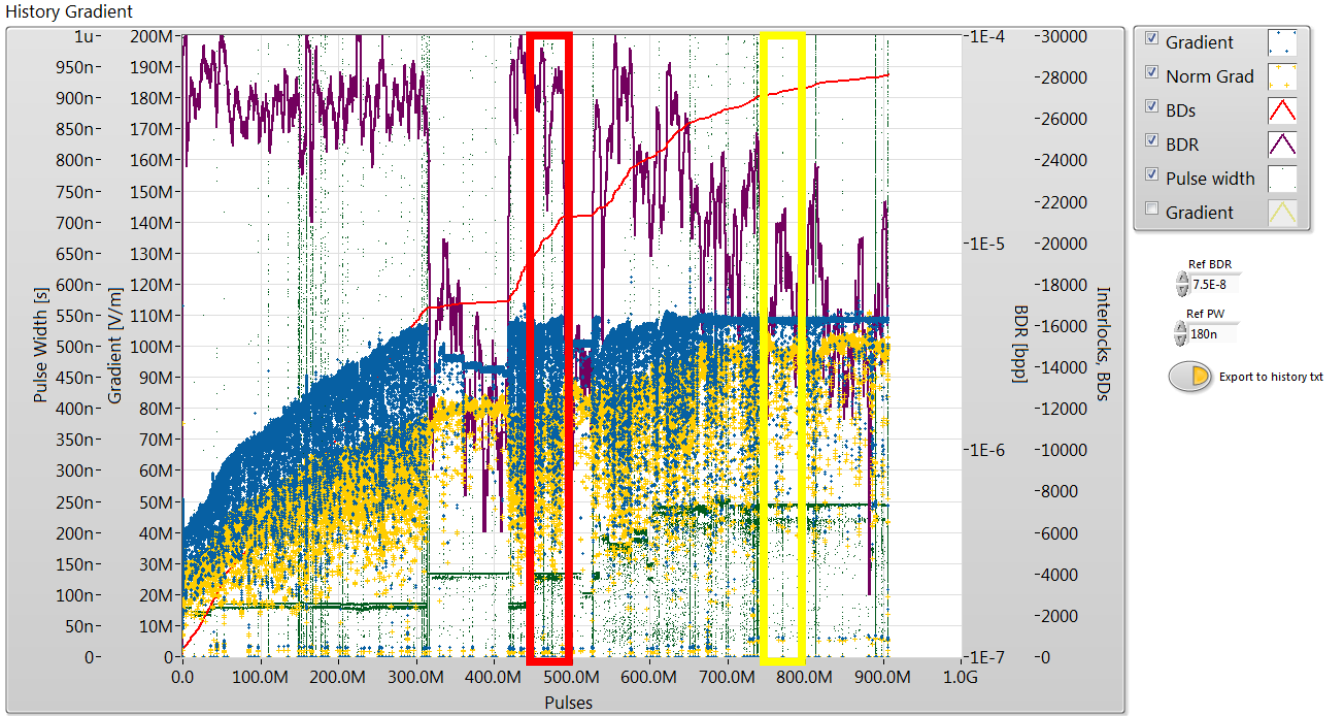


BDR statistics – TD26CCN3



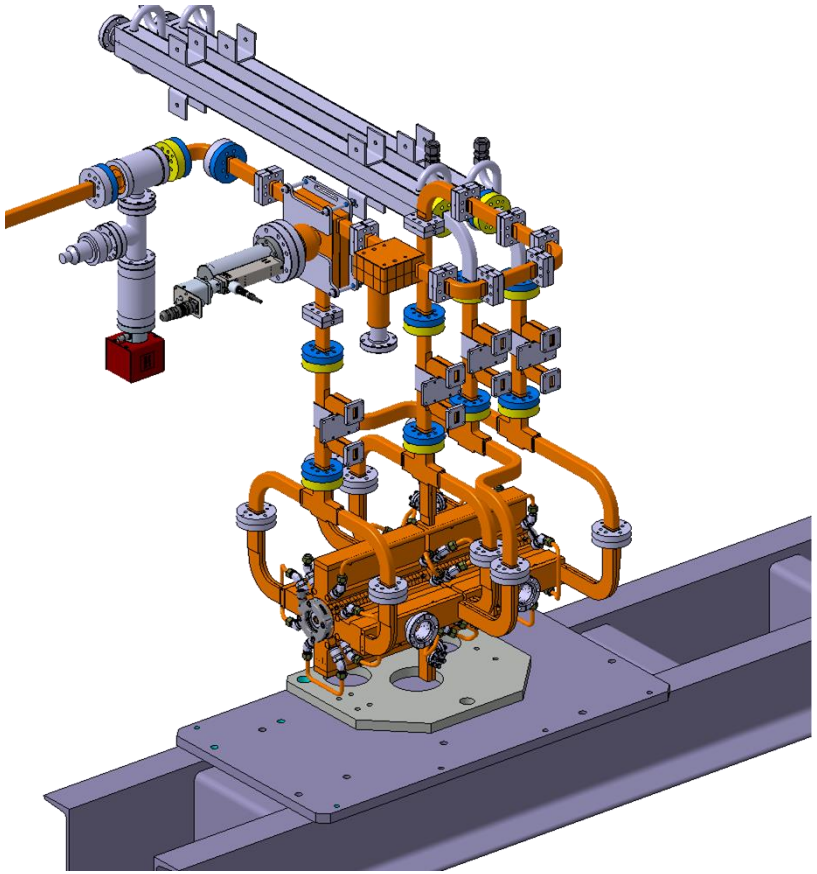


Gradient **Norm. Gradient** **Pulse length** **BDR**



Future Developments

- Xbox 1: work under way for testing with beam.
- Xbox 2: planning to install a superstructure – currently testing a high power phase shifter and power splitter.
- Radiation diagnostics
  - Cherenkov fibres: used to detect emitted particles from field emission and breakdown. Ongoing work to improve measurement.
  - Calorimetry of emitted particles (already done on Sbox)
  - Pixel detector?



Thank you!

Questions?

Comparison of BDR windows