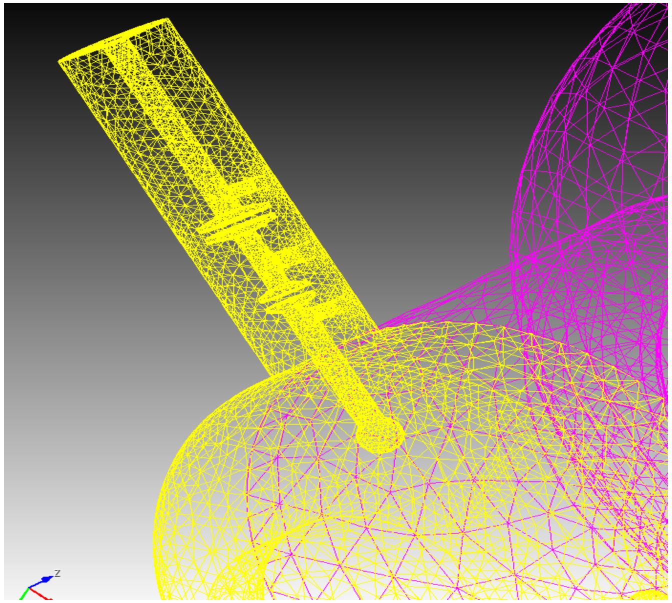
Progress on the 704 MHz High-Current Cavity BNL3

Presented at

SLHiPP-2 meeting



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Stony Brook University, Brookhaven National Laboratory, CERN and Advanced Energy Systems

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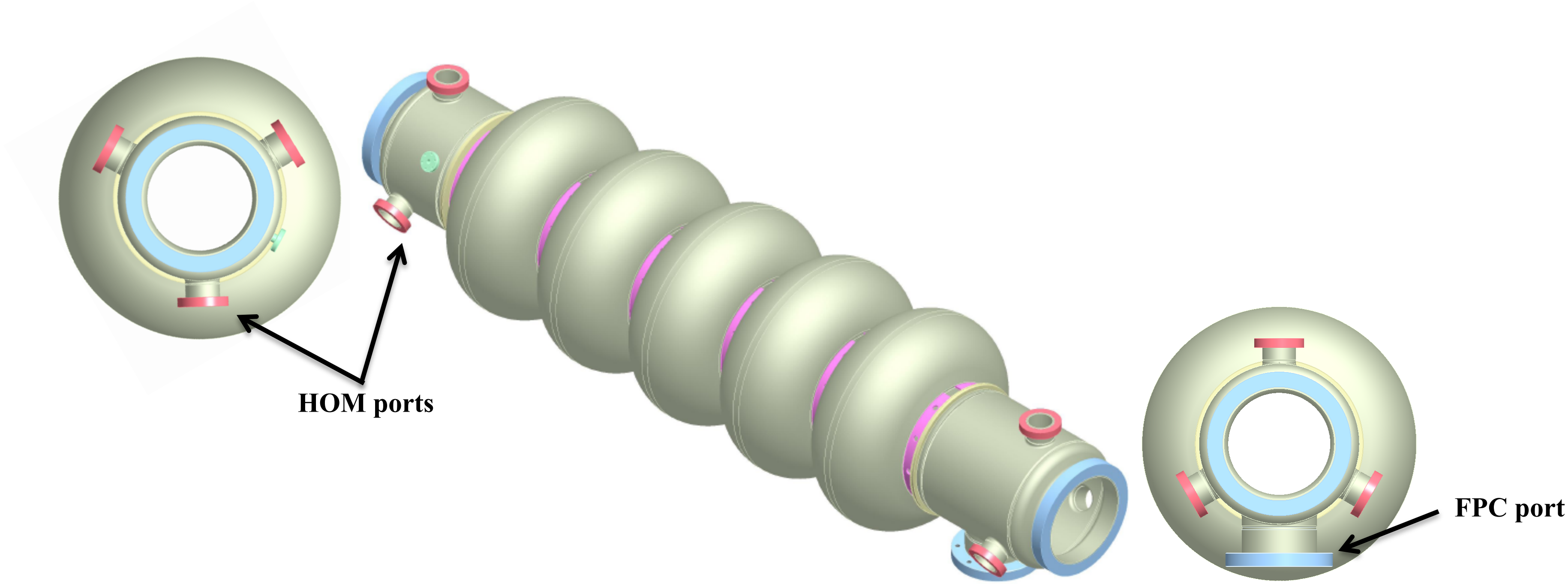
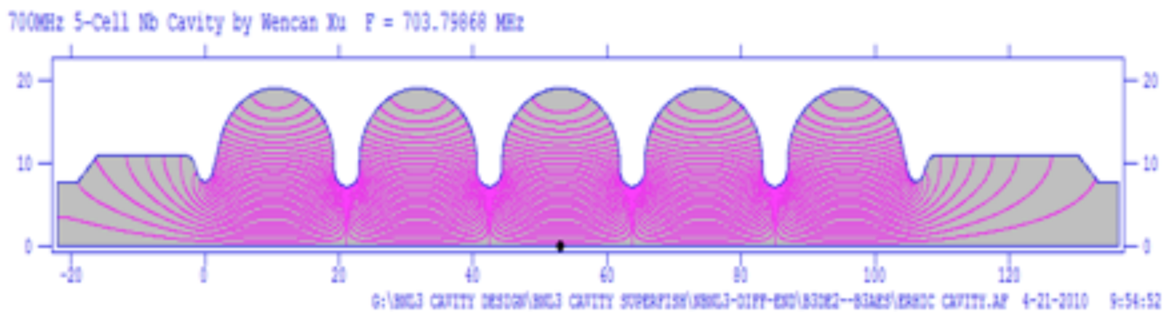
Motivation for this project

- Develop a high-current cavity with good SRF and acceleration performance and superb HOM damping.
- We like to think of this as a universal cavity at 704 MHz, capable of accelerating efficiently electrons and protons at high β under conditions where HOMs are of concern.
- We built a similar cavity, called the BNL1 cavity, which has been tested repeatedly and which has a well known performance.
- The current cavity, BNL3, builds upon this experience and improves upon it.

Five-cell SRF cavity with strong HOM damping



RF performance of BNL3



Parameters	BNL1	BNL3
Frequency [MHz]	703.5	703.8
Coupling factor [%]	3.00	3.02
Geometry Factor	225	283
R/Q [Ohm]	404.0	506.3
E_{pk}/E_{acc}	1.97	2.46
B_{pk}/E_{acc} [mT/MV/m]	5.78	4.26
Length [cm]	152	158
Beam pipe radius [mm]	120	110

