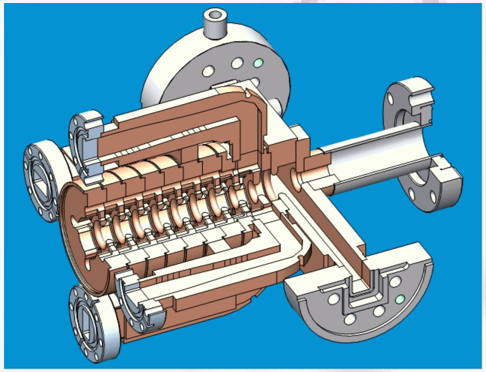
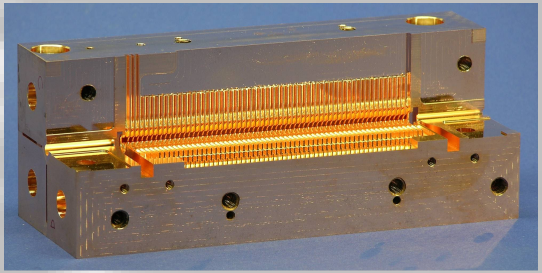
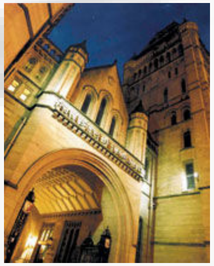
Wakefield Suppression for CLIC – A Manifold Damped and Detuned Structure

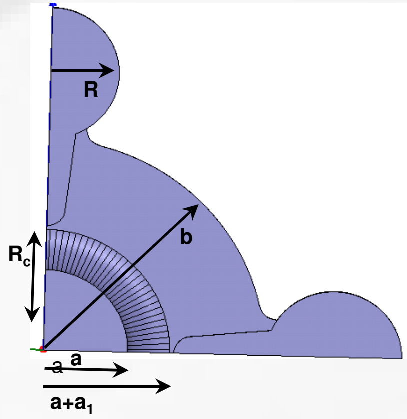


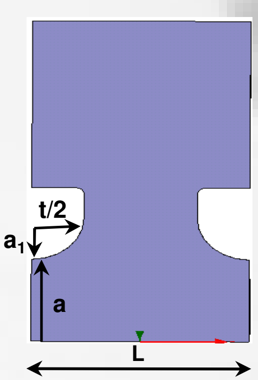
Roger M. Jones

Cockcroft Institute and The University of Manchester









CLIC09 Workshop, October 12th - 15th, 2009, CERN

Wake Function Suppression for CLIC -Staff

- Roger M. Jones (Univ. of Manchester faculty)
- Alessandro D'Elia (Dec 2008, Univ. of Manchester PDRA based at CERN)
- Vasim Khan (Ph.D. student, Sept 2007)
- Part of EuCard (European Coordination for Accelerator Research and Development) FP7 NCLinac Task 9.2

V. Khan, CI/Univ. of Manchester Ph.D. student pictured at EPAC 08

A. D'Elia, CI/Univ. of Manchester PDRA based at CERN (former CERN Fellow).

- Collaborators: W. Wuensch, A. Grudiev (CERN)

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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. Single-structure based on the eight-fold interleaved for HP testing.*
5. Concluding remarks

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

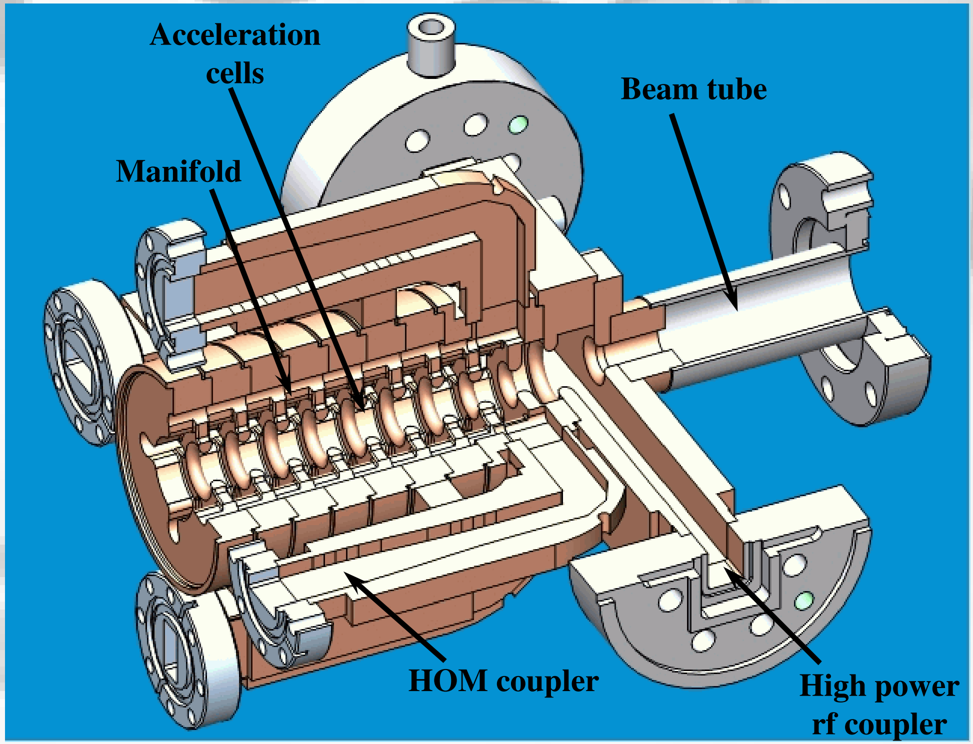
➢The present CLIC structure relies on linear tapering of cell parameters and heavy damping with a Q of ~10.

➢Wake function suppression 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

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1) RF breakdown constraint

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

2) Pulsed surface temperature heating

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

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

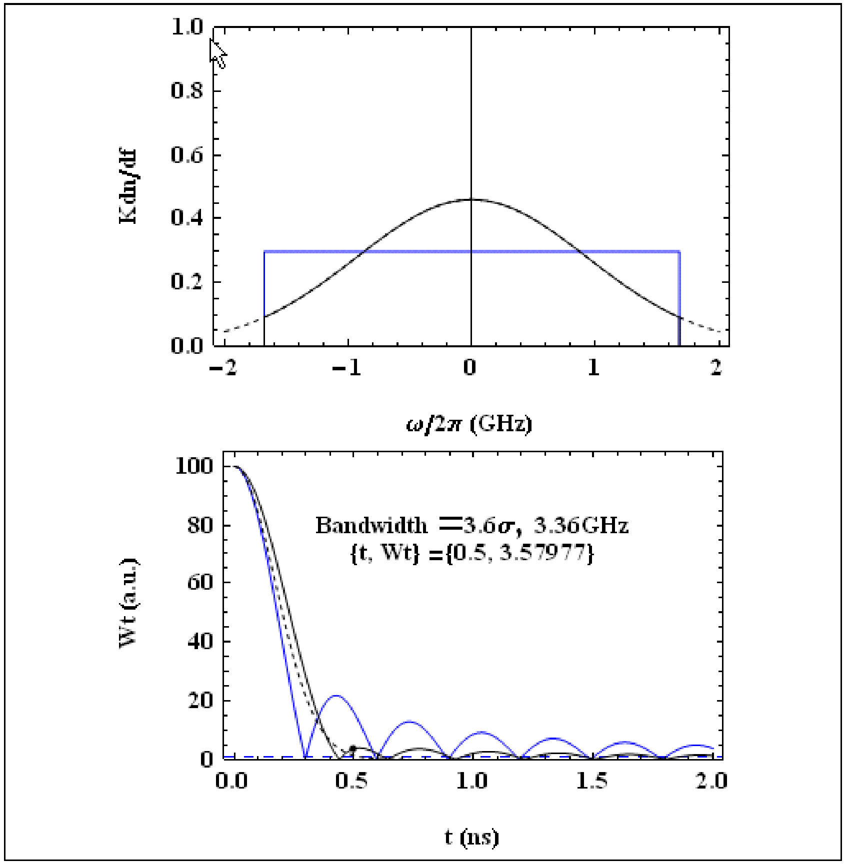
$$W_{t1} \le \frac{6.667 \times 4 \times 10^9}{N} (V/[pC.mm.m])$$

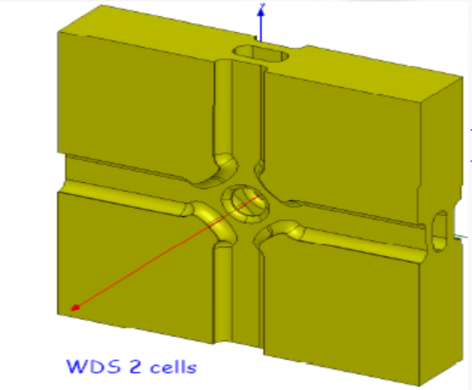
Wake experienced by successive bunches must also be below this criterion

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:
Δf ~ 1GHz
Q~ 10

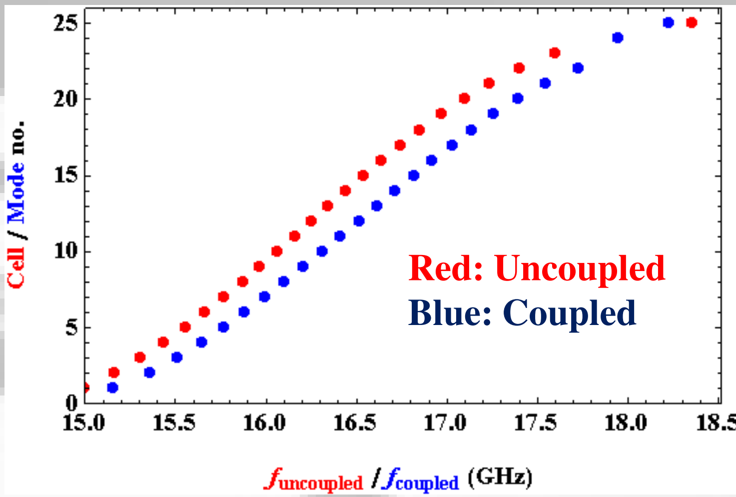
Truncated Gaussian :

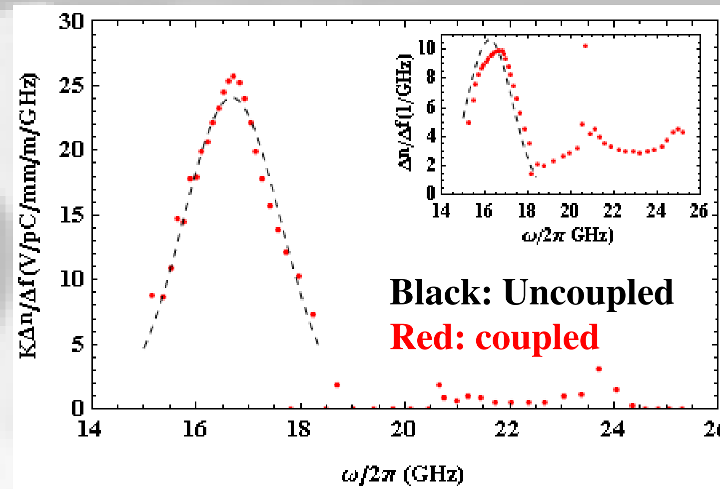
$$W_t = 2\bar{K}e^{-2(\sigma\pi t)^2}\left|\chi(t,\Delta f)\right|$$

