Overview of Recent HOM Coupler Development

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Outline

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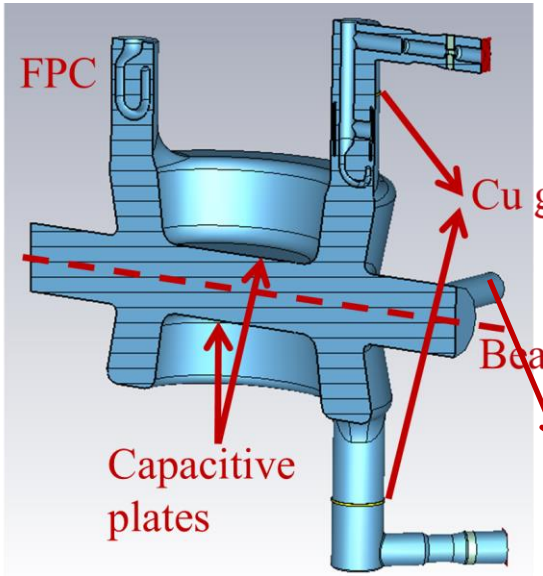
Introduction

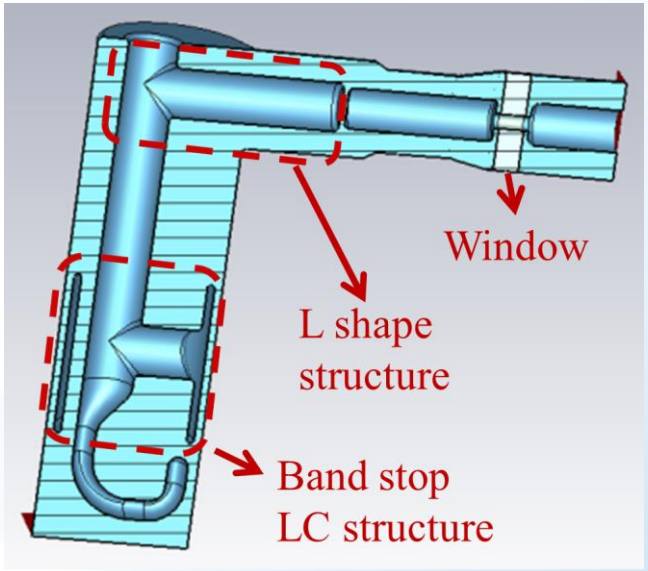
- Charged particle bunch + SRF cavity
  -> generate electromagnetic (EM) fields
  -> interact with, and influence the motion of this specific bunch and the following bunches.
- Consequence:
  -> beam quality degradation, beam energy loss, beam instability, or beam breakup.
  -> limited beam intensity operation
  -> interact with the SRF cavity and result in unwanted RF heating.
- Design of HOM damping
  a multi-physics problem that involves RF, thermal, mechanical, and beam-cavity interaction issues.
- There are three major varieties of HOM couplers: beam pipe absorber, coaxial (loop/antenna) coupler and waveguide coupler.

↘ THBA05

Recent Advances: Double Quarter Wave



DQWCC with 3 HOM filters.
There is a transverse electric field between the two capacitive plates, offering the crabbing voltage when the beam passes at an appropriate phase for the 400 MHz fundamental mode.

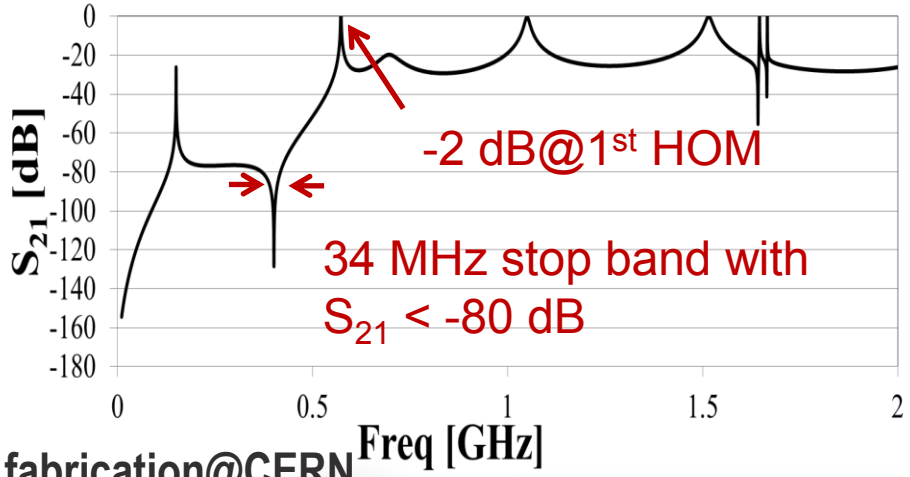


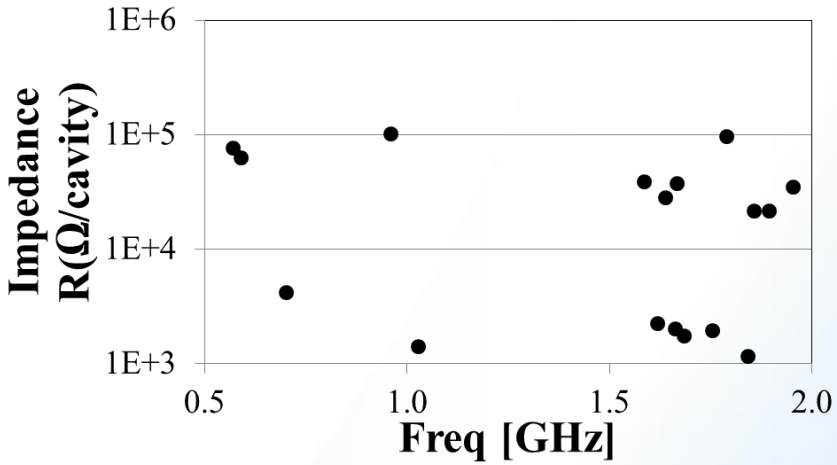
HOM filter
The HOM filter consists of a band stop LC structure right above the hook to minimize the RF loss on the Cu gasket that will be used to connect the cavity and the filter, and an L shape structure on the top to form a pass band starting from 570 MHz, the frequency of the first HOM.

THPB052, THPB069, THPB081

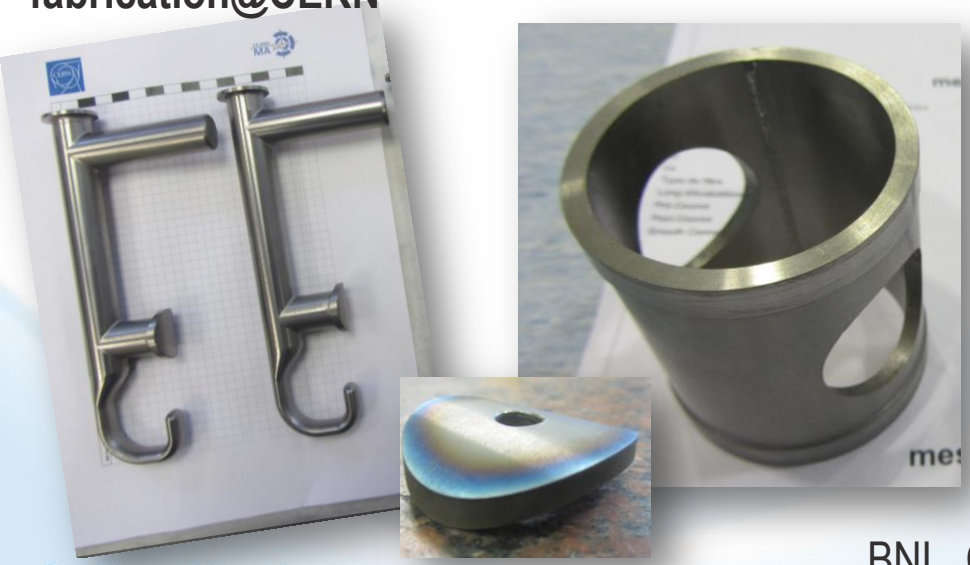
Recent Advances: Double Quarter Wave (2)

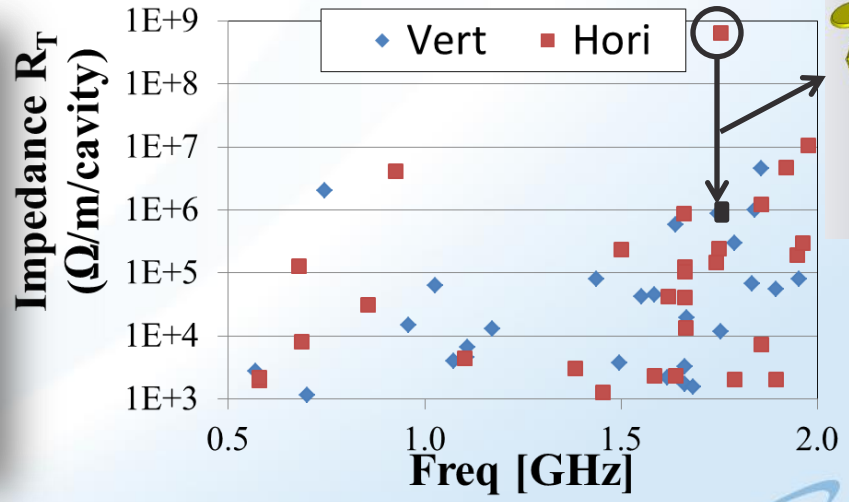
S_{21} of the HOM filter, with TE_{11} mode on the hook side and TEM mode on the port side.