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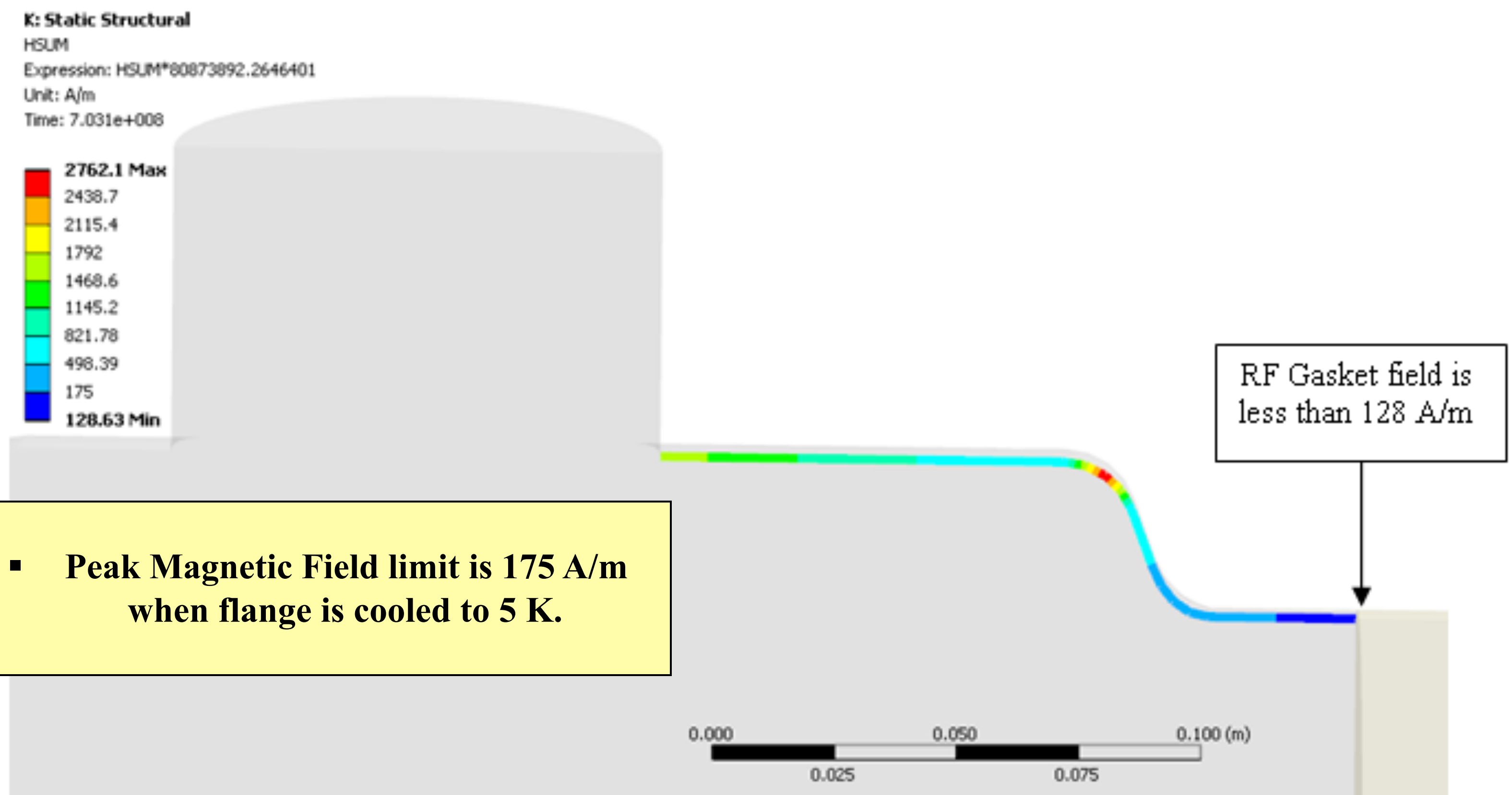
Magnetic fields near FPC end flange



- **Peak Magnetic Field limit is 175 A/m when flange is cooled to 5 K.**

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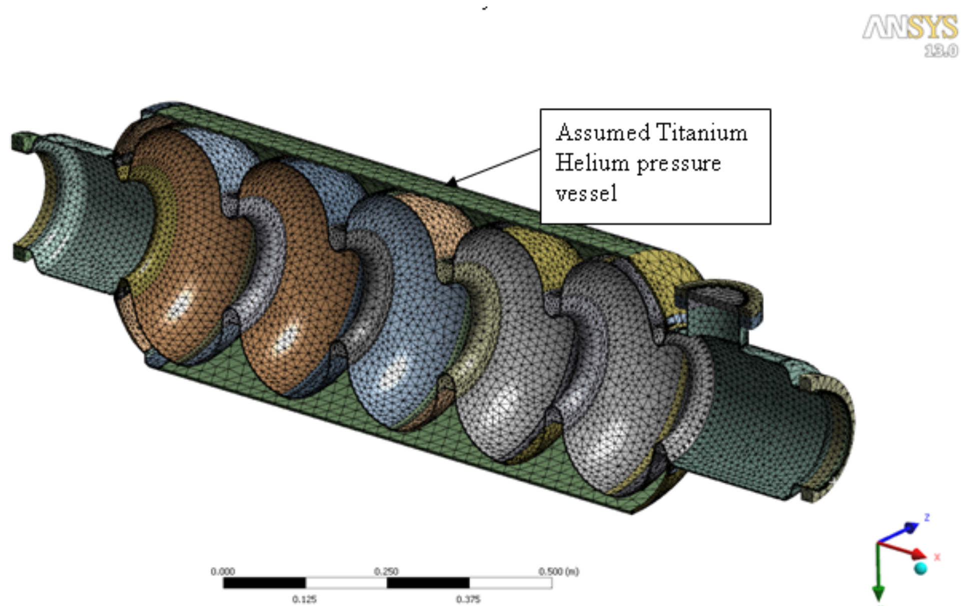
Mechanical performance of BNL3

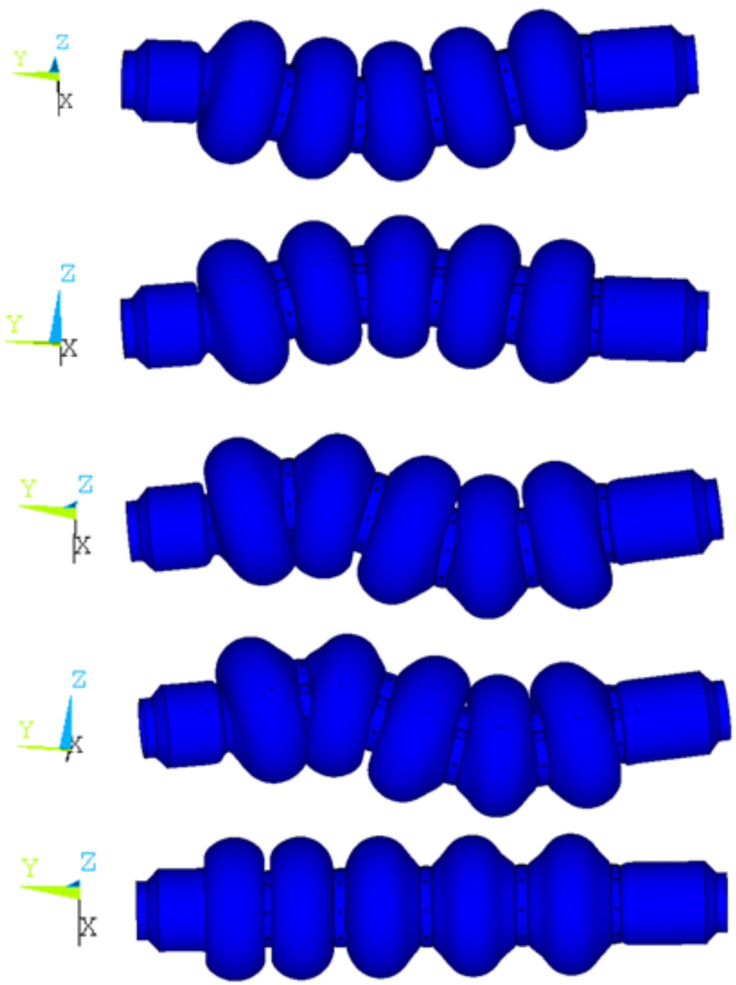
Frequency Effect [2 K]	Frequency sensitivity
Tuner [kHz/in.]	4000
Lorentz detuning coefficient, k [Hz/(MV/m)^2]	1.36
Helium pressure sensitivity [Hz/mbar]	26

Condition	Δf [kHz]
BCP, 0.007'' material removal	-511.755
Cool down to 2 K	998.433
Lorentz force (CW Operation)	-0.84375
Helium pressure 0.4596 psi (31.68 mbar) at 2K	0.864
Baseline frequency shift from initial manufacturing to operation	486.69

- **At 2K the tuner range is 350 kHz with a maximum load of 2200 lbs. .**
- **The range depends on the maximum tuner load that can be generated.**



