HIGHER BAND LRWFS SIMULATIONS, BEAM DYNAMICS AND PLANS FOR FURTHER WORK

Overview

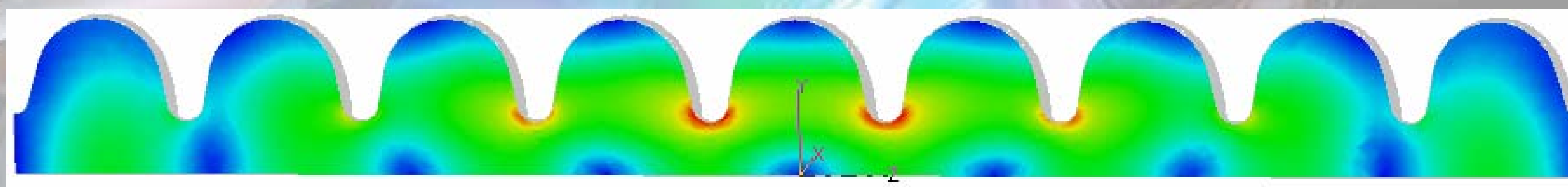
1. **Review of emittance dilution due to ~ first 3 bands.**
2. **Influence of higher dipole bands on emittance dilution.**
3. **Plans for the future –methods and applications to new proposed cavity shapes**

1. EMMITANCE DILUTION DUE FIRST TWO BANDS OF DIPOLE LONG-RANGE WAKES

Modal expansive of wake seen by beam traversing ~ 20,000 cavities:

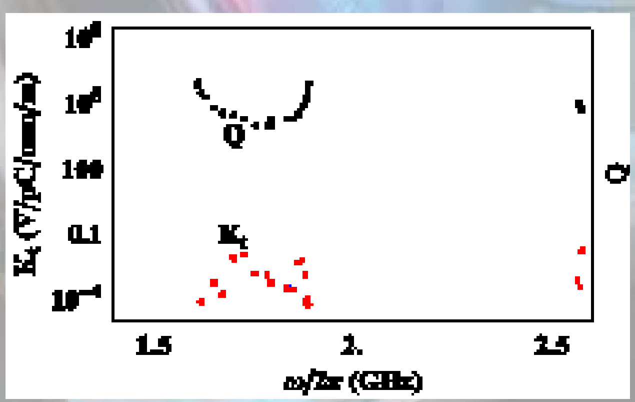
$$W(s) = 2\mathrm{Re}\left\{\sum_{n=1}^{N} K_n e^{i\omega_n s/c} e^{-\omega_n s/2Q_n c}\right\} U(s)$$

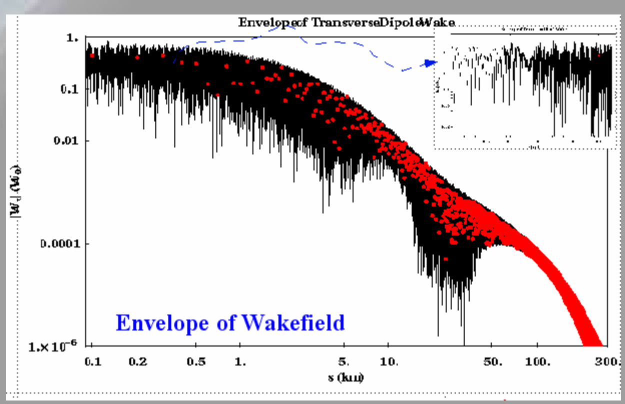
Where N is the number of modes, U(t) is the unit step function, the nth mode has a quality factor of Qn, a kick factor $K_n = \left|\int_0^L E_z(s) e^{i\omega_n s/c} ds\right|^2 / 4U_n$ **(E_z = axial E-field and U_n =energy stored in mode n) and a synchronous frequency $\omega_n/2\pi$.**



Typical dipole field in 9-cell TESLA-style cavity computed with HFSS

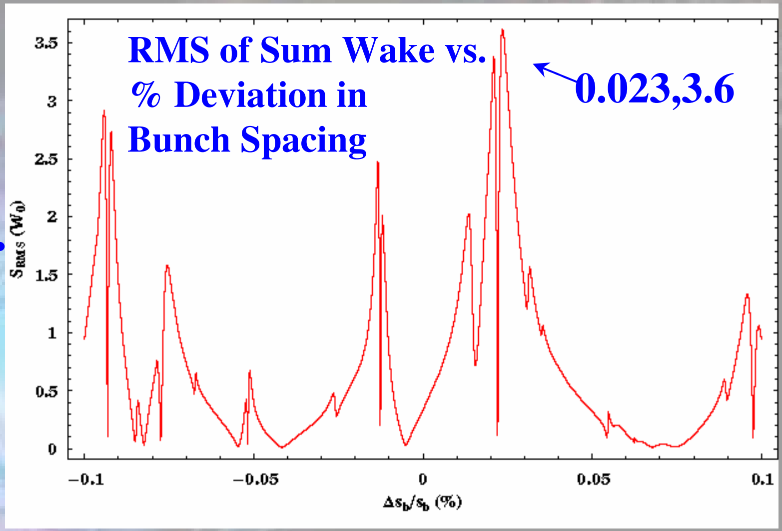
- **Calculate Ks, kick factors and $\omega_n/2\pi$, eigenfreqs for lower (~ 3 bands) with HFFS.**
- **Measure Qs for lower bands ('cold' measurement).**
- **Sum modes to obtain wakefield.**

