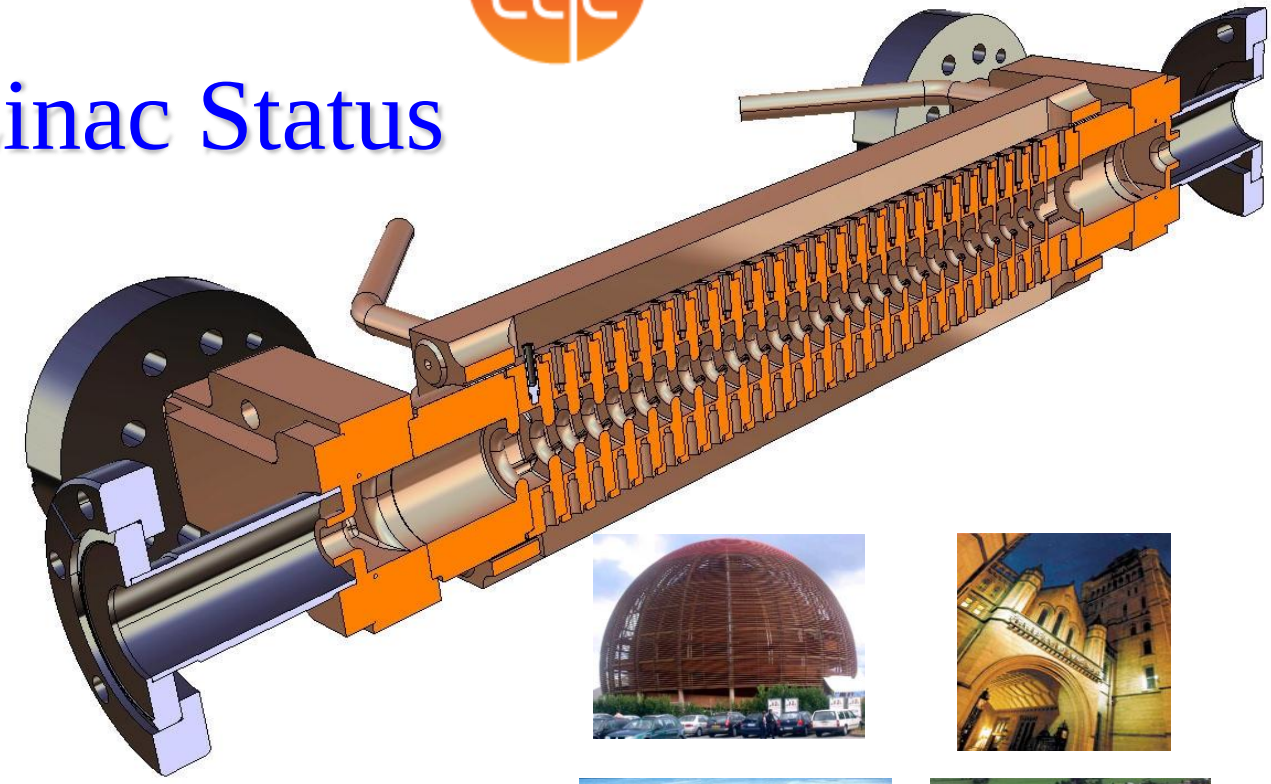
CLIC Main Linac Status

A – Under fabrication
B – Modified interleaved design



Roger M. Jones
The University of Manchester and
The Cockcroft Institute

http://indico.cern.ch/conferenceDisplay.py?confId=204269

Wake Function Suppression & HG Research 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 Grad. April 2011, now CERN Fellow

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

I. Nesmiyan, CI/Univ. of Manchester PDRA.

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

L. Carver, Sept 2011 CI/Univ. of Manchester Ph.D. student –based at Yale

- Major Collaborators: W. Wuensch, A. Grudiev, I. Syrachev, R. Zennaro, A. Latina, D. Schulte, G. Riddone (CERN), T. Higo (KEK)

Overview

Entails:

1. **Suppressing long range transverse wakefield**
2. **Ensuring the e.m. surface fields (corresponding to accel. mode) are minimised**

Challenging!!

Three Main Parts:

1. ***Review of salient features of manifold damped and detuned linacs.***

2. ***Status of Fabrication of CLIC_DDS_A –out of family of 8.***
3. ***Further Plans for Optimisation: CLIC_DDS_B:***
   R.F. design & Beam Dynamics Considerations.
   + Recent Klystron Work.
4. ***Expenditure***
5. ***Future CLIC-k Studies***

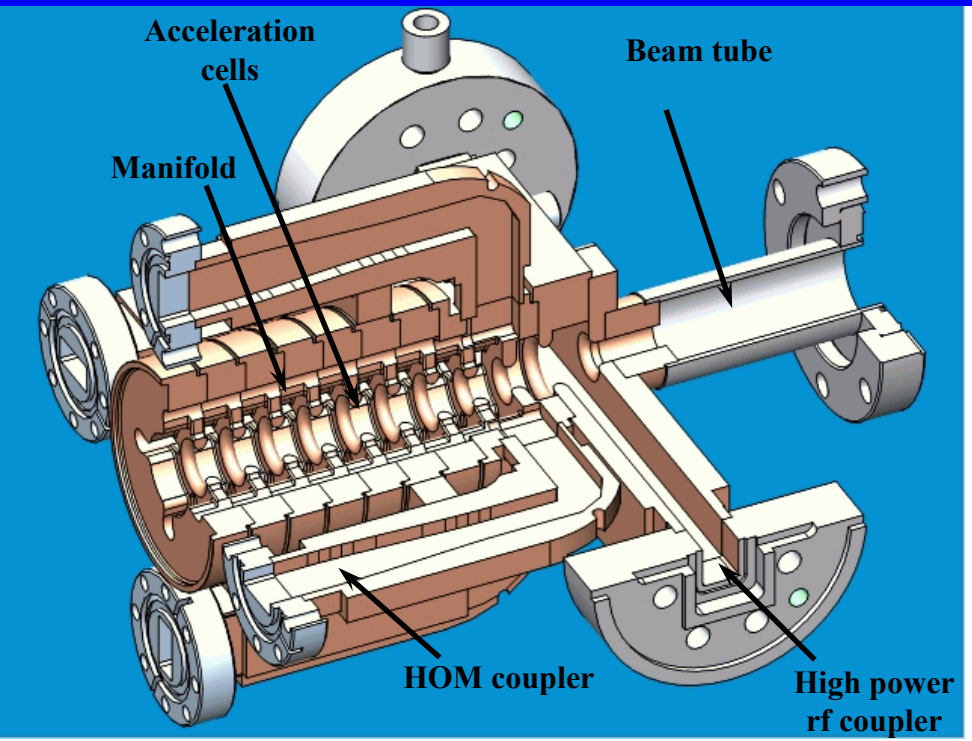
Introduction –Present CLIC baseline vs. alternate DDS design

- 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.
- Choke mode suppression provides an alternative, but may negatively impact R_{sh} and can have a significant impact on breakdown

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

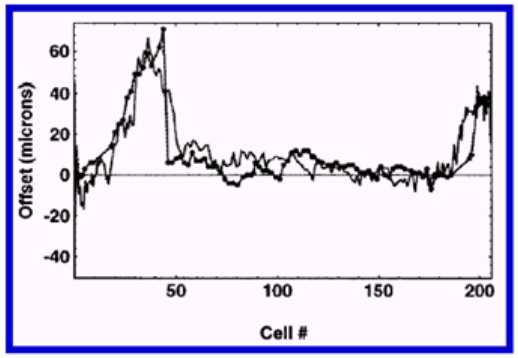
1. **Detuning the dipole bands by forcing the cell parameters to have a precise spread in the frequencies –presently Gaussian Kdn/df- and interleaving the frequencies of adjacent structures.**
2. **Moderate damping Q ~ 500-1000**

Features of CLIC DDS Linac

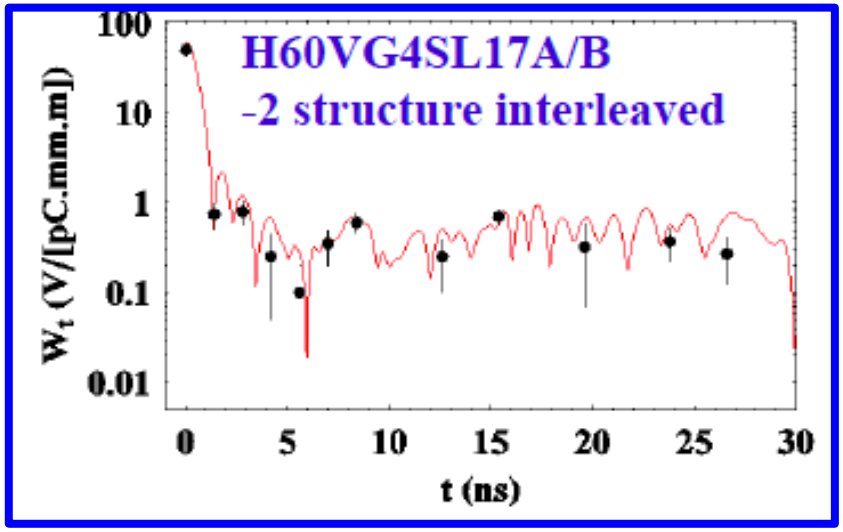


- NLC/G(J)LC SLAC/KEK RDDS structure (left) illustrates the essential features of the conceptual design
- Each of the cells is tapered –iris reduces (with an erf-like distribution –although not unique)
- HOM manifold running alongside main structure removes dipole radiation and damps at remote location (4 in total)
- Each of the HOM manifolds can be instrumented to allow:
  1) Beam Position Monitoring
  2) Cell alignments to be inferred

- CMM (Coordinate Measurement Machine) data compared to ASSET power minimisation data remapped to frequency
- Dots indicate power minimisation



Remote Cell Alignment Diagnostic



Transverse Wake Suppression (SLAC ASSET dots, red Simulation)

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 $\langle a\rangle/\lambda$ and $\Delta a/\langle a\rangle$

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

CLIC_DDS Design and Beam Dynamics

1. **Relaxed parameters, modify bunch spacing from 6 to 8 rf cycles and modify bunch population. Wake well-suppressed and seems to satisfy surface field constraints. CLIC_DDS_C and subsequently CLIC_DDS_E ($\Delta f \sim 3.6\sigma \sim 13.75\%$) –SUCCESS (on suppressing wakes and meeting breakdown criteria). A single (24 cell) structure is under fabrication –referred to as CLIC_DDS_A. Characteristics and status reported.**

2. **Additional research in progress to improve the overall collider efficiency – resorting back to 6 rf cycles (bunch spacing 0.5 ns) –and known as CLIC_DDS_B. $2\pi/3$ vs $5\pi/6$ (HDDS) and structures of varying phase advances explored (PDDS)**

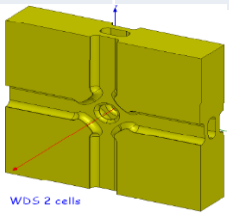
- **Both aspects have benefited from an analytical matrix-based technique (D. Schulte) which allows a rapid determination of worst case regimes of emittance dilution as wakefields and other parameters are varied.**
- **Full beam dynamics simulations with PLACET indicate looser tolerances on the wakefields**

Initial CLIC_DDS Design –Δf determination

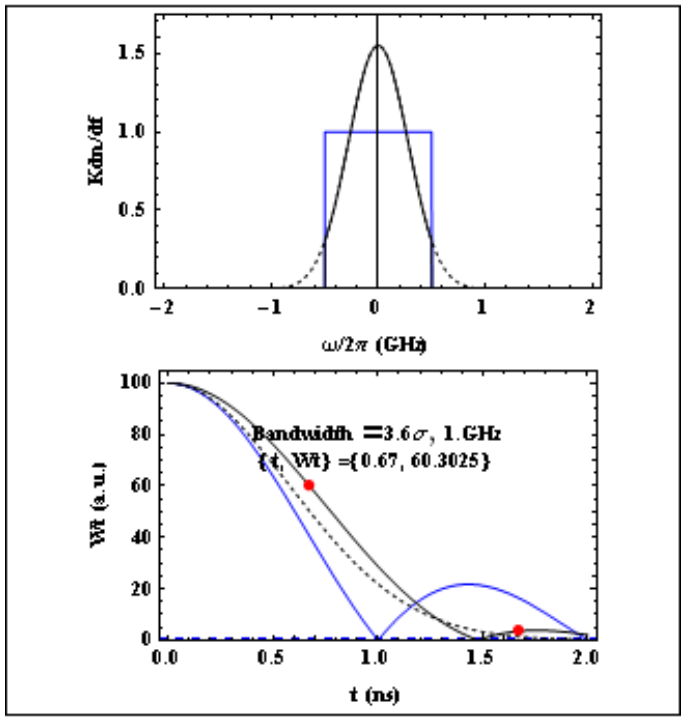
of Accelerator Science and Technology

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

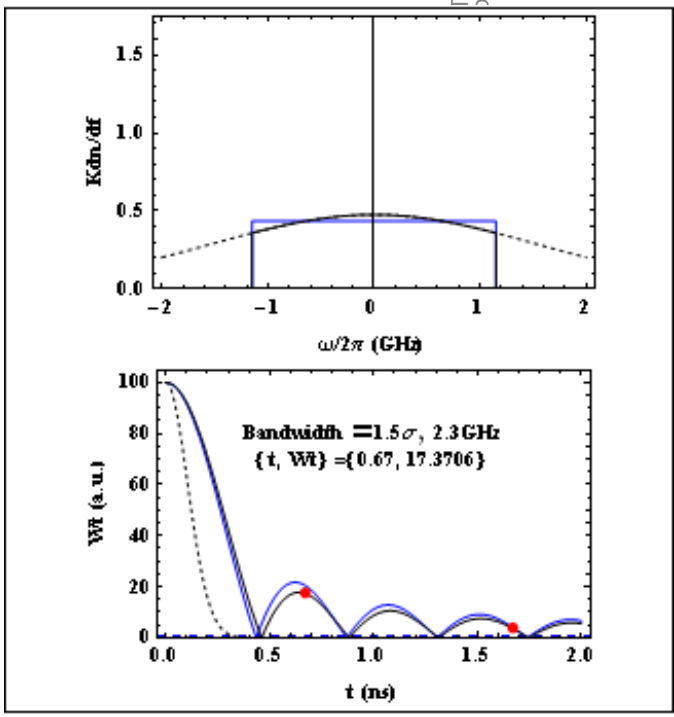
Lowest dipole
Δf ~ 1GHz
Q~ 10



CLIC_G



Bandwidth Variation

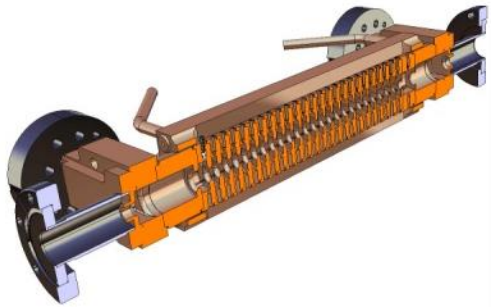


σ Variation

Truncated Gaussian :

