Improvement of HOM Damping for the 2-cell JLEIC Ion Ring Cavities

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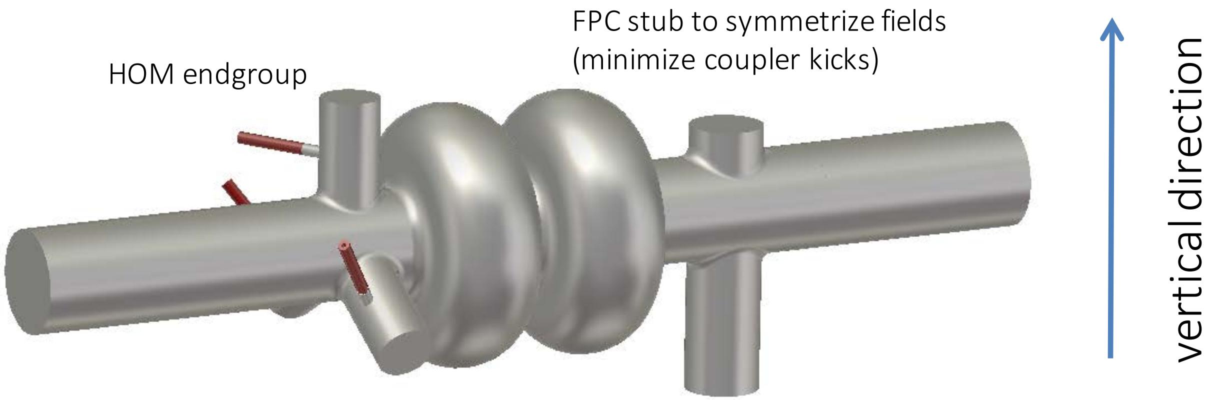
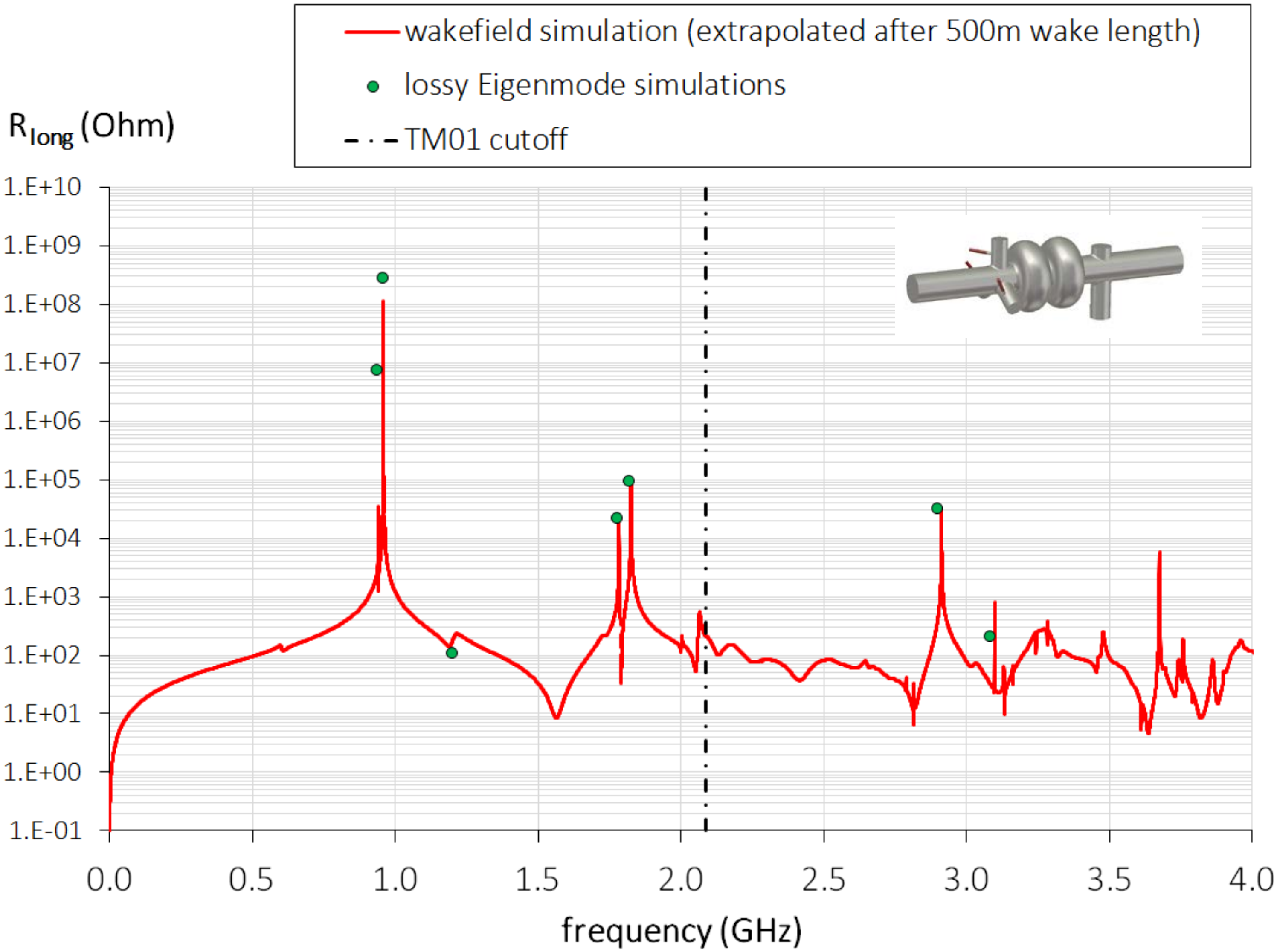
Introduction

