Progress on the CLIC DDS 380 GeV Staged Design

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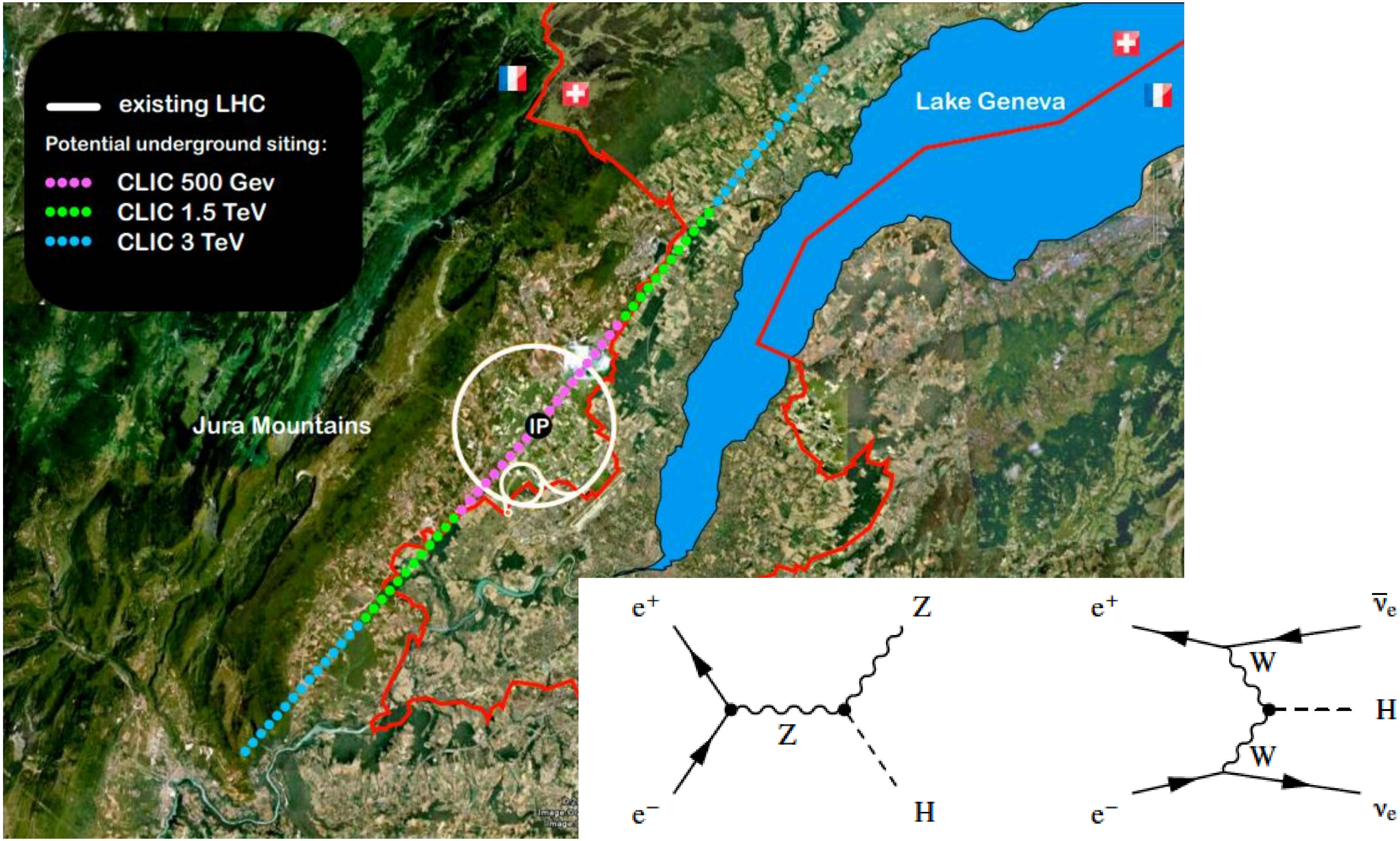
Compact LInear Collider (CLIC) staged designs, (e- e+)



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Accelerating structure for 380 GeV staged design

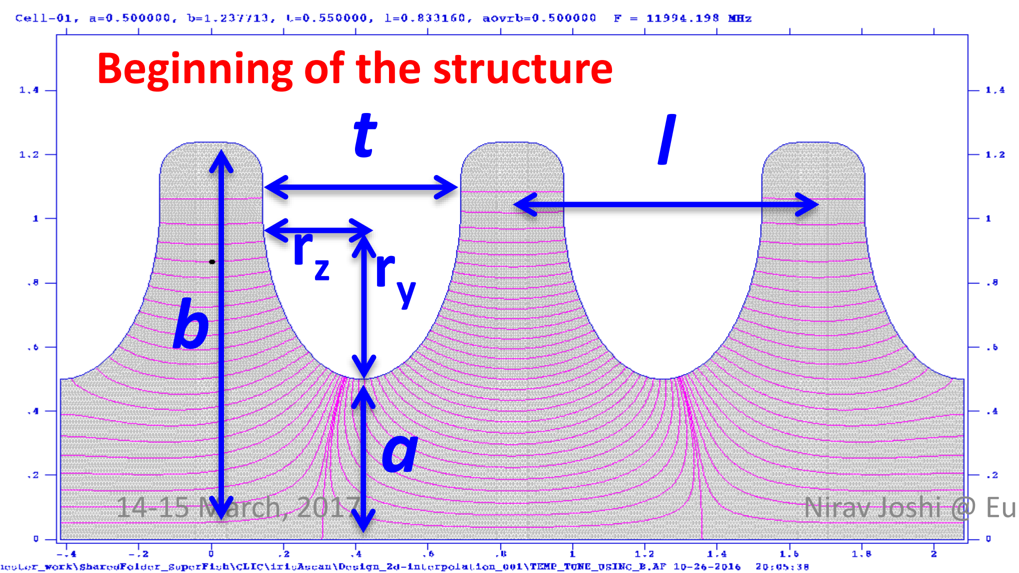
- 380 GeV stage will also use "Two Beam Acceleration" (TBA), in which power is extracted from a lower energy, high current "Drive beams", and is used to accelerate the relatively lower current "Main beams".
- Higher bunch charge increases beam loading, which due to higher surface field reduces the gradient to 72 MV/m from 100 for the 3 TeV design.
- The reduction in gradient is compensated by increasing the number of accelerating cells to 33.
- The change in parameters also result in tighter wakefield limitations of 3.7 V/pC/mm/m.

