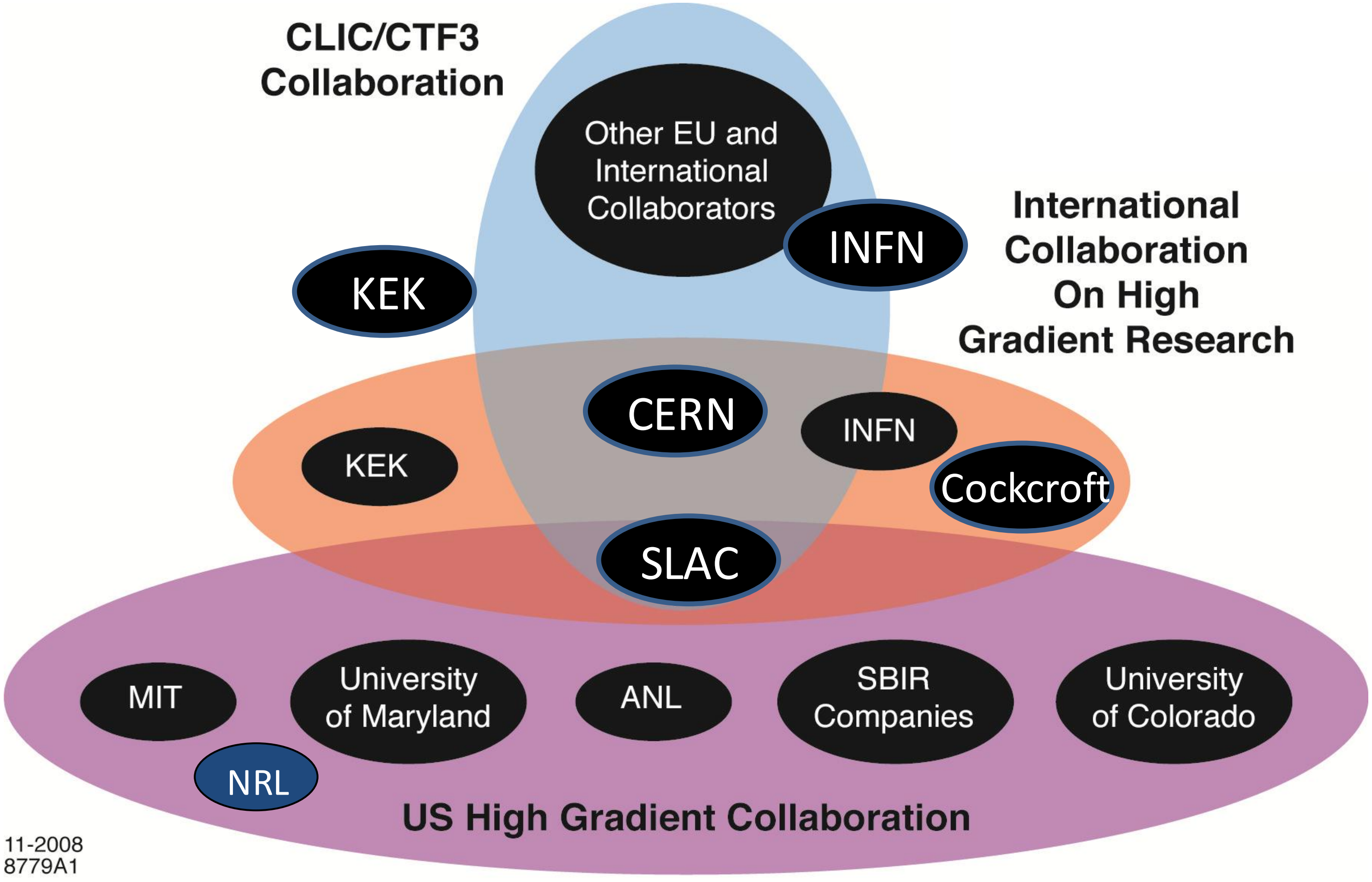
The US High Gradient Collaboration Vision for Research and Development on Ultra High Gradient Accelerator Structures

Sami Tantawi, SLAC
(on behalf of the collaboration)

International Collaboration on High Gradient Research



The original challenge that was put forward by the original proposal for the High Gradient Collaboration

What gradient can be reliably achieved using warm technology?

- The original, optimistic view (PAC 1986) : E. Tanabe, J. W. Wang and G. A. Loew, "Voltage Breakdown at X-Band and C-Band Frequencies," :
  - The authors report experimental results showing that the Surface Electric Field limit at 9.3 GHz (X-Band) exceeds 572 MV/m in pulses of up to 4.5 microseconds
  - Results predict an on-axis gradient of at least 250 MV/m
- Reality sets in (by 2001):
  - The operating limit determined by experiments on the NLC Test Accelerator showed that high gradient accelerator structure operating at X-band would not survive long term operation without computer/feedback protection and the breakdown rate above 65 MV/m can not be tolerated for a collider application.
- **The challenge**: we wish to ***understand*** the limitations on accelerator gradient in warm structures

- **Our goal** is to push the boundaries of the design to achieve:
  - Ultra-high-gradient; to open the door for a multi-TeV collider
  - High rf energy to beam energy efficacy, which leads to an economical, and hence feasible designs
  - Heavily damped wakefield

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

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Five Year Report

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

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Vision for the Next 5 Years (Guide lines that will be given to collaborators for planning theire work proposals)

- The collaboration during the next 5 will address 4 fundamental research efforts:
  - Continue basic physics research, materials research frequency scaling and theory efforts.
  - Put the foundations for *advanced* research on efficient RF sources.
  - Explore the spectrum from 90 GHz to THz
  - Address the challenges of the Muon Accelerator Project (MAP)

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Continue basic physics research, materials research frequency scaling and theory efforts.

- We have created the basic infrastructure for this effort and it is time to reap the benefits:
  - Apparatus for testing high gradient materials without brazing; most of the materials will come from collaborators and testing will happen at SLAC, AWA, MIT etc.
  - Observation of breakdown phenomena; we have build the devices; electronics will come mostly from collaborators and testing will happen at SLAC
  - Experiments with mixed electric and magnetic fields. This takes place this year and next year at SLAC.
  - Tie loose ends with current experiments
- The pace of these effort will depend on the availability of testing stations.
- Frequency scaling efforts will take place at MIT; their 17 GHz system is just about ready for "high repetition rate" operation
- Theory effort still centered at University of Maryland

Put the foundations for advanced research on efficient RF sources

- New ideas from SLAC; provisional patent soon.
- Research on advanced special purpose codes.
- Research on multi-beam overmoded devices.
- Advanced cathodes and modulation techniques.
- Collaboration efforts with MIT university of Maryland, Yale and NRL,……

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Explore the spectrum from 90 GHz to THz

- Sources at MIT
- Developments of suitable sources at 90 GHz
- Developments of THz stand alone sources
- Utilize the FACET at SLAC and AWA at ANL

Basic Physics Research Full Size Accelerator Structures

- Resonant Ring Structures
  - Geometrical Studies
  - Martial studies
- CERN Structures
- Dielectric Structures
- New Distributed Coupling Standing Wave Accelerator Structures

Basic Physics Research Others

- Pulsed Heating Setup
  - Material Studies
- Mixed E&H Setup
- Superconducting Material/Low Temperature Material Testing
  - Novel RF materials
  - Stratified materials

RF Sources Research

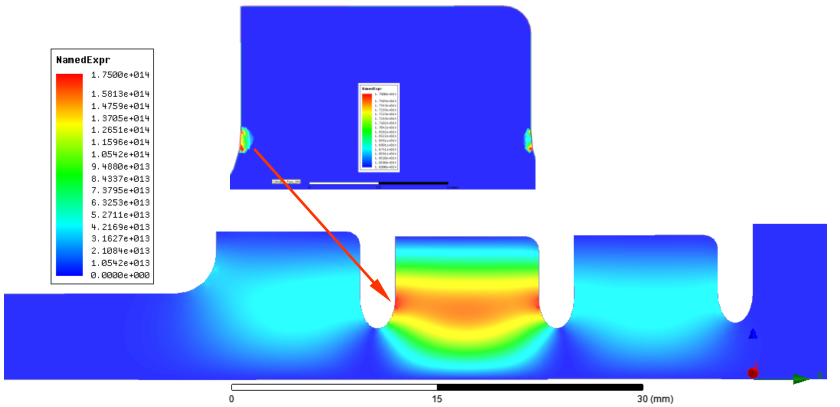
- Overmoded Magnetrons
- Massively Multimoded Klystrons
- Large signal codes
- Novel RF sources

There are other efforts in the group which is not the subject of this presentation

Calculating ratio between MaxSc and Max H^2, 1C-SW-A3.75-T2.6-Cu (eigen.) and 1C-SW-A3.75-T2.2-Cu (Jeff's model, driven)

