Current SLAC Structure Studies and Plans

V.A. Dolgashev, S. G. Tantawi,
SLAC

The X-Band Accelerating Structure Design and Test-Program Workshop
CERN, 18 - 19 June 2007

Outline

- Single Cell TW structure
- Single Cell SW structure
- Discussion

Work on single cell traveling wave and standing wave structures is done in collaboration with Yasuo Higashi and Toshiyasu Higo from KEK

Motivation

- **Predict** breakdown limits for practical structures of *different shapes*, *materials*, *circuits*

To do this, we need to understand the physics of rf breakdown.

Difficulties

- Full scale structures are long, complex, expensive and difficult to simulate

Solution

- *High gradient waveguides* with gradients, power and pulse energy close to that of practical structures
- Single Cell Traveling Wave and Standing Wave Structures

Single Cell Structures

Traveling Wave

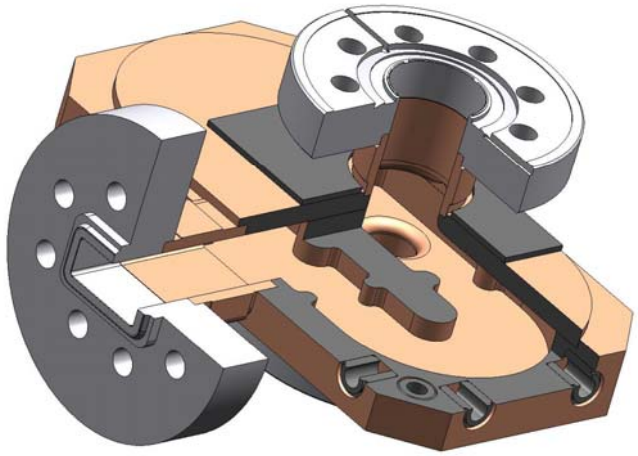
- Fields are the same as in first cell of NLC structure T53VG3
- High electric and magnetic fields are ***only in this cell*** (not in couplers)
- ***Reusable couplers*** – mode launchers that transform the TE_{10} mode of rectangular waveguide into the "accelerating" circular TM_{01} mode

Standing Wave

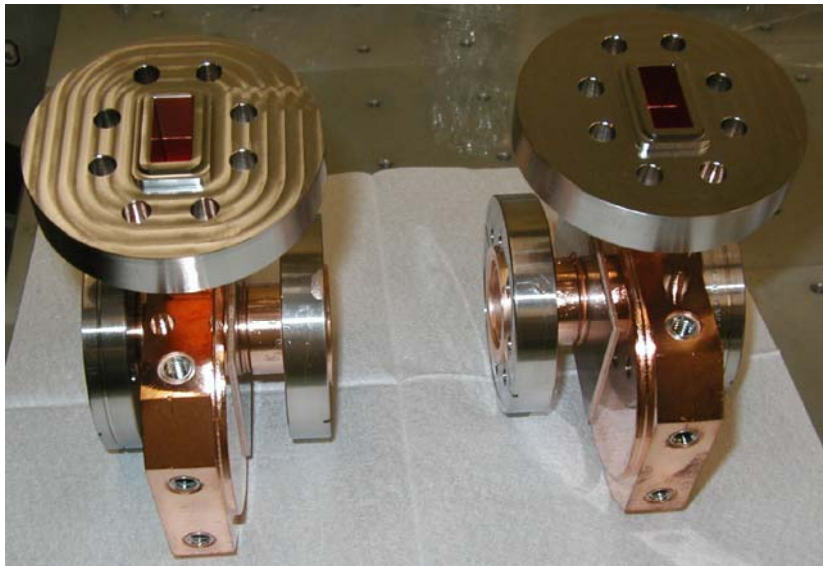
- Fields in the middle cell of the SW structure are similar to fields of a large-aperture SW structure SW20a565
- Fields in the middle cell twice as high as in other two cells

- Breakdowns in one cell => ***easy diagnostic***
- Small geometry => ***easy simulation*** with 3D particle and electromagnetic codes

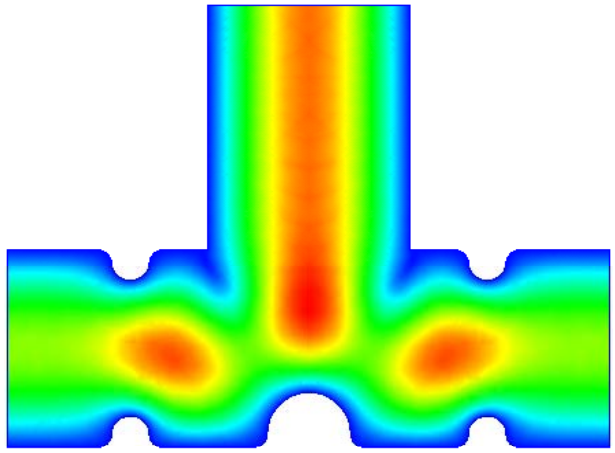
TM_{01} Mode Launcher



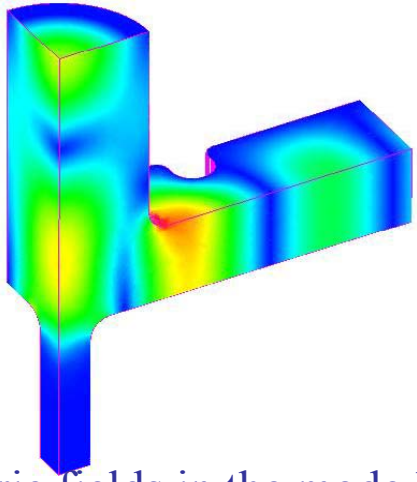
Cutaway view of the mode launcher



Two mode launchers



Surface electric fields in T splitter,
E_{max}= 30 MV/m for 100 MW

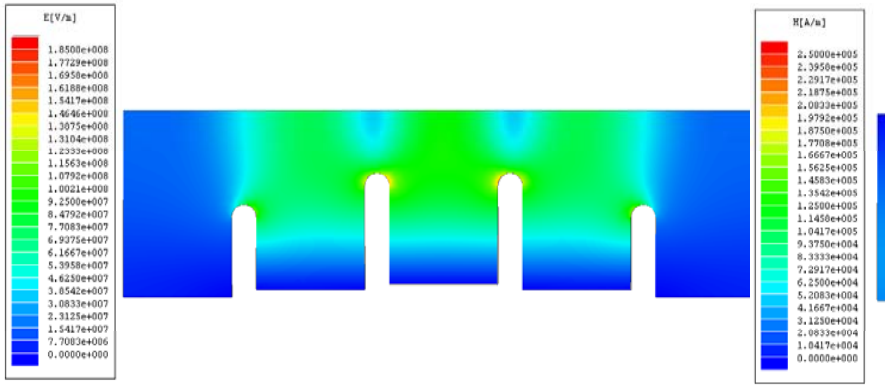


Surface electric fields in the mode launcher
E_{max}= 49 MV/m for 100 MW

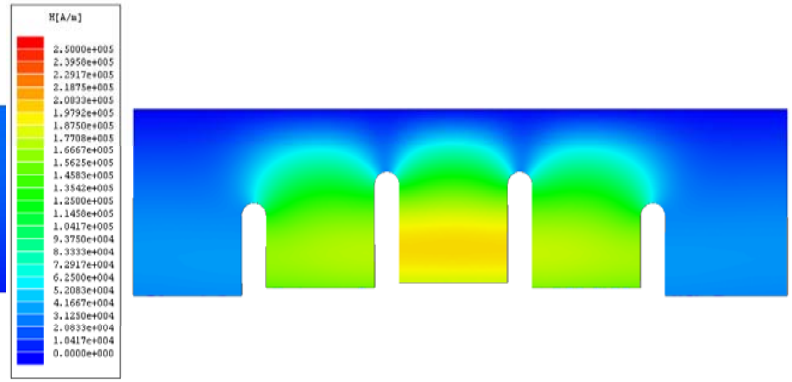
C. Nantista

Single Cell Traveling Wave Structures

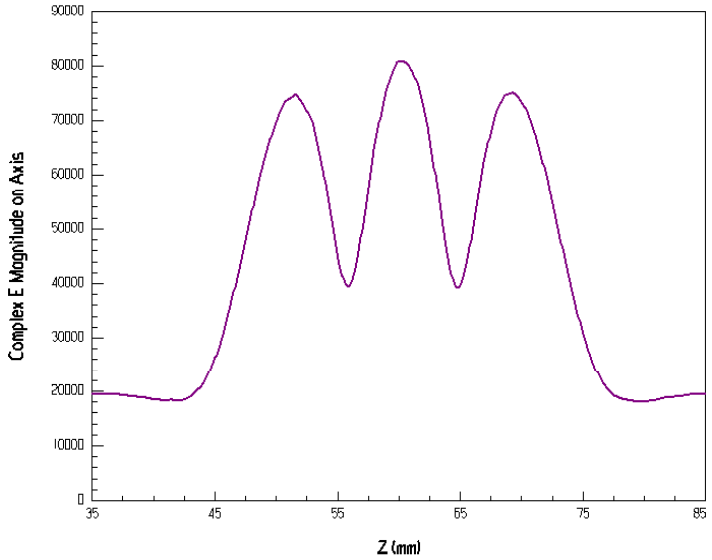
Single Cell Traveling Wave Structure, first cell of **T53VG3**



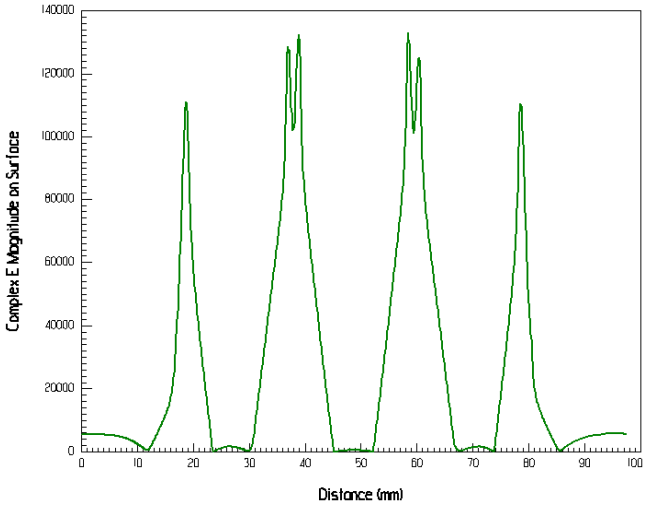
Amplitude of electric fields in single cell TW structure for 40 MW of input power.



Amplitude of magnetic fields in single cell TW structure for 40 MW of input power.