- A two-cell ion-ring SRF cavity with 3 scaled JLab-type coaxial HOM couplers has been used earlier for 1st JLEIC studies
- The monopole and dipole impedances have been evaluated at the time (10th March 2017) and utilized for bunch instability studies



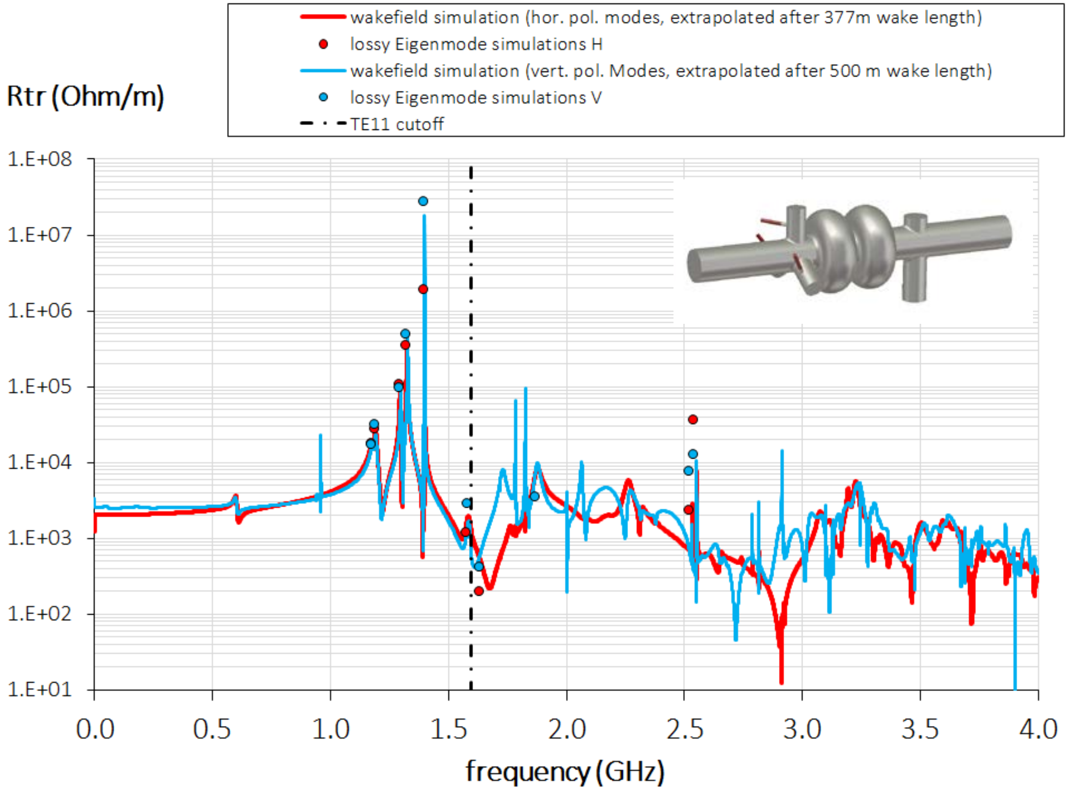
Two-cell 952.6 MHz cavity

Monopole Impedance Spectrum



Dipole Impedance Spectrum

- The HOM end-group with three couplers spaced apart by 120 deg. in azimuth has been conceived to couple to all dipole mode polarizations aiming for equal strength
- The dipole mode pair at 1.39 GHz (highest impedance) still exhibits a difference of ~1 order or magnitude in impedance → vertical polarization is damped the least



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Longitudinal Coupled-Bunch Instability

- An analysis of the longitudinal coupled-bunch instability (LCBI) by Rui Li in 2018 (*THPAK122*, Proc. of IPAC 2018) aimed to identify the LCBI growth rates of the individual mode with the dominant contribution to the LCBI in the ion ring (ditto for electron rings)
- One HOM-endgroup with 3 couplers equally distributed by 120 deg. C in azimuth is conceived to couple well to both polarization of transverse modes

Longitudinal HOMs for Ion Ring RF Cavities

frequency	R/Q on axis (EU definition)	External Q	R_{long} (EU definition)
GHz	Ohm		Ohm
0.9408	2.68	2.98E+06	7.98E+06
0.9526	104.02	2.83E+06	2.95E+08
1.7719	3.99	5.64E+03	2.25E+04
1.8140	19.05	5.27E+03	1.00E+05
2.8948	3.63	9.17E+03	3.33E+04
3.0794	0.01	2.65E+04	2.23E+02

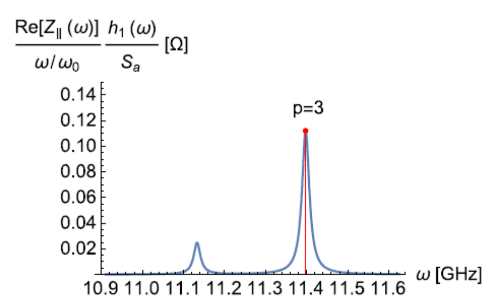
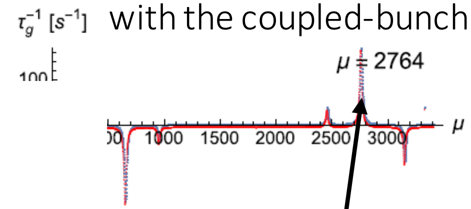


Figure 3: Zoom-in view of the summand of effective impedance for p=3 and $\mu = 2764$.

