Status of High Gradient Tests of Single Cell Standing Wave Structures at SLAC

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SLAC National Accelerator Laboratory

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CERN, CICG

Outline

- Motivation
- Planned experiments
- Recent results
  - Geometry
  - Hard materials

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

- S. Tantawi (US High Gradient Collaboration spokesperson), A. Yeremian (day-to-day operation and coordination of TS4, *etc*.), J. Lewandowski (rf measurements, software and TS6-TS8 operation, *etc.*) *of Accelerator Technology Research*
- E. Jongewaard, C. Pearson, A. Vlieks, J. Eichner, D. Martin, C. Yoneda, L. Laurent, A. Haase, R. Talley, J. Zelinski, J. Van Pelt, R. Kirby and staff *of Klystron Lab.*
- Z. Li*, Advanced Computation*

In close collaboration with:

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

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

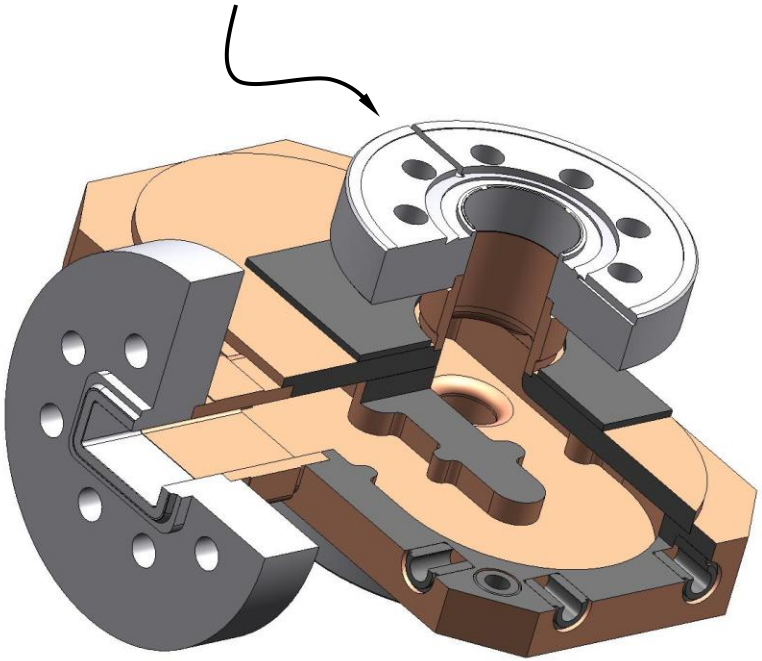
Solution

- *Single cell 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

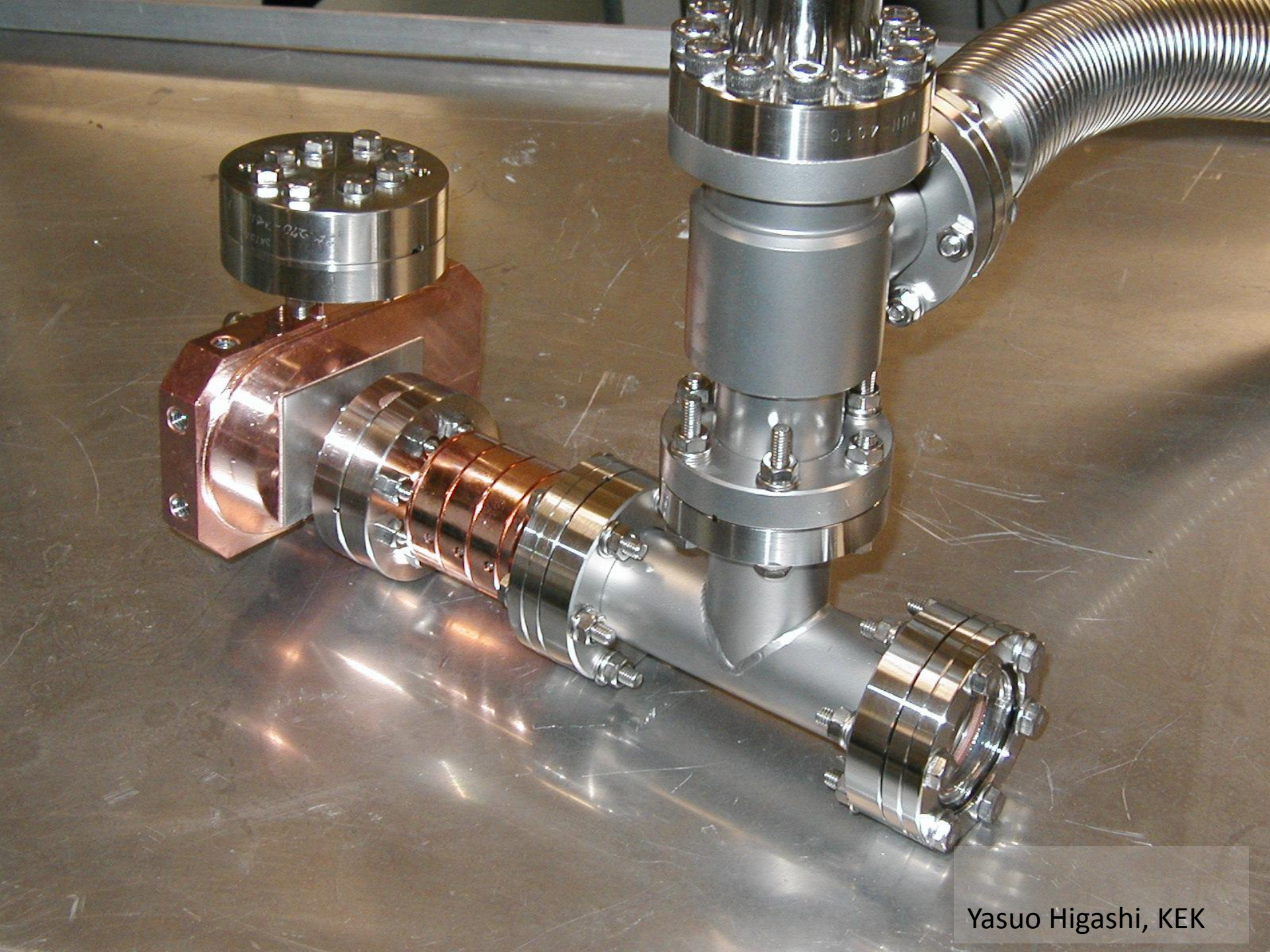


Cutaway view of the mode launcher

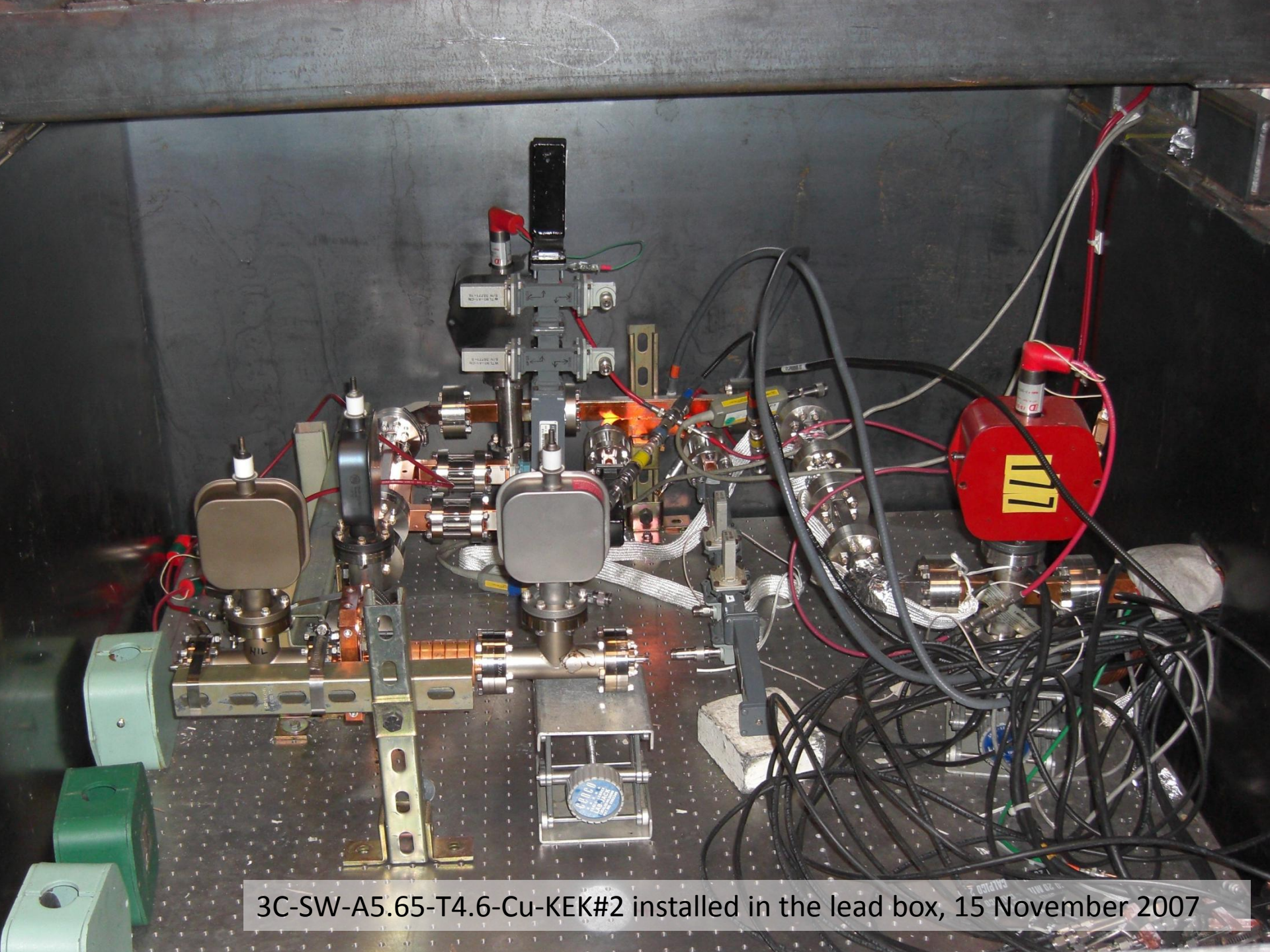
Two mode launchers

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*, 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,* 1 tested
- Low shunt impedance, made of molybdenum *1C-SW-A5.65-T4.6-Mo,* 1 tested
- Low shunt impedance, hard copper electroformed *1C-SW-A5.65-T4.6-Electroformed-Cu,* 1 tested
- High shunt impedance, choke with 4mm gap, *1C-SW-A3.75-T2.6-4mm-Ch-Cu,* 2 tested
- High shunt impedance, elliptical iris, *a/lambda* = 0.143, *1C-SW-A3.75-T2.6-6NCu*, 1 tested
- High shunt impedance, elliptical iris, *a/lambda* = 0.143, *1C-SW-A3.75-T2.6-6N-HIP-Cu*, 1 tested
- High shunt impedance, elliptical iris, *a/lambda* = 0.143, *1C-SW-A3.75-T2.6-7N-Cu*, 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,* 1 tested
- High shunt impedance soft CuAg, *1C-SW-A3.75-T2.6-CuAg*, 1 tested
- High shunt impedance hard CuZr, *1C-SW-A3.75-T2.6-Clamped-CuZr*, 1 tested
- High shunt impedance dual feed side coupled, *1C-SW-A3.75-T2.6-2WR90-Cu,* 1 tested
- High shunt impedance single feed side coupled ,1C-SW-A3.75-T2.6-1WR90-Cu-SLAC-#1, 1 tested
- High shunt impedance hard CuCr, *1C-SW-A3.75-T2.6-Clamped-CuCr*, 1 tested

Now 32nd test is about to start,

single feed side coupled

3C-SW-A3.75-T2.6-2WR90-Cu-SLAC-#2

Next experiments, as for October 2010

New diagnostics:

High shunt impedance, full choke cell with a viewport, 1C-SW-A3.75-T2.6-Ch-View-Port-Cu

Geometry tests:

Photonic-Band Gap, low shunt impedance, elliptical rods, *1C-SW-A5.65-T4.6-PBG2-Cu*
High shunt impedance, triple choke, copper, *1C-SW-A3.75-T2.6-4mm-TripleCh-Cu*
High shunt impedance, reduced magnetic field, copper *1C-SW-A3.75-T2.2-Cu* ***(see Jeff Neilson's talk)***

Materials:

High shunt impedance, made of hard CuAg, *1C-SW-A3.75-T2.6-Clamped-CuAg,*
Highest shunt impedance, made of hard CuCr, CuAg, CuZr, *1C-SW-A2.75-T2.0-Clamped-CuCr, CuAg, CuZr*
High shunt impedance, triple choke, Molybdenum, *1C-SW-A3.75-T2.6-4mm-TripleCh-Mo*
High shunt impedance, Cu-Mo, *1C-SW-A3.75-T2.6-Cu-Mo*
High shunt impedance, Cu-Stainless Steel, *1C-SW-A3.75-T2.6-Cu-SUS*
Highest shunt impedance, cryogenic test, *1C-SW-A2.75-T2.0-Cryo-Cu*
High shunt impedance, Stainless Steel coated with copper, *1C-SW-A3.75-T2.6-SUS-Coated-Cu*

