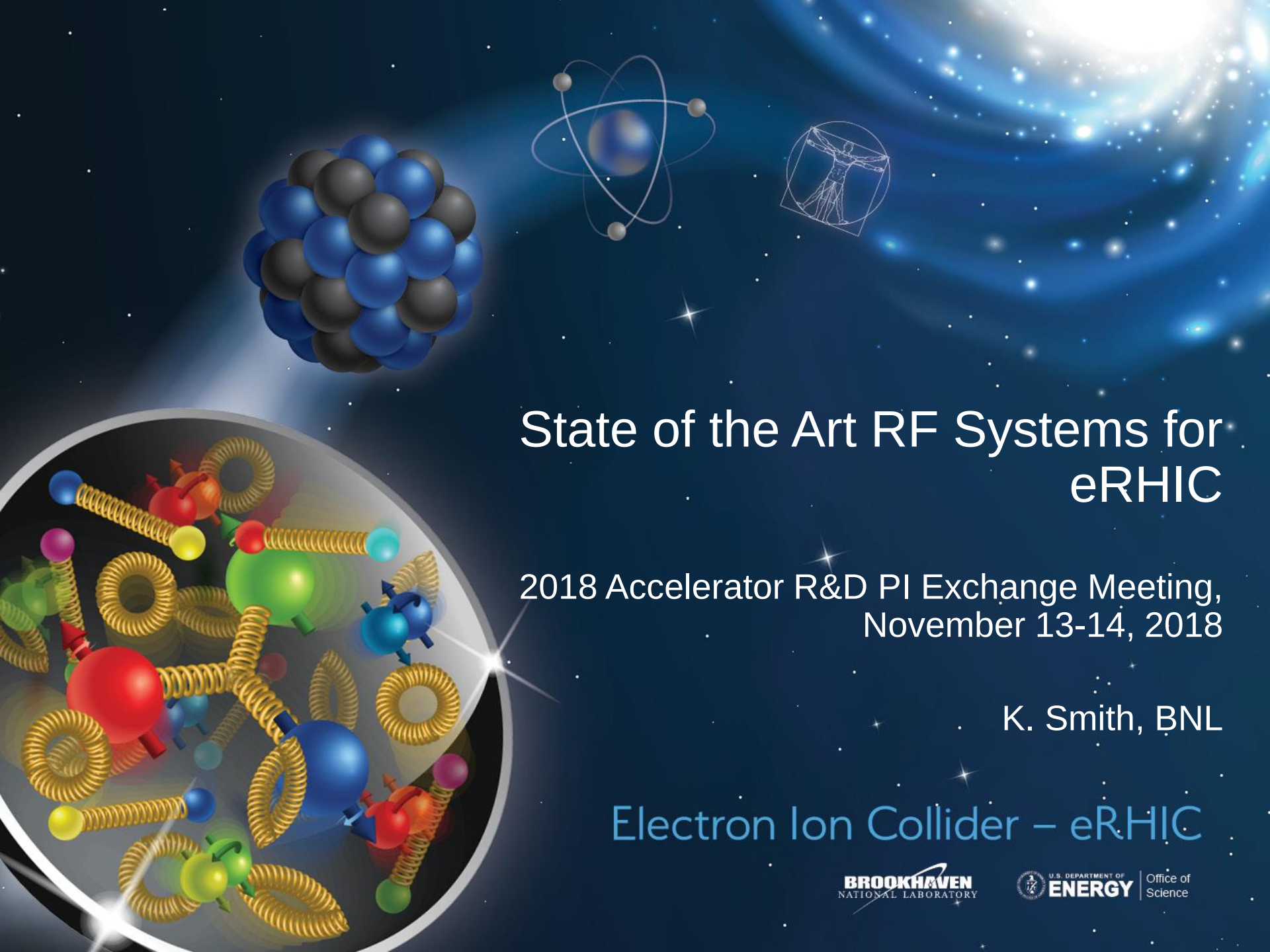


State of the Art RF Systems for eRHIC

2018 Accelerator R&D PI Exchange Meeting,
November 13-14, 2018

K. Smith, BNL

Electron Ion Collider – eRHIC

BROOKHAVEN NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY | Office of Science

Outline

- R&D Description
- R&D Goals and Deliverables
- R&D Schedule and Budget
- R&D Status
  - 650 MHz Cu and SRF 5-Cell Cavity Prototypes
  - 563 MHz SRF 2-Cell Cavity
  - 500 kW CW Variable Q_{ext} Power Coupler
- Summary

R&D Description

Funding Source	PI	Report[1] Rows	Priority & Sub-Priority	Total $
FY17 Lab Base	Kevin Smith	11, 13	High, B	$477K

- This R&D topic comprised several sub-topics which represented eRHIC related RF concerns at the time of the Community Review of EIC Accelerator R&D, as identified in the subsequent report of the panel ("Jones Report"[1]).

