NLCTA Structure Tests Post NLC/GLC

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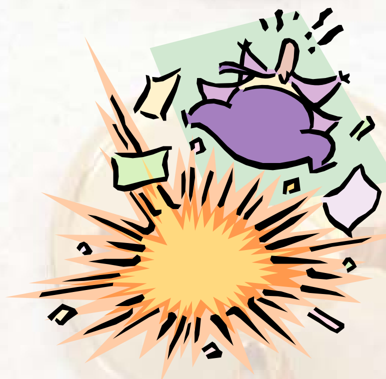


X-Band Structure Stations at NLCTA in ESB

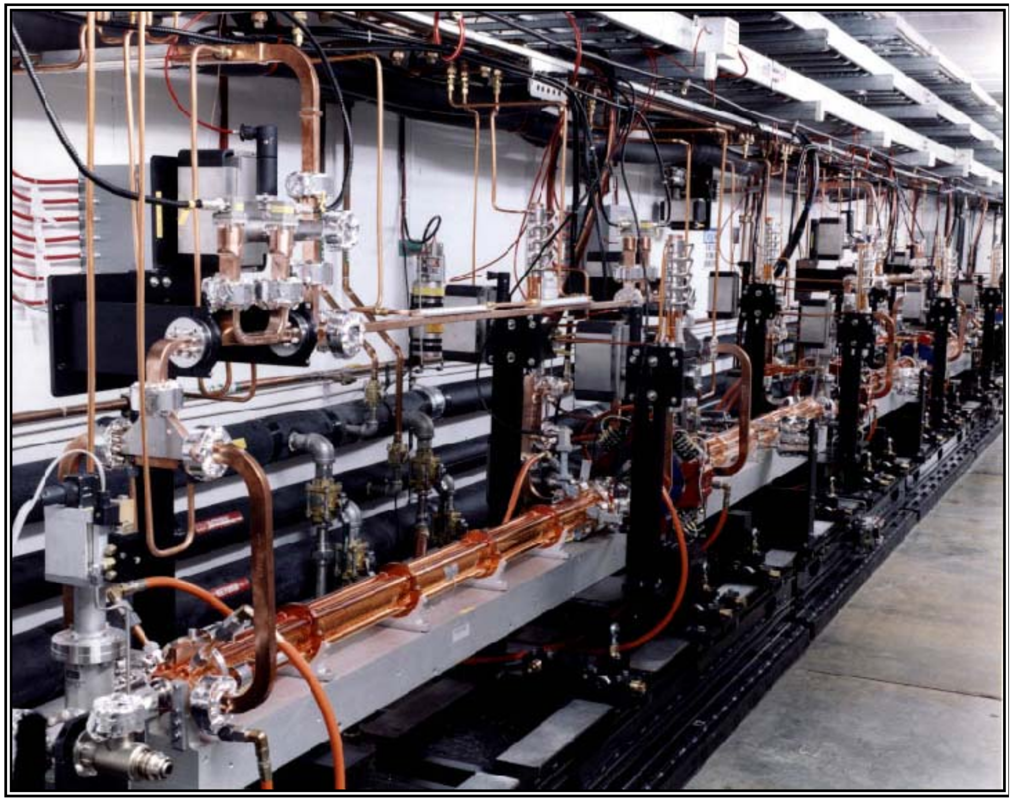
Station 1 and 2 each:

Are powered by two 50 MW Klystrons
whose 1.5 us pulses are combined
and compressed using SLED-II

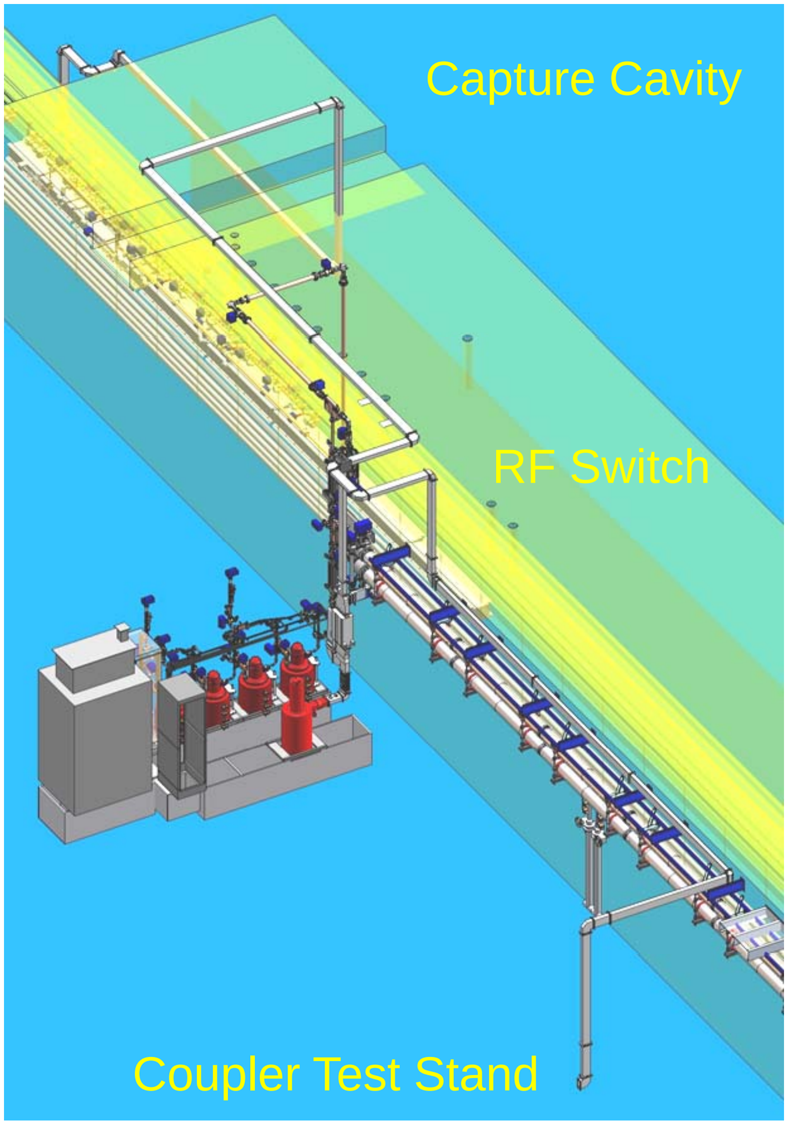
Produce up to ~ 300 MW at 240 ns
~150 MW at 400 ns

Have two, 2.5 m slots for structures

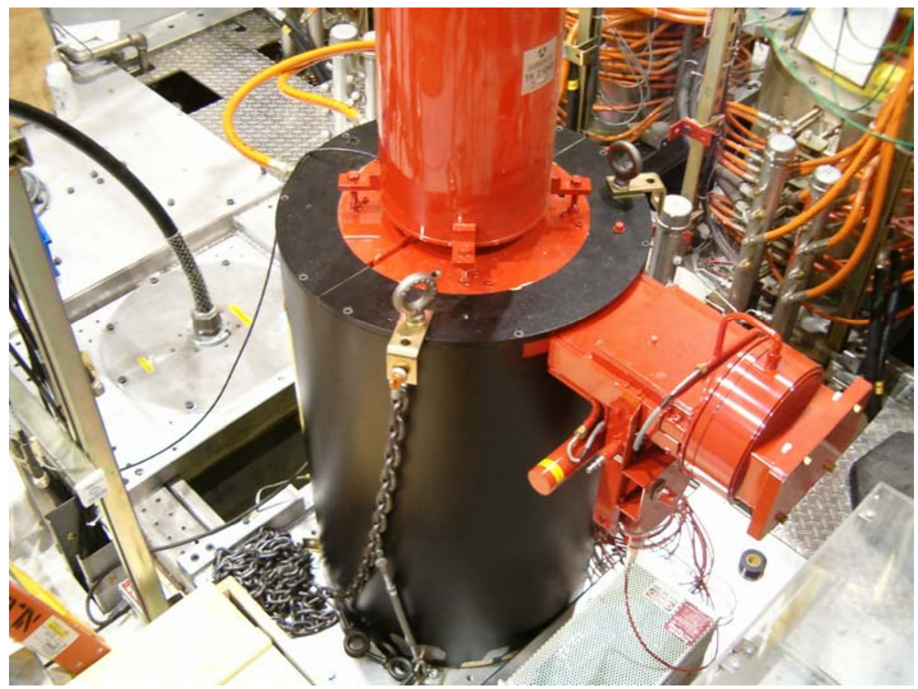
Can run 24/7 using automatic controls



L-Band (1.3 GHz) Test Stand at ESB



- Produces 5 MW, 1.4 msec pulses at 5 Hz with a TH2104C klystron and a SNS-type modulator
- Source powers a coupler test stand and a normal-conducting ILC e+ capture cavity



NLCTA X/L-Band Structure Tests Post NLC/GLC

Structure	Presenter
• Vent tests of FXC-003	CA
• H75VG4S18	CA
• C30vg4-W	SD?
• HDX11-Cu	CA
• T53VG3MC	CA
• HDX11-Mo	CA
• HDX11-Cu-Redux	CA
• 5 Cell L-band	CA
• T18vg2.4	SD

FXC-3 Vent Experiments

- Purging with nitrogen or venting to either filtered or unfiltered tunnel air had minimal impact. That is,
- After 10-100 breakdowns at full power, the rates decreased to that before the vents (~ 1 in 10 hours for 60 Hz operation at 65 MV/m with 400 ns NLC-like pulses).
- However, when the structure was heated to about 160 degC and then vented to filtered air for an hour, the breakdown rate increased substantially, and after a week of rf processing, it had not fully recovered.
- So still puzzled by earlier ‘bad’ structures, and the occasional big impact from N2 purges many meters away (beam line particulates may be part of the problem).

Longer, Higher Group Velocity NLC/GLC Structure

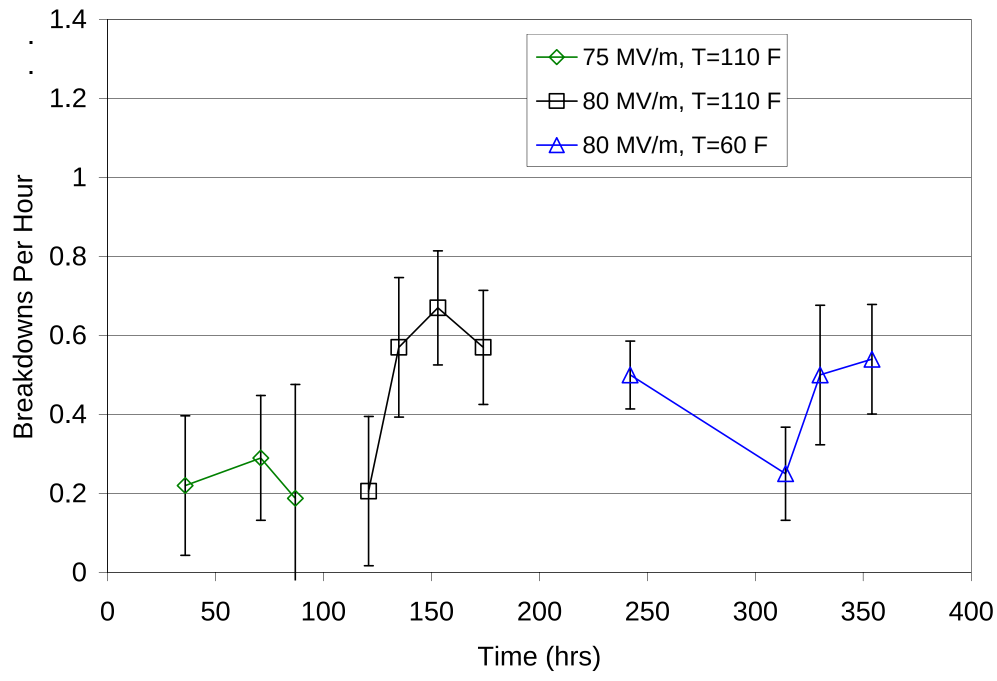
75 cm long, a/λ = 18%, initial vg = 4%, requires 173 MW for 100 MV/m operation

With 150 ns square pulses, breakdown rate = 6e-6 at 102 MV/m – same bkd rate/length as the T18_VG2.4 structure (a/λ = 13%, 56 MW for 100 MV/m)

Slotted Cells

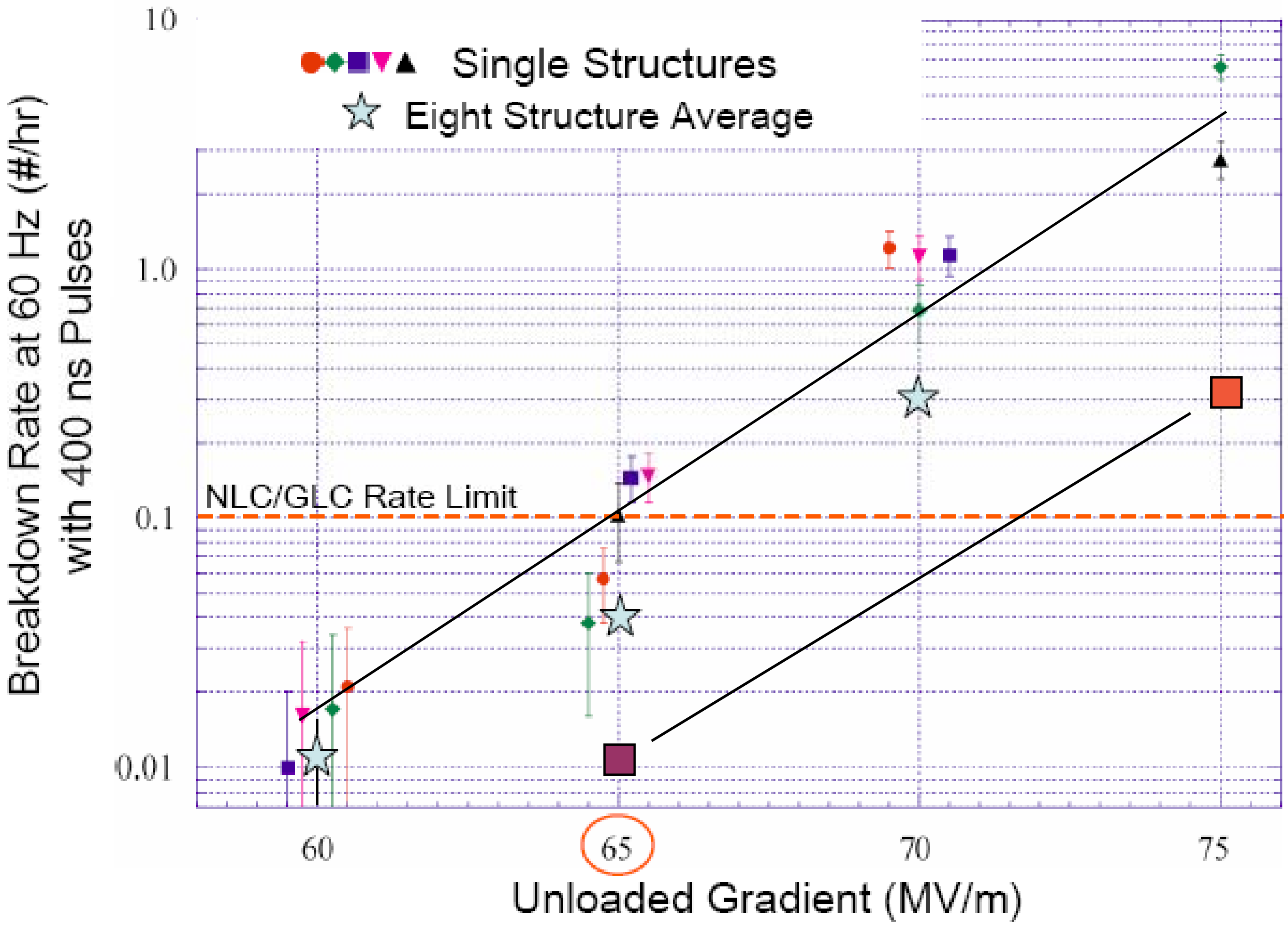
H75VG4S18 Cool Down Test

- Operated structure at 60 Hz with 400 ns ramped pulses up to 80 MV/m.
- Lowered cooling temperature from 43 degC to 15 degC (and increased frequency by 5.4 MHz) – see little effect on bkd rate.



High Gradient Performance

5 Structures after ~ 500 hr of Operation and 8 Structure Average after > 1500 hr of Operation



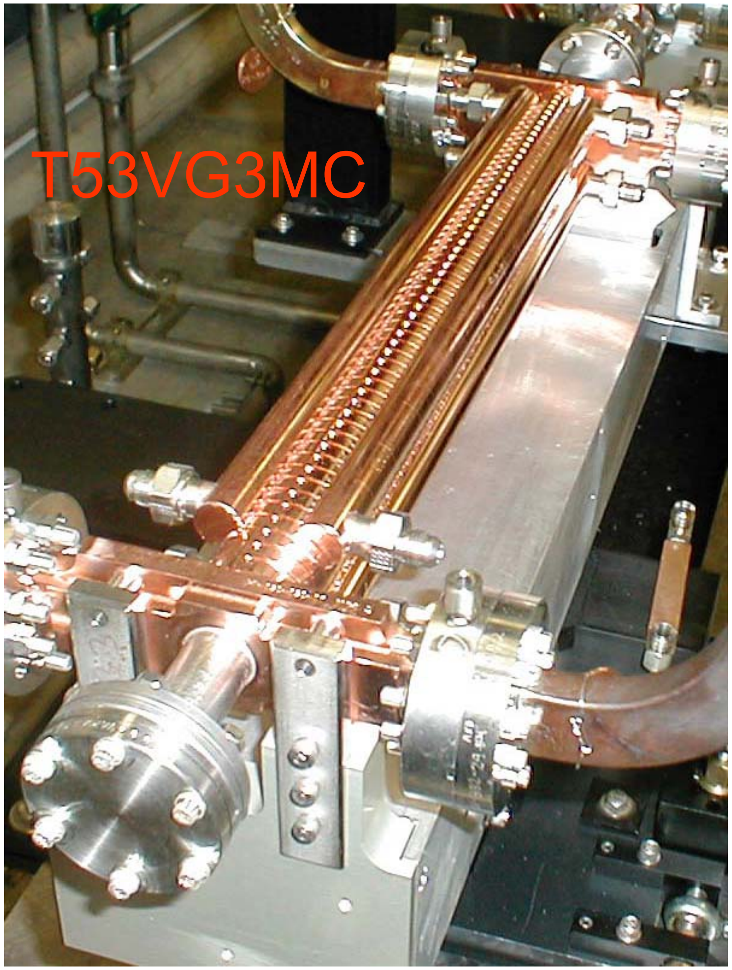
FNAL FXB6 structure

KEK H75VG4S18 test in early 2006 with 400 ns pulses

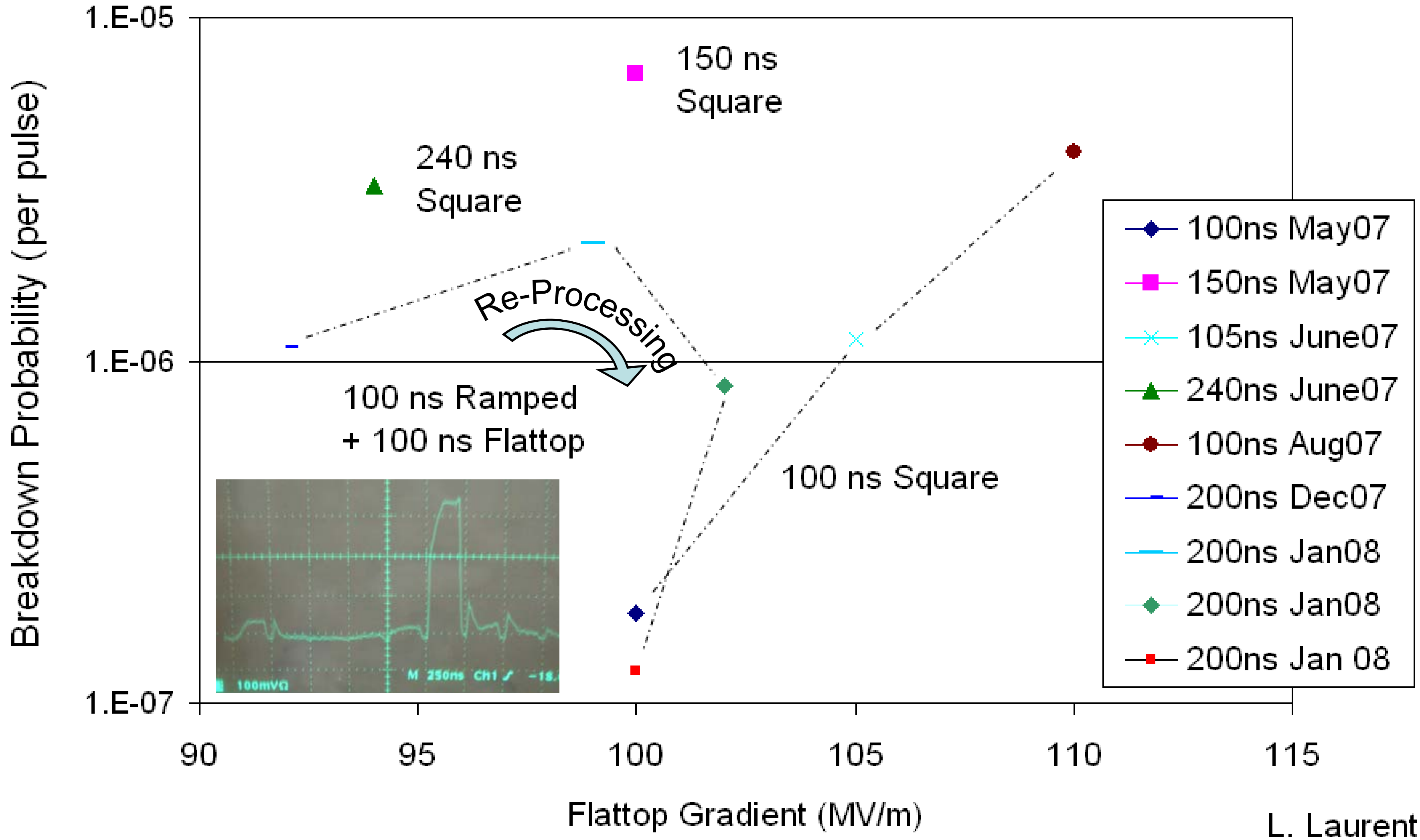
Early NLC/GLC Low Vg Test Structure

First with Mode Converter input coupler – performed exceptionally well in 2002

- 53 cm long, a/λ = 13%, initial vg = 3.3%, requires 98 MW for 100 MV/m operation
- In 2002, breakdown rate < 5e-7 at 90 MV/m with 400 ns square pulses
- Reinstalled in 4/07 and have since run 2300 hours with shorter pulses (includes two vents to SLED system)
- In following plot, most points based on 60 Hz operation for more than 50 hours