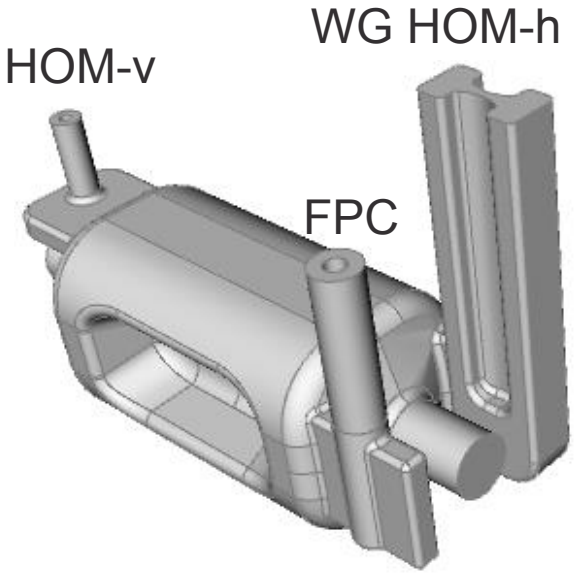
fabrication@CERN



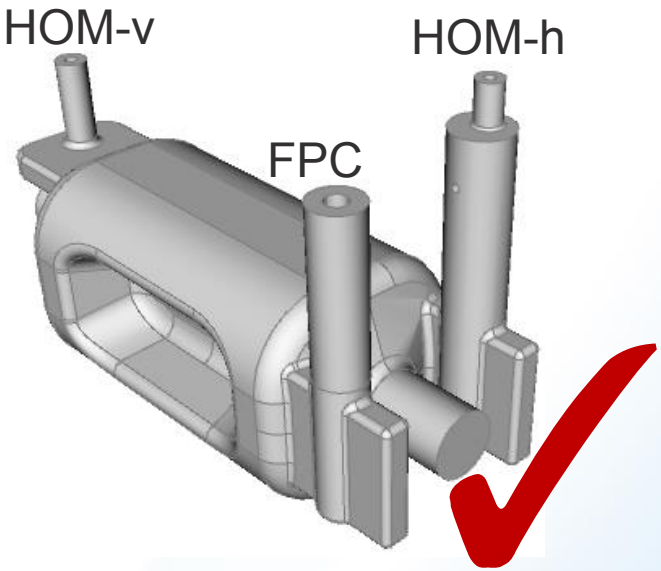


BNL, CERN and UK collaboration

Recent Advances: RF Dipole



- Ridged waveguide H-HOM coupler
- No filter needed, need enough length to minimize power leakage
- High power handling option



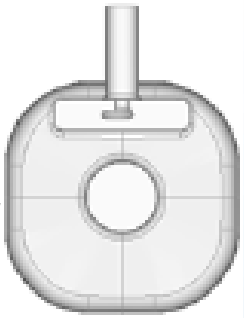
- Hi-pass filter H-HOM coupler
- Relatively compact
- Need to understand high power handling capability

- Couplers in low field regions
- Two designs have the same coupler-to-cavity interface

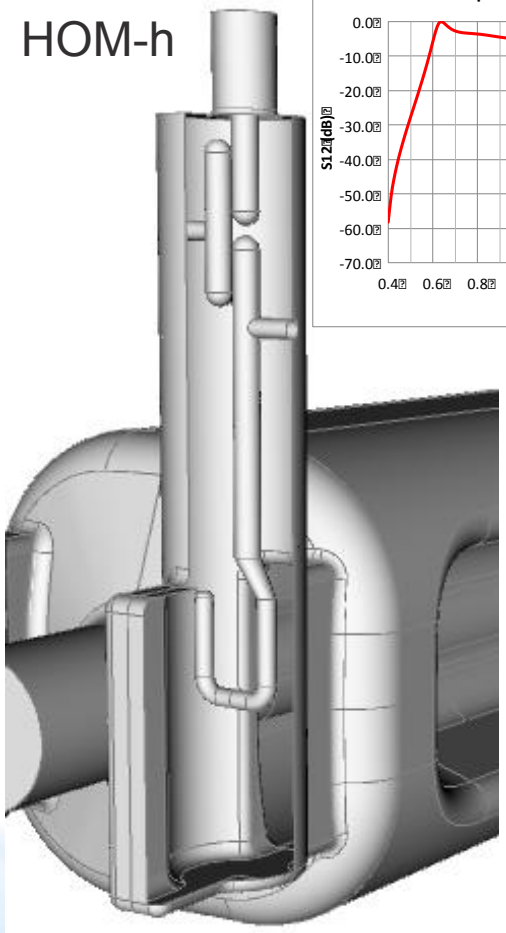
THPB054, THPB069, THPB081

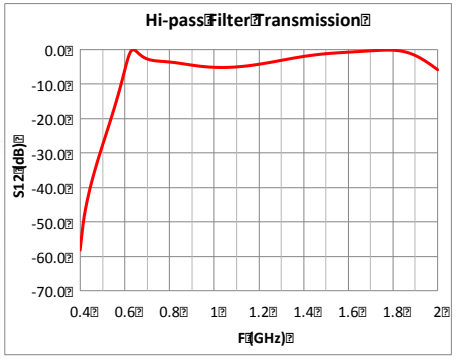
Recent Advances: RF Dipole (2)

