Overview of High-Gradient RF Tests at CERN

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On behalf of the CLIC ML Collaboration.

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Mini-MeVArc Session

16/06/2021

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1. **Introduction to CLIC.**
2. RF Conditioning and Breakdown.
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Compact Linear Collider (CLIC) Overview

- CLIC is a concept for a next generation high energy physics (HEP) facility.
- Staged implementation to collide electrons and positrons at energies from 250 GeV to 3 TeV (e+ e- collider).
- To achieve this in a reasonable length accelerating structures operating at an accelerating gradient of 100 MV/m are proposed.

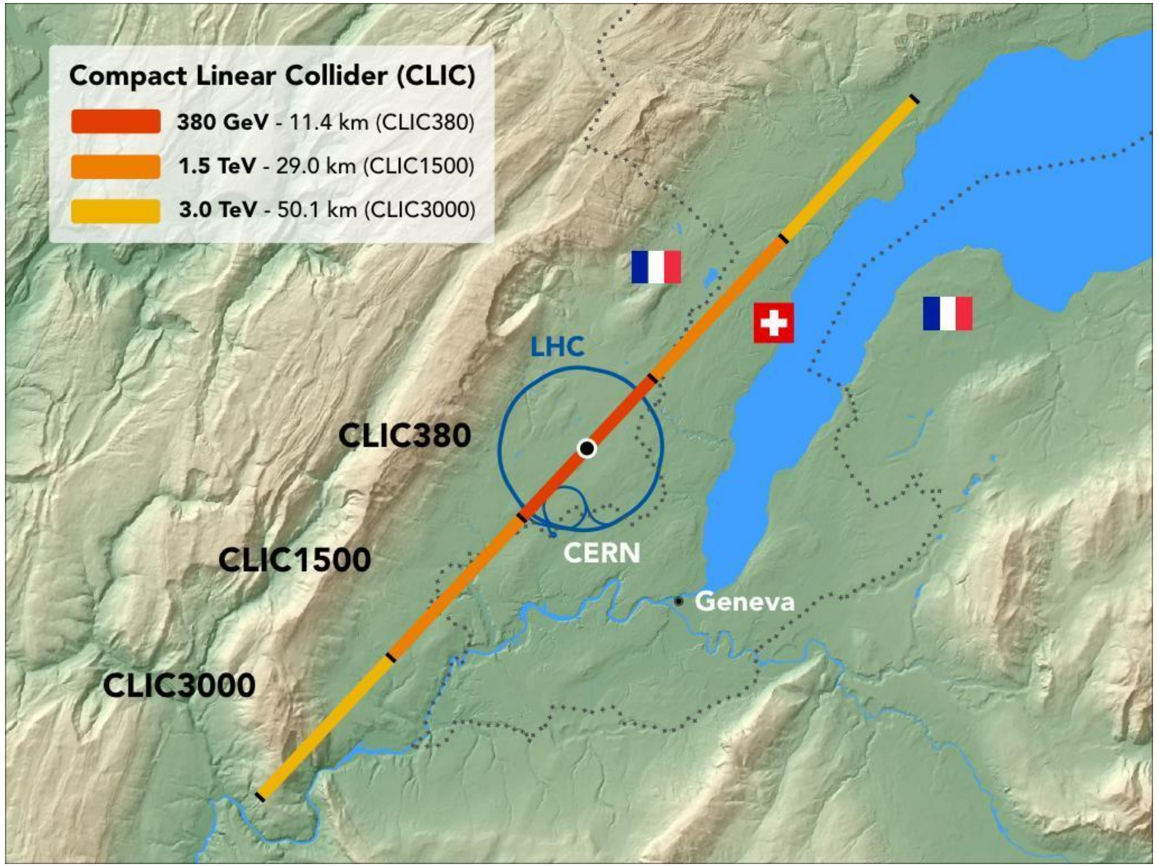


Figure: Overhead view of the planned CLIC layout.[1]

RF Acceleration

- These structures are of a travelling wave (TW) normal conducting design.
- The basic principle of operation is the synchronisation of a traversing particle with an oscillating voltage between a series of capacitive discs.

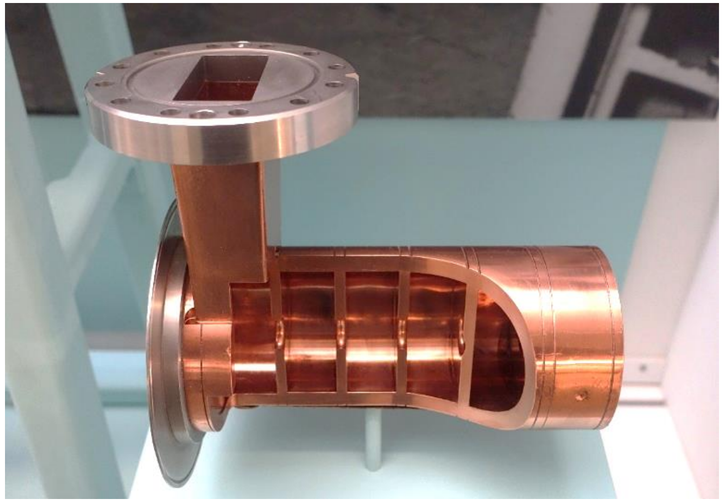


Figure: Cutaway of a copper LINAC. [2]

