High Gradient Research Progress

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7/21/2007

US Collaboration on High Gradient Research for a Multi-TeV Linear Collider

- Current Members:
  - Laboratories:
    - Argonne National Laboratory
    - Lawrence Berkeley National Laboratory
    - Naval Research Laboratory
    - Stanford Linear Accelerator Center (Also the host of the collaboration)
  - Universities :
    - University of Maryland
    - Massachusetts Institute of Technology

US Collaboration on High Gradient Research for a Multi-TeV Linear Collider

- Business Associates
  - Omega-P, Inc.
  - Calabazas Creek Research, Inc.
  - Haimson Research Corporation
  - Tech-X Corporation
  - Communications and Power Industries

- Foreign Colleagues
  - CERN
  - KEK

US Collaboration on High Gradient Research for a Multi-TeV Linear Collider

- Governance Structure
  - Spokesman
    - Sami Tantawi, SLAC
  - Advisory Council
    - Prof. Ron Ruth of SLAC (11.4 GHz research/overall technical coordination);
    - Dr. Richard Temkin of MIT (high frequency research and RF source development);
    - Dr. Gregory Nusinovich of UMD (theory and code development)
    - Dr. Wei Gai of ANL (other experimental programs).
  - Scientific Secretary
    - Dr. Ted Lavine, SLAC (Pending)

Goals

- The purpose of this collaboration is to perform research to determine the gradient potential of rf-powered particle beam accelerators, and to develop the necessary accelerator technology to achieve those high gradients.
- Harnessing the momentum of the concluded NLC/JLC development programs and working in conjunction with the ongoing CLIC studies, the collaboration will explore the possibility of pushing the useable acceleration gradient from the 65 MV/m reliably achieved in NLC structures up towards 180 MV/m or higher.
- Advancing the state-of-the-art in this area is essential to the realization of a post-ILC, multi-TeV linear collider using two-beam rf power generation.

Scope

- This collaboration should not be viewed as an umbrella for general research into RF accelerator technology or other advanced accelerator techniques.
- For example, the general development of RF sources, modulators, and RF components are not included in this effort.
- Specific technology may be included, provided that it is required for achieving the goals expressed in the introduction.
- As our research proceeds, the collaboration may enhance or limit the scope of our work plan to include additional techniques or technologies which address the primary goal of the achievement of high acceleration gradient.

Methodology

- This research and development effort will include studying the rf breakdown phenomenon itself, theoretically and experimentally.
- It will aim to establish a better understanding of the frequency scaling of the limiting gradient, as well as its dependence on material, surface preparation, structure design, pulsed heating, etc.
- It will explore the high gradient barriers due to choices made in linear collider programs to date.
- The experimental side of this effort will entail the upgrade of test facilities and the development of new high-power rf sources specifically designed for high gradient testing.
- The final goal is to produce and successfully test at very high gradient an accelerator structure suitable for use in a multi-TeV two-beam linear collider.

Methodology: We must lay a technical and theoretical foundation

- Our research should be systematic and thorough, but it must be targeted due to limited resources.
- We have to address fundamentals early.
- These include, but are not limited to
  - Frequency scaling
  - Geometry dependence
  - Energy, power and pulse length
  - Materials
  - Surface processing technique (etching, baking, etc.)
  - Theory
  - …

High Gradient Research at SLAC

- As the host, we concentrated on being accessible to the rest of the collaboration:
  - Improve our test facilities at 11.424 GHz
    - 2-pack, ASTA and individual stations
  - Cost effective testing:
    - SLAC can provide their reusable couplers and supply compatible flanges. Hence, other groups need only to worry about the design of the accelerator structure “proper”
    - We are introducing new types of gate valve to minimize, time, effort and cost for installation of different experiments
    - We are introducing a new test stand for low temperature high power measurements

High Gradient Research at SLAC

- As the host, we tried to unify the on going efforts:
  – We encouraged groups to take advantage of the available resources at SLAC for building and manufacturing accelerator structures. This could considerably save time and element mistakes.
  – Encourage a coherent theoretical modeling efforts, this is going to materialize soon through our collaboration with the university of Maryland
  – We started a collaborative efforts with MIT, ANL, … on novel structures.
  – We are also working with CERN, LANA and SNS on material characterizations with our novel cavities

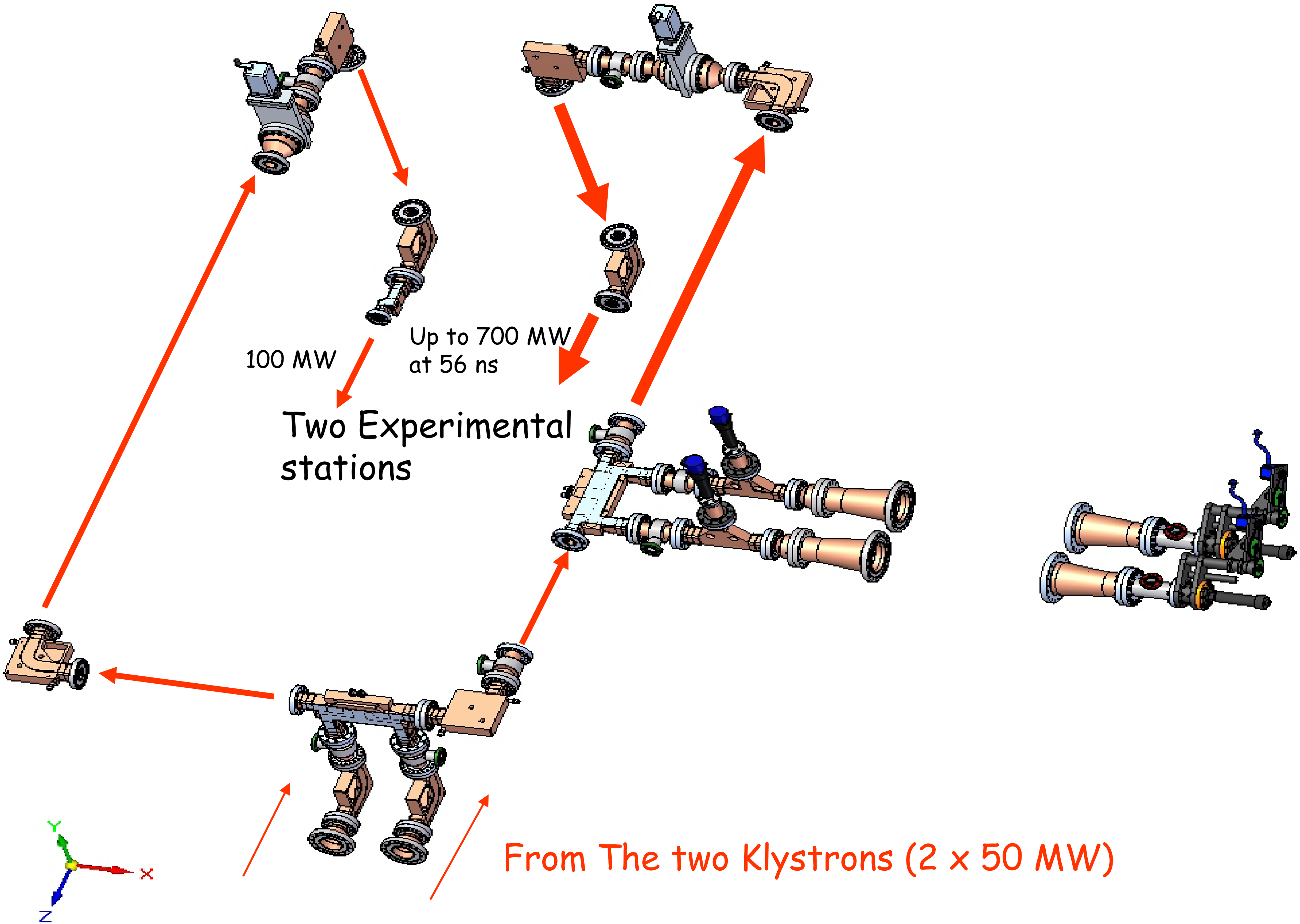
Outline

- Experimental facilities and components
  - Test Stands in the klystron department
  - ASTA
  - Two-PAC
  - NLCTA
  - MIT/NRL/CERN
- Experimental program
  - Single cell structure testing
  - Full structure testing
  - Pulsed heating
  - Material testing
- Planned Experiments and on going research

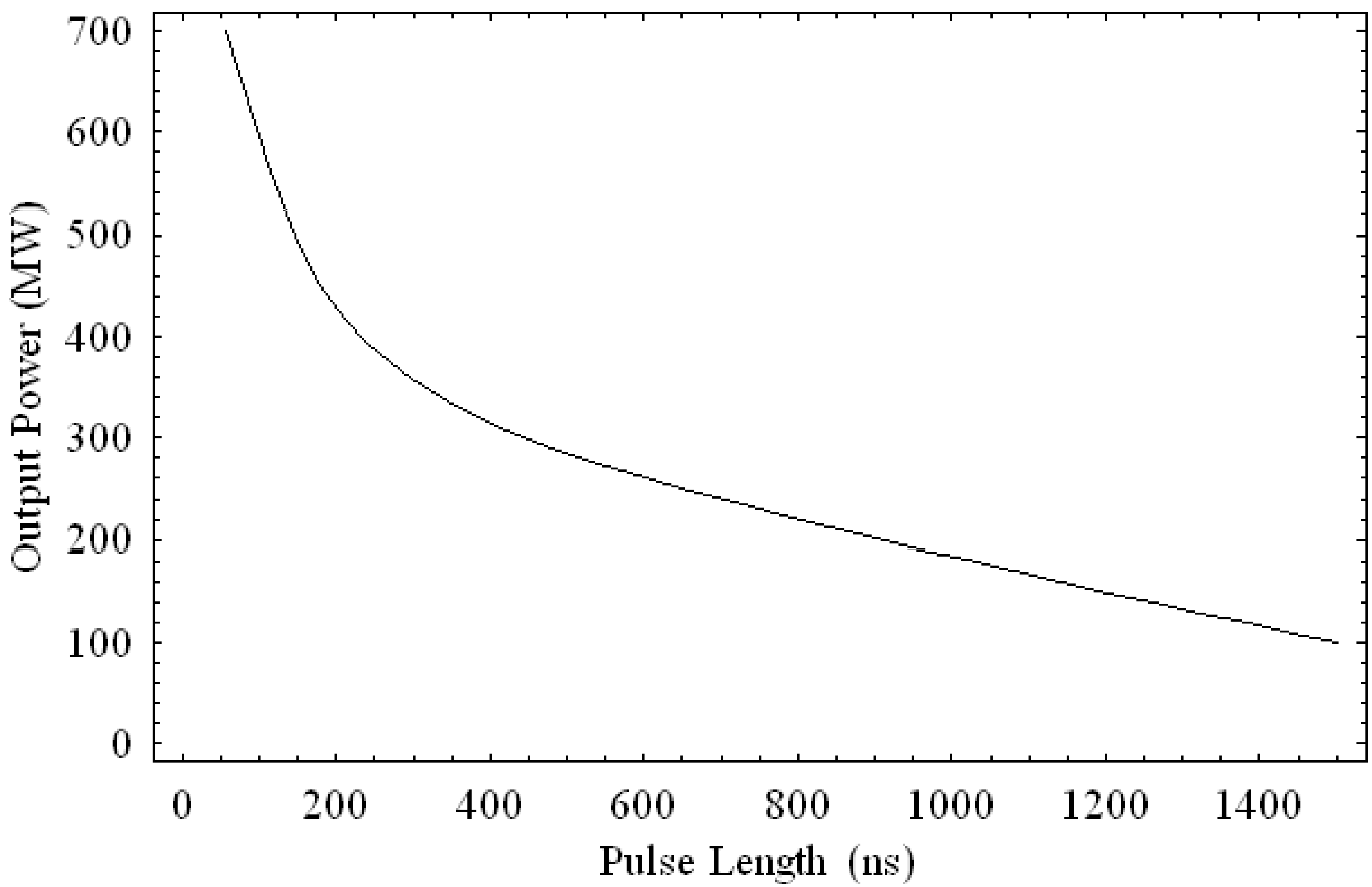
Pulse compressors at ASTA and Two-Pack

- All New overmoded components for high reliability (So that we are testing structure rather than RF system)
- Flexible pulse length and gain
- High efficiency
- Each is powered by two klystrons

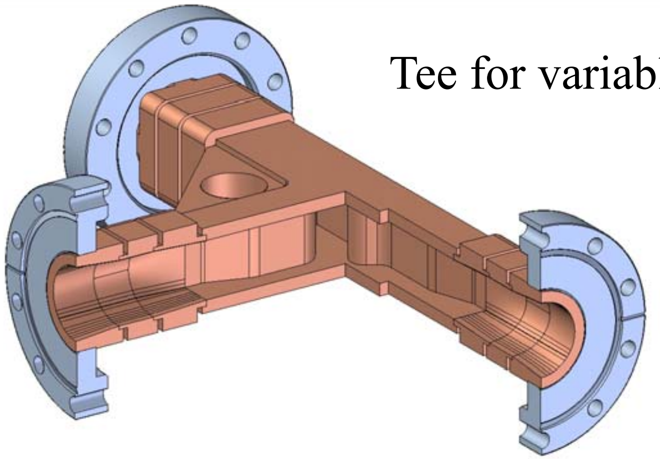
ASTA Pulse Compressor



ASTA SLED-II Output

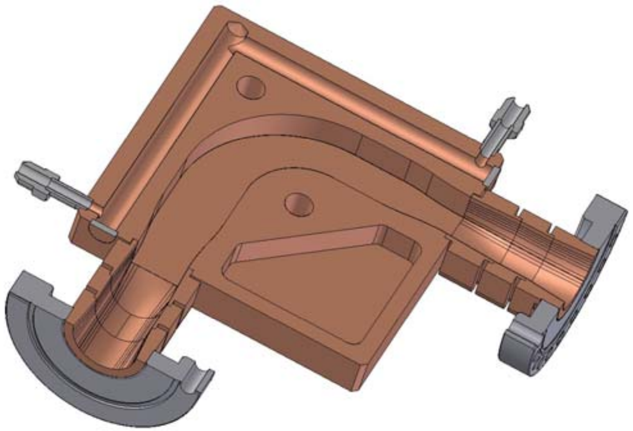


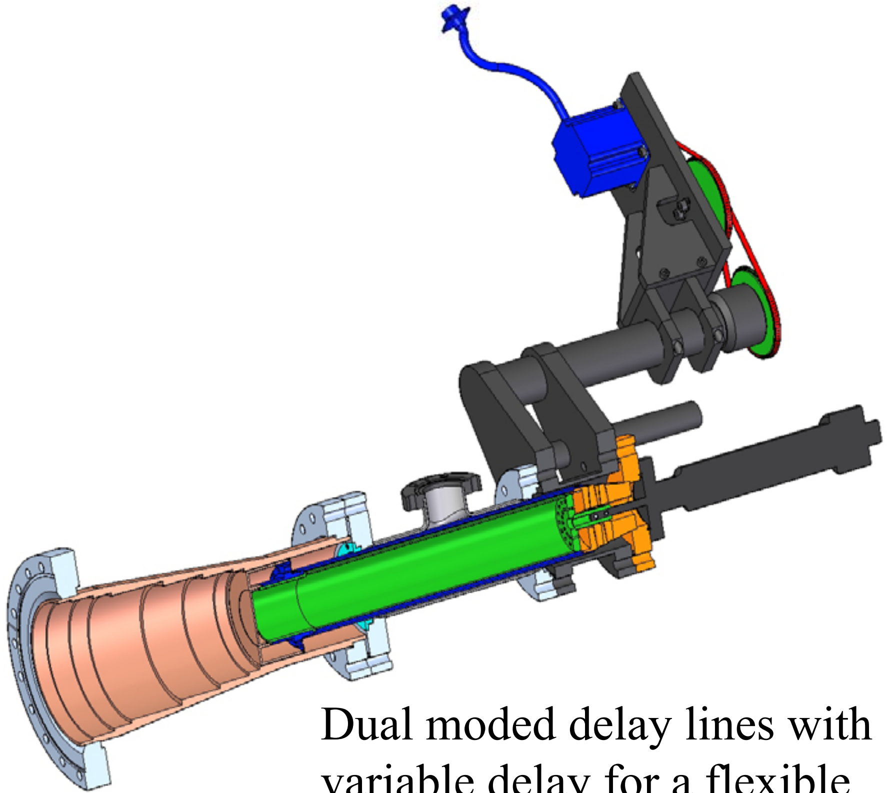
Components To Support The Experimental Facilities