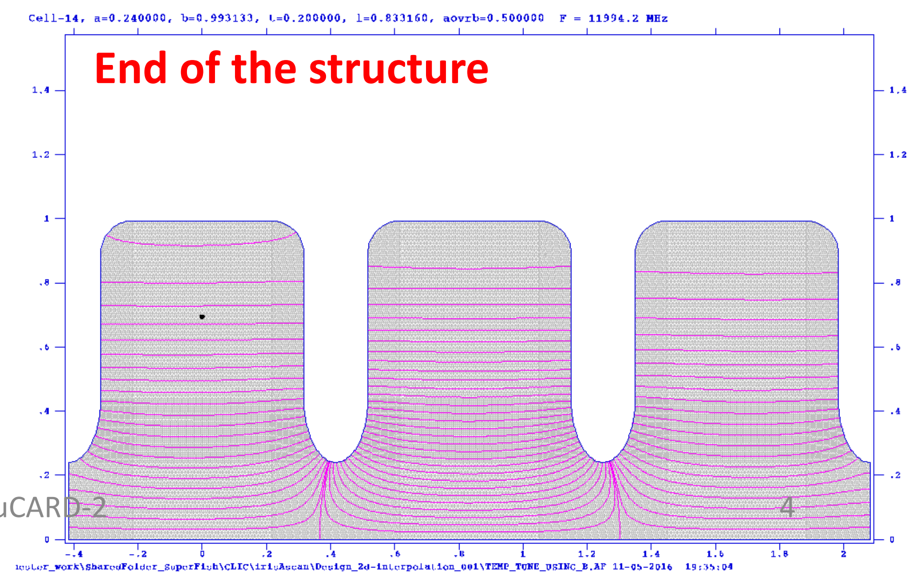
Parameters	3 TeV	380 GeV
Length of main linac (km)	48	11
Frequency (GHz)	11.994	11.994
Synchronous phase (deg)	120	120
# of cells	26	33
E_{acc} [MV/m]	100	72
# particles/bunch [10^9]	3.72	5.2
Bunch separation [ns]	0.5	0.5
# bunches/train	312	352
Wakefield [V/pC/mm/m]	6.3	3.7

DDS Accelerating Structure Design

- Pulsed operation: Normal conducting, travelling wave structure.
- Power from input coupler travels through the cells. Part of the power is lost as heating of cell walls, some part accelerate the beam, while the remaining couples in to next cell.
- Constant gradient structure: Iris radius (*a*) of the cells are reduced along the structure to increase beam coupling to compensate for reduction in power.
- Detuned structure (Maximize the dipole bandwidth): Frequency of dipole mode detuned by changing (*a*) and iris thickness (*t*) while monopole frequency is kept constant at accelerating frequency by tuning (*b*).
- Iris aspect ratio give another parameter to optimise the cells.

Monopole simulations with Superfish





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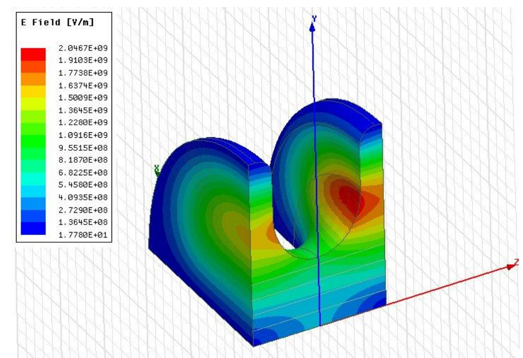
DDS Accelerating Structure Design

- Monopole simulations from Superfish are cross-verified with 3D EM simulations with HFSS, and are in very good agreement.
- Dipole modes are calculated using quarter cell geometry and symmetry boundaries in HFSS.
- Principle RF parameters of interest calculated from Simulations.

$$Q = \frac{\omega U}{P}$$

$$\frac{R}{Q}(r) = \frac{|V|^2}{\omega U r^{2m}} = \frac{4k_{\|}(r)}{\omega r^{2m}} \qquad V_{\|}(r) = \int_0^L E_z(r,z)exp^{-i\omega z/c}dz$$

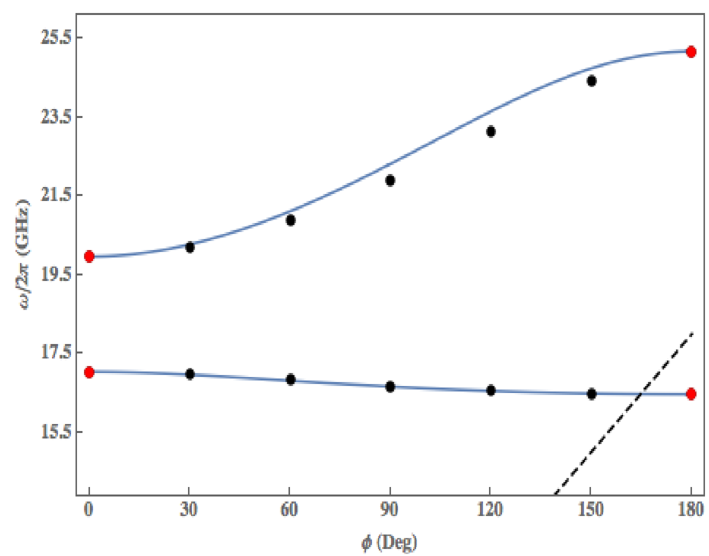


Loss factor $k_{\|}(r) = \frac{|V|^2}{4U}$ $\qquad v_g = \frac{d\omega}{dk}$

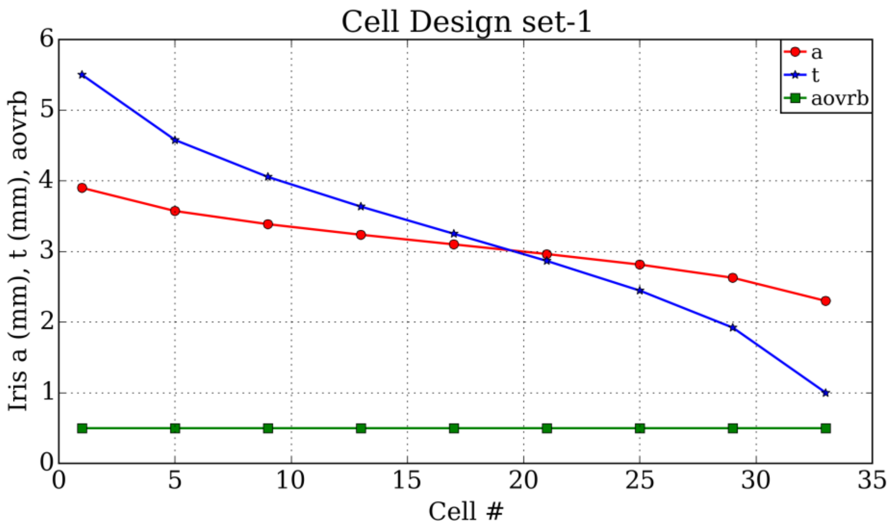
Kick factor $K_{\perp} = \frac{k_{\|}c}{r^{2m}\omega L}$

Circuit model and dispersion relation:

$$\left(\frac{1+\eta\cos\phi}{\omega_m^2} - \frac{1}{\omega^2}\right)\left(\frac{1-\hat{\eta}\cos\phi}{\hat{\omega}_m^2} - \frac{1}{\omega^2}\right) - \frac{\eta\hat{\eta}}{\omega_m^2\hat{\omega}_m^2}\sin^2\phi = 0.$$