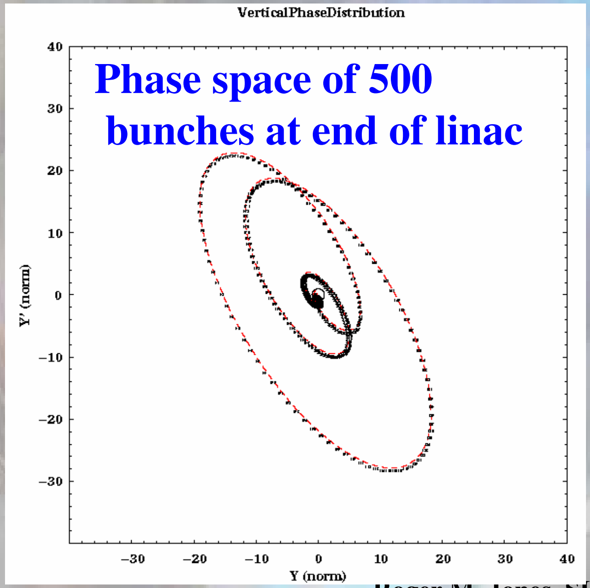


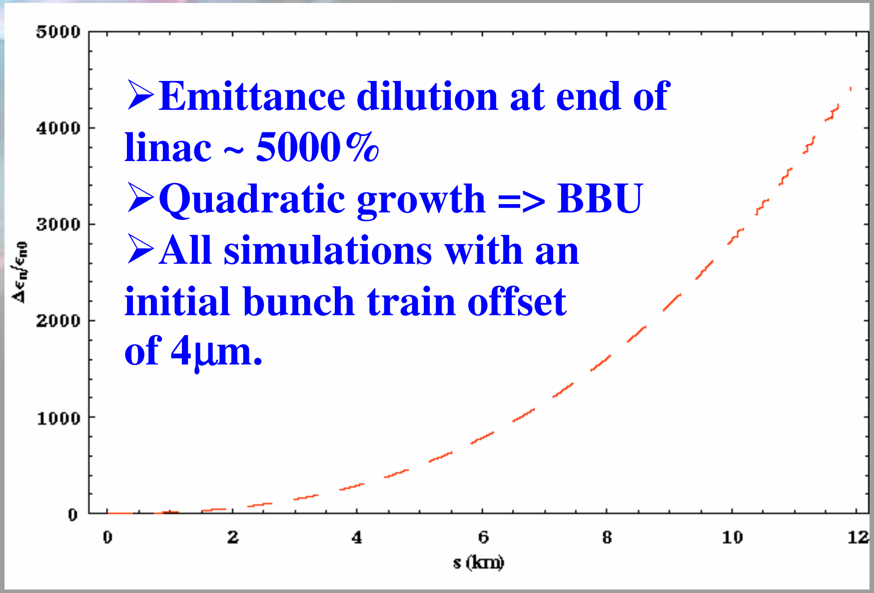


Beam Dynamics

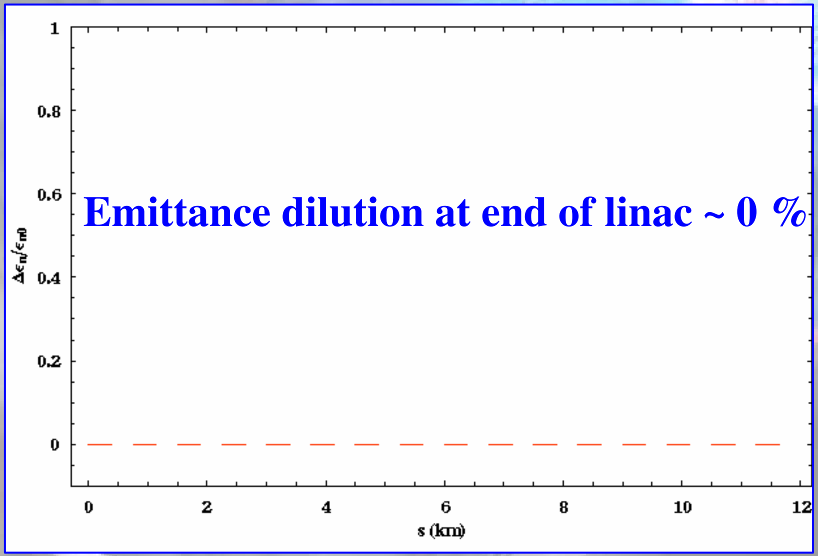
- ➢Form the Sum Wakefield (at a particular bunch it is defined as the sum of the wakes at all preceding bunches.
- ➢Take RMS value as it a good predictor of BBU.
- ➢Vary bunch spacing => similar to a systematic
- ➢error in all cell freqs
- ➢Locate peak in the RMS of the Sum Wakefield
- ➢Track beam down linac under this worst case
- ➢resonant condition

