Pulsed DC system at CERN

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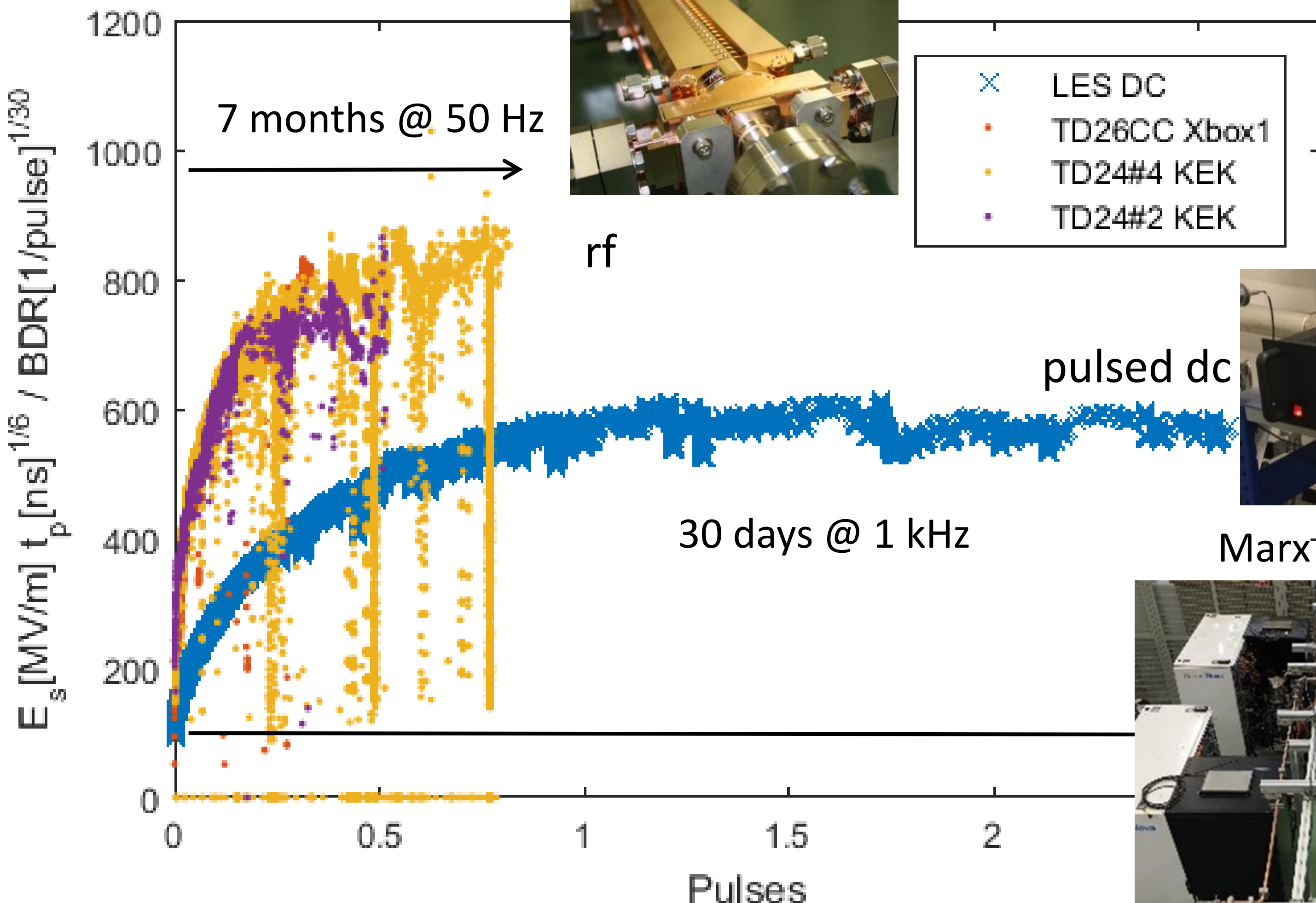
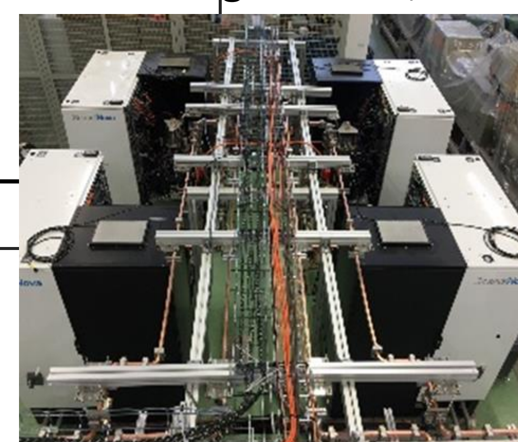
Motivation



Marx generator, 6kHz

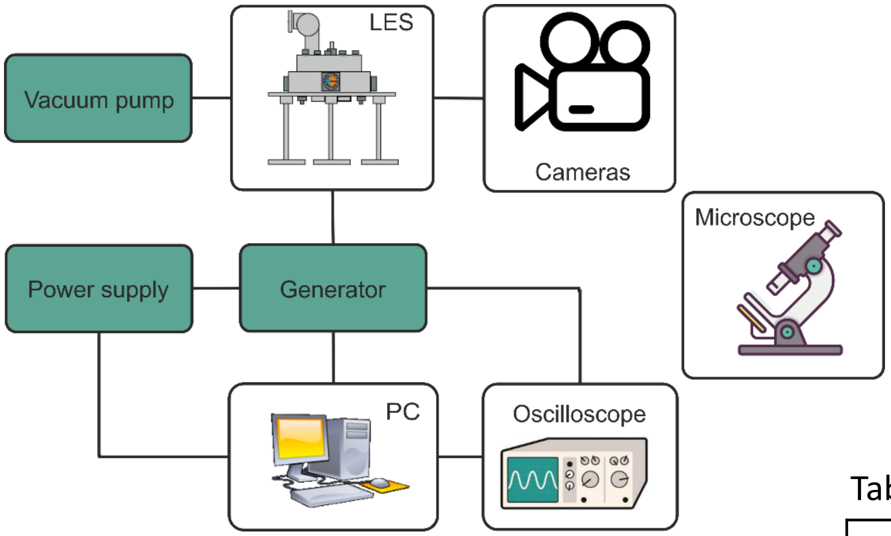


XBox-3: 6 MW, **400 Hz!**

From Walter's presentation

Pulsed DC System

vacuum system for high-gradient studies



Advantages of the Pulsed DC system compared to RF:

- ✓ Simple samples
- ✓ Simpler generator
- ✓ Easier diagnostics
- ✓ Faster
- ✓ Inexpensive

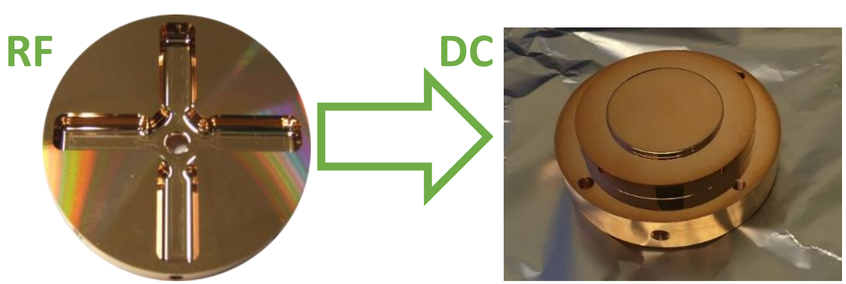


Table 1. Materials used for electrodes at Pulsed DC systems.

Material	Description
Vacuum fired Cu	Provided from SLAC. C10100 OFHC Copper. Run through a simulated H2 braze cycle (~1000°C) then vacuum fired at 700°C for 48 Hrs.
CuAg	Provided from SLAC. C10700 CuAg, with Ag content 0f 0.085%
SS	Provided from SLAC. 304L Stainless Steel Uses as Anode at the test with Vacuum fired Cu and CuAg.
Nb	Niobium
Hard Cu	OFE-copper, as-machined. 3 different couples of electrodes were tested with different parameters.
Soft Cu	Hard Cu followed the same treatment methods as Accelerating Structures during bonding procedure (up to 1040ºC) and baking (up to 650ºC).

