Damping Effect Studies for X-band Normal Conducting Standing Wave Structures

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Outline

Part I (Omega3P)

- Introduction
- X-band iris slot structure
- X-band choke mode structure
- X-band waveguide damped structure
- Conclusions

Part II

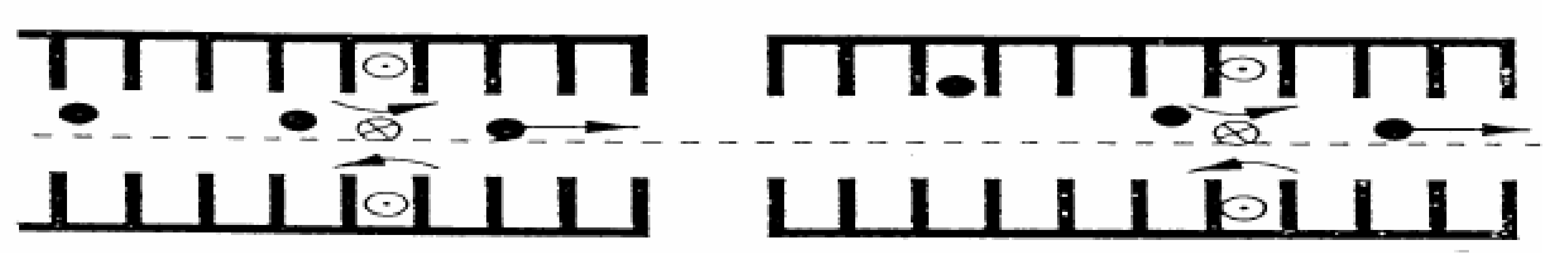
- RF-thermal effect in TTFIII coupler (S3P, ANSYS)
- Wakefield in S-band TW structure (MAFIA, ABCI)

Introduction

• Multi-TeV colliders should have the capability to accelerate low emmittance beam with high rf efficiency.

• X-band NC HG structure is one of the promising candidates.

• The structures must be efficient in acceleration and effective in damping the high order dipole mode (maintain transverse beam stability for multi-bunch operation).



• Long range transverse wake field need to be addressed in the structure design process.

Introduction

$$W_z(s) = \sum_n 2k_{0n} e^{-\frac{\omega_{mn} s}{2Q_{mn}\beta c}} \cos\left(\frac{\omega_{mn} s}{\beta c}\right) \qquad s \geq 0$$

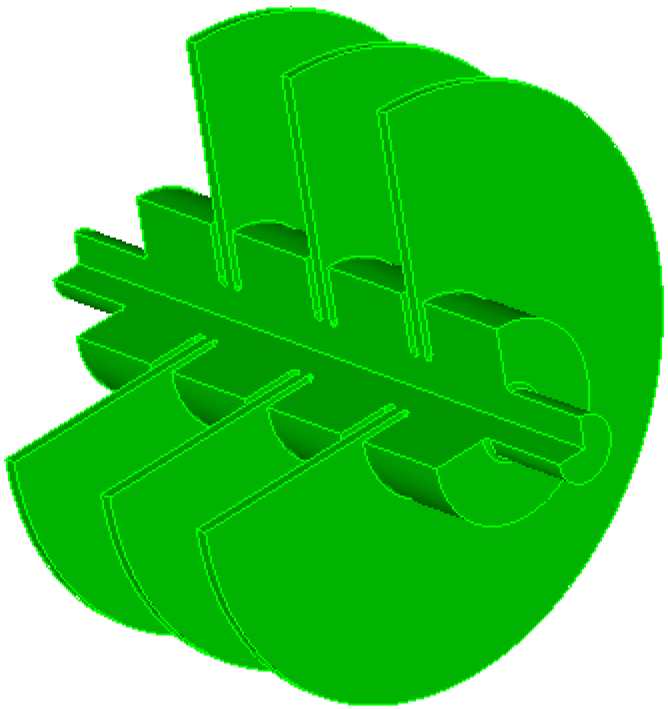
$$\vec{W}_\perp(s) = \hat{r}\left(\frac{r'}{a}\right)\sum_n 2\frac{\beta c k_{1n}}{a\omega_{1n}} e^{-\frac{\omega_{1n} s}{2Q_{1n}\beta c}} \sin\left(\frac{\omega_{1n} s}{\beta c}\right) \qquad s \geq 0$$

- For X-band structure with Qext<20, the dipole mode can be damped to ~25% at the 8th and <1% at the 16th RF period.
- With introduction of detuning effect, dipole mode can be further suppressed, which will ease the multi-bunch operation.

- Dipole mode damping in three kinds of X-band, π-mode SW structures were studied (iris slot structure, choke mode and waveguide damped structure) with Omega3P. We try to optimize the structure to let Qext<20 in the first several dipole bands. Damping effect on acceleration mode is also discussed.

Iris slot structure

- Initial idea is to feed power into each cell directly from one of four feeds to reach very high working gradient, so we pick 4 cell structure in our study.
- A slot is located in the center of each iris, which splits each iris into two parts.
- A HOM load made from a cylindrical absorber is located at the outer radius of the slot.



Effect on acceleration mode

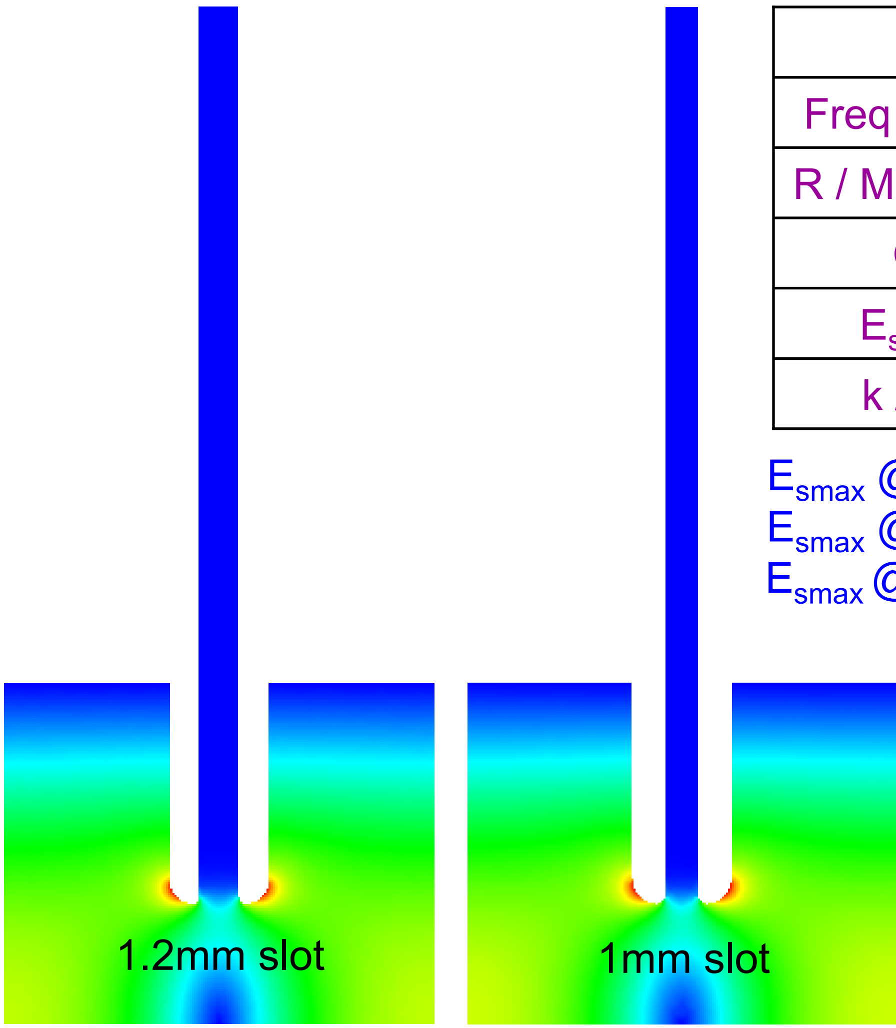
Regular Cell

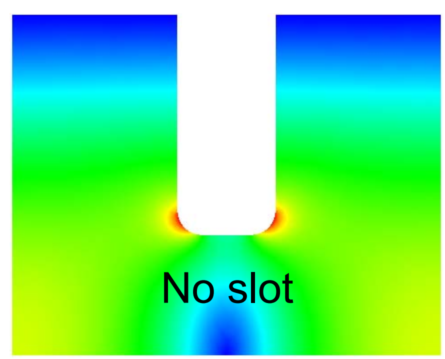
Slot has little effect on acceleration mode.

Iris thickness: 3mm
Length of 1 period: 13.12mm

	No slot	1mm slot	1.2mm slot
Freq / MHz	11423.87	11423.70	11423.68
R / Mohm/m	87.24	86.42	86.45
Q	8327	8328	8325
E_s/E_a	2.665	2.683	2.739
k / %	0.9557	1.0466	1.0533

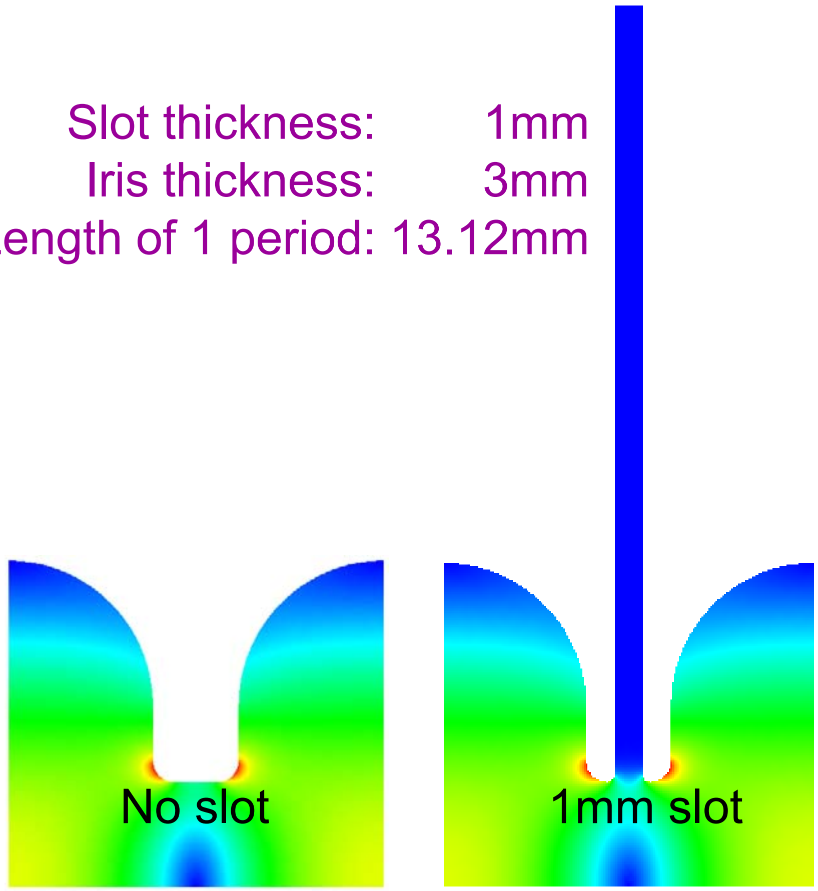
E_{smax} @ (1.9819e-04, 4.2491e-03, 5.0795e-03) (L)
E_{smax} @ (1.5699e-03, 3.8603e-03, 8.0148e-03) (M)
E_{smax} @ (4.9067e-04, 4.0822e-03, 8.0091e-03) (R)