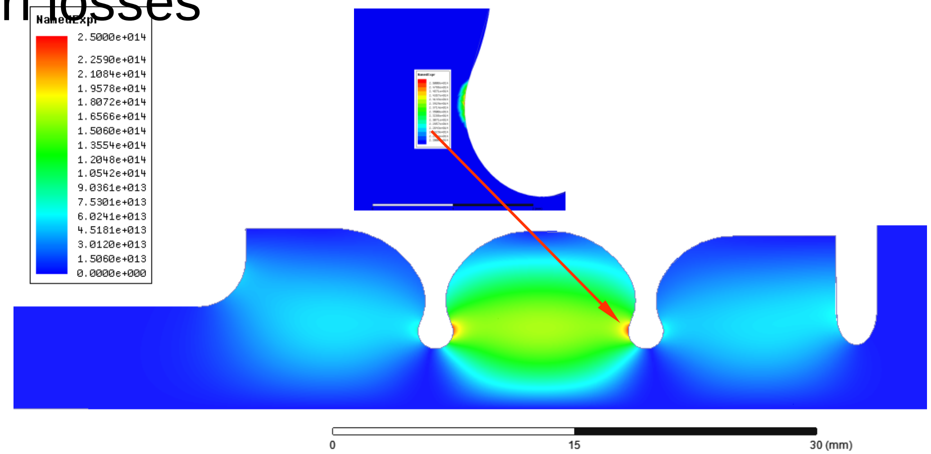
10 MW rf losses

1C-SW-A3.75-T2.6-Cu

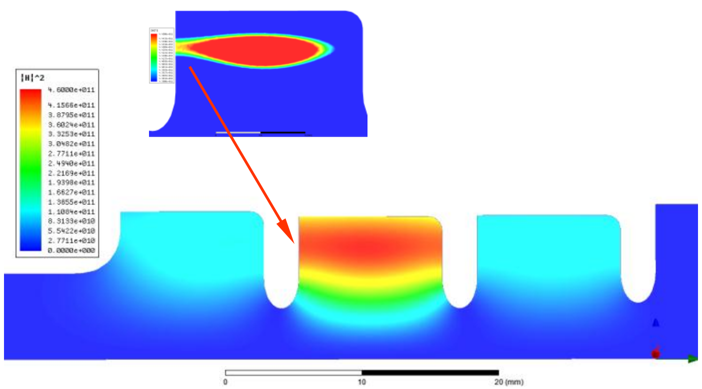


Max. Poyning Vector 1.73 e14 W/m^2

1C-SW-A3.75-T2.2-Cu

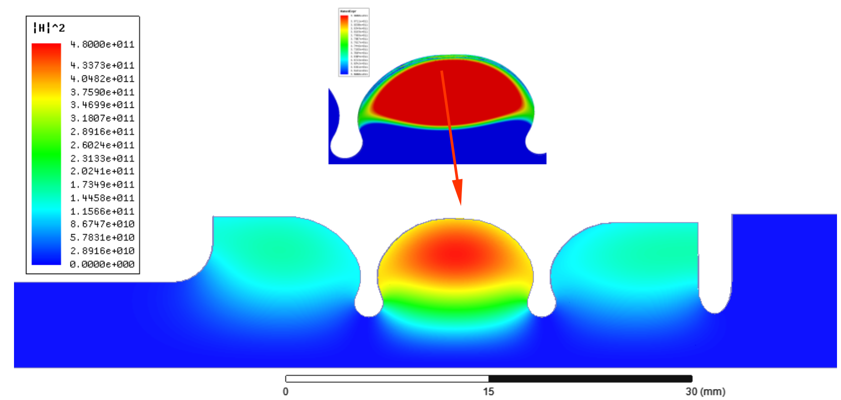


Max. Poyning Vector 2.4e14 M/m^2



Max. |H^2| 4.44e11 (A/m)^2

Ratio is 390 Ohm



Max. |H^2| 3.8e11 (A/m)^2

Ratio is 632 Ohm

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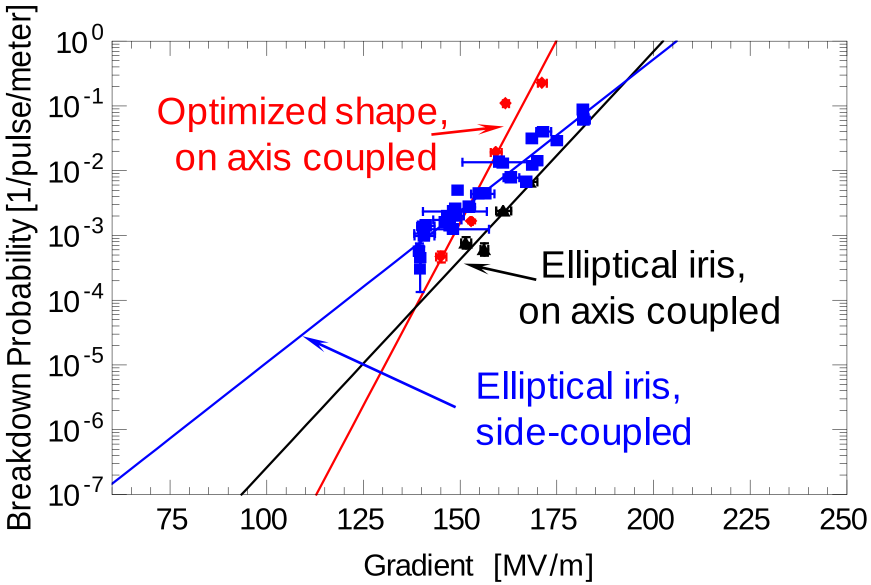
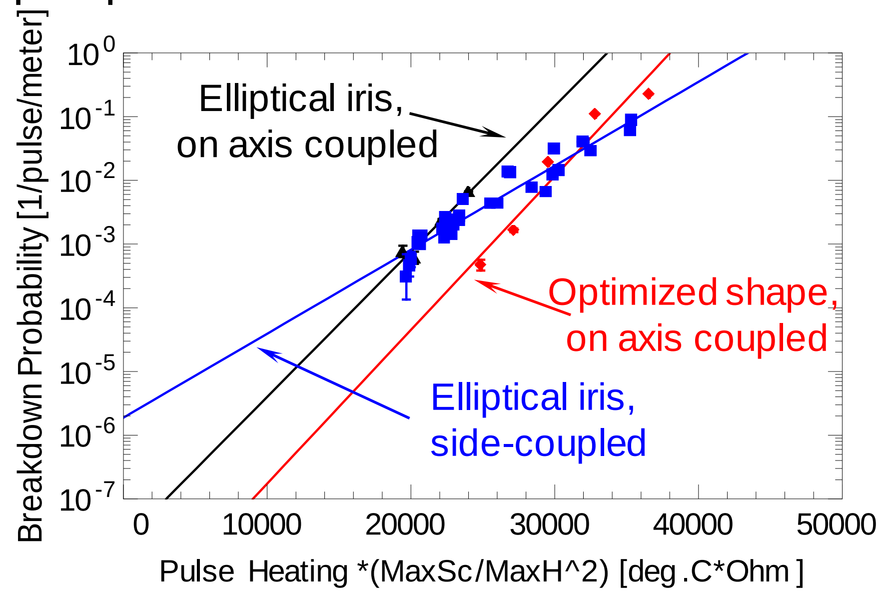
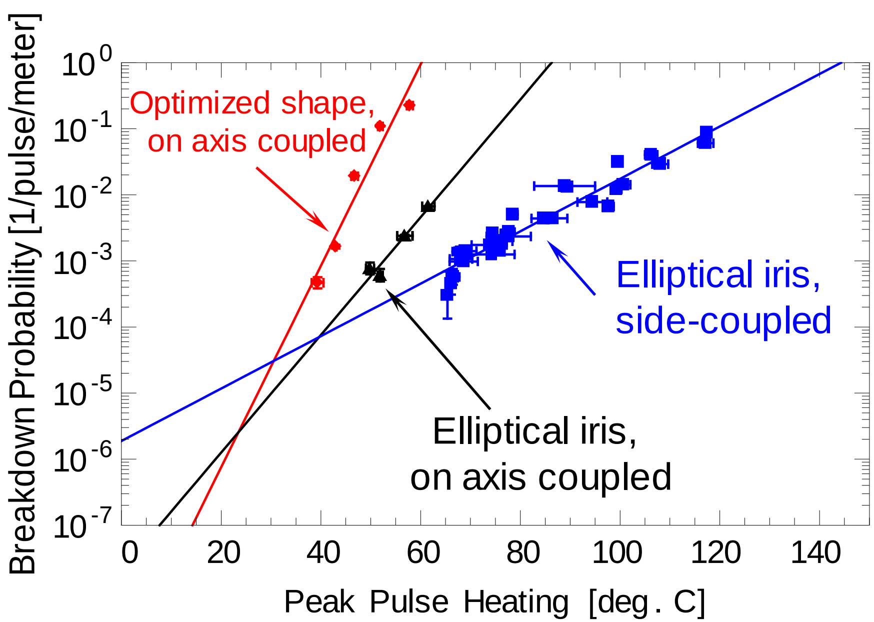
Very Preliminary breakdown data for optimized shape 1C-SW-A3.75-T2.2-Cu-SLAC-#1, comparison of 3 structures of 3.75 mm aperture and different geometries, 150 ns shaped pulse







