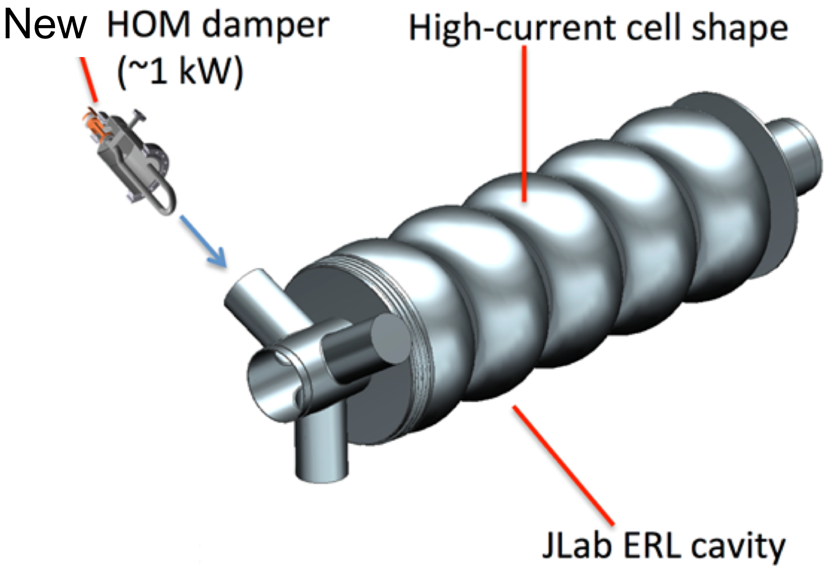
HOM, Cavity design and Prototyping

R. Rimmer

JLab



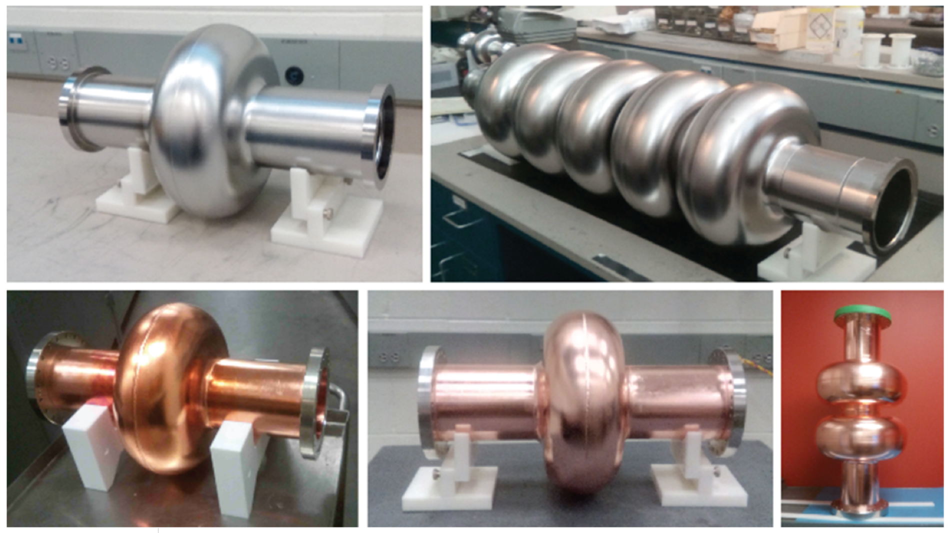
PERLE collaboration meeting 1/11/22

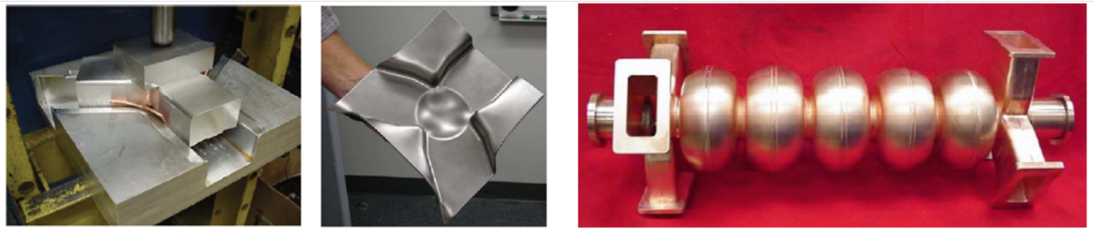
Outline

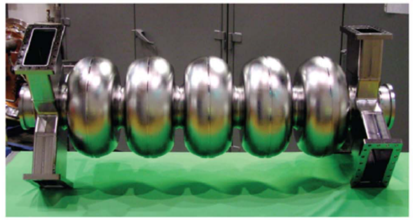
- Jlab 802.5 MHz prototype
- New variants:
- Frank's end group modifications
- FCC 5-cell (Shahnam's Thesis)
- PERLE HOM study (Carmelo's study)
- EIC cooler ERL
- ERL roadmap/path forward

Jlab 802.5 MHz prototype (F. Marhauser et. al.)

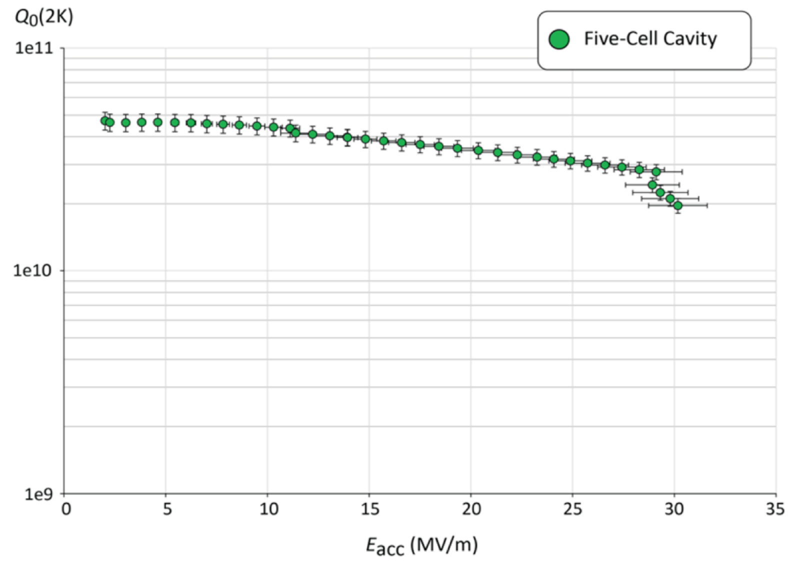
- Shared DNA with Jlab FEL, JLEIC cooler and CEBAF “C75” cavities
- 1-cell and 5-cell Nb prototypes
- 2x Cu 1-cells for thin film coating
- 2-cell Cu “kit” for further HOM development
- End group design was to come from CERN
- Most parts available for PERLE if useful
- Dies and fixtures available at Jlab.







748.5 MHz JLab High Current
ERL-FEL cavity protoype

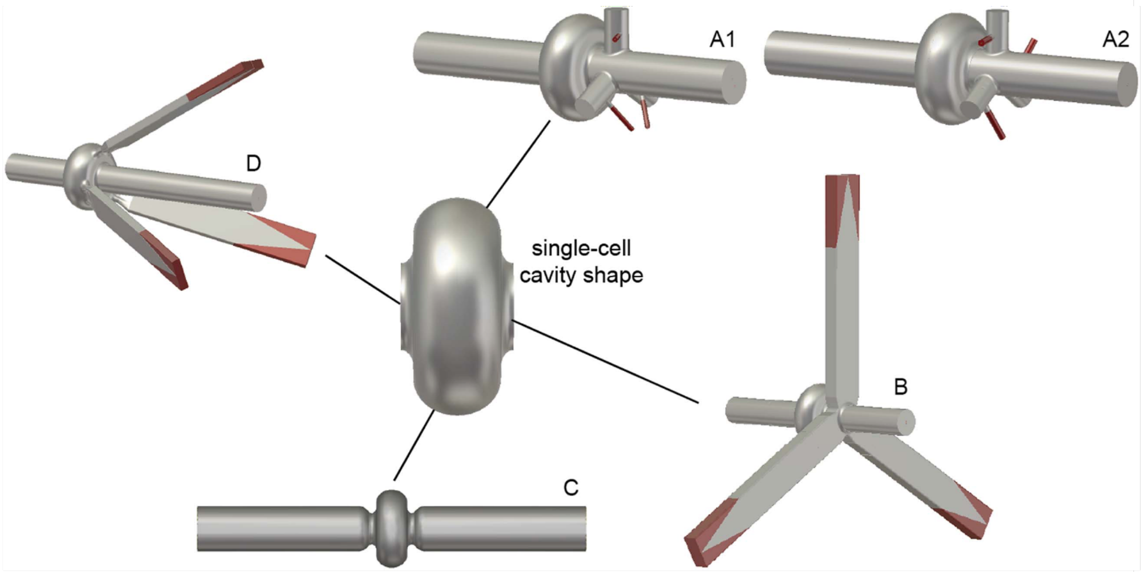


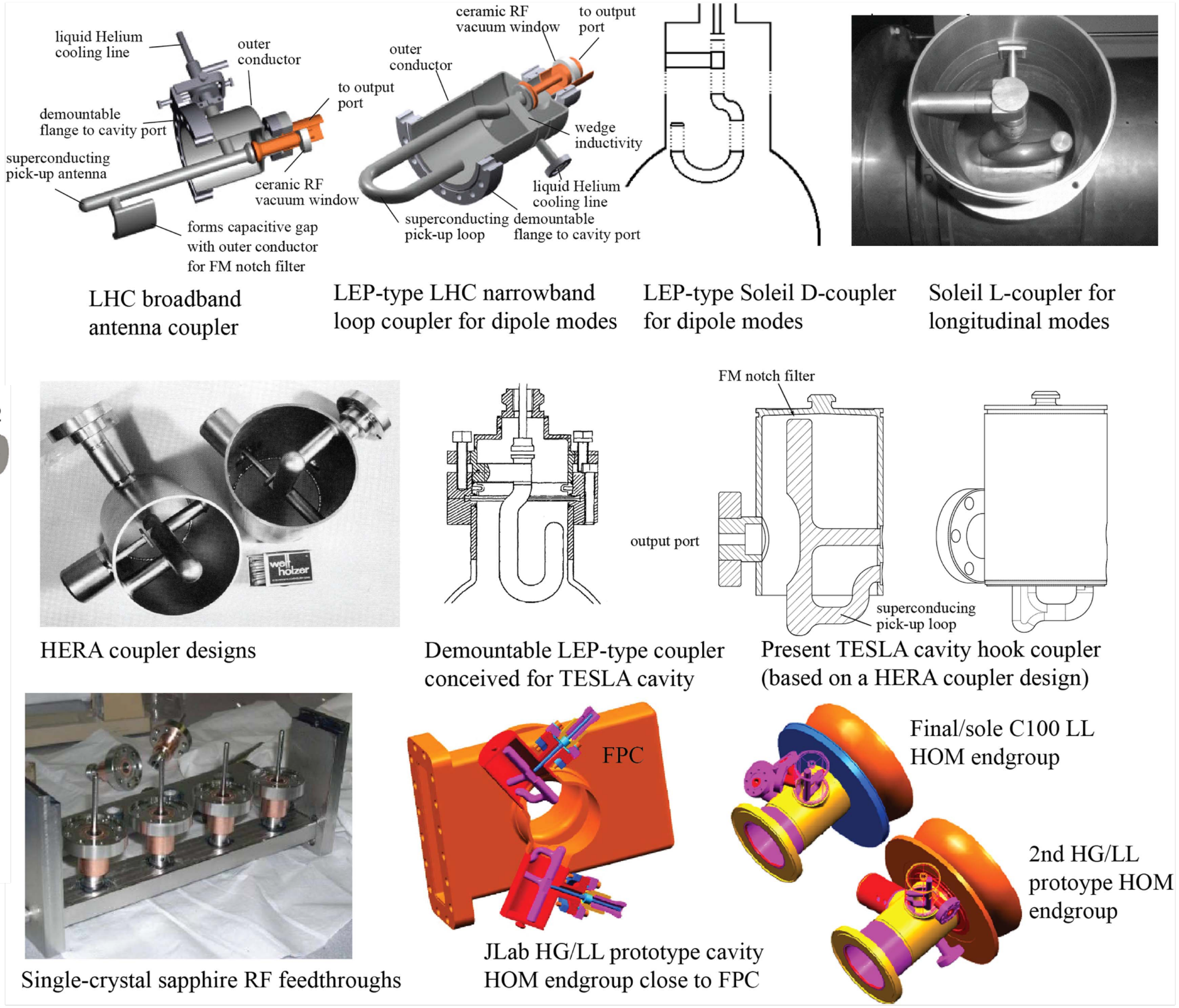
192.R. Rimmer et al. The JLab Ampere-Class Cryomodule. *Proceedings of the 12th Workshop on RF Superconductivity (SRF’05)*, 2005.
193.[193] R.A. Rimmer, W. Clemens, D. Forehand, J. Henry, P. Kneisel, K. Macha, F. Marhauser, L. Turlington, and H. Wang. Recent Progress on High-Current SRF Cavities at JLab. *Pro- ceedings of the International Particle Accelerator Conference (IPAC’10)*, 2010.

