Design of HOM damping for high current SRF cavities for Electron Ion Collider (eRHIC) at BNL

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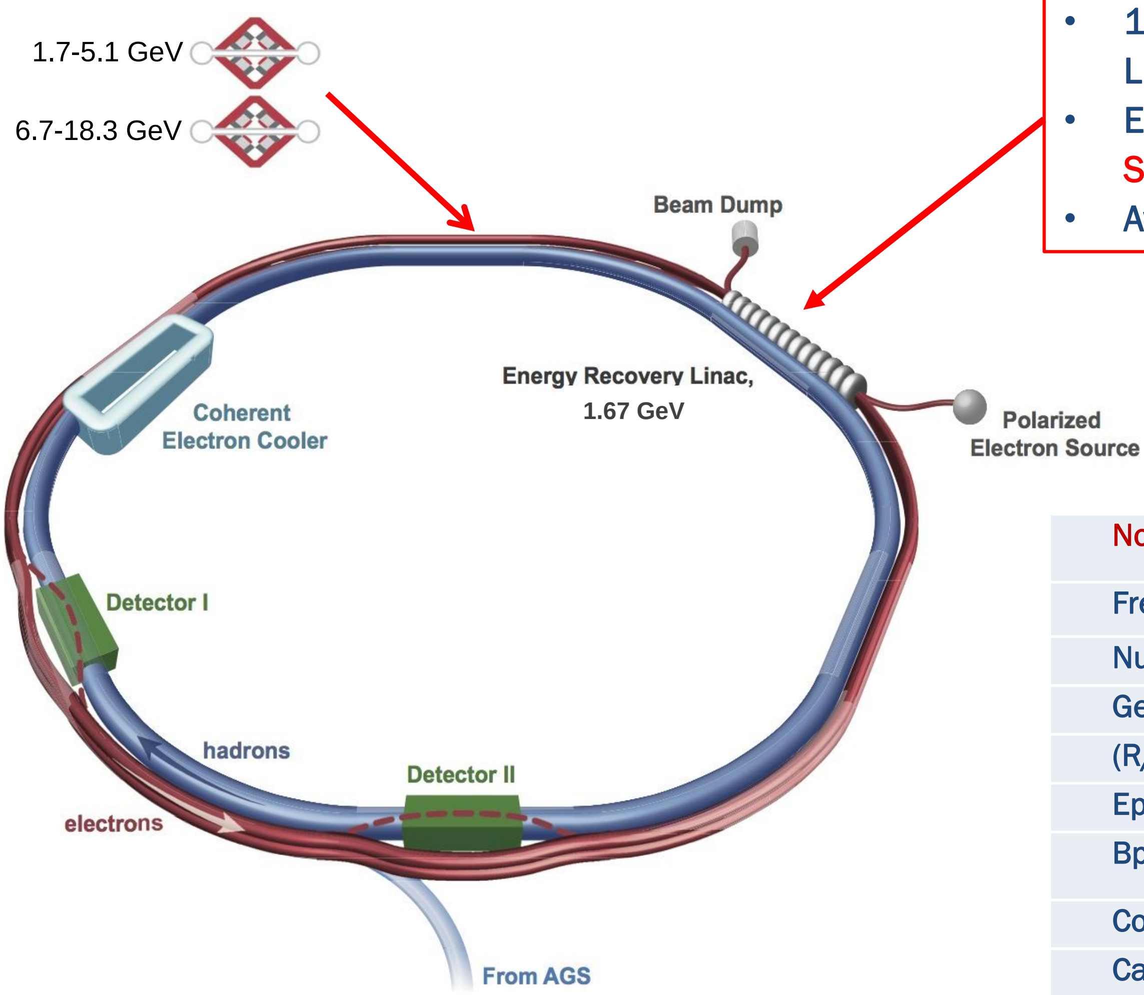
DOE Headquarters
Germantown, MD, Room A-410

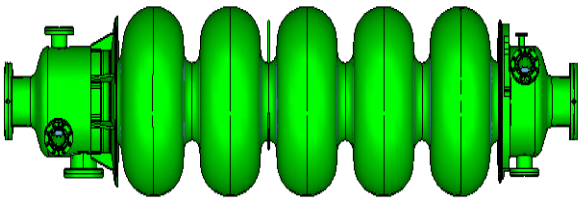
Description of the Proposal, Status and Budget

- This proposed R&D is a collaboration among Brookhaven National Laboratory (BNL), Argonne National Laboratory (ANL) and Lawrence Berkeley National Laboratory (LBNL) to study the **Design of HOM damping for high current SRF cavities for Electron Ion Collider (eRHIC) at BNL**. BNL serves as the lead laboratory and oversees the R&D planning and progress.
  - ANL team focuses on the room temperature beamline absorber and RF windows for the waveguides;
  - LBNL conducts **R&D on waveguide HOM damping coupler and multipacting simulation studies;**
  - The prototypes of the damping scheme will be integrated and tested at BNL.
- **LBNL has finished all the proposed tasks with the awarded funding of $80 k in FY16**
- The proposed R&D task is on the priority list of **Jones EIC R&D Report**: **LR, No. 11, high priority, sub-panel-B**, in addition the R&D efforts and outcomes have potential application for the SRF cavity for electron cooling.