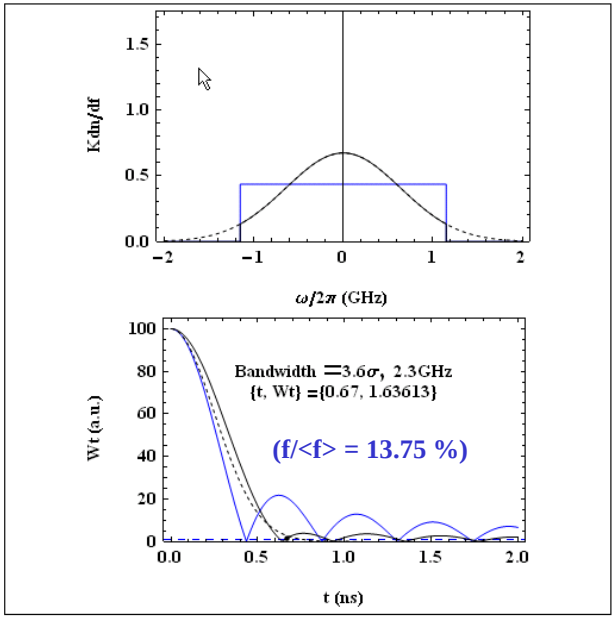
$$W_t = 2\bar{K}e^{-2(\sigma\pi t)^2}\left|\chi(t,\Delta f)\right|$$

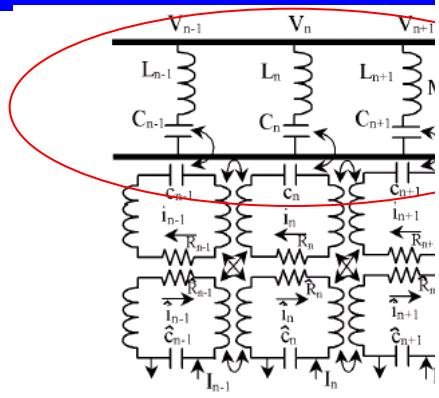
$$\text{where : } \chi(t,\Delta f) = \frac{\mathrm{Re}\left\{\mathrm{erf}\left(\left[n_\sigma - 4i\pi\sigma t\right]/2\sqrt{2}\right)\right\}}{\mathrm{erf}\left(n_\sigma/2\sqrt{2}\right)}$$



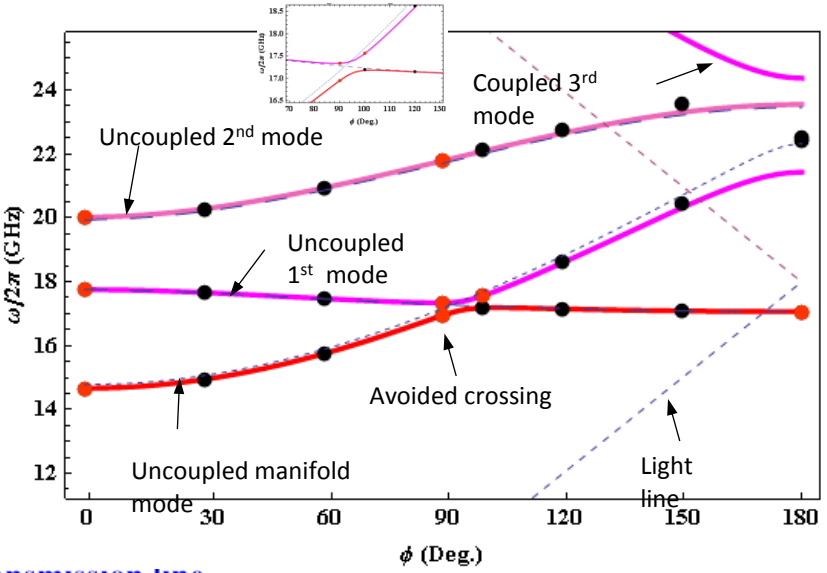
CLIC_DDS Uncoupled Design

Relaxed parameters tied to surface field constraints





Three cells in the chain ar
TM modes couple to the be
and TE modes and excited a
to the manifold is via TE
manifold is modeled as a transmission line
periodically loaded with L-C elements.



Mid-Cell

➢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)

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

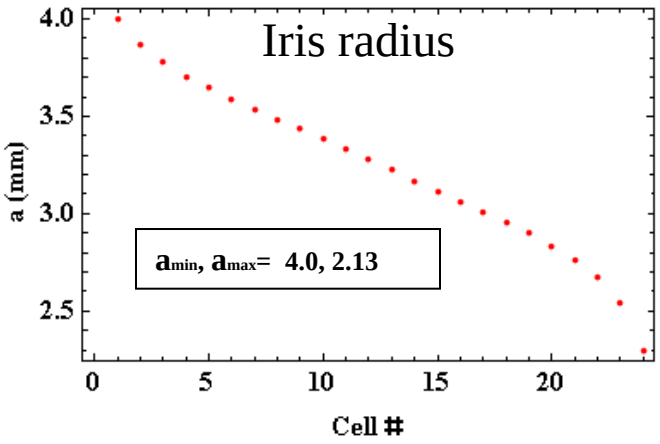
- Iris radius = 2.13 mm
- Iris thickness = 0.7 mm,
- ellipticity = 2
- Q = 6355
- R'/Q = 20,090 Ω/m
- vg/c = 0.9 %c

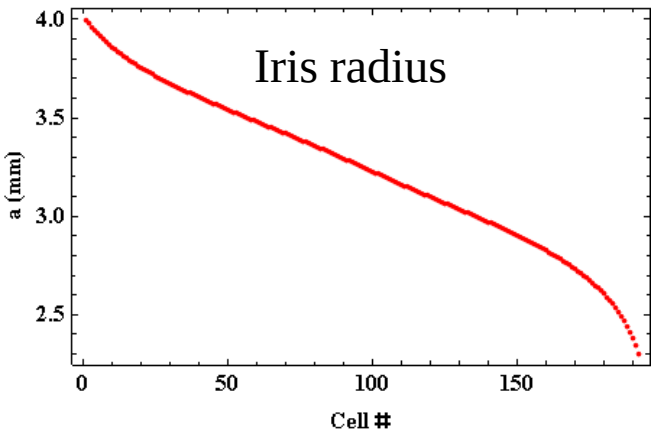
Cct Model Including Manifold-Coupling

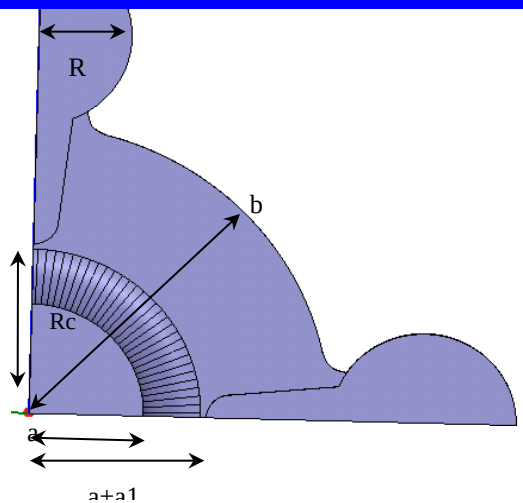
➢Spectral Function - including Manifold-Coupling, to calculate overall Wakefunction!

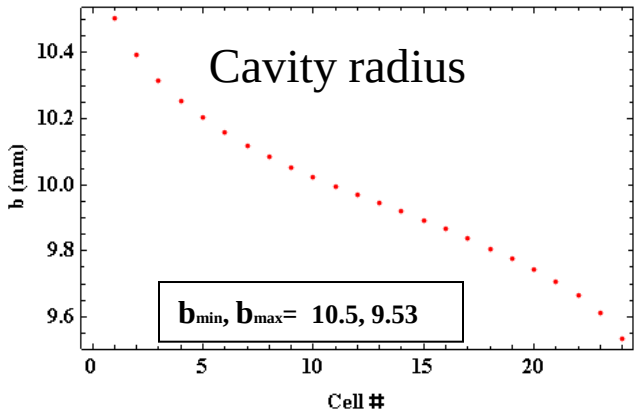
➢Not possible by other methods.

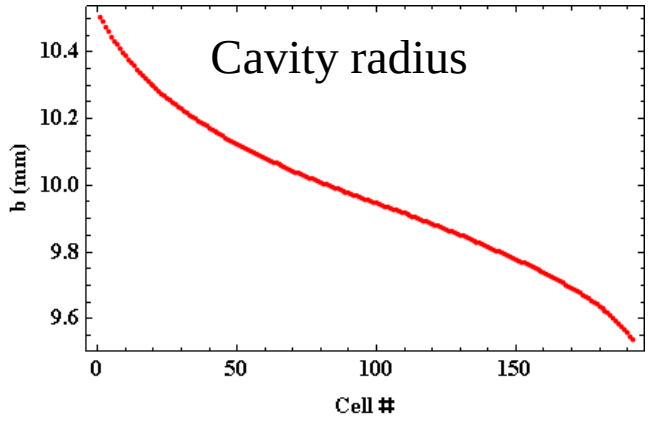
Structure Geometry: Cell Parameters

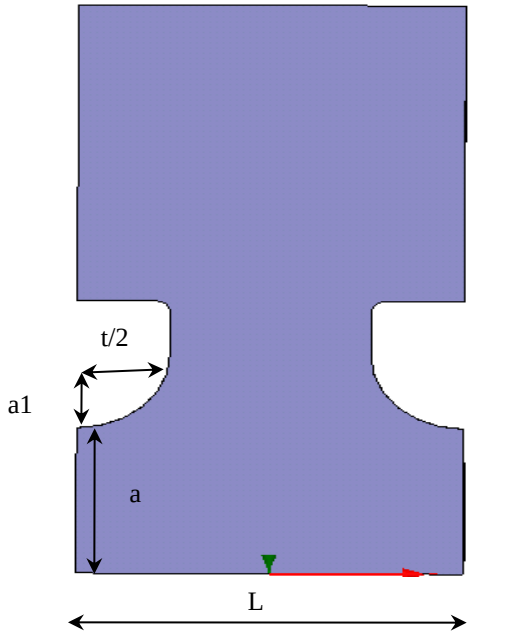












Sparse Sampled HPT
(High Power Test)

Fully Interleaved
8-structures

Summary of CLIC_DDS_C

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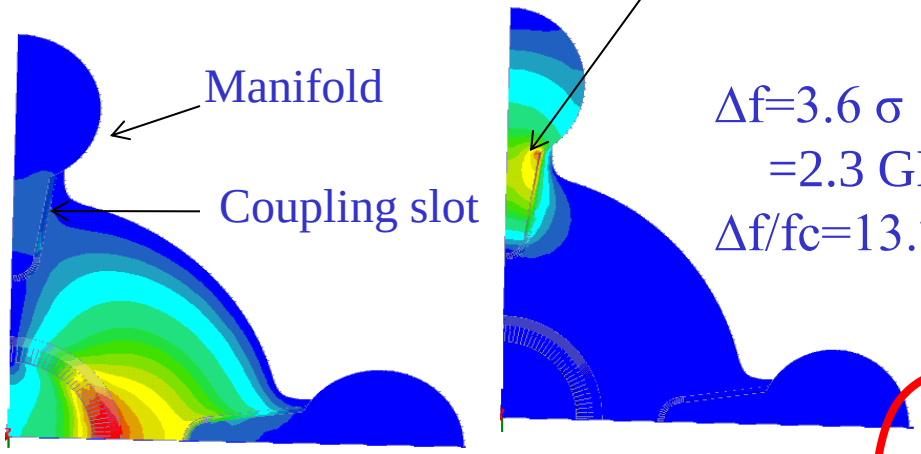
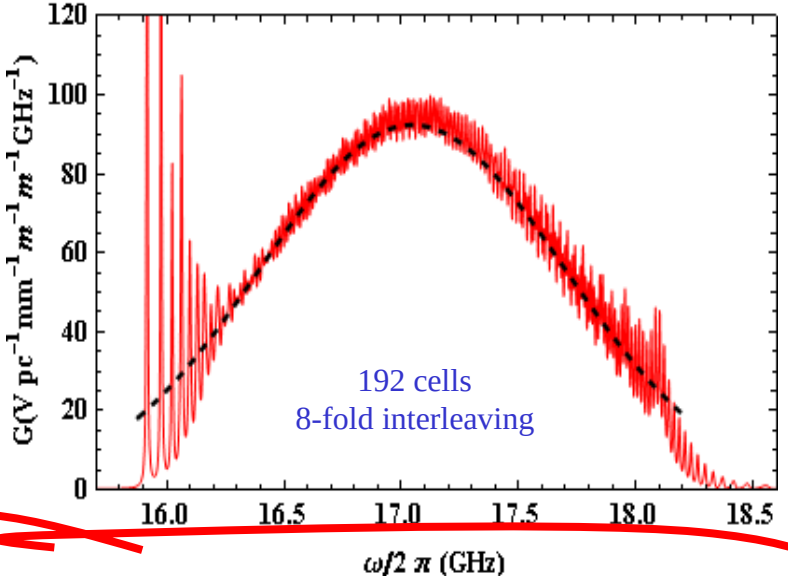
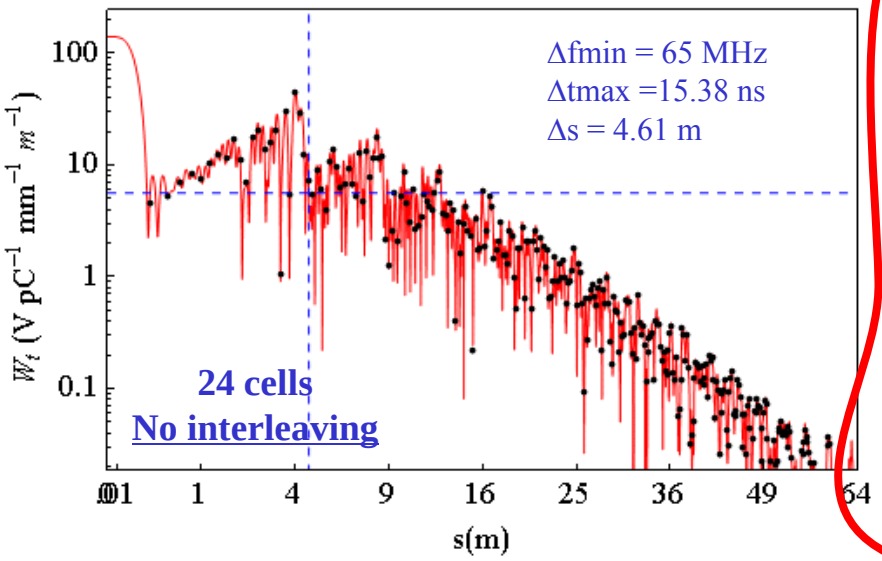
Dipole mode