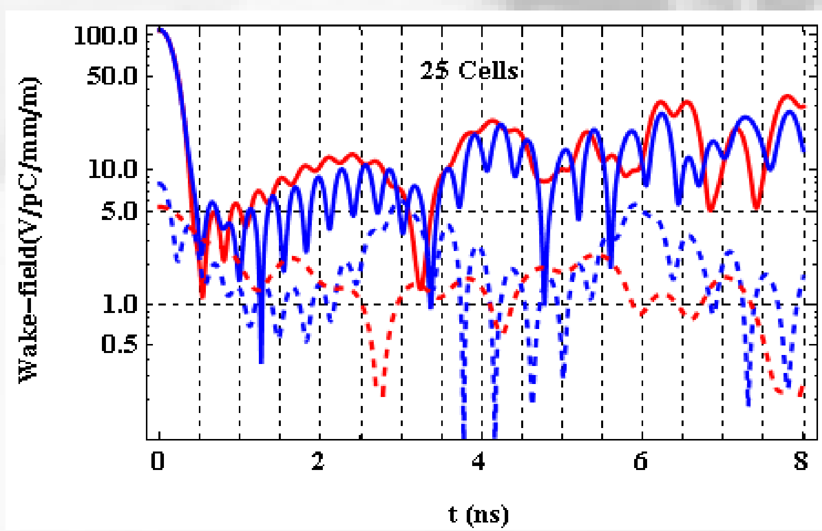
$$\text{where}: \quad \chi(t,\Delta f) = \frac{\mathrm{Re}\left\{\mathrm{erf}\left(\left[n_\sigma - 4i\pi\sigma t\right]/2\sqrt{2}\right)\right\}}{\mathrm{erf}\left(n_\sigma/2\sqrt{2}\right)}$$

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

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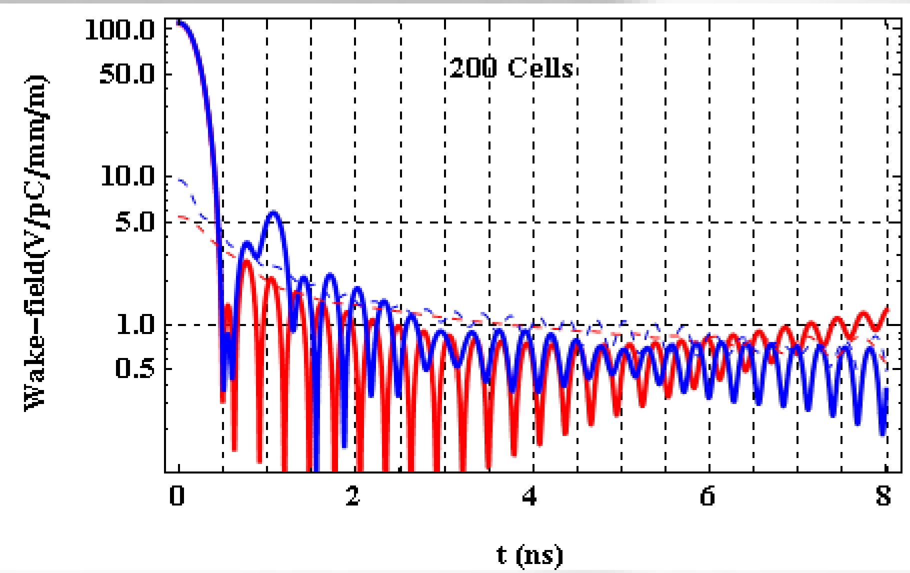
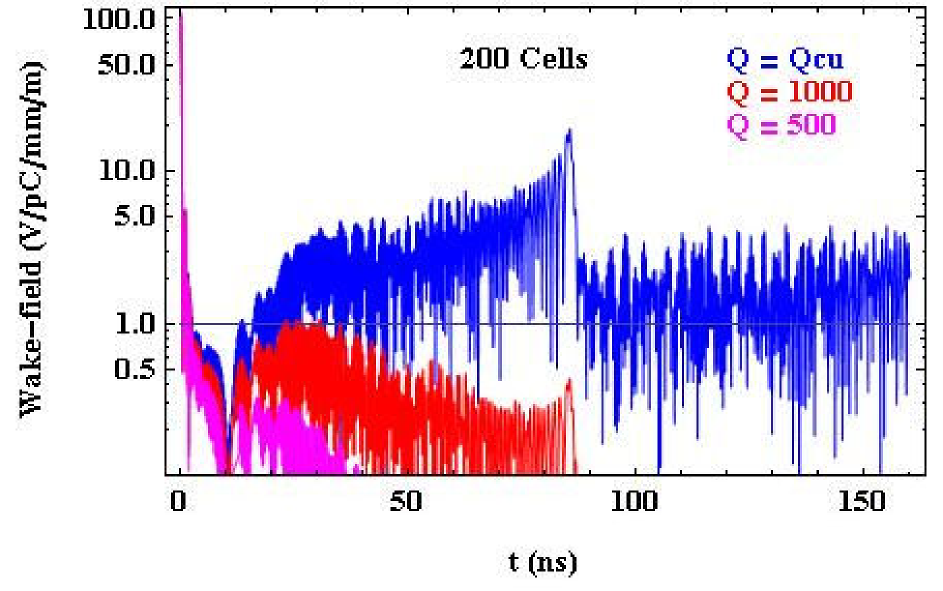




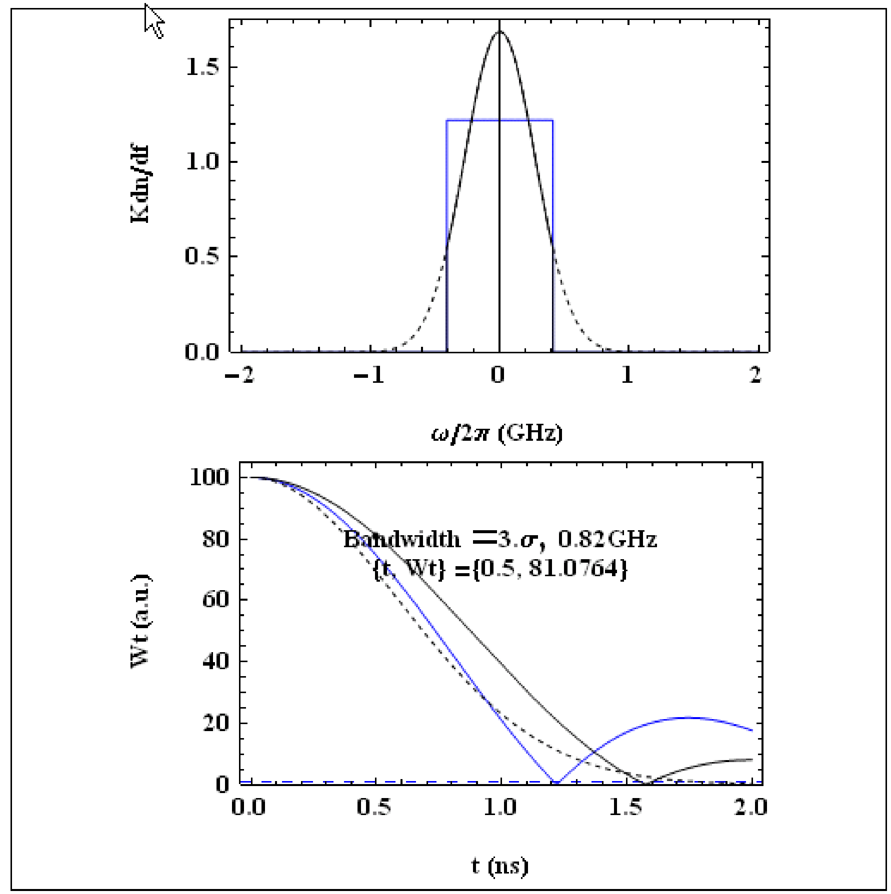
First dipole Uncoupled, coupled.
Dashed curves: second dipole

- **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:

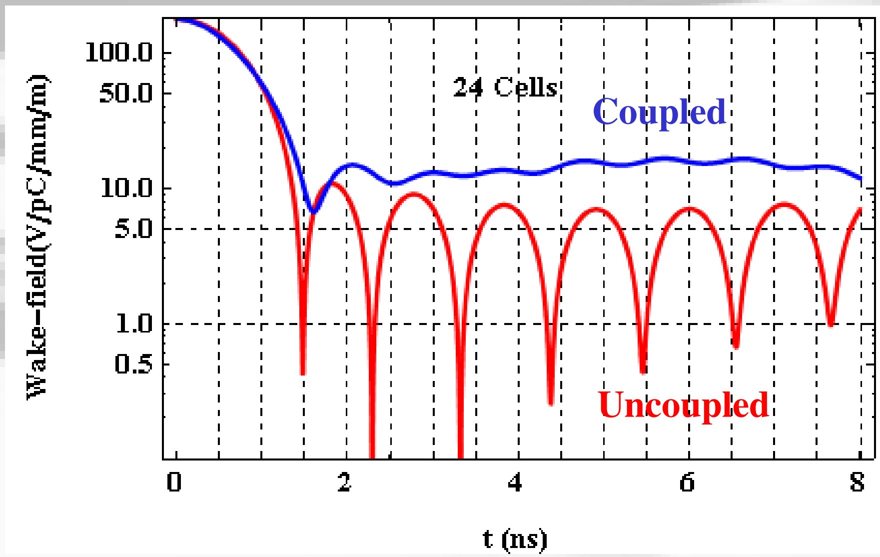
$\langle a \rangle/\lambda = 0.11$

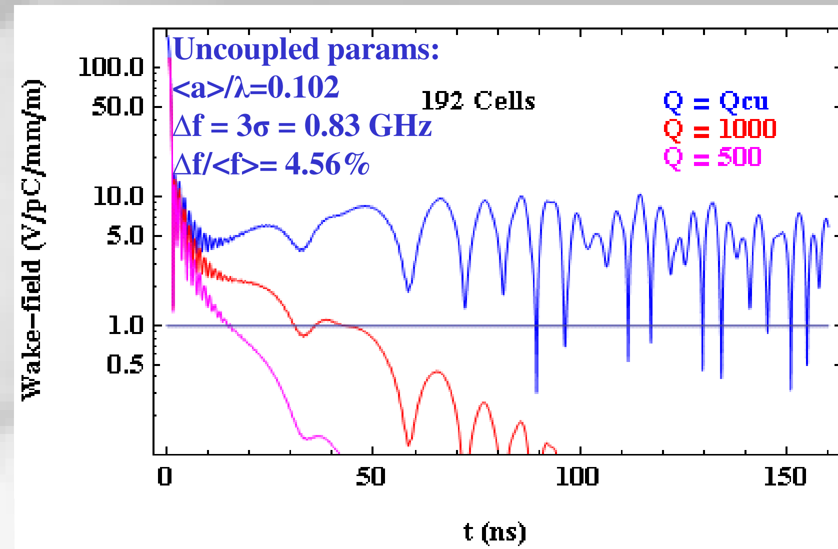
$\Delta f = 3\sigma \sim 0.82$ GHz

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

CLIC_DDS Uncoupled Design tied to CLIC_G Parameters

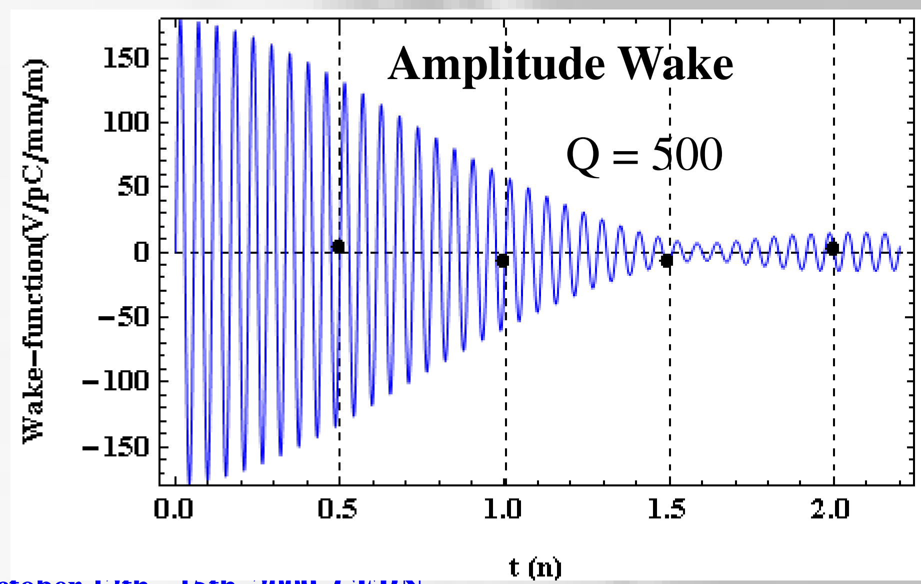
3. Gaussian distribution linked to CLIC_G parameters



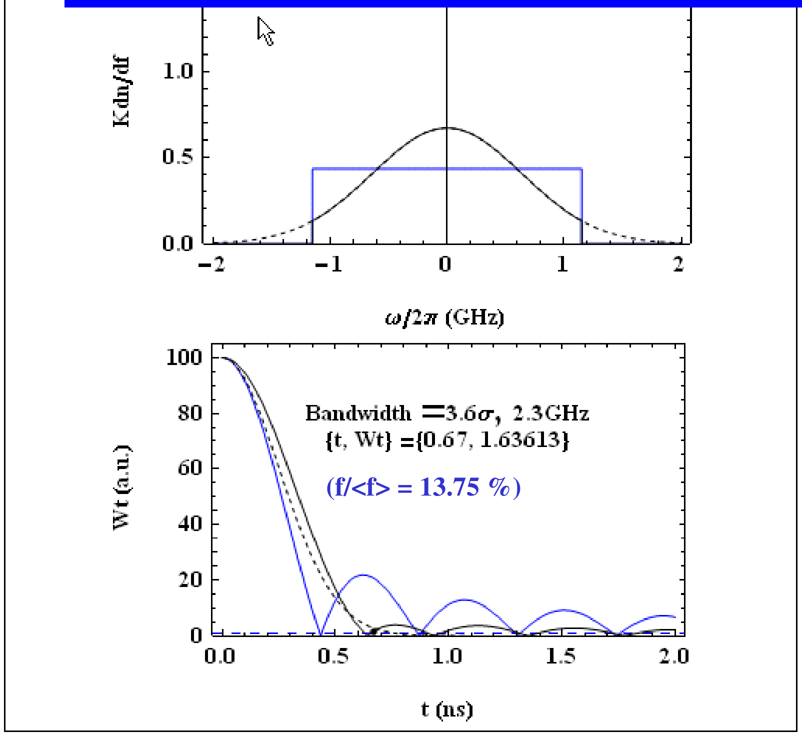


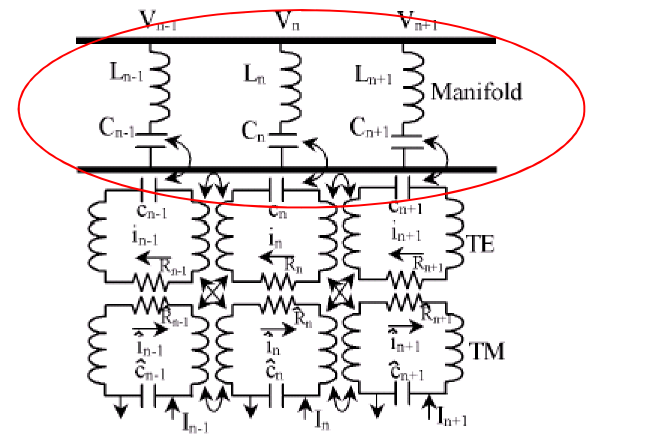
- Systematically shift cell parameters (aperture and cavity radius) in order to position bunches at the zero crossing in the amplitude of the wake function.

- Efficacy of the method <u>requires a suite of simulations in order to determine the manufacturing tolerances</u>.



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 = 11,640 Ω/m
- vg/c = 2.13 %c

Cell 24

- Iris radius = 2.13 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. RF Efficiency: CLIC_G vs CLIC_DDS

CLIC_G structure (~0.8 GHz)**:**

- <a>/λ=0.11, from beam dynamics constraints ~3.72 x 10^9 particles per bunch
- Heavy damping allows an inter bunch spacing ~0.5 ns.
- This leads to about 1 A beam current and rf –to-beam efficiency of ~28%.

$$I = \frac{3.72\times10^{9}\times1.6\times10^{-19}}{\frac{6}{11.9942\,\text{GHz}}} = 1.19\,\text{A}$$

$$W_T^{limit} = \frac{10\times100\times4\times10^{9}}{150\times3.72\times10^{9}} = 7.1\,\text{V/pc/mm/m}$$

CLIC_DDS structure (~2.3 GHz):

- <a>/λ=0.126, and 4.5x10^9 particles
- Moderate Q~500 imposed an inter bunch spacing of 8 cycles (~ 0.67 ns).

$$I = \frac{4.75\times10^{9}\times1.6\times10^{-19}}{\frac{8}{11.9942\,\text{GHz}}} = 1.13\,\text{A}$$

$$W_T^{limit} = \frac{10\times100\times4\times10^{9}}{150\times4.75\times10^{9}} = 5.6\,\text{V/pc/mm/m}$$

- Bunch spacing is increased in CLIC_DDS
- Beam current is compensated for by increasing the bunch population (subject to beam dynamics constraints) and hence the rf-to-beam efficiency of the structure is not affected significantly.

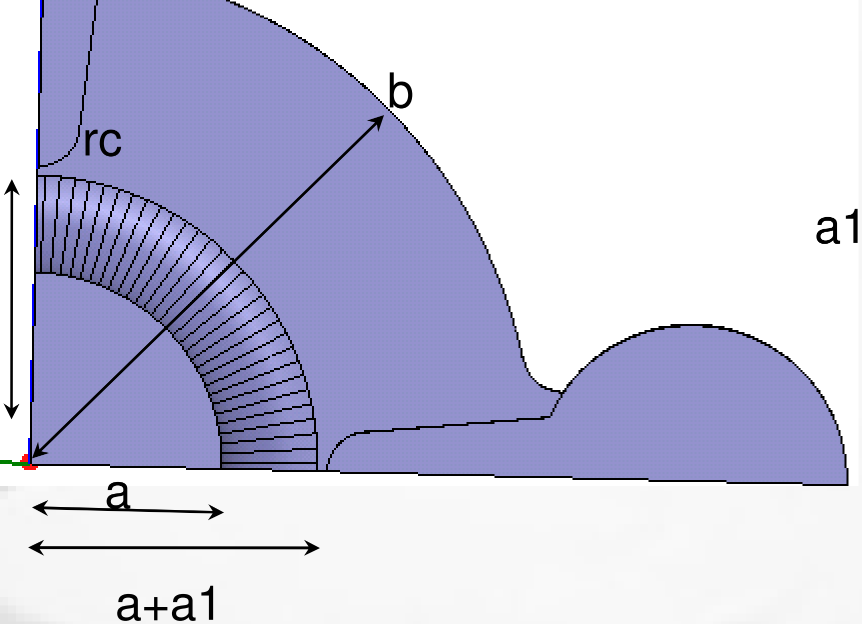
4. RF Summary

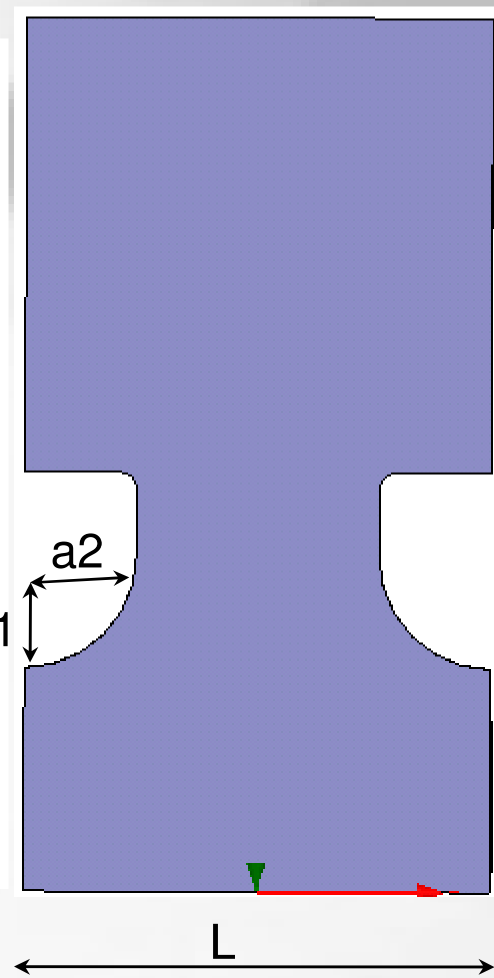
Parameters	CLIC_G (Optimised) [1,2]	CLIC_DDS (Sparse sampled, Single structure)	CLIC_DDS (8-fold interleaved)
Bunch space (rf cycles/ns)	6/0.5	8/0.67	**8/0.67**
Limit on wake (V/pC/mm/m)	7.1	5.6	**5.3***
Number of bunches	312	312	**312**
Bunch population (10^9)	3.72	4.7	**5.0***
Pulse length (ns)	240.8	273	**272.2***
Fill time (ns)	62.9	42	**40.8***
Pin (MW)	63.8	72	**75.8***
Esur max. (MV/m)	245	232	**236**
Pulse temperature rise (K)	53	47.3	**51**
RF-beam-eff.	27.7	26.6	**26.7***
Figure of merit (a.u.)	9.1	8.41	**8.29***

