Monte Carlo Model of High-Gradient Conditioning and Operation

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High-Voltage Conditioning

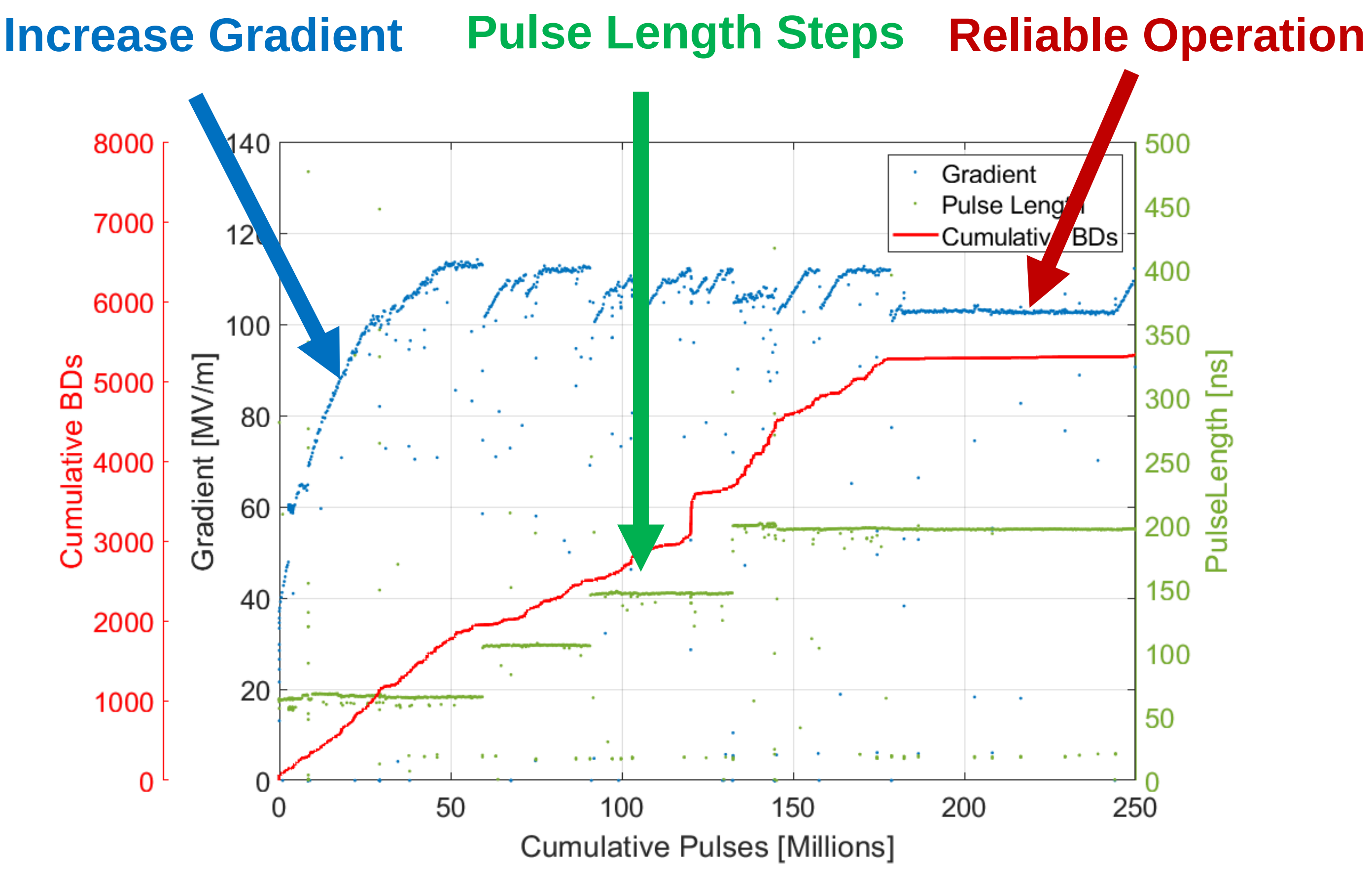
High-gradient structures (and high-power RF components) are often limited by breakdown.

To achieve stable high-power performance, they must be **conditioned**. At CERN, the procedure is generally looks something like this:

I. **Increasing gradient/power while keeping constant BDR.**

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

III. **Finally, the BDR drops. Stable operation achieved.**



Automation of Conditioning

Some years ago, a conditioning algorithm was developed to automate the process.

Offers a consistent and reproducible method of component testing, in short: **the power is slowly increased while tracking an operator-selected BDR [1,2].**

Has since conditioned many structures and components, similar procedures are also in place at Daresbury, SLAC, and elsewhere within CERN [3,4].