HOM-v

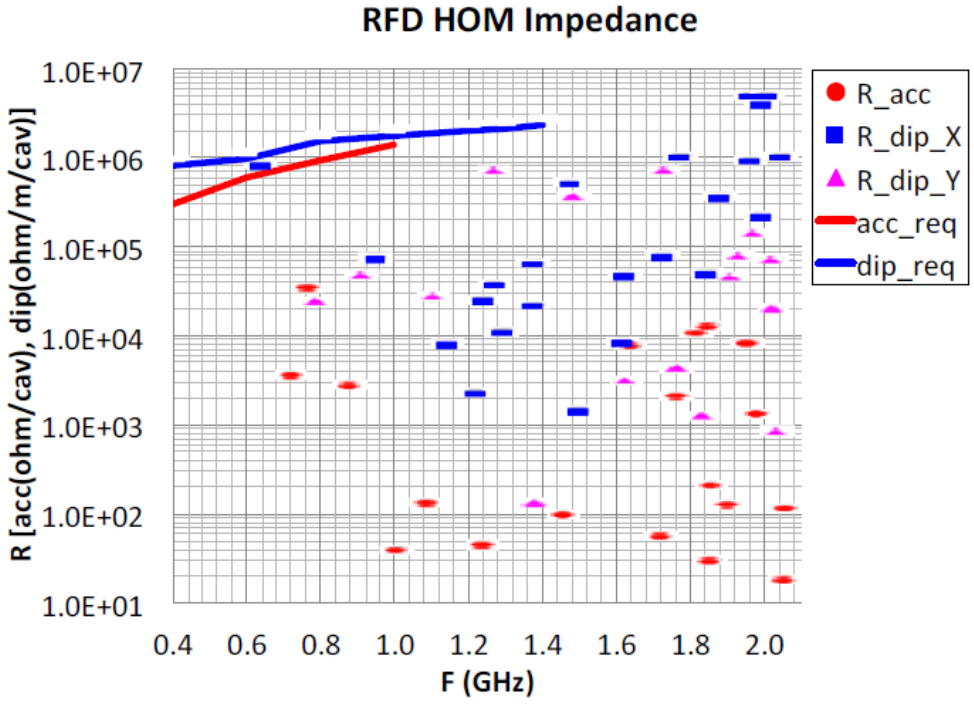


HOM-h



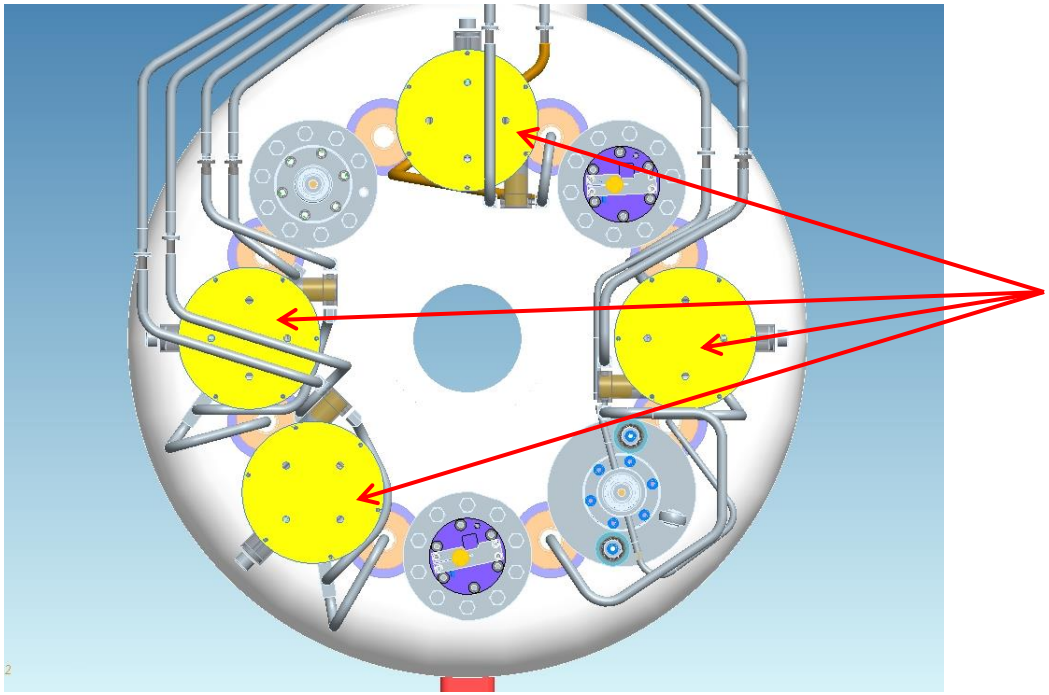


- Coupler demountable from cavity
- 50 ohm pickup demountable from filter body
- Low fields in coupler
- Coupling hook and T need to be superconducting (minimize RF heating)



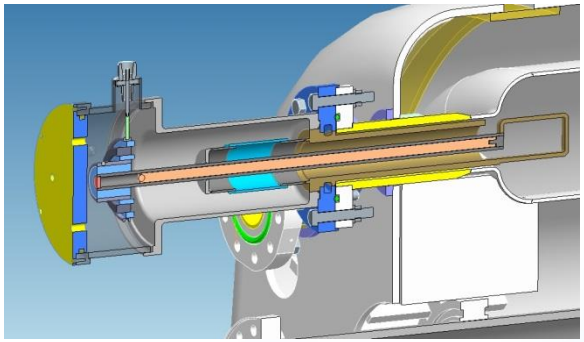
ODU, SLAC, FNAL, CERN and UK collaboration

Recent Advances: 56 MHz QWR



During commissioning, the cavity voltage was limited by a quench in the HOM coupler assembly with maximum reached cavity voltage of 330 kV in CW operation and 550 kV in pulsed operation

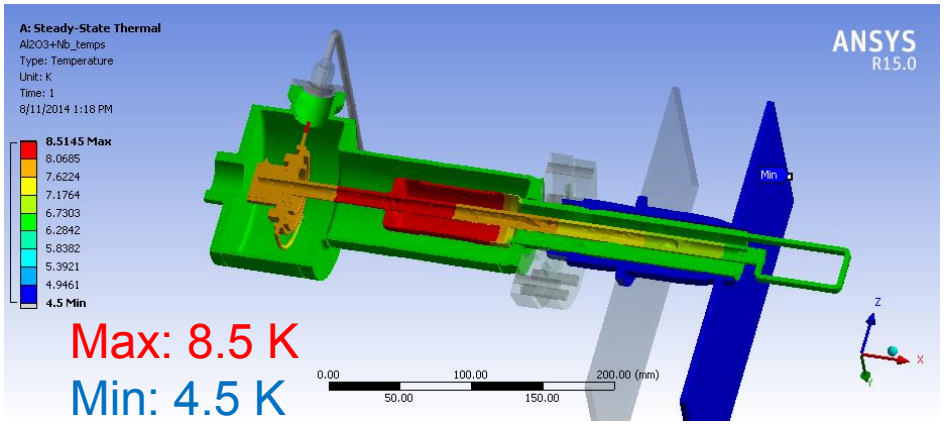
HOM couplers with high pass filter

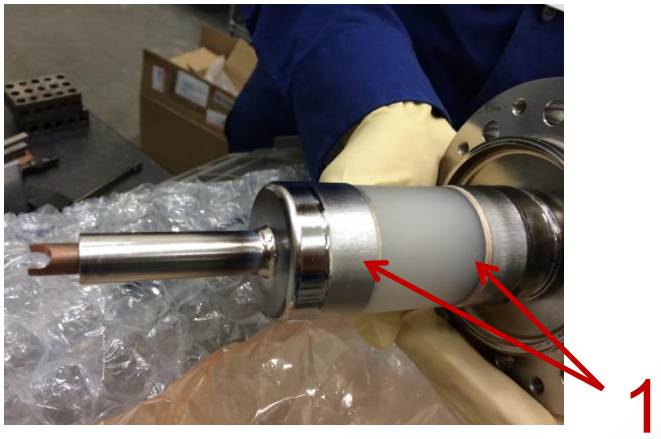


There are 4 ports at the end of the 56 MHz cavity reserved for HOM couplers. The loop antenna penetrated fully into the cavity. A high-pass filter designed beyond the loop provided a strong rejection to the fundamental mode, while letting all the HOMs transmitted to the external load.

THPB063, WEBA07

Recent Advances: 56 MHz QWR (2)



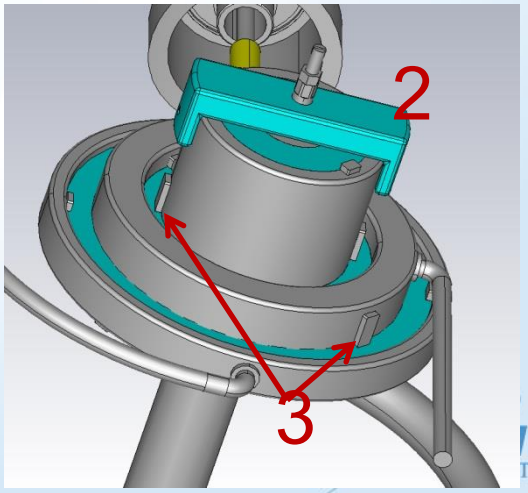


The braze material at the sapphire – Nb cuff joint is InCuSil, which is normal conducting at 4.5 K.

Thermal analysis (Steve Bellavia) shows that at 1/6th of the design field, the InCuSil material would bring the adjacent Nb (T_c = 9.2 K) to 8.5 K. It is currently our best candidate for the quench.

The following changes have been made:

1. Remove the sapphire window.
2. Add tuning bridge at the end of the filter stack to provide locking to the filter tuning position.
3. Replace the Stycast with stoppers to eliminate the outgassing in UHV.



