Progress in High Gradient Accelerator Research at MIT

Presented by
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MIT Physics and Plasma Science and Fusion Center

US High Gradient Research Collaboration Workshop
STANFORD LINEAR ACCELERATOR CENTER

HEP office of high energy physics

Office of Science U.S. Department of Energy

May 23, 2007

MIT Accelerator Research Collaborators

MIT Plasma Science and Fusion Center

A. Cerfon, Y. Hidaka, A. Kesar, R. Marsh,
I. Mastovsky, W. Mulligan, M. Shapiro, J. Sirigiri

US High Gradient Collaboration (through SLAC)

Haimson Research Corp.

J. Haimson

STAR (Simulation Technology & Applied Research, Inc.)

J. DeFord; working with **SLAC (**Kwok Ko)

Los Alamos National Lab

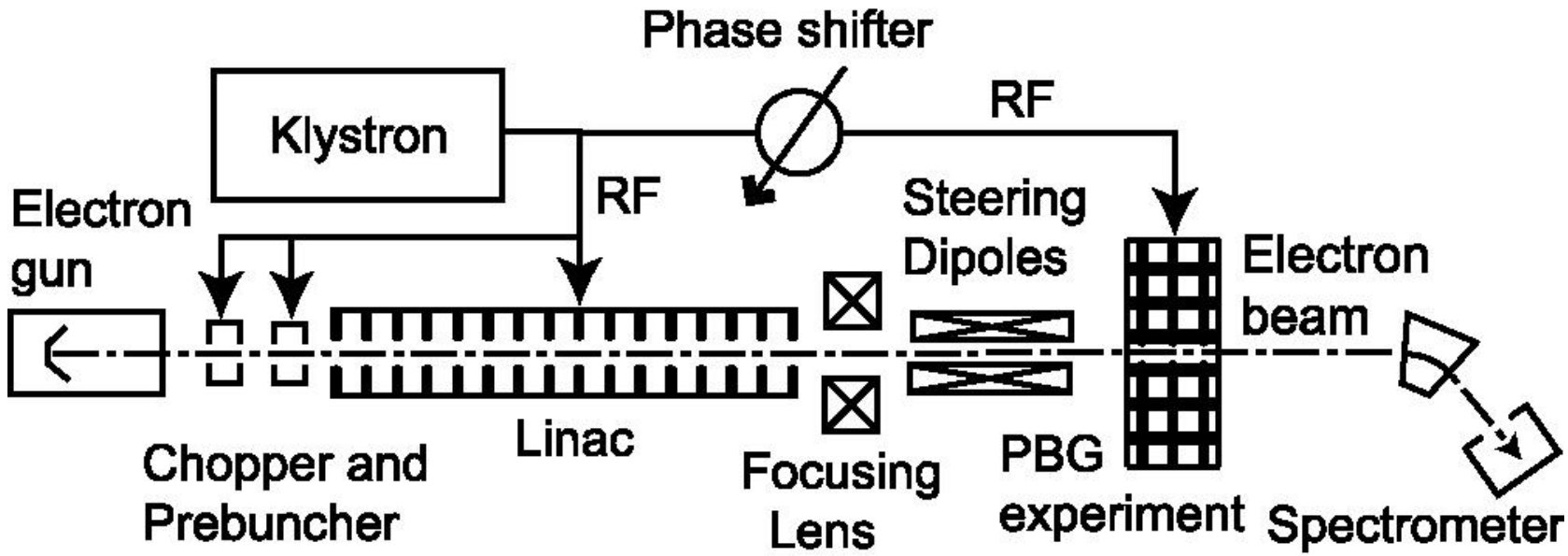
E. Smirnova, L. Early

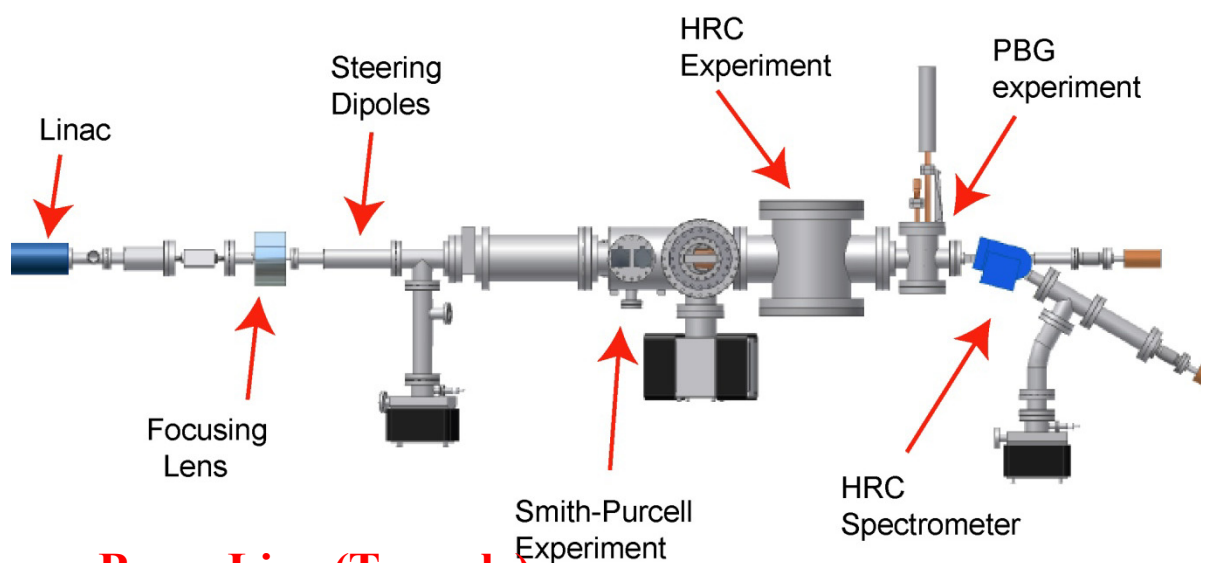
Several Proposed Collaborations

OUTLINE

- **Introduction**
  - **MIT / HRC (Haimson Research Corp.) 17 GHz Accelerator Laboratory**
- Recent Accomplishments
- Ongoing Research
- Planned Research

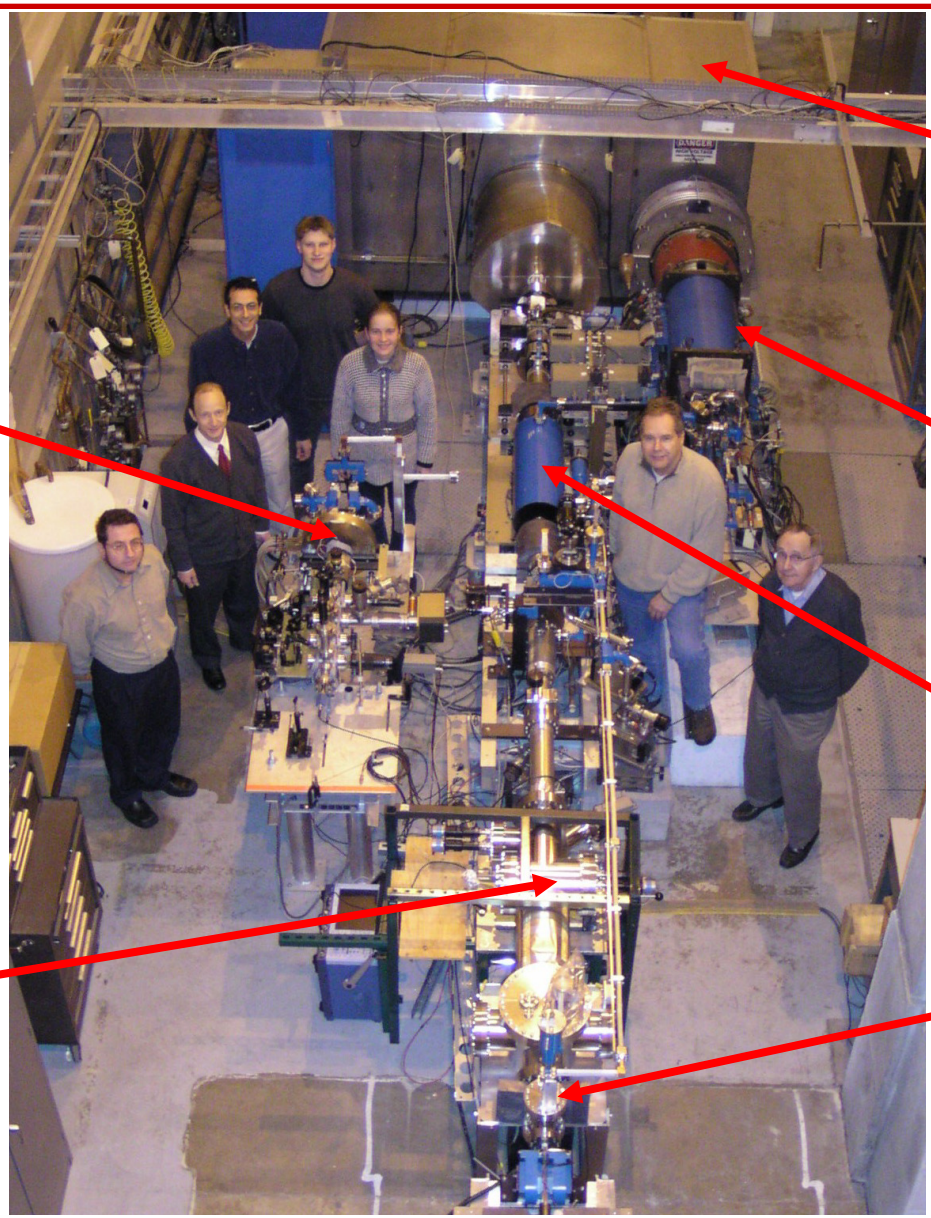
Experimental Schematic





Beam Line (To scale)

17 GHz Accelerator Lab and User Facility at MIT



Modulator
700 kV, 780A
1 μs flattop

Klystron 25 MW
@ 17.14 GHz

25 MeV Linac
0.5 m, 94 cells

Novel High Gradient Structure / Photonic Bandgap Test Stand

RF Break-down / RF Gun Test Stand

THz Smith-Purcell Expt.

