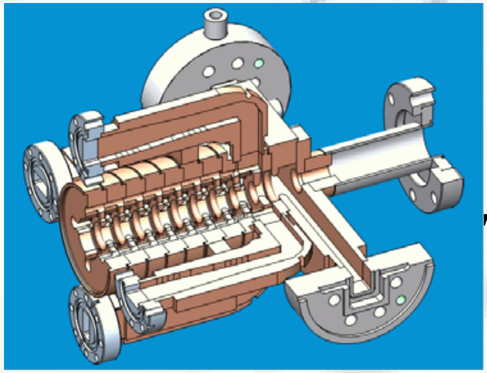
Wakefield Suppression for CLIC – A Manifold Damped and Detuned Structure



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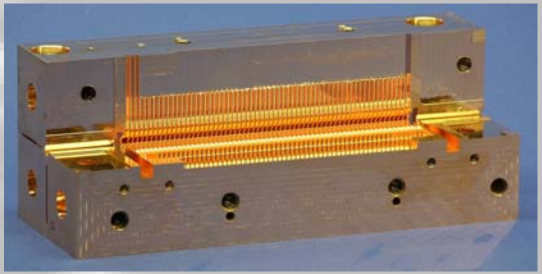

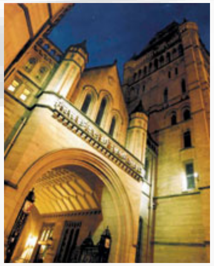

Wake Function Suppression for CLIC -Staff

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Overview

Three Main Parts:

1. **Introduction/features of manifold damped and detuned linacs.**
2. ***Initial design indicating required bandwidth and necessary sigma of Gaussian***
3. ***Design tied to CLIC_G –interleaving, zero-crossing***
4. ***Design with relaxed parameters –modified bunch spacing, bunch population etc. Based on moderate damping on strong detuning***
5. **Concluding remarks**

1. Introduction –Present CLIC baseline vs. alternate DDS design

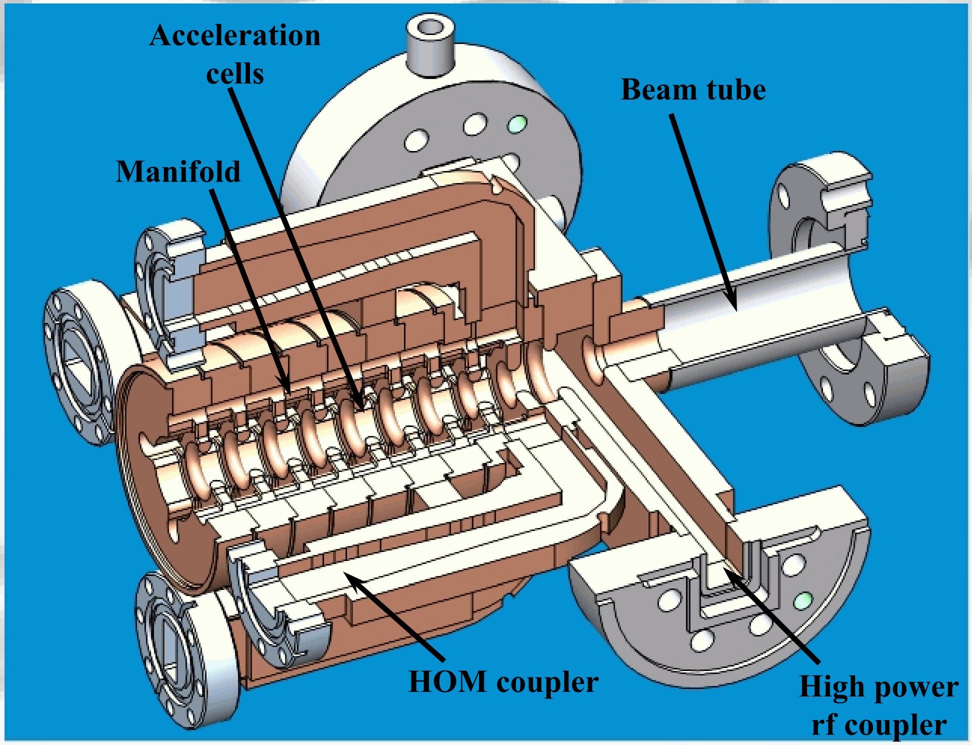
➢The present CLIC structure relies on linear tapering of cell parameters and heavy damping with a Q of ~10.

➢Wake function suppression in entails heavy damping through waveguides and dielectric damping materials in relatively close proximity to accelerating cells.

➢ Alternative scheme, parallels the DDS, developed for the NLC/GLC entails:

1. Detuning the dipole bands by forcing the cell parameters to have a precise spread in the frequencies –presently Gaussian Kdn/df- and interleaving the frequencies of adjacent structures.
2. Moderate damping Q~500

1. Features of CLIC DDS Accelerating Structure



- SLAC/KEK RDDS structure illustrates the essential features of the conceptual design
- Each of the cells is tapered –iris reduces with an erf-like distribution
- HOM manifold running alongside main structure removes dipole radiation and damp at remote location (4 in total)
- Each of the HOM manifolds can be instrumented to allow:
  1) Beam Position Monitoring
  2) Cell alignments to be inferred

1. CLIC Design Constraints

1) RF breakdown constraint

$$E_{sur}^{\max} < 260 MV / m$$

2) Pulsed surface heating

$$\Delta T^{\max} < 56 K$$

3) Cost factor

$$P_{in} \sqrt[3]{\tau_p} \Big/ C_{in} < 18 MW \sqrt[3]{ns} \Big/ mm$$

Beam dynamics constraints

1) For a given structure, no. of particles per bunch N is decided by the <a>/λ and Δa/<a>

2) Maximum allowed wake on the first trailing bunch

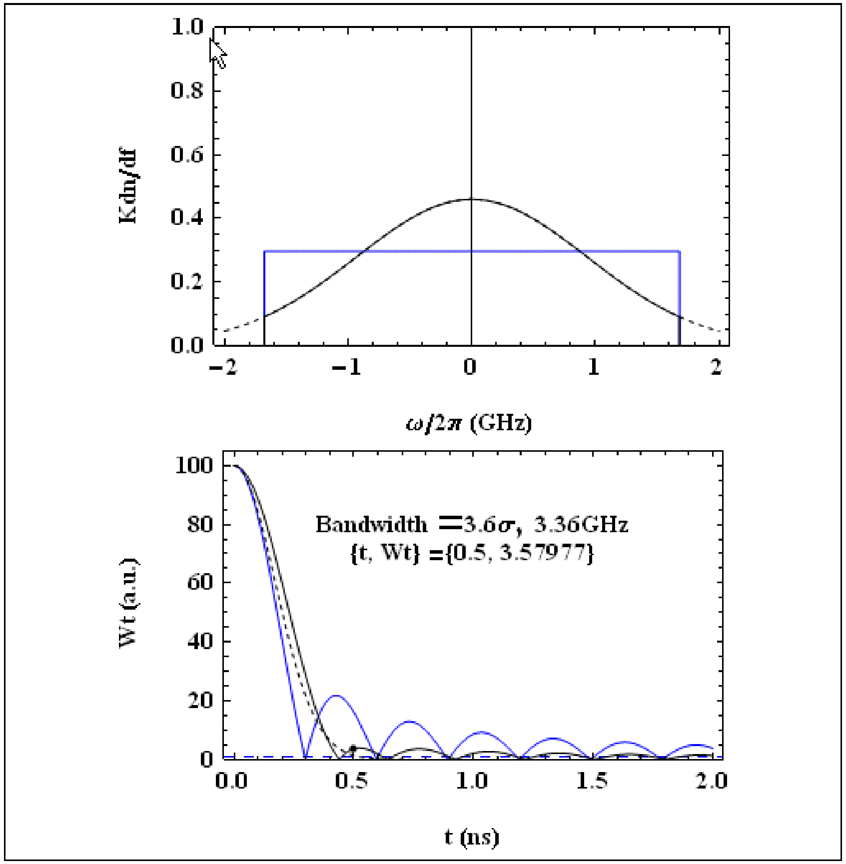
$$W_{t1} \leq \frac{6.667 \times 4 \times 10^9}{N} (V / pC / mm / m)$$

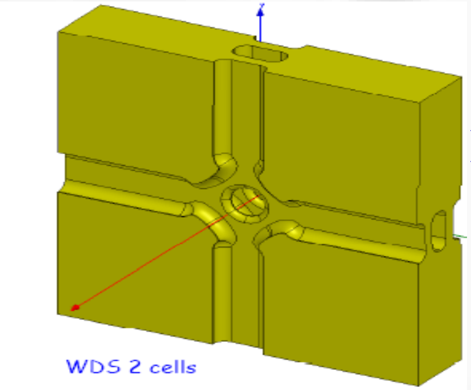
Wake experienced by successive bunches must also be below this criterion

