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Title: Pushing the Gradient Limitations of Superconducting Photonic Band Gap Structure Cells

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Pushing the Gradient Limitations of Superconducting Photonic Band Gap Structure Cells

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Advanced Accelerator Concepts Workshop 2012

June 12th, 2012

Outline

- Background and motivation.
- Reduction of surface magnetic fields.
- Suppression of wakefields.
- Thermal analysis.
- Plans and conclusion.

Background and motivation

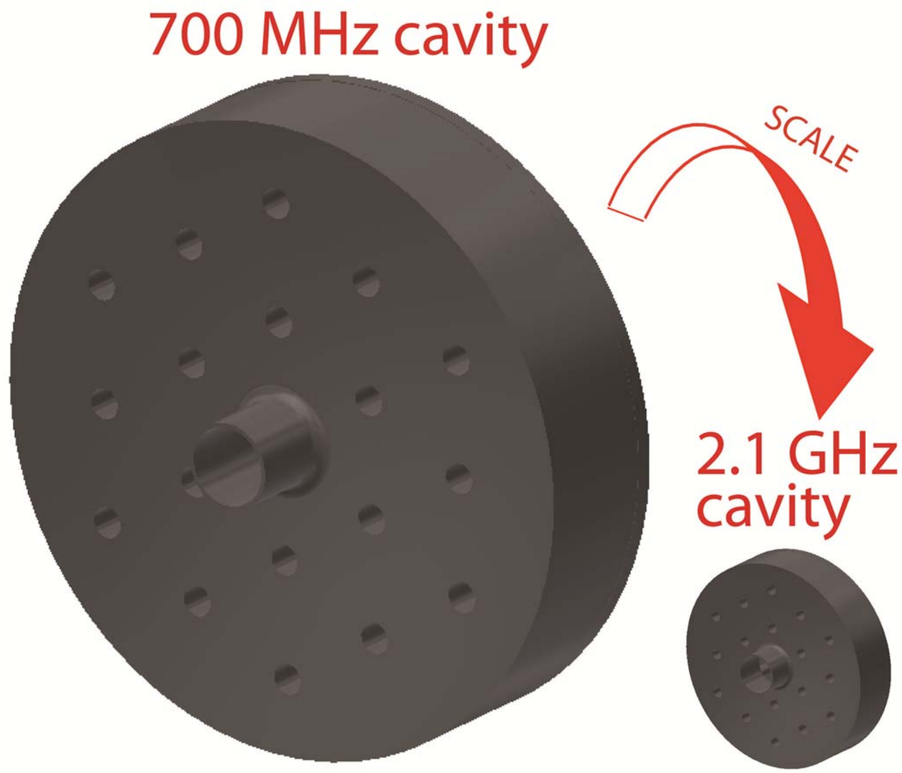
Motivation

- Superconducting photonic band gap resonators present us with unique means to place higher order mode couplers in an accelerating cavity and efficiently extract HOMs.
- An SRF PBG resonator with round rods was successfully tested at LANL demonstrating operation at 15 MV/m.
- Gradient in the SRF PBG resonator was limited by magnetic quench.
- To increase the quench threshold in PBG resonators one must design the new geometry with lower surface magnetic fields and preserve the resonator's effectiveness for HOM suppression.

LANL 2.1 GHz SRF PBG resonator – basic design

The SRF PBG resonator was designed at 2.1 GHz.

Rod radius	0.665 in
Rod spacing	2.217 in
Diameter of the cavity	11.5 in
Cell length (π-mode)	2.812 in
Diameter of the beam pipe	1.25 in
Q_0 (4K)	$1.5*10^8$
Q_0 (2K)	$5.8*10^9$



Comparison between electromagnetic solvers

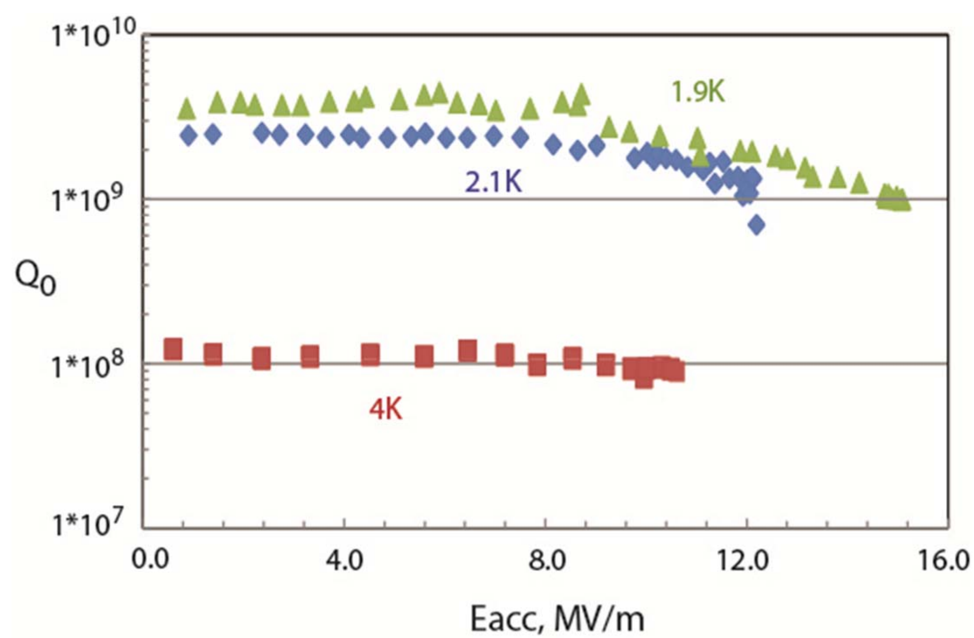
We can model SRF PBG resonators with 3 different electromagnetic solvers. We can increase accuracy of computations until solvers agree within 1-2%.

