Progress on the 704 MHz High-Current Cavity BNL3

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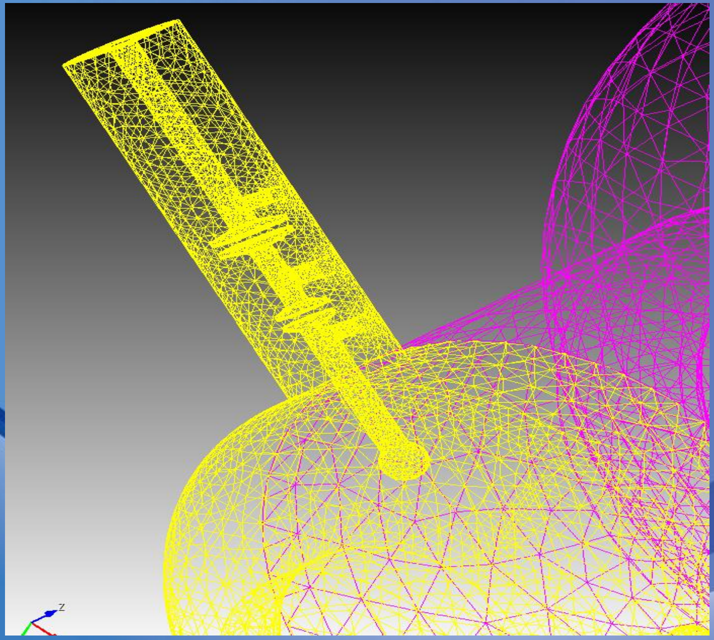

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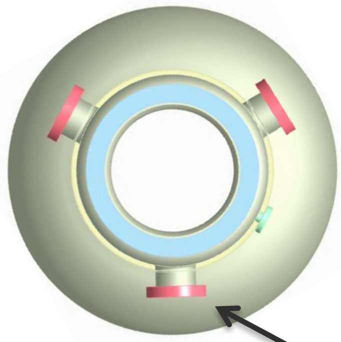
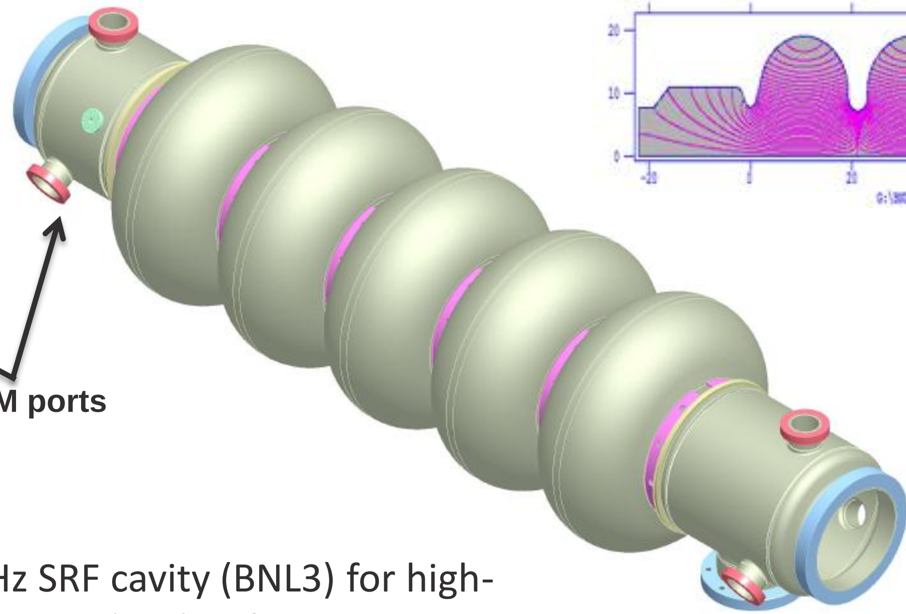
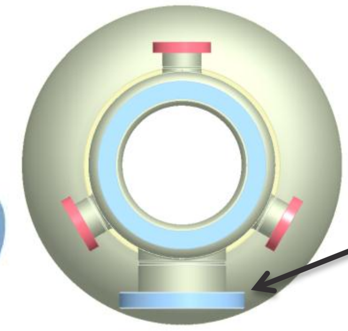
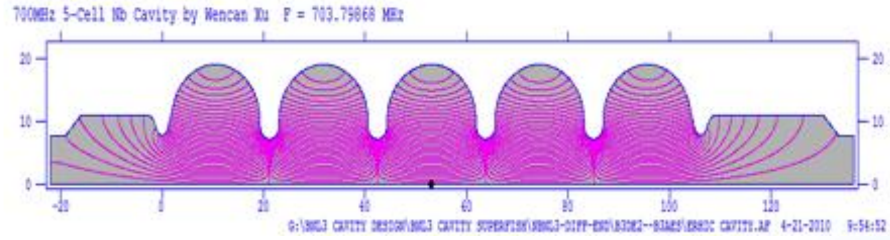
Five-cell SRF cavity with strong HOM damping