- References within the report (Report Pg. 9) are:
  - #11: "SRF High Power HOM Damping", Panel Priority: High, Sub-Priority: B.
  - #13, "High Peak Current Multi-Turn Electron LINAC", Panel Priority: High, Sub-Priority: B.

- The specific R&D topic for this presentation, with description, goals and deliverables is described in the BNL EIC R&D plan[2] , May 31, 2017.
  - Section 2.4: "Superconducting RF Cavity Development for eRHIC"

[1] https://science.energy.gov/~/media/np/pdf/Reports/Report_of_the_Community_Review_of_EIC_Accelerator_RD_for_the_Office_of_Nuclear_Physics_20170214.pdf

[2] "Accelerator Research and Development Plan for Electron Ion Collider (EIC) Activities", F. Willeke, May 31, 2017

R&D Goals and Deliverables[2]

- Development of an optimized superconducting 647 MHz multi-cell cavity for acceleration of electrons in a recirculating linac.
  - Goal: Perform RF measurement of the warm and cold 647MHz prototypes and compare to the conceptual design parameters and numerical simulation with emphasis on HOM characterization and high field performance.
  - Deliverable: Test report on 647MHz superconducting cavity vertical cold tests including comparison with design values.

- Development of a 563 MHz 2-cell superconducting cavity for the electron storage ring.
  - Goal: Complete conceptual design of an RF cavity for the electron storage ring which minimizes the number of cryomodules for 18GeV operation and has sufficient HOM damping to minimize coupled bunch growth rates to an acceptable level.
  - Deliverable: Storage ring cavity and HOM damper conceptual design.

- Development of a 500 kW CW variable coupling input coupler for the storage ring cavity.
  - Goal: Complete the conceptual design of a variable coupling, high power input coupler.
  - Deliverable: Conceptual design of a 500kW CW variable coupling input coupler.

R&D Schedule & Budget

	Reference [2], 05/31/2017	
R&D Activity Deliverable	**Start Date**	**End Date**
650 MHz Cu Cavity RF Characterization	June 14, 2017	August 7, 2017
650 MHz Nb Cavity Vertical Test	January 26, 2017	October 19, 2017
563 MHz Nb Cavity 2-Cell Cavity Conceptual Design	December 1, 2017	December 26, 2017
500 kW CW Variable Q_{ext} Input Coupler Conceptual Design	December 1, 2016	February 28, 2018

	Actual	
R&D Activity Deliverable	**Start Date**	**End Date**
650 MHz Cu Cavity RF Characterization	June 2017	August 2017
650 MHz Nb Cavity Vertical Test	September 2018	Ongoing*
563 MHz Nb Cavity 2-Cell Cavity Conceptual Design	May 2017	September 2017*
500 kW CW Variable Q_{ext} Input Coupler Conceptual Design	May 2017	September 2017*

* See follow on slides.

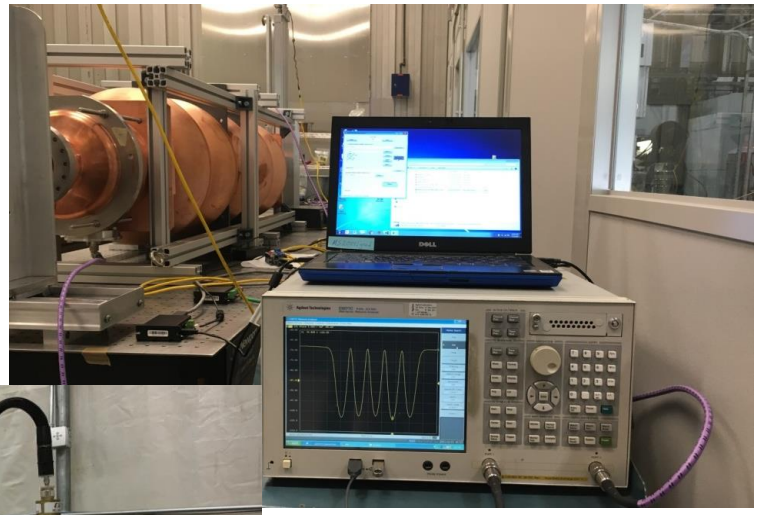
Summary of Expenditures by Fiscal Year (FY):