Ref: Grudiev and Wuensch, Design of an x-band accelerating structure for the CLIC main linacs, LINAC08

1. Baseline CLIC_G Design

Structure	CLIC_G
Frequency (GHz)	12
Avg. Iris radius/wavelength <a>/λ	0.11
Input / Output iris radii (mm)	3.15, 2.35
Input / Output iris thickness (mm)	1.67, 1.0
Group velocity (% c)	1.66, 0.83
No. of cells per cavity	24
Bunch separation (rf cycles)	6
No. of bunches in a train	312





Lowest dipole band:
$\Delta f \sim 1$GHz
Q~ 10

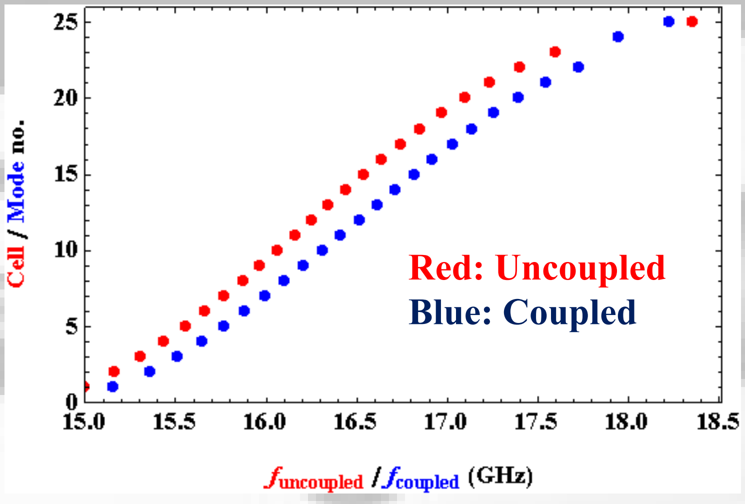
Truncated Gaussian :

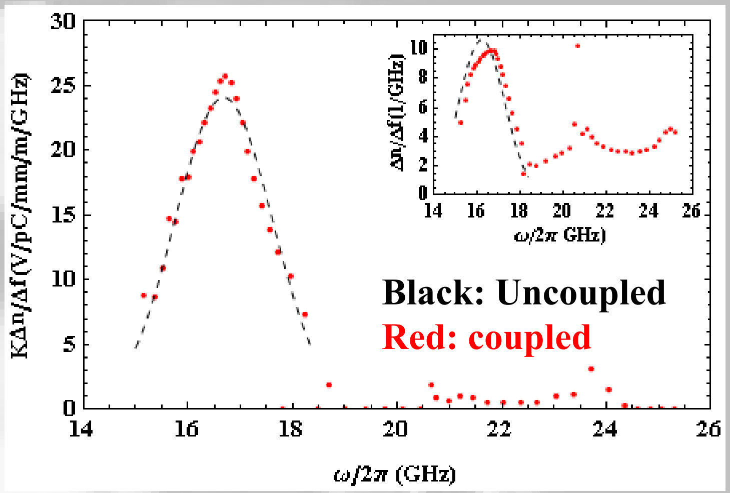
$$W_t = 2\bar{K} e^{-2(\sigma\pi t)^2} \left|\chi(t,\Delta f)\right|$$

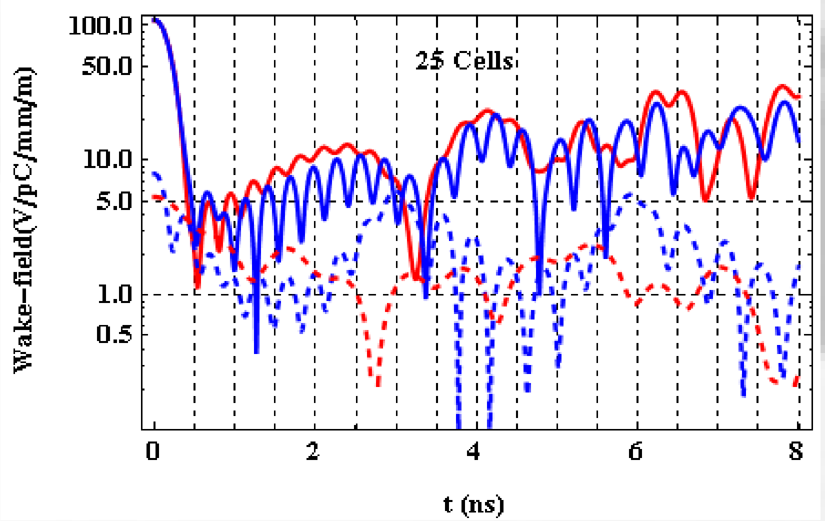
$$\text{where: } \chi(t,\Delta f) = \frac{\mathrm{Re}\left\{\mathrm{erf}\left(\left[n_\sigma - 4i\pi\sigma t\right]/2\sqrt{2}\right)\right\}}{\mathrm{erf}\left(n_\sigma/2\sqrt{2}\right)}$$

CLIC_DDS Uncoupled Design

2. Initial design for CLIC DDS





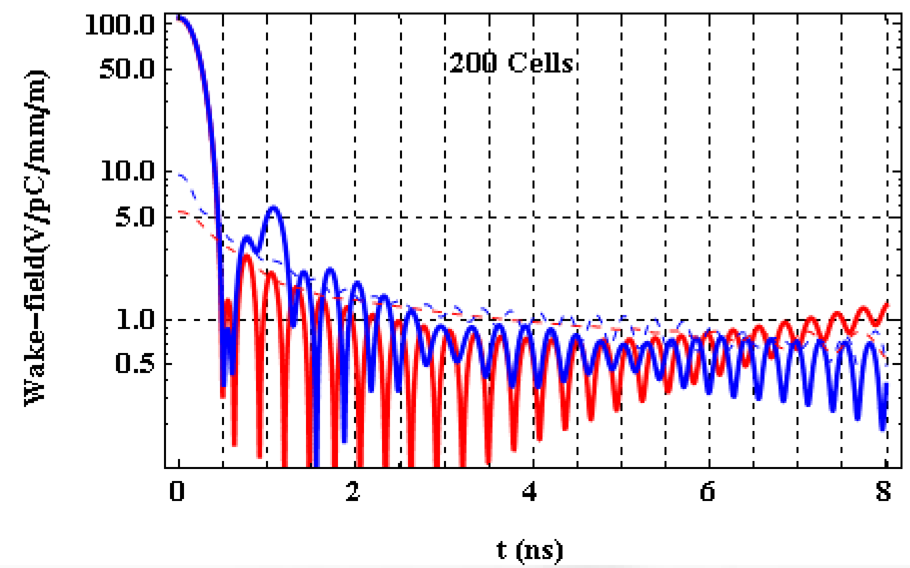


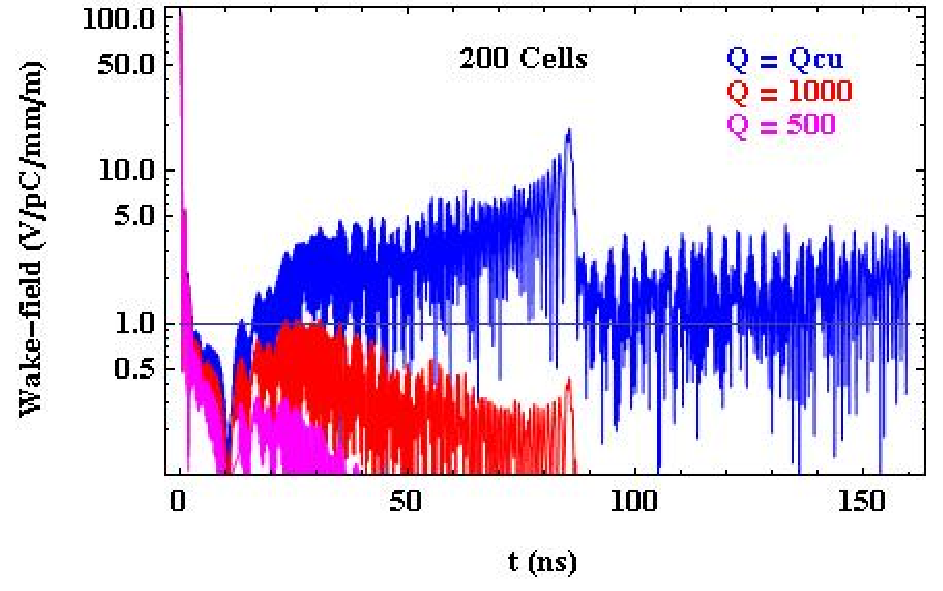
Solid curves: First dipole
Red: Uncoupled
Blue: Coupled
Dashed curves: second dipole

$W_t(0)$=110 V/pc/mm/m
W_{t1}~ 2 V/pc/mm/m

Ref: Khan, Jones. Proc. of EPAC08

2. Initial design for CLIC DDS





First dipole Uncoupled, coupled.
Dashed curves: second dipole

- 8-fold interleaving employed
- Finite no of modes leads to a recoherance at ~ 85 ns.
- For a moderate damping Q imposed of ~1000, amplitude of wake is still below 1V/pc/mm/m

- 3.3 GHz structure does satisfy the beam dynamics constraints
- However, it fails to satisfy RF breakdown constraints.