MAJOR OPERATING PARAMETERS

Haimson / MIT 17 GHz Accelerator

Parameter	Value
Klystron	25 MW, 17.14 GHz
Beam Energy	10-25 MeV
Average Current	0.2 A
Peak Current	80 A
Electrons/Bunch	10^8 (20 pC)
Emittance	2.5π mm-mrad
Beam Waist	1mm
Min. Bunch Length	60 μm (180 fs)

- Fully operational, outside users encouraged

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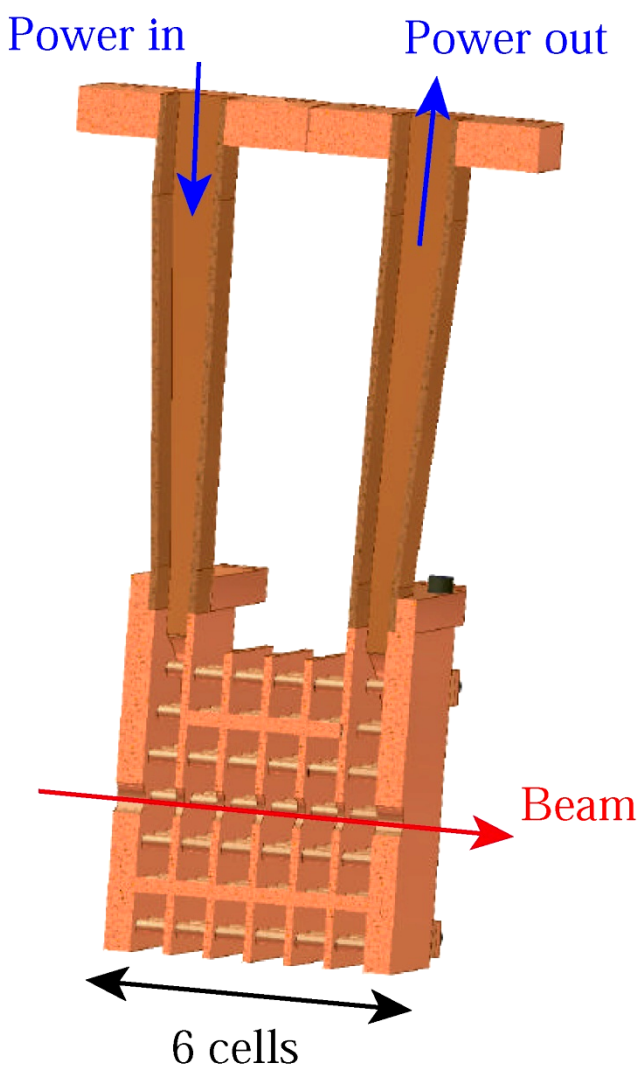
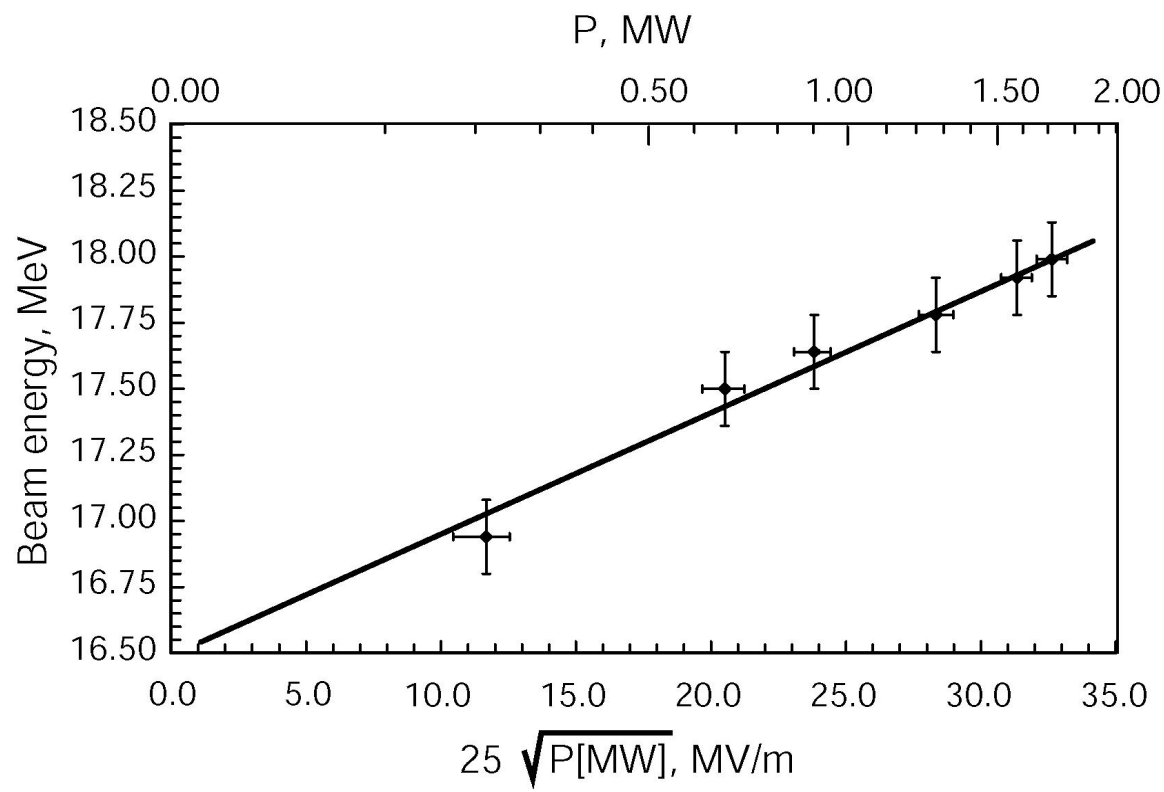
Accomplishments: PBG Accelerator Expt.

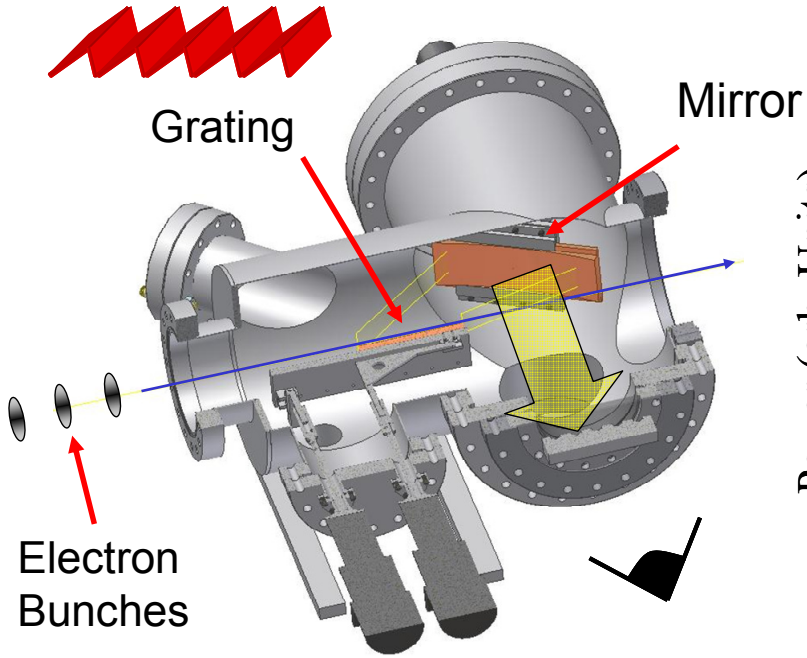


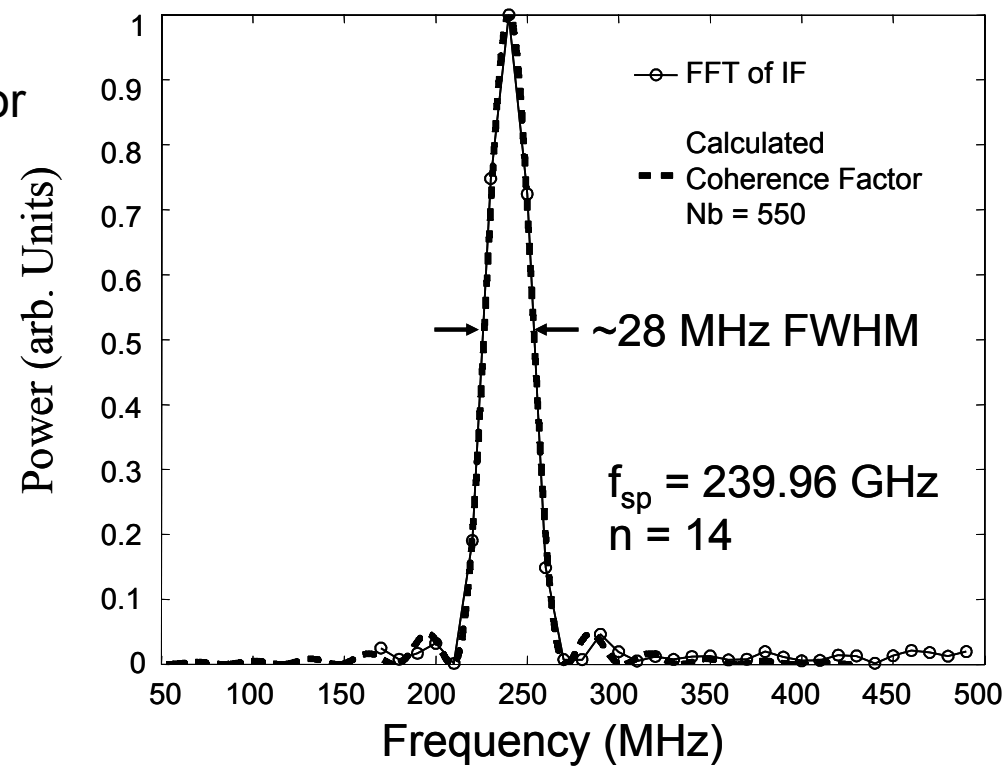


- First successful experimental PBG accelerator demonstration.

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

Accomplishments: Smith-Purcell THz Rad. Expts.



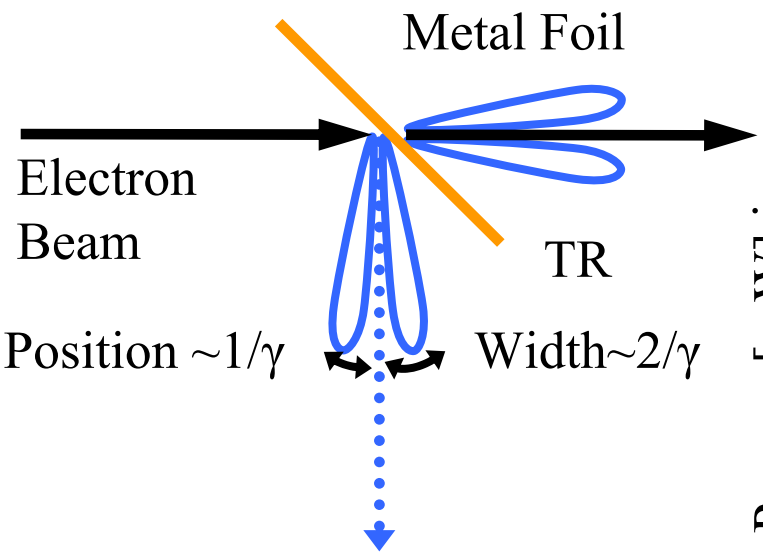


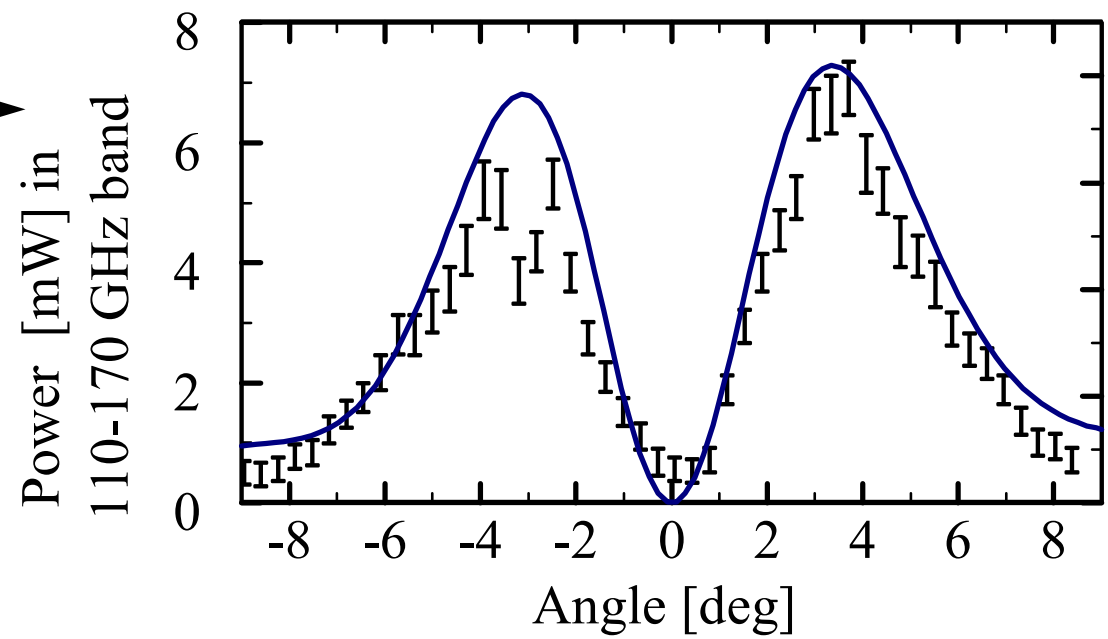
- First observation of frequency-locked SPR indicating that the SPR can be a powerful, coherent, THz source.

