HOM Damper of SRF Cavity for LEReC

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Outline

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- 704 MHz SRF booster cavity
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- Method to calculate wake potential
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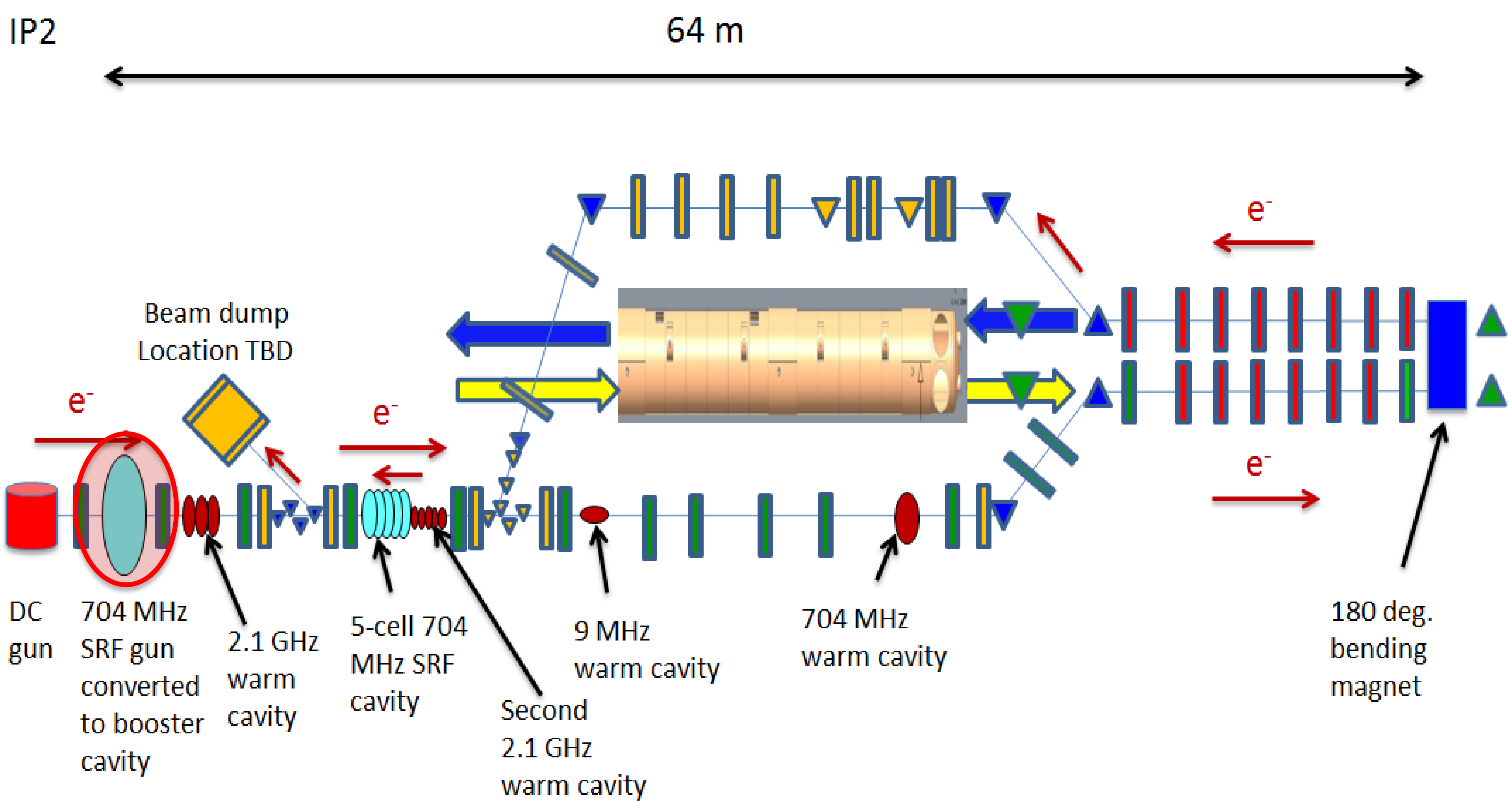
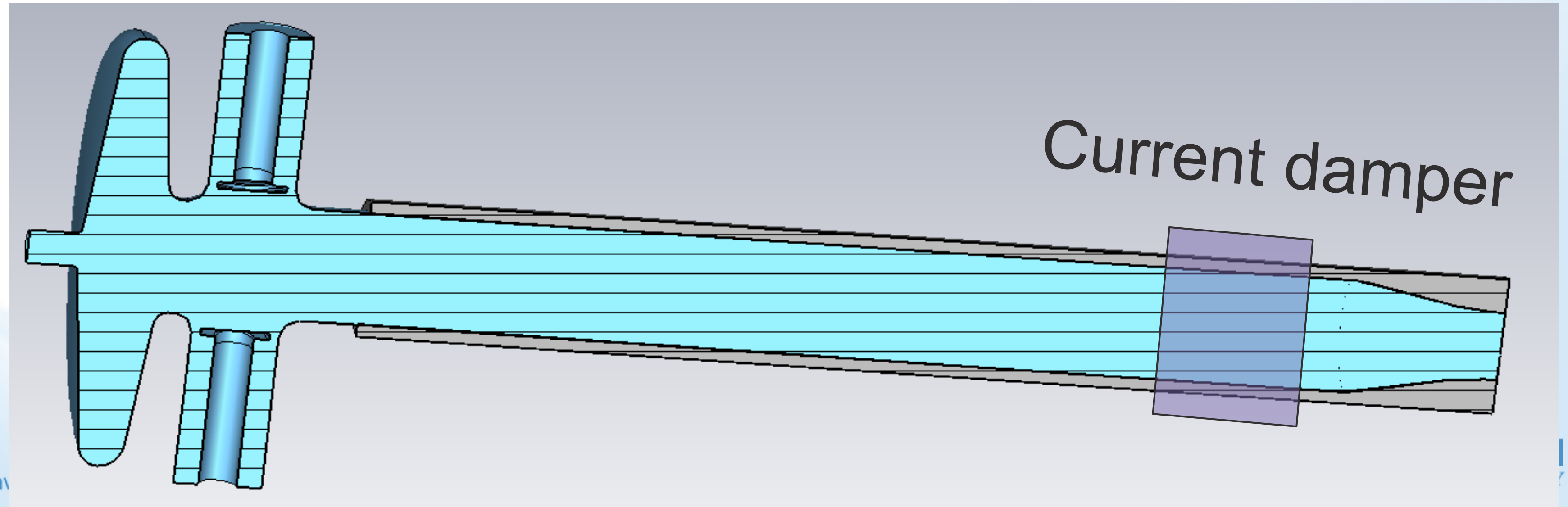
LEReC layout