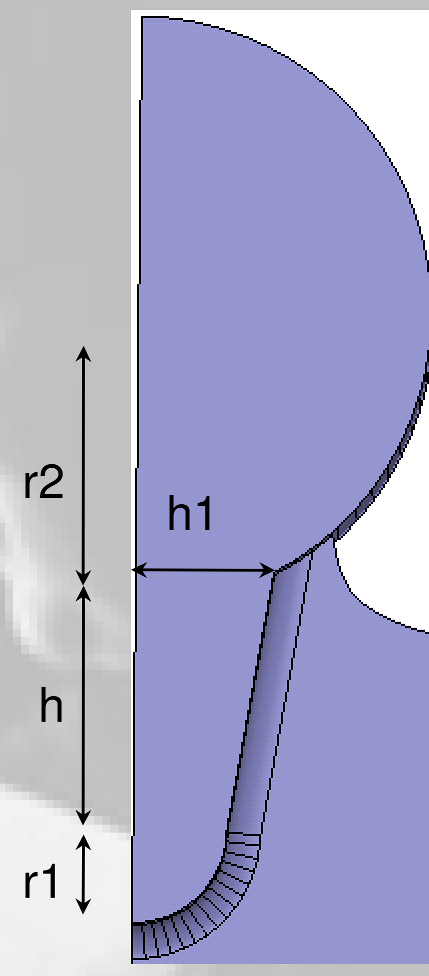
[1] A. Grudiev, CLIC-ACE, JAN 08
[2] H. Braun, CLIC Note 764, 2008
*** Mean value of 8 structures**

4. Relaxed parameters tied to surface field constraints

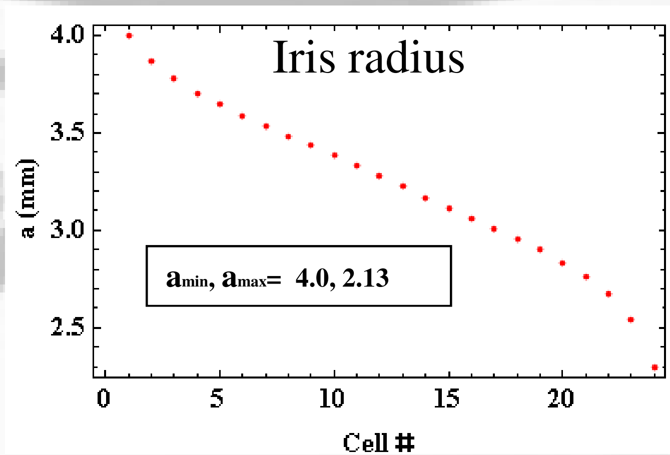
- Full circuit model employed with manifold parameterisation achieved with HFSS v11 simulations
- 7 fiducial cells chosen out of 24 cells and subsequently for 192 cells

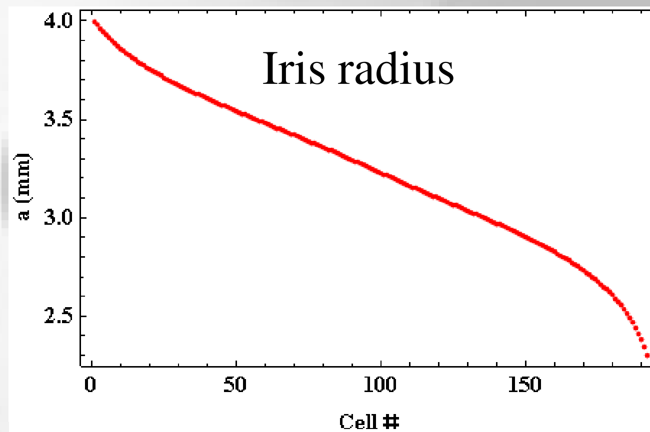


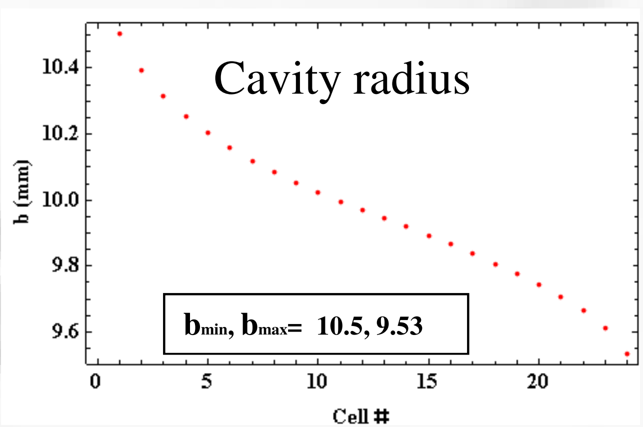


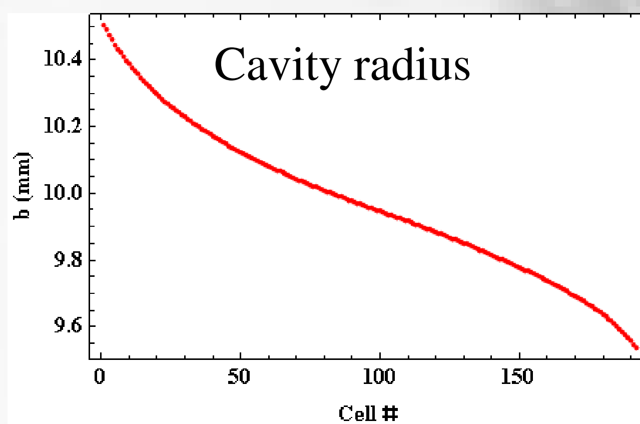


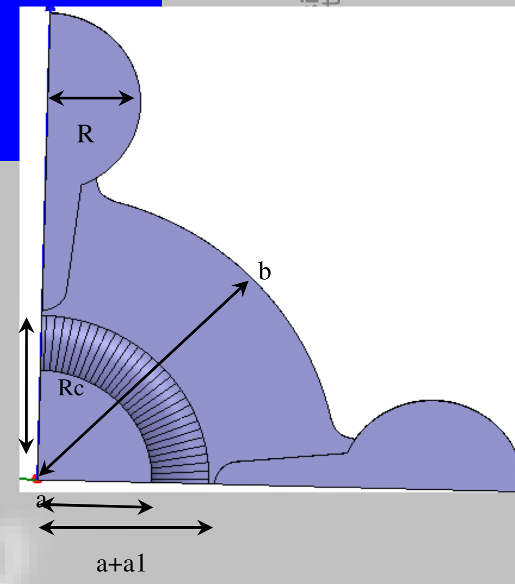
4. Structure Geometry: Cell Parameters

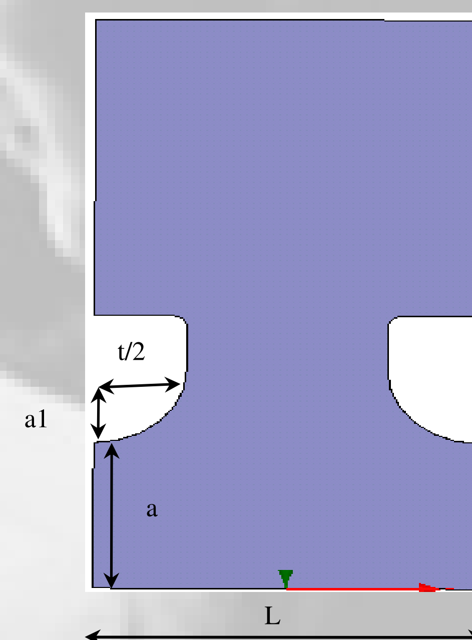








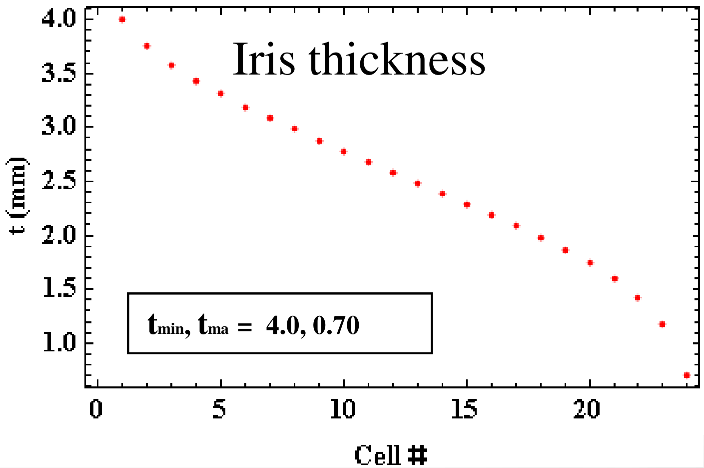


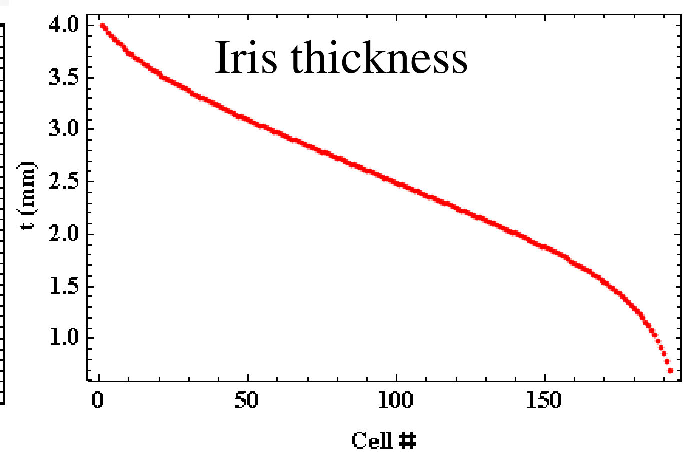


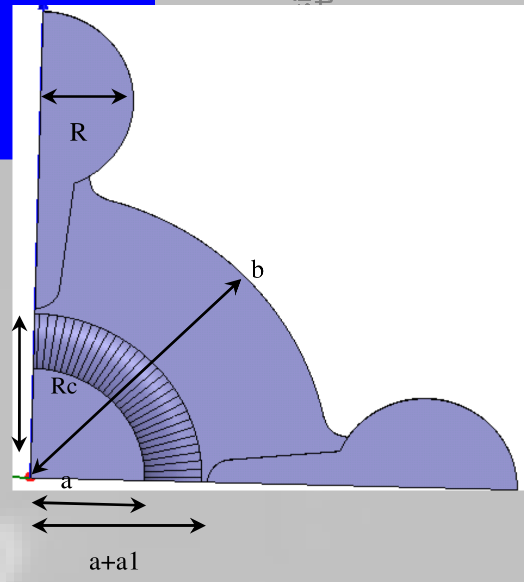
Sparse Sampled HPT
(High Power Test)