Introduction: ERL SRF Linac in FFAG Lattice eRHIC



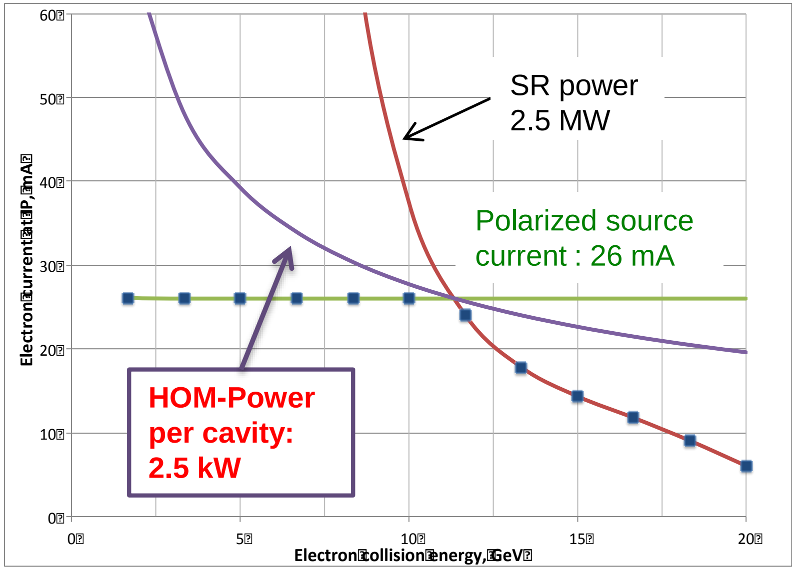
- 1.67 GeV Energy Recovery Linac (ERL);
- Eighty 647.4 MHz (5-cell) HOM damped SRF Cavity;
- Available tunnel space: 200 m.



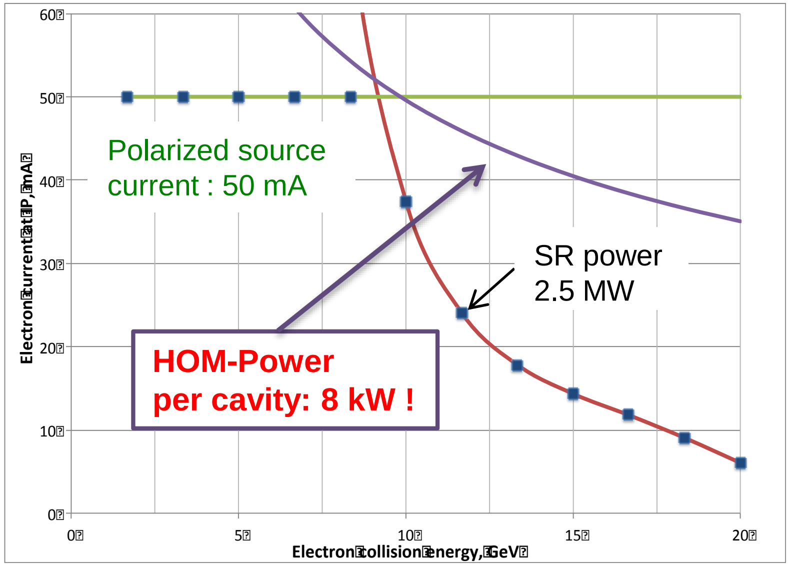
Nominal Parameters	5-cell cavity
Frequency [MHz]	647
Number of cells	5
Geometry factor [Ω]	273
(R/Q)/Cavity [Ω]	502
Epeak/Eacc	2.27
Bpeak/Eacc [mT/MV/m]	4.42
Coupling factor [%]	2.8
Cavity length [m]	1.72

eRHIC ERL Electron Beam Current Limits

Nominal design



Ultimate design



- Bunch length **6 = 3 mm** in eRHIC design, which gives a loss factor of 2.6 V/pC calculated by ABCI.
- There are two designs with max e-beam current in linac of 340 mA as nominal and 500 mA as the ultimate design generating 2.5 kW and 8 kW HOM power calculated by single bunch loss factor, respectively.

