Design of Dielectric and Metallic PBG Structures

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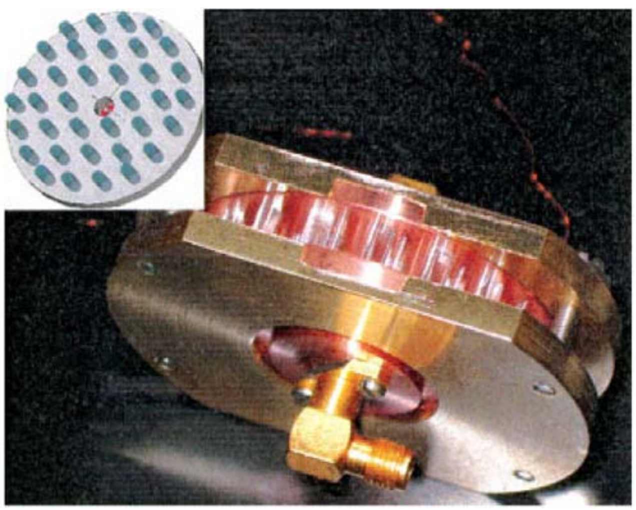
OUTLINE

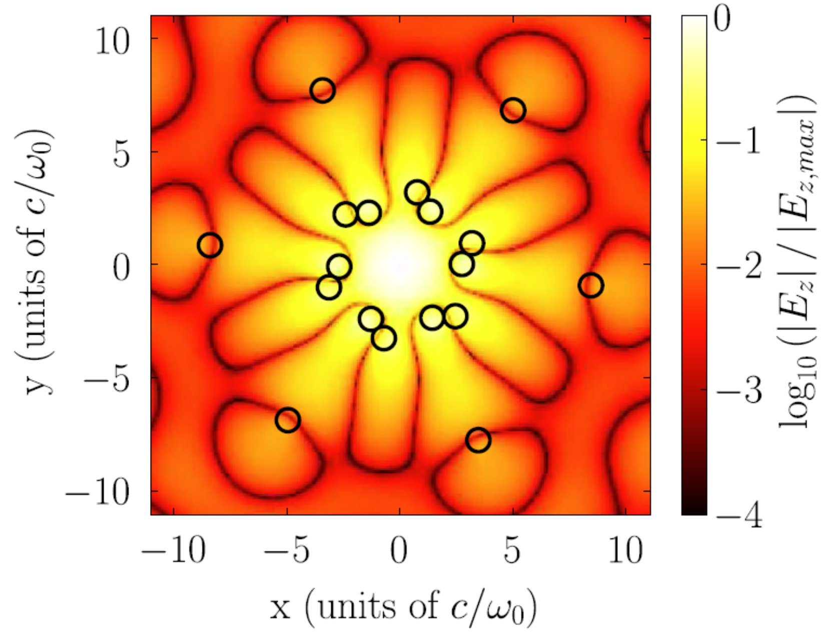
- Introduction
- Dielectric PBG Structure Experiment
- New results in Metallic PBG Structure Theory
- Conclusions

Previous Research: Dielectric-rod PBG

- Sapphire-rod cavities cold tested by Masullo et al. (Naples)
- Numerically-optimized cavities designed w/ improved wakefield damping by Bauer et al. (UC Boulder, Tech-X Corp.)
- Dispersion engineering numerical studies by Seviour (Lancaster U.)

