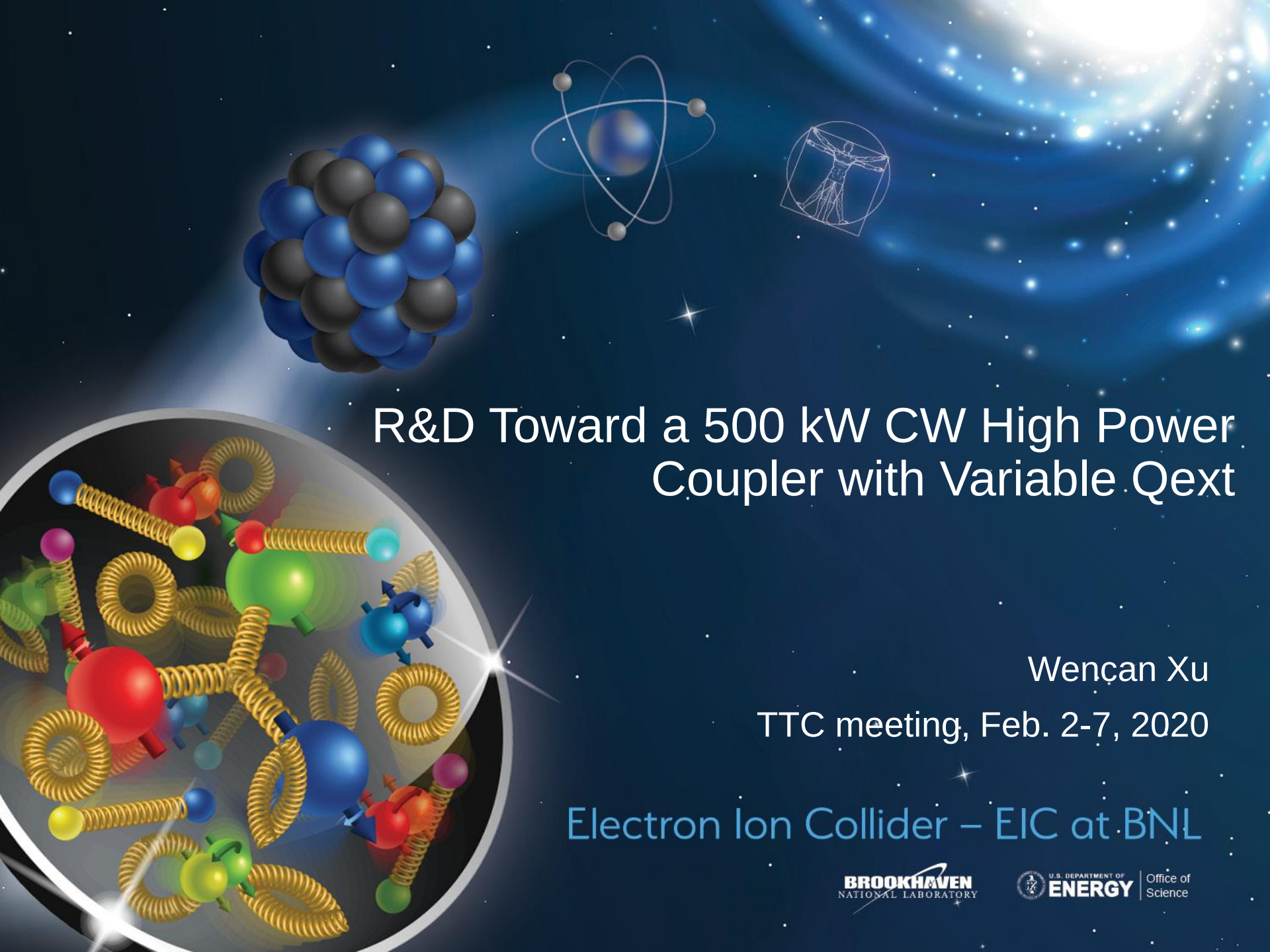


R&D Toward a 500 kW CW High Power Coupler with Variable Qext

Wencan Xu

TTC meeting, Feb. 2-7, 2020

Electron Ion Collider – EIC at BNL

BROOKHAVEN NATIONAL LABORATORY

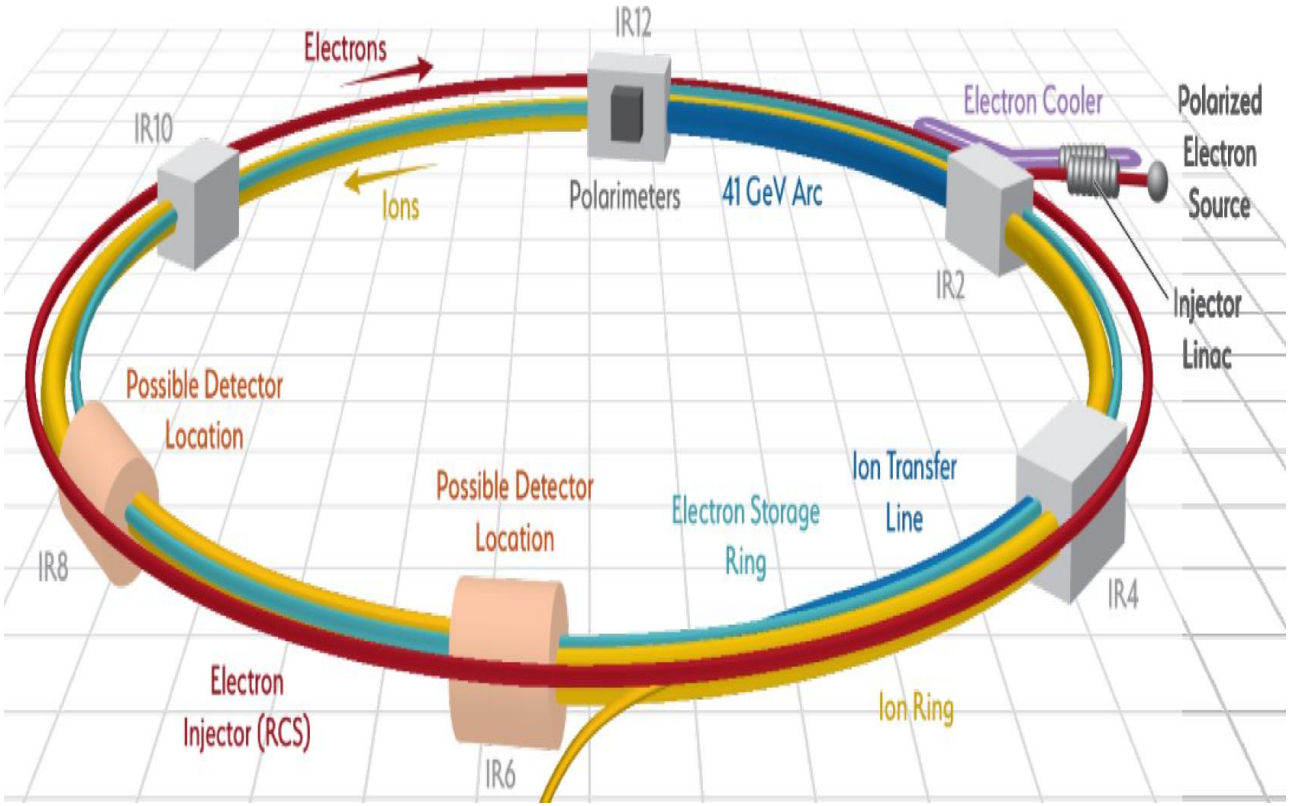
U.S. DEPARTMENT OF ENERGY | Office of Science

