The Cockcroft Institute of Accelerator Science and Technology

CLIC

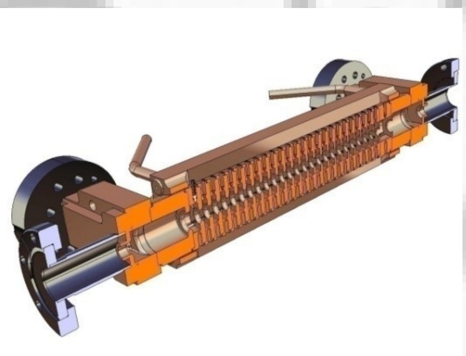
MANCHESTER 1824 The University of Manchester

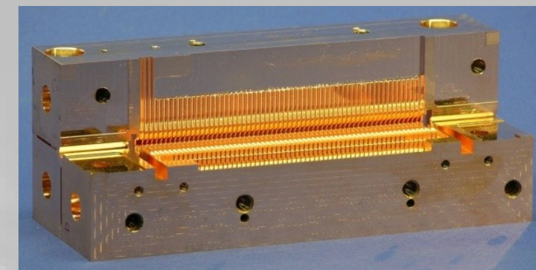
Detuned and Manifold-Damped HG Linacs for CLIC

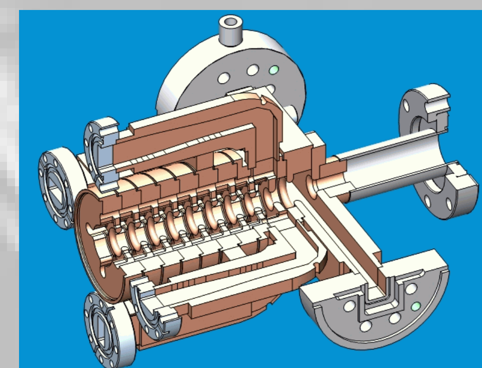
Roger M. Jones

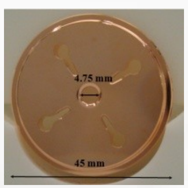
Cockcroft Institute and

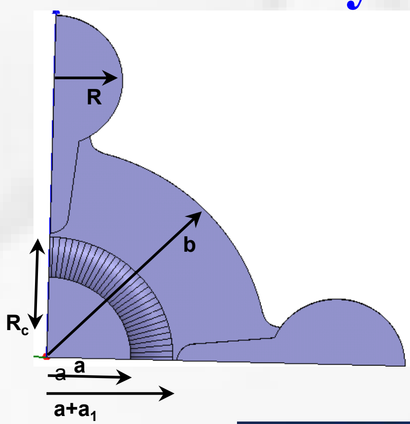
The University of Manchester

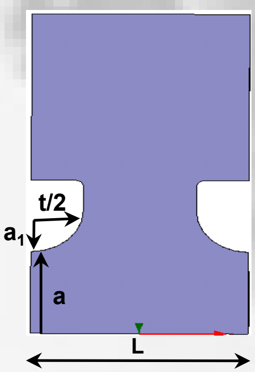


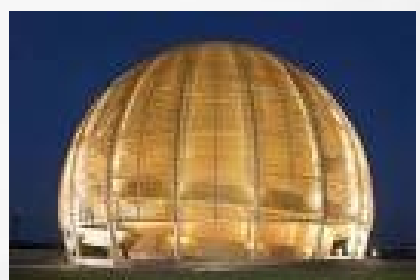


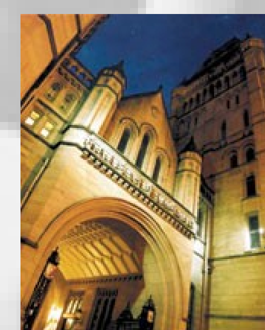












Overview

1. **Past experience in X-Band Linear Accelerating Structure Design: NLC /GLC (Next Linear Collider/Global Linear Collider).**
   -Vast (more than 15 years) experience obtained in a collaborative (SLAC/KEK/FNL) design and fabrication of a host of test structures.
   -Principles of wakefield suppression and built-in structure diagnostic discussed

2. **Alternate Design for Wakefield Suppression for CLIC: Initial studies at Cockcroft Inst./Univ. Manchester**
   -Method described in 1 applied to CLIC

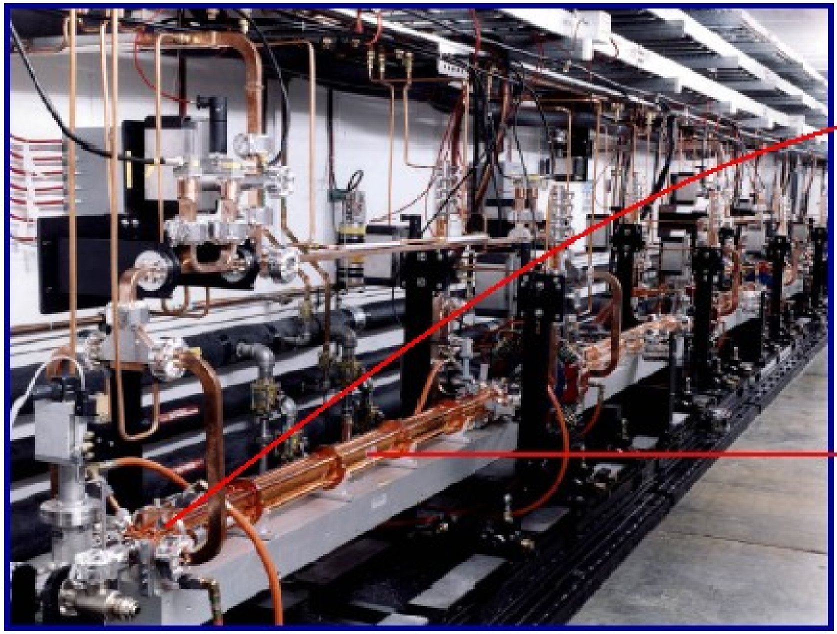
1. Review of General Methods of Wake-Field Damping

1. Strong Damping (Q~10) => loss in the shunt impedance of the monopole mode.
a) Magnetic coupling –azimithal slots (kidney slots)
b) Electric coupling – longitudinal slots

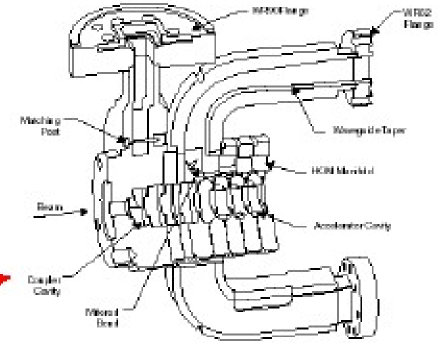
2. Resonant suppression
a) single frequency: $f_{dipole} = (n/2)\, f_{bunch}$ (zero-mode crossing)
b) multiple frequency, beat-note: $f_{dipole1} - f_{dipole2} = n\, f_{bunch}$

3. Non-resonant suppression –Detuning
a) Rectangular Kdn/df (kick factor weighted mode density) => sinc function wake
b) Gaussian Kdn/df => Gaussian wake function
c) Truncation of Gaussian necessitates light damping in addition to detuning
d) Less sensitivity to frequency errors
e) Less impact on fundamental mode shunt impedance

1. DDS Accelerators Installed in NLCTA at SLAC



NLCTA (Next Linear Collider Test Accelerator)



Cross-Sectional View of Input End of DDS
(Damped Detuned Structure)

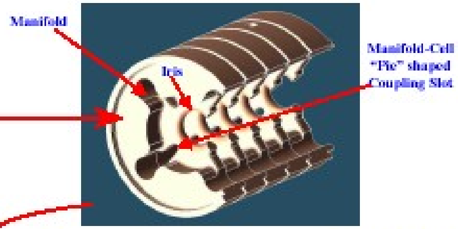
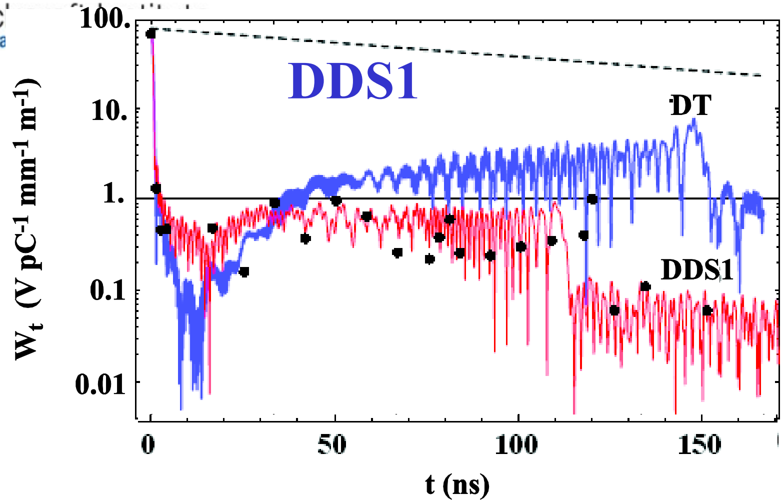


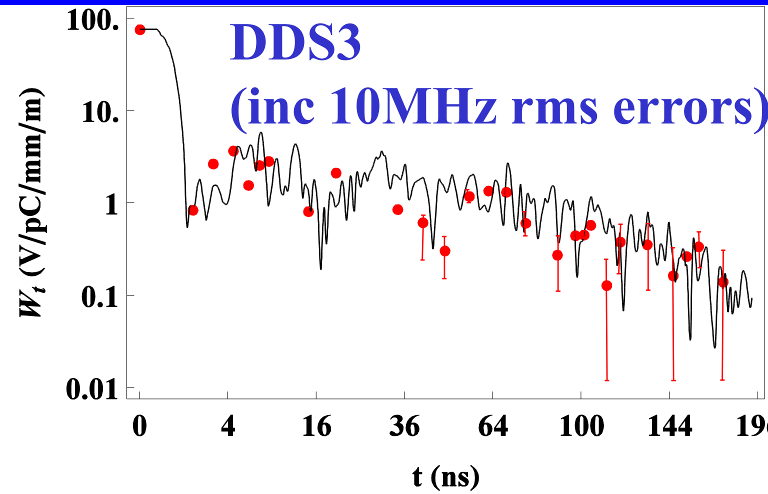
Illustration of Several Cells in DDS

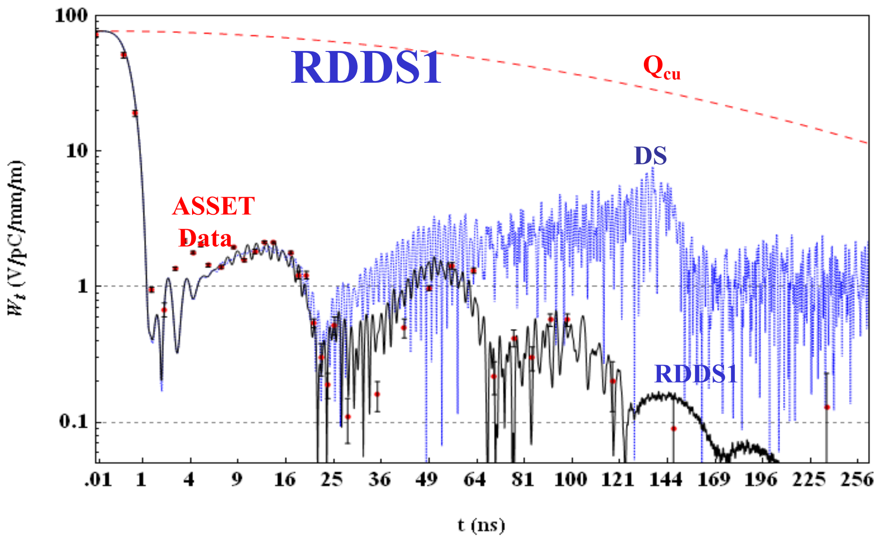
1.(R)DDS HIGHLIGHTS: Features and Achievements/Lessons

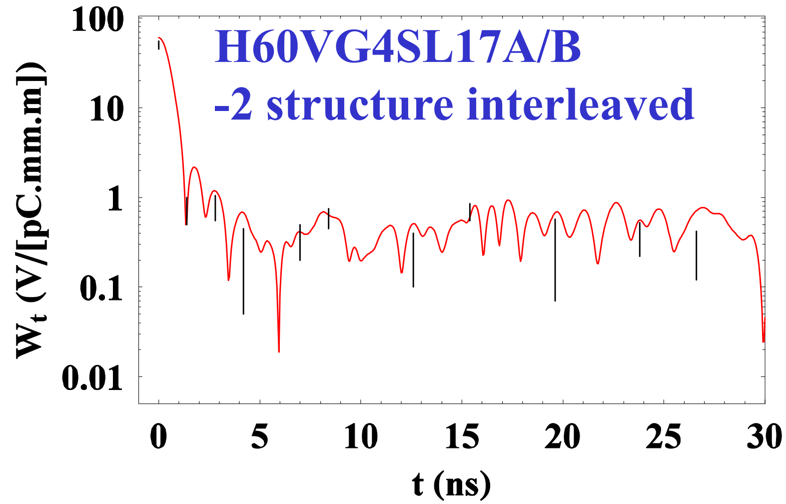
Many involved in the NLC/JLC programme (SLAC, KEK, FNAL, LLNL).

1. GLC/NLC Exp vs Cct Model Wake

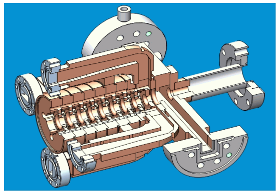






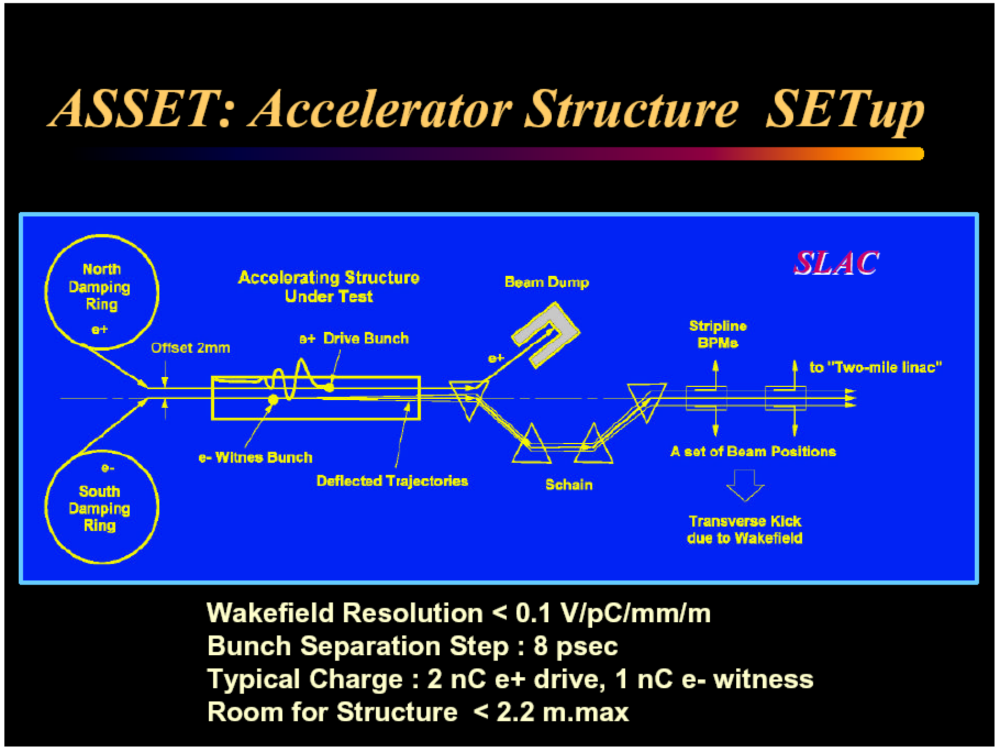


Conspectus of GLC/NLC Wake Function Prediction and Exp. Measurement (ASSET dots)



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.

1. Measurement of Wakefields/HOMs



- ➢$W_\perp$ is the transverse wake function at time t behind the drive bunch, E_w (~ 1.2 GeV) is the witness bunch energy and Δy_d is the offset in the drive bunch from the electrical centre of the accelerating structure.
- ➢Wake function units are transverse voltage per drive charge (en_d), drive offset and structure length (L_s), and $\zeta = e^2 L_s n_d \exp(-\omega^2\sigma^2/c^2)$

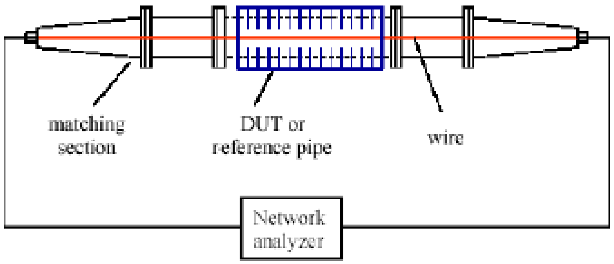
- ➢Electron bunch serves as the witness bunch
- ➢In traversing the DUT, the witness bunch is deflected by the wake function generated by the positron drive bunch.
- ➢Witness bunch passes though chicane and down linac where trajectory is recorded by BPMs
- ➢ The transverse wake function is determined by measuring the change in the witness bunch deflection per unit change in the drive bunch offset in the structure.

- ➢Angular kick imparted to the witness bunch is found from ratio of the transverse to longitudinal energy: $\Delta\theta_y = \zeta W_\perp(t)\Delta y_d / E_w$

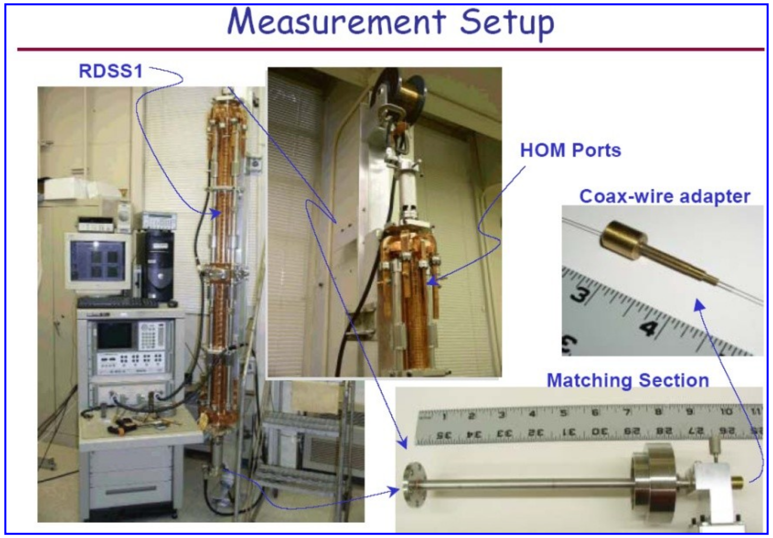
Ref: R. M. Jones, *Wake field Suppression in High Gradient Linacs for Lepton Linear Colliders*, Phys. Rev. ST Accel. Beams 12, 104801, 2009

1. Determination of HOMs in Structure via Stretched Wire Measurement

- Simulate beam by propagating pulse along wire
- Time domain =>measure distortion of current pulse
- Frequency domain =>measure S parameter (S_{21})
- Centered wire =>monopole mode
- Offset wire => dipole mode
- Method proposed by Matt Sands (~1974)
- Advantages
  -fast, inexpensive method to characterize beam impedance, loss factors, wakefield
  -does not require SLAC linac!



Schematic of Experimental Setup



- ➢Illustrated is an X-band Set-up at SLAC.
- ➢Designed as part of the GLC/NLC programme.
- ➢Able to accommodate 1.8m structures.
- ➢Several other configurations in use internationally.

