Recent High Gradient Tests of at SLAC

Valery Dolgashev,

SLAC National Accelerator Laboratory

CLIC09 Workshop,
October 12th - 16th, 2009
CERN

Outline

- Single Cell SW structures tests
- Test at Accelerator Structure Test Area (ASTA)

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

- S. Tantawi (US High Gradient Collaboration spokesperson), A. Yeremian, J. Lewandowski *of Accelerator Technology Research*
- E. Jongewaard, C. Pearson, A. Vlieks, J. Eichner, D. Martin, C. Yoneda, L. Laurent, A. Haase, R. Talley, J. Zelinski and staff *of Klystron Lab*.
- Z. Li, *Advanced Computation*

Single Cell SW structures done in close collaboration with :

- Y. Higashi, *KEK, Tsukuba, Japan*
- B. Spataro, *INFN, Frascati, Italy*

ASTA tests done in collaboration with CERN's CLIC team

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

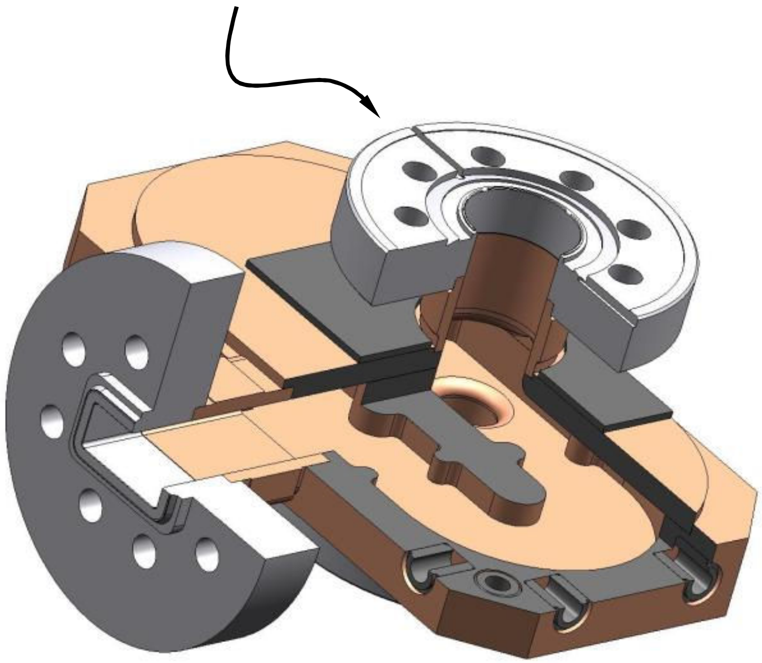
Solution

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

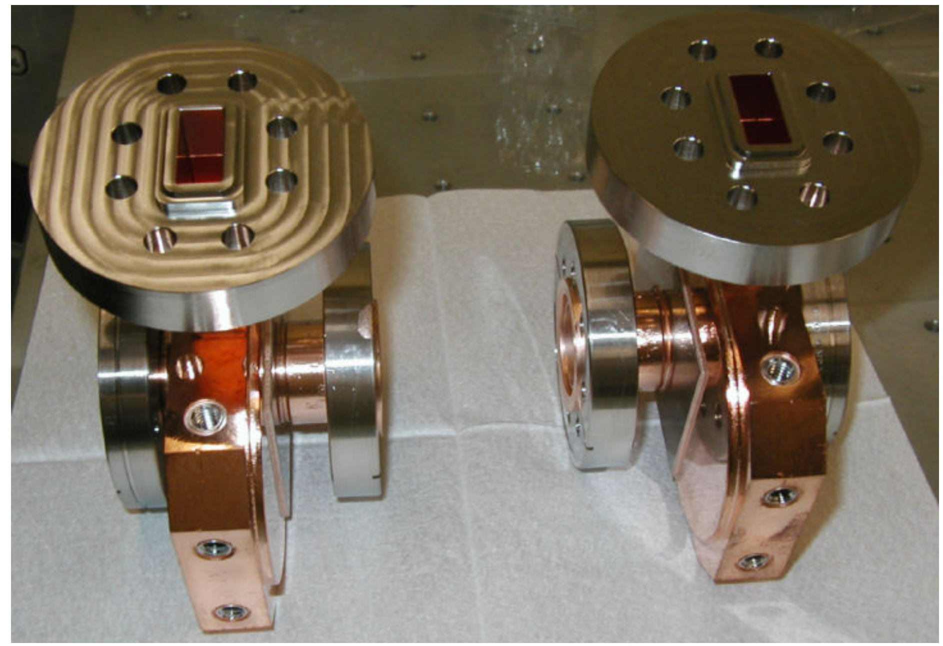
We want to predict breakdown behavior for practical structures

Reusable coupler: TM_{01} Mode Launcher

Pearson's RF flange



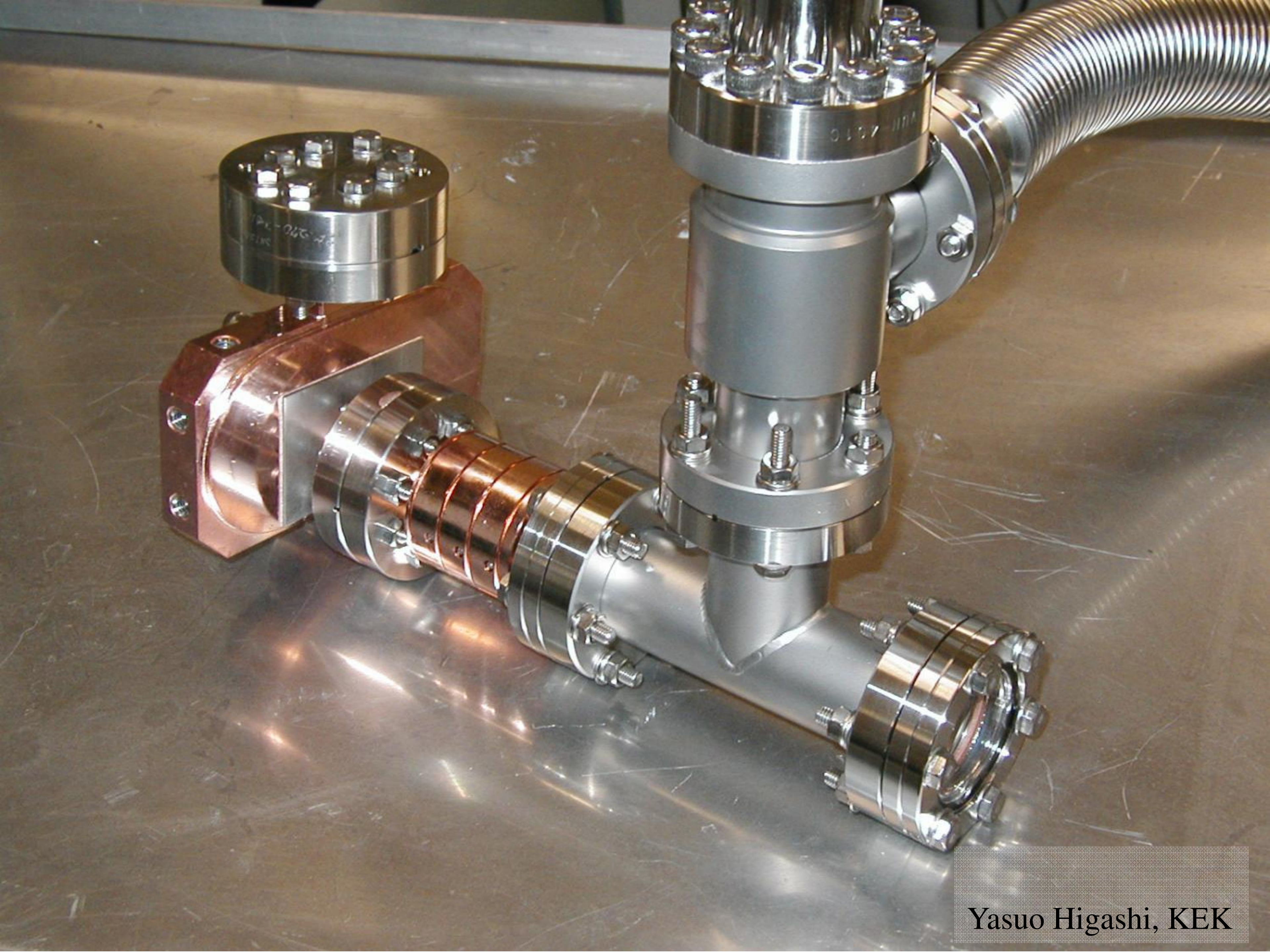
Cutaway view of the mode launcher



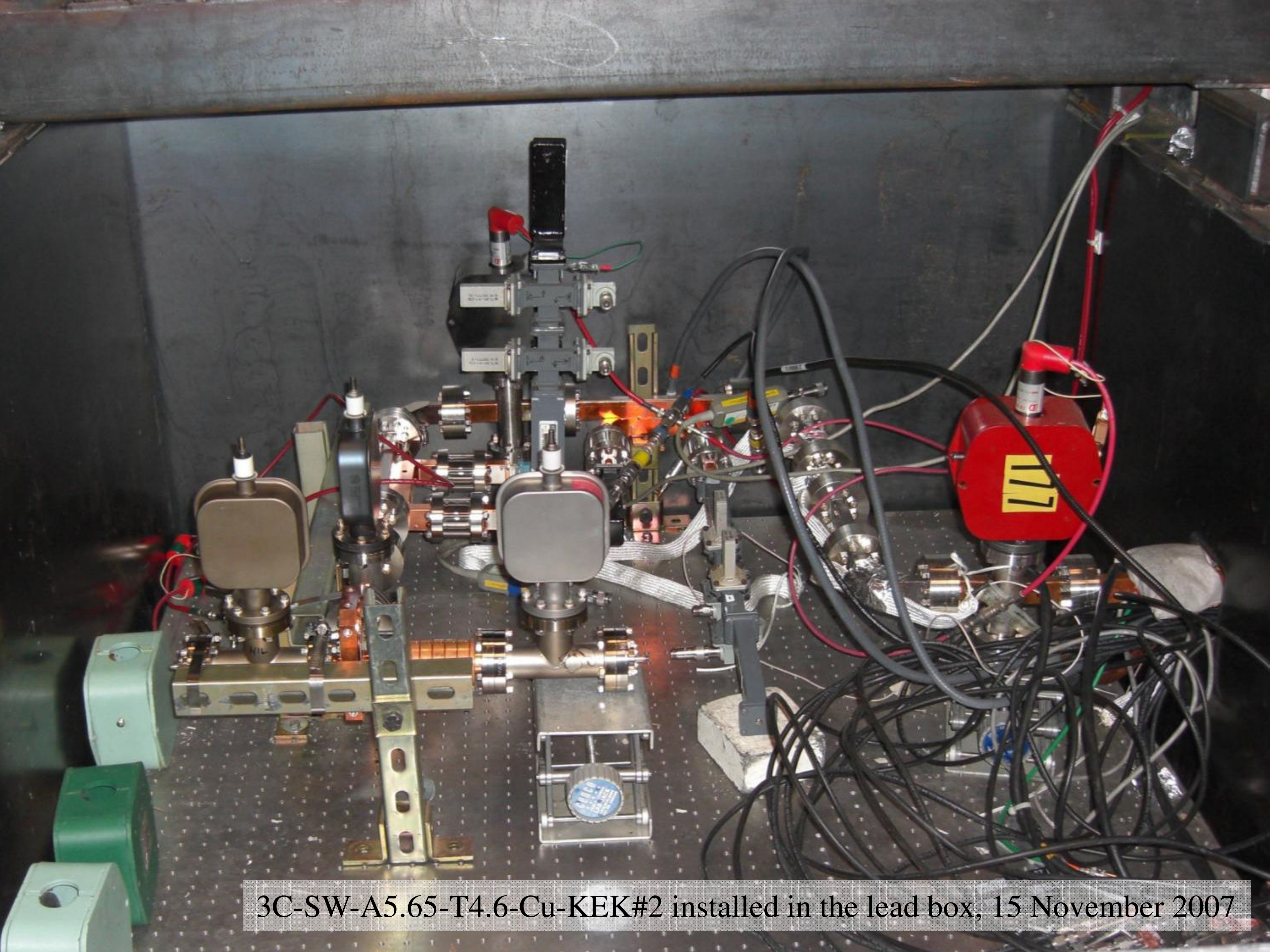
Two mode launchers

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
- Low shunt impedance, choke with 1mm gap, *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
- High shunt impedance, elliptical iris, *a/lambda* = 0.143, *1C-SW-A3.75-T2.6-6NCu-KEK-#1*, 1 tested
- Low shunt impedance, made of CuAg, *1C-SW-A5.65-T4.6-CuAg-SLAC-#1,* 1 tested
- High shunt impedance hard CuAg structure *1C-SW-A3.75-T2.6-LowTempBrazed-CuAg-KEK-#1,* 1 tested
- High shunt impedance soft CuAg, *1C-SW-A3.75-T2.6-CuAg-SLAC-#1*, 1 tested

Now 24^{th} test is under way,

Low shunt impedance copper structure joined by electroforming

1C-SW-A5.6-T4.6-Electroformed-Cu-Frascati-#1

Next experiments, as for 10th October 2009

Reproducibility tests:

High shunt impedance, elliptical iris, *1C-SW-A3.75-T2.6-Cu*

High shunt impedance, 4mm choke, *1C-SW-A3.75-T2.6-4mm-Choke-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 *3C-SW-A3.75-T2.6-TwoWR90-Cu*

Photonic-Band Gap, low shunt impedance, elliptical rods, *1C-SW-A5.65-T4.6-PBG-Elliptical-Cu*

Materials:

High shunt impedance, made of hard CuZr, *1C-SW-A3.75-T2.6-Calmped-CuZr*

Low shunt impedance hard CuZr, *1C-SW-A5.67-T4.6-LowTempBrazed-CuZr-Frascati-#1*

High shunt impedance, made of 7N large grain copper, *1C-SW-A3.75-T2.6-7NCu*

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*ZO/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

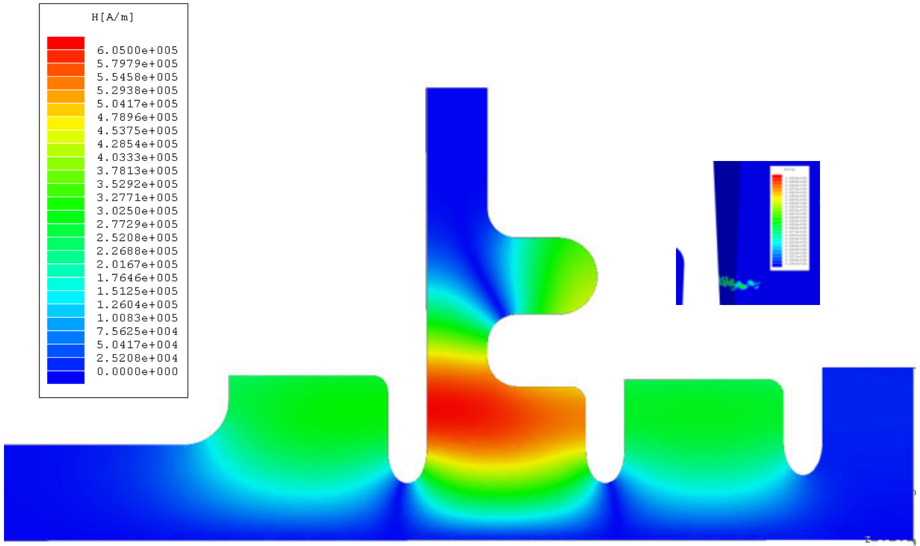
- 1C-SW-A3.75-T2.6-4mm-Ch-Cu-SLAC-#1
- 1C-SW-A5.65-T4.6-Mo-Frascati-#1
- 1C-SW-A5.65-T4.6-CuAg-SLAC-#1
- 1C-SW-A3.75-T2.6- LowTempBrazed
-CuAg-KEK-#1
- 1C-SW-A3.75-T2.6-CuAg-SLAC-#1

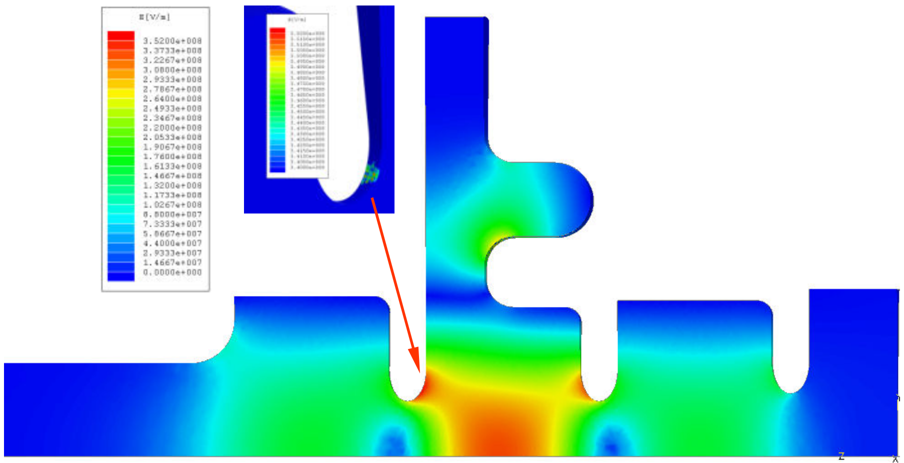
Geometry test

4mm choke structure

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

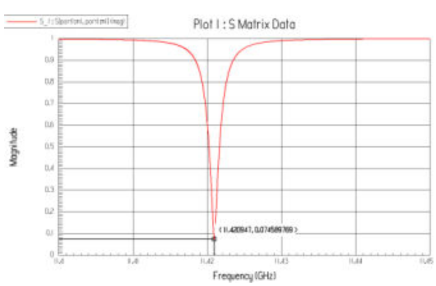
Next choke structure: 1C-SW-A3.75-T2.6-Cu-4mm-Choke, 10 MW losses

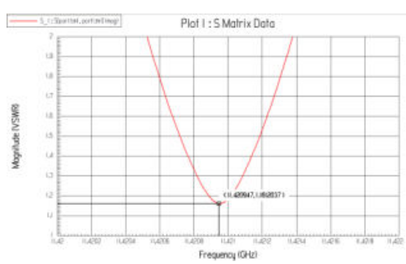


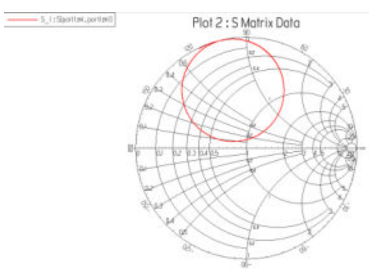


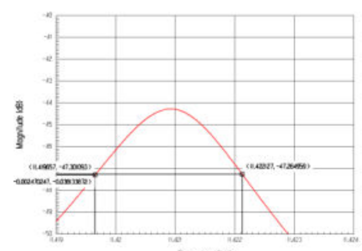
Maximum magnetic field 604 kA/m
(SLANS 602.065 kA/m)

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

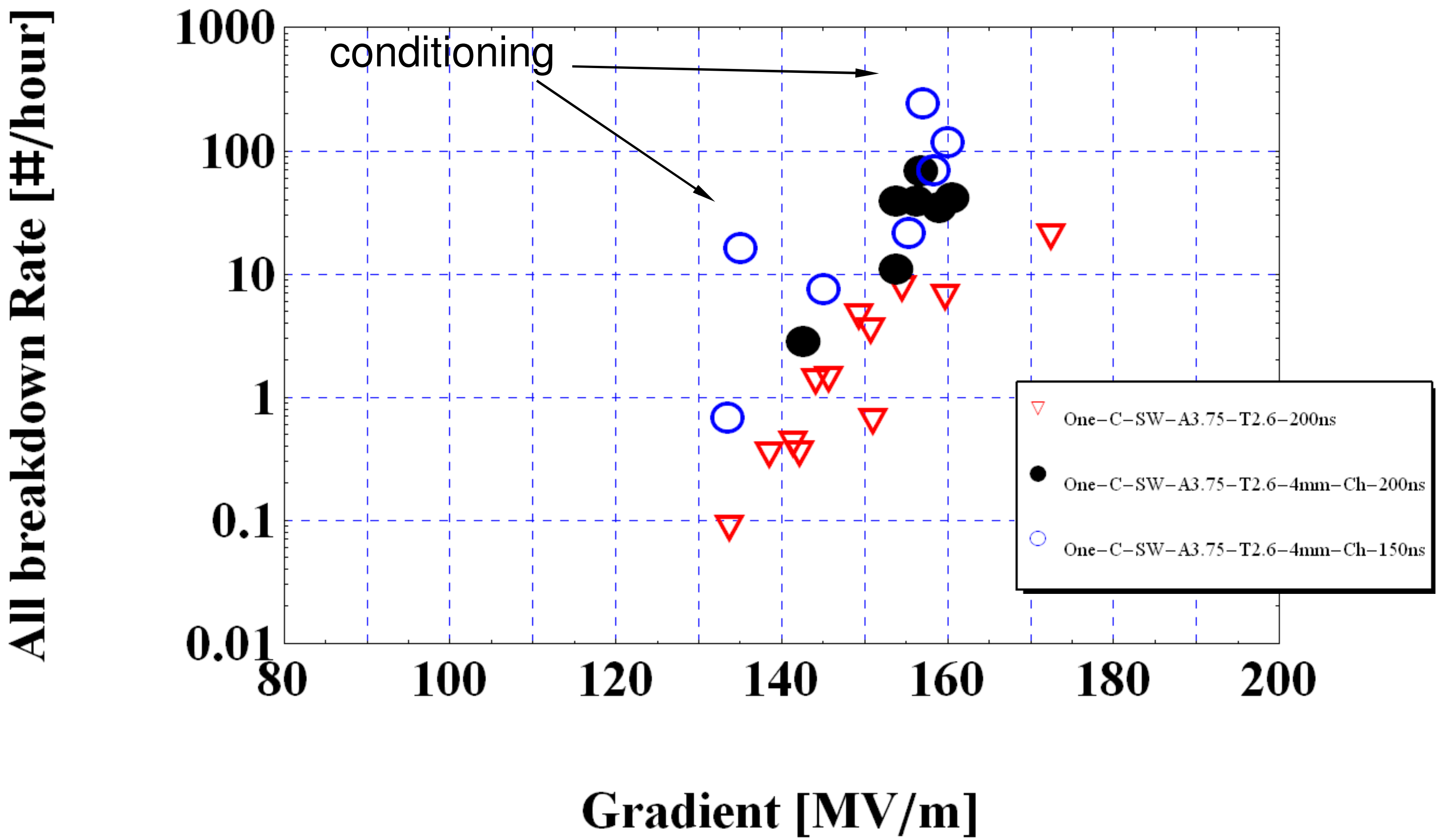
(SLANS 11.42391 GHz) (SLANS 1.04952)

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

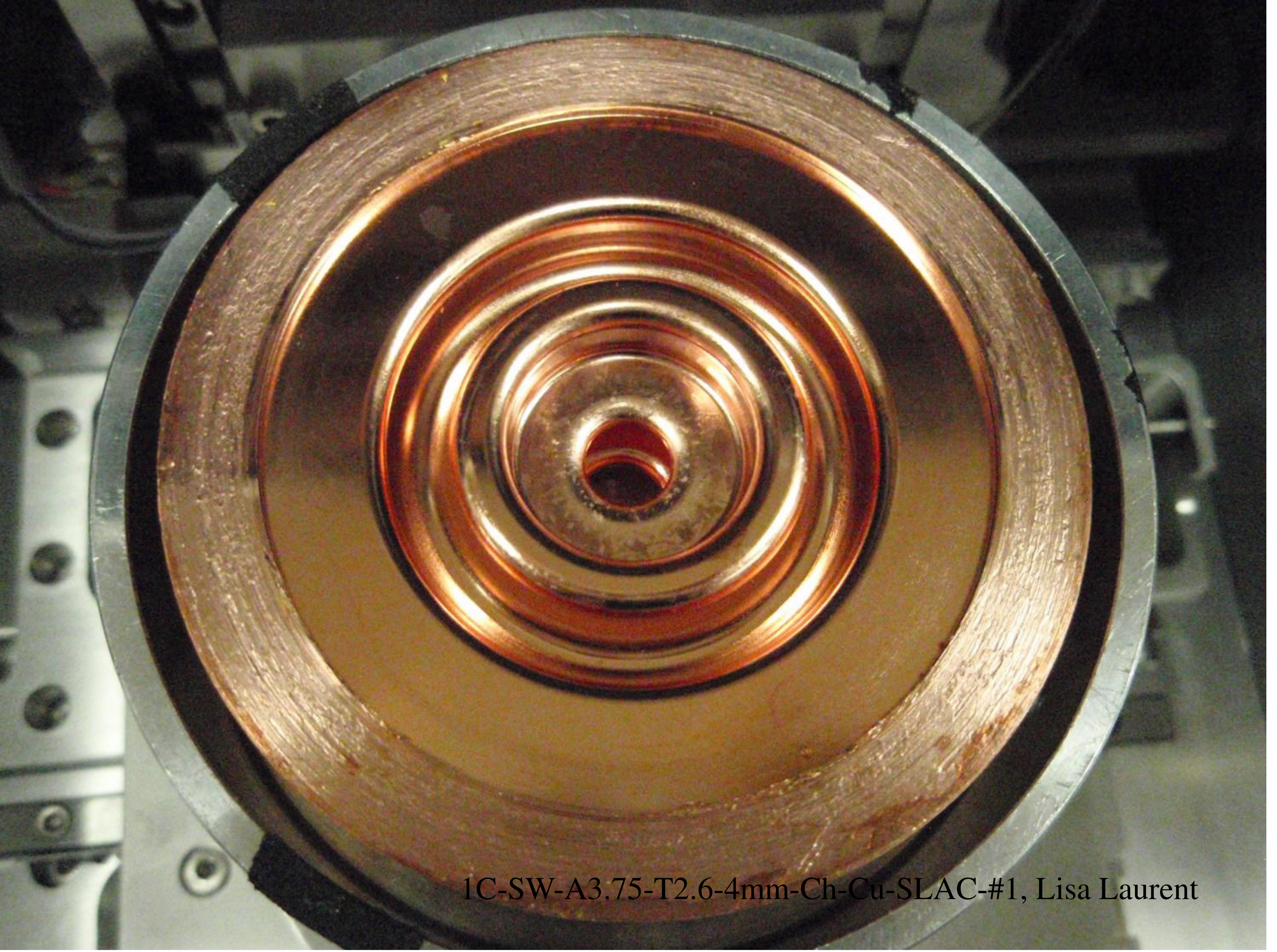
$$\frac{11.421}{0.002470247}\cdot\left(1 + 1.1612037^{-1}\right) = 8.605\times\ 10^{3}$$