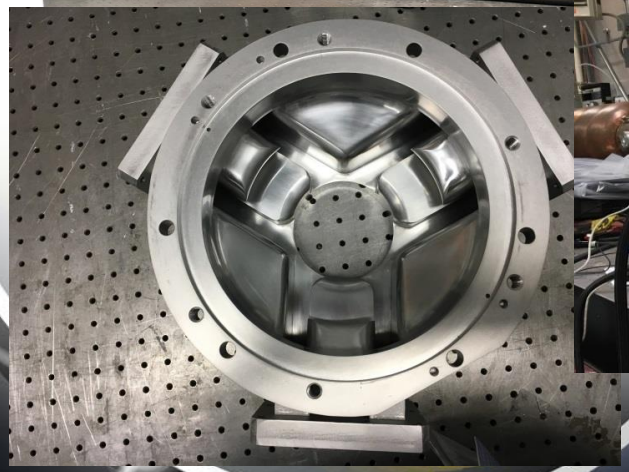
Lab Base R&D	FY10+FY11	FY12+FY13	FY14+FY15	FY16+FY17	Totals
a) Funds allocated				476,757	476,757
b) Actual costs to date				476,757	476,757

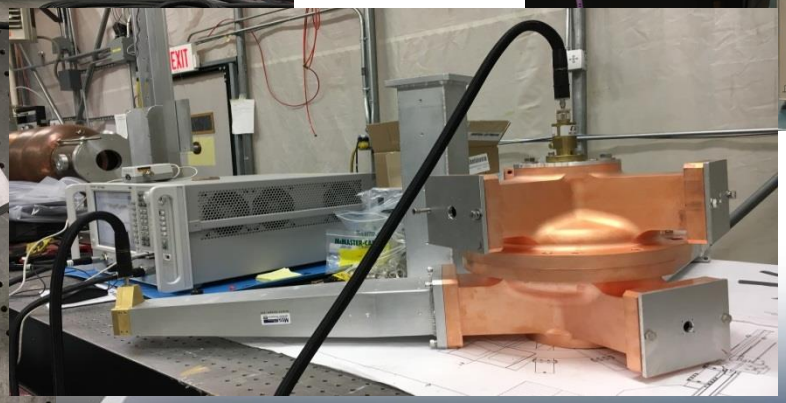
Funding for the work on this R&D topic is not continued on the FY18 NP Accelerator R&D FOA.

R&D Status – 650 MHz 5-Cell Cavity

- Development of an optimized superconducting 647 MHz multi-cell cavity for acceleration of electrons in a recirculating linac.
  - Deliverable: Test report on 647MHz superconducting cavity vertical cold tests including comparison with design values.
- 650 MHz Cu prototype measurement completed August 7, 2017.
  - Characterization of cavity and HOM spectrum agreed well will predictions from simulations.





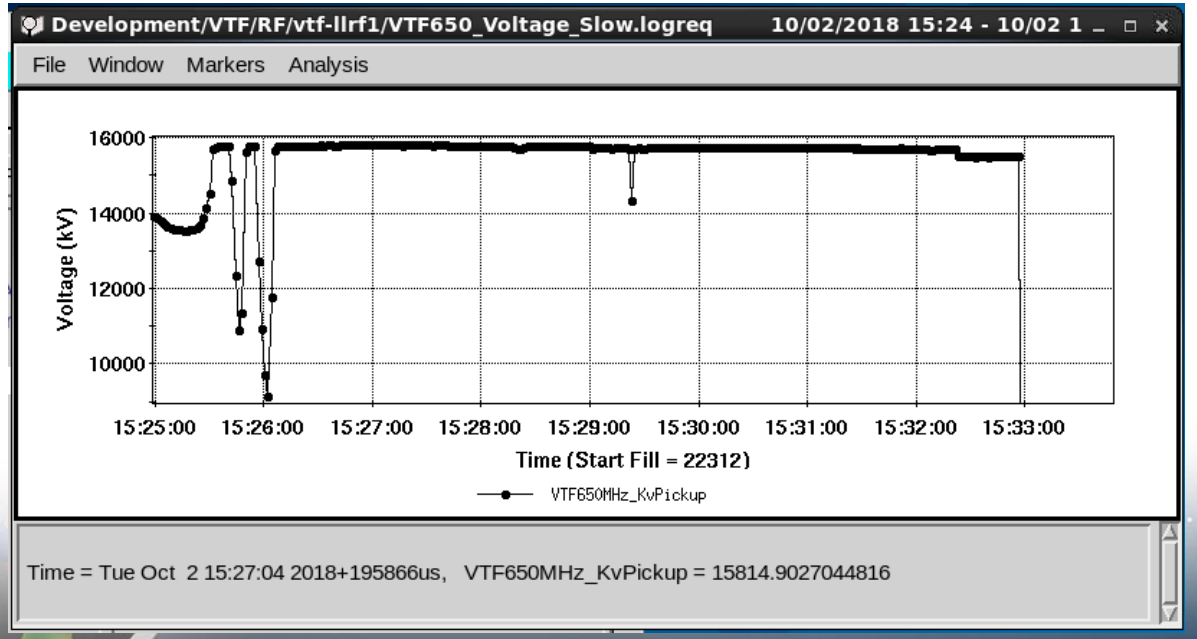


R&D Status – 650 MHz 5-Cell Cavity

- Development of an optimized superconducting 647 MHz multi-cell cavity for acceleration of electrons in a recirculating linac.
  - Deliverable: Test report on 647MHz superconducting cavity vertical cold tests including comparison with design values.