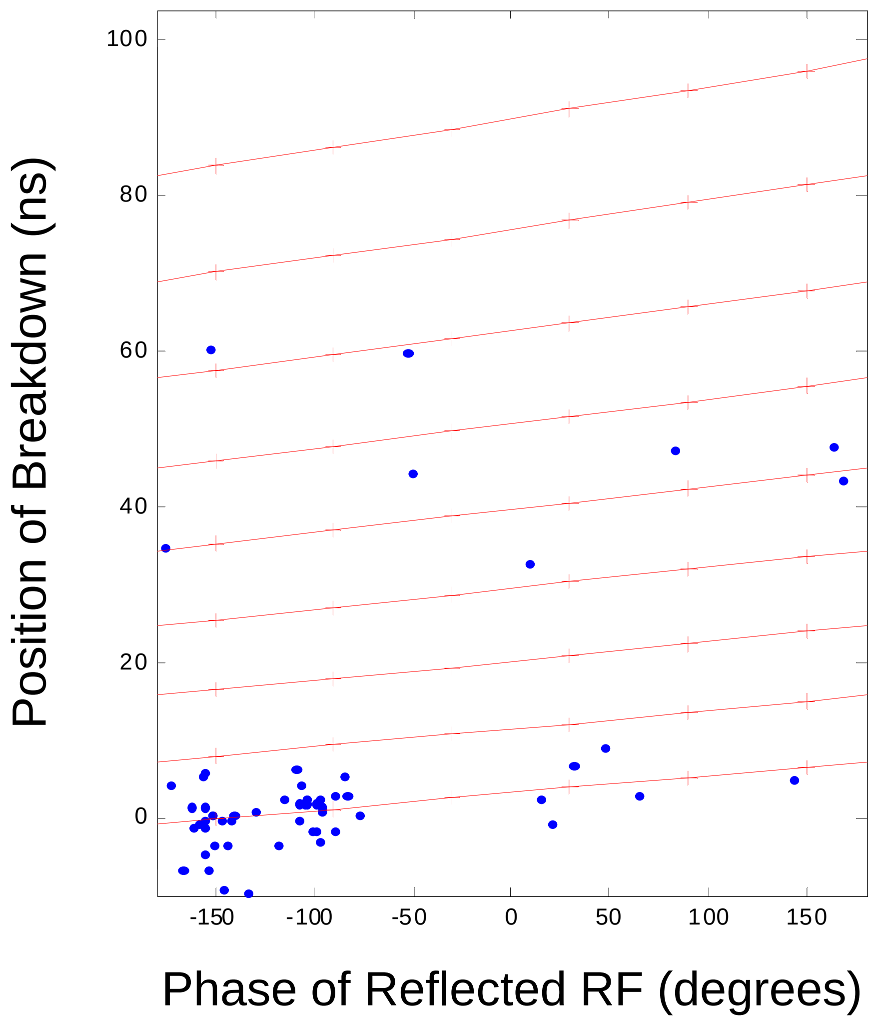
Short Pulse Operation of T53VG3MC



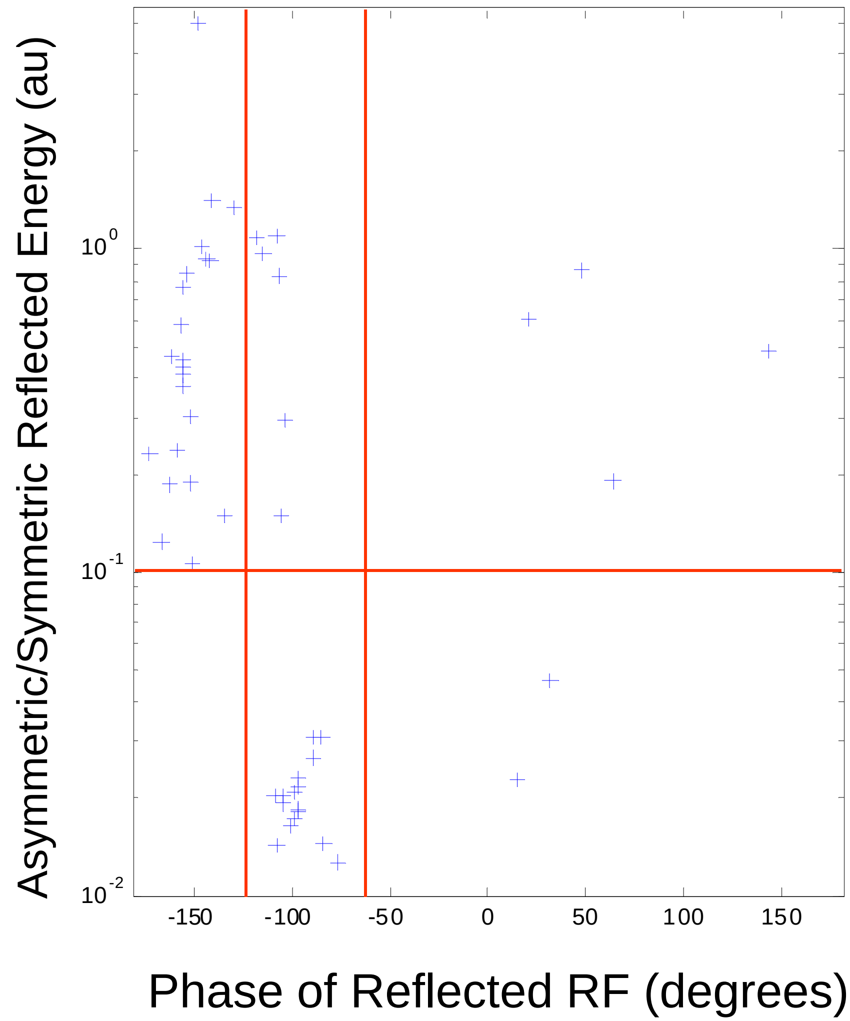
L. Laurent

Revisit earlier problem of structures with enhanced breakdown in first few cells – as an example, the first two cells of H60VG3S18 dominated breakdown rate at 65 MV/m with 400 ns pulses

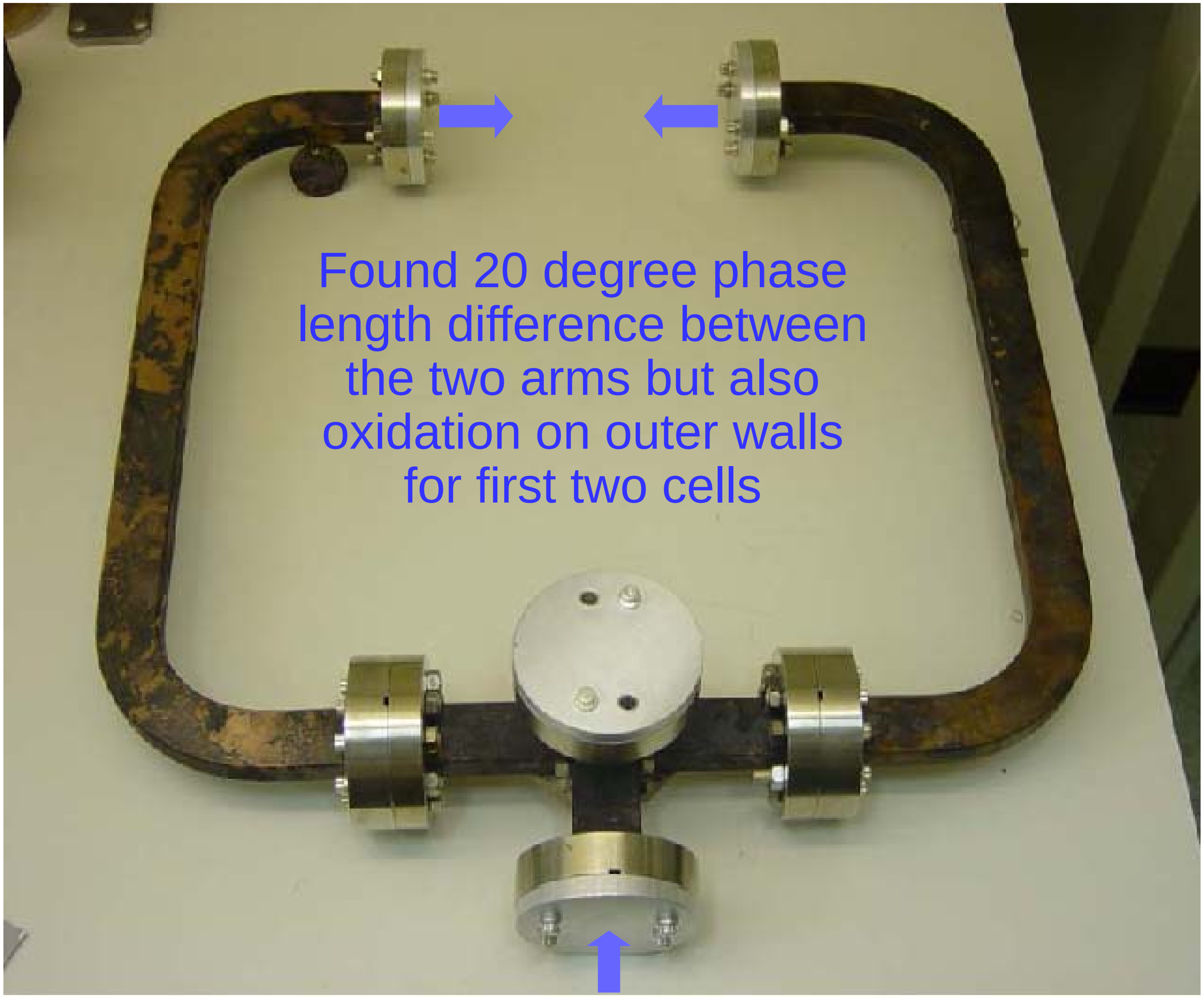
All Events



Events in First 6 Cells

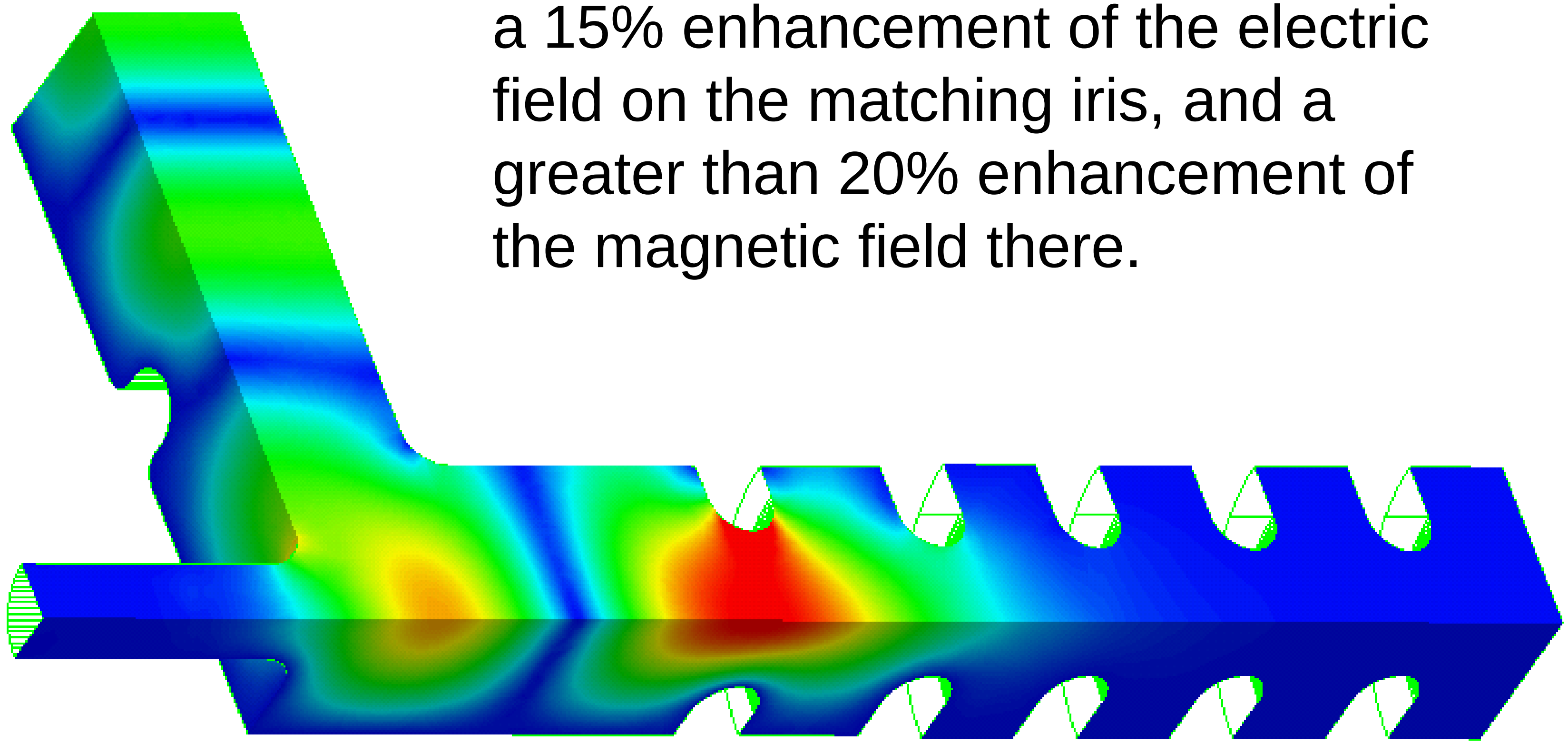


H60VG3S18 Autopsy Revelations



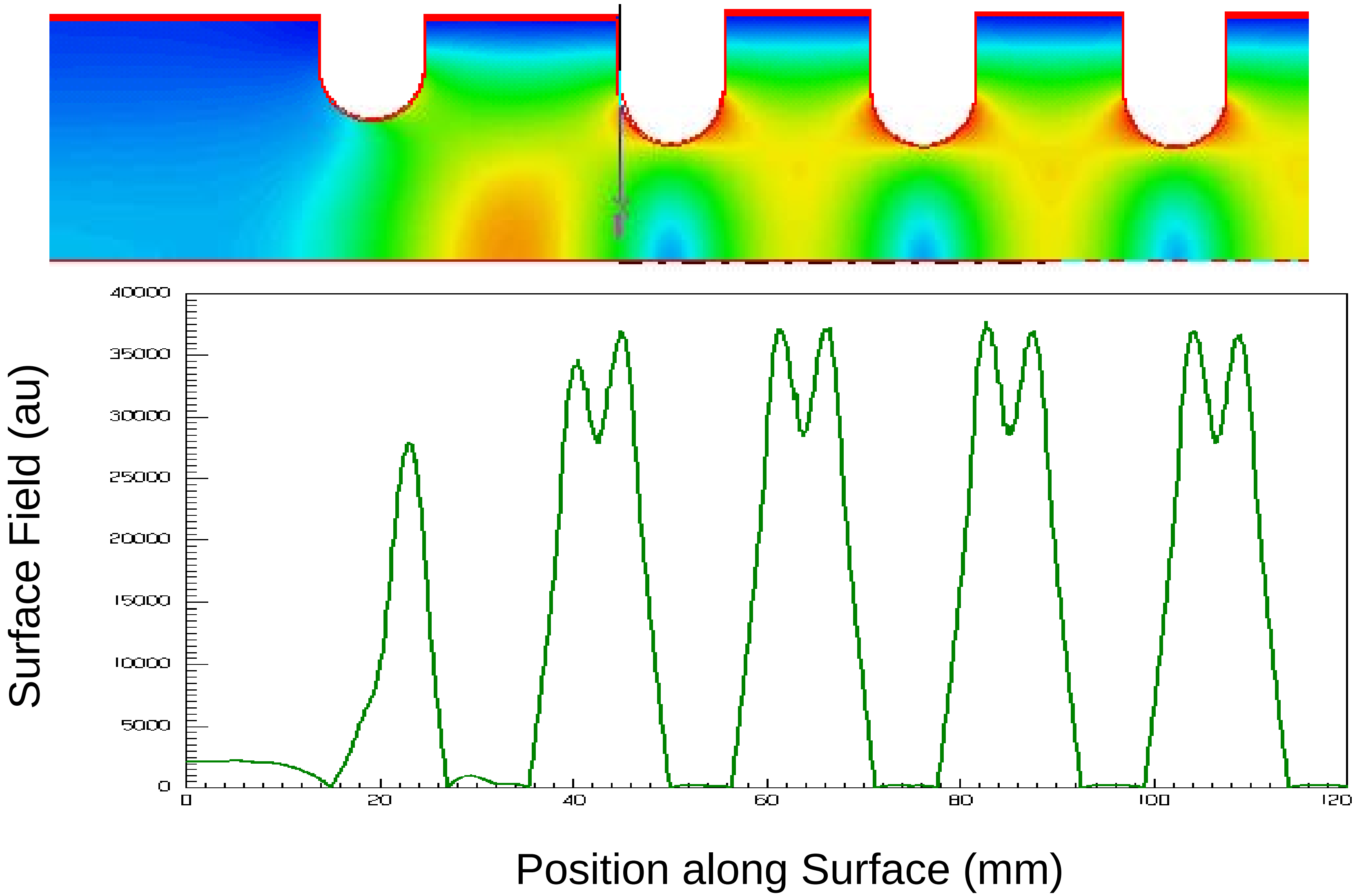
Effect of H60VG3S18 WG Phase Mismatch

Depending on phase, produce up to a 15% enhancement of the electric field on the matching iris, and a greater than 20% enhancement of the magnetic field there.



Electric Field Pattern in Structure Excited Asymmetrically

H60VG3S18 Field Profile with Mode Converter Coupler (Symmetrically Excited)

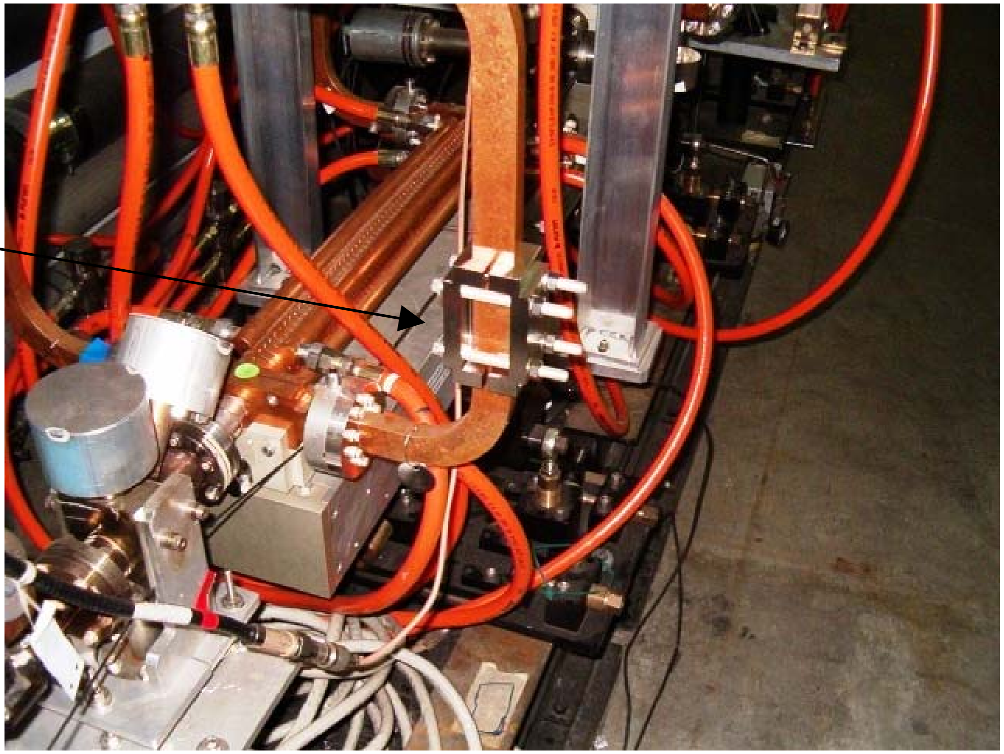


Feed Arm Mismatch Test with T53VG3MC

Built device to squeeze one feed arm to produce ~ 20 deg X-band phase shift

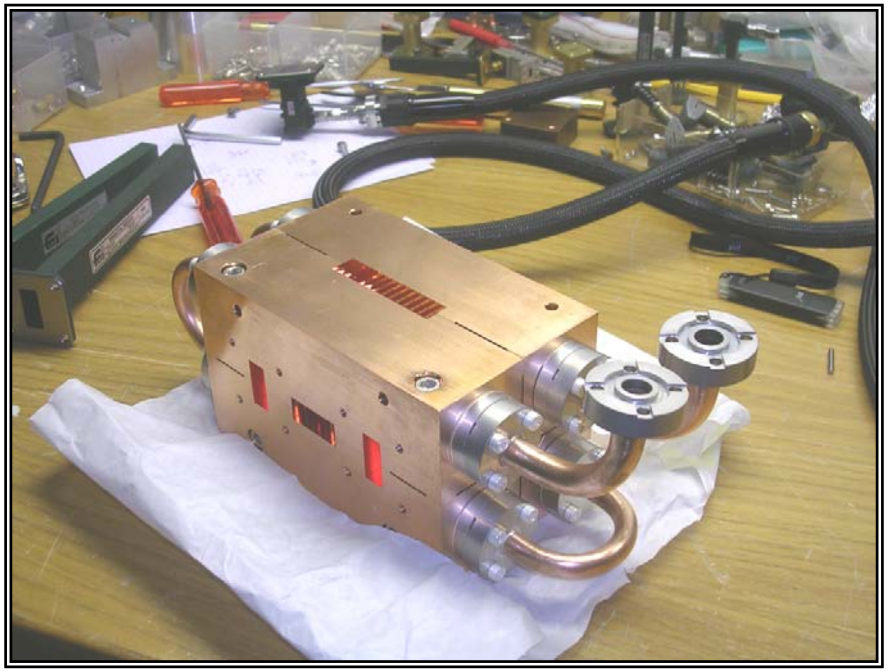
Measured 3.7% power in asymmetric port of magic tee that feeds power to the two arms (expected 3.0%, was < 0.1% before squeeze)

Observed no change in breakdown rate



HDX11 (C11vg5Q16) High Power Test Results at NLCTA

Scaled version of CERN 'HDS11 small'
Parameters are the right-most in the table (set '2') – for 100 MV/m, input power = 164 MW



f [GHz]	11.424
a/λ	0.19, 0.16
$\Delta\varphi$ [°], l_c [mm]	60, 4.374
$a_{1,2}$ [mm]	4.987, 4.200
$d_{1,2}$ [mm]	1.445, 1.445
$Q_{1,2}$	3820, 3760
$r/Q_{1,2}$ [LinacΩ/m]	11000, 13000
$v_g/c_{1,2}$ [%]	8.0, 5.1
for E_{acc} [MV/m]	150
$P_{1,2}$ [MW]	680, 370
$E_{s1,2}$ [MV/m]	270, 250
$\Delta T_{1,2}$ [K]	32, 28