Cell shape optimization

Slot thickness: 1mm
Iris thickness: 3mm
Length of 1 period: 13.12mm



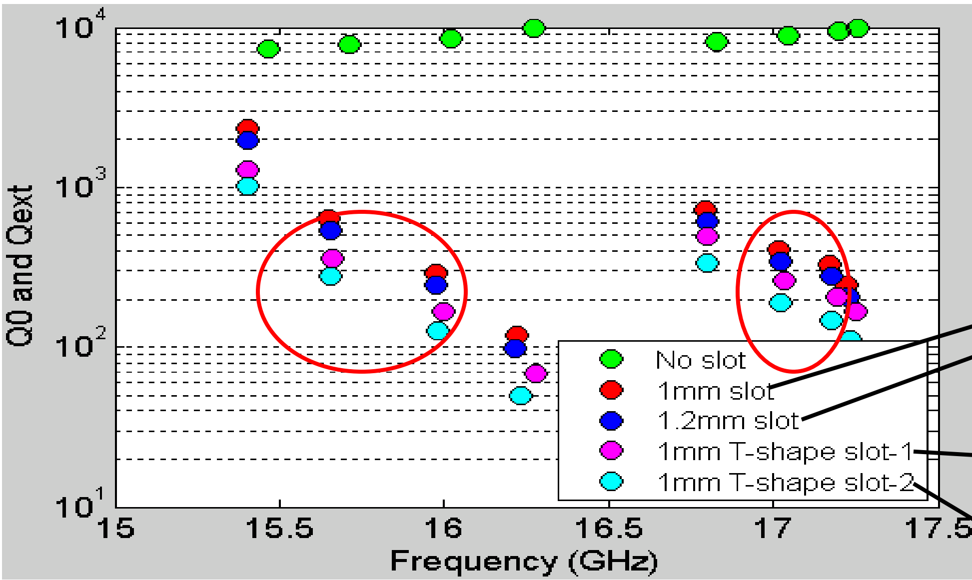
Regular Cell

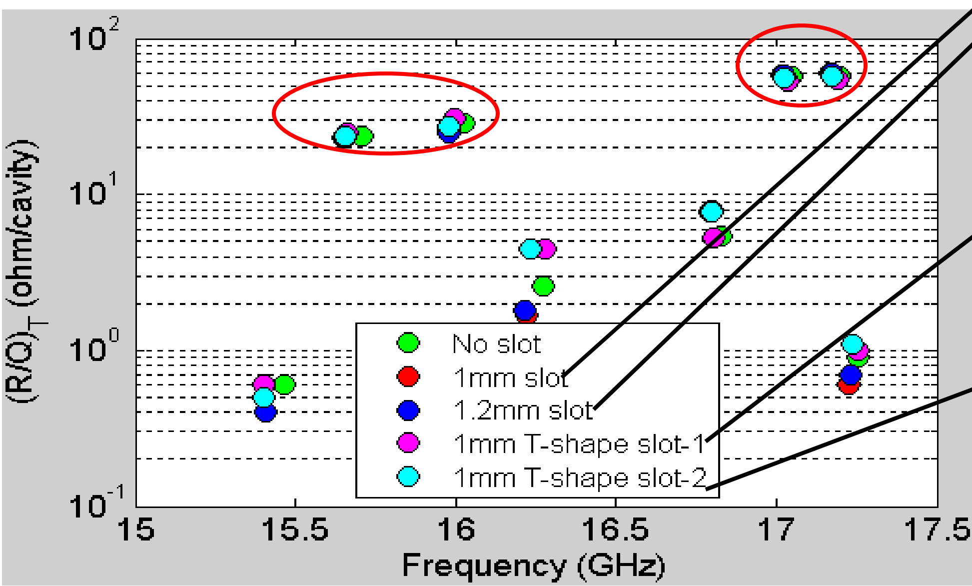
One way to further increase impedance.

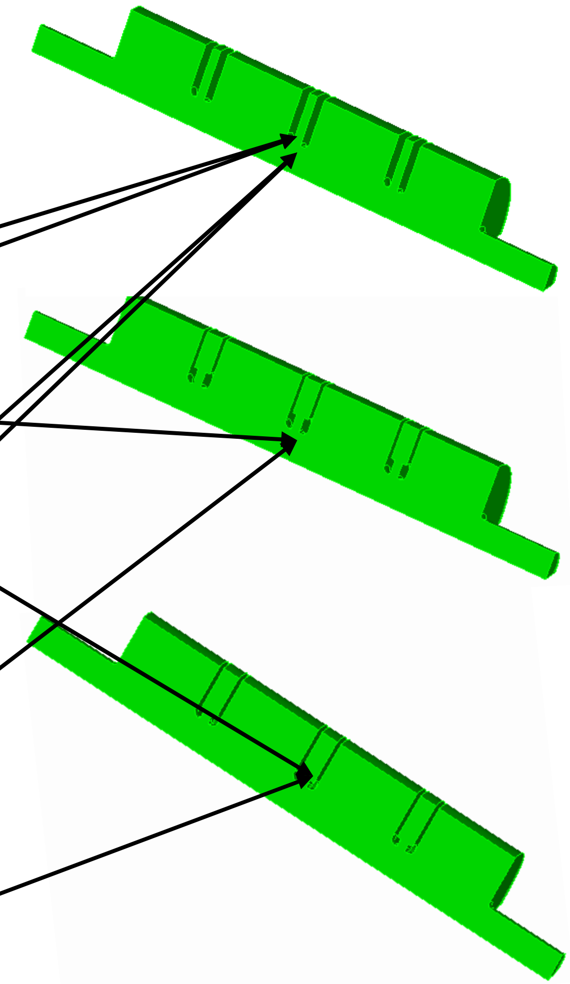
	No slot	With slot
Freq / MHz	11423.84	11423.74
R / Mohm/m	97.28	96.39
Q	9521.69	9523.13
Es/Ea	2.607	2.634
k / %	0.9142	1.0014

Esmax @ (1.9404e-04, 4.1523e-03, 8.0109e-03) (L)
Esmax @ (5.0545e-04, 4.0949e-03, 7.9984e-03) (R)

Dipole mode damping



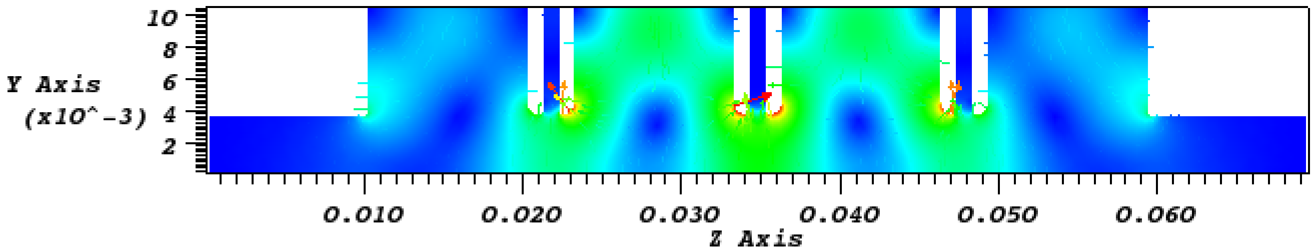




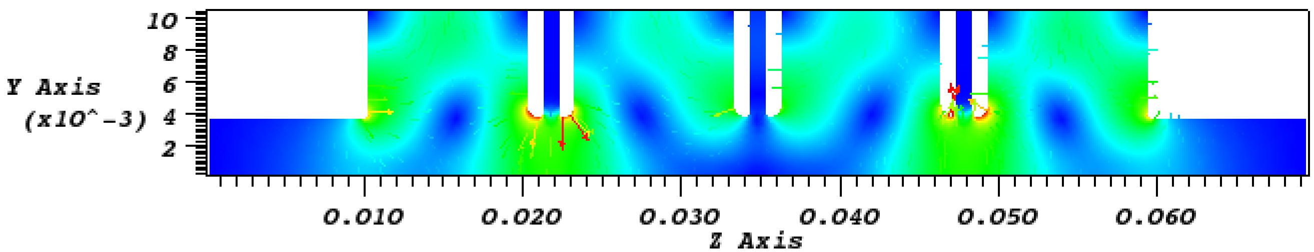
$(R/Q)_T$ is calculated at transverse offset 3mm with unit Ohm/cavity.

