Novel Ridge Waveguide HOM damping Scheme for High Current SRF cavity

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On behalf of HOM damping team

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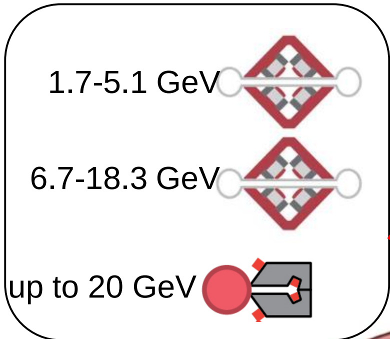
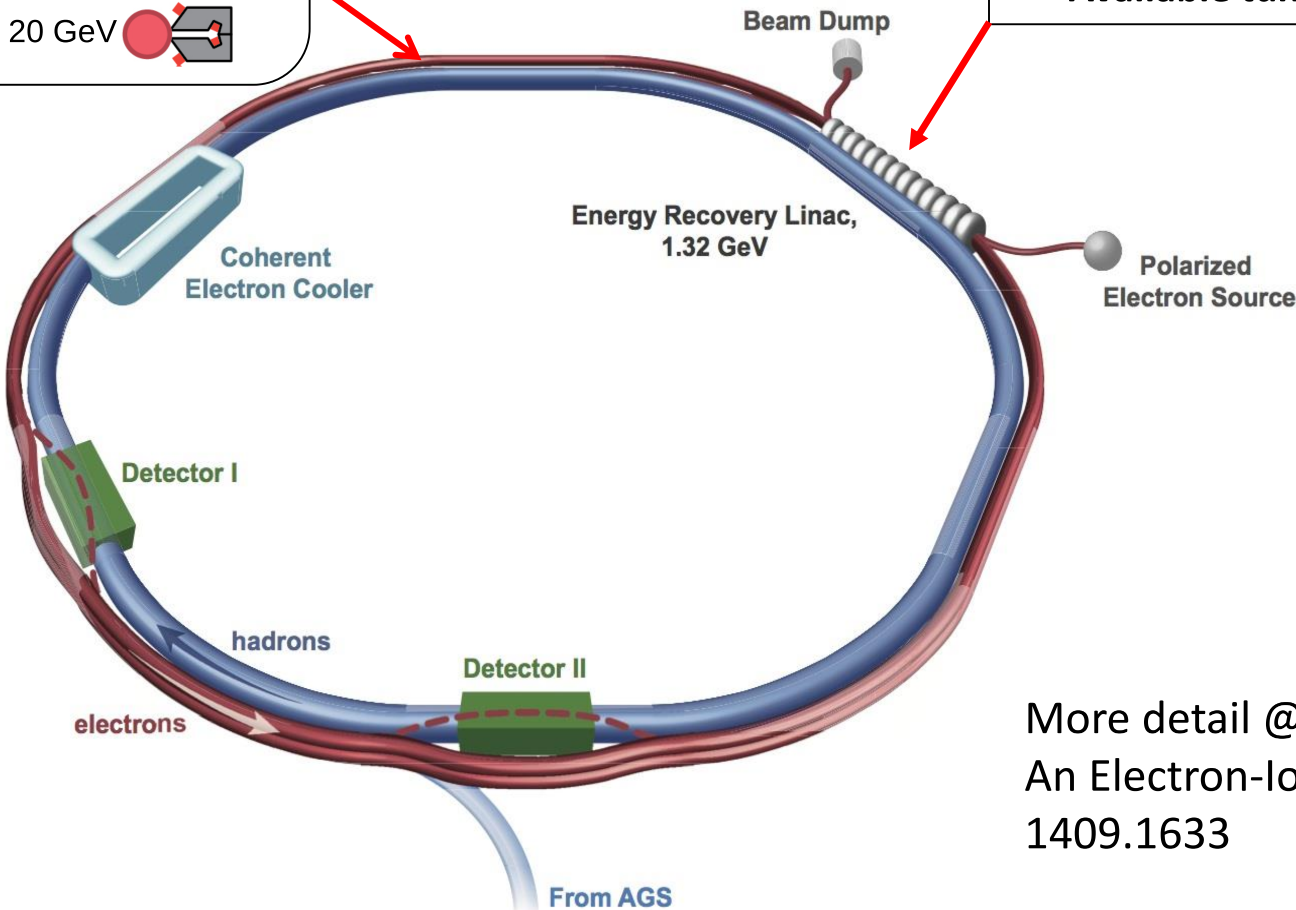
Outline

- HOM damping requirement of eRHIC SRF linac
- Ridge waveguide HOM damping for compact linac: HOM damping scheme, BBU, energy spread
- HOM damping for “Low-risk” linac
- Summary

ERL SRF linac in FFAG lattice eRHIC



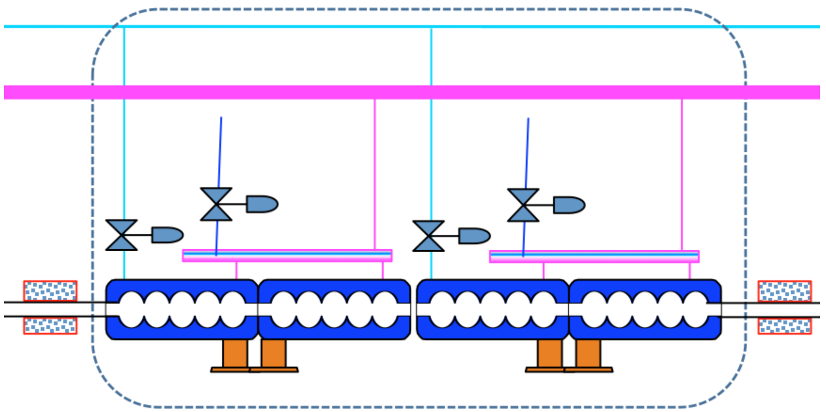
- **1.67 GeV main Energy Recovery Linac;**
- **80 647.4 MHz 5-cell–SRF Cavity;**
- **Available tunnel space: 200 m.**

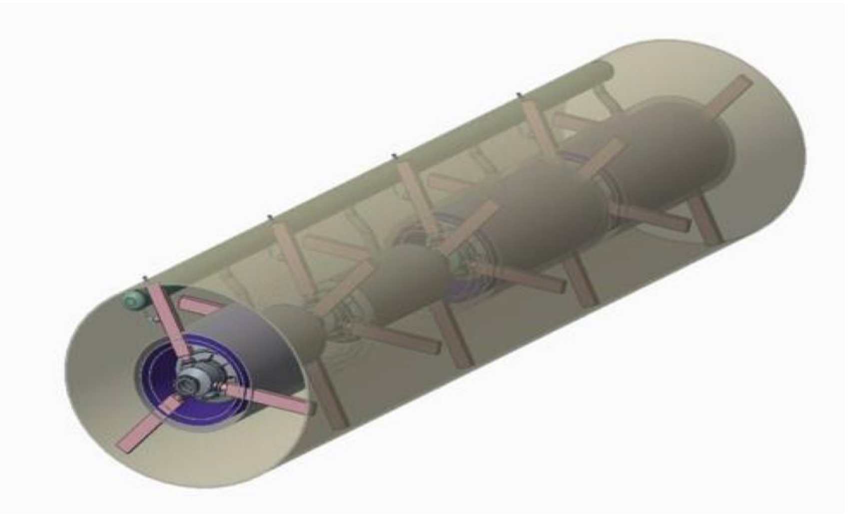


More detail @ eRHIC Design Study: An Electron-Ion Collider at BNL, arxiv: 1409.1633

Linac Parameters for compact

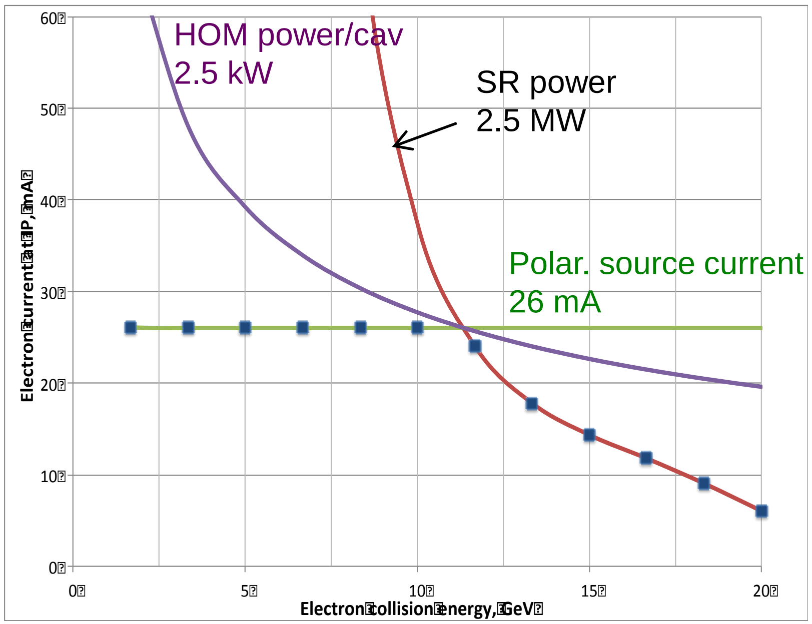
Energy gain [MeV]	83
Number of cavity	4
Accelerating gradient [MV/m]	18
RF coupler per cavity	1
Operation temperature [k]	1.9
Q factor at operating gradient	3E10
Number of ridge waveguide per cavity	6
Number of RT beam line absorber	2
Cavity length (flange-to-flange) [m]	1.72
Effective cavity length [m]	1.1576
End Transition [m]	0.55
Inter-cavity length	0.1
Valve	0.15
Beam line damper	0.35
Length of module with RT absorber [m]	8.78
Real-estate gradient (MV/m)	9.5
No. of cryomodule	20
No. of cavities	80
Total linac length	175.68
Linac gain (GeV)	1.67



