Progress in unconventional RF structures

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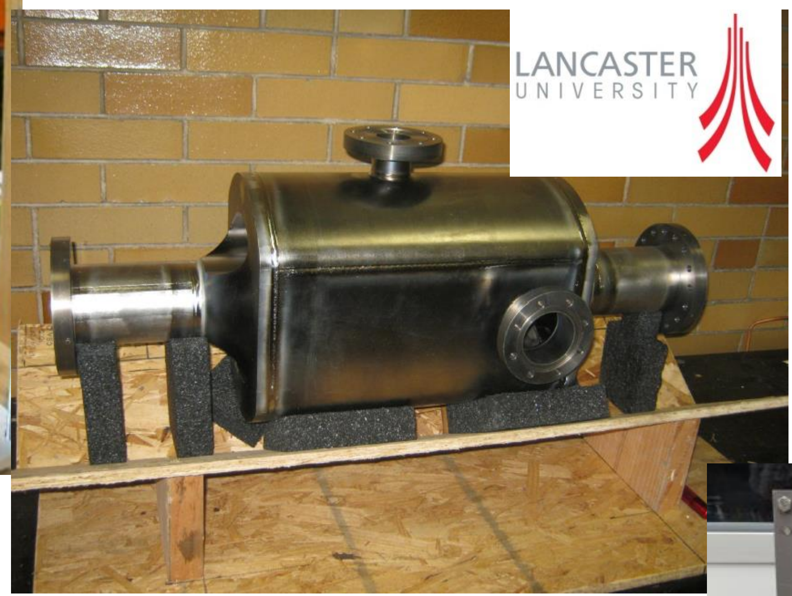
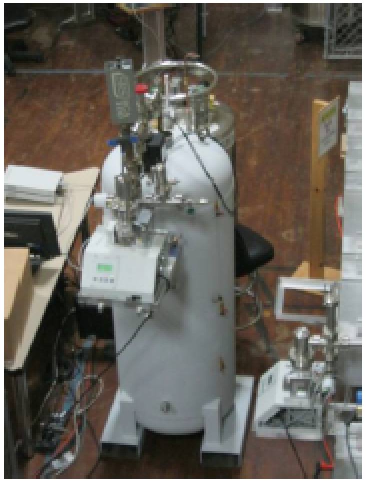
Compact SRF Crab cavities

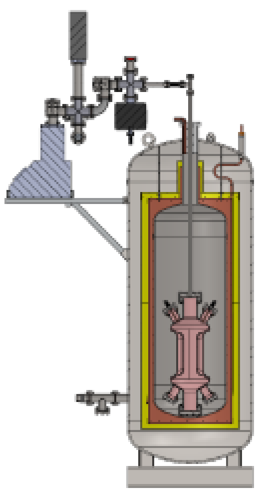
- We start our tour of the weird and wonderful with compact crab cavities.



A few years ago these three designs were considered quite exotic but now we have three prototypes in niobium

