# High Gradient Tests of Photonic Accelerator Structures at 11.4 and 17 GHz

Presented by

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# Collaborators / Acknowledgements


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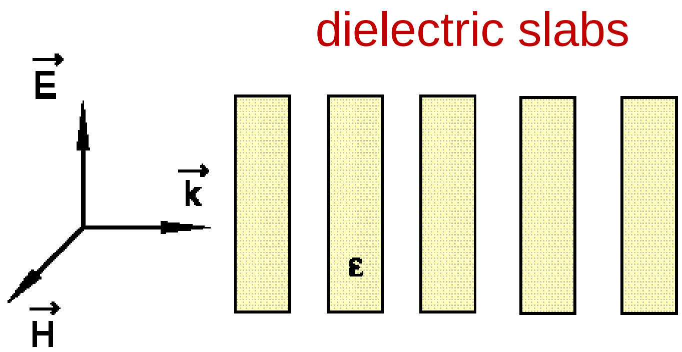
# Outline

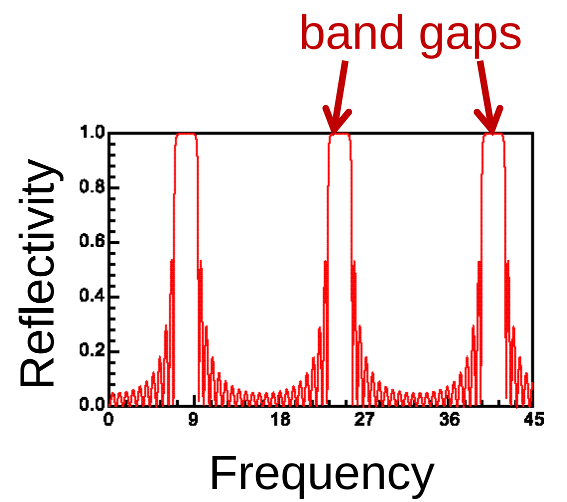
- **Introduction**
- Research at 17 GHz at HRC/MIT Accelerator Laboratory
  - Planned User Facility
- Single-cell X-Band Breakdown Studies at SLAC
  - Round-Rod PBG Testing
  - Elliptical-Rod PBG Testing
- Summary and Conclusions

# Frequency Selective PBG Lattice

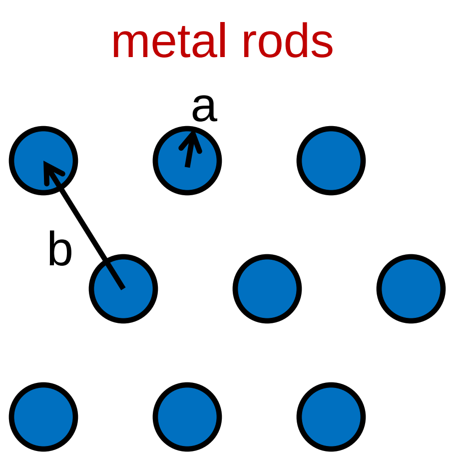
- Wave propagation is disallowed at certain frequency ranges (**Photonic Band Gap - PBG**) in a periodic lattice.

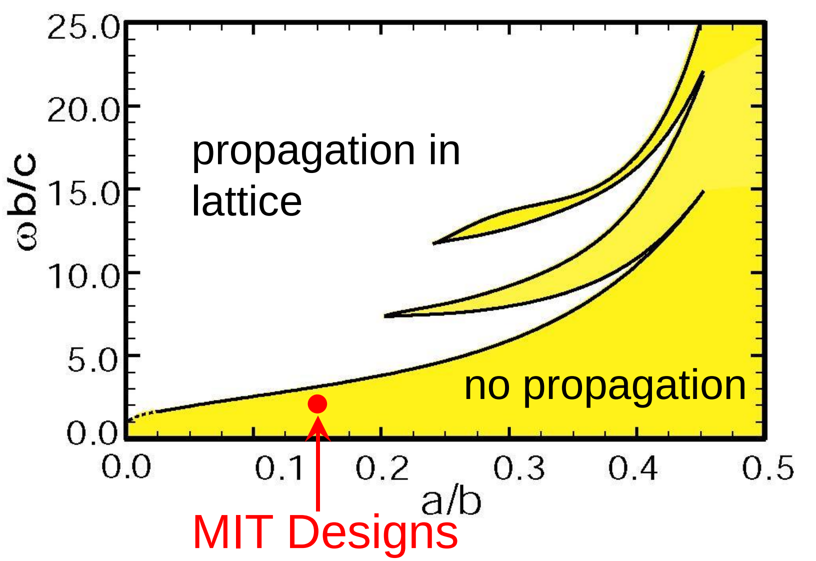
1D lattice:




2D lattice:

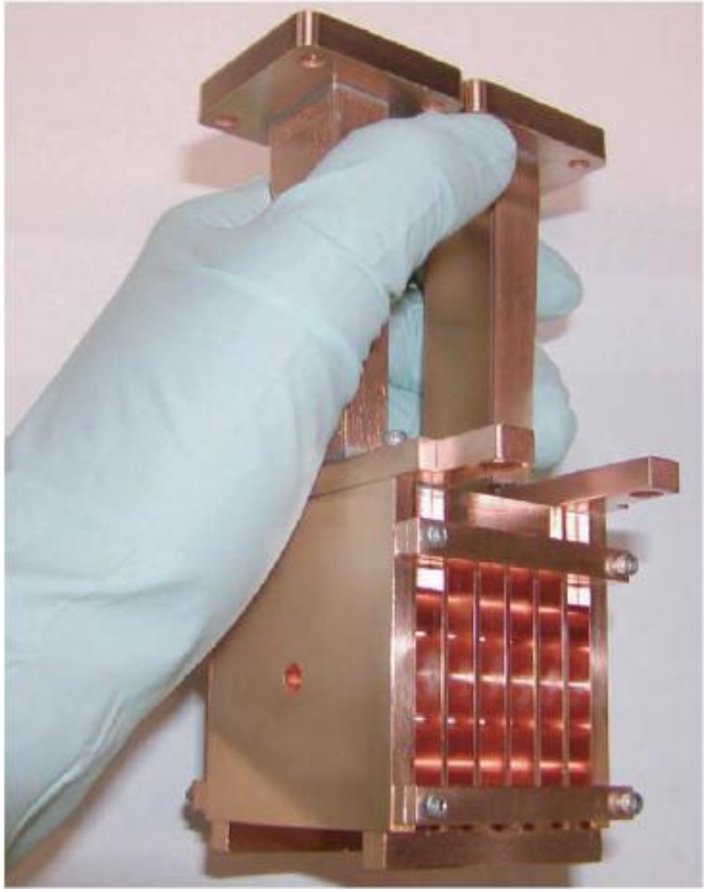



Smirnova et al. , J. Appl. Phys., 2002

# Microwave PBG Accelerators

- Experimental results validate concept
- Demonstrated acceleration at 17 GHz at MIT (Smirnova 2005)
  - 35 MV/m achieved
- High-power testing at SLAC at 11 GHz (Marsh 2009)
  - 100 MV/m achieved
  - Showed influence of high H fields on breakdown