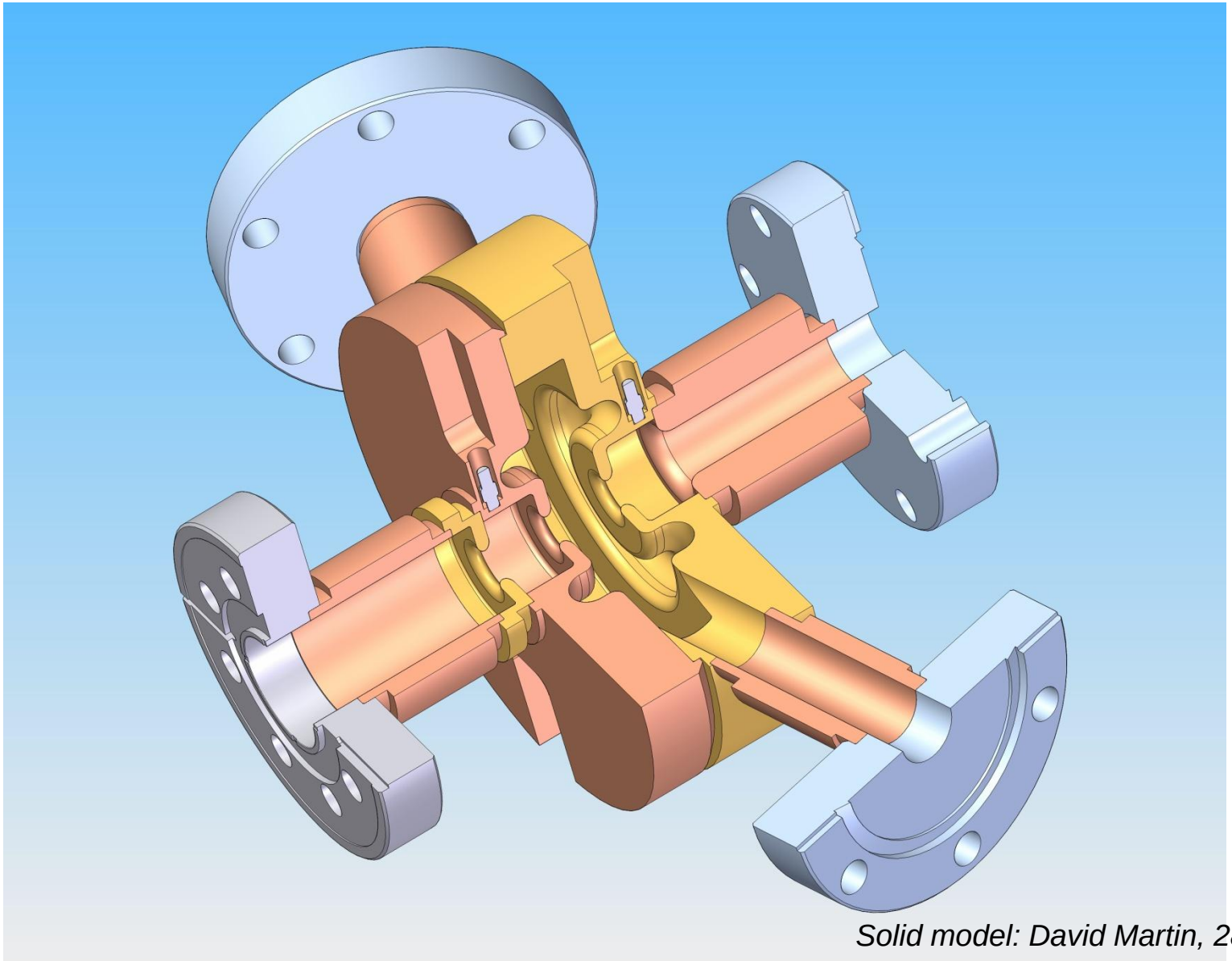
Reproducibility tests:

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

New diagnostics

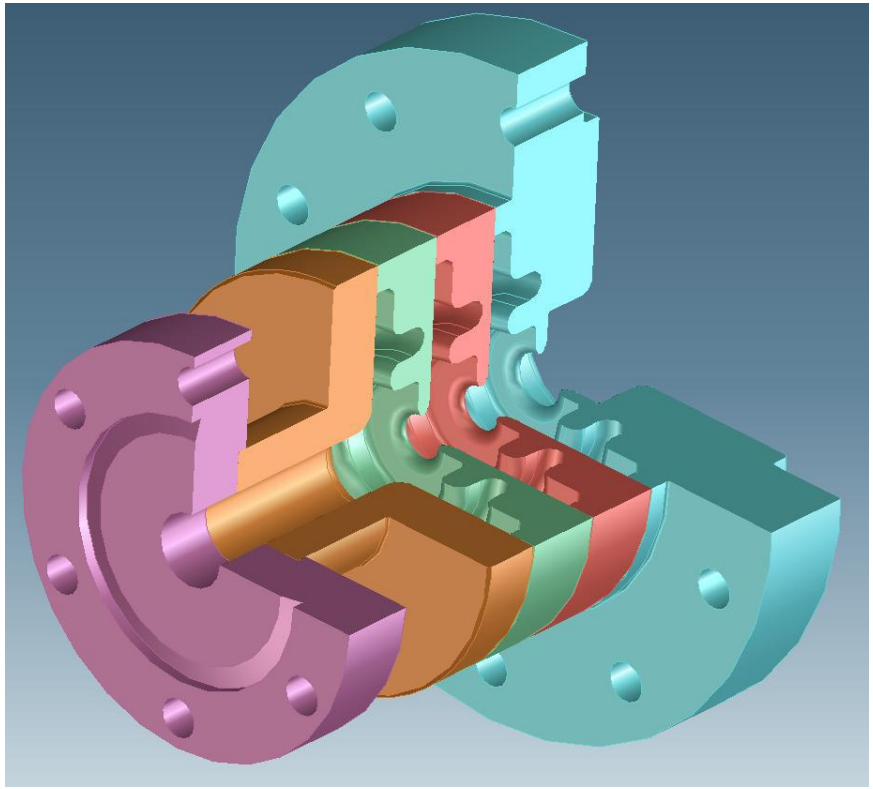
In-situ microscopic observation of surface change and rf breakdowns:

Full cell choke and two view ports *1C-SW-A3.75-T2.6-Ch-View-Port-Cu-SLAC-#1,2*

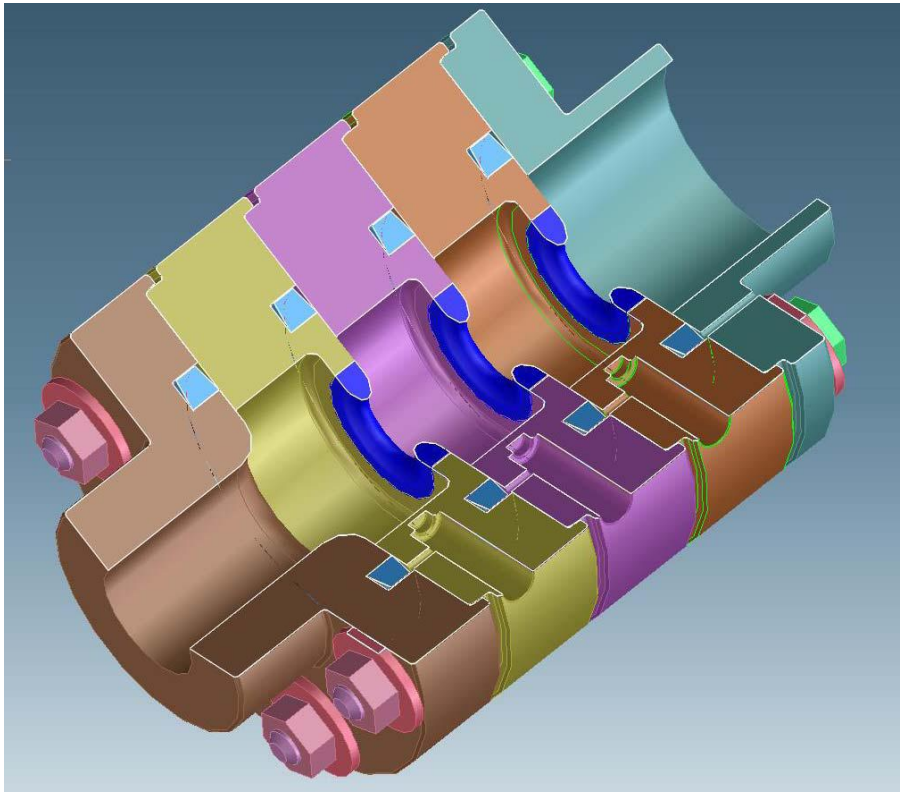


Solid model: David Martin, 28 April 2010

Geometry and material test
Structure joining techniques that avoid high temperature treatment



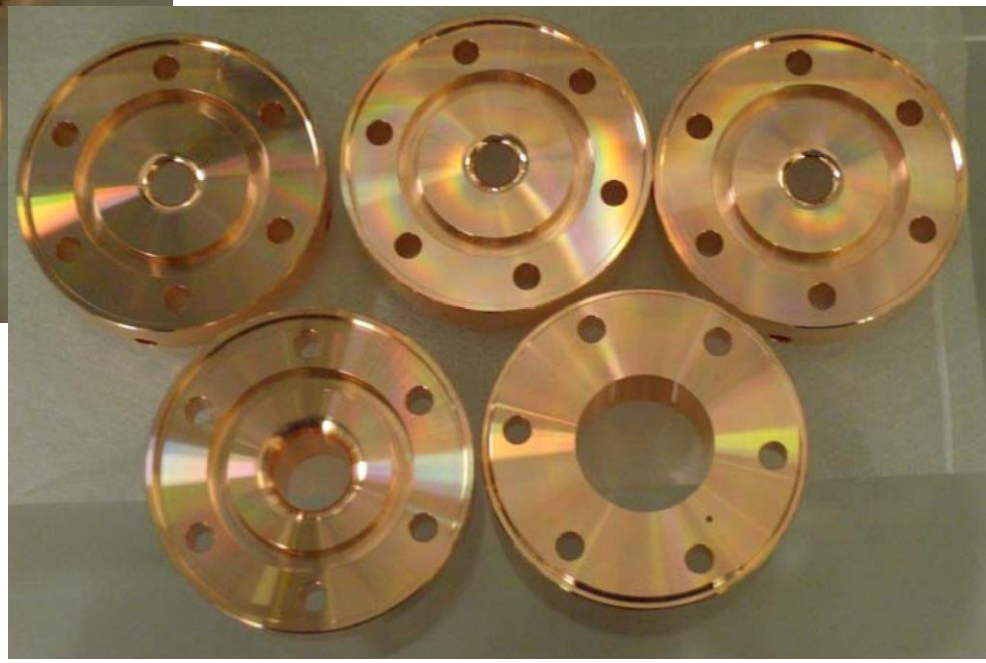
1C-SW-A3.75-T2.2-Cu,Mo-KEK, similar configuration is under development in INFN-Frascati