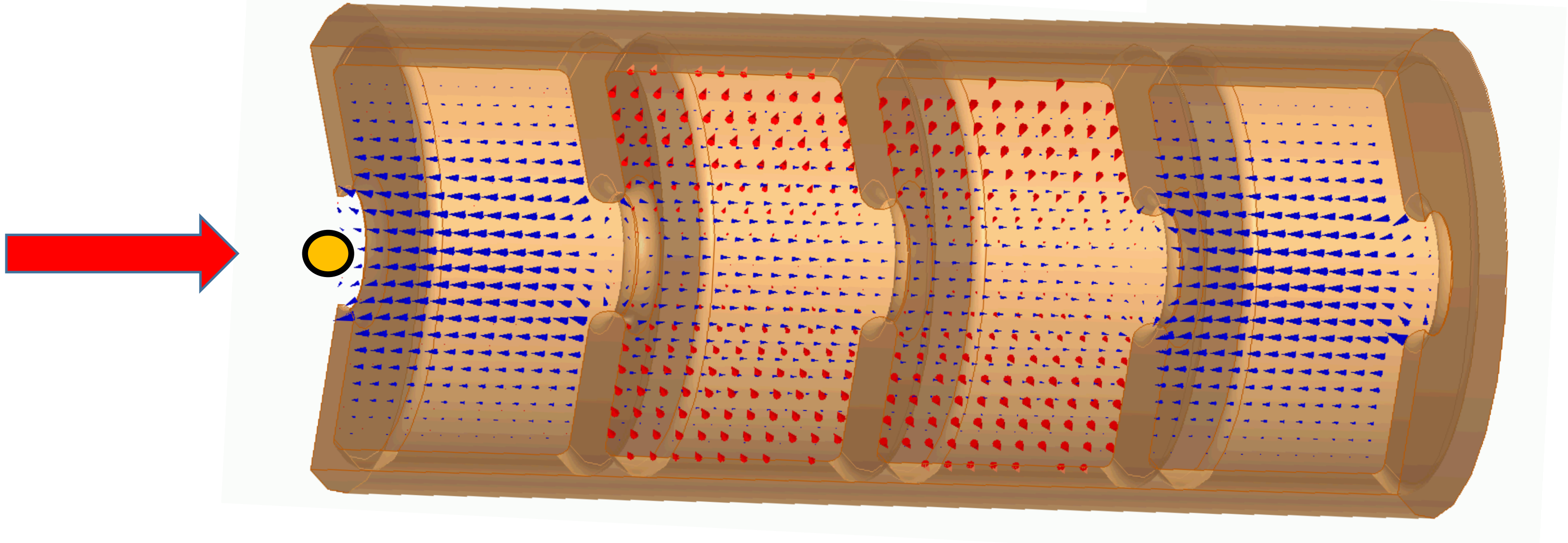
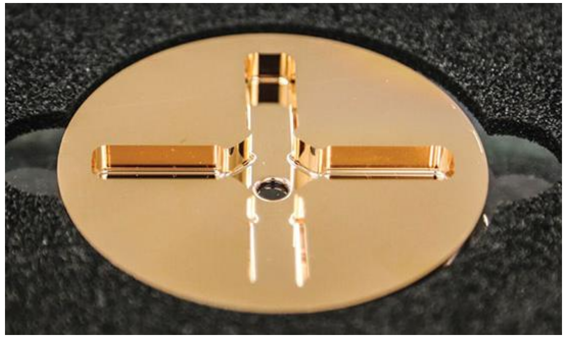
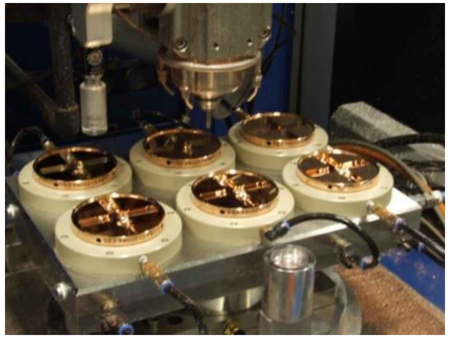


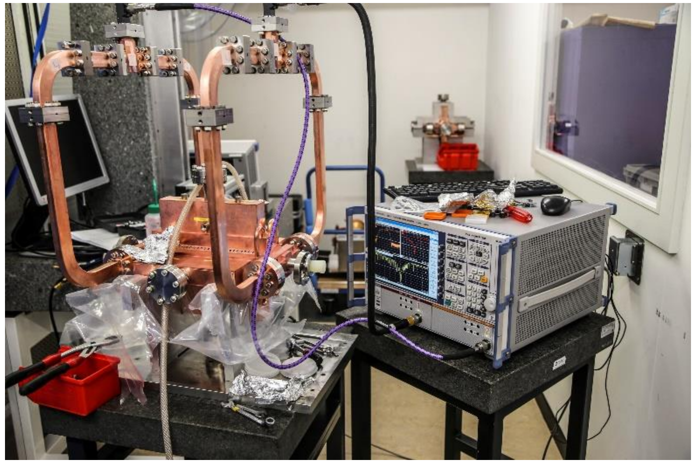
Figure: Simulated electric fields in a copper LINAC and a synchronous passing particle.

Technology for CLIC

The CLIC collaboration has invested much effort in the development of such structures:

- X-band (11.994 GHz) Travelling Wave Structures.
- OFE copper, hydrogen bonded 1040 °C.
- Accelerating gradient (particle energy gain) = 100 MV/m.



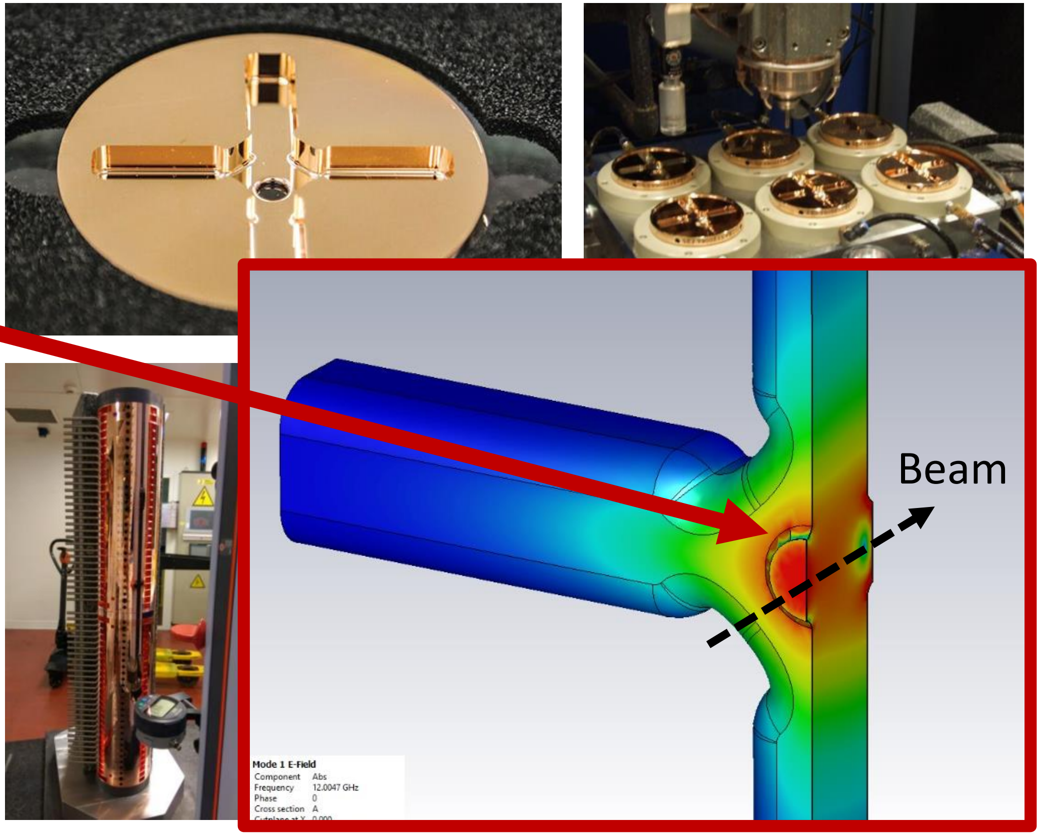
Figures: Precision machined disc (top left), metrology of discs (top right), stacking and alignment (bottom left) and VNA measurement of an assembled and tuned structure (bottom right).

