Study of RF Breakdown in Normal Conducting Waveguides and Single Cell Structures

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This work is funded by DOE

CERN High Gradient RF Workshop 2006
September 25-27, 2006

Outline

- Waveguides
  - –Different geometries
  - –Different materials
- Single Cell Structures

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

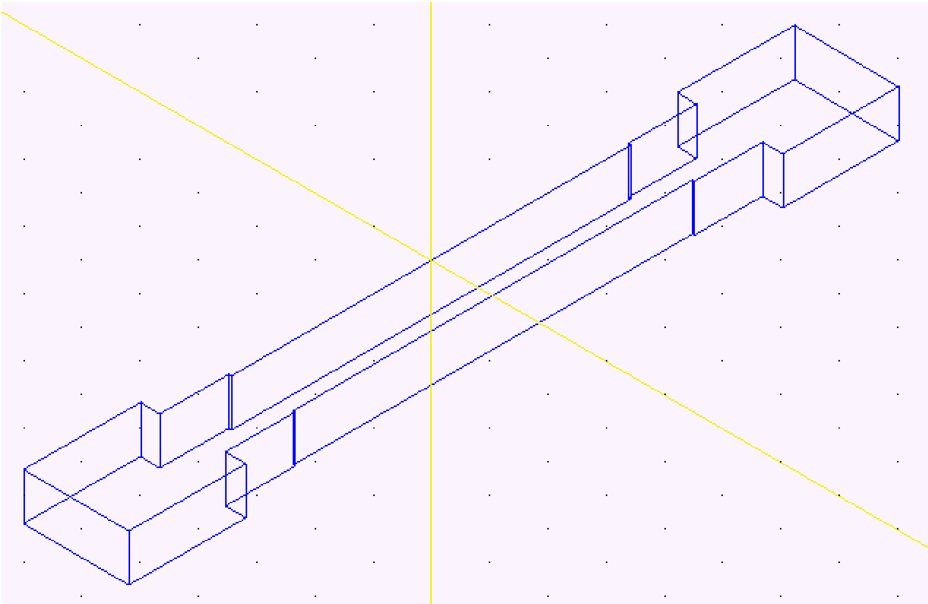
- *High gradient waveguides* with gradients, power and pulse energy close to that of practical structures
- Single Cell Traveling Wave and Standing Wave Structures

If we cannot understand small structures we will not be able to understand full scale structures

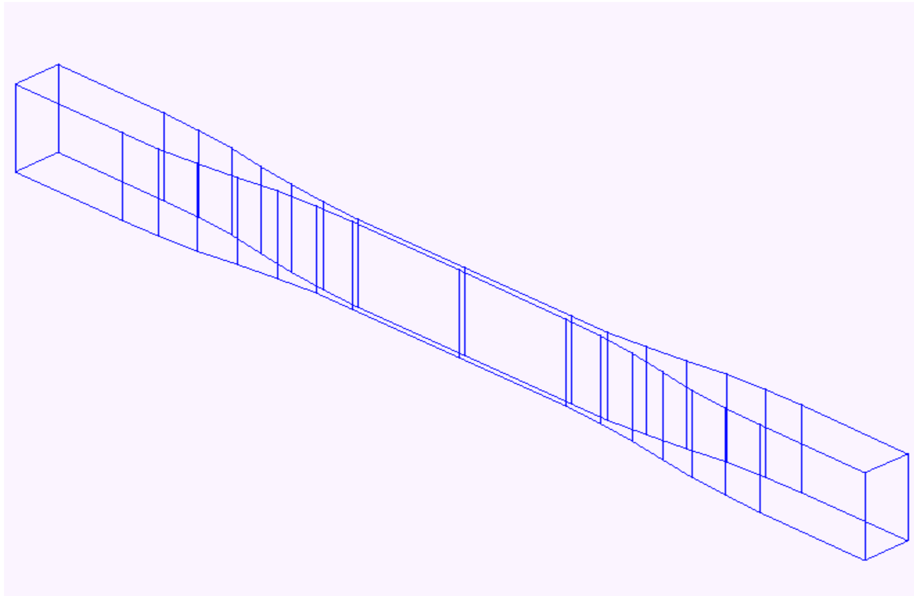
Operating conditions for X-band traveling wave accelerating structures and high power waveguides

- RF power ~100 MW
- Area of high electric field ~ 10 cm^2
- Pulse width ~1μs
- Energy absorbed in the breakdown ~10 J
- Distance between metal surfaces ~1 cm

Geometries



Low magnetic field waveguide, height 10 mm

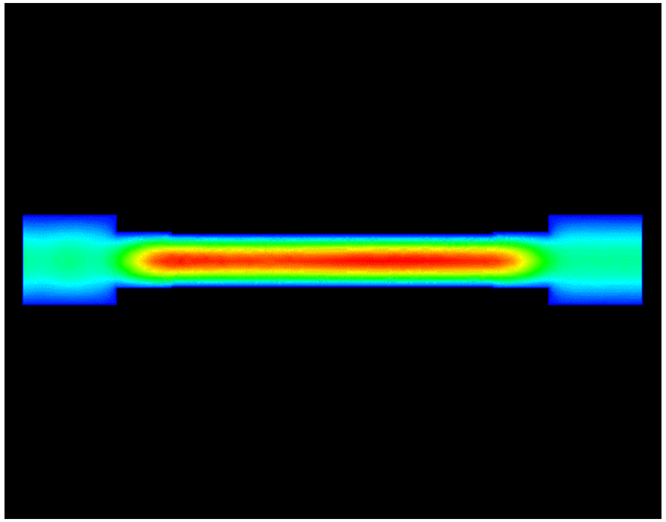


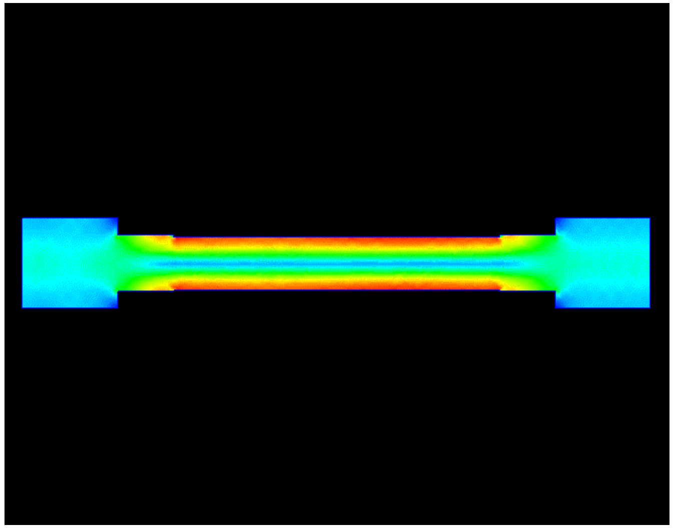
High magnetic field waveguide, height 1.3 mm

•The peak electric field **surface area equal** that of the low magnetic field waveguide
•For a given input power both waveguide have the **same peak electric field** — **80 MV/m at 100 MW** of rf power
•**Ratio** between magnetic field in the middle of wide wall (maximum surface electric field) between both guides = **21**