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

The HOM-Damped Cavity for eRHIC ERL

- To meet the beam dynamics requirements of eRHIC ERL, the SRF cavity needs to be designed and built to
  - Provide required acceleration voltage with high efficiency;
  - Damp all harmful HOM modes (well) below the threshold.
- Cavity with ridged waveguide (RWG) damping

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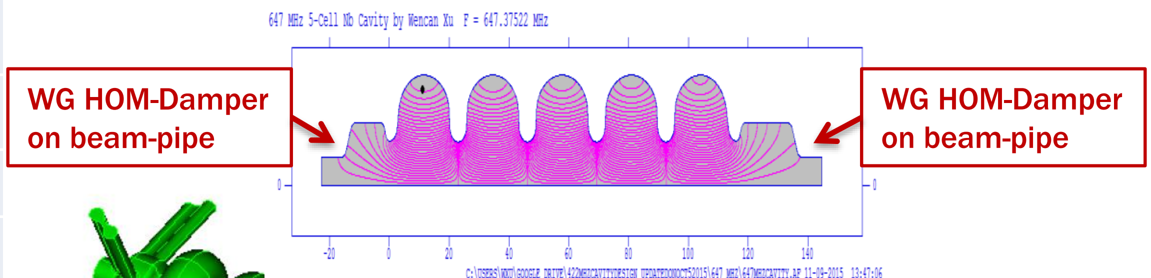
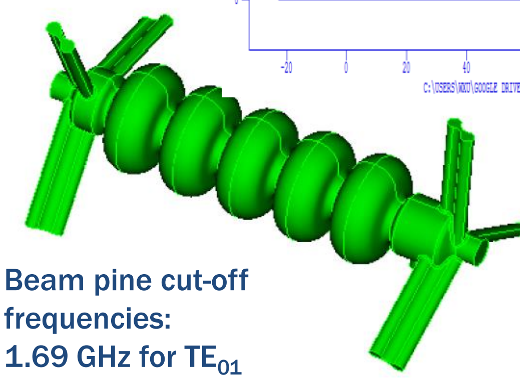
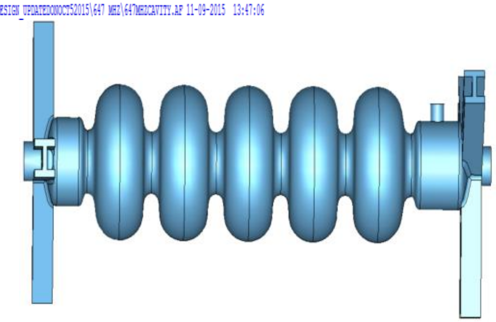
Fundamental accelerating mode





Beam pine cut-off frequencies:
1.69 GHz for TE_{01}
and 2.21 GHz for TM_{11}



HOMs are damped by RWG dampers and absorbers on beam line

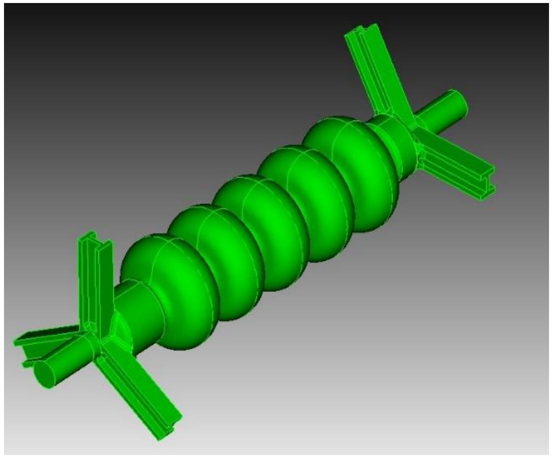
Design of the BNL HOM Damping for High Current SRF Cavities for eRHIC ERL

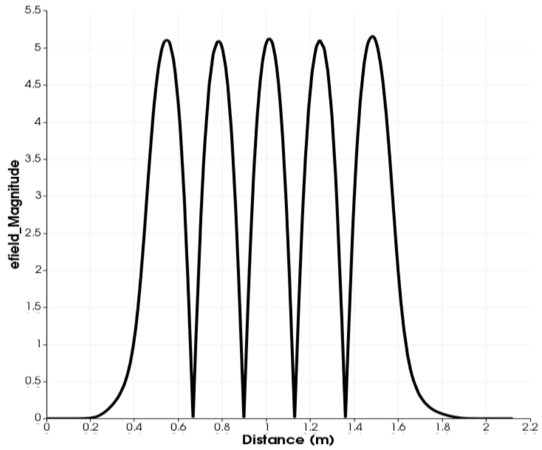
- Is there any multipacting in the BNL 5-cell cavity design at the accelerating mode, including in the HOM damping waveguides?
- Can the RWG effectively couple out and damp the harmful HOMs below the beam pipe cut-off frequencies?
- HOMs above the beam pipe cut-off frequencies will be dissipated on the beam line absorber (ANL)
- Can we design and build HOM dampers/absorbers and RF windows to manage the HOM power?