Technology for CLIC

At CERN we regularly operate these TW LINACs and other novel RF components at:

- Peak surface fields ≈ 220MV/m
- Peak input power: 40 - 50 MW.
- RF Pulse length ≈ 200 ns (12 Joules per pulse).

However, components can't operate at this level immediately. They are limited by breakdown (vacuum arcs).



Figures: Precision machined disc (top left), metrology of discs (top right), stacking and alignment (bottom left) and VNA measurement of an assembled and tuned travelling wave high gradient accelerating structure (bottom right).

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High-Voltage Conditioning

Limited by breakdown (vacuum arcing) and must be conditioned:

I. **Increasing gradient/power while keeping constant breakdown rate.**

II. **Decrease power, increase the pulse length (50, 100, 150, 200ns) and ramp back up.**

III. **Finally, the BDR drops and we run reliably.**

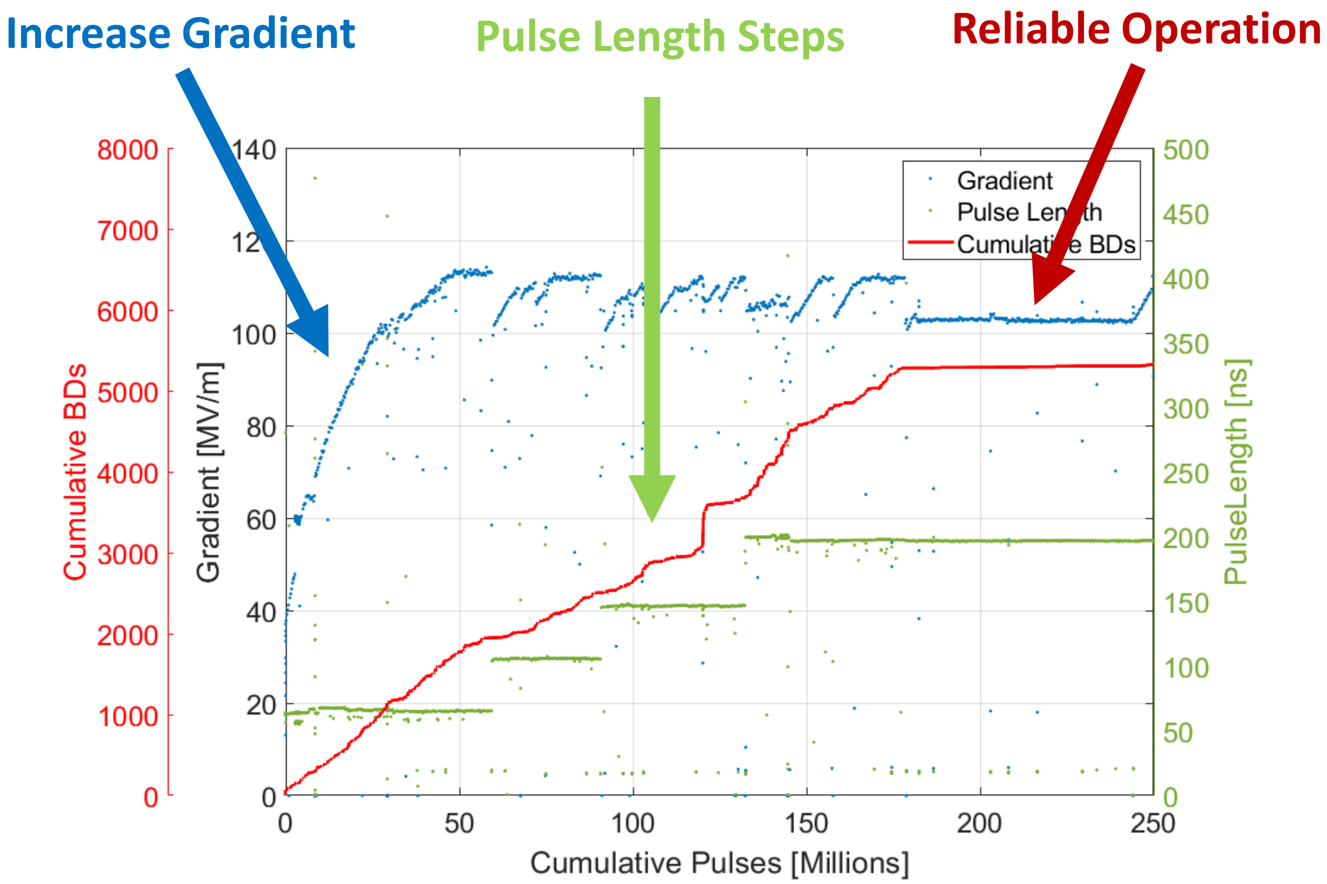

Figure: Test results of the PSI2 structure showing a typical conditioning curve.

High-Voltage Conditioning

Structures must be conditioned i.e. The power is gradually increased over time while monitoring for breakdowns.

- **Accomplished algorithmically at CERN** (for details see[3,4]).
- Structures condition on the **number of pulses not the number of breakdowns [5]**.

