Optimum frequency and gradient for CLIC main linac

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Outline

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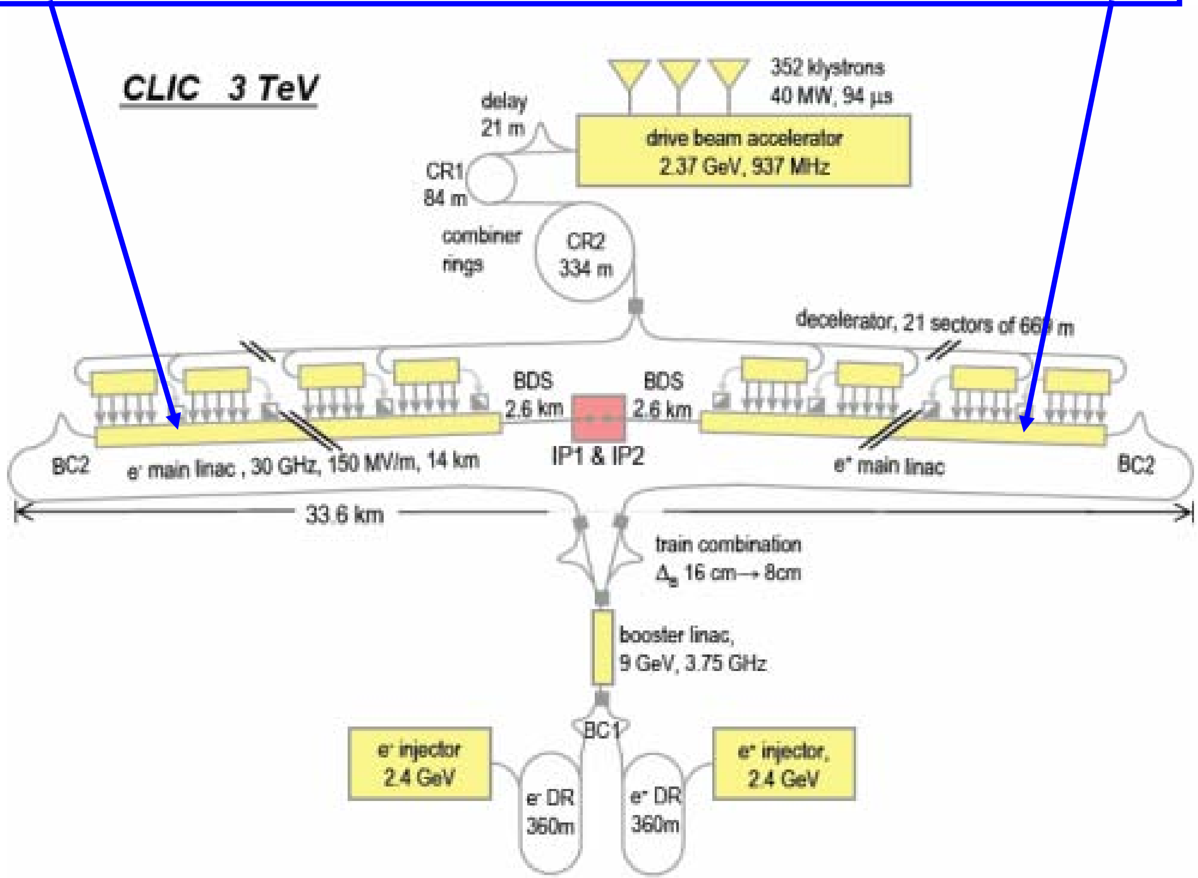
- Optimization procedure
- Optimization results
- Conclusions

Compact LInear Collider (CLIC) main linac



Higher gradient->

- Shorter linac
- Lower cost
- Better for beam dynamics

=> 150 MV/m

Higher frequency->

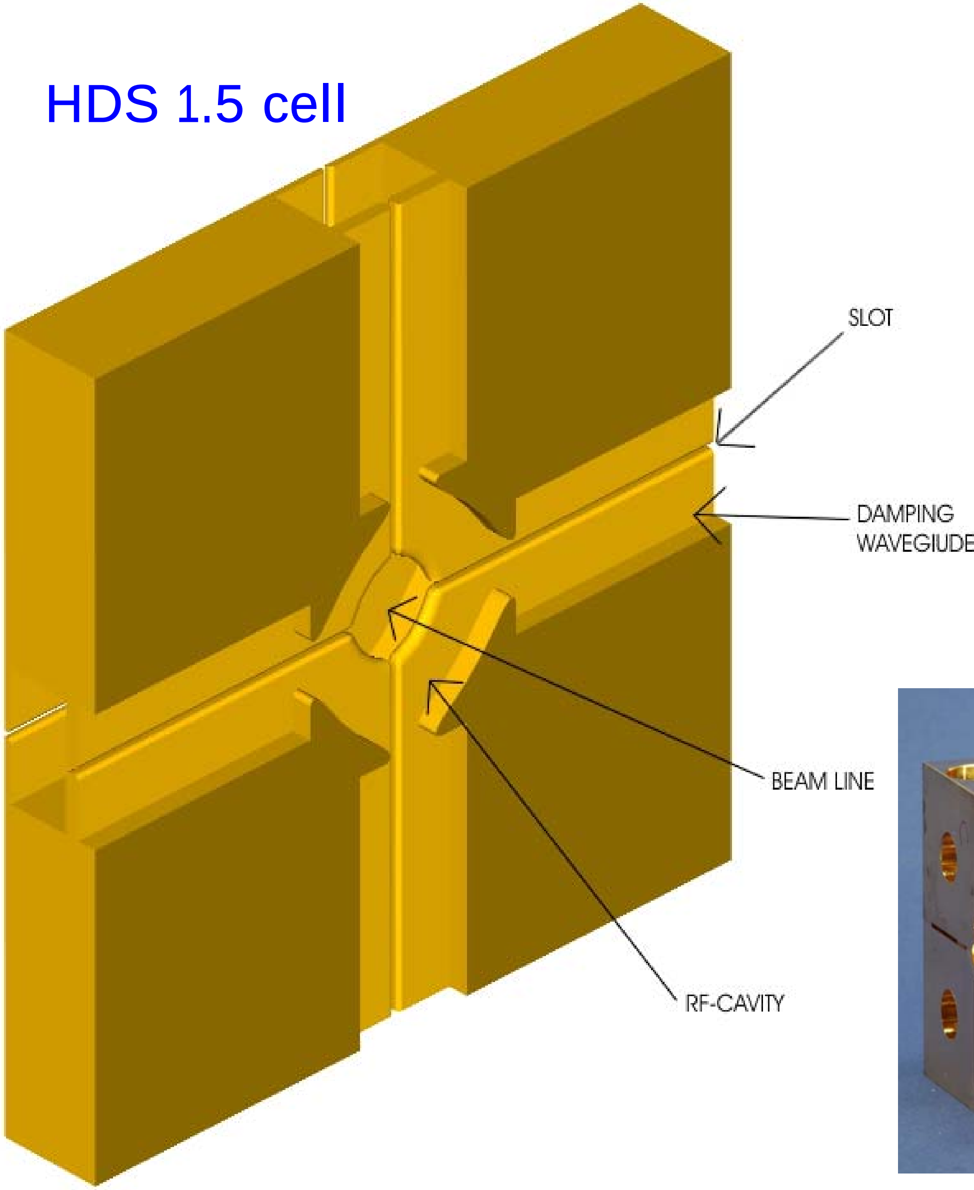
- Higher gradient (old)
- Lower peak power
- Higher efficiency
- More compact -> Cost