Cavity vibrational modes at 2 K



78.0 Hz

80.1 Hz

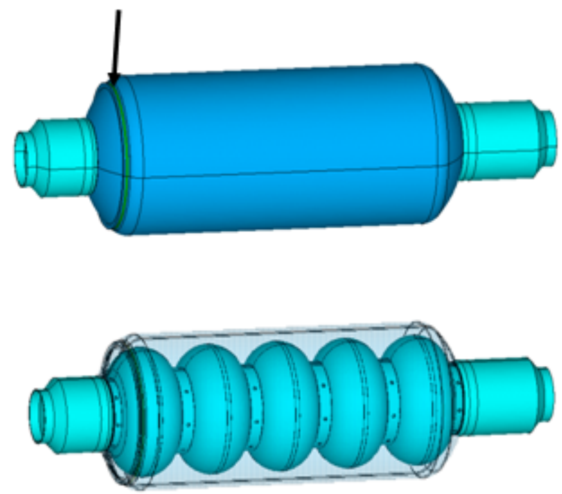
162.2 Hz

167.4 Hz

188.5 Hz

At 2K

Stiffener Radius of 10.45 cm



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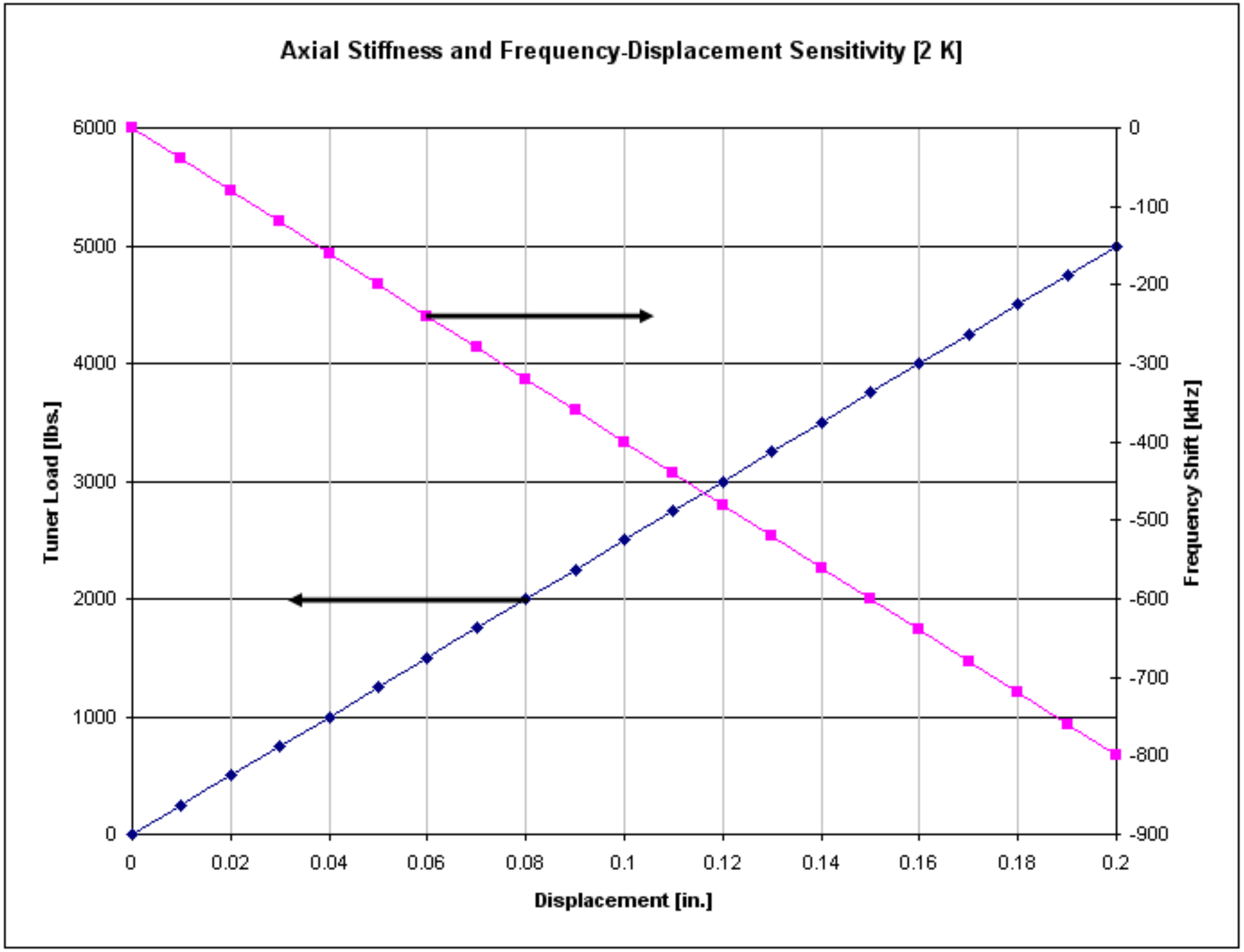
Cavity tunability



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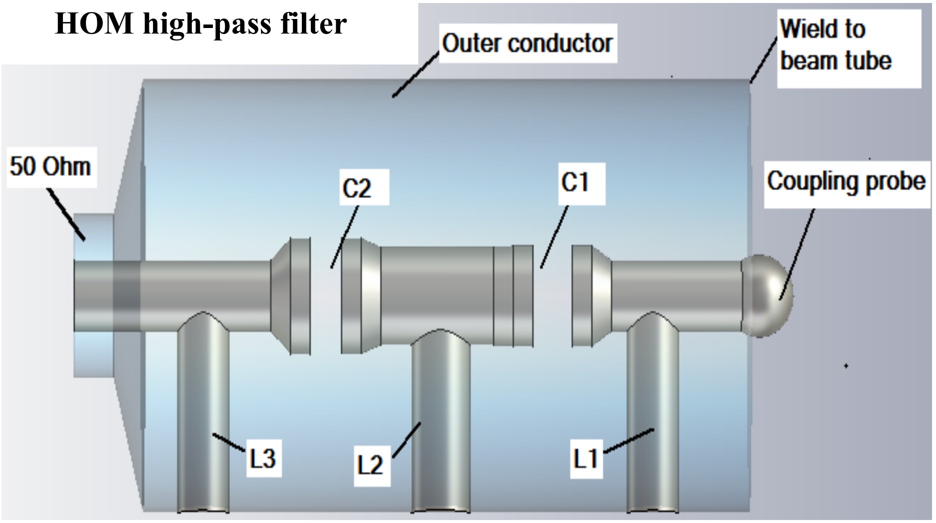
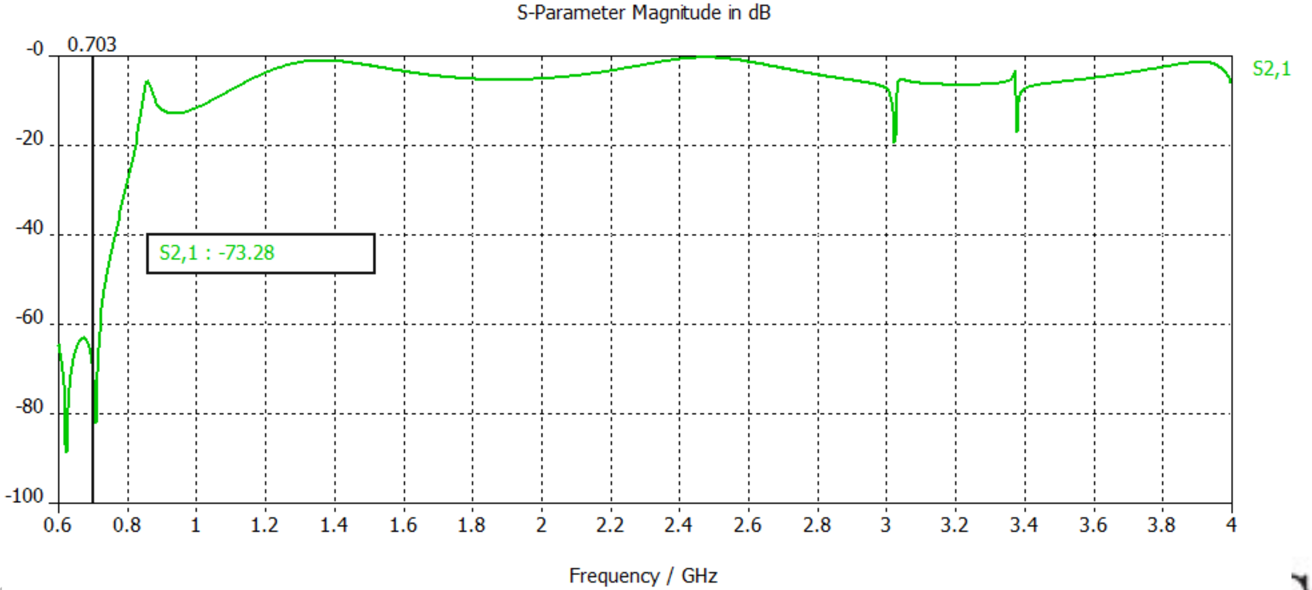
HOM damping with antenna-type couplers

- A two-stage high-pass filter rejects fundamental frequency, but allows propagation of HOMs toward an RF load.
  - 1st HOM is at 0.82 GHz.

