SRF R&D for eRHIC

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On behalf of team

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Outline

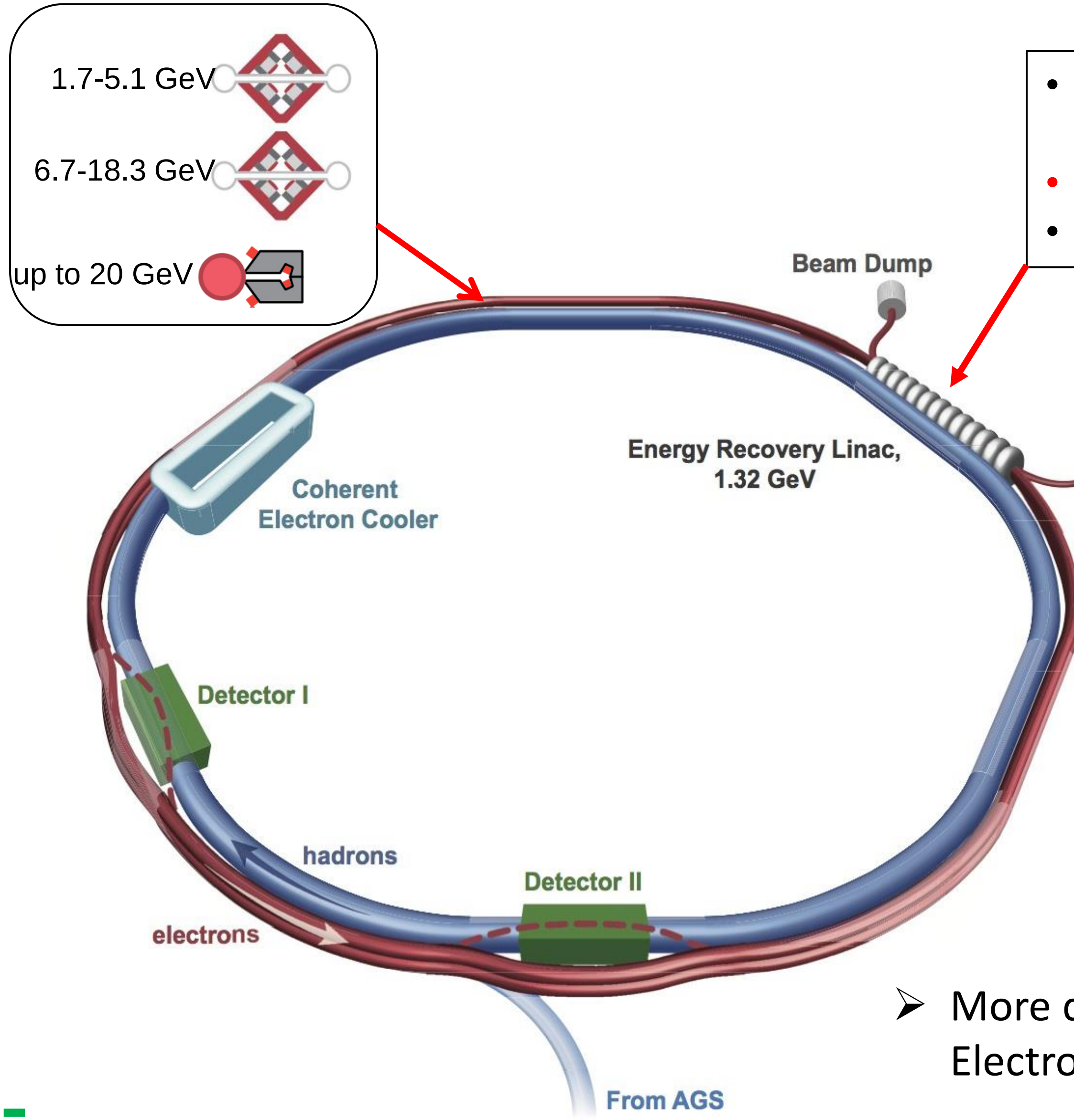
I. Progress and R&D plan on SRF cavity

II. HOM damping for low-risk and FFAG lattice eRHIC

III. Summary

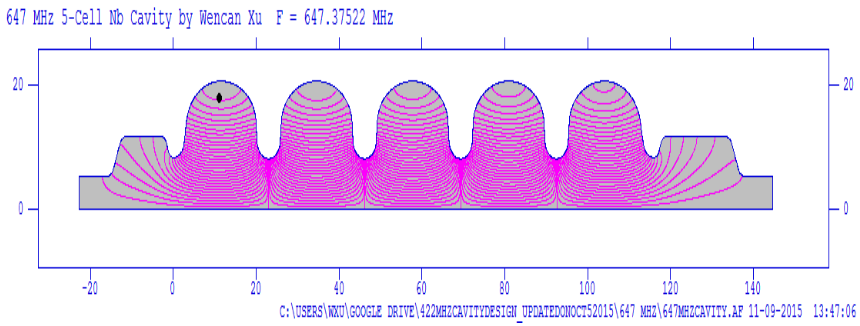
ERL SRF linac in FFAG lattice eRHIC

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

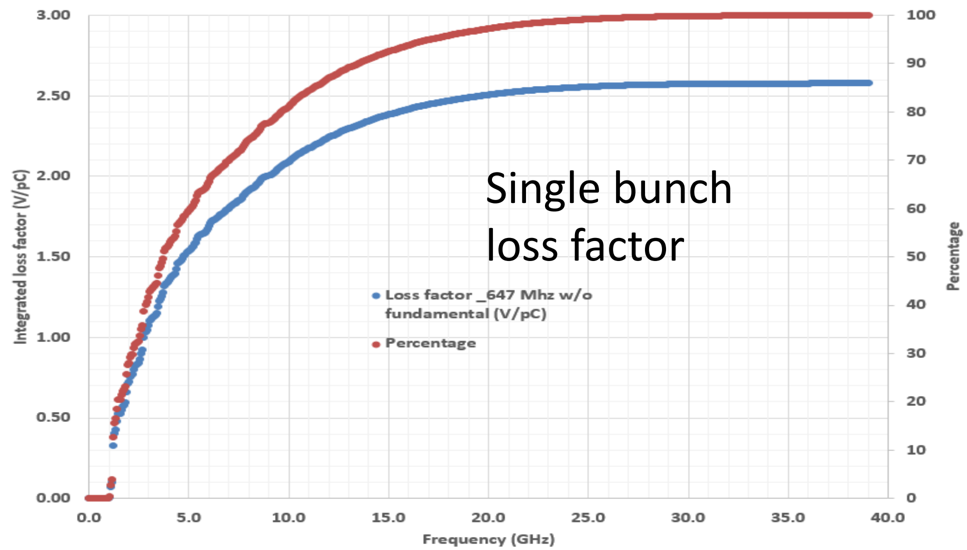


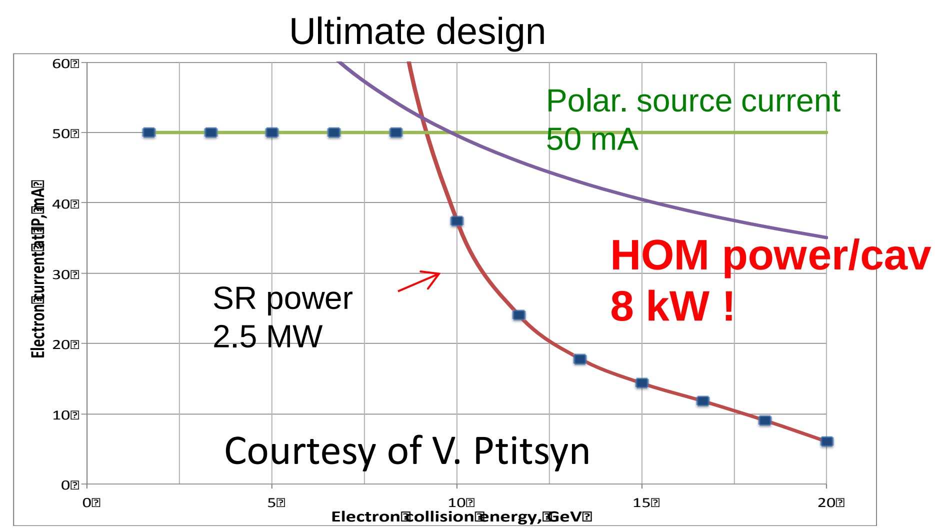
- 647 MHz 5-cell cavity.
- Gradient: 18 MV/m@Q0=3e10.
- FPC power: 30 kW, Qext: 2e7
- 4 cavity per cryomodule
- HOM damping: Ridge WG and RT absorber
- More detail @ eRHIC Design Study: An Electron-Ion Collider at BNL, arxiv: 1409.1633

RF design of 647 MHz cavity



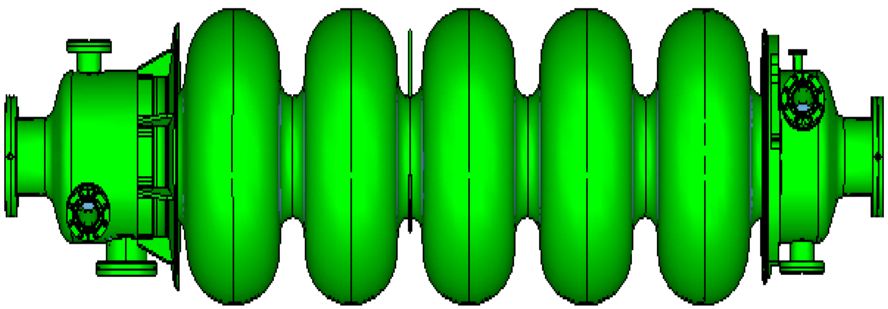
Parameters	647 MHz 5-cell cavity
Frequency [MHz]	647
Number of cells	5
Geometry factor [Ω]	273
(R/Q)/Cavity [Ω]	502
Epeak/Eacc	2.27
Bpeak/Eacc [mT/MV/m]	4.42
Coupling factor [%]	2.8
Cavity length [m]	1.72