=> 30 GHz

The aim of the study is to find the best parameters for CLIC main linac performance in terms of luminosity per input power. This is not necessary the overall cost optimum (still to be done).

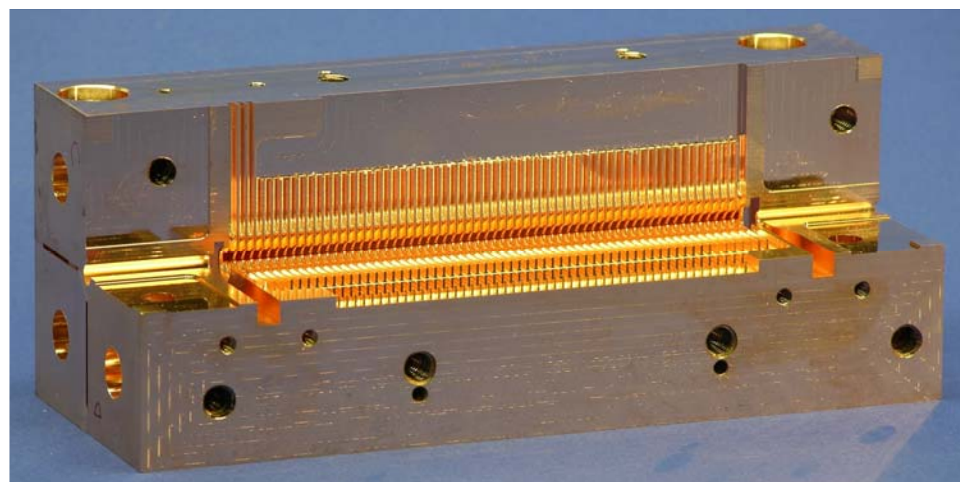
Introduction

HDS 1.5 cell

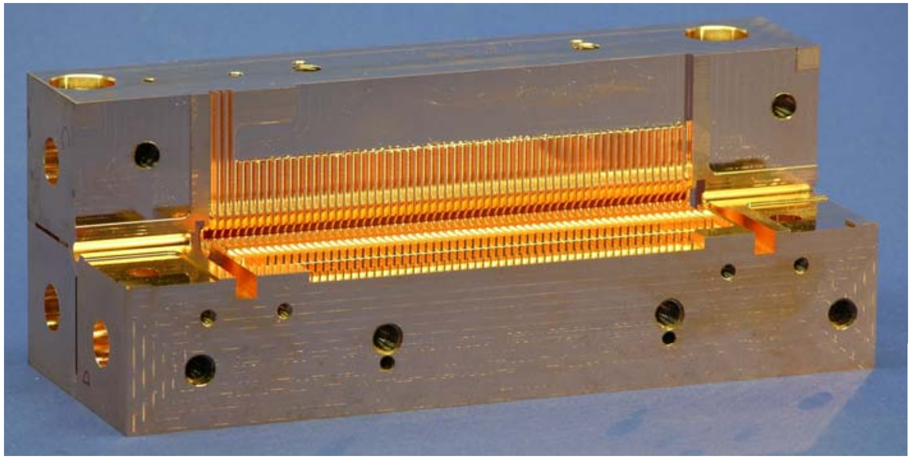


Hybrid Damped Structure (HDS)

