Directions for CLIC structures: Lower energy machines and overview of damping alternatives

A. Grudiev

18/04/2012

HG2012, KEK Tsukuba

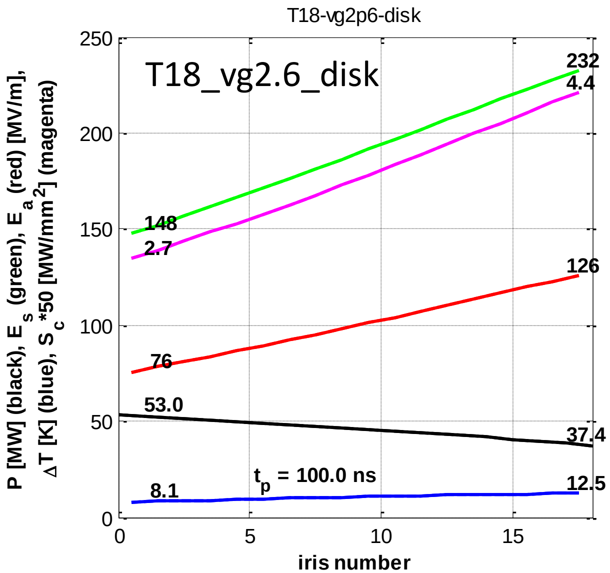
Outline

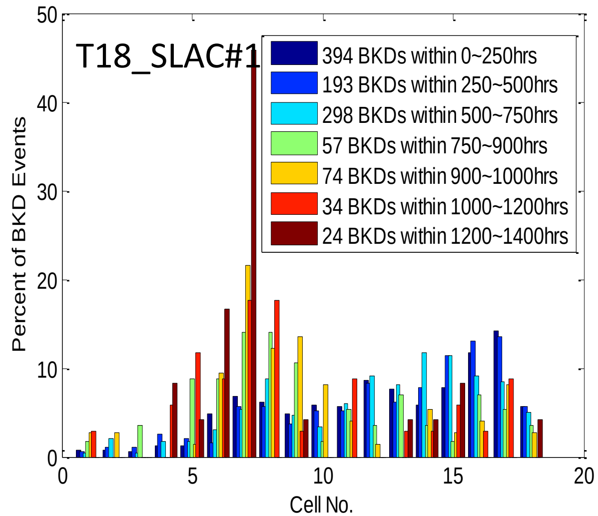
- 3 TeV and lower enegry CLIC structures
  - Structure tapering
  - Single feed coupler
  - 500 GeV structure
  - Intermediate energy structure
- Overview of the damping alternatives
  - DDS
  - Choke mode damping

Motivations 3 TeV CLIC structure

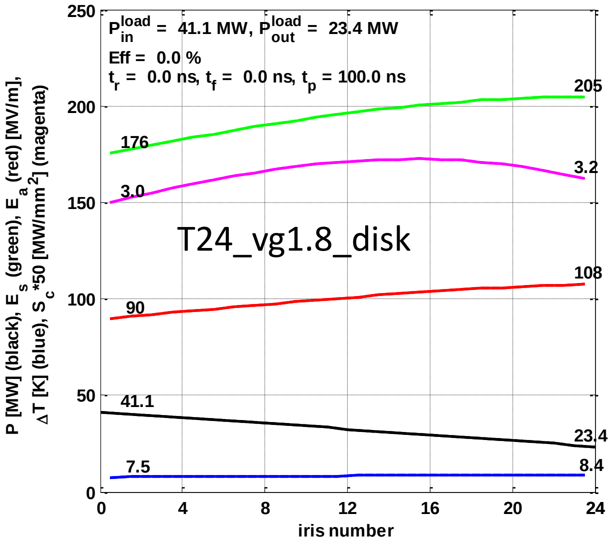
1. The CLIC_G structure has been designed in 2008. We have learned a lot since then **but** the structure is not tested yet and we cannot say for sure if it satisfied CLIC requirements or not.
2. All what we learned so far indicate that CLIC_G is on the edge. We need a reliable test results in order to see where is(are) the weak point(s) of CLIC_G, then we can try to improve it.
3. Moreover, CLIC parameters are frozen since 2008. There is no need in a design of a new structure with different parameters (length, aperture, gradient, etc.).
4. In summary, there is no strong motivation on the new RF design, nevertheless, several new structure prototypes are being designed along two lines:
    a. improve high gradient performance for the same bunch charge by tuning the structure tapering
    b. simplification of the associated RF network by introducing compact couplers with single feed (CCSF)

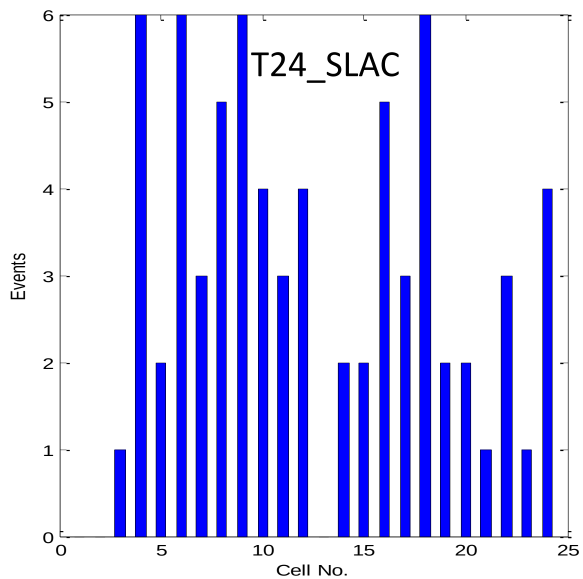
Maximum average gradient versus tapering

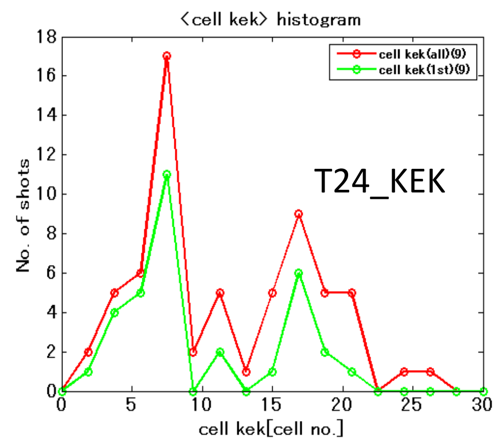




- If we forget for the moment about the hot cell #7, the BDR is higher in the last cell, where field quantities are higher.
- N.B., in T24, the BDR distribution is more flat but there are also other differences
- **What is the optimum tapering ?**