704 MHz SRF booster cavity

- Cavity size: ~190mm radius, beam pipe: 50mm radius, then taper to 30.1625mm.
- Beam pipe cut-off: TM01 2.30 GHz, after taper 3.81 GHz.
- TM010 frequency: 704 MHz, Q0: 10^10, R/Q: 94.9 Ω.
- TM020 frequency: 1.489 GHz, Q0: 10^10, R/Q: 50.7 Ω, τ: 10^9 nS. (measured at 1.47834 GHz)
- If not well damped, the TM020 with 0.12 V/pc will produce 24 V with a single bunch, and 59 V with 31 bunches in a train. If it beats the train frequency at 9 MHz, It is going to be a disaster.
- The current damping scheme does not damp TM020.
- Possible ways: lower the quality factor & avoid multiples of 9MHz.
- TM020 mode is not the only mode we are worrying about. Modes at 1.28GHz, 1.71GHz, 2.26GHz, and lots of other HOMs that give smaller, but still dangerous effect.



Choice of damping scheme

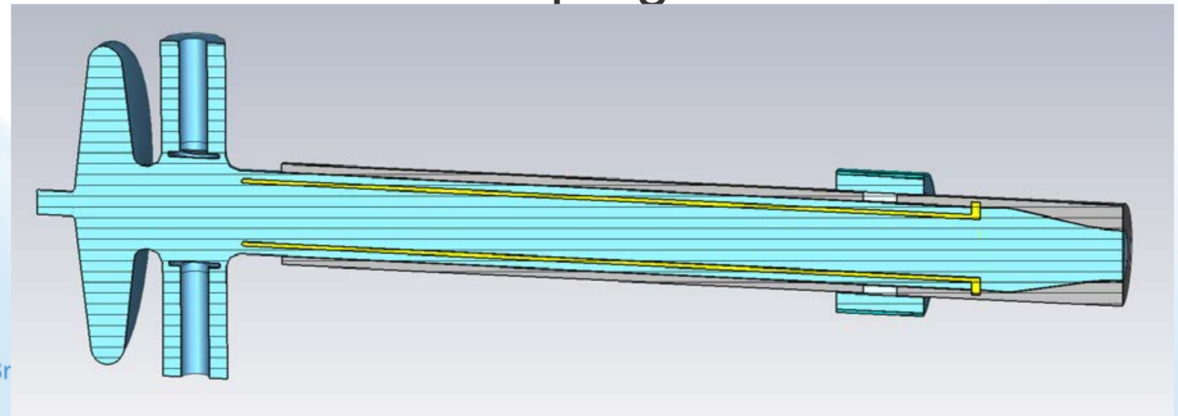
- Use tuner to change the freq of TM020

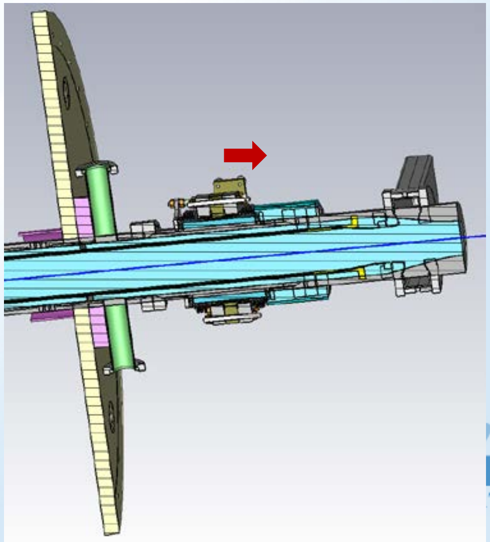
  Failed due to the freq change of TM020 is <0.1MHz in the whole tuning range.
- Use phase shifters to change the freq of TM020

  Failed due to the freq change of TM020 is <60kHz.
- Move damper closer to the cavity

  Significant loss from the fundamental mode.
- Use FPC to damp the HOMs

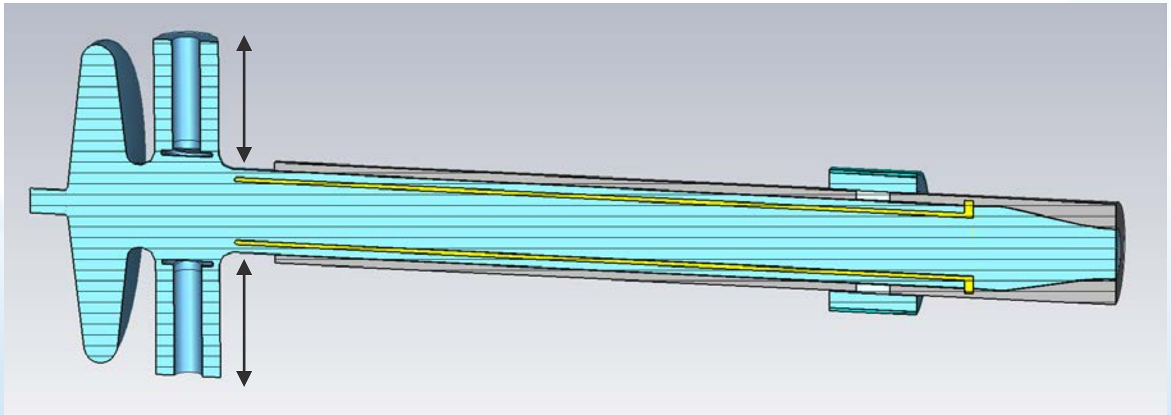
  Good idea, but does not work with the current doorknob design due to its narrow band at 704MHz, and needs high power diplexer. (The RF window is relatively broadband though)
- Coaxial damping scheme