R&D Status – 650 MHz 5-Cell Cavity

- 650 MHz Nb prototype vertical test successful and continuing.
  - After two days of test, cavity approaching design CW gradient (15.8 MV/m, design 16 MV/m) and with a low field Q_0 ~2E10.
  - Tests temporarily halted due to mechanical issue with VTF shield top.
- These are very good results.
  - Initial post-processing intentionally limited to bulk BCP, 600 degC bake, light BCP, HPR and assembly: No 120 degC or other low T bake, no EP, etc.
  - Idea is to explore what cavity performance the minimum post-processing can provide. Once high field limits are known, then further post-processing and testing.



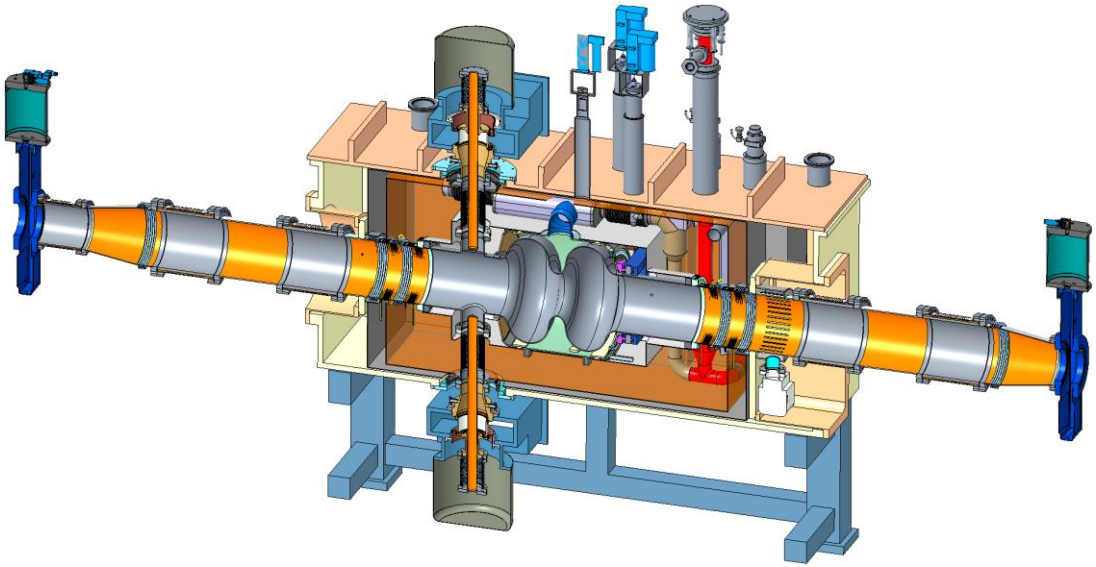
R&D Status – 563 MHz 2-Cell Cavity

- Development of a 563 MHz 2-cell superconducting cavity for the electron storage ring.
  - Deliverable: Storage ring cavity and HOM damper conceptual design.
- 563 MHz Cavity and HOM damper conceptual design completed September 2017.
- R&D work for this topic continued through April 2018, to more fully develop the concept and prepare for the eRHIC Pre-Conceptual Design Review, April 24-25, 2018, and the RR cost estimate.

eRHIC Electron Storage Ring Parameters

Parameter	Unit	5 GeV (Beam-beam limit)		10 GeV (Maximum lumi)		18 GeV (SR Power Limited)
		Med Lumi	High Lumi	Med Lumi	High Lumi	
Peak Luminosity	$10^{34}cm^{2}s^{-1}$	0.056	0.307	0.44	1.05	0.145
# Bunches		660	1320	660	1320	330
Bunch Charge	nC	48	24	48	24	10
Bunch length	rms mm	23	23	19	19	17
Average Current	A	2.48	2.48	2.48	2.48	0.26
Synchronous Voltage	MV/turn	1.29		3.67		38.5
Sync Rad Power	MW	3.2		9.2		10.0

