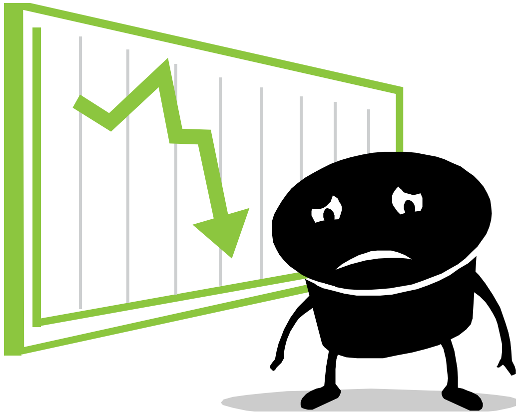
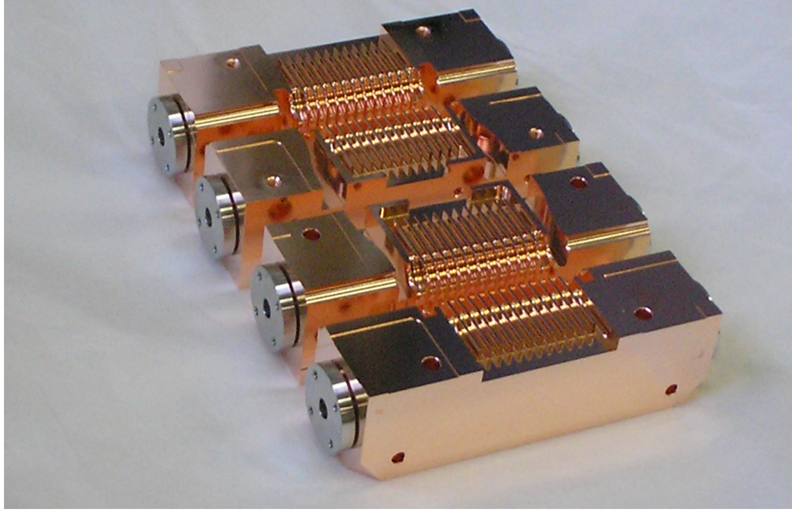


High Gradient Performance of CLIC-Designed Structures

Chris Adolphsen

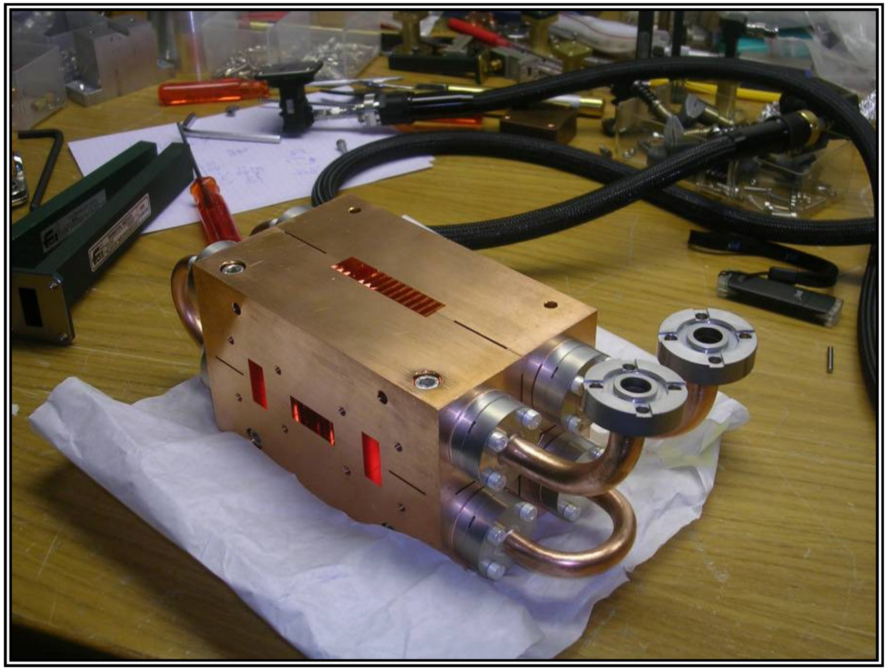
10/12/09

CLIC Quad Structure Tests



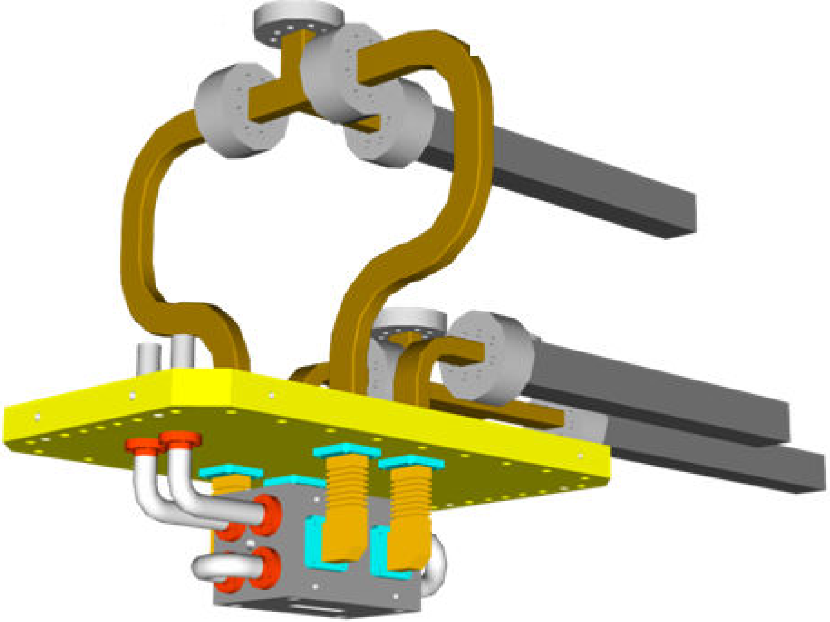
In NLCTA Beamline	Structure	Note	Performance
11/06 – 2/07	C11vg5Q16	First X-band Quad - Irises Slotted	Poor: 57 MV/m, 150 ns, 2e-5 BDR – grew whiskers on cell walls
2/08 - 4/08	C11vg5Q16 Redux	Refurbished	Initially good (105 MV/m, 50 ns,1e-5 BDR) but one cell degraded
4/07 – 10/07	C11vg5Q16-Mo	Molybdenum Version of Above	Poor: 60 MV/m, 70 ns, 1e-6 BDR
10/08 – 12/08	TD18vg2.6_Quad	No Iris Slots but WG Damping	Very Poor: would not process above 50 MV/m, 90ns – gas spike after BD
Test at KEK 08/09 - present	TD18vg2.6_Quad	50 μm Rounded Iris Edges	Very Poor: after 400 hours, only reached 60 MV/m with 50 ns pulses

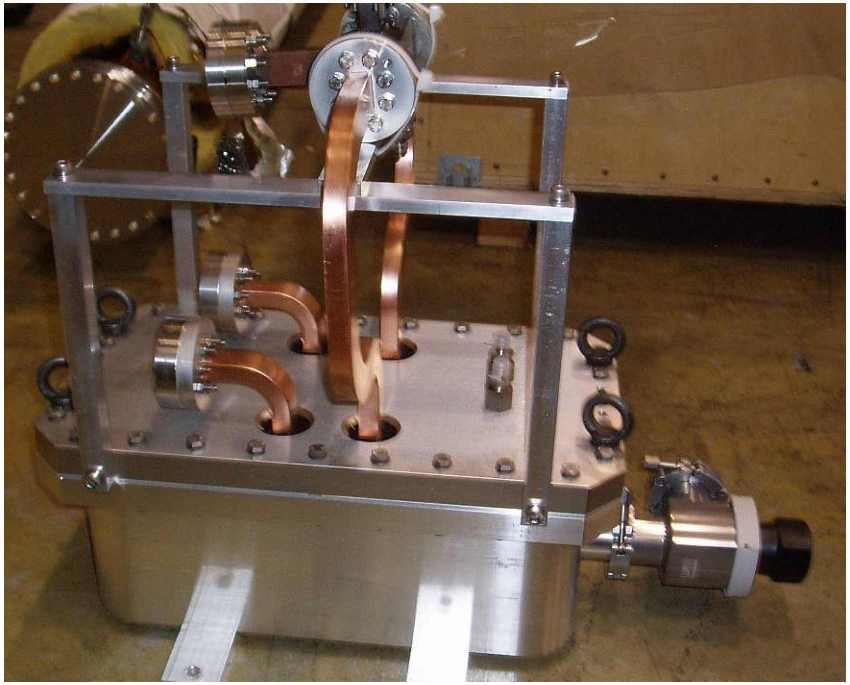
HDX11 X-Band Damped Quad Structure



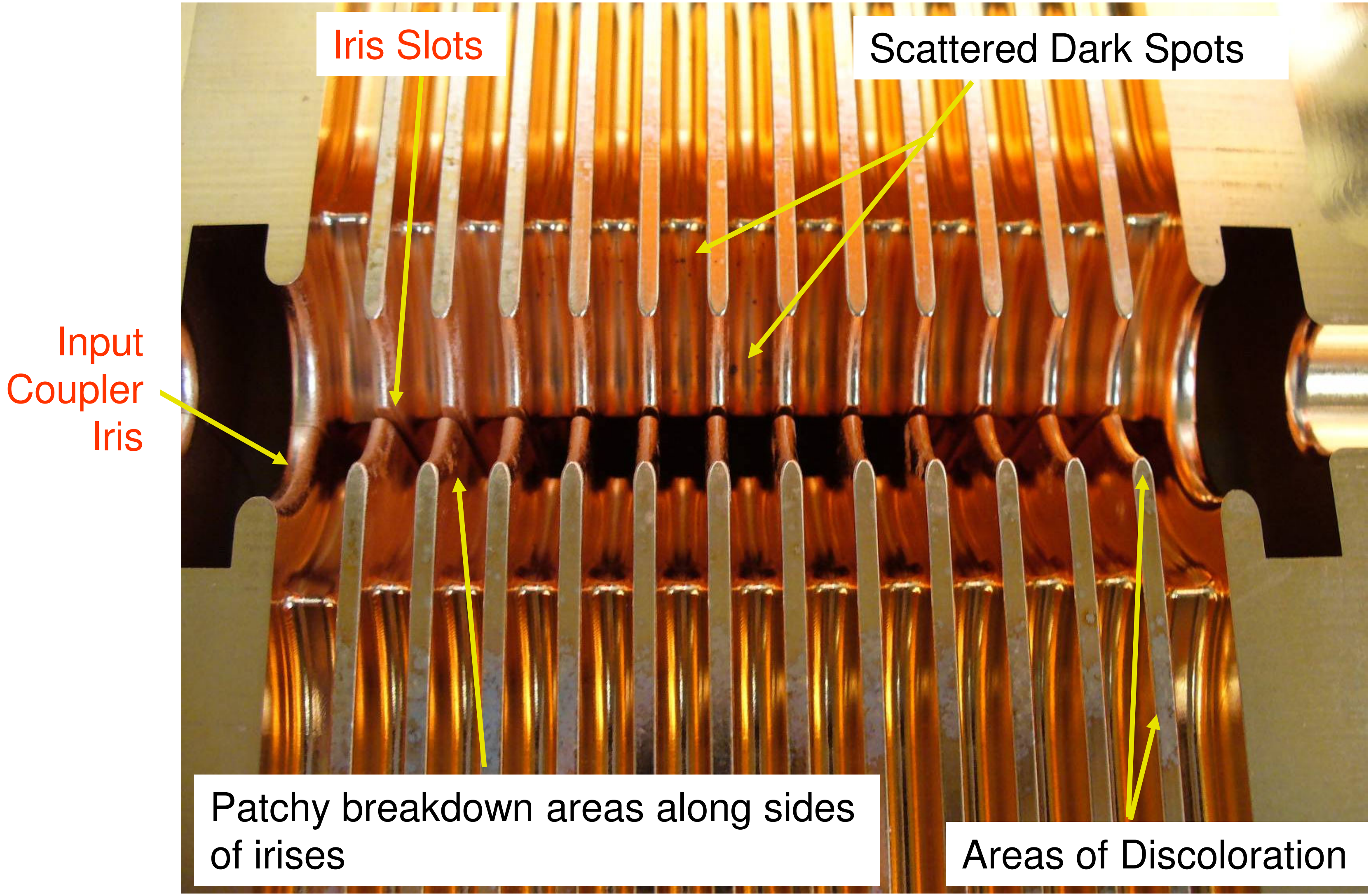
Number of Cells	11 + 2 Matching
a/λ	16 %
Phase per Cell	60 deg
Es/Ea	1.6
vg/c	5.1%
Iris Thickness	1.4 mm
Q	3760
r/Q	13 kOhm/m
For Eacc =	100 MV/m
Input Power	164 MW

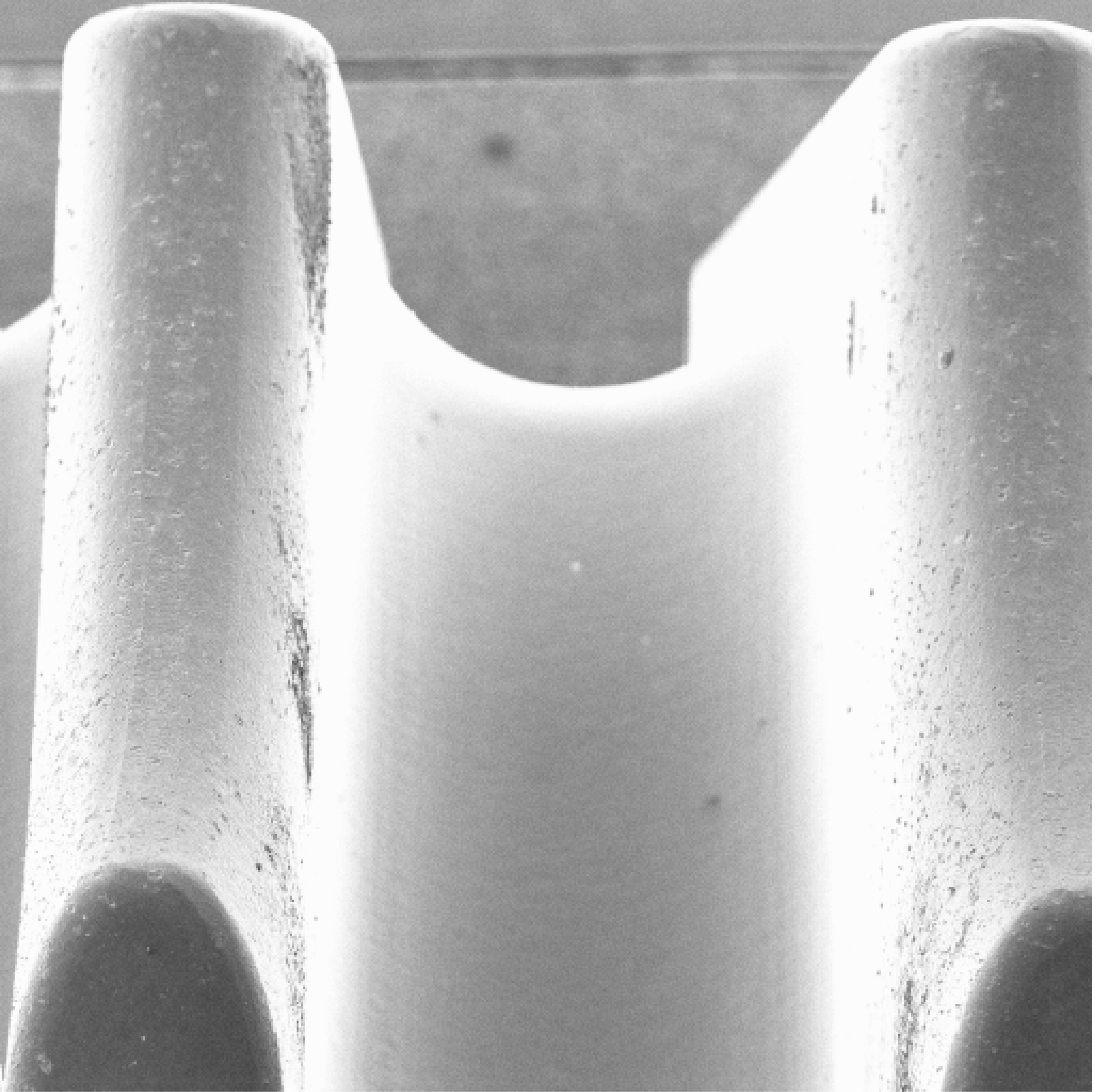
Structure Installed in a Vacuum Can for Testing