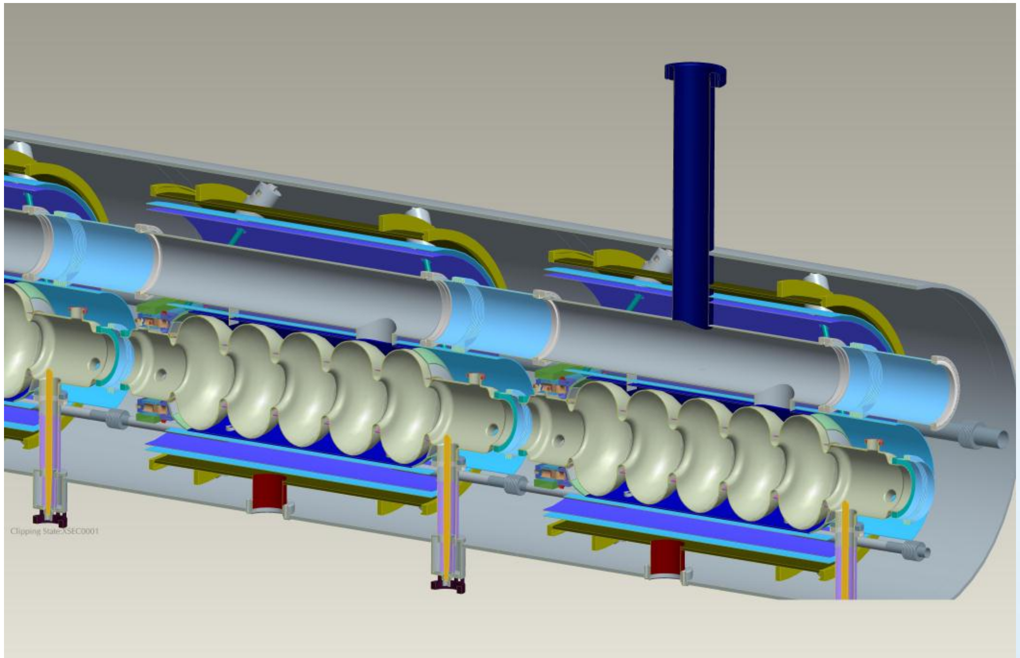


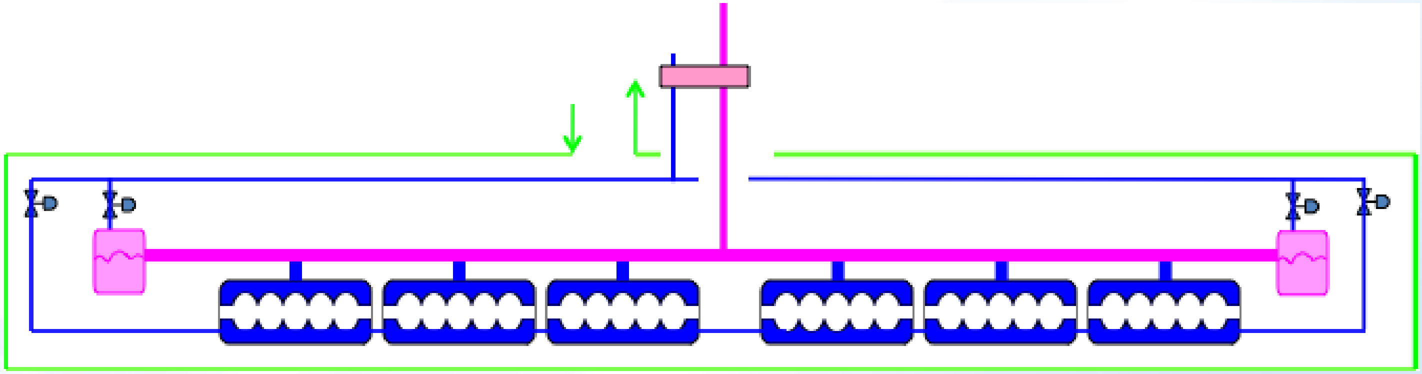
- A five-cell 703.8 MHz SRF cavity (BNL3) for high-current applications is under development.
- We use our experience with BNL1 cavity.
- The cavity is optimized and designed for applications such as eRHIC, ESS and SPL.
- Reduced peak surface magnetic field -> reduced cryogenic load.
- Three antenna-type couplers will be attached to a large diameter beam pipes at each end of the cavity and will provide strong HOM damping while maintaining good fill factor for the linac.
- HOM tolerances from BBU simulations.

Parameters	BNL1	BNL3
Frequency [MHz]	703.5	703.8
No. of cells	5	5
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

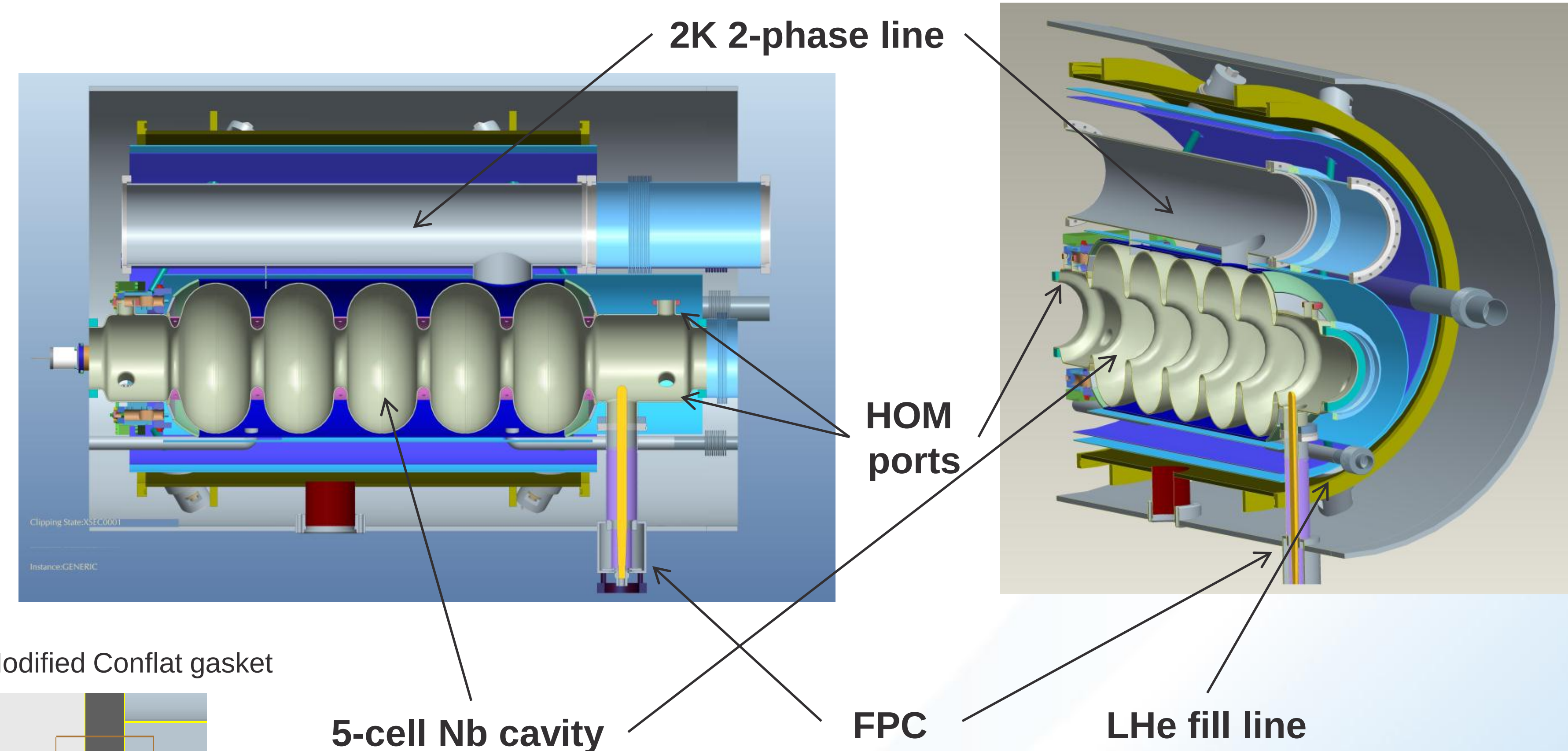
eRHIC layout

- The linac will consist of two halves (up to 60 cavities), connected in the middle to the cryogenic system operating at 1.9 K.
- The linac design is in early conceptual phase.
- At each end of the linac there will be a 1 meter long endcap transition to room temperature.
- To fit into available space in the IPs, we are designing very compact single-cavity cryounits with short, 8-cm, interconnects between them.
- The cryounits will be “easily” replaceable.
- There will be no magnets inside the linac.
- The linac filling factor will be 0.64.