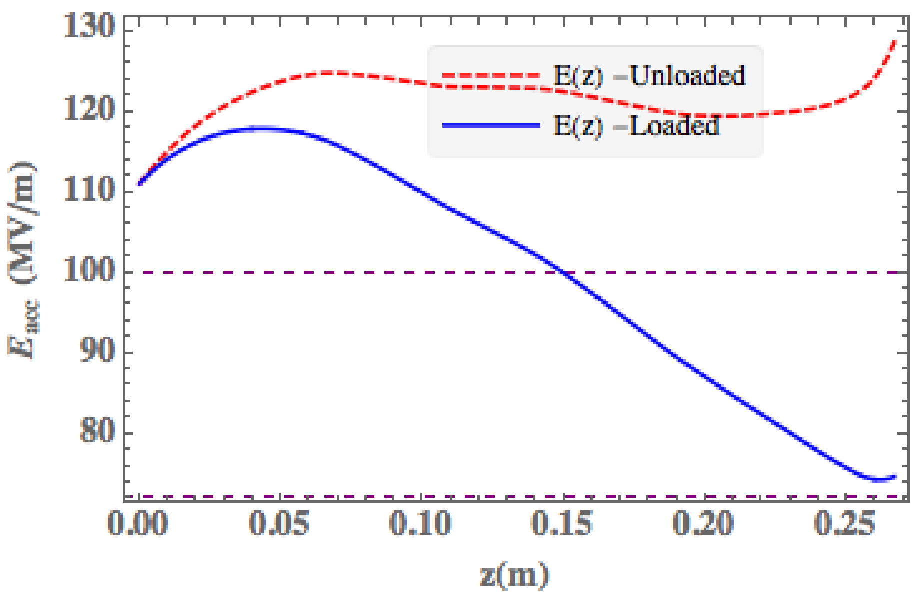


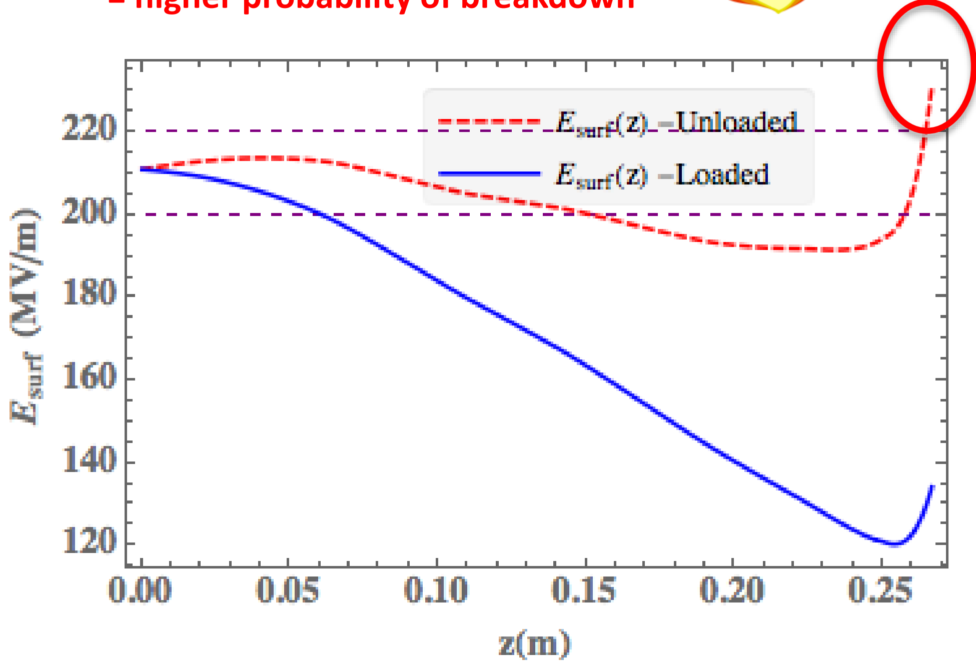
Structure design: Design iterations



- Iris radius and thickness changed to achieve enough dipole detune bandwidth, but the higher surface electric field will cause break down.
- Each parameter iteration requires EM simulation with superfish and HFSS which is time consuming.

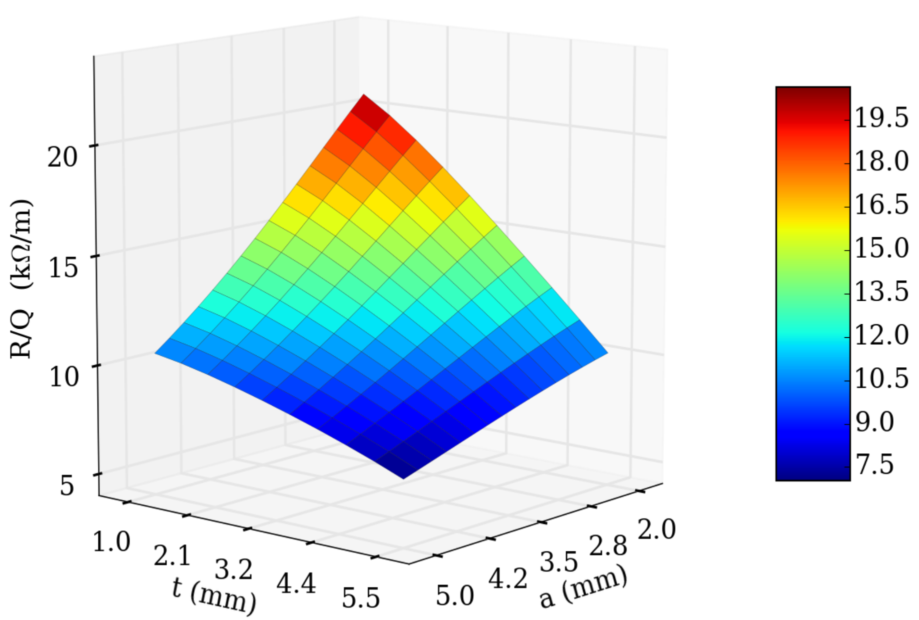
Surface field higher than 220 MV/m = higher probability of breakdown

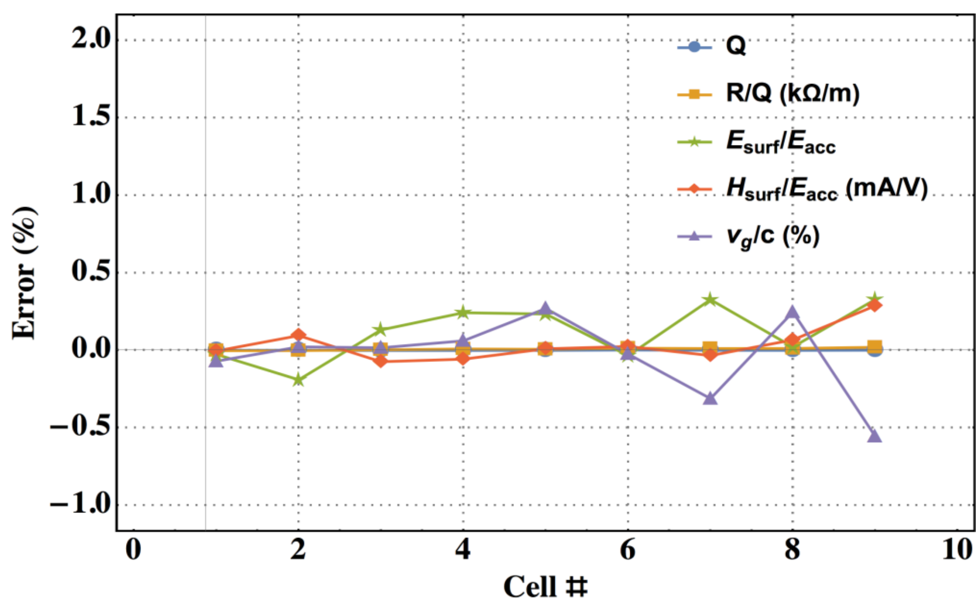




Structure design: 2D interpolation

- Iris radius 'a' scanned from 5.0 to 2.0mm in step of 0.2 mm
- Iris thickness 't' scanned from 6.0 to 1.0mm in step of 0.5mm in Superfish
- In total, 176 cells optimised using Superfish and tuning script in python.
- Dipole parameters interpolated using
- Interpolate Q, R/Q, E_{surf}, H_{surf}, V_g and dipole synchronous frequency and kicks.