Marx generator

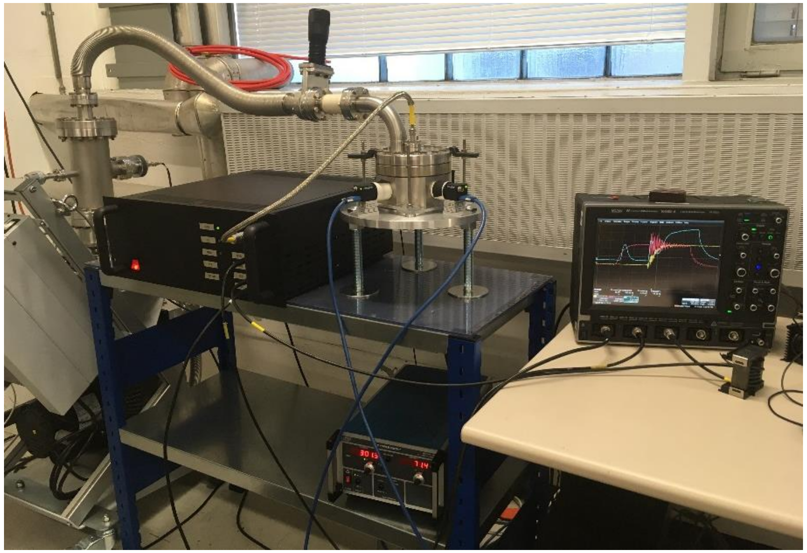


Fig. 4.1. Photo of Marx generator together with LES.

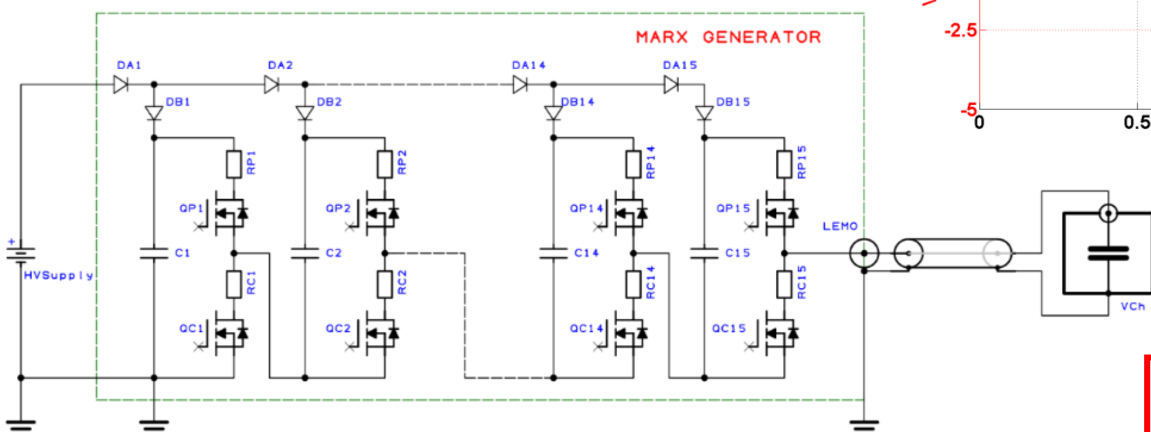


Fig. 4.2. Simplified schematic of Marx generator for Pulsed DC system.

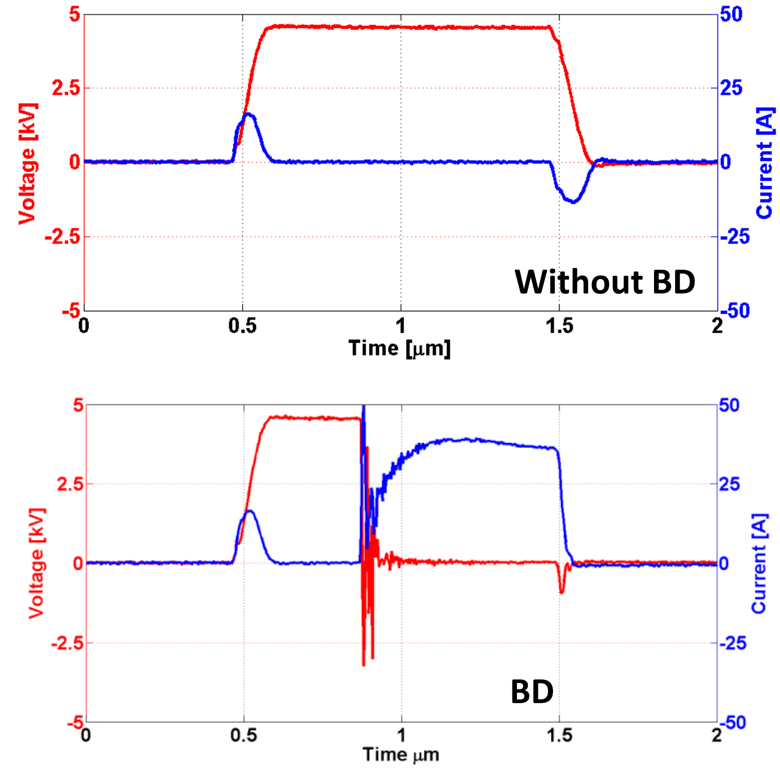


Fig. 4.3. The waveforms taken with Marx generator and LES with 1 μs pulse (0.6 μs delay is used in BD case).

Repetition rate: 2 kHz
Pulse length: 500 ns – 1 ms.

The main news

- The algorithm of recovering after BD (ramp) was implemented.
- Conditioning tests with different materials:
  - ✓ SS and Cu electrodes;
  - ✓ SS CuAg;
  - ✓ Nb
  - ✓ Hard Cu;
  - ✓ Soft Cu.
- The first couple of electrodes with new design have been tested (as-machined OFE-Cu) together with BD localization technique.
- Dark current measurement – will be shown separately.

Recovering after BD (ramp)

Motivation:

- To minimized effect of BD crater.
- To study the effect of different ramp's parameters to the results.

Parameters for ramps:
1. **Ramp factor** (0.2);
2. **Number of pulses** per step (100);

For linear ramp:

3. **Number of steps**;

For exponential ramp:

3. **Factor** (curve's radius).

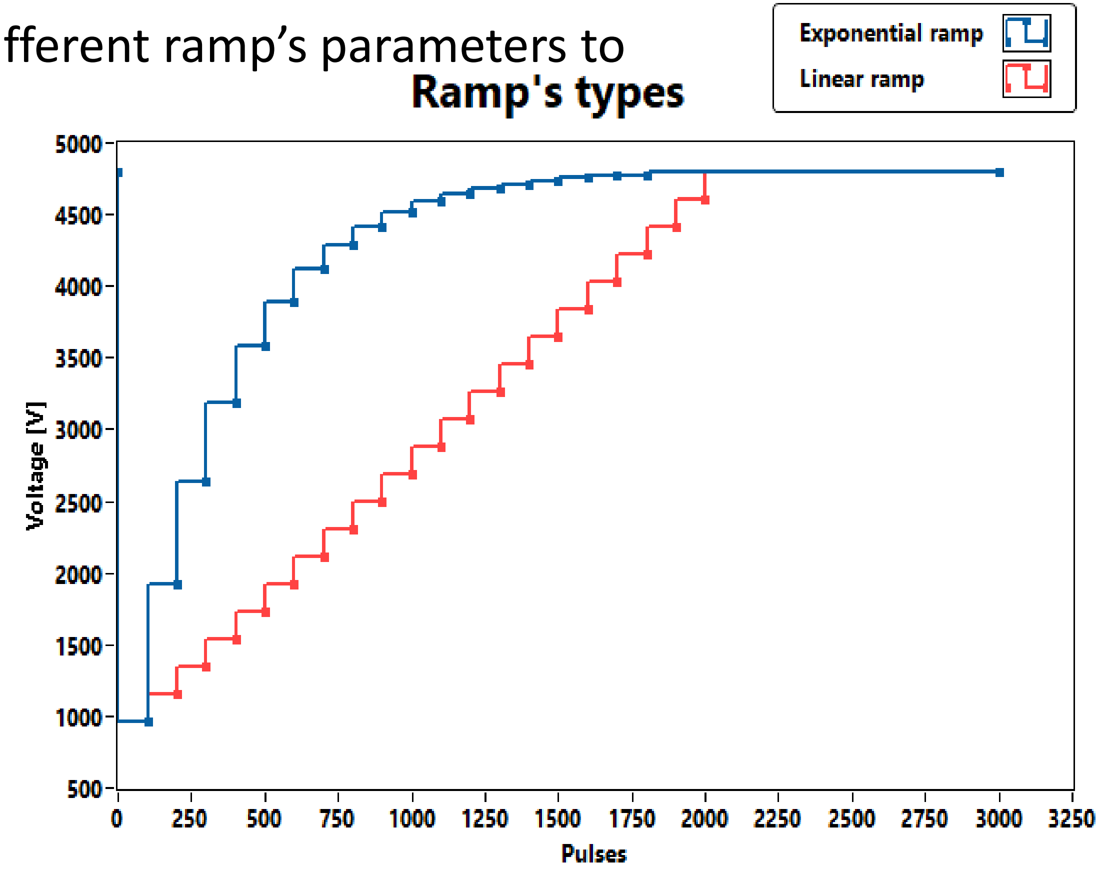


Fig. 6. The explanation of algorithms.

