High Power Crab Cavity Testing

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EuCARD-2 3rd Annual Meeting of the

Malta.

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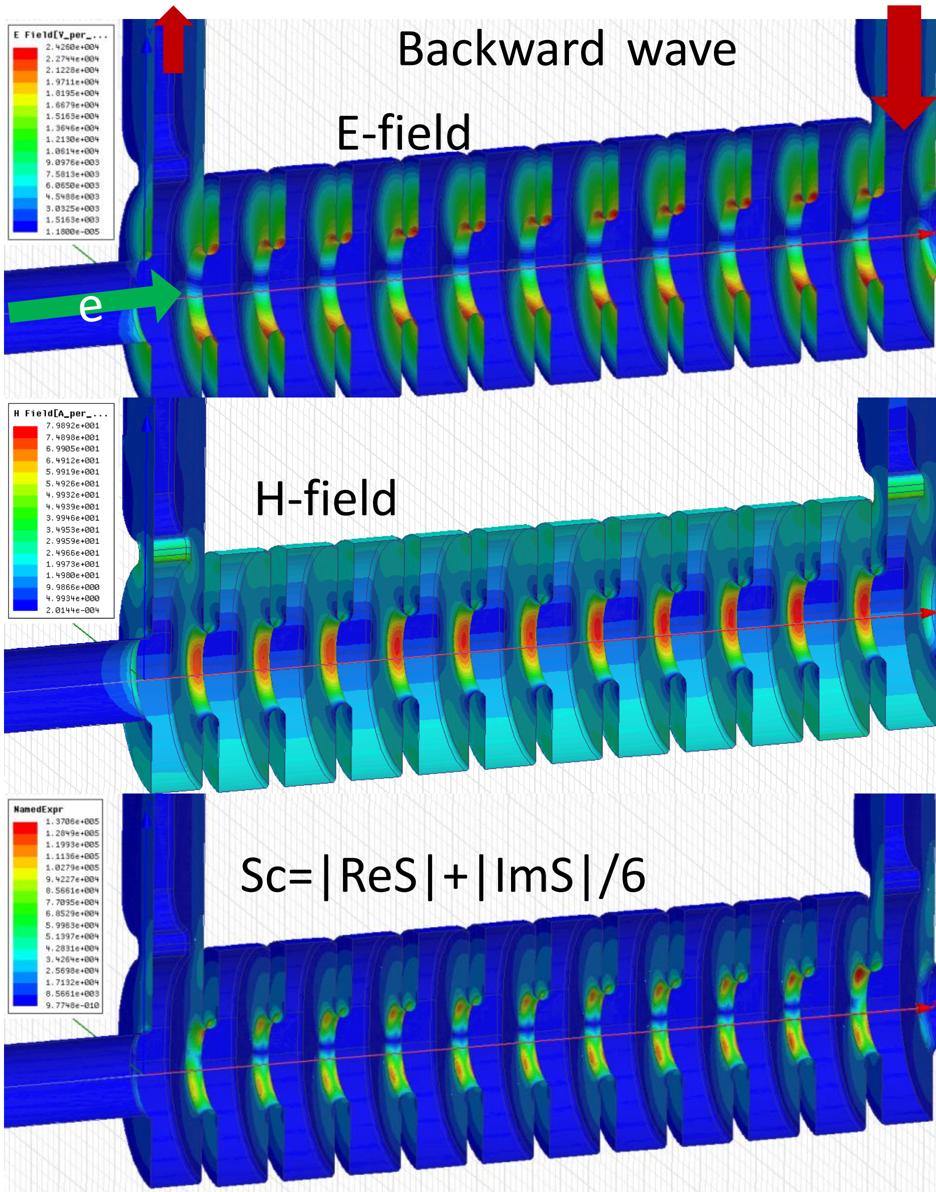
Outline

- Crab Cavity Overview
  - Field profiles + Comparison with other structures
- Xbox-2
  - Layout
  - Diagnostics
- High Power Test Results
  - Full history plot
  - BDR dependencies
  - BD evolution compared with other high gradient structures
  - BD cell locations
- Post Mortem Results
  - Cutting and nomenclature
  - Breakdown crater positions and with respect to surface field quantities.
  - BD cell locations
  - B-field effects
- Conclusions
  - Post mortem observations
  - High power performance comparisons.

Crab Cavity Design



Property	CLIC T24 (unloaded)	LCLS deflector	CLIC Crab (un-damped)
Input Power	37.2 MW	20 MW	13.35 MW
Transverse Kick	-	24 MV	2.55 MV
Peak surf. E-field	219 MV/m	115 MV/m	88.8 MV/m
Peak surf. H-field	410 kA/m	405 kA/m	292 kA/m
Peak Sc [3]	3.4 MW/mm^2	-	1.83 MW/mm^2
Group Velocity	1.8-0.9%c	-3.2%c	-2.9%c
# Cells	24	117	12

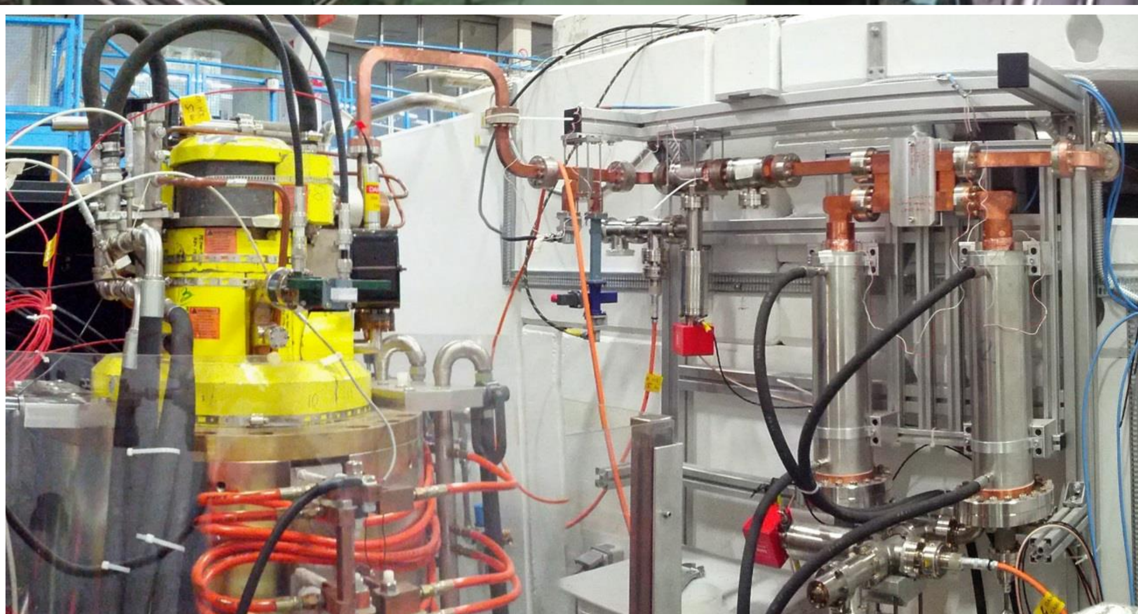
Location of each surface property is different on the iris. May be able to determine which surface property causes the most breakdowns/damage using post-mortem analysis.

G. Burt

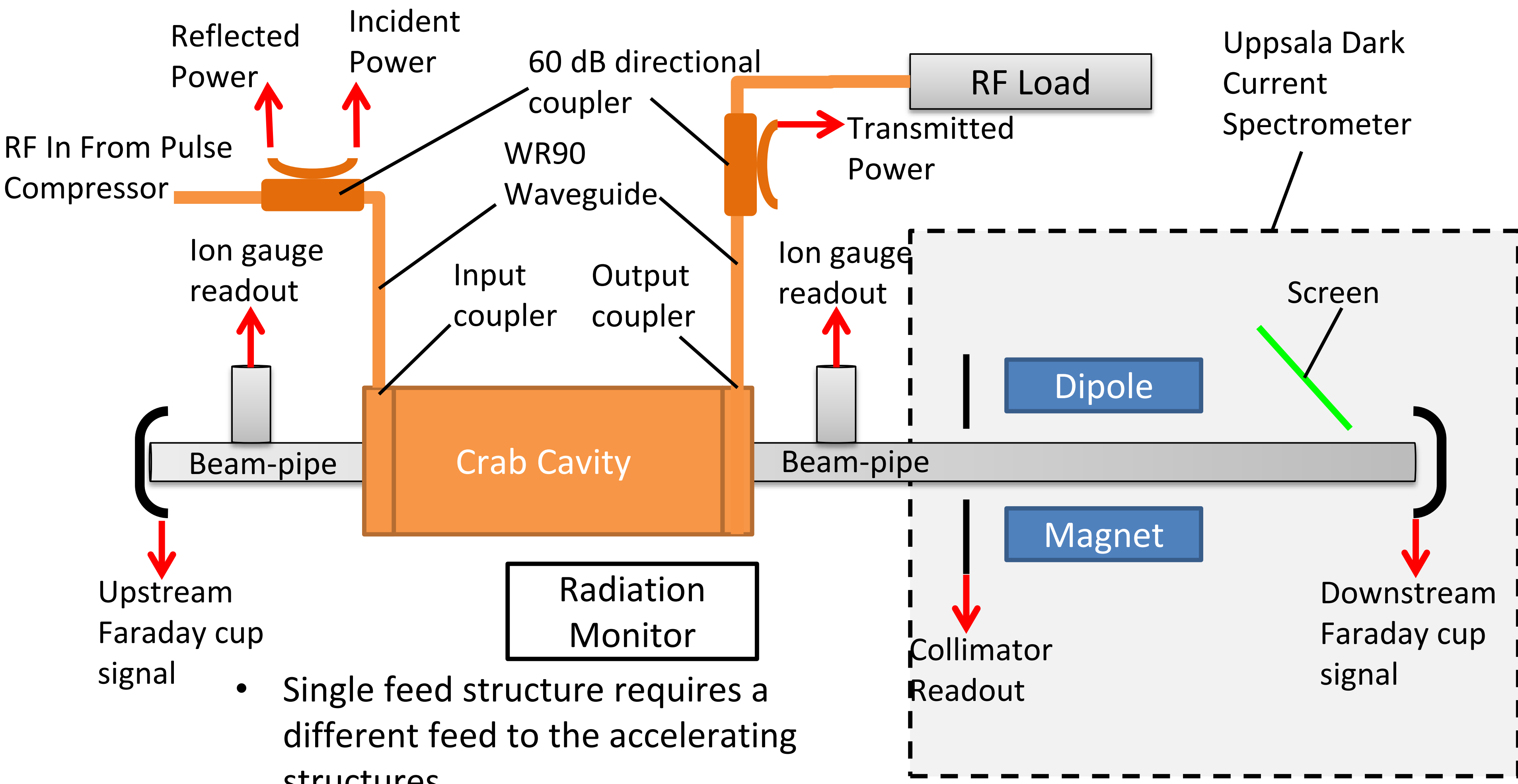
A. Grudiev V. Dolgashev P.Ambattu

Xbox-2

- Scandinova Modulator
- Klystron (50MW, 1.5us pulse) For Crab cavity test: SLAC XL5 klystron
- Pulse compressor (250ns, ratio ~3)
- Stainless steel load

