The Dogleg Experiment
Results 2016

Frank Tecker

Theo Argyropoulos

Eugenio Senes

Jorge Giner Navarro

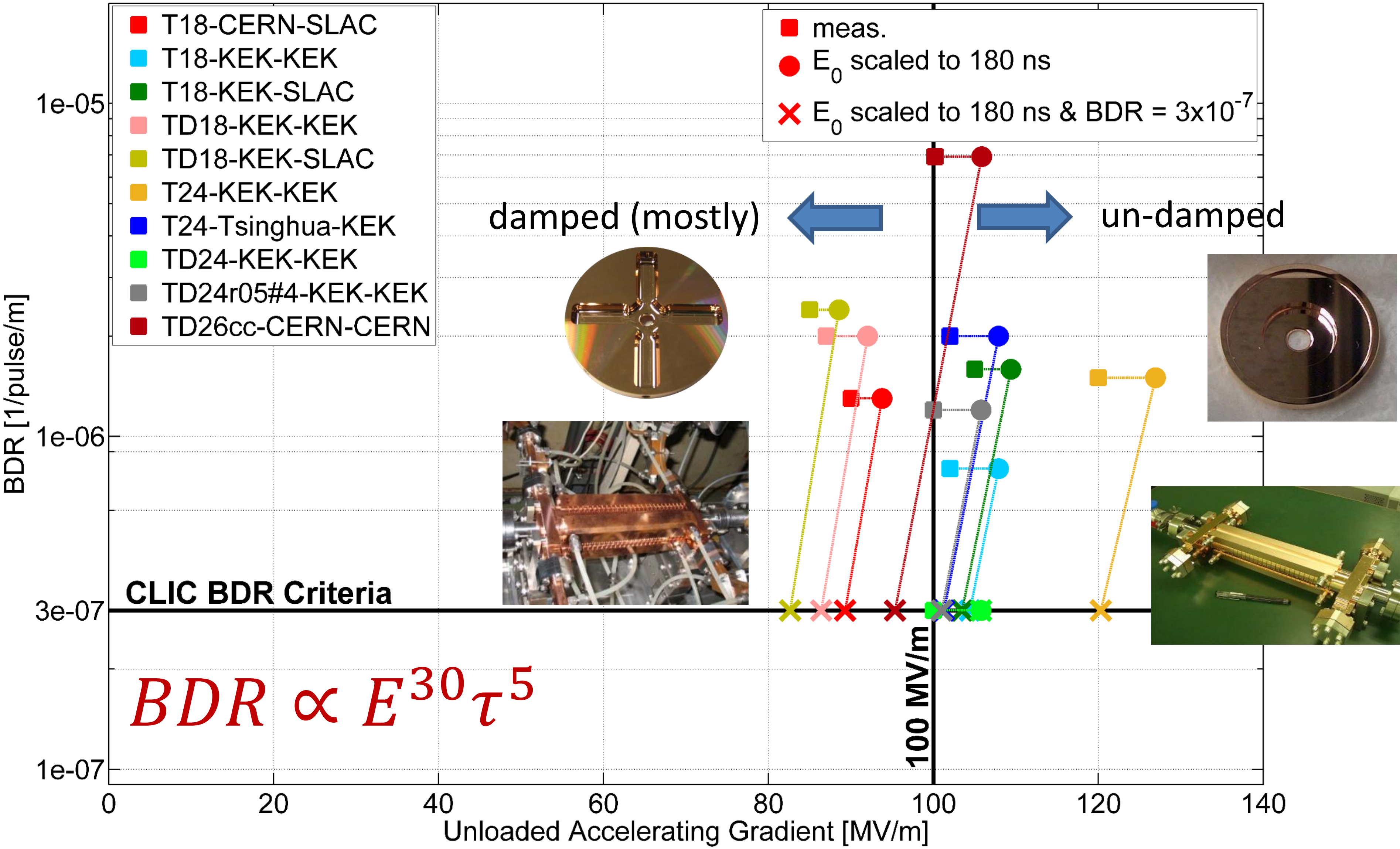
et

XBOX-CTF3 Team

Outline

- Motivation
- Experimental Setup
- The structure
- Beam-Loading measurements
- Results Breakdown Rate
- Results Breakdown Localization
- Conclusions

Motivation



T18-CERN-SLAC
T18-KEK-KEK
T18-KEK-SLAC
TD18-KEK-KEK
TD18-KEK-SLAC
T24-KEK-KEK
T24-Tsinghua-KEK
TD24-KEK-KEK
TD24r05#4-KEK-KEK
TD26cc-CERN-CERN
meas.
E_0 scaled to 180 ns
E_0 scaled to 180 ns & BDR = $3x10^{-7}$
damped (mostly)
un-damped
CLIC BDR Criteria
100 MV/m
$BDR \propto E^{30}\tau^{5}$
BDR [1/pulse/m]
1e-05
1e-06
3e-07
1e-07
0
20
40
60
80
100
120
140
Unloaded Accelerating Gradient [MV/m]

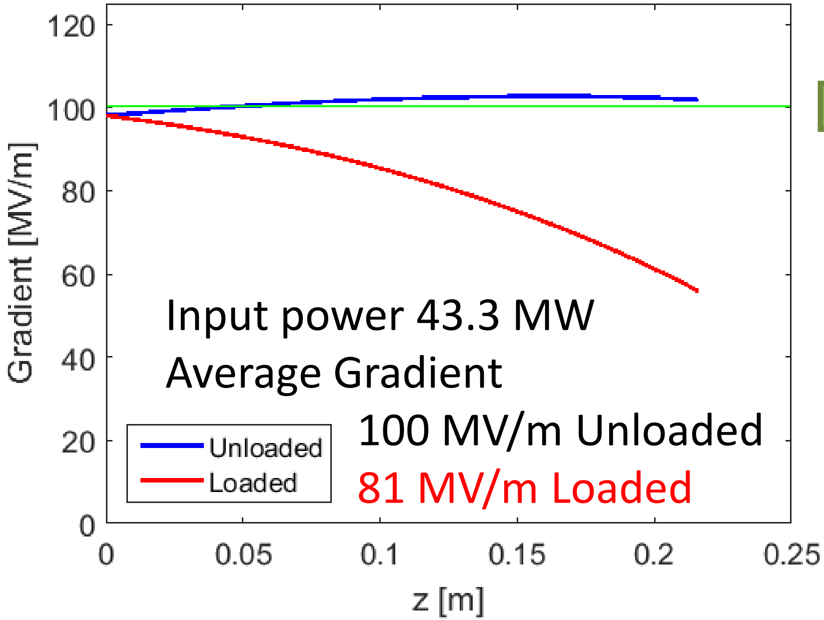
Motivation

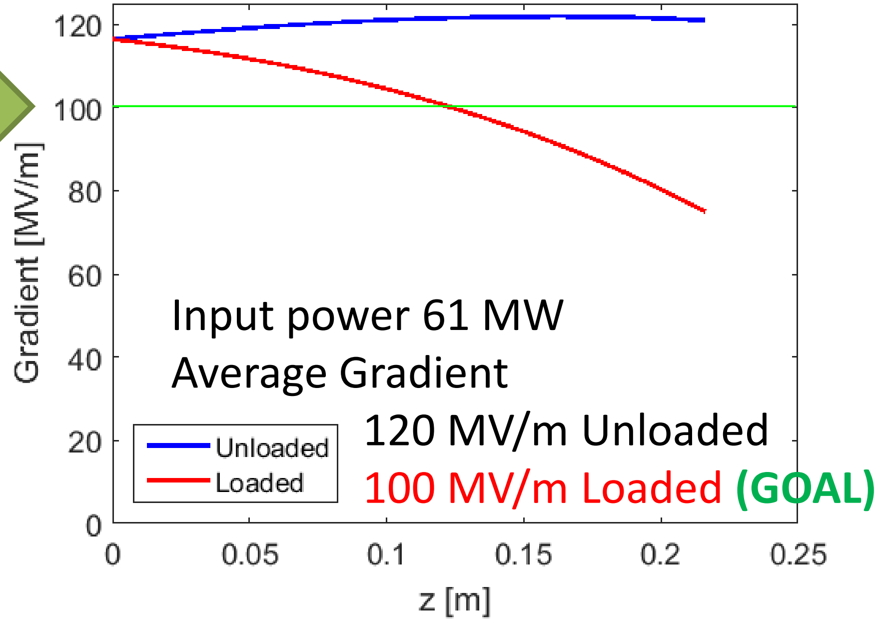
- Beam interferes with the fields configuration in the structures
- Accelerating gradient profile in the structure becomes different when loaded with beam.

Consequently, the beam energy gain would be lower:

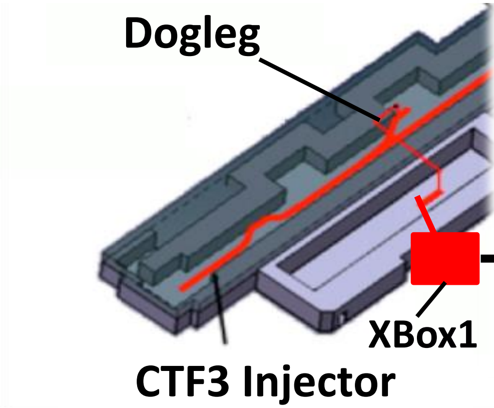
$$\Delta W = q \cdot \int_0^L E_{acc}(z)\, dz = q \cdot \langle E_{acc} \rangle \cdot L$$

And it needs higher input power to keep the same acceleration: this means higher fields are supported (**how is breakdown rate affected?**)