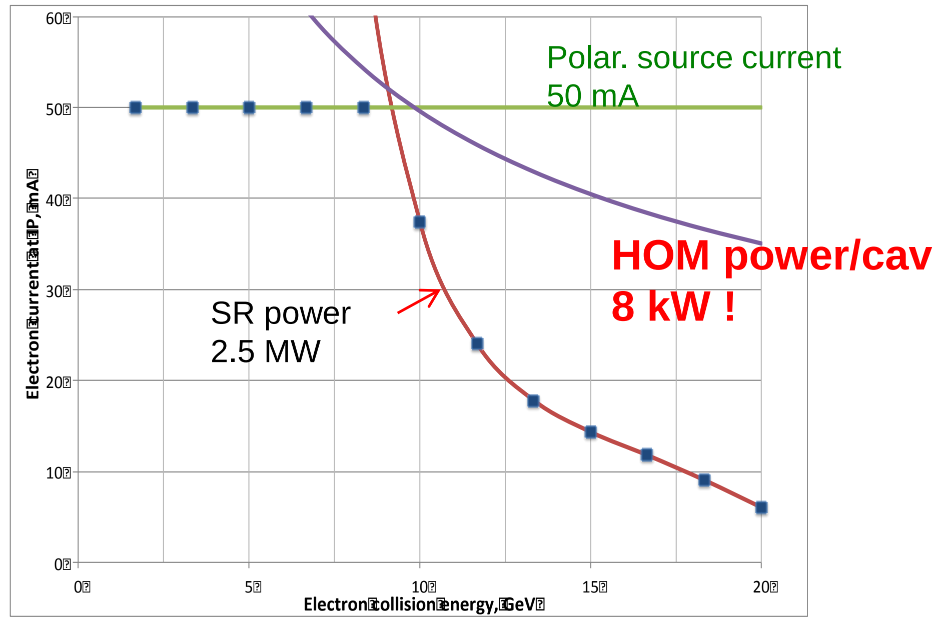


eRHIC ERL electron beam current limits

Nominal design



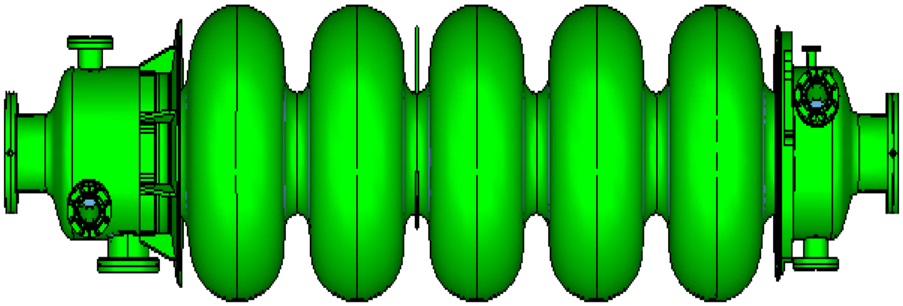
Ultimate design

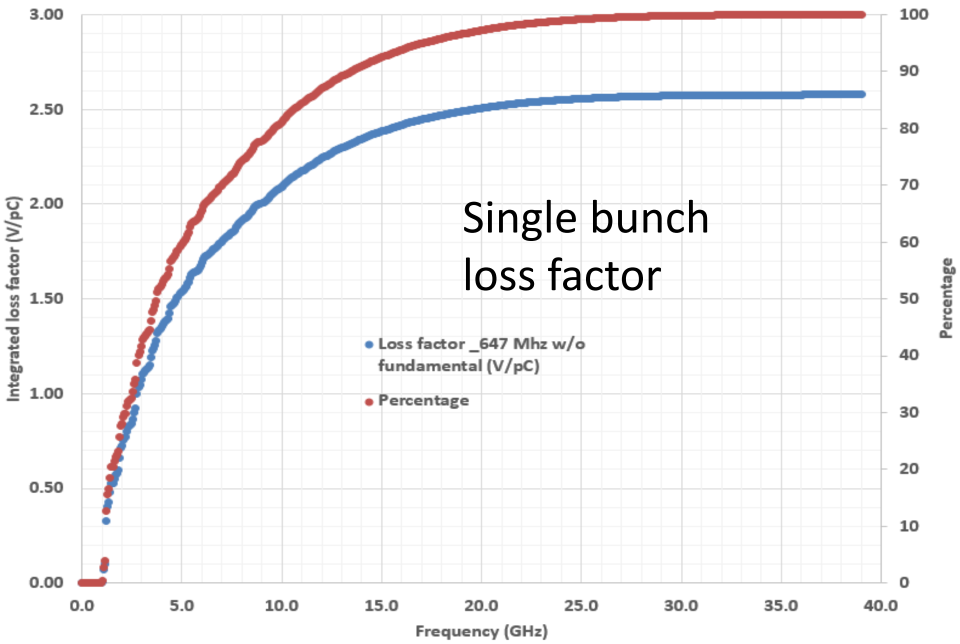


- Bunch length in eRHIC design is with sigma of 3mm, which has loss factor of 2.6 V/pC calculated by ABCI.
- There are two designs with max ebeam current in linac of 340 mA for nominal design and of 500 mA for ultimate design, which, respectively, generates 2.5 kW and 8 kW HOM power calculated by single bunch loss factor.

plot@ V. Ptitsyn, Luminosity staged linac-ring design, eRHIC R&D advisory committee Review, April 7-8, 2016

RF and mechanical design of 647 MHz cavity

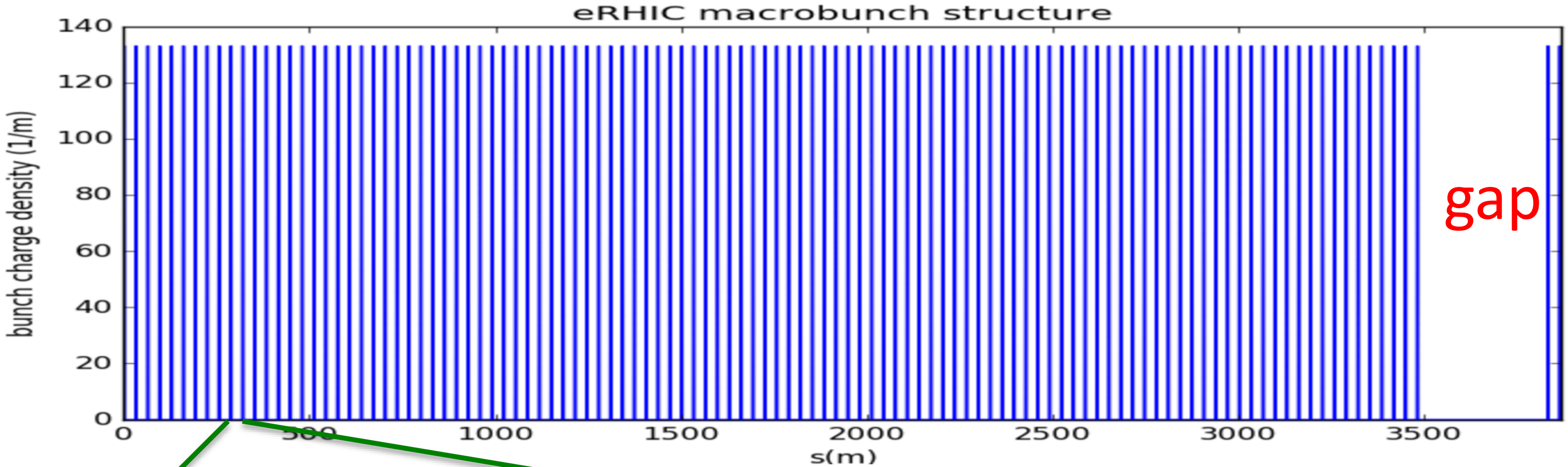


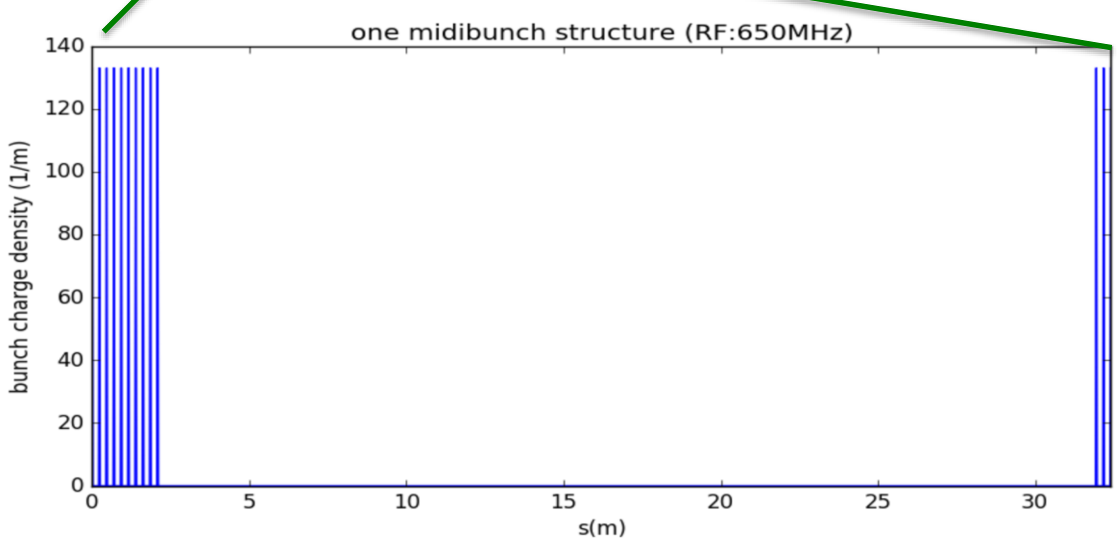


Parameters	647 MHz 5-cell cavity
Frequency [MHz]	647
Number of cells	5
Geometry factor [Ω]	273
(R/Q)/Cavity [Ω]	502
Epeak/Eacc	2.27
Bpeak/Eacc [mT/MV/m]	4.42
Coupling factor [%]	2.8
Cavity length [m]	1.72

- The tuning range for eRHIC cavity is 173 kHz to match different Proton energy.
- Tremendous mechanical analysis was carried out, and decided to have 4 mm wall thickness without Stiffness ring. This makes a reasonable tuner load, mechanical stress bellow 7000 psi.
- With tabs on the middle cell of the cavity, the first mechanical mode is longitudinal mode and is 107 Hz.
- The cavity will be fabricated in RI.

eRHIC bunch structure





i(t)=A(t)xB(t) x C(t)

