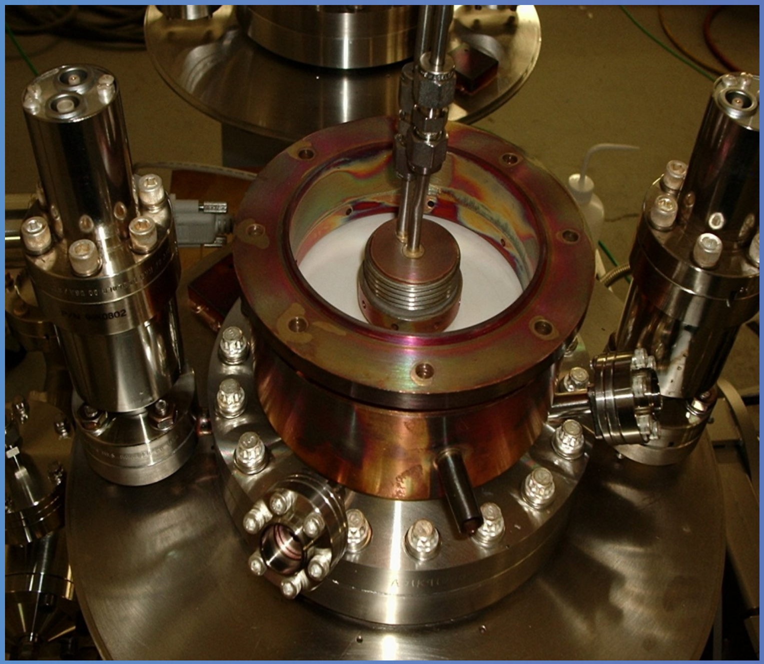
Fundamental power couplers for present and future projects at BNL



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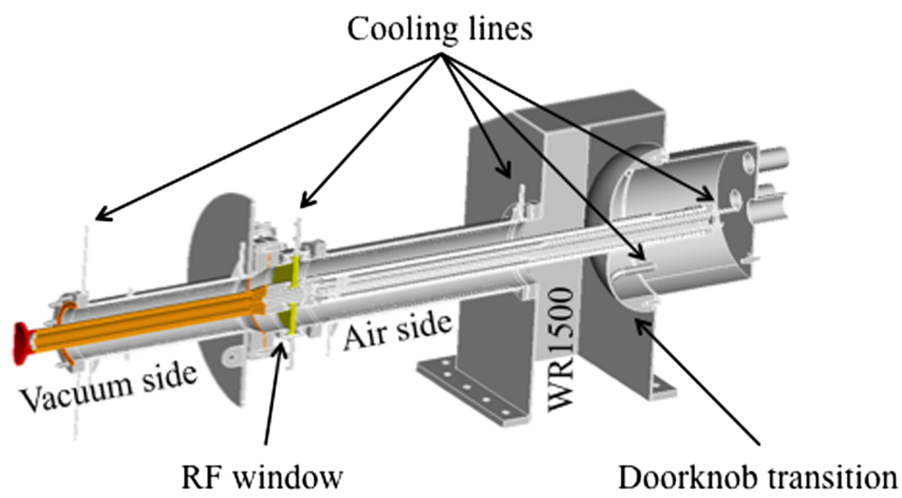
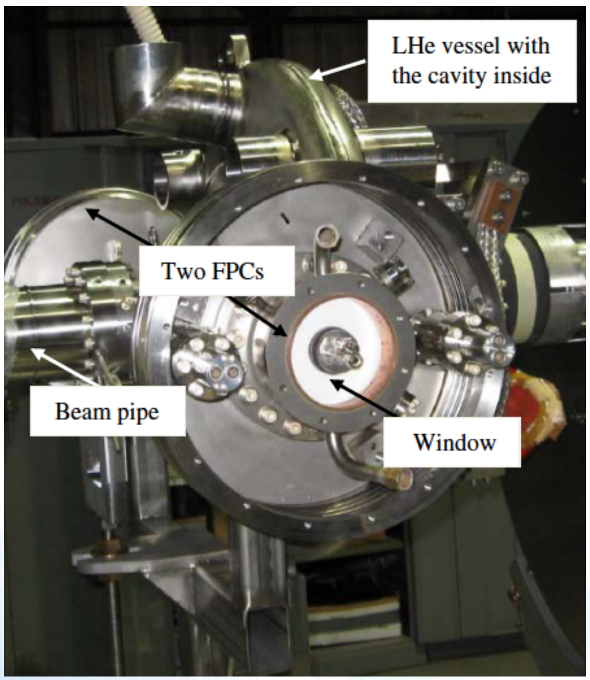
FPCs for SRF cavities at BNL's Collider-Accelerator Department

- All FPCs are of a coaxial type with a single RF window.
- For medium CW RF power (20 to 50 kW) at 704 MHz we purchased RF window/antenna assembly from Toshiba. These are SNS-type windows. The are installed on the 5-cell cavities at the R&D ERL and at Coherent electron Cooling Proof-of-Principle experiment.
- R&D ERL SRF gun has two FPCs designed by AES for an RF power up to 1 MW CW.
- For our future electron-ion collider eRHIC we plan to use similar fundamental power couplers.