HOM-damping options

F. Marhauser

- Wide survey of existing and new options
- Also in context of JLEIC ERL and storage ring
  - Waveguides selected for cooler ERL
  - On-cell damper development started for ESR

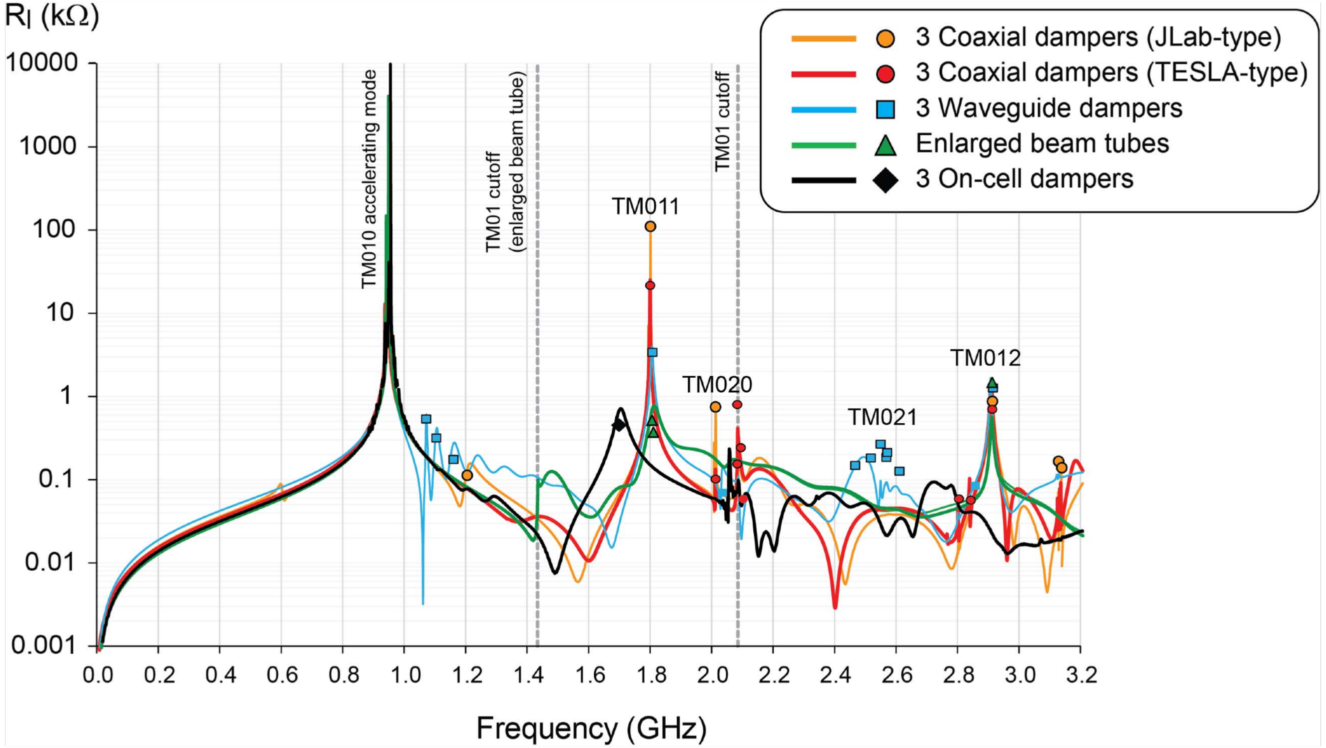


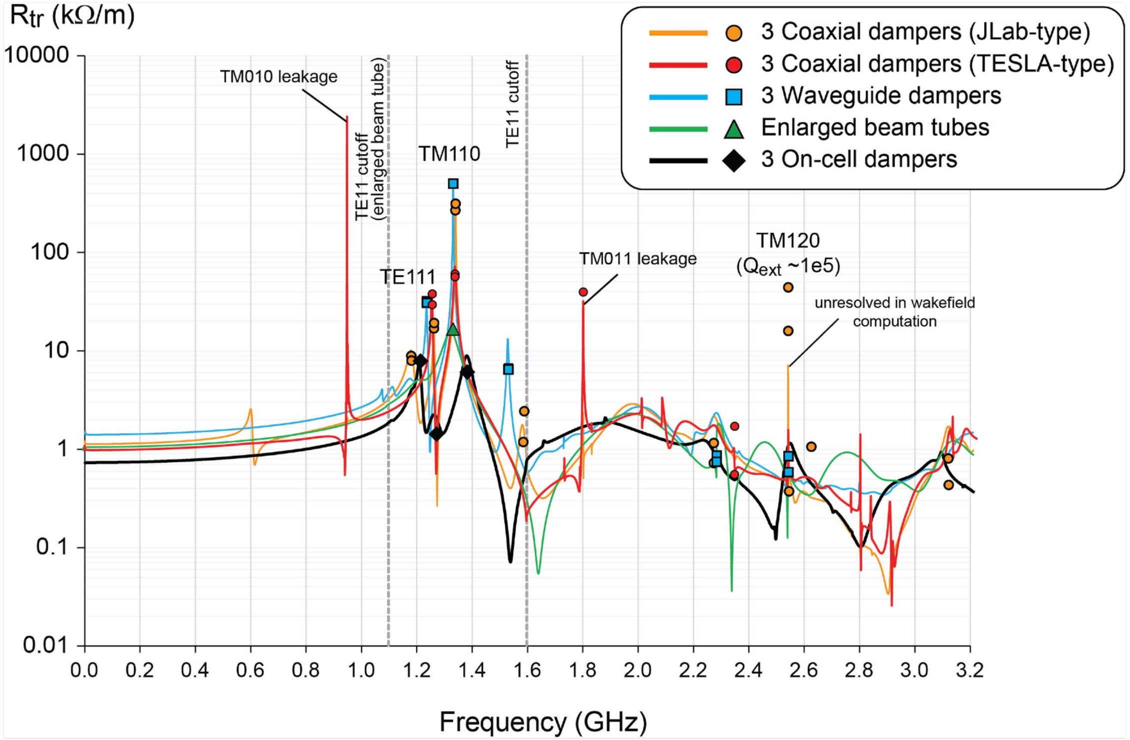


F. Marhauser. Next generation HOM damping. *Superconducting Science and Technology Topical Review 30 (2017) 063002*, 30(6):38, 2017

JLEIC 1-cell cavity with various HOM damper options

F. Marhauser





F. Marhauser. Next generation HOM damping. *Superconducting Science and Technology Topical Review 30 (2017) 063002*, 30(6):38, 2017

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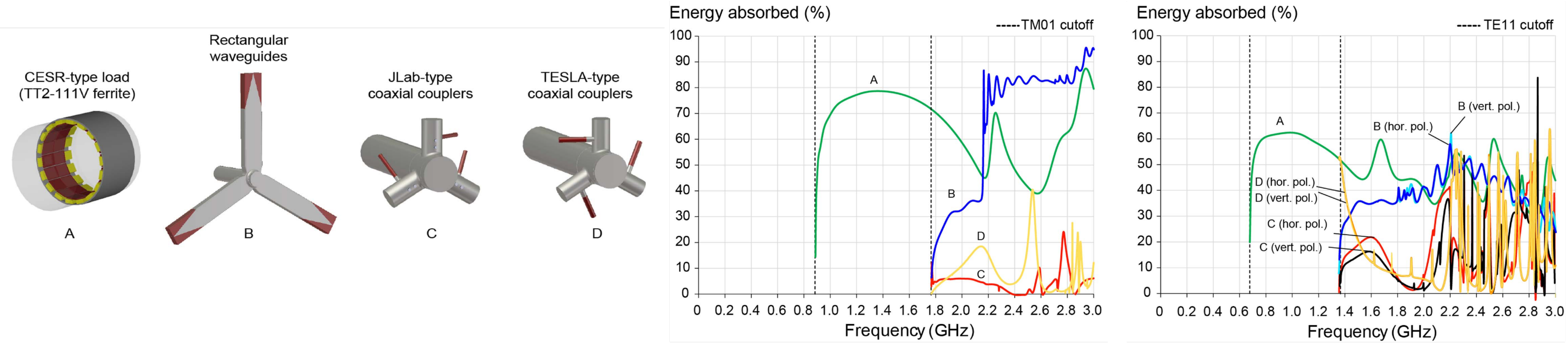
HOM end group S-parameyer study

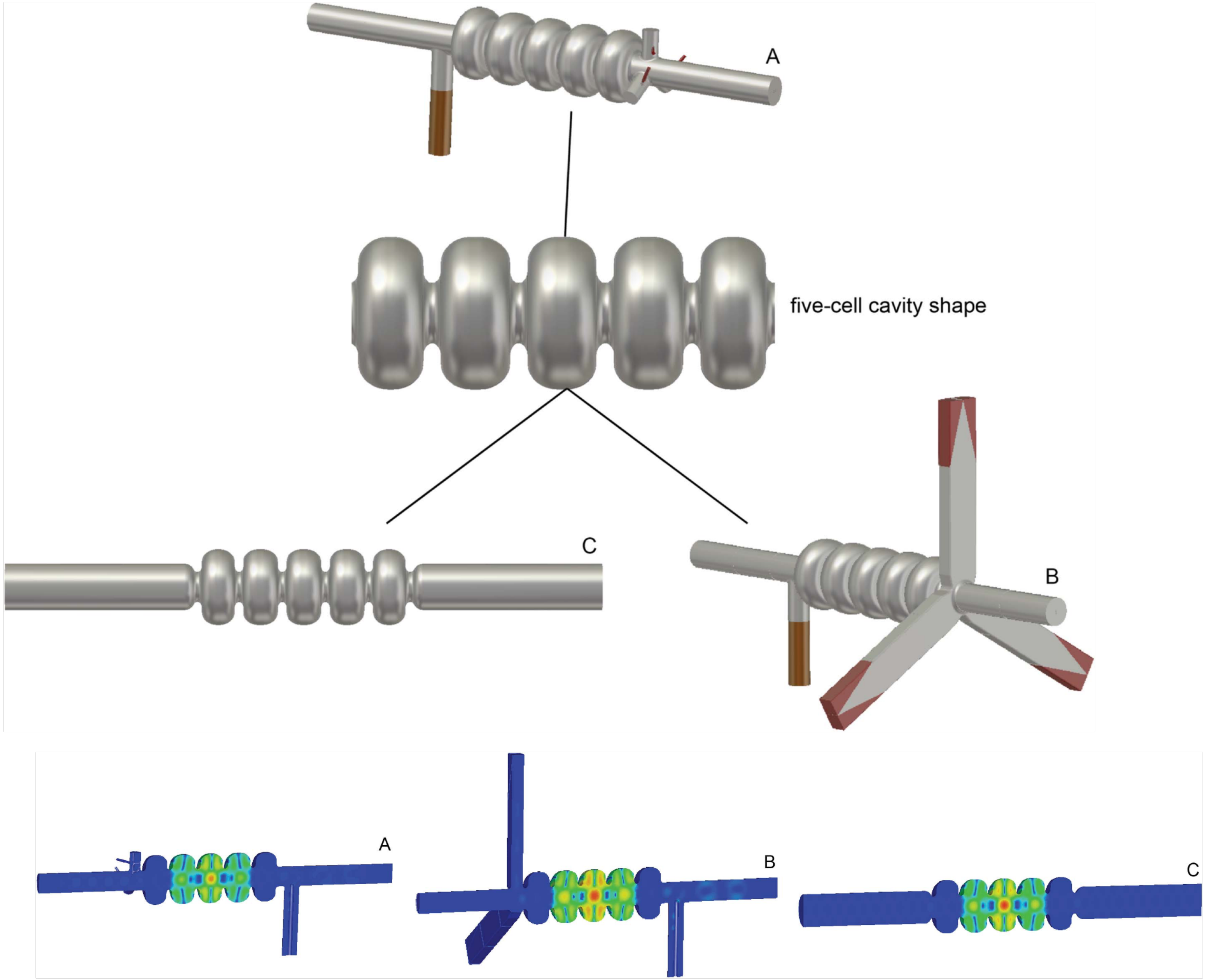
Figure 22. *S*-parameter calculations performed in frequency domain for the four cases depicted in the legend. The energy absorbed in the dampers is given in percentage of the incident wave, either when launching a TM01 or TE11 waveguide mode, respectively, into the beam tube on one side. The other beam tube is matched. The energy does not account for the energy transmitted from one to the other beam tube. For the TE11 modes, the calculations for Case B–D were done separately for the horizontal and vertical polarization. The relevant cutoff frequencies are indicated by the dashed vertical lines.