V.A. Dolgashev, 18 September 2008

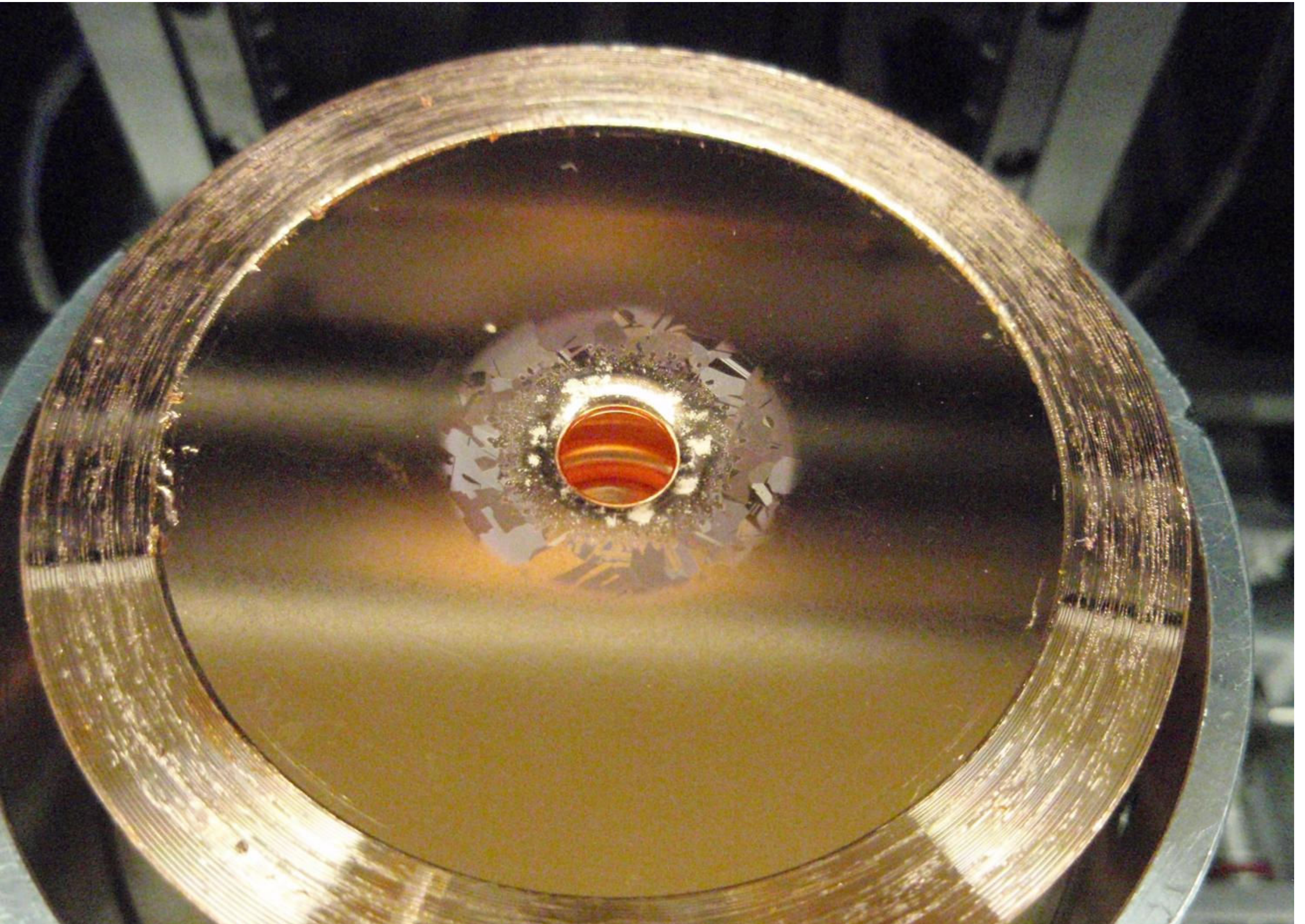
Gradient comparison between 1C-SW-A3.75-T2.6-Cu-SLAC-#1 and 1C-SW-A3.75-T2.6-4mm-Ch-Cu-SLAC-#1



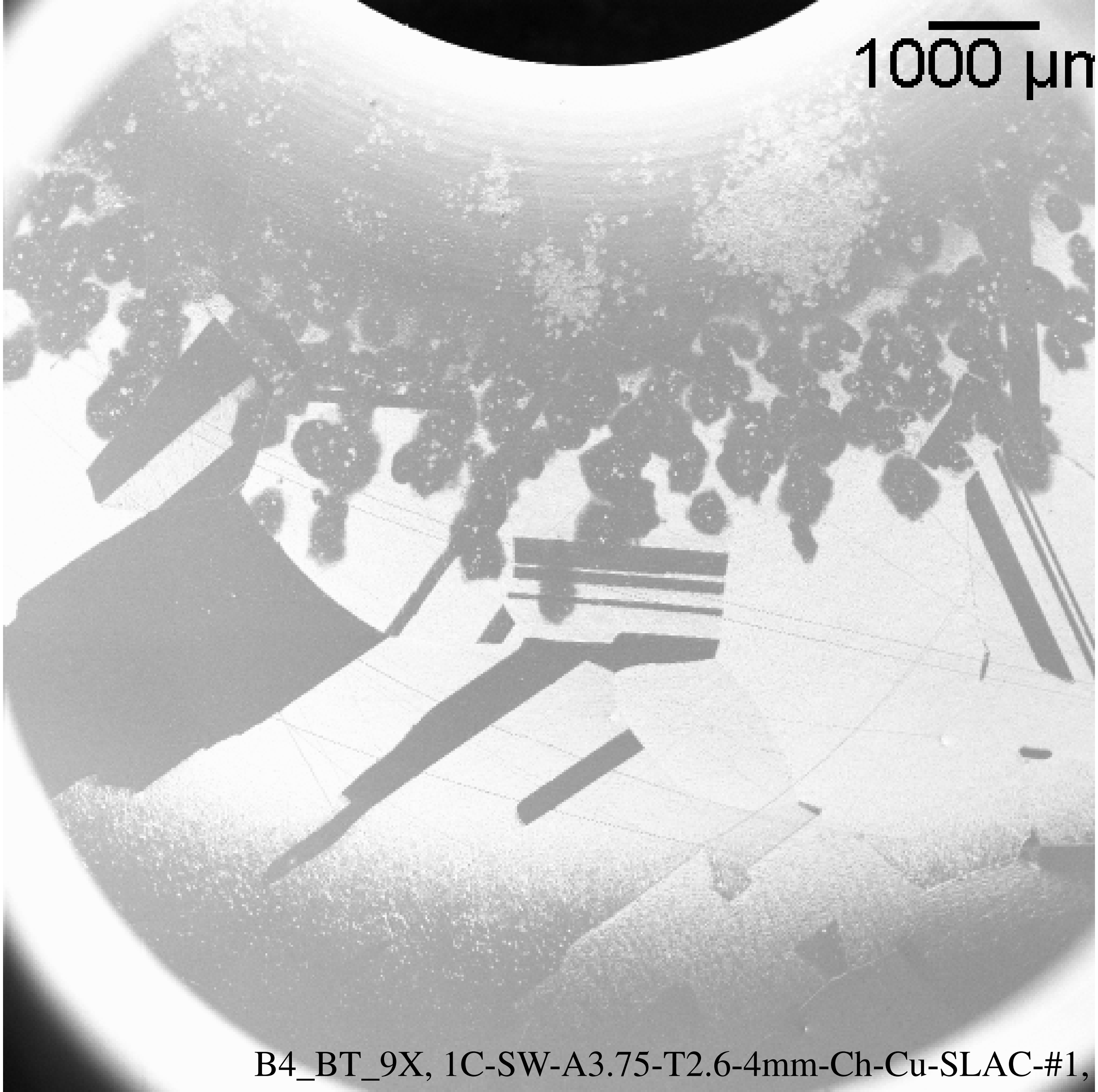
V.A. Dolgashev, 20 May 2009



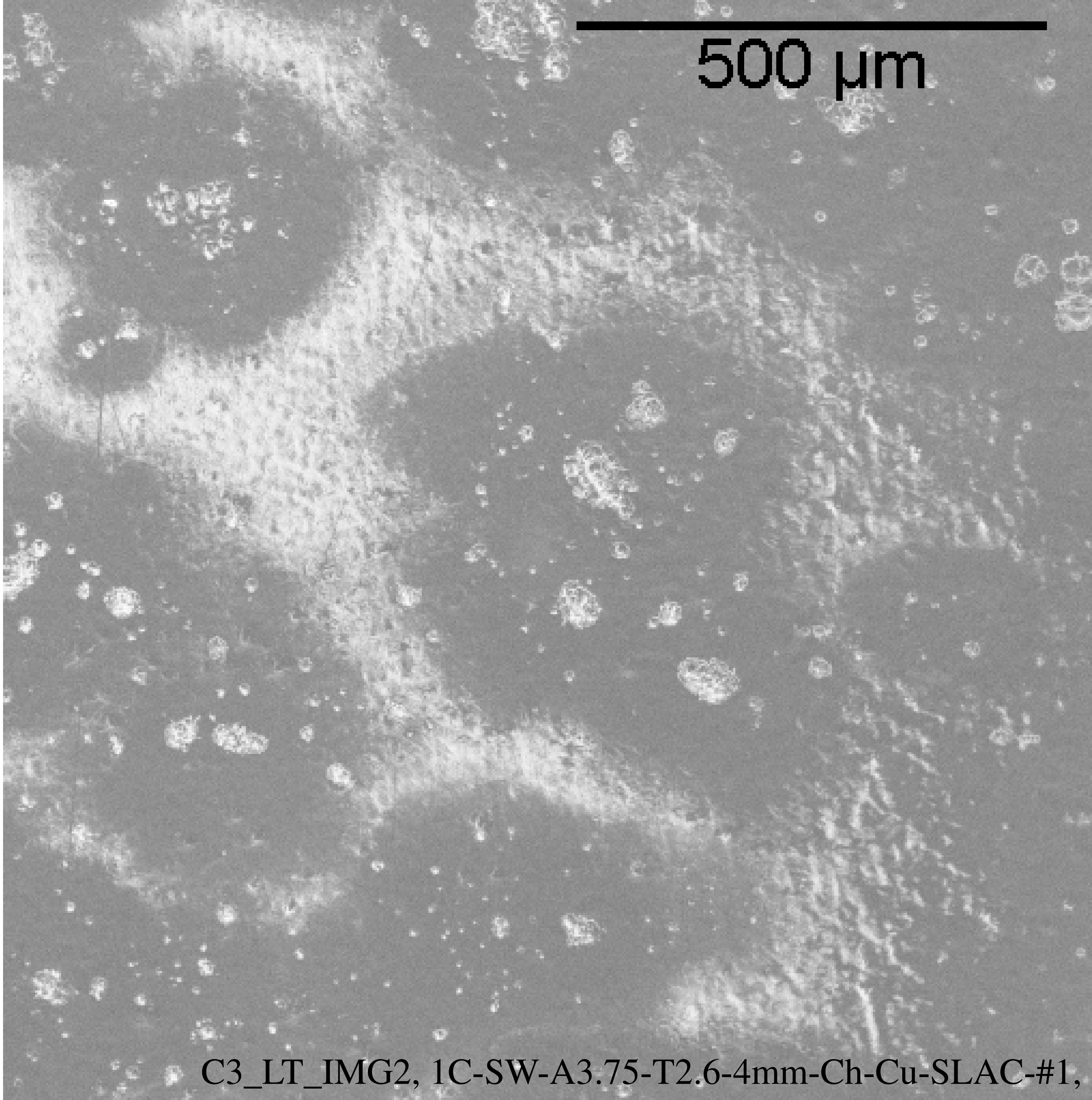
1C-SW-A3.75-T2.6-4mm-Ch-Cu-SLAC-#1, Lisa Laurent



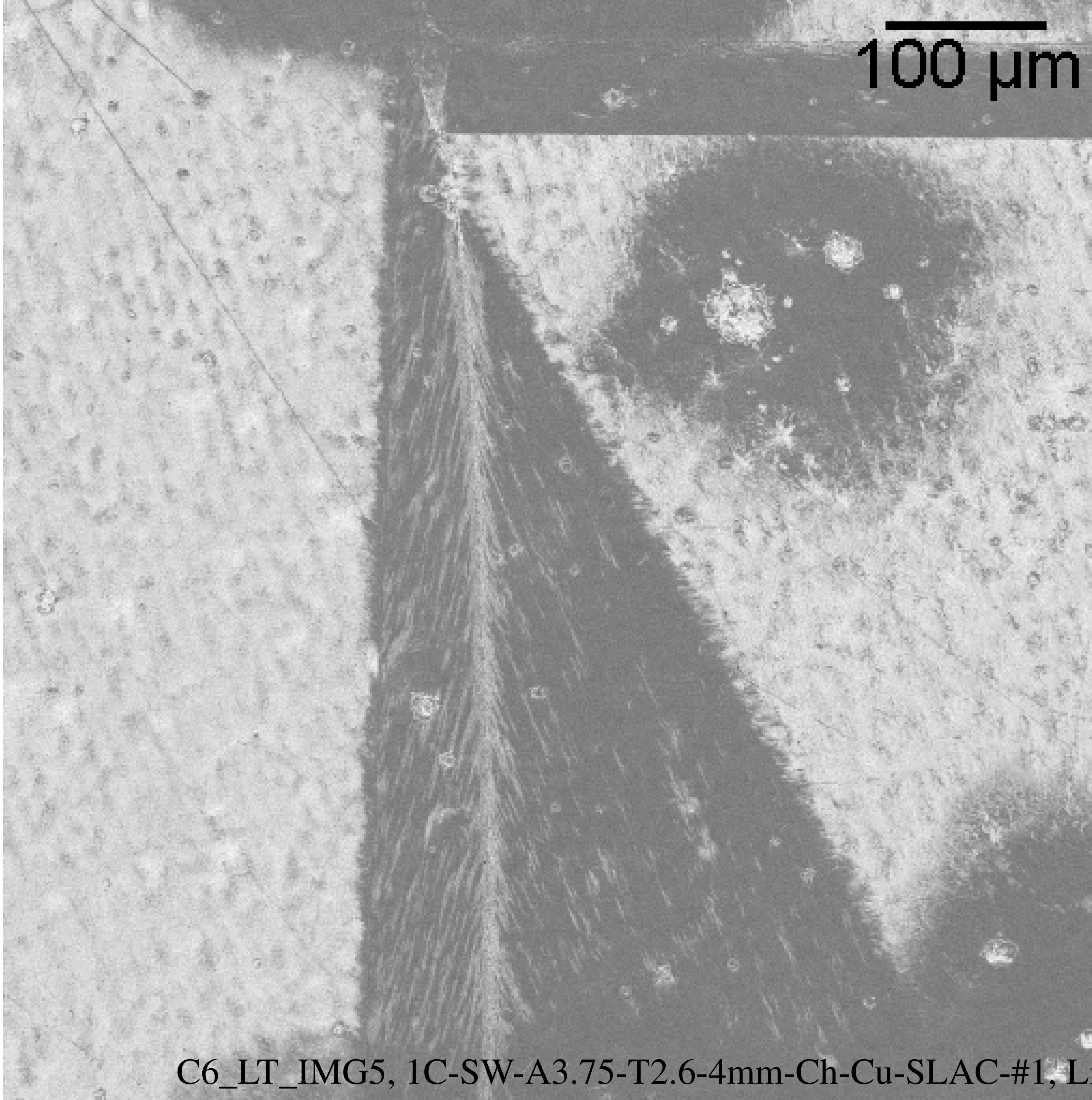
1C-SW-A3.75-T2.6-4mm-Ch-Cu-SLAC-#1, Lisa Laurent



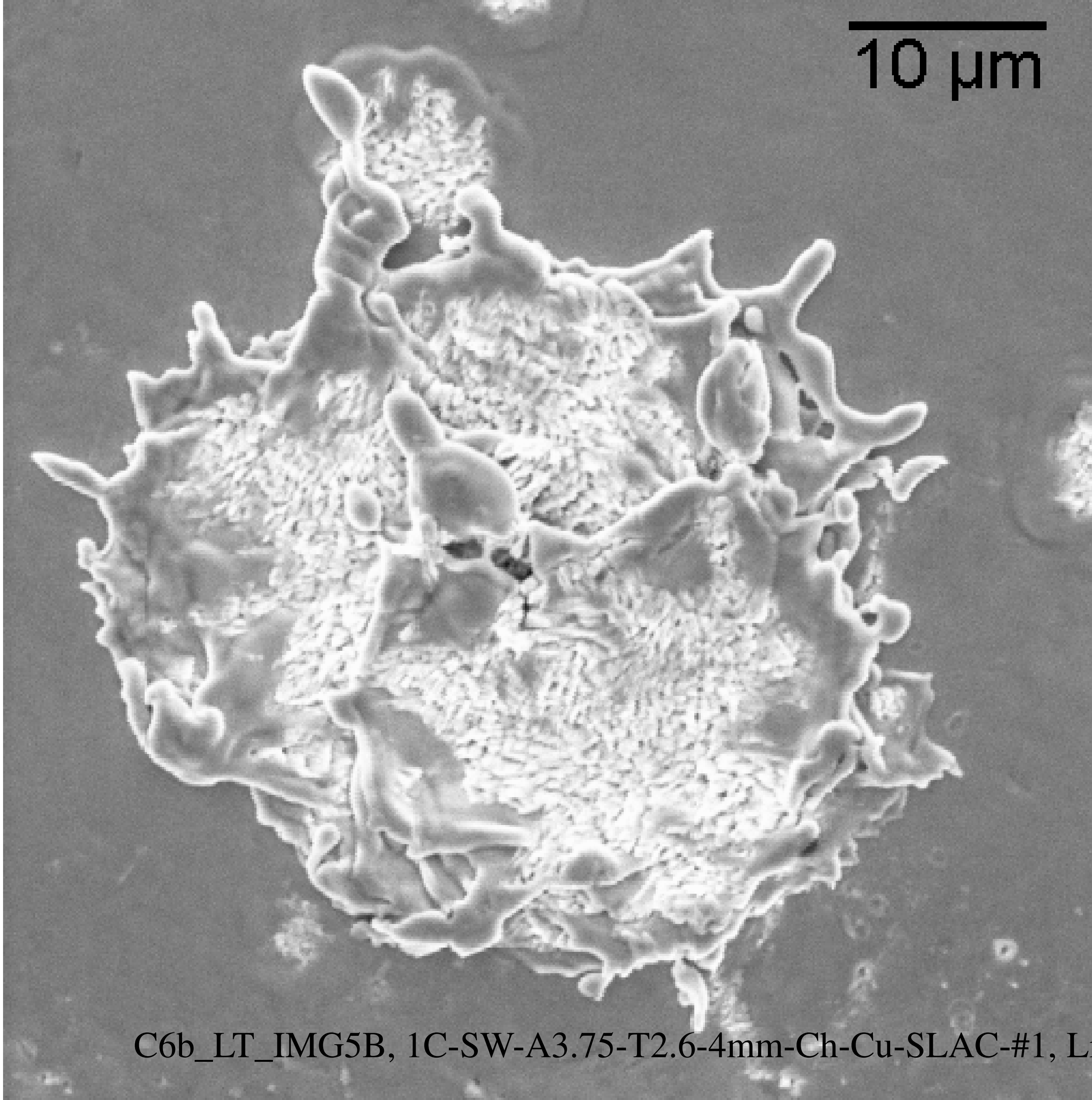
B4_BT_9X, 1C-SW-A3.75-T2.6-4mm-Ch-Cu-SLAC-#1, Lisa Laurent



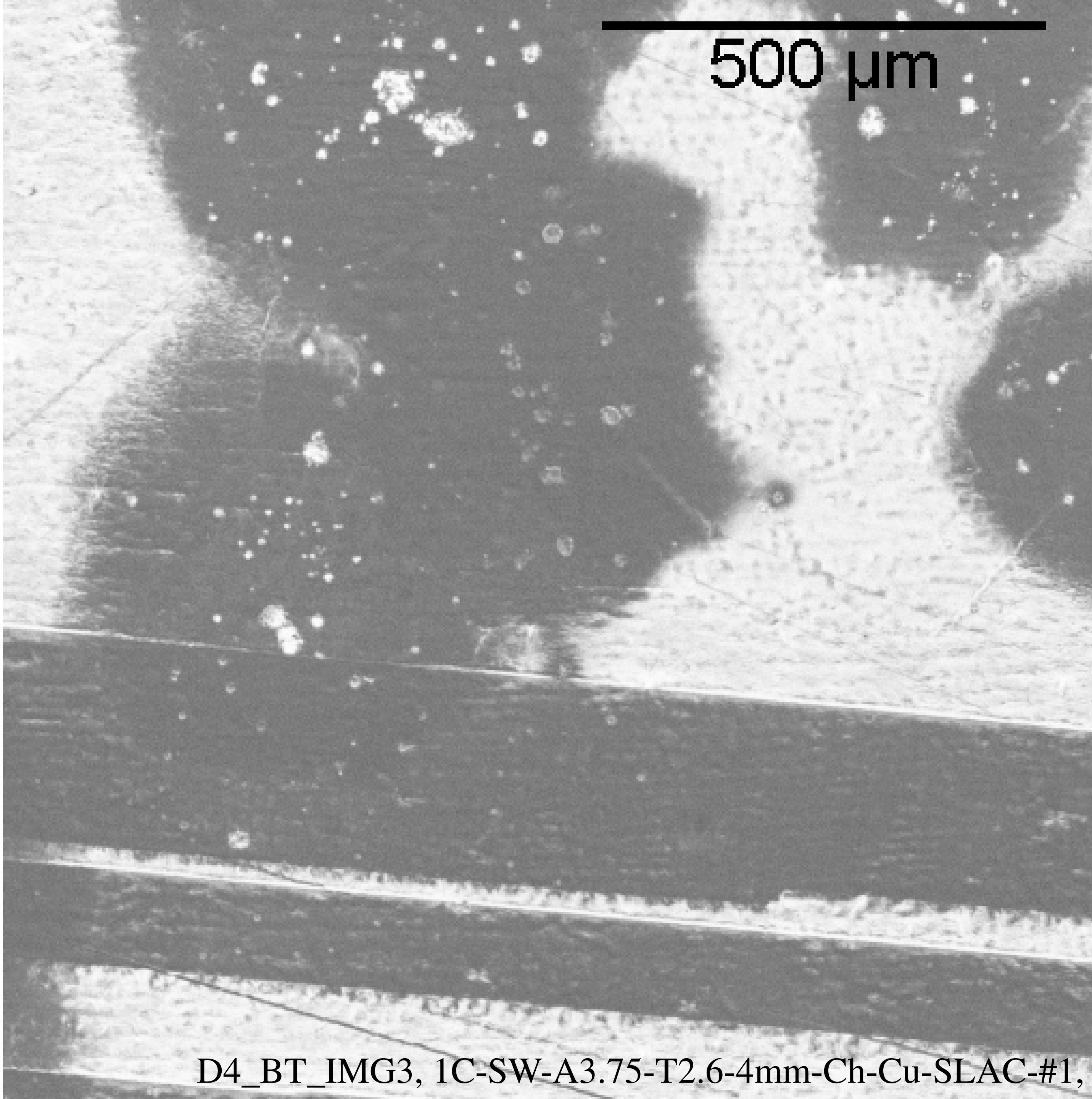
C3_LT_IMG2, 1C-SW-A3.75-T2.6-4mm-Ch-Cu-SLAC-#1, Lisa Laurent



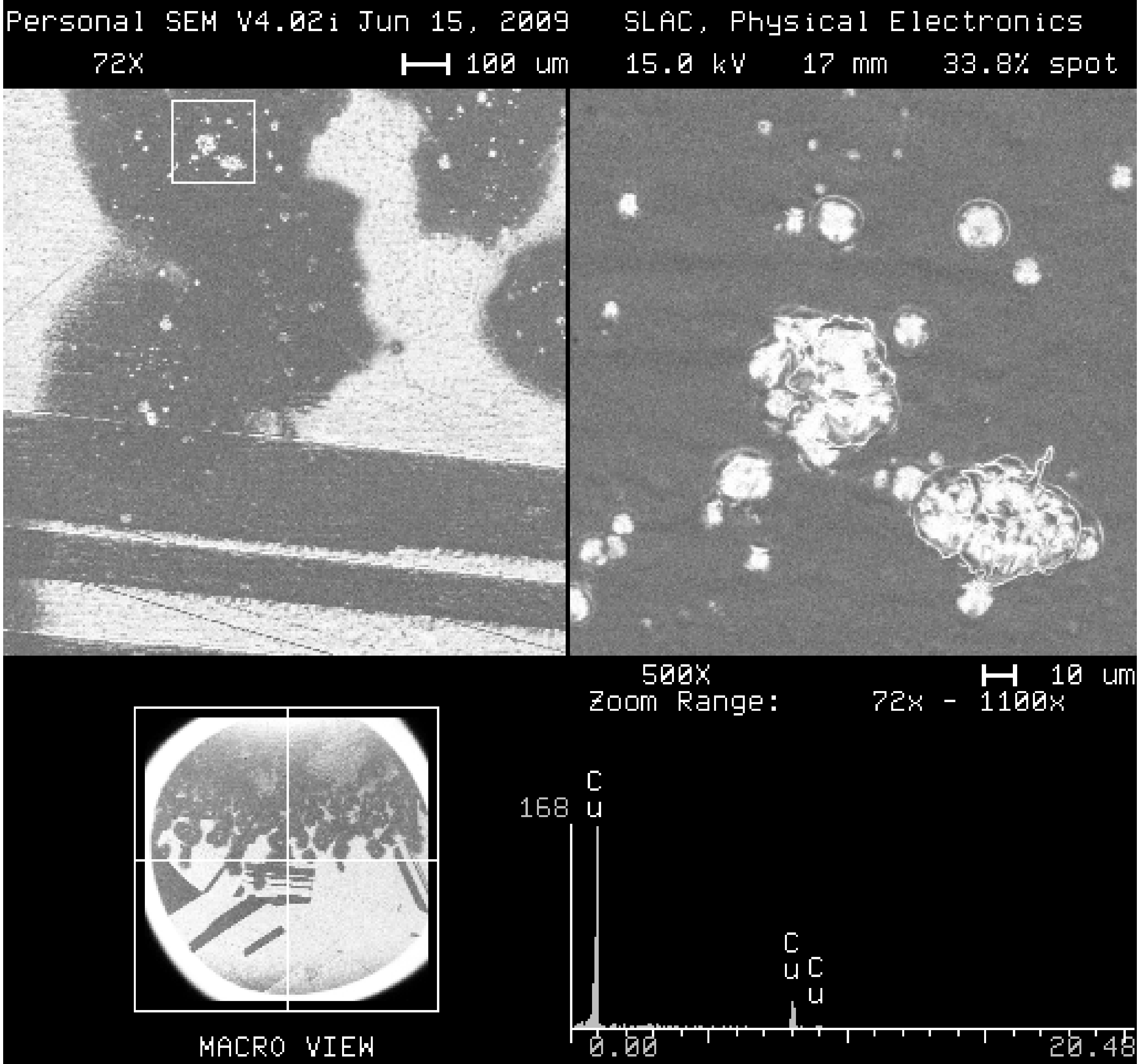
C6_LT_IMG5, 1C-SW-A3.75-T2.6-4mm-Ch-Cu-SLAC-#1, Lisa Laurent