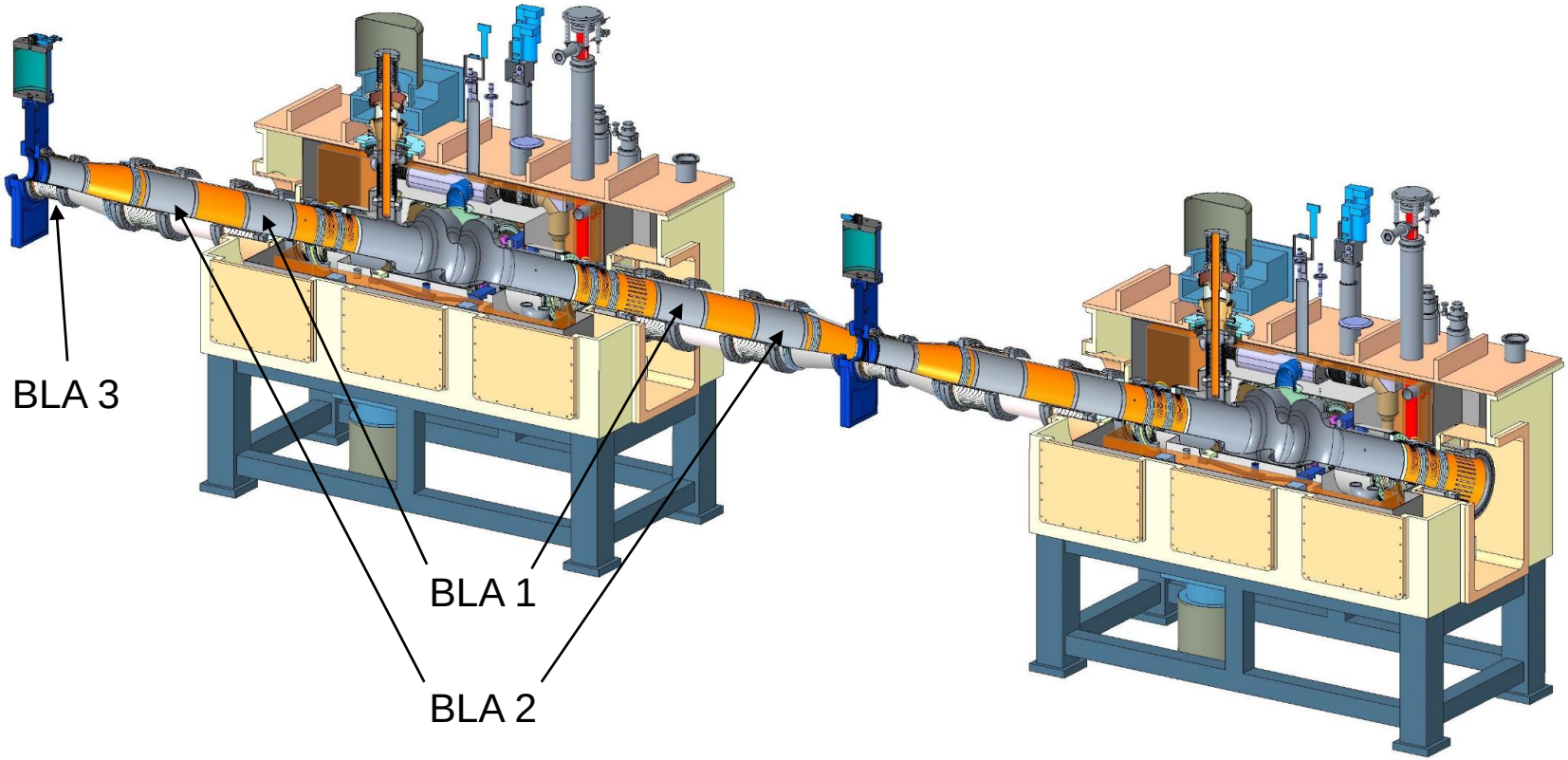
R&D Status – 563 MHz 2-Cell Cavity



- 563 MHz is harmonic 7200 of the RHIC revolution frequency.
- Single 2-cell cavity per cryomodule.
- 2x 500 kW adjustable fundamental power couplers.
- 4x SiC Beamline HOM Absorbers (BLAs).
- Multiple IOT amplifier is the likely option for the power source.