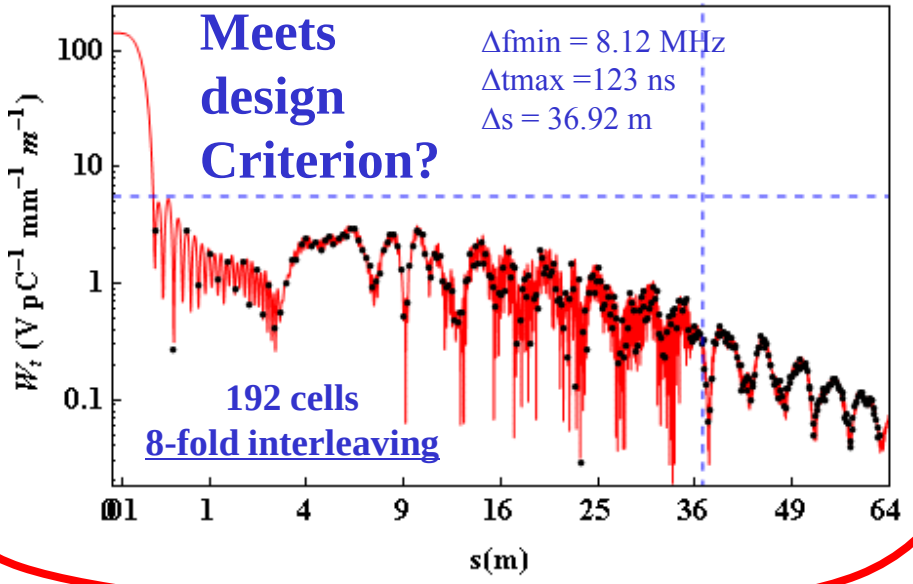
Manifold mode



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

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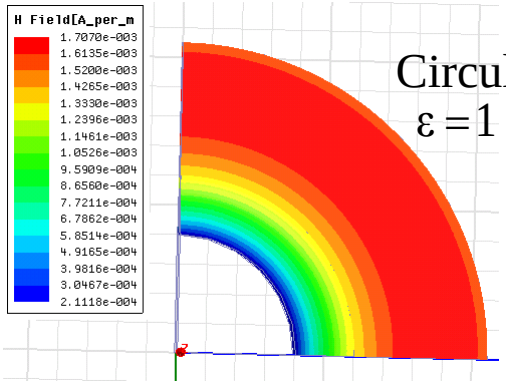
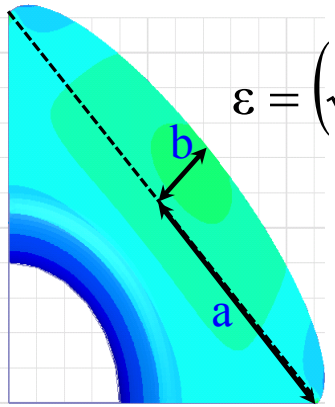
Single undamped cell
Iris radius=4.0 mm

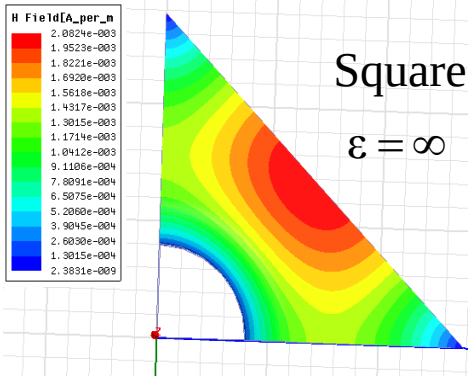


Circular
$\varepsilon = 1$

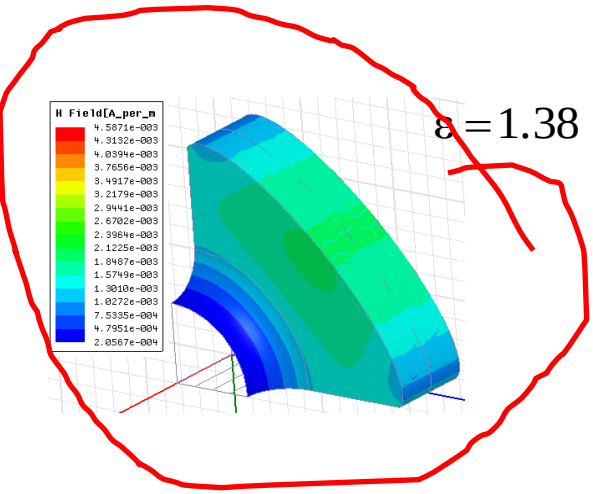


$$\varepsilon = \left(\sqrt{2} - 1\right)\frac{a}{b}$$

Convex ellipticity

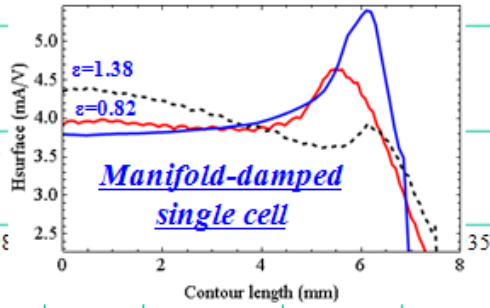


Square
$\varepsilon = \infty$



$\varepsilon = 1.38$

	Circular	Rectangular	Elliptical (Convex)	0		0				
ε of cavity	1	∞	4.14	2.07	1.38	0.82				
f_{acc}(GHz)	12.24	12.09	11.98	12.0	11.99	11.98				35
Eacc(V/m)	0.43	0.43	0.42	0.43	0.43	0.42	0.42	0.43	0.43	0.42
H^{sur}_{max}/Eacc (mA/V)	3.64	4.86	4.71	4.54	4.29	3.75	3	4.94	4.99	5.11
E^{sur}_{max}/E_{acc}	2.27	2.27	2.33	2.28	2.28	2.33	2.33	2.27	2.27	2.33



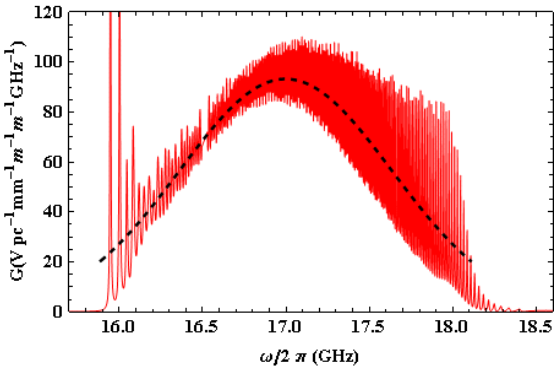
Iris radius = 4. 0 mm
Iris thickness = 4.0 mm

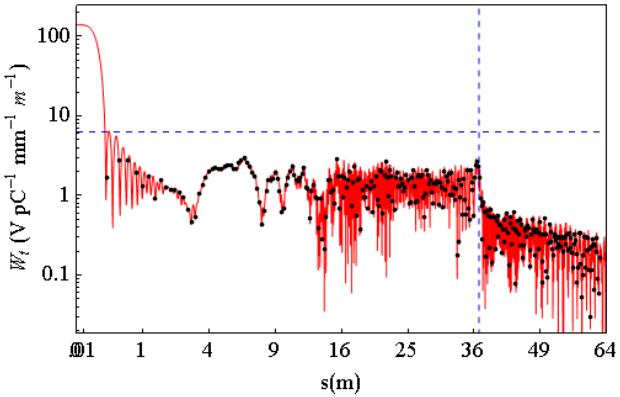
0 Chosen design

R.M. Jones, (

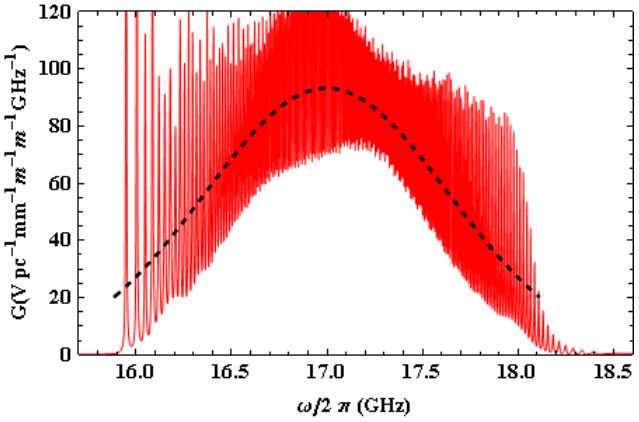
CLIC_DDS_E vs CLIC_DDS_ER Wakefield

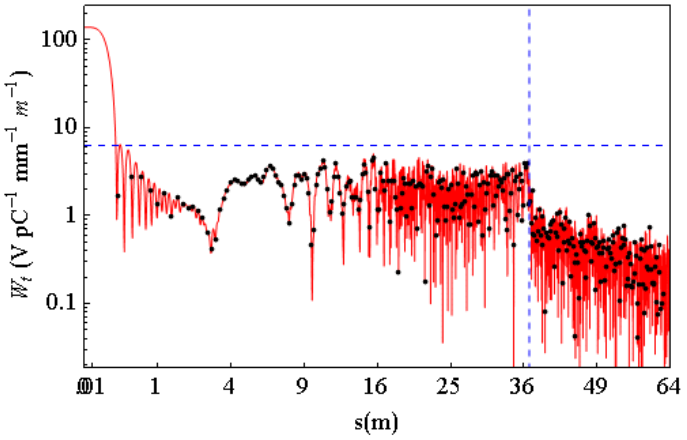
Spectral Function **Wakefunction**





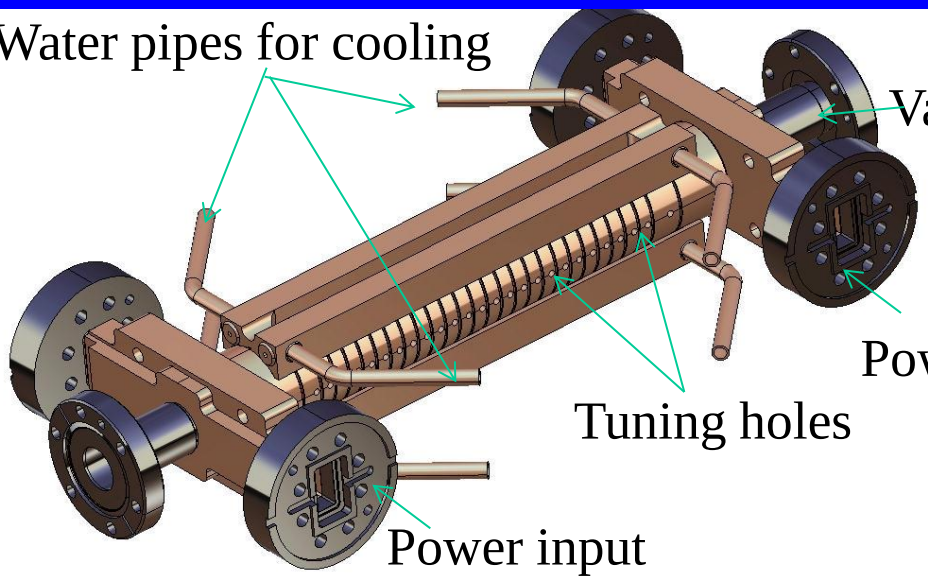
CLIC_DDS_E :Rc=6.2 - 6.8 mm (optimised penetration)

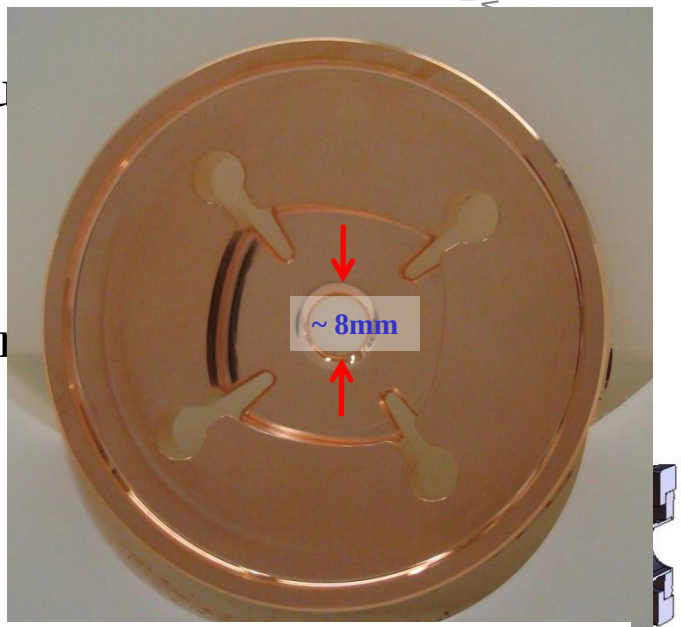




- **CLIC_DDS_ER : Rc=6.8 mm const (a single one of these structures constitutes CLIC_DDS_A, being built for HP testing)**
- **Wakefield suppression is degraded but still within acceptable limits.**

Mechanical Eng. Design of DDS_A





- **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**
- **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**

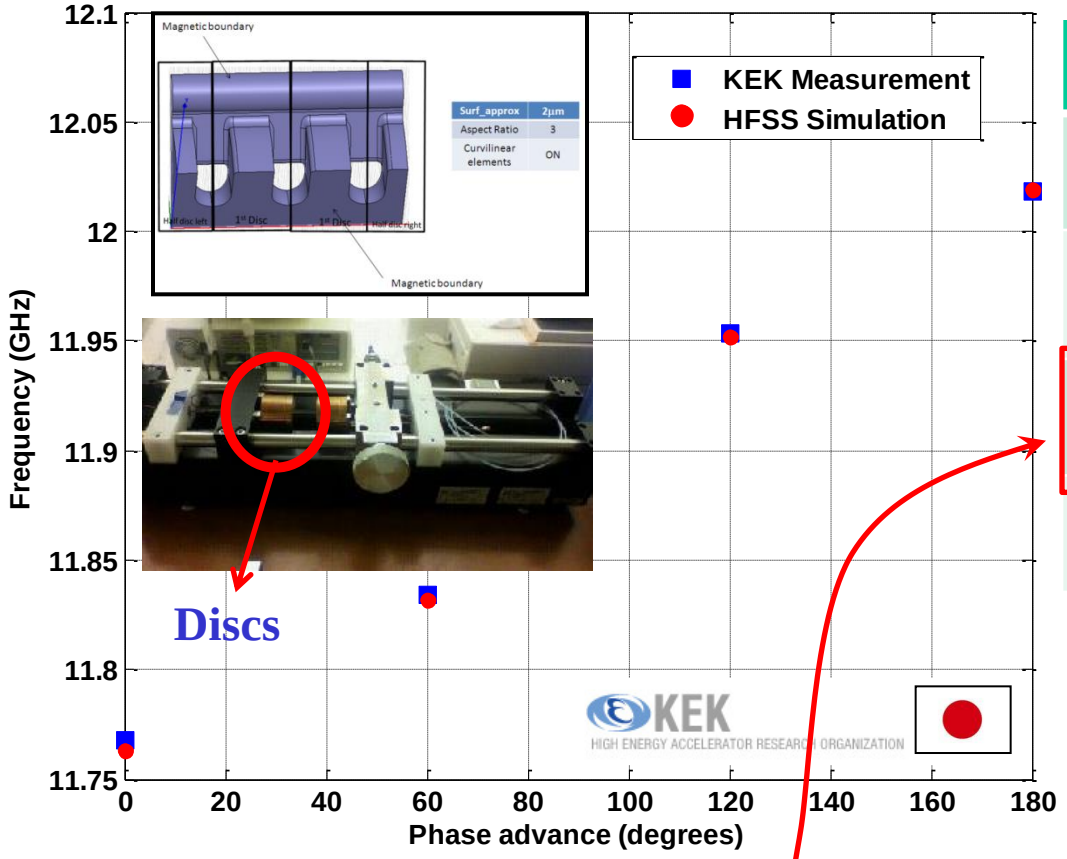
- **Qualification cells complete!**
- **Metrology and bonding of 4-cell stack tested at CERN**
- **Encouraging results**

