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

<table>
<thead>
<tr>
<th></th>
<th>5-cell cavity</th>
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<tbody>
<tr>
<td>Frequency [MHz]</td>
<td>647</td>
</tr>
<tr>
<td>Number of cells</td>
<td>5</td>
</tr>
<tr>
<td>Geometry factor [Ω]</td>
<td>273</td>
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<tr>
<td>(R/Q)/Cavity [Ω]</td>
<td>502</td>
</tr>
<tr>
<td>Epeak/Eacc</td>
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Bunch length \( b = 3 \text{ mm} \) 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 pipe 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 by 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

Move the waveguides to beam pipe:
- No damping for the longitudinal impedances.
- Almost the same damping for transverse impedances.

2. 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.

3. 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 $\beta = 1$ 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 1\textsuperscript{st} Passband HOM Monopole Modes

- The longitudinal impedance is calculated by $t3p$.

<table>
<thead>
<tr>
<th>Mode</th>
<th>$f$ (GHz)</th>
<th>$Q_e$</th>
<th>$Q_0$</th>
<th>$R/Q$ (ohm)</th>
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<td>1</td>
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<td>2333</td>
<td>40788</td>
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<td>2</td>
<td>1.217</td>
<td>991</td>
<td>39562</td>
<td>84.8</td>
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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

• This proposed R&D is a collaboration among Brookhaven National Laboratory (BNL), Argonne National Laboratory (ANL) and Lawrence Berkeley National Laboratory (LBNL). BNL served as the lead laboratory for the proposal and oversee the R&D planning, progress and management.
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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, ...