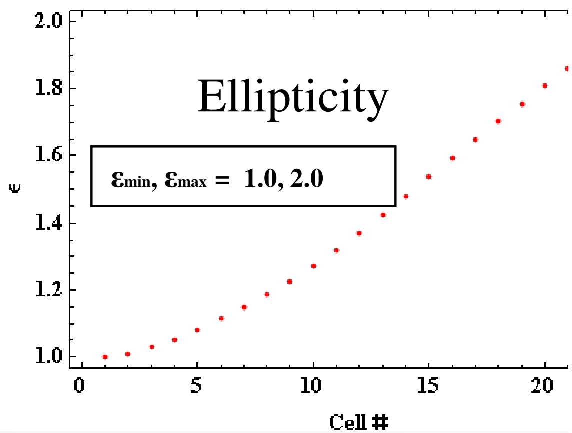
Fully Interleaved
8-structures

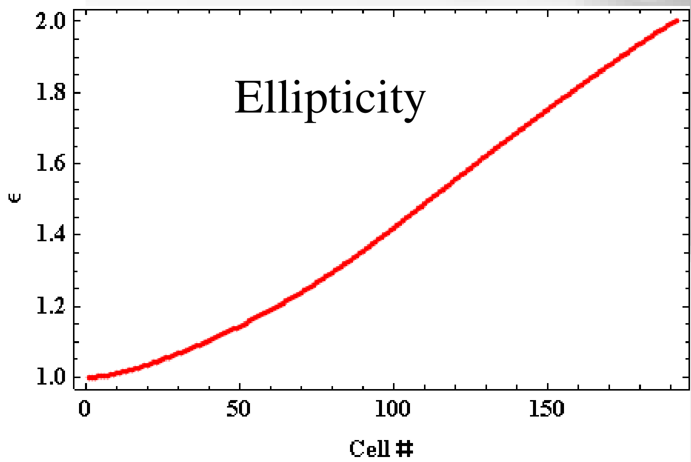
4. Structure Geometry: Cell Parameters

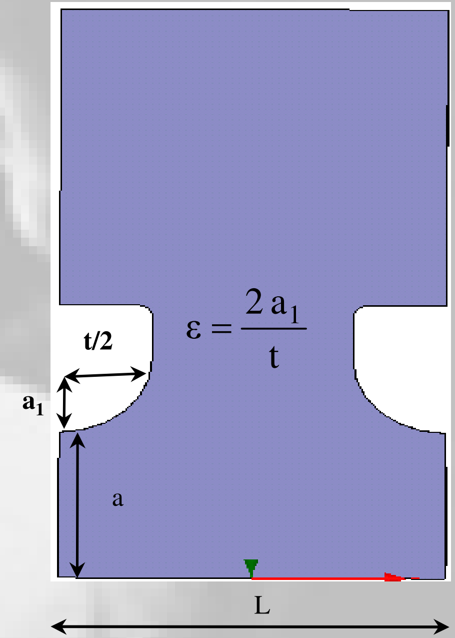








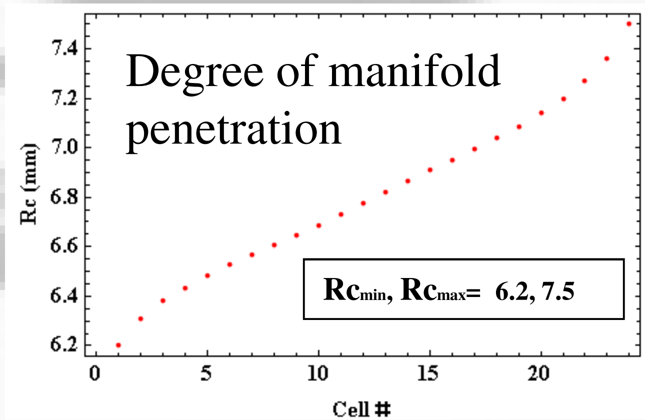


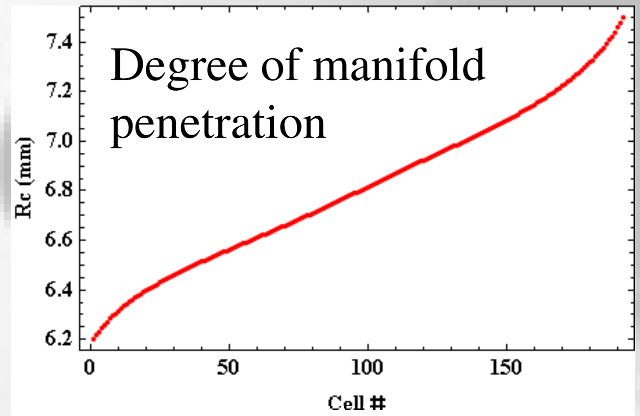


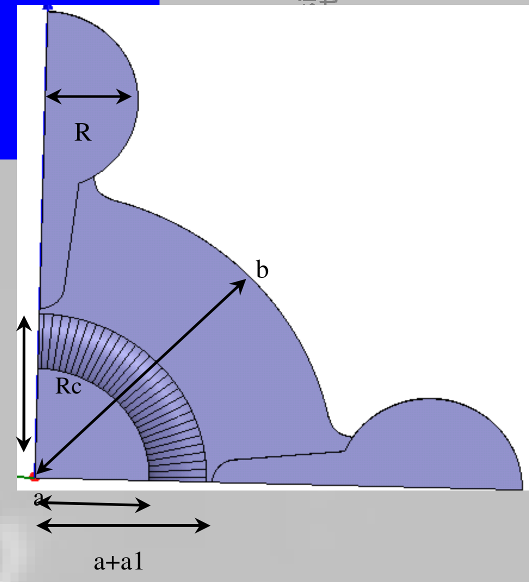
Sparse Sampled HPT (High Power Test)

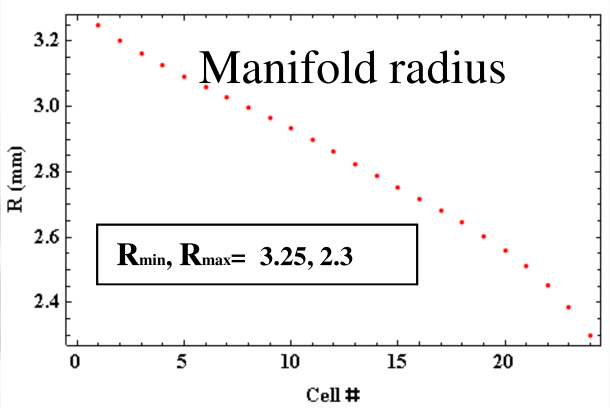
Fully Interleaved 8-structures

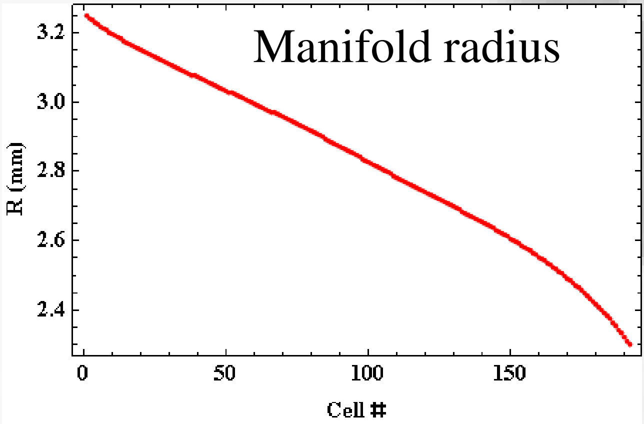
4. Structure Geometry: Manifold Parameters

