Status of High Gradient Tests of Normal Conducting Single-Cell Structures

Valery Dolgashev, Sami Tantawi (SLAC)

Yasuo Higashi (KEK)

Robert Siemann Symposium and ICFA Mini-Workshop,
July 7th - 10th, 2009
SLAC National Accelerator Laboratory

This work is made possible by the efforts of SLAC's

- A. Yeremian, J. Lewandowski *of Accelerator Technology Research*
- E. Jongewaard, C. Pearson, J. Eichner, D. Martin, C. Yoneda, L. Laurent, R. Talley, J. Zelinski and staff *of Klystron Lab.*
- Z. Li, *Advanced Computation*

In collaboration with :

- B. Spataro, *INFN, Frascati*

Outline

- Introduction
- Strategy
- Results

Single Cell Accelerator Structures

Goals

- Study rf breakdown in *practical* accelerating structures: dependence on circuit parameters, materials, cell shapes and surface processing techniques

Difficulties

- Full scale structures are long, complex, and expensive

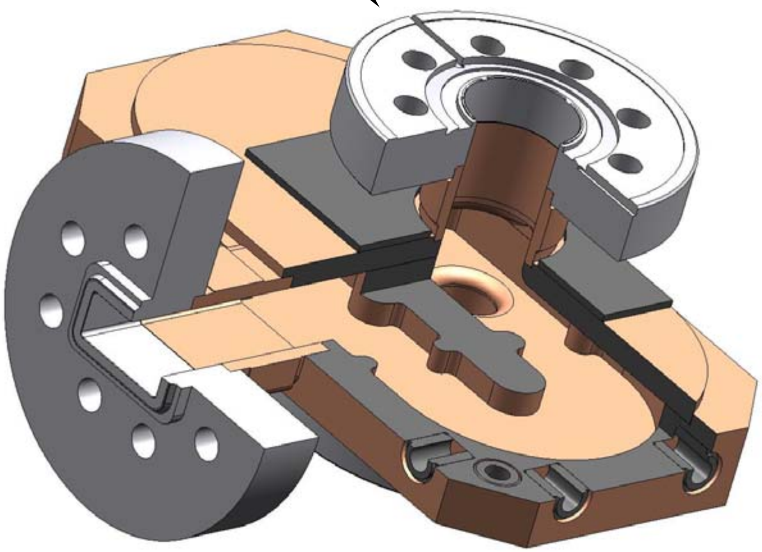
Solution

- *Single cell Traveling wave (TW)* and *single cell standing wave (SW)* structures with properties close to that of full scale structures
- Reusable couplers

We want to predict breakdown behavior for practical structures

Reusable coupler: TM_{01} Mode Launcher

Pearson's RF flange

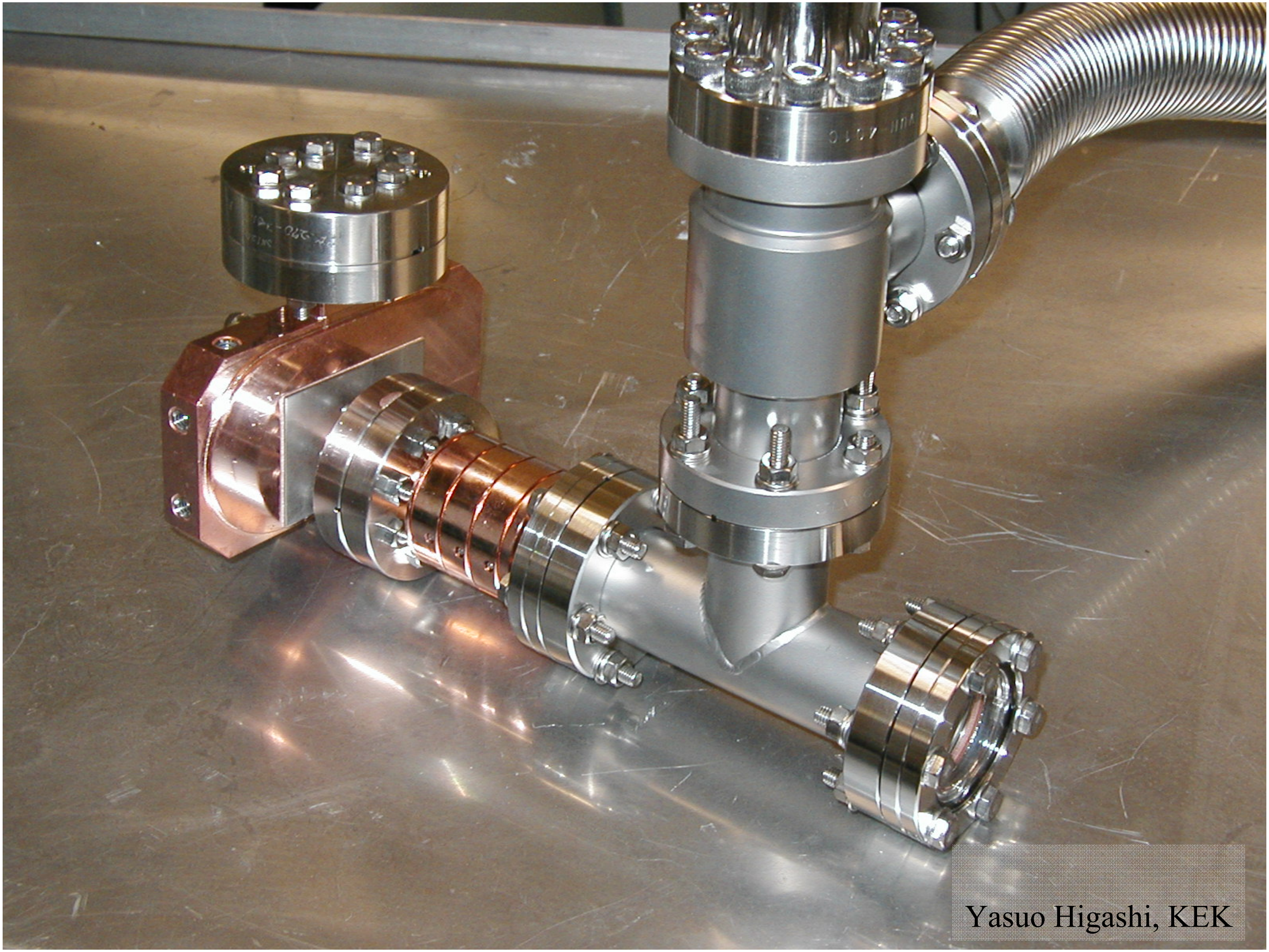


Cutaway view of the mode launcher

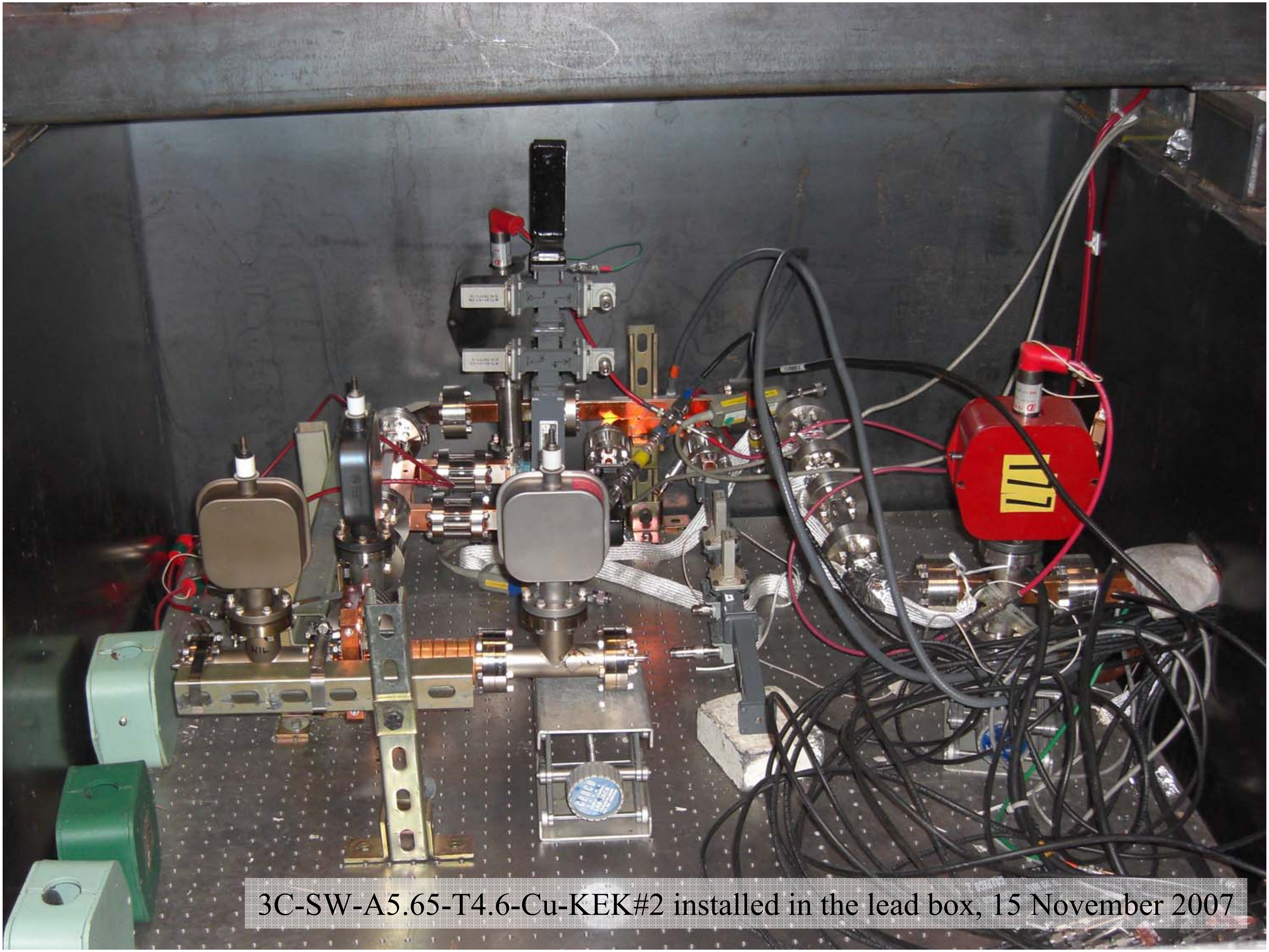
Two mode launchers

Surface electric fields in the mode launcher
E_{max}= 49 MV/m for 100 MW

S. Tantawi, C. Nantista



Yasuo Higashi, KEK



3C-SW-A5.65-T4.6-Cu-KEK#2 installed in the lead box, 15 November 2007

High Power Tests of Single Cell Standing Wave Structures

Tested

- Low shunt impedance, *a/lambda* = 0.215, *1C-SW-A5.65-T4.6-Cu*, 5 tested
- Low shunt impedance, TiN coated, *1C-SW-A5.65-T4.6-Cu-TiN*, 1 tested
- Three high gradient cells, low shunt impedance, *3C-SW-A5.65-T4.6-Cu,* 2 tested
- High shunt impedance, elliptical iris, *a/lambda* = 0.143, *1C-SW-A3.75-T2.6-Cu*, 1 tested
- High shunt impedance, round iris, *a/lambda* = 0.143, *1C-SW-A3.75-T1.66-Cu*, 1 tested
- Choke with 1mm gap in high gradient cell, *1C-SW-A5.65-T4.6-Choke-Cu*, 2 tested
- Low shunt impedance, made of CuZr, *1C-SW-A5.65-T4.6-CuZr,* 1 tested
- Low shunt impedance, made of CuCr, *1C-SW-A5.65-T4.6-CuCr,* 1 tested
- Highest shunt impedance copper structure *1C-SW-A2.75-T2.0-Cu-SLAC-#1*, 1 tested
- Photonic-Band Gap, low shunt impedance, *1C-SW-A5.65-T4.6-PBG-Cu,* 1 tested
- Low shunt impedance, made of hard copper *1C-SW-A5.65-T4.6-Clamped-Cu-SLAC#1,* 1 tested
- Low shunt impedance, made of molybdenum *1C-SW-A5.65-T4.6-Mo-Frascati-#1,* , 1 tested
- High shunt impedance, choke with 4mm gap, *1C-SW-A3.75-T2.6-4mm-Ch-Cu-SLAC-#1,* 1 tested
- Low shunt impedance, made of CuAg, *1C-SW-A5.65-T4.6-CuAg-SLAC-#1,* 1 tested

Now 21th test about to start,
low temperature brazed , high shunt impedance hard CuAg structure
1C-SW-A3.75-T2.6-CuAg-KEK-#1

Next experiments, as for 8th July 2009

Reproducibility tests:

High shunt impedance, elliptical iris, *1C-SW-A3.75-T2.6-Cu*
High shunt impedance, round iris, *1C-SW-A3.75-T1.66-Cu*
Low shunt impedance, made of CuZr, *1C-SW-A5.65-T4.6-CuZr*
Three high gradient cells, low shunt impedance, *3C-SW-A5.65-T4.6-Cu*

Geometry tests:

Three cells, WR90 1mm gap choke coupling to power source,
3C-SW-A5.65-T4.6-Cu-WR90
One cell one-side WR90 coupled *1C-SW-A3.75-T2.6-OneWR90-Cu*
3-cell symmetrically WR90 coupled *2C-SW-A3.75-T2.6-TwoWR90-Cu*

Materials:

High shunt impedance, made of CuZr, *1C-SW-A3.75-T2.6-CuZr*
High shunt impedance, made of CuAg, *1C-SW-A3.75-T2.6-CuAg*
High shunt impedance, made of hard CuAg, *1C-SW-A3.75-T2.6-Low-Temp-Brazed-CuAg*

Parameters of *periodic* structures, Eacc=100 MV/m

Name	**A2.75-T2.0-Cu**	**A3.75-T1.66-Cu**	**A3.75-T2.6-Cu**	**A3.75-T2.6-Ch-4mm-Cu**	**A5.65-T4.6-Choke-Cu**	**A5.65-T4.6-PBG-Cu**	**A5.65-T4.6-Cu**	***T53VG3***
Stored Energy [J]	0.153	0.189	0.189	0.294774	0.333	0.311	0.298	*0.09*
Q-value [x1000]	8.59	8.82	8.56	8.39	7.53	6.29	8.38	*6.77*
Shunt Impedance [MOhm/m]	102.891	85.189	82.598	52.03	41.34	36.46	51.359	*91.772*
Max. Mag. Field [A/m]	2.90E+05	3.14E+05	3.25E+05	3.45E+05	4.20E+05	8.95E+5	4.18E+05	*2.75E+05*
Max. Electric Field [MV/m]	203.1	266	202.9	210.4	212	212	211.4	*217.5*
Losses in one cell [MW]	**1.275**	**1.54**	**1.588**	**2.521**	**3.173**	**3.60**	**2.554**	***0.953***
a [mm]	2.75	3.75	3.75	3.75	5.65	5.65	5.65	*3.885*
a/lambda	**0.105**	**0.143**	**0.143**	**0.143**	**0.215**	**0.215**	**0.215**	***0.148***
Hmax*Z0/Eacc	1.093	1.181	1.224	1.300	1.581	**3.371**	1.575	*1.035*
t [mm]	2	1.664	2.6	2.6	4.6	4.6	4.6	*1.66*
Iris ellipticity	1.385	0.998	1.692	1.692	1.478	1.478	1.478	*1*
Ph. advance/cell [deg.]	180	180	180	180	180	180	180	*120*

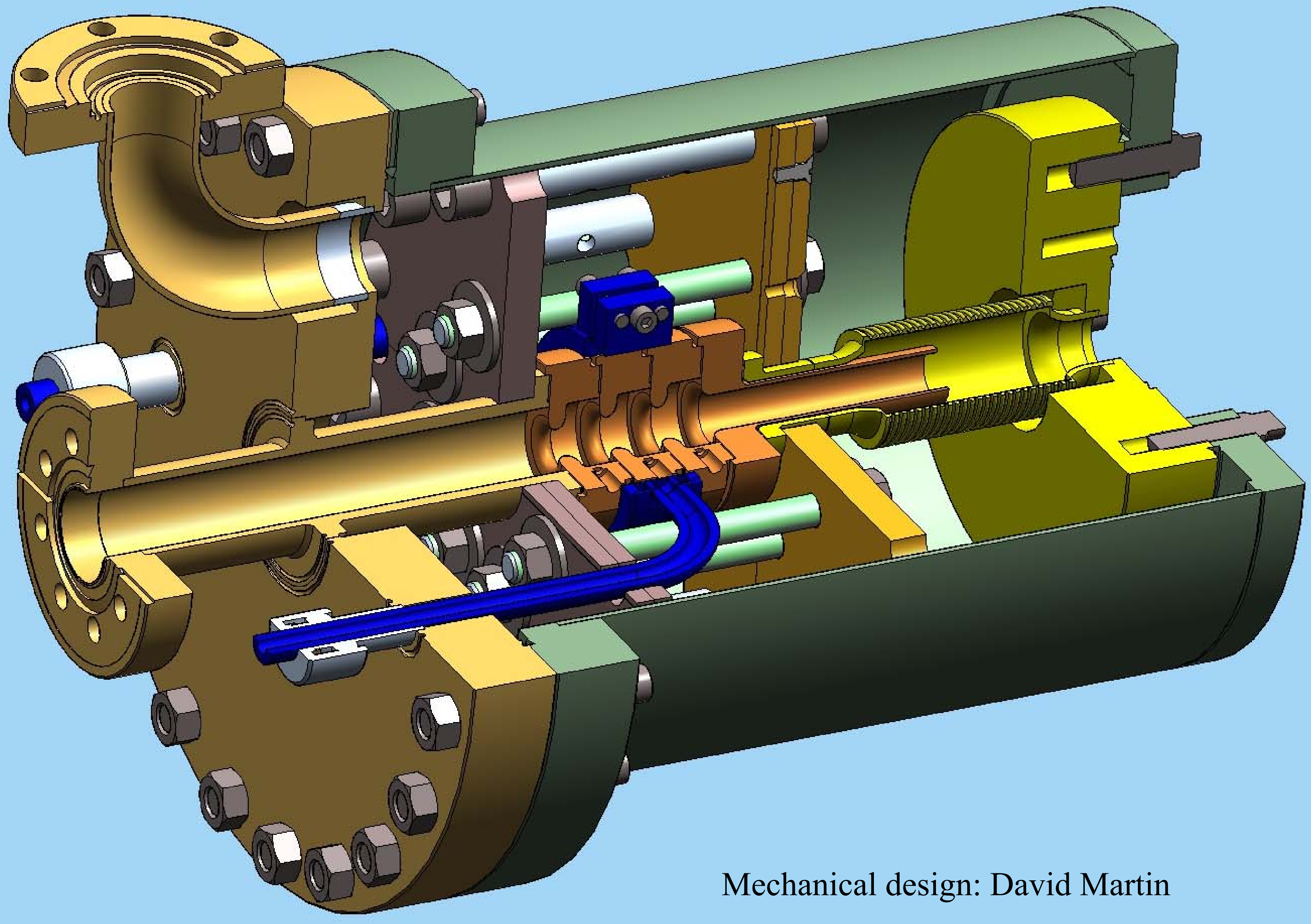
V.A. Dolgashev, 12 May 2009

Results

1C-SW-A5.65-T4.6-Clamped-Cu-SLAC#1
1C-SW-A3.75-T2.6-4mm-Ch-Cu-SLAC-#1
1C-SW-A5.65-T4.6-Mo-Frascati-#1
1C-SW-A5.65-T4.6-CuAg-SLAC-#1

Copper alloys

Clamped structure,
hard copper,
1C-SW- A5.65-T4.6-Clamped-Cu-SLAC-#1

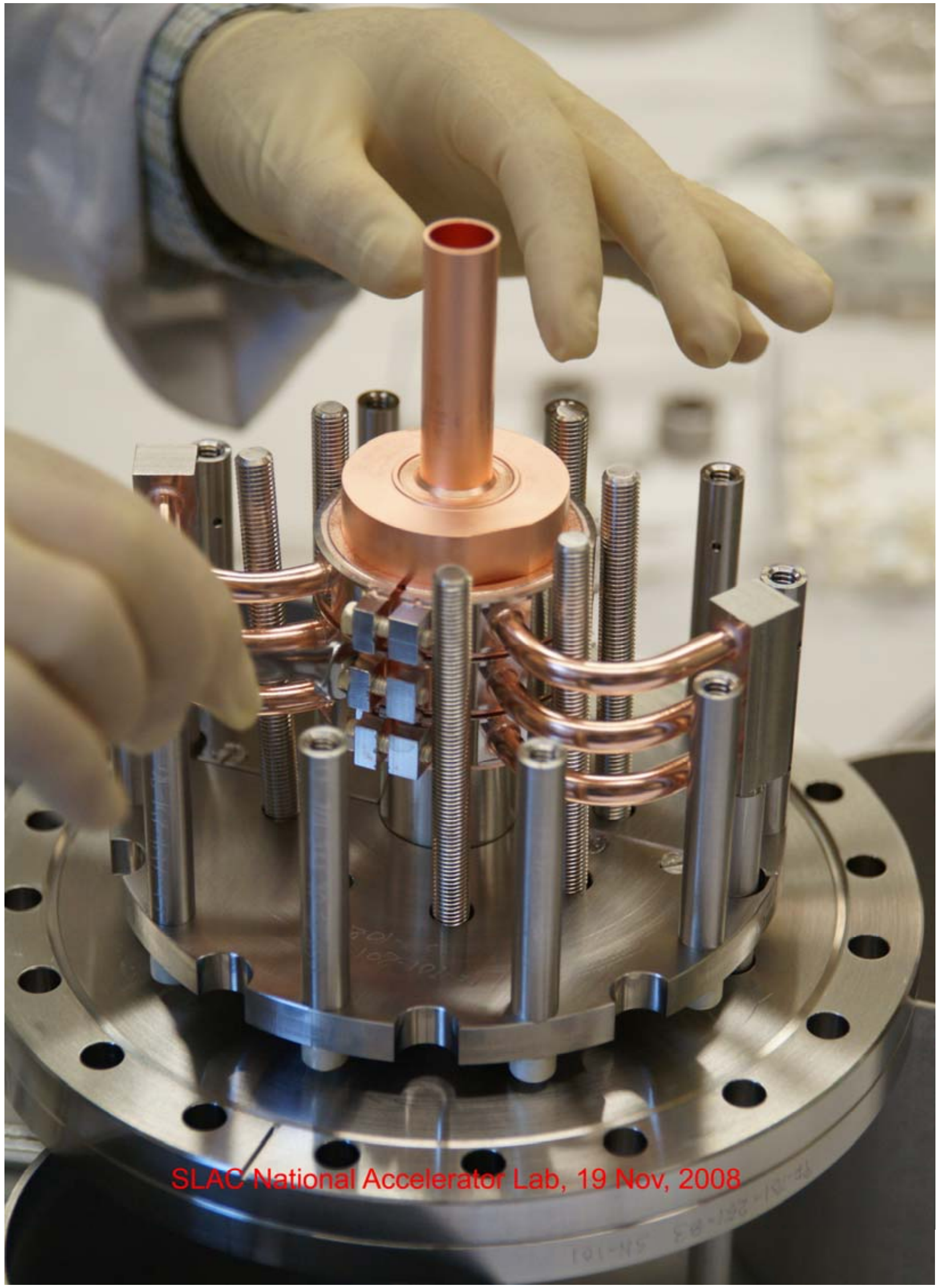


Mechanical design: David Martin

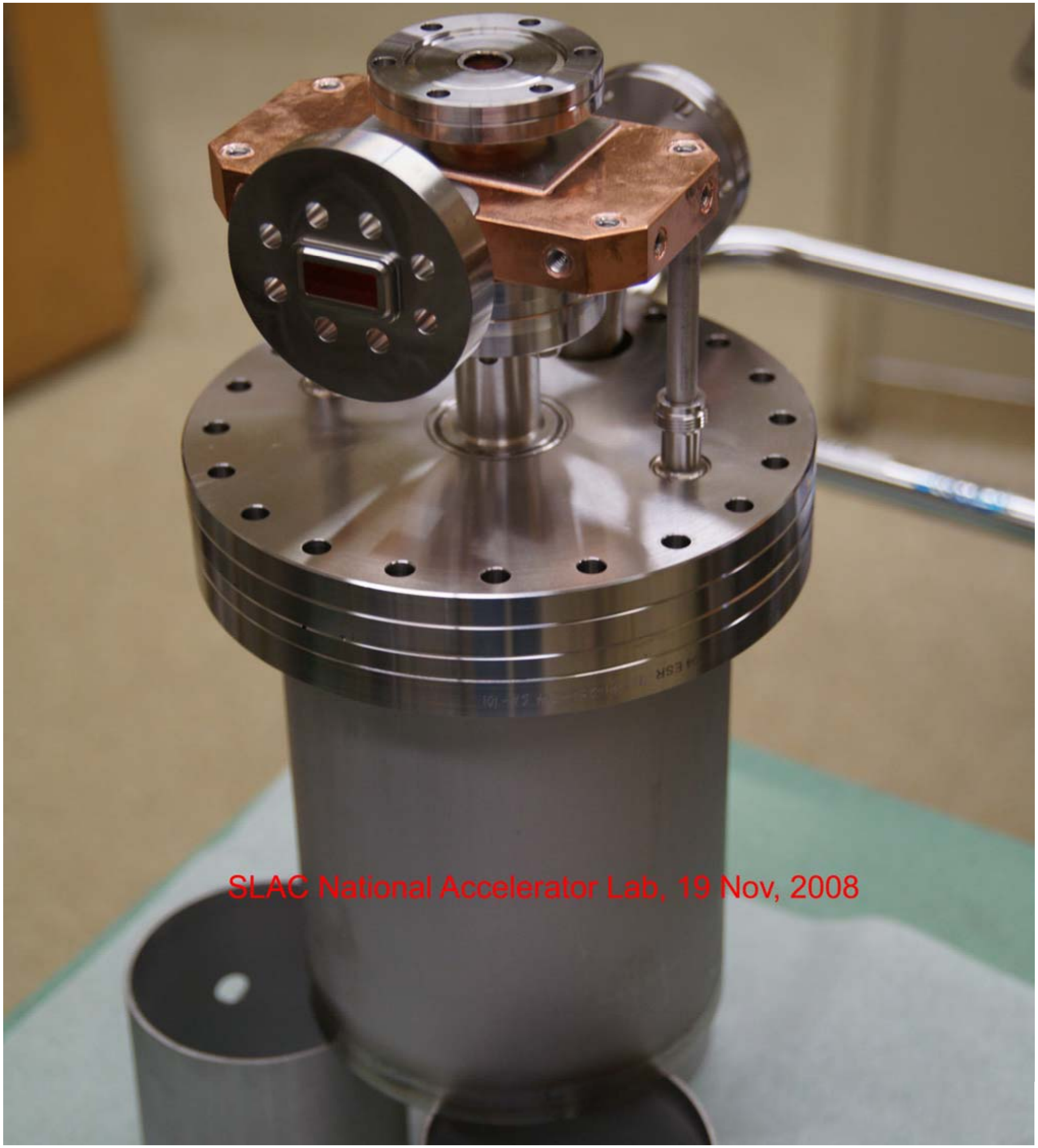
SLAC National Accelerator Lab, 19 Nov, 2008