Comparison between the solvers
2.1 GHz resonator with cylindrical rods

	Frequency	Emax/Eacc	Hmax/Eacc, mTesla/(MV/m)
CST Studio, hexagonal mesh	2.100 GHz	2.32	8.63
CST studio, tetrahedral mesh	2.100 GHz	2.16	8.44
HFSS	2.099 GHz	2.22	8.55

LANL 2.1 GHz SRF PBG resonator - testing

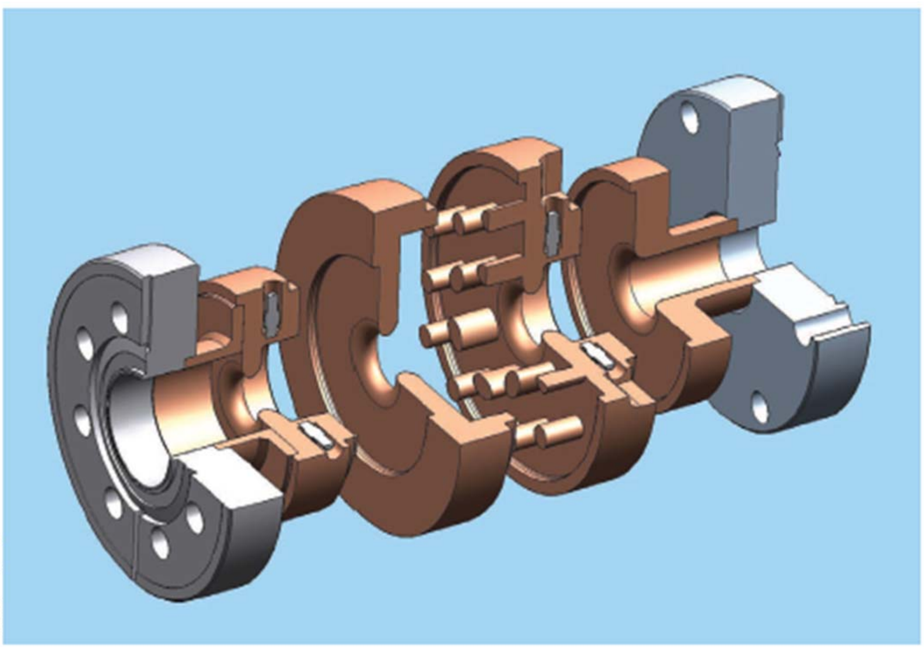
LANL 2.1 GHz SRF PBG resonators were fabricated at Niowave, Inc. and tested at LANL in March-April, 2012. Measured characteristics were very close to theoretical predictions. **Maximum achieved gradient is 15 MV/m.**

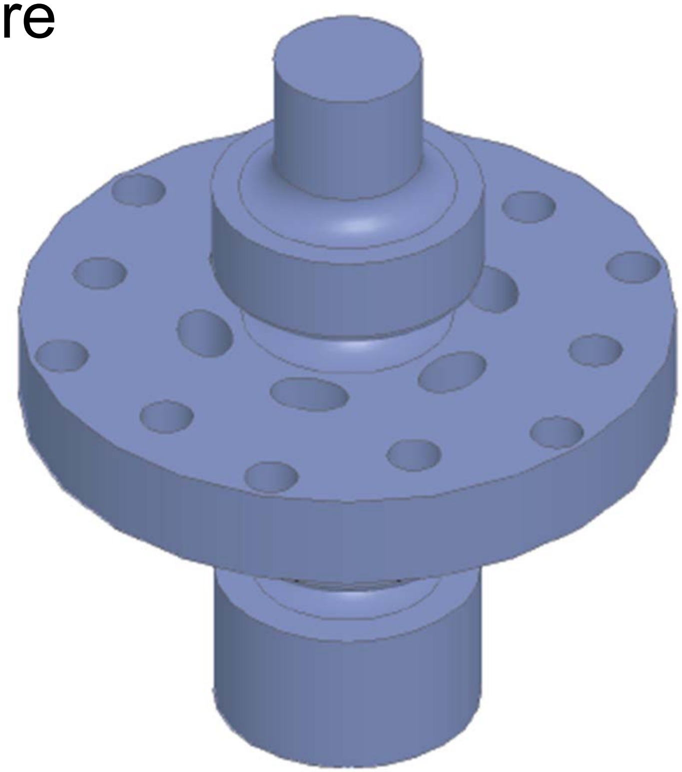


MIT PBG resonators with elliptical rods

The idea to decrease peak surface magnetic field in PBG resonators by changing shape of the rods from round to elliptical was first expressed by the MIT team in 2009.

The elliptical rods of the MIT structure had ellipticity of 1.5.



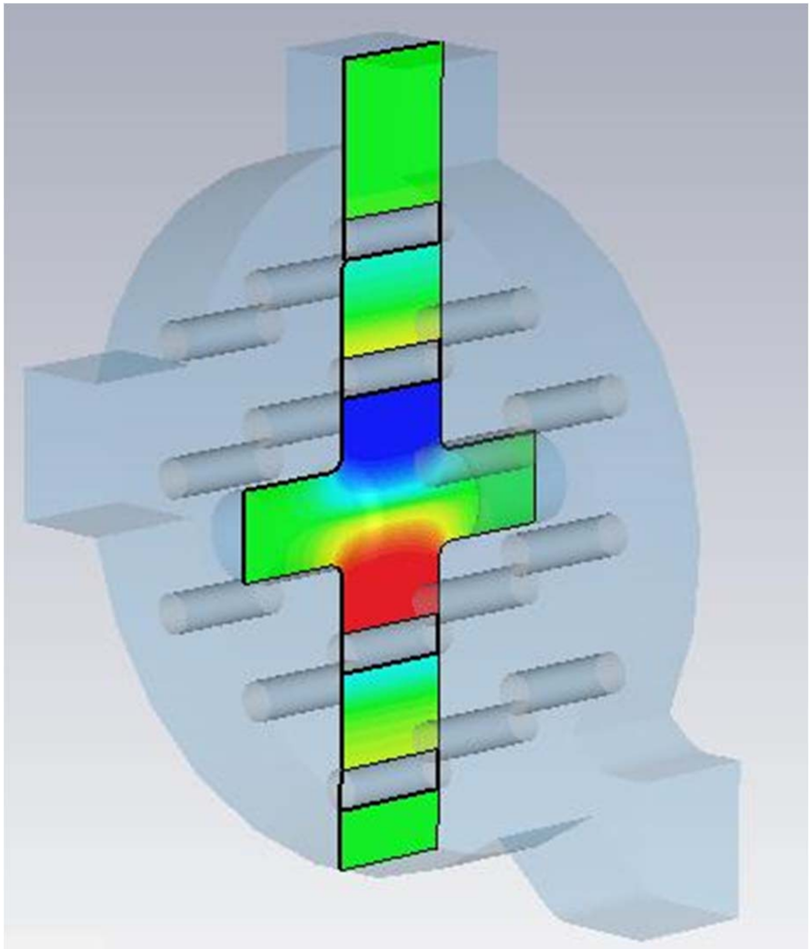


Reduction of surface magnetic fields

Peak surface magnetic fields in PBG resonators

• High magnetic fields in a PBG structure occur on the rods.