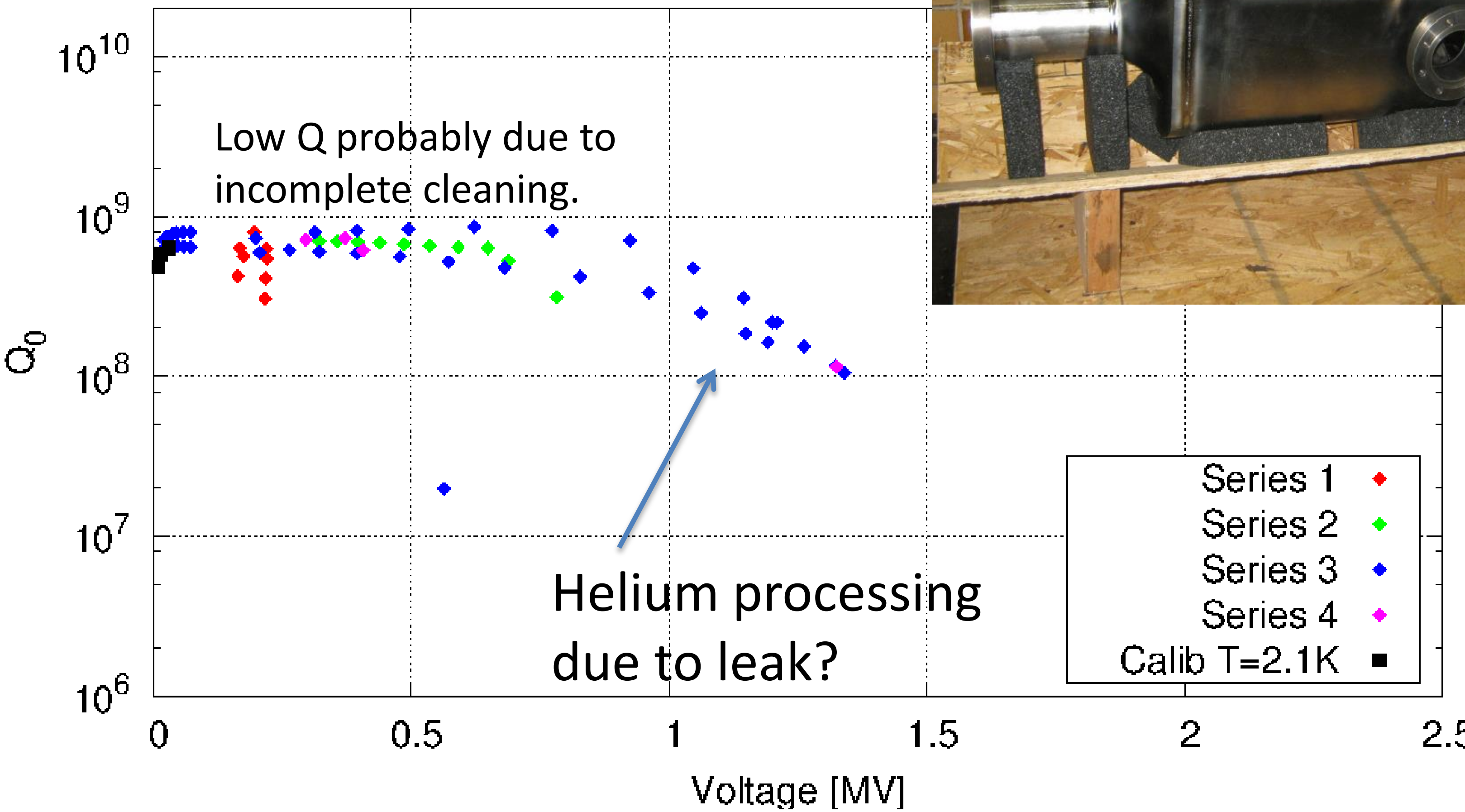
Test of 750 MHz Crabbing Cavity





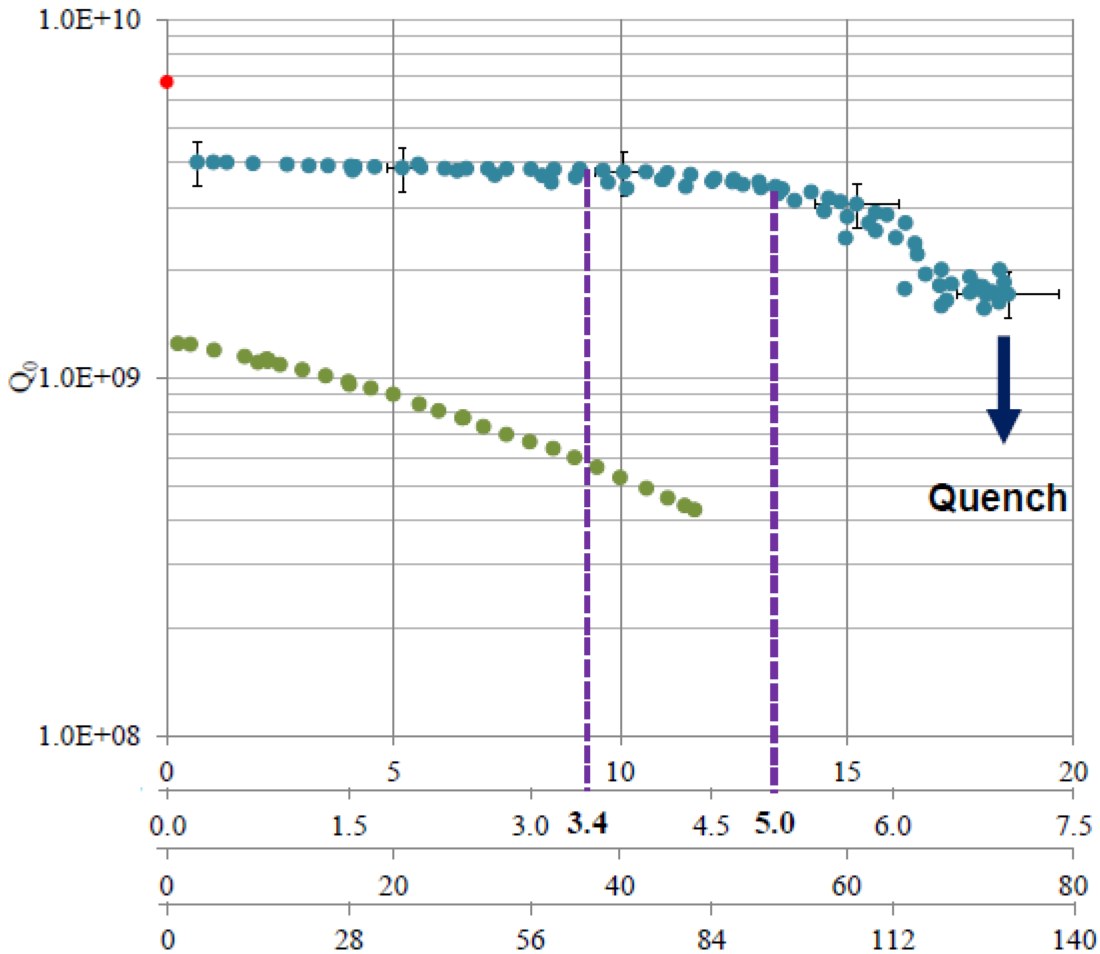
- Collaboration between ODU and Niowave
  - Crabbing system for electron-ion collider
- Test results
  - successfully cooled with liquid He to the superconducting transition in ~2.5 hours (quickly through Q disease danger zone)
  - low-field cavity Q observed at 2-3×10^8 (theoretical 5.5×10^8)
  - able to put ~10 W into the cavity fields before reaching first significant multipacting barrier
  - able to condition the cavity up to 50 W forward power before halting the test due to radiation
  - no hard limits to cavity performance observed (no cavity quench)

1st test results



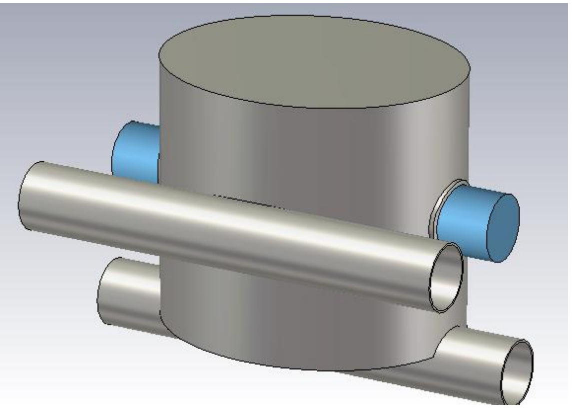
The first high field tests were with the 4R crab cavity, but this was limited by a severe vacuum leak.

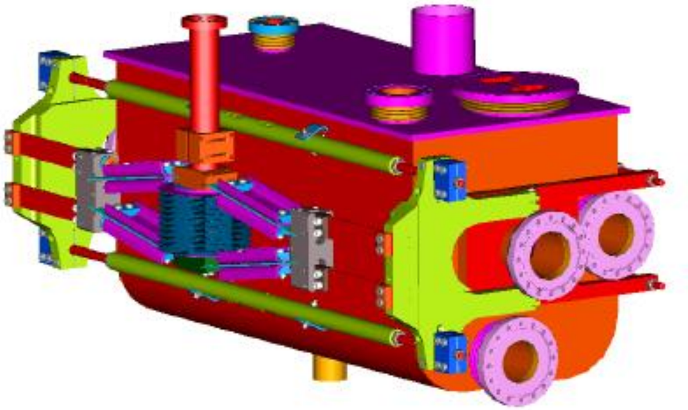
2 K Test Results

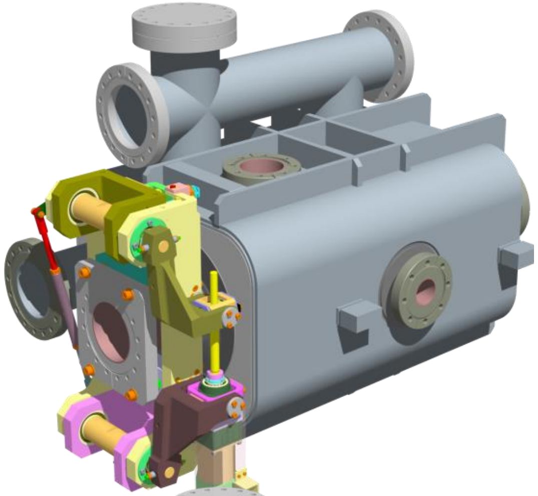


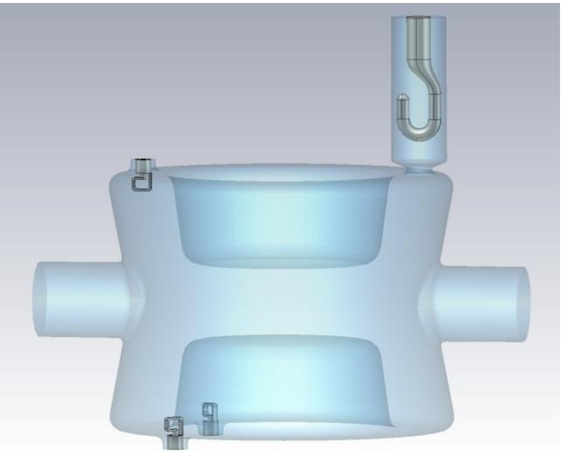
- Expected $Q_0 = 6.7\times10^9$
  - At R_S = 22 nΩ
  - And R_{res} = 20 nΩ
- Achieved $Q_0 = 4.0\times10^9$
- Achieved fields
  - E_T = 18.6 MV/m
  - V_T = 7.0 MV

