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High Power Couplers and HOM Couplers Developments for High Intensity Applications

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Outline

I. High power coupler development

- High power FPC evolution.
- EIC development of 1 MW (TW) wide-bandwidth high-power coupler

II. HOM coupler development

- Overview of existing HOM dampers
- EIC development of beamline SiC HOM damper

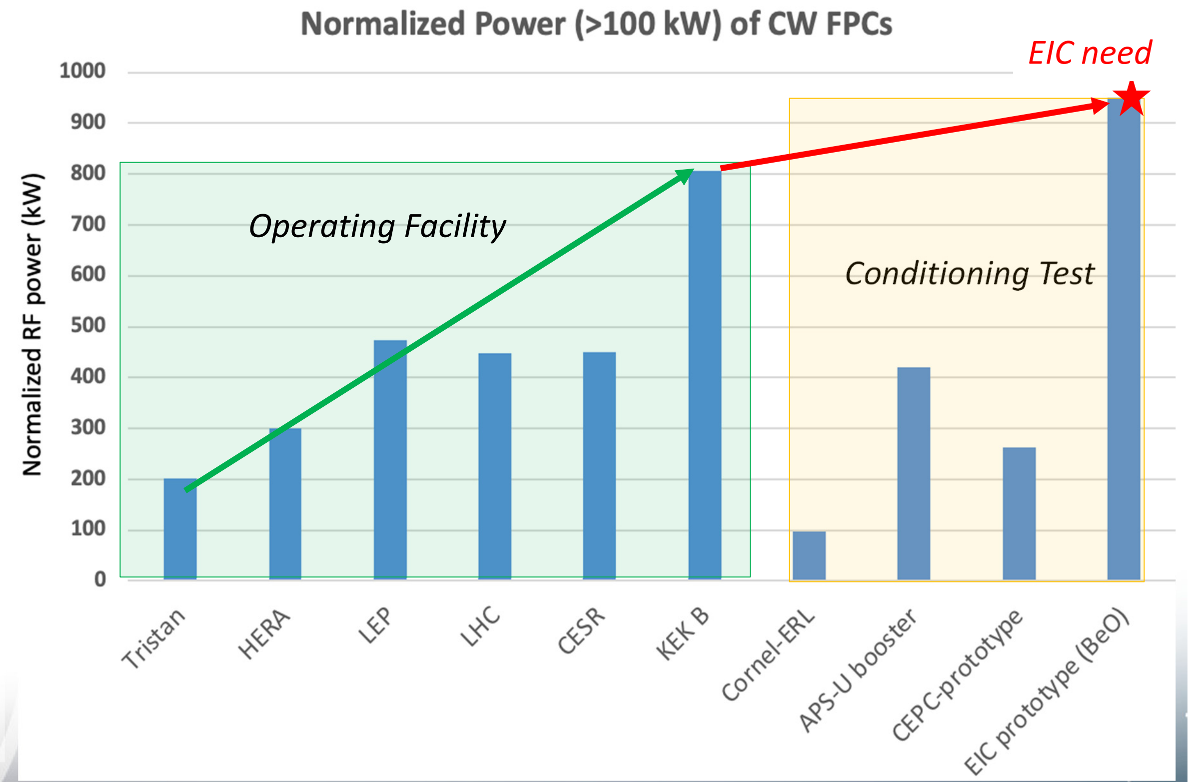
III. Closing comments

Note: In this presentation I focus on recent developments. There are many excellent FPC and HOM coupler/damper reviews in the SRF conference proceedings and USPAS classes which I cite in my paper contribution.