FPCs for the R&D ERL SRF gun





- A 500-kW coaxial fundamental power (FPC) coupler belongs to the family of TRISTAN/KEKB/SNS couplers.
- Two couplers can provide up to 1 MW of RF power to the R&D ERL SRF gun.
- FPC has a planar berillia window.
- Inside the cryostat the copper-plated stainless steel outer conductor is cooled by helium gas.
- Copper inner conductor is cooled by water.
- Air-side inner and outer conductors are cooled by water.
- Window assembly has ports for vacuum gauges and arc detectors.
- Doorknob transition to WR1500.
- Pringle-shaped tip of the antenna to enhance coupling (similar to that of Cornell ERL injector).
- Designed by AES, manufactured by CPI/Beverly, then tested off-line, installed on the cryomodule and conditioned at BNL.

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Design, simulations, and conditioning of 500 kW fundamental power couplers for a superconducting rf gun

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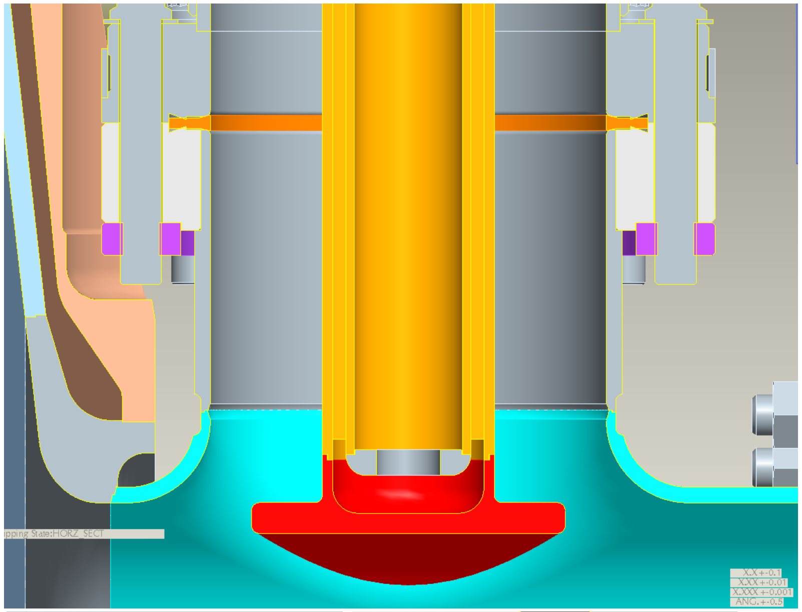
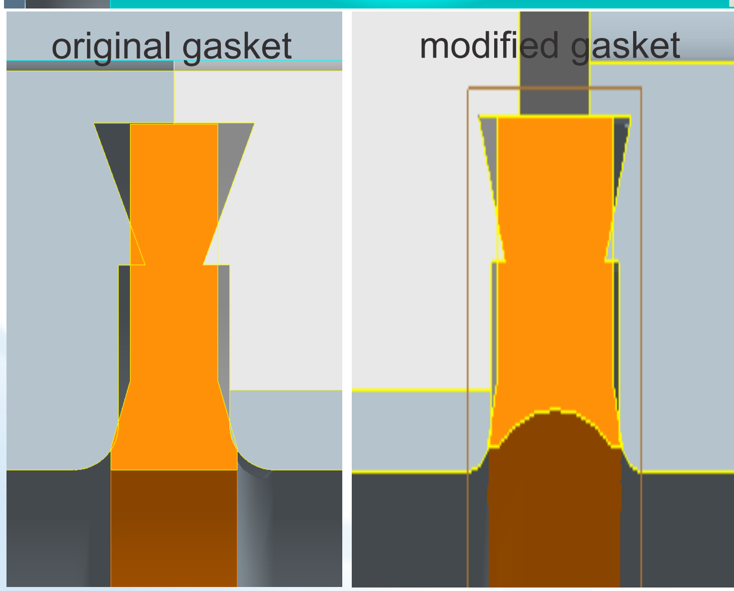
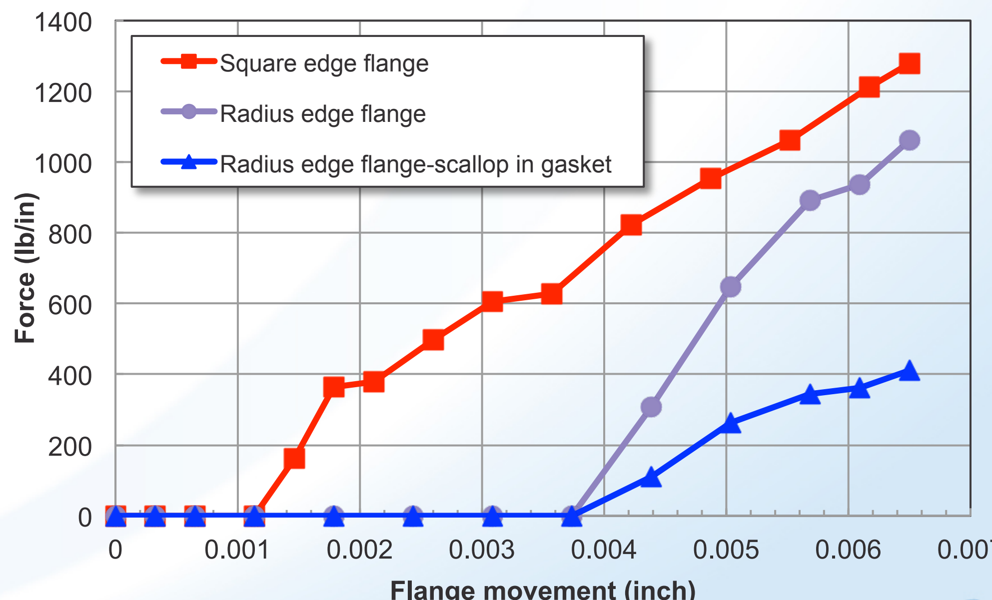
Conflat gasket with RF seal