Tee for variable iris

Bends for low loss transmission and reliable RF systems

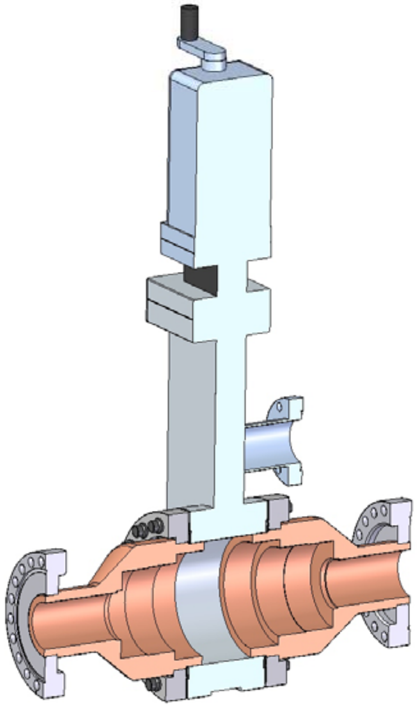


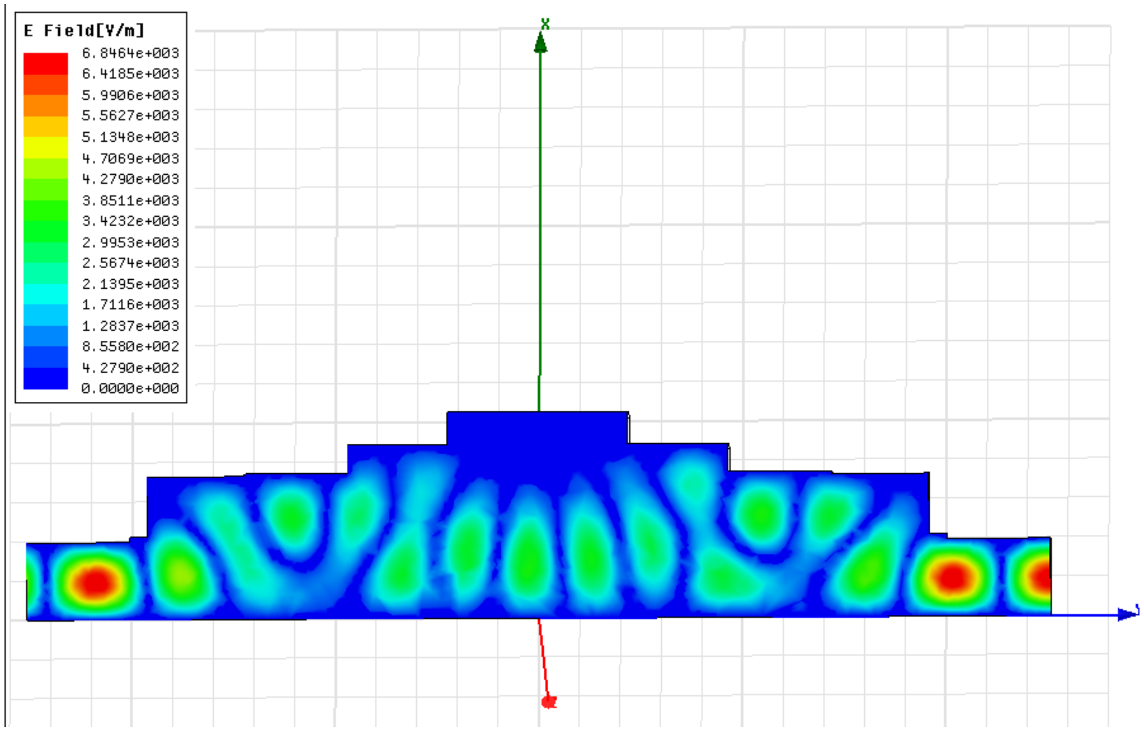


Dual moded delay lines with variable delay for a flexible pulse width

All these components have designed and in different stages of manufacturing

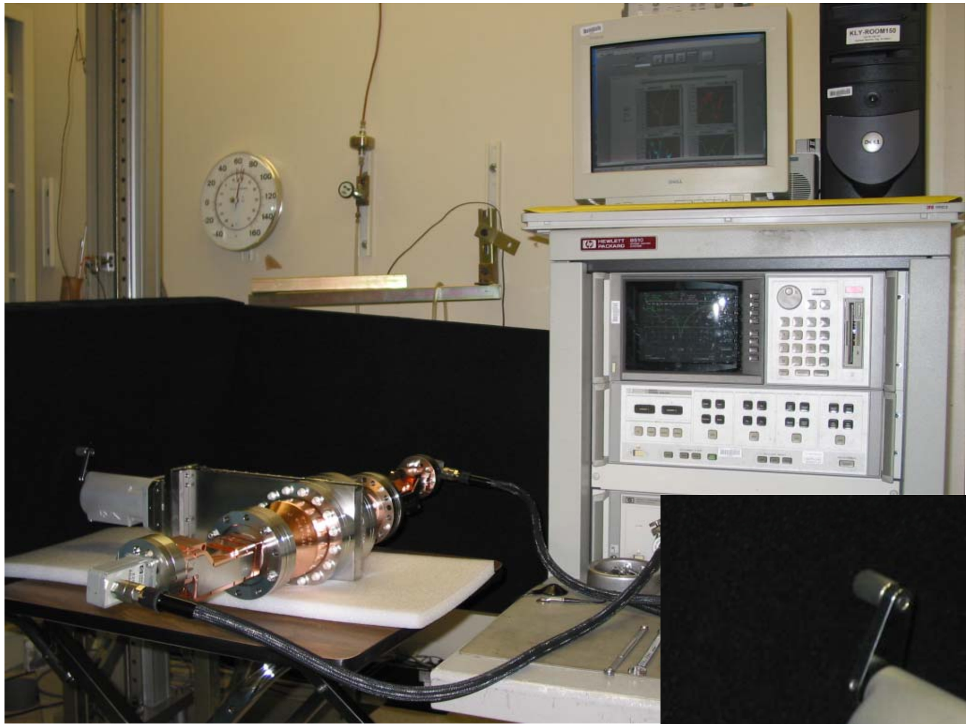
Gate Valve

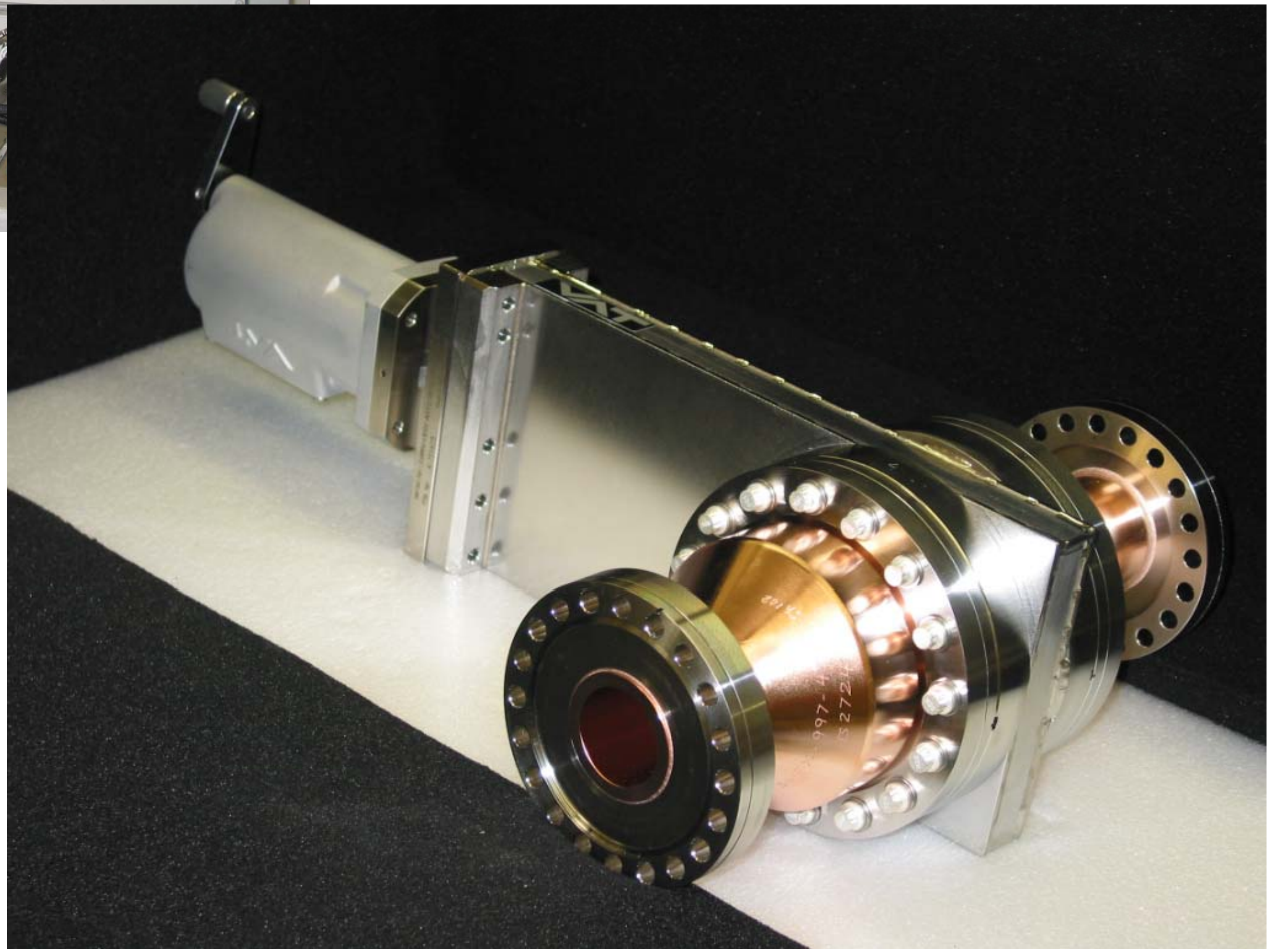


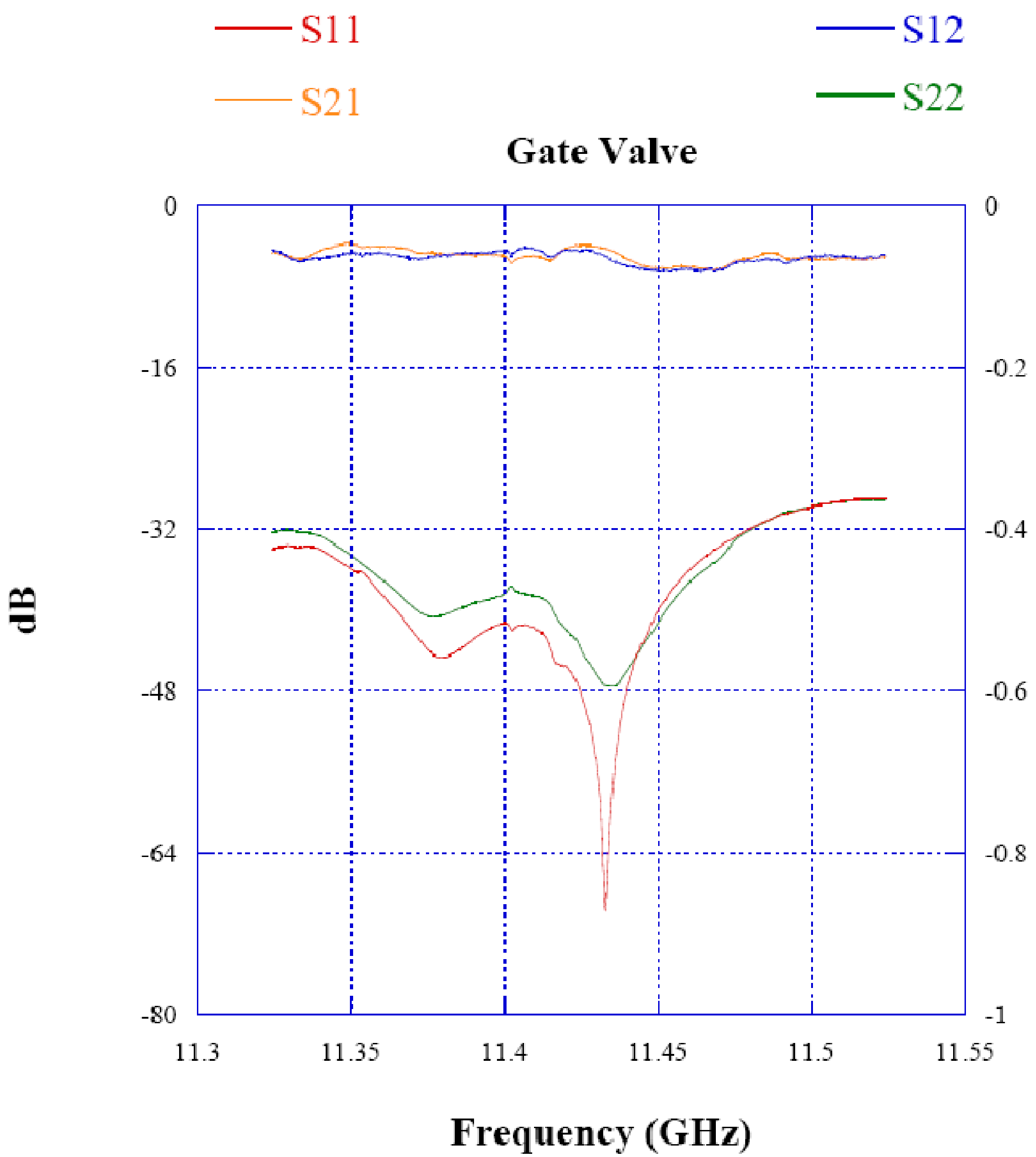


We have designed a new type of gate valves to allow fast exchange of experimental structure. This will cut the change time from a week to one day