Normalized power of FPCs

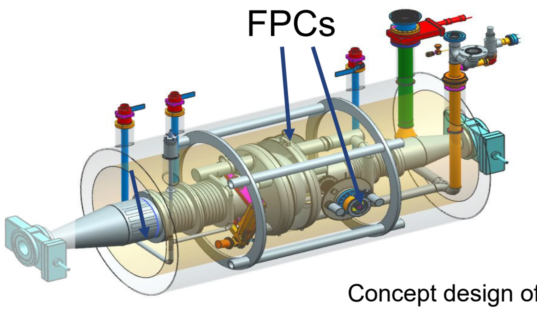
- *New FPCs are based on previous worldwide and evolving experience.*
- Normalize FPC power
  - *Transmission line RF losses dominate heating, although RF window is the weak point.*
  - *Need to consider both frequency and power when comparing different couplers.*
  - *Here I use:*

  Power x sqrt(freq[MHz]/500) [kW]
- EIC eSR FPCs to operate at MW level of normalized power.

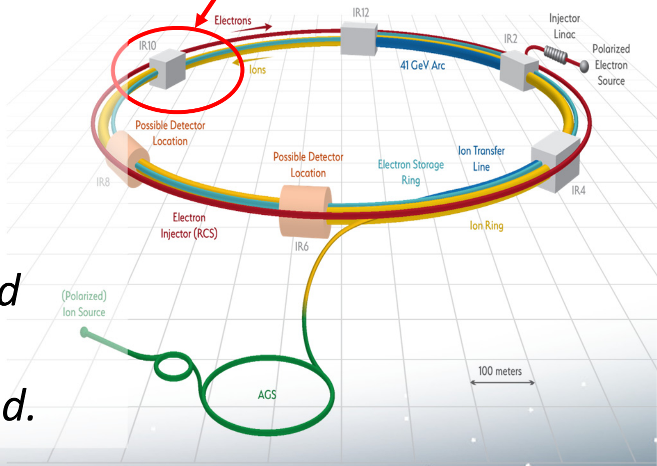


FPC for EIC ESR SRF cavity

- *The highest power coupler for all EIC SRF/RF cavities are the couplers for eSRF SRF cavity*
  - *Frequency: 591 MHz*
  - *CW 380 kW per coupler, 2 couplers per cavity*
  - *Abort gap:*
    - *92% TW operation*
    - *8% full reflection*
- *FPC design/testing criteria*
  - *CW 1 MW (TW) or 500 kW (SW)*
- *MW FPC R&D status*
  - *BeO RF windows successful up to ~500 kW (SW), but need improved reliability and easier handling.*
  - *A new alumina (99.5%) RF window FPC is being developed.*