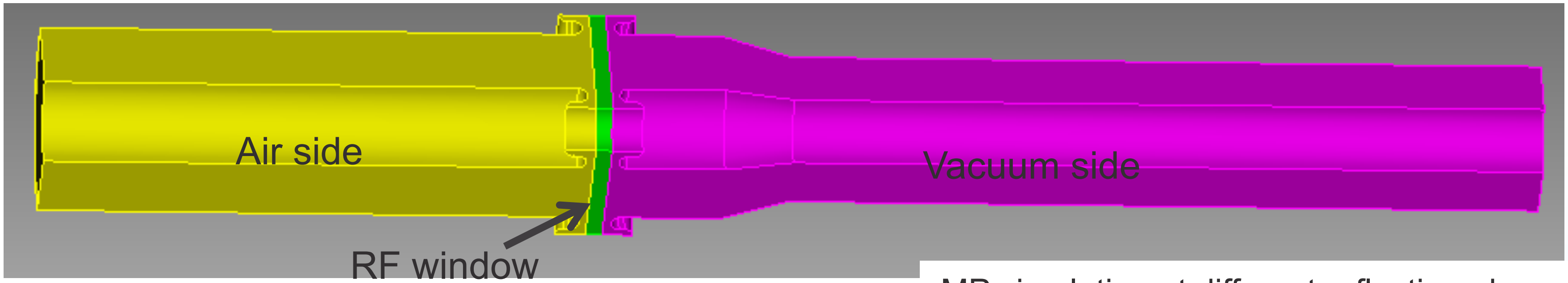




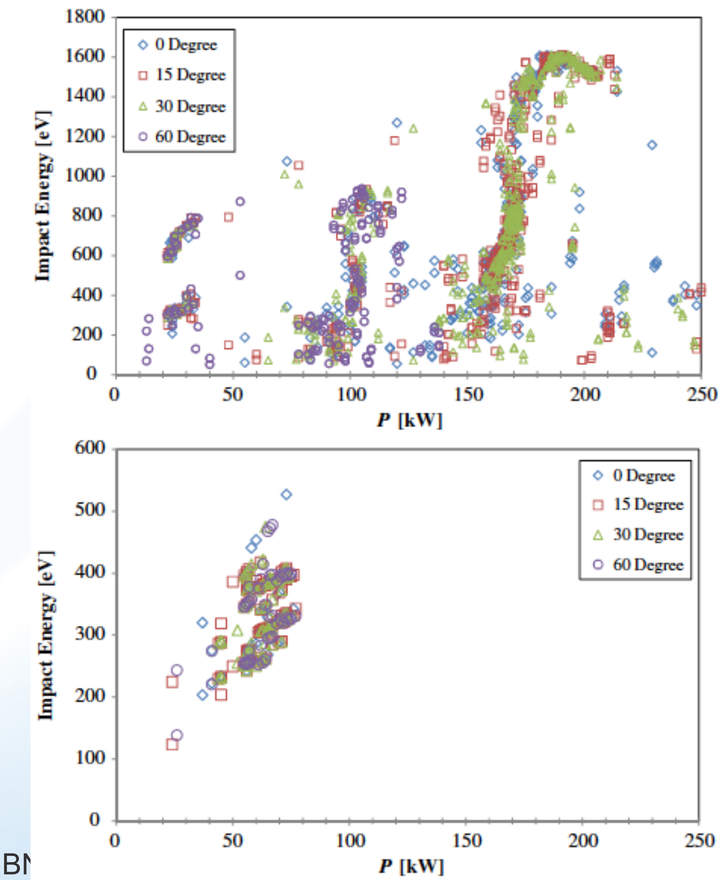
- A custom Conflat gasket with RF seal is used between the FPC and the SRF gun cavity.
- We have found that the original gasket was difficult to seal as the flanges had to crush the gasket in two places, which required very high force.
- A modification was proposed to alleviate the problem. It is used now on the SRF gun cavity/FPC interface.
- We may use similar gaskets in the future for beam pipe seals.



Simulations of multipacting with Track3P



MP simulation at different reflection phases:
Top – coax line; Bottom – window.