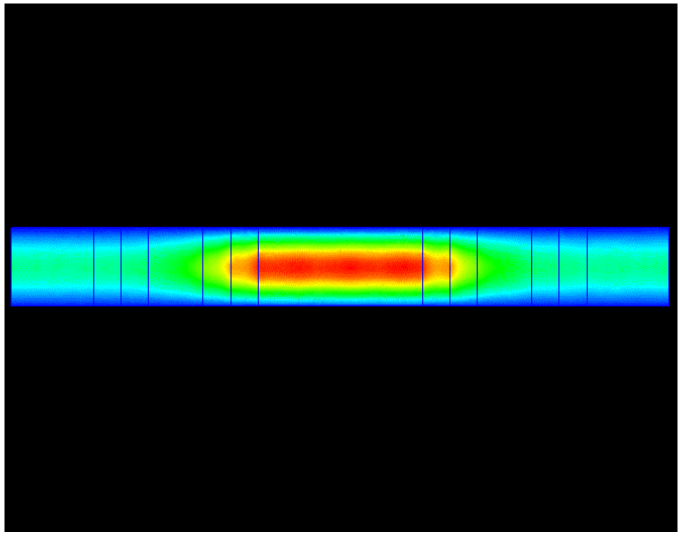
Field Distribution

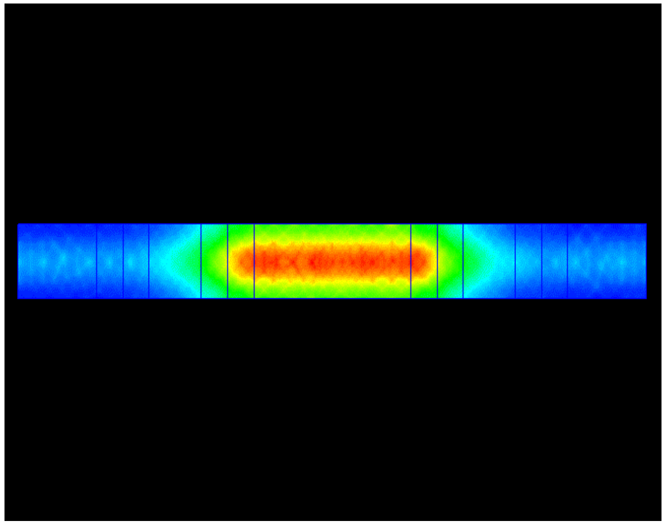
Electric field | Magnetic field





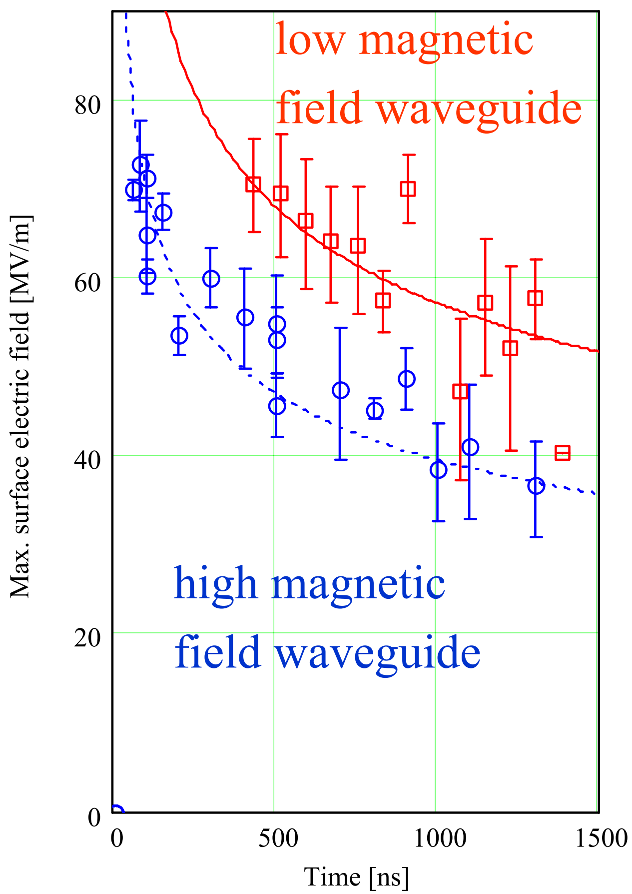
Low magnetic field waveguide



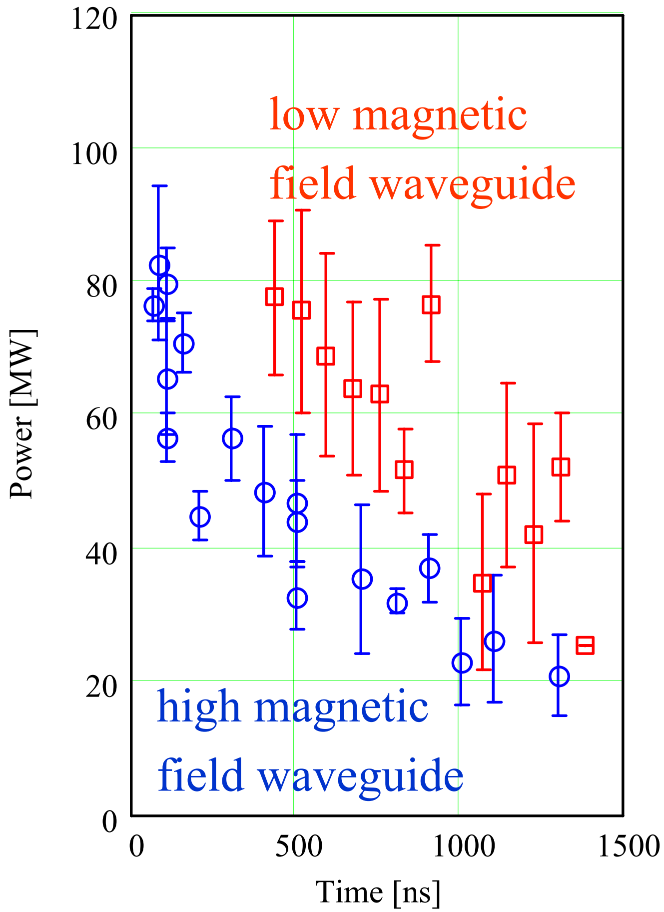


High magnetic field waveguide

Breakdown threshold measurements for waveguides with different geometries

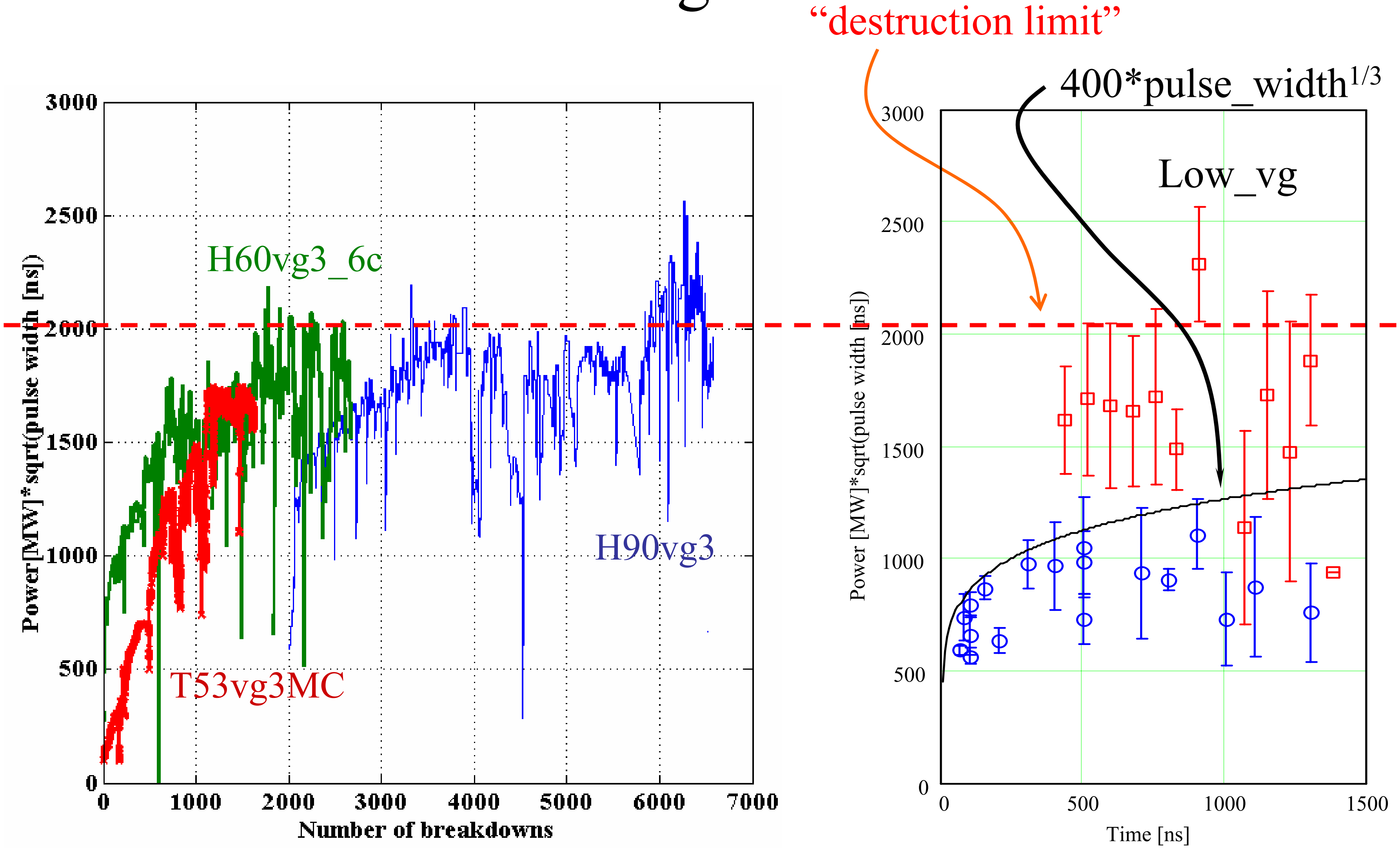


Peak surface electric field *vs.* pulse length



Power *vs.* pulse length

Comparison of *Power*sqrt(pulse widths)* for 3 accelerating structures and 2 copper waveguides



Accelerating structures

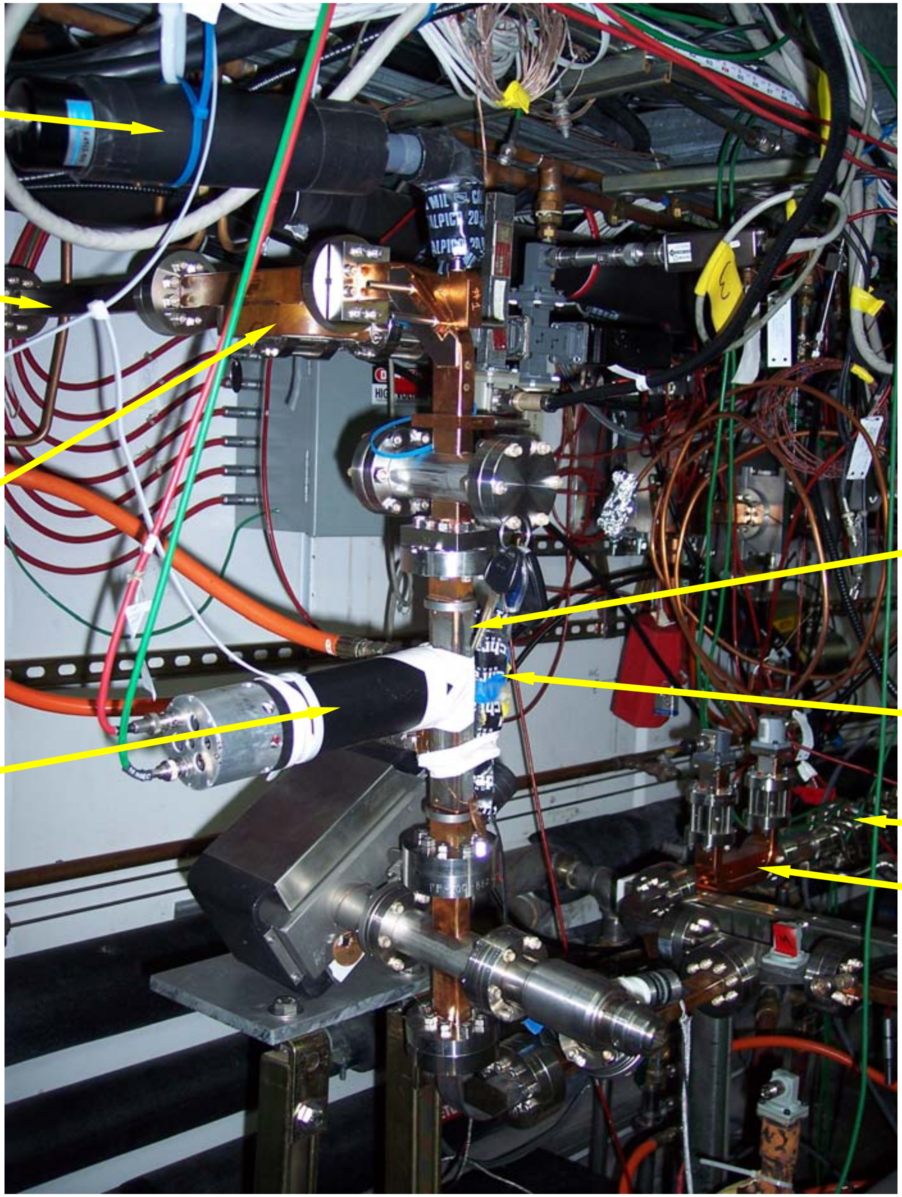
Waveguides

Materials in low magnetic field waveguide

- Copper
- Stainless steel
- Gold
- Molybdenum

We like to thank Lisa Laurent
and NLCTA team for their help with molybdenum waveguide experiment.