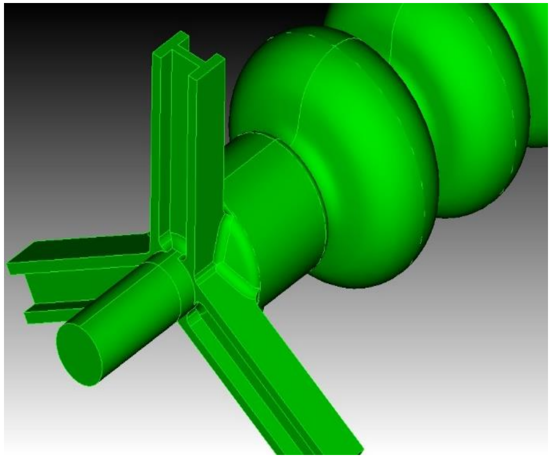
Main Goals of the Proposal

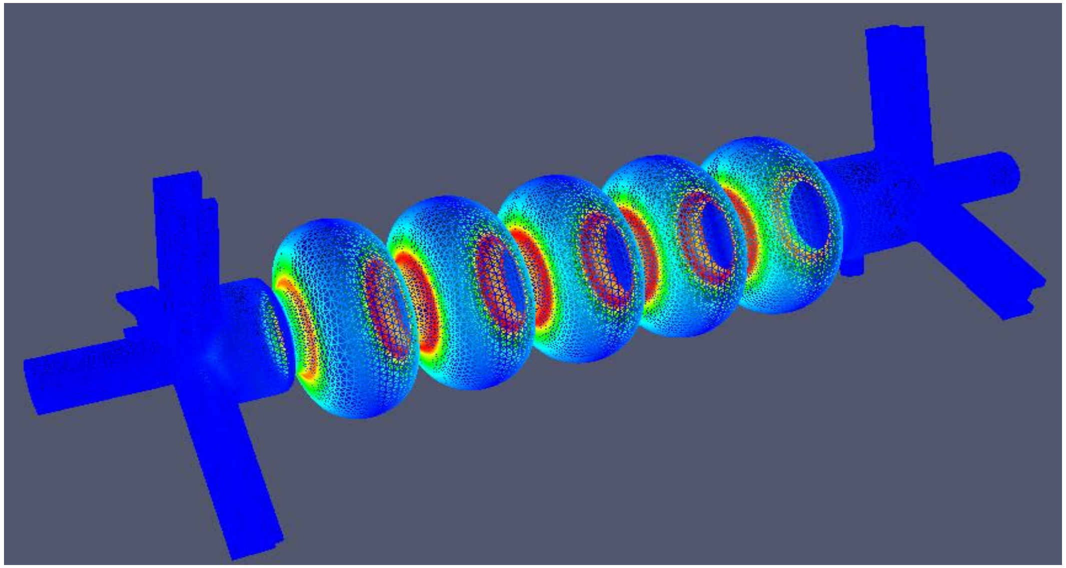
- **LBNL team focuses on the RF and multipacting simulation studies of the cavity system which includes the BNL 5-cell SRF cavity with waveguide HOM and on beamline HOM dampers using ACE3p code:**
  I. Verification and optimization of the waveguide HOM damper for the 5-cell SRF cavity, including the mode spectra of fundamental and HOM modes;
  II. Support the optimization design studies of the waveguide HOM dampers
  III. Preliminary multipacting simulation studies of the 5-cell SRF cavity with waveguide HOM damping
  IV. Support BNL low power RF measurements of the prototype cavity and finish documentation.

Fundamental Mode of the 647 MHz 5-cell Cavity with 3-HOM Dampers on Each Side, Simulated by ACE3p









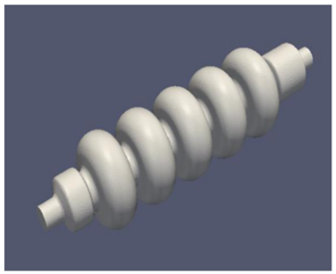
ACE3p model of the 5-cell SRF cavity and ridged waveguide damping was built using the dimensions provided BNL collaborators:

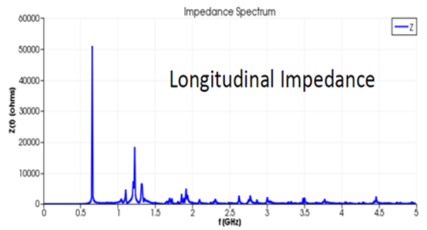
- **Electrical field distribution of the fundamental accelerating mode**
- **Accelerating mode is well contained**
- **Good field flatness**
- **Simulation results agree very well with the BNL CST MWS results**