CW A(t): RF 647.5 MHz

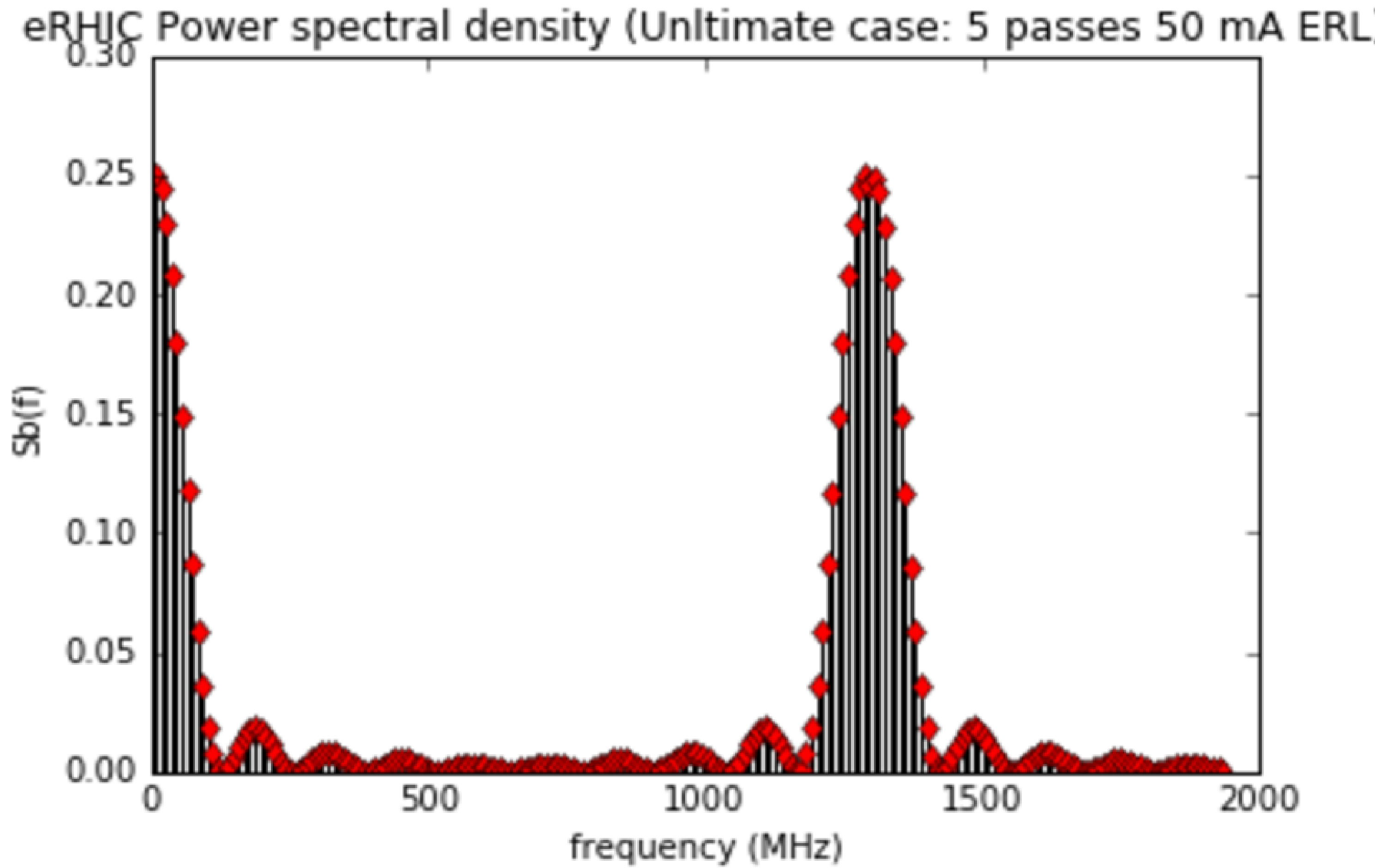
Midi bunch B(t): 9.38 MHz

Macro bunch C(t): revolution freque
78KHz (120 9.38 MHz)

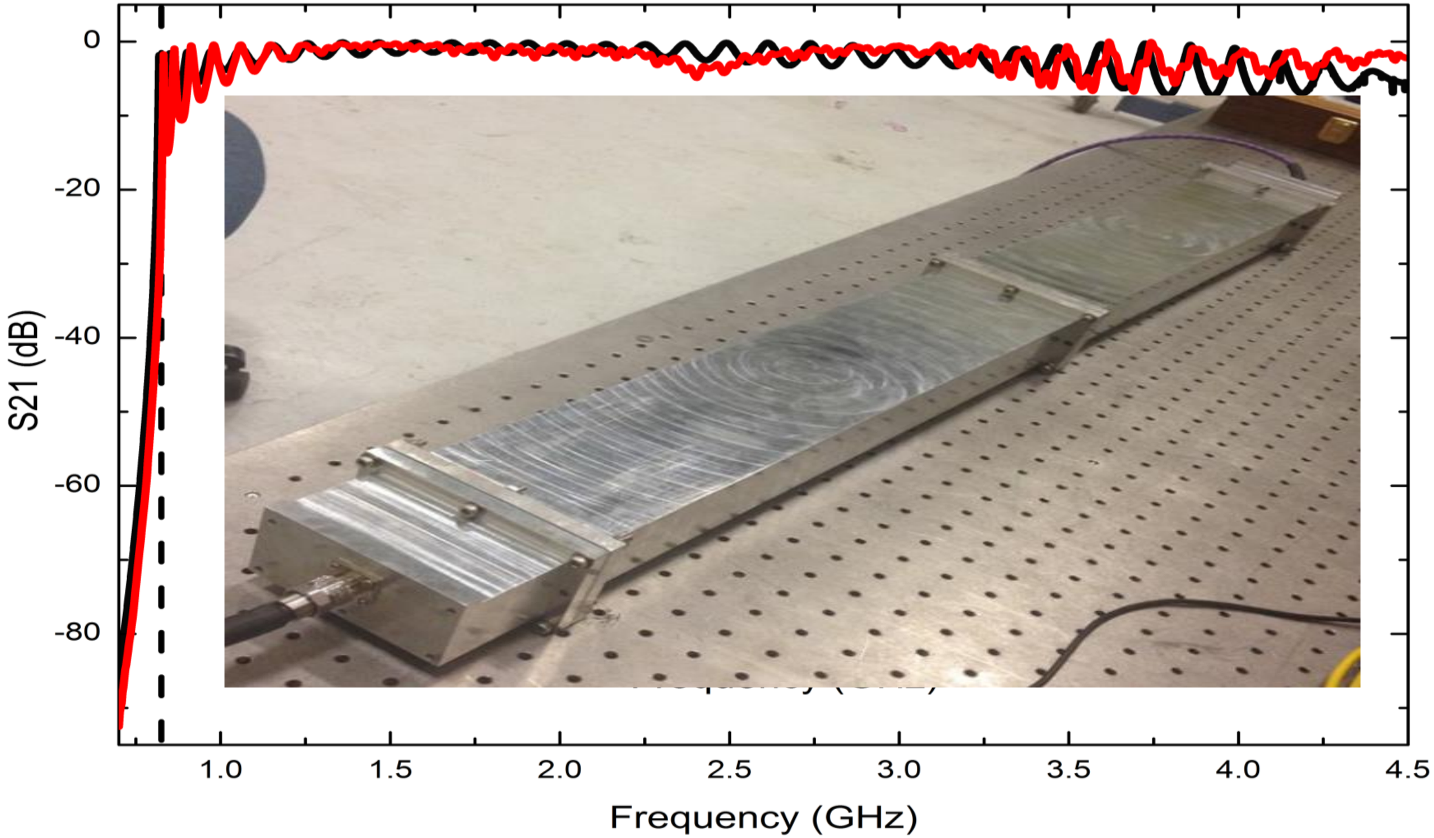
Gap: 10 9.38MHz

eRHIC bunch structure

$$i_b(t) = \frac{1}{h9 * h78} \sum_{m=-\infty}^{\infty} \sum_{n=-\infty}^{\infty} C_m Sinc\left(\frac{n}{h9}\right) Sinc\left(\frac{k}{h78}\right) e^{j(m\omega_{rf} + n\omega_9 + k\omega_{78})t}$$

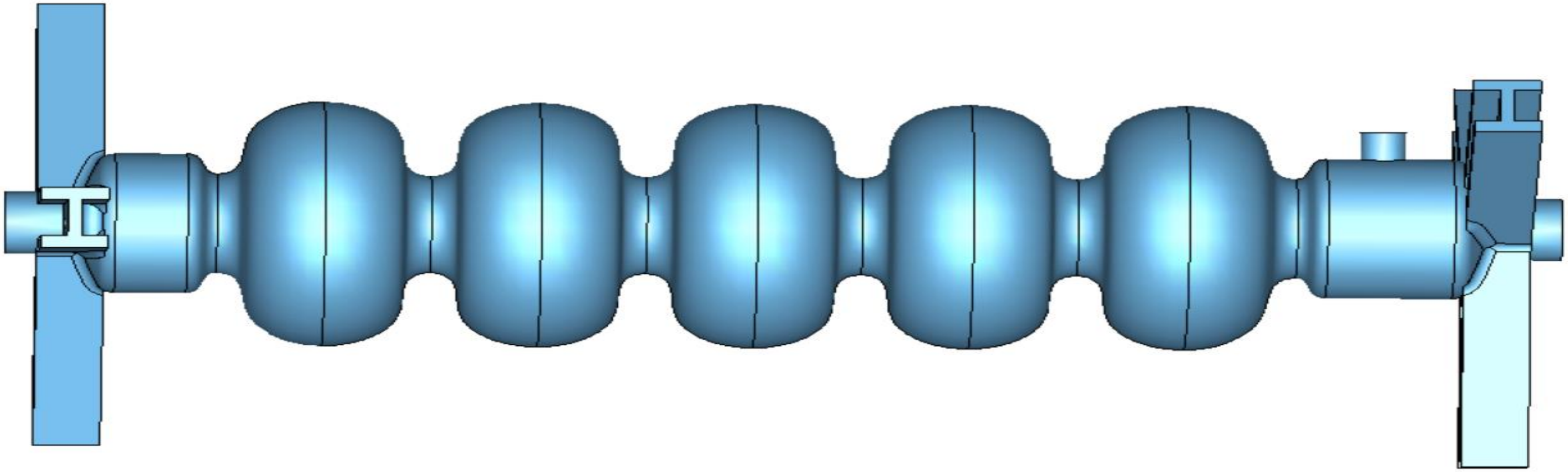


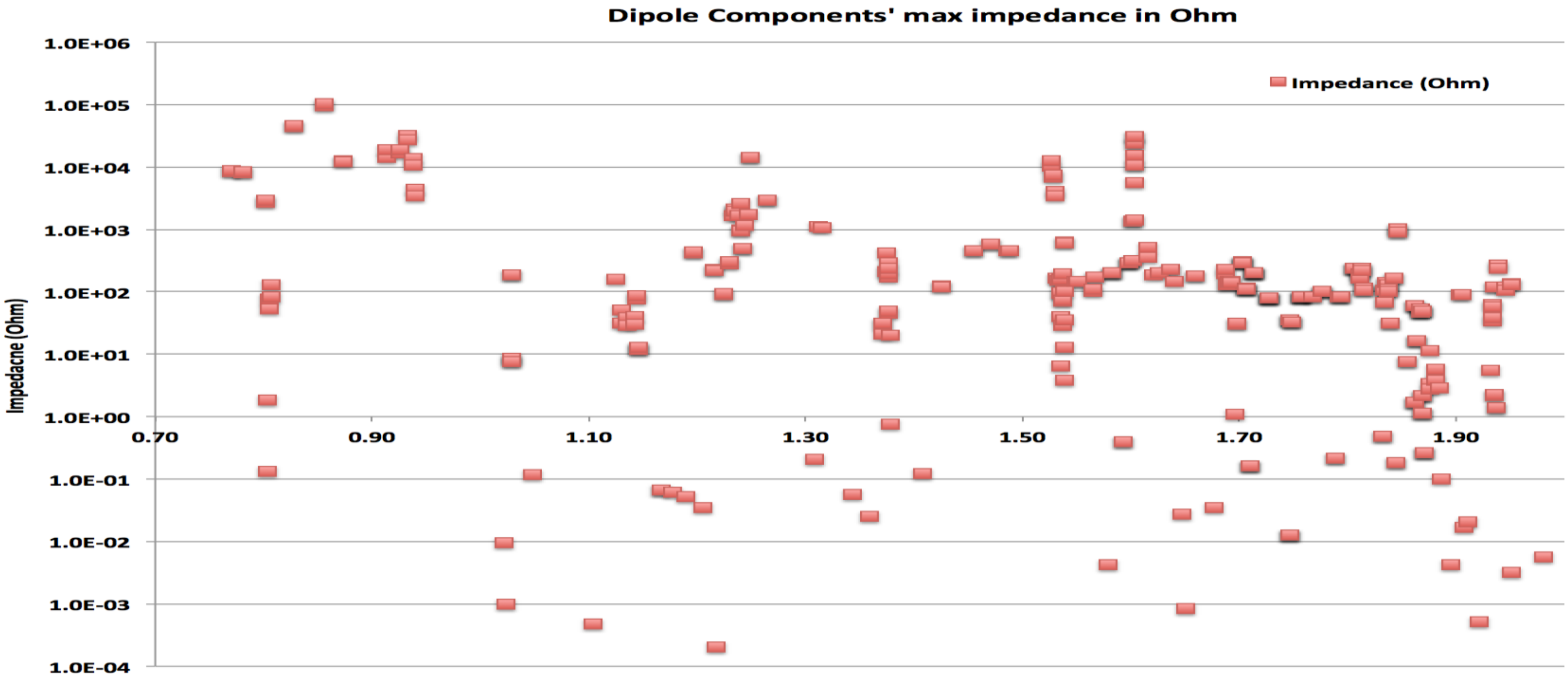
Conceptual design of Ridge waveguide damper (1)



- Ridge WG is a nature high pass filter with higher bandwidth, smaller size (1/4) than regular WG.
- Ridge WG has lower conduction heat load and is easier to cool.