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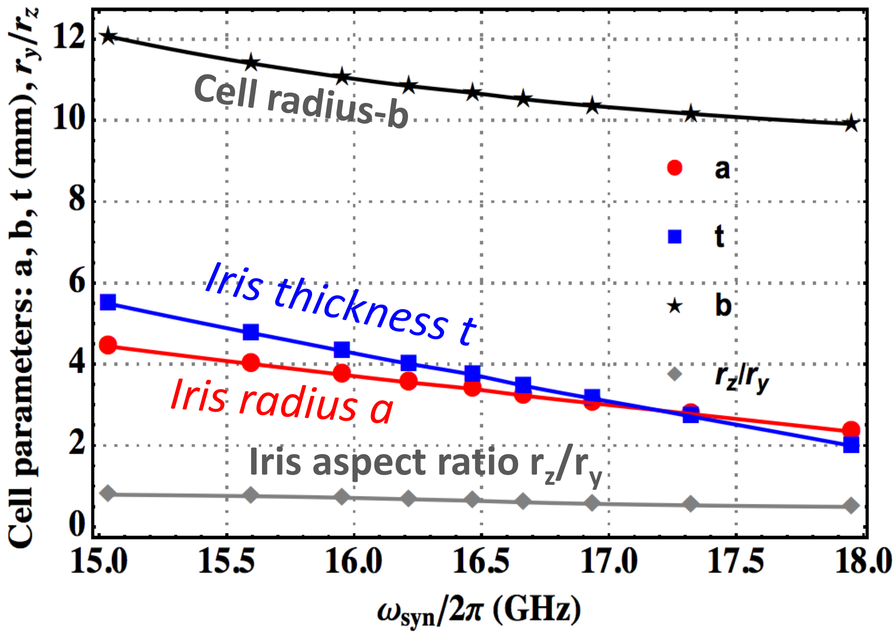
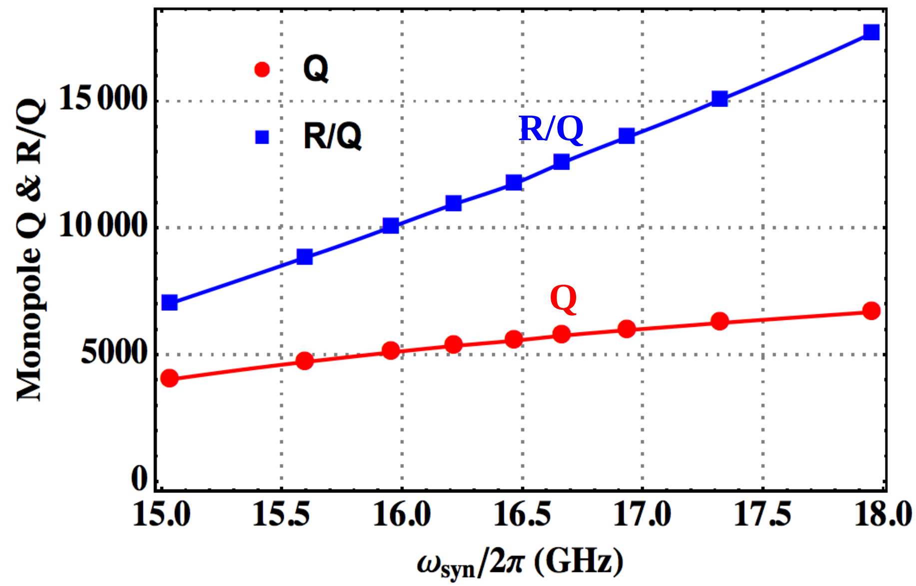
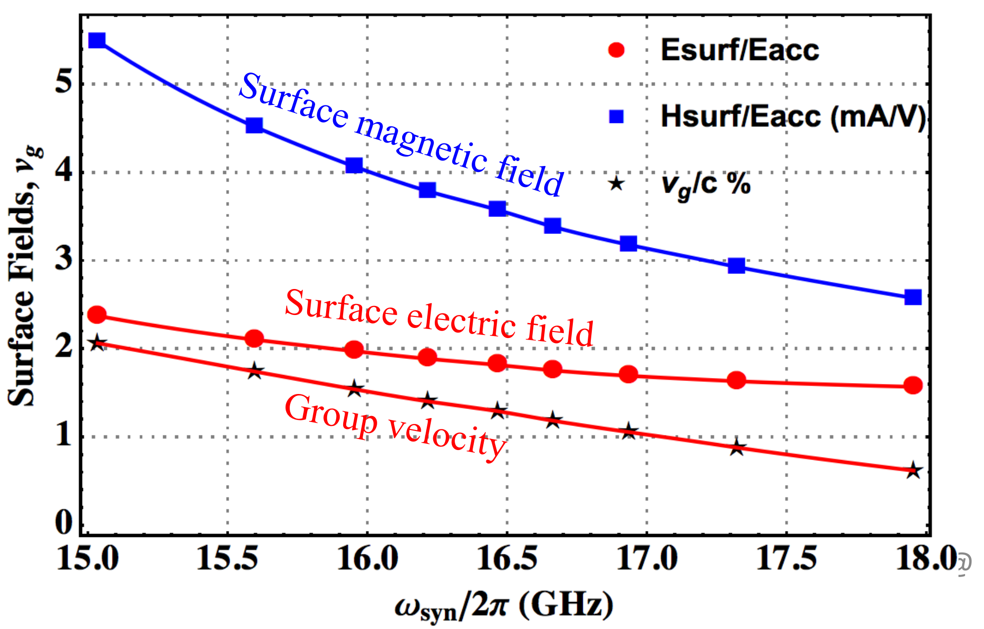
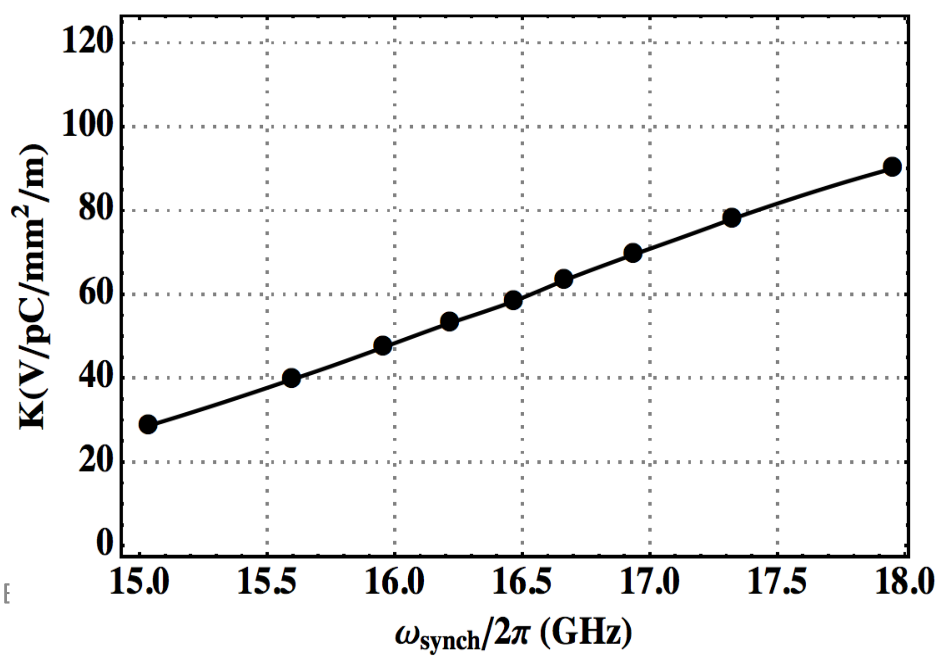
72 MV/m structure for 380 GeV CLIC design