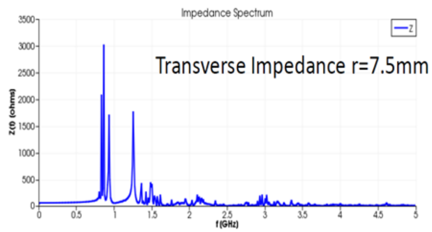
Impedance of the 647 MHz 5-cell Cavity with 3-HOM Dampers on Each Side, Simulated by ACE3p

1

T3P calculation







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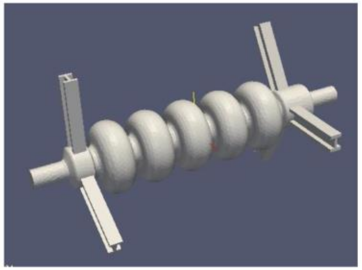
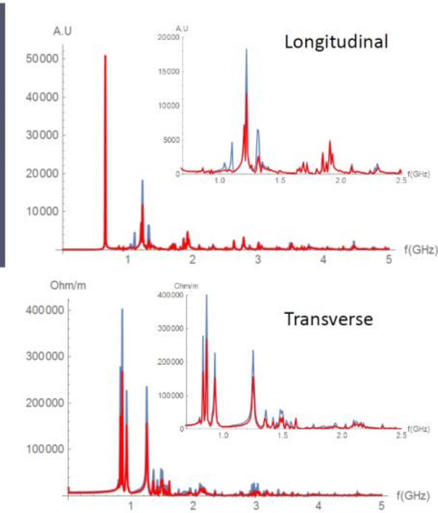


- The waveguide model from Wencan: we use this model as the baseline to compare the damping effects of other waveguide designs.
- In the impedance plots, blue is without damper, red is with damper.



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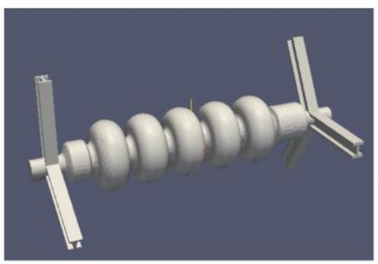
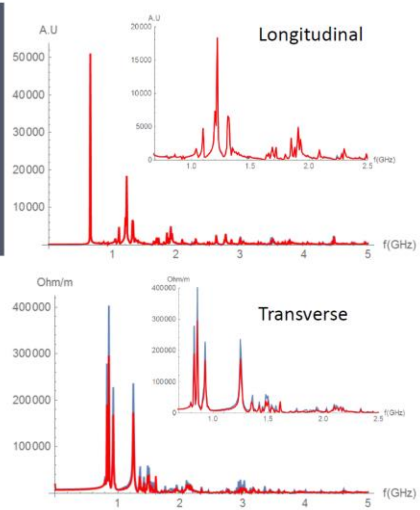


Move the waveguides to beam pipe:

- No damping for the longitudinal impedances.
- Almost the same damping for transverse impedances.



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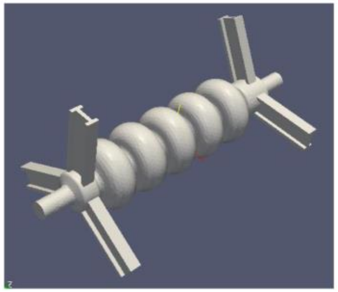
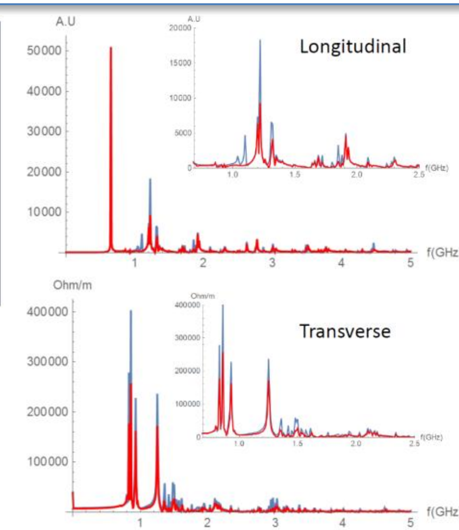


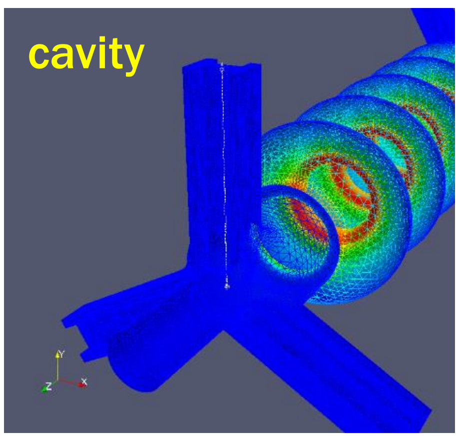
Enlarged waveguide:

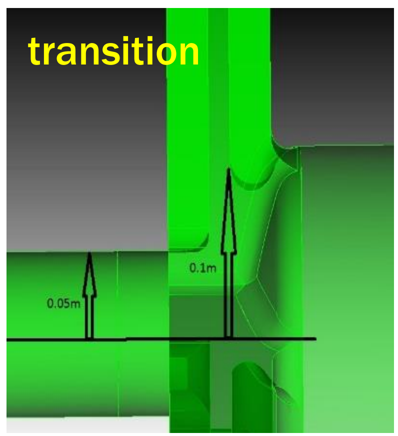
- More damping for longitudinal impedances.
- Almost the same damping for transverse impedances.