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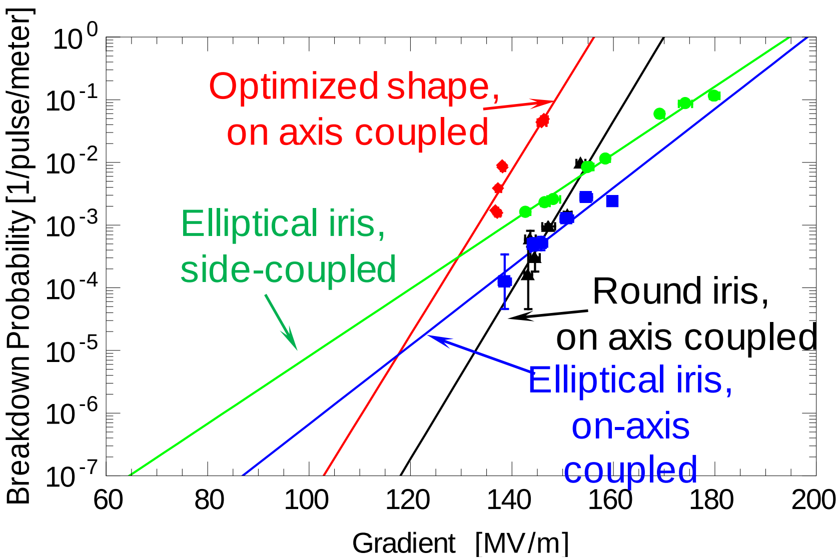
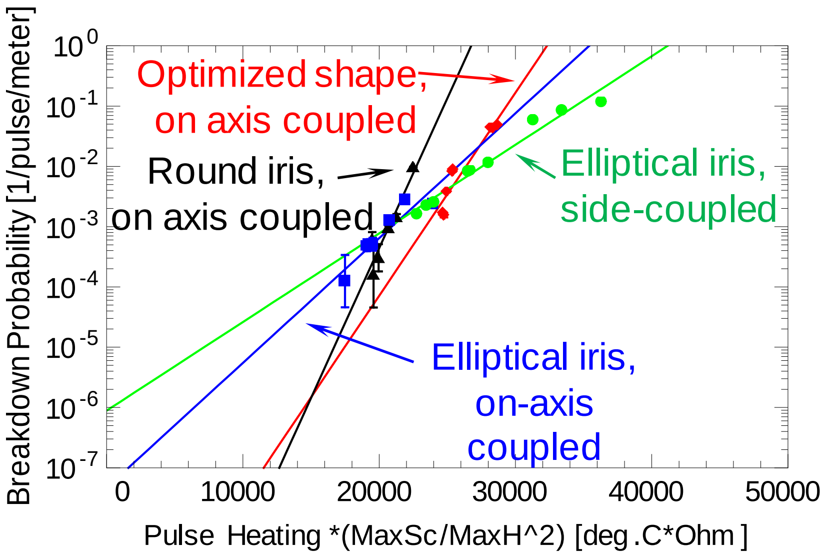
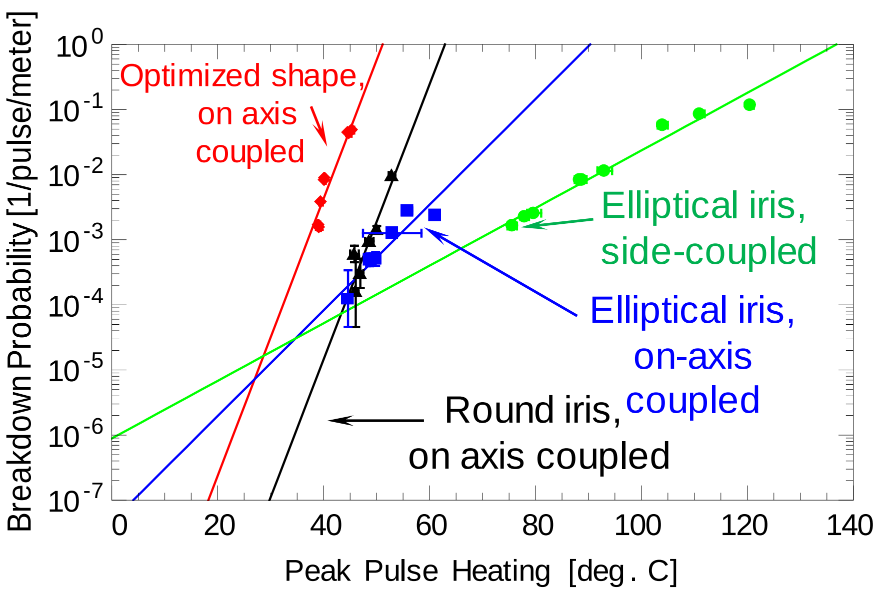
V.A. Dolgashev, 13 January 20

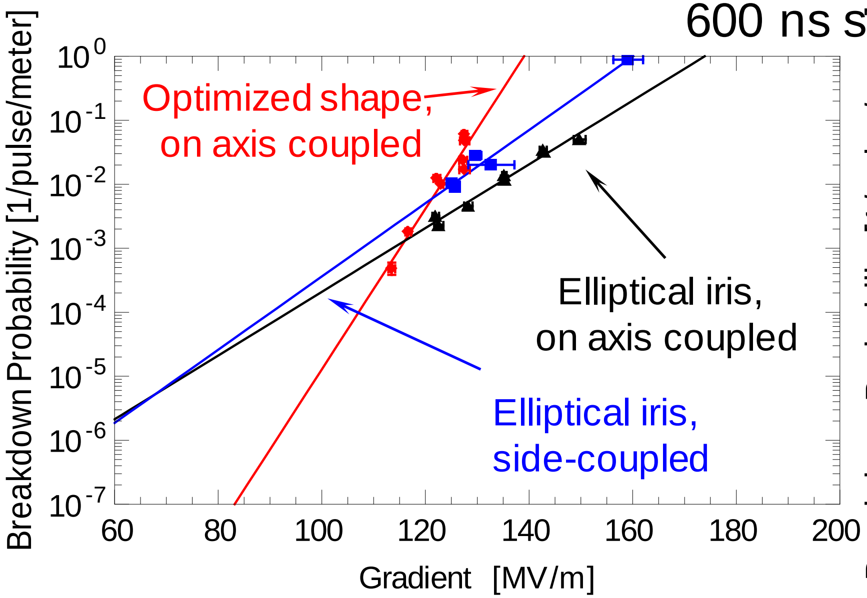
Very Preliminary breakdown data for optimized shape 1C-SW-A3.75-T2.2-Cu-SLAC-#1, comparison of 3o n-axis coupled structures and one side-coupled structure of 3.75 mm aperture , shaped pulse with 200 ns flat part

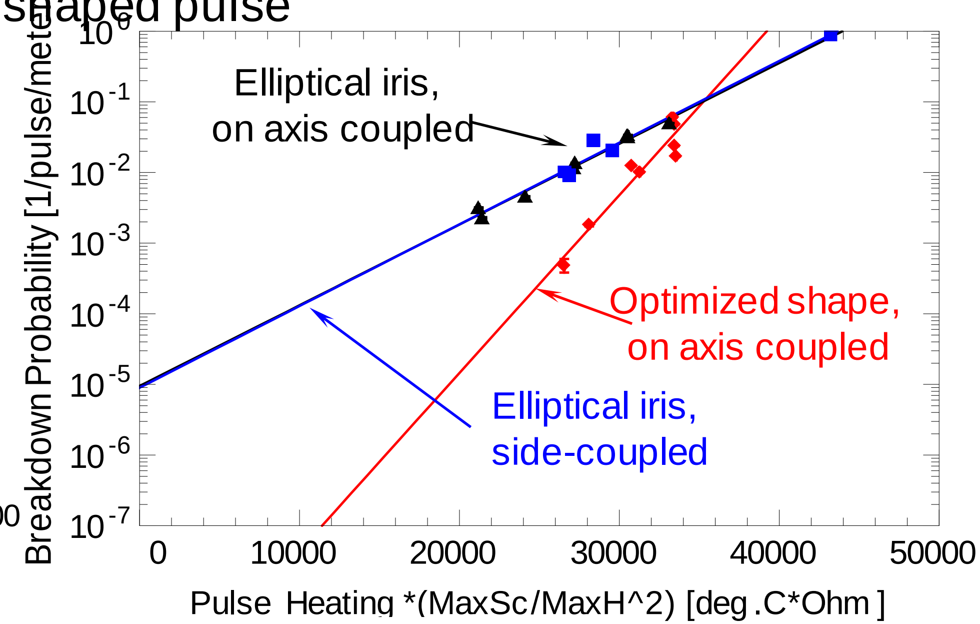


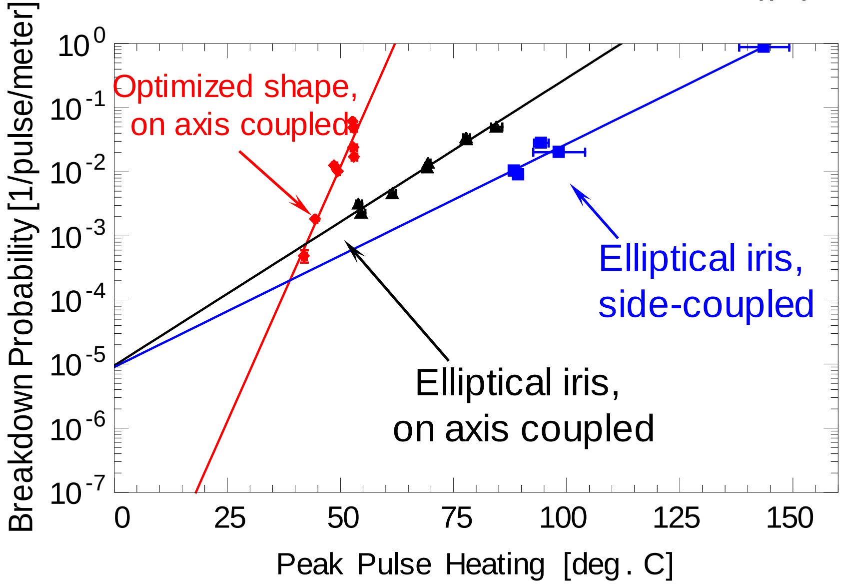




Very Preliminary breakdown data for optimized shape 1C-SW-A3.75-T2.2-Cu-SLAC-#1, comparison of 3 structures of 3.75 mm aperture and different geometries, 600 ns shaped pulse