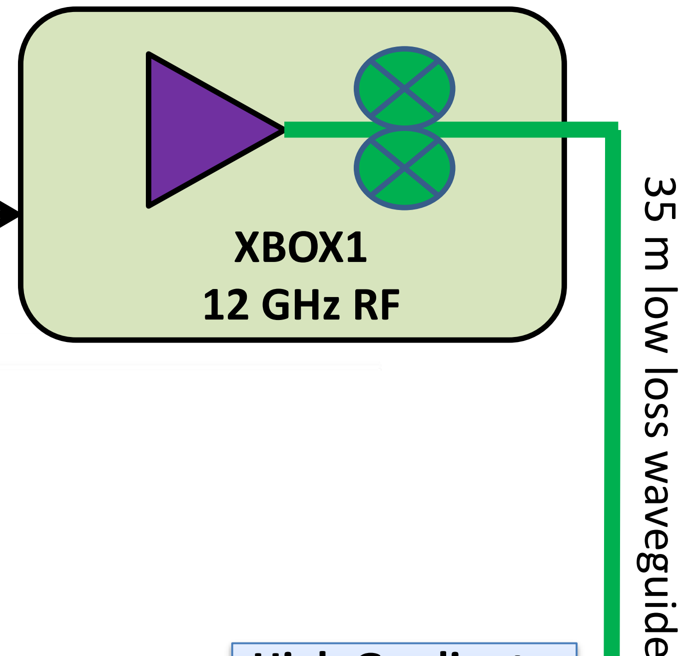




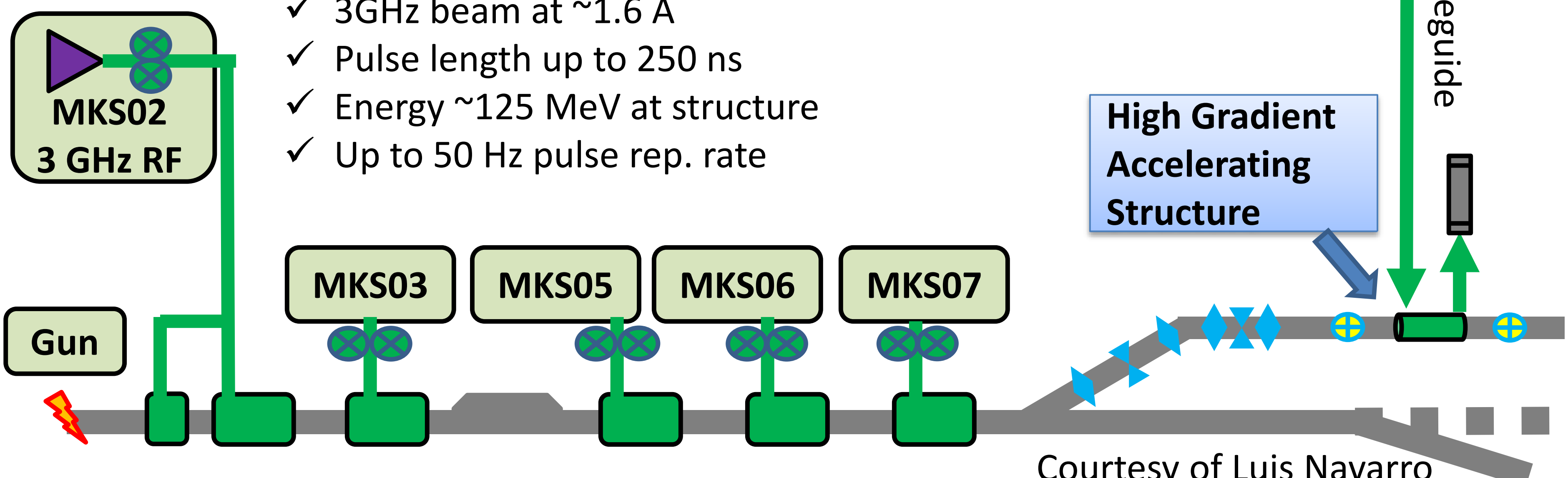
Experimental setup



12 GHz RF:
- ✓ 90 MW RF power
- ✓ Up to 50 Hz rep. rate



Beam:
- ✓ CTF3 Drive Beam modified
- ✓ 3GHz beam at ~1.6 A
- ✓ Pulse length up to 250 ns
- ✓ Energy ~125 MeV at structure
- ✓ Up to 50 Hz pulse rep. rate

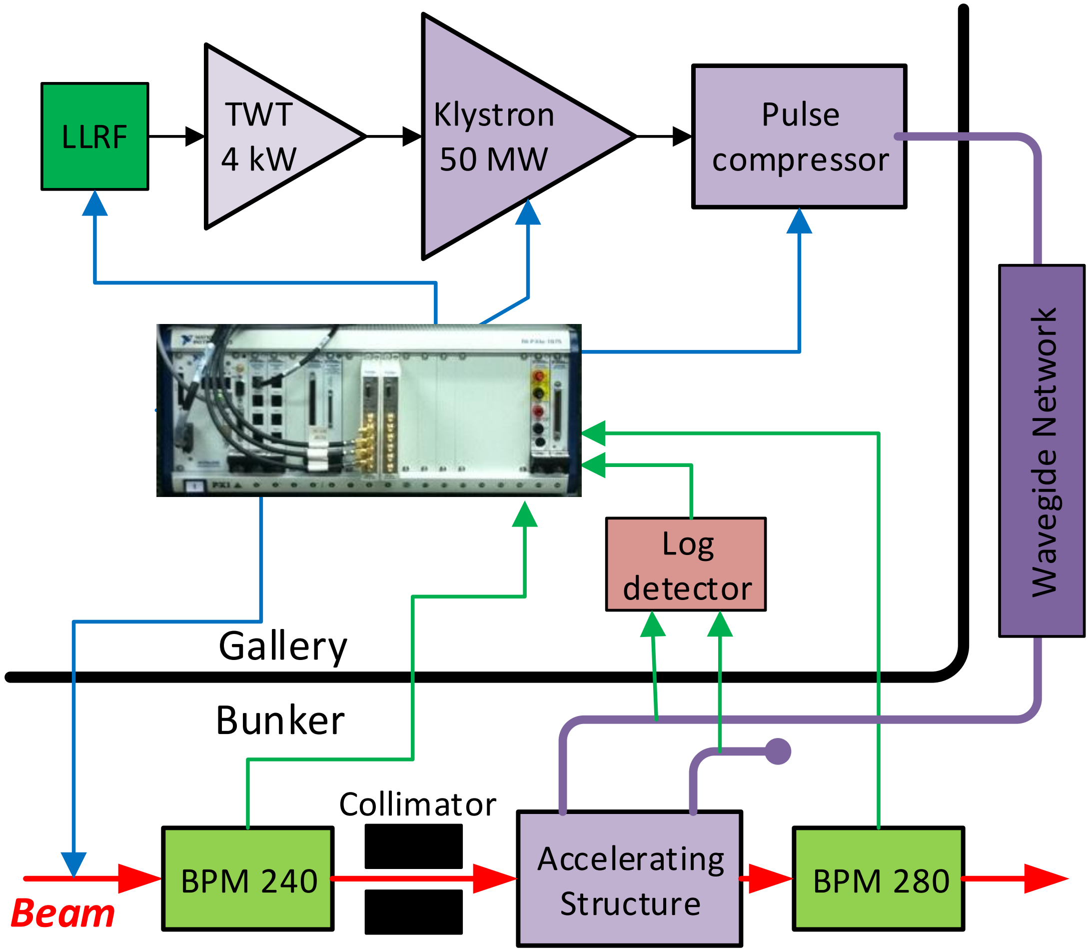


Courtesy of Luis Navarro

Experimental setup

NI PXI controller

- Control of Power and Phase to the structure from LLRF and Pulse compressor tuning
- Acquisition from Log-detectors, IQ-signals, water-chillers, vacuum readouts.

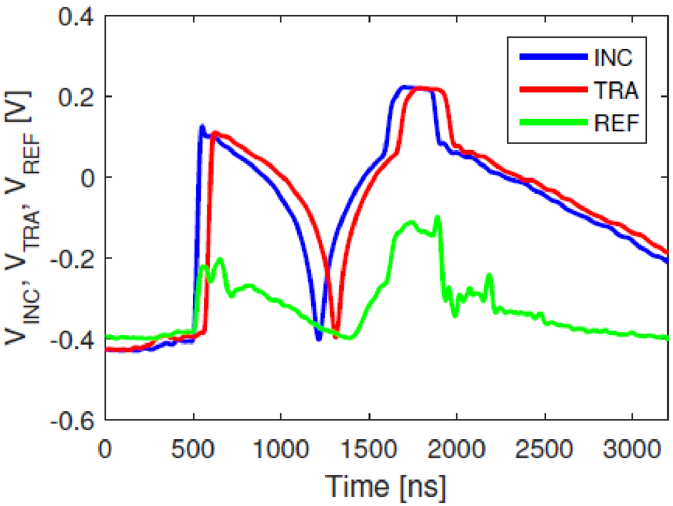


Experimental setup

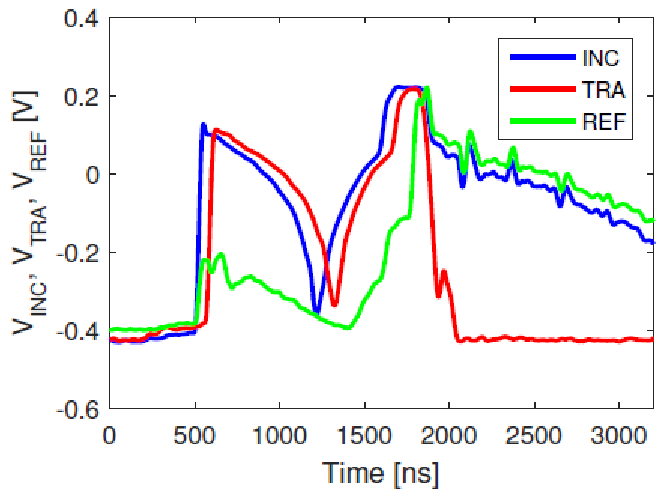
How do we detect Breakdowns?

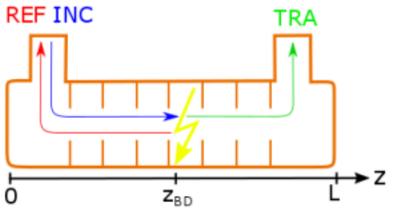
- Typically Faraday Cups are installed at both ends to detect emitted burst of electrons and ions from breakdowns. But in Dogleg, beam is passing through and it's not possible to install them.
- External Radiation Monitors (e.g. BLMs, PMs…) are blind to breakdowns because of the beam losses.
- We use **only RF signals** (incident, transmitted, reflected) to detect Breakdowns.

Normal event



BREAKDOWN event

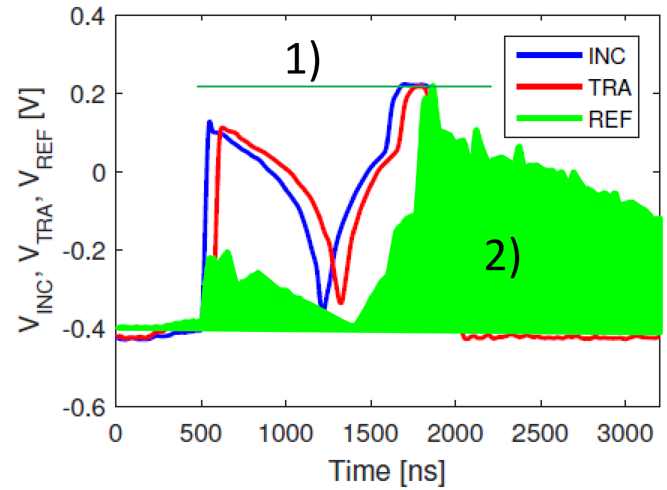




Experimental setup

How do we detect Breakdowns?