Recovering after BD

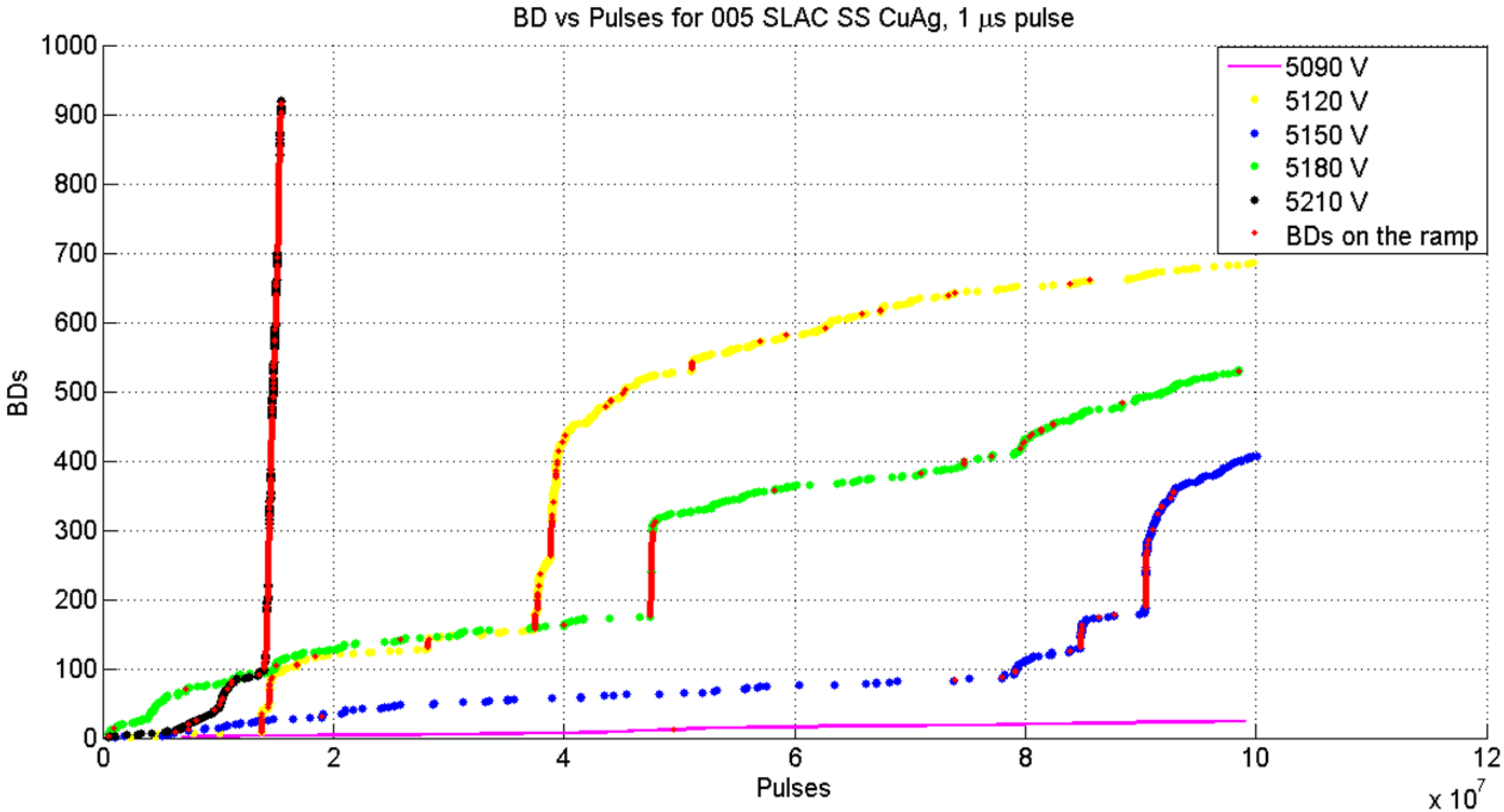


Fig. 7. Effect of ramp to the results.

Conditioning for different materials

Motivation:

- ❑ This algorithm was implemented at Pulsed DC system to be similar to RF test.
- ❑ The conditioning is needed for training of materials to be able to reached higher electrical field.

Table 1. The example of parameters for conditioning test.

Parameter	Value
Max number of pulses per cycle	100 000
Safe pulses	20 000
Gain voltage at 0	-10 V
Gain after timeout	10 V
Initial voltage	600 V (~10 MV/m)
Max BDR	5E-5

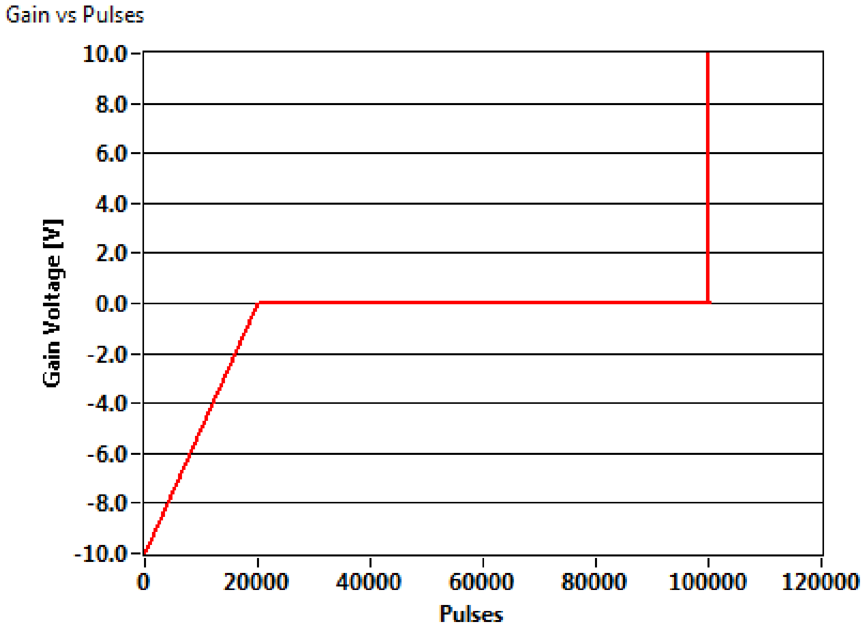


Fig. 8. Visualization of conditioning algorithm.

Conditioning for different materials

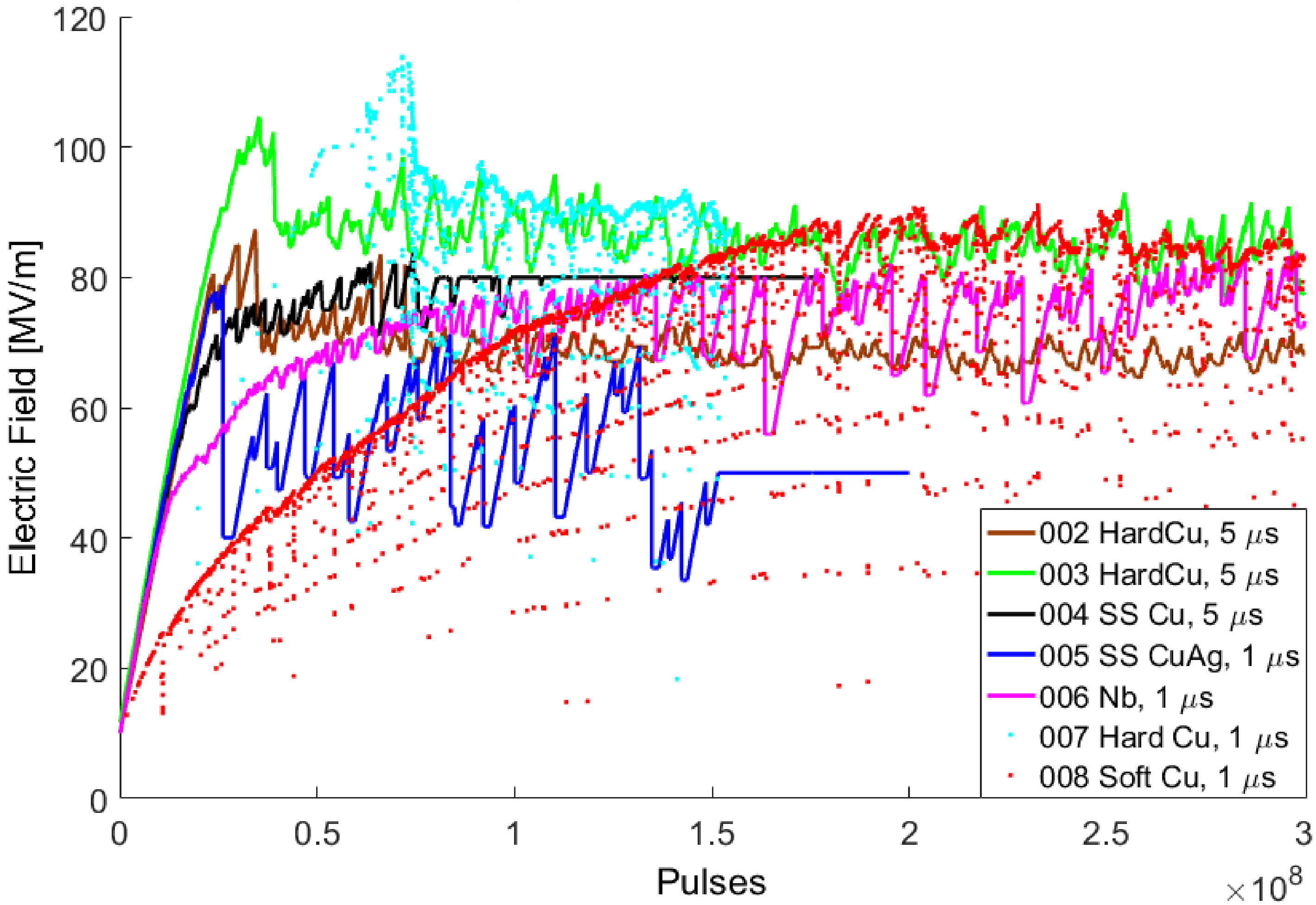


Fig. 9. Comparison of the conditioning for electrodes tested at pulsed DC systems. During all tests the spacer for 60 µm gap was used, except 002 Hard Cu (100 µm).