Molybdenum waveguide installed at NLCTA



Photomultiplier

Input RF
From SLED
pulse compressor

Input directional
coupler

X-ray detector

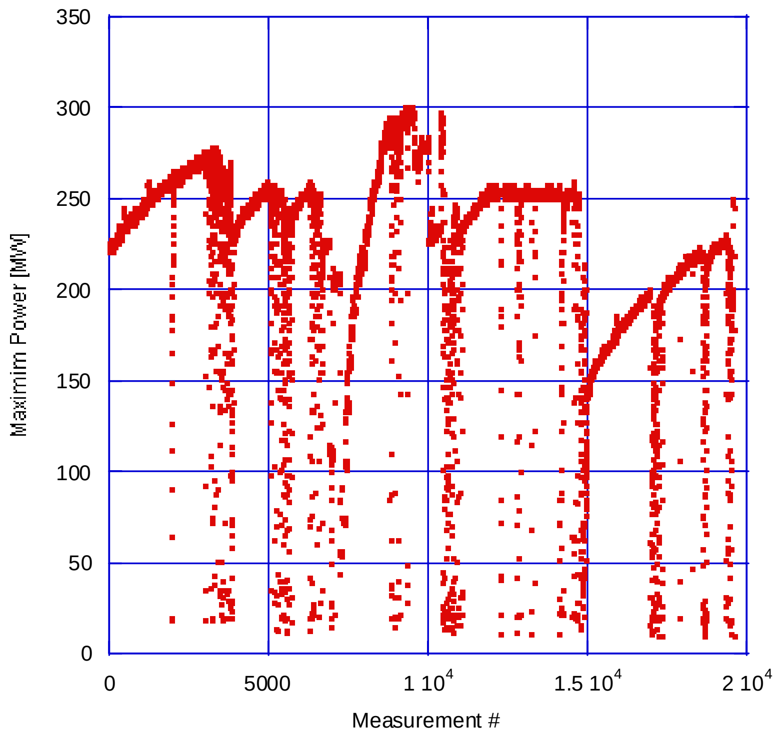
Molybdenum waveguide

Scintillator

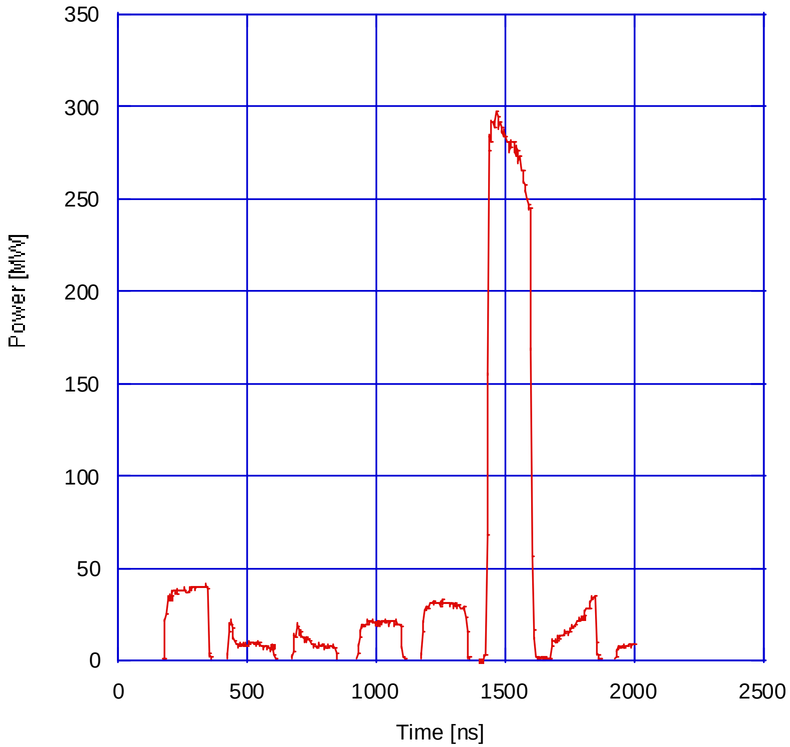
RF load

Output directional
coupler

Processing of molybdenum waveguide

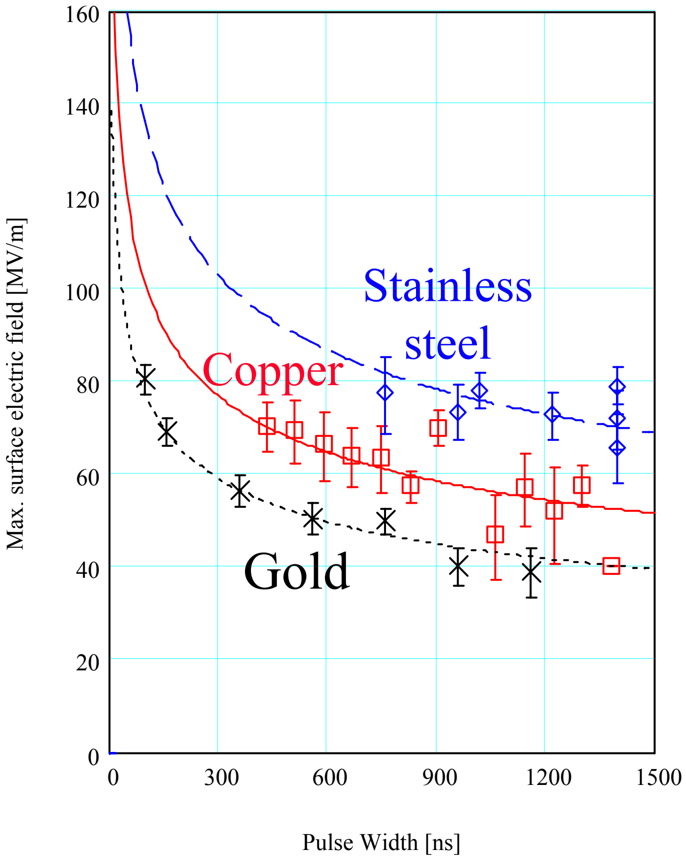


Peak power vs. measurement number
(one measurement every 2 sec)



Input pulse shape

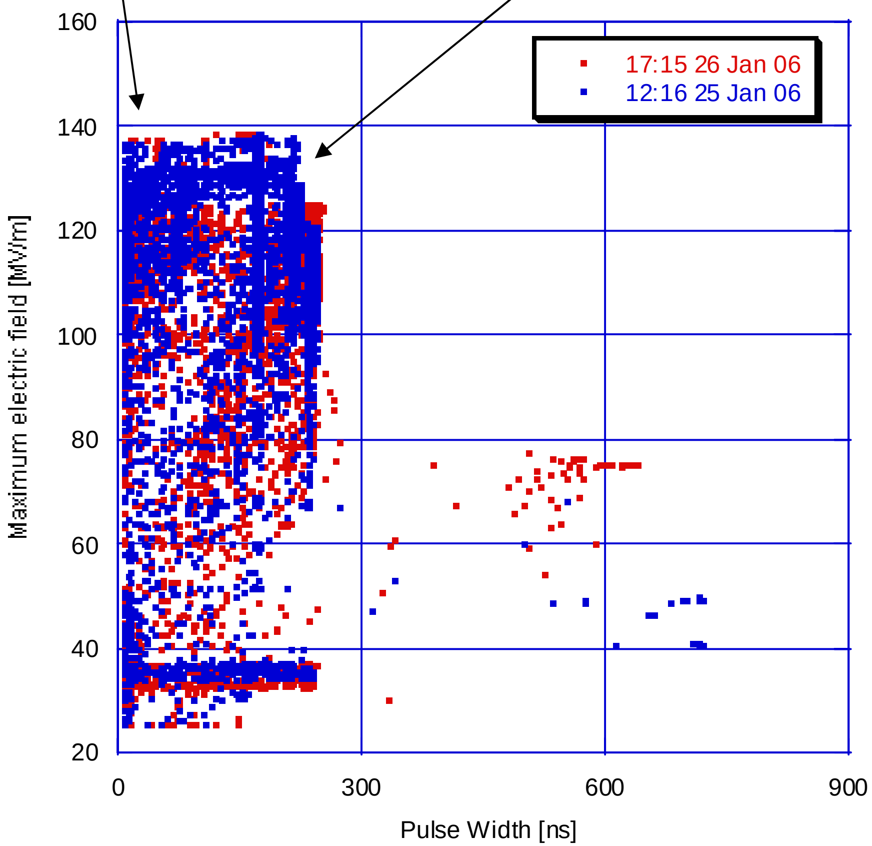
Low magnetic field waveguides with different surface materials



Breakdown threshold measurements for low-magnetic-field waveguides with different materials

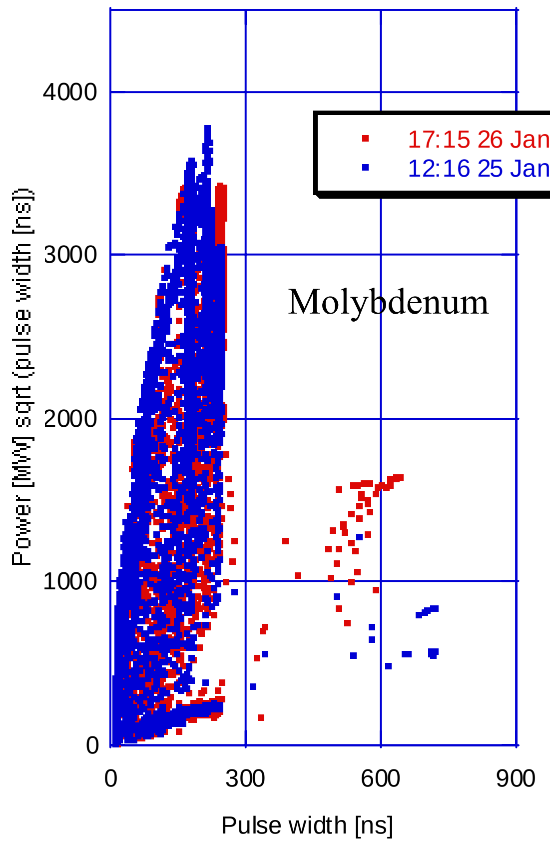
No breakdowns, limited by available power