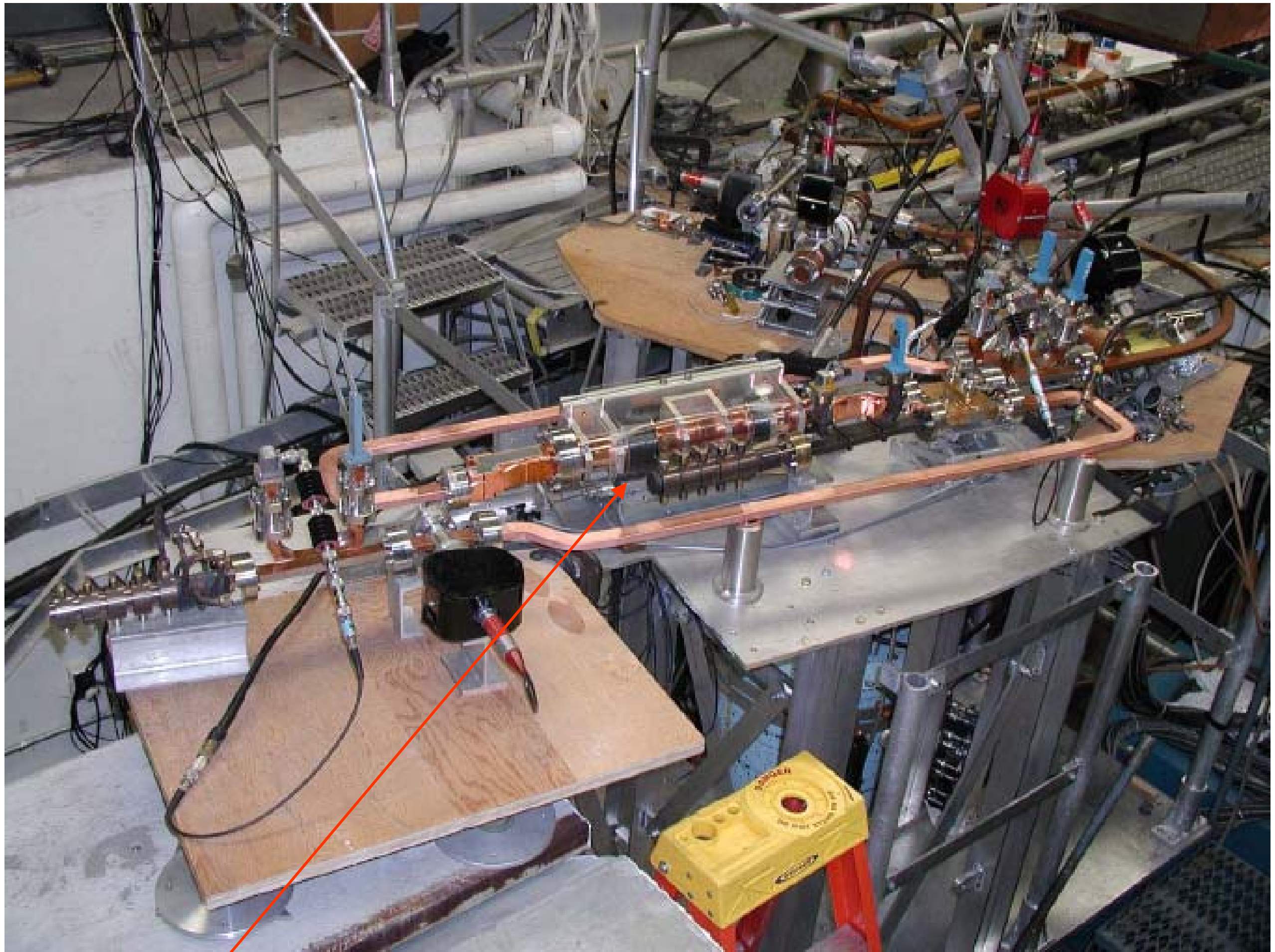
A. Grudiev, “Development Of A Novel Rf Waveguide Vacuum Valve,” Proceedings of EPAC 2006, Edinburgh, Scotland


KLY-ROOM150




S11
S12
S21
S22
Gate Valve
0
-16
-32
-48
-64
-80
0
-0.2
-0.4
-0.6
-0.8
-1
dB
11.3
11.35
11.4
11.45
11.5
11.55
Frequency (GHz)

X-band Setup at NRL

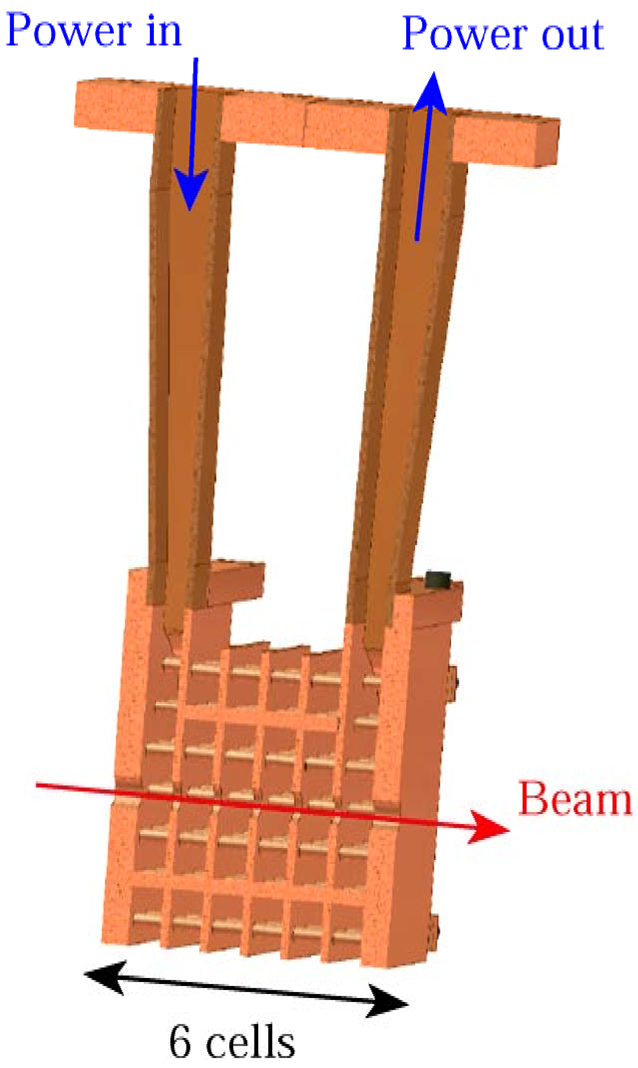


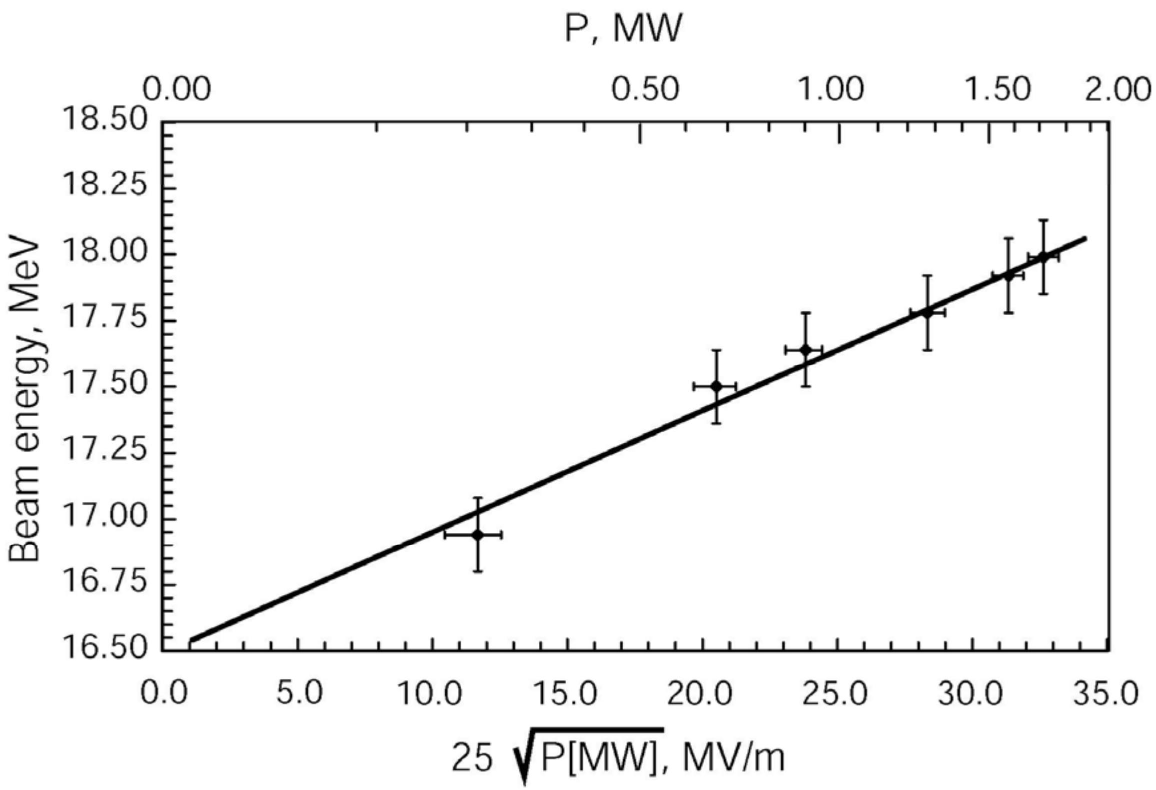
SLAC components (A combiner specifically designed and build for NRL)

MIT User Facility

- Planned collaborations through the High Gradient Collaboration:
  - Continue long term collaboration with Haimson Research
  - Testing of Univ. CO dielectric PBG structures, part of High Gradient Collaboration (G. Werner, J. Cary)
  - Proposed collaboration with SLAC / CERN
- Test RF breakdown, novel structures
- Facility Upgrade:
  - Phase I: Purchase new DC power supply, 65 kV, 30 kJ/s for higher repetition rate operation; funded by supplement in 2006.
  - Phase II: Design and procurement of modulator components to complete the upgrade - not yet funded.

Accomplishments: PBG Accelerator Expt.





- First successful experimental PBG accelerator demonstration.

E. I. Smirnova et al., Physical Review Letters (2005).

Experimental Facilities

- ASTA is being reconfigured for operation with two X-band klystron and a pulse compressor
- The two-pack modulator is up and running and the system is being expected to run fully this summer
- We are making an enormous number of RF components to make the experimental procedure simple
- NRL’s RF components have been manufactured and fully delivered
- MIT power supply have been ordered, delivery is due late spring/summer

High power tests at X-band which was performed during the last few month

- Molybdenum CERN structure
- Copper CERN Structure
- Old NLC structures
- Single Cell traveling wave structures
- ANL dielectric structure
- Semiconductor (si) breakdown test
- Superconducting Material Test
- Single Cell Standing wave accelerator structure
- CERN’s Pulsed heating

Single Cell Structures

Traveling Wave

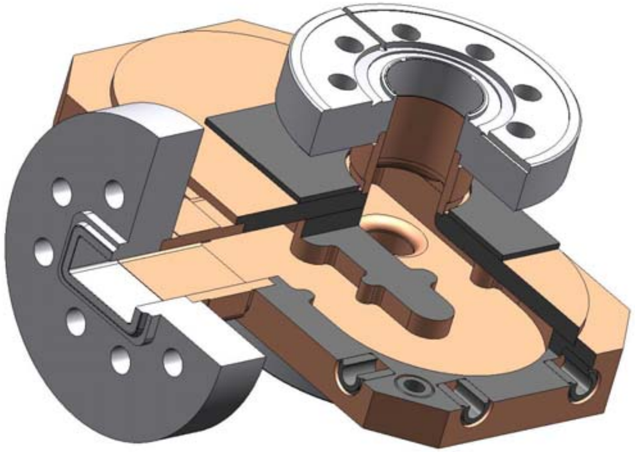
- Fields are the same as in first cell of NLC structure T53VG3
- High electric and magnetic fields are ***only in this cell*** (not in couplers)
- ***Reusable couplers*** – mode launchers that transform the TE_{10} mode of rectangular waveguide into the "accelerating" circular TM_{01} mode

Standing Wave

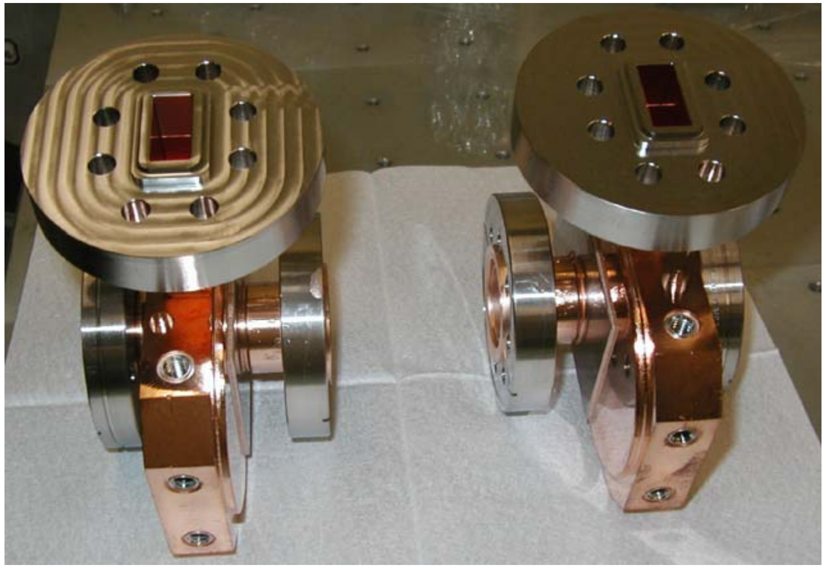
- Fields in the middle cell of the SW structure are similar to fields of a large-aperture SW structure SW20a565
- Fields in the middle cell twice as high as in other two cells