On axis electric field



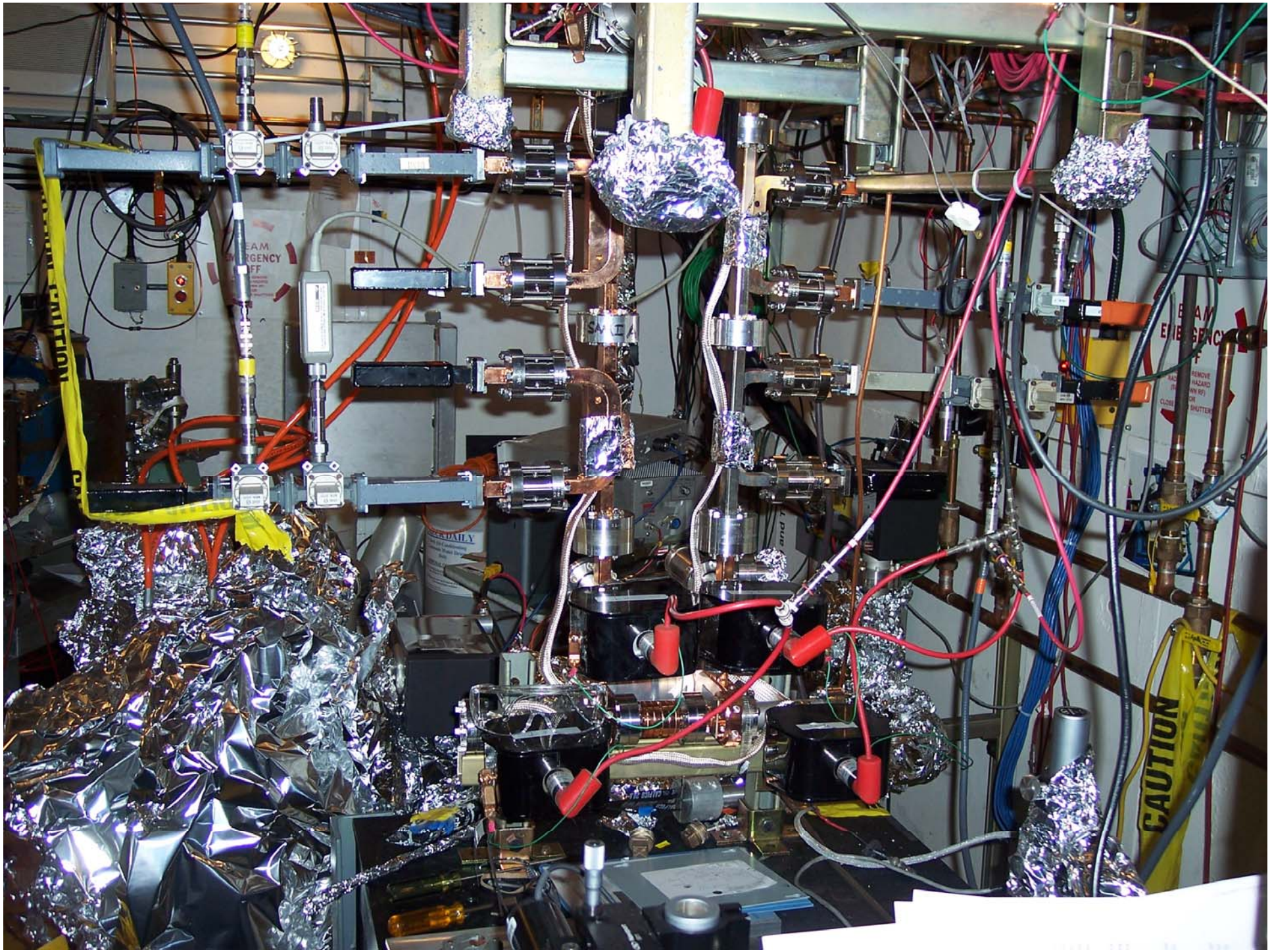
Surface electric field

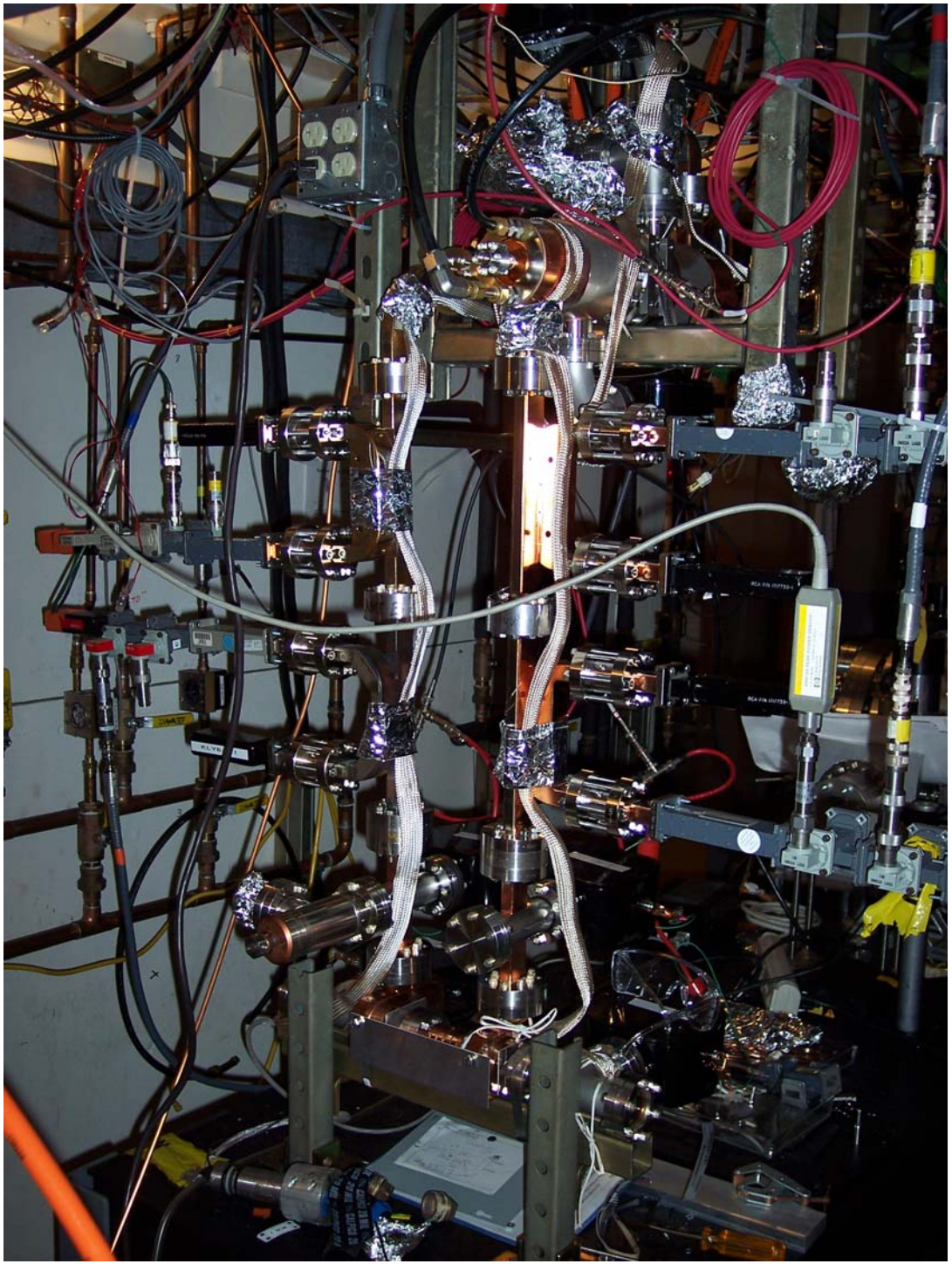
For 50 MW of input power this structure has 70 MV/m acceleration and 150 MV/m maximum surface field.

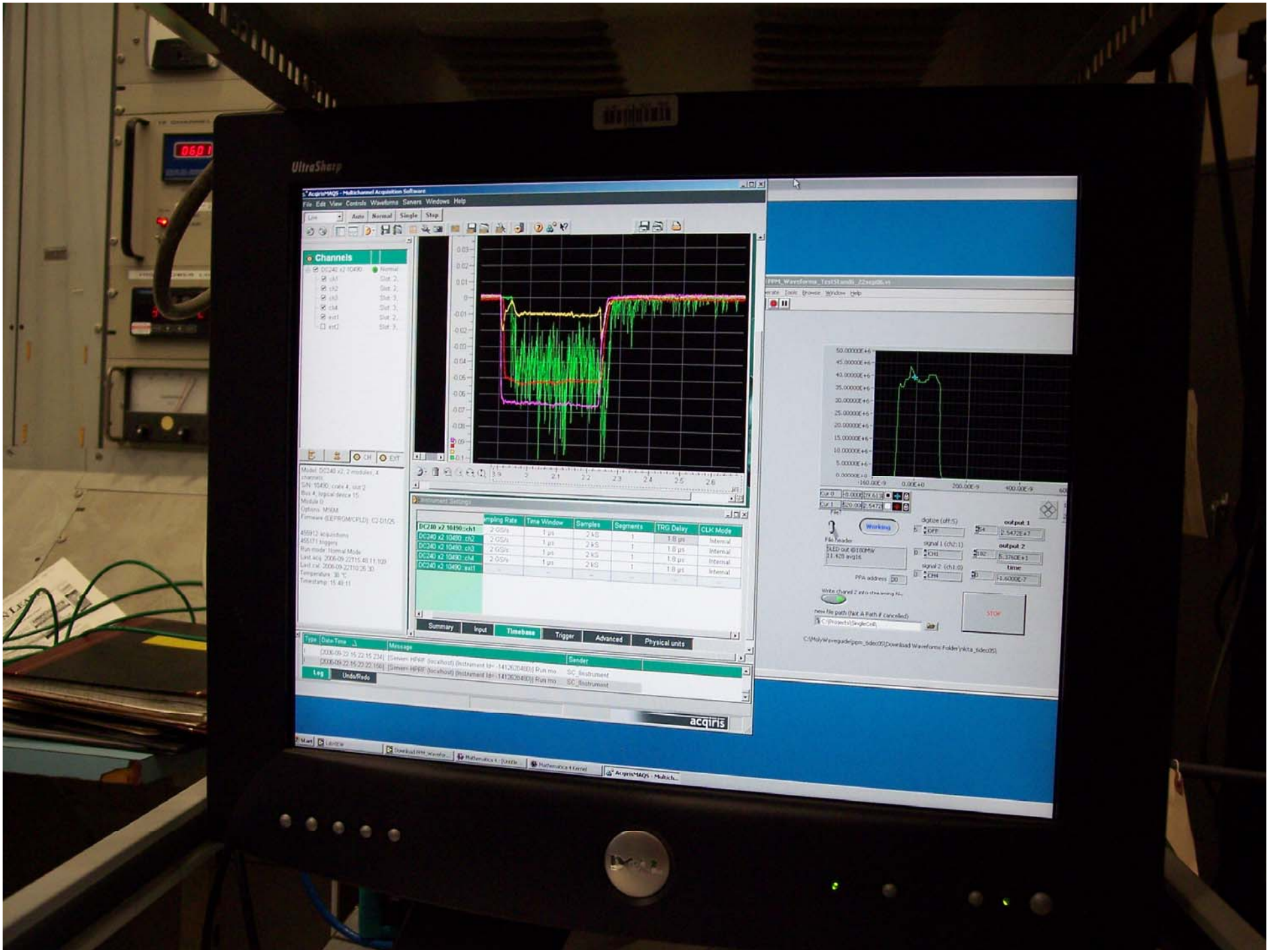
C. Nantista

High Power Test

High power test of single cell structures is done at Klystron Test Lab with great help of Chris Pearson, John Eichner, Lisa Laurent, Arnold Vlieks, Chuck Yoneda, John Glenn, John Van Pelt *and others*.


CAUTION



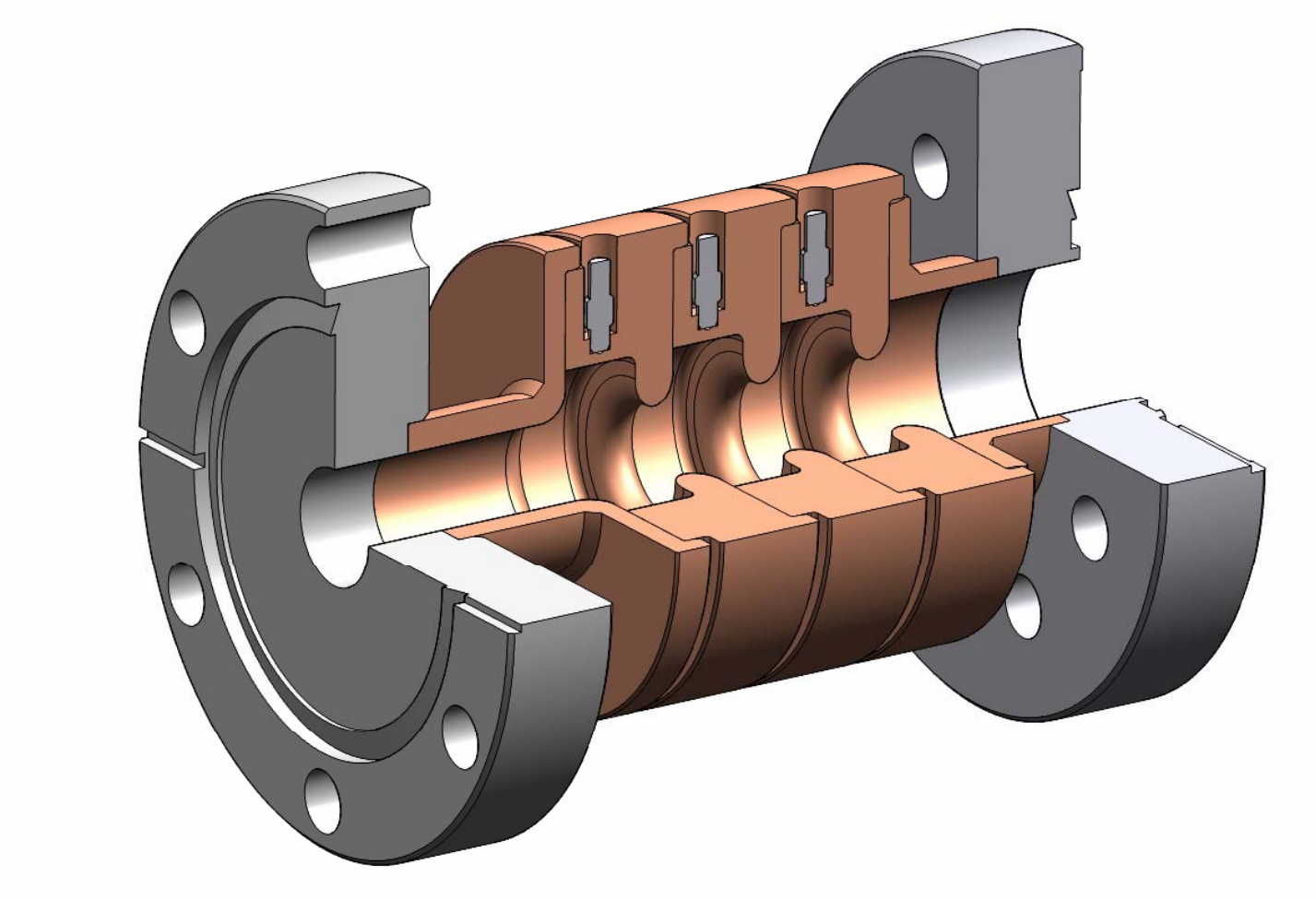

UltraSharp
Channels
Summary
Input
Timebase
Trigger
Advanced
Physical units
acqiris

Results of High Power Test of First Single Cell Traveling Wave Structure

- The structure was process to maximum power of 41 MW. This corresponds to accelerating gradient in the middle cell of 61 MV/m. At about a 1.2 μs pulse width we had breakdowns in feeding waveguides.
- Removable coupler (mode launcher) as well as TM_{01} rf flange (designed by Chris Pearson) seems to be working well .
- The onset of X-ray radiation is at ~100 MV/m peak surface fields.
- Processing of the structure sandwiched by the mode launchers was limited by breakdowns and out-gassing in feeding waveguide system, likely on the roof of the bunker. Because of that, we could not get statistics on breakdowns in the single-cell-structure itself.