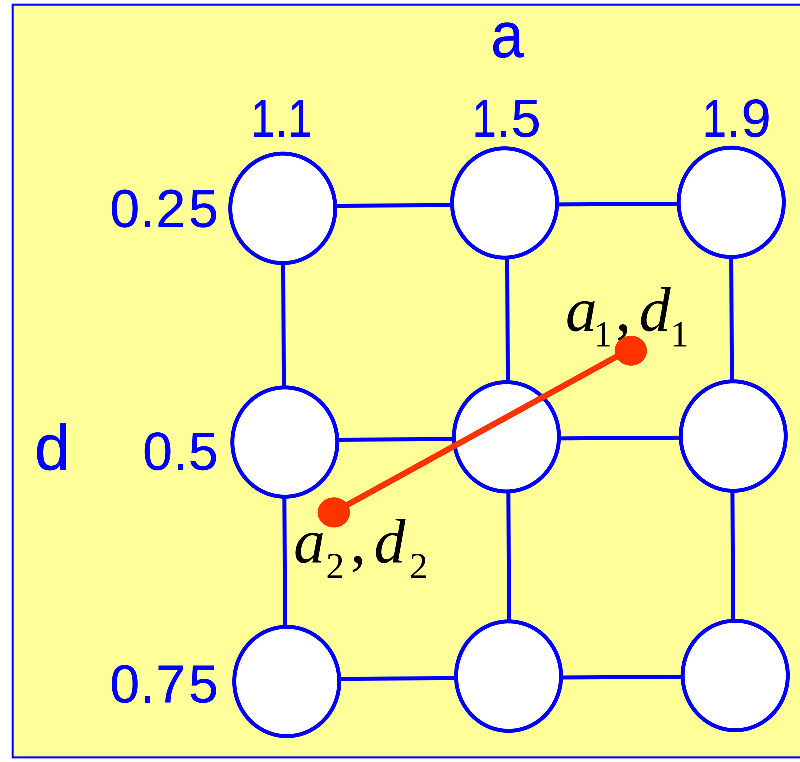
- Excellent wakefield damping
- E_{surf}/E_{acc} and H_{surf}/E_{acc} are only by 7 and 9 % higher than in undamped cell, respectively
- 4 metal pieces per structure
- No brazing is necessary
- Good pumping capabilities



Optimization procedure



Single cell parameter interpolation

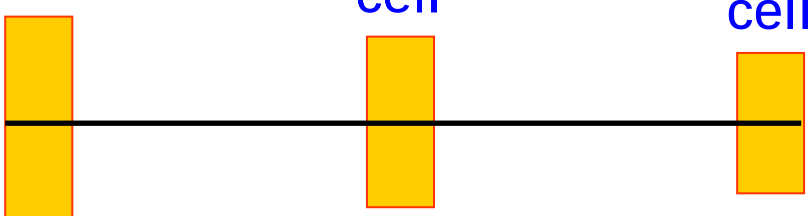


Structure parameters are calculated using parameters of the three cells:

first cell

middle cell

last cell



Optimization parameter space

All structure parameters are variable:

$\langle E_{acc} \rangle = 90 – 150$ MV/m,

$f = 12 – 30$ GHz,

$\Delta\varphi = 50^o - 130^o$,

$\langle a \rangle/\lambda = 0.09 - 0.21$,

$\Delta a/\langle a \rangle = 0.01 – 0.6$,

$d_1/\lambda = 0.025 - 0.1$, $d_2 > d_1$

$N_{cells} = 15 – 300$.

N structures:

7

10

9

24

60

61

4

221.356.800

Optimization constraints

Beam dynamics constraints:

N depends on $\langle a \rangle/\lambda$, $\Delta a/\langle a \rangle$, f and $\langle E_{acc} \rangle$ because of short-range wake

N_s is determined by condition: $W_{t,2}$ = 10 V/pC/mm/m for N = 4×10^9

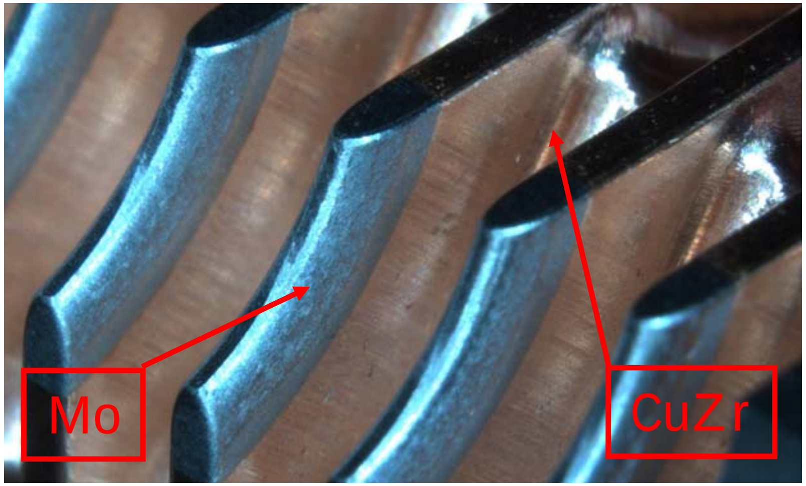
rf breakdown and pulsed surface heating (rf) constraints:

$E_{surf}^{max} < 380$ MV/m & $P_{in} t_p^{1/2}/C < 24$ MWns$^{1/2}$/mm & $\Delta T^{max} < 56$K

30 GHz, Mo | X-band, Cu <-> 30 GHz, Mo | CuZr

Posters: MOPLS128; MOPLS103

Bi-metallic HDS



N.B. Applying the same constraints to different structures implies that the structures are equally challenging