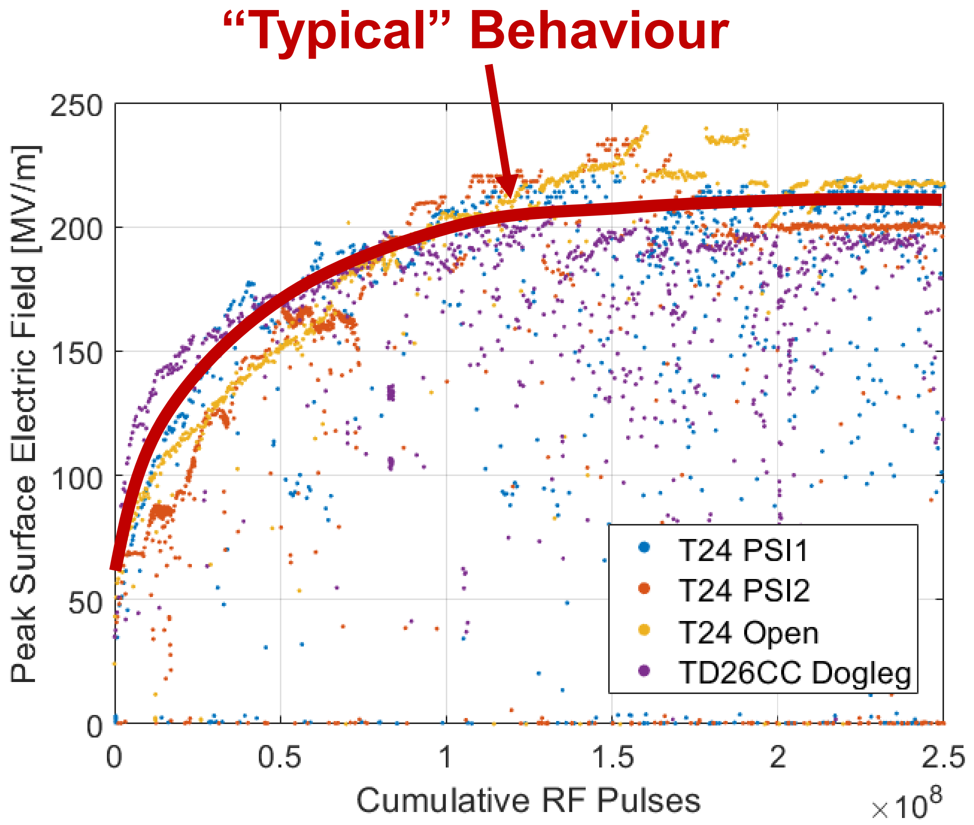
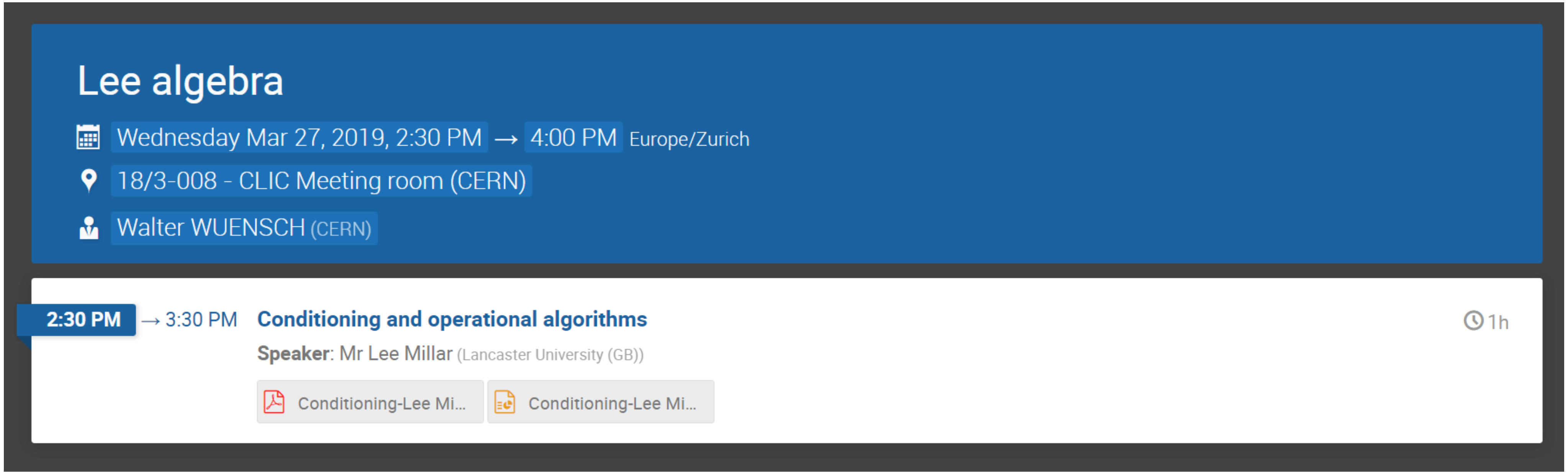


Figure: Preliminary conditioning of several X-band structures tested at CERN.

Automation of Conditioning

A bit of backstory…..



Why Model Conditioning?

The Physics Case:

- Many attempts have been made to connect theory to the measurements (e.g. probabilistic behaviour of BDs, BDR vs gradient), but they generally only address a single facet of the problem. Real operation is more complex.

The Pragmatic Case:

- Conditioning procedures are largely anecdotal. Despite being essential the conditioning process has yet to be optimised (tests require a long timeframe/significant expense, difficult to do experimentally).

The first attempt at a comprehensive integration of HG operation to address these issues.