Conditioning RF and DC

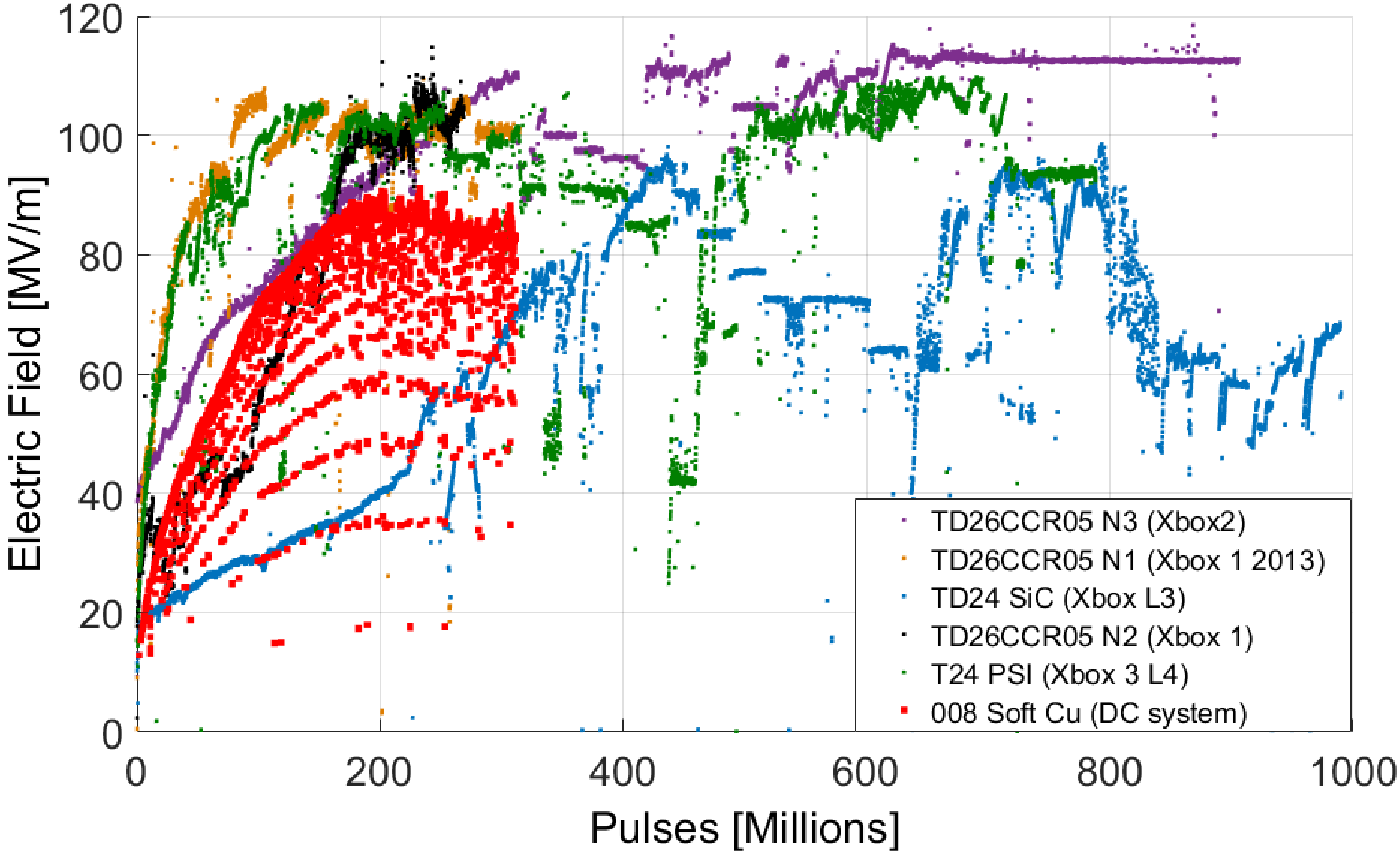
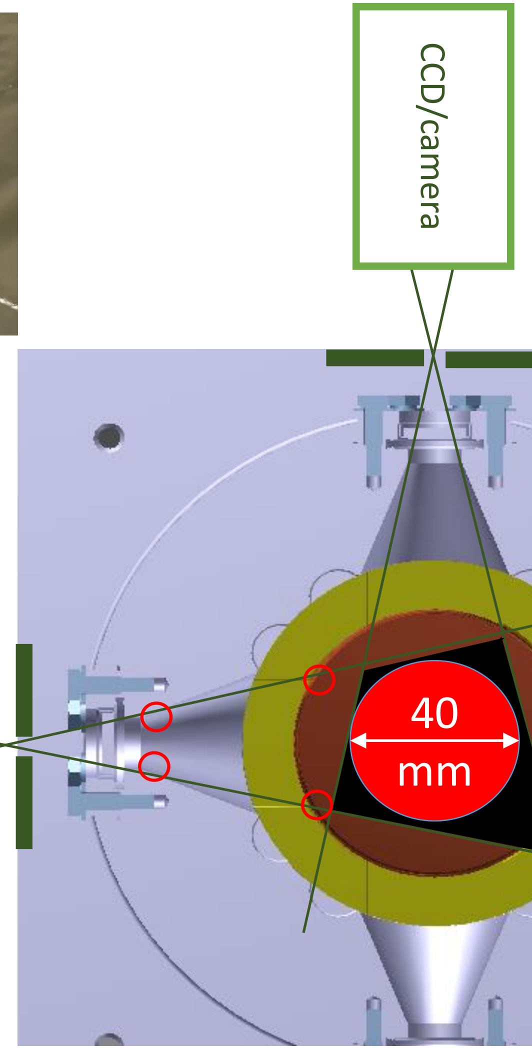


Fig. 10. Comparison of data from RF and DC.

...courtesy of Xboxes team

BD localization technique



Electrode restrictions

Motivation:

- ❑ find the position of BDs;
- ❑ find how crater after BD relates to the next BD location.

Some info

- Obscura-type cameras are used;
- Cameras shutters is open for 3 s followed by 5 ms of blindness for readout and data transfer.

Fig. 11. The schematic of visible region inside Large Electrodes System.

BD localization technique

The main data from test:

Number of breakdowns detected by Marx generator: 29 697.

Number of breakdowns detected by cameras: 29 639.

Difference in data: ~0.2%.