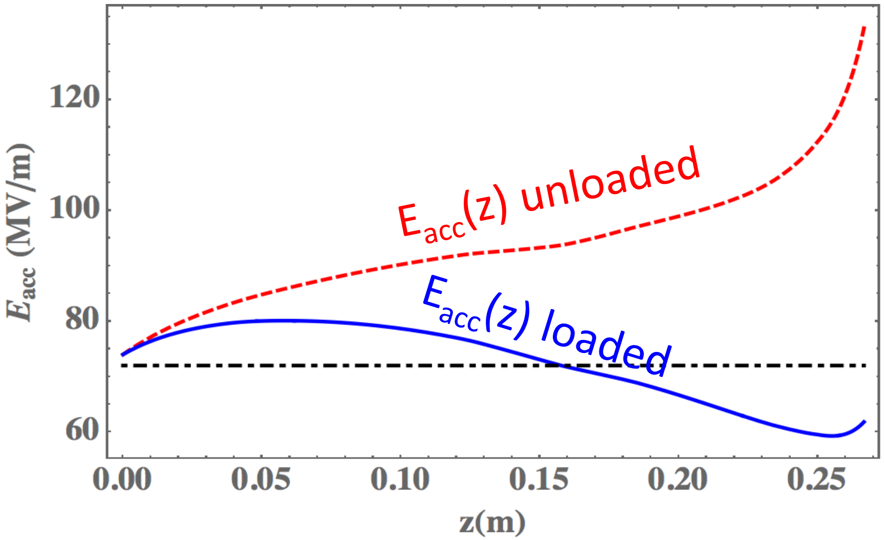








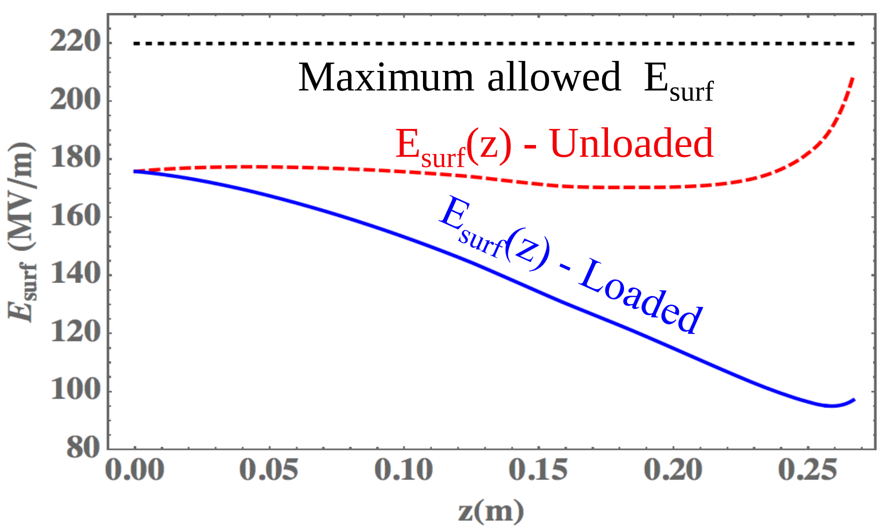
72 MV/m structure for 380 GeV CLIC design

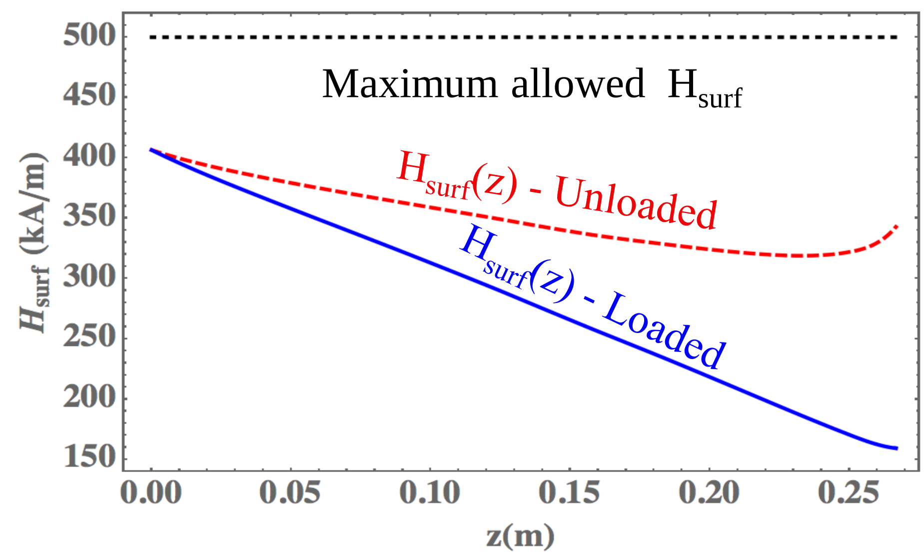


$$\frac{dP_N}{dz} = -\frac{w_r}{Q_N}\frac{P_N}{v_{gN}} - \sqrt{\frac{w_r}{v_{gN}}\left(\frac{R}{Q}\right)_N}\, I\sqrt{P_N}$$

$$E_N = \sqrt{\frac{P_N w_r \left(\frac{R}{Q}\right)_N}{v_{gN}}}$$

- The structure will provide average acceleration gradient of 72 MV/m, for 64 MW.
- Surface electric field well below 220 MV/m.
- The magnetic field is well below 500 kA/m