Outline

- FPC requirements and challenges for the electron storage ring SRF cavities at BNL EIC.
  - RF Power: CW 400 kW per coupler (92% of time in TW and 8% of time in full reflection).
  - Q_{ext} tuning range: a factor of 10 (2.5×10^4 - 2.6×10^5).
- R&D progress on testing high power waveguide tuner and high power coupler at BNL.
  - RF power: CW 500 kW, full reflection.
  - Q_{ext} tuning range: a factor of 20.
- Summary and plan

BNL EIC layout

- BNL EIC aims to build a new electron accelerator to collide electron bunches with ion bunches from the existing RHIC complex.

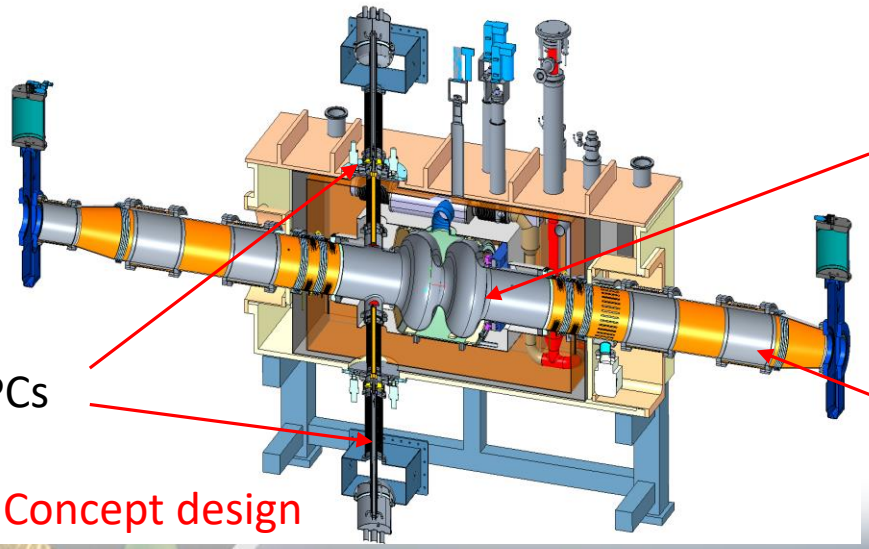


- Among all EIC RF systems, one of the most critical and challenging components is the high power, Q_{ext} tunable FPC for the electron storage ring 591 MHz SRF system.

- *EIC at BNL: https://www.energy.gov/articles/us-department-energy-selects-brookhaven-national-laboratory-host-major-new-nuclear-physics;*

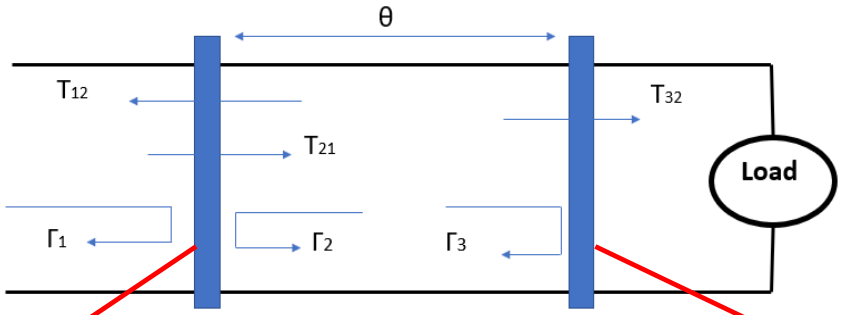
Requirements and challenges

- Wide operating scenarios of EIC electron storage ring:
  - Electron Energy: 5- 18 GeV
  - Average Electron Beam Current: 0.27-2.5 A
  - Required Voltage per Turn: 11.1 - 68.1 MV
  - Synchrotron Radiation Power: 1 – 10 MW
- To satisfy all operating scenarios and minimize the installed RF power, high power (400 kW), tunable Q_{ext} (2.5×10^4 - 2.6×10^5) FPCs are required.
- This LDRD program aims to test a 500 kW waveguide tuner for tuning Q_{ext} over a factor of 20, and an existing 500 kW fixed power coupler.

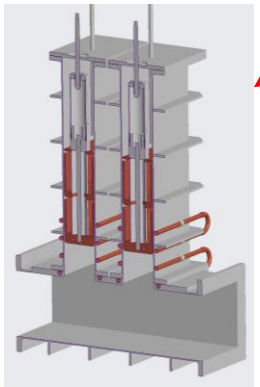


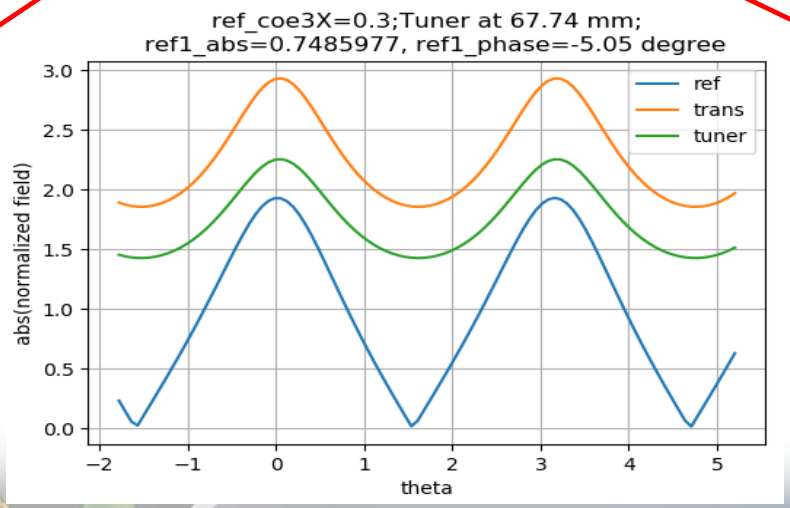
R&D on tunable FPC

- There are two ways to adjust Q_{ext} :
  - Vary FPC's position/insertion in a cavity
  - Vary impedance seen by the cavity, through a impedance transformer
- As BNL has an existing 500 kW fixed fundamental power coupler design*, we decided to keep this and develop a high power waveguide tuner to adjust Q_{ext}.