HOM high-pass filter





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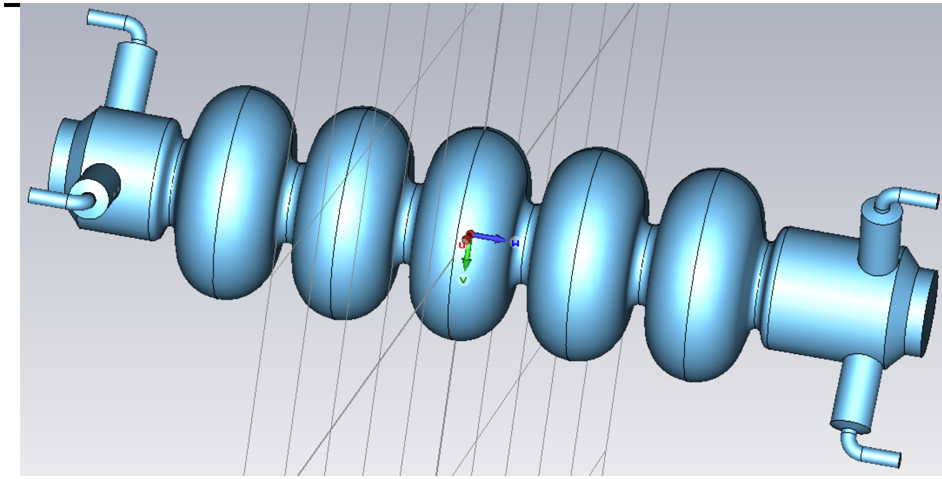
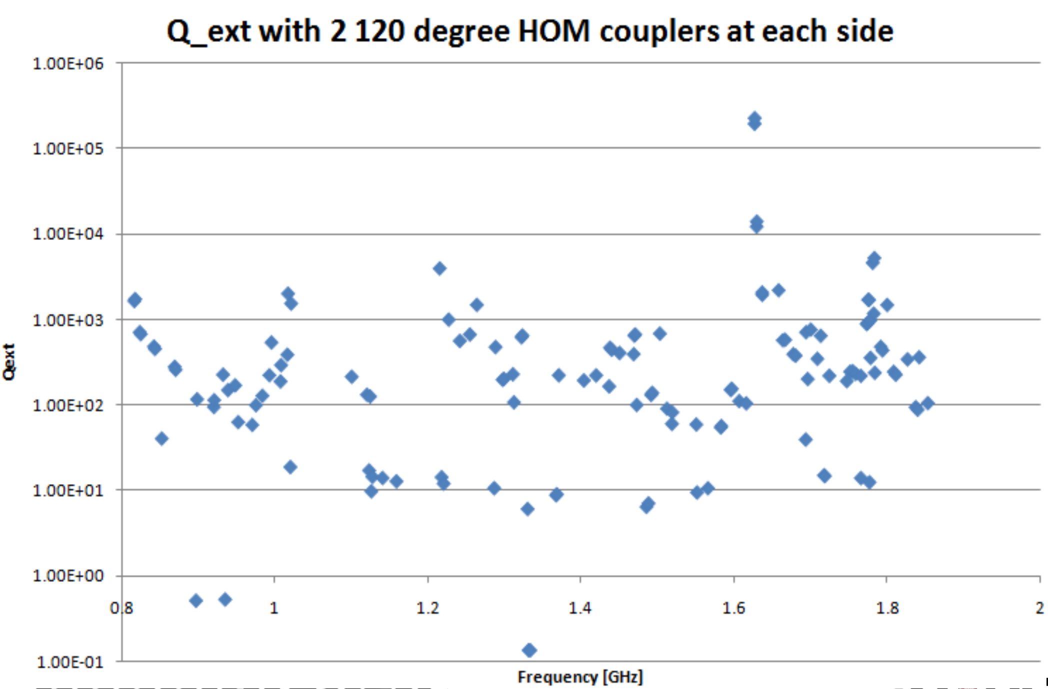
HOM damping





- Total HOM power to extract is 7.3 kW per cavity at eRHIC 3.5 nC, 50 mA, 6 passes up + 6 passes down energy (loss factor 3.5 V/pC).
  - Simulated a model with two HOM couplers per side using CST MWS.
    - Modes at 1.62 GHz have R/Q of ~0.1 Ohm.
- Q_{ext} required from BBU simulations for dipole modes is ~40,000.

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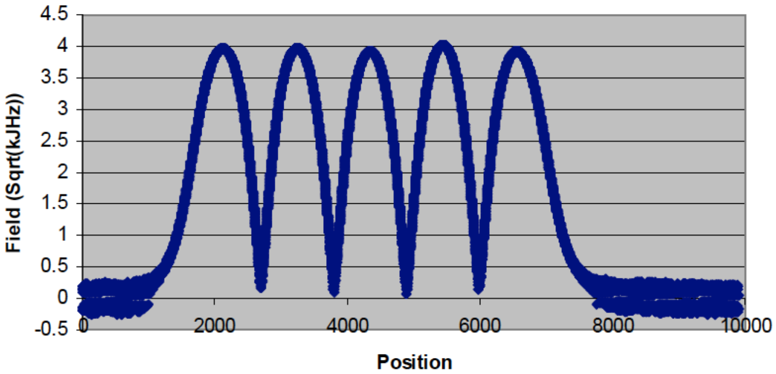
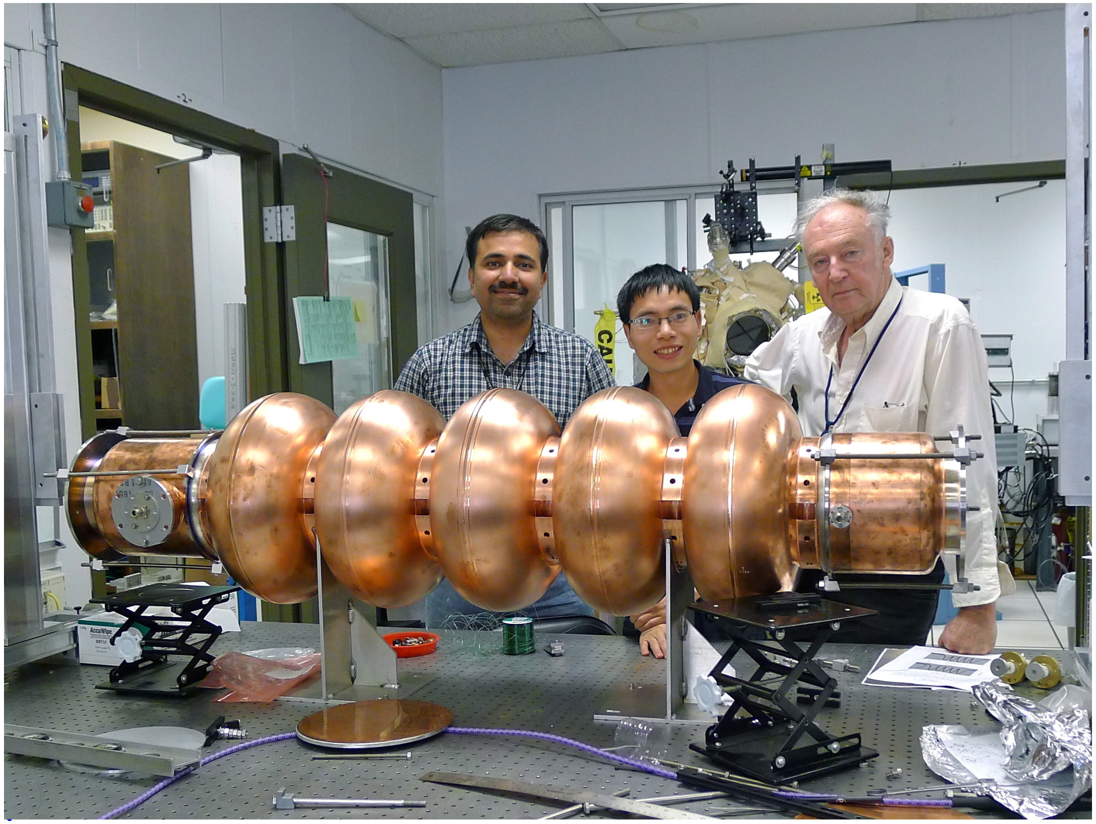
The copper cavity prototype