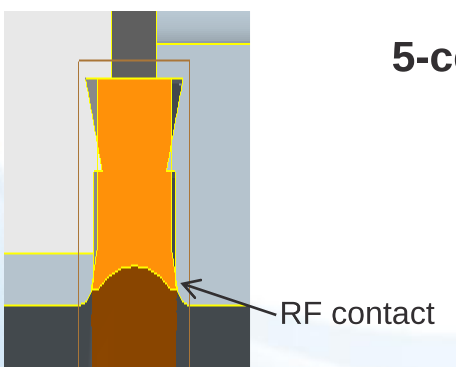




Cryounit layout



Modified Conflat gasket



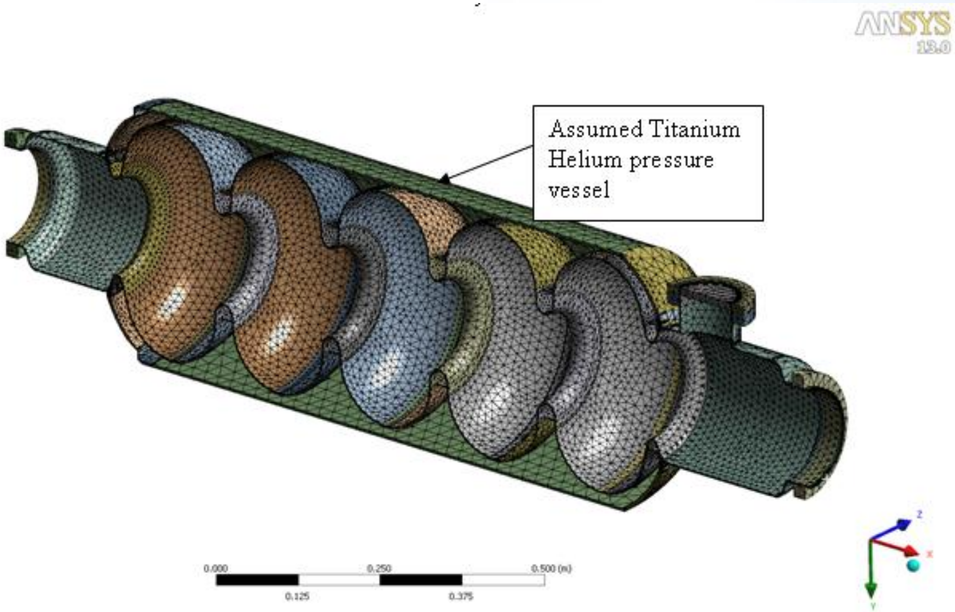
- The cavities in titanium helium vessels will be supported by nitronic rods.
- There will be short (1-2 convolutions) bellows between the cryounits.
- Modified Conflat seals with RF contact (similar to ones used in BNL ERL gun FPCs) will be used on beam pipes.

Cavity operational characteristics

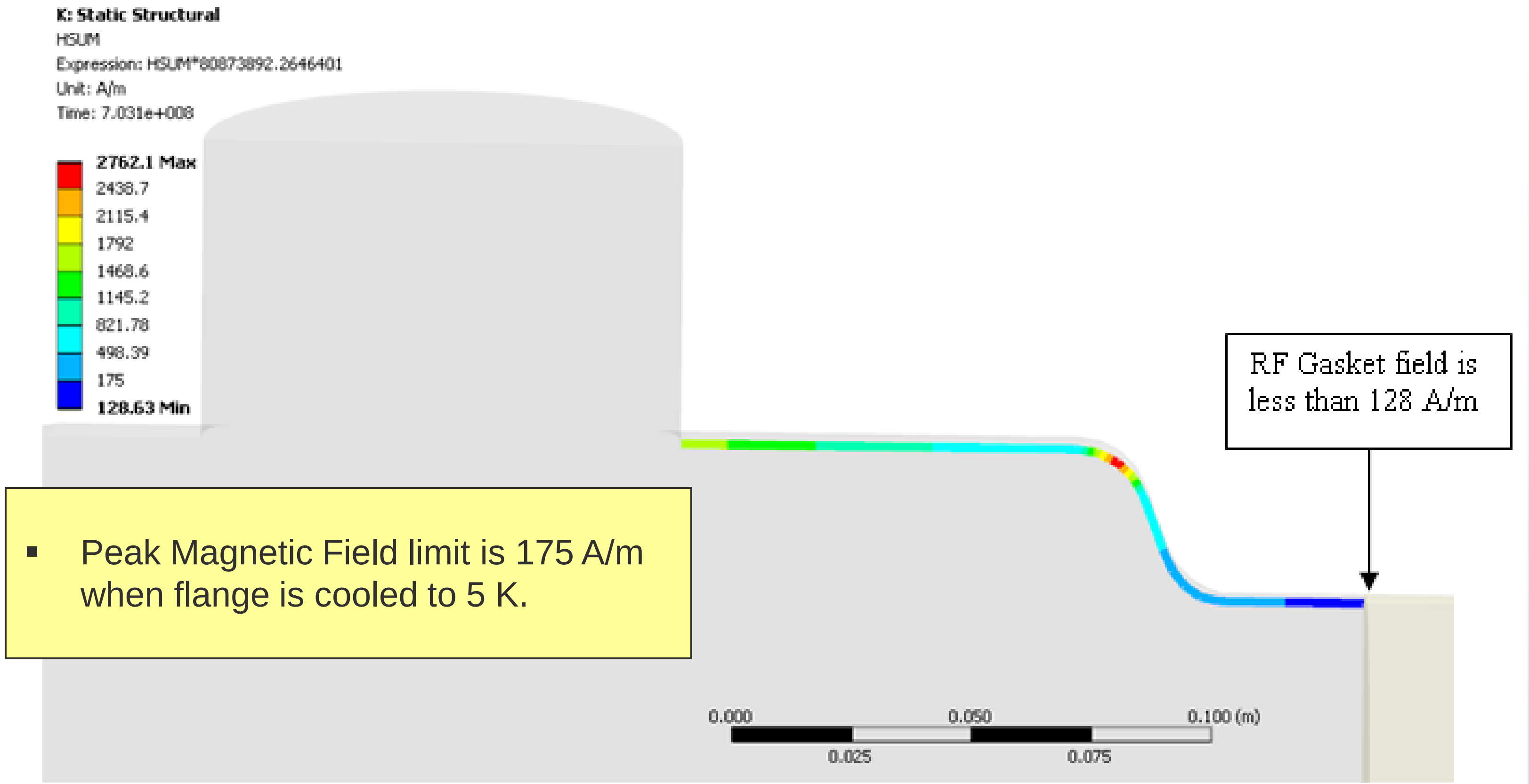
Frequency Effect [2 K]	Frequency sensitivity
Tuner [kHz/in.]	4000
Lorentz detuning coefficient, k [Hz/(MV/m)^2]	1.36
Helium pressure sensitivity [Hz/mbar]	26

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.