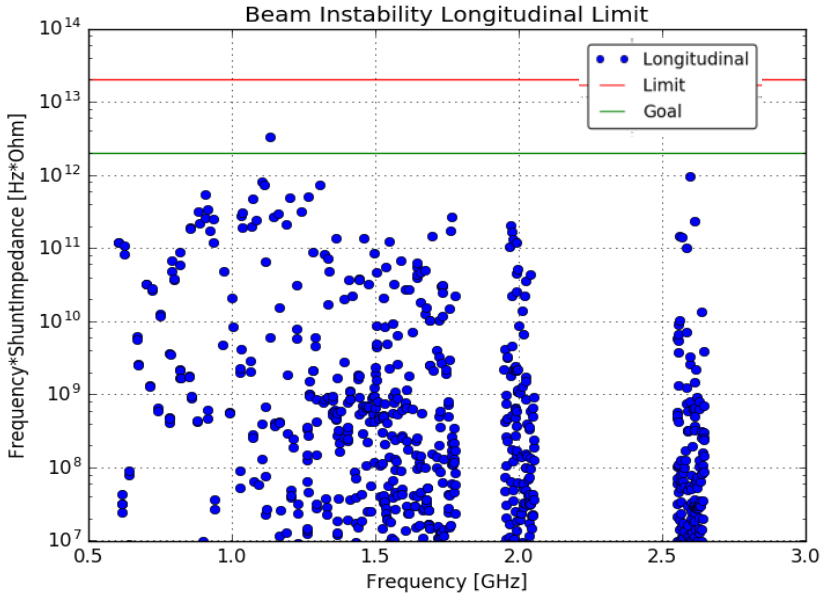
Parameter	Value
Frequency	563 MHz
R/Q_{acc_def}	146 Ω
E_p/E_{acc}	2.75
B_p/E_{acc}	5.21 mT/MV/m
Operating Gradient	4.1 to 11.3 MV/m
Operating Temperature	2.0 K

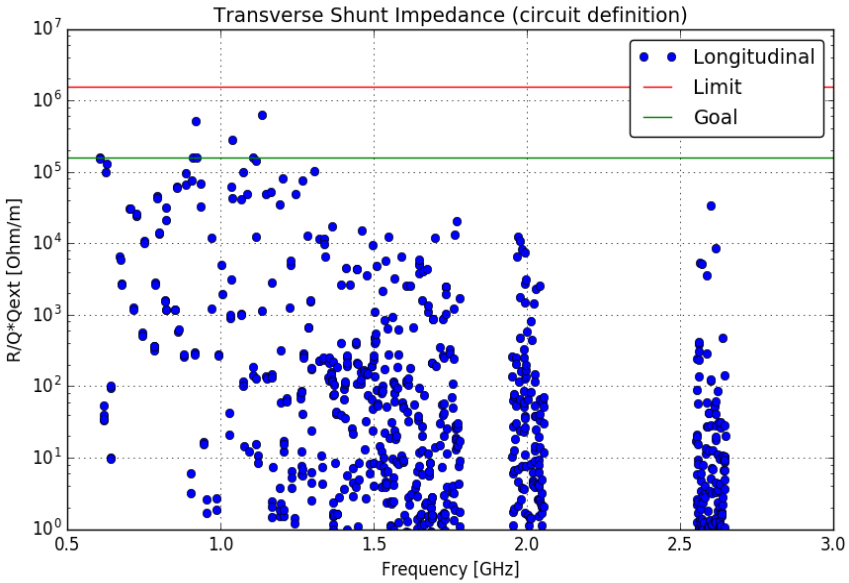
R&D Status – 563 MHz 2-Cell Cavity

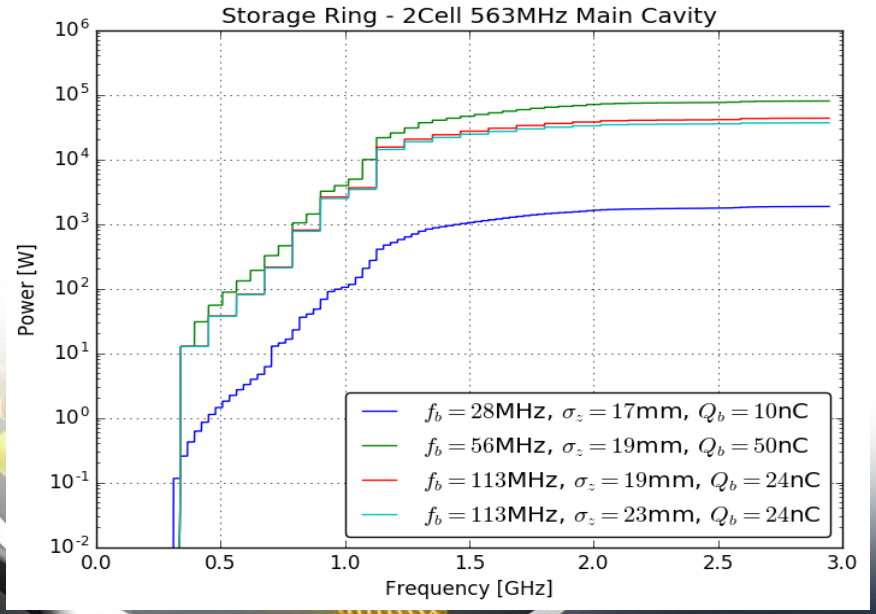


- Two sets of SiC warm Beamline Absorbers (BLA1 and BLA2) are optimized to damp HOMs.
  - 20kW per absorber at I_{beam} = 2.5 A.
- SiC absorber development is now supported by BNL LDRD #19-017.