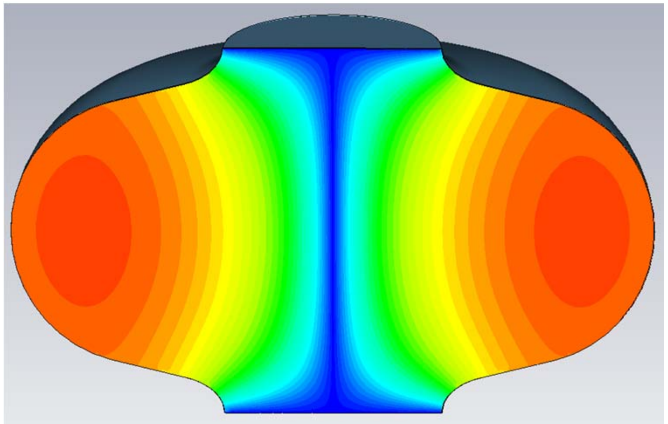
• Geometry and the shape of PBG rods must be adjusted to minimize the surface magnetic fields.



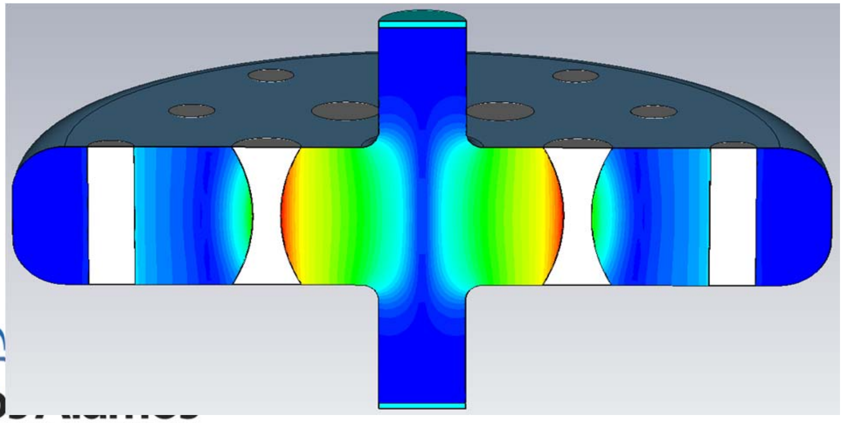
Reduction of surface fields by changing shape of PBG rods

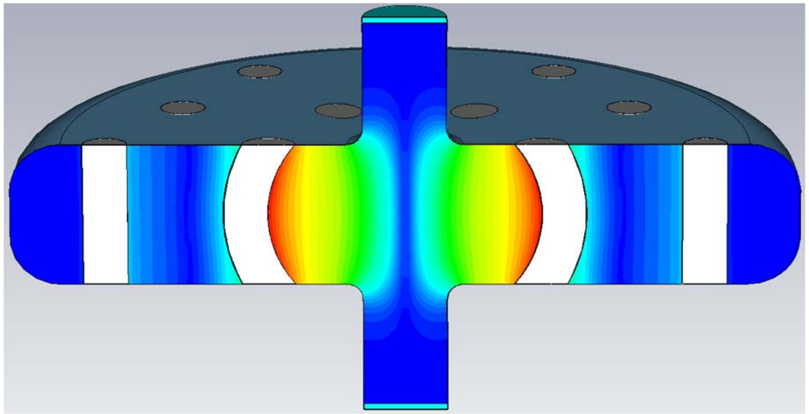
Bending the surface of an elliptical cavity pushes the high magnetic field away from the surface. However, bending the rods of the PBG structure did not produce the same effect.

Elliptical resonator



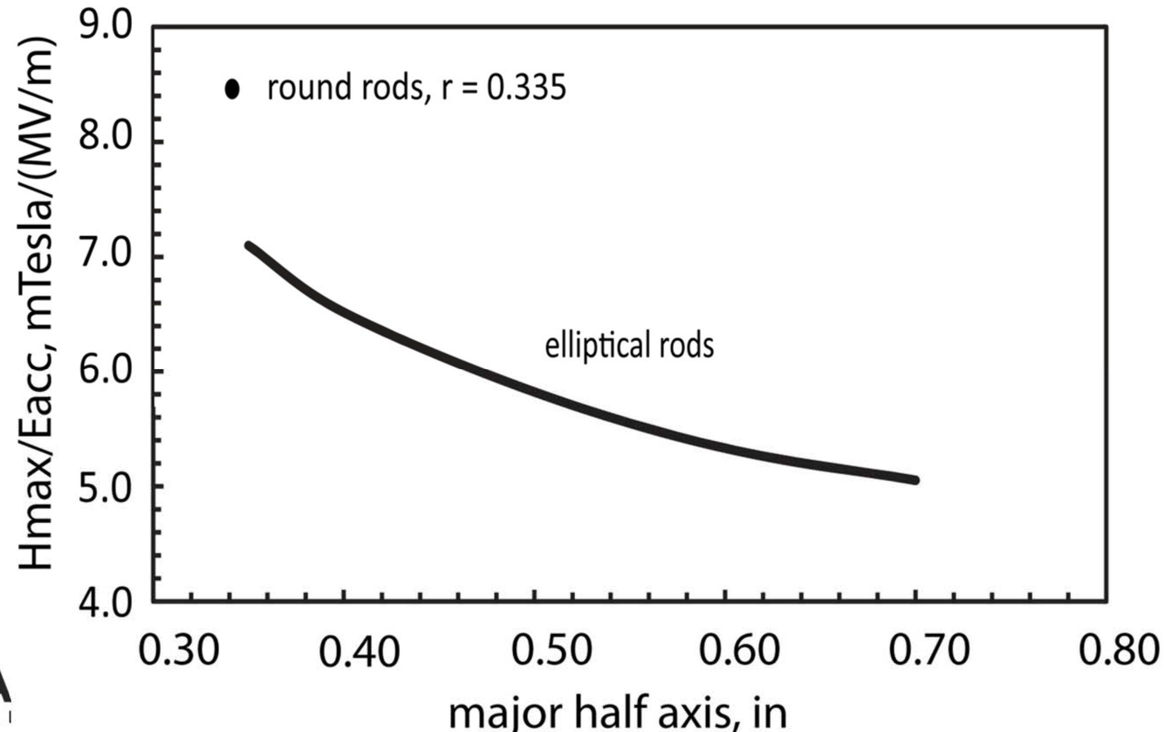
PBG resonators with bended PBG rods of different shapes.