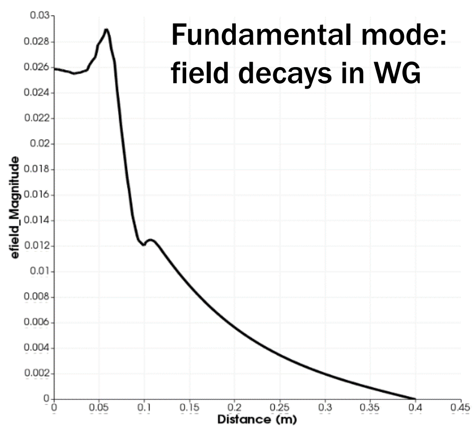


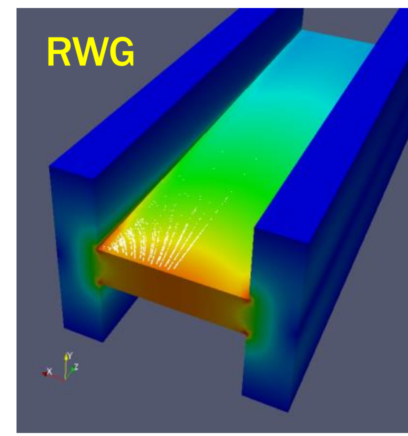
Multipacting Simulation Studies to Identify Potential MP Areas: Fundamental Mode

- Our studies focus on three areas, inside the cavity, the enlarged beam-pipe and the interface between the beam-pipe and ridged waveguides.
- The RF field strength is normalized with *E* field along the center (with relativity β = 1 transient effect)
- MP scanning from 0.25 MV/m to 16 MV/m with 0.25 MV/m interval, and tracking for 20-60 RF cycles





