LA-UR-12-22007

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Title: An Update on the DOE Early Career Project on Photonic Band Gap Accelerator Structures

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Intended for: Advanced Accelerator Concepts Workshop, 2012-06-11 (Austin, Texas, United States)

An Update on the DOE Early Career Project on Photonic Band Gap Accelerator Structures

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Advanced Accelerator Concepts Workshop (AAC 2012)

June 12th, 2012

Los Alamos NATIONAL LABORATORY EST.1943

NNSA

Outline

- Background and motivation.
- PBG resonators for accelerators do date.
- 2.1 GHz SRF PBG cavity – design and testing.
- Plans for the 11.7 GHz wakefield experiment.
- Conclusion and plans.

Background and motivation

Background: beam breakup in SRF accelerators

- Average current in multi-cell SRF cavities is limited by beam breakup (BBU) instabilities caused by higher order modes (HOM), which if not damped can have high quality factor Q.
- Since BBU threshold scales with frequency as $1/f^2$, present SRF cavities designed for high current operation use low frequency, necessitating high charge per electron bunch.
- Operating at high frequency and low bunch charge reduces the risks of brightness degradation in electron beam transport.
- High current and high frequency SRF cavities require loading the HOMs to reduce their Q_{ext} to lower than 100 and removing HOM power from the liquid helium environment.

Methods for BBU suppression

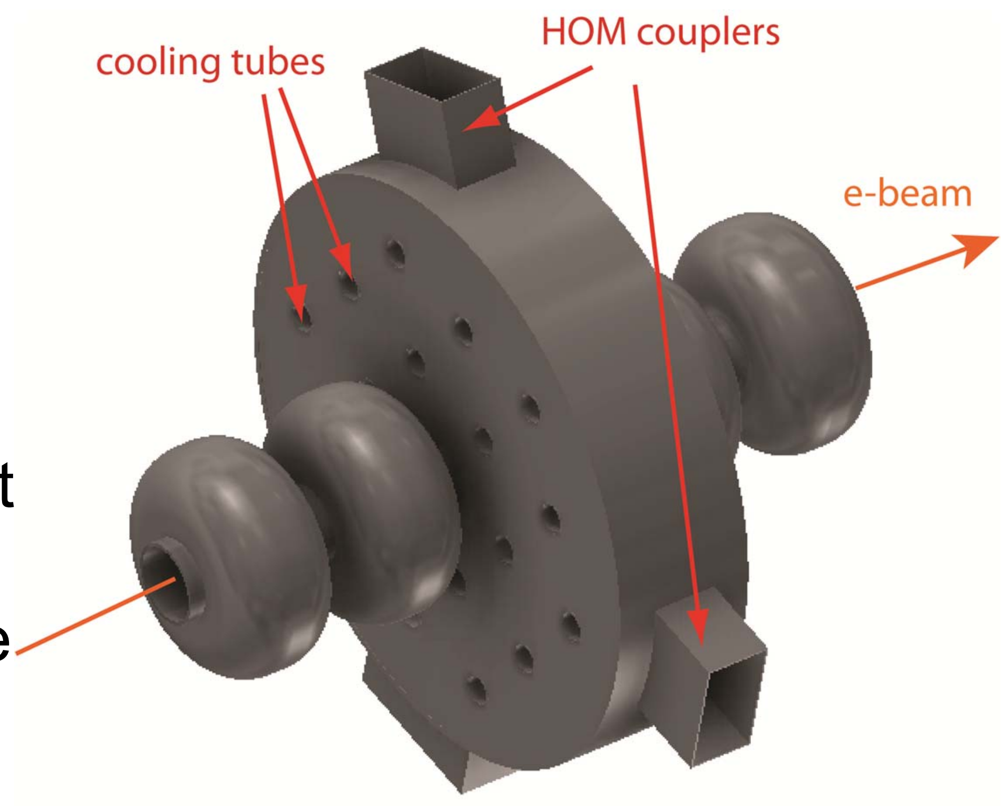
The primary approach to avoiding beam instabilities is to lower the external Q-factors for the HOMs.