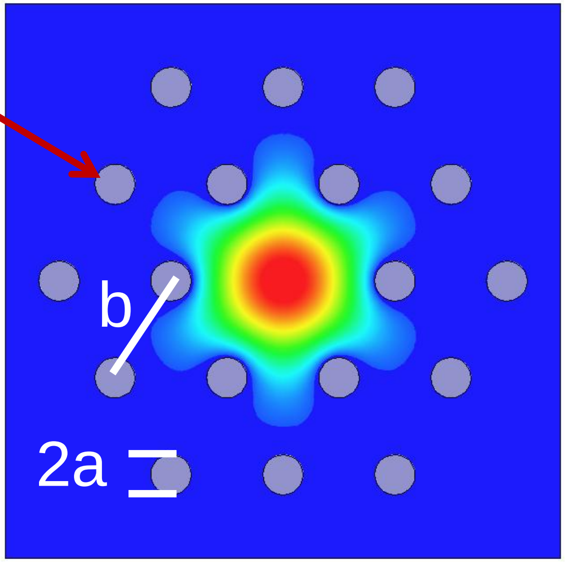


# Motivation for PBG Accelerator – 1. Wakefields

- Accelerator cavities suffer from parasitic modes (wakefields)
  - pillbox cavities can’t be used in a linear collider!
- An ideal cavity would support only the operating mode
  - A frequency-selective PBG cavity can accomplish this
- Theoretical and experimental studies of high order modes / wakefields substantiate the reduced HOMs in PBG structures

metal rods

$TM_{0,1}$–like Mode



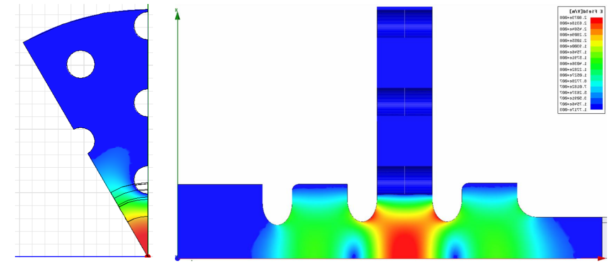

•PBG Expt. Wakefield Studies:
Jing et al. PRSTAB 2009 (X-Band)
Marsh et al. PAC09 (17 GHz)
Marsh et al. NIM A 2010 (17 GHz)

# Motivation for PBG – 2. Pulsed Heating Research

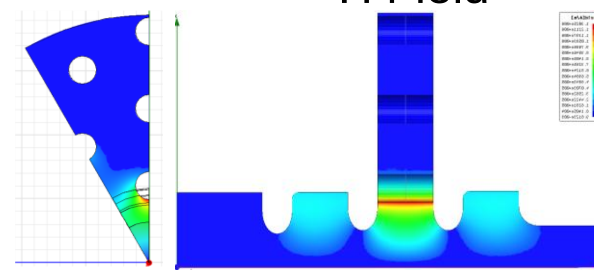
- PBG Cavities with Strong Wall Heating: Circular Rod PBG Cavities with small a/b
  - Small a/b PBG cavities have high H-Fields and heating (ΔT) at the inner metal rod surface
    - Marsh, PAC2009 and Marsh et al. PRSTAB 2011.
  - The gradient and E-field depend very weakly on a/b; values are similar to pillbox cavities
  - A systematic study of PBG cavities of varying a/b will allow the separate study of E- and H-Field effects at high gradient – planned at MIT

- PBG Cavities with reduced Wall Heating: Elliptical rod structures
  - Elliptical rod structure now under study at SLAC

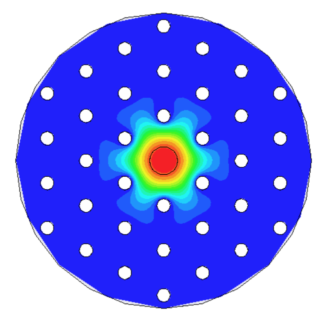
E Field



H Field

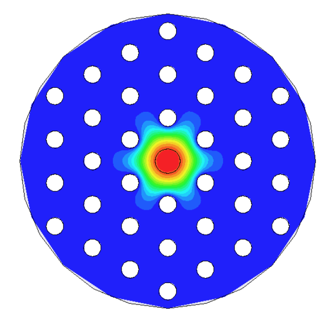


PBG a/b=0.15



“Hot Rod”

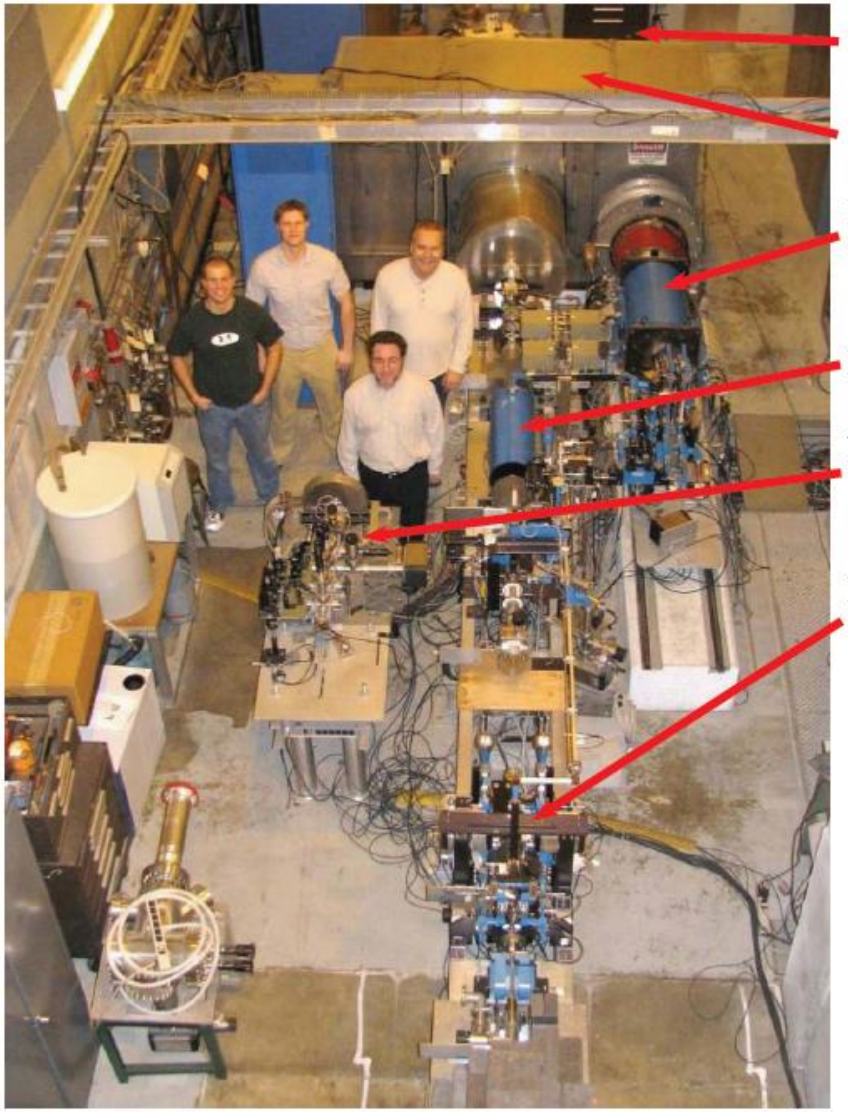
PBG a/b=0.3



“Cool Runner”

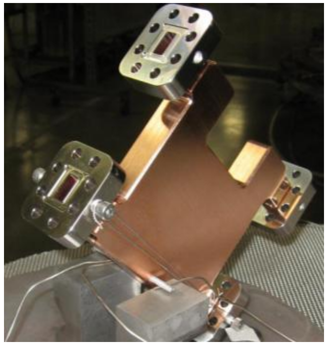
# MIT/HRC Accelerator and Test Stand

| MIT HRC Accelerator Parameters | |
|---|---|
| Modulator Voltage | 700 kV |
| Modulator Pulsed Power | 500 MW |
| Modulator Pulse Length | 1.0 μs Flat-top |
| Klystron Power | 25 MW |
| RF Frequency | 17.14 GHz |
| Linac Energy | 25 MeV |
| Linac Length | 0.5m, 94 cells |
| Test Stand Power | 4 MW |