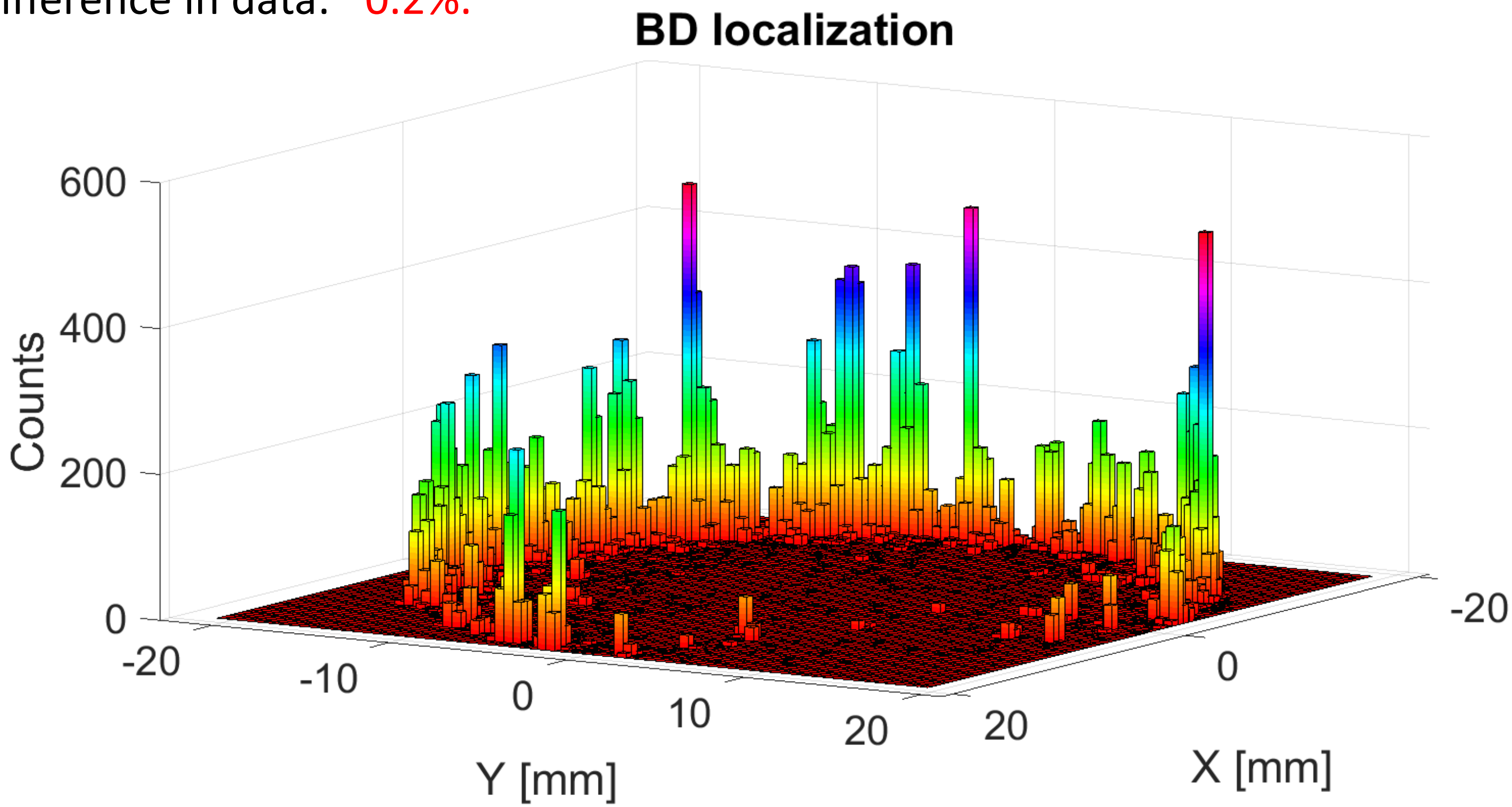


Fig. 12. 3D map for 007 Hard Cu data taken with cameras.

Distance between BDs

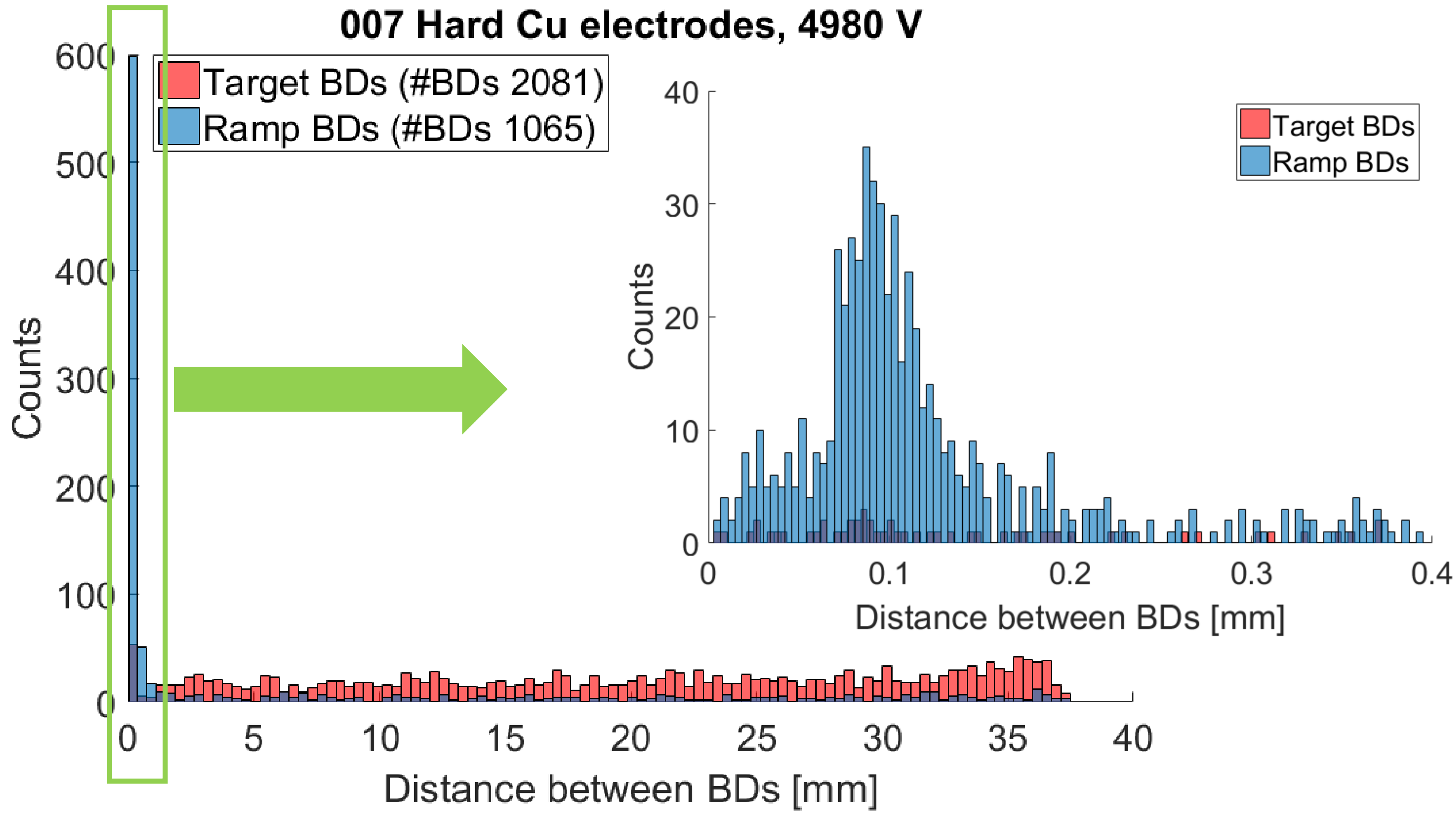
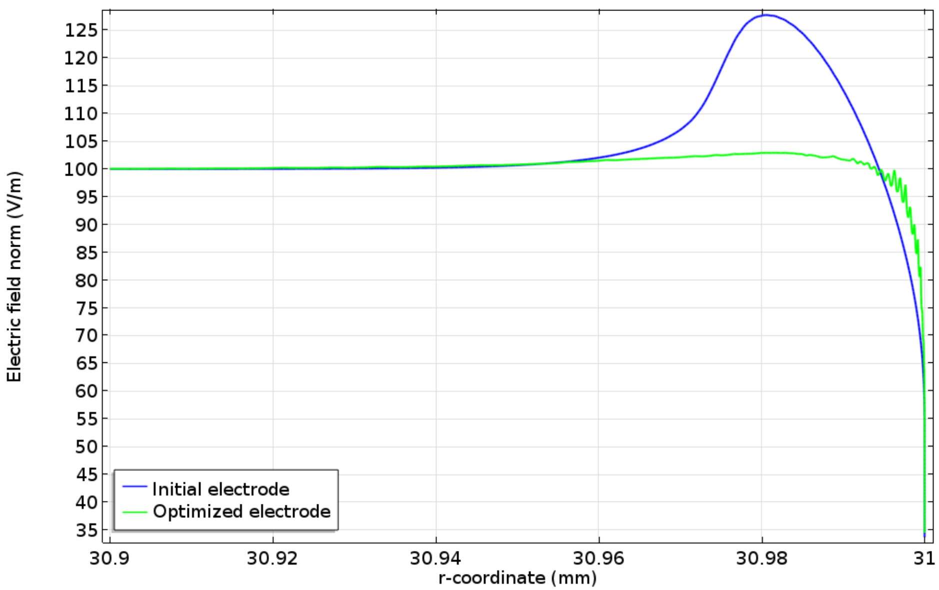


Fig. 13. Analysis of distances between BDs based on ramp separation.