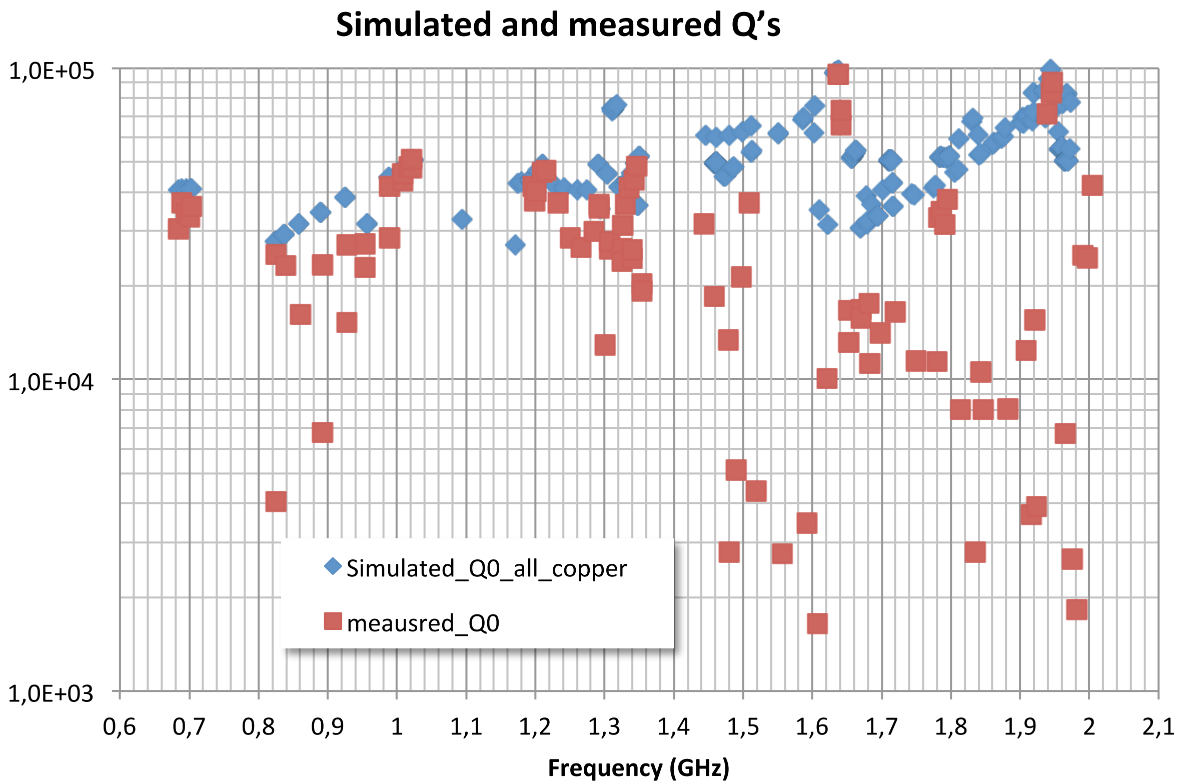
Cavity was fabricated by AES.

Tuned to specs (98.5% field flatness).

Acceptance measurements are finished.

Detailed HOM studies under way.

Q factors of Higher-Order-Modes



- The simulated *Q*'s agree reasonably well with the measured *Q*'s for most of the modes.
- As expected, the measured *Q*'s are a little lower than the simulated *Q*'s due to imperfect copper surface.
- The modes with relatively low *Q* are the splitting modes. As the -3 dB bandwidth method is used, *Q*'s for some of such modes can not be measured correctly. We plan to improve this by using a more elaborate resonance curve fitting algorithm.