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

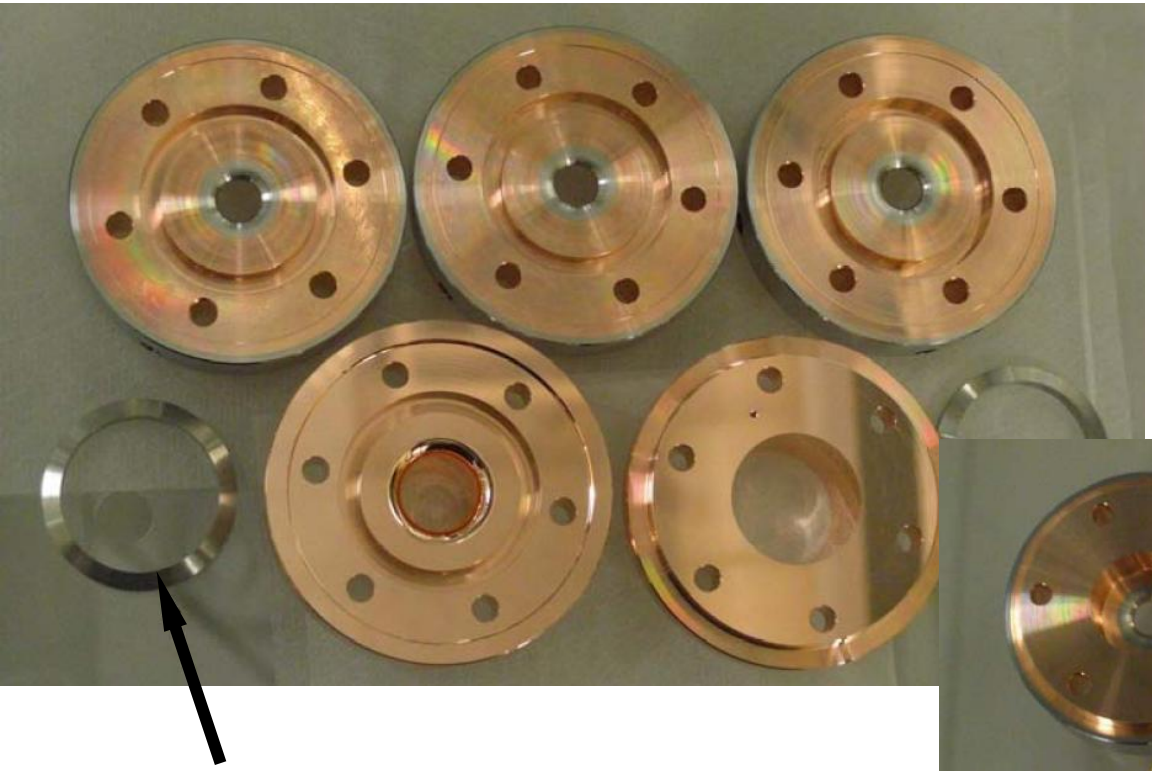
Y. Higashi, KEK

Material test
1C-SW-A3.75-T2.6-Clamped-CuAg-KEK

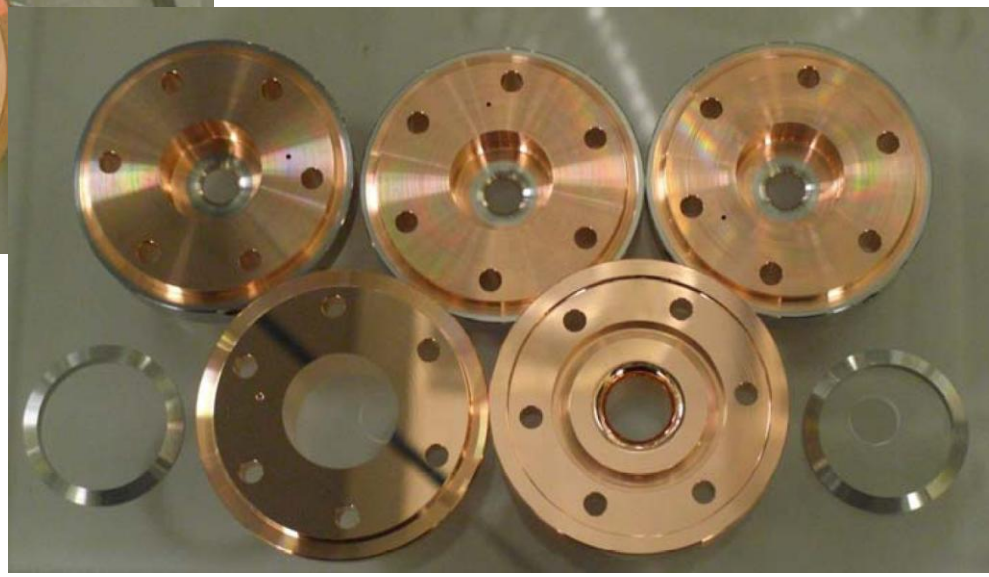


Y. Higashi, KEK

Material test
1C-SW-A3.75-T2.60-Cu-SUS-Clamped-KEK



Ag coated SUS gaskets

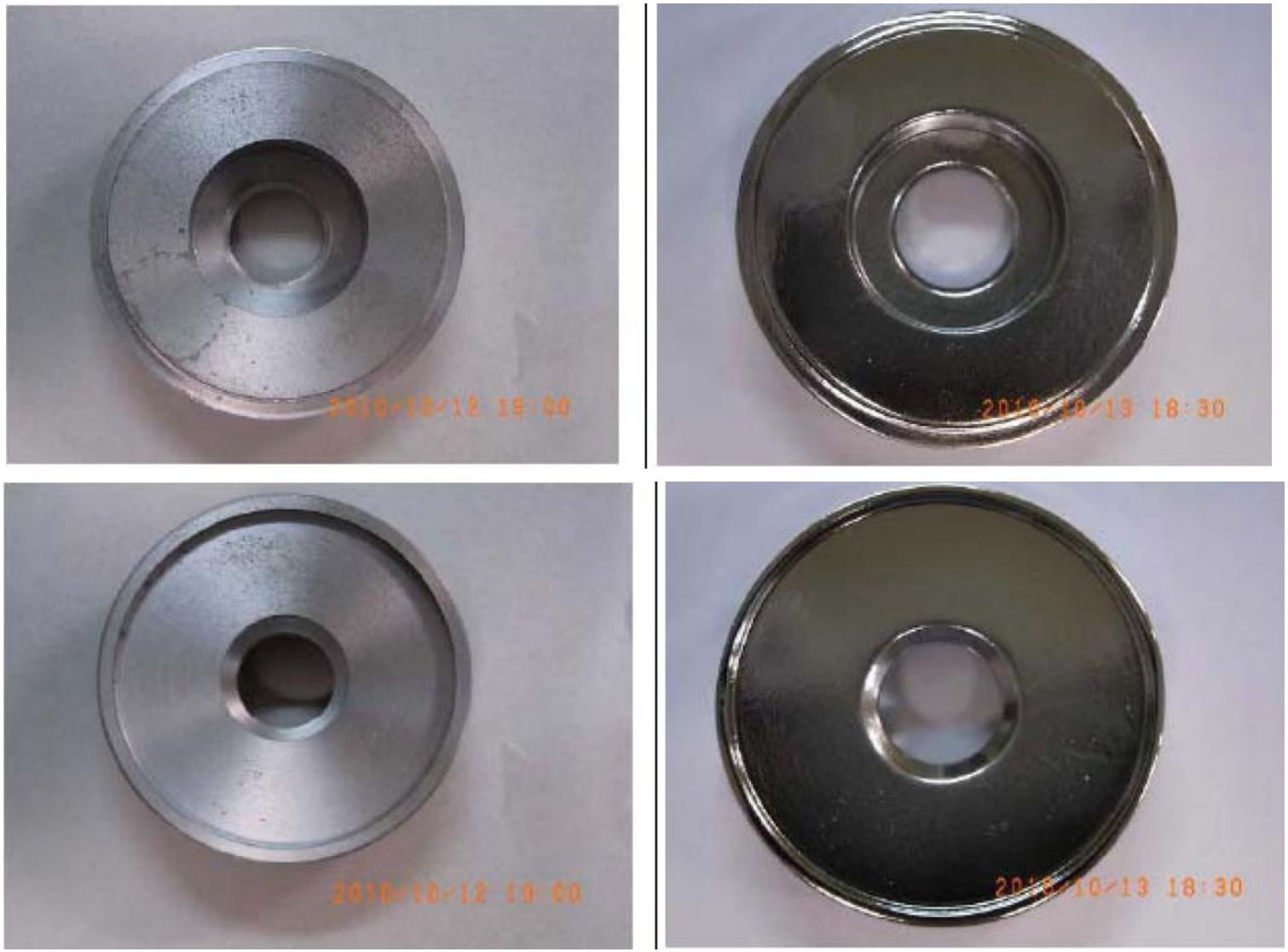


Y. Higashi, KEK

Material test
1C-SW-A3.75-T2.60-Cu-Mo-Clamped-KEK

Y. Higashi, KEK

Material test, electropolishing

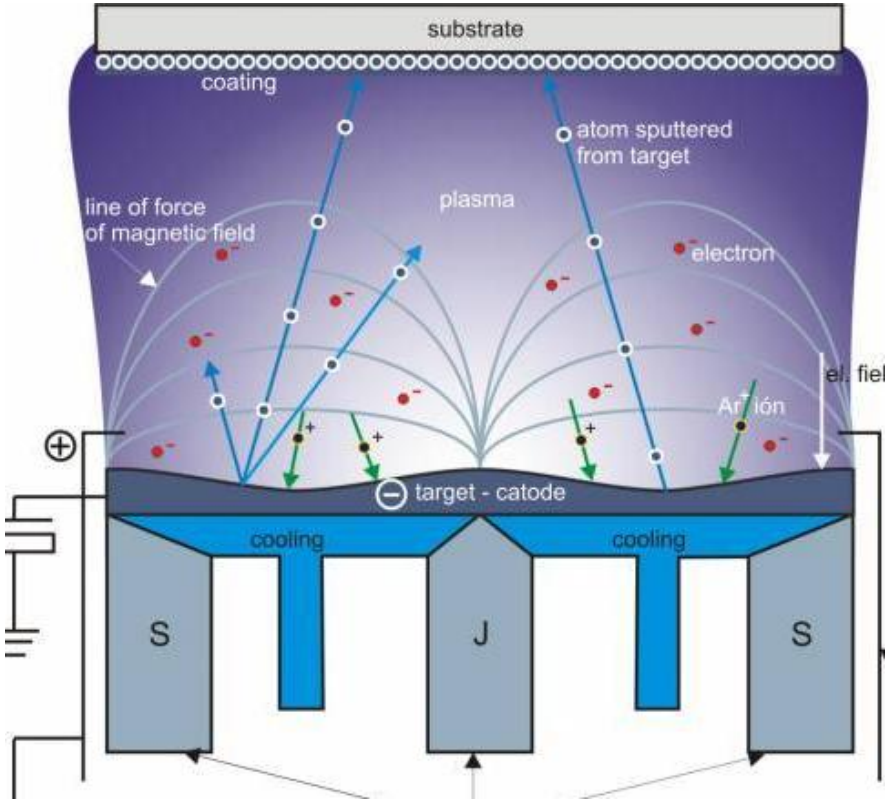


Before electropolishing

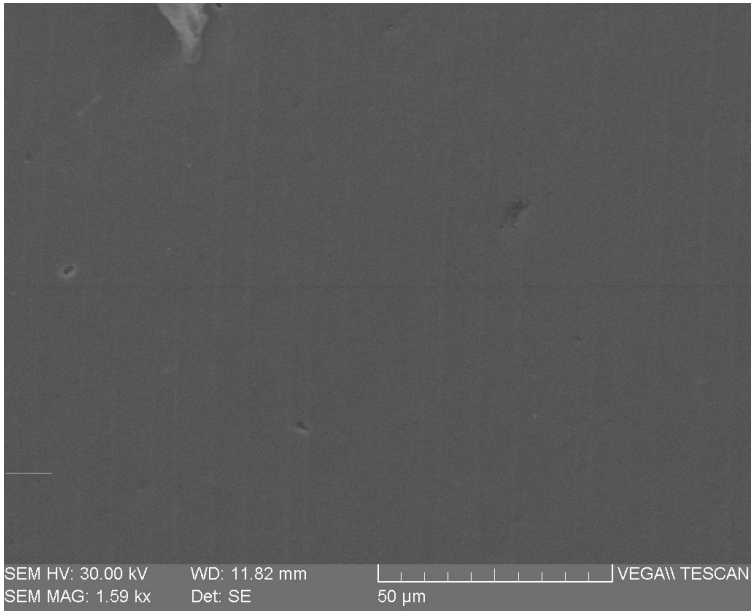
After

Y. Higashi, KEK

Material testing, Mo spattering on Cu



Schematic diagram of a DC magnetron plasma source



SEM Picture of copper dish machined at very low roughness sputtered with 300nm of Molybdenum after a thermal treatment of 2 hours at 300 C.

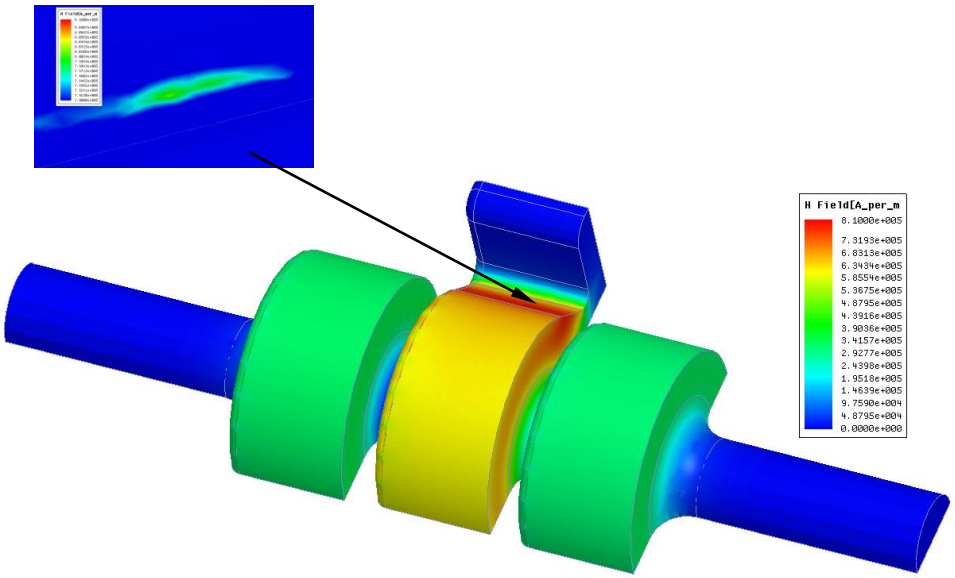
B. Spataro, INFN-Frascati

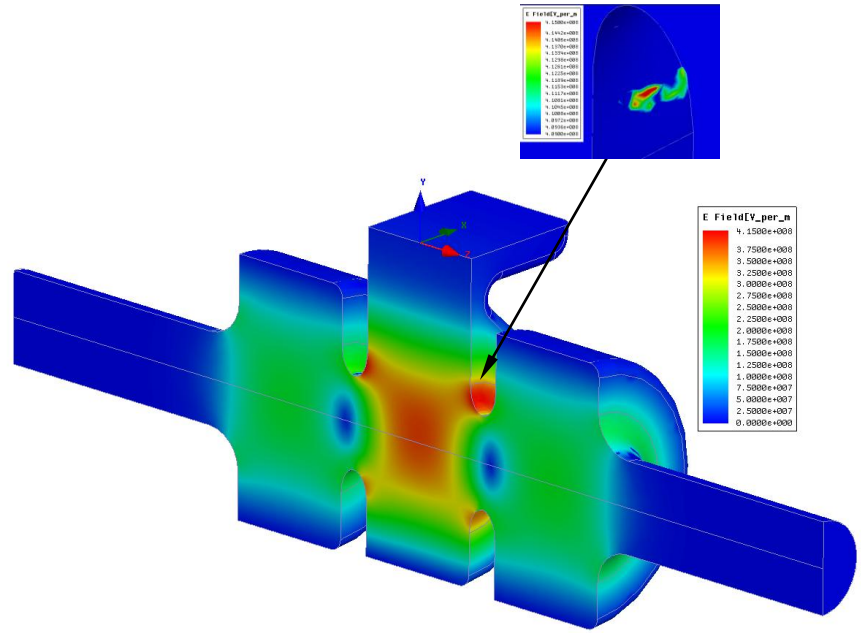
Results

- Geometry test
  1C-SW-A3.75-T2.6-1WR90-Cu-SLAC-#1
- Material test
  1C-SW-A3.75-T2.6-Clamped-CuCr-SLAC-#1

Geometry test
High shunt-impedance single-feed side-coupled
1C-SW-A3.75-T4.6-1WR90-Cu-SLAC-#1

Side-coupled ingle feed 1C-SW-A3.75-T2.6-1WR90-Cu-SLAC-#1
Calculating Zenghai's geometry with HFSS, driven, 10 MW input