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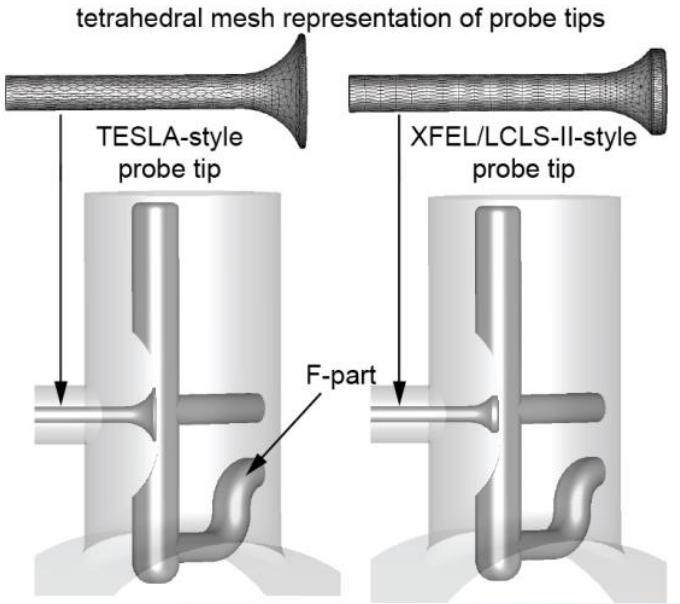
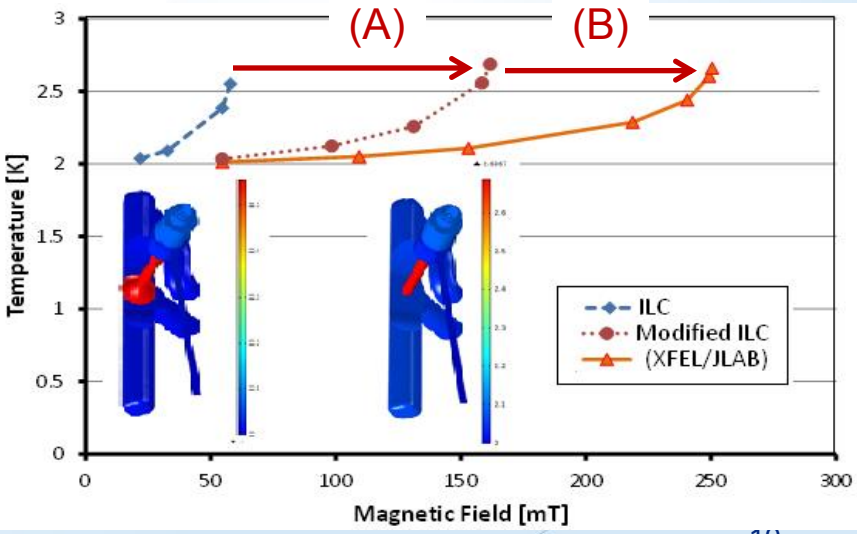
Recent Advances: TESLA-shape

THPB089

- Mature design, with more than a hundred being operated up to 35 MV/m in short pulse mode (a few percent duty factor) with beam current up to 10 mA.
- For CW operation, an insufficient heat conduction of the ceramic window on HOM feedthroughs causes heating of the Nb antenna above its T_c, and limits the cavity operation in the range of 5 and 14 MV/m.
- JLab, DESY and KEK modified the coupler design by (A) trimming the shape of the HOM antenna, and (B) using material with better thermal conductivity. With these modifications, the cavity can easily achieve 20 MV/m with less than 200 mK temperature increase on the HOM antenna tip.

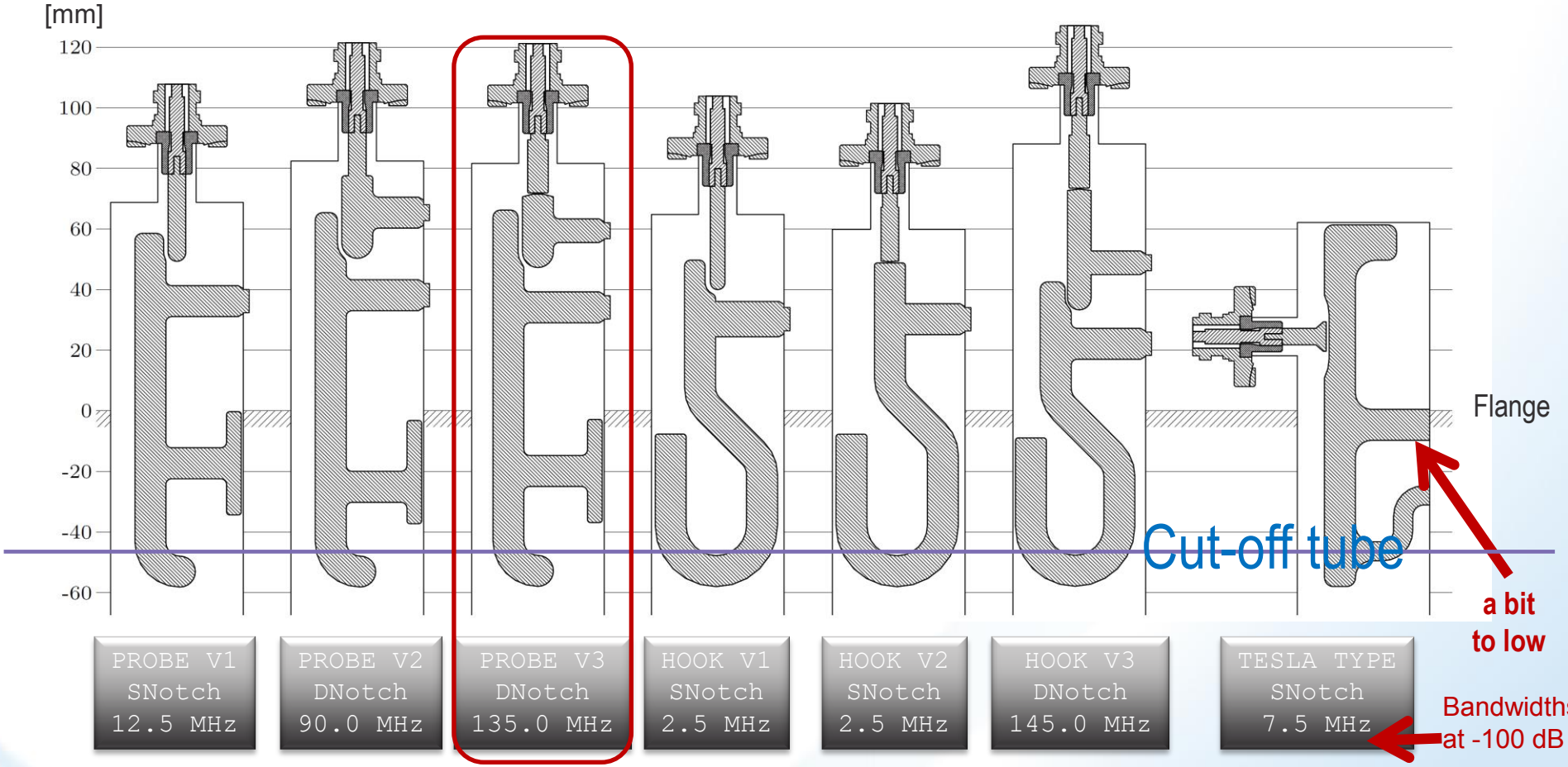




N. Solyak, M. Awida, A. Hocker, T. Khabibobulline, and A. Lunin@FNAL, F. Marhauser@JLab, J. Sekutowicz@DESY, M. Sawamura@JAEA, H. Sakai, E. Kako, K. Umemori@KEK