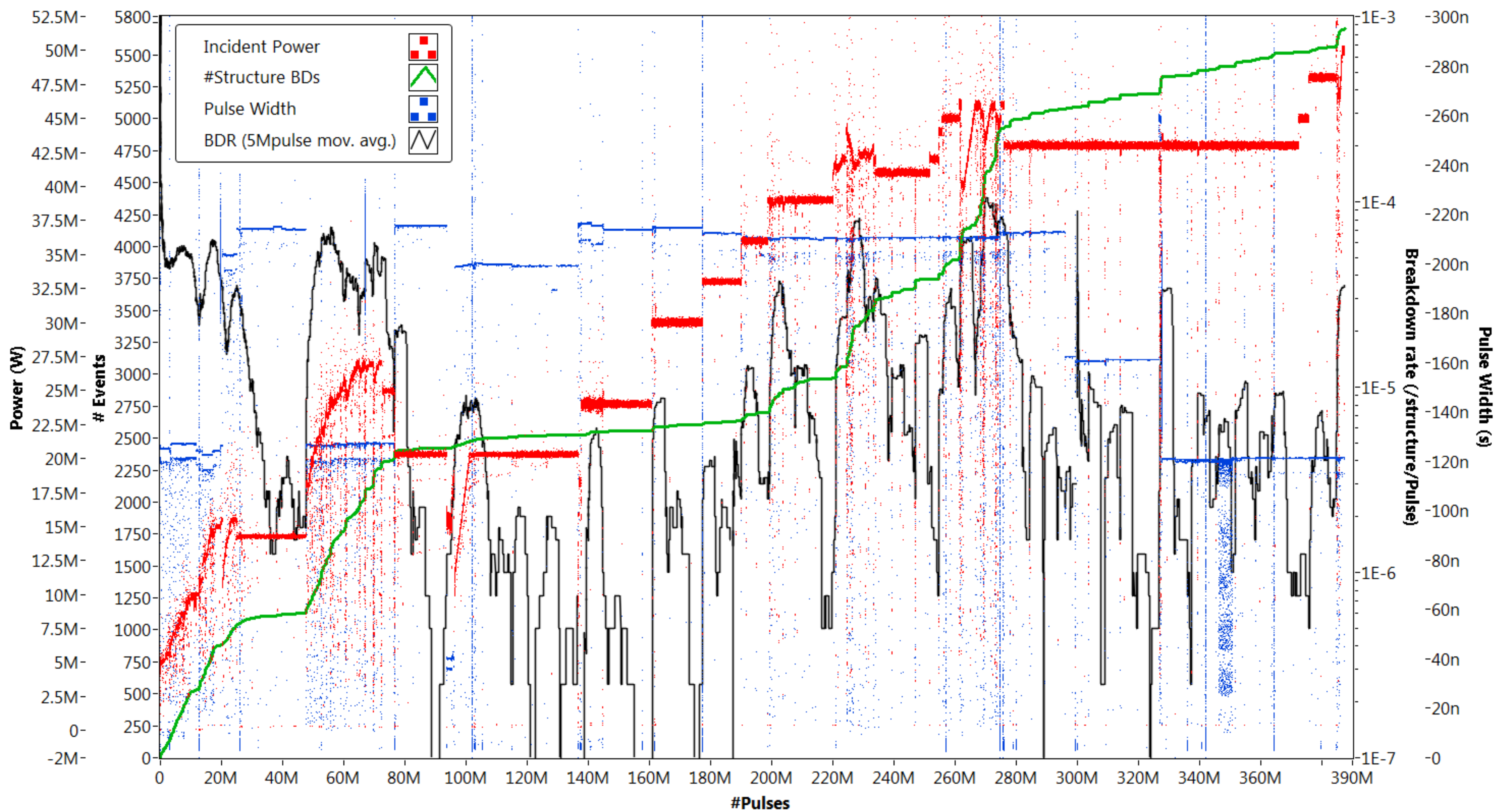


Xbox-2 Diagnostics



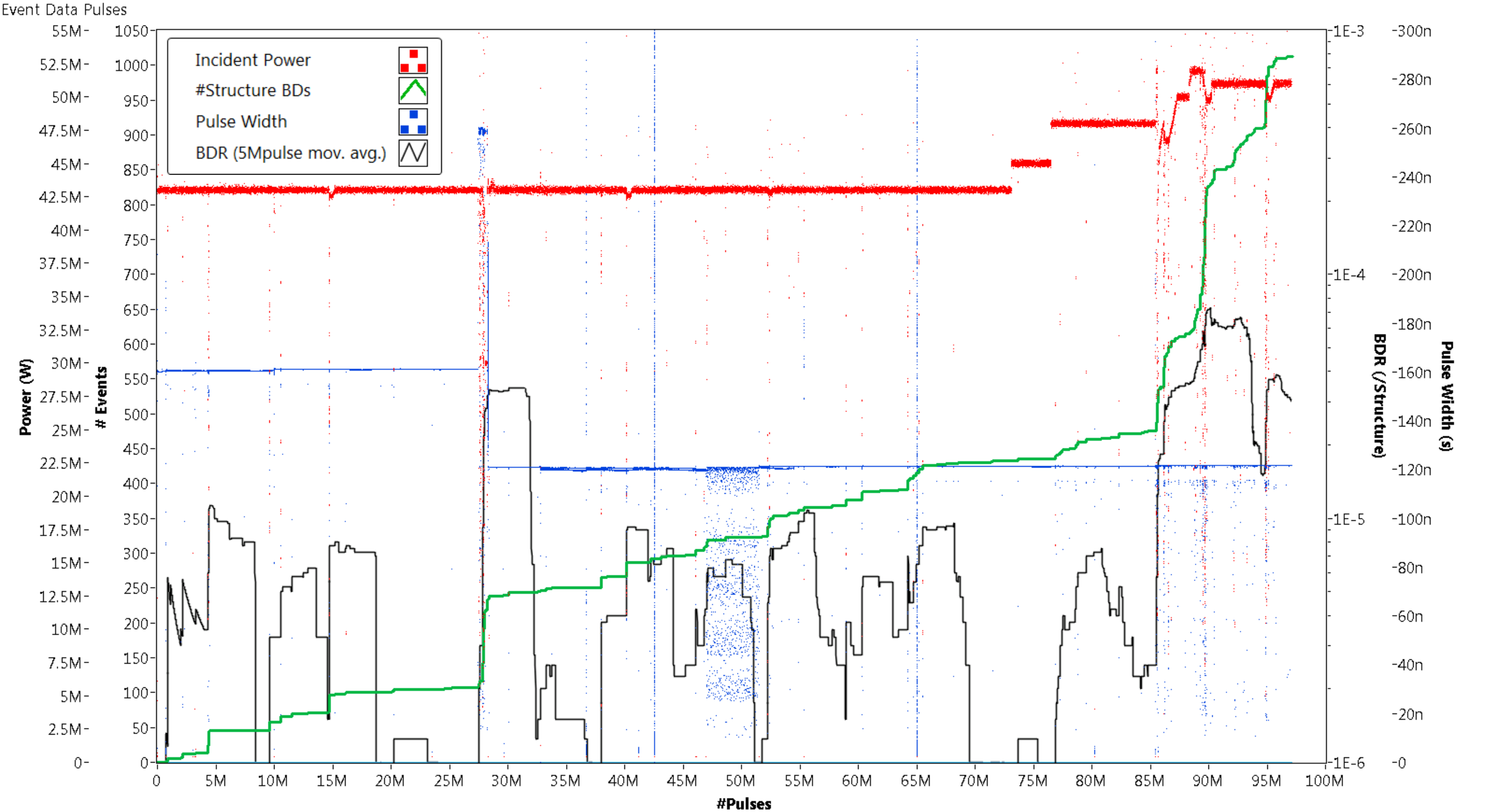
- Single feed structure requires a different feed to the accelerating structures.

Full Processing History



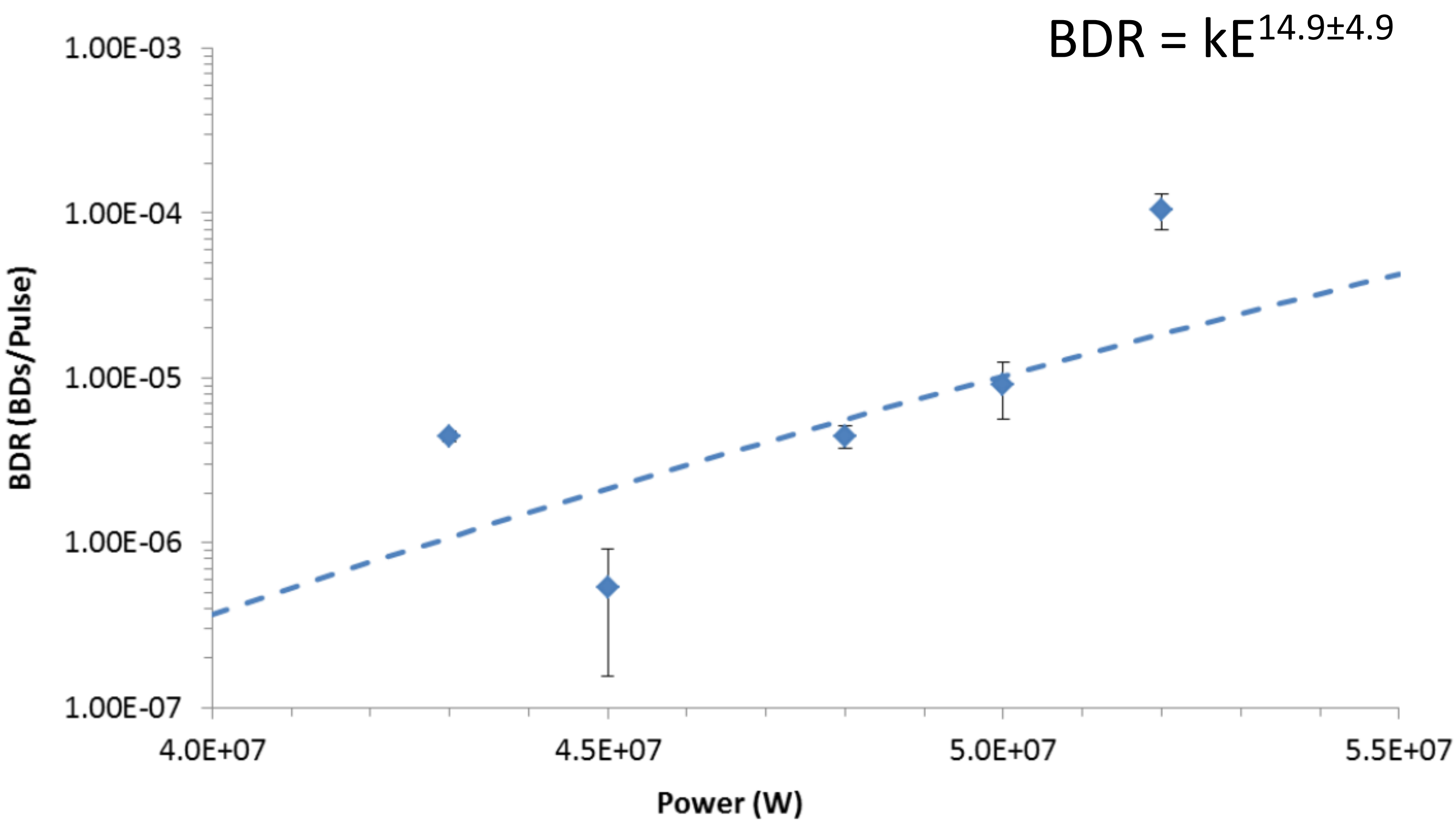
Structure has seen almost 390 million pulses with over 5700 breakdown events.
Performed well above the operating limit of 13.35 MW: **43MW, 200ns flat-top, BDR 3e-6**.
Peak power reached**: 51 MW, 100 ns flat-top, BDR 3e-5**.

Pulse width and Power Dependencies

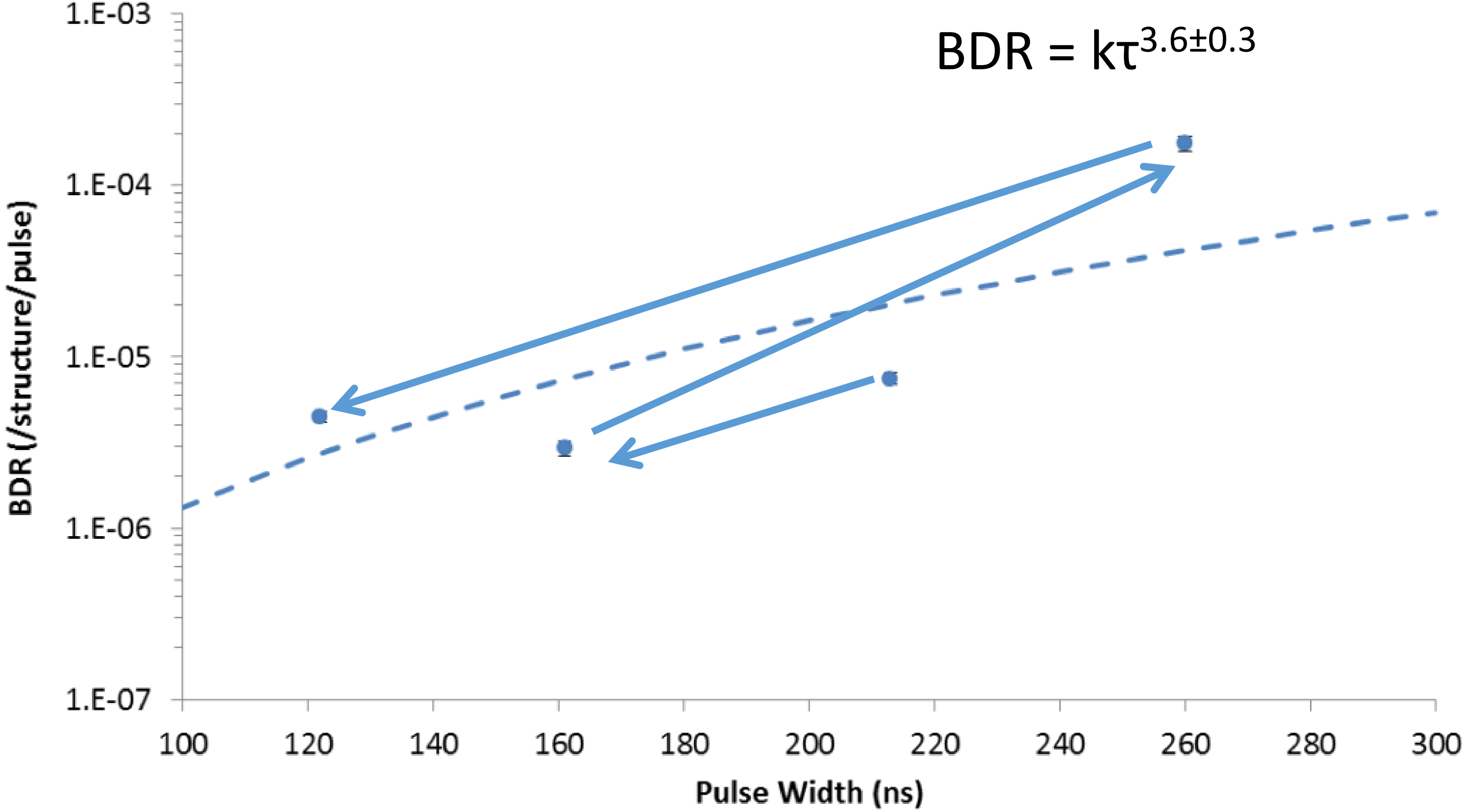


After pushing the structure to its limit at 200ns pulse width, pulse width and power level were changed to collect enough data to measure the pulse width and power dependency on the BDR.