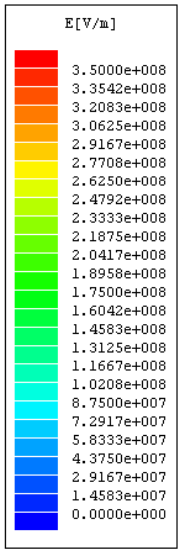
Single Cell Standing Wave Structures

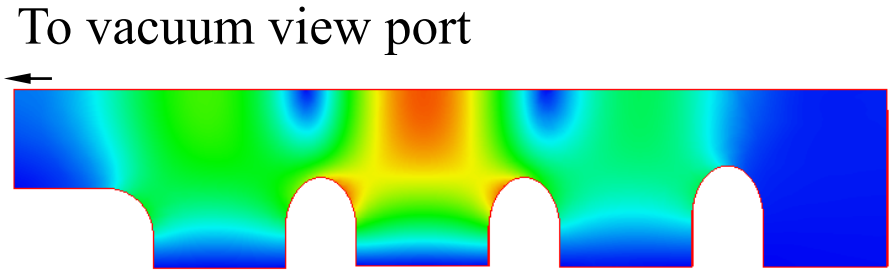
3D model of single cell SW structure



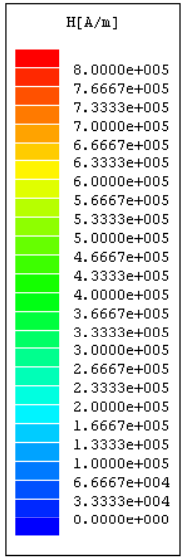
David Martin

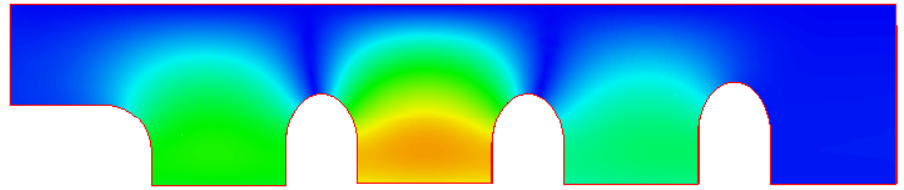
Single Cell Standing Wave Structure HFSS Calculation





Amplitude of electric fields for 10 MW input power, maximum surface field 310 MV/m

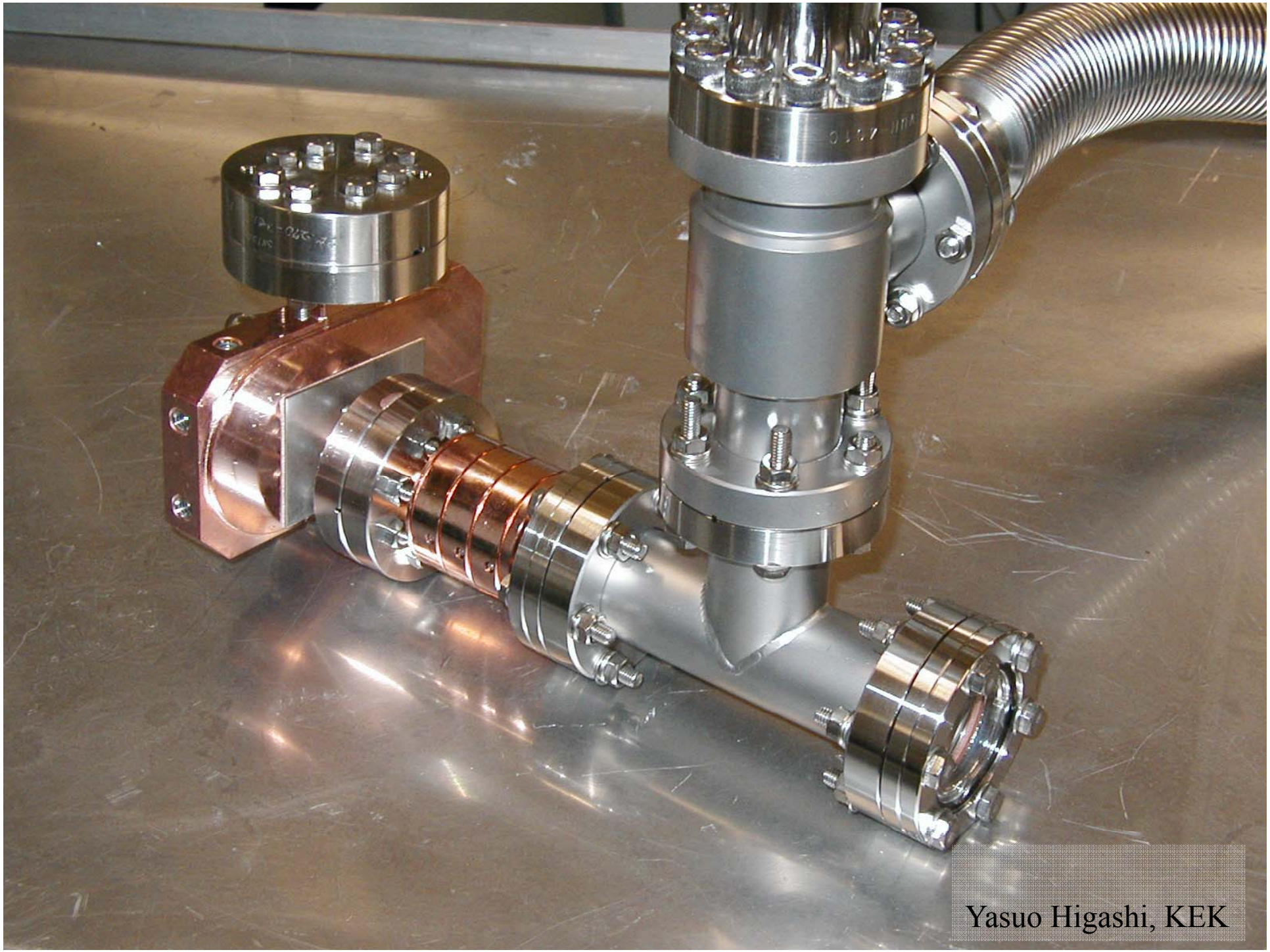




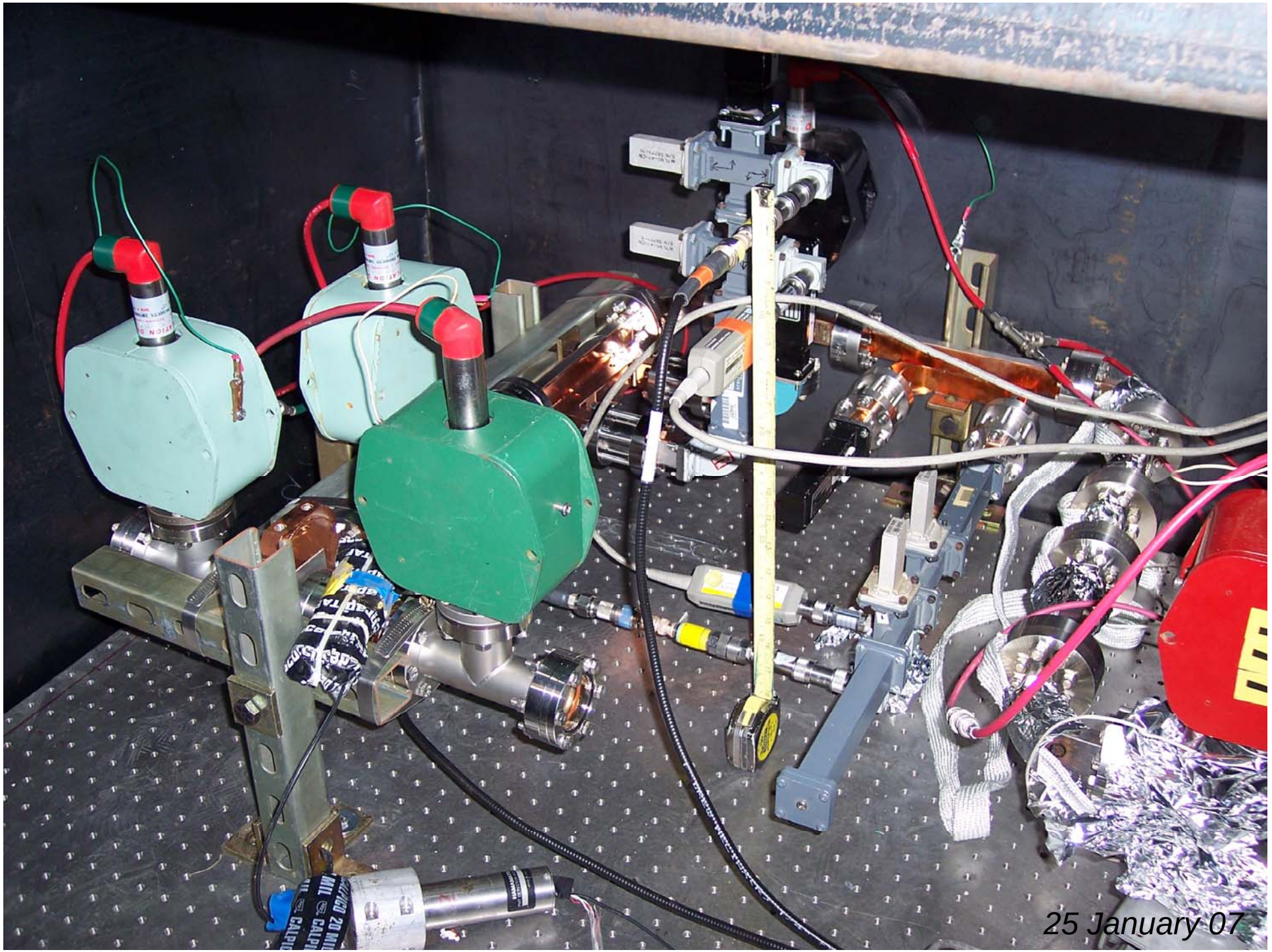
Amplitude of magnetic fields for 10 MW input power , maximum magnetic field 634.5 kA/m