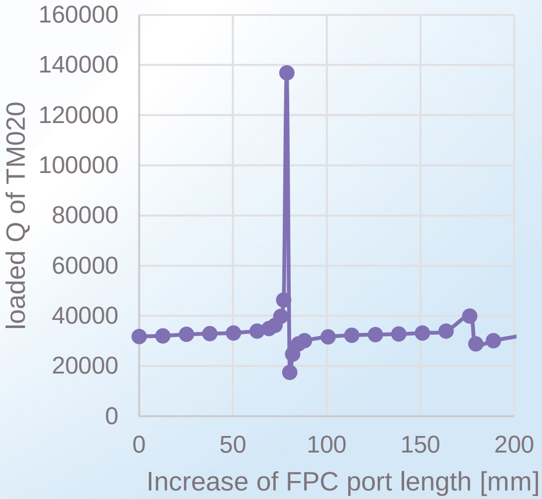




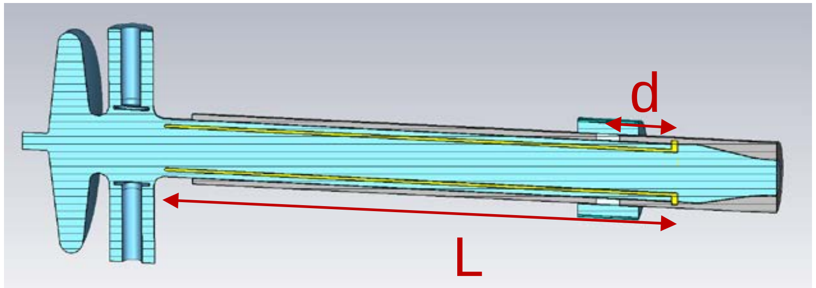
Effect of the boundary condition

- The bc of the FPC port is going to affect the simulation
- Increase the length of the FPC ports, while keeping the bc the same (metal bc). The loaded quality factor is going to heavily affected with metal bc at certain locations.
- Resonance may happen inside FPC port (real or not real) if bc is not carefully considered.
- The real case:
  For fundamental mode, The FPC ports are terminated with matched loads. (Cannot separate the loss on the load and the Ferrite)
  For HOMs, the doorknob will reflect most power back.

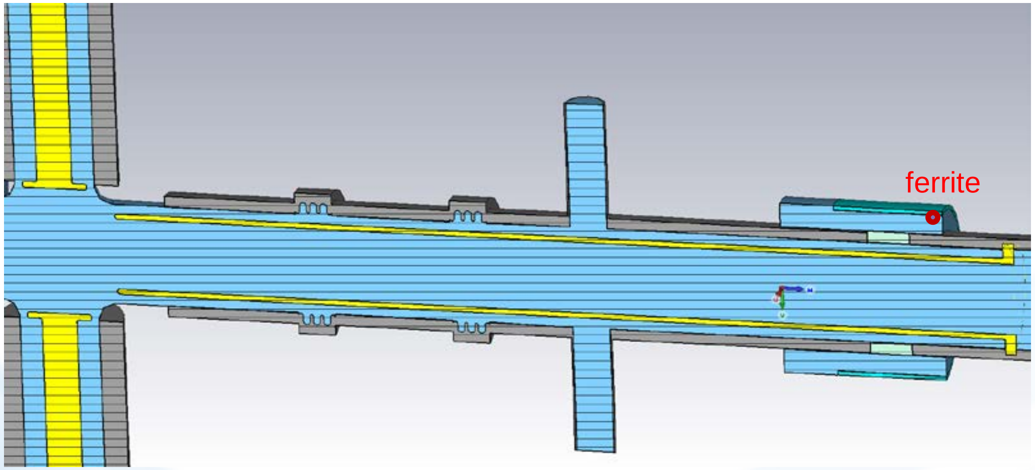


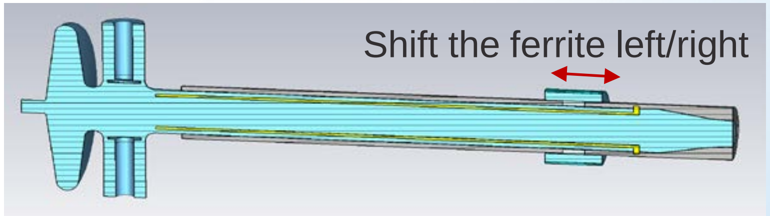


Optimization

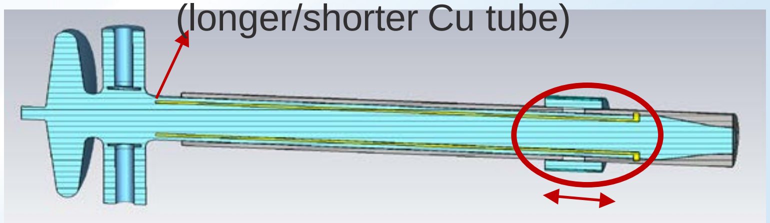


- To minimize the damping to TM010, d~λ010/4, L~N/2*λ010.
- To maximize the damping to TM020, d~λ020/2, L~(N/2+1/4)λ020.
- λ020>2*λ010   (2.135 for pillbox, measured to be 2.1)
- Use the bc from the previous page, and optimize by maximize the ratio of 1/Qferrite of TM020 over (H field on ferrite (o) of TM010)^2





While keeping this end the same (longer/shorter Cu tube)



Shift the assembly left/right

Method to calculate wake potential (1)

- Single bunch by CST Particle Studio™ .
- Single bunch constructed from Eigen modes by CST Microwave Studio™.
- Single bunch / Multi bunch / Multi train by shifting – adding the single bunch wake potential.
- A 10^6 Q in GHz range will require 50 km wake length, which is not easy for CST Particle Studio™. Not easy to shifting-adding the worst case with slightly different resonant frequency.
- The "reconstruction" method can be used to analyse each HOM separately. (NOT easy for 50 km as well!)