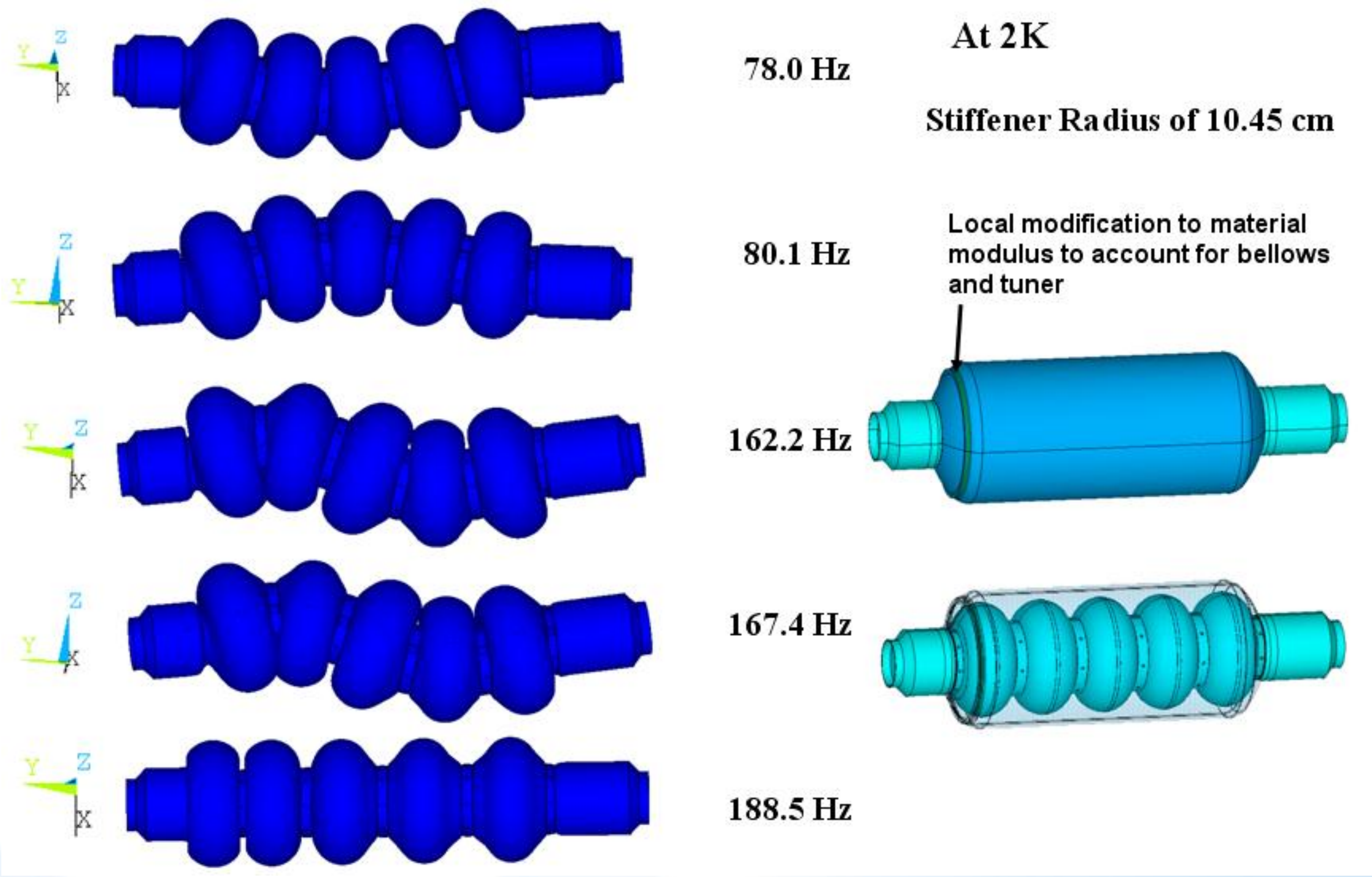


Magnetic fields near FPC end flange

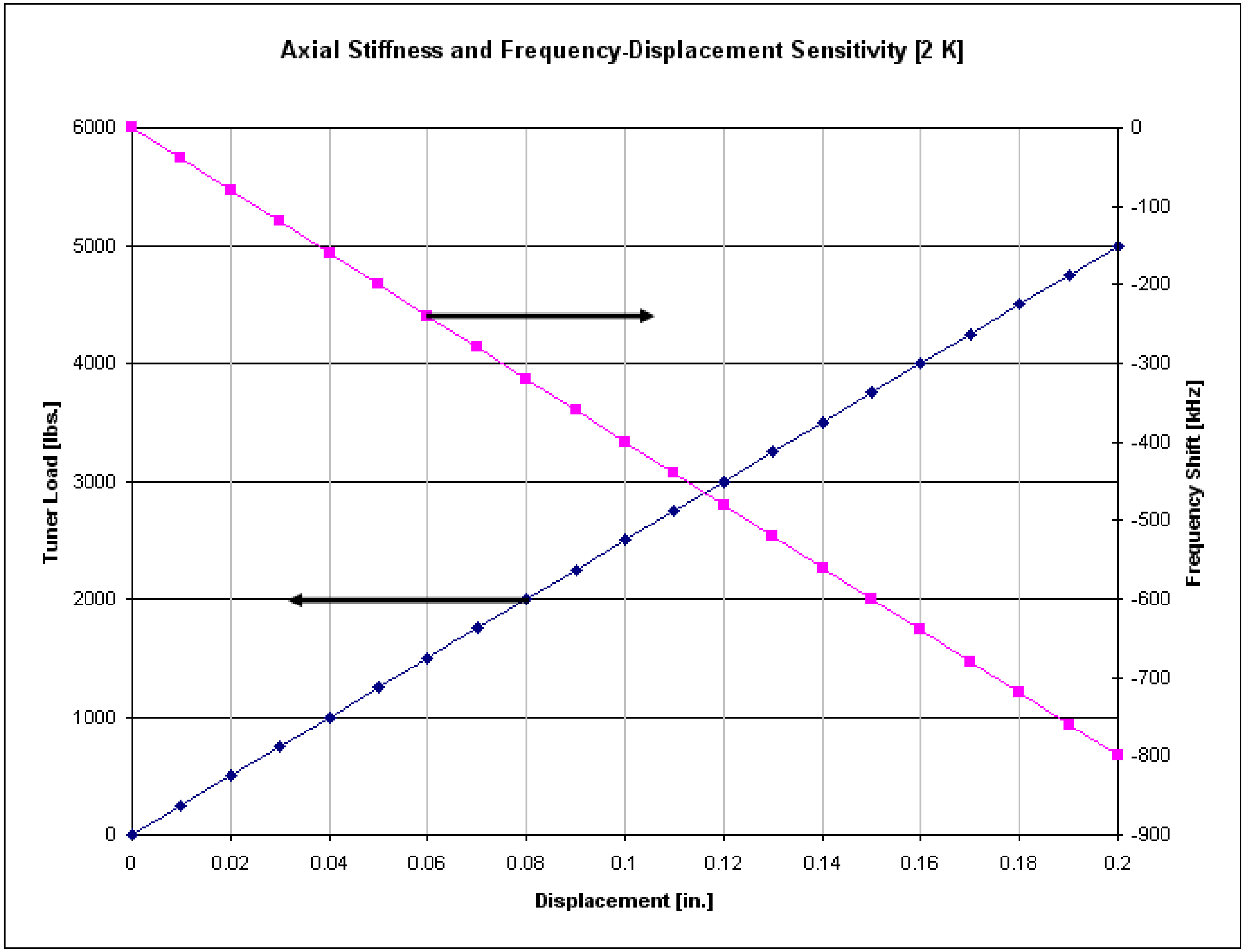


- Peak Magnetic Field limit is 175 A/m when flange is cooled to 5 K.