Ref: F. Caspers, *Bench methods for beam-coupling impedance measurement* (Lecture notes in beams: intensity limitations vol 400) (Berlin, Springer, 1992)

Wire Wakefield Measurement Technique

1. Determination of Cell Offset From Energy Radiated Through Manifolds

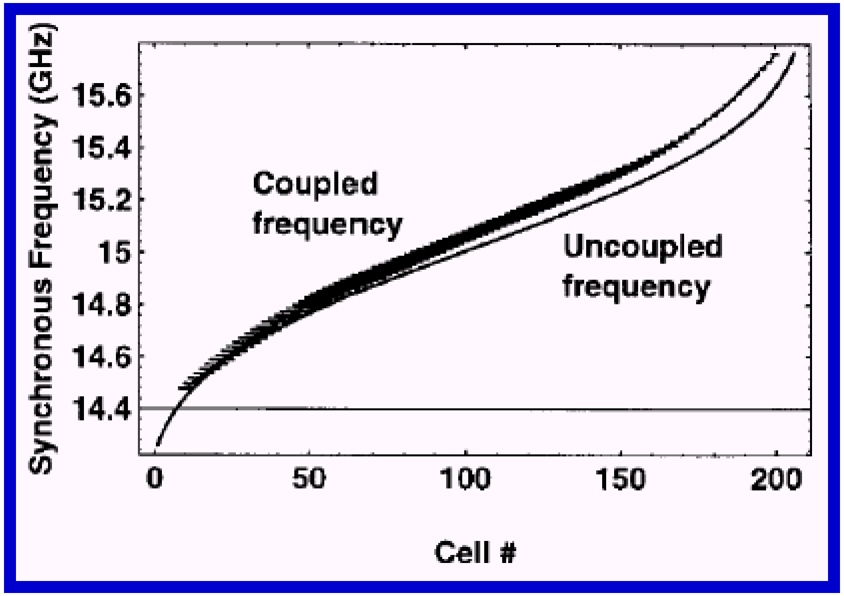
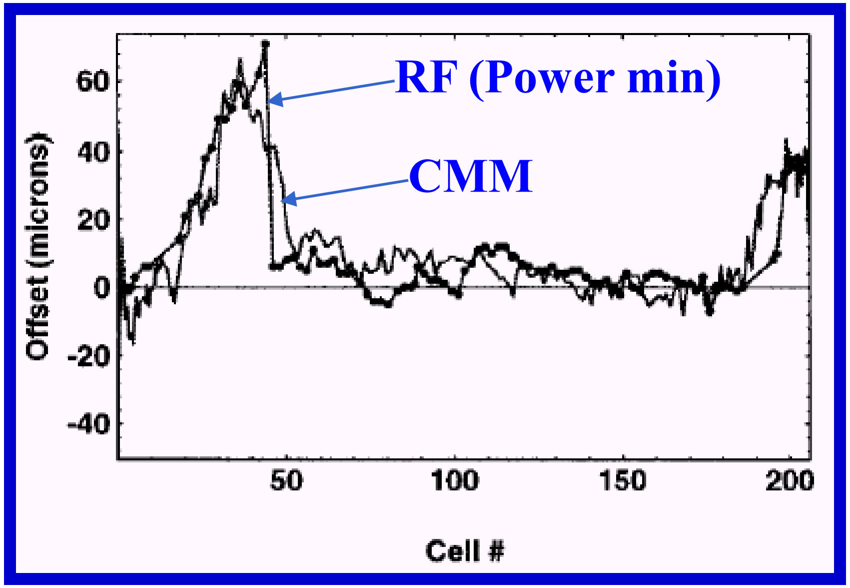
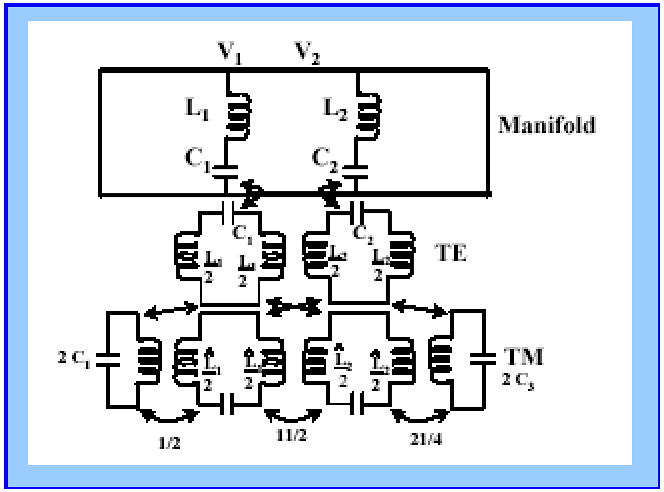


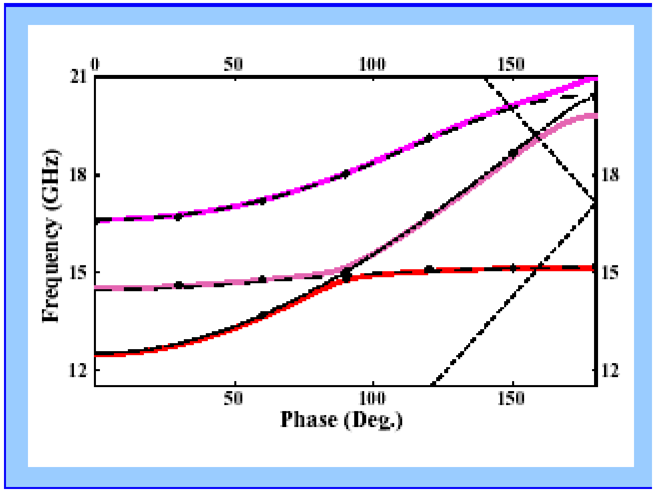
Illustration of the deviation of the synchronous frequency from the uncoupled one due to cell-to-cell detuning. The short horizontal lines indicate the extent to which cell offsets may be localized by frequency



Comparison of the CMM (Coordinate Measuring Machine) data set versus the ASSET power minimization position data remapped from frequency to cell number for DDS1.

1. Verification of Synchronous Frequencies from Measurement of Cell Stacks

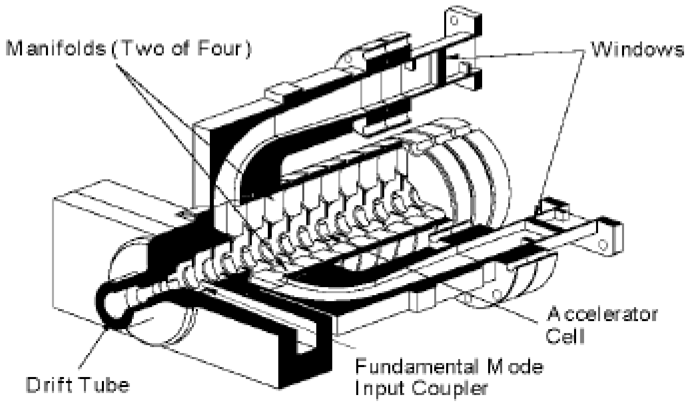


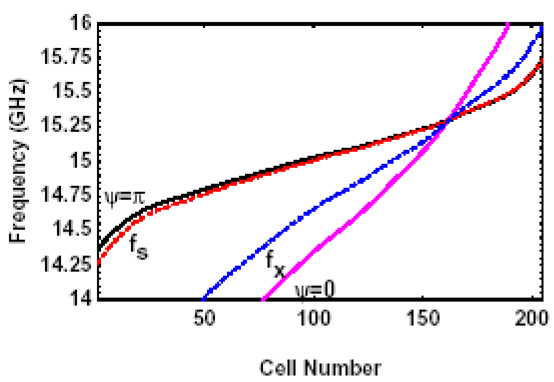


Circuit diagram and Brillouin diagram corresponding to RDDS1 cell stack 98 to 103 (average cell 100.5). The points are obtained from an experimental measurement and the lines are obtained from the circuit model in which the original design was prescribed prior to the experiment

ψ	60	90	120	150	180
f_{exp}	13.7 14.7856	14.8048 15.0292	15.110 16.759	15.1388	15.1923
f_{mode}	13.6358 14.7686	14.7803 15.1544	15.0399 16.7701	15.1256	15.1556
f_{av}	13.6356 14.7759	14.7759 15.1539	15.0404 16.6918	15.1271	15.1537

1. Summary of Manifold Suppression of Wakefields in Detuned Structures





•The manifold is a single mode TE_{10} and it is cut off to the accelerating mode (thus there is little impact on the accelerating mode)

•Each manifold is tapered to maintain good coupling

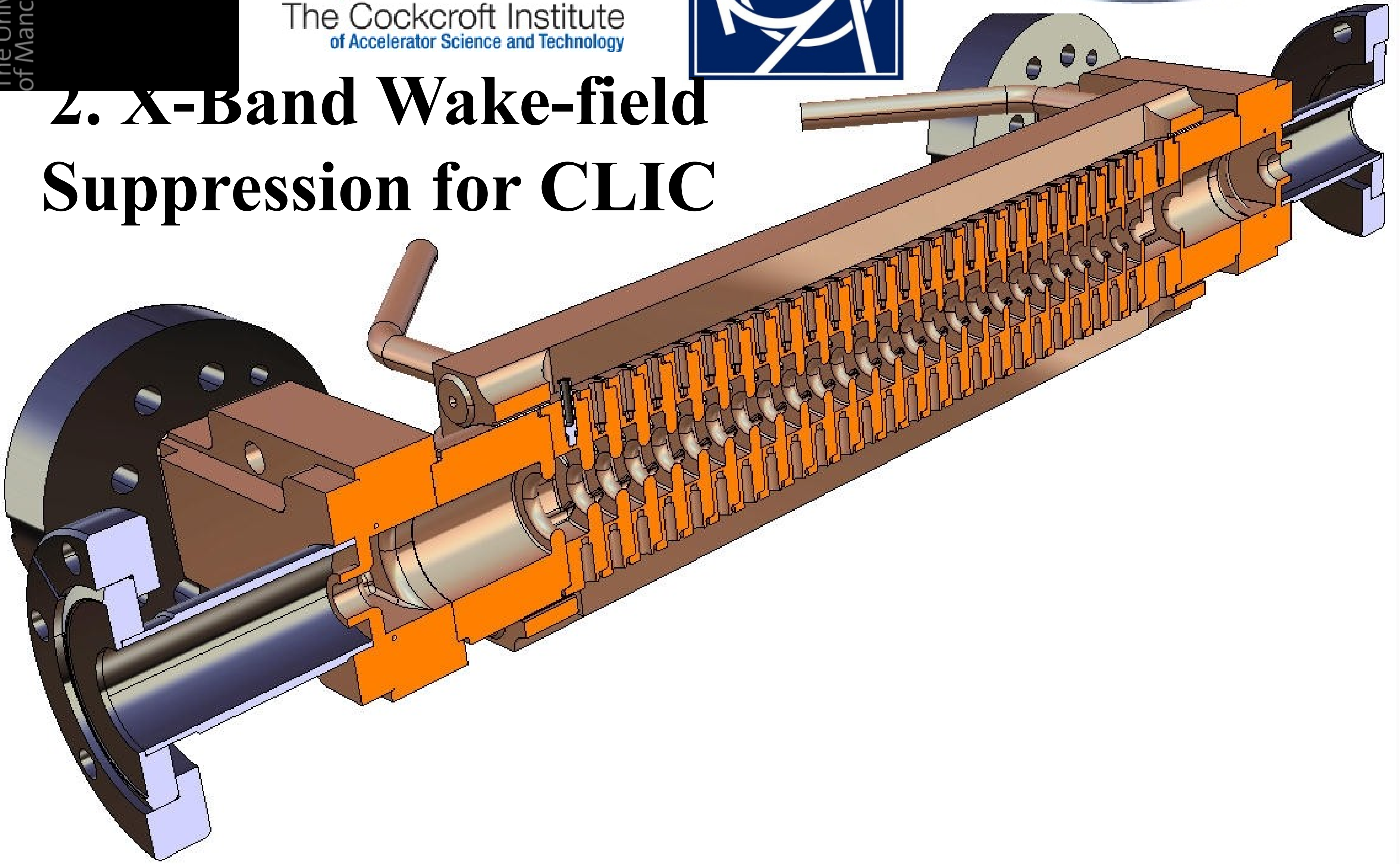
• RDDS has circular manifolds (superior pumping compared to rectangular guide).

• From mechanical considerations it is required to decouple 4 cells from either end of the structure.

• Detuned structure modes are localized standing waves with a spectrum of phase velocities.

• Both beam coupling and manifold coupling as functions of frequency are localized around particular cells.

2. X-Band Wake-field Suppression for CLIC

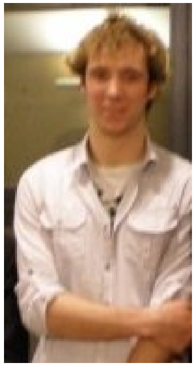


Main Linac Wake Function Suppression for CLIC -Staff

- Roger M. Jones (Univ. of Manchester faculty)
- Alessandro D'Elia (Dec 2008, Univ. of Manchester PDRA based at CERN)
- Vasim Khan (PhD student, Sept 2007)
- Nick Shipman (PhD student Sept 2010, largely focused on breakdown studies)
- Part of EuCARD (European Coordination for Accelerator Research and Development) FP7 NCLinac Task 9.2

V. Khan, CI/Univ. of Manchester Ph.D. student graduated April 2011 (now CERN Fellow)

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



N. Shipman, CERN/CI/Univ. of Manchester Ph.D. student)

L. Carver CI/Univ. of Manchester Ph.D. student, Sept 2011.

- Major Collaborators: W. Wuensch, A. Grudiev, I. Syrachev, R. Zennaro, G. Riddone (CERN)

Introduction –Present CLIC baseline vs. alternate DDS design

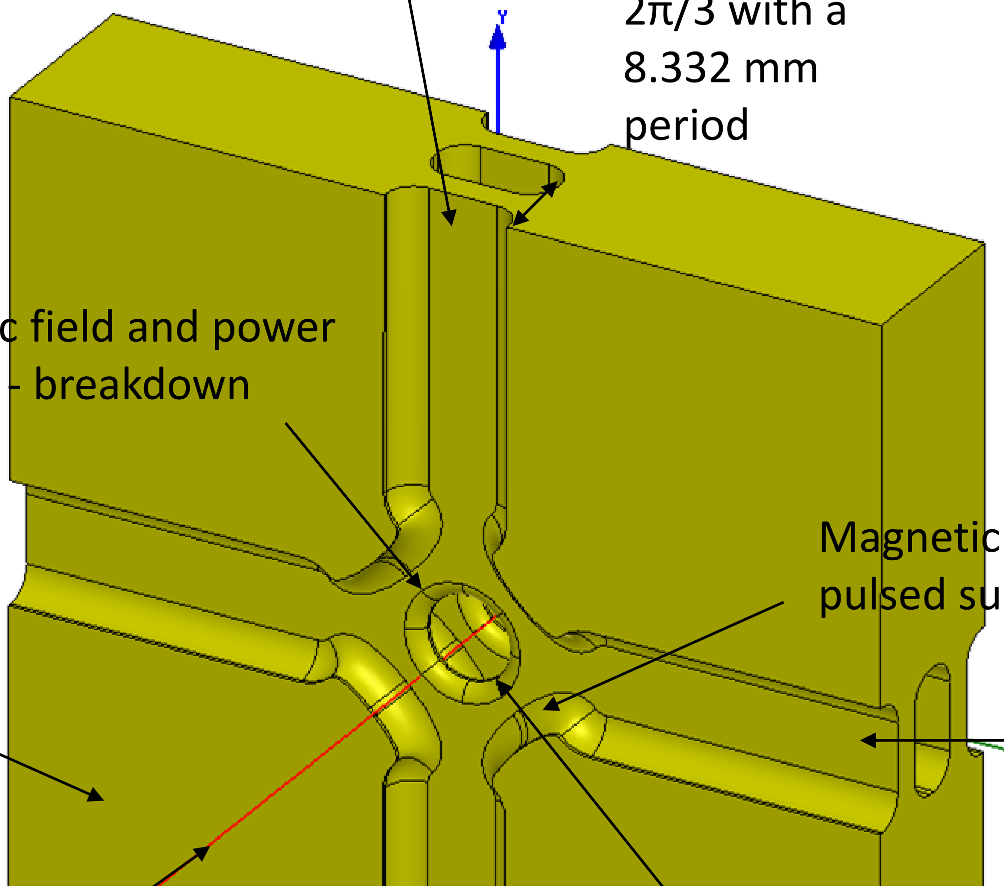
- The present CLIC structure relies on linear tapering of cell parameters and heavy damping with a Q of ~10.
- Wake suppression is effected through waveguides and dielectric damping materials in relatively close proximity to accelerating cells.
- Choke mode suppression provides an alternative, but as shown for SW (V. Dolgashev *et al*), it will negatively impact R_{sh} -planned TW structures are worth investigating though

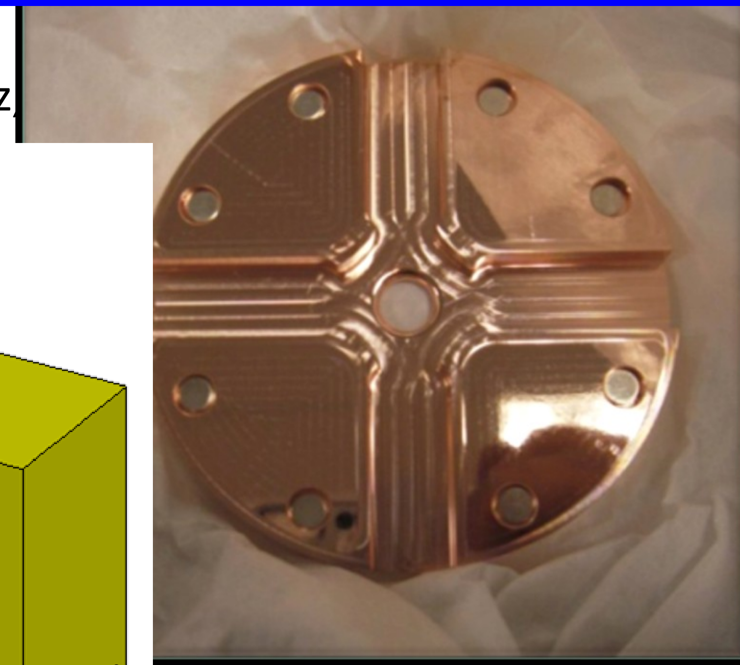
- **A viable alternative is presented by our CLIC_DDS design -parallels the DDS developed for the GLC/NLC, and entails:**

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 ~ 500-1000**

Current CLIC Baseline Accelerating Structure

11.9942 GHz, 2π/3 with a 8.332 mm period





CLIC Design Constraints

1) RF breakdown constraint

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

2) Pulsed surface temperature heating

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

3) Cost factor

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

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

Initial CLIC_DDS Designs

Two initial approaches. Final method adopted which entails:

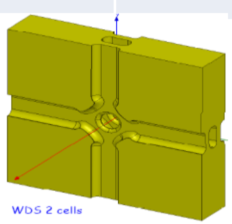
- **Relaxed parameters, modify bunch spacing from 6 to 8 rf cycles and modify bunch population.**
- **Wake well-suppressed for interleaved structures and satisfies surface field constraints. CLIC_DDS_C ($\Delta f \sim 3.6\sigma$, 13.75%)**
- **SUCCESS (on suppressing wakes and meeting breakdown criteria) -from theoretical viewpoint!**
- **Need to Investigate:**
  1. **Ability of structure to cope with high power/gradients**
  2. **Experimental verification of wakefield suppresssion**

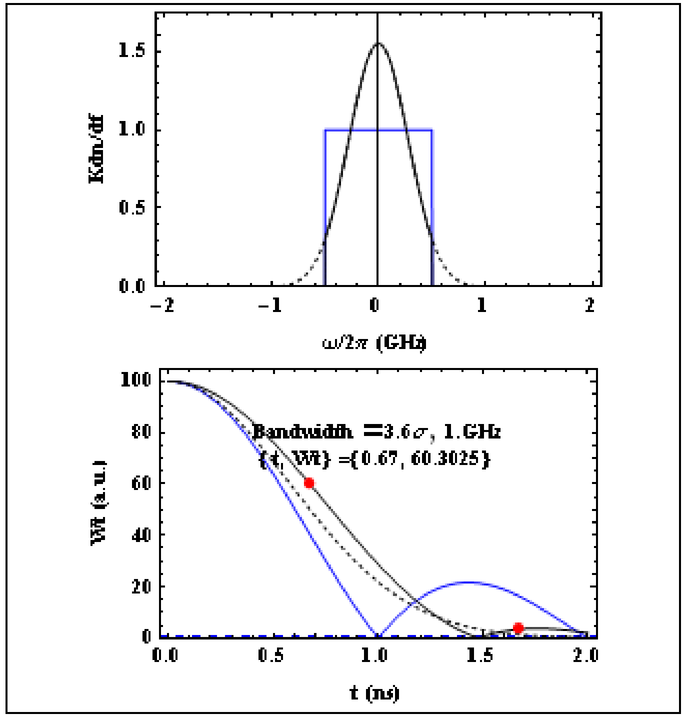
2.1 Initial CLIC_DDS Design –Δf determination