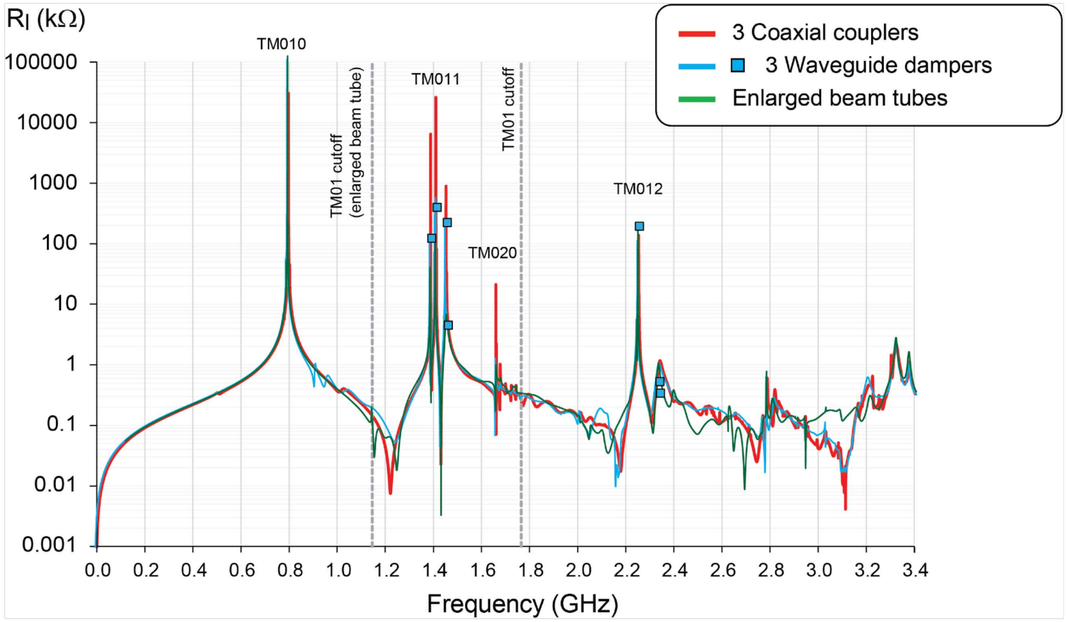


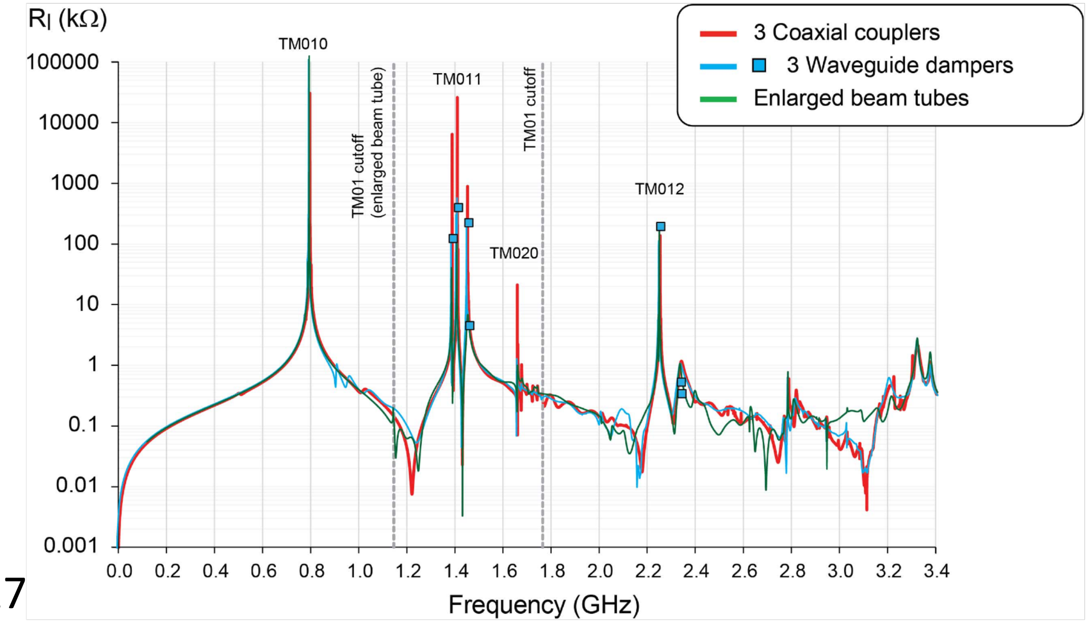
F. Marhauser. Next generation HOM damping. *Superconducting Science and Technology Topical Review 30 (2017) 063002*, 30(6):38, 2017

HOM study extended to 5-cells

F. Marhauser





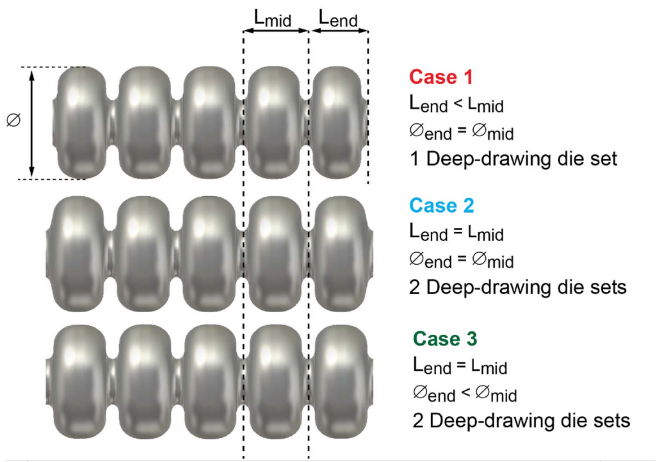


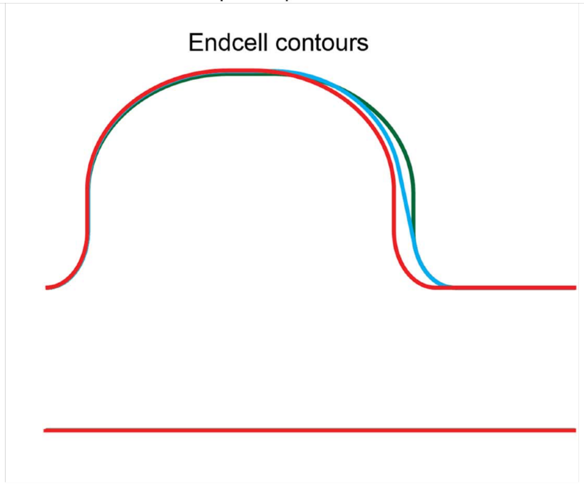
Frank Marhauser 2017 *Supercond. Sci. Technol.* 30 063002, 30(6):38, 2017

New Jlab variants

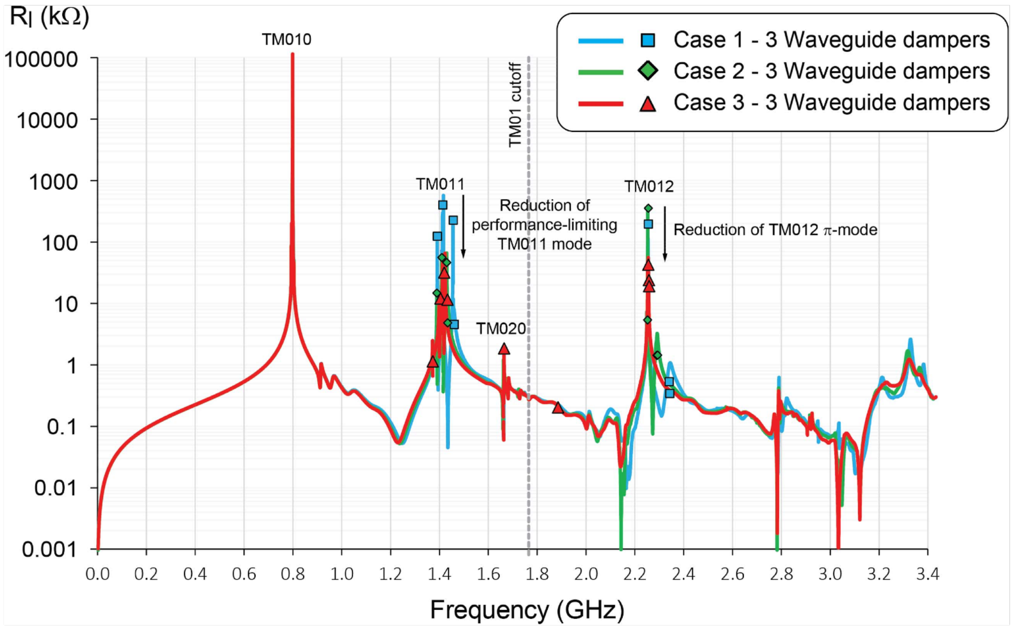
F. Marhauser

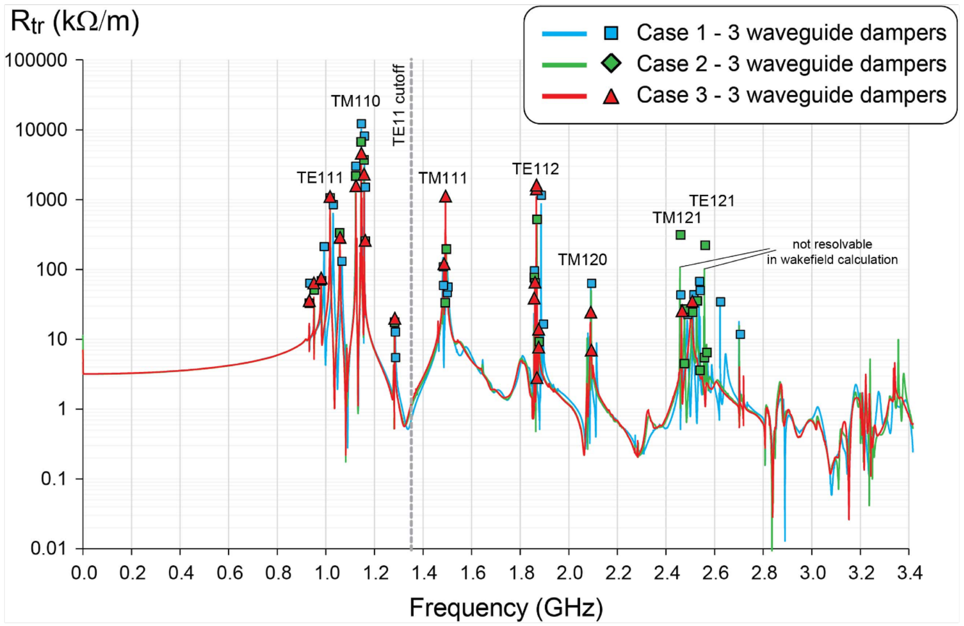
- Modified end cell profiles
- Reduction of TM011 and TM012 modes
- Some increases in dipole modes





Parameters*	JLab Case 1	JLab Case 2	JLab Case 3
Frequency [MHz]	801.58	801.58	801.58
Number of Cells	5	5	5
Material	Bulk Nb.	Bulk Nb.	Bulk Nb.
Temperature [K]	2.0	2.0	2.0
Cavity active length [mm]	917.911	935.536	935.536
Mid-cell length [mm]	187.107	187.107	187.107
End-cell length [mm]	178.295	187.107	187.107
R/Q [Ω]	524.25	520.63	522.70
(R/Q)/(cell number) [Ω]	104.85	104.13	104.54
Geometry Factor (G) [Ω]	274.505	201.490	278.112
G*(R/Q) [Ω^2]	143909.2	149901.7	145369.1
(R/Q)*G/(cell number) [Ω^2]	28781.85	29980.35	29073.83
B_{pk}/E_{acc} (mid-cell) [mT/(MV/m)]	4.62	4.70	4.66
E_{pk}/E_{acc} (mid-cell) [-]	2.38	2.30	2.27
Iris radius [mm]	65	65	65
Beam Pipe radius [mm]	65	65	65
Mid-cell equator diameter [mm]	328	328	328
End-cell equator diameter [mm]	328	328	325
Wall angle [degree]	0	11.95	0
Cell-to-cell coupling of mid cells [%]	2.93	2.92	2.91
$k_{\|\|}(\sigma_z = 3\ \mathrm{mm})$ [V/pC]	2.74	2.4	2.74
Cutoff TE11 [GHz]	1.35	1.35	1.35
Cutoff TM01 [GHz]	1.77	1.77	1.77