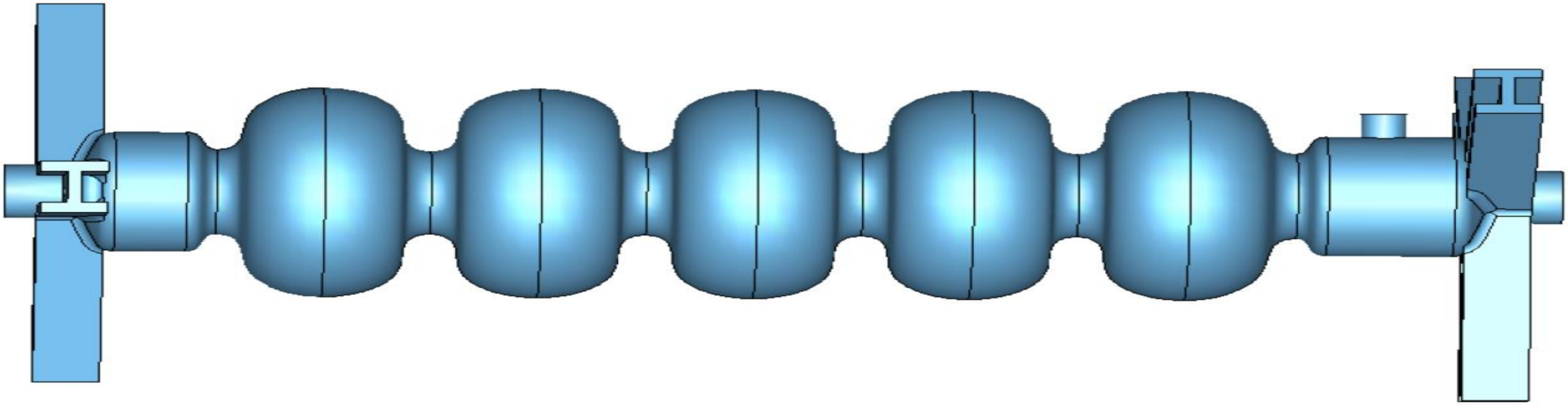
Uniform Ridge Waveguide HOM damping results





V

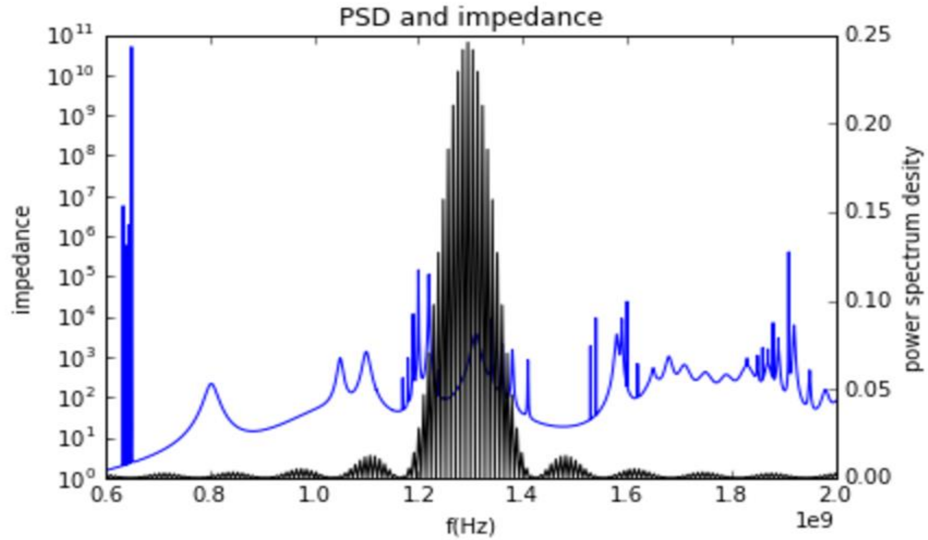
BBU Simulation results



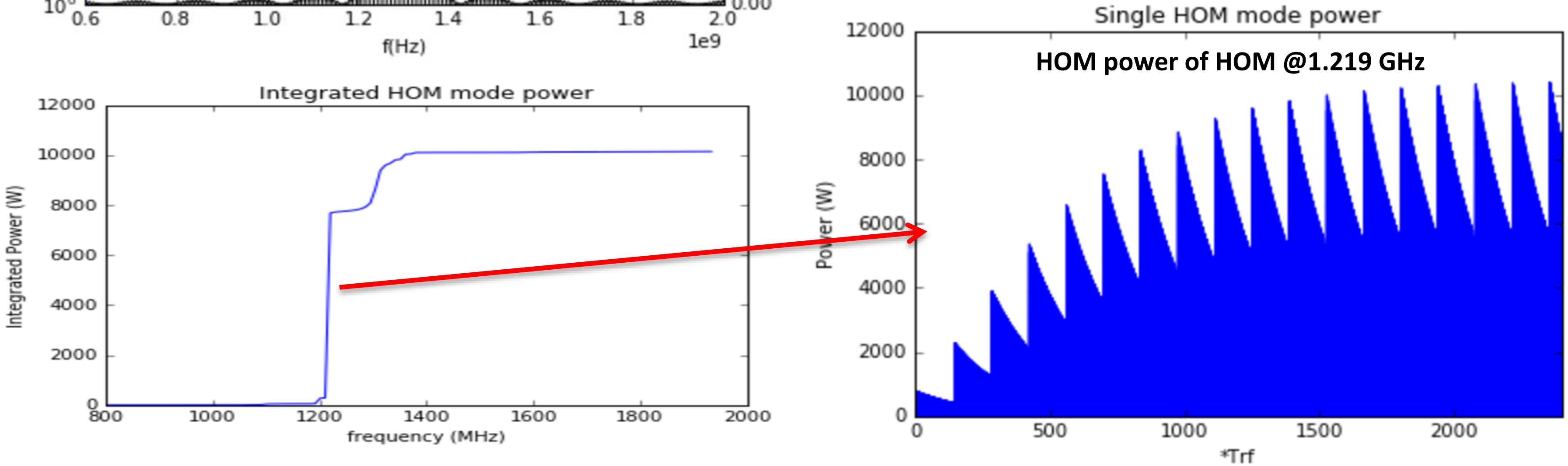
Lattice file	12 passes		
Final energy	20 GeV		
Results	frequency spread		Threshold current (mA)
	1.00E-03		67.5
	0		20.625

- HOM’s frequency spread ($\Delta f/f$) is important factor for BBU, the worst case is $\Delta f/f=0$. Even with this case, the threshold current is 18 mA, which is more than a factor of 3 of the requirement of 6 mA in eRHIC design.
- Usually, for a cavity fabrication, the frequency deviation is a few MHz or $\Delta f/f > 1E-3$.
- With $\Delta f/f=1E-3$, the threshold current is 67.5 mA > a factor of 10 of the requirement.

Spectral density for 5 Passes 50 mA ERL

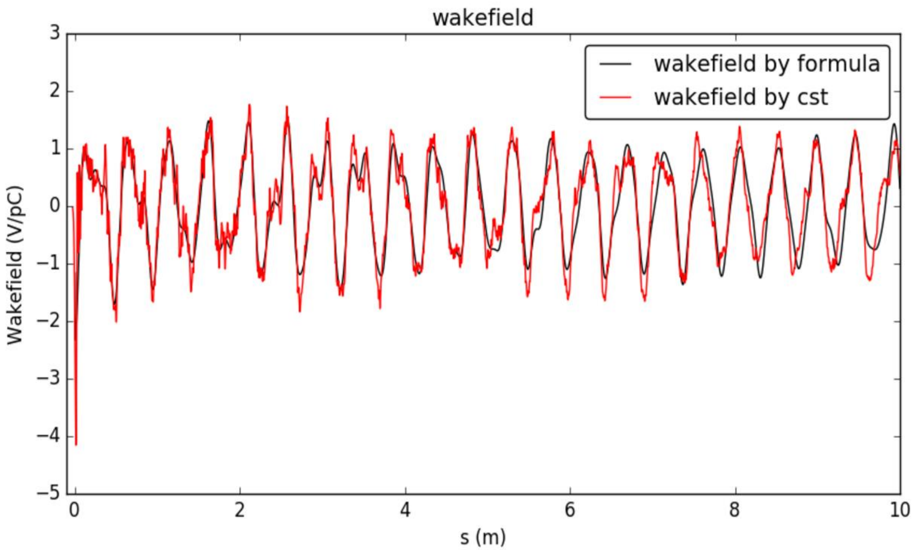


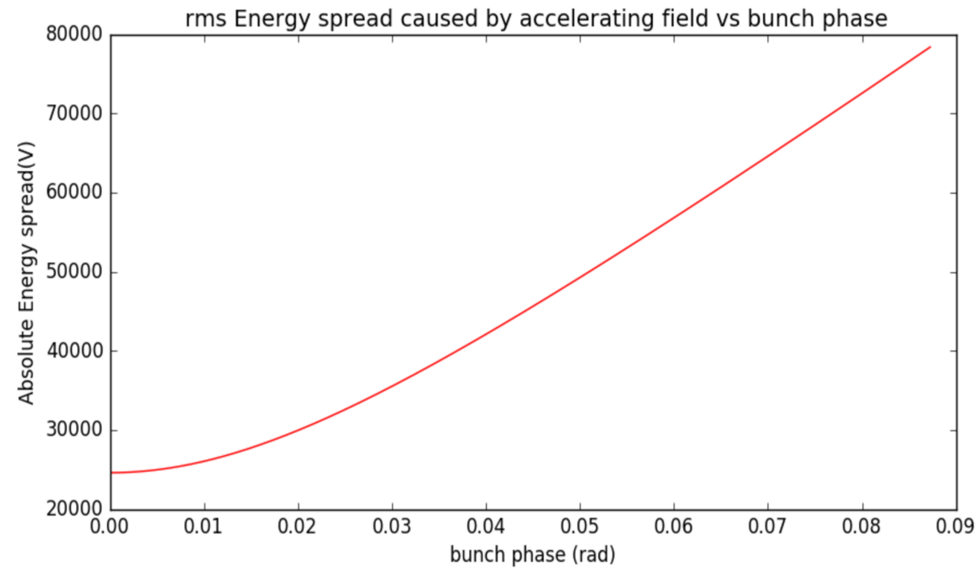
$$P_{HOM}\left(w,Q_{ext},t\right)=\frac{\left|V\left(\left(w,Q_{ext},t\right)\right)\right|^{2}}{\frac{R}{Q}*Qext}$$