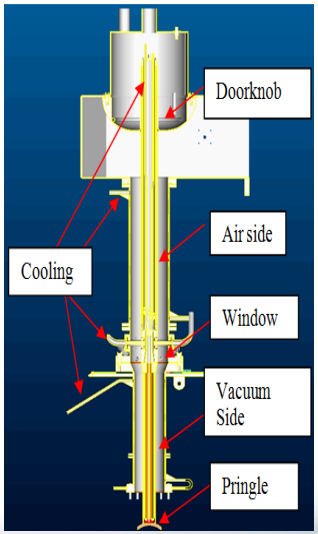


Waveguide Tuner



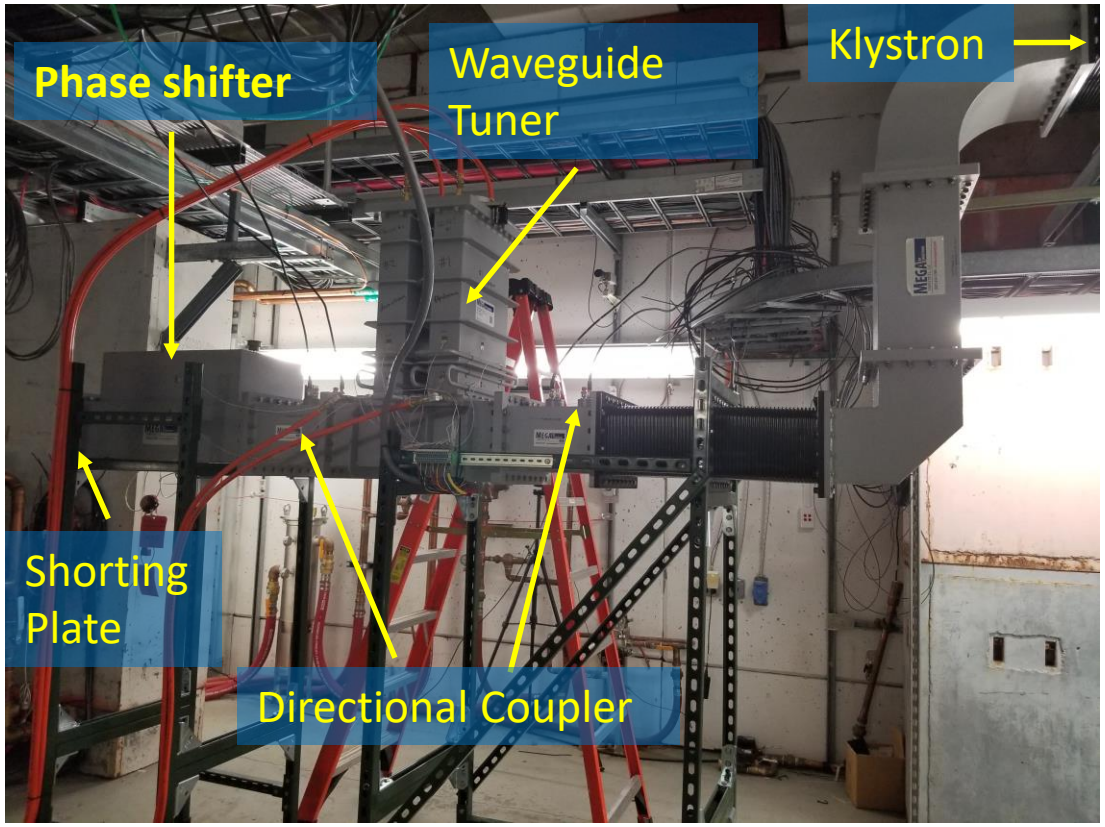


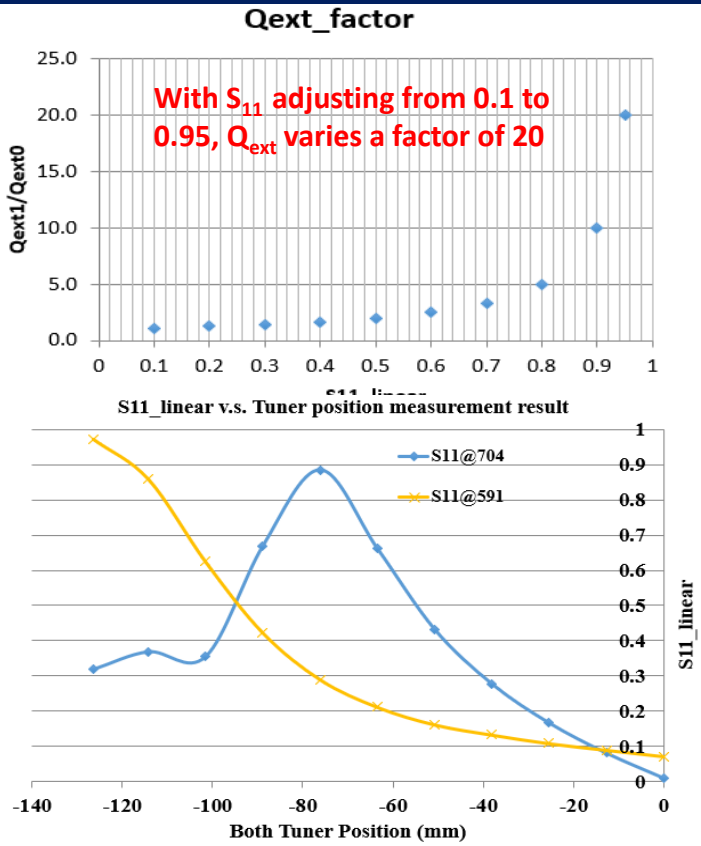
CW 500 kW Fixed FPC*



** Wencan Xu, et al. PRSTAB 072001 (2012)*

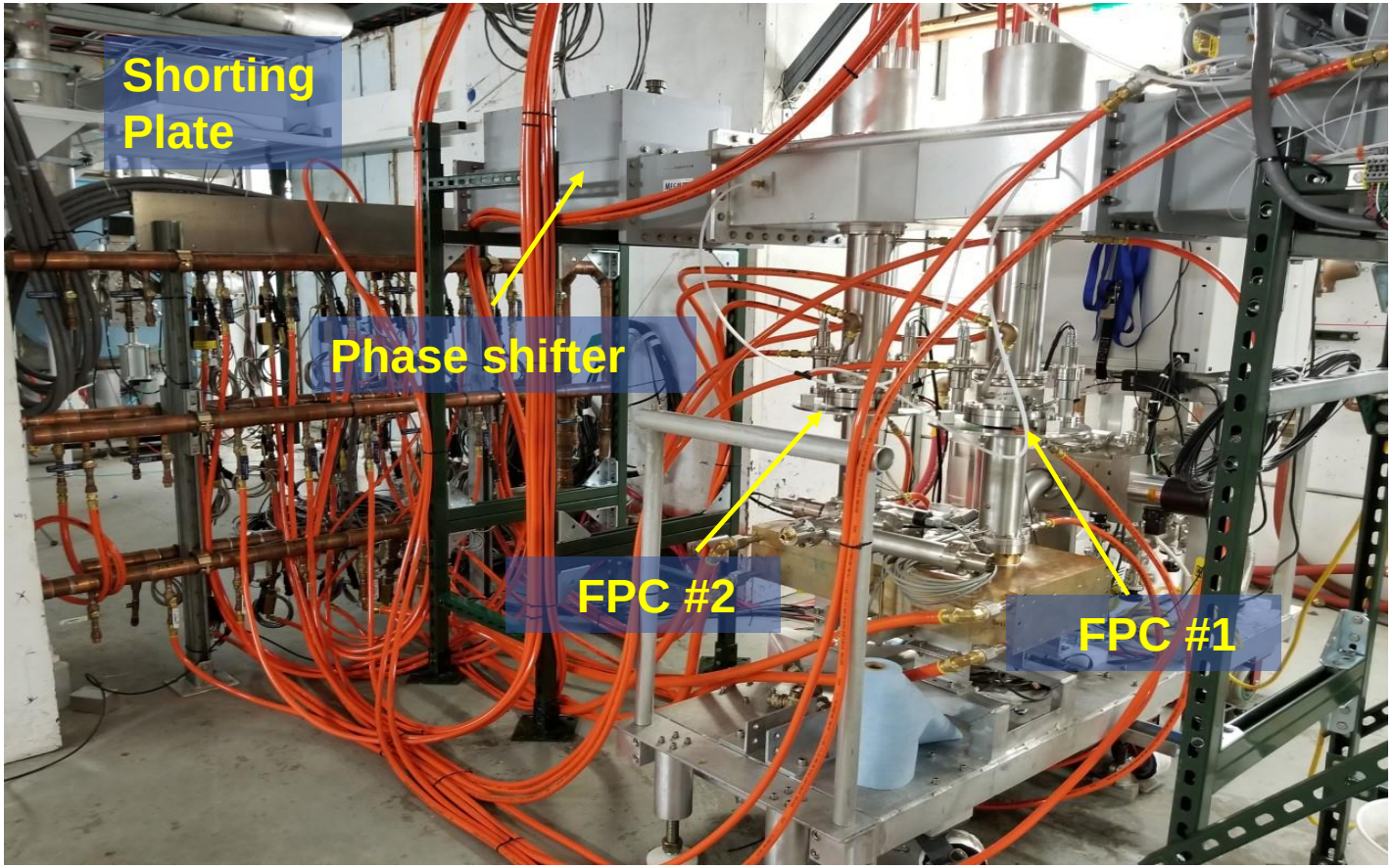
Test of waveguide tuner





- High power testing used an existing 1 MW 704 MHz klystron and high power phase shifter, which provides a 0 – 40^{o} shift for a total of 80^{o} on reflected wave.
- The main concern for waveguide tuner is over heating, and extensive RF-thermal simulations were carried out.
- The tuner was tested up to 500 kW CW. The highest temperature ever reached was 58 ^{o}C, which agrees with our simulation results and meets our operating criteria.