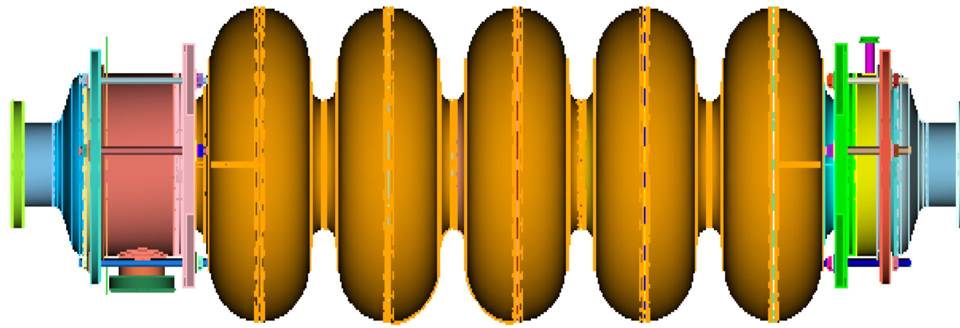


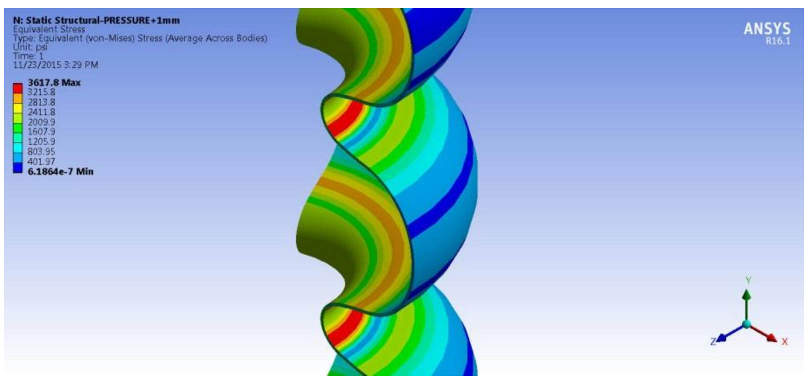
mechanical design of 647 MHz cavity

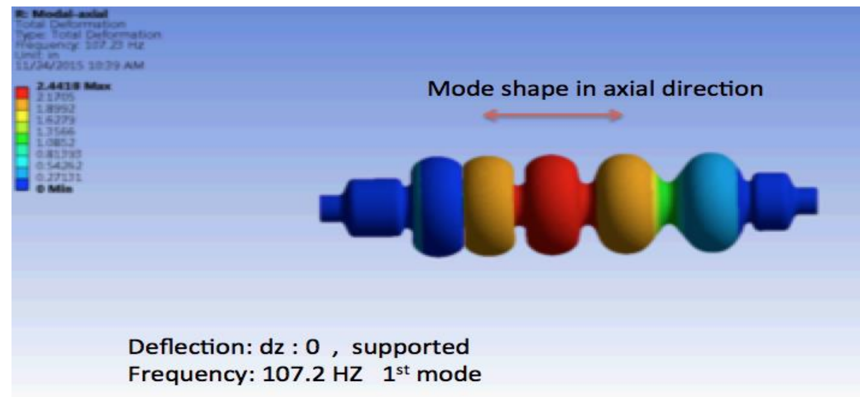
Nb cavity



Cu cavity







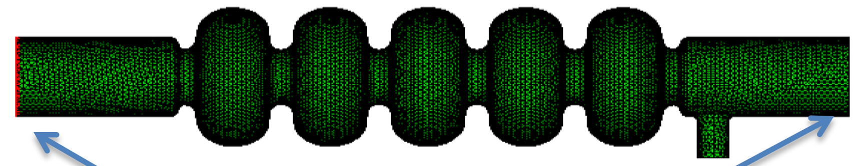
- The tuning range for eRHIC cavity is 173 kHz to match different Proton energy.
- Tremendous mechanical analysis was carried out, and decided to have 4 mm wall thickness without Stiffness ring. This makes a reasonable tuner load, mechanical stress bellow 7000 psi.
- With tabs on the middle cell of the cavity, the first mechanical mode is longitudinal mode and is 107 Hz.
- Two cavities are fabricated by RI: one Nb cavity for caivty's performance study and one Cu cavity with demountable endgroup for HOM measurement.

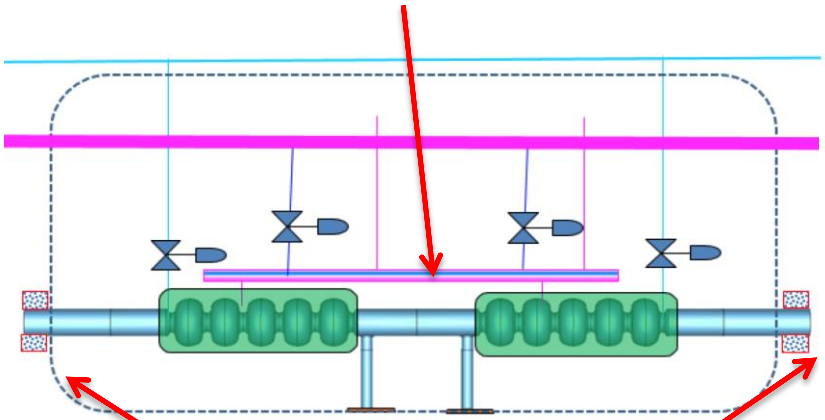
HOM damping for eRHIC

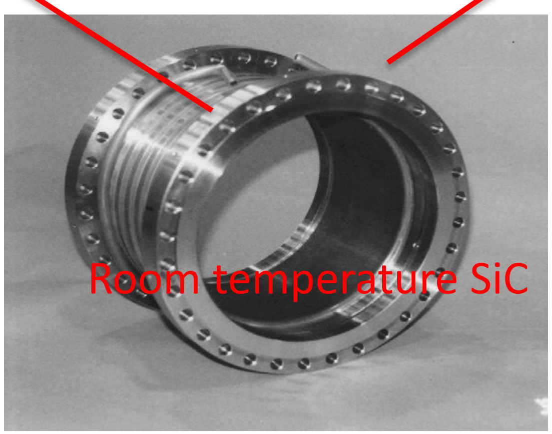
- **HOM damping for Low-Risk Linac-Ring:**
  - **Linac configuration: 2 X 1.5 GeV linac per turn, 2 cavities and 2 RT beampipe absorbers per cryomodule**
  - **Maximum HOM power (50 mA 4-pass 12 GeV ERL, bunch charge: 5.3 nC, rms bunch length 3 mm);**
  - **Bunch pattern optimization (from HOM power point of view)**
  - **BBU simulation results**
- **FFAG lattice based eRHIC design:**
  - **Linac configuration: 1 X 1.67 GeV Linac per turn; 4 cavities per cryomodule; ridge waveguide plus RT absorber for HOM damping**
  - **Maximum HOM power (50 mA 5-pass 12 GeV ERL, bunch charge: 5.3 nC, rms bunch length 3 mm);**
  - **BBU simulation results**

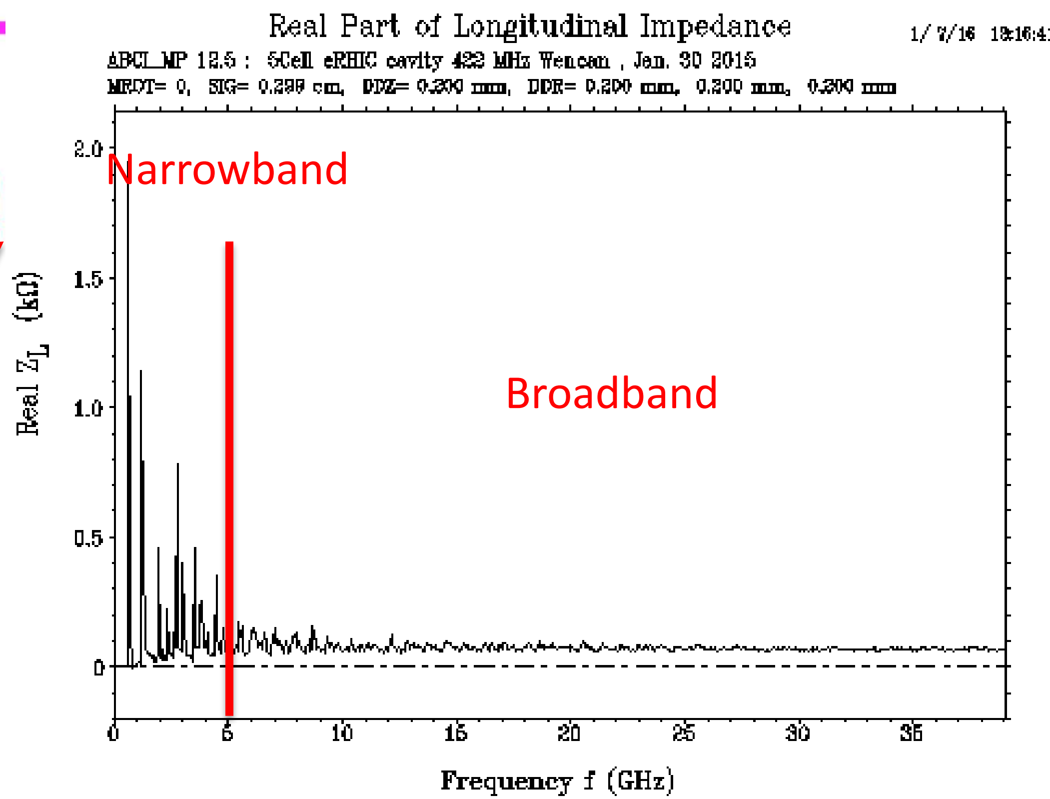
HOM evaluation for Low-risk linac

- As there are some new modes between two cavities, a damping maybe required between cavity