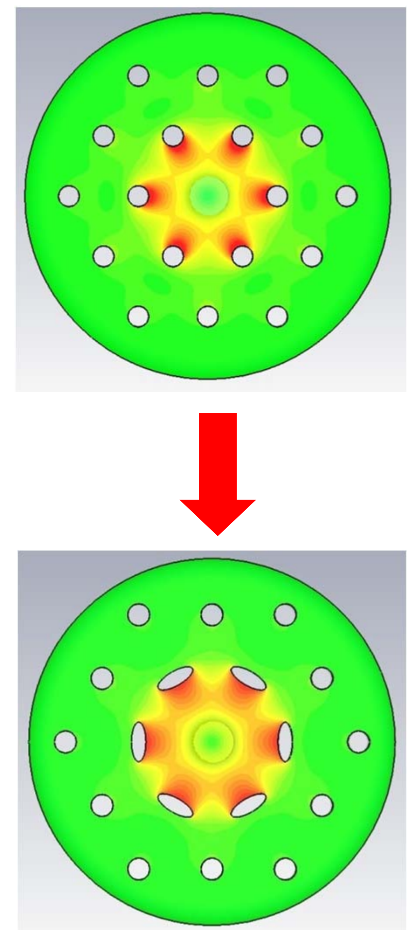




Reduction of surface fields with elliptical rods

Changing the cross-section of the rods from round to elliptical decreases the curvature and reduces maximum surface magnetic fields up to 40 per cent.

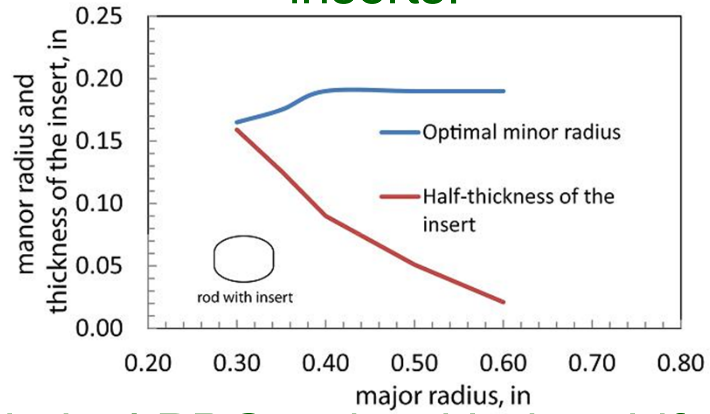




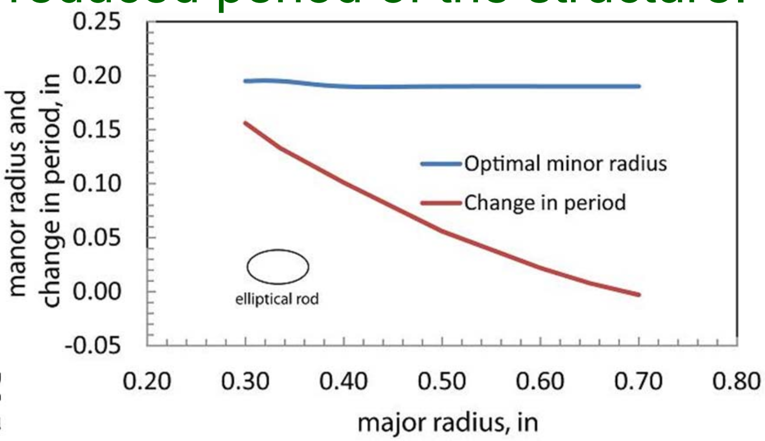
Adjusting the geometry to compensate for the frequency shift

The minor radii of elliptical rods were adjusted first to minimize peak fields. The dimensions of the structure were adjusted second to tune the cavity for the frequency of 2.1 GHz.

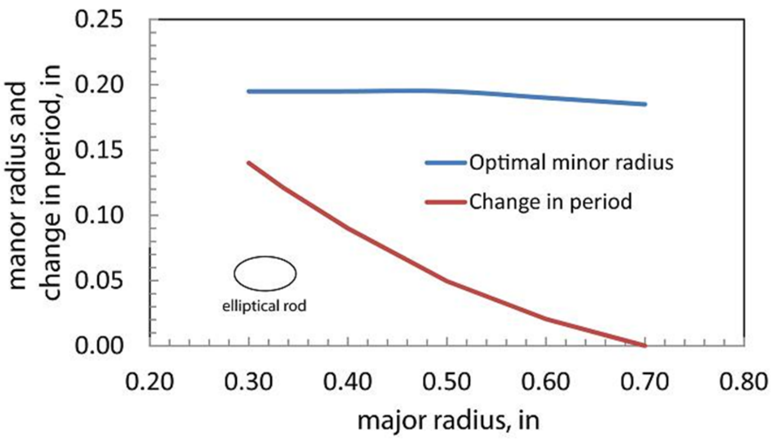
PBG rods with rectangular inserts.



Elliptical PBG rods with the reduced period of the structure.



Elliptical PBG rods with the shifted first row of rods.