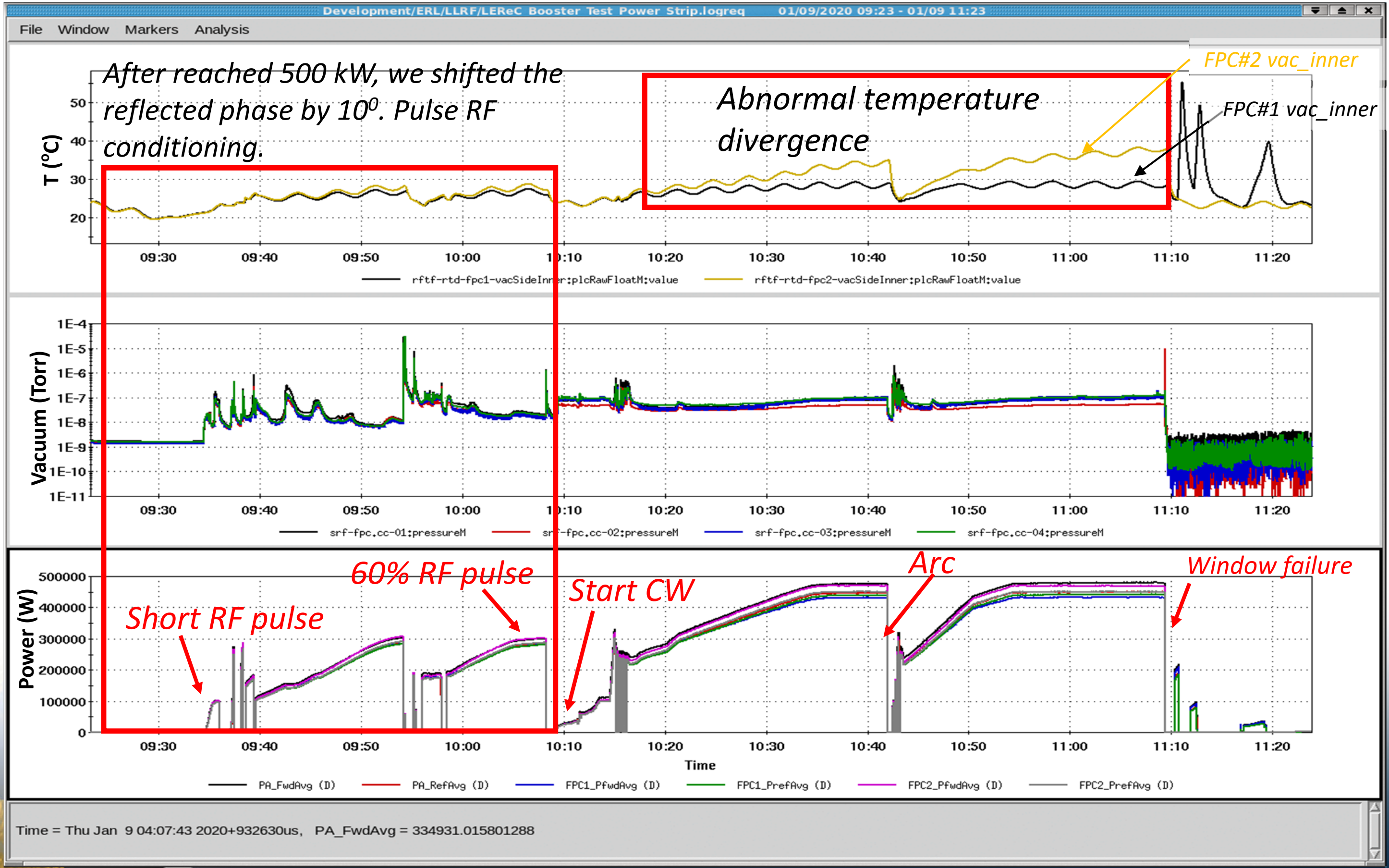
Concept design of ESR SRF cryomodule
Courtesy : Jim Henry



