An update on the superconducting photonic band gap structure resonator experiment

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Outline

- Background and motivation.
- PBG resonators for accelerators do date.
- 2.1 GHz SRF PBG cavity – design and testing.
- 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

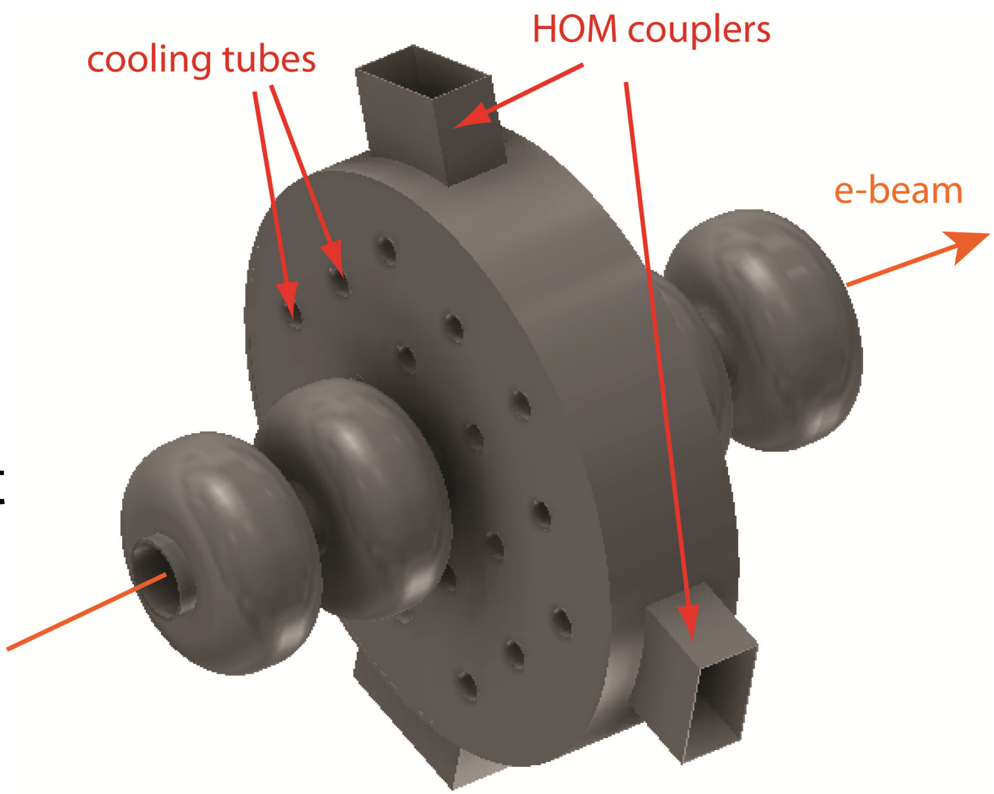
The primary approach to avoiding beam instabilities is to lower the external Q-factors for the HOMs.

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

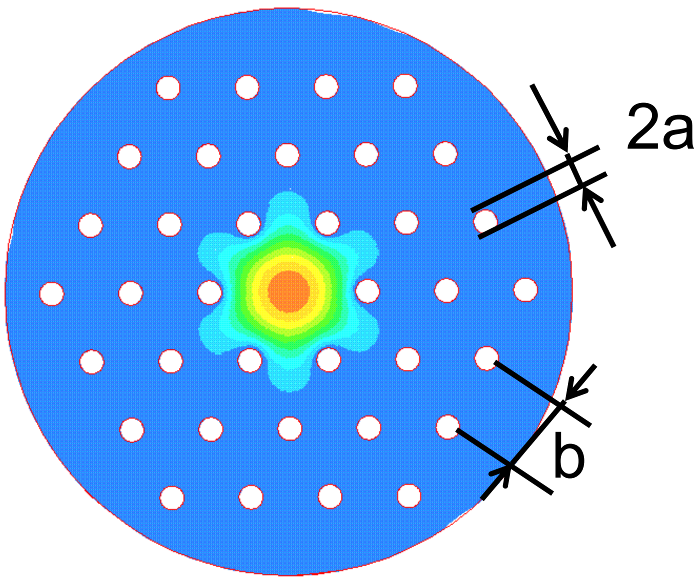
- Much lower external Q-factors for HOMs
- Higher real estate gradient
- Possibility to scale SRF accelerators to higher frequency $\Longrightarrow$ more compact accelerators with reduced footprint, lower bunch charge (higher brightness).