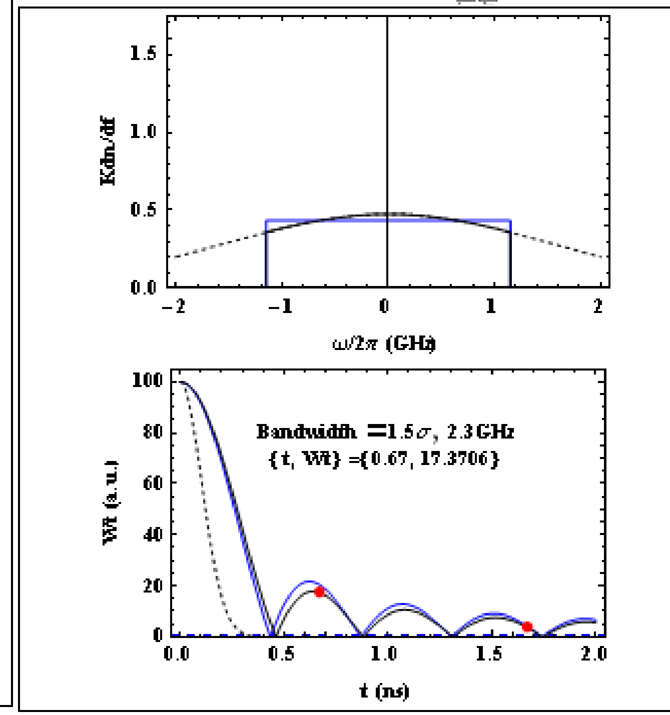
Structure	CLIC _G
Frequency (GHz)	12
Avg. Iris radius/wavelength <a>/λ	0.11
Input / Output iris radii (mm)	3.15, 2.35
Input / Output iris thickness (mm)	1.67, 1.0
Group velocity (% c)	1.66, 0.83
No. of cells per cavity	24
Bunch separation (rf cycles)	6
No. of bunches in a train	312

Lowest dipole
Δf ~ 1GHz
Q~ 10

CLIC_G







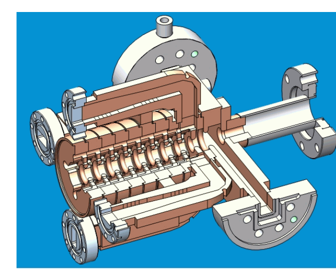
Bandwidth Variation

σ Variation

Truncated Gaussian :

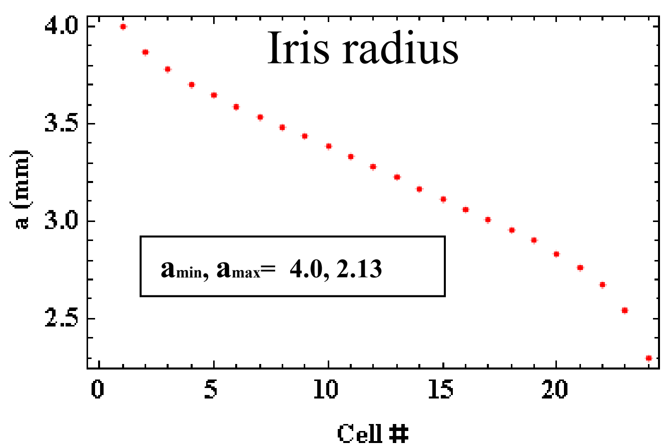
$$W_t = 2\bar{K} e^{-2(\sigma\pi t)^2} \left|\chi(t,\Delta f)\right|$$

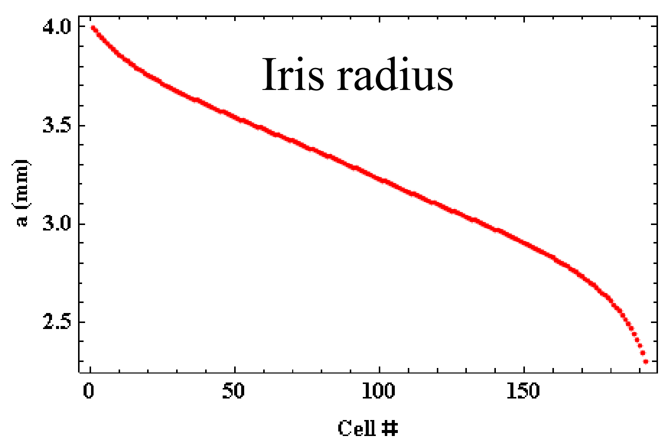
where : $$\chi(t,\Delta f) = \frac{Re\left\{erf\left(\left[n_\sigma - 4i\pi\sigma t\right]/2\sqrt{2}\right)\right\}}{erf\left(n_\sigma/2\sqrt{2}\right)}$$

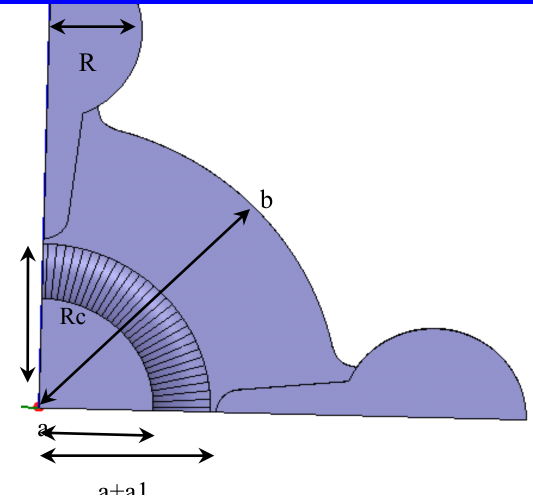


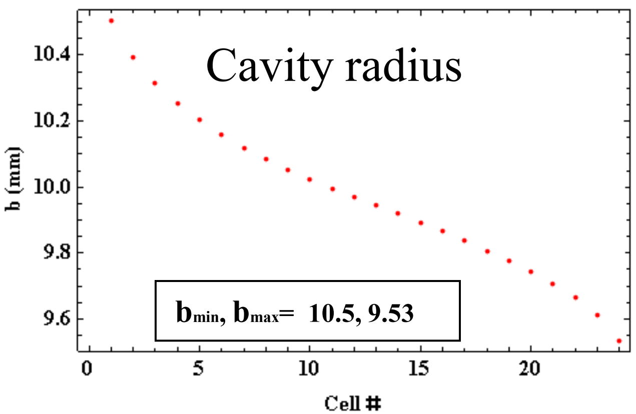
⇒ CLIC_DDS Uncoupled Design

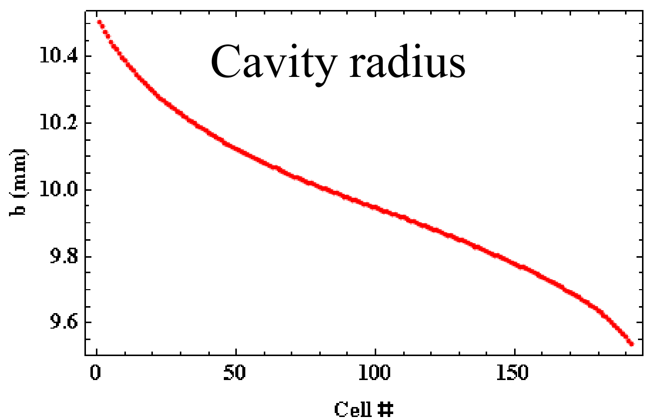
Structure Geometry: Cell Parameters

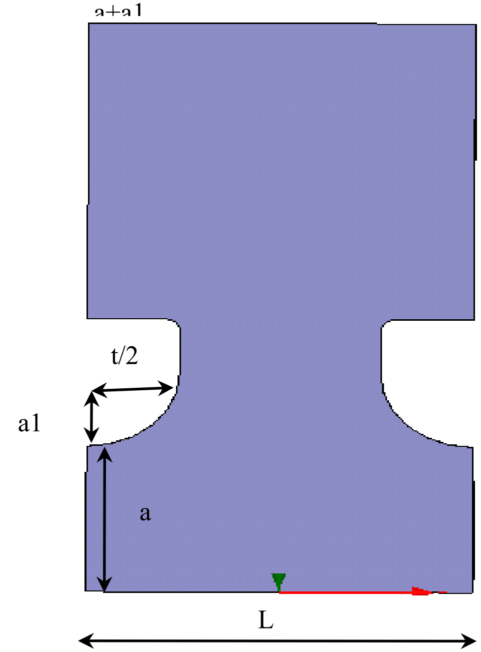












Sparse Sampled HPT
(High Power Test)

Fully Interleaved
8-structures

Summary of CLIC_DDS_C

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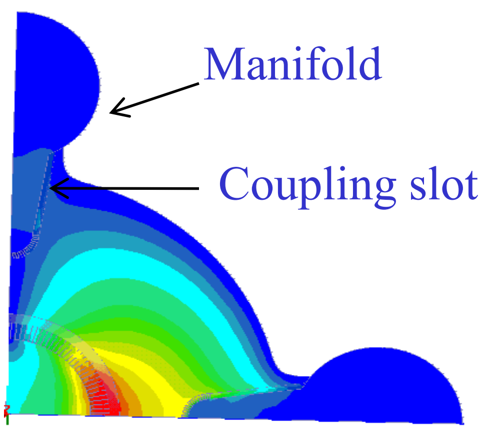
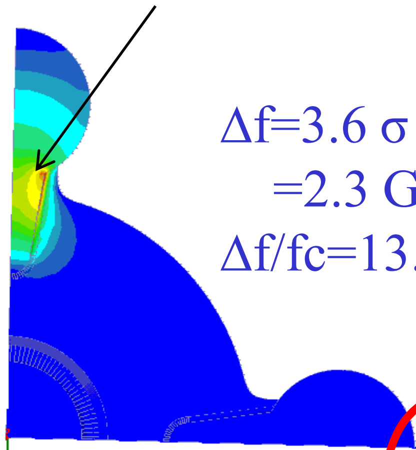
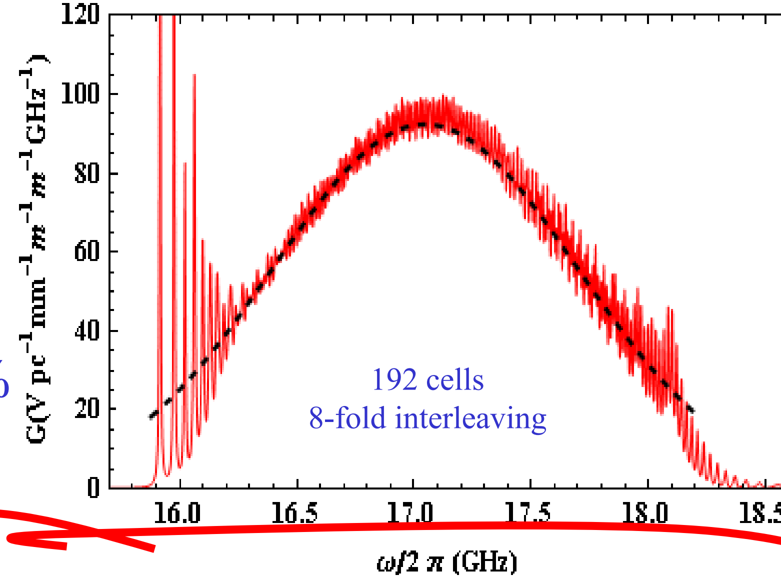
Dipole mode

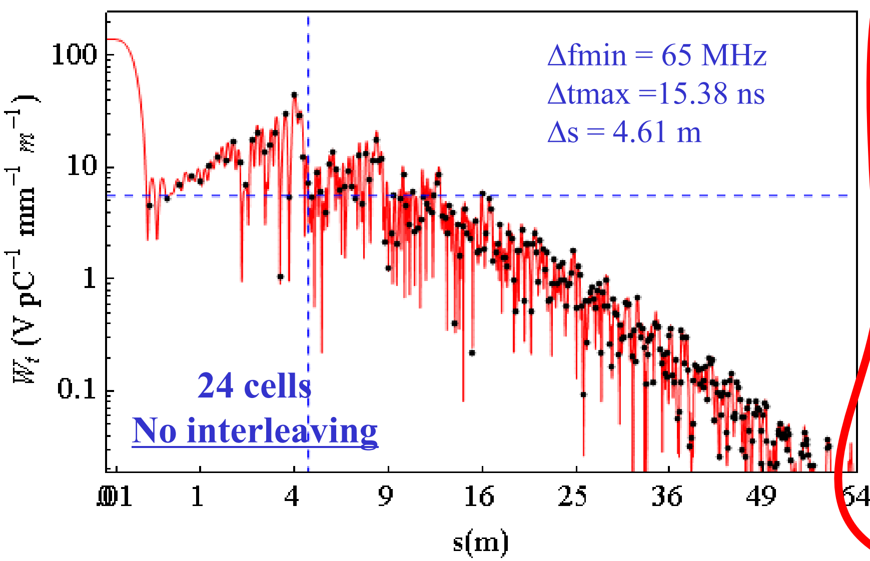


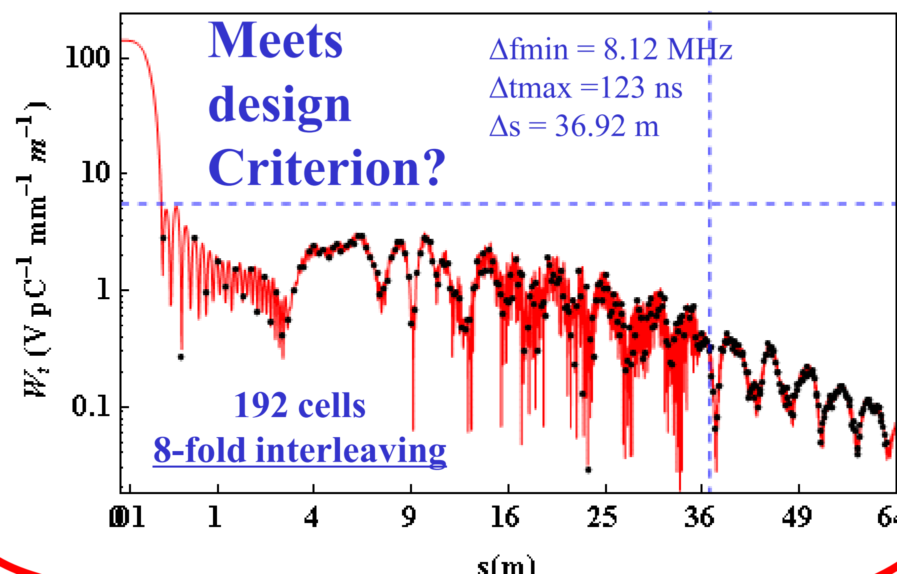
Manifold mode



Δf=3.6 σ
=2.3 GHz
Δf/fc=13.75%







CLIC_DDS_E

➢Enhanced H-field on various cavity contours results in unacceptable ΔT (~65° K).

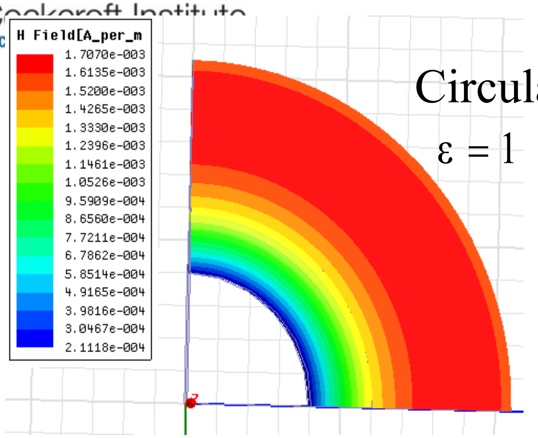
➢Can the fields be redistributed such that a ~20% rise in the slot region is within acceptable bounds?
⇒Modify cavity wall

➢Explore various ellipticities (R. Zennaro, A. D'Elia, V. Khan)