Pulse width and Power Dependencies



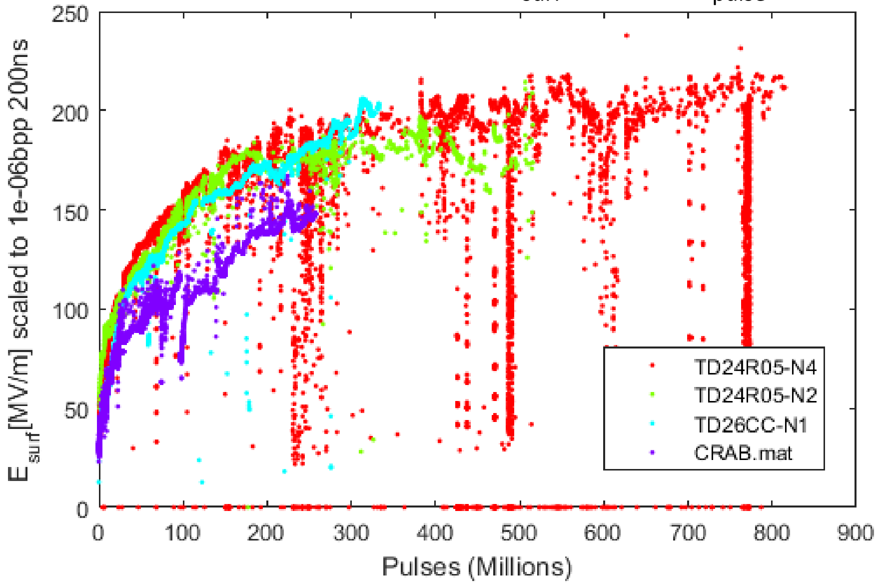
Pulse width and Power Dependencies



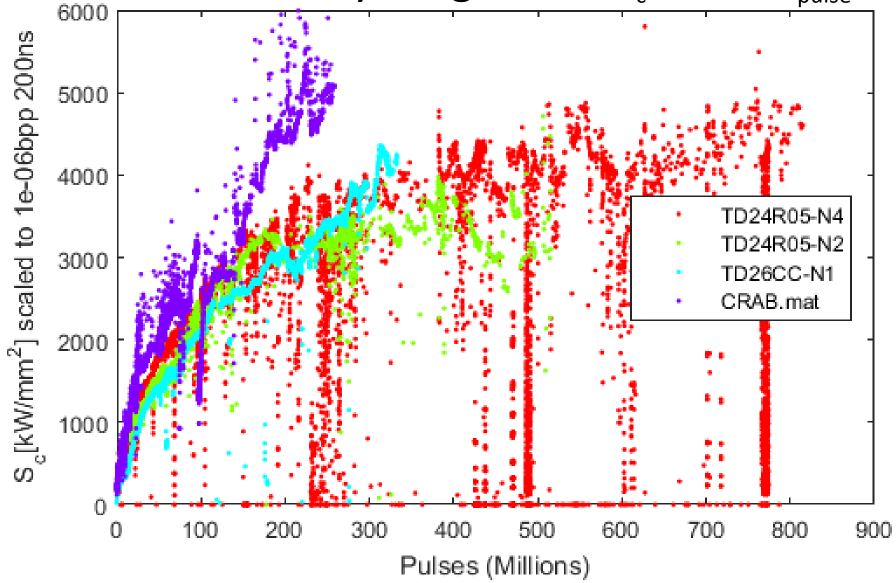
Some structure degradation occurred after running at 250 ns flat-top; the BDR for 120 ns pulse width is higher than that of 160 ns.

Time Evolution of BDR compared to other High Gradient Structures

Surface electric field $E_{surf} \sim BDR^{1/30}\, t_{pulse}^{-1/6}$

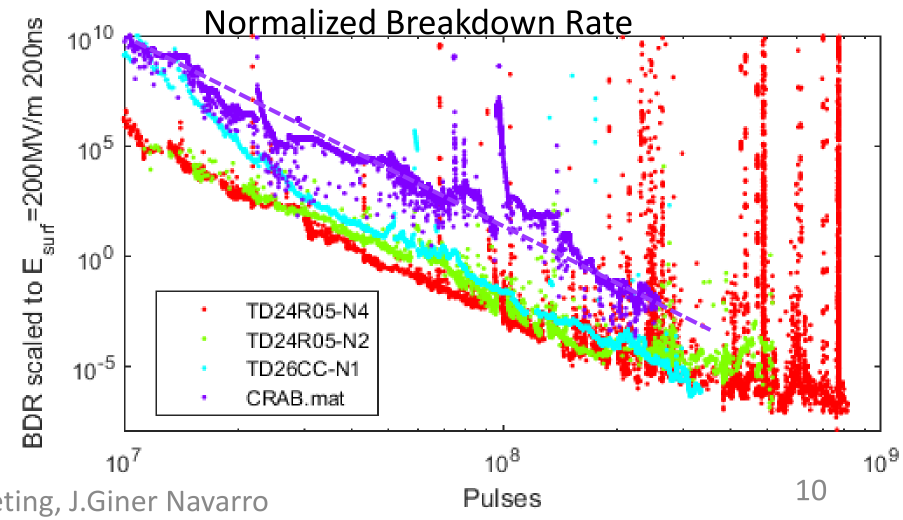


Modified Poynting vector $S_c \sim BDR^{1/15}\, t_{pulse}^{-1/3}$

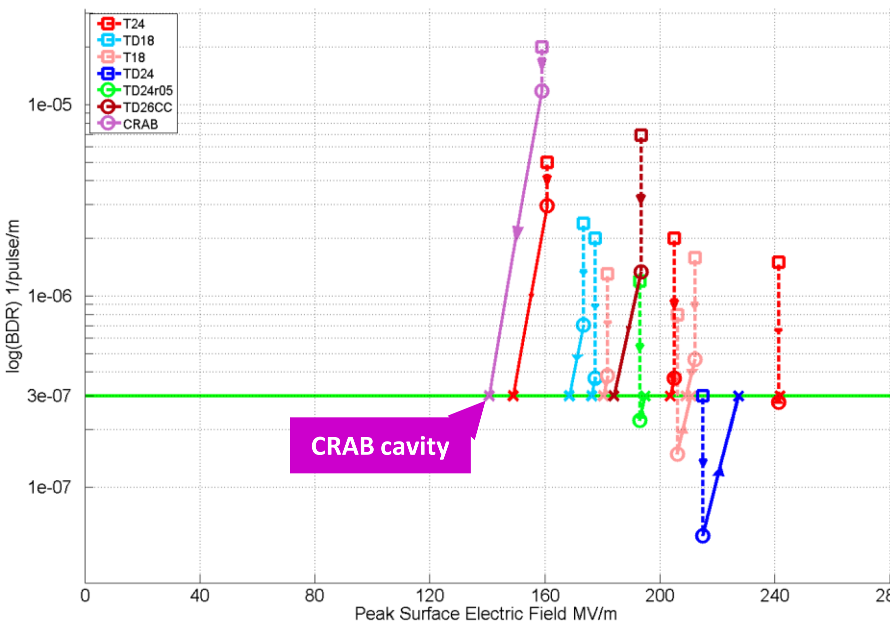


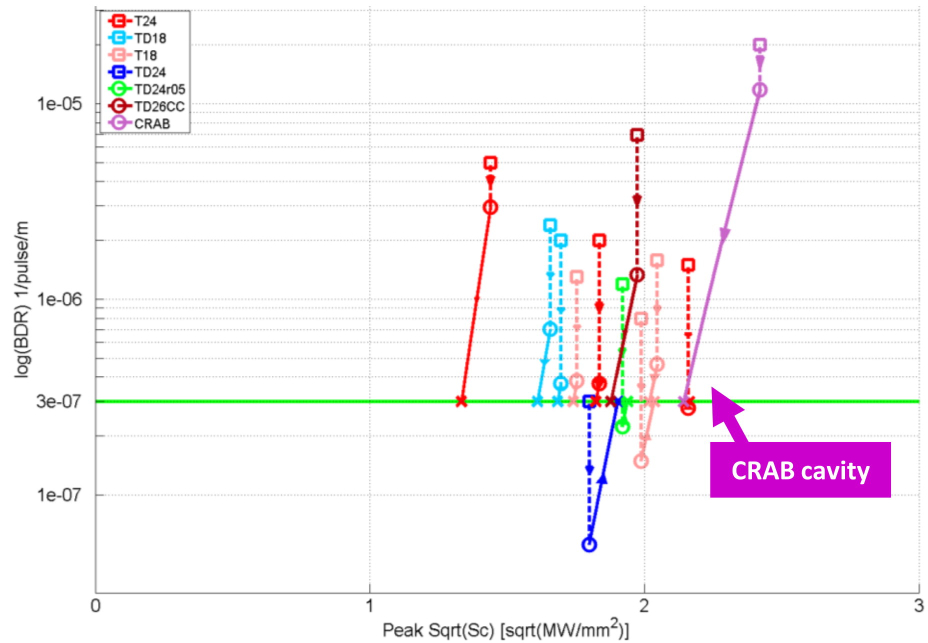
The structure has reached higher levels of Sc, but surface E field were lower.

Breakdown rate seem to decrease with similar rate than other CLIC accelerating structures.



Final performance comparison



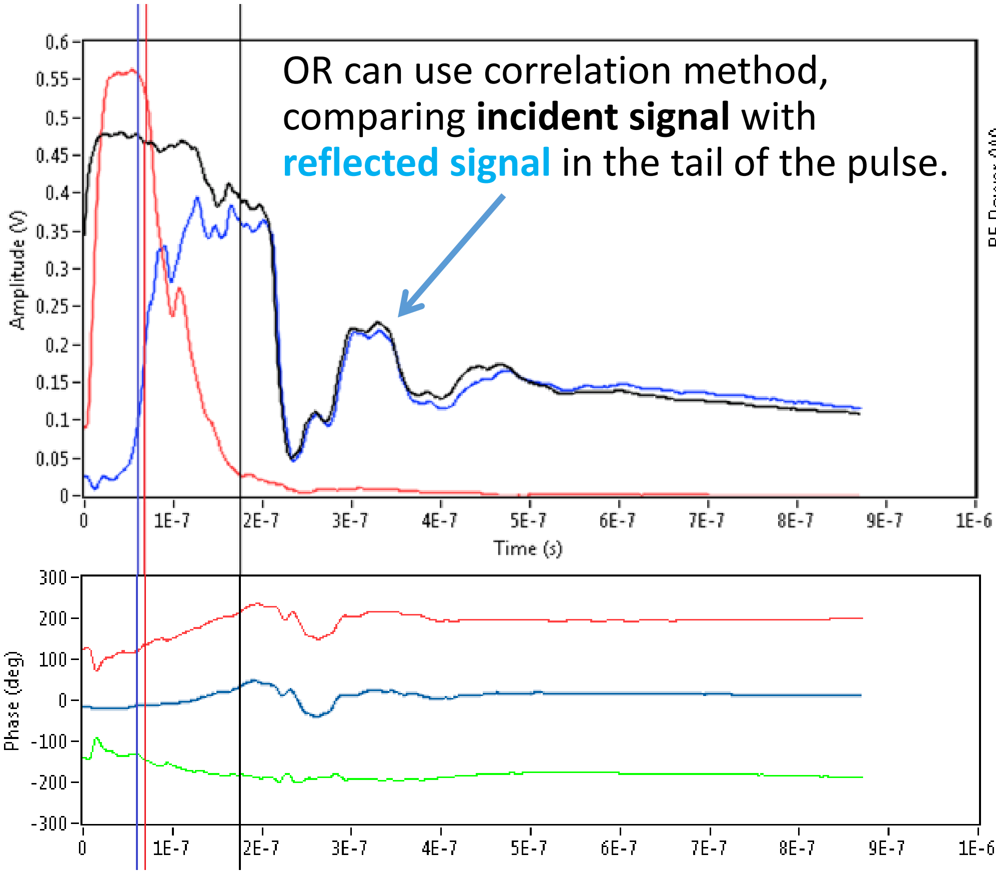


In terms of peak surface E field and peak Modified Poynting vector

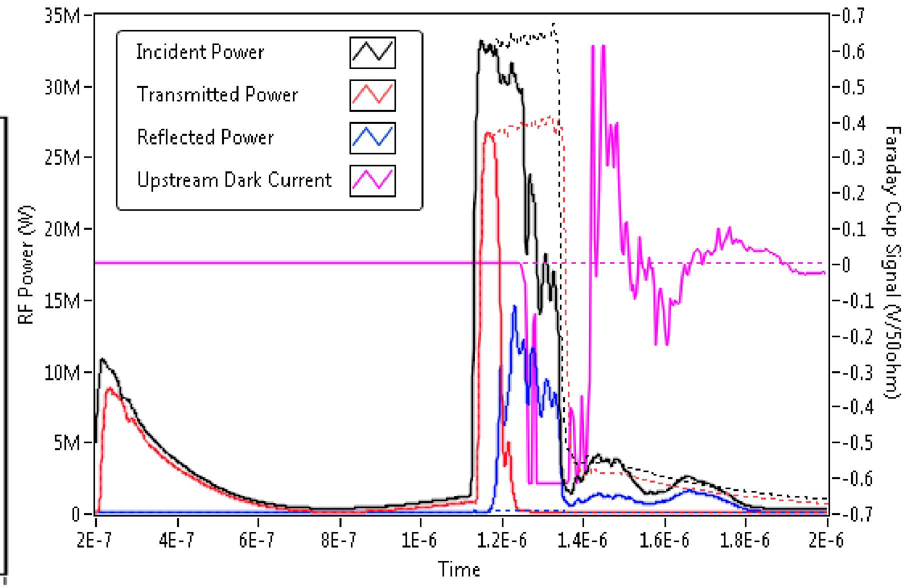
BD events and location

The time difference between the falling edge of the **transmitted signal** and the rising edge of the **reflected signal** are used to find the breakdown cell. With the phase used to isolate to the nearest 3rd cell (for 120° phase advance structures)

OR can use correlation method, comparing **incident signal** with **reflected signal** in the tail of the pulse.