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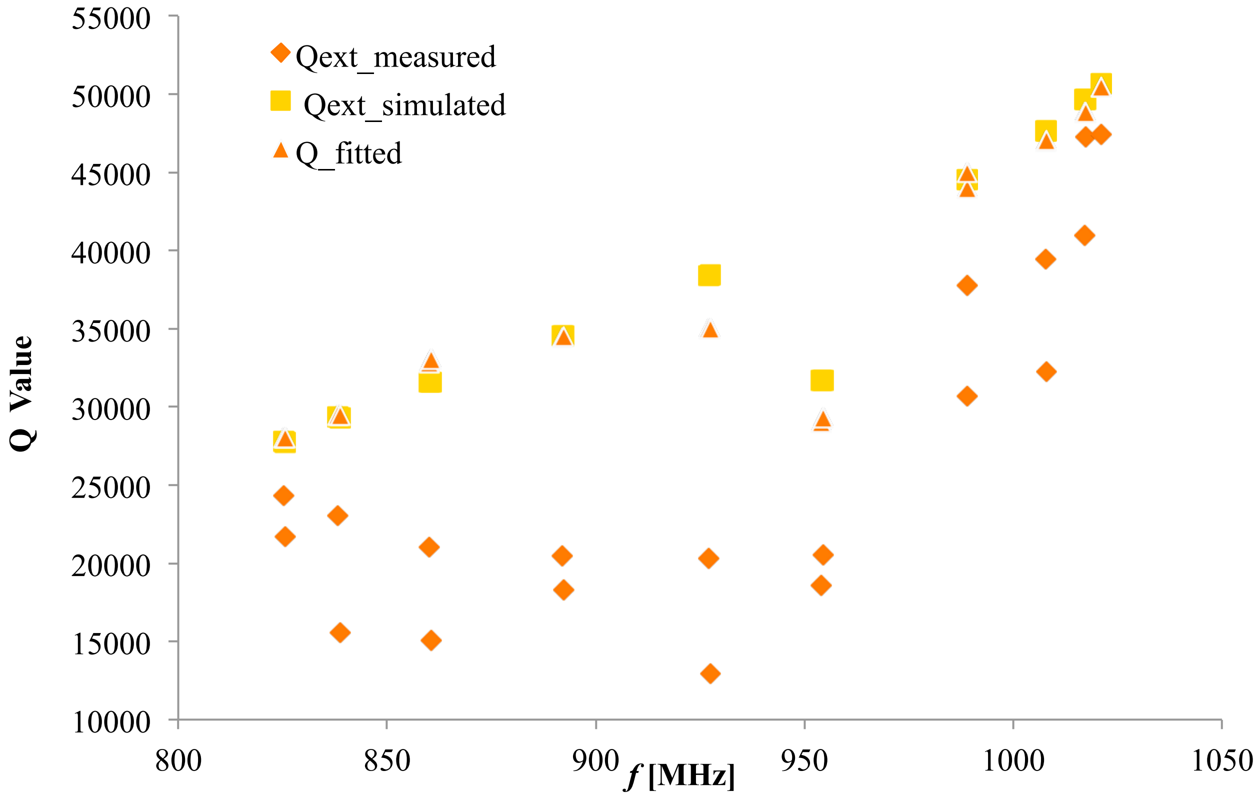
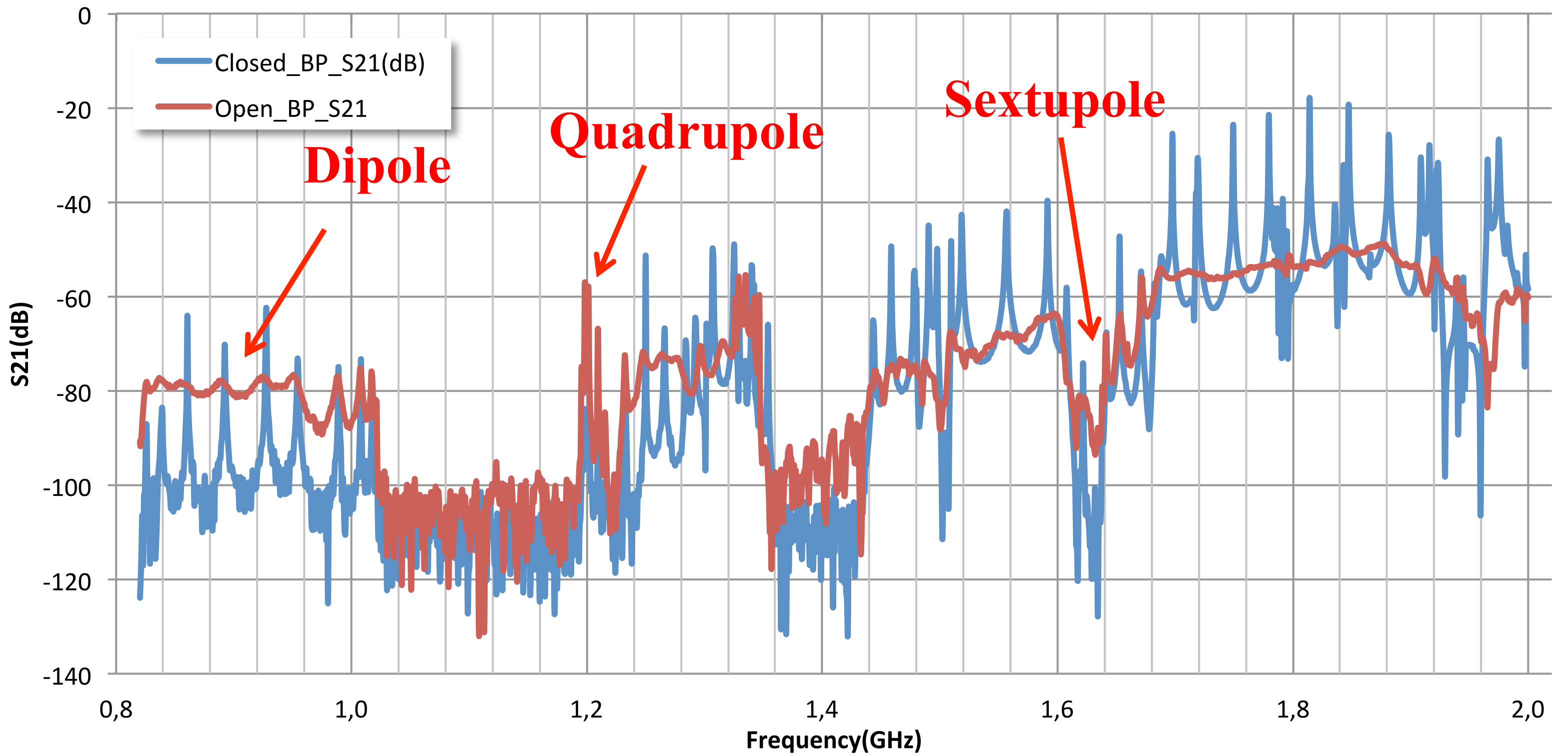
Improvement of Q measurements

By fitting nearly overlapping resonances a great improvement of the measured data can be achieved. Now the agreement with Microwave Studio is considerably better. (Wencan Xu, manuscript in preparation).



HOM Spectrum



- All dipole modes are damped extremely well with the open beam pipes.
- Two quadrupole modes around 1.21 GHz are distorted too much by the two different boundary conditions.
- Two sextupole modes at 1.63 GHz are trapped, as expected from simulations.

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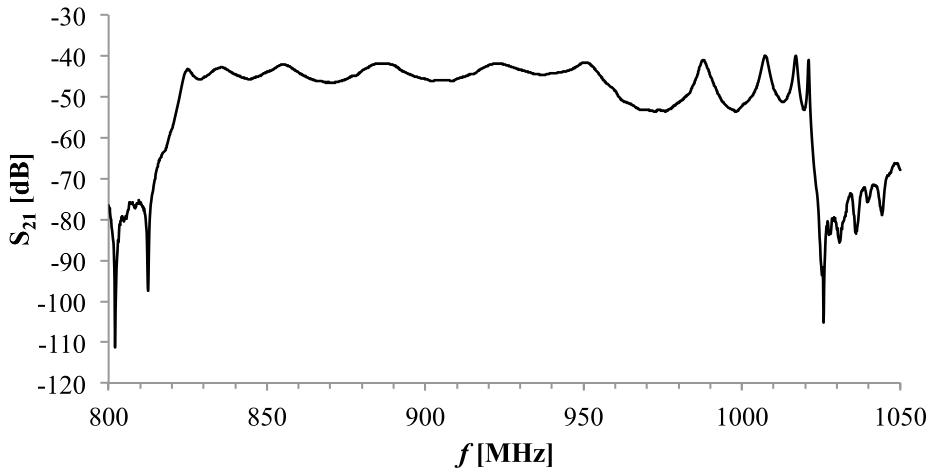
First Dipole passband



Mode	Measurement		Simulation		Comments
	f [MHz]	Q_{ext}	*f* [MHz]	Q_{ext}	
1	987.790	266	987.86	212	Dipole
2	1007.38	439	1007.83	384	Dipole
3	1017.00	955	1018.61	833	Dipole
4	1021.03	2878	1023.16	2830	Dipole

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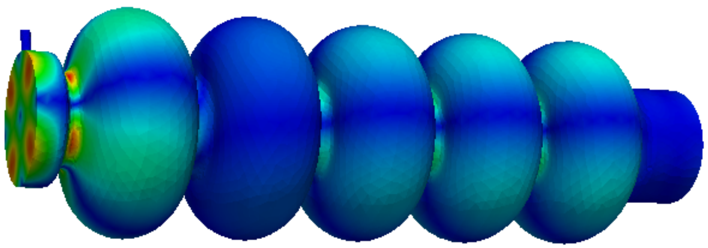
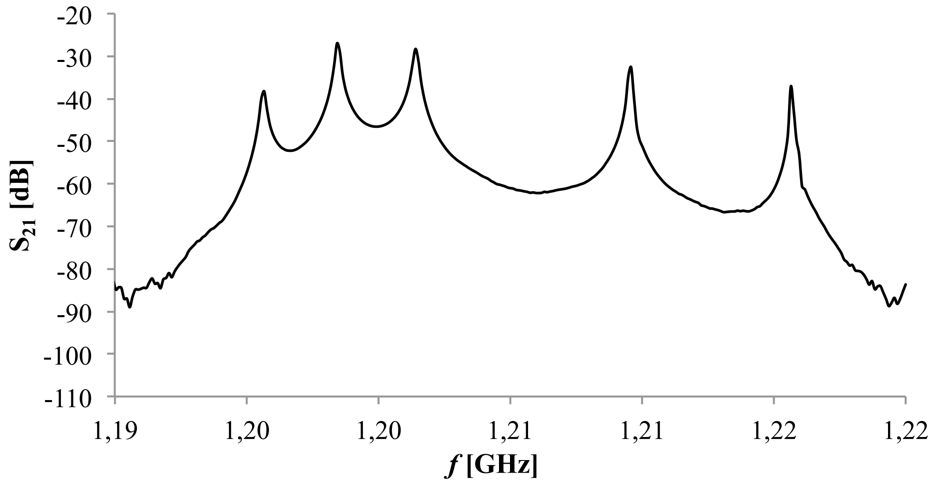
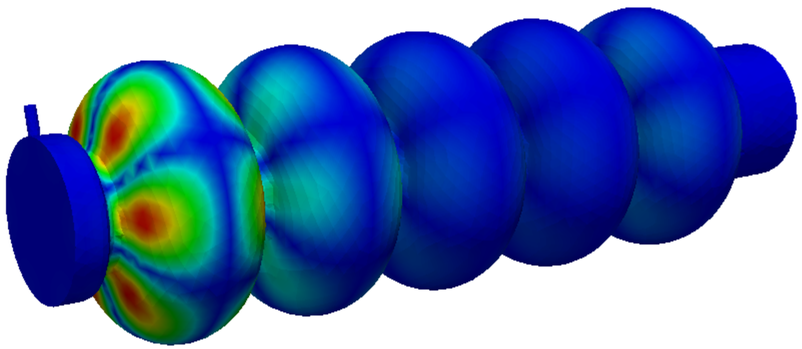
First quadrupole passband