Limited by breakdowns in SLED

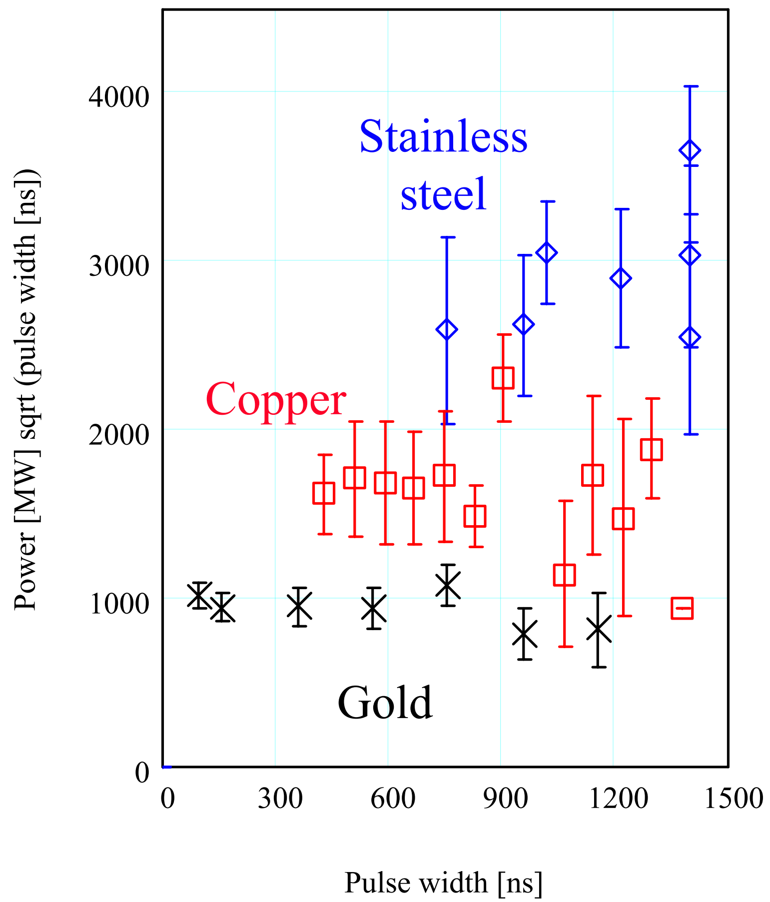


Peak power *vs.* pulse width during processing of molybdenum waveguide

Comparison of Power*sqrt(Pulse Width) for low-magnetic-field waveguides made of different metal



Peak Power*sqrt(Pulse Width) *vs.* pulse width during processing for molybdenum waveguide



Breakdown Power*sqrt(Pulse Width) *vs.* pulse width for copper, gold and stainless steel

Waveguide Summary

•**Macroscopic geometry is a very important parameter in breakdown phenomena.** High magnetic field waveguide has a lower breakdown threshold than low-magnetic-field waveguide. The electric field gap is much smaller (1.3mm *vs*. 10mm) in the high magnetic field waveguide. This gap dependence contradicts a DC model of the breakdown, where breakdown threshold usually decreases with increased gap.

•**Breakdown properties are strongly dependant on surface material.** The stainless steel waveguide we tested had a higher breakdown threshold than copper. Gold had a lower threshold than copper.

•For molybdenum waveguide, direct comparison was possible only to gold waveguide. This comparison shows the superiority of the molybdenum waveguide. **If we project molybdenum results using dependence P*sqrt(pulse width) to longer pulse width, we consider molybdenum superior to copper and possibly close to the performance of the stainless steel waveguide.**

More tests

- Stainless still high magnetic field waveguide and chromium-plated low magnetic field waveguide were made at SLAC and available for the test

Single Cell Structures

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

Single Cell Structures

Traveling Wave

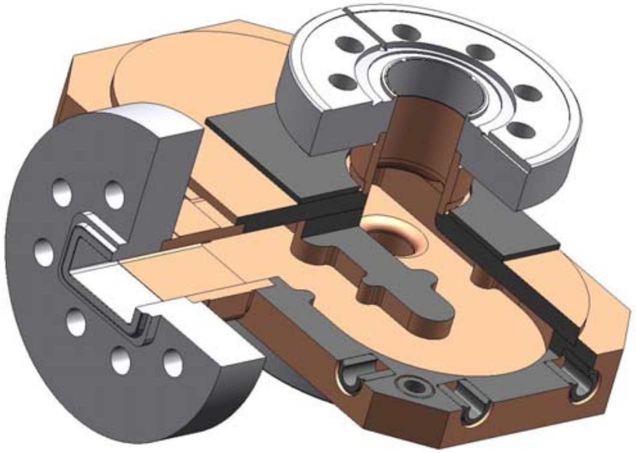
- Fields are the same as in first cell of NLC structure T53VG3
- High electric and magnetic fields are ***only in this cell*** (not in couplers)
- ***Reusable couplers*** – mode launchers that transform the TE_{10} mode of rectangular waveguide into the “accelerating” circular TM_{01} mode

Standing Wave

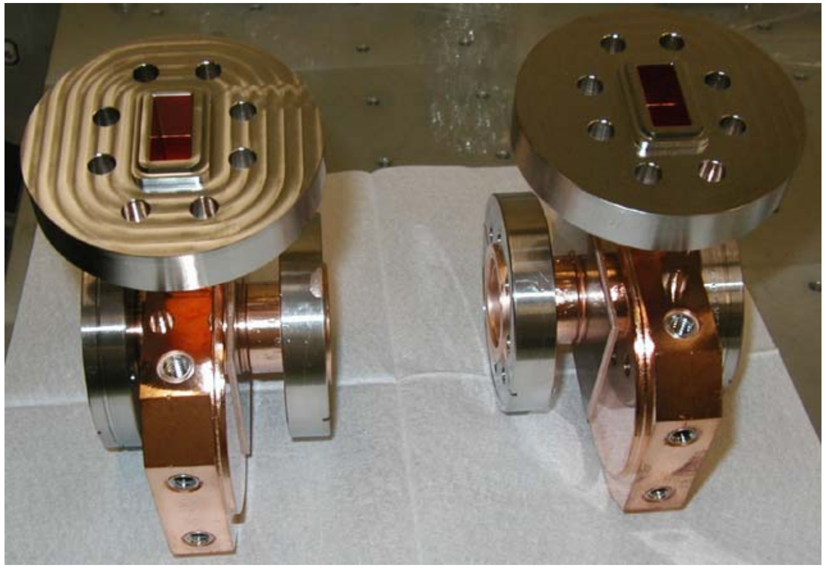
- Fields in the middle cell of the SW structure are similar to fields of a large-aperture SW structure SW20a565
- Fields in the middle cell twice as high as in other two cells

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

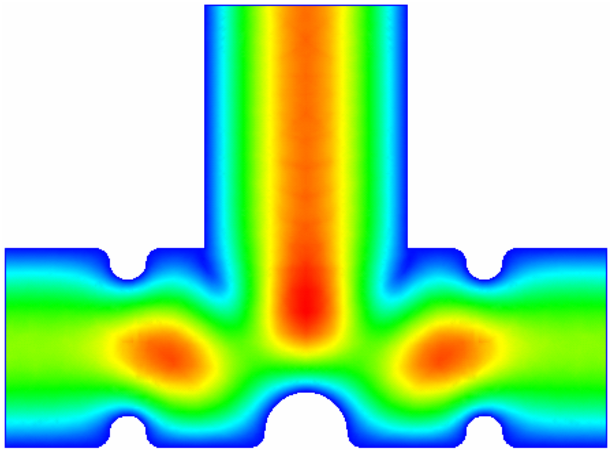
TM_{01} Mode Launcher



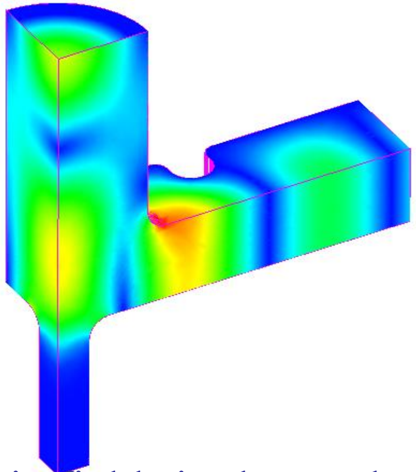
Cutaway view of the mode launcher



Two mode launchers



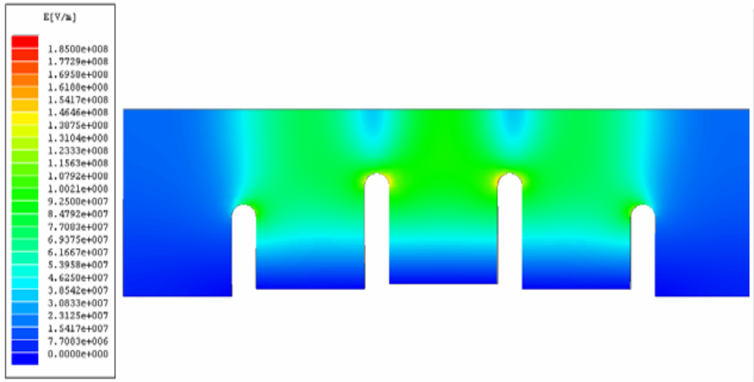
Surface electric fields in T splitter,
E_{max}= 30 MV/m for 100 MW



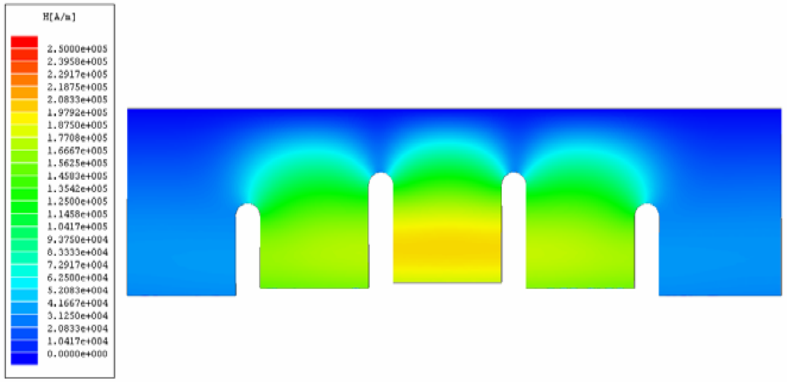
Surface electric fields in the mode launcher
E_{max}= 49 MV/m for 100 MW