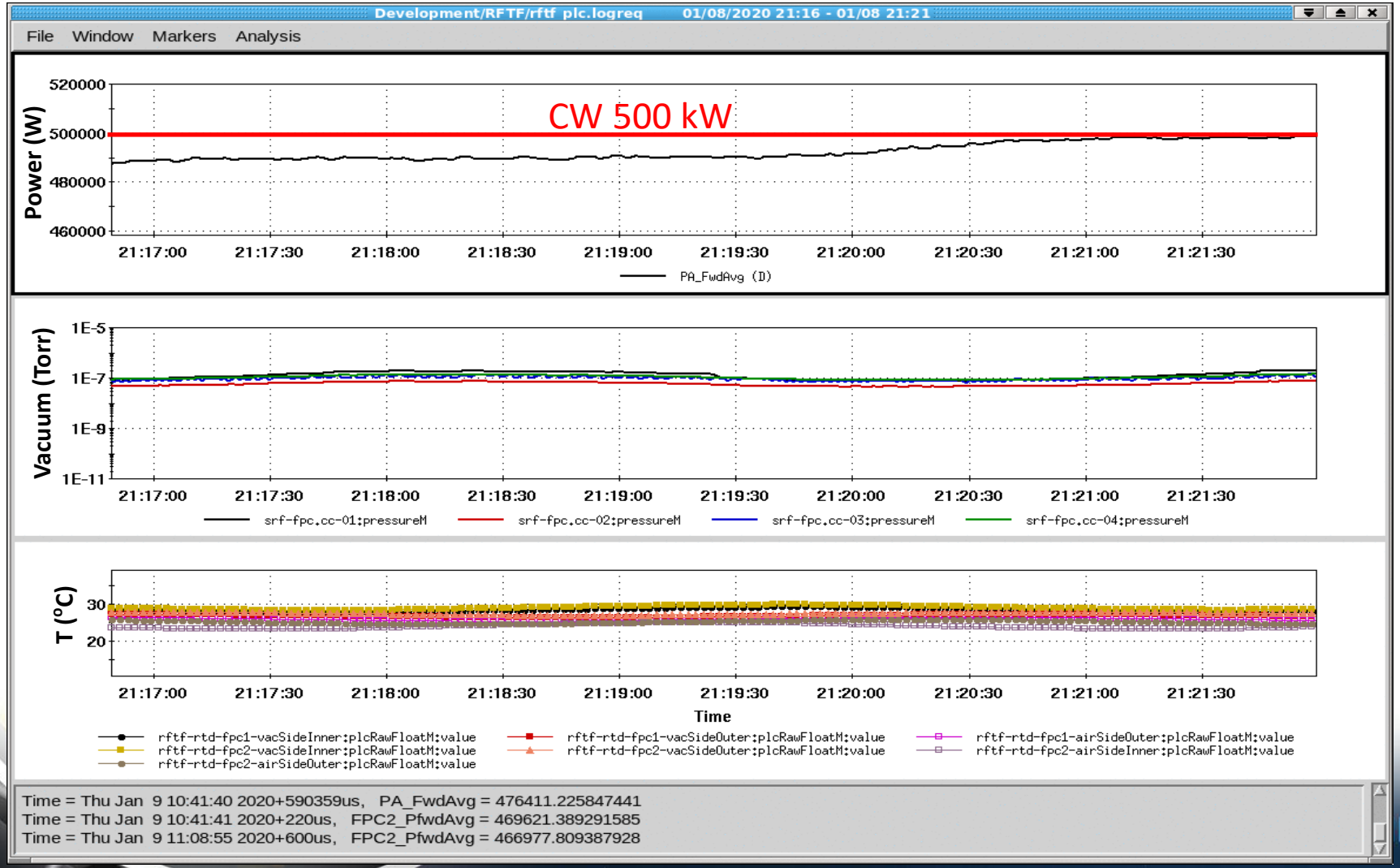
Test of high power FPCs



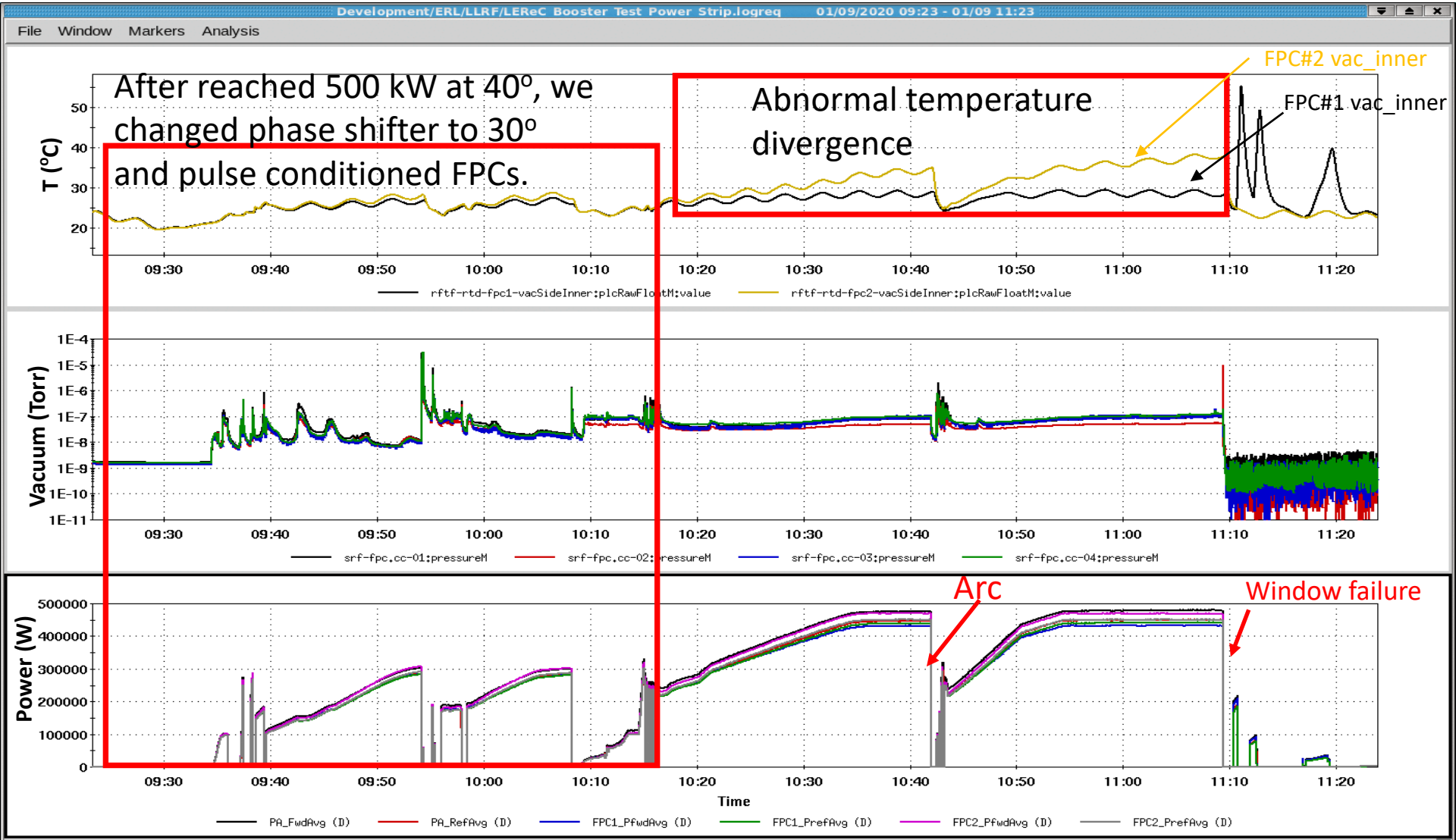
- The other goals for this R&D program include :
  1) To verify the FPCs for EIC (400 kW) application.
  2) To test the limit of this FPCs (500 kW per design).
- The system interlock signals include arc detectors, vacuum, water flow and temperature, thermal sensors on critical locations and access control.

Result(1): FPC conditioned to 400 kW and above

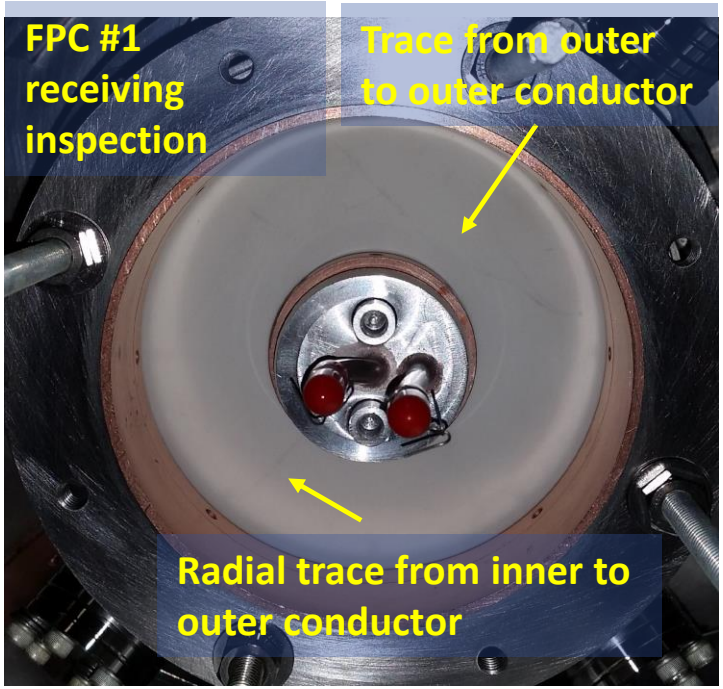
- FPC conditioning procedure was
  1) Increase RF power from short pulse (20 us) to CW at increasing power(170, 300, 400 kW), scanning phase in 10 degree for each power.
  2) To verify the design of 500 kW CW operating at various phases.