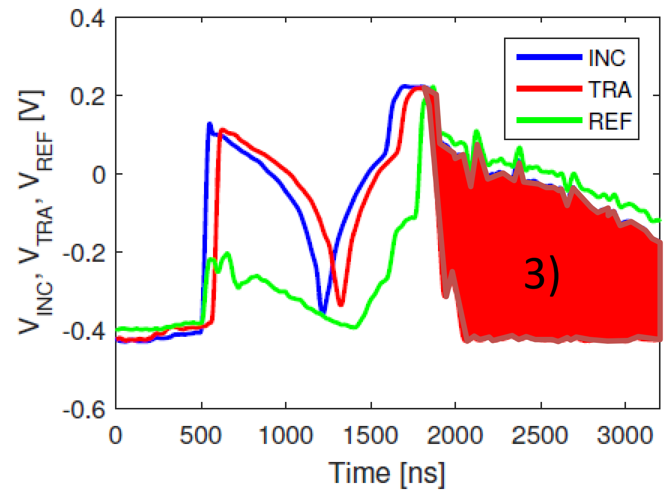
1) Peak Reflected Power $\max(REF)$



2) Reflected Energy $\int REF(t)dt$

3) Missing Transmitted Energy

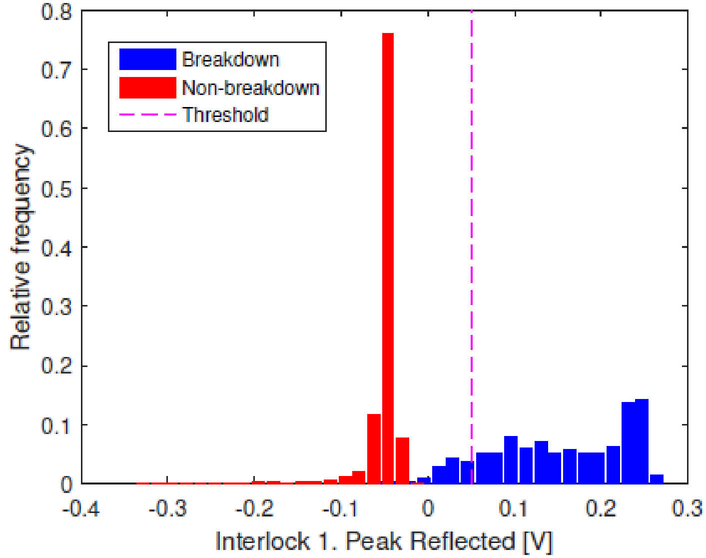
$$\int \big(INC(t) - TRA(t)\big)dt$$



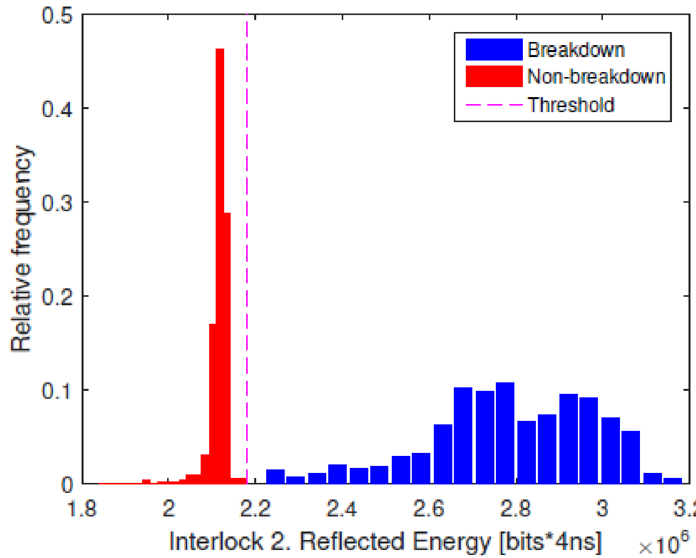
Using log-detectors, Interlocks (2) and (3) offer a good distinction between breakdowns and normal events.
Redundancy is also important in order not to miss any breakdown.

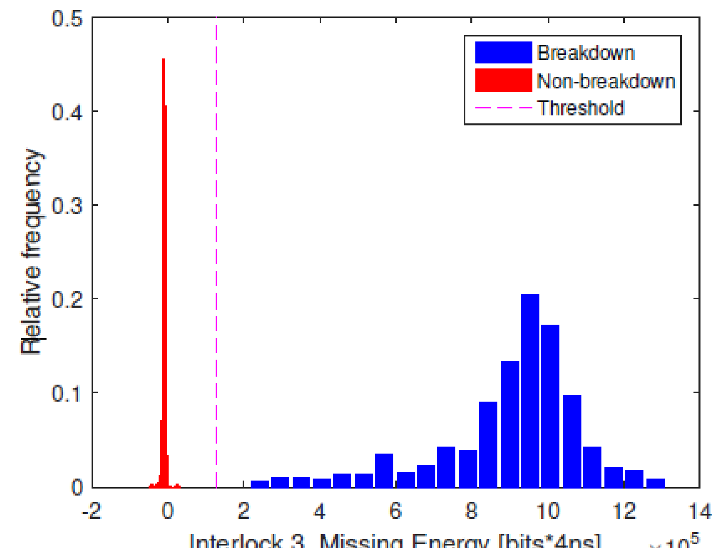
Experimental setup

How do we detect Breakdowns?

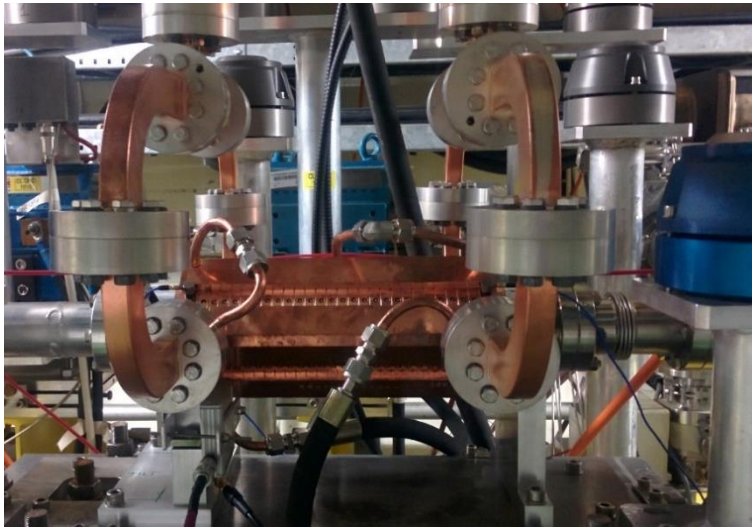


Some statistics of the three interlock levels for the recorded breakdowns in Unloaded run in 2015





The structure: TD26CC-#1


TD26CC-N1 installed at the beamline of the CTF3 Linac

The TD26CC-#1 was processed in 2013 by Xbox-1 at CTF2 after a long test of 6 months.

The test at **100 MV/m** gradient and **250 ns** pulse length showed a **breakdown rate of 7e-6 bpp/m**.

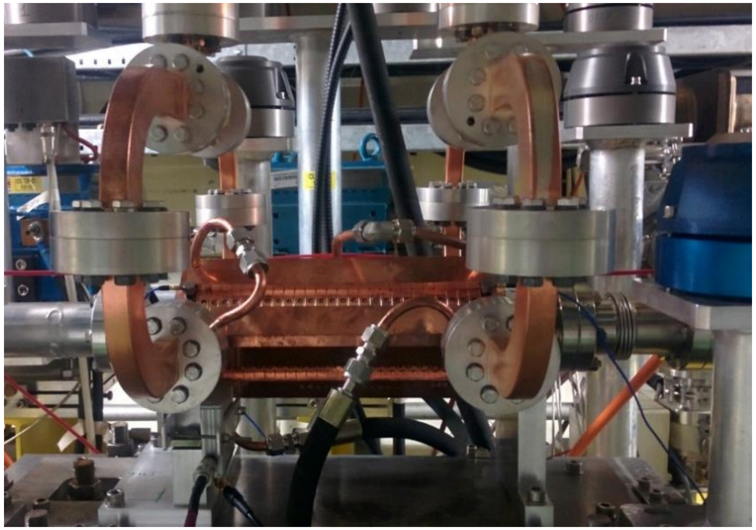
For CLIC requirements we expected a performance at a maximum gradient of **95 MV/m**

This structure was accidentally **vented** for few weeks at the testing place.

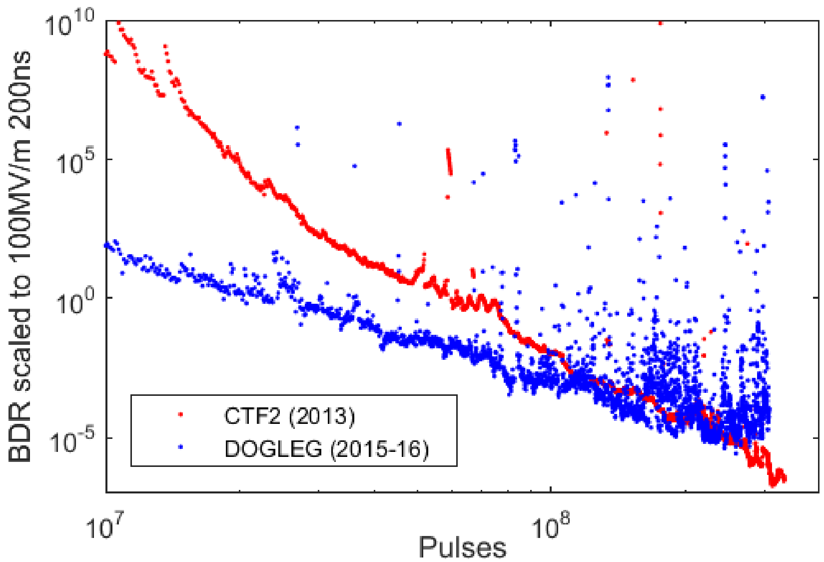
It was re-baken out at 650 deg C and installed again for a new test at the CTF3 Linac for the **Dogleg beam-loading experiment**.

We found that the structure **needed to be reconditioned**.