R&D Status – 563 MHz 2-Cell Cavity







- HOM damper design results meet the limit set by beam instability.
- In all operational scenarios, the maximum HOM power is 20 kW per SiC damper, or 79 kW per cavity.

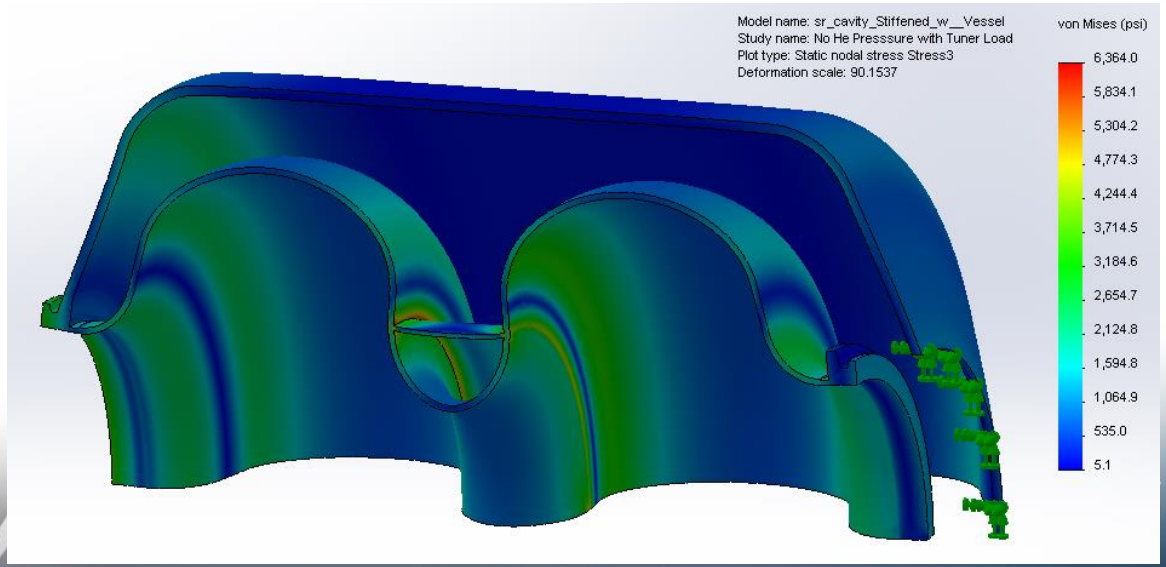
R&D Status – 563 MHz 2-Cell Cavity

- Preliminary mechanical analysis of cavity mechanical eigenmodes, tuning range, stress and deformation with and without stiffeners – begins to guide further cavity optimizations.

Mode No.	Frequency(Hertz)
1	234.75
2	236.08
3	367.09
4	374.35
5	394.66

- First five mechanical eigenmode frequencies, with stiffening ring.
- All are greater than 200 Hz.

- Maximum stress for applied tuner force of 2000 lbs.
- Resulting deflection provides approximately 125 kHz tuning.
- Maximum stress within acceptable bounds.



R&D Status – 500 kW CW Variable Q_{ext} Coupler

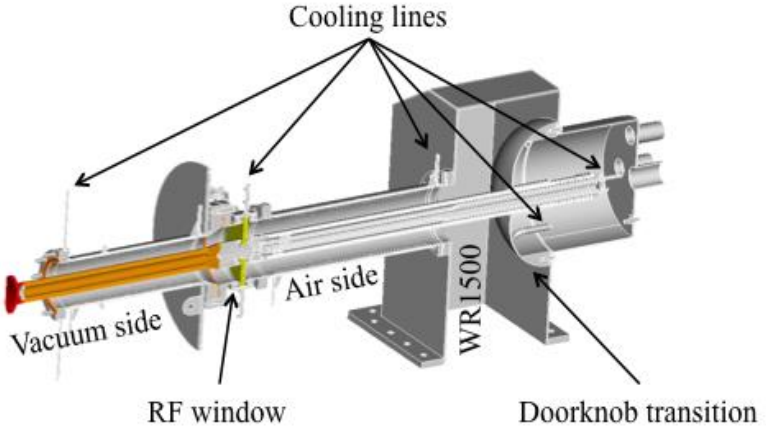
- Development of a 500 kW CW variable coupling input coupler for the storage ring cavity.
  - Deliverable: Conceptual design of a 500kW CW variable coupling input coupler.