3rd dipole band

Dipole mode 3rd band TM111
With 1mm slots for 4-cell structure

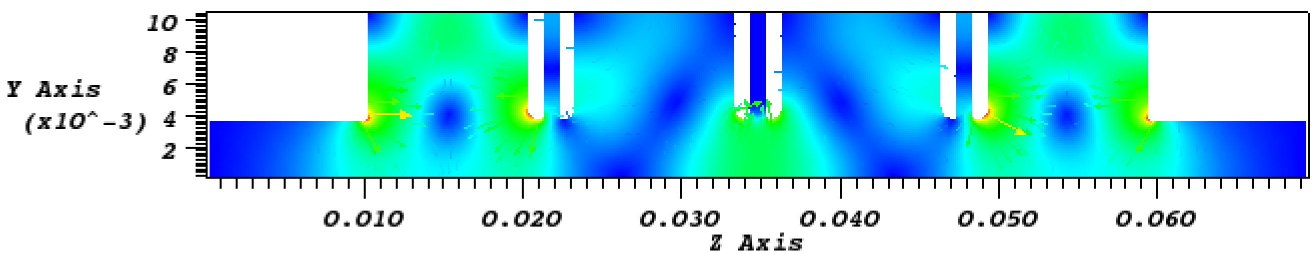


20945.63MHz
Q0: 6033.37
Qext: 9311.37
(R/Q)T=59.16

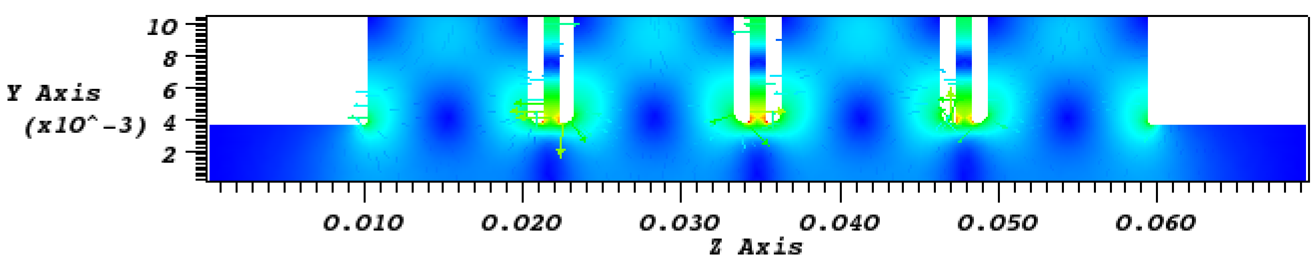


21194.28MHz
Q0: 6270.86
Qext: 1969.58
(R/Q)T=16.54

Not damped



21582.90MHz
Q0: 6578.54
Qext: 604.94
(R/Q)T=7.37



21969.83MHz
Q0: 7004.62
Qext: 214.60
(R/Q)T=0.54

Iris slot structure summary

Advantage

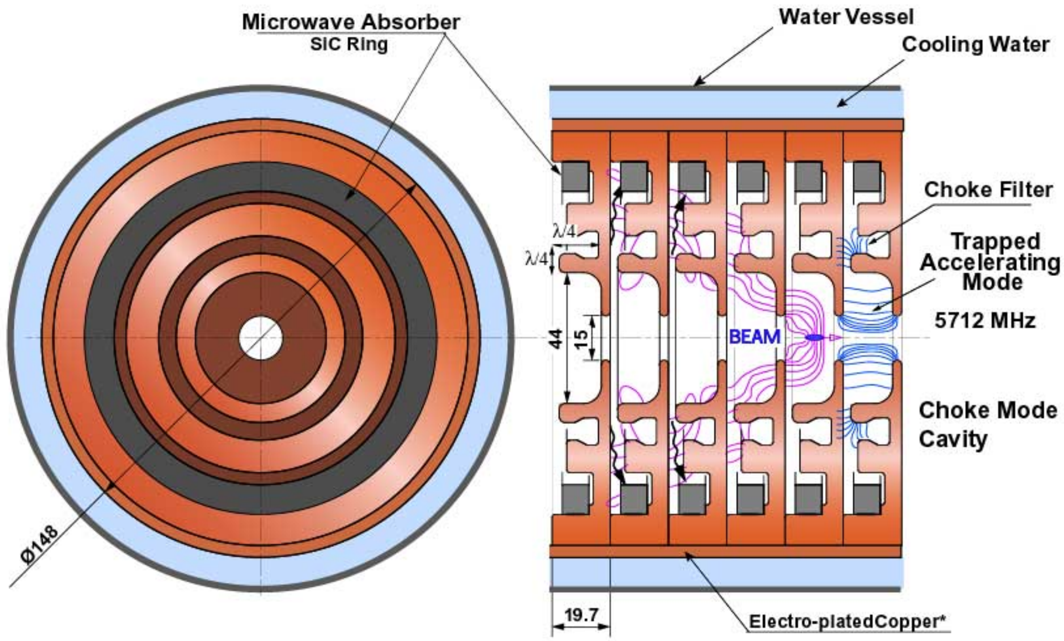
- Very small effect on the acceleration mode.
- Easy to feed power into every one cell from one of four feeds to reach very high gradient. Every one cell can have a power input coupler.

Disadvantage

- Dipole mode in the first two dipole bands can only be damped moderately, Qext is around 100-300.
- Particular mode in higher dipole band with relatively high (R/Q)T can not be damped well.

Need to look other damping schemes …

Choke mode structure

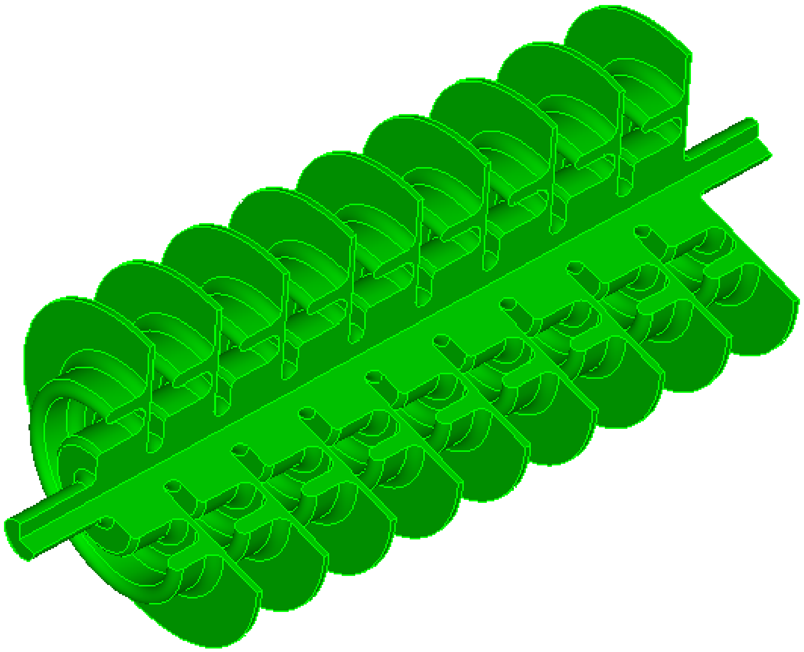


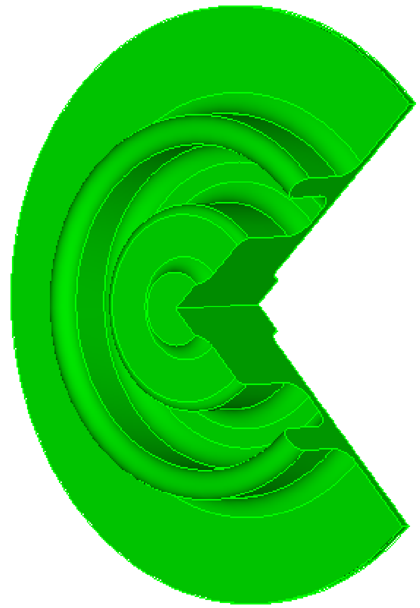
http://www-xfel.spring8.or.jp/cband/e/AccStructure.htm

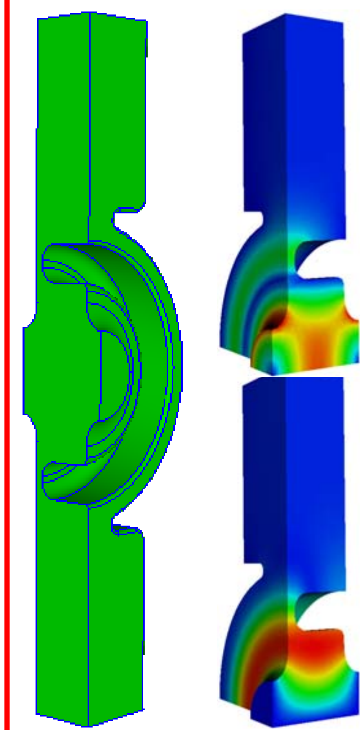
- Successfully demonstrated @ S-band and C-band traveling wave structures.
  - T. Shintake, Jpn. J. Appl. Phys. Vol. 31, Nov. 1992.
  - H. Matsumoto et al. EPAC 96, Jun. 1996.
- Dipole modes' Qext can be lower than 20.

Choke mode structure

In our study we pick 9 cell structure, the real case may be different.



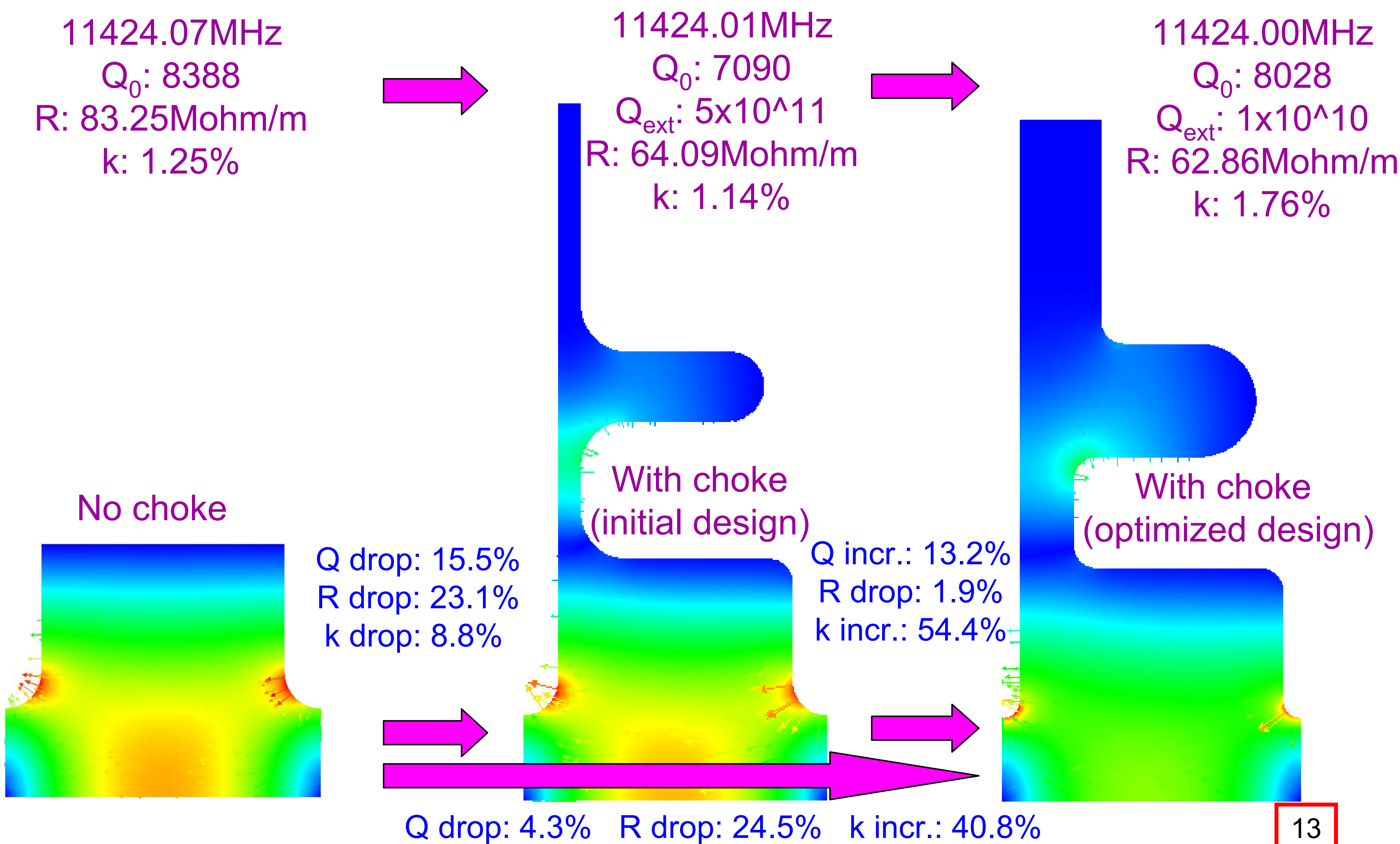




Three reasons to pick 9 cell:

- Impossible to feed each cell separately.
- Standing wave structure, which can not have too many cells as traveling wave structure.
- Enlightened by TESLA 9 cell superconducting cavity.