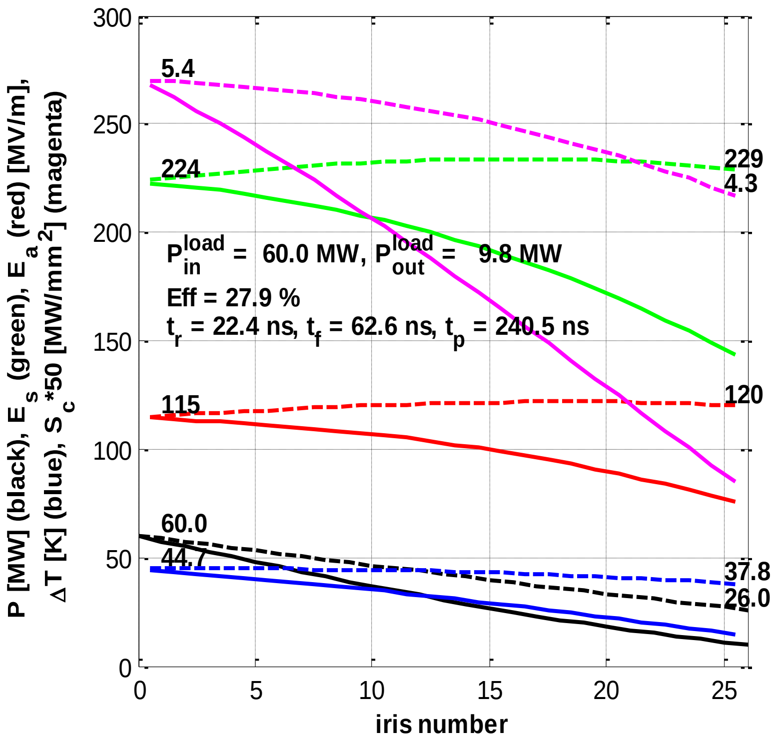


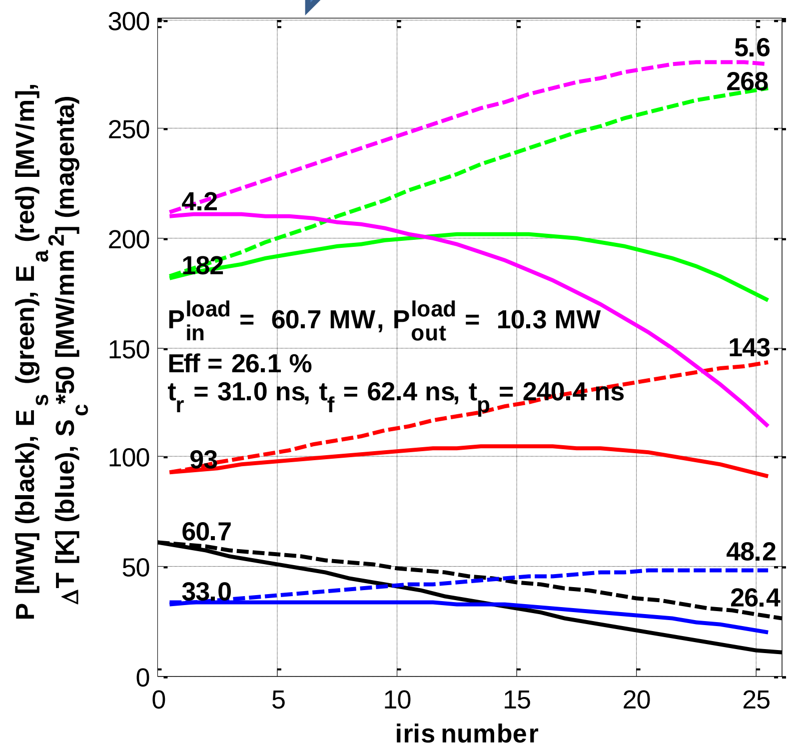


Const unloaded versus const loaded gradient ?

We will try to answer this question in the dedicated test in ‘dog-leg’ area in CTF3 (2013)

CLIC-G → CLIC-O





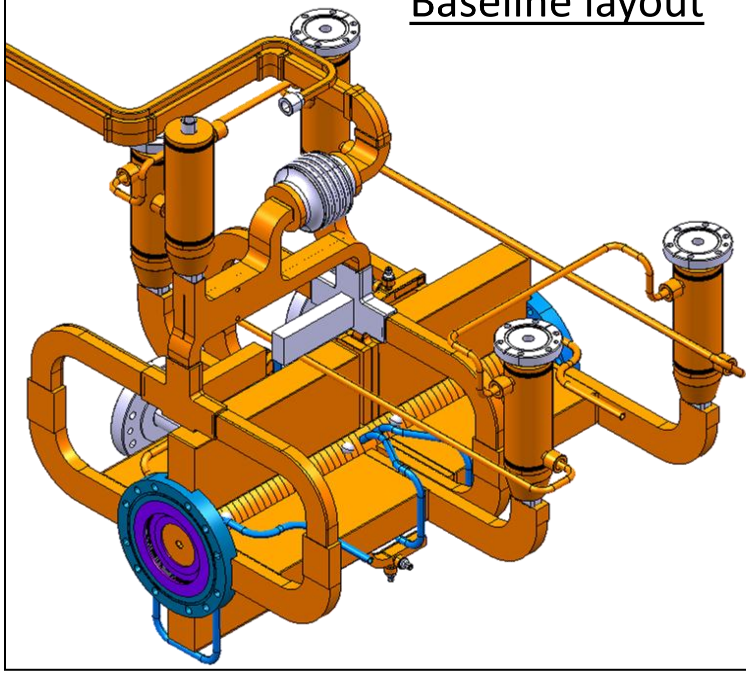
See more on the different tapering design at LCWS2011, Granada:

http://ilcagenda.linearcollider.org/contributionDisplay.py?contribId=80&sessionId=19&confId=5134

Alternative layout of CLIC SAS based on compact coupler with single feed (CCSF)