Recent Advances: SPL

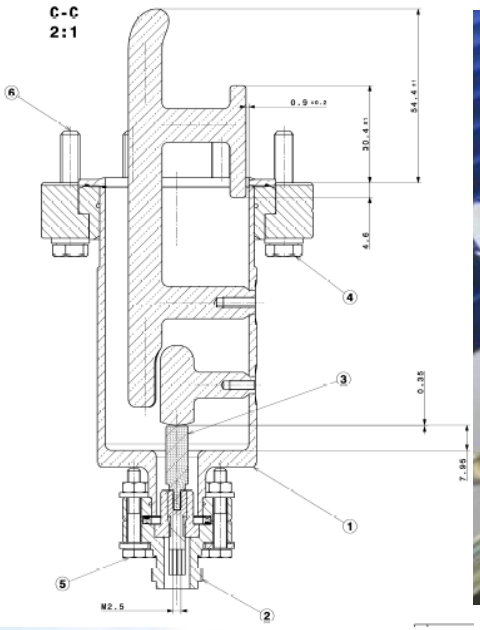
MOPB078

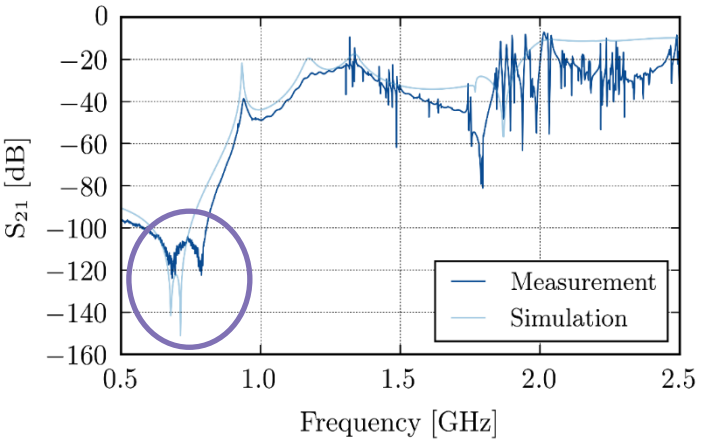


- Single notch designs easier to fabricate but they are more sensitive and have a lower selectivity
- Hook designs have a better coupling to dipole modes/ Probe designs better for monopole modes
- Notch filter of the TESLA design nicely tunable but design is not reasonable for SPL cavity

Recent Advances: SPL(2)

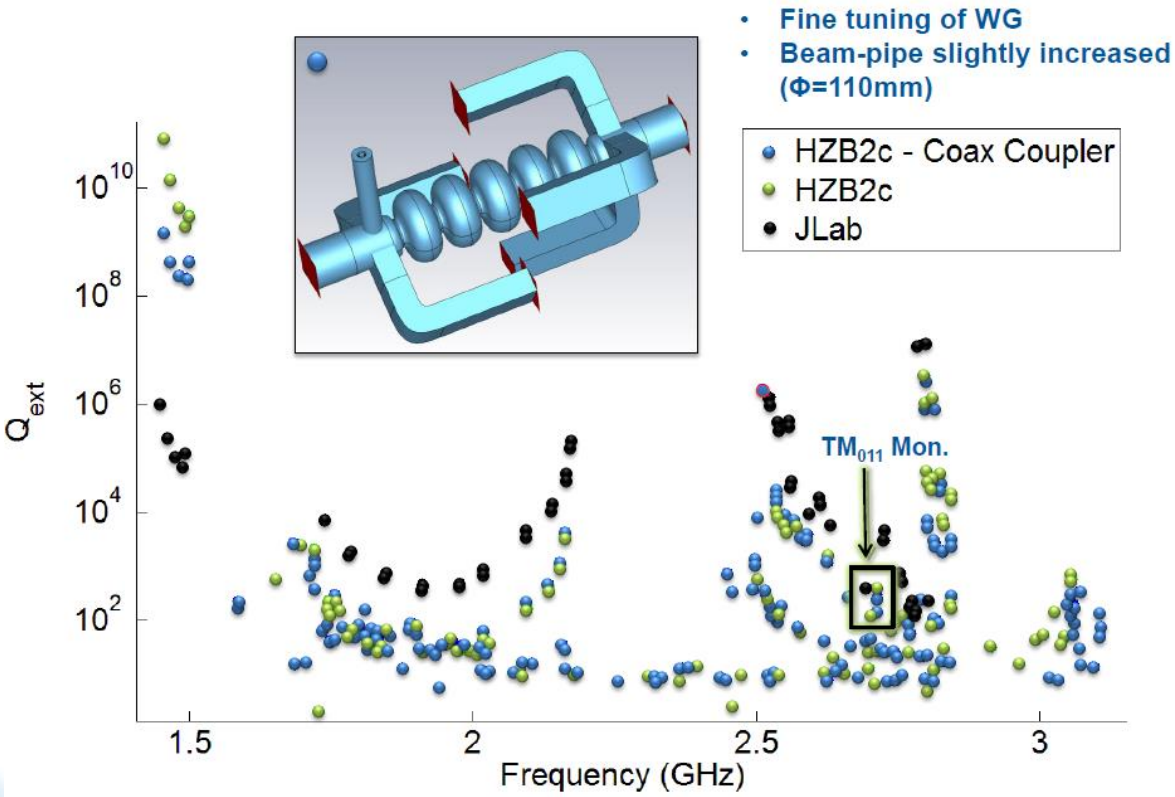
- Bulk copper prototype of the probe coupler fabricated
- Further adjustment of the notch plate required after test on the copper cavity
- Foreseen for leakage test, warm and cold tests cavities and multipacting analysis in the near future





K. Papke, F. Gerigk, U. van Rienen, Francois Pillon, Thierry Renaglia, Nuria Valverde Alonso, Thomas Sahner, @CERN, IEF-IAE

Recent Advances: BESSY-VSR



TUAA03

- 15 ps long bunches and 1.5 ps short bunches will be stored simultaneously in the 1.5 GHz cavities.
- These cavities will operate in CW at high field levels (E_{acc} = 20 MV/m) with high beam current (I_b = 300 mA), which makes the HOM damping really challenging.
- Five waveguide couplers and one coaxial coupler on the enlarged beam pipes near end cells.

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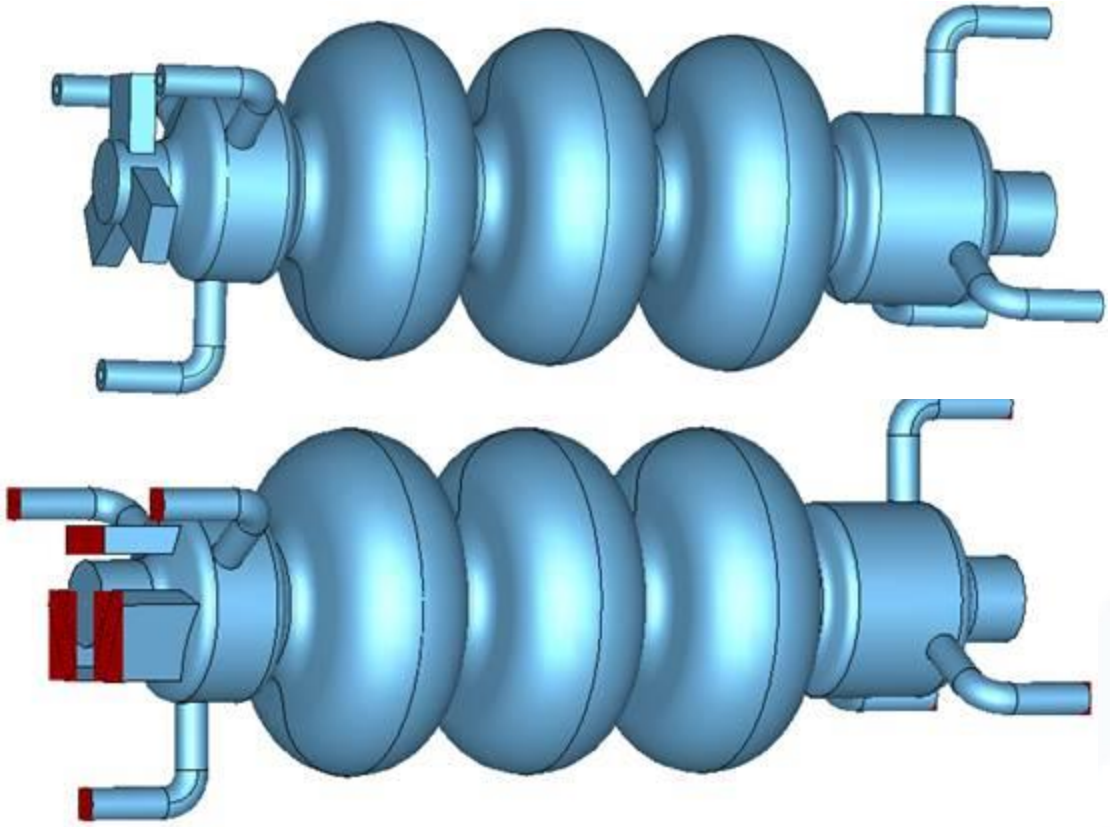
Recent Advances: eRHIC