Method to calculate wake potential (2)

- Longitudinal R/Q (use β=1): $\left(\frac{R}{Q}\right) = \frac{|V_z|^2}{\omega U}$

β	1	0.9	0.8
TM010	94.6	89.1	82.1
TM020	48.6	37.7	27.3

- Wake potential: $W_{\parallel}(\tau) = \frac{\omega_r R_s}{4Q_r} e^{-\frac{\tau^2}{2\sigma^2}} Re\left\{\left(\frac{j}{2Q_r} + 1\right) w\left(\frac{z_1}{\sqrt{2}}\right)\right\}$

  with $z_1 = \omega_r \sigma + j\left[\frac{\omega_r \sigma}{2Q_r} - \frac{\tau}{\sigma}\right]$ & $\int_0^{+\infty} dt e^{-a^2 t^2 + jzt} = \frac{\sqrt{\pi}}{2a} w\left(\frac{z}{2a}\right)$

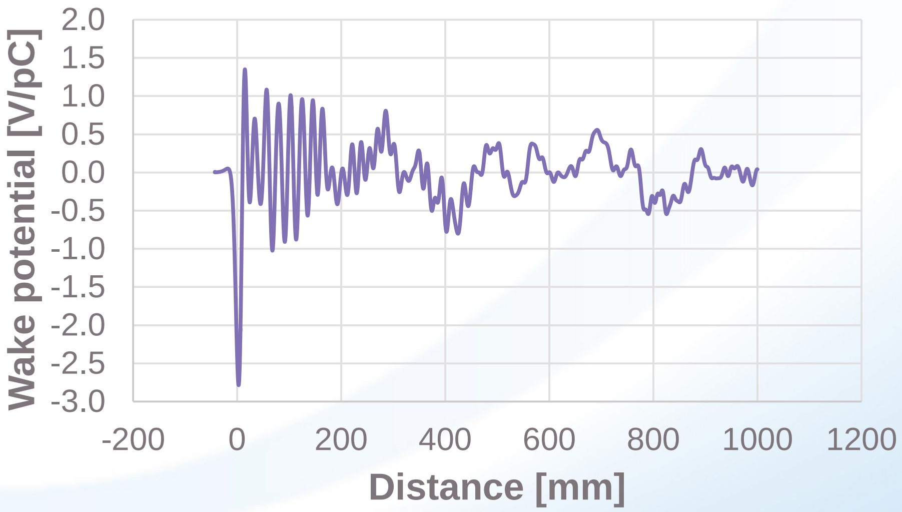
- *Single bunch:* $\sum_{HOMs} W_{\parallel}(\tau - (N-1)T_1)$

  $MultiBunch\_W_{\parallel}(\tau) = \sum_{N=1}^{31} \sum_{HOMs} W_{\parallel}(\tau - (N-1)T_1)$