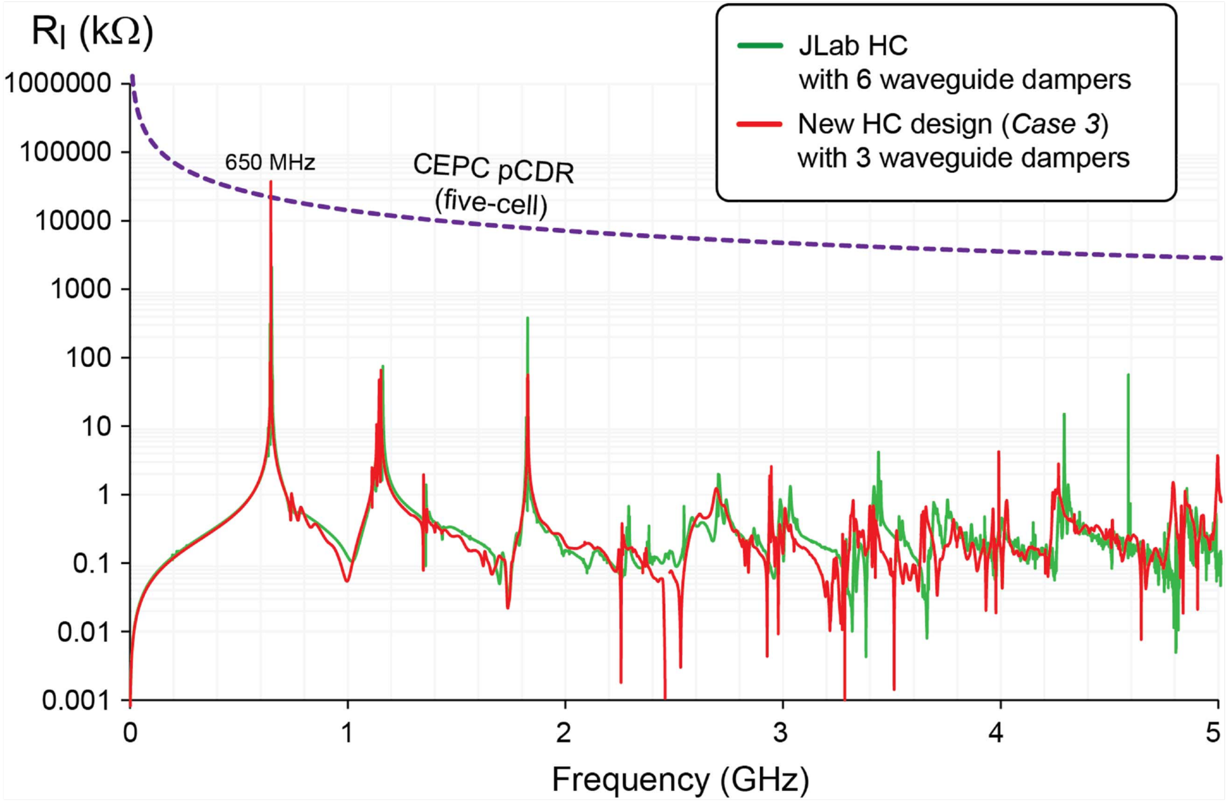


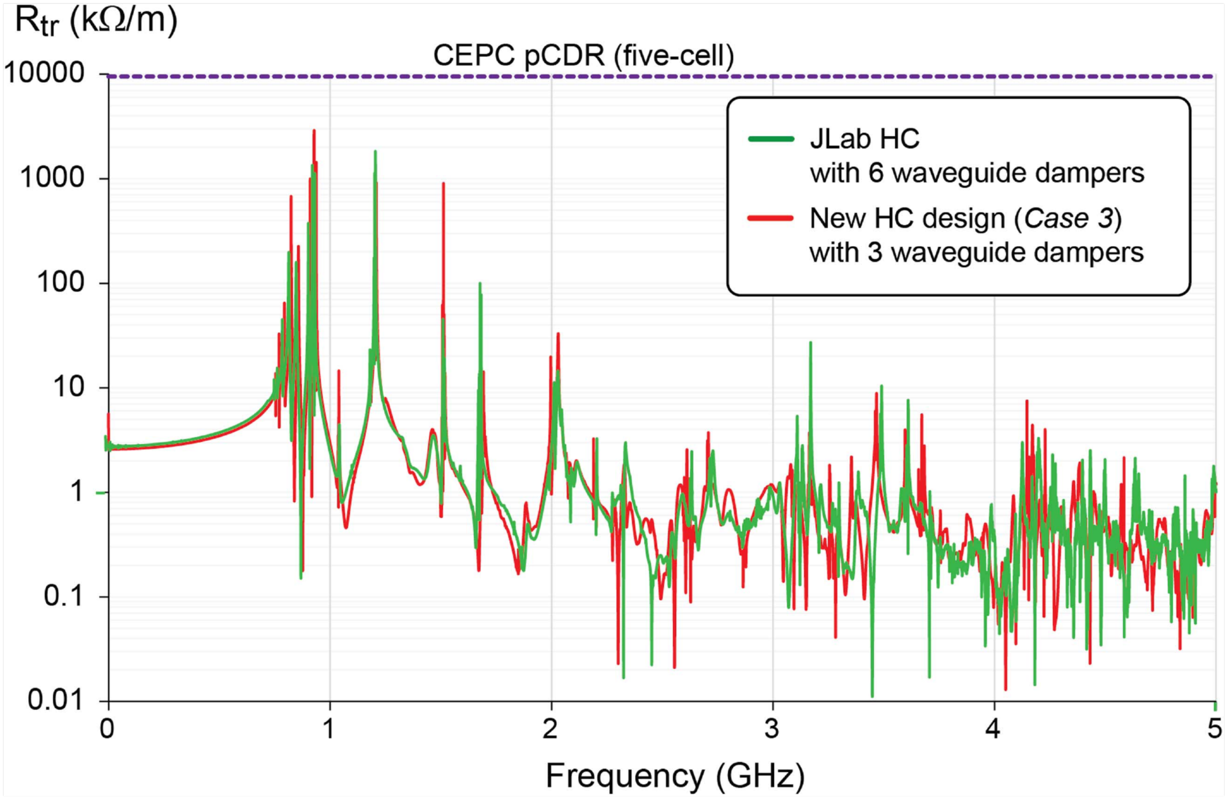


F. Marhauser

Example: 5-cell 650 MHz cavity in CEPC, 16.6 mA, 384 cavities

- But **is it needed?** Depends on thresholds, for CEPC probably no, for FCC yes?





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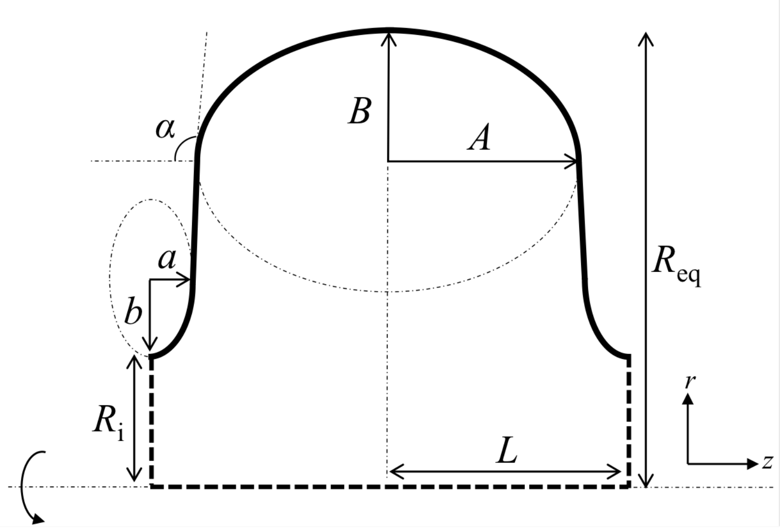
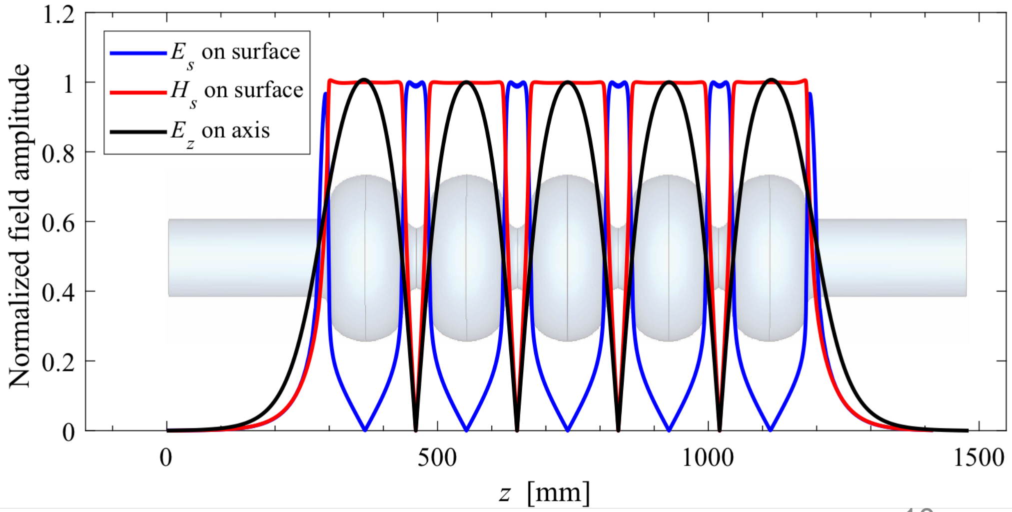
New variant: Shahnam's thesis

Accelerating cavity and higher order mode coupler design for the Future Circular Collider
Dissertation zur Erlangung des akademischen Grades Doktor-Ingenieur (Dr.-Ing.)
der Fakulta¨t fu¨r Informatik und Elektrotechnik der Universita¨t Rostock
vorgelegt von
Shahnam Gorgi Zadeh, geboren am 11.09.1986 in Shiraz aus Rostock
Eingereicht: Rostock, 05. November 2020 Verteidigt:

- Modified cell profile to avoid flat end wall, different end cells
- Multi-parameter optimization
- Applied to 400 MHz 1 and 4 cells and 800 MHz 5-cell cavities





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FCC 5-cell

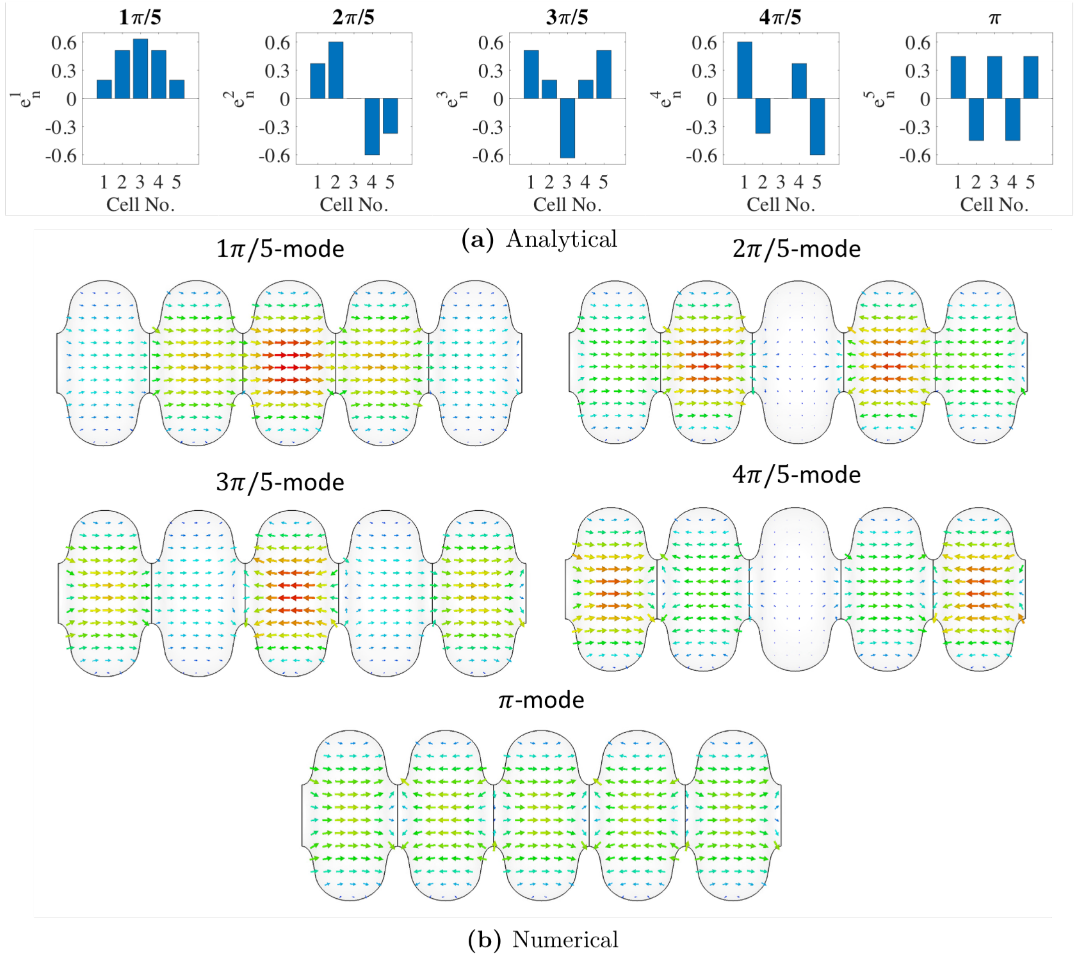


Figure 2.2: (a): Relative field distribution in the cells of a five-cell cavity calculated analytically using equation (2.32). (b): Electric field distribution of the modes in the TM_{010} passband of a five-cell cavity calculated numerically using PMC boundary condition at both ends in the longitudinal direction and PEC elsewhere.