- The measurement of sub-picosecond bunch lengths using SPR was demonstrated: good fit with the theoretical results.

S. E. Korbly et al., Physical Review Letters (2005).

Coherent Transition Radiation

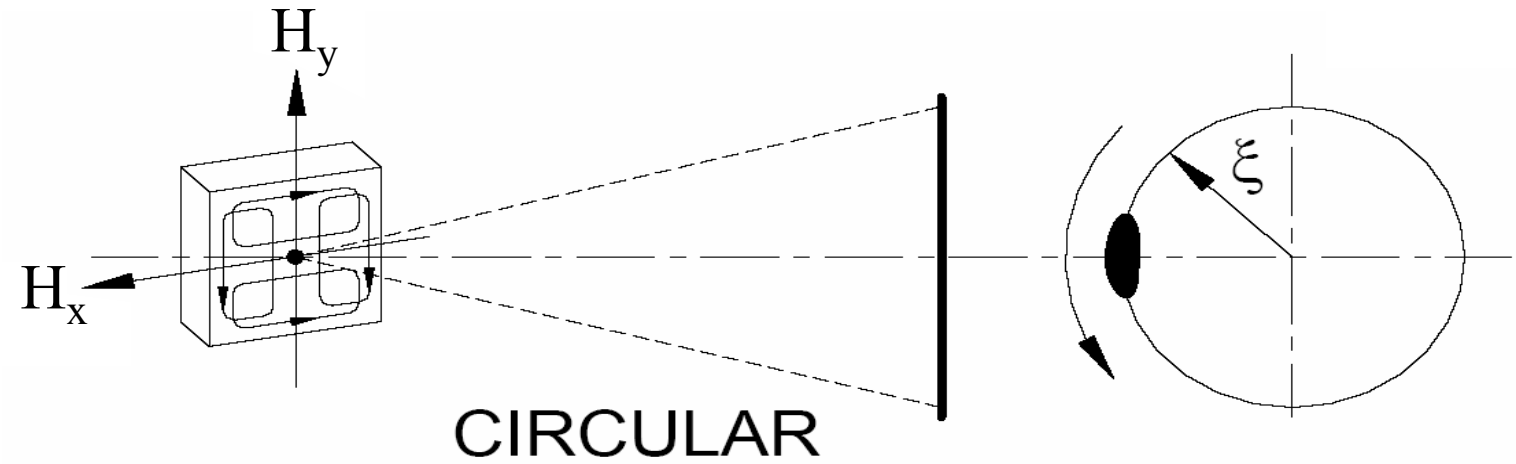


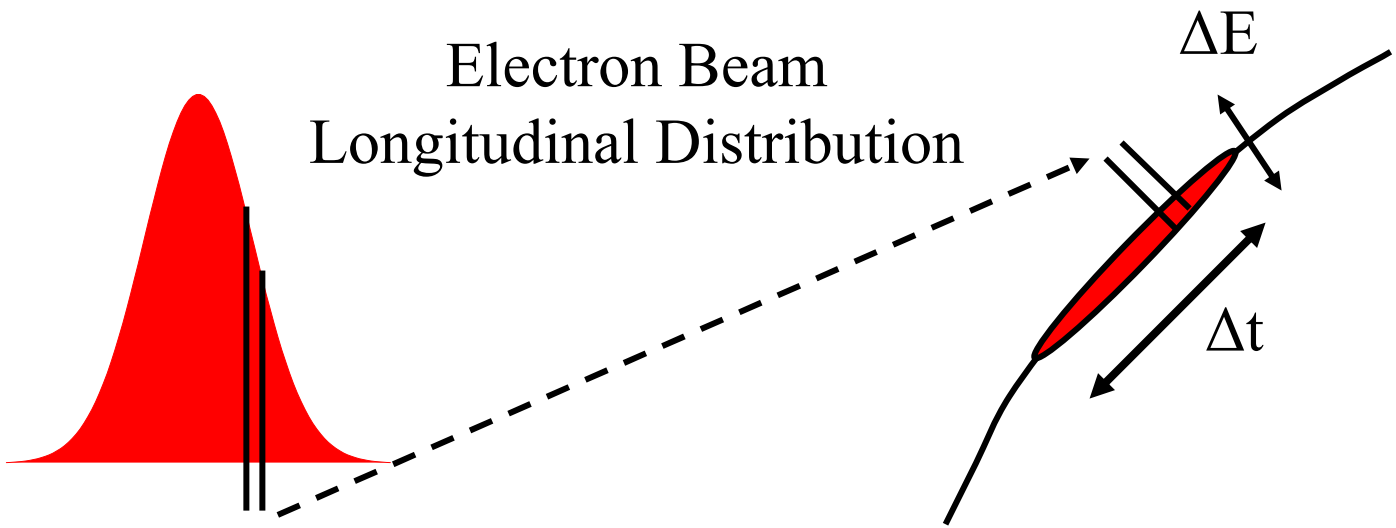


- Radiation as charge passes from one dielectric medium into another, in this case vacuum to metal
- EFIE Code vs.WR6 Diode measurements
  - Power calculated in 110-170 GHz band
- Results compared on Absolute scale!

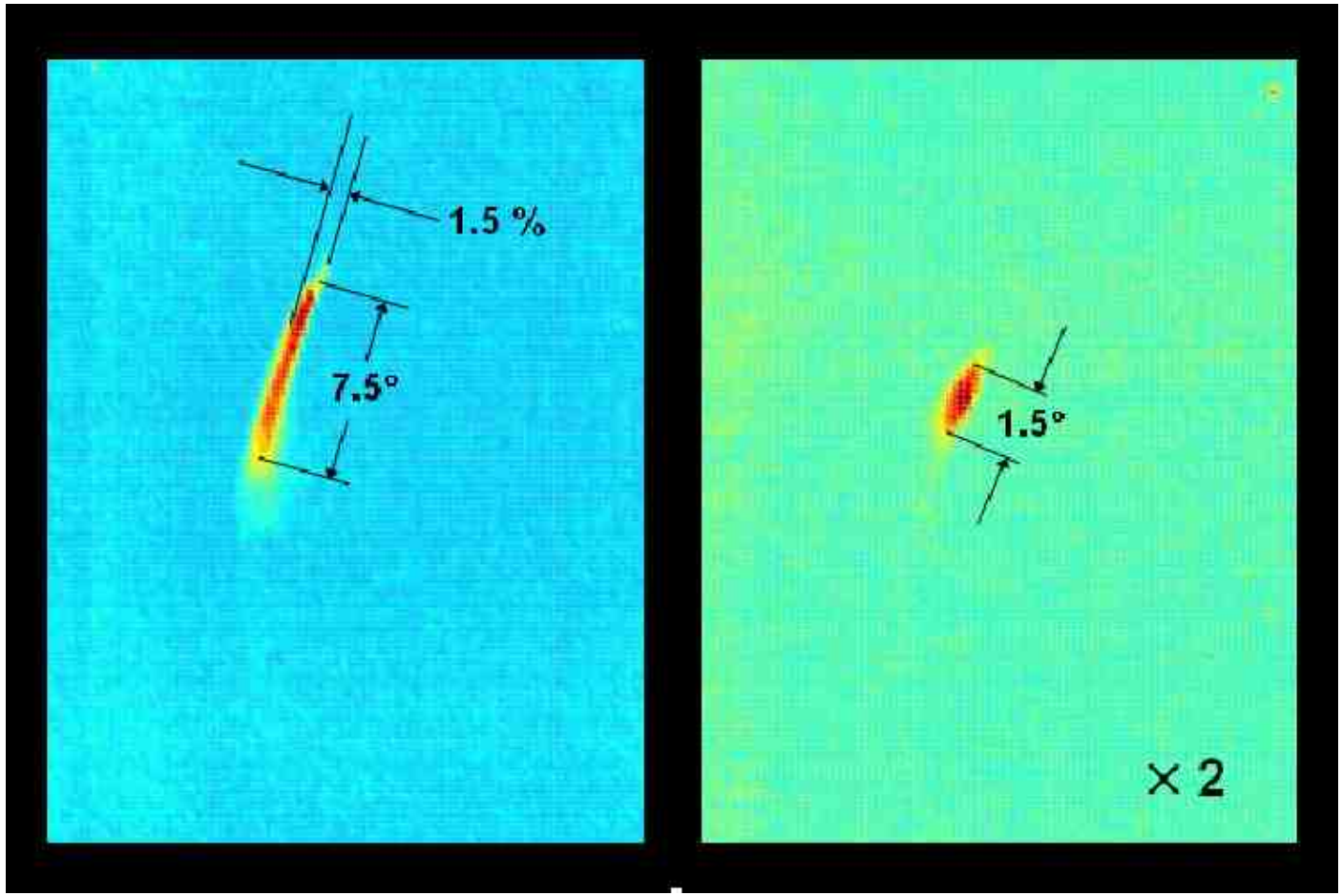
R. Marsh et al., submitted for publication (2007).

HRC: Deflector





Measured Bunch Spectra



1.2 ps

240 fs

Shortest bunches are 160 fs

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- Planned Research

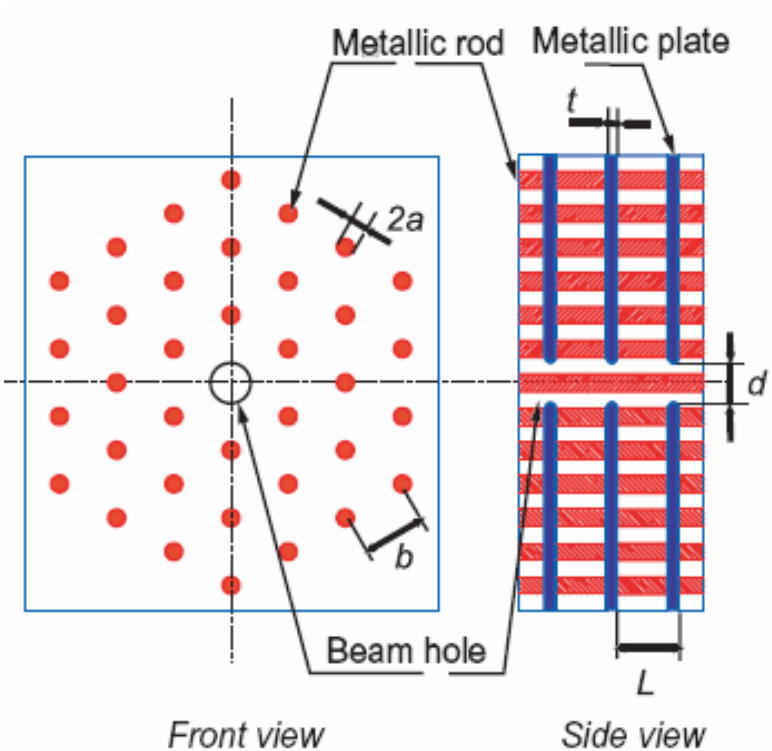
Ongoing Research

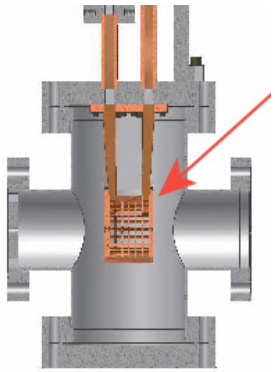
- **Photonic Bandgap Structures**
  - Measurement of Wakefields using existing PBG structure
  - Comparison with Wakefield Calculations
    - Collaboration w. J. DeFord (SBIR funded)

- **Haimson Collaboration**
  - 76 dB High Gain Relativistic Klystron (completed Fall, 2006)
  - Breakdown tests in “Power Amplifier” (2007)
  - Proposed Choppertron (2008, if funded).