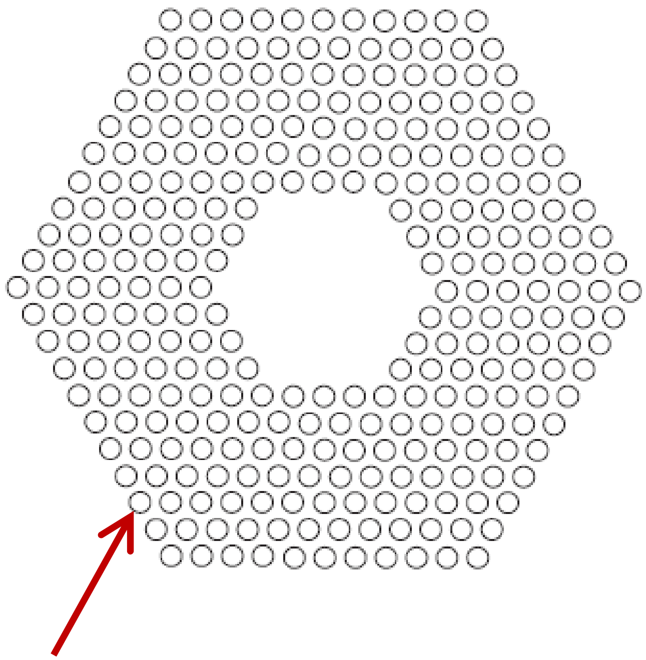


Masullo et al, *Microwave Opt. Tech. Lett*. 2006

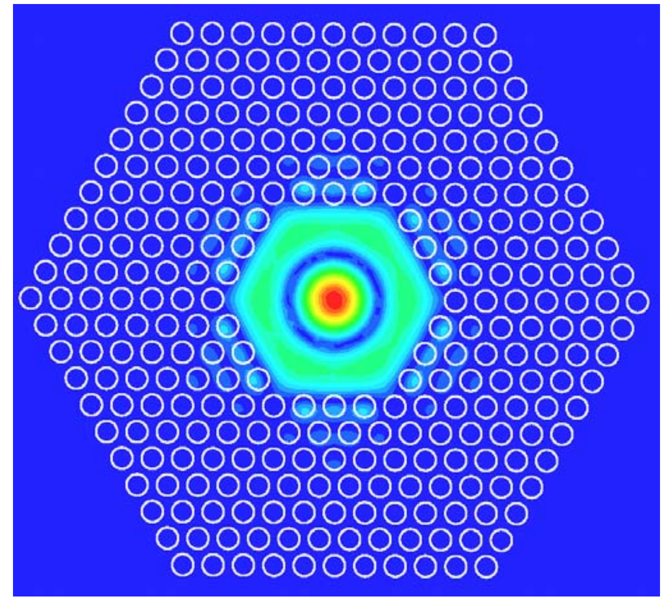


Bauer et al. *J. Appl. Phys.* 2009

17 GHz TM_{02} PBG Accelerator Cavity



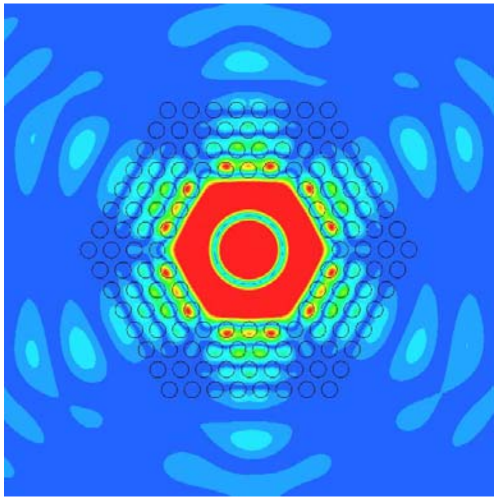
sapphire rods, ε = 9.3, 1.6 mm radius



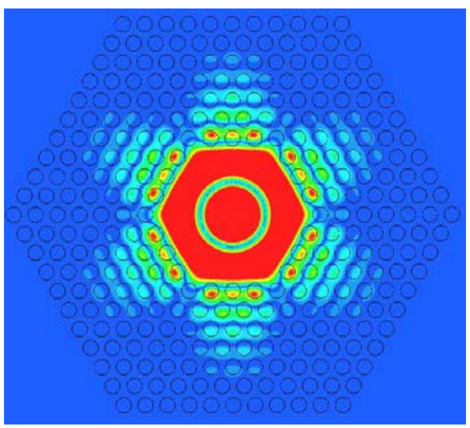
TM_{02}-like mode

- TM_{02} -like mode at 17 GHz
- TM_{01} mode not confined

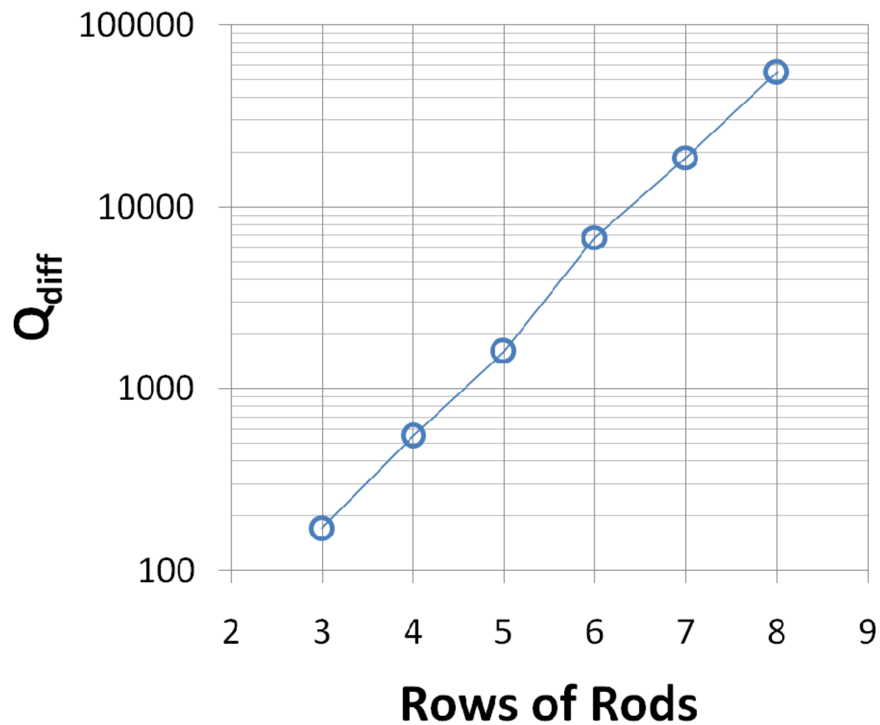
Diffractive Q



4 rows, $Q_{diff} \approx 500$

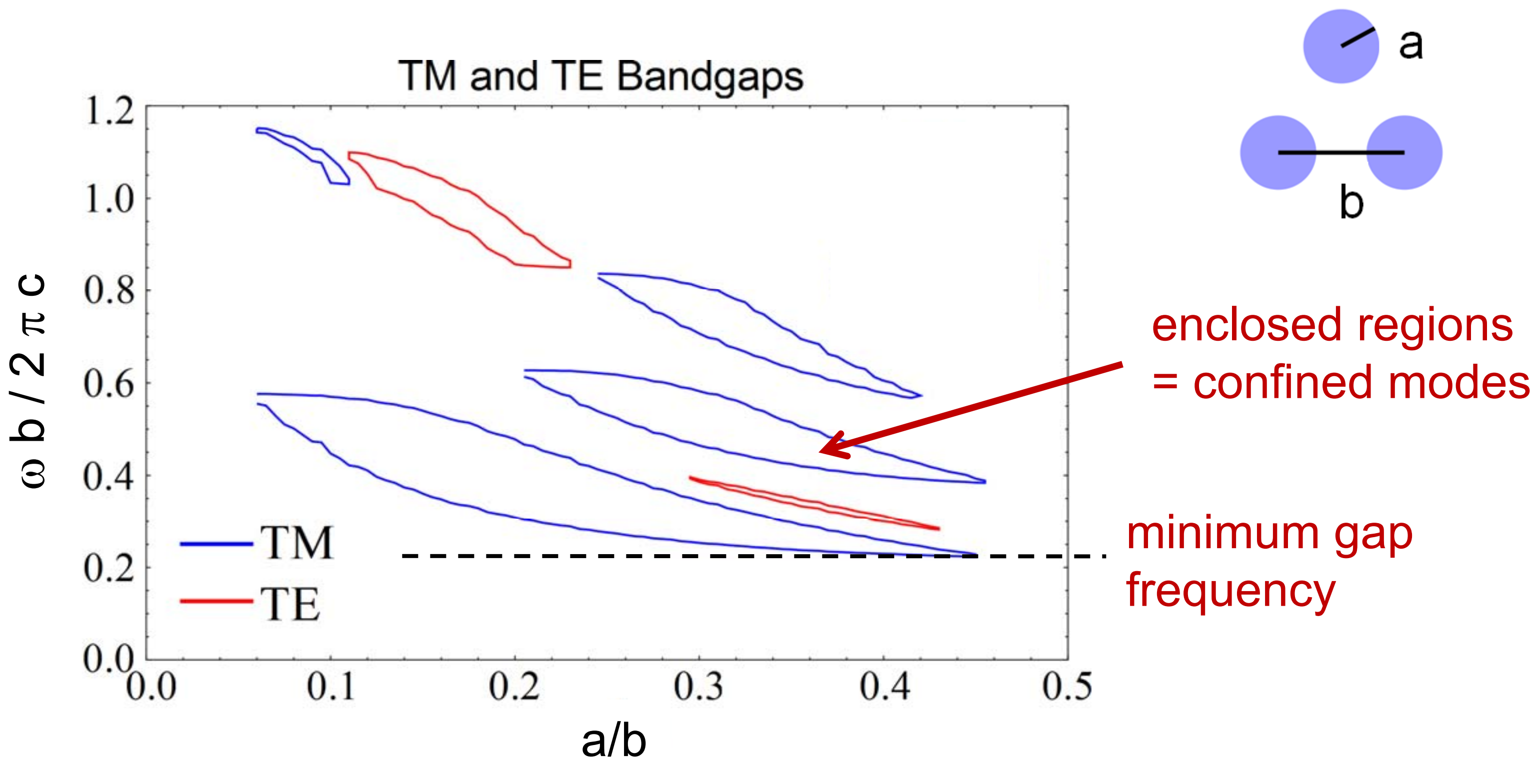


7 rows, $Q_{diff} \approx 19{,}000$



- Simulated radiation loss
- Need more rows of rods than metal structure
- Advanced designs could have fewer rows