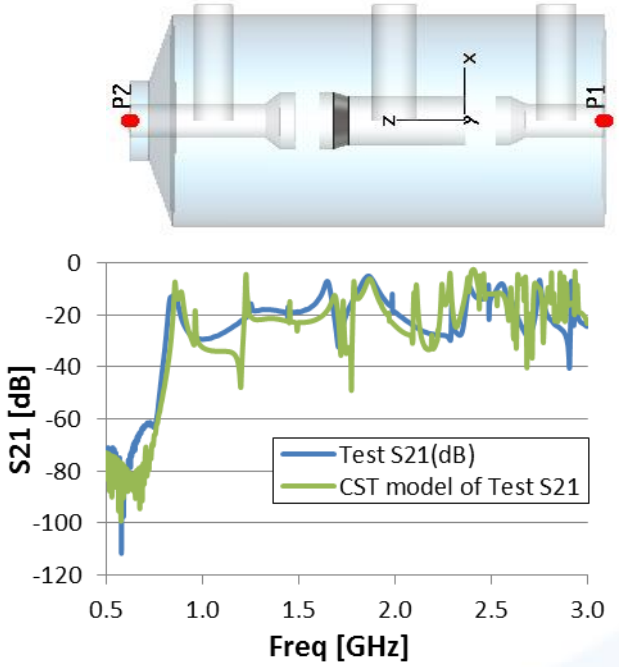
THPB074

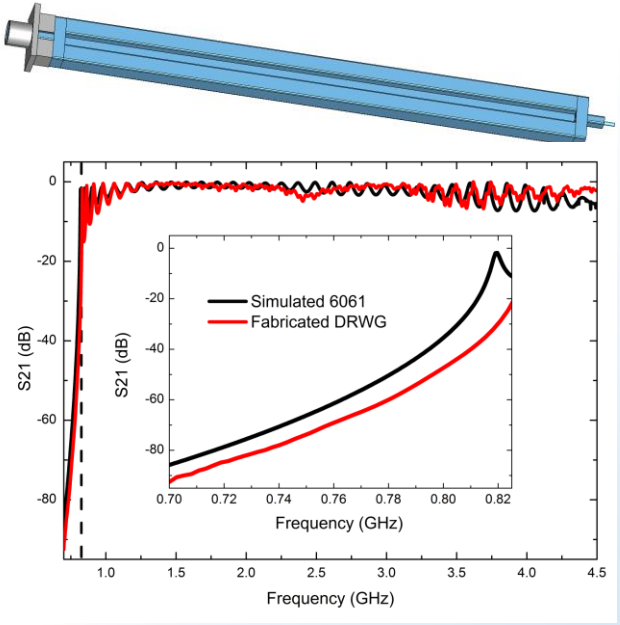


- eRHIC: high current, high bunch charge, short bunch length, multi-pass CW operation.
- A total 7.3 kW HOM power per 5-cell cavity, with frequency up to 30GHz.
- A combination of coaxial coupler, waveguide coupler and beam-pipe absorber is going to be used.
- Two possible damping schemes, with beam-pipe absorbers not shown.

Recent Advances: eRHIC (2)

- Initially designed for 704MHz, will convert to 422MHz.
- Between the two notches, s21 < -65 dB, 1st HOM is 0.82 GHz, S21 = -23 dB,
- Capacitors can be add to the transmission line to reduce the thermal conduction
- Dual ridge waveguide, as a natural high pass filter, is chosen to minimize WG geometry size.

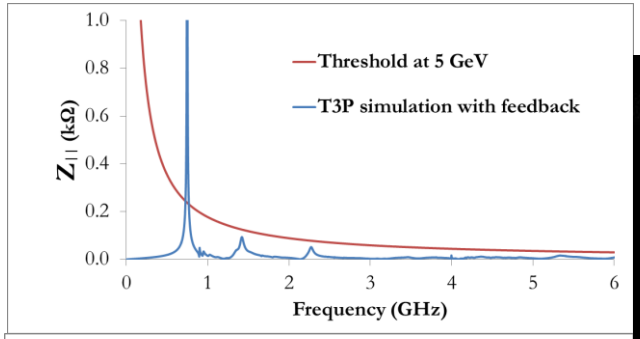


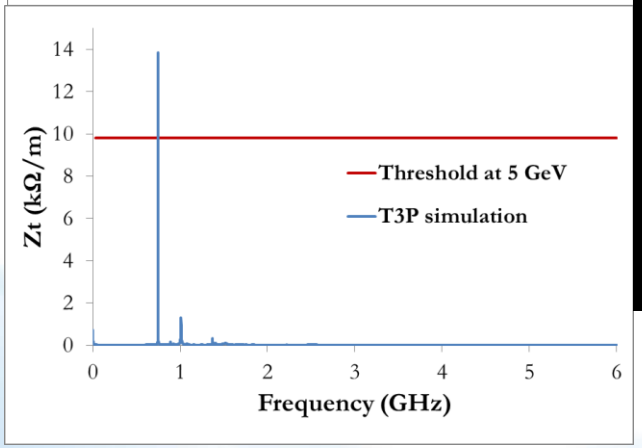


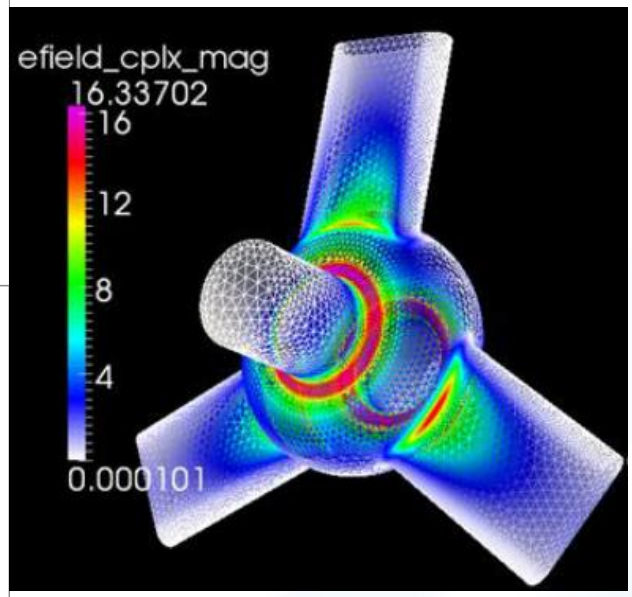
Wencan Xu, C. Xu, H. Hahn, Q. Wu, S. Belomestnykh, I. Ben-Zvi @BNL

Recent Advances: MEIC

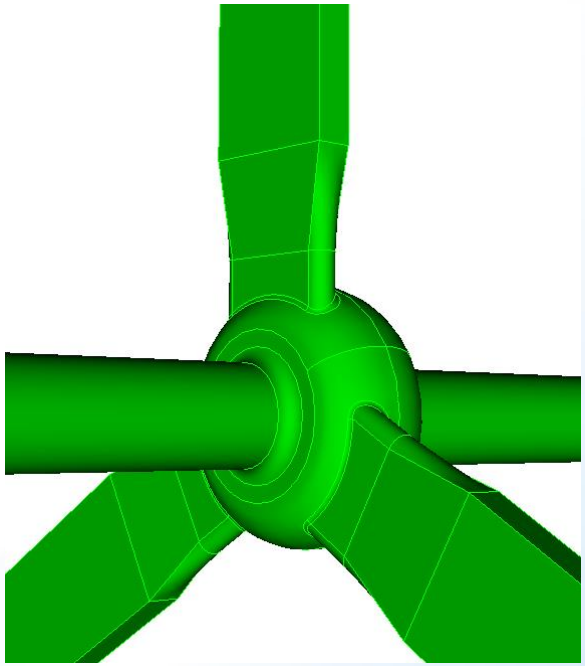
- Single-cell, on-cell damping cavity for MEIC.
- Transverse impedance Optimization with on-cell waveguide number, size and location.