Effect on acceleration mode

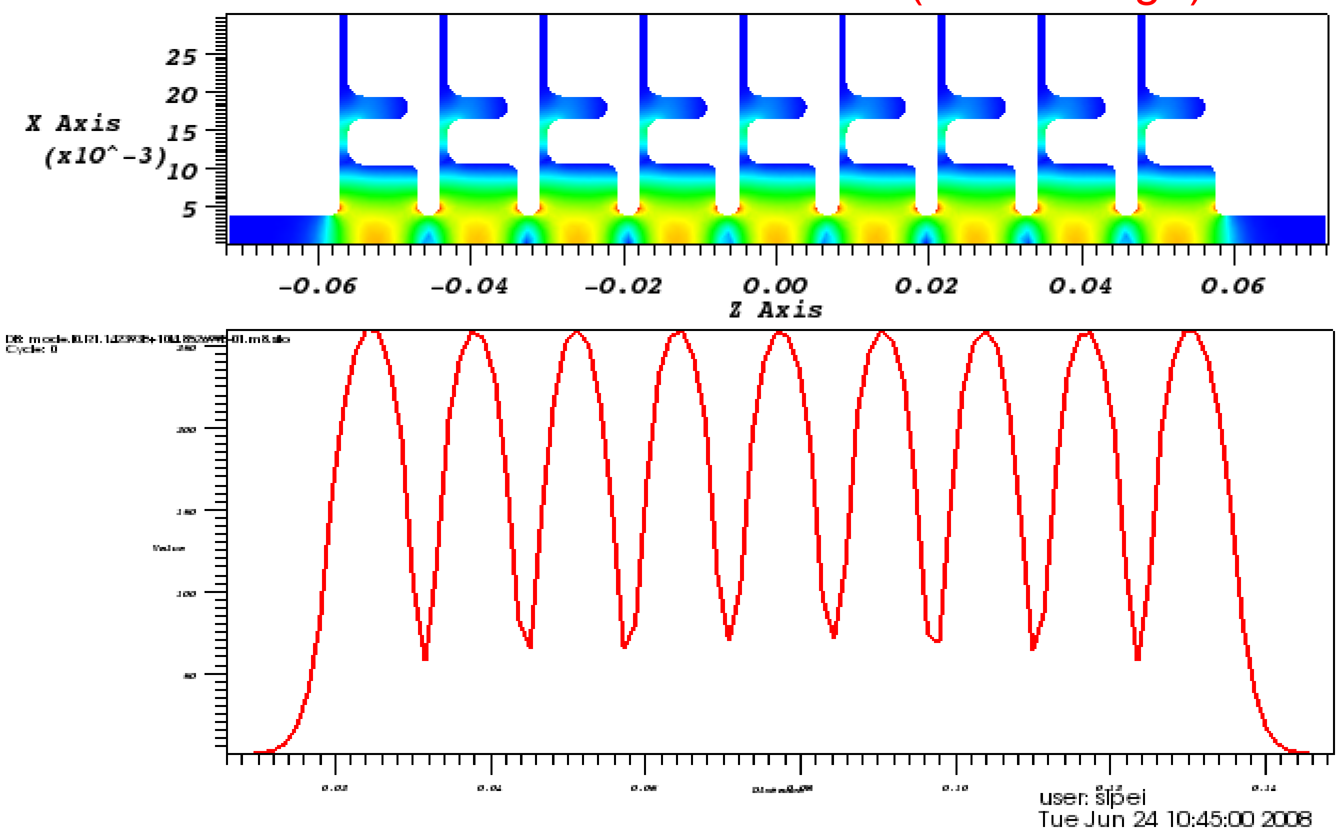


Effect on acceleration mode

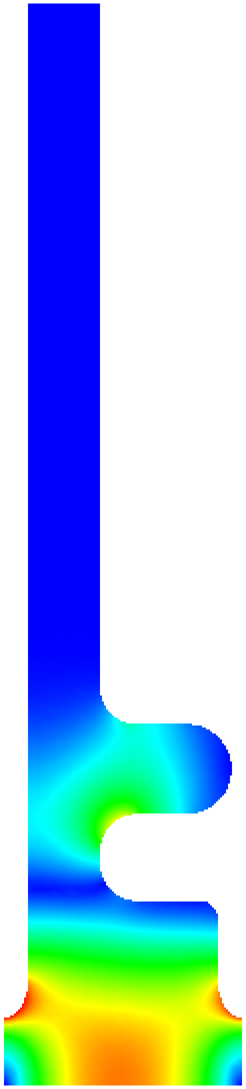
Due to the nonsymmetrical feature of the choke mode structure, in order to get one flat axis electric field pattern, the left and right end cells need to have different dimensions.

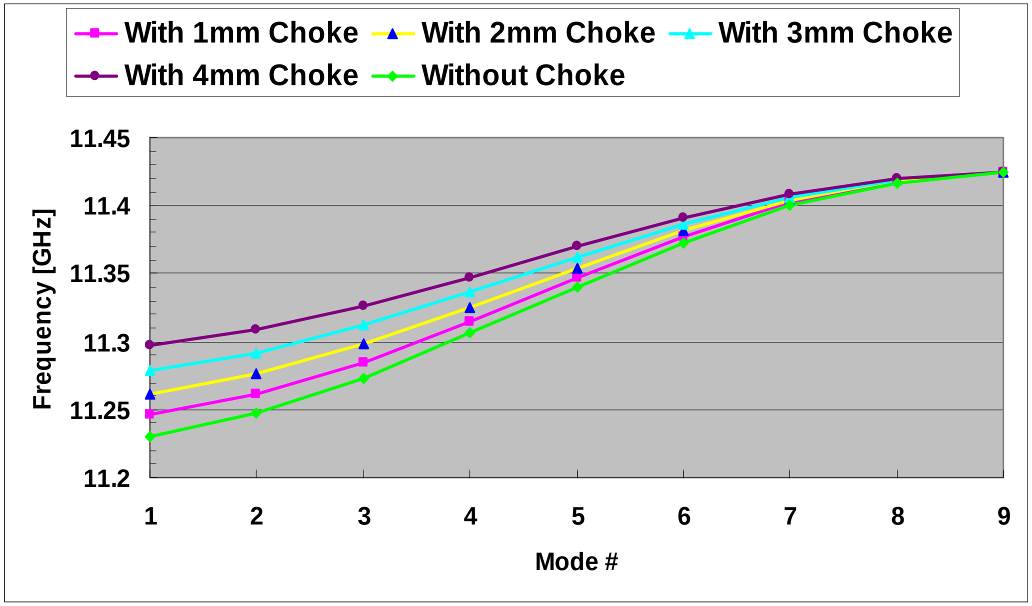
11423.93MHz, Q_0: 7081, Q_{ext}: 1.2x10^10, R_{eff}: 64.14Mohm/m

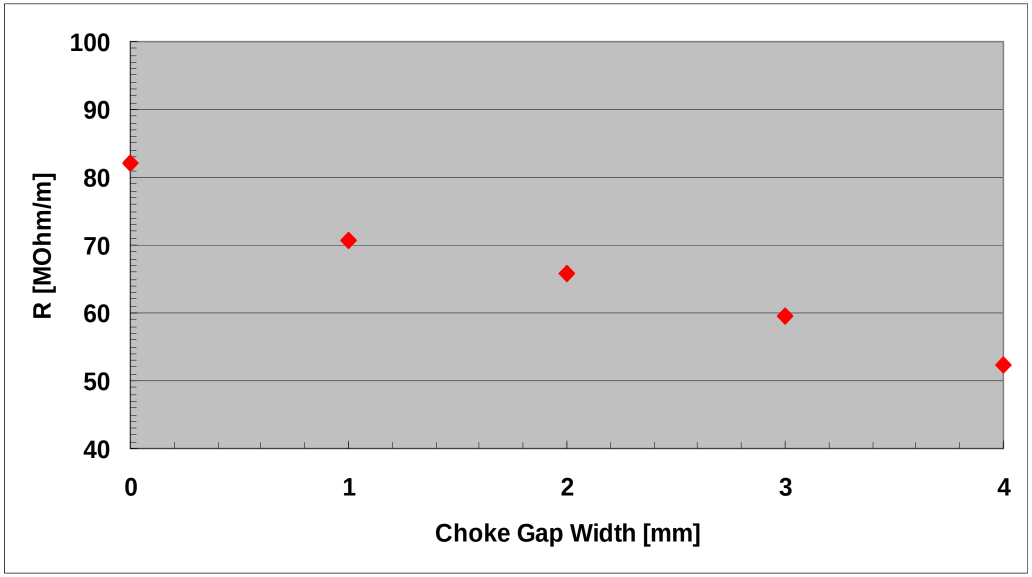
9cell choke mode structure (initial design)