3. Gaussian distribution linked to CLIC_G parameters

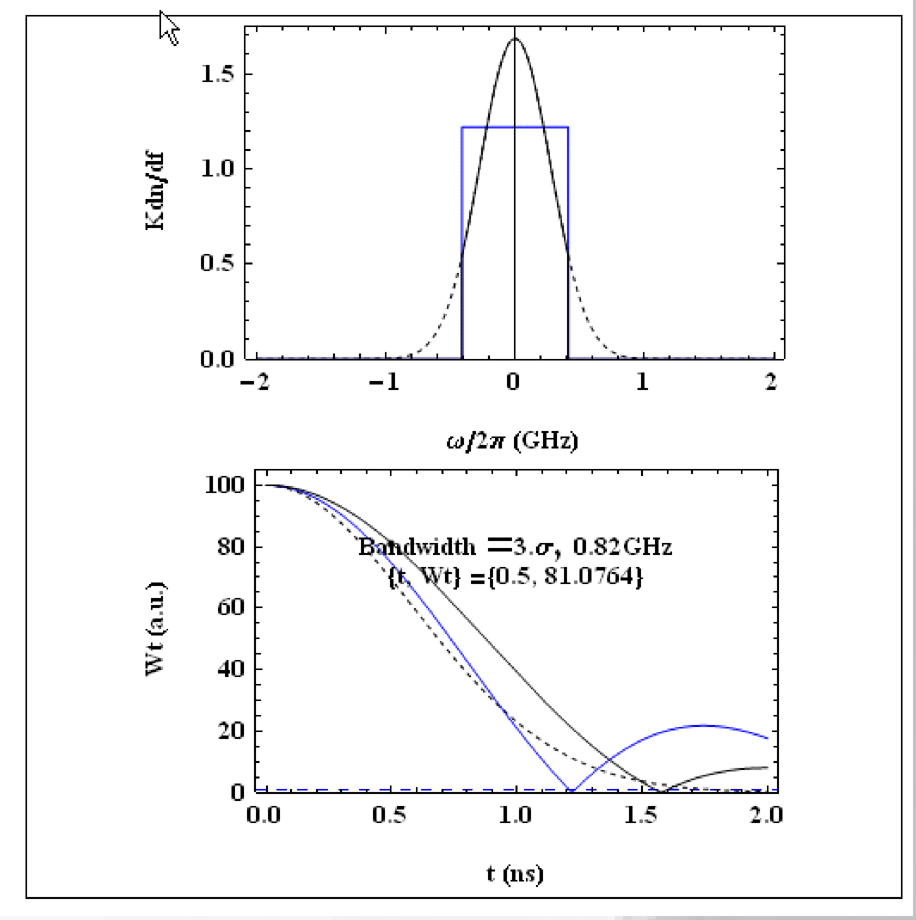
Cell	a (mm)	b (mm)	t (mm)	Vg/c (%)	f1 (GHz)
1	3.15	9.9	1.67	1.63	17.45
7	2.97	9.86	1.5	1.42	17.64
13	2.75	9.79	1.34	1.2	17.89
19	2.54	9.75	1.18	1.0	18.1
24	2.35	9.71	1.0	0.86	18.27

Uncoupled parameters:

$\langle a \rangle/\lambda = 0.11$

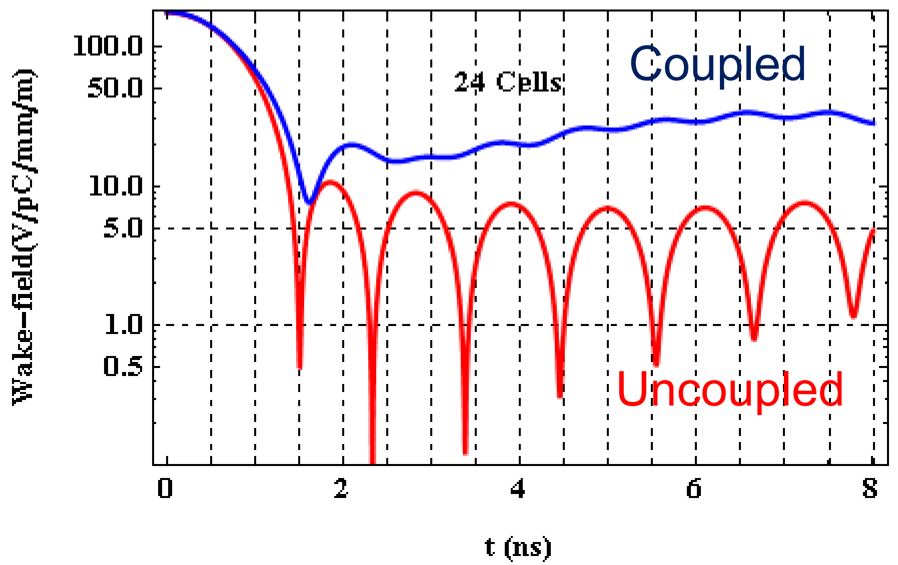
$\Delta f = 3\sigma \sim 0.82$ GHz

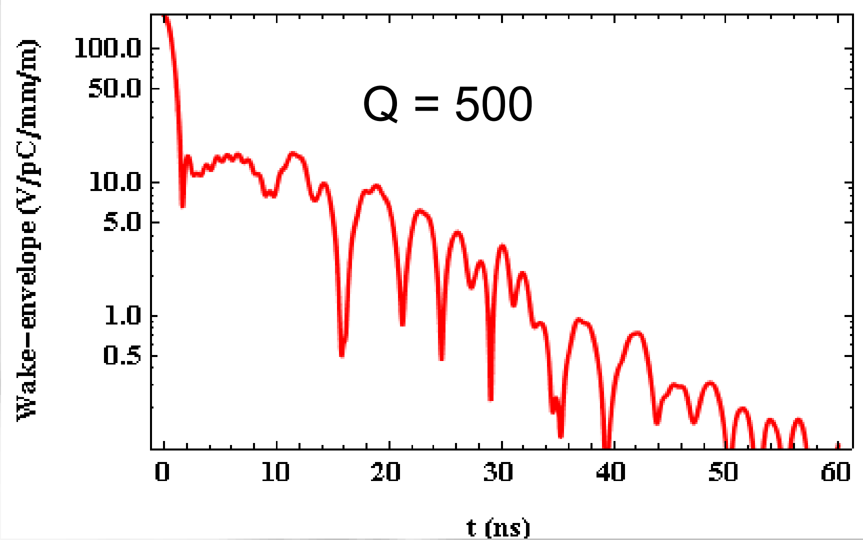
$\Delta f/\langle f \rangle = 4.5$ %

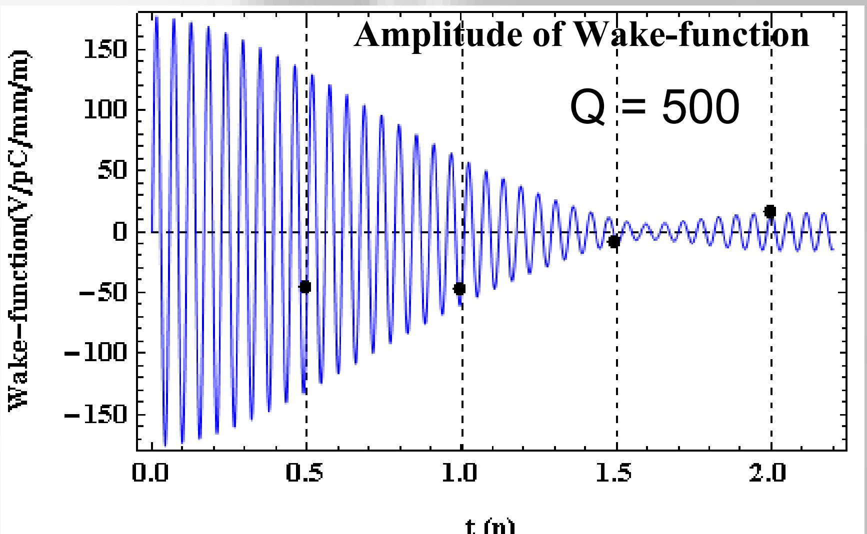


CLIC_DDS Uncoupled Design tied to CLIC_G Parameters

3. Gaussian distribution linked to CLIC_G parameters



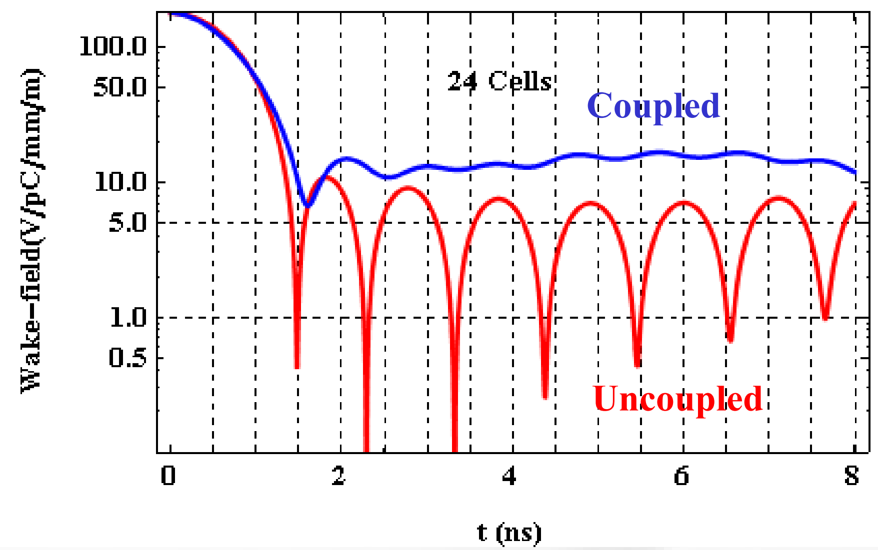


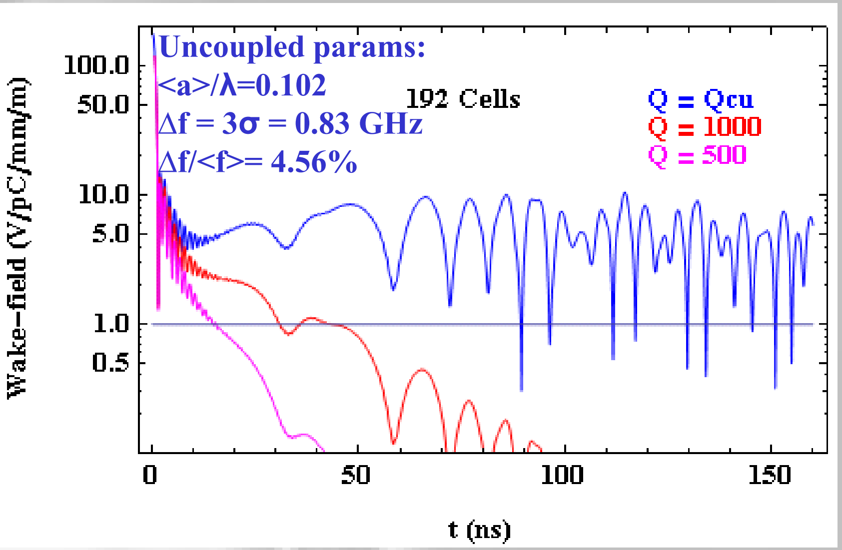


- Clearly the wake from the structure pinned to the CLIC_G parameters does not meet the design constraints!

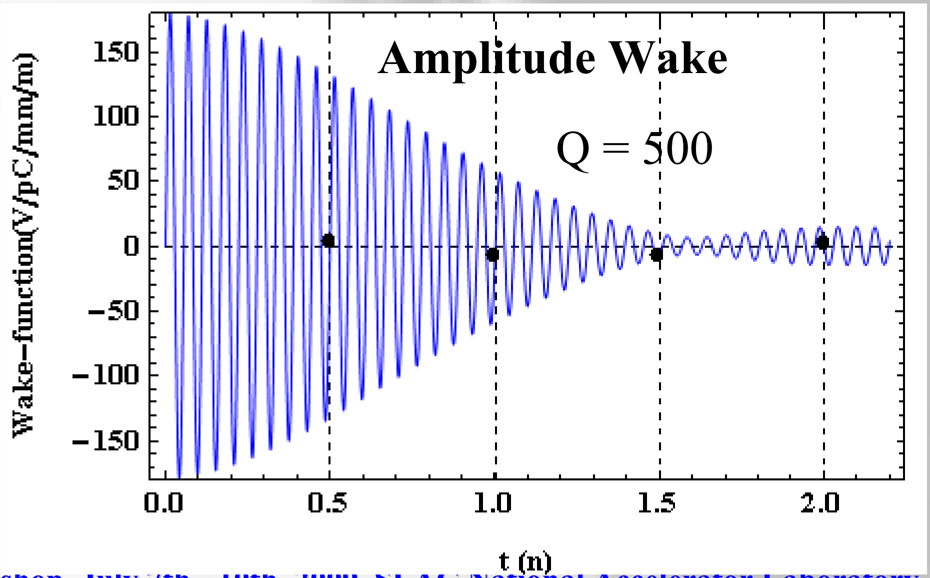
Ref: Khan and Jones, Proc. PAC09

3. Gaussian distribution linked to CLIC_G parameters



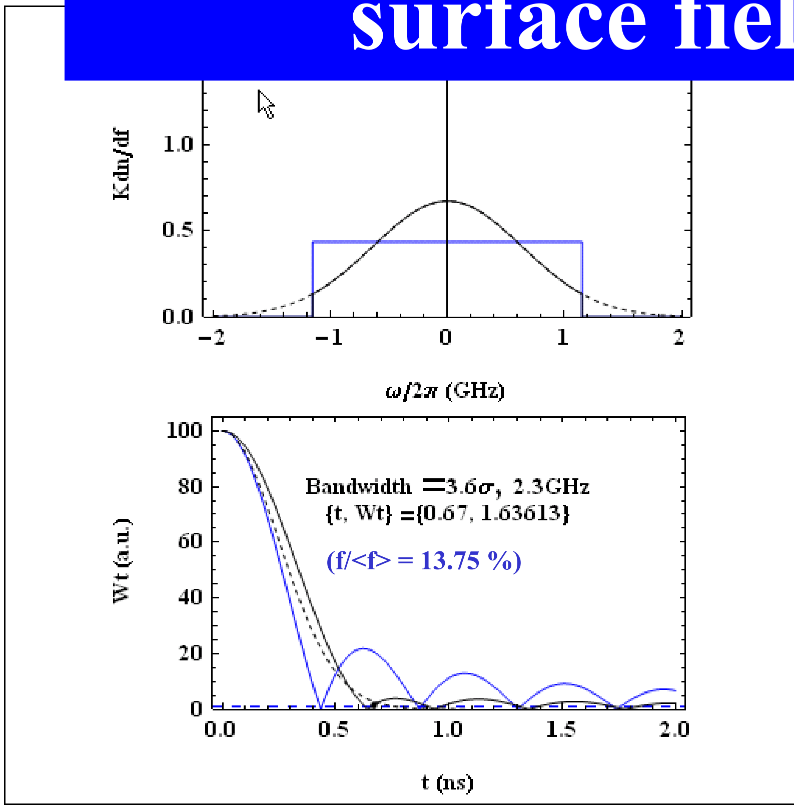


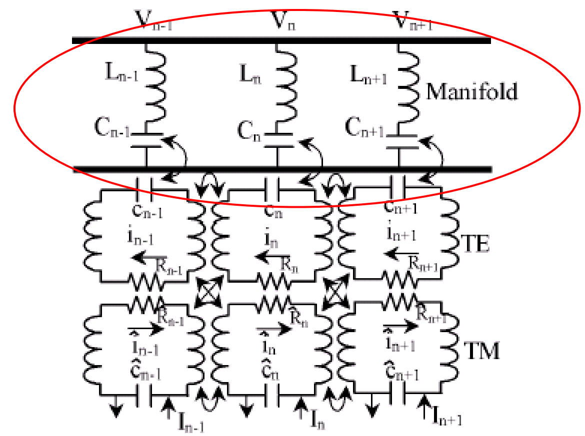
➢Systematically shift cell parameters (aperture and cavity radius) in order to position bunches at the zero crossing in the amplitude of the wake function.



➢Efficacy of the method requires a suite of simulations in order to determine the manufacturing tolerances.

4. Relaxed parameters tied to surface field constraints





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.