Optimization figure of merit

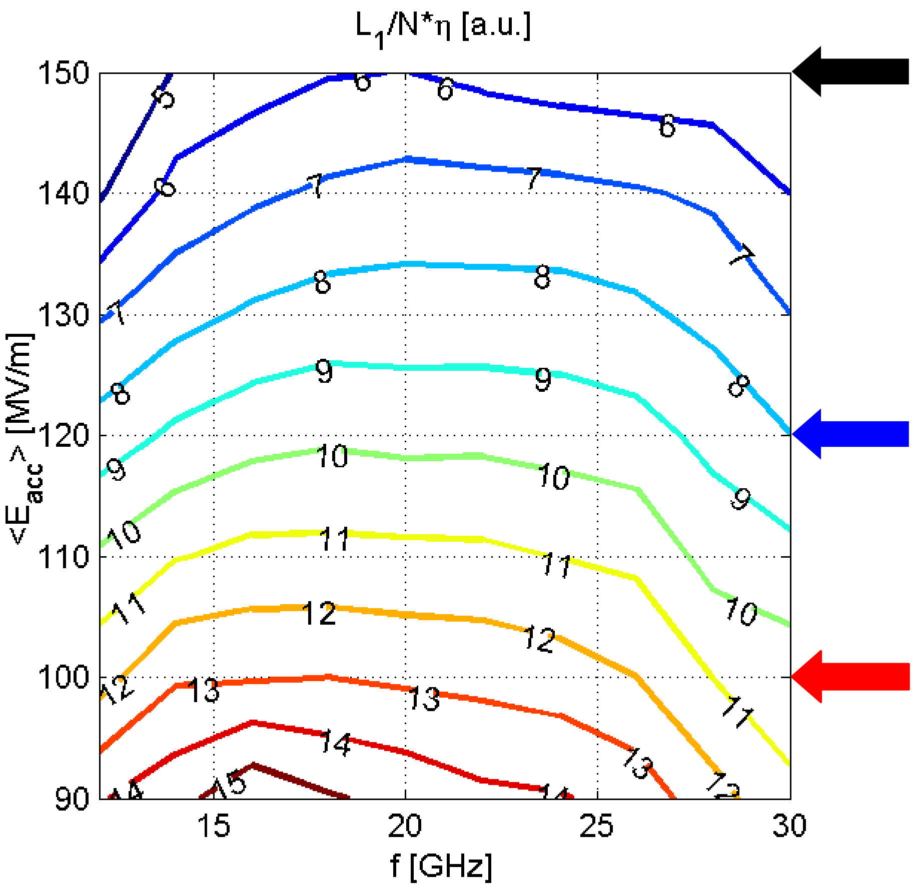
Luminosity per linac input power:

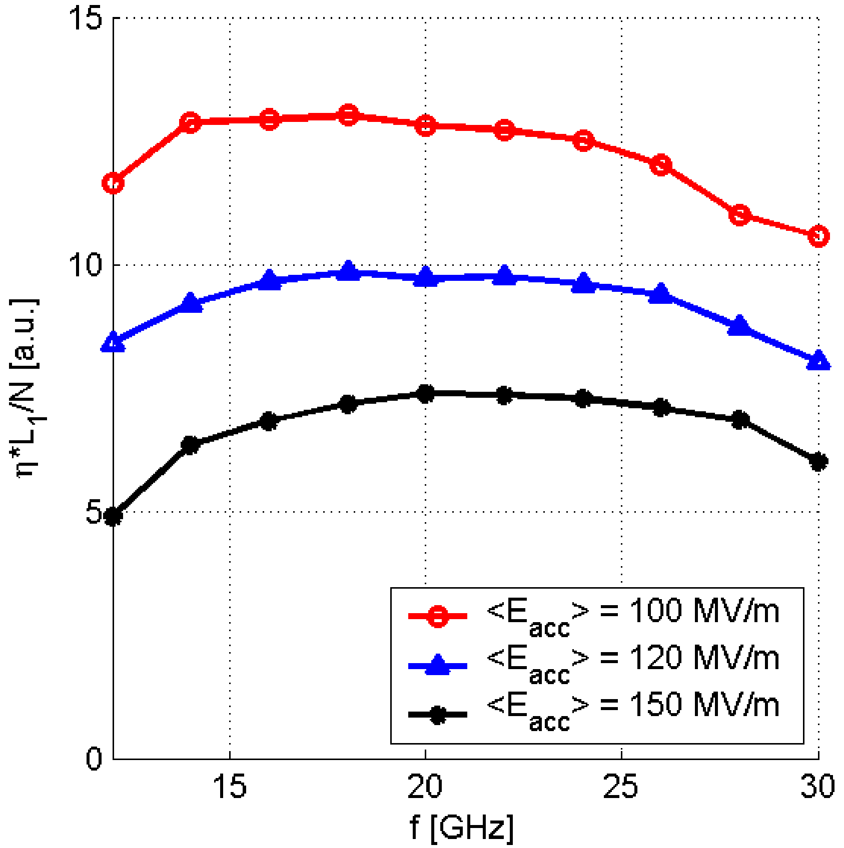
$$\frac{L}{P_l} = \frac{L_{b\times} N_b f_{rep}}{\frac{eE_c N N_b f_{rep}}{\eta}} = \frac{1}{eE_c} \bullet \frac{L_{b\times}}{N}\eta$$