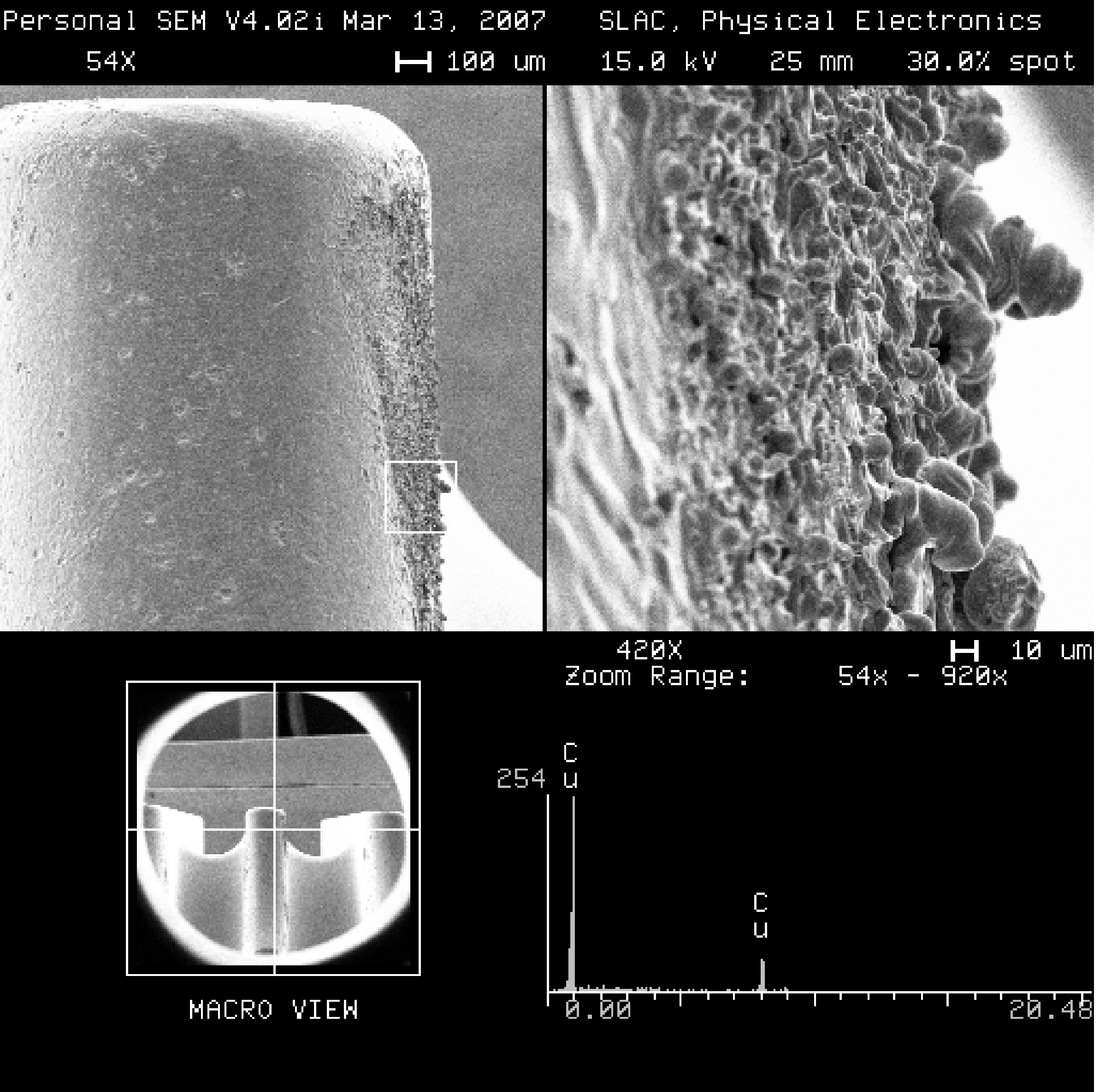
Visual/SEM Inspection after Processing





Iris 7&8
(Top Right)

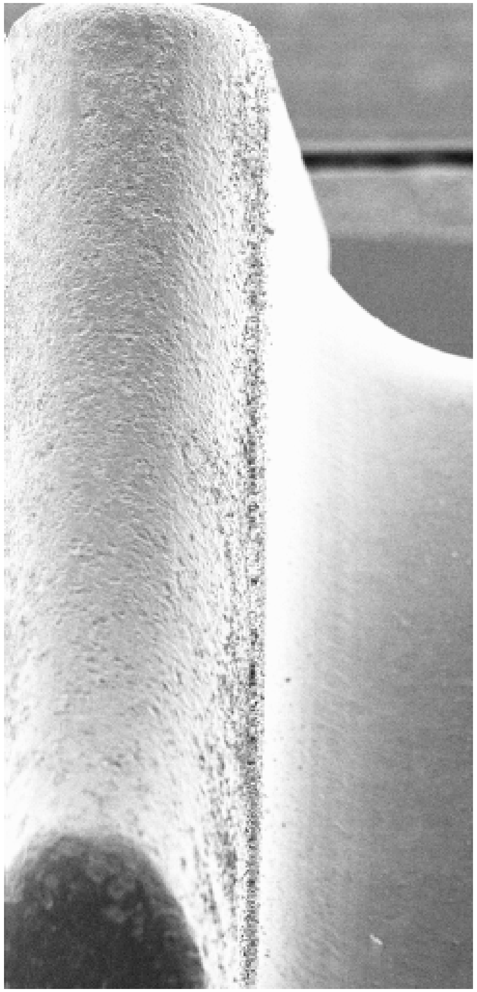
Iris 7
(Top Right)



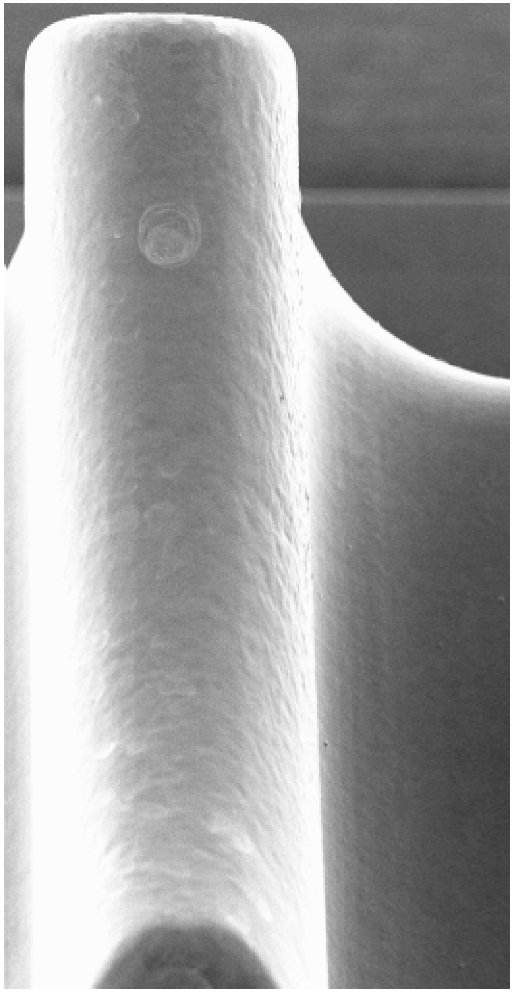
After First Run, Decided To

- 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

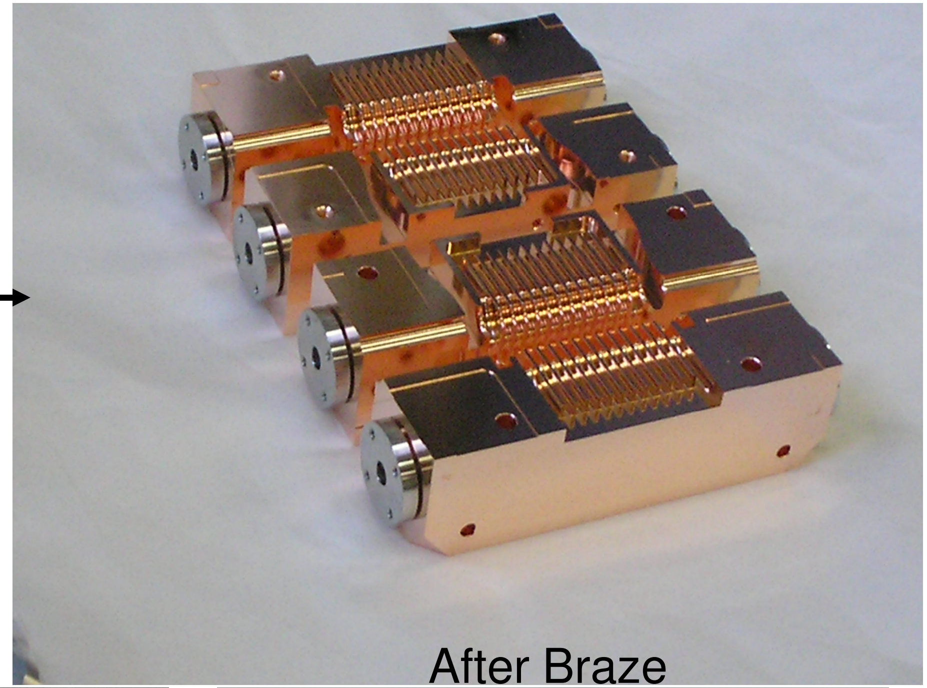


Before Electropolish

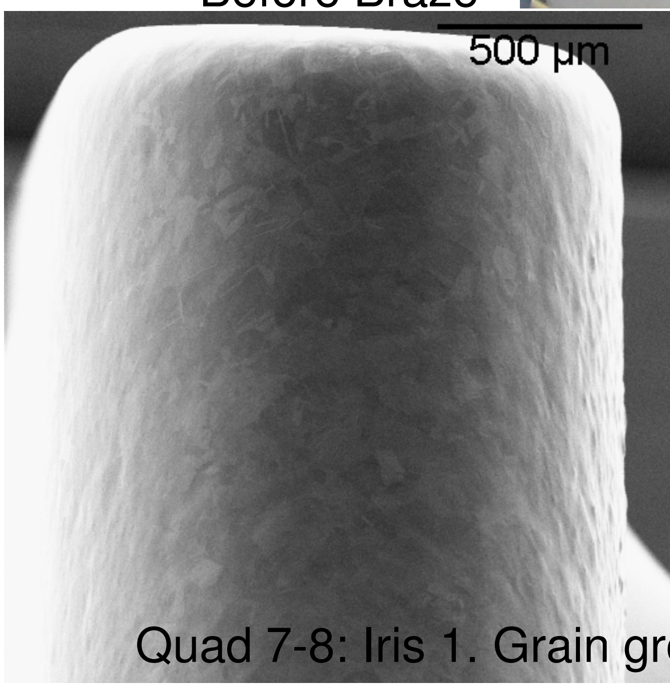


After 7-minute Electropolish

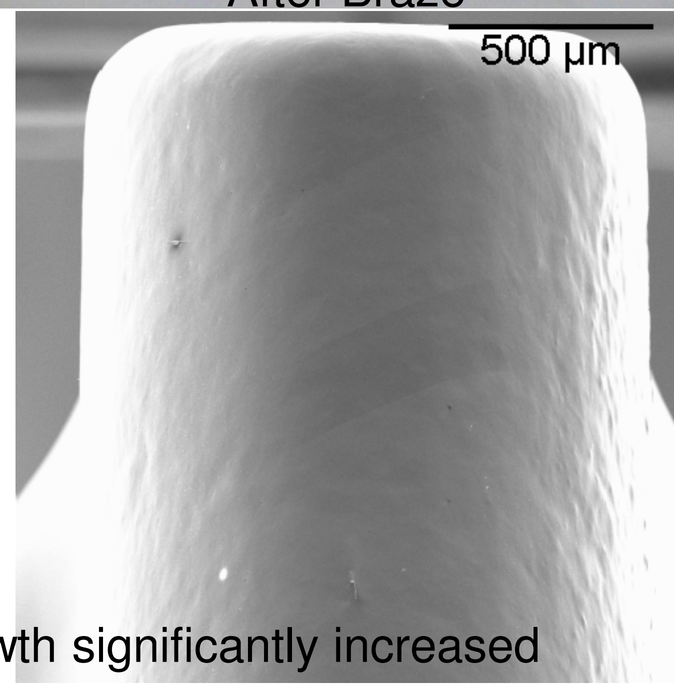
After Brazing on New Water Fittings



Before Braze

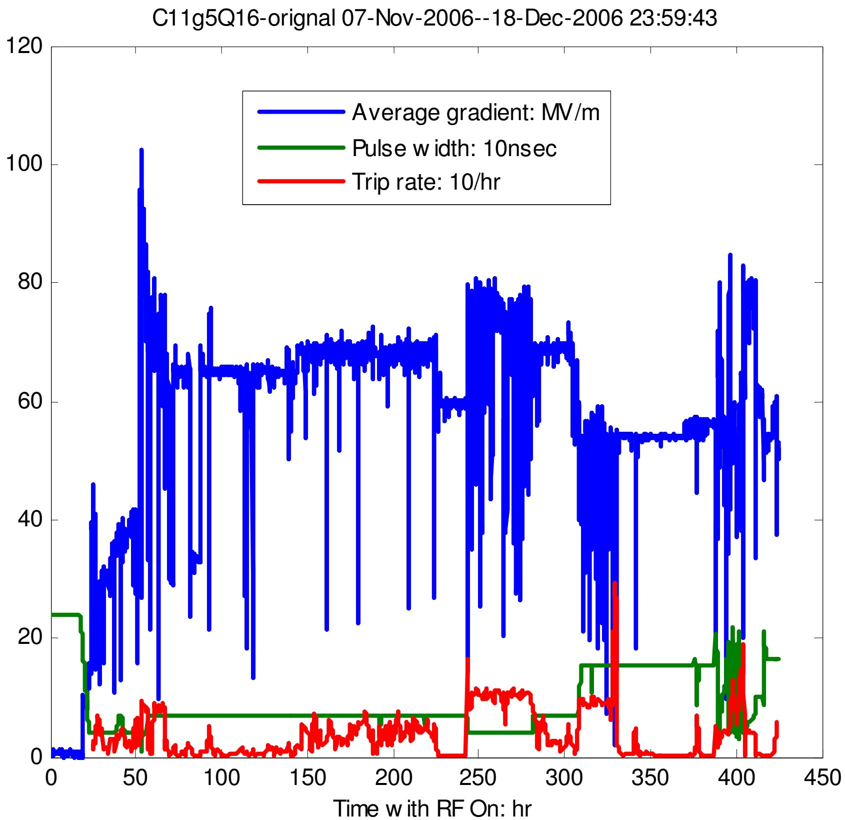


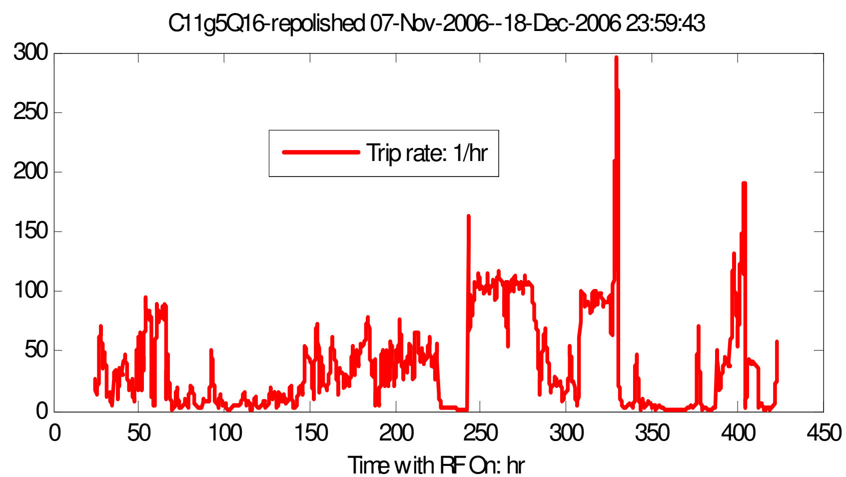
After Braze



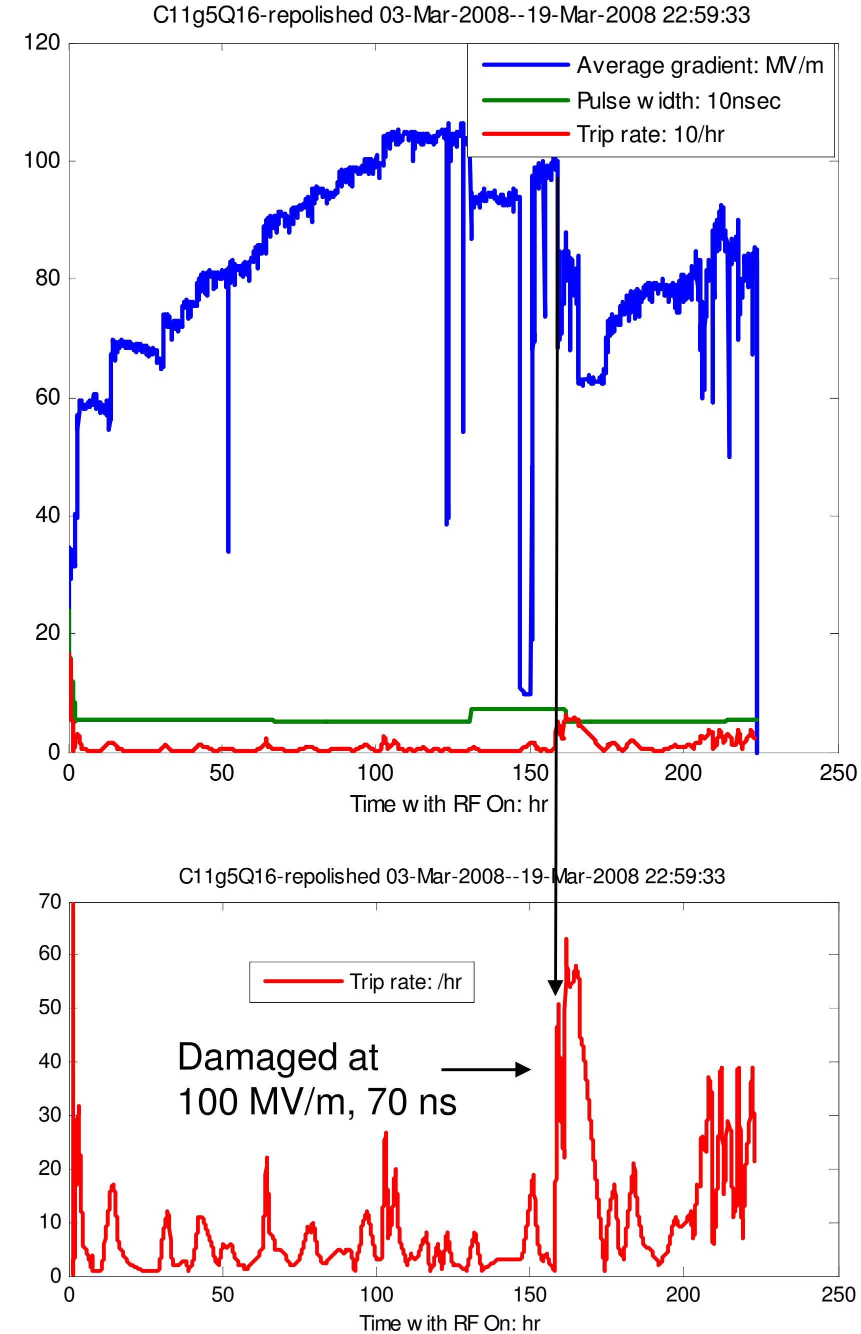
Quad 7-8: Iris 1. Grain growth significantly increased