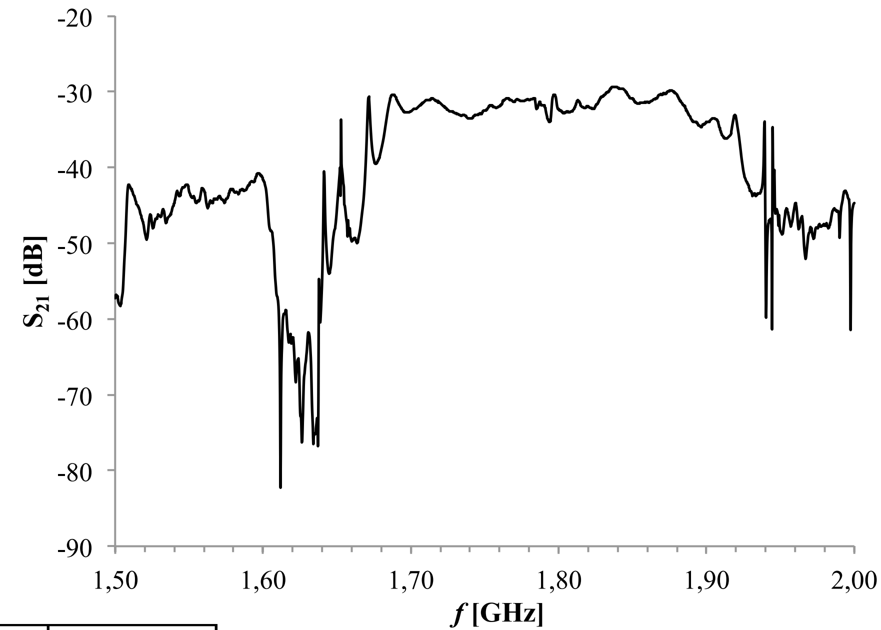




Mode	Measurement		Simulation		Comment
	f [GHz]	Q_{ext}	f [GHz]	Q_{ext}	
1	1.19564	6.42×10^3	1.1930	5.39×10^3	Quadrupole
2	1.19846	6.86×10^3	1.19782	5.79×10^3	Quadrupole
3	1.20142	5.68×10^3	1.204	8.61×10^3	Quadrupole
4	1.20955	1.10×10^4	1.2099	2.73×10^4	Quadrupole
5	1.21568	2.81×10^4	1.2099	2.89×10^4	Quadrupole

Sextupoles





Mode	Measurement		Simulation		Comment
	f [GHz]	Q_{ext}	*f* [GHz]	Q_{ext}	
1	1.6528038	2.47×10^4	1.65619	1.67×10^4	Sextupole
2	1.6549650	2.81×10^4	1.65918	1.35×10^5	Sextupole
3	1.6588321	3.11×10^4	1.65645	1.11×10^4	Sextupole
4	1.9392750	4.48×10^3	1.937	1.14×10^3	Quadrupole
5	1.9446545	9.99×10^3	1.941	2.29×10^3	Quadrupole

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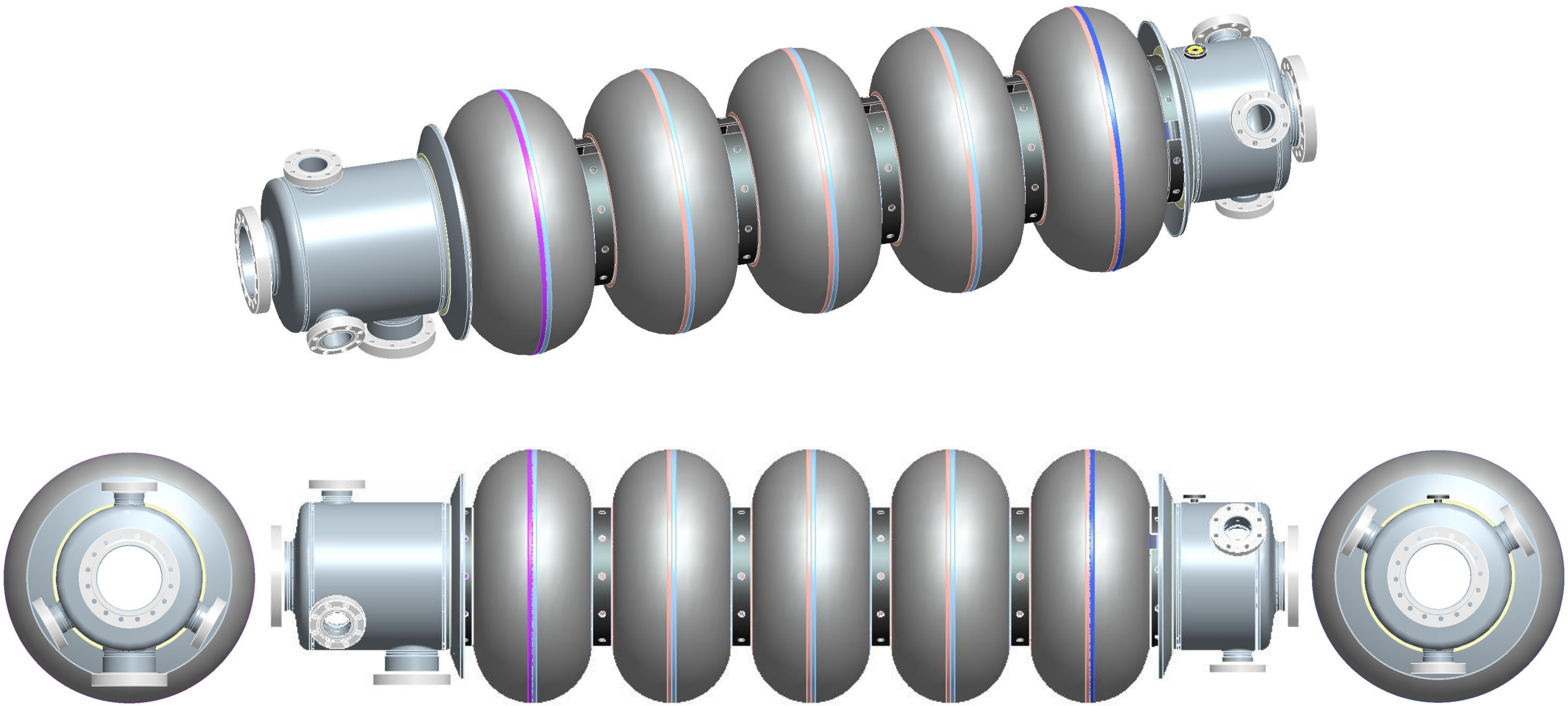
Niobium cavity configuration



Niobium cavity fabrication has started.