Cavity vibrational modes at 2 K



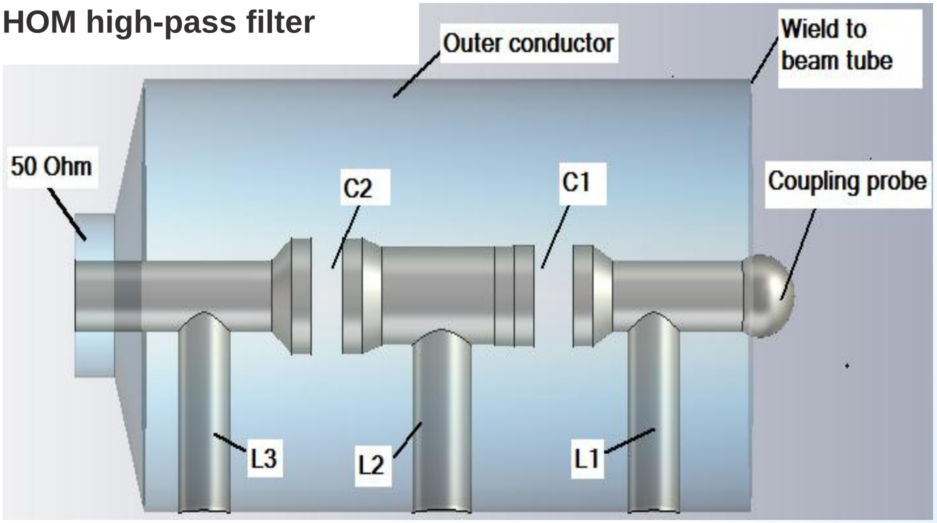
Cavity tunability

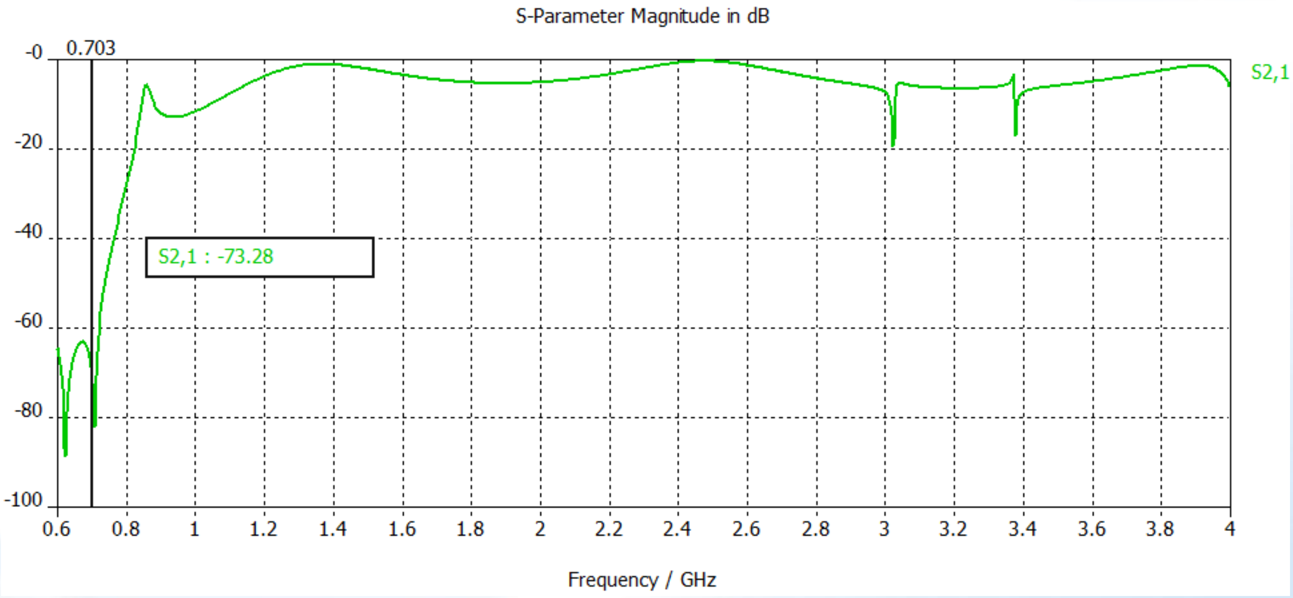


HOM damping with antenna-type couplers

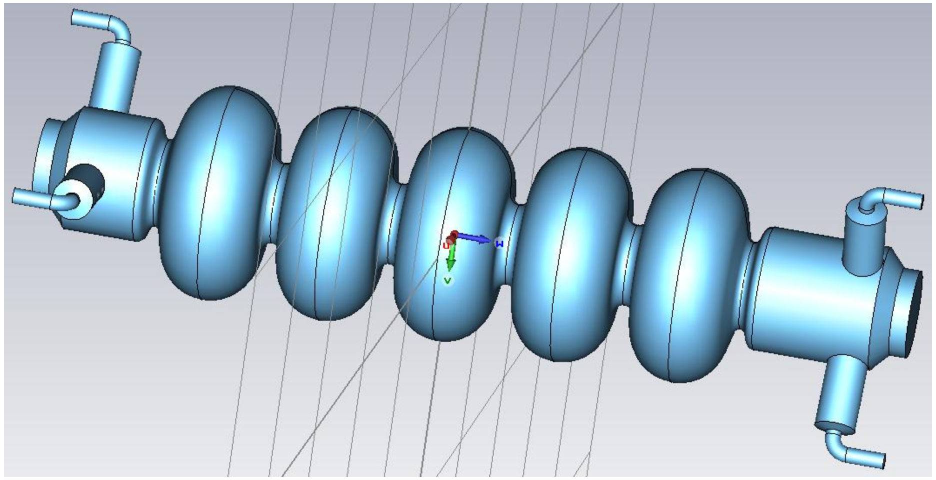
- A two-stage high-pass filter rejects fundamental frequency, but allows propagation of HOMs toward an RF load.
- 1st HOM is at 0.82 GHz.