The structure: TD26CC-#1



TD26CC-N1 installed at the beamline of the CTF3 Linac



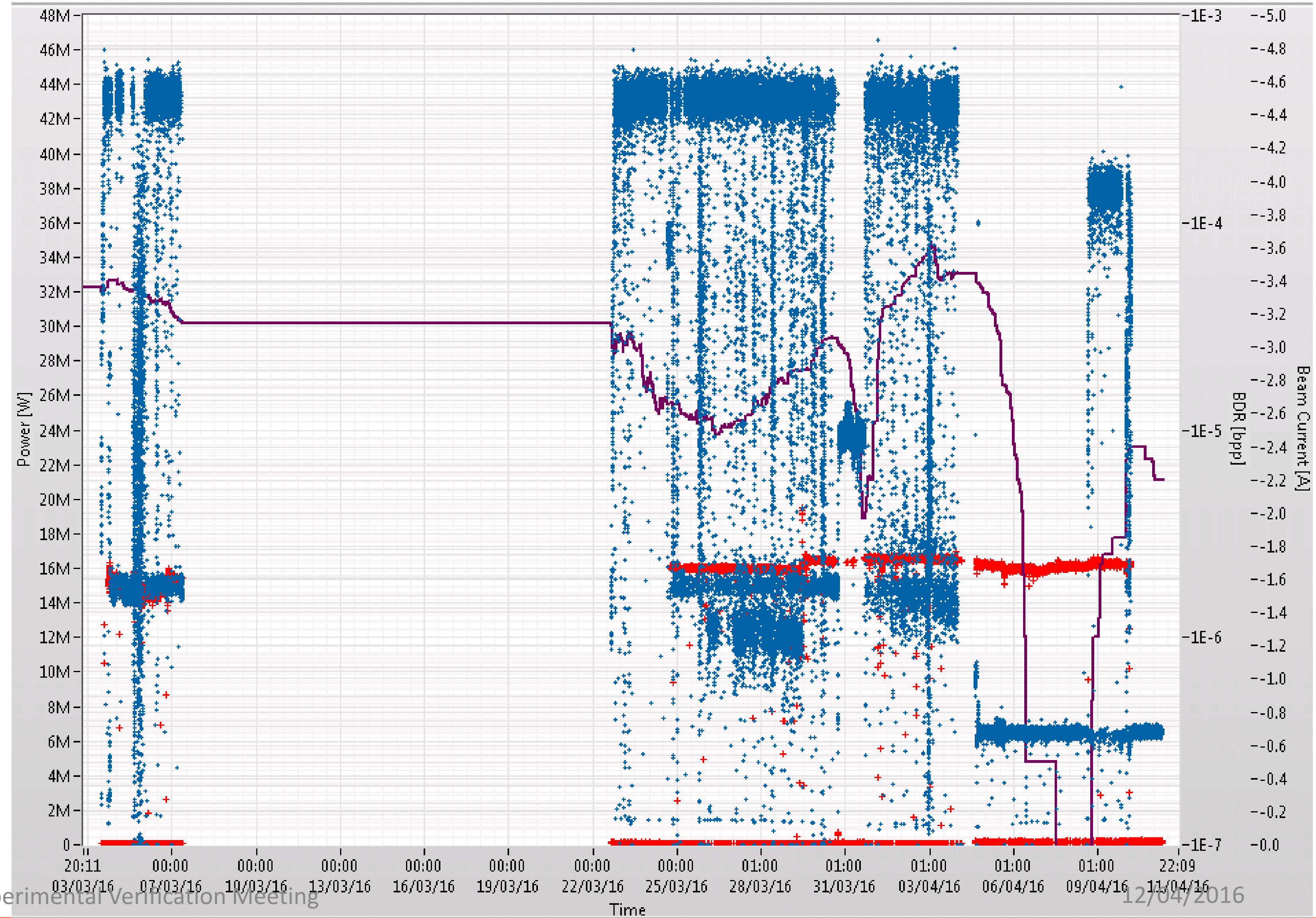
After venting and bake-out, conditioning speed is very much lower.

Conditioning has reached a saturation level: no breakdown rate improvement seen in the last 100M pulses

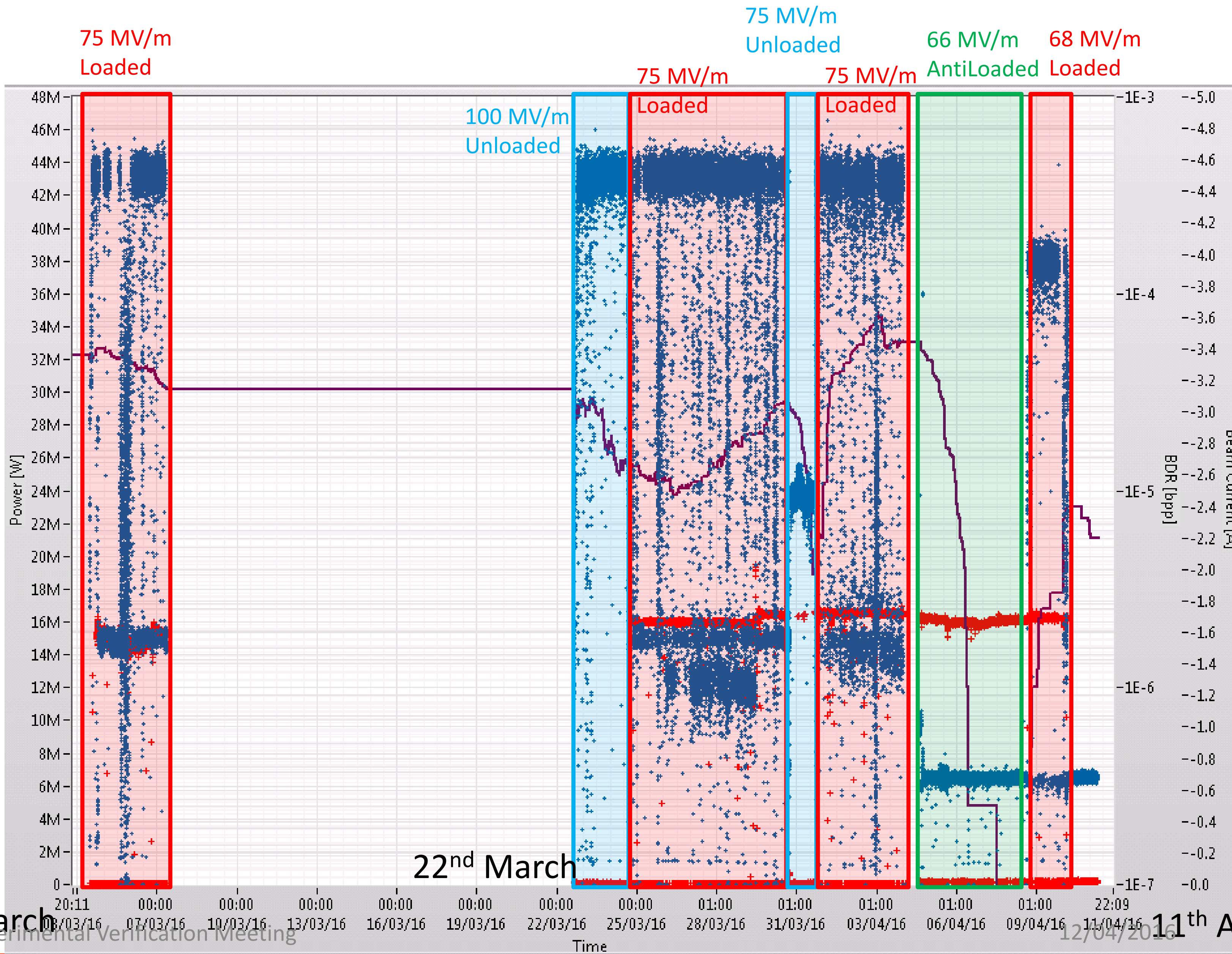
BDR ~ 1.5e-5 BD/pulse ~ 7e-5 BD/pulse/meter @100 MV/m avg unloaded gradient

Saturation allows the comparison of long measurements at different gradients and configurations.