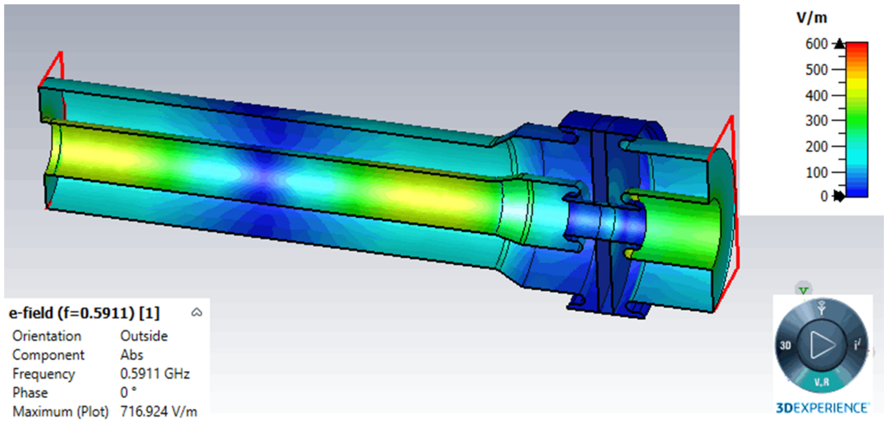
EIC complex

High Power FPC w/ BeO RF Window Test

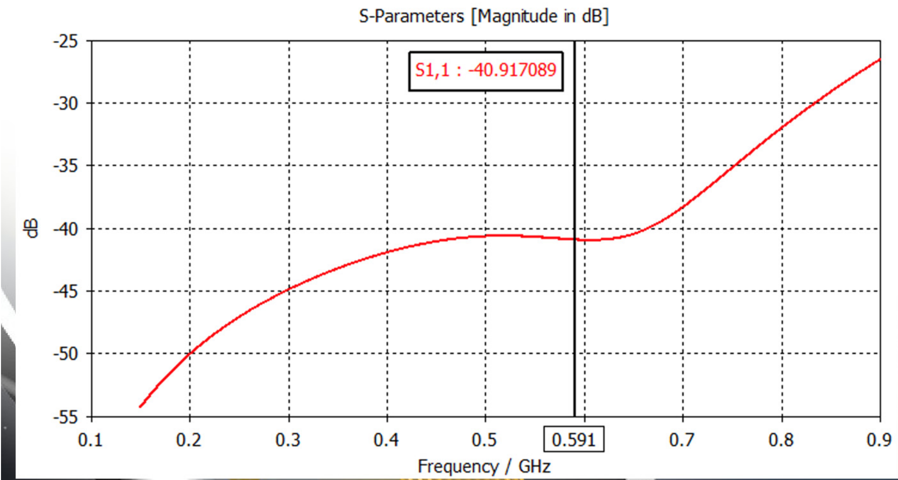
- *BeO window FPC test*
  - *Successful CW 400 kW, SW, all phases.*
  - *Successful CW 500 kW, SW, at one phase.*
  - *Window failure at second phase, due to arcing in FPC airside*
- *BeO FPC demonstrated feasibility of EIC operating power level, proof of principle.*

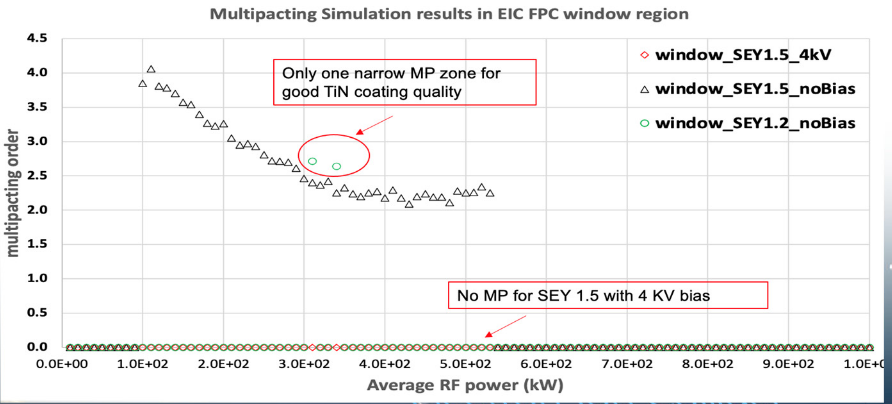


EM results of EIC alumina FPC



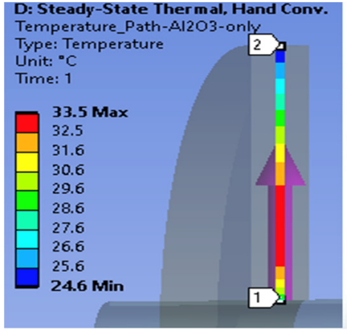
- *Window material: 99.5 % alumina*
- *Broadband window design*
- *Field around window optimized to reduce MP and peak fields around braze/choke.*
- *MP simulations are encouraging:*
    - *With an ideal window TiN coating (SEY=1.2), we may not need bias.*
    - *We are designing the coupler to include an optional 4.5 kV DC bias, just in case.*