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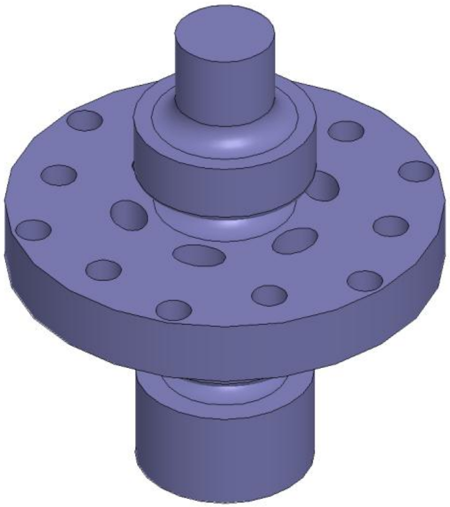
V.A. Dolgashev, 24 January 20

Elliptical-rod Design at 11 GHz

- Standing wave design with 2 matching cells, one test cell
- Axially powered via TM_{01} mode launc
- Structure has elliptical inner rods
  - Spread large H field over larger region → reduce pulsed heating



Performance at 100 MV/m		
	Round	Elliptical
Power	5.9 MW	4.4 MW
Peak Surface E Field	208 MV/m	207 MV/m
Peak Surface Magnetic Field	**890 kA/m**	**713 kA/m**
Pulsed Heating for 150ns Flat Pulse	131 K	84 K

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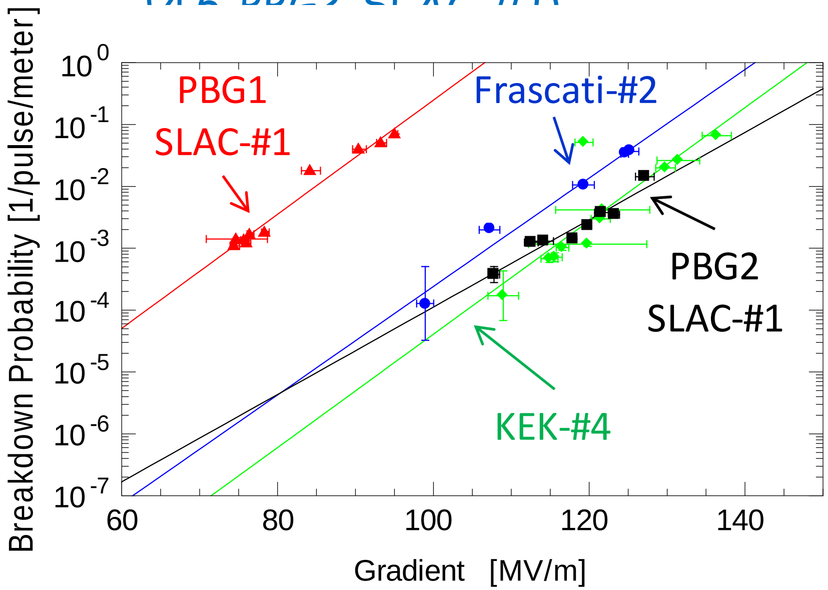
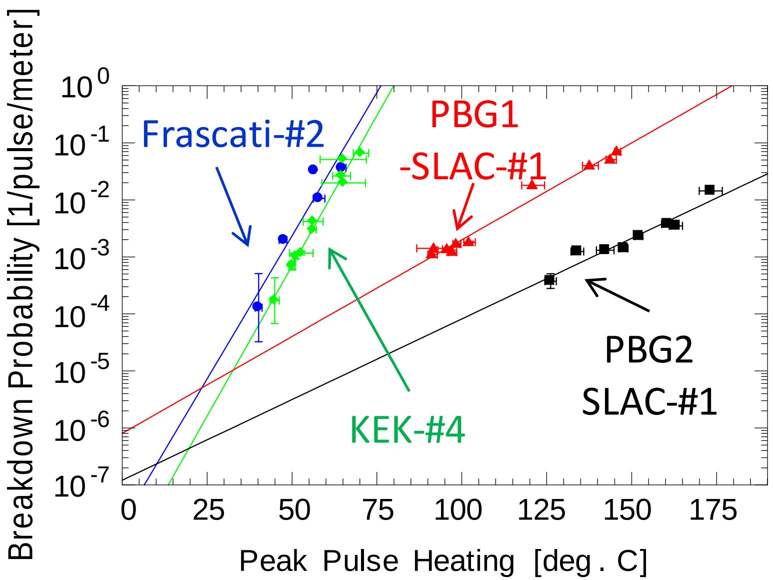
B. J. Munroe, MIT

Breakdown rate vs. gradient and pulse heating for 2 disc-loaded and two PBG single-cell structures, *shaped* pulse 150 ns (A5.65-T4.6-KEK-#4, A5.65-T4.6-Frascati-#2, A5.65-T4.6-PBG-SLAC-#1, , A5.65-T4.6-PBG2-SLAC-#1)