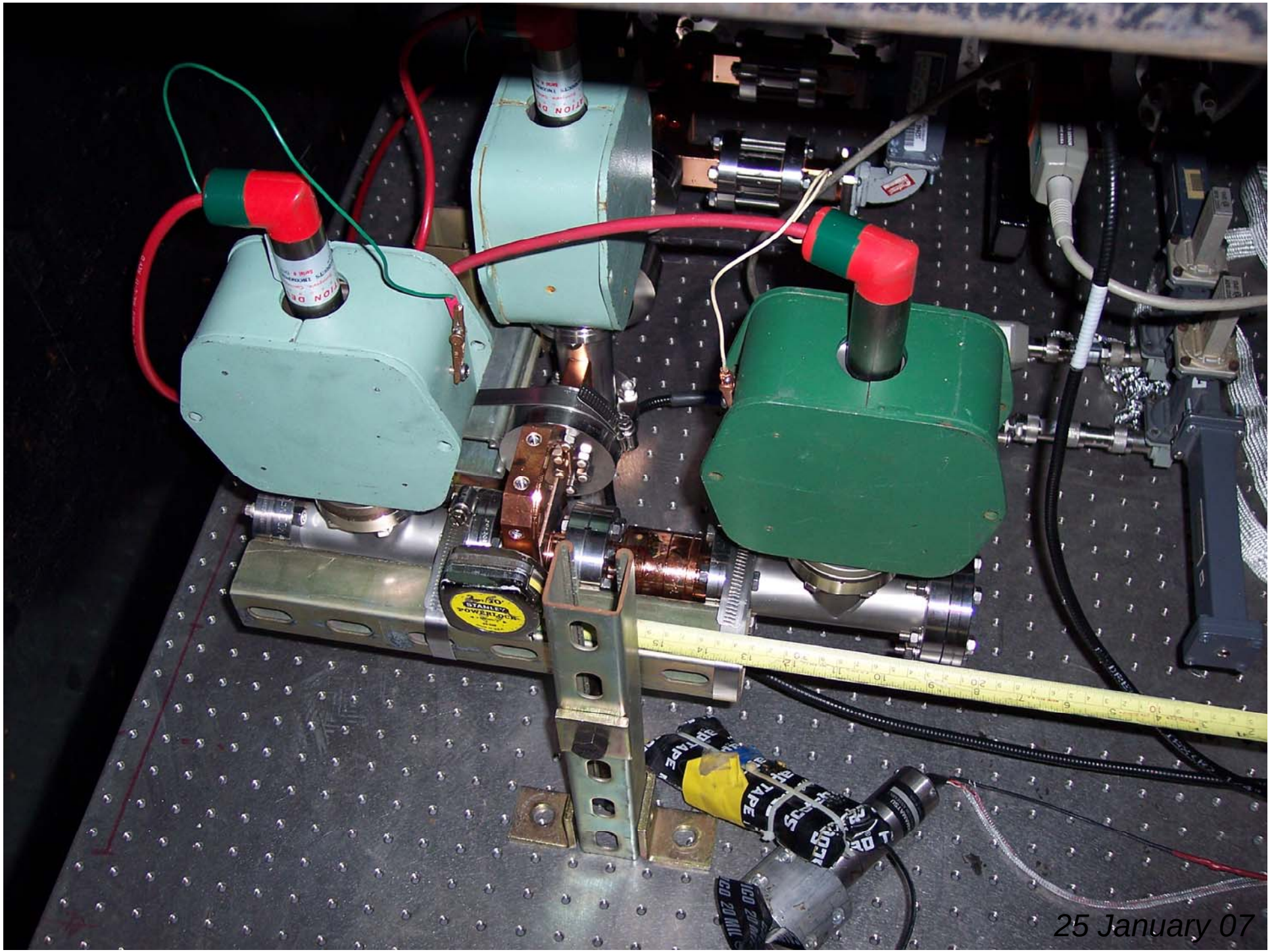
Single Cell Traveling Wave and Standing Wave Structures