Electrodes design optimization (simulation)

Initial optimization calculations



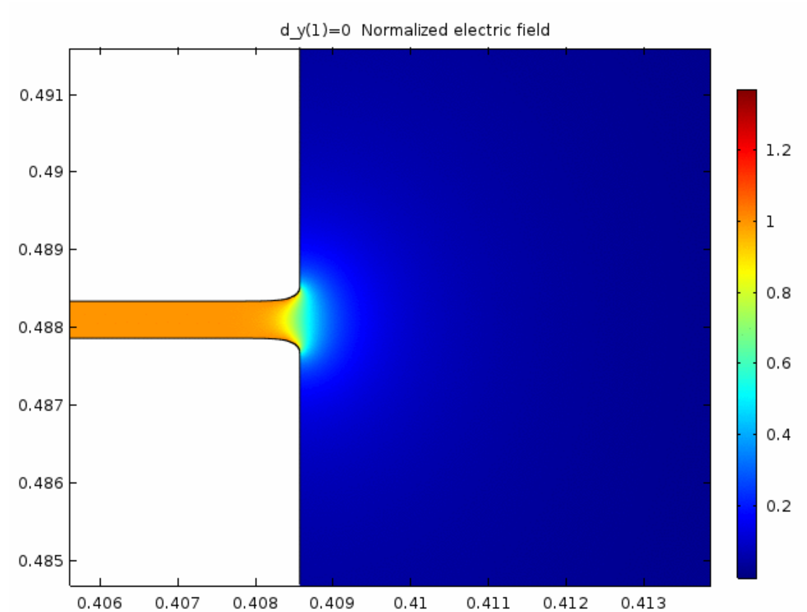
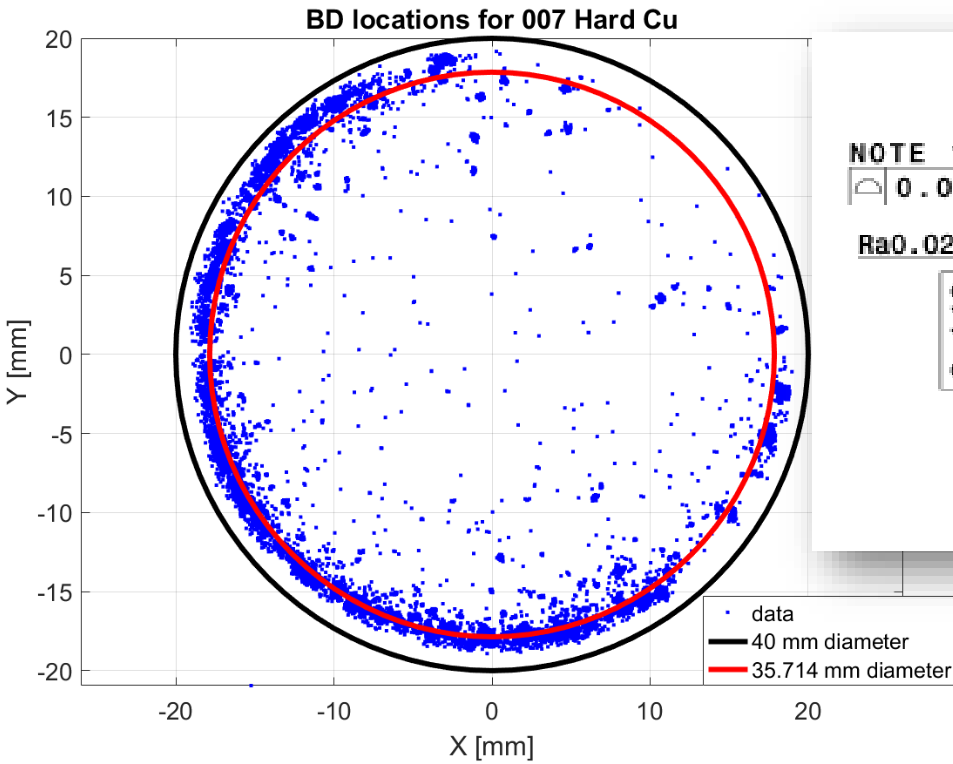


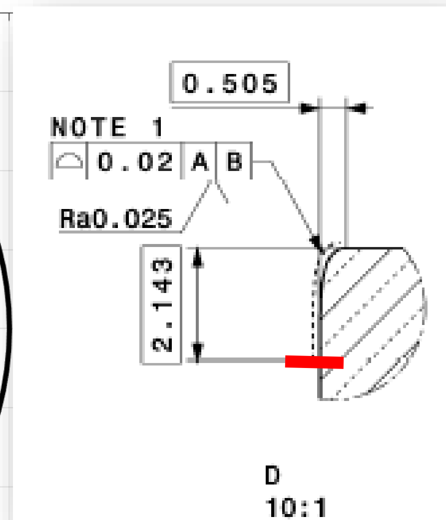
Fig. 14.1. Maximum field enhancement ~1.06 in new CAD geometry, vs. ~1.03 in optimized and ~1.25 in initial one.

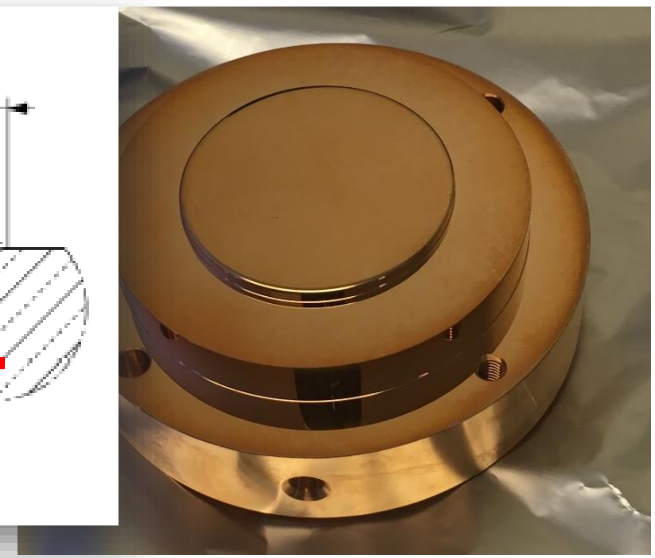
Fig. 14.2. Electric field distribution during electrode displacement.

...courtesy of V. Zadin, University of Tartu

Electrodes design optimization (first test)







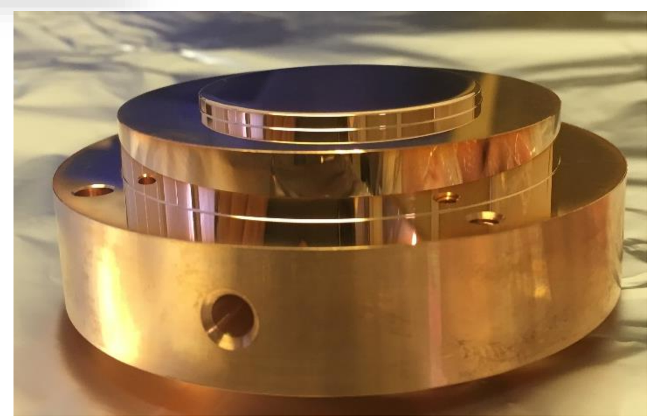


Fig. 15. BDs localization after optimization of electrode geometry for as-machined Cu (i.e. Hard Cu).