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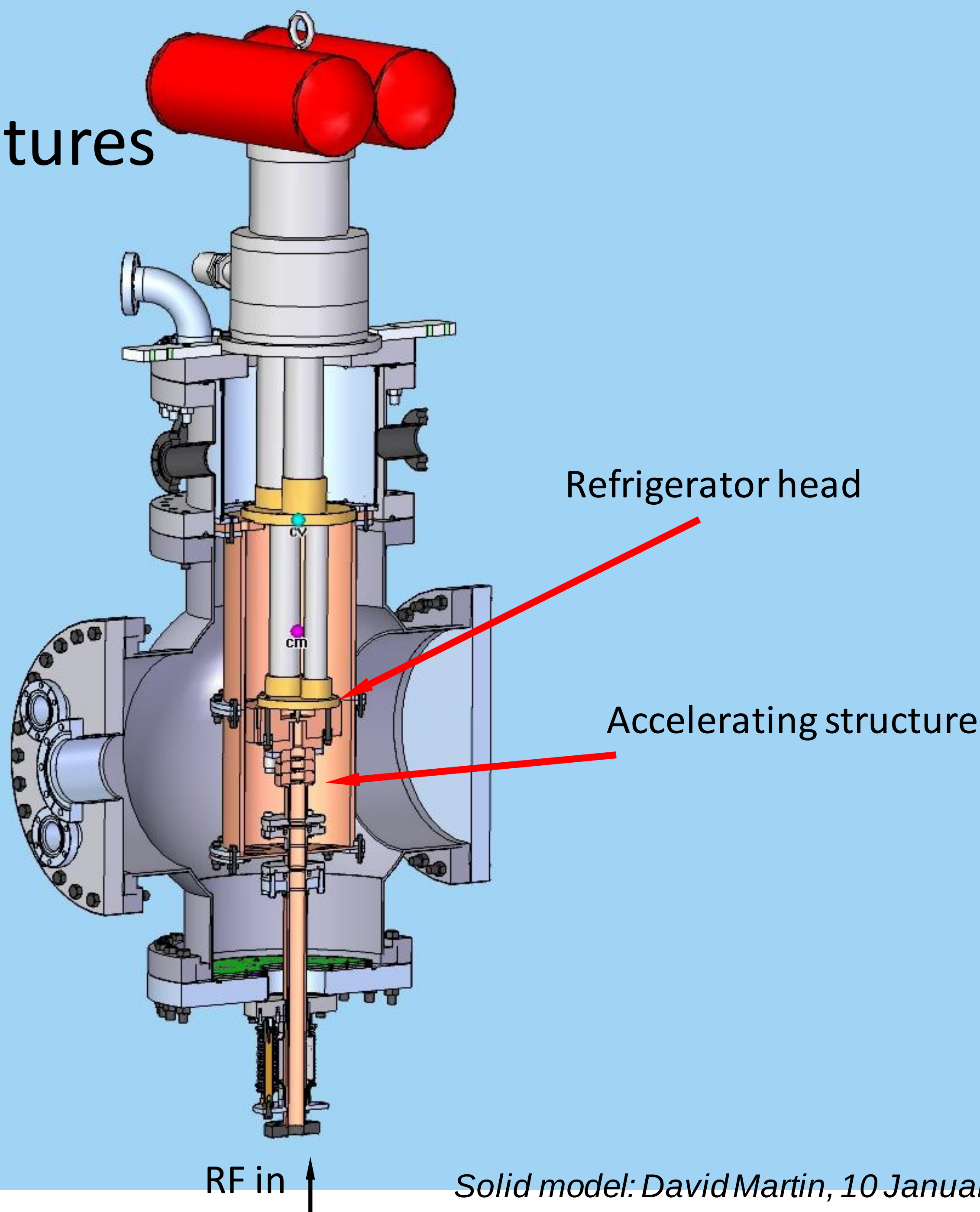
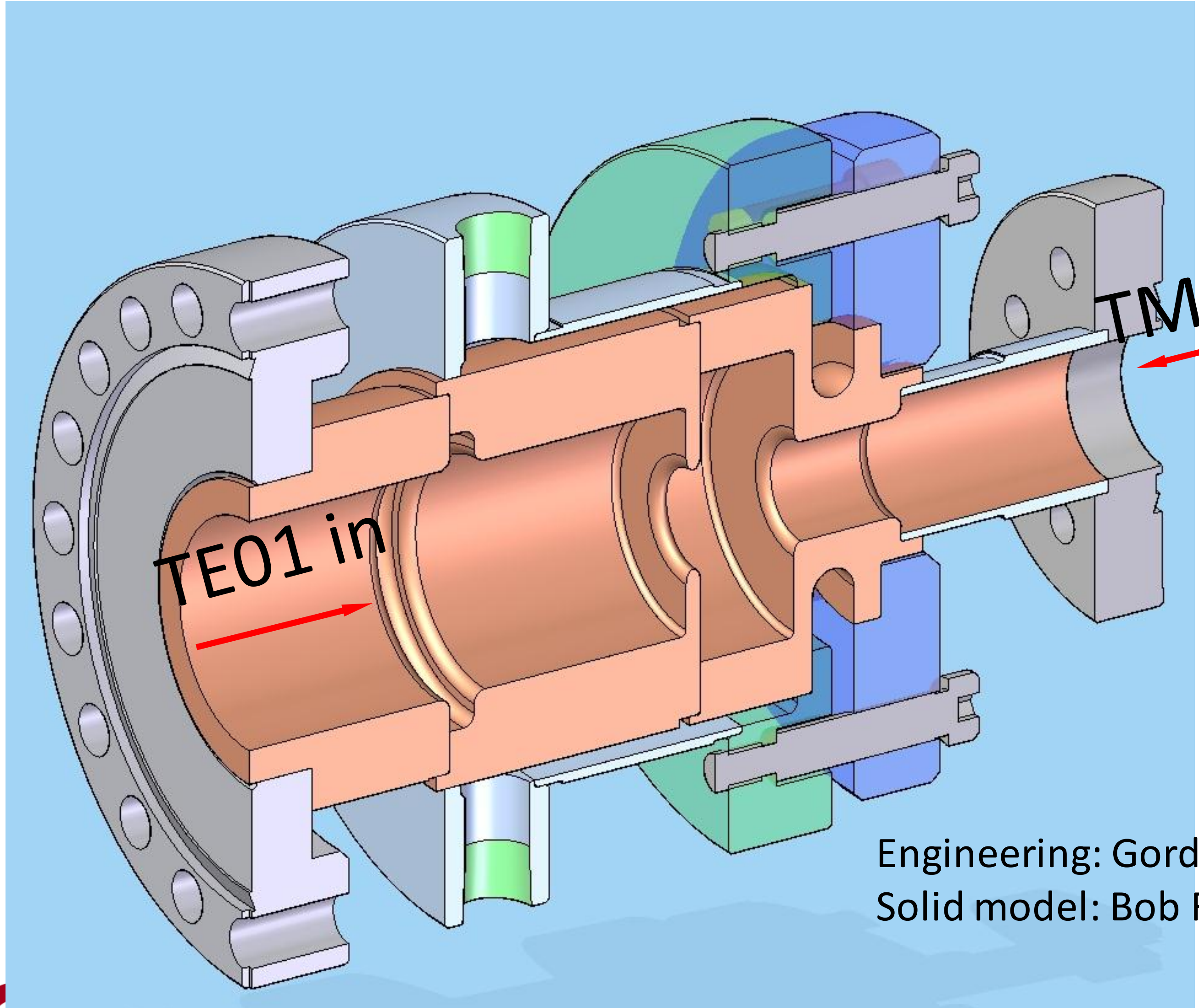
Experiments at cryo temperatures



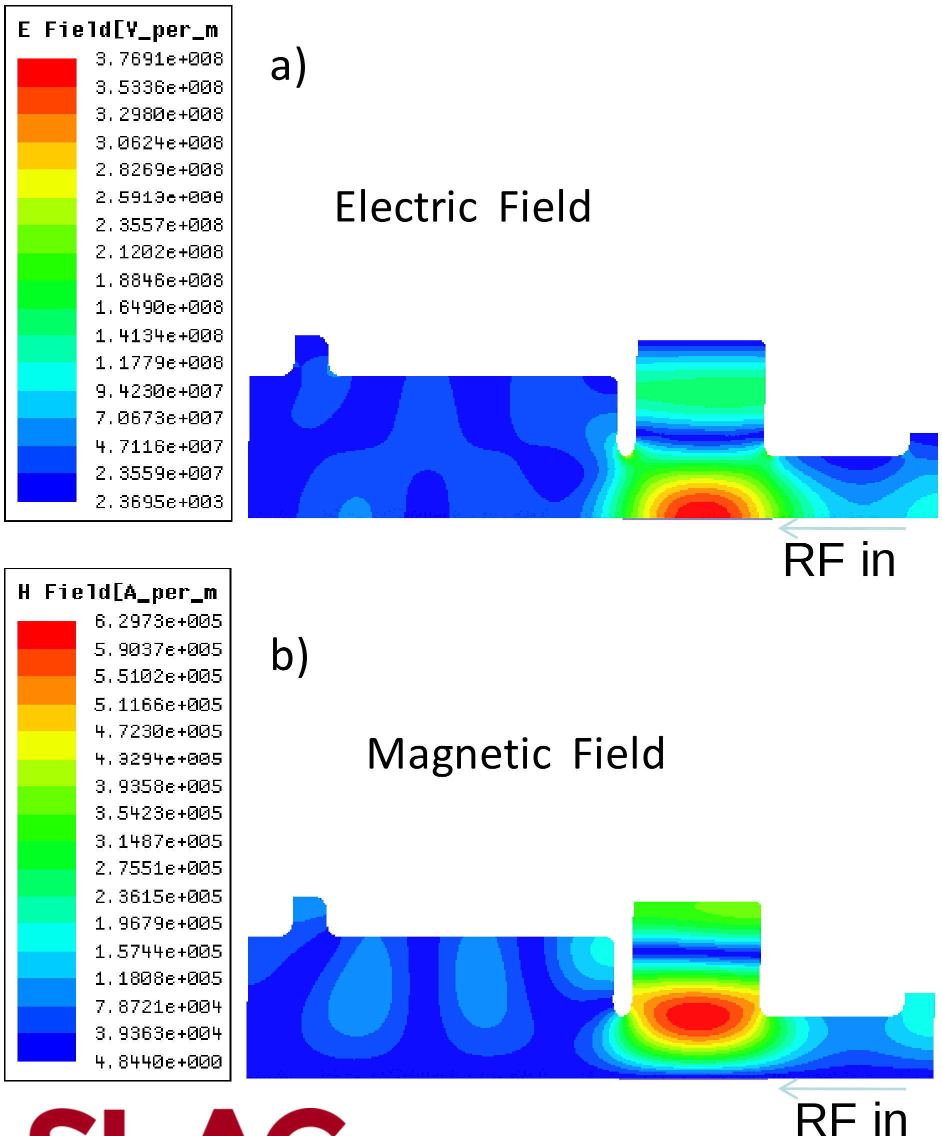
Solid model: David Martin, 10 January 2011