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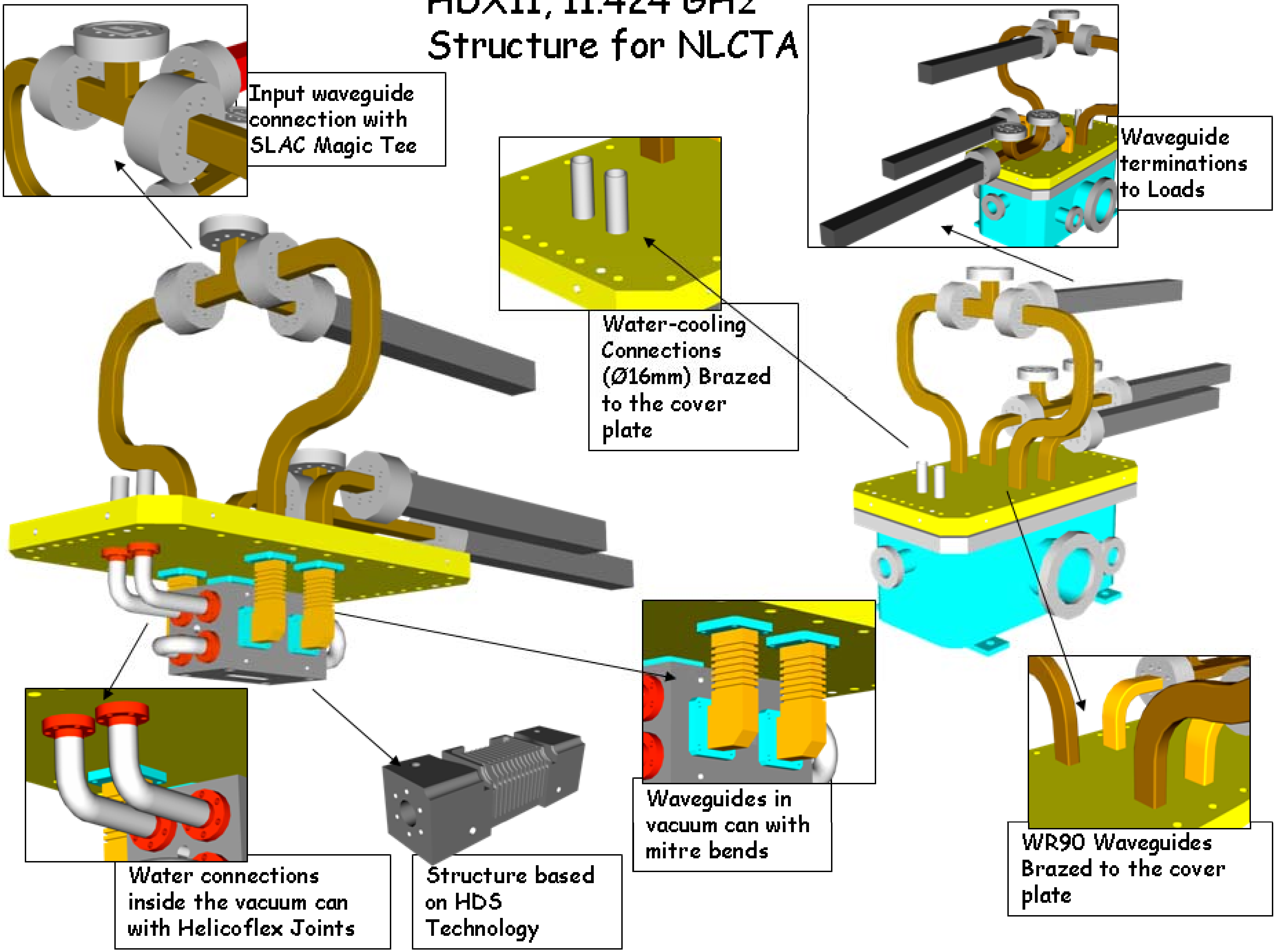
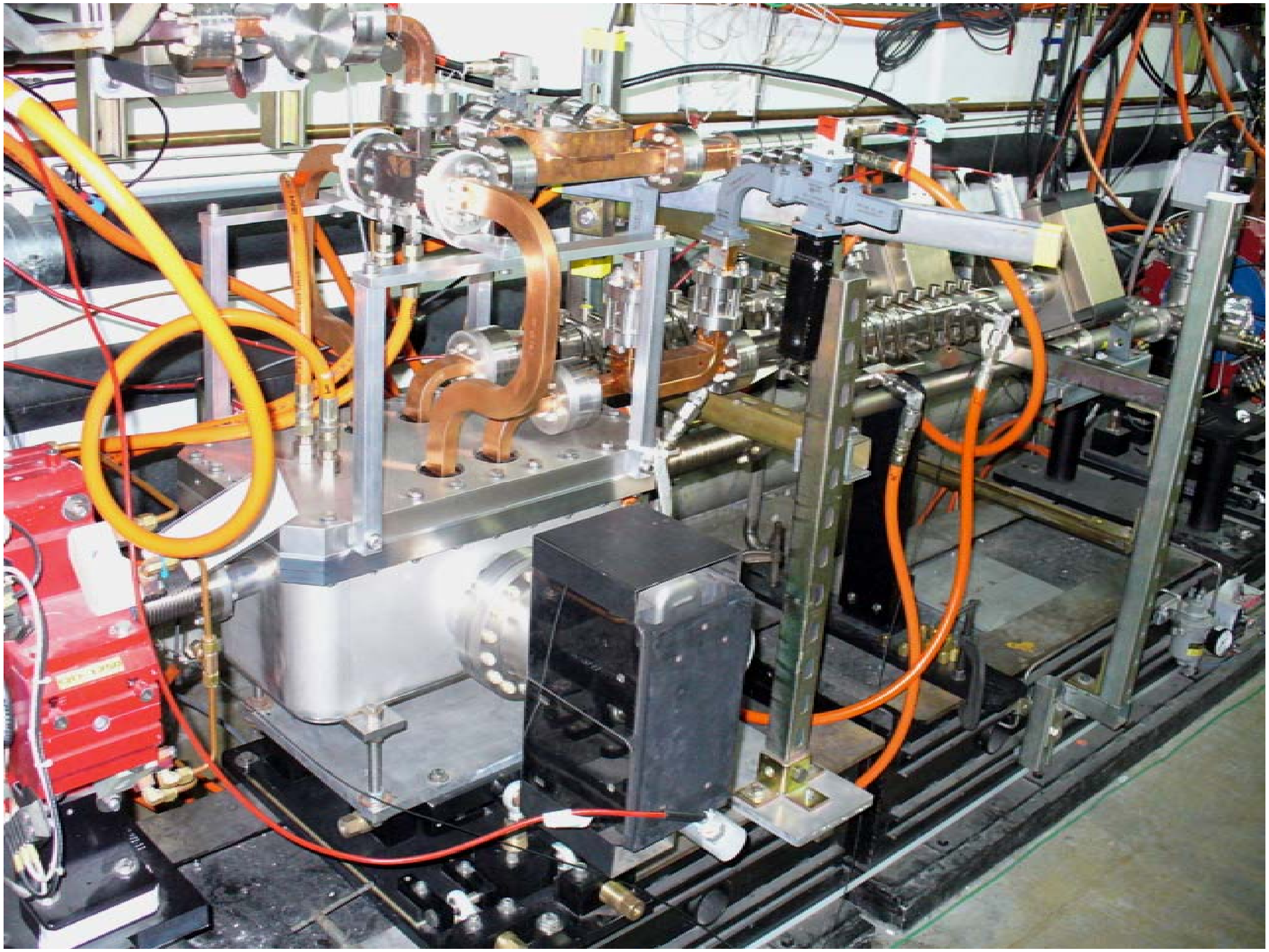
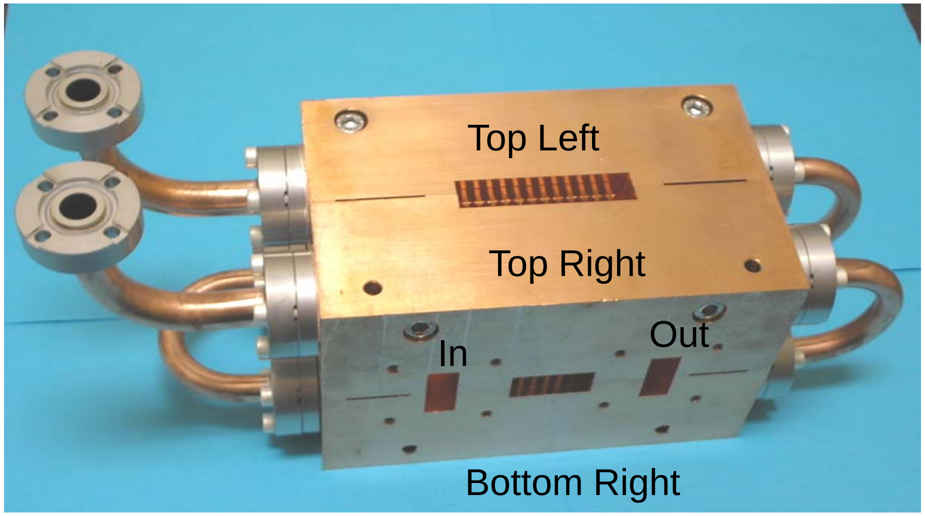
HDX11, 11.424 GHz Structure for NLCTA

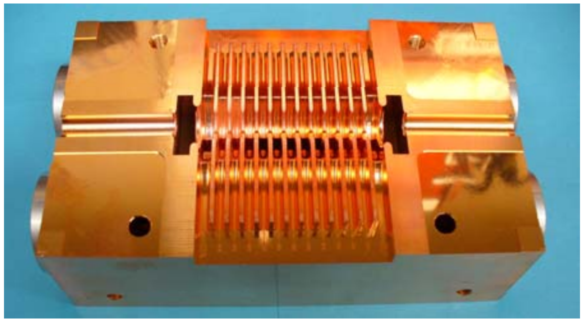


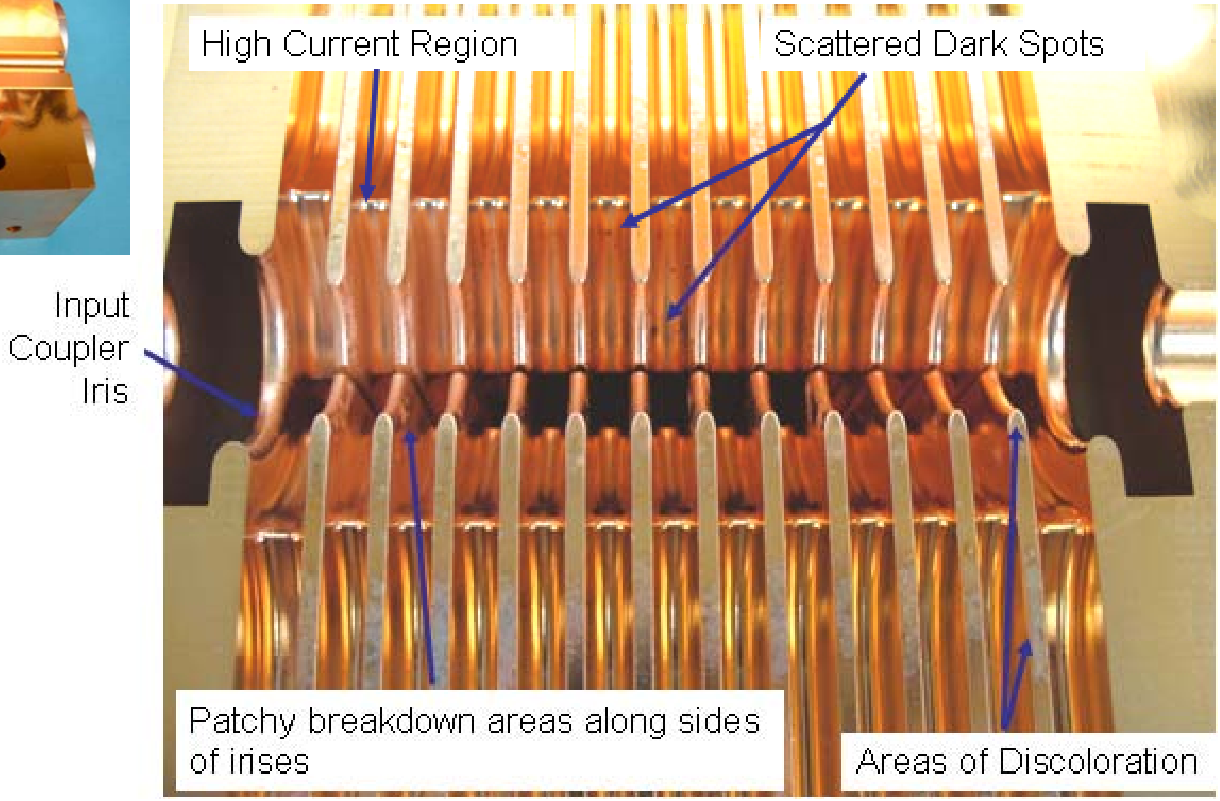
HDX in NLCTA



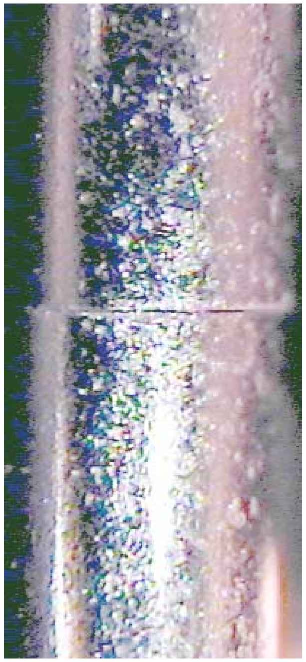
CERN Copper HDX-11 Quadrant Structure After First Test with 20k Bkds

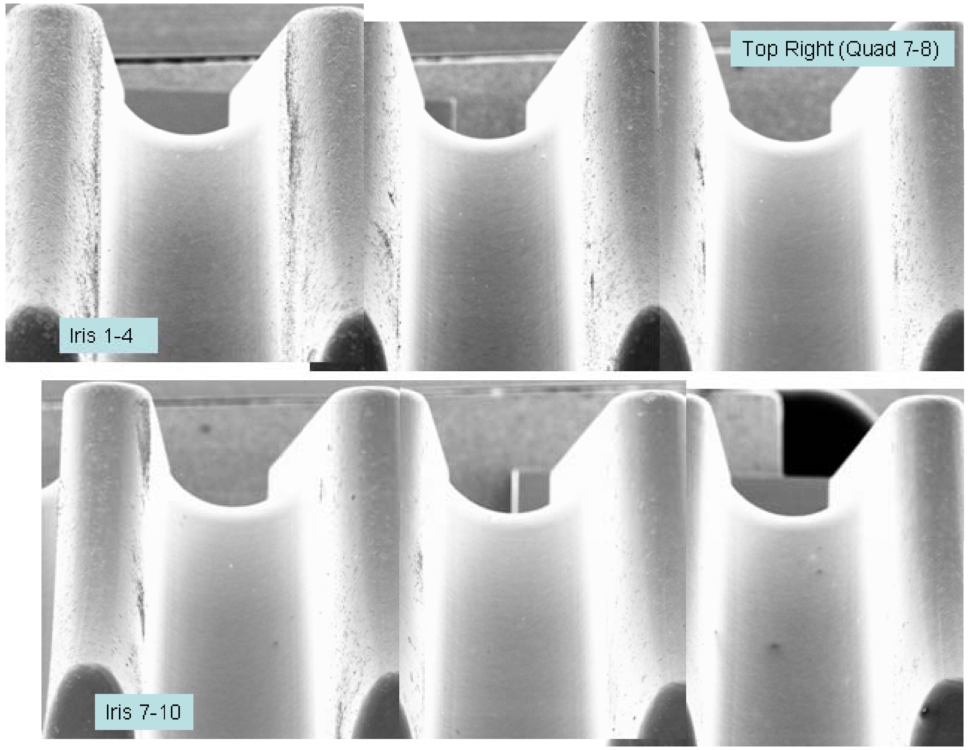




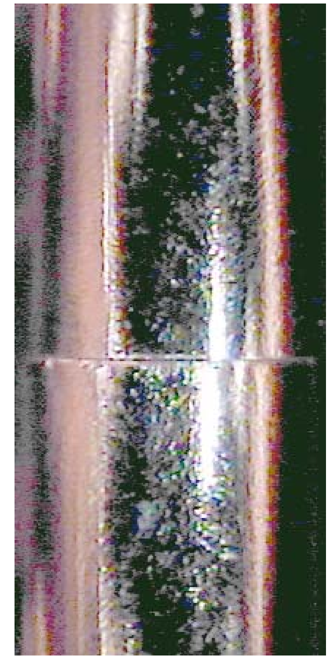


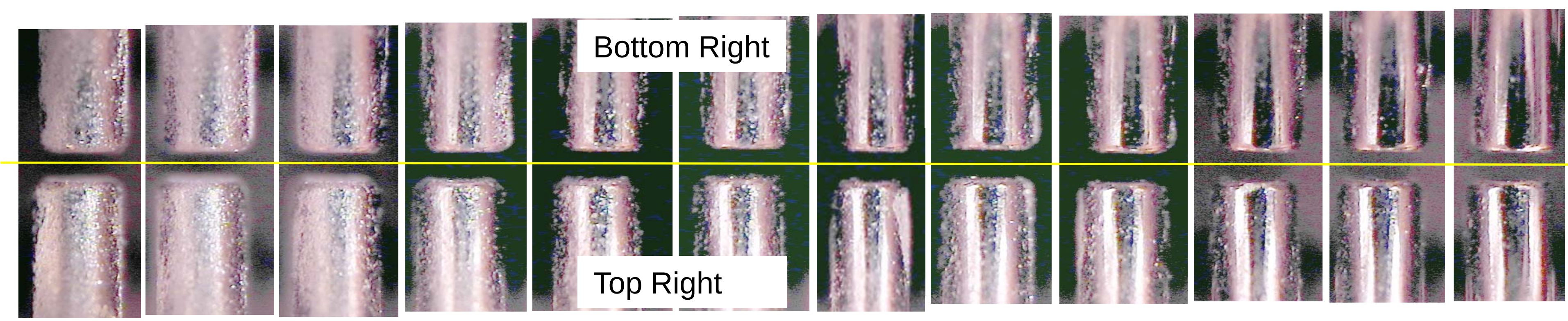
Input



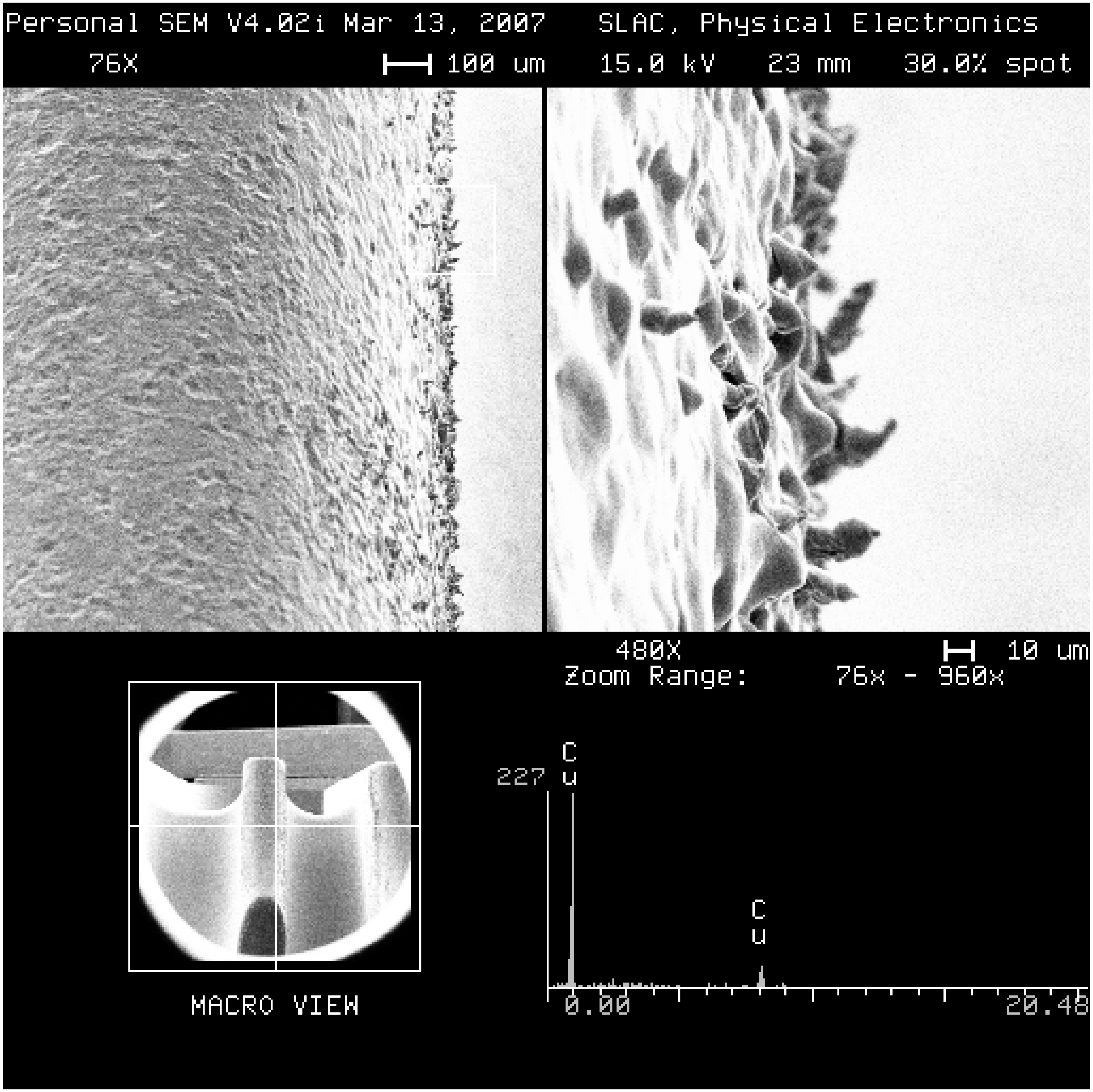


Output



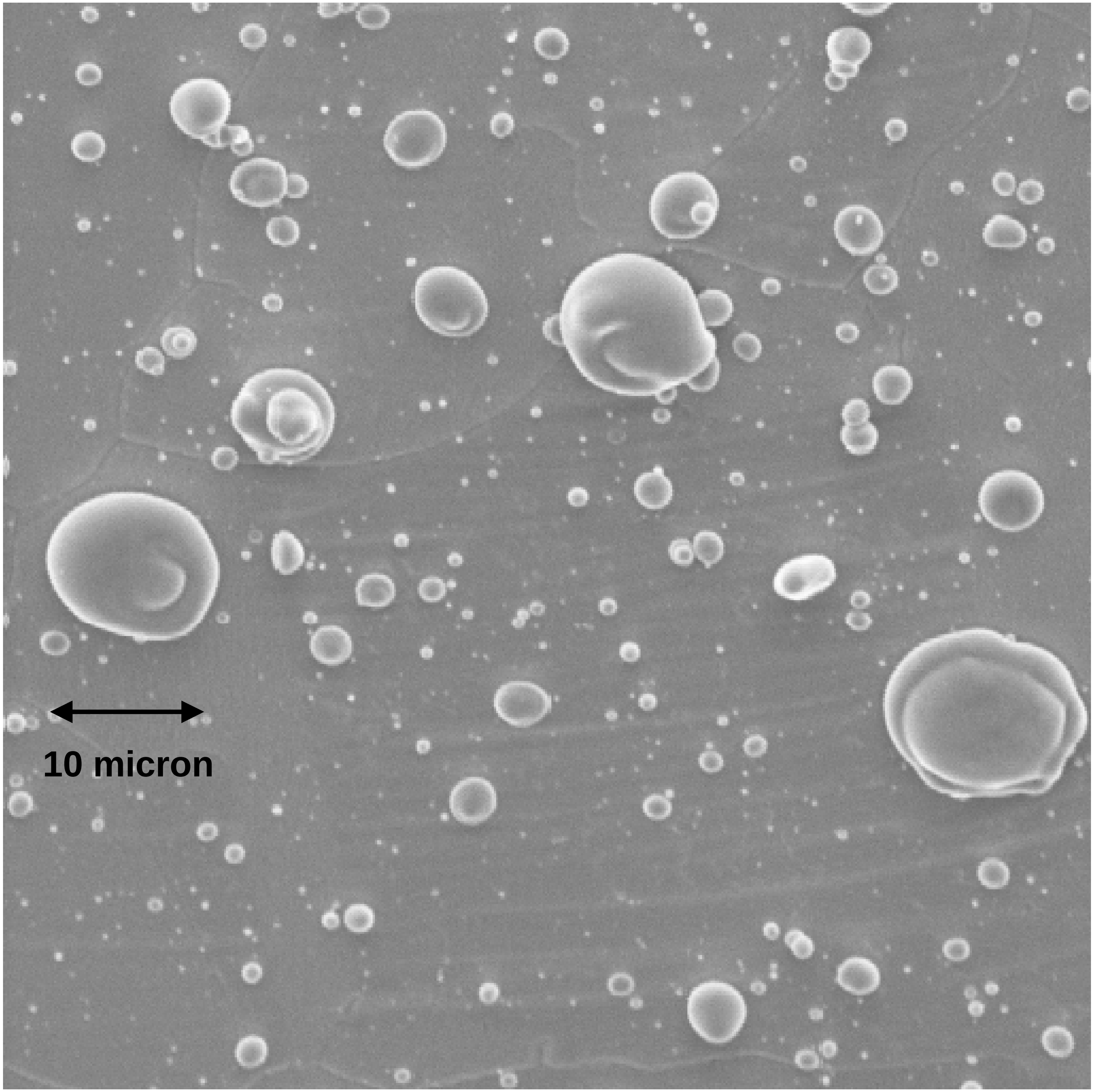


1 2 3 4 5 6 7 8 9 10 11 12



Iris 1
(Top Right)

Not only were the ups irises heavily pitted, but ‘whiskers’ grew from the sides of most irises

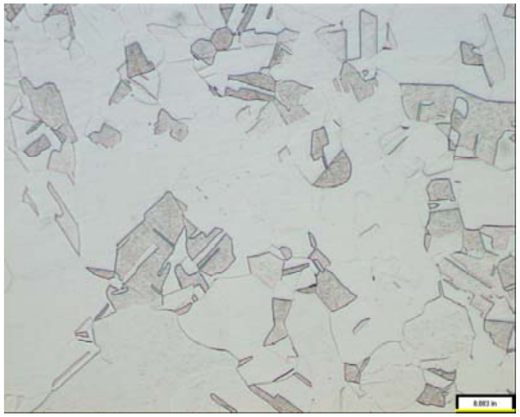


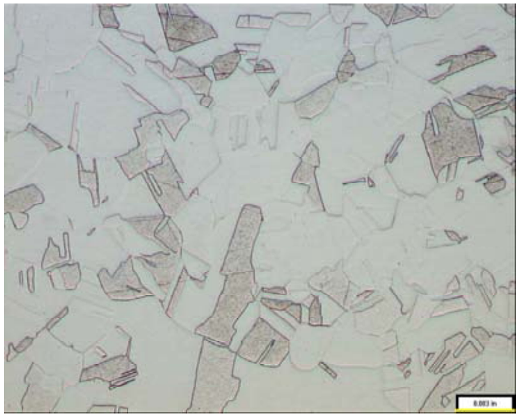
Iris 2&3 (Bottom Right)

Also, Cu splatter seen at bottom of the cells

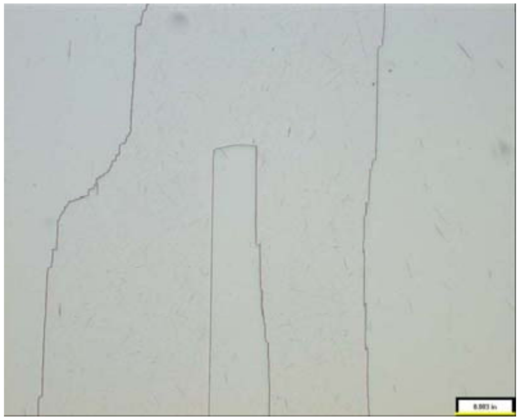
Is this the origin of the whiskers on the side walls ?