- The simulations were carried out for the FPC conditioning setup: standing wave, full reflection at different phases .
- MP was found in the coaxial line and at the window.
- MP zones are not sensitive to the RF frequency. However, the strength of multipacting varies with the frequency change.

FPC conditioning

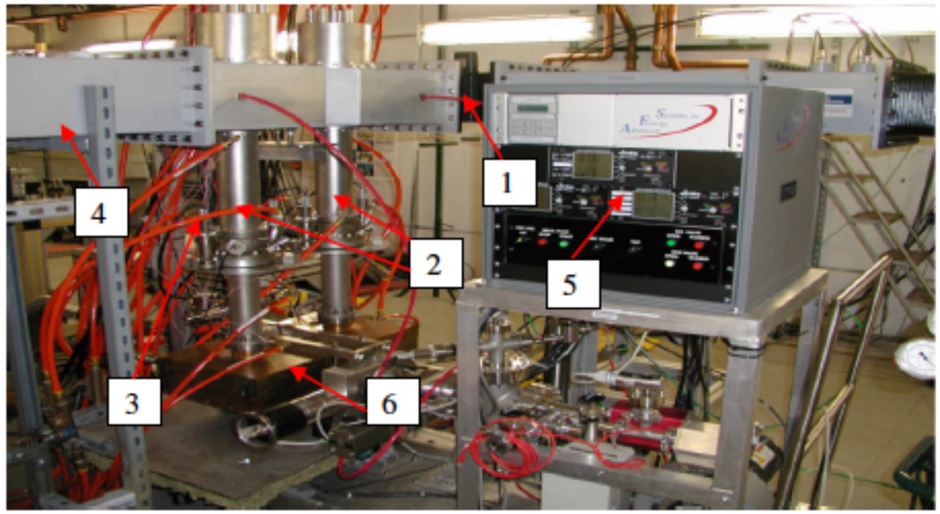
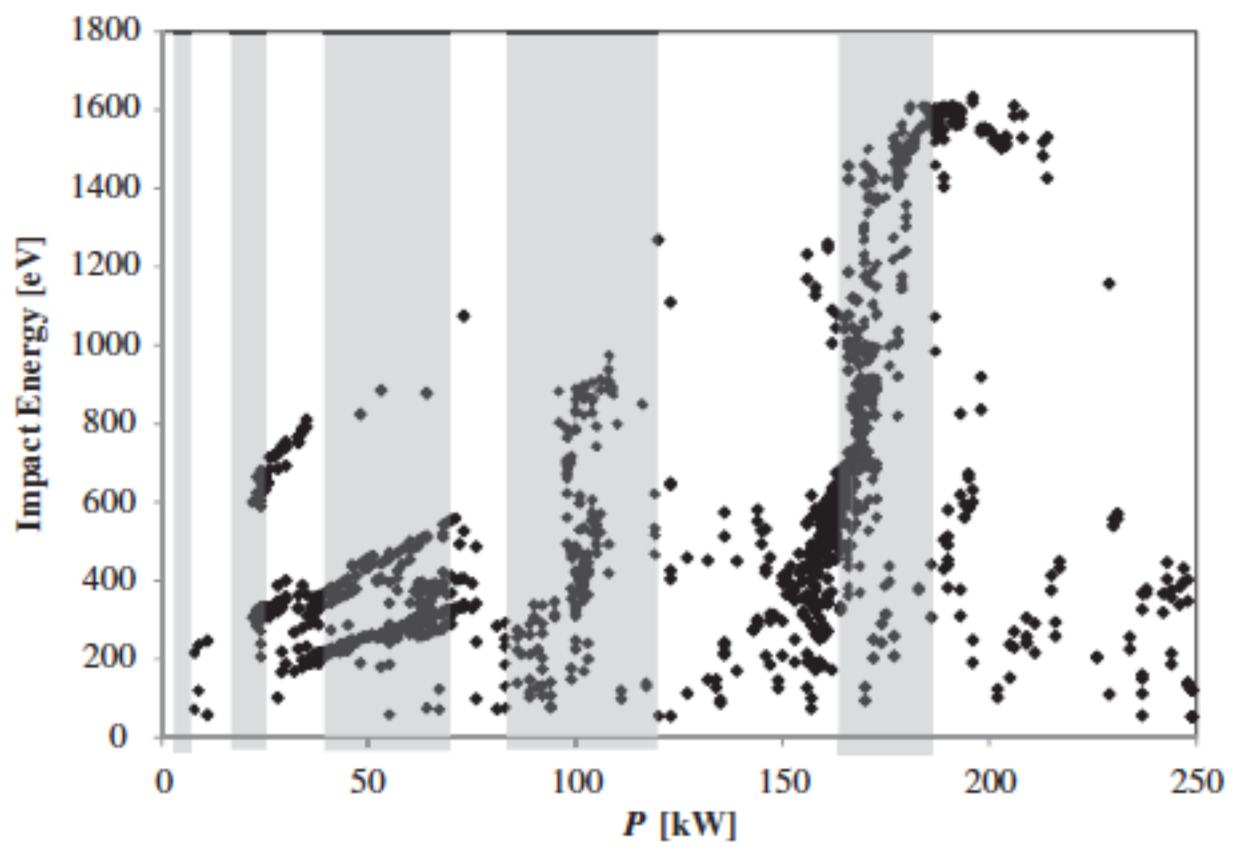


FIG. 15. Assembly of the FPCs for conditioning: 1—waveguide connecting to 1 MW klystron; 2—two FPCs; 3—cooling hoses; 4—waveguide phase shifter and a short plate; 5—vacuum instrument on the conditioning cart; 6—connecting waveguide.