CLIC_DDS_E Elliptical Design –E Fields

Circular

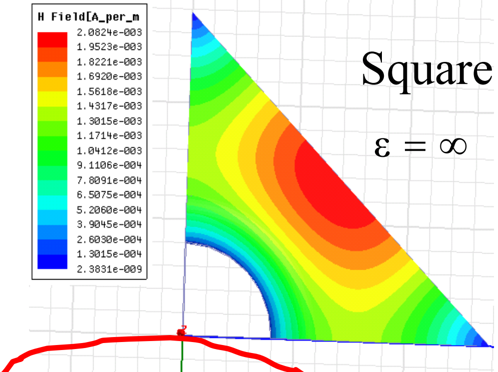
ε = 1



Single undamped cell
Iris radius=4.0 mm

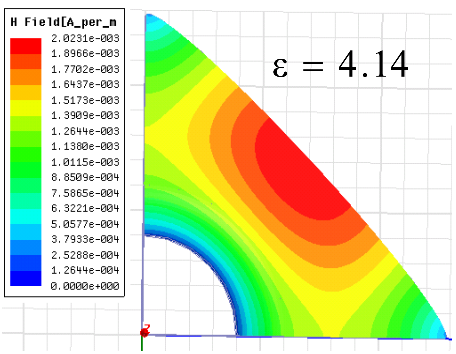
Square

ε = ∞

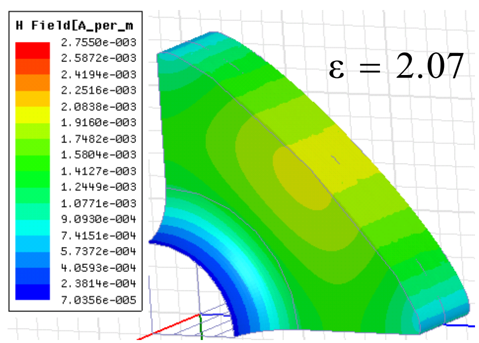


Convex ellipticity

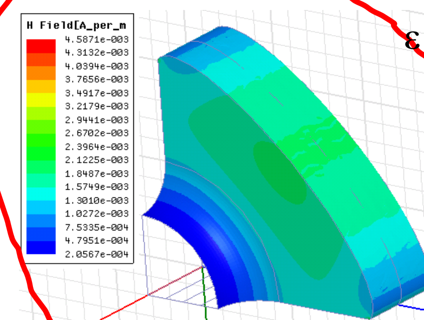
ε = 4.14



ε = 2.07

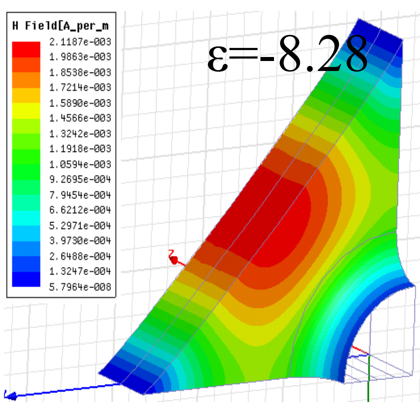


ε = 1.38

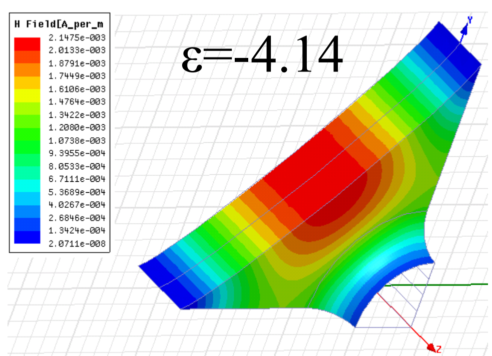


Concave ellipticity

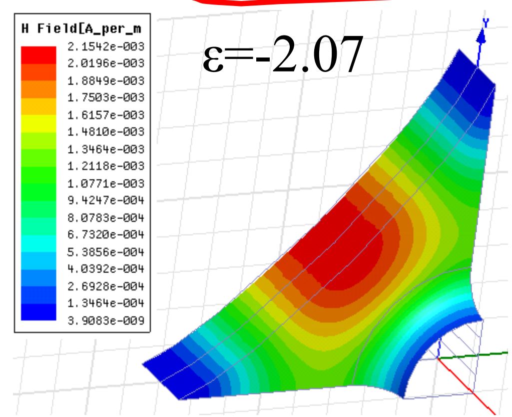
ε=-8.28



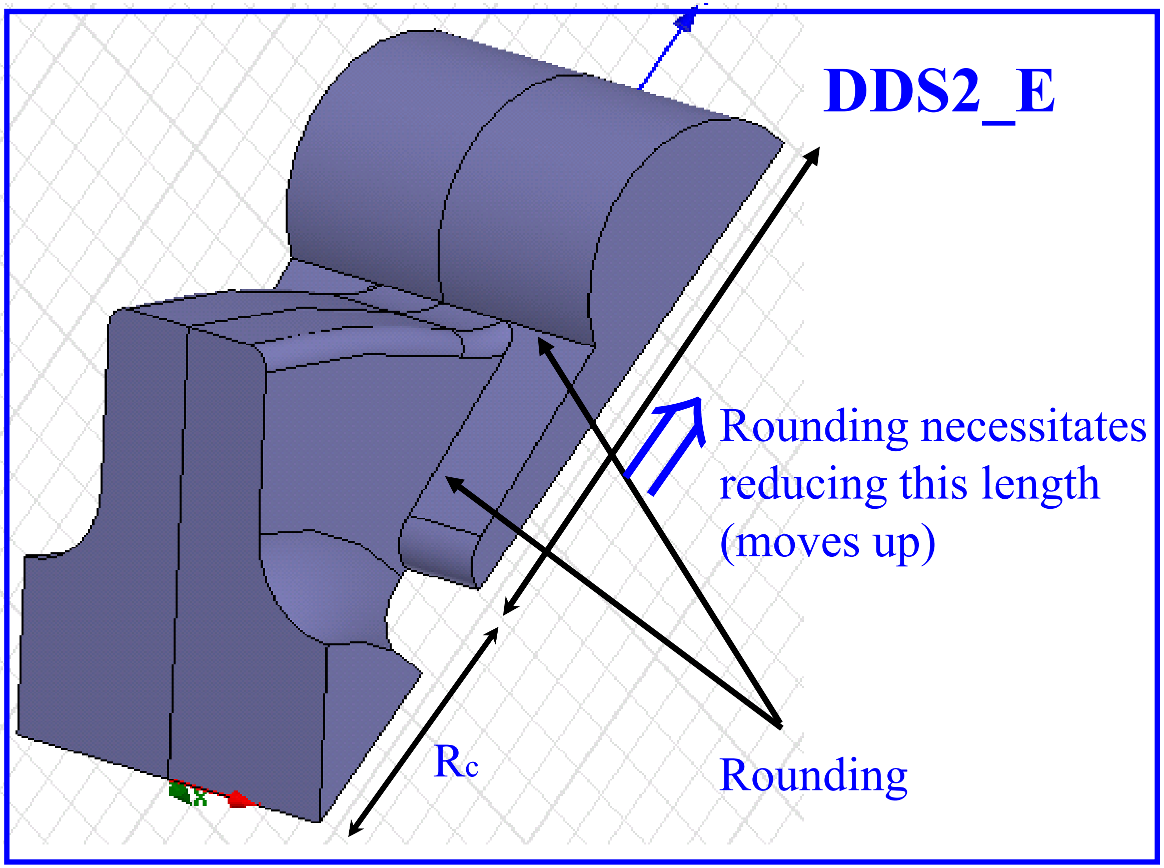
ε=-4.14

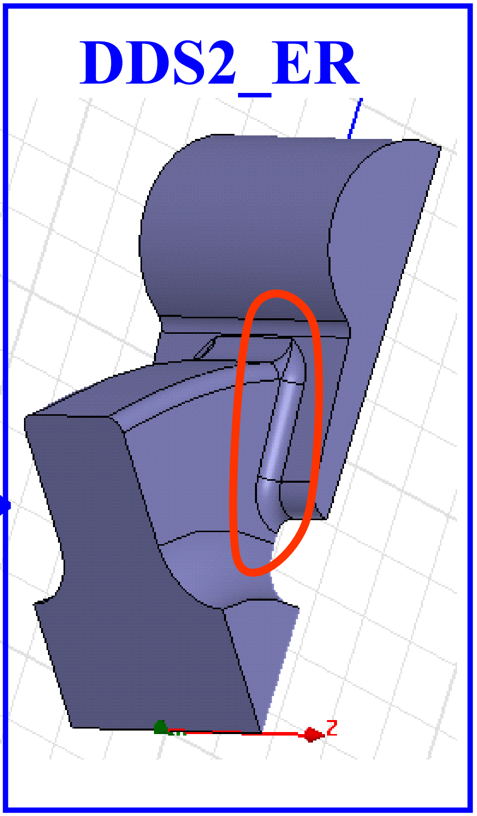


ε=-2.07



4. CLIC_DDS_E: Modified Design Based on Engineering Considerations





- ➢To facilitate machining of indicated sections, roundings are introduced (A. Grudiev, A. D'Elia).
- ➢In order to accommodate this, R_c needs to be increased ⇒ DDS2_ER.
- ➢Coupling of dipole modes is reduced and wake-suppression is degraded. How much?

4. CLIC_DDS_E vs CLIC_DDS_ER Wakefield

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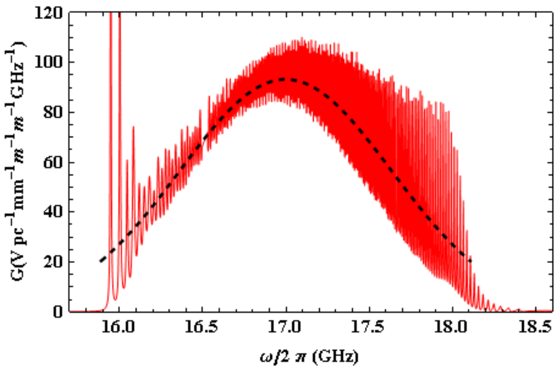
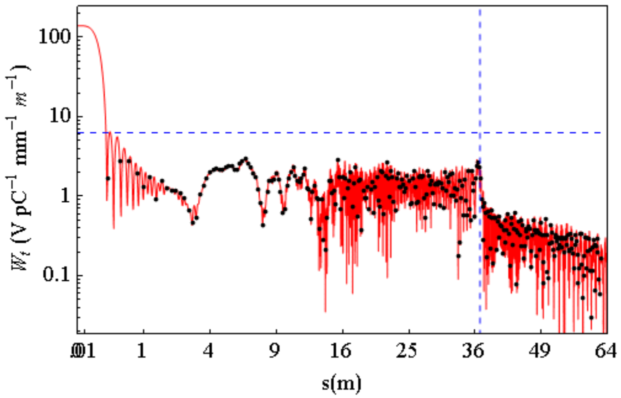
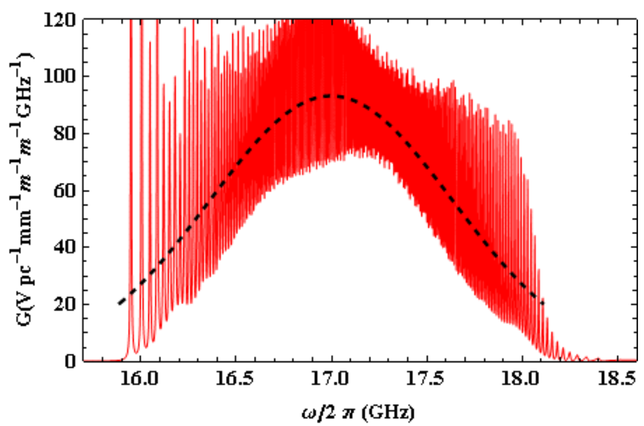
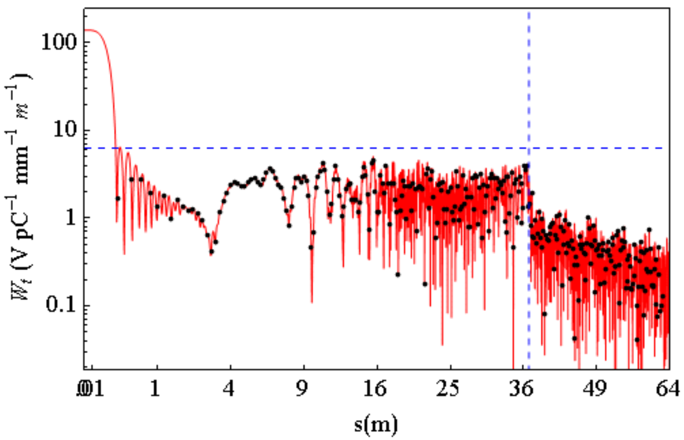
Spectral Function **Wakefunction**





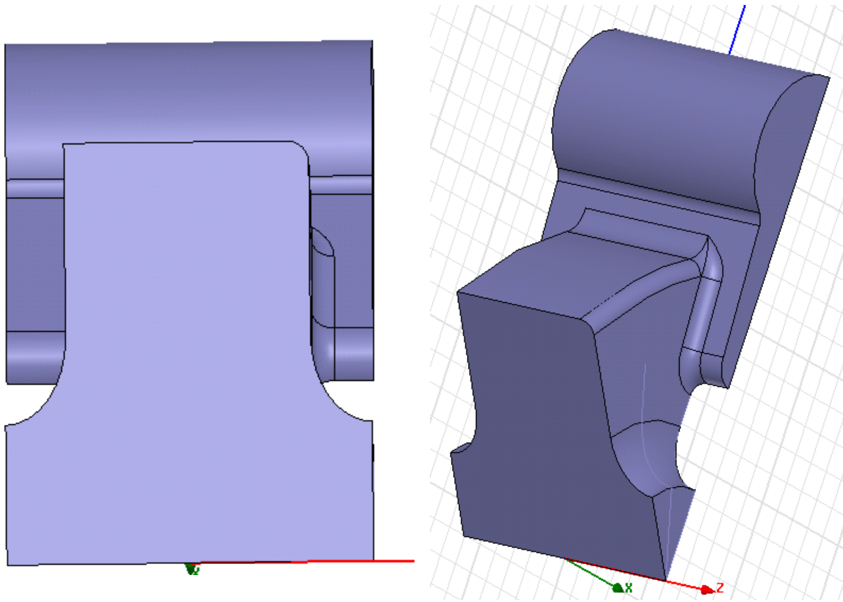
CLIC_DDS_E :Rc=6.2 - 6.8 mm (optimised penetration)





- **CLIC_DDS_ER : Rc=6.8 mm const (a single one of these structures constitutes CLIC_DDS_A, being built for HP testing)**
- **Wakefield suppression is degraded but still within acceptable limits.**

4. CLIC_DDS_A: Structure Suitable for High Power Testing



➢Info. on the ability of the 8-fold interleaved structure to sustain high e.m. fields and sufficient ΔT can be assessed with a single structure.

➢Single structure fabricated in 2011, CLIC_DDS_A, to fit into the schedule of breakdown tests at CERN.

➢Design is based on CLIC_DDS_ER

➢To facilitate a rapid design, the HOM couplers have been dispensed with in this prototype.

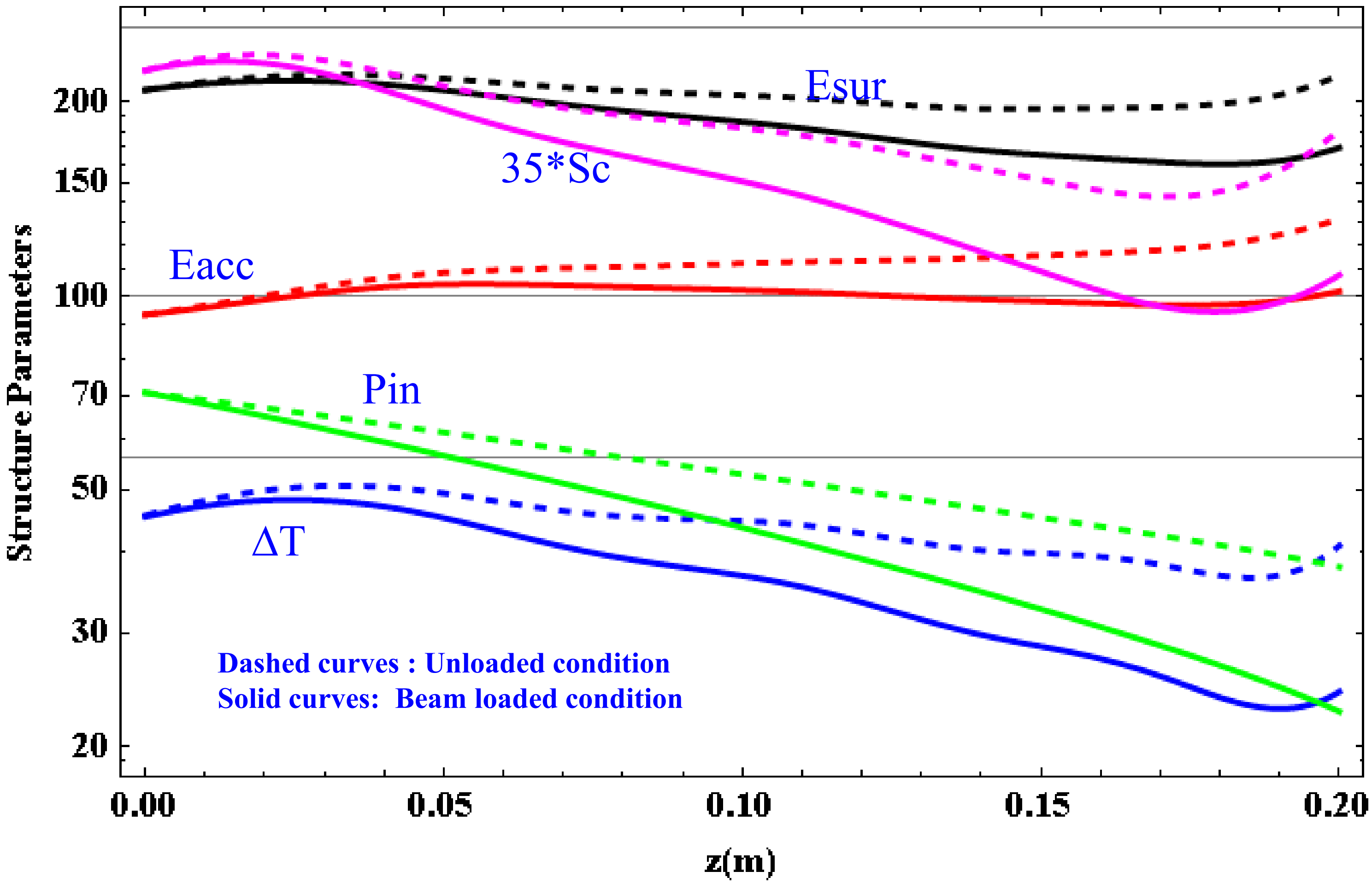
➢Mode launcher design utilised

➢SRF design complete!

➢Mechanical drawings, full engineering design completed!

➢Qualification end cells fabricated. Recently received (Oct 15 2010!)!

4. CLIC_DDS_A Parameters



Max. Values

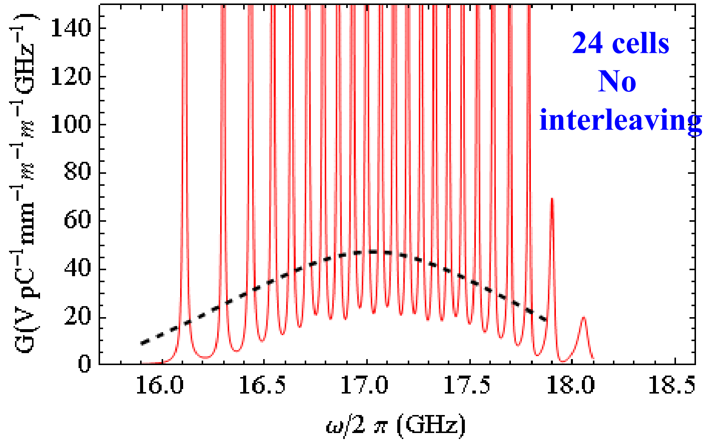
Esur=220 MV/m
ΔT = 51 K
Pin= 70.8
Eacc_UL=131 MV/m
Sc=6.75 W/μm^2
RF-beam-eff=23.5%

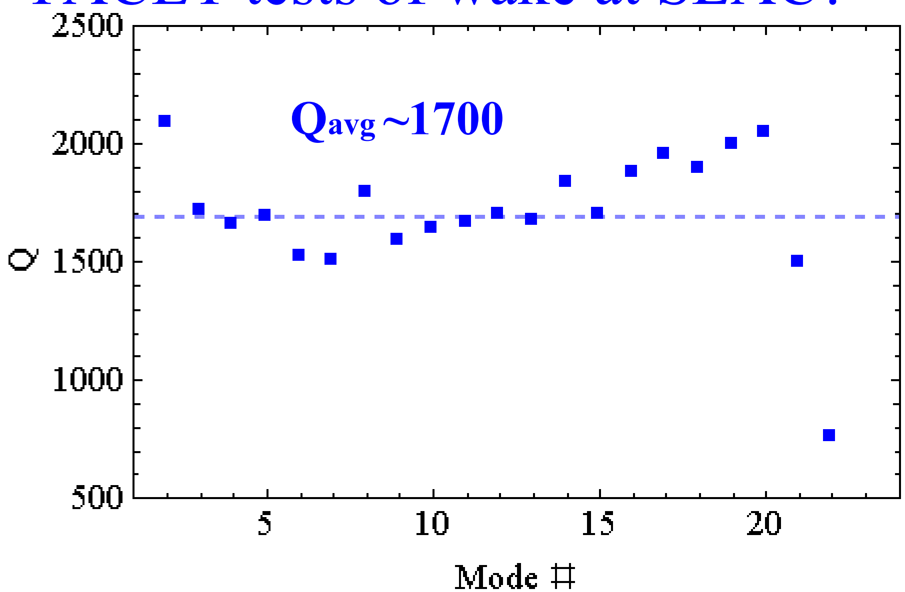
CLIC_G Values

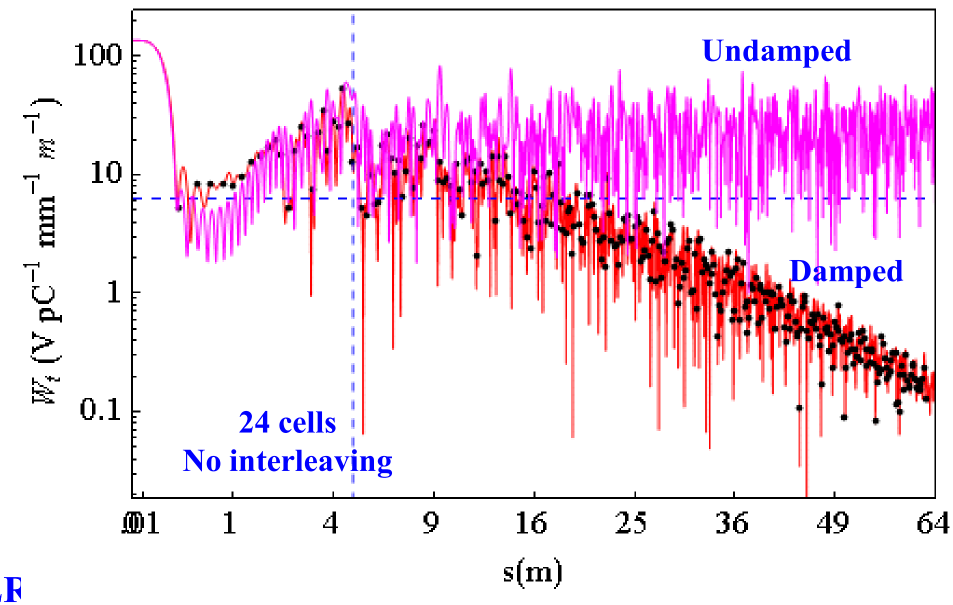
Esur=240 MV/m
ΔT = 51 deg.
Pin= 63.8
Eacc_UL=128 MV/m
Sc=5.4 W/μm^2
RF-beam-eff=27.7%

4. CLIC_DDS_A Wake

- Wake of a non-interleaved 24 cell structure –first structure of 8-fold interleaved structure chosen.
- Motivated by high gradient testing
- Wake is measurable and provides a useful comparison to simulations (but will not, of course, meet beam dynamics criteria)
- FACET tests of wake at SLAC?