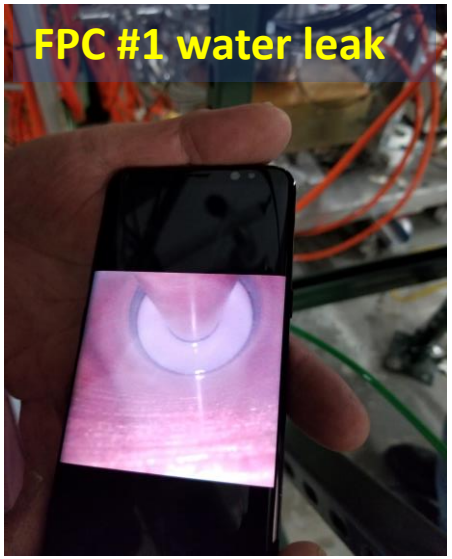


FPC test results (2): FPC #1 window failed at 480 kW

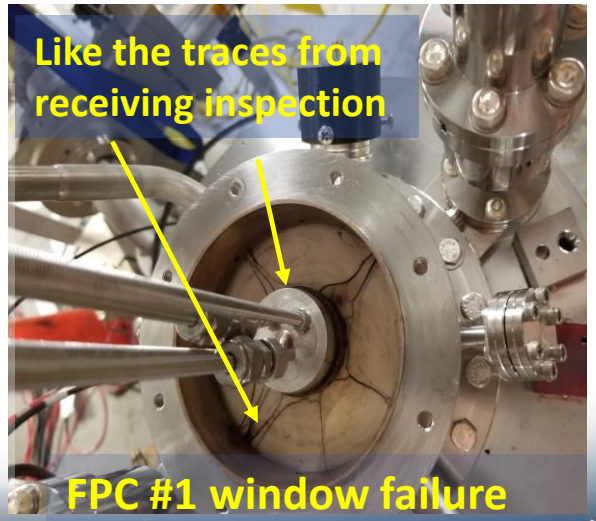


FPC test results (3): FPC #1 history





- FPCs have been conditioned at high power for more than 100 hours, prior to FPC #1 window failure.
- The couplers were conditioned up to CW 500 kW at 40°, but the FPC #1 window failure happened at 480 kW at 30°.
- History of FPC #1: traces found during receiving inspection, DI water leak to the air side window, doorknob arcing.
- We are still investigating the root causes for the failure.



Summary and Plan

- BNL EIC requires 400 kW FPCs with Q_{ext} adjustable by a factor of 10, for storage ring SRF cavities.

- This LDRD program demonstrates proof-of-principle of the Waveguide Tuner (Q_{ext} adjustable by a factor of 20) and FPCs (400 kW CW, full reflection, various phases) for BNL EIC.

- More work has to be done, prior to qualifying this for BNL EIC project.

  - We need to investigate the root-cause(s) for the FPC #1 window failure.

  - Short term plan is to test FPC #2 and a spare coupler to various power levels for more extended periods first. Then, they will be pushed to the failure limit.

Acknowledgement

BNL: K. Smith, S. Seberg, Z. Conway, D. Holmes, C. Brutus, J. Genco, R. Anderson, J. Jamilkowski, D. Gassner, P. Kankiya, N. Laloudakis, J. Butler, D. Livoti, L. Vogt, M. Hamilton, G. McIntyre, D. Philips, D. Weiss, A. Zaltsman…