First Run

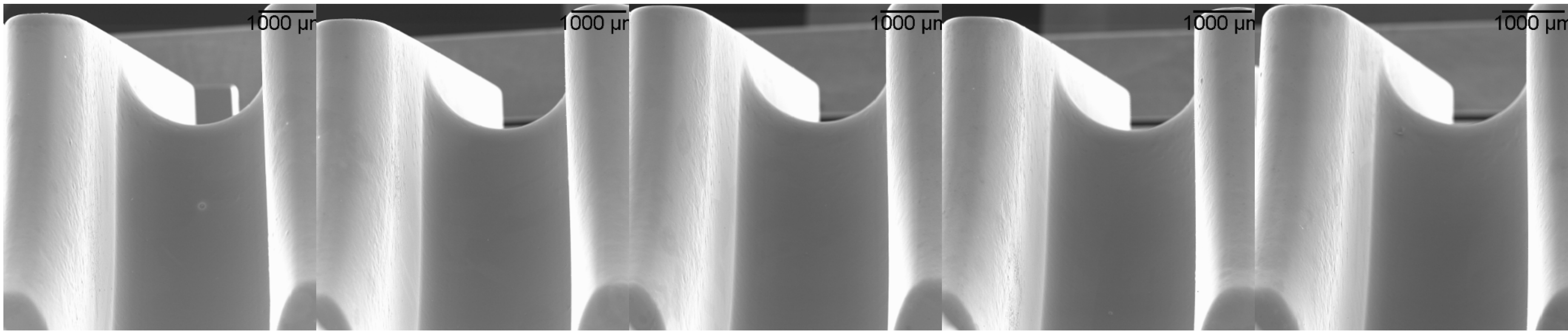




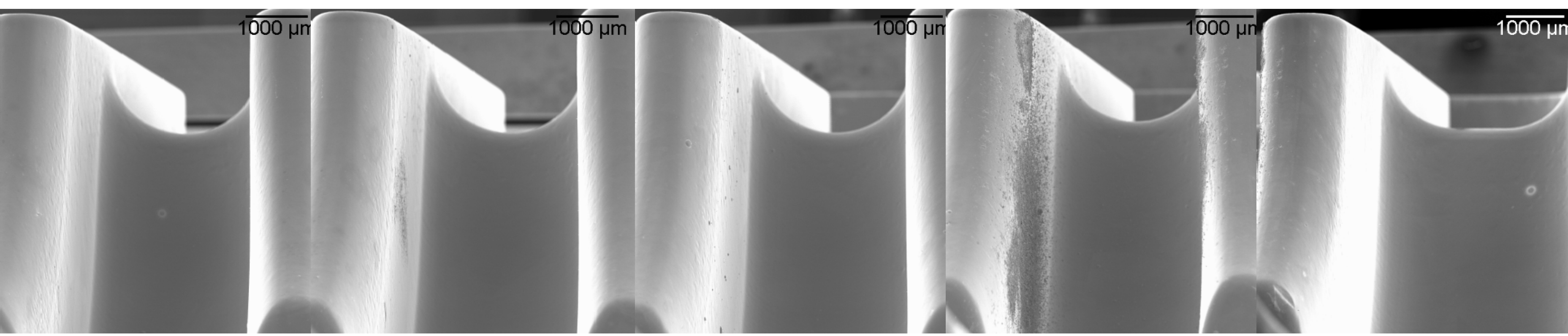
Second Run



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

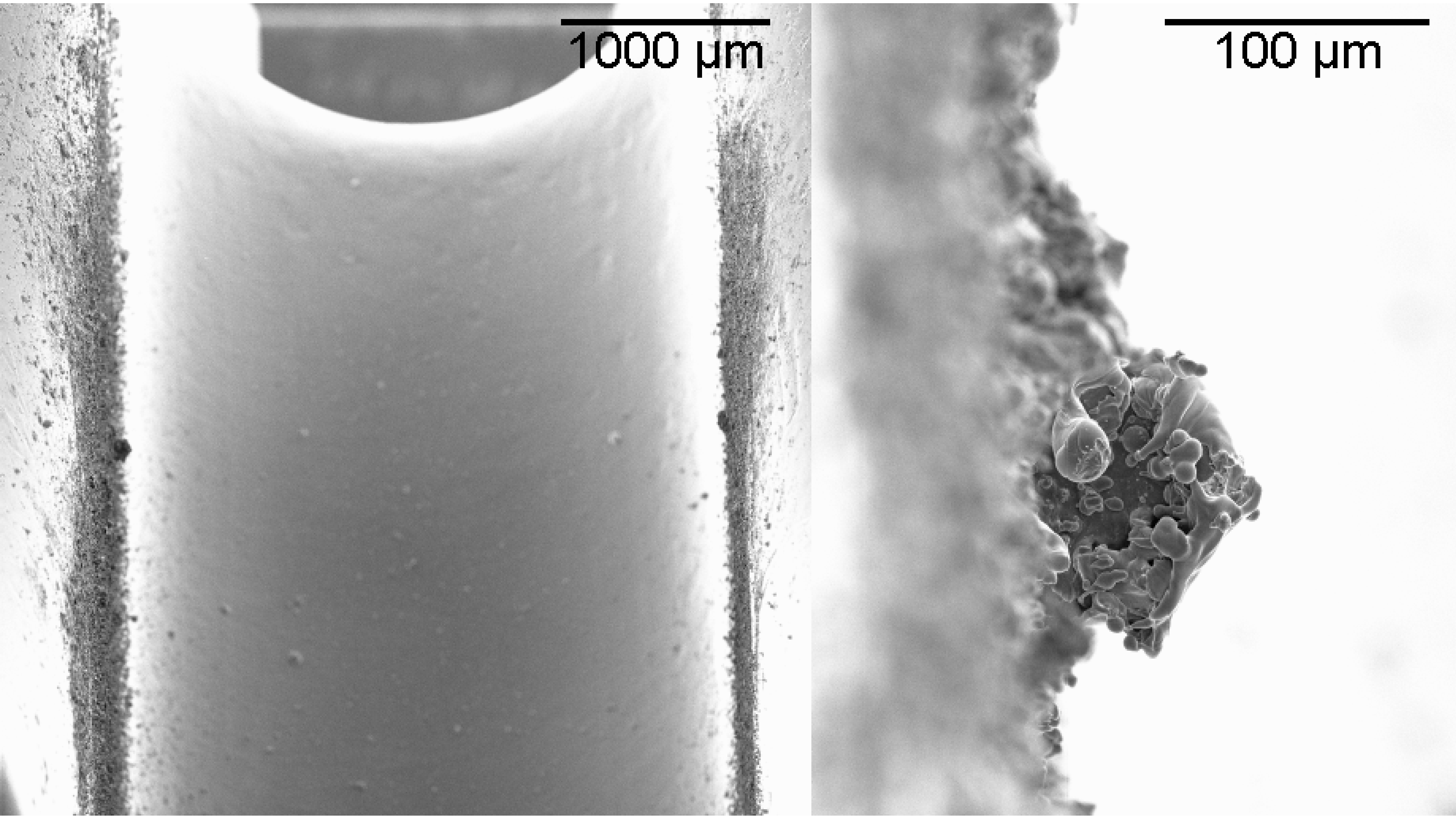


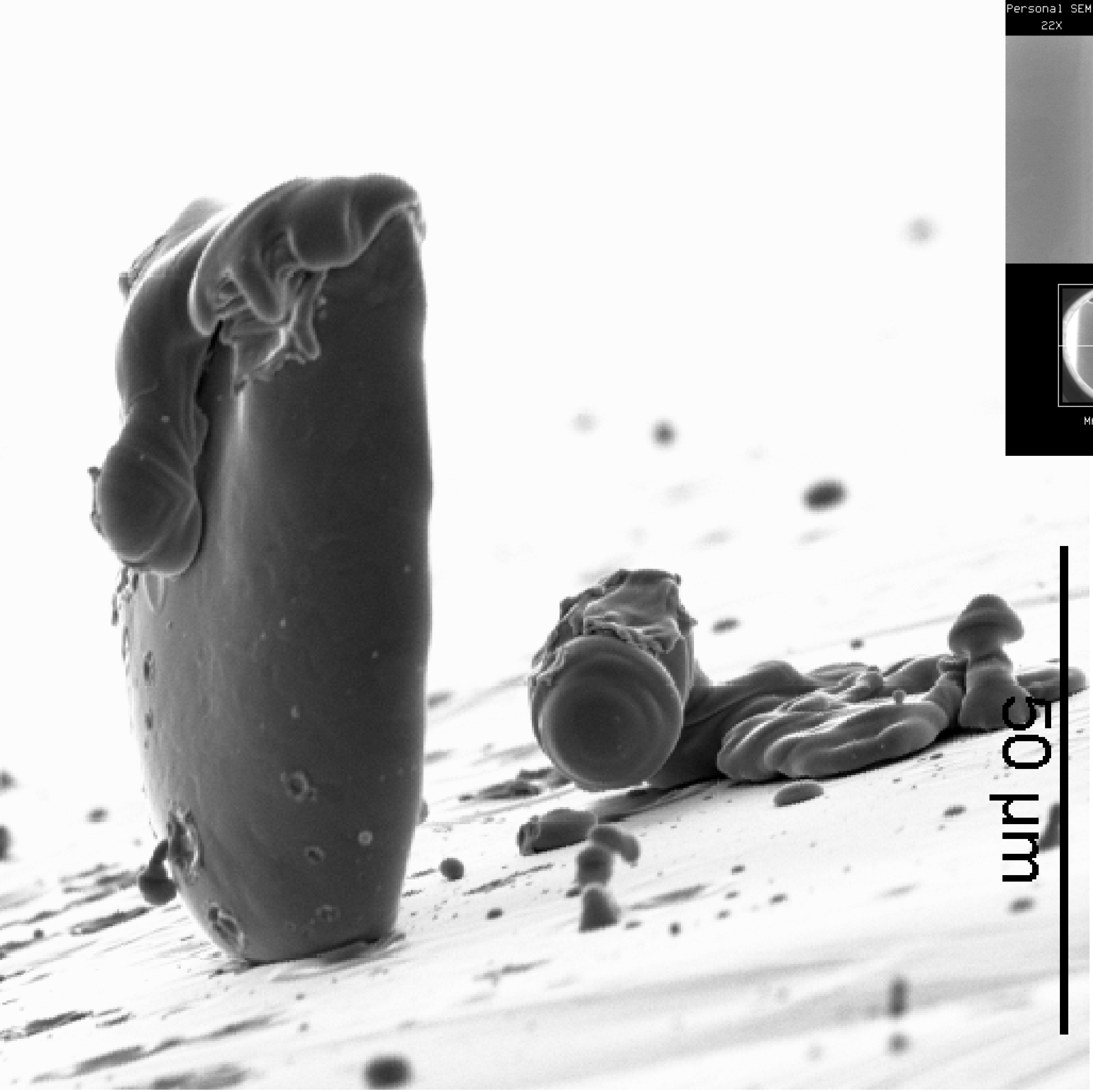
9 cell | 8 cell | 7 cell | 6 cell | 5 cell

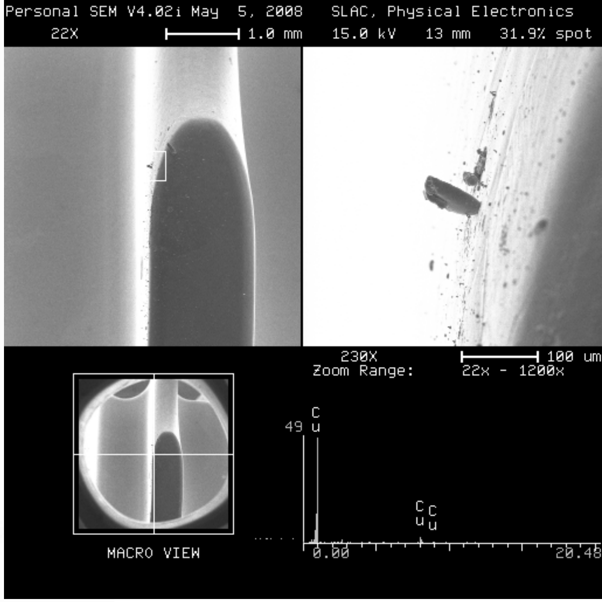


4 cell | 3 cell | 2 cell | 1 cell | 0 cell

Opposing 'Tips' on Side Walls







‘Stonehenge’ First Iris above the Damaged Quadrant

Molybdenum HDX11

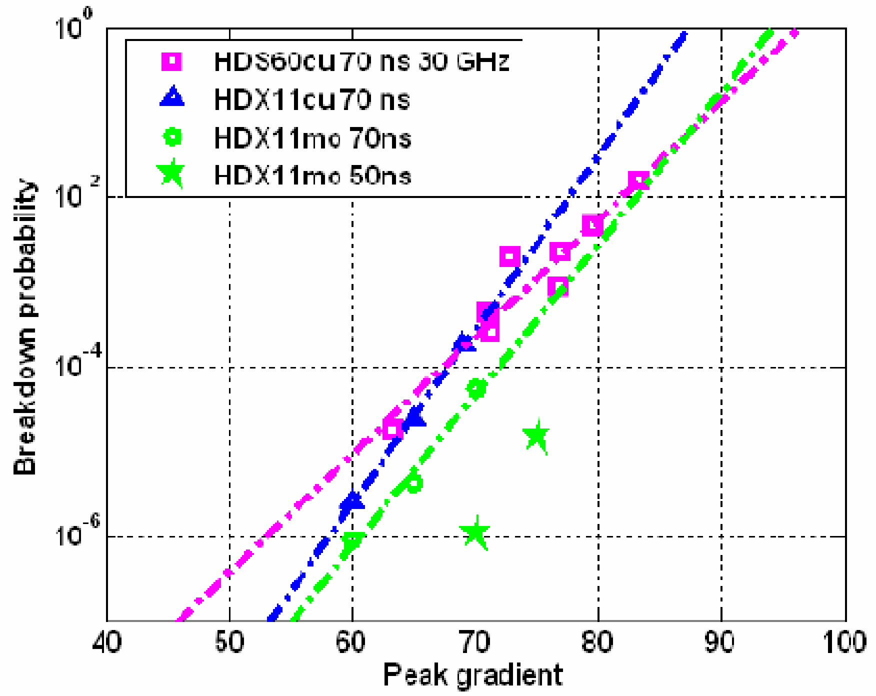
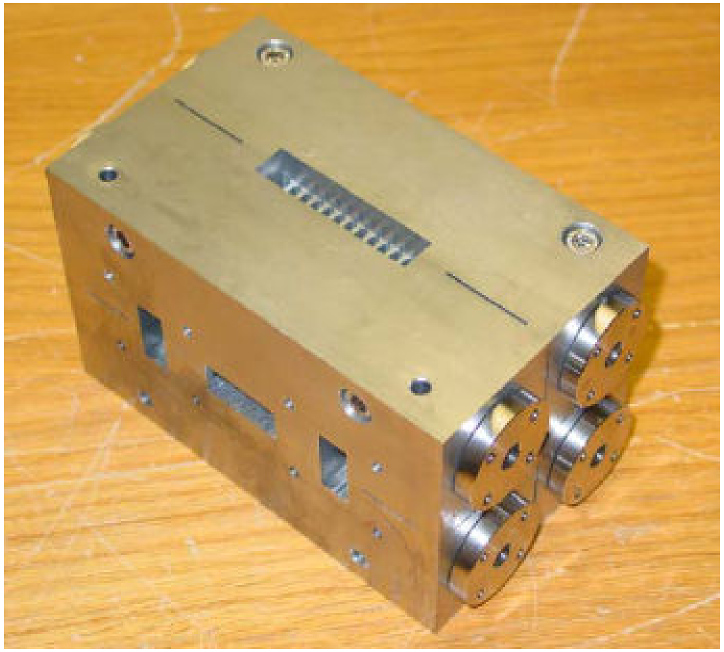


Figure 2: Break down rates as a function of the peak accelerating gradient for different structures and pulse length. The results of the x-band structures made out of copper and molybdenum are compared to a scaled version at 30 GHz made out of copper (HDS60cu).