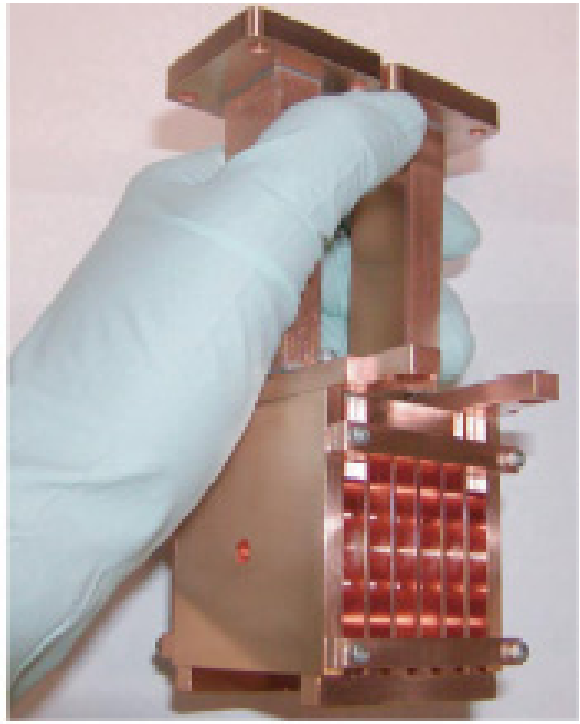
- **Design of Advanced HGA Structures**
  - Dielectric PBG structures
  - Surface mode structures
  - Dielectric structures

Metallic PBG Structure





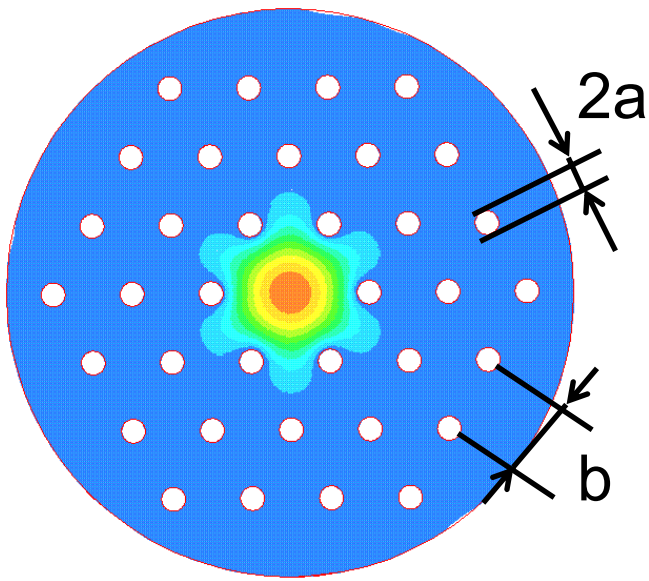
a	1.08 mm
b	6.97 mm
d	3.88 mm
L	5.83 mm



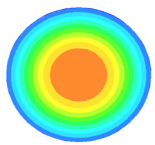
- Triangular lattice of metallic rods, with defect
- 6 cell traveling wave structure, group vel. = 0.013c

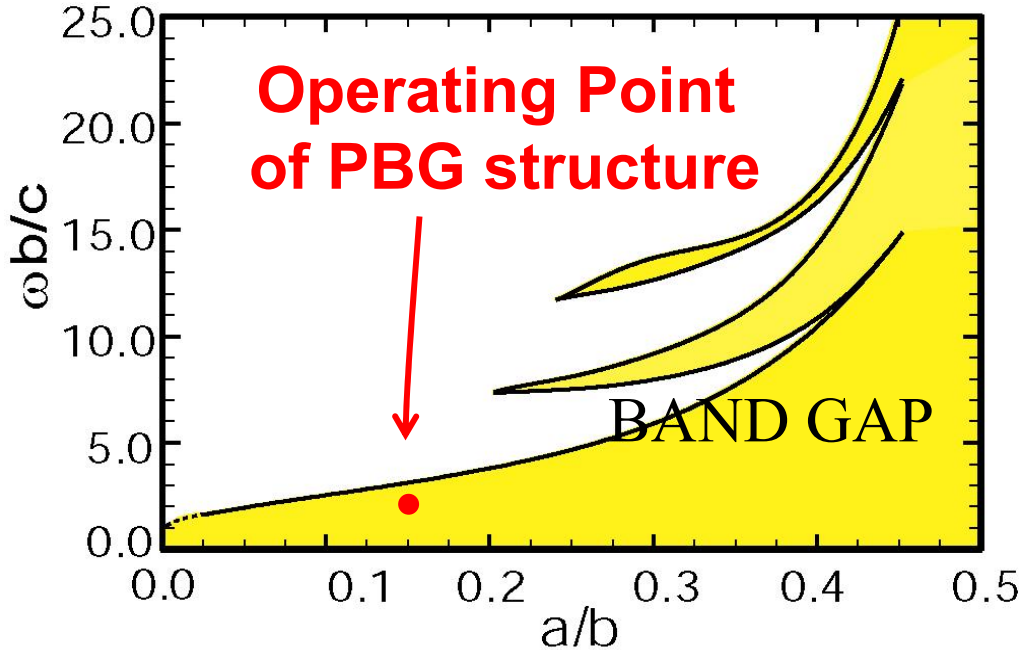
Mode selectivity in PBG cavities

PBG Cavity, triangular lattice
a/b=0.15, **TM_{01} –like mode**



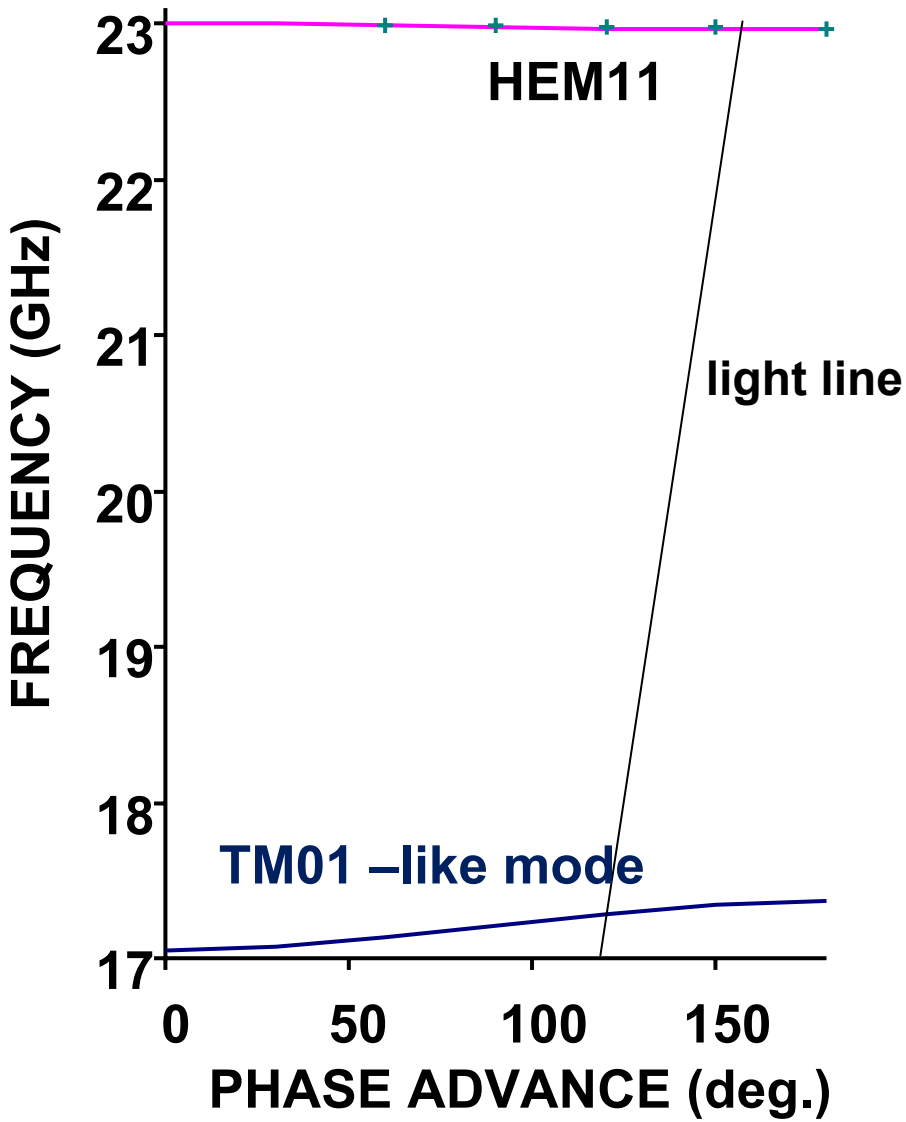
Pillbox Cavity, TM_{01} mode





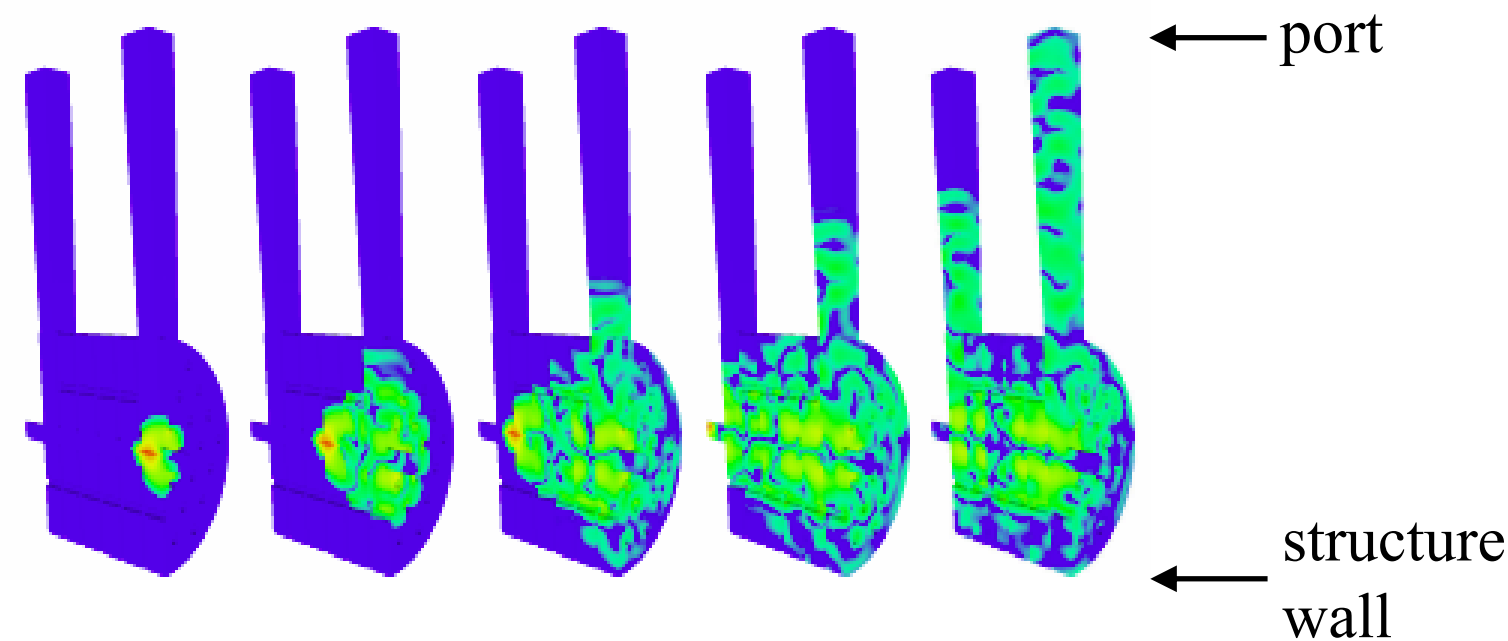
- **Only one eigenmode is supported by the PBG lattice**