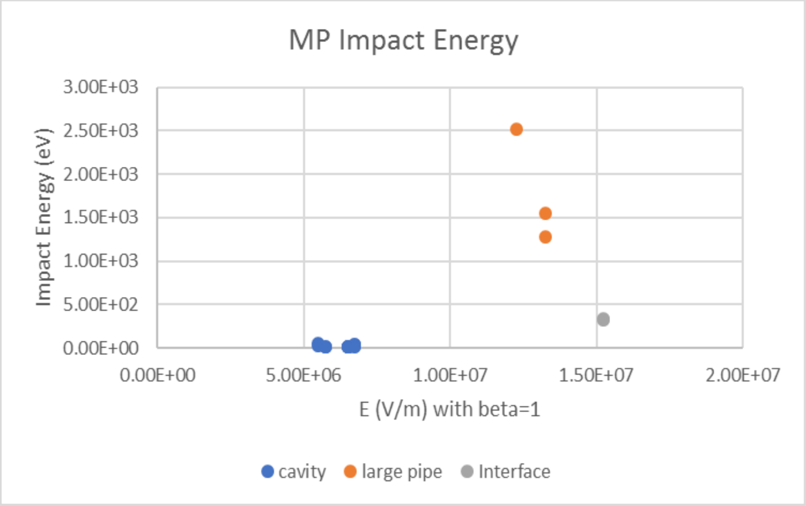


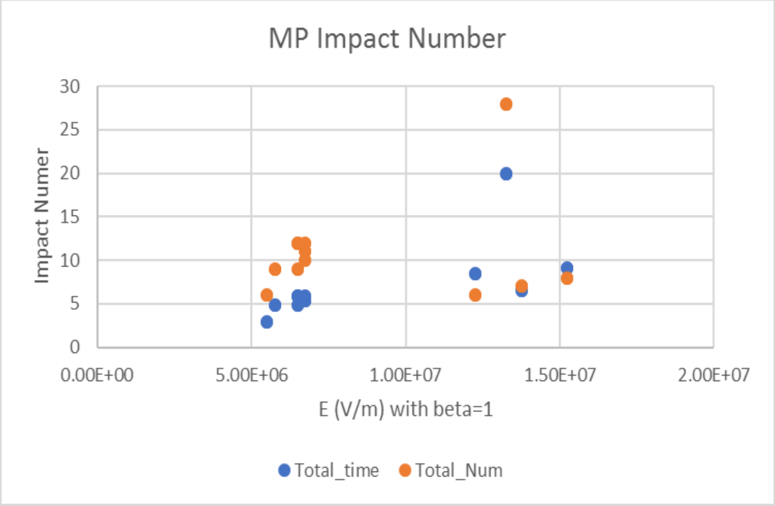


- All the geometry details are included in the MP simulation model

Multipacting Simulation Results of the Fundamental Accelerating Mode

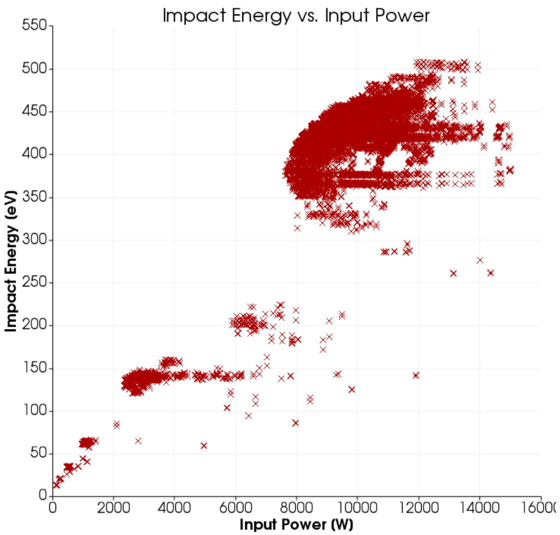
- **The MP simulation results show:**
  - In the cavity body: a few MP patterns, but the impact energy is too low to create any sustainable MP.
  - In the cavity-waveguide transition: a few MP patterns at 13 MV/m with impact energy around 1400 eV and at 15 MV/m with impact energy around 400 eV.
  - MP orders are between 1 and 1.5.

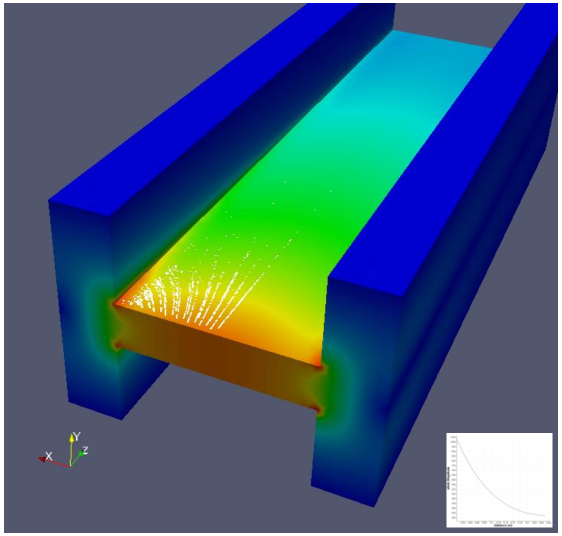


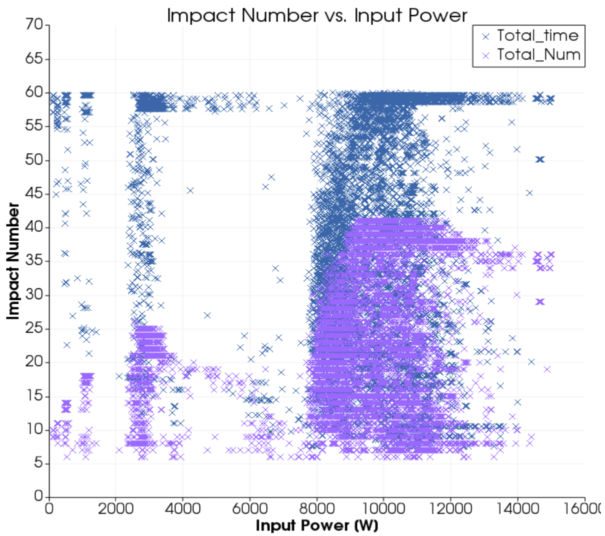


Simulation Studies to identify potential dangerous MP regions in the RWG

- Electrons emitted from port interface of the RWG, tracking for 60 RF cycles; Input power scaled from 10 W to 15 kW
- Persistent MP appears from 2.2 kW to 6.0 kW and from 8.0 kW to 15.0 kW.
- MP impact energy:
  - From 2.2 to 7.8 kW, the MP impact energy is between 100 to 200 eV.
  - Above 7.8 kW, the impact energy is between 300 eV to 500 eV.
- MP impact order:
  - Major low order MPs are order-3 around 2.8 kW
  - MP order-1.5 from 9 kW to 12 kW.