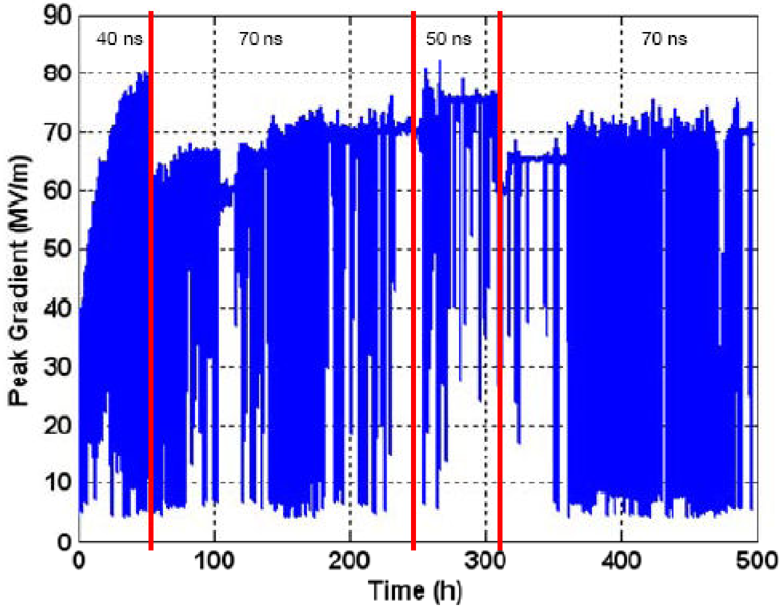
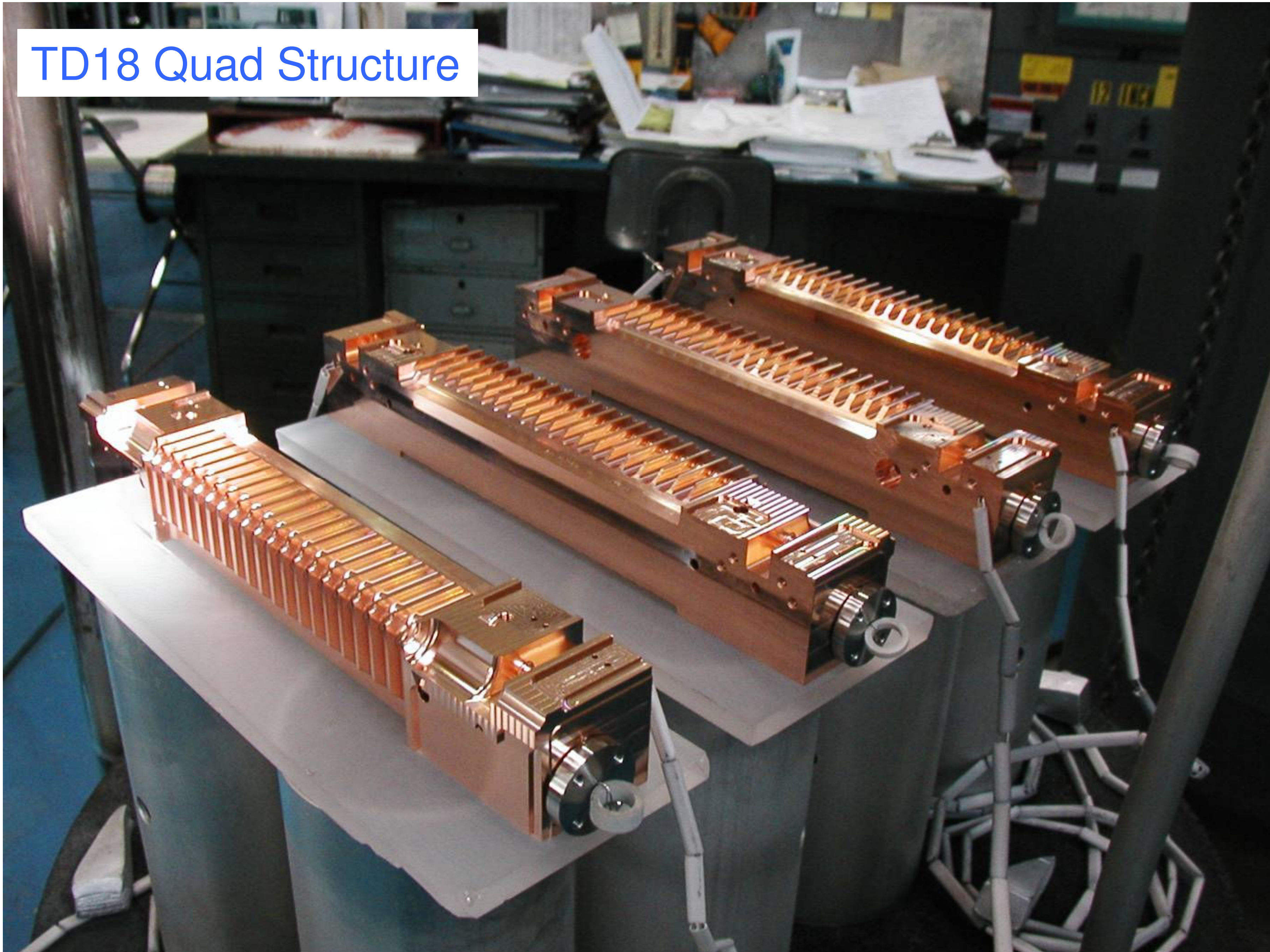
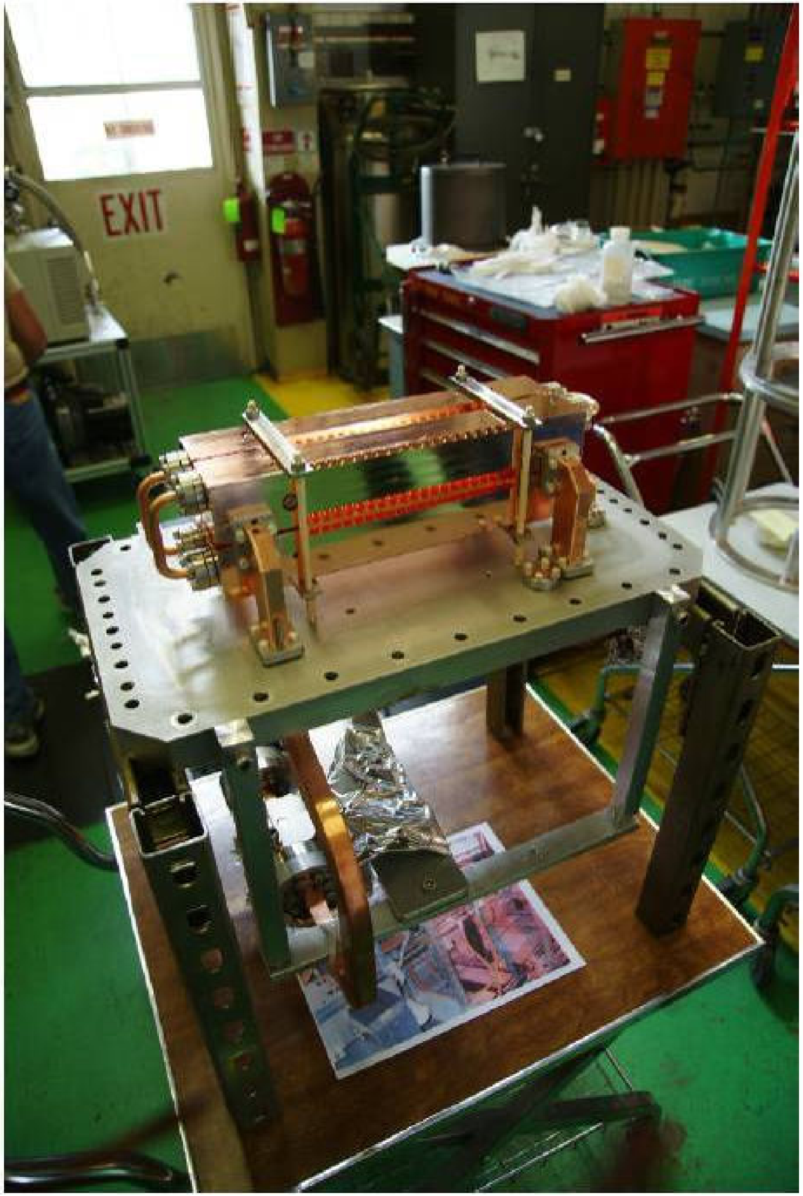


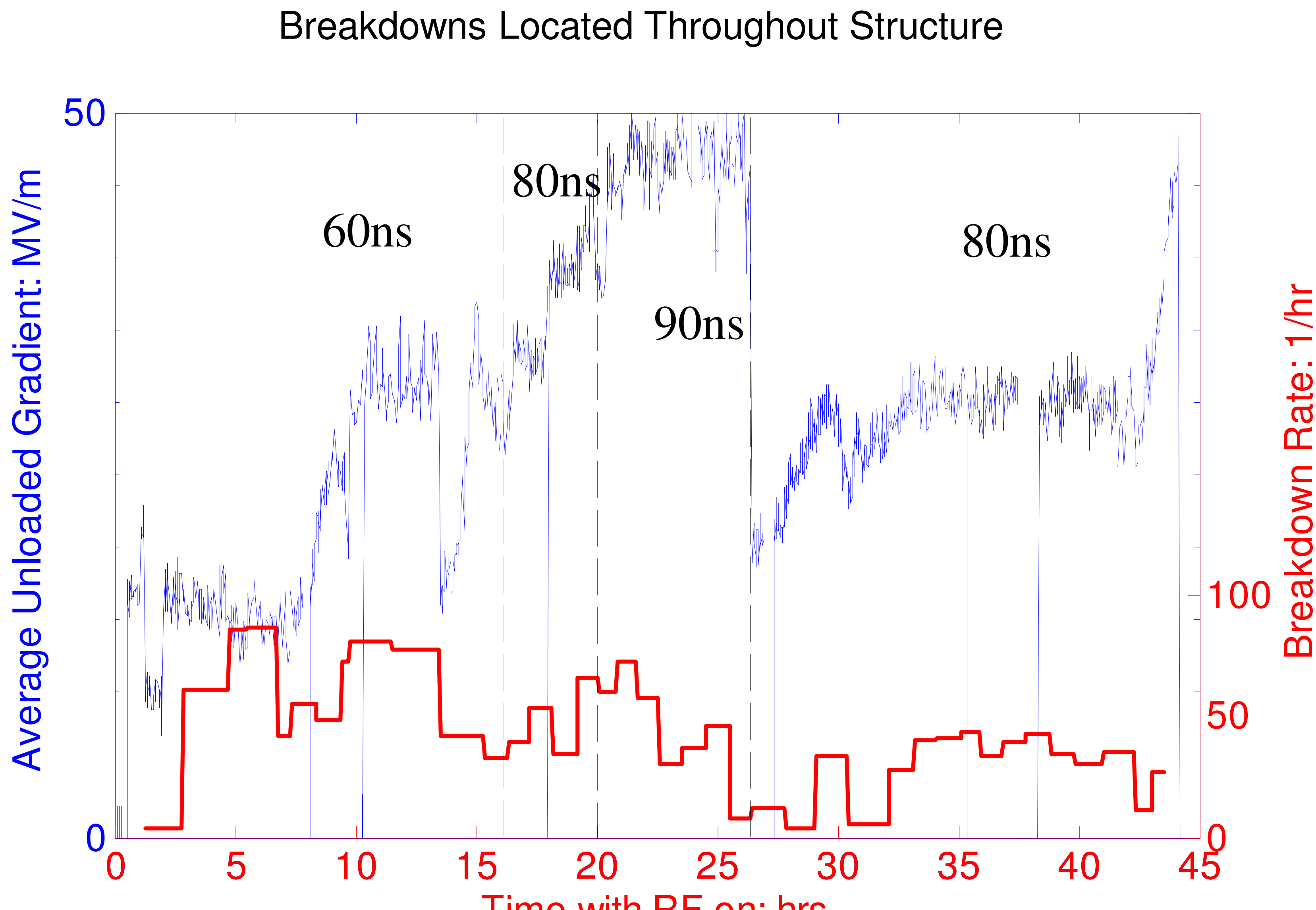
Figure 2: Conditioning history of HDX11 molybdenum structure.