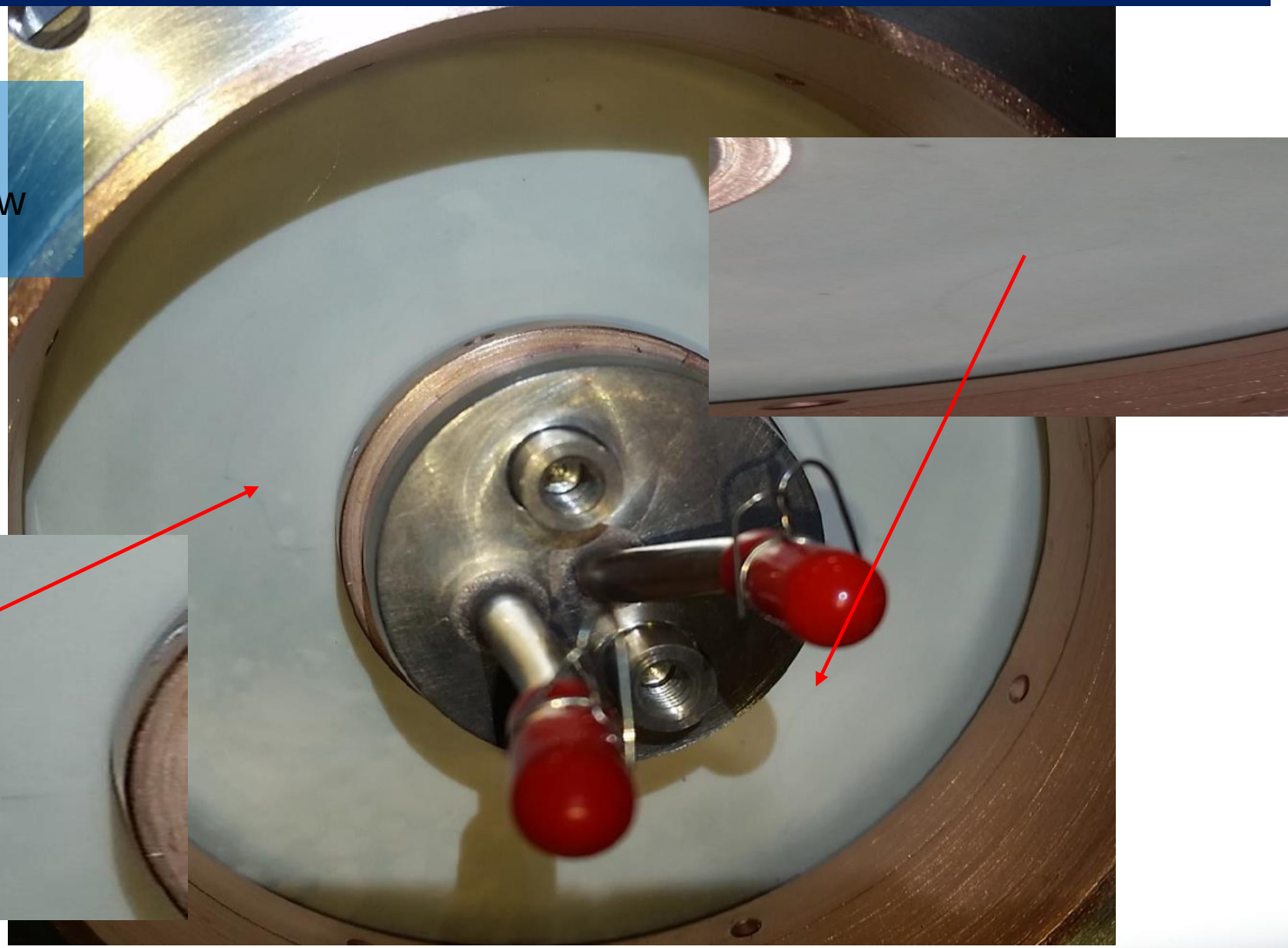
TJS: Tom Schulteiss

CERN: Eric Montesinos

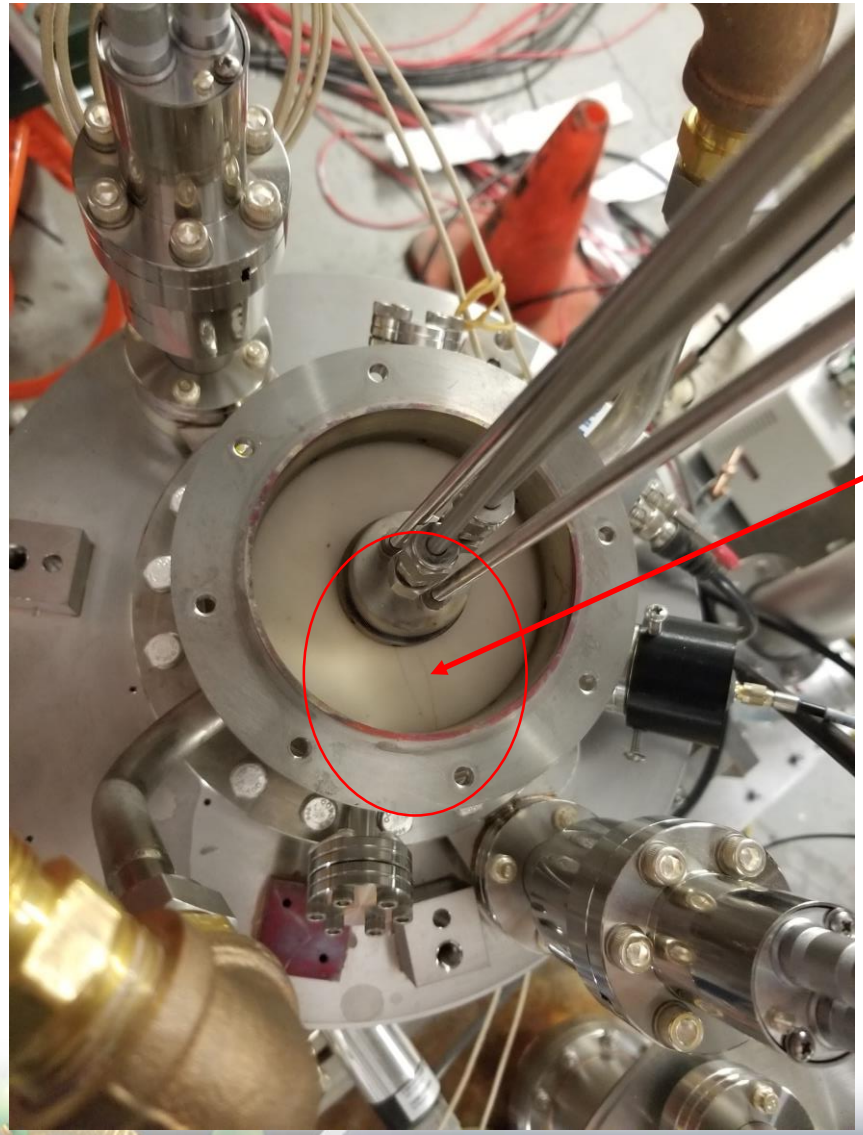
- Back up slides

FPC #2 Receiving inspection

FPC #2 window looked much better than FPC #1 window from the beginning.