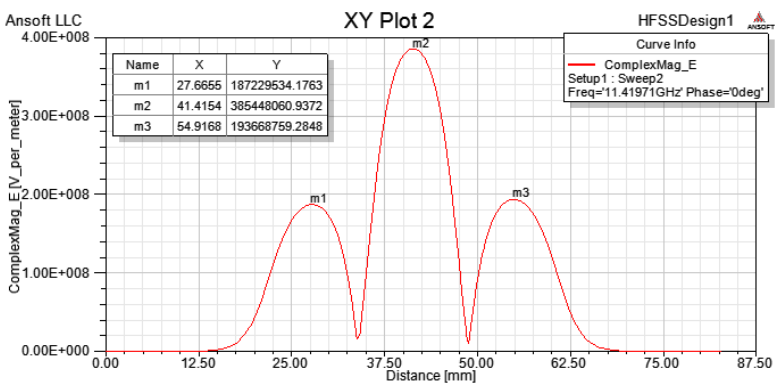


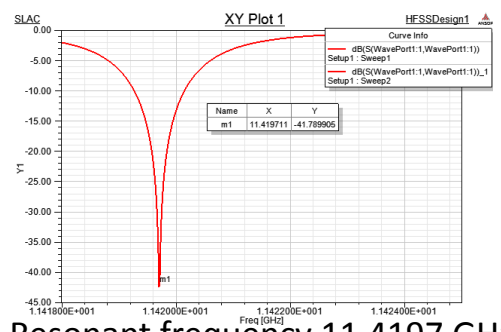
Maximum magnetic field 800 kA/m, $H_{1WR90} / H_{SLANS} = \frac{800}{668} = 1.198$

(SLANS 1C-SW-T3.75-A2.6-Cu 668.0 kA/m)

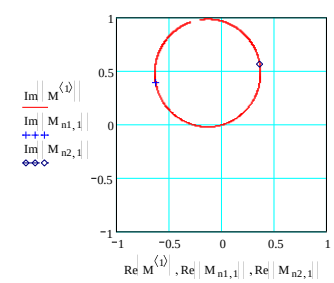
Maximum electric field 412 MV/m, $E_{1WR90} / E_{SLANS} = \frac{412}{398.9} = 1.033$

(SLANS 398.9 MV/m)





Resonant frequency 11.4197 GHz



Maximum on axis peak electric field 385 MV/m, field balance $\frac{3854}{1872 + 1936} = 1.012$

(SLANS 384 MV/m)

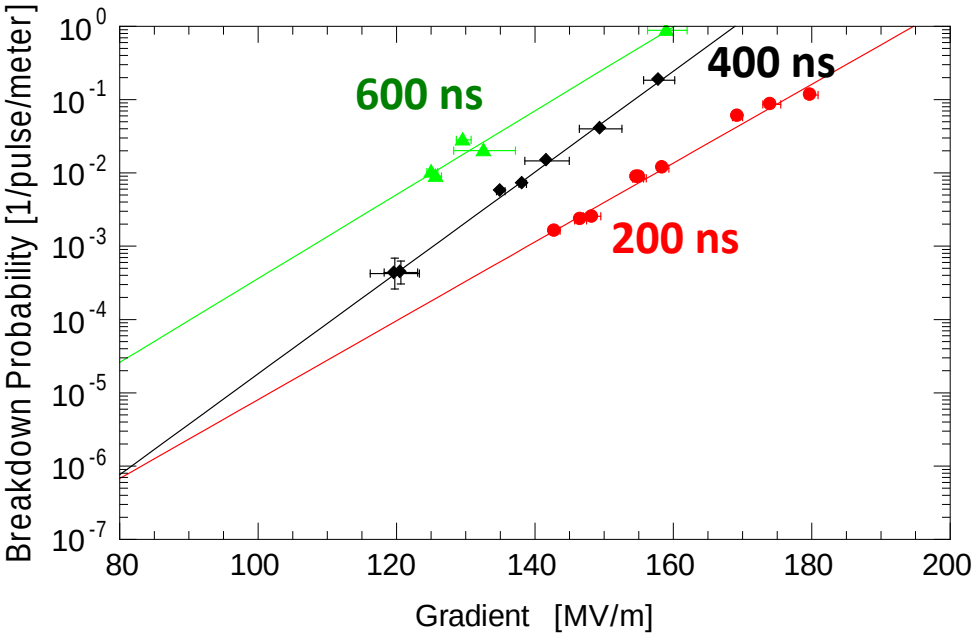
$$\frac{f_{floor\left(\frac{n1+n2}{2}\right)}}{f_{n1} - f_{n2}} = 4.309 \times 10^3$$

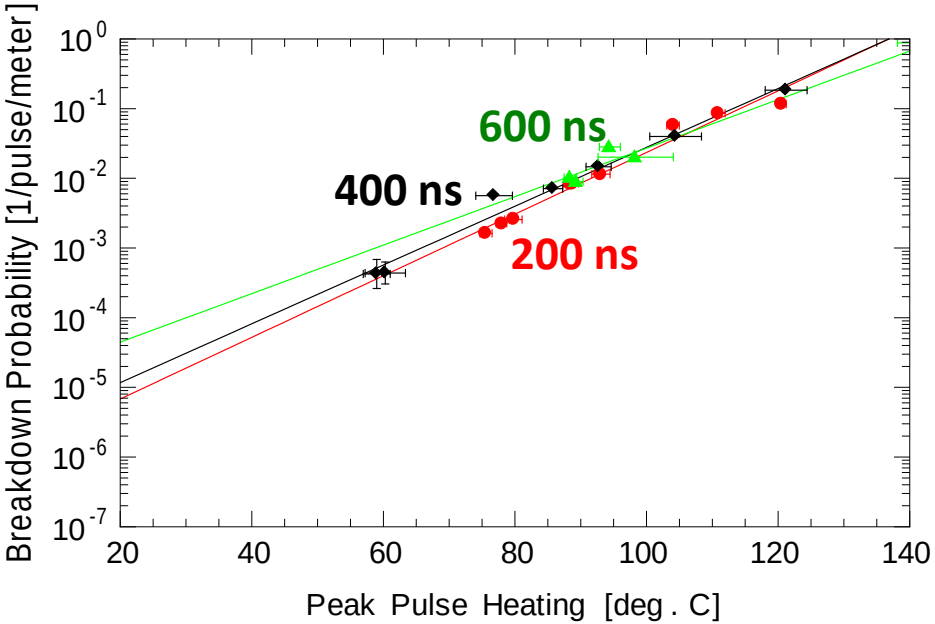
$$Qo := 2 \cdot \left| 4.309 \times 10^3 \right|$$

$$Qo = 8.618 \times 10^3$$

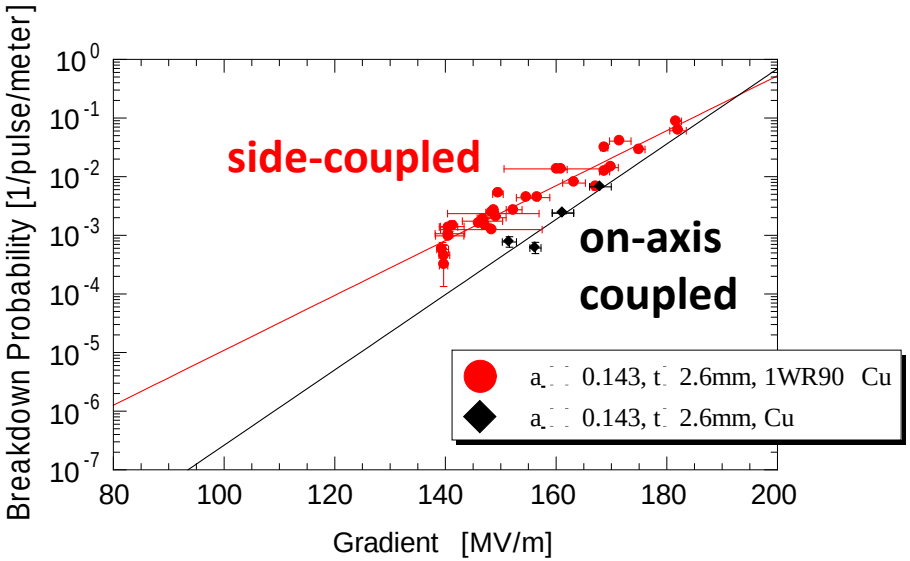
V.A. Dolgashev, 7 June 2010

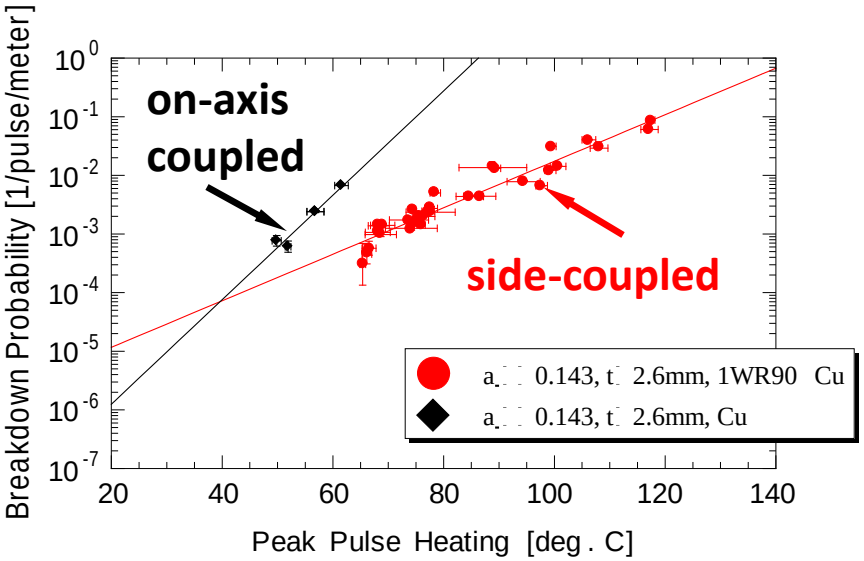
Single-feed side-coupled structure 1C-SW-A3.75-T2.6-1WR90-Cu-SLAC-#1, Dependence of breakdown rate for different pulse length of flat part of the shaped pulse.





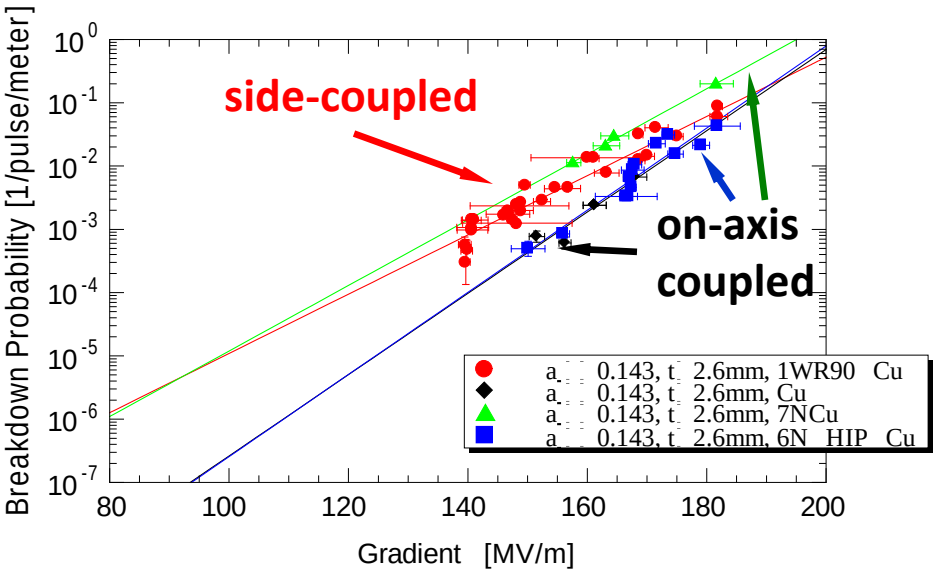
Comparison of side-coupled copper structure with on-axis coupled copper structures of same iris geometry (1C-SW-A3.75-T2.6-Cu), shaped pulse with 150 ns flat part