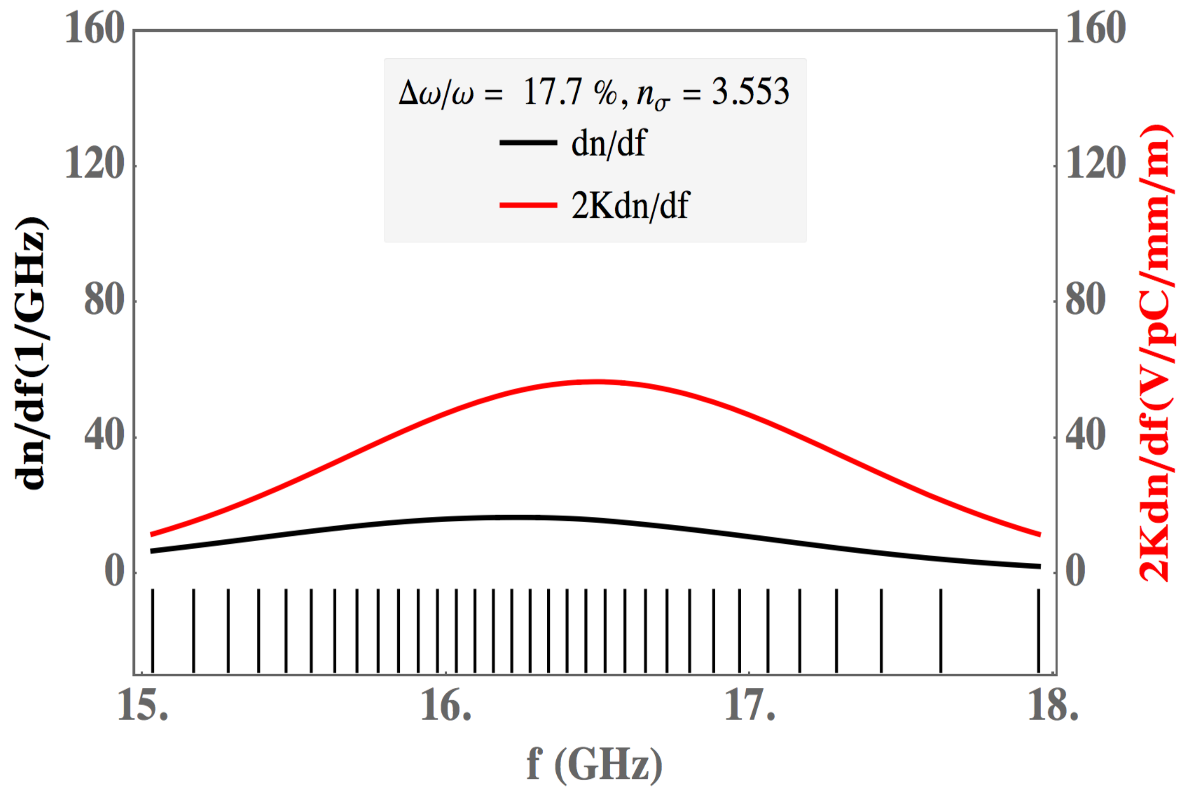




Dipole detuning and wake calculation

- The dipole frequencies are detuned such that the kick factor weighted density distribution function follows a well behaved decaying function, e.g. Gaussian or *Sech*

$$2K\frac{dn}{df} = Ae^{-\frac{(f-f_c)^2}{2s^2}}$$



- The ideal Gaussian function will have infinite bandwidth, but the real structure has limited bandwidth *Δf = 2.92GHz* , which will result in ringing of the wakefield.

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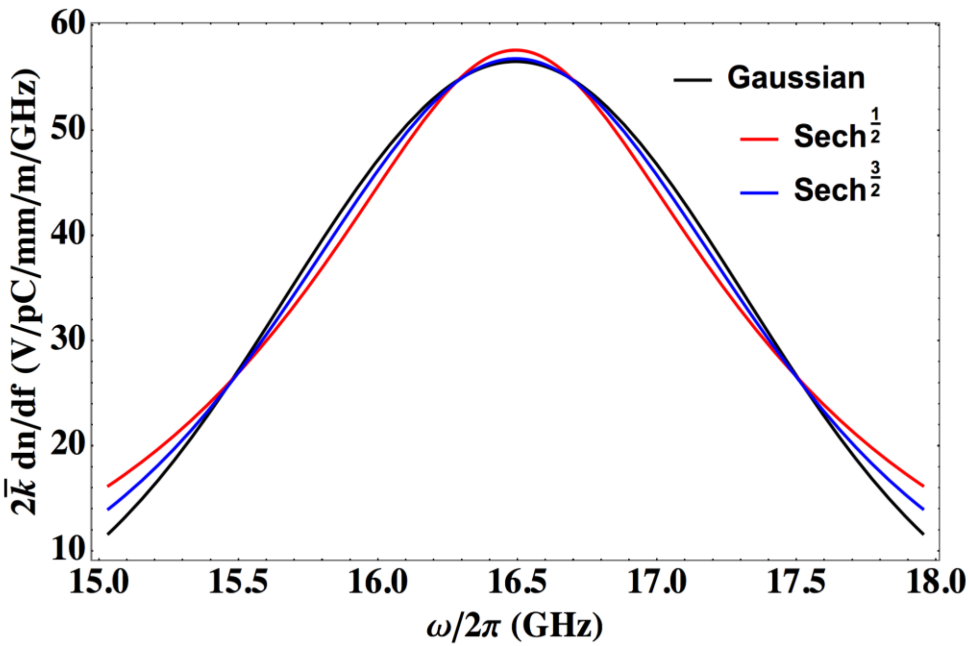
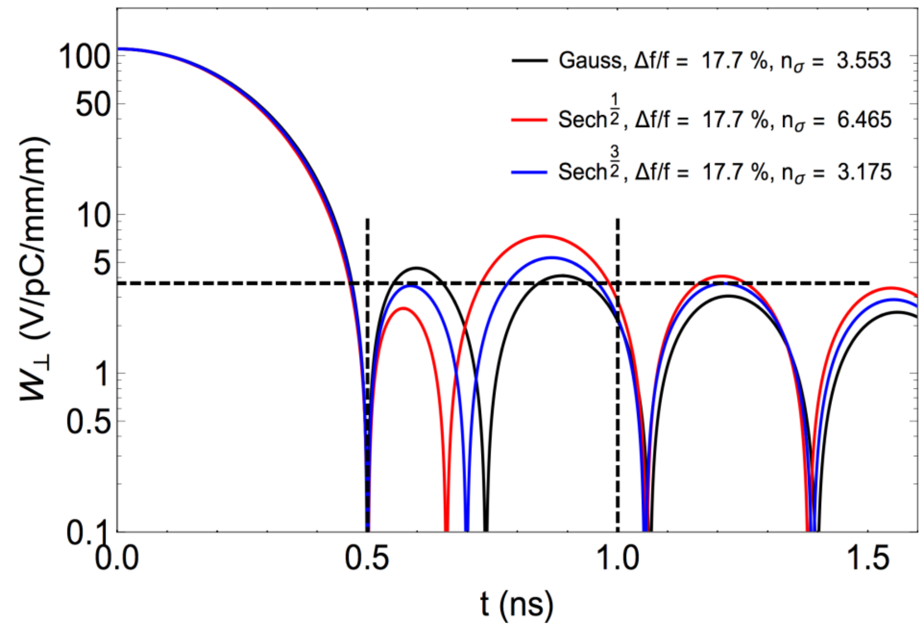
Dipole detuning and wake calculation

- The wakefield is inverse Fourier transform of the
- The width of the function can be optimised to put the first following bunch on amplitude zero of the wakefield envelop.

$$W_{\perp} = \left(2\bar{K}\right) e^{-2\left(\pi t \sigma\right)^{2}} \frac{\left[Erf\left(\frac{\Delta f - 4 i \pi t \sigma^{2}}{2\sqrt{2}\sigma}\right) + Erf\left(\frac{\Delta f + 4 i \pi t \sigma^{2}}{2\sqrt{2}\sigma}\right)\right]}{2 Erf\left(\frac{\Delta f}{2\sqrt{2}\sigma}\right)}$$

- The wakefields for different frequency distribution functions are compared.