dependence of growth rate with the coupled-bunch mode



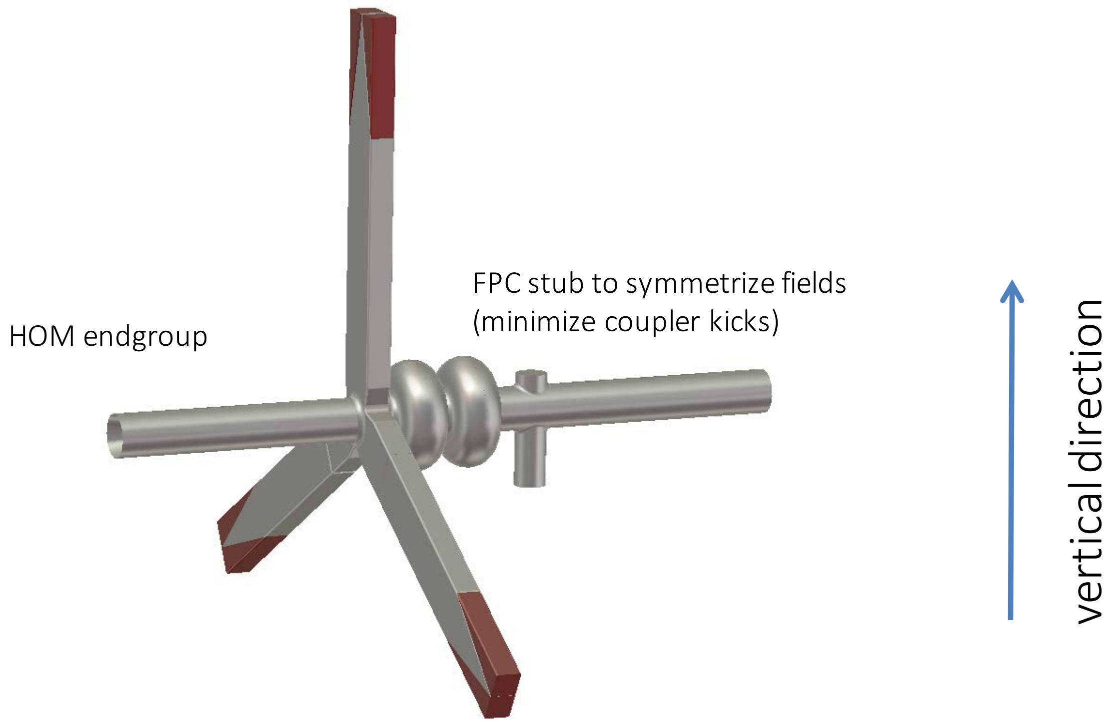
CBI growth rate vs. the coupled-bunch μ for
on beam, by direct summation over p (red) or
l results [5] (blue).

- Due to the strong growth rate, HOM further damping is desired

Largest LCBI growth rate ($1/\tau = 1/5.9$ ms $= 169.5\ s^{-1}$)