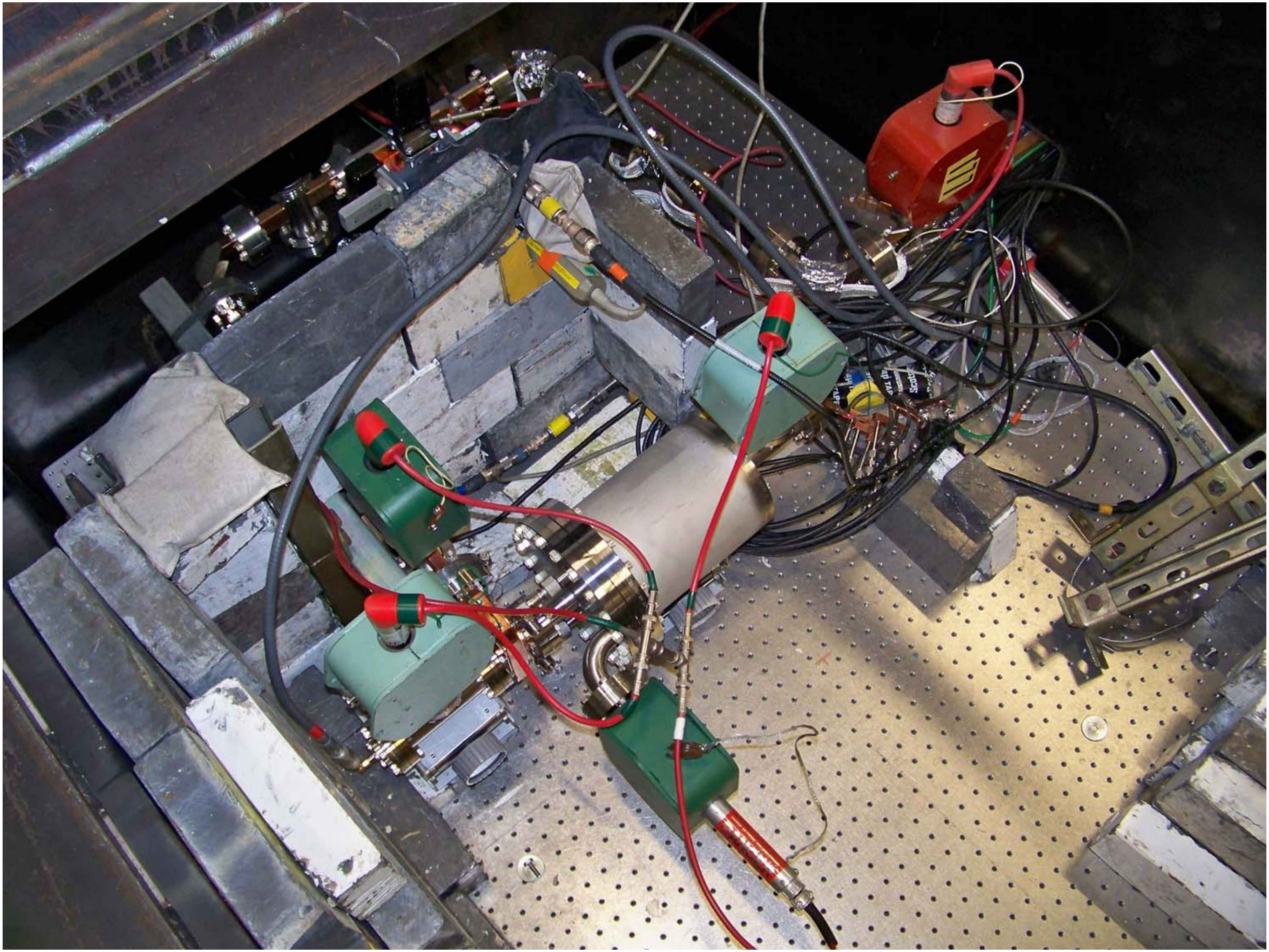

SLAC National Accelerator Lab, 19 Nov, 2008


SLAC National Accelerator Lab, 19 Nov, 2008

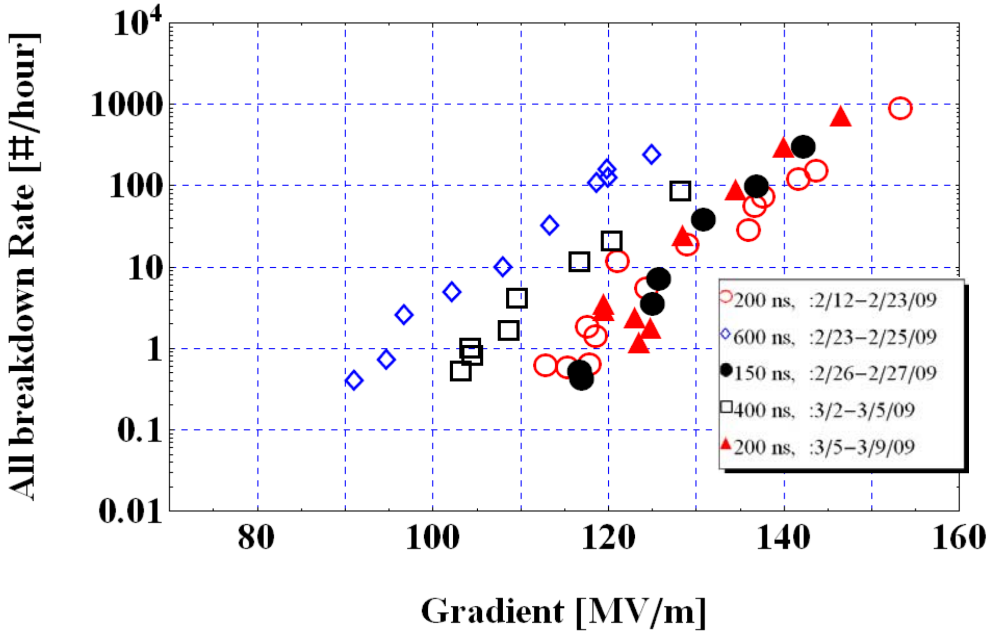


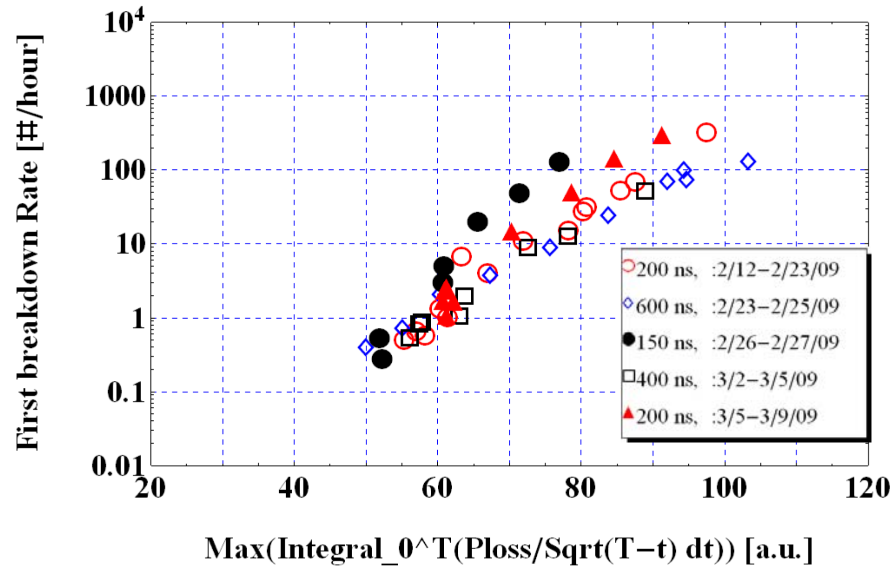
SLAC National Accelerator Lab, 19 Nov, 2008

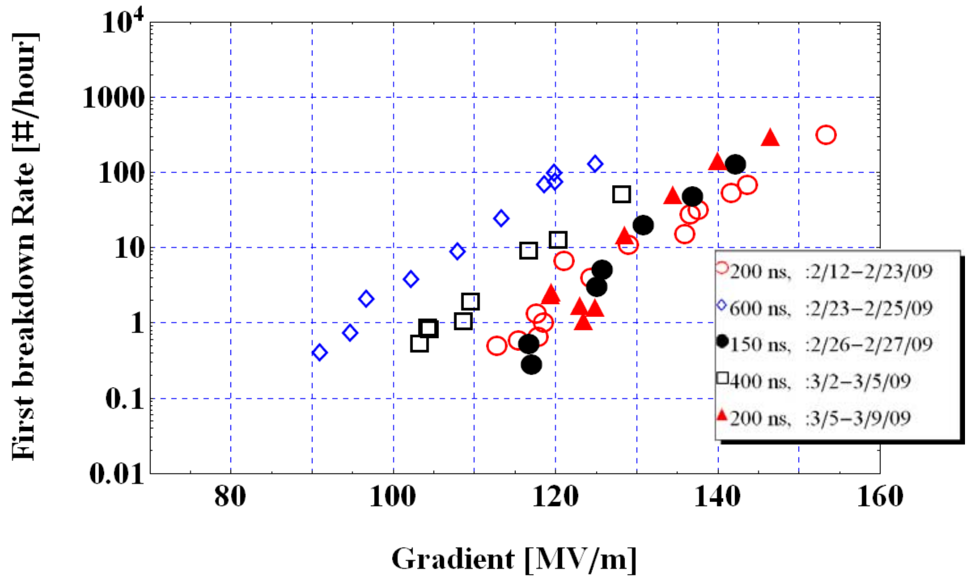

SLAC National Accelerator Lab, 19 Nov, 2008



1C-SW- A5.65-T4.6-Clamped-Cu-SLAC-#1

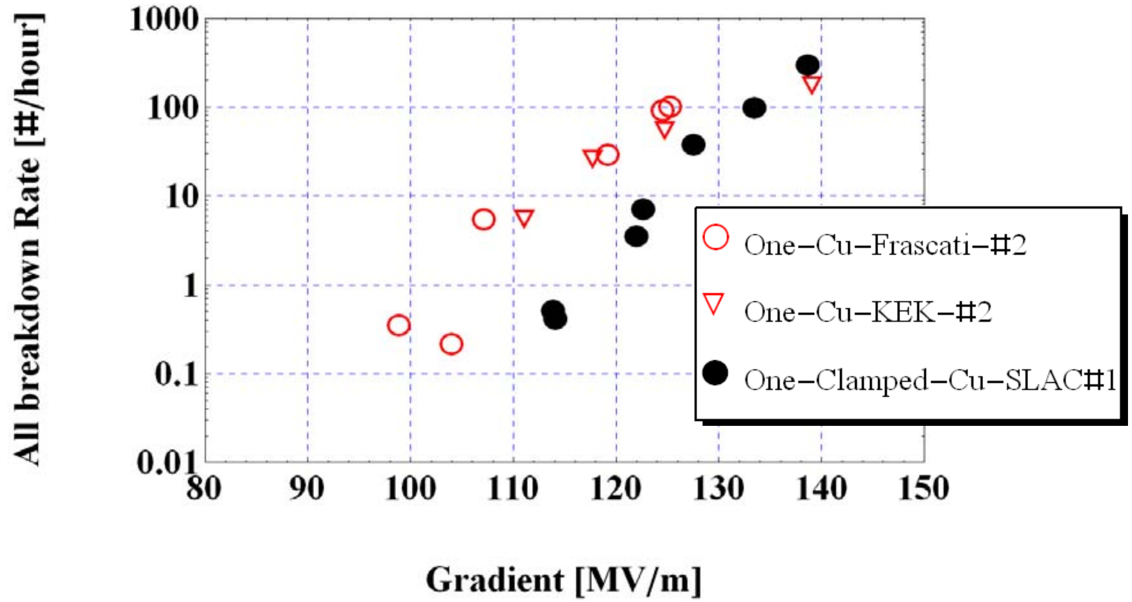


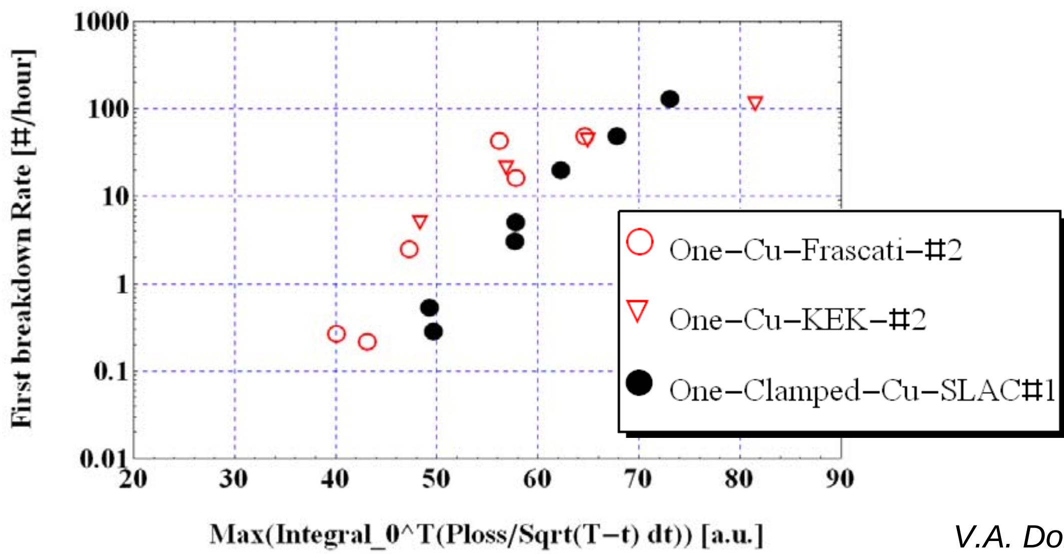




V.A. Dolgashev 11 March 2009

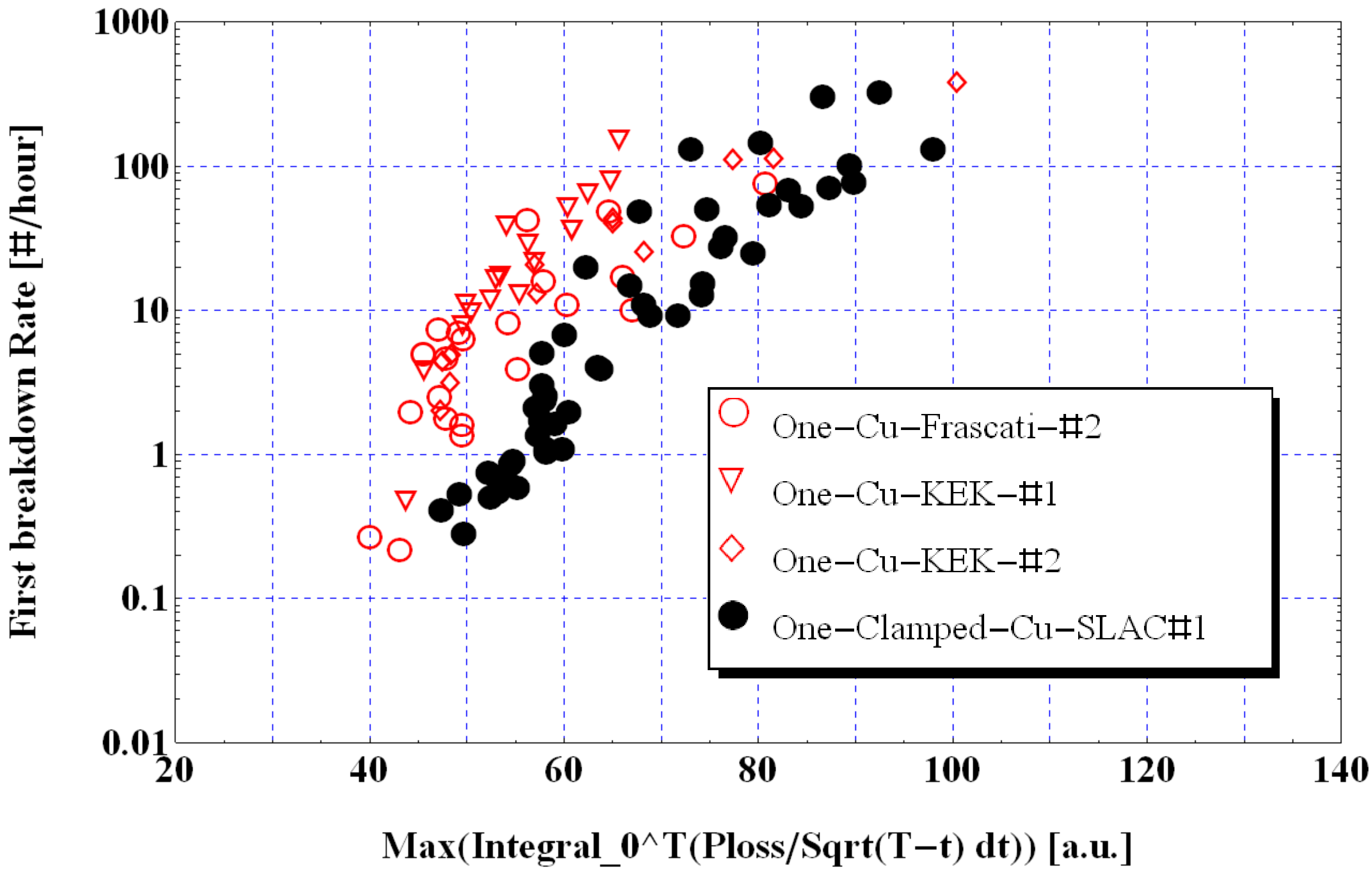
Comparison of peak pulse heating for two 1C-SW- A5.65-T4.6-Cu structures and 1C-SW- A5.65-T4.6-Clamped-Cu , *shaped* pulse, flat part 150 ns



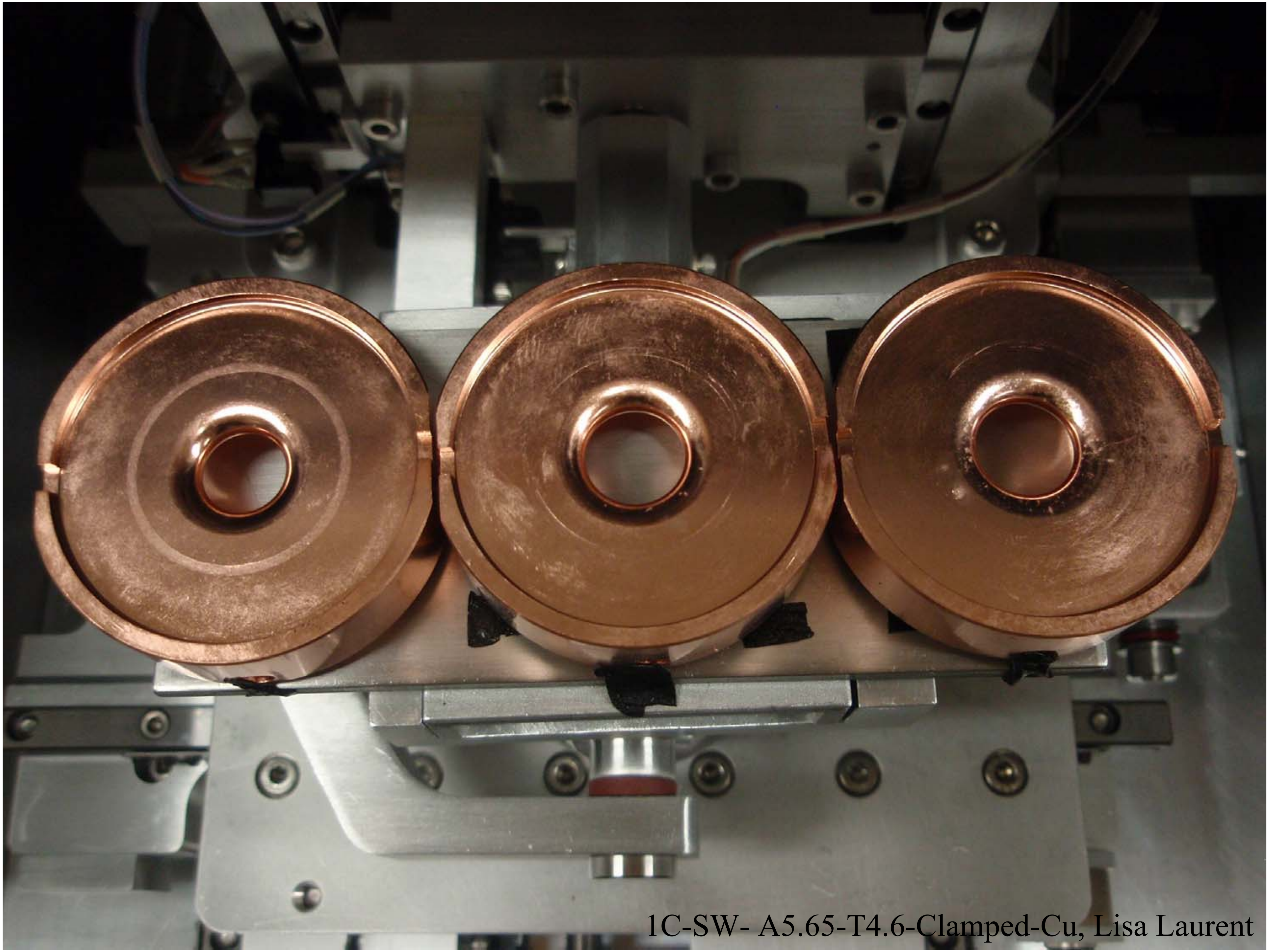


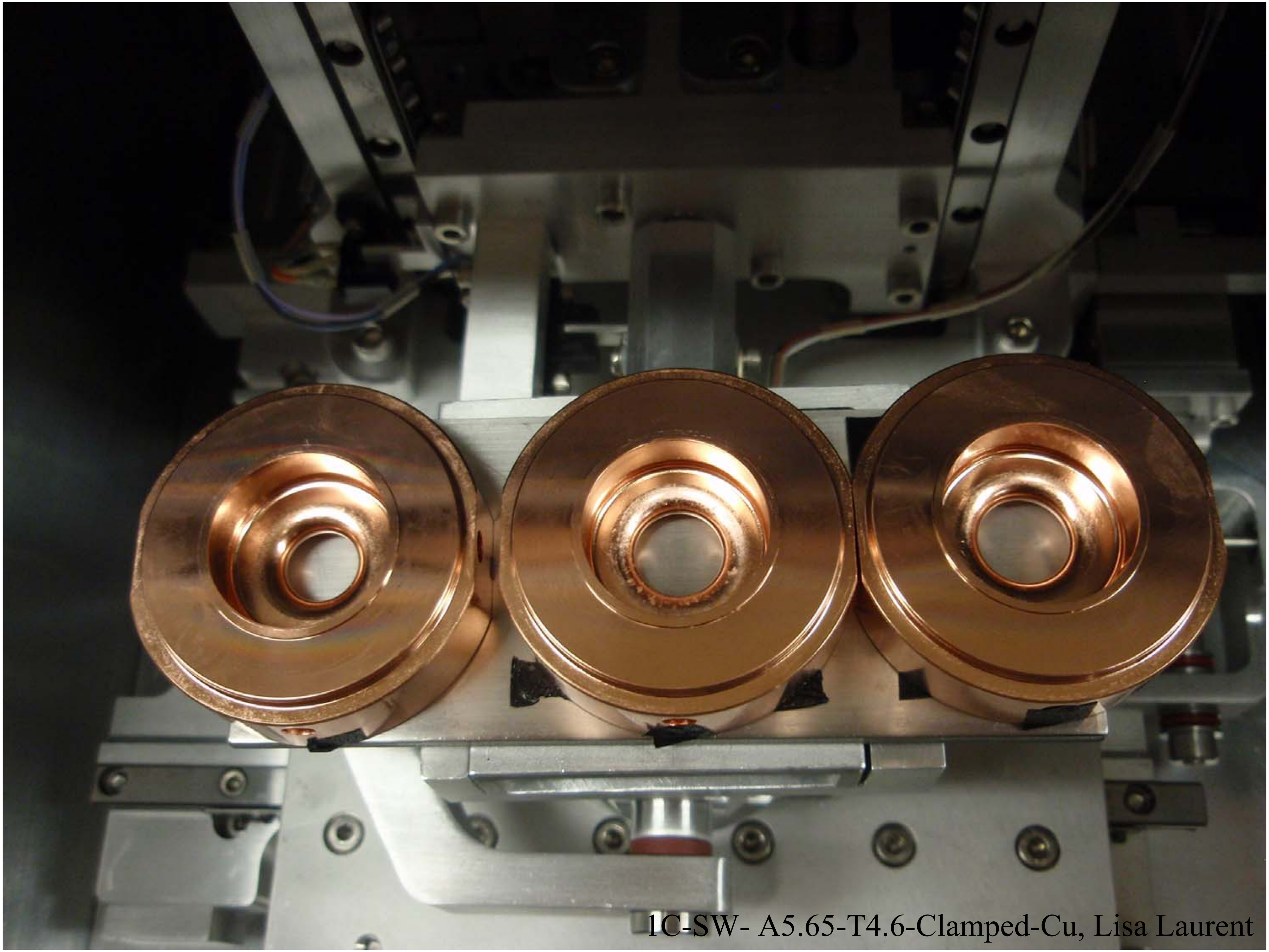
V.A. Dolgashev 11 March 2009

Comparison of peak pulse heating for three 1C-SW- A5.65-T4.6-Cu structures and 1C-SW- A5.65-T4.6-Clamped-Cu