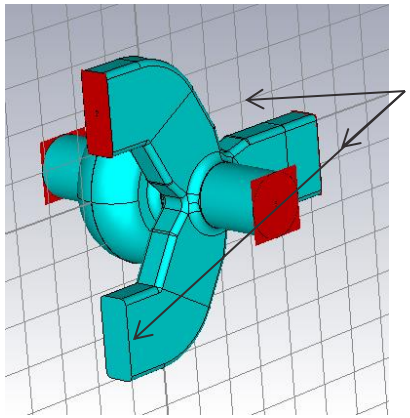
Original 750MHz design



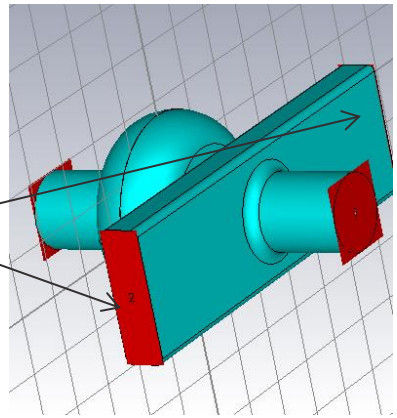
Scaled 952.6MHz design

- First SRF cavity design will be 952.6MHz on ion-ring. Next is on e-ring.
- Two-cell design is possible for ion-ring.

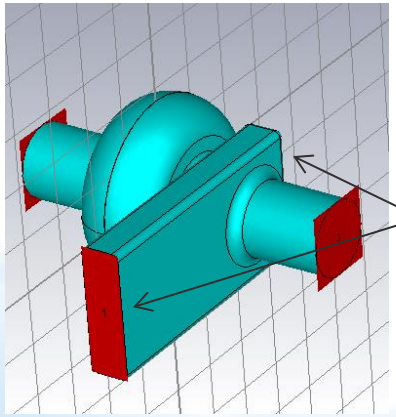
Recent Advances: MEIC(2)



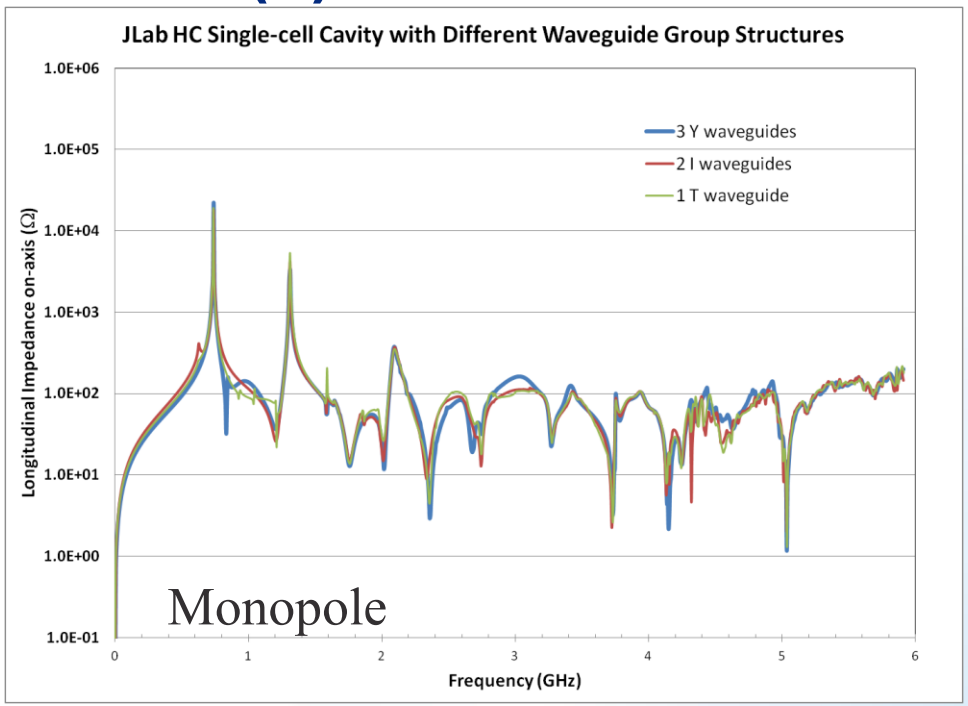
Original 3 "Y" waveguides



Modified 2 "I" waveguides



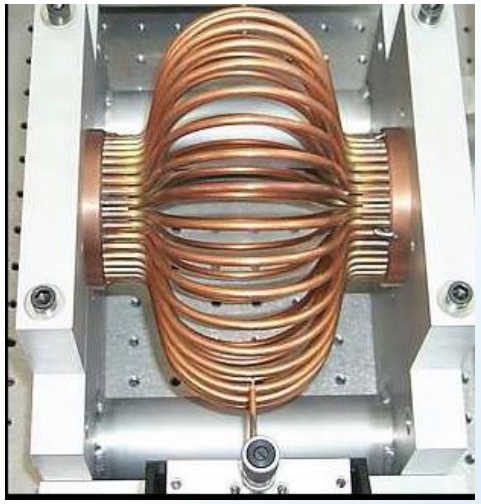
Modified 1 "T" Waveguide with stub



- For MEIC-ERL electron cooler 5-cell cavity.
- Modified waveguide width can allow both TE10 and TE20 modes propagate in order to damp both polarization of HOMs.
- One "T" type waveguide places on each side of cavity is recommended and one is in x direction, another is in y direction.

Recent Advances: new ideas (1): PBG cavity

Cage cavity, can also convert to PBG if wires are properly placed.



- Naturally suppressing wake field, easy to damp HOMs.
- Successful single cavity high power test.
- On-going multi-cell test.

WEA2A02

Evgenya I. Simakov, W. Brian Haynes, Michael A. Madrid, Frank P. Romero, Tsuyoshi Tajima, Walter M. Tuzel, D. Shchegolkov, J.W. Lewellen@LANL
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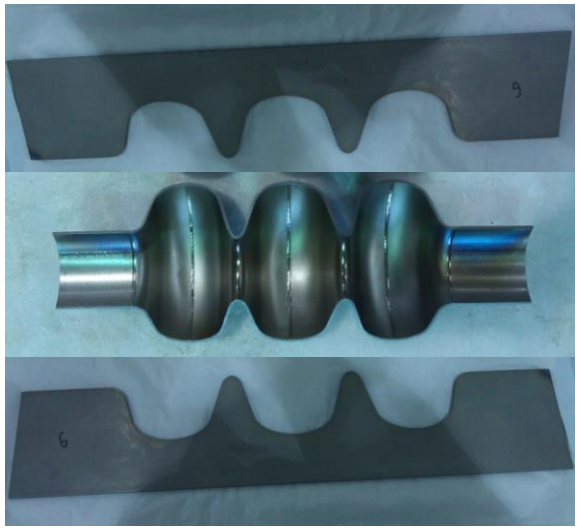
Recent Advances: new ideas (2): slot cavity



- A 1.3 GHz 3-cell slotted cavity prototype has been fabricated.
- The cavity was processed at the standard procedure for SC cavity at IHEP.
- 4.2K vertical test was carried out and the cavity show great potential on ERL application.
- 2K vertical test will be done soon (as of Jun 2015).

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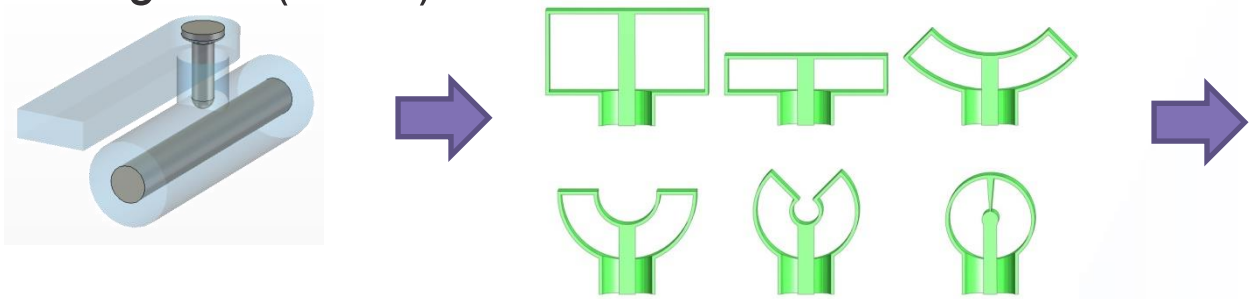
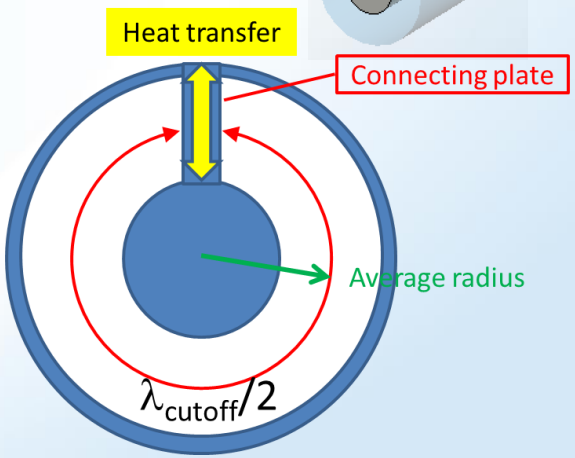
Recent Advances: new ideas (3): CWG