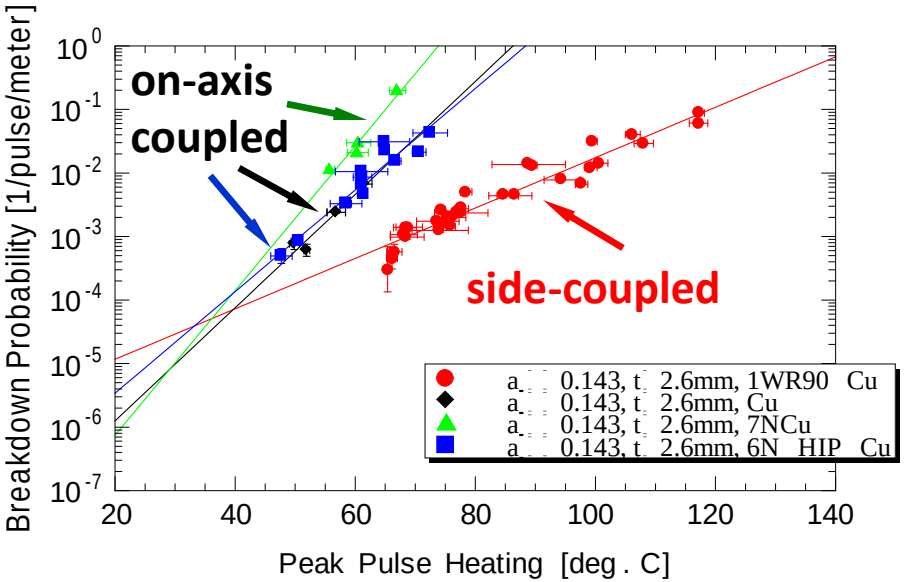




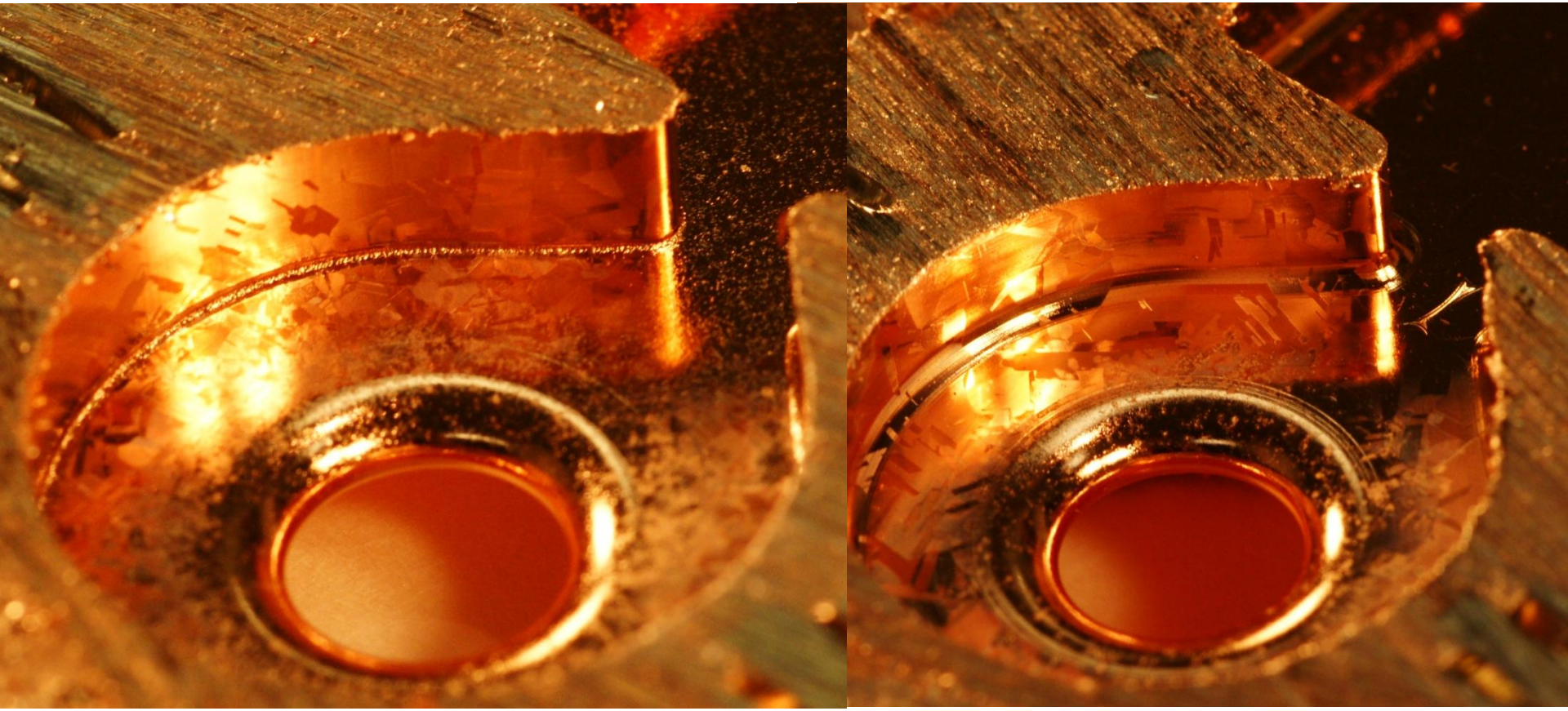
No obvious increase of breakdown rate due to increased pulse heating on coupler edges.

Comparison of one side-coupled copper structure with three on-axis coupled copper structures of same iris geometry (1C-SW-A3.75-T2.6-Cu), shaped pulse with 150 ns flat part

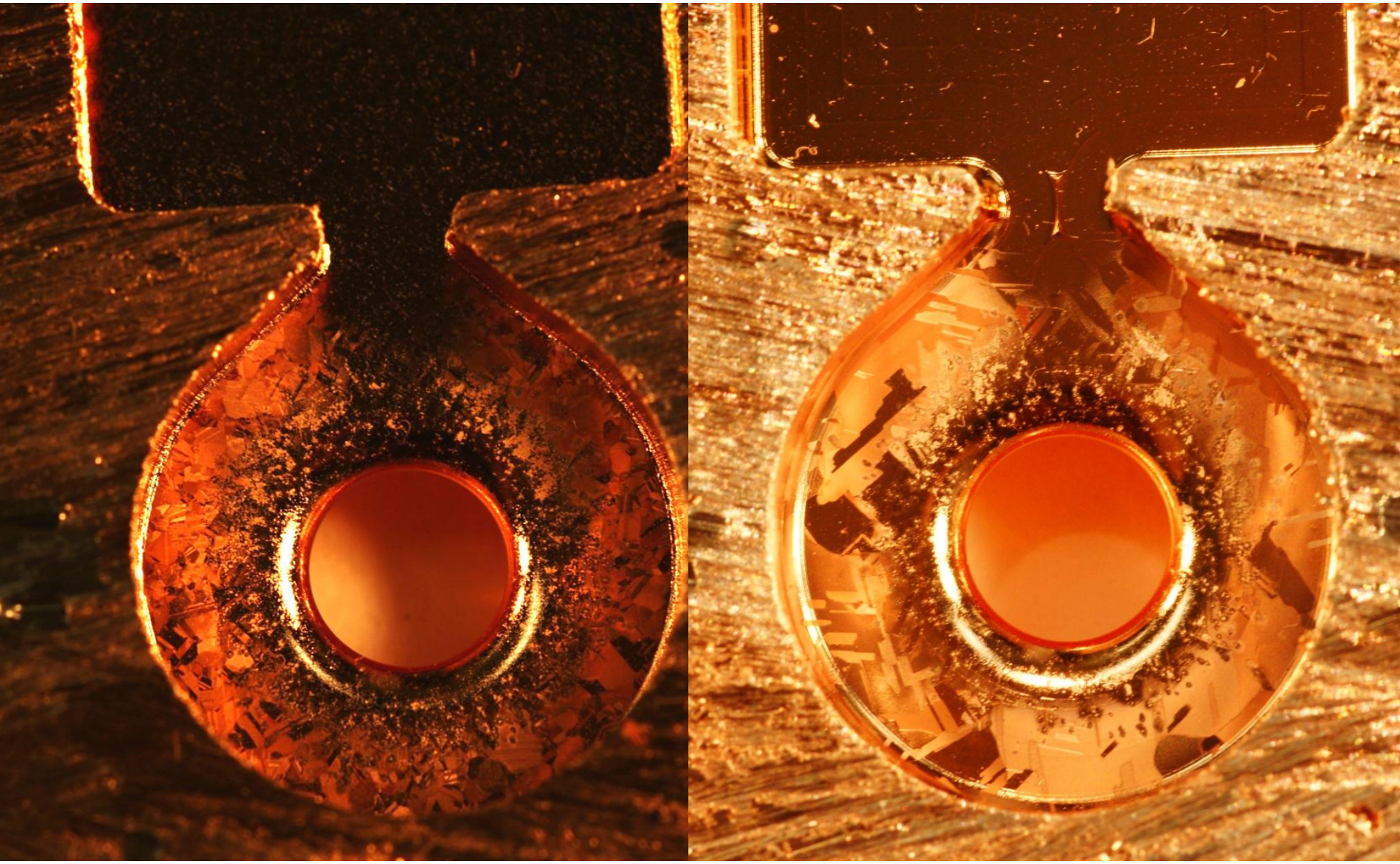




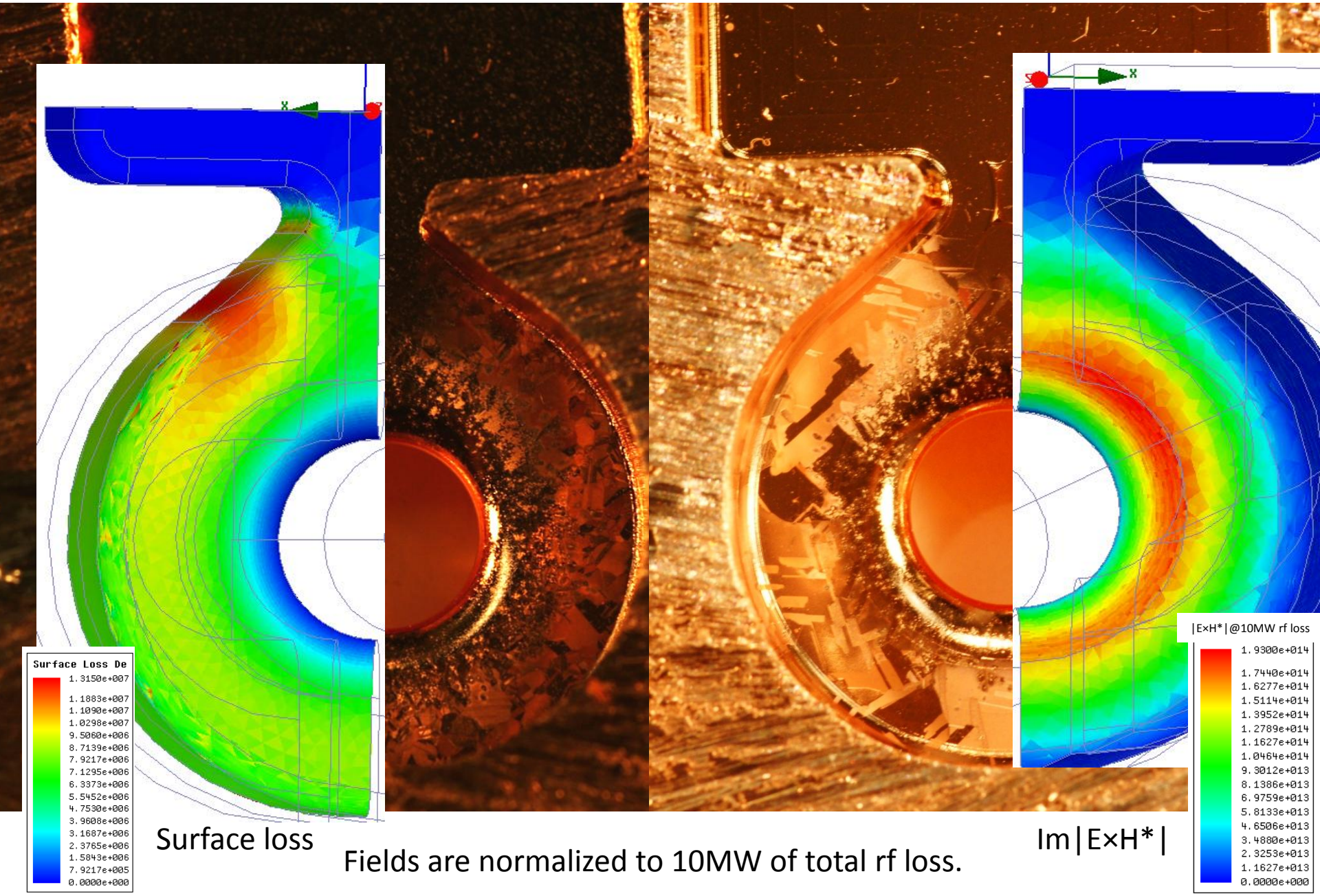
1C-SW-A3.75-T4.6-1WR90-Cu-SLAC-#1



Coupling cell of 1C-SW-A3.75-T4.6-1WR90-Cu-SLAC-#1



Coupling cell of 1C-SW-A3.75-T4.6-1WR90-Cu-SLAC-#1

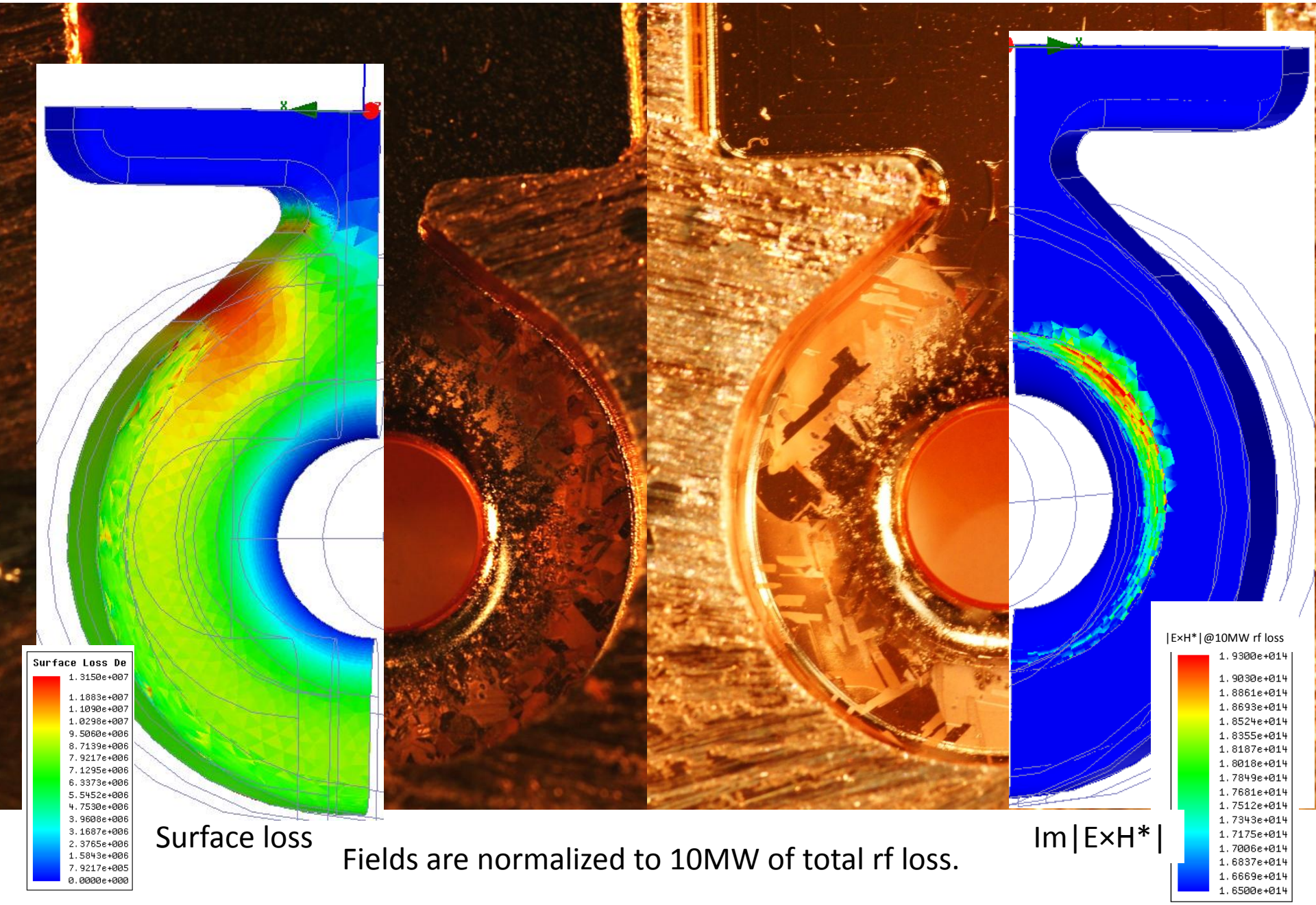


Surface loss

Im|E×H*|

Fields are normalized to 10MW of total rf loss.