Yasuo Higashi, KEK


Yasuo Higashi, KEK

25 January 07


25 January 07


25 January 07

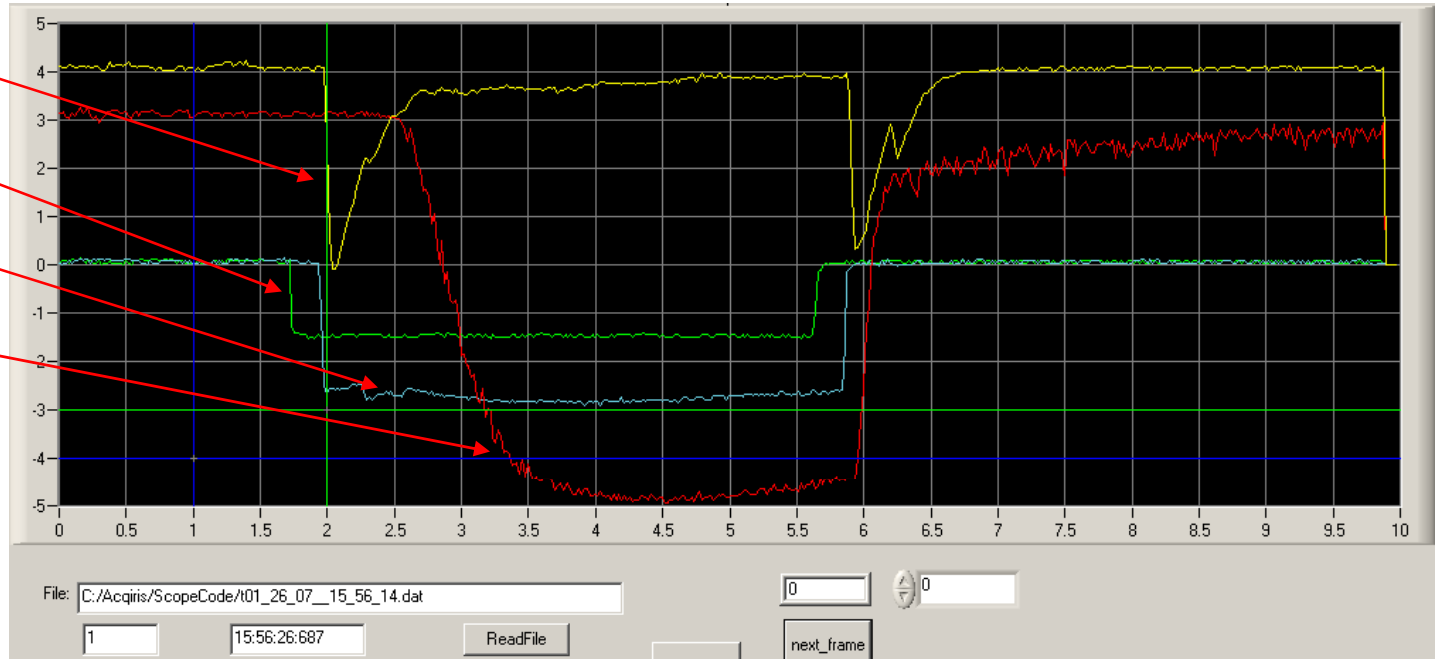
Breakdowns in Single Cell SW structure

Reflected

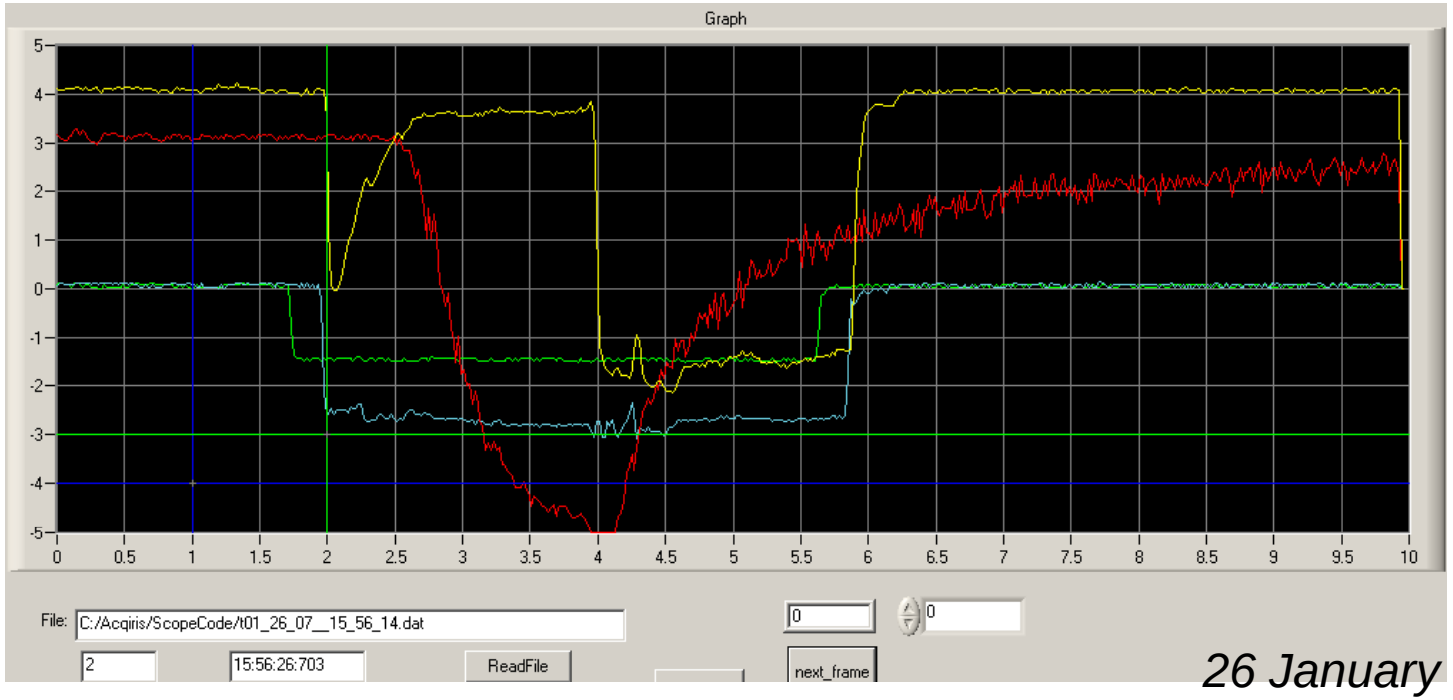
TWT

Forward

PMT



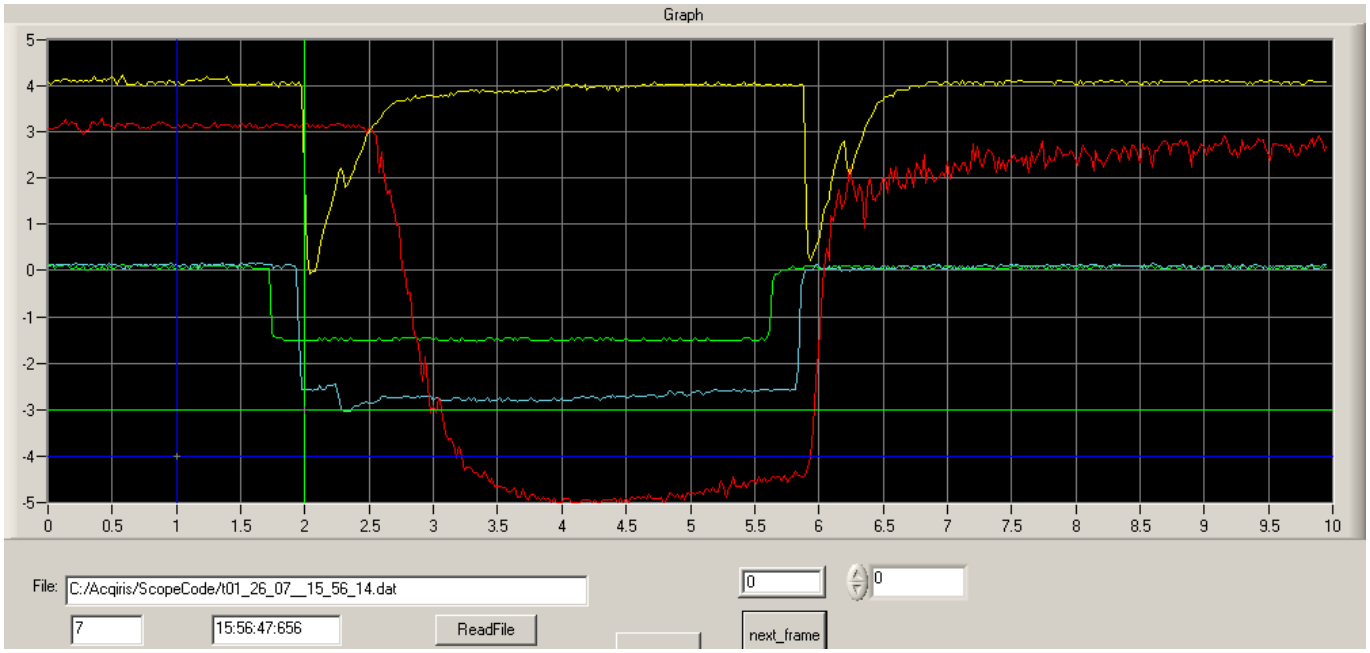
Pulse Before Breakdown



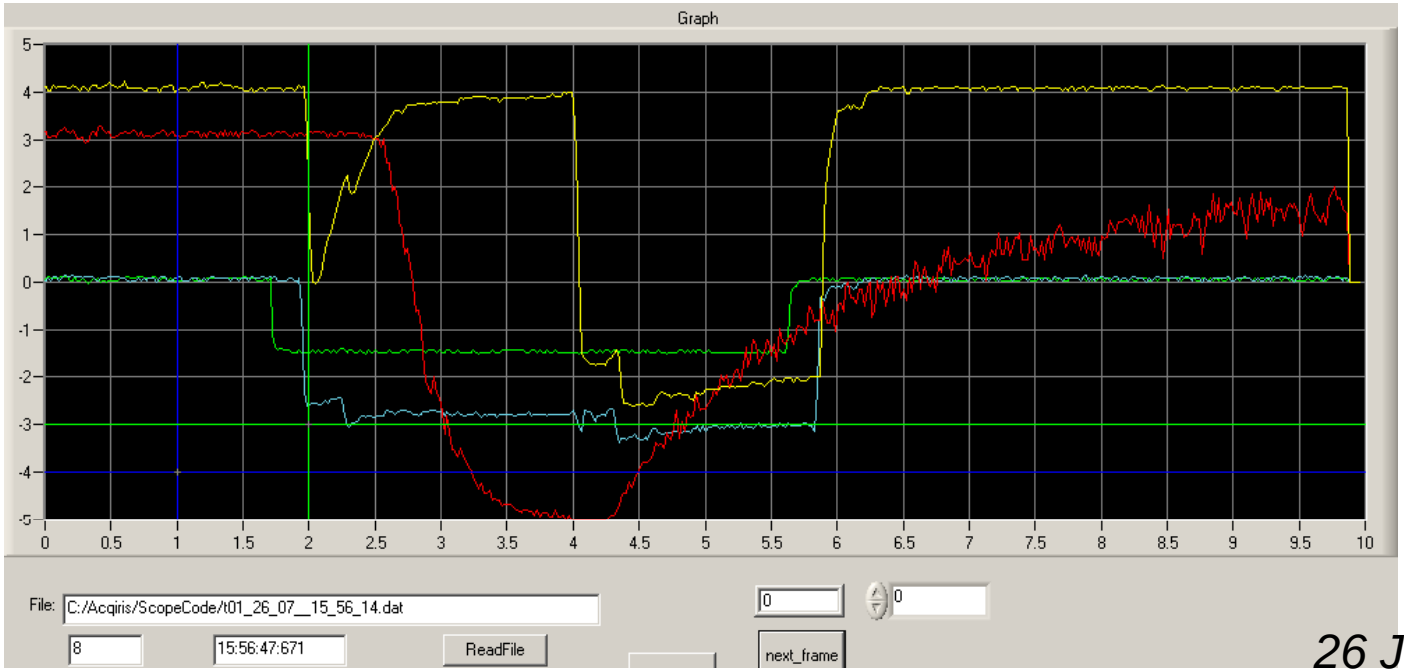
Breakdown

Breakdowns in Single Cell SW structure

Pulse Before Breakdown

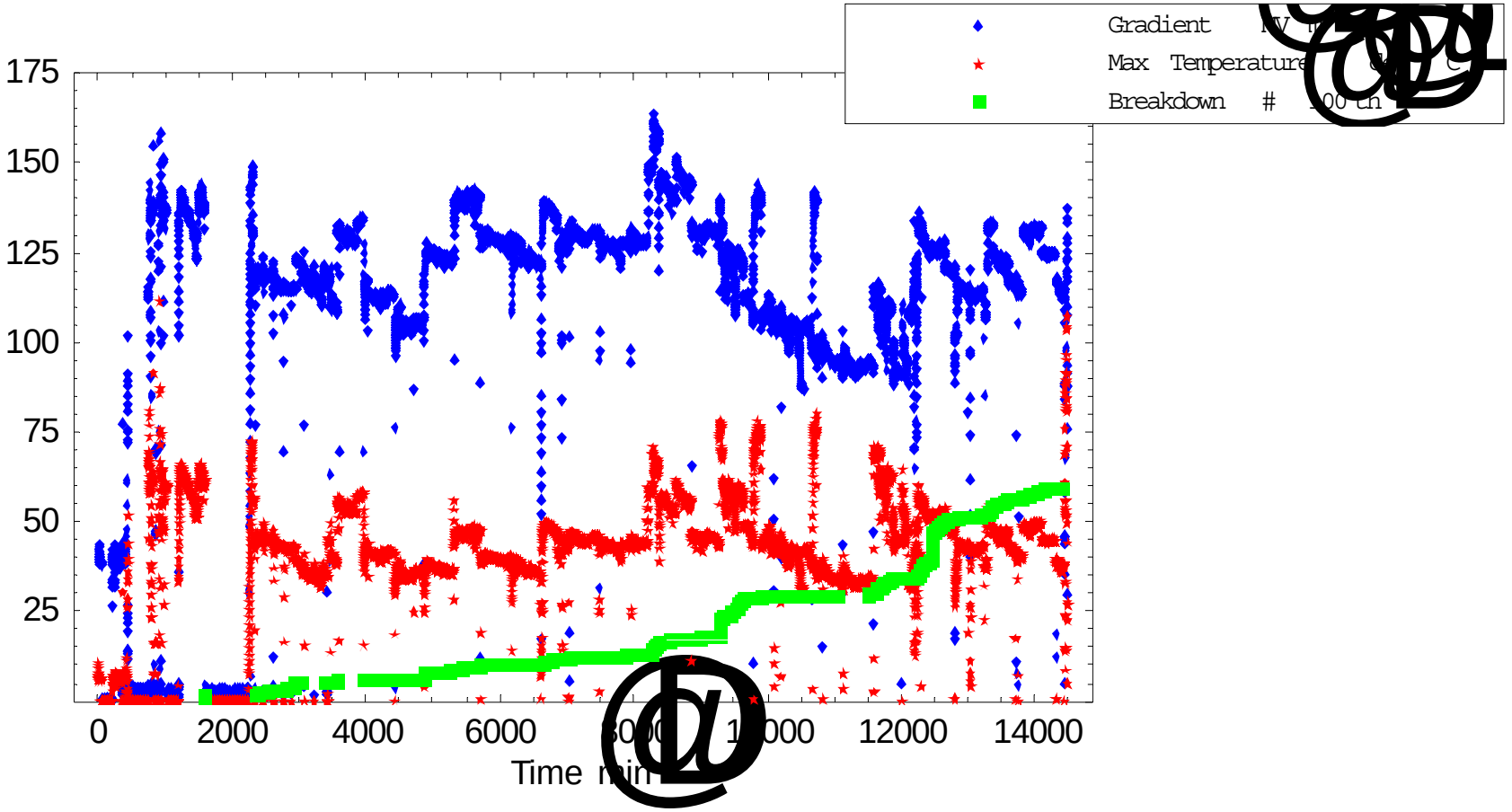


Breakdown

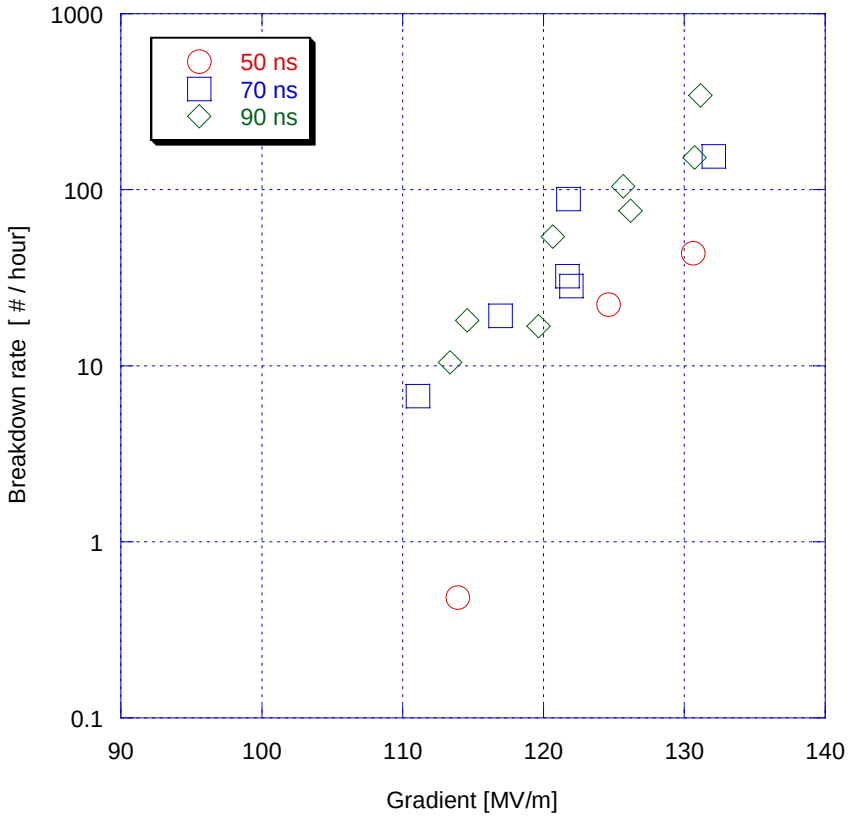


26 January 07

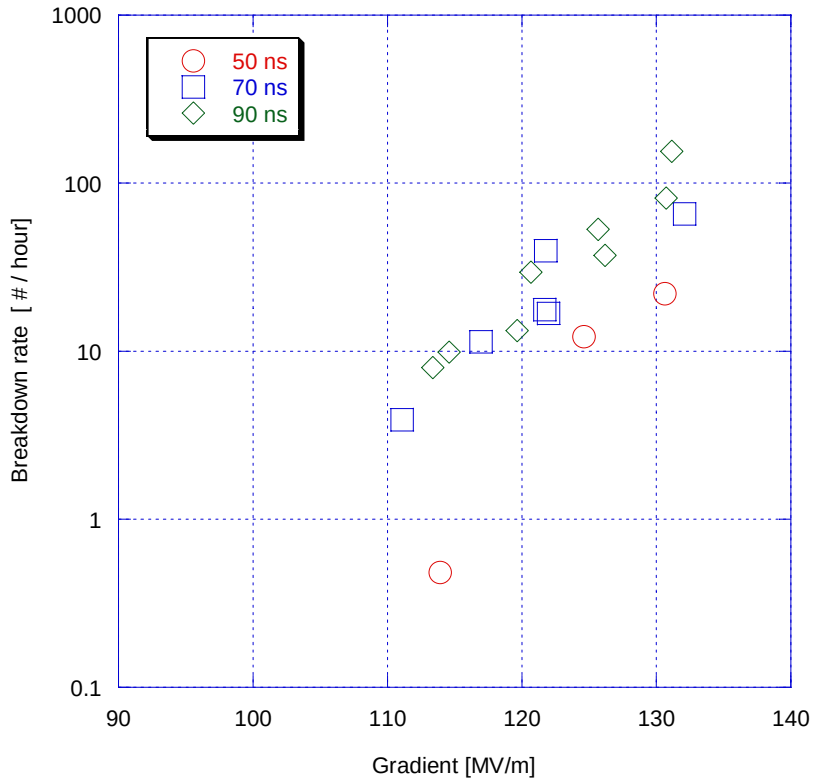
Processing history of first single cell standing wave structure