G. Riddone, V.Soldatov, CERN

Fabrication Status of CLIC_DDS_A

- MORIKAWA, under direction of KEK (T. Higo), has produced 5 disks - cold RF measurements and metrological control performed in November 20
- Initial measurements on cells performed at KEK (T. Higo)
- Five, in principle, identical cells delivered to CERN together with two half cells to be used for measurements –for further measurements a CERN
- Cells completed metrological control
- Stack setup for RF measurements built at CERN (next slide)
- Measurements completed
- Full production of all cells completed 2013
- Full 24 (+2 matching cells) structure diffusion bonded
- Awaits bonding of waveguides and tuning stubs

First Comparison Between KEK Measurements & Simulations on Morikawa Cells



	HFSS*	KEK	Δ
Mode 0 (MHz)	11762.8	11767.5	-4.7
Mode π/3 (MHz)	11831.6	11833.75	-2.15
Mode 2π/3§ (MHz)	11951.7	11953.75	-2.05
Mode π (MHz)	12019.0	12018.437	0.6

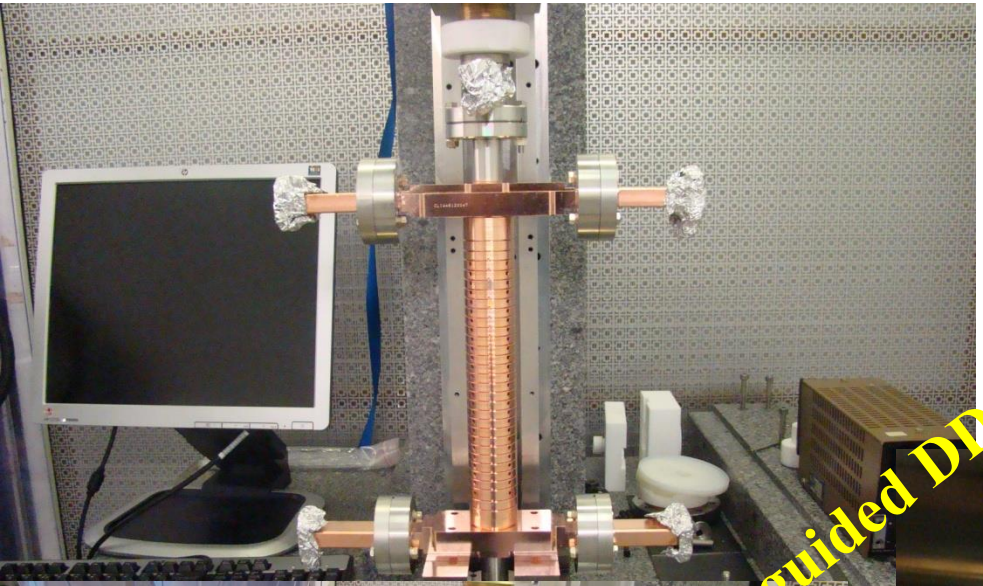
* HFSS scaled in air using ε_r=1.000618

§This cell is the *actual* cell –non-symmetrical and equipped with an averaging of b. This explains the difference in the frequency from the nominal value of 11994.6MHz

Tuning range ~20MHz

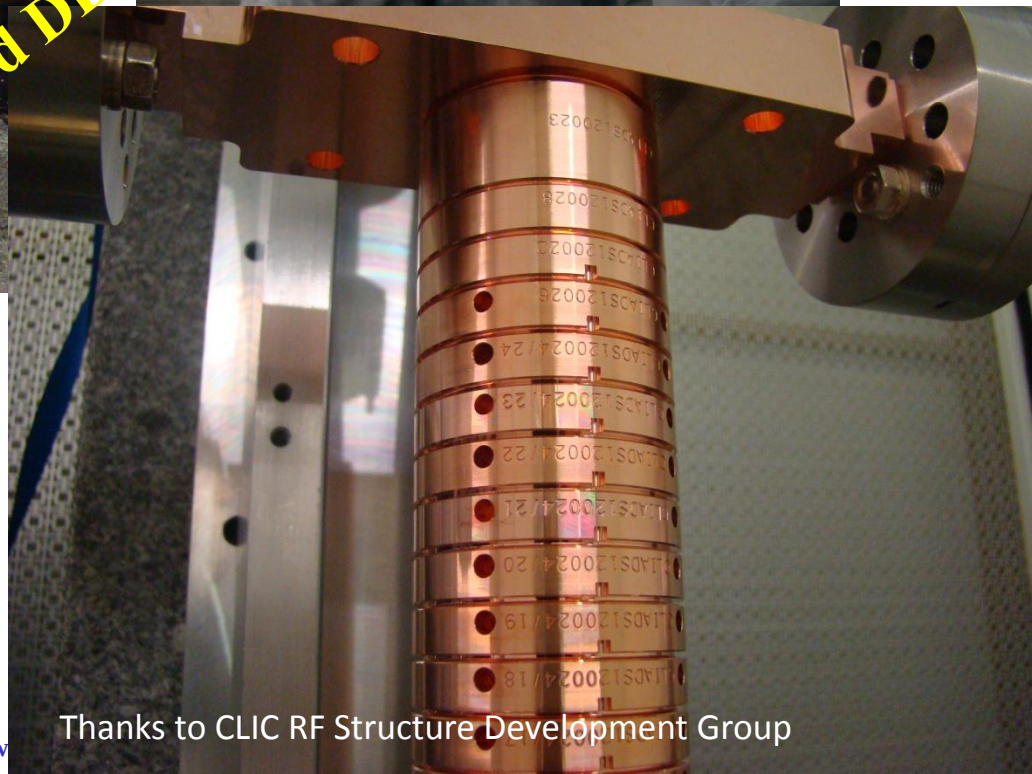
Indicative of ~2 μm fab tolerance!

DDS_A Prototype –Measured at CERN



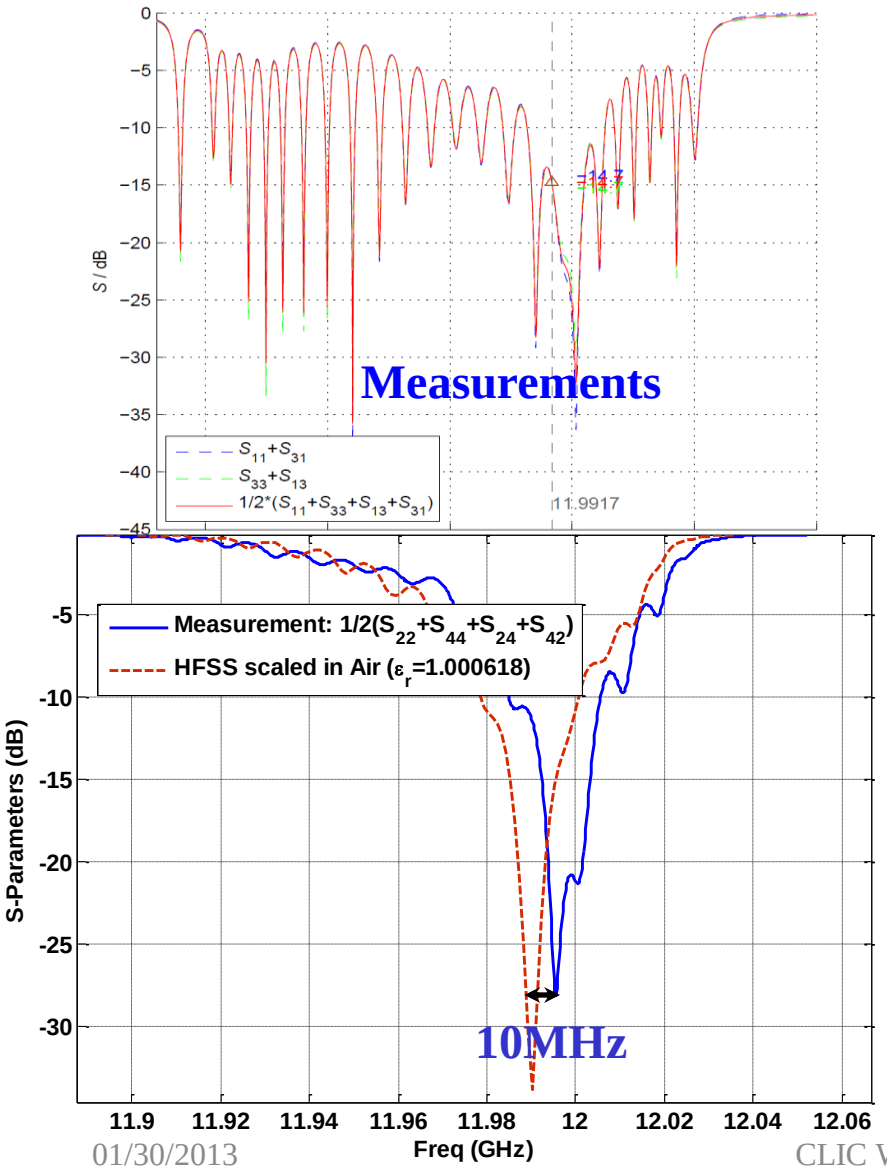
Particular thanks to R. Wegner, V. Khan and A. Olyunin who participated in measurements

