Recent results on the design an optimization of CLIC main linac accelerating structure

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Outline

- Introduction
- Hybrid Damped accelerating Structure (HDS) design
- Optimization of CLIC main linac accelerating structure

CLIC main linac parameters

- Frequency $f = 29.985\ GHz$
- Average loaded accelerating gradient $\left\langle E_{acc}^{load} \right\rangle = 150\ {}^{MV}\!/\!_{m}$
- Number of particles in the bunch $N = 4 \times 10^9$
- Number of bunches in the train $N_b = 154$
- Number of rf cycles between bunches $N_{cycles} = 20$
- Pulse length $t_p = 130\,ns$
- Transverse long-range wakefields $W_{t,2} < 20\ {}^{V}\!/\!_{pC\cdot mm\cdot m}$

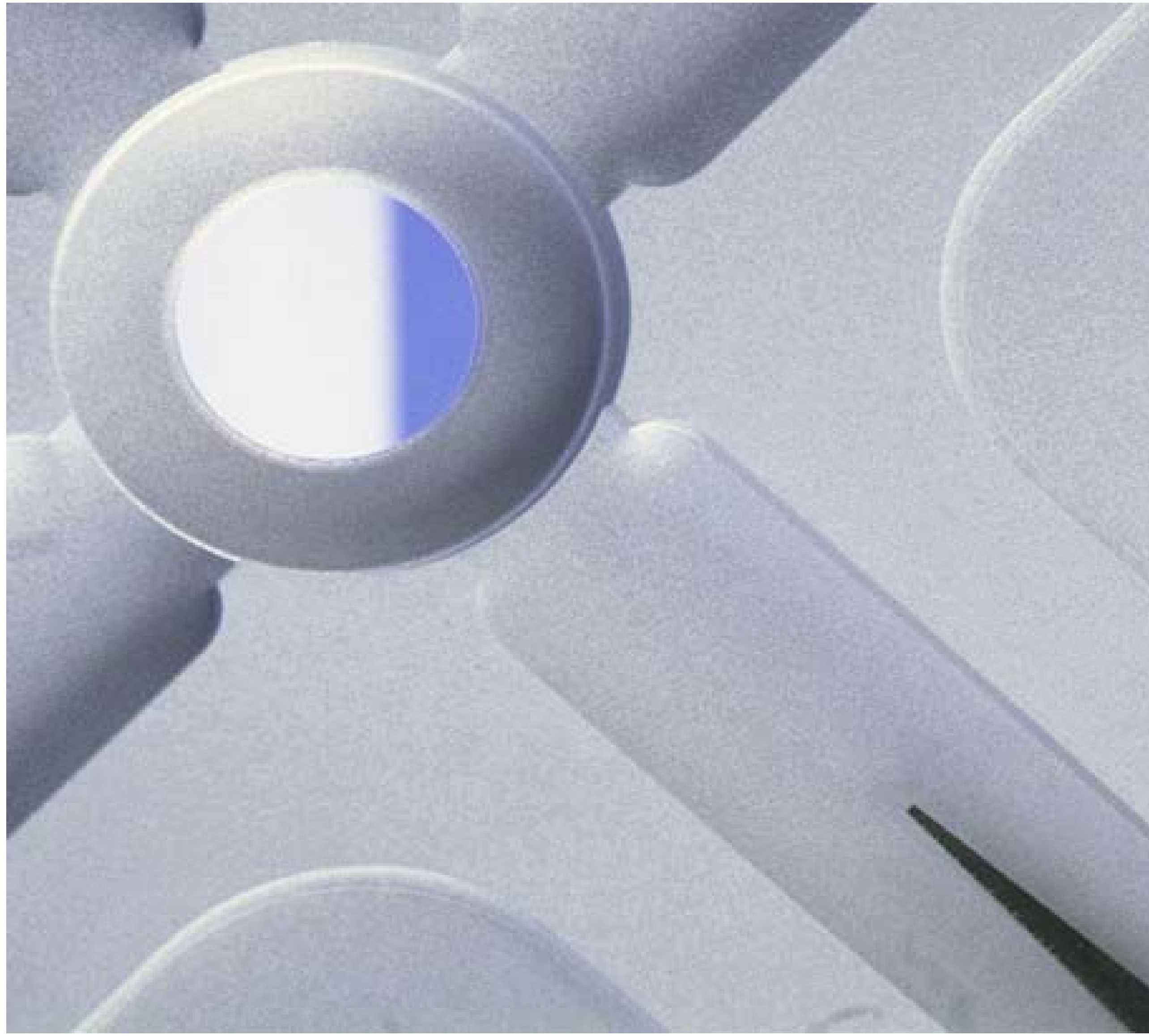
Geometry and parameters of TDS

$$E_{surf}^{\max} = 420 \, {}^{MV}\!/_{m}$$

$$\Delta T^{\max} > 800 \, K$$

$$W_{t,2} = 20 \, {}^{V}\!/_{pC \cdot mm \cdot m}$$

$$P_{in} = 250 \, MW$$



Geometry and parameters of XDS

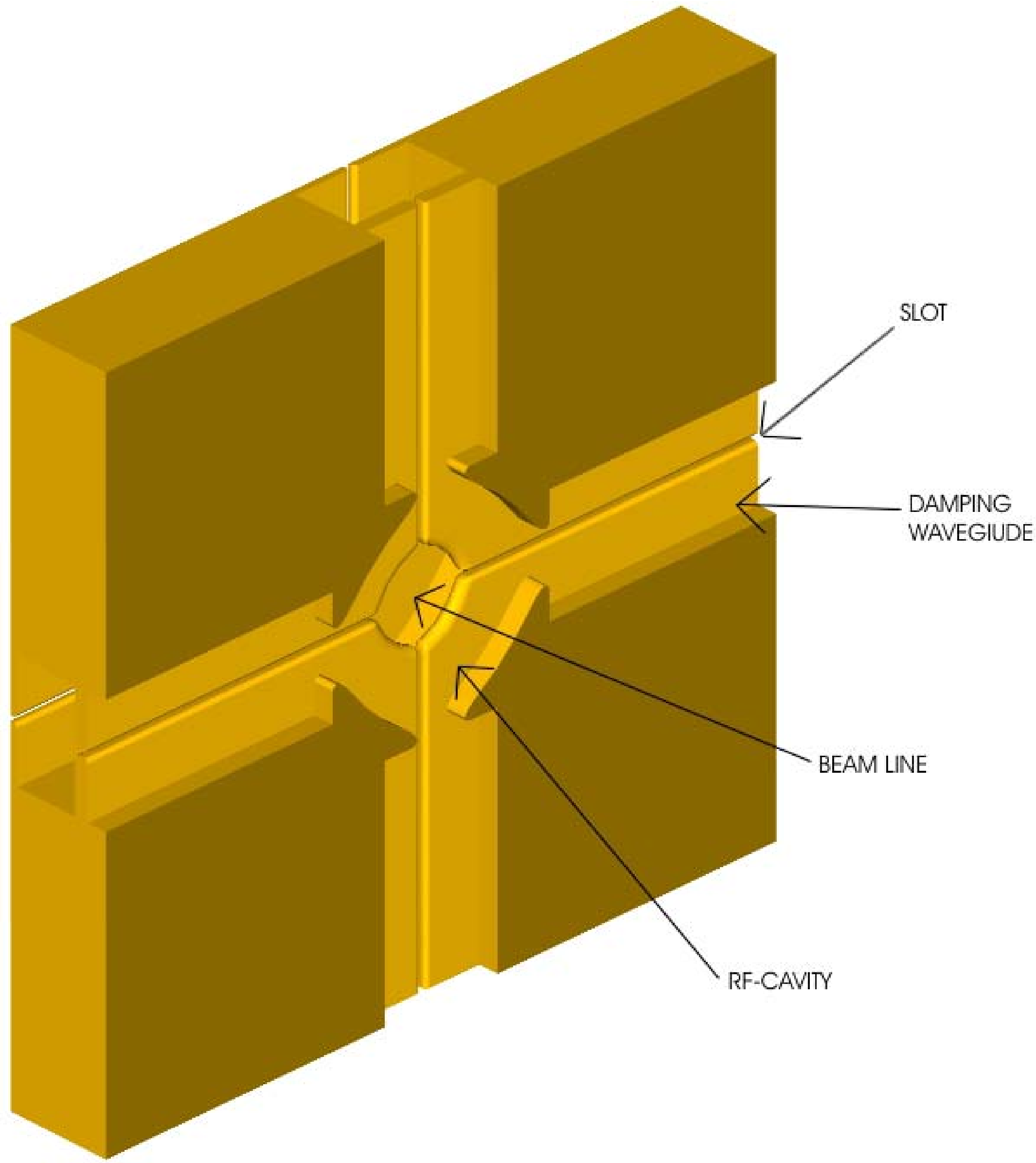
$$E_{surf}^{\max} = 347 \, {}^{MV}\!/_{m}$$