Suppression of wakefields

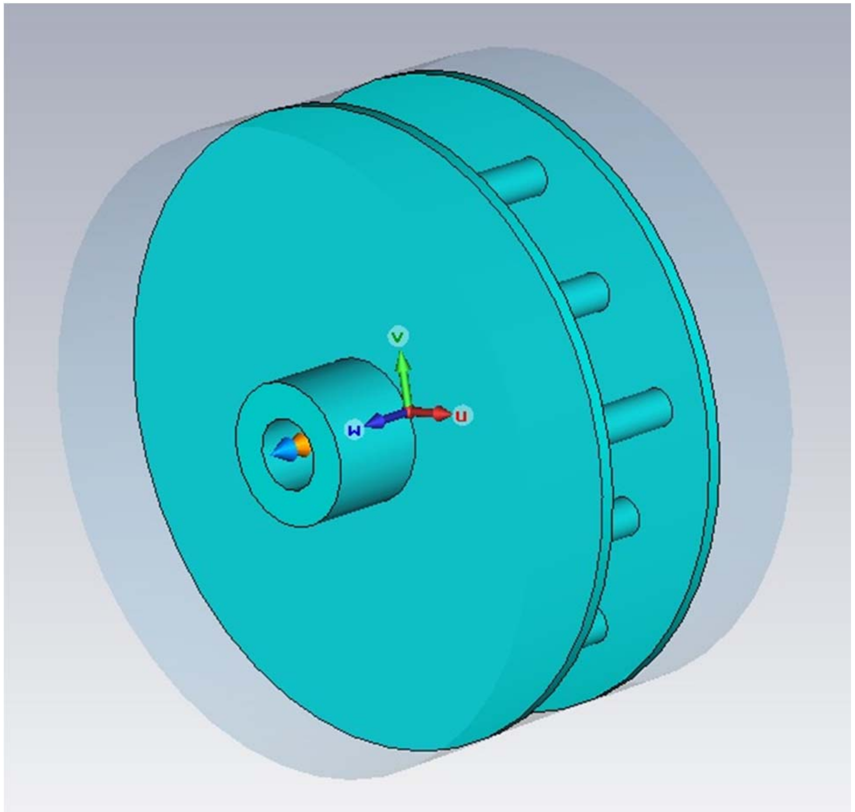
Characterization of HOMs: two methods

We modeled HOMs in a PBG geometry with opened side walls in two ways:

• We excited the cavity with an electron beam (Particle Studio) and looked at decays of wakefields.

• We excited the cavity with a current pulse (Microwave Studio) and looked at decays of stored microwave energy.

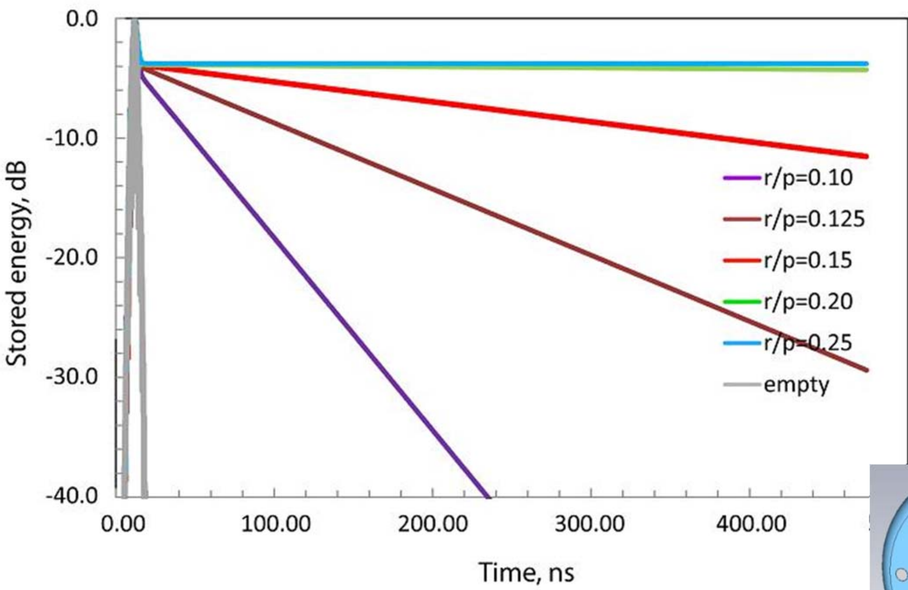
The second method runs faster and is easier to converge.



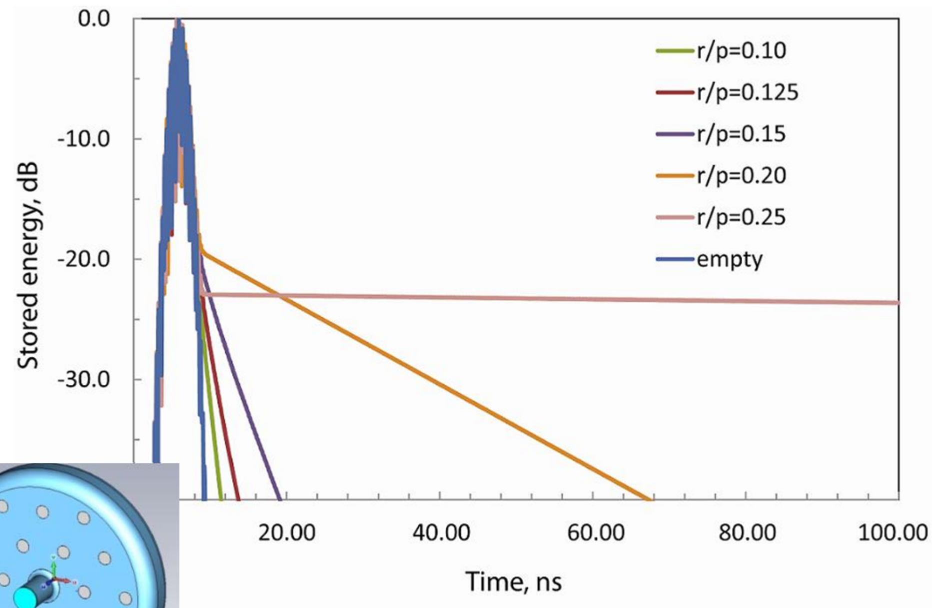
Characterization of HOMs: proof-of-principle

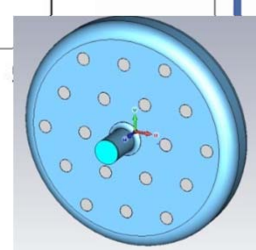
The graphs below illustrates the proof-of-principle application of the energy decay method for characterization of HOMs in a PBG cavity with cylindrical rods.