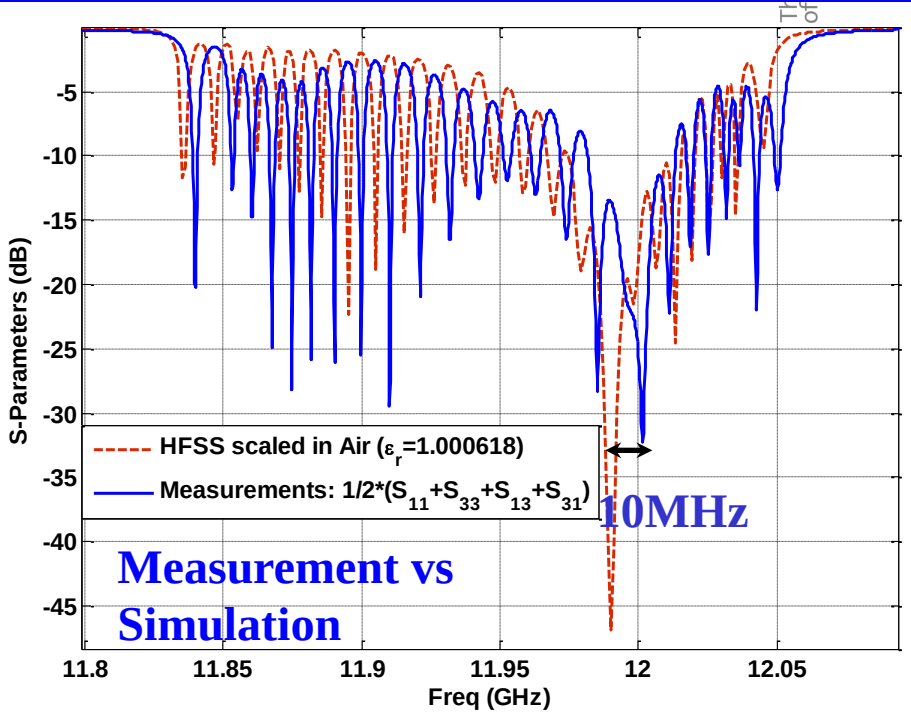
T. Higo (KEK) guided DDS_A production



Thanks to CLIC RF Structure Development Group

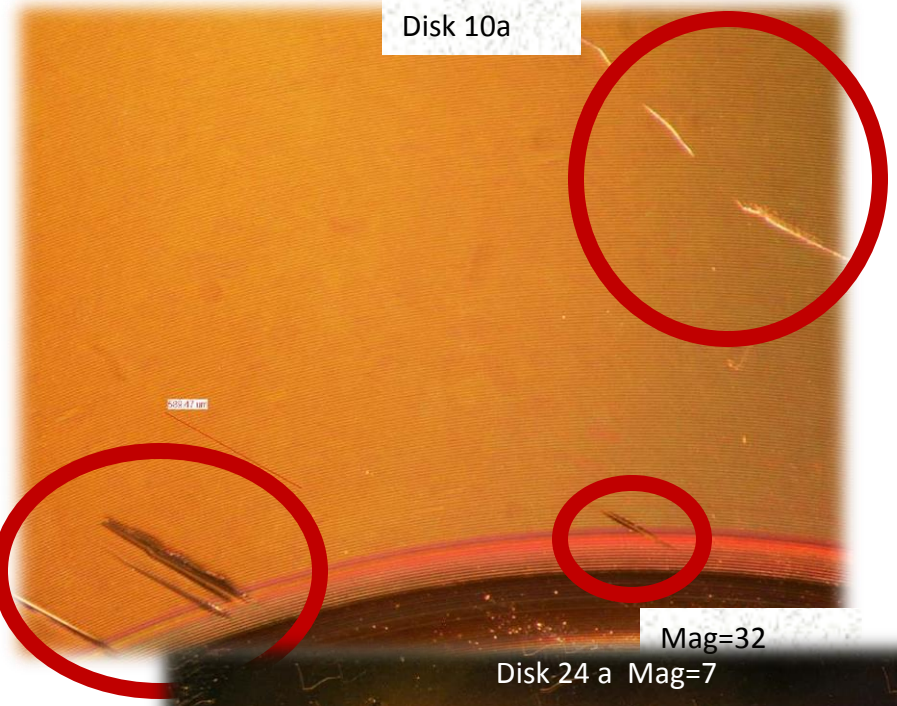
DDS_A Prototype –RF Measurements

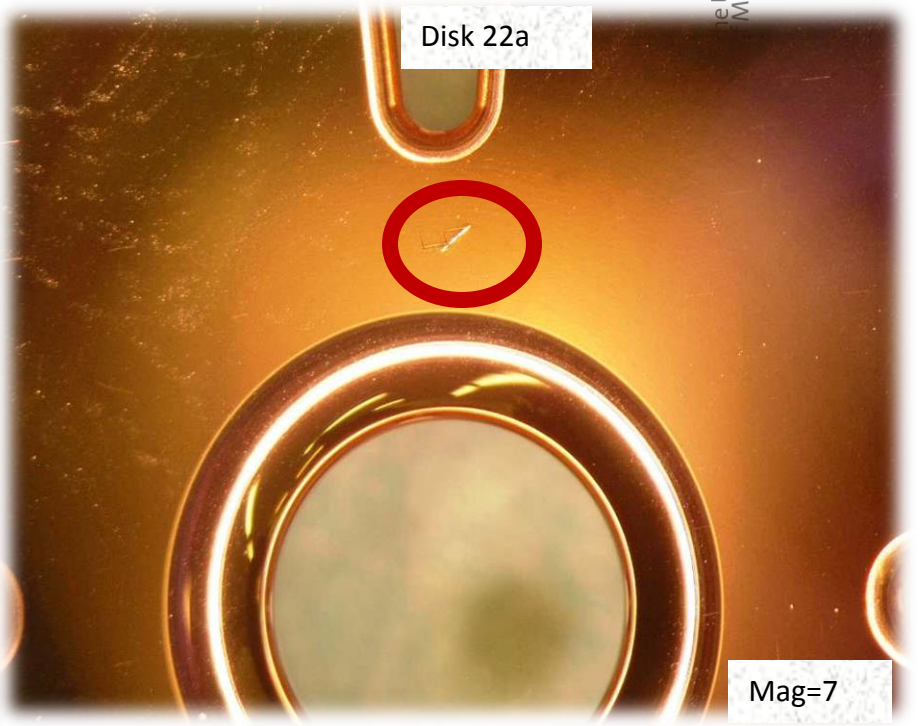




- Stacks measured prior to diffusion bonding
- These early measurements indicated ~ 10MHz discrepancy (measured higher)
- Within tuning range and hence acceptable from an RF standpoint

DDS_A Surface Inspection

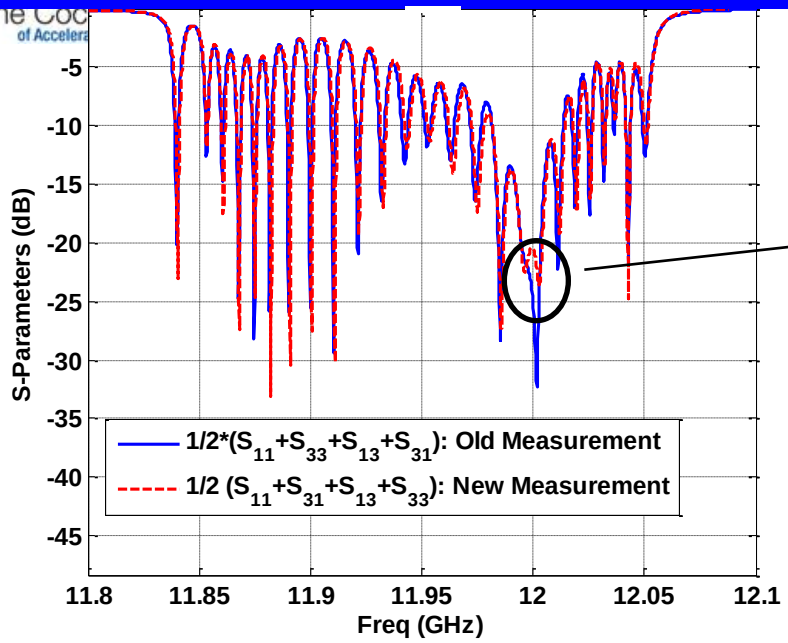


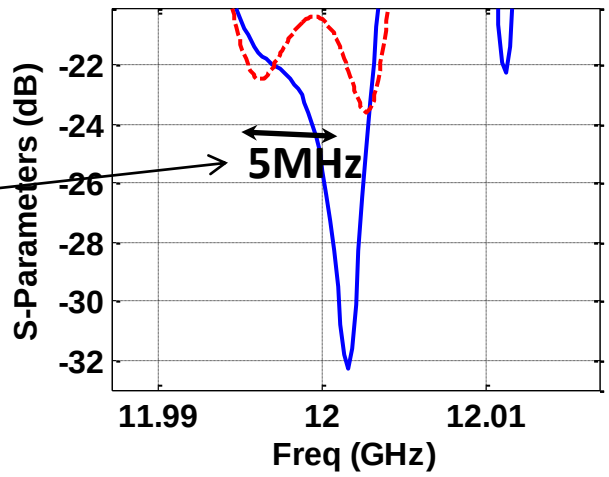


- **Marks and scratches are clearly evident on the disks.**
- **Consequently discs N10, N22 and N24 were re-machined at Morikwa under direction of T. Higo (KEK)**

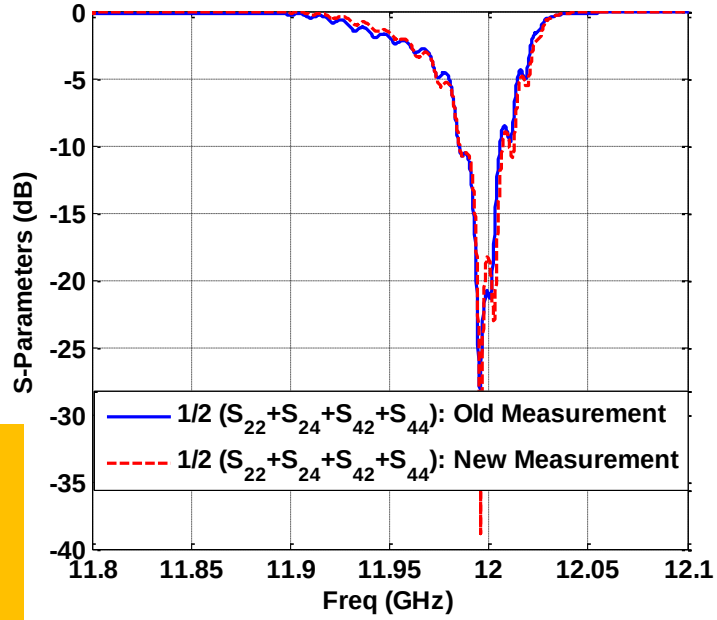
Courtesy of A. Olyunin

DDS A Prototype –RF Measured



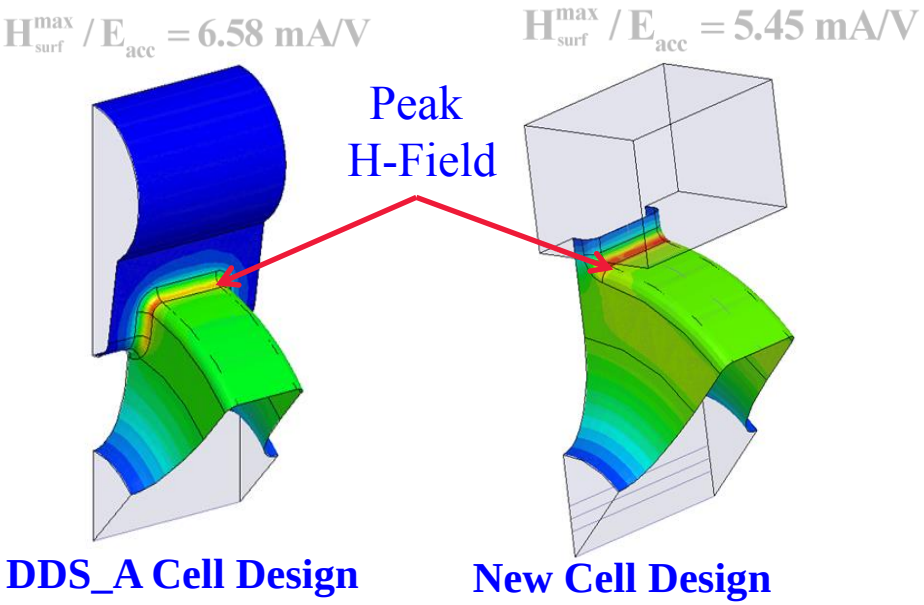


- Comparison of earlier cells (2/10/2012) with a new stack of re-machined cells (13/11/2012)
- Peak was not visible in previous measurement –indicates the stack is 5MHz below the old one. (and hence +5MHz larger than HFSS)



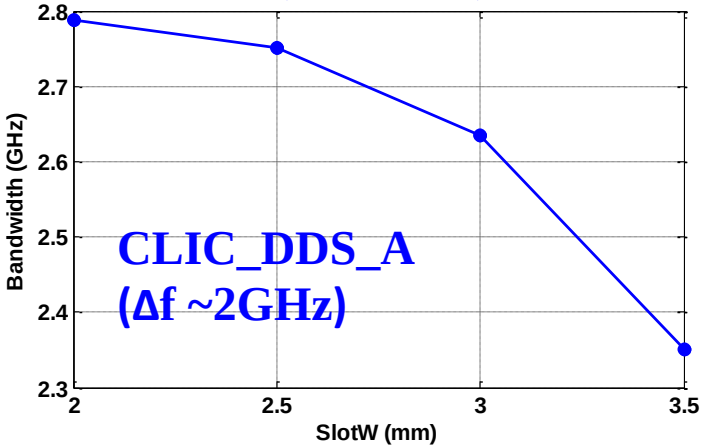
- Etching of disks complete
- Disks were subsequently successfully diffusion bonded at Bodycoat.

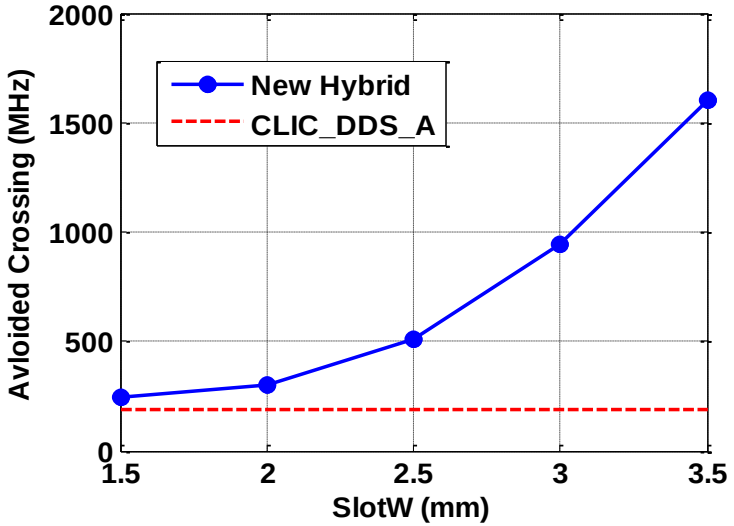
DDS_B Enhanced Coupling Designs



Iris aperture (mm)	4.04	
Length (mm)	8.3316	
Iris thick. (mm)	4	
Iris ellip.	2	
Avoid. Cross. (MHz)	DDS_A Design	New Design
	120	132

A. D'Elia et al., THPPC022, PAC12

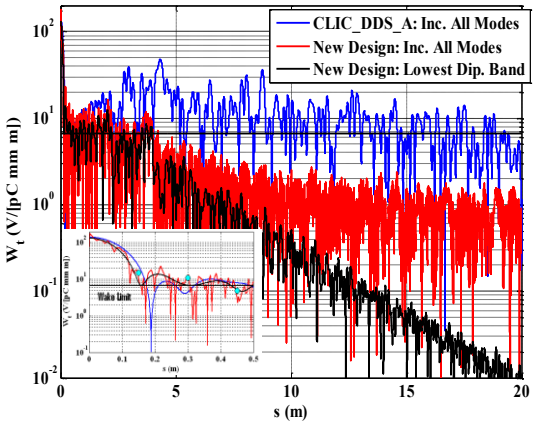


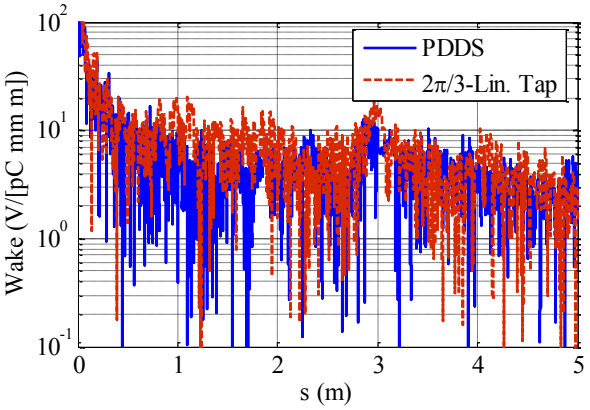


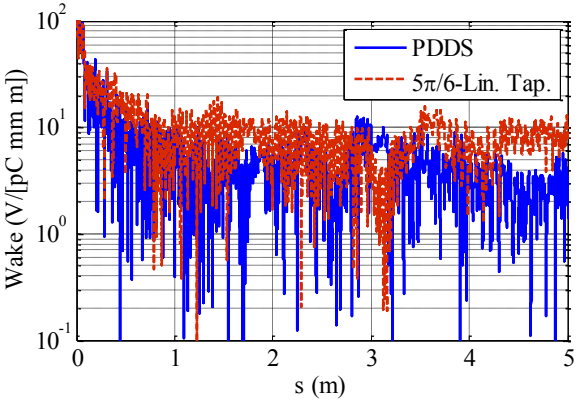
- Improved manifold damping of HOMs from (proportional to the Avoided Crossing) and bandwidth (Δf)
- Surface H-Field reduced by ~17%

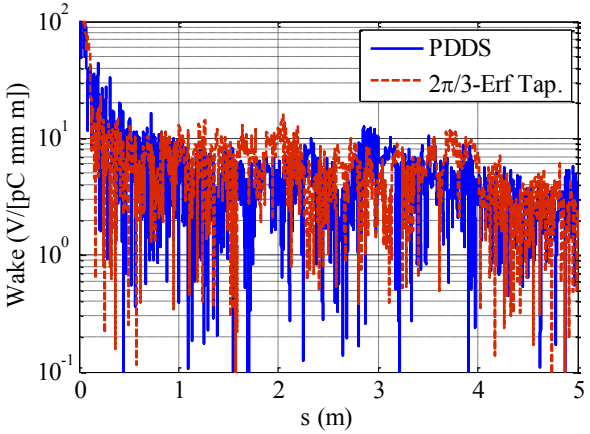
DDS_B Enhanced Coupling Designs

- **Additional studies in progress aim at increasing bandwidth of lower dipole band whilst also suppressing higher order dipole bands**
- **These utilise a 5π/6 structure to reduce overall wakefield**
- **A structure of tapering phase advance per cell (PDDS) effects enhanced manifold coupling**
- **Higher band wakefields are also suppressed by virtue of a combination of these techniques.**