$$\Delta T^{\max} = 122 \, K$$

$$W_{t,2} = 45 \, {}^{V}\!/_{pC \cdot mm \cdot m}$$

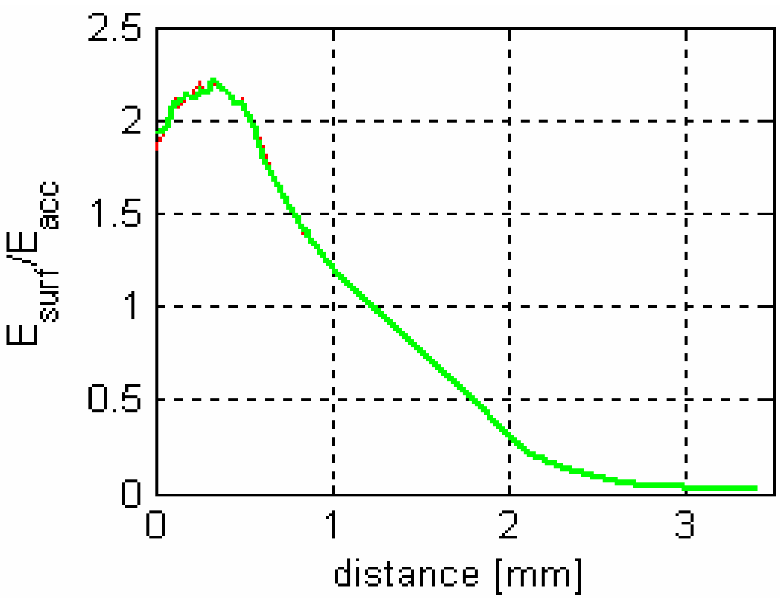
$$P_{in} = 125 \, MW$$

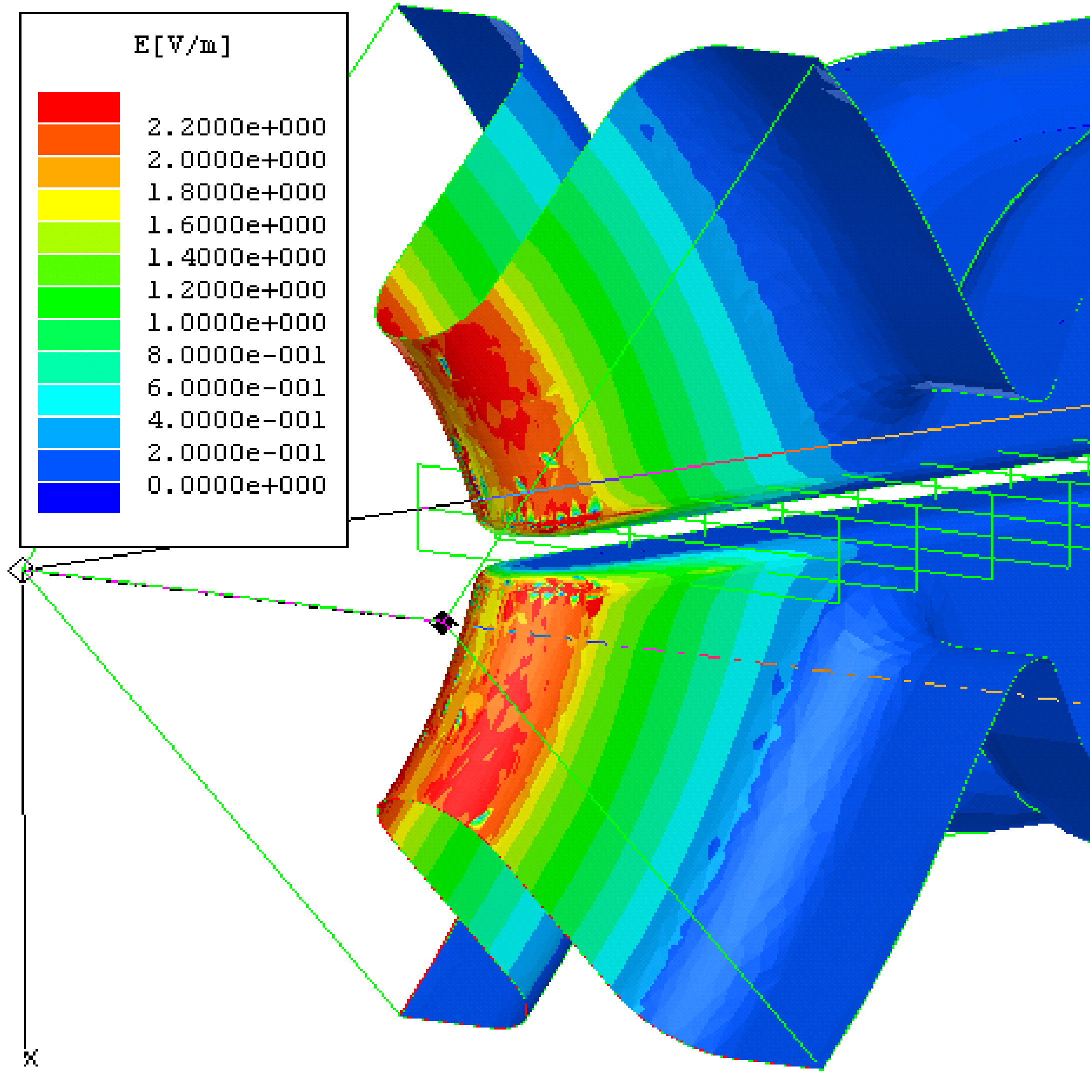
Geometry of HDS cell



Surface electric field in HDS cell