Wakefields in a PBG Structure



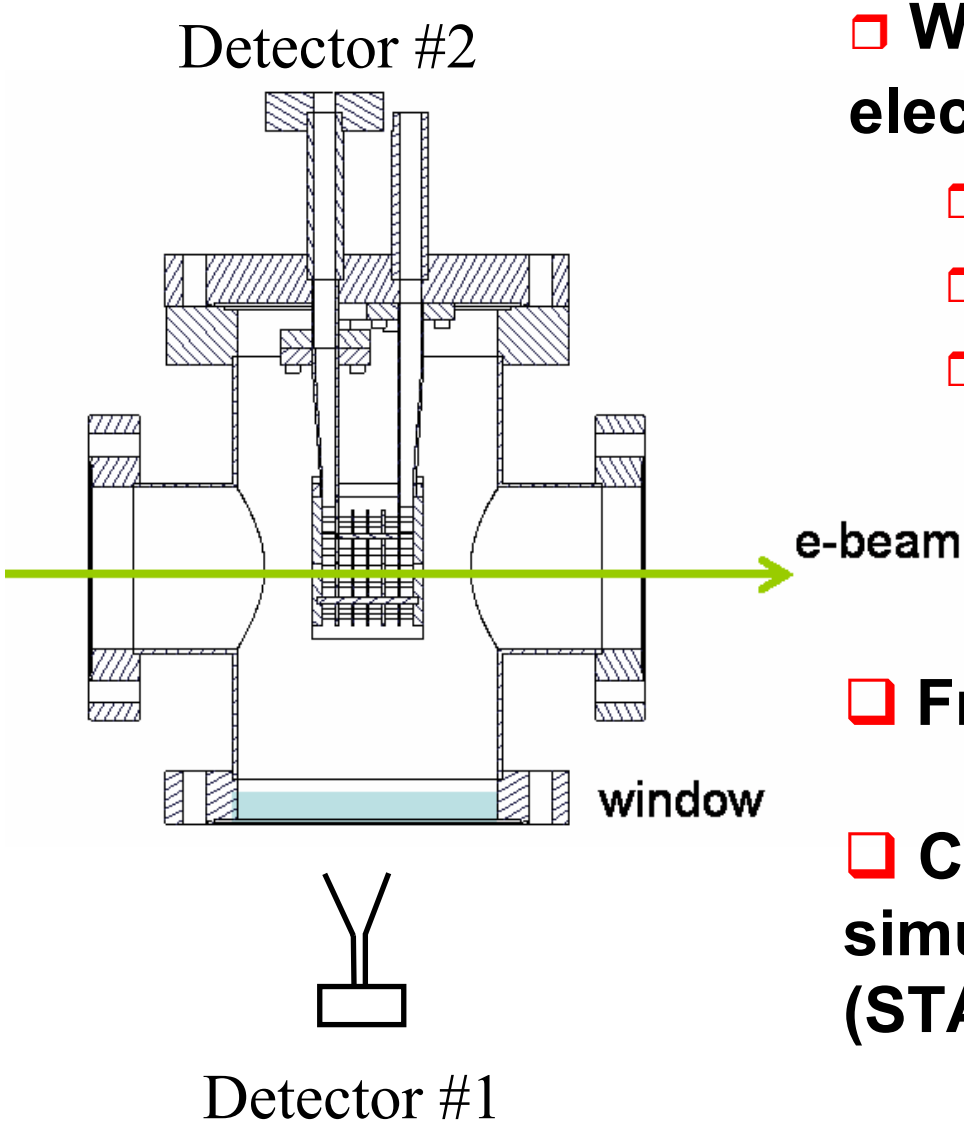
- There is only one confined eigenmode in a PBG structure
- The dipole mode at 23 GHz is not confined, Q~100
- It has zero group velocity
- What wakefields will be seen in the experiment?
- Is the dipole mode in a PBG structure less dangerous than in a conventional structure?

Wakefield Simulations



- Magnetic field magnitude in the MIT 6 cell PBG structure
  - Beam bunch injected off axis
- Calculated by J. DeFord (STAR) and K. Ko (SLAC)

PBG Wakefield and HOM Expt.



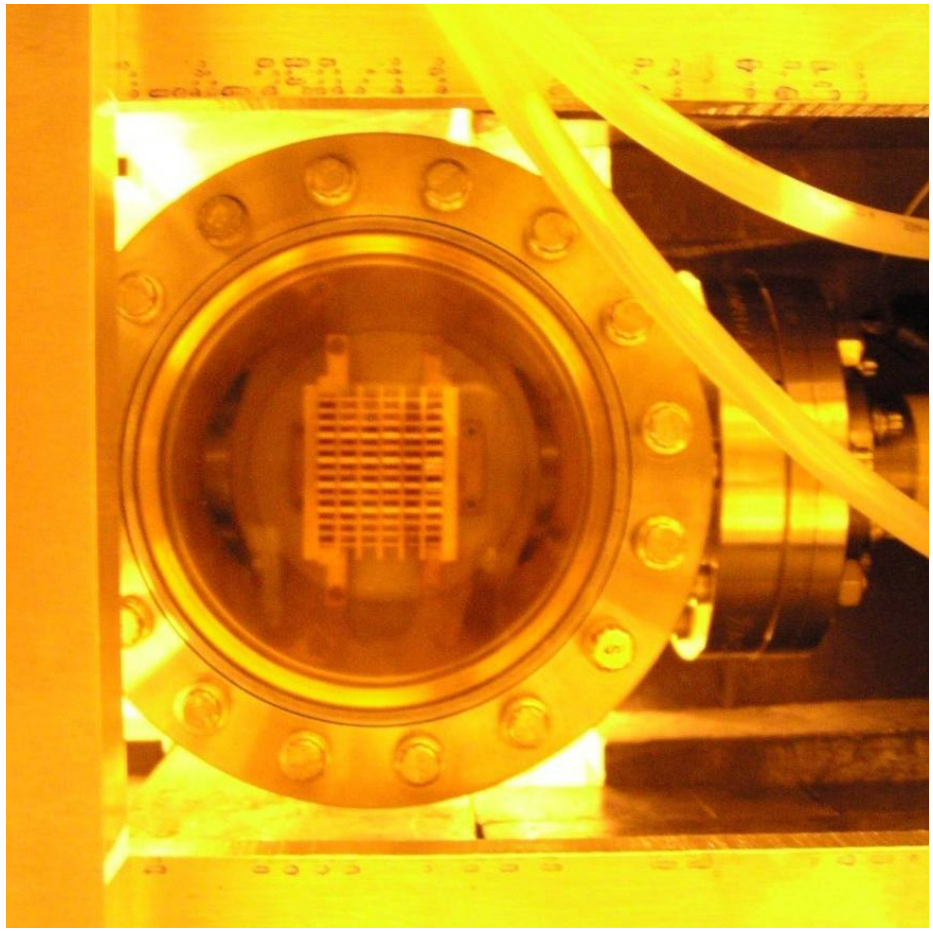
- Wakefields generated by the electron beam
  - No μwave input
  - Measure Power vs. Freq
  - Measure dependence on I, beam displacement

- Frequency range to 1 THz

- Compare results with simulations by DeFord (STAR) and Ko (SLAC)

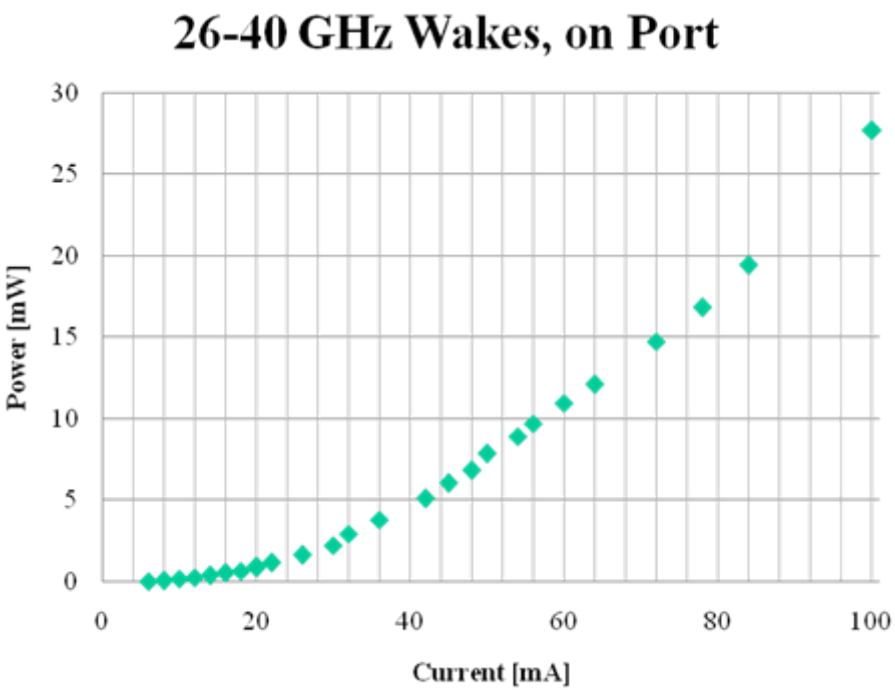
Experimental Setup

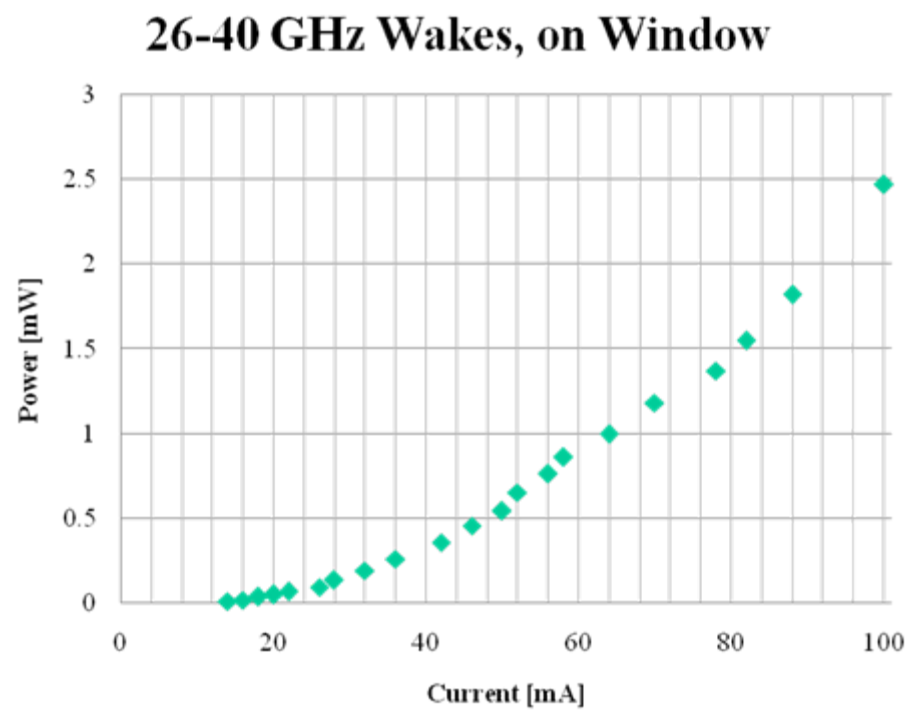
- Diodes (17 GHz, and 26-40 GHz) with Horn antennae
- Used both on Port Window, and Chamber Window