Beam-Loading measurements



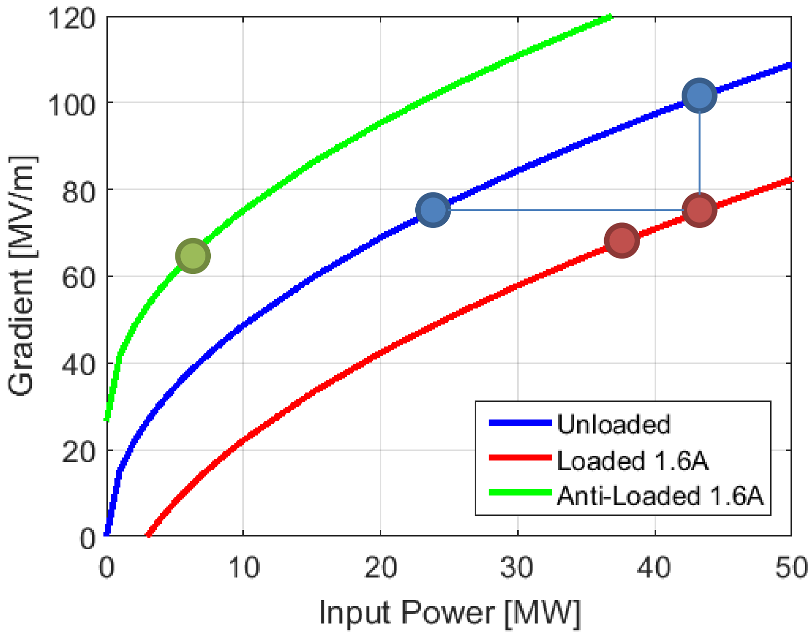
Beam-Loading measurements

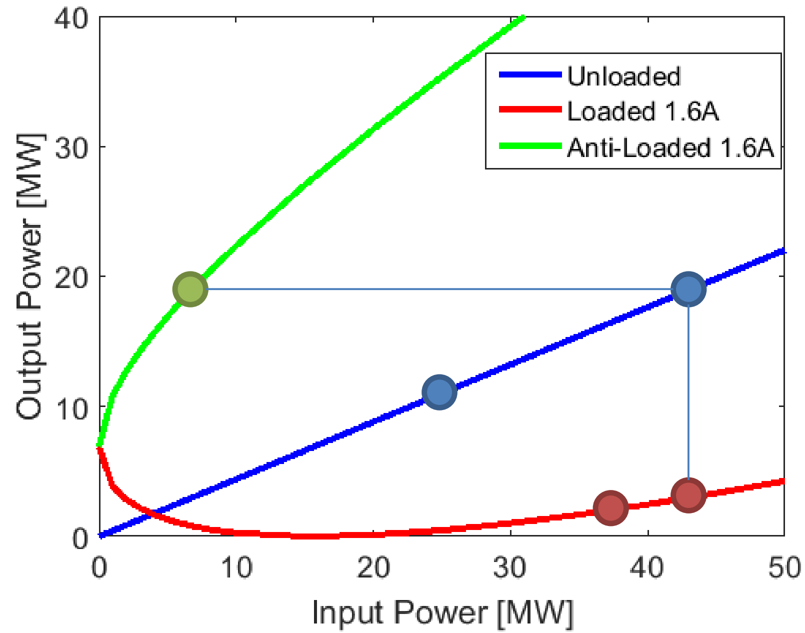


4th March

11th April

Beam-Loading measurements



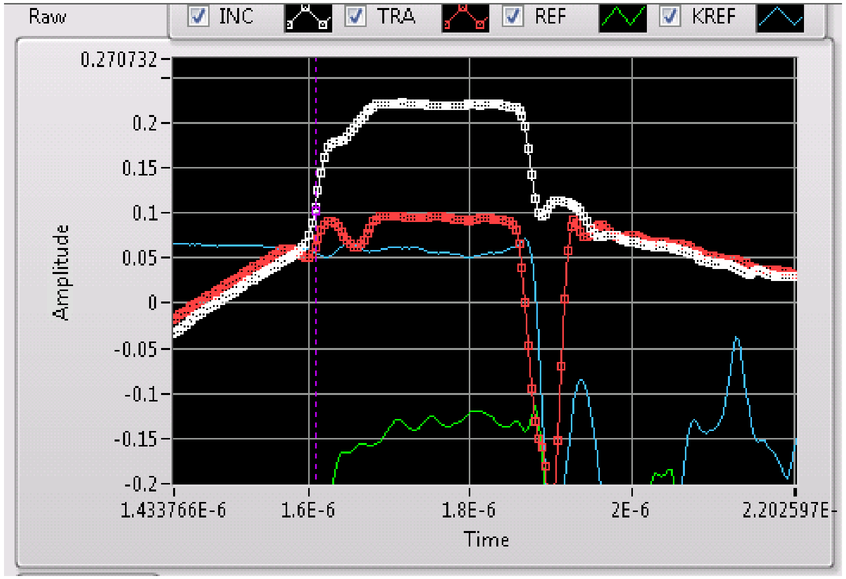


Measurements for comparison:

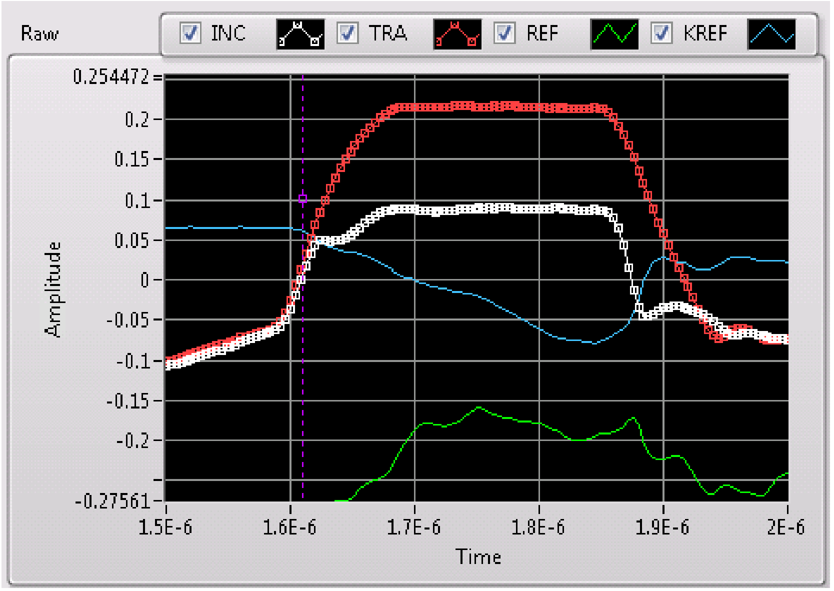
- Same input power (43.3 MW) Unloaded – Loaded
- Same average gradient (75 MV/m) Unloaded – Loaded
- Same output power (21 MW) or output gradient Unloaded - Antiloaded

Beam-Loading measurements

LOADED



ANTI-LOADED



RF pulse shape was configured to be as the CLIC nominal pulse:

70 ns rising time (filling time) +180 ns flat-top

Beam length was set to load the whole pulse, not only the flat-top, so that we guarantee fields are never higher than steady state.

In anti-loaded, beam is set also at the beginning of the rising pulse.

Results Breakdown Rate

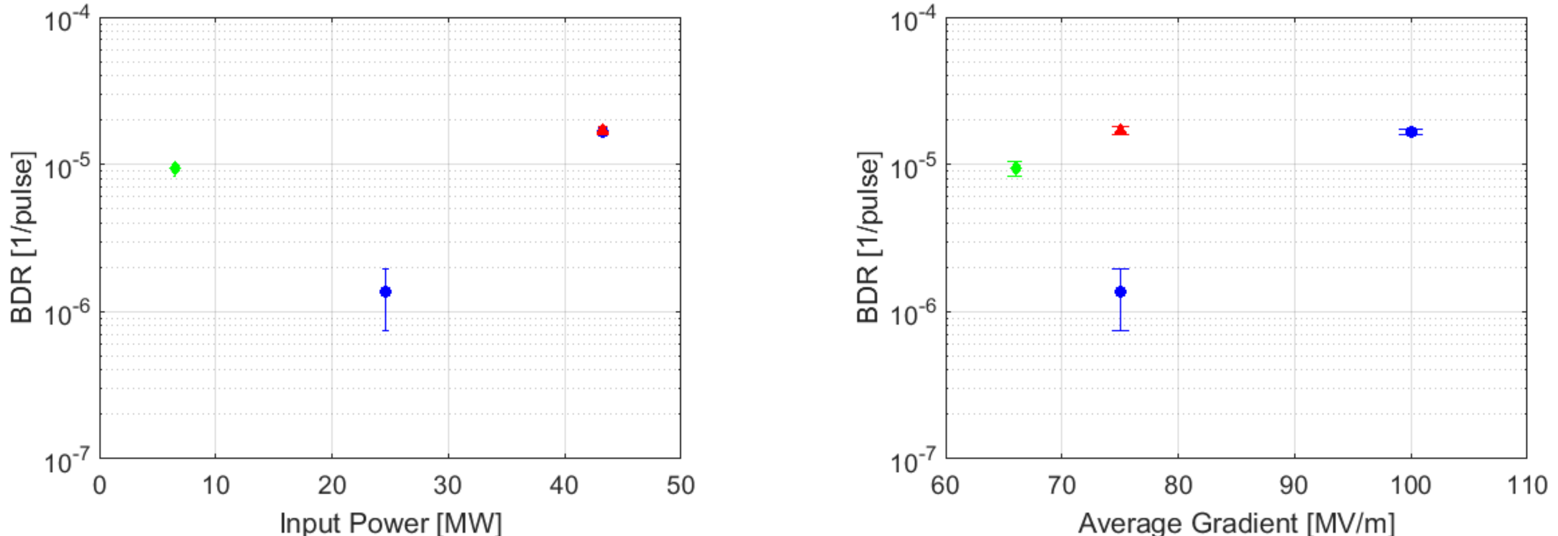
See results documentation in
https://wikis.cern.ch/display/CTF3OP/TD26+Structure+runnings

From	To	Input Power (MW)	Beam Current (A)	Loading	# PULSES	# BDs	BDR ($x10^{-5}$ bpp)
24/02/2016 01:00	01/03/2016 12:00	43.3	0	Unloaded	22517650	368	**1.63 +/- 0.09**
04/03/2016 19:30	07/03/2016 08:00	43.3	1.5-1.6	Loaded	1057750	10	**0.95 +/- 0.3**
22/03/2016 19:00	24/03/2016 15:00	43.3	0	Unloaded	7279050	113	**1.55 +/- 0.15**
24/03/2016 18:30	30/03/2016 16:00	43.3	1.6	Loaded	4070150	42	**1.03 +/- 0.16**
30/03/2016 20:00	31/03/2016 17:00	24.6	0	Unloaded	3672400	5	**0.136 +/- 0.061**
31/03/2016 18:00	04/04/2016 02:00	43.3	1.6	Loaded	6007950	140	**2.33 +/- 0.19**
04/04/2016 18:30	08/04/2016 16:00	6.5	1.6	Anti-Loaded	8112500	76	**0.94 +/- 0.11**
08/04/2016 17:30	09/04/2016 21:15	38	1.6	Loaded	2242600		
		43.3	0	Unloaded			

Results Breakdown Rate

Combining all the measurement runs:

Input Power (MW)	Beam Current (A)	Average Gradient (MV/m)	Loading	# PULSES	# BDs	BDR ($x10^{-5}$ bpp)
43.3	0	100	Unloaded	29796700	481	**1.61 +/- 0.07**
43.3	1.6	75	Loaded	11288100	192	**1.70 +/- 0.12**
6.5	1.6	66	Anti-Loaded	8112500	76	**0.94 +/- 0.11**
24.6	0	75	Unloaded	3672400	5	**0.14 +/- 0.06**
38	1.6	68.5	Loaded	…	…	**…**

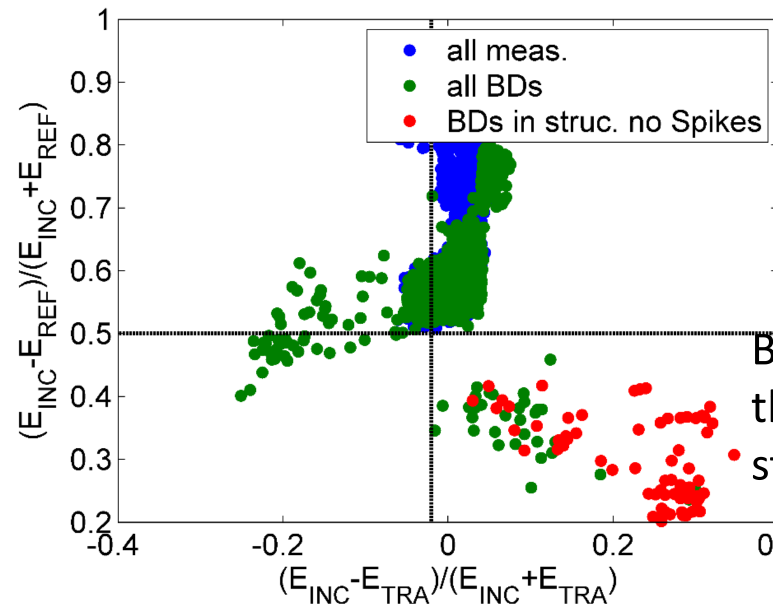


Results Breakdown Rate

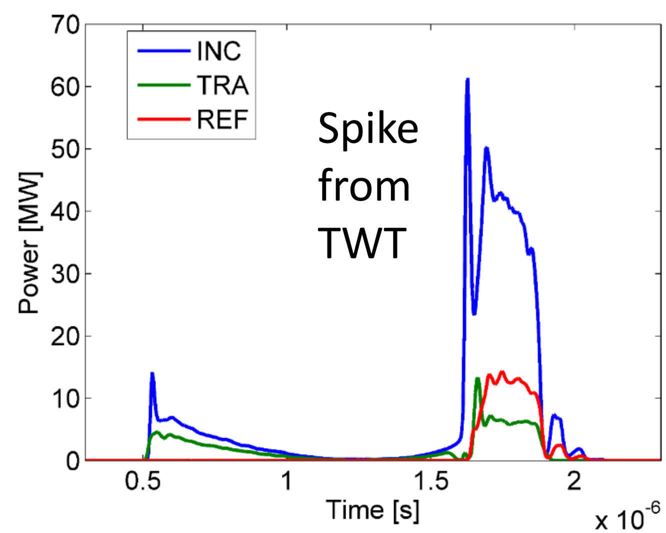
How do we count Breakdowns?