Dielectric-rod PBG Lattice

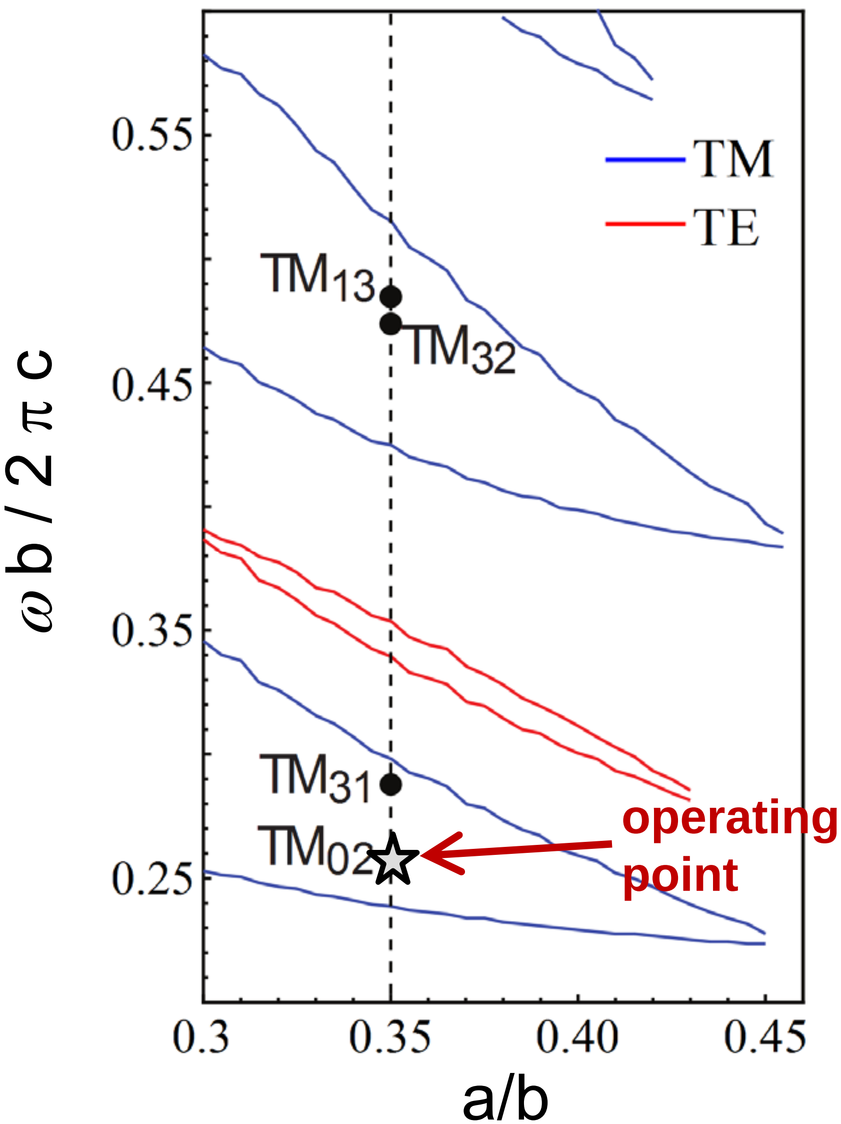


- Has a minimum gap frequency, unlike metal lattice
- Allows overmoded design (e.g. TM_{02})

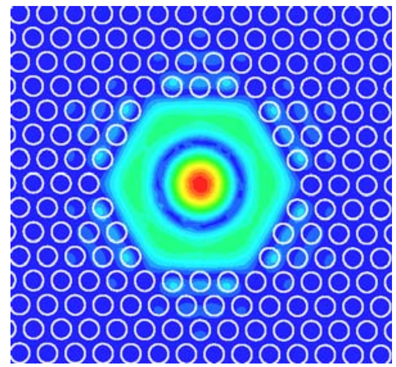
Calculated with code MPB, S. Johnson et al.

Higher-order modes

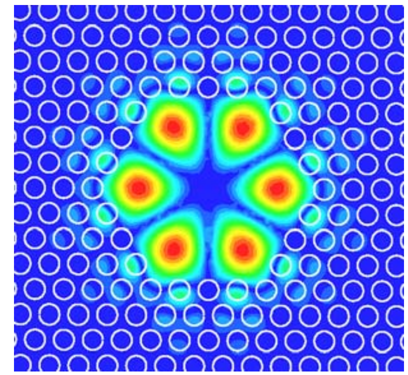
Band Gap Map



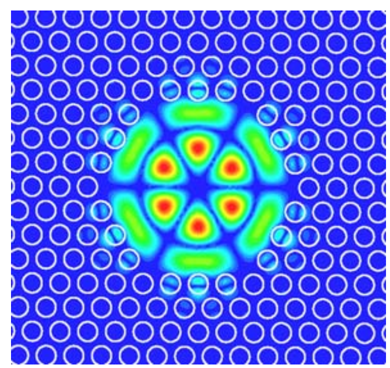
- Operating point has no lower-order modes
- A few higher-order modes allowed
  - these must be damped