Dual Mode Accelerating Structure

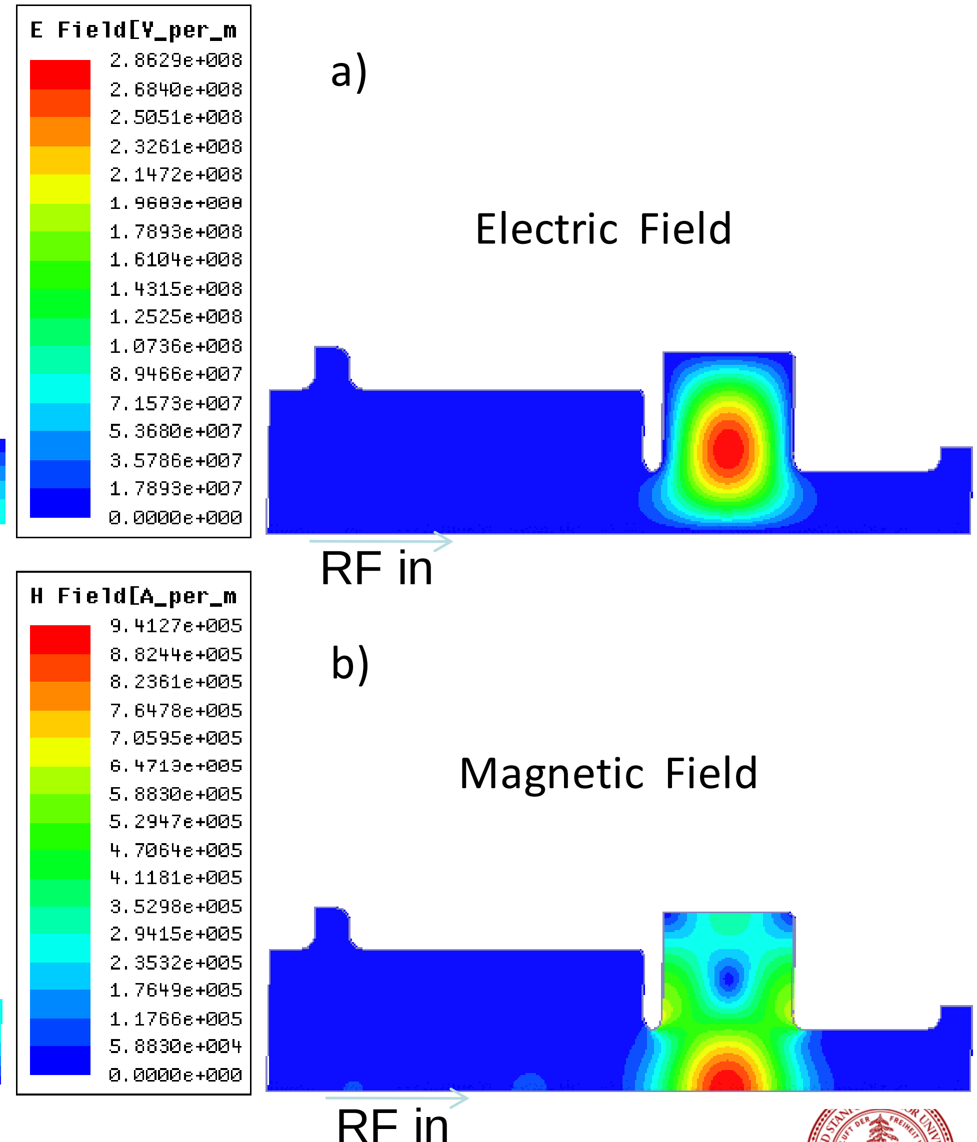


RF Electric and Magnetic Fields for 10MW Power Loss

TM020 Mode



TE011 Mode



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A.. D. Yeremian, V. A. Dolgashev, S. G. Tantawi, 2011

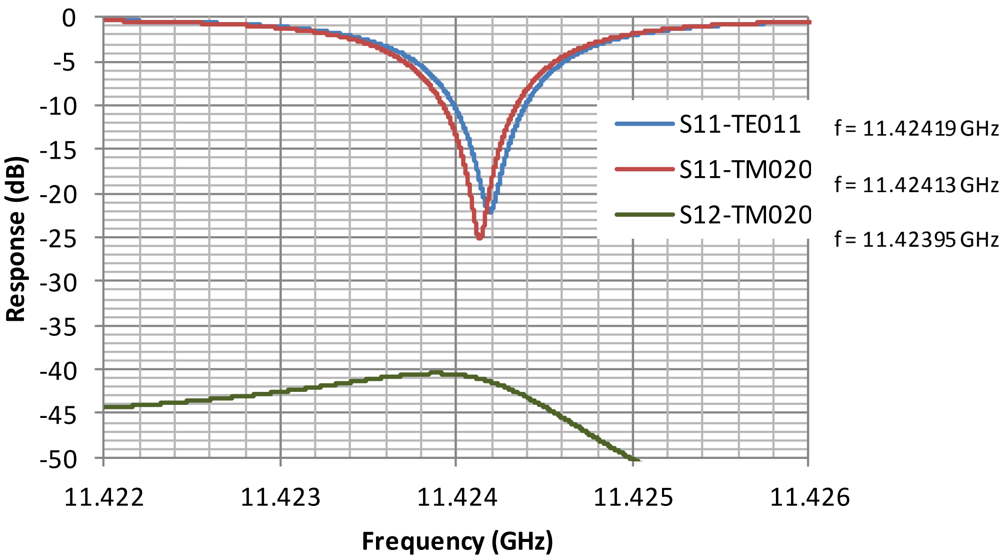
Cavity Parameters for Speed-of-Light Electron TM020 mode

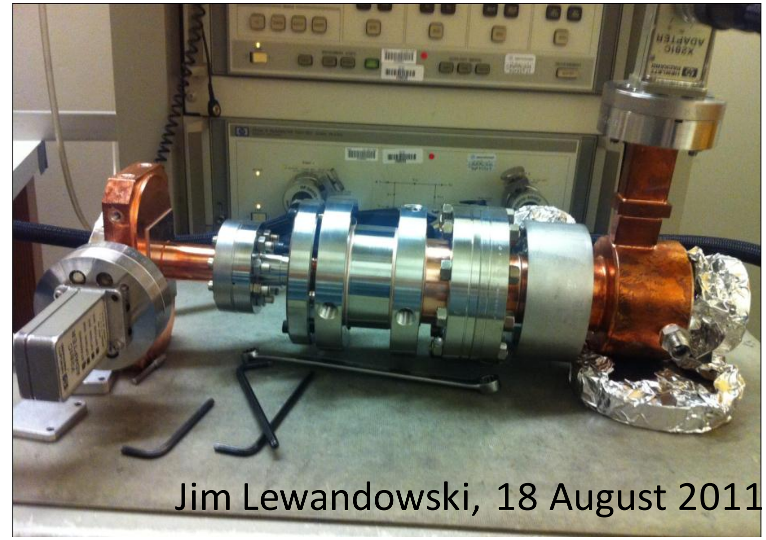
Shunt Impedance = 29.40 MOhm/m

	10MW Loss	**100 MV/m**
Ave on-axis Acc. (MV/m)	121.78	100.00
Accel. Across Cav. (MeV)	2.41	1.98
Max. Surface E (MV/m)	278.26	229.30
Max. Surface H (kA/m)	506.40	416.29
Stored Energy (J)	2.69	1.81
Power Loss (MW)	10.00	6.74

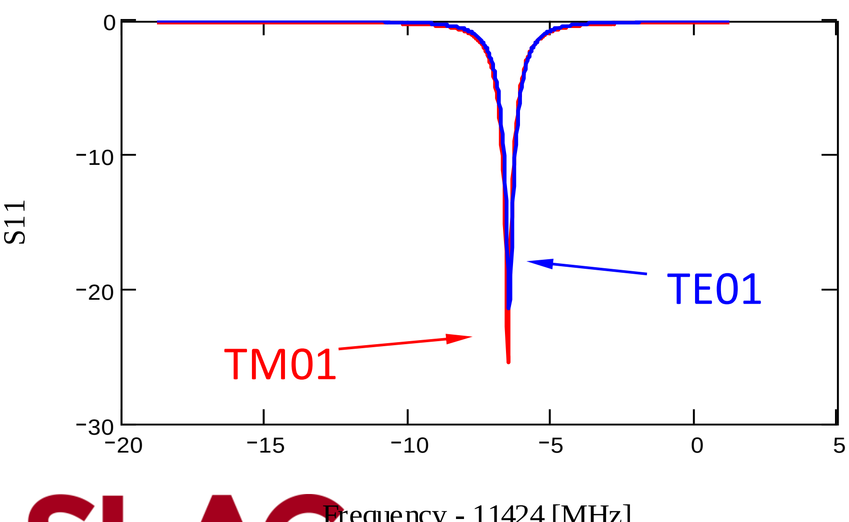
For the same gradient surface electric and magnetic fields are similar to those in single cell standing wave structures

Dual-mode cavity tuning





Simulation



Measurement

Parameter	Simulation	Meas. @ Rm T
f_{TE011} - GHz	11.42419	11.42175
f_{TM020} - GHz	11.42413	11.42119
Qo_{TE011}	19754	20240
Qo_{TM020}	19292	19485
$S11_{TE011}$-dB (fraction)	-22 (0.078)	-22 (0.08)
$S11_{TM020}$-dB (fraction)	-25 (0.056)	-25 (0.05)
b_{TE01}	1.17	1.18
b_{TM01}	1.11	1.11
Shunt Imp. - MOhm/m	29.4	-