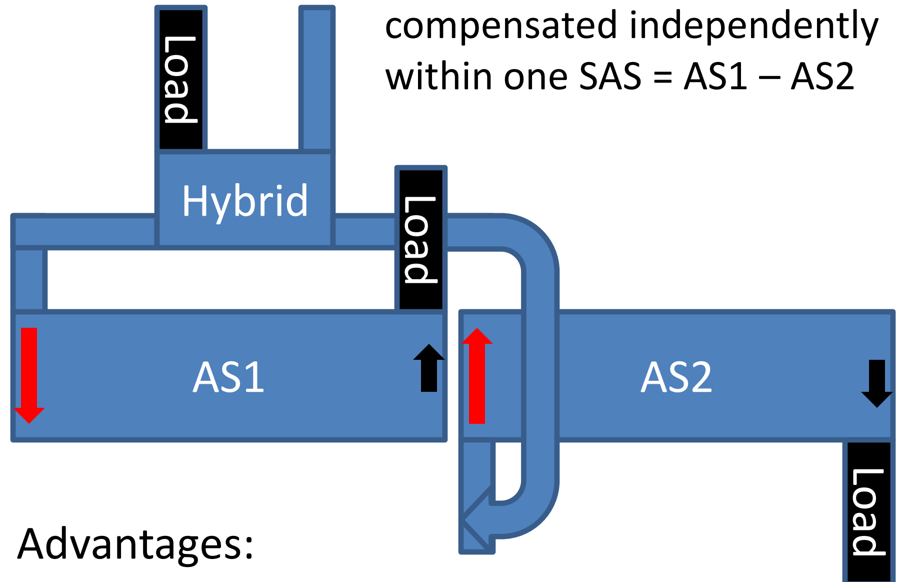
Image courtesy of A. Samoshkin

Baseline layout



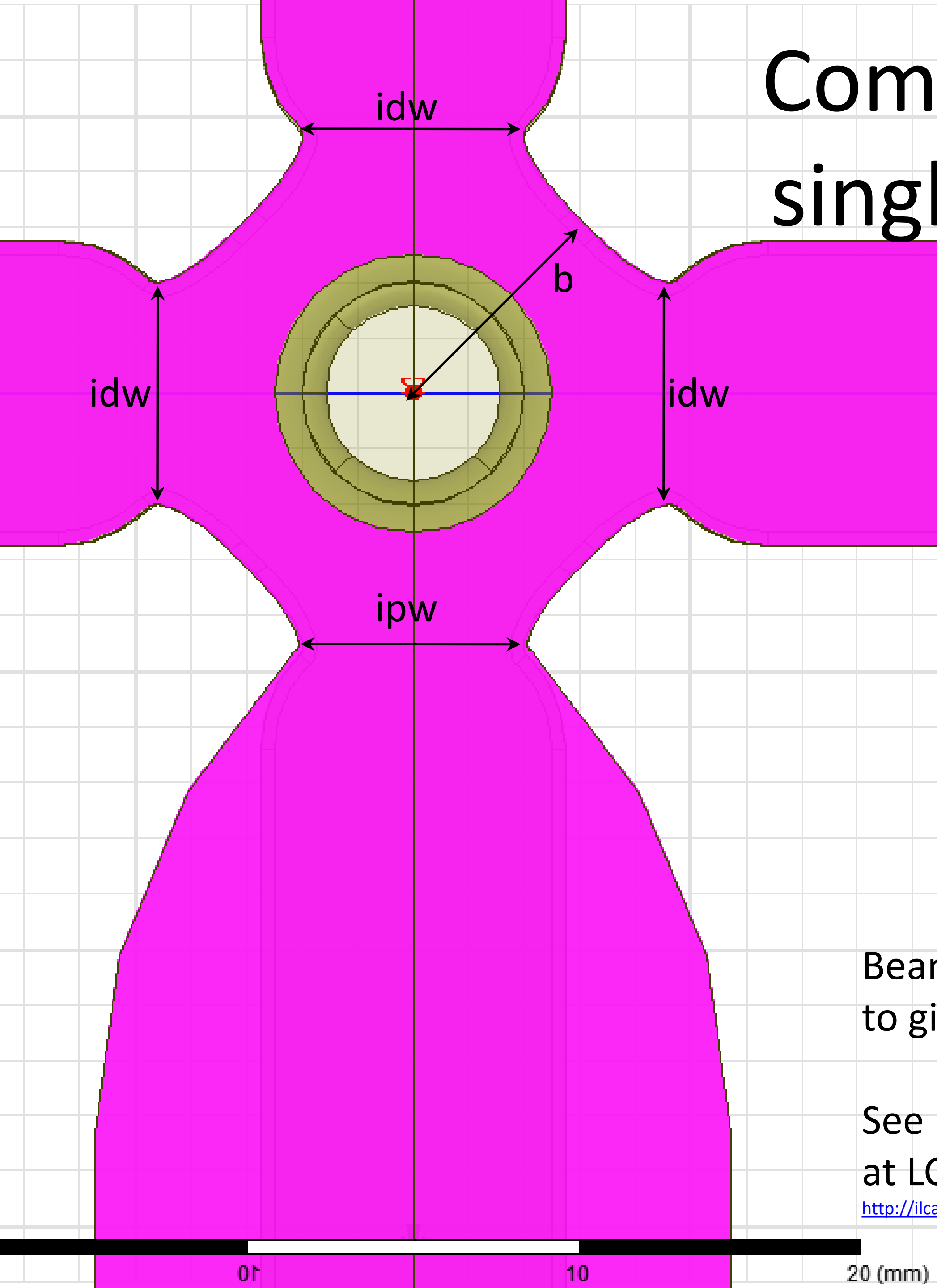
Alternative layout:

- **Input** and **Output** kicks are compensated independently within one SAS = AS1 – AS2

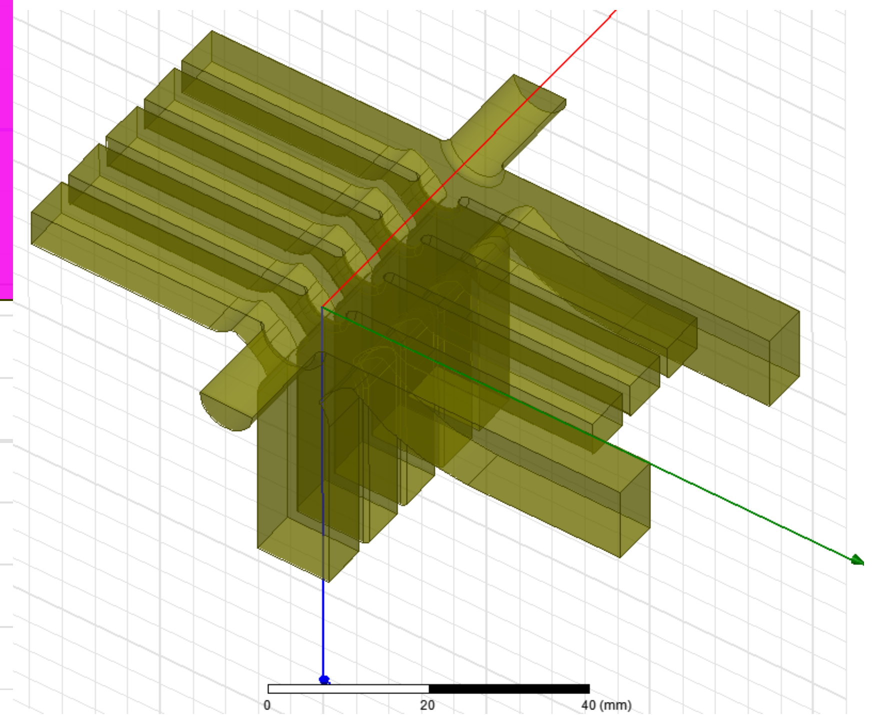


Advantages:

- No splitters (HOMagic-T)
- 3 loads per SAS instead of 5
- less waveguides
- group delay difference between two AS can be adjusted to 0
- more space for input/output waveguide connection to the AS



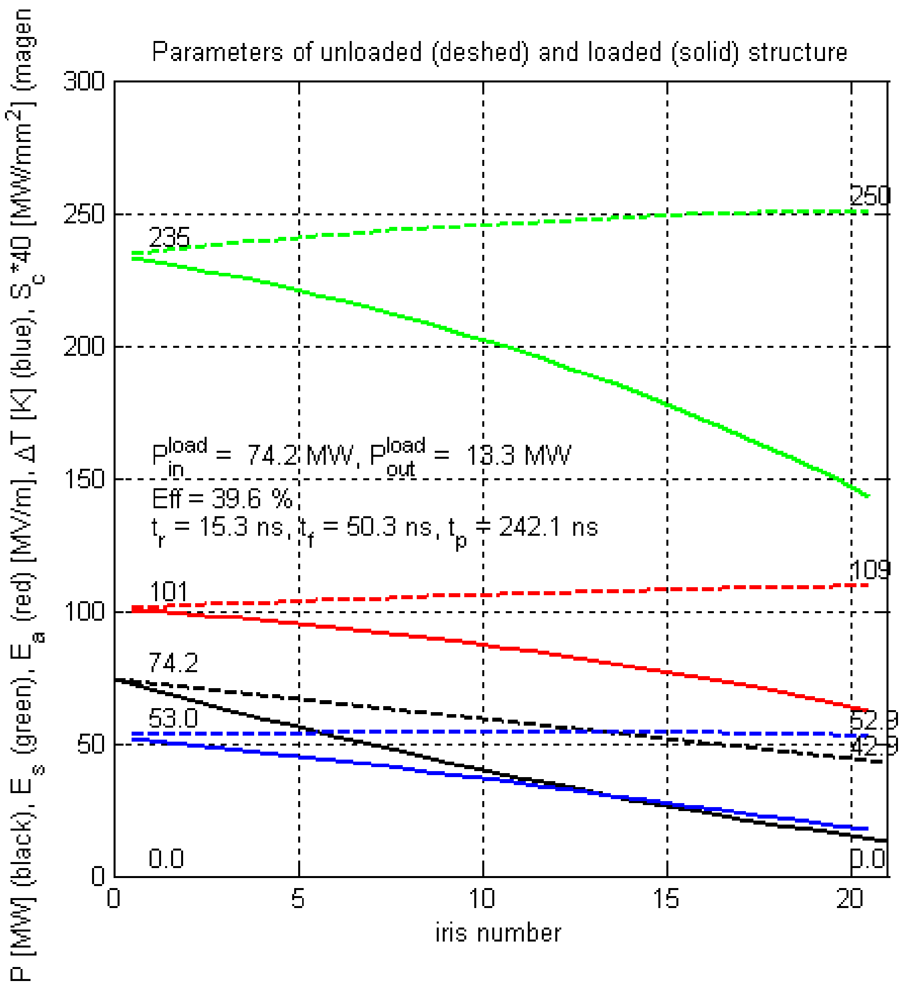
Compact coupler with single feed, geometry