Decay of the fundamental mode.



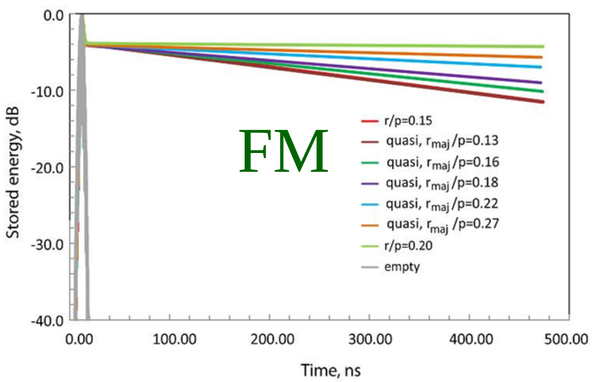
Decay of HOMs.

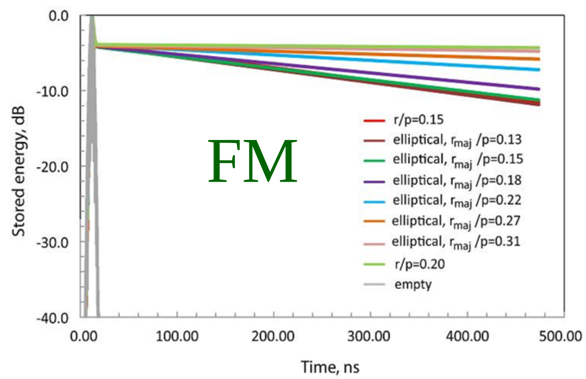


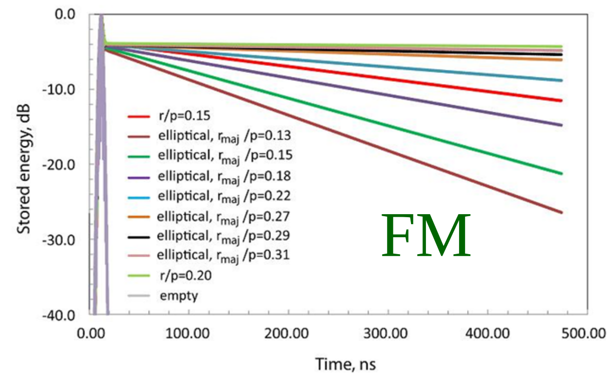


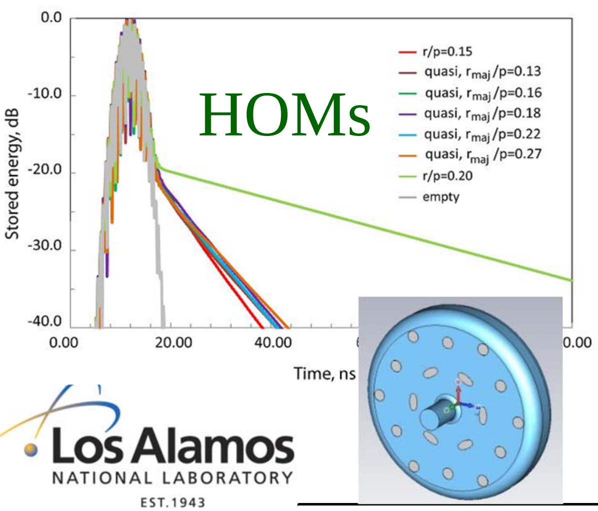
Characterization of HOMs in new geometries

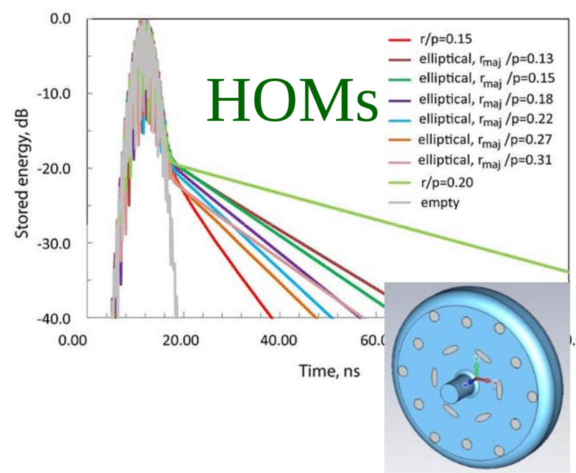
Elliptical rods with inserts.	Elliptical rods with shifted period.	Elliptical rods with shifted first row.