BD localization technique

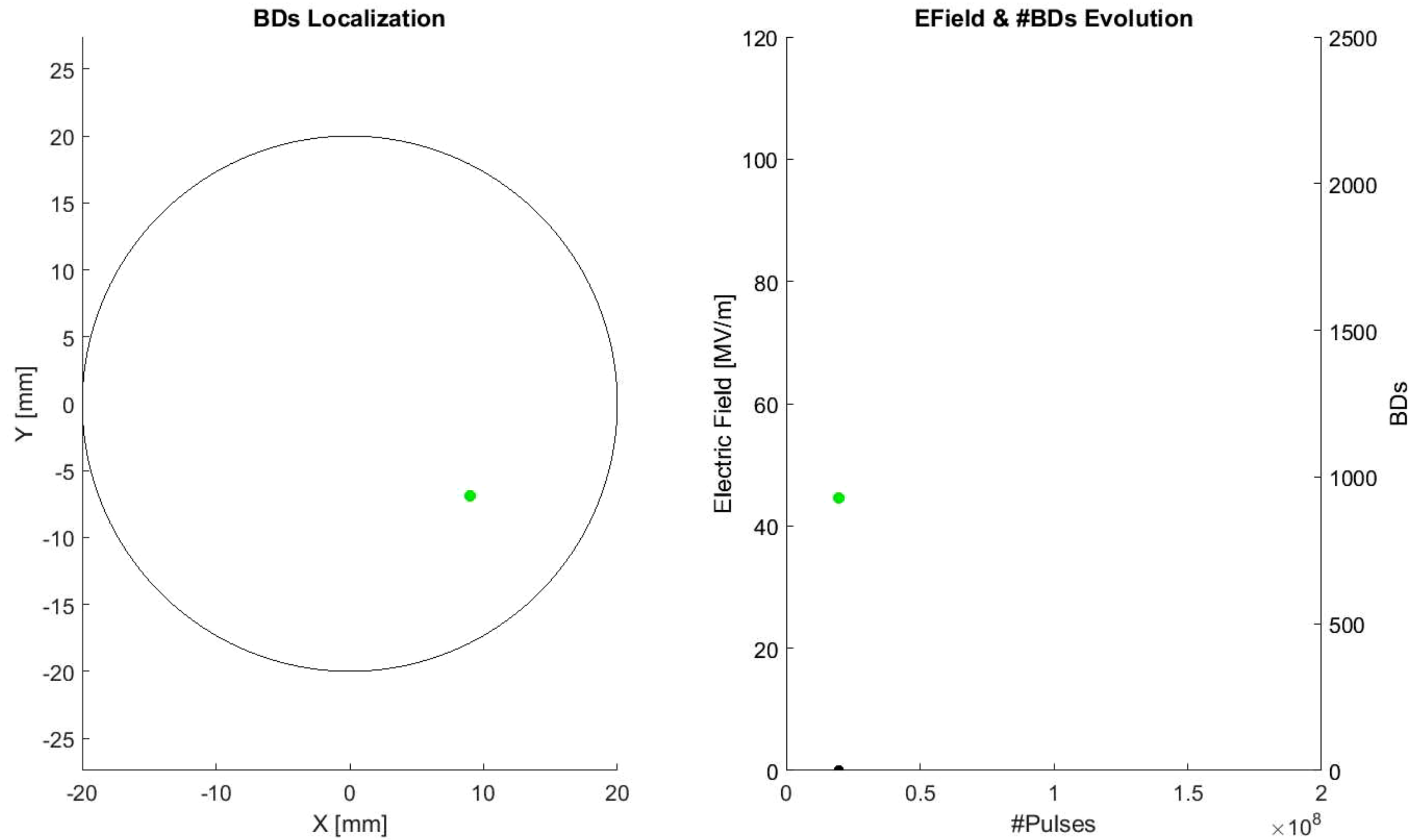


Fig. 16. Visualization of BDs evolution at the surface for 007 Hard Cu electrodes (video works only in slide show mode (red dots corresponded to BDs occurred at the optimized region (slide 15).

Power Law

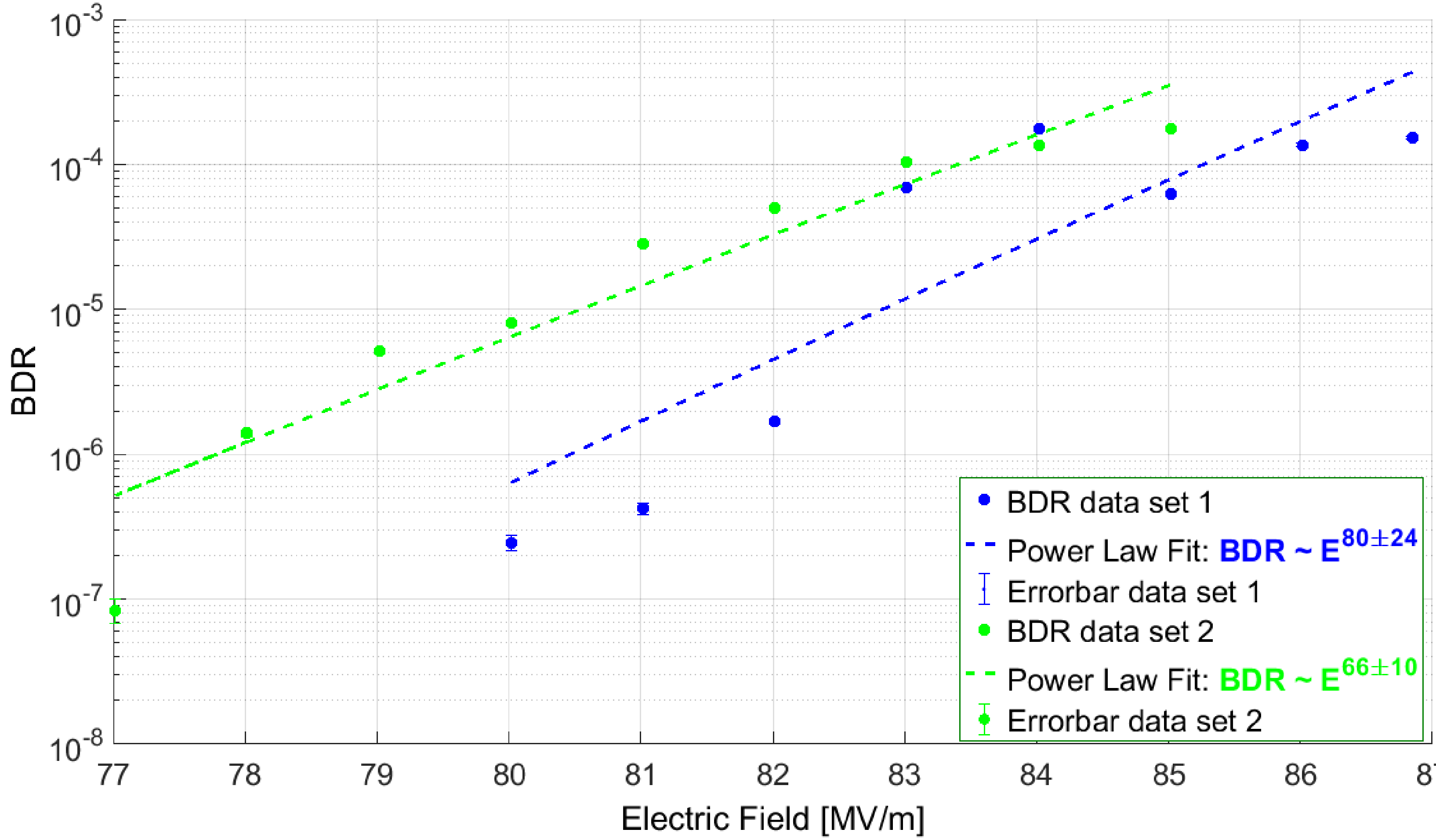


Fig. 17. Data taken with 007 Hard Cu electrodes, 1 μs pulse length, decreasing order of voltages with 60 V step.

Probability density

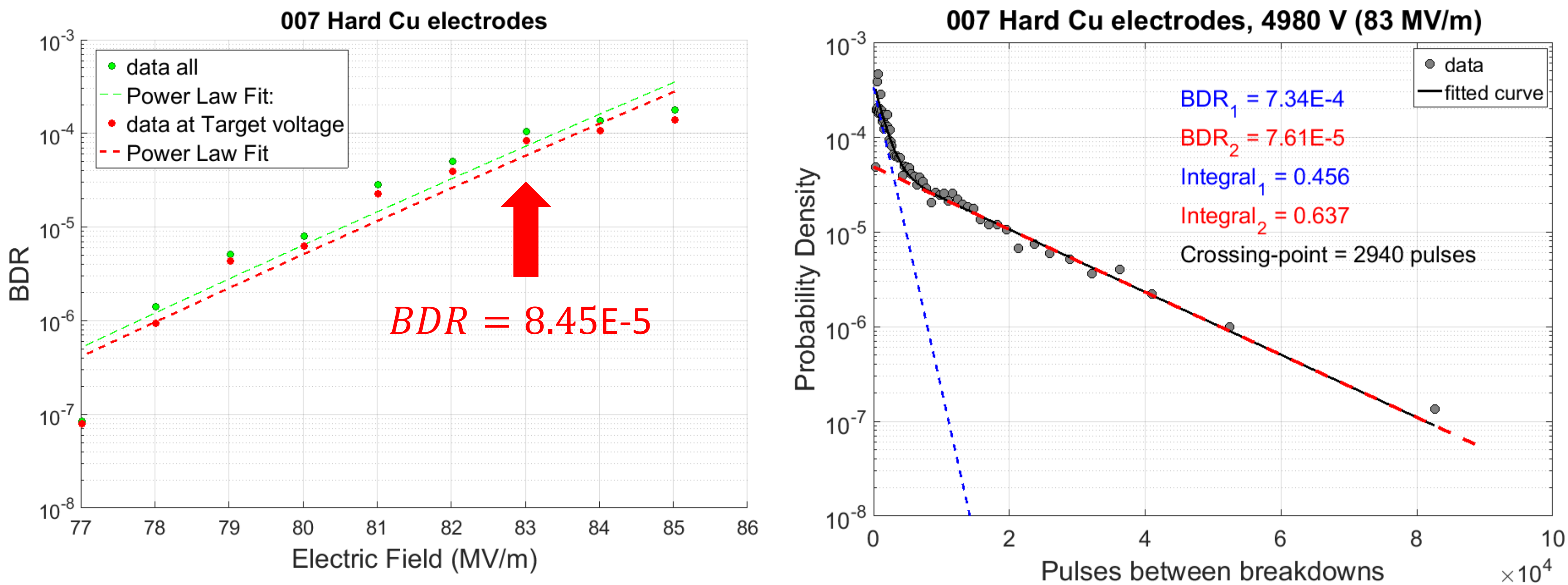


Fig. 18. a) effect of ramp algorithm to results; b) the example of PDF analysis.