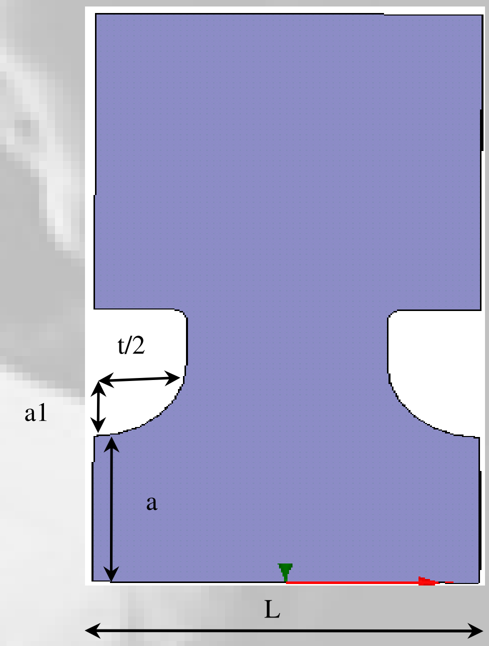








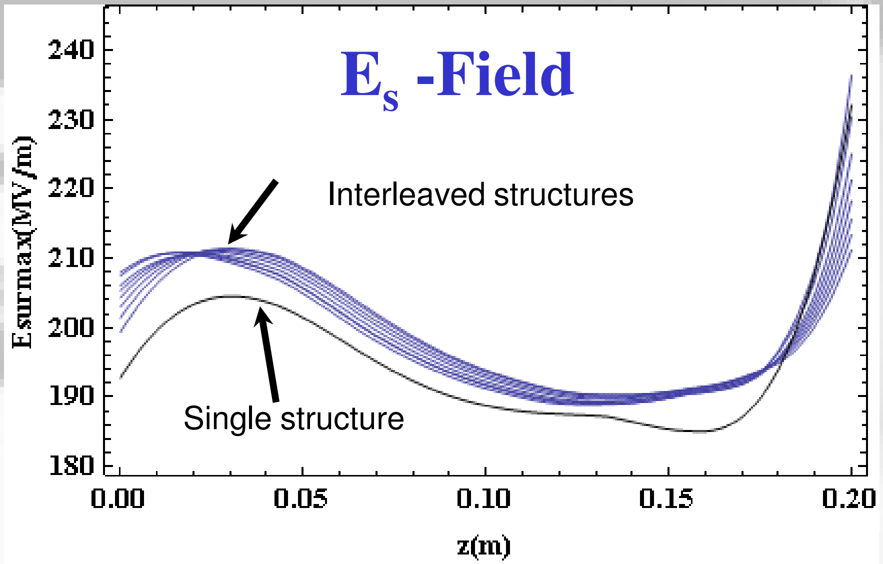


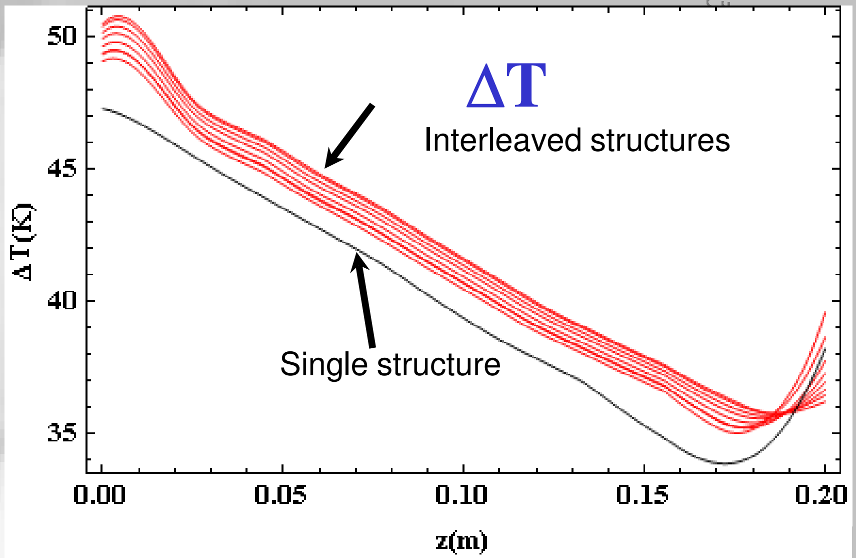


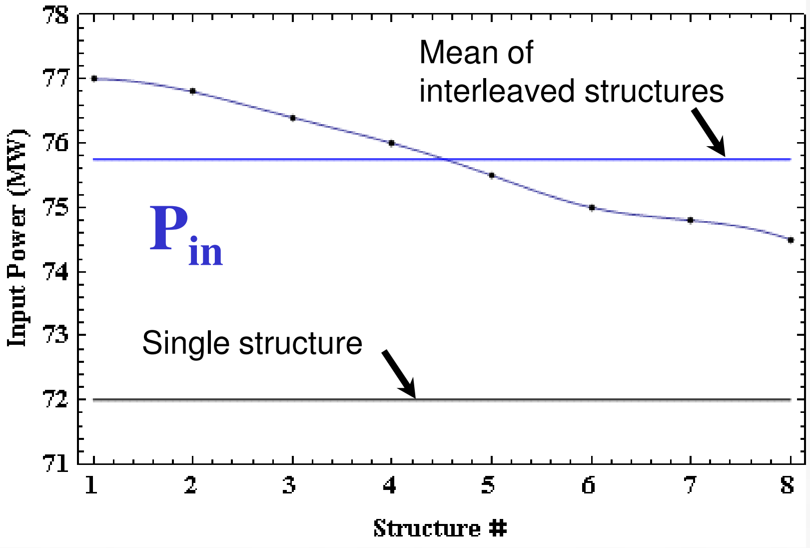
Sparse Sampled HPT (High Power Test)

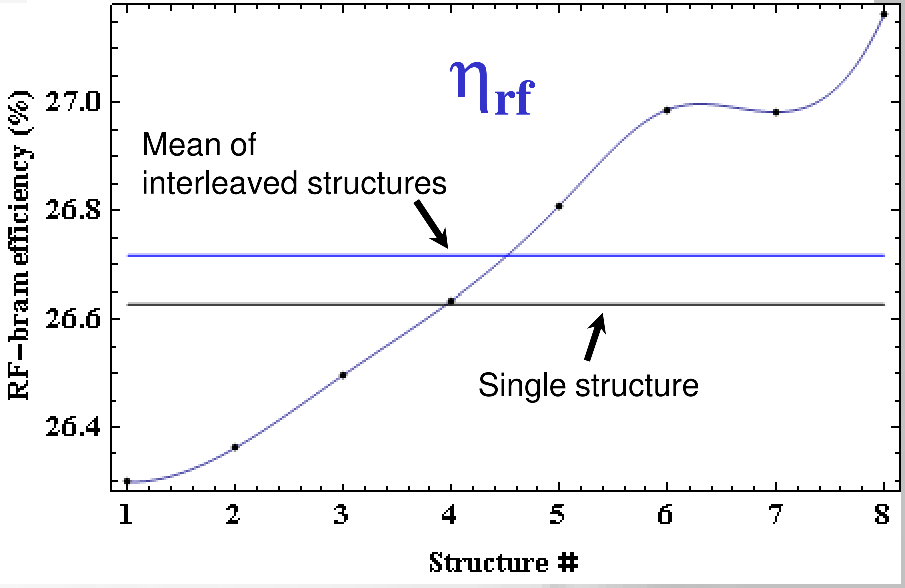
Fully Interleaved 8-structures

4. Surface Fields, ΔT and RF Efficiency

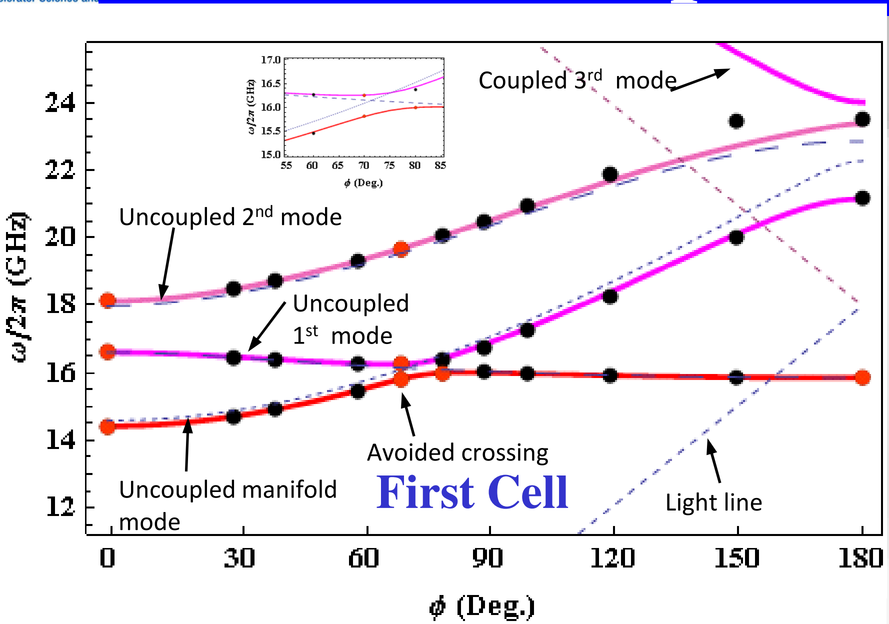


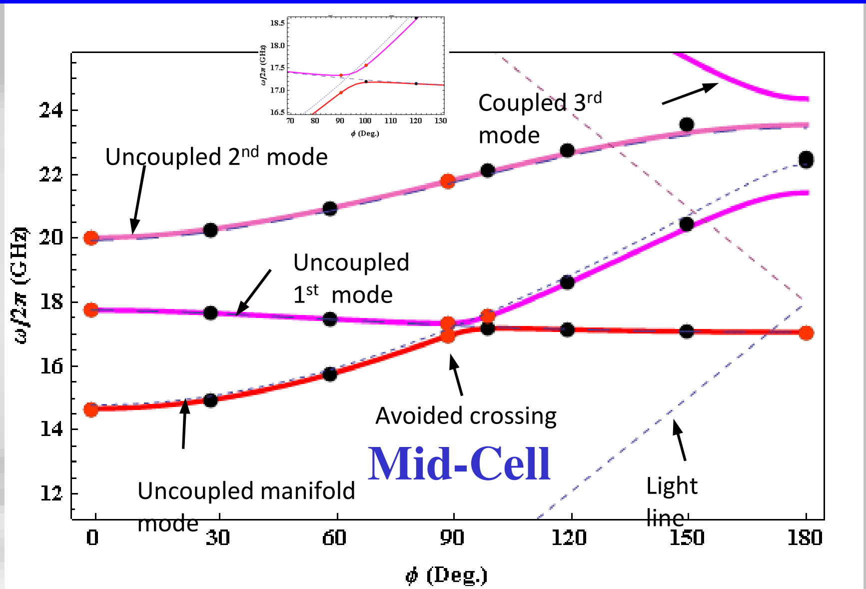




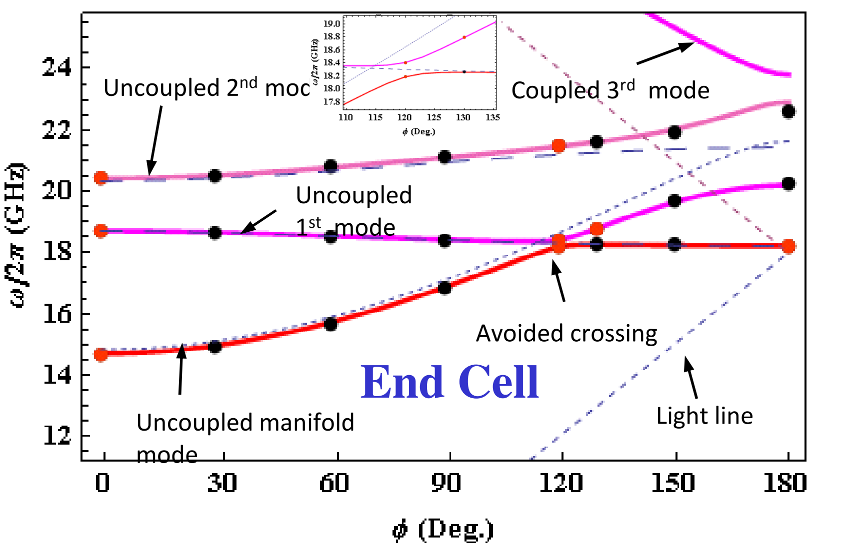


4. Relaxed parameters –full cct model

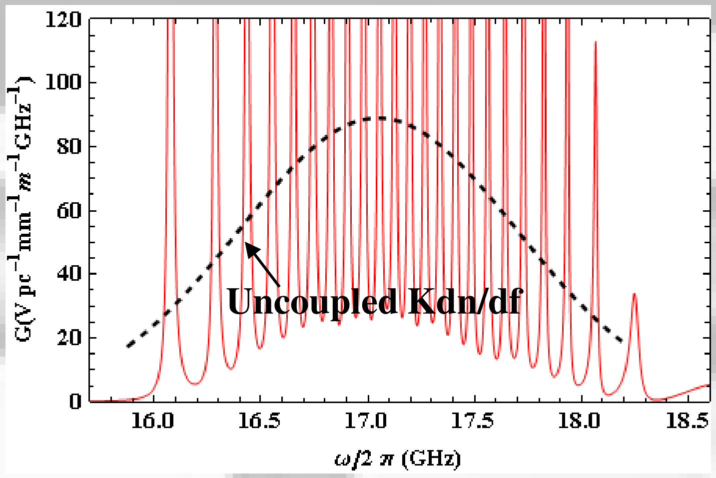




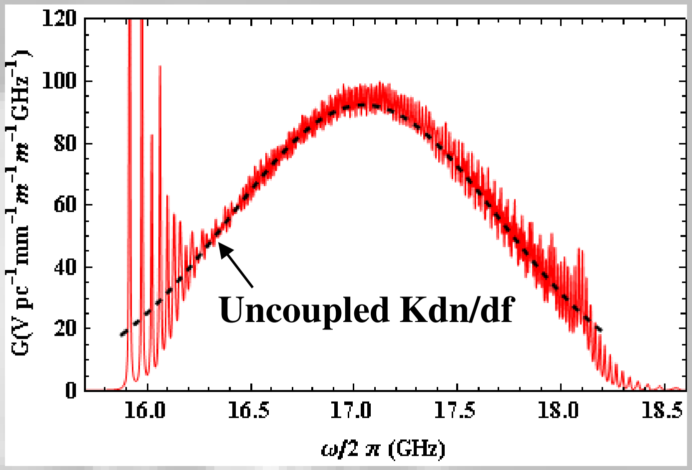
- ➢Dispersion curves for select cells are displayed (red used in fits, black reflects accuracy of model)
- ➢Provided the fits to the lower dipole are accurate, the wake function will be well-represented
- ➢Spacing of avoided crossing (inset) provides an indication of the degree of coupling (damping Q)