NB: Cleanliness of preparation shown to affect number of breakdowns during conditioning, not ultimate performance. [6]

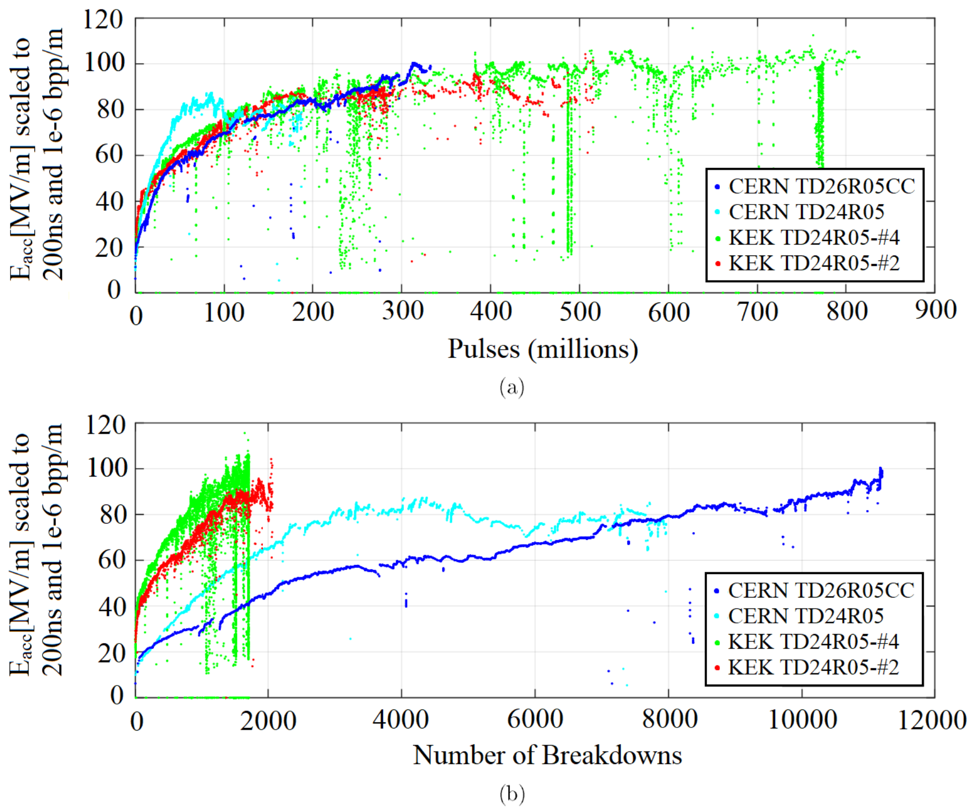

Figure: Scaled gradient vs. cumulative no. pulses (top) and scaled gradient vs. cumulative no. breakdowns (bottom) for four different structures [5].

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High-Voltage Conditioning

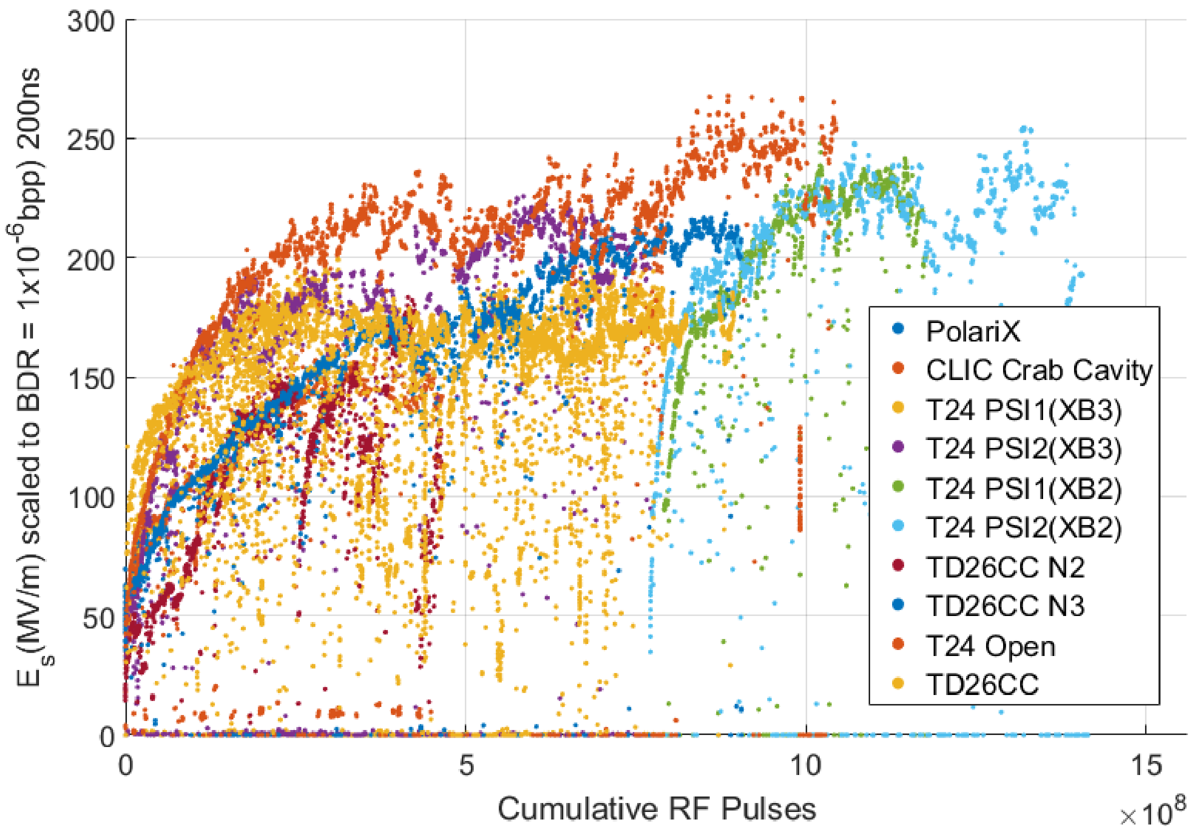
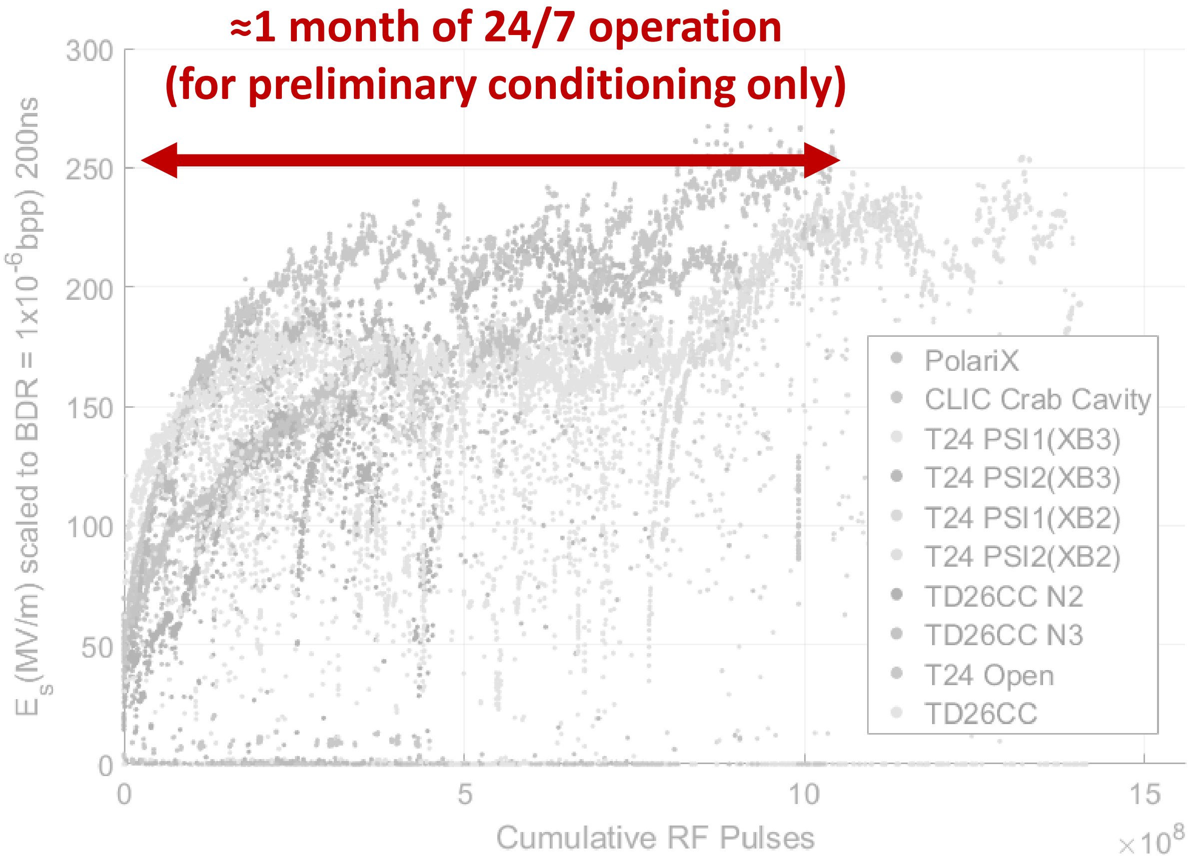