Single Cell Traveling Wave Structures

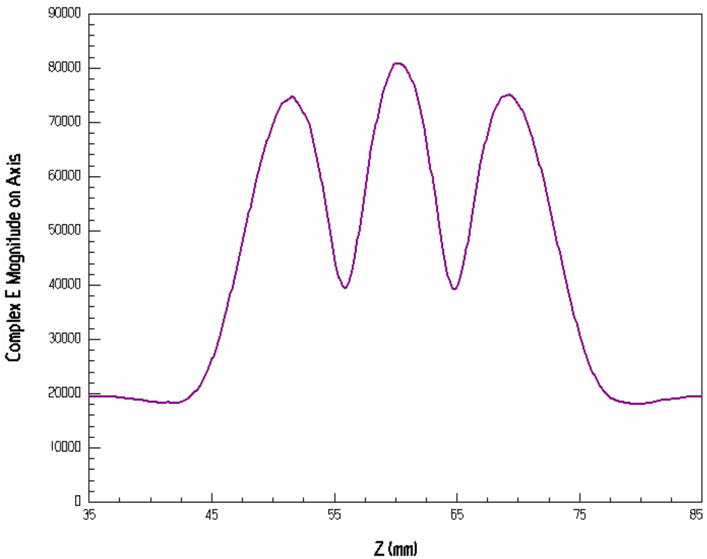
Single Cell Traveling Wave Structure



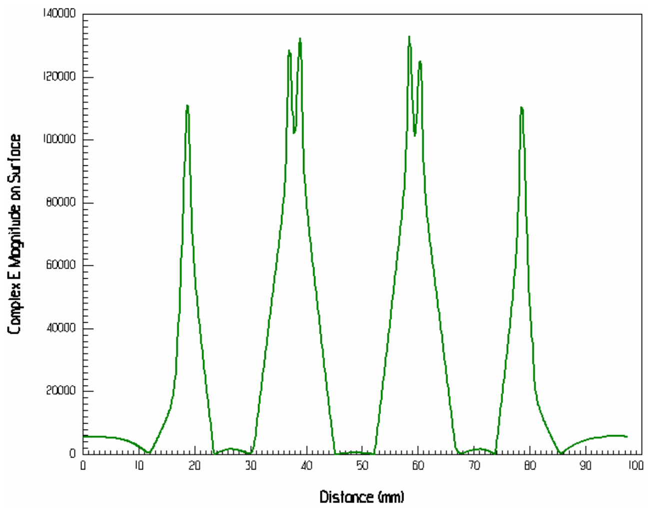
Amplitude of electric fields in single cell TW structure for 40 MW of input power.



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



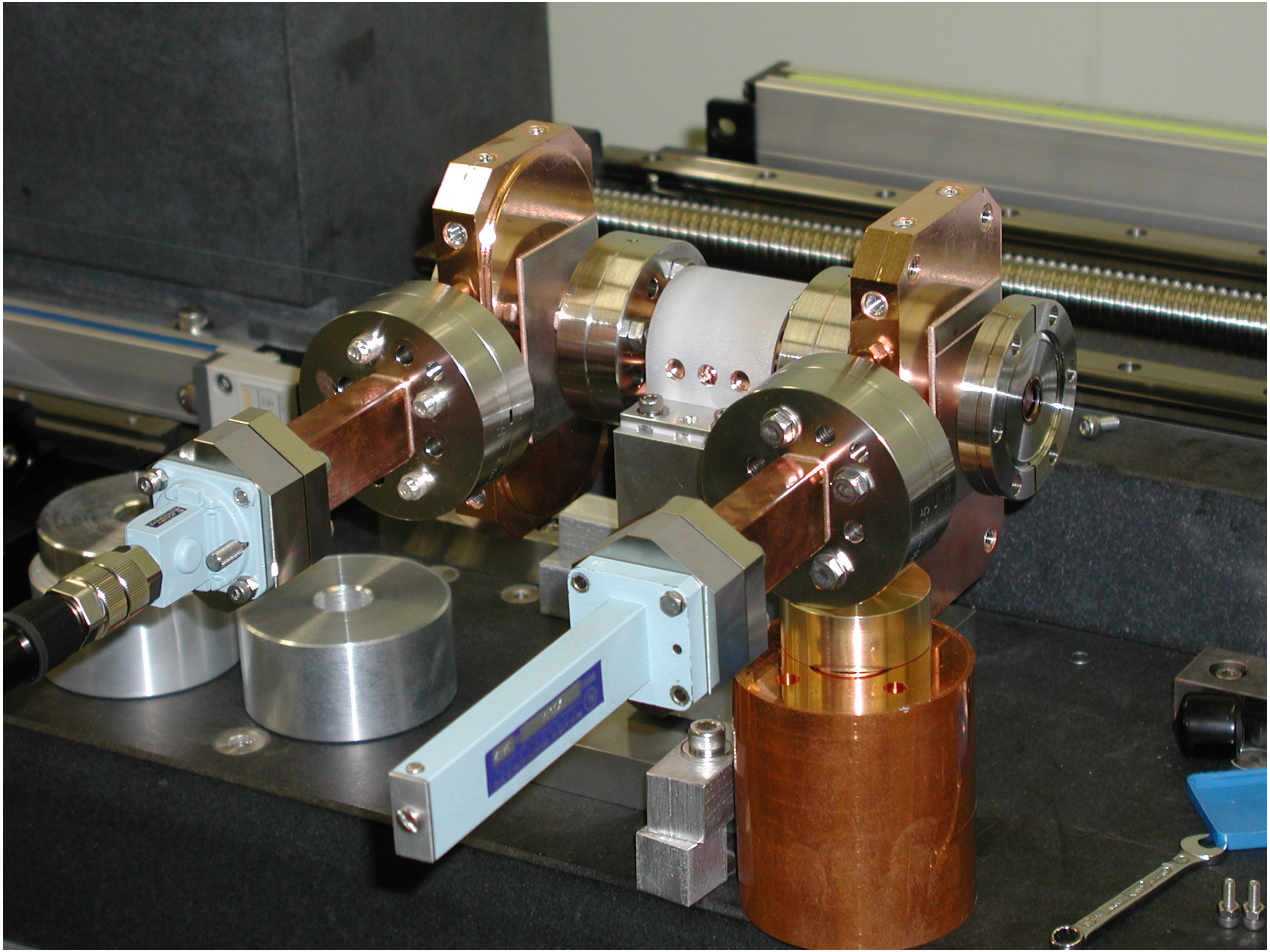
On axis electric field



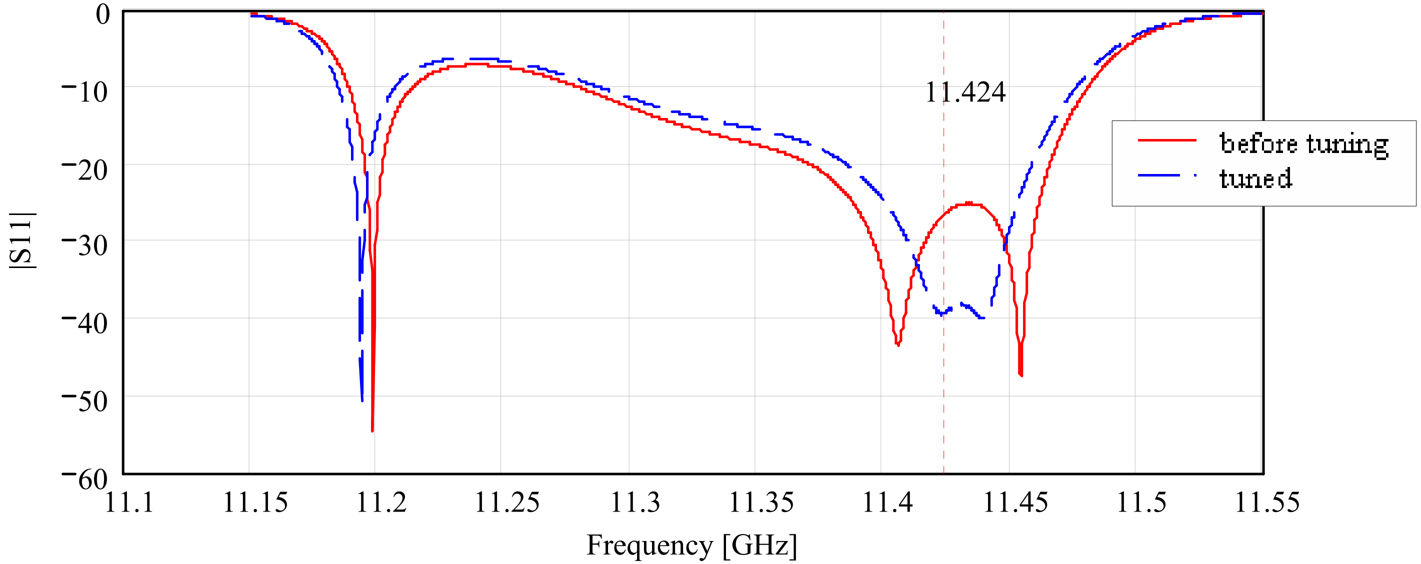
Surface electric field

For 50 MW of input power this structure

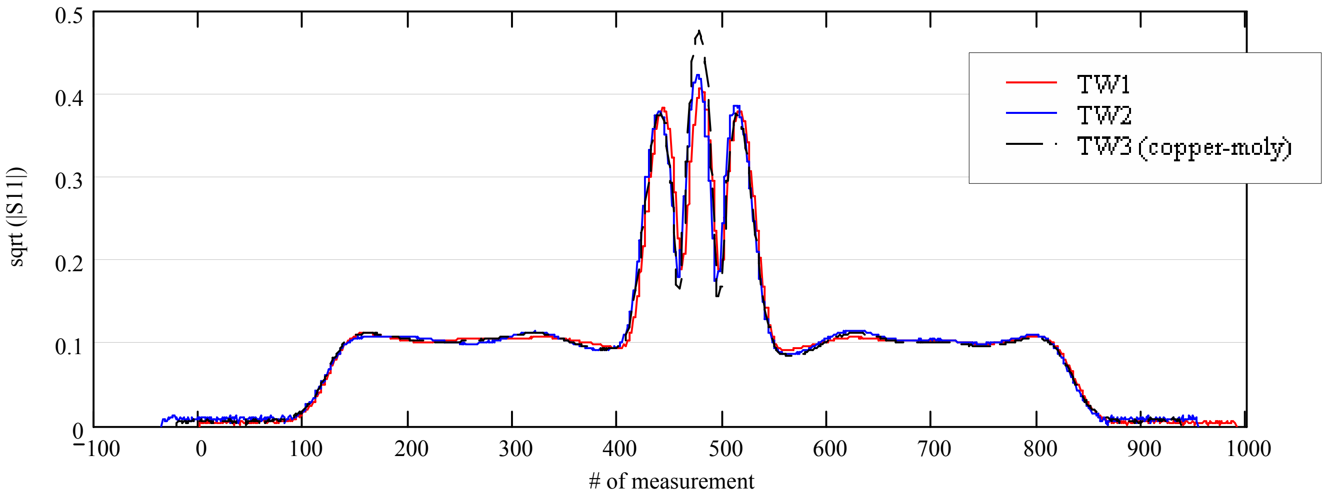
has 70 MV/m acceleration and 150 MV/m maximum surface field.