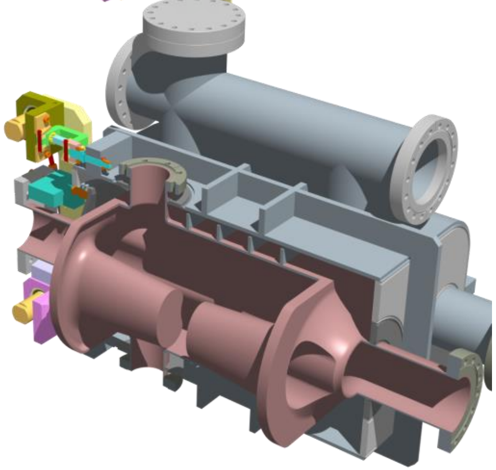
He Jacket Design

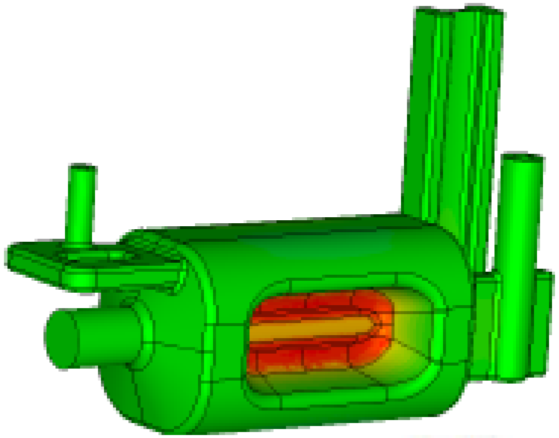




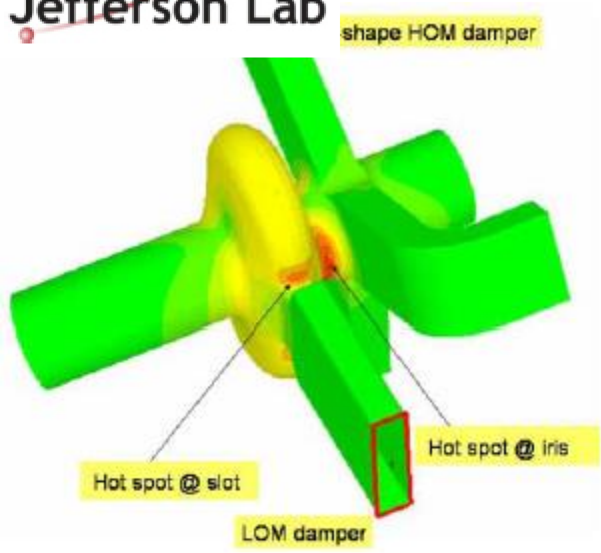






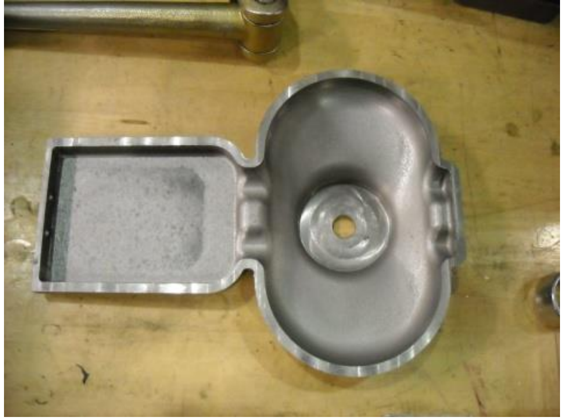


Jefferson Lab

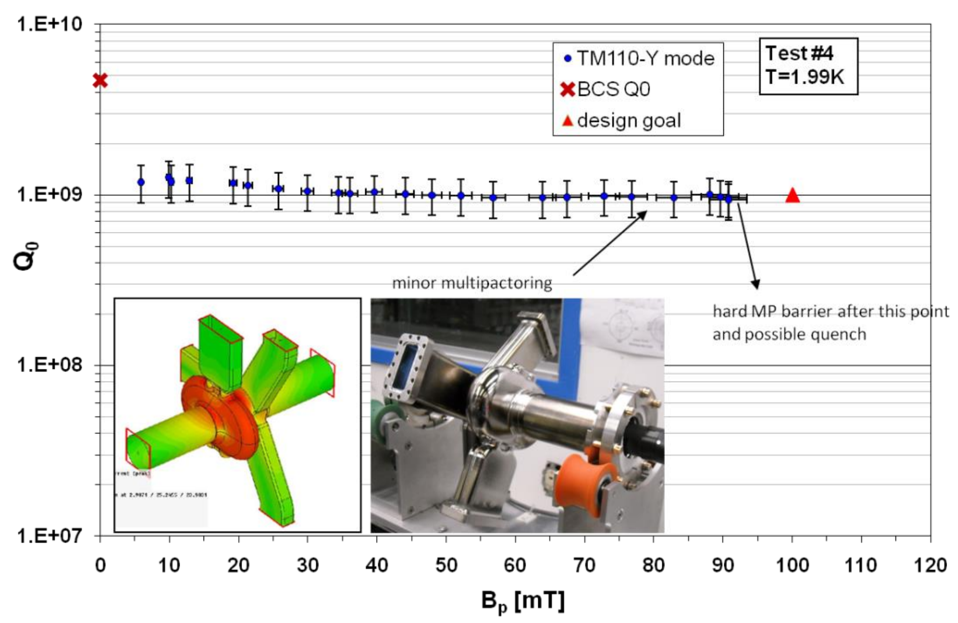


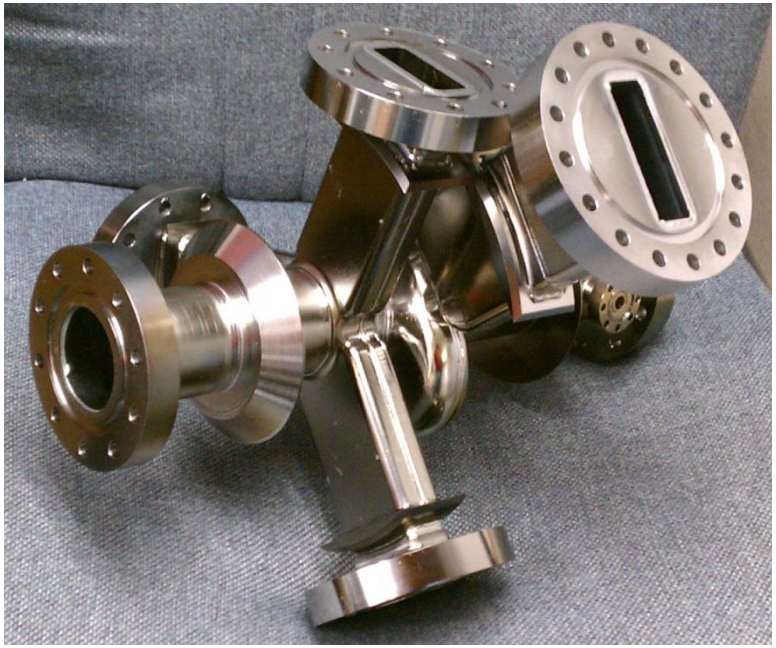
SPX Cavity

- Another novel crab cavity is the SPX crab.
- This uses on-cell coupling to strongly damp the fundamental monopole mode.

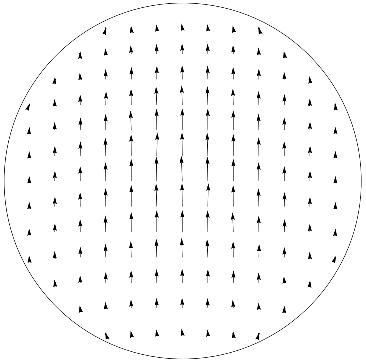


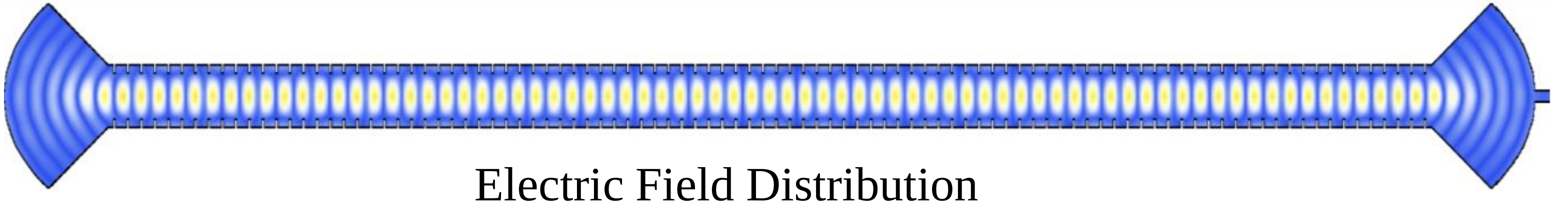
"Alternate" Prototype Crab Cavity (CC-A2 for SPX Project) Vertical Test at JLab