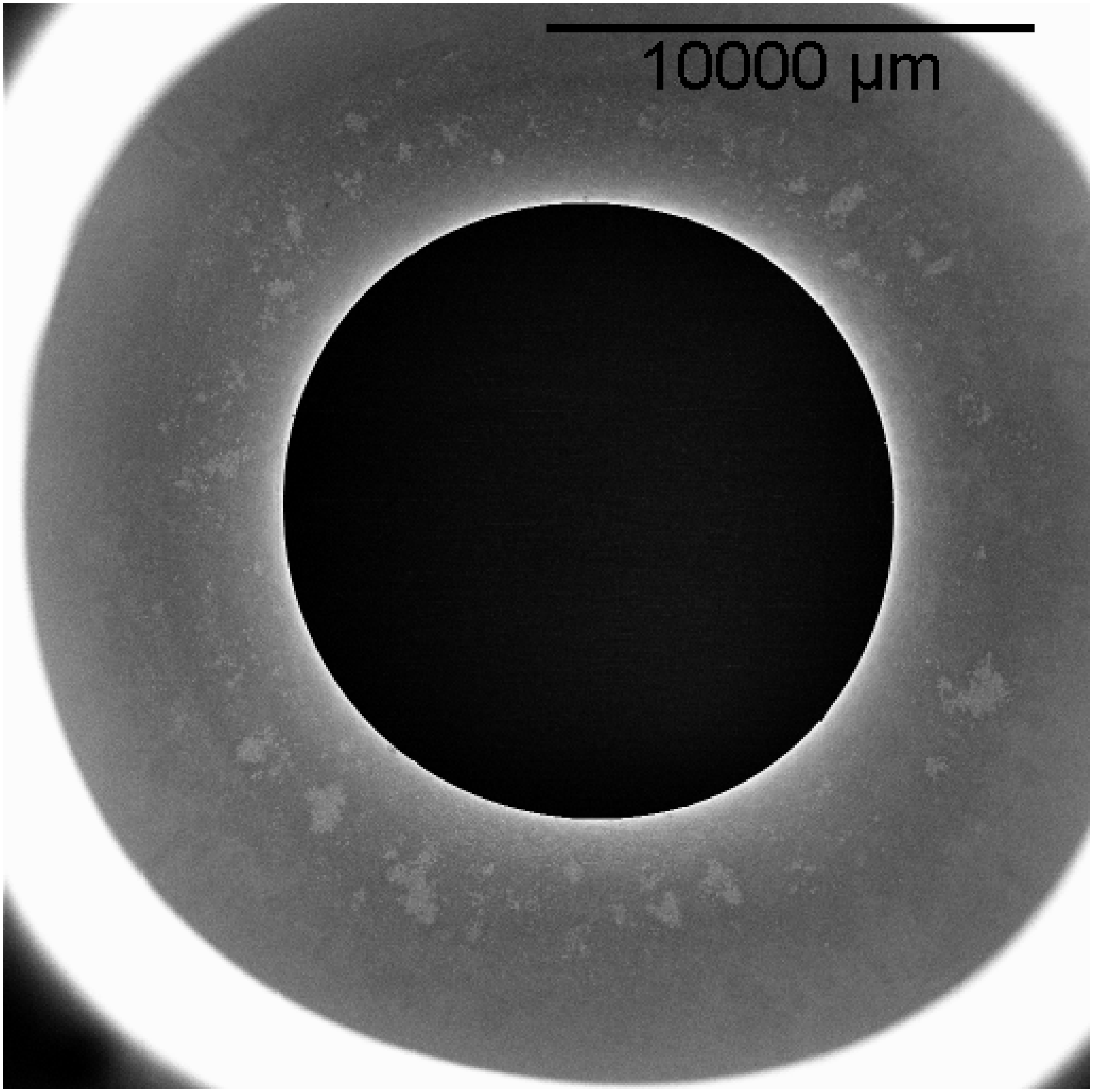
V.A. Dolgashev 11 March 2009


1C-SW- A5.65-T4.6-Clamped-Cu, Lisa Laurent

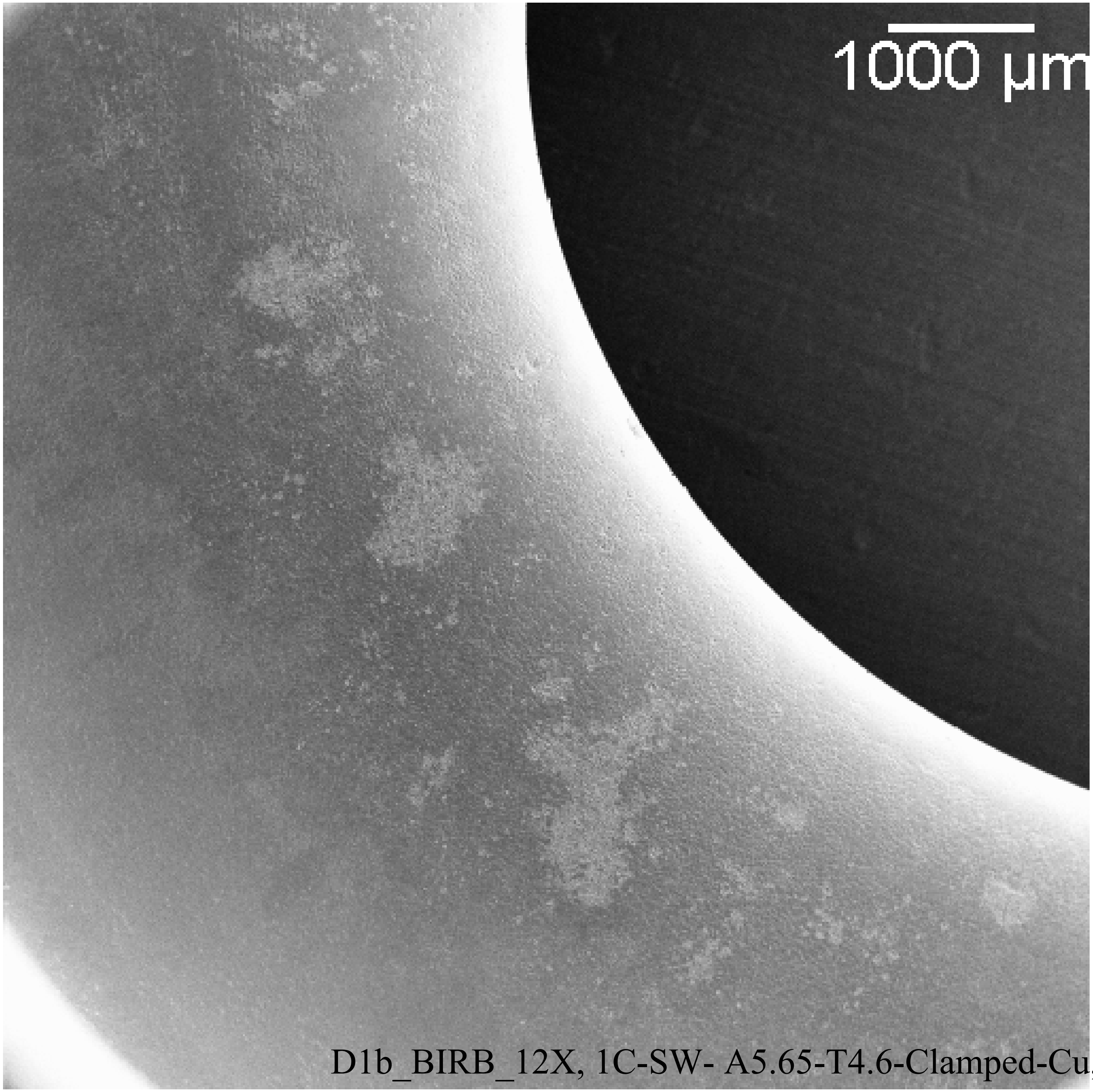


1C-SW- A5.65-T4.6-Clamped-Cu, Lisa Laurent

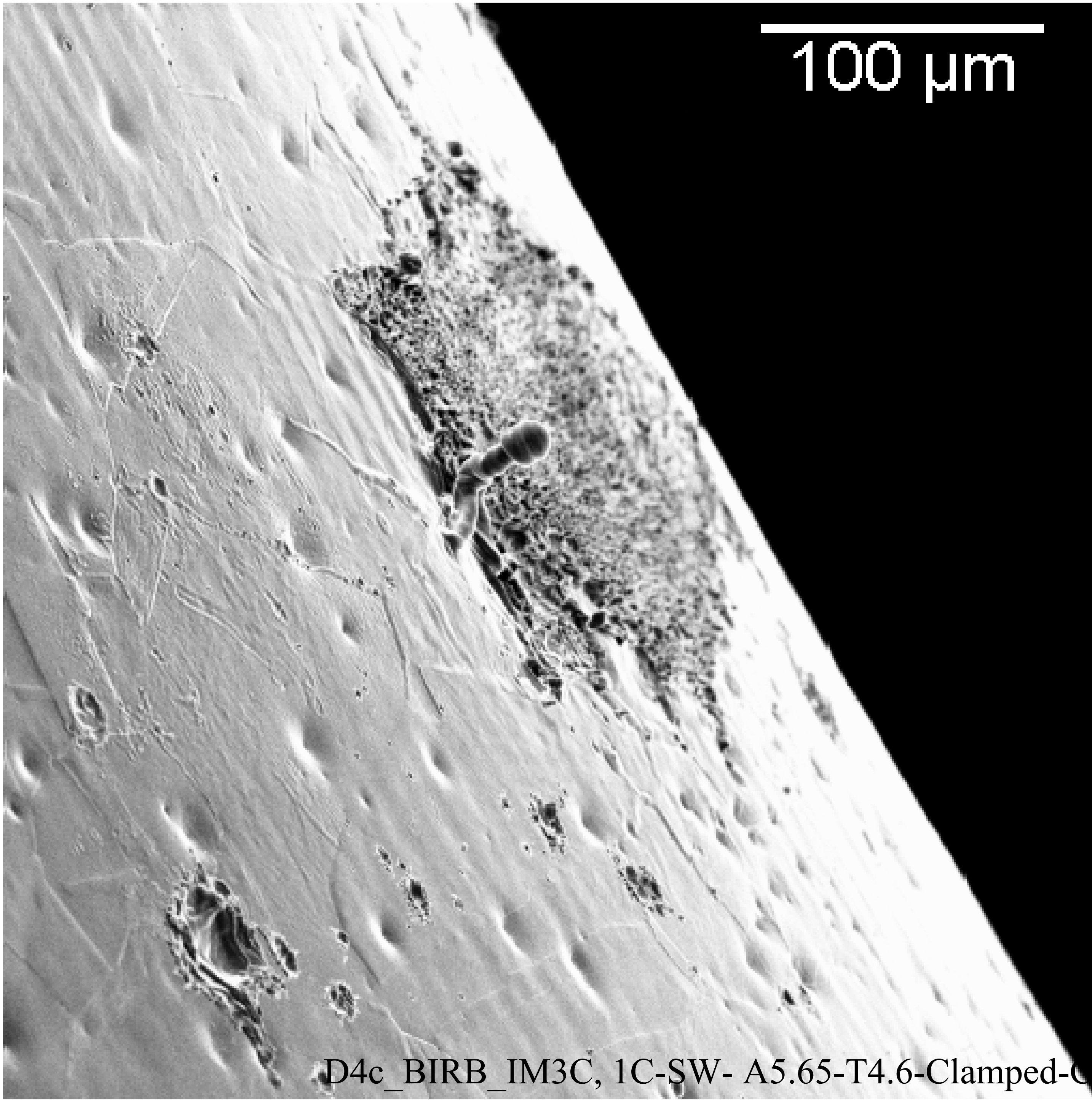
Damaged “patches”



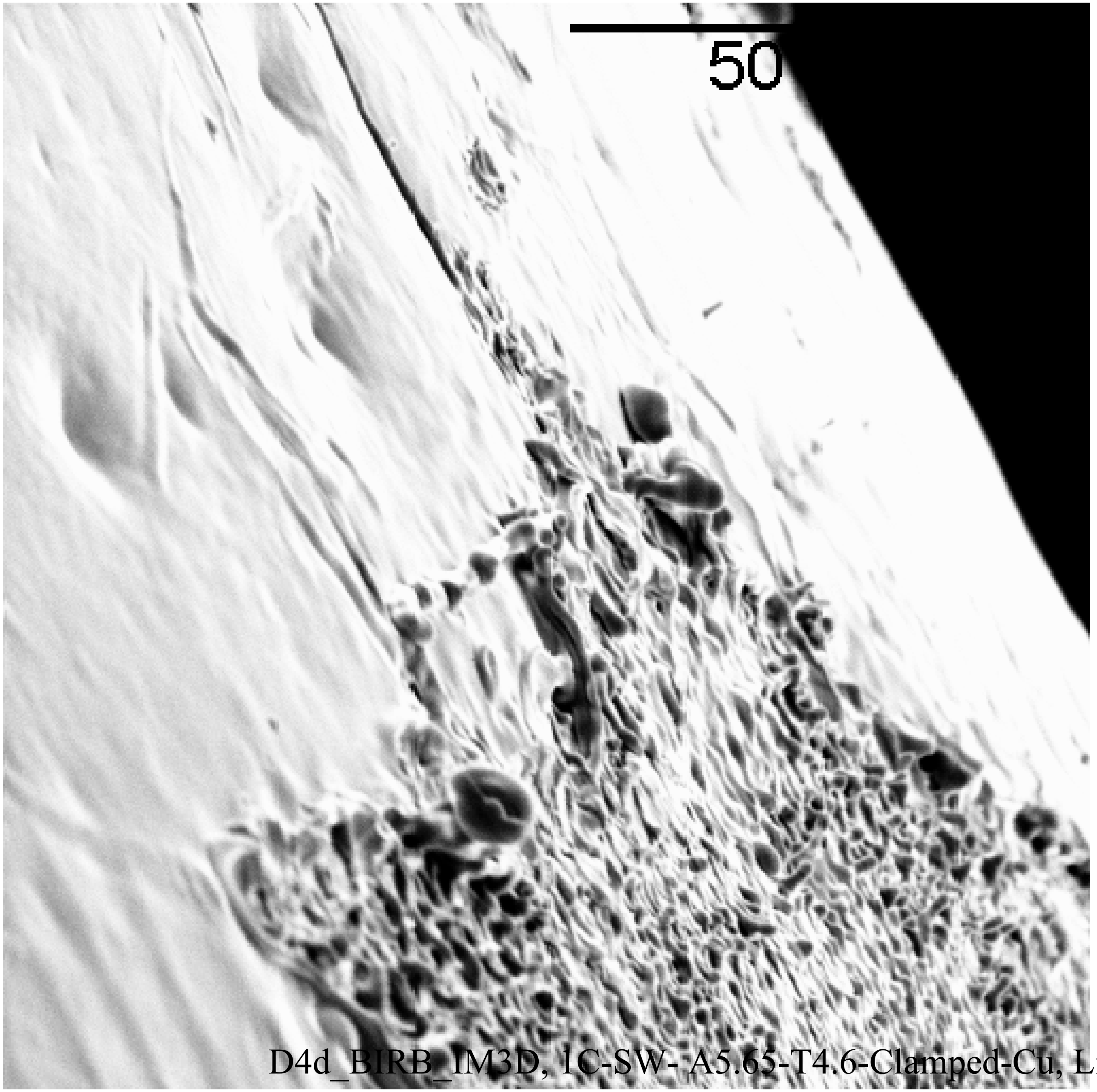
D1a2_BIRB_5X, 1C-SW- A5.65-T4.6-Clamped-Cu, Lisa Laurent



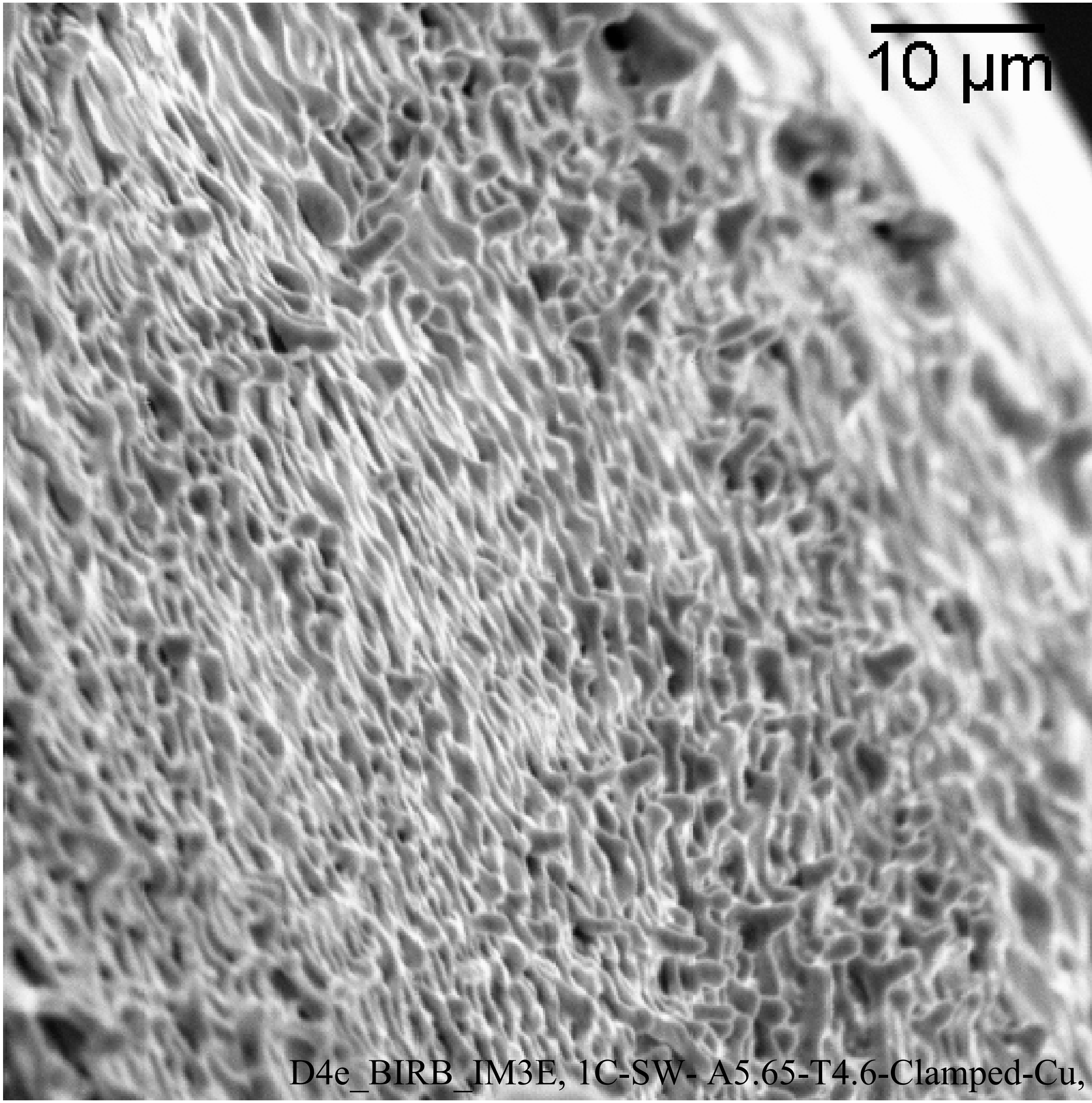
D1b_BIRB_12X, 1C-SW- A5.65-T4.6-Clamped-Cu, Lisa Laurent