Beam Dynamics

Direct Effect

- **Assumes bunches are effected one- on-one –usual assumption for many years!**
- ***a* is a matrix which describes the wake**
- **In addition for CLIC_G Q ~ 10 and this effectively enables W_t to be neglected after to nearest neighbours**

Indirect Effect

- **Assumes bunches are influenced by succeeding bunches –many bunch coupling**

Bunch k kicks j: $\boxed{y_j = a_{j-k} y_k}$

$$a_{j,k} = \begin{cases} \dfrac{LW_t\left(z_j - z_k, s\right)Ne^2}{2k_b E(s)} & \text{" } j > k \\ 0 & \text{" } j \le k \end{cases}$$

L is the cell length, s is the distance down linac, N is the number of particles per bunch, k_b is betatron focussing and E is the energy

At end of linac all bunches in a matrix:

$$\boxed{y_f = (1+a)y_i}$$

Ref: D. Schulte: PAC09, FR5RFP055; PRST-AB 14,084402 (2011)

Beam Dynamics

Indirect Effect

- **Straightforward to build this up in an iterative process for m bunches –each bunches communicates with its neighbour and this ripples down the chain**
- **Figures of merit:**
  F_c representative of coherent oscillations of the train -the rms over the whole train
  F_{rms} the bunch to bunch rms

$$y_f = \left(1 + \frac{a}{m}\right)^m y_i$$

In the limit of an infinite number of bunches

$$\boxed{\begin{aligned} y_f &= A y_i \\ A &= \exp(a) \end{aligned}}$$

$$\boxed{\begin{aligned} F_c &= \frac{1}{n}\sum_k \left|\sum_j A_{kj}\right|^2 \\ F_{rms} &= \frac{1}{n}\sum_{k=0}^{n-1}\sum_{j=1}^{k}\left|A_{j,k}\right|^2 \end{aligned}}$$

Returning to a finite number of bunches Taylor expand:

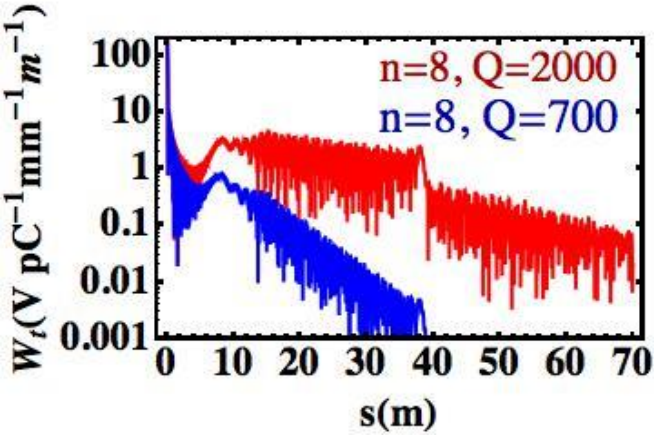
$$A = \sum_{k=0}^{\infty}\frac{a^k}{k!} = \sum_{k=0}^{n-1}\frac{a^k}{k!}$$

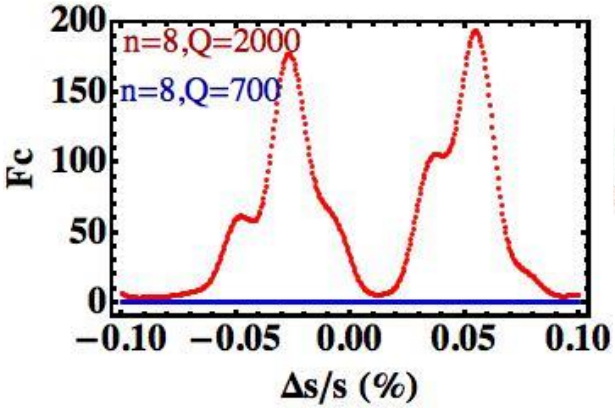
$$\left(a^n = 0 \text{ since } a_{jk} = 0'' \qquad j \le k\right)$$

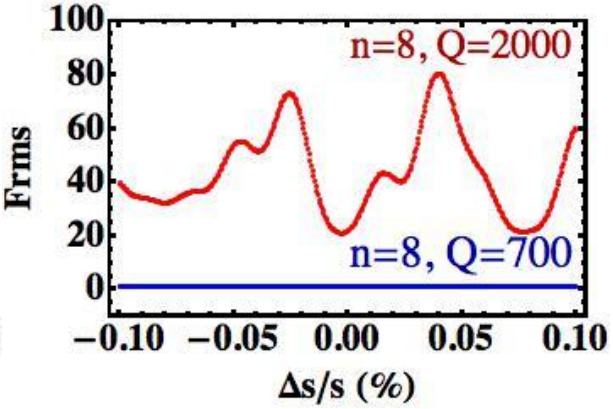
Beam Dynamics Based on Matrix Method

- **Present structure (DDS_A), entails 8-fold interleaving with an effective Q ~2000.**
- **Analytical matrix method implies a Q ~ 700 is necessary to manage emittance dilution**

Design	Fc	Frms
DDS, n=8, Q=2000, uncoupled wake	32	22
DDS, n=8, Q=700, uncoupled wake	1.027	1.476
CLIC_G, Q~10	1	4.9



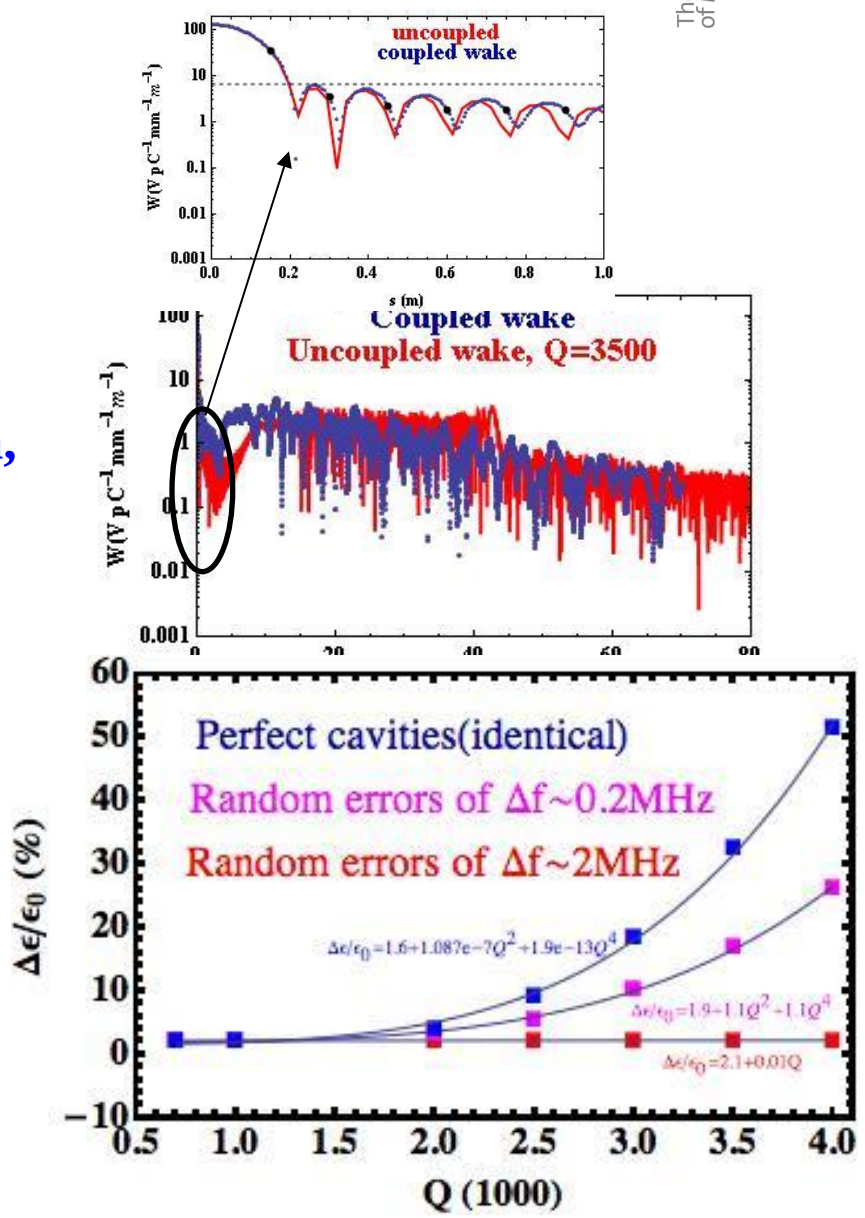




- **Does the assumption of repeatable cavities (identical frequencies) impose too stringent a limit on the wakefield suppression?**

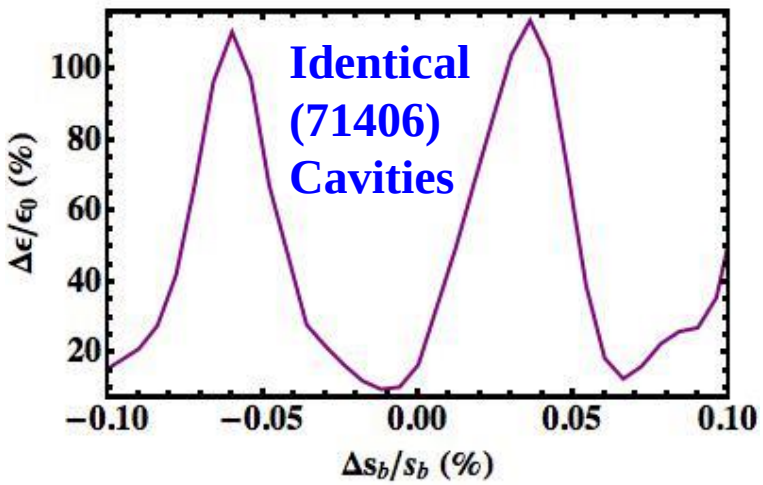
Beam Dynamics Based on PLACET Simulations

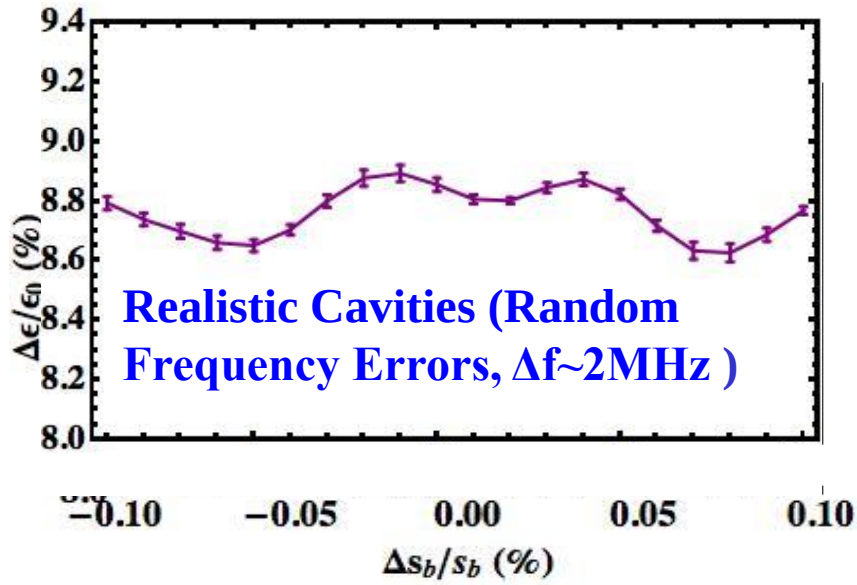
- **Errors, corresponding to those encountered due to fabrication, are distributed randomly amongst the complete linac (>71000 structures)**
- **The coupled wake consisted of an 8-fold interleaved version of DDS_A (V.F. Khan, et al, J.NIMA.2011.06.045, 2011).**
- **An uncoupled wakefield with broadly similar characteristics is used to demonstrate the principal**
- **Clearly the introduction of limited frequency errors markedly reduces the impact of the wakefields on emittance dilution (these simulations assume σ_z=44μm, n_b=312, $\Delta E_0/E_0$~1%)**



Beam Dynamics Based on PLACET Simulations

- Here we focus on DDS_A interleaved 8-fold with an imposed Q of 2000
- Systematic frequency errors are investigated by small changes in the bunch spacing (using a realistic bunch train – n_b=312, σ_z=44μm , $\Delta E_0/E_0$=1%).
- A large emittance growth occurs relatively close to the nominal bunch spacing.
- Adding realistic random frequency errors from cavity to cavity reduces the emittance dilution by an order of magnitude.