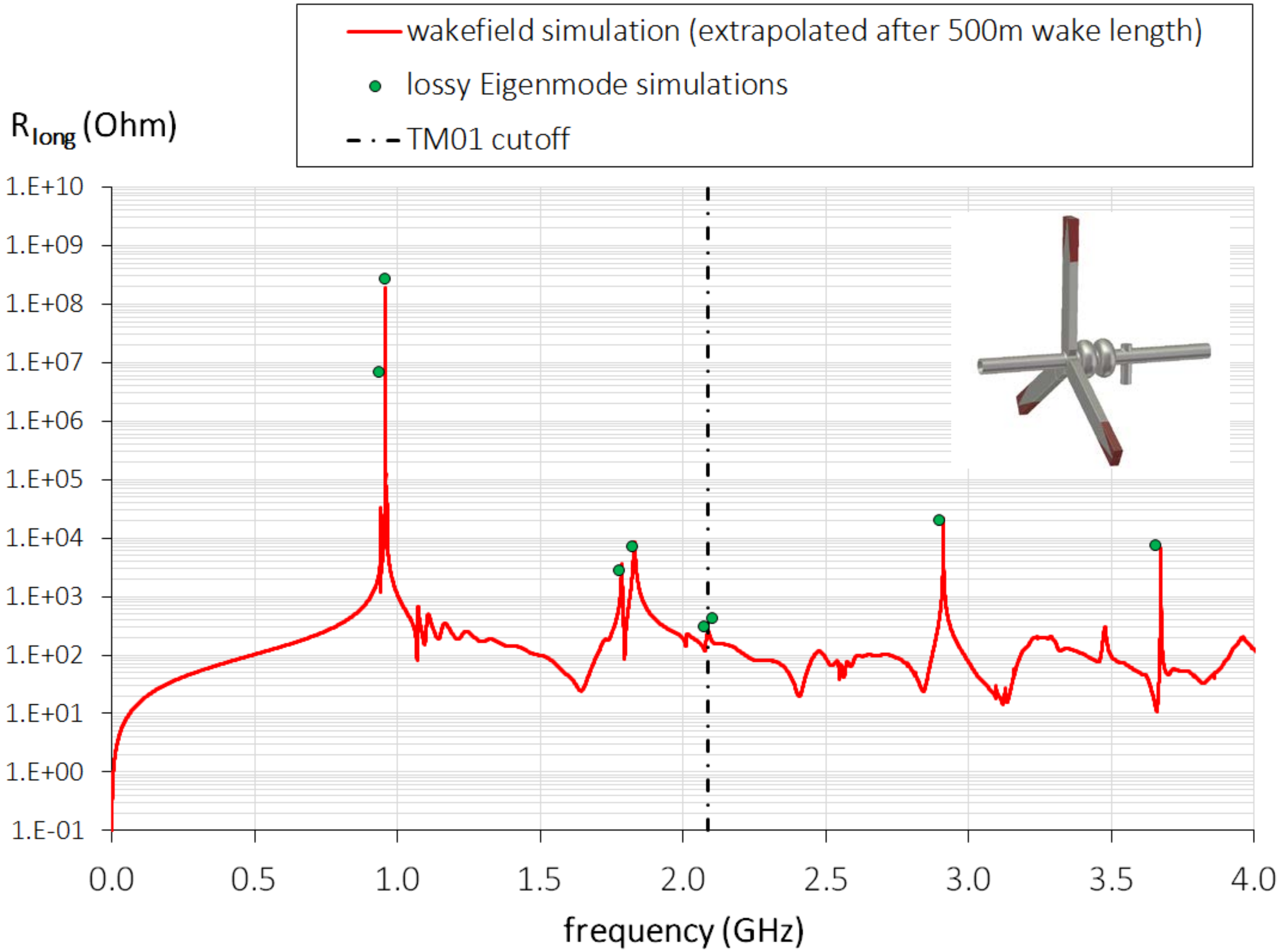
Introduction

- To improve the damping, the coaxial couplers have been replaced with waveguide couplers