# 17 GHz Test Stand / User Facility

- Powered by HRC 17 GHz Klystron
  - 4.2 dB hybrid coupler; up to 4 MW of power available
- Test stand will be completed in Spring, 2011
  - 17 GHz $TM_{01}$ mode launchers built by SLAC
- Planned experiments on MIT PBG structures
  - Microwave breakdown with improved diagnostics
  - Metallic PBG Structures
  - Dielectric PBG Structures
- **Users Welcome!**
  - That means you

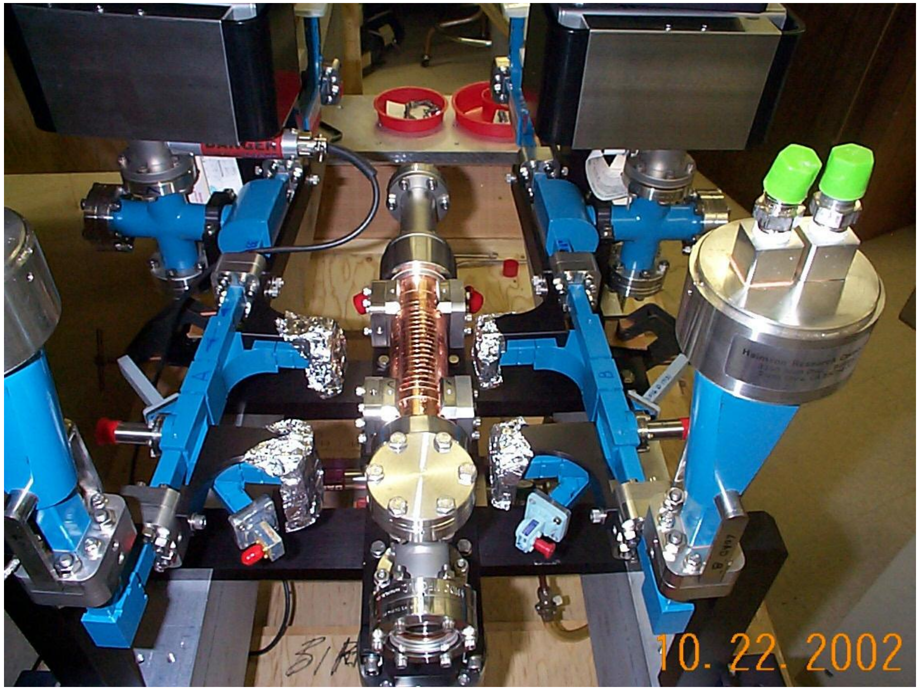


HRC Hybrid

SLAC 17 GHz Launcher

# Collaboration with Haimson Research

- Test of Choppertron
- Testing of Brazed Molybdenum/Copper Disk Irises in 17 GHz Linac Structures




**View of All-Copper 17 GHz Linac Structure and 4X Peak Power Amplifier System.**

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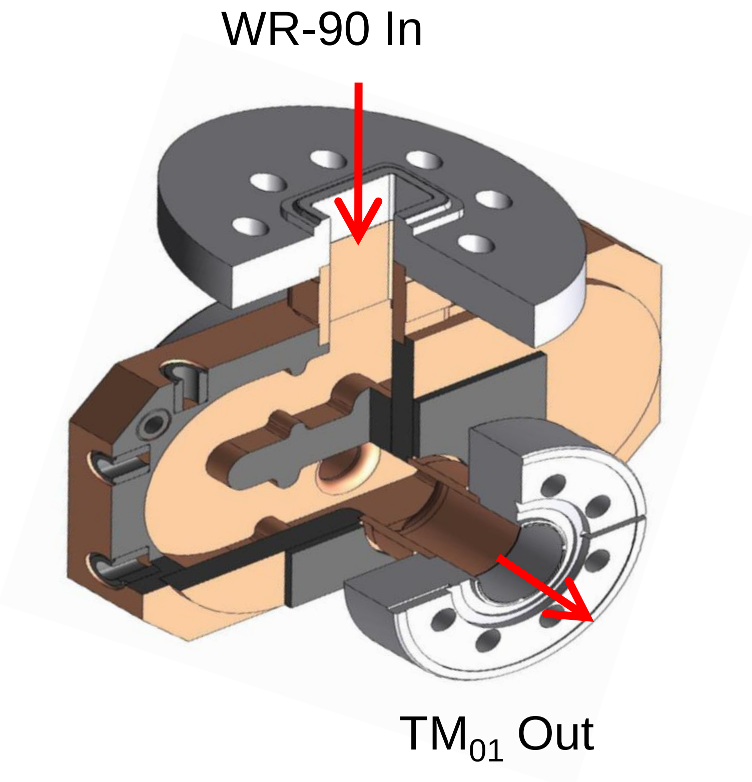
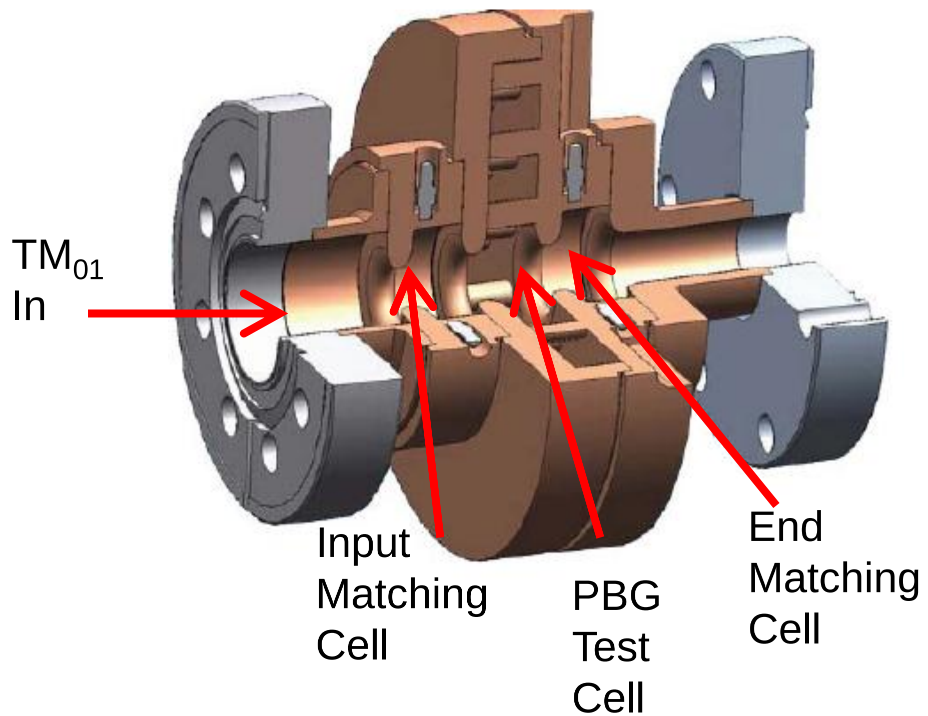
# X-Band Single Cell Testing at SLAC

- Standing wave design with half field in each of 2 coupling cells and full field in test cell
- Reusable $TM_{01}$ mode launchers are used to power structures via axial coupling