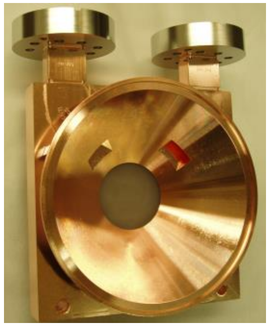
Microwave Undulators

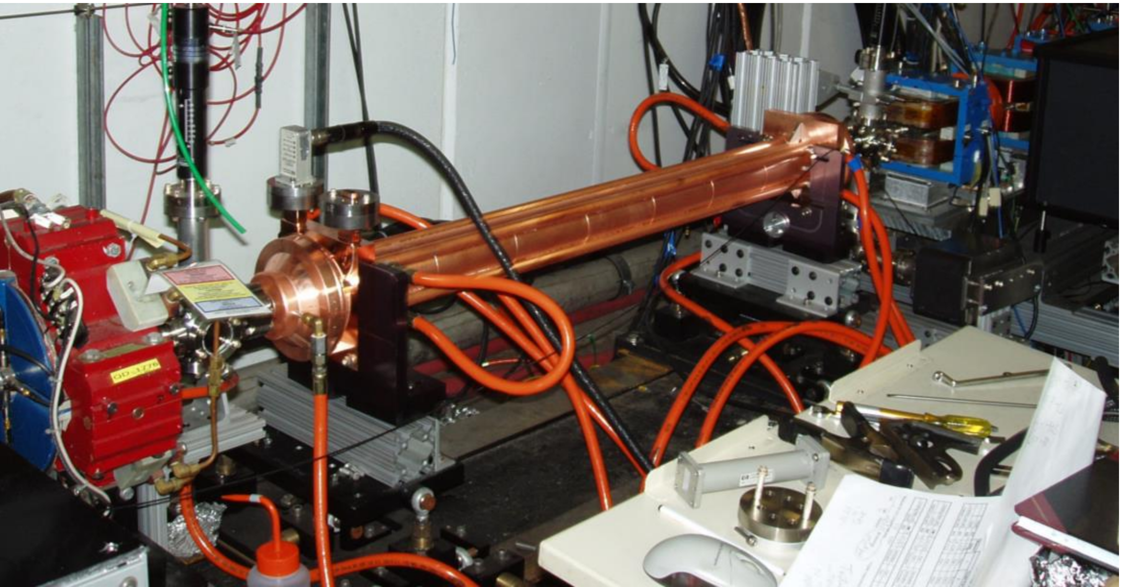


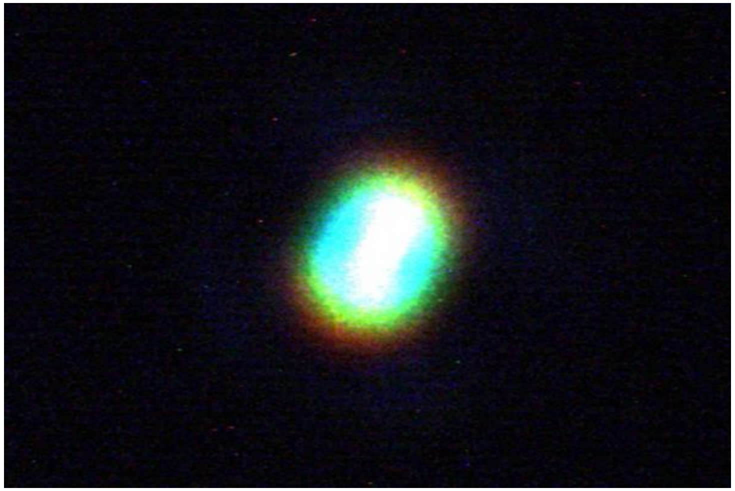


Electric Field Distribution

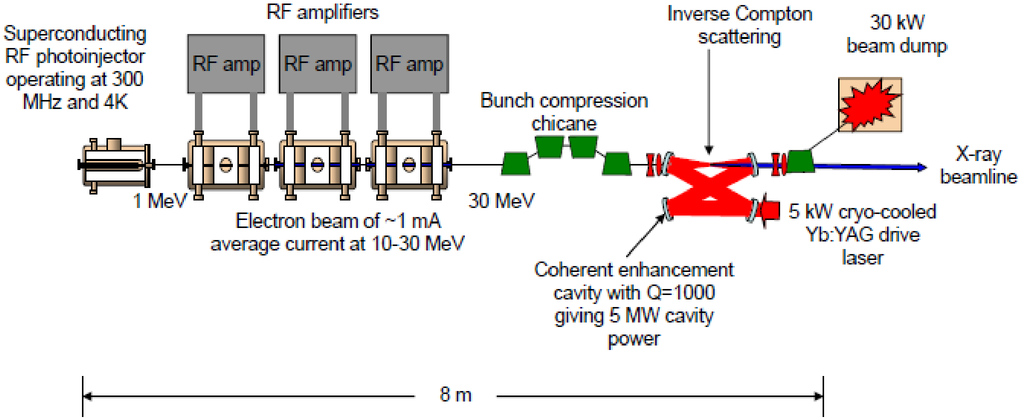
- Another RF device using dipole fields is the Microwave Undulator.
- These use the transverse fields to wiggle the electron beam.
- The advantage is a small period and dynamically variable polarisation.



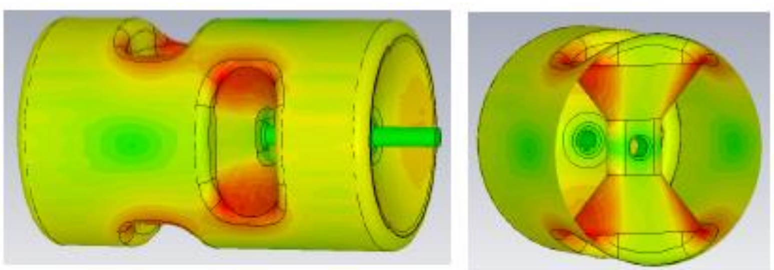




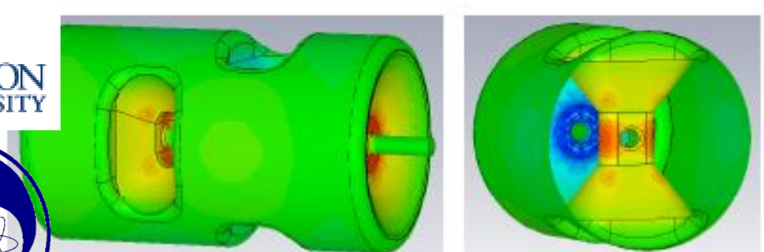
High Beta Spoke Cavities



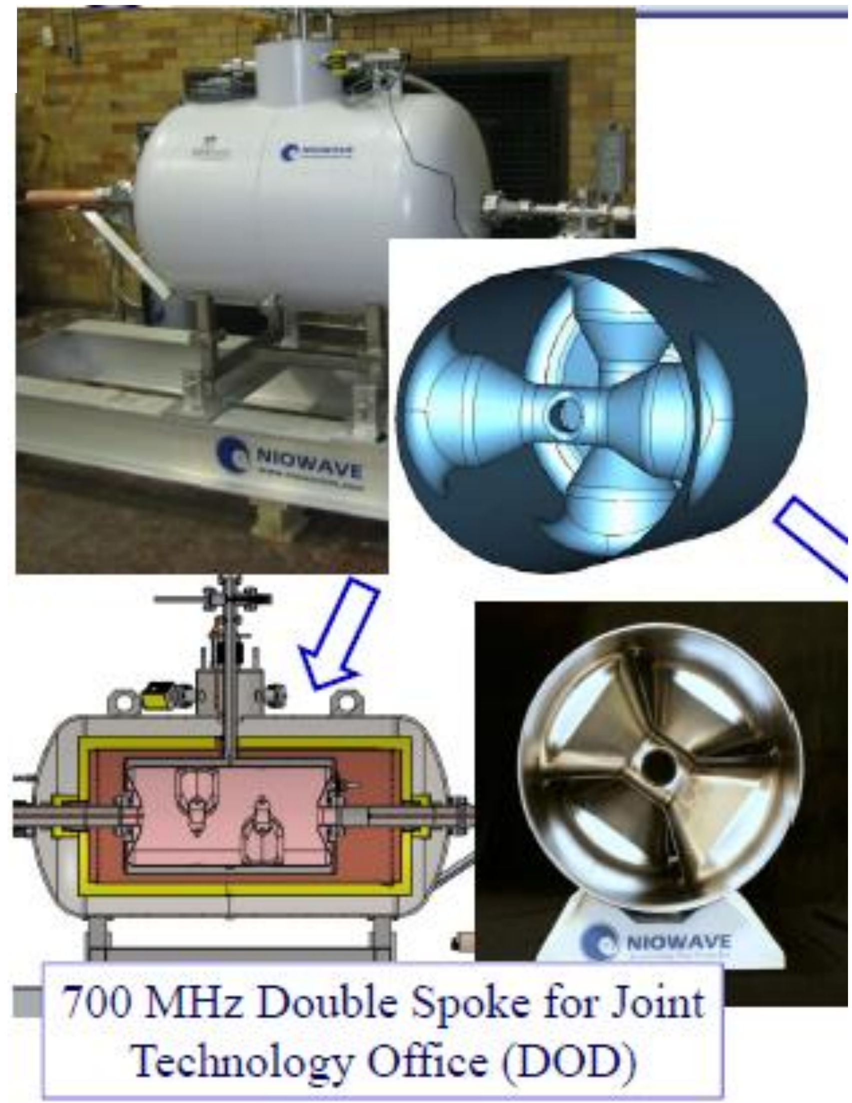
Spokes are traditionally used for medium beta but ODU propose a spoke for β=1 electrons. The cavity has a high Q at low frequency while having the same size as an L-band cavity.