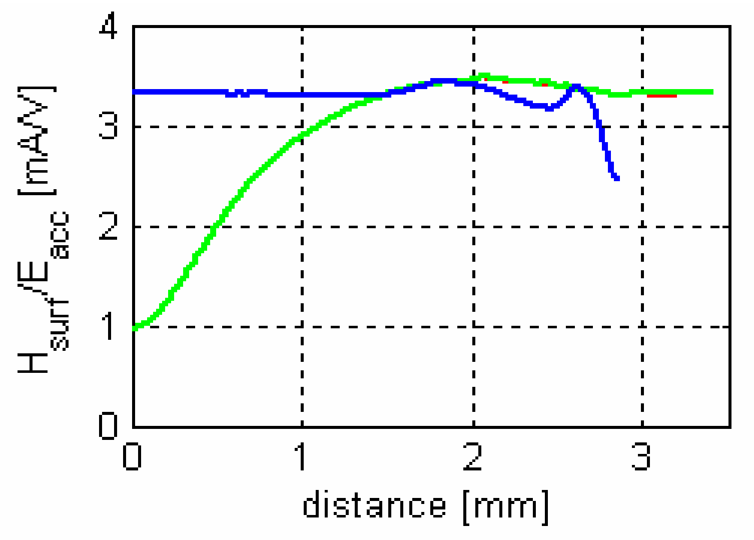
$$E_{surf} / E_{acc} = 2.2$$

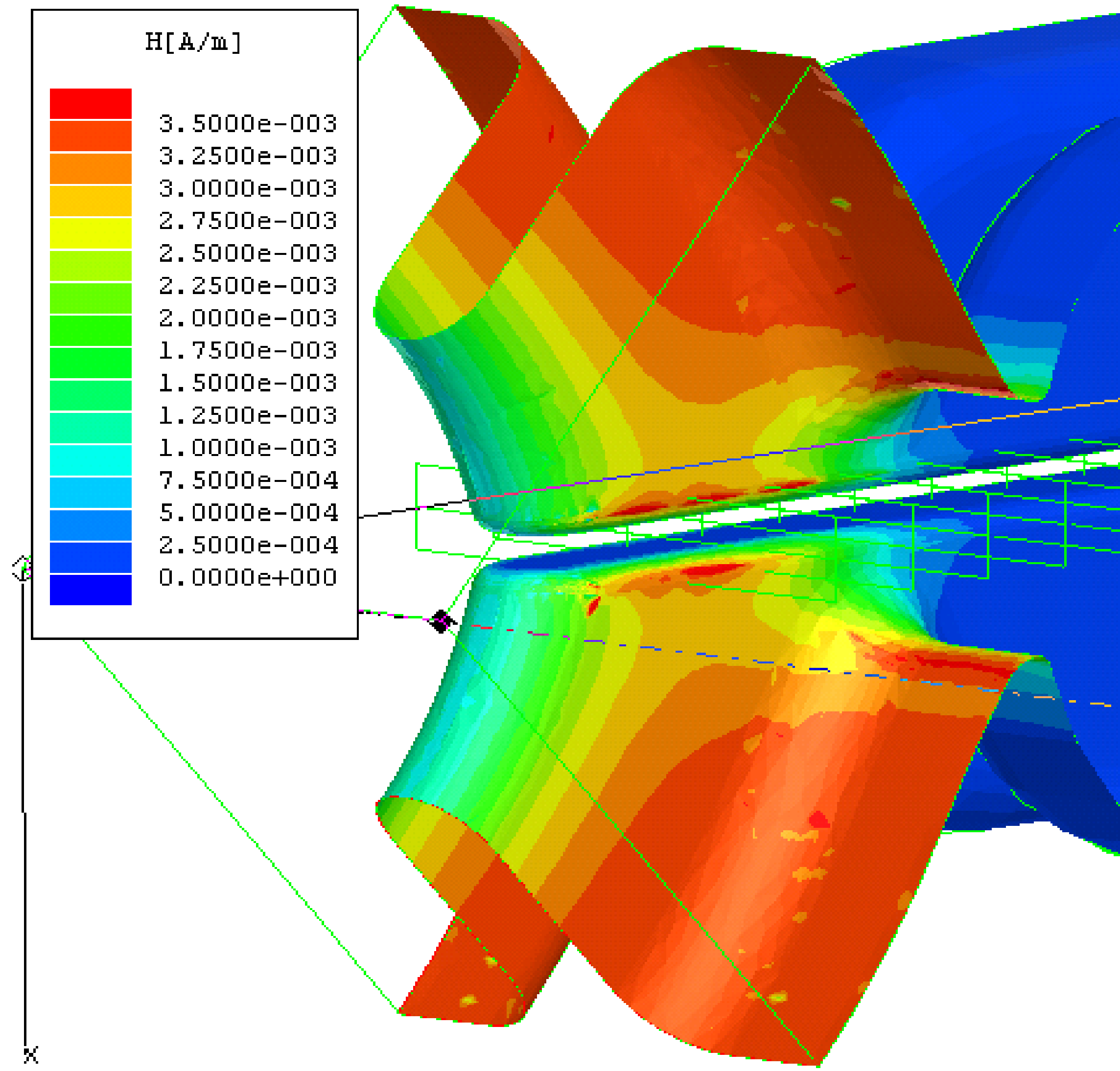




Surface magnetic field in HDS cell

$$H_{surf} / E_{acc} = 3.45\ mA / V$$





Comparison to undamped cell

	HDS	same a	same v_g
$a\,[mm]$	1.9	1.9	1.97
$v_g / c\ [\%]$	7.64	6.88	7.64
Q	3709	3889	3903 (-5%)
$r/Q\ [\Omega/m]$	26848	28004	26896 (0%)
E_{surf} / E_{acc}	2.2	2.03	2.05 (+7%)
$H_{surf} / E_{acc}\ [mA/V]$	3.45	3.12	3.15 (+9%)