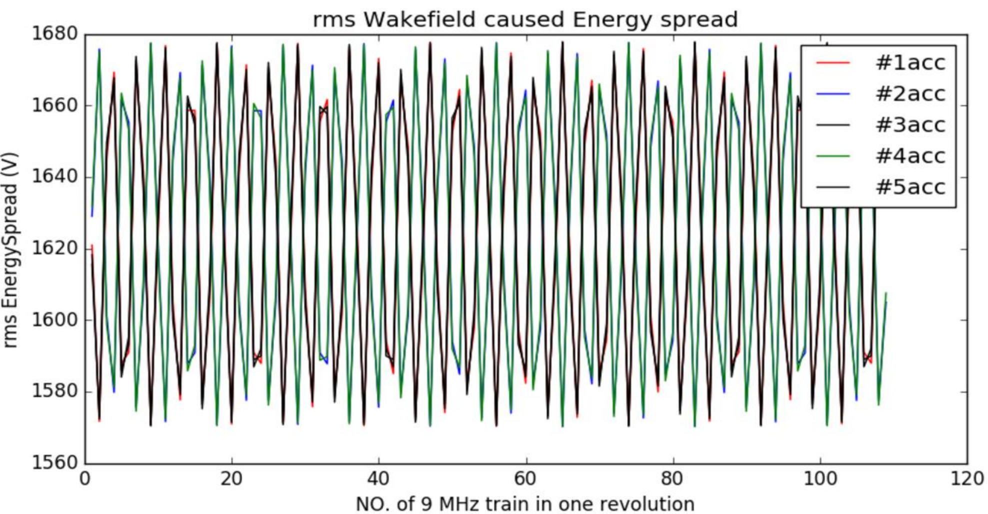


- ➢ **If some modes line up with the beam spectrum, the HOM power can be above 10 kW (depending how close is the HOM frequency and beam current spectrum).**

Energy spread caused by wakefield

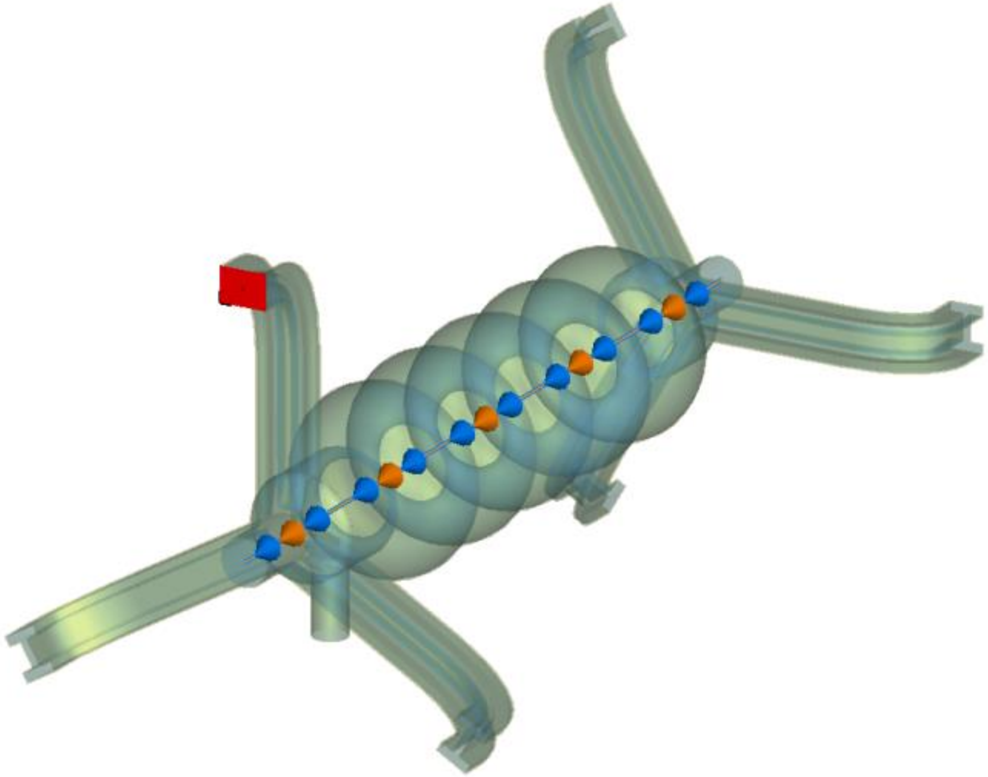






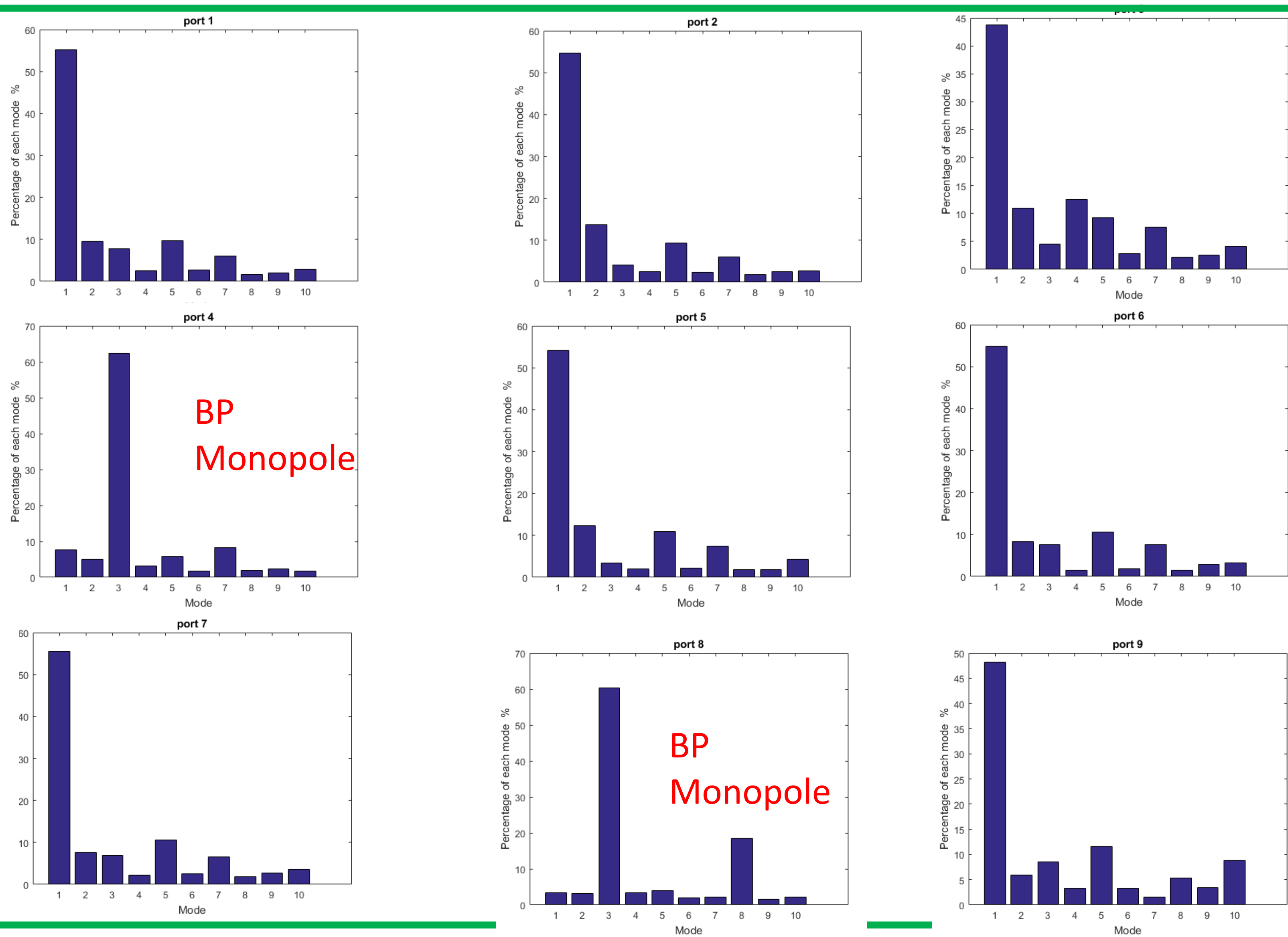
- All the calculation use rms 3mm gaussion bunch
- Single bunch Wakefield: build the wakefield by formula (only up to 2 GHz) and compare with cst results.
- rms Energy spread caused by wakefield (eRHIC bunch structure) is about 1700 V, < 25 kV of energy spread caused at zero RF phase (0.1% of energy gain in a cavity)

HOM power distribution (Y. Gao)

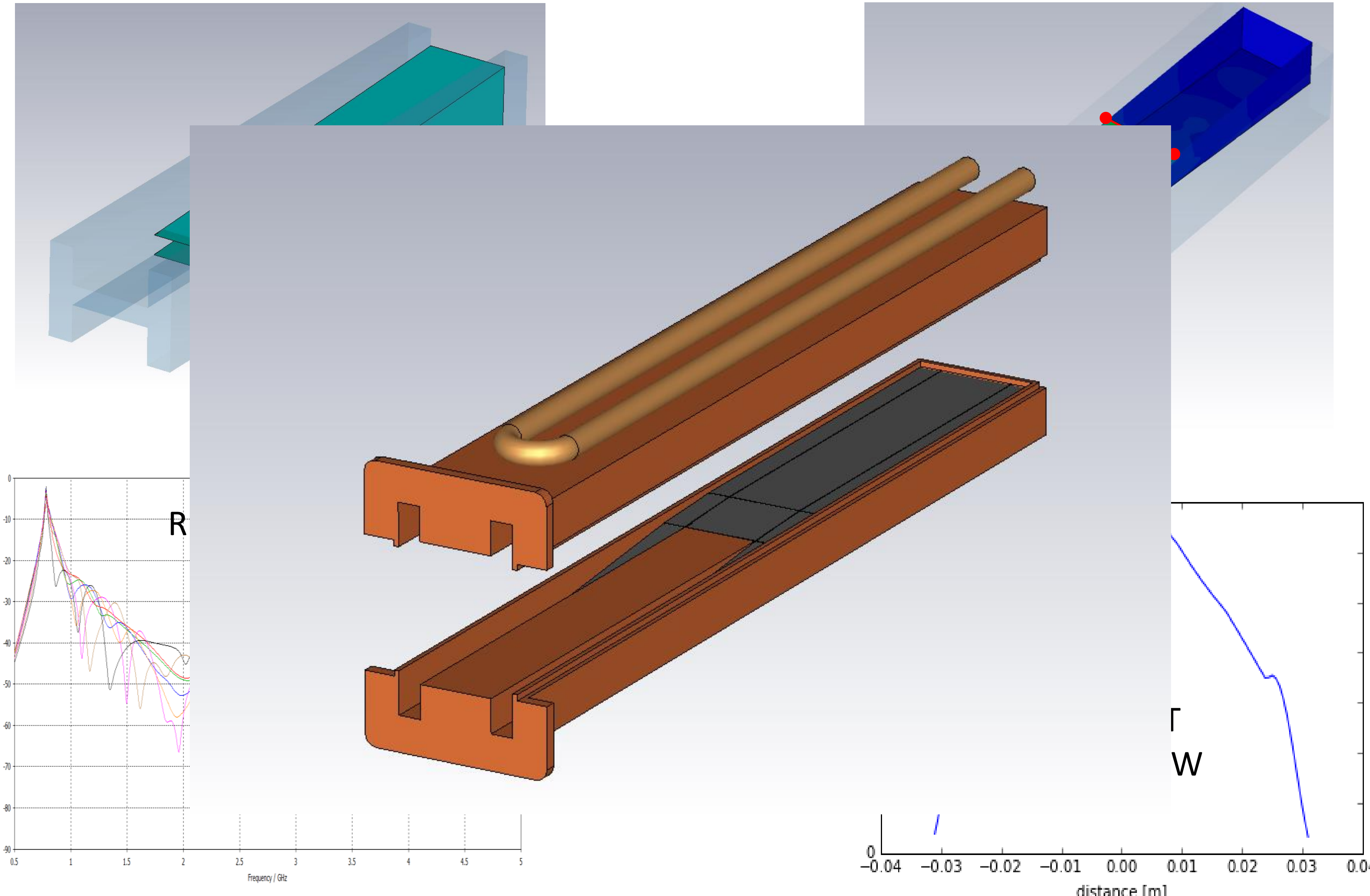


- This is to simulate the HOM power at each mode of every port.