Peak surface magnetic field



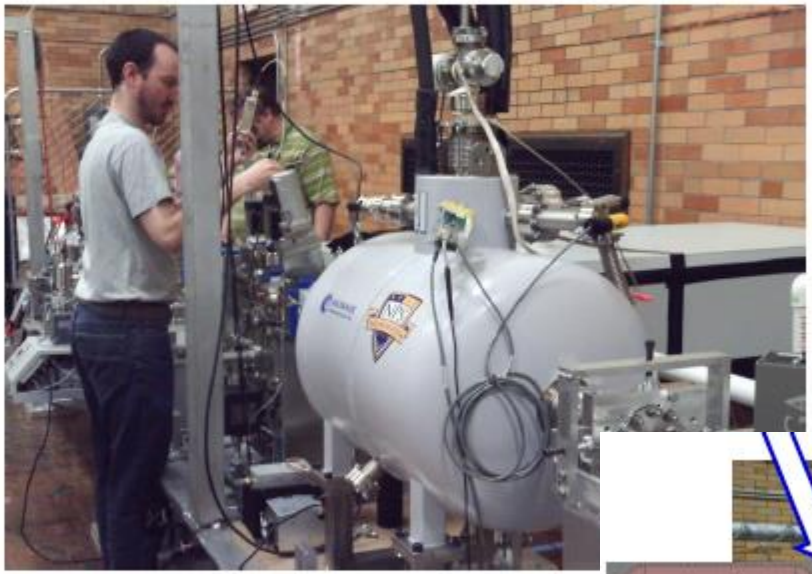
Peak surface electric field

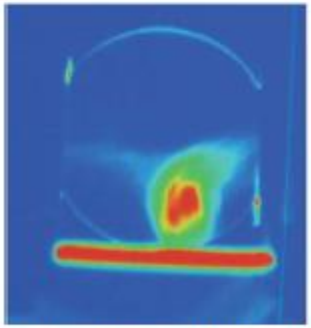


Old Dominion University

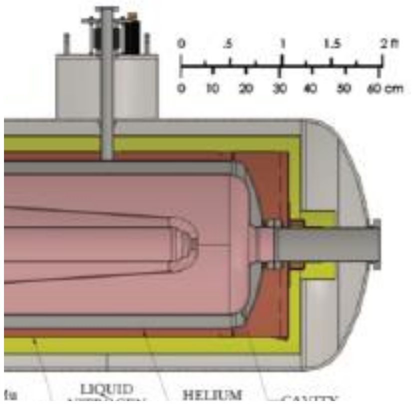
QW Electron Guns

- BNL, Niowave, NPS, Univ. Wisconsin are proposing quarter wave SRF guns. The low frequency allows long low space charge beams.

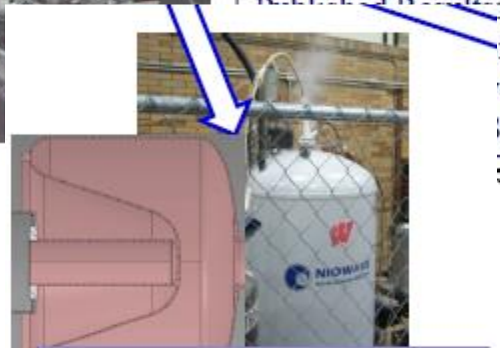




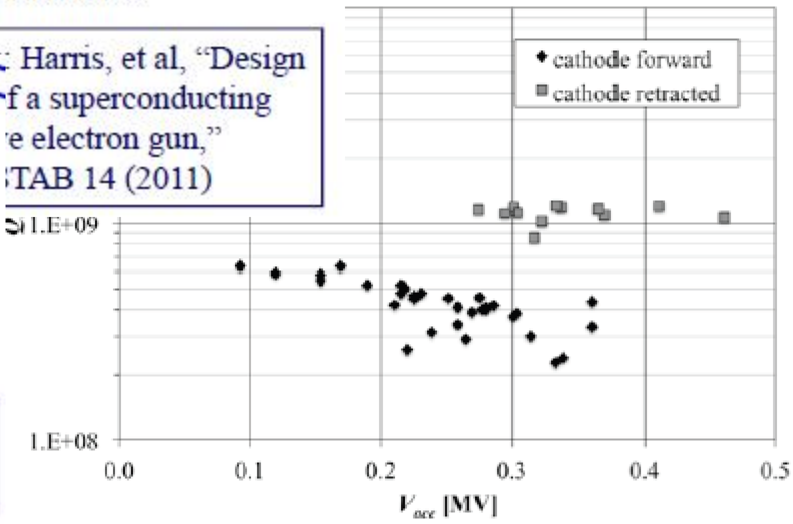
High brightness photoelectron beam image on YAG scintillator.



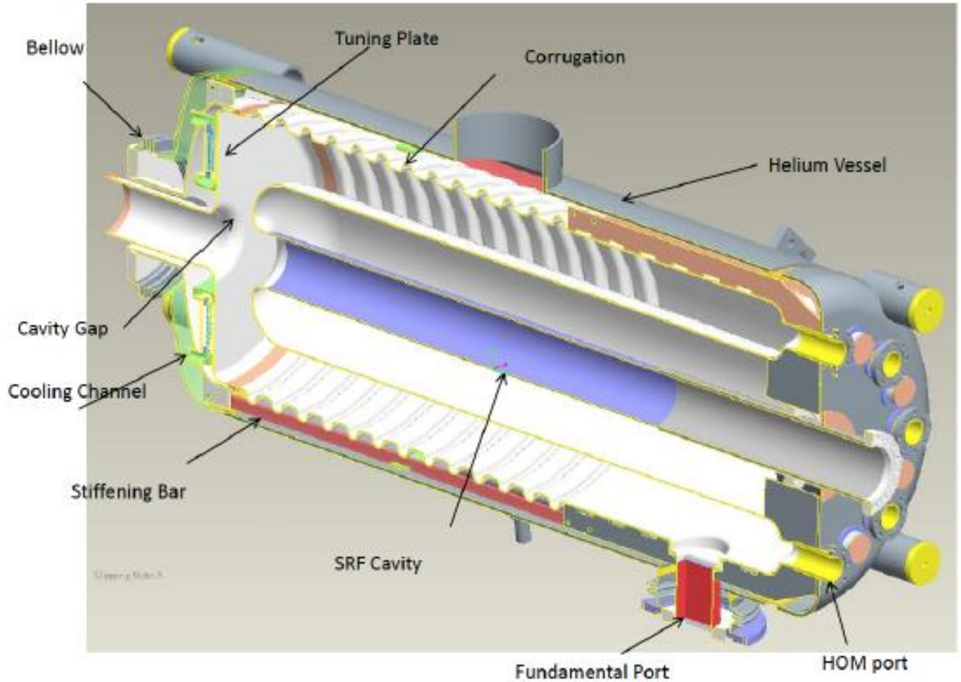
Harris, et al, "Design ...f a superconducting ...e electron gun," ...TAB 14 (2011)

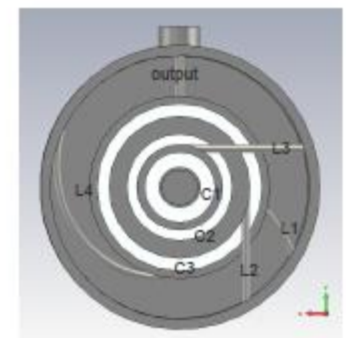


Univ. of Wisconsin FEL electron gun



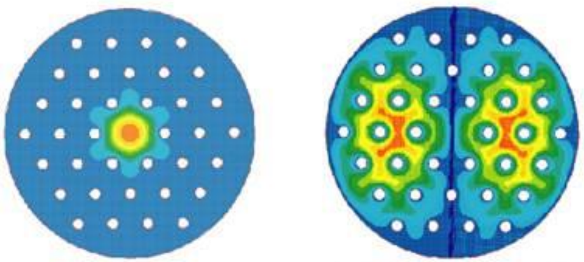
56 MHz cavity





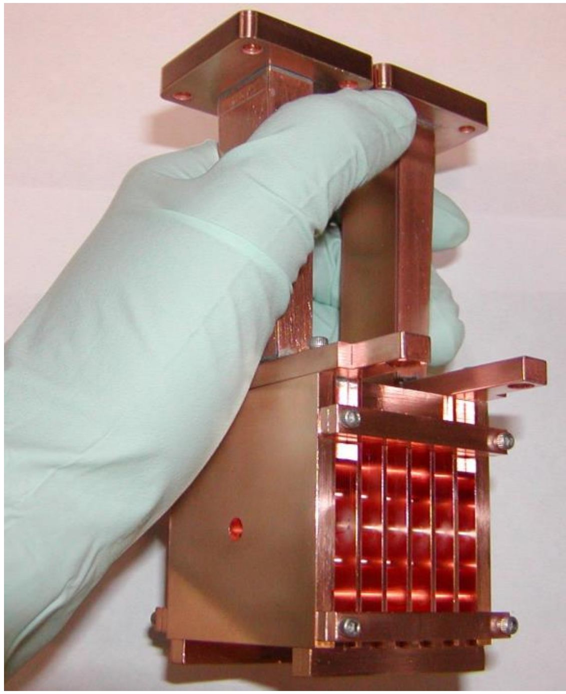
- BNL are developing a 56 MHz quarter wave cavity to provide longer RF buckets in RHIC. The very low frequency SRF system is quite uncommon, and the quarter wave is in the longitudinal direction to reduce transverse size.
- It also includes a novel Chebyeshev filter on the HOM coupler.