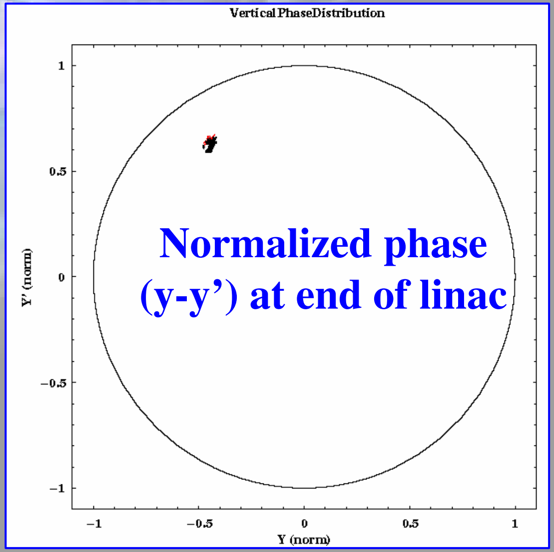




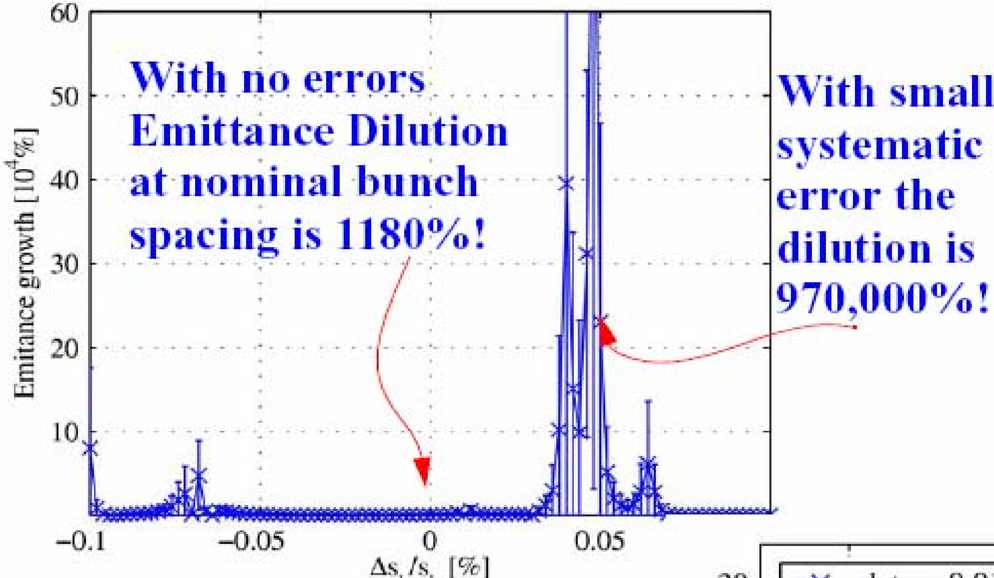


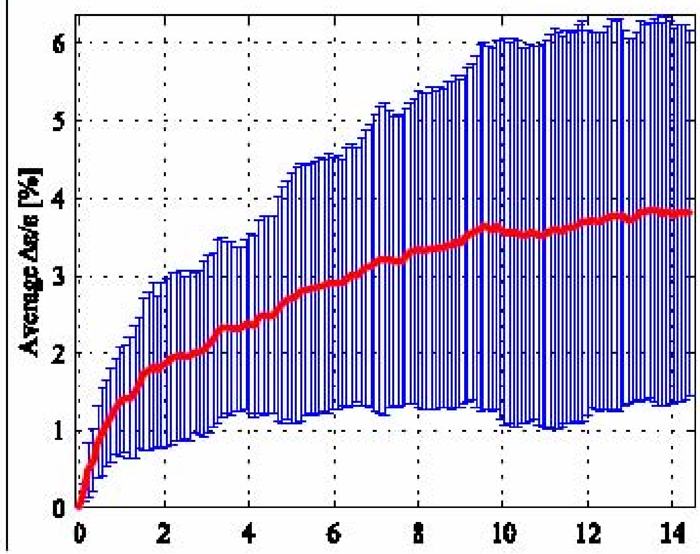
- Add random frequency errors to each cavity
- These errors occur naturally as a result of the process of fabricating thousands of these cavities
- 2MHz RMS error chosen (but it is rather insensitive to the RMS value)
- Emittance dilution due to long-range wakes is entirely alleviated!



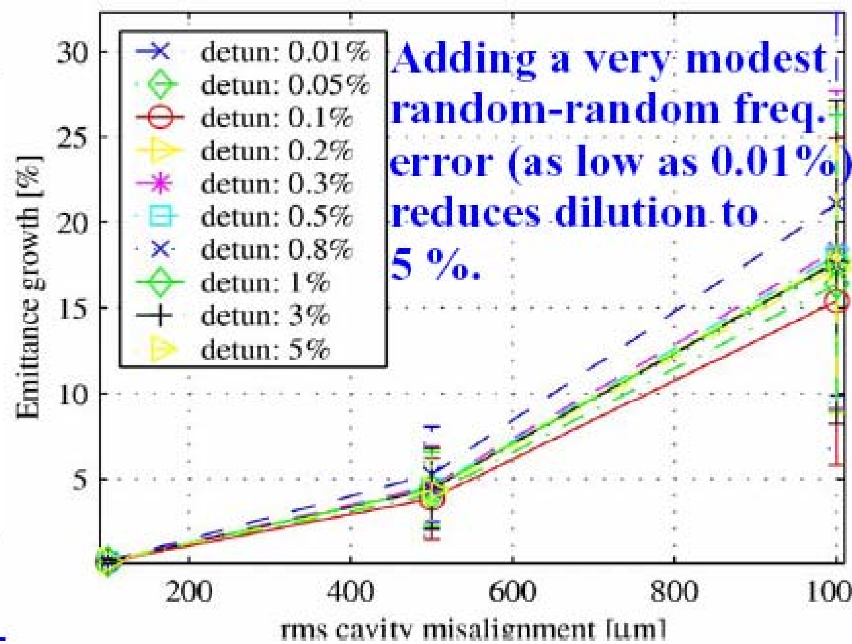


Random Cavity Misalignments



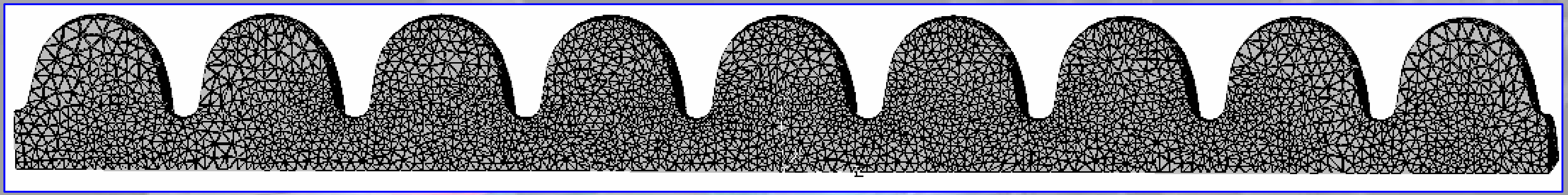


RMS Frequency Detuning (%)	RMS Misalignment (μm)		
	100	500	1000
0	47.2±53.6	1180±1339	4721±5357
0.01	0.20±0.11	5.12±2.77	20.47±11.08
0.05	0.17±0.08	4.20±2.07	16.80±8.29
0.1	0.17±0.10	4.18±2.53	16.71±10.12
0.2	0.18±0.08	4.38±2.02	17.51±8.08
0.3	0.18±0.09	4.55±2.30	18.19±9.21
0.5	0.19±0.10	4.68±2.44	18.71±9.74
0.8	0.18±0.10	4.58±2.41	18.31±9.66
1.0	0.17±0.08	4.20±2.00	16.79±8.01
3.0	0.18±0.09	4.42±2.32	17.66±9.29
5.0	0.19±0.08	4.67±2.11	18.66±8.44