Distance between BDs

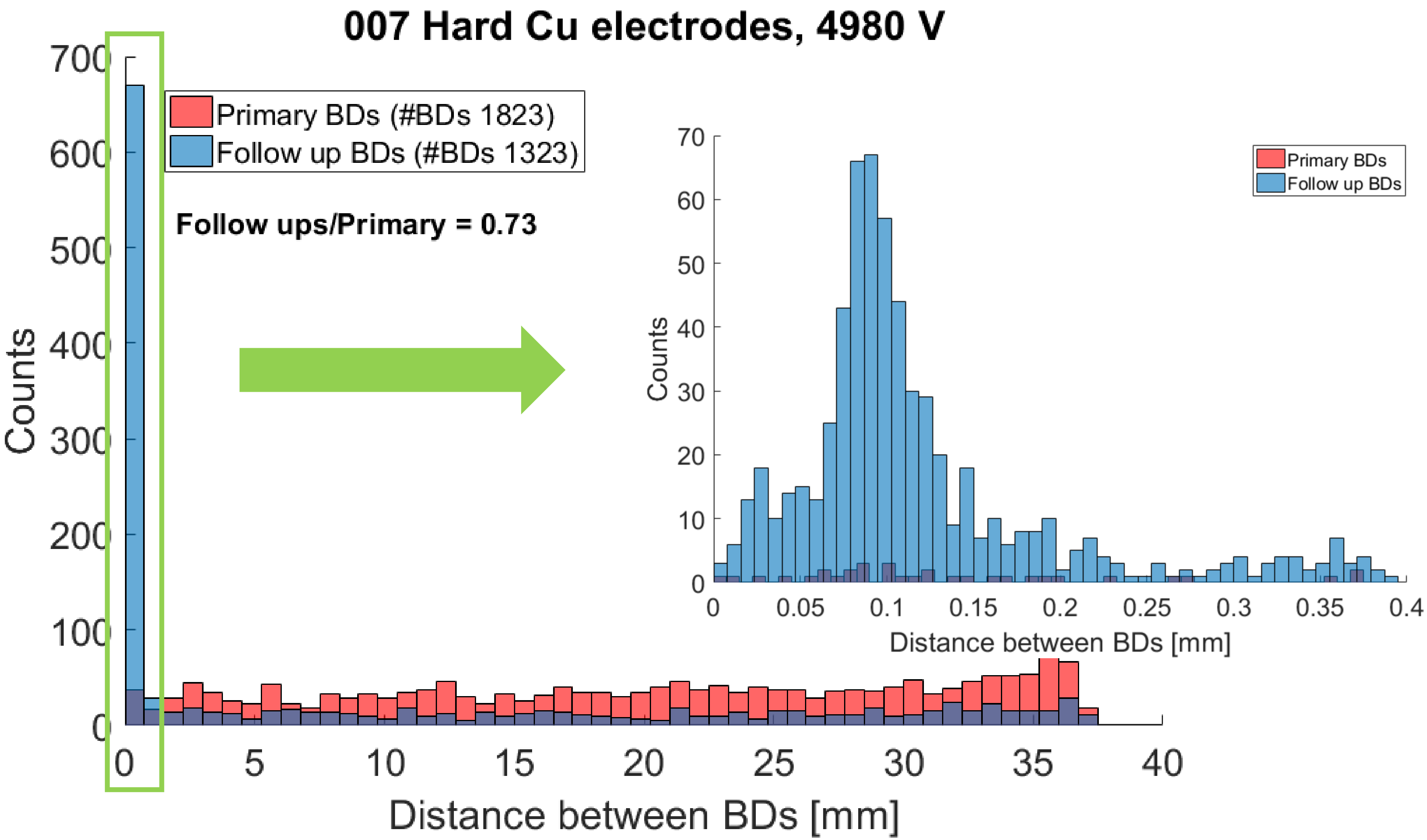


Fig. 19. Analysis of distances between BDs based on separation for primary and follow up BDs.

Pulse length effect to the BDR

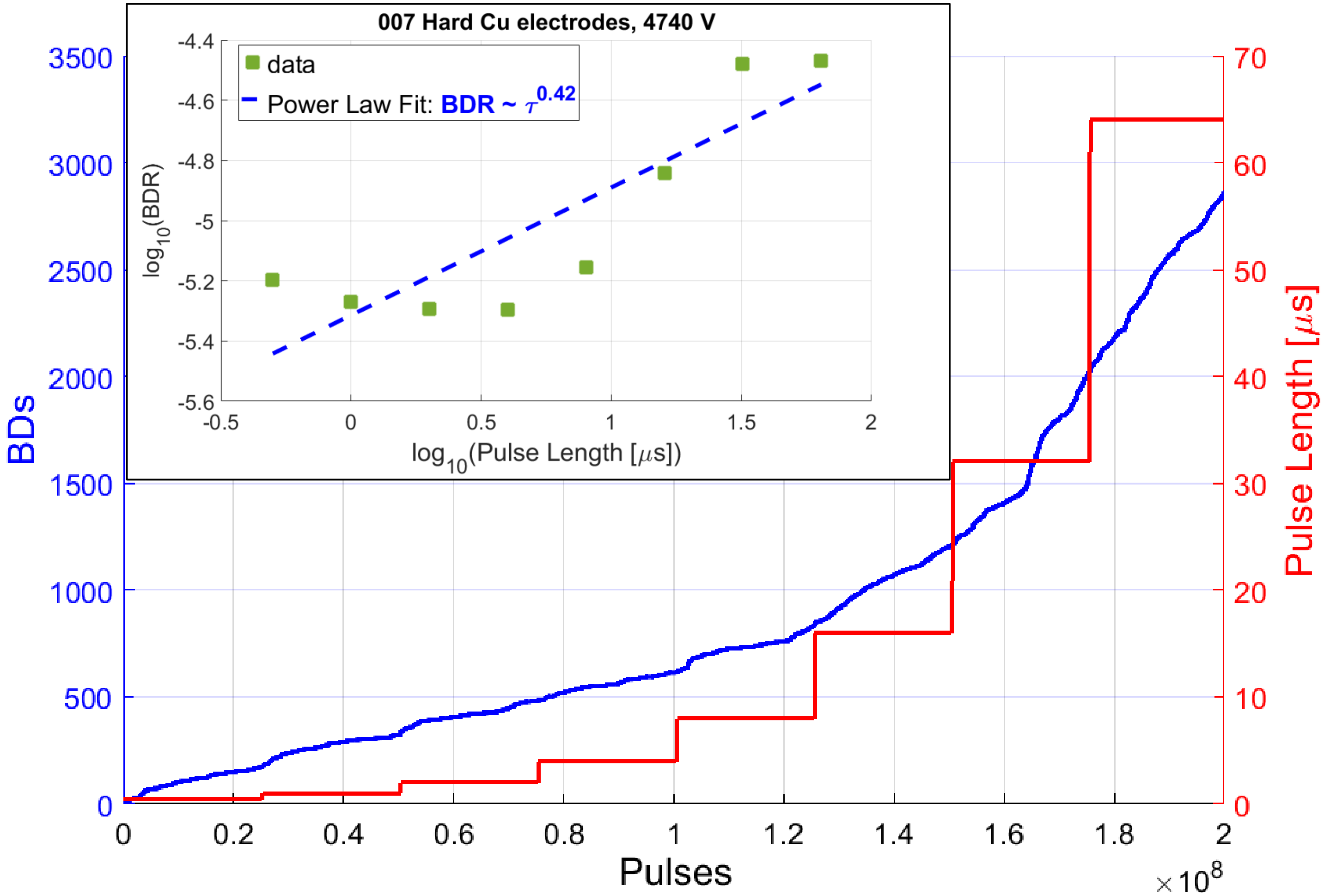


Fig. 20. The evolution of BDs during test with different pulse lengths (0.5 – 64 µs).

Summary

Table 1. Statistic for the last year.

	Electrodes	#BDs	#Pulses
002	Hard Cu	4 529	546 793 547
003	Hard Cu	5 690	1 046 481 193
004	SS & Cu	2 540	2 214 948 187
005	SS & CuAg	33 596	21 632 276 420
006	Nb	73 238	15 120 904 337
007	Hard Cu	29 697	2 707 753 999
008	Soft Cu	4 109	311 293 290
	Total	**153 399**	**43 580 450 973**

Summary

- ✓ Different materials are tested at pulsed DC systems.
- ✓ The new design for electrodes are implemented (Hard Cu electrodes have been already tested, Soft Cu should be tested soon).
- ✓ Several types of tests are available at Large Electrodes System:
  - Conditioning test;
  - BDR vs Electric field (Power law);
  - BD localization (Distance between consecutive BDs).
  - Pulse length dependency;
  - Time to BDs

  and others.