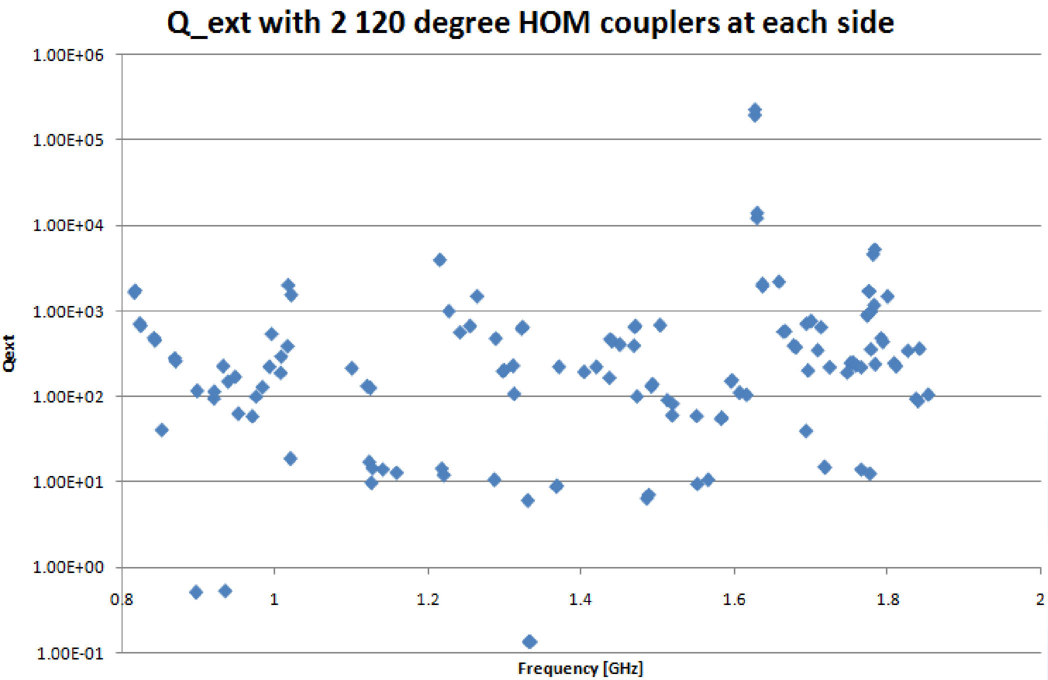
HOM high-pass filter





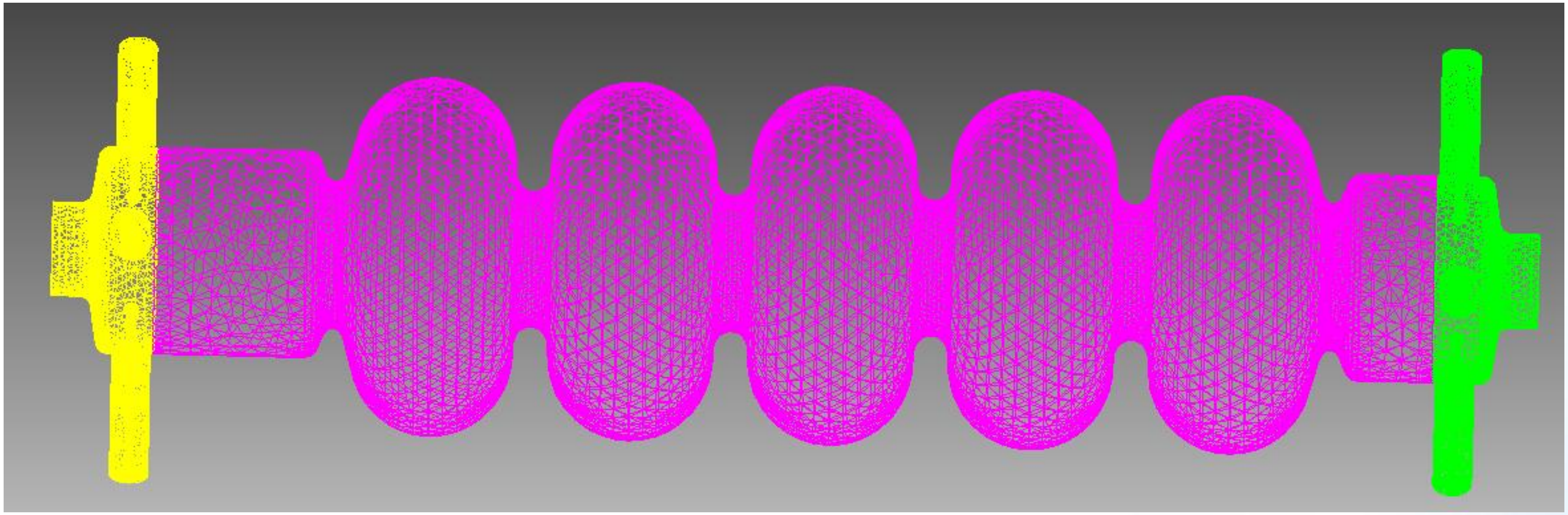
HOM damping

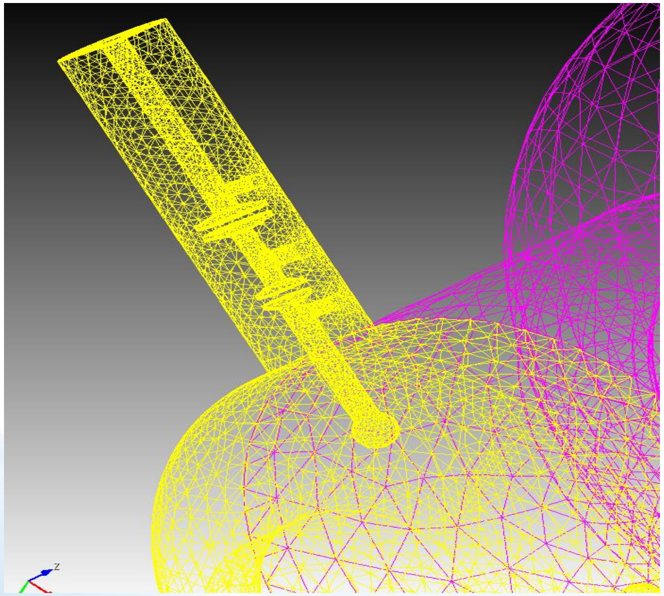




- Total HOM power to extract is 7.3 kW per cavity at eRHIC 3.5 nC, 50 mA, 6 passes up + 6 passes down energy (loss factor 3.5 V/pC).
- Simulated a model with two HOM couplers per side using CST MWS.
- High-Q modes at 1.62 GHz are sextupole ones and have low R/Q.
- Q_{ext} required from BBU simulations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

Next steps in HOM damping design

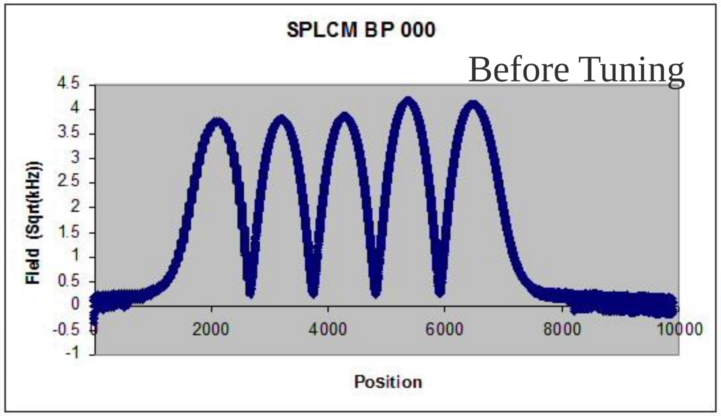


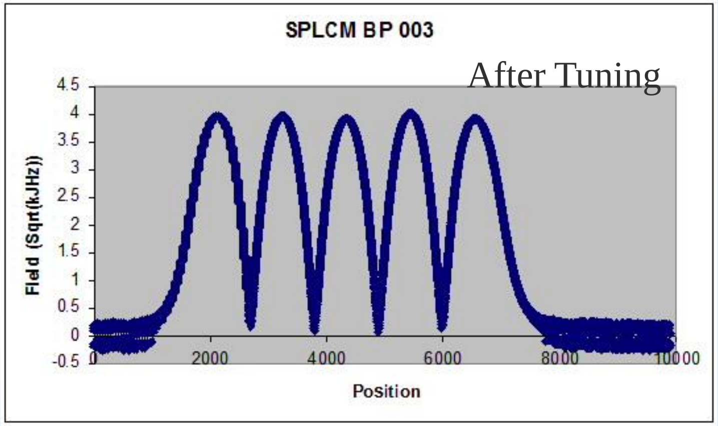


- As significantly more computer resources are required, we use Omega3P.
- Model with three HOM couplers at each end.
- Adding FPC should fix mode polarization.
- Finalize antenna length/position.
- Add high-pass filter.
- Simulate a string of cavities.
- Compare results with measurements on the BNL3 copper model.