Uncoupled parameters

Cell 1

- Iris radius = 4.0 mm
- Iris thickness = 4.0 mm ,
- ellipticity = 1
- Q = 4771
- R'/Q = 1,1640 Ω/m
- vg/c = 2.13 %c

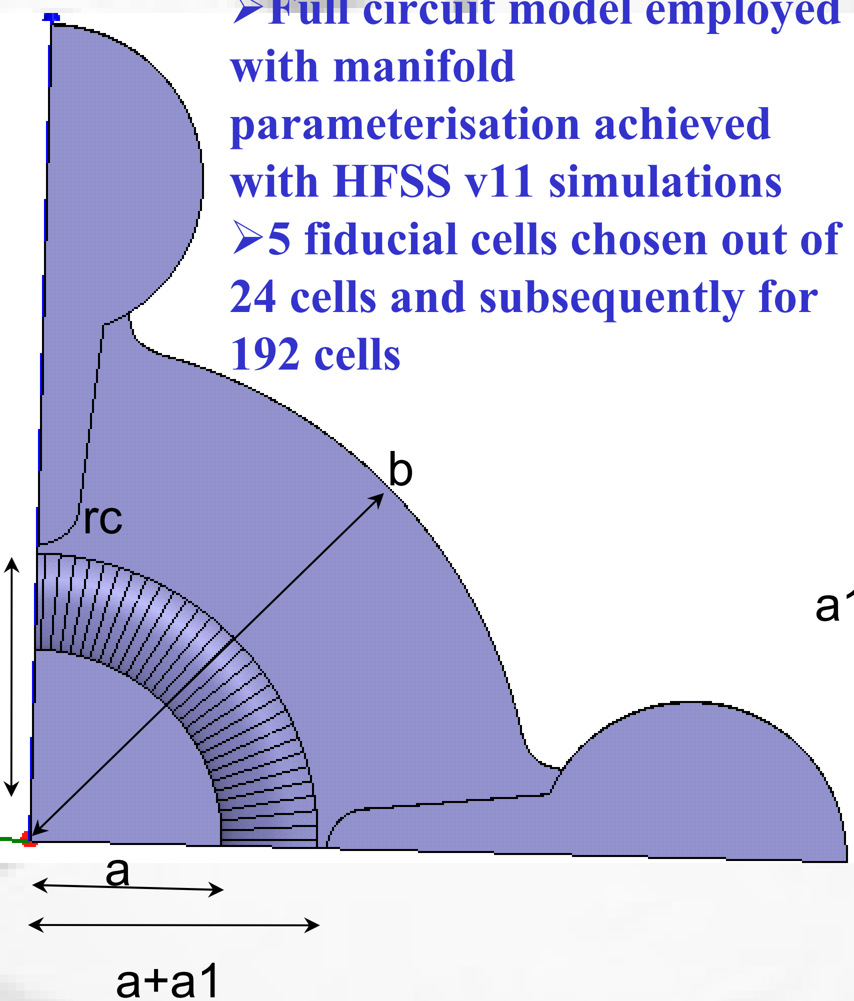
Cell 24

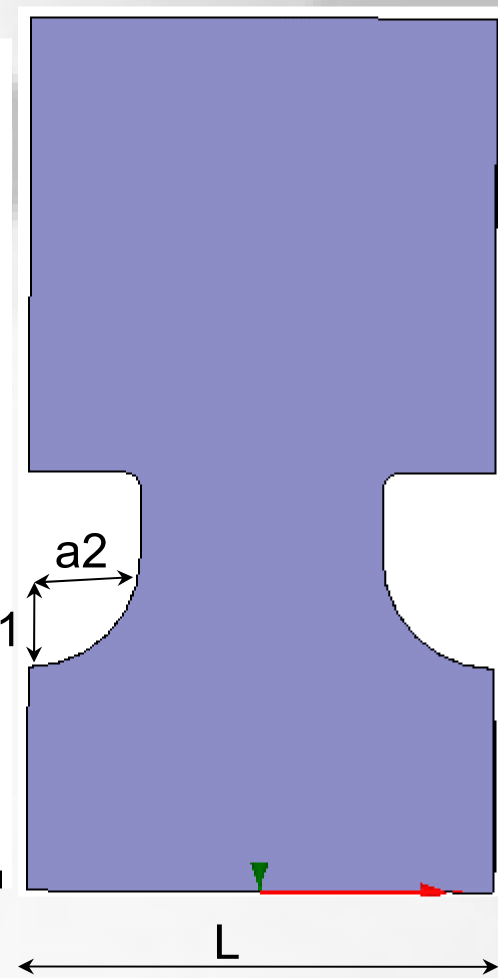
- Iris radius = 2.3 mm
- Iris thickness = 0.7 mm,
- ellipticity = 2
- Q = 6355
- R'/Q = 20,090 Ω/m
- vg/c = 0.9 %c

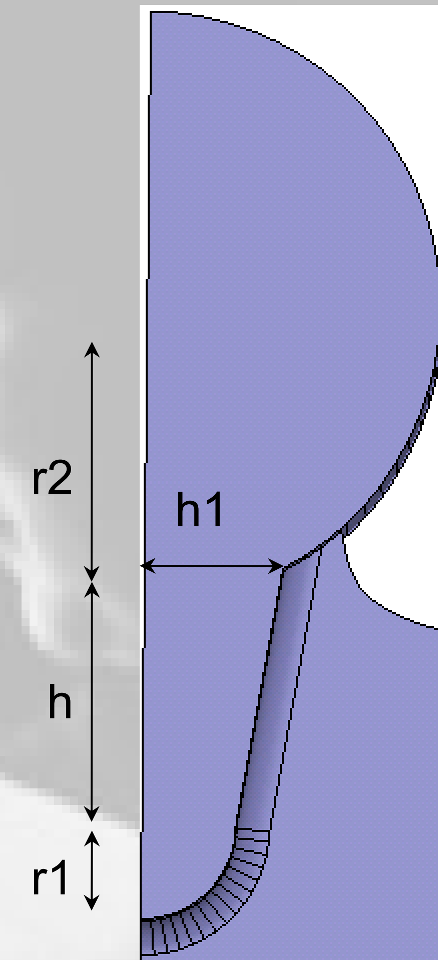
Cct Model Including Manifold-Coupling

4. Relaxed parameters tied to surface field constraints

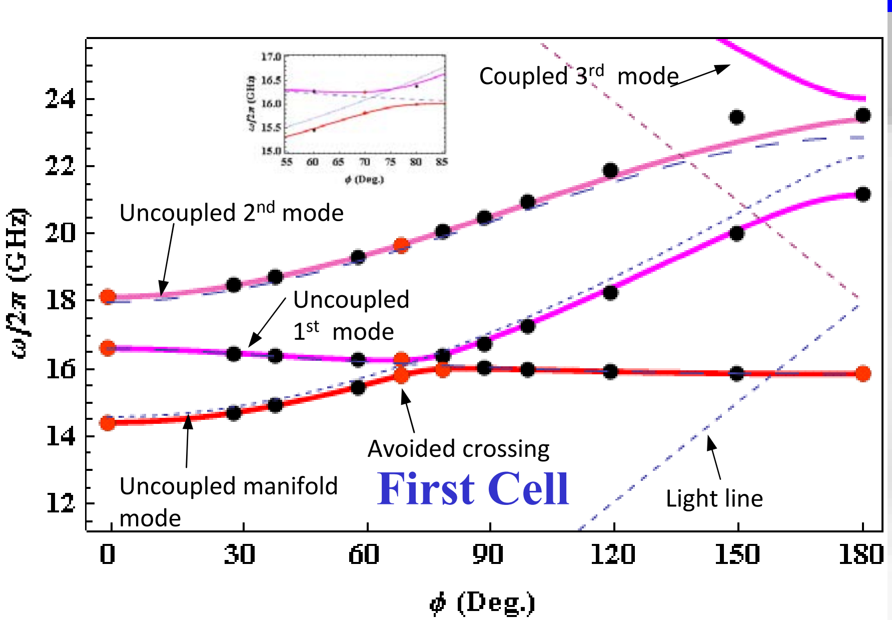
- Full circuit model employed with manifold parameterisation achieved with HFSS v11 simulations
- 5 fiducial cells chosen out of 24 cells and subsequently for 192 cells