Breakdown rate *vs* accelerating gradient for flat pulse

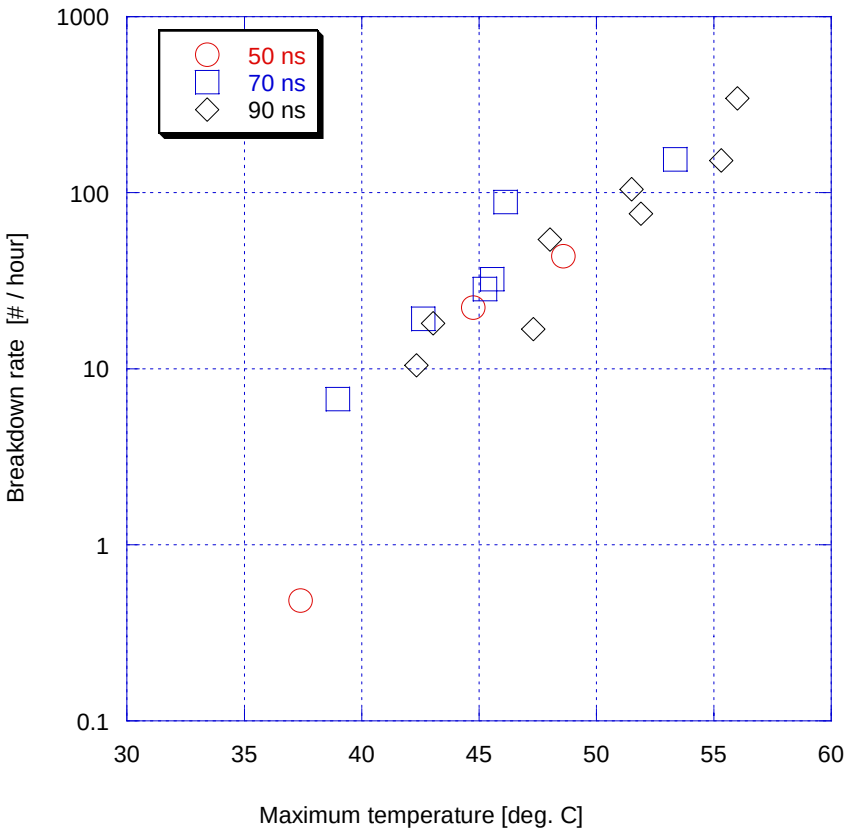


All breakdowns

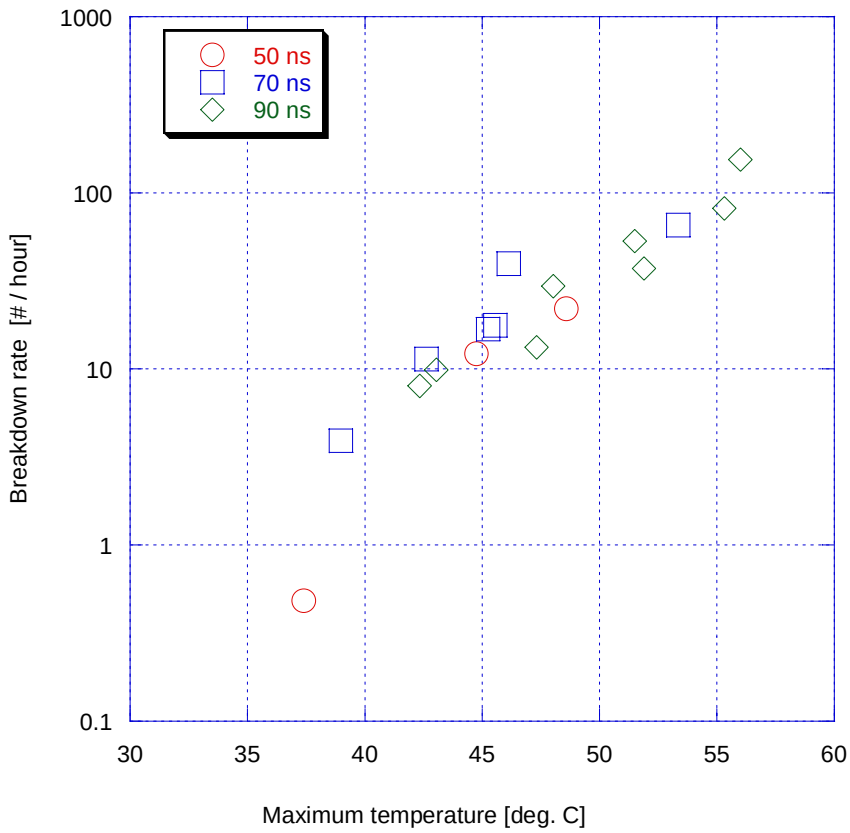


First breakdowns

Breakdown rate *vs* pulse heating temperature, flat pulse

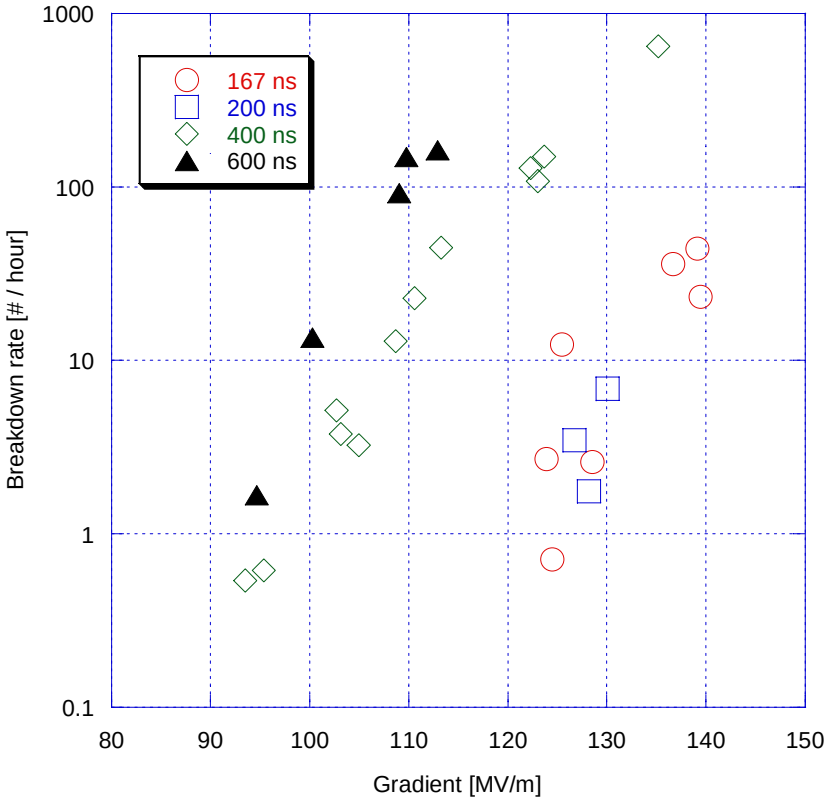


All breakdowns

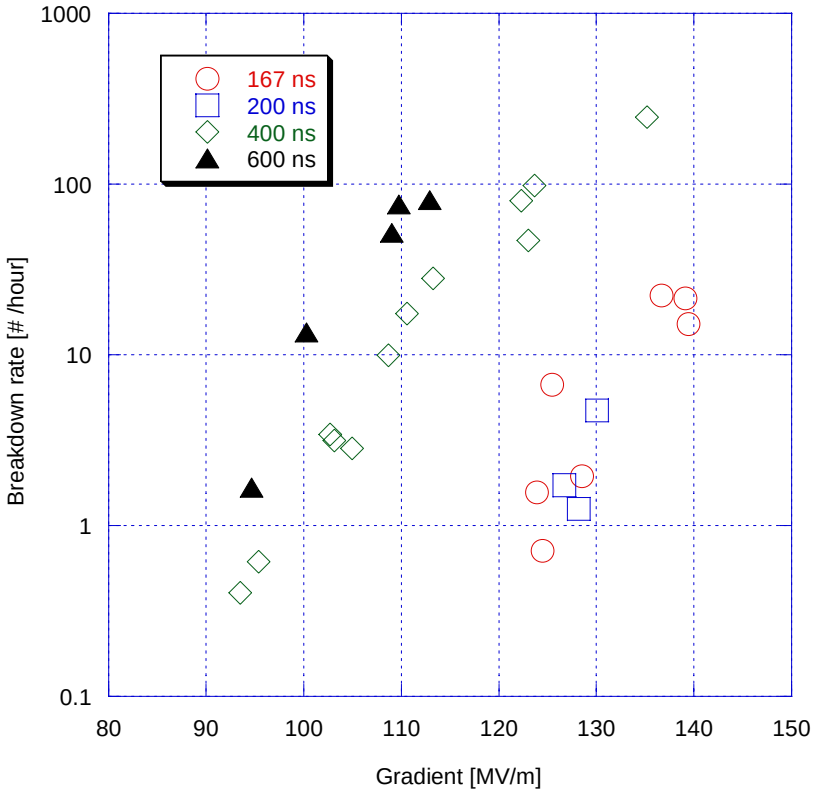


First breakdowns

Breakdown rate *vs* accelerating gradient for "standard" pulse

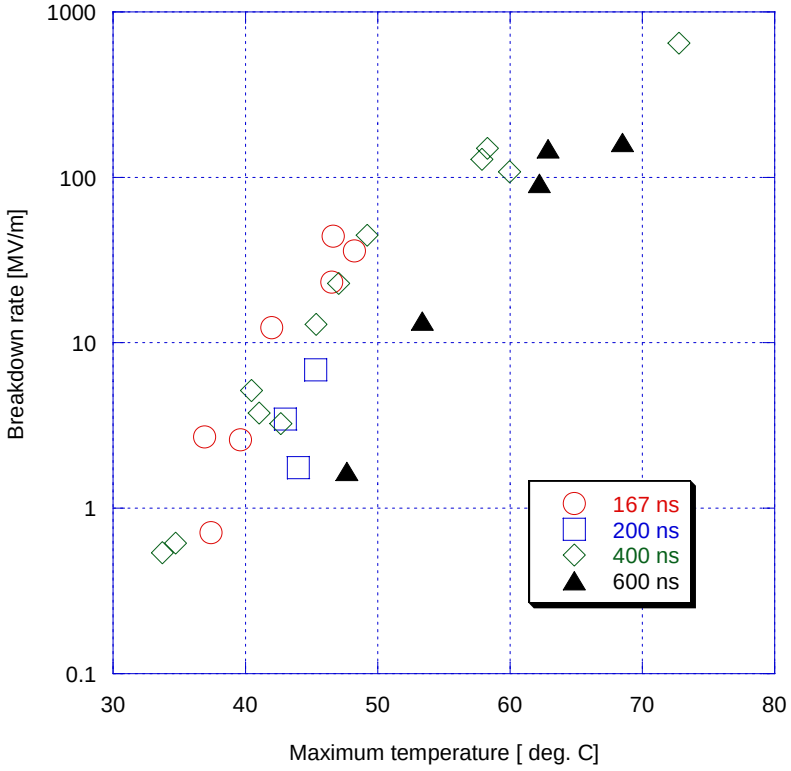


All breakdowns

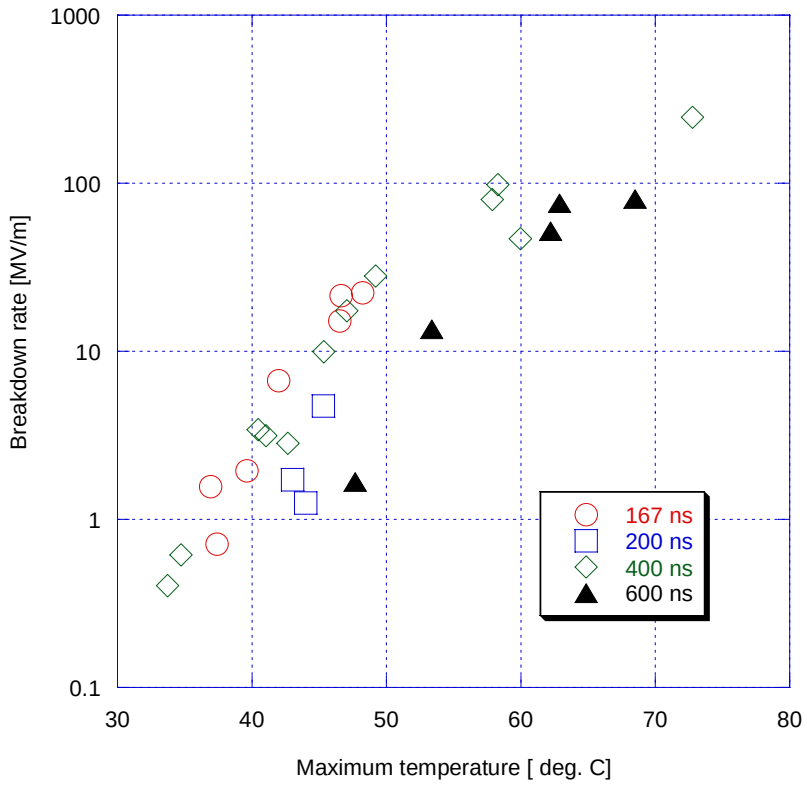


First breakdowns

Breakdown rate *vs* pulse heating temperature, for “standard” pulse

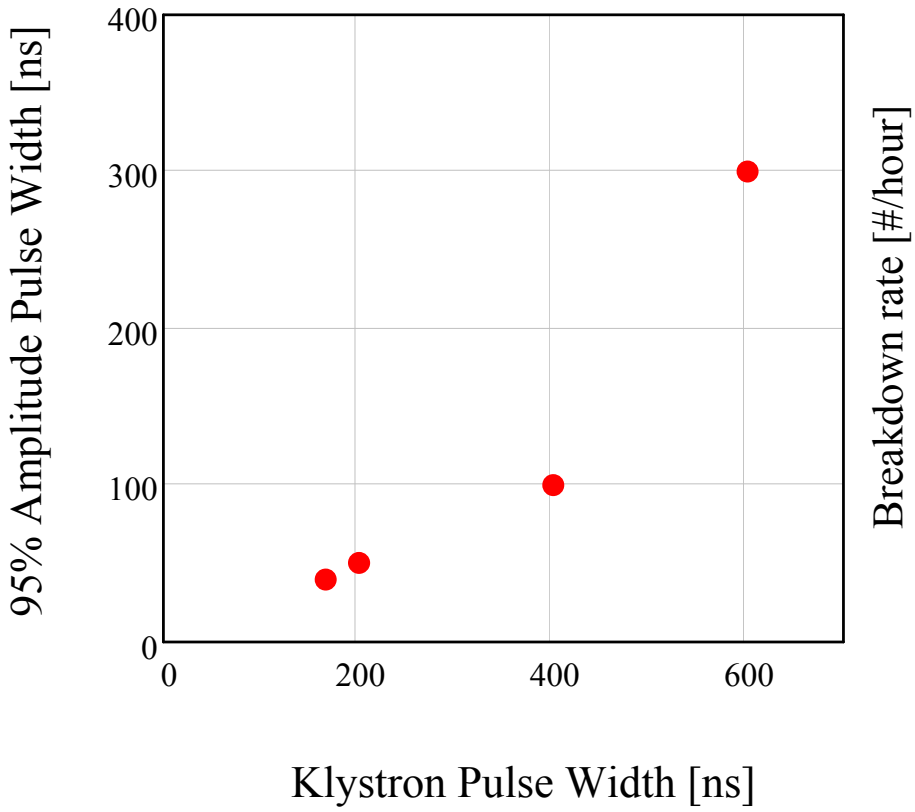


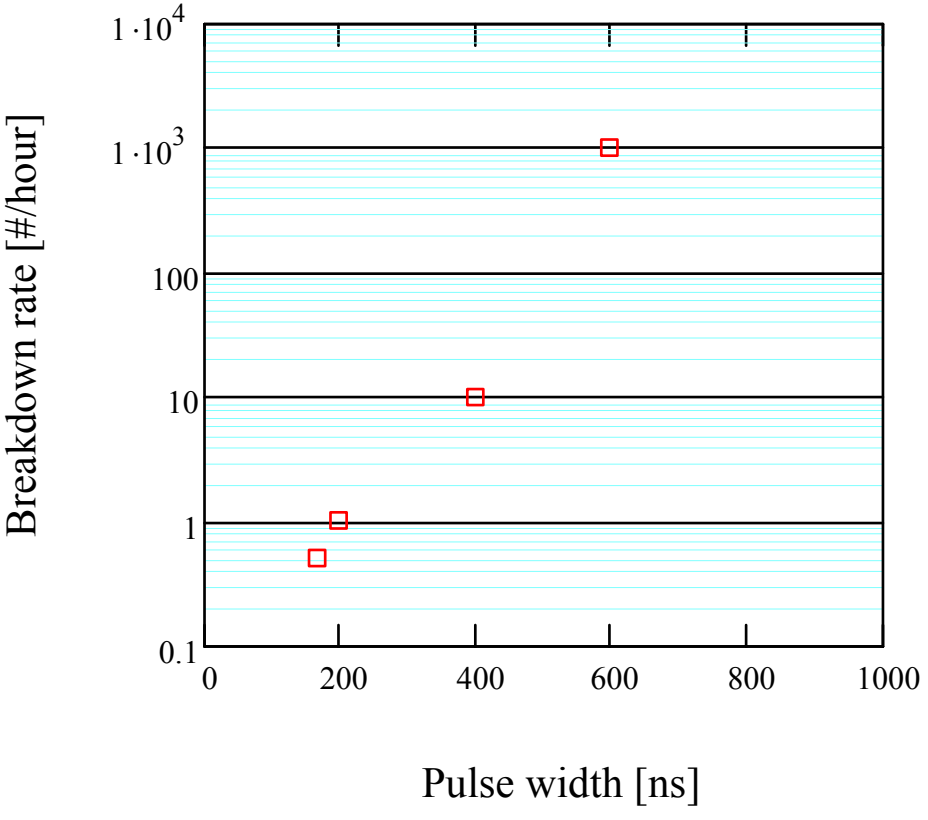
All breakdowns



First breakdowns

Pulse length and breakdown rate, “standard” pulse





Accelerating gradient 120 MV/m,
all breakdowns

Discussion

Disclaimer: this is first data for single cell standing waves structure

Expected:

•Hit pulse heating limit in the structure

•See structure beam loading with dark current-> beam loading limit

•Set pulse length, run at low gradient, condition to high gradient->works at low gradient with low breakdown rate

Got:

•Structure has breakdown rate of about 1 breakdown per minute at 55-60 deg. C of calculated maximum pulse heating, with weak dependence on pulse length

•Structure had no noticeable saturation of dark current.

•After first few hours of conditioning breakdown properties of the structure were changing very slow -> small “conditioning” histeresis

•Structure operaing off resonanse have roughly same breakdown rate for same field-> trigger is determined by fields inside the structure, few MW of power avalible outside the structure has small effect on the breakdown rate.