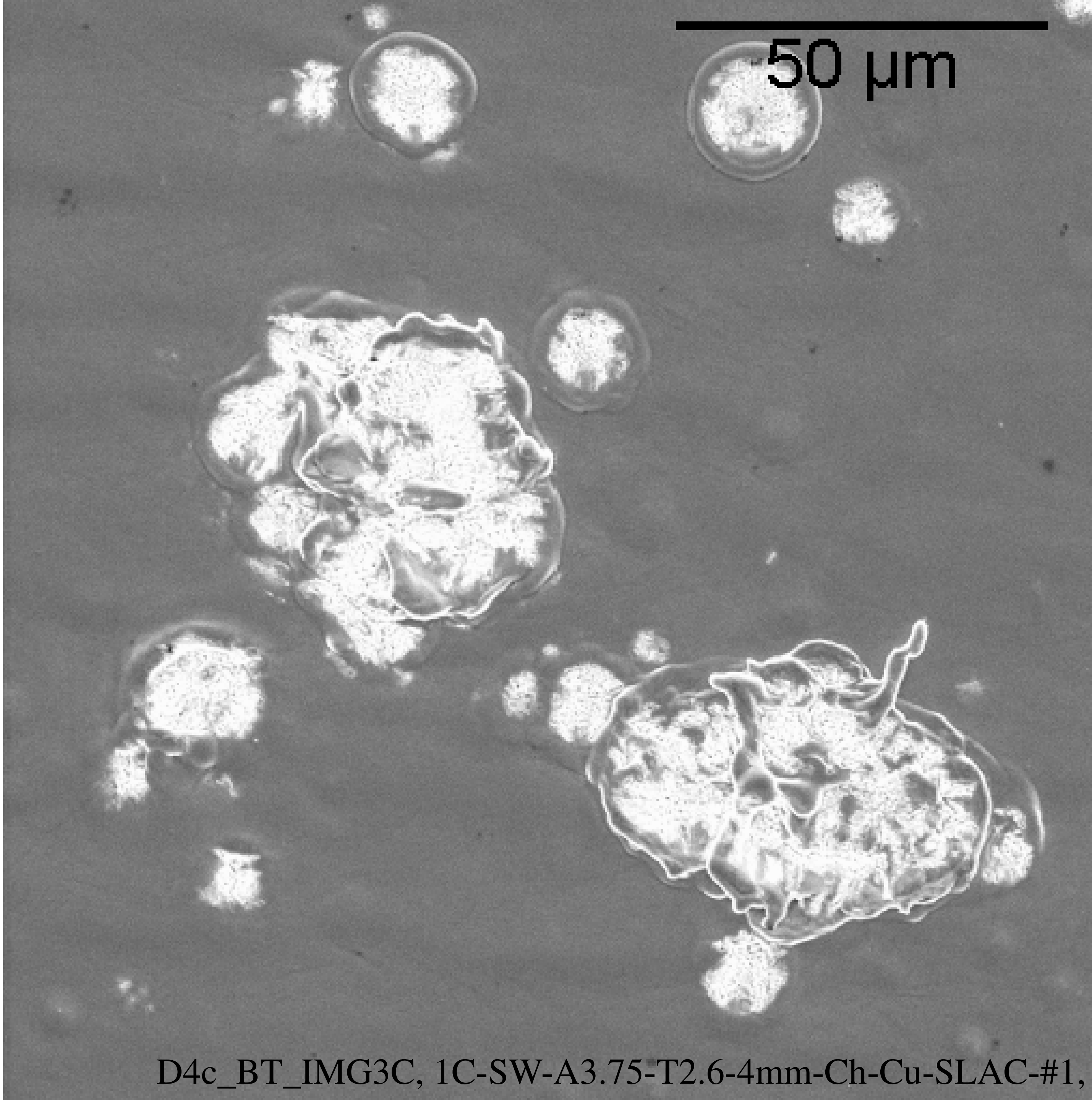
C6b_LT_IMG5B, 1C-SW-A3.75-T2.6-4mm-Ch-Cu-SLAC-#1, Lisa Laurent



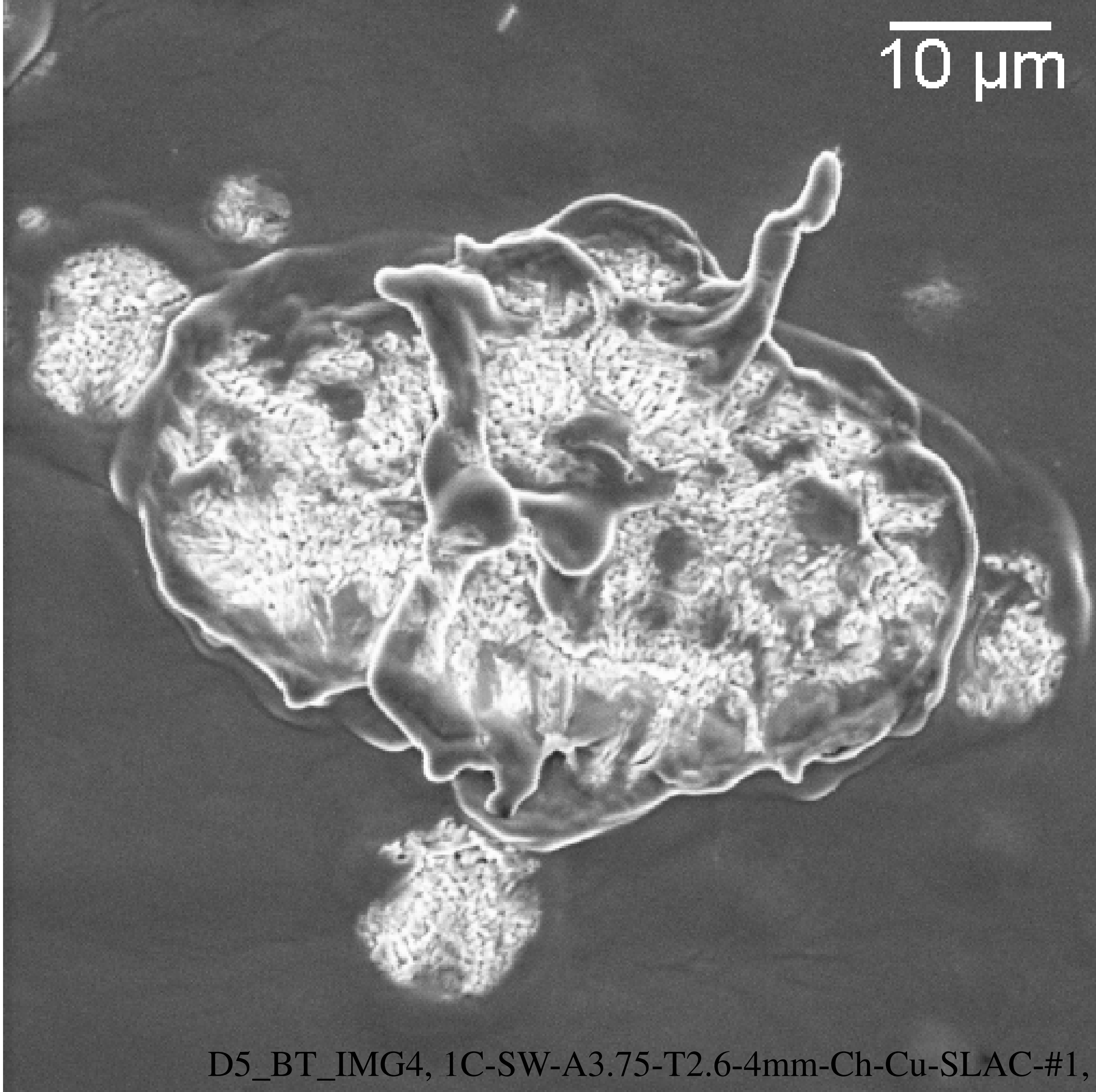
D4_BT_IMG3, 1C-SW-A3.75-T2.6-4mm-Ch-Cu-SLAC-#1, Lisa Laurent



D4b_BT_IMG3B, 1C-SW-A3.75-T2.6-4mm-Ch-Cu-SLAC-#1, Lisa Laurent



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

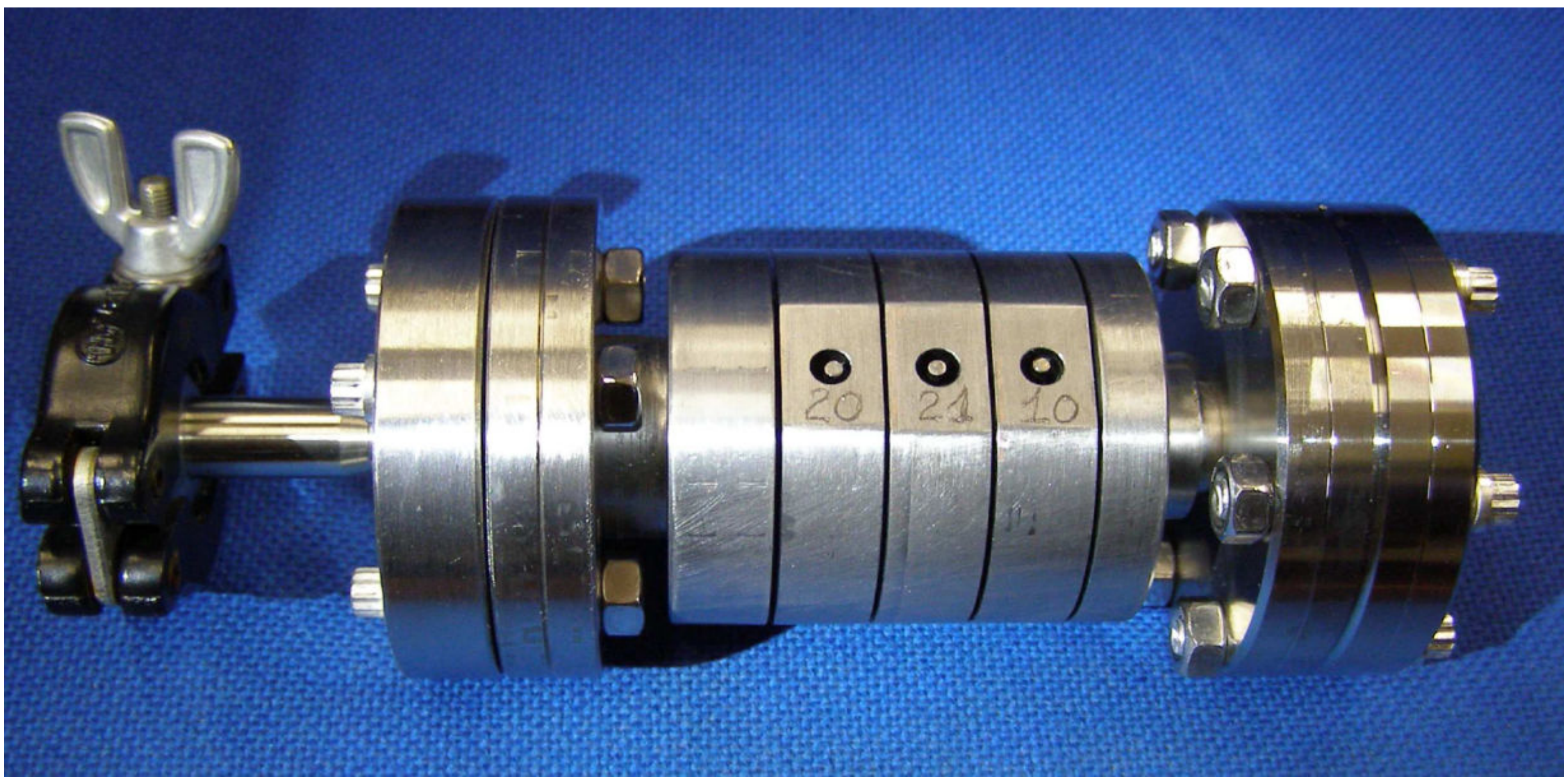
INFN
Istituto Nazionale
di Fisica Nucleare
Laboratori Nazionali di Frascati

SPARC

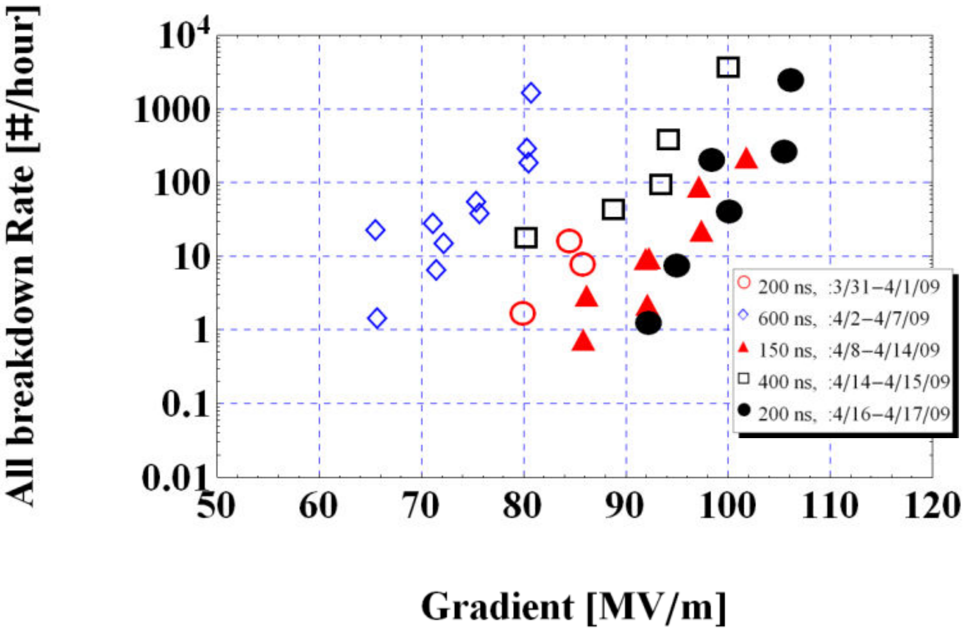
SPARC-RF-08/003
December 19, 2008

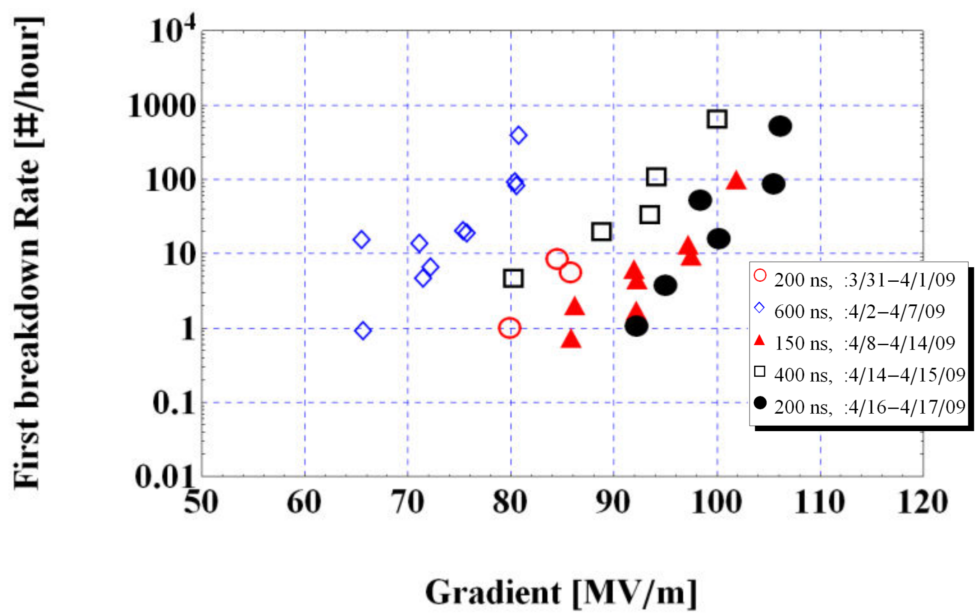
Status report on SALAF technical activity during the second half of 2008

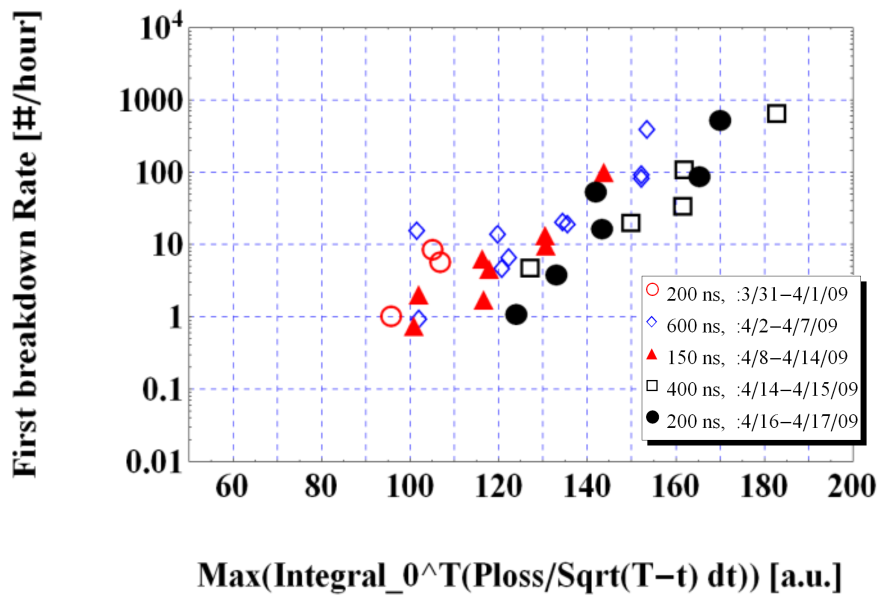
S. Bini, P. Chimenti, V. Chimenti, R. Di Raddo, V. Lollo, B. Spataro, F.Tazzioli



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







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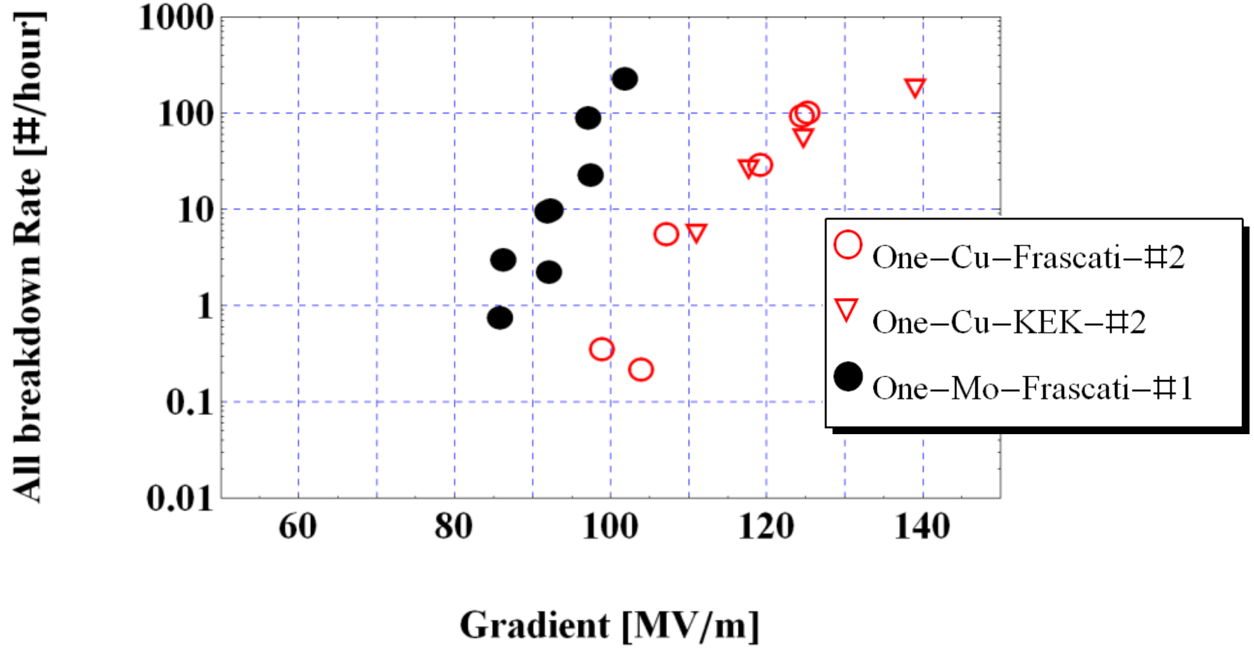
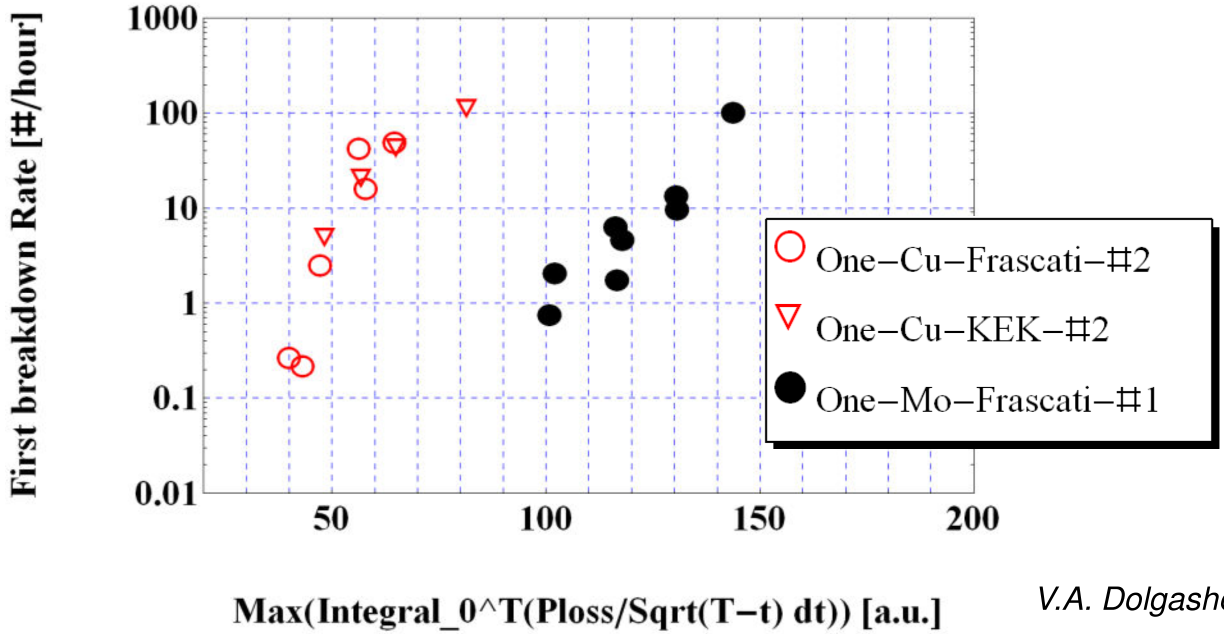
Comparison of peak pulse heating for two copper and one molybdenum 1C-SW- A5.65-T4.6-Cu structures, *shaped* pulse, flat part 150 ns





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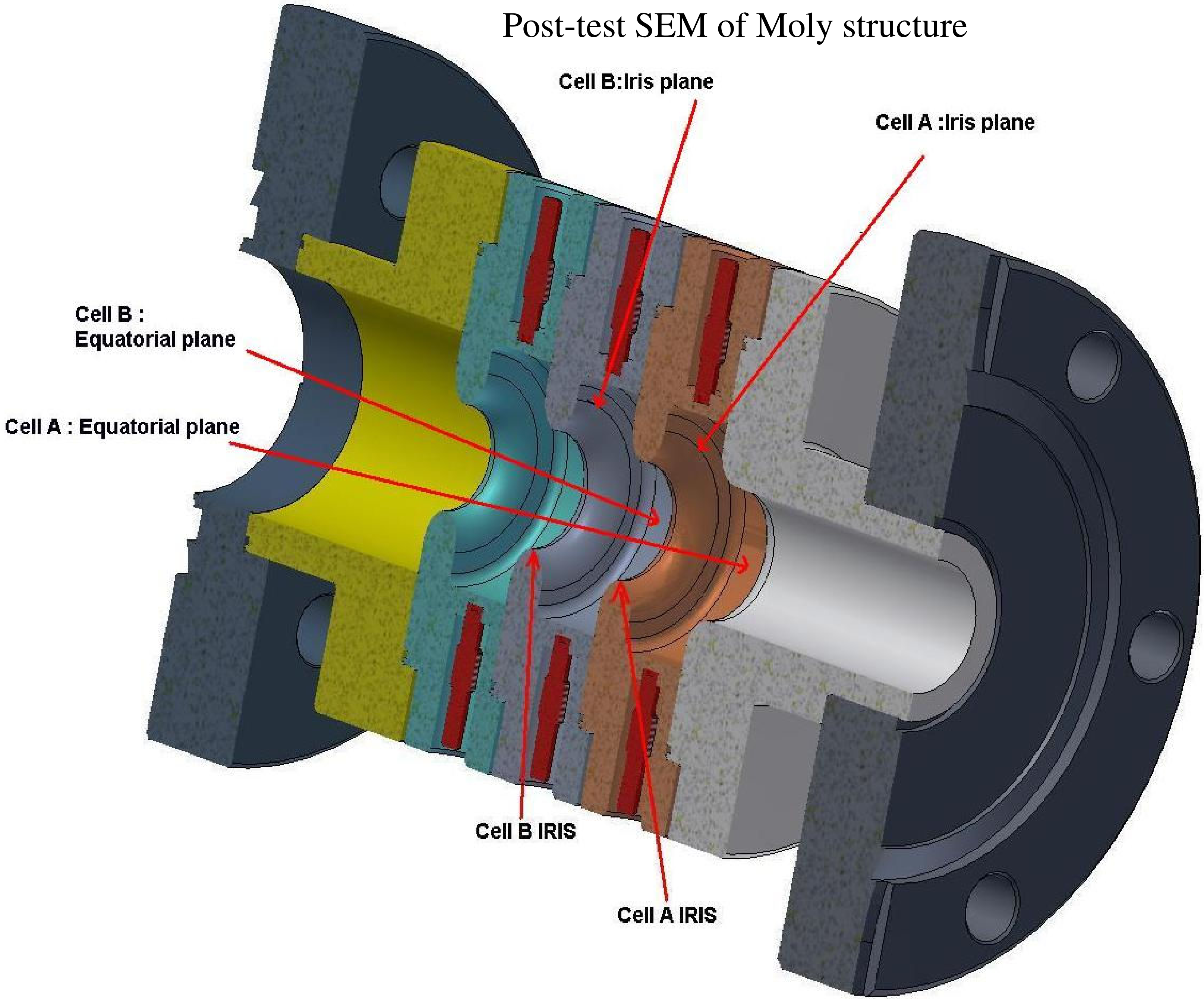
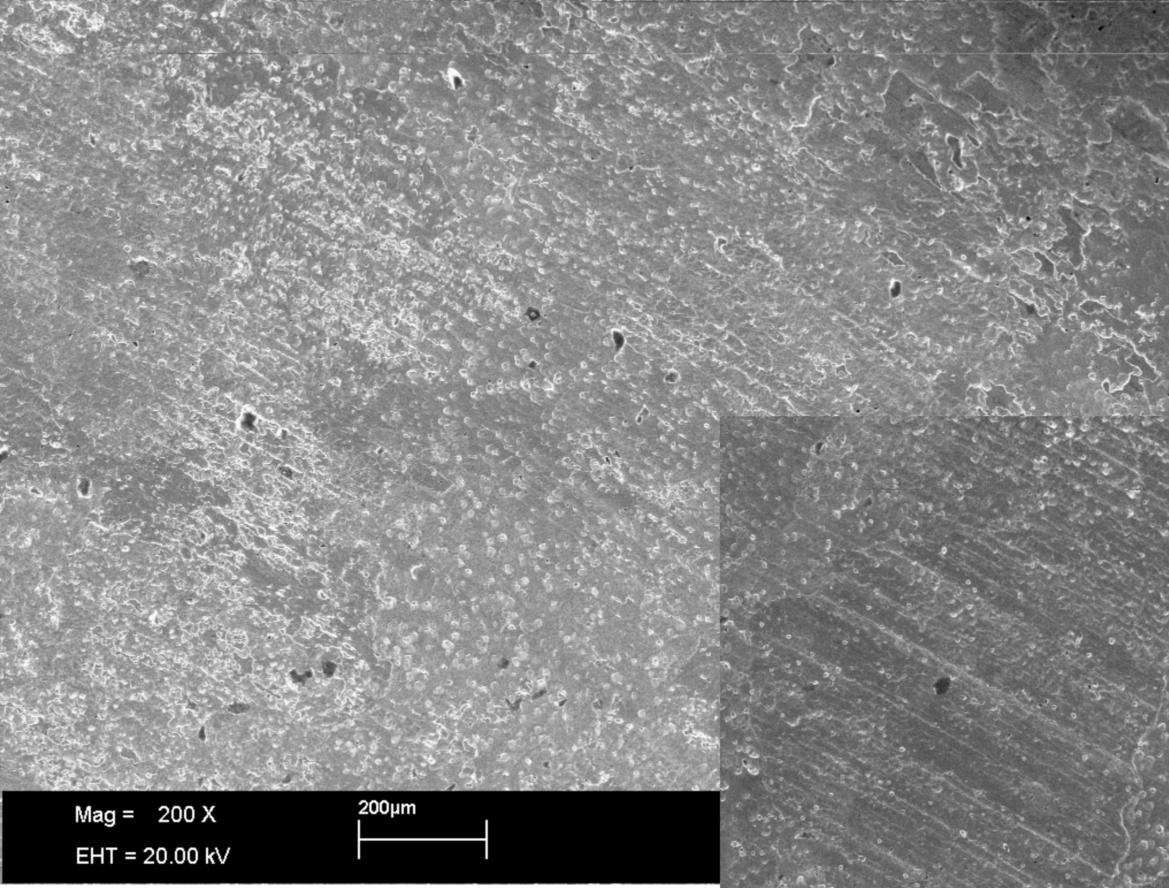
Post-test SEM of Moly structure