Verified that Copper was of Good Quality





Metallography of CERN Copper before H2 Fired (100x magnification) revealed an oxygen-free copper, cold worked with equiaxed, recrystallized grains that contained twinned regions. Very little contamination was observed.

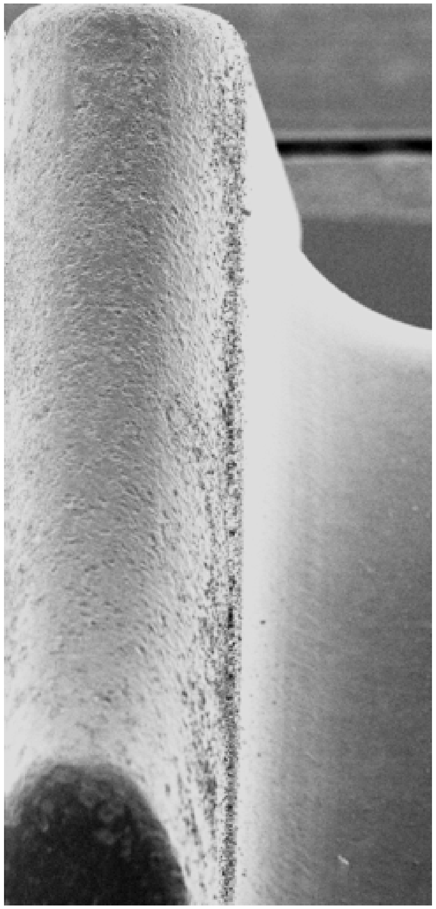


Metallography of CERN Copper after H2 Fired (100x magnification) revealed large, coarse, well-defined crystals consistent with grain growth due to high temperature annealing. Classification is ASTM F68 Class 1 for type A (cross grain), B (within grain), & C (grain boundary).

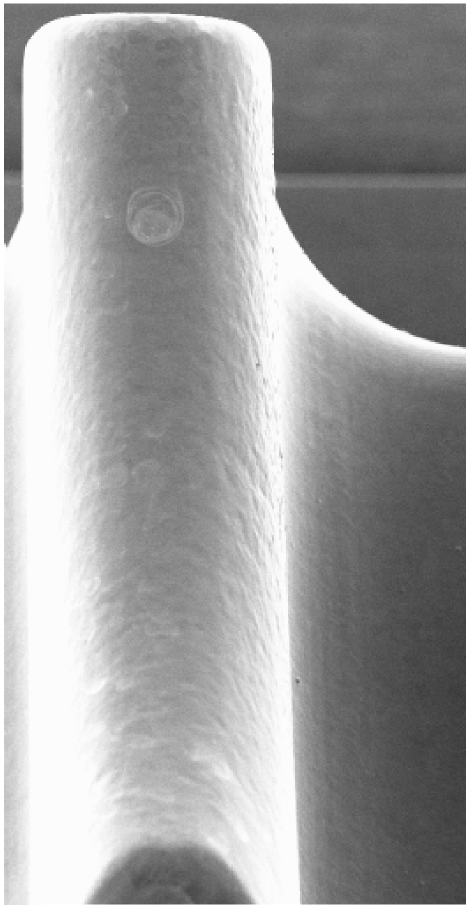
So Decided To

- Electro-polish surface to smooth pits and whiskers
- Fire at 1050 degC (when brazing on water fittings) to grow large grains
- Attempt to better align quadrants
- Re-install in the can with the orientation reversed so the ‘good’ end now sees the input power.

Iris 1 Before and After Electro-Polishing



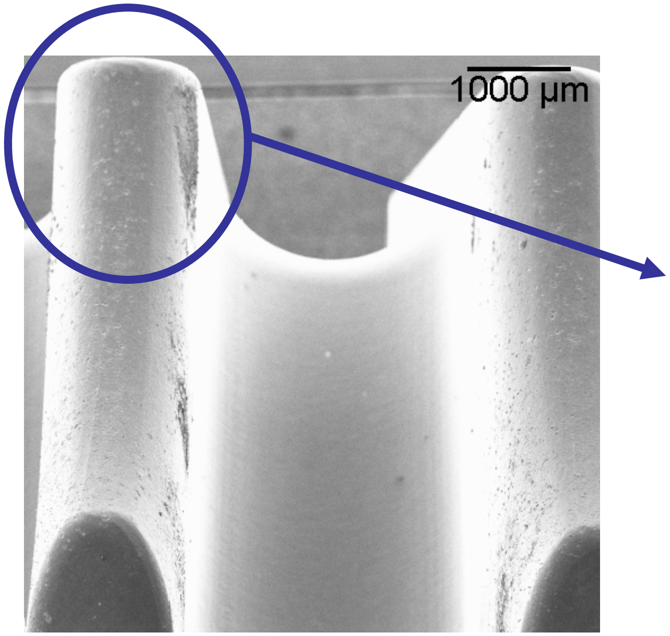
Before Electropolish

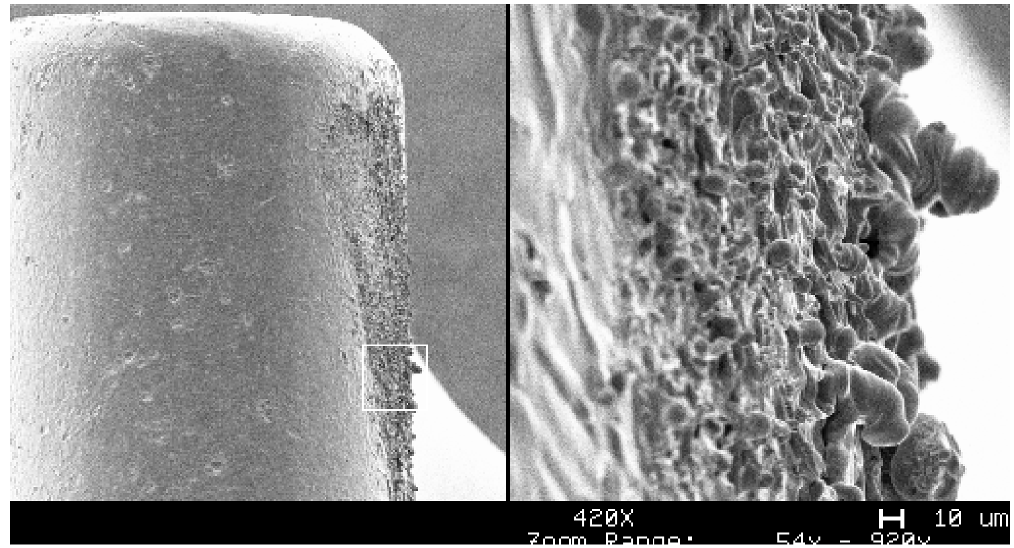


After 7-minute Electropolish

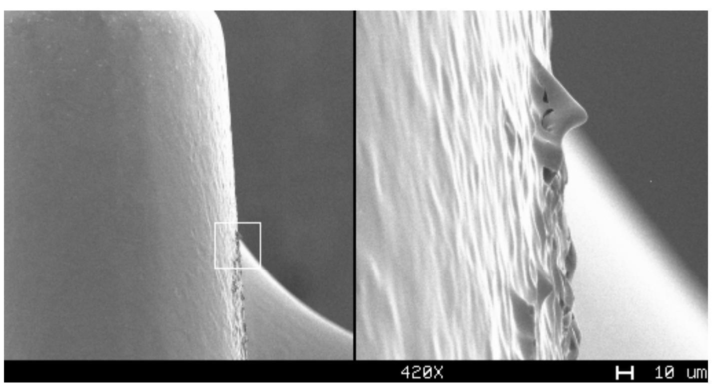
A short (~5-sec) chemical etch should be completed after the electropolishing step to remove residue (right) – was not done however.

Iris 7 Had a Pronounced ‘Growth’ and Was Hardest to Smooth

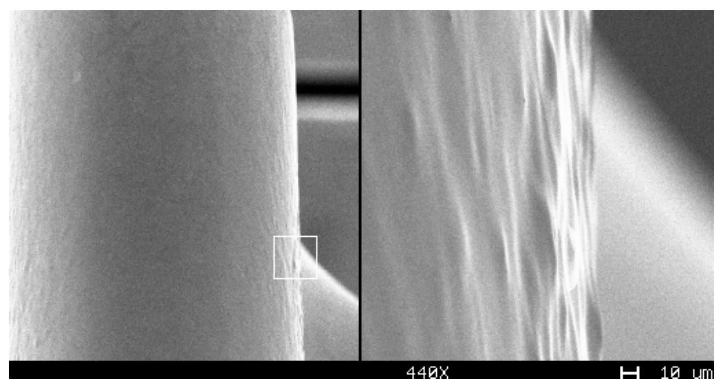




Before Electropolish

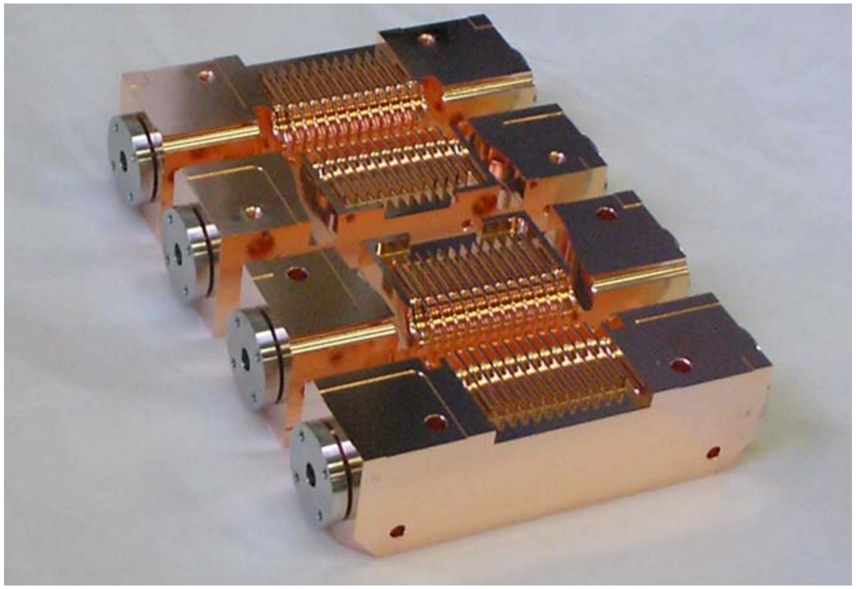


3-minute Electropolish

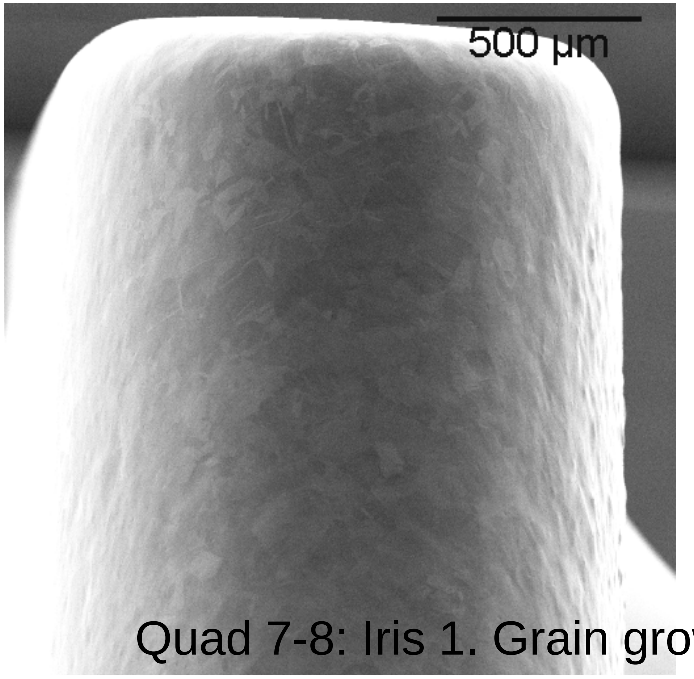


7-minute Electropolish

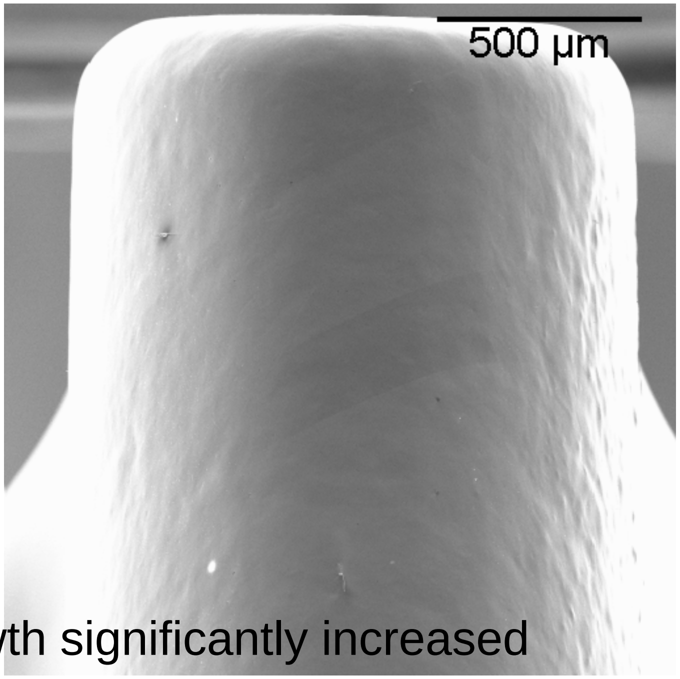
After Brazing on New Water Fittings



Before Braze

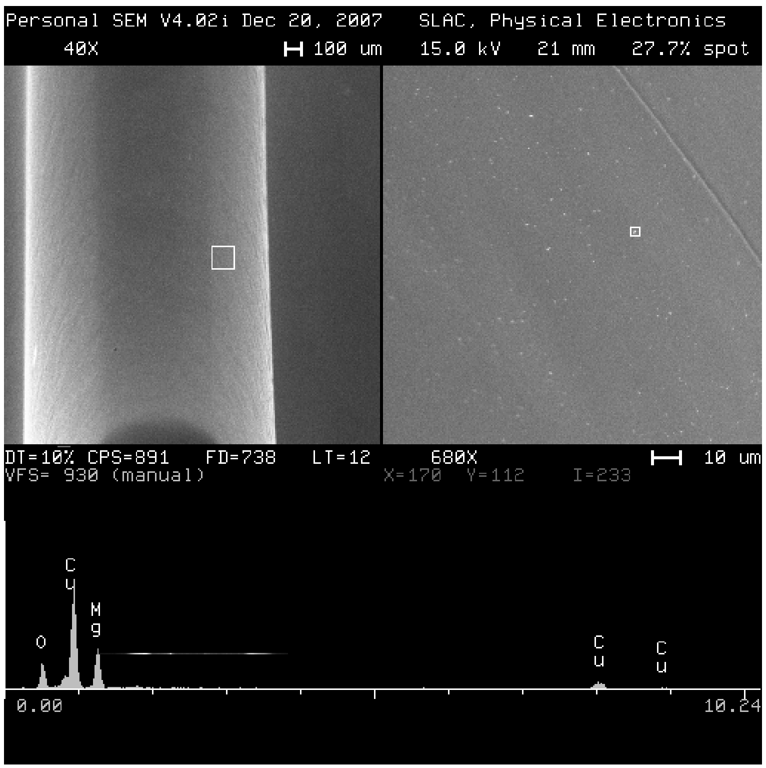


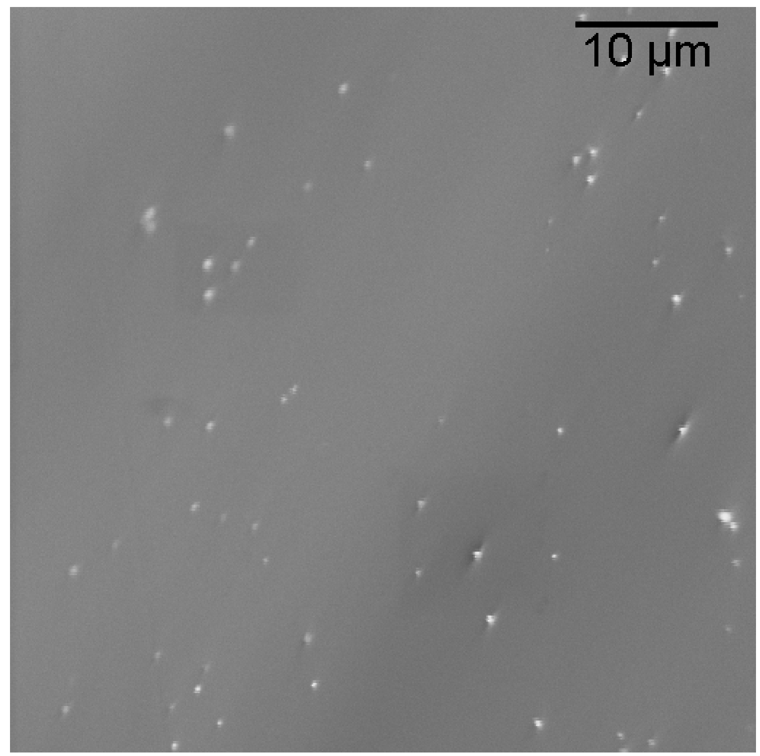
After Braze



Quad 7-8: Iris 1. Grain growth significantly increased

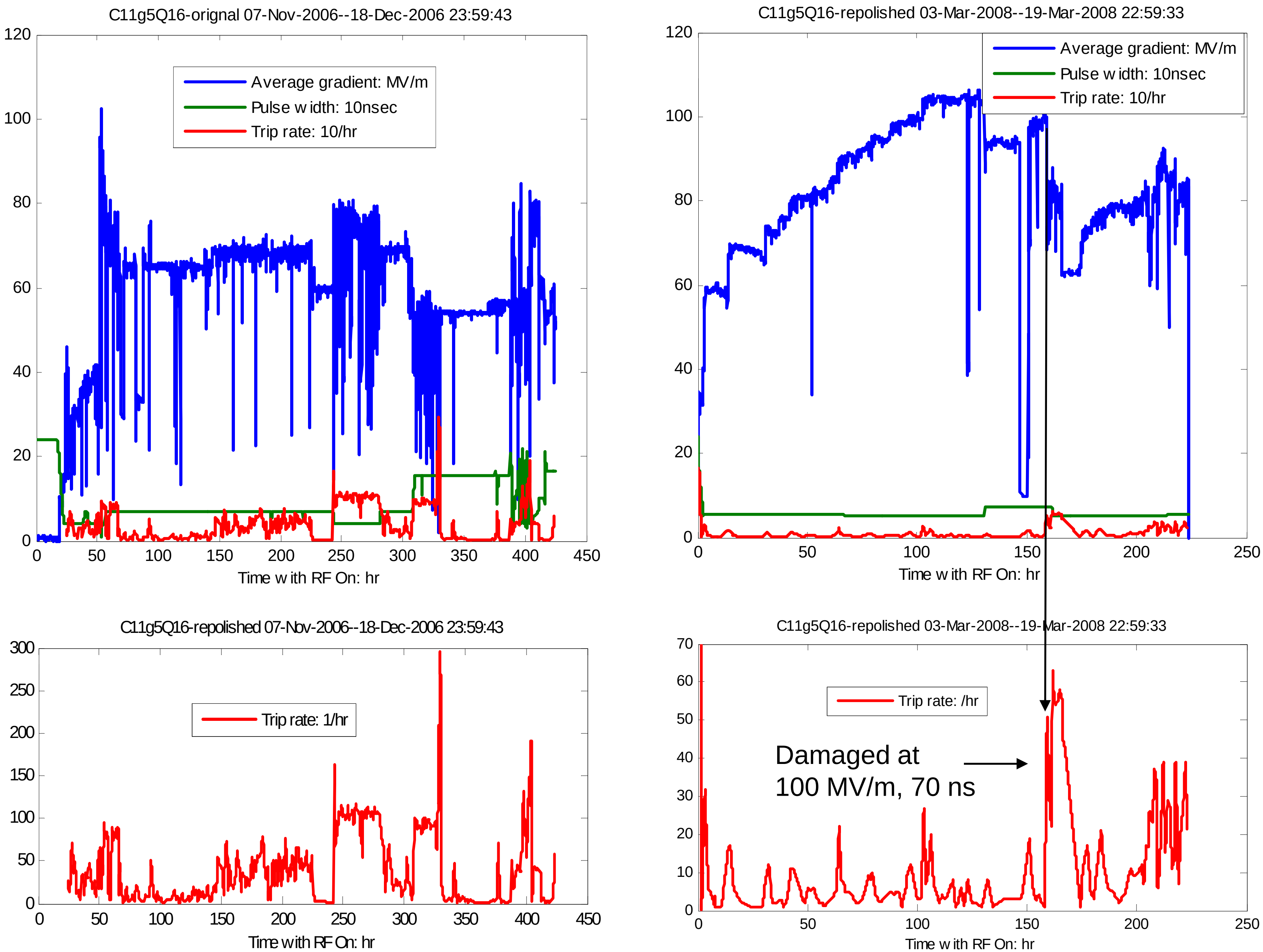
However, Found Small Magnesium Particles on the Surface after Electropolishing and H2 Firing