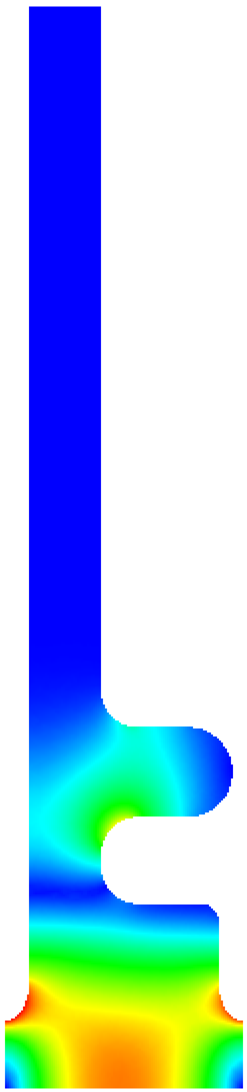
Effect on acceleration mode

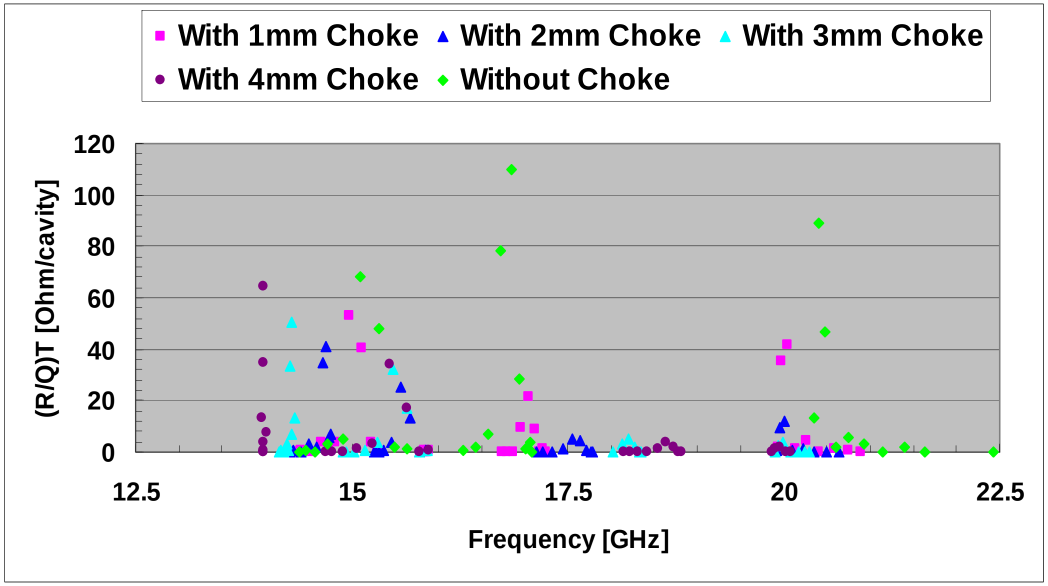


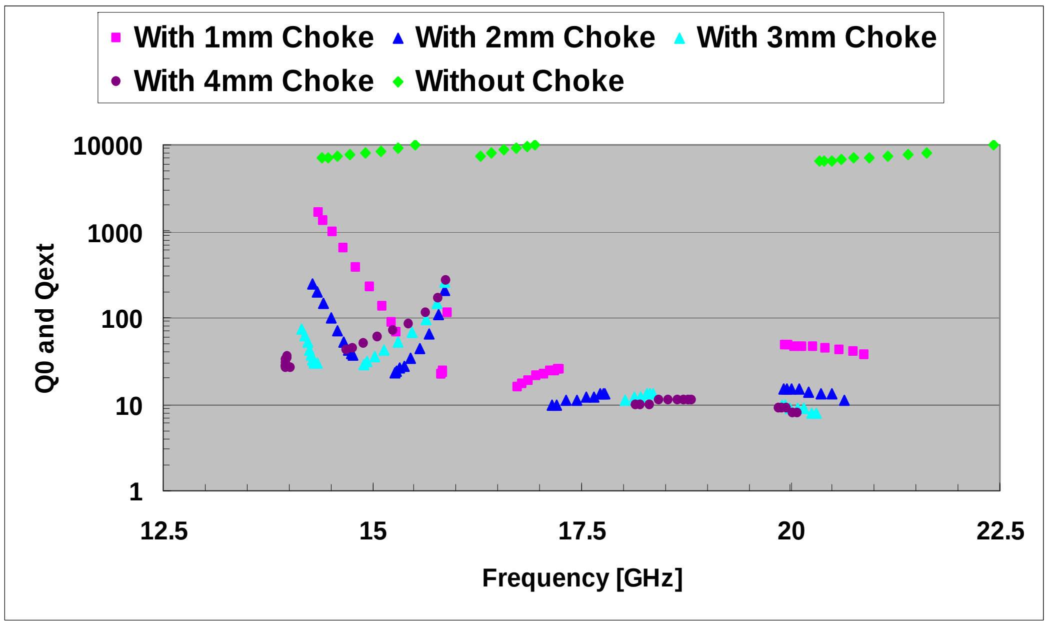




Choke gap effect on dipole mode



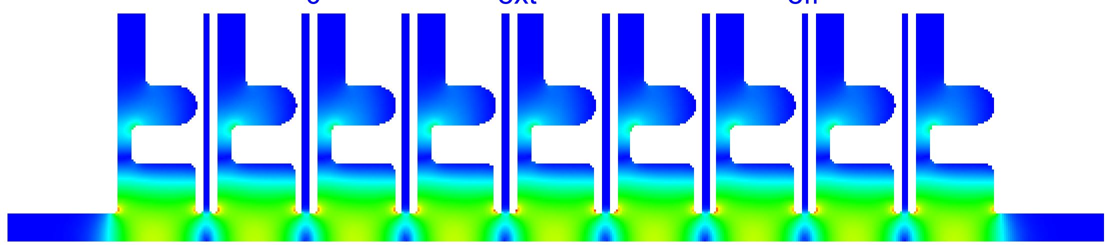


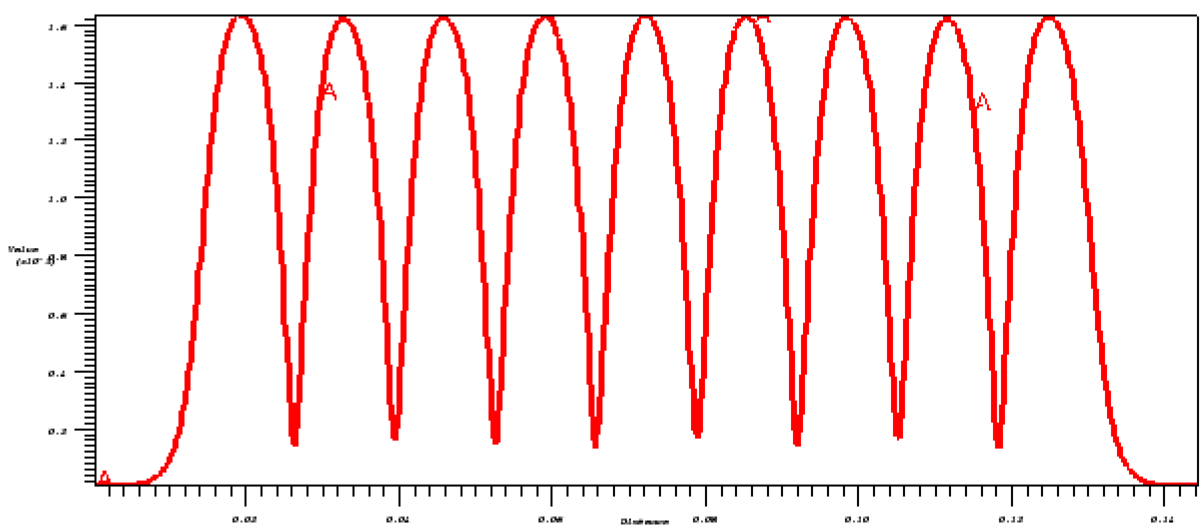


Iris and choke hybrid structure

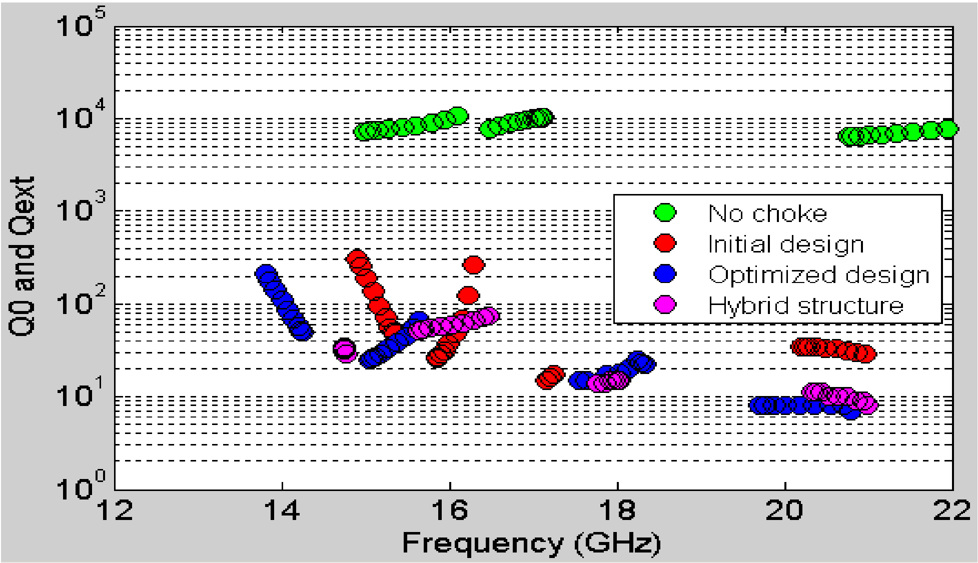
Besides the “iris slot” and “choke mode” structure, the hybrid structure with both “iris slot” and “choke” was also studied.

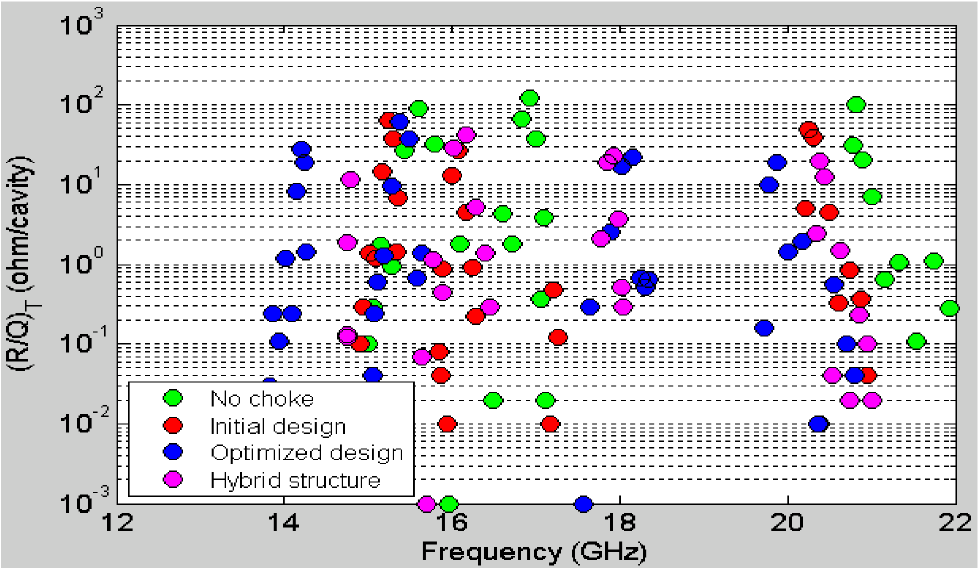
11423.60MHz, Q_0: 7220, Q_{ext}: 1.4x10^6, R_{eff}: 62.99Mohm/m





Dipole mode damping





Modes in the first 3 dipole bands are shown, but the non-symmetric feature of the structure results in redundant modes.

In general, hybrid structure has lowest dipole modes' Qext. However, there is no much benefit because of complexity to fabricate than choke mode structure, and the Q_{ext} of acceleration mode is also the lowest.

Choke mode structure summary

Advantage

- Nearly all dipole modes can be damped well.
- No RF heat concentration at any location, gradient may not limited by pulse heating.
- Qext of dipole mode is ~30-70, still relatively higher.

Disadvantage

- Accelerating mode's performance is deteriorated.
- Choke filter may reflect some dipole modes to the accelerating cell, which will affect the beam orbit.
- Load need to be optimized to absorb dipole modes.
- Hard to fabricate due to the complicated shape.

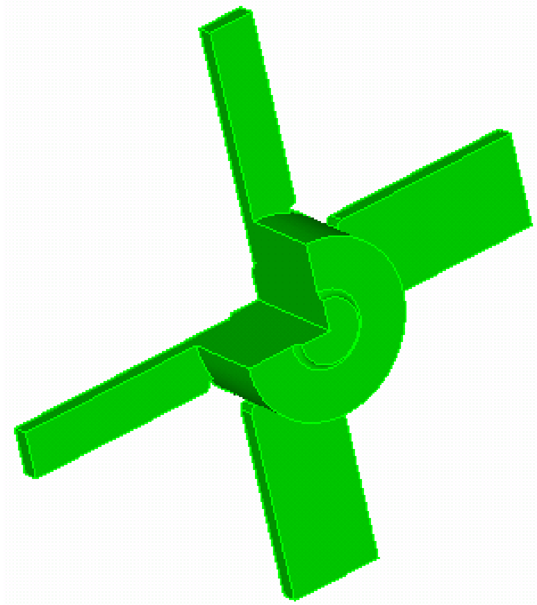
Still need to look other damping schemes …

Waveguide damped structure

Successfully demonstrated by CLIC for traveling wave structure.