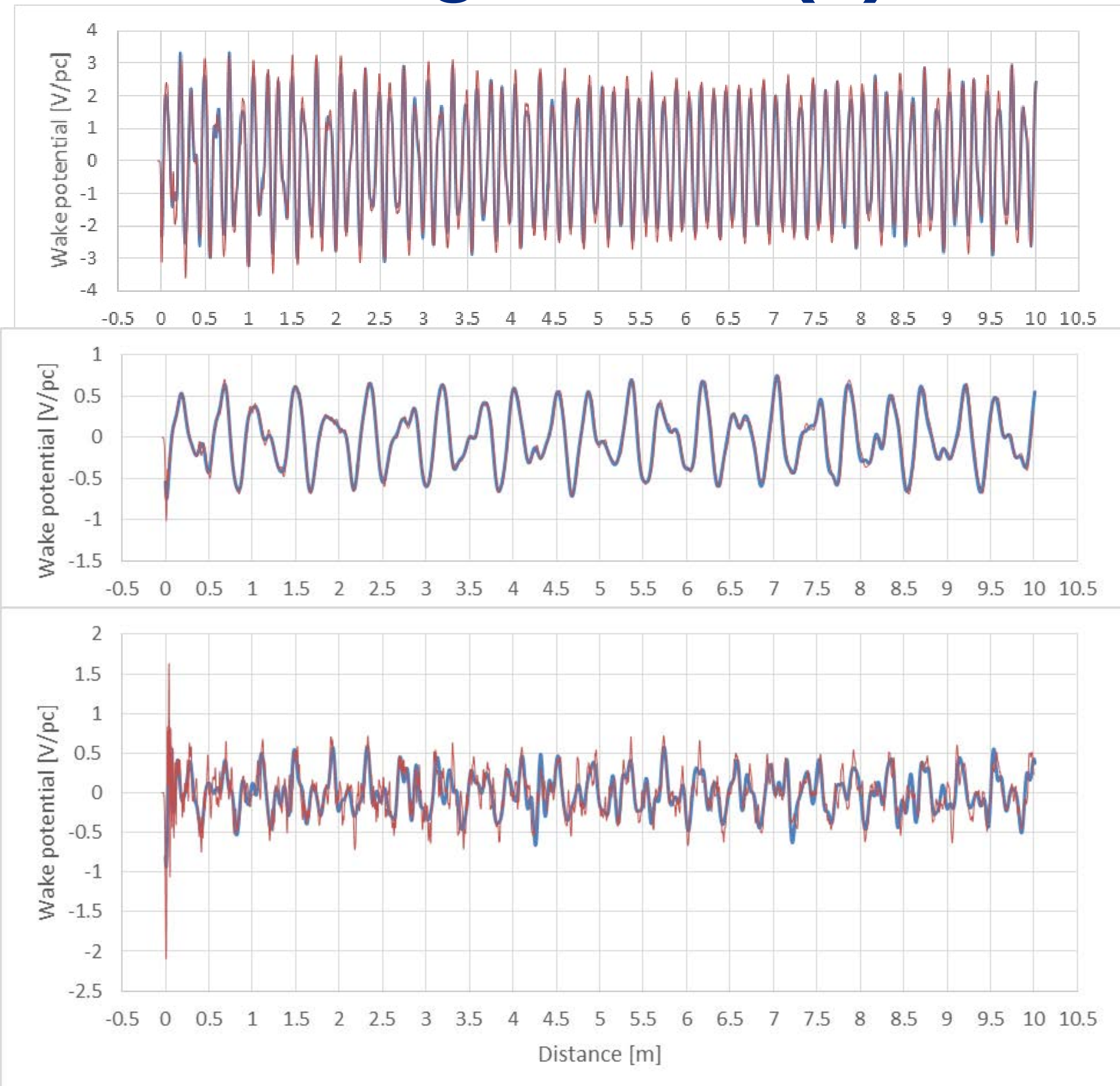
  $$MultiTrain\_W_{\parallel}(\tau) = \sum_{k} MultiBunch\_W_{\parallel}(\tau - (k-1)T_2)$$

Short range wake (1)

- Short range wake simulation using CST wake field solver gives -2.8~+1.4 V/pC wake potential, corresponds to -1.4~+0.7 $\times 10^{-4}$ dp/p peak to peak.
- More precise result will come from Peter Thieberger



Short range wake (2)



10m single bunch wake potential

a) 2.1 GHz warm cavity (top);
b) 704 MHz warm cavity (middle);
c) 704 MHz booster SRF cavity (bottom).

Blue curves are from the reconstruction of Eigen mode simulation, and red curves are from CST Particle Studio™.

Long range wake (1)

- Using the actual model, calculate all modes (including dipole modes for emittance growth analysis).
- Calculated with 100pC/bunch & σ=33ps.
- Worst case: the modes that are close (±20 MHz) to the multiple of 704 MHz will beat the multiple, and all modes will beat the frequency ~9 MHz.