TD18 Quad Structure



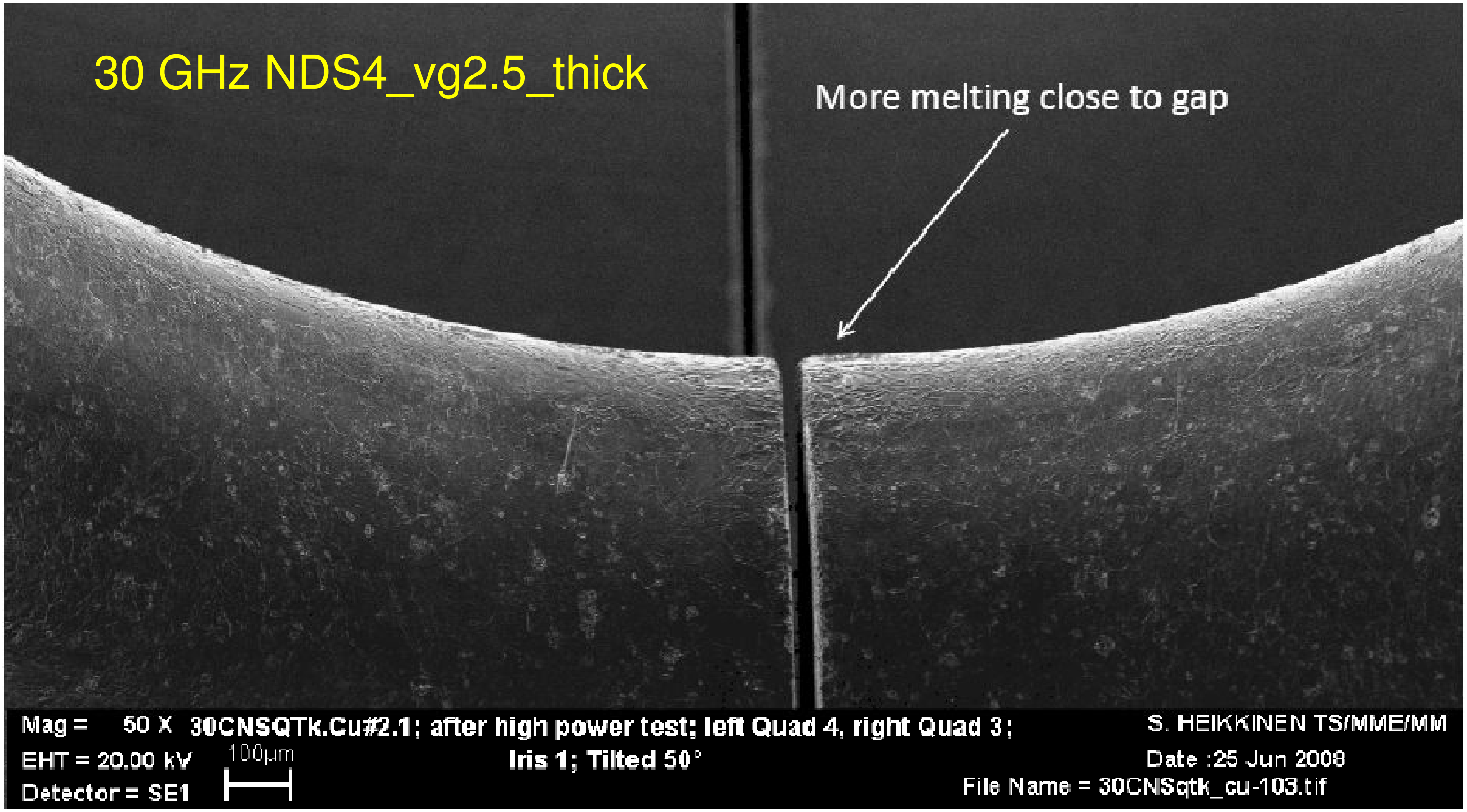

EXIT

TD18 Quad Processing History



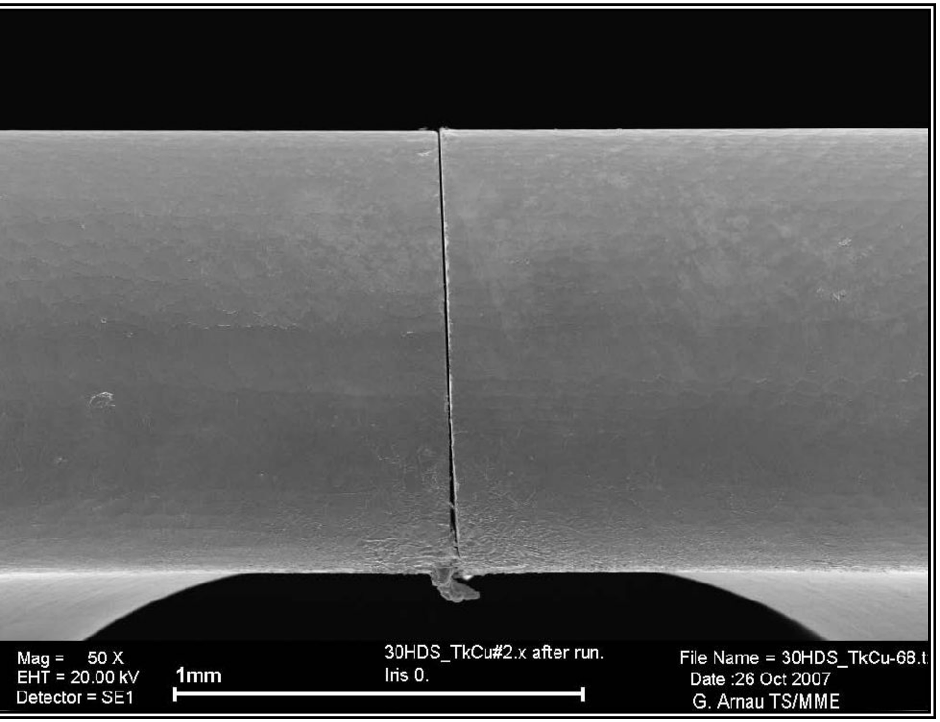
TD18 Quad Post-Run Examination

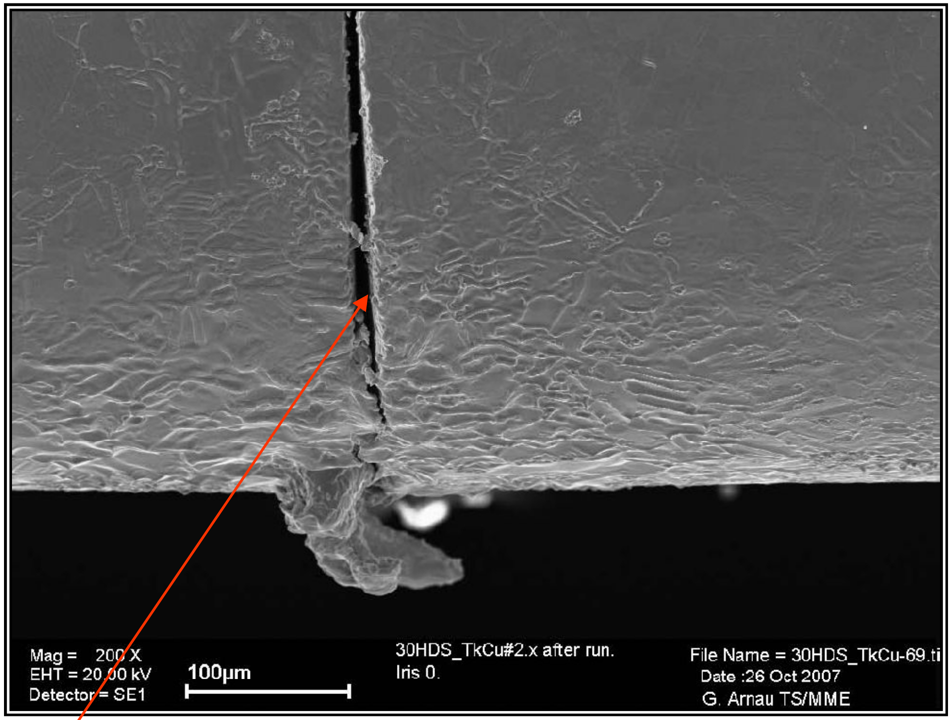
Not able to take good photos or SEM images, but saw damage similar to CERN 30 GHz HDX-like structures except practically no pitting on the irises (i.e., all breakdowns near joints)



30 GHz HDS4_Thick Post Mortem

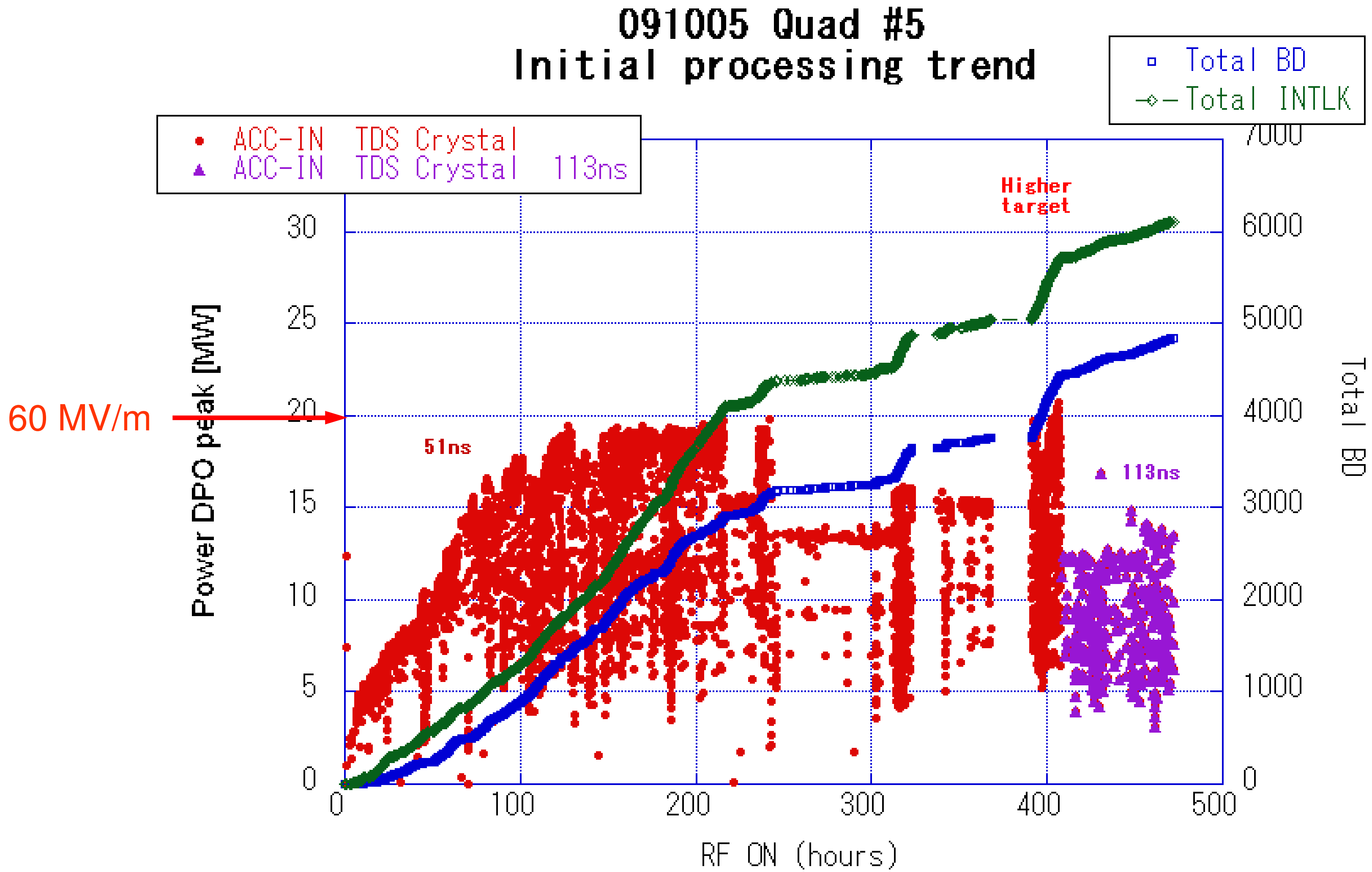
See similar metal protrusions in the TD Quad structure





Edges rounded (50 micron radius) in TD18 produced at KEK

Recent KEK Results from Testing a TD18 Quad Structure with 50 μm Rounded Iris Edges



Summary of 30 GHz Structures

All measured data at 70 ns pulse length and 10^{-3} breakdown rate

Structure	a/λ (%)	P (MW)	E (MV/m)
HDS60vg8.0	19	16.1	61
HDS60vg5.1	16	13.3	75
HDS4vg2.6_thick	17.5	7.5	67
NDS4vg2.5_thick	17.5	8.6	75
C30vg4.7	17.5	21.0	94
C40vg7.4_π/2	20	19.2	65
C30vg4.7_sb	17.5	20	92

→

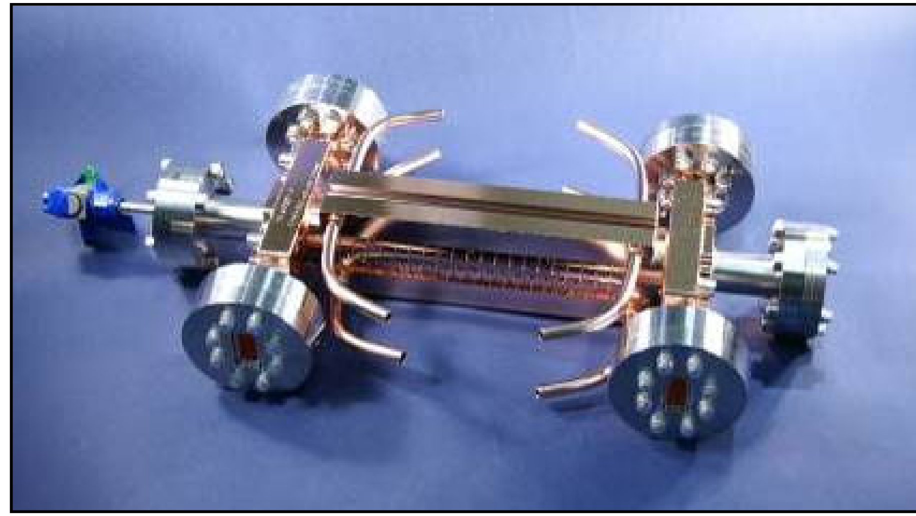
CLIC Disk Structure Tests

In NLCTA Beamline	Structure	Note	Performance
4/08 – 7/08	T18vg2.6-Disk SLAC_1	Cells by KEK, Assembled at SLAC	Good: 105 MV/m, 230 ns at LC BDR spec of 8e-7/pulse/m but hot cell developed
7/08 – 10/08	T18vg2.6-Disk SLAC_1	Powered from Downstream End	Good: 163 MV/m, 80 ns, 2e-5 BDR in last cell, consistent with fwd operation
12/08 – 2/09	T18vg2.6-Disk CERN_1	CERN Built, Operate in Vac Can	Very Poor: very gassy with soft breakdowns at 60 MV/m, 70 ns
Test at KEK 10/08 – 06/09	T18vg2.6-Disk KEK_1	Cells by KEK, Assembled at SLAC	Good: 102 MV/m, 240 ns at LC BDR spec – no bkd location info
7/09 – 8/09	T24vg1.8Disk CERN_1	CERN Built, Cells Pre-Fired	Poor: achieve < 60 MV/m after 100 hours with pulse lengths < 100 ns
5/09 - present	T18vg2.6-Disk SLAC_2	Cells by KEK, Assembled at SLAC	Good: after 280 hours, 97 MV/m, 230 ns at LC DBR spec – one hot cell

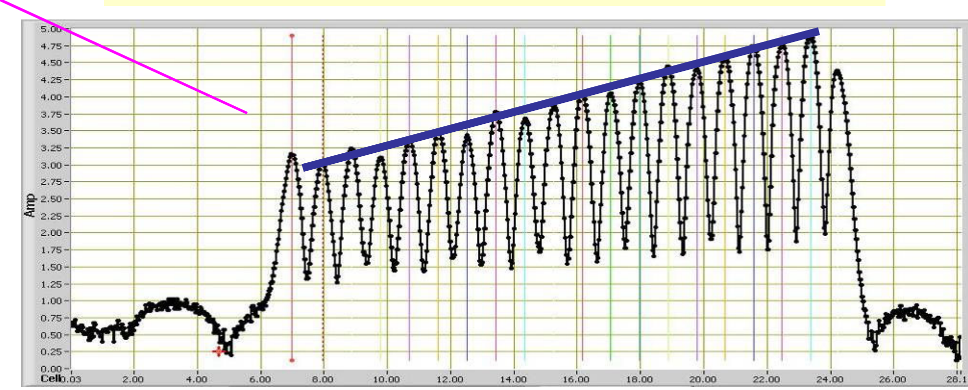
T18-Disk Structure

(First attempt at an optimal CLIC structure)

Cells	18+input+output
Filling Time: ns	36
Length: cm	29
a/λ (%)	15.5 ~ 10.1
v_g/c (%)	2.6 - 1.0
S_{11}/ S_{21}	0.035 / 0.8
Phase Advance Per Cell	$2\pi/3$
Power Needed $<E_a>$ = 100 MV/m	55.5 MW
Unloaded E_a(out)/E_a(in)	1.55
E_s/E_a	2
Pulse Heating ΔT: K (75.4MW@200ns)	16.9 - 23.8