Collision energy is constant

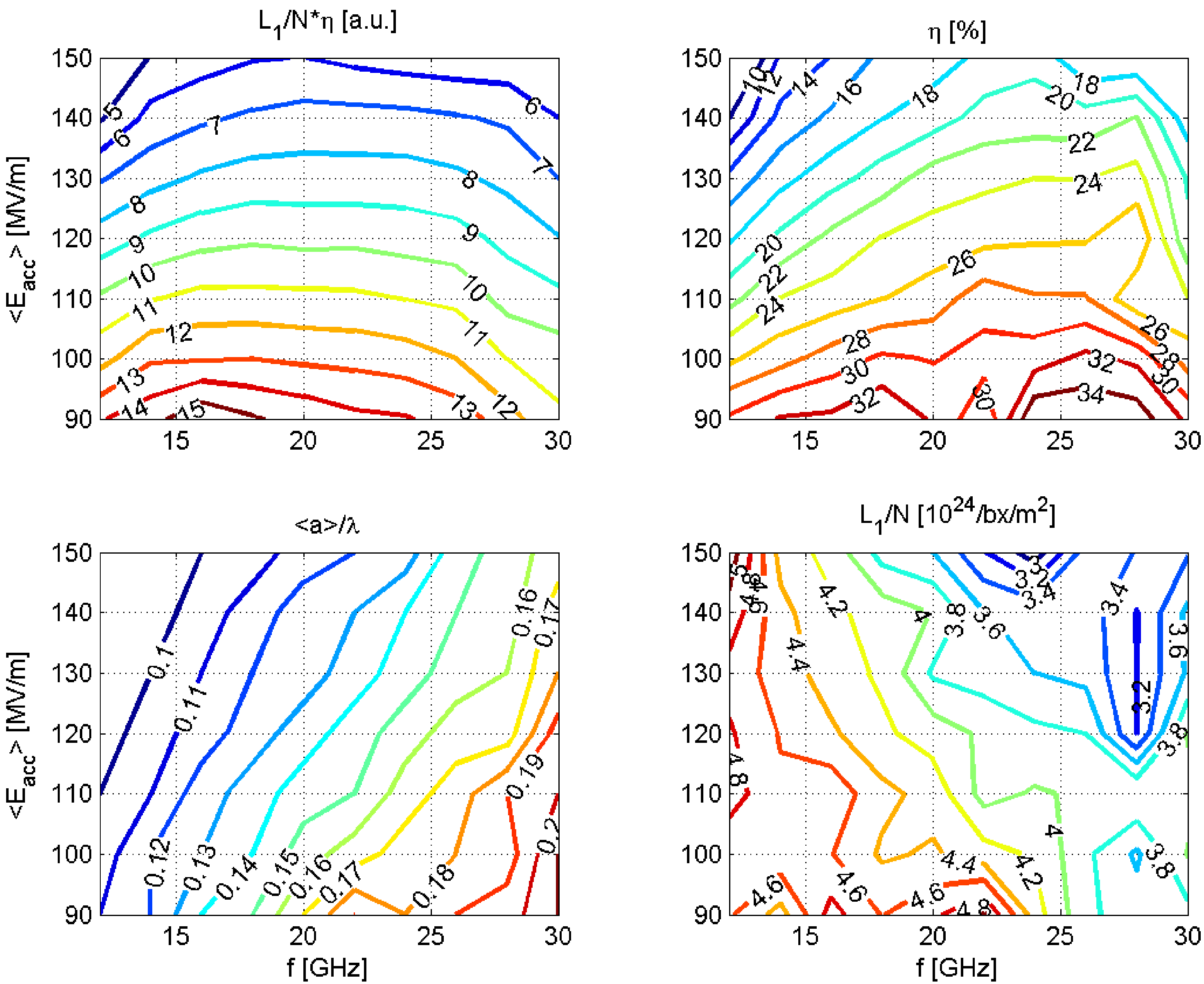
Figure of merit

Optimization results

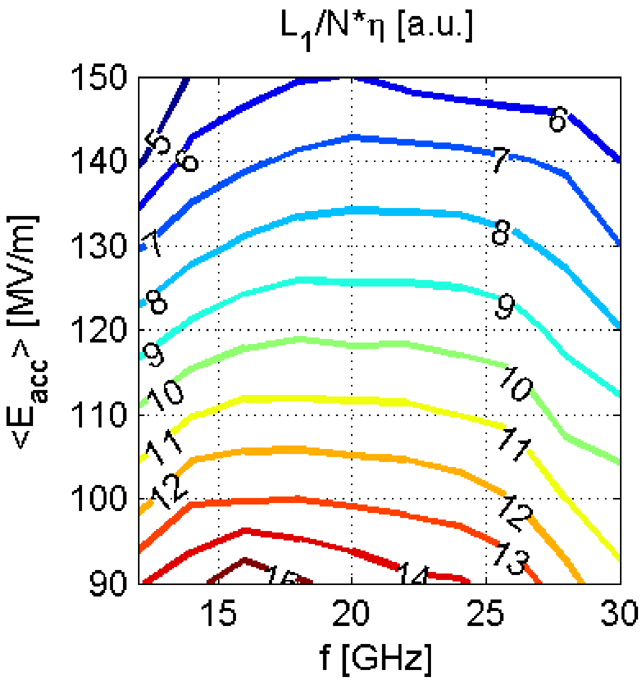




Optimization results



Optimization for different rf constraints

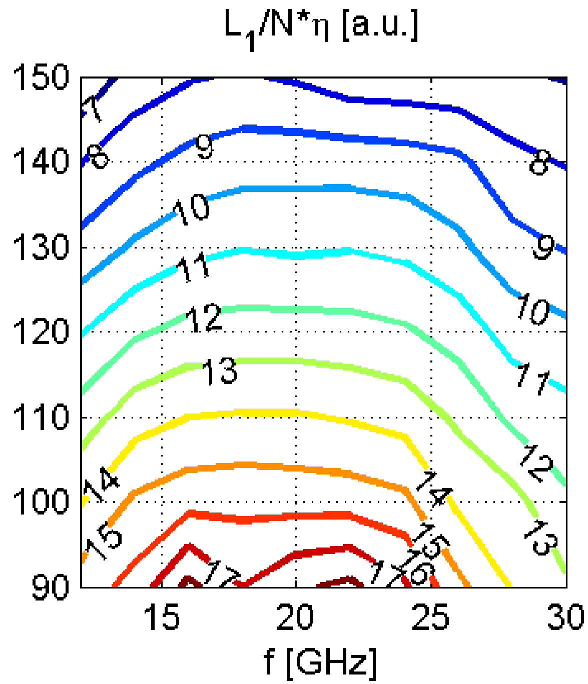


$\Delta T^{max} < 56$ K

$E_{surf}^{max} < 380$ MV/m

$P_{in}t_p^{1/2}/C < 24$ a.u.