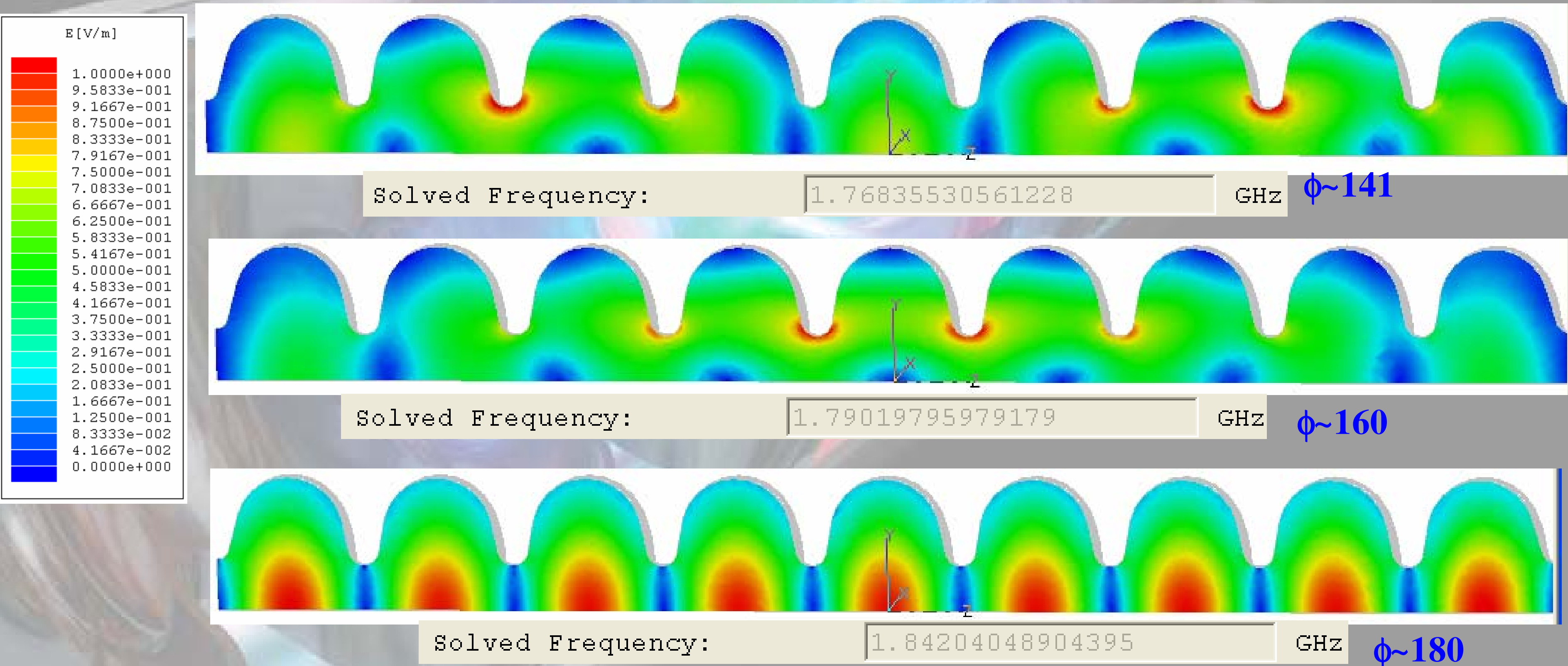


-cf SLAC-PUB-10684

2. EMMITANCE DILUTION DUE HIGHER BANDS OF DIPOLE LONG-RANGE WAKES

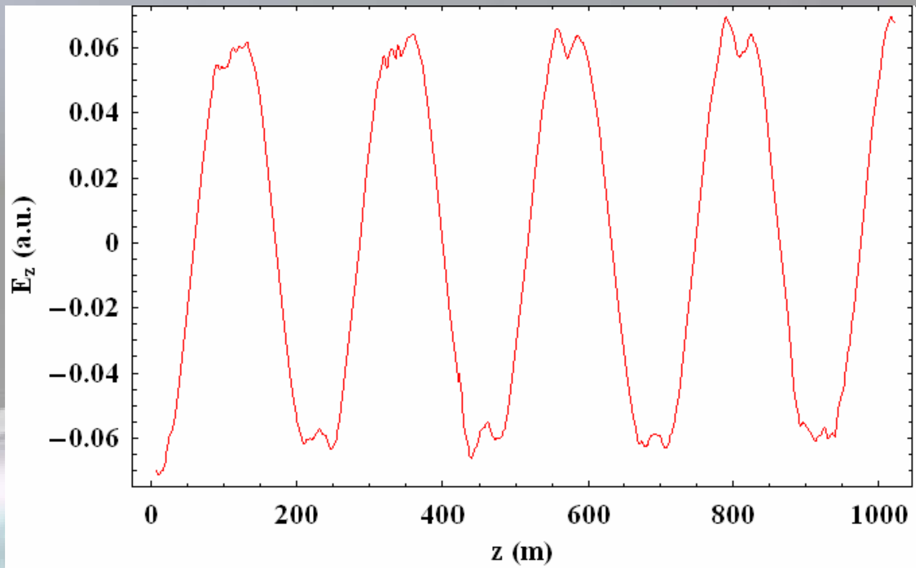


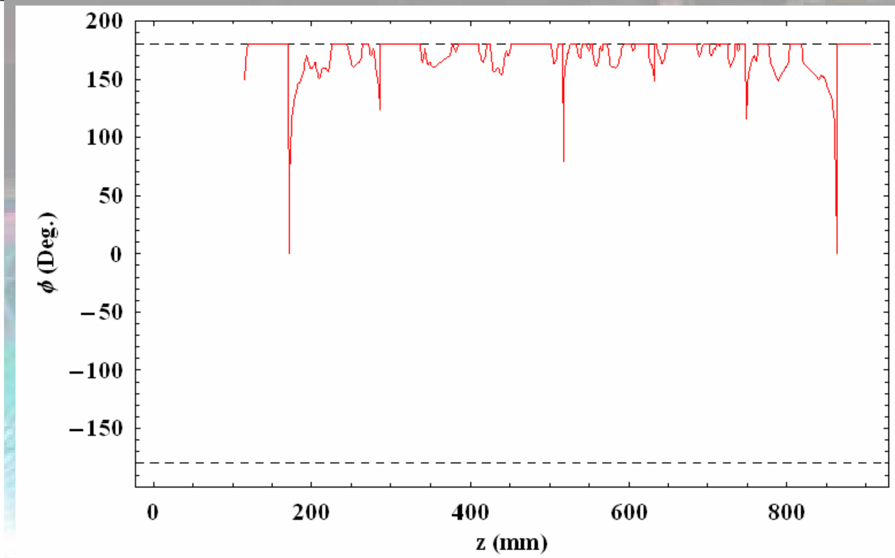
HFSS Mesh for 9-Cell TESLA Cavity

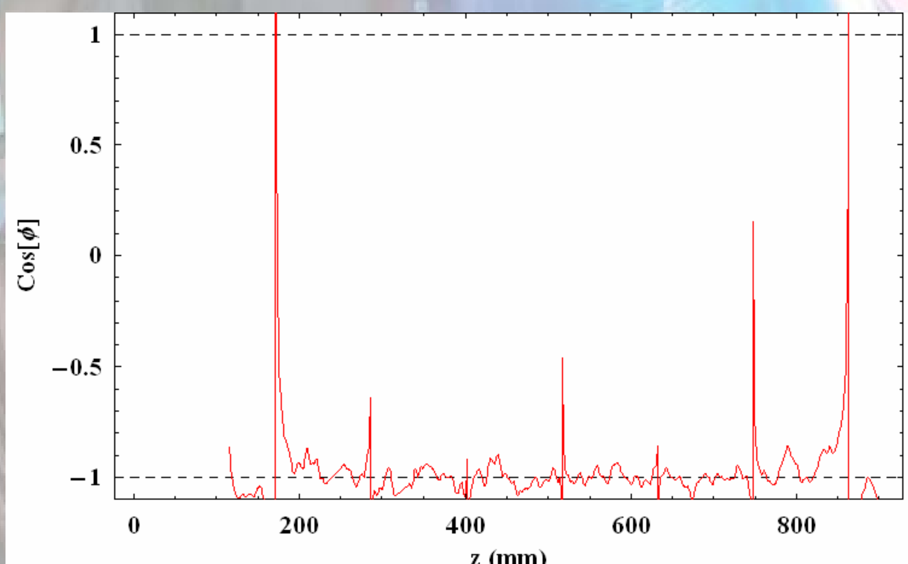


Representative set of HOMs are Illustrated

Application of Periodic Boundary Conditions







For a period system in general we have :

$$E_z(r, z + L_{cell}) = E_z(r, z)\,\mathrm{Exp}(i\,\phi)$$