Beam dynamics colleagues are working on to give their OK for using it for CLIC.

See more on the single feed coupler design at LCWS2011, Granada:
http://ilcagenda.linearcollider.org/contributionDisplay.py?contribId=80&sessionId=19&confId=5134

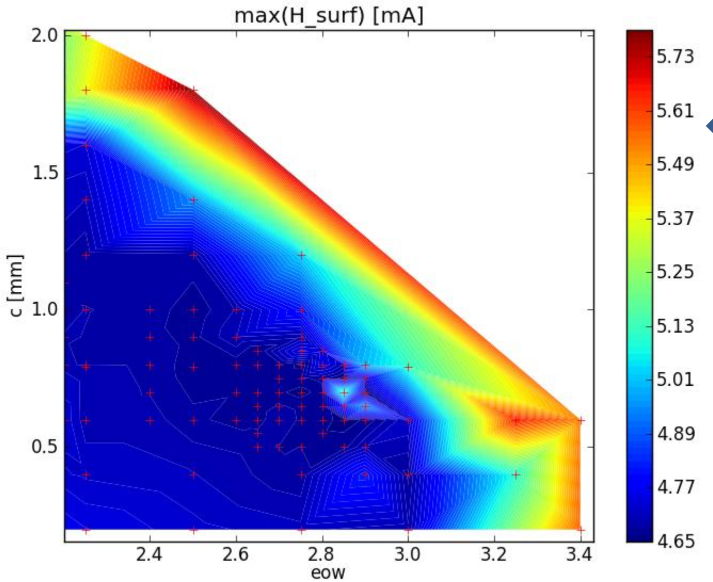
500 GeV CLIC structure: CLIC_502



Preliminary design is done in 2008

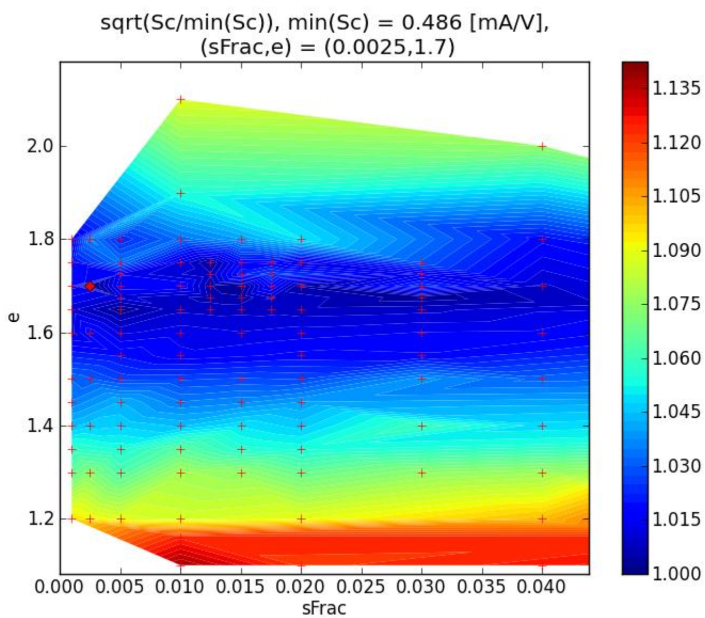
Case	3TeV nominal	500 GeV 1st stage
Structure	CLIC_G	CLIC_502
Average accelerating gradient: $\langle E_a \rangle$ [MV/m]	100	80
rf phase advance: $\Delta\varphi$[º]	120	150
Average iris radius/wavelength: $\langle a \rangle/\lambda$	0.11	0.145
Input/Output iris radii: $a_{1,2}$ [mm]	3.15, 2.35	3.97, 3.28
Input/Output iris thickness: $d_{1,2}$ [mm]	1.67, 1.00	2.08, 1.67
Group velocity: $v_g^{(1,2)}/c$ [%]	1.66, 0.83	1.88, 1.13
N. of reg. cells, str. length: N_c, l [mm]	24, 229	19, 229
Bunch separation: N_s [rf cycles]	6	6
Luminosity per bunch X-ing: $L_{b\times}$ [m^{-2}]	1.22×10^{34}	0.57×10^{34}
Bunch population: N	3.72×10^9	6.8×10^9
Number of bunches in a train: N_b	312	354
Filling time, rise time: τ_f, τ_r [ns]	62.9, 22.4	50.3, 15.3
Pulse length: τ_p [ns]	240.8	242.1
Input power: P_{in} [MW]	63.8	74.2
$P_{in}/Ct^P_p{}^{1/3}$[MW/mm ns$^{1/3}$]	18	17
Max. surface field: E_{surf}^{max} [MV/m]	245	250
Max. temperature rise: ΔT^{max} [K]	53	56
Efficiency: η [%]	27.7	39.6
Figure of merit: $\eta L_{b\times}/N$ [a.u.]	9.1	3.3