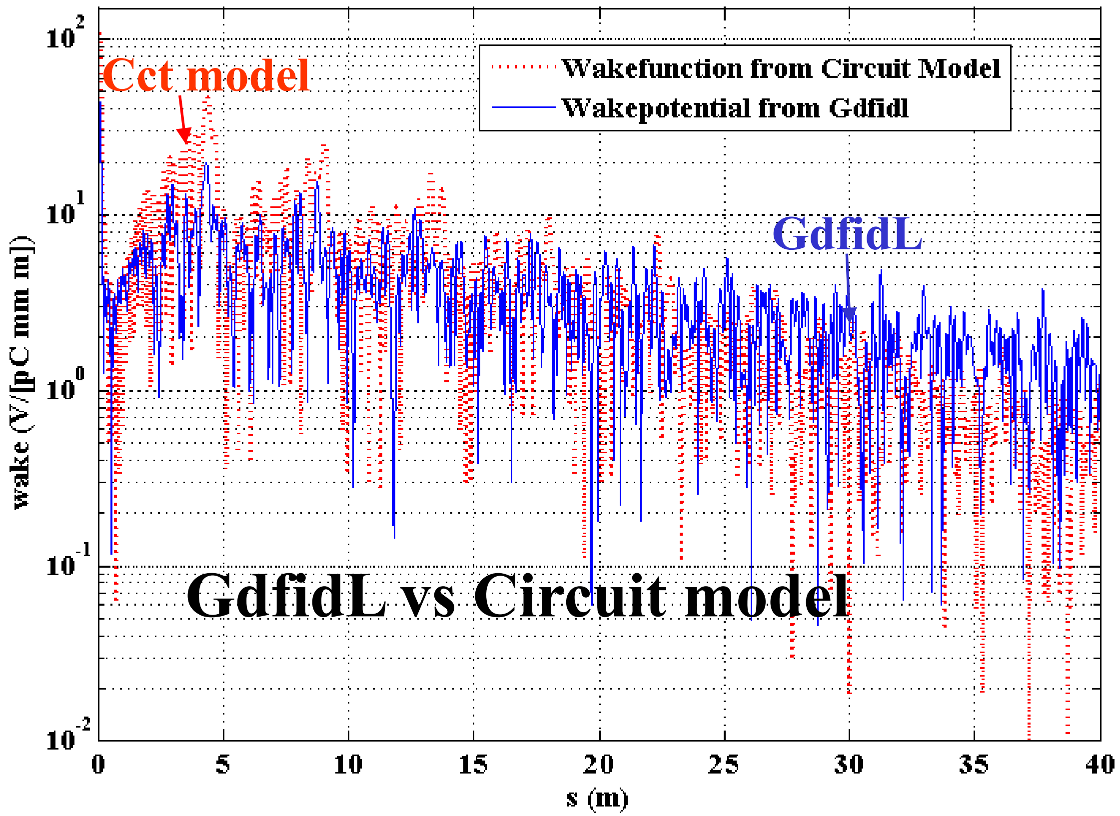




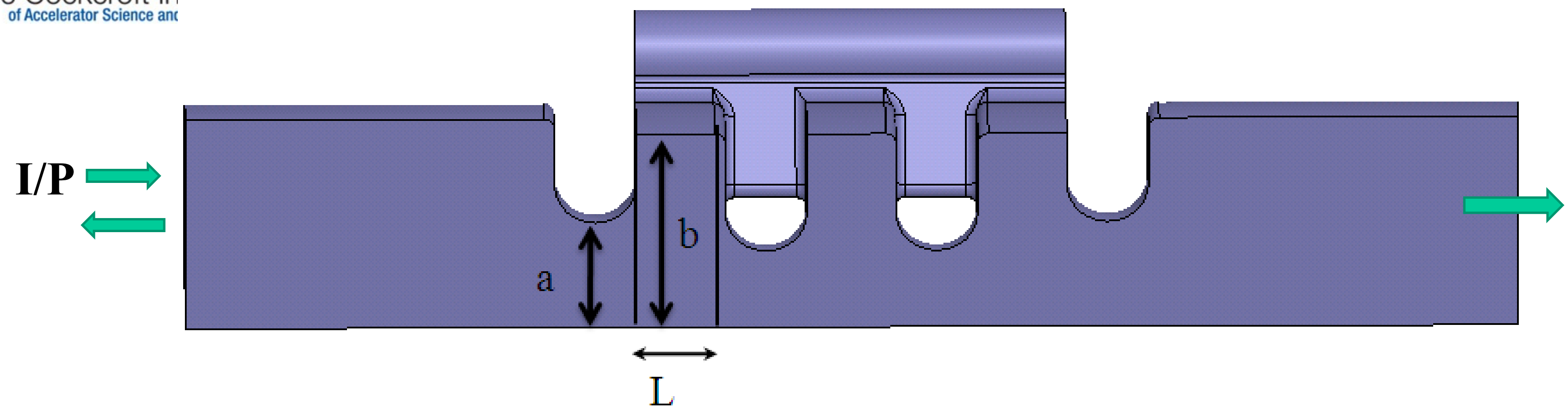


4. CLIC_DDS_A Wake

- ➢Recent simulations with GdfidL (finite difference based code)
  - ❑Single structure simulated
  - ❑GdfidL simulations do not include the loading of the dipole mode by the fundaments, coupler (Q~36)
- ➢Nonetheless, reasonable agreement with circuit model and damping is expected to be sufficient



4. Matching CLIC_DDS_A



- Firstly, match-out either end of structure with regular cells:
  - Structure for test will utilise a mode launcher
  - Initially, simulate a structure with one regular cell and two matching cells at either end and we study the minima in S_{11} as a function of the geometrical parameters of the matching cells (a, L –adopt L variation, rather than b, from space considerations)
  - Add additional (2, then 3) identical standard cells (const. imp) and follow the same procedure and modify parameters of matching cells to minimise S_{11}
  - The matching condition (on a, L) is that which coincident with all 3 simulations.
- Secondly, once complete, match-out the full, tapered structure based on this match.

4. CLIC_DDS_A

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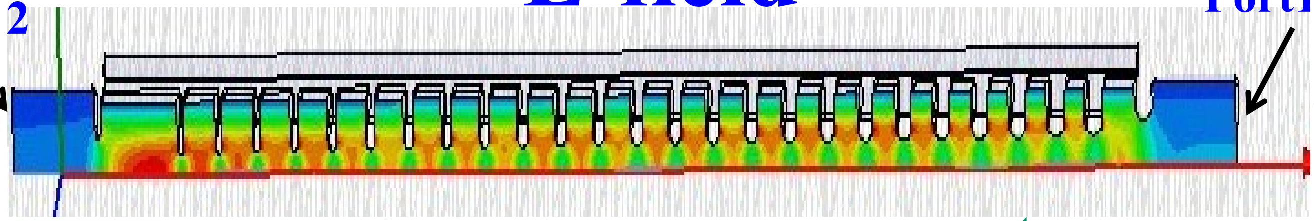
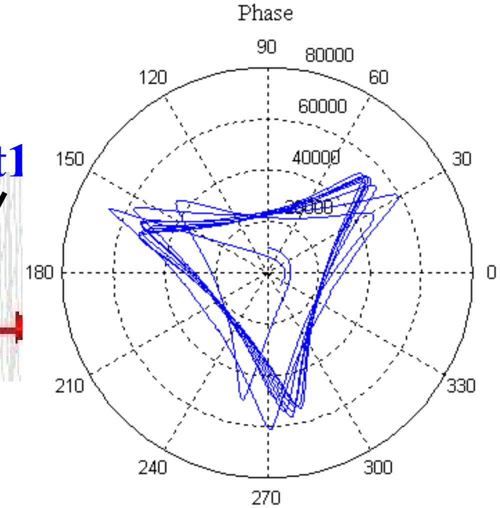
- ➢ Match-out the full, tapered structure
- ➢ E-field and S_{11} shown

E-field

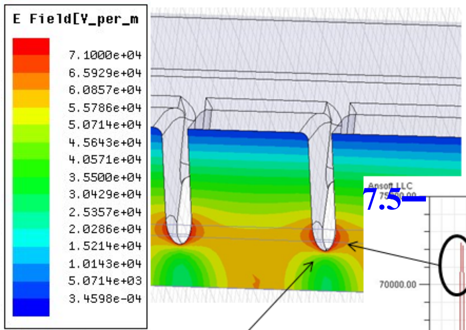
Port 2

Port1



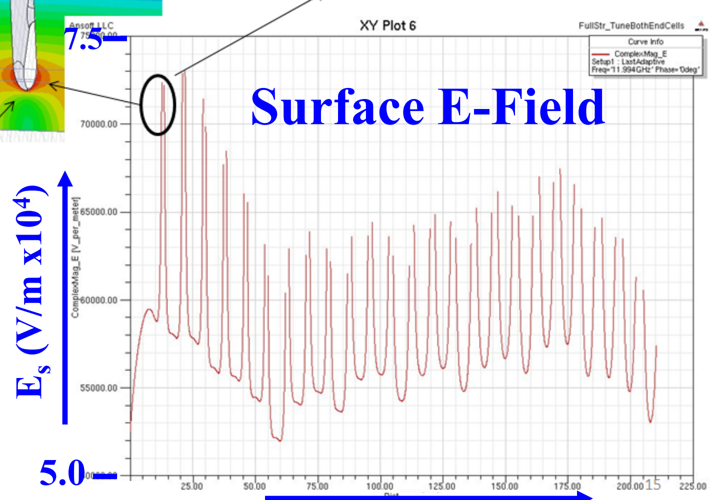


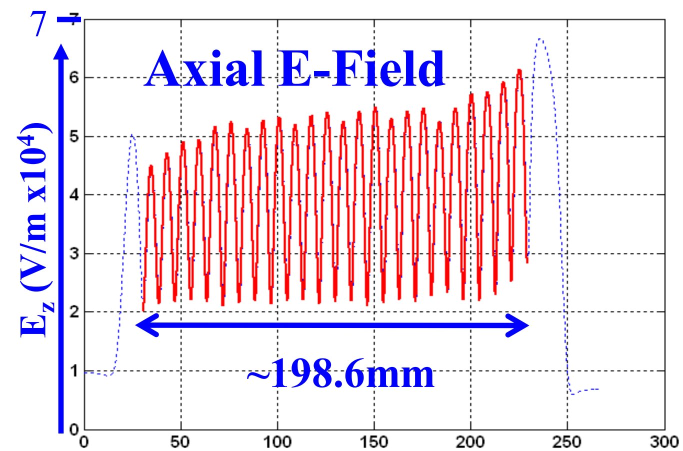
Beam



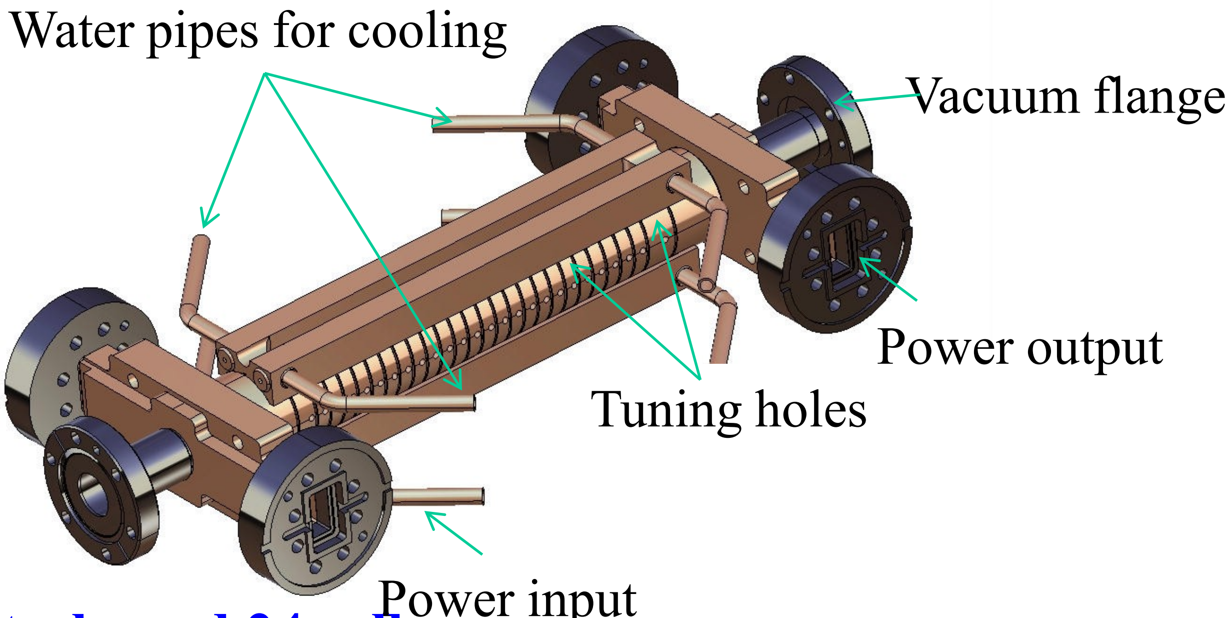
Matching cell

Matching side=72.34MV/m
Regular cell side= 72.175MV/m
Ratio=0.2%

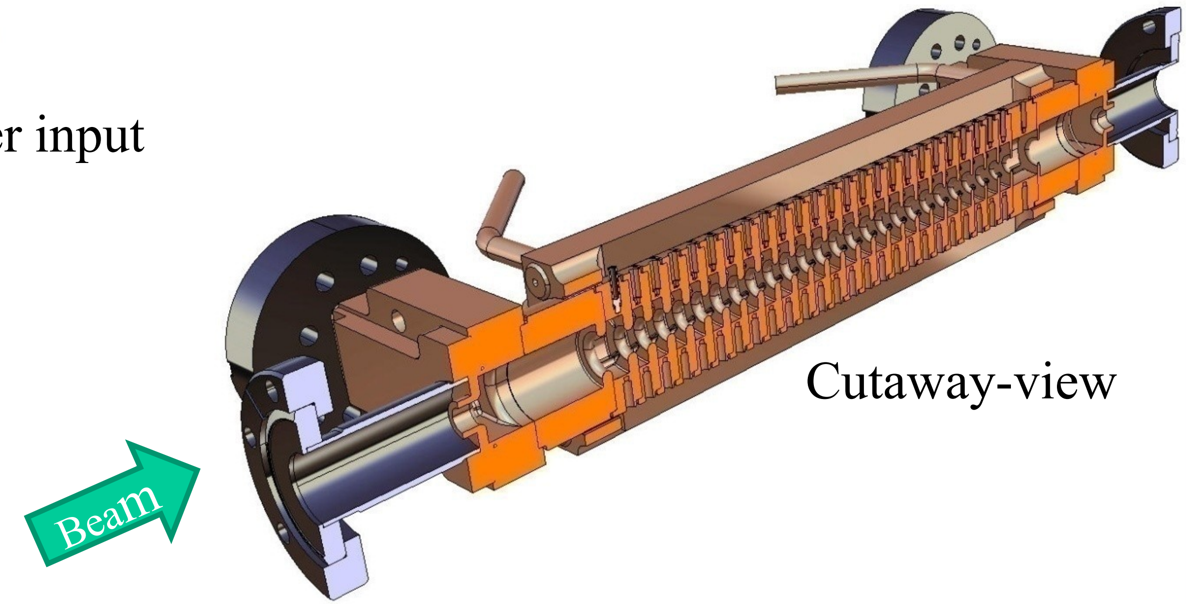




2. Mechanical Eng. Design of DDS_A



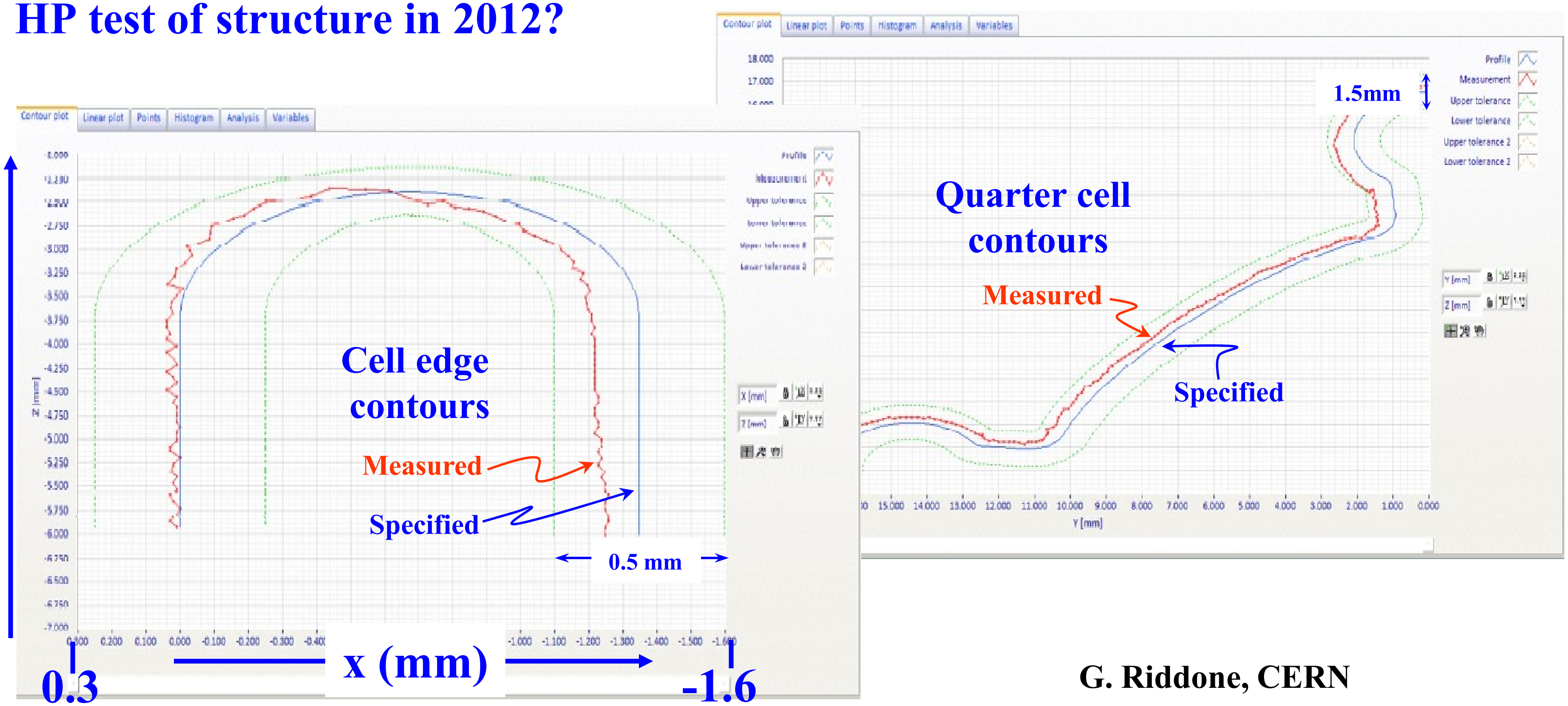
- **Non-interleaved 24 cell structure –first structure of 8-fold interleaved structure chosen.**
- **High power (~71MW I/P) and high gradient testing**
- **To simplify mechanical fabrication, uniform manifold penetration chosen**



V.Soldatov, CERN

2. Cell Qualification of CLIC_DDS_A

- VDL (Netherlands) have machined and measured several cells –end cells. (recvd by CERN Oct 2010)
- Global profiles made with optical Zygo machine are illustrated for disk 24
- Design, tolerance bounds and achieved profile shown
- Morikawa (Japan) will fabricate cells –rf test at KEK
- Fabrication and bonding of complete structure by last quarter of 2011
- HP test of structure in 2012?