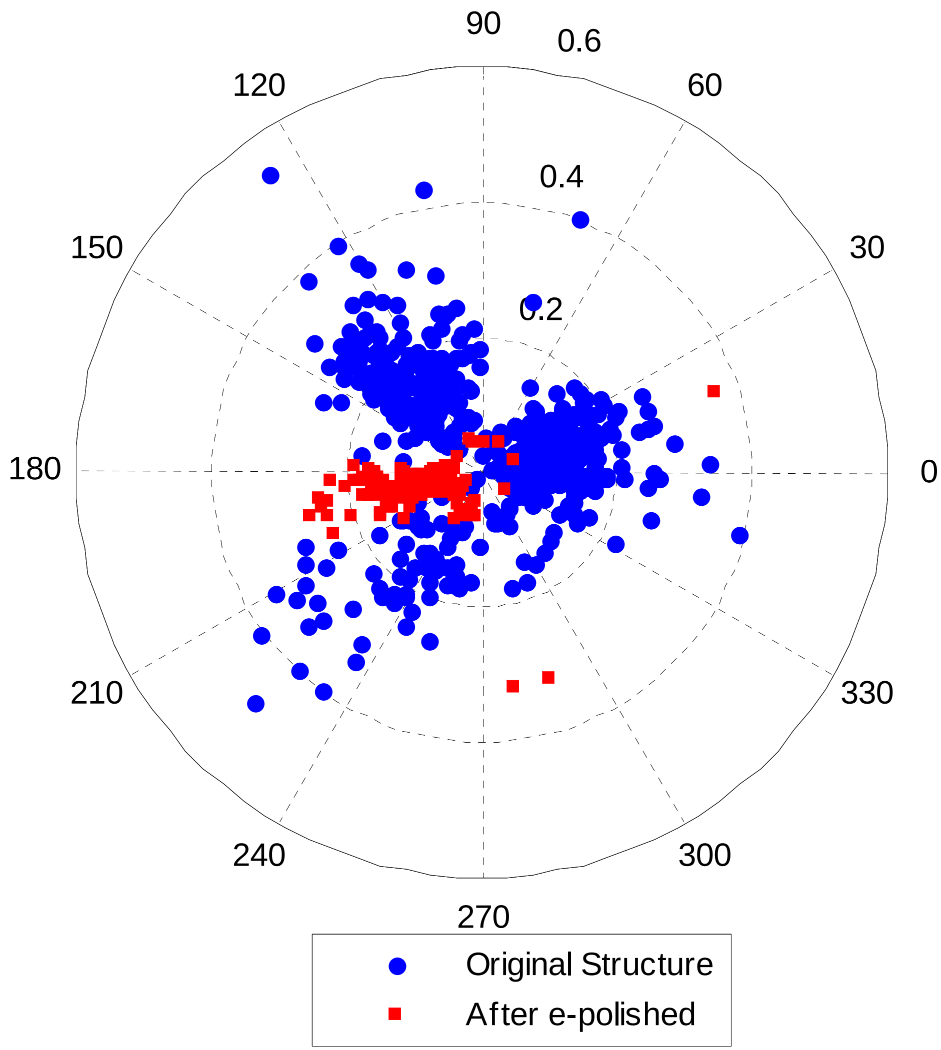


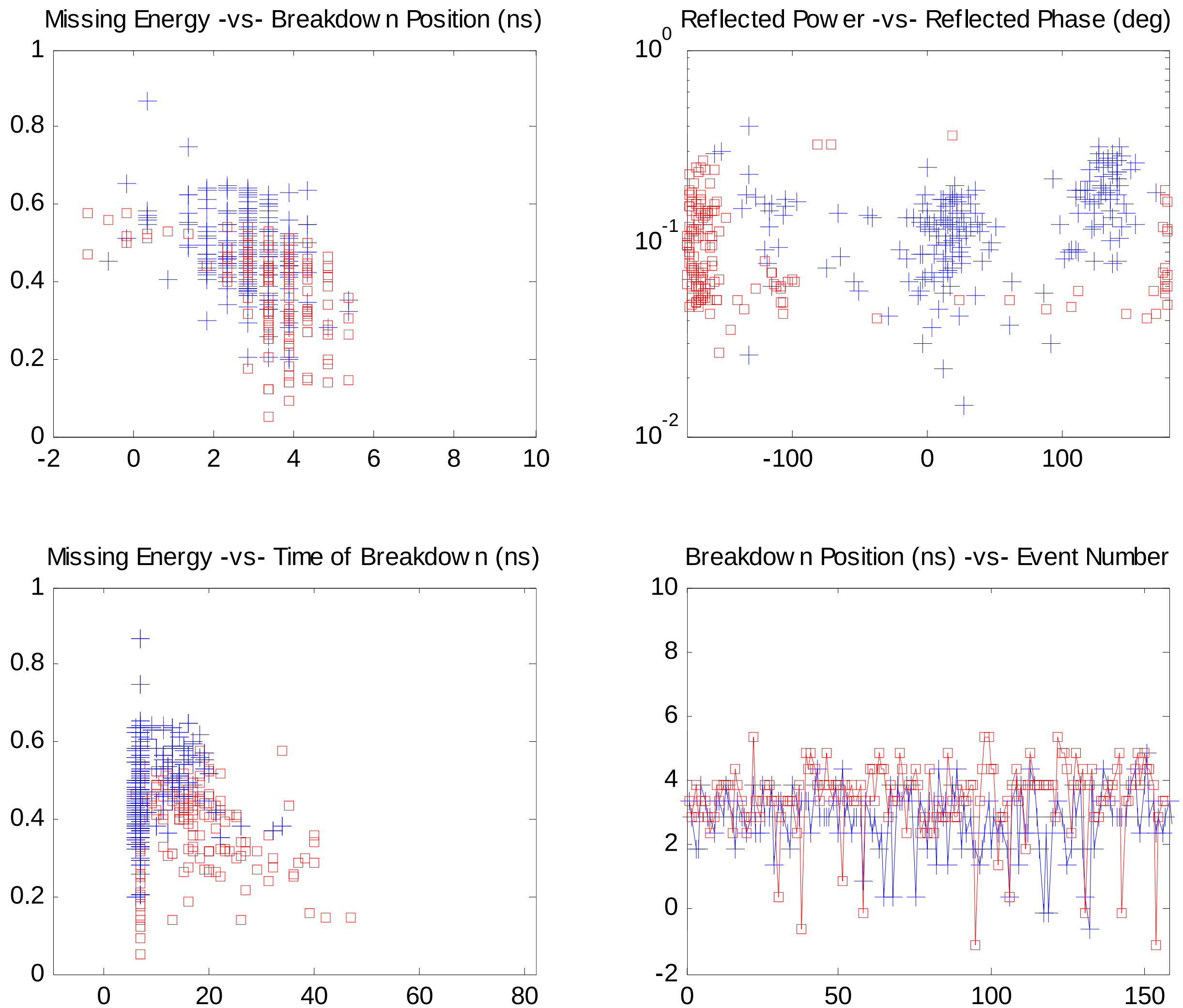
First Run

Second Run



Peak Reflected RF Power (Fraction of Input Power) Versus Reflected RF Phase (Deg)



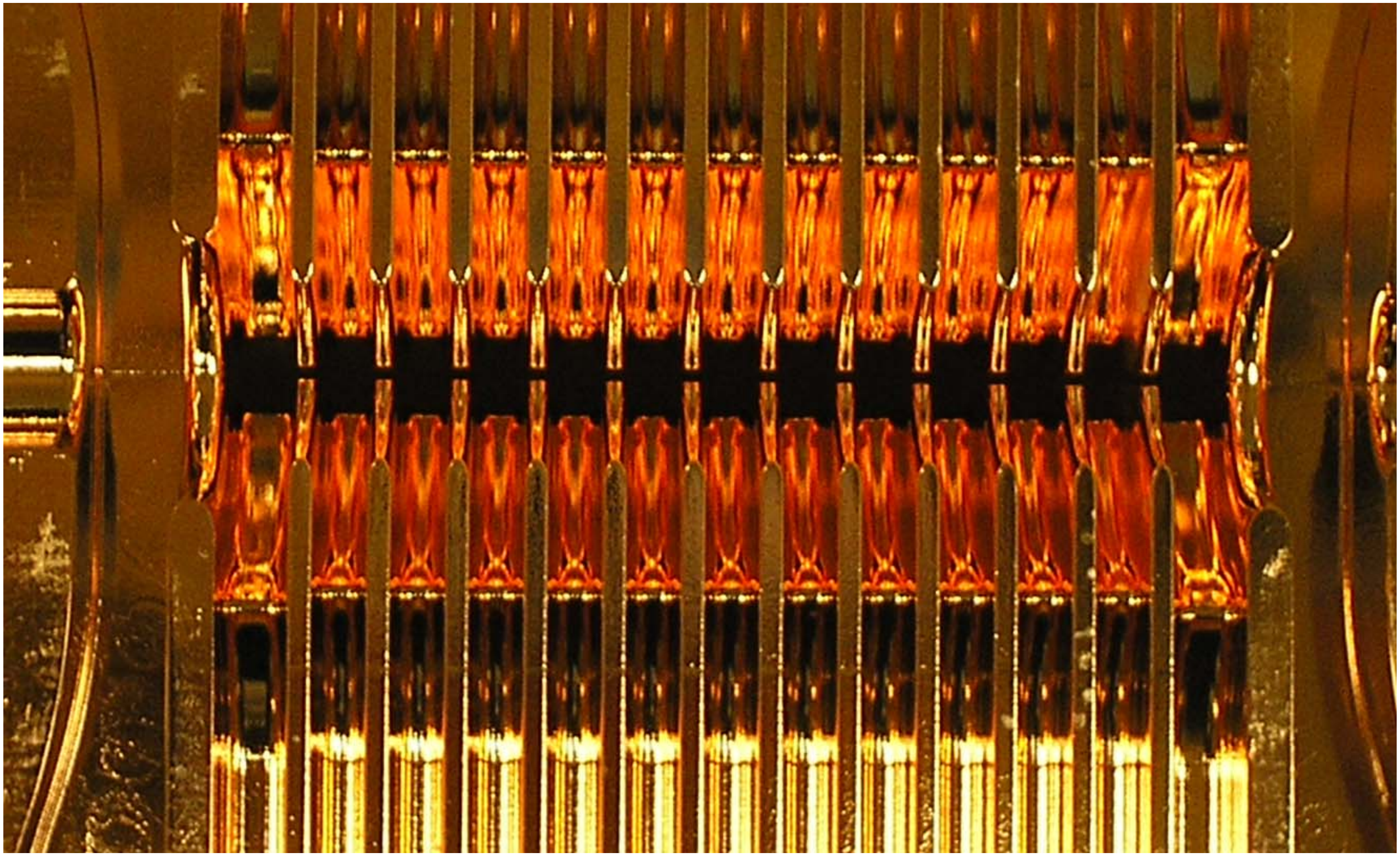


Blue cross: the original structure running at 70ns@68MV/m

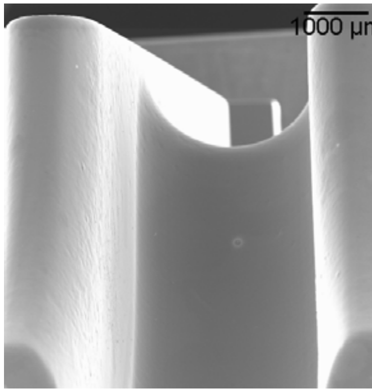
Red square: structure after e-polished at 50ns@80MV/m

Autopsy after Second Run

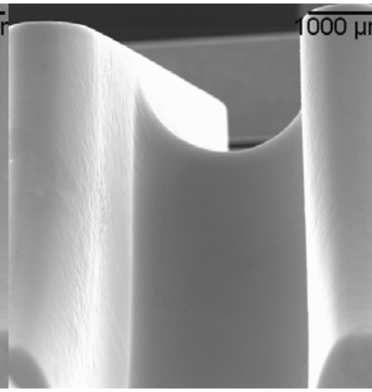
(Much less damage, better aligned)



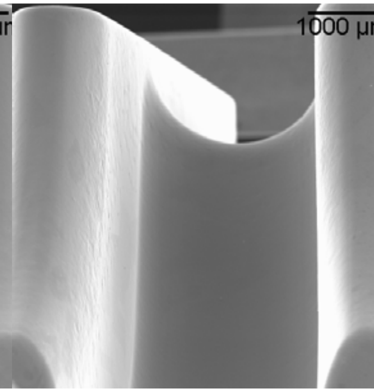
SEM Photos after Second Run: Nearly all Damage on Sides of Cell 1