Coupling cell of 1C-SW-A3.75-T4.6-1WR90-Cu-SLAC-#1

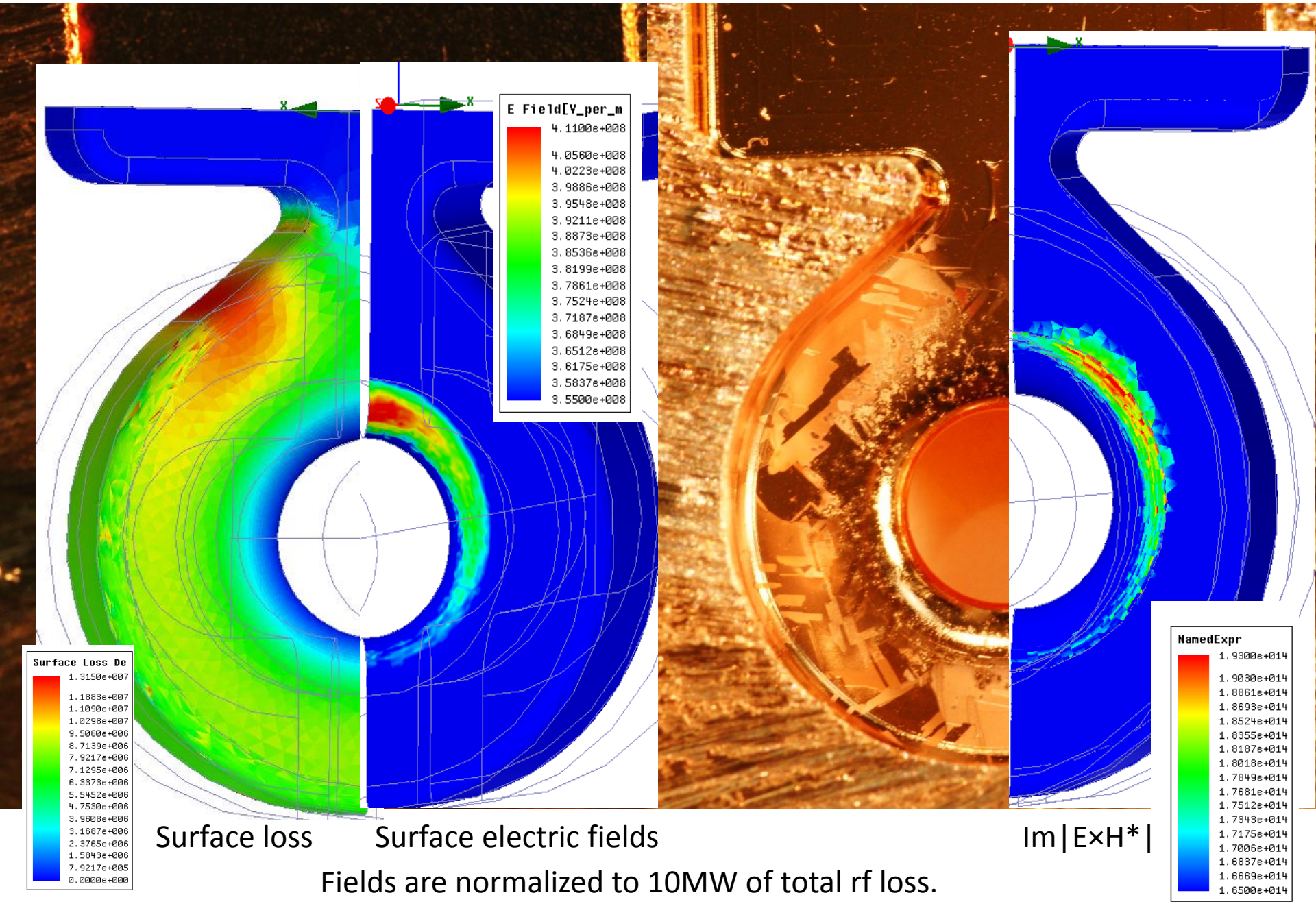


Surface loss

Im|E×H*|

Fields are normalized to 10MW of total rf loss.

Coupling cell of 1C-SW-A3.75-T4.6-1WR90-Cu-SLAC-#1



Surface loss Surface electric fields Im|E×H*|

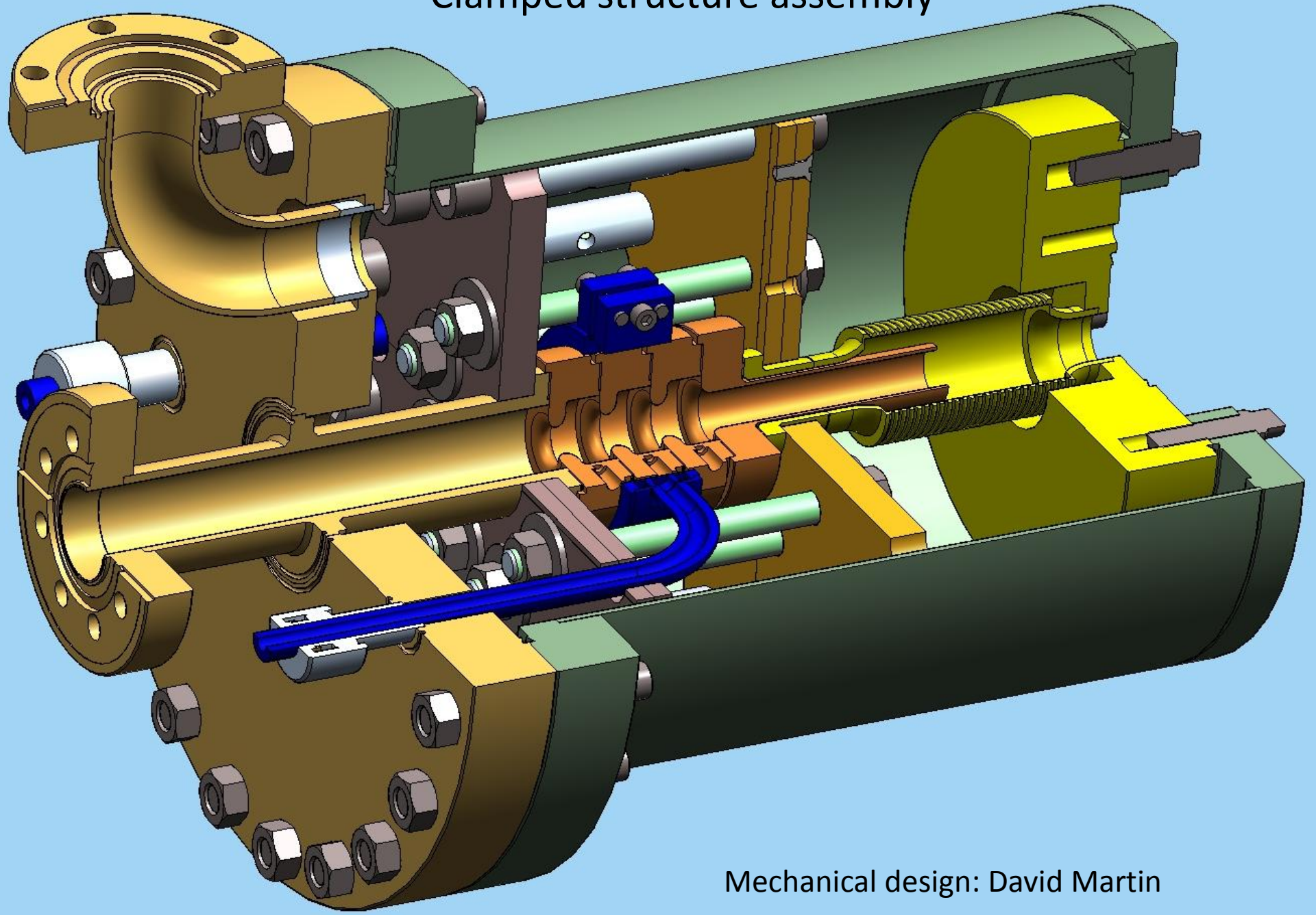
Fields are normalized to 10MW of total rf loss.

Coupling cell of 1C-SW-A3.75-T4.6-1WR90-Cu-SLAC-#1

Material test

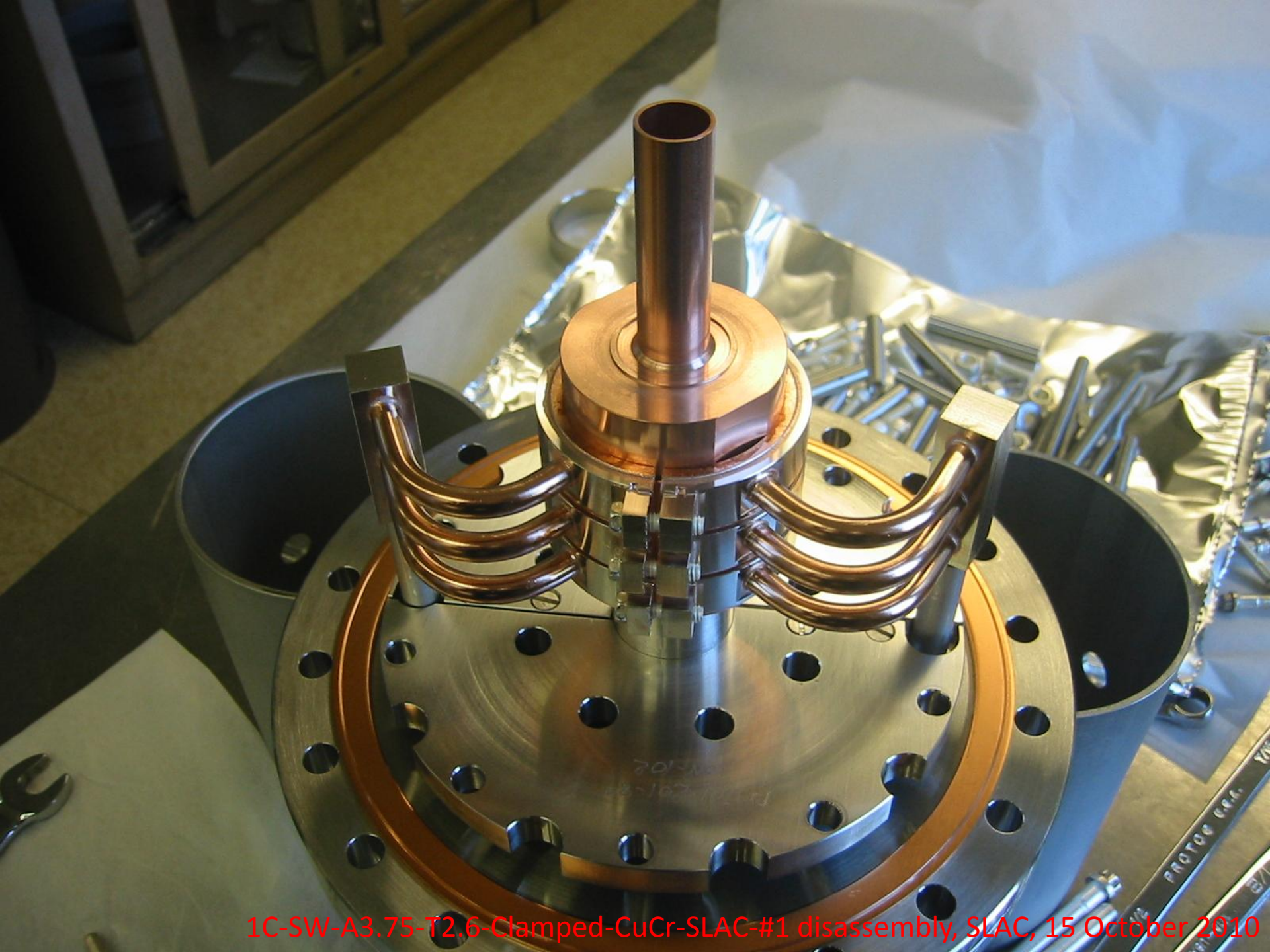
High shunt-impedance, hard-CuCr, 1C-SW-A3.75-T2.6-Clamped-CuCr-SLAC-#1