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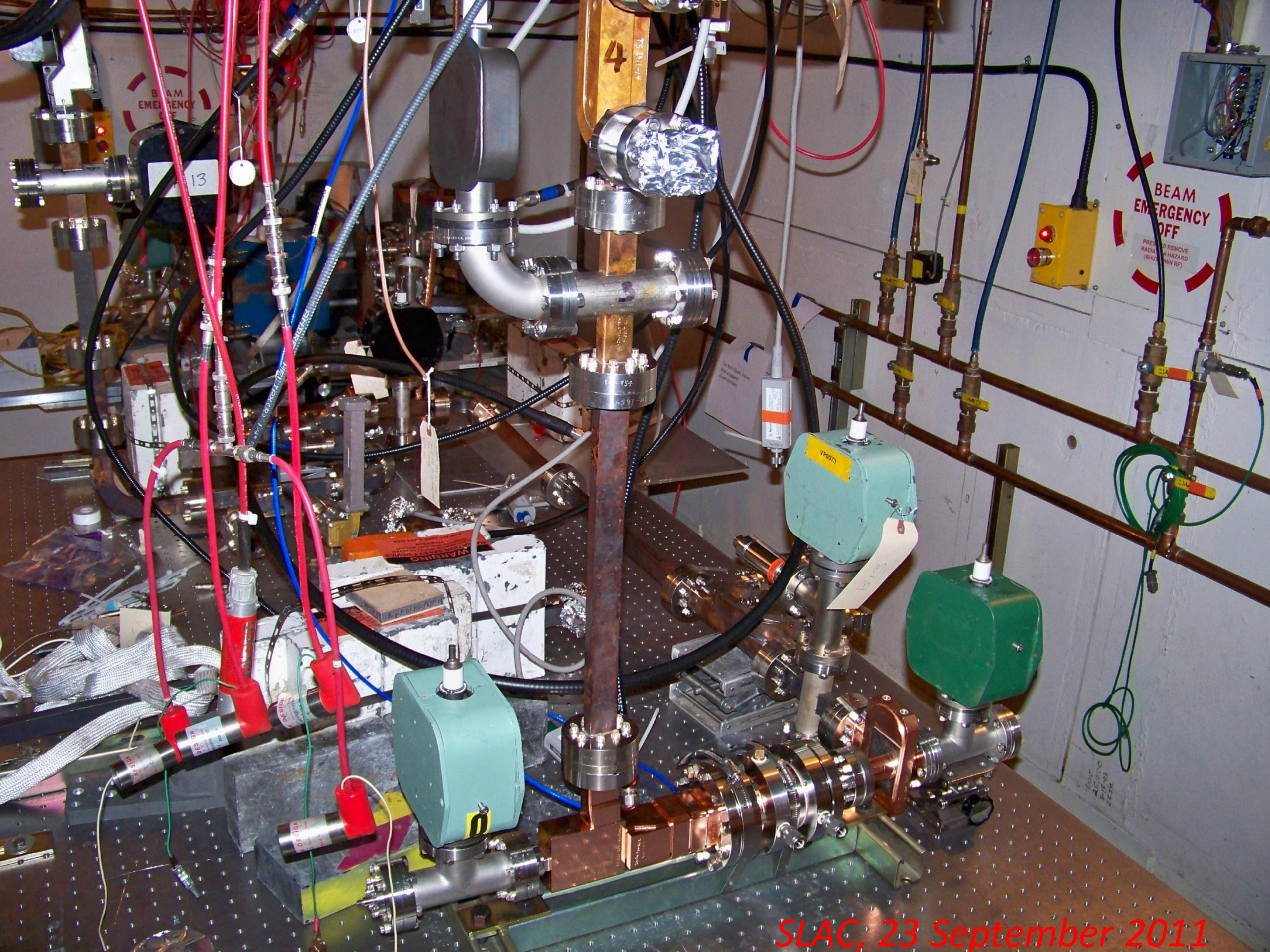
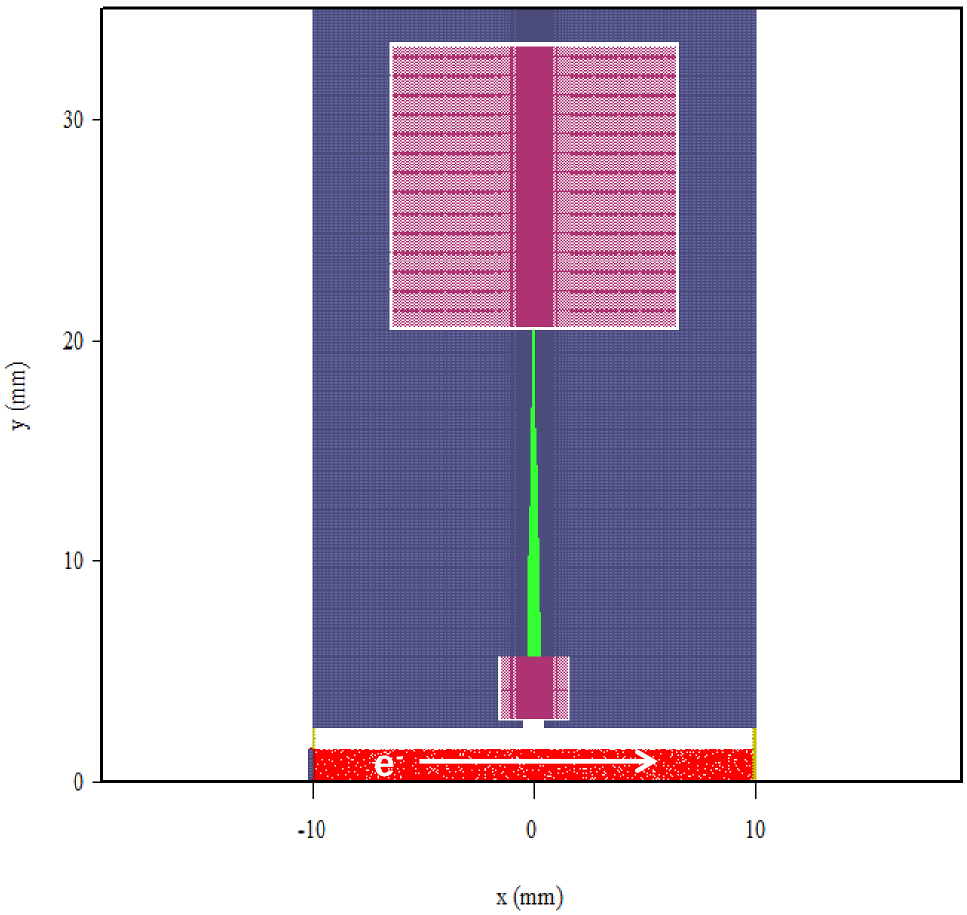