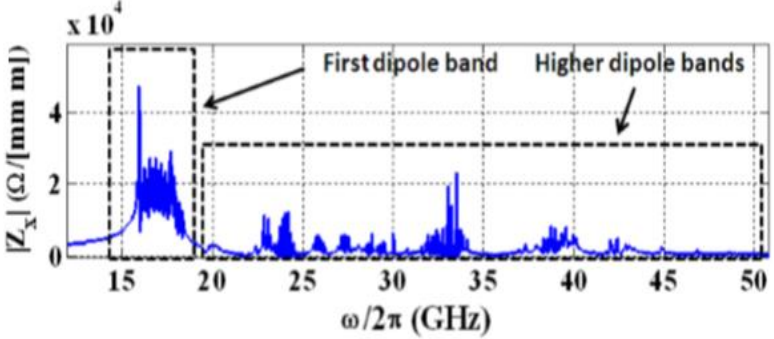




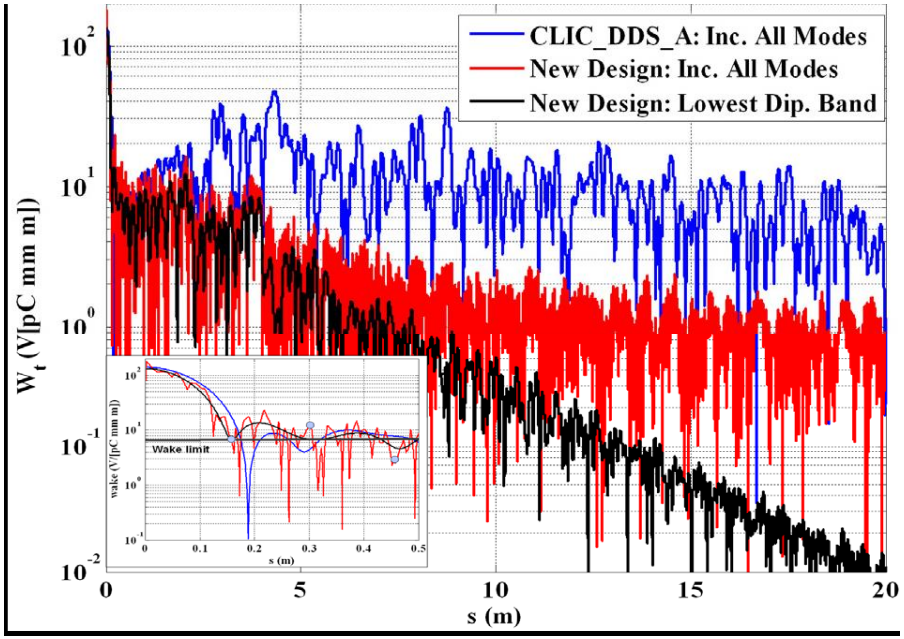
Beam Dynamics Based on PLACET Simulations

- The enhanced coupling design (A. D'Elia, IPAC12) indicates improved wakefield suppression
- The 1st dipole band includes Qs in the range 200 to 600
- The majority of the kick factors are contained within the first dipole band –with a significant component also located in the 7th band

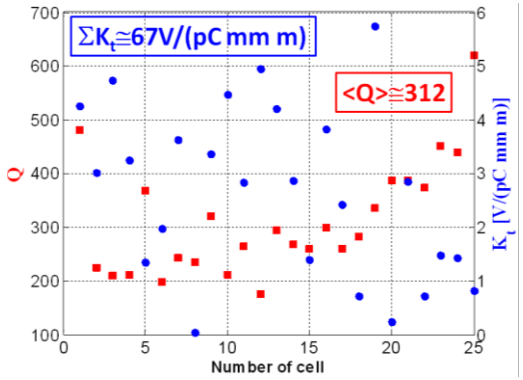
Impedance of Enhanced Design



Wakefield of Enhanced Design



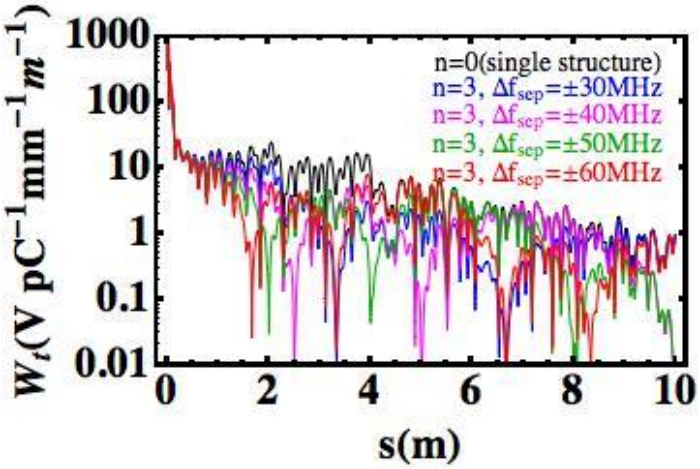
Q & Kicks of Enhanced Design



Beam Dynamics Based on PLACET Simulations

- Simple three-fold interleaving is affected by shifting all frequencies: $\pm\Delta f_{sep}$.
- Straightforward to achieve this interleaving
- Simulations conducted with PLACET with a 'realistic' beam (σ=44μm, n_b=312, $\Delta E_0/E_0$~1%) indicate interleaving significantly improves the emittance dilution.

Envelope of Transverse Wakefield of Enhanced Design (all bands inc.)



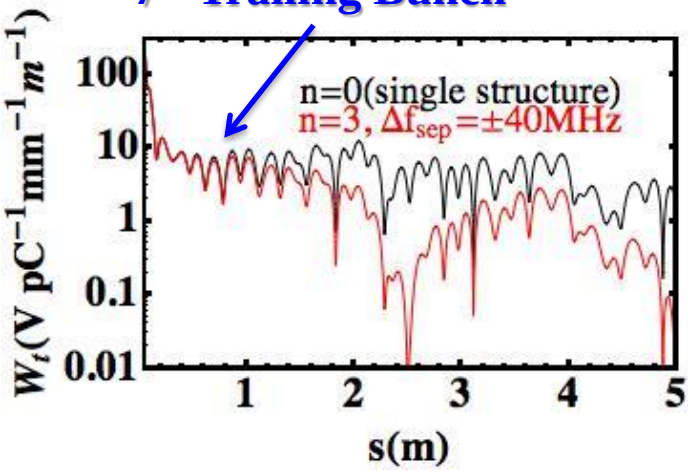
Structure	Emittance Dilution	
	Perfect Cavities	Random Errors
Single structure	71e6%	17.4e3%
n=3, Δfsep =±40MHz	10.568%	5.137%
n=3, Δfsep =±50MHz	3.15%	3.27%
n=3, Δfsep =±60MHz	2.808%	2.78%

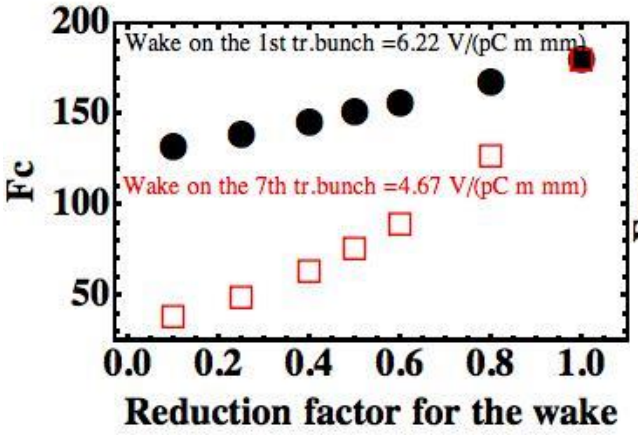
Beam Dynamics Based on PLACET Simulations

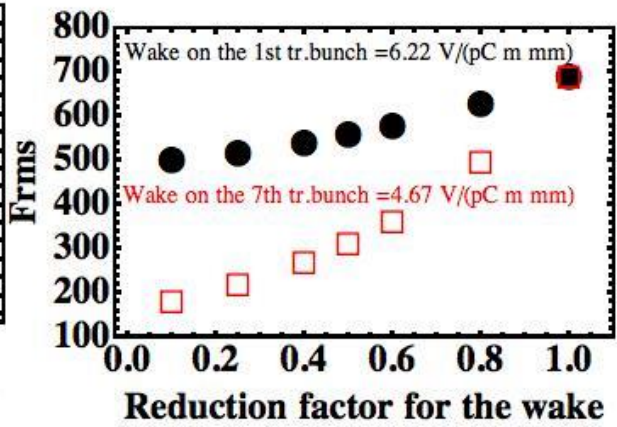
- Beam dynamics in CLIC_B is clearly driven by first trailing bunch (all additional ones are rapidly damped)
- 40 MHz is specifically chosen for non-optimal interleaving
- Modifying the amplitude of the wake on the 7th bunch illustrates a strong influence of the remaining wakefield

Envelope of Transverse Wake

7th Trailing Bunch



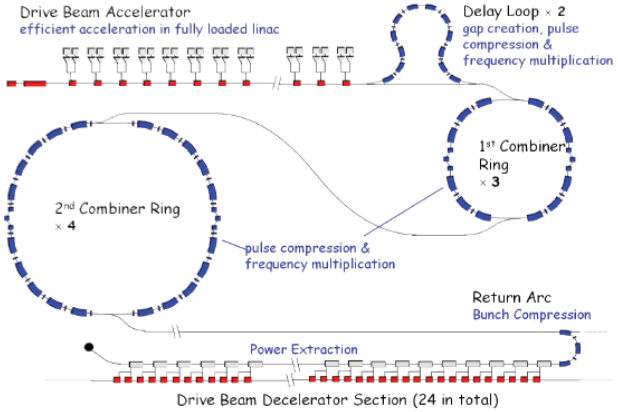




Klystron Studies -Introduction

The Cockcroft Institute of Accelerator Science and Technology

CLIC drive beam complex @ 3 TeV:



From CLIC CDR (2012):

Table A.6: Drive Beam parameters

Parameter	Symbol	Value	Unit
Drive Beam basic parameters			
Energy (decelerator injection)	$E_{\mathrm{in,dec}}$	2.37	GeV
Energy (final, minimum)	$E_{\mathrm{fin,dec}}$	0.24	GeV
Average current in pulse	I_{dec}	101	A
Train duration	τ_{train}	244	ns
No. bunches / train	$N_{b,\mathrm{dec}}$	2928	
Bunch charge	$Q_{b,\mathrm{dec}}$	8.4	nC
Bunch separation	$\Delta_{b,\mathrm{dec}}$	0.083	ns
Bunch length, r.m.s.	$\sigma_{z,\mathrm{dec}}$	1	mm
Normalized emittance, r.m.s.	$\gamma\varepsilon_{\mathrm{dec}}$	150	μm rad
Drive Beam linac			
RF frequency	f_{RF}	999.5	MHz
Total number of klystrons	N_{kly}	2 * 819	
Klystron peak power	P_{kly}	15	MW
Repetition frequency	f_{rep}	50	Hz
Pulse length (total train)	τ_{pulse}	142	μs
Beam current per pulse	I_{DB}	4.2	A
Charge per pulse	Q_{pulse}	0.6	mC
Number of bunches / pulse	$N_{b,\mathrm{pulse}}$	7.1	10^4
Bunch length (r.m.s.)	σ_z	4	mm
Normalized emittance (at injection)	$\gamma\varepsilon_i$	100	μm rad
Total energy spread (at injection)	$\Delta E/E$	1	%
RF → Drive Beam efficiency	$\eta_{b,\mathrm{RF}}$	89	%

The average RF power at the accelerating structure input is 174 MW with challenging specifications in terms of stability:

- **± 0.05° in phase**
- **0.2% in amplitude**

Very high efficiency sources needed to provide this power at affordable cost (efficiency>70%)

$$\eta = \frac{P_{out}}{P_0} = \frac{P_{out}}{I_0 V_0}$$

Multibeam Klystrons proposed:

- **15 MW output power with small current per beamlet low perveance – good efficiency (state-of-the-art around 65%)**

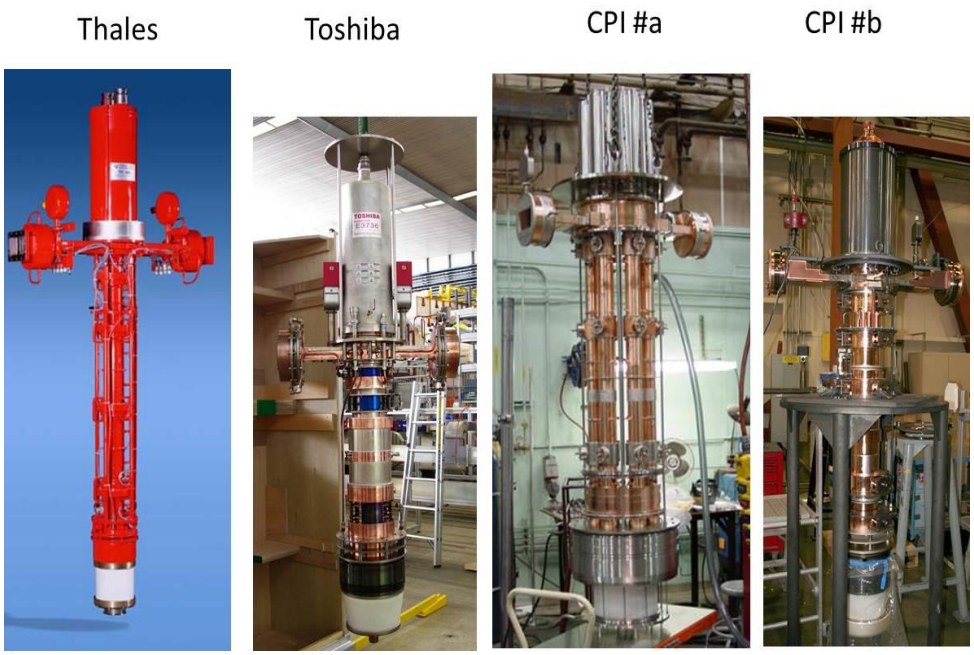
- **"multibeam" cavities: all beams interact in the same cavities**

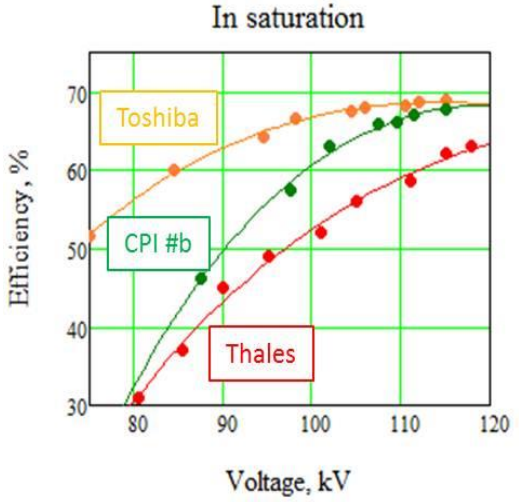
Future Klystron - Prospects

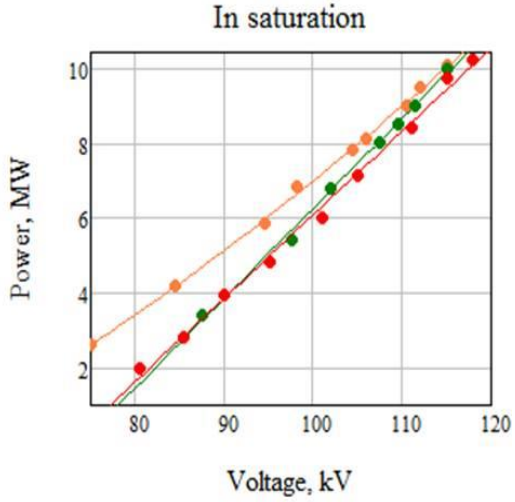
The Cockcroft Institute of Accelerator Science and Technology

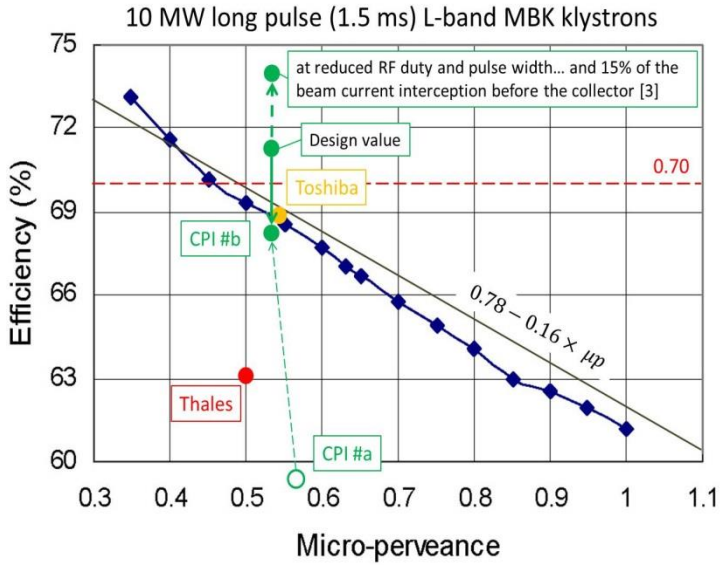
State of art: L-band 10 MW MBK klystrons for ILC.