Method	Problems
Ferrite HOM dampers (Q_{ext} ~ 100)	• Located in beam pipes outside of the cryostat. Greatly reduce real estate gradient. • Loss of electrical conductivity leads to charging of ferrite HOM dampers at cryogenic temperature.
HOM couplers (Q_{ext} ~ 1000)	• Located in beam pipes. Reduce real estate gradient. • Do now sufficiently damp HOMs.

PBG structures for SRF accelerators

PBG structures present us with a unique way to place HOM couplers in an accelerating cavity

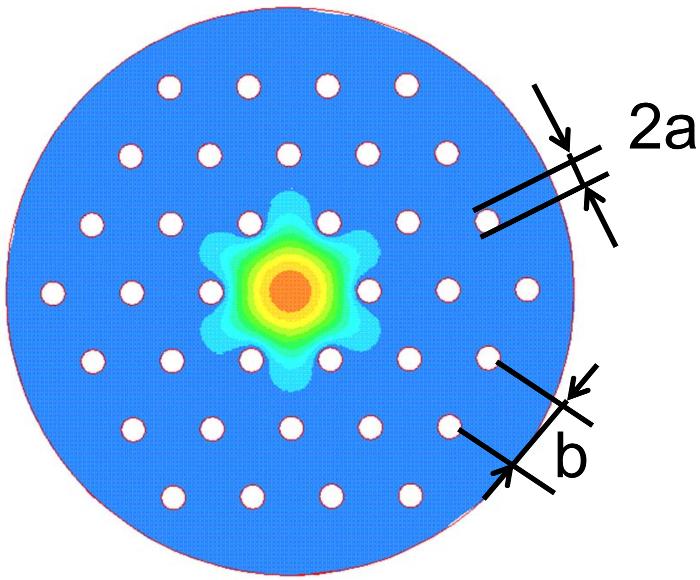
- Much lower external Q-factors for HOMs
- Higher real estate gradient
- Possibility to scale SRF accelerators to higher frequency $\Longrightarrow$ more compact accelerators with reduced footprint, lower bunch charge (higher brightness).