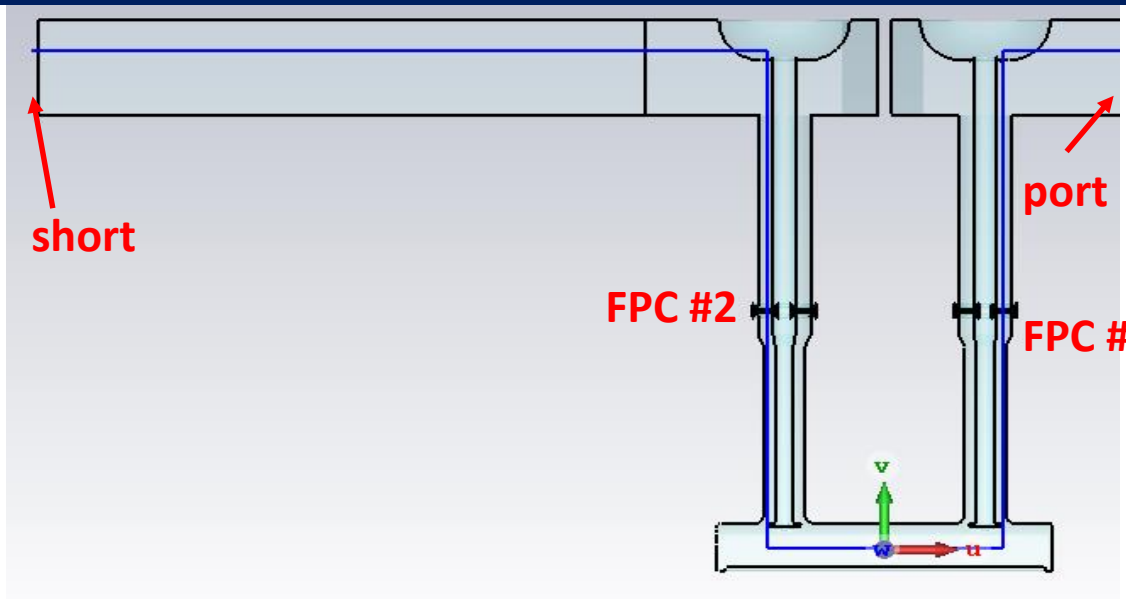


FPC #2 window

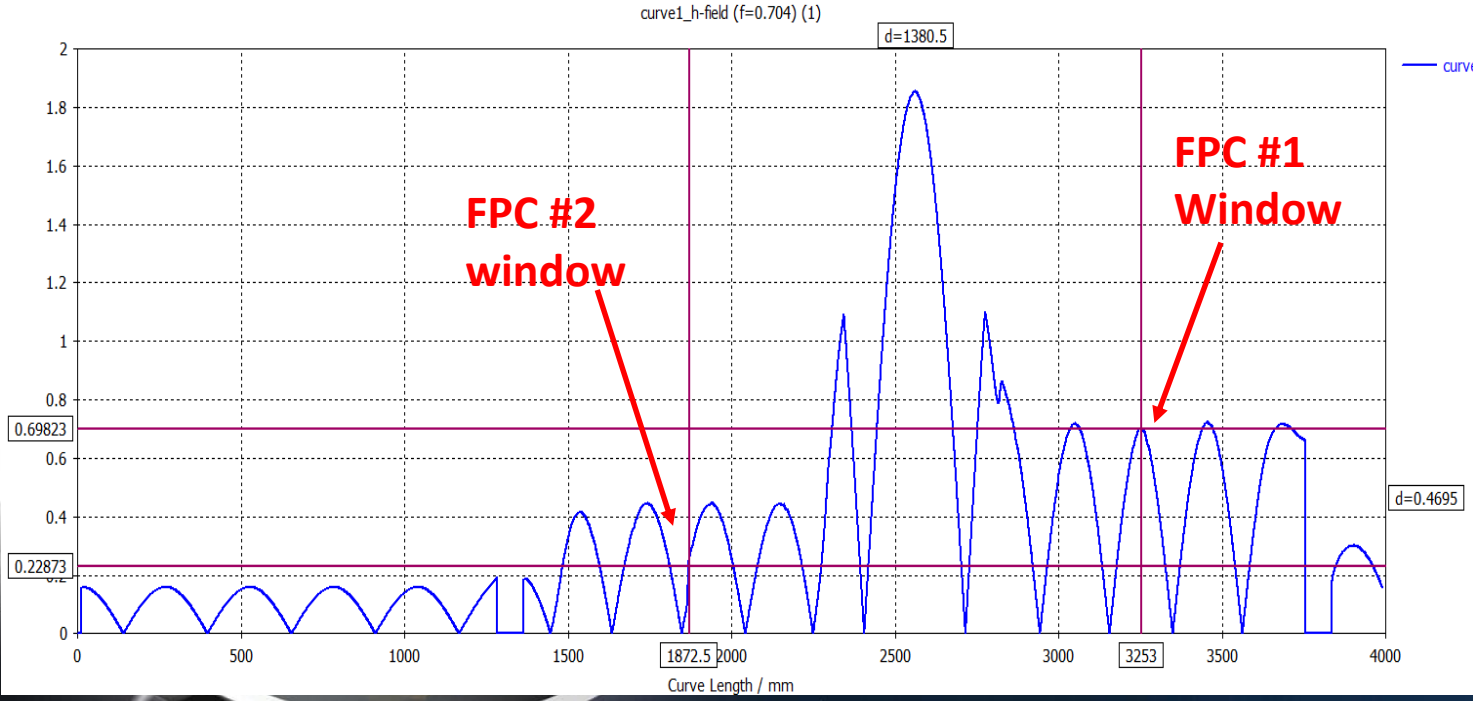


Need more inspection!

Field at 30 degree case

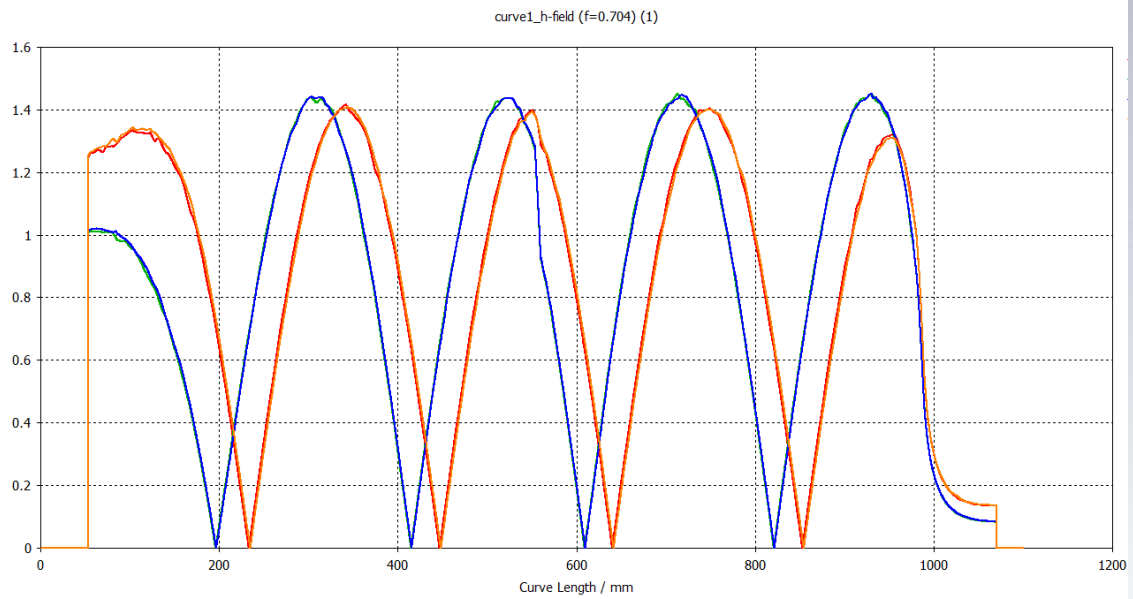


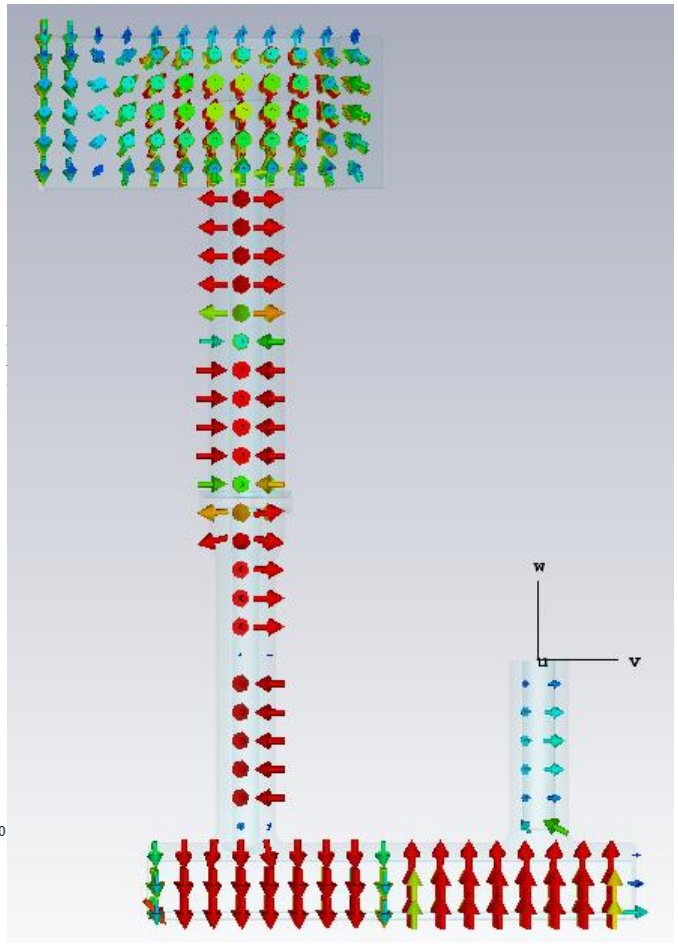
- Distance of two window is 3.2 wavelength at 704 MHz.
- Maximum H field at FPC #1 window. And about 1/3 of the maximum field at FPC #2 window.
- Zero E field at FPC #1 window. And about 2/3 of maximum E-field at FPC #2 window.



One FPC conditioning

- Conditioning with One FPC for long time at various power levels for hundreds of hours.
- Will test the limit of this coupler as well.





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
Cavity voltage	MV	11.1		23.7		68.10
Sync phase	rad	3.010		2.966		2.541
Sync Rad Power	MW	3.2		9.2		10.0