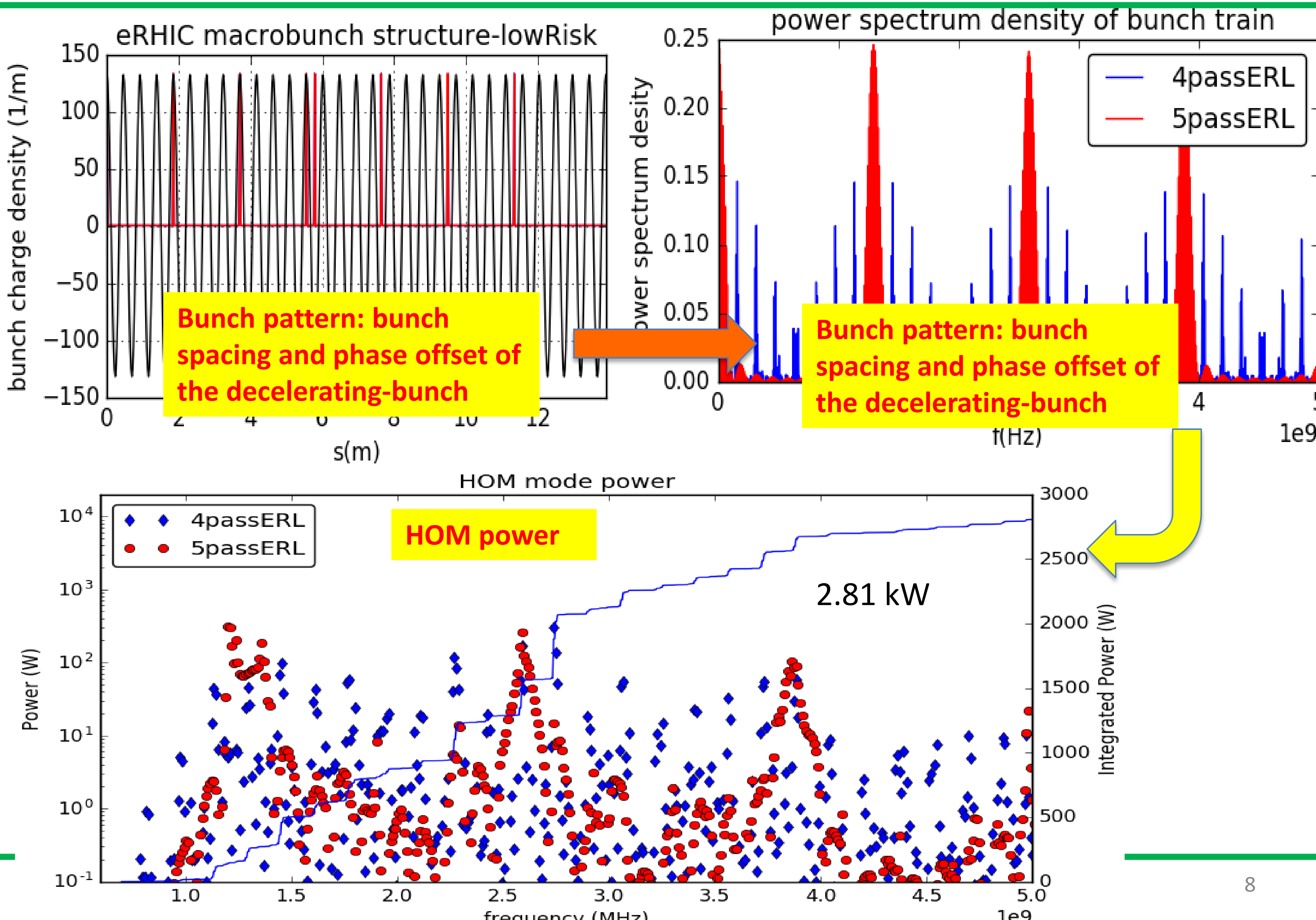




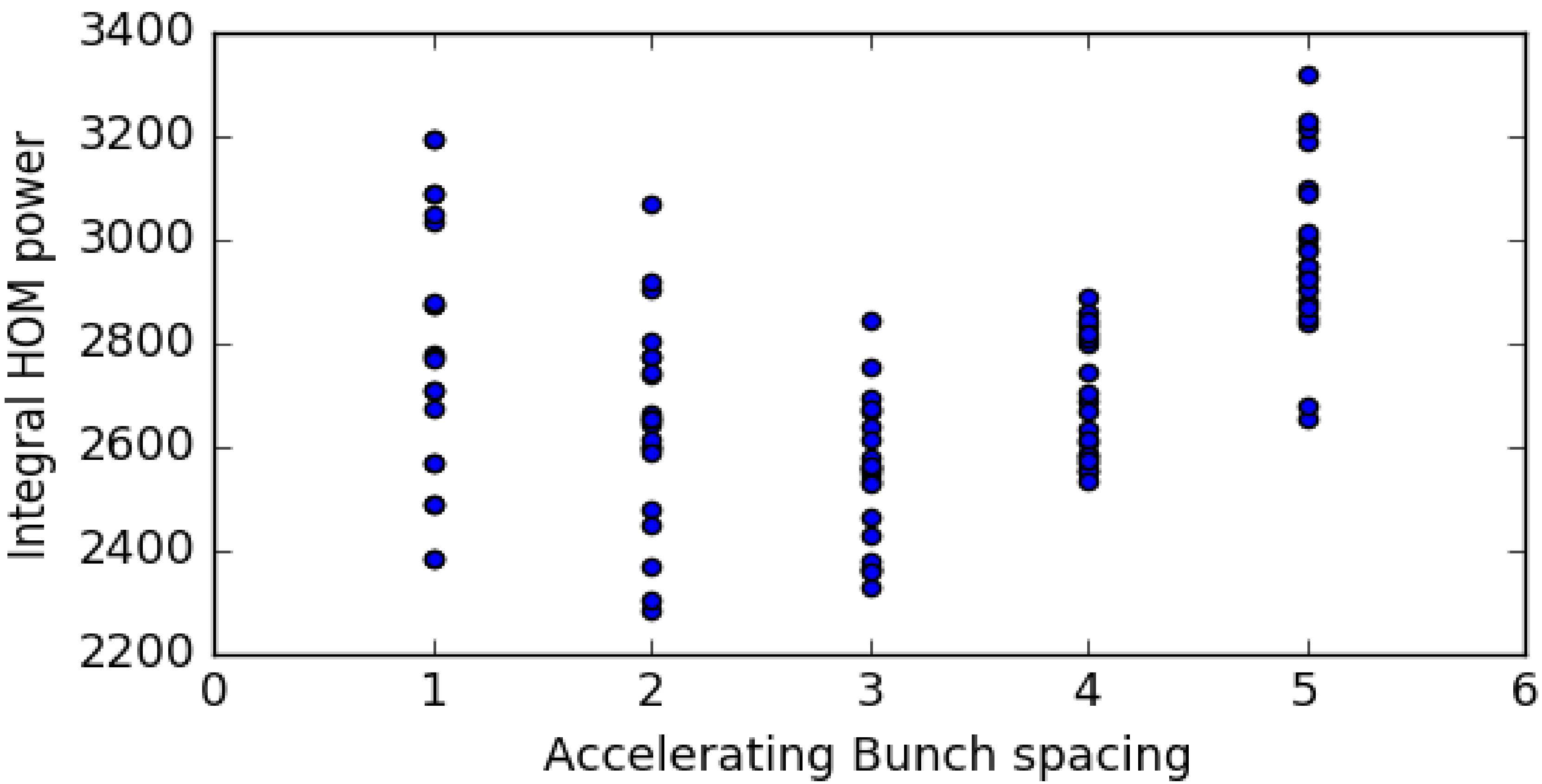




Narrow band HOM power (1): Bunch pattern optimization

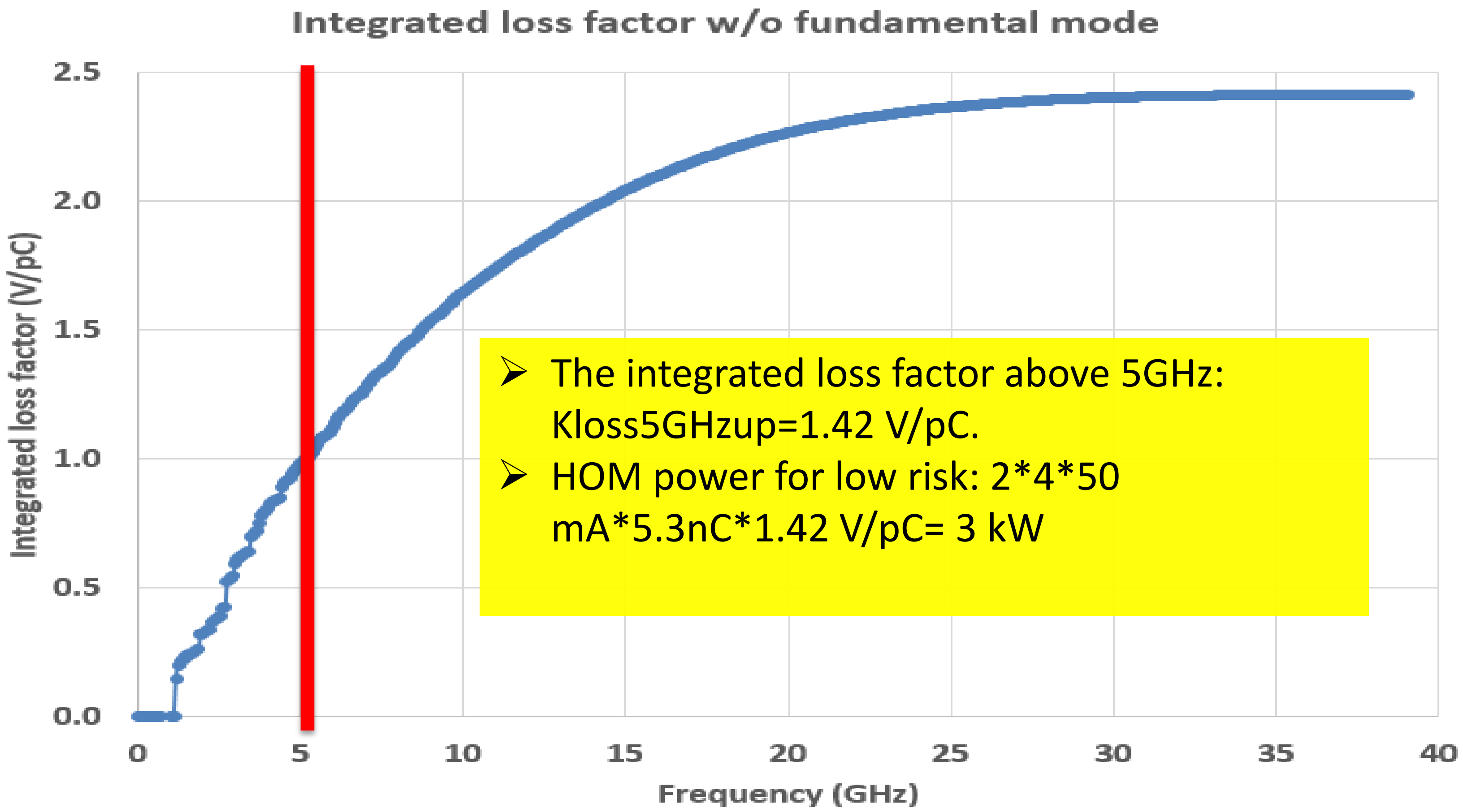


Narrow band HOM power (2): Bunch pattern optimization



- ✓ Maximum bunch spacing (5) is fixed by RHIC tunnel.
- ✓ Tuning the decelerating bunch offset the HOM power varies from 2.3 kW to 3.3 kW.
- ✓ However, if HOM frequency overlaps with the bunch spectrum, this power can be much higher.