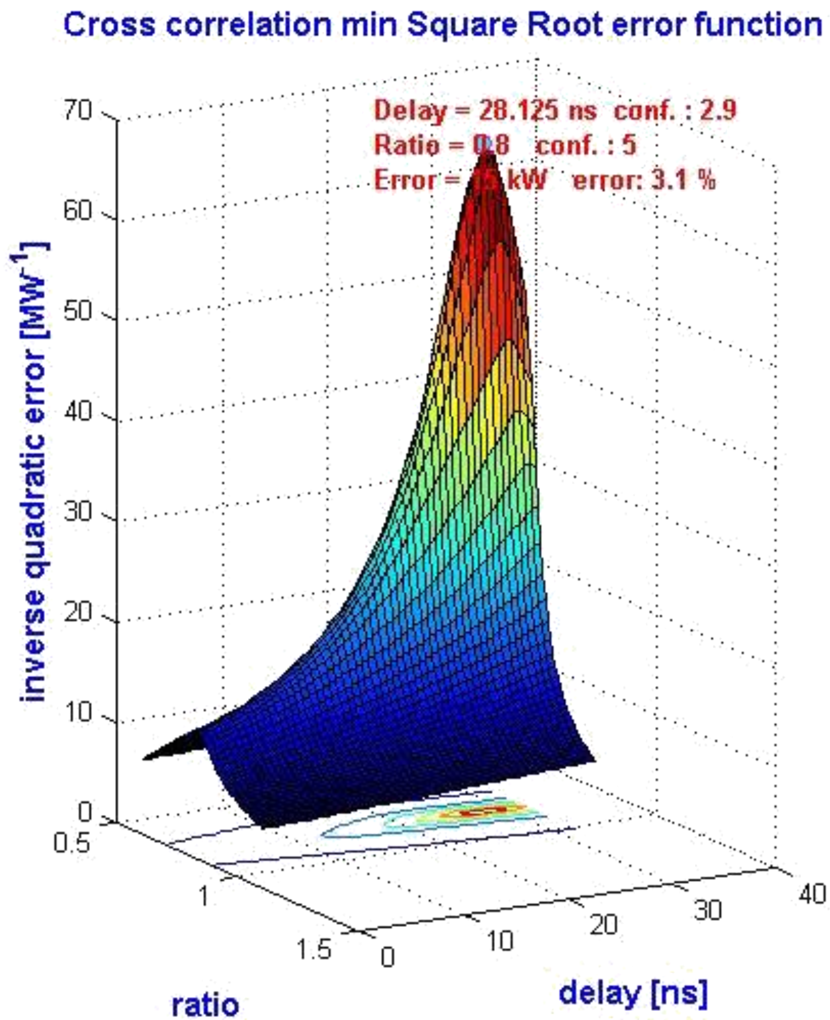
Breakdown pulse (solid lines) with the preceding pulse shown (dotted lines)

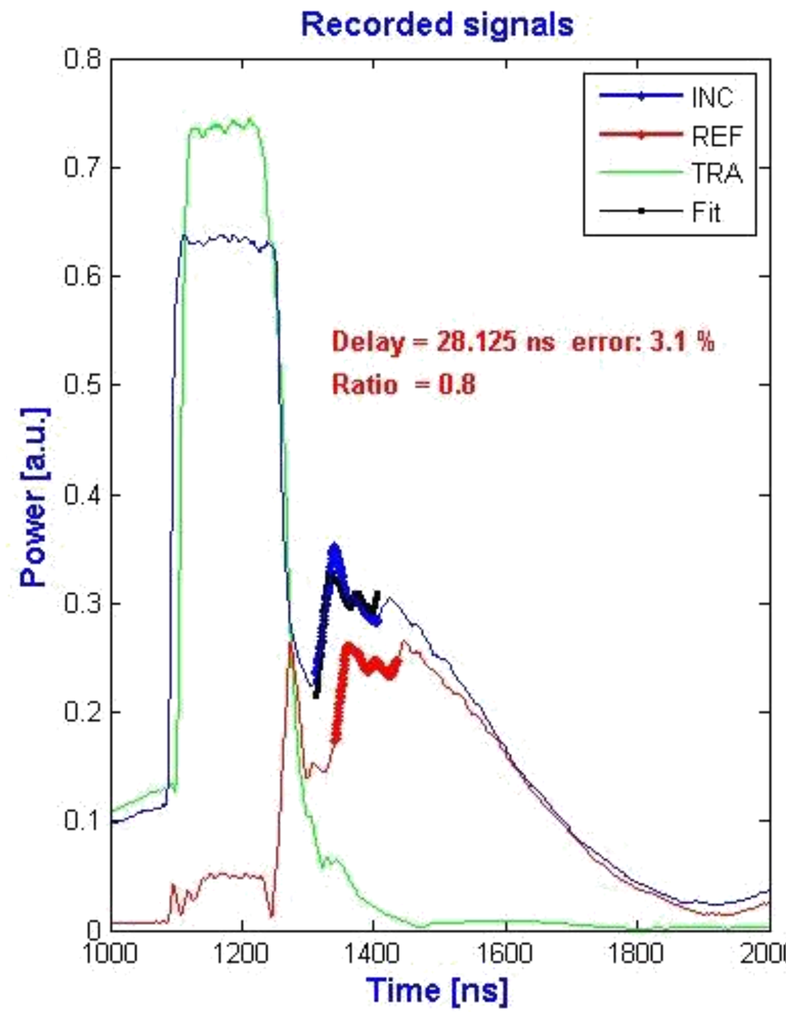


Phase measured during a breakdown is used for breakdown cell location. Once the breakdown is established the phase between the incident and reflected pulse remains at approx. -200 degrees.

Correlation Method: A good correlation

Delay 28.1 ns (close to the RF output)





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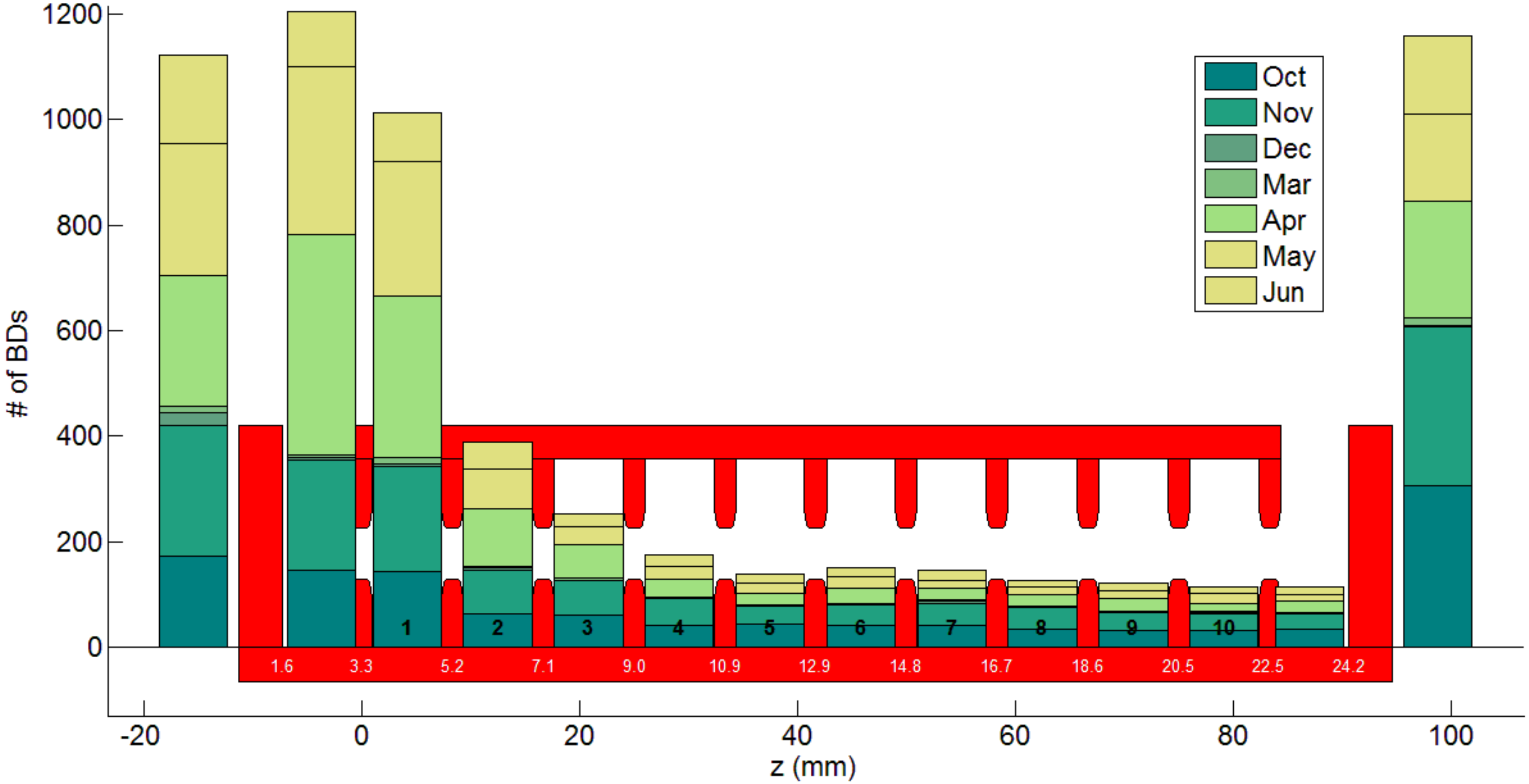
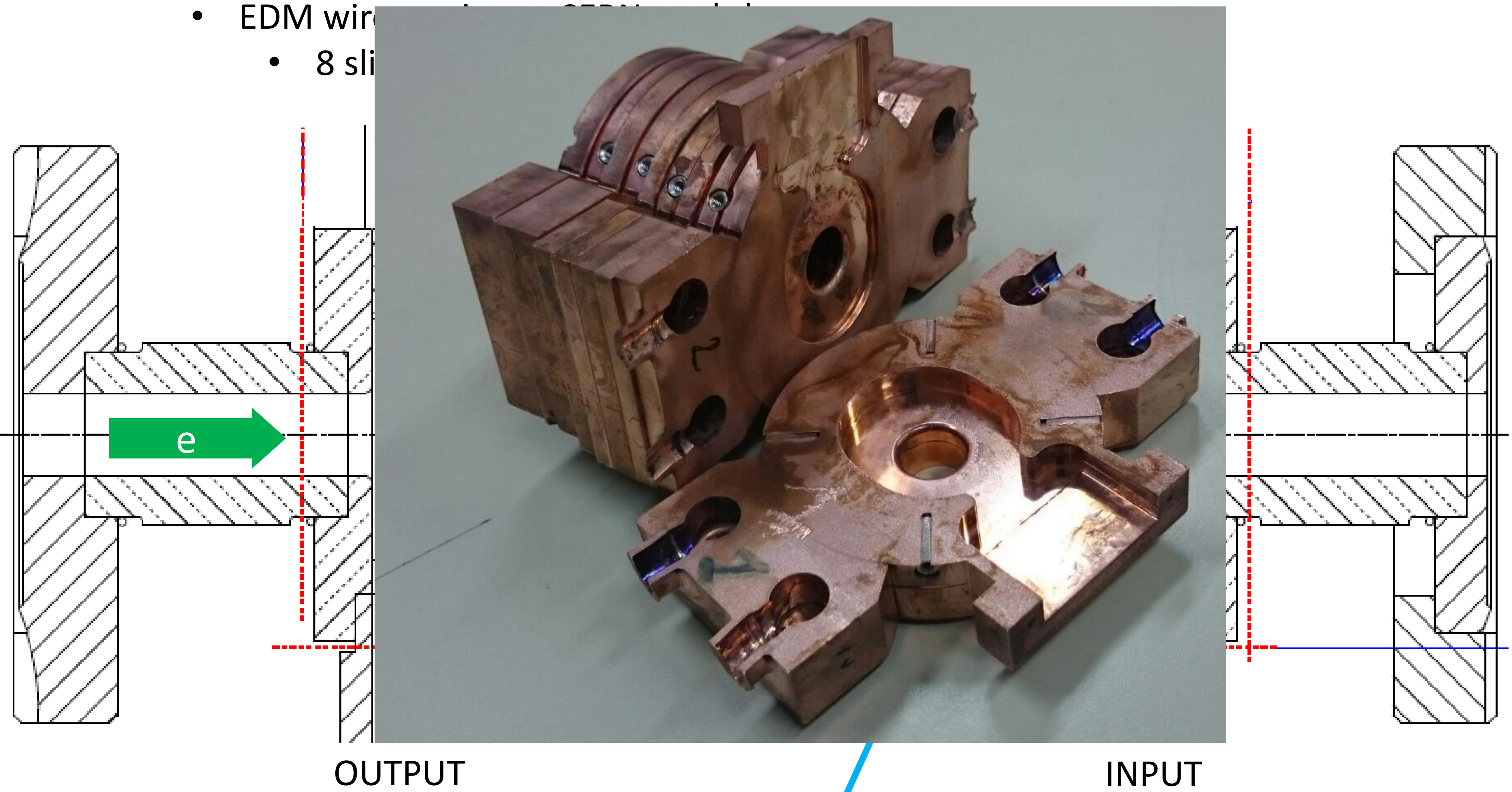
Breakdown Cell distribution



Vast majority of BDs occur in the coupling cell and first regular cell.