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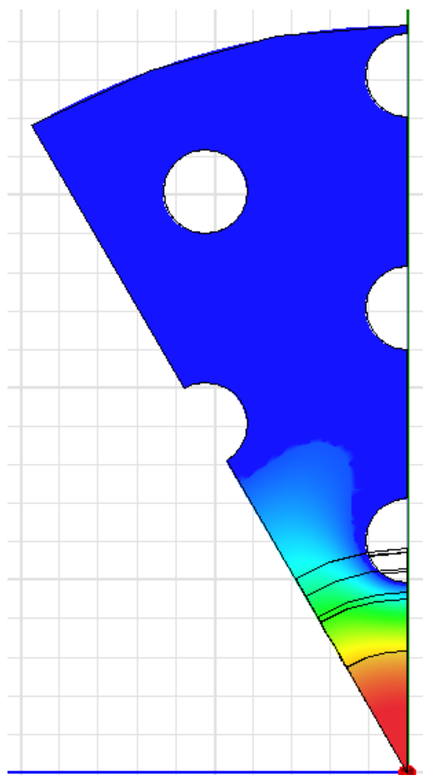
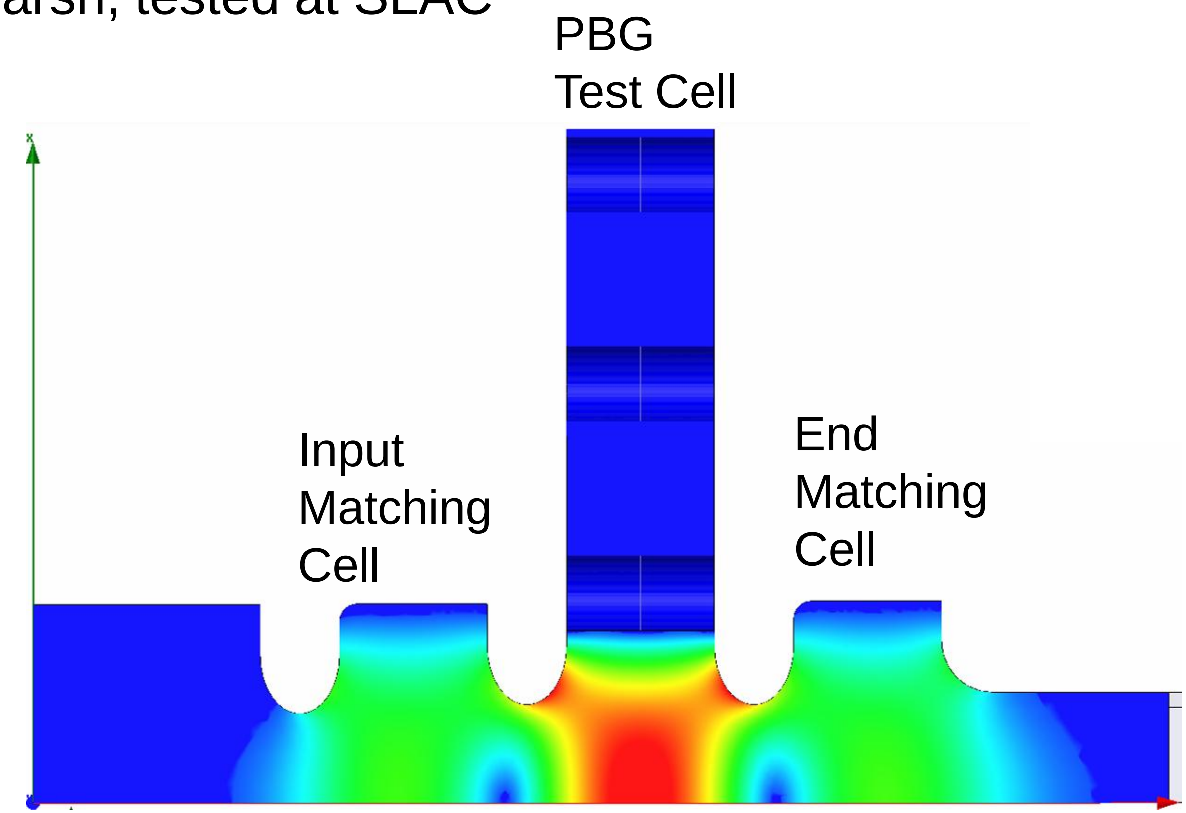
# 11 GHz Structure Design

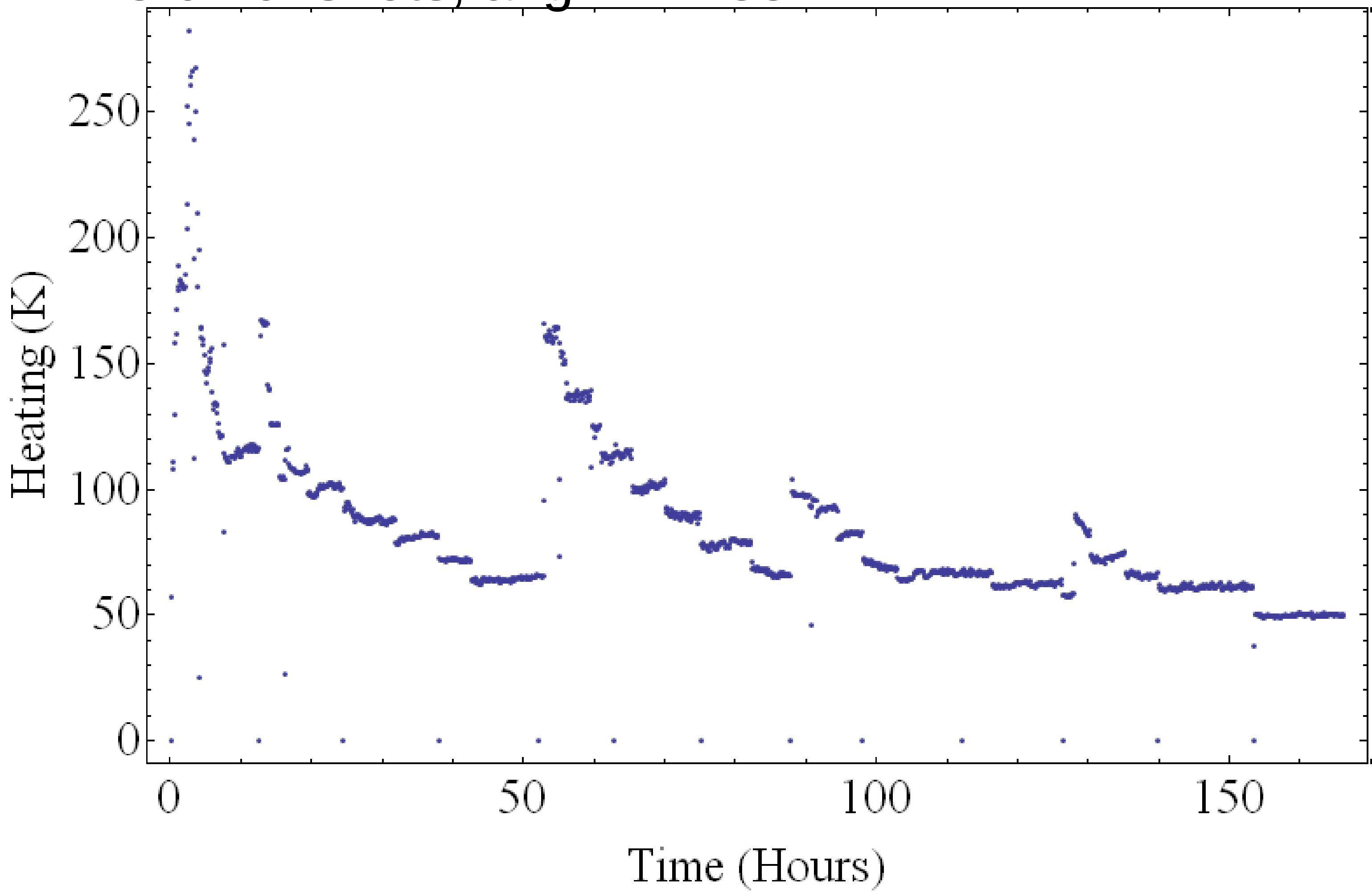
- Round-rod PBG (RR PBG) designation: 1C-SW-A5.65-T4.6-Cu-PBG-SLAC#1
- 3 rows of round rods, all rows identical
  - Design by R. Marsh, tested at SLAC