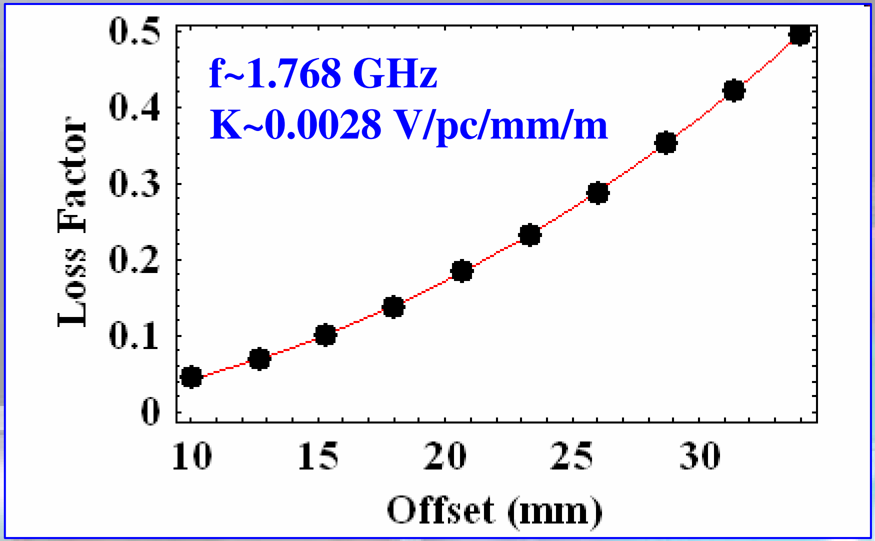
$$E_z(r, z - L_{cell}) = E_z(r, z)\,\mathrm{Exp}(-i\,\phi),$$

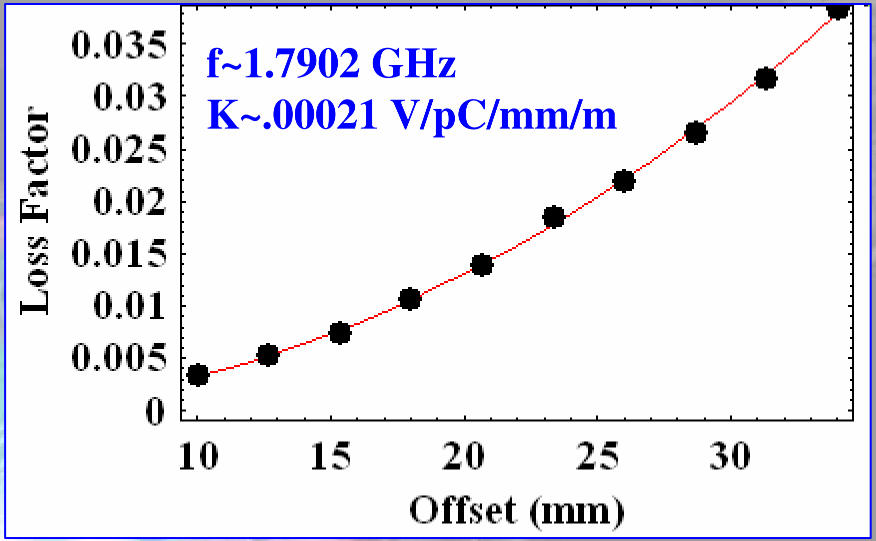
where L_{cell} = Period

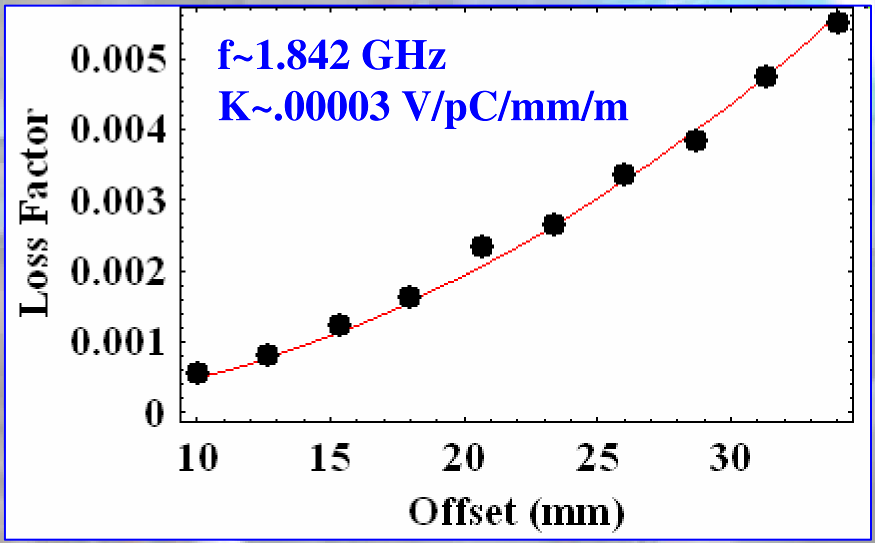
Thus we use :

$$\mathrm{Cos}(\phi) = \frac{E_z(r, z + L_{cell}) + E_z(r, z - L_{cell})}{2\,E_z(r, z)}.$$

Kick Factors for Selected Higher Band Modes







- First two modes are clearly TM-like
  => larger kick factors
- Third mode is TE-like
  => smaller kick factor

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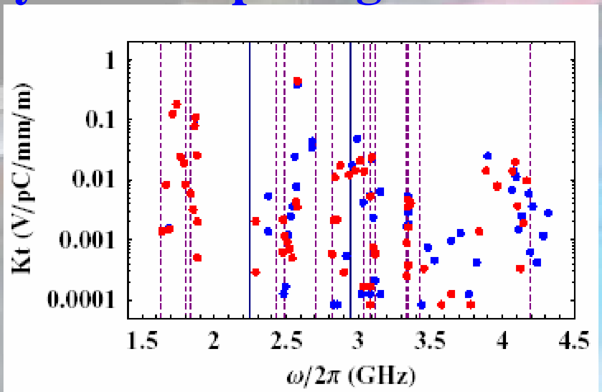
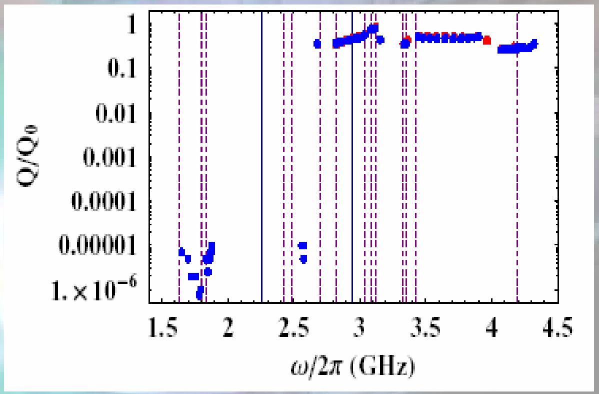
Effect of Higher Dipole Band Modes on Emittance Dilution

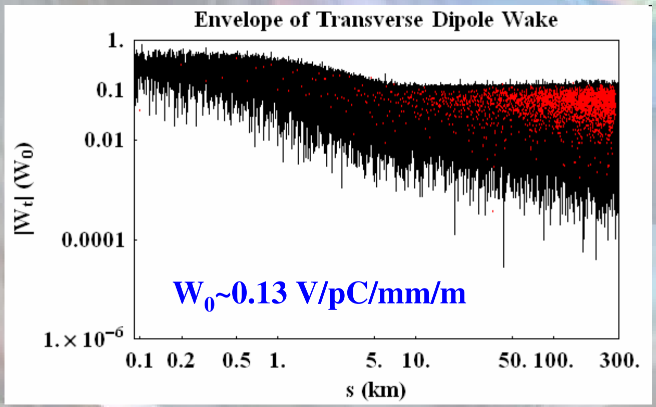
- Add an additional 4 bands (up to ~ 4.2 GHz)
- Do not damp the additional upper bands included (use their natural modal Q)
- Simulate emittance growth using 'natural' Qs and set upper 4 band Qs~10^6
- Vary bunch spacing and nearest peak in the RMS of the sum wakefield



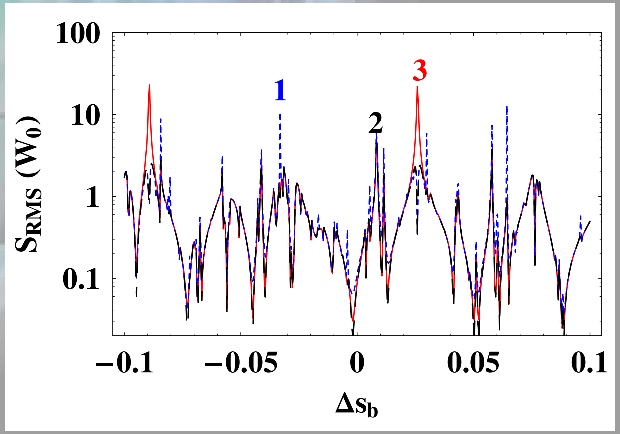
Kick Factors for Dipole HOM



HOM Dipole Qs



Envelope of Wakefield Including Natural Qs of Band Modes



RMS of Sum Wakefield for Natural Qs (Blue Dashed), $Q=10^6$ for Upper Band Modes (Black), Rogue Mode (Red)

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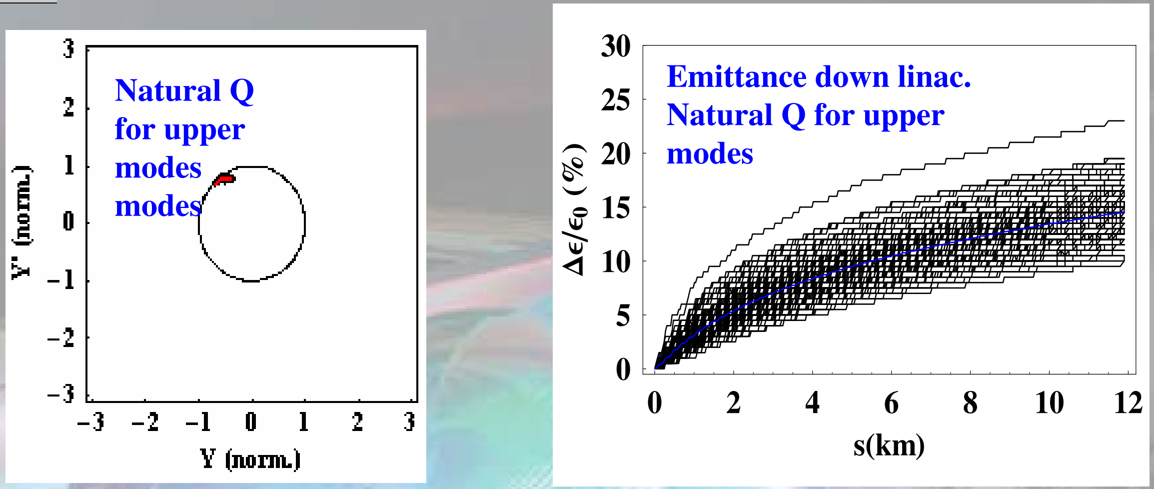
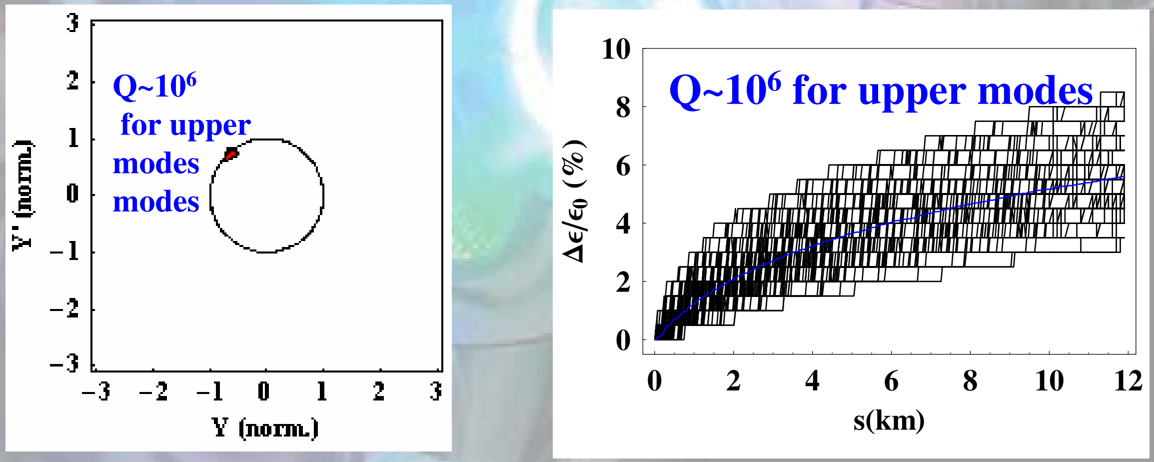
Emittance Dilution due to Higher Band Dipole Modes



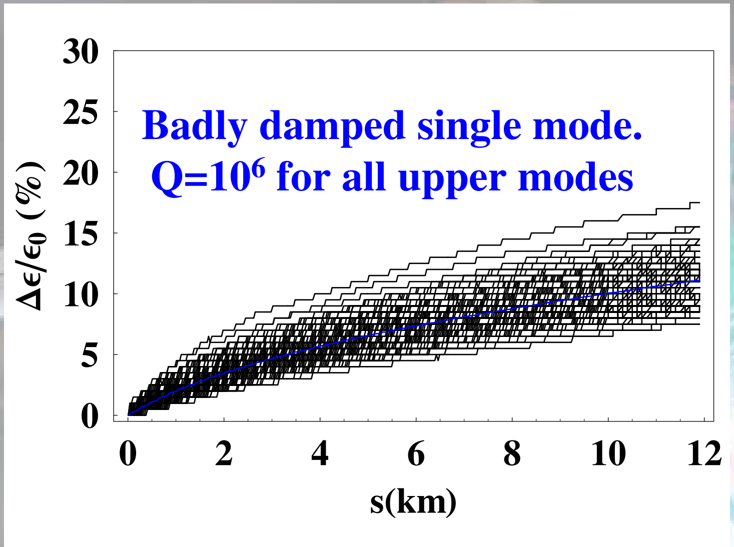
Case 1

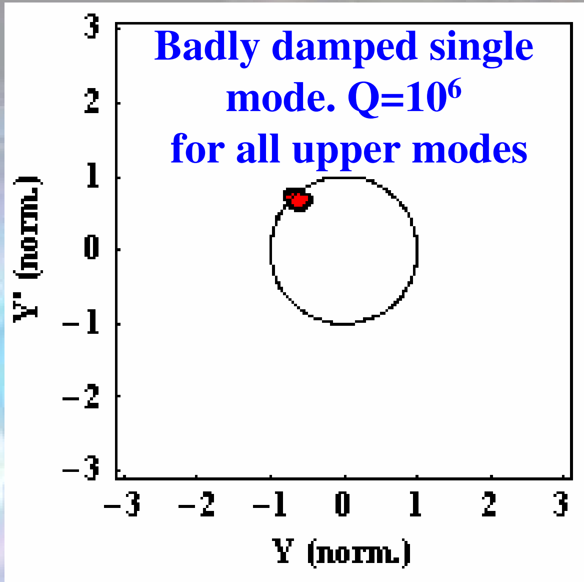


Case 2

- Small emittance dilution results from these modes!
- The additional bands contribute ~ 18% more kicks to the beam.

Emittance Dilution due to Rogue Mode Present Amongst Higher Band Dipole Modes





Case 3

- Relatively small emittance dilution occurs in all cases.
  - Even for the case of no damping (C1) of the upper 4 bands no more 25 % or so emittance growth occurs (mean value over 200 machines ~ 15%)
  - Damping upper band modes very modestly ($Q \sim 10^6$) and failing to damp the mode with the highest kick factor still results in no more than 20 % emittance growth
  - Bunch to bunch feed should be able to reduce this emittance growth to negligibly small values.
  - Trapped modes will of course cause significant emittance dilution. Care must be taken to avoid this situation.

See SLAC-PUB 11235

3.R&D REQUIRED FOR NEW CAVITY DESIGNS.

We need to be able to accurately and *rapidly* characterize the modes in these cavities. To this end we will use:

1. **Circuit modeling of cavities and superstructures.**
2. **Segmented or cascading of small sections.**

R&D necessary (at different levels): Rong-Li Geng

Considerable R&D will be required and different check points:

<u>Wake fields:</u>

a) The allowed iris diameter must be specified from theoretical analysis. This is a trade off between allowable emittance growth (luminosity) and cost.

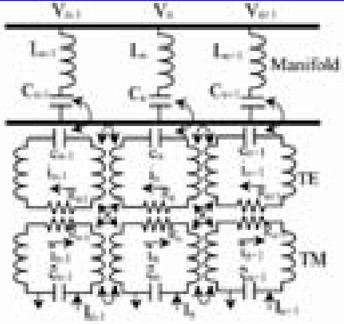
b) Complete wake field analysis must be carried out computationally and checked with measurements.

c) Cold tests of wake fields must be carried out on two or more adjacent cavities.

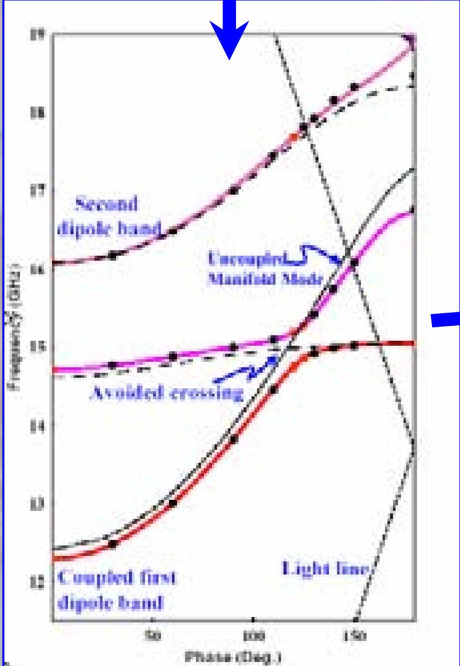
d) Wake fields must be checked in modules with beam.

Circuit Model Applied to X-Band NLC Structure

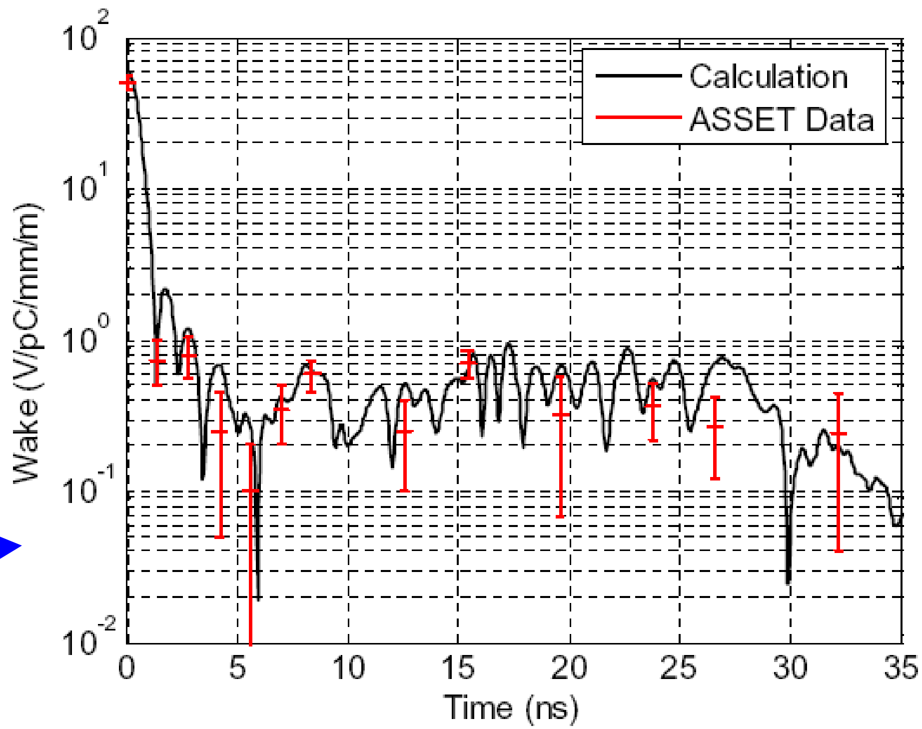
-The last you will see of warm-based wakes for awhile!

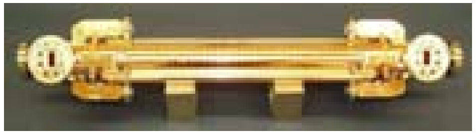


Three cells in the chain are illustrated. TM modes couple to the beam . Both TM and TE modes and excited and the coupling to the manifold is via TE modes. The manifold is modeled as a transmission line periodically loaded with L-C elements.



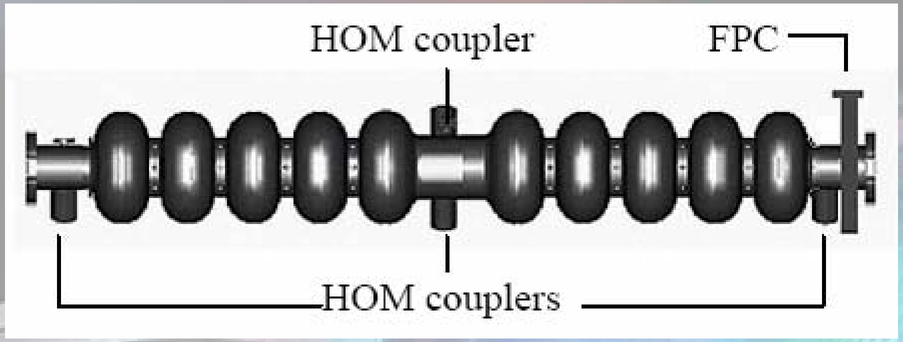
Transverse Wakefield Measurements of a Pair of H60VG4 Structures (H60VG4SL17A,B)



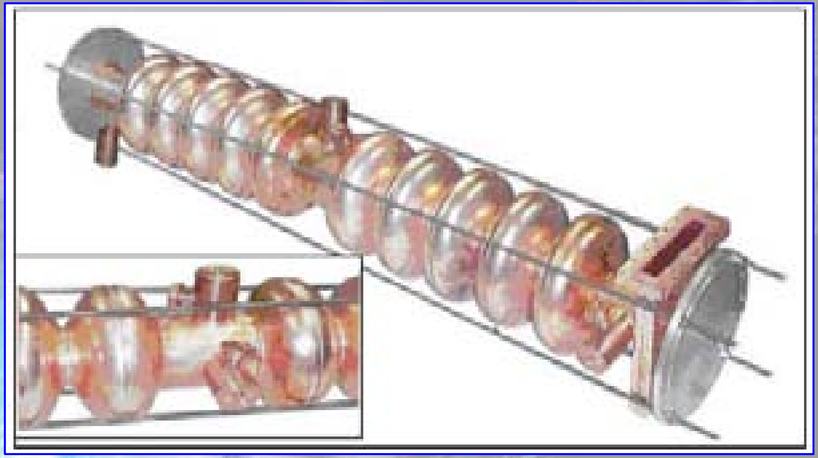


-- Mauro Pivi, Steffen Doebert, Chris Adolphsen
-- Roger Jones

Circuit Model of Superstructures



2x5 cavity superstructure indicating HOM couplers and single FPC (Fundamental Power Coupler) J. Sekutowicz et al PAC 2003



Cu model of 2x5 cavity superstructure. J. Sekutowicz et al PAC 2003

- These types of structures are ideal candidates for circuit modeling and cascading of segments of the accelerator.
- In cascading, the S-matrices of small sections are calculated accurately and the overall scattering matrix is calculated by cascading them.

- This method allows a rapid determination of the wakefield and moreover, allows errors (random and systematic) to be rapidly incorporated in the simulations.

Higher Order Dipole Wakefield Bands Summary

- Minimal emittance dilution is expected to occur due to the higher order dipole bands (a worst case machine had an emittance dilution of ~ 20% dilution in these calculations).

- Influence of higher order dipole bands on mode coupling also requires a careful analysis.

- Applying circuit modeling and cascading of segments of the structure will allow for a rapid determination of the wakefield.