Figure: Initial conditioning of many structures conditioned to date normalised to BDR and Pulse length. Note the asymptotic behaviour.

High-Voltage Conditioning



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CERN's Test Facility

To investigate the phenomena and test new accelerating structures/RF components three X-band (12GHz) test stands have been developed at CERN.

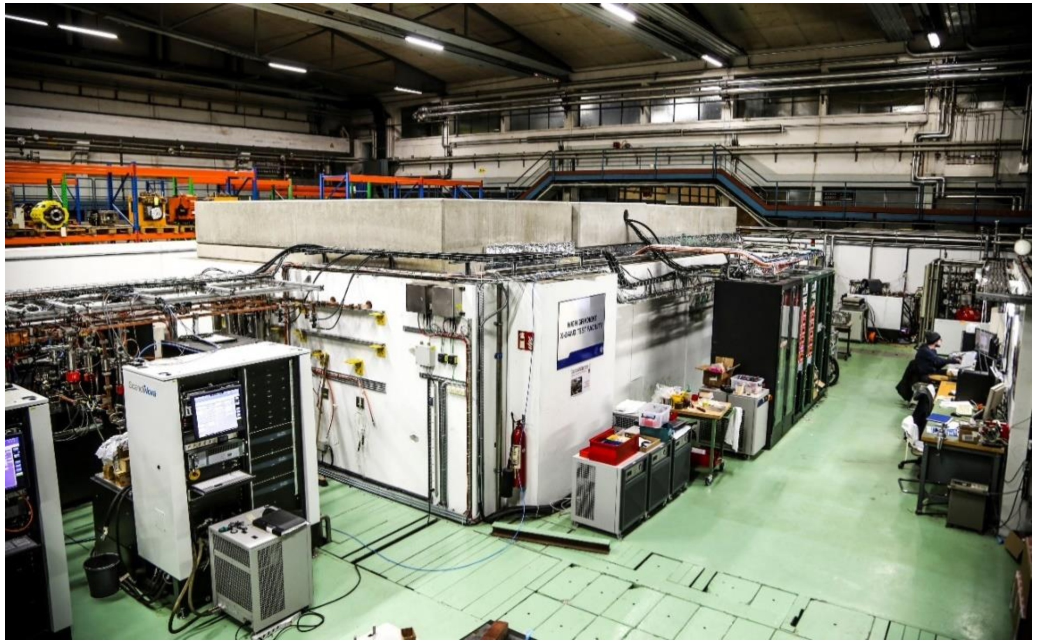


Figure: Exterior of the 12GHz high-gradient test facility at CERN.