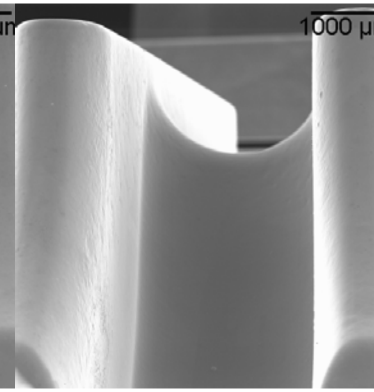
9 cell



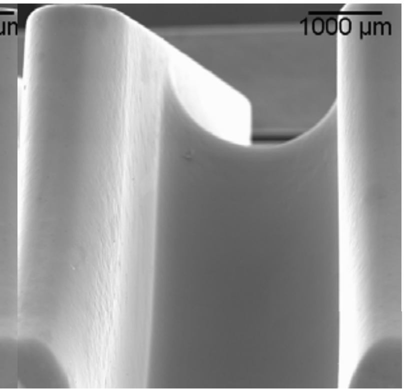
8 cell



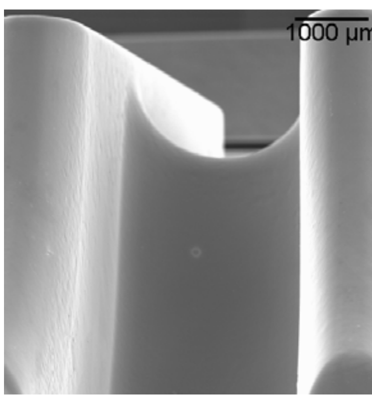
7 cell



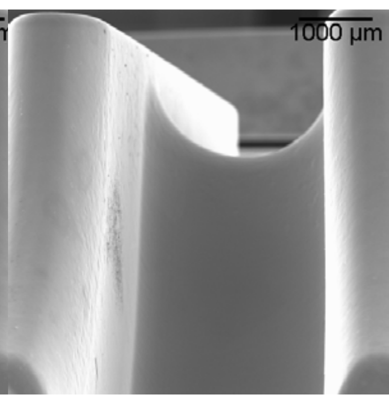
6 cell



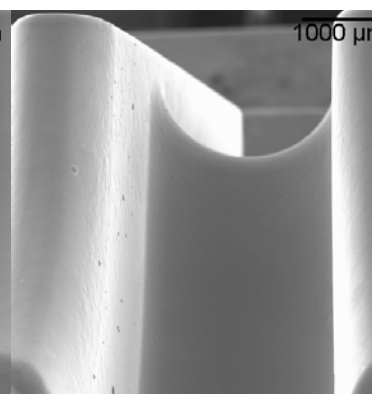
5 cell



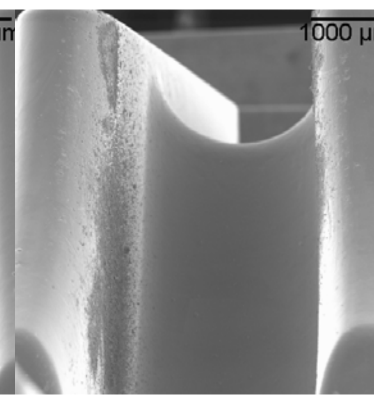
4 cell



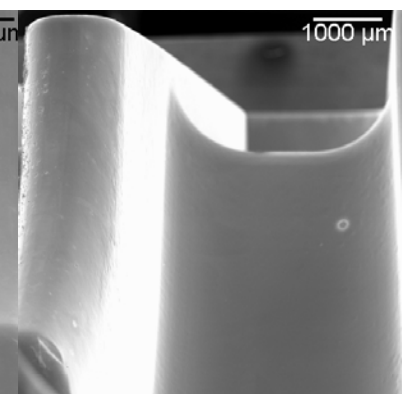
3 cell



2 cell

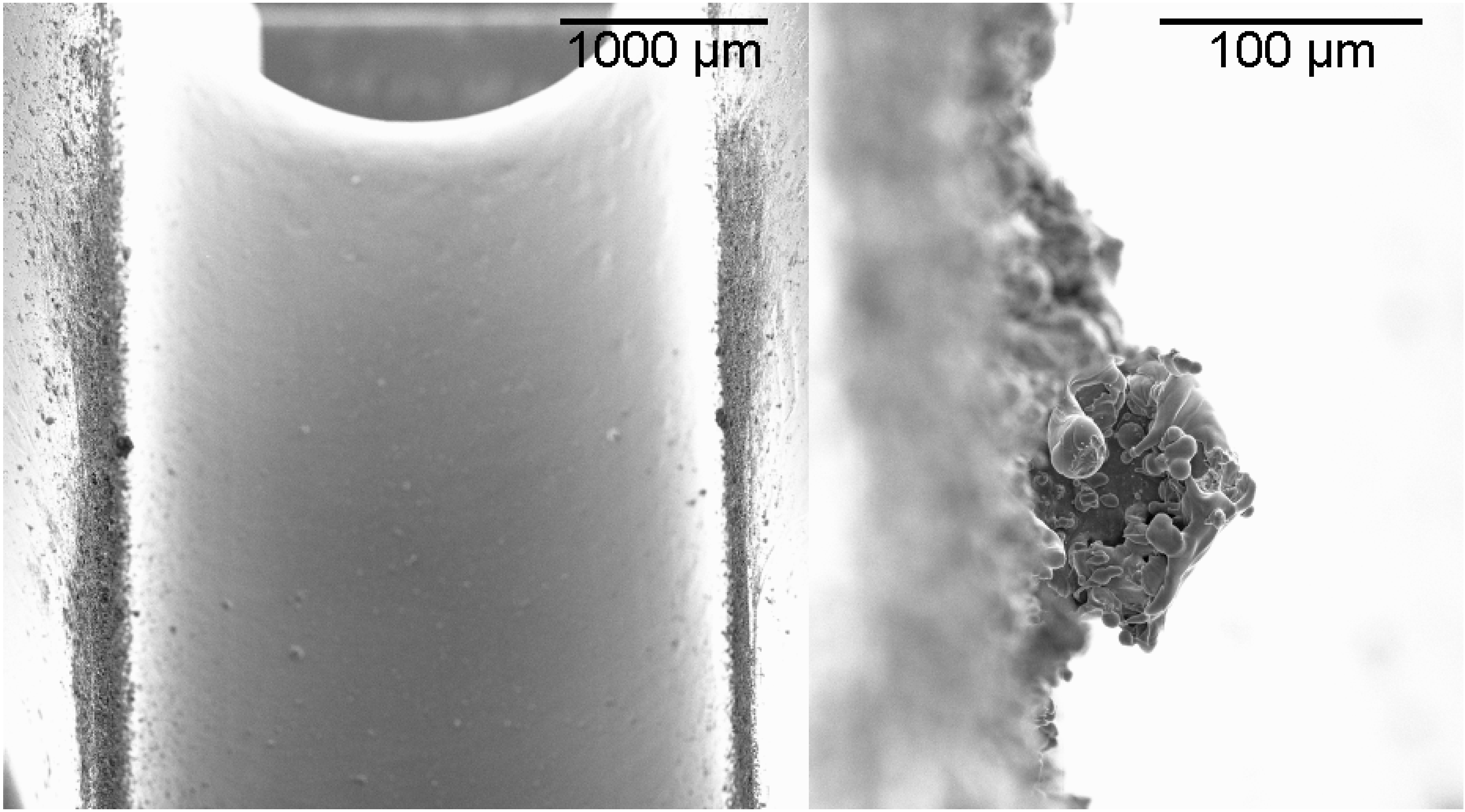


1 cell

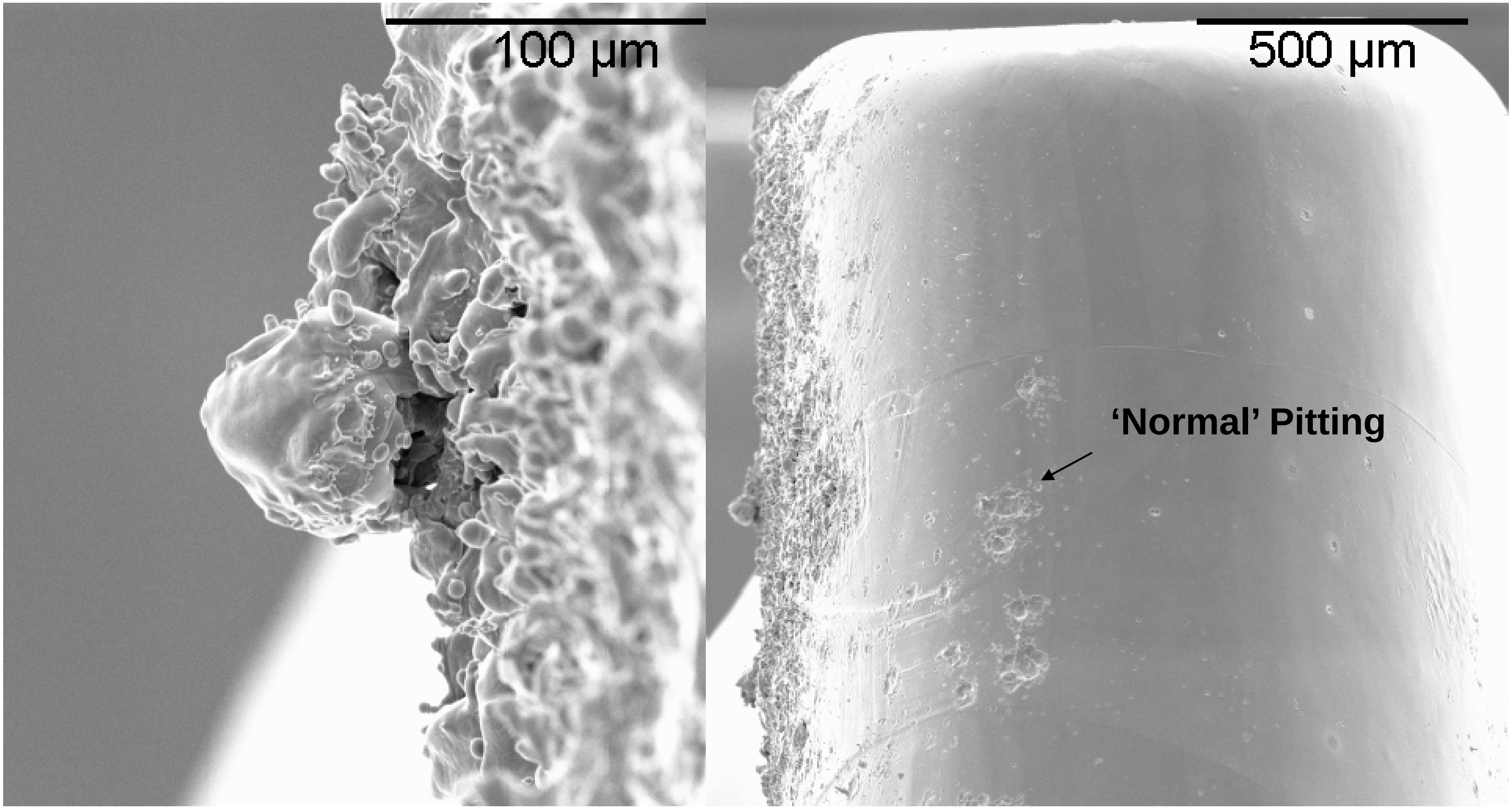


0 cell

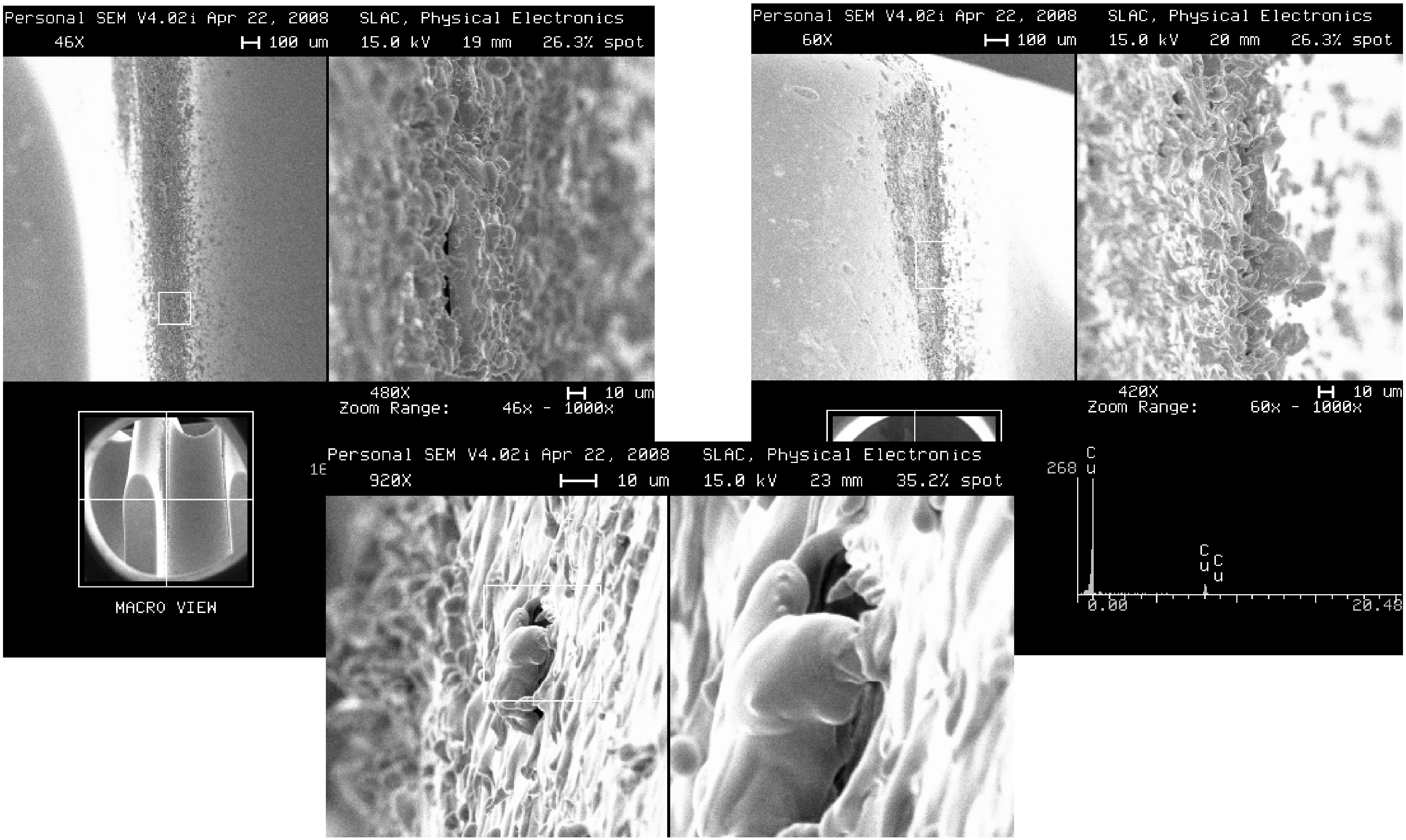
See Opposing 'Tips' on Side Walls



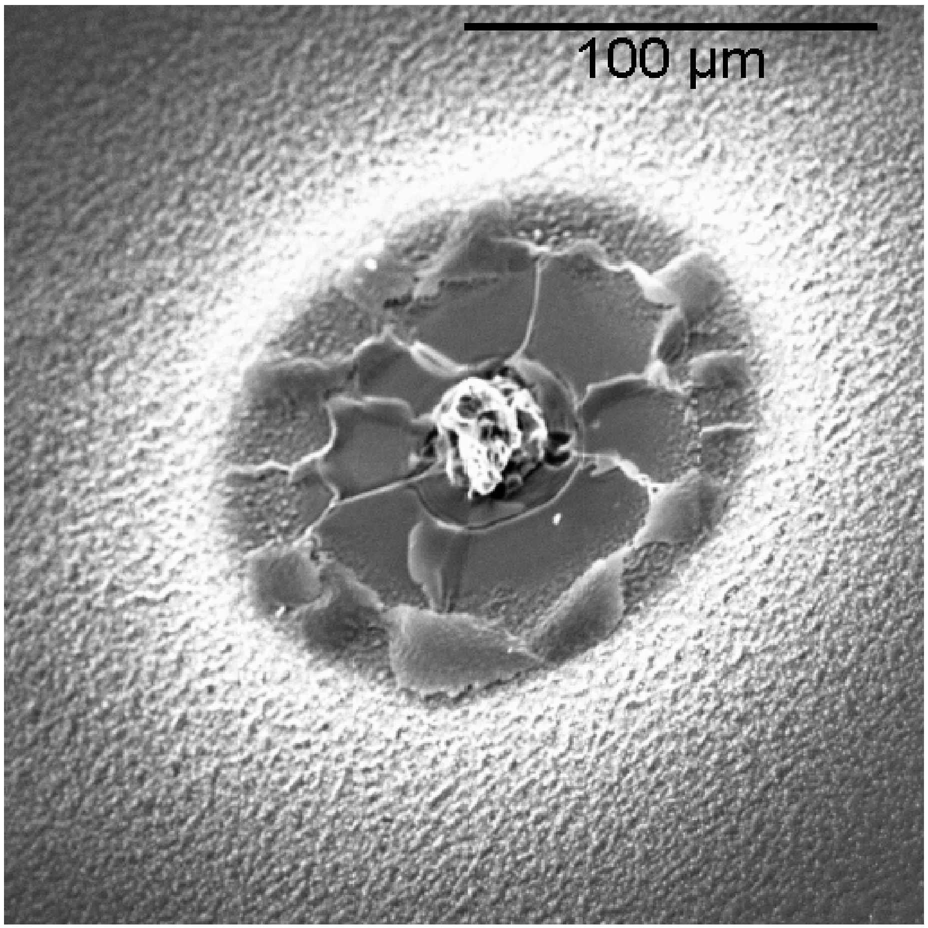
And More Growing Out of Iris 1

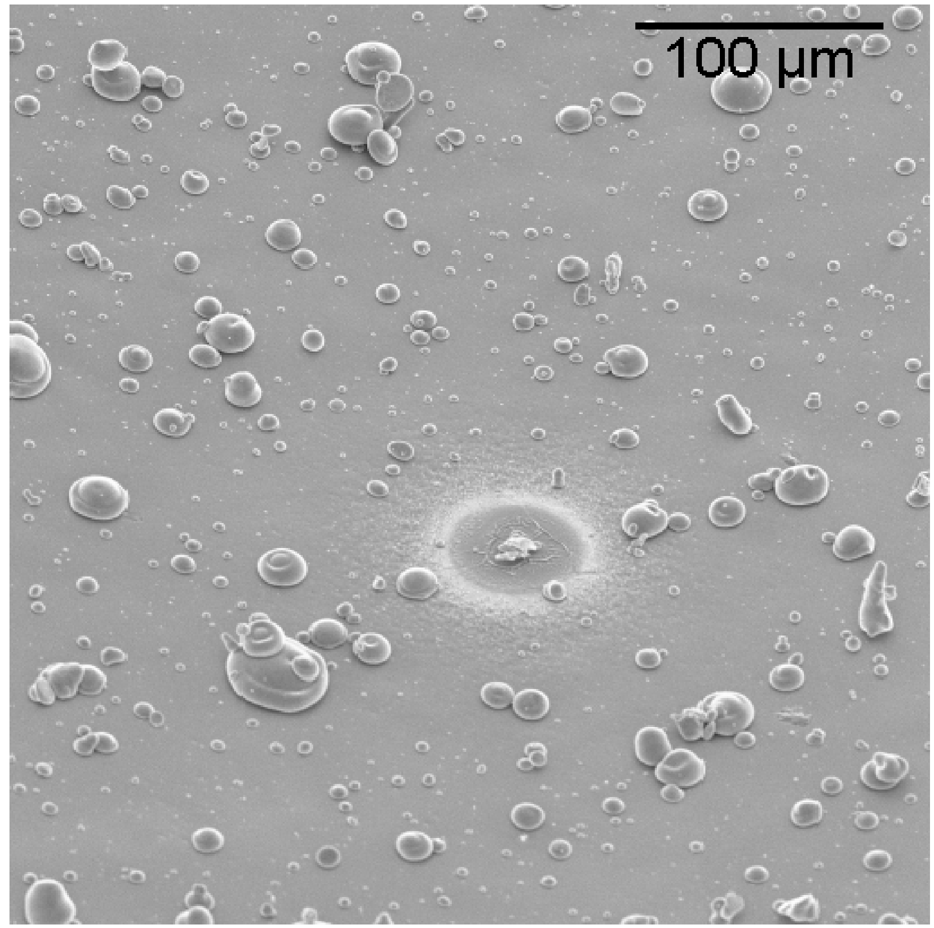


And a Triangular Patch on Iris 2 (Like Iris 7 in First Run) – Also see voids (loose splatter ?)

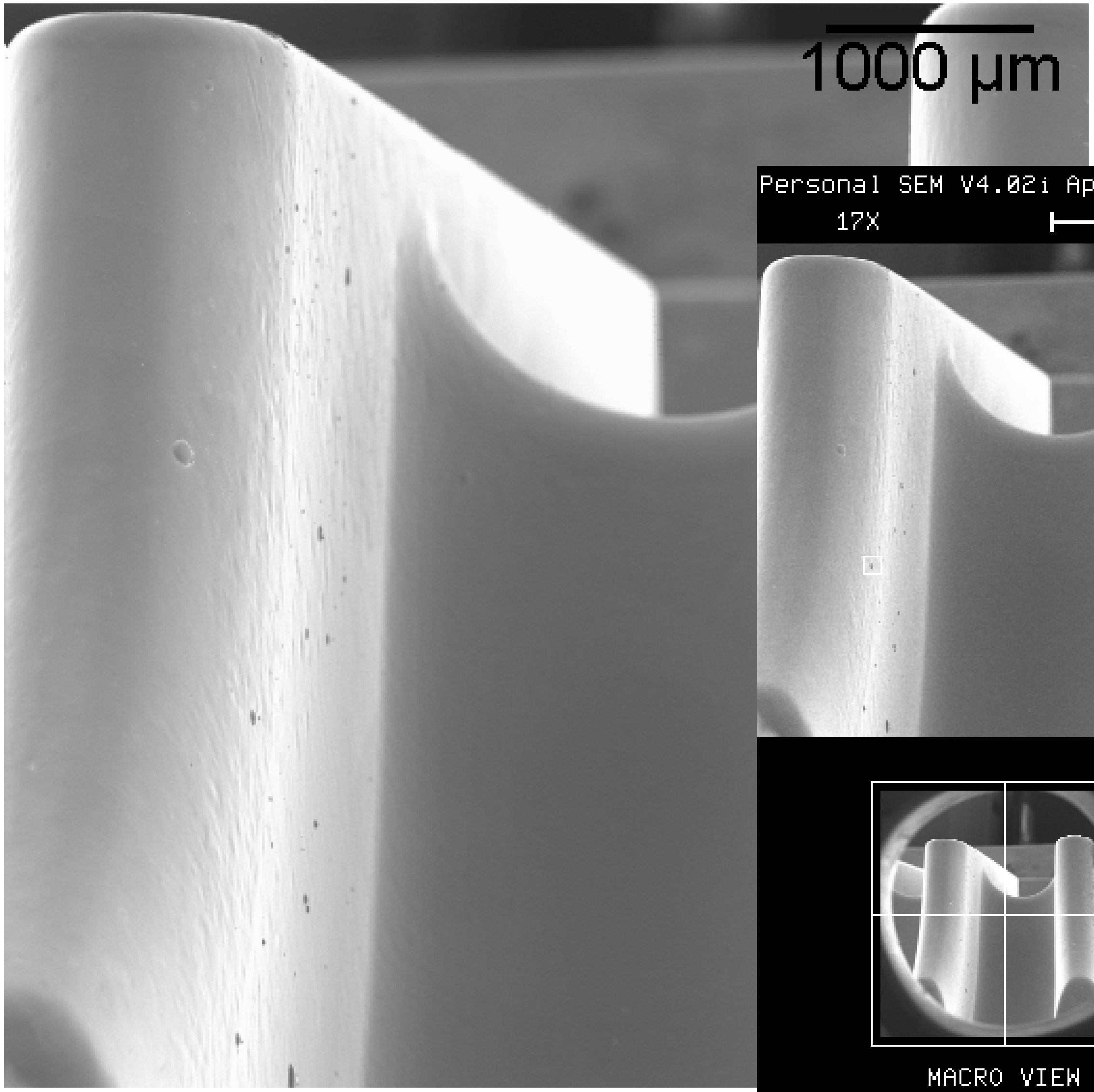


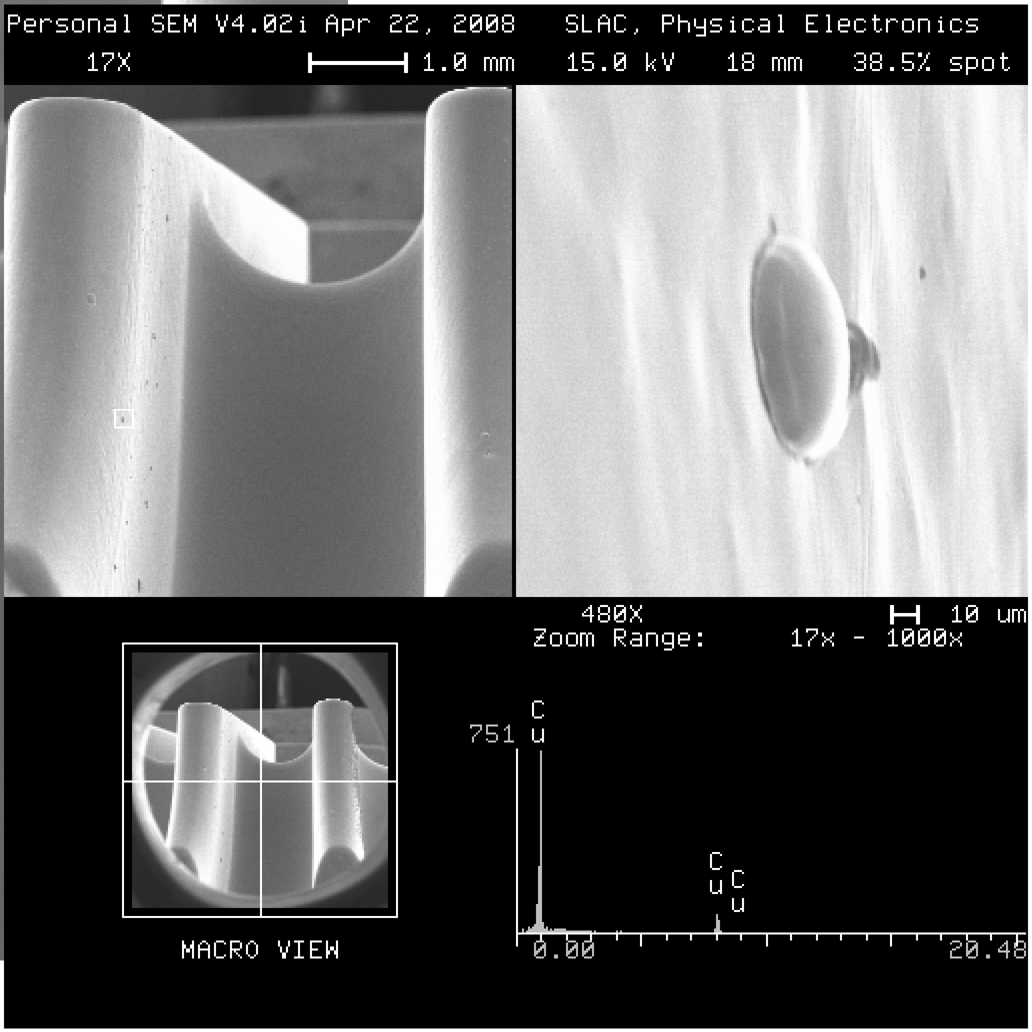
Interesting Particle and Splatter on Cell Bottom



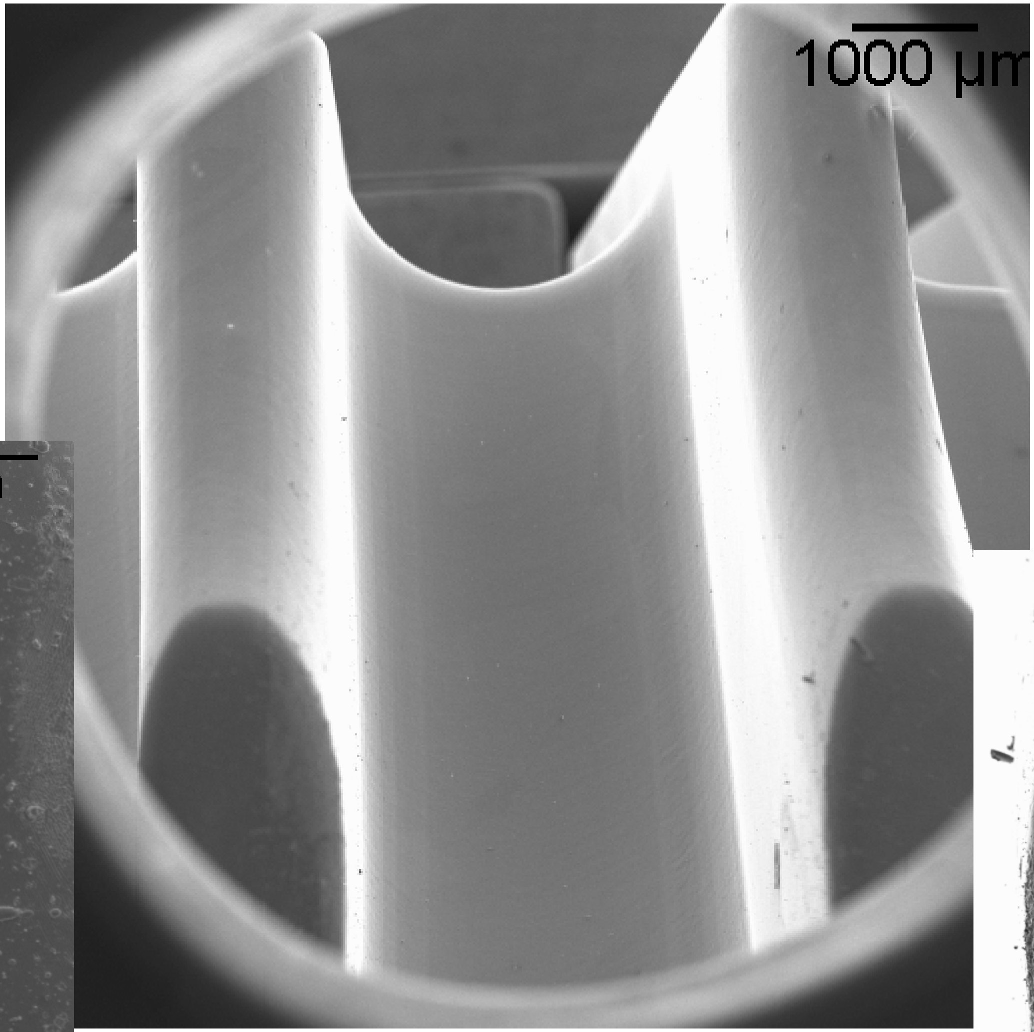


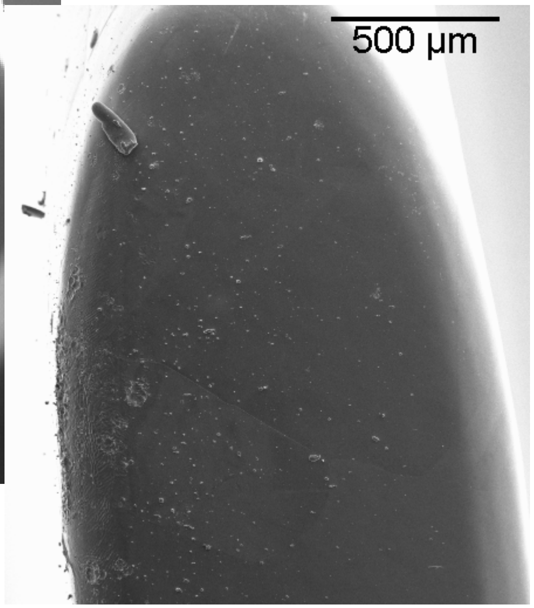
Iris 3 Appears to Have Long-Range Splatter