RF design of CLIC_502 prototype using ACE3P

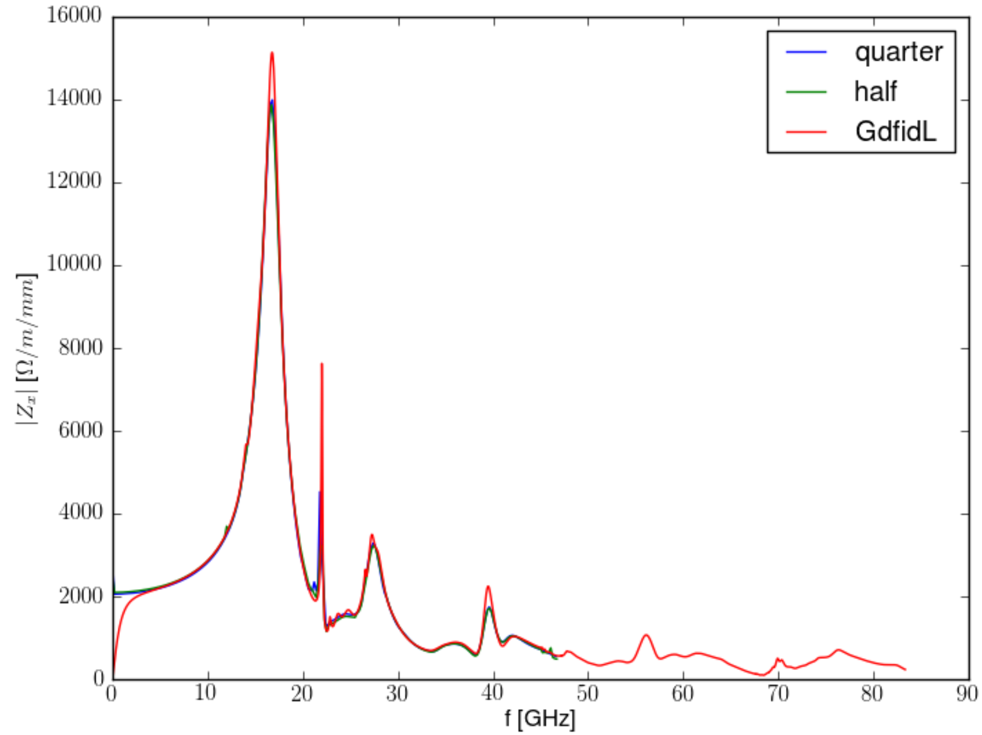


Optimization of the surface fields in the cells

Work in progress



Transverse wake in the CLIC_G 1st cell benchmark



Work of Kyrre Sjøbæk , CERN/Oslo University

Intermediate energy CLIC (1.5 TeV?)

- For the staged approach there will be a set of parameters to be optimized at an intermediate energy ~1.5 TeV taking into account cost and performance of CLIC.
- As a consequence, there probably will be a new accelerating structure for the CLIC main linac to be designed in the near future.
- This work is just taking shape in the CLIC staged approach working group lead by Daniel Schulte

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- Overview of the damping alternatives
  - CLIC DDS
  - Choke mode damped CLIC_G
  - Comparison to waveguide damped CLIC_G

The University of Manchester

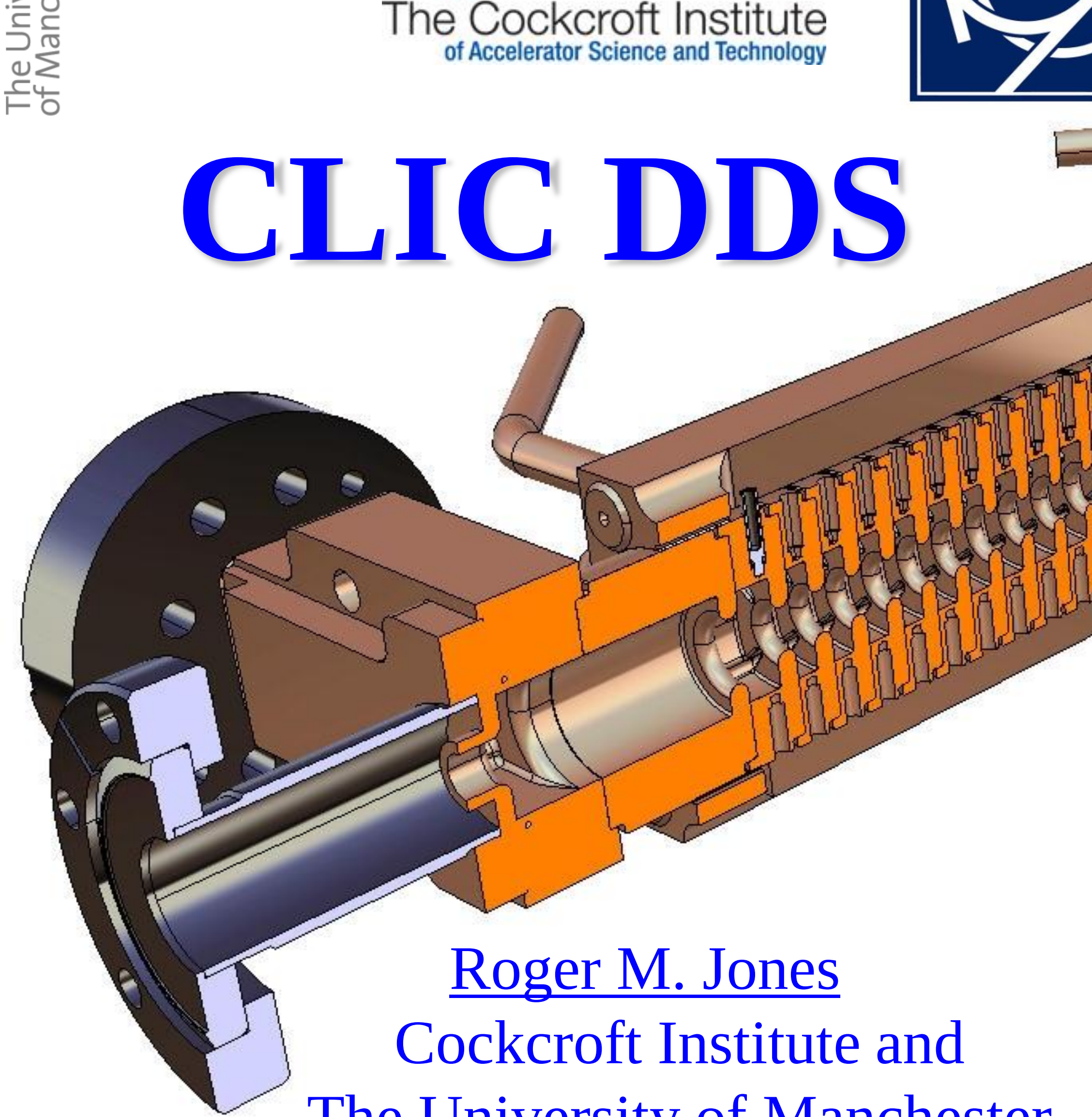
MANCHESTER 1824

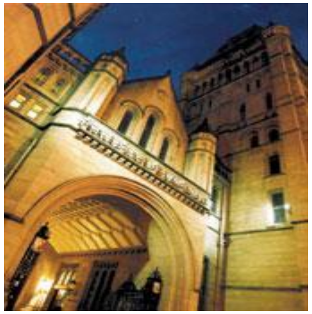
The Cockcroft Institute of Accelerator Science and Technology