D4c_BIRB_IM3C, 1C-SW- A5.65-T4.6-Clamped-Cu, Lisa Laurent

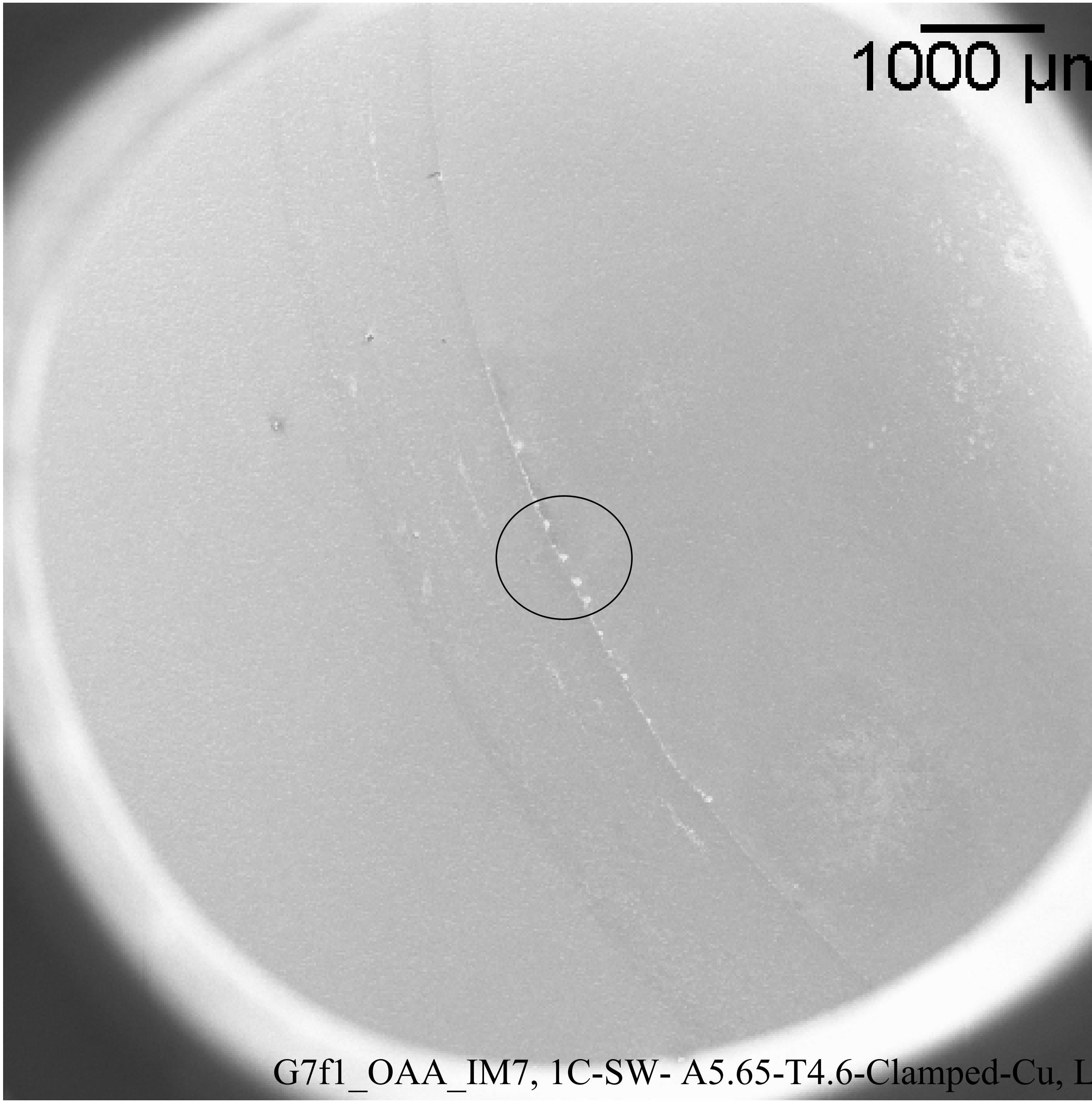


D4d_BIRB_IM3D, 1C-SW- A5.65-T4.6-Clamped-Cu, Lisa Laurent

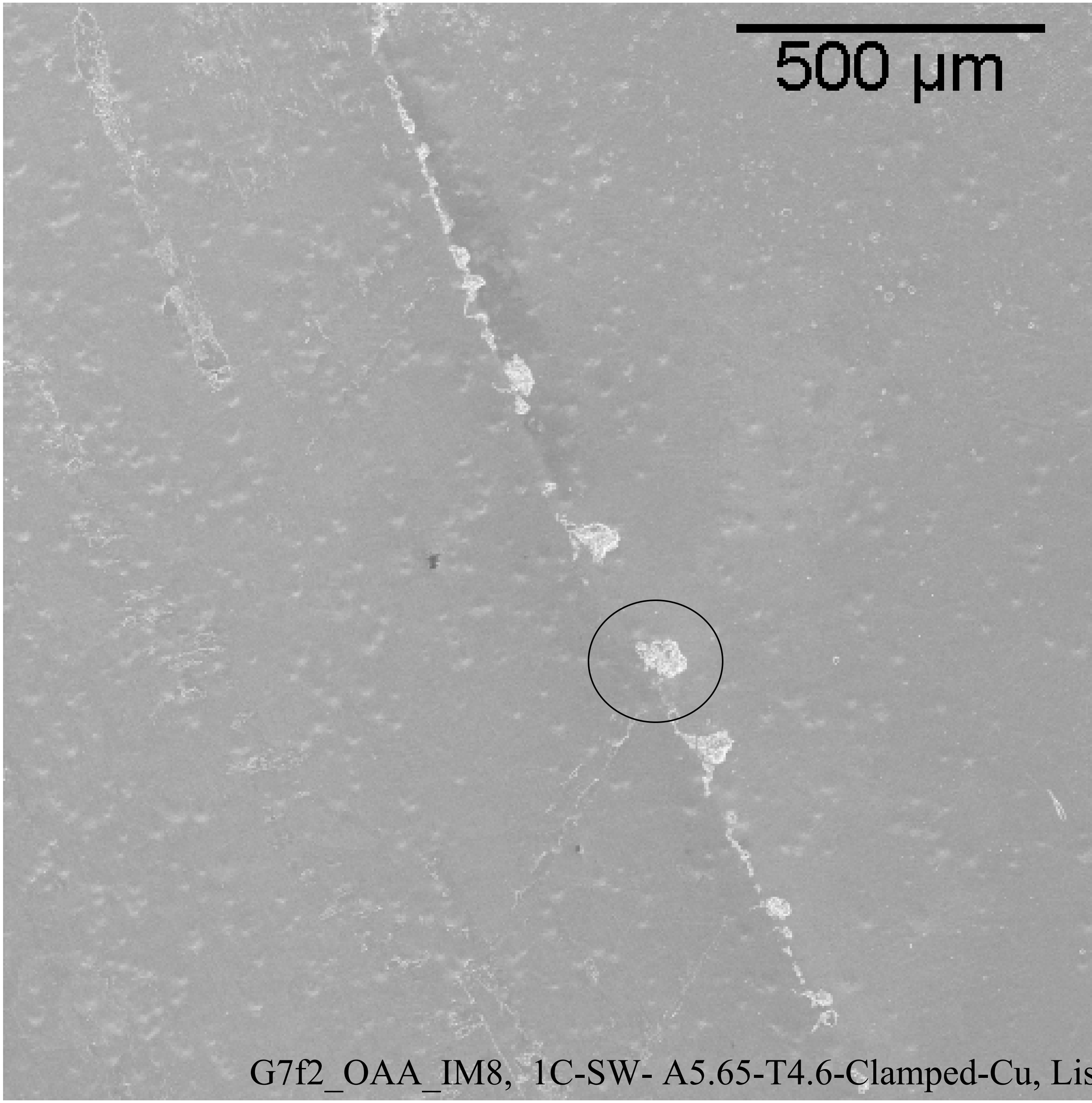


D4e_BIRB_IM3E, 1C-SW- A5.65-T4.6-Clamped-Cu, Lisa Laurent

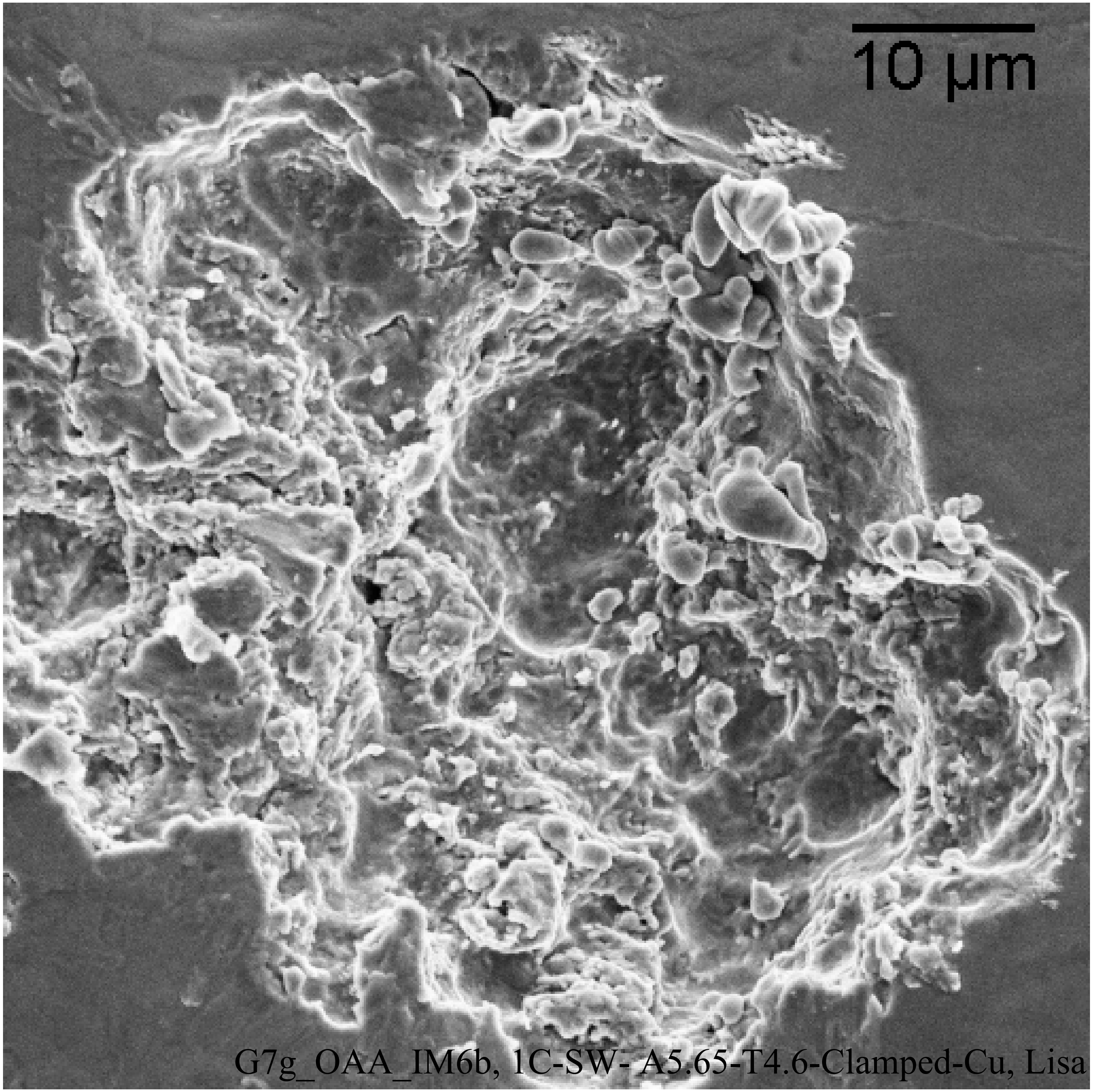
Erosion of joint between pressed cell



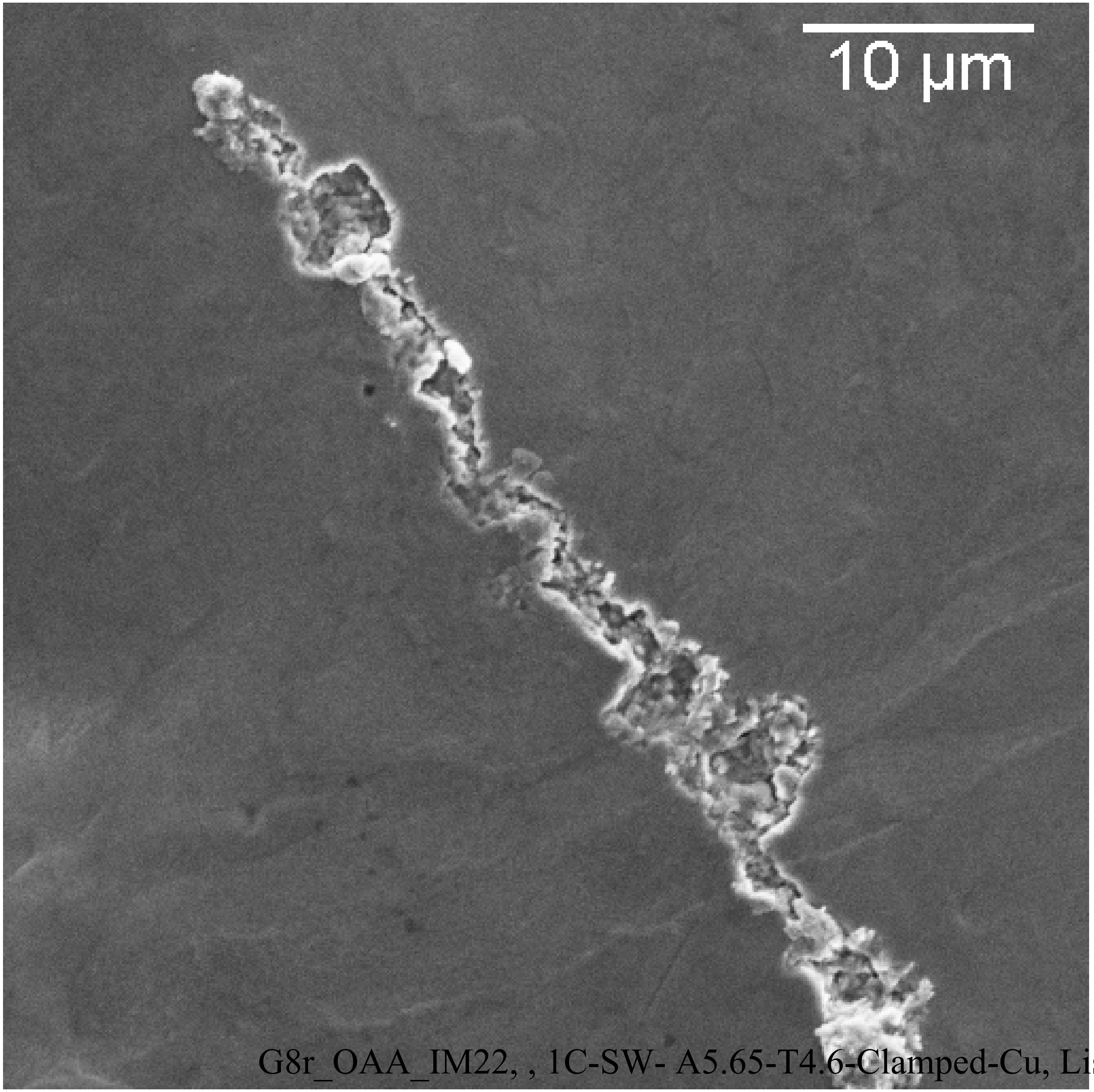
G7f1_OAA_IM7, 1C-SW- A5.65-T4.6-Clamped-Cu, Lisa Laurent



G7f2_OAA_IM8, 1C-SW- A5.65-T4.6-Clamped-Cu, Lisa Laurent



G7g_OAA_IM6b, 1C-SW- A5.65-T4.6-Clamped-Cu, Lisa Laurent



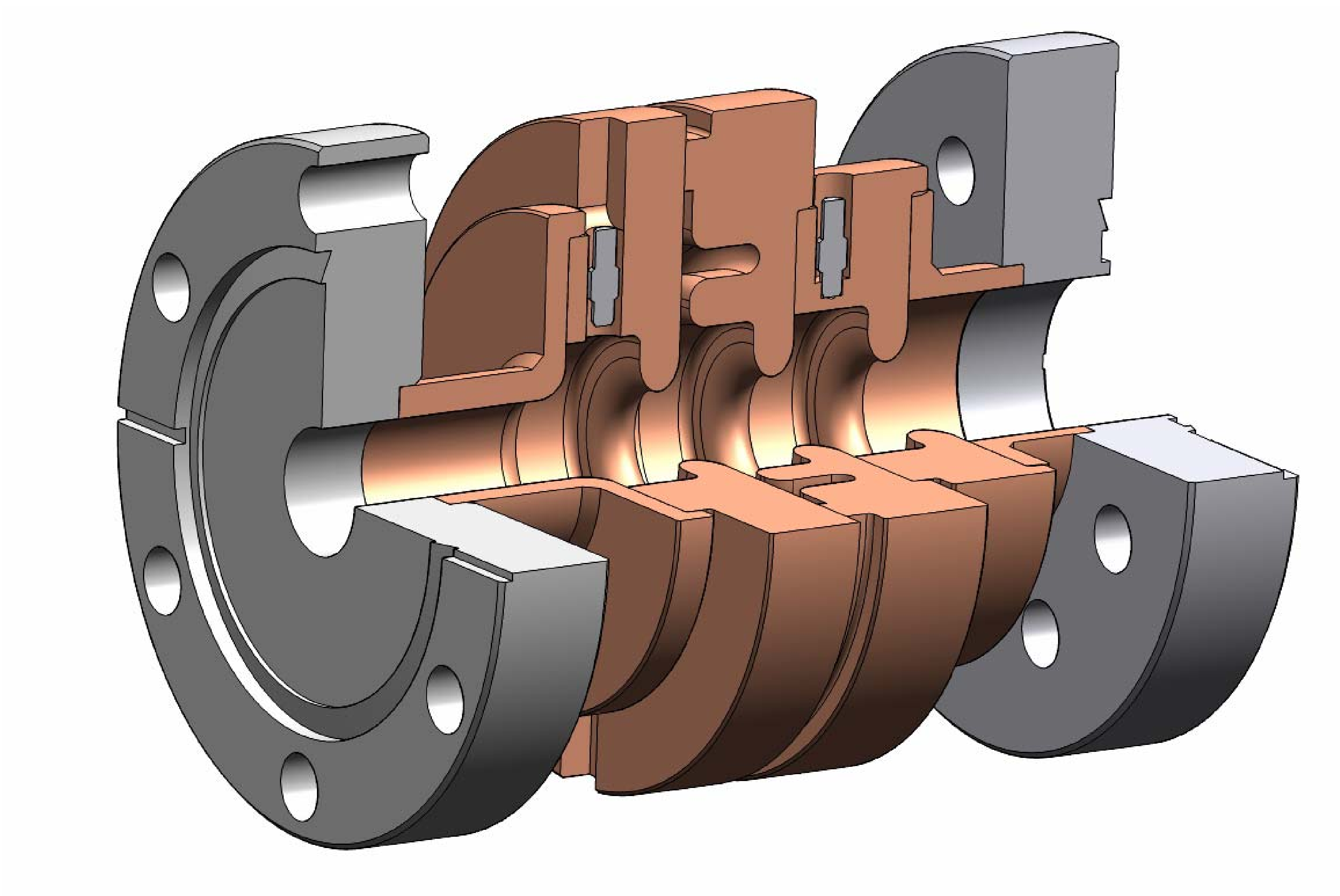
G8r_OAA_IM22, , 1C-SW- A5.65-T4.6-Clamped-Cu, Lisa Laurent

Geometry test

4mm choke structure

1C-SW-A3.75-T2.6-4mm-Ch-Cu-SLAC-#1

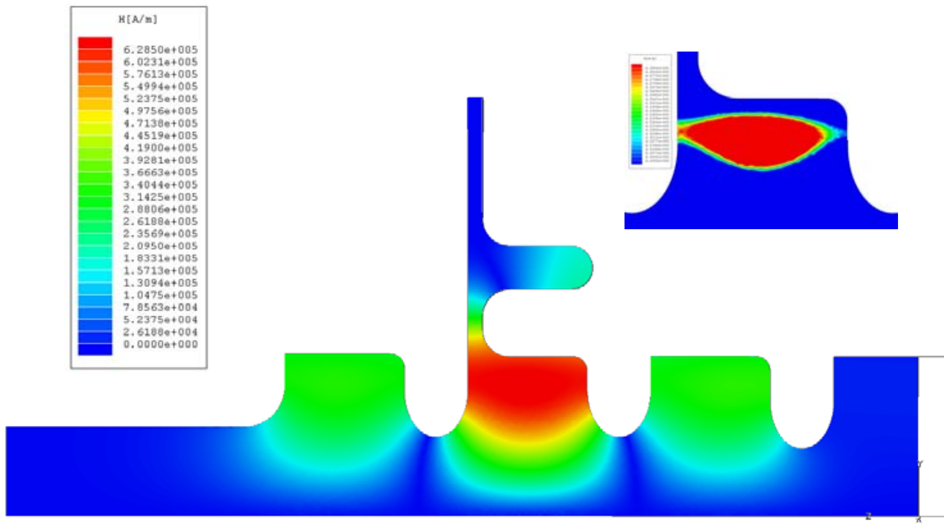
Before: Choke with 1mm gap

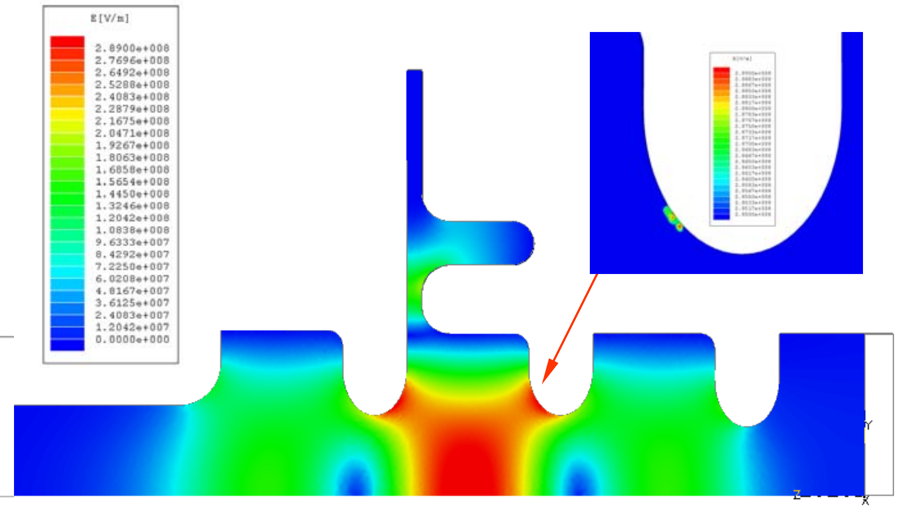


1C-SW-A5.65-T4.6-Cu-Choke

1C-SW-A5.65-T4.6-Cu-Choke

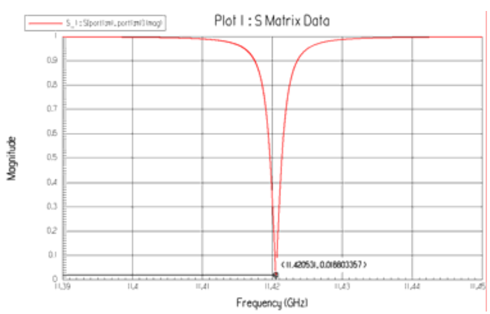
10 MW input

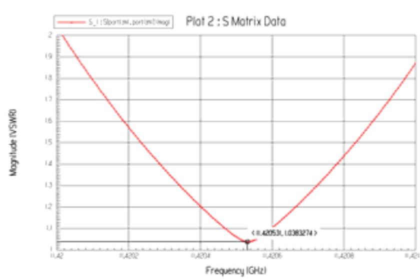


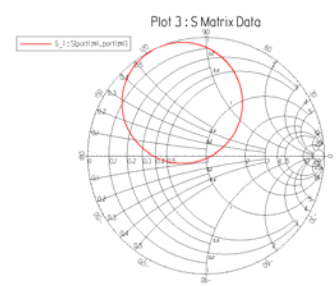


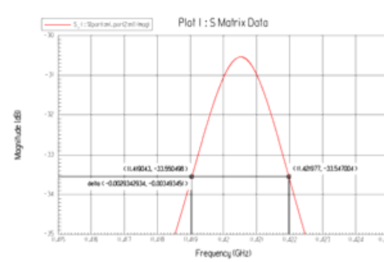
Maximum magnetic field 628.5 kA/m
(SLANS 627.5 kA/m)

Maximum electric field 289 MV/m
((SLANS 297.7 MV/m)









$$\frac{11.42053}{0.00293429} = 3.892\times 10^{3}$$

$$\frac{11.42053}{0.00293429}\cdot(1 + 1.03832) = 7.933\times 10^{3}$$

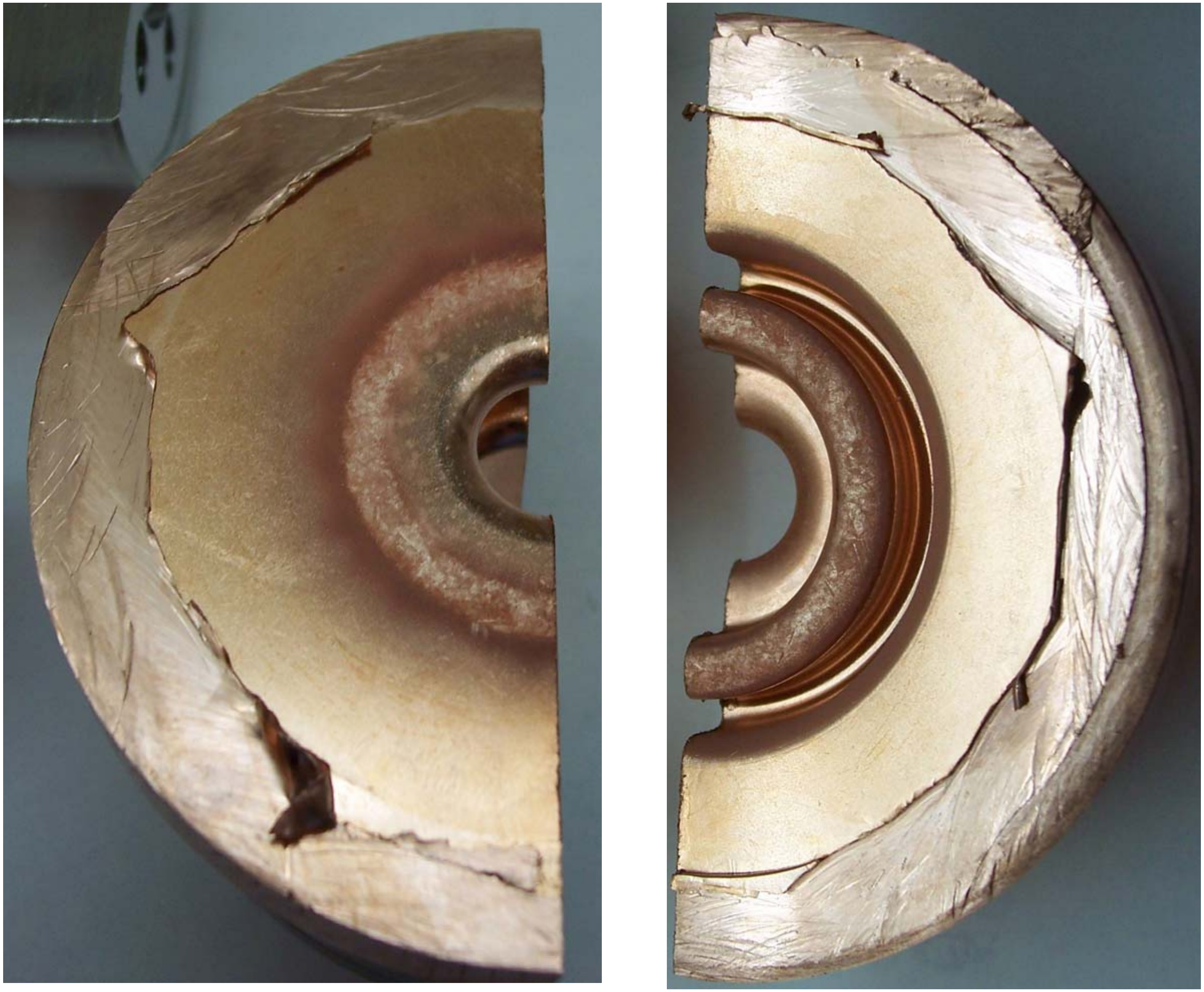
Resonance at 11.42053 GHz β = 1.03832

(SLANS 11.424 GHz) (SLANS 1.045)

Over-coupled loaded Q
Unloaded Q=7,933
(SLANS 7,933.5)

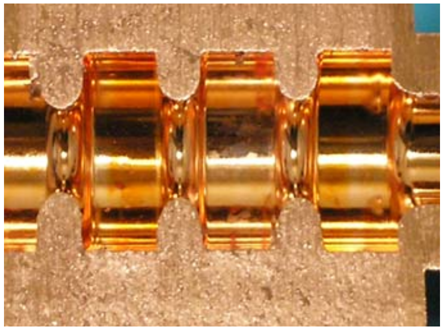
V.A. Dolgashev, 25 September 2007

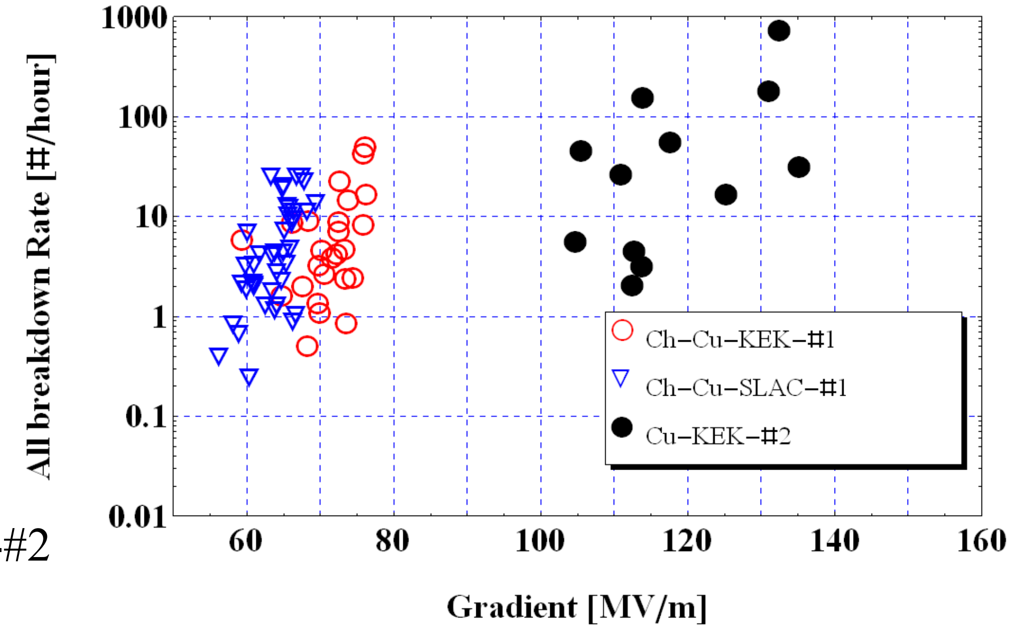
1C-SW-A5.65-T4.6-**Ch**-Cu-SLAC-#1



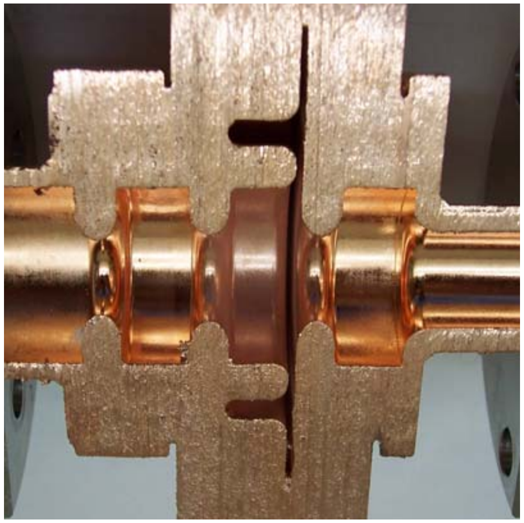
1C-SW-A5.65-T4.6-**Ch-**Cu-SLAC-#1

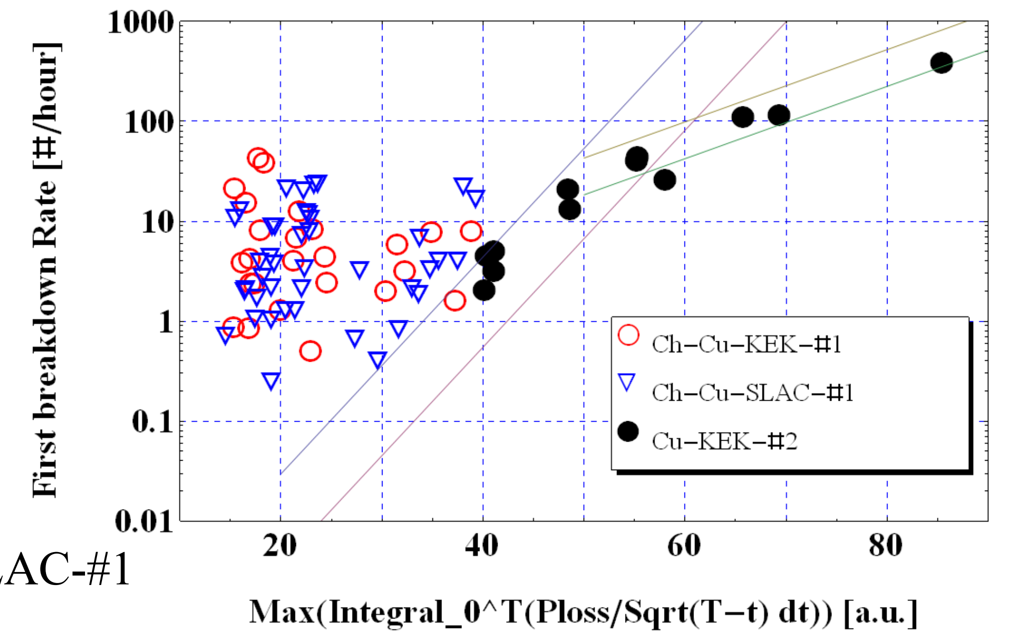
Choke *vs.* no Choke





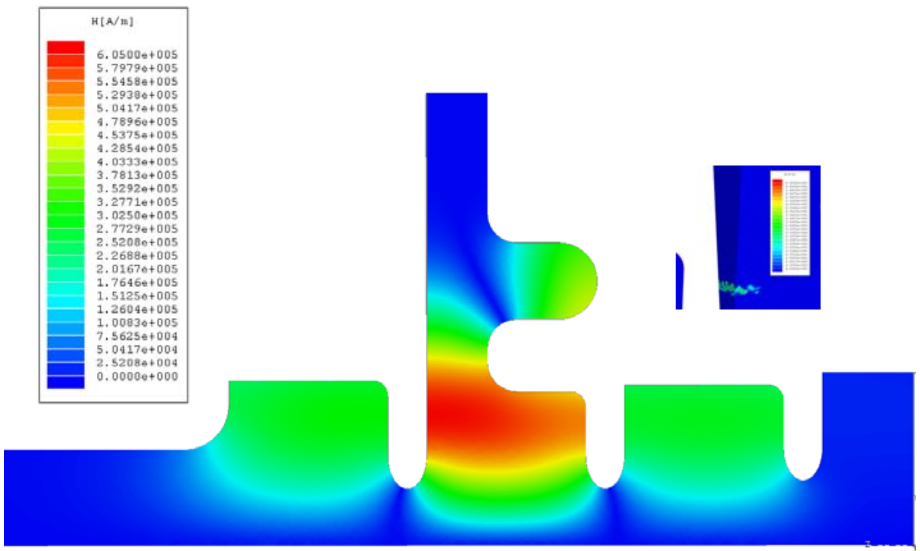
1C-SW-A5.65-T4.6-Cu-KEK-#2

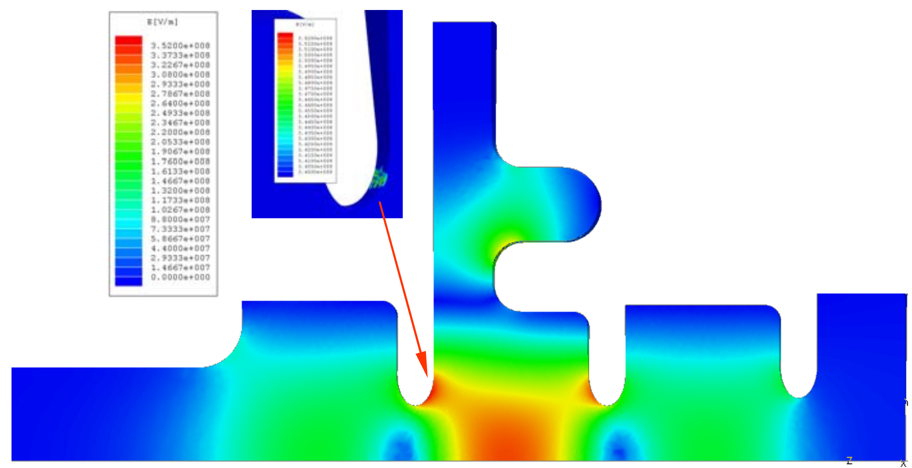




1C-SW-A5.65-T4.6-**Ch**-Cu-SLAC-#1

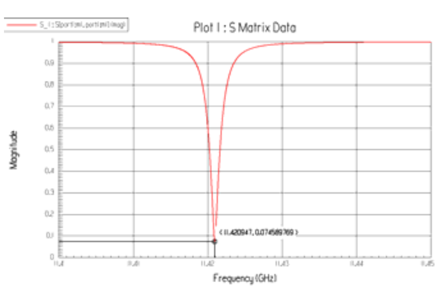
Next choke structure: 1C-SW-A3.75-T2.6-Cu-4mm-Choke, 10 MW losses