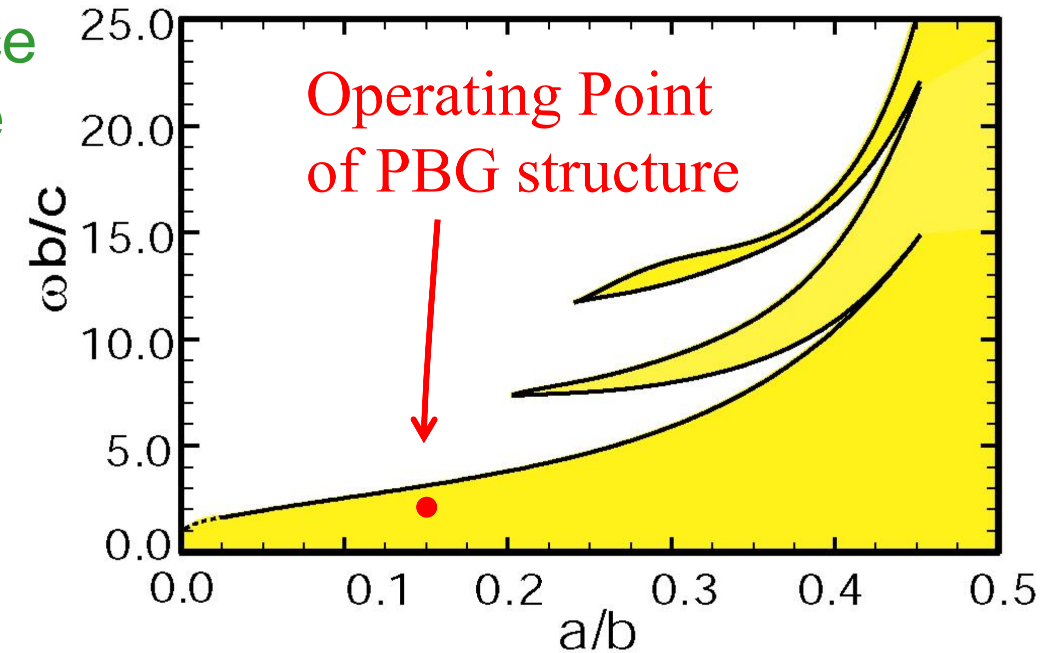


PBG resonators for accelerators to date

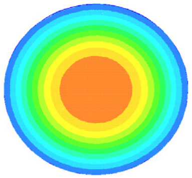
PBG resonators

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





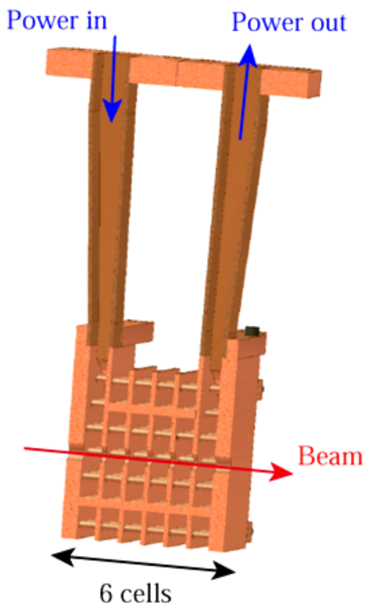
Pillbox Cavity, TM_{01} mode

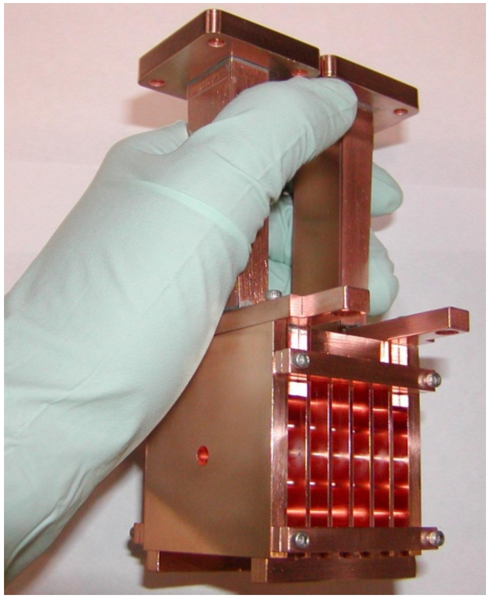


Single mode operation.
No higher order dipole modes.
This structure is employed for the MIT PBG accelerator