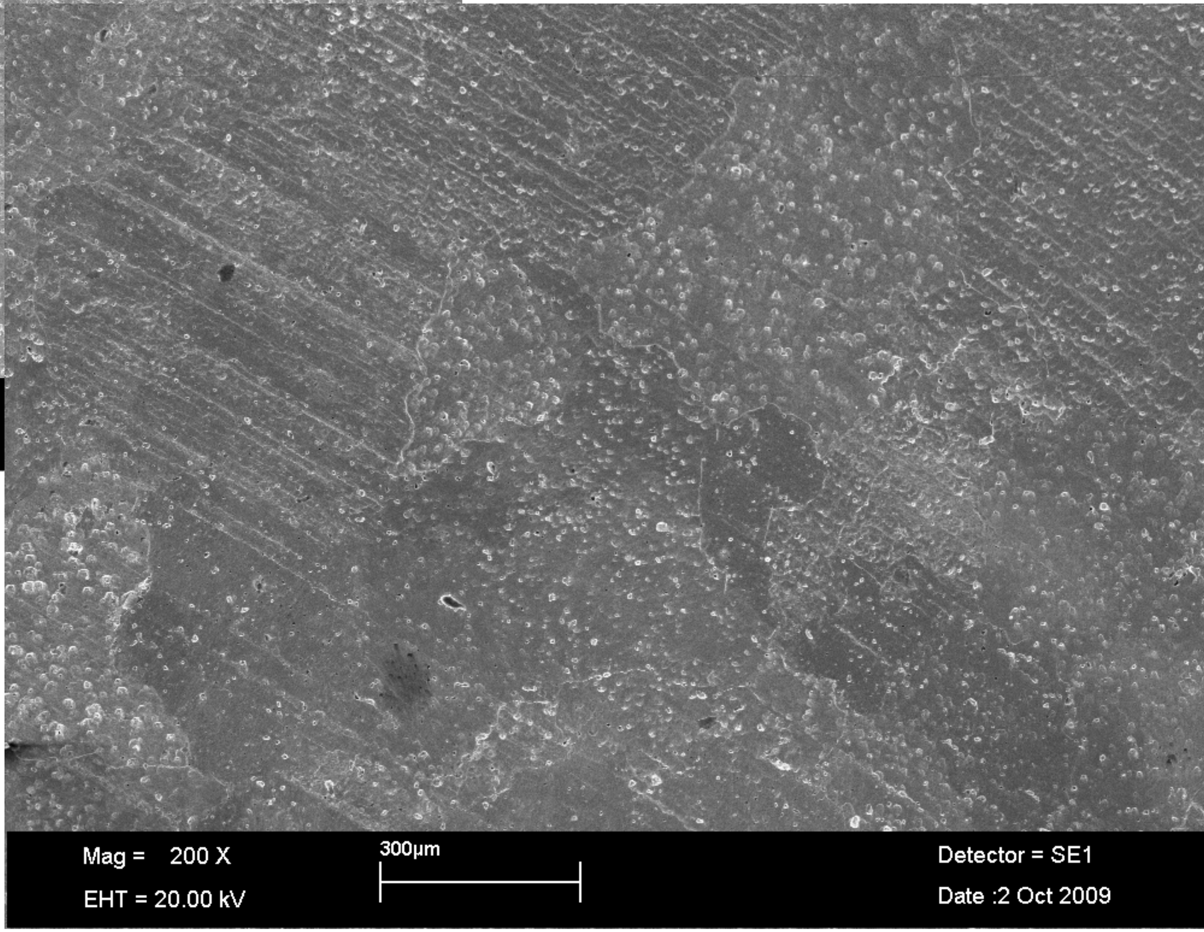


Simone Bini, INFN Frascati, October 2009

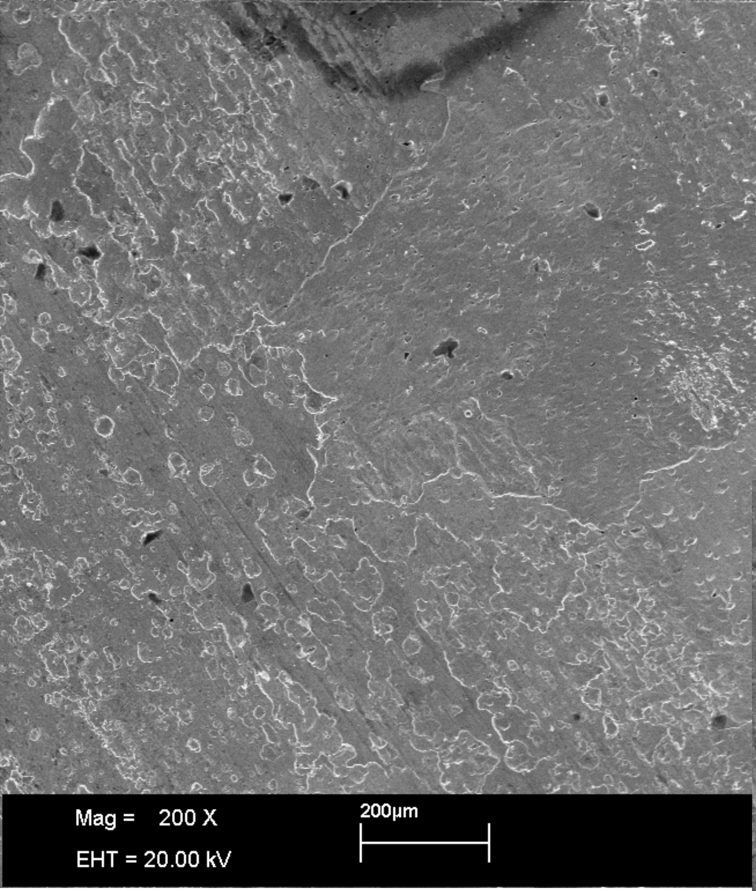


A iris plane 200x

B iris plane 200x

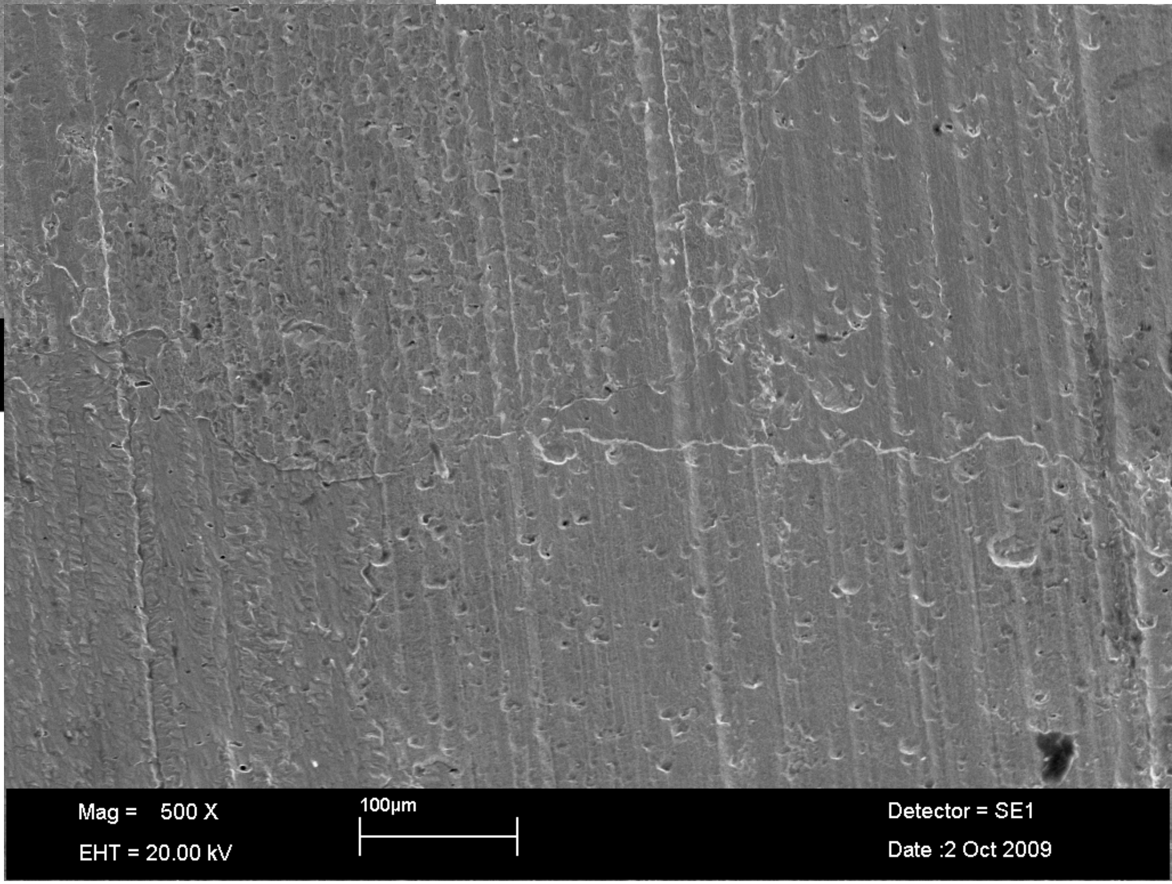


Simone Bini, INFN Frascati, October 2009



A equatorial plane 200x

B equatorial plane 500x



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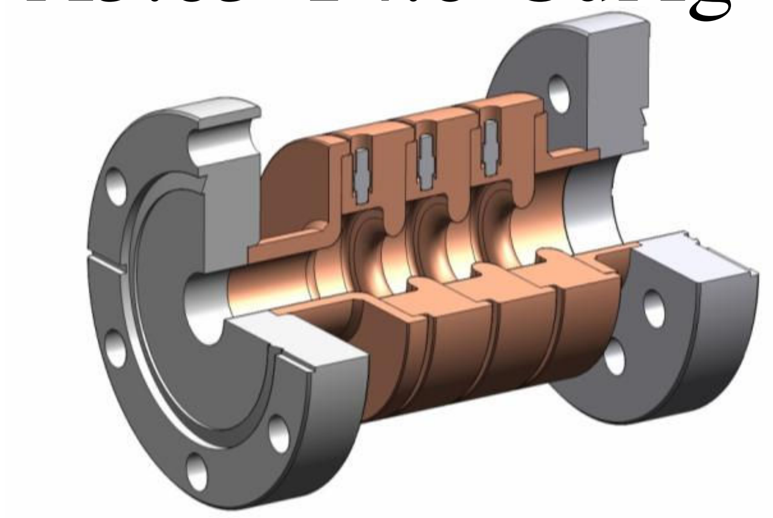
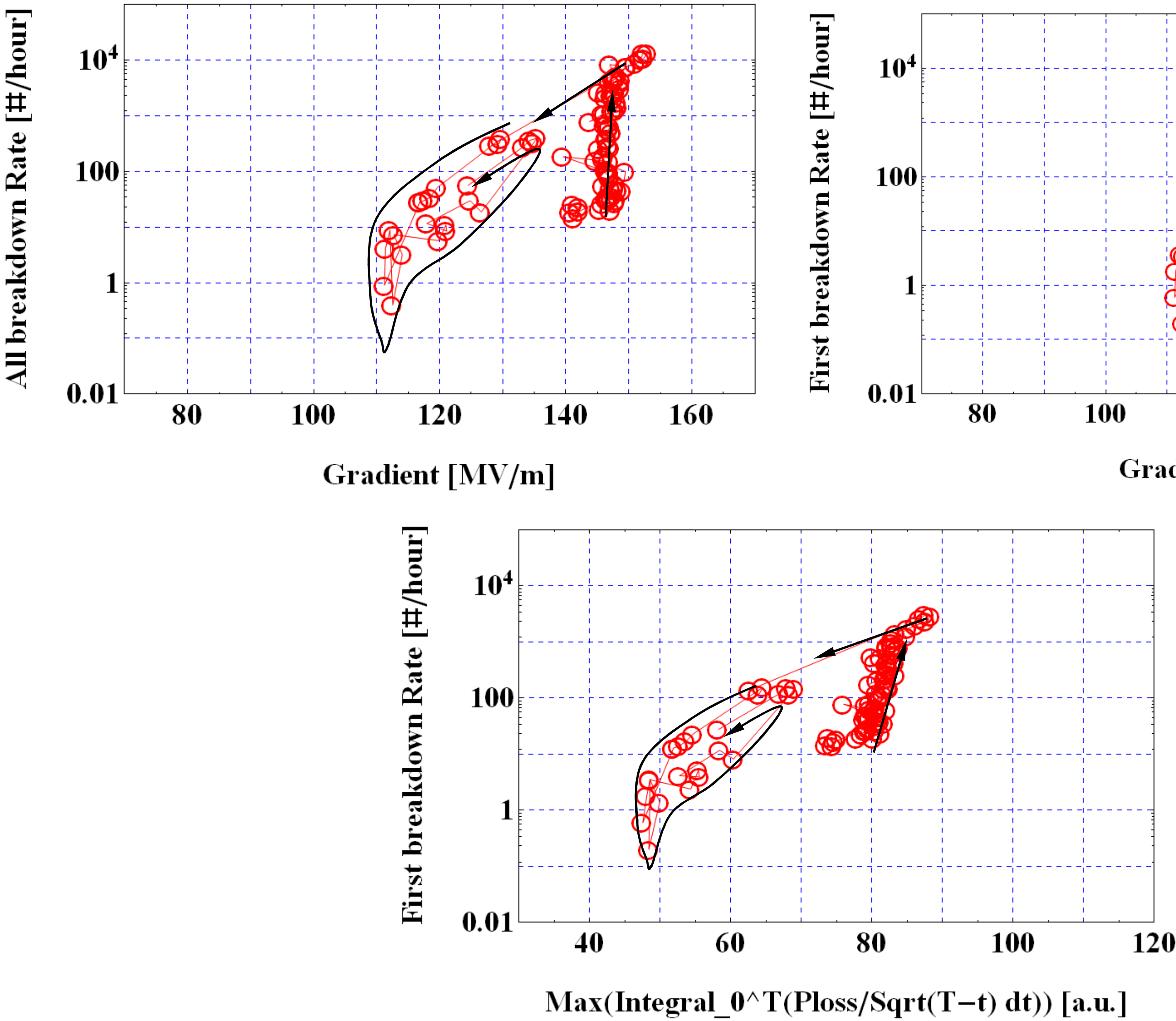
Copper alloys

Low shunt impedance Soft CuAg structure,

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



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



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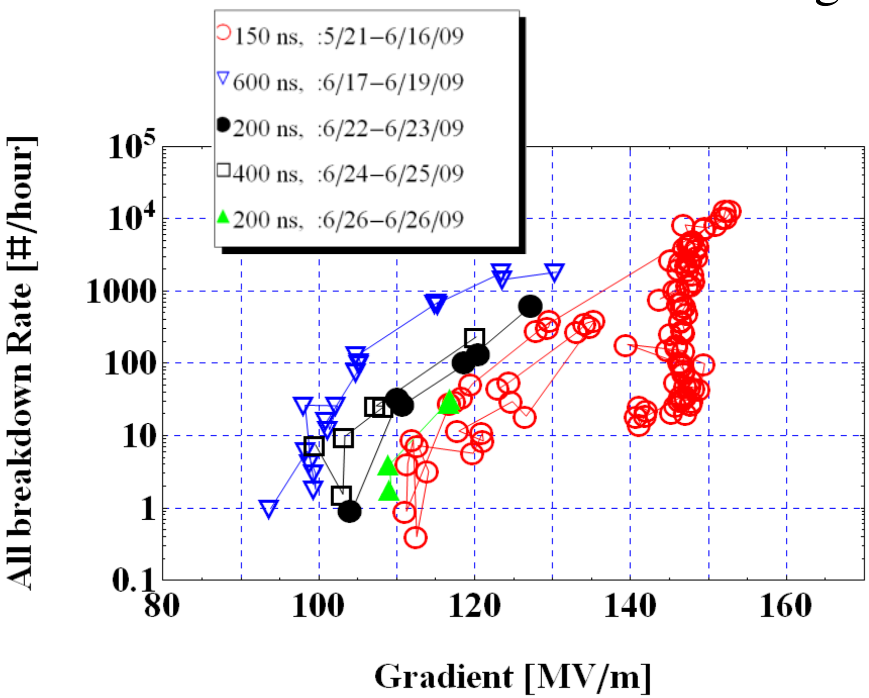
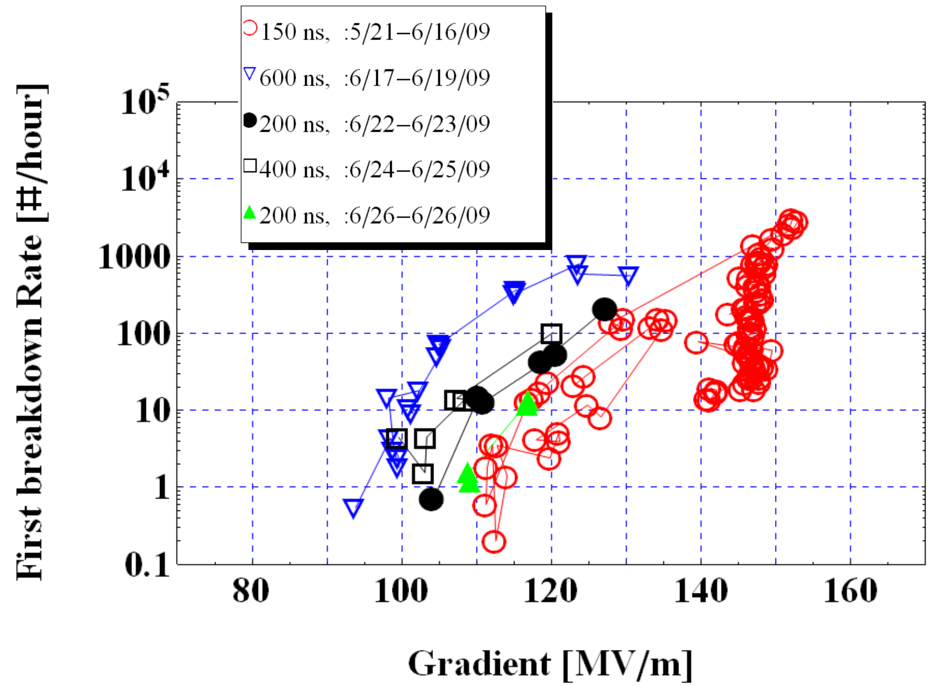
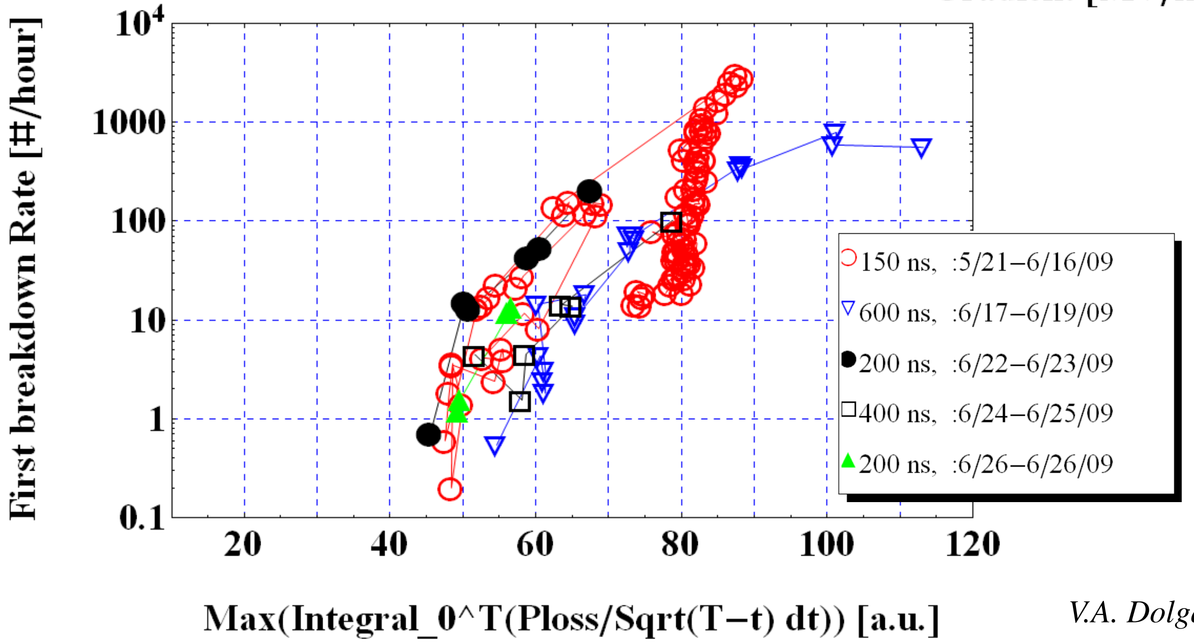
A5.65-T4.6-CuAg-SLAC-#1 shaped pulse

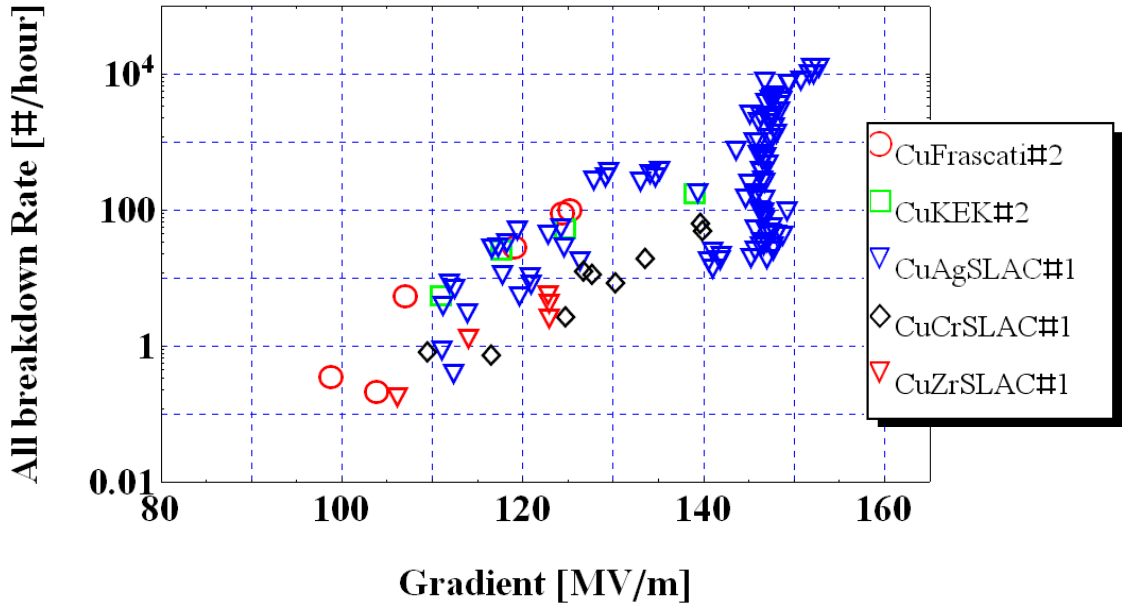


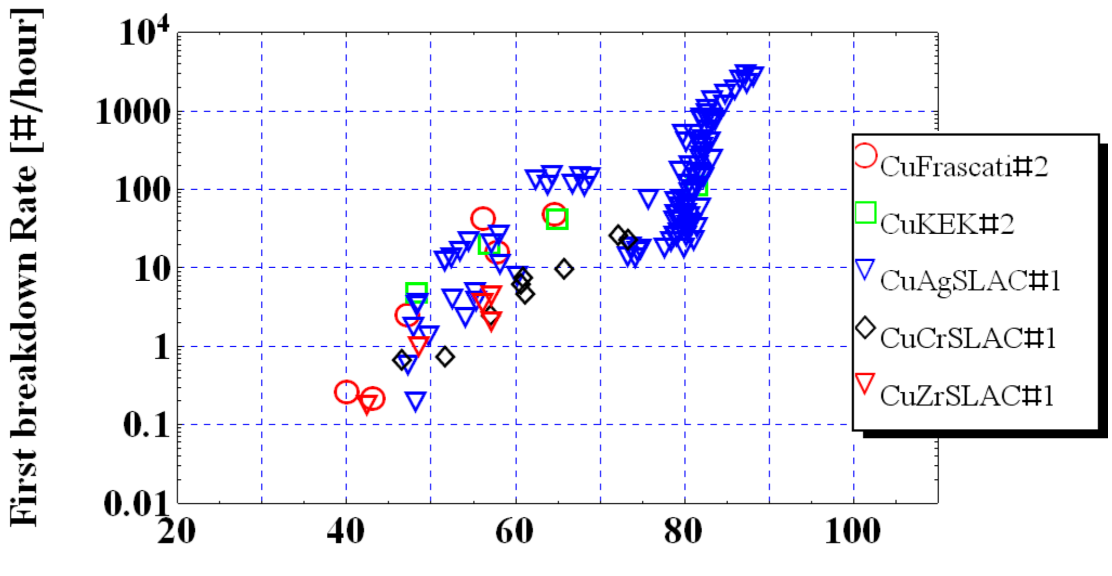




V.A. Dolgashev, 6 October 2009

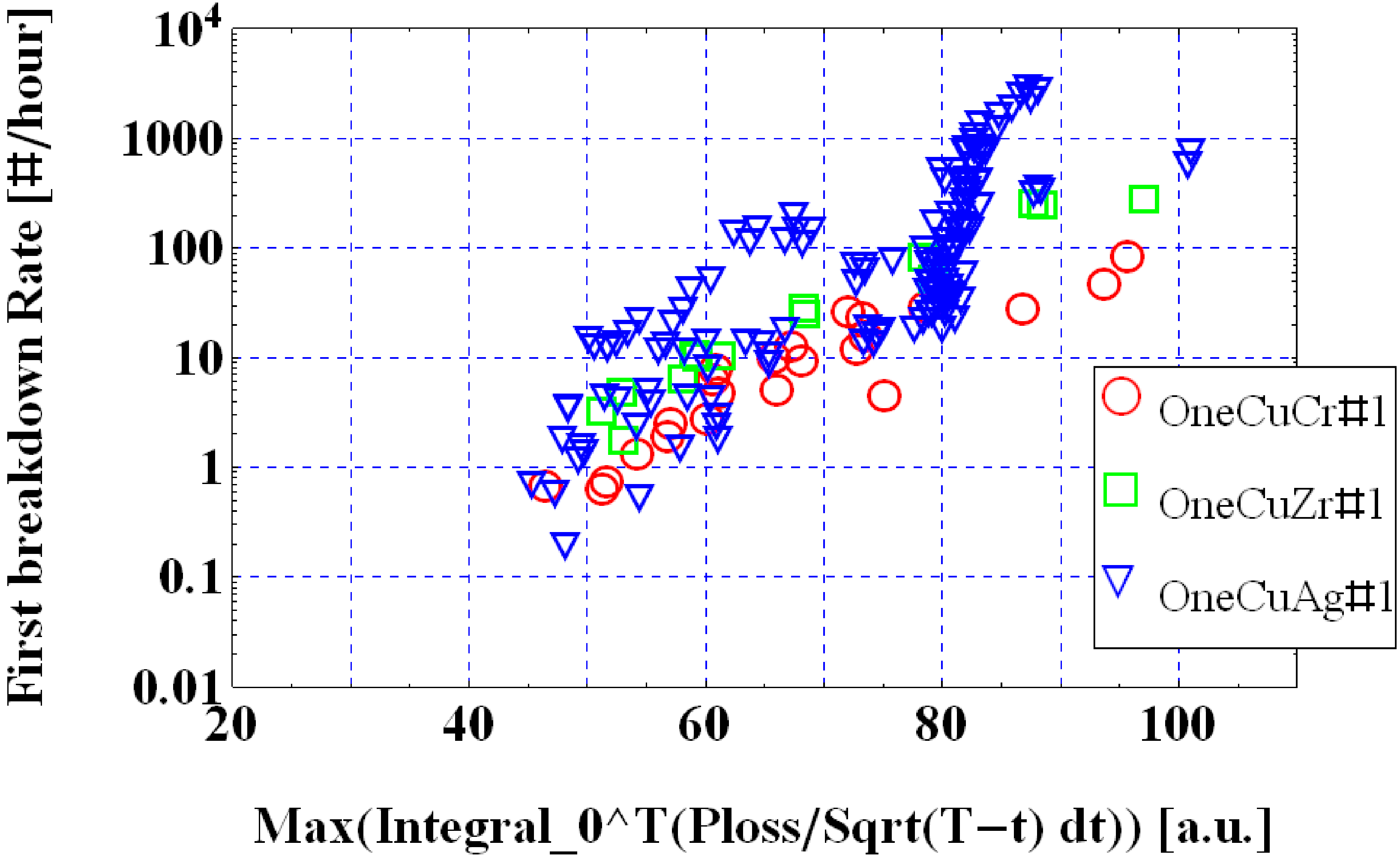
Comparison of A5.65-T4.6-CuAg-SLAC-#1, 150ns flat pulse with other A5.65-T4.6 structures