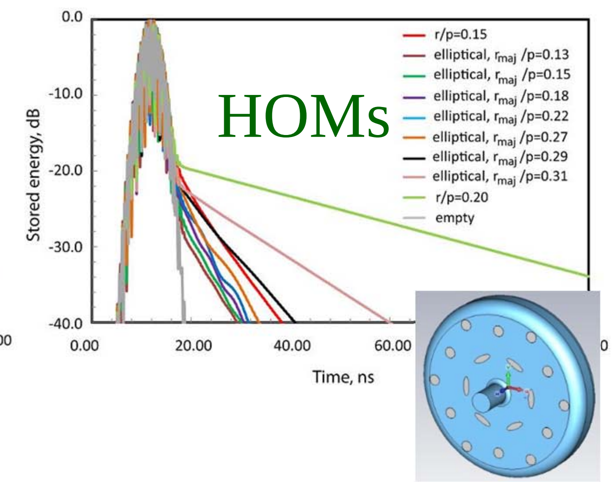






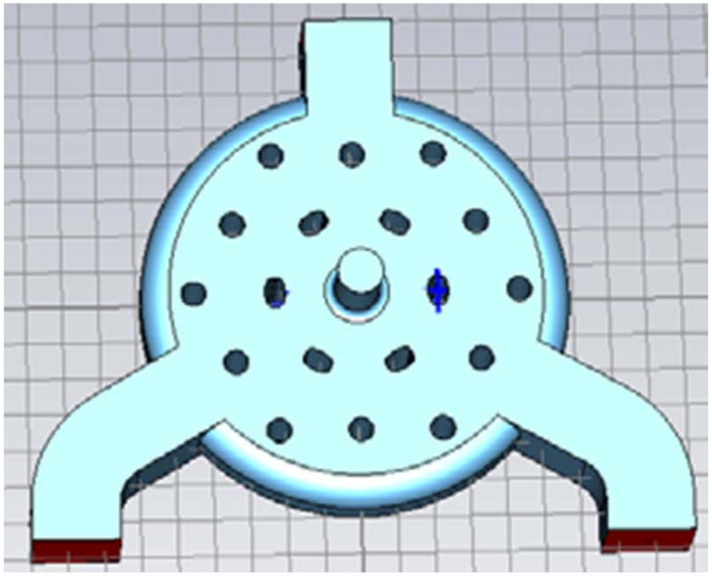


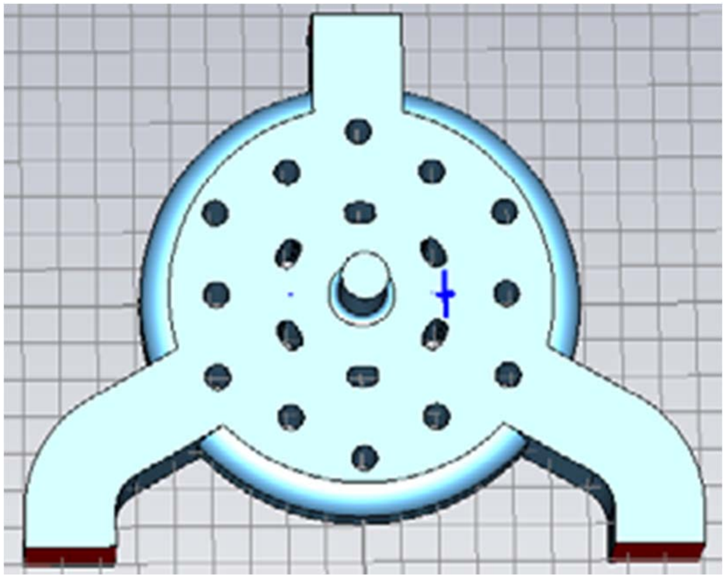




Design of the couplers

Once the open PBG structure is optimized for HOM suppression, we started modeling HOM attenuation in geometries with different configurations of waveguide couplers. This work is ongoing.



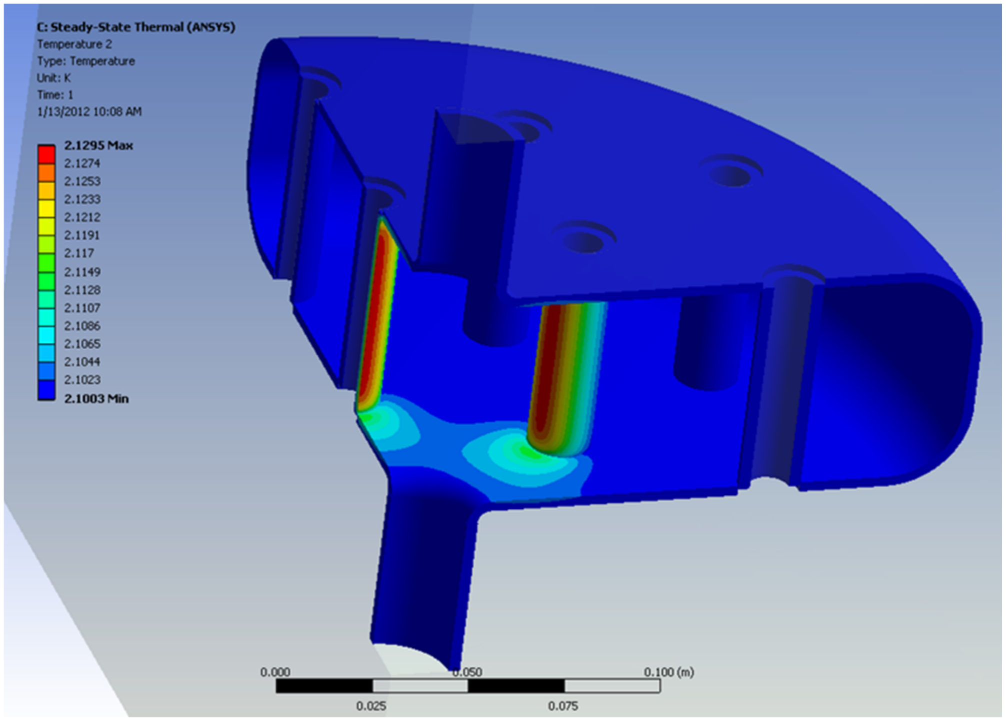


Thermal analysis

Thermal analysis @ 2K

Thermal analysis was conducted to rule out the possibility of thermal quench due to inadequate cooling of niobium by liquid helium inside of the rods.

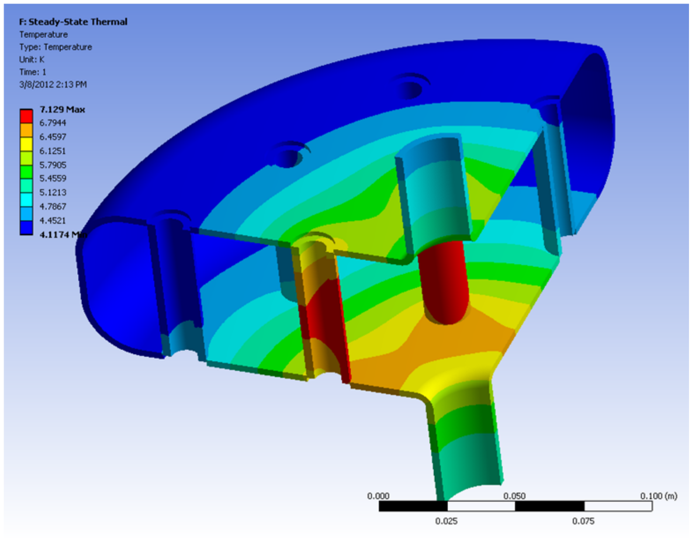
- Thermal analysis was performed with ANSYS software.
- Analysis was performed first at 2 Kelvin when liquid Helium is in a superfluid state.
- No thermal issues were discovered at 2 Kelvin for gradients up to 30 MV/m.