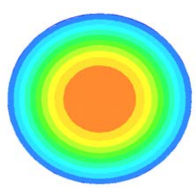
PBG resonators for accelerators to date

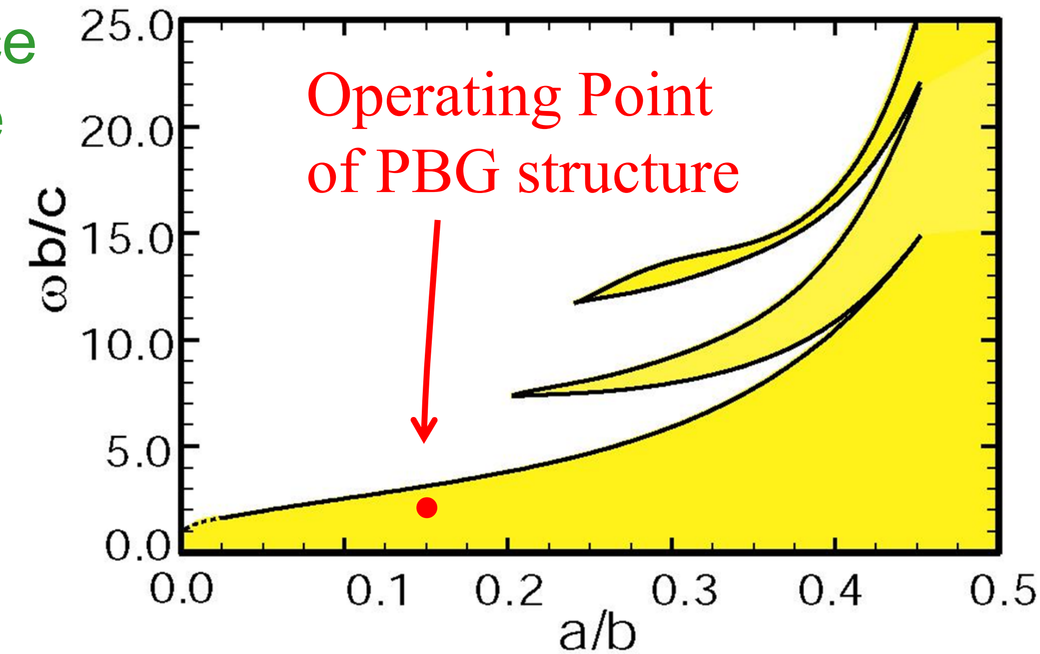
PBG resonators

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



Pillbox Cavity, TM_{01} mode

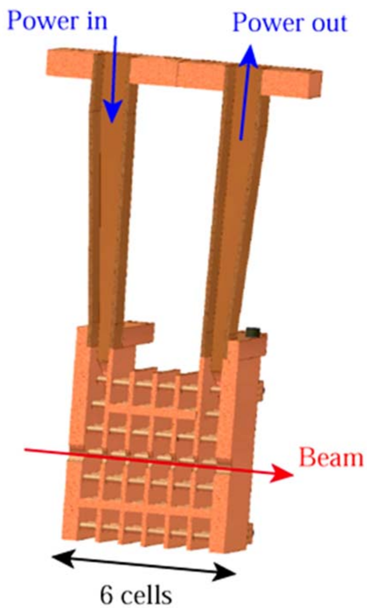


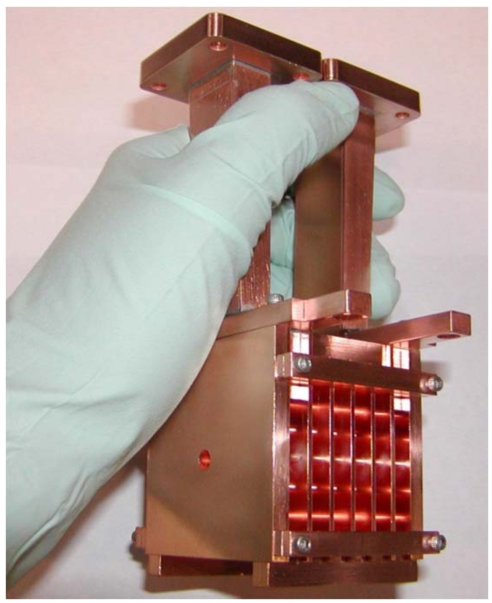


Single mode operation.
No higher order dipole modes.
This structure is employed for the MIT PBG accelerator

MIT PBG accelerator

MIT PBG accelerator at 17 GHz – first experimental demonstration of acceleration in a PBG structure:



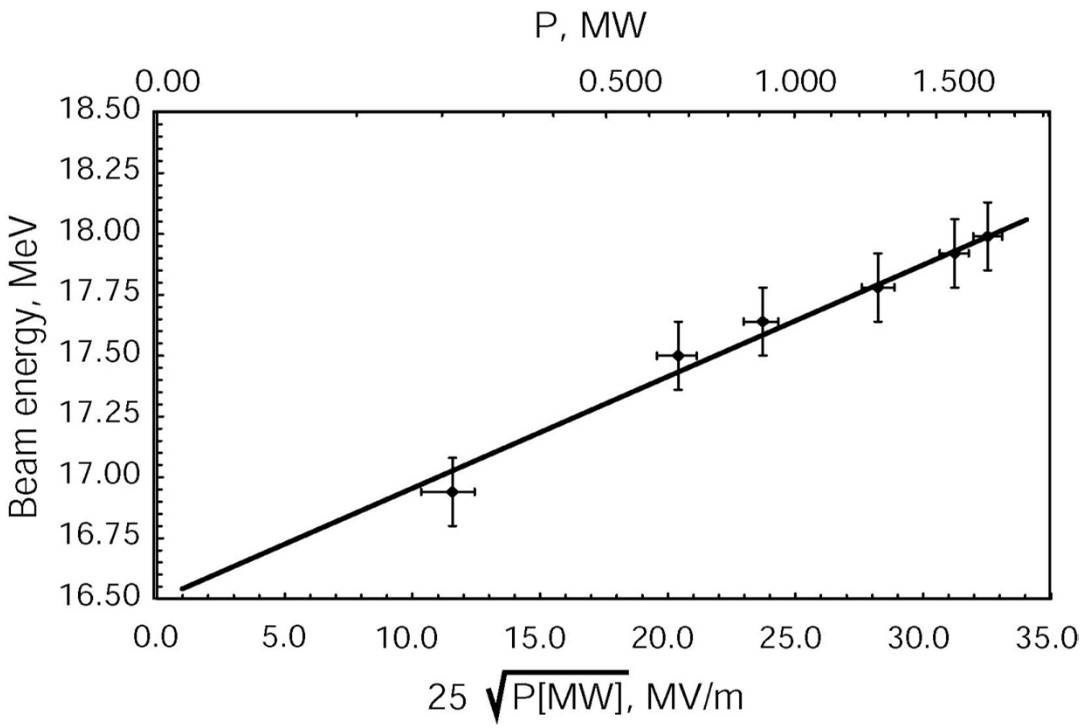


- A 6 cell TW PBG accelerator structure.
- Frequency: 17.137 GHz.
- Open structure, wakefields radiate freely into the vacuum chamber.

Rod radius	1.08 mm
Rod spacing	6.97 mm
Cavity radius	24.38 mm

First demonstration of a PBG accelerator

- Beam energy increased with power as $P^{1/2}$, as expected.
- First successful PBG accelerator demonstration.



E.I. Smirnova *et al.*, Phys. Rev. Lett. **95(7),** 074801 (2005).

SRF PBG resonators to date

- The UCSD team fabricated several SRF PBG cavities at 11 GHz.
- Fabrication was done at CEBAF.
- The cavity was open and had 3 rows of PBG rods.
- The unloaded Q-factor was measured at 4.8K and was dominated by radiation losses.

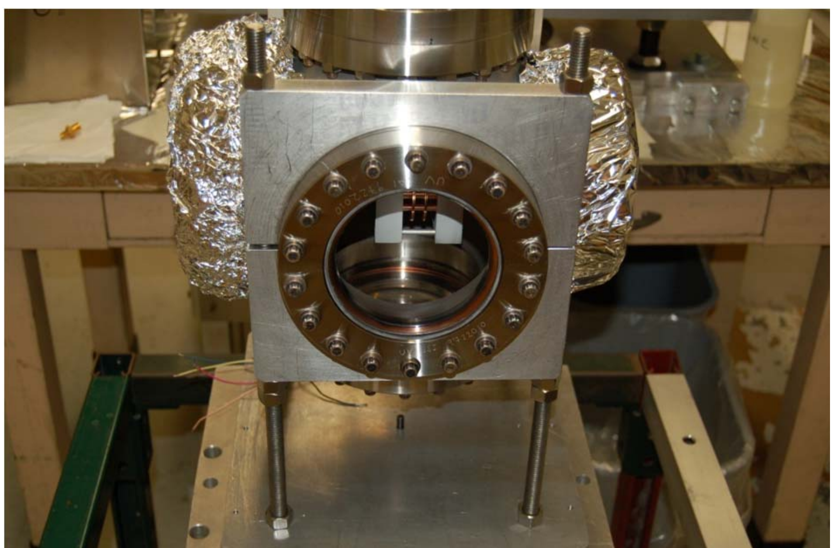
D.R. Smith et al., AIP Conference Proceedings, 398, p. 518, (1997).

- The INFN-Napoli team fabricated SRF PBG cavities at 6 GHz and at 16 GHz.
- The cavities were fabricated from a bulk piece of Nb with no welds.
- The cavity was open and had 3 rows of PBG rods.
- The unloaded Q-factor was measured at 1.5 K and was dominated by radiation losses.

M. R. Masullo et al., Proceedings of EPAC 2006, p. MOPCH167, (2006).

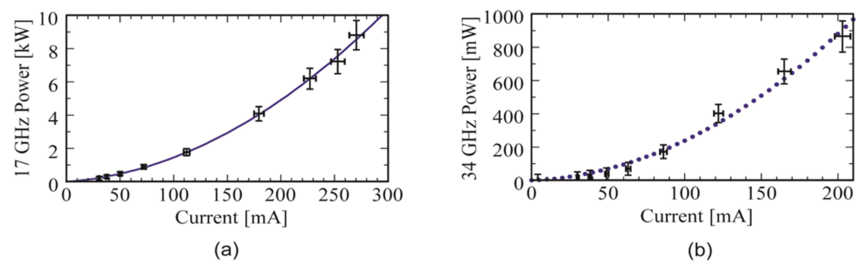
PBG resonators for testing wakefields

ANL fabricated a 3-cell standing wave structure at 11.4 GHz, tested it with a high charge electron bunch and measured Qs of HOMs.