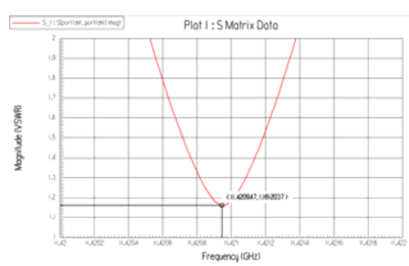


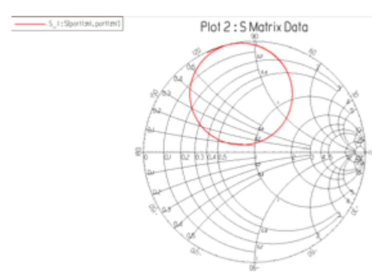


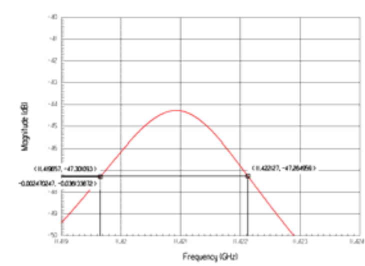
Maximum magnetic field 604 kA/m
(SLANS 602.065 kA/m)

Maximum electric field 347 MV/m
(SLANS 350.85 MV/m)









$$\frac{11.421}{0.002470247} = 4.6234243\times 10^{3}$$

Resonance at 11.420947 GHz β = 0.861

(SLANS 11.42391 GHz) (SLANS 1.04952)

Under-coupled loaded Q
Unloaded Q=8,605
(SLANS 8,668)

$$\frac{11.421}{0.002470247}\cdot\left(1 + 1.1612037^{-1}\right) = 8.605\times 10^{3}$$

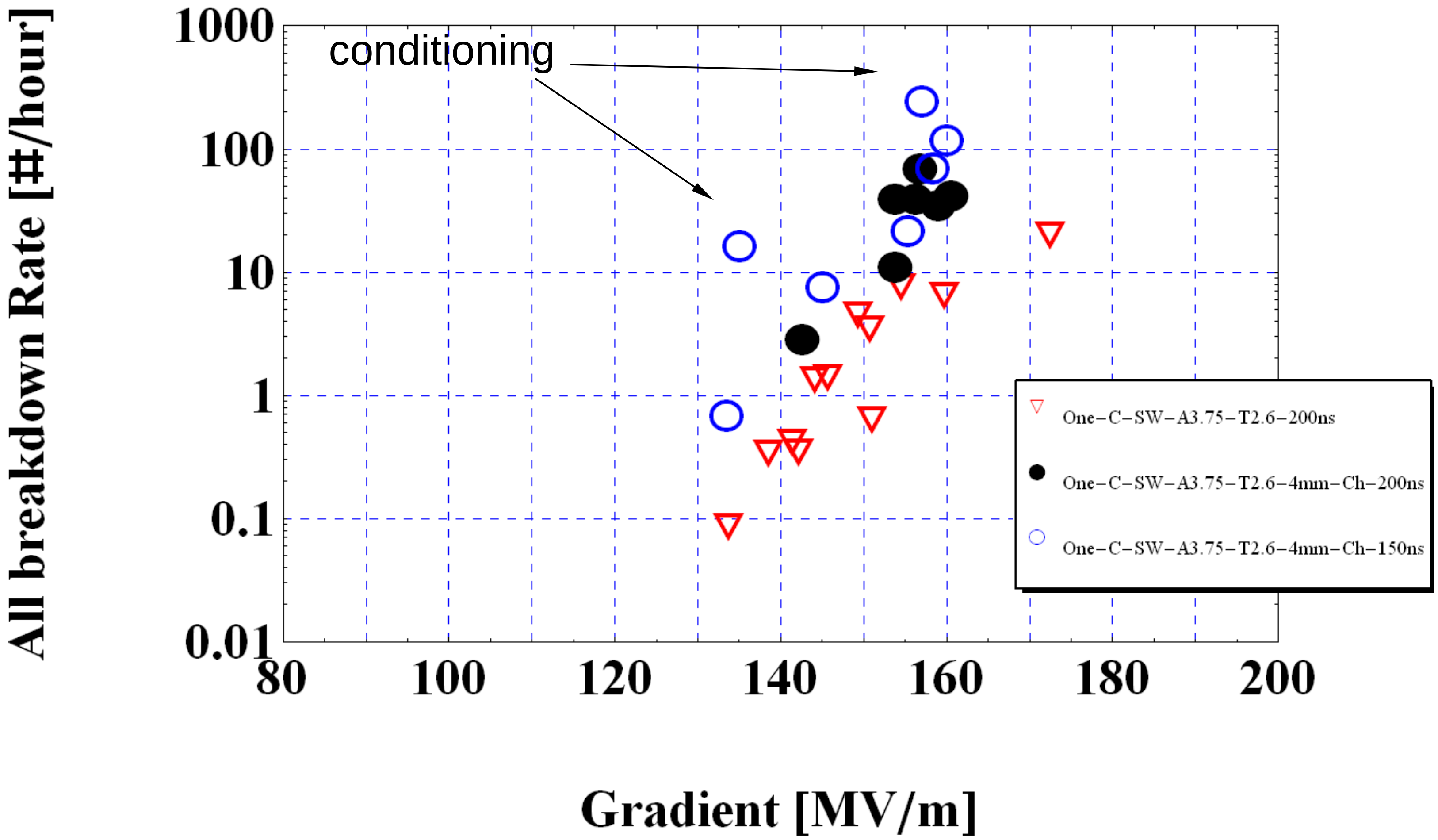
V.A. Dolgashev, 18 September 2008

Parameters of *periodic* structures, Eacc=100 MV/m

Name	A2.75-T2.0-Cu	A3.75-T1.66-Cu	A3.75-T2.6-Cu	A3.75-T2.6-Ch-4mm-Cu	A5.65-T4.6-Choke-Cu	A5.65-T4.6-PBG-Cu	A5.65-T4.6-Cu	*T53VG3*
Stored Energy [J]	0.153	0.189	0.189	0.294774	0.333	0.311	0.298	*0.09*
Q-value [x1000]	8.59	8.82	8.56	8.39	7.53	6.29	8.38	*6.77*
Shunt Impedance [MOhm/m]	102.891	85.189	82.598	52.03	41.34	36.46	51.359	*91.772*
Max. Mag. Field [A/m]	2.90E+05	3.14E+05	3.25E+05	3.45E+05	4.20E+05	8.95E+5	4.18E+05	*2.75E+05*
Max. Electric Field [MV/m]	203.1	266	202.9	210.4	212	212	211.4	*217.5*
Losses in one cell [MW]	**1.275**	**1.54**	**1.588**	**2.521**	**3.173**	**3.60**	**2.554**	***0.953***
a [mm]	2.75	3.75	3.75	3.75	5.65	5.65	5.65	*3.885*
a/lambda	**0.105**	**0.143**	**0.143**	**0.143**	**0.215**	**0.215**	**0.215**	***0.148***
Hmax*Z0/Eacc	1.093	1.181	1.224	1.300	1.581	**3.371**	1.575	*1.035*
t [mm]	2	1.664	2.6	2.6	4.6	4.6	4.6	*1.66*
Iris ellipticity	1.385	0.998	1.692	1.692	1.478	1.478	1.478	*1*
Ph. advance/cell [deg.]	180	180	180	180	180	180	180	*120*

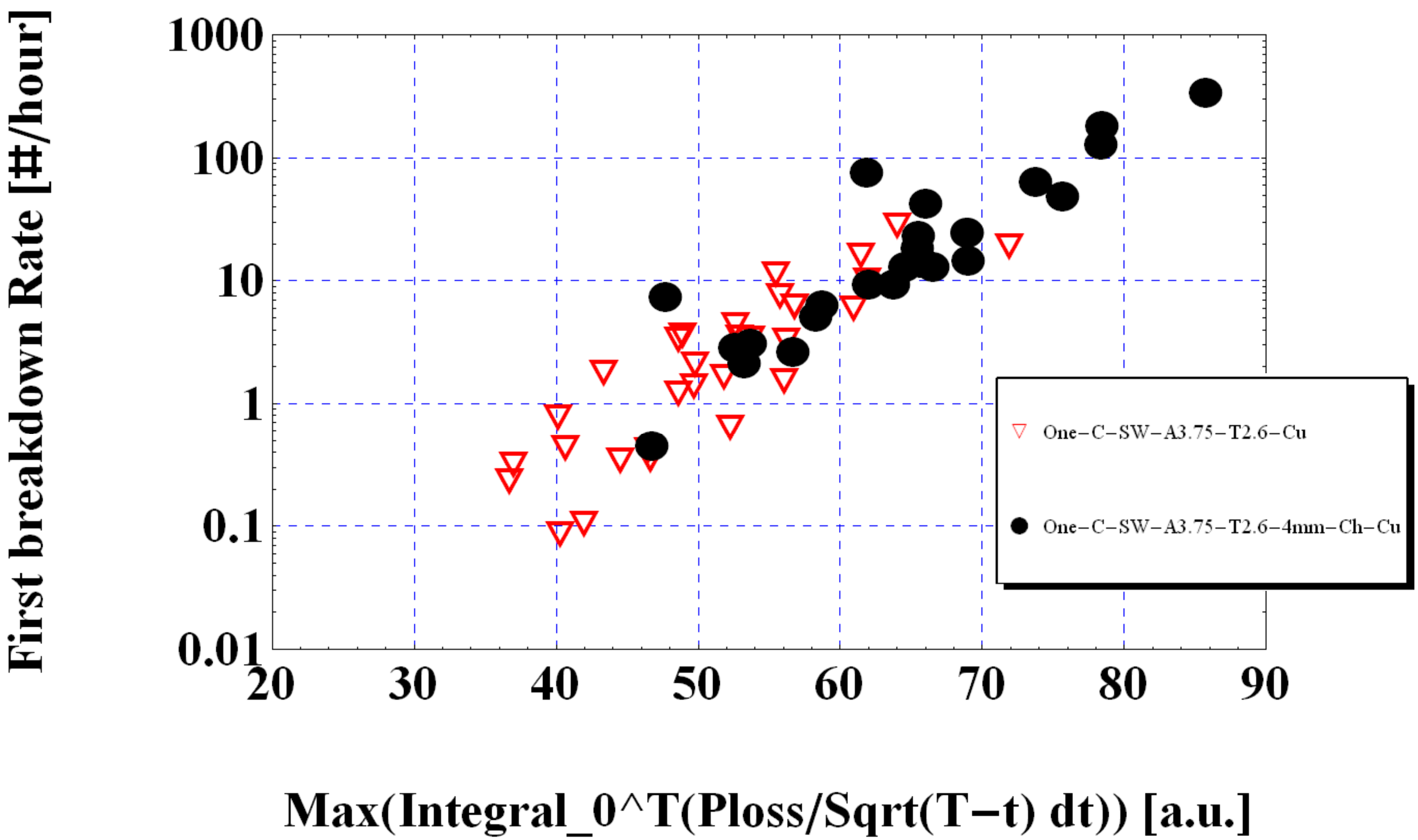
V.A. Dolgashev, 12 May 2009

Gradient comparison between 1C-SW-A3.75-T2.6-Cu-SLAC-#1 and 1C-SW-A3.75-T2.6-4mm-Ch-Cu-SLAC-#1

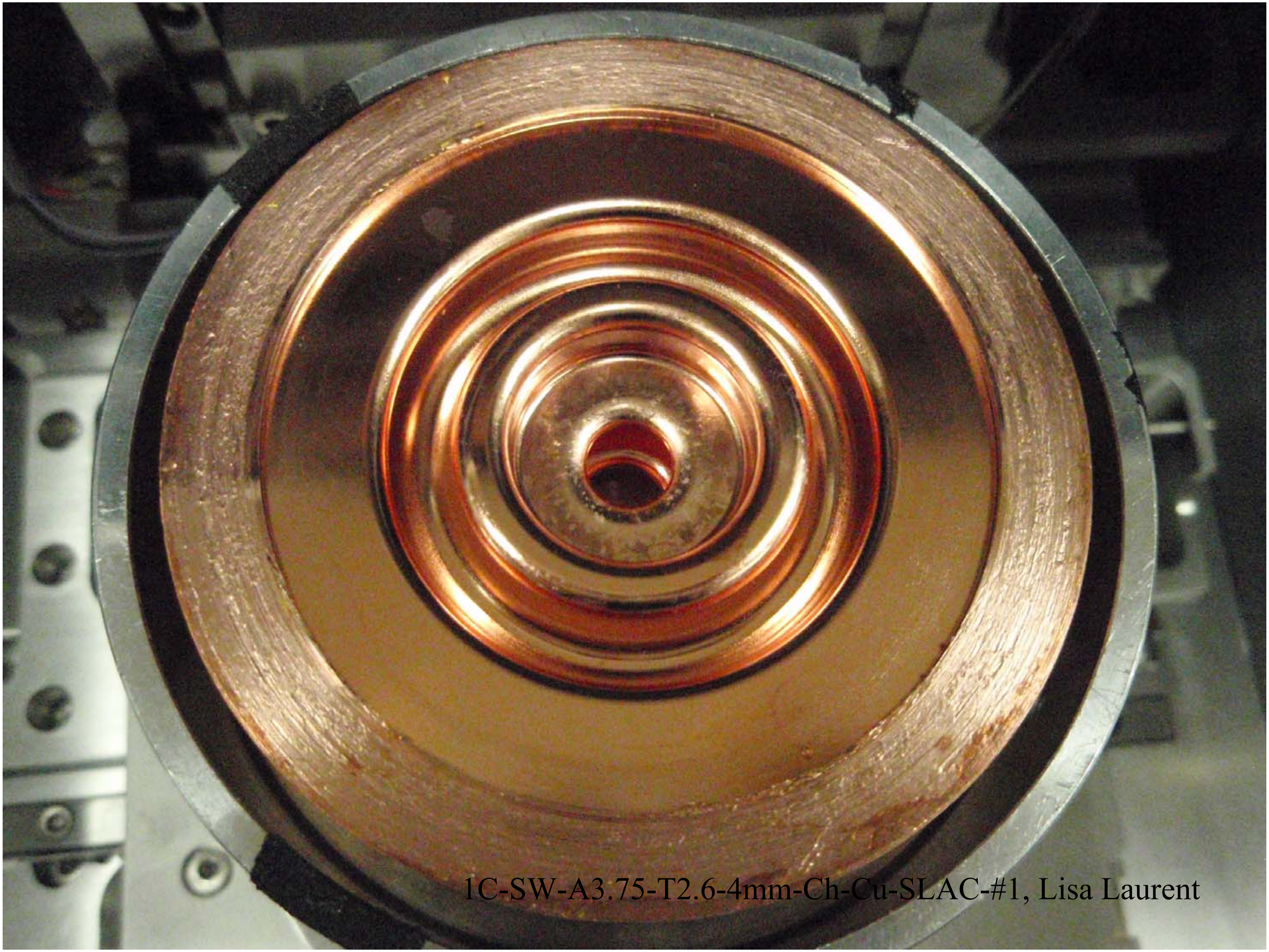


V.A. Dolgashev, 20 May 2009

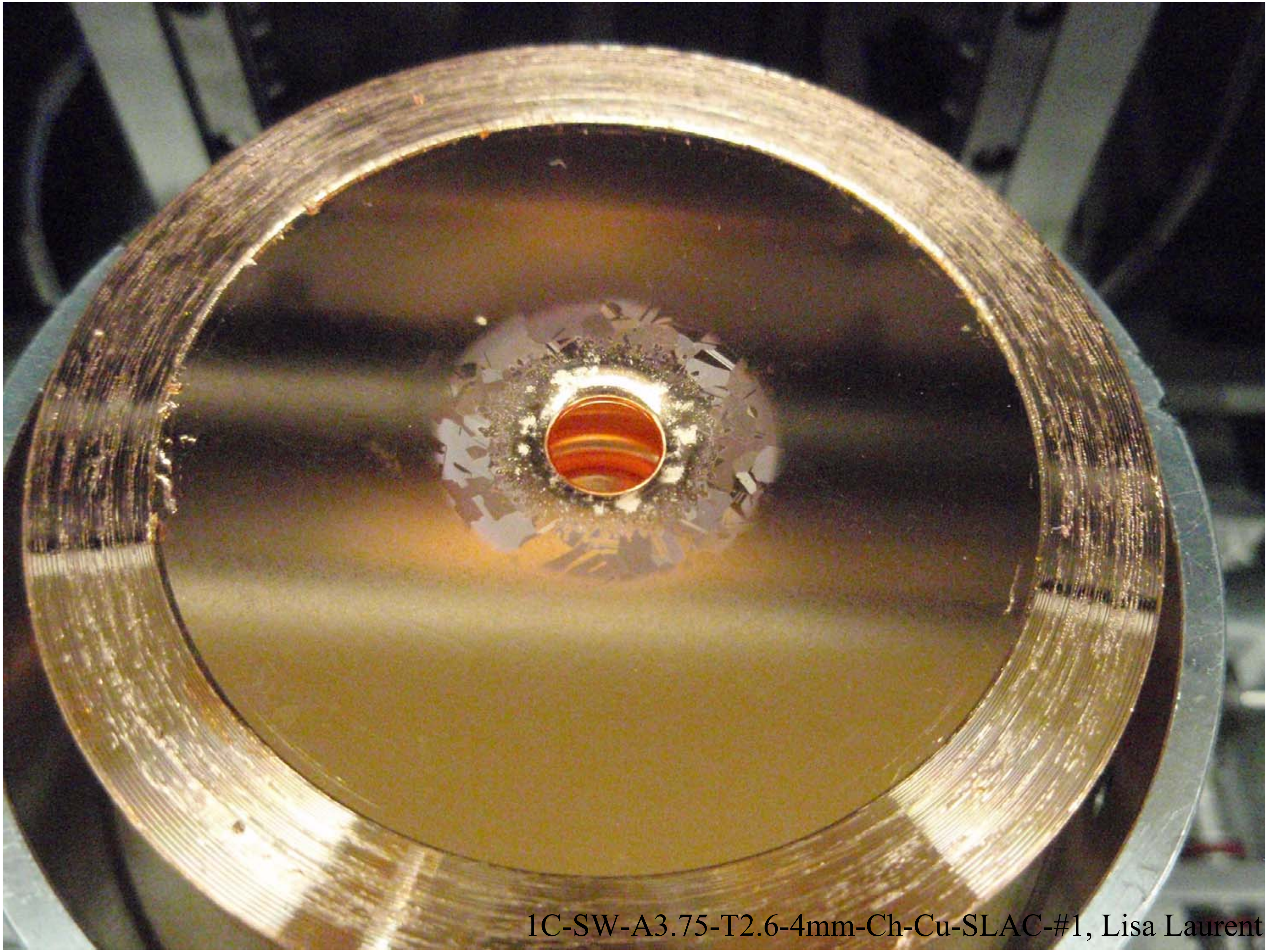
Comparison of A3.75 structure without choke and with 4mm choke