First Results 26-40 GHz Band

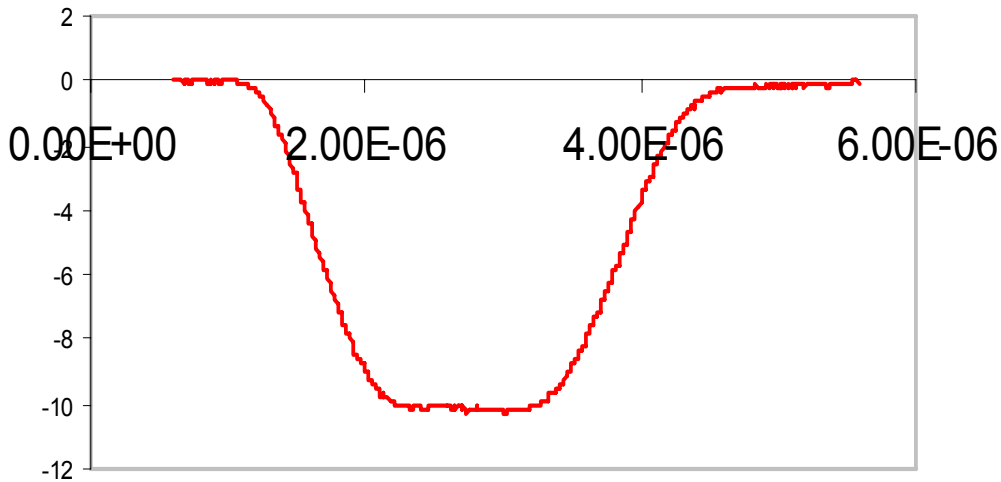
- 26-40 GHz radiation measured with calibrated receiver
  - Dipole mode at 23 GHz is received by this detector
- Quadratic dependence with current observed
- **More data and more theoretical results are needed**



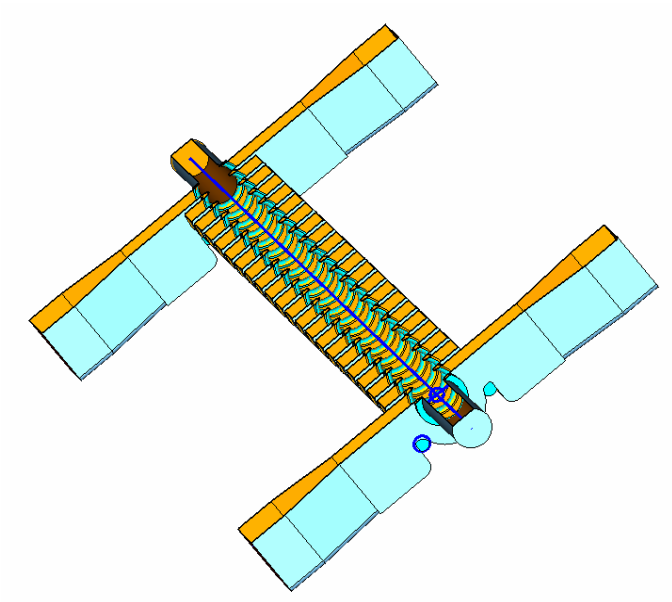


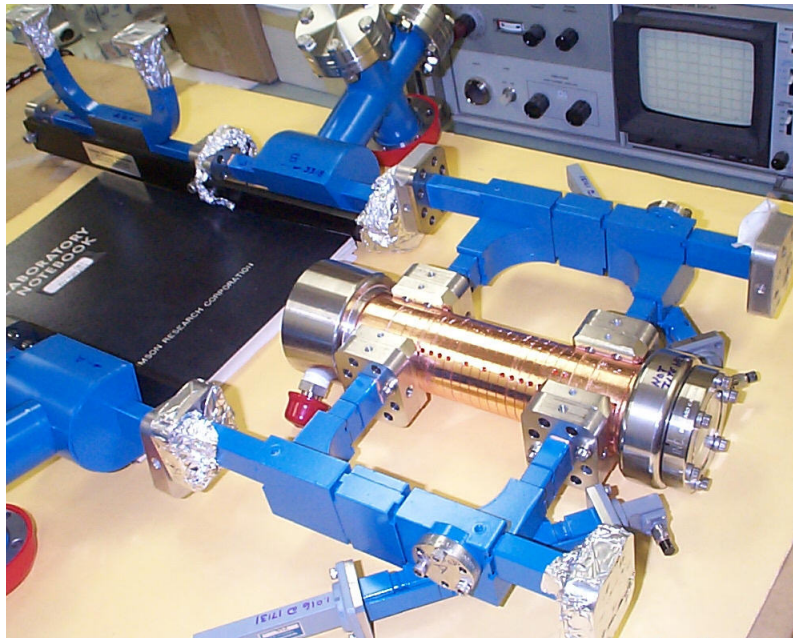
HRC High Gain Klystron in Operation at MIT

Collector	89.9	A
Gun Volts	545	kV
P. Beam	49	MW
P. RF Out	25	MW
Efficiency	52	%
P. Drive	0.6	W
Gain	76	dB



HRC: Test of 22 Cell Cu Linac Test Structure





- 17 GHz Test structure built in 2002
  - Structure was located at Univ. MD for many years.
- **STATUS: Arrived at MIT late 2006, Installed May 07**
- **FIRST TESTS: Planned Late Summer 2007**
- **GOAL: Measure breakdown limit of pure Cu structure**
  - Baseline for comparison with “hardened” structures

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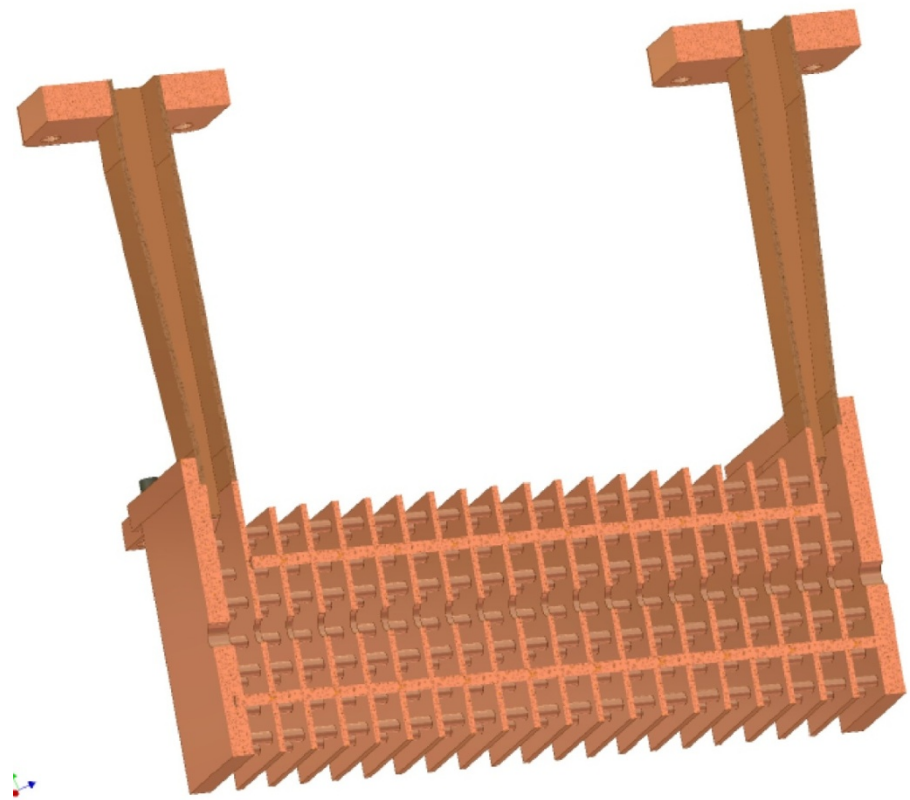
Future plans : Advanced PBG Expts.

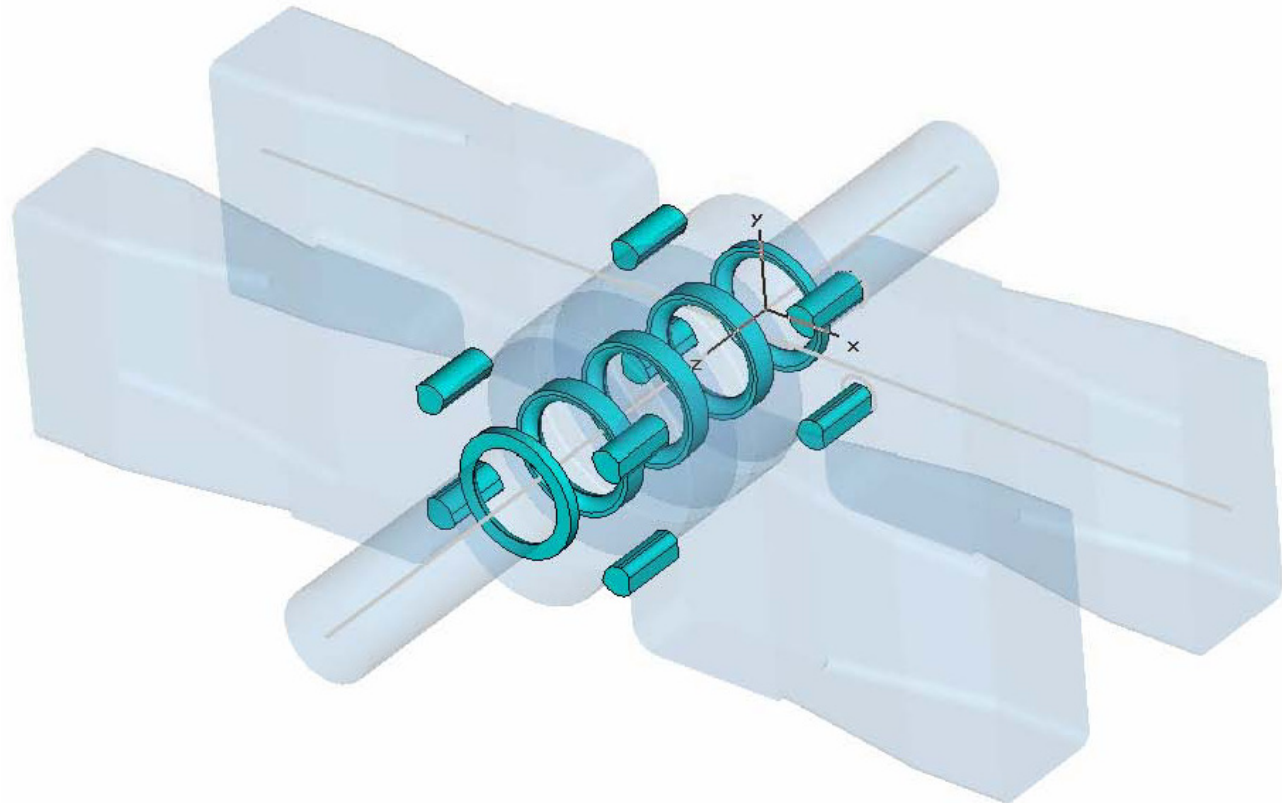
A longer PBG accelerator structure is planned