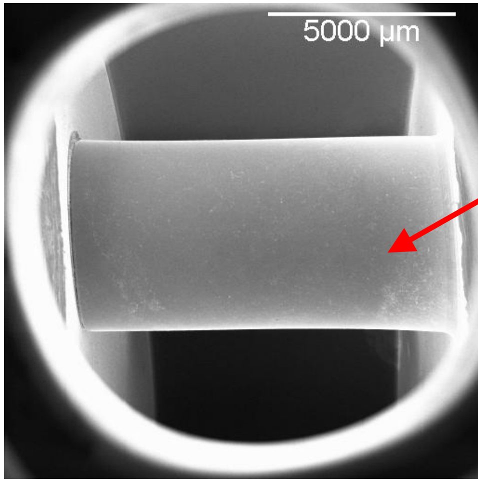
# Round-Rod PBG Pulsed Heating Results

- Very high ΔT on early shots,
  - ~ 3.6 $10^7$ shots, avg ΔT = 83K

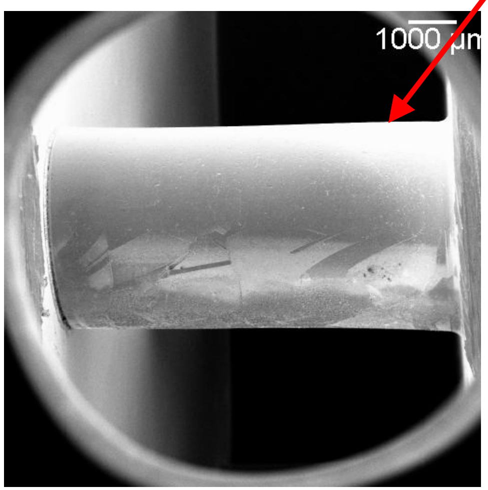


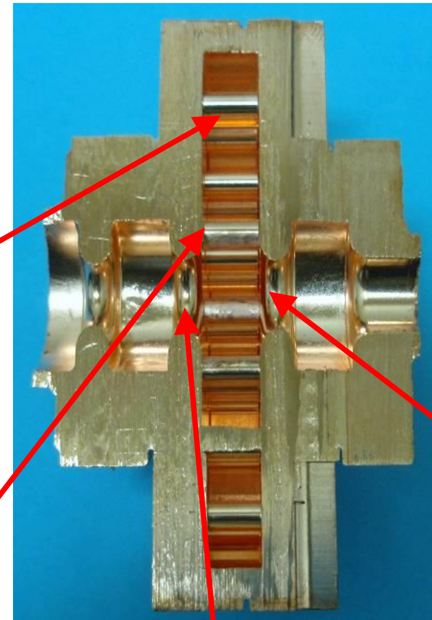
# Round-Rod PBG Autopsy

Outer Rod

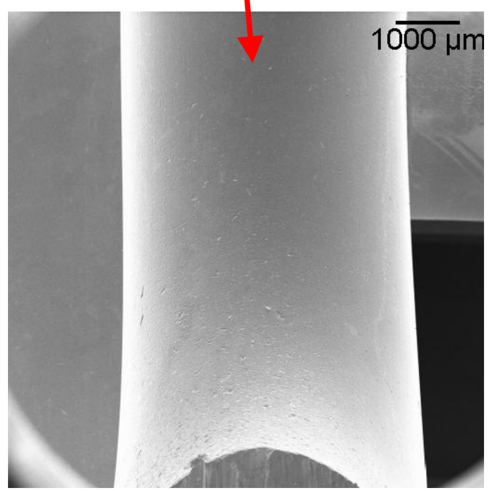



Inner Rod

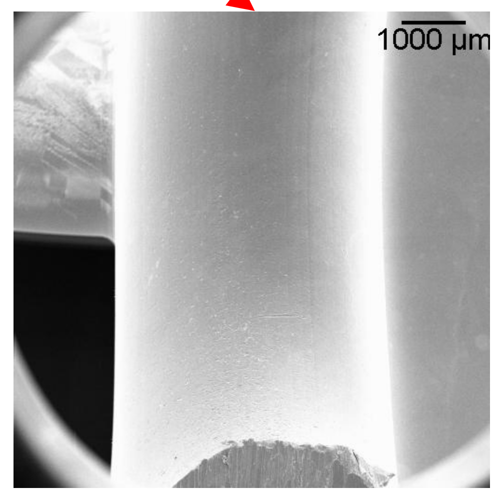


- No damage on iris
  - High E region
- Pulsed heating damage on rods
  - High H region




Input Iris




Output Iris

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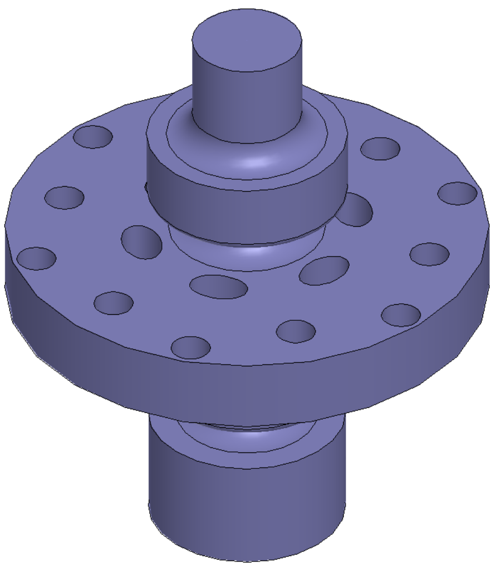
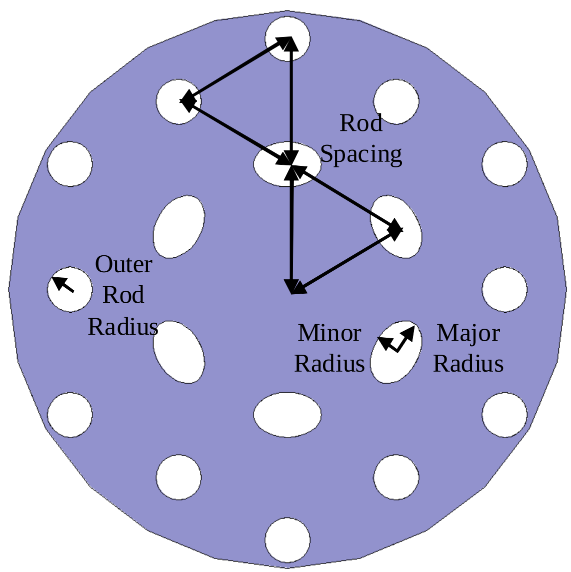
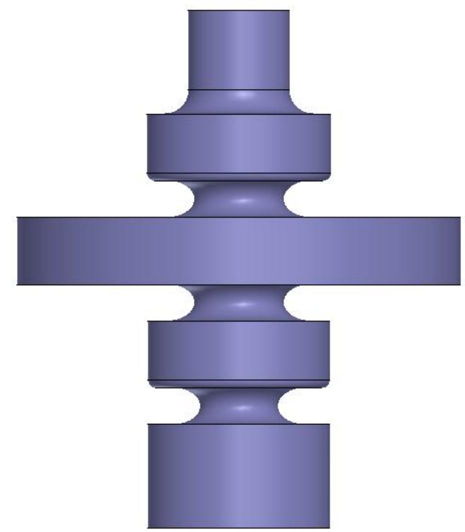
# Improved Design at 11 GHz