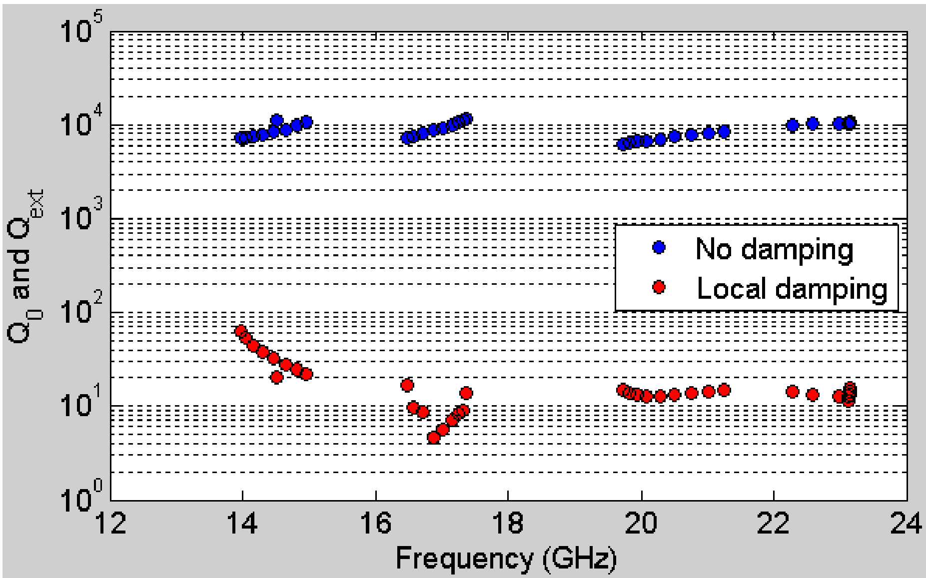
π -mode in single cell with 1.5 mm iris thickness

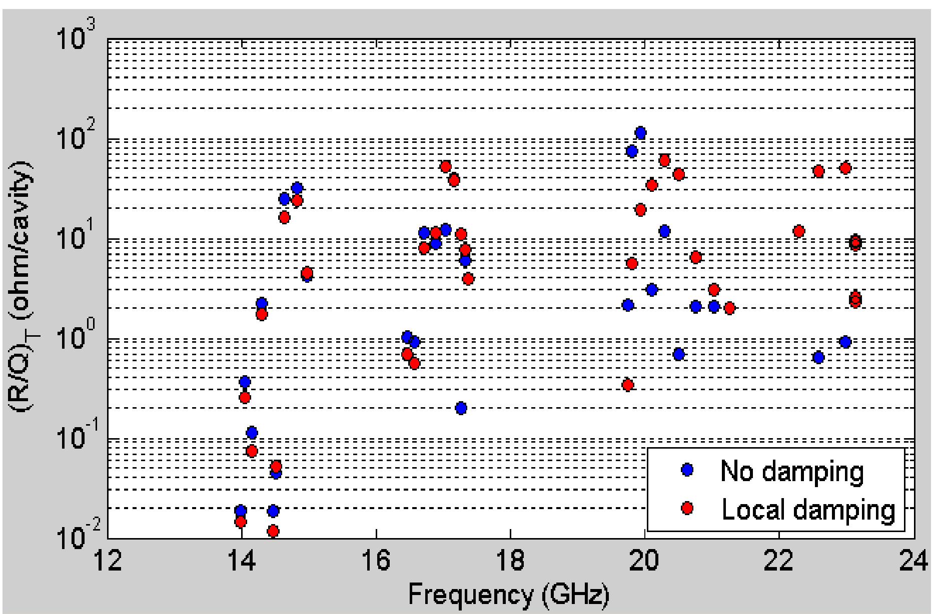
	No damping	Local damping
Freq. / MHz	11424.16	11424.02
R / MΩ/m	87.01	61.05
Q_0	8921	6636
k / %	2.16%	2.07%



Here the waveguide and coupling iris used are 11mm×2mm and 9mm×2mm, respectively. Shunt impedance and Q_0 of are reduced by 30% and 25%, which can be recovered to some extent by further optimization.

Dipole mode damping





Modes in the first 4 dipole bands are shown.

All of the dipole modes in the 2nd to 4th bands have Q_{ext} lower than 20. For the dipole modes with high (R/Q)T in the 1st band, Q_{ext}s are still lower than 30.

Waveguide damped structure summary

Advantage

- Nearly all dipole modes can be damped well.
- Qext of dipole mode is less than 30. Heavy damping can be achieved with proper design of iris openings.
- Load design is simpler to design and fabricate than iris slot structure and choke mode structure.

Disadvantage

- Accelerating mode's performance is deteriorated.
- Pulse heating around waveguide coupling irises may limit the structure performance.

Conclusions

- Three types of damping were studied without considering detuning.
- For iris slot structure, slot has little effect on the acceleration mode and the lowest Qext of dipole mode with high (R/Q)T is 100-300. Particular dipole modes in higher band with relatively high (R/Q)T can not be damped well.
- For choke mode structure, with reduction of acceleration mode's impedance by 25% and Q0 by 5-15%, Qext's of most dipole modes with high (R/Q)T are between 30 and 70, nearly all dipole modes can be damped well.

Conclusions

- Waveguide damped structure is the most promising one to reach Qext<20 for dipole modes, however the damping waveguide increases pulse heating temperature around the coupling irises between cavity and waveguides, which can be mitigated by optimizing the waveguide and coupling iris.
- To further suppress the dipole modes' effect on beam performance, detuning can be used as well.

RF-thermal effect in TTFIII Coupler

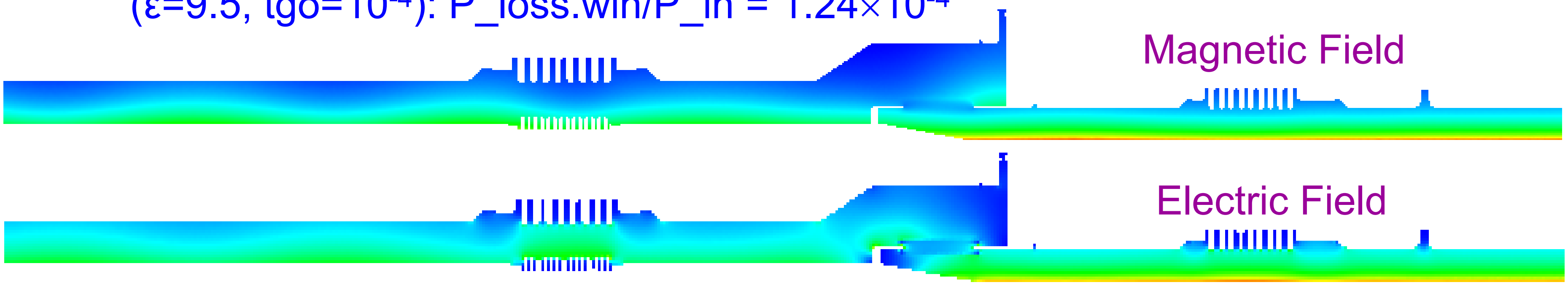
- The main RF power coupler is one key components of SC linac. It provides RF power to the cavity and interconnects different temperature layer (2K, 4K, 70K and 300K).
- TTFIII like coupler will be applied to Project-X @ average power 15kW (vs 2kW for ILC).
- In collaboration with FNAL, we need to redesign the copper coating on the warm inner conductor to rebalance the dynamic and static loads. Finally, we need to lower the temperature rise along this conductor.
- RF-thermal effect needs to be studied definitely.

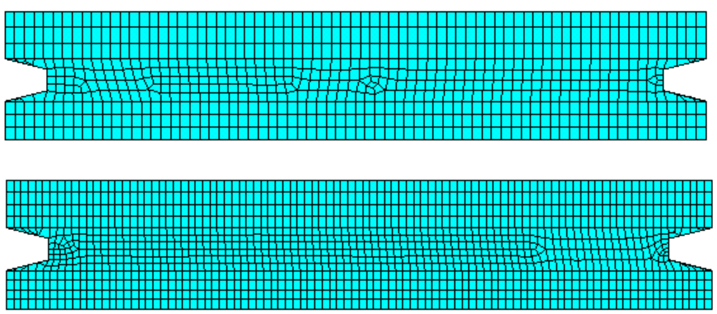
RF-thermal effect in TTFIII Coupler

Dielectric loss ratio to the input power

Power Losses in the 70K ceramic window
(ε=9.5, tgδ=10^{-4}): P_loss.win/P_in = 1.24×10^{-4}