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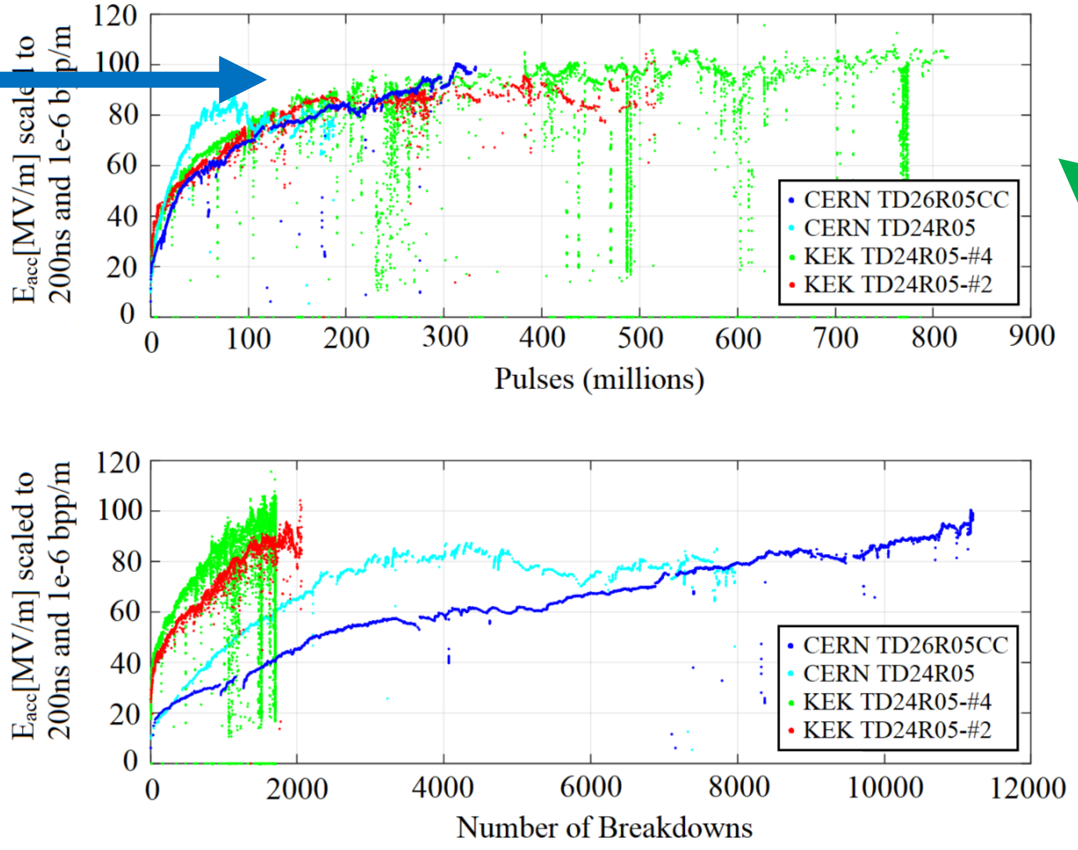
Simulation Setup: Assumptions of the Model

Asymptotic behaviour (no indefinite conditioning)