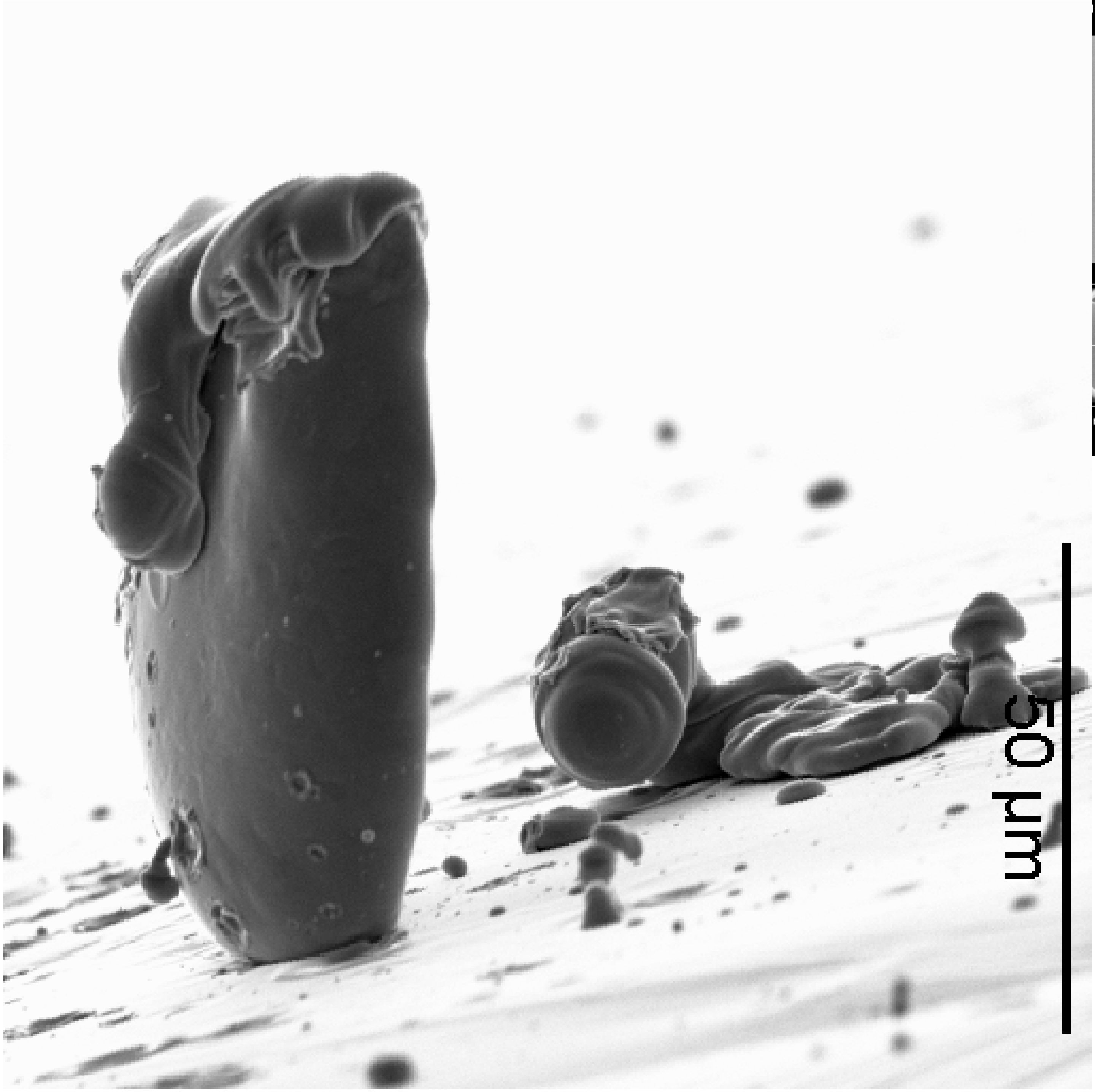


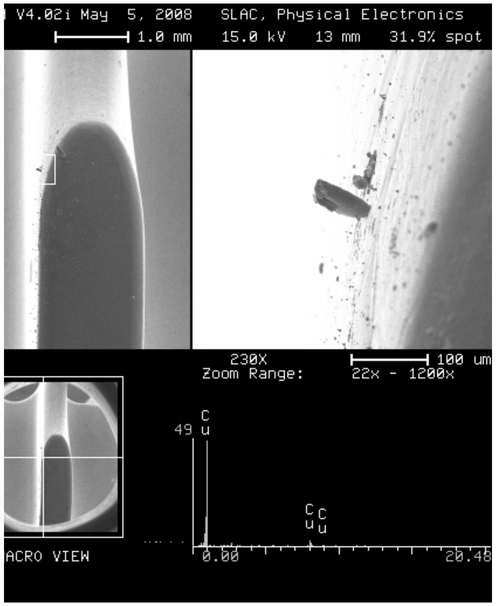


Iris 1 (right) and 2 (left) in Quadrant above the One Damaged



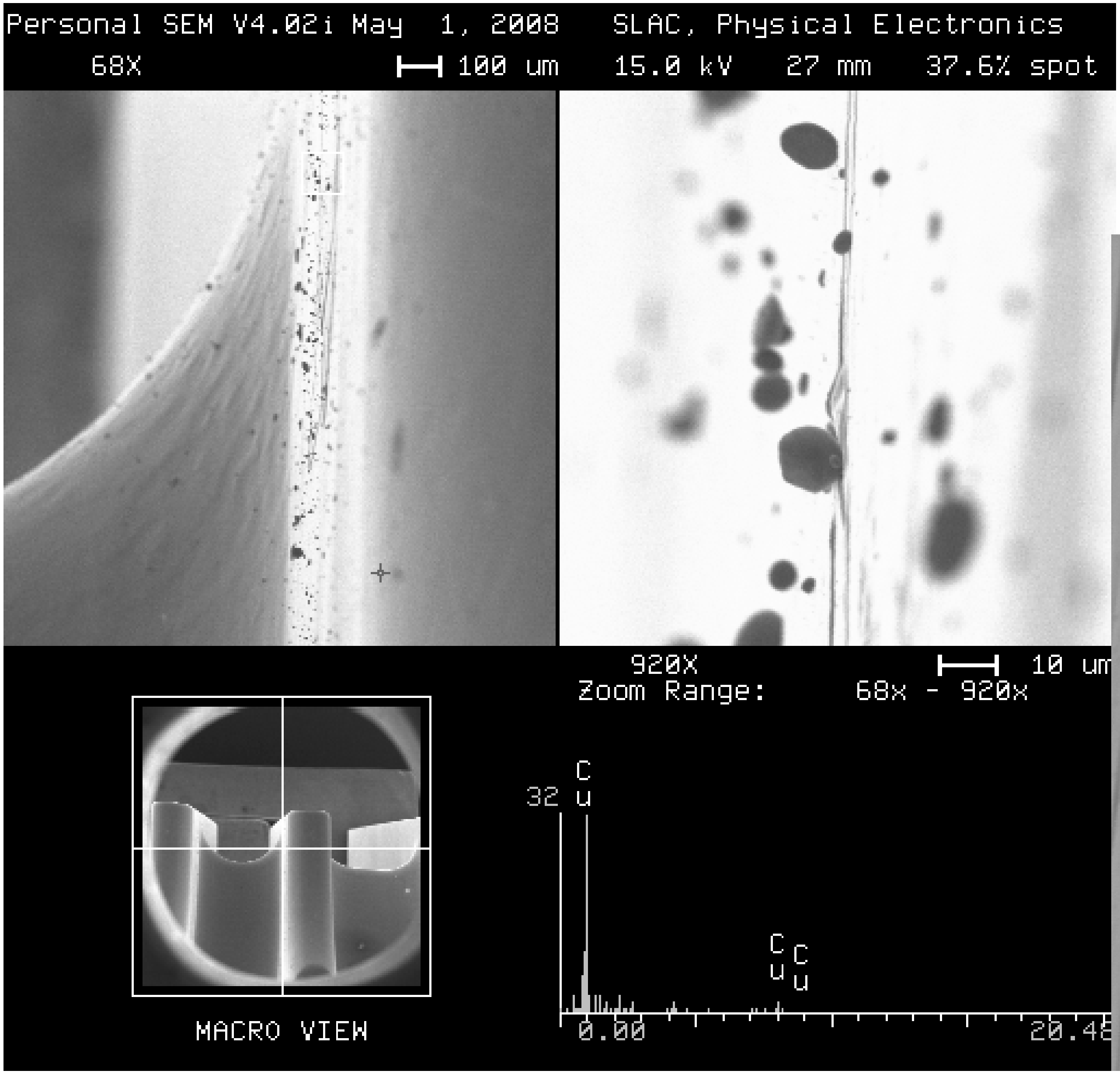


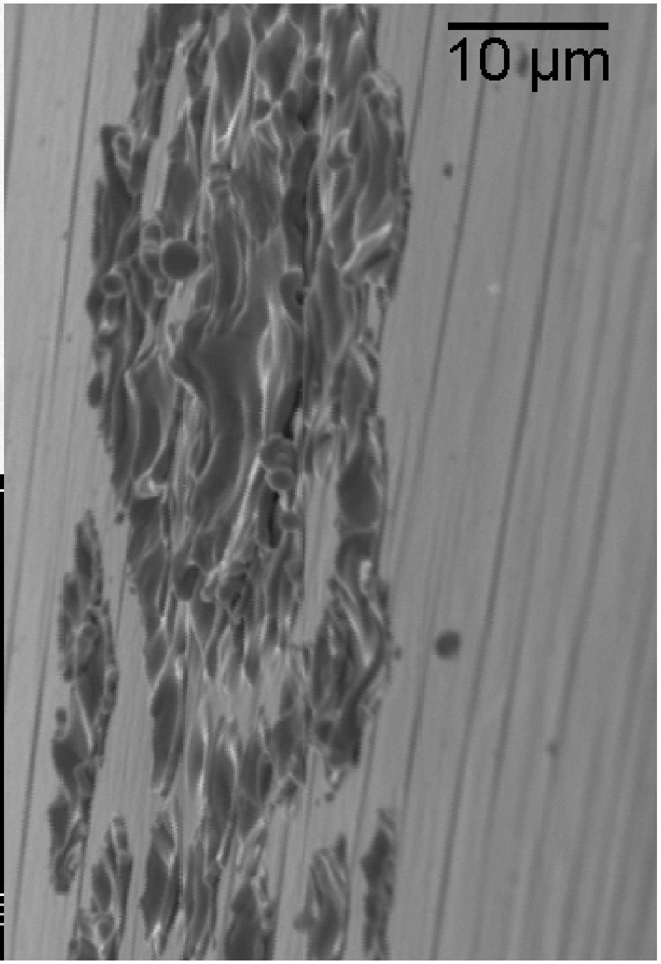




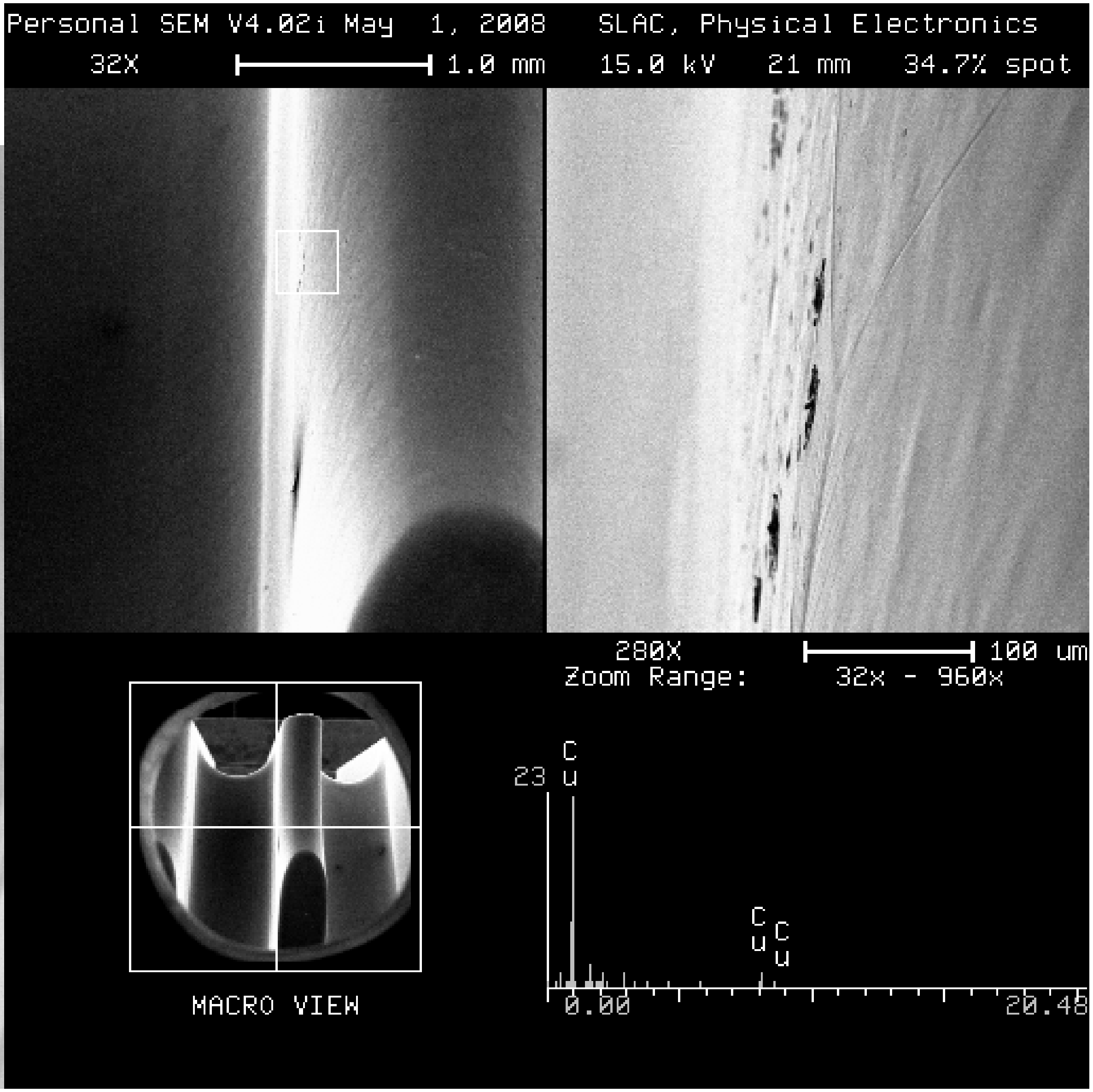
‘Stonehenge’
First Iris
above the
Damaged
Quadrant

Splatter on First Iris across from Damaged Quadrant

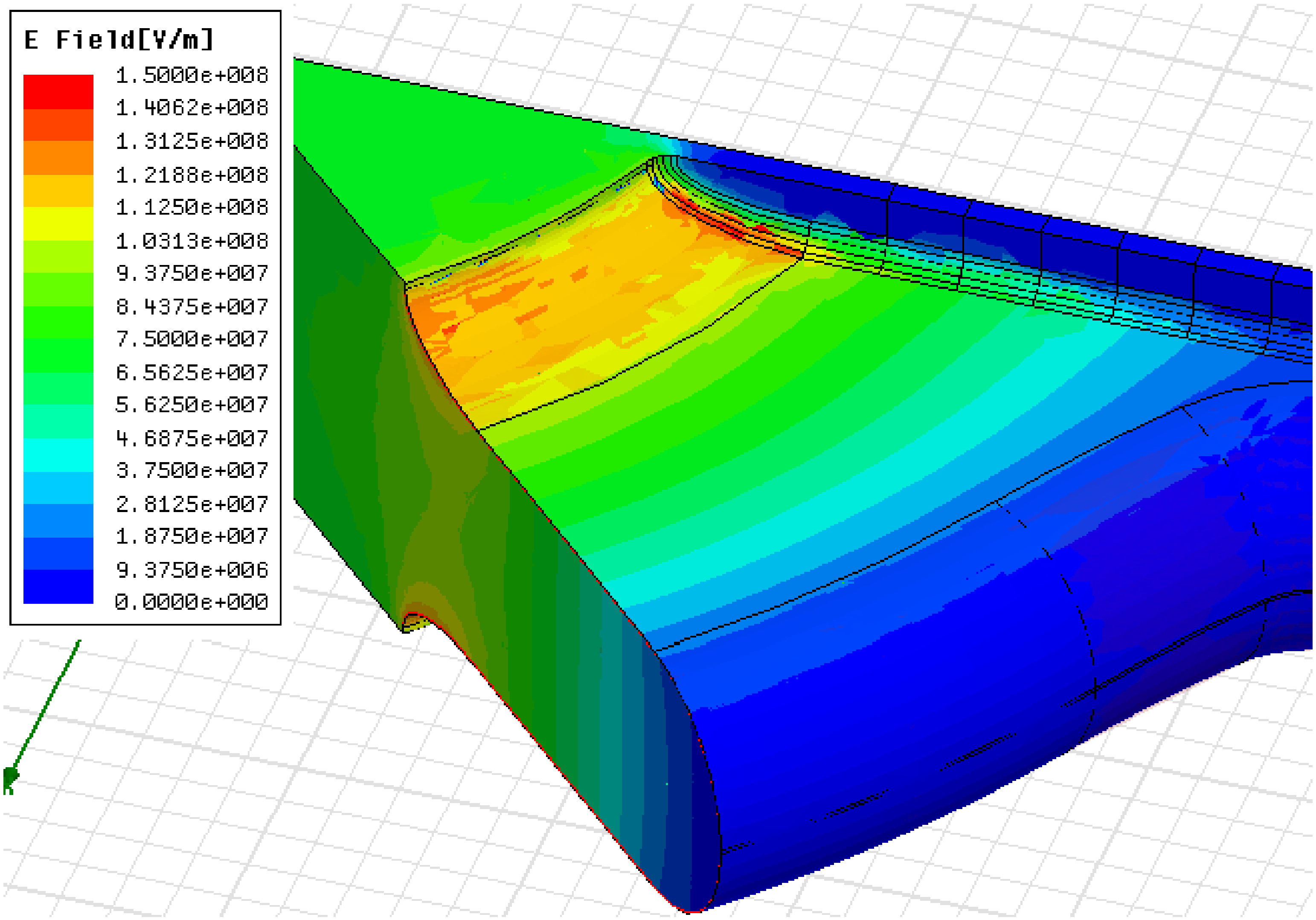




Splatter on Third Iris on Quadrant across from One Damaged – Different Source ?



HDX E Field



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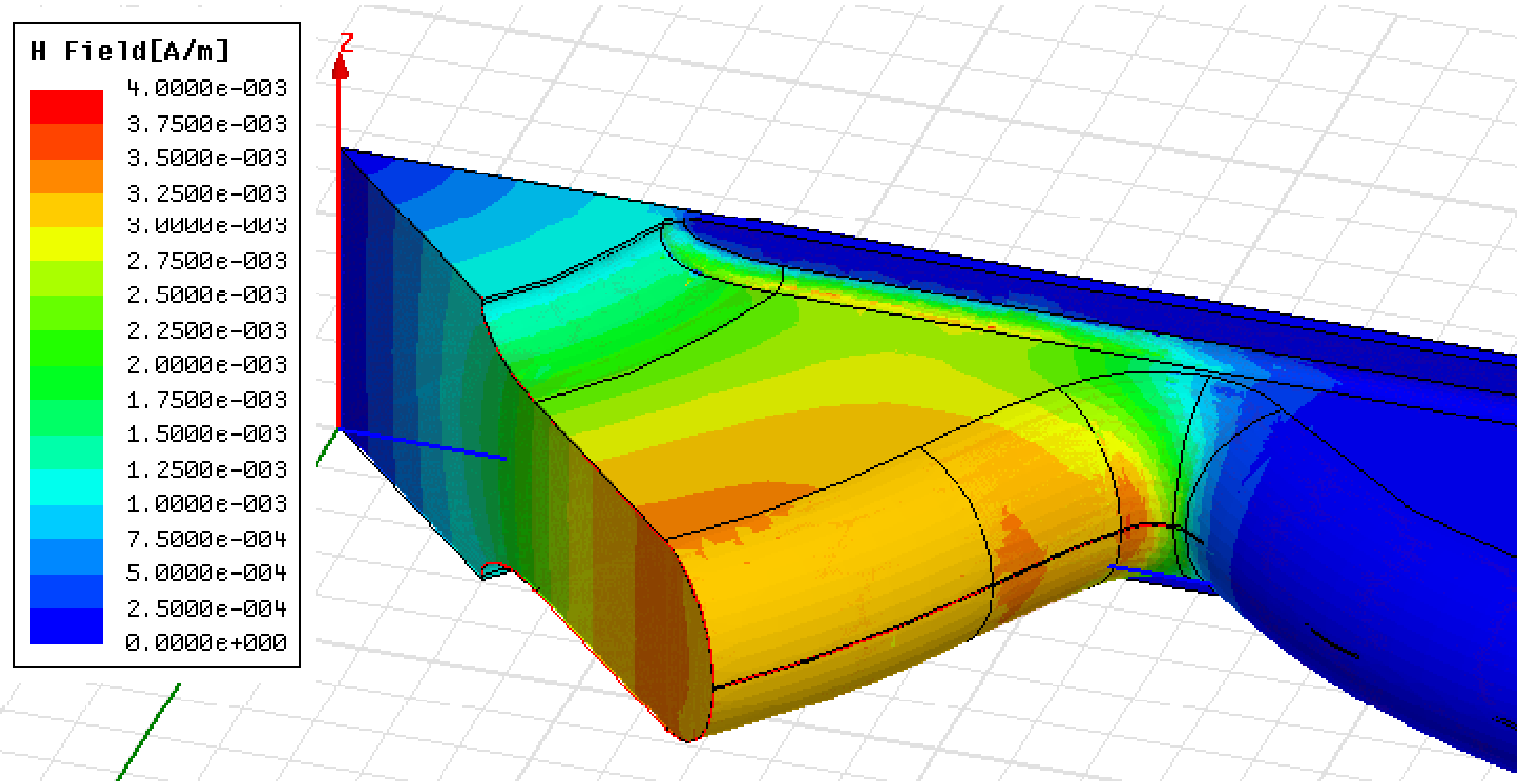
HDX H Field

Surface magnetic field distribution in HDX11 for 1V/m accelerating gradient



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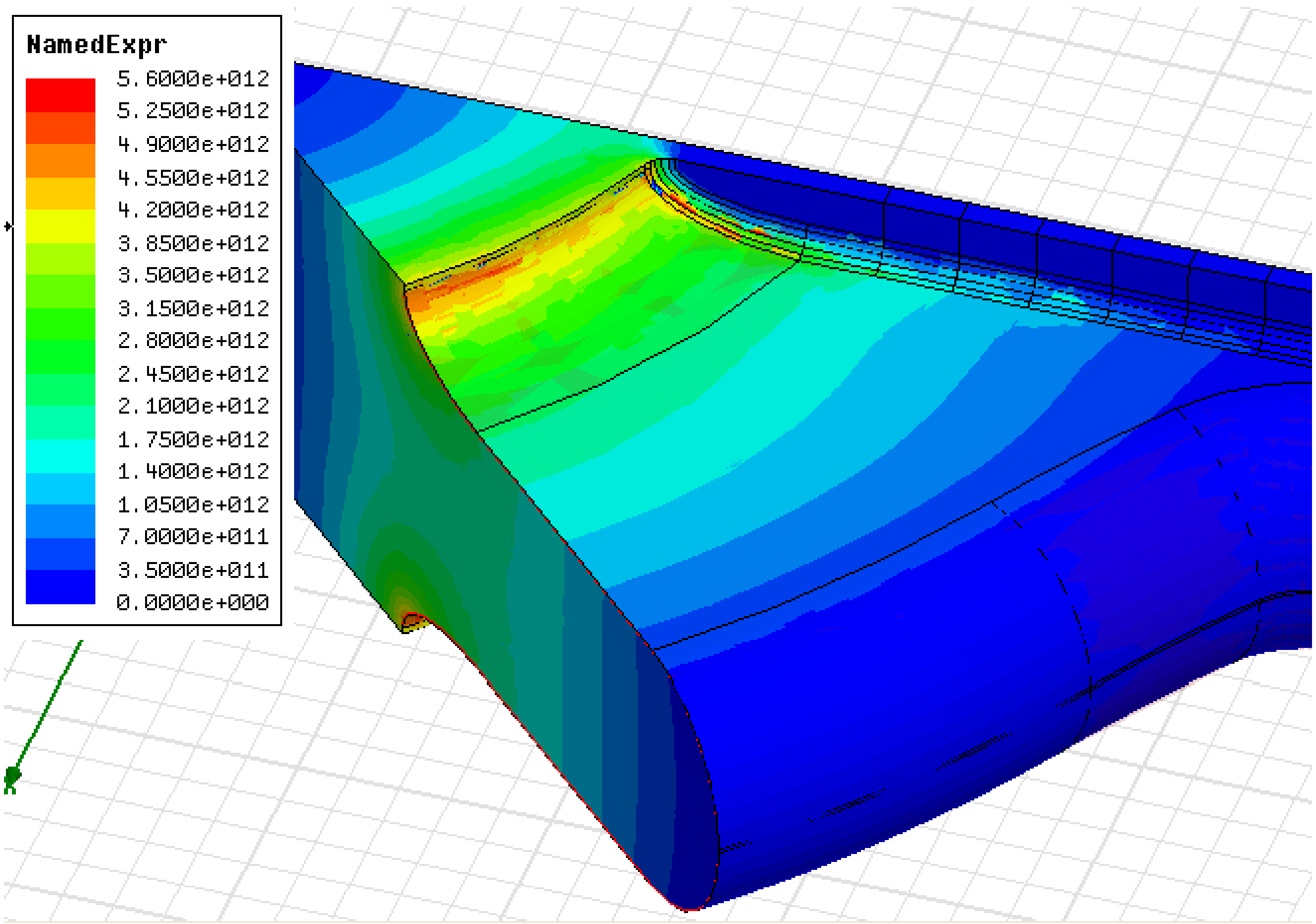
HDX Sc = Re{S} + 0.2 Im{S} Amplitude



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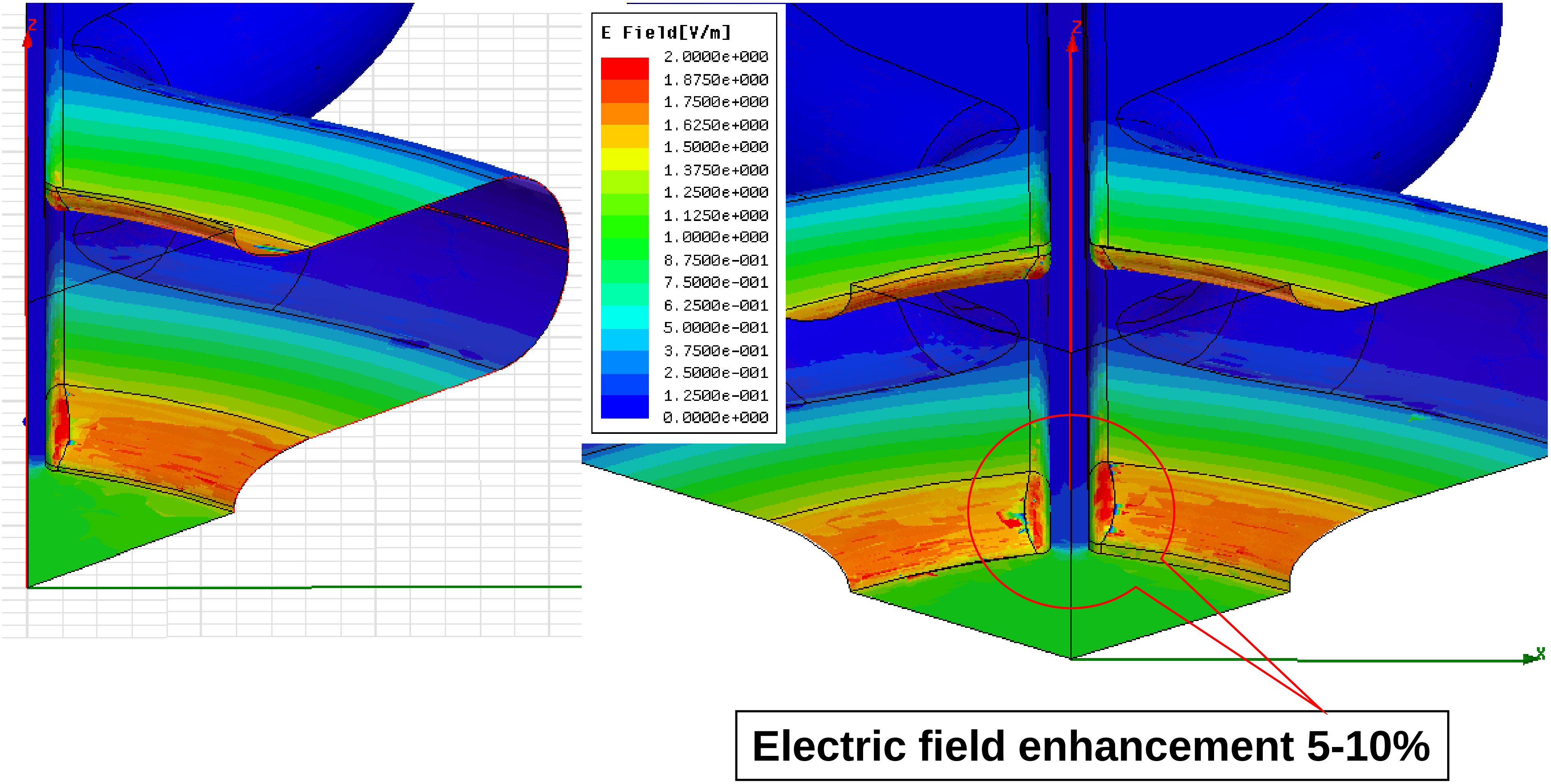
Electric Field with Quadrant Misalignment

140 micron Longitudinal Misalignment



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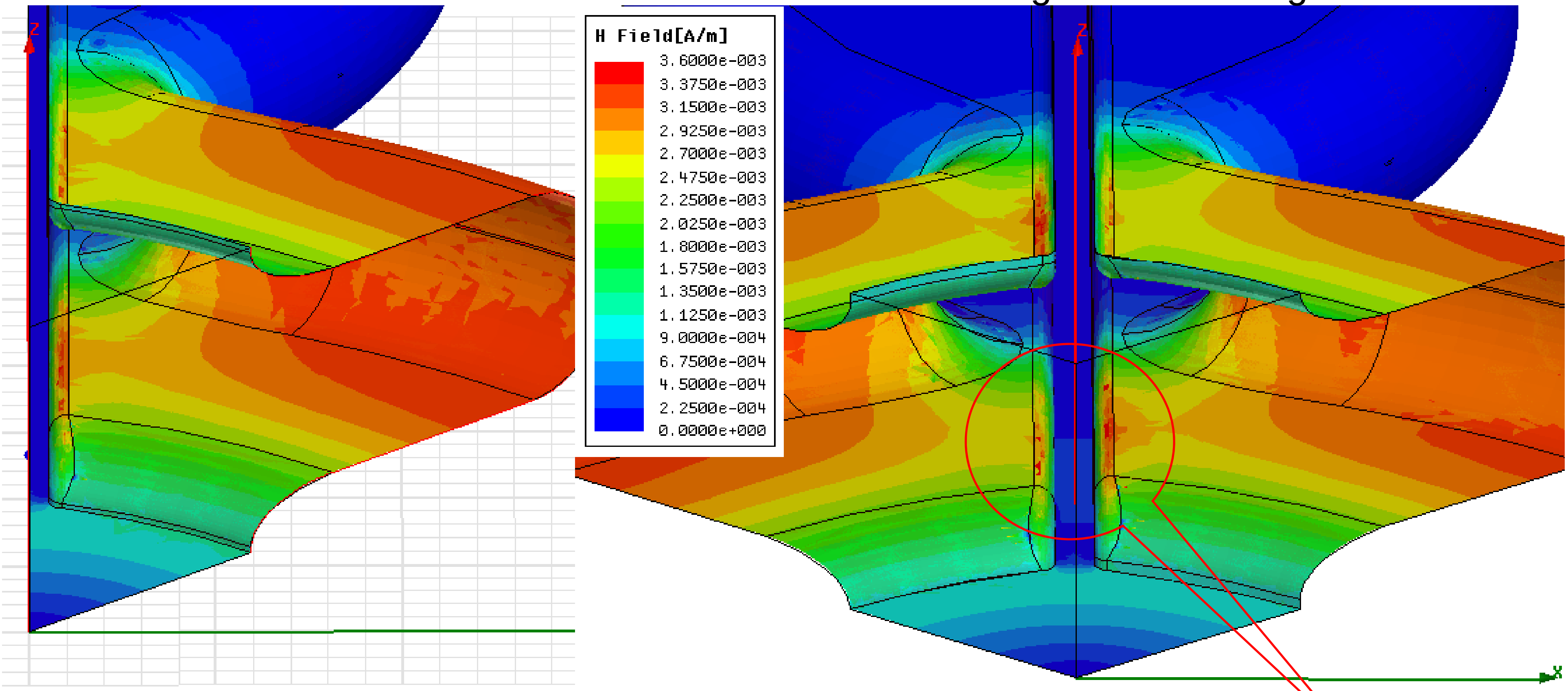
Magnetic Field with Quadrant Misalignment