S3P simulation





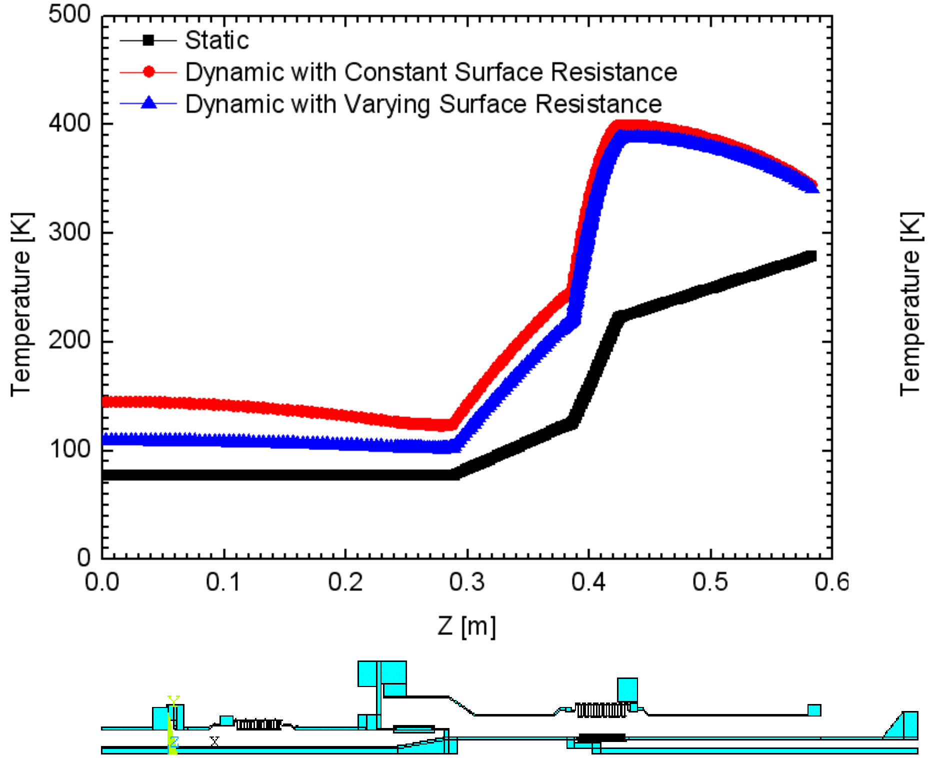
ANSYS Simulation

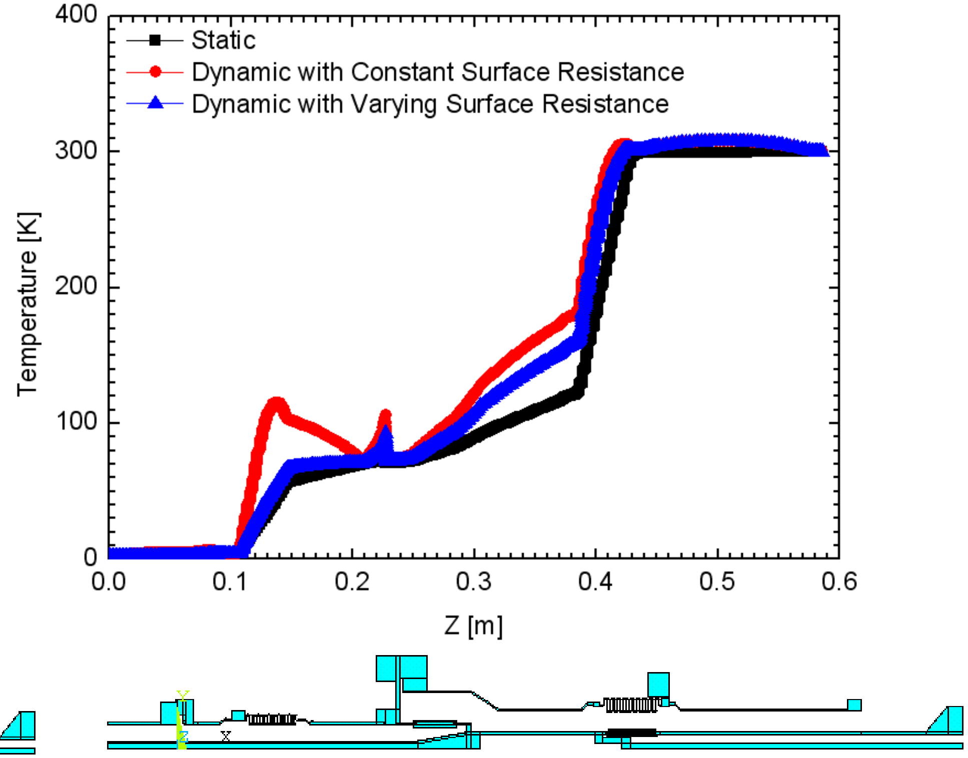
Power Losses in the 70K ceramic window
(ε=9, tgδ=10^{-4}): P_loss.win/P_in = 1.22×10^{-4}

RF-thermal effect in TTFIII Coupler

Temp. dist. for different RF loss calculation method

100μm on inner and 10μm on outer with RRR=100

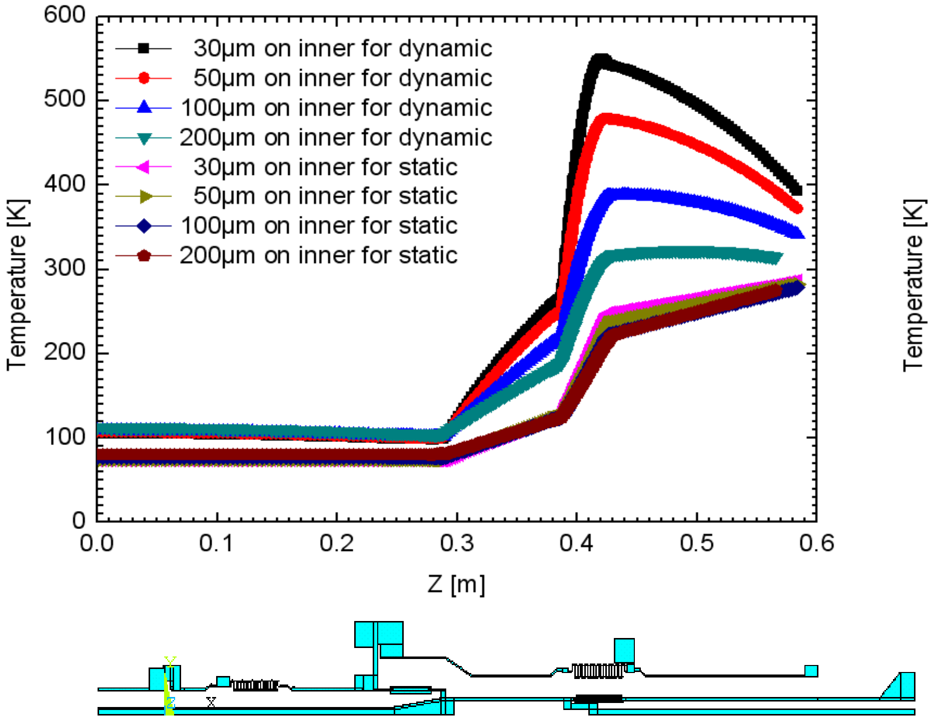


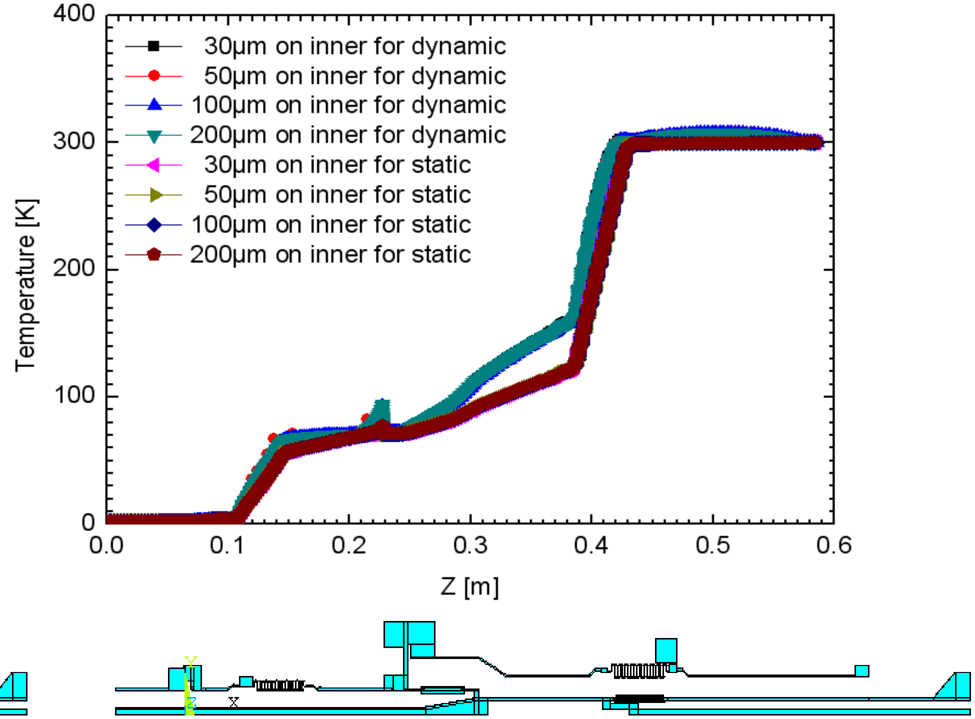


RF-thermal effect in TTFIII Coupler

Temp. dist. with different thickness of Cu coating

10μm on outer with RRR=100, resistance dependence on temperature considered

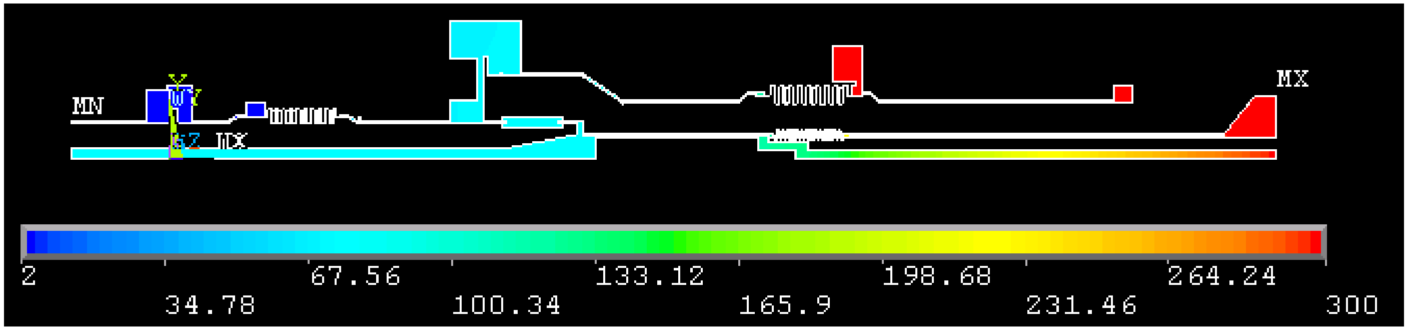




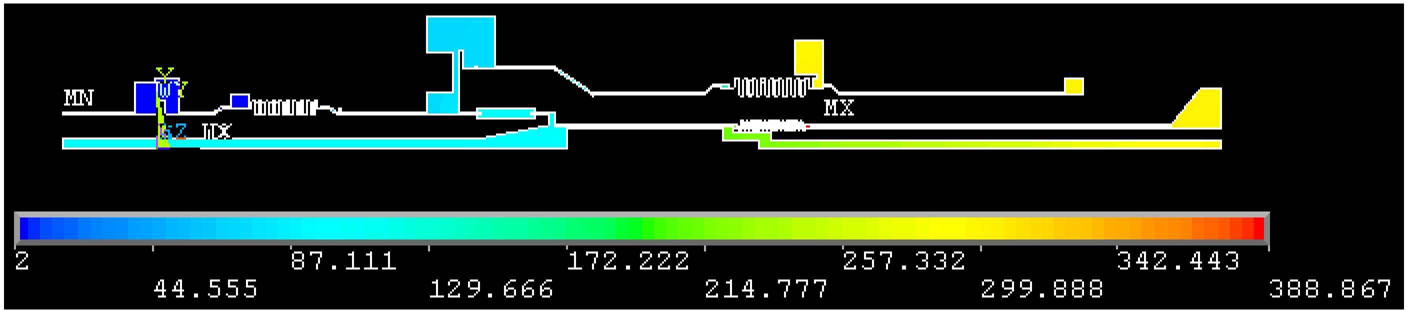
RF-thermal effect in TTFIII Coupler

Temp. dist. for 100μm on inner and 10μm on outer (RRR=100)

Static Case



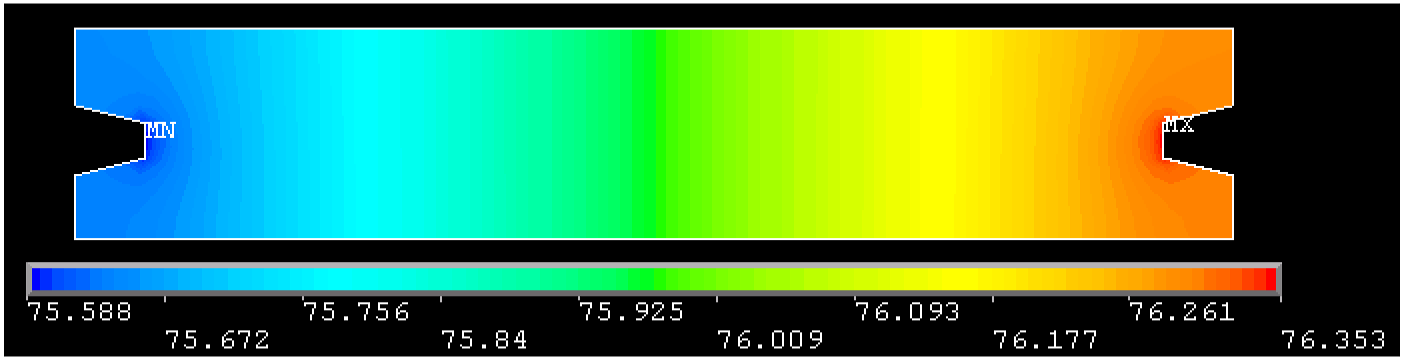
Static+dynamic case
Surface resistance dependence on temperature considered