C. Jing et al., PR STAB 12, 121302 (2009).

The MIT team ran a beam test of the the 6-cell 17 GHz PBG accelerator structure with a train of 200 picosecond electron bunches with the charge of 1-18 pC per bunch. Radiation was observed at the output port of the structure.

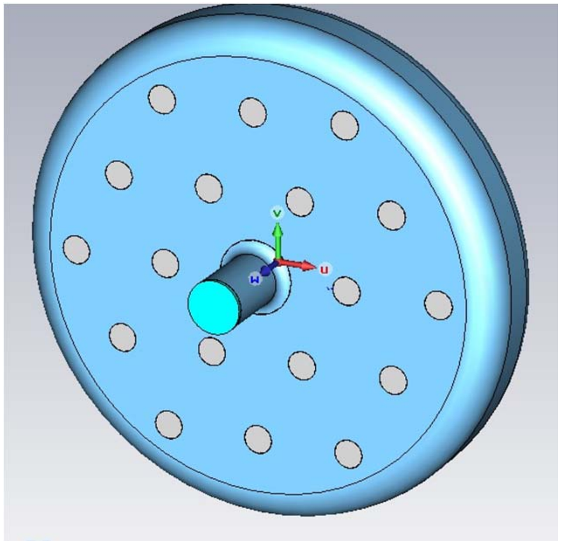


R.A. Marsh et al., NIMA 618, 16 (2010).

2.1 GHz SRF PBG cavity – design and testing

SRF PBG resonator – basic design

The SRF PBG resonator was designed at the frequency of 2.1 GHz.



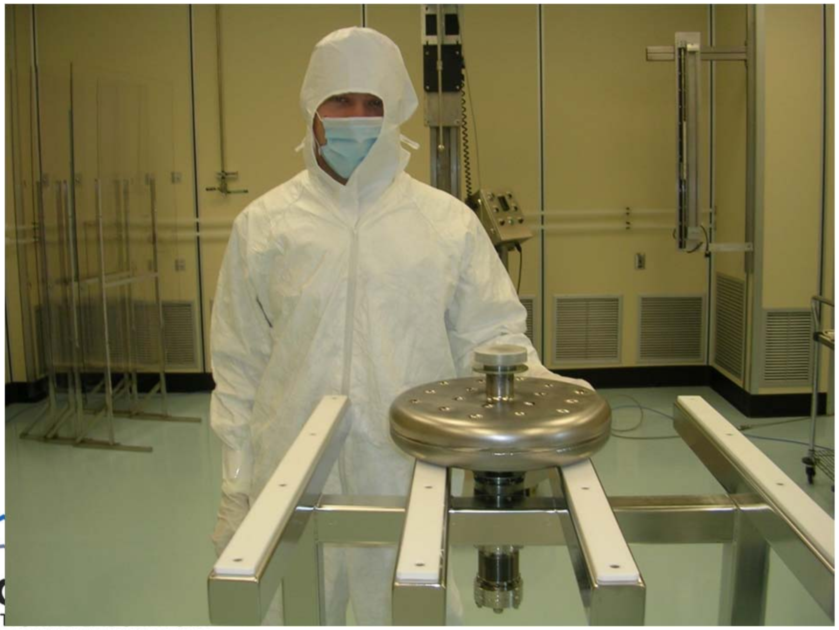
Spacing between the rods, p	56.56 mm
OD of the rods, d	17.04 mm = 0.3*p
ID of the equator, D0	300 mm
Length of the cell, L	60.73 mm (λ/2)
Beam pipe ID, Rb	1.25 inches = 31.75 mm
Radius of the beam pipe blend, rb	1 inch = 25.4 mm
Q_0 (4K)	$1.5*10^8$
Q_0 (2K)	$5.8*10^9$
R/Q	145.77 Ohm
E_{peak}/E_{acc}	2.22
B_{peak}/E_{acc}	8.55 mT/(MV/m)

Fabrication of 2.1 SRF PBG resonators

- The 2.1 GHz PBG cavity was fabricated at Niowave, Inc. from a combination of stamped sheet metal niobium with RRR>250 and machined ingot niobium components with RRR>220.
- After welding, a Buffered Chemical Polish etch was performed to prepare the RF surface for testing.