Nominal set of rf constraints

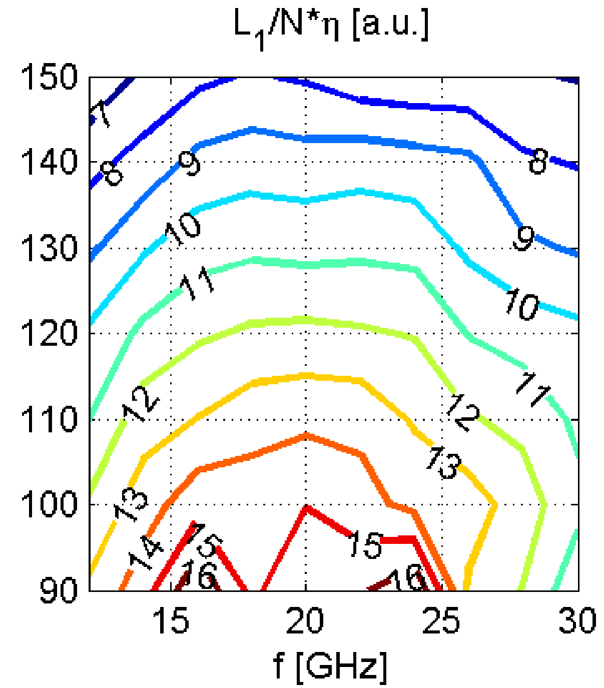


$\Delta T^{max} < 56$ K

$E_{surf}^{max} < 380$ MV/m

$P_{in}t_p^{1/2}/C < 30$ a.u.

Increased power limit



$\Delta T^{max} < 40$ K

$E_{surf}^{max} < 380$ MV/m

$P_{in}t_p^{1/2}/C < 30$ a.u.

Reduced pulsed surface heating limit

Main linac parameter list

For CLIC design luminosity: $L_1 = 3.3 \times 10^{34} cm^{-2} s^{-1}$

Accelerating gradient: $<E_{acc}>$ [MV/m]	**150**	**150**	**100**	**100**
Frequency: f [GHz]	**30**	**20**	**30**	**18**
Repetition frequency: f_{rep} [Hz]	**1182**	**538**	**559**	**243**
RF input power: P_l [MW/linac]	**151**	**132**	**75.1**	**60.9**
RF energy per pulse: P_l/f_{rep} [kJ/linac]	**127**	**245**	**135**	**250**
Main linac length: l_{linac} [km/linac]	**14**	**14**	**21**	**21**

The last two rows show two parameters which have no influence on the presented figure of merit but which will have big impact on the overall cost optimization.

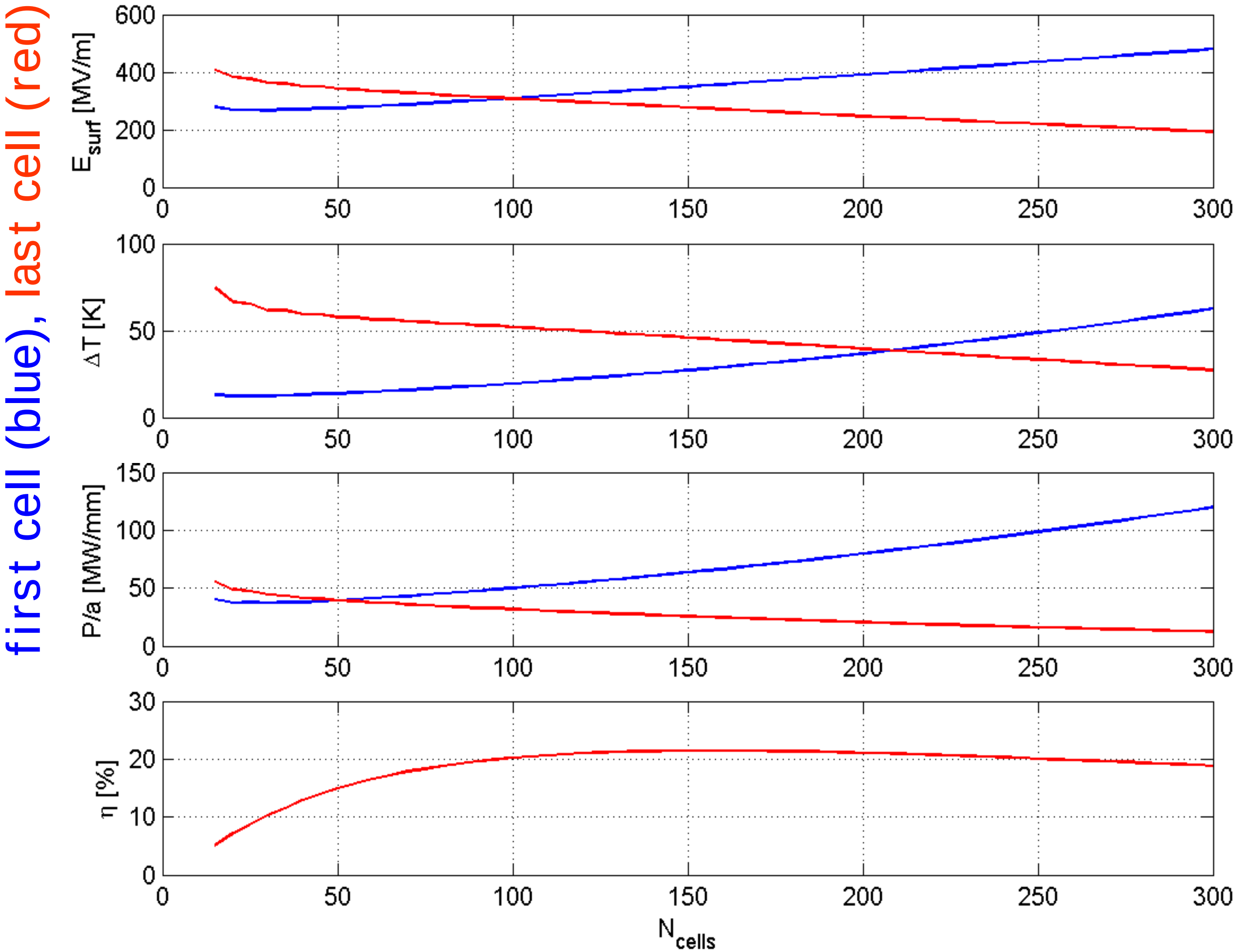
Conclusions

- Optimization of CLIC main linac parameters has been done taking luminosity per input power as a figure of merit
- Optimum gradient has not been found in the range from 90 to 150 MV/m, the lower the gradient the higher the figure of merit
- Optimum frequency is in the range of 16-20 GHz
- Optimum frequency shows weak dependence on the rf constraints
- Changing the operating frequency and gradient from the present design values of 150 MV/m at 30 GHz to the optimum frequency of 18 GHz at 100 MV/m will reduce the average linac input power by factor 2.5

Back up slides

Choice of N_{cells}

4 structures are chosen from 285.