Broadband HOM power



- The integrated loss factor above 5GHz: Kloss5GHzup=1.42 V/pC.
- HOM power for low risk: 2*4*50 mA*5.3nC*1.42 V/pC= 3 kW

✓ The total HOM power is 3.4 kW (narrow band) + 3 kW (broadband) =6.4 kW.

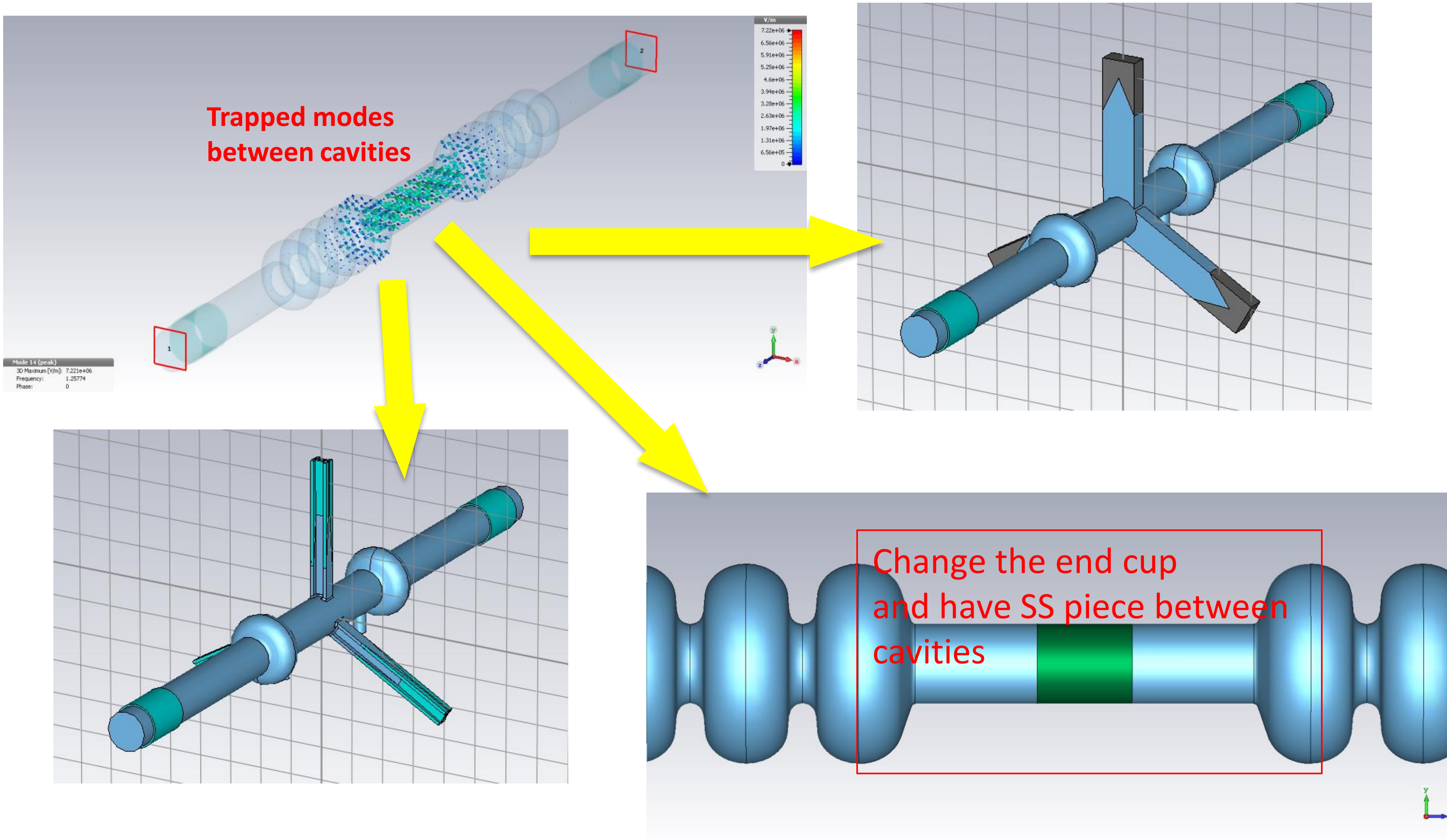
✓ The HOM damper design goal for low risk linac design is 15 kW, which is to cover the potential overlapping of HOM frequency and beam spectrum.

BBU results of Low-risk linac (*Y. Hao*)

RMS Frequency spread	6 passes Need 12 mA		4 passes Need 50 mA	
	Threshold current (mA)	Min current of 50 seeds (mA)	Threshold current (mA)	Min current of 50 seeds (mA)
0	16	N/A	27	N/A
1e-3	45+/-3	41	78+/-5	65
3e-3	99+/-11	81	168+/-18	132

- BBU simulation done with GBBU code.
- With reasonable frequency spread, the threshold current reaches the requirements with a >2 factor of margin.

Issues for low-risk linac configuration (P. Kolb)



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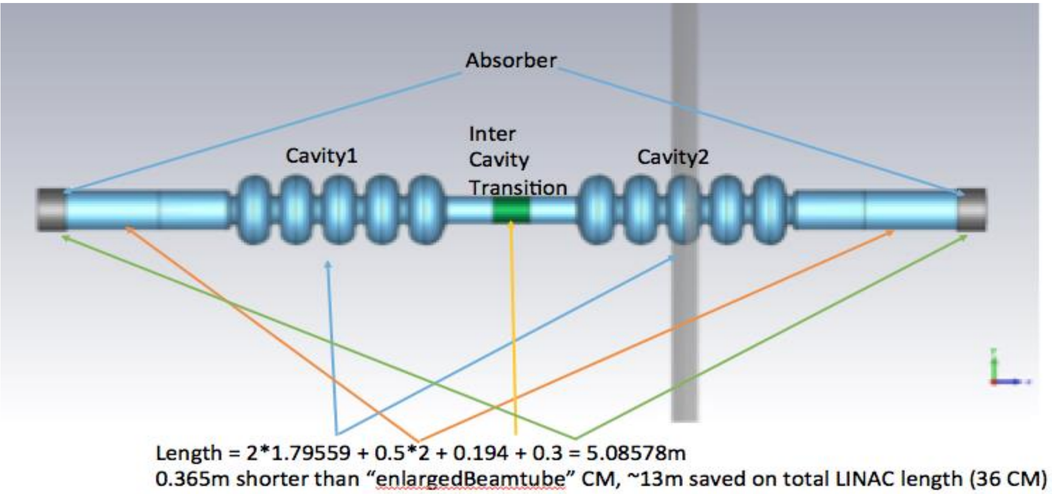
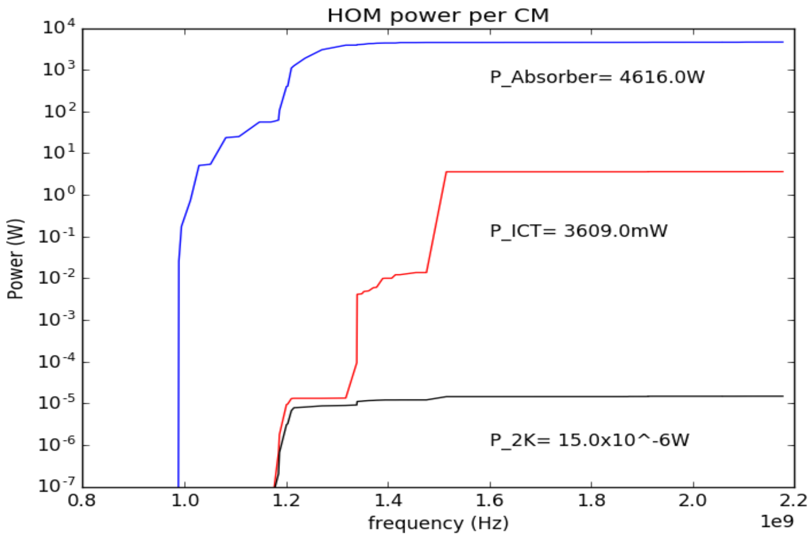
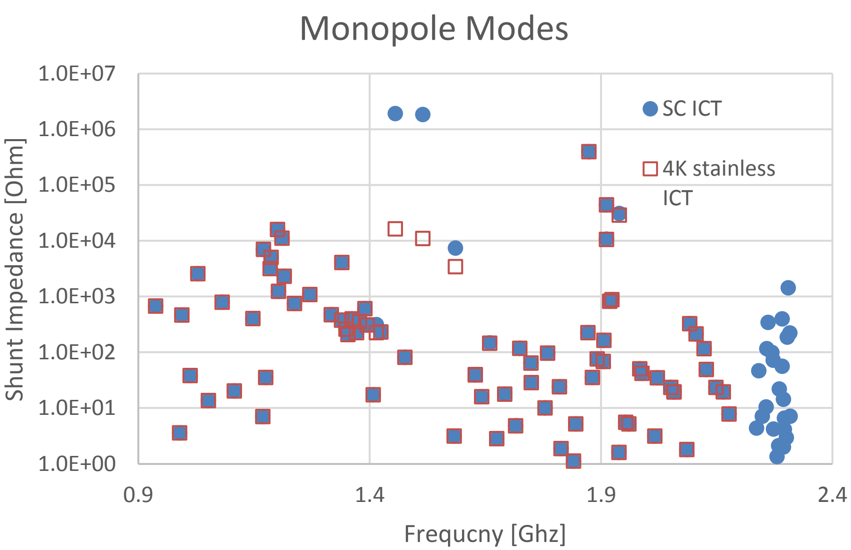
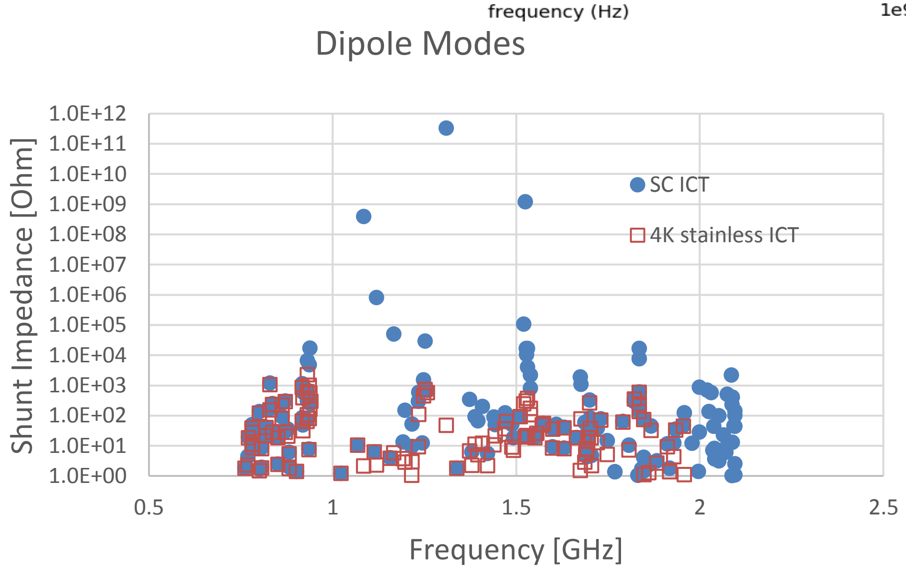
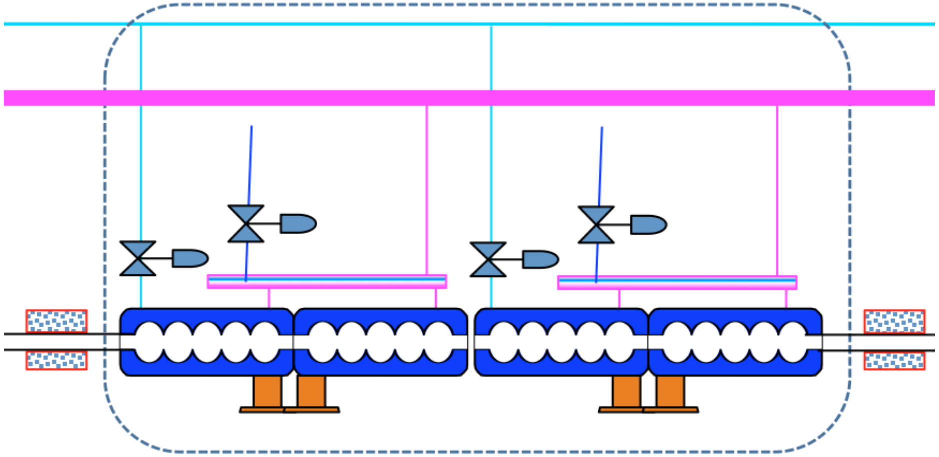