MIT PBG accelerator

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



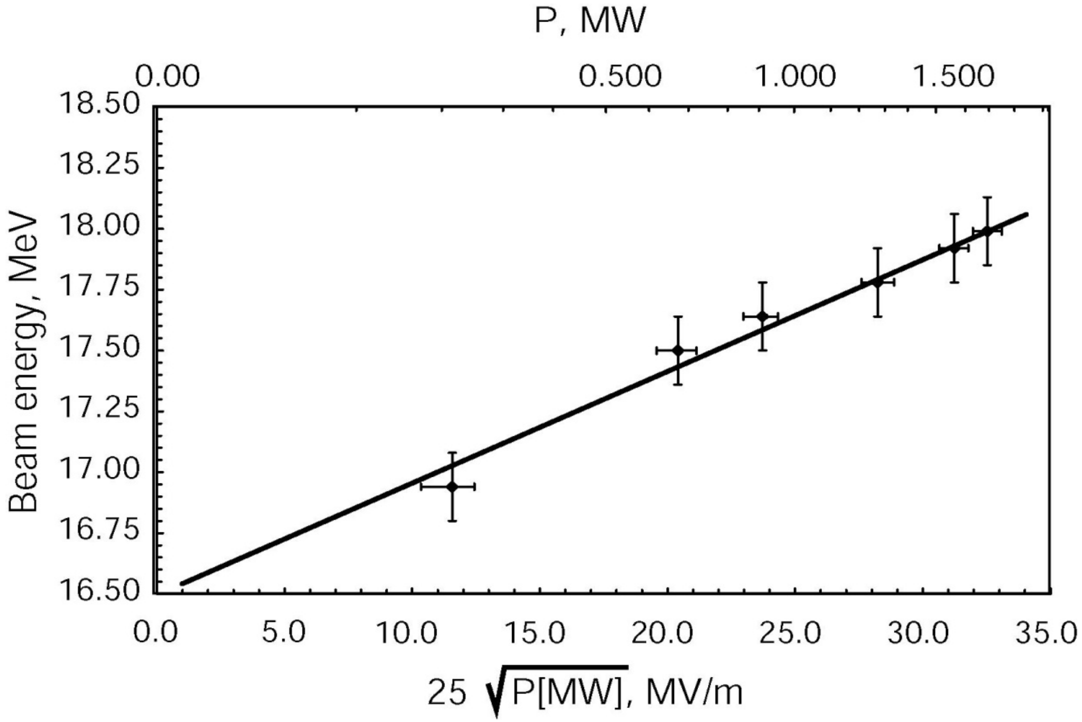


- A 6 cell TW PBG accelerator structure.
- Frequency: 17.137 GHz.
- Open structure, wakefields radiate freely into the vacuum chamber.

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

First demonstration of a PBG accelerator

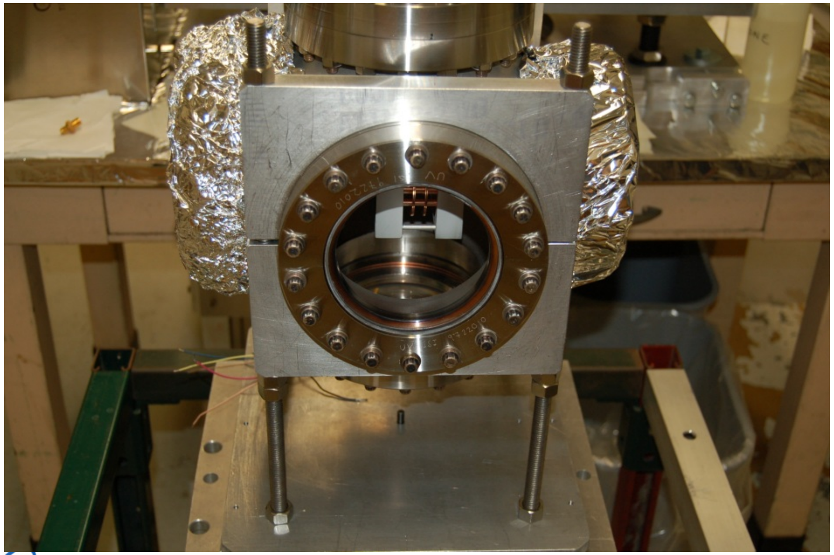
- Beam energy increased with power as $P^{1/2}$, as expected.
- First successful PBG accelerator demonstration.