SLAC, 23 September 2011



Standing Wave Resonant Load
Qo ~ 3000
Qe ~ 1000

Tapered Waveguide with Dielectric

Klystron Output Cavity
Qo ~ 3000
Qe ~ 25

MAGIC2D Simulation Parameters and Geometry

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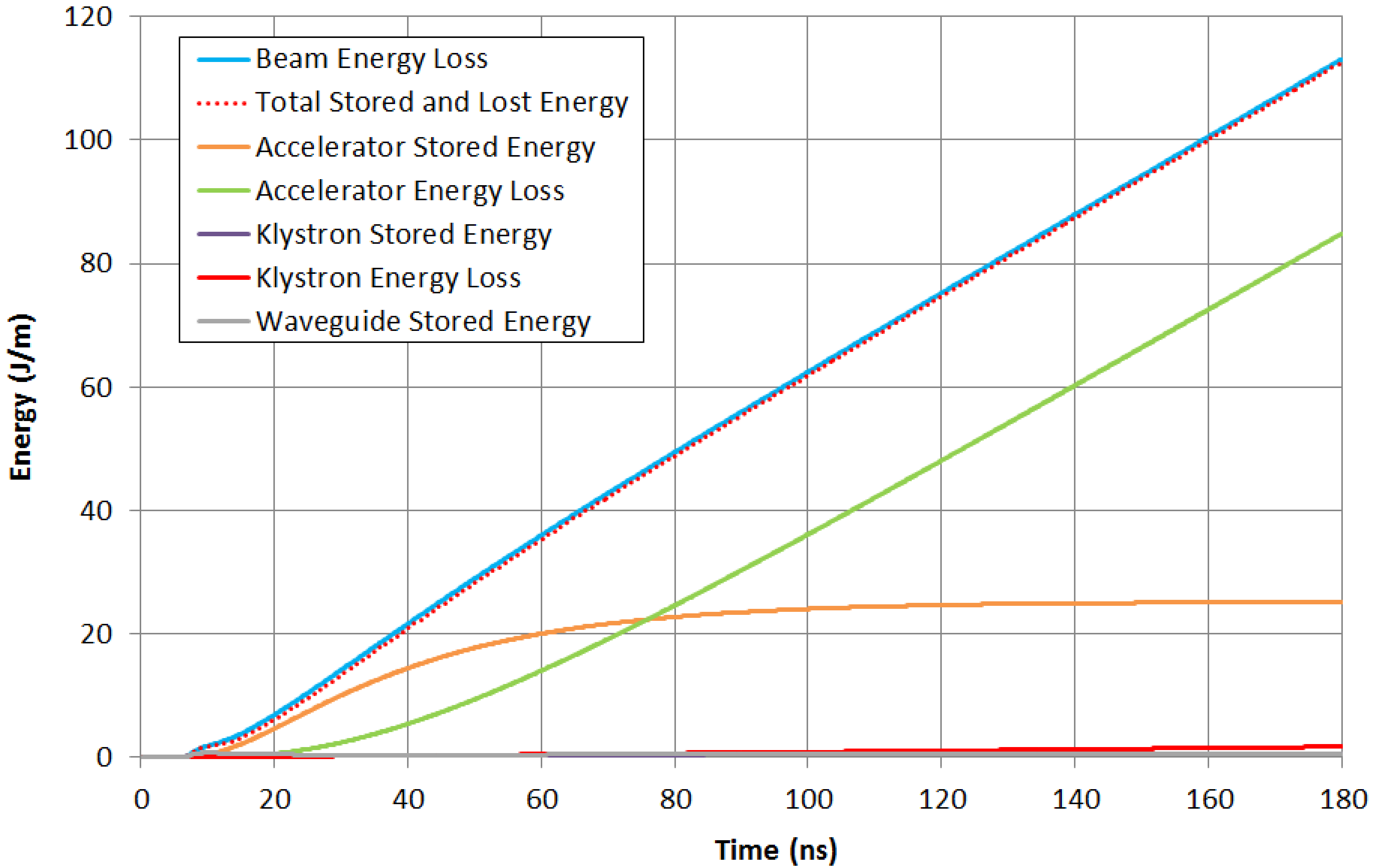
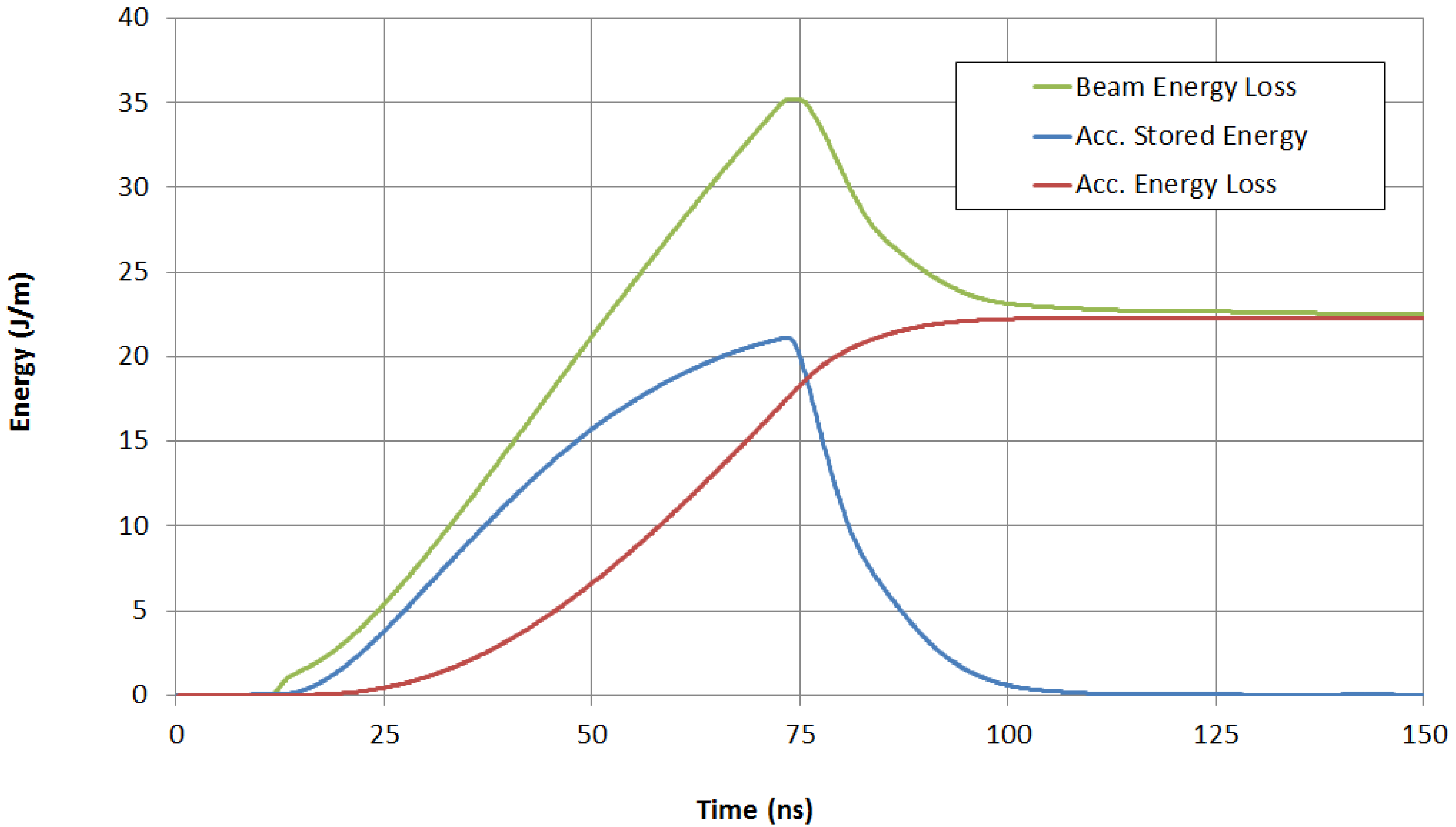
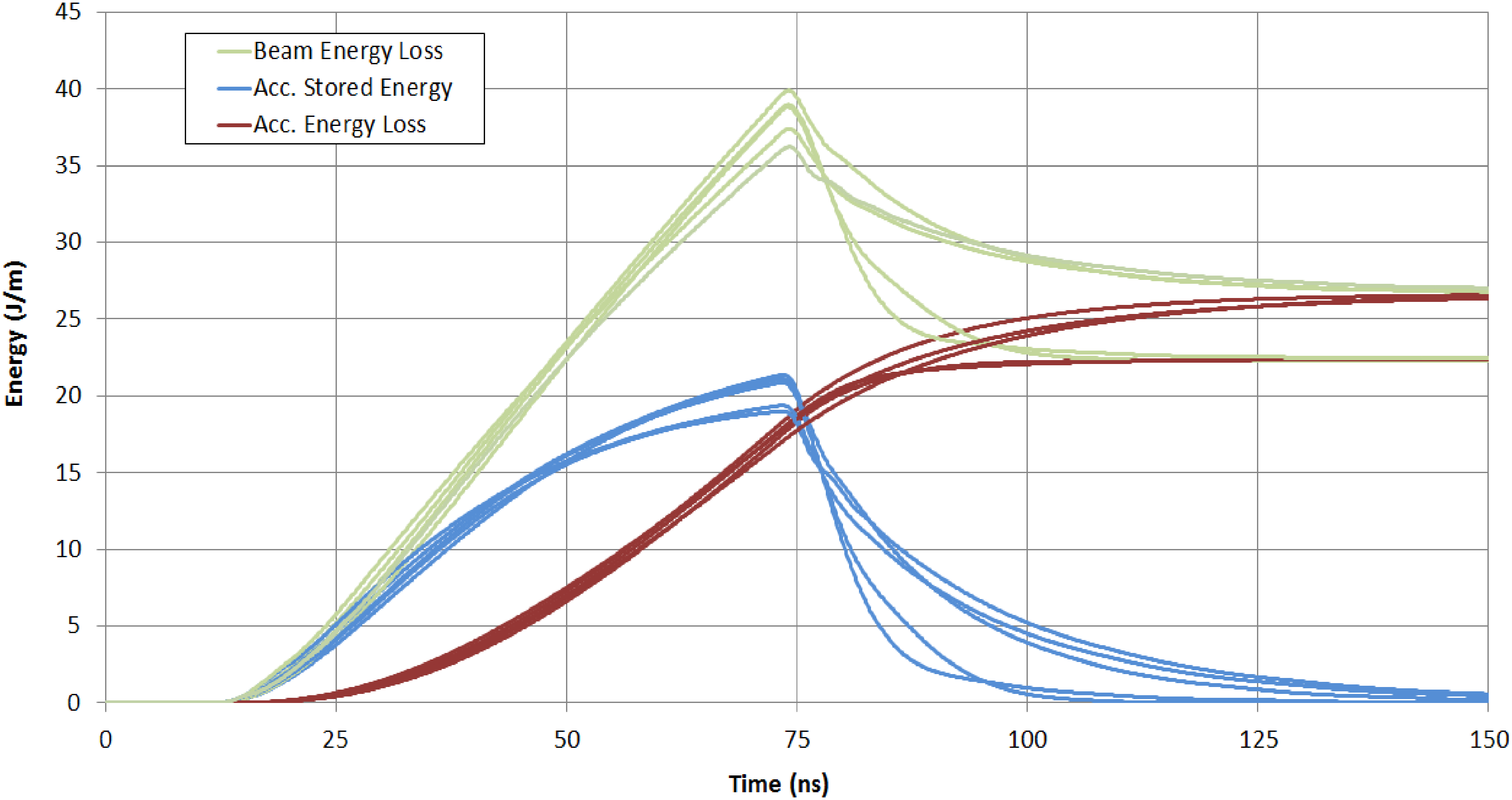


Energy Conservation for an RF Step Function



Energy for an RF Pulse



Results for Various Phasing Between Acc. Cavity and Klystron

Summary

- We have followed our published working plane and our effort is now paving the way for a new understanding of the gradient limits of room temperature accelerators and will allow us to break these barriers for the development of ultra-high gradient structures.
- The work being done is characterized by a strong national and international collaboration. This is the only way to gather the necessary resources to do this work.
- Standing wave structures have shown the potential for gradients of 150 MV/m or higher
- Further understanding of materials properties may allow even greater improvements
- During our next phase of research we will :
  - Continue basic physics research, materials research frequency scaling and theory efforts.
  - Put the foundations for *advanced* research on efficient RF sources.
  - Explore the spectrum from 90 GHz to THz
  - Address the challenges of the Muon Accelerator Project (MAP)
-