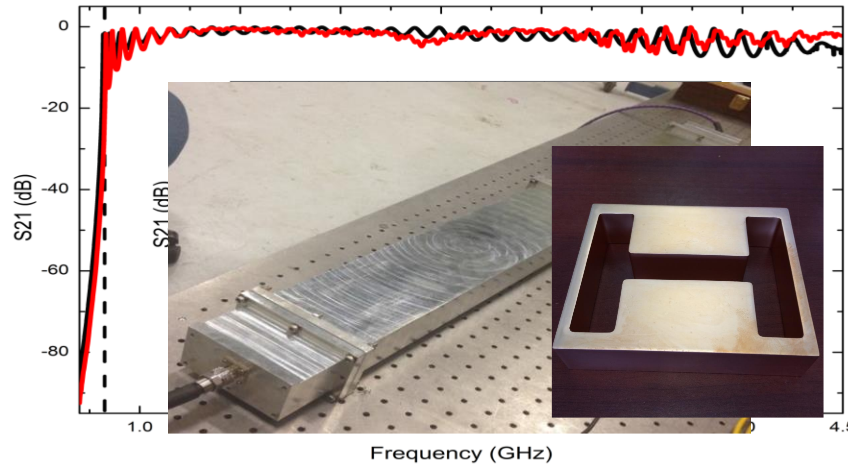


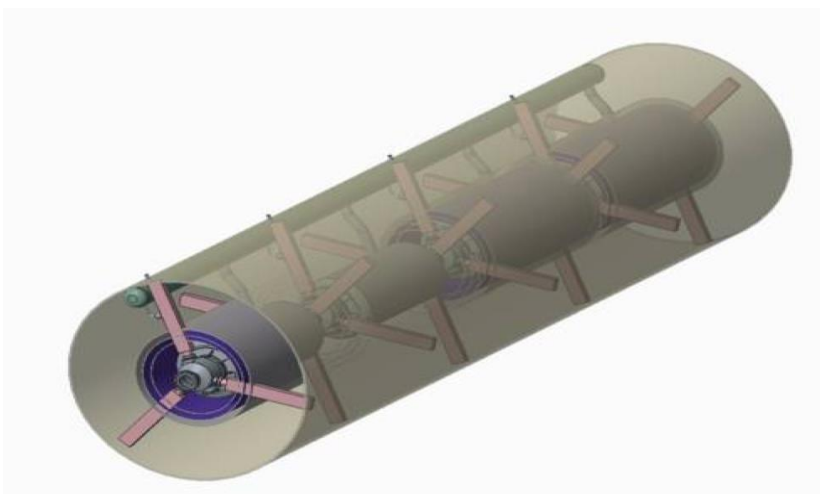




HOM damping for FFAG lattice

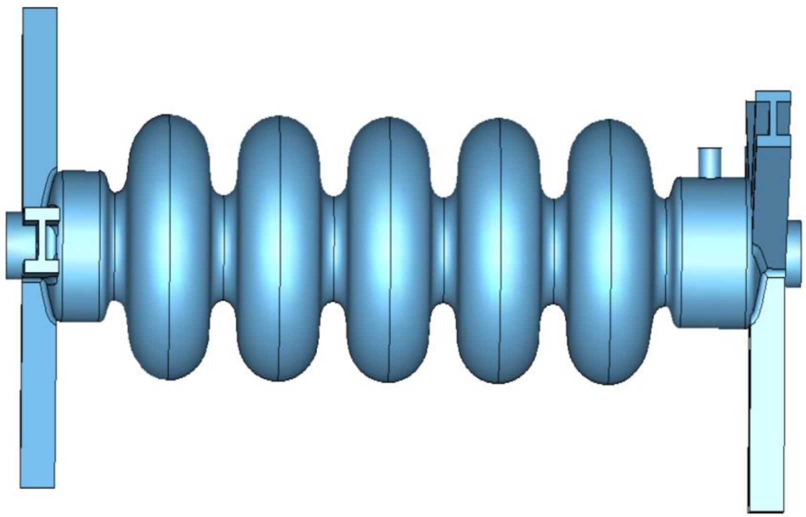


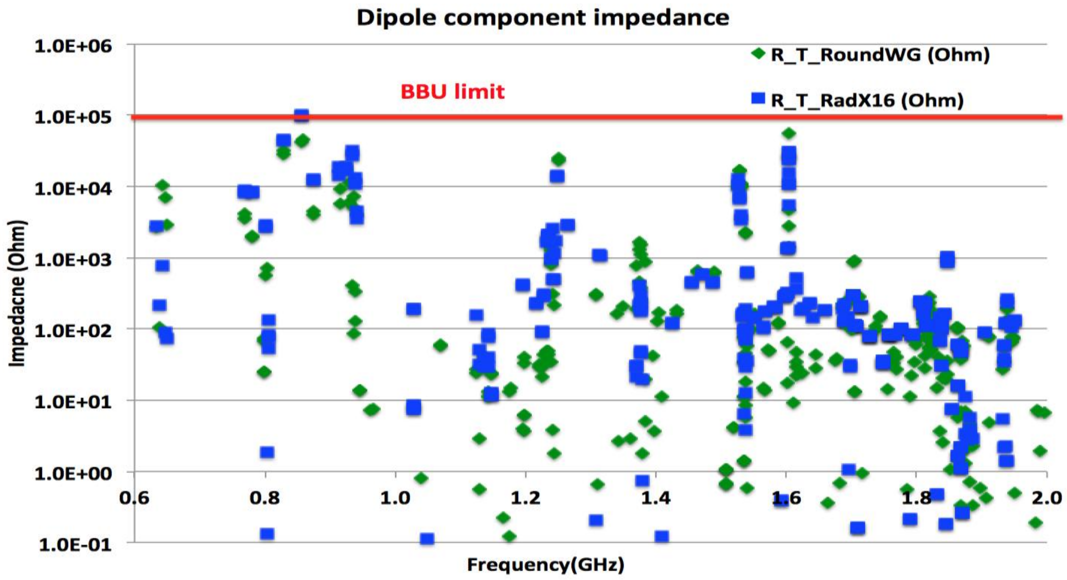


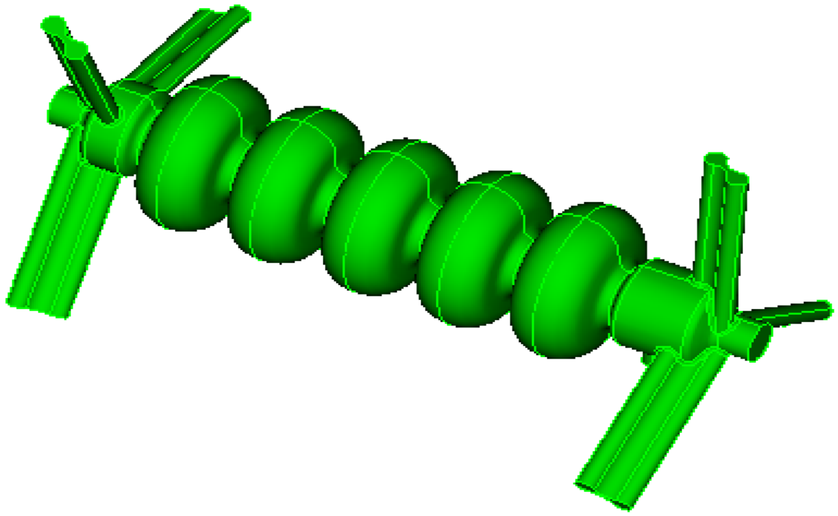


- **Two types of HOM damper for different frequency:**
  - ✓ **Five or six Ridge WG HOM damper, so each waveguide will take about 2 kW.**
  - ✓ **Two room temperature HOM damper for one cryomodule (one at each side) for high frequency HOMs.**
- **Ridge waveguide**
  - ✓ **Ridge WG is a nature high pass filter with higher bandwidth, smaller size (1/4) than regular WG.**
  - ✓ **Ridge waveguide has larger bandwidth.**
  - ✓ **Ridge WG has lower conduction heat load and is easier to cool.**