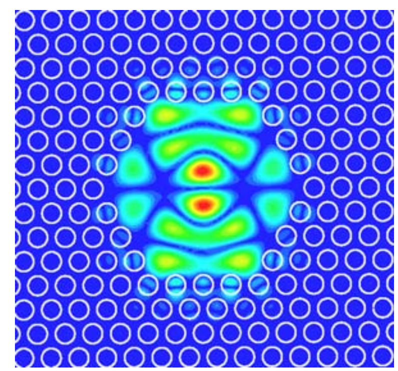
TM_{02} ,17 GHz



TM_{31} ,19 GHz



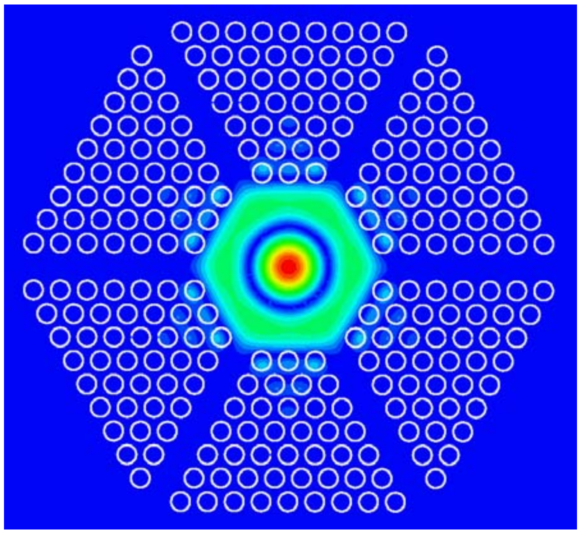
TM_{32} ,31.6 GHz



TM_{13} ,31.7 GHz

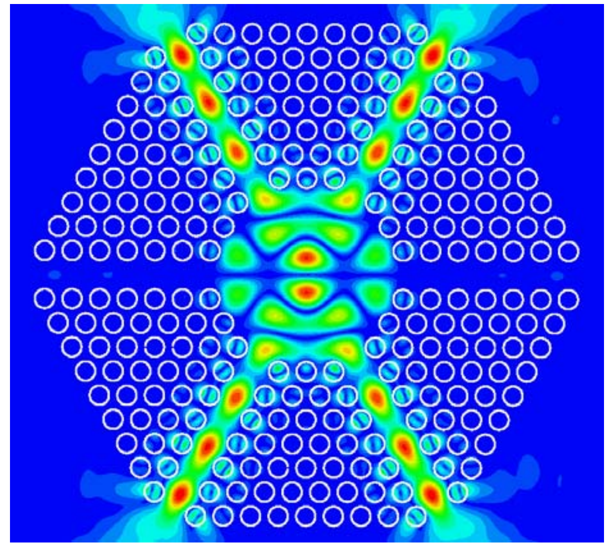
Damping higher-order modes

- Six radial rows of rods removed to damp HOMs



TM_{02} mode

diffractive Q ~ 18,000



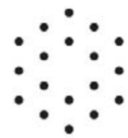
damped TM_{13} mode

diffractive Q ~ 100

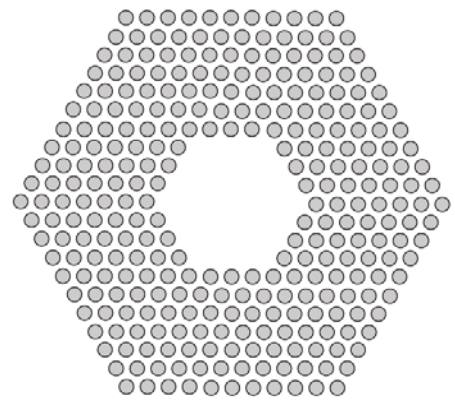
Comparing Cavities

- Compare pillbox cavity and two PBG cavities:

pillbox
TM_{01}



metal-rod PBG
TM_{01}



dielectric PBG
TM_{02}

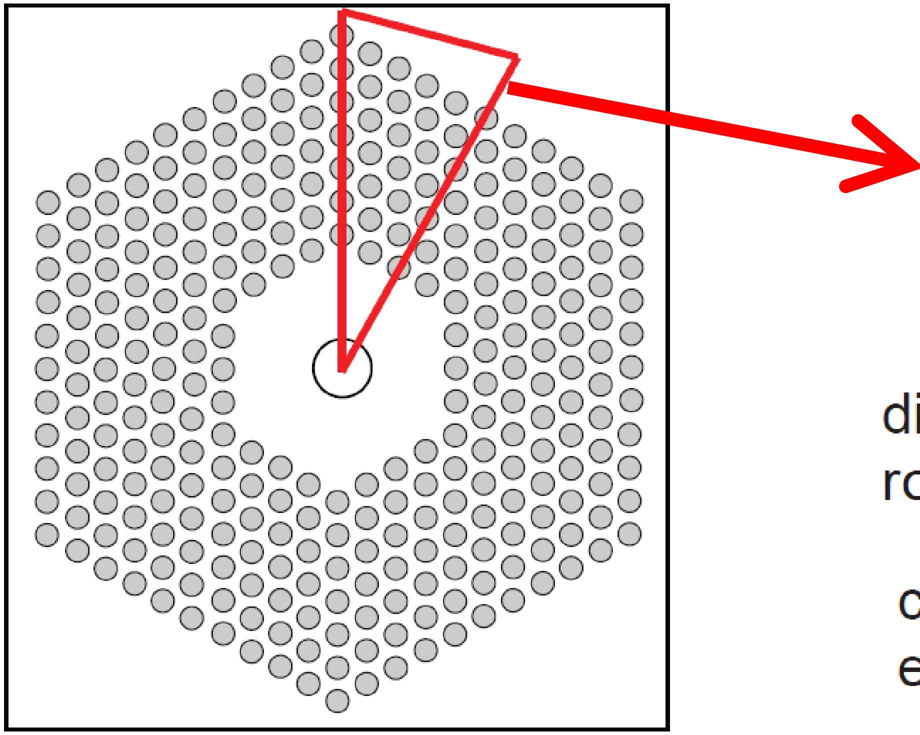
(to scale)

- Figures of merit – peak surface H field, peak surface E field for a given accelerating gradient:

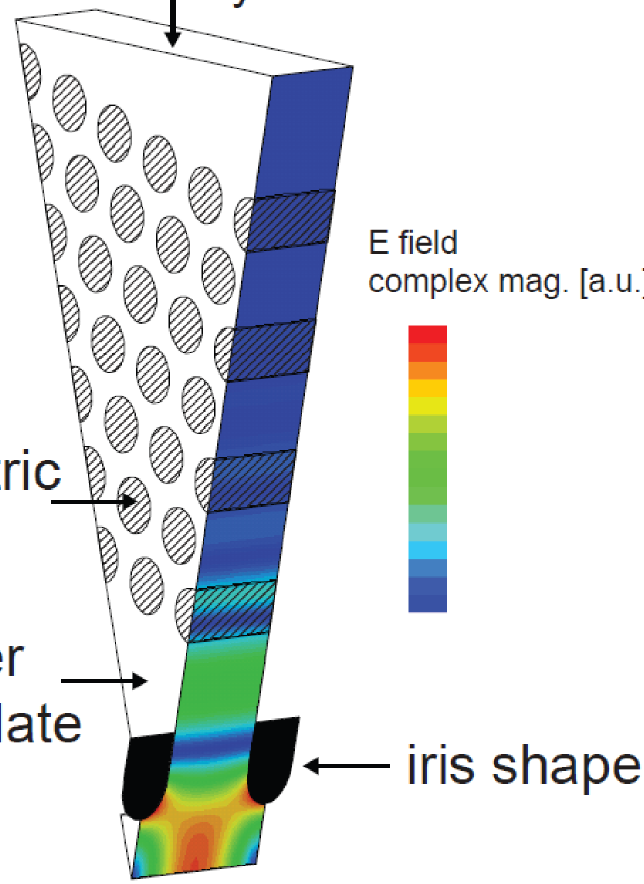
$$G = \frac{1}{L}\int_{-L/2}^{L/2} E_z(z) cos(\omega z/c) dz$$

HFSS Model – Single Cell

30-degree wedge symmetry:



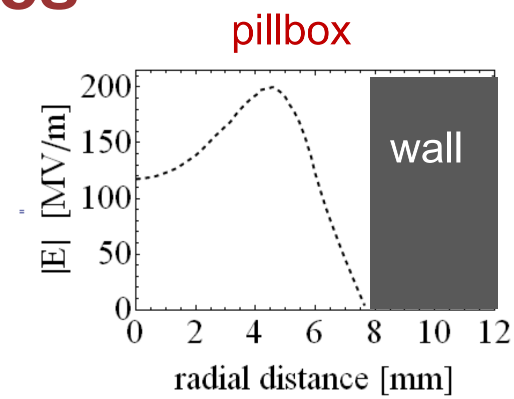
Front view

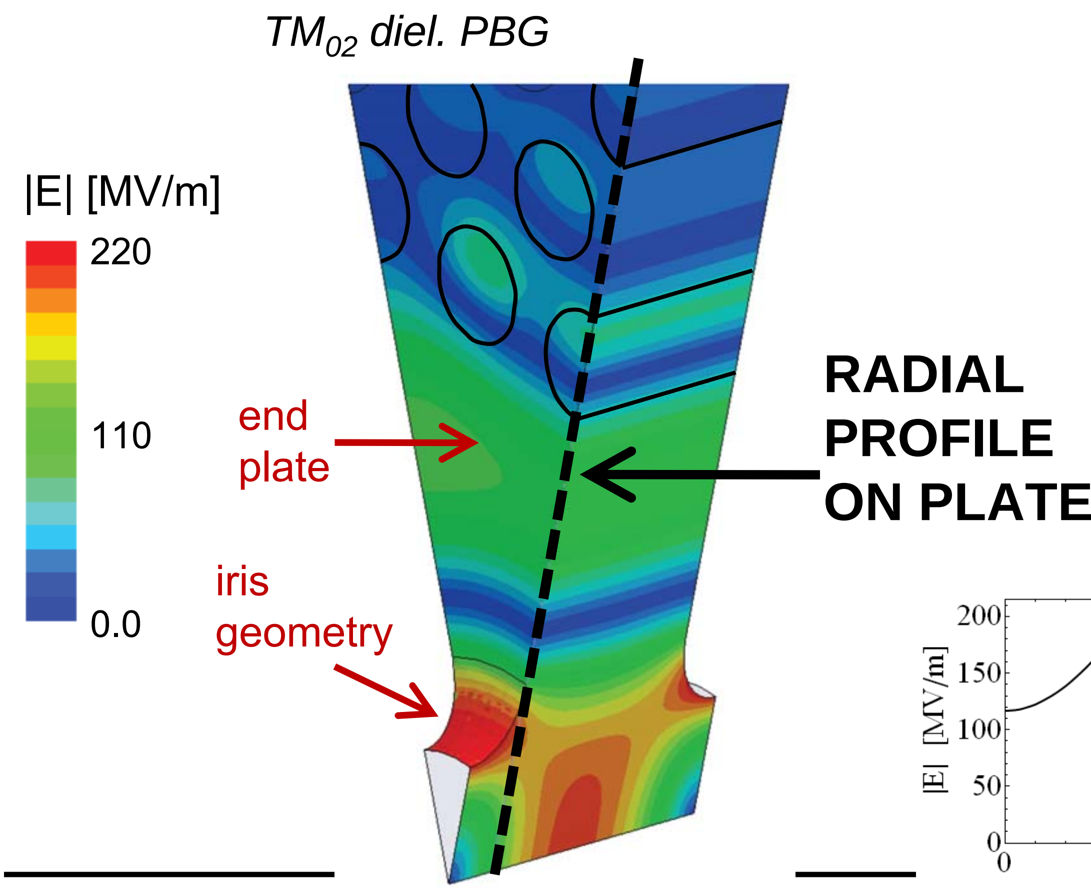


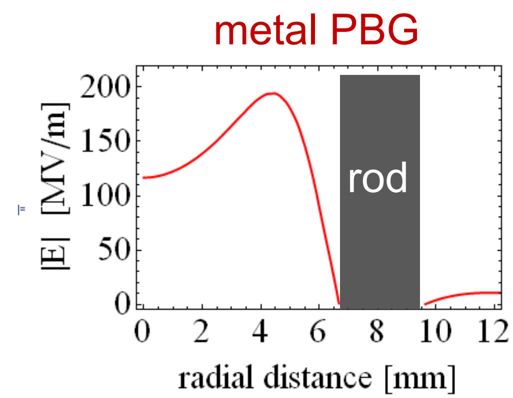
3D cut-away view

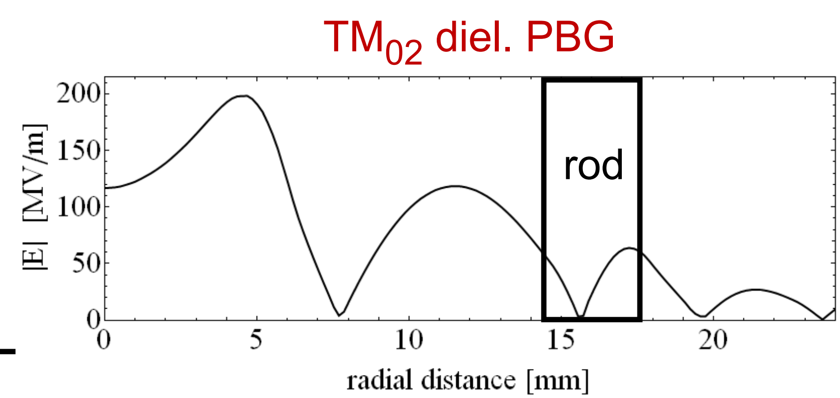
E Field Radial Profiles

- All cavities have 100 MeV/m gradient
- Radial E fields identical near axis and at iris
- E = 60 MV/m at inner rod