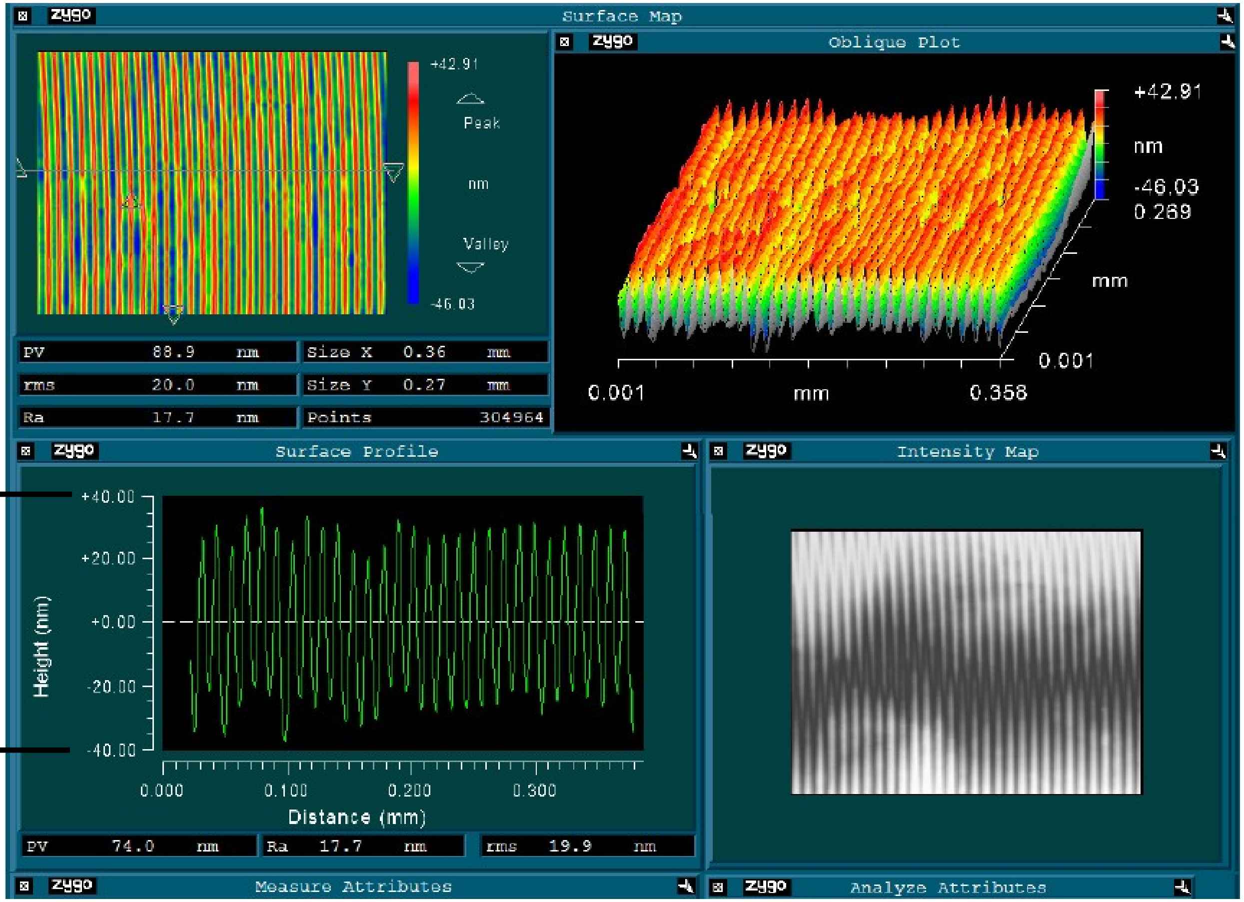
G. Riddone, CERN

2. Cell Qualification of CLIC_DDS_A

- Local profile made with an optical Zygo machine
- Local profiles indicate < 50nm variation in surface roughness
- Cell 24 displayed

+40 nm

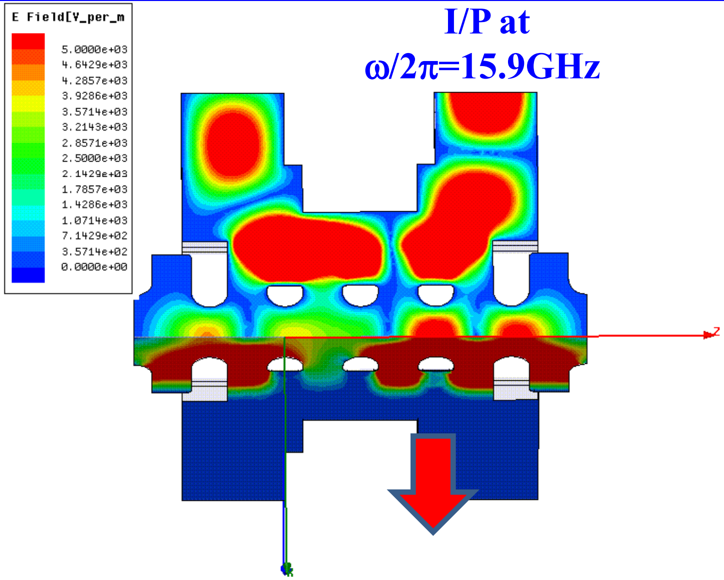
-40 nm



G. Riddone, CERN

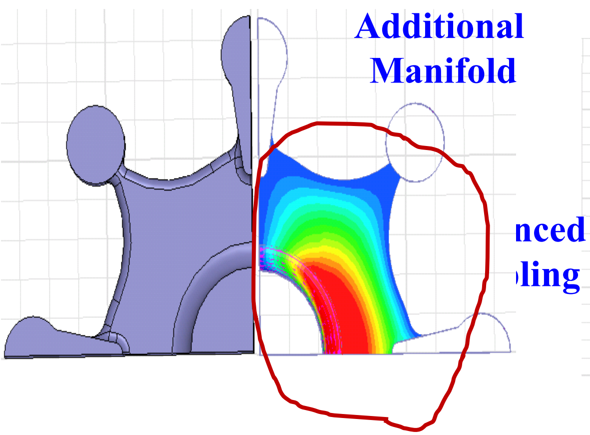
2. Work in Progress +Future Plans

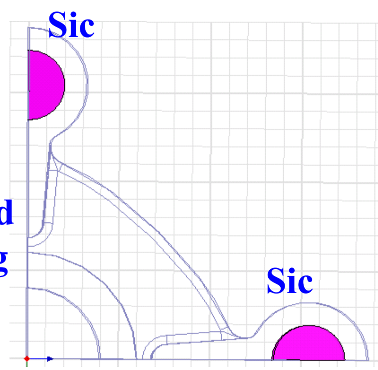
- CLIC_DDS_A is equipped with mode launchers –aim is to demonstrate ability to sustain HP
- CLIC_DDS_B includes full HOM ports
- Matching the HOM coupler for CLIC_DDS_B (dipole band ~ 15.9 GHz – 18 GHz)



- Construct pair of structures with full damping features
- Moving to a high phase advance (HPA) structure allows other parameters to be optimised
- 5π/6 phase advance structure design in progress
- In the HPA design further features being explored
- Additional manifold (8), add SiC?

Standard DDS Manifold





2. Main Linac Future Plans –EuCARD2

- CLIC_DDS_B includes full HOM ports
- Matching the HOM coupler for CLIC_DDS_B (dipole band ~ 15.9 GHz – 18 GHz)
- Construct pair of structures with full damping and HP features
- Structures will be built in collaboration with CERN, SLAC and KEK?
- High power tested at CERN
- Coarse wakefield features tested at CTF3?
- Precision wakefield tested at SLAC: ASSET/FACET?

- Total ~£570k: Materials -£100k (£50k/structure), Manpower -£300k (4.5 FTE), travel £20k

2. Main Linac Future Plans –EuCARD2

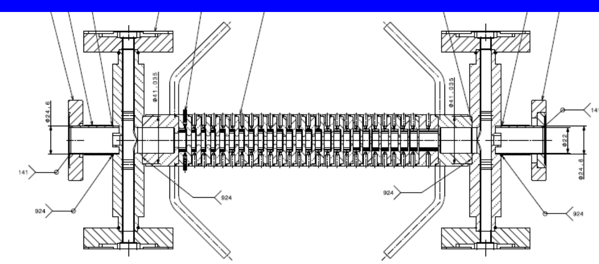
- Consolidate proposals into one main proposal
- Eu Partners/Collaborators: CERN (Structures group – Wuensch, Riddone, et al), PSI (Dehler, Seidel)

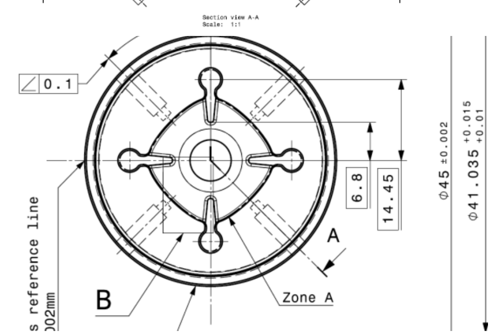
Acknowledgements

- I am pleased to acknowledge a strong and fruitful collaboration between many colleagues and in particular, from those at CERN, University of Manchester, Cockcroft Inst., SLAC and KEK.
- Several at CERN and KEK within the CLIC programme, have made critical contributions: W. Wuensch, A. Grudiev, I. Syrachev, R. Zennaro, G. Riddone (CERN), T. Higo Y. Higashi (KEK).

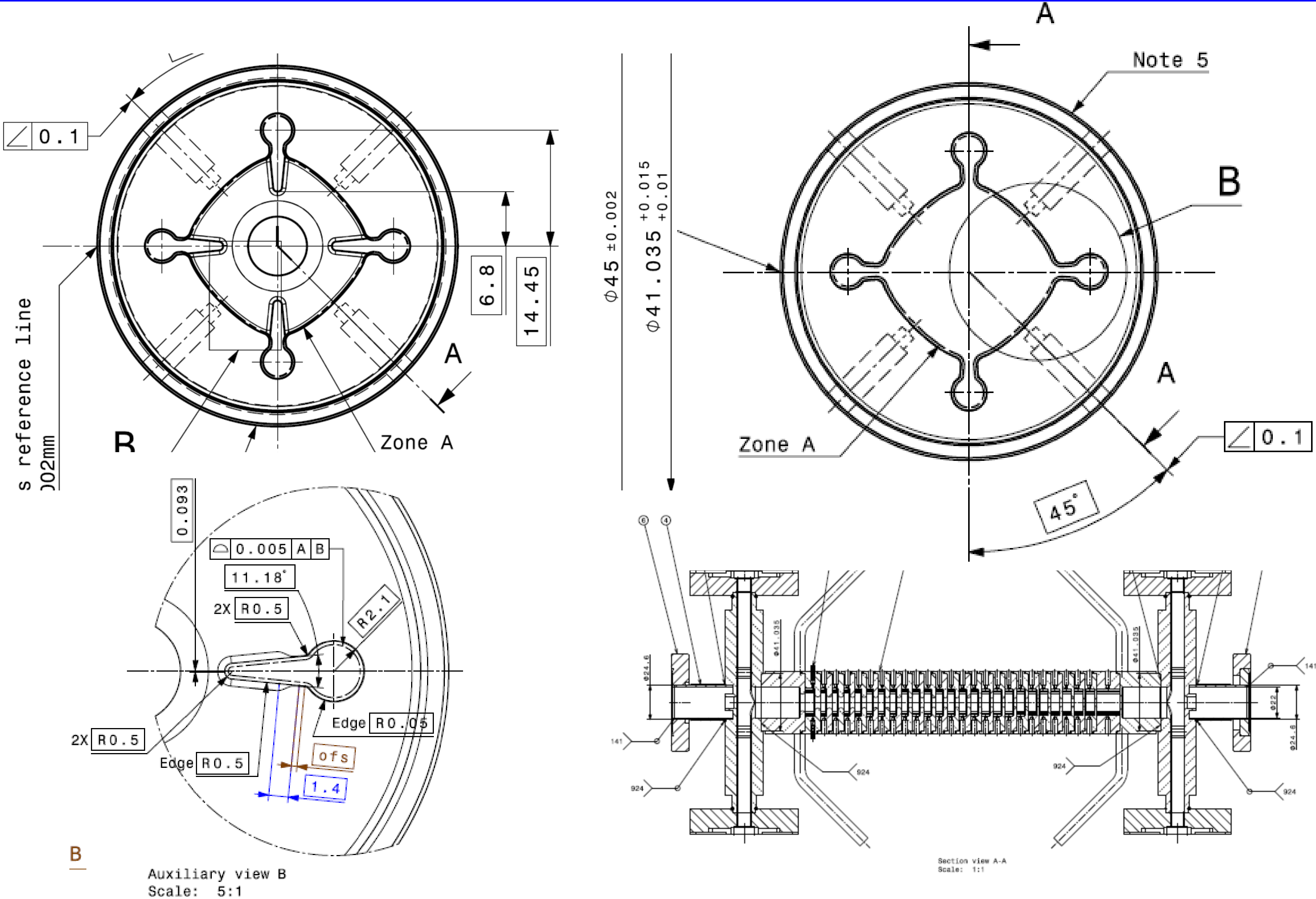
CLIC DDS Related Pubs.

1. **R. M. Jones, *et. al*, PRST-AB, 9, 102001, 2006.**
2. **V. F. Khan and R.M. Jones, EPAC08, 2008.**
3. **V. F. Khan and R.M. Jones, LINAC08, 2008.**
4. **V. F. Khan and R.M. Jones, Proceedings of XB08, 2008.**
5. **R. M. Jones, PRST-AB, 12, 104801, 2009.**
6. **R. M. Jones, *et. al*, NJP, 11, 033013, 2009.**
7. **V. F. Khan and R.M. Jones, PAC09, 2009.**
8. **V. F. Khan, *et. al*, IPAC10, 2010.**
9. **V. F. Khan, *et. al*, LINAC10, 2010.**





CLIC_DDS_A Mechanical Eng. Design



3. SC Proposals –EuCARD2

1. HOMs in SC cavities –continuation of work at FLASH -> XFEL. Eu Partners/Collaborators: University of Manchester (Jones et al), DESY (Baboi et al), University of Rostock (Van Rienen, Hans-Walter Gloch et al)
2. SC spoke mode cavities. Eu Partners/Collaborators: University of Manchester (Jones et al), ESS (Lindroos, Peggs et al). Simulation design, (test at Max-Lab, Lund).
3. Sputtering thin films on Cu substrate 100 MHz quarter wave cavities. Eu Partners/Collaborators: University of Manchester (Jones et al), CERN (Pasini et al), University of Lancaster (Seviour et al)

N.B. The above SC proposals are in early stage of interest. Expect further developments over the next week or so.

3.1 HOM Diagnostics in SC Accelerator Cavities -Staff

- **Sub-task leaders**: Nicoleta Baboi (DESY), Ursula van Rienen (Univ. Rostock), Roger M. Jones (CI/Univ. Manchester).

- PDRAs: Hans-Walter Glock (Univ. Rostock), Ian Shinton (CI/Univ. of Manchester)
- PhDs: Nawin Juntong (CI/Univ. Manchester), Chris Glasman, Pei Zhang (CI/Univ. Manchester/DESY)

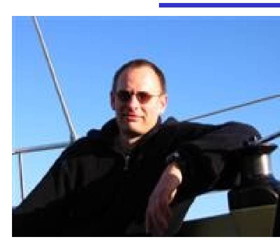
WP 10.5.2

I. Shinton, CI/Univ. of Manchester PDRA

N. Juntong, CI/Univ. of Manchester PhD student (PT on FP7)

C. Glasman, CI/Univ. of Manchester PhD student (PT on FP7)

WP 10.5.3



H-W Glock, Univ. of Rostock, PDRA

T. Flisgen, Univ. of Rostock, PhD Student

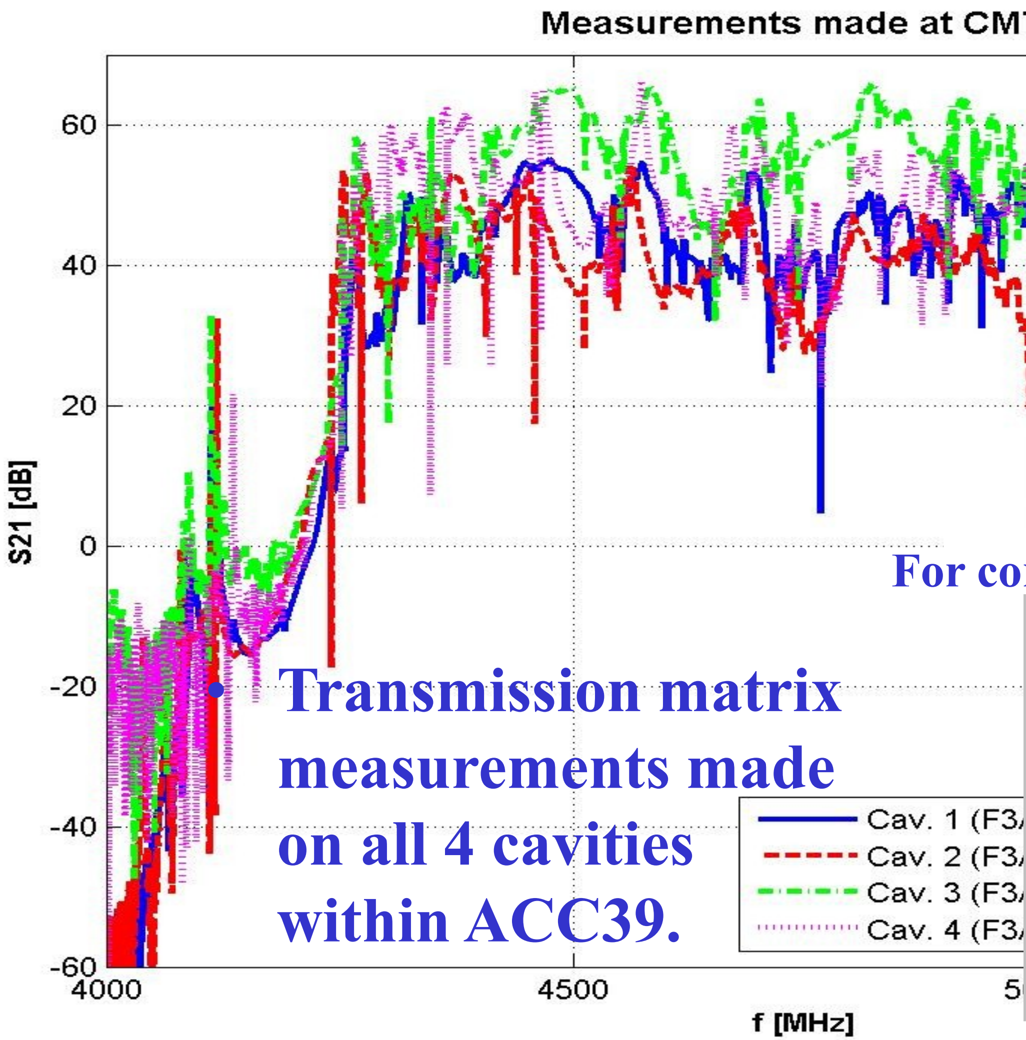
U. Van Rienen, Univ. of Rostock

WP 10.5.1

N. Baboi, DESY

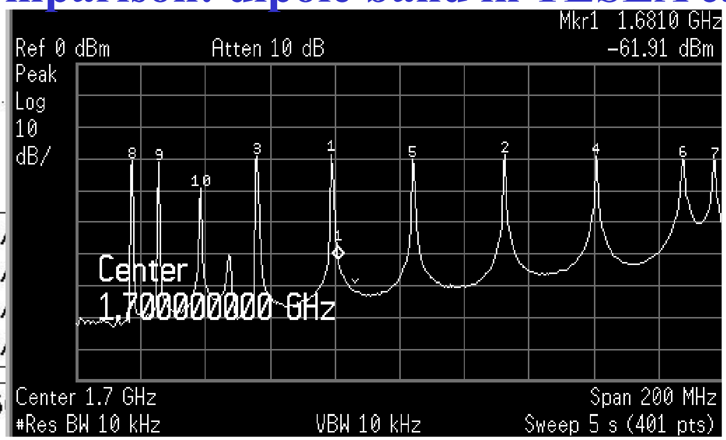
P. Zhang, DESY/Univ. Of Manchester

3.1 ACC39 Spectra Measured in CMTB: Focused on Dipole and Other Bands

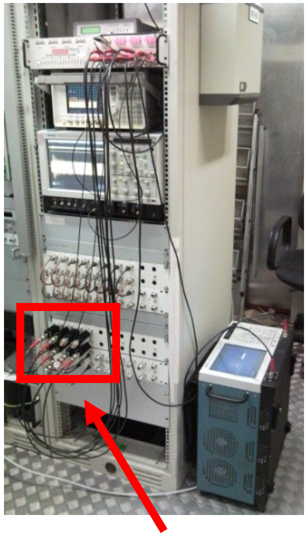


- Transmission matrix measurements made on all 4 cavities within ACC39.