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

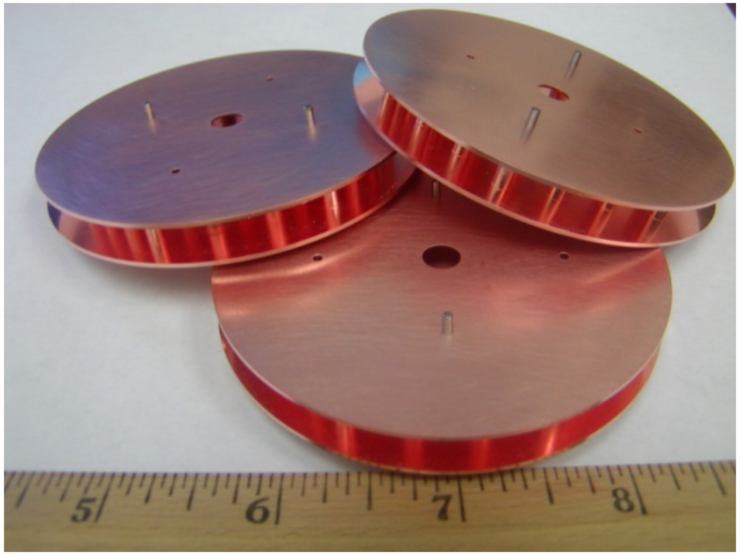
PBG resonators for testing wakefields

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).

We started a project at LANL to fabricate a 16-cell TW 2π/3-mode structure at 11.7 GHz and measure its wakefield spectrum.



E. Simakov et al., p. WEPPP033, this conference.

SRF PBG resonators

- 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).

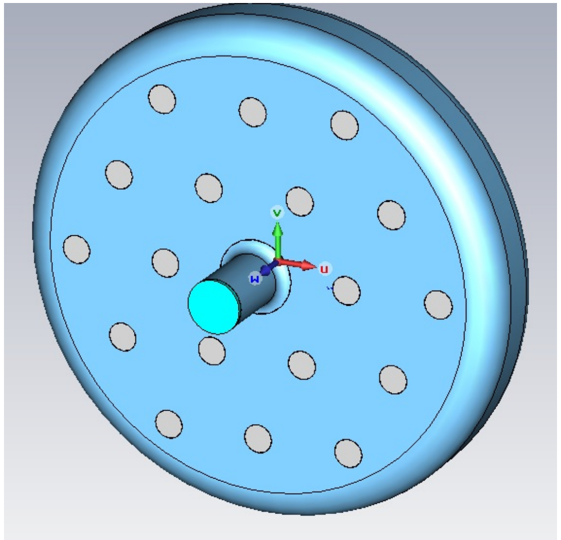
- The INFN-Napoli team fabricated SRF PBG cavities at 6 GHz and at 16 GHz.
- The cavities were fabricated from a bulk piece of Nb with no welds.
- The cavity was open and had 3 rows of PBG rods.
- The unloaded Q-factor was measured at 1.5 K and was dominated by radiation losses.

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

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)