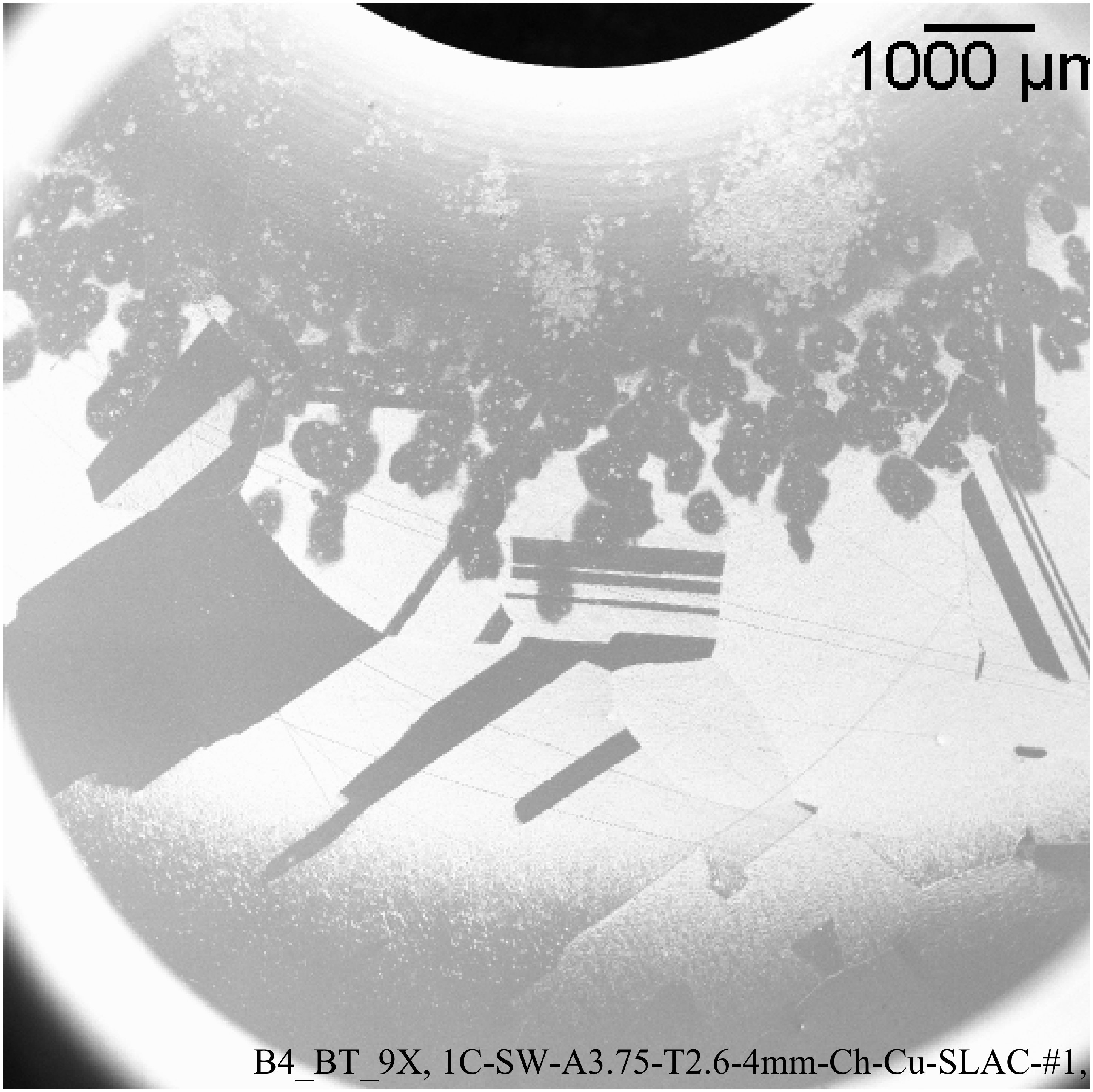


V.A. Dolgashev, 20 May 2009

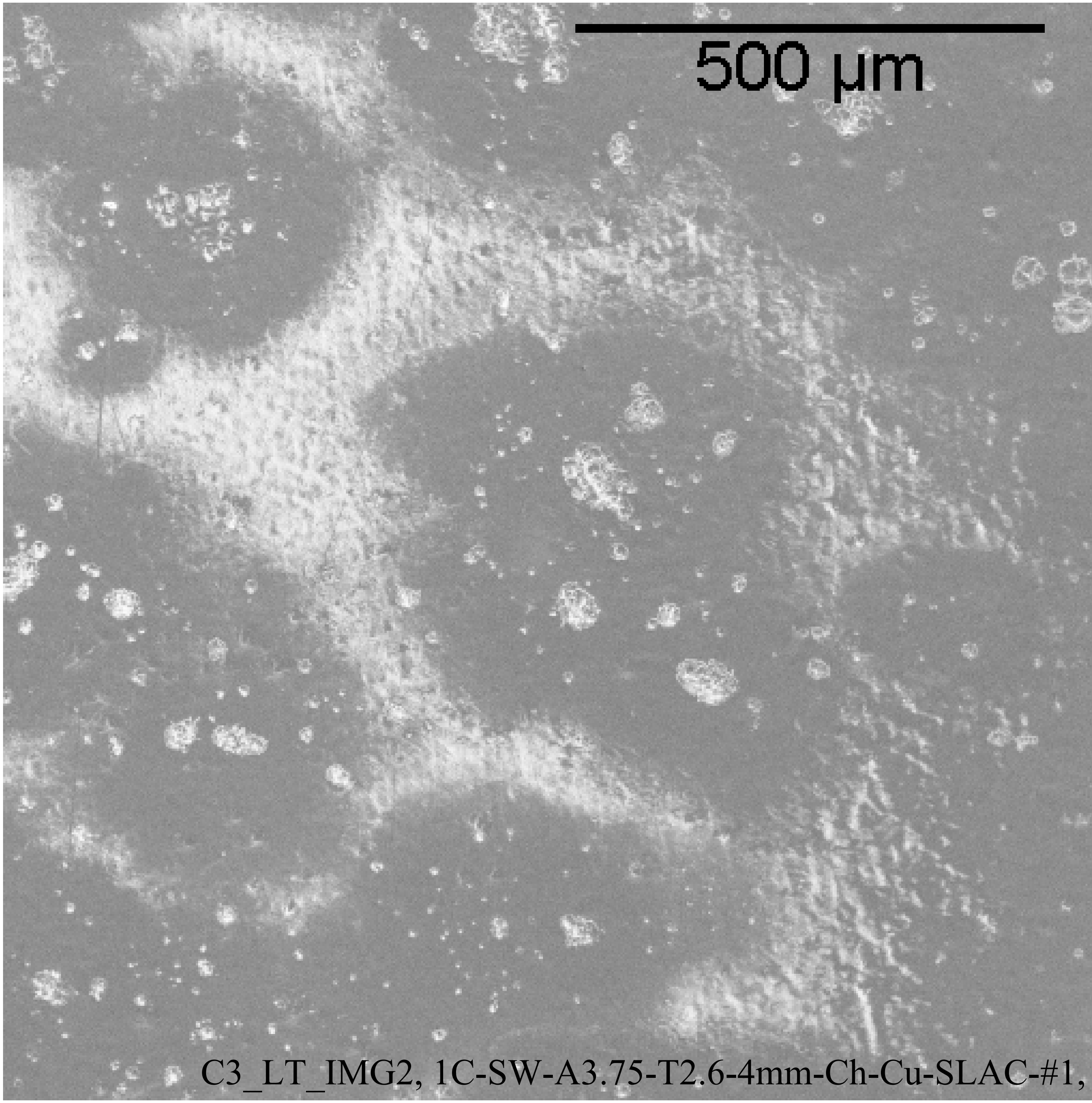


1C-SW-A3.75-T2.6-4mm-Ch-Cu-SLAC-#1, Lisa Laurent

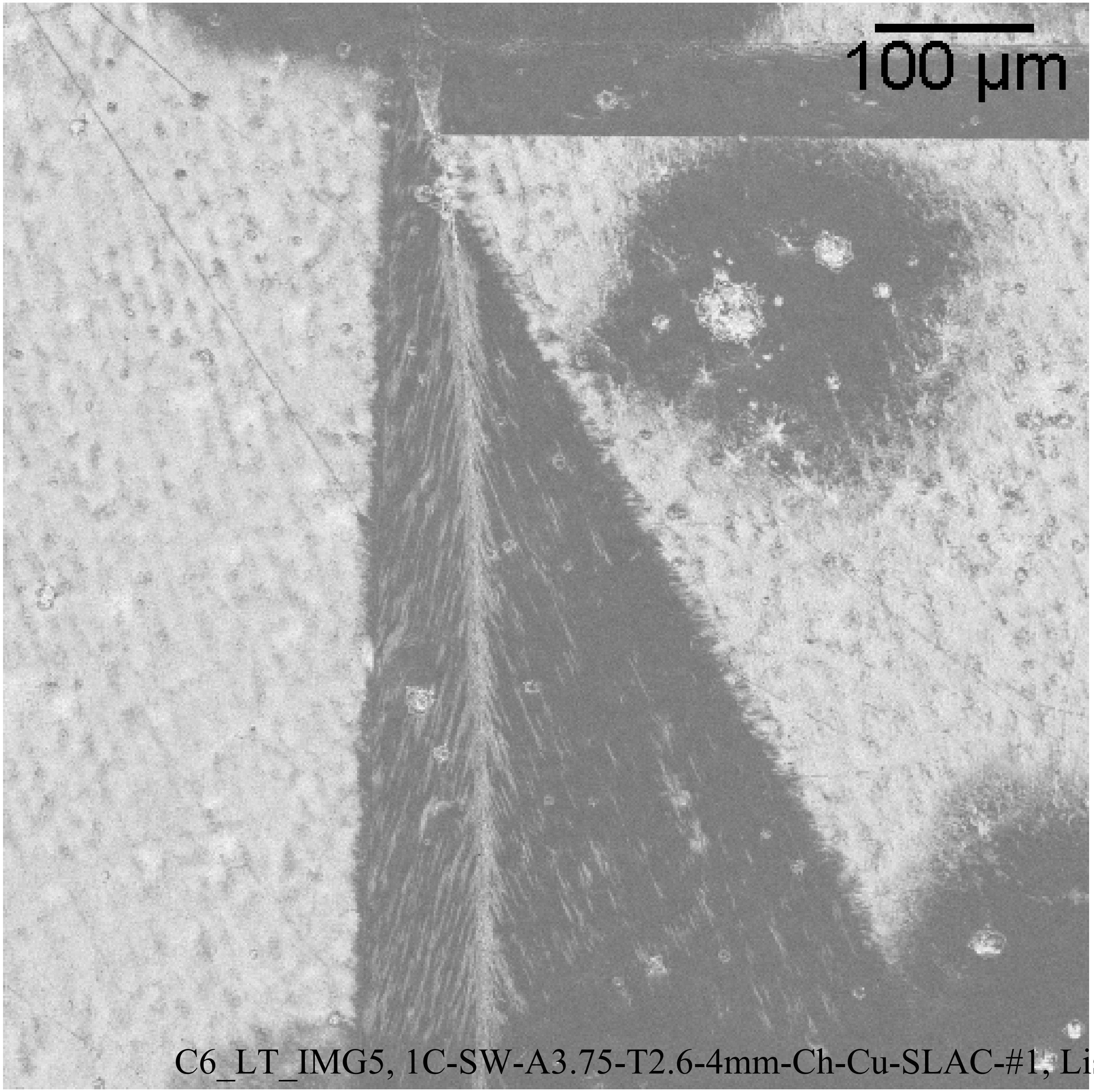

1C-SW-A3.75-T2.6-4mm-Ch-Cu-SLAC-#1, Lisa Laurent



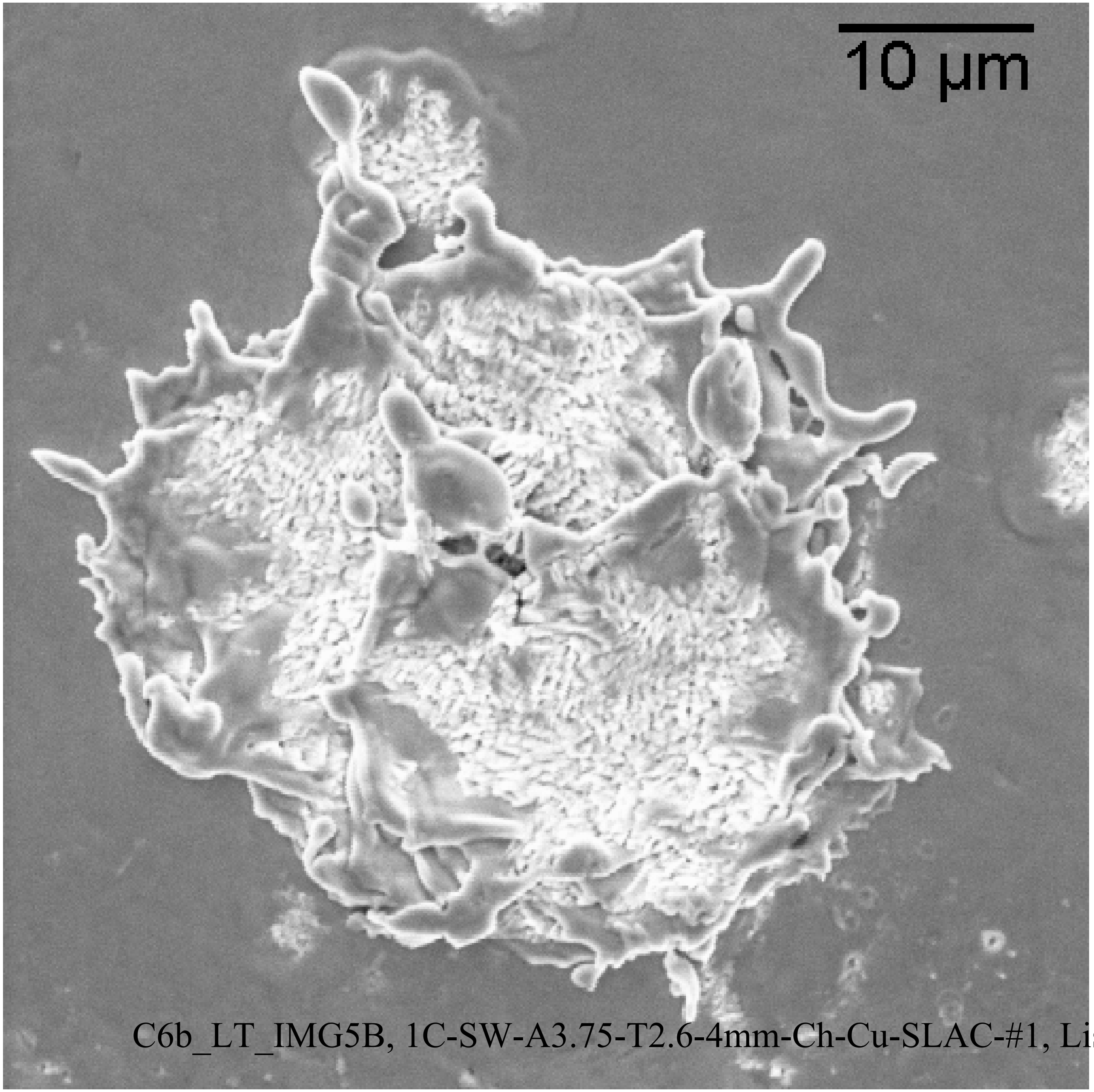
B4_BT_9X, 1C-SW-A3.75-T2.6-4mm-Ch-Cu-SLAC-#1, Lisa Laurent



C3_LT_IMG2, 1C-SW-A3.75-T2.6-4mm-Ch-Cu-SLAC-#1, Lisa Laurent



C6_LT_IMG5, 1C-SW-A3.75-T2.6-4mm-Ch-Cu-SLAC-#1, Lisa Laurent



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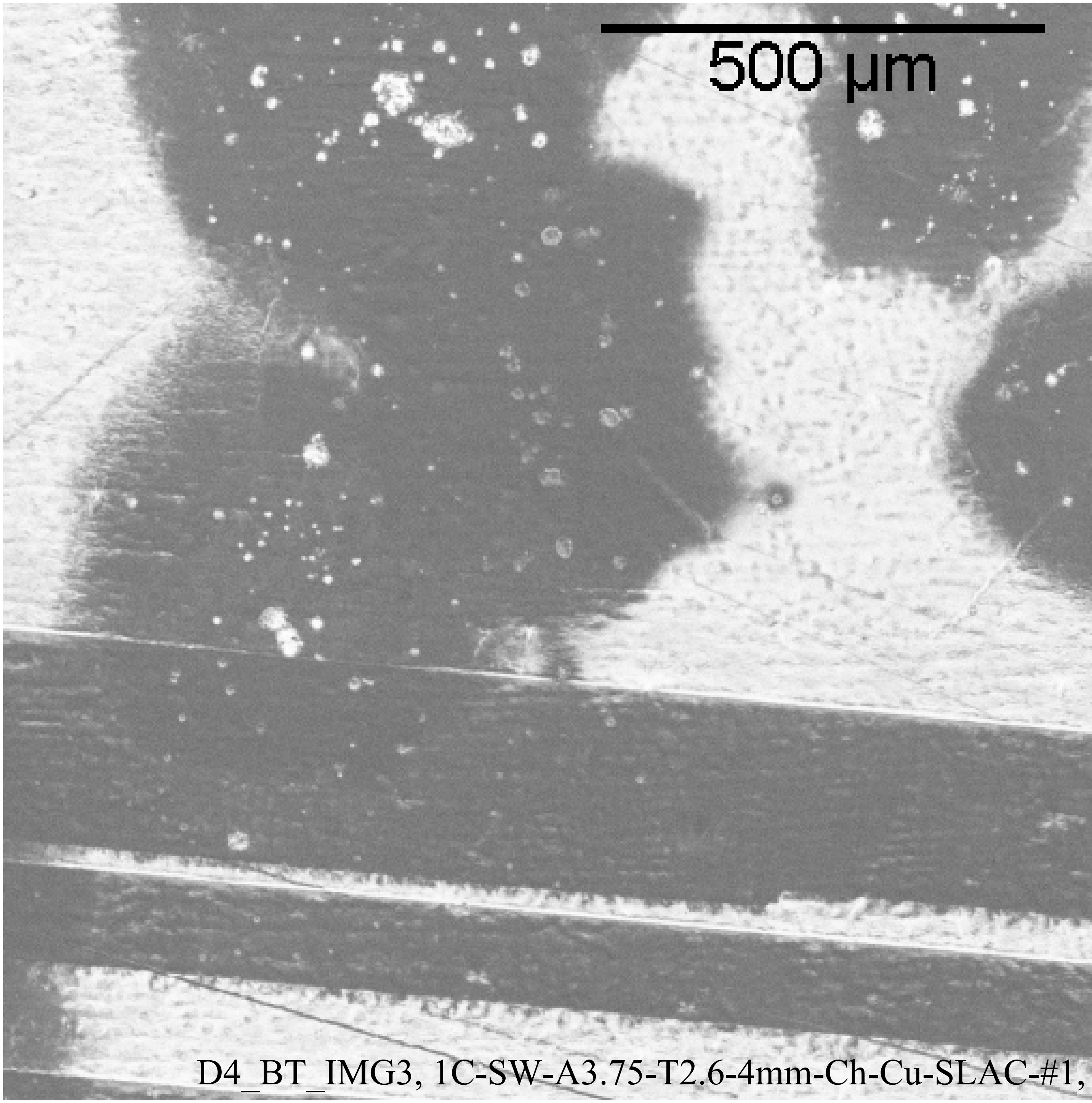
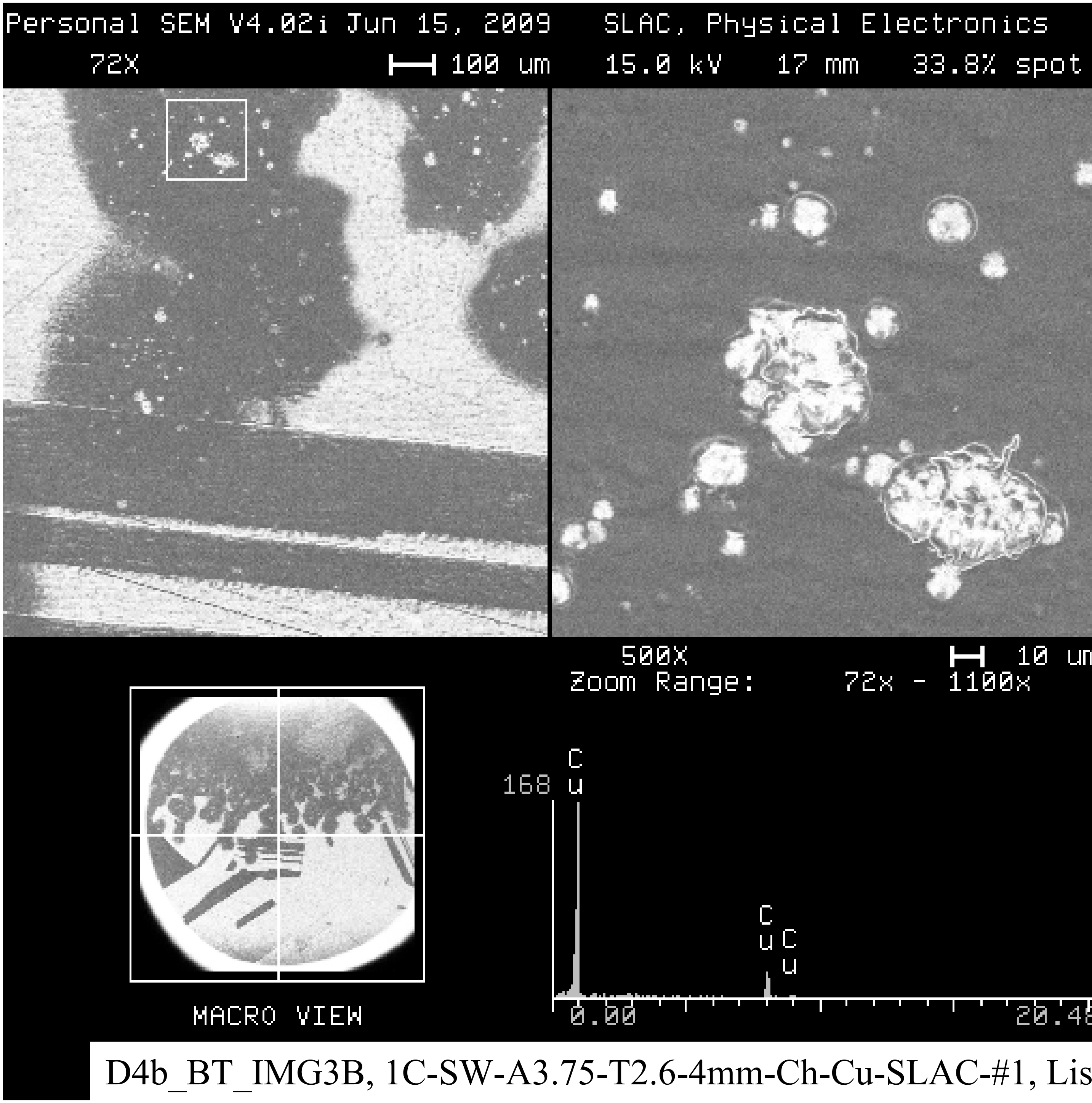


D4_BT_IMG3, 1C-SW-A3.75-T2.6-4mm-Ch-Cu-SLAC-#1, Lisa Laurent



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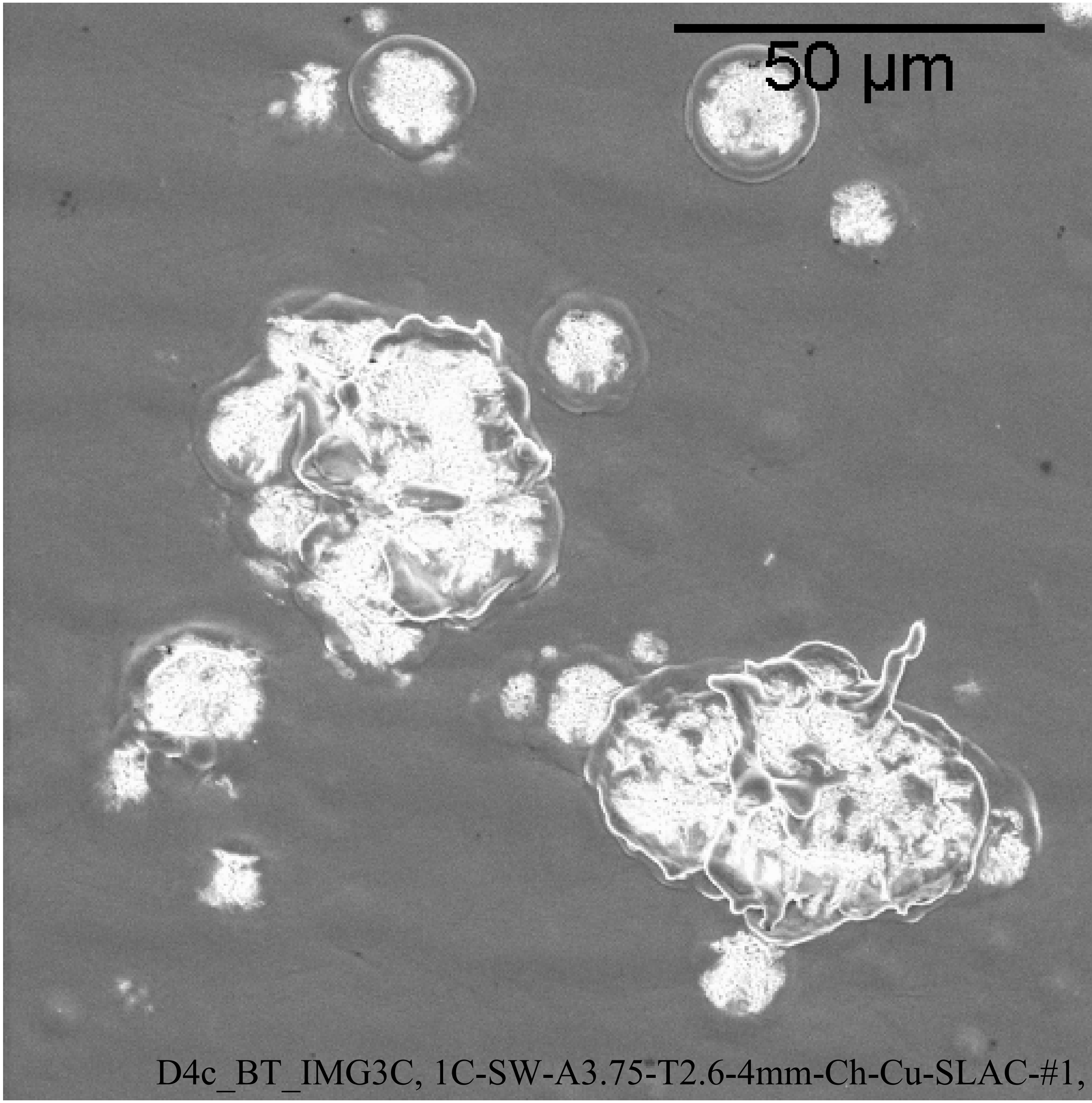
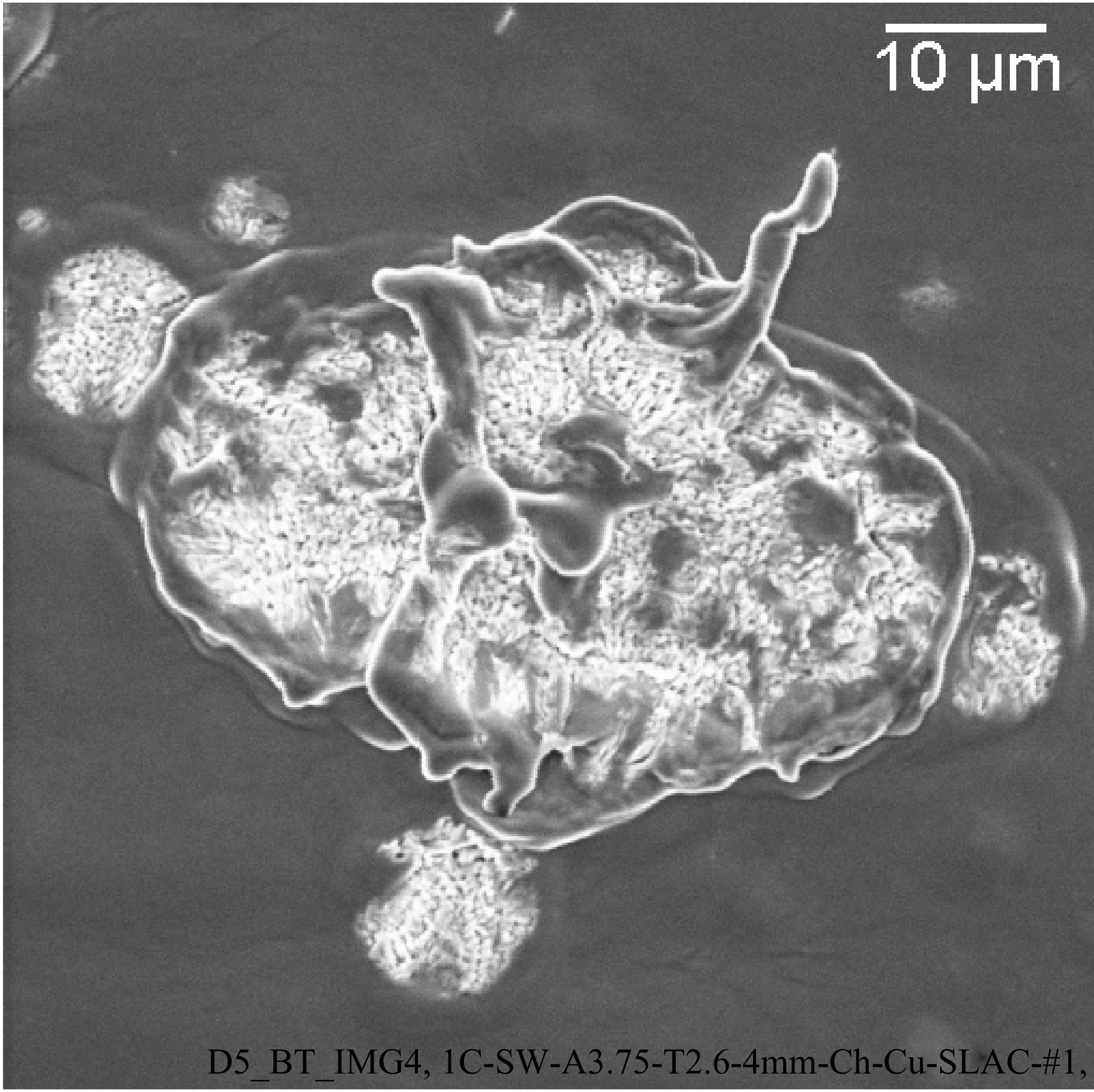