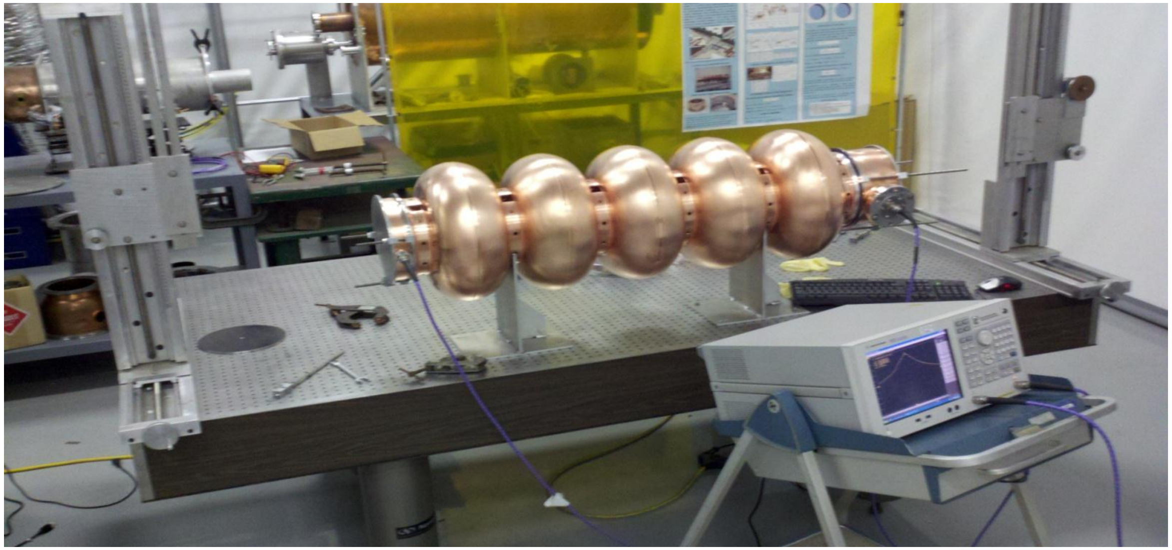
The copper cavity prototype

- Cavity was fabricated by AES.
- Tuned to specs (98.5% field flattness).
- Acceptance measurements are finished: ready to begin fabrication of Nb cavity.
- Detail HOM studies will continue.

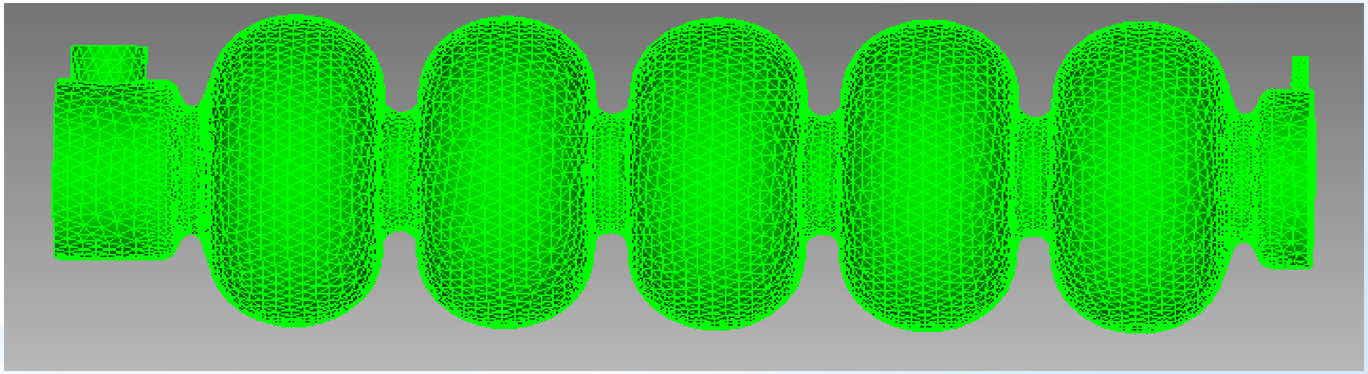




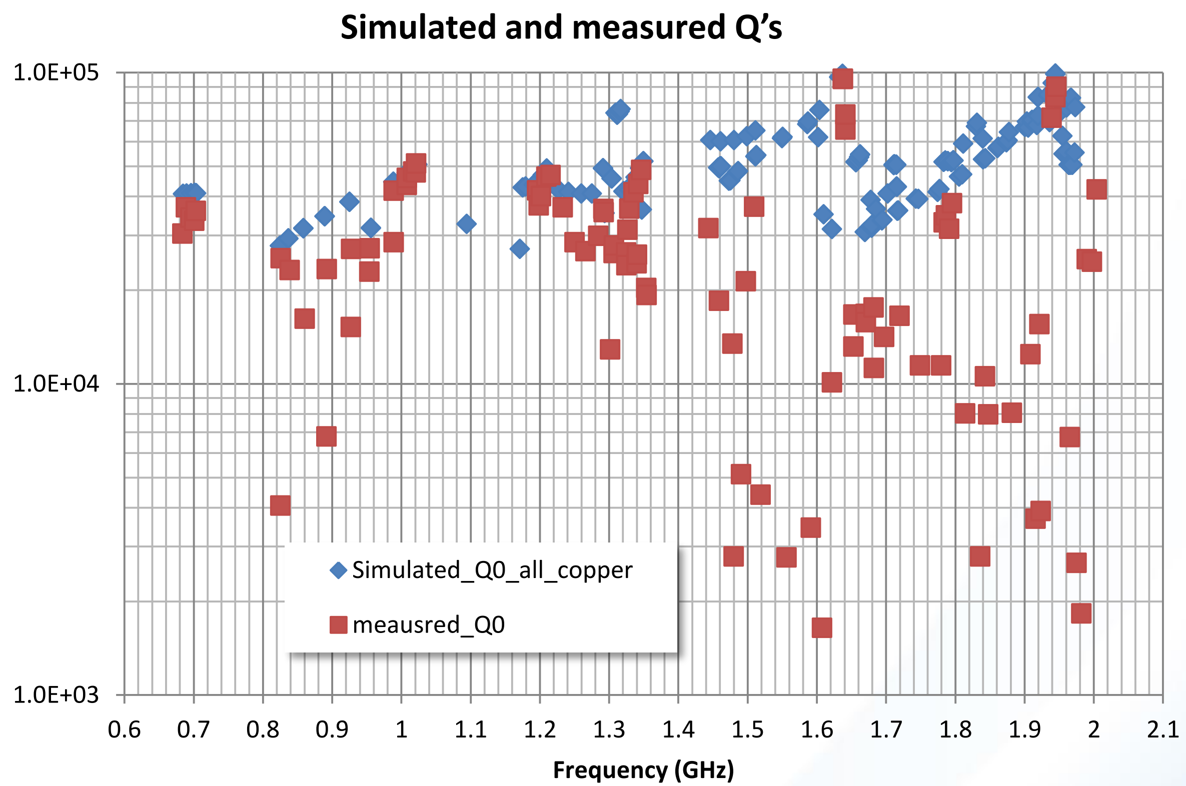
Measurement setup and model



- Very weak coupling at both FPC and PU ports.
- Whole copper, including the end plates at both sides.