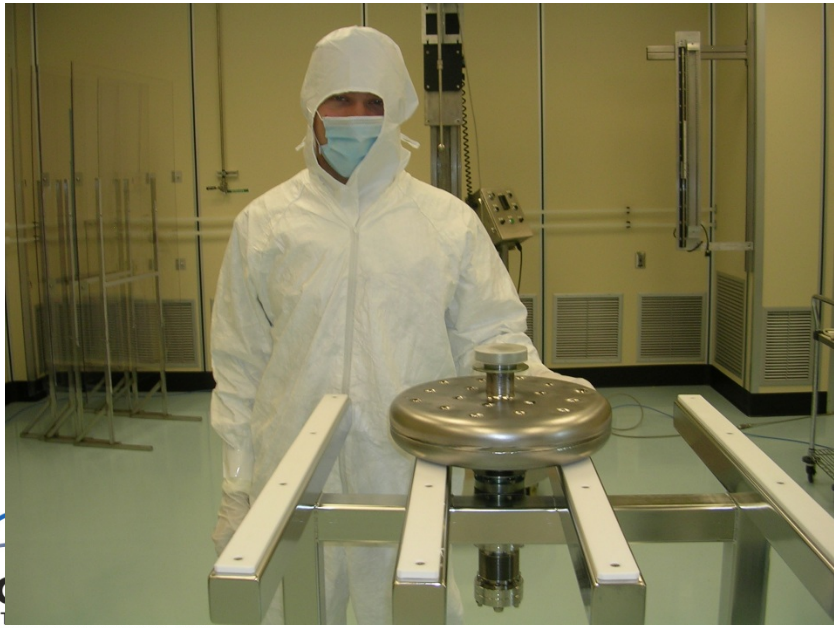
Fabrication of 2.1 SRF PBG resonators

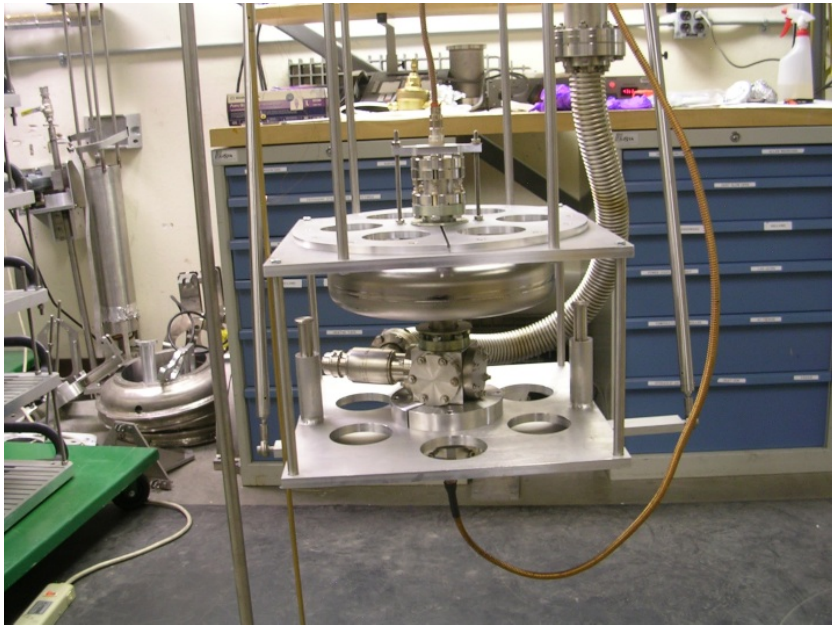
• The 2.1 GHz PBG cavity was fabricated at Niowave, Inc. from a combination of stamped sheet metal niobium with RRR>250 and machined ingot niobium components with RRR>220.

• 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.