Cutting and nomenclature

- EDM wir
  - 8 sli



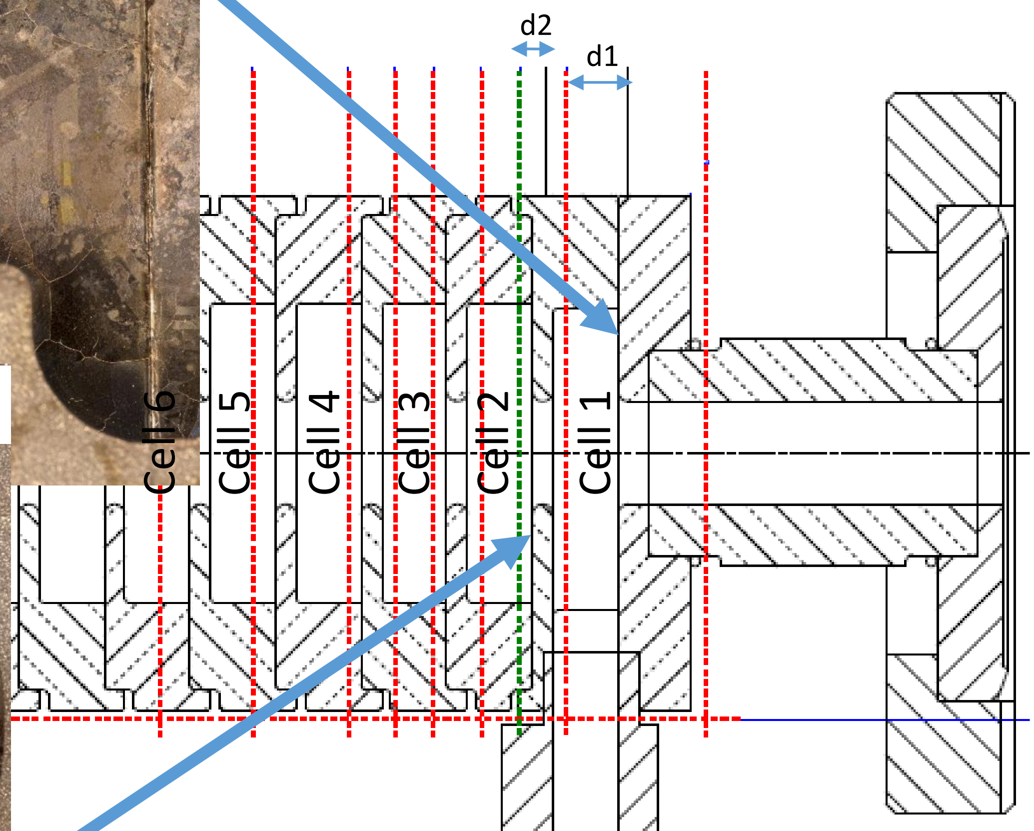
Iris 1 = Iris in the INPUT side
Iris 2 = Iris in the OUTPUT side

Example: Cell 4 – Iris 1

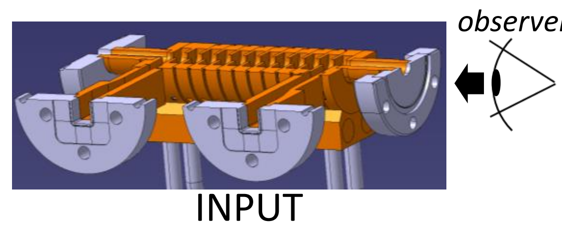
Cell 1 Iris 1 (Far from wire during cutting)

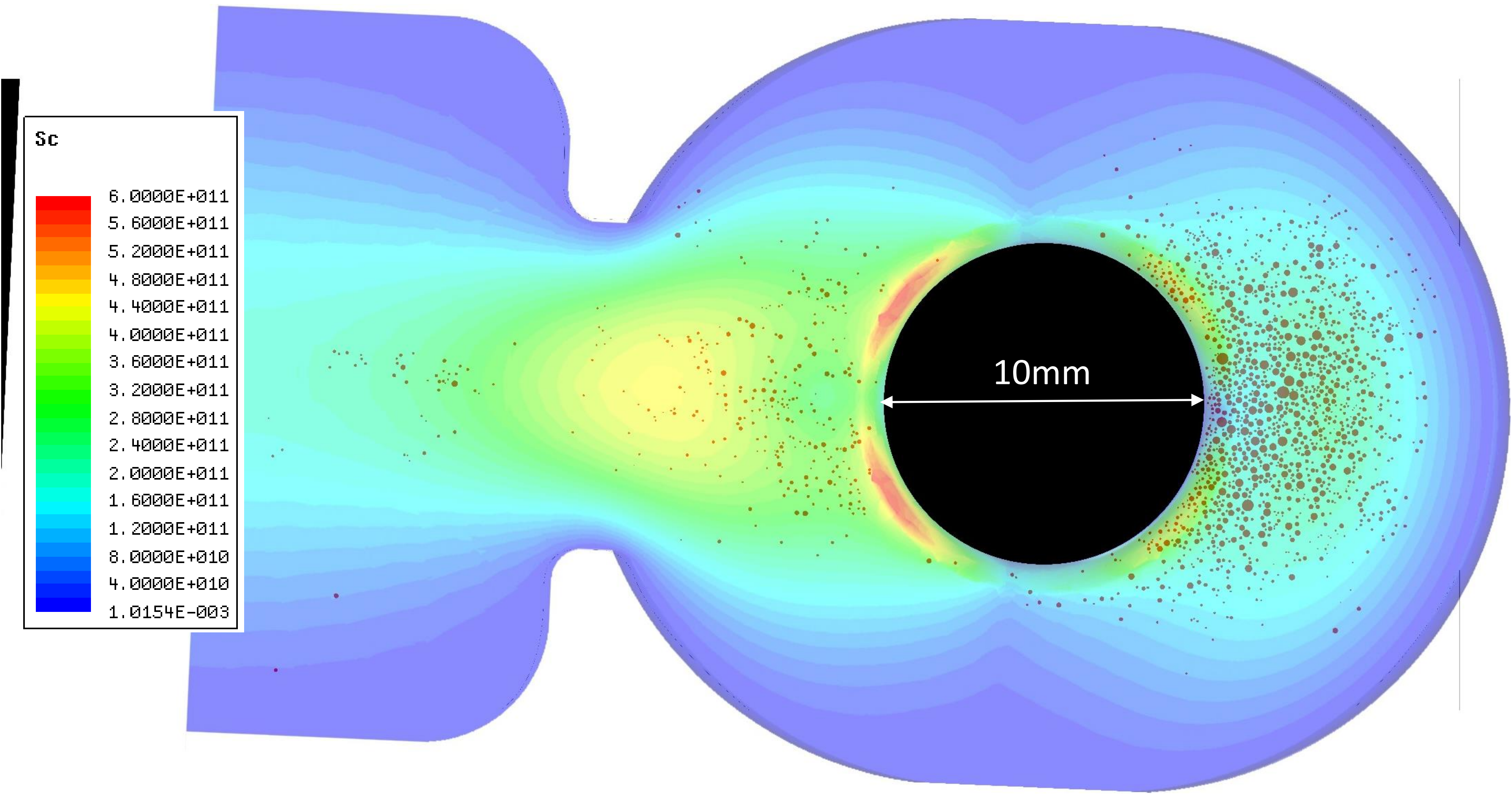
Cell 2 Iris 1 (Close to wire during cutting)