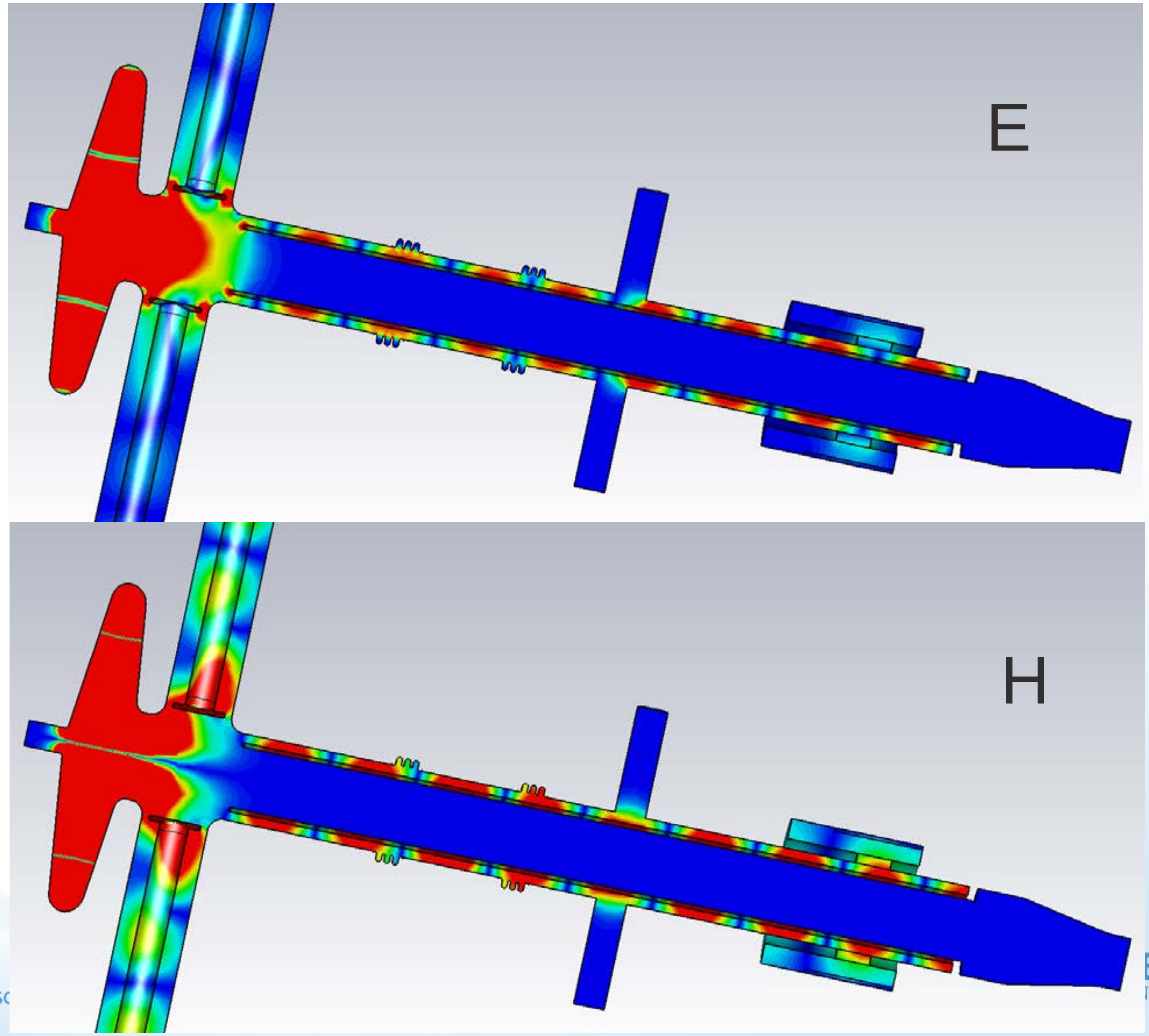
Long range wake (2)

With TM020 0.7MHz away from the harmonic of 9MHz:

- 30 bunches/train, multitrain configuration gives 0.62kV fluctuation, corresponds to $\pm 3.1 \times 10^{-4}$ dp/p peak to peak.
- 31 bunches/train, multitrain configuration gives 0.70kV fluctuation, corresponds to $\pm 3.5 \times 10^{-4}$ dp/p peak to peak.