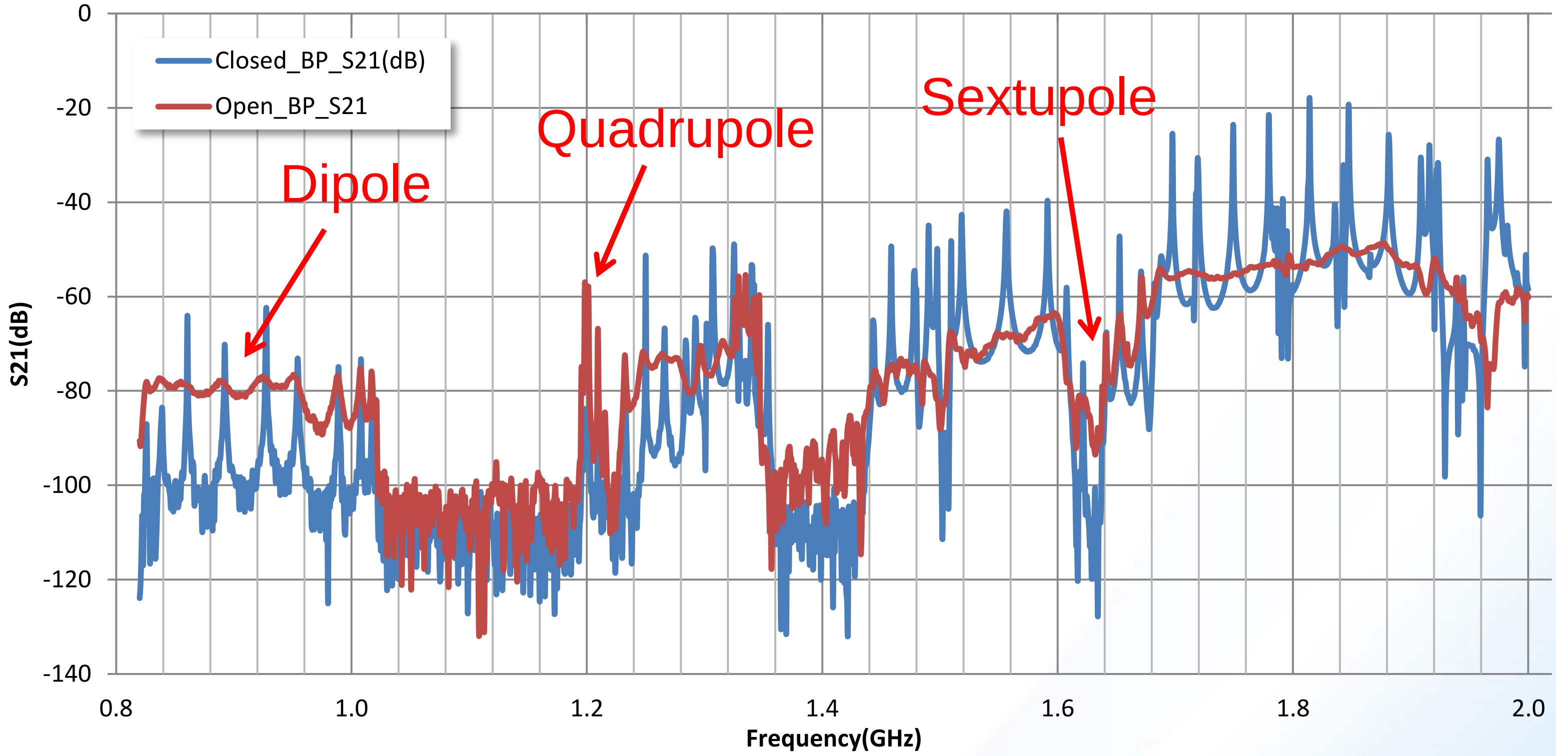


Q factors of Higher-Order-Modes



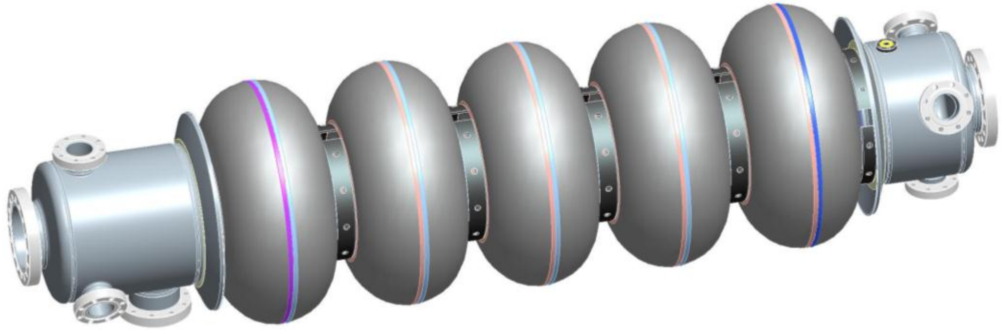
- The simulated *Q*'s agree reasonably well with the measured *Q*'s for most of the modes.
- As expected, the measured *Q*'s are a little lower than the simulated *Q*'s due to imperfect copper surface.
- The modes with relatively low *Q* are the splitting modes. As the -3 dB bandwidth method is used, *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.

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.

Niobium cavity configuration



- Niobium cavity fabrication has started.
- The plan is to finish cavity fabrication and perform vertical testing in 2012.
- The design of the single-cavity cryomodule has begun with the goal to have the cryomodule complete by summer of 2013.
- It will be used for Coherent electron Cooling Proof-of-Principle (CeC PoP) experiment in RHIC starting with Run-14.

Summary

- The BNL3 cavity has been designed in detail and optimized.
- Experience from operational BNL1 cavity has been used extensively.
- A copper prototype cavity has been delivered to BNL and the HOM studies has begun.
- 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 couplers are being developed.
- The coupler uses high pass filters to prevent unwanted loading of the fundamental mode.
- Computer simulations with CST MWS and Omega3P are in progress.
- The simulation results will be compared with measurements of the BNL3 copper model.
- Fabrication of the niobium cavity and design of the single-cavity cryomodule have begun.

A1: Cavity Tuning Summary

The following table shows the fields measured between each of the cell tunings.

Cell	Initial	Tune 1	Tune 2	Tune 3
C1	90.0%	92.8%	91.5%	98.6%
C2	91.1%	93.3%	93.0%	98.7%
C3	92.4%	93.4%	94.4%	97.6%
C4	100.0%	100.0%	100.0%	100.0%
C5	98.4%	97.4%	96.6%	97.6%
Spread (+/-)	5.0%	3.6%	4.2%	1.2%
Tilt	8.4%	4.6%	5.1%	-1.0%
Mean	94.4%	95.4%	95.1%	98.5%

We see that after tuning was completed the spread was +/- 1.2%, tilt was -1.0% and the mean field was 98.5%. The table below shows the cavity modes measured between each of the cell tunings.

Mode	Initial	Tune 1	Tune 2	Tune 3
0	683.791	683.818	683.936	683.825
1	689.140	689.177	689.204	689.088
2	695.378	695.413	695.484	695.441
3	701.013	701.058	701.064	701.008
4	703.165	703.196	703.243	703.162

This tuning was completed quite successfully. The same tooling and methods will be used on the Niobium cavity although for that tuning effort we will adjust the overall frequency as well as the field profile.

Summary of Dumbell Tuning

DB #	Freq (Lab) (MHz)	Ql	Tcu ©	Tair ©	BP (inHg)	RH (%)	Freq Target (MHz)	dF (MHz)	dF/dL (MHz/in)	dL (in)
1	702.156	6248	21.7	22	29.74	44	703.281	1.125	38.532	0.029
2	702.126	7897	21.7	22	29.74	44	703.281	1.155	38.532	0.030
3	702.082	6567	21.6	22	29.74	44	703.281	1.199	38.532	0.031
4	702.164	7071	21.9	22	29.74	44	703.281	1.117	38.532	0.029