Photonic Bandgap

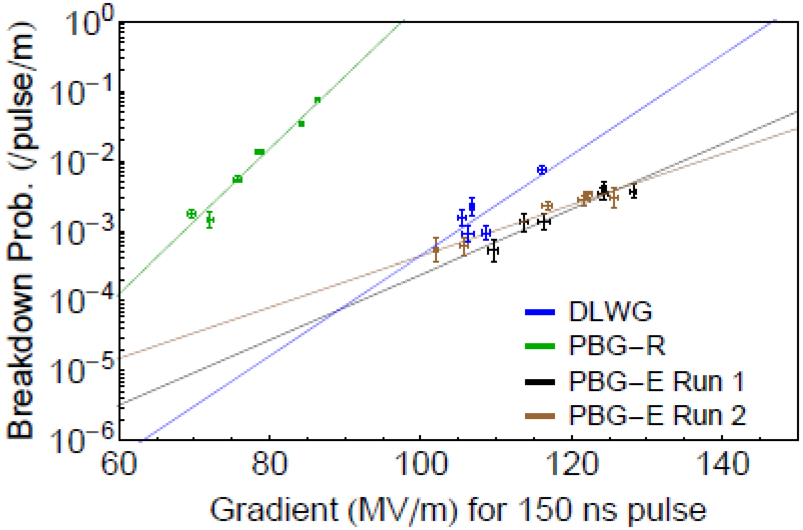


TM$_{01}$ TM$_{11}$, not confined

a/b = 0.15, one mode confined

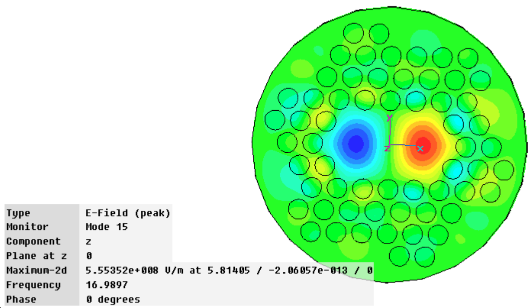


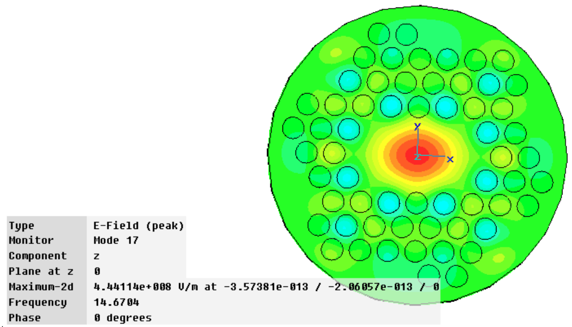
- Photonic bandgaps offer the possibility of confining only a few modes in the cavity.
- MIT have been working towards PBG's with similar performance to normal cavities.

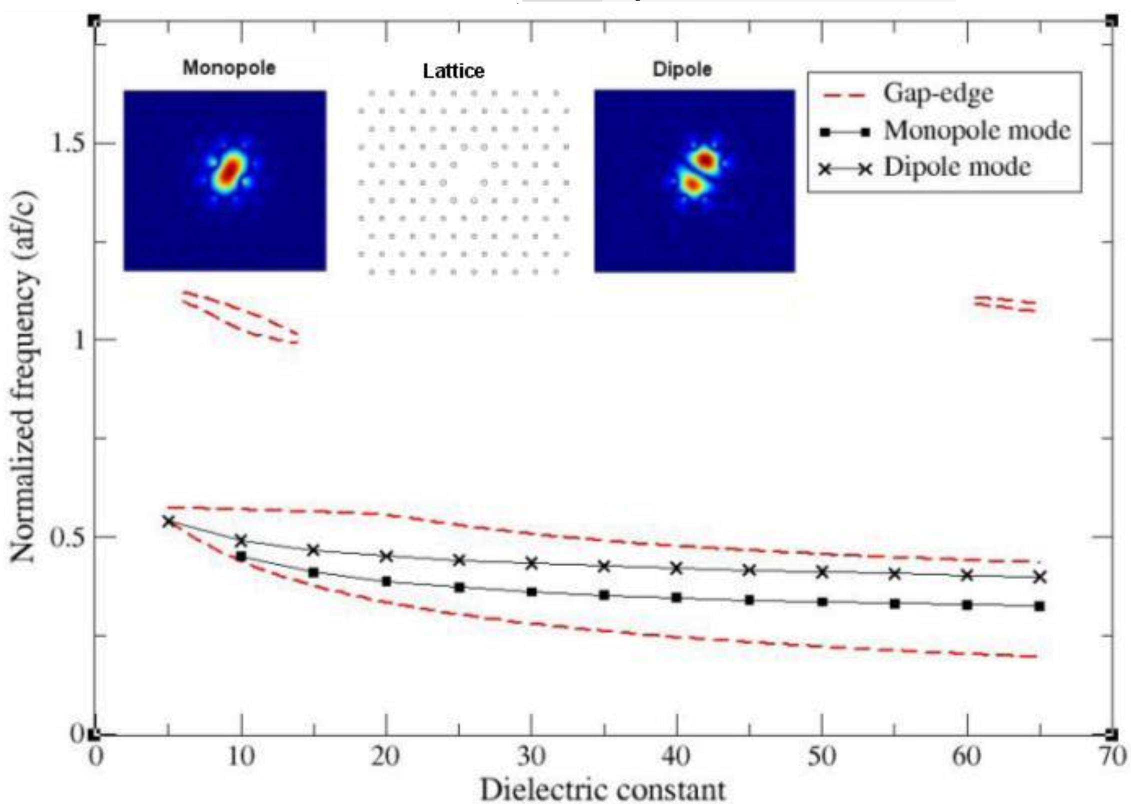


NATIONAL ACCELERATOR LABORATORY

PBG crab cavities





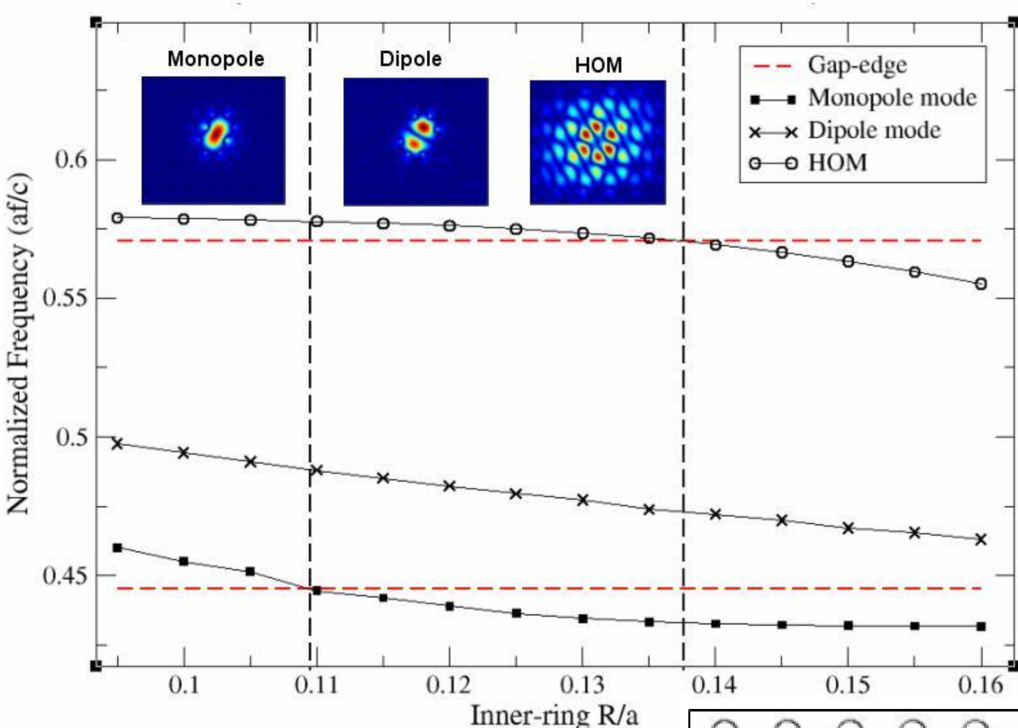


A PBG dipole cavity would allow the construction of a crab cavity with no trapped higher order modes.