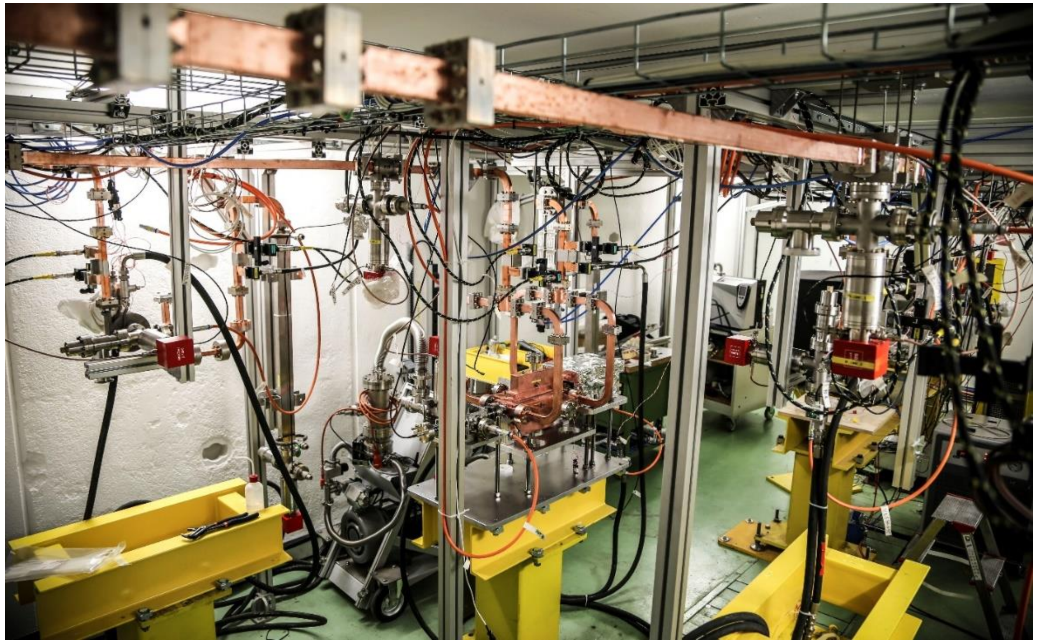
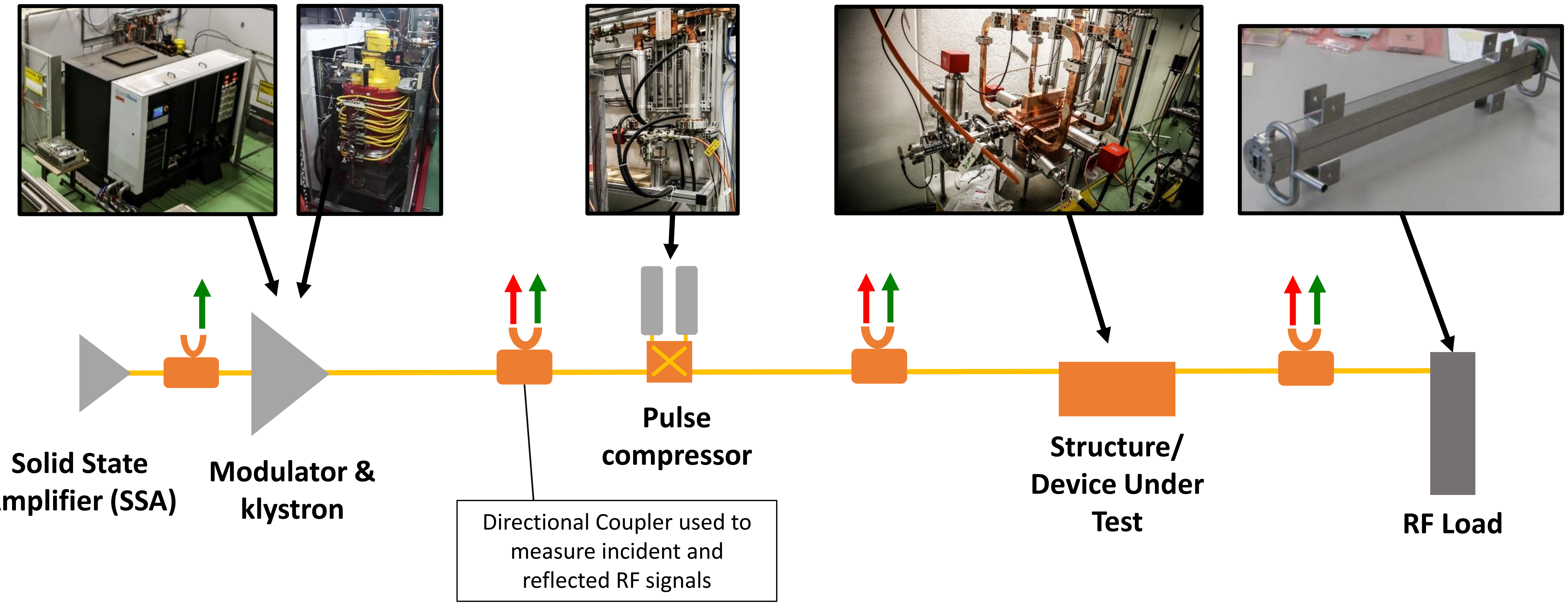
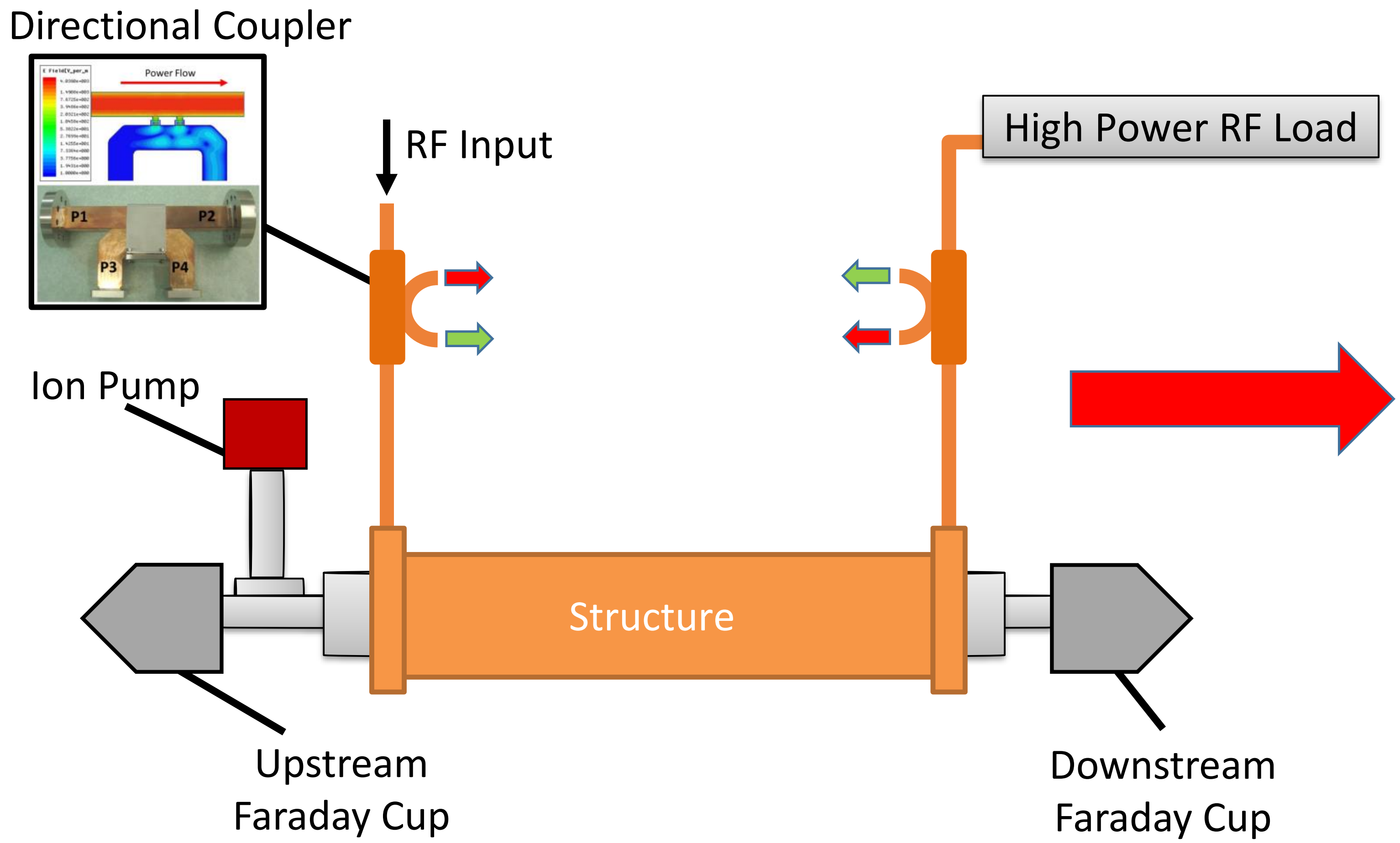


Figure: Accelerating structures under test inside the bunker.