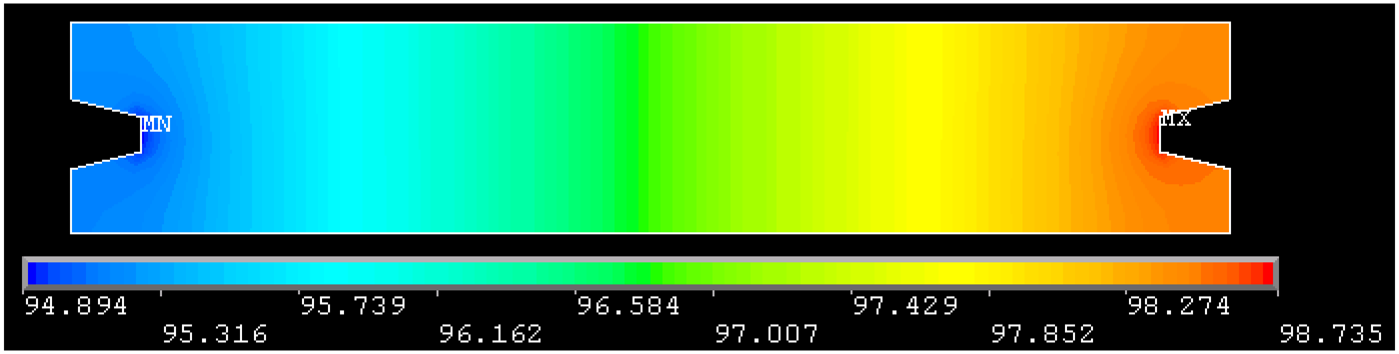
RF-thermal effect in TTFIII Coupler

Window temp. dist. for 100μm on inner and 10μm on outer (RRR=100)

Static Case



Static+dynamic case
Surface resistance dependence on temperature considered



RF-thermal effect in TTFIII Coupler

Power losses for Cu coating with different thickness and RRR=100

For dynamic case, surface resistance dependence on temperature was considered.

Cu Coating		Case	P	P	P_{in}	P_{out}	P_{win}	P_{total}	T_{max}, K
In	Out		2K	4K	70K				
30	10	ST	0.044	0.438	1.618	0.992	0	3.092	300
30		DYN+ST	0.252	0.747	9.929	3.856	1.801	16.585	550
50		ST	0.044	0.438	2.016	0.993	0	3.491	300
50		DYN+ST	0.252	0.747	10.510	3.844	1.799	17.152	479
100		ST	0.044	0.439	2.928	0.992	0	4.403	300
100		DYN+ST	0.252	0.747	11.381	3.811	1.796	17.987	388
200		ST	0.044	0.439	4.506	0.991	0	5.980	300
200		DYN+ST	0.253	0.750	12.565	3.825	1.808	19.201	323

RF-thermal effect in TTFIII Coupler

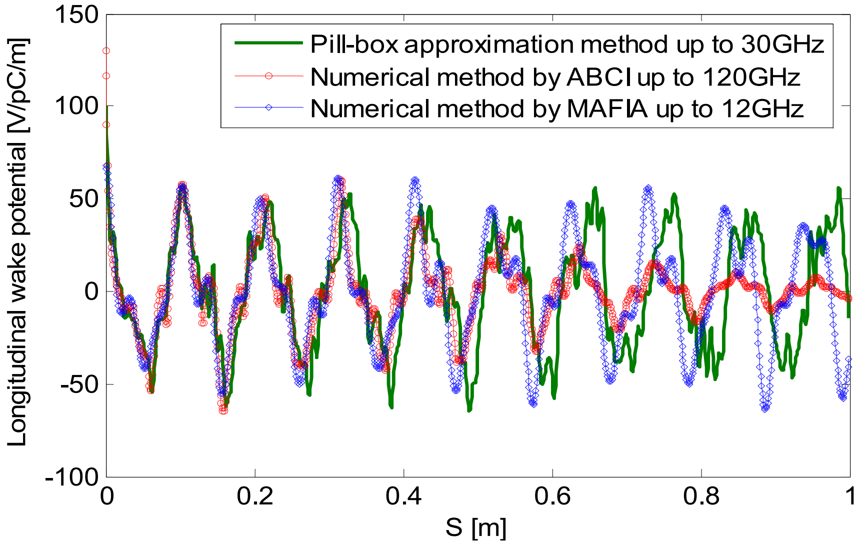
Summary

- RF-thermal effect on TTFIII power coupler for Cu coating with RRR=100 on inner conductor in range of 30-200 μm has been done.
- Increasing the Cu coating thickness will increase the static loads from 3.092W to 5.980W, so the total thermal loads increase from 16.585W to 19.201W. Dynamic loads stay almost constant.
- If tolerable temperature rise is ~150°, then ~100 μm Cu coating is OK.
- Air cooling of inner conductor in warm part of TTFIII coupler can significantly help (similar to Cornell ERL design).

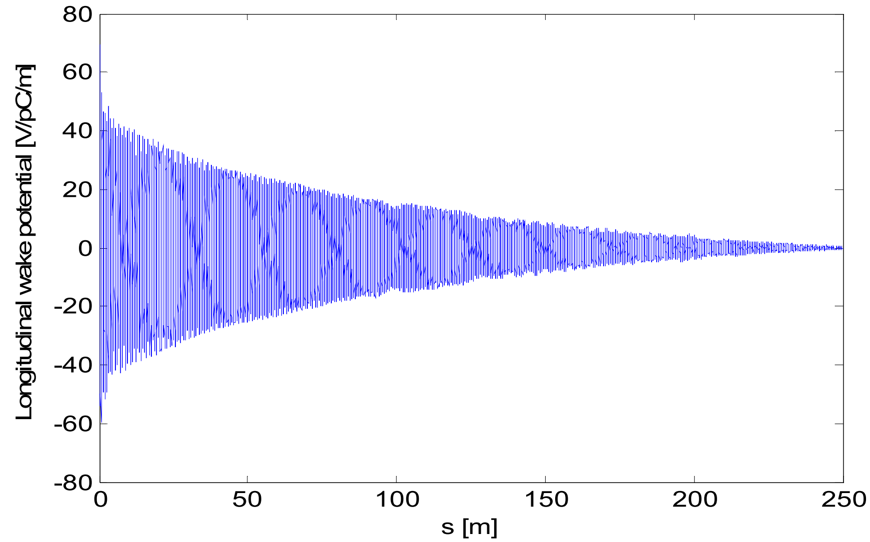
Wakefield in S-band TW structure

Long range longitudinal wakefield in disk loaded S-band traving wave constant gradient structure

S can be comparable with structure length *L*



S can be comparable with light speed multiply filling time cT_f



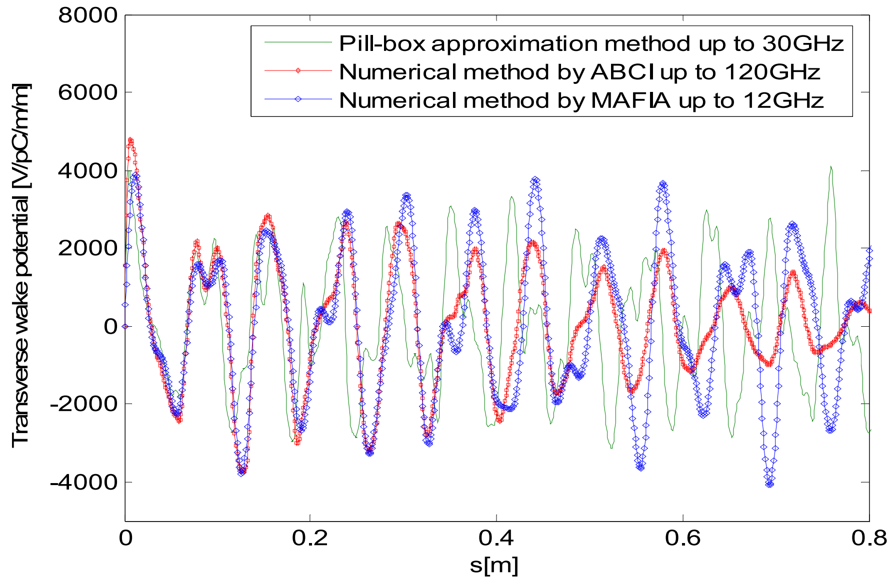
Group velocity effect need to be considered.

$$W_z(s) = 2k_{01}e^{-\frac{\omega_{01}s}{2Q_{01}\beta c}}\cos\left(\frac{\omega_{01}s}{\beta c}\right)\left(1-\frac{1-e^{\frac{2s\tau}{\beta cT_f}}}{1-e^{-2\tau}}\right)+\sum_{n>1}2k_{0n}e^{-\frac{\omega_{0n}s}{2Q_{0n}\beta c}}\cos\left(\frac{\omega_{0n}s}{\beta c}\right)$$

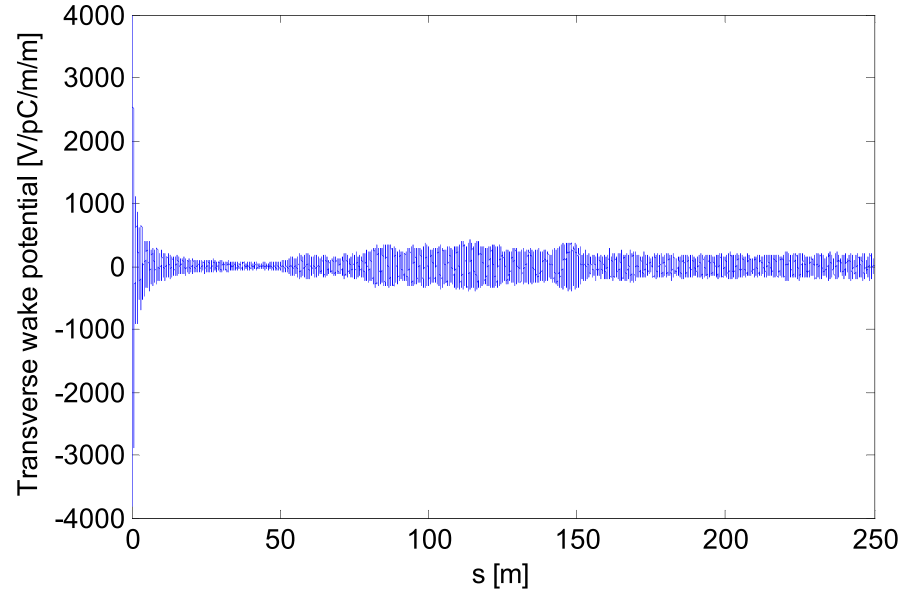
Wakefield in S-band TW structure

Long range transverse wakefield in disk loaded S-band traving wave constant gradient structure

S can be comparable with structure length *L*



S can be comparable with light speed multiply filling time cT_f



Group velocity effect need not to be considered due to the much larger detuning effect.

Thank you all for your attention!