CERN

EuCARD

CLIC DDS





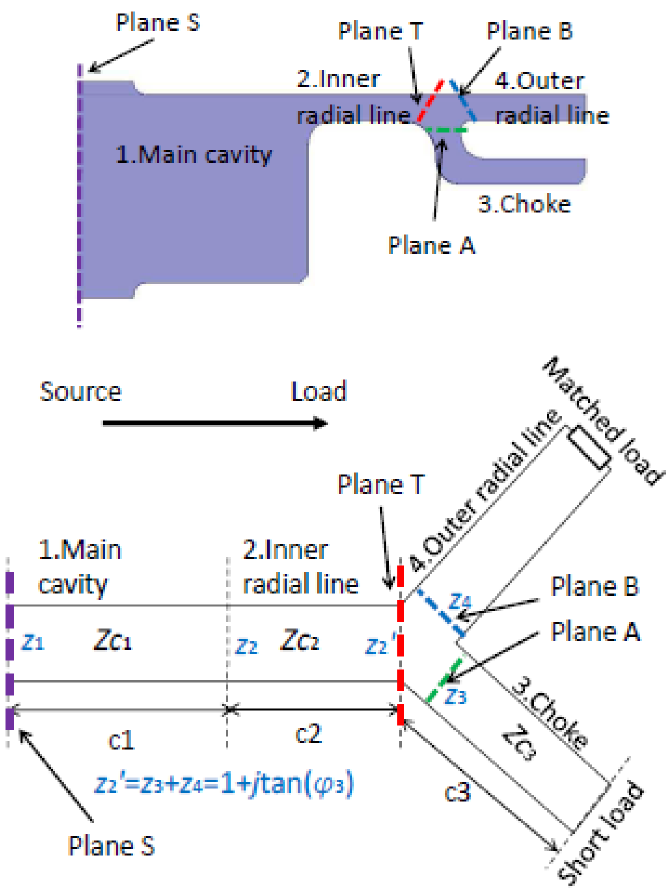
Roger M. Jones

Cockcroft Institute and

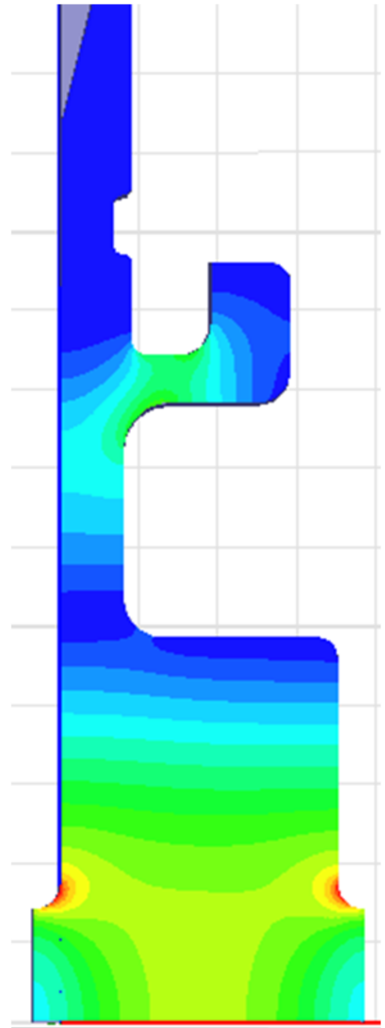
The University of Manchester

Choke mode damped CLIC structure
Jiaru Shi, Hao Zha (Tsinghua University)

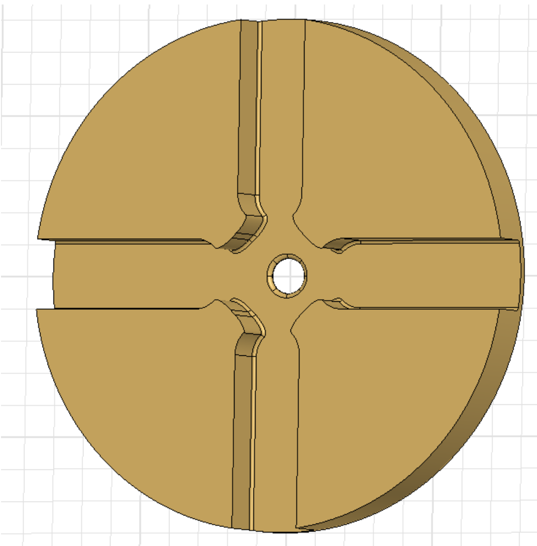
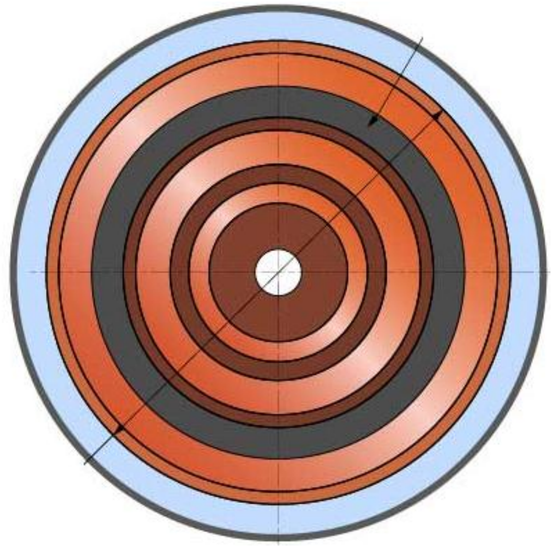
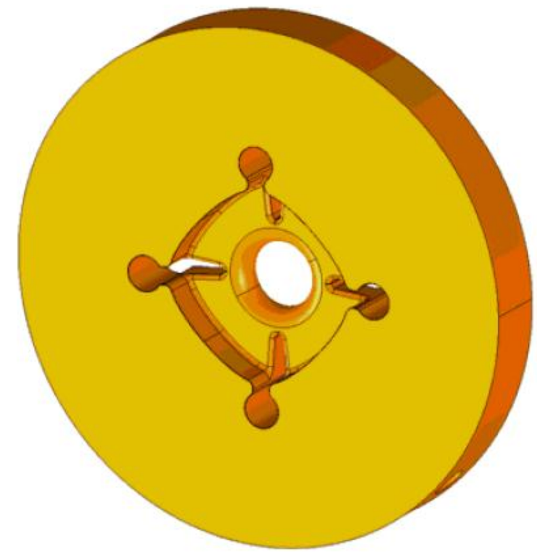
Enormous progress in wakefield suppression from radial choke **to**



Courtesy of Jiaru Shi and Hao Zha



See more in Jiaru's talk

CLIC_Main Linacs
Multi-bunch wake effect in various damping schemes

Vasim Khan

07.03.2012

CLIC RF structure group meeting, CERN

D. Schulte, PAC09, FR5RFP055

$$a_k = i\sum_j \frac{L_j\beta_j}{2E_j} W(z_k) Ne^2 \approx 380 m^2 GeV^{-1} W(z_k) Ne^2 \qquad a_1 \approx 1.5$$

In CLIC_G

Kick on only following trailing bunch

Direct effect

$$a = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ i\,a1 & 0 & 0 & 0 & 0 \\ 0 & i\,a1 & 0 & 0 & 0 \\ 0 & 0 & i\,a1 & 0 & 0 \\ 0 & 0 & 0 & i\,a1 & 0 \end{pmatrix}$$

A=Exp[a]

Direct and indirect effect

$$A = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ i\,a1 & 1 & 0 & 0 & 0 \\ -\frac{a1^2}{2} & i\,a1 & 1 & 0 & 0 \\ -\frac{i\,a1^3}{6} & -\frac{a1^2}{2} & i\,a1 & 1 & 0 \\ \frac{a1^4}{24} & -\frac{i\,a1^3}{6} & -\frac{a1^2}{2} & i\,a1 & 1 \end{pmatrix}$$