2.1 GHz resonators – preparation for tests

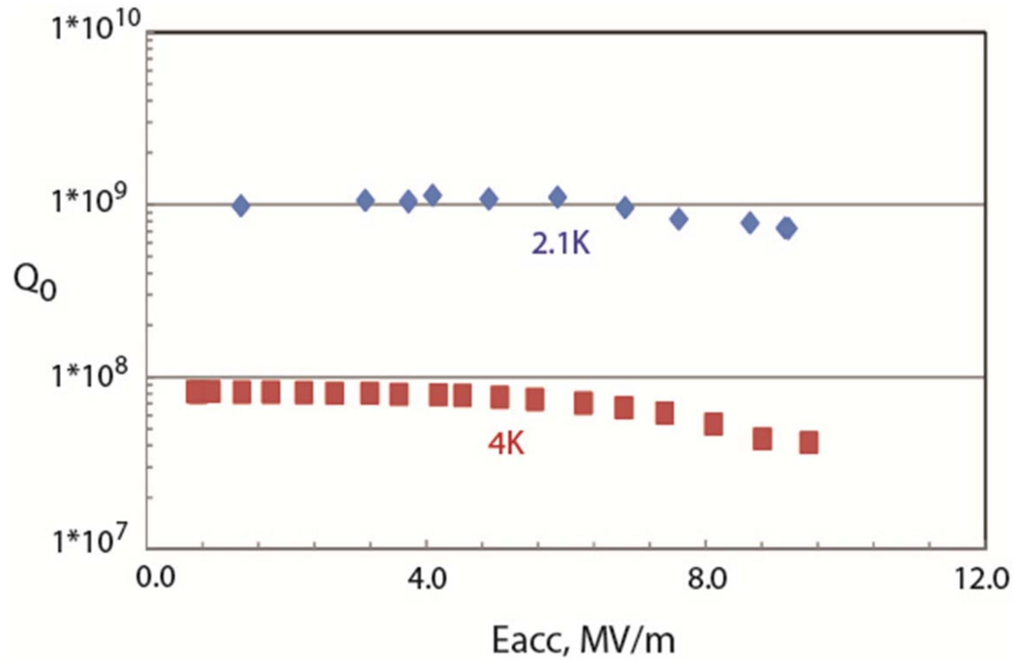
Each cavity was opened in a class 100 clean room and a pickup coupler flange and a flange with a matched moveable power coupler were attached. The cavity was then sealed and taken out of the clean room, set on the vertical cryostat insert, pumped down and leak checked.



Test results – resonator 1

Resonator 1 was tested on March 27-30th, 2012. This cavity was opened up a few times in the clean room during preparation for the experiment. It also developed a super leak at 2 Kelvin.

Frequency	2.10669 GHz
Q_0 (4K)	$8.2*10^7$
Q_0 (2K)	$1.1*10^9$
Maximum E_{acc} (4K)	9.5 MV/m
Maximum E_{acc} (2K)	9.1 MV/m
B_{peak} (4K)	81 mT
B_{peak} (2K)	78 mT