D4c_BT_IMG3C, 1C-SW-A3.75-T2.6-4mm-Ch-Cu-SLAC-#1, Lisa Laurent



D5_BT_IMG4, 1C-SW-A3.75-T2.6-4mm-Ch-Cu-SLAC-#1, Lisa Laurent

New materials

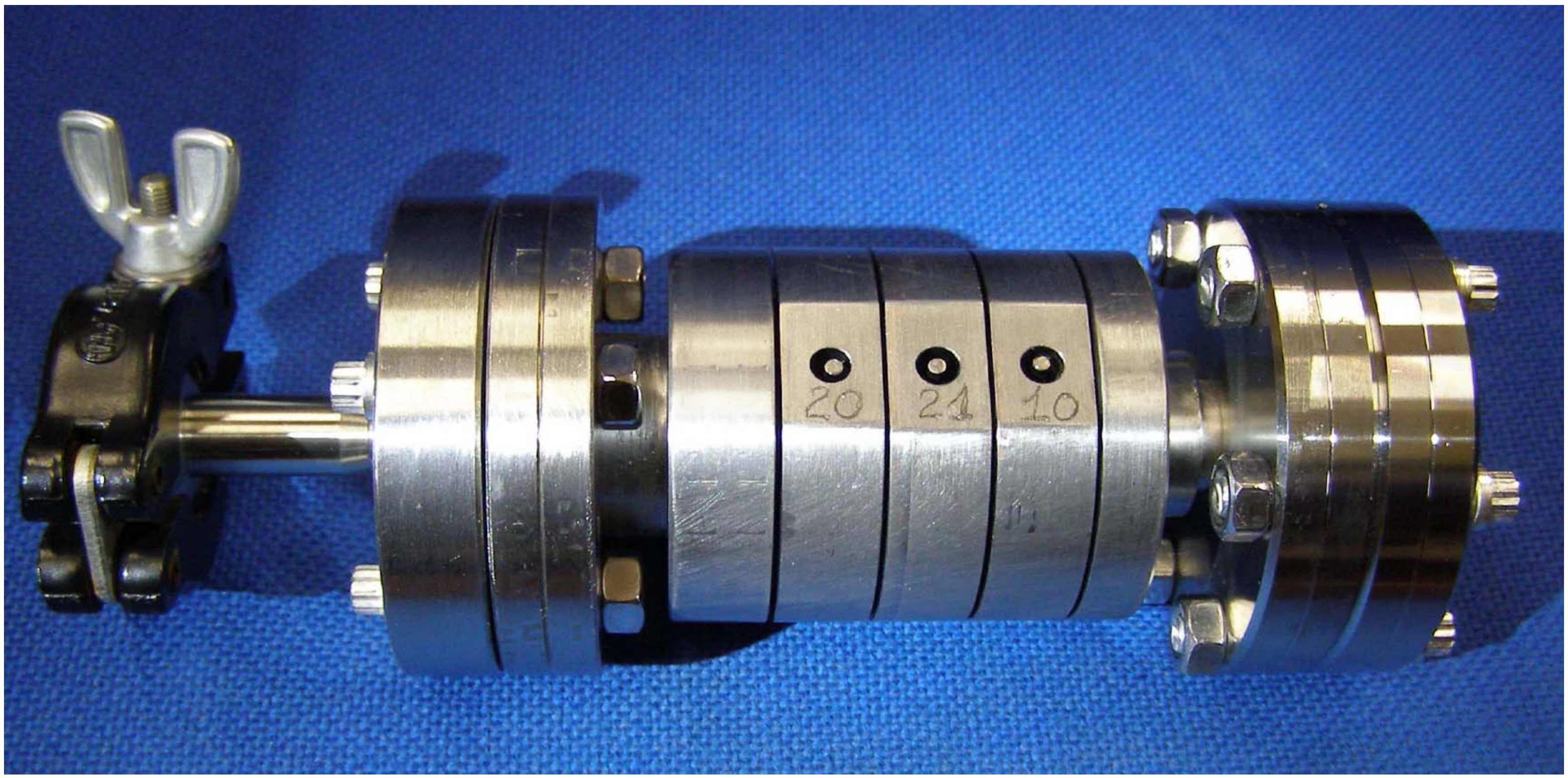
Molybdenum structure

1C-SW-A5.65-T4.6-Mo-Frascati-#1

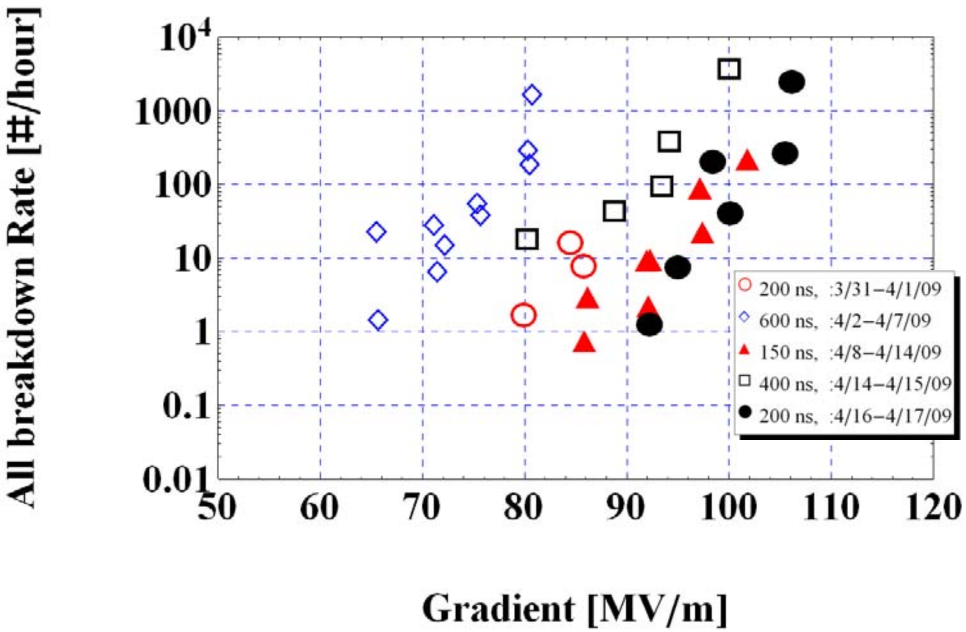
SPARC-RF-08/003
December 19, 2008

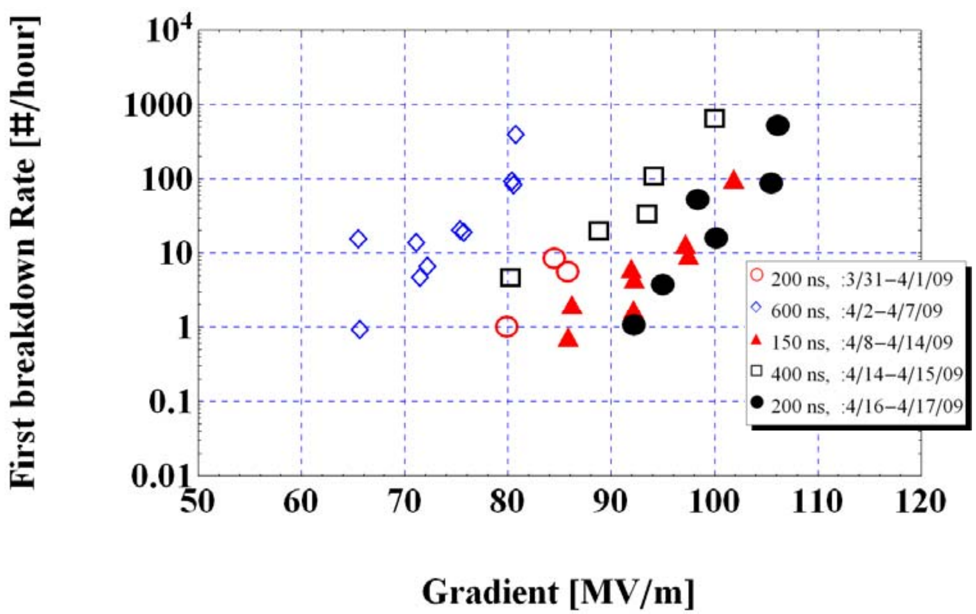
Status report on SALAF technical activity during the second half of 2008

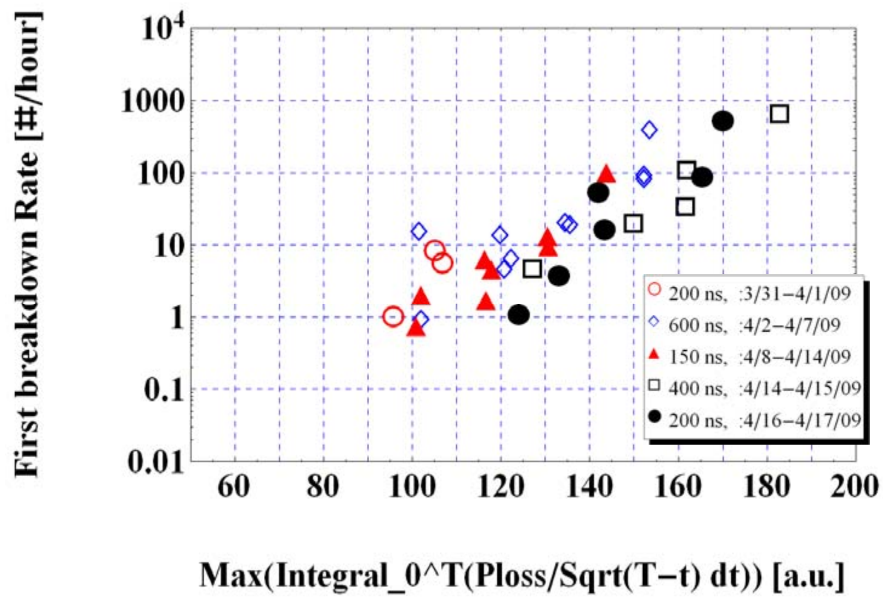
S. Bini, P. Chimenti, V. Chimenti, R. Di Raddo, V. Lollo, B. Spataro, F.Tazzioli



1C-SW-A5.65-T4.6-Mo-Frascati-#1

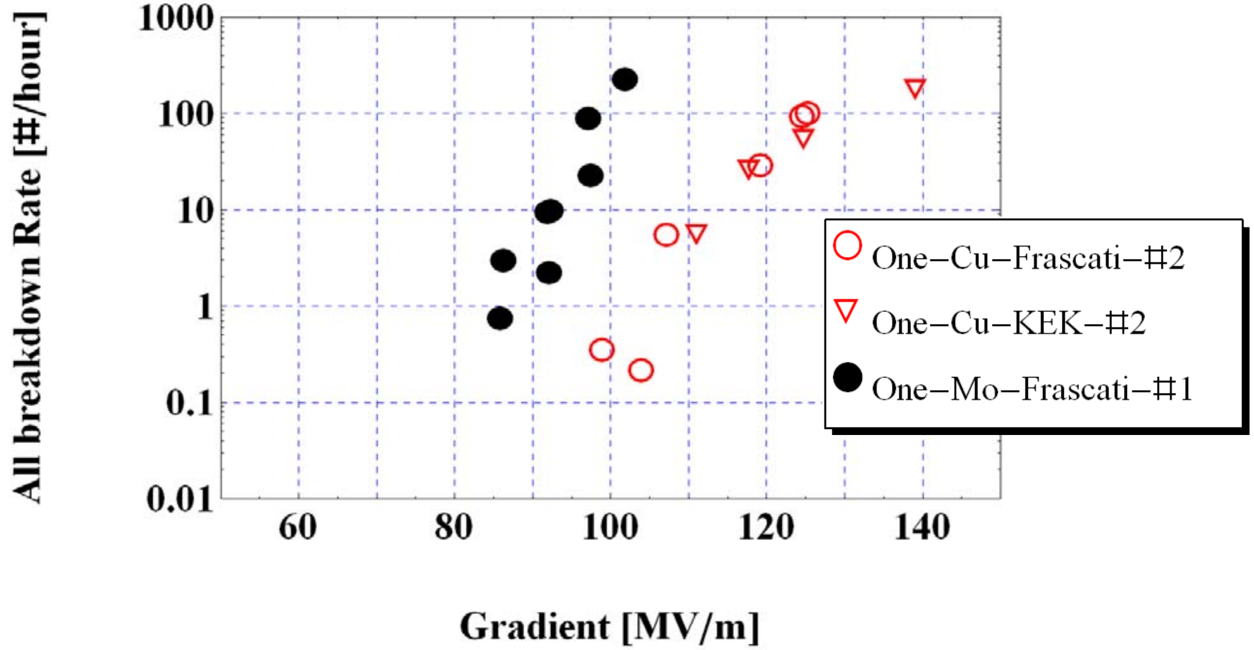


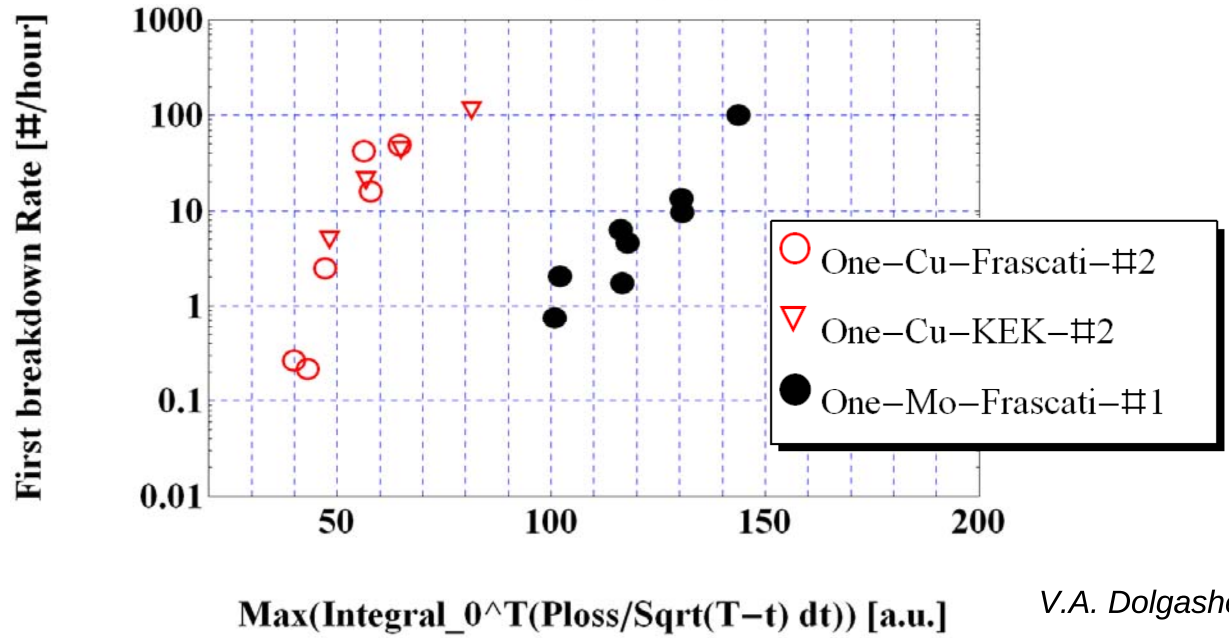




V.A. Dolgashev 4 May 2009

Comparison of peak pulse heating for two copper and one molybdenum 1C-SW- A5.65-T4.6-Cu structures, *shaped* pulse, flat part 150 ns





V.A. Dolgashev 4 May 2009

Copper alloys

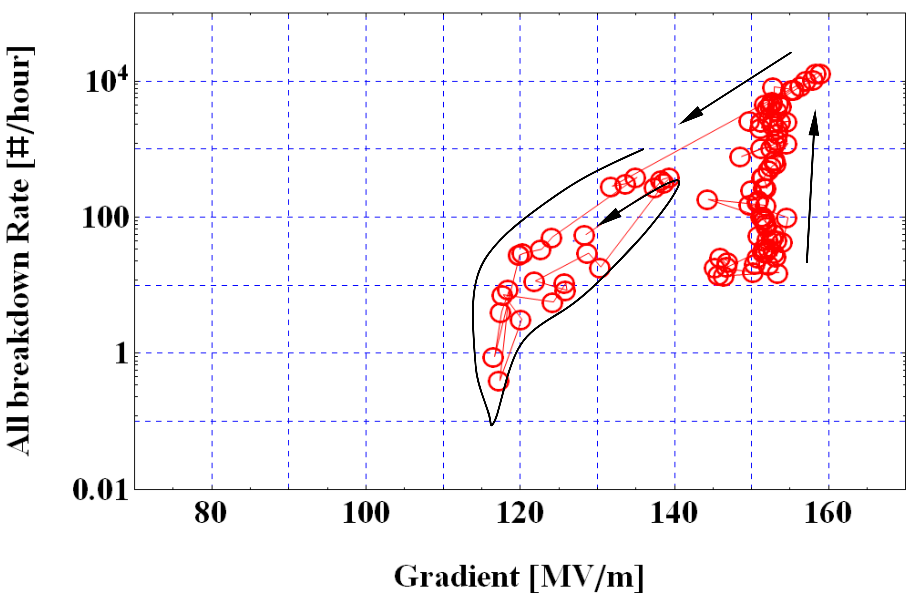
Soft CuAg structure,

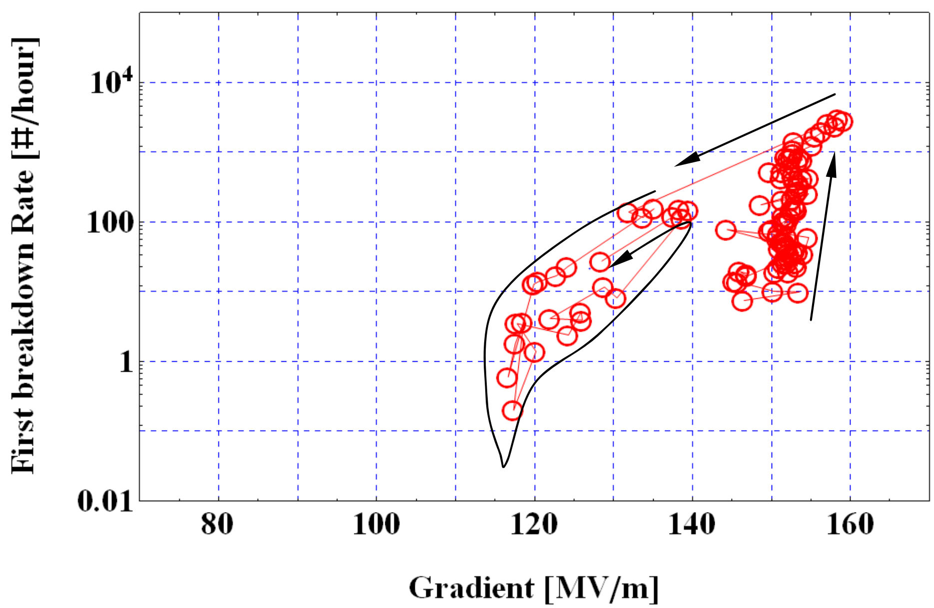
1C-SW-A5.65-T4.6-CuAg-SLAC-#1,

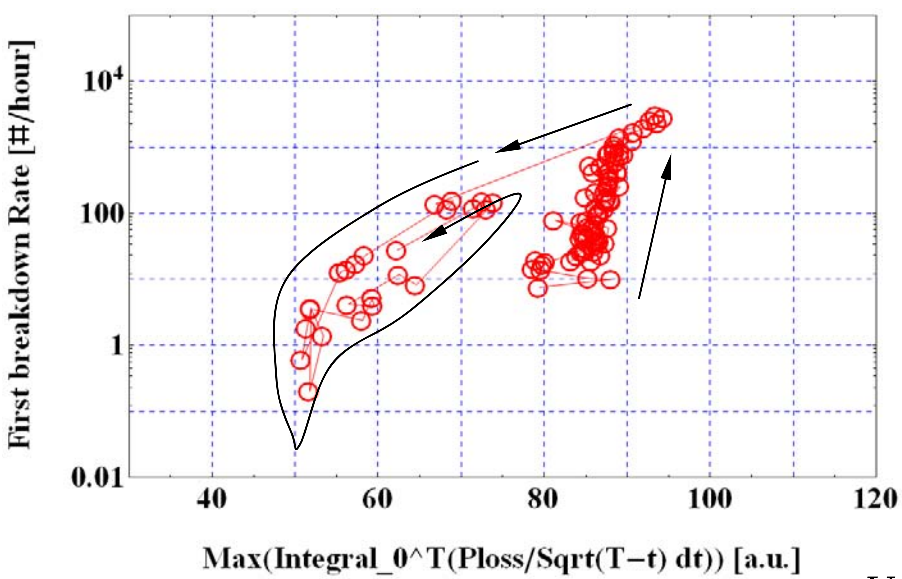
Disclaimer: This is “working” data, it is not final in any way

150 ns flat Study of breakdown rate transients, 150 ns flat

the data will be corrected later using beadpull results



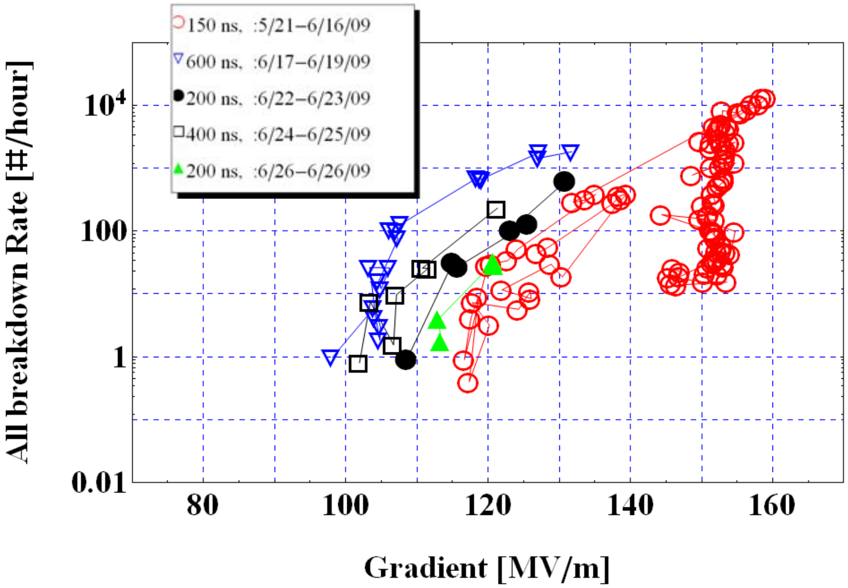


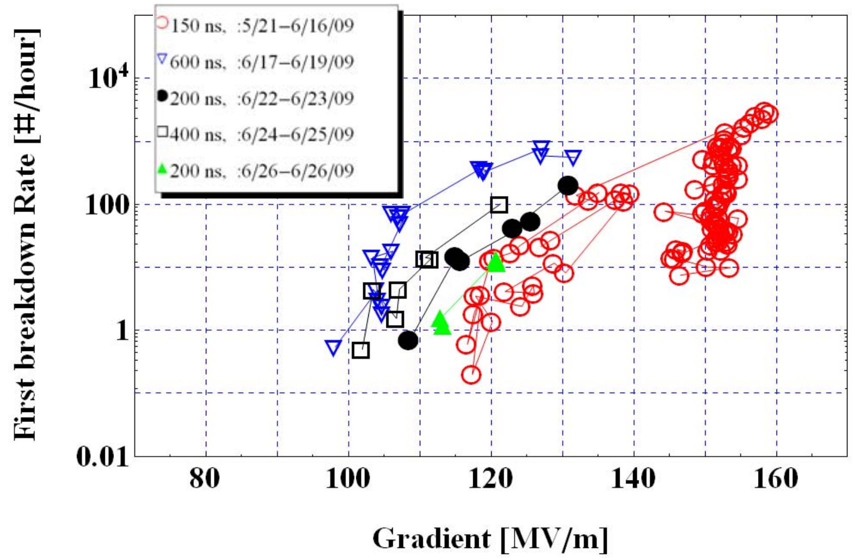


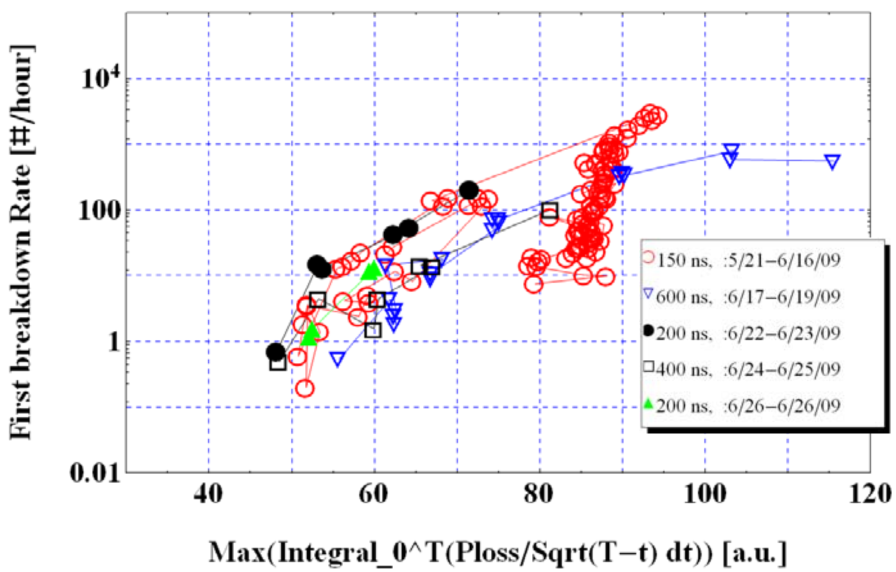
V.A. Dolgashev, 1 July 2009

A5.65-T4.6-CuAg-SLAC-#1 flat pulse

the data will be corrected later using beadpull results



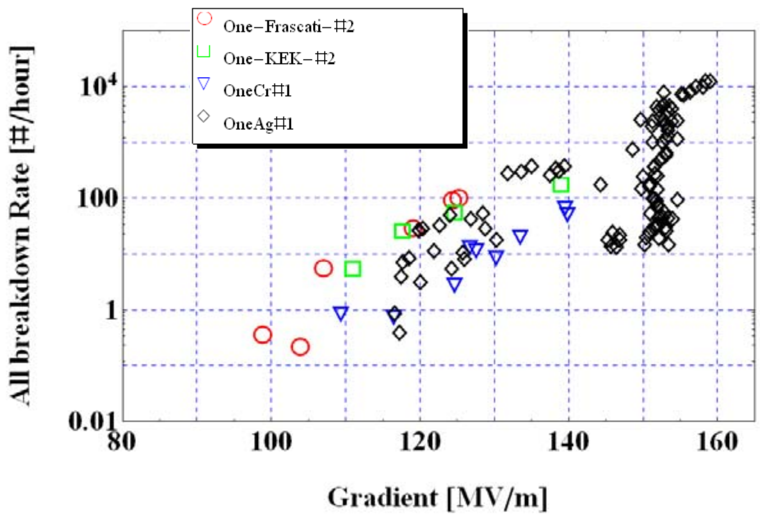


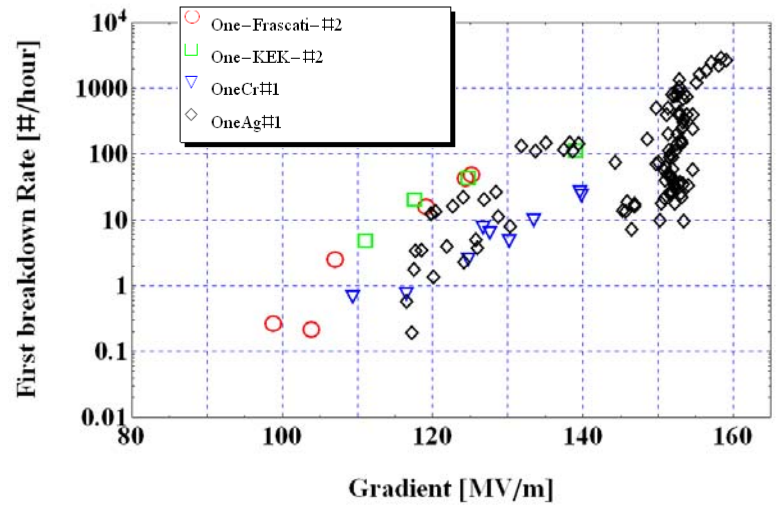


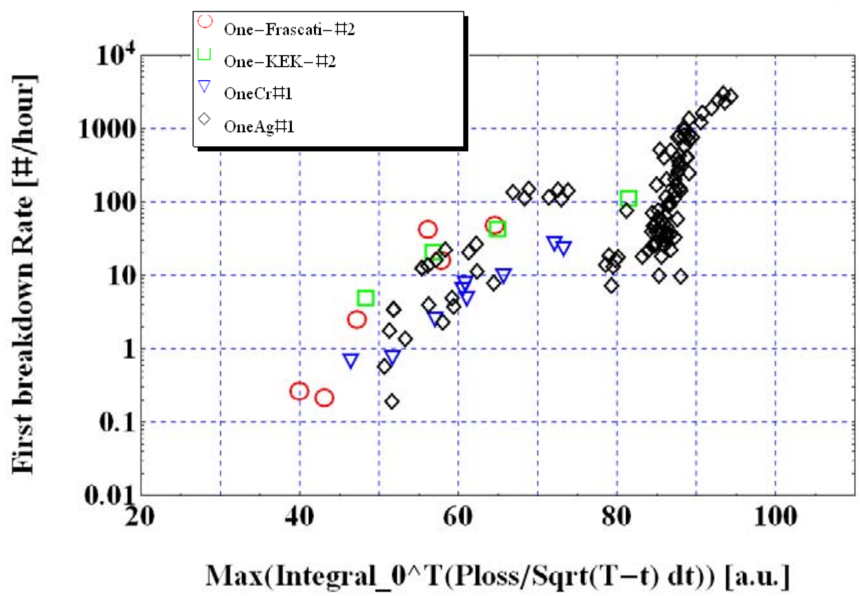
V.A. Dolgashev, 1 July 2009

Comparison of A5.65-T4.6-CuAg-SLAC-#1, 150ns flat pulse with other A5.65-T4.6 structures