For comparison: dipole band in TESLA cavi

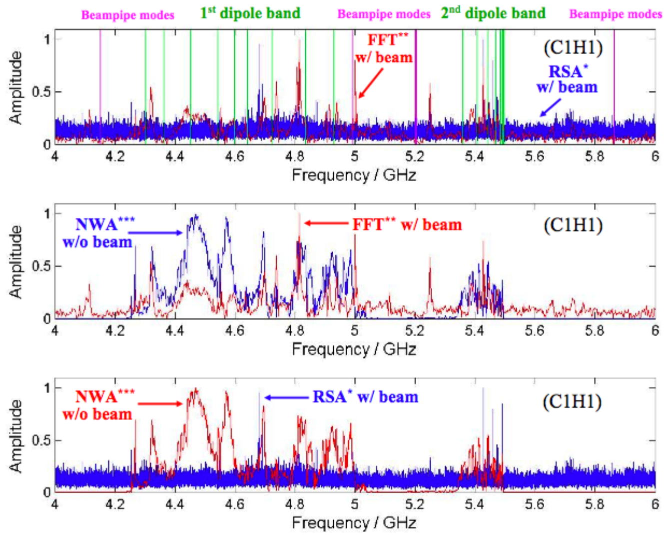


3.1 Beam-Excited Spectra of HOMs

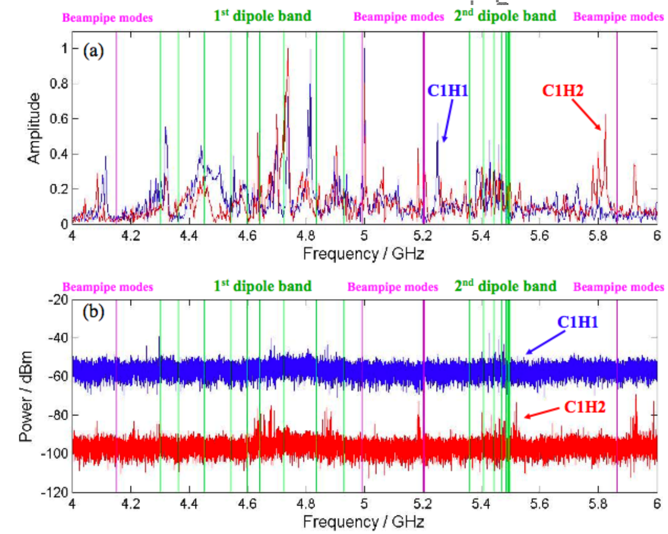


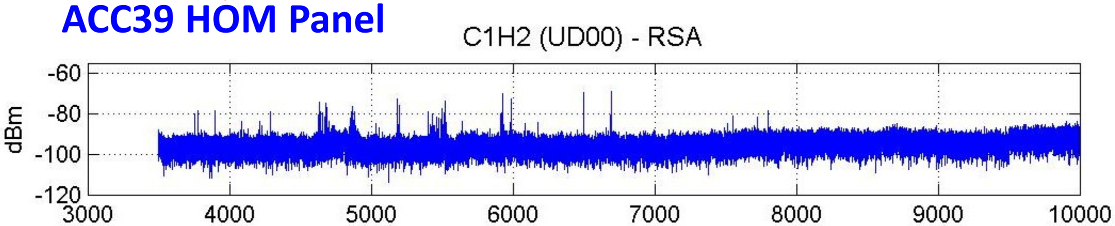
ACC39 HOM Panel

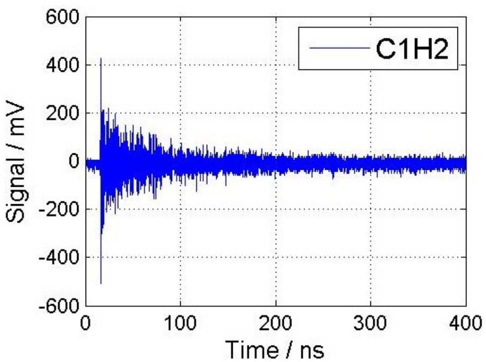
Dipole spectra comparison



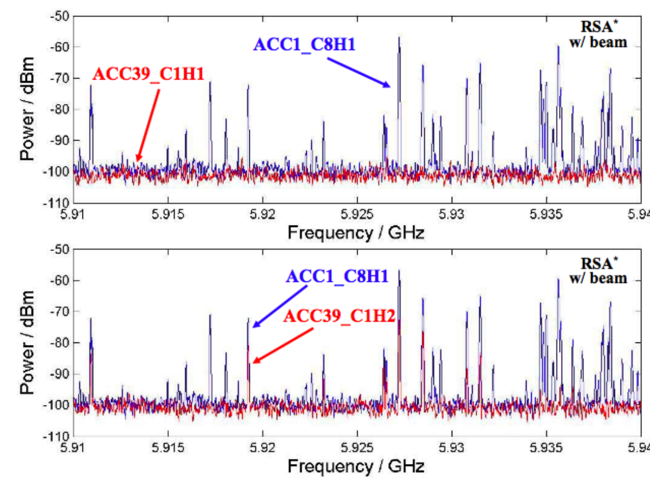
c.f. HOM Coupler Spectra







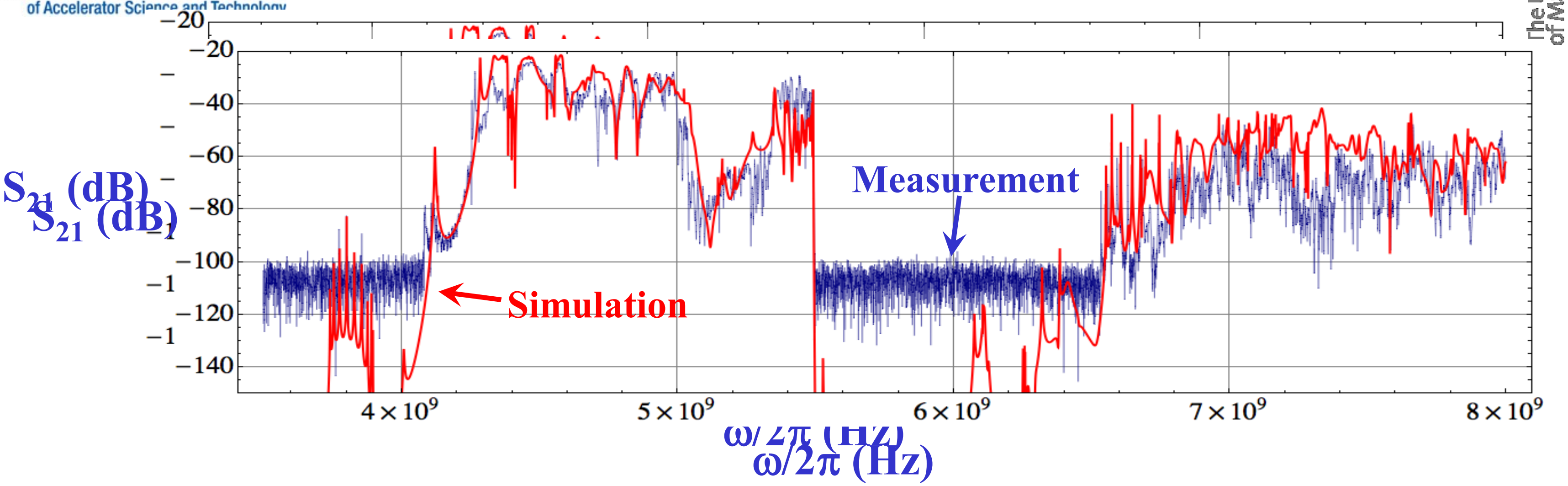
Transmission from ACC1



Outlook

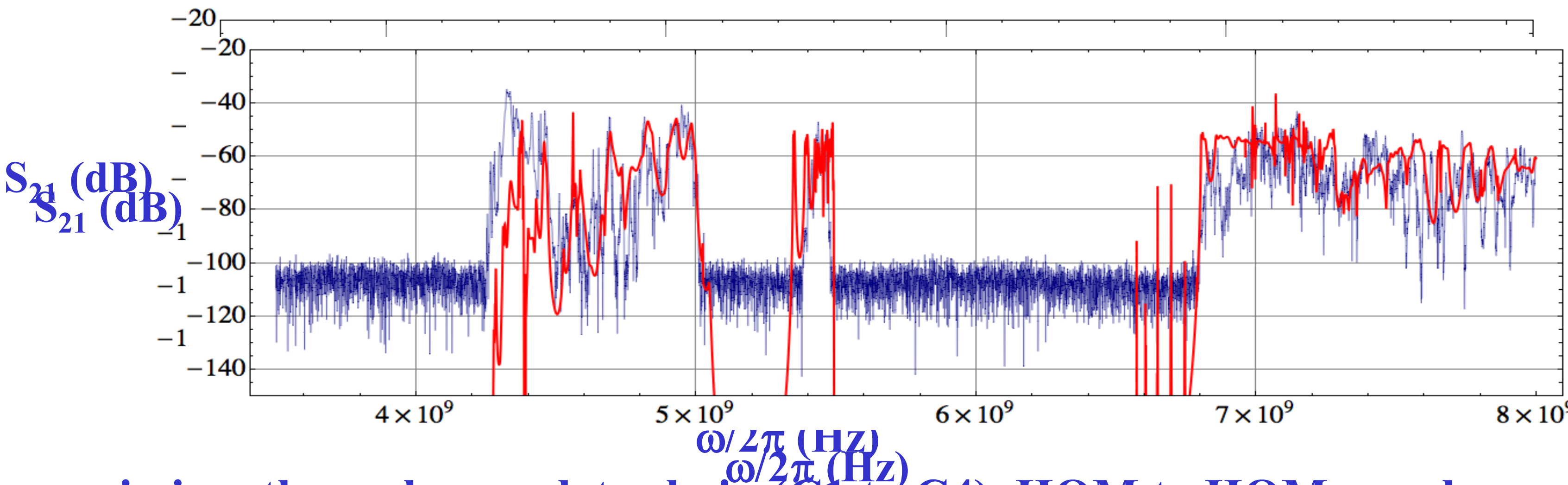
- Detailed beam-excited mode study
- Find suitable mode(s) for diagnostic electronics design

3.1 S21 Simulation in ACC39



Transmission through a single non-isolated cavity (C3) in chain of 4 cavities

Transmission through a single non-isolated cavity (C3) in chain of 4 cavities



Transmission, through complete chain (C1 to C4), HOM to HOM coupler

Transmission, through complete chain (C1 to C4), HOM to HOM coupler

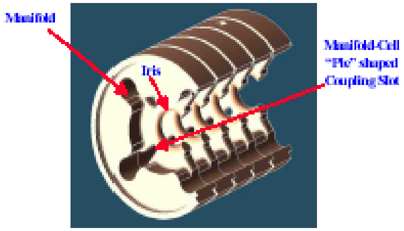
Extra Slides!

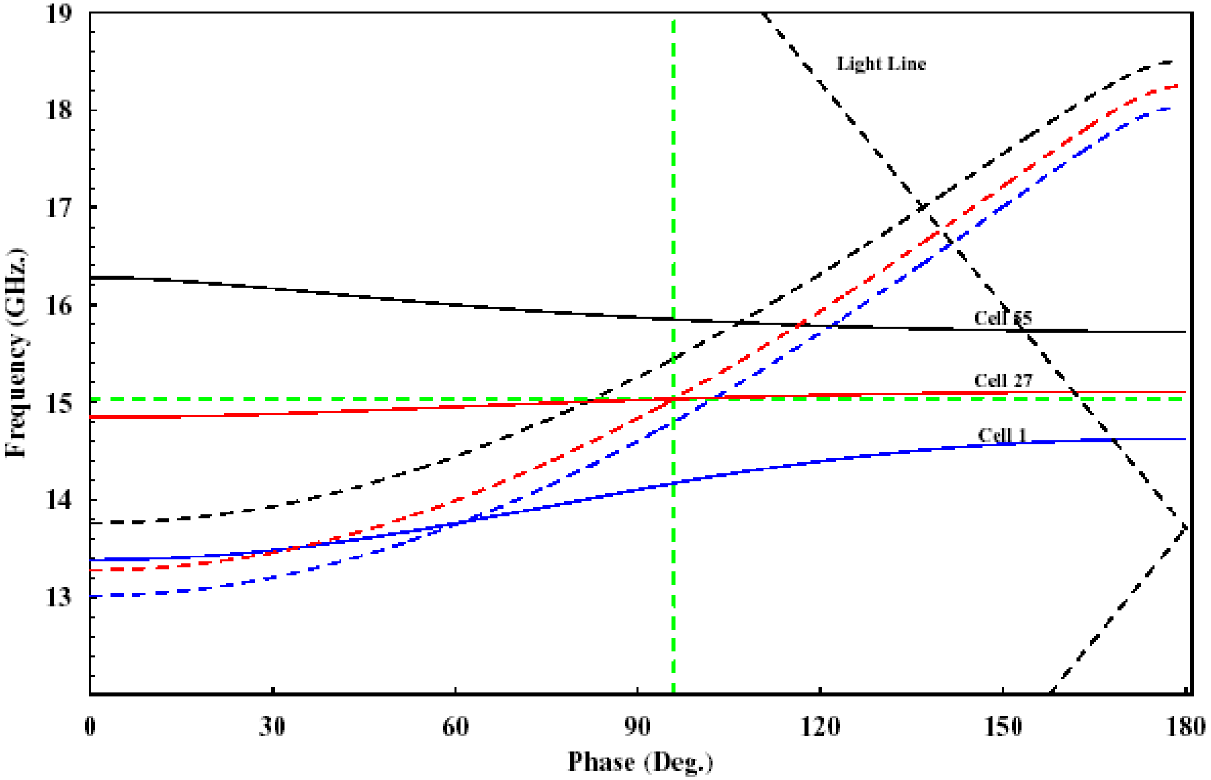
1. Physics of Manifold Mode Coupling to Dipole Modes

How Does Manifold Damping Work?

The fig. illustrates the dispersion curves from 3 cells of 55-cell accelerating DDS

* Strong coupling to the manifold occurs where dipole and manifold curves of the same color cross
*For mode 27 this occurs at ~15.03 GHz (green dashed line) at ~95.9 deg.
*Interpolation between the dipole curves shown at 0 and 180 suggests the mode is localized to cells: 20 to 34
*Also, from where the light line crosses 15.03 at ~162.6 deg.: the mode is excited at cell 20





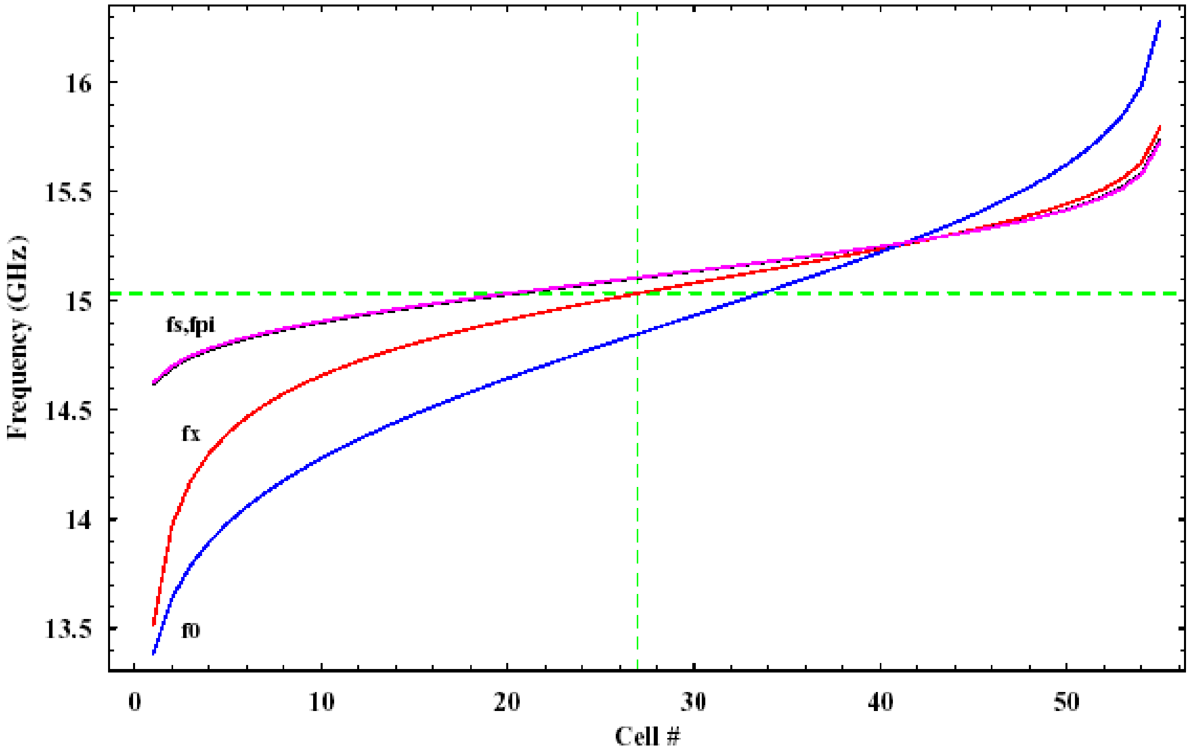
1. Coupling Along Complete Structure

* In general, the beam propagates down the accelerating structure and is localized to a limited number of cells
(it becomes progressively more localized as it moves down the structure towards the zero group velocity point)
* It couples to the manifold several cells away from the excitation point.

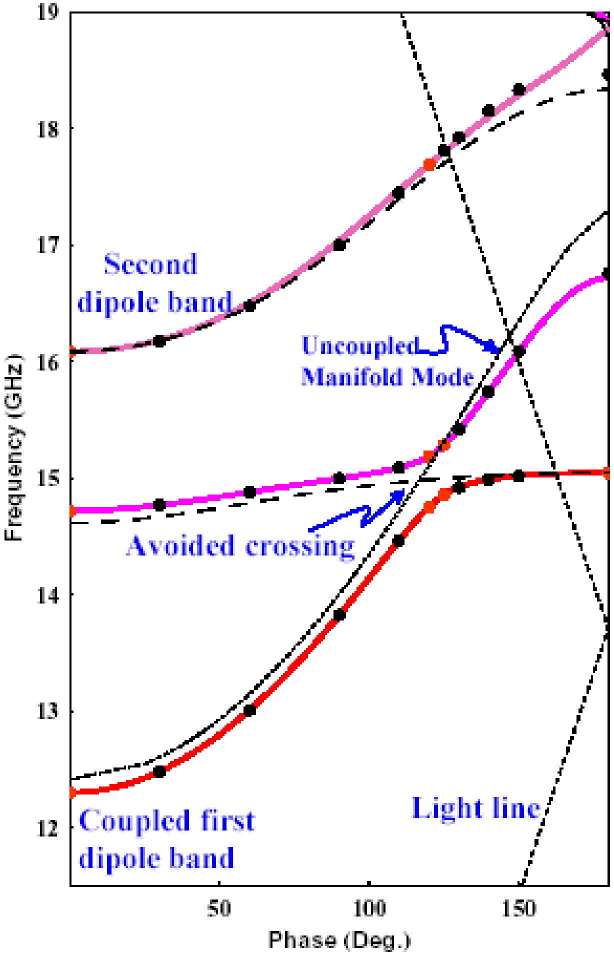
Mode Synchronous With the Light Line is Denoted: **fs**

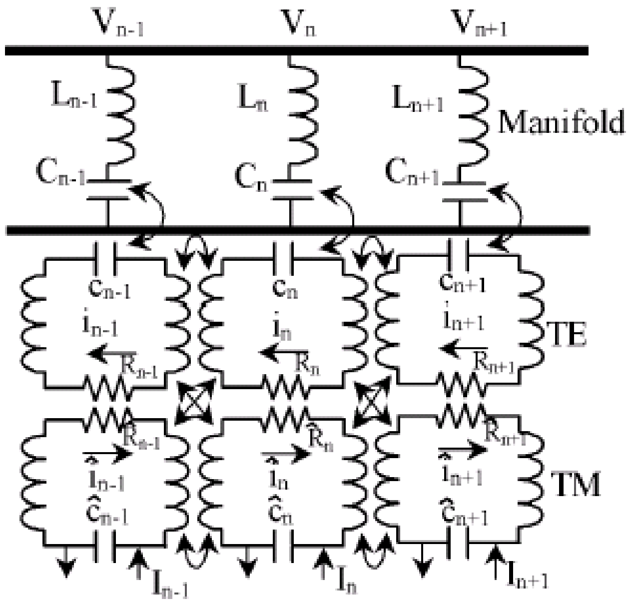
Mode Corresponding to Crossing of Manifold and Cell-Mode by: **fx**

Zero and Pi Modes by: **f0, fp**



1. Circuit Model of DDS





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.