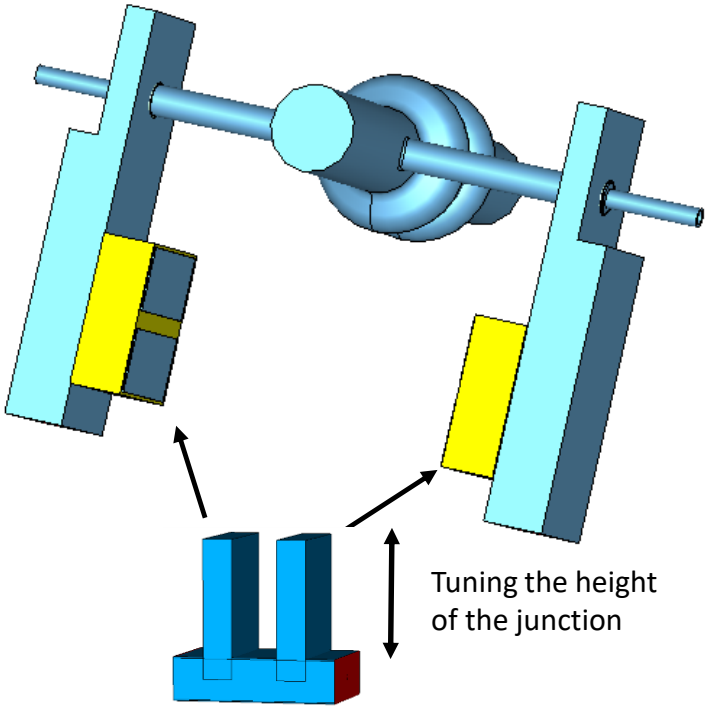
- Conceptual design completed February 2018.

- The coupler leverages existing and well developed fixed coupler.
  - 500 kW CW coupler designed for a MW class SRF photo-cathode gun.
  - Tested on high power test stand to 125 kW full reflected.
  - Operated at 125 kW CW and over 300 kW pulsed with full reflection on the SRF photo-cathode gun.
  - Currently operational on the LEReC 704 MHz SRF Booster Cavity.

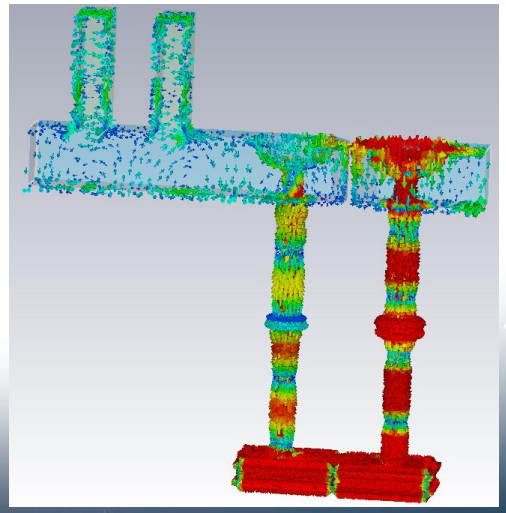
- Further development of this has now been funded by BNL LDRD 18-028.
  - Deliverable is a two coupler, high power test ending September 2019.
  - Test leverages existing 704 MHz, 1MW CW klystron.

R&D Status – 500 kW CW Variable Q_{ext} Coupler





- Two 500 kW power couplers supply up to 1 MW per cavity.
- Q_{ext} must be adjusted from 4E4 – 2.8E5 for optimal match (See table, Slide 9).
- Adjustment does not need to be continuous, or under operating RF power.
- The realization of Q_{ext} adjustment is done through impedance tuning with a waveguide junction, essentially stub tuners.



Summary

- Several sub-topics were included under this R&D.
- All deliverable work for the eRHIC Ring-Ring concept has been completed.
- 650 MHz 5-Cell Nb cavity is in vertical test and has achieved very close to design gradient and excellent Q_0. Testing continues.
- Conceptual design R&D for the 563 MHz 2-Cell Electron Storage Ring cavity, cryomodule and HOM absorbers has progressed well past the nominal deliverables.
  - BNL LDRD 19-017 now supporting SiC HOM absorber development.
- Conceptual design of the 500 kW, variable Q_{ext} power coupler was completed.
  - BNL LDRD 18-028 now supporting power coupler development and high power test.

Thank You for Your Attention.