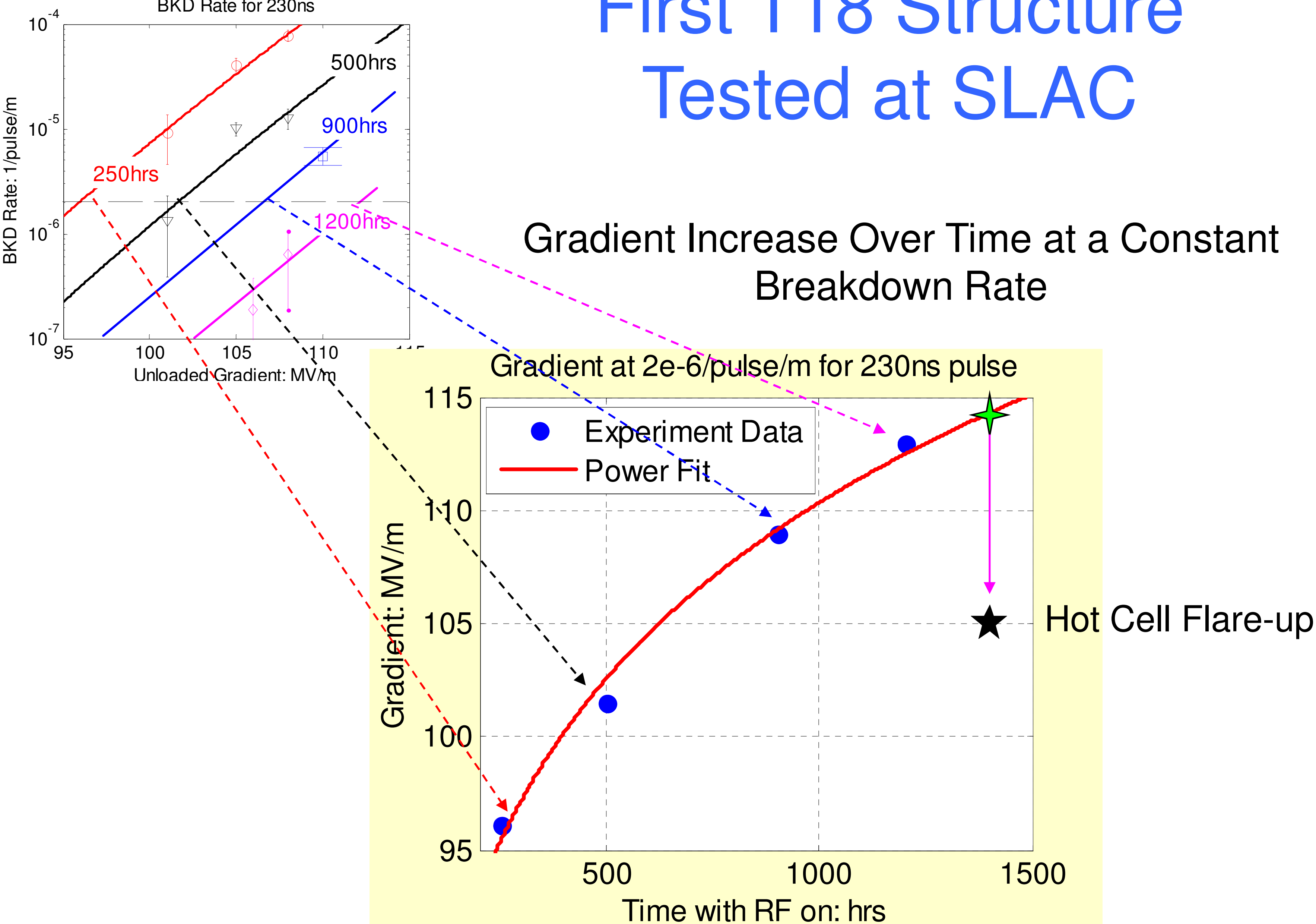


Field Profile Along the Structure

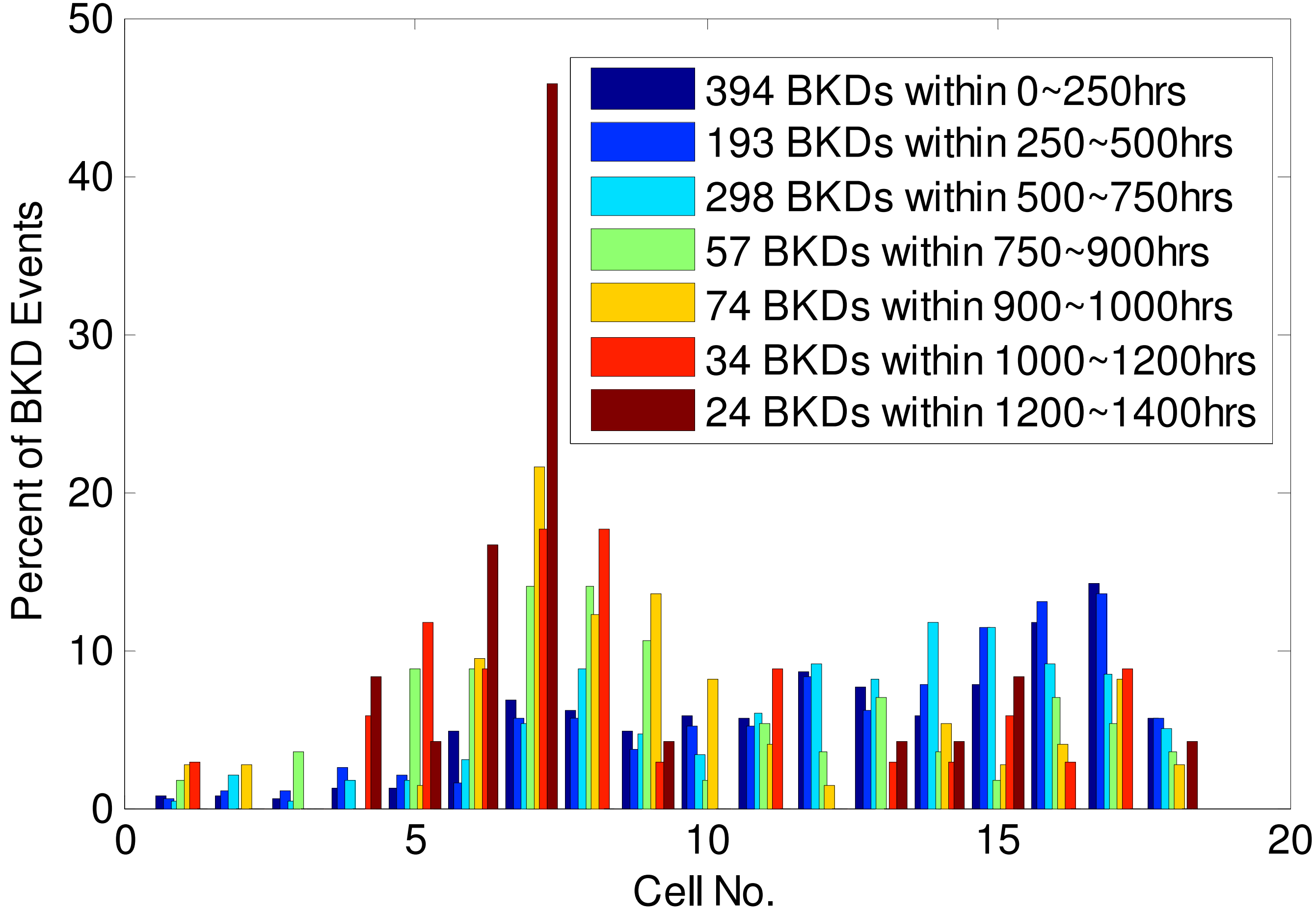


First T18 Structure Tested at SLAC

Gradient Increase Over Time at a Constant Breakdown Rate



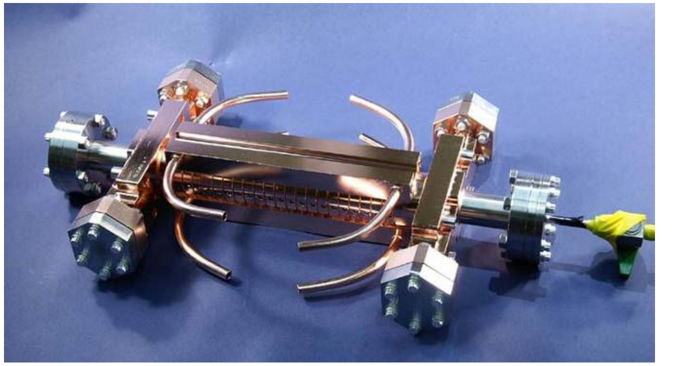
BKD Distribution Along Structure at Different Stages of Processing

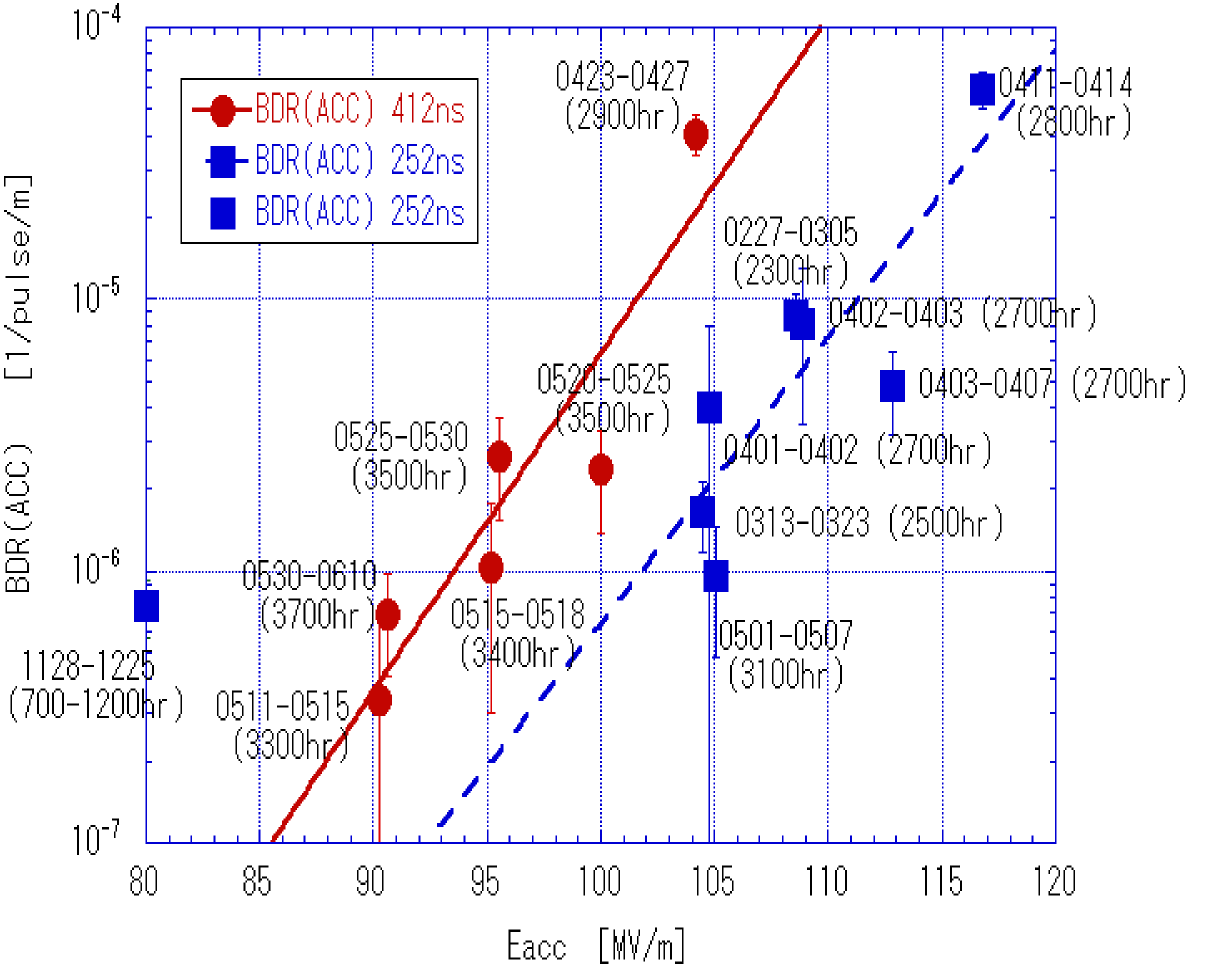


Did not find visual evidence related to the hot cell in a post-run boroscope exam – typical of NLC/GLC structures, many of which had hot cells

First T18 Structure Tested at KEK

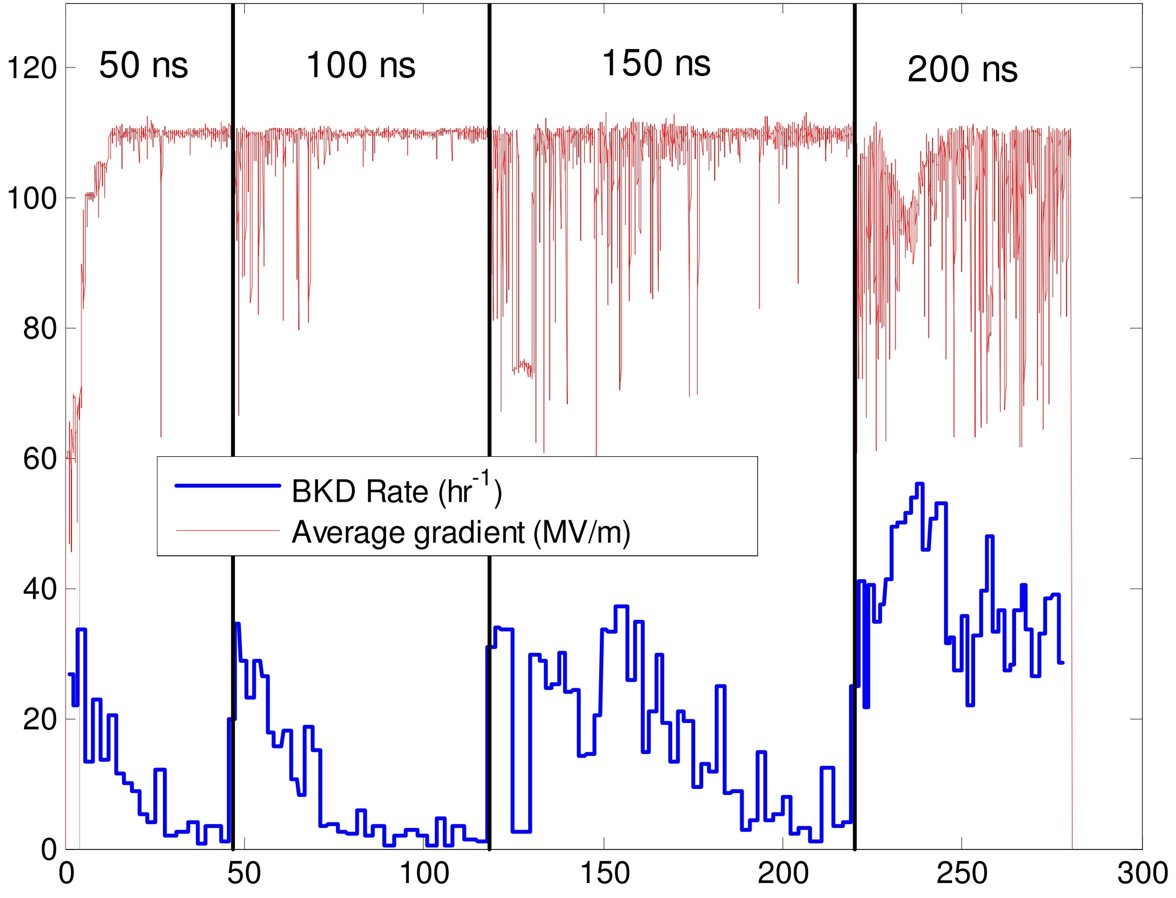
Operated 3900 hours



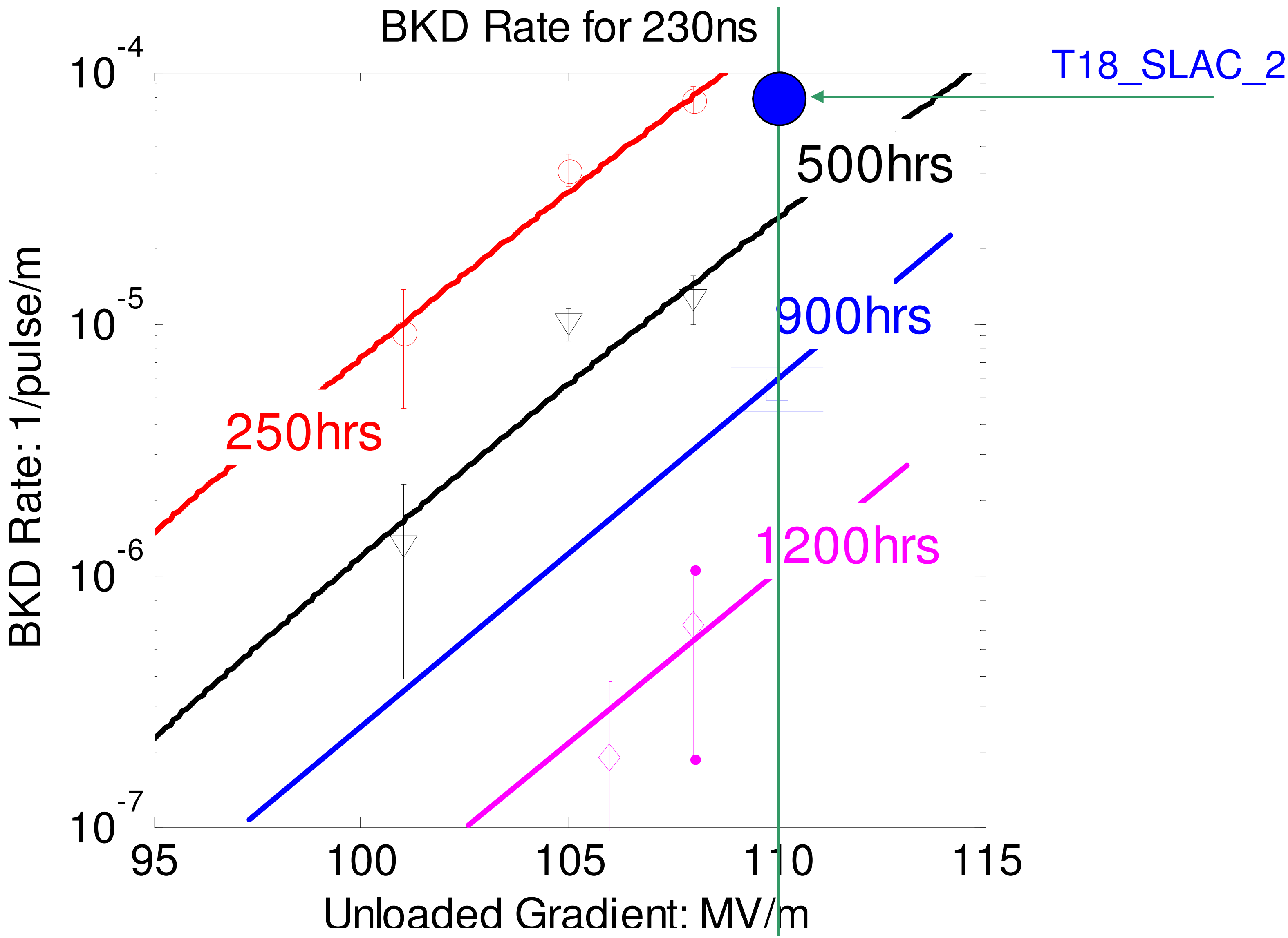


Second T18 Structure Tested at SLAC

This time, processed structure by progressively lengthening the pulse at constant gradient (110 MV/m)