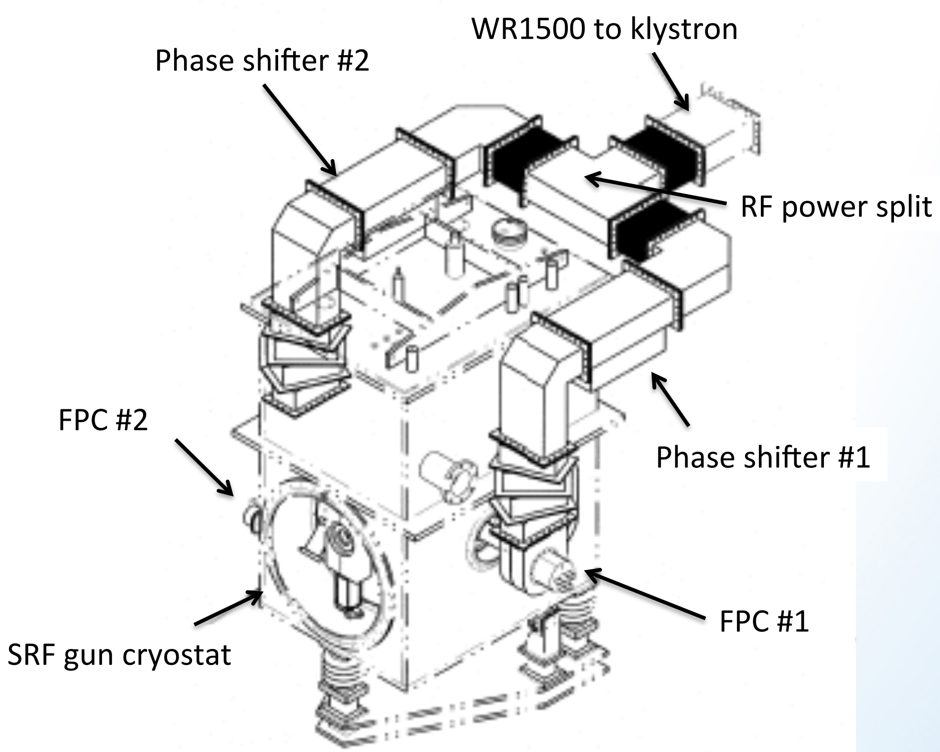
- Conditioning was performed in standing wave mode.
- It began in various pulse modes, from 100 μs/10 ms to 2 ms/10 ms pulse length/period, followed by the CW mode with gradual increase of RF power to the maximum value.
- The phase shifting up to 45 degrees is performed via the remotely controlled phase shifter.
- The output of the klystron is controlled by a computer program with feedback on vacuum.
- RF power was limited to 125 kW in CW mode to keep local field levels at standing wave maximum the same as they would be at 500 kW.
- RF power in pulse mode was up to 250 kW (limited by the klystron collector).

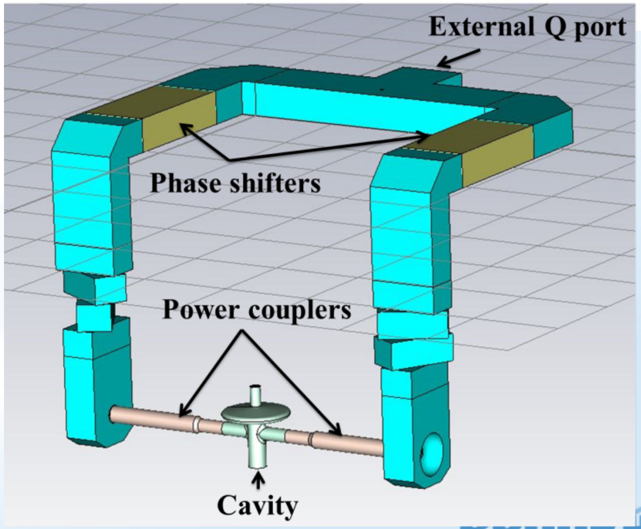
Comparison with simulations



- During the test, we encountered and conditioned multipacting zones at 8 to 10 kW, 16 to 25 kW, 40 to 70 kW, 85 to 120 kW, and about 165 to 185 kW.
- These is a reasonable agreement between the simulations and the experiment.