Effect of discrete frequency and inter leaving

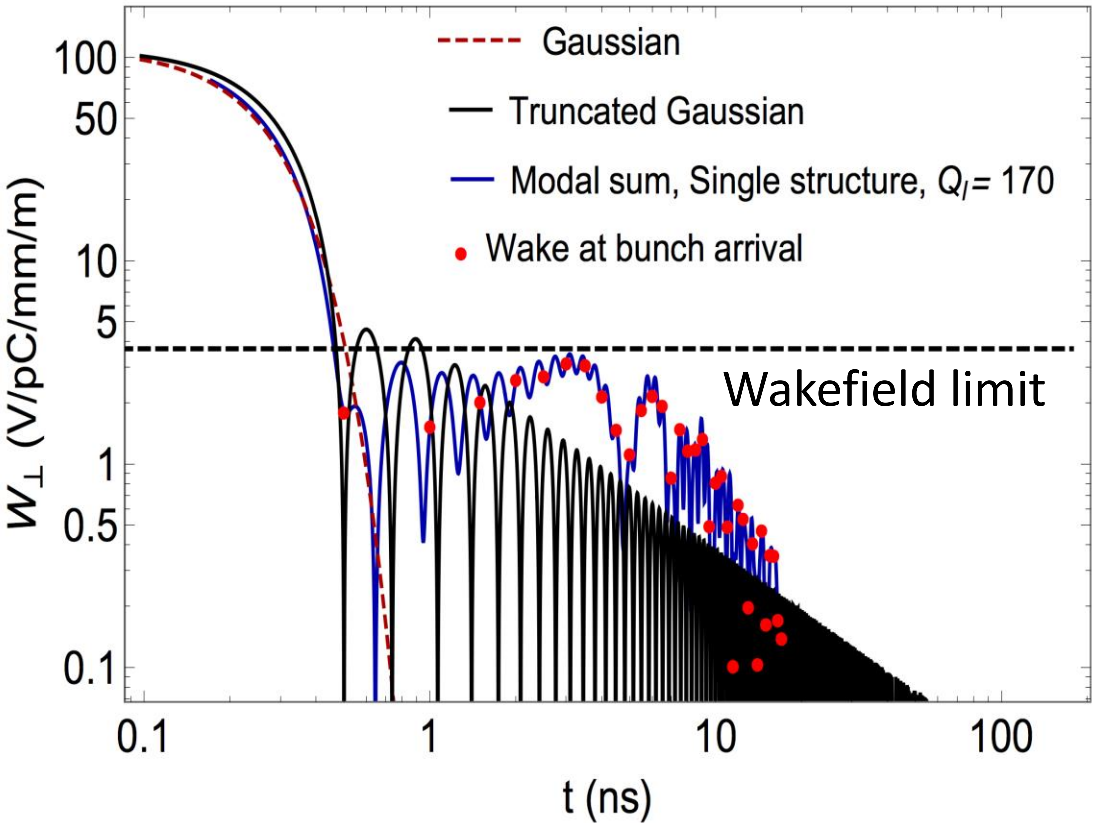
- Due to limited number of cells the frequency distribution function is not continuous. Due to this discontinuity the wakefield recoheres after some time.

- The total resultant wakefield can be calculated as sum of individual modal fields.

$$W_{\wedge} = 2\left|\sum_{n=1}^{N_{cell}} K_n \exp\left(i w_n t\left[1+\frac{i}{2Q_n}\right]\right)\right|$$

- Single structure required loaded Q of 170, to keep the wakefield below the beam dynamics limit of 3.7 V/pC/mm/m.

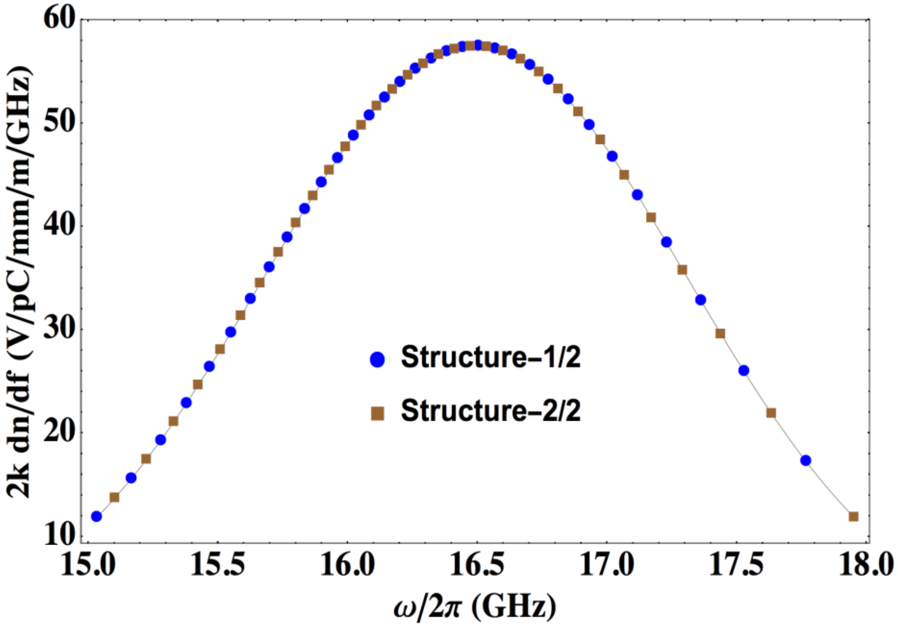
- The agreement between the continuous frequency distribution wakefield and discrete function improves.