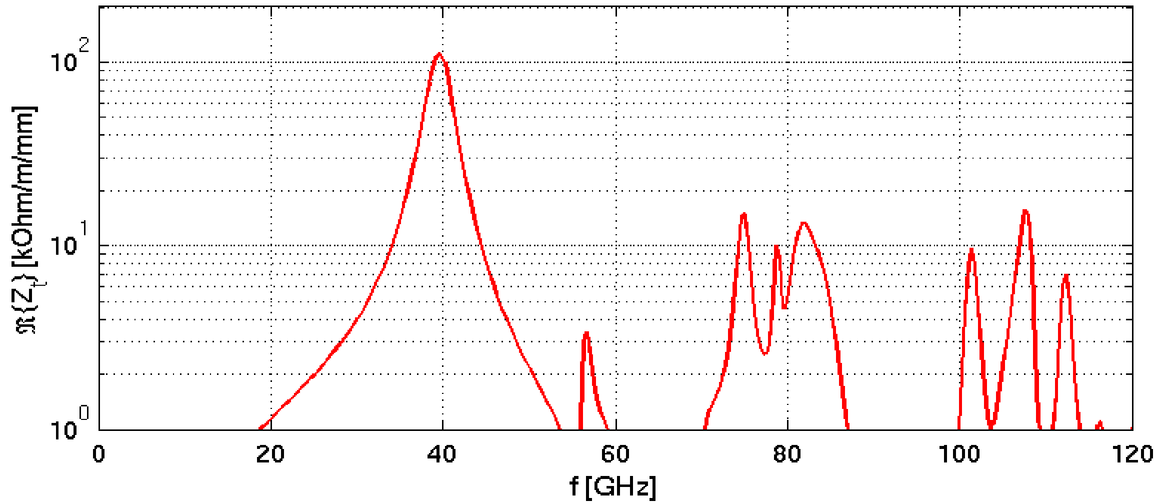
Transverse wakefields calculation

GdfidL in time-domain

$$A_1 = 2220\ V/pC\,mm\,m$$

$$f_1 = 39.6\ GHz$$

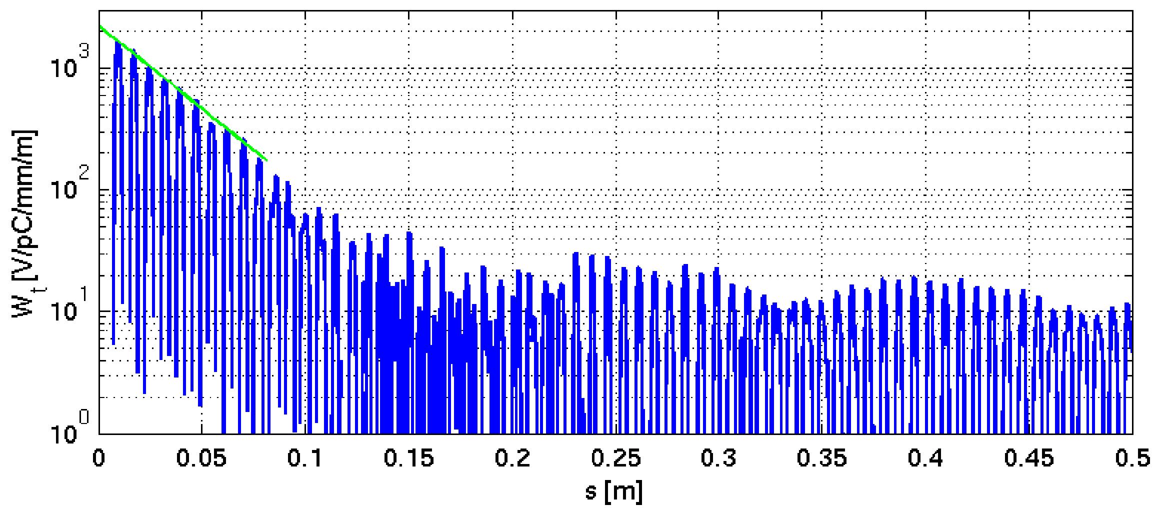
$$Q_1 = 13.3$$



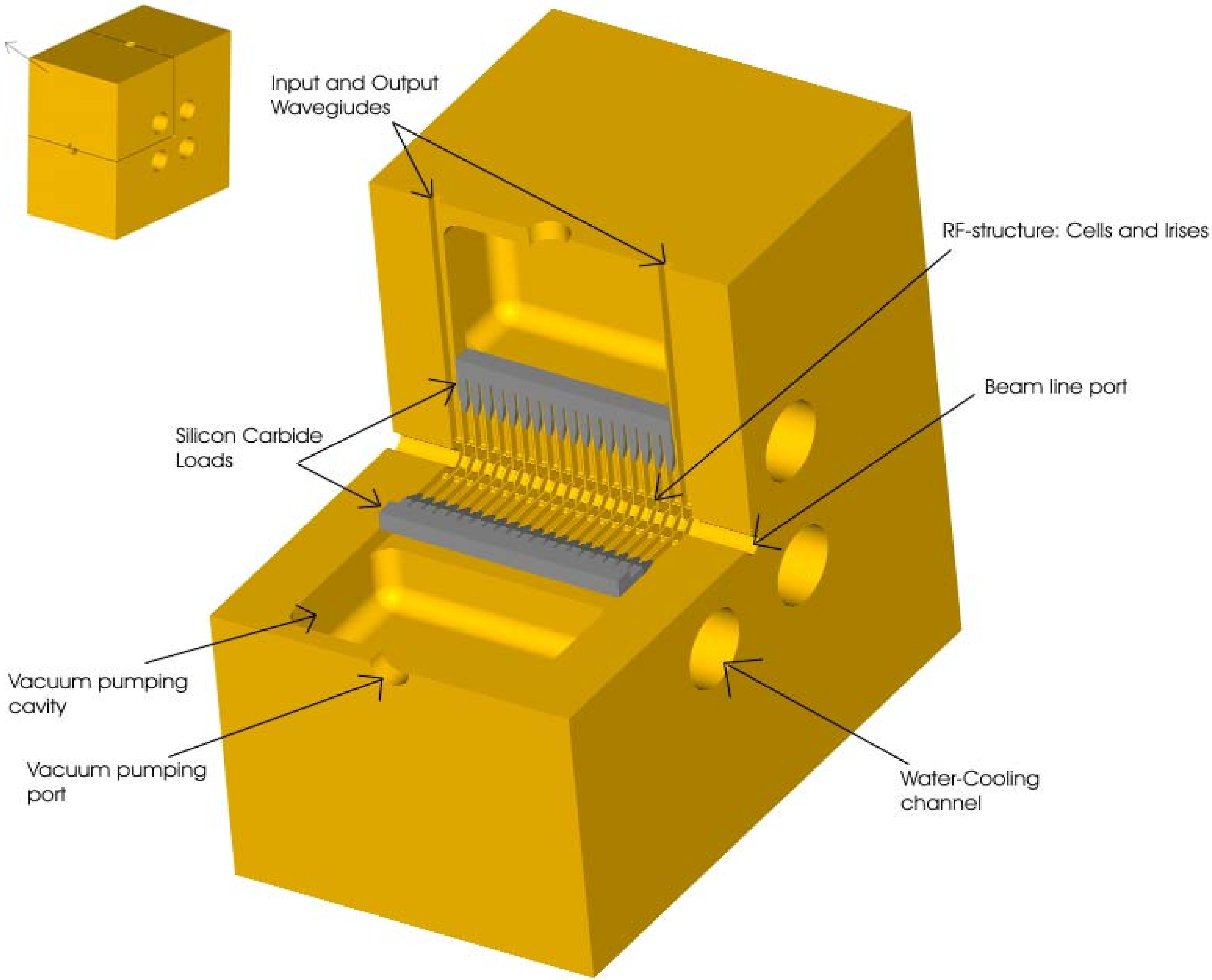
HFSS in frequency-domain

$$f_1 = 39.7\ GHz$$

$$Q_1 = 12.2$$



Schematic of HDS



Advantages and disadvantages

PRO

+ Excellent 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

+ Better water cooling

+ No water/vacuum joints

+ No vacuum can is necessary

+ Good pumping capabilities

CONTRA

- new technology needs to be shown (machinability, tolerances, etc.)

- potential of coupling the main mode to the load during breakdown

2-cells calculation of the structure