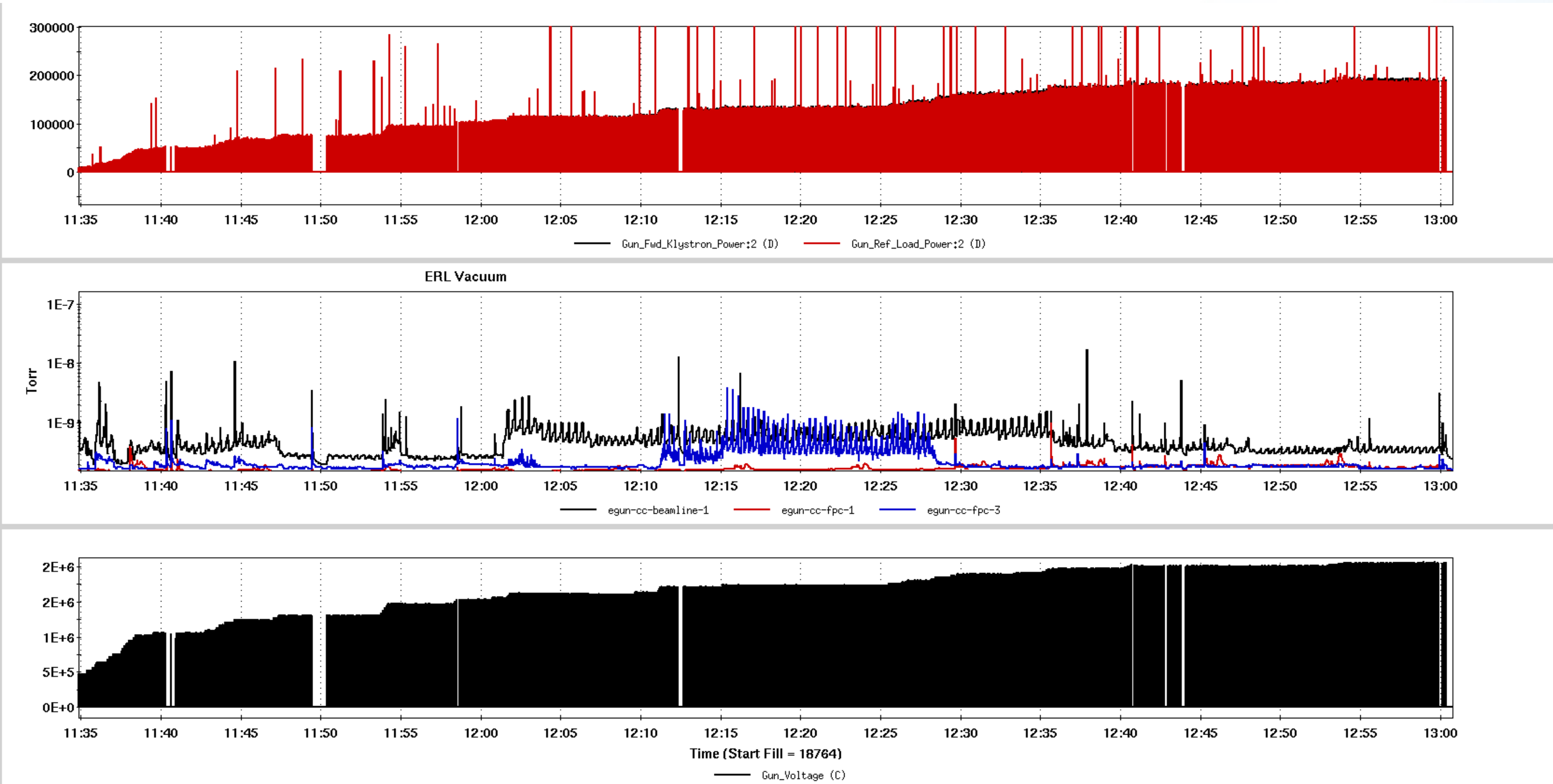
FPCs on the SRF gun





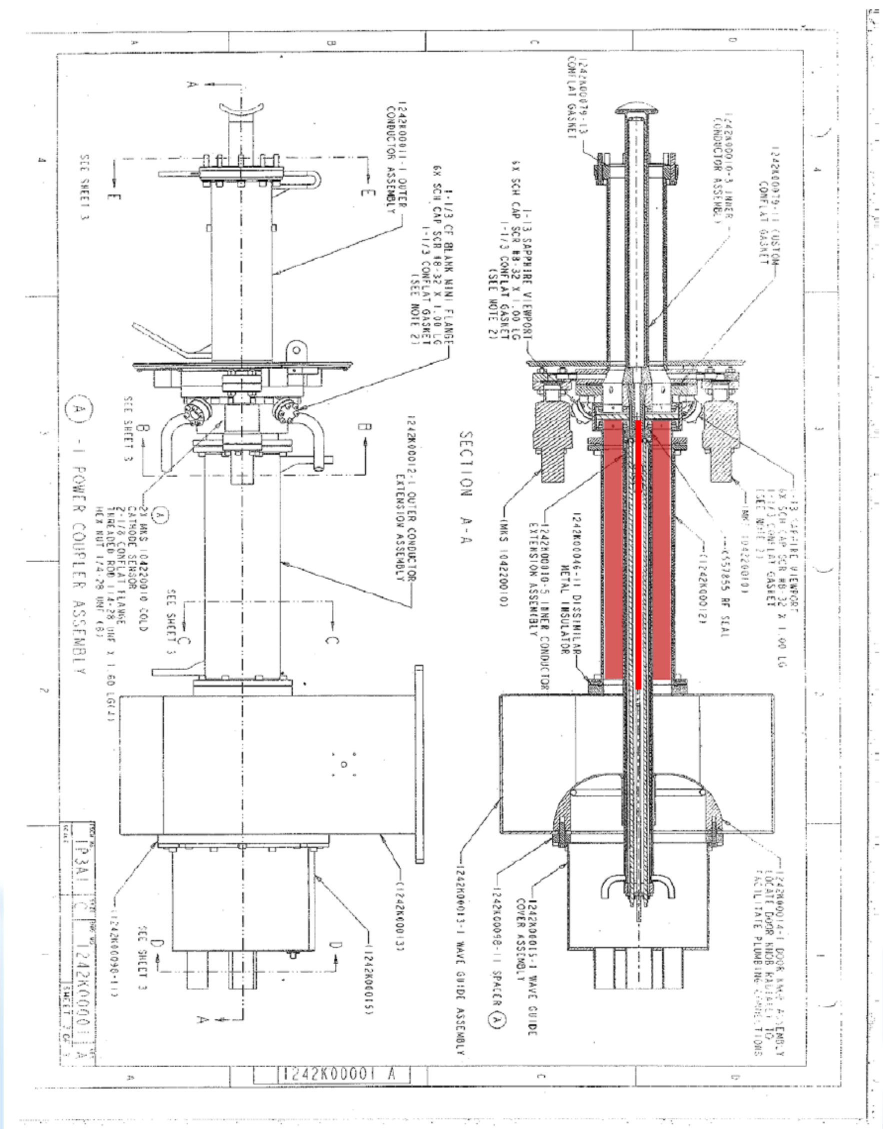
Operational experience with SRF gun

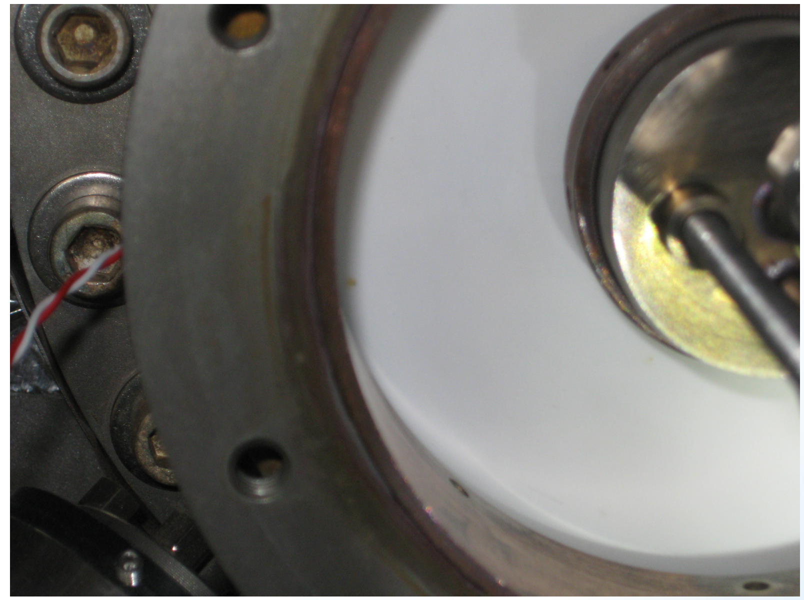
- FPCs are performing well during the SRF gun commissioning. Most of the required conditioning is due to MP in the cathode area or due to FE in the gun cavity.