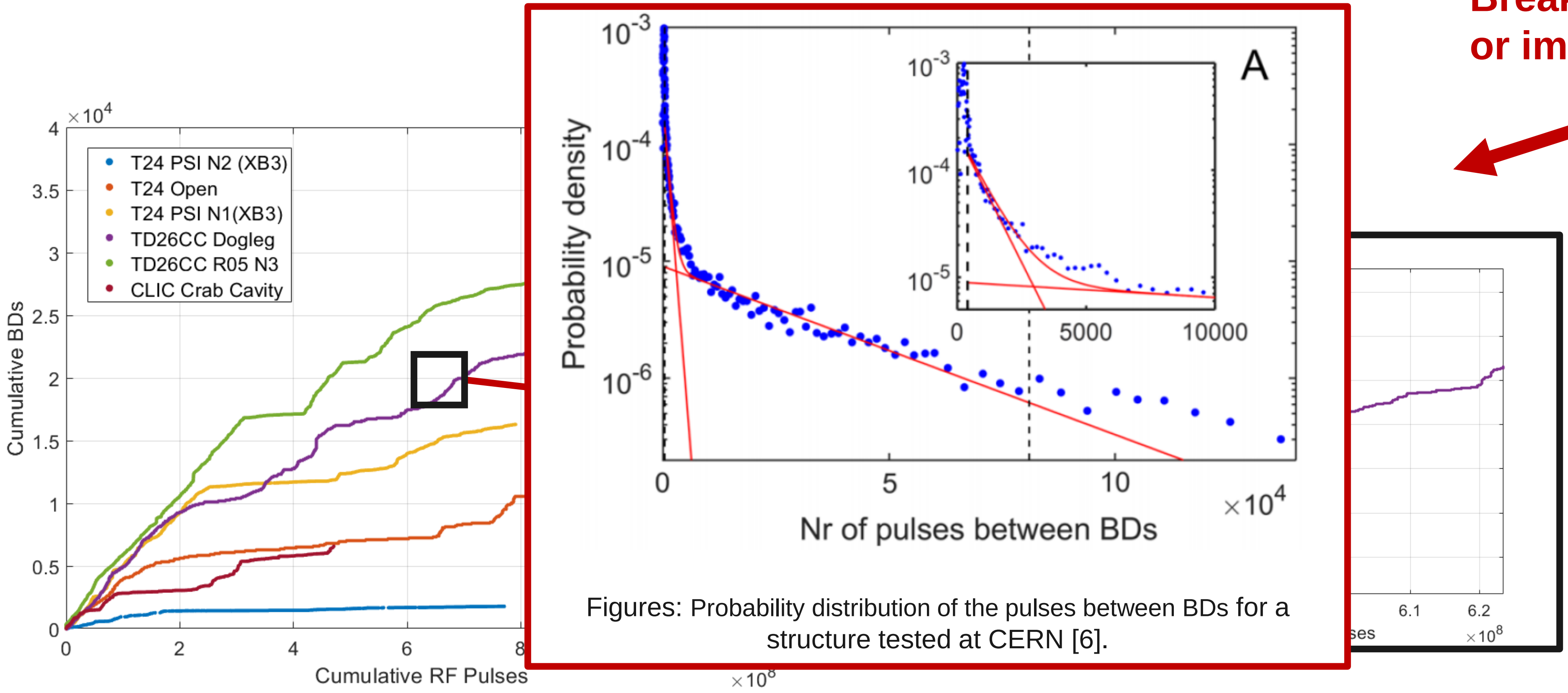


Structures proceed most comparably in pulses.

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

Simulation Setup: Assumptions of the Model

Breakdowns can worsen or improve the surface.

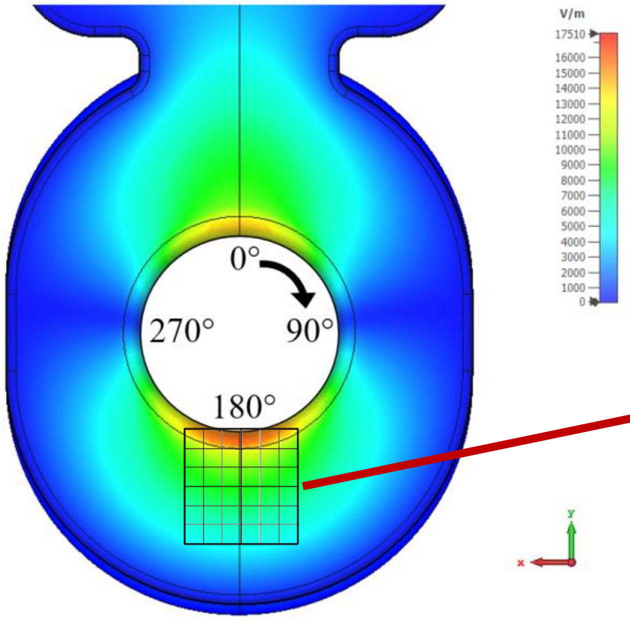


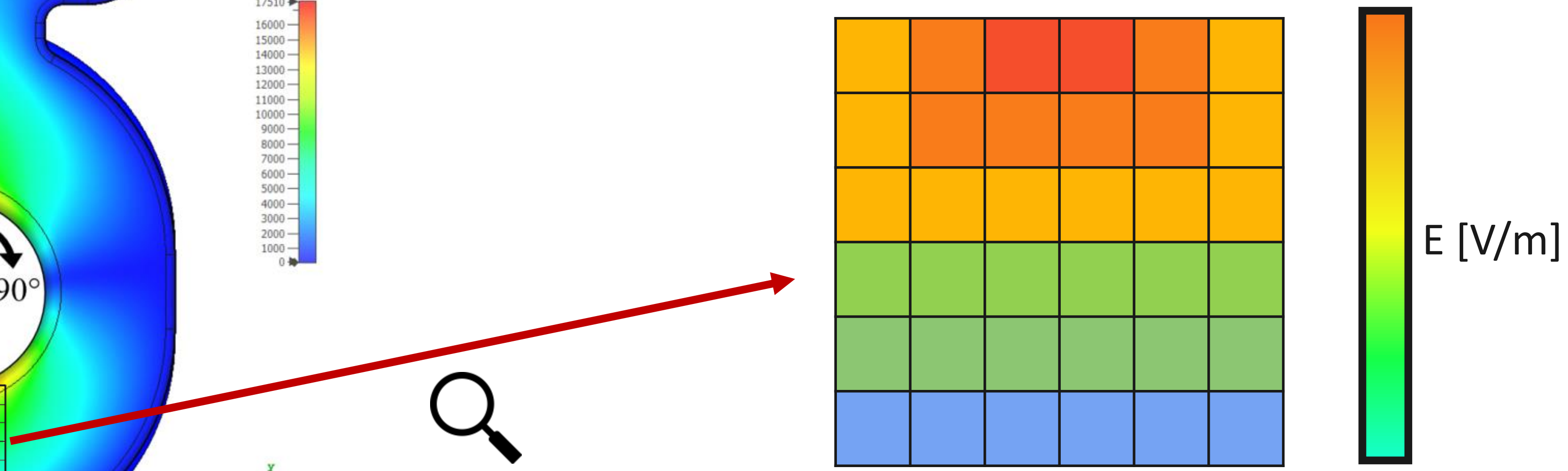
Figures: Probability distribution of the pulses between BDs for a structure tested at CERN [6].

Figures: Cumulative breakdowns vs pulses for various structures tested at CERN.

Simulation Setup

Field distributions typically non-uniform and the effect of breakdown is a local one, well suited to a grid approach. Doing so also opens up many other simulation possibilities.





Simulation Setup: Assumptions of the Model

These assumptions are implemented via empirically derived equations (**specifics in the bonus slides**).