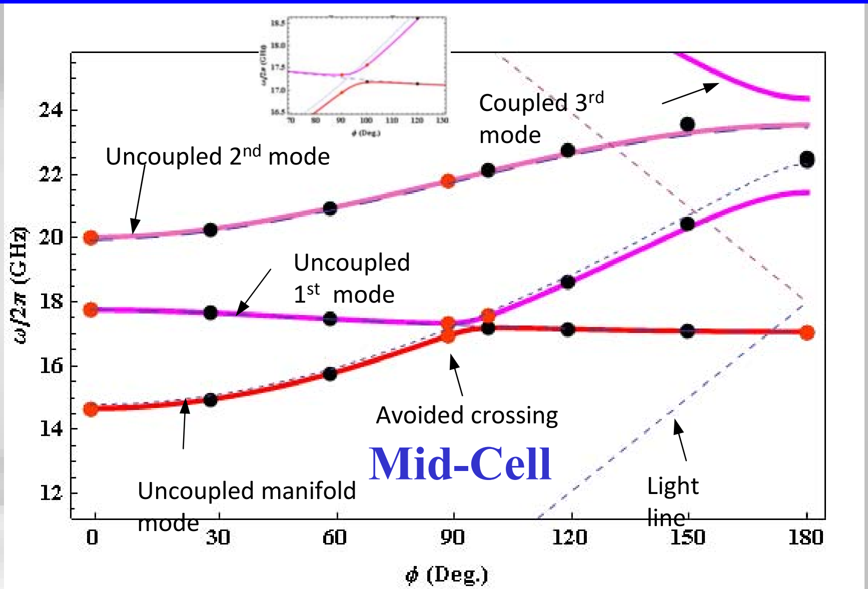




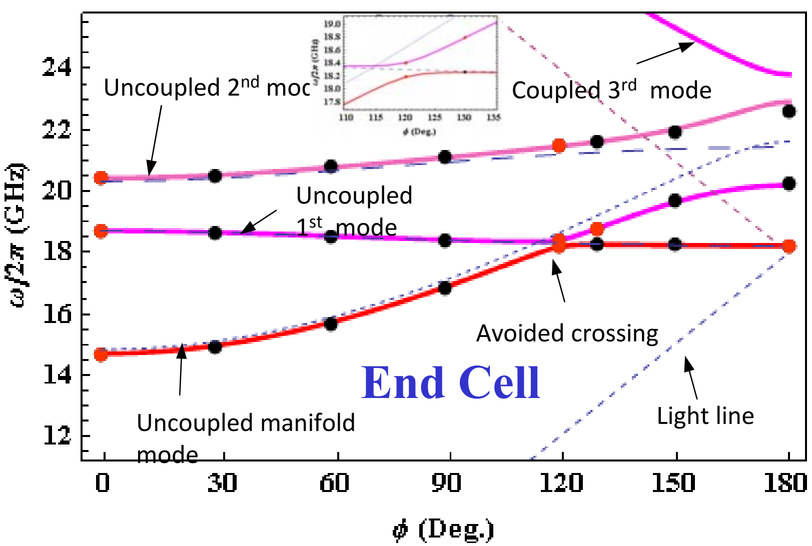


4. Relaxed parameters –full cct model

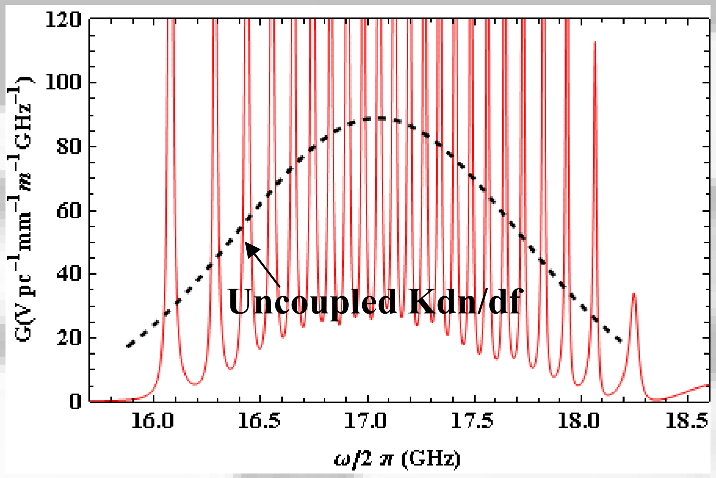




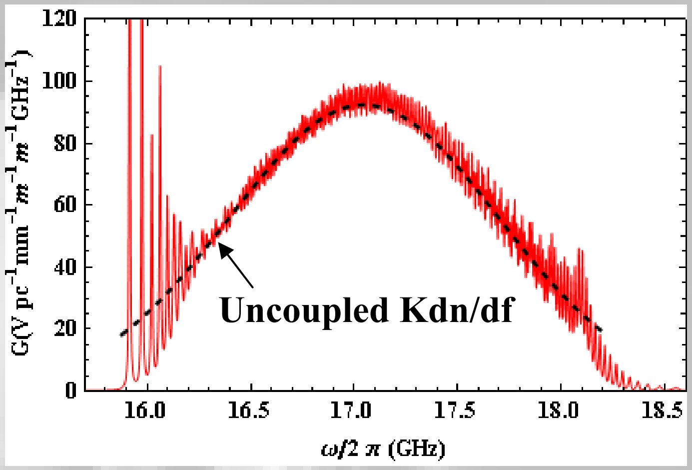
- Dispersion curves for select cells are displayed (red used in fits, black reflects accuracy of model)
- Provided the fits to the lower dipole are accurate, the wake function will be well-represented
- Spacing of avoided crossing (inset) provides an indication of the degree of coupling (damping Q)



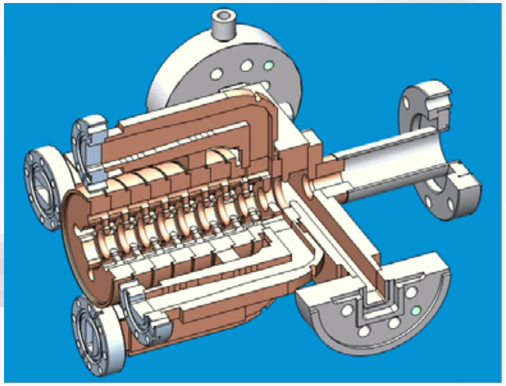
4. Relaxed parameters (RP)–Spectral fn.