- There is a constant flow of nitrogen at the air side of the coupler.
- To avoid water freezing inside the antenna, the water is blown out after each run.
- Had one incident of the FPC overheating. Found some dust inside the air side of the FPC. The FPC returned to normal operation after cleaning.

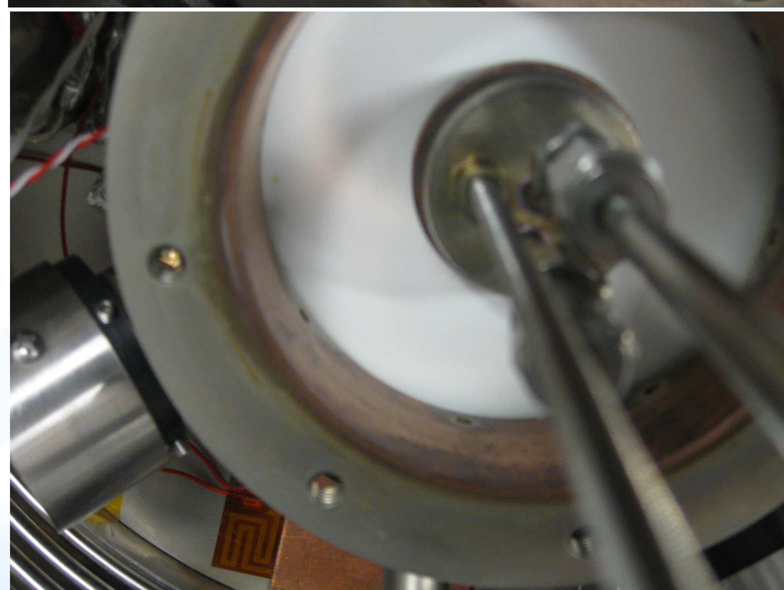


Operational experience with SRF gun (2)