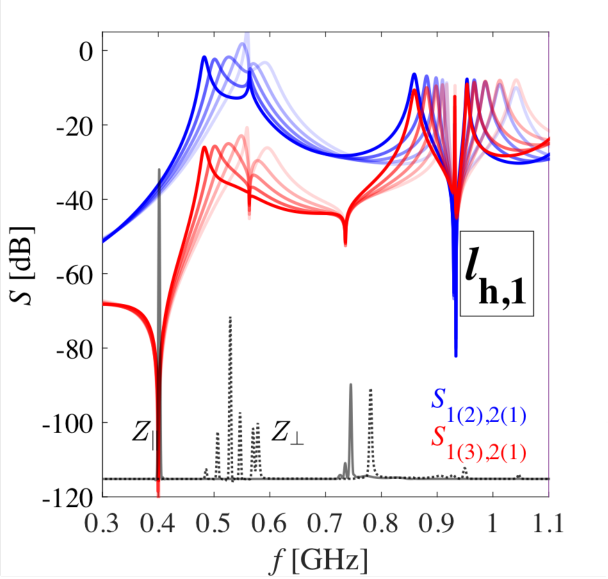
Table 4.3: RF parameters of the proposed four-cell (FCC_{UROS4}) and five-cell (FCC_{UROS5}) cavities. The cavities are compared with two five-cell cavities designed for operation in PERLE [78, p. 61].

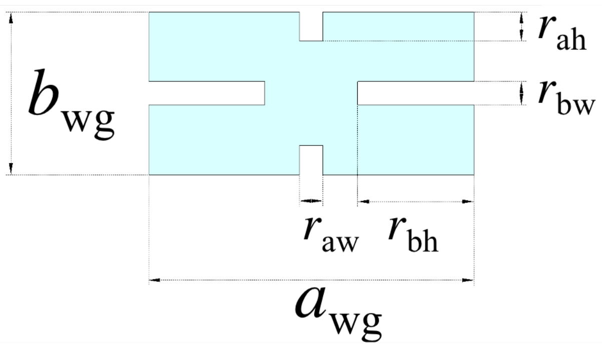
Parameters	FCC_{UROS4}*	FCC_{UROS5}*	$CERN_2$	$JLab_2$
Frequency, f_0 [MHz]	400.79	801.58	801.58	801.58
Number of cells, N_{cell}	4	5	5	5
$R/Q_{\|\|,0}$ [Ω]	411.3	520.6	393	523.9
G [Ω]	273.2	272.9	283	274.6
$G \cdot R/Q_{\|\|,0}$ [Ω^2]	112367	142072	111219	143862
B_{pk}/E_{acc} (middle cell) [$\frac{mT}{MV/m}$]	4.2	4.2	4.92	4.2
E_{pk}/E_{acc} (middle cell)	2.0	2.0	2.4	2.26
Cavity active length, L_{active} [mm]	1465.1	919.5	935	917.9
Radius of the middle cells, R_i [mm]	120	60	80	65
Beam pipe radius, R_{bp} [mm]	156	78	80	65
Wall angle of middle cell, α [°]	100	100	102.5	90
k_{cc} of the middle cell [%]	2.25	2.25	5.75	3.21
k_{cc} of the cavity [%]	1.92	2.04	5.19	2.93
Field flatness, η_{ff} [%]	99	99	96	99
$k_{\|\|}$ (σ_z = 2 mm) [V/pC]	2.27	3.37	2.63	2.74
f_{cut} TE_{11} for R_{bp} [GHz]	0.563	1.126	1.10	1.35
f_{cut} TM_{01} for R_{bp} [GHz]	0.7355	1.471	1.43	1.77
N_{cell}^2/k_{cc}	833	1225	481	853

* The designed cells are adapted to a four-cell cavity at 400.79 MHz and a five-cell cavity at 801.58 MHz.

FCC HOM damping options

- Multi-parameter optimization
- Include DQW type
- Include ridged WG
- Beam pipe diameter is larger than JLab





(a) Parametrization of the QRWG

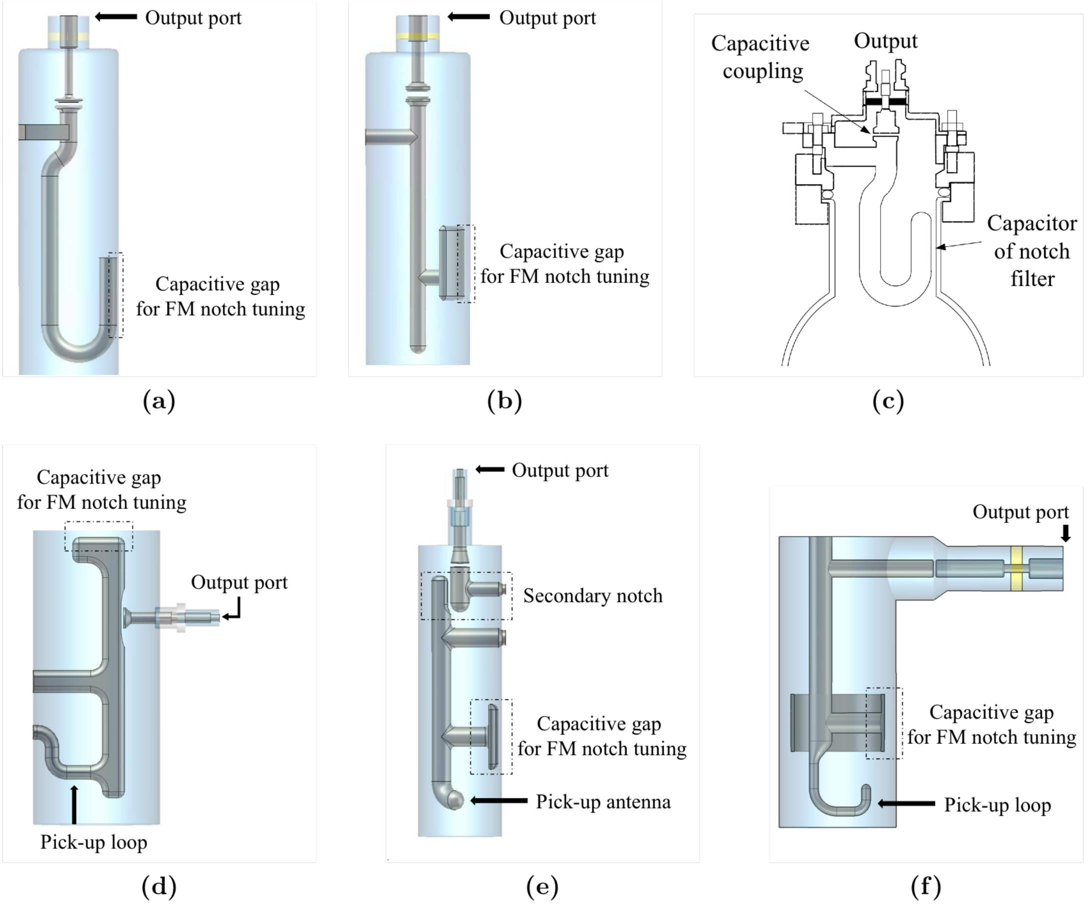
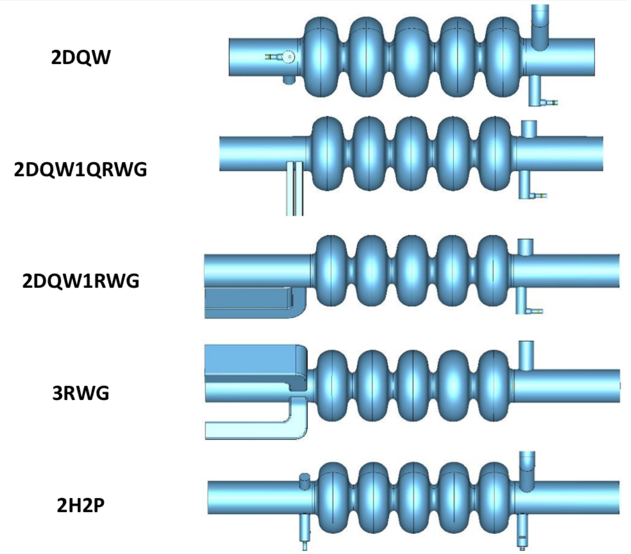
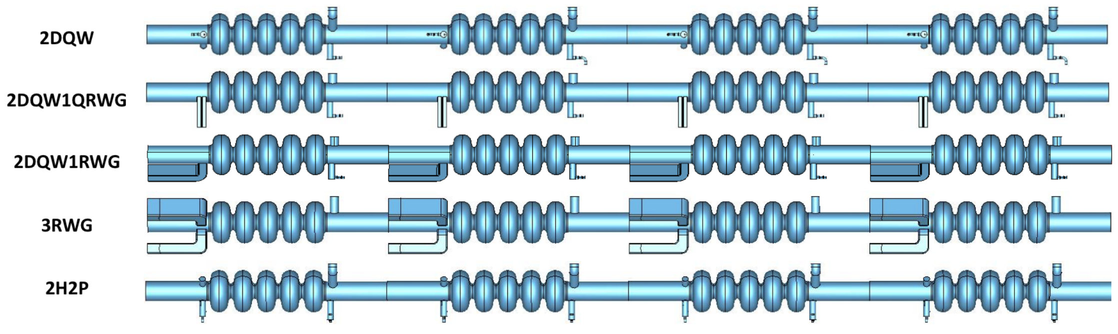
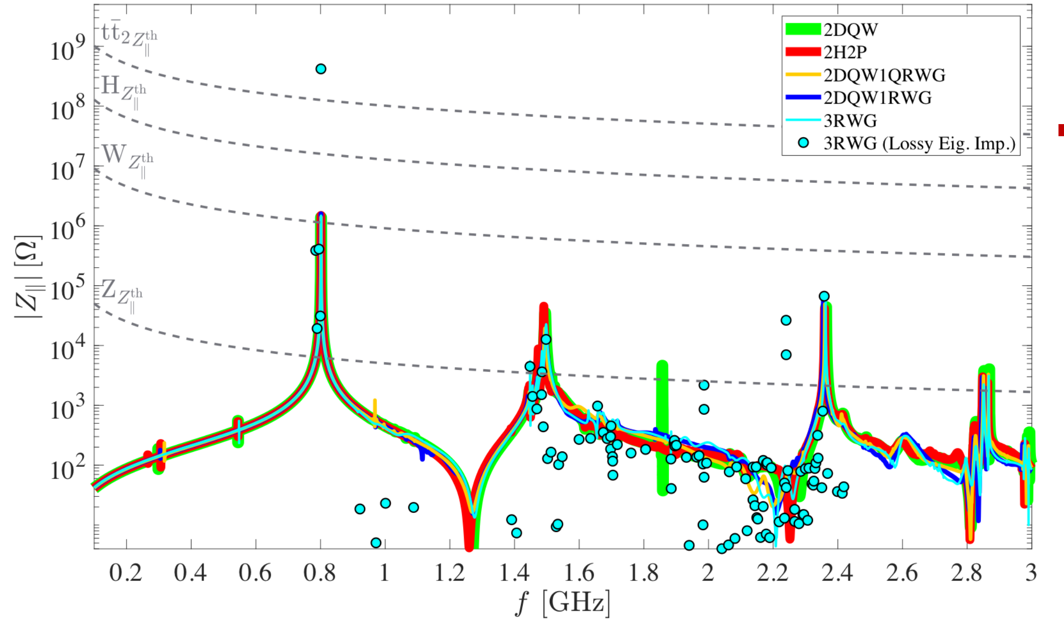


Figure 5.4: (a): Coaxial hook-type coupler developed for the LHC and specifically designed to damp the first dipole band [119, 120]. (b): Coaxial probe-type coupler designed for the LHC with a broad-band transmission behavior [119, 120]. (c): Demountable version of the TESLA coupler [121] (figure adapted from [65]: CC BY 3.0). (d): Welded version of the TESLA coupler [121]. (e) Double notch HOM coupler proposed for the Superconducting Proton Linac (SPL) [122]. (f) Cross-section of the DQW HOM coupler designed for the crab cavities of the HL-LHC [123].