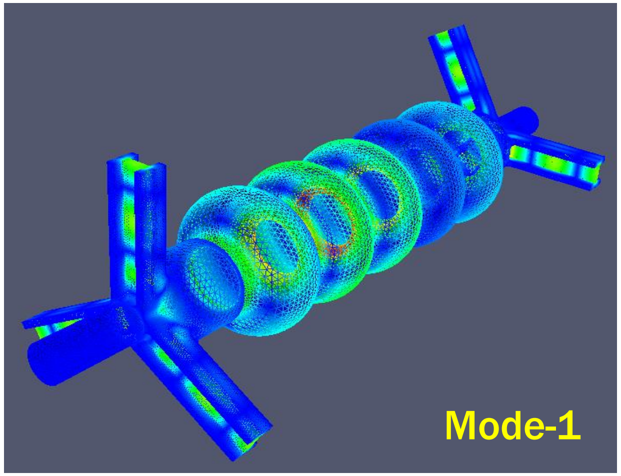


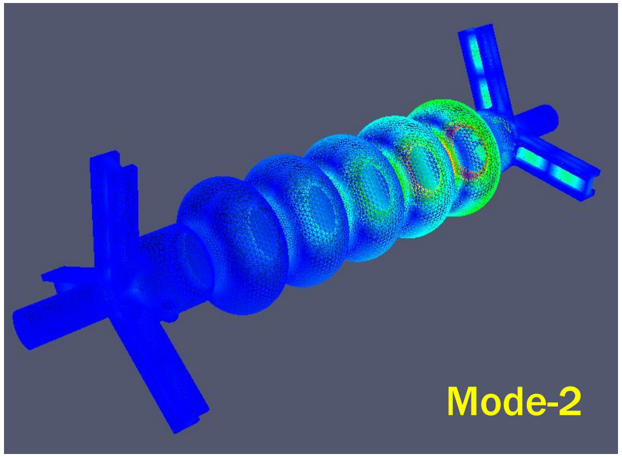


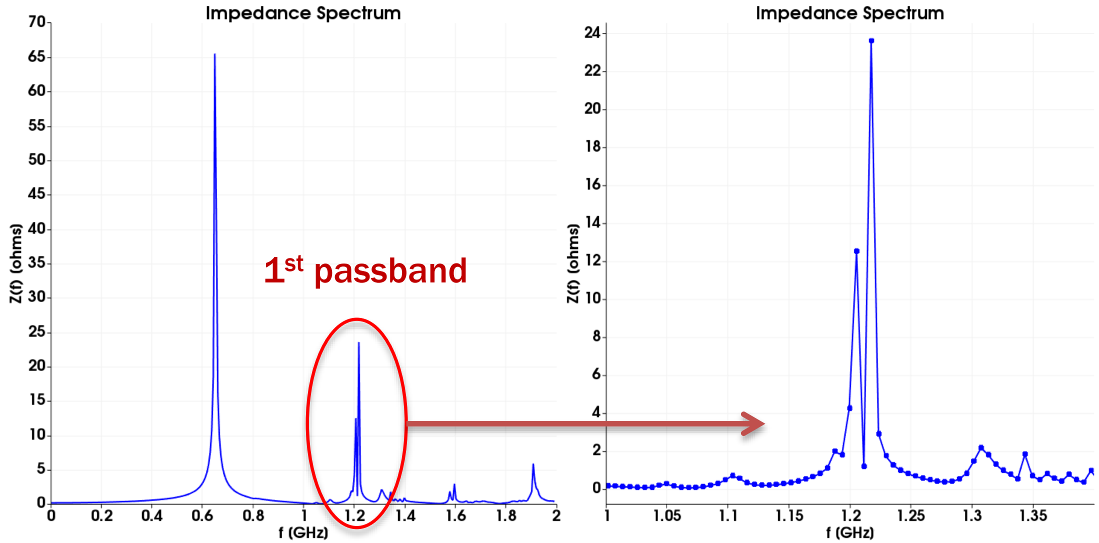


MP of the 1st Passband HOM Monopole Modes

- **The longitudinal impedance is calculated by t3p.**







Mode	F (GHz)	Q_e	Q_0	R/Q (ohm)
1	1.204	2333	40788	48.3
2	1.217	991	39562	84.8

HOMs coupled out to RWGs, MP simulations conducted in a section of the RWGs, with power scaled with the stored cavity energy, scanned from 10 to 2,000 watts in one RWG

No MP was found!

Summary

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  - ANL team focuses on the room temperature beamline absorber and RF windows for the waveguides;
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A successful & productive collaboration with BNL and ANL

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- The proposed R&D task is the priority list of Jones EIC R&D Report: LR, No. 11, high priority, sub-panel-B, the R&D efforts and outcomes have potential application of the SRF cavity for electron cooling.

Acknowledgement

- **LBNL Colleagues:**
  - **Tianhuan LUO** (main contributor), Yawei YANG and Serena PERSICHELLI

- **Collaborators**
  - BNL: **Wencan XU**, Kevin SMITH, Alex ZALTSMAN, …
  - ANL: **Sanghoon KIM**, Peter OSTROUMOV (MSU now) Michael Kelly, …