140 micron Longitudinal Misalignment

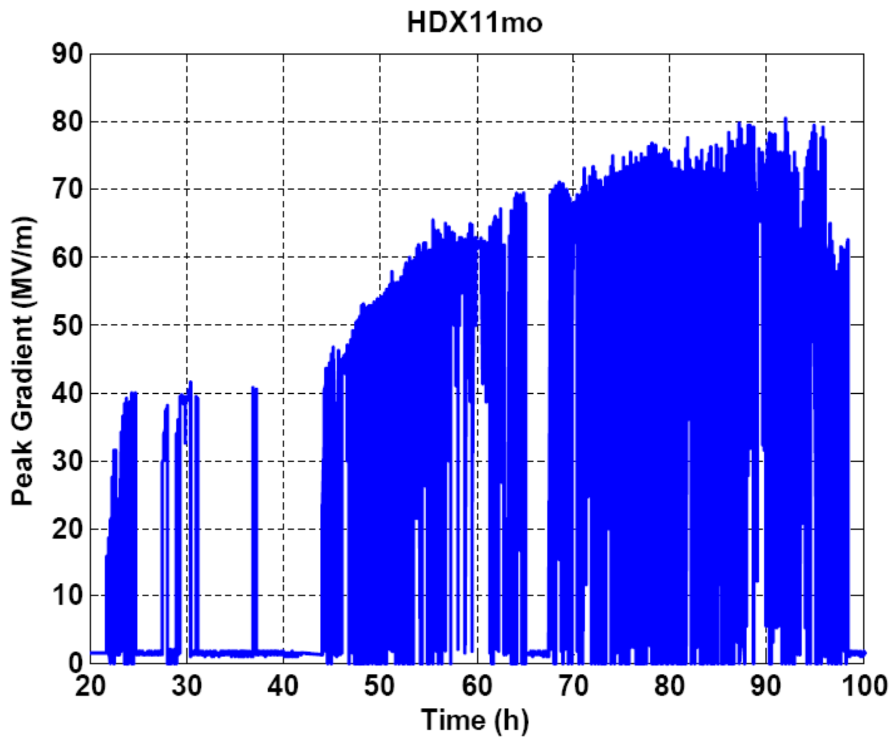


Magnetic field enhancement 5-10%

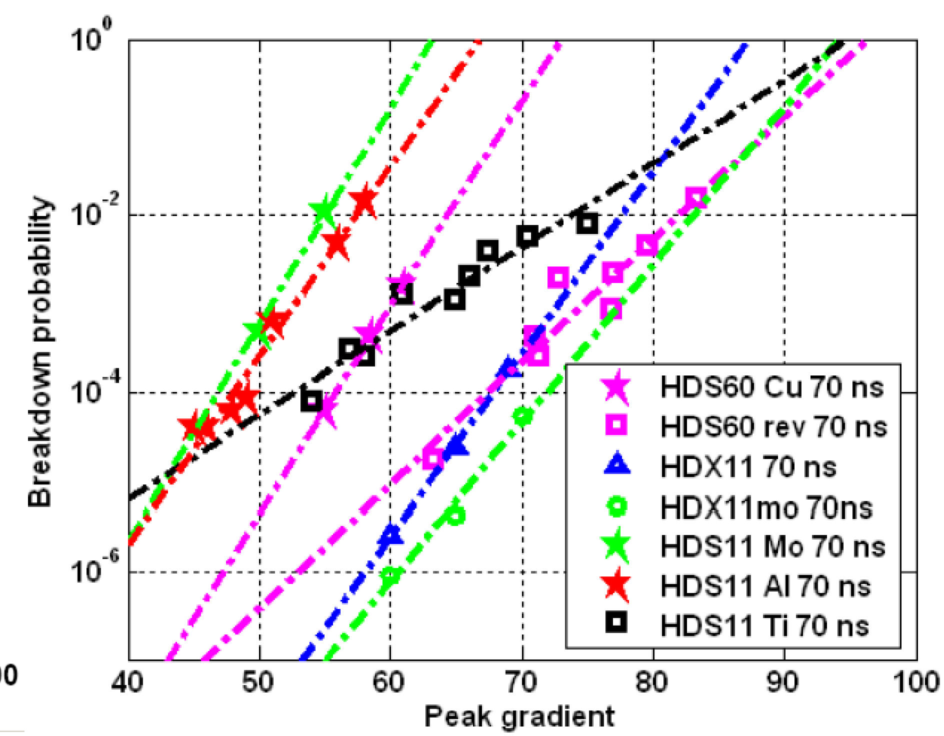
Other Quadrant Structures

A Moly HDX structure was also tested at NLCTA – it performed poorly (see green curves) as did 30 GHz Cu, Mo, Al, and Ti versions at CERN. The Mo version tested at SLAC was never autopsied, although a Mo clamped struture was and showed surface cracking. A 120 deg, slotted Cu X-band version will be tested next.

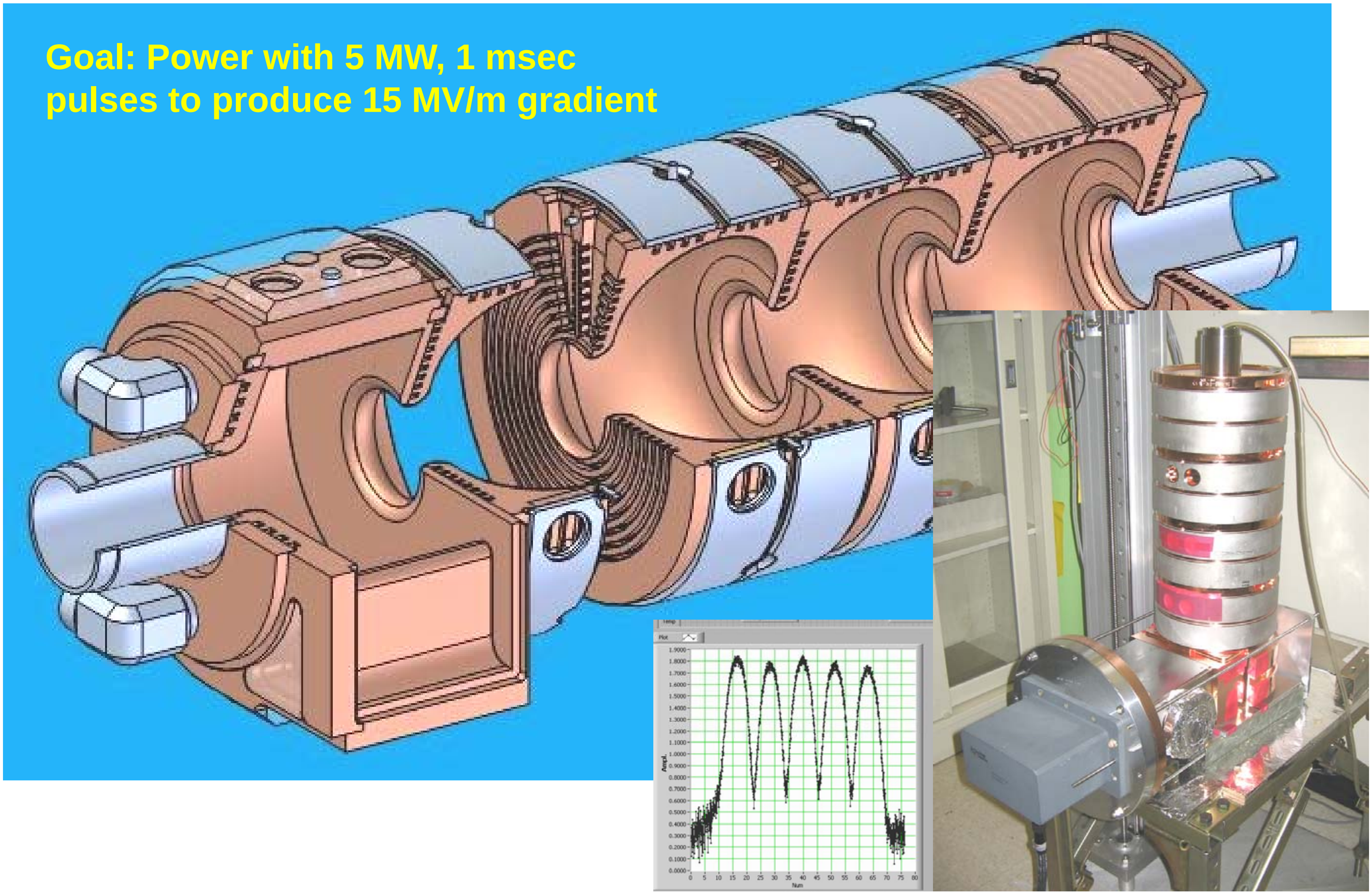
Processing at 40 ns



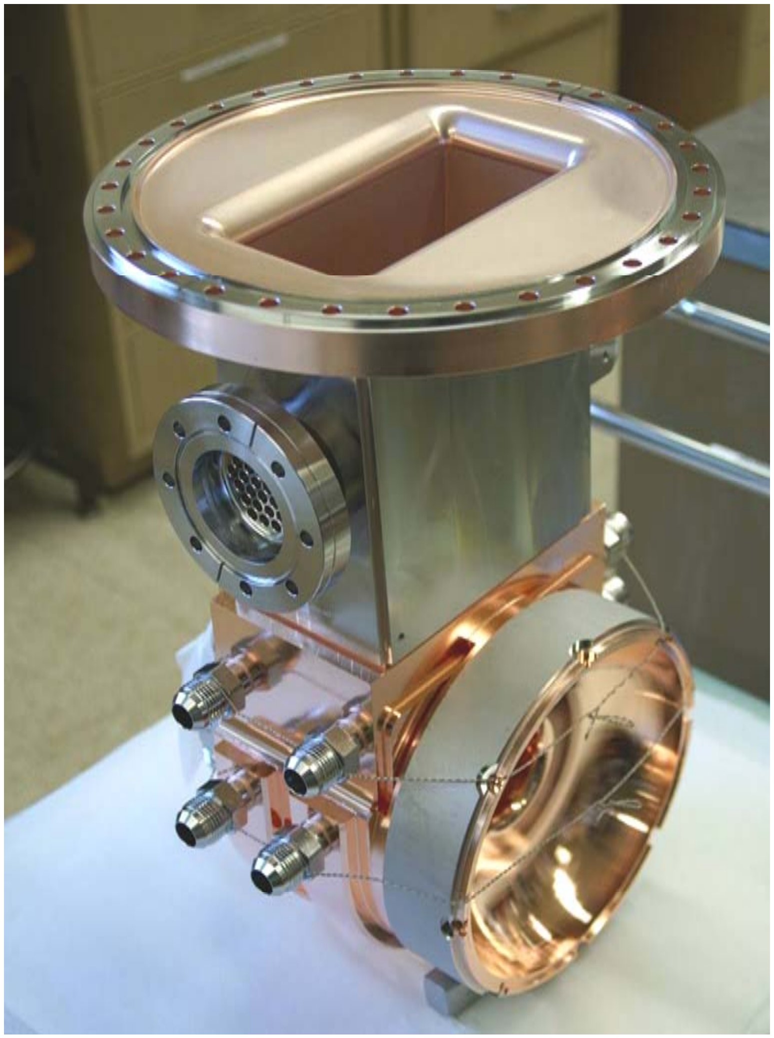
All HDS-type structures tested so far



ILC Positron Capture Cavity Prototype

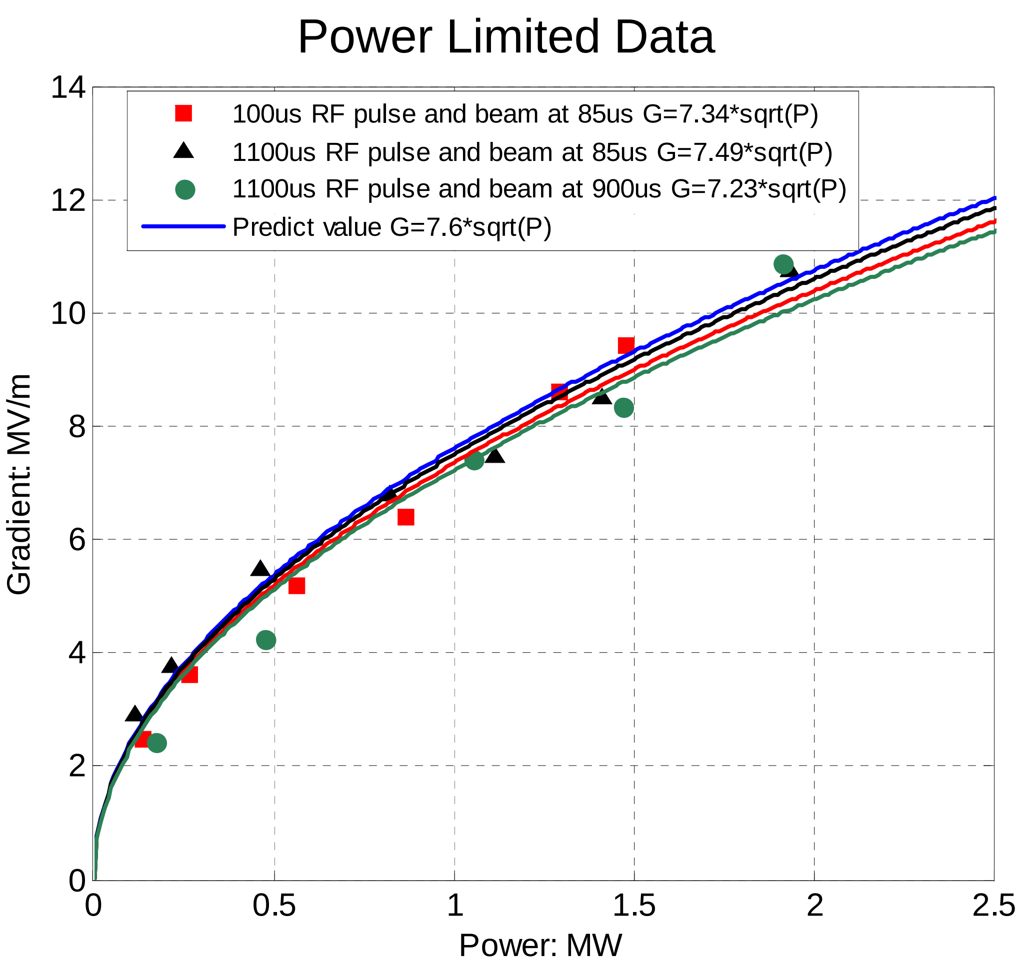


Brazed Coupler and Body Subassemblies Before Final Brazing

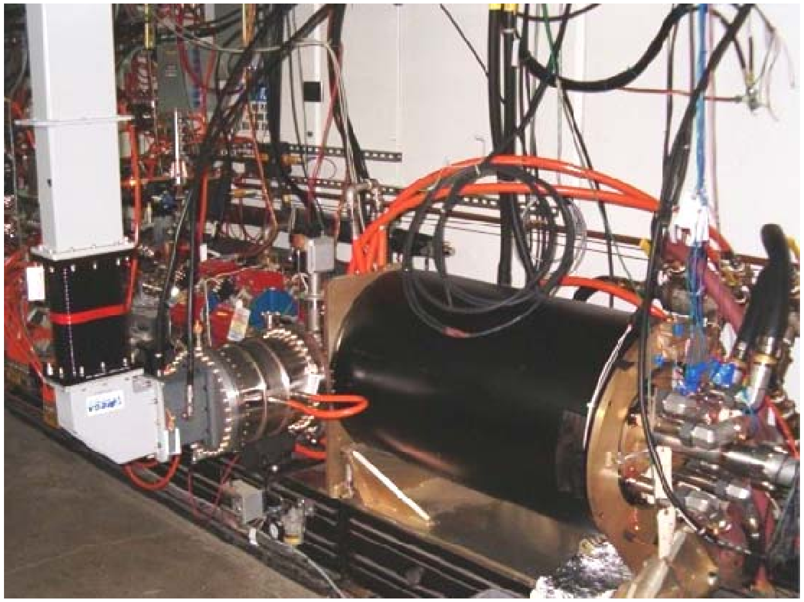


Cavity Gradient Measurements with Beam

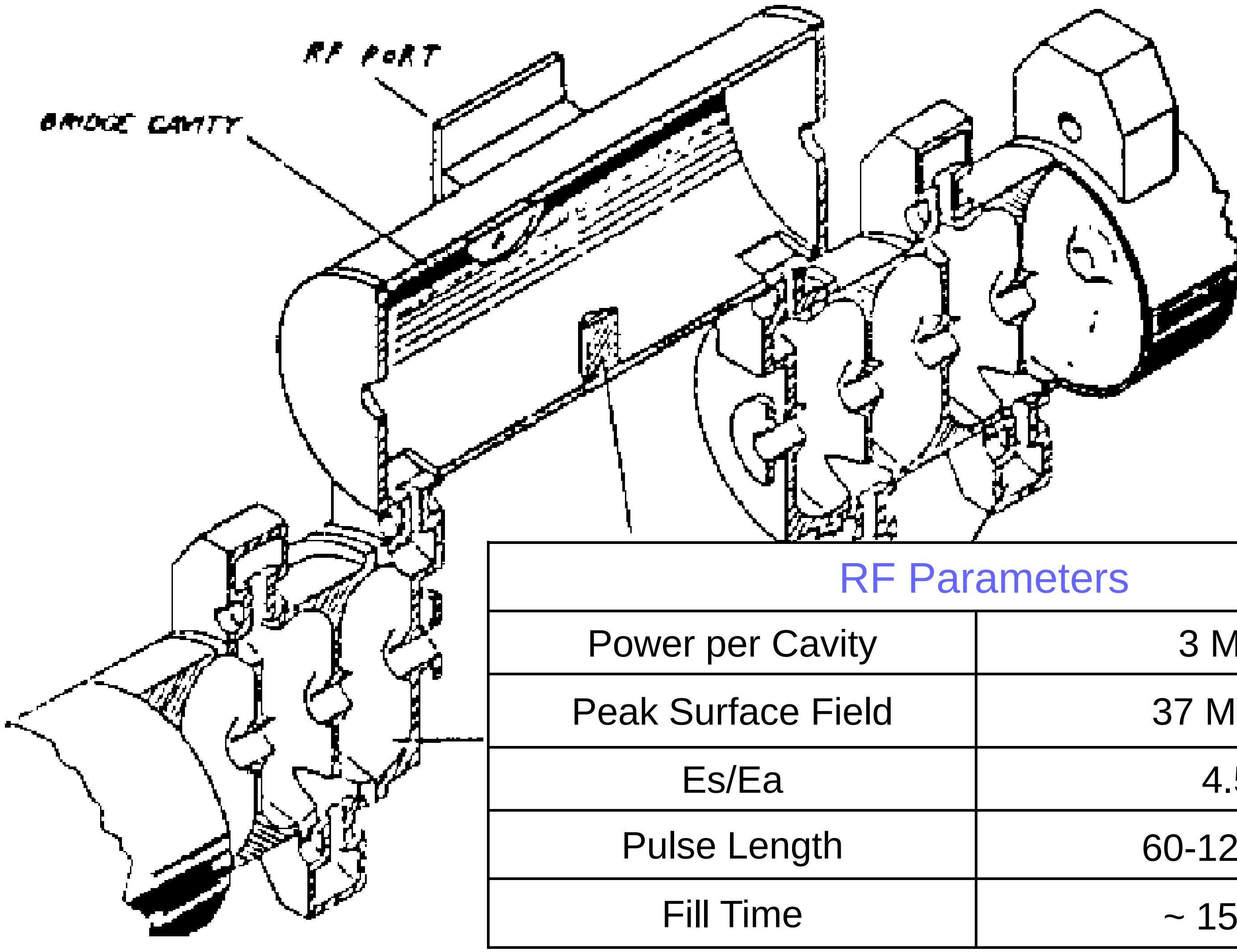
World's First L-Band (1.3 GHz) Cavity Operation in an X-band (11.4 GHz) Linac



Cavity in Solenoid Magnet at NLCTA

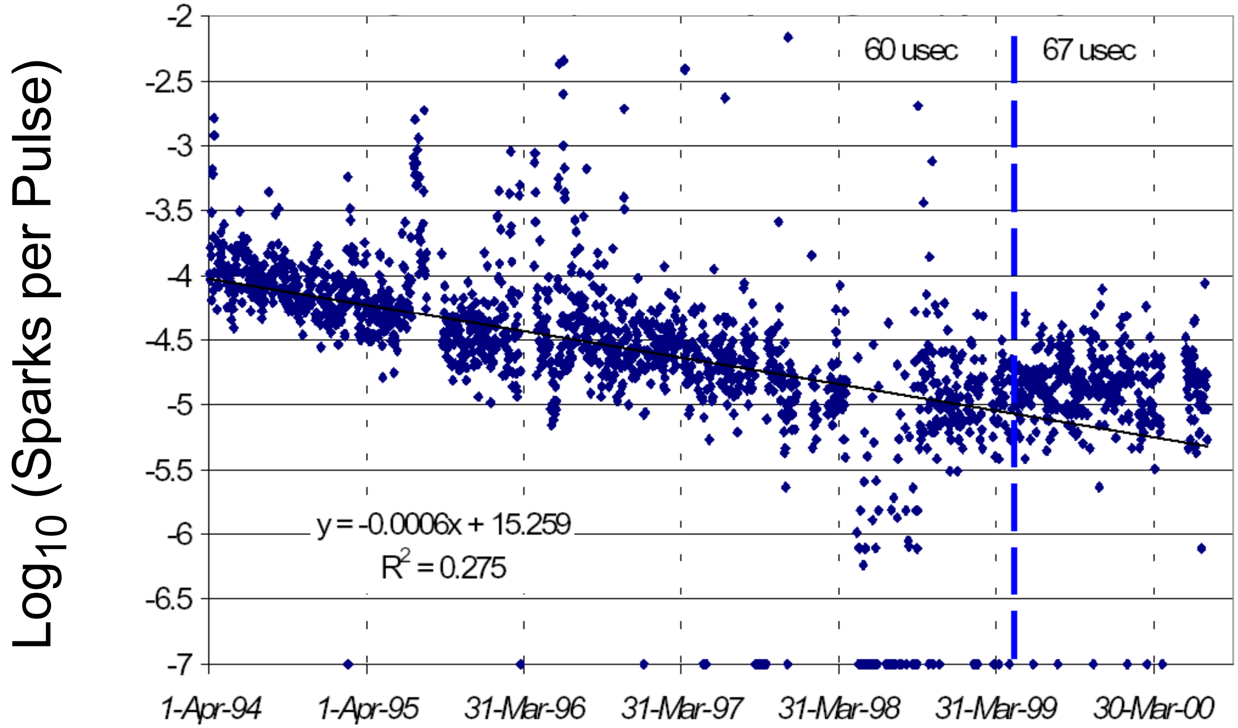


FNAL 805 MHz Side-Coupled SW ($\pi/2$) Cavities



RF Parameters	
Power per Cavity	3 MW
Peak Surface Field	37 MV/m
Es/Ea	4.5
Pulse Length	60-120 μs
Fill Time	~ 15 μs

Module 3 (64 Cells) Spark Rate Over ~ 5 Years at 1.3 Million Pulses/day



Also Observed That

Rate ~ $(E/Eo)^{19.5}$ for 33-60 MV/m surface fields (~ $(E/Eo)^{19}$ at X-band).

Rate ~ Pulse Length^4 (~ $\text{Length}^{3.3}$ at X-band).

Recover after vent to air in a few minutes to hours (same as X-band)

Summary

- Jury still out on the viability of quad structure design, which has many new features: slots, misalignments, small grains and milled surfaces. The 60 deg HDX structure appears to be limited by splatter propagation – not clear whether splatter due to breakdown or dark current heating + fields (will simulate this).
- Operating structures that are close to meeting CLIC requirements: T53, H75 and T18.
- An L-band cavity has been processed to 15 MV/m, where it is breakdown limited with long (1 ms) pulses. It shows similar breakdown characteristics as other lower frequency structures.