However, one must be careful not to trap other modes in the band-gap as well.

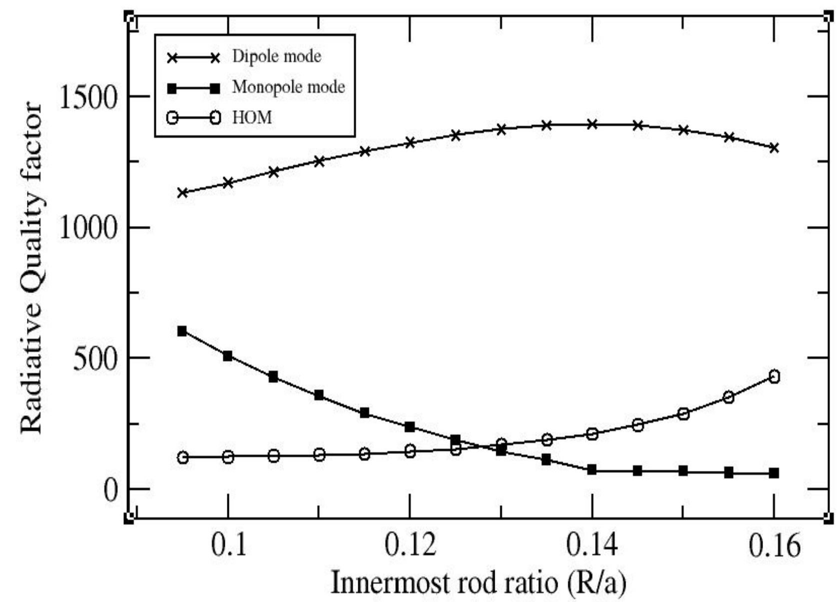
Lancaster and Huddersfield

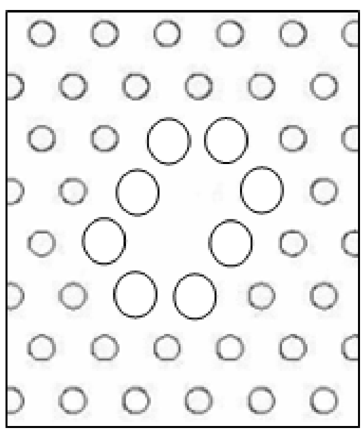
PBG Crab Cavities



A solution was found, where the rods around the defect (two missing rods) where enlarged.

This pushes the modal frequencies down allowing the monopole to be pushed out of the bandgap.

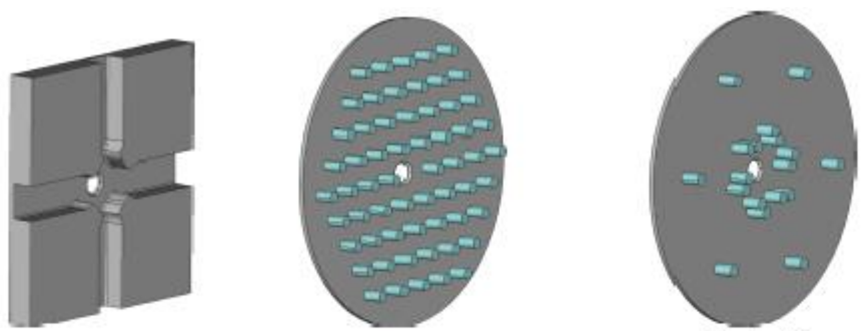




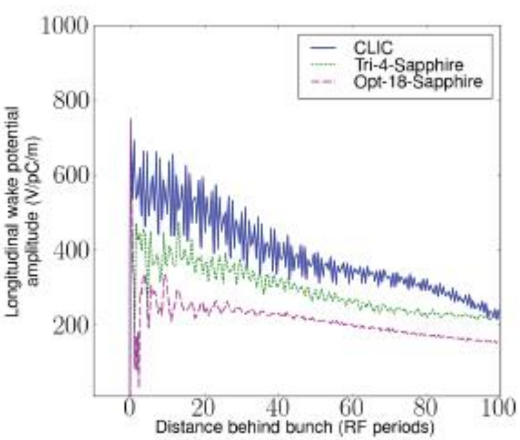
Lancaster and Huddersfield

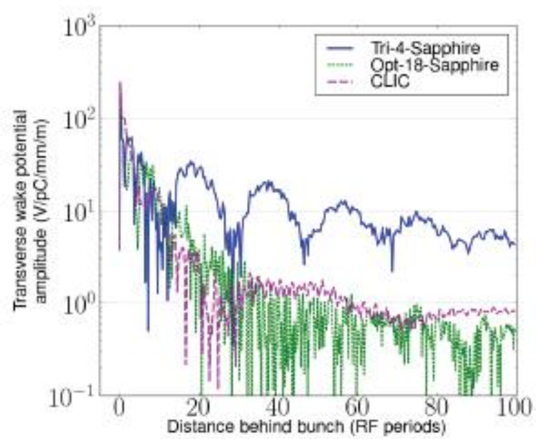
Irregular crystal cavities

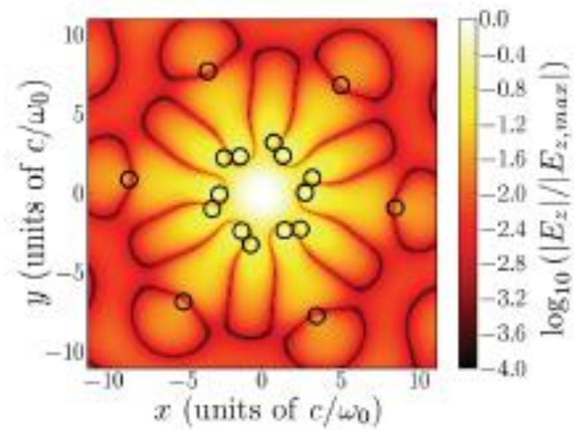
- Colorado U. and TechX used computation optimisation to find the best lattice and the results were quite surprising.