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

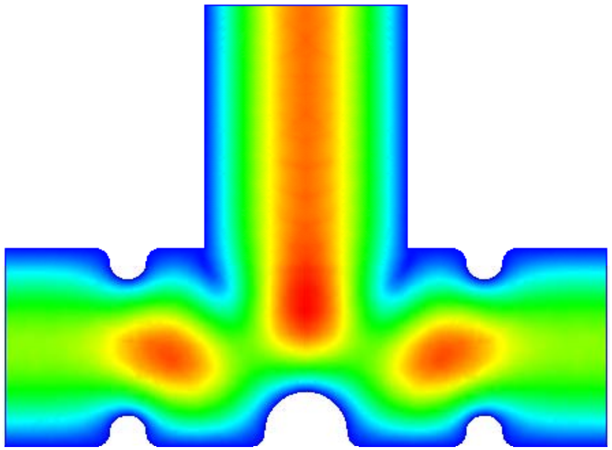
TM_{01} Mode Launcher



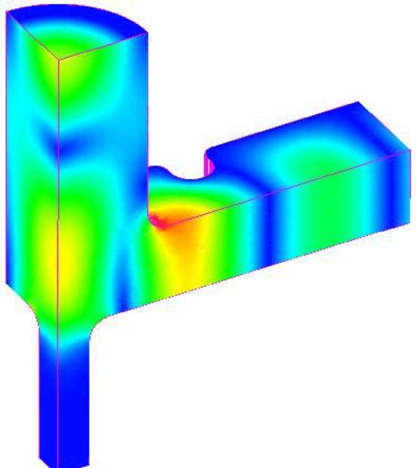
Cutaway view of the mode launcher



Two mode launchers

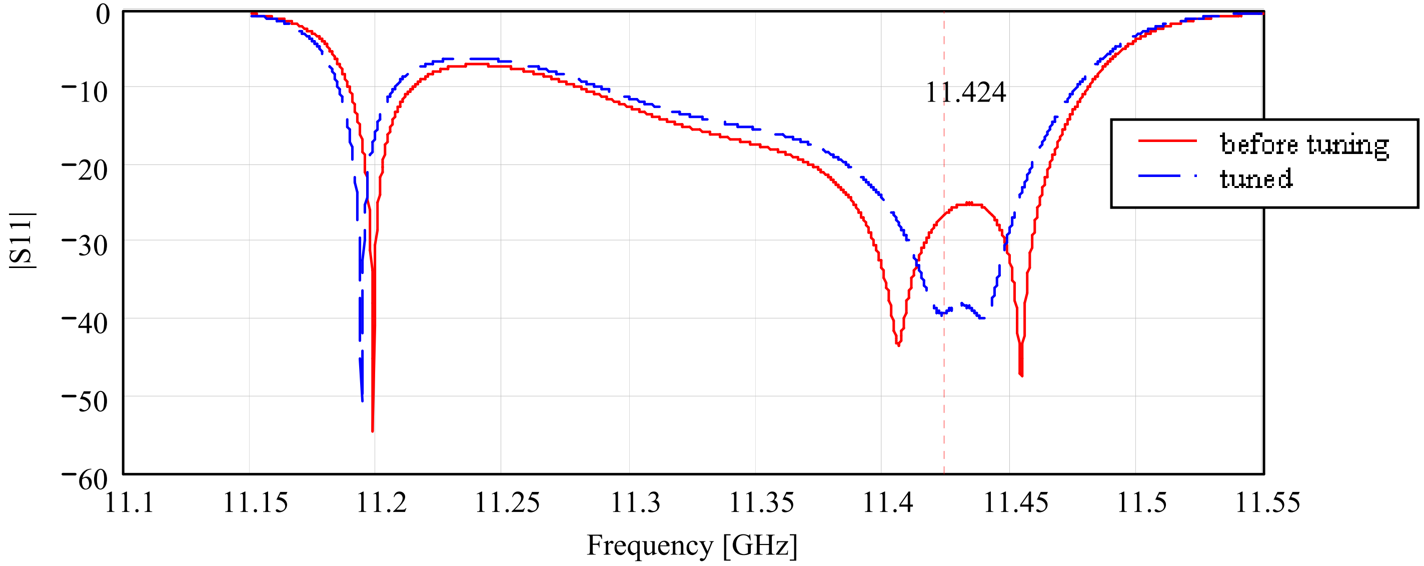


Surface electric fields in T splitter,
E_{max}= 30 MV/m for 100 MW

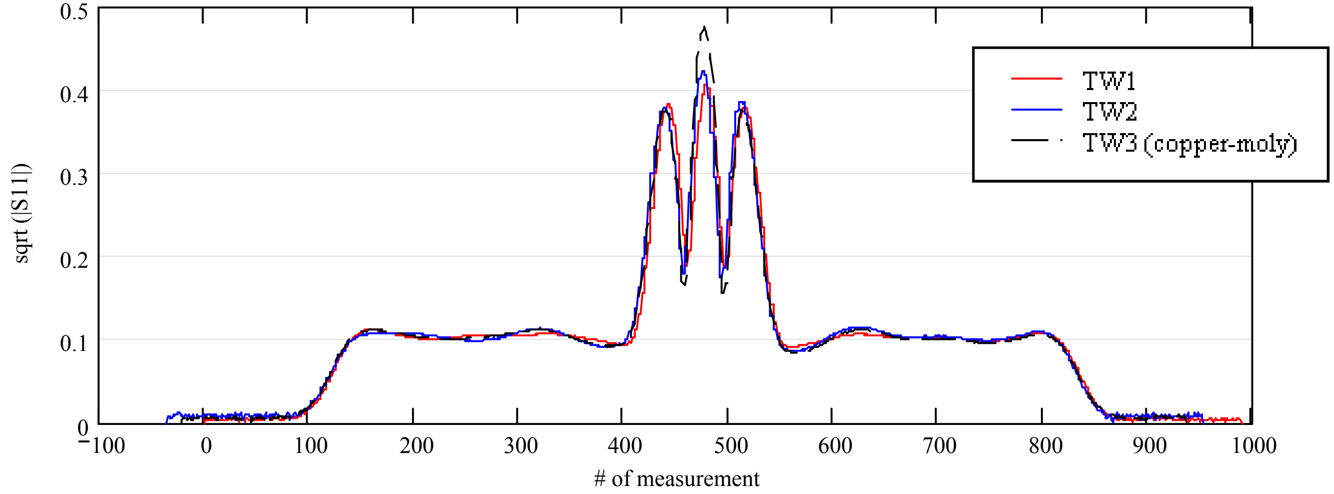


Surface electric fields in the mode launcher
E_{max}= 49 MV/m for 100 MW

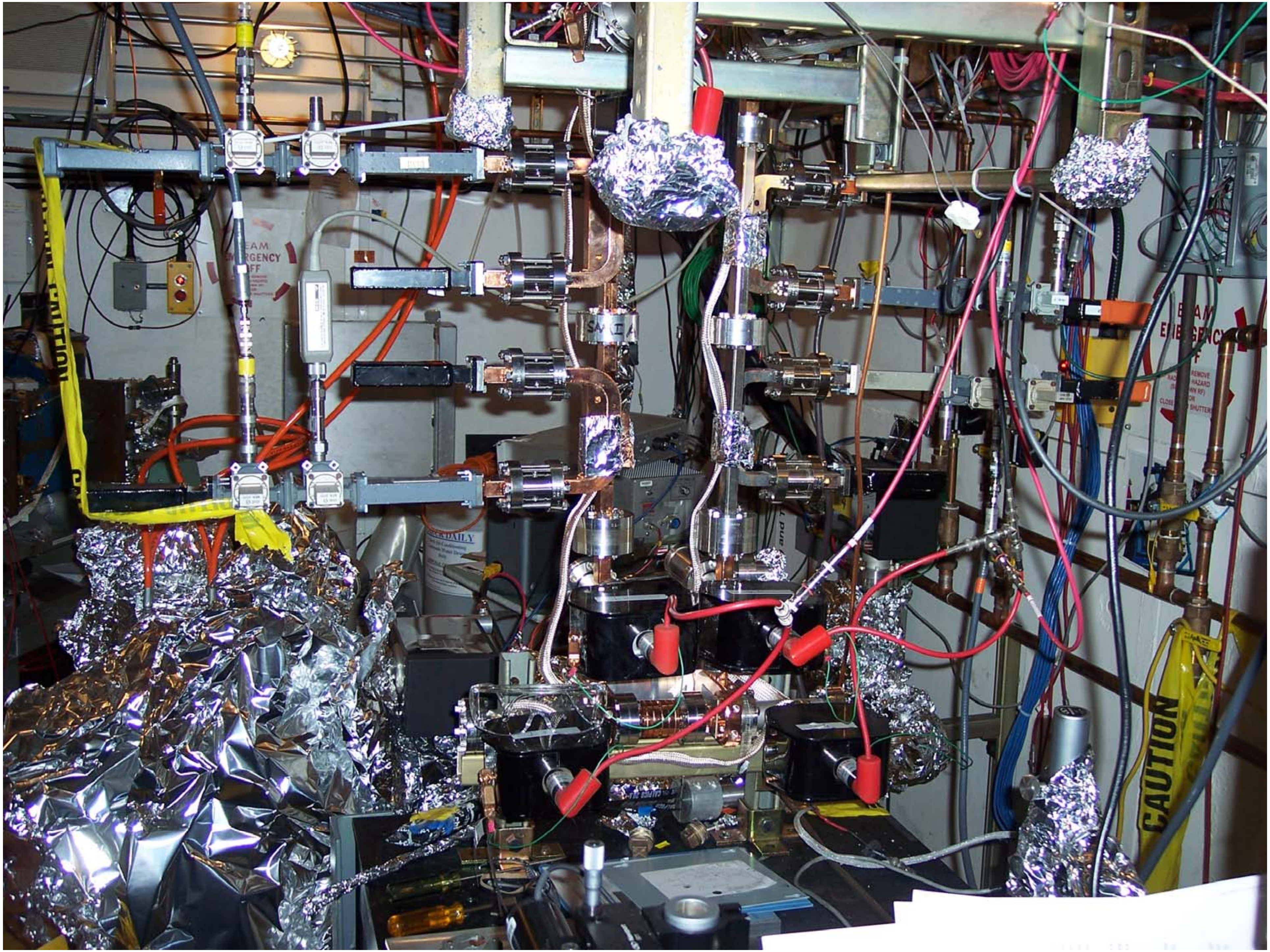
Cold Test With Single Cell Traveling Wave Structure

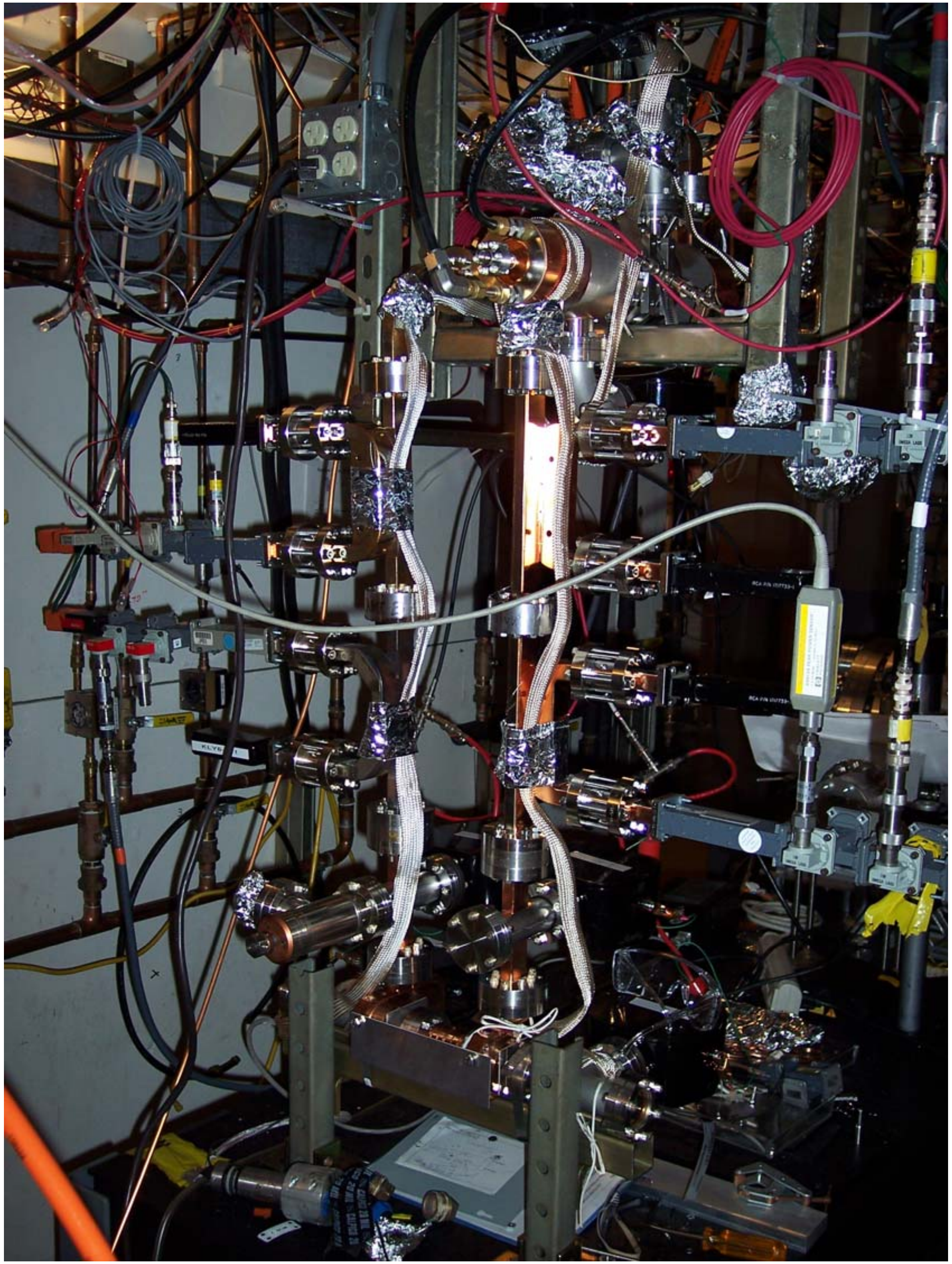


Reflection from single cell TW structure before and after tuning



On axis field profile for three single cell TW structures


CAUTION

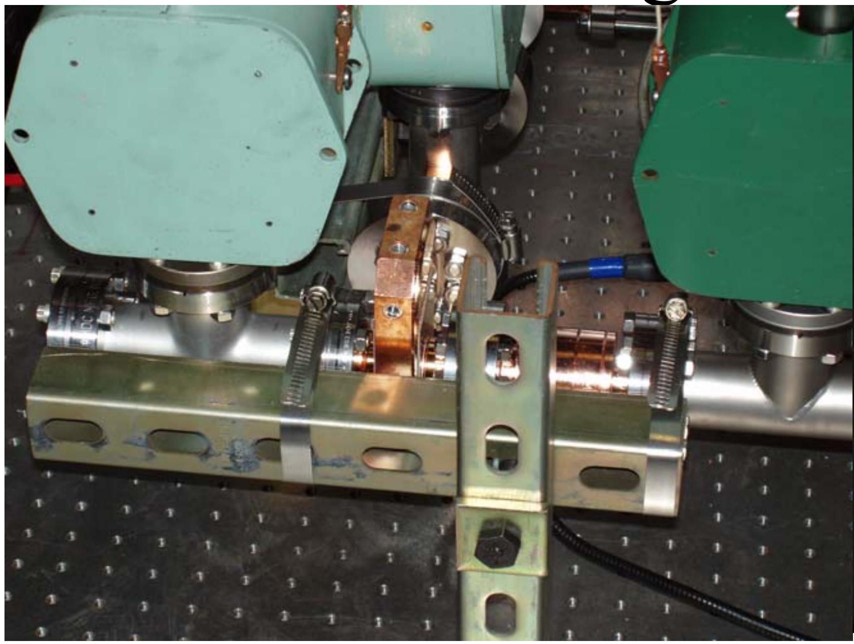
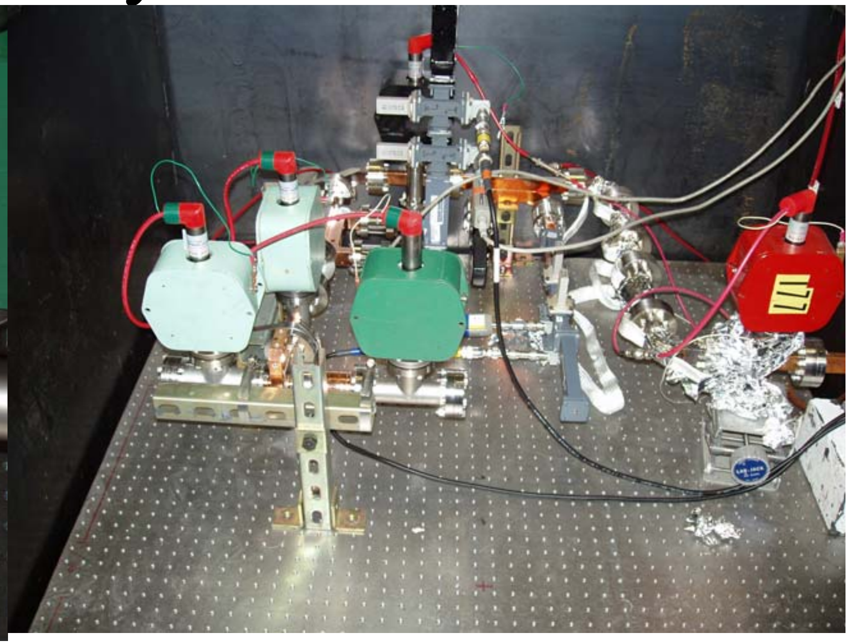