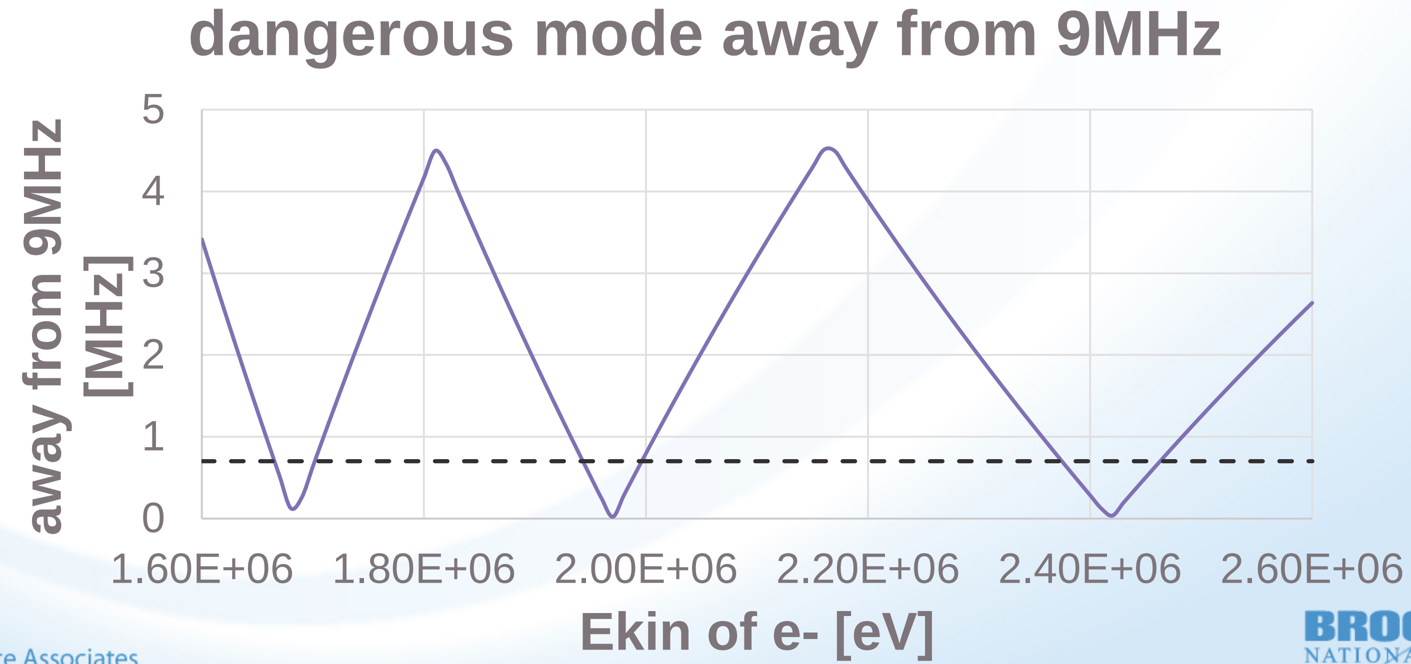
Long range wake (2)

Dangerous mode:



Choice of operating energy

- Needs to combine this analysis with the analyses to normal conducting cavities to determine operational Ekin.
- Needs to measure the frequencies of the “dangerous modes” of the normal conducting cavities.



Emittance growth (1)

- Transverse $(R/Q)_T$: $\left(\frac{R}{Q}\right)_T = \frac{\left|V_z(r_0) - V_z(0)\right|^2}{\omega U \left(\frac{\omega}{c} r_0\right)^2}$
- Wake potential: $W_\perp(\tau) = \frac{\omega_r r_0}{c} \frac{\omega_r r_0}{c} \frac{\omega_r R_\perp}{4Q_r} e^{-\frac{\tau^2}{2\sigma^2}} Im\left\{w\left(\frac{z_1}{\sqrt{2}}\right)\right\}$
- Shifting-adding to get multi bunch multi train result.
- The modes that are close to the multiple of 704 MHz have low *$(R/Q)_T$*
- The high *$(R/Q)_T$* modes give the most perturbation since we assumed all modes will beat 9 MHz.

Emittance growth (2)

- Critical modes: vertical kick (aligned with FPC) at 1.0058 GHz and horizontal kick at 1.0050 GHz.
- Estimated maximum kick: vertical at 0.20 kV and horizontal at 0.06 kV, for 5 mm displacement.
- These two resonances are 0.8 MHz away and they will not beat ~9 MHz simultaneously.
- Δx‘: 0.10 mrad (0.20kV/2MV), Δε: 1.35 mm*mrad (π*4.3mm*0.10mrad).
- Specification ε: 2.5 (π*)mm*mrad, the SRF booster cavity contribute at most 54%.
- Smaller displacement gives smaller emittance , i.e, 2 mm for 22%.
- If the actual result turns out to be much better, the displacement limitation can be relaxed accordingly.

Conclusion:

- HOM damper is optimized to give most damping for TM020, and least for TM010.
- Single bunch wake potential is calculated
- Multi bunch wake potential reveals a max $\pm 3.5 \times 10^{-4}$ dp/p peak to peak.
- Analyzed the possible choices of the operating energy.
- Emittance growth is not critical.

- Multipacting simulation, and thermal/mechanical simulation will follow.

Thank you!