$$F_c = \frac{1}{n}\sum_k \left|\sum_j A_{kj}\right|^2$$

$$F_c \approx 1$$

$$F_{rms} = \frac{1}{n}\sum_{k=0}^{n-1}\sum_{j=1}^{k} A_{k,j} A^*_{k,j}$$

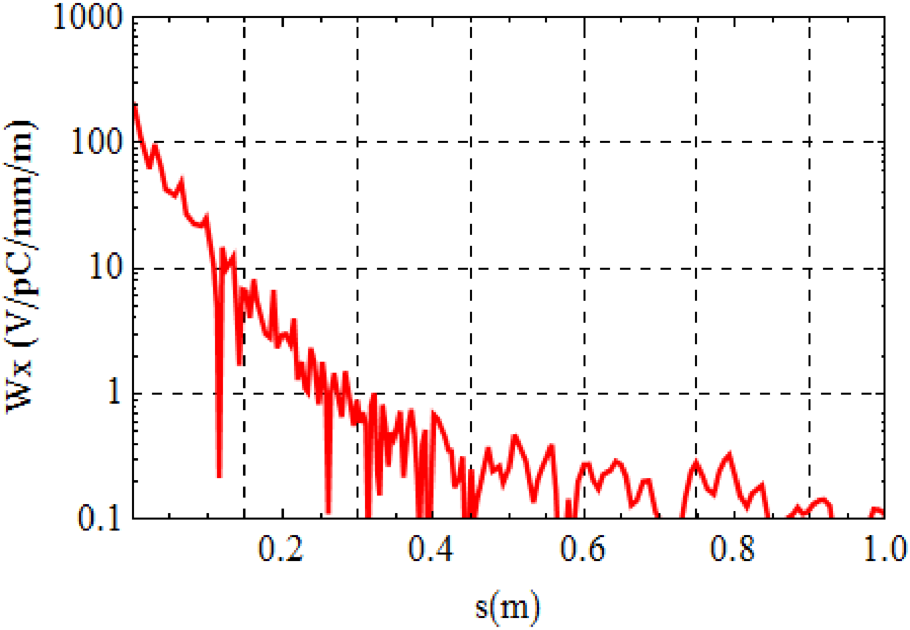
$$F_{rms} = \left(1 + \sum_{i=0}^{n-1} A_{0i}^2\right) \approx 4.9$$

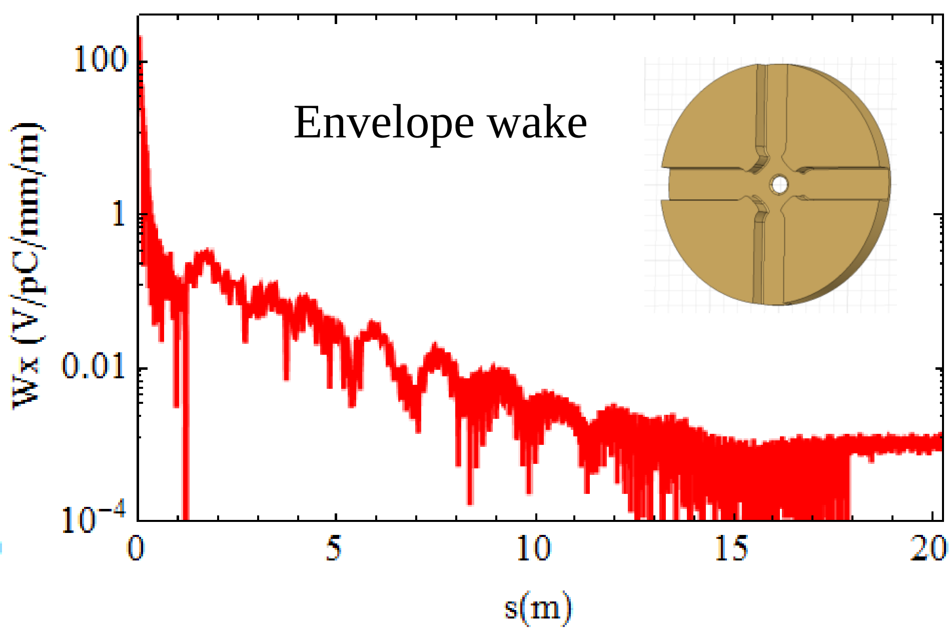
$$\{u, \lambda, v\} = \mathrm{SVD}[A]$$

$$\lambda = \begin{pmatrix} \lambda_1 & 0 & 0 \\ 0 & \lambda_2 & 0 \\ 0 & 0 & \lambda_{nb} \end{pmatrix}$$