Results of High Power Test of First Single Cell Traveling Wave Structure

- 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 Accelerator Structure

- The structure has been tested and the second structure is being tested by the end of this

Breakdowns in Single Cell SW structure

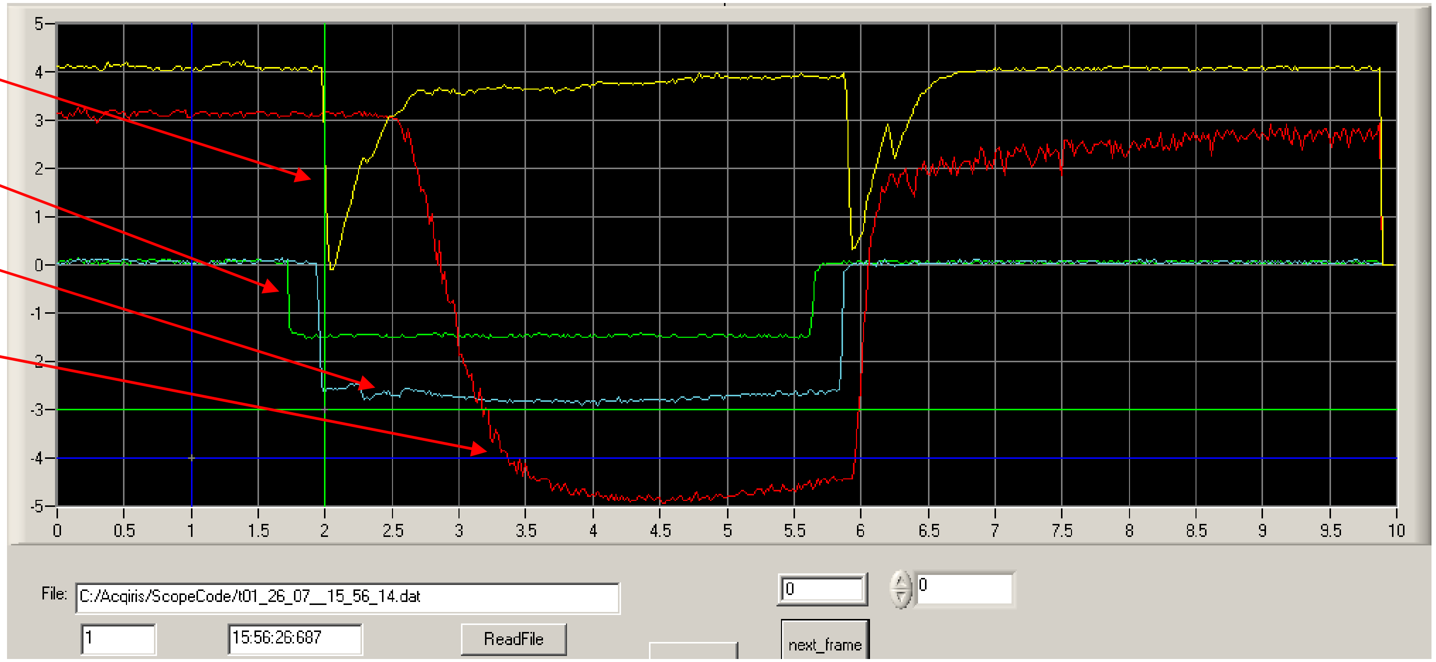
Reflected

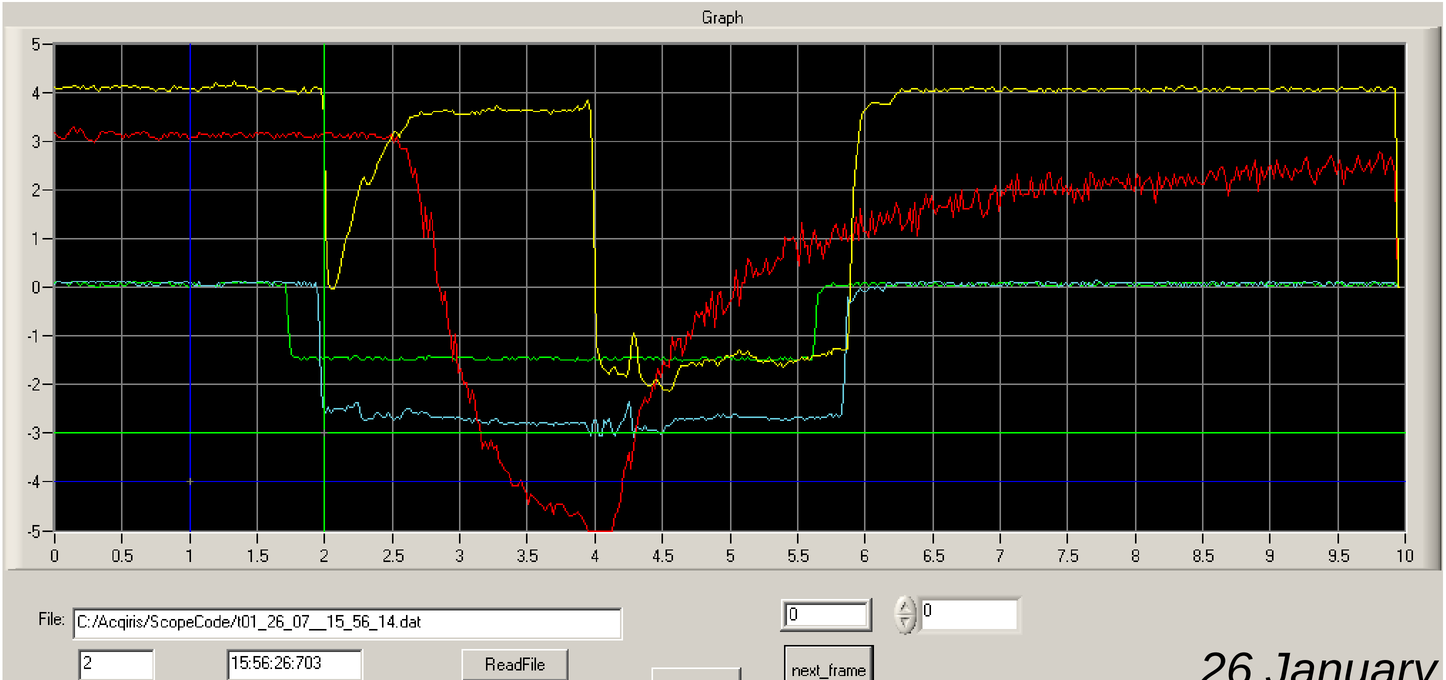
TWT

Forward

PMT

Pulse Before Breakdown

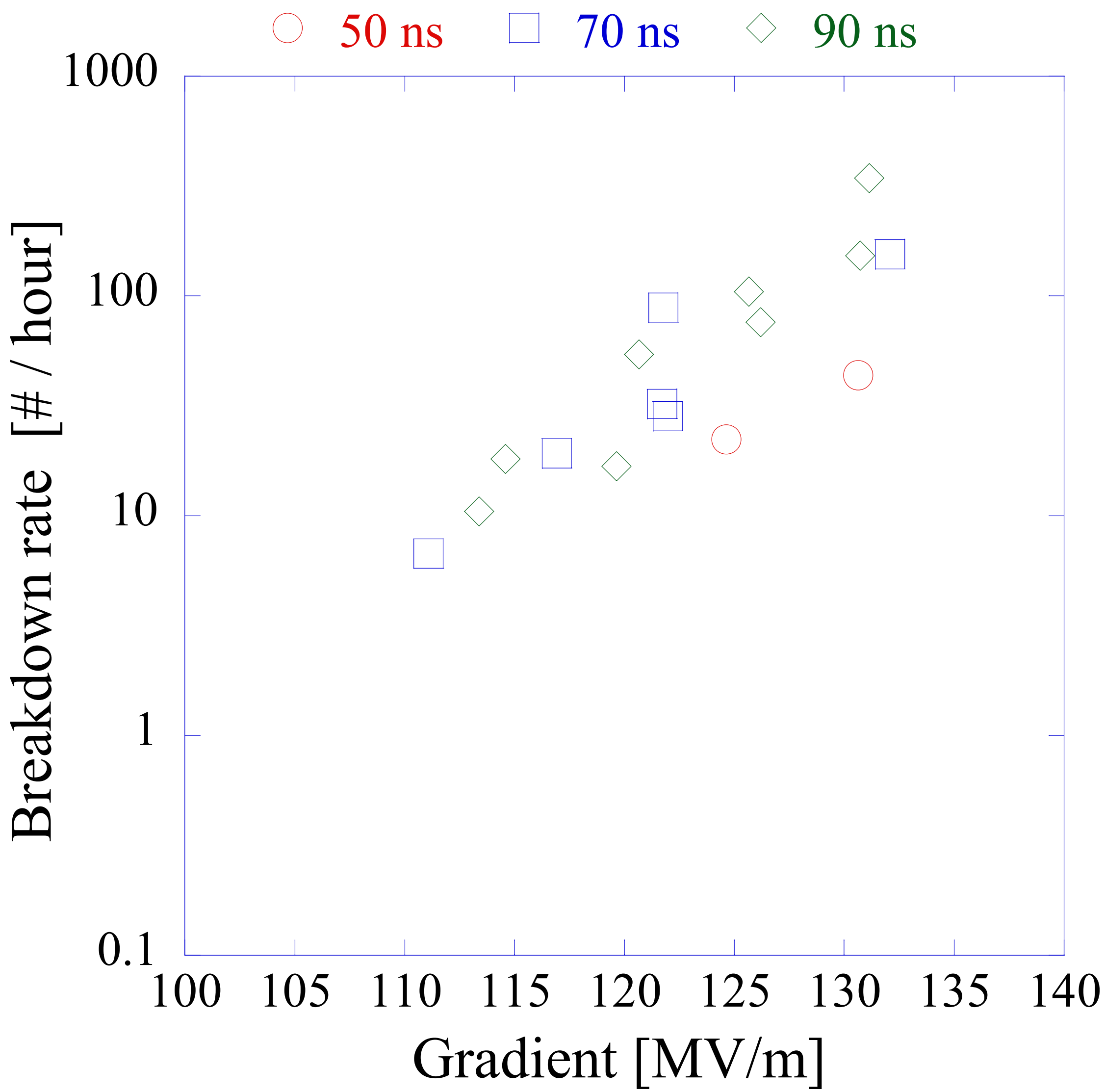




Breakdown

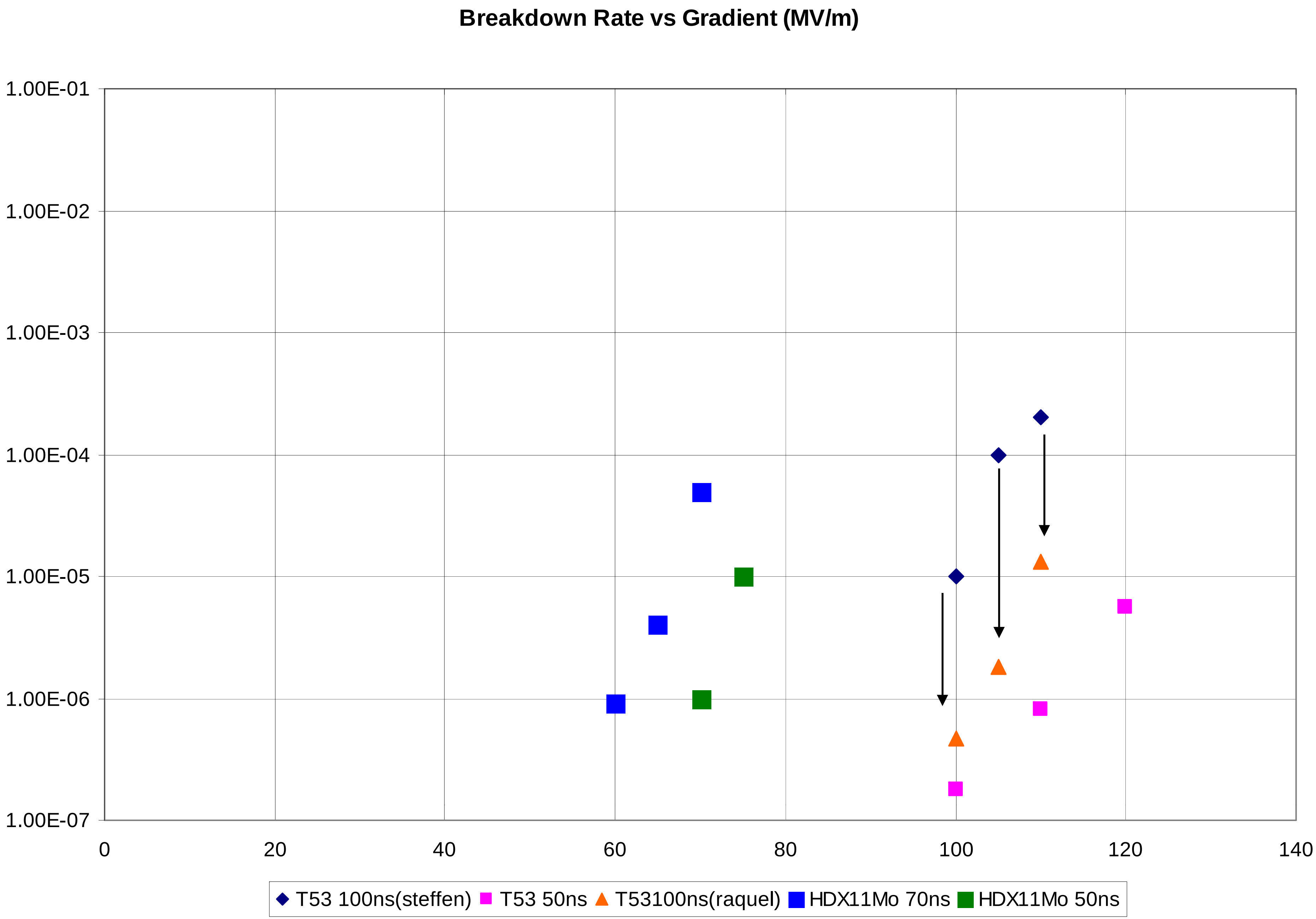
26 January 07

Standing-Wave Structure Result Summary at Repetition Rate of 60 Hz (a/λ~0.21)



Four Quadrants of a Novel Structure Design Developed by the CLIC group at CERN

(X-band version being Tested at NLCTA)



Breakdown Rate vs Gradient (MV/m)
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
0
20
40
60
80
100
120
140
T53 100ns(steffen)
T53 50ns
T53100ns(raquel)
HDX11Mo 70ns
HDX11Mo 50ns