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Machined Mid Cells

Ready for BCP & Iris Welding

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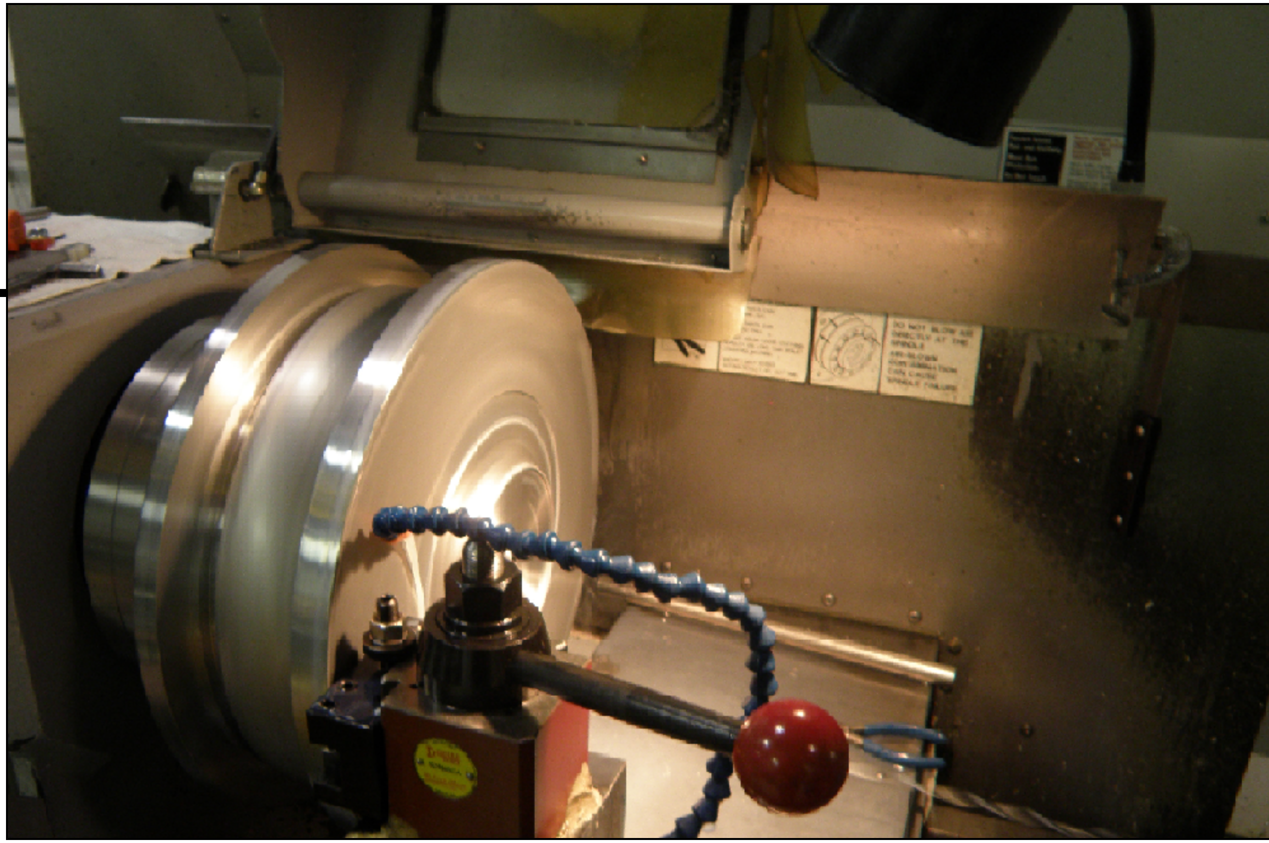

Machining of Weld Preps on Transition Cells

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Rolled & Machined
Iris Stiffener Rings

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Machined Tubes & Flanges
Ready for Braze Assembly

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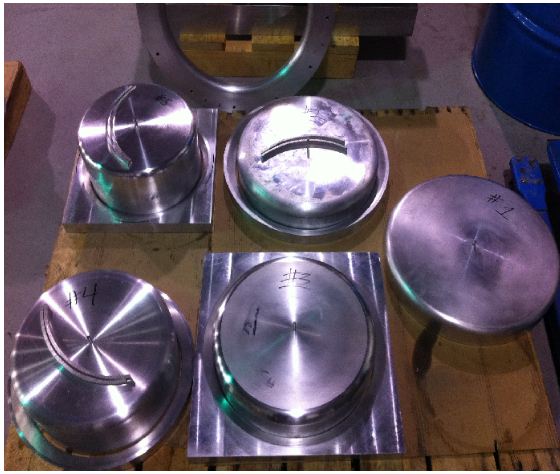
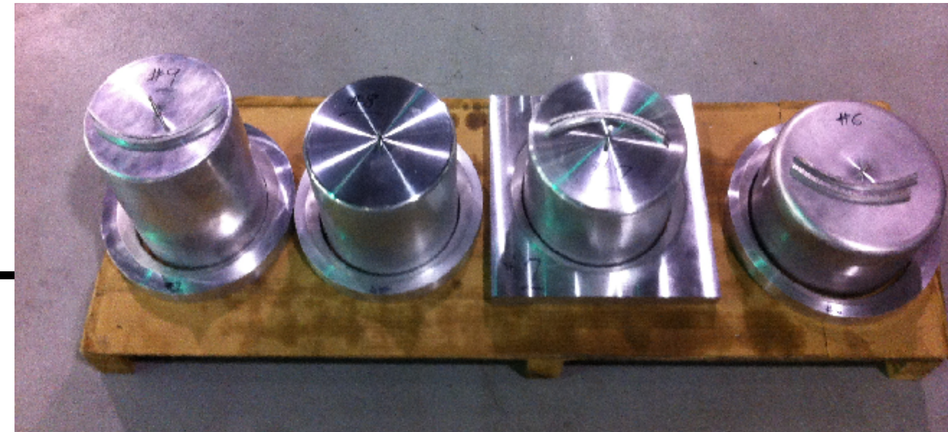
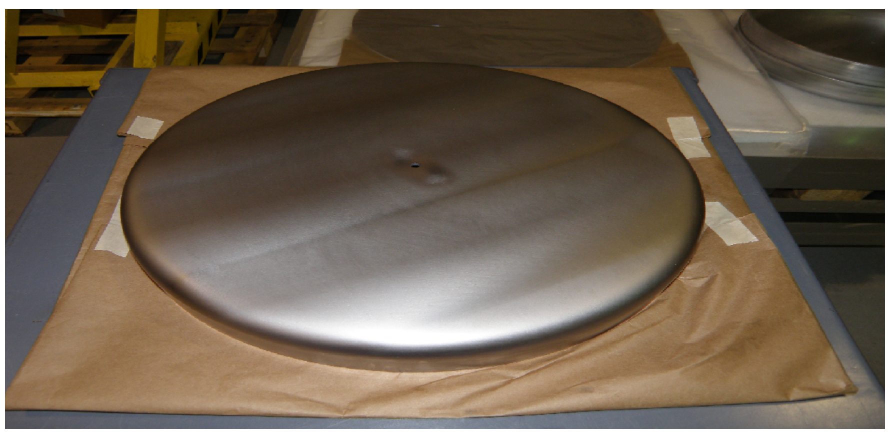


Deep Draw Tooling For Beam Tubes
Draw Stations 1-5



Deep Draw Tooling For Beam Tubes
Draw Stations 6-9

Niobium Beam Tube after 1st Draw Operation



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Vertical Testing, Horizontal Cryomodule

Niobium cavity fabrication is expected to be done mid-June.

BCP and vertical testing will commence immediately at our facilities.

Request for Proposals (RFP) has been issued to construct the cryomodule.

Summary

The BNL3 cavity has been designed in detail and optimized.

Experience from operational BNL1 cavity has been used extensively.

All dipole modes are damped well up to 2 GHz. All dipole modes with relatively high R/Q (below 1 GHz) are damped extremely well.

Three high Q sextupole modes were found in the simulations and measurements.

Antenna-type HOM coupler are being developed, with high pass filters to prevent unwanted loading of the fundamental mode.

The niobium cavity is being fabricated, to be complete mid-June 2012.

A request for proposals is out for the cryomodule fabrication.