Typical Test Stand Set-up



Diagnostics and Acquisition System



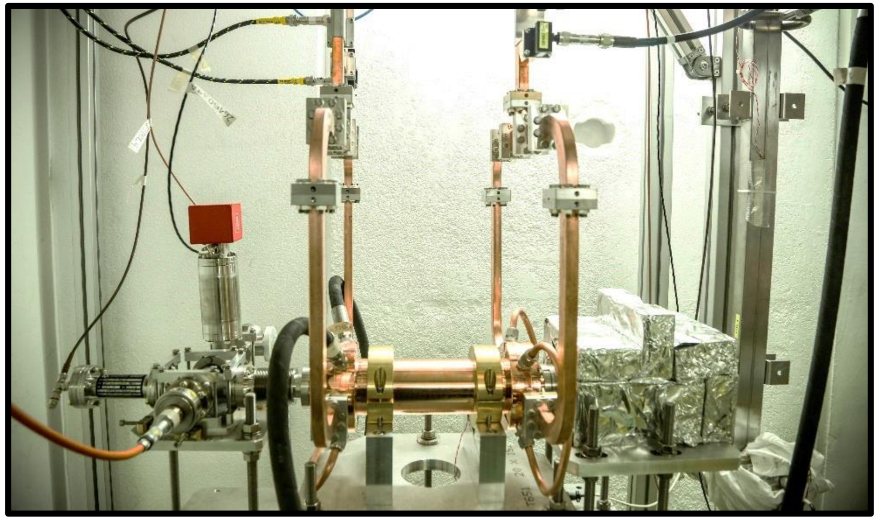
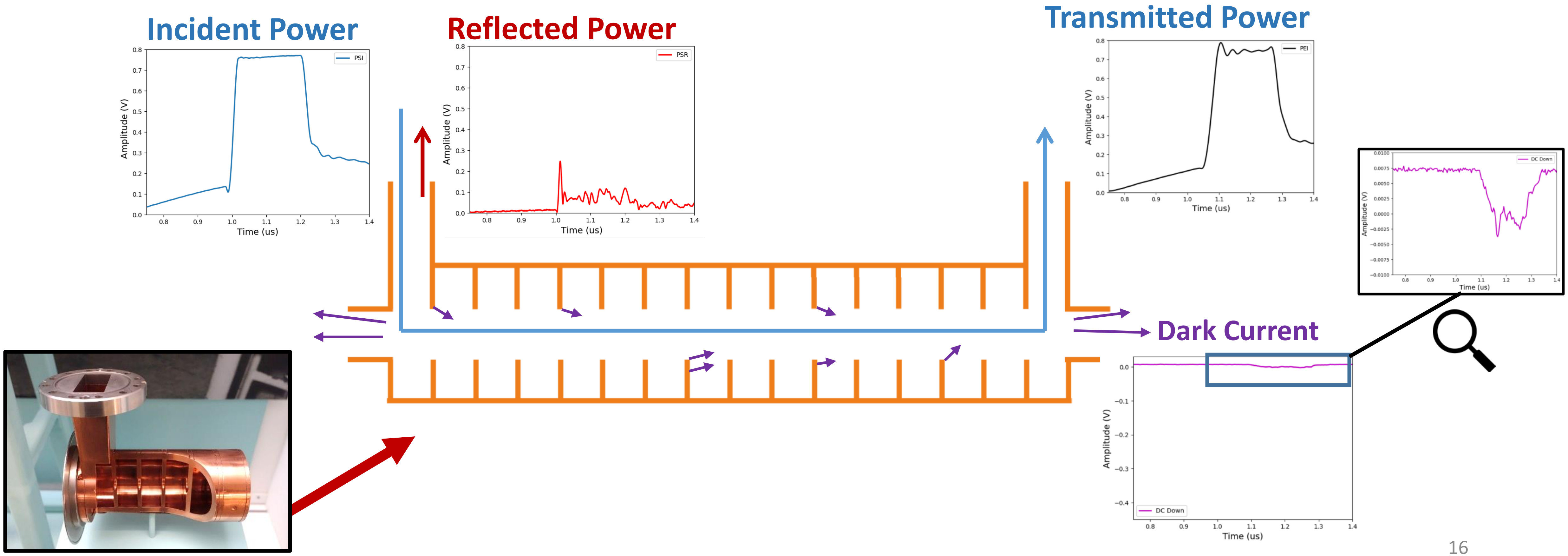


Figure: PSI2 structure installed in the Xbox-2 test slot.