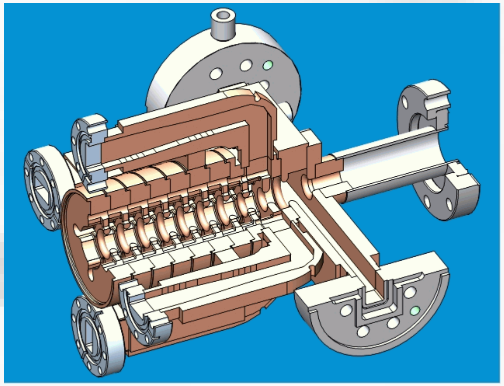
4. Relaxed parameters (RP)–Spectral fn.



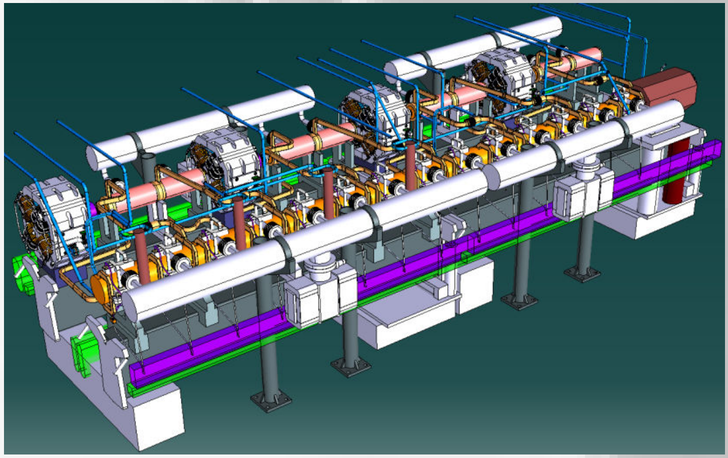
Single non-interleaved structure



8-fold interleaved structure

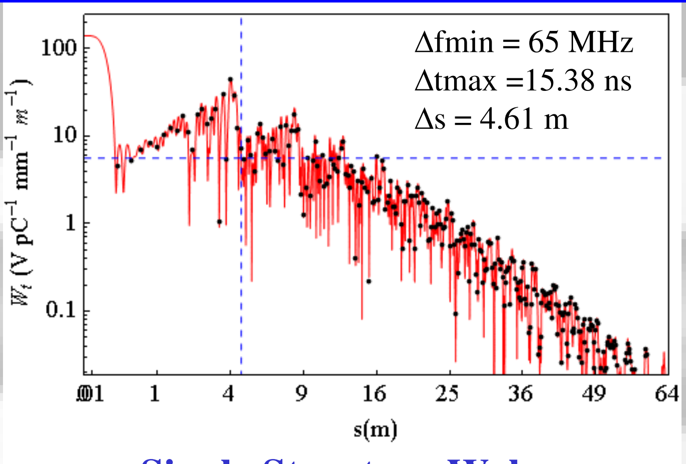


Potential Structure for CFT3 Module

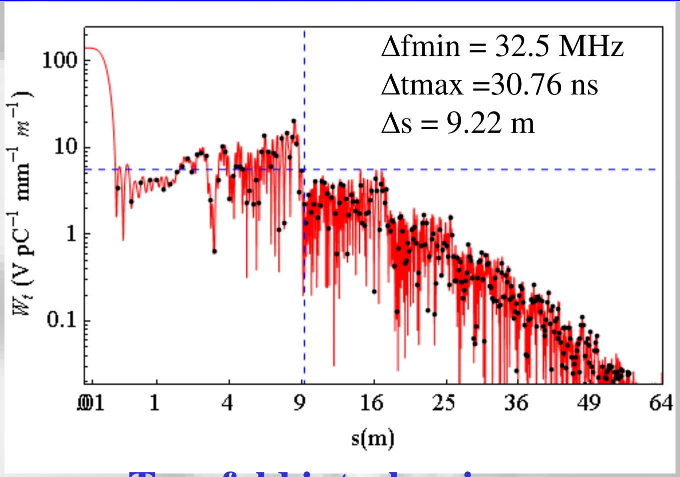


Eight structures in each CTF3 module

4. Relaxed parameters (RP)–Wakefunction

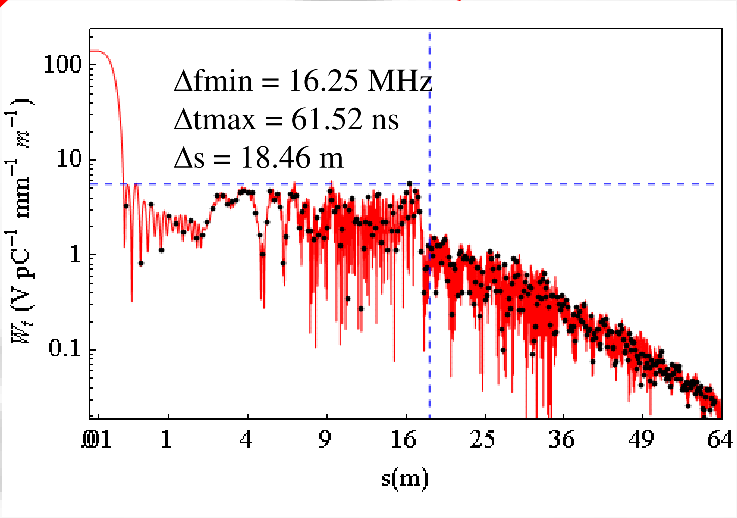


Single Structure Wake

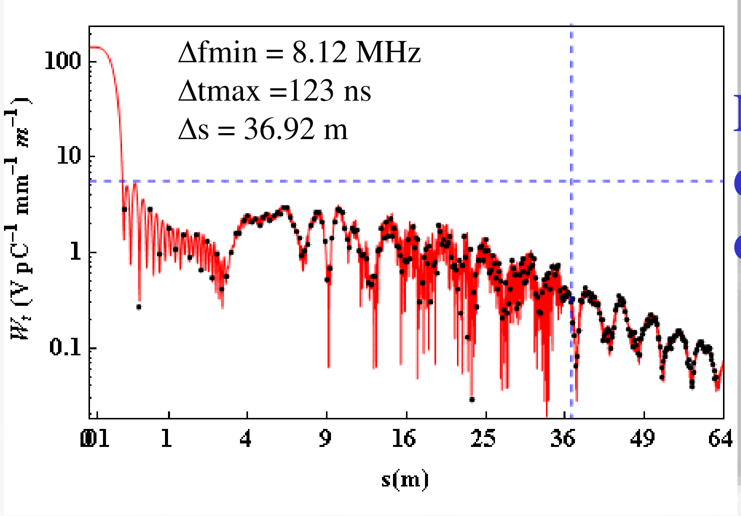


Two-fold interleaving

Fails design criterion!



Four-fold interleaving

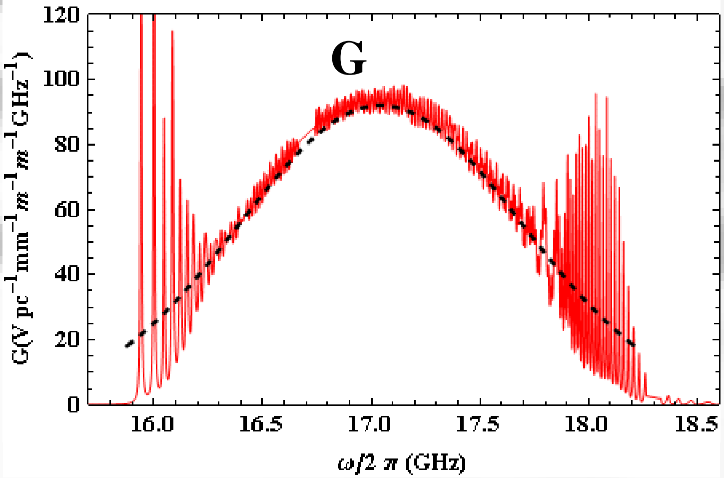


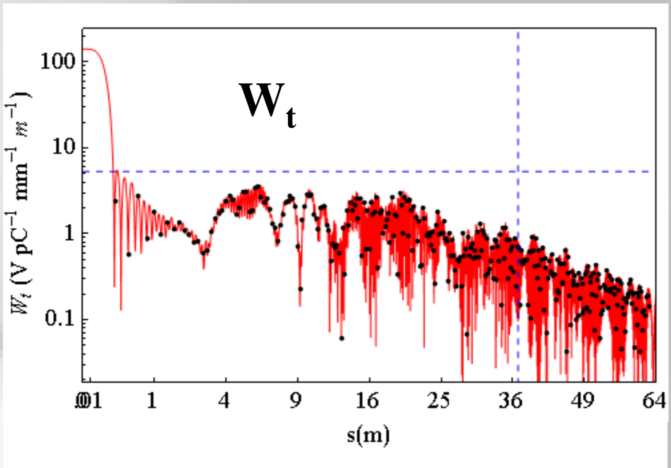
Eight-fold interleaving

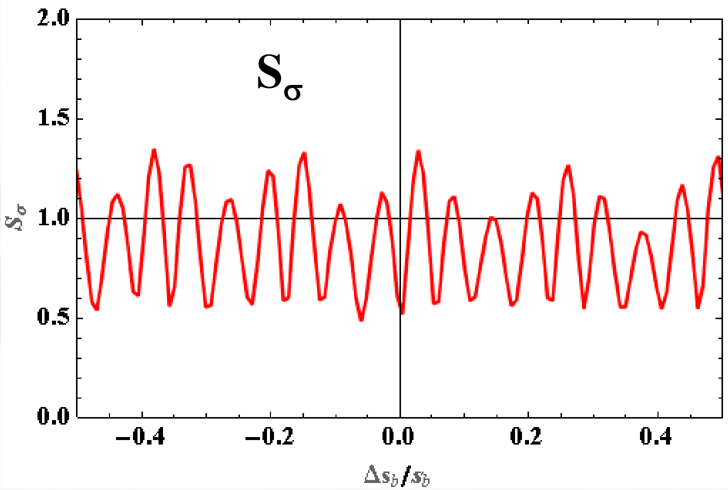
Meets design criterion!