More results:

•Conditioning was very fast: in few hours can run at any gradient, limited by high breakdown rate.

•Breakdown damage is in “patches” on high-field iris

What's next?

Structure properties:

•Low shunt impedance-> high maximum magnetic field/ accelerating field ratio, high stored energy

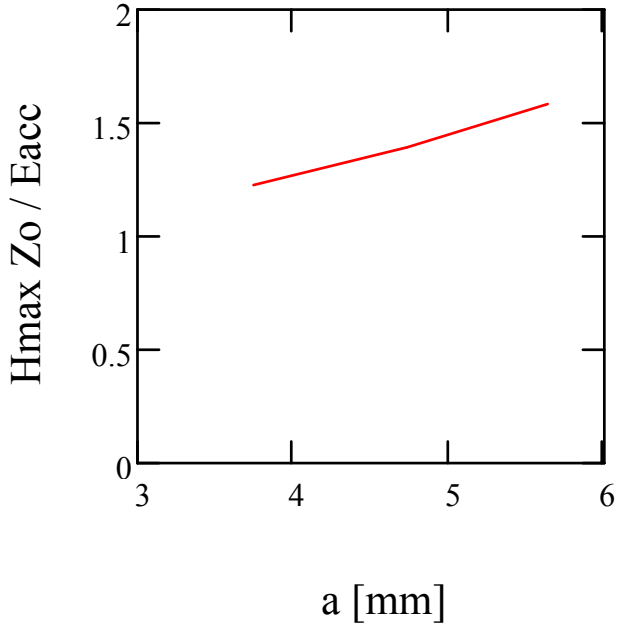
•Large $a/\lambda = 0.215$

•Thick iris with elliptical shape

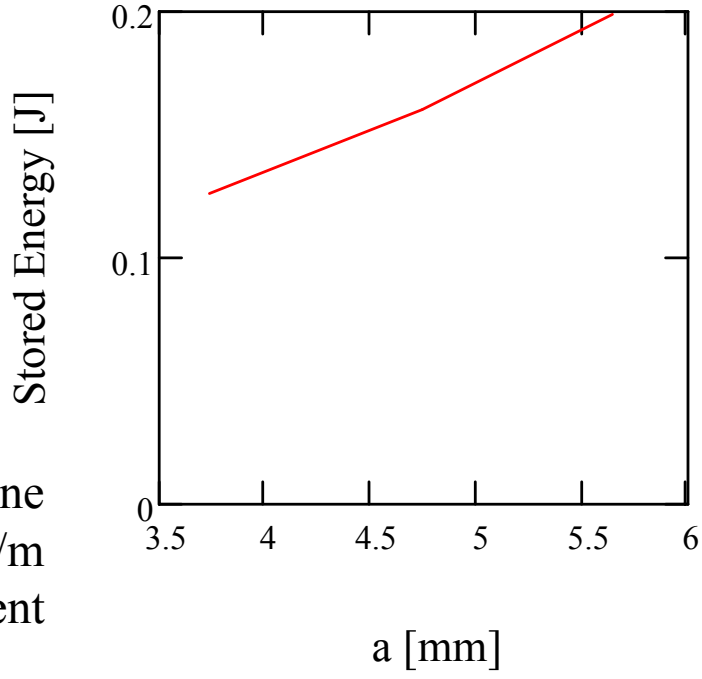
•Very aggressive surface processing

How we test these parameters

1. *Stored energy*: 3-cell structure of the same shape
2. *Magnetic field and stored energy:* High shunt impedance structure, reduce a/λ
3. *Distribution of electric and magnetic filed on the iris*: Thin iris with the same a/λ



Energy stored in one cell for 100MV/m gradient



Structure with wakefield damping

Options:

- Damping waveguides
- Bi-periodic structure with loading in narrow cells
- Chokes
  - Choke does not increase cell magnetic fields (first structure never reached this limit?)
  - Choke increases stored energy in the cell -> May increase damage?
  - Small gap -> Multipactor? Increased damage?

Possible Evolution toward practical damped structure:

- Single-cell-choke structure
- 3-cell-choke structure with symmetric waveguide feed
- two 3-cell-choke structures with power divider (hybrid)
- 47 cm structure (12×3-cell-structures) with compact power distribution system

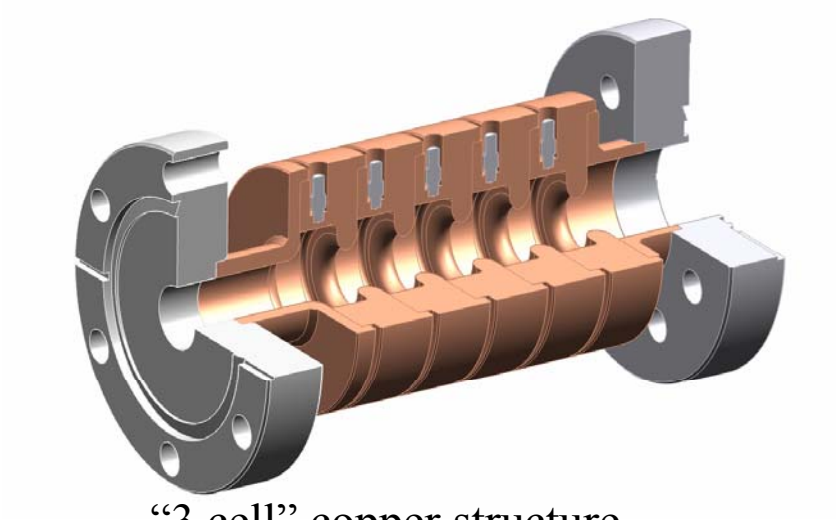
Materials

- Stainless Steel – TW
- Molybdenum – TW, SW
- Copper with Moly inserts- TW
- Pure cupper – SW
- Copper Zirconium – SW, TW