- Higher group velocity ~0.05c
- Demonstration of wakefield suppression in hot test
- Studies of RF breakdown
- Advance the understanding of PBG accelerator fabrication
- 17.1 GHz studies at MIT
- 11.4 GHz studies at SLAC

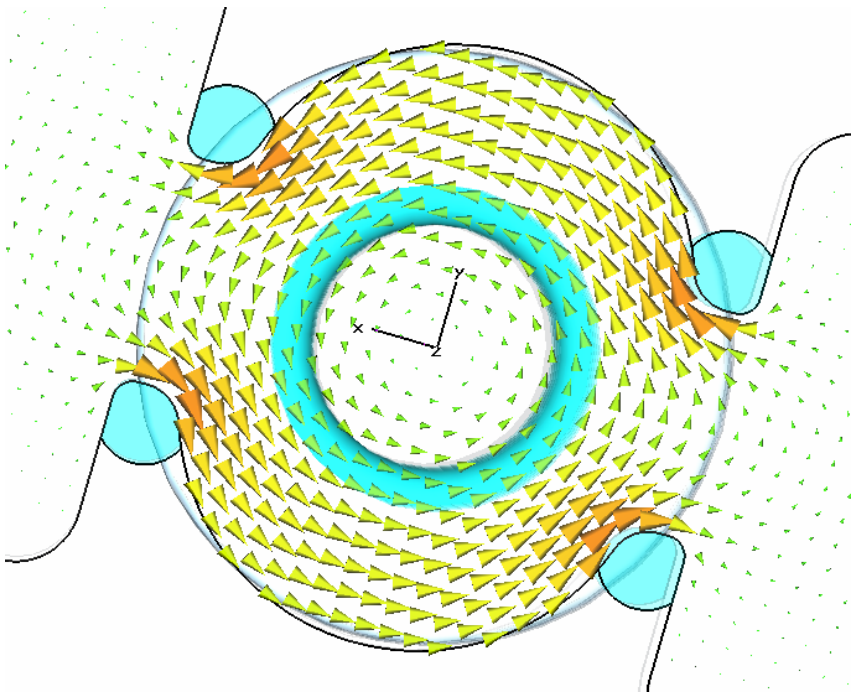


HRC: Gradient Hardened Structure Elements

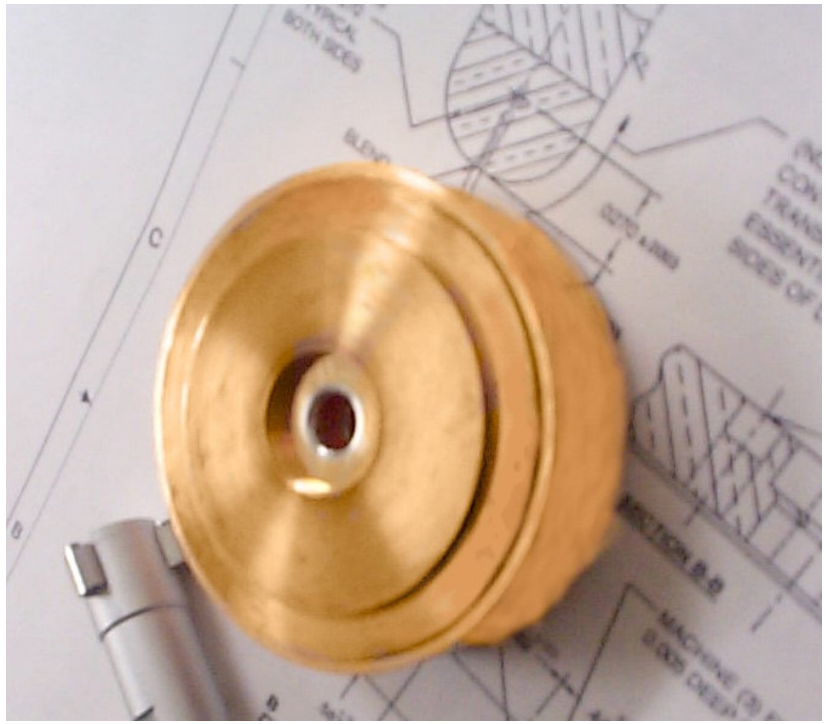
- Simulation Model of Racetrack Coupler with Optimized Profile Brazed Insert Lips and Disc Irises for High Gradient Linac



HRC: Improved 17 GHz Structure Using Inserts



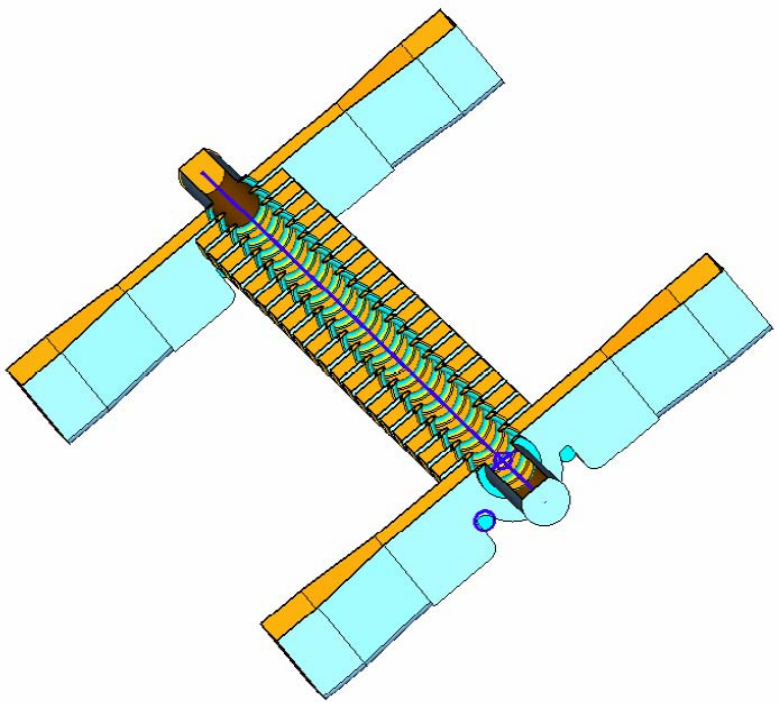
Racetrack Coupler with Optimized Brazed Insert Lips (SS) for High Gradient Linac

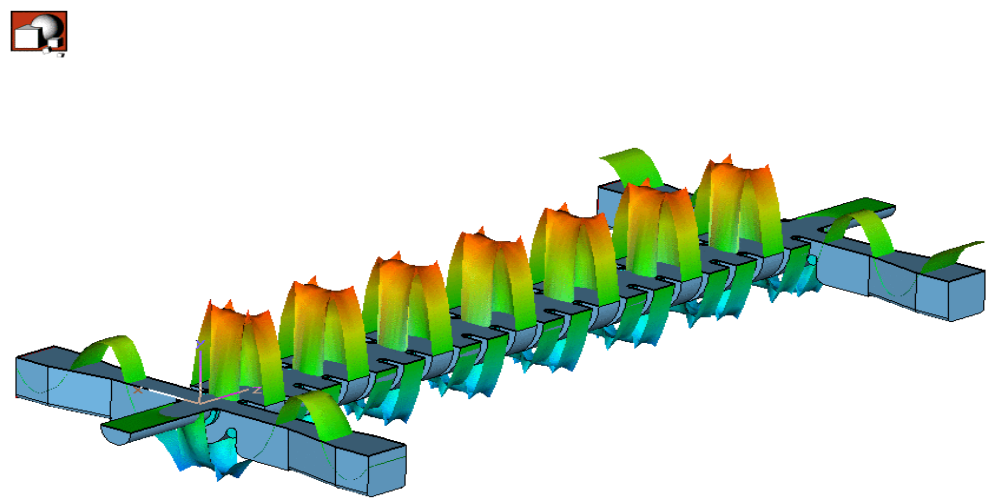


Brazed Molybdenum/Copper Disc for 17 GHz Linac Test

- **STATUS: Fabrication complete at HRC, testing in 2007**
- **Results could demonstrate a major increase in gradient capability for warm accelerators!**

2π/3 Mode 22 Cell Hardened TW Linac Structure Designed for Operation in the 17 GHz Dual Ring 4X Power Amplifier

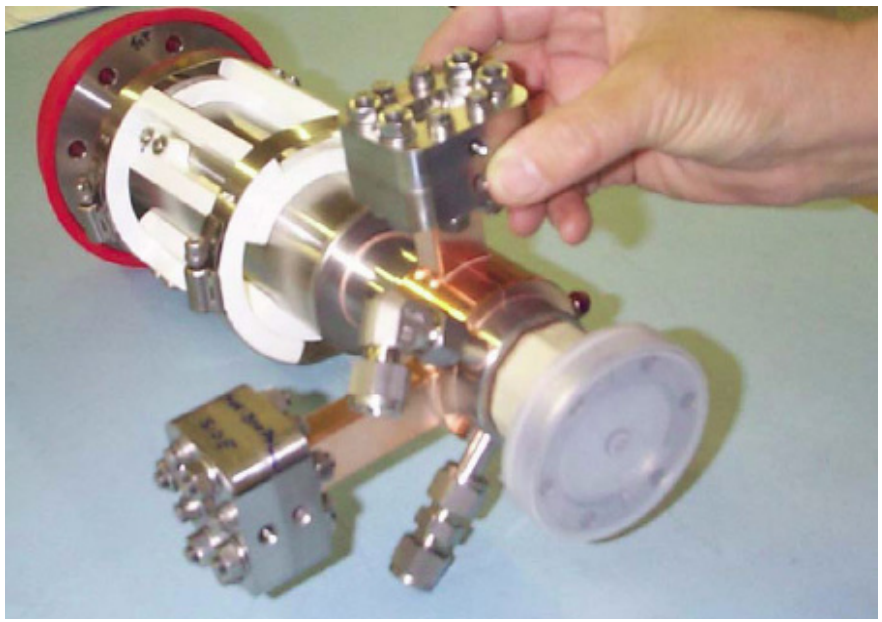


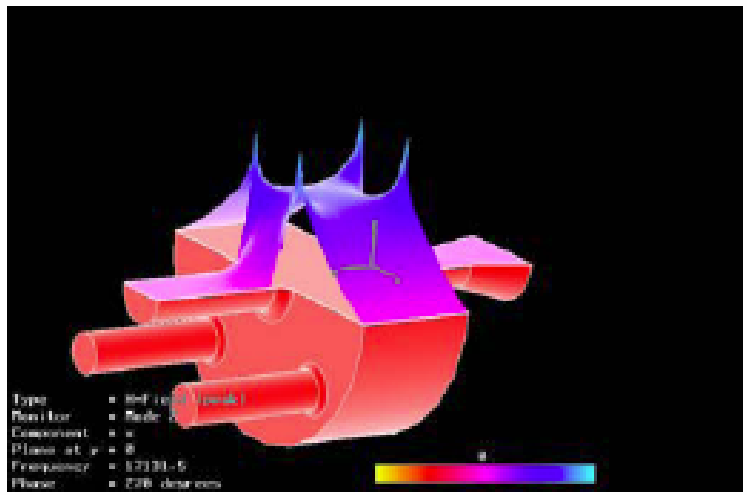


HRC: Choppertron RF Source

- The Phase I effort addresses the problem of developing a high power RF generator suitable for research in the frequency range of 17 to 23 GHz.