Clamped structure assembly

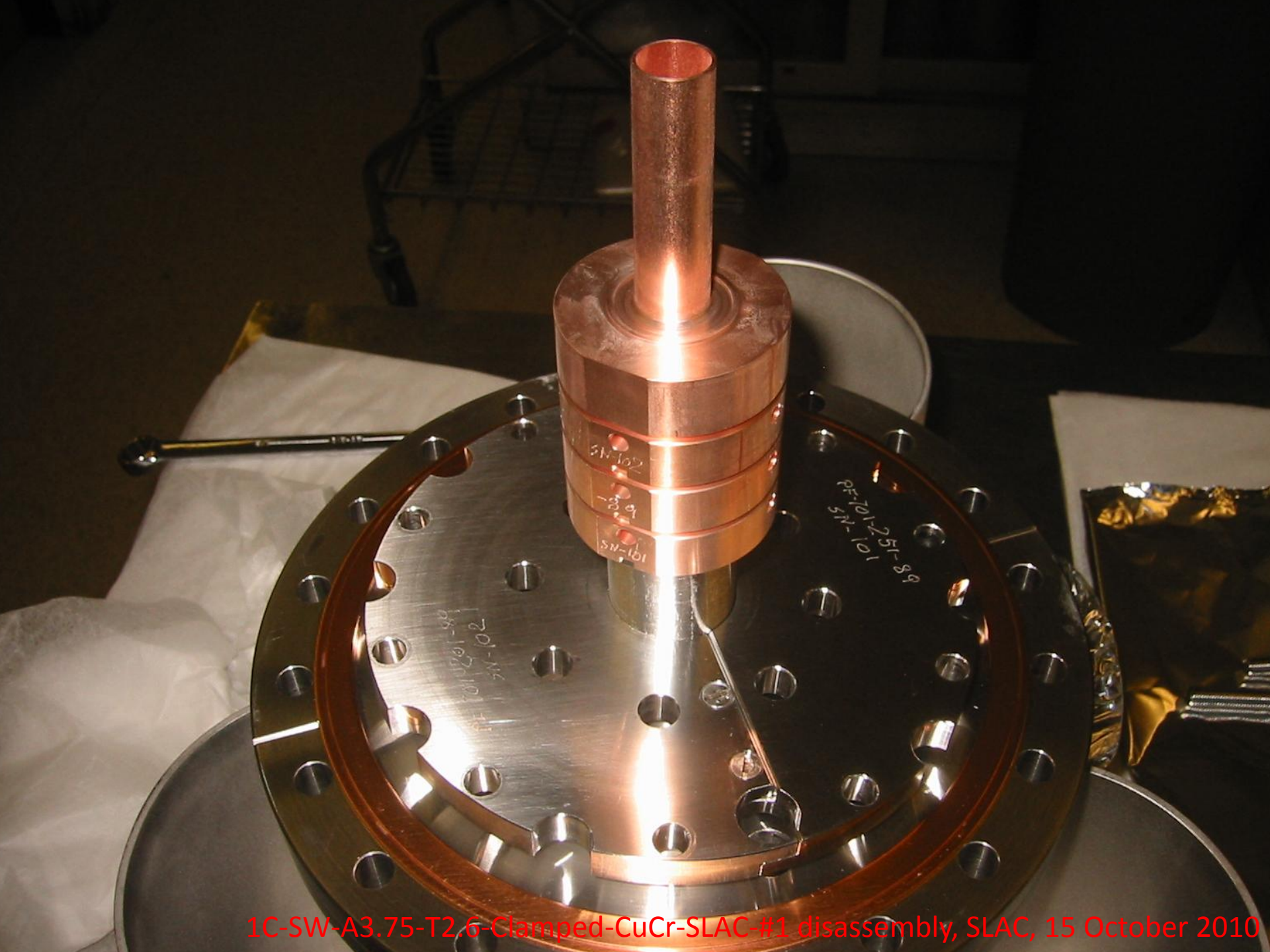


Mechanical design: David Martin

1C-SW-A3.75-T2.6-Clamped-CuCr-SLAC-#1 disassembly, SLAC, 15 October 2010



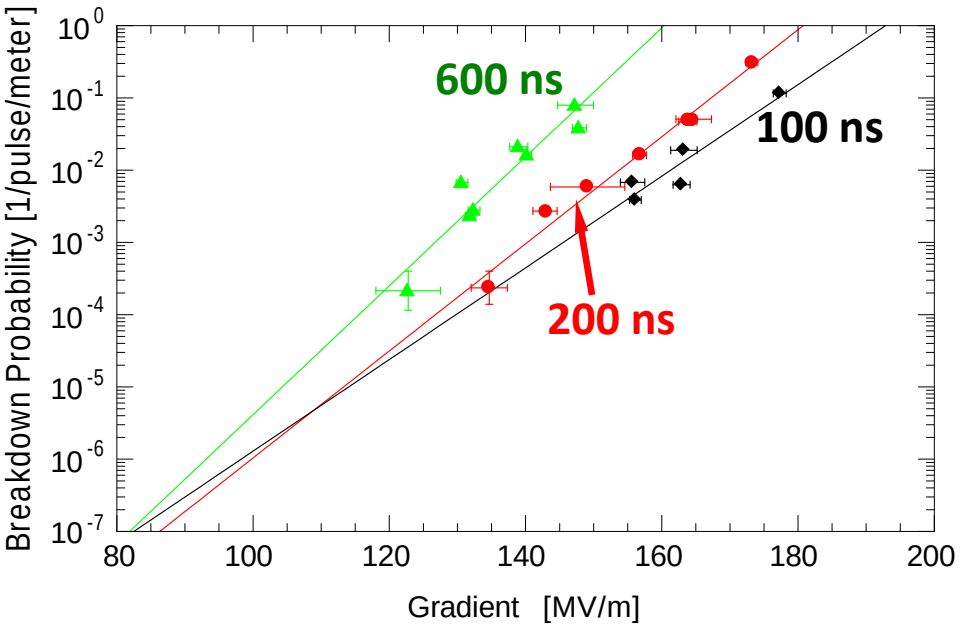
1C-SW-A3.75-T2.6-Clamped-CuCr-SLAC-#1 disassembly, SLAC, 15 October 2010

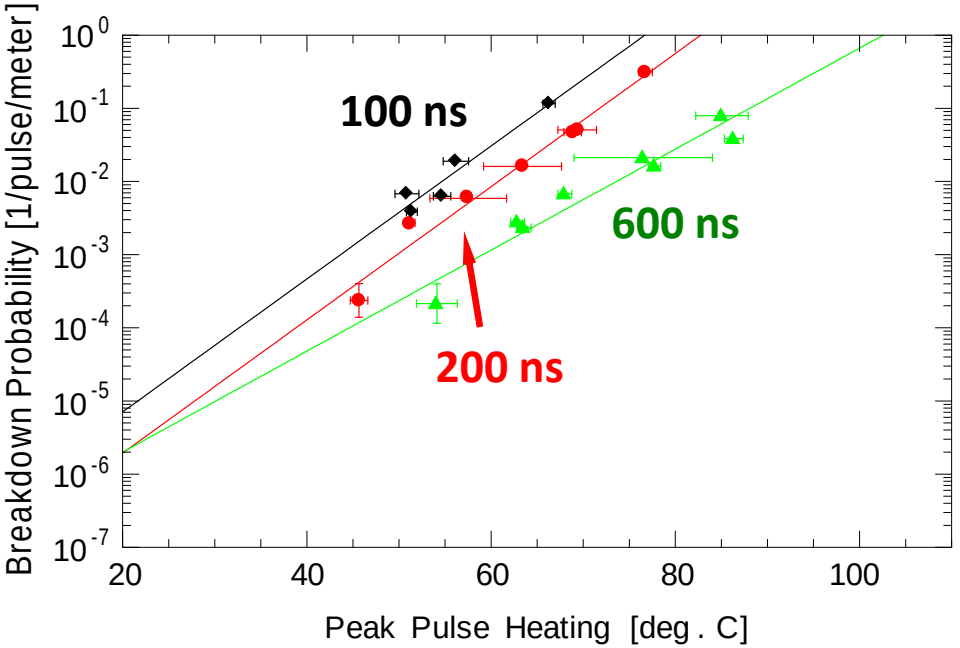


1C-SW-A3.75-T2.6-Clamped-CuCr-SLAC-#1 disassembly, SLAC, 15 October 2010

1C-SW-A3.75-T2.6-Clamped-CuCr-SLAC-#1 after test

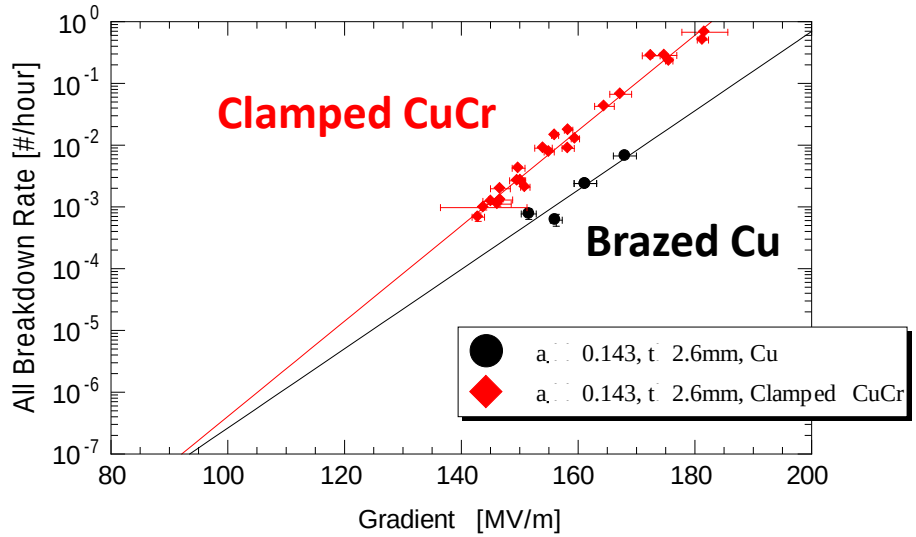
High shunt impedance structure made of hard CuCr, 1C-SW-A3.75-T2.6-Clamped-CuCr-SLAC- #1, Dependence of breakdown rate for different pulse length of flat part of the shaped pulse.

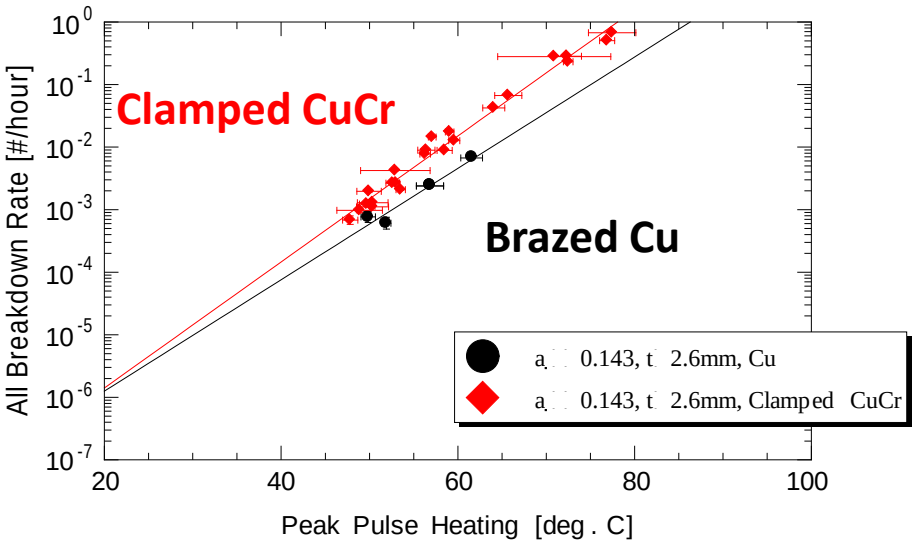




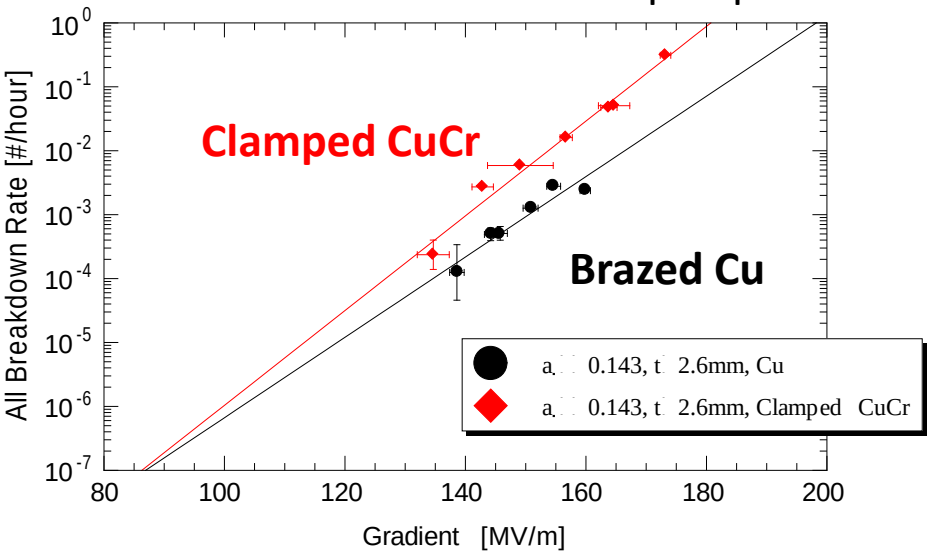
No obvious correlation with pulse heating.

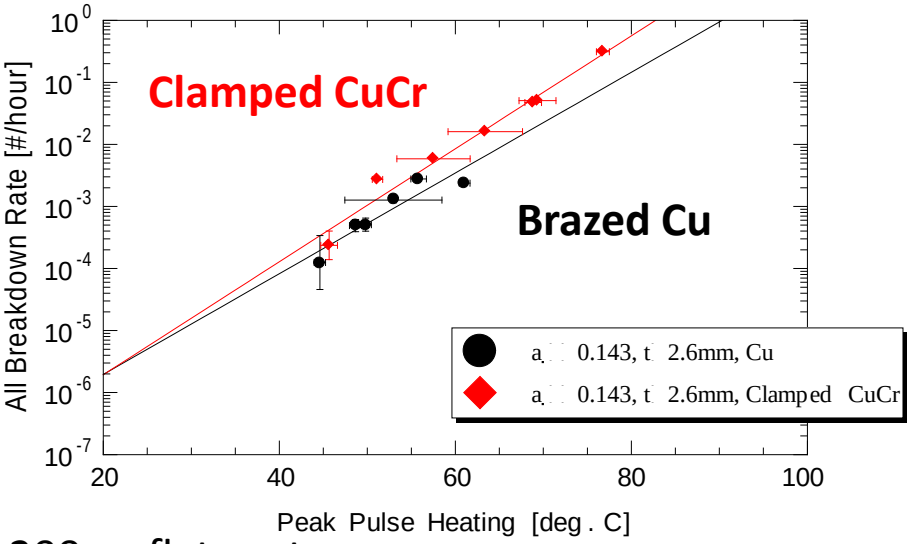
Comparison of two structures same geometry, one brazed Cu another clamped CuCr