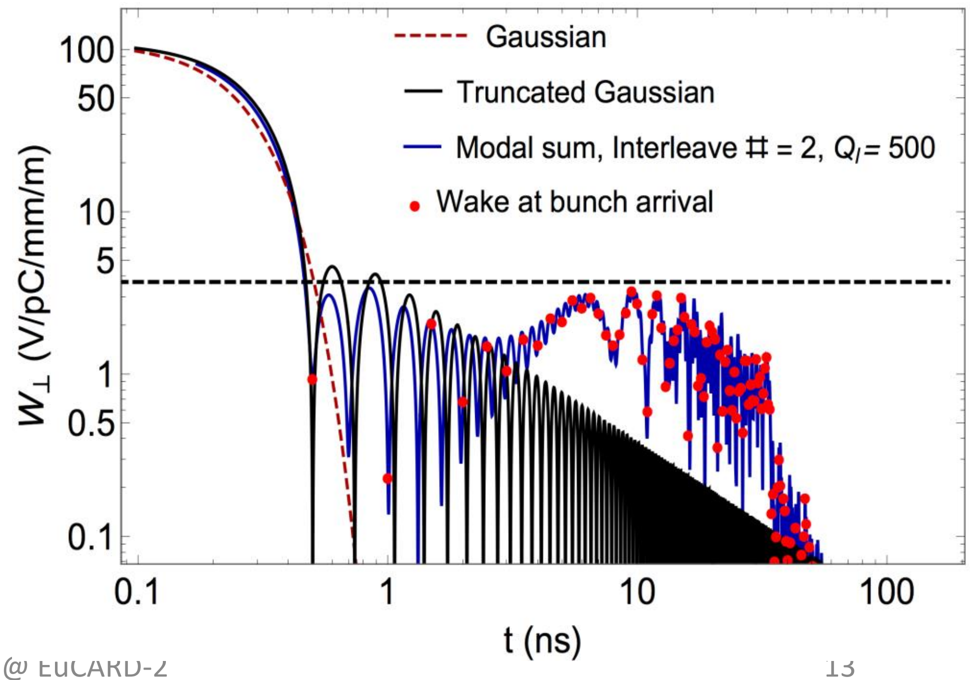


Effect of discrete frequency and inter leaving

- The effective number of cells can be increased by making the consecutive structures with slightly different frequencies.
- The recoherence of wakefield is delayed with higher number of cells, which effectively increase the required Q_l to 500.
- The agreement between the discrete and continuous structure wakefield improved.

Two fold interleaving





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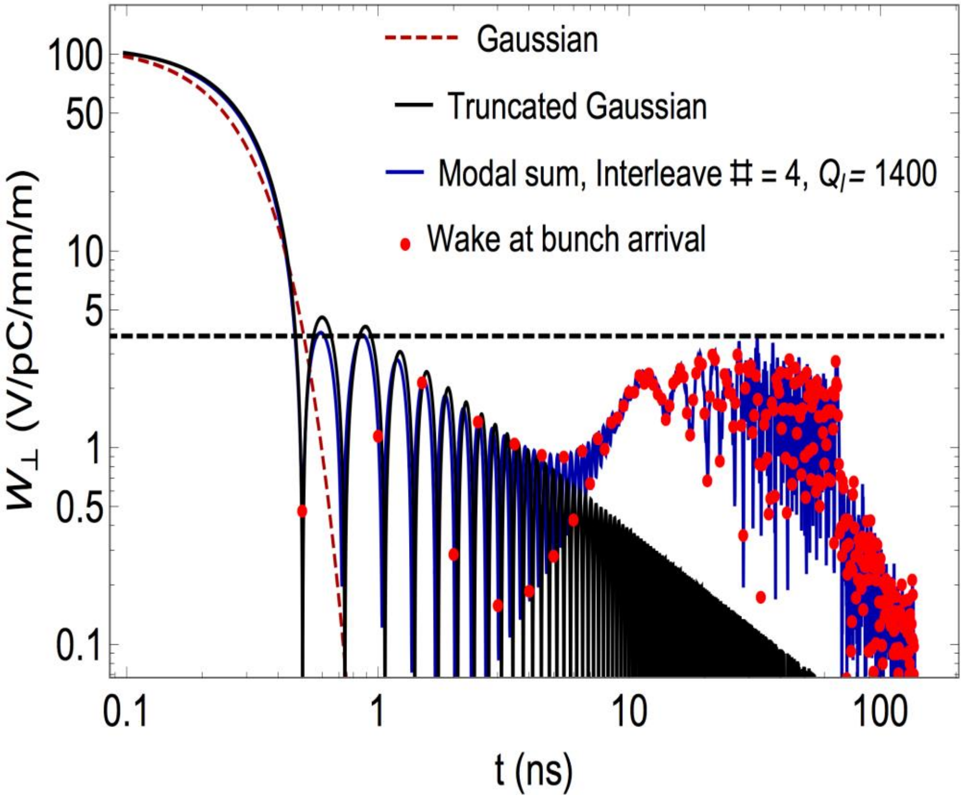
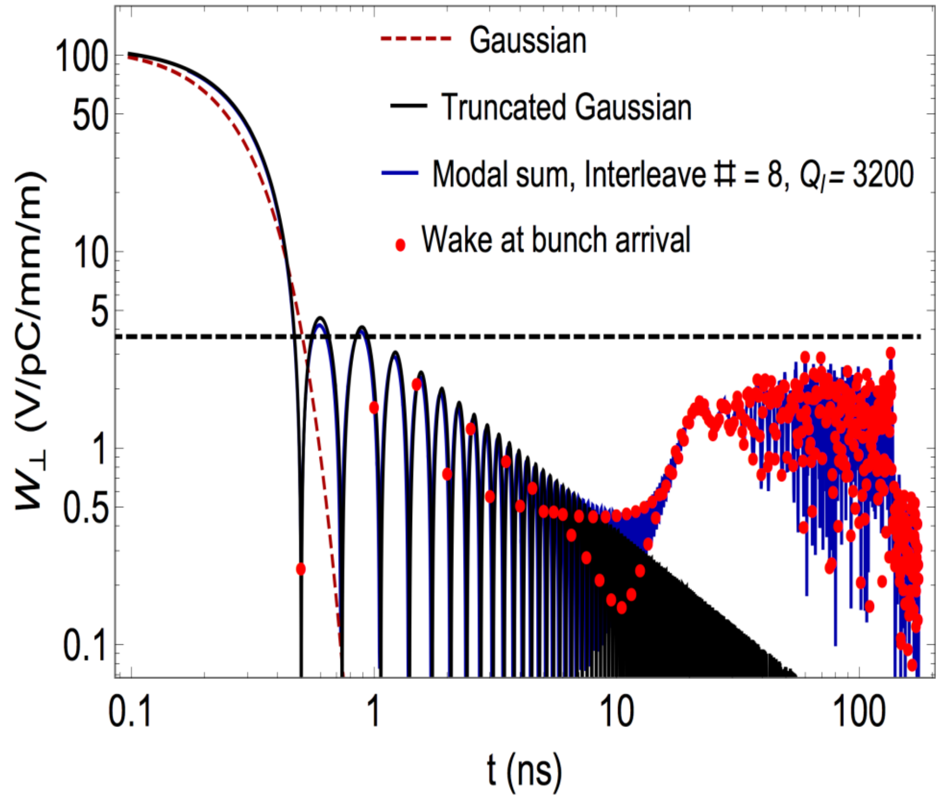
Effect of discrete frequency and inter leaving

- The limit on Q can be further relaxed to 1400 and 3200 with higher order of interleaving, which also improves agreement between the discrete and continuous structure wakefield.

Four fold interleaving



Eight fold interleaving !!!?



Conclusions

- Extensive design study has been carried to develop a normal conducting travelling wave damped detuned accelerating structure for the CLIC 380 GeV staged design.
- For expedite the design iterations, a 2D parameter interpolation base was developed by simulating 176 cells using Superfish and automatic tuning algorithm developed in python.
- A design with uncoupled cells has been developed which will provide the required accelerating gradient of 72 MV/m for input power of 64 MW.
- The surface electric and magnetic fields are below 210 MV/m and 400 kA/m.
- Wakefield from different continuous frequency distribution profiles have been compared analytically, and the wakefield at bunch arrival time is below the wakefield limit.
- The recoherence of wakefield due to discrete cell frequency distribution has been studied using modal sum method and required loaded Q values are identified for different interleaved structures.

- Cells structures coupled through manifold are under simulation to achieve the required loaded Q values.

Thank you