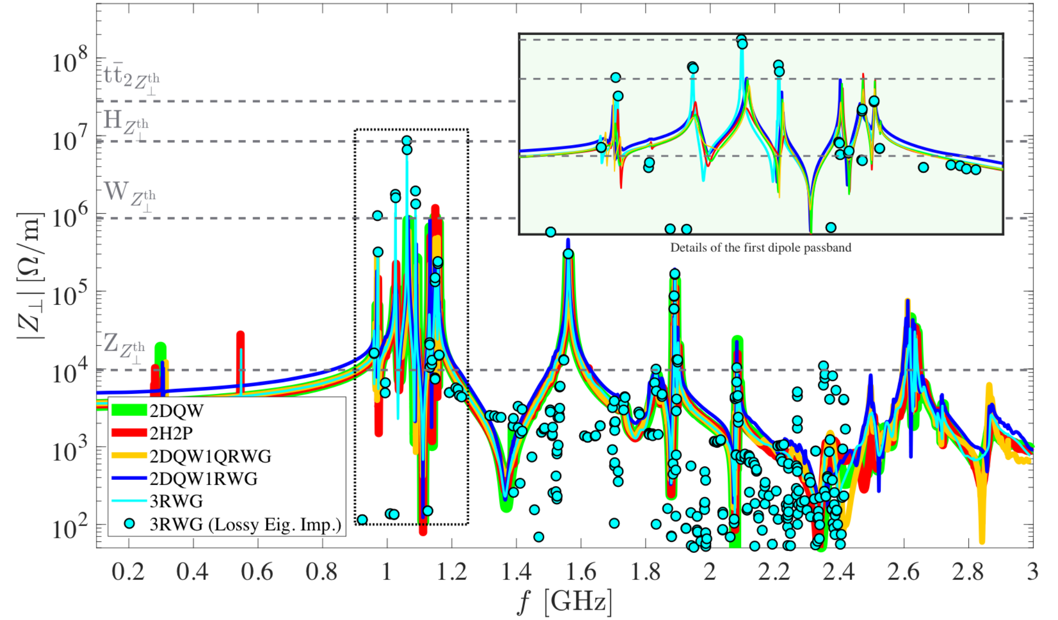
FCC 5-cell with various HOM options







(a) Longitudinal impedance



(b) Transversal impedance

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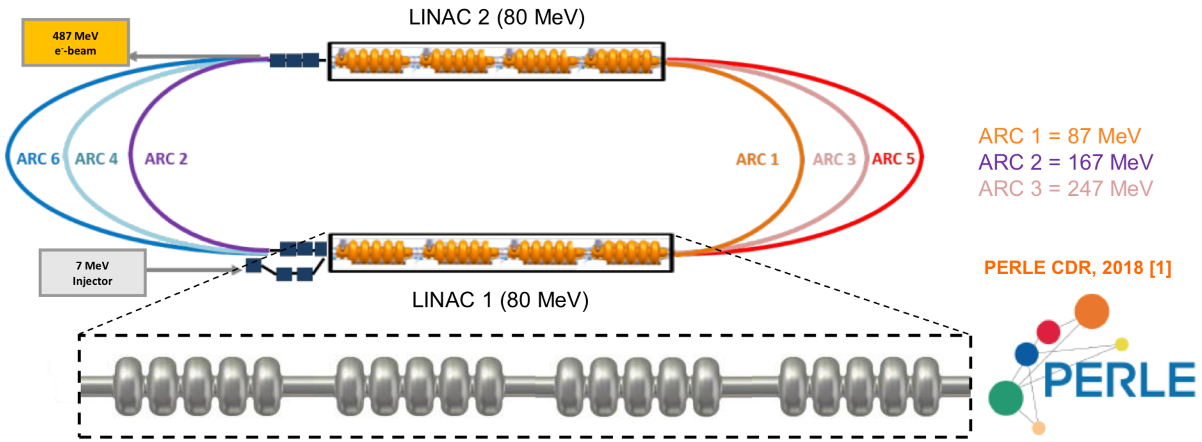
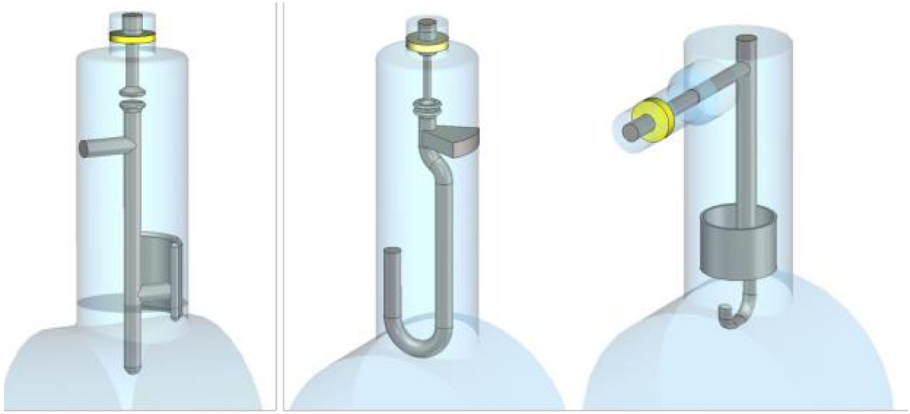
PERLE HOM study: Carmelo

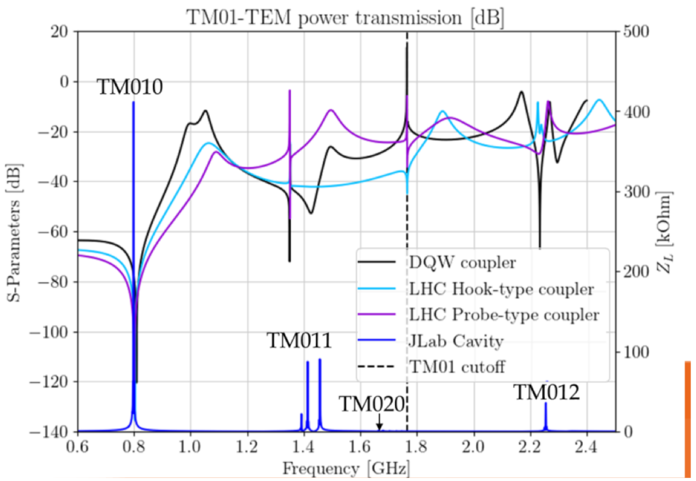


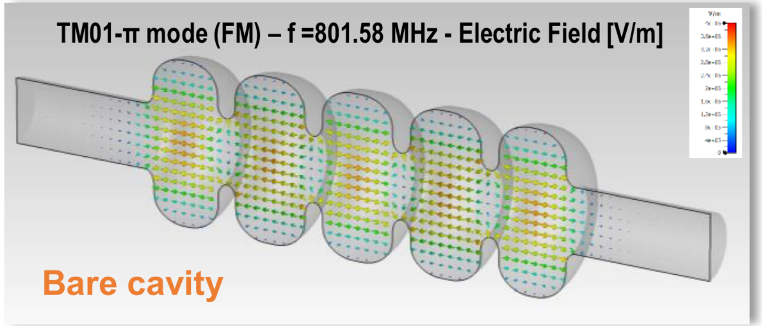
Four 5-cell 801.58 MHz elliptical Nb cavities

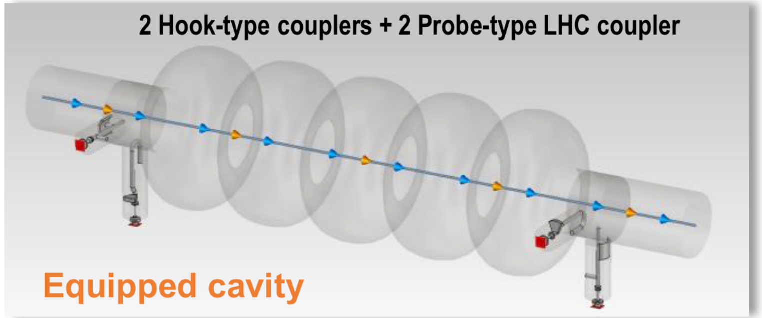
Target Parameter [2]	Unit	Value
Injection energy	MeV	7
Electron beam energy	MeV	500
Normalized Emittance Yεx,y	mm·mrad	6
Average beam current	mA	20
Bunch charge	pC	500
Bunch length	mm	3
Bunch spacing	ns	25
RF frequency	MHz	801.58
Duty factor	CW (Continuous Wave)	



LHC Probe-type coupler *LHC Hook-type coupler* *DQW coupler*







HOM-damping studies of a 5-Cell Elliptical Superconducting Cavity for PERLE , Carmelo Barbagallo , PERLE SRF Meeting, 03 December 2021

PERLE HOM study: Carmelo

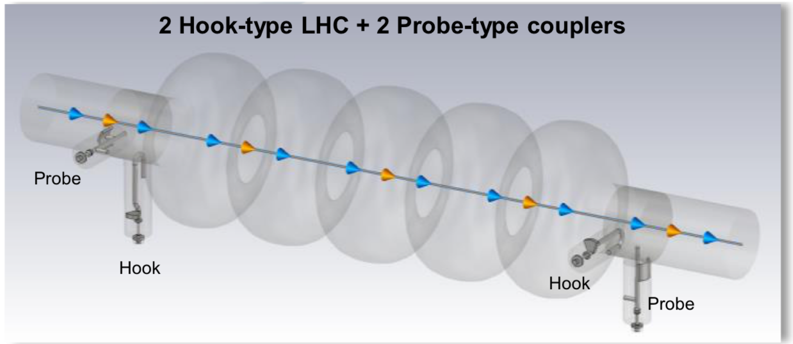
Experimental activities:

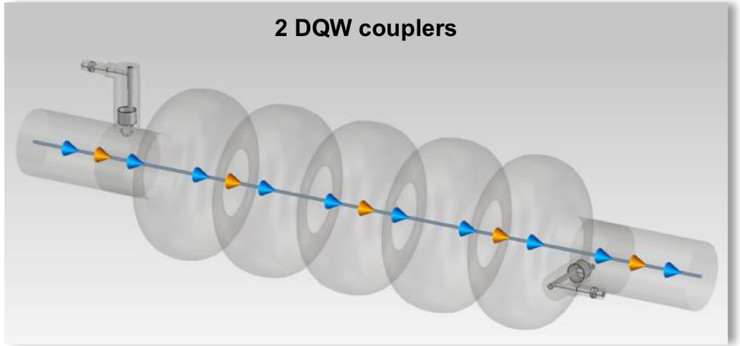
- Cavity end-cell modifications? (improve the damping of TM011 and TM012 mode)
  - Do we plan to do perform the modifications at JLab or at CERN, where and when?
  - Measurements on the cavity
- Tube modification to install HOM couplers
- Realization of the HOM couplers and installation on the cavity
- Integration of the PERLE cavity in the SPL cryomodule
- Thermal treatments (Nitrogen doping) on the cavity?
- Integration of the SPL Power Coupler
- Test of the full dressed cavity on the vertical cryostat

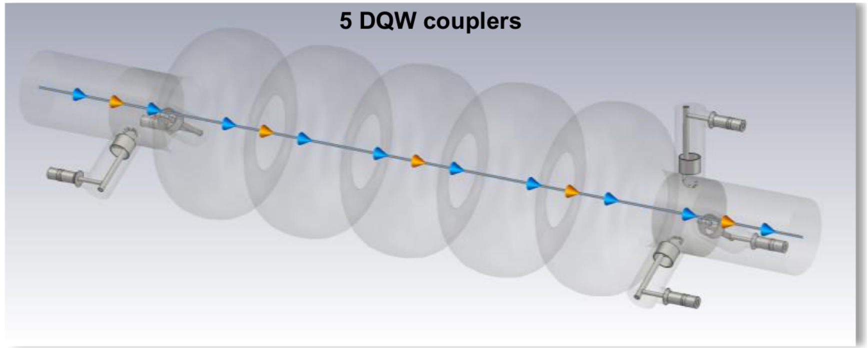
Future perspectives:

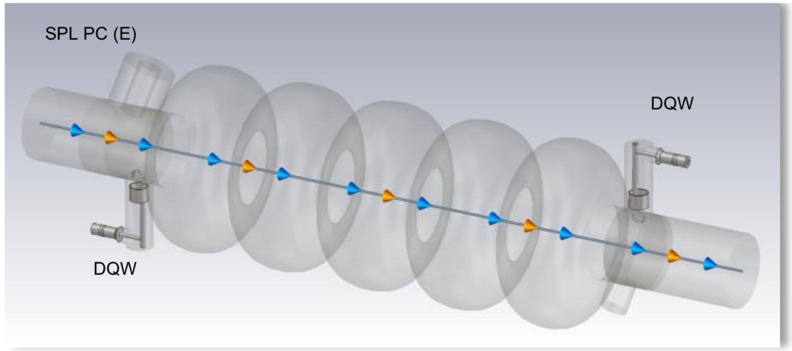
- Optimization of the cavity end-cells to improve the coupling of the TM012 π-mode to the beam tubes
- Optimization of HOM couplers, and study of other HOM couplers (JLAB, TESLA)
- Thermal studies for HOM couplers (HOM power and dissipation)
- Planning of the experimental activities (CERN and JLab)

PERLE HOM study: Carmelo









Other suitable HOM-damping schemes :

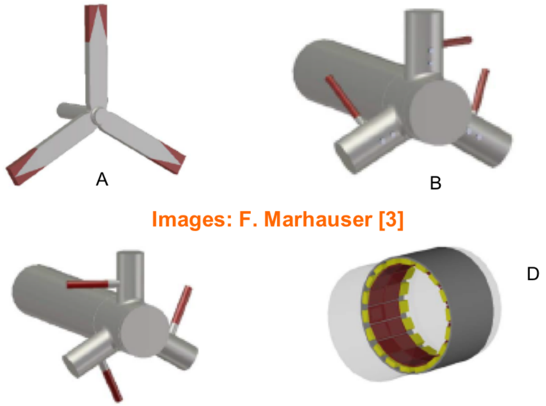
•Rectangular waveguide dampers (A)

•JLab-Type coaxial couplers (B)

•TESLA-Type coaxial couplers (C)

•Add absorbers in cavity-interconnecting beam tubes (D)

•Coupling through Fundamental Power Coupler (E)



HOM-damping studies of a 5-Cell Elliptical Superconducting Cavity for PERLE , Carmelo Barbagallo , PERLE SRF Meeting, 03 December 2021

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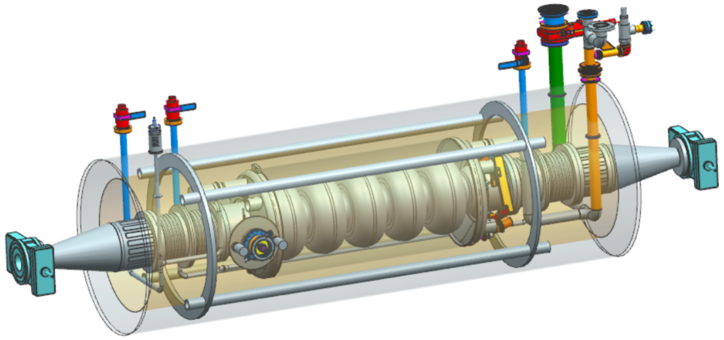
EIC high energy cooler

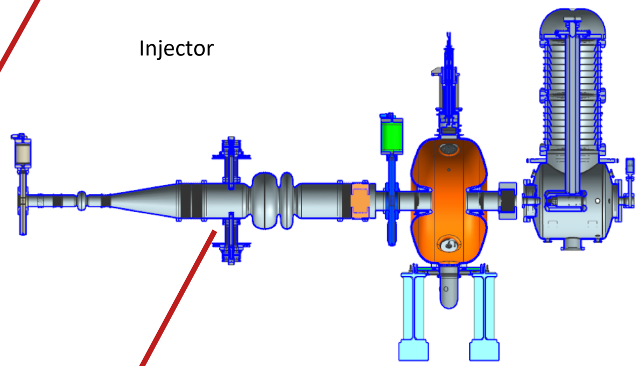
- Work in progress

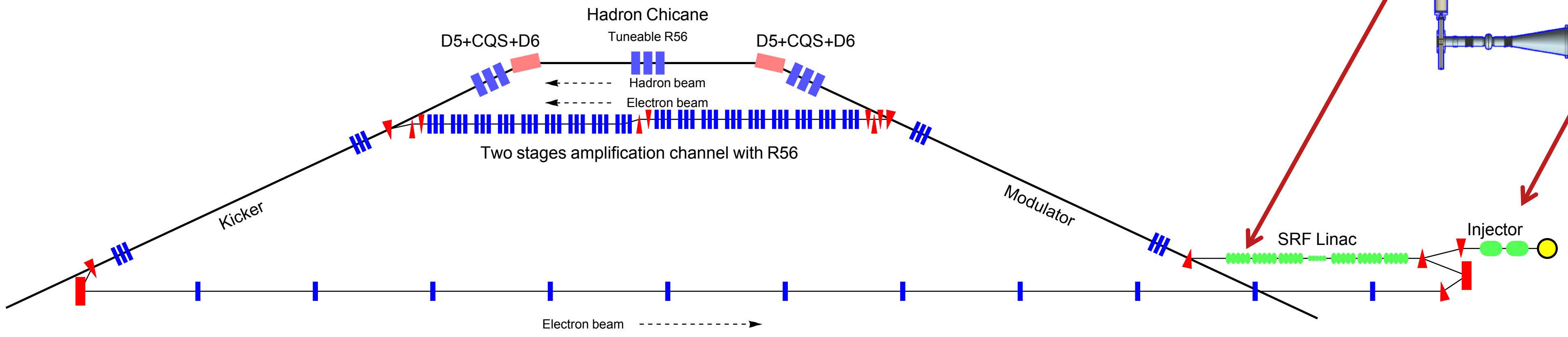
- Single Pass **150 MeV ERL**, 98.5 MHz bunch frequency
- **8 x 591 MHz, 5-cell** elliptical + **1.77 GHz** third harmonic
- Maximum 180 MV installed voltage, Eacc **15.8 MV/m**
- 8 x 591 MHz, **65 kW CW**, SSA RF Power Amplifiers
- **1 nC** per bunch, **~100 mA** single pass current
- Injector: DC photocathode gun, 197 MHz buncher, 591 MHz acceleration, 1.77 GHz linearizer.



Cooler- 591 MHz ERL cavity

Injector

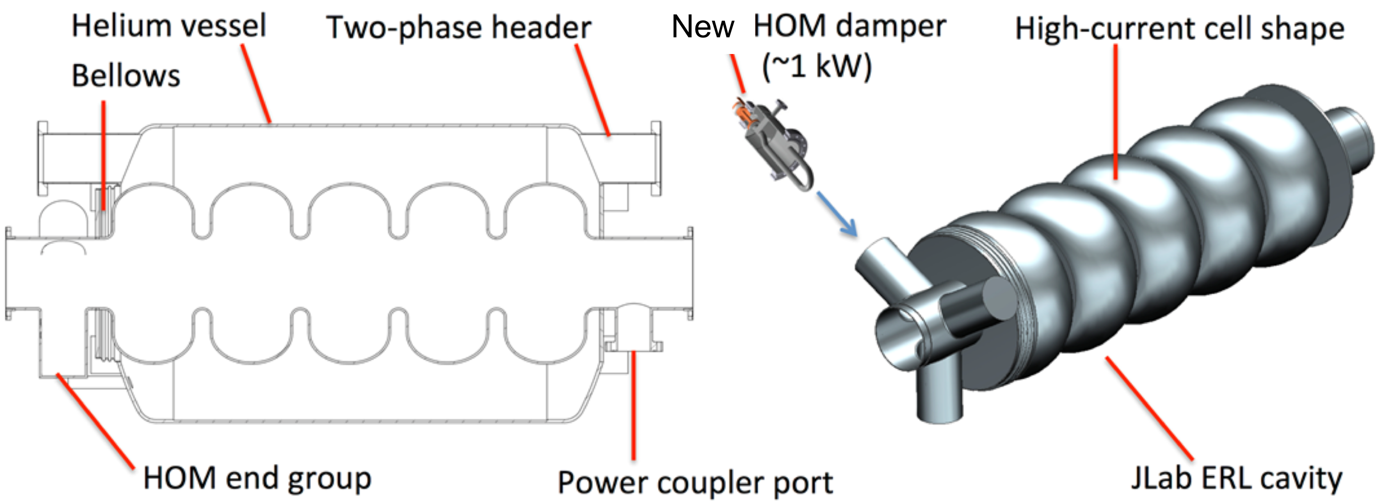




“The accelerator design progress for EIC strong hadron cooling”, E. Wang et. Al., TUPAB036 Proc. IPAC21, Brazil.

ERL roadmap/path forward

- Develop firm requirements for PERLE
  - BBU thresholds
  - Bunch parameters
  - Fill pattern
- Complete HOM study
  - Carmelo to visit Jlab
  - Determine if new end cells needed
- Use Cu models to verify design
- Finalize FPC interface
- Modify Jlab prototype cavity
- Fabricate prototype HOM couplers
- Vertical test at Jlab or CERN
- Integrate into He tank and SPL module
- Build or procure 4 production cavities



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Thank You

Recent progress and ideas: notes by Walid Kaabi and Max Klein, in contact with many of you, presented by MK, PERLE Collaboration Board Meeting, 24.7.2020

Proposal of a Near-Term Contribution of JLab to the International PERLE Collaboration (TASK 4)

Frank Marhauser, Max Klein
2020-07-20

1) Detailed numerical HOM coupler study to finalize the design (TASK T4-3)
    a. Time-line: 0.5 – 1 year
    b. Funding estimate: ~0.25 - 0.5 FTE (SSS), 1 PW (ESM)

2) Production of 1st prototype HOM endgroup based on 1) (TASK T4-2)
    a. Time-line: 1 year
    b. Funding estimate: ~0.1 FTE (SSS), 2 PW (A/C II), 1 PW (TD III), 3 PW (ESM), 1 PW (AC I).

Note: This includes using the existing 5-cell SRF cavity and replacing a blank beam tube with a HOM endgroup to demonstrate the usability of the design (incl. vertical tests at 2 K)

This was worked out in Consultation with Achille, Walid and Bob
It has been made known to Andrey, Andrew, Oliver on Wednesday .
Work would involve Collaboration of Jlab with IJCLab and CERN

Recent progress and ideas: notes by Walid Kaabi and Max Klein, in contact with many of you, presented by MK, PERLE Collaboration Board Meeting, 24.7.2020

Proposal of a Near-Term Contribution of JLab to the International PERLE Collaboration (TASK 4)

Frank Marhauser, Max Klein
2020-07-20

This was worked out in Consultation with Achille, Walid and Bob
It has been made known to Andrey, Andrew, Oliver on Wednesday .
Work would involve Collaboration of Jlab with IJCLab and CERN

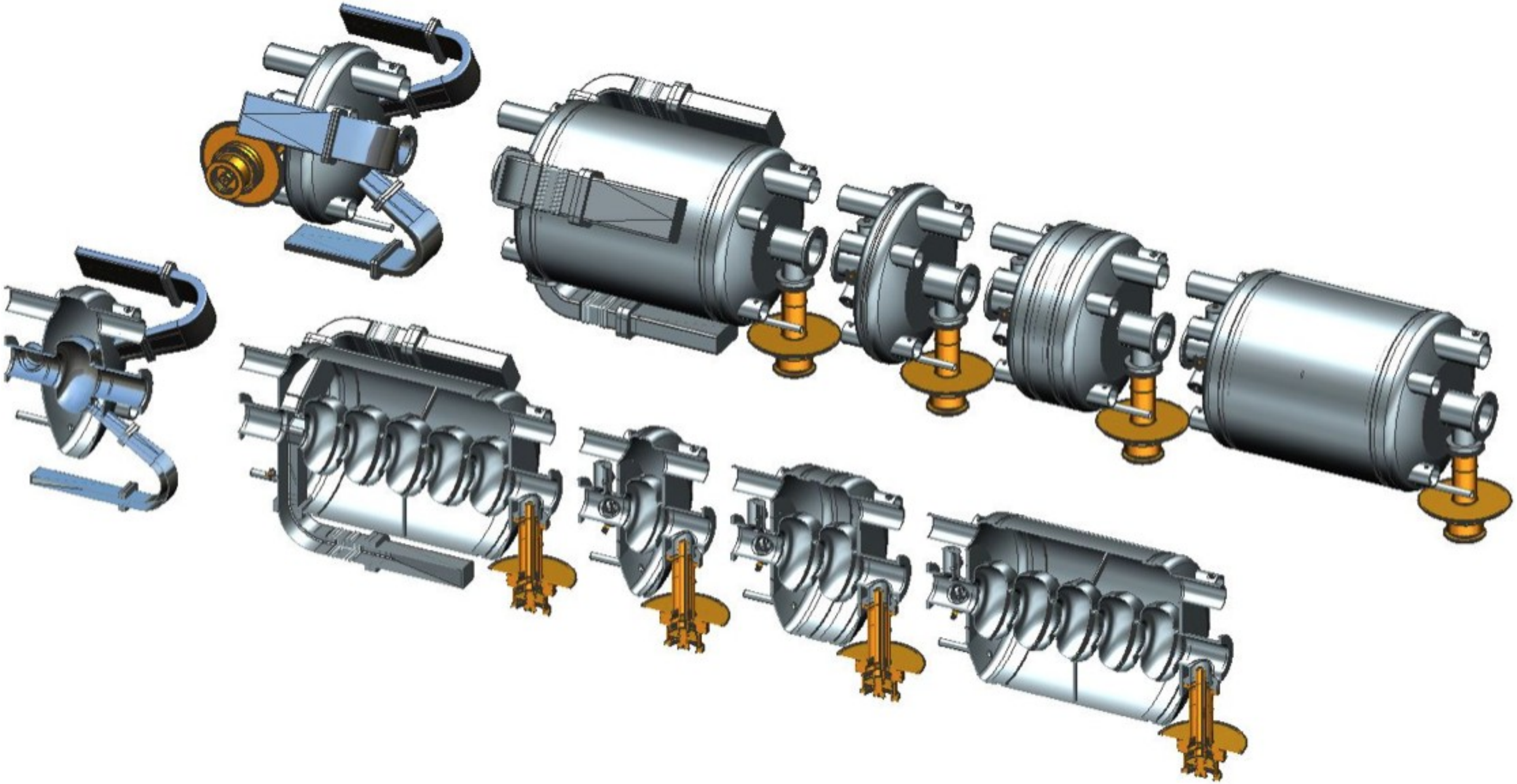
Depending on the success of 2) and the finalization of the power coupler design and study (TASK T4-4), and considering the accommodation of the cavities in the cryomodule (TASK T4-5), JLab would offer to continue with:

3) Fabrication of 4 SRF Cavity Production Units for PERLE (TASK T4-2) for PERLE @ 250 MeV
   a. Time-line: 2-3 years
   b. Funding level TBD
   c. The full scope as part of a), i.e. He tank and tuner design needs to be discussed and will impact the deliverables

If the tasks can be completed consecutively and successfully with minor delays, the delivery of 4 cavity production units could be feasible by 2025, so 3 years ahead of milestone 3 (End Phase 1) allowing ample time for cryomodule assembly and perhaps spare cavity production as needed.

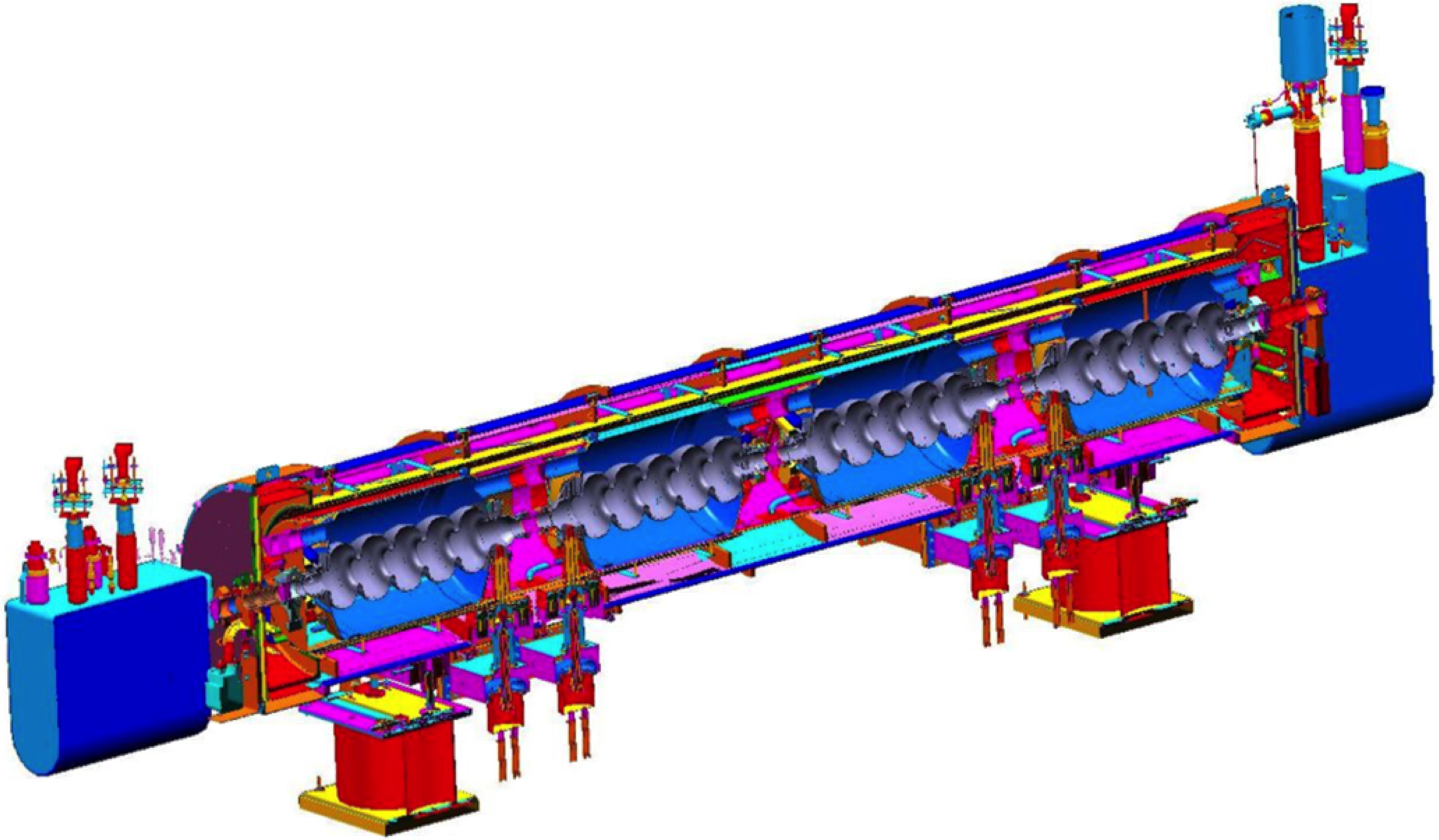
Jlab modular cryostat

Dimensions loosely based on SNS cryomodule



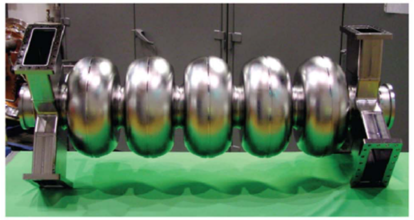
PERLE CM concept based on SNS cryostat

-

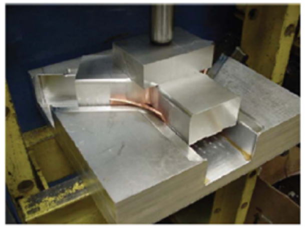


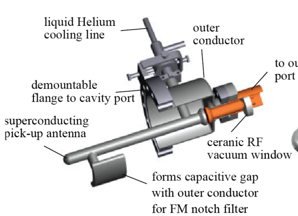
Jefferson Lab

HOM damping options

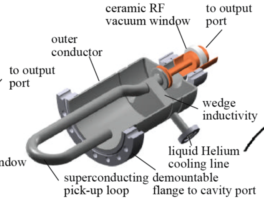


748.5 MHz JLab High Current ERL-FEL cavity protoype

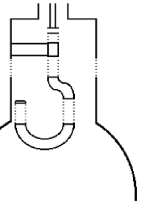




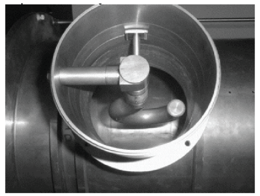
LHC broadband antenna coupler



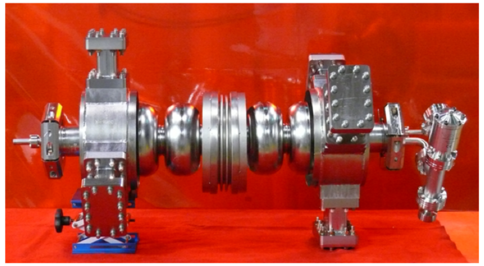
LEP-type LHC narrowband loop coupler for dipole modes

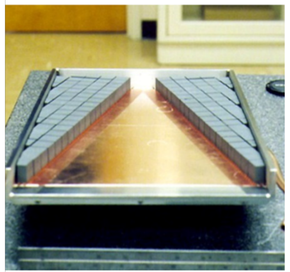


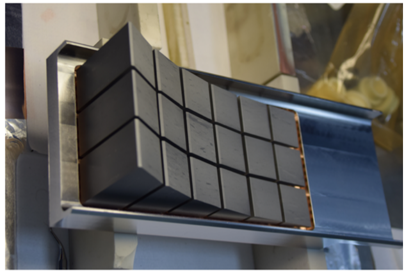
LEP-type Soleil D-coupler for dipole modes

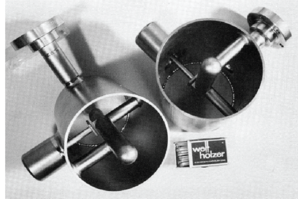


Soleil L-coupler for longitudinal modes

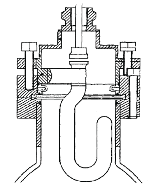




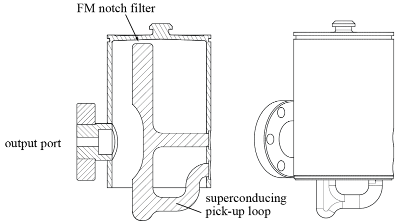




HERA coupler designs

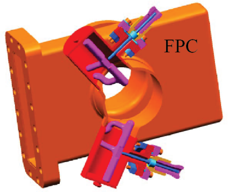


Demountable LEP-type coupler conceived for TESLA cavity

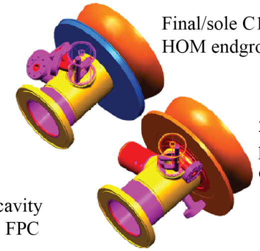


Present TESLA cavity hook coupler (based on a HERA coupler design)

Single-crystal sapphire RF feedthroughs

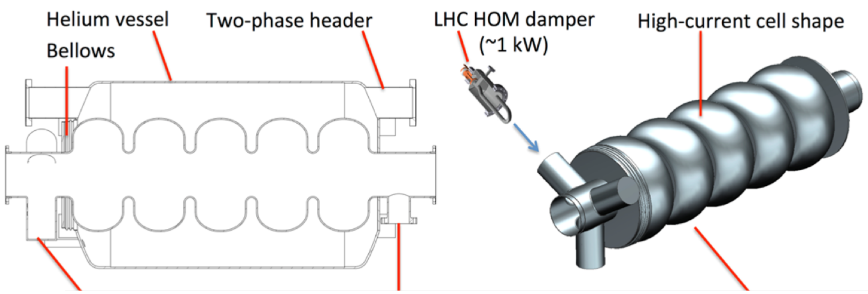


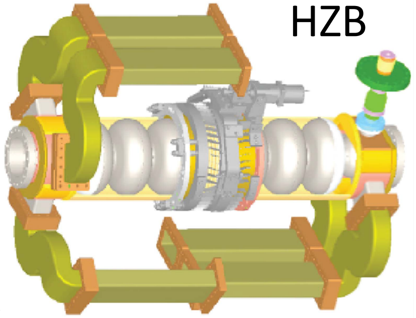
JLab HG/LL prototype cavity HOM endgroup close to FPC

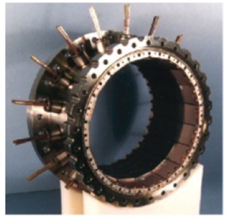


Final/sole C100 LL HOM endgroup

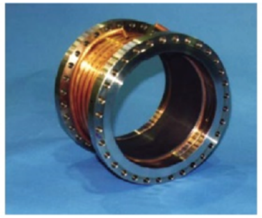
2nd HG/LL protoype HOM endgroup





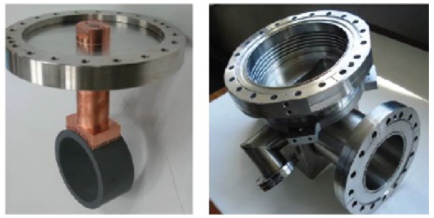


CESR multi-KW cavity beam line absorber



KEKB multi-kW cavity beam line absorber

Cornell injector beam line absorber for up to 200 W at 80 K temperature



DESY inter-cryomodule beam line absorber for 100 W at 70 K temperature