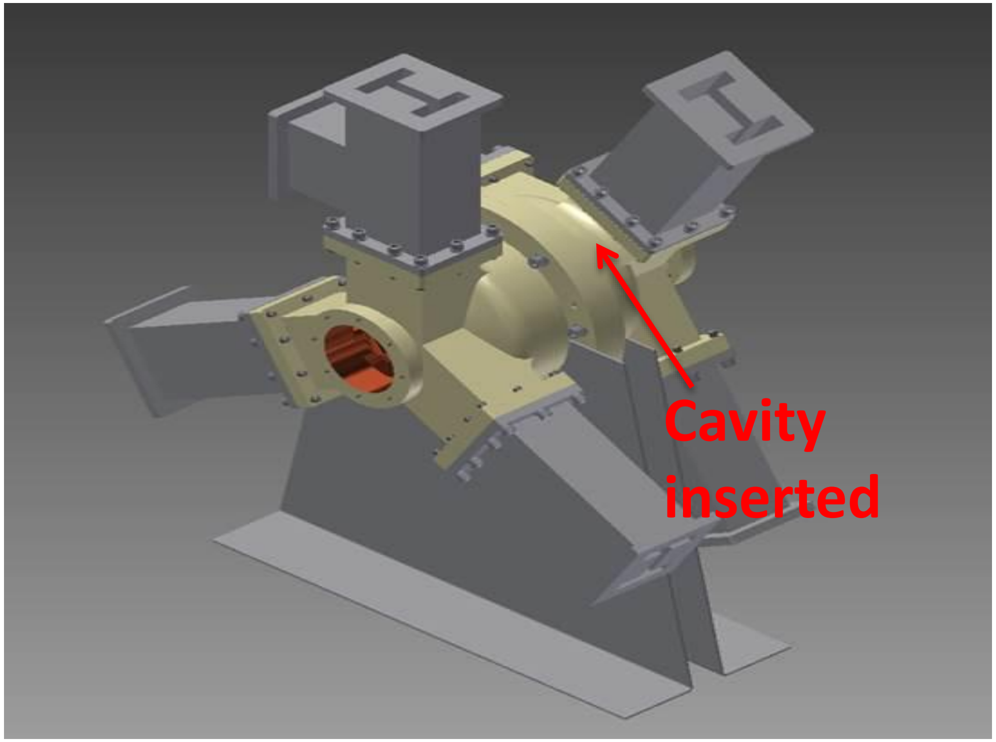
Percentage of modes for each port (Y. Gao)

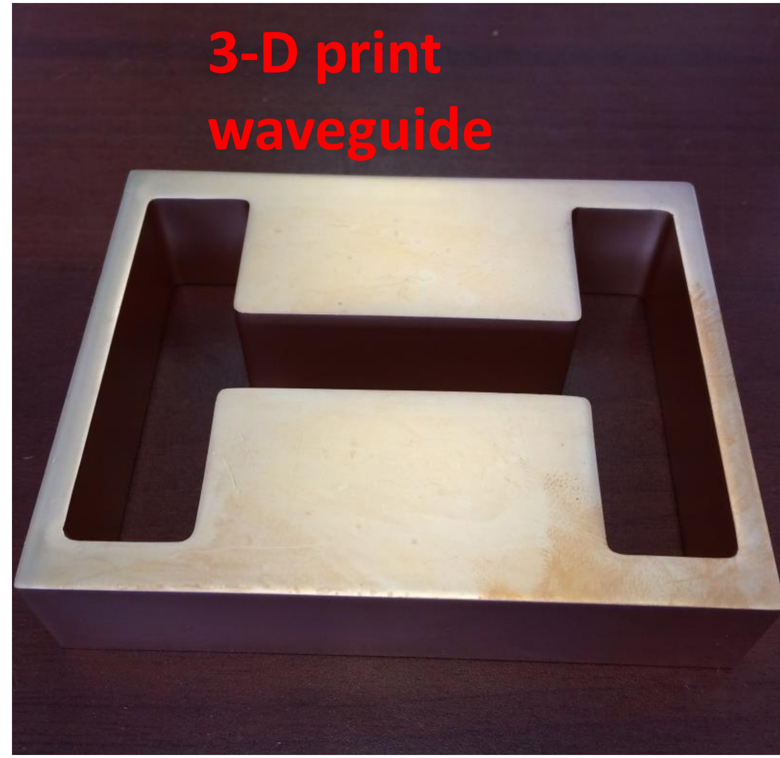


HOM absorber design (P. Kolb)