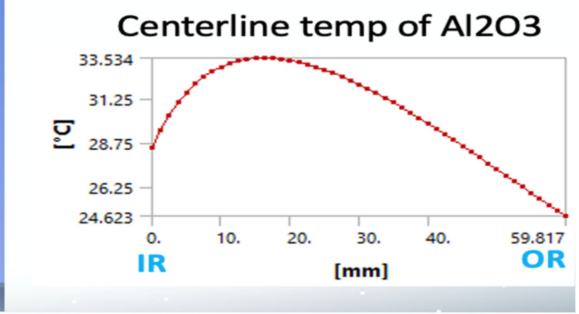


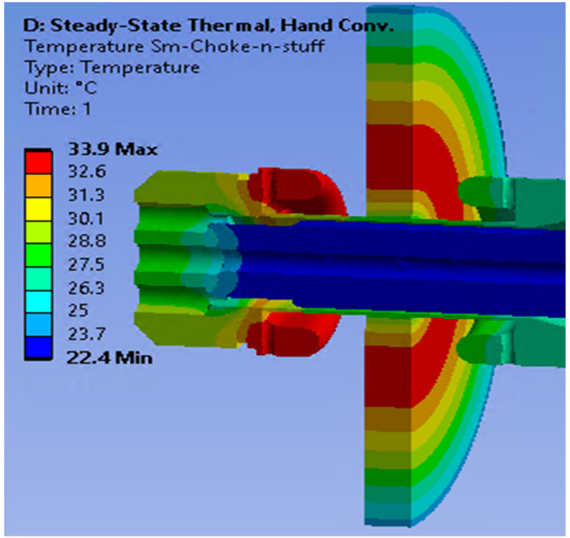


Thermal and mechanical analysis of EIC alumina FPC

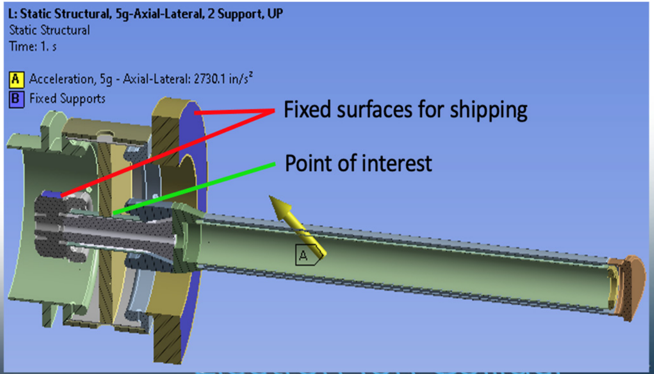
- RF-thermal-mechanical simulation results (1 MW, TW):
  - Maximum ΔT in alumina ceramic is 10 C.
  - Highest temperature is 34 C on the chock joint tip.







- Mechanical robustness evaluated for handling and transportation
  - 1st mechanical modal frequency: 100 Hz
  - 5g shock load calculation results are encouraging

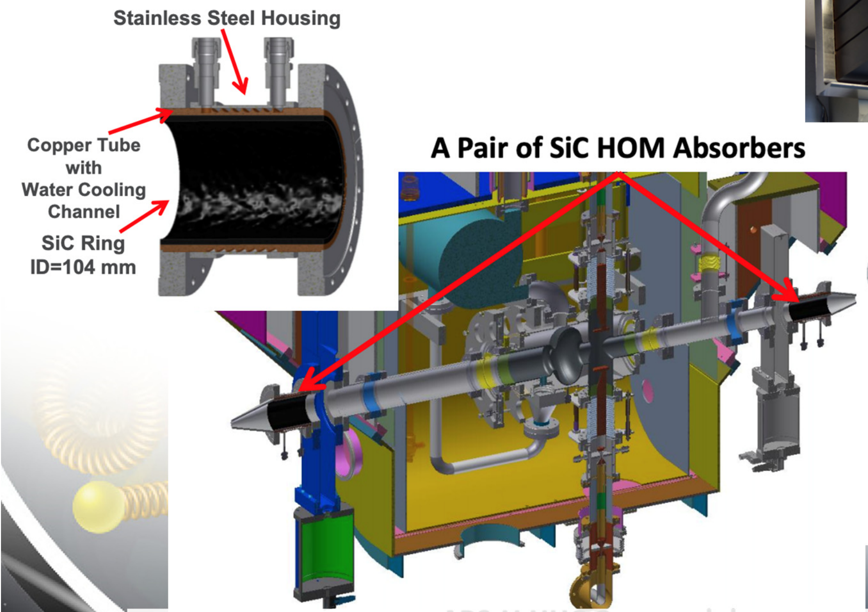


ANSYS Simulation (5g)	Max Equiv. Stress (Von-Mises) (all) (psi)	Max Equiv. Stress (Von-Mises) (copper) (psi)	Max. Principal Stress (Al_2O_3) (psi)	Min. Principal Stress (Al_2O_3) (psi)	Max. Lateral Deflection (inches)
Lateral / Axial toward	*4,773*	*4,312*	*4,936*	*-4,547*	*0.0073*