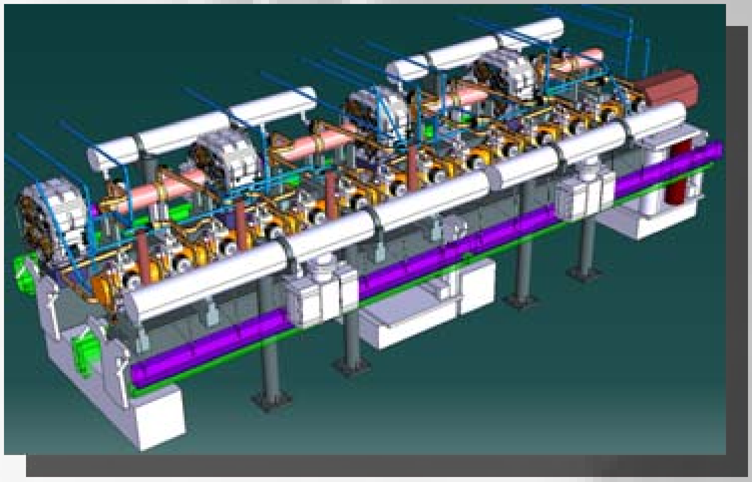
Single non-interleaved structure



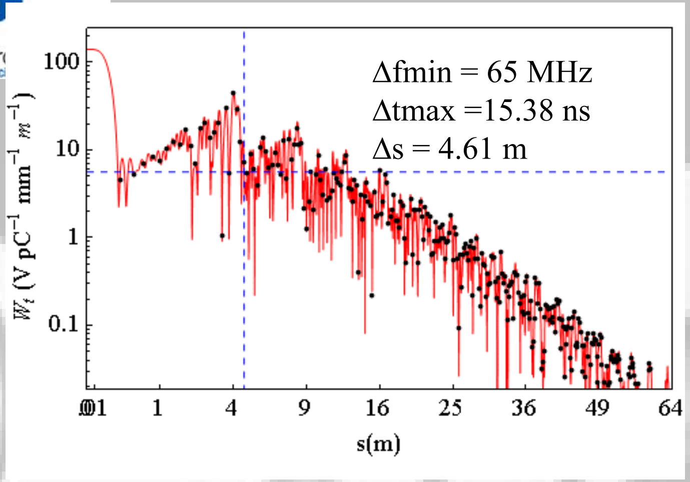
8-fold interleaved structure



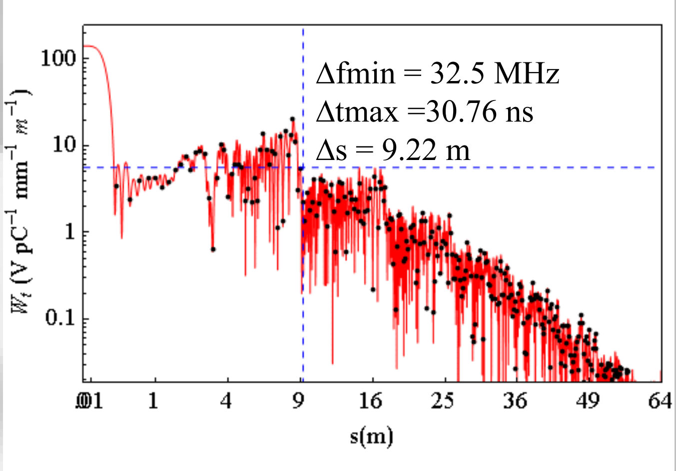
Potential Structure for CFT3 Module



Eight structures in each CTF3 module

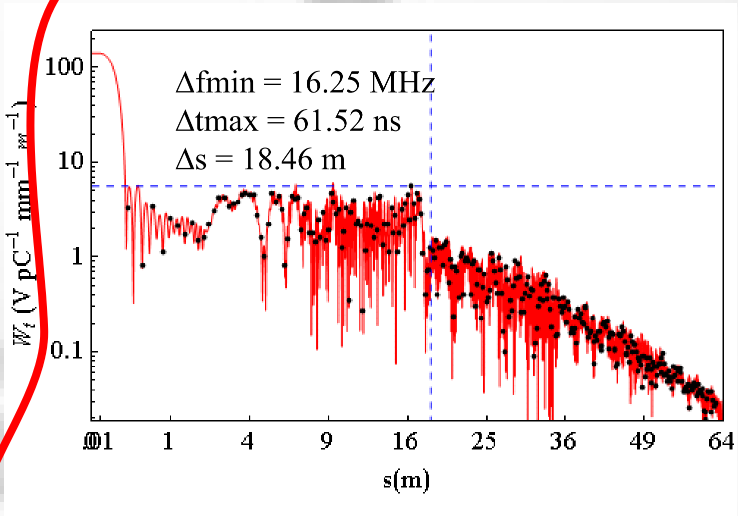


Single Structure Wake

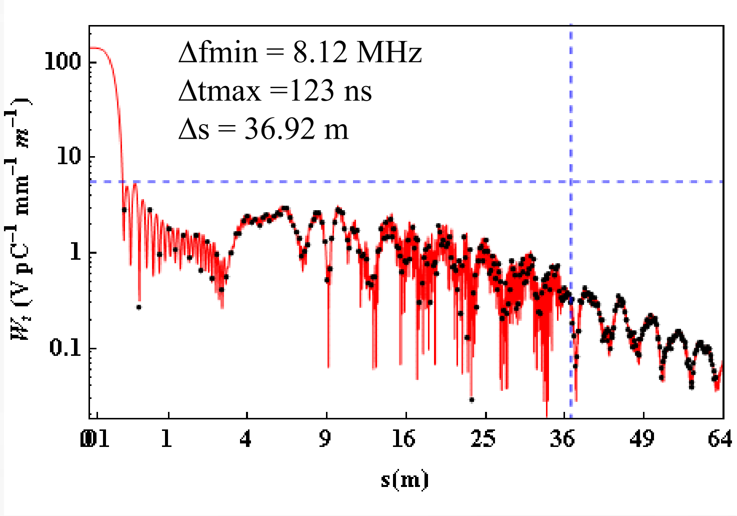


Two-fold interleaving

Fails design criterion!



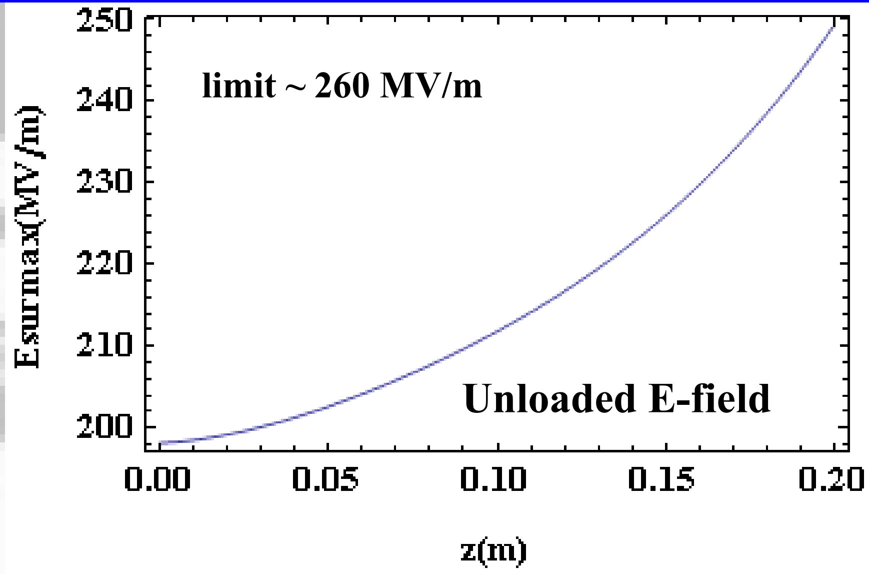
Four-fold interleaving

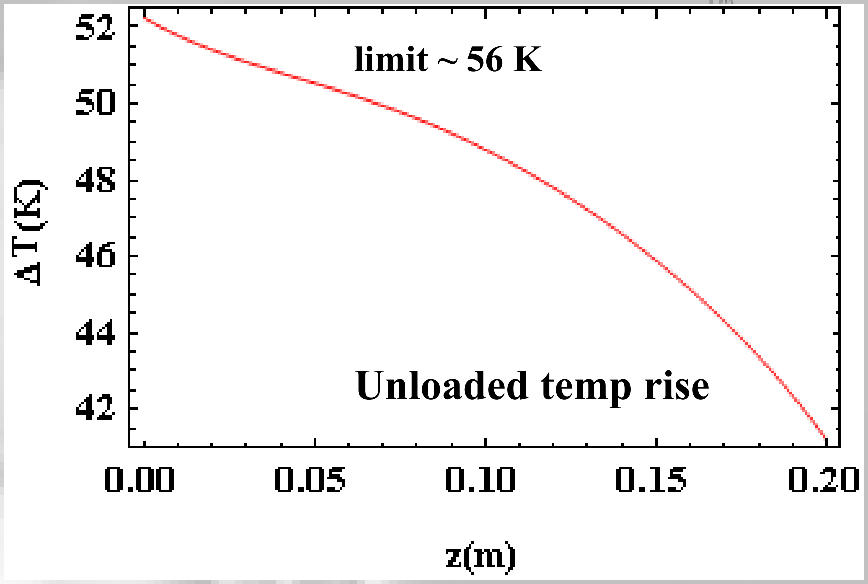


Eight-fold interleaving

Meets design criterion!

4. Relaxed parameters (RP)–Efficiency Calc.





$$\tau_p = t_b + t_{fill} + t_r - \left(t_{fill} \frac{(1-pp)}{2} + t_r \left(1 - \frac{pp}{2} \right) \right) = 246 \text{ ns}$$

$$\Delta T \propto \sqrt{\tau_p}$$

$$P_{in} = 74.5\text{MW}$$

$$pp = \frac{P_{out}^{L}}{P_{out}^{UL}} = \frac{21.12}{37.77} = 0.56$$

$$t_b = \frac{8 \times 312}{11.9942} = 208.1 \text{ ns}$$

$$t_{fill} = 40 \text{ ns}$$

$$t_r \sim 23 \text{ ns}$$

$$\eta_{CLIC\_DDS} = \frac{\text{beamenergy}}{\text{pulseenergy}} = \frac{I < Eacc > L\ t_b}{P_{in}\left(t_b + t_r + t_{fill}\right)}$$

$$\Rightarrow \boxed{\eta_{CLIC\_DDS} = 23.4\%} \quad @\ I = 1.13 \text{ A}$$

$$\boxed{\eta_{CLIC\_G} = 27.7\%} \quad @\ I = 1.19\text{A}$$

Initial, non-optimised!