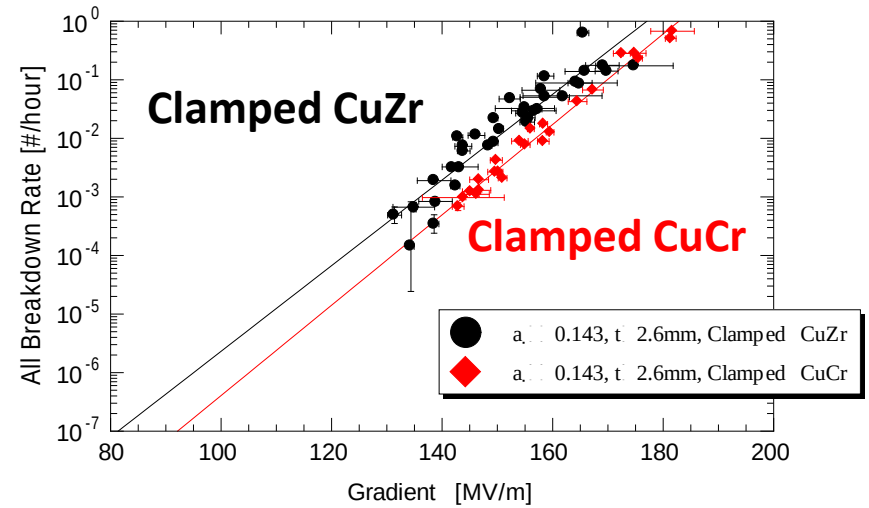
Shaped pulse with 150 ns flat part

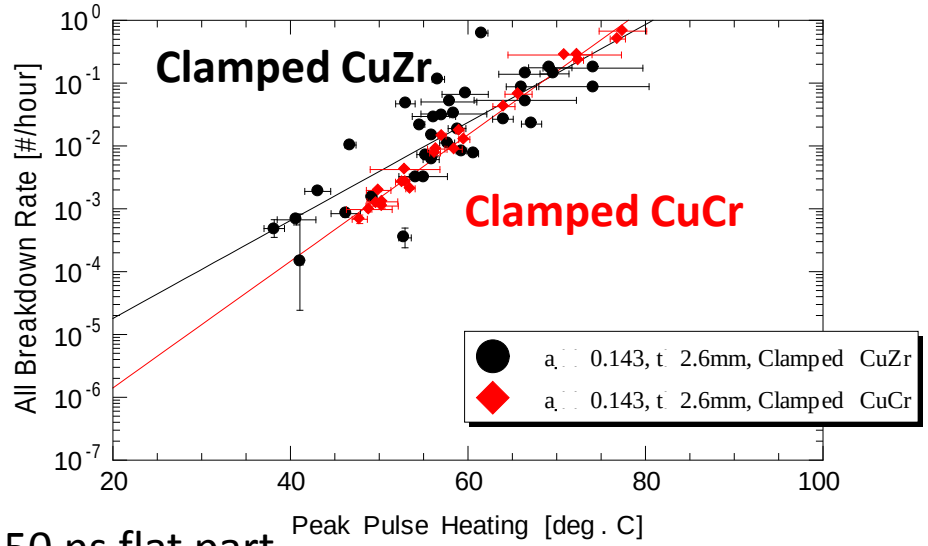




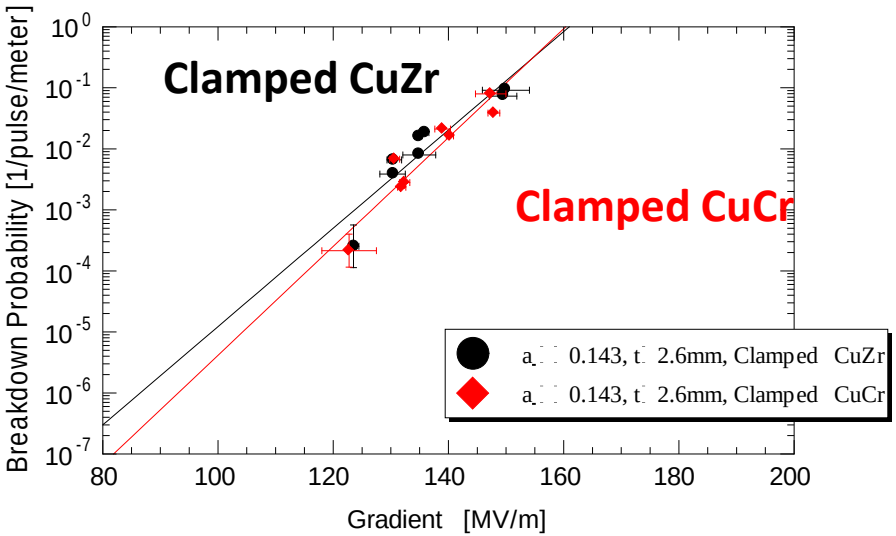
Shaped pulse with 200 ns flat part

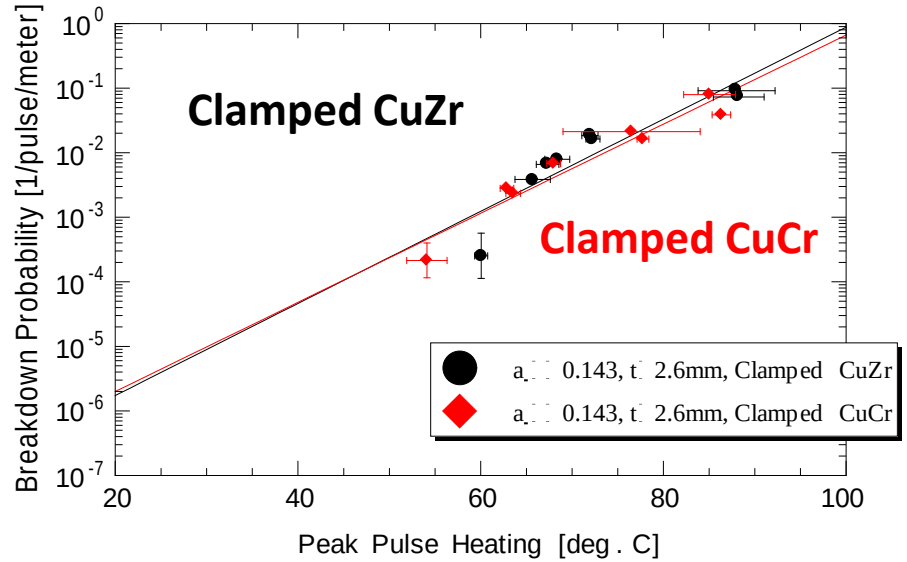
Comparison of two clamped structures with the same geometry made of hard CuCr and CuZr





Shaped pulse with 150 ns flat part





Shaped pulse with 600 ns flat part

Main Results

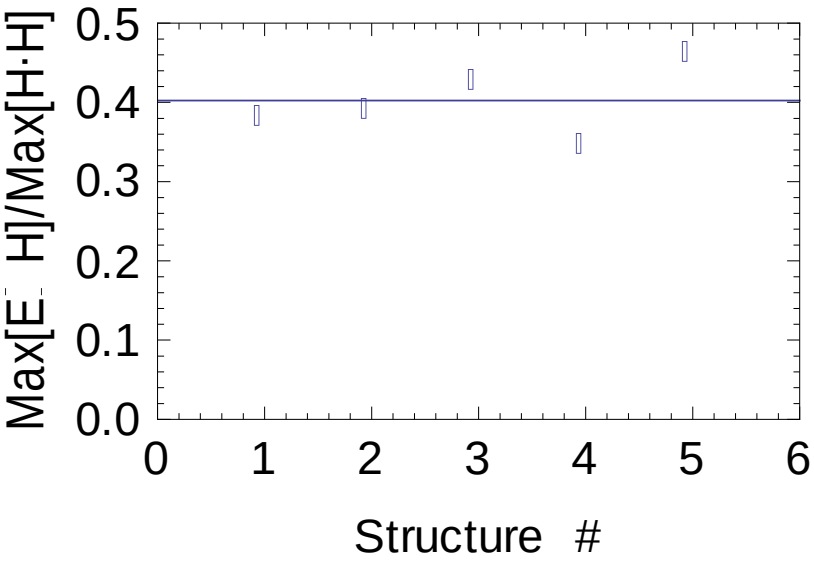
High-shunt-impedance side-coupled structure had about the same breakdown rate as on-axis-coupled structure with peak pulse heating about 40% higher.

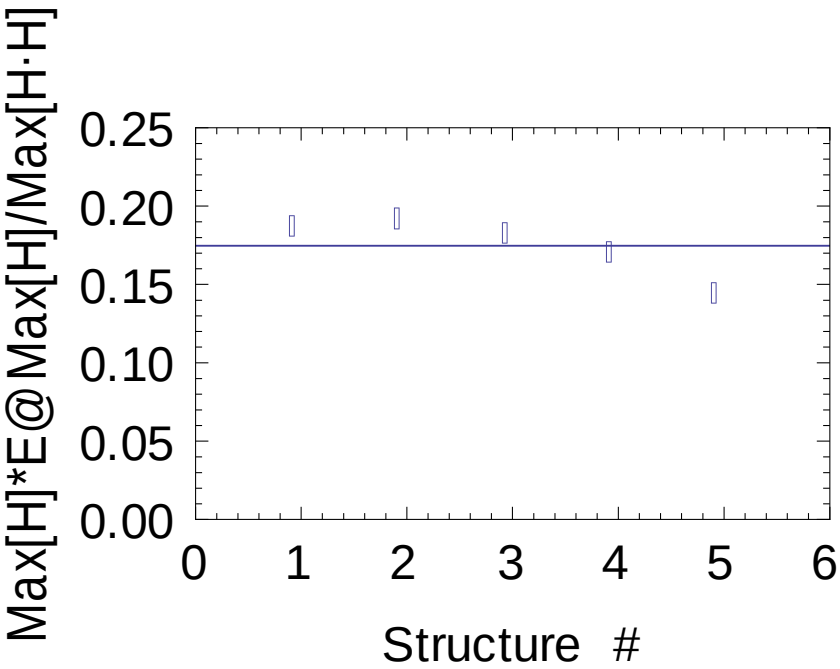
High-shunt-impedance structure made of hard CuCr had similar breakdown rate to hard CuZr structure and higher breakdown rate than the brazed Cu structure.

Discussion

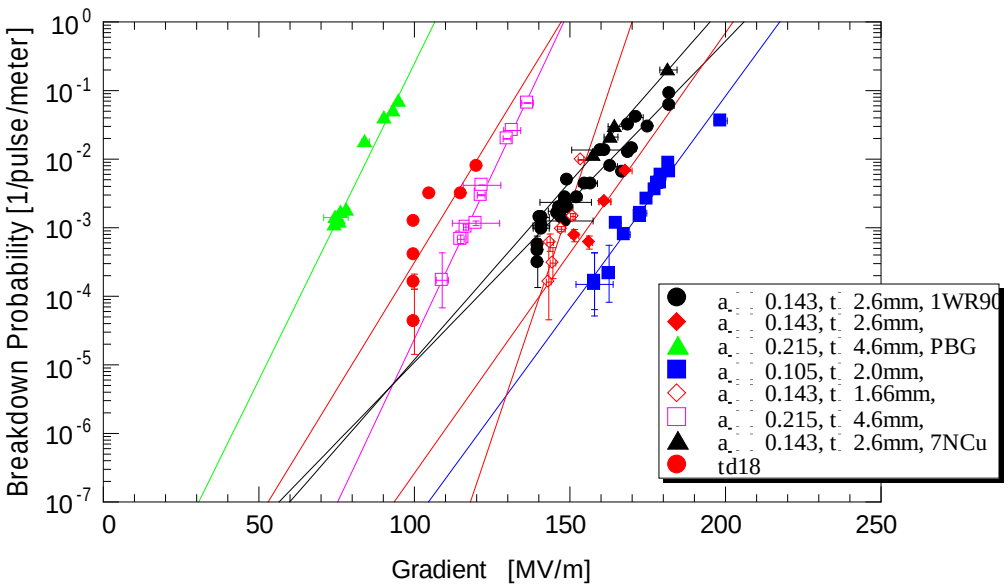
Pulse heating or Alexei's Im(P_surf)?

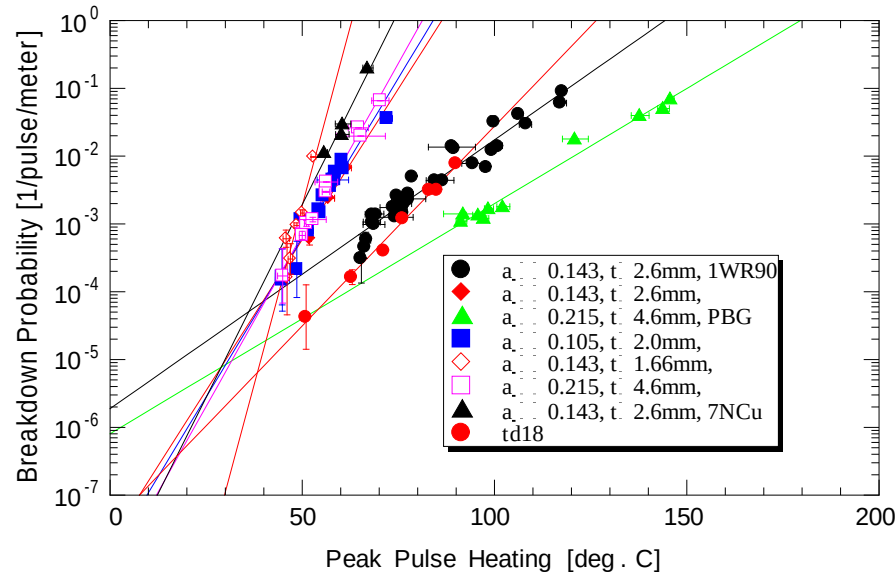
#	1	2	3	4	5
Name	A2.75 -T2.0 -Cu	A3.75 -T2.6 -Cu	A3.75-T1.66 -Cu	A5.65-T4.6 -Cu	A3.75-T2.6-1 Wr90-Cu
Max[ExH]/Max[H^2](kOhm)	0.384631	0.392	0.425	0.346	0.464
Max[H]*E@Max[H]/Max[H^2] (kOhm)	0.186642	0.192	0.181	0.170	0.144





Summary of breakdown rate vs. pulse heating for different structures, including TD18 and PBG





V.A. Dolgashev, 18 October 2010

Summary

We have successful international collaboration on testing program and that continuously producing new information on breakdown physics.

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