- Filter out all BDs outside the structure (Pulse compressor, waveguides, fake interlocks…) looking at RF signals
- Filter out all BDs induced by spikes (TWT glitch)
- Filter out all BDs caused by missed beam pulses
- Filter out all secondary BDs that are triggered immediately after a spike or non-beam BD

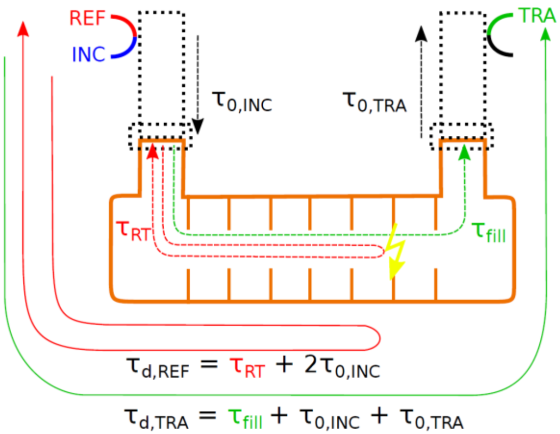
This method filters out around 90% of interlocks we had (not efficient but essential)

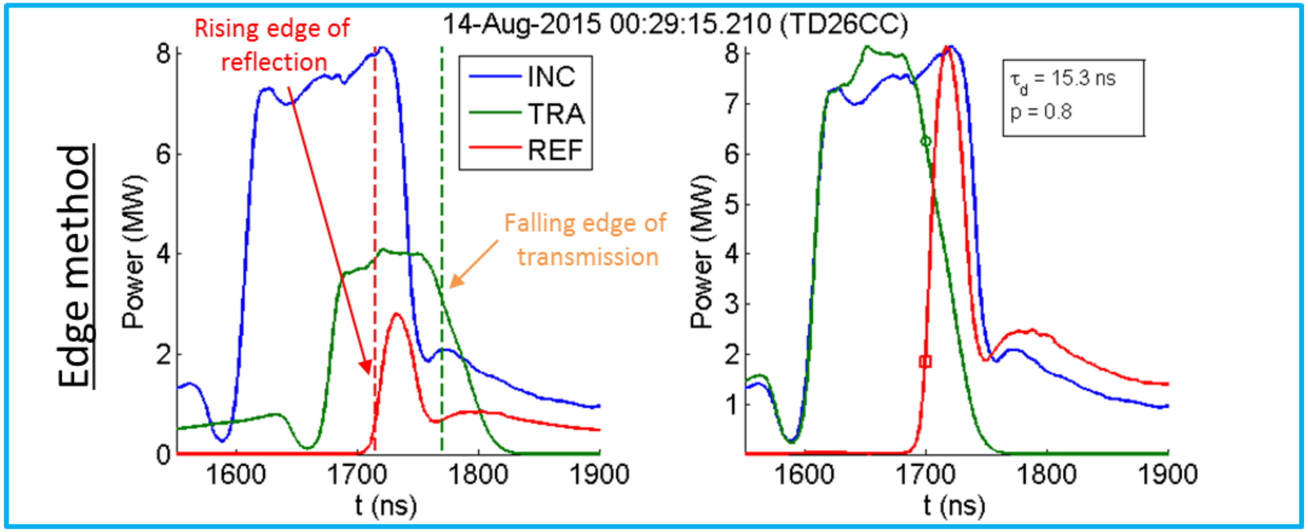


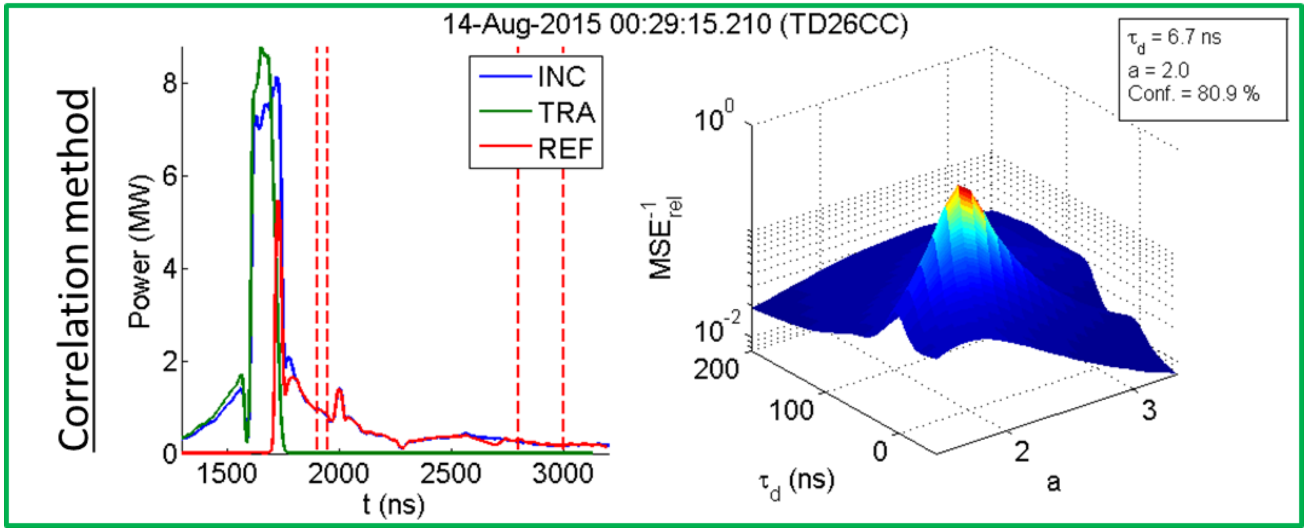
BDs in the struct



Results Breakdown Localization

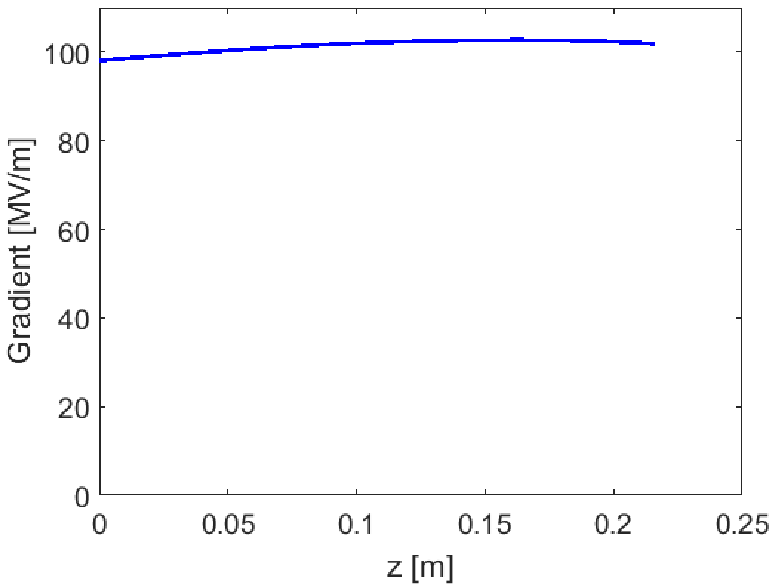


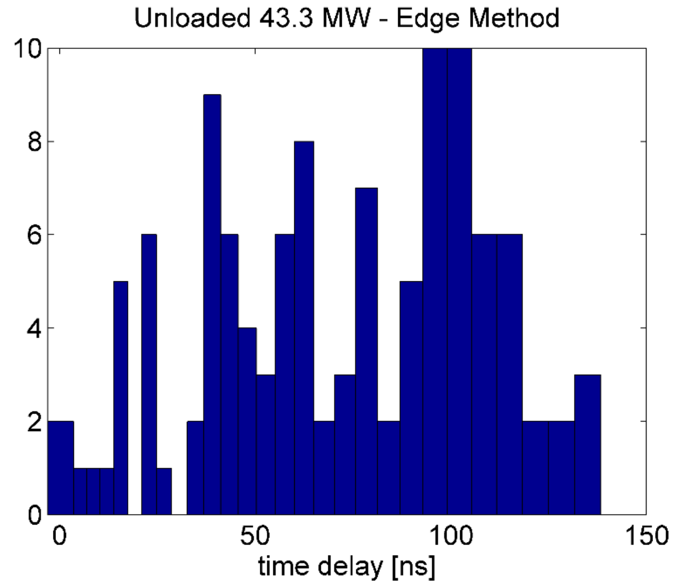


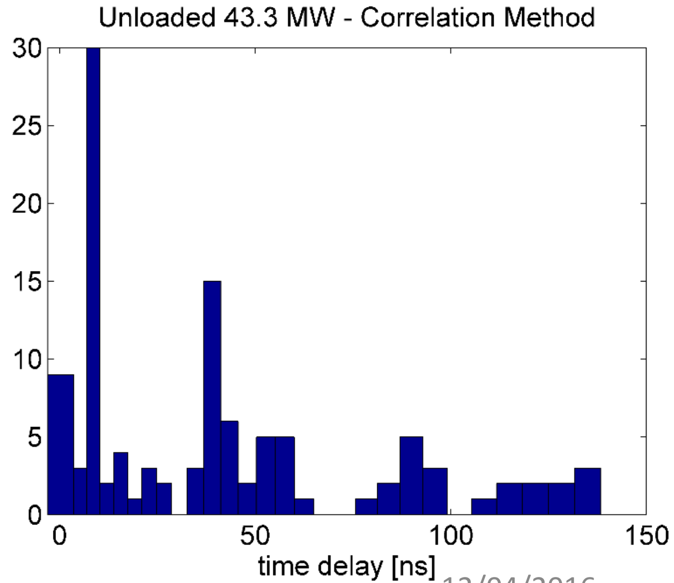


Results Breakdown Localization

UNLOADED
Input Power 43.3 MW
Average Gradient 100 MV/m
Output Gradient 100 MV/m







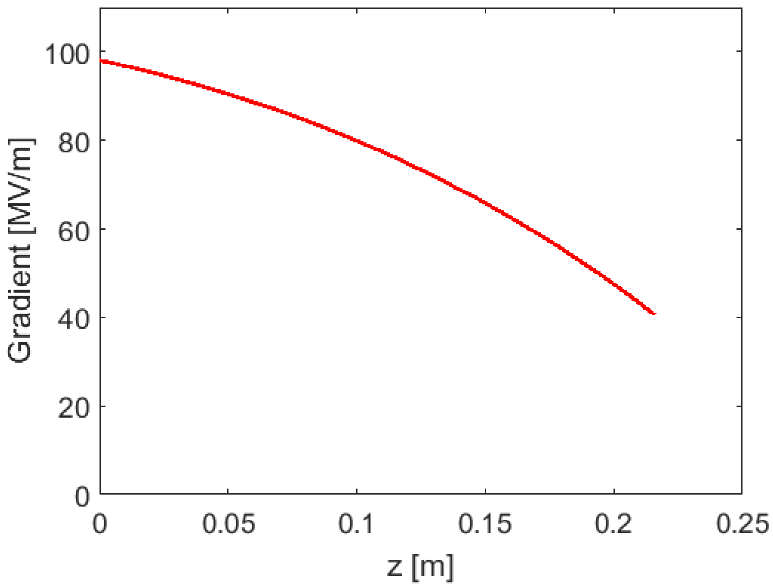
Results Breakdown Localization

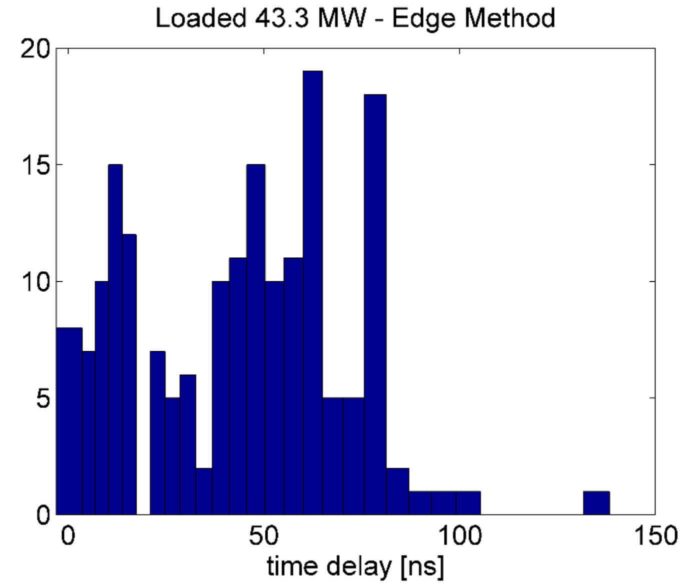
LOADED

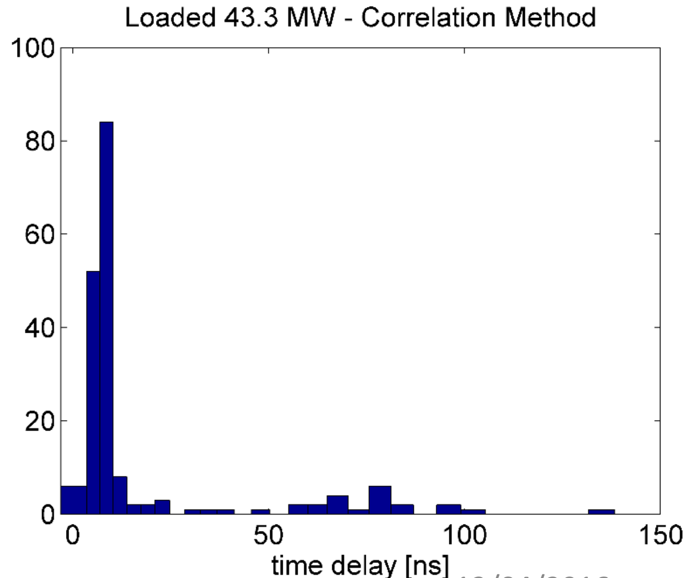
Input Power 43.3 MW

Average Gradient 75 MV/m

Output Gradient 40 MV/m

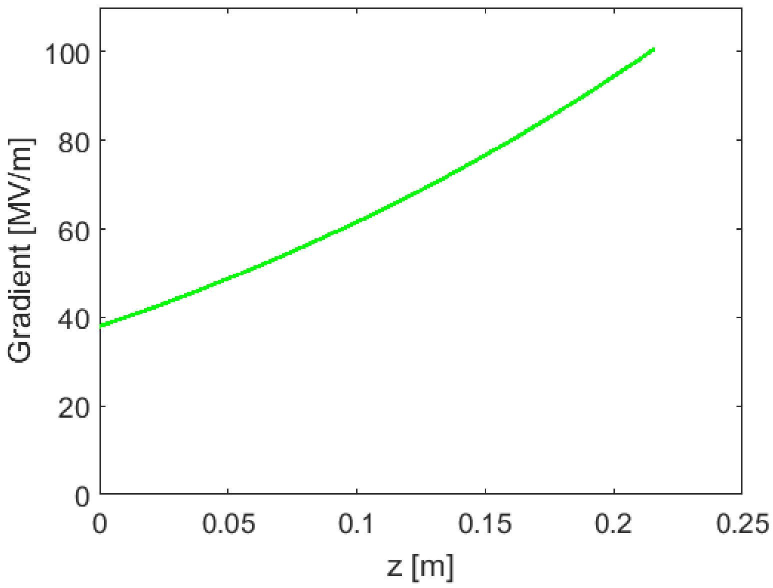