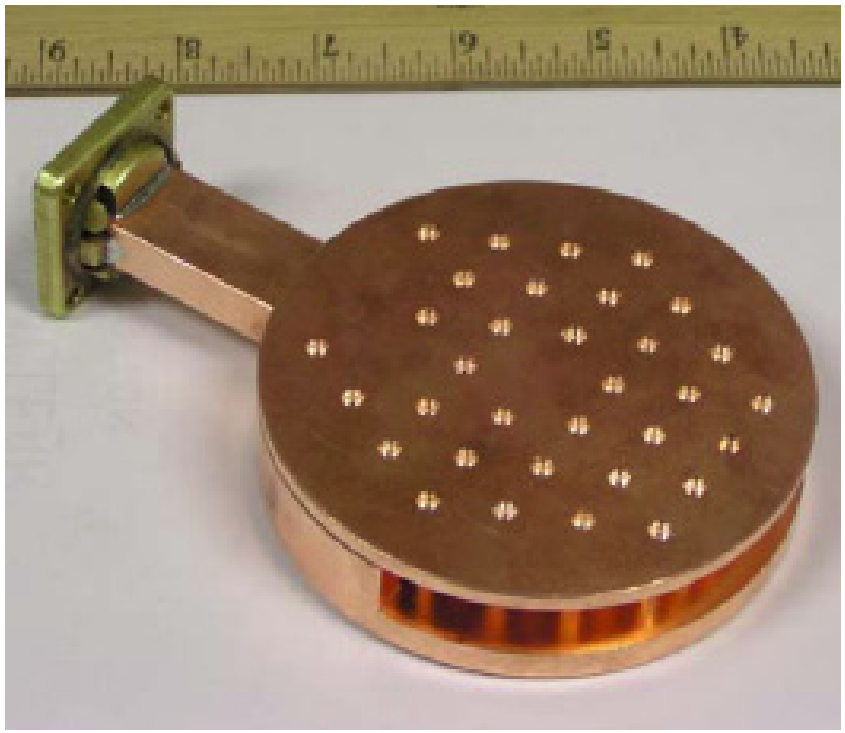
- **STATUS: FY06 Phase I Award, work complete, Phase II request submitted.**





TM_{110} mode transverse H_x distribution on the x–z plane at y = 0.

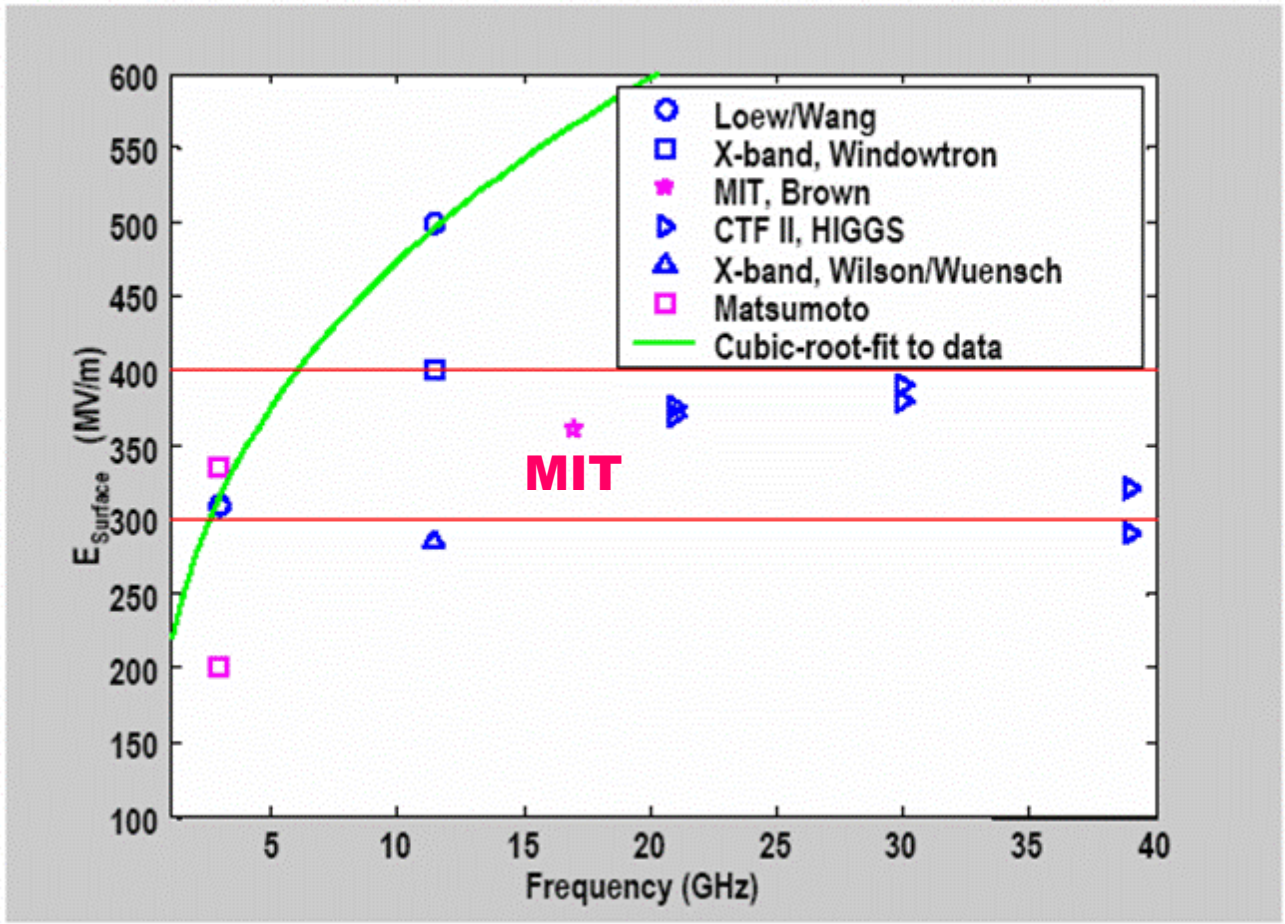
Future Plans: RF Breakdown



- Build PBG cavity to test RF structures at > 200 MV/m to understand breakdown regime.
- PBG cavity allows full view of cavity fields
- Conduct theoretical research in support of experiments.

Breakdown vs. Frequency

Result from CTF II frequency scaling experiment in comparison with peak surface fields achieved in other experiments



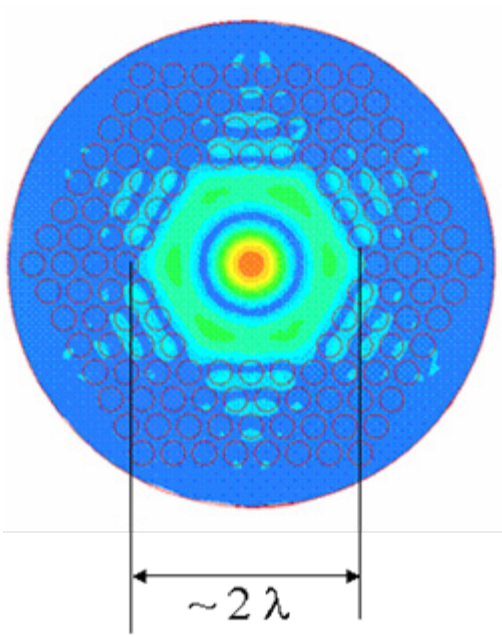
→ No indication of field limit increase with frequency !

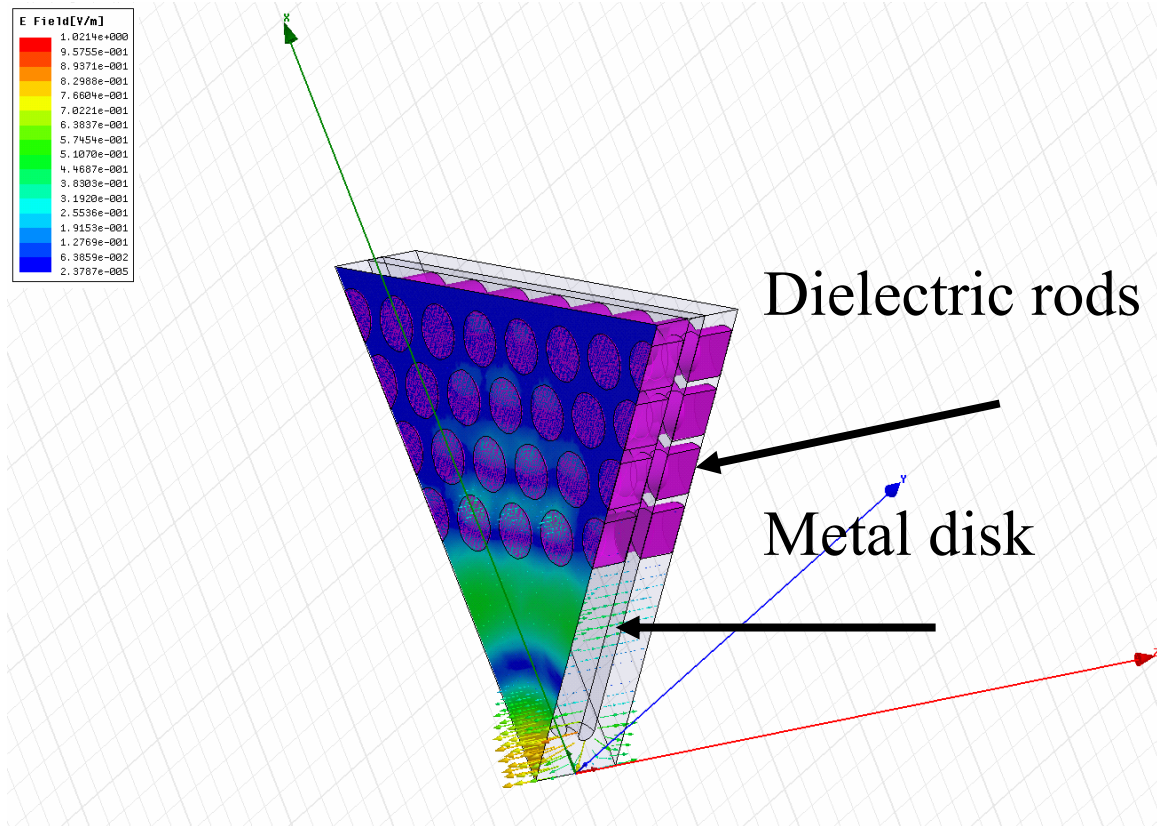
- No apparent frequency scaling
- ~ 400 MeV/m is upper limit for surface field
- 200 MeV/m may be the limit for gradient in a TW linac

From: Braun, CERN, ILC 2006

Example of Metal-Dielectric PBG structure

TM_{02}–like mode





- ❒ Higher order operating mode TM_{02} confined
- ❒ Large dimensions, large beam hole
- ❒ Suitable for higher frequencies (up to 100 GHz)

MIT User Facility Upgrade

- **Upgrade of MIT Facility for 20 Hz operation.**
  - Present operation possible at 5 Hz
  - Routine operation at 2 Hz
- Phase I: Purchase of new power supply, 65 kV, 30 kJ/s
  - Order placed December 22, 2006
  - 0.5% ripple; 20-25 pulses per second
  - Delivery expected June, 2007
- Phase II: Design and procurement of modulator components to complete the upgrade.
  - DOE HEP has agreed to fund this Phase in 2007
- In use by Haimson Research Corp.
- **New users / collaborators are encouraged**

Conclusions

- MIT research at 17 GHz complements research at 11.4 GHz at SLAC and 12 GHz at CERN
- Haimson Research components provide a state-of-the-art accelerator facility
- Accomplishments include:
  - Photonic Structure research
  - Breakdown studies
  - THz radiation and beam diagnostics studies
- Future Plans include:
  - Wakefield studies of photonic structures
  - Facility upgrade for high repetition rate operation
  - Testing of “hardened” structures with Haimson power amplifier
  - Tests of advanced, novel structures (PBG) at high gradient
  - RF Breakdown research at 17 GHz