$$F_{worst} = \lambda_1^2 \approx 20$$

TD26_vg1.8_discR05_CC: GdfidL simulations with PML



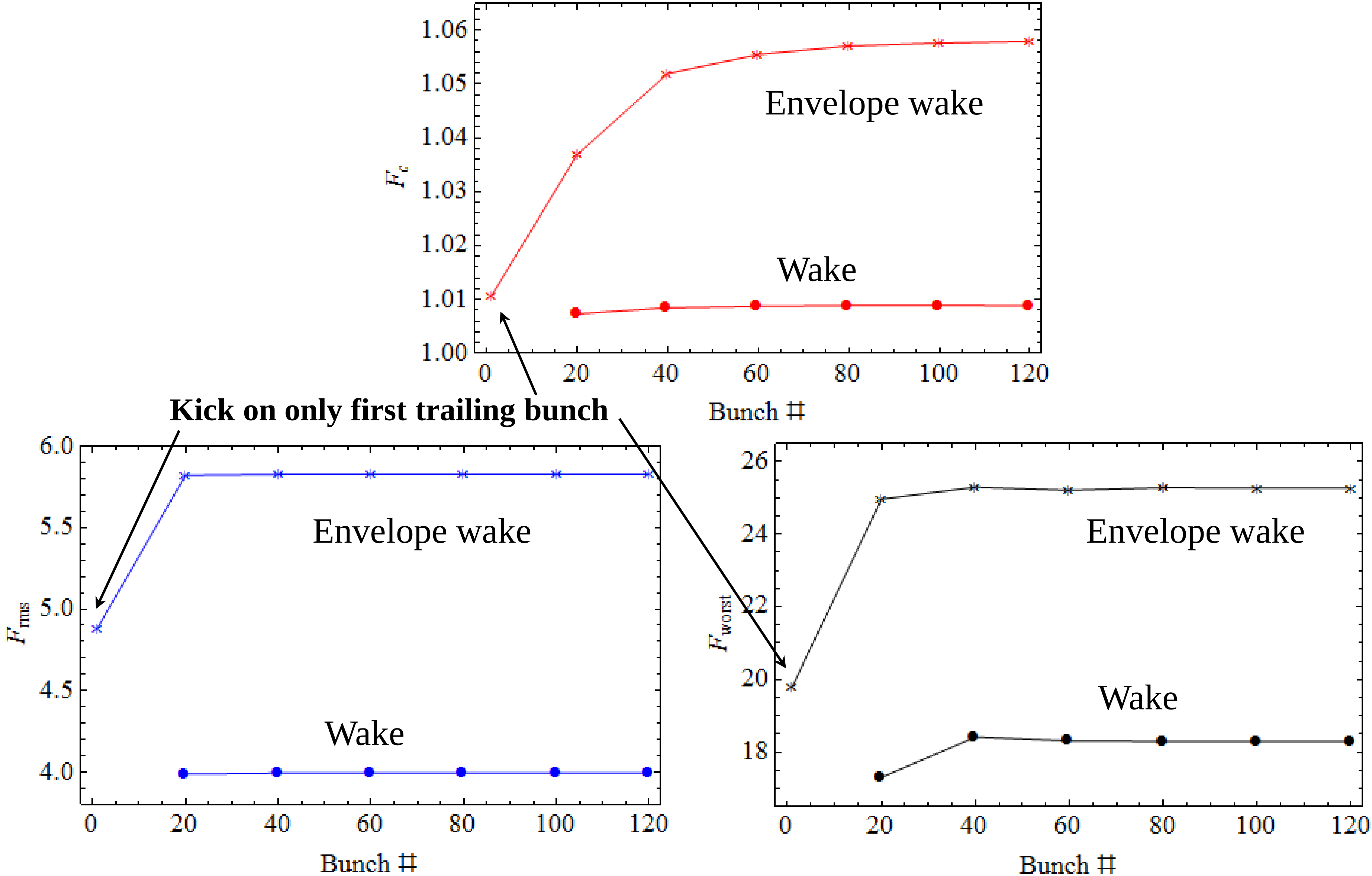


Kick on multiple bunches

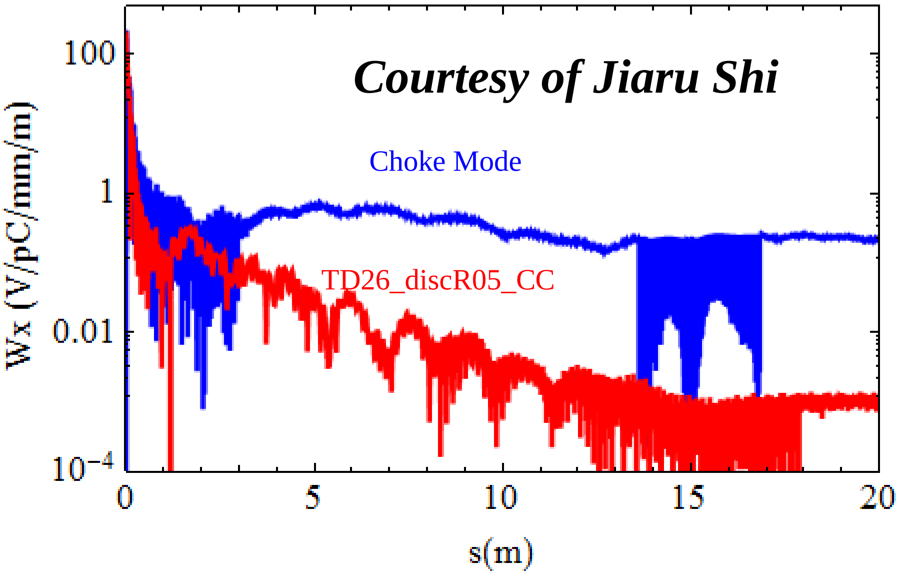
$$a=\begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ i\,aa_1 & 0 & 0 & 0 & 0 \\ i\,aa_2 & i\,aa_1 & 0 & 0 & 0 \\ i\,aa_3 & i\,aa_2 & i\,aa_1 & 0 & 0 \\ i\,aa_4 & i\,aa_3 & i\,aa_2 & i\,aa_1 & 0 \end{pmatrix}$$

$$A=\begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ i\,aa_1 & 1 & 0 & 0 & 0 \\ \frac{1}{2}\left(-aa_1^2+2\,i\,aa_2\right) & i\,aa_1 & 1 & 0 & 0 \\ \frac{1}{6}\left(-6\,aa_1\,aa_2+i\left(-aa_1^3+6\,aa_3\right)\right) & \frac{1}{2}\left(-aa_1^2+2\,i\,aa_2\right) & i\,aa_1 & 1 & 0 \\ \frac{1}{24}\left(aa_1^4-12\,aa_2^2-24\,aa_1\,aa_3-12\,i\left(aa_1^2\,aa_2-2\,aa_4\right)\right) & \frac{1}{6}\left(-6\,aa_1\,aa_2+i\left(-aa_1^3+6\,aa_3\right)\right) & \frac{1}{2}\left(-aa_1^2+2\,i\,aa_2\right) & i\,aa_1 & 1 \end{pmatrix}$$

Amplification factors



Alternative designs preliminary results

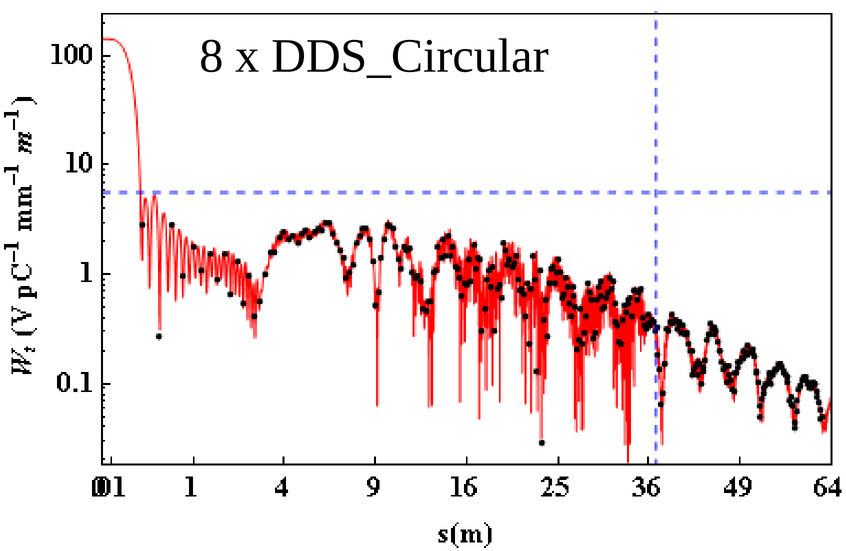


Wake (with phase information)

$nb_{311}=\{F_c,F_{rms},F_{worst}\}=\{357.924, 31.6057, 1094.08\}$

Envelope Wake

$nb_{311}=\{F_c,F_{rms},F_{worst}\}=\{1515.58, 151.144, 6480.98\}$



CERN and Uni. Manchester + C.I. collaboration

Structure	Wake (with phase information)		
	F_c	F_{rms}	F_w
DDS_A	1.29×10^{24}	1.25×10^{27}	1.32×10^{28}
8 x DDS_A	3.4×10^{5}	2.8×10^{7}	7.5×10^{8}
8 x DDS (Circular cells)	6573	5×10^{6}	1.55×10^{8}

Comparison damping scheme alternative

Structure	CLIC_G_WDS	CLIC_G_CDS	8 x DDS* (Circular cells)
Average accelerating gradient: <E_a> [MV/m]	100	100	100
rf phase advance: $\Delta\varphi$[º]	120	120	120
Average iris radius/wavelength: <*a*>/λ	0.11	0.11	0.126
Input/Output iris radii: $a_{1,2}$ [mm]	3.15, 2.35	3.15, 2.35	4.0, 2.3
Input/Output iris thickness: $d_{1,2}$ [mm]	1.67, 1.00	1.67, 1.00	4.0, 0.7
Group velocity: $v_g^{(1,2)}$/c [%]	1.66, 0.83	1.38, 0.73	2.06, 1.07
Bunch separation: N_s [rf cycles]	6	6	8
Bunch population x number of bunches: *N x Nb*	3.72×10^9 x 312	3.72×10^9 x 312	4.2×10^9 x 312
Input power: P_{in} [MW]	63.8	67.8	73
Max. surface field: E_{surf}^{max} [MV/m]	245	246	320
Max. temperature rise: ΔT^{max} [K]	53	23	72
Efficiency: η [%]	27.7	24.5	23
F_c	1.06	80	6573
F_{rms}	6	15	5 x 10^6
F_w	26	1300	1.55 x 10^8

Summary and Outlook

❖ Several new structure prototypes are under consideration which have a potential of improving CLIC_G performance or/and cost

❖ 500 GeV structure prototype RF design is under way

❖ Both new high-gradient test results for CLIC_G and possible reconsideration of CLIC parameters can significantly change motivations and the boundary conditions for the CLIC accelerating structure design.

❖ Alternative damping structures show promising results but more work still to be done to arrive to a complete solution satisfying CLIC requirements