Uniform Ridge Waveguide HOM damping results

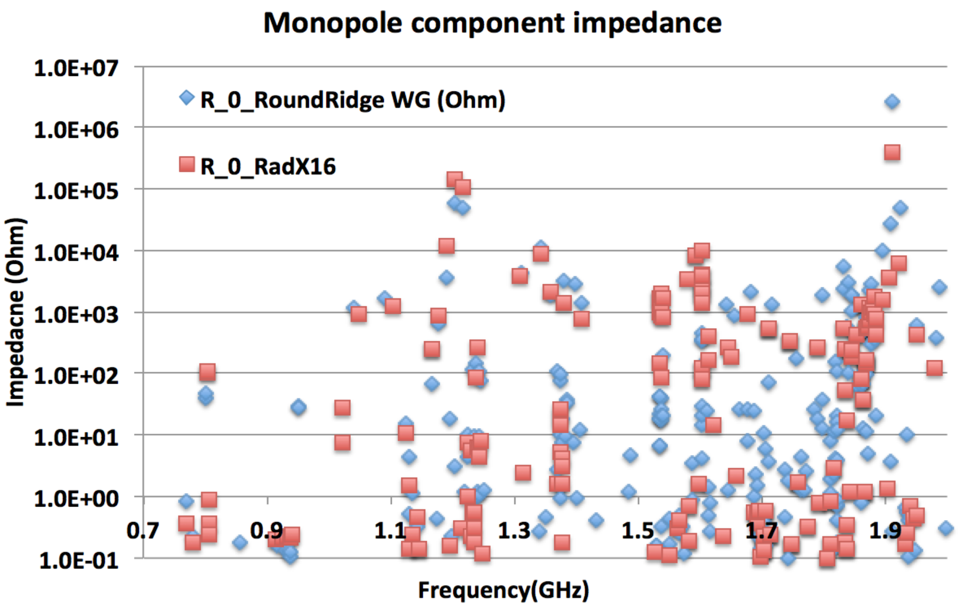


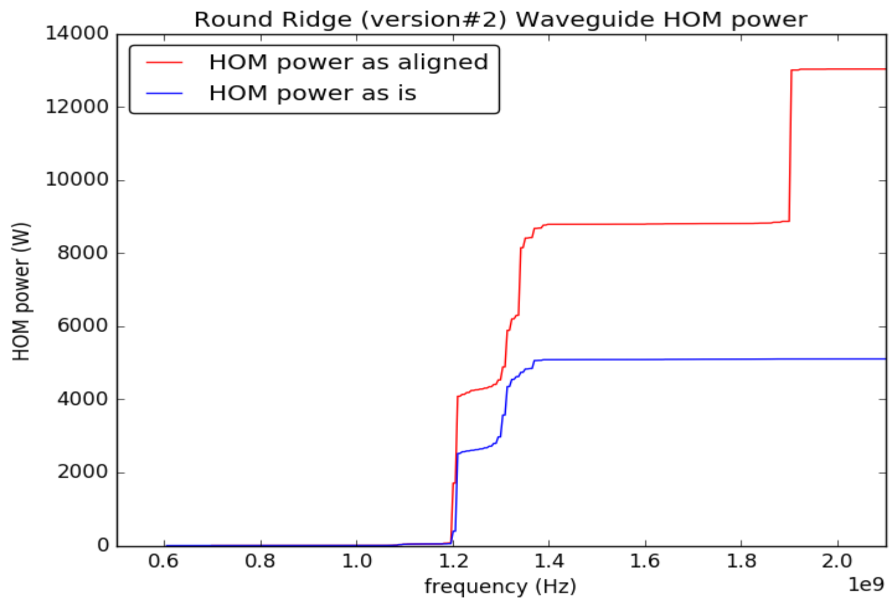


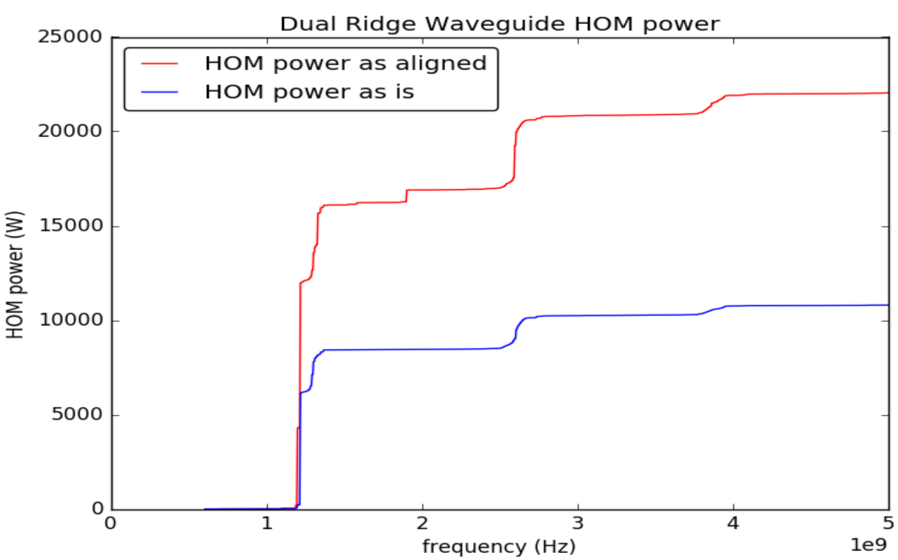


- Two versions of ridge of ridge waveguide is ongoing optimization: rectangular ridge waveguide and round ridge waveguide (prefer for mulitpacting-free).
- Optimization condition: Dipole mode for BBU, and monopole mode for HOM power.
- The BBU threshold of rectRidgeWG is well above the requirement. Round Ridge waveguide BBU simulation has not done.

HOM power for FFAG lattice ERL (5-pass)