1. Each pulse improves (conditions) the surface.

2. We asymptotically approach a limit, above which no improvement takes place.

3. Breakdowns may worsen or improve the surface i.e. grid element (using a factor taken from a Gaussian distribution).

The model is then built around the idea of **progressive modification of the surface on a pulse-to-pulse basis**.

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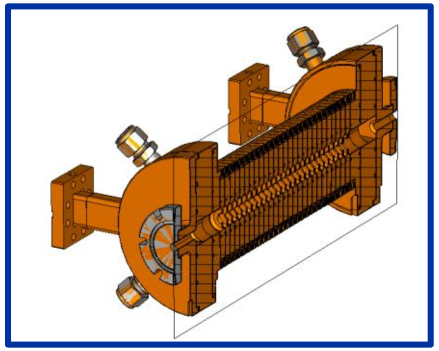
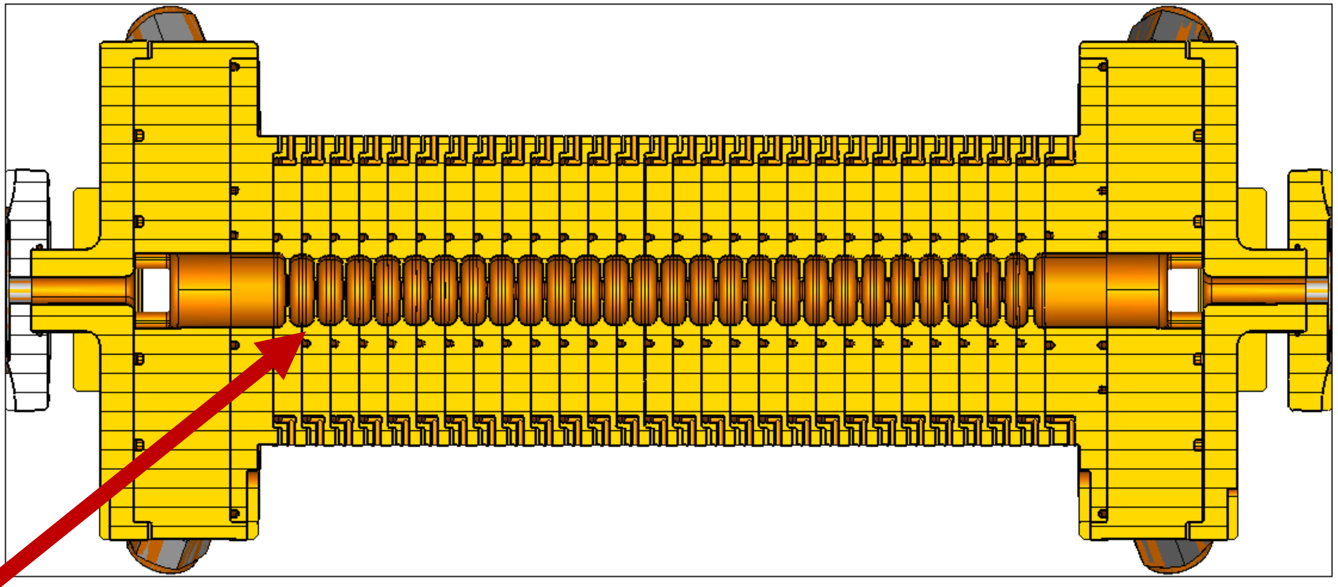
A Visual Example: CLIC Prototype Structure