- First structure saw significant heating for modest gradient
- New design should reduce heating for the same gradient
- Elliptical inner rods reduce pulsed heating by almost a factor of 2
  - 2 rows, inner elliptical, outer round

| | Round Rod Structure | Elliptic Rod Structure |
|---|---|---|
| $E_{peak}$ for 10 MW $P_{in}$ | 280 MV/m | 310 MV/m |
| $H_{peak}$ for 10 MW $P_{in}$ | 1300 kA/m | 1070 kA/m |

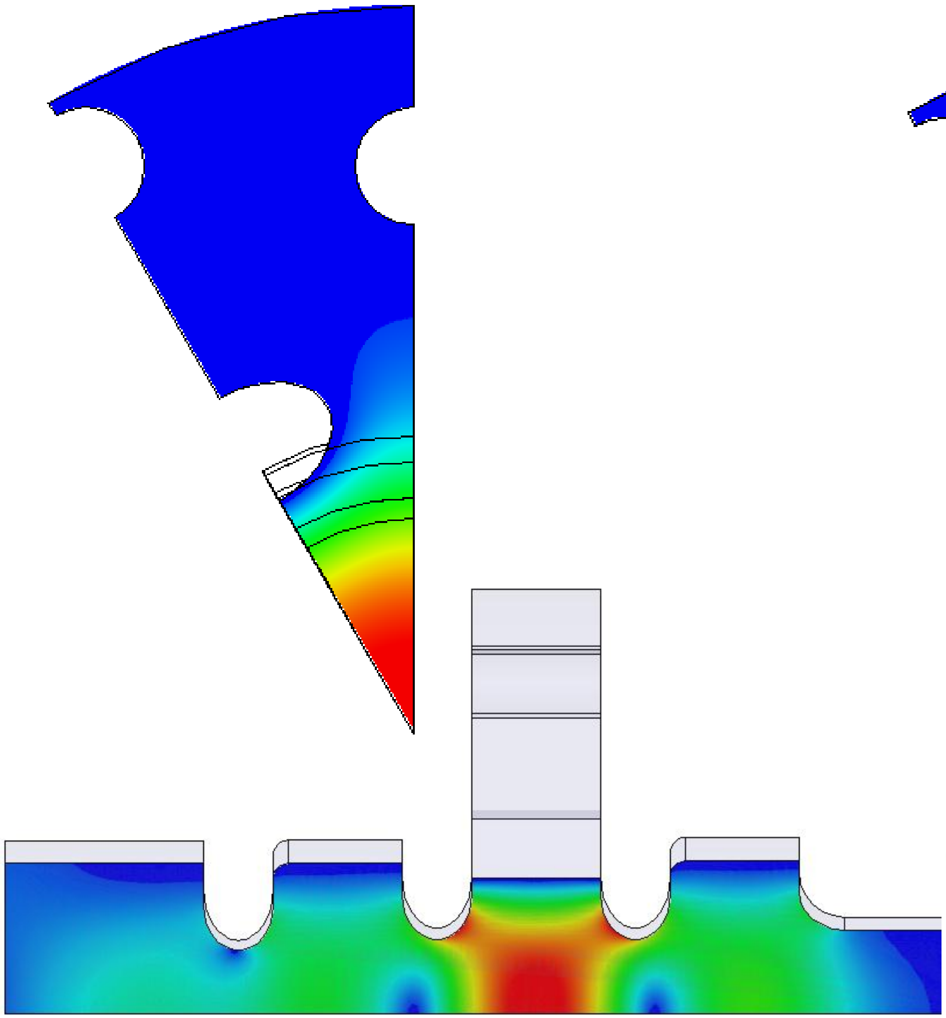




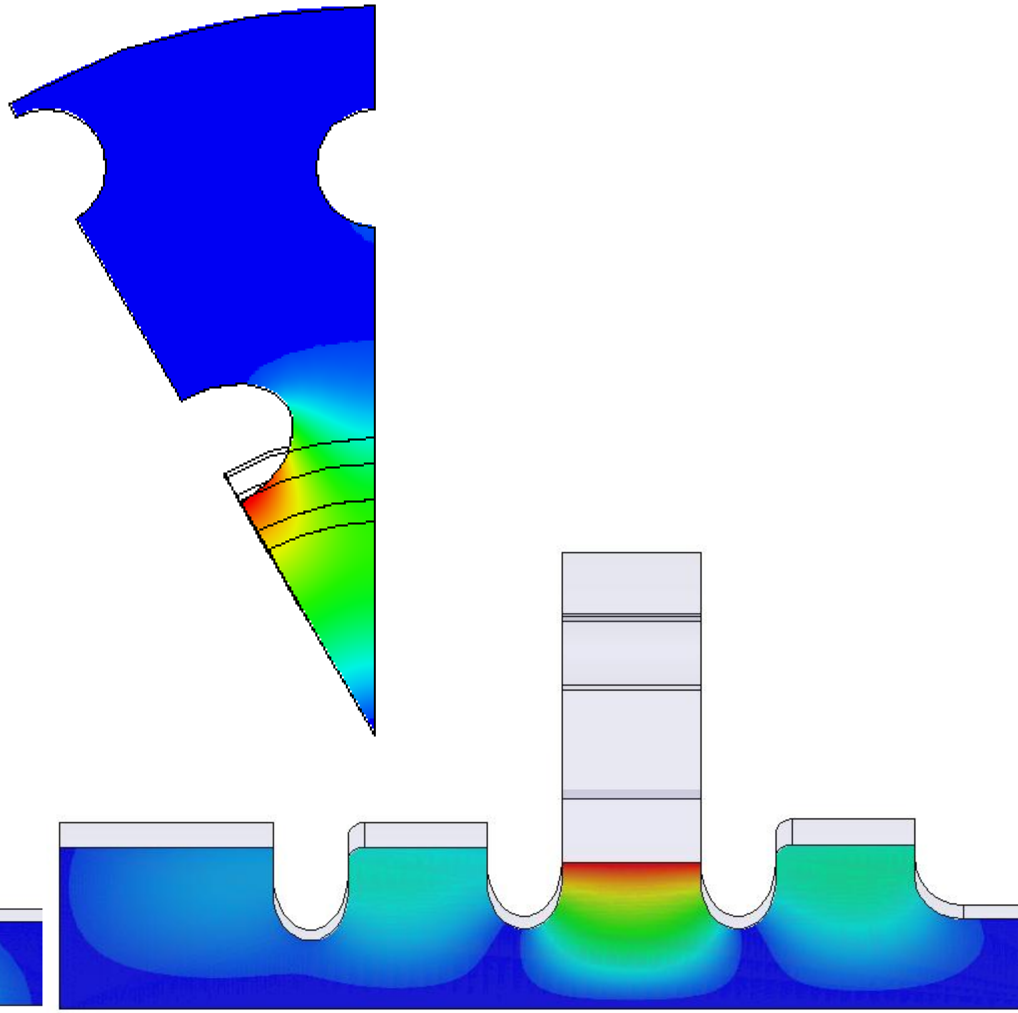