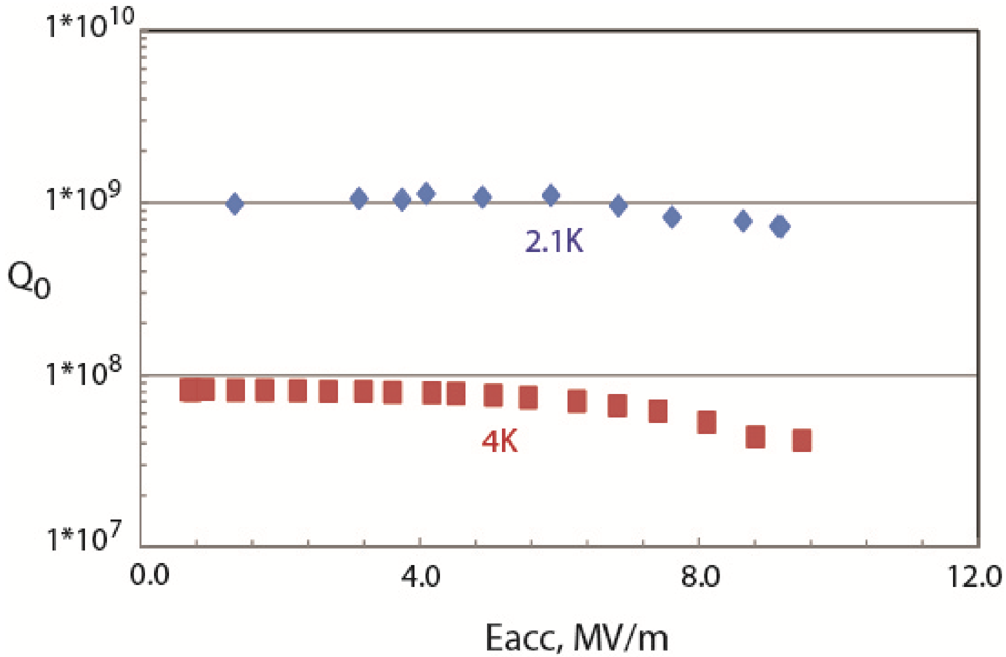




Test results – resonator 1

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

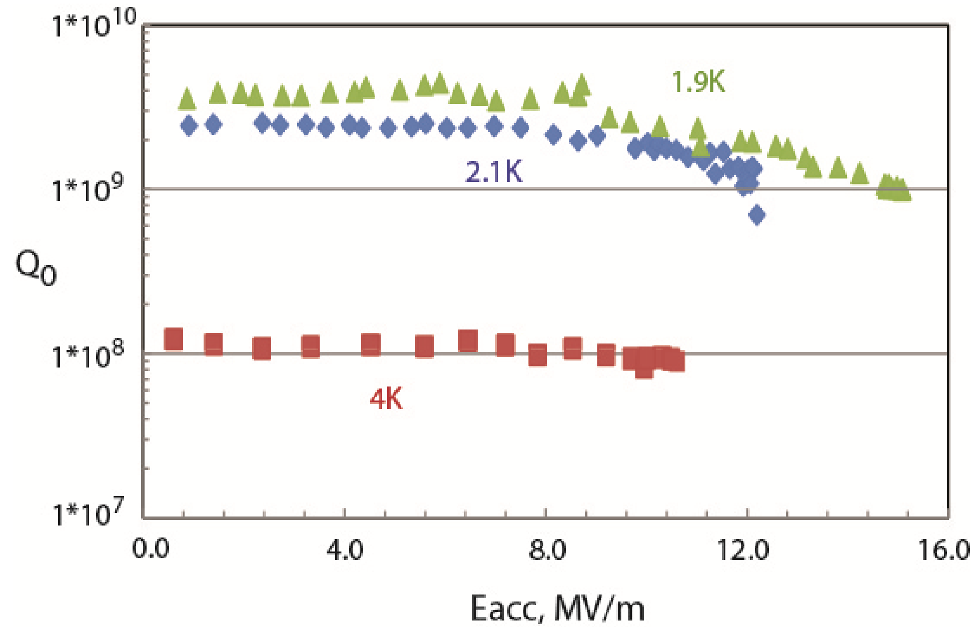


Test results – resonator 2

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.



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.

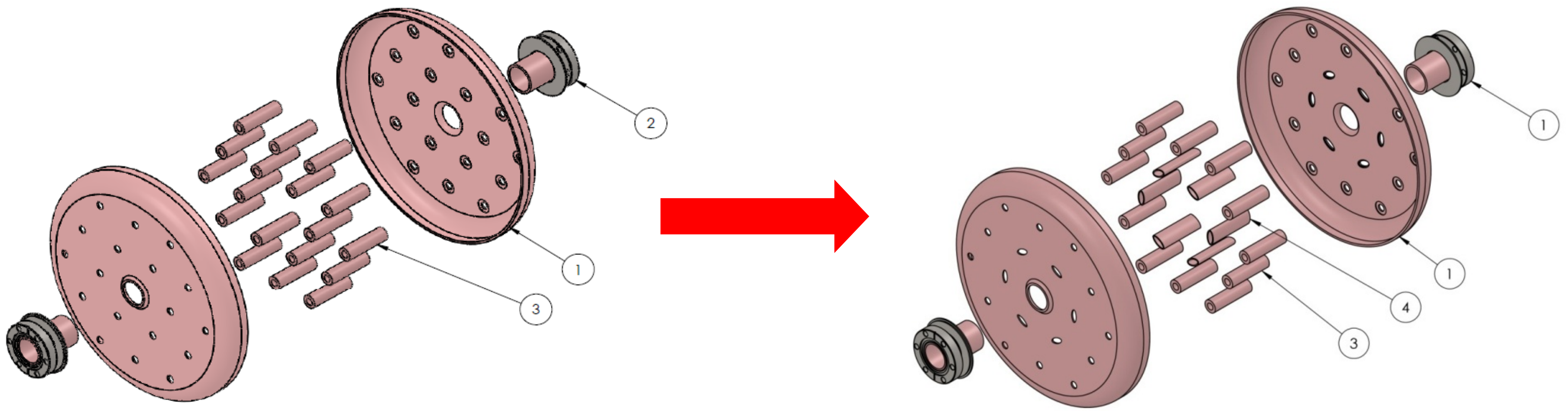
• Measured characteristics of the resonators were in good agreement with theoretical predictions.

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

• PBG resonators is an effective way to incorporate HOM couplers into SRF accelerating structure and forms a pathway for getting SRF technology to higher frequencies of operation.

Plans for the next year

- Demonstration of wakefield suppression with a PBG structure incorporated into an SRF accelerator section is the next goal of the project.
- A spin-off of this project sponsored by ONR was initiated to fabricate a PBG cavity with elliptical rods with higher gradient limitations.



E. Simakov et al., p. WEPPP035, this conference.