V.A. Dolgashev, 6 October 2009

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

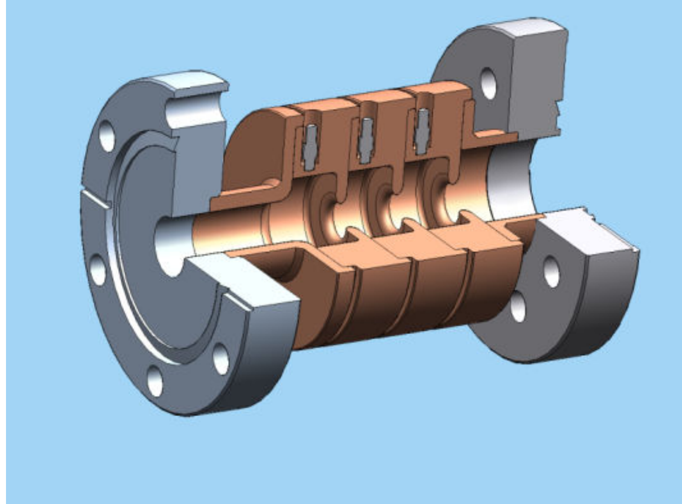


V.A. Dolgashev, 6 October 2009

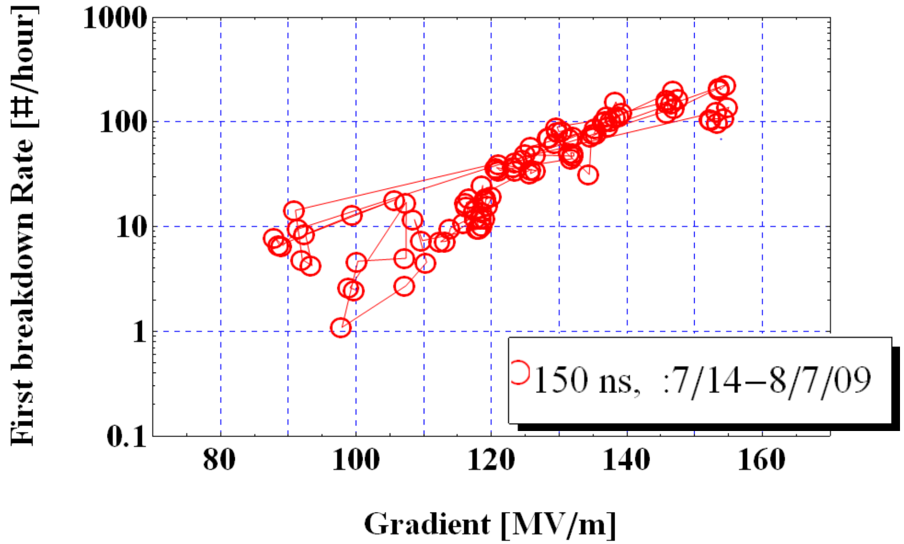
Copper alloys

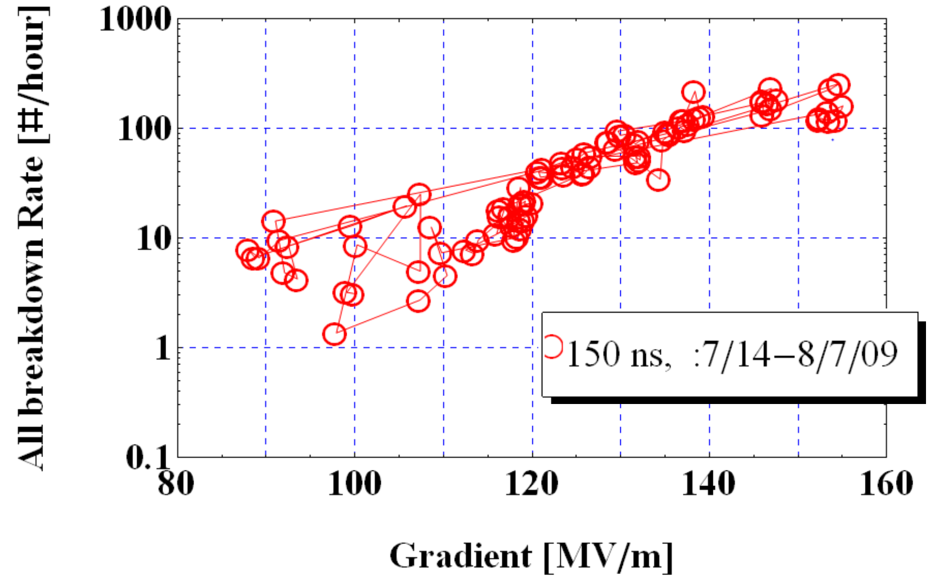
Hard CuAg, Low –Temperature Brazed High Shunt Impedance structure, 1C-SW-A3.75-T2.6- LowTempBrazed-CuAg-KEK-#1

Re-test of this structure is next in the queue

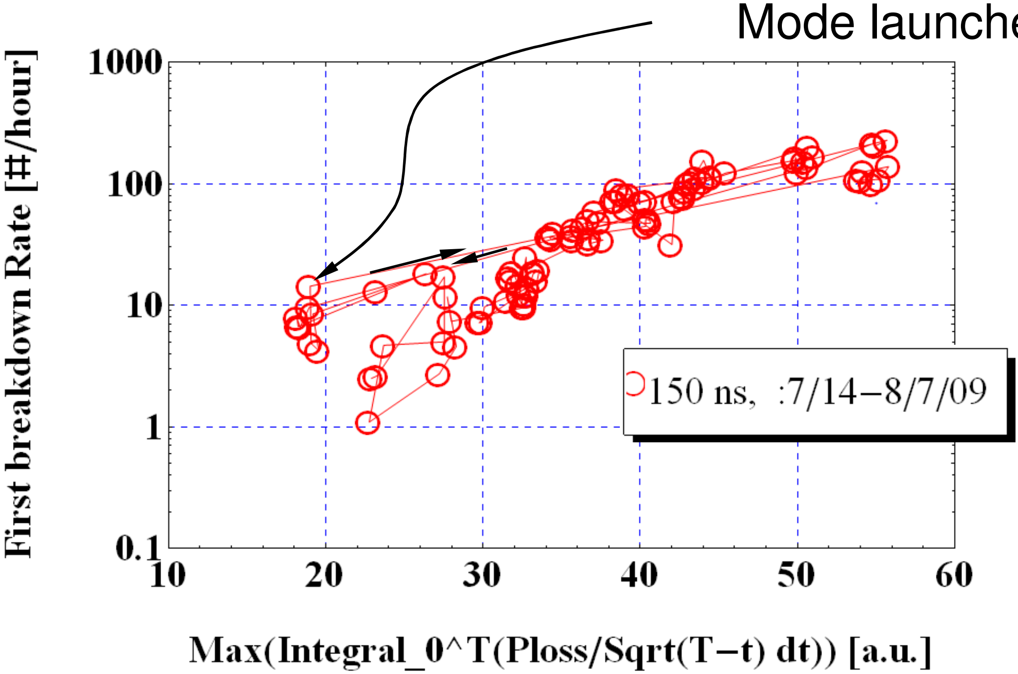


1C-SW-A3.75-T2.6- LowTempBrazed-CuAg-KEK-#1





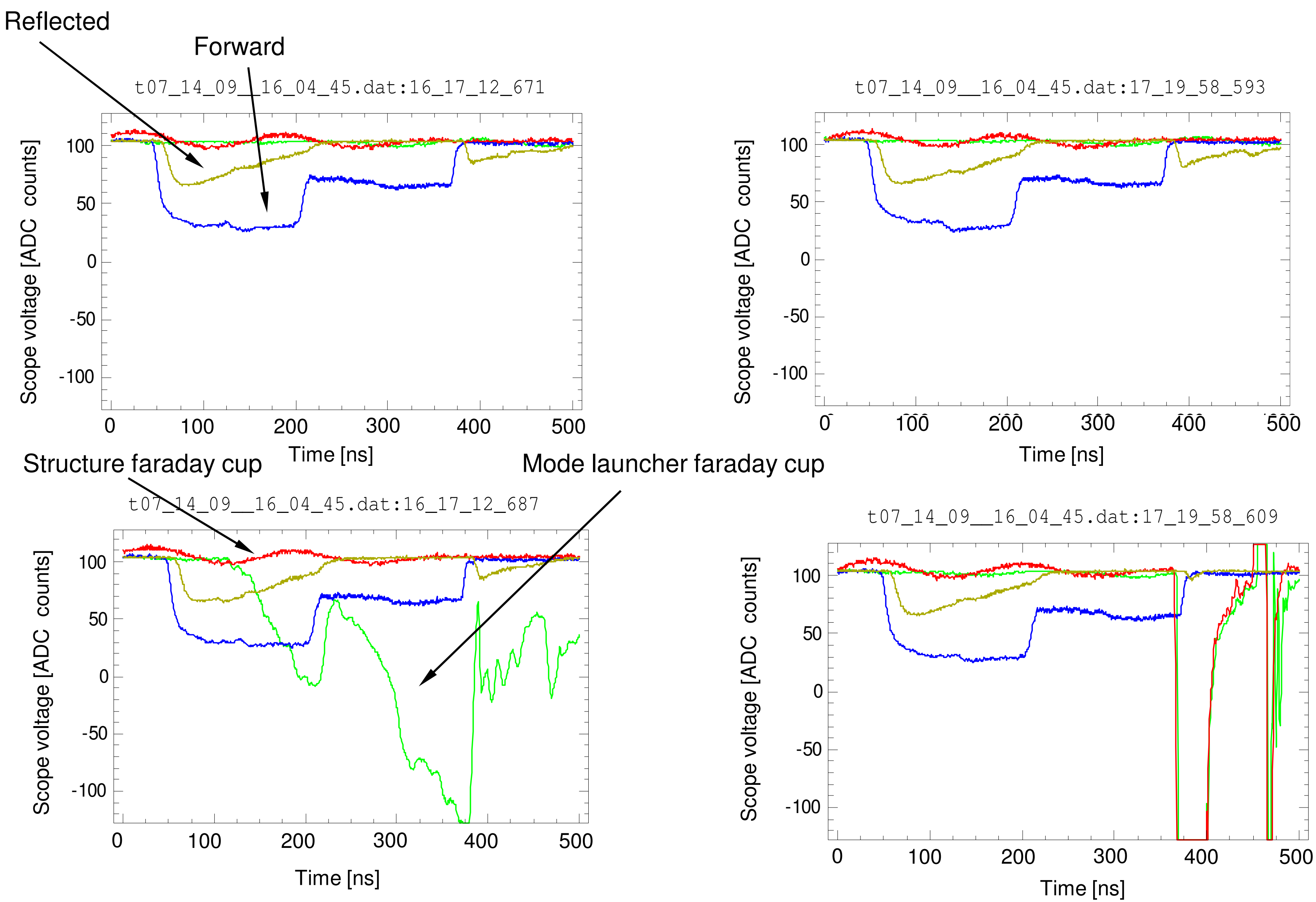
Mode launcher induced breakdowns



Most of the breakdown rate is integrated over 100 minutes to show reproducibility of the breakdowns rate

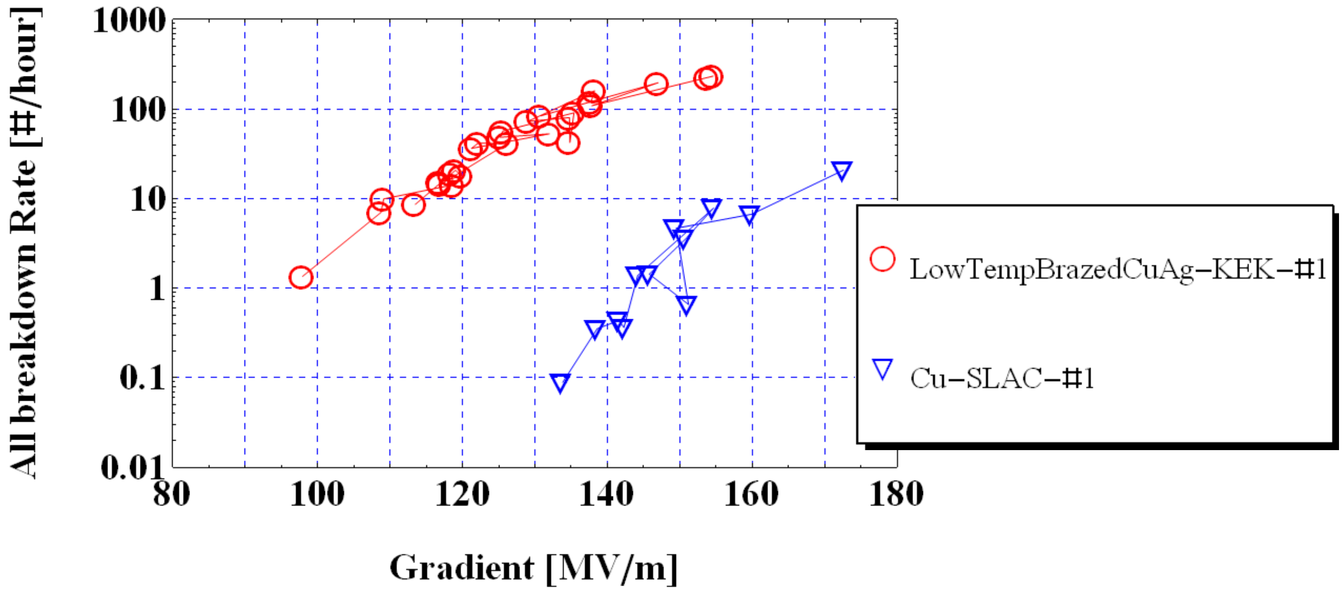
V.A. Dolgashev, 6 October 2009

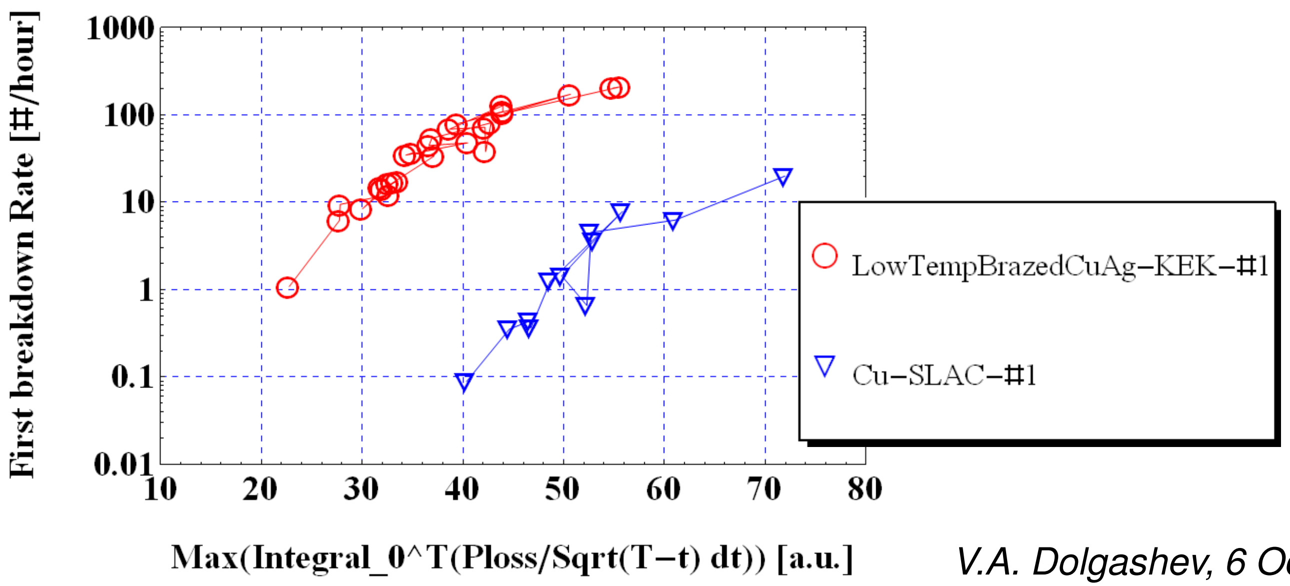
Digitizer traces for mode "launcher breakdown" and "cavity breakdown"



V.A. Dolgashev, 1 October 2009

Comparison of breakdown performance of two 1C-SW-A3.75-T2.6 structures: high temperature brazed copper Cu-SLAC-#1 (shaped pulse, 200 ns flat) and low temperature brazed copper-silver LowTempBrazed-CuAg-KEK-#1 (shaped pulse, 150 ns flat)