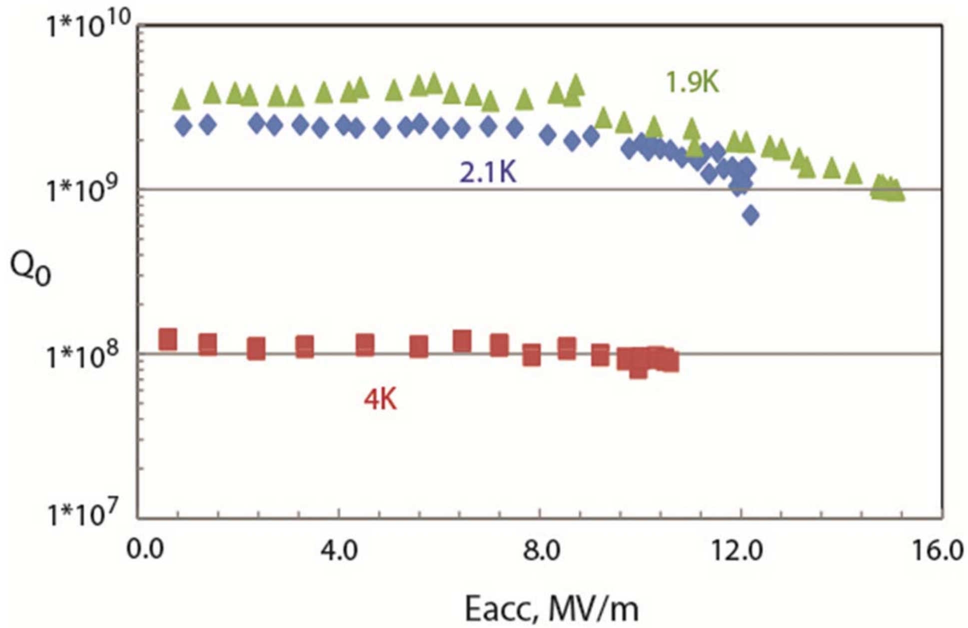


Test results – resonator 2

Resonator 1 was tested on April 23-27, 2012. Measured characteristics were very close to theoretical predictions.

Frequency	2.09984 GHz
Q_0 (4K)	$1.2*10^8$
Q_0 (2K)	$3.9*10^9$
Maximum E_{acc} (4K)	10.6 MV/m
Maximum E_{acc} (2K)	15.0 MV/m
B_{peak} (4K)	91 mT
B_{peak} (2K)	129 mT

Maximum achieved gradient is 15 MV/m.