Cold Test With Single Cell Traveling Wave Structure



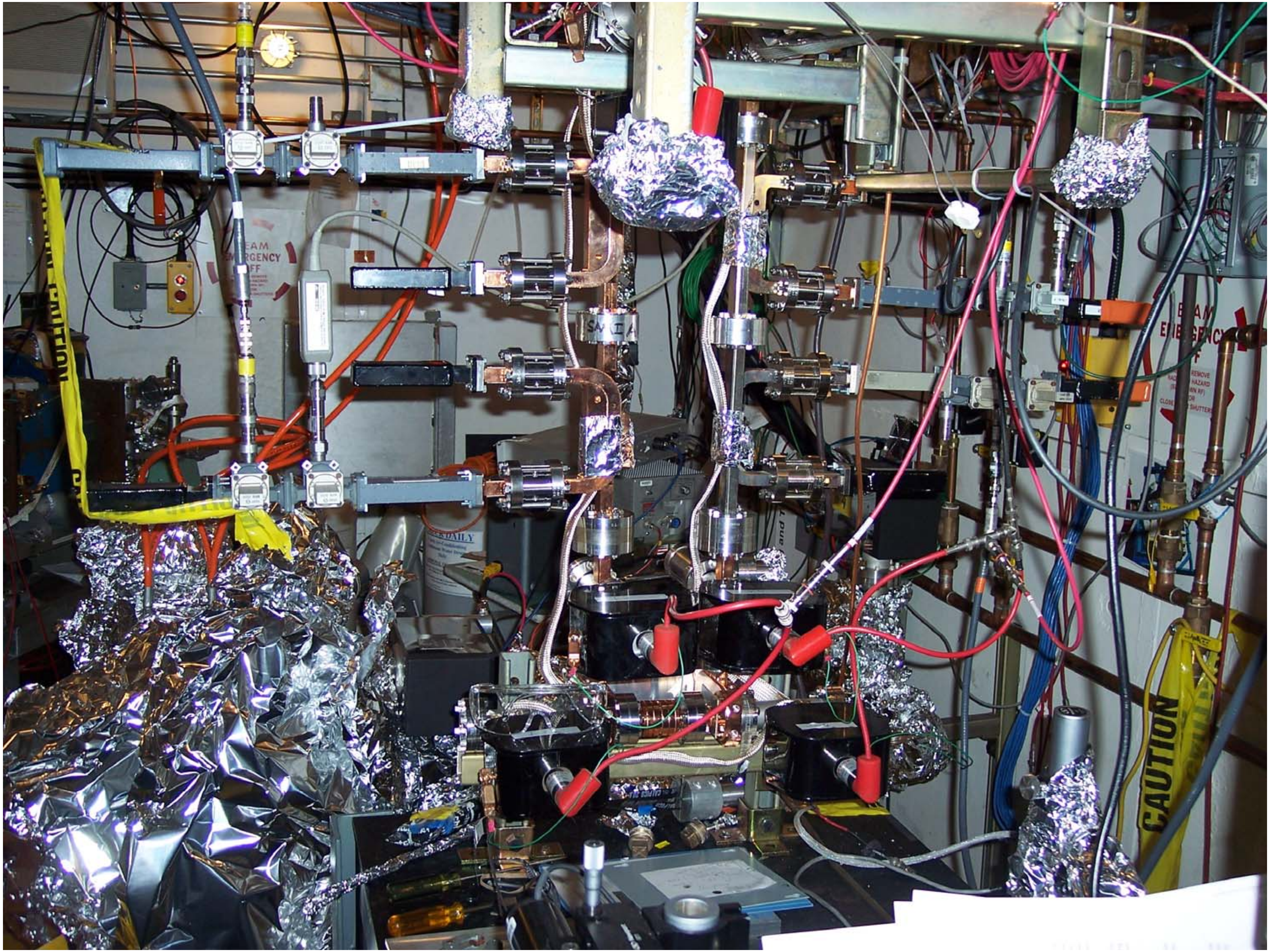
Reflection from single cell TW structure before and after tuning

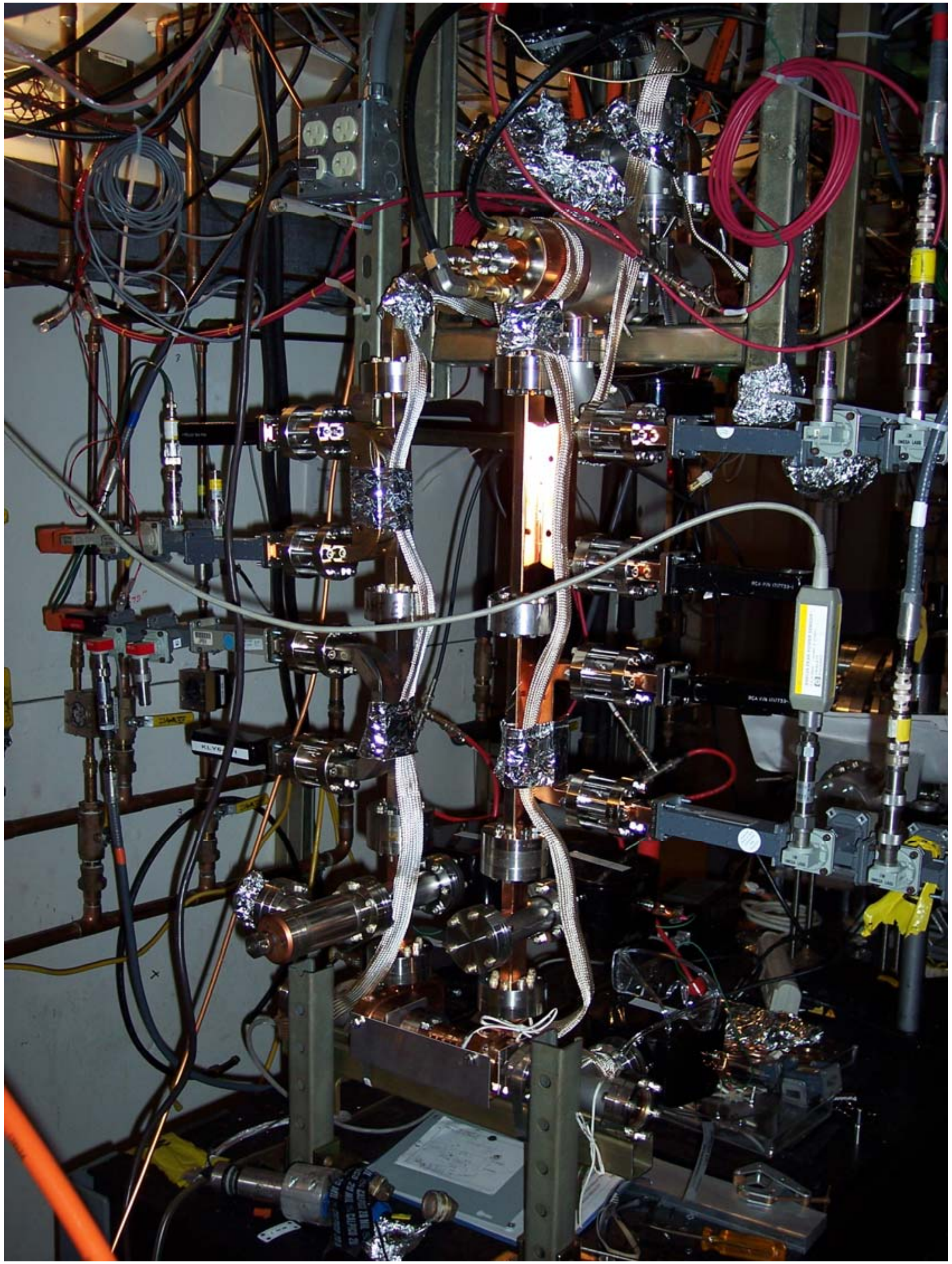


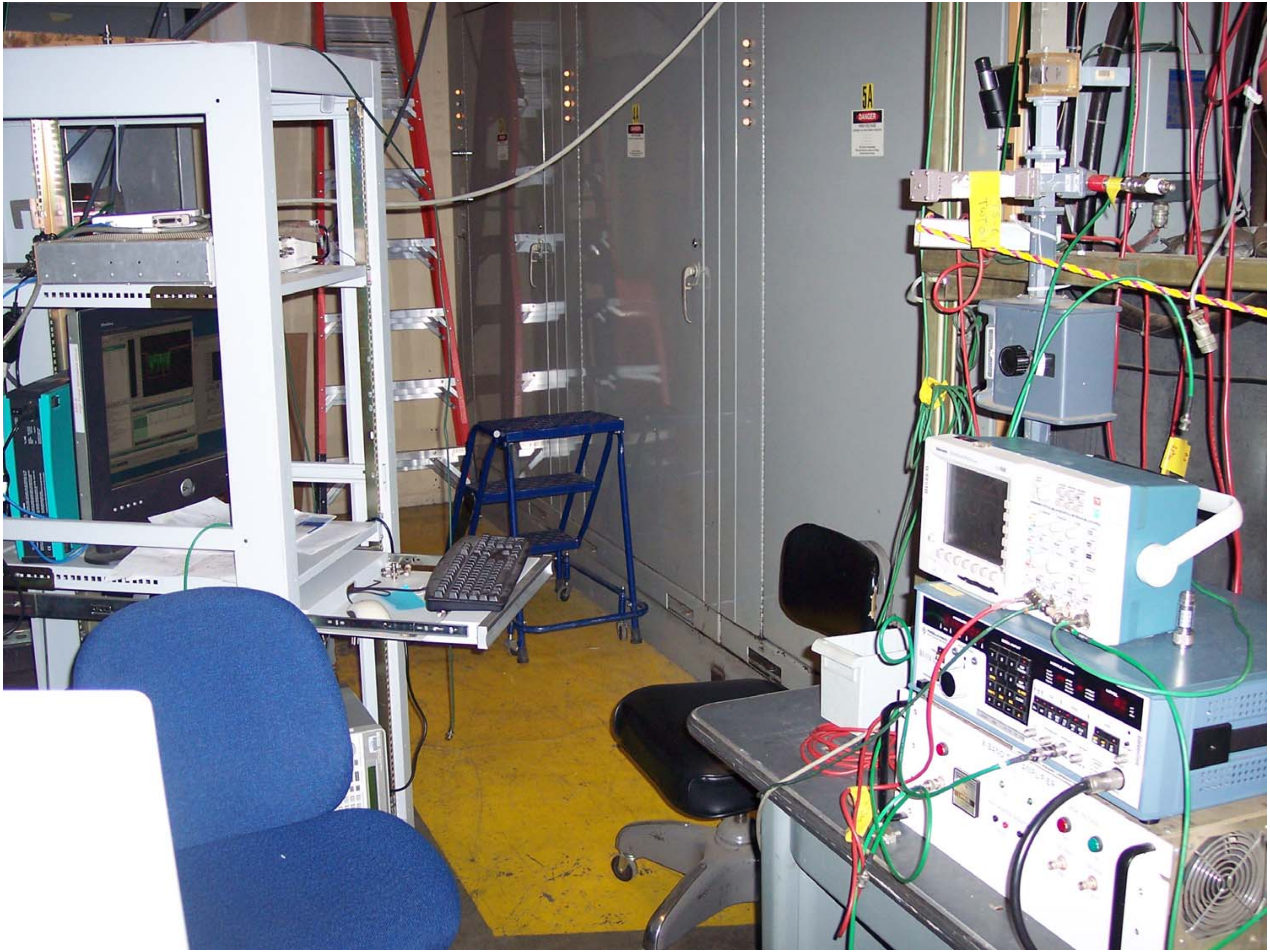
On axis field profile for three single cell TW structures