In terms of the efficiency at 10 MW peak RF power level, the existing MBK klystrons provides values very close to the 70%, as is specified in CLIC CDR.







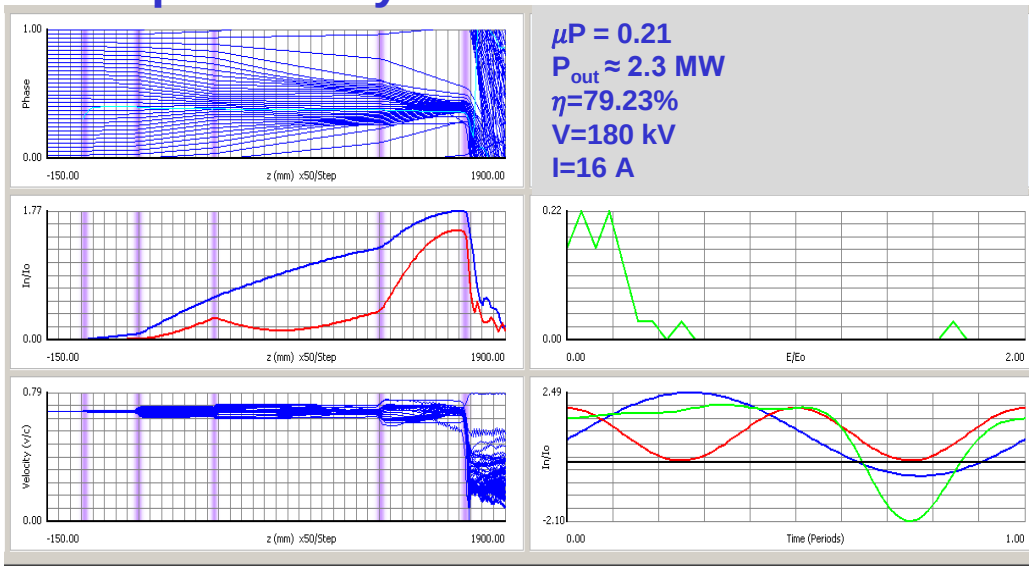


Efficiency and RF Klystron Design

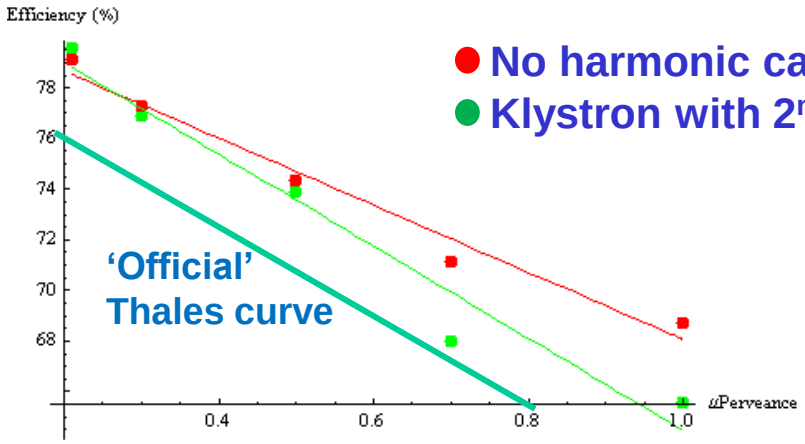
Dedicated campaign to make parametric study of the high efficiency klystrons (I. Syratchev, C. Marrelli, in collaboration with Lancaster University), using 1D klystron computer code AJDISK (SLAC).

Study made for 5-cavities devices with and without second harmonic bunching cavities

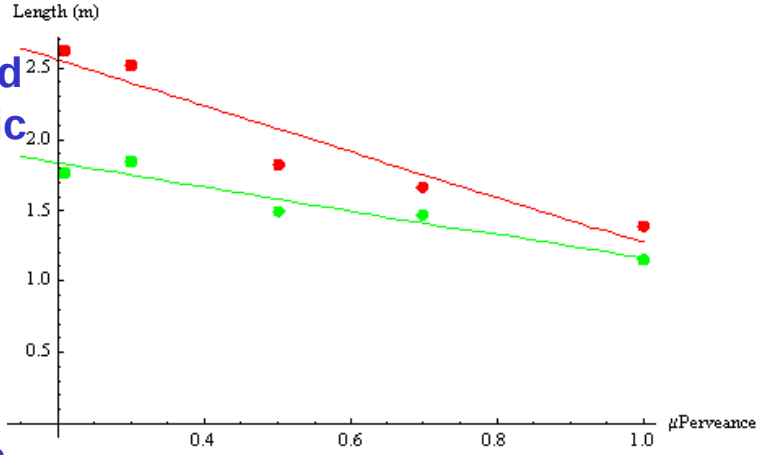
Example of a klystron with 2nd harmonic cavity:



$\mu P = 0.21$
$P_{out} \approx 2.3$ MW
$\eta = 79.23\%$
V=180 kV
I=16 A



- No harmonic cavities used
- Klystron with 2nd harmonic



Findings and Future Perspectives

- **Detailed simulations on efficiency vs perveance for klystrons equipped with harmonic and non-harmonic cavities have indicated realistic limits expected for the overall efficiency. Several codes have been compared for this purpose (C. Marrlelli/I. Syrachev). This facilitates knowledge-based communication with klystron manufacturers –not biased by the industry potentials, expertise and cost issues**

- **Very high efficiencies are possible in both devices, esp. at very low perveance (μP <0.5).**

- **The second harmonic cavity, at low perveance, makes the klystron significantly shorter, but it is difficult to implement in case of a multibeam klystron with a high number of beams (ex 30).**

- **Alternatives approach have been suggested (Guzilov et al.): low frequency cavities in order to reduce the velocity spread before the output. This possibility is also under study.**

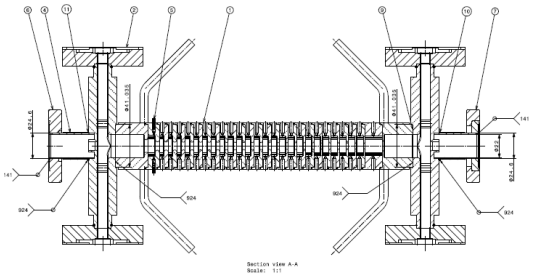
- **The ongoing 1D simulations (including study of phase stability, sensitivity to input values and sweep over main design parameters) will be taken as guidelines for the development of the new L-band high efficiency klystron, to be developed in collaboration with companies.**

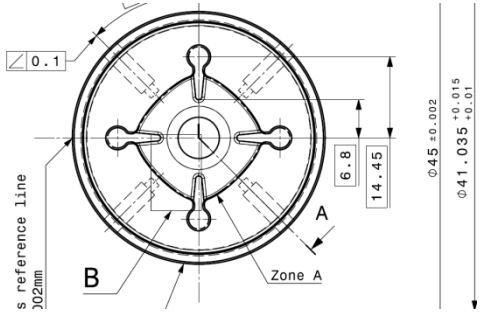
Acknowledgements

- 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

CLIC DDS Selected Pubs.

1. **V. F. Khan, *et. al*, IPAC10, 2010.**
2. **V. F. Khan, *et. al*, LINAC10, 2010.**
3. **R.M. Jones, NIMA, 2011.**
4. **V.F. Khan *et. al*, NIMA, 2011.**
5. **V.F. Khan, PhD thesis, 2011.**
6. **A. D'Elia et el, IPAC 2012.**
7. **I. Nesmiyan et al, IPAC 2012**
8. **A. D'Elia et al., NA-PAC 2013.**





Conclusions

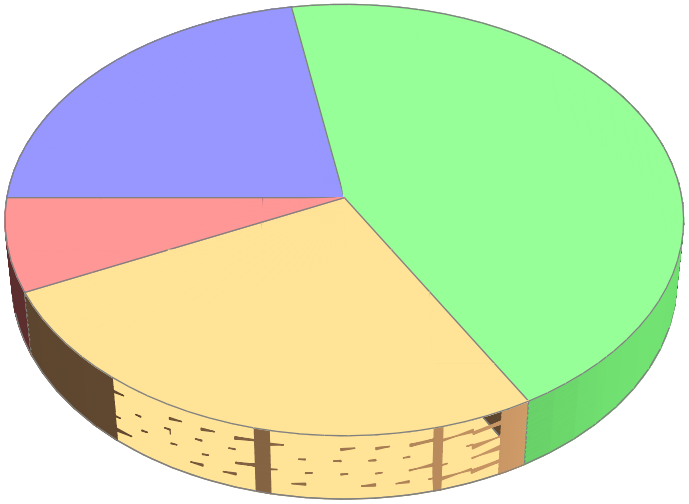
- DDS_A (cells fabricated at Morikawa) have been diffusion bonded – RF measurements indicate the structure is within the design specs (5MHz from design).
- High power tests are anticipated once scheduled into the CLIC testing programme
- DDS_B constitutes a series of new designs (varying phase in particular –PDDS) in which the original 6 RF cycle bunch spacing is resorted to in order to improve the overall efficiency of the collider. Adhering to the matrix based analysis imposes severe restrictions on the wakefield – whilst ensuring the surface e.m. fields are kept within manageable limits.
- Initial beam dynamics simulations, including realistic frequency errors, indicate relaxed requirements on wakefield suppression –up 10^{th} band (50 GHz)
- Klystron studies indicate enhanced efficiency possible (>70%)

Future R&D Anticipated in 2013/2014

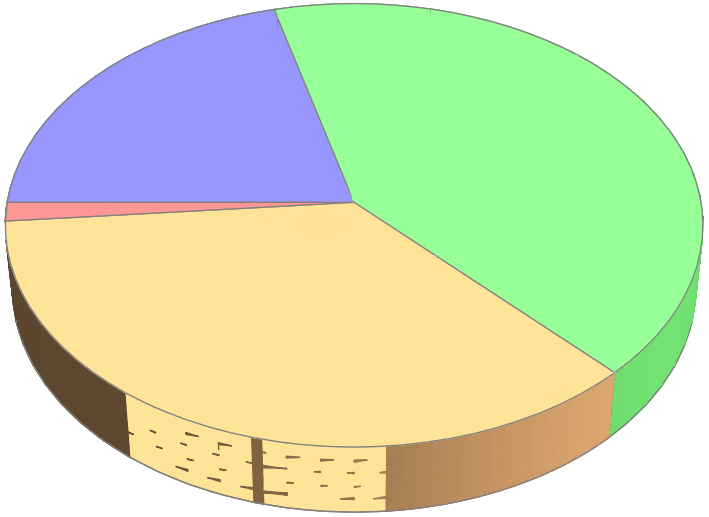
- CLIC_DDS_A requires attachment of couplers and tuning stubs
- CLIC_DDS_A fully bonded single cavity almost complete! High power/high gradient test will be first demonstration of CLIC_DDS –needs to be scheduled!
- Further work on the impact of the interleaved wakefields on misalignments

4. Expenditure

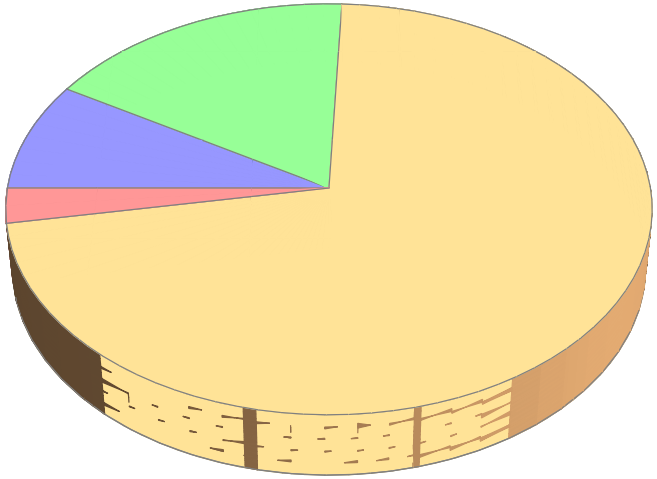
Staffing

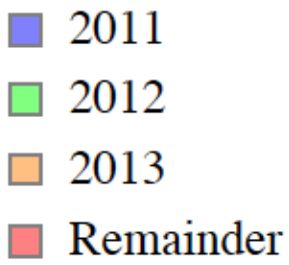


Travel



Consumables





4. Expenditure

Staffing

- Univ. Faculty: R.M. Jones.
- PDRAs: I.Nesmiyan, C. Marrelli.
- PhD: N. Shipman (minimal)

Travel

- IPAC12, KEK X-Band CLIC Workshop, CLIC workshop at CERN, NA-PAC13
- Various fruitful visits (I. Nesmiyan) to CERN entailing discussions on rf and beam dynamics with CLIC rf and beam dynamics groups

Consumables

- GdfidL

This is broad indication of expenditure. If desired, a detailed breakdown can be provided by Univ. of Manchester Research Office

5. Future CLIC-k Studies 2014 - 2017

- **Short-term (2014):**
- **An investigation of the capability of SW structures to sustain high gradients will be instituted. A preliminary structure, CLIC_SW1 will be designed in 2014, suitable for tested in the high power test facility at CLIC. The focus of this initial research is on the ability of the structure to sustain high gradient. This structure will not be equipped with the full wakefield suppression features**

- **Medium to long-term (2015):**
- **CLIC_SW1 will be fabricated by the second quarter of 2015. This will be scheduled for high power testing at CLIC. In addition, the beam dynamics of a full series of SW structure will be studied and a design, suitable for CLIC will be completed: both the 375 GeV, and intermediate designs up to a 3 TeV center of mass will be investigated.**

- **Long-term (2016):**
- **A further SW structure, CLIC_SWD1, will be fabricated in the last quarter of 2016 and evaluated in the high power test facility at CLIC, and later tested for its HOM suppression properties at CTF3 and ASSET at SLAC. This structure will be furnished with full wakefield suppression.**

5. Future CLIC-k Studies -Deliverables

1. A single SW structure, with no provision for HOM damping, will be designed, fabricated and high power tested. This is anticipated to be complete by the second quarter of 2015.

2. A report on the beam dynamics of SW structures in 375 GeV, and intermediate stages up to a 3 TeV collider, will be completed by the end of 2016

3. A further structure, equipped with full wakefield suppression, will be designed, fabricated and scheduled for testing at CLIC by the last quarter of 2016.