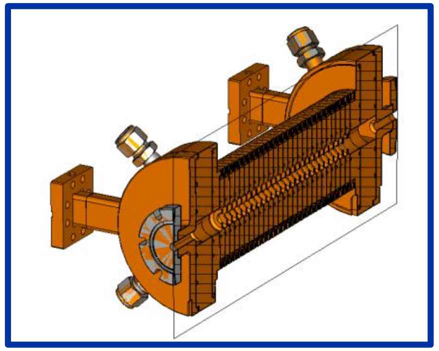


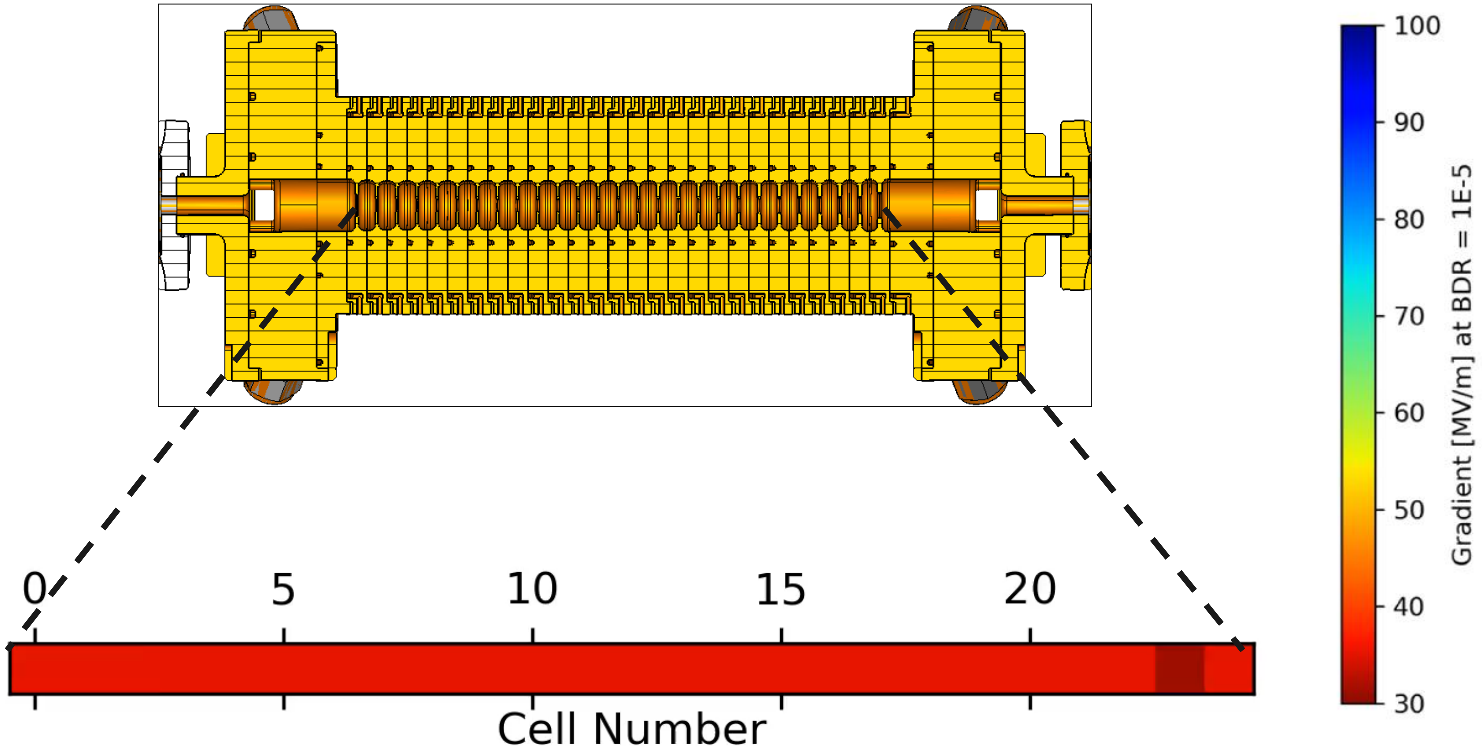
(Assuming field flatness for this example)



Modelling each cell as a grid element.