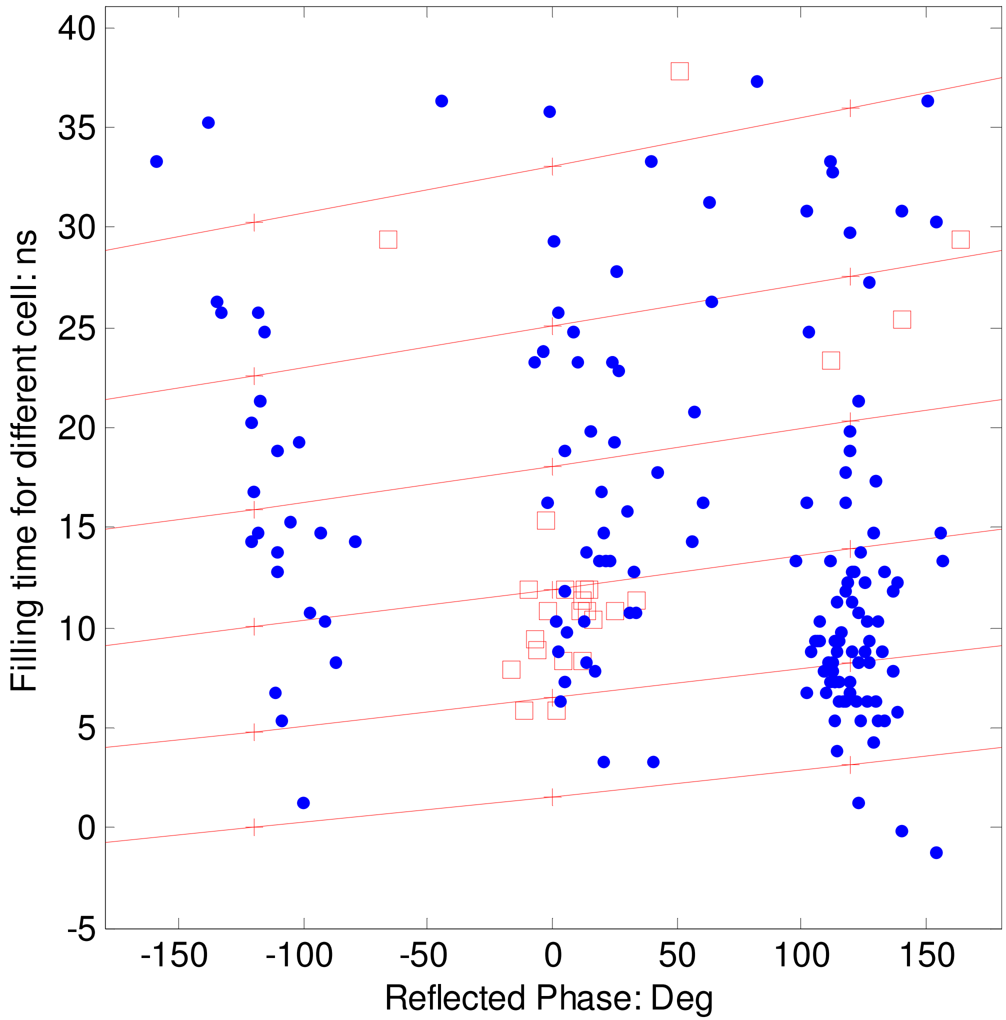
Comparison of current BDR rate (blue circle) with the rate curves from the First SLAC T18 structure at different processing times

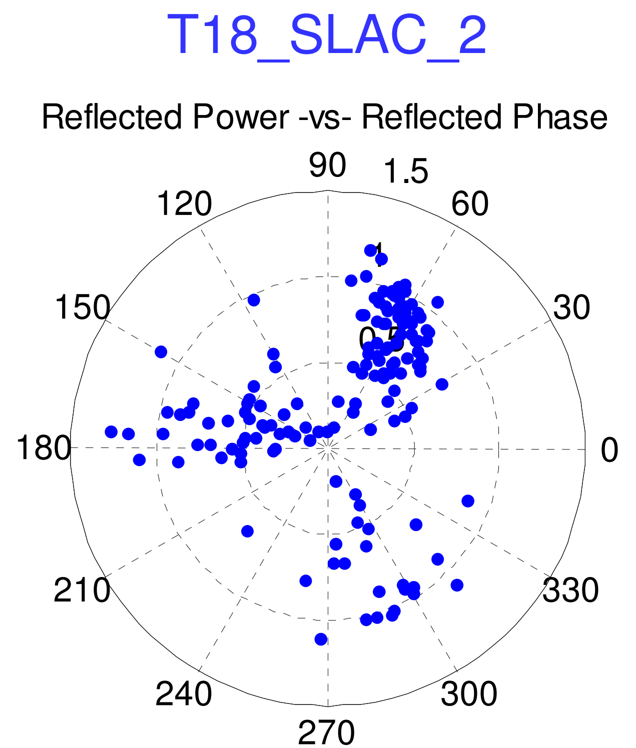


RF Breakdown Locations

Blue dots: T18_SLAC_2 after 250 hrs running

Red squares: T18_SLAC_1 after 1200 hrs running





CERN Built T18

Cells made by Kugler, no etch, 820 degC vacuum braze at CERN, installed in a vacuum can at SLAC

Copper grain size small due to 'low' braze temperature

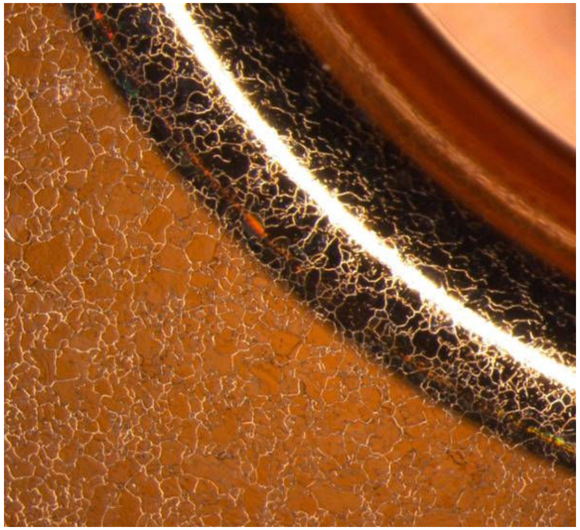
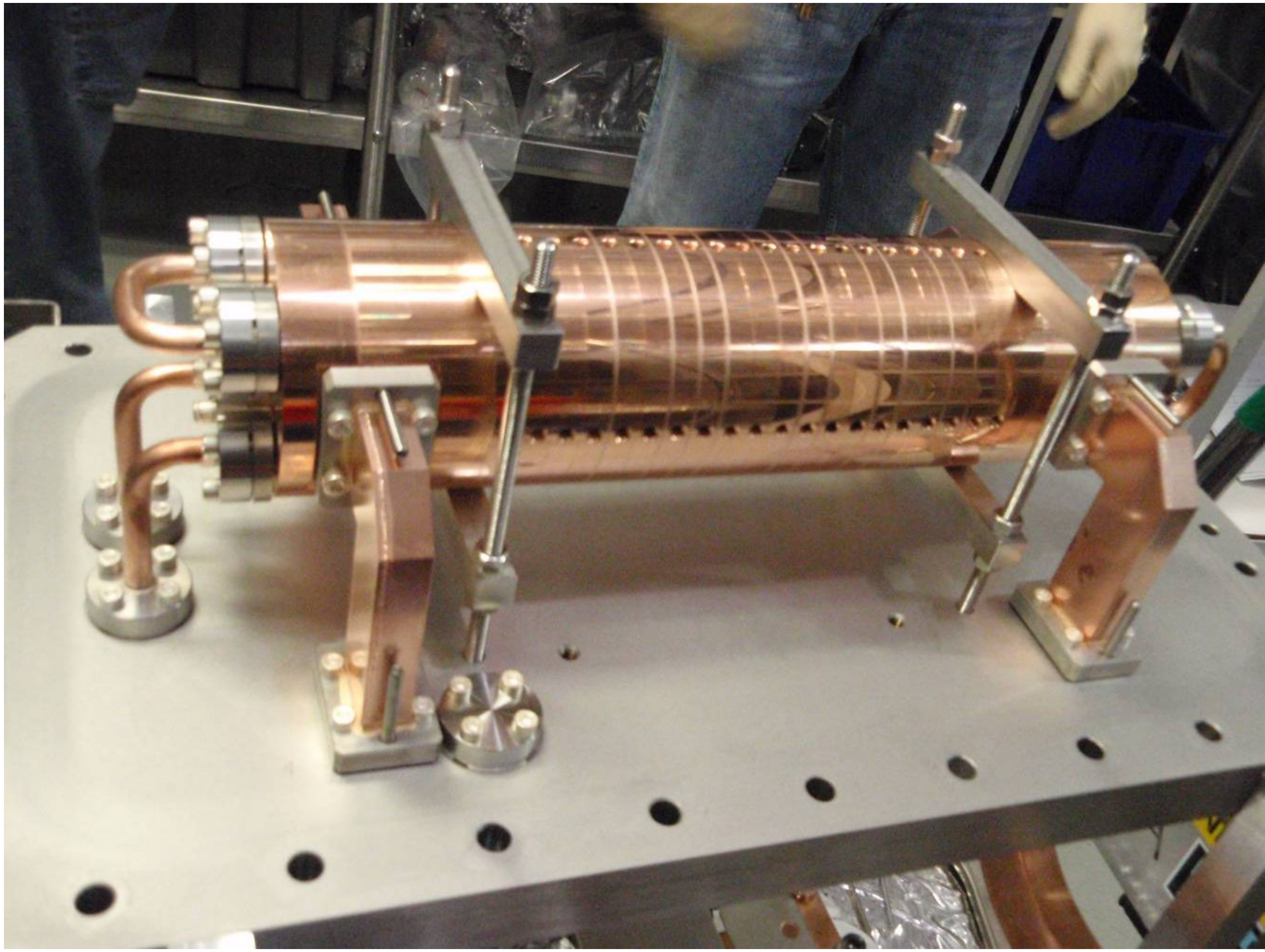
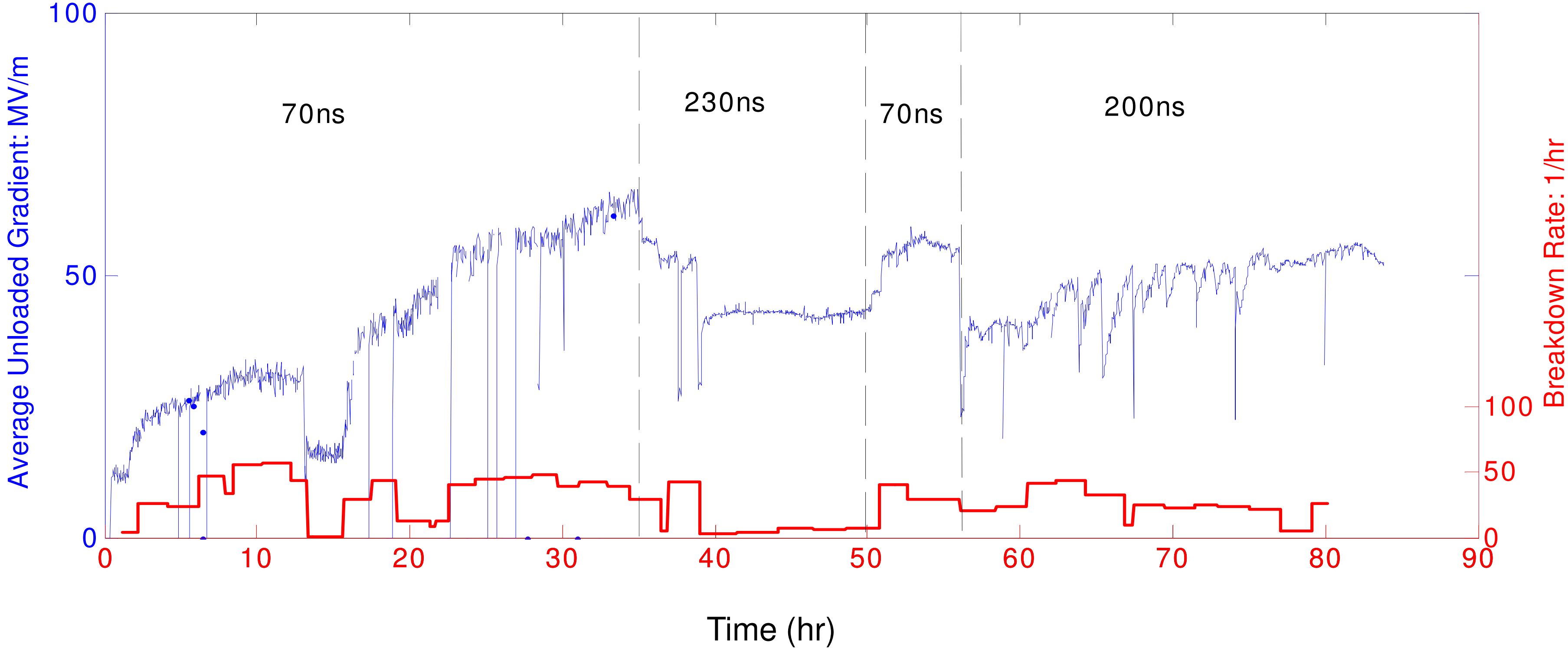


Photo of Iris



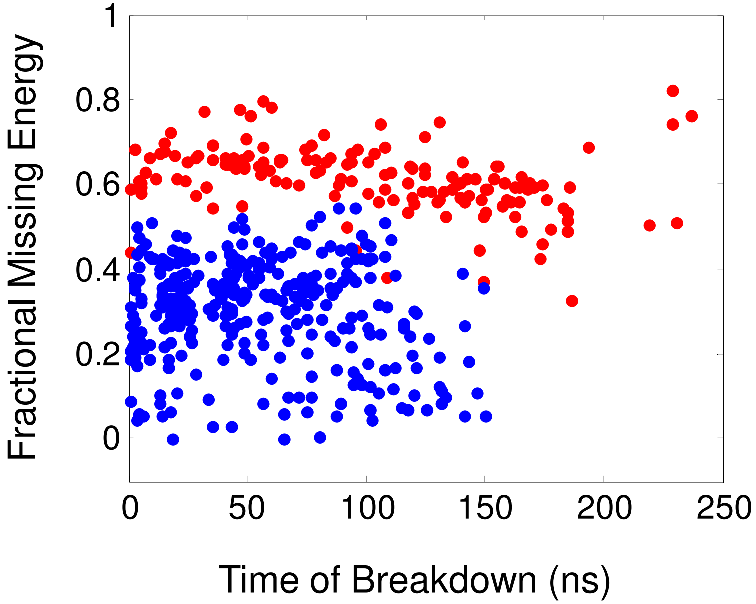
CERN T18 Processing History

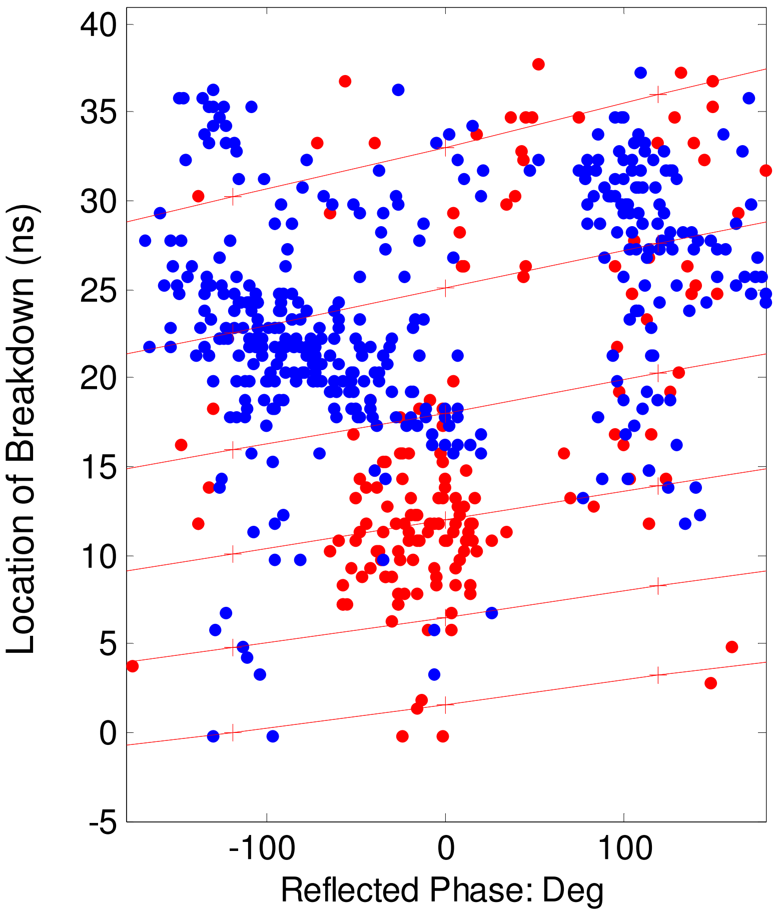


Breakdown Characteristics

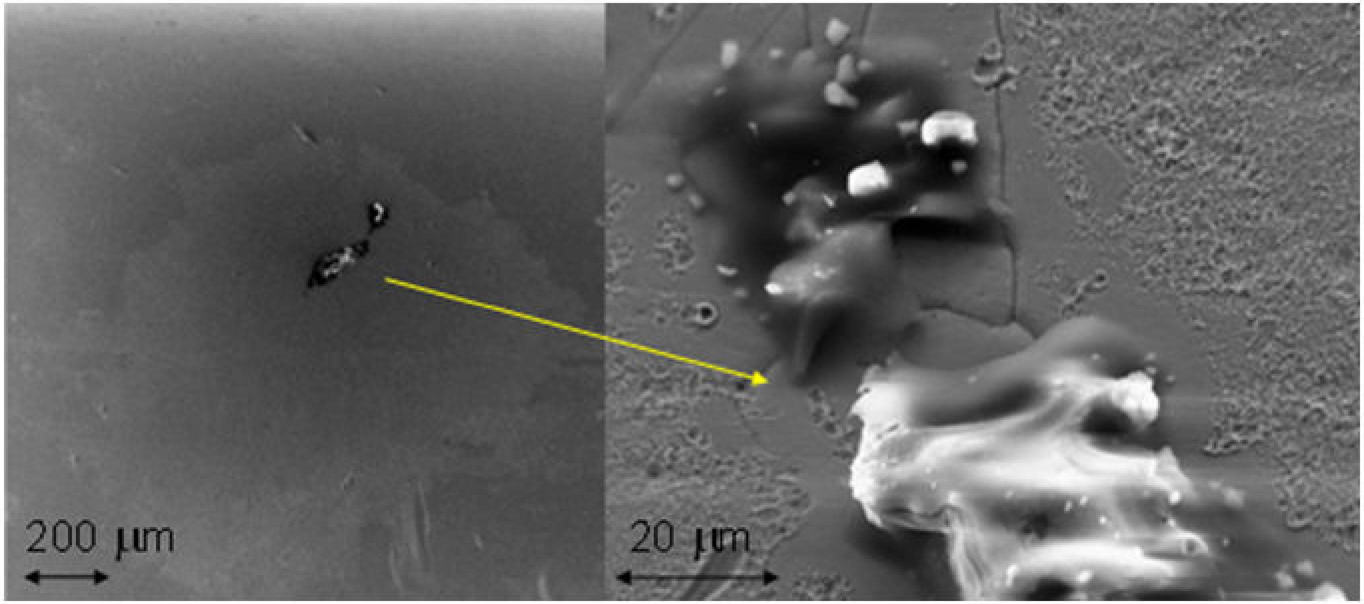
T18_Disk_1 during last 500 hrs, ~ 115 MV/m, 220 ns