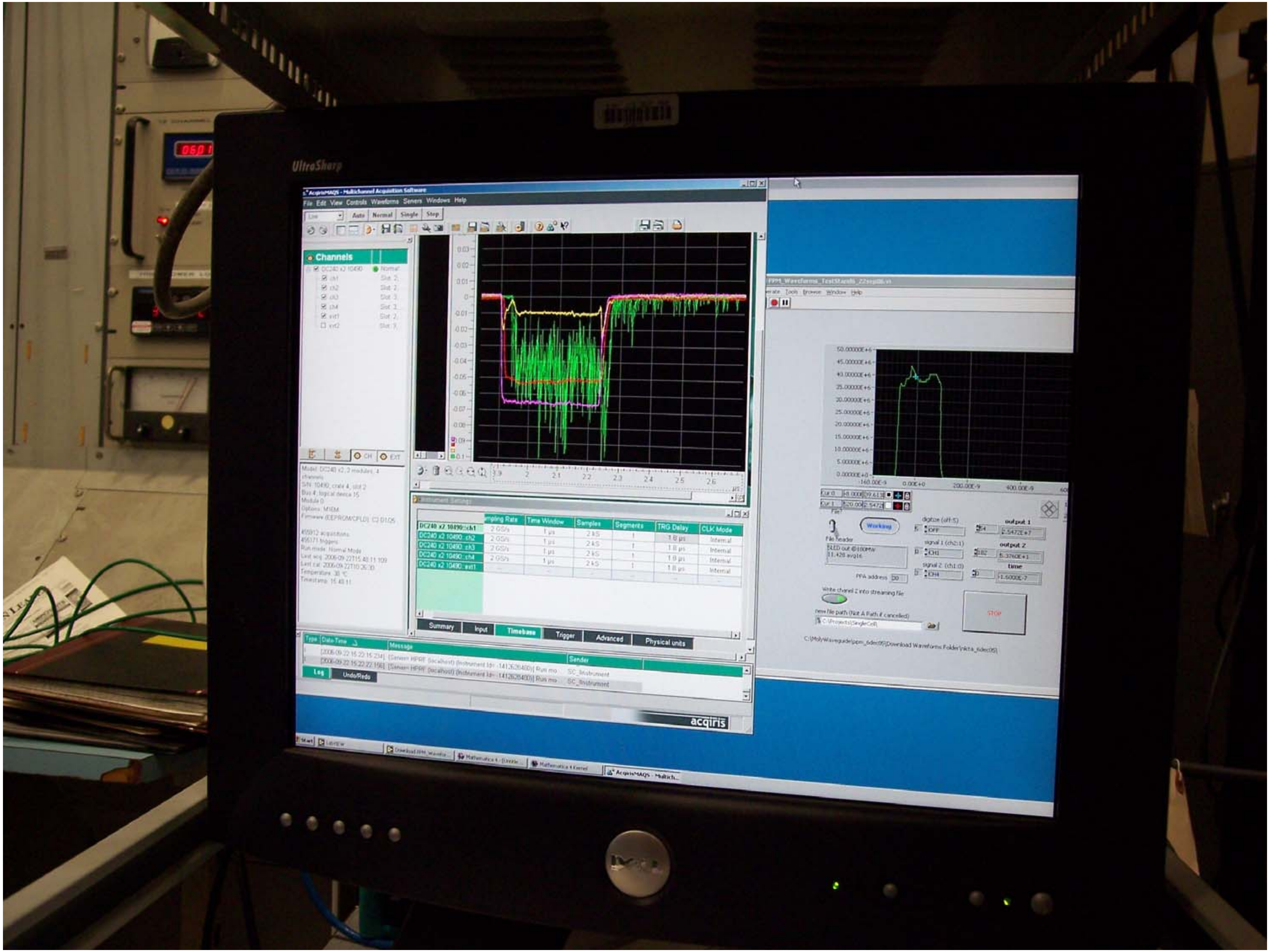
High Power Test

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.


CAUTION

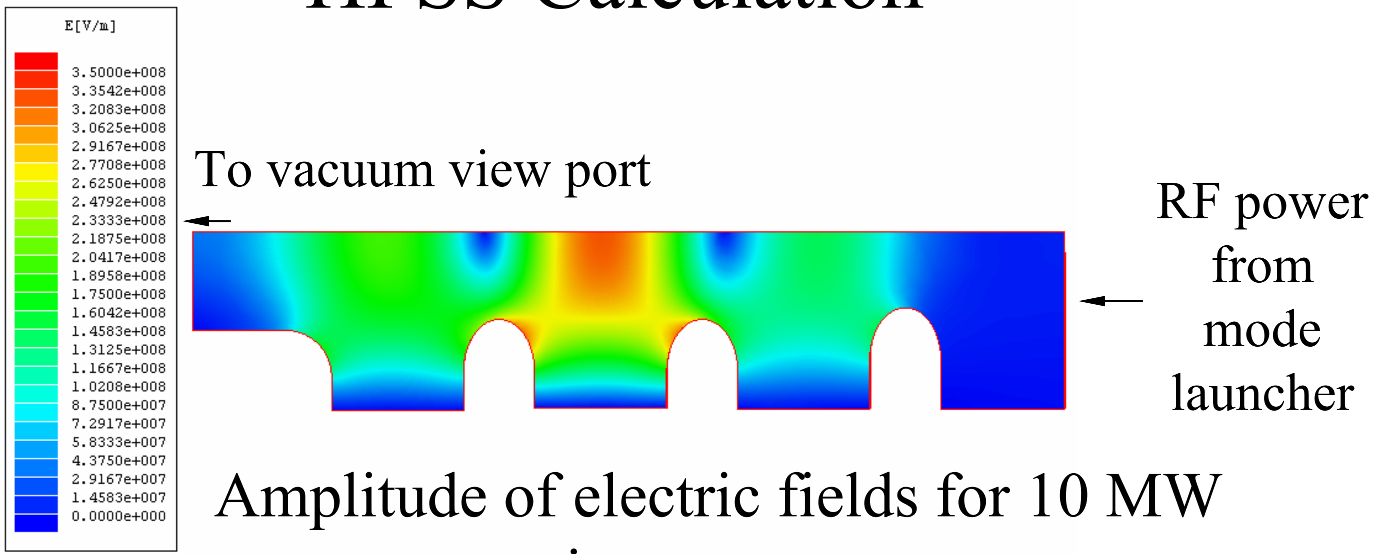



5A
DANGER

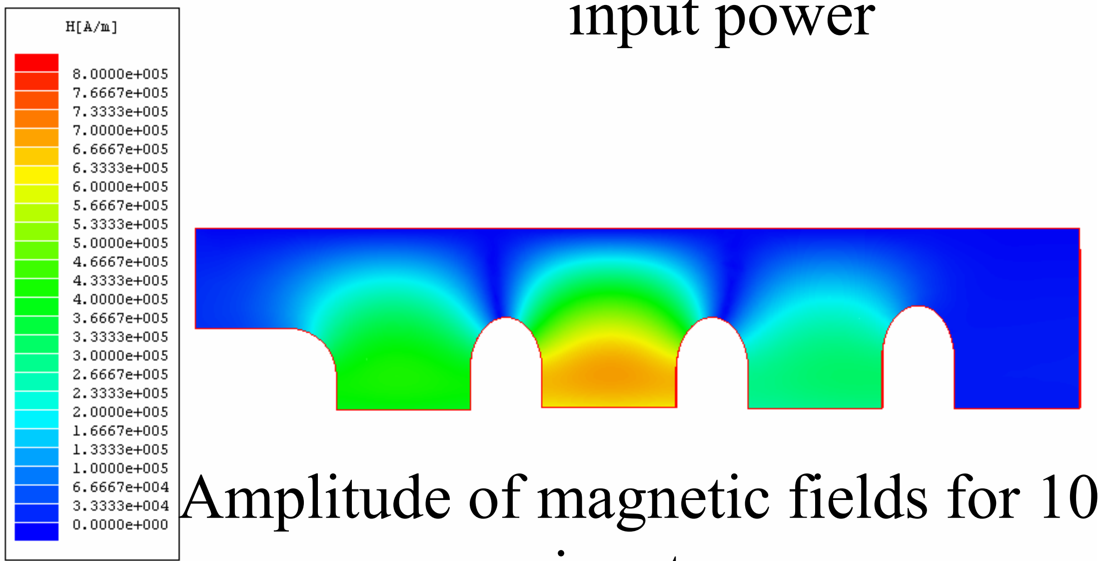

UltraSharp
AcqirisMAQS - Multichannel Acquisition Software
File Edit View Controls Waveforms Servers Windows Help
Auto Normal Single Stop
Channels
Time Window
Samples
Segments
TRG Delay
CLK Mode
Summary
Input
Timebase
Trigger
Advanced
Physical units
Working
STOP
acqiris