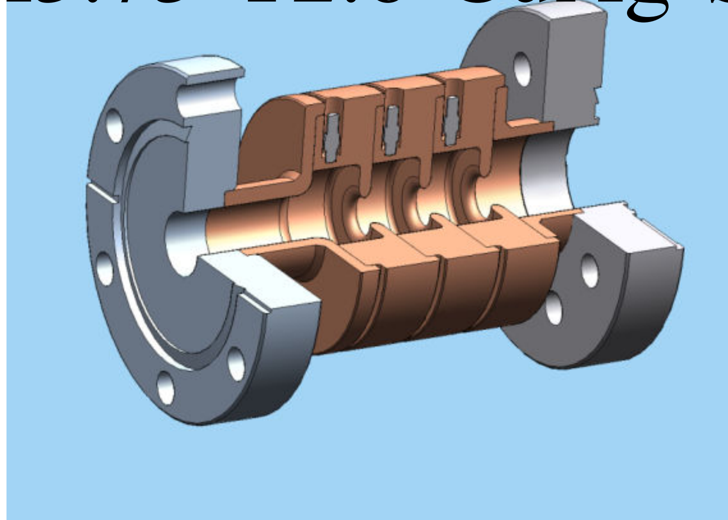


V.A. Dolgashev, 6 October 2009

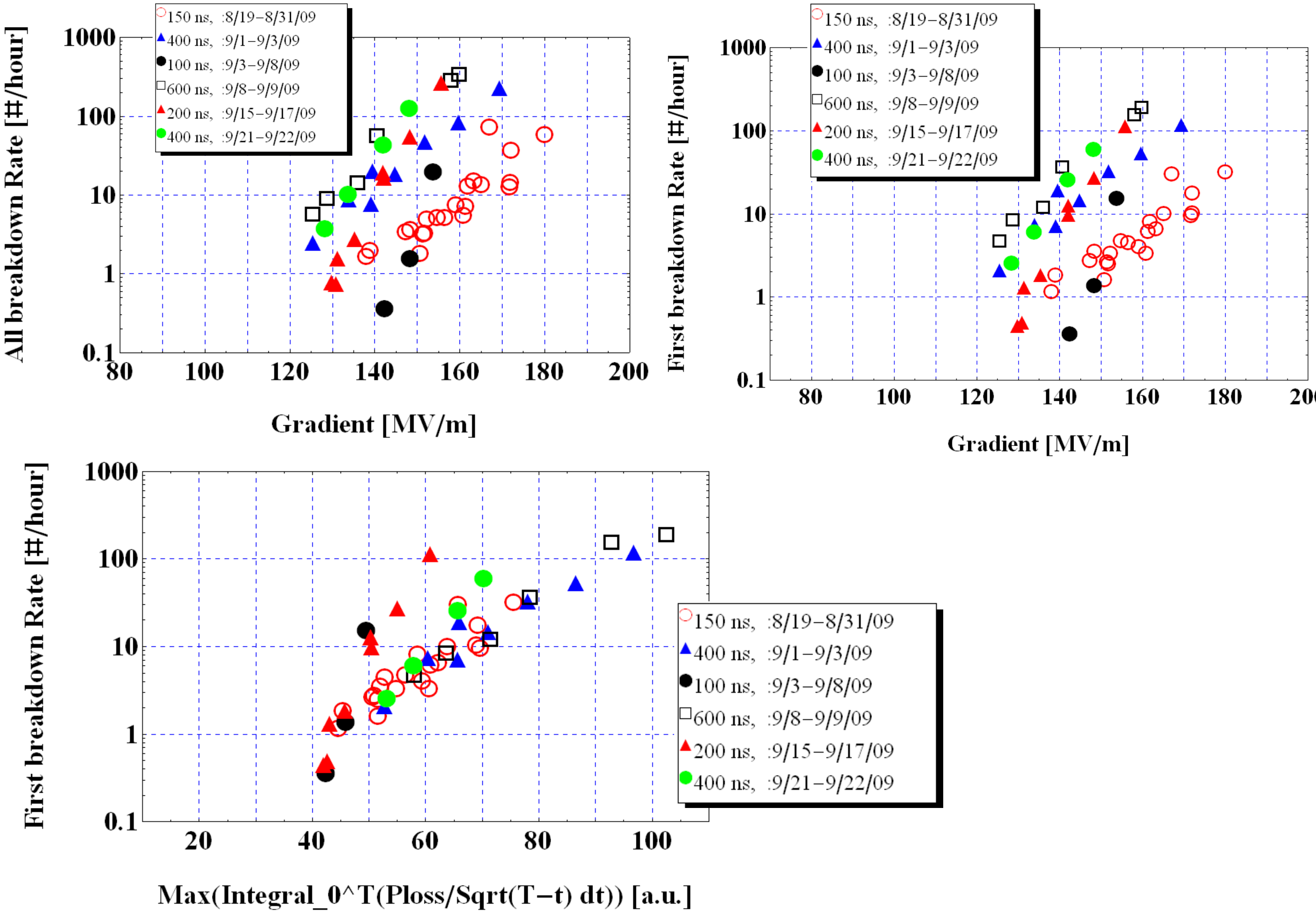
Copper alloys

High shunt impedance Soft CuAg structure,

1C-SW-A3.75-T2.6-CuAg-SLAC-#1,

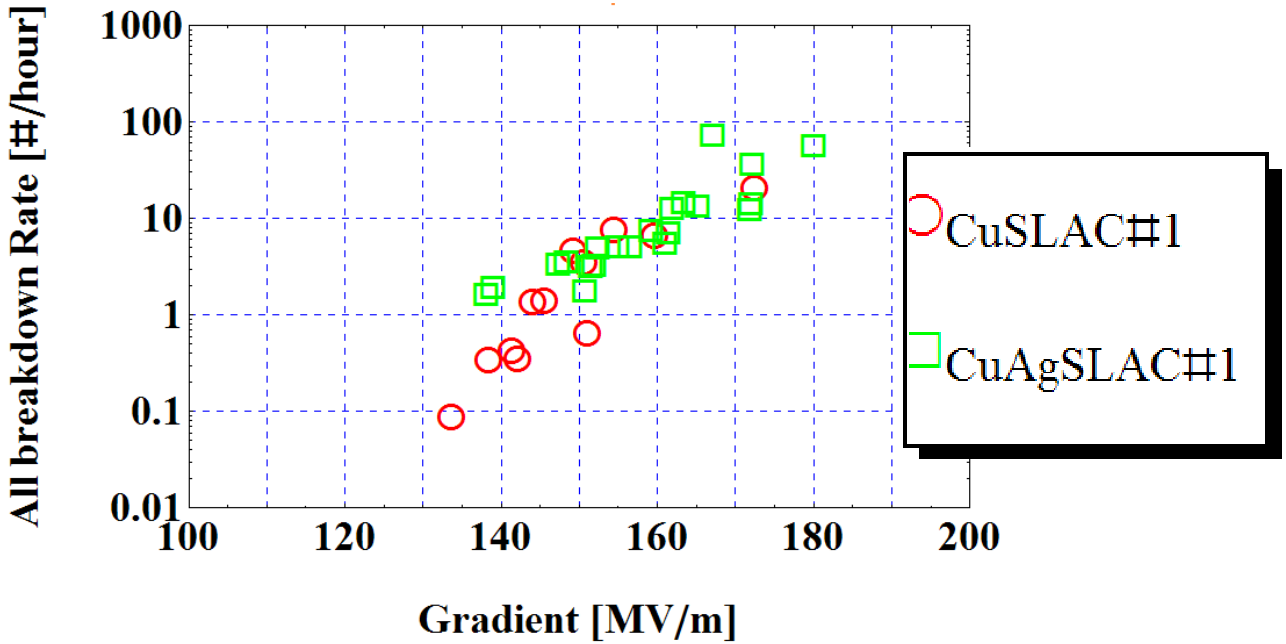


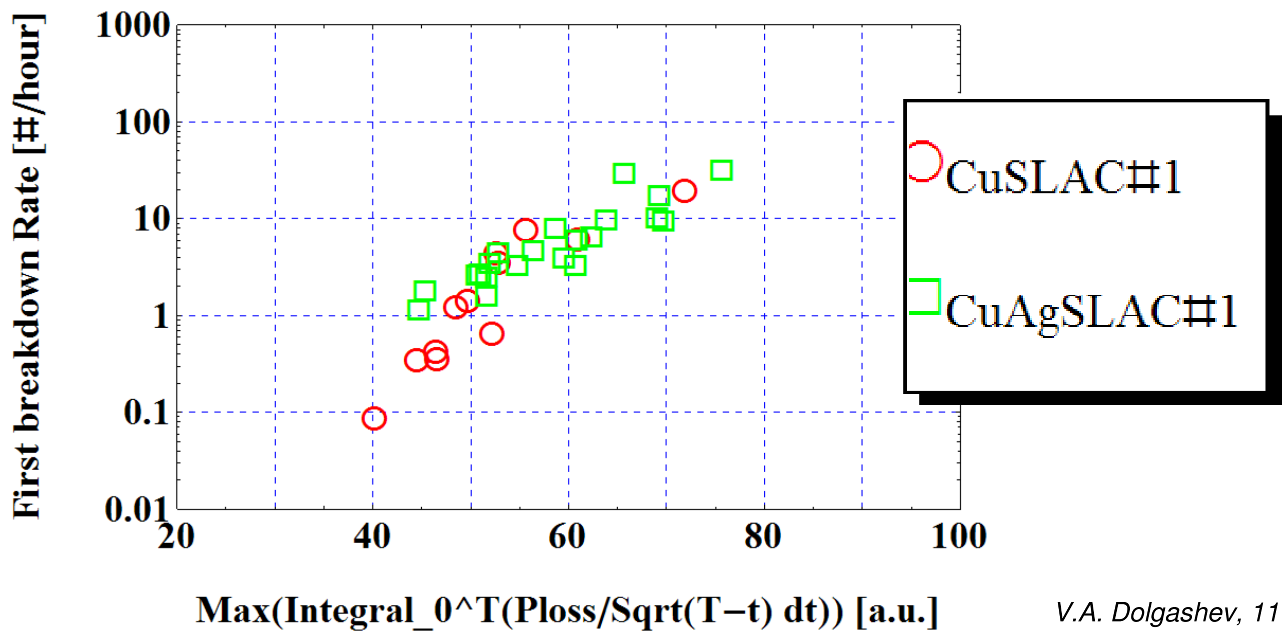
One-C-SW-A3.75-T2.6-CuAg-SLAC-#1



V.A. Dolgashev, 5 October, 2009

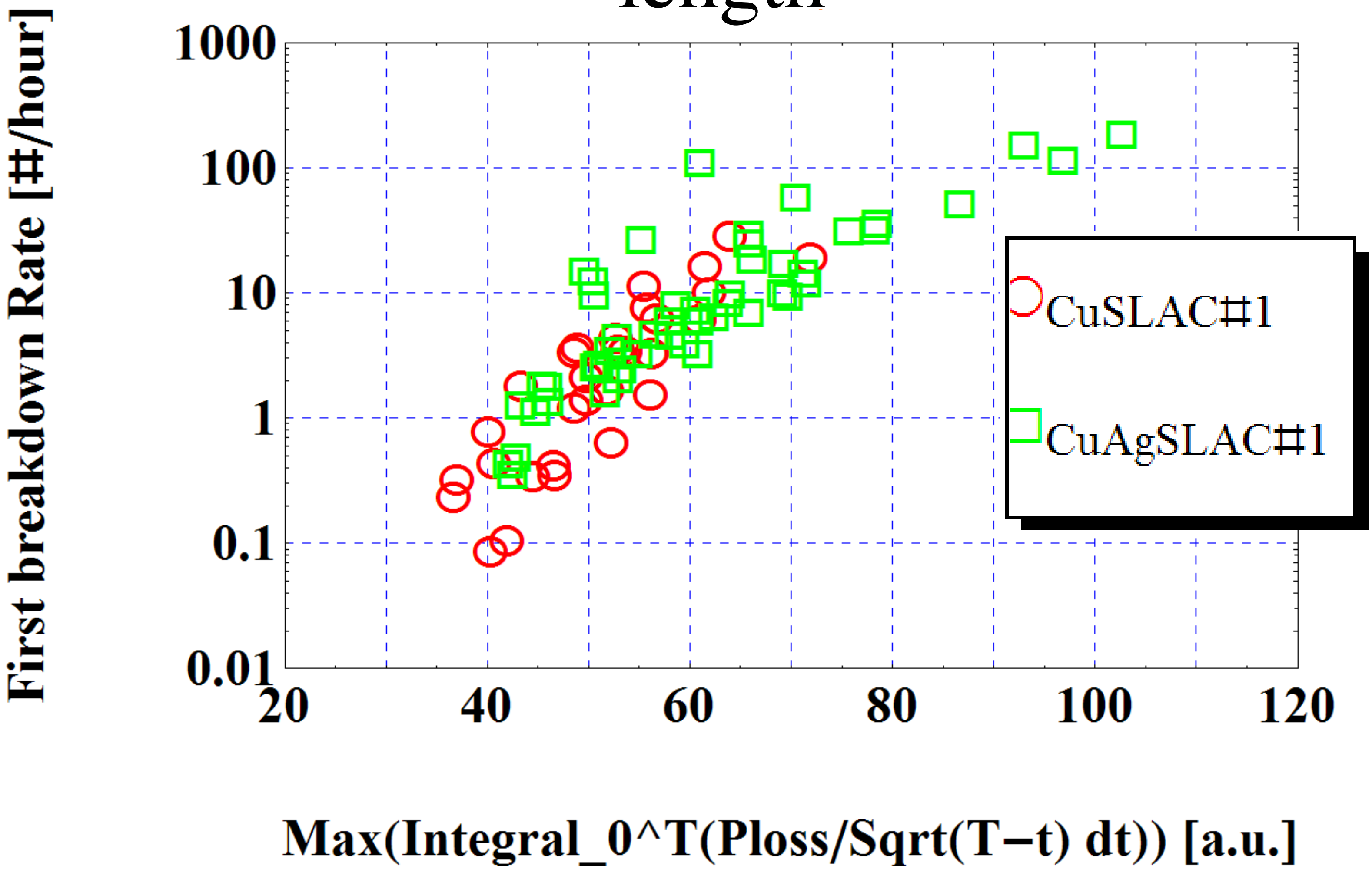
Comparison of soft Cu and soft CuAg 1C-SW-A3.75-T2.6 structures, 150 ns shaped pulse





V.A. Dolgashev, 11 October, 2009

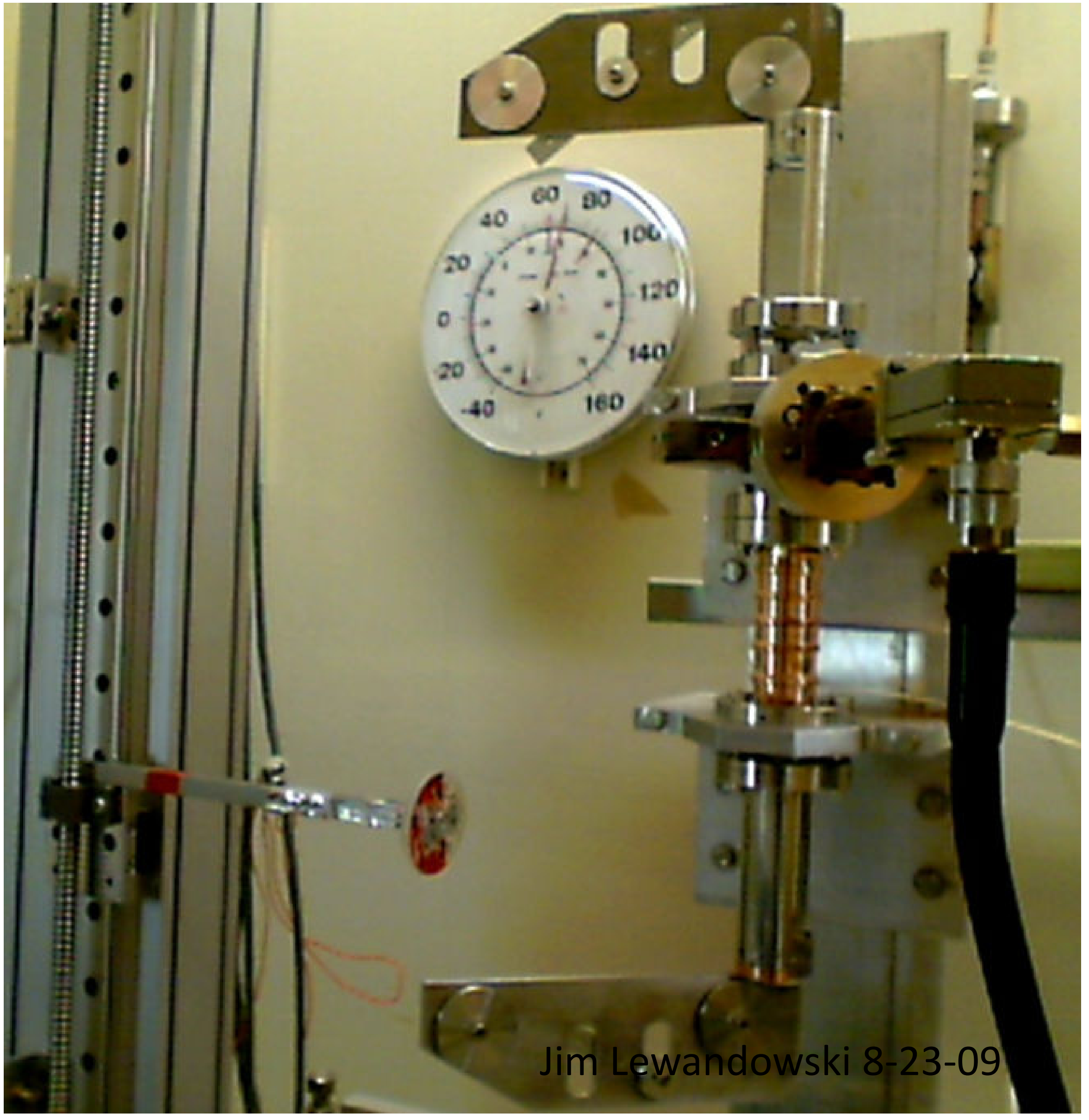
Comparison of soft Cu and soft CuAg 1C-SW-A3.75-T2.6 structures, all pulse length



V.A. Dolgashev, 11 October, 2009

Test under way

1C-SW-A5.6-T4.6-Electroformed-Cu-Frascati-#1



ASTA tests

- CLIC Power Extraction and Transfer Structure (PETS)
- 10 Cell Traveling Wave structure (C10)
- Igor's WR90 Choke flange
- CERN's new WR90 RF flange

Accelerator Structure Test Area (ASTA) new RF system

•Designed for economical testing of TW, SW accelerator structures, and waveguides.

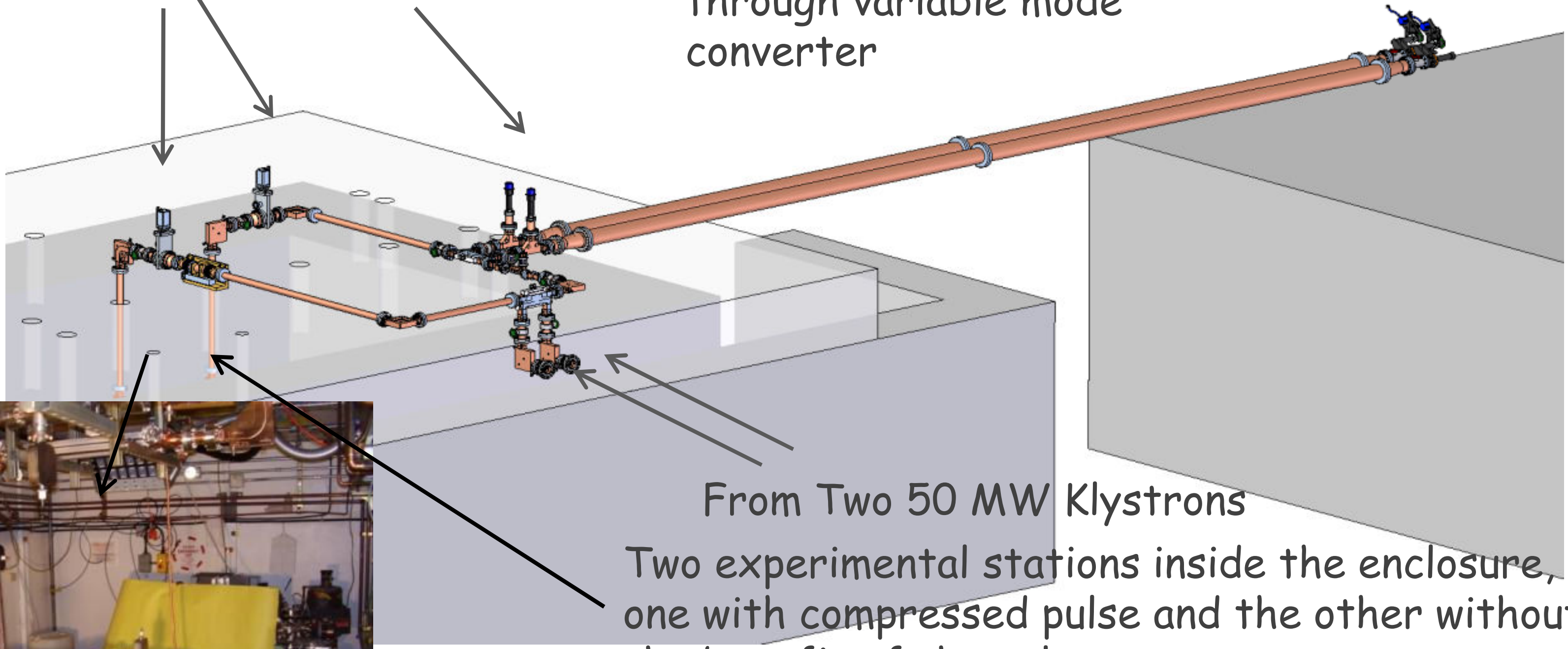
•Add an electron gun to test gradients next year

•Versatile structure for future applications (beyond high gradient work)

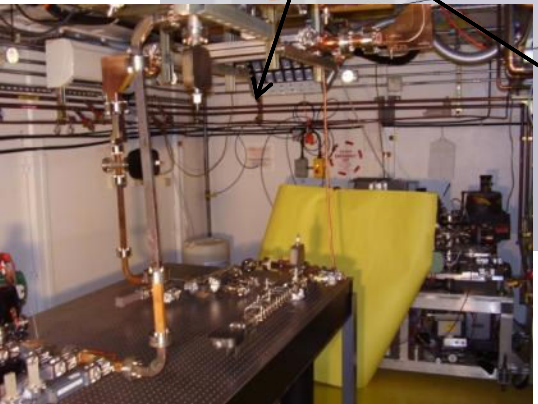
Gate Valves

Variable iris

Variable Delay line length through variable mode converter

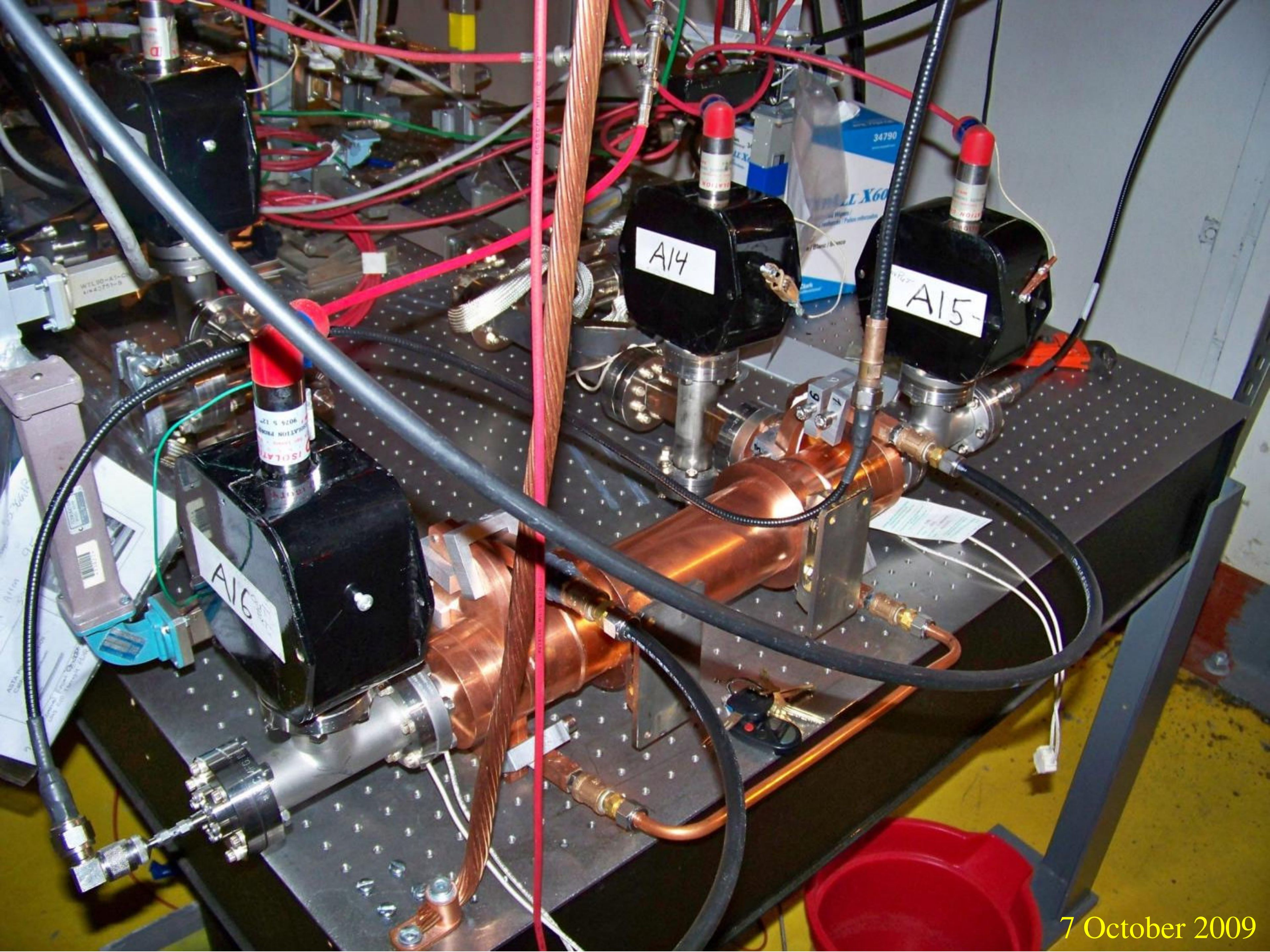


From Two 50 MW Klystrons



Two experimental stations inside the enclosure, one with compressed pulse and the other without the benefit of the pulse compressor.

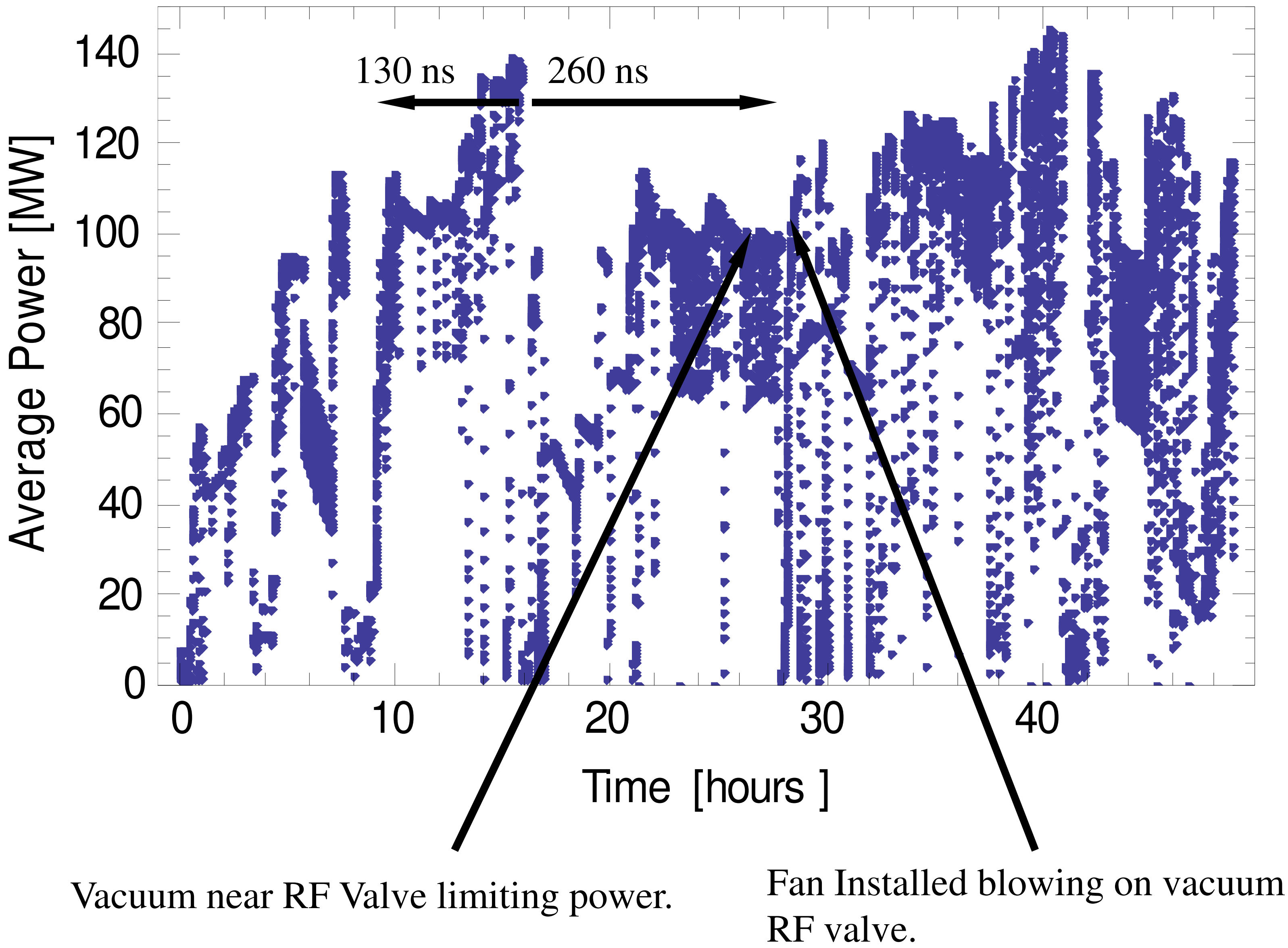
CLIC Power Extraction and Transfer Structure (PETS)



7 October 2009

PETS Processing Status

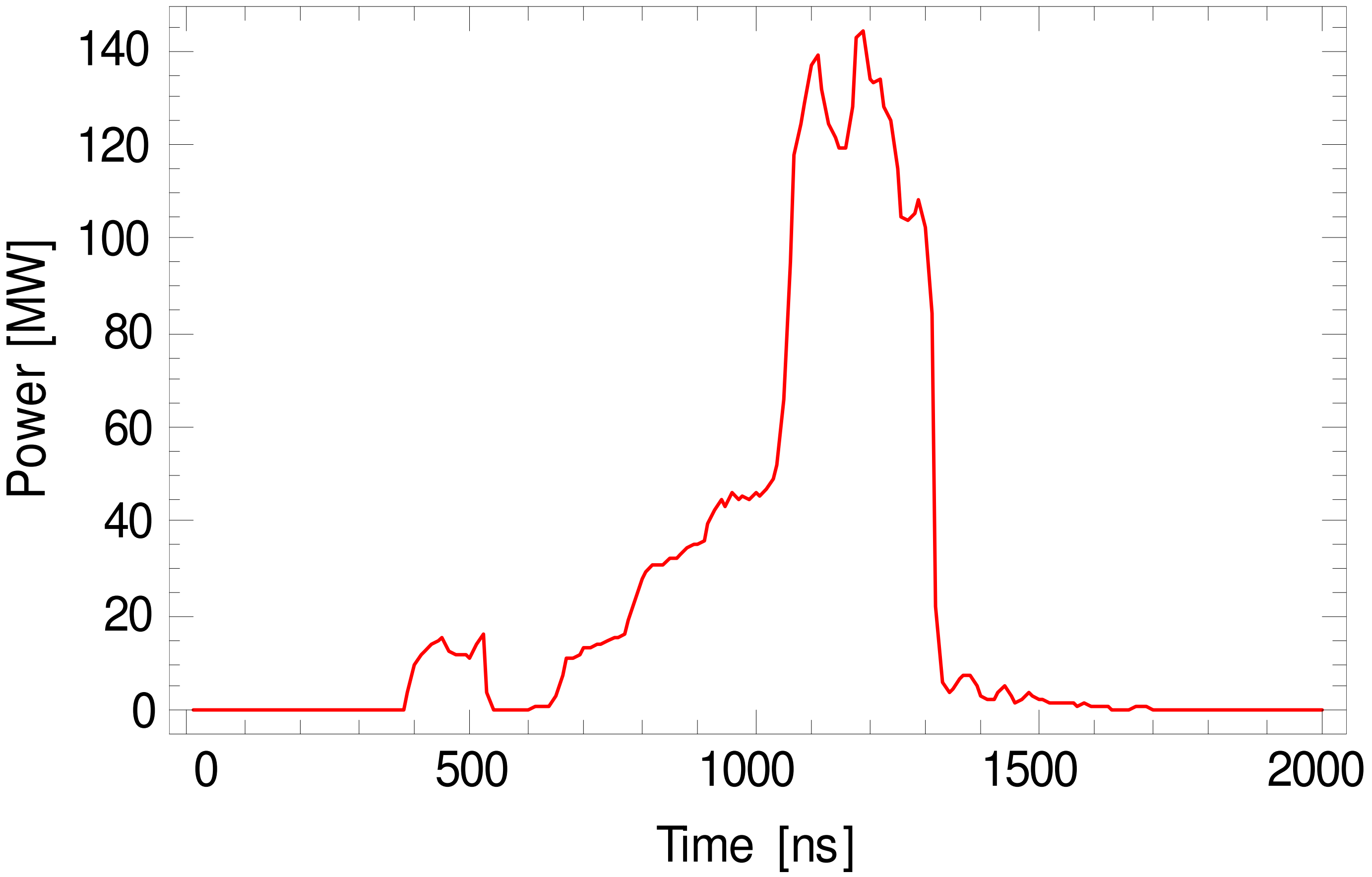
- PETS reinstalled into SLEDed line of ASTA and processing restarted October 6 after full bake of waveguide vacuum system. Structure now has clamped on cooling blocks for input and output coupler.
- Initial 130ns pulse width processing was quick up to average power ~150MW where we changed to the 260ns pulse at 5pm October 7th.
- During processing Oct. 8-9, although we observe breakdowns in PETS, vacuum near “vacuum RF valve” on top of ASTA bunker trips system. Baseline vacuum the near the valve is high.