the data will be corrected later using beadpull results



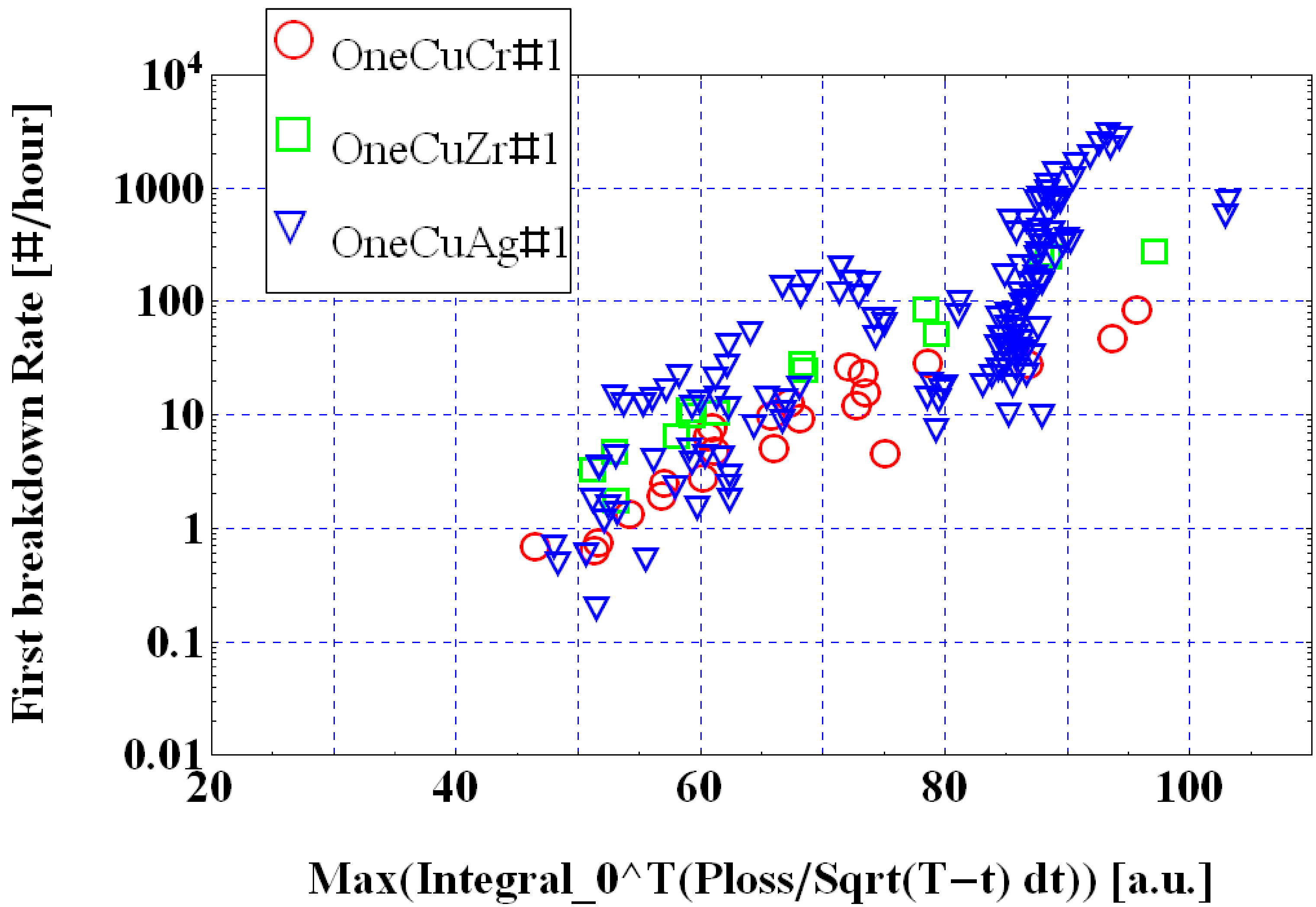




V.A. Dolgashev, 1 July 2009

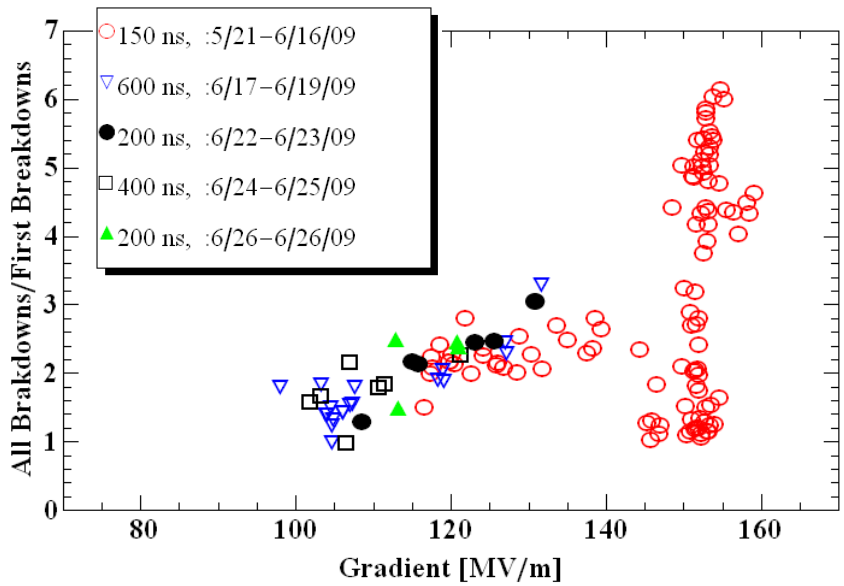
Comparison of A5.65-T4.6-CuAg-SLAC-#1, with
A5.65-T4.6 structures made of CuCr and CuZr

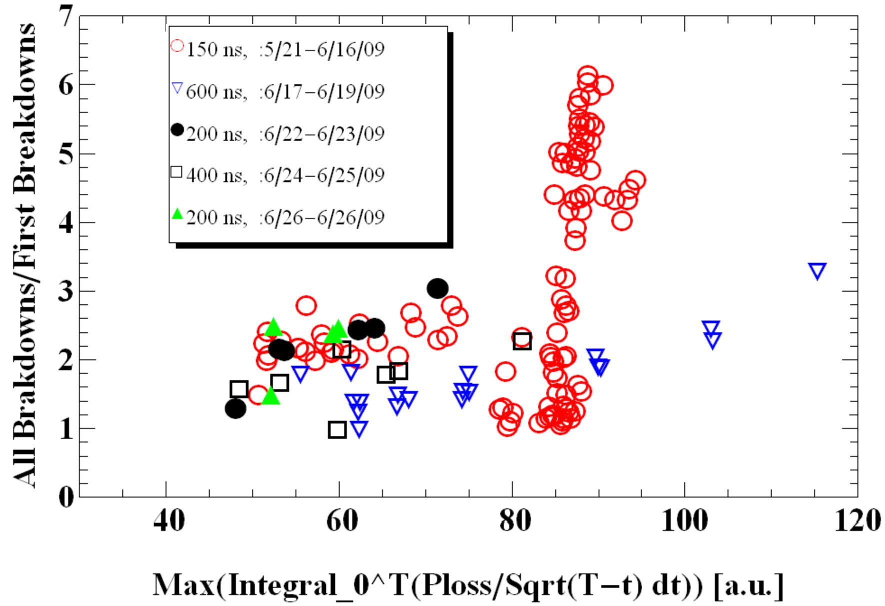
the data will be corrected later using beadpull results



V.A. Dolgashev, 1 July 2009

Ratio of All breakdowns to first breakdowns for A5.65-T4.6-CuAg-SLAC-#1,
the data will be corrected later using beadpull results

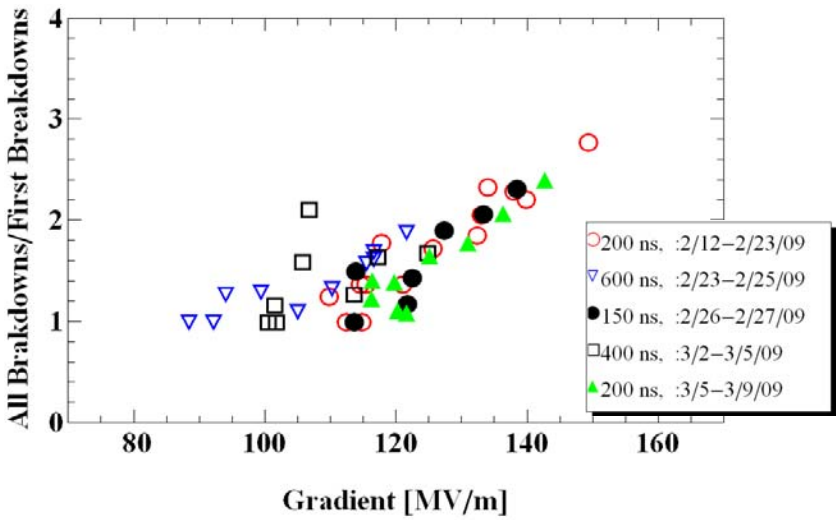


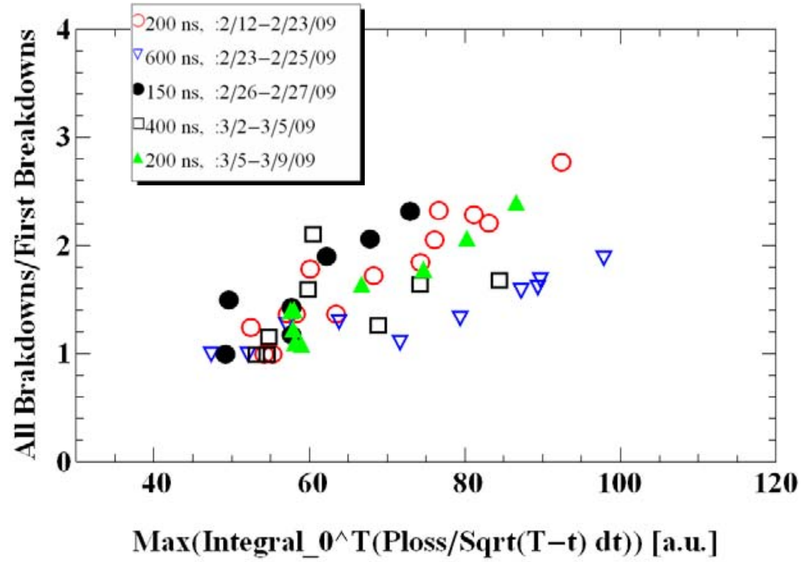


V.A. Dolgashev, 1 July 2009

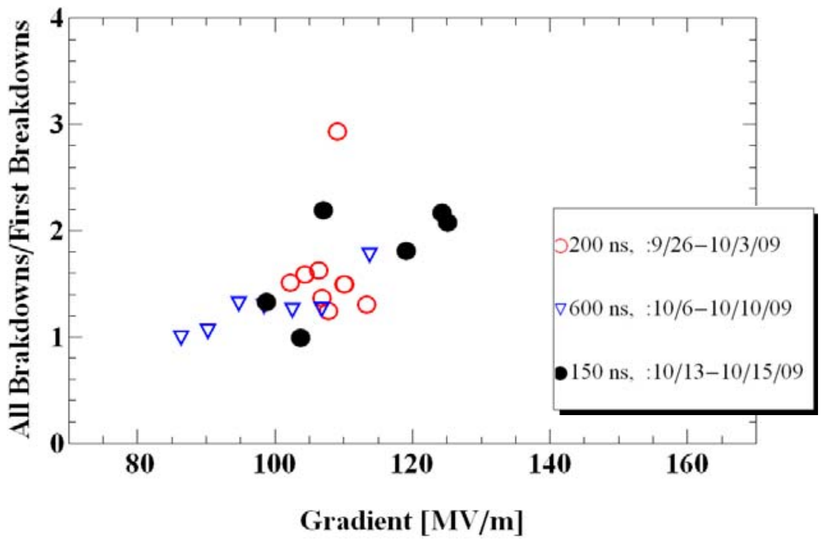
Correlated breakdowns

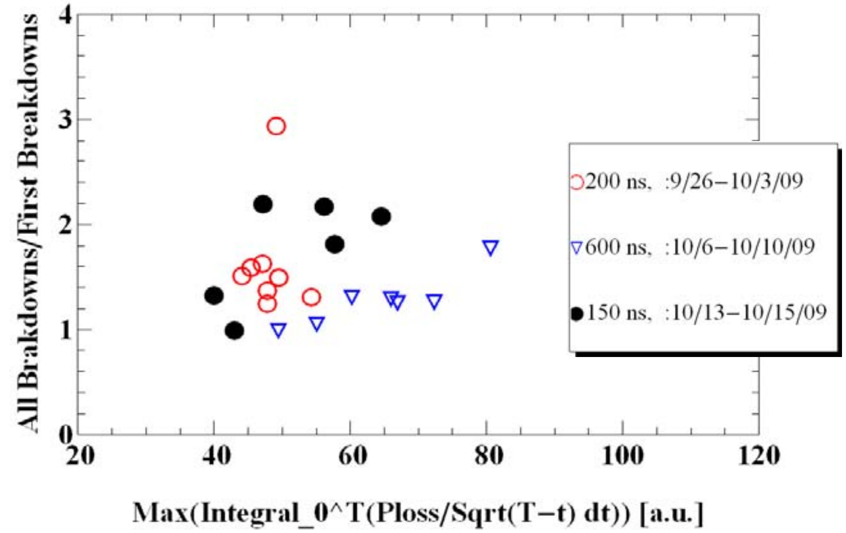
Ratio of All breakdowns to first breakdowns for





1-C-SW-A5 .65-T4 .6-Clamped-Cu-SLAC #1

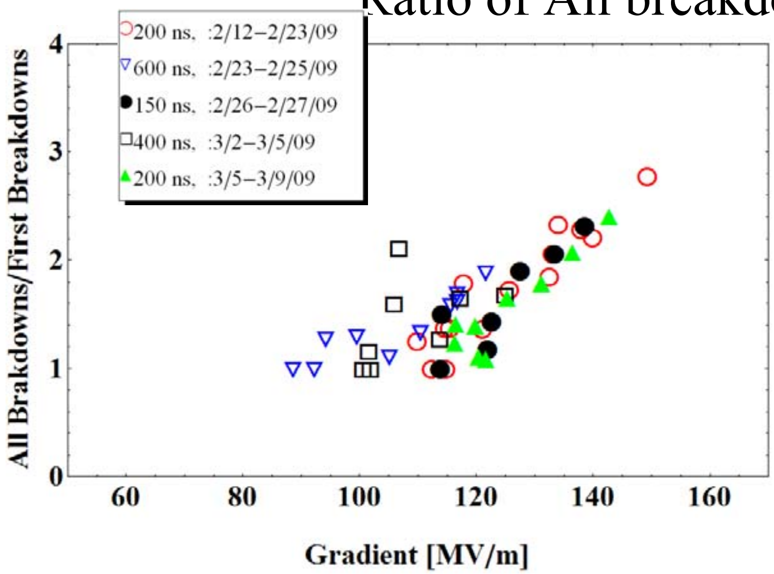


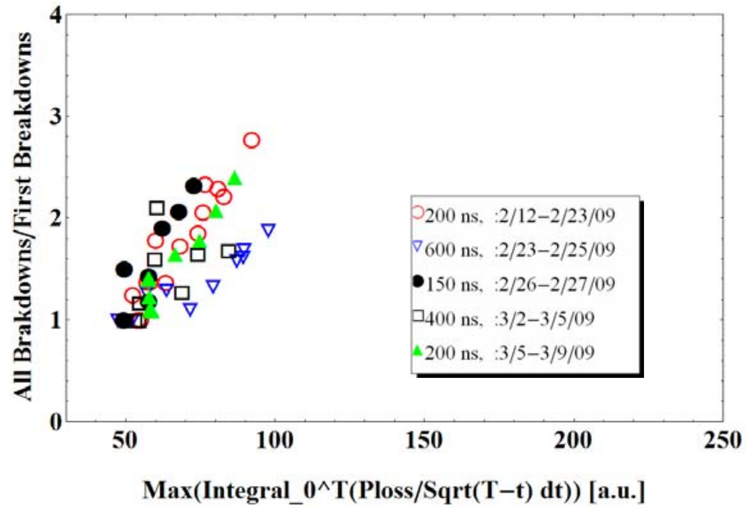


1-C-SW-A5.65-T4.6-Cu-Frascati-#2

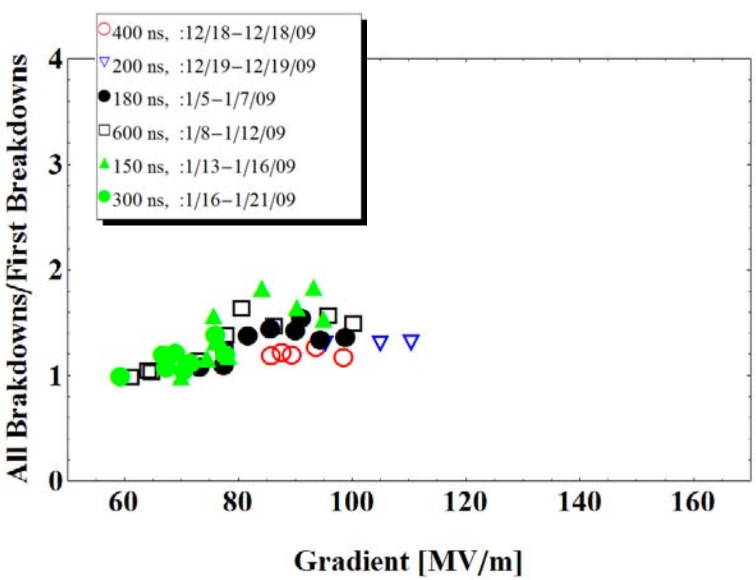
V.A. Dolgashev, 1 July 2009

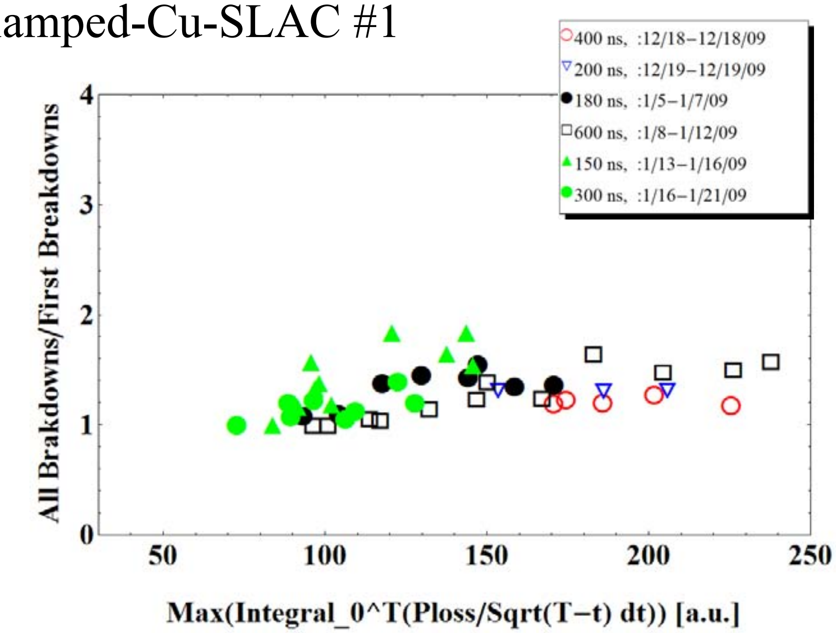
Ratio of All breakdowns to first breakdowns for





1-C-SW-A5 .65-T4 .6-Clamped-Cu-SLAC #1

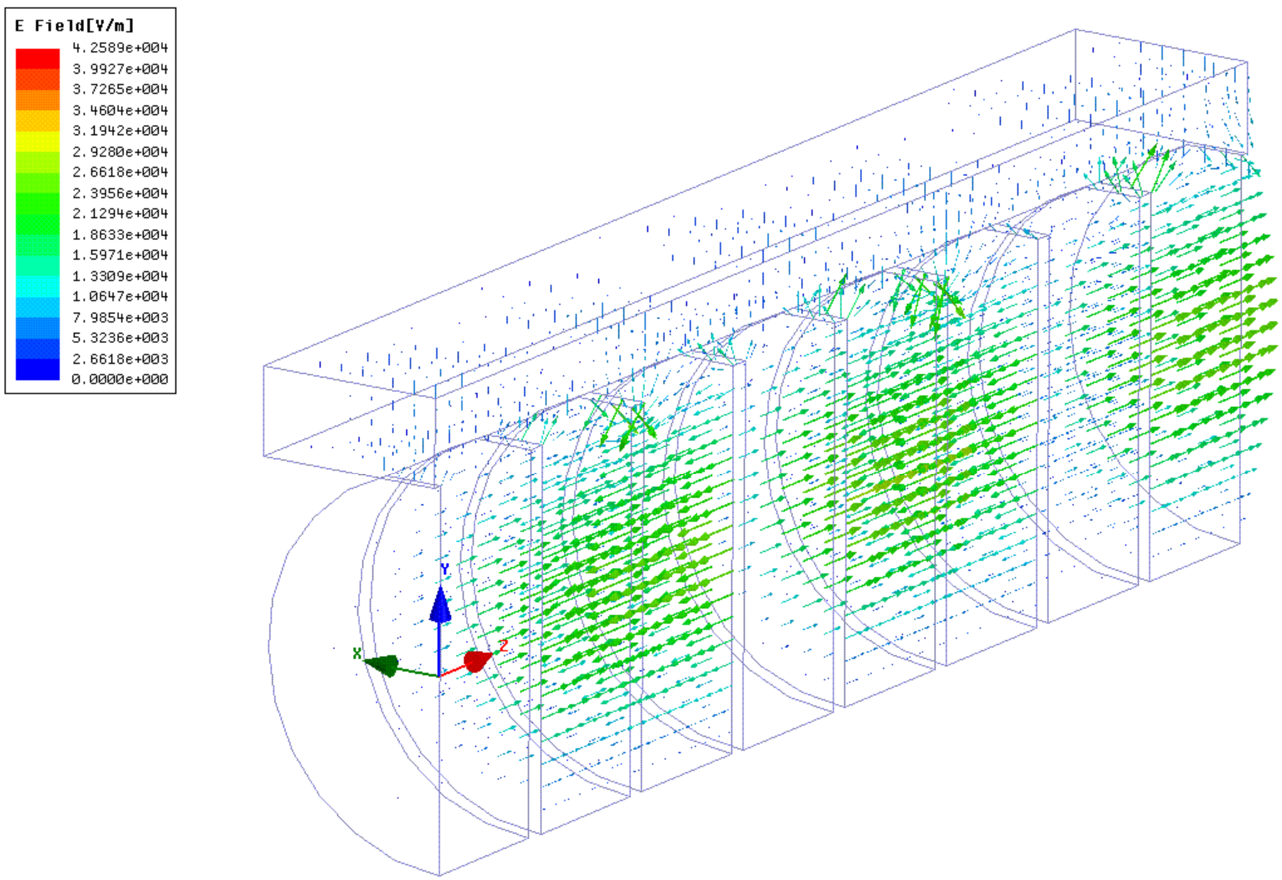




1-C-SW-A5.65-T4.6-PBG-Cu-SLAC-#1

V.A. Dolgashev, 8 July 2009

Travelling Wave parallel coupled structure



Summary

We have a test setup with short turn-around time that produces useful data. The stand started working January 2007 and now 20th structure is installed, low temperature brazed , high shunt impedance hard CuAg structure

1C-SW-A3.75-T2.6-CuAg-KEK-#1