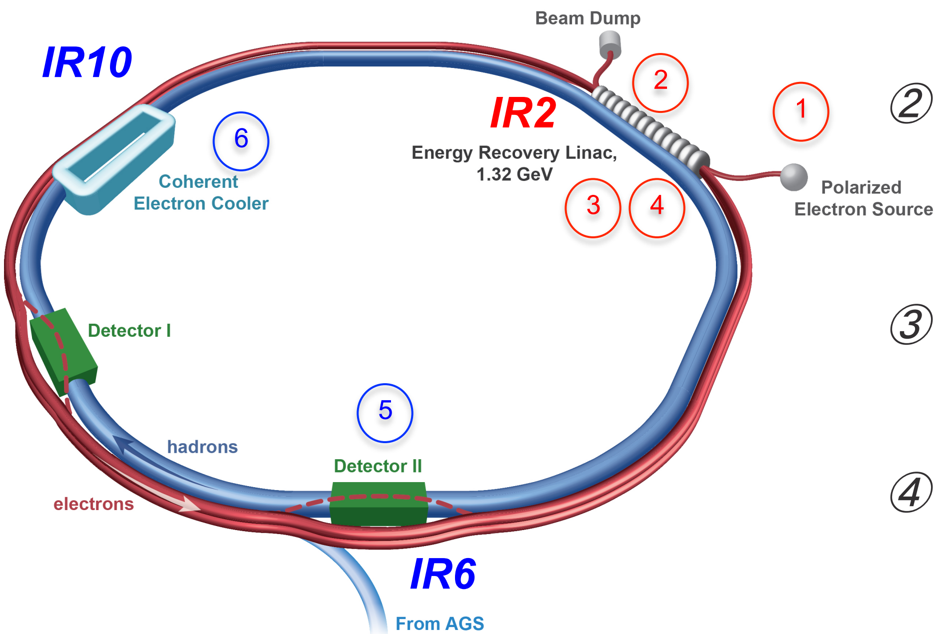
Areas in red indicate elevated levels of beryllium







eRHIC superconducting RF systems



① *12 MeV injector*: 84.5 MHz and 253 MHz QWR bunchers; 422 MHz booster cavity (3-cell, 11.3 MV/m).

② *Main 1.322 GeV SRF linac*, operating at 422 MHz. The final ERL energy is 15.9 GeV with 12 passes and 21.2 GeV with 16 passes: **42** five-cell cavities operating at 18.5 MV/m.

③ *844 MHz (second harmonic) SRF linac* for energy loss compensation: **6** two-cell cavities, delivering 400 kW per cavity.

④ *5th harmonic (2.1 GHz) SRF linac* for energy spread compensation: **8** five-cell cavities operating at 18.7 MV/m.

⑤ *SRF crab cavities* for hadrons and electrons around detectors. The former system will include 2nd and 3rd harmonics cavities for linearization. RF frequencies: 225 MHz, 450 MHz, 676 MHz (**4**, **2**, **1** cavities at each side of the detector for ions plus one 676 MHz cavity for electrons.)

⑥ *SRF ERL for Coherent Electron Cooling* (CEC) of the hadron beam. A 84.5 MHz QWR *SRF gun as an injector*, **26** QWR SRF cavities operating at 84.5 MHz and **9** QWRs operating at 253 MHz.

FPC requirements for some eRHIC systems

System	Frequency	RF power	Qext	No. of couplers
Main linac	422 MHz	30 kW	3.5×10^{7}	42
Energy loss compensator*	**845 MHz**	**200 kW**	$\mathbf{5.3\times10^{4} – 2.8\times10^{5}}$	**6 × 2***
Injector elliptical cavity*	422 MHz	61 kW	2.3×10^{6}	1 × 2*
Injector QWR*	84.5 MHz	26 kW	2.5×10^{5}	1 × 2*

** Two FPCs per cavity*

- We will need to design and adjustable FPC for the energy loss compensator cavities.
- It turns out that the Toshiba RF window is well matched even at 84.5 MHz.
- Some cavities will use two FPCs either to reduce the power per coupler or to symmetrize the transverse kick.

Summary

- All FPCs discussed in this presentation are of a coaxial type with a single RF window.
- For medium CW RF power (20 to 50 kW) Toshiba (SNS-type) windows can be used in a wide range of RF frequencies.
- For higher RF power (up to 1 MW) this RF window/coupler can be upgraded with additional cooling. Two FPCs for the R&D ERL SRF gun were conditioned off-line, installed on the cryomodule and are operational.
- For our future electron-ion collider eRHIC we plan to use similar approach. Most of the FPCs will be fixed, except for the energy loss compensation linac.
- Development of the adjustable FPCs at 845 MHz will begin soon. Collaboration on this design would be welcome.