A Visual Example: CLIC Prototype Structure

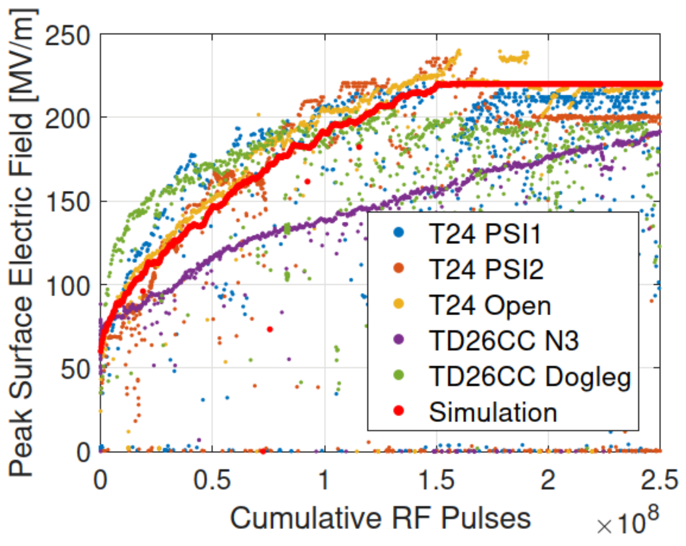


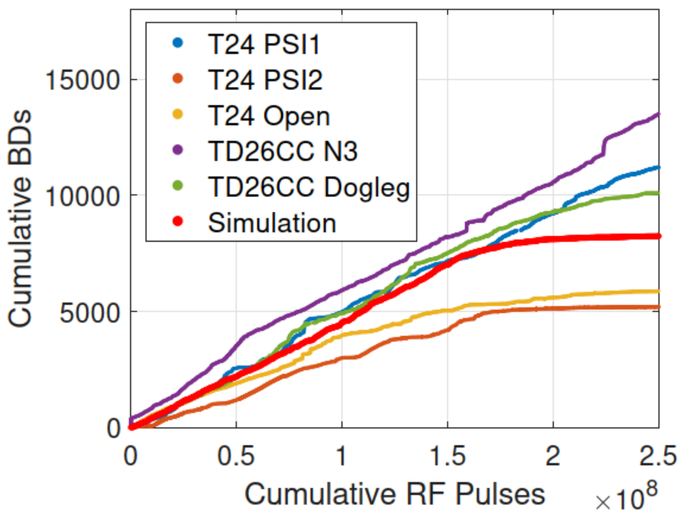


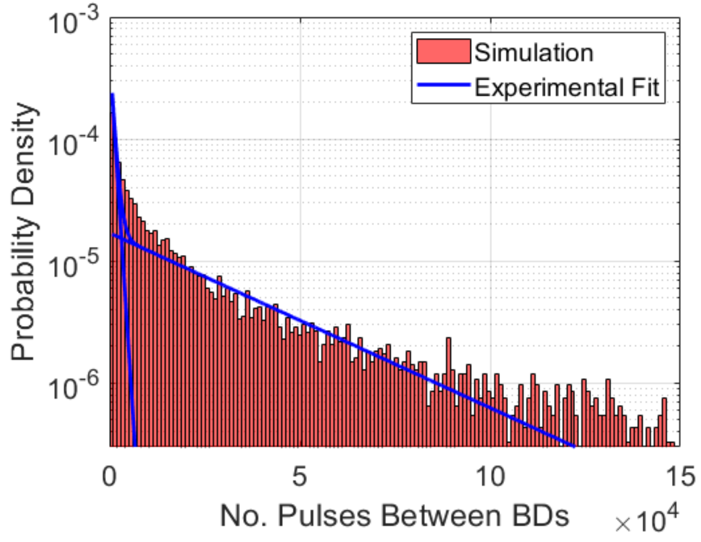
"Conditioned state" of cell surfaces

Benchmarking: CLIC Structure Conditioning

Simulated conditioning in red (25 grid elements).







A Few Other Studies

Not enough time to present everything, but other ongoing studies include:

- Spatially Resolved Conditioning.
- Effects of changing the parameters in our conditioning algorithm.
- Multi-Structure simulations.
- DC Case (fitting to LES data).

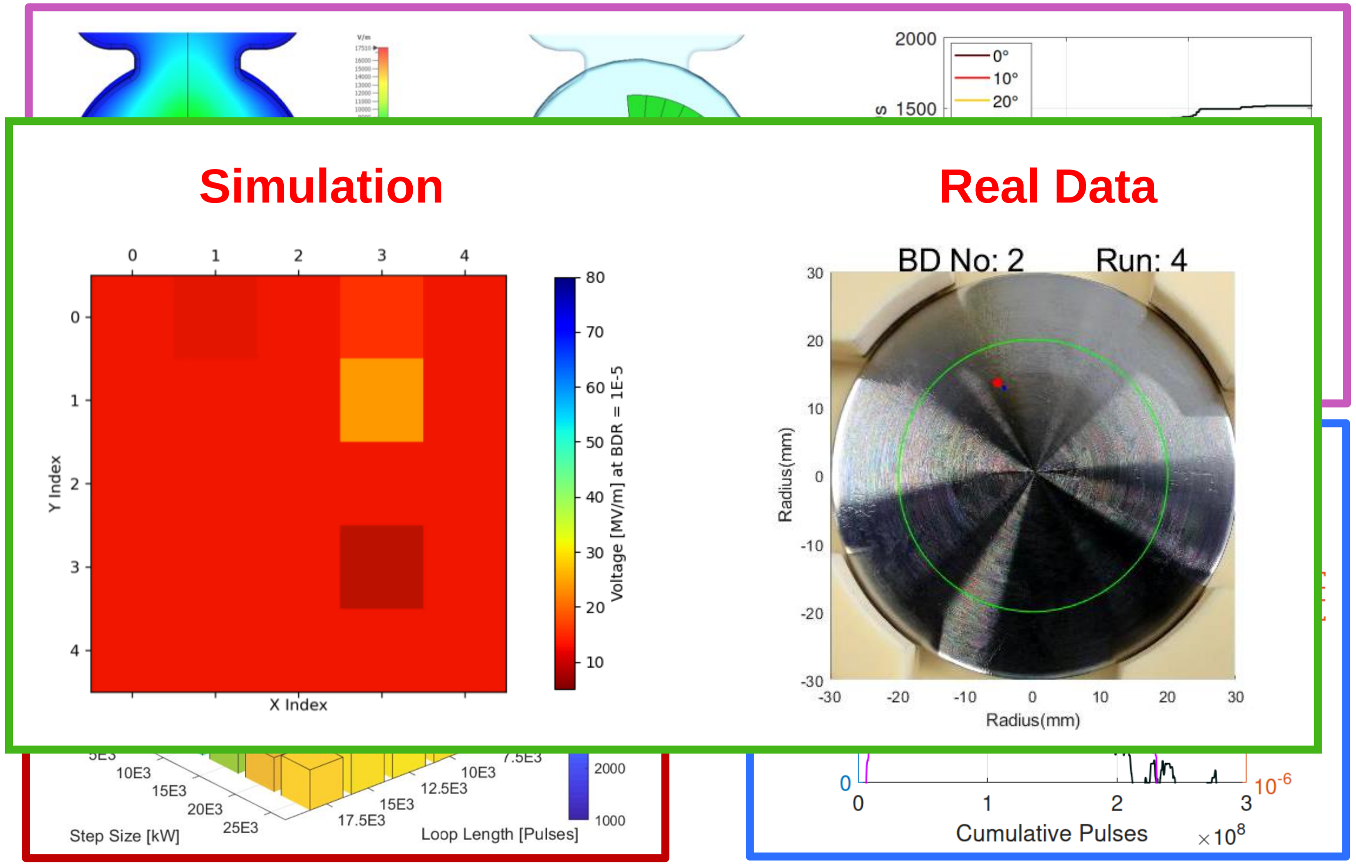


Figure: Additional ongoing Monte Carlo studies. DC Electrode clip courtesy of Ruth Peacock.

Contents

1. Overview of High-Gradient Conditioning.
2. Simulation Setup.
3. Results of the Model.
4. **Conclusion and Future Work.**

Conclusion & Future Work

A discretised model based on the idea of the progressive modification of the surface has been created and shows reasonable agreement with HG test data.