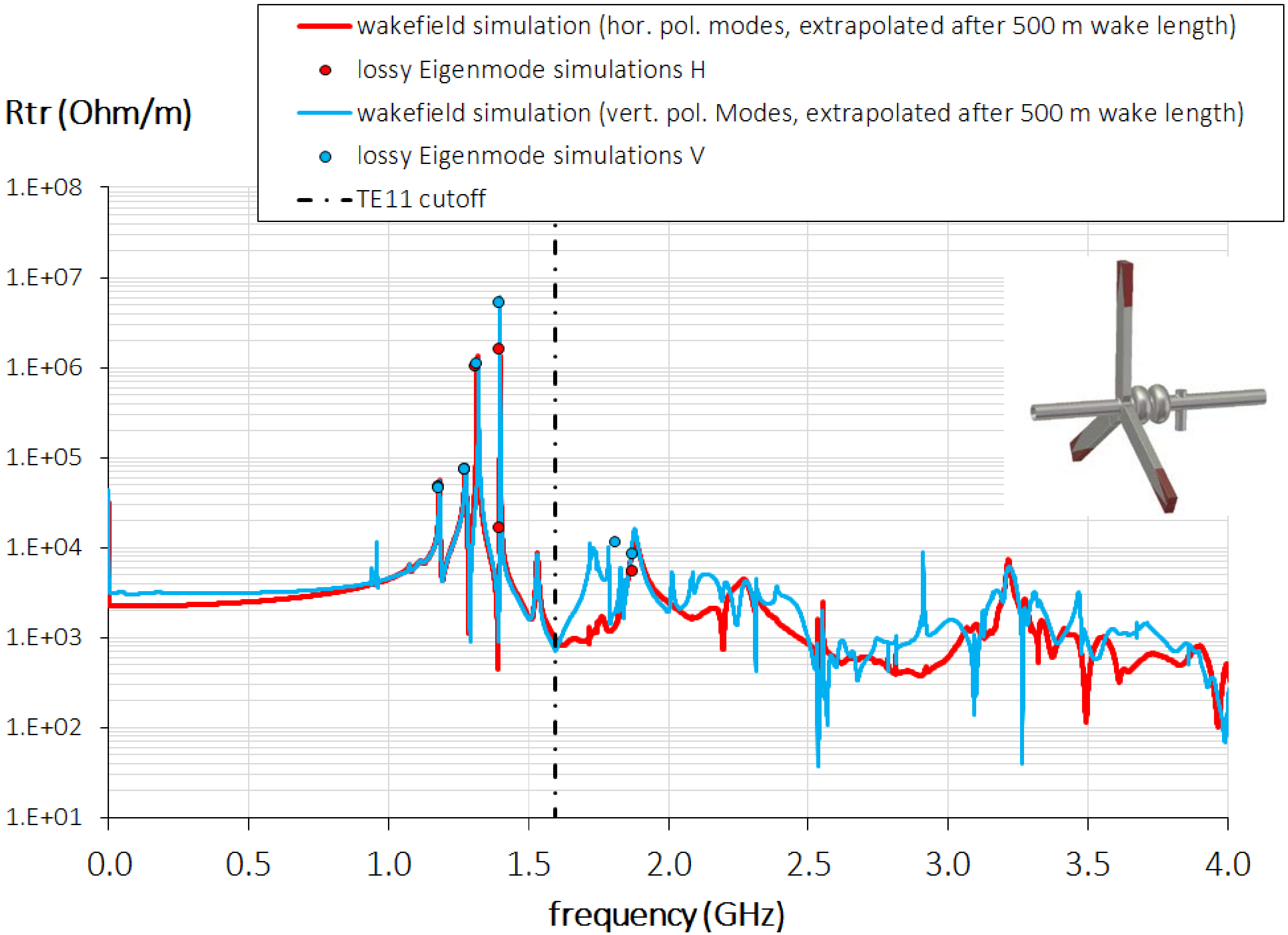


Two-cell 952.6 MHz cavity

Monopole Impedance Spectrum



Dipole Impedance Spectrum



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Longitudinal HOMs for Ion Ring RF Cavities

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2.8948	3.63	9.17E+03	3.33E+04
3.0794	0.01	2.65E+04	2.23E+02

frequency	R/Q on axis (EU definition)	External Q	R_{long} (EU definition)
GHz	Ohm		Ohm
0.9346	2.374	2.98E+06	7.07E+06
0.9526	100.246	2.84E+06	2.85E+08
1.7745	**4.480**	6.60E+02	**2.96E+03**
1.7890	0.119	5.27E+03	6.25E+02
1.8185	**18.382**	4.02E+02	**7.39E+03**
1.9991	0.268	2.98E+02	7.98E+01
2.0986	2.684	1.61E+02	4.32E+02
2.1024	3.658	4.82E+01	1.76E+02
2.8938	0.998	2.22E+02	2.21E+02
2.8949	3.295	6.21E+03	2.05E+04
3.6530	0.238	3.22E+04	7.66E+03

- With the cavity using waveguide dampers, the driving LCBI mode impedance has been damped by ~1 order of magnitude
- The neighboring mode with the highest monopole impedance had been damped by more than 1 order of magnitude → now the HOM at ~2.9 GHz has the highest impedance of ~2e4 Ohm (apart from the TM_{010} LOM), which is ~38% lower than before (3.3e4 Ohm)