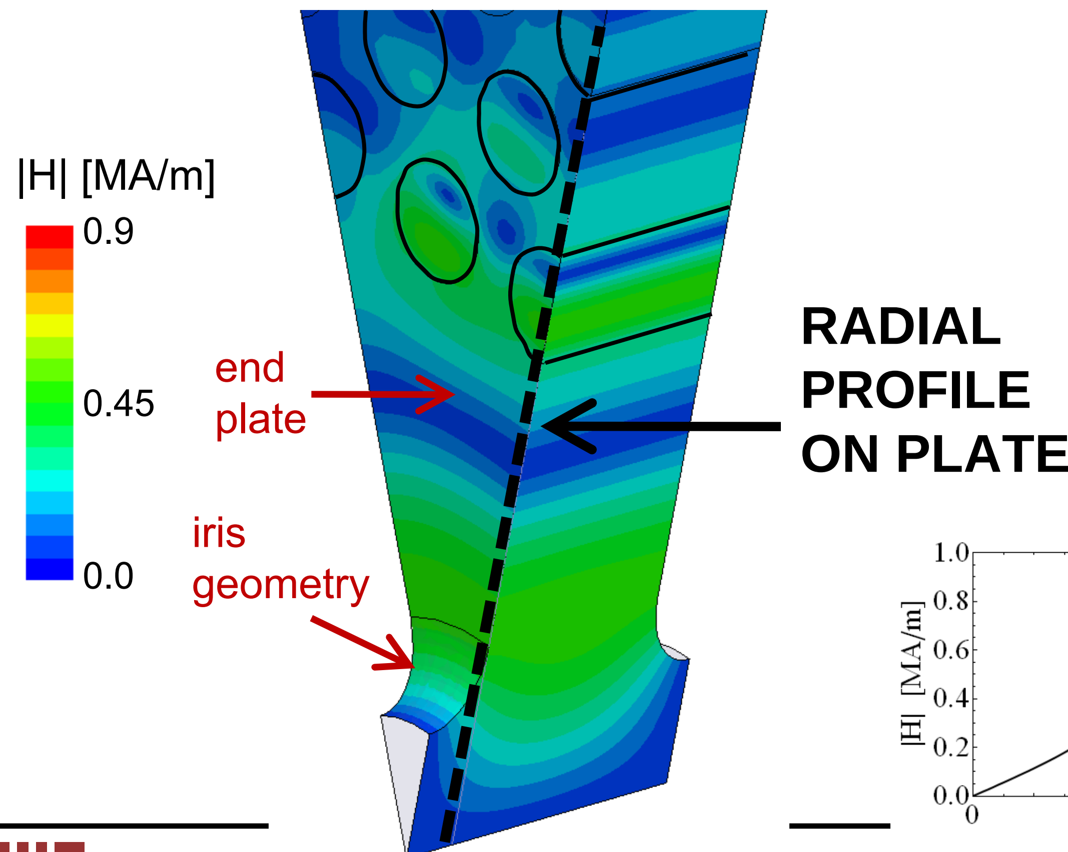




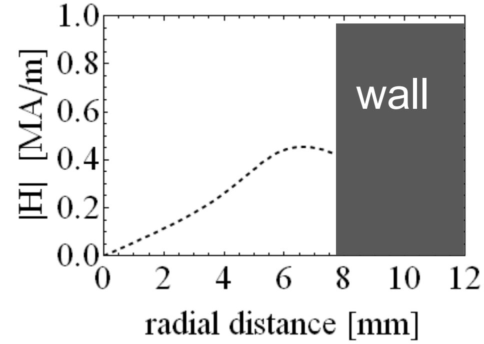
H Field Radial Profiles

- Compare H fields at 100 MeV/m gradient
- TM_{02} PBG same as pillbox - no H enhancement

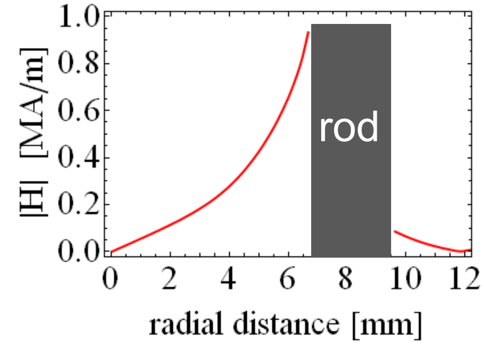
TM_{02} diel. PBG



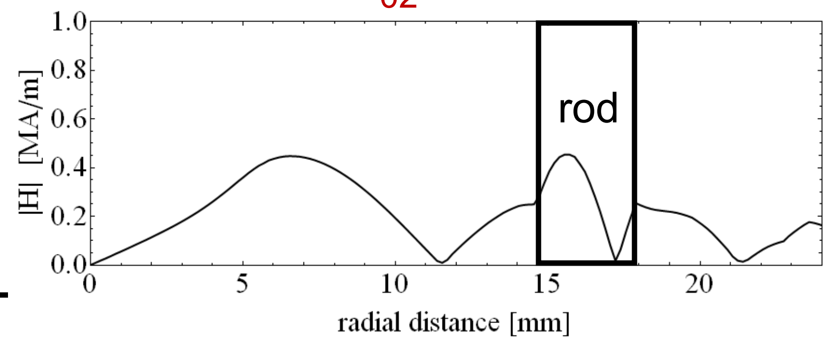
pillbox



metal PBG

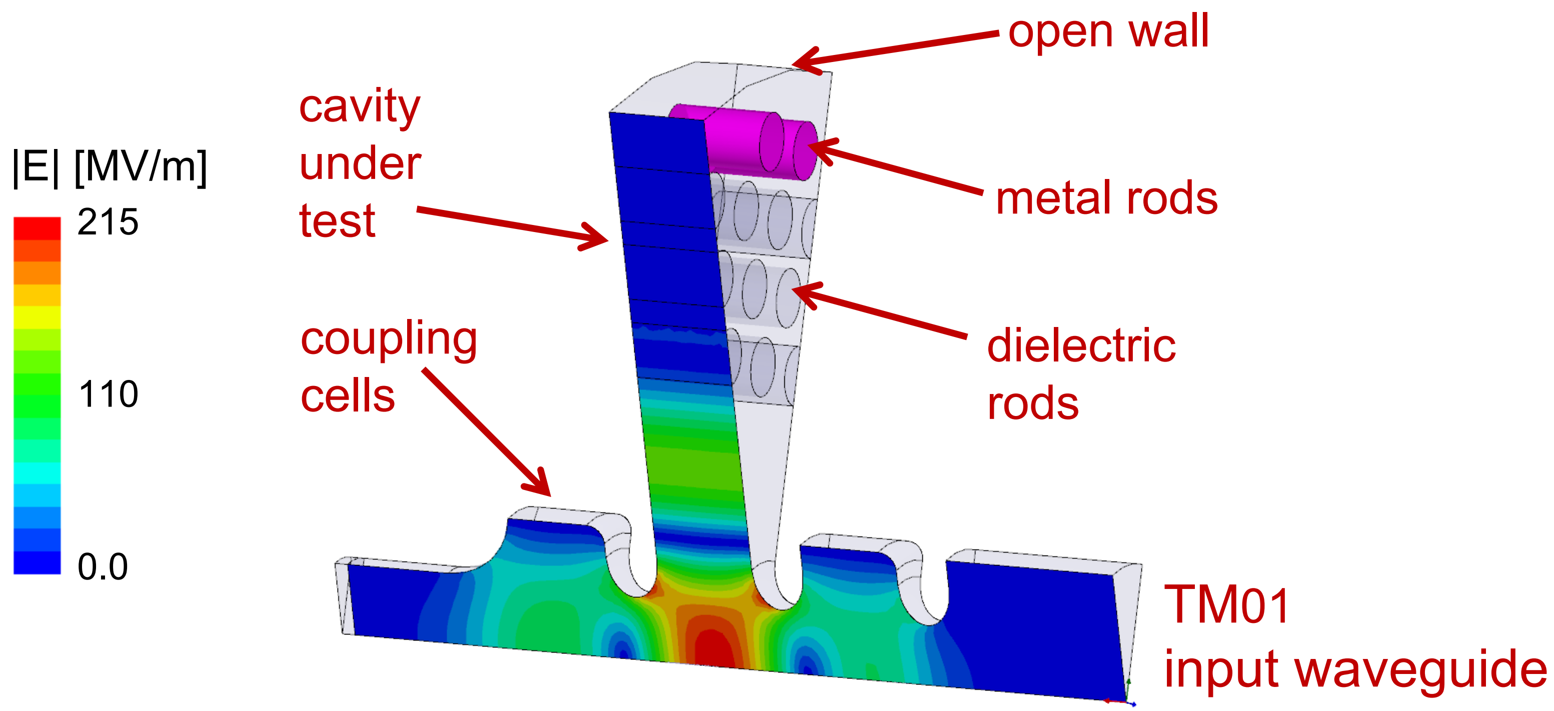


TM_{02} diel. PBG



Experiment Plans

- High-power test of 17 GHz overmoded sapphire-rod structure
  - may use metal rods in outer row to allow fewer rods