T18_Disk_CERN during last 40 hrs, ~ 50 MV/m, 200 ns





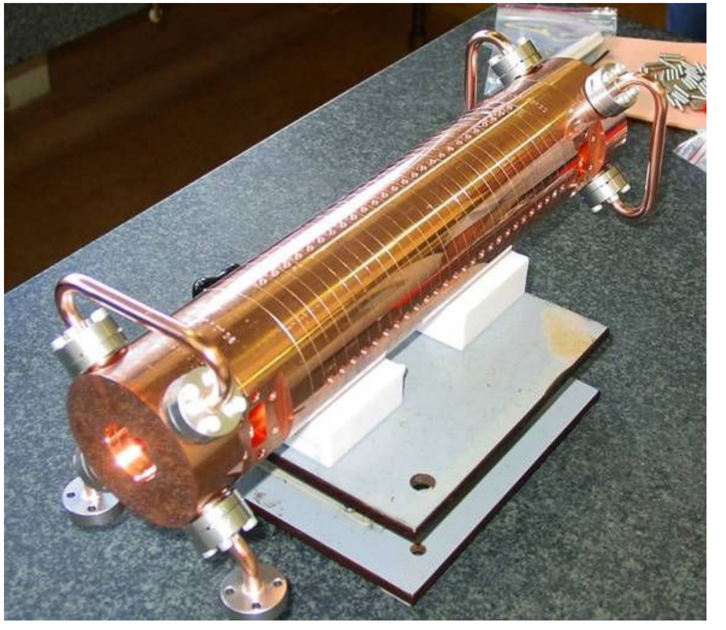
Iris 12 Autopsy



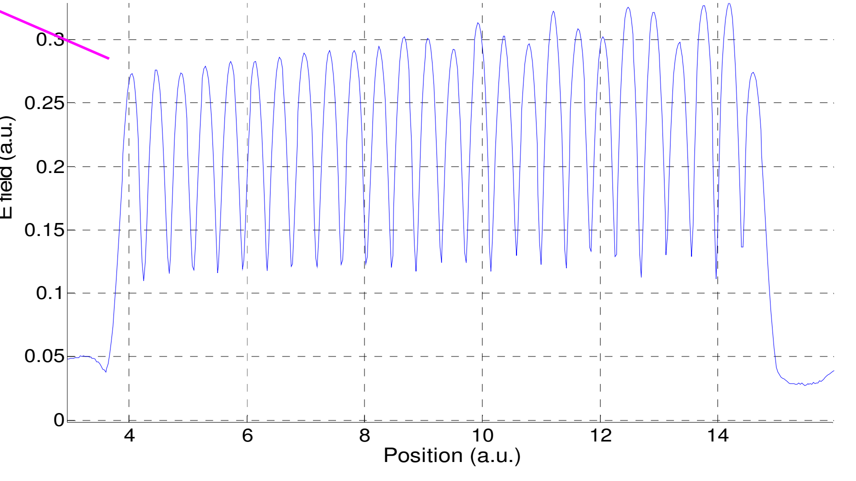
A 200 micron long calcium and carbon rich object that appears to have caused surface melting over a 1 mm wide area on this iris

CERN T24 Disk Structure

Cells	24+input+output
Filling Time: ns	61
Length: cm	30 (wg2wg) 23 (24+2 cells)
a/λ (%)	12.6 - 9.4
v_g/c (%)	1.8 - 0.9
S_{11}/S_{21}	0.016 / 0.715
Phase Advance Per Cell	$2\pi/3$
Power Needed $<E_a>$ = 100 MV/m	42.4 MW
Unloaded E_a(out)/E_a(in)	108/90
E_s/E_a	2
Pulse Heating ΔT: K (<100MV/m>@100ns)	7.5 – 8.4

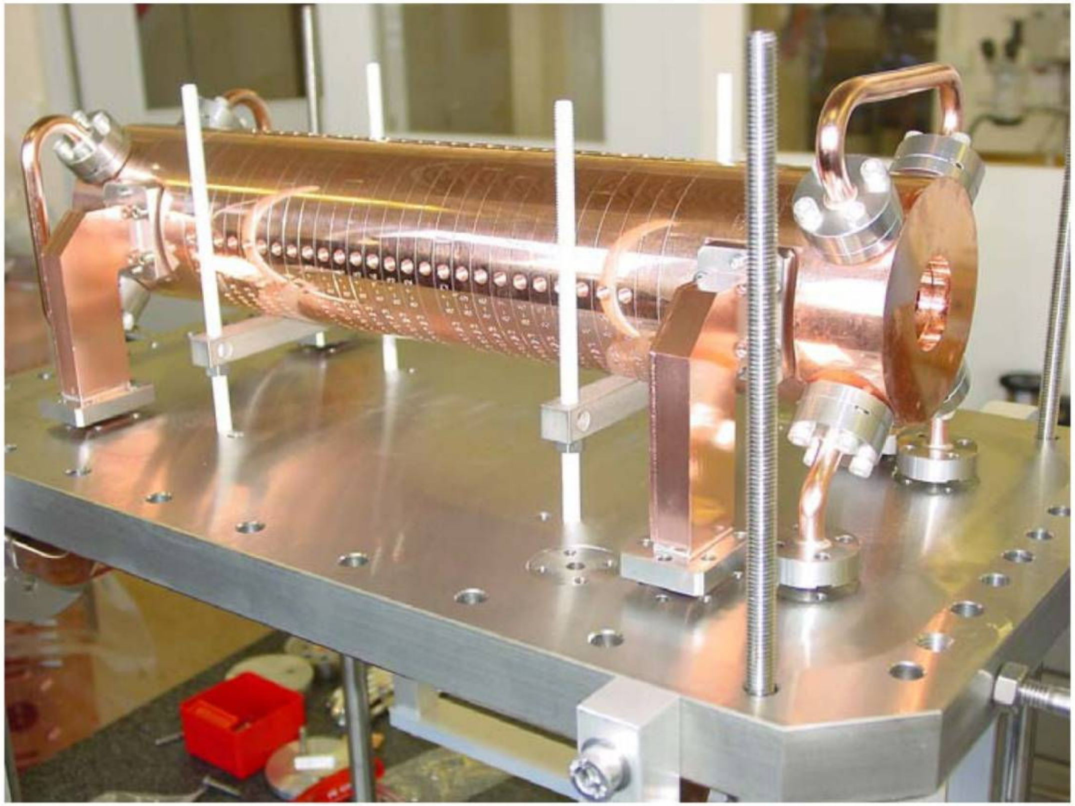


Field Profile Along the Structure

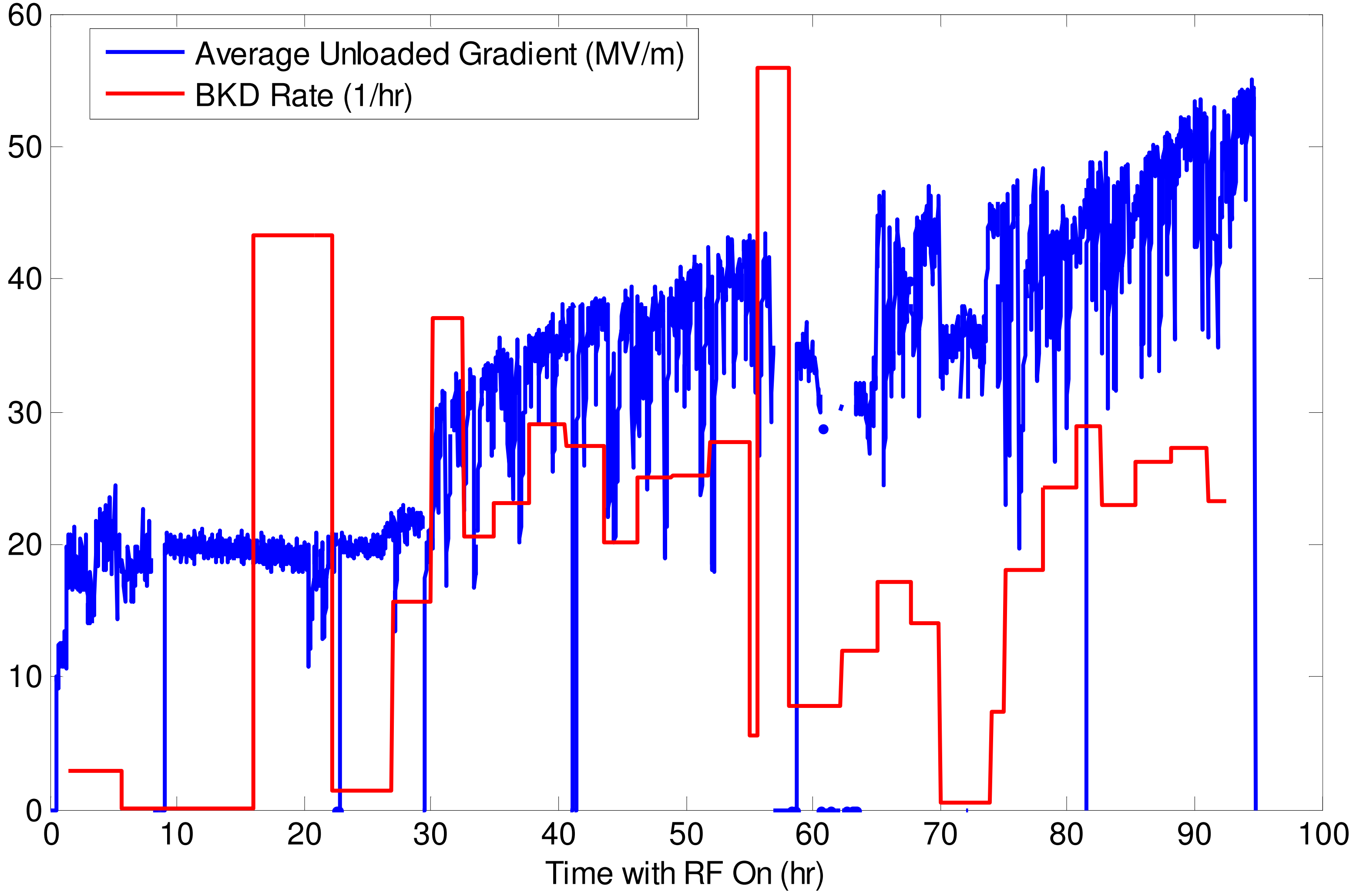


T24 Fabrication

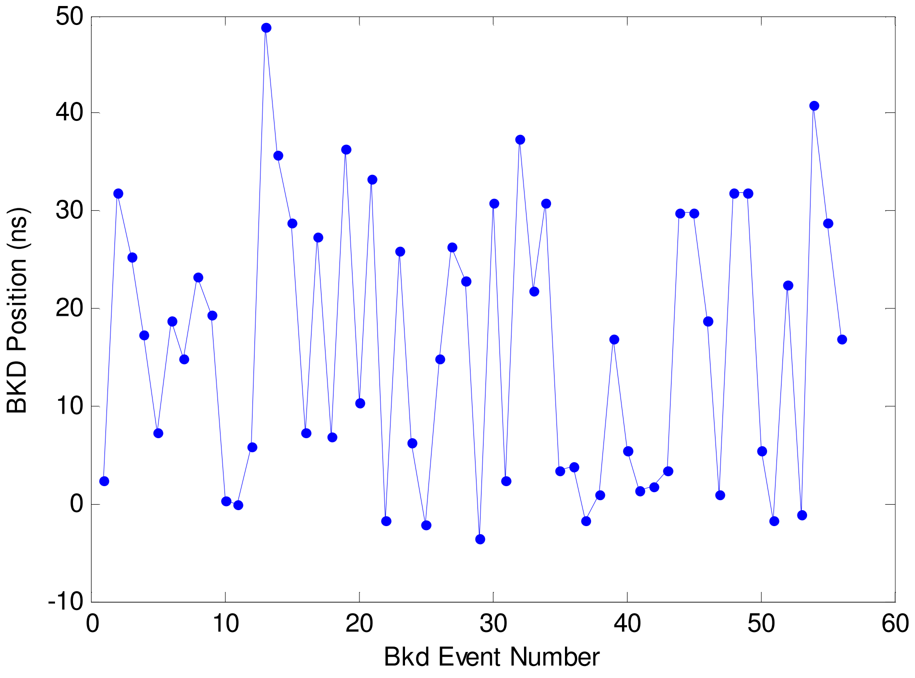
- Manufactured at VDL, Q4 ‘08
- Assembly at CERN with “new” procedure (following T18 task force) Apr-Jun 09
- Pre-fire of disks at 1040 ˚C. Resulting uneven surface caused braze leaks
- Cells oxidized at one point but it was removed with 650 ˚C bake
- Now back at CERN for evaluation

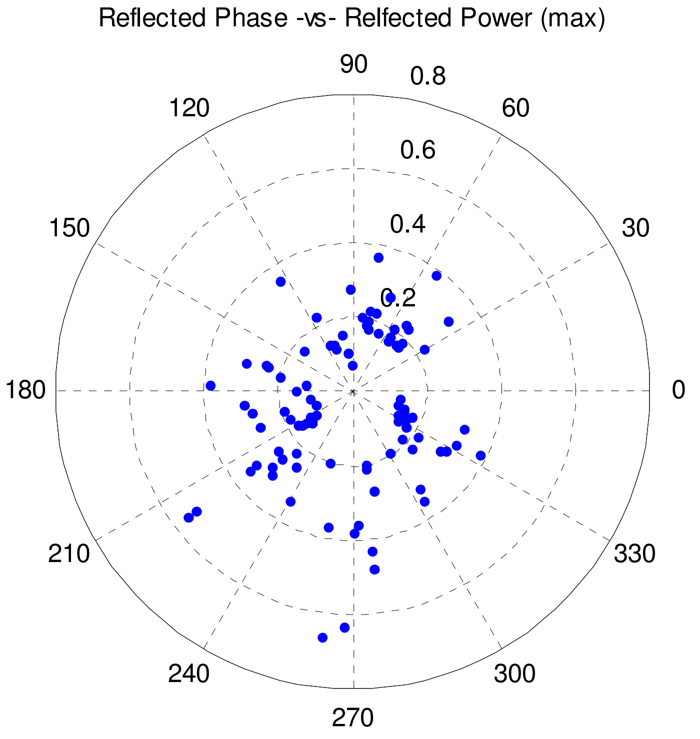


T24 Processing History at 100 ns and Shorter Pulse Lengths



Breakdown Locations





Summary

- With strong dependence on structure fabrication technique, cannot evaluate performance dependence on structure geometry (a,vg,phi)
- Quad approach does not appear viable
  - Need to improve quad ‘z’ alignment and reduce virtual leaks
  - Probably cannot allow irises to touch nor have a low phase advance per cell (which lowers Es/Ea)
  - Should do a final test of a $2\pi/3$, brazed version with slots
- T18 design is very promising, but not optimal for CLIC
  - Three versions have operated at CLIC-like parameters although they take $>$ 1000 hours of operation to achieve low breakdown rates
- Future
  - CERN adopting SLAC-like structure assembly techniques
  - Verify T24 with HOM damping meets CLIC specs (will test TD18_disk first)