$d_1 >> d_2$

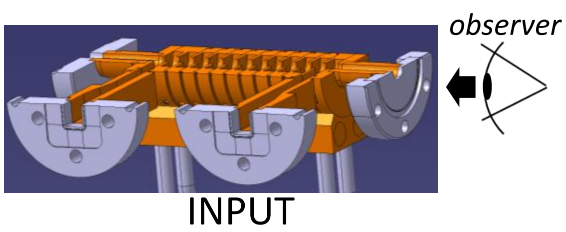


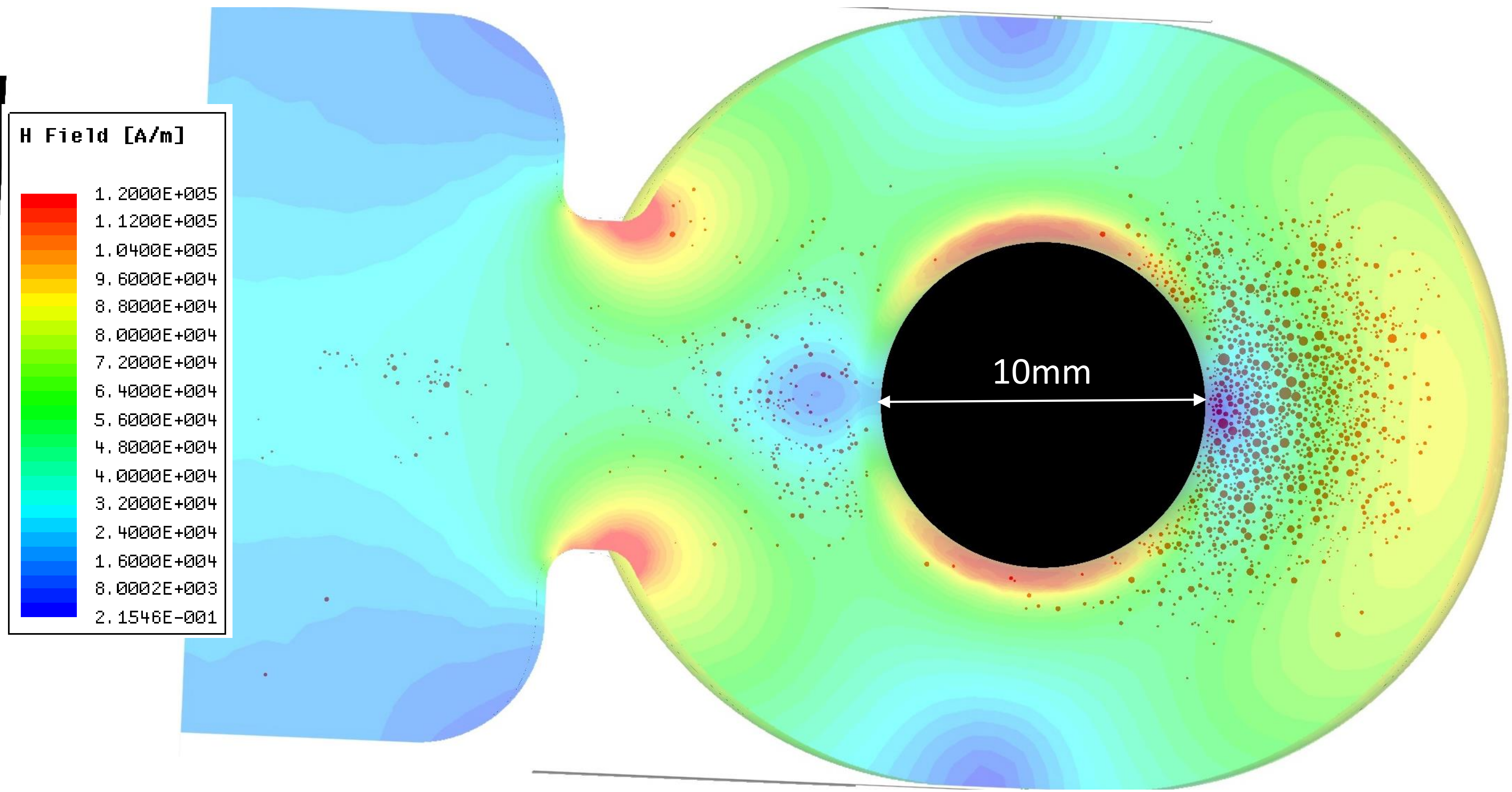
Cell 1 – Iris 1 Vs Sc-Field



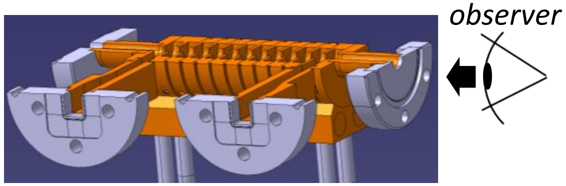


Cell 1 – Iris 1 Vs H-Field

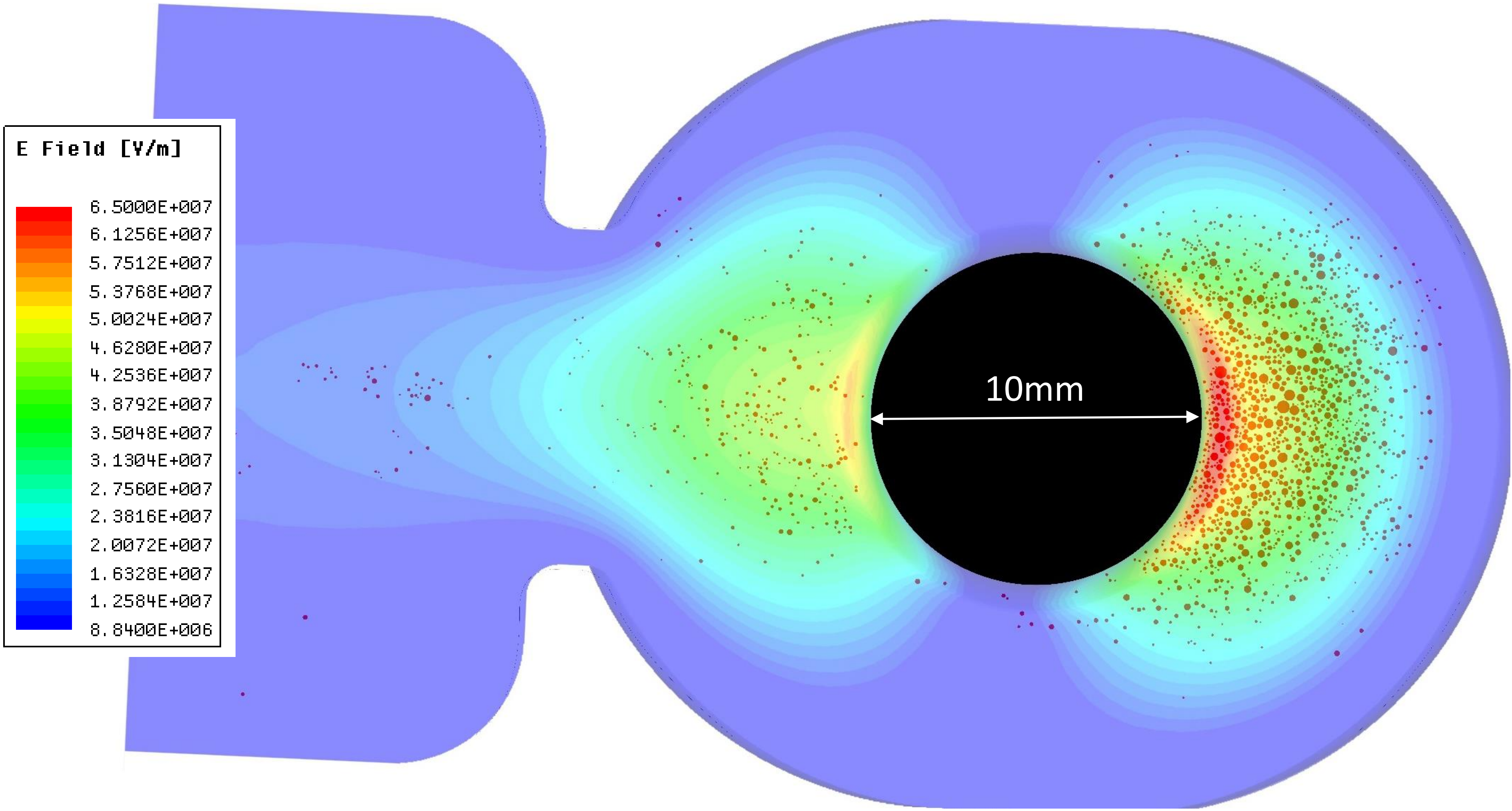




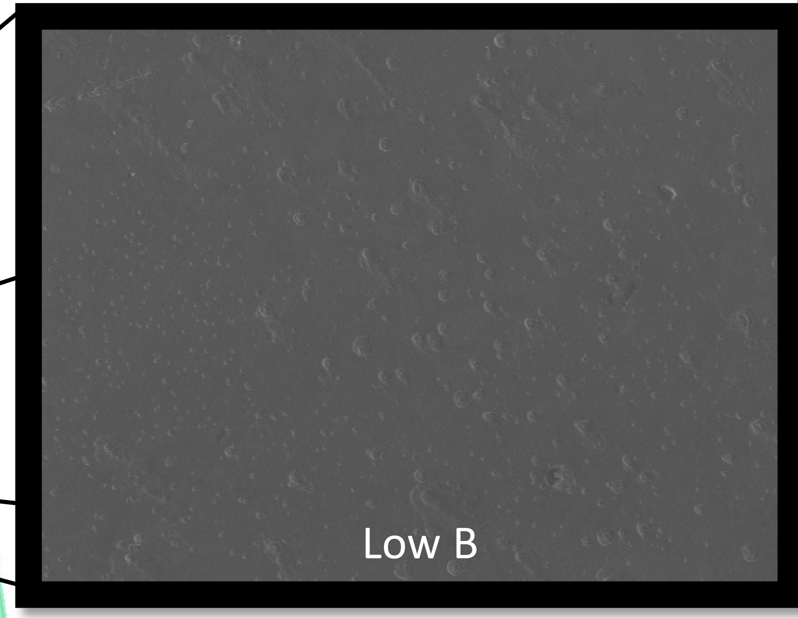
Cell 1 – Iris 1 Vs E-Field

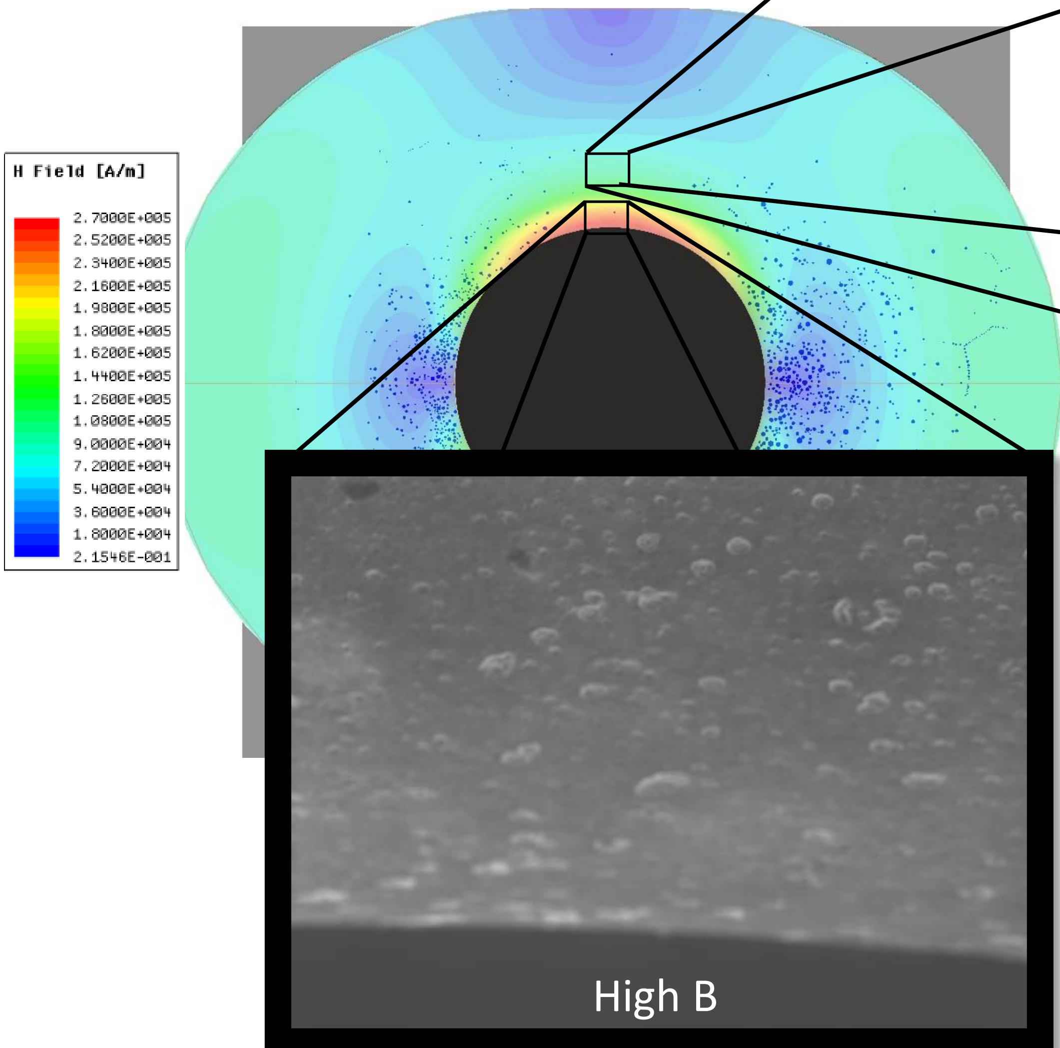


INPUT



B-Field Effects: Cell

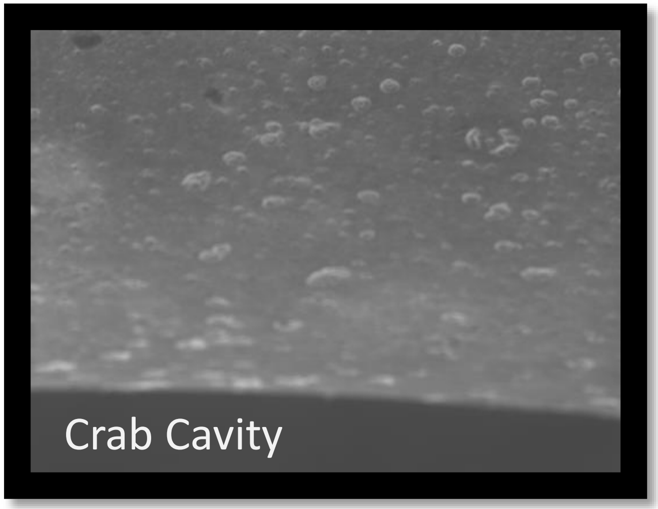




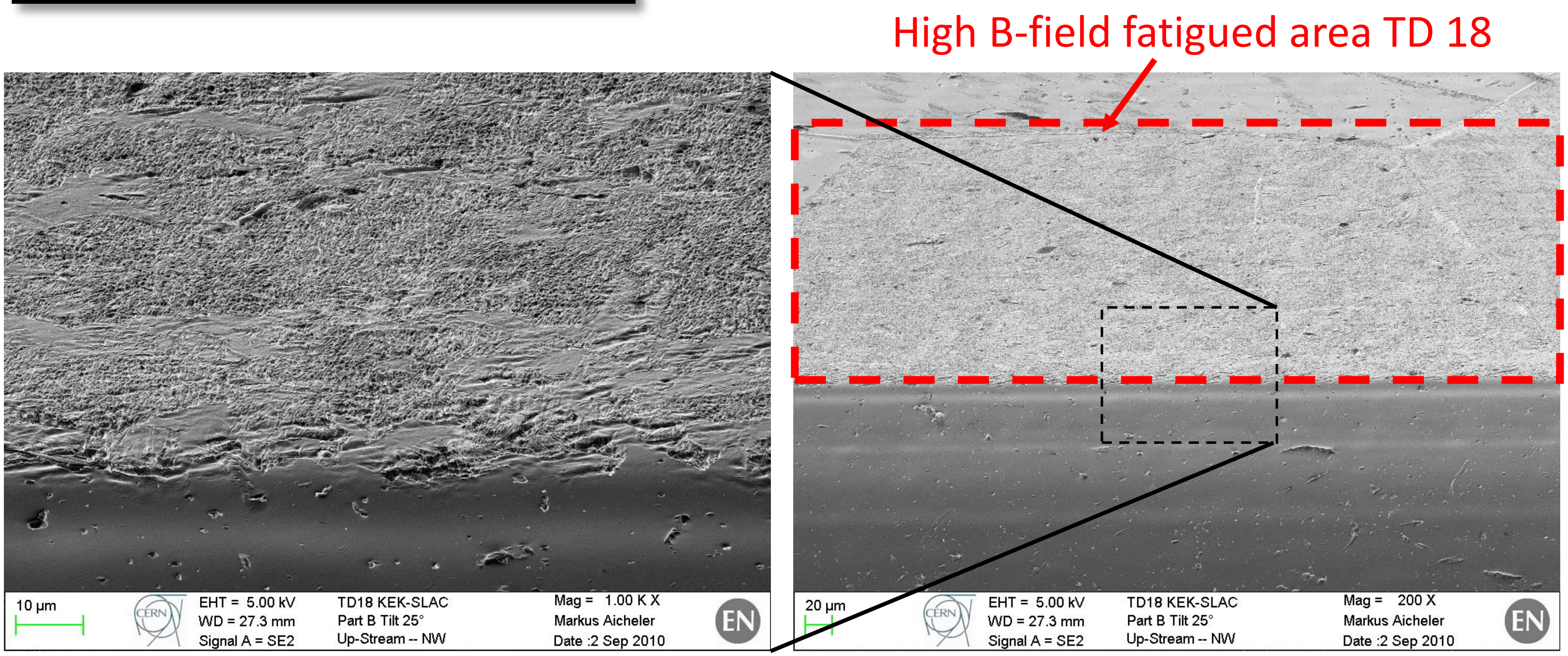
No fatigue signs in surface

Spots are due to EBM cutting fluid contamination NOT RF damage.