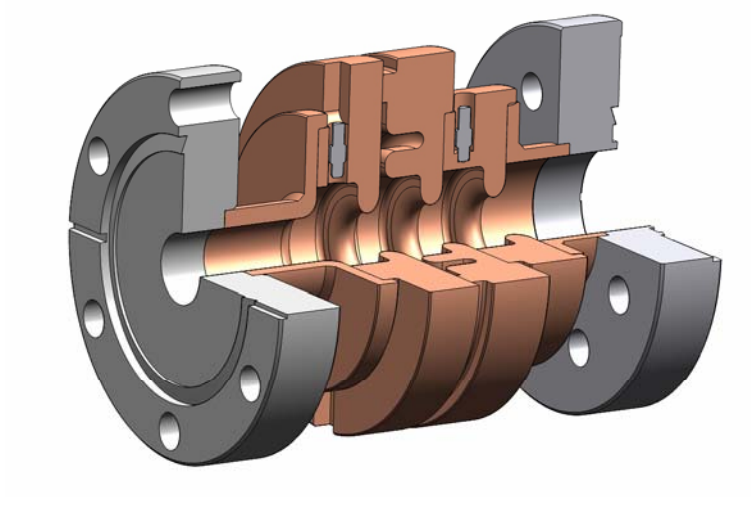
Surface processing

- High pressure water rinsing
- Hardening
- Plating
- …

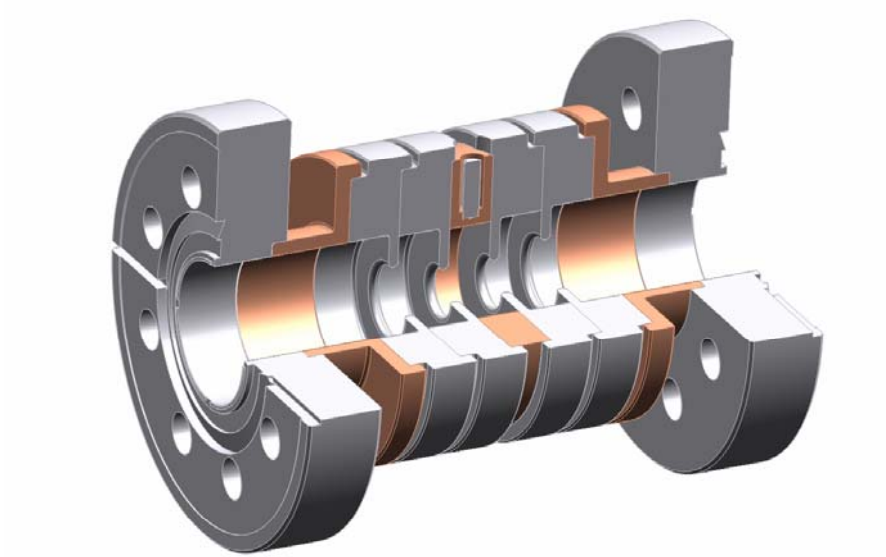
Future structures



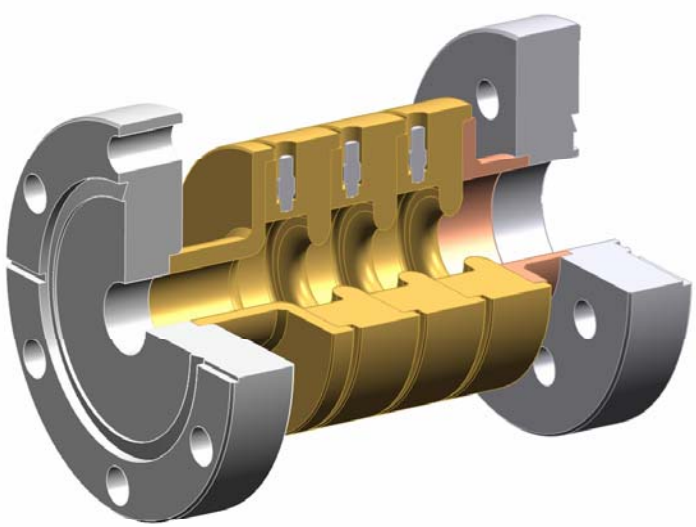
"3 cell" copper structure



Single cell structure with choke



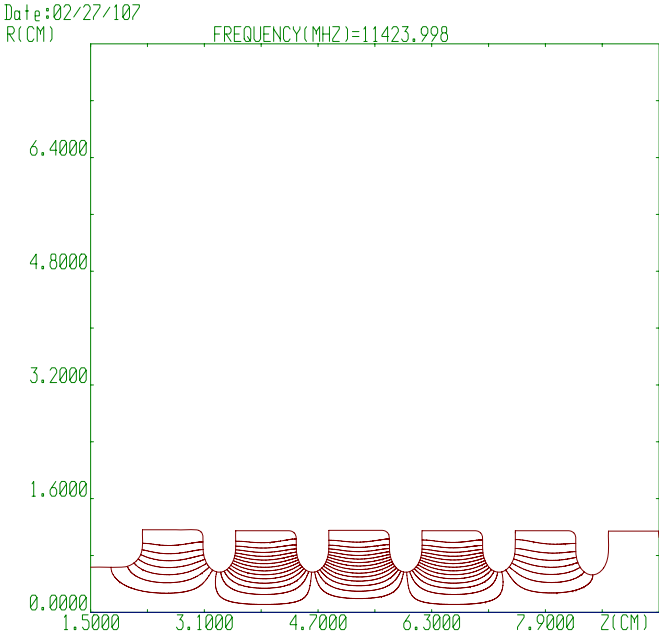
Stainless Steel "single cell" traveling wave structure



Copper Zirconium single cell structure

3 Cell Standing Wave Structure

Tuned for **equal fields on the axis**, normalized for 10 MW losses, maximum electric field 230 MW/m; maximum magnetic field 4.57A/m



MODE	K**2	K(1/cm)	F(MHz)	EPS
3	5.23725E+00	2.28850E+00	1.09192E+04	2.46944E-05
4	5.33816E+00	2.31045E+00	1.10239E+04	1.32425E-05
5	5.45269E+00	2.33510E+00	1.11416E+04	2.80533E-05
6	5.62500E+00	2.37171E+00	1.13162E+04	9.89956E-06
7	5.73264E+00	2.39429E+00	**1.14240E+04**	5.10727E-06
10	1.60569E+01	4.00711E+00	1.91193E+04	1.14853E-02

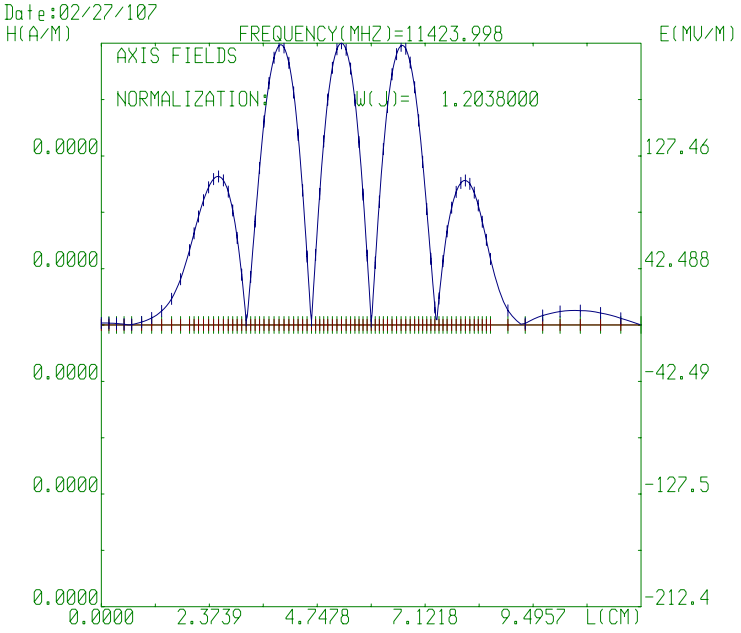
SLANS NUMBER OF MODE 7; ACCURACY 5.107E-06
CAVITY RADIUS 1.1621 CM, LENGTH 11.8696 CM
FREQUENCY ..... 1.1424E+04 MHZ
LENGTH OF WAVE ..... 2.62423 CM
WAVE VALUE 2.3942926 1/CM
QUALITY FACTOR ..... 8.6412E+03
STORED ENERGY ..... 1.2038E+00 J
TRANSIT TIME FACTOR .... -.6233E+02
EFFECTIVE IMPEDANCE .... 1.812E+02 OHM
SHUNT IMPEDANCE ..... 1.56602 MOHM
MAXIMUM MAG. FIELD ..... 4.571E+05 A/M
NEAR POINT R= .990 CM , Z= 4.853 CM
MAXIMUM ELEC.FIELD ..... 2.300E+02 MV/M
NEAR POINT R= .628 CM , Z= 4.757 CM
ACCELERATION ..... 5.596E+00 MEV
ACCELERATION RATE ..... 4.715E+01 MEV/M
AVERAGE E.FIELD ON AXIS 7.564E-01 MV/M
KM (Emax/Accel.rate).... 4.87775
KH (Hmax*Z0/Accel.rate). 3.65253

S_matrix result:

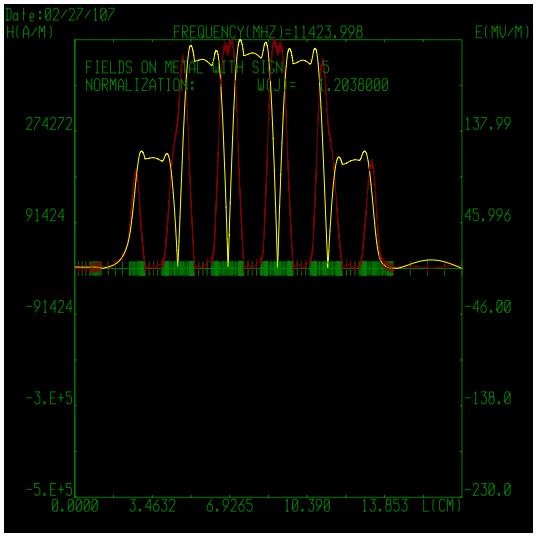
$$\text{Result} = \begin{pmatrix} 0.1378387906 \\ 1.1423912 \times 10^{4} \\ 8.038827790 \times 10^{3} \end{pmatrix} \begin{matrix} \text{[MHz]} \\ Q \end{matrix}$$

Q_s_matrix/Q_copper

$$\left(\frac{8038.8}{8641.2}\right)^{-1} = 1.075$$

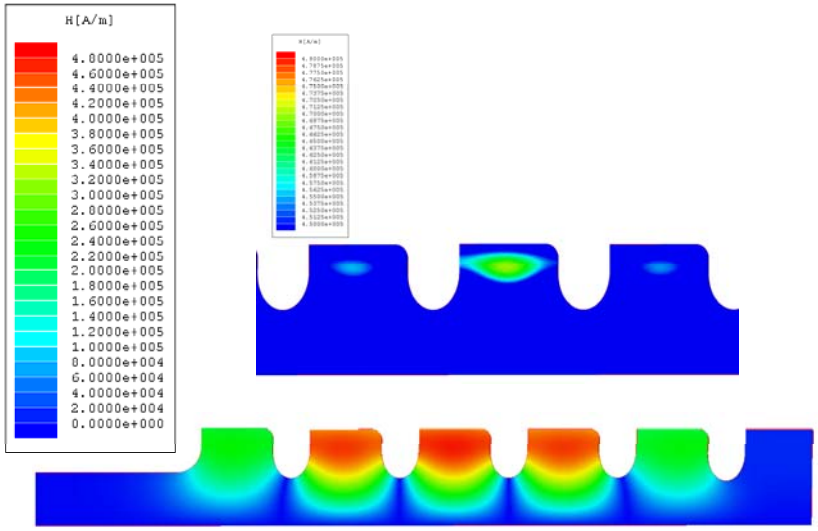


SLANS geometry file:sw3cl_cu.ge0

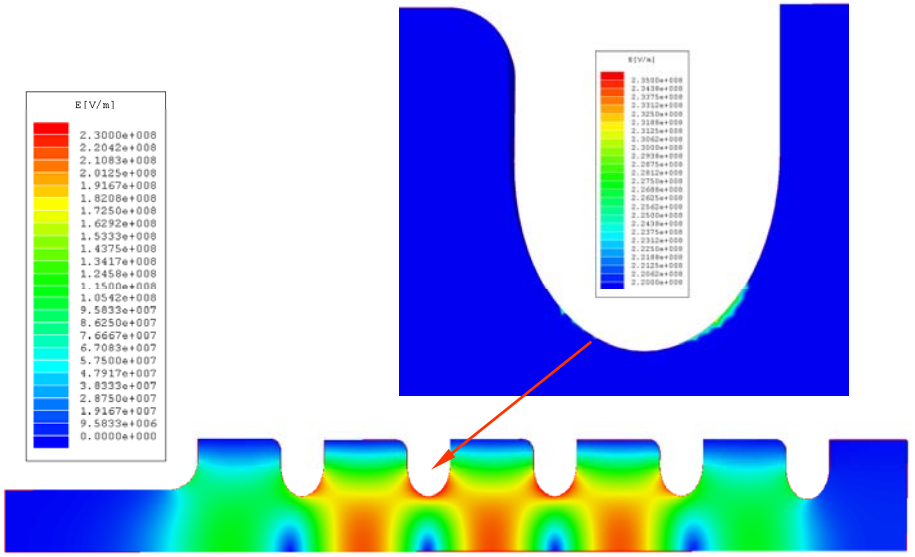


V.A. Dolgashev 27 February 2007, 17:07

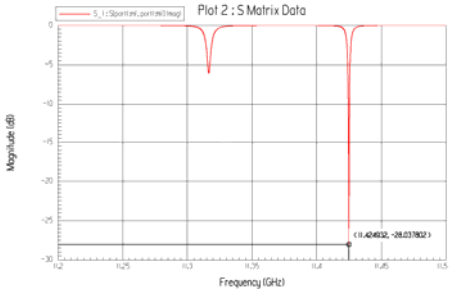
Verification of SLANS results with HFSS, 10 MW input

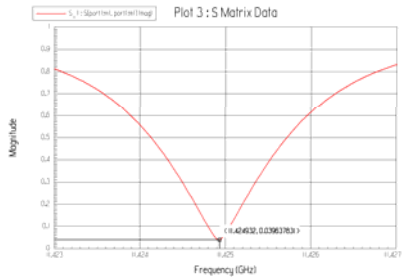


Maximum magnetic field 458 kA/m
(SLANS 457 kA/m)



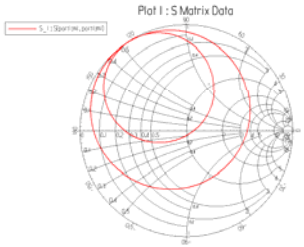
Maximum magnetic field 230 MV/m
(SLANS 230 MV/m)





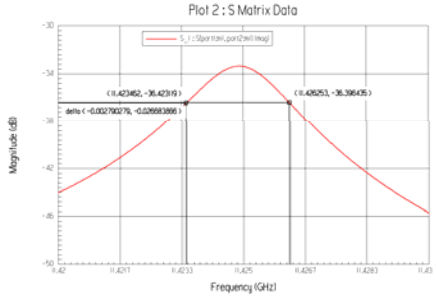
Resonance at 11.4249 GHz
(SLANS 11.424 GHz)

β = 1.083
(SLANS 1.075)



Over-coupled loaded Q

Unloaded Q
(SLANS 8.64e3)



$$\frac{11.4249}{0.00279027} = 4.095 \times 10^3$$

$$4.095(1 + 1.083) \cdot 10^3 = 8.53 \times 10^3$$

V.A. Dolgashev, 2 March 2007

Manufacturing of 3-cell SW structure at KEK

Yasuo Higashi, KEK