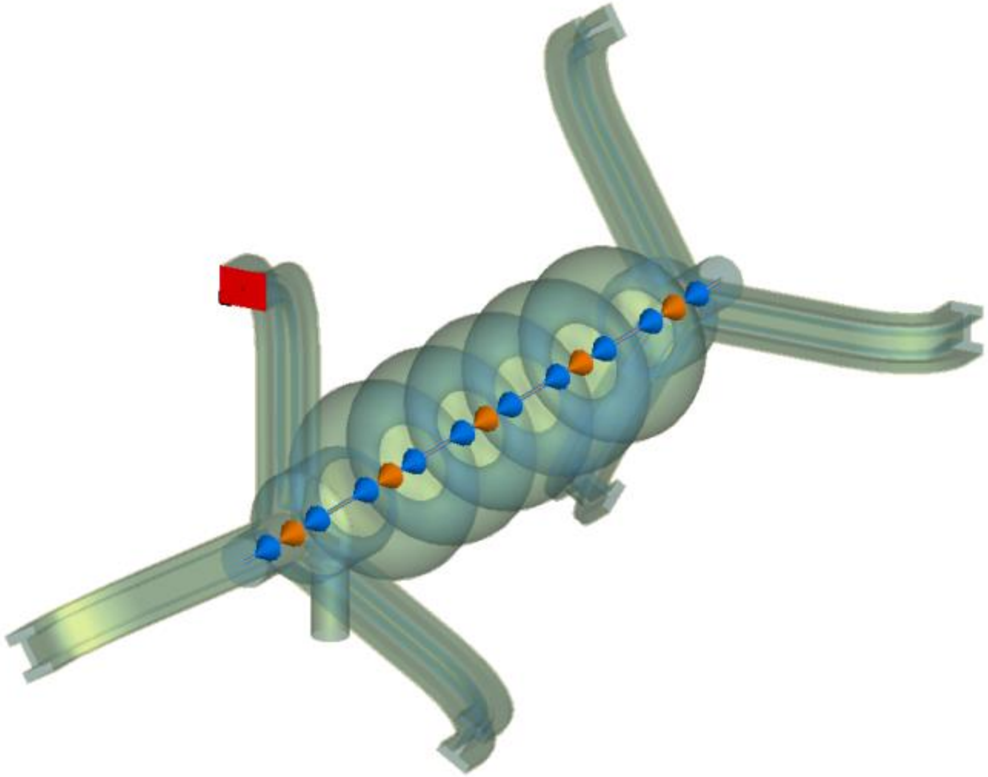






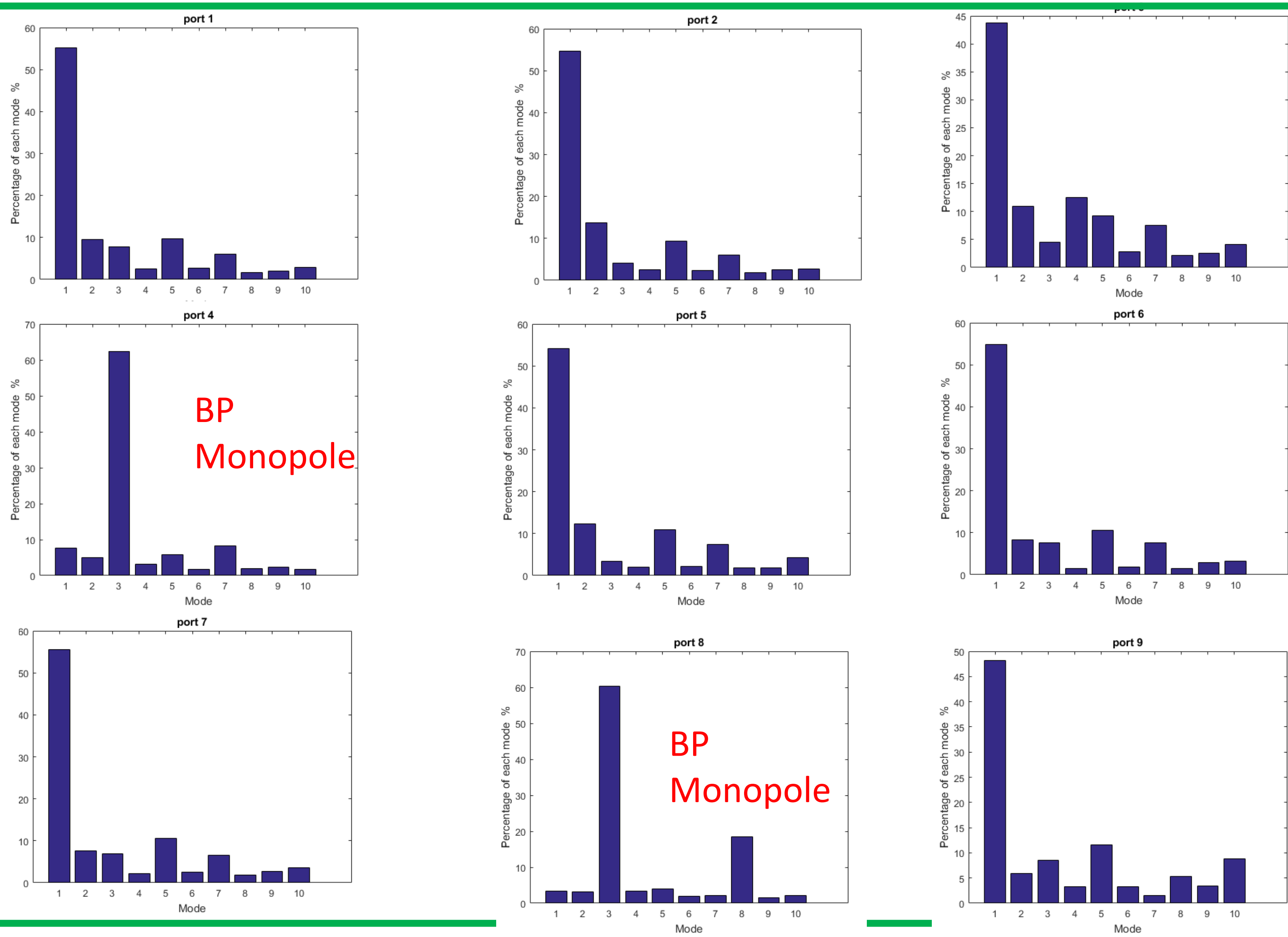
- The main point here is that the HOM power can be "manipulated" by the optimization of the HOM damper design => frequency shift and impedance.
- Both versions are not finalized .

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)



Summary

- **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.**

- **Low-risk linac design is almost completely evaluated: 15 kW per cavity of HOM power; BBU threshold current; Trapped modes between cavities are studied and resolved.**

- **R&D on HOM damping schemes with round/rectangular ridge waveguide and HOM damper are on progress.**

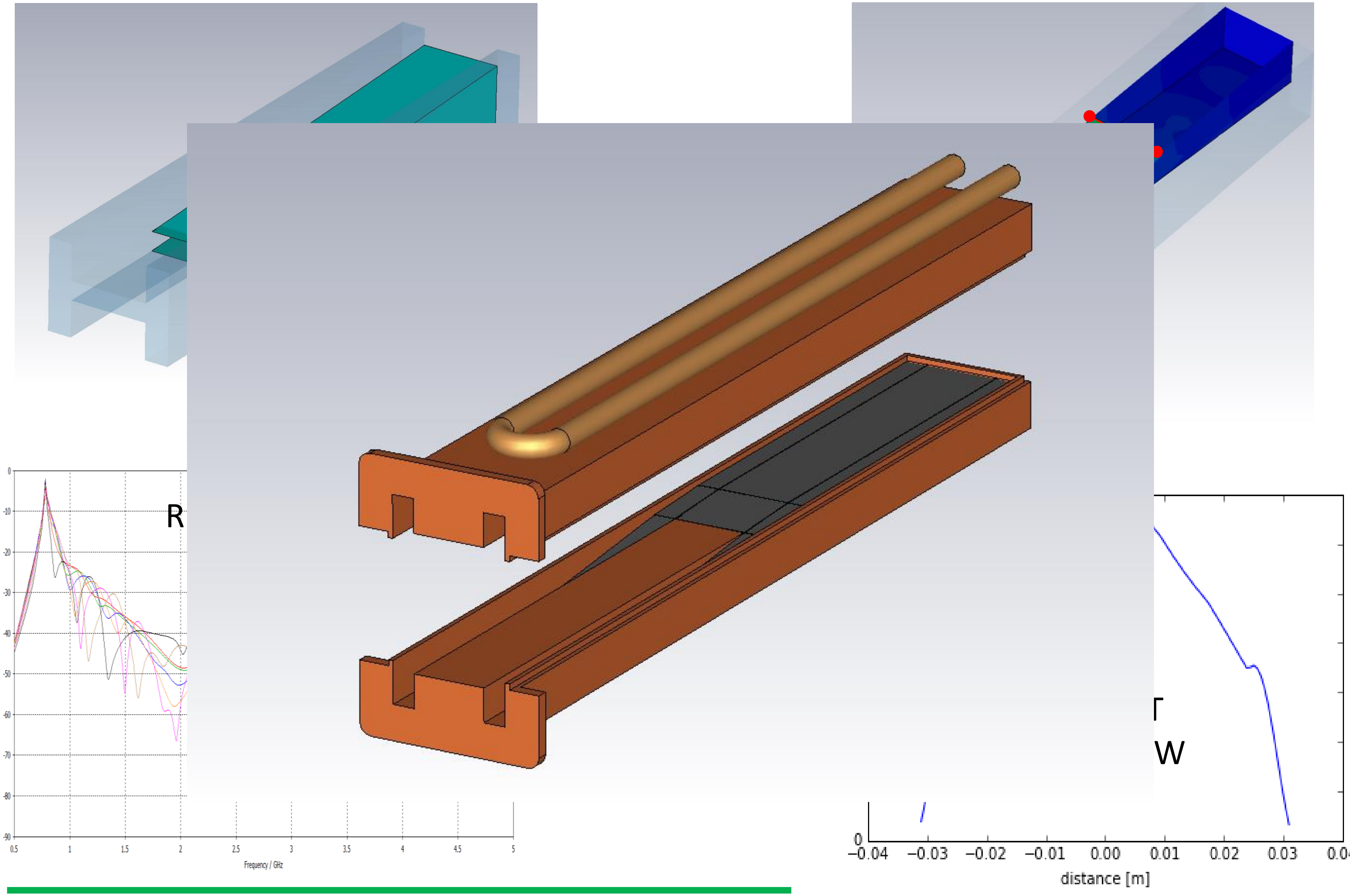
Acknowledgement (incomplete list)

- ✓ **BNL : Philipp Kolb, Michael Blaskiewicz, Harald Hahn, Yongfeng Gao, Vadim Ptitsyn, Kevin Smith, Kevin Mernick, Chen Xu, Hao Yue, Alex Zaltsman, Gary McIntyre, Rich Porqueddu, Ilan Ben-Zvi, Ferdinand Willeke…**

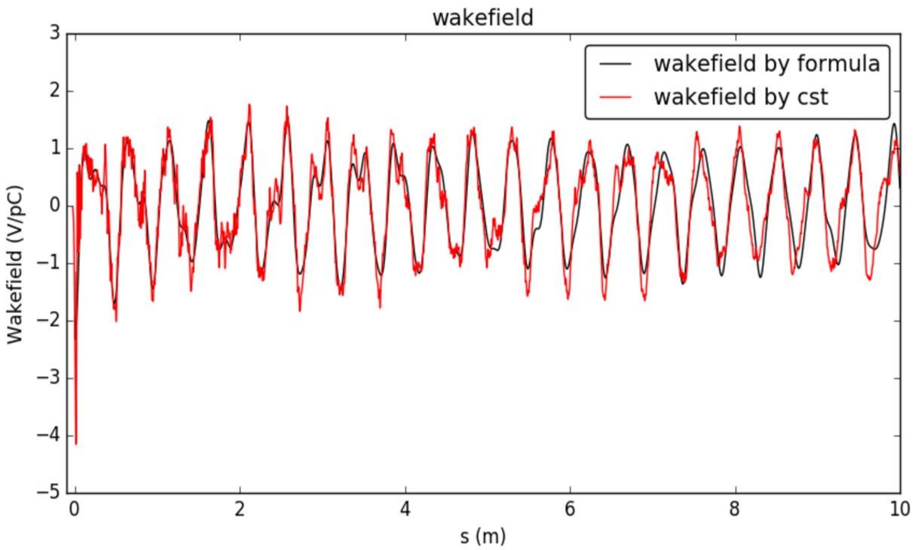
- ✓ **Thank you for helpful and encouraged discussion from**
  - **Jlab: Bob Rimmer, Haipeng WangFrank Marhauser , Jiquan Guo, …;**
  - **LBNL: Derun Li, Yawei Yang, Tianhuan Lou…;**
  - **ANL: Peter Ostroumov, Michael Kelly, Sanghoon Kim..**