Single Cell Standing Wave Structures

Single Cell Standing Wave Structure HFSS Calculation

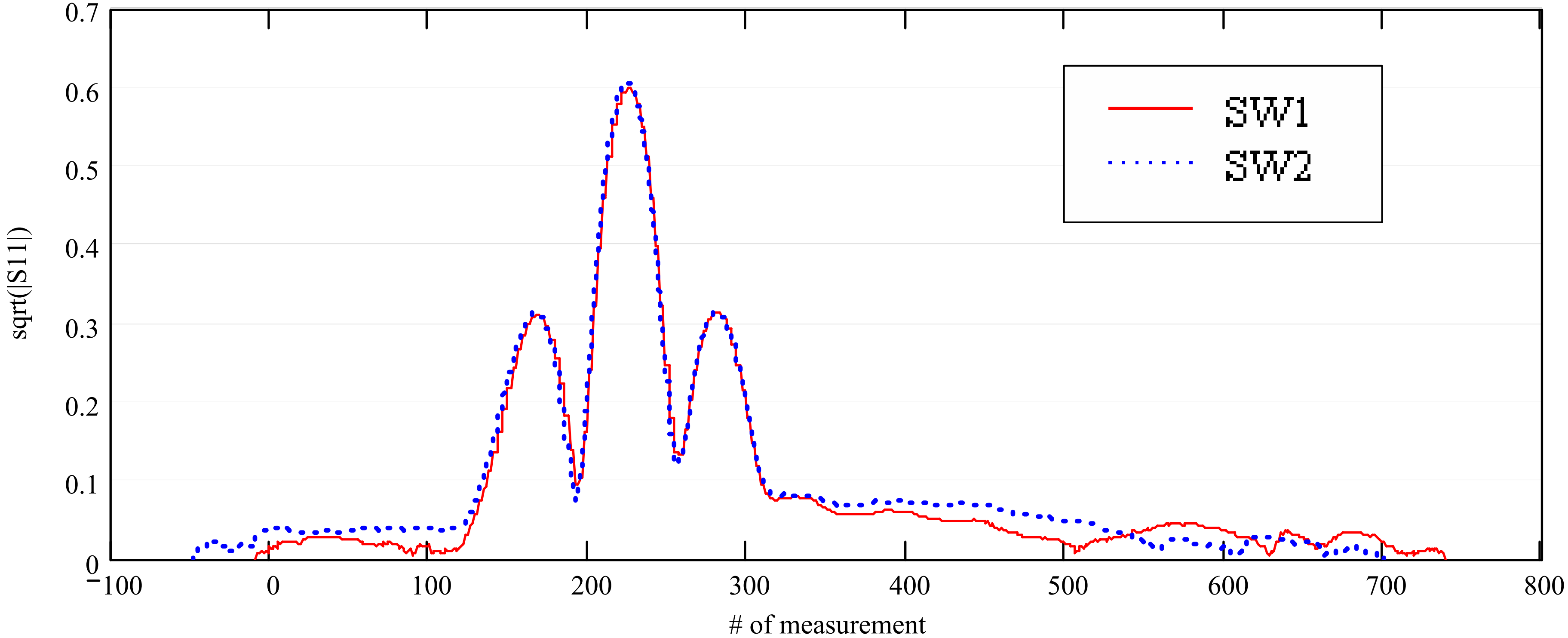


Amplitude of electric fields for 10 MW input power



Amplitude of magnetic fields for 10 MW input power

Bead-Pull Measurements



On axis field profile for single cell SW structures

Single Cell Traveling Wave and Standing Wave Structures

Molybdenum Structures

Input cell of SW structure

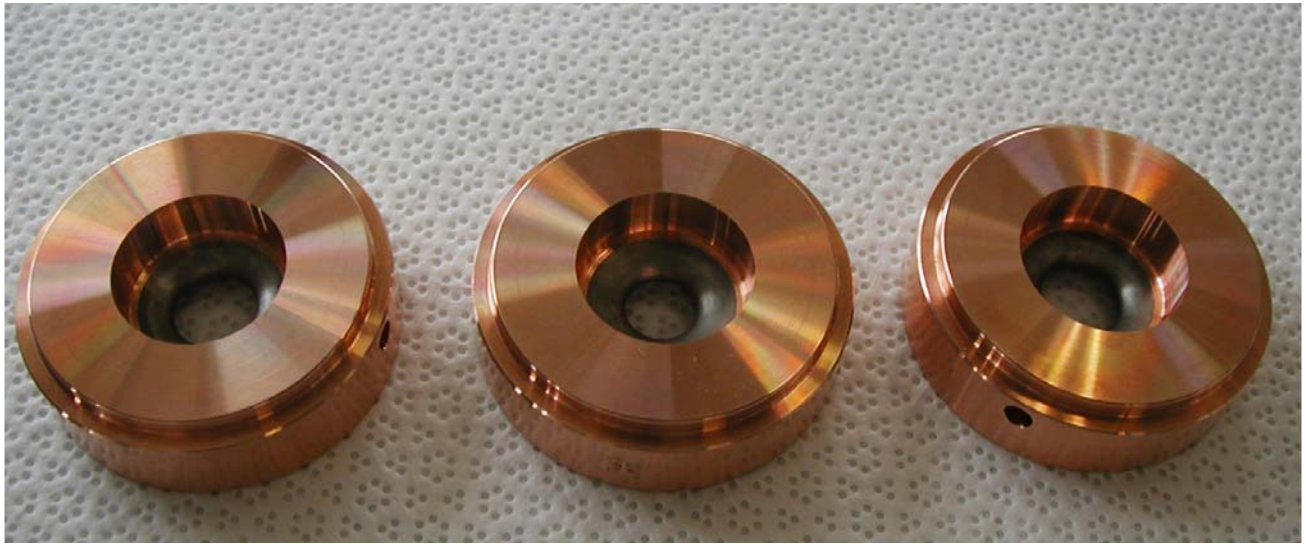
Molybdenum Structures

Molybdenum SW structure

Molybdenum TW structure

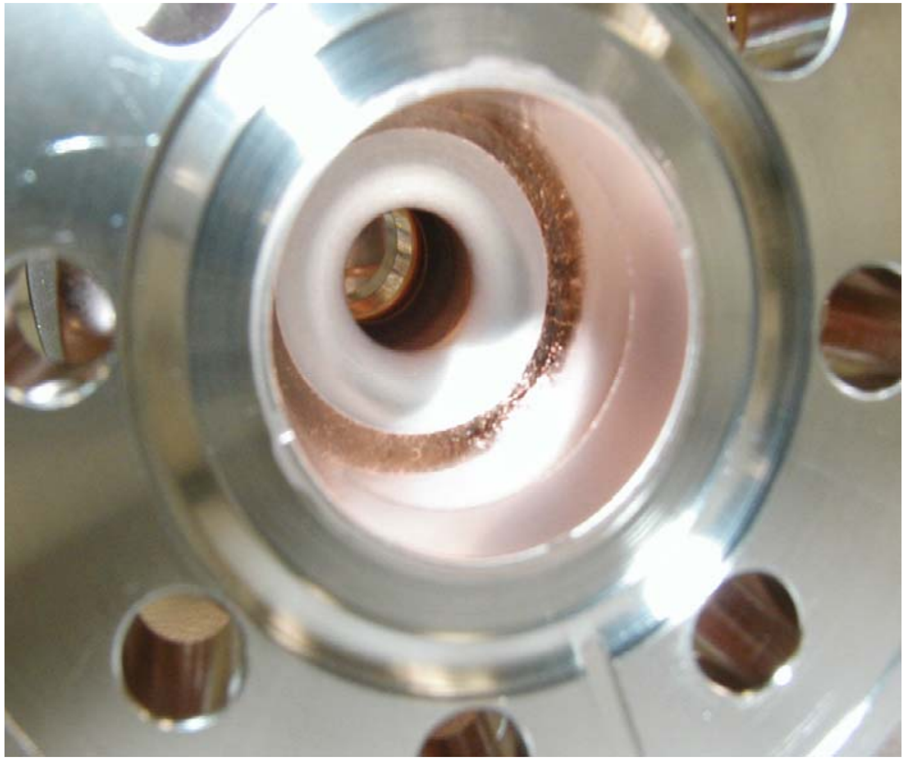
Molybdenum-Copper Structures

Molybdenum-copper
SW structure cells

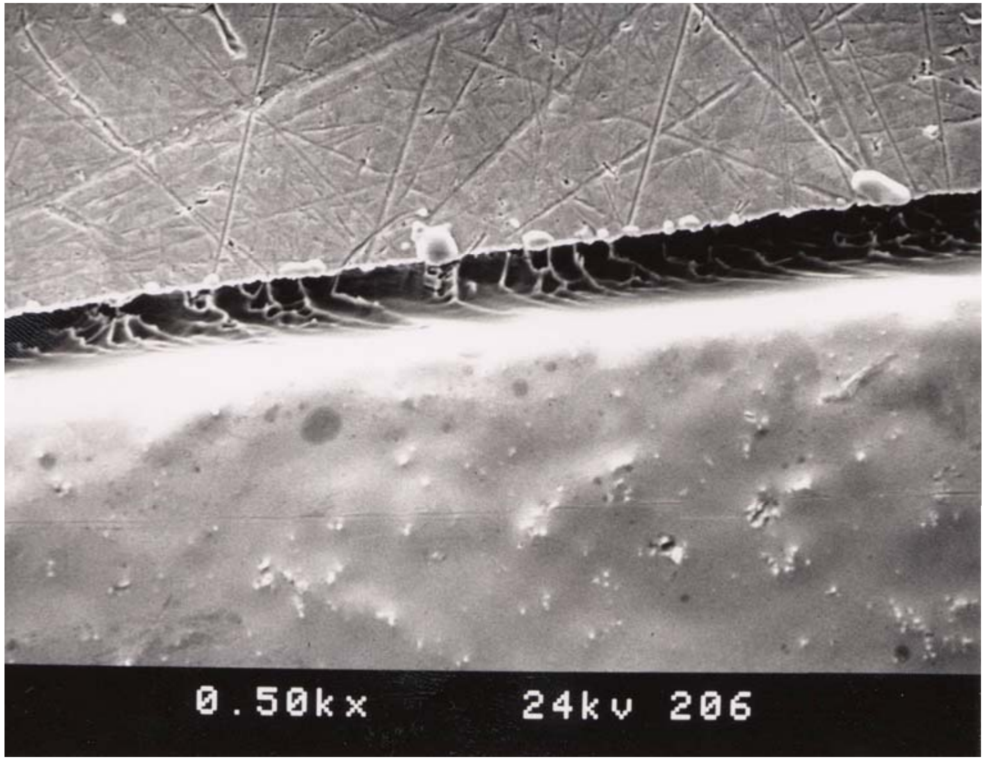


Molybdenum-copper
TW structure cells

Molybdenum-Copper Structures



Input of single cell SW structure



Interface of molybdenum and copper after etching

Status of Single Cell Structure Tests

- We started high power conditioning of SLAC-made single cell traveling wave structure. At present setup klystron is capable of delivering of 50 MW and 1.5 μs rf.
- We expect shipment of single cell standing wave structures from KEK this month (Y. Higashi).