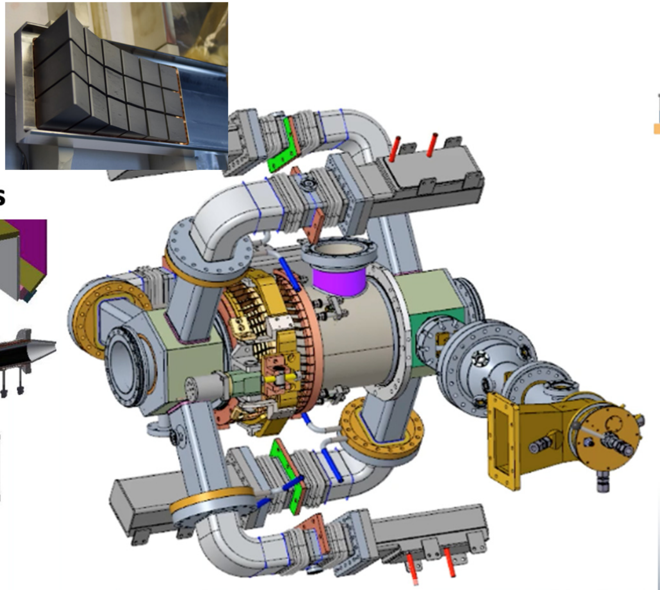
Courtesy : Jesse Fite

HOM damper for SRF cavities

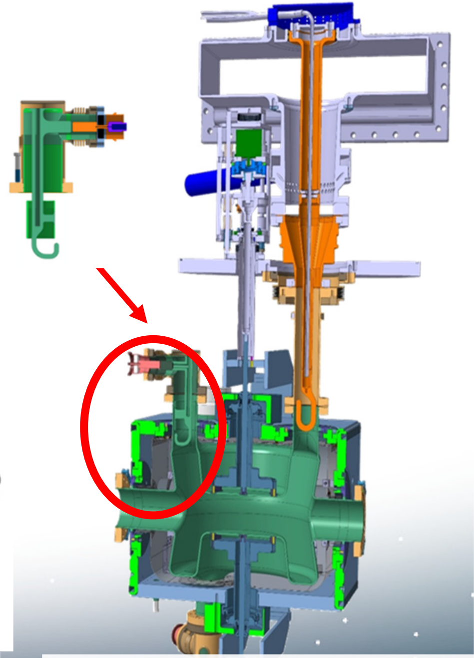
- *HOM plays a prominent role in determining accelerator limitations and beam quality.*
- *Three main HOM dampers used on SRF cavities: beamline, waveguide and probe/loop HOM damper.*