Summary of Structure Testing Results

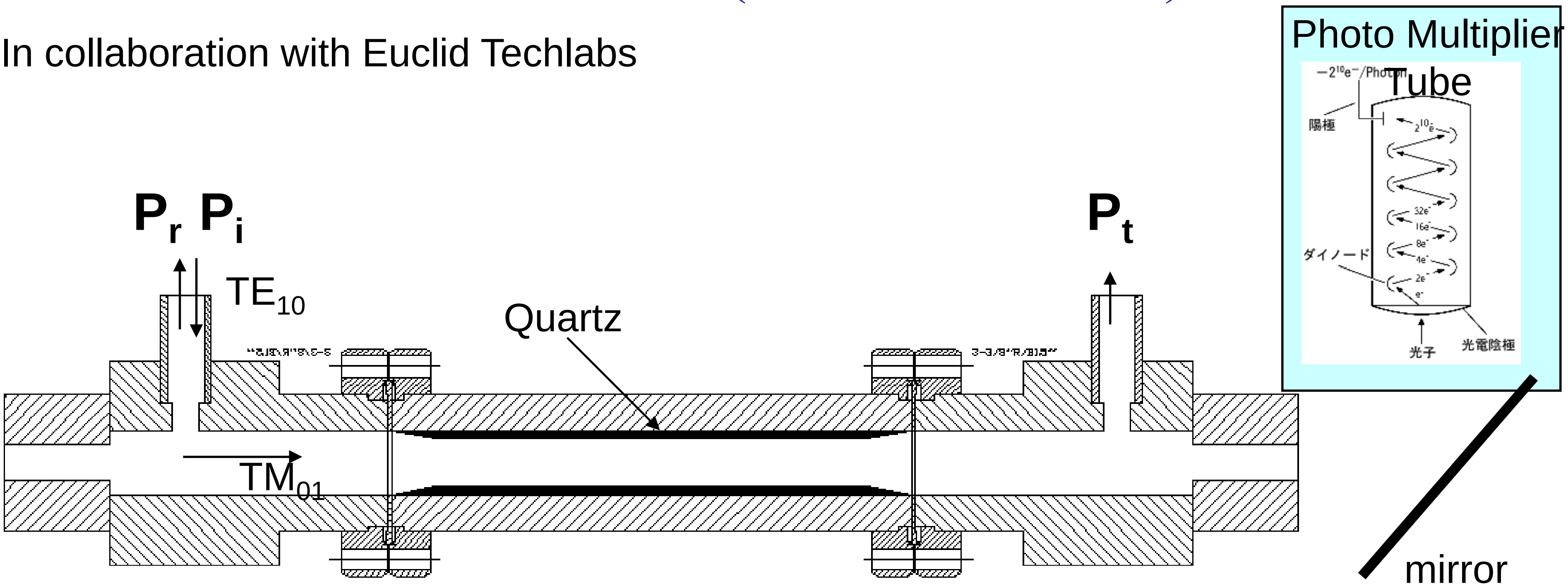
- Standing wave structure > 100 MV/m for very low breakdown rate at 90 flat pulse width after the filling time (equivalent 180 ns for TW structures) $a/\lambda \sim 0.21$

- H75vg4S18, it is < unity at 94 MV/m with 150 ns pulses. $a/\lambda \sim 0.17$

- T53VG3MC, it is < unity at 100 MV/m with 150 ns pulses. $a/\lambda \sim 0.13$

Recent High Power Fused-quartz DLA Structure Test at SLAC (Nov-Dec 2006)

In collaboration with Euclid Techlabs



Synopsis:

- Studied multipactor at higher power with SLAC XL-4 klystron
- Reached highest power tested to date: 37 MW (previous 12 MW)
- Used short pulse (20 ns & 50 ns) for initial test
- Diagnostics: Power and light monitoring.

Future Work

- Frequency Scaling Studies
  - It is conjectured that the frequency scaling for copper structures is fundamentally due to incidental pulse length parameters which favor higher frequencies because of the shorter filling time.
  - However to date a systematic study which uses the same geometry at different frequencies have never been conducted.
  - We are now at position that will allow us to do this and we should take the chance and conduct such a series of experiments. At SLAC 11.424 frequency sources are available, at MIT, soon there will be a high repetition rate reliable source at 17 GHz, and finally at CERN there is a room for testing structures at 30 GHz (May be also possible at Yale).
  - We intend to build a set of reusable couplers and a set of single cell standing wave accelerator structures with a/l of about 0.21 to test at different frequencies. The test at 11.424 is under way at SLAC; we will duplicate its geometry at 17 and 30 GHz.

Future Work

- Geometry Studies
  - Standing wave structures, traveling waves structures with different phase advances and iris shapes. In this category, we are planning to test 4 structures in the immediate future:
    - Three cell standing wave structure
    - Standing wave structure with optimized cell shape to minimize magnetic field
    - Standing wave structure with optimized cell shape to minimize the peak magnetic field times the electric field on the surface
    - Standing wave structures with reduced a/l
  - Heavily damped structures, 3 different types that are under studies:
    - Choked structures
    - Bi-periodic standing wave structures
    - The MIT photonic band gap structures

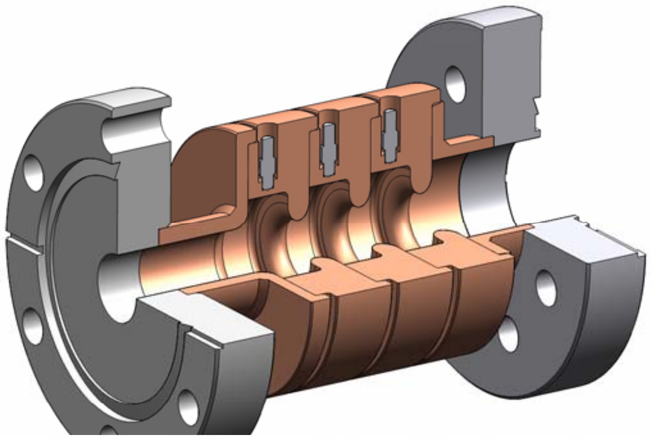
Future Work

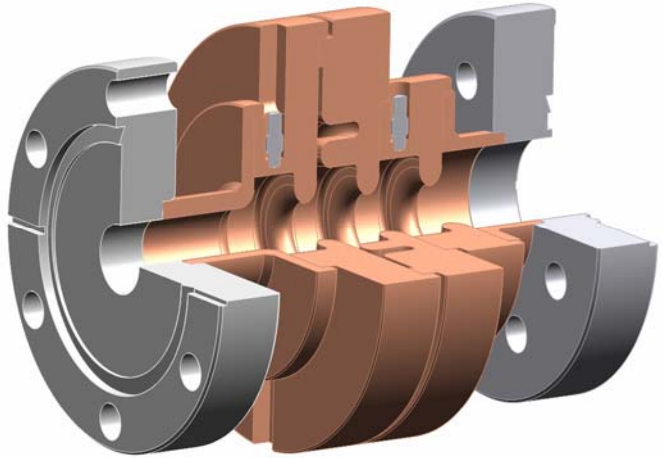
- Material Studies

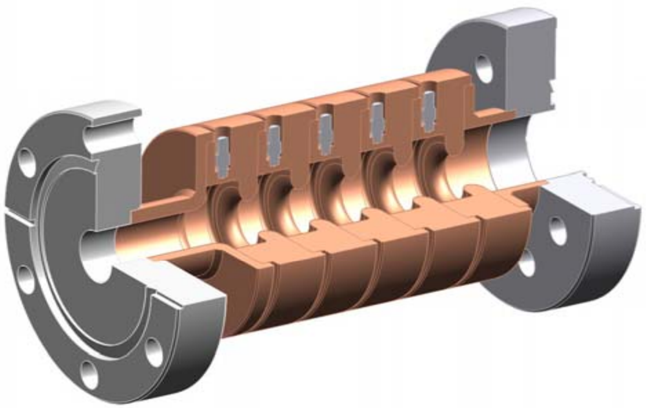
Materials is one of the key parameter that hold the potential for a breakthrough for high gradient accelerator structures. Initially we intend to concentrate on cupper alloys and processing of copper surfaces we are going to study:

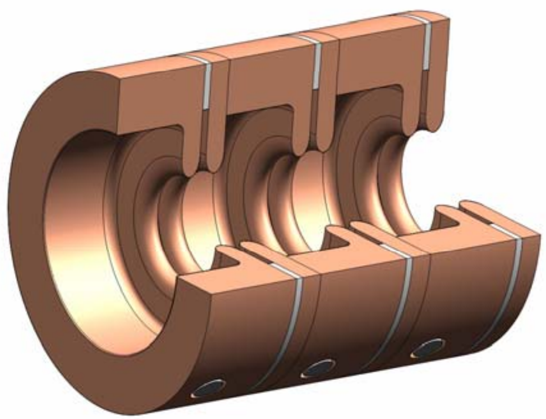
- Copper Zirconium
- Copper Beryllium
- Copper silver

Structure Shapes

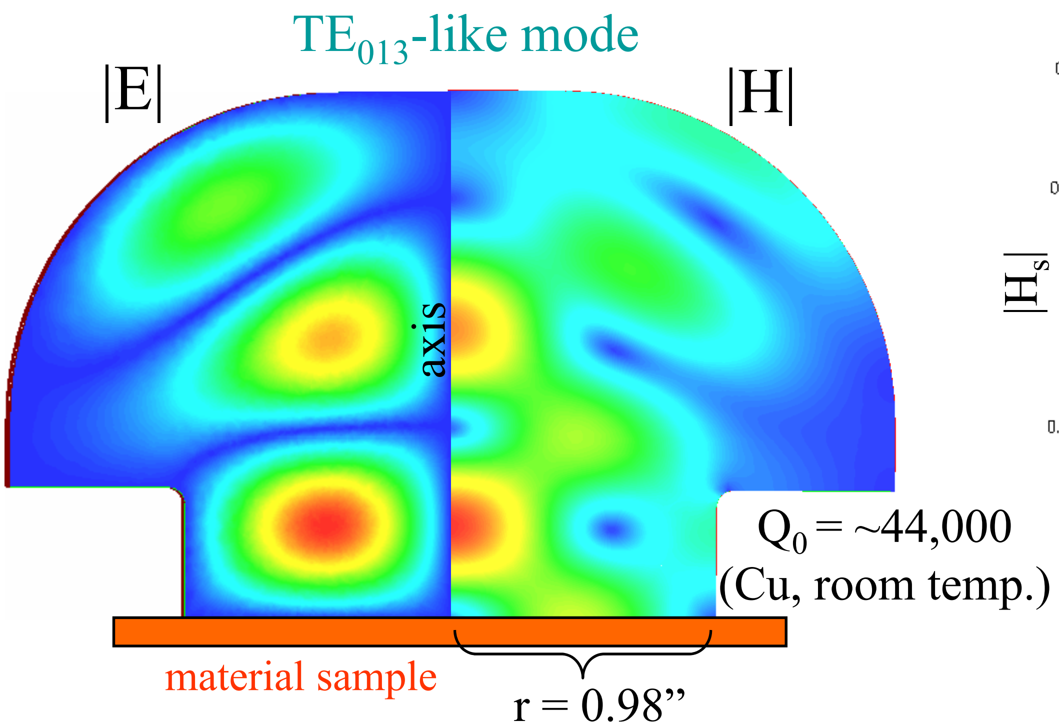


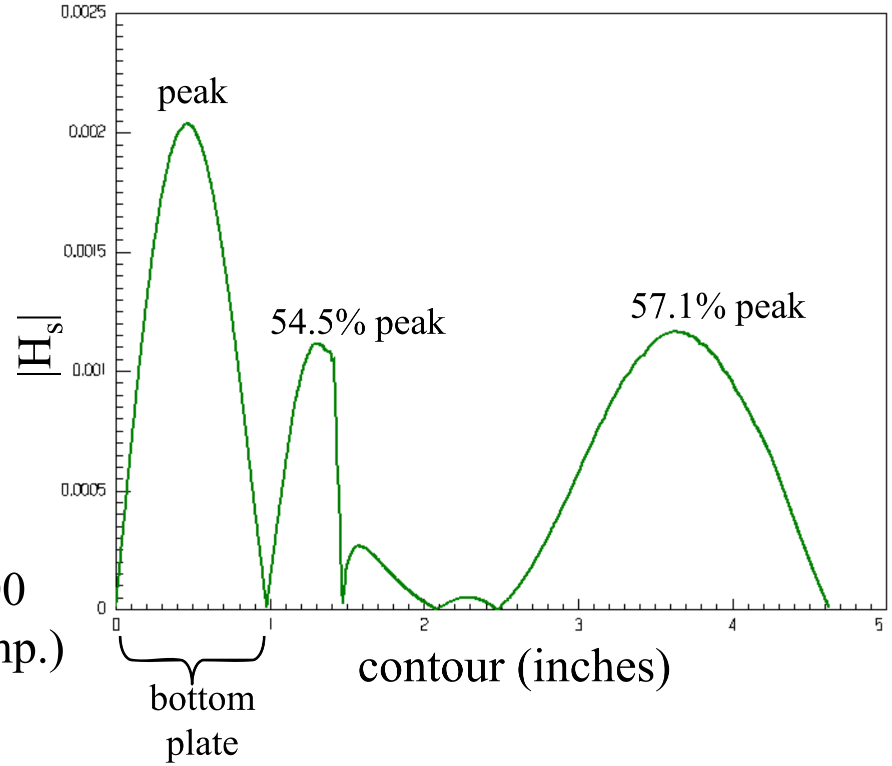






The Mushroom Cavity





<u>Why X-band</u> (~11.424 GHz)?:

- •high power & rf components available
- •fits in cryogenic dewar
- •small (3”) samples required

<u>Features:</u>

•No surface electric fields (no multipactor)

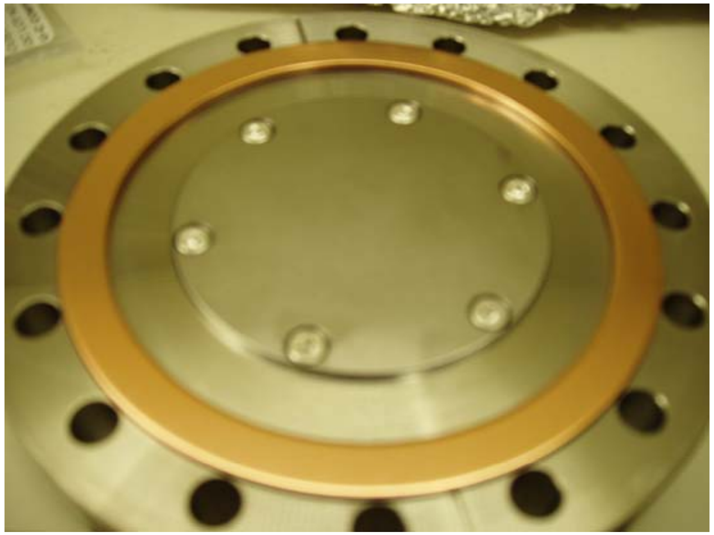
•Magnetic field concentrated on bottom (sample) face (75% higher than anywhere else)

•Purely azimuthal currents allow demountable bottom face (gap).