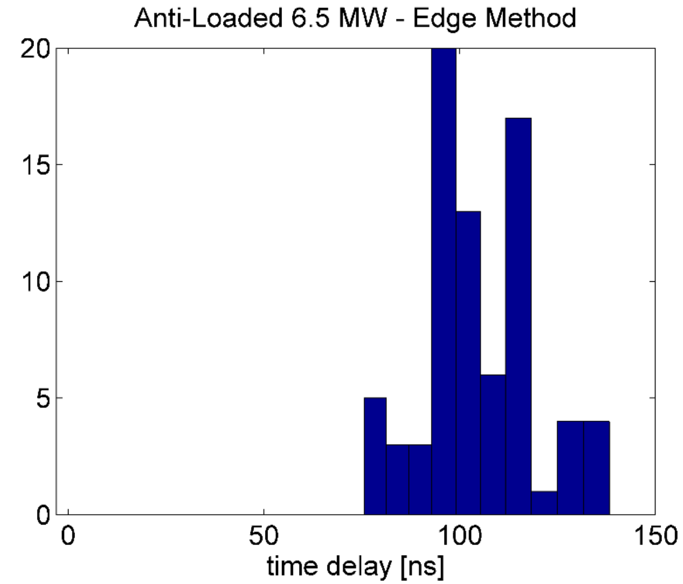


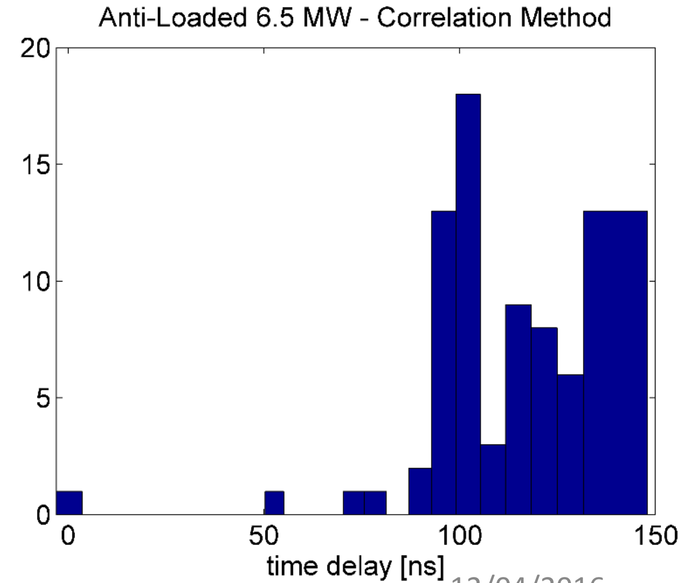


Results Breakdown Localization

ANTI-LOADED
Input Power 6.5 MW
Average Gradient 66 MV/m
Output Gradient 100 MV/m

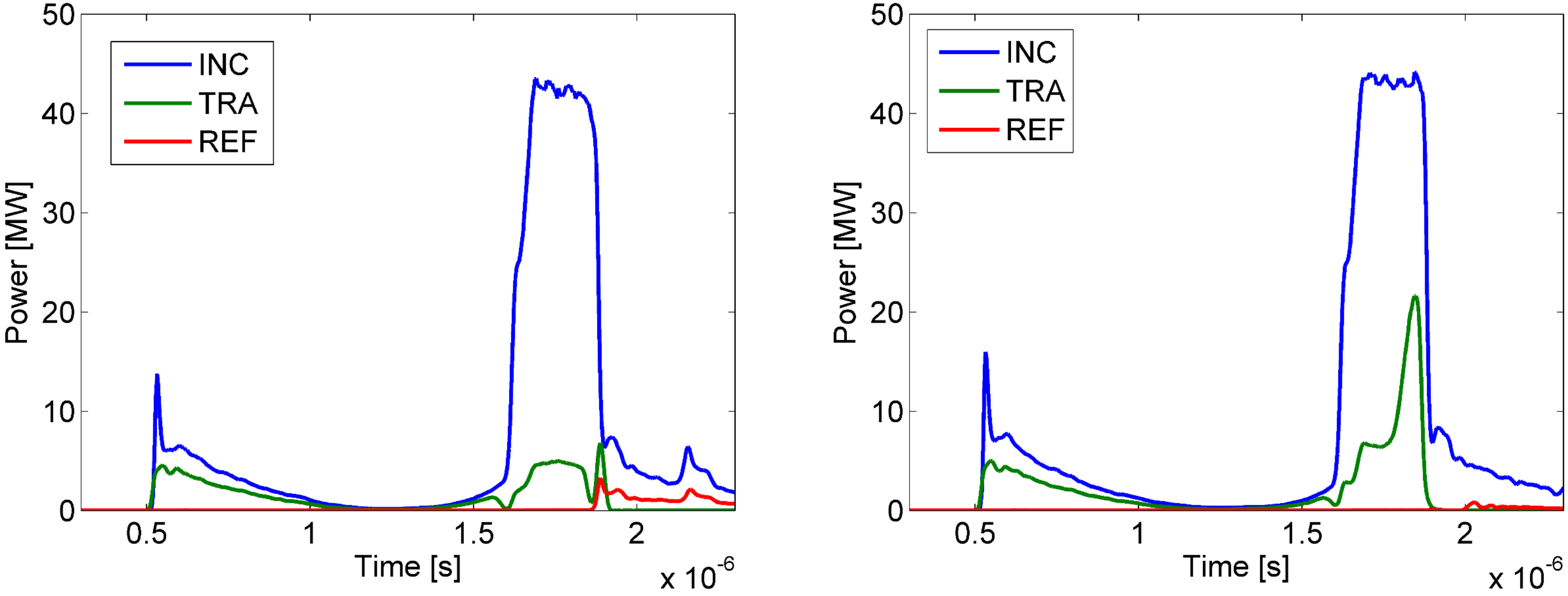






Results Breakdown Localization

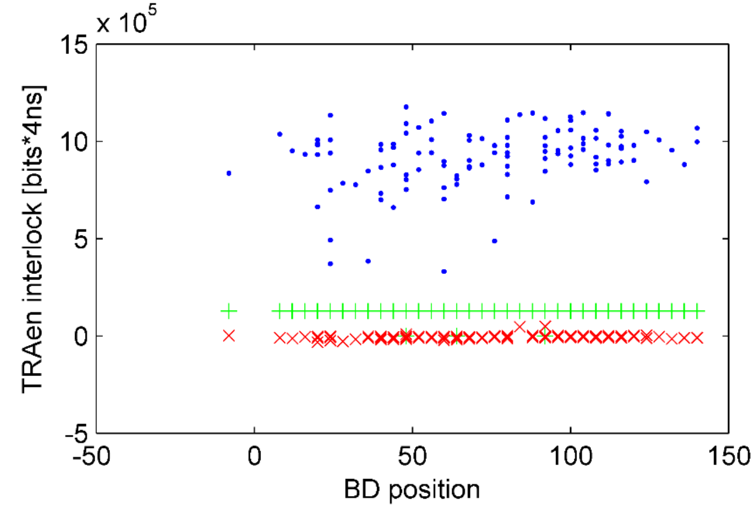
Some examples of Breakdowns in the structure

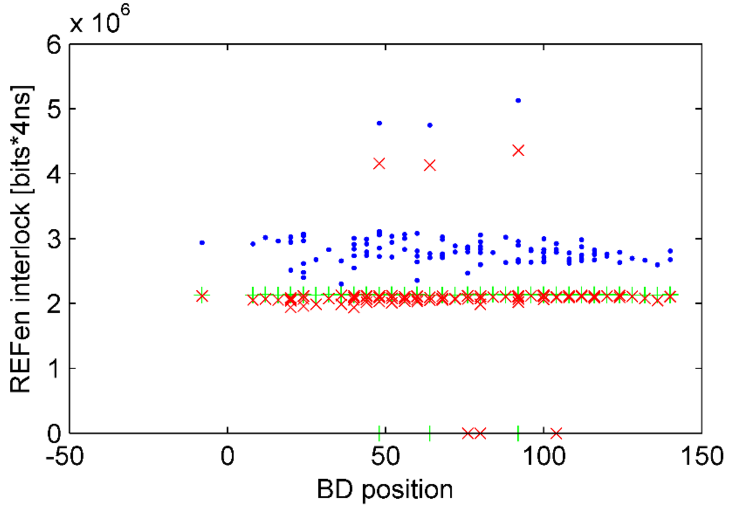


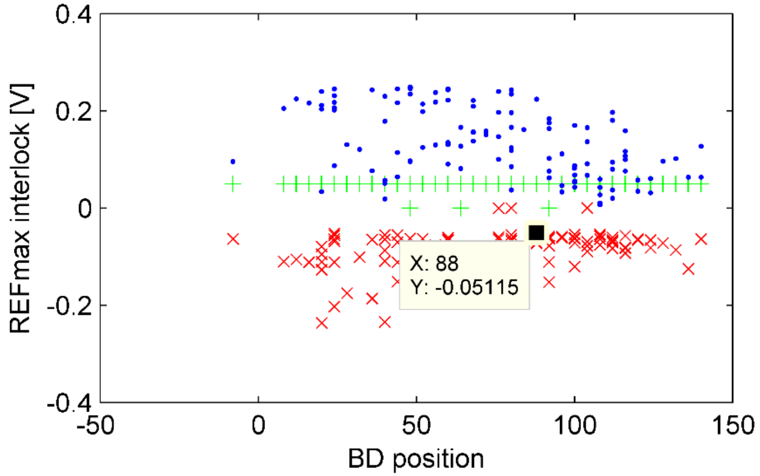
Often, when a BD takes place, transmitted power slightly drops and rises again. This can be explained as the plasma formation that starts reflecting power and cuts out the transmission, but afterwards beam produces power to a higher level than the beam loading (thanks to the high beam current 1.6 A)

Results Breakdown Localization

How sensitive are we in detecting breakdowns along the structure?







Run Unloaded

BD position between 0 and 140 ns

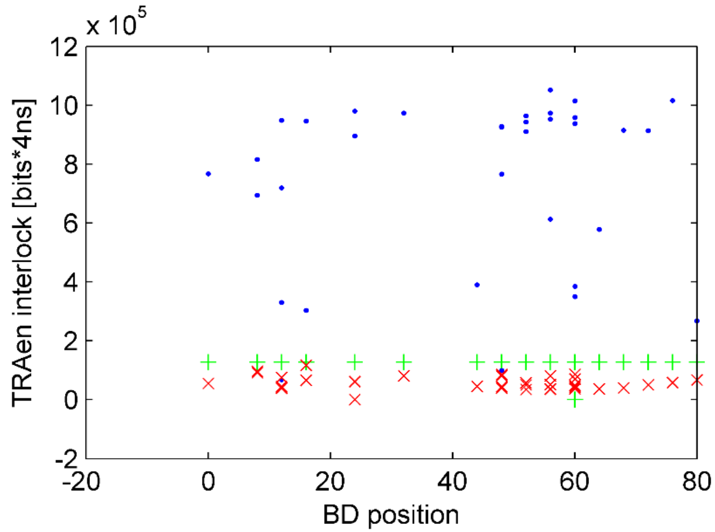
Blue: Breakdown

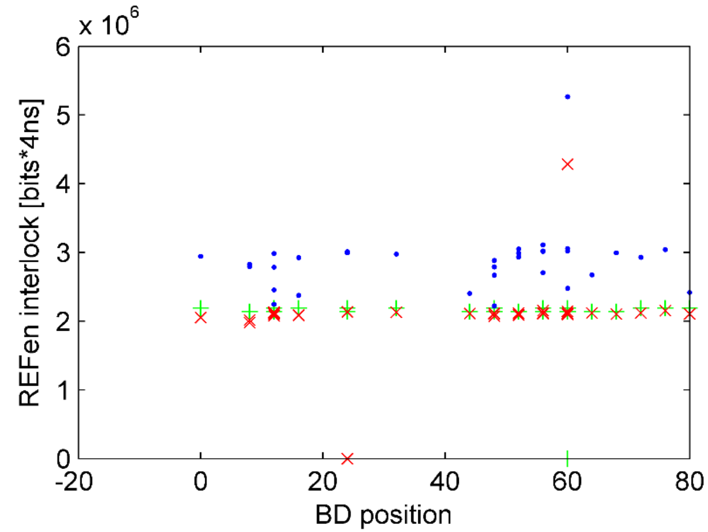
Red: Previous pulse (not a BD)

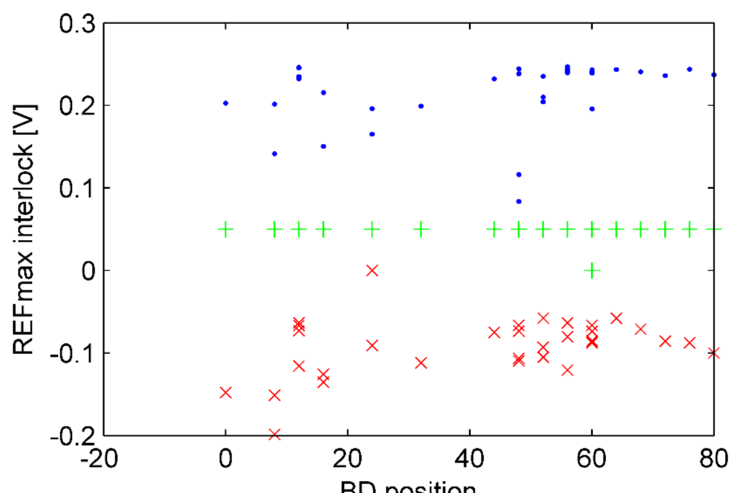
Green: Interlock threshold

Results Breakdown Localization

How sensitive are we in detecting breakdowns along the structure?







Run Loaded

BD position between 0 and 140 ns

Blue: Breakdown

Red: Previous pulse (not a BD)

Green: Interlock threshold

Conclusions

- First results of the Beam Loading experiment with a CLIC-G TD26CC structure in Dogleg (CTF3) have been presented.
- First measurements have been taken to compare beam loading results with unloaded tests with similar parameters: input power, average gradient, output gradient
- This is a phenomenology study, not at CLIC nominal operation settings: higher beam current and length
- Results show no difference in BDR when feeding with same input power, and seems to be **correlated with the peak gradient.**
- Breakdown localization analysis shows consistently **more accumulation of breakdowns at front when loaded, and at the end when anti-loaded**
- This suggests the idea of avoiding higher fields by tapering the structure so that **loaded gradient is constant.**

THANK YOU FOR YOUR ATTENTION

Acknowledgements to all Xbox and CTF3 teams members that contributed to the hard realization of this experiment!