– 3.5 MW input power, for ~ 100 MeV/m accel. gradient

– Will investigate effect of high surface H field, and E field in rods

Conclusions on Dielectric PBG

- Designed overmoded accelerator cavity from dielectric-rod PBG
  - does not confine lower-order mode
  - HOMs can be suppressed
- Overmoded cavity can mitigate high pulsed heating seen in metal-rod PBG high-gradient testing
  - has same peak surface H field as pillbox cavity
- Testing of 17 GHz overmoded accelerator cavity to begin at MIT
  - compare with metal-rod PBG; learn about H field role in breakdown at dielectric-metal interface

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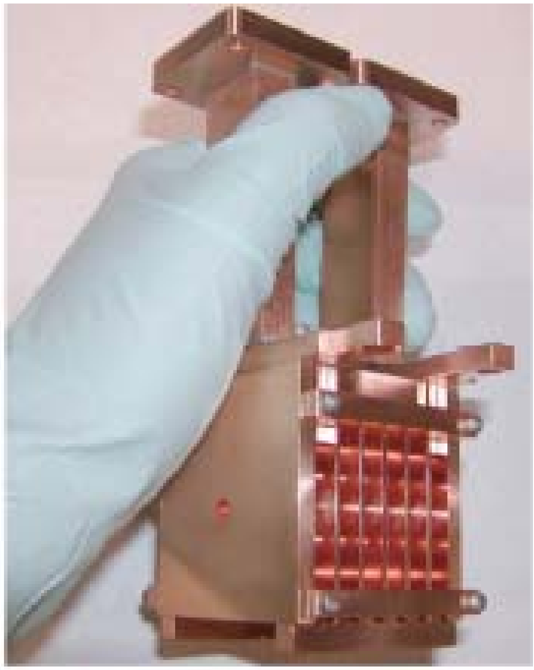
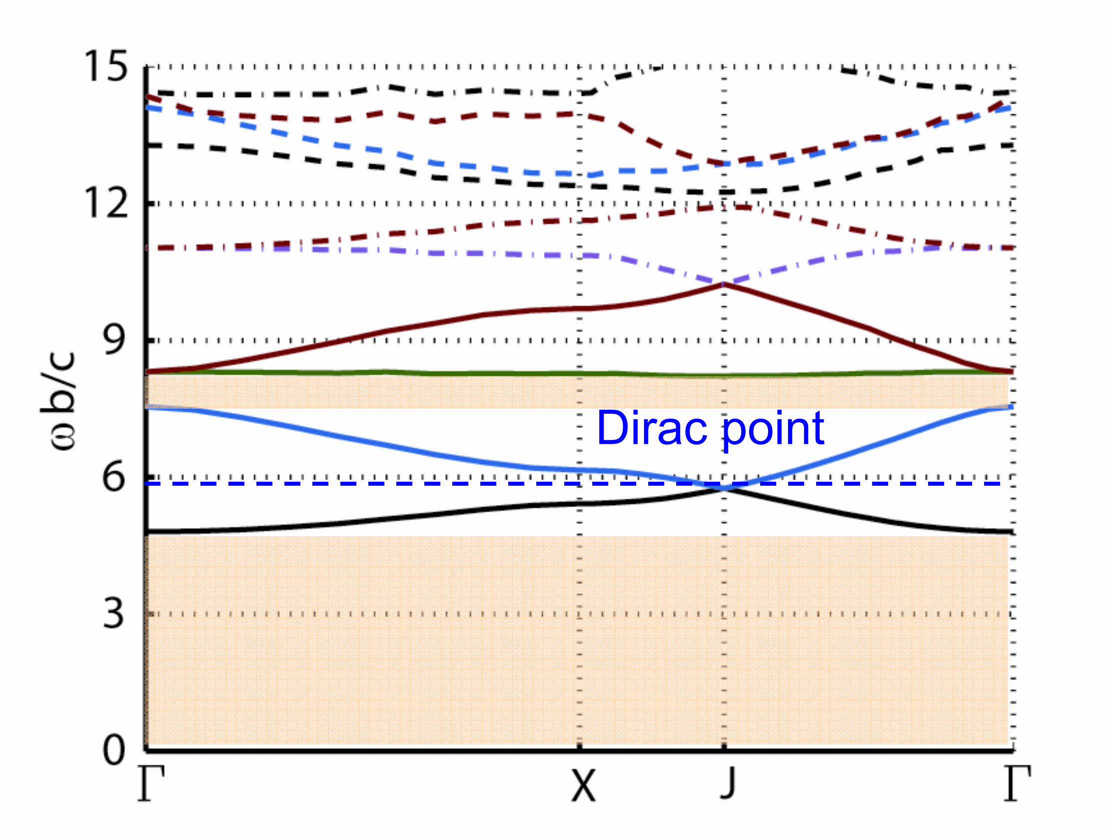
Metallic PBG Structure Simulation

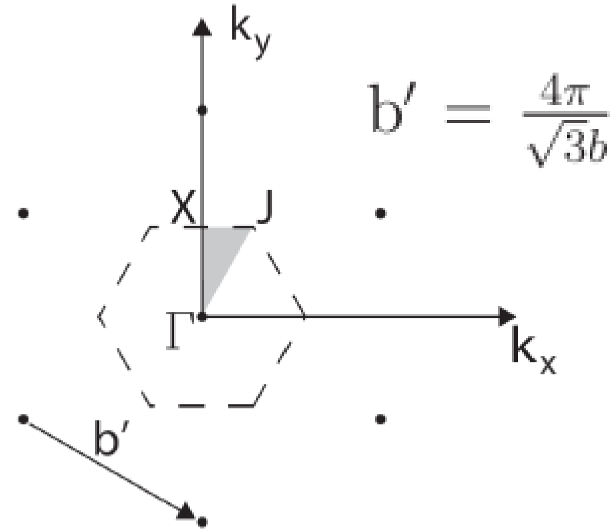
- We are conducting more detailed simulations of metallic PBG structures
  - Continuing research on wakefields and high order modes in metallic PBG structures
  - Dirac point may increase confinement of HOMs