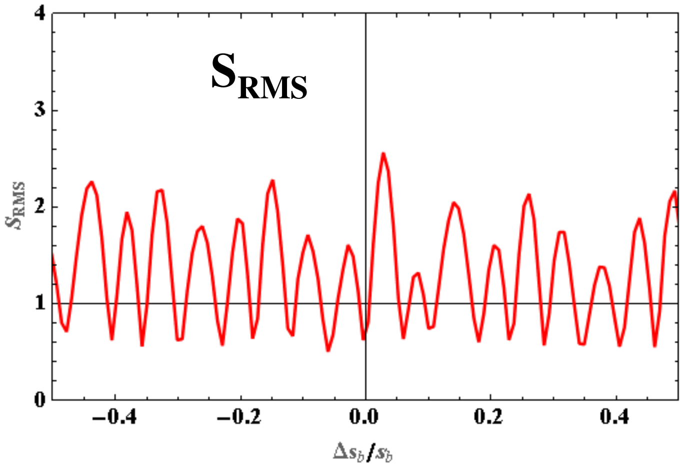
CLIC09 Workshop, October 12th - 15th, 2009, CERN

4. Relaxed parameters (RP)– Decoupling 2 End Cells









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. Requires beam dynamics simulations to validate this.

- 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*.

- The sparse sampled structure will enable the high power rf properties to be tested –includes max and min values of distribution. This will be a representative single-structure test of the features of the complete 8-fold interleaved structure!

4. Concluding remarks

➢Beam dynamics simulations needed to investigate the required tolerances. Preliminary steps, S_{RMS} calculations, in progress (Alessandro + Vasim). Initial simulations have also been conducted on sensitivity of end-cell couplings.

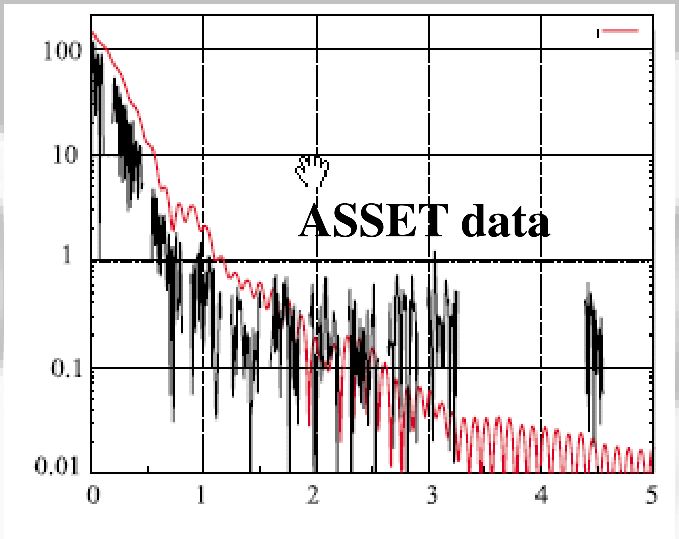
➢HOM/Fundamental coupler designs need investigation (Alessandro)

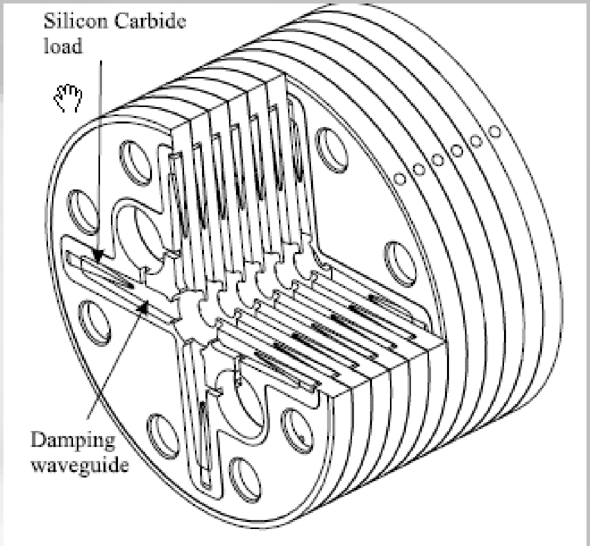
➢Additional optimisation also in progress on improving the Q by changing the flat-top cavity to a curved geometry –expect ~10% improvement.

➢Some additional optimisation of cavity slots may be possible.

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

5. Extra Slides



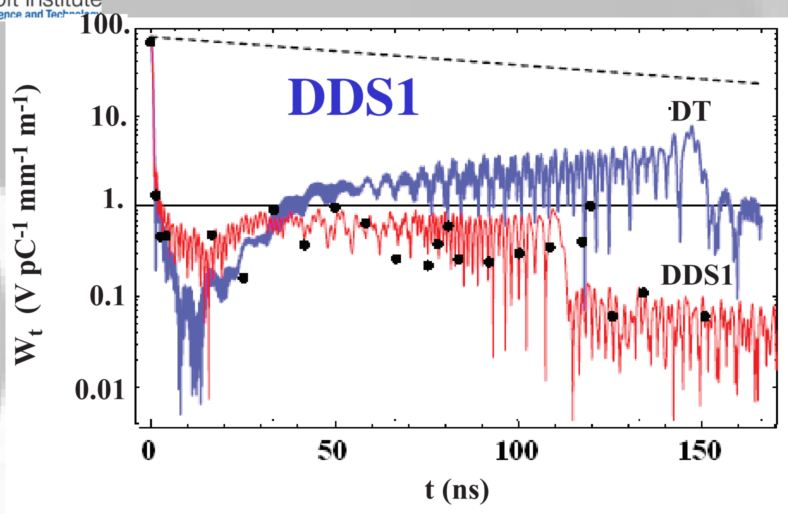


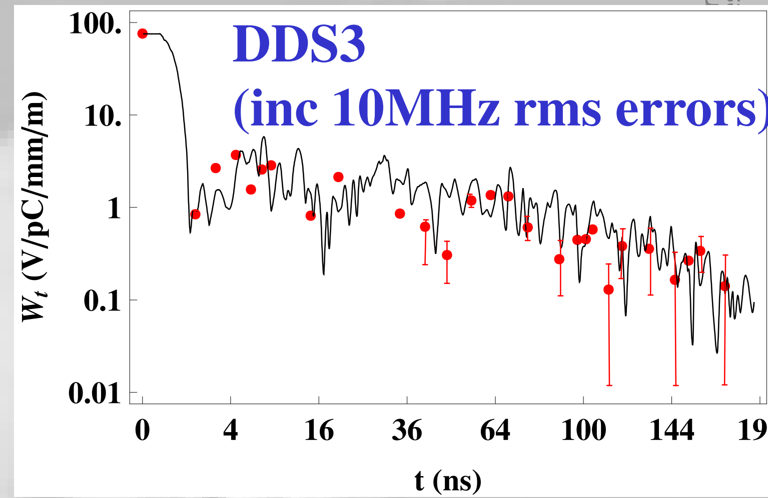
CLIC 30 GHz TDS Prediction vs Exp

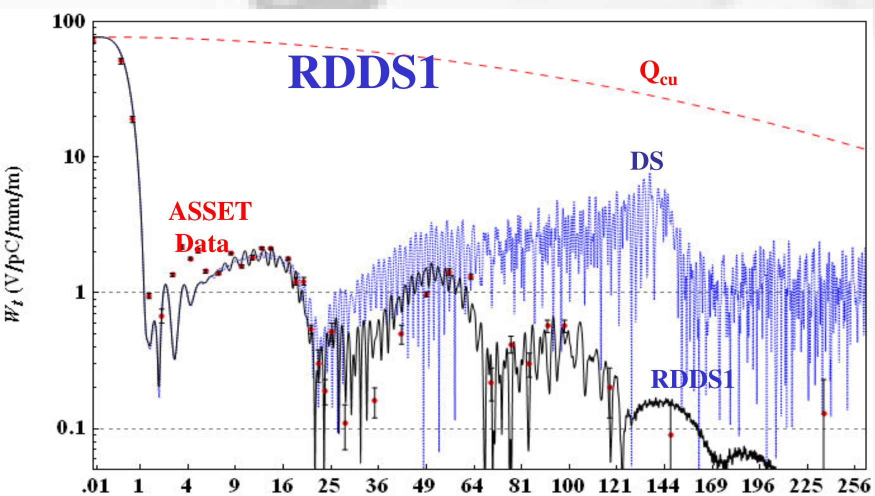
- Good agreement achieved up to ~ 2 ns
- Resonance, not included in prediction simulations, at 7.6 GHz, *external* to structure leads discrepancy between theory/exp.

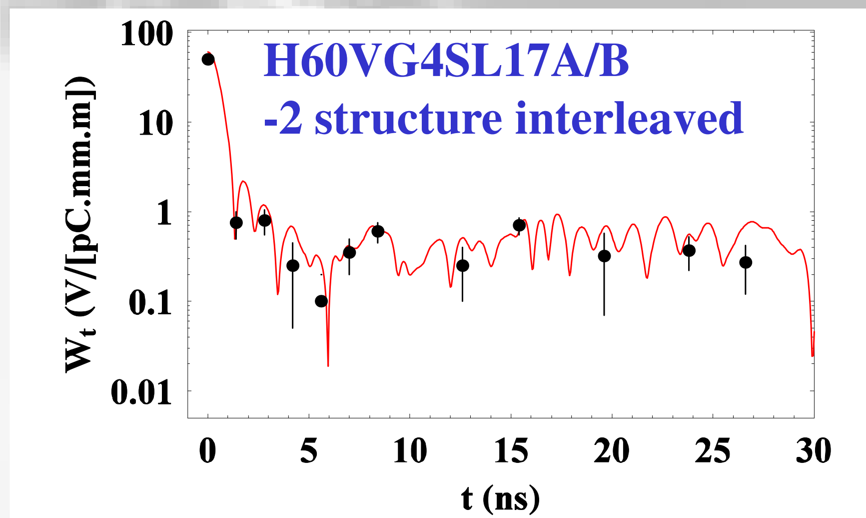
Ref: I. Wilson et al., Proceedings of the 2000 European Particle Accelerator Conference (EPAC00), Vienna, Austria, 2000

5. Extra Slides

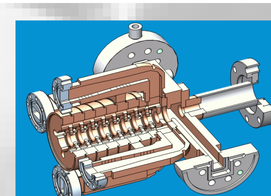








Conspectus of NLC/GLC Wake Function Prediction and Measurement (ASSET dots)



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.
3. R.M. Jones, Phys.Rev.ST Accel. Beams, Oct.,2009.