Beamline SiC HOM damper in APS-U HHC cavity



Waveguide HOM damper in BESSY VSR 1.5 GHz Demo cavity



Probe/loop HOM damper on LHC crab cavity

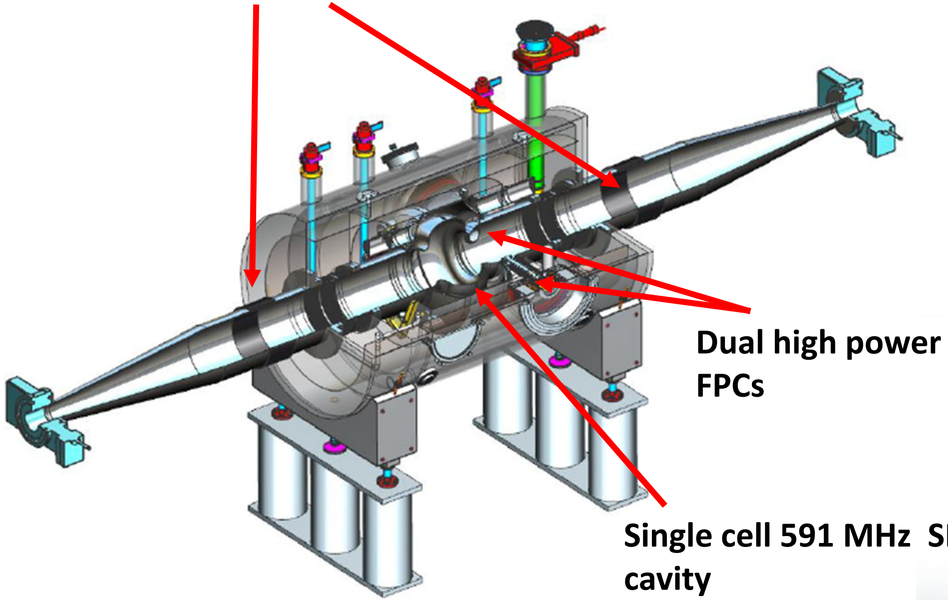
Features of HOM dampers

Type of HOM damper	Bandwidth	Power	Real estate space	cooling	Applications in Projects
Beampipe HOM damper	*Broadband (above beampipe's cutoff frequency)*	*High*	*Longitudinal space for thermal transition from 2/4K to 77/300k*	*Water or LN2*	*KEK B, Cbeta APS-U SRF cavity, Euro XFEL LeREC booster cavity*
Probe/loop HOM damper	*Bandstop or high pass filter, Notches at high frequency*	*Low - medium*	*small*	*Conductive cooling*	*Euro XFEL LHC SRF cavities LCLS II*
Waveguide HOM damper	*Broadband (above waveguide's cutoff frequency)*	*High*	*Large transversal space requirement*	*water*	*CEBAF BESSY 1.5 GHz VSR bERLPro*

- SiC beampipe HOM damper was chosen for damping HOMs in EIC electron storage ring SRF cavity, which HOM power is up to 50 kW per cavity.

HOM damping requirement for EIC ESR SRF cavity

EIC ESR cryomodule concept design



Courtesy: Frank Marhauser and Jim Henry

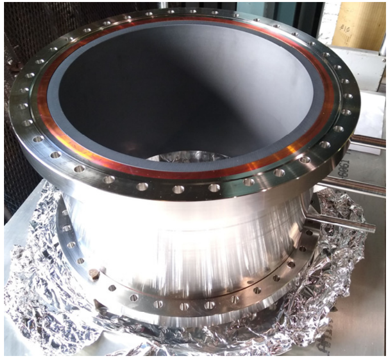
Max. HOM power in EIC operating scenarios

Parameter	Value
Number of Bunches	1160
Bunch Harmonic Number	1260
Bunch Frequency [MHz]	98.5
Energy [GeV]	10
Particles per Bunch [1E10]	17.2
Bunch Charge [nC]	27.6
Bunch Length [mm]	8
HOM Power [kW/cavity]	48.6
HOM Power per Absorber [kW]	24.3

- *EIC ESR needs 17x 591 MHz SRF cryomodules operating in all operating scenarios.*
- *Two SiC HOM dampers will share the HOM damper power in a cryomodule.*