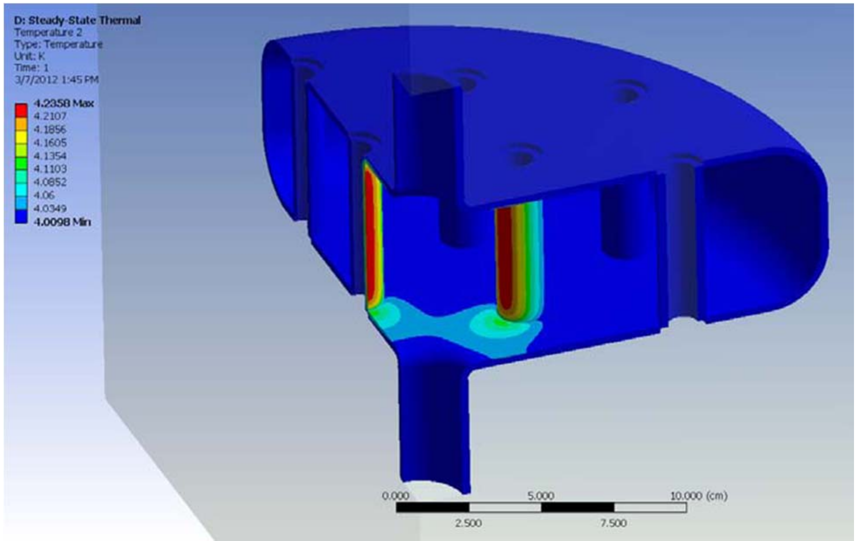
Thermal analysis @ 4K

Thermal analysis @ 4K is more complicated. The heat can be transferred by two mechanisms: conduction and free convection. Ansys simulations demonstrate that the free convection alone does not provide for adequate cooling of the structure at 4K. Full computational fluid dynamics analysis is needed to understand the coupling of two mechanisms.

Free convection



Conduction

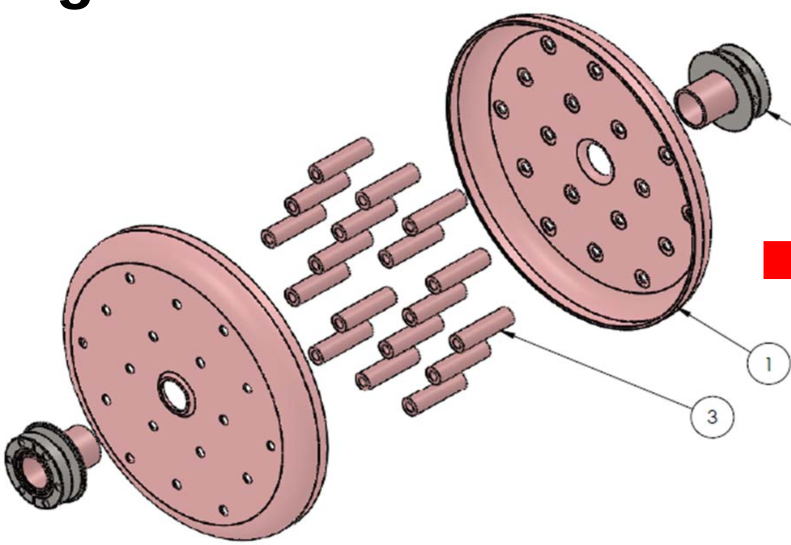


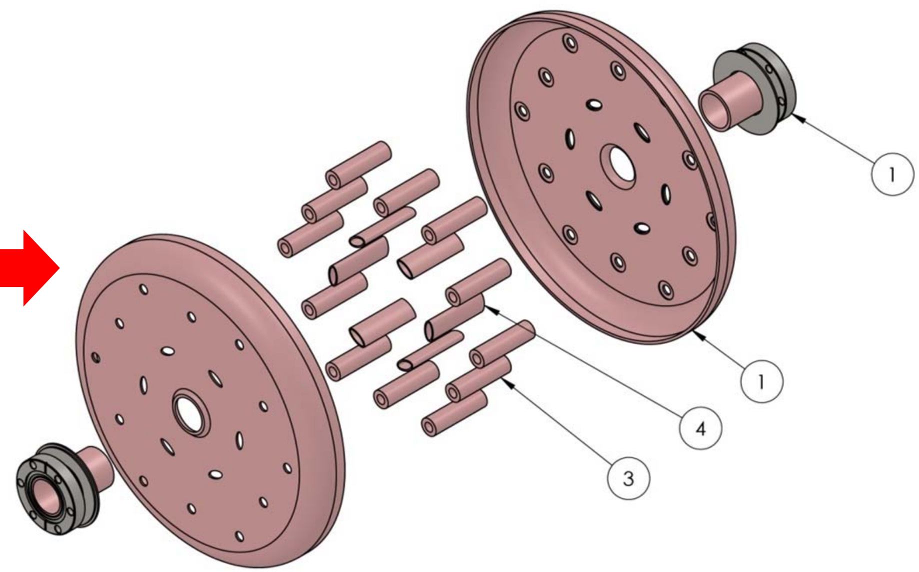
Plans and conclusion

Plans for the next year

Within the next year we plan to fabricate a PBG cavity with elliptical rods and experimentally demonstrate its high gradient operation and limitations.

We expect to observe the 40% increase in achievable gradients!





Conclusions

• The main objective of the this research is to push the limits for the high-gradient operation of SRF PBG cavities.

•A NCRF PBG cavity technology is established. The proof-of-principle operation of SRF PBG cavities is demonstrated.

• SRF PBG resonators are effective for outcoupling HOMs.

• PBG technology can significantly reduce the size of SRF accelerators and increase brightness for future FELs.