For example:

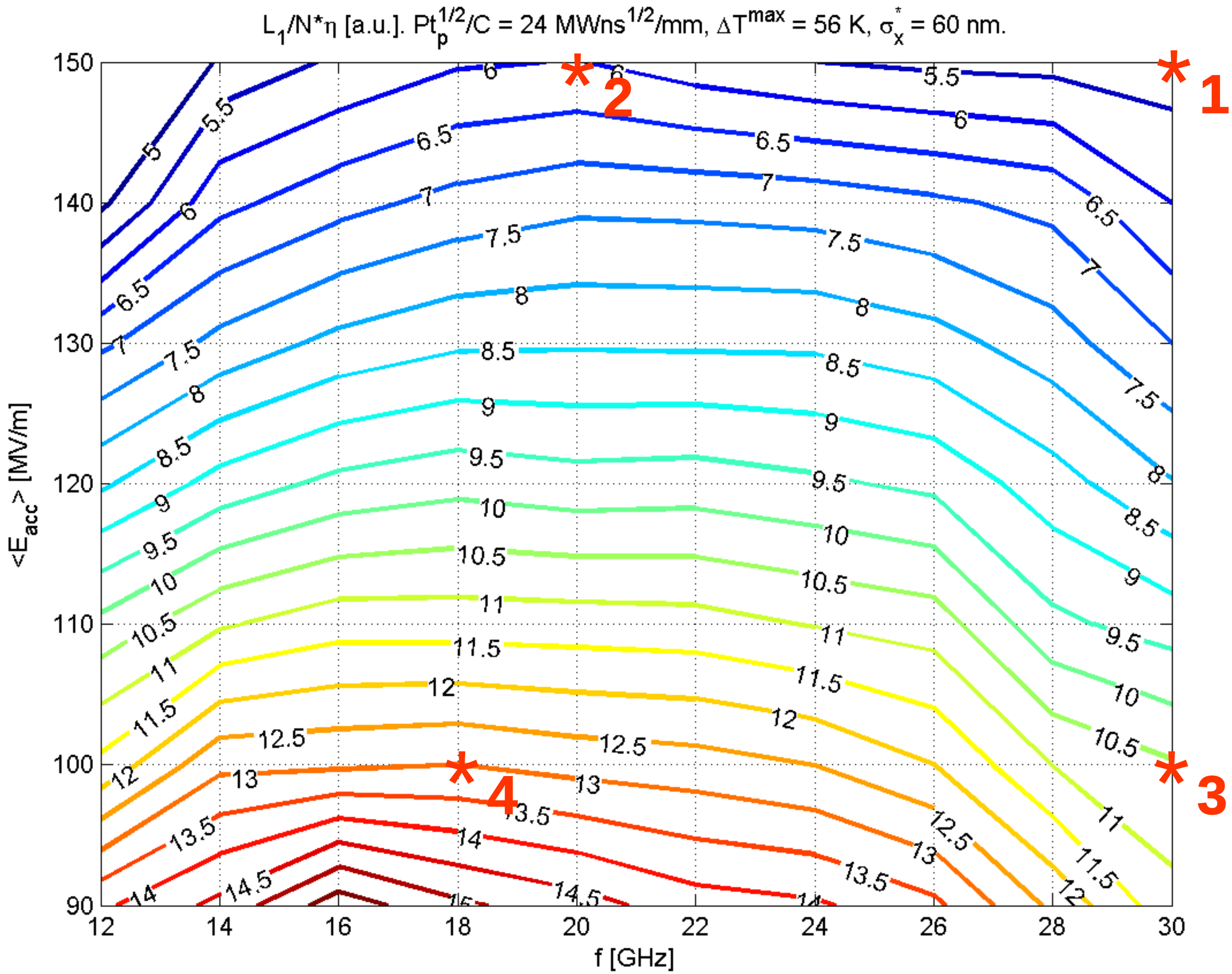
N_{cells} = 100 – E_{surf} = const,

N_{cells} = 210 – ΔT = const,

N_{cells} = 50 – P/C = const

N_{cells} = 150 – $Max(\eta)$

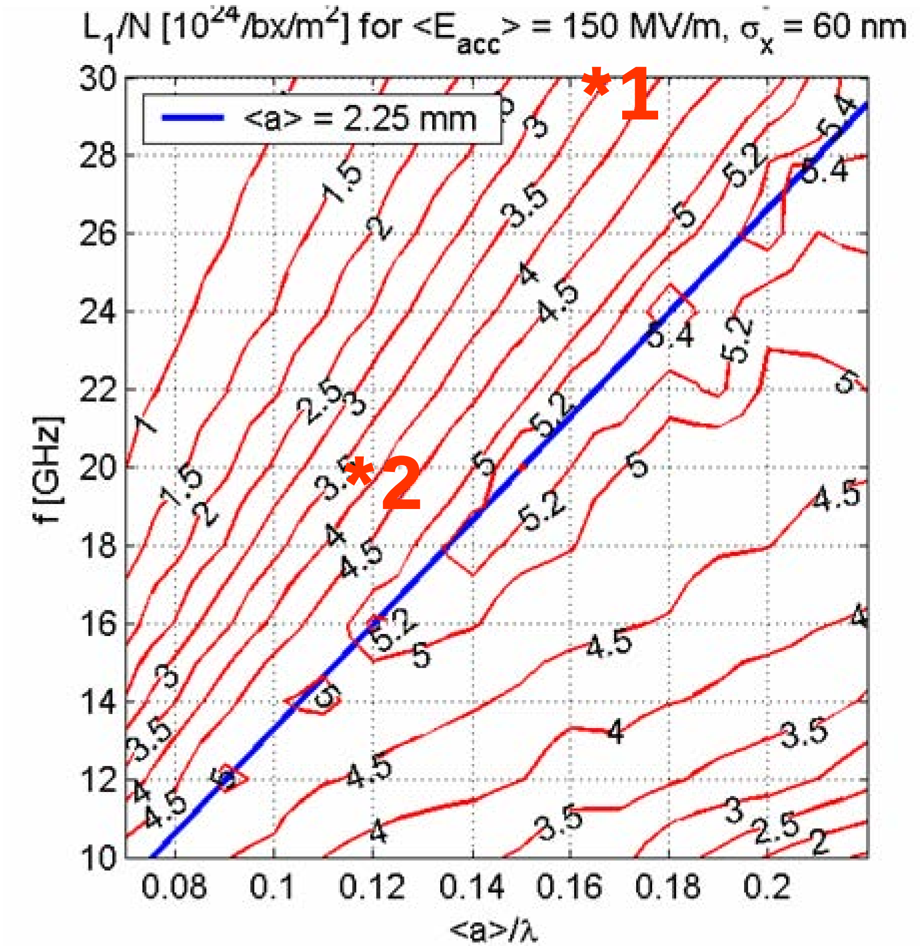
Optimization results



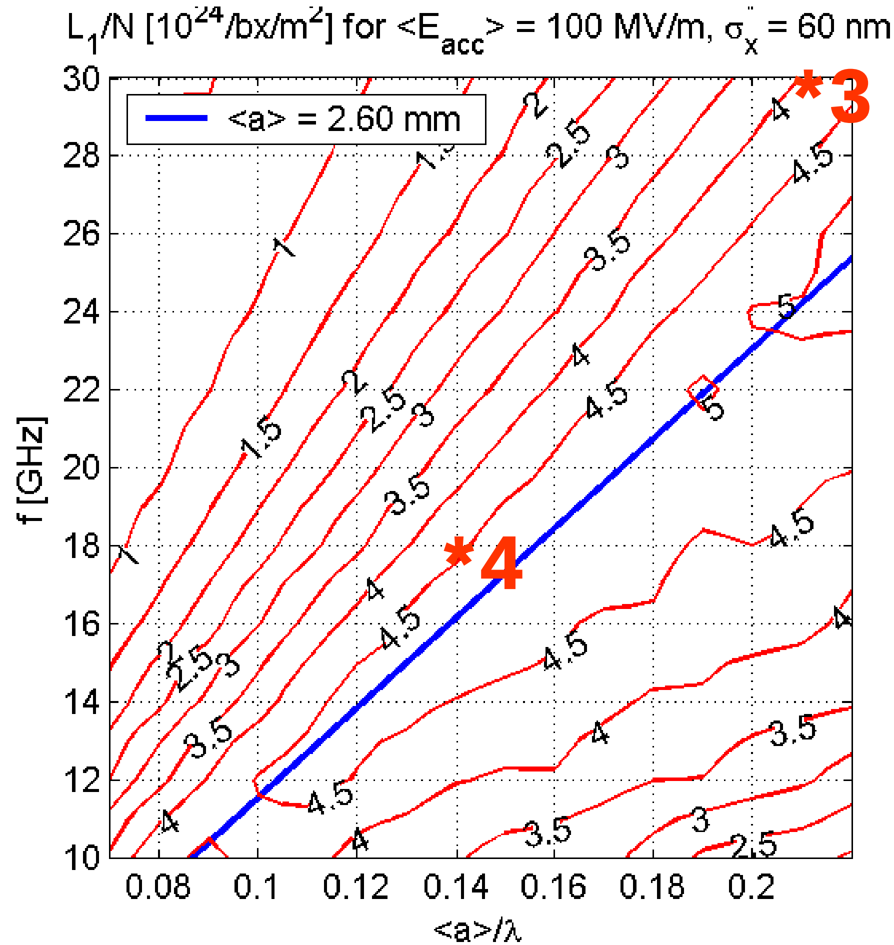
L_1/N for different gradients

CLIC

$\langle E_{acc}\rangle$ = 150 MV/m



$\langle E_{acc}\rangle$ = 100 MV/m



Parameter list of structures: 1-4

Structure #	1	2	3	4
Accelerating gradient: $<E_{acc}>$ [MV/m]	150	150	100	100
Frequency: f [GHz]	30	20	30	18
RF phase advance per cell: $\Delta\varphi$ [°]	50	50	50	50
Average iris radius over wavelength: $<a>/\lambda$	0.165	0.115	0.21	0.14
Input/Output iris radii: $a_{1,2}$ [mm]	2.14, 1.16	2.21, 1.24	2.63, 1.58	3.03, 1.63
Input/Output iris thickness: $d_{1,2}$ [mm]	0.25, 0.45	0.38, 0.38	0.25, 0.4	0.42, 0.42
Number of cells, structure length: N_c, l [mm]	69, 96	36, 75	127, 176	72, 167
Bunch separation: N_s [rf cycles]	6	5	6	5
Number of bunches in a train: N_b	42	79	59	102
Pulse length: τ_p [ns]	14.7	31.8	17.4	43.6
Input power: P_{in} [MW]	85	60	96	70
Efficiency: η [%]	16.1	17.1	26.9	30.4
Luminosity per bunch X-ing: $L_{b\times}$ [m^{-2}]	0.66×10^{34}	0.78×10^{34}	1.00×10^{34}	1.33×10^{34}
Bunch population: N	2.03×10^{9}	2.20×10^{9}	2.55×10^{9}	3.11×10^{9}
Figure of merit: $\eta L_{b\times}/N$ [a.u.]	5.24	6.02	10.55	13.01

2.5 times