Average Power [MW]
0
20
40
60
80
100
120
140
0
10
20
30
40
Time [hours]
130 ns
260 ns
Vacuum near RF Valve limiting power.
Fan Installed blowing on vacuum
RF valve.

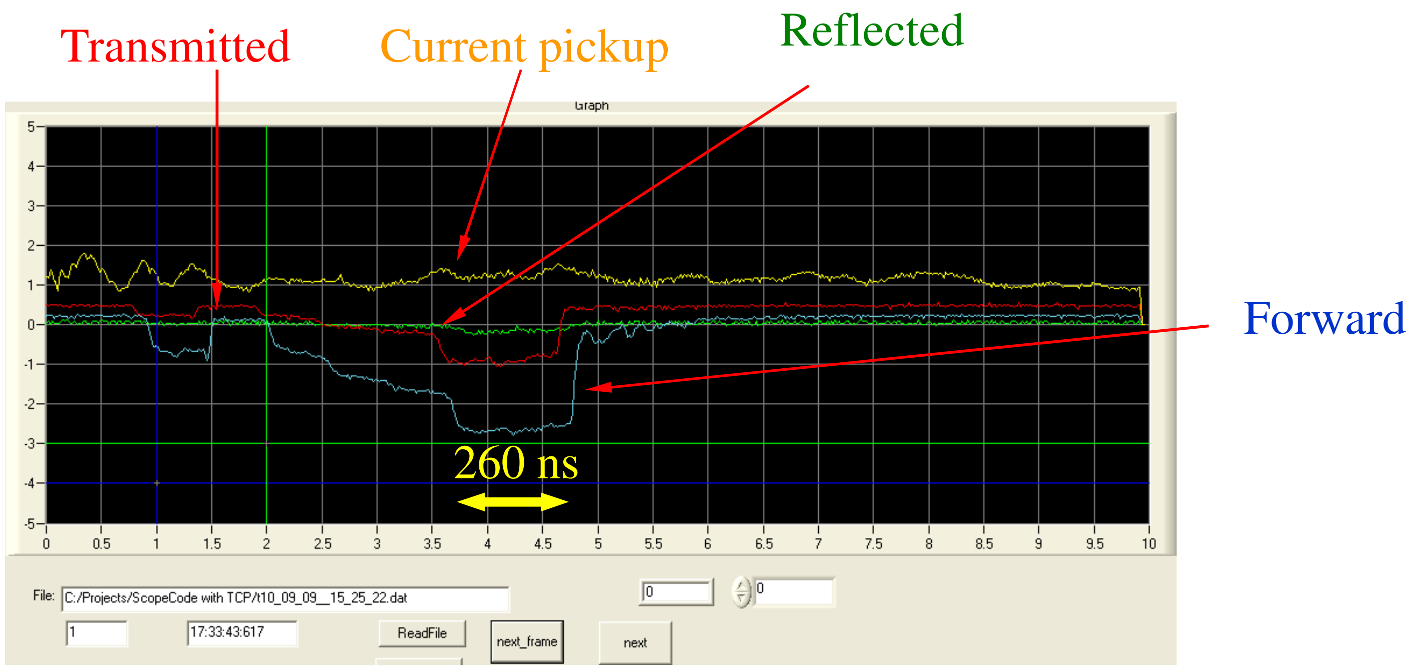
RF Pulse into PETS

Trace:8000 Time:{9,10,2009,14,51,53,852} Max. Power = 144.346 MW, Average Power:123.871 MW, PulseLength:0.24[us]

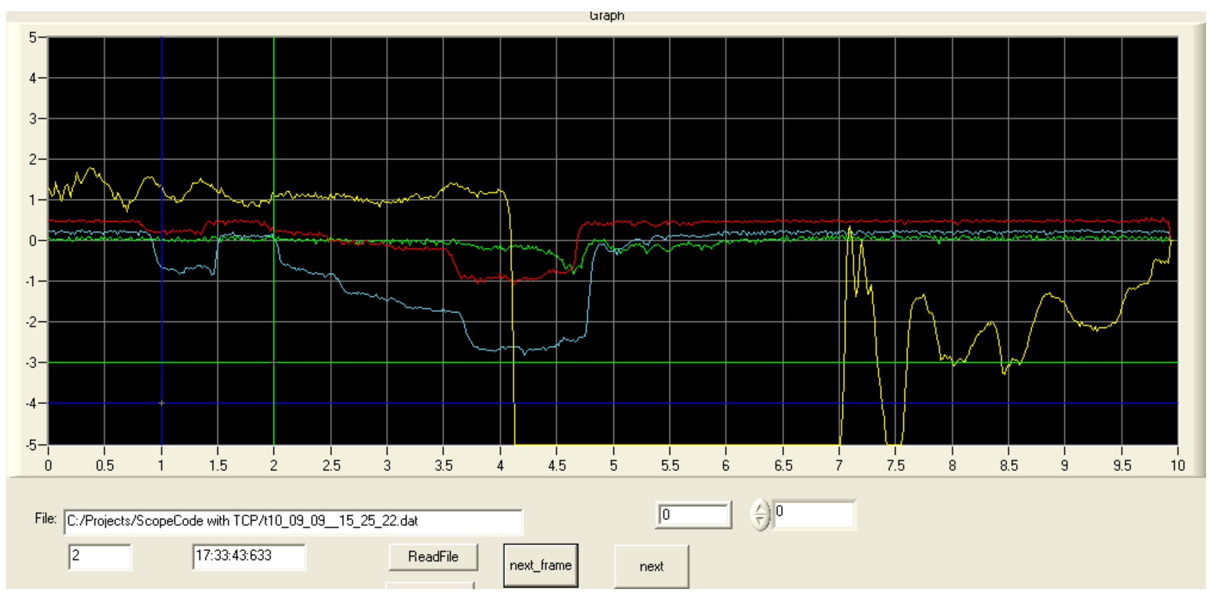


Typical PETS breakdown

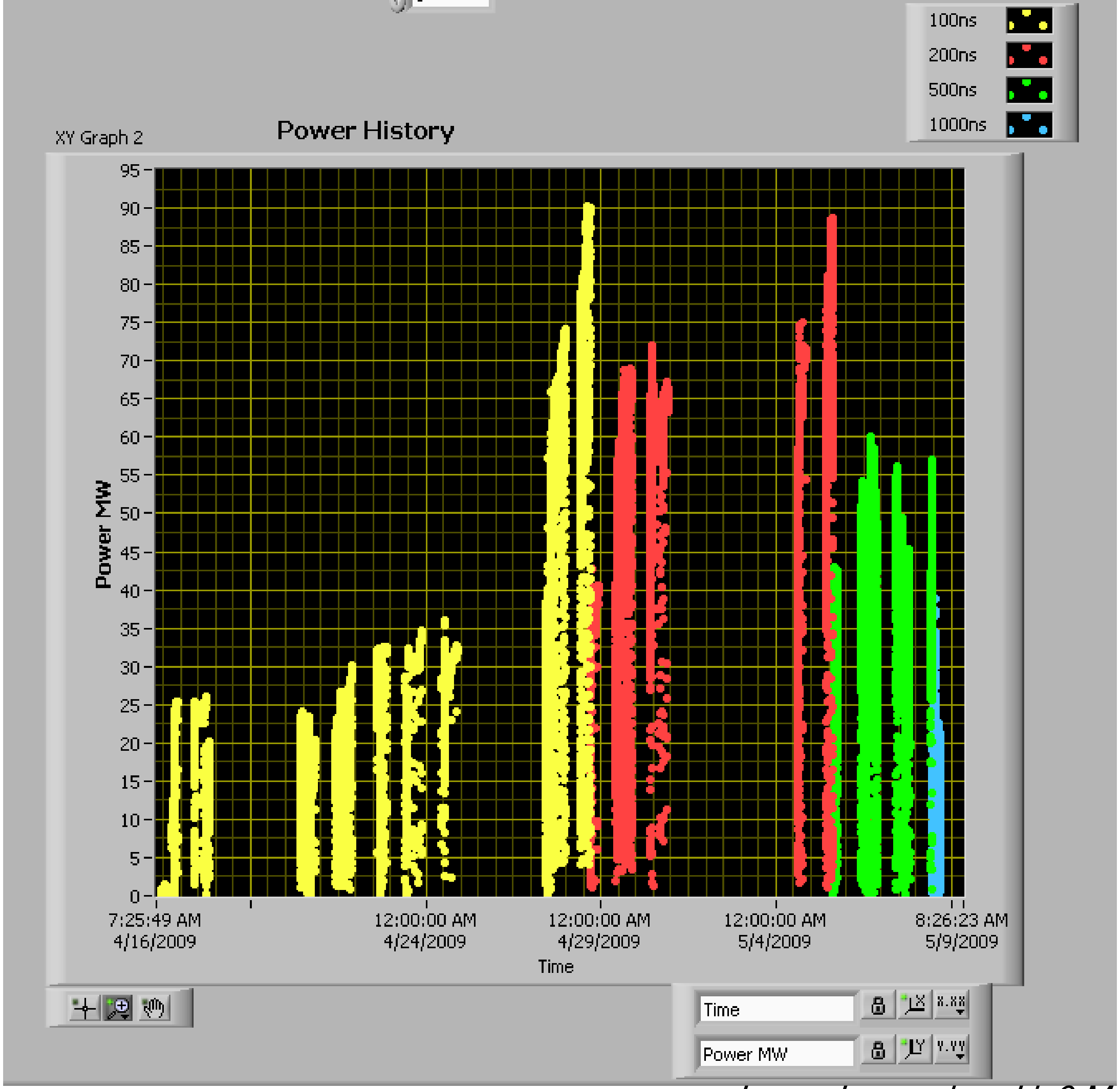
Pre-breakdown pulse



Breakdown pulse



Igor’s choke WR90flange



James Lewandowski, 9 May 2009

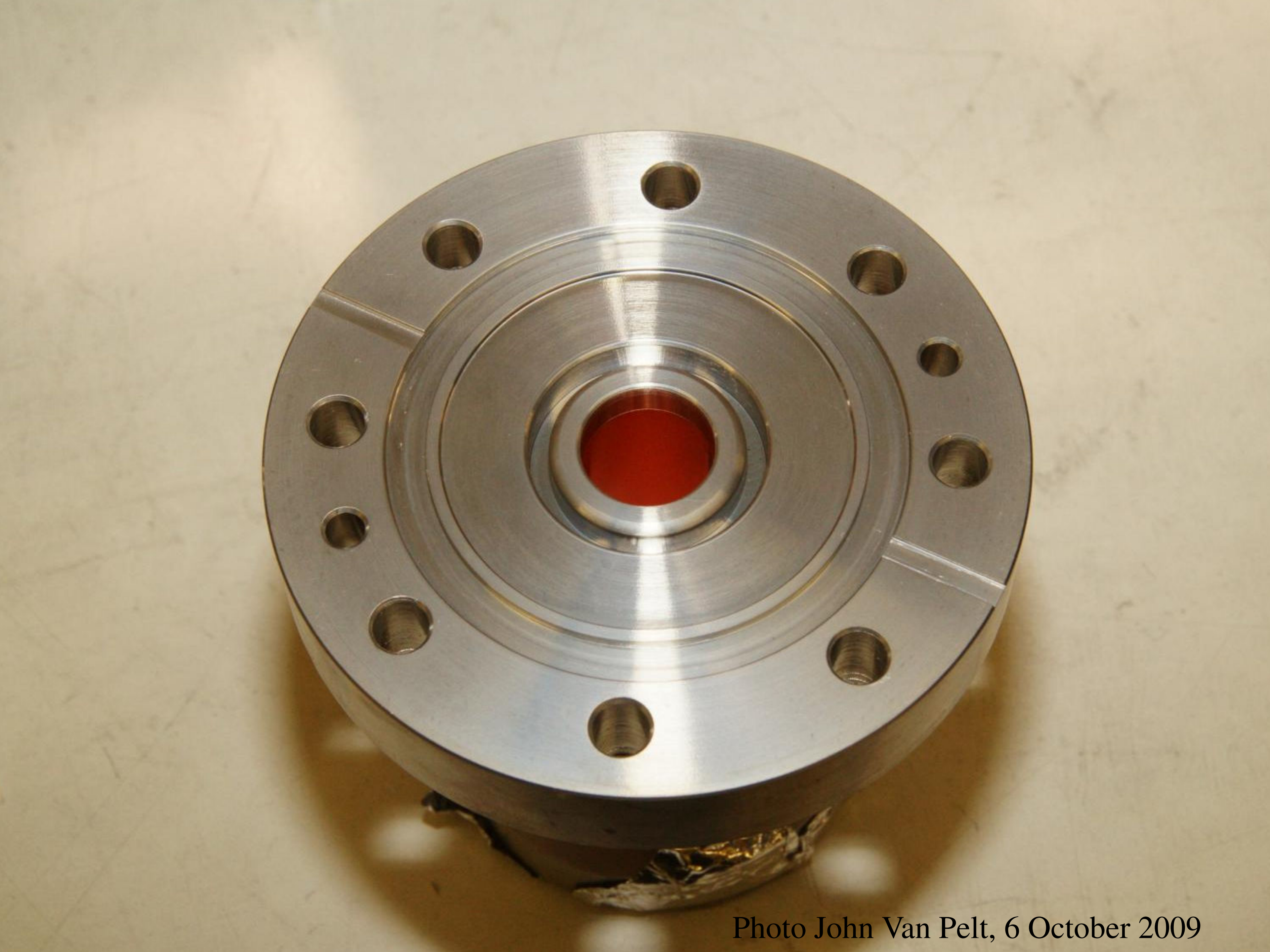


Photo John Van Pelt, 6 October 2009

Photo John Van Pelt, 6 October 2009

10 Cell Traveling Wave structure (C10)

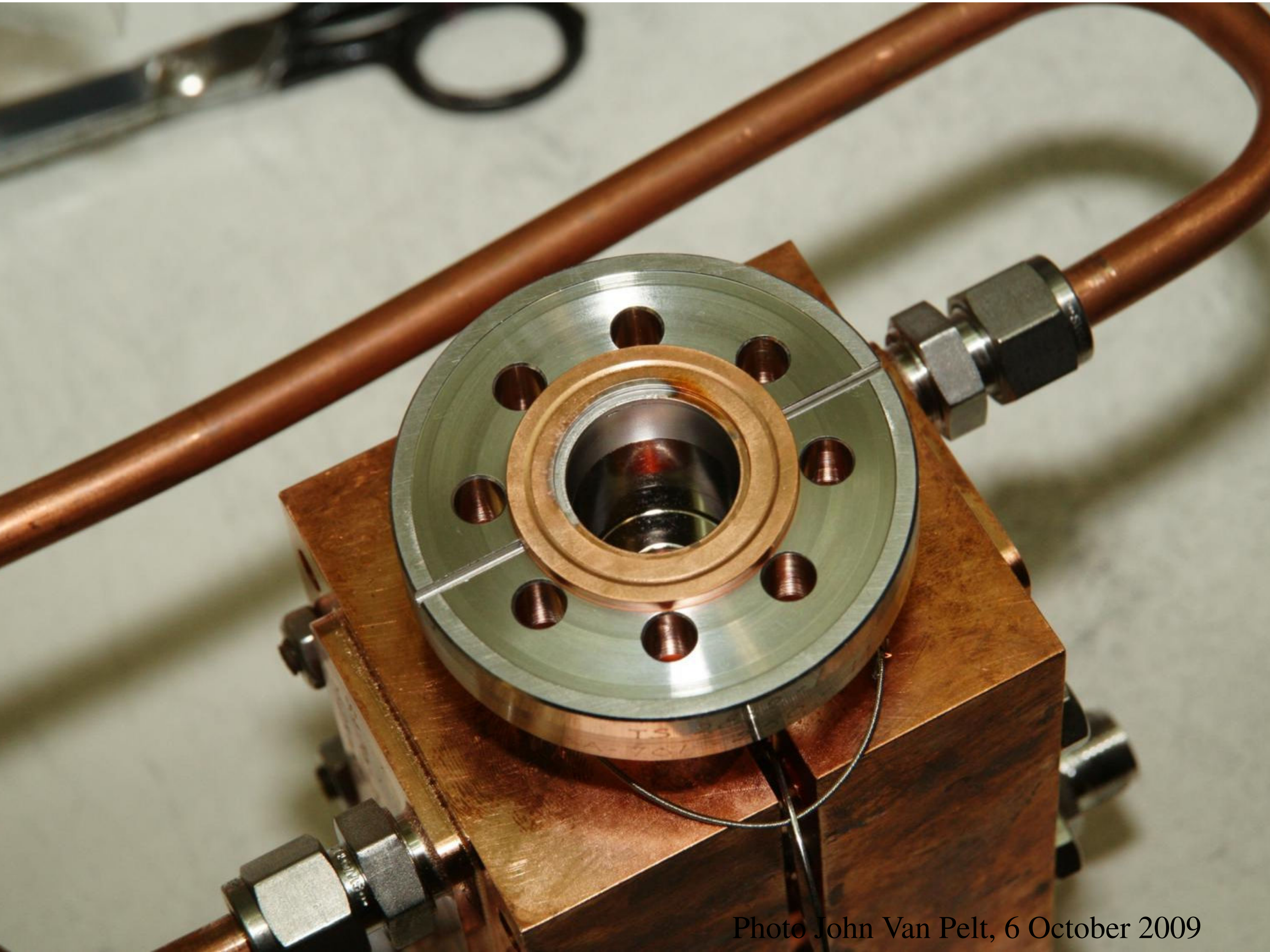


Photo John Van Pelt, 6 October 2009

Photo John Van Pelt, 6 October 2009

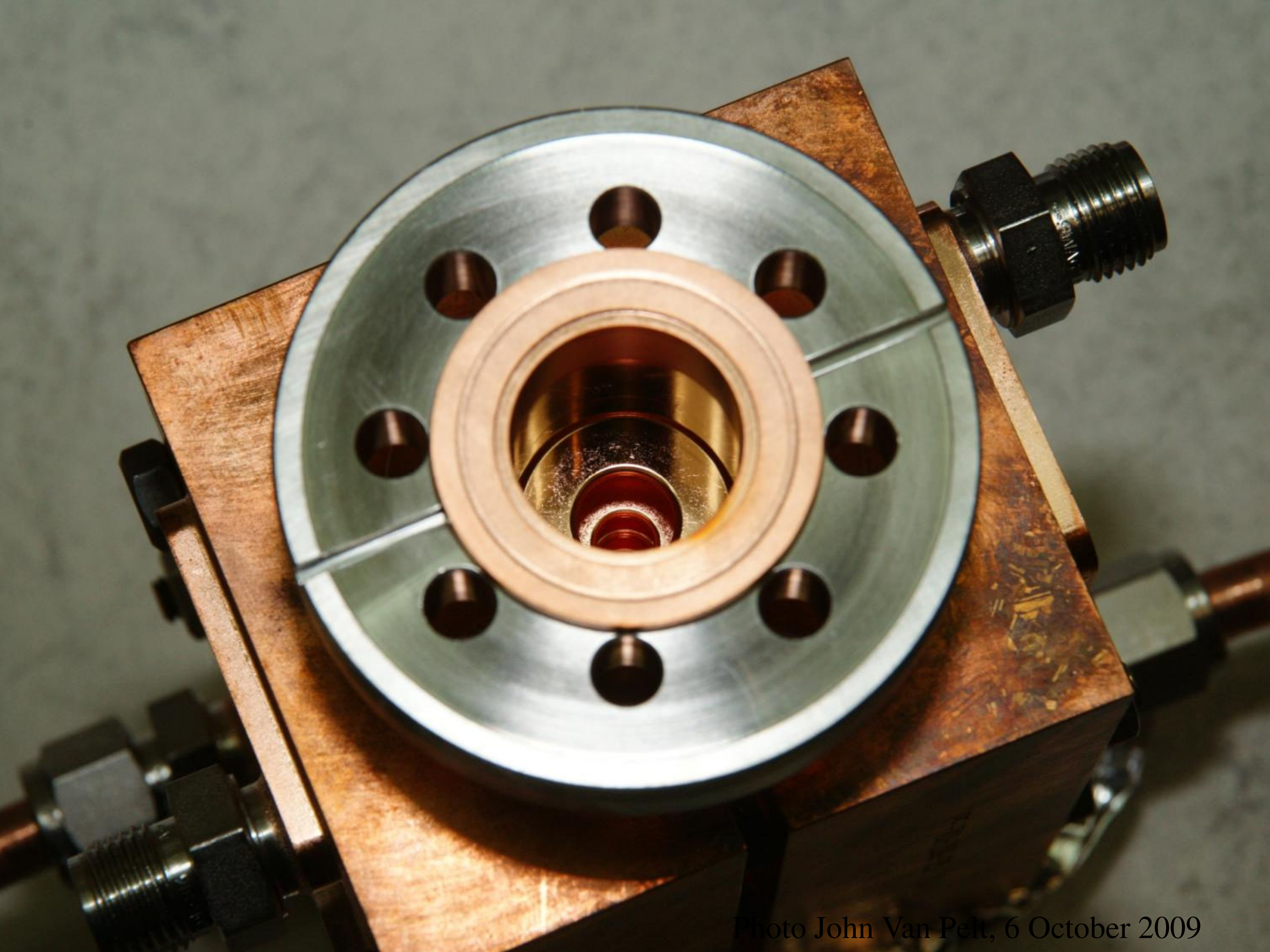
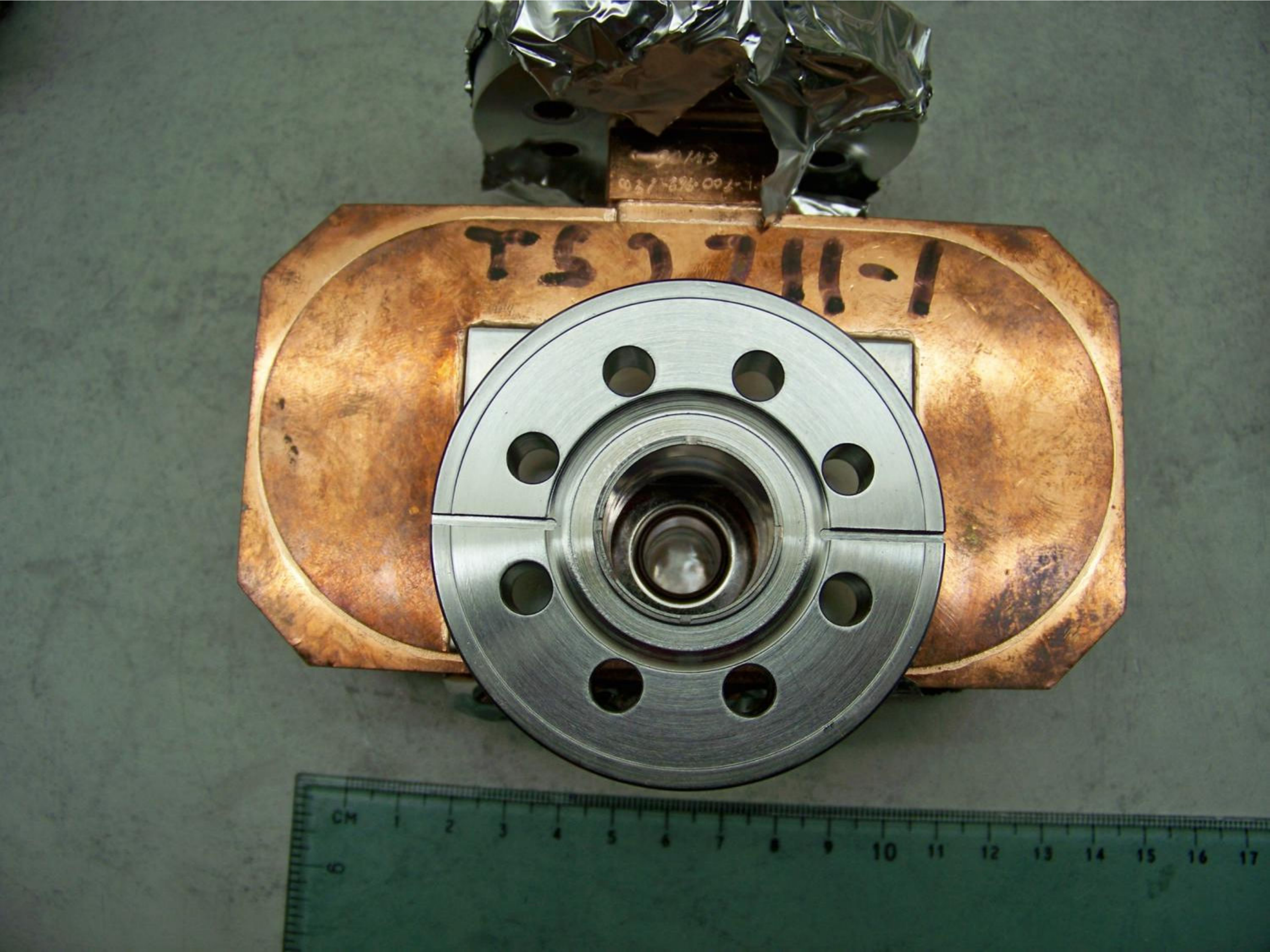
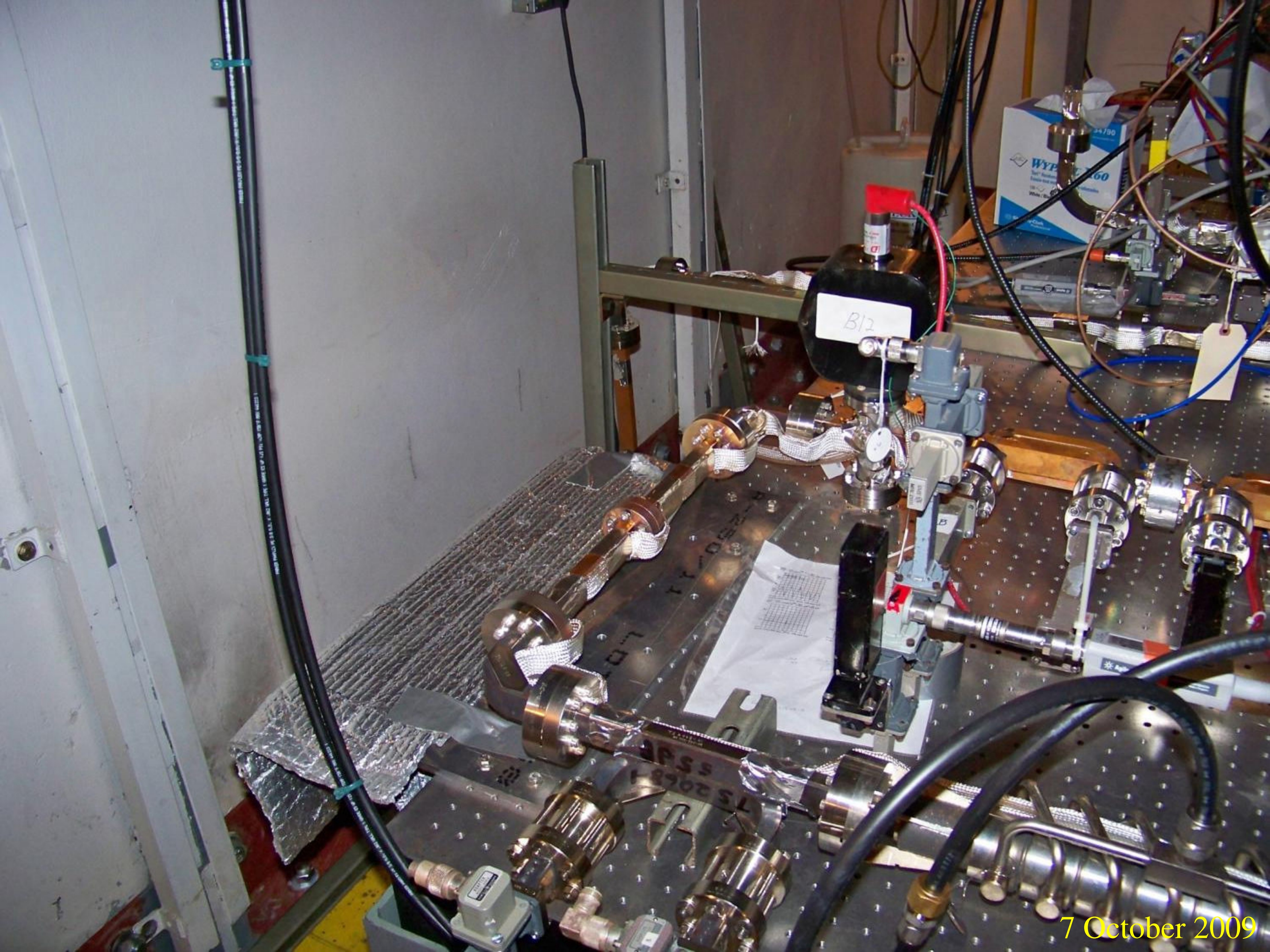