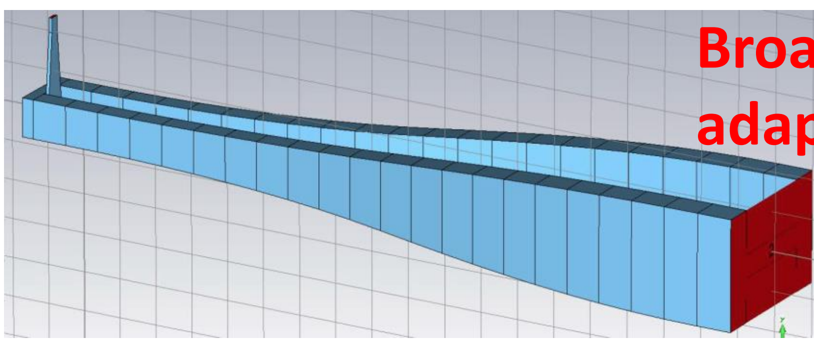


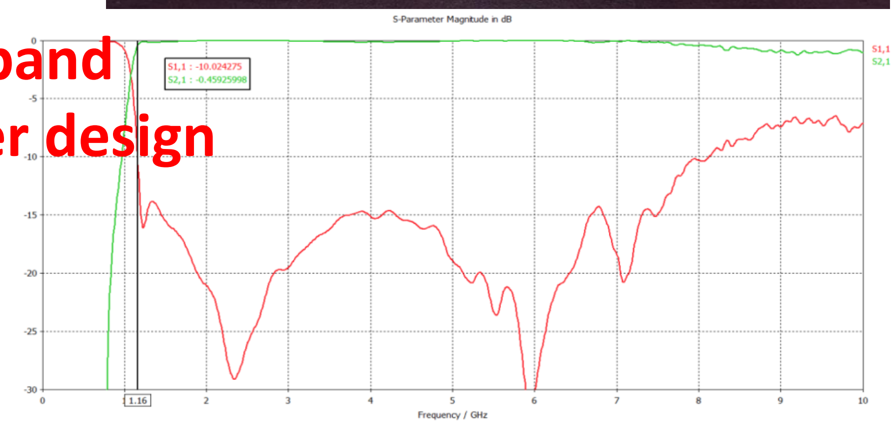
Prototyping



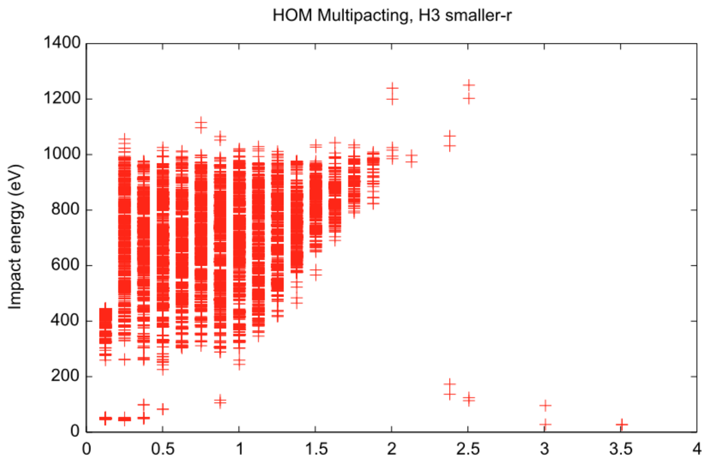


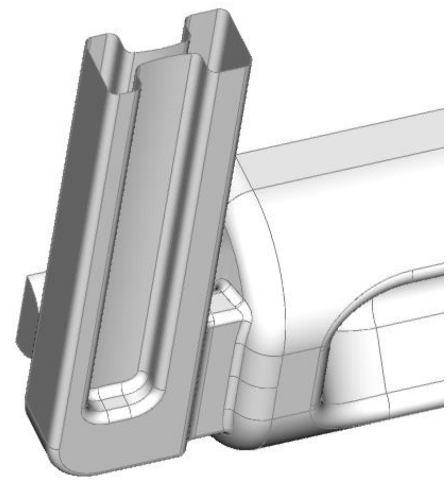
Broadband
adapter design

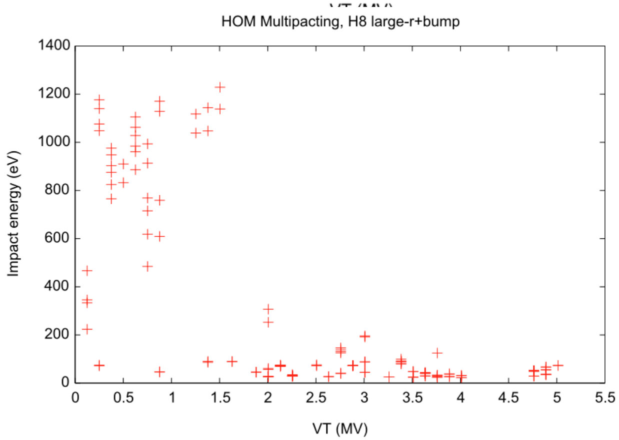


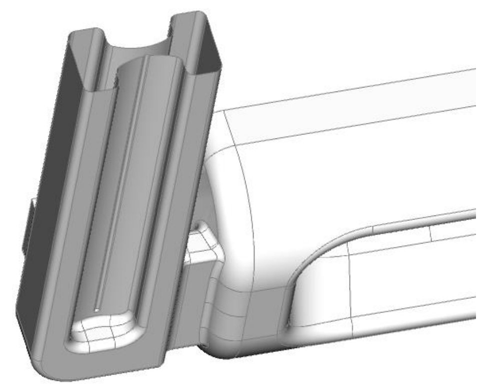


Variety of the HOM dampers: Round Ridge WG



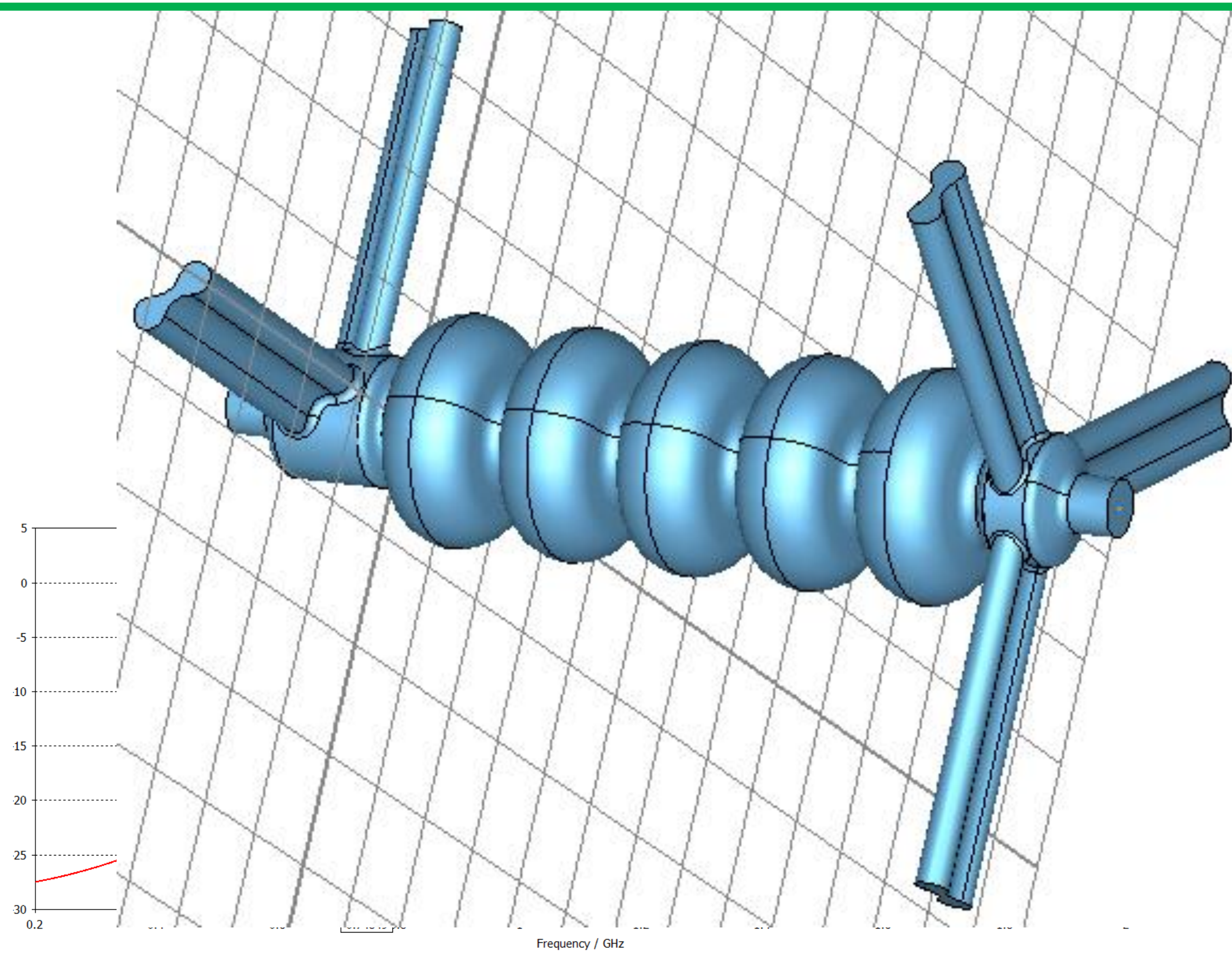






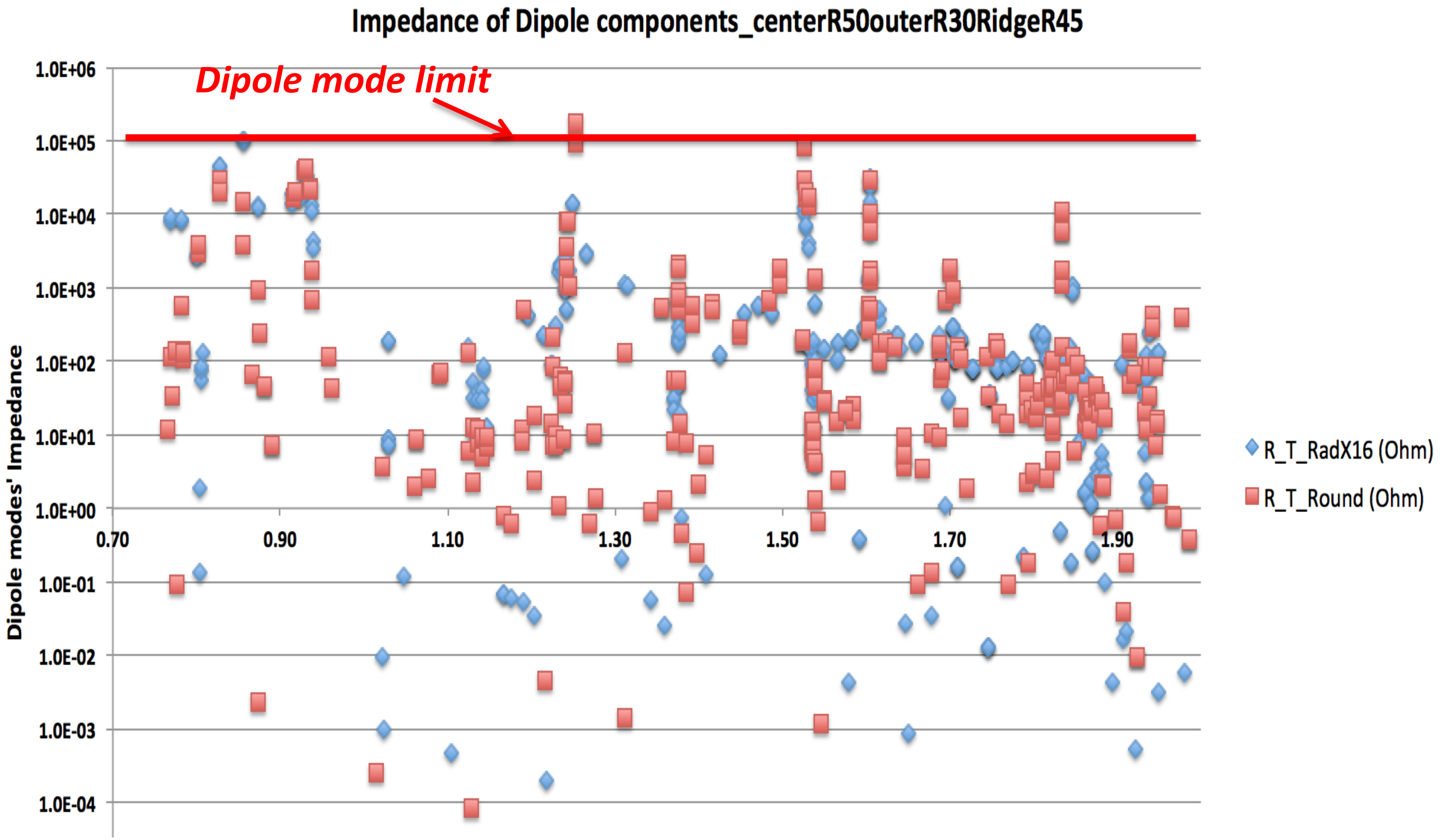
- Multipacting in the ridge waveguide by Zenghai Li, Suba De Silva and Jean Delayen. Sources of the information: Zenghai Li LARP CM20 April 8-10, 2013
- A bump one side of the ridge has to be add to suppress MP.

Rounded HOM damper: Parameters



- ✓ Multipacting free (Will be verified by simulation after it is finalized)
- ✓ Work on progress.