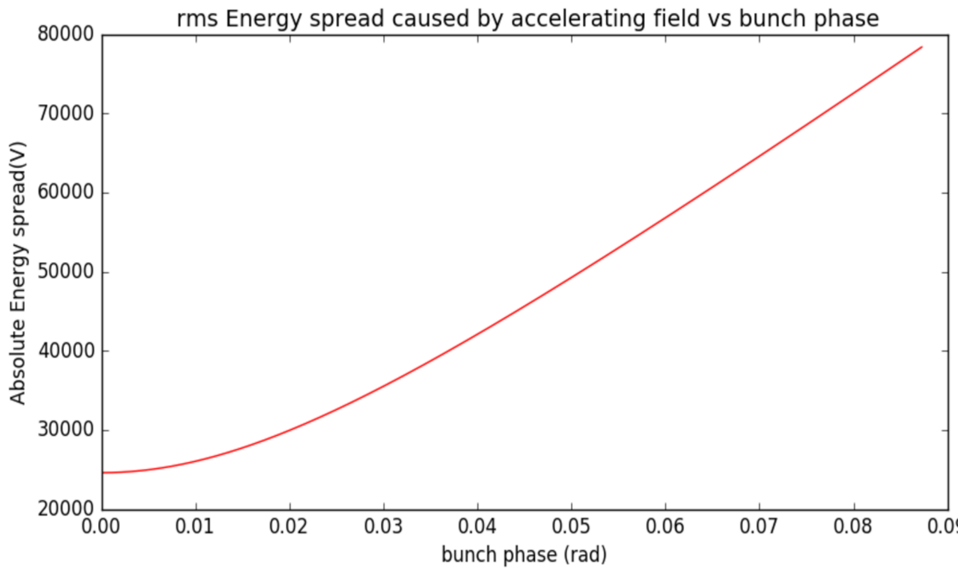
- ✓ **Thank you to Fulvia for supporting the collaboration.**

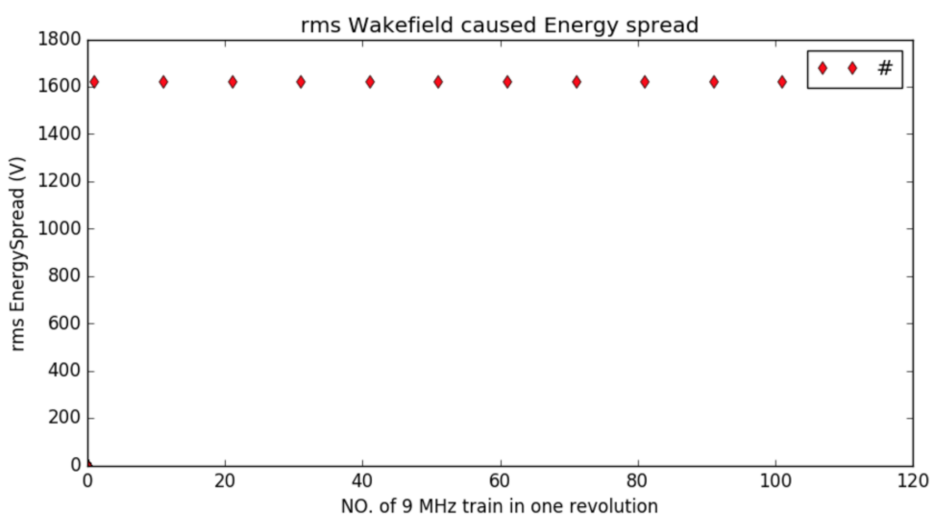
HOM absorber design (P. Kolb)



Energy spread caused by wakefield is small

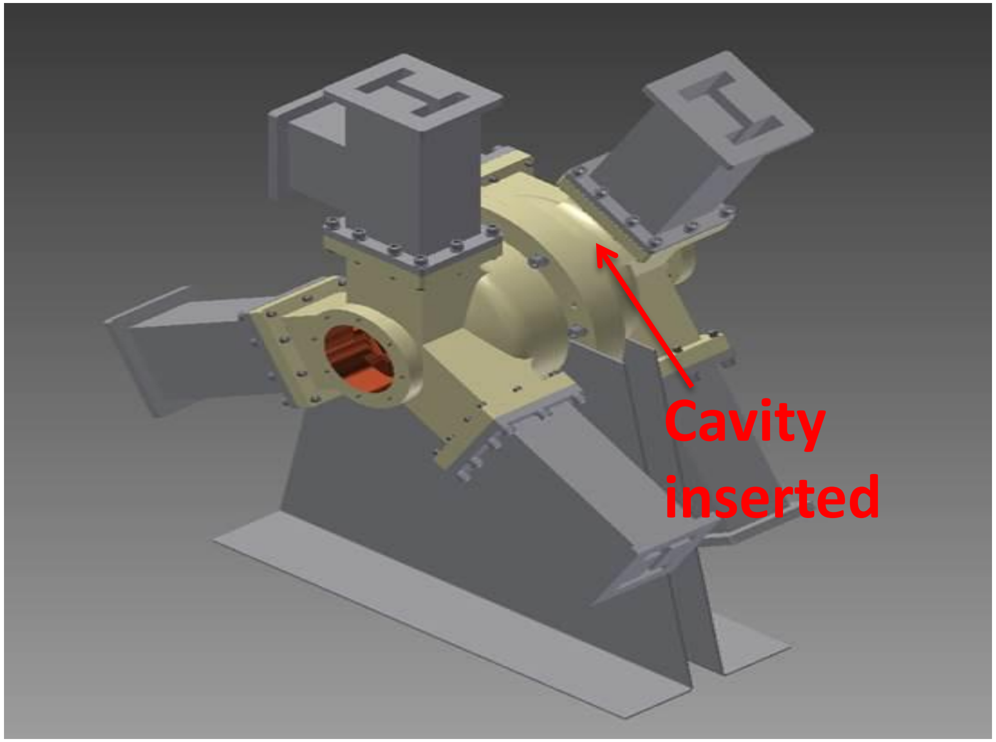


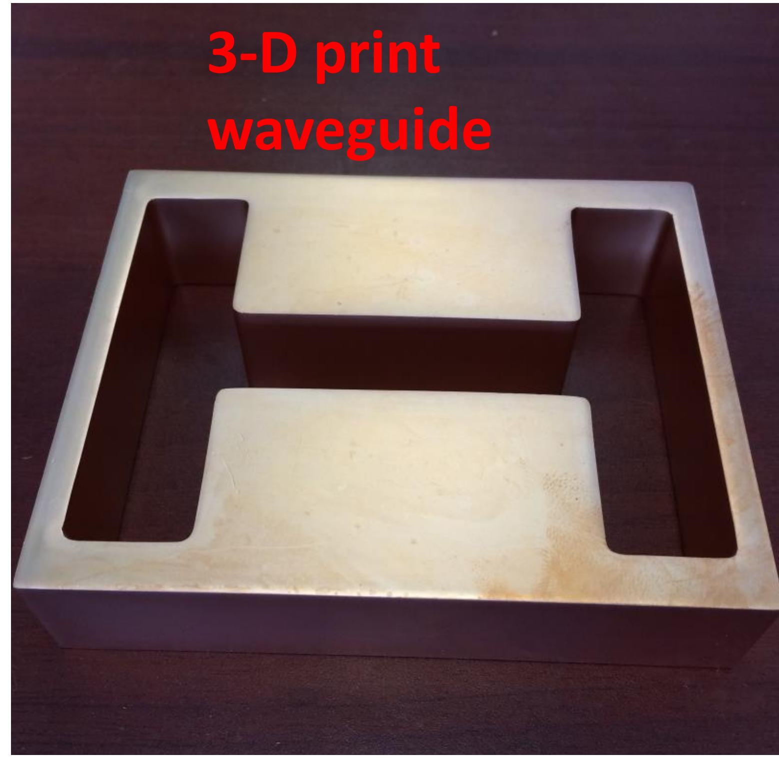


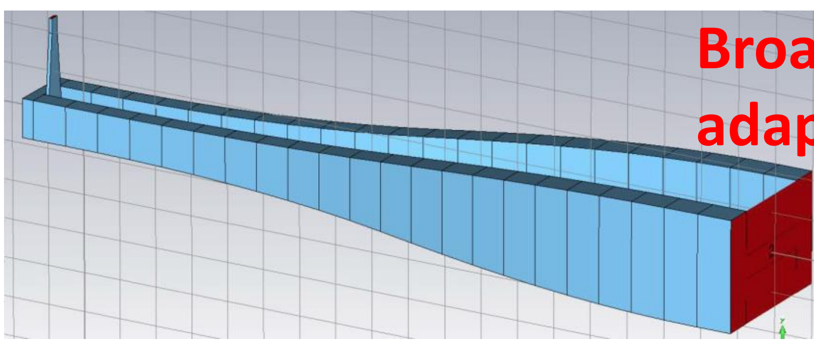


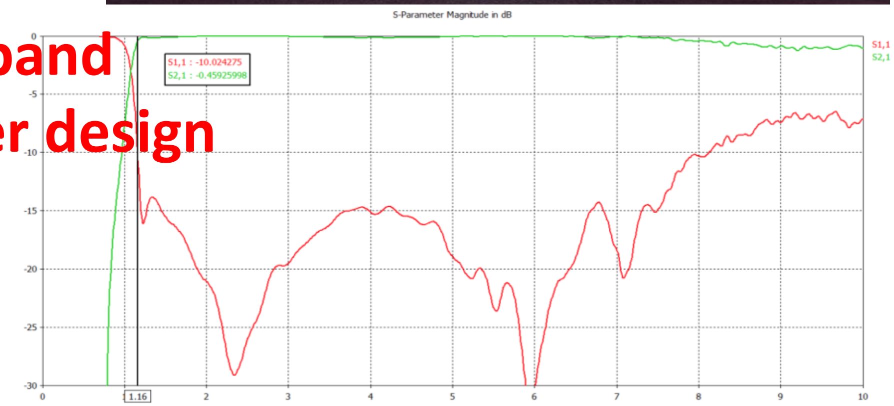
- All the calculation use rms 3mm gaussion bunch
- Single bunch Wakefield: build the wakefield by formula (only up to 2 GHz) and compare with cst results.
- rms Energy spread caused by wakefield (eRHIC bunch structure) is about 1700 V, < 25 kV of energy spread caused at zero RF phase (0.1% of energy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

Prototyping









Broadband
adapter design