Future work includes:

- Addition of a pulse length dependence.
- Trial alternative probabilistic models/conditioning theories.
- Trial entirely different conditioning algorithms.
- Addition of vacuum conditioning/other facets of operation.

Thank you. Questions?

References

[1] –B. Woolley, “High Power X-band RF Test Stand Development and High Power Testing of the CLIC Crab Cavity,” Lancaster University, United Kingdom, 2015.

[2] – L. Millar, “Conditioning and Operational Algorithms”, Presentation, Available online: https://indico.cern.ch/event/719535/

[3] – L. Cowie, G. Burt, W. Millar, and D. Scott, “High Power RF Conditioning on CLARA”, in 9th International Particle Accelerator Conference, 2018, p. THPAL085.

[4] – P. McIntosh, A. Hill, and H. Schwarz, “An automated 476 MHz RF cavity processing facility at SLAC”, in Proceedings of the 2003 Particle Accelerator Conference, vol. 2, 2003, pp. 1273–1275 Vol.2.

[5] – J. Giner Navarro, Breakdown Studies for High Gradient Rf Warm Technology in: CLIC and Hadron Therapy Linacs, University of Valencia, 2016.

[6] – Statistics of vacuum breakdown in the high-gradient and low-rate regime. Wuensch, W. et al. 10, s.l. : American Physical Society, 2009, Phys. Rev. Accel. Beams 20, 011007 – Published 25 January 2017, Available online: https://journals.aps.org/prab/pdf/10.1103/PhysRevAccelBeams.20.011007

Bonus Slide: A (very) Simple Model Outline

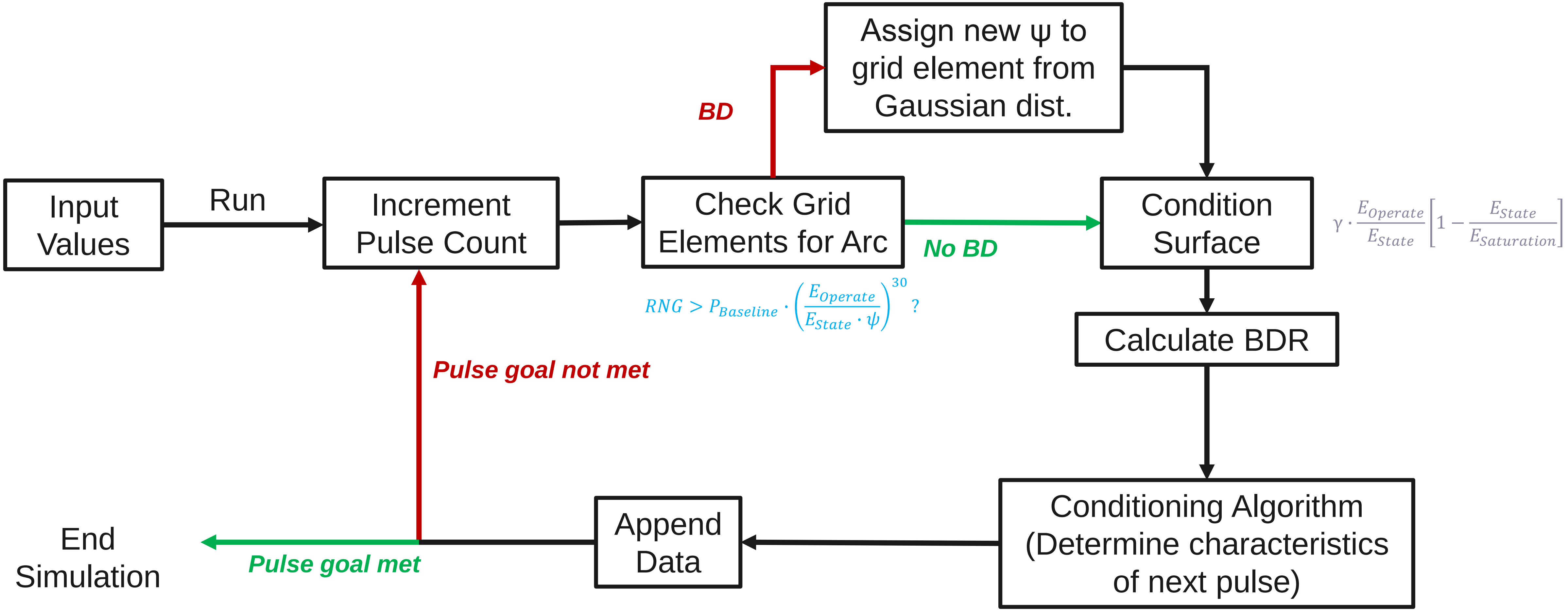


Figure: Simplified block diagram of the model showing the equations implemented.

Bonus Slide: Definition of Model Terms

$P_{Baseline}$ = The instantaneous probability of breakdown for a given device operating at the level to which it has been conditioned.

$E_{Operate}$ = The electric field level in MV/m at which the device operates.

E_{State} = The surface electric field level to which the device has been conditioned in MV/m. Operation at this field level results in a probability of breakdown which is equal to $P_{Baseline}$.

E_{Sat} = The saturation point for a given material in MV/m. Operation above this level does not result in any further improvement in E_{State} and thus this is the maximum surface field attainable at the reference breakdown rate after the device has been fully conditioned.

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