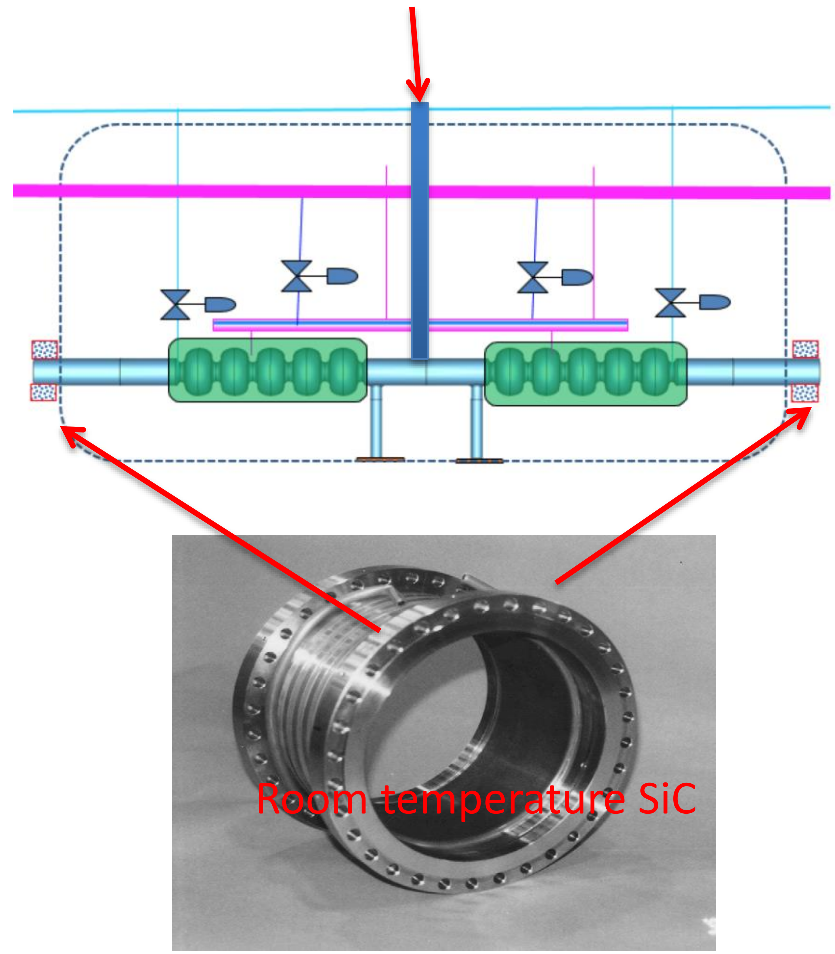
Preliminary result: Impedance



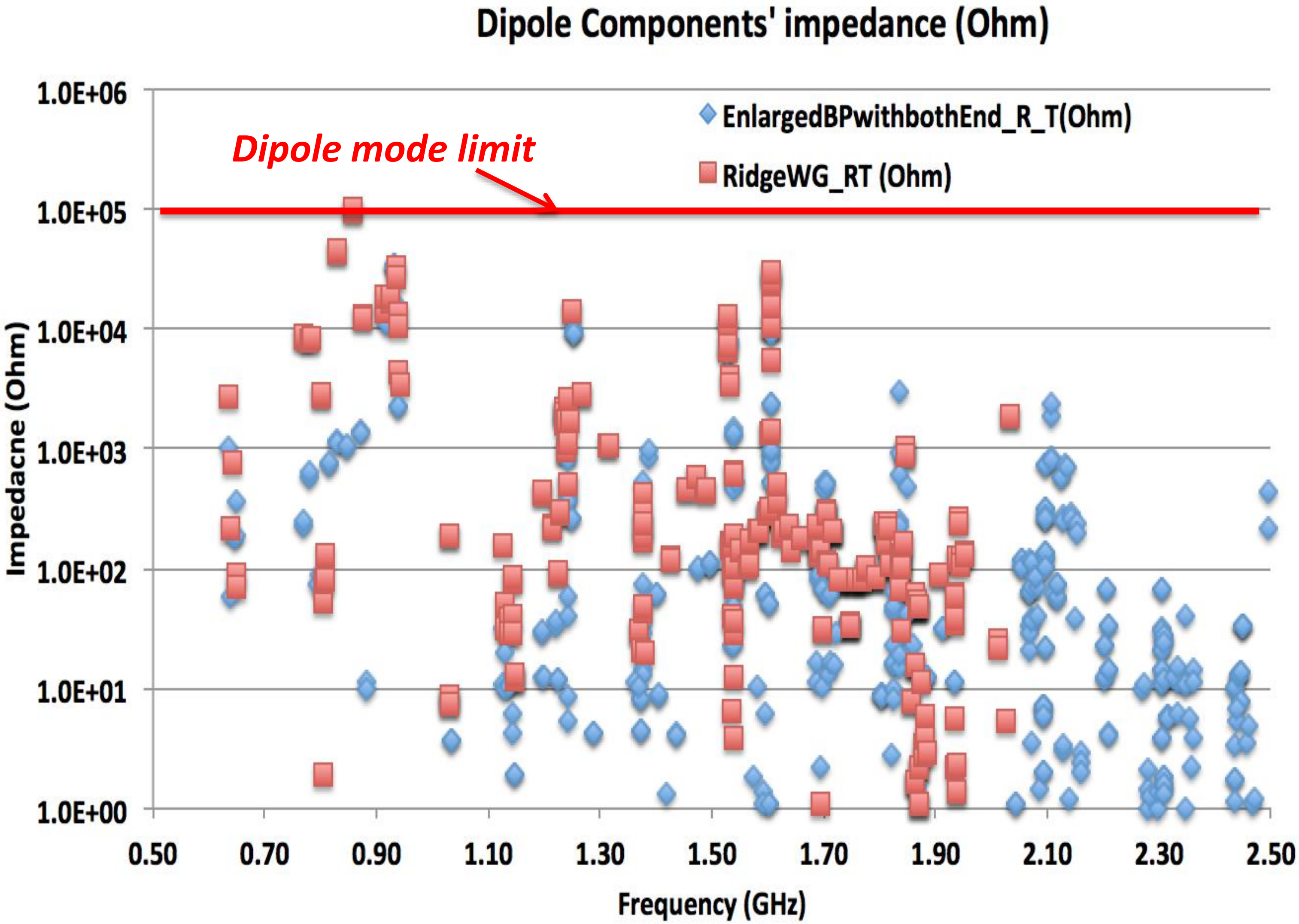
Low Risk Linac design

Energy gain per pass [GeV]	1.5
Number of cavity	2
Accelerating gradient [MV/m]	18
RF coupler per cavity	1
Operation temperature [k]	1.9
Q factor at operating gradient	3E10
Number of ridge waveguide per cavity	0
Number of RT beam line absorber	2
Cavity length (flange-to-flange) [m]	1.95
Effective cavity length [m]	1.15
End Transition [m]	0.55
Inter-cavity length	0.1
Valve	0.15
Beam line damper	0.35
Length of module with RT absorber [m]	5.5
No. of cryomodule	36
No. of cavities	72
Total linac length	198

As there are some new modes between two cavities, a ridge WG damper in between the cavities will needed as well.

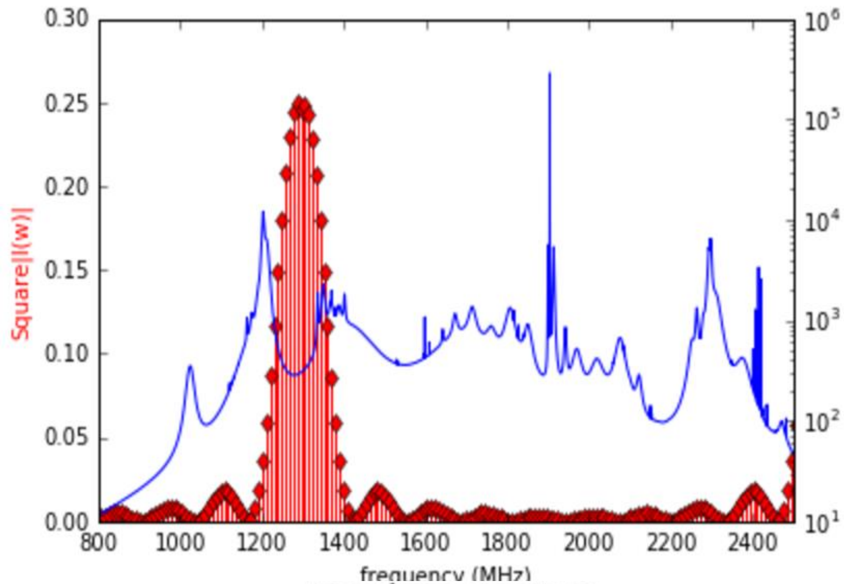


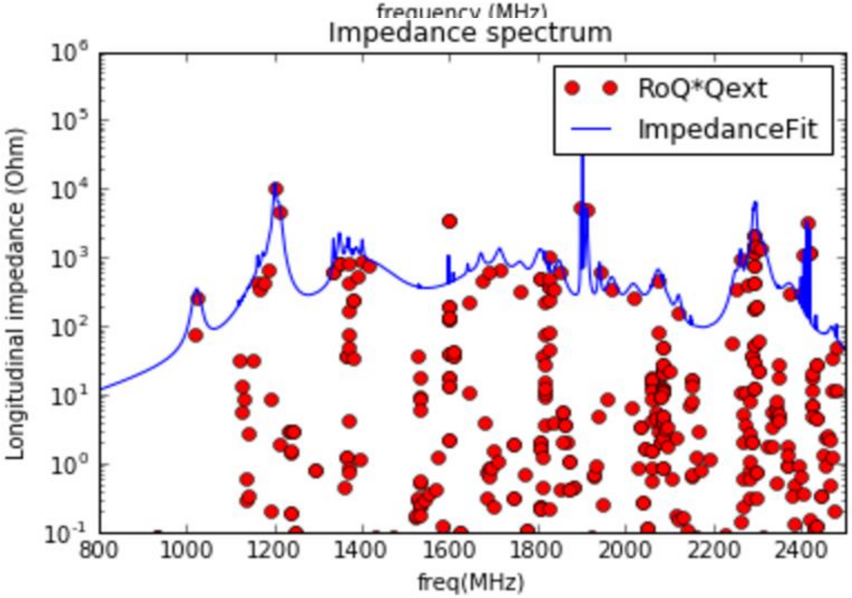
HOM impedance for low-risk linac

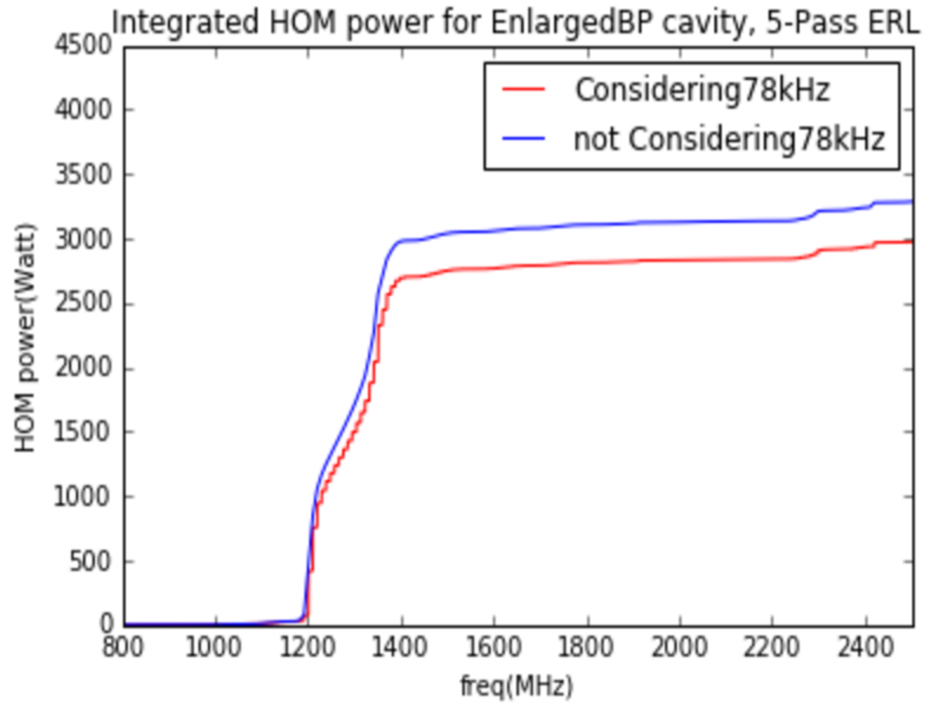


✓ BBU simulation will be done as soon as the lattice design is completed.

HOM power up to 2.5 GHz of low-risk linac







- This is HOM power is calculated with beam (5-pass ERL) and HOM spectrum, and it is frequency is only up to 2.5 GHz.
- This HOM power is much lower than the rectangular ridge waveguide mainly because of the frequency of HOM shifted.

Summary

- eRHIC ERL SRF linac, based on 650 MHz 5-cell cavities, requires extremely good HOM damping for to reach high current, high luminosity.
- 650 MHz SRF cavity was designed for damping all the HOMs. A Nb and Cu cavity are under fabricating by RI. The Cu cavity will be fabricated for HOM study. The Nb cavity will be carried out performance study, and then modified by adding HOM dampers.
- R&D on HOM damping scheme includes ridge waveguide for low frequency and beam piper absorber for high frequency HOM. Rectangular ridge waveguide is designed and prototyping.
- While working on R&D on the compact linac scheme (with ridge waveguide and beampipe absorber), a "Low risk" linac scheme with lower HOM power and lower dipole impedance is under evaluating.

Acknowledgement (incomplete list)

- ✓ **BNL team: Philipp Kolb, Ilan BenZvi, Harald Hahn, Kevin Yongfeng Gao, Vadim Ptitsyn, Kevin Smith, Kevin Mernick, Chen Xu, Hao Yue, Alex Zaltsman, Rich Porqueddu…**

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  - **Jlab: Bob Rimmer, Haipeng Wang, Frank Marhauser…;**
  - **LBNL: Derun Li, Yawei Yang, Tianhuan Lou…;**
  - **ANL: Peter Ostroumov, Michael Kelly, Sanghoon Kim..**
  - **Mega: Lisa Cummings, Peter Matthews..**