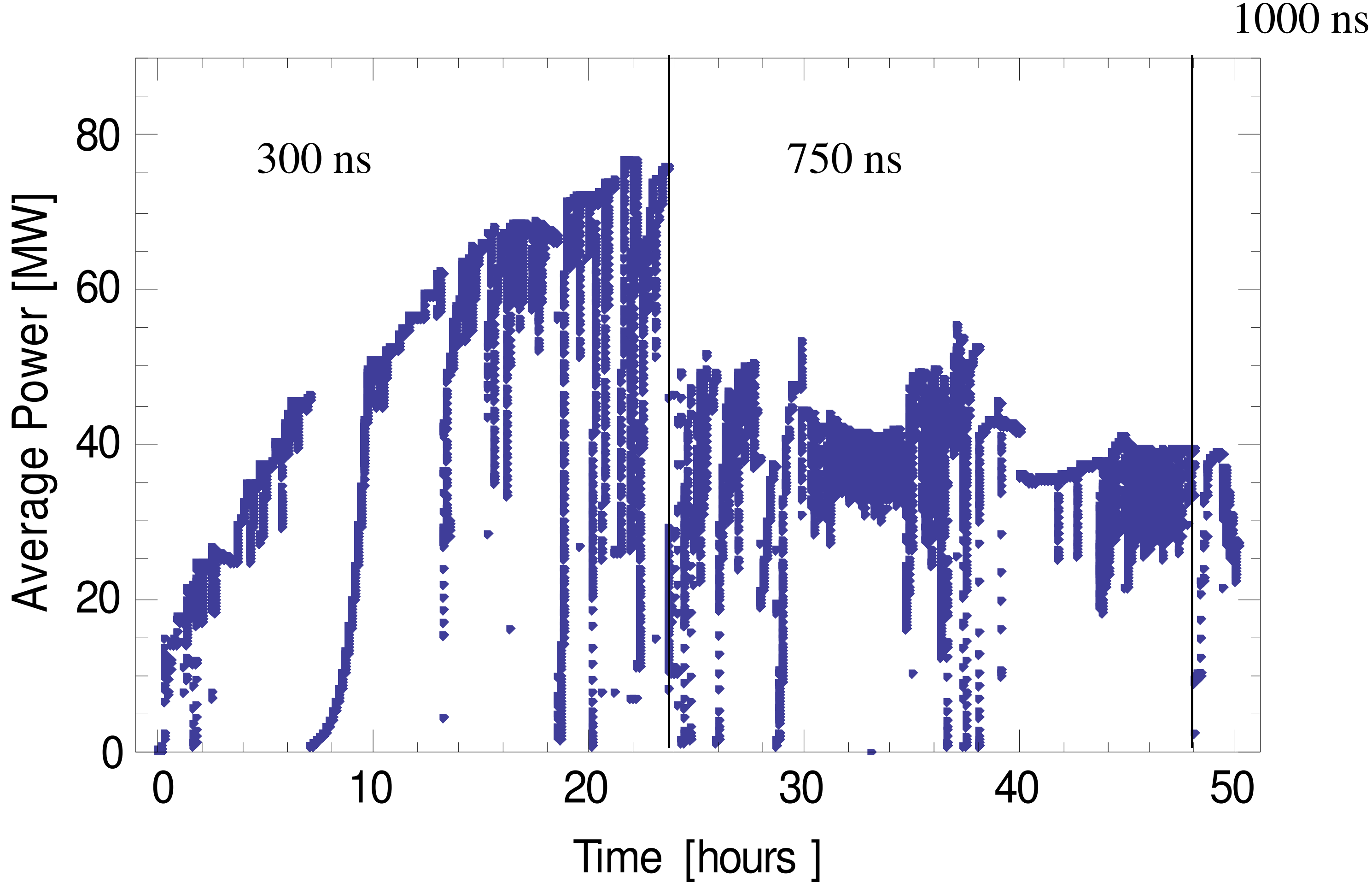
Photo John Van Pelt, 6 October 2009



CERN’s new WR90 RF flange

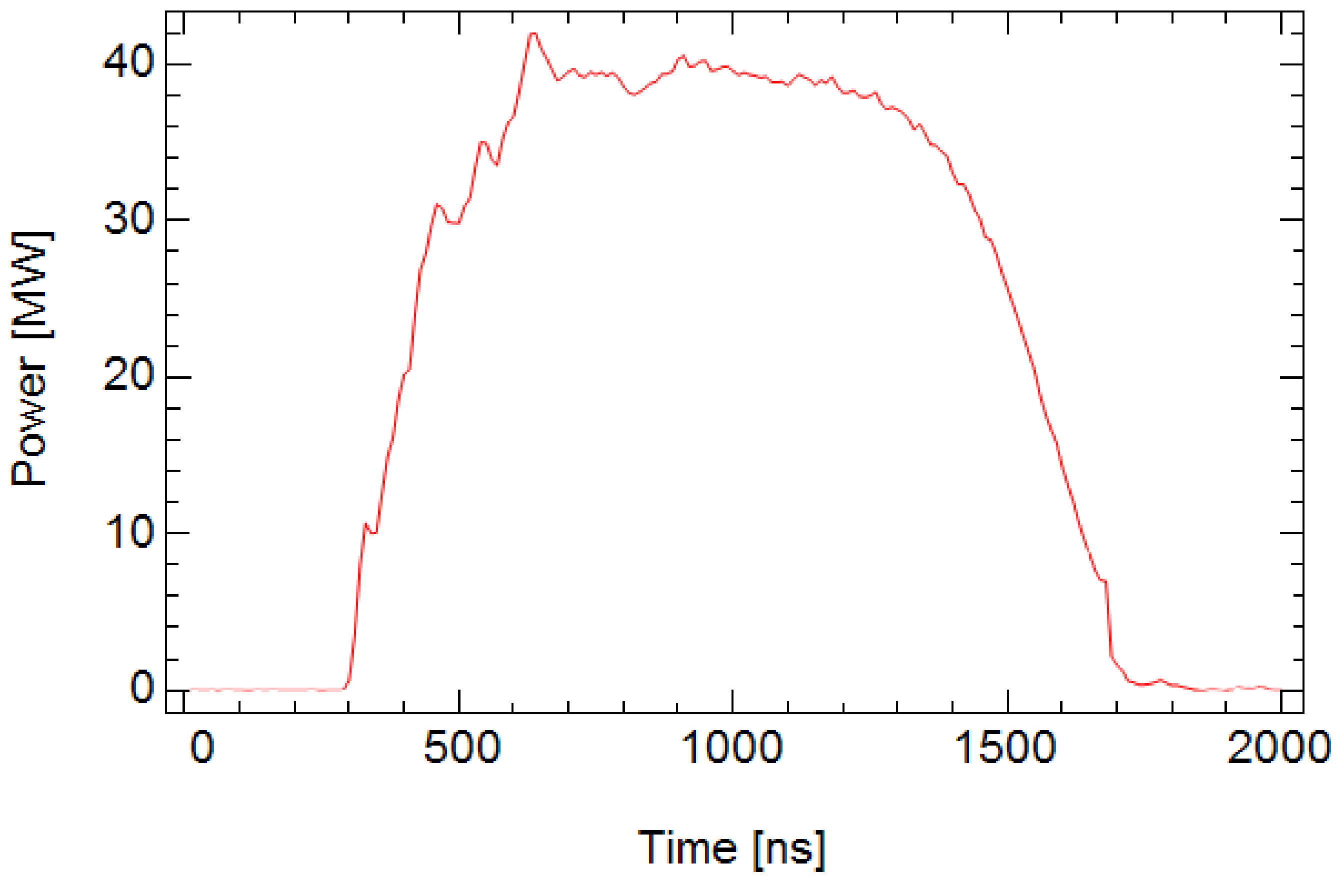

B12
7 October 2009

CERN WR90 RF flange processing



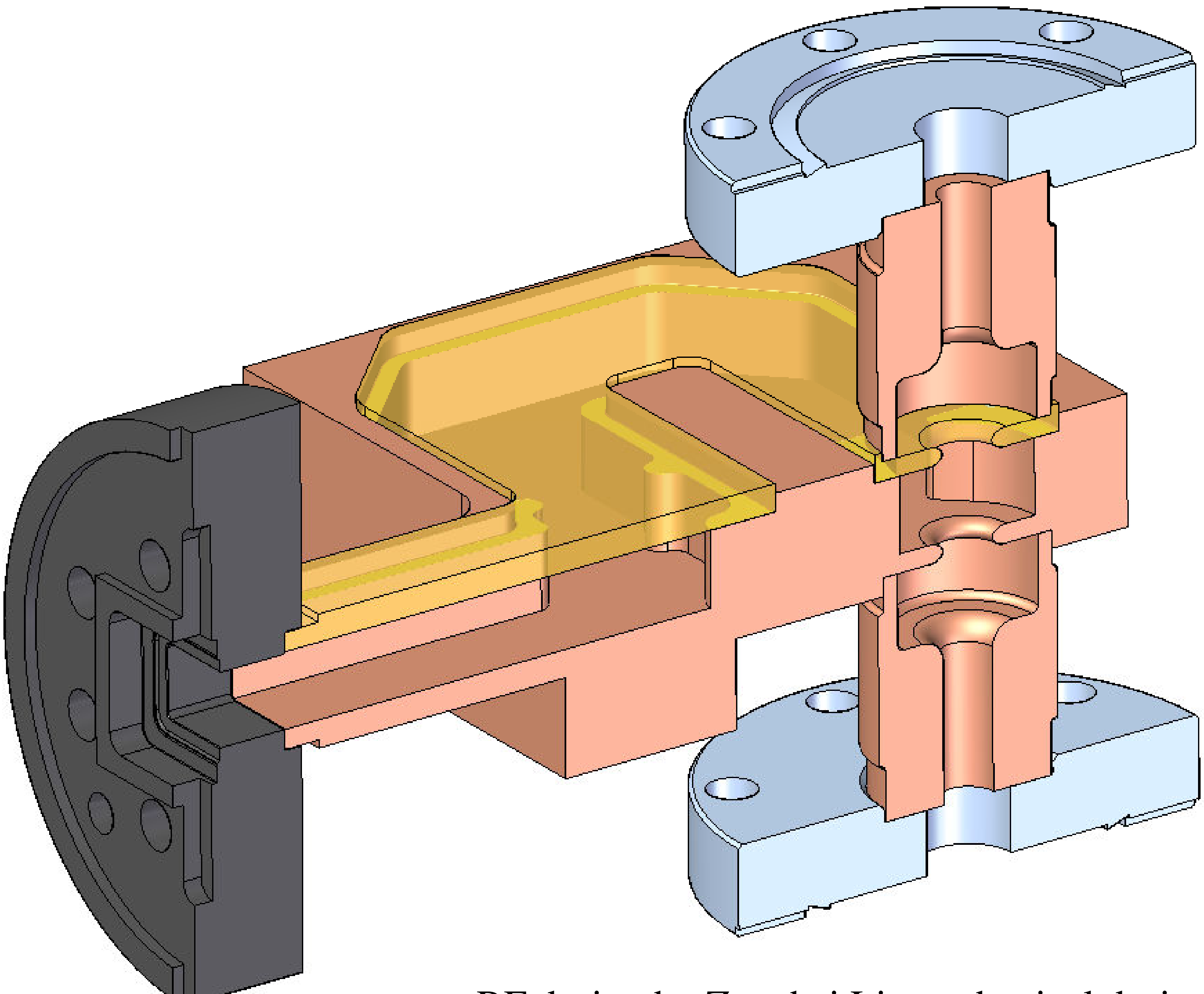
CERN WR90 RF flange processing, pulse shape

Trace:2000 Time:{17,9,2009,9,22,0,861} Max. Power = 42.0243 MW, Average Power:37.3689 MW, PulseLength:1.01[us]



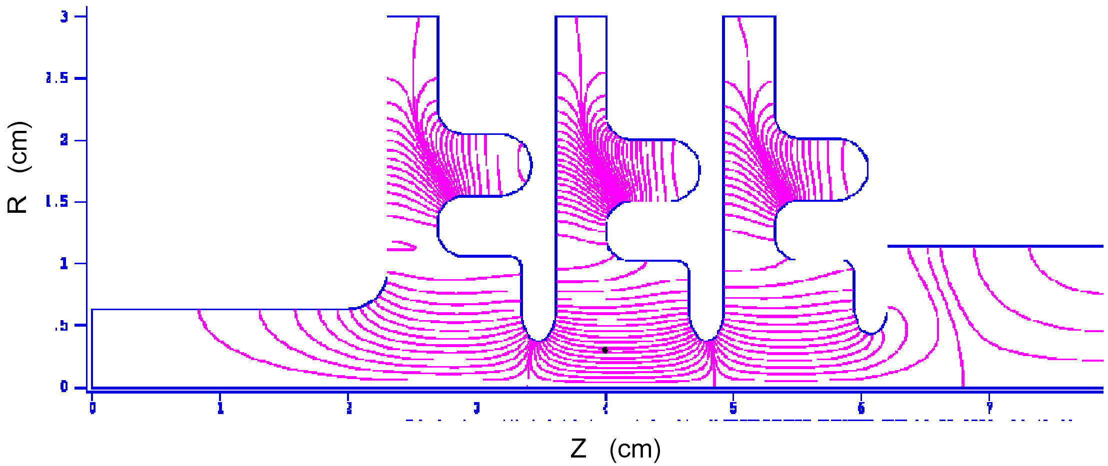
New developments

3-cell symmetrically WR90 coupled *3C-SW-A3.75-T2.6-TwoWR90-Cu*

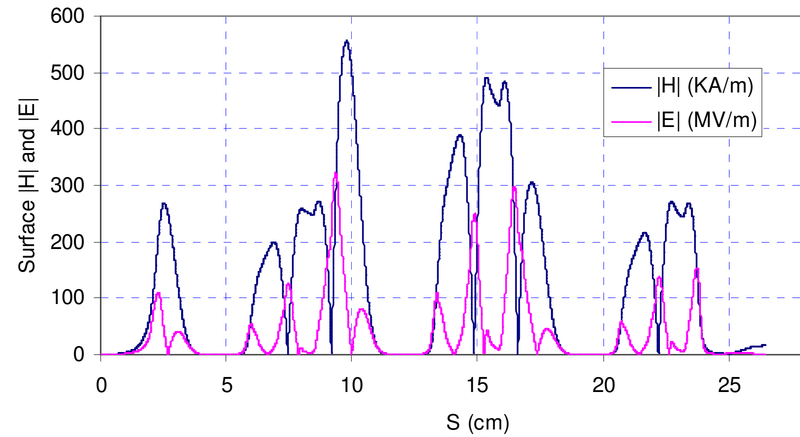


RF design by Zenghai Li, mechanical design by David Martin

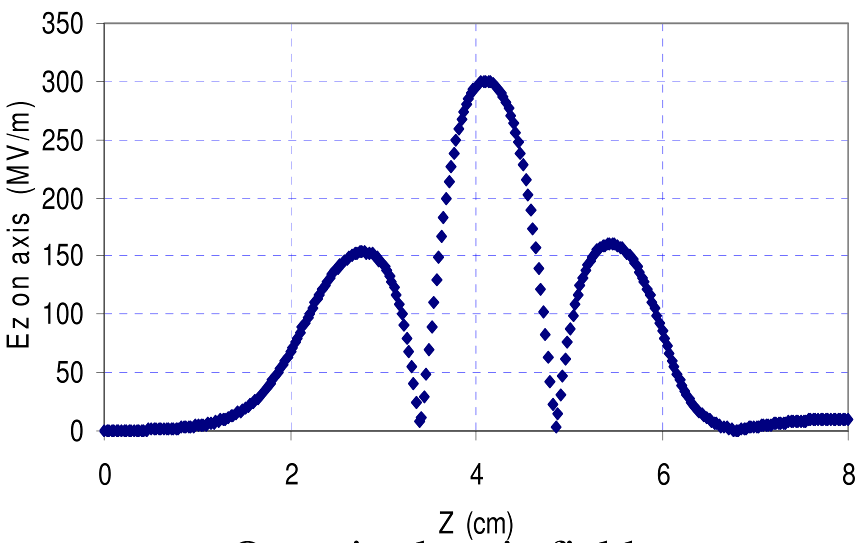
Single cell SW-A3.75-T2.6 with 4mm gap triple choke fields normalized for 10 MW losses, maximum electric field 322.1 MW/m; maximum magnetic field 555.0 kA/m



Electric force lines



Surface fields



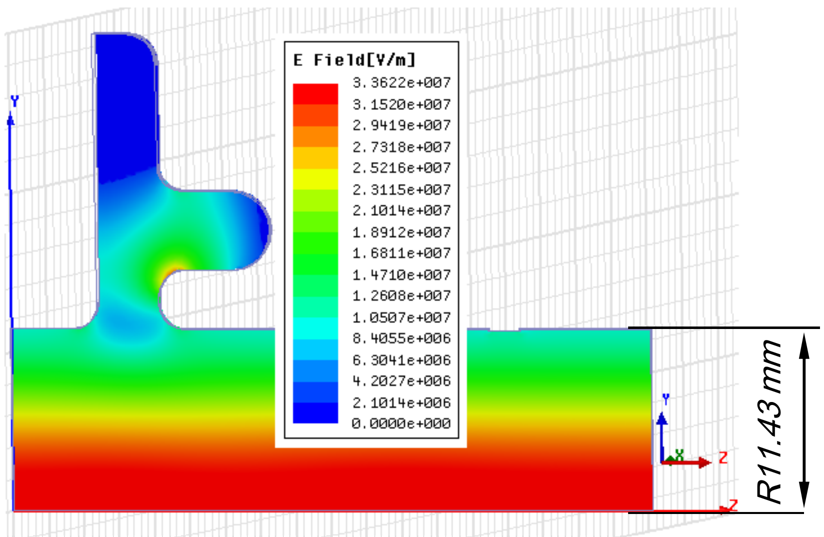
On-axis electric fields

MODES	F (MHz)
1	8239.8
2	11330.0
3	**11426.3 ← π Mode**
4	14808.8
5	14865.0

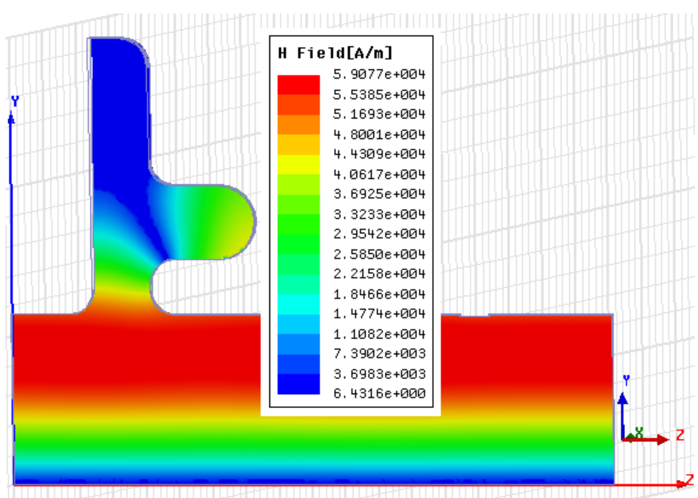
FREQUENCY .... 11426.303 MHz
QUALITY FACTOR .... 8645 (no chokes 8910)
STORED ENERGY .... 1.2041 J
Emax...................... ..... 322.1 MV/m (no chokes 398.9 MV/m)
near point R=0.465873 cm Z= 3.5868 cm
Hmax........................... 555.0 kA/m (no chokes 668 kA/m)
near point R=0.875583 cm Z= 3.116 cm
Zo*(Hmax/Emax)....... 0.6495 (no chokes 0.631)

A. D. Yeremian, 9 October 2009

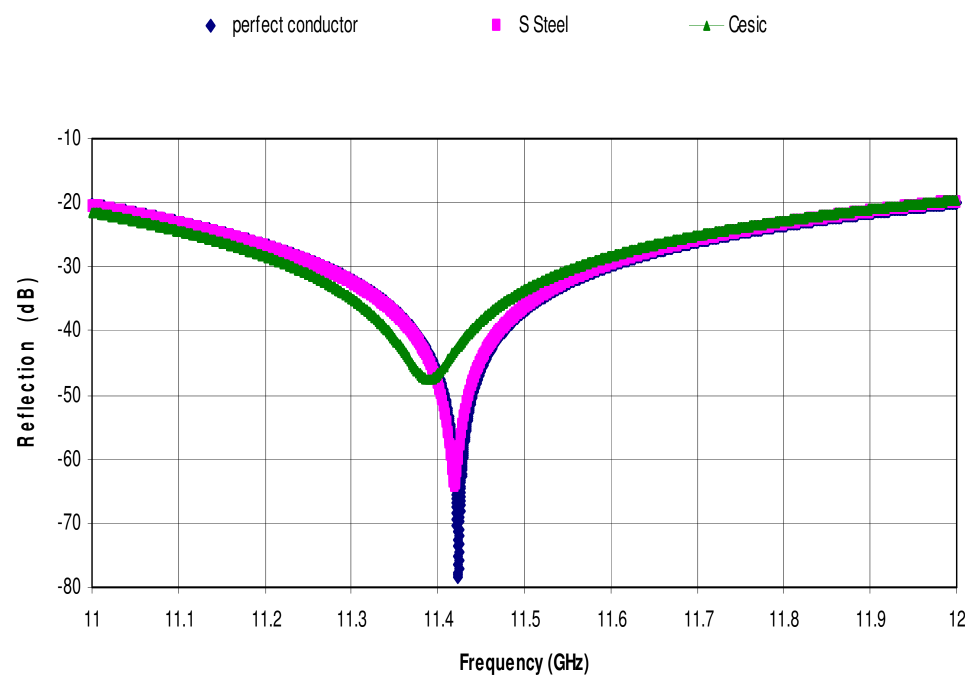
Choke flange for TM01 mode launcher



Electric Fields for 100MW input



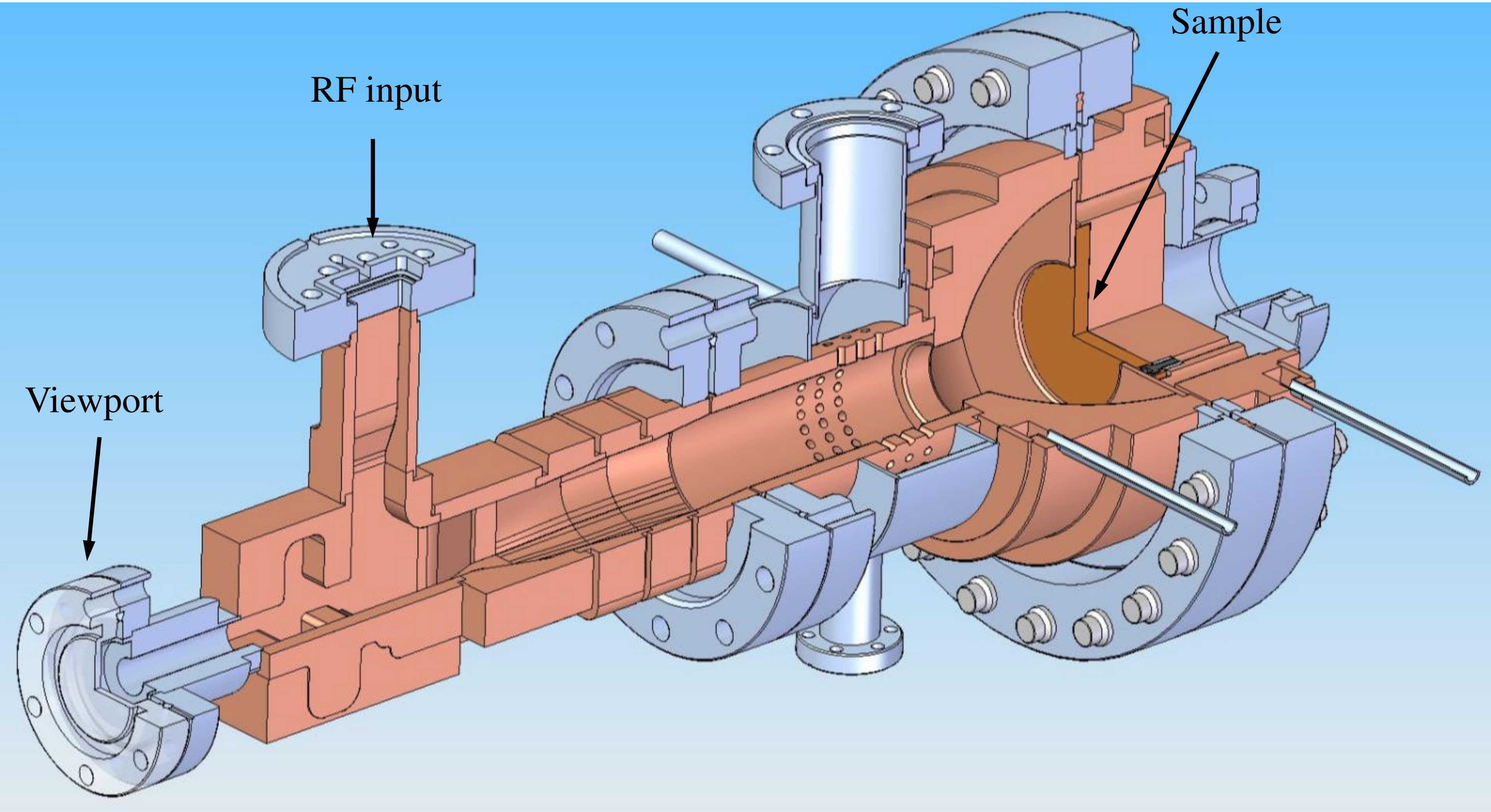
Magnetic Fields for 100MW input



S11 vs. frequency for perfect conductor, stainless steel, and Cesic

A. D Yeremian, August 31, 2009

New pulse heating cavity for in situ observation of pulse heating damage



Cavity RF designed by Takuya Natsui (University of Tokyo) the design is based on Sami Tantawi's cryogenic cavity, mechanical design by David Martin

Summary

Test stations in SLAC klystron laboratory produce wealth of experimental data.

We welcome more new ideas and test structures.