Brillouin Diagram: Dirac Point

Metallic lattice: a/b=0.25



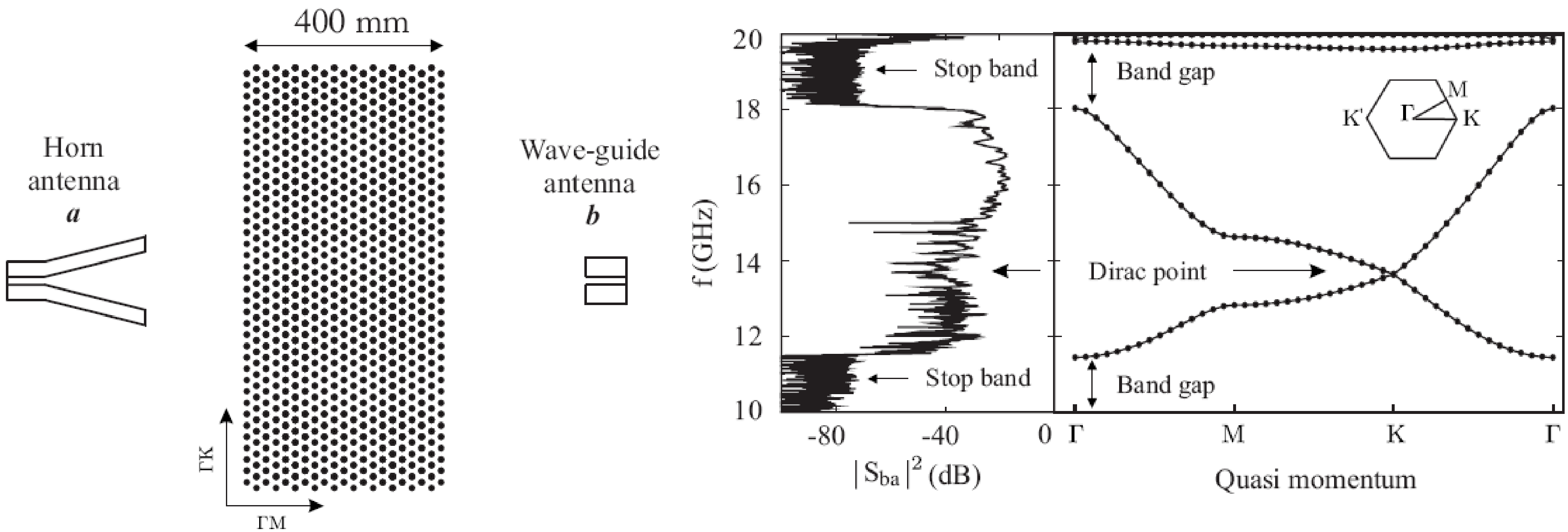


- Dirac point is a crossing of dispersion curves

$$\Gamma : \vec{k}_\perp = 0; X : \vec{k}_\perp = (2\pi / \sqrt{3}b)\hat{e}_y;$$

$$J : \vec{k}_\perp = (2\pi / \sqrt{3}b)((1/\sqrt{3})\hat{e}_x + \hat{e}_y)$$

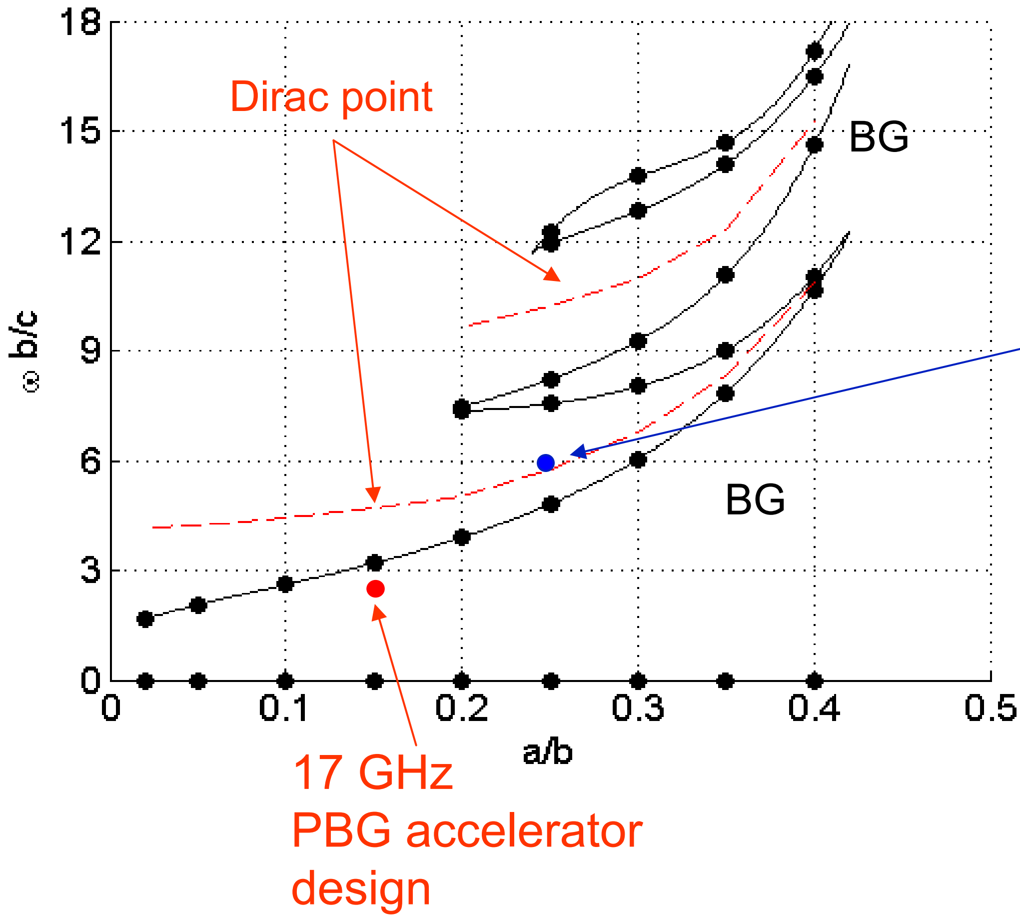
Experimental Study of Dirac Point

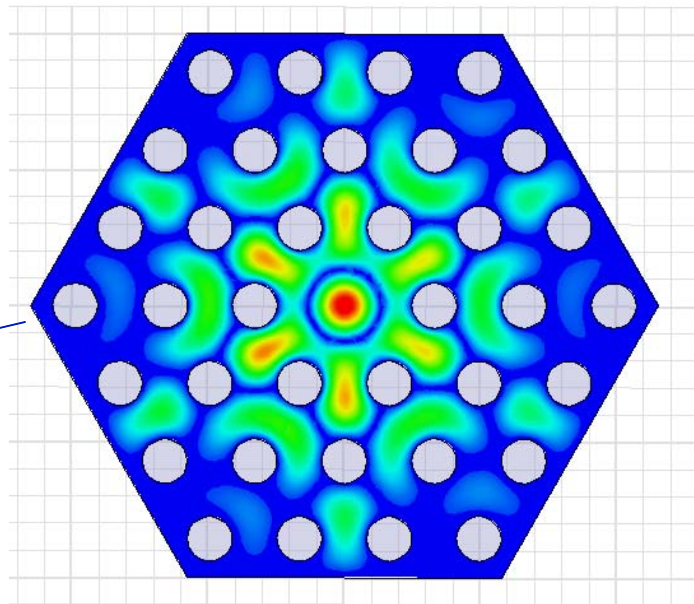


S. Bittner et al., PRB **82**, 014301, 2010

No transmission in bandgaps. Transmission reduced by 20 dB at Dirac point.

Simulation of Dirac Point Map





• Example of a Low Q Mode confined at a Dirac point (a/b=0.25)

Dirac point calculation results

- Dirac point map was added to bandgap map
- Low Q mode found at Dirac point frequency
  - More research planned

Conclusions

- 17 GHz Dielectric PBG structure designed for testing at MIT
  - Sapphire rods and metal disks will be used
  - No magnetic field enhancement
- Comparison with metallic structures useful for understanding breakdown and high gradient limits
- New interesting properties of metallic PBG structures
  - Dirac point map calculated for metallic structures
  - Partially confined defect mode

Acknowledgements

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