Backup Slides for more Info

Proposal

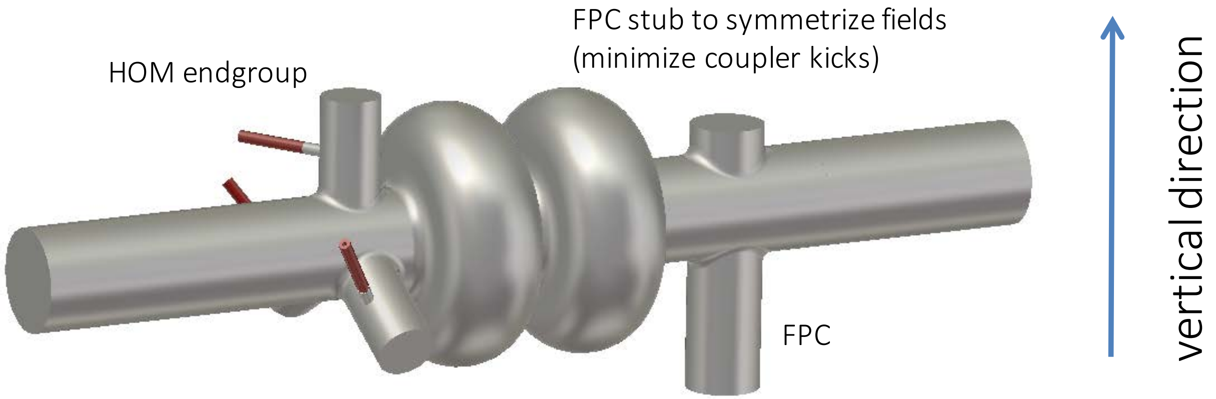
- JLEIC ion ring cavities likely require less severe damping than JLEIC electron ring
- Therefore we conceive two-cell cavities instead of single-cell cavities
- One HOM-endgroup with 3 couplers equally distributed by 120 deg. C in azimuth is conceived to couple well to both polarization of transverse modes
  - This mitigates polarization-dependent HOM damping, e.g. seen in cavities with 2 couplers per endgroup
- The fundamental input coupler (FPC) attached to the cavity side opposite to the HOM endgroup may contribute to the HOM-damping

Some Definitions

- Wakefield calculations deliver the broad coupling impedance in a single calculation
  - One calculation for longitudinal and one for transverse (here dipole) modes (can be two for the dipole modes if both mode polarizations are investigated)
  - Each wakefield calculation must be truncated after a user-defined time, which might leave the impedance of high-Q modes unresolved (RF fields are still ringing in cavity)
  - Therefore the impedance spectrum is extrapolated analytically, which improves the accuracy
  - The impedance spectrum is also normalized by the bunch spectrum as used in the calculation
- Eigenmode calculations have been carried out for the most relevant modes
  - Despite verification of the wakefield calculation, the Eigenmode calculations delivers both the R/Q and external Qs (=loaded Qs, no wall losses assumed) for each mode, which are needed for BBU studies
- Note that the characteristic cavity impedance R/Q and thus beam-induced impedance ($R/Q \cdot Q_{ext}$) used is according to the circuit definition (EU definition) ($R/Q = U_{eff}^2/(2 \cdot Q \cdot P_{avg})$), which is half of the value per US definition ($R/Q = U_{eff}^2/(Q \cdot P_{avg}) = U_{eff}^2/(\omega \cdot W)$). The latter is calculated by the Eigenmode solver (by default)
- The R/Q of transverse modes depends on the off-set (r) of the beam from the cavity axis
  - For dipole modes the characteristic cavity impedance R/Q scales quadratically with r^2
  - Per Panofsky-Wenzel theorem, the longitudinal impedance (R/Q_{long}) equals the transverse impedance (R/Q_{tr}) at an offset $r = 1/k = \omega / c_0$
  - We normalize the transverse R/Q according to $R/Q_{tr} = R/Q_{long}(r)/(k \cdot r^2)$, which then is a constant (except singularity at origin) and yields units of Ω/m, ditto for the impedance ($R_{tr} = R/Q_{tr} \cdot Q_{ext}$)
  - This impedance is used when plotting dipole mode impedance spectra

1st Design

- In the 1st design the HOM endgroup consists of three scaled JLab-type coaxial couplers, i.e. scaled uniformly to meet the proper beam tube diameter (ID = 110 mm)
- The orientation of the coupler hooks inside the HOM cans is according to the C100 cavities, which however is not an optimum orientation for most-efficient HOM-damping
- Option I: One may improve the broadband damping by using TESLA-type coaxial couplers instead (to be investigated)
- Option II: The use of three waveguide couplers instead of coaxial couplers (like JLab High Current cavity design) provides better HOM power handling without the need of a fundamental mode rejection filter (to be investigated)
- Other options may be considered depending on needs and requirement and



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