# Elliptical-Rod PBG Field Profiles

- Electric field

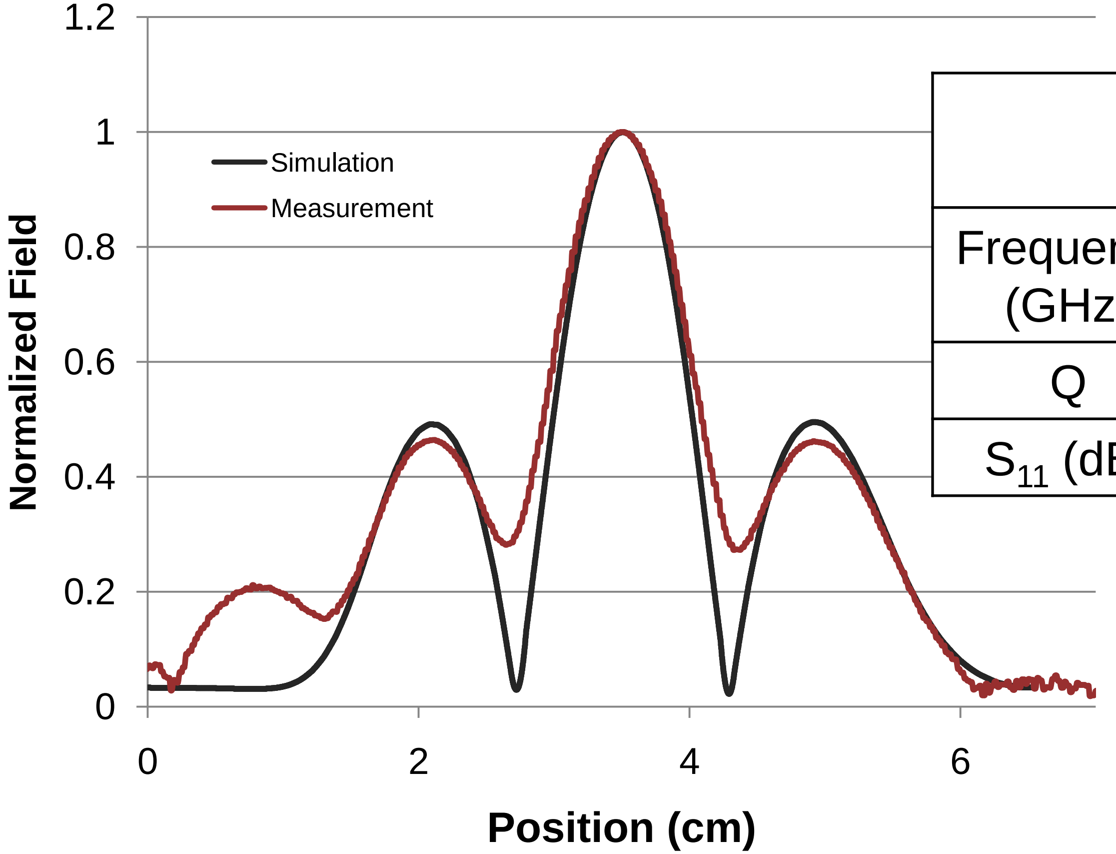


- Magnetic Field



# Cold Test of Elliptical-Rod PBG

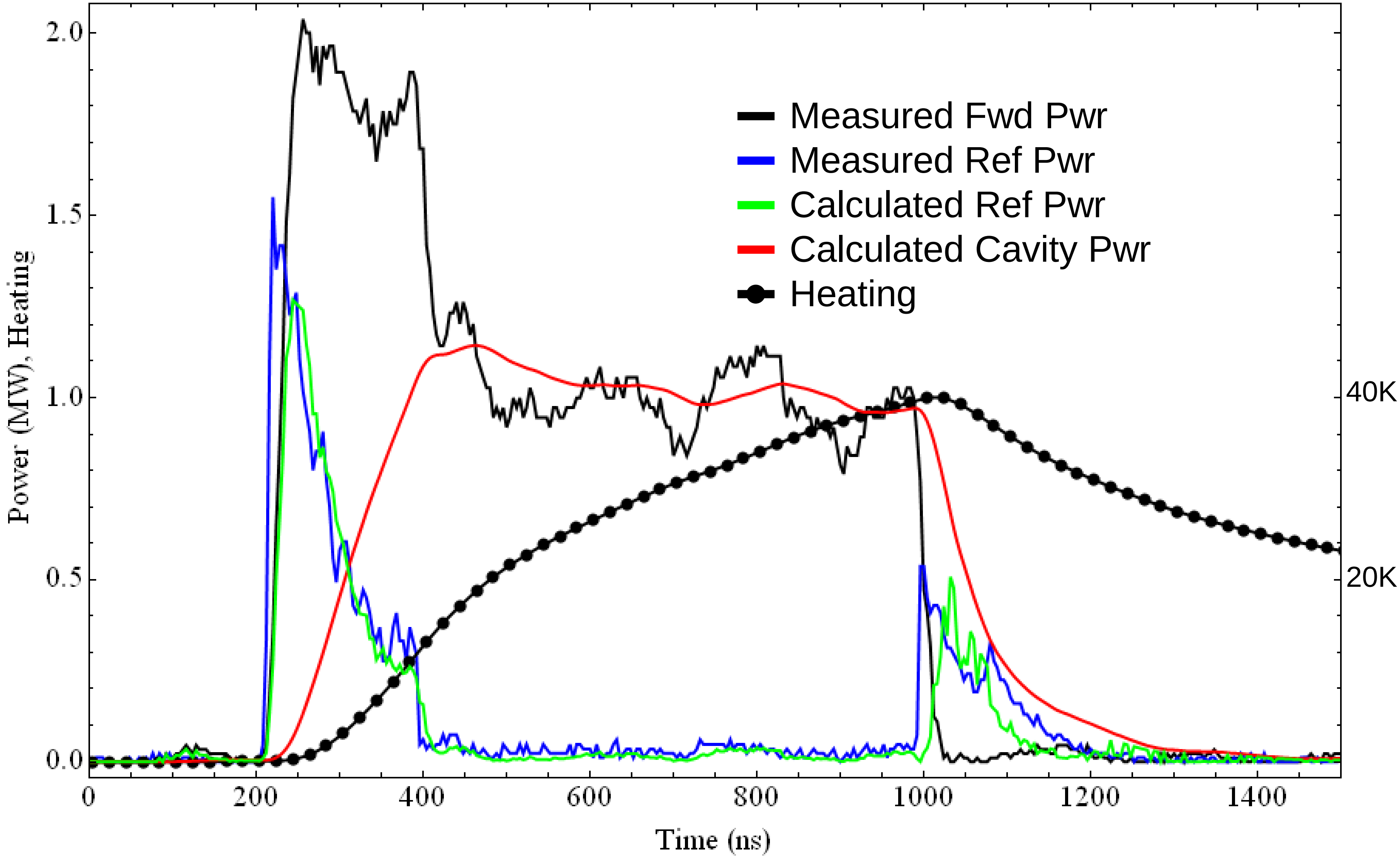
- Cold test procedure:
  - Q is calculated from $S_{11}$ measurements
  - Non-resonant bead pull is used to determine field profile




| | Measured | Design Value |
|---|---|---|
| Frequency (GHz) | 11.440 | 11.427 |
| Q | 7792 | 8304 |
| $S_{11}$ (dB) | -18 | -50 |