"Cold" Tests (Room Temperature)

room temp. measurements

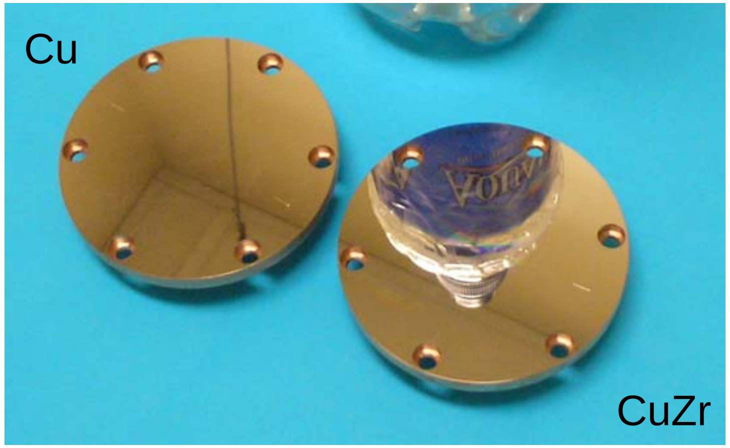
	HFSS (Cu)	Copper	Niobium
f_r	11.424	11.4072	11.4061
Q_L	30,991	29,961	20,128
β	0.4383	0.4611	0.2728
Q_0	44,575	43,775	25,619
Q_e	101,694	94,944	93,906