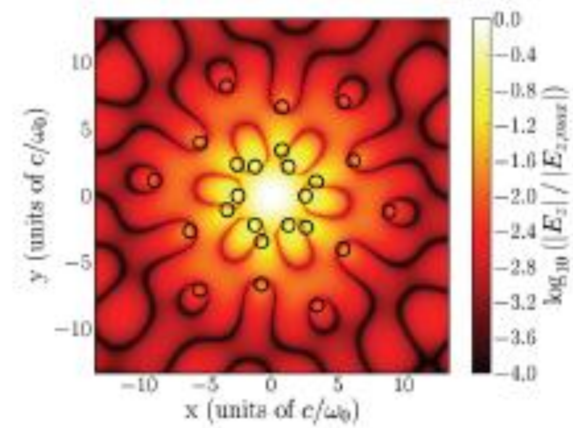


CLIC Tri-4 Opt-18

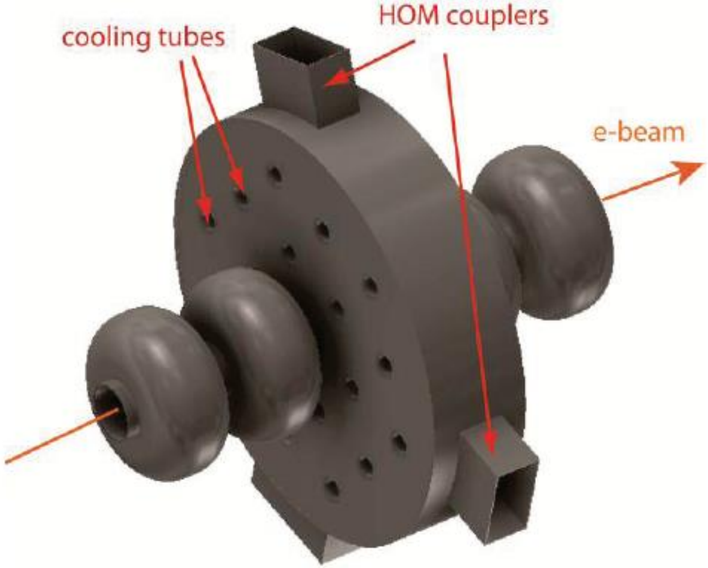






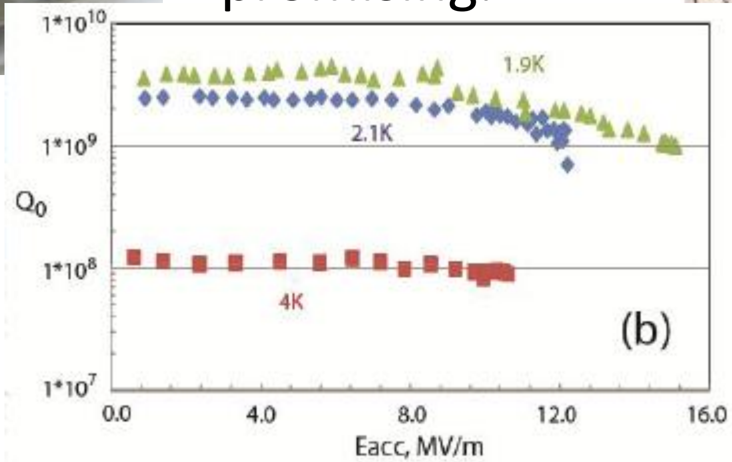


SRF PBG



Los Alamos have been looking at using an SRF PBG as a HOM damper.

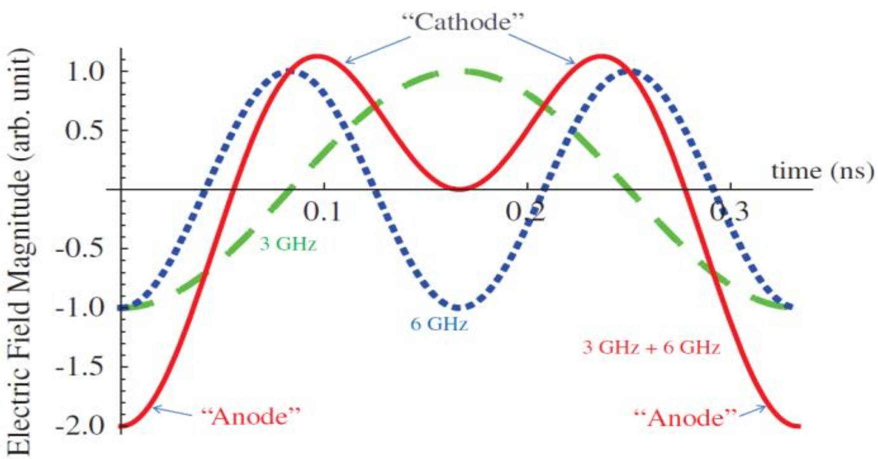
Vertical test results look promising.



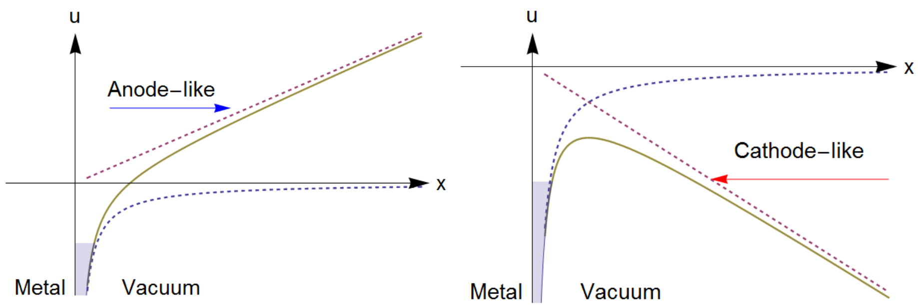
Motivation: Multi-Harmonic to Increase Breakdown Threshold

Superimposing harmonically-related modes

- may yield RF electric fields that point into metallic cavity surfaces to be always smaller than fields that point away from the surfaces



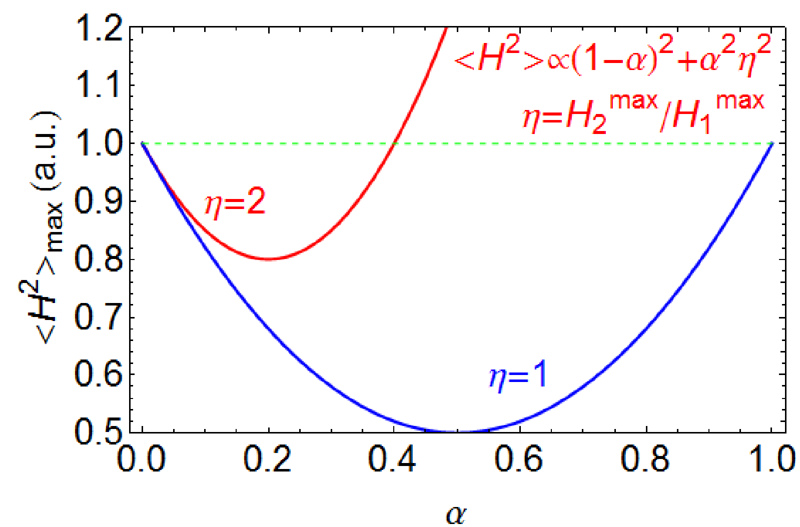
Potential energy **u** of an electron near the surface of a metal with **x** the distance of electron from surface.



- may lower the pulsed surface heating. By superimposing two modes $\tilde{H} = (1-\alpha)\tilde{H}_1 + \alpha\tilde{H}_2$

$$\Delta T \propto \langle \tilde{H}^2 \rangle = \langle \tilde{H}_1^2 \rangle \left[(1-\alpha)^2 + \alpha^2 \langle \tilde{H}_2^2 \rangle / \langle \tilde{H}_1^2 \rangle \right] < \langle \tilde{H}_1^2 \rangle$$

(Ideal pillbox $\eta = H_2^{max}/H_1^{max} = 2$)



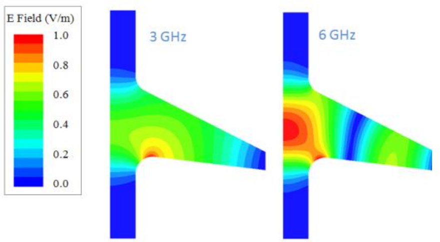
Y. Jiang, L.R. Carver, R. M. Jones & J.L. Hirshfield

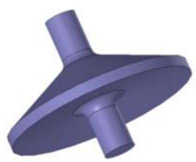
Multi-Harmonic Cavity

TM020 Type MHC:

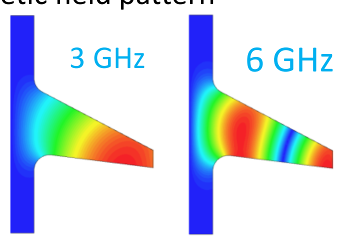
- Superposition of TM_{010} and its 2nd - harmonic TM_{020}
- Longitudinal non-symmetric
- Anode-Cathode effect featured, peak accelerating field can be close to or even higher than the breakdown threshold

Electric field pattern





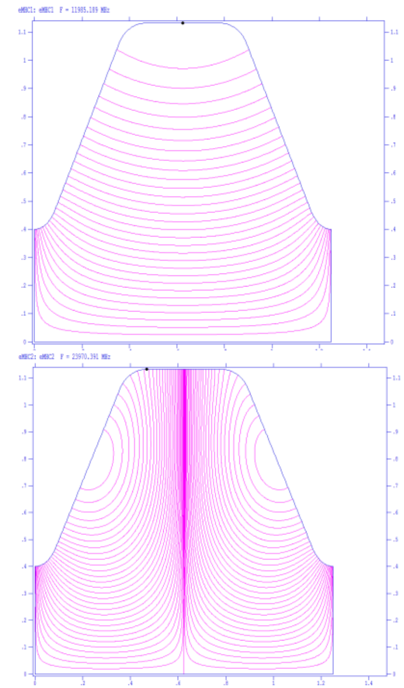
Magnetic field pattern



Asymmetric Bimodal Accelerator Cavity for Raising rf Breakdown Thresholds, S.V. Kuzikov, S.Yu. Kazakov, Y. Jiang, and J. L. Hirshfield, PRL 104, 214801 (2010)

TM011 Type MHC:

- Superposition of TM_{010} and its 2nd - harmonic TM_{011}
- Elliptical cavity to lower the surface magnetic field
- Pulsed heating temperature rise 20% less than single mode only with the same acceleration gradient



Y. Jiang, L.R. Carver, R. M. Jones & J.L. Hirshfield