Comparison to TD18

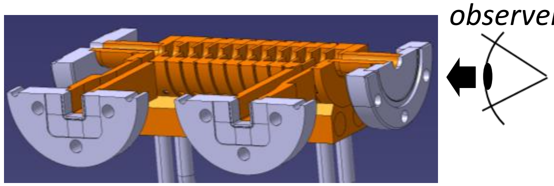


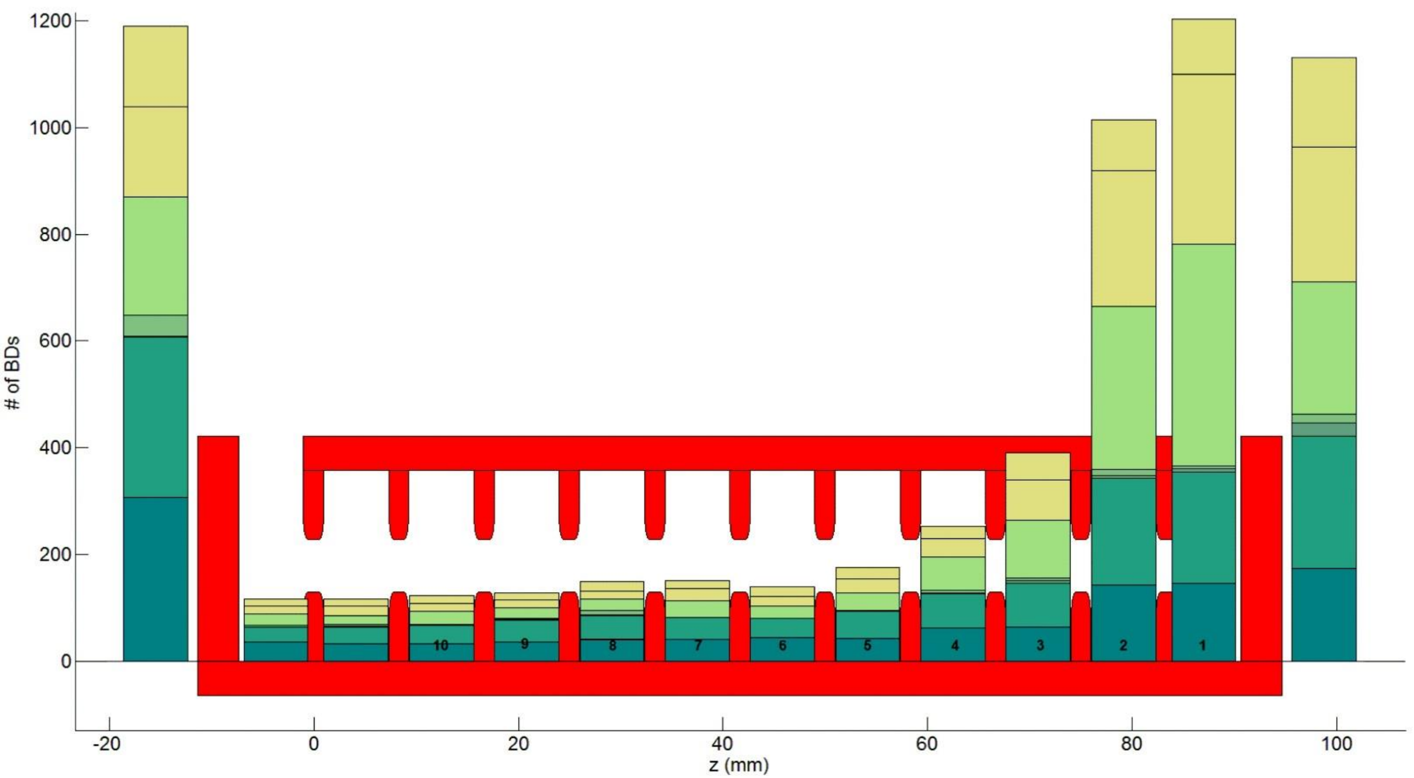
- In previously tested TD 18 CLIC accelerating structure, surface fatigue is seen due to high B-field/surface heating.
- A clear distinction in surface quality was seen.
- Crab cavity shows no such effect.



Markus Aicheler http://indico.cern.ch/event/106251/contributions/26603/

BD Positions

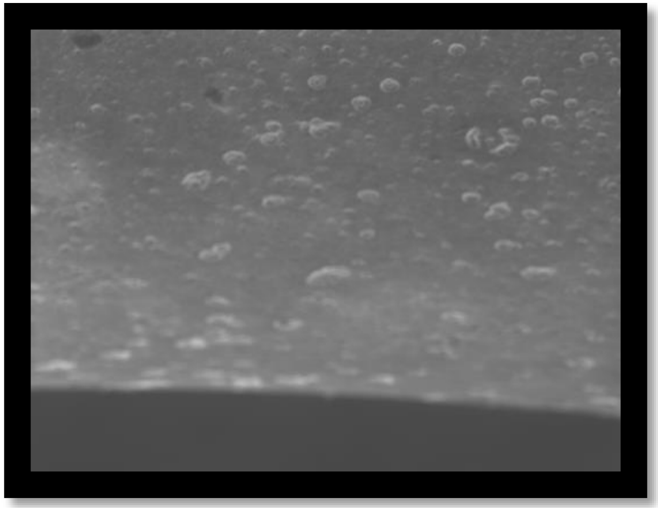


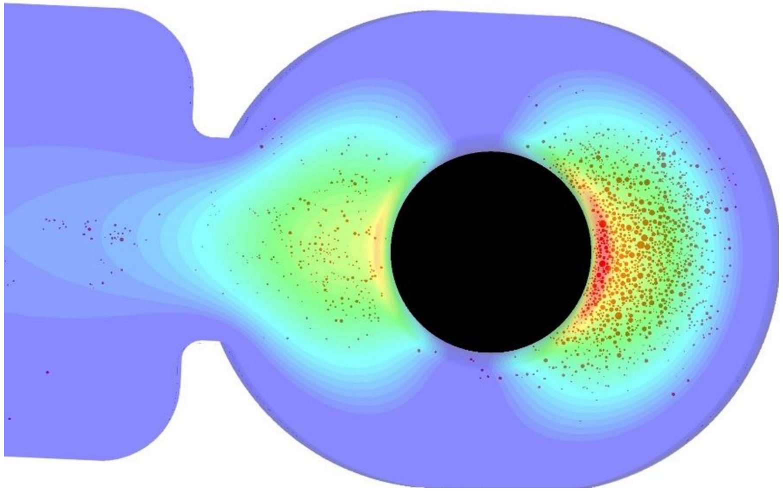


Number of craters seen is approximately double that of the breakdowns detected in the RF case.

Summary of observations

- Structure conditioning speed and final performance correlates with Sc more than E-field.
- Distribution of BDs within each cell follows the peak surface electric field.



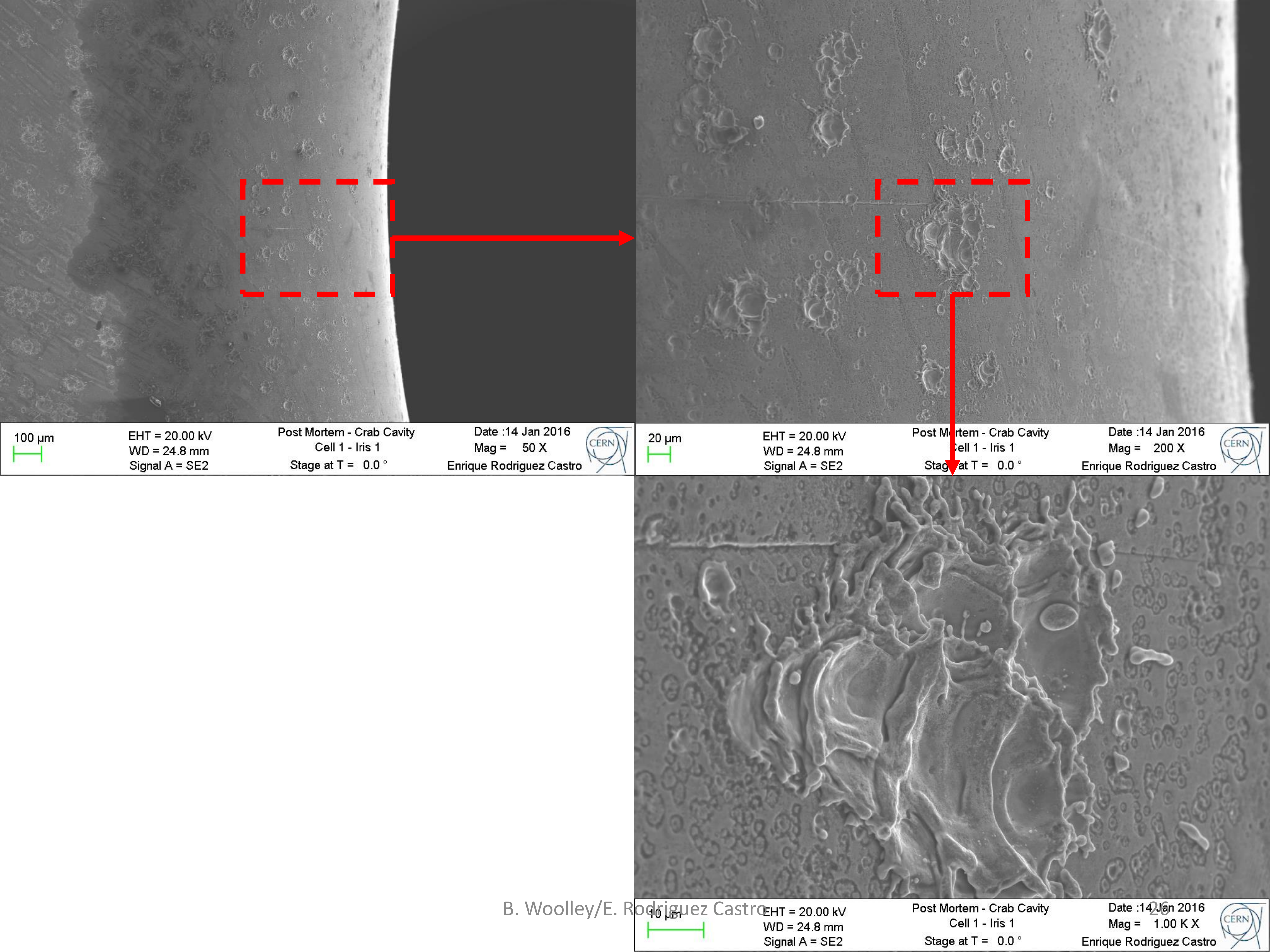


- No obvious damage seen due to the high B-fields/ surface heating on the iris.
- Correlation of BD distribution across the whole structure correlates well between the SEM and RF diagnostics (so far).

Conclusion

- Crab Cavity has been successfully designed, fabricated, high power tested and undergone post mortem examination.
- RF performance was far higher than expected, with the structure able to run stably at 43MW, 200ns pulse width, BDR 3e-6.
- Through the post mortem inspection it has shown that Sc is best theory so far in determining final structure performance but..
- Area of peak Sc doesn’t show highest density of BD craters → instead it is the high E-field areas.
- There is no observable damage in the high B-field/pulsed heating area on the iris.

Thank you!


100 µm
EHT = 20.00 kV
WD = 24.8 mm
Signal A = SE2
Post Mortem - Crab Cavity
Cell 1 - Iris 1
Stage at T = 0.0 °
Date :14 Jan 2016
Mag = 50 X
Enrique Rodriguez Castro
CERN
20 µm
EHT = 20.00 kV
WD = 24.8 mm
Signal A = SE2
Post Mortem - Crab Cavity
Cell 1 - Iris 1
Stage at T = 0.0 °
Date :14 Jan 2016
Mag = 200 X
Enrique Rodriguez Castro
CERN
EHT = 20.00 kV
WD = 24.8 mm
Signal A = SE2
Post Mortem - Crab Cavity
Cell 1 - Iris 1
Stage at T = 0.0 °
Date :14 Jan 2016
Mag = 1.00 K X
Enrique Rodriguez Castro
CERN

Crab Cavity Comparisons

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Input Power	37.2 MW	20 MW	13.35 MW	**40 MW**
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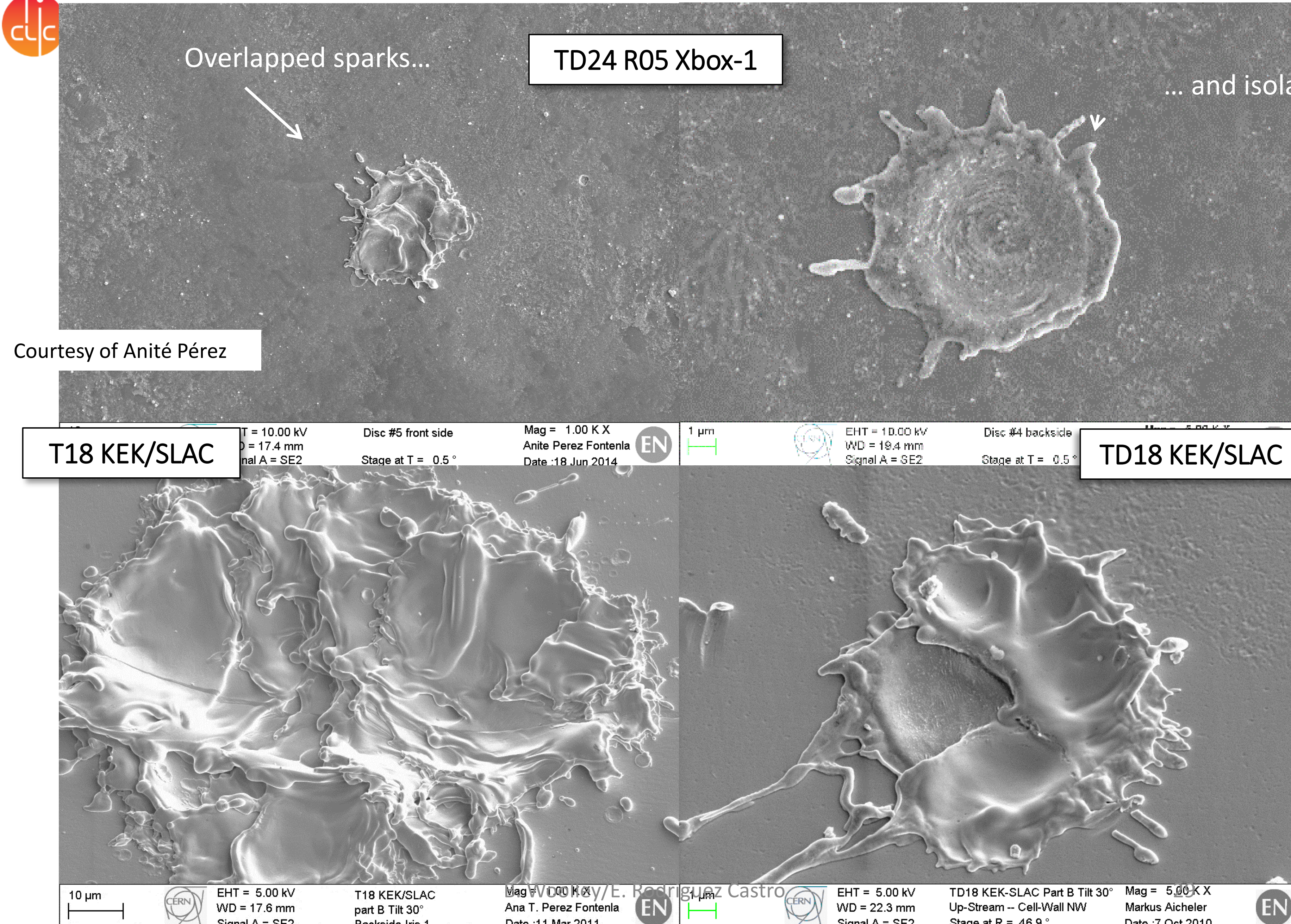
Peak surf. H-field	410 kA/m	405 kA/m	292 kA/m	**505 kA/m**
Peak Sc	3.4 MW/mm^2	-	1.83 MW/mm^2	**5.48 MW/mm^2**
dT 200 ns	8 K	33 K	17 K	**51 K**
Group Velocity	1.8-0.9%c	-3.2%c	-2.9%c	**-2.9%c**
# Cells	24	117	12	**12**