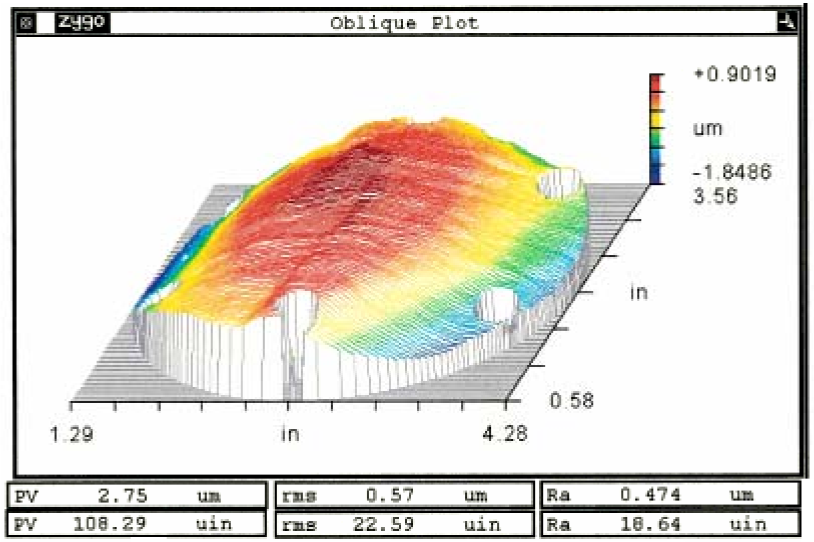
Nb sample mounted in bottom flange

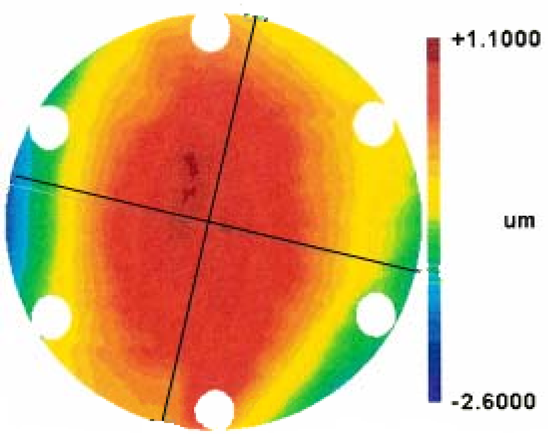
HP 8510C Network Analyzer

Pulse Heating Experiment: Cu and CuZr



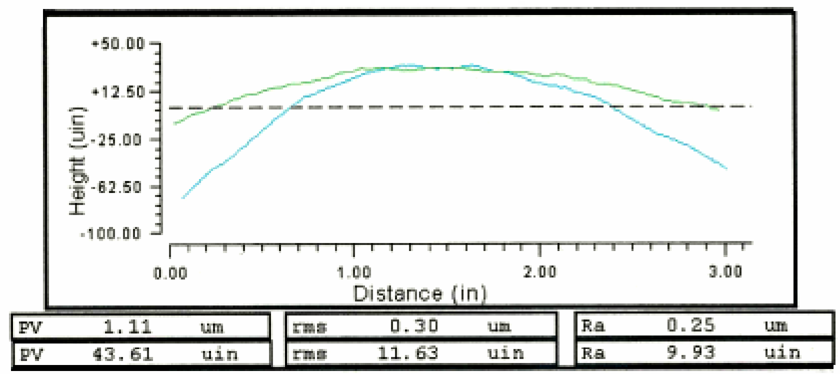
Surface Profilometry: Copper



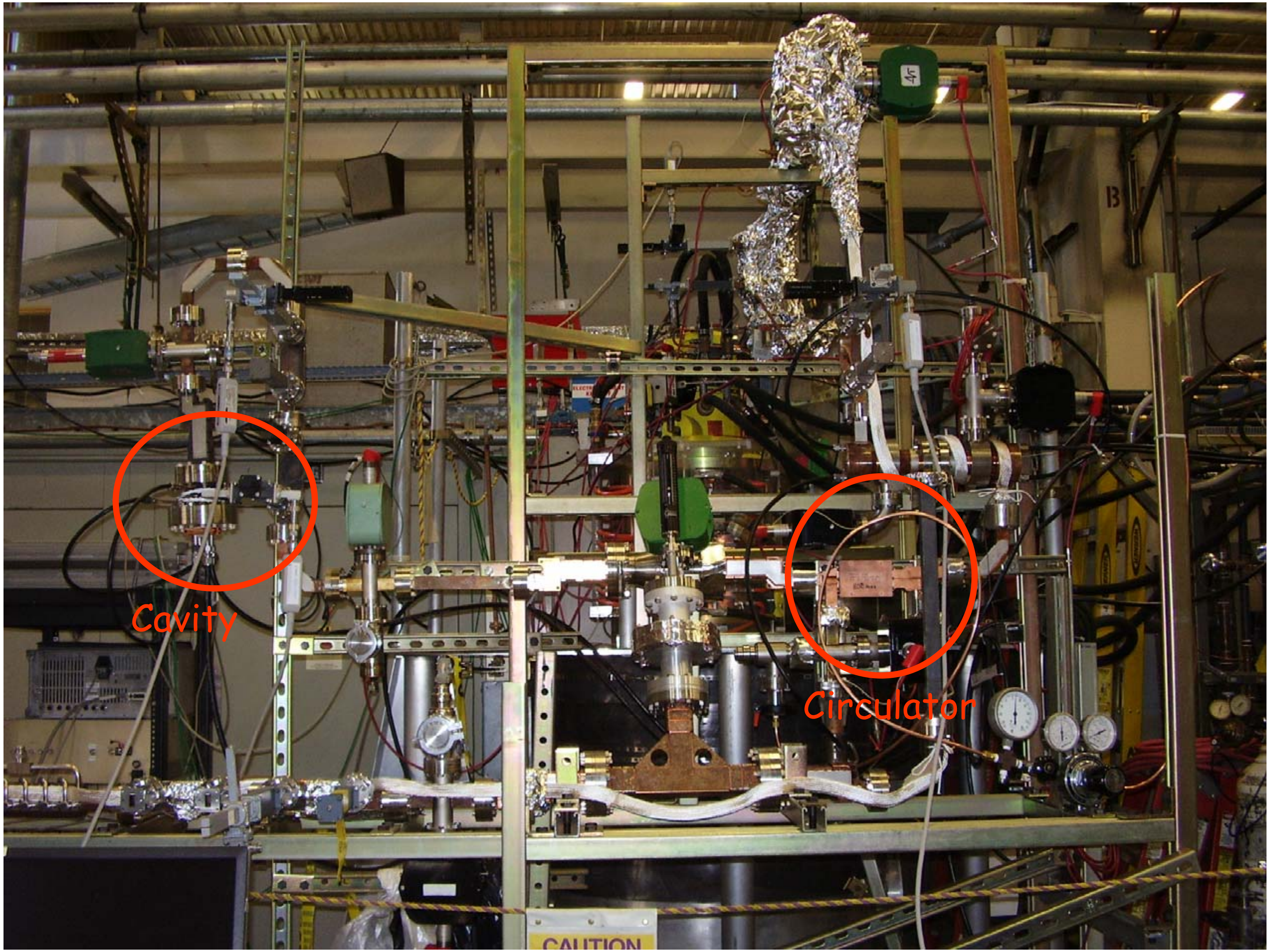


Cross Section

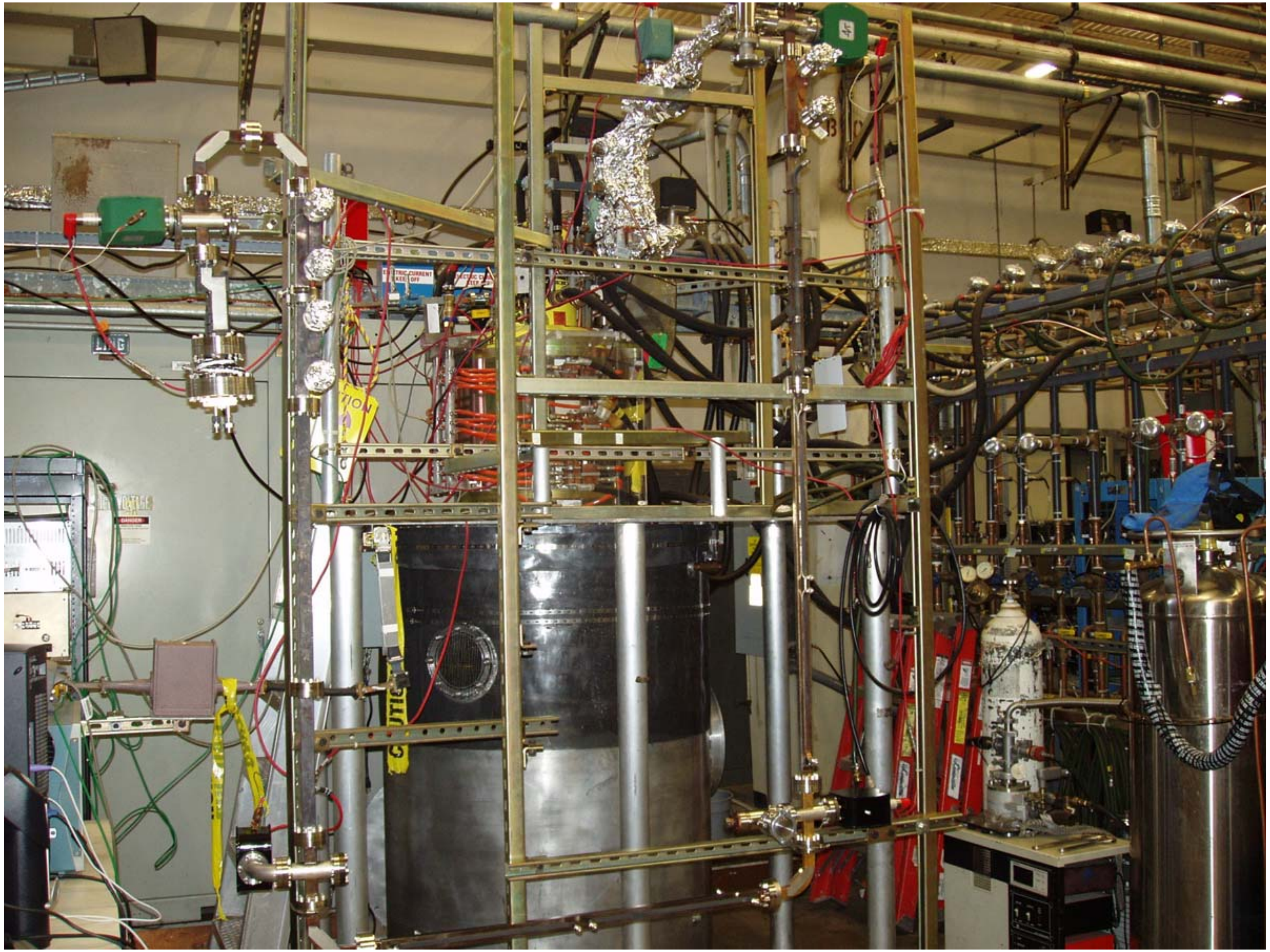
Surface Profile



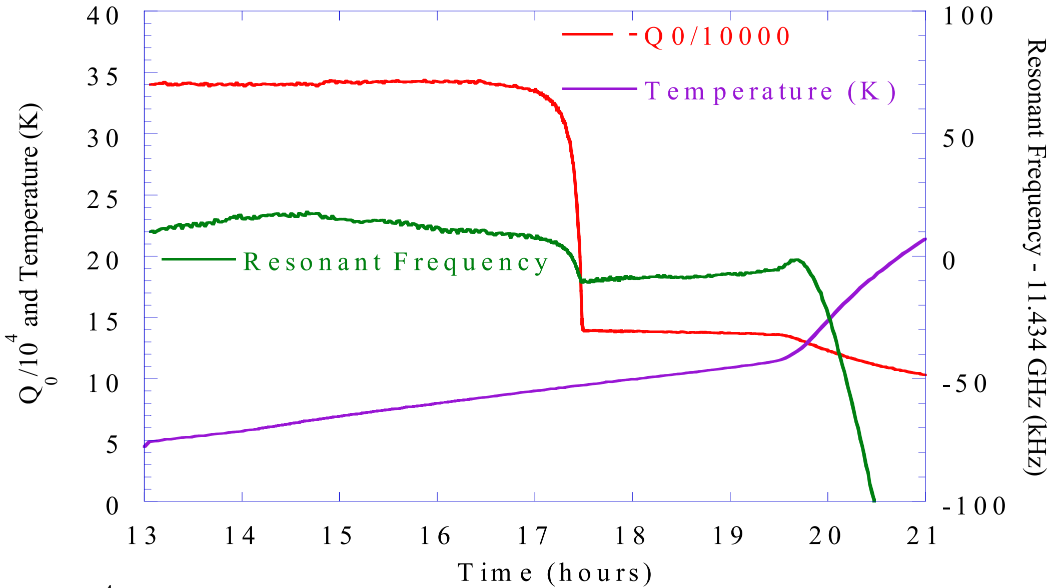
Pulsed Heating Experiment



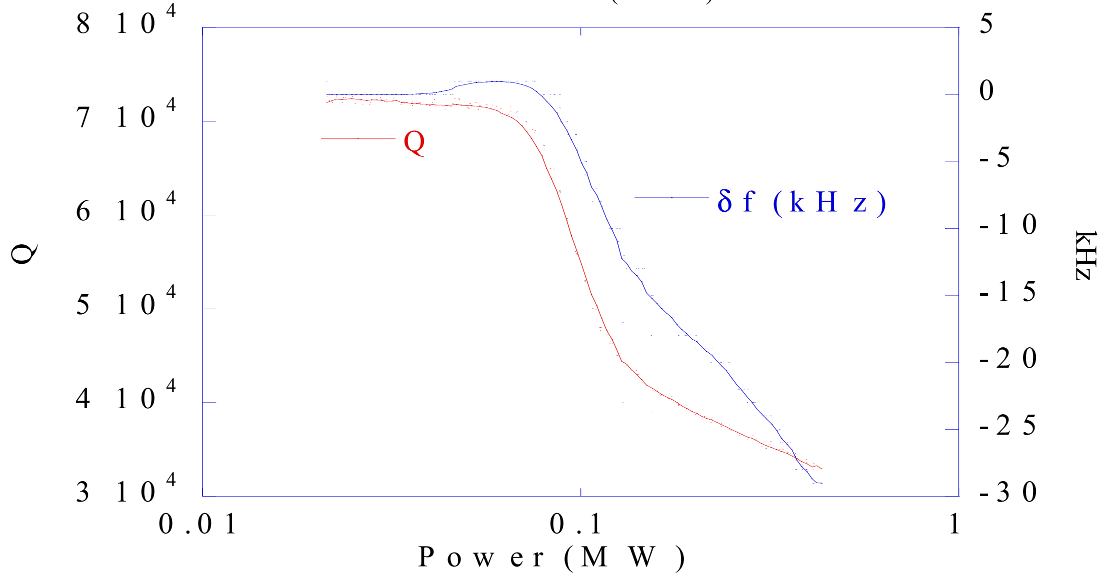
Pulsed Heating Experiment



Fundamental Research in RF Superconducting Materials



Low-power test

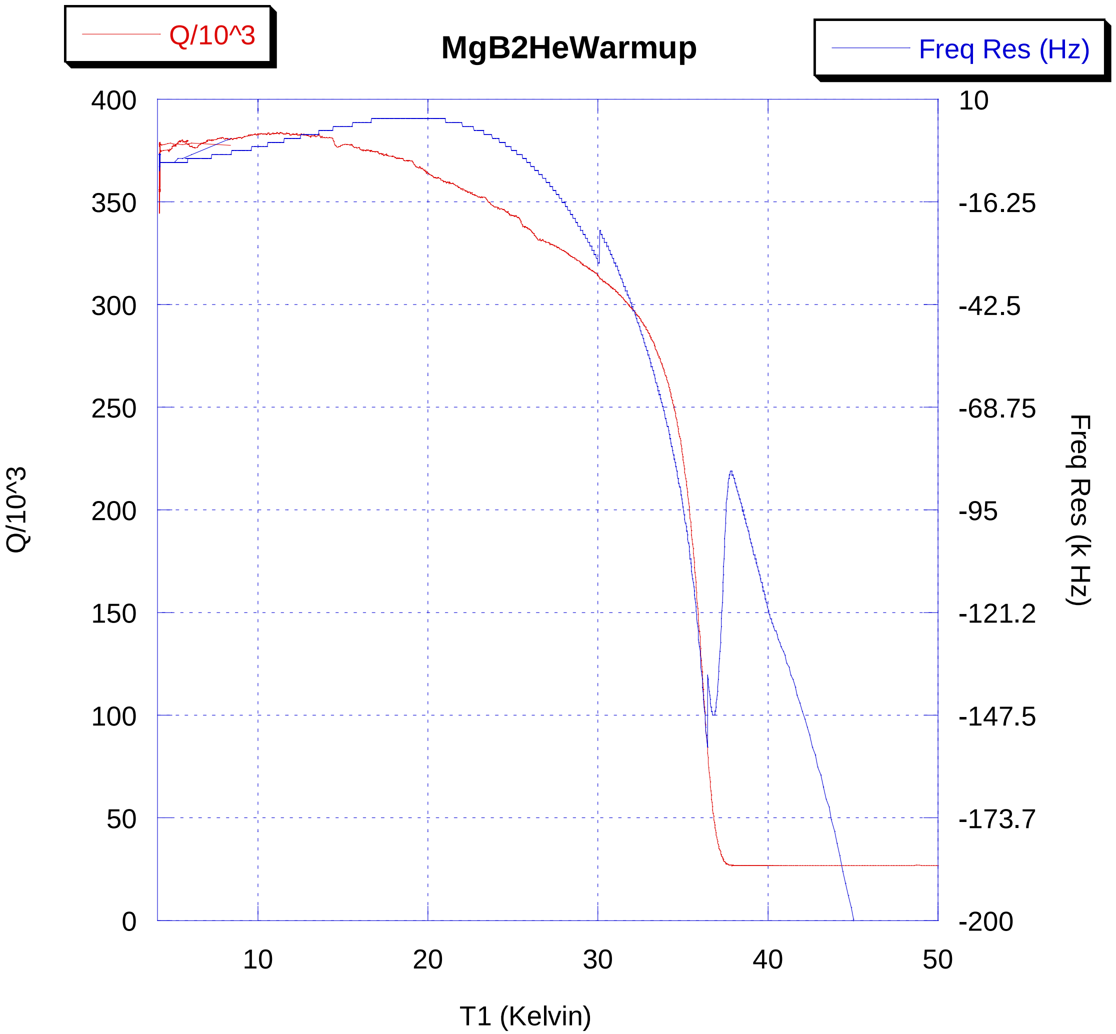


High-power test

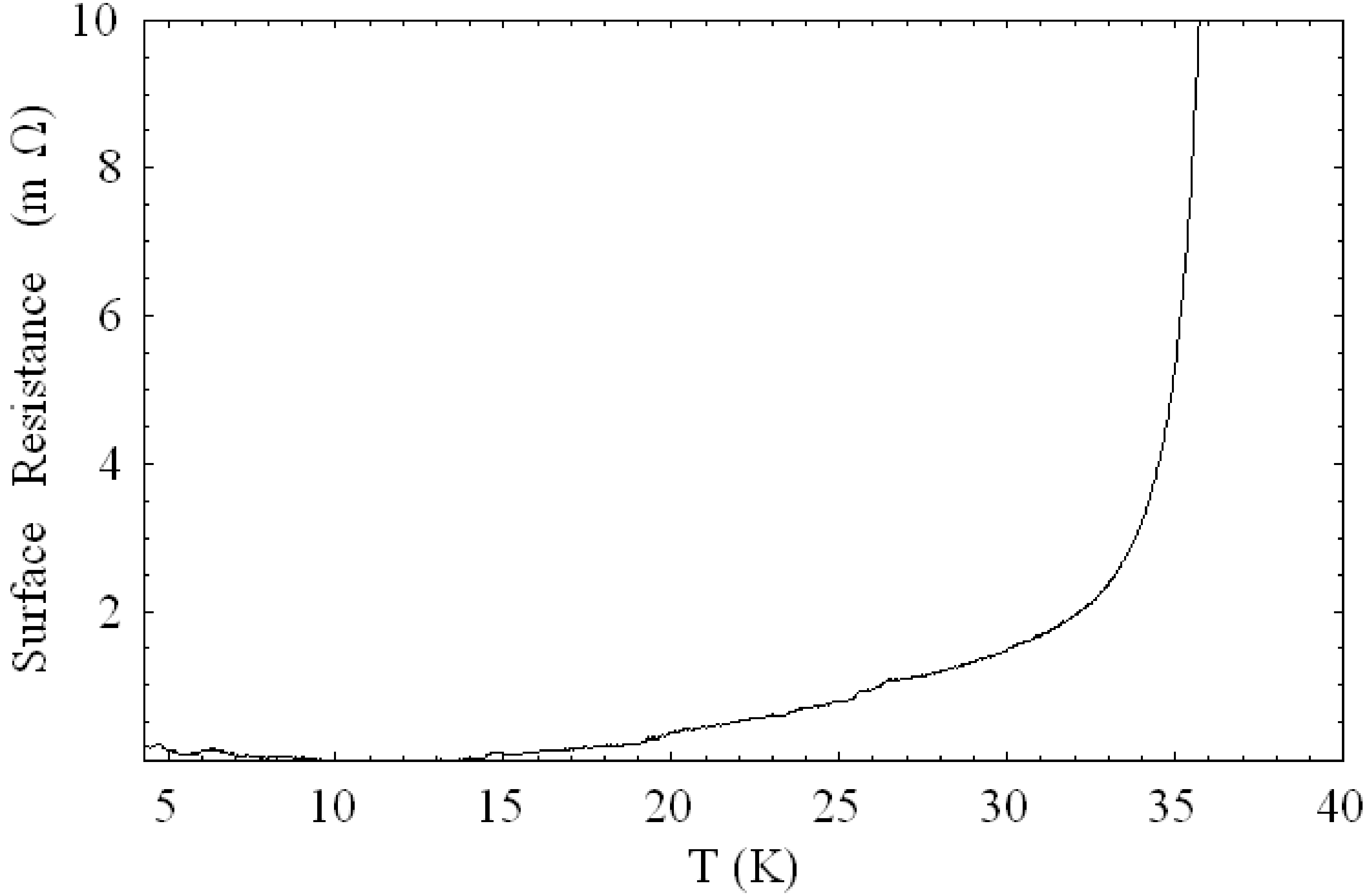
New test setup for inexpensive accurate characterization of high-field RF properties of materials and processing techniques

Sami Tantawi et. al.

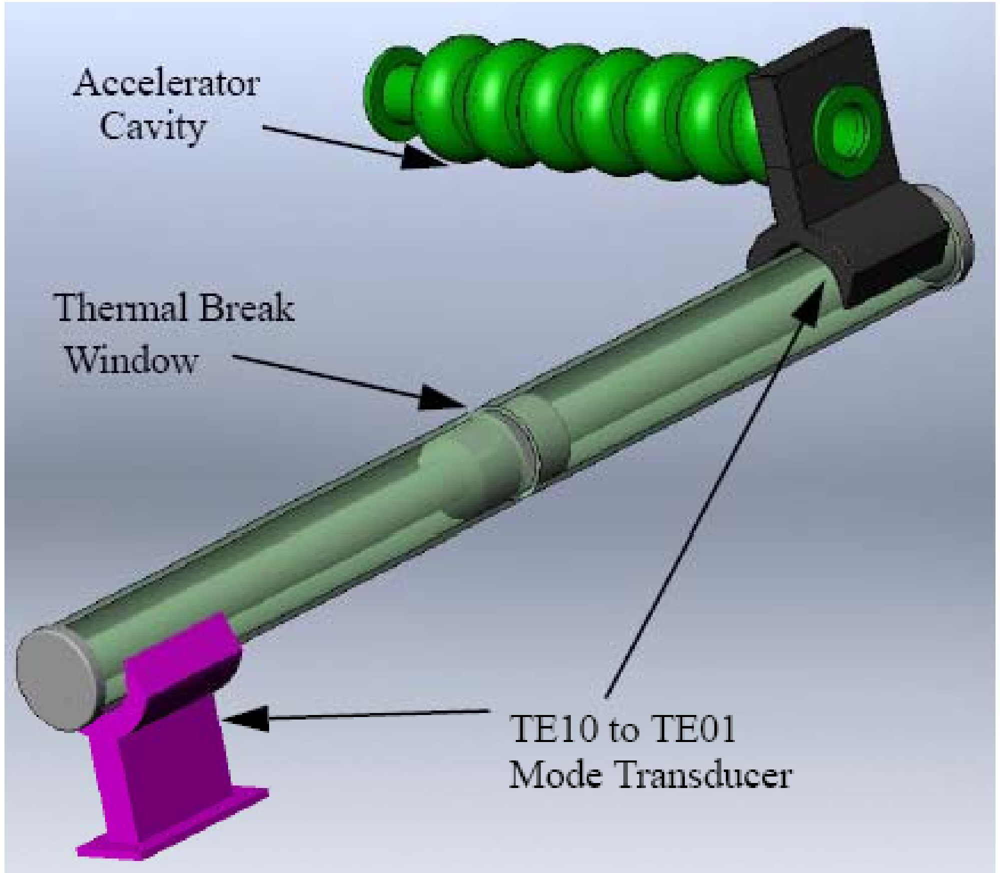
MgB_2


Q/10^3
MgB2HeWarmup
Freq Res (Hz)
400
350
300
250
200
150
100
50
0
10
-16.25
-42.5
-68.75
-95
-121.2
-147.5
-173.7
-200
10
20
30
40
50
T1 (Kelvin)
Q/10^3
Freq Res (k Hz)

MgB_2

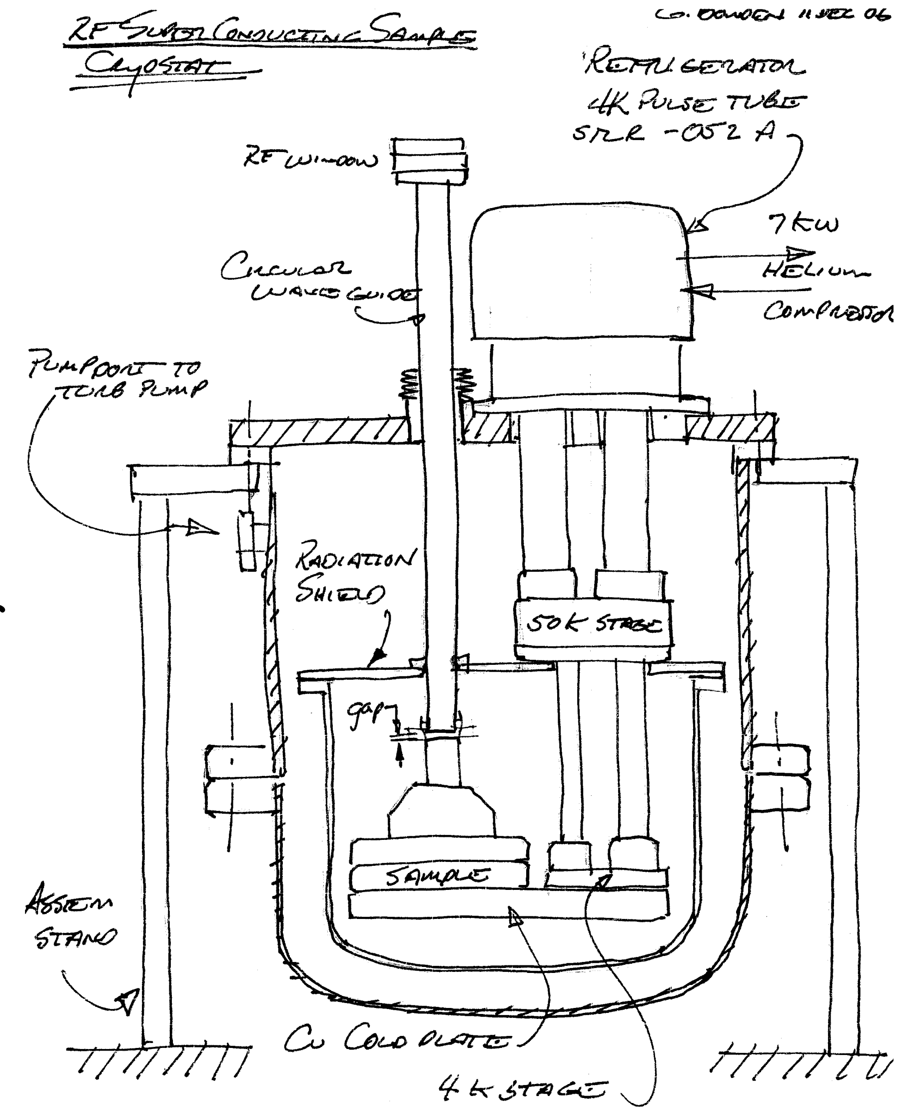


Conceptual drawing of power coupler using overmoded TE_{01} waveguide technology.



New Cryogenic System

- This new closed cycle cryogenic system will enable us to make fast changes and more frequent, experiments
- This new test facility will be used by collaborators from ANL, SNS, LANL, Texas A&M, etc.
- We are collaborating with various institutes on the design of similar facilities at different frequencies
- We will apply for DoE support to enhance these activities.



Summary

- We have made significant progress on our facilities
- We have made significant progress in test facilities around the US
- The collaboration is taking off with SLAC as the Host
- We have made progress with copper test structure
- We are about to embark on the experimental program which includes materials, geometries, frequency scaling, and strong wake field damping.
- The theoretical effort taking shape within the collaboration and will by tied to the experimental program.

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