**Wakefield damping in a pair of X-band accelerators for linear colliders.R.M. Jones , et al, Phys.Rev.ST Accel.Beams 9:102001,2006.

1. Circuit Model Equations

Coupling Between Manifold-Cell

$$V_n = -j\left(I_n/C_n + i_n\kappa_n/\sqrt{C_n c_n}\right)/\omega$$

$$v_n = -j\left(i_n/c_n + I_n\kappa_n/\sqrt{C_n c_n}\right)/\omega$$

Matrix Elements

$$R_{nn} = -2\cos\phi_n,\quad R_{nn\pm1} = 1$$

$$\cos\phi_n = \cos\phi_{0n} - \alpha_n\left(\pi L/c\right)^2 F_n^2/\left(F_n^2 - f^2\right)\mathrm{sinc}\,\phi_{0n}$$

$$\phi_{0n} = \left(2\pi L/c\right)\sqrt{f^2 - F_{cn}^2}$$

$$H_{nn} = 1/f_n^2 + \Gamma_n^2/\alpha_n/\left(F_n^2 - f^2\right)$$

$$H_{nn\pm1} = \eta_{n\pm1/2}/\left(2f_n f_{n\pm1}\right)$$

$$H_{nn\pm1} = \pm\eta_{x,n\pm1/2}/\left(2f_n\hat{f}_{n\pm1}\right)$$

$$\hat{H}_{nn} = 1/\hat{f}_n^2,\quad \hat{H}_{nn\pm1} = -\hat{\eta}_{n\pm1/2}/\left(2\hat{f}_n\hat{f}_{n\pm1}\right)$$

$$G_{nn} = \Gamma_n\left(\pi L/c\right)^2 F_n^2/\left(F_n^2 - f^2\right)\sqrt{2\,\mathrm{sinc}\,\phi_{0n}}$$

Network Equations in Matrix Form:

$$RA = Ga$$

$$\left(H - 1/f^2\right)a + H_x\hat{a} = GA\left(= GR^{-1}Ga\right)$$

$$\left(\hat{H} - 1/f^2\right)\hat{a} + H_x^t = B/f^2$$

- In the 9-parameter model each parameter is determined from MAFIA or Omega3 simulations to produce Brillouin diagrams for a limited number of fiducial cells.

- The remaining cells are obtained by interpolation and non-linear error function (Erf) fits.

1. Determination of Parameters

•There are nine parameters to be determined (5 associated with the cells and 4 with the manifold).

•These are determined by specializing to uniform structures as we did in the case of a DS. The dispersion curves for the three lowest modes are matched to those determined from simulations using MAFIA and Omega3:

$$\left[\overbrace{\left(\frac{1+\eta\cos\psi}{f_0^2}+\frac{\Gamma^2}{\alpha\left(F^2-f^2\right)}-\frac{1}{f^2}\right)}^{\text{TE Cell Mode}}\overbrace{\left(\frac{1-\hat{\eta}\cos\psi}{\hat{f}_0^2}-\frac{1}{f^2}\right)}^{\text{TM Cell Mode}}-\overbrace{\frac{\bar{\eta}^2}{f_0^2\hat{f}_0^2}\sin^2\psi}^{\text{TE-TM Coupling}}\right]\overbrace{\left(\cos\psi-\cos\phi\right)}^{\text{Manifold Mode}}=$$

$$\underbrace{\left(\frac{F^2}{F^2-f^2}\right)^2\left(\frac{\pi L}{c}\right)^2\left(\frac{1-\hat{\eta}\cos\psi}{\hat{f}_0^2}-\frac{1}{f^2}\right)\sin\phi_0}_{\text{Coupling to Manifold}}$$

•Setting $\Gamma = 0$ it is evident that the above breaks up into 3 equations: $\cos\psi = \cos\phi$, the manifold equation, and a two band dispersion relation

We require 9 points on the curves. Three dispersion are used and the 6 $\psi = 0, \pi$ points. This guarantees that the mode curves given by the circuit match the end points. The remaining 3 points are taken near the avoided crossing. They guarantee that the curves cross at the correct phase and that the shape of the avoided crossing is well represented (the coupling strength is determined in this region).

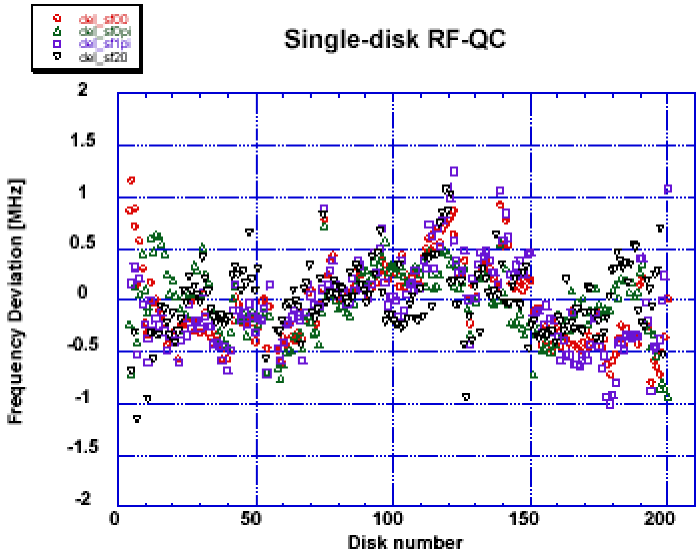
Thus we form:

$$\begin{bmatrix} D_1(p) \\ \cdots \\ \cdots \\ D_9(p) \end{bmatrix} = 0$$

where $D_n(p)$ represents the dispersion relation obtained from the nth ψ point and p represents 9 parameters.

These 9 coupled non-linear equations are solved for the 9 parameters and the 3 dispersion curves are obtained. This procedure was followed for 11 cells of DDS1 and intermediate cells are obtained by interpolation and error function fitting procedures.

1. Fabrication Tolerances from a Beam Dynamics/Wakefield Suppression Perspective



•Small dimensional errors, generated when fabricating the irises and cavities of an accelerator structure, give rise to errors in the synchronous frequencies.

• For RDDS1 it was possible to machine the cells to an accuracy of better than 1 μm

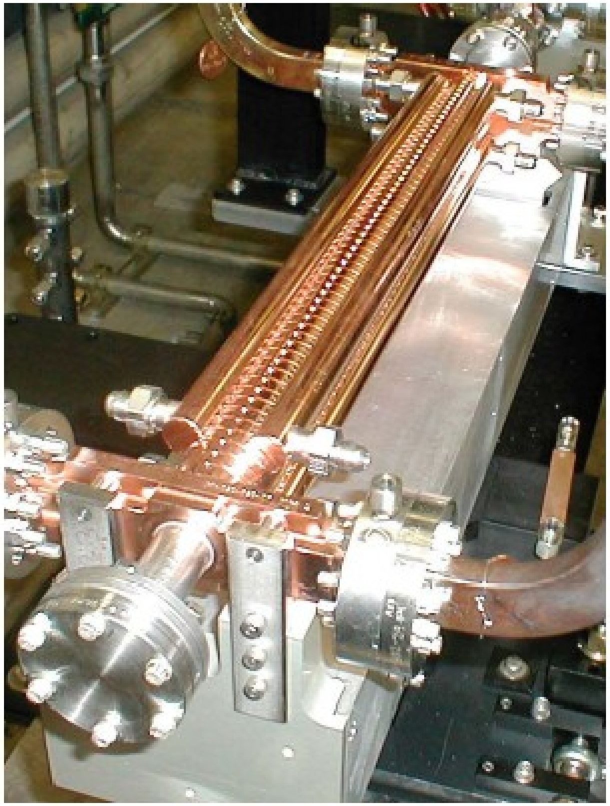
•However, when fabricating several thousand such structures, looser tolerances may reduce the fabrication costs

•The linac H90VG5 will consist of 9440 nominally identical 90cm structures, each of which contains 83 slightly different cells. Shown here is an automated measurement of critical cell dimensions performed at KEK

1. New High Phase Advance Structures

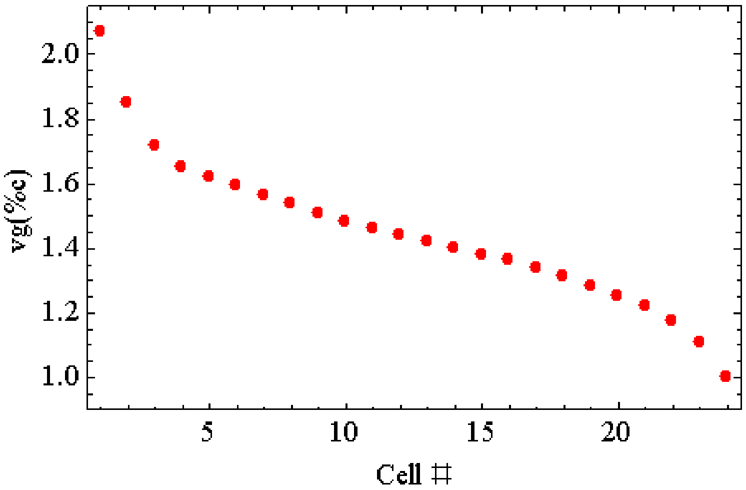
New structures under test:
H90VG5, H60VG3 H75VG4.
These structures will include detuning combined with manifold damping

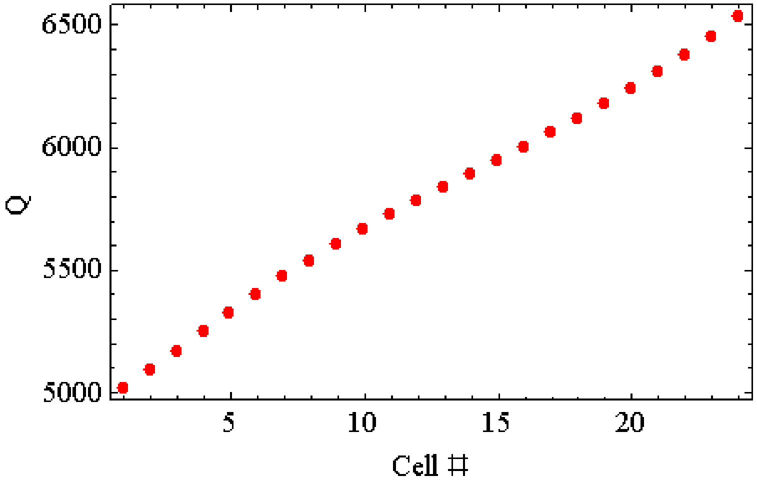
H-Series Cells Illustrating "Pie" Shaped Slots to Damping Manifolds

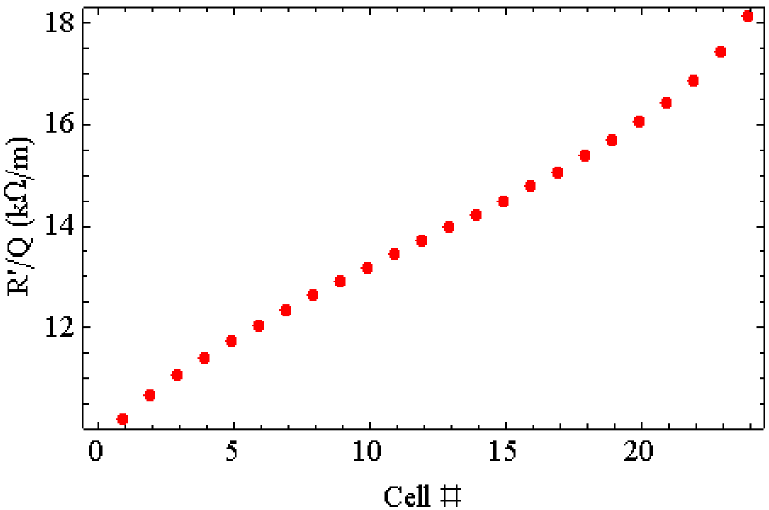


Test Structure Undergoing High Power Evaluation

4. CLIC_DDS_A Fundamental Mode Parameters

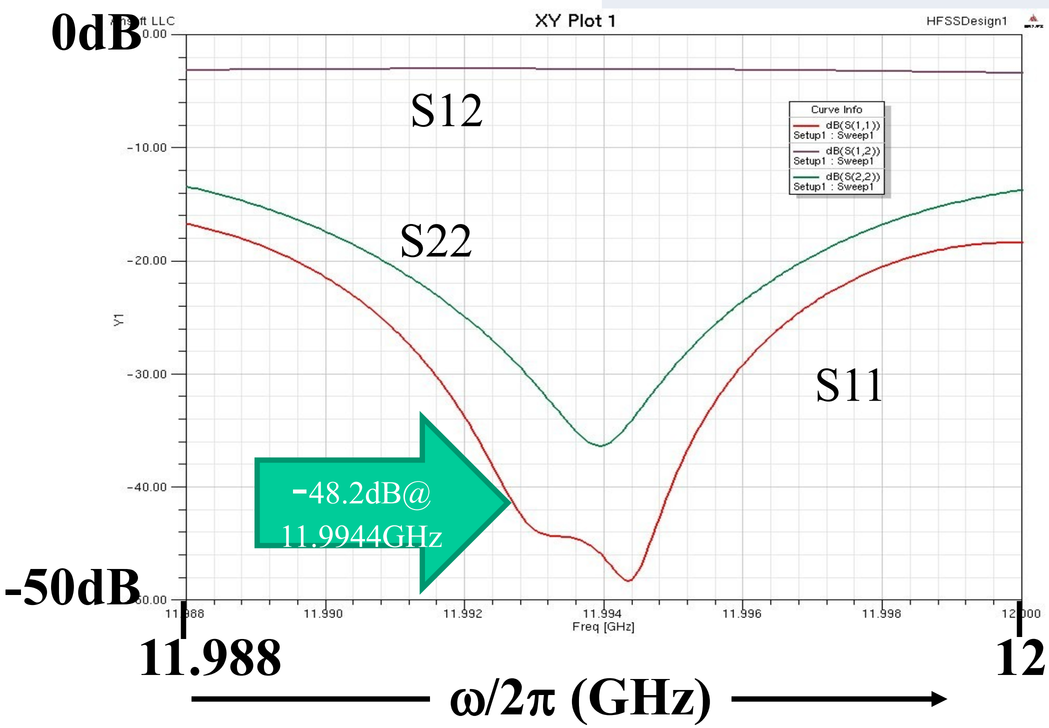


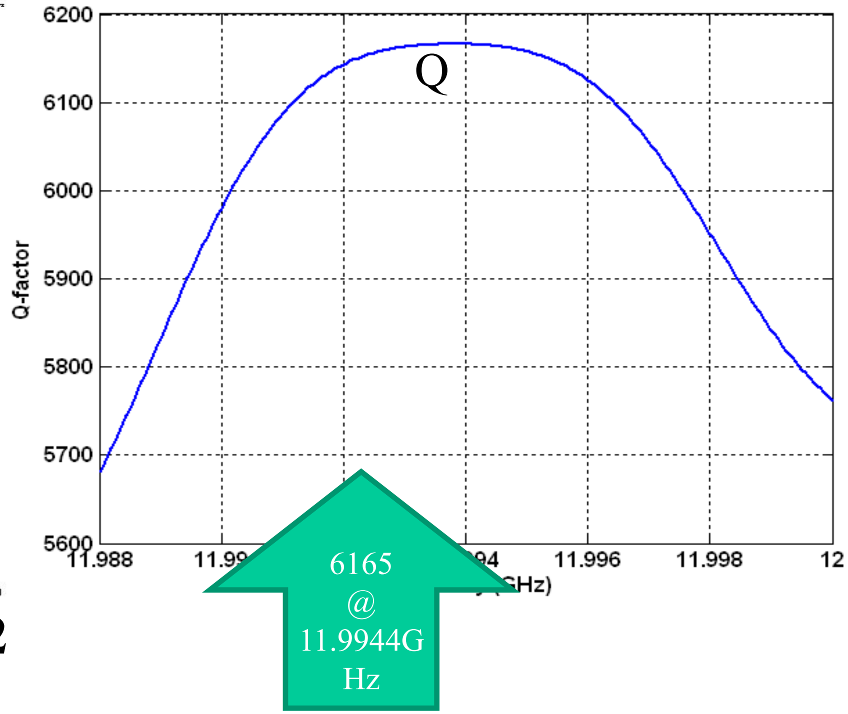




2. CLIC_DDS_A S Params

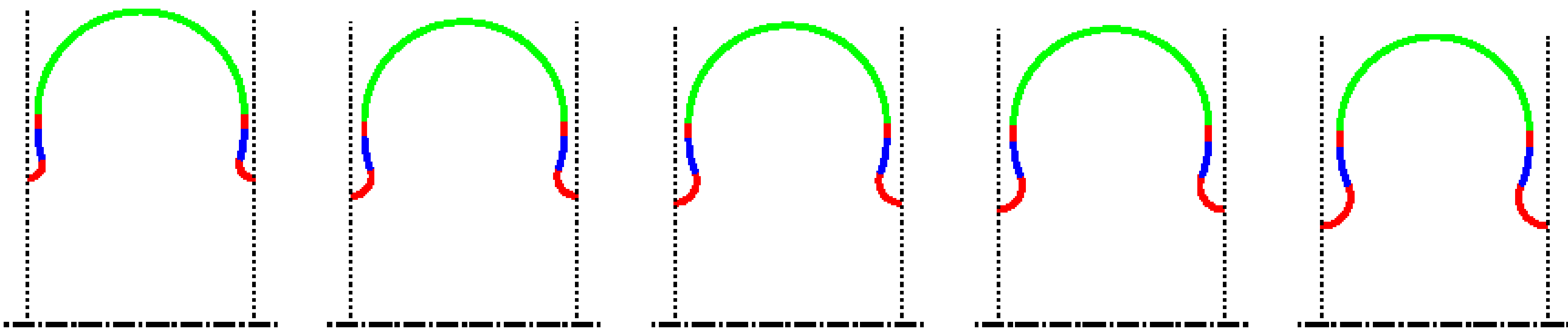
V_{26} [V]@P_{in} = 1 W	2678
G_{26} [V/m]@P_{in} = 1 W	13481
P_{in} [MW]@<G_{26}=100MV/m >	55.03





1. Tapering (Effects Detuning) of RDDS Accelerator

X-Band Round Detuned Structure (param-c), a/λ=0.18



Cell 001	Cell 052	Cell 103	Cell 154	Cell 206
a = 5.65953mm	a = 4.97649mm	a = 4.70741mm	a = 4.45370mm	a = 3.81706mm
Q = 8300.38	Q = 7970.96	Q = 7846.88	Q = 7733.49	Q = 7462.76
R = 76.8596 MΩ/m	R = 86.7337 MΩ/m	R = 90.6774 MΩ/m	R = 94.3869 MΩ/m	R = 103.476 MΩ/m
R/Q = 9259.76	R/Q = 10881.21	R/Q = 11555.85	R/Q = 12204.95	R/Q = 13865.69
V_g/c = 0.1135	V_g/c = 0.0744	V_g/c = 0.0612	V_g/c = 0.0499	V_g/c = 0.0272
E_s/E_a = 3.00790	E_s/E_a = 2.51850	E_s/E_a = 2.41357	E_s/E_a = 2.32035	E_s/E_a = 2.18890