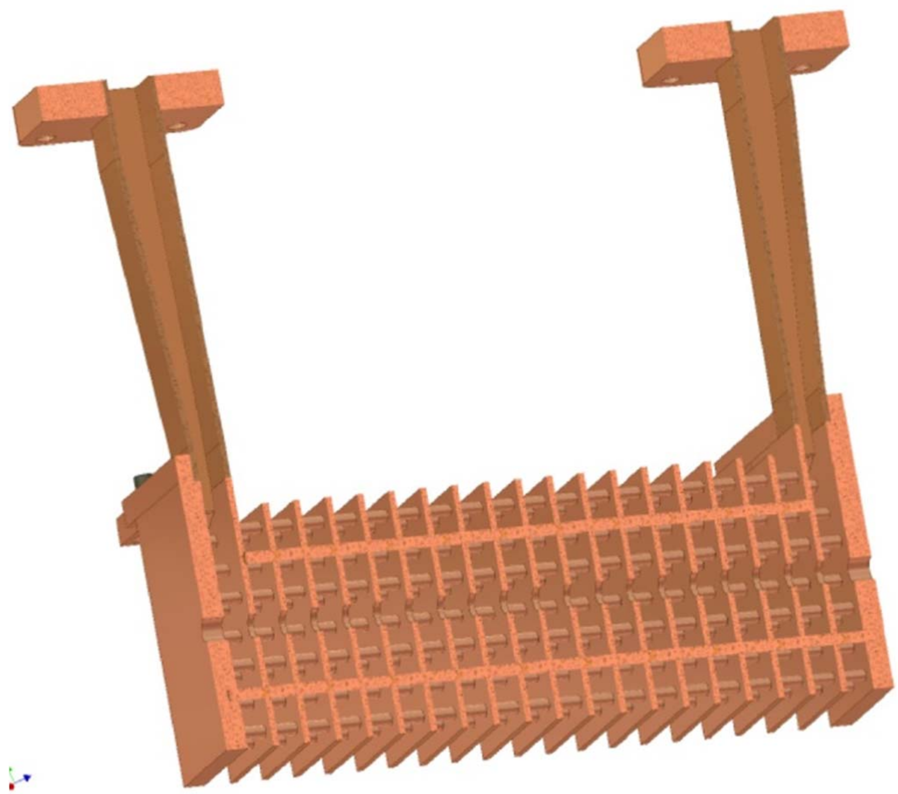


Plans for the 11.7 GHz wakefield experiment

The 16 cell structure

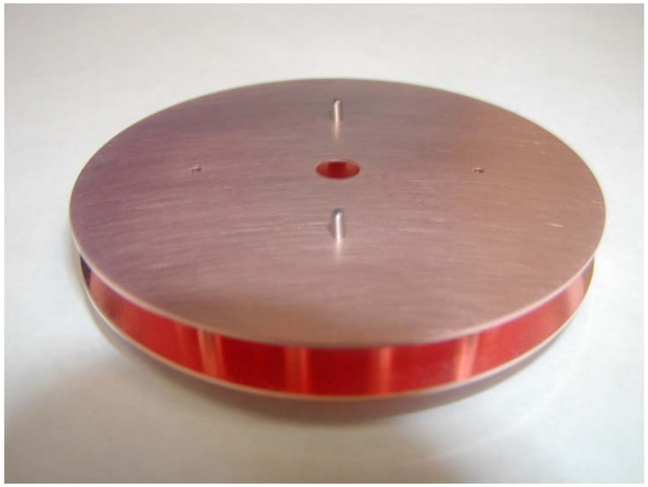
The 16-cell PBG structure for the wakefield testing was designed at the frequency 11.7 GHz (9 times the frequency of AWA). Very close scale of the MIT 17 GHz structure.

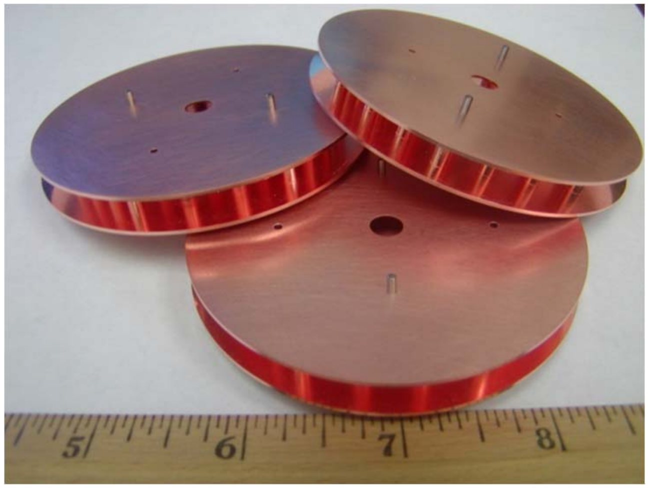
Frequency	11.700 GHz
Phase shift per cell	$2\pi/3$
Q_w	5000
r_s	72.5 MΩ /m
$[r_s/Q]$	14.5 kΩ /m
Group velocity	0.015c
Gradient	15.4 $\sqrt{P[MW]}$ MV/m



Test cells

Three TW test cells were fabricated in order to benchmark the tuning and brazing processes before fabricating and assembling the 16 cell structure. The cells were electroformed by Custom Microwave, Inc. The frequency of the cells was tested with the two E-field antennas on axis.





Tuning of the test cells

The cells were tuned by etching. Target frequency 11.659 GHz.

	Cell #1	Cell #2	Cell #3
Frequency as fabricated	11.672 GHz	11.677 GHz	11.689 GHz
Frequency after the first etch (1 minute each cell)	11.665 GHz	11.672 GHz	11.682 GHz
Frequency after the second etch (1 minute cells #1 and #2, 2 minutes cell #3)	11.659 GHz	11.665 GHz	11.673 GHz
Frequency after the third etch (1 minute cells #2, 1+1 minutes cell #3)		11.659 GHz	11.660 GHz

Brazing is the next step.

Conclusion and plans

Conclusions

• We performed fabrication of two SRF PBG resonators at 2.1 GHz and demonstrated their proof-of-principle operation at high gradients.

• Measured characteristics of the resonators were in good agreement with theoretical predictions.

• We demonstrated that SRF PBG cavities can be operated at 15 MV/m accelerating gradients.

• We completed the design and started fabrication of the 16-cell PBG accelerating structure at 11.7 GHz for wakefield testing at AWA.

Plans for the next few years

- Demonstration of wakefield in a room-temperature 16-cell PBG structure is the next goal of the EC project.
- Design of the 5-cell SRF module incorporating a PBG coupler will follow.
- A spin-off of this project sponsored by ONR was initiated to fabricate a PBG cavity with elliptical rods with higher gradient limitations.