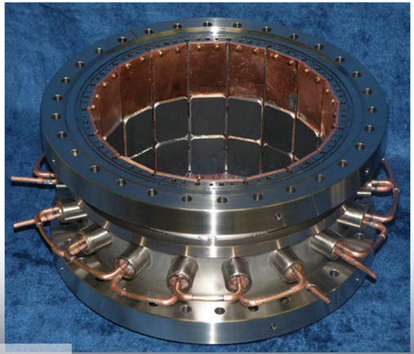
Two prototype SiC HOM dampers

- Solid cylindrical SiC HOM damper

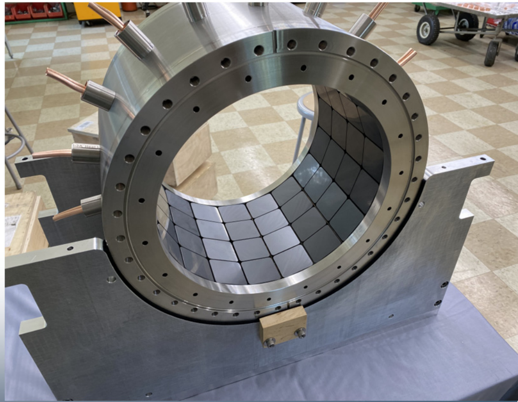


- Tile-style SiC HOM damper

SBIR project with TJS Technologies LLC

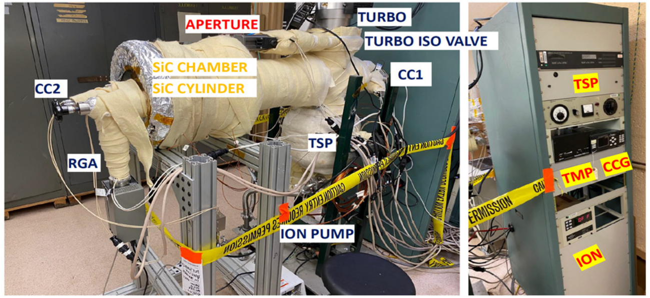


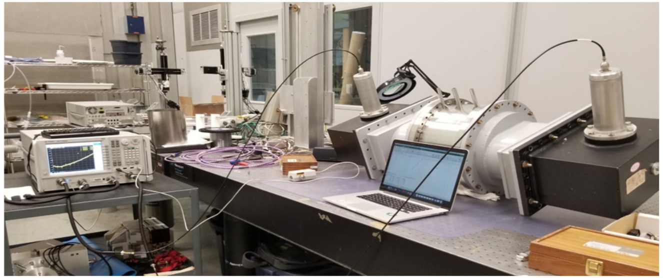
Courtesy: T. Schultheis

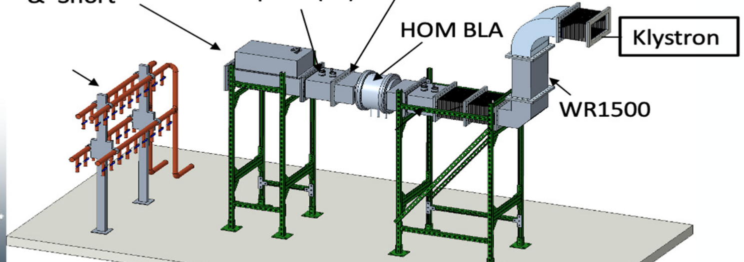


HOM damper test status and plan

- First outgassing test were completed with solid SiC HOM damper.
  - Outgassing rate is 2.2e-10 torr-liters/sec-cm²
  - Demonstrated interference-fit SiC assembly satisfies the high vacuum needs in EIC SRF cavities.
- Low power measurement on solid SiC HOM damper result is close to expectation. ➔ We will need 62 kW to test the 24 kW absorption at 704 MHz.
- Next step:
  - Outgassing and low power measurement on tile-style SiC HOM damper
  - High power test at 704 MHz to verify power handling (dissipation = 24 kW)







Closing Comments

- High power FPCs are used successfully in SRF cavity applications worldwide and are critical for the future success of high intensity accelerators.
  - FPC performance is evolving, driven by the need of high intensity accelerator.
  - Recent development of 1 MW/500 kW (TW/SW) FPCs are progressing and encouraging.
- HOM coupler development:
  - HOM dampers address a wide bandwidth and range of power levels for SRF cavities.
  - Status and plan of 24 kW SIC HOM damper absorbers for EIC eSR SRF cavity were presented.
- Future applications may need even more power and I am excited to see all developments in these areas.

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