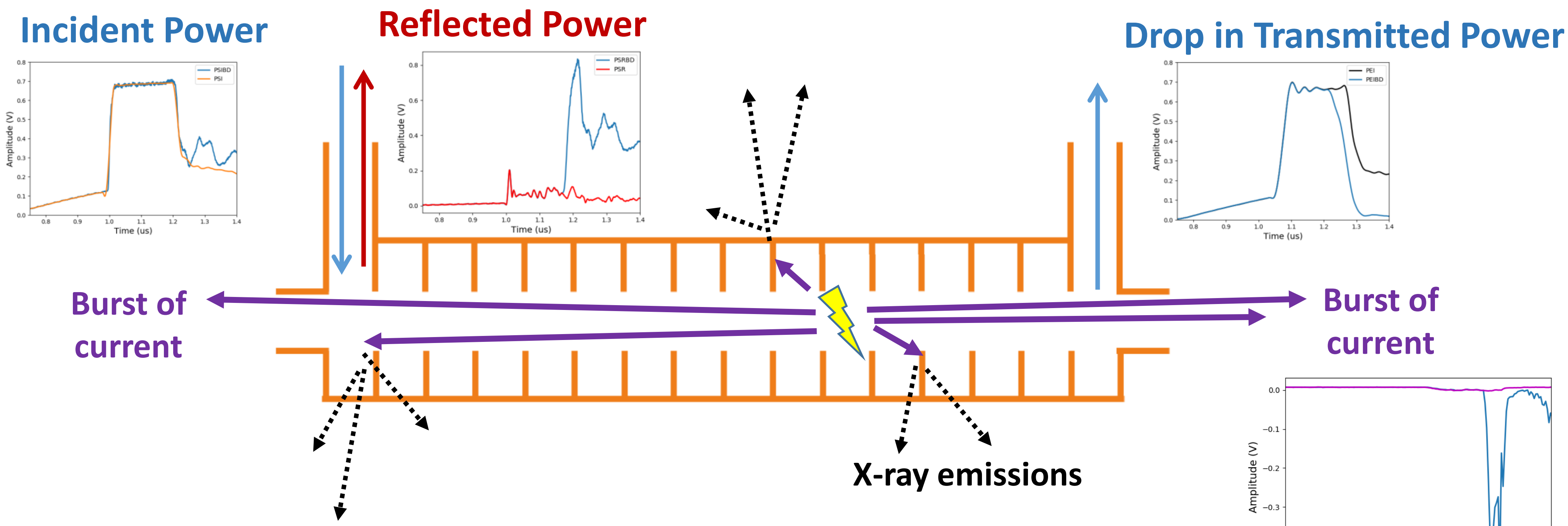
Characteristics of an RF Pulse

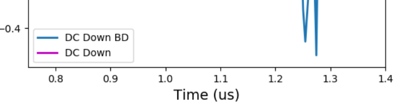
A typical RF pulse has the following characteristics:



Characteristics of RF Breakdown

In an RF context breakdowns are accompanied and often detected by:





For a collider this results in beam loss/degradation and hence a reduced luminosity on that pulse.

Data Acquisition

Tested many structures.

Alongside the waveforms, we also acquire auxiliary data i.e. vacuum and temperature sensors throughout the system.

Typically accumulate 1-200GB of data per test which is analysed manually by an operator with a hypothesis.

Recently, a machine learning framework has been developed and applied to search for breakdown precursors, with interesting results…

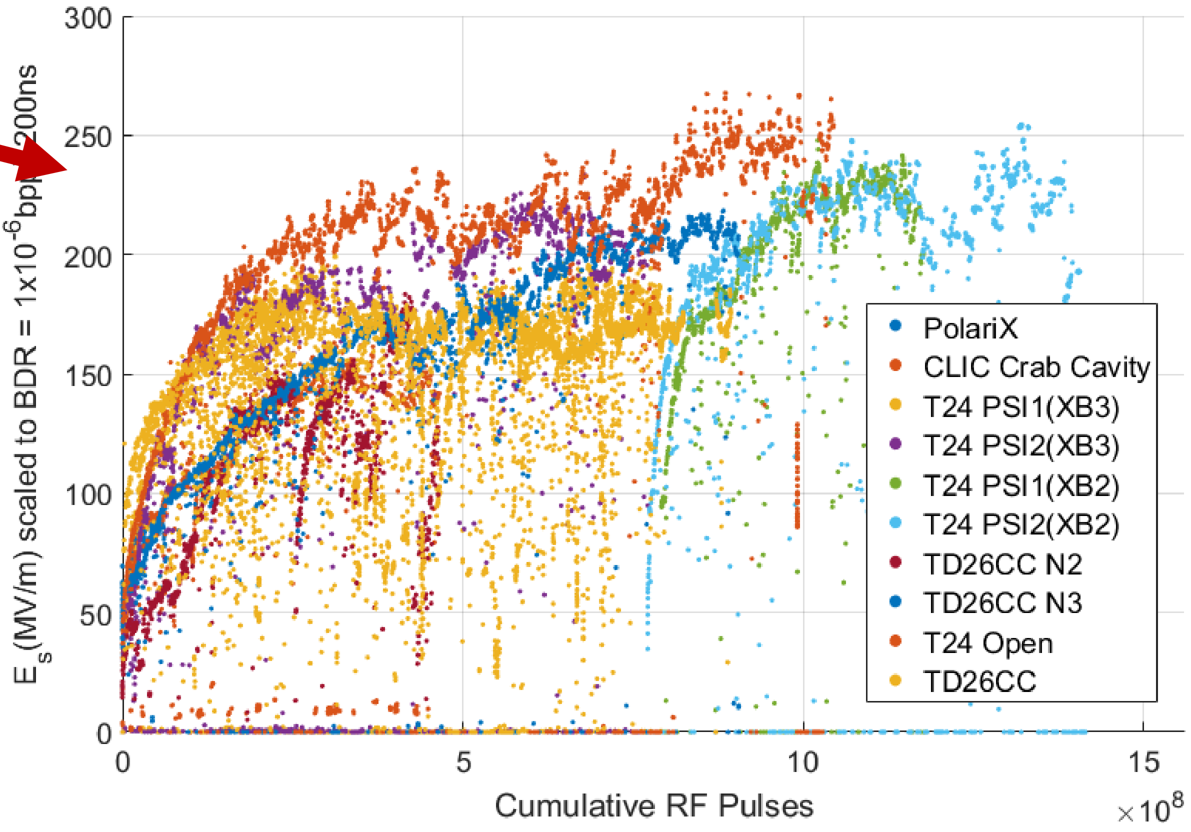


Figure: Initial conditioning of many structures conditioned to date normalised to BDR and Pulse length. Note the asymptotic behaviour.

And now, over to Christoph…

References

[1] - http://cds.cern.ch/record/2297076?ln=en
[2] - Exhibit in the National Museum of American History, Washington, DC, USA. Available: https://upload.wikimedia.org/wikipedia/commons/6/65/Linear_accelerator_%28cutaway_section%29%2C_Stanford_Linear_Accelerator_Center%2C_1962-1966_-_National_Museum_of_American_History_-_DSC00009.jpg
[3] – B. Woolley, "High Power X-band RF Test Stand Development and High Power Testing of the CLIC Crab Cavity," Lancaster University, United Kingdom, 2015.
[4] –L.Millar, "Conditioning and Operational Algorithms", Presentation, Available online: https://indico.cern.ch/event/719535/
[5] - J. Giner Navarro, Breakdown Studies for High Gradient Rf Warm Technology in: CLIC and Hadron Therapy Linacs, University of Valencia, 2016.
[6] - Study of Basic Breakdown Phenomena in. Dolgashev, V.A. Tsukuba, Japan : s.n., 2010. XXV International Linear Accelerator Conference (Presentation).