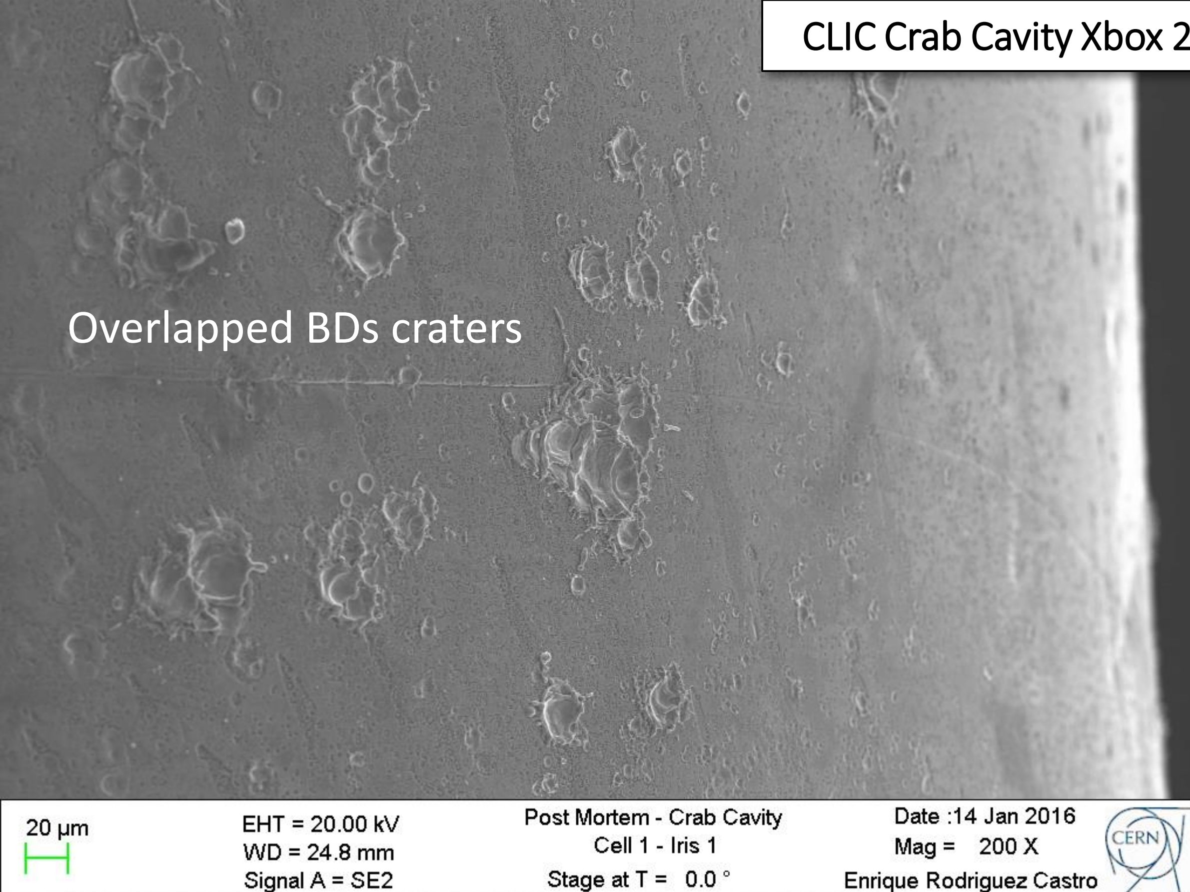
H- field and modified Poynting vector ‘Sc’ seem to be quite high for the highest stable operating point of the un-damped, CLIC crab cavity. However, due to the cavity's short length and relatively high BDR (one order of magnitude higher compared with the CLIC nominal), the results are not so surprising. A careful study and normalisation to the CLIC parameters is required.

Extra Slides

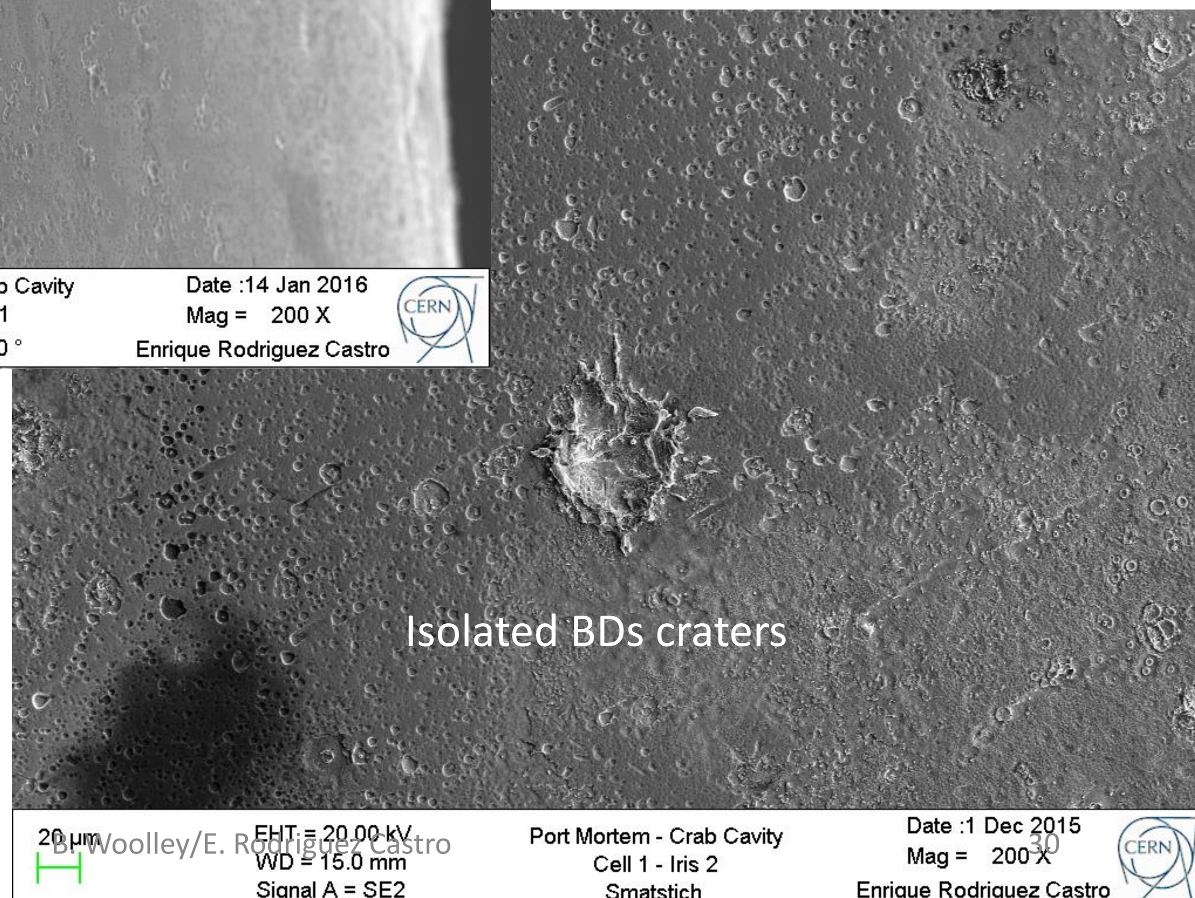
High gradient structures BD morphology



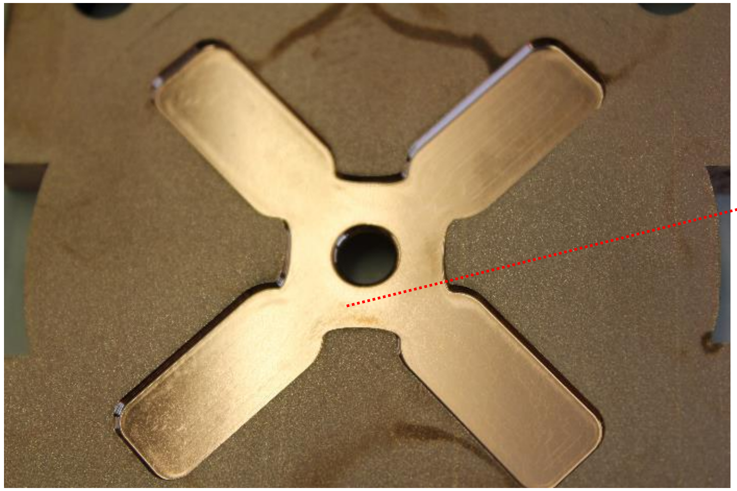
CLIC Crab Cavity Xbox 2

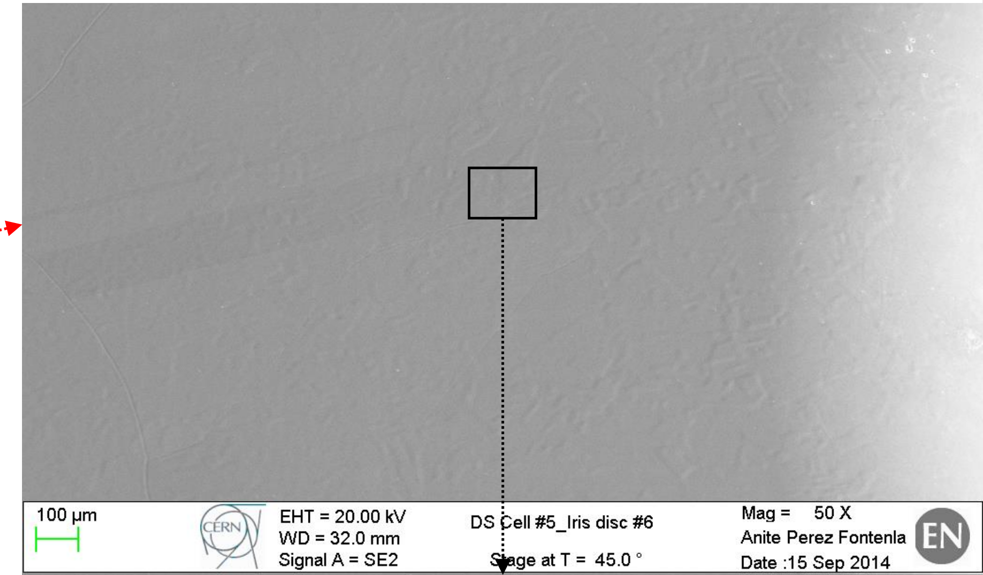


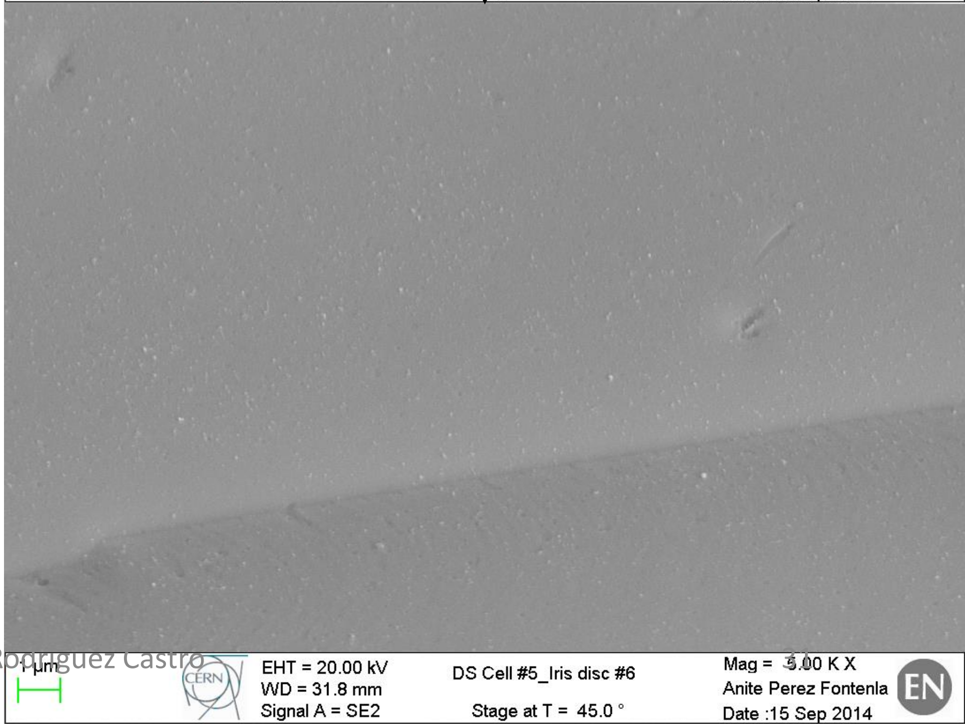
Craters have similar morphology to other high gradient structures.



TD24 R05







- EDM wire cutting (2014 Post Mortem analysis TD24 R05)