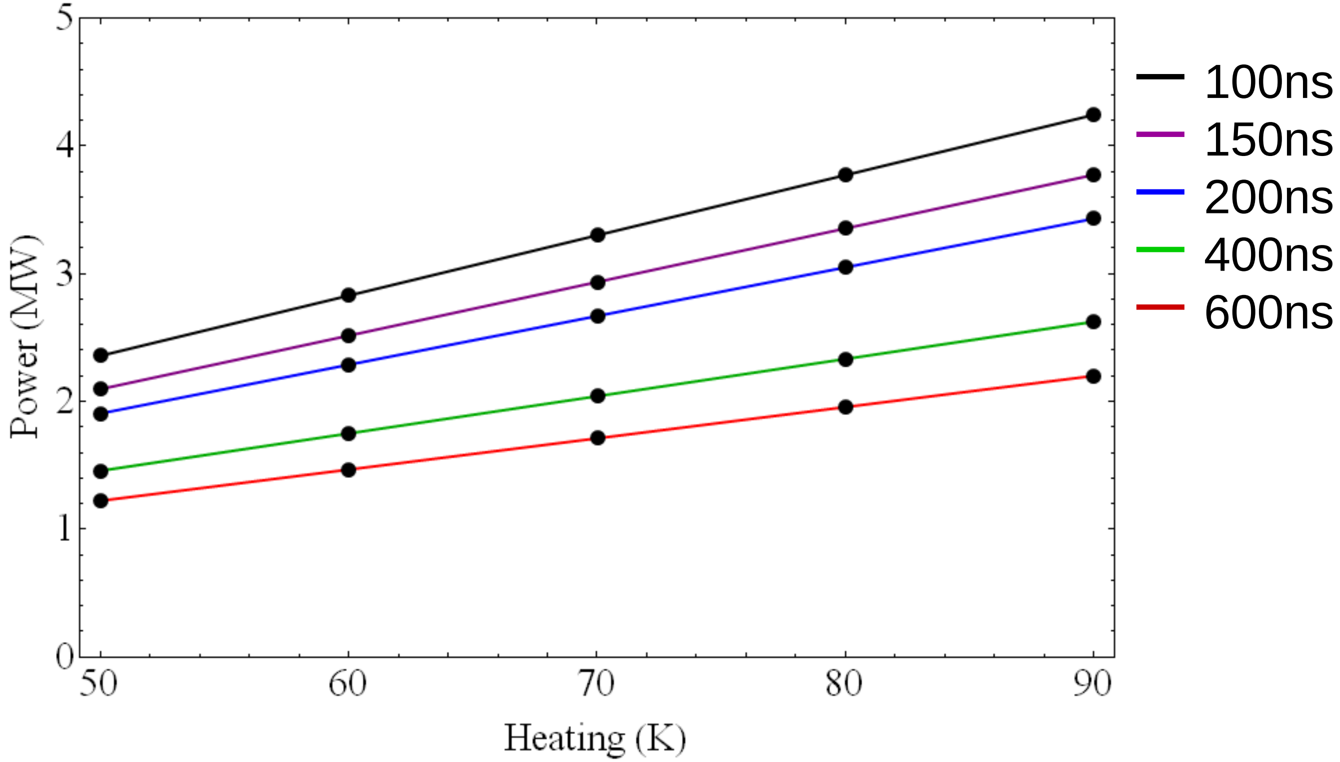
# Sample Power and ΔT vs Time During Testing

- 600ns, 1MW pulse



# Testing Protocol

- Pulsed heating is a major concern!
- Test in phases by limiting pulsed heating:
  - From 50K to 90K in 10K increments
- Pulsed heating limit sets power limit for each pulse length:

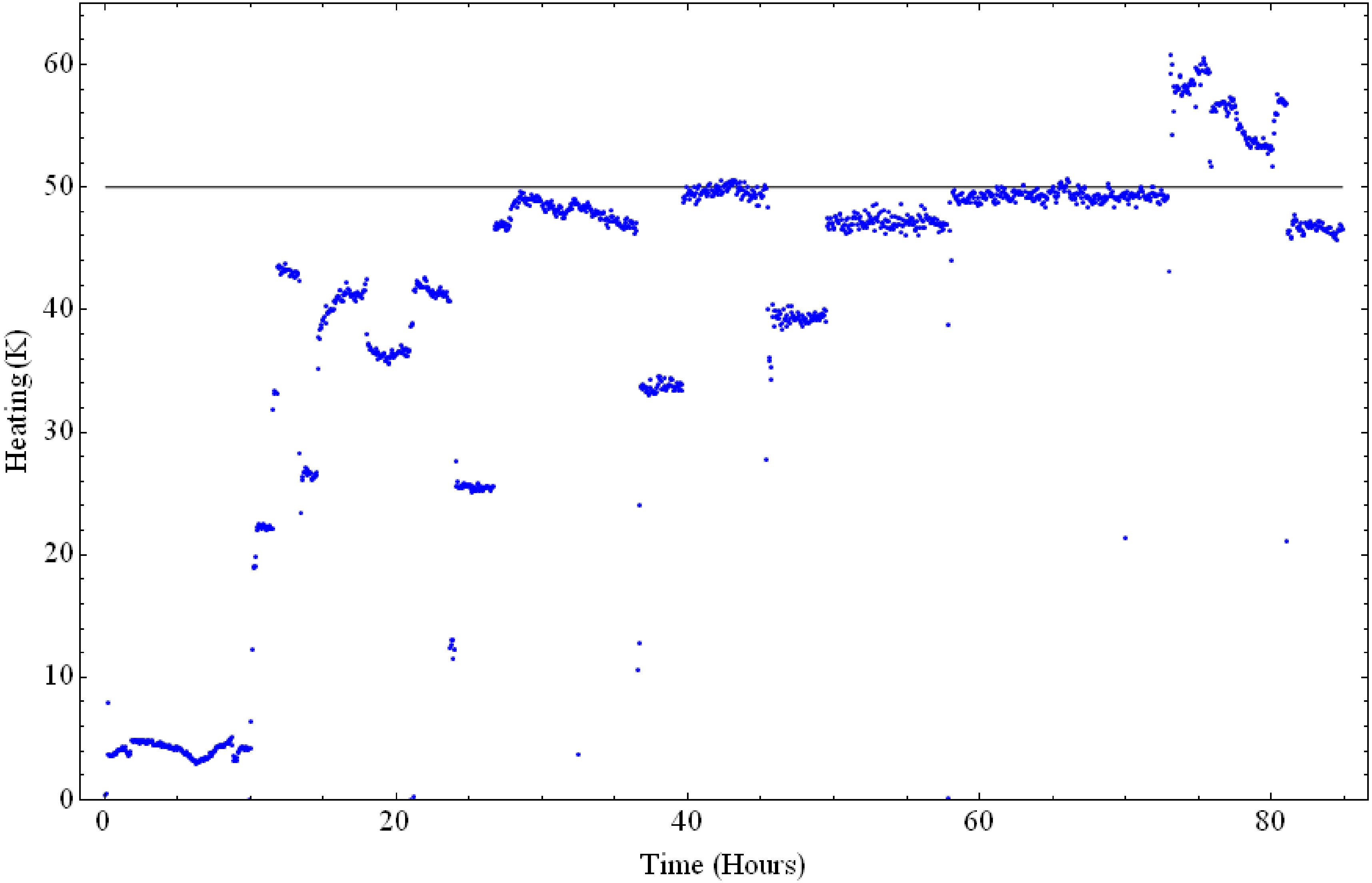


# Testing Protocol (2)

- Record breakdown rate at standard conditions at the end of each phase: 200ns, >10hrs at each power level, e.g.
  - 50K: 1.9MW
  - 70K: 1.9MW, 2.3MW, 2.7MW
- Allows us to compare performance during each phase
- Even small numbers of breakdowns give us limits on breakdown rate
- Should indicate a pulsed heating temperature rise beyond which structure performance degrades

# Current Pulsed Heating Data

- Heating limit of ΔT < 50K maintained during phase 1



# Conclusions

- Photonic Structures have unique properties
  - Reduced high order modes and wakefields
  - Useful for studies of pulsed heating
- Photonic Bandgap Structures have now been studied at high gradient and high rep rate at SLAC
  - Damage seen in first studies using circular rods
  - Second tests underway on elliptical rod structure
  - Hope to understand pulsed heating
- MIT 17 GHz Test Stand nearing completion
  - Tests of metallic and dielectric structures
  - Users welcome!