- C-Shape Waveguide (CWG): deforming coaxial-waveguide coupler



- Feature
  - Existing cut-off frequency
    - Average perimeter of coaxial line is half of cutoff wavelength (compact)
    - High pass filter
  - Connecting inner and outer conductors
    - Effective cooling of inner conductor through connecting plate
  - Easy to connect to a coaxial structure
- Plan to test it on cERL main linac to overcome HOM crack problem



Masaru Sawamura@JAEA

Summary

The recent advances of the HOM coupler designs are reviewed, including:

- Coaxial coupler designs on DQW and RFD crab cavities, on SPL cavity, and on QWR 56 MHz cavity;
- Waveguide coupler designs on MEIC 952.6 MHz single cell cavity, on MEIC electron cooler cavity, and on BESSY-VSR cavity;
- A combination of coaxial coupler, waveguide coupler and beam pipe absorber for eRHIC SRF cavity.
- New ideas like PBG cavity, cage cavity, slot cavity, C-shape waveguide

References

[1] R. Eichhorn, Higher Order Mode Absorbers for High Current SRF Applications, in *these proceedings*.

[2] T. Khabiboulline, N. Solyak. *International Workshop on Higher-Order-Mode Damping in Superconducting RF Cavities*; *Oct 11-13 2010*; *Cornell University, NY*2010 http://www.classe.cornell.edu/Events/HOM10/rsrc/LEPP/Events/HOM10/Agenda/MP5_Khabiboulline.pdf.

[3] J. Sekutowicz. *International Workshop on Higher-Order-Mode Damping in Superconducting RF Cavities*; *Oct 11-13 2010*; *Cornell University, NY*2010 http://www.classe.cornell.edu/Events/HOM10/rsrc/LEPP/Events/HOM10/Agenda/MP6_Sekutowicz.pdf.

[4] E. Kako. *Tesla Technology Collaboration: 1st topical meeting on CW-SRF*; *Jun 12-14 2013*; *Cornell University, NY*2013 http://indico.classe.cornell.edu/event/17/session/10/contribution/49/material/slides/0.pptx.

[5] N. Solyak, M. Awida, A. Hocker*, et al.*, *Higher Order Mode Coupler Heating in Continuous Wave Operation*, Physics Procedia ICFA mini Workshop on High Order Modes in Superconducting Cavities, HOMSC14, (2014).

[6] Q. Wu, Beam Commisioning of the 56 MHz QW cavity in RHIC, in *these proceedings*.

[7] B. Xiao, L. s. Alberty, S. Belomestnykh*, et al.*, *Design, prototyping, and testing of a compact superconducting double quarter wave crab cavity*, Phys. Rev. Spec. Top. Accel. Beams 18, 4, 041004 (2015). http://link.aps.org/doi/10.1103/PhysRevSTAB.18.041004.

[8] B. P. Xiao, S. Belomestnykh, I. Ben-Zvi*, et al.*, HIGHER ORDER MODE FILTER DESIGN FOR DOUBLE QUARTER WAVE CRAB CAVITY FOR THE LHC HIGH LUMINOSITY UPGRADE, in *Proceedings of the 6th International Particle Accelerator Conference, Richmond, VA, USA, 2015*.

[9] Z. Li, L. Ge, J. R. Delayen*, et al.*, HOM Damping Coupler Design for the 400-MHz RF Dipole Compact Crab Cavity for the Lhc Hilumi Upgrade, in *Proceedings of the 4th International Particle Accelerator Conference, Shanghai, China, 2013,* https://accelconf.web.cern.ch/accelconf/IPAC2013/papers/wepwo072.pdf.

[10] A. Yamamoto. *LARP / HiLumi-LHC Collaboration Meeting*; *May 7-9 2014*; *Brookhaven National Lab, NY, USA*2014 https://indico.bnl.gov/conferenceDisplay.py?confId=730.

[11] Z. Li, J. R. Delayen, S. U. D. Silva, FPC AND HI-PASS FILTER HOM COUPLER DESIGN FOR THE RF DIPOLE CRAB CAVITY FOR THE LHC HILUMI UPGRADE, in *Proceedings of the 6th International Particle Accelerator Conference, Richmond, VA, USA, 2015,* https://jacowfs.jlab.org/conf/y15/ipac15/prepress/WEPWI004.PDF.

[12] Q. Wu, I. Ben-Zvi, SIMULATION OF THE HIGH-PASS FILTER FOR 56MHz CAVITY FOR RHIC, in *Proceedings of the 1st International Particle Accelerator Conference, Kyoto, Japan, 2010,* p. 3078. https://accelconf.web.cern.ch/accelconf/IPAC10/papers/wepec085.pd.

References (cont'd)

[13] N. Huque, BNL 56 MHz HOM DAMPER FABRICATION AT JLAB, in *these proceedings*.

[14] A.Vélez, H. W. Glock, J.Knobloch, *et al.*, HOM DAMPING OPTIMIZATION DESIGN STUDIES FOR BESSY VSR CAVITIES, in *Proceedings of the 6th International Particle Accelerator Conference, Richmond, VA, USA, 2015,* https://jacowfs.jlab.org/conf/y15/ipac15/prepress/WEPMA013.PDF.

[15] W. Xu, I. Ben-Zvi, S. Belomestnykh, *et al.*, NEW HOM COUPLER DESIGN FOR HIGH CURRENT SRF CAVITY, in *Proceedings of 2011 Particle Accelerator Conference, New York, NY, USA, 2011,* p. 925. http://accelconf.web.cern.ch/accelconf/pac2011/papers/tup060.pdf.

[16] C. Marques, Master's thesis, Stony Brook University, (2014)

[17] H. Hahn, S. Belomestnykh, I. Ben-Zvi, *et al.*, FERRITE COVERED CERAMIC BREAK HOM DAMPER, in *Proceedings of 16th International Conference on RF Superconductivity, Paris, France, 2013,* p. 1040. http://accelconf.web.cern.ch/AccelConf/SRF2013/papers/thp055.pdf.

[18] S. Wang, J. Guo, F. Lin, *et al.*, CAPTURE, ACCELERATION AND BUNCHING RF SYSTEMS FOR THE MEIC BOOSTER AND STORAGE RINGS, in *Proceedings of the 6th International Particle Accelerator Conference, Richmond, VA, USA, 2015,* https://jacowfs.jlab.org/conf/y15/ipac15/prepress/TUPWI034.PDF.

[19] R. A. Rimmer, J. Guo, J. Henry, *et al.*, RF SYSTEM REQUIREMENTS FOR A MEDIUM-ENERGY ELECTRONION COLLIDER (MEIC) AT JLAB, in *Proceedings of the 6th International Particle Accelerator Conference, Richmond, VA, USA, 2015,* https://jacowfs.jlab.org/conf/y15/ipac15/prepress/WEPWI022.PDF.

[20] C. Xu, S. A. Belomestnykh, W. Xu, *et al.*, SECOND HARMONIC CAVITY DESIGN FOR SYNCHROTRON RADIATION ENERGY COMPENSATOR IN ERHIC PROJECT in *these proceedings*.

[21] S. Arsenyev, High gradient tests of the five-cell superconducting RF module with a PBG coupler cell, in *these proceedings*.

[22] J. Noonan, T. L. Smith, M. Virgo, *et al.*, CAGE CAVITY: A LOW COST, HIGH PERFORMANCE SRF ACCELERATING STRUCTURE, in *Proceedings of 16th International Conference on RF Superconductivity, Cite INternationale Universitaire, Paris, France, 2013,* p. 950. http://accelconf.web.cern.ch/AccelConf/SRF2013/papers/thp026.pdf.

[23] M. Sawamura, R. Hajima, R. Nagai, *et al.*, NEW DESIGN OF HOM COUPLER USING COAXIAL-LIKE ROUNDED WAVEGUIDE, in *Proceedings of 16th International Conference on RF Superconductivity, Cite INternationale Universitaire, Paris, France, 2013,* p. 1081. http://accelconf.web.cern.ch/AccelConf/SRF2013/papers/thp068.pdf.

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