Ref: A. Grudiev, CLIC-ACE, JAN 08

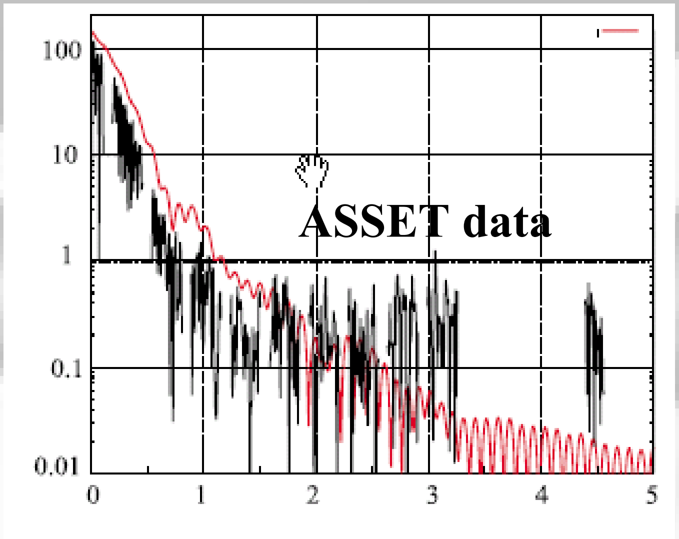
4. Concluding remarks

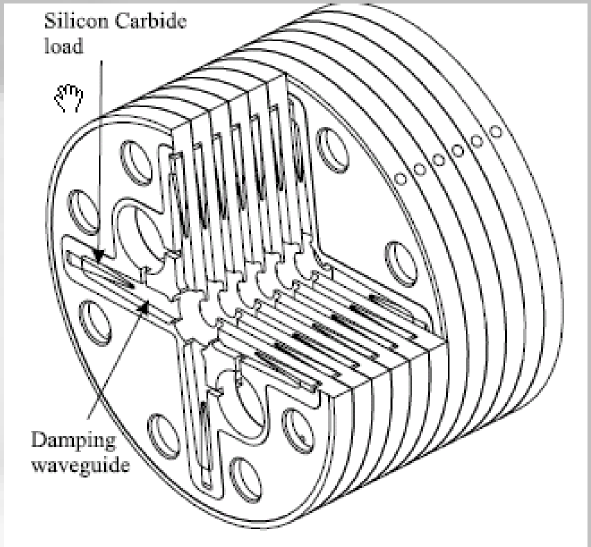
- The last two designs (ZC and RP) both meet both the beam dynamics and the breakdown constraints

- The design closely tied to the CLIC_G design requires the bunches to be located on the avoided crossing in the wake. This will need a comprehensive set of beam dynamics simulations in order to ensure realistic manufacturing tolerances are achievable.

- The modified design with relaxed parameters meets both constraints and in particular with full interleaving, experience with NLC/GLC structures leads us to conclude it *will lead to relaxed manufacturing tolerances*. These initial simulations are in the process of being optimised (efficiency enhancement calcs.)

- These new designs should be verified with experimental testing of wake function (revive ASSET??)

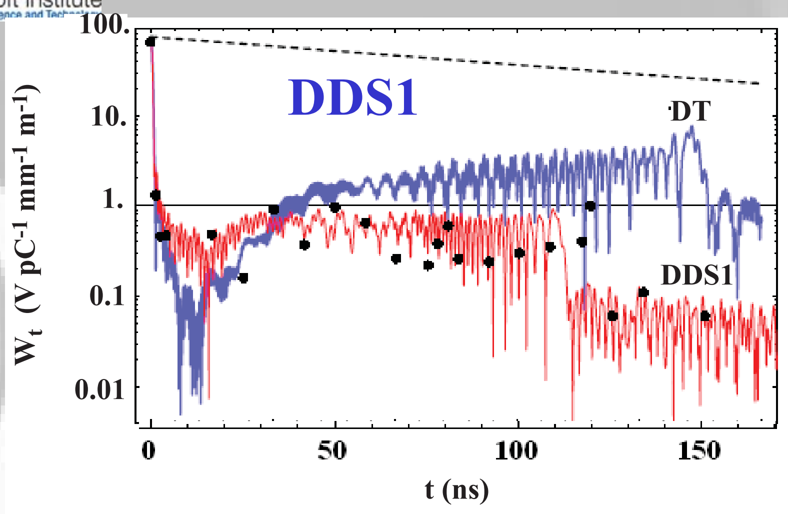


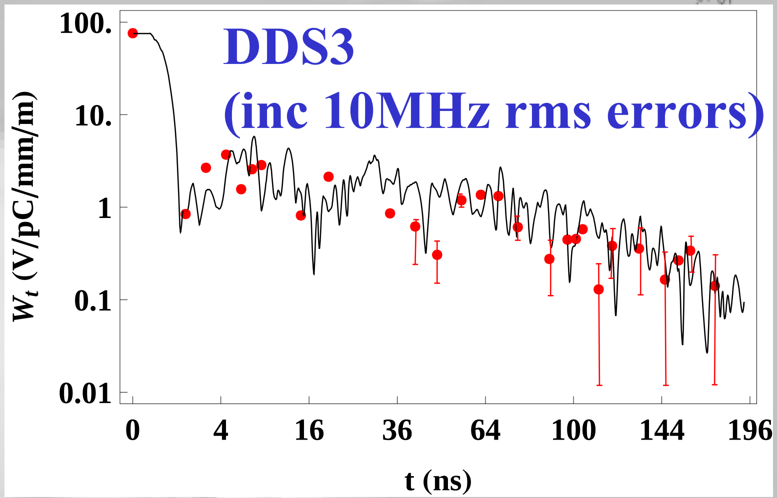


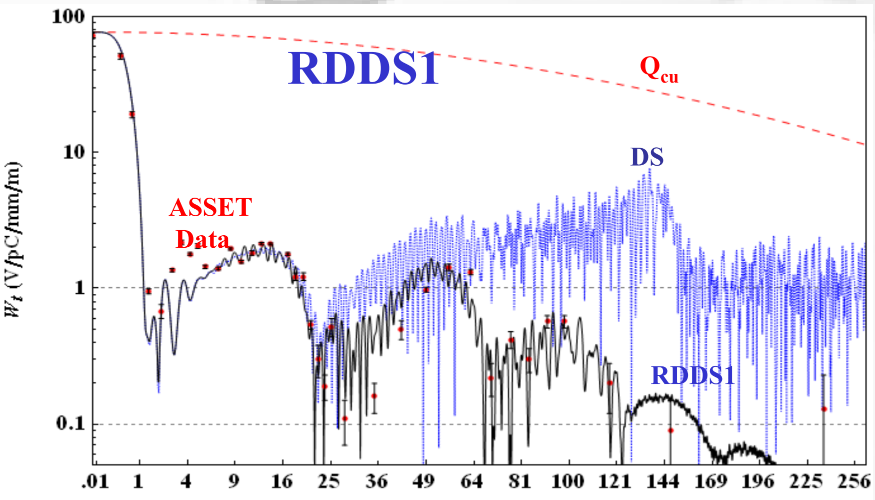
CLIC 30 GHz TDS Prediction vs Exp

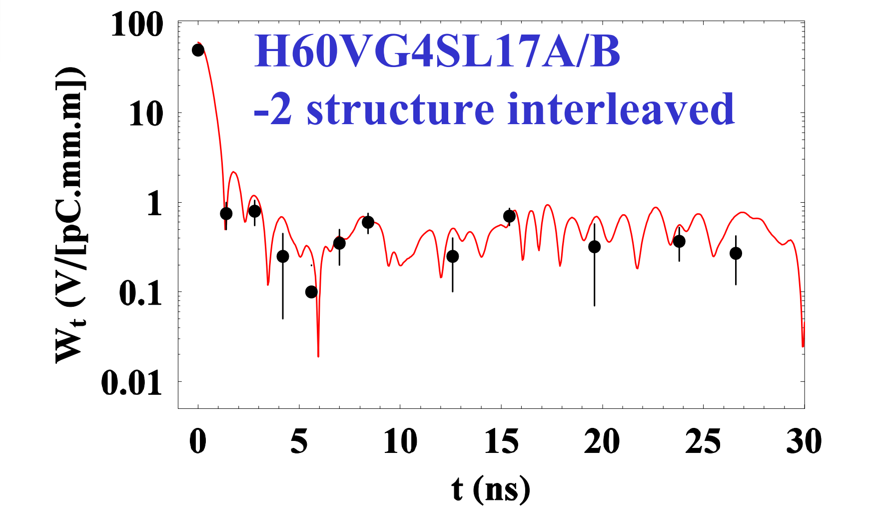
- **Good agreement achieved up to ~ 2 ns**
- **Resonance, not included in prediction simulations, at 7.6 GHz, *external* to structure leads discrepancy between theory/exp.**

Ref: I. Wilson et al., Proceedings of the 2000 European Particle Accelerator Conference (EPAC00), Vienna, Austria, 2000

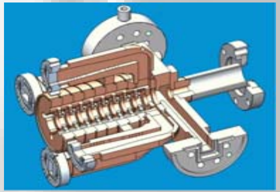








Conspectus of NLC/GLC Wake Function Prediction and Measurement (ASSET dots)



Refs: 1. R.M. Jones,et al, New J.Phys.11:033013,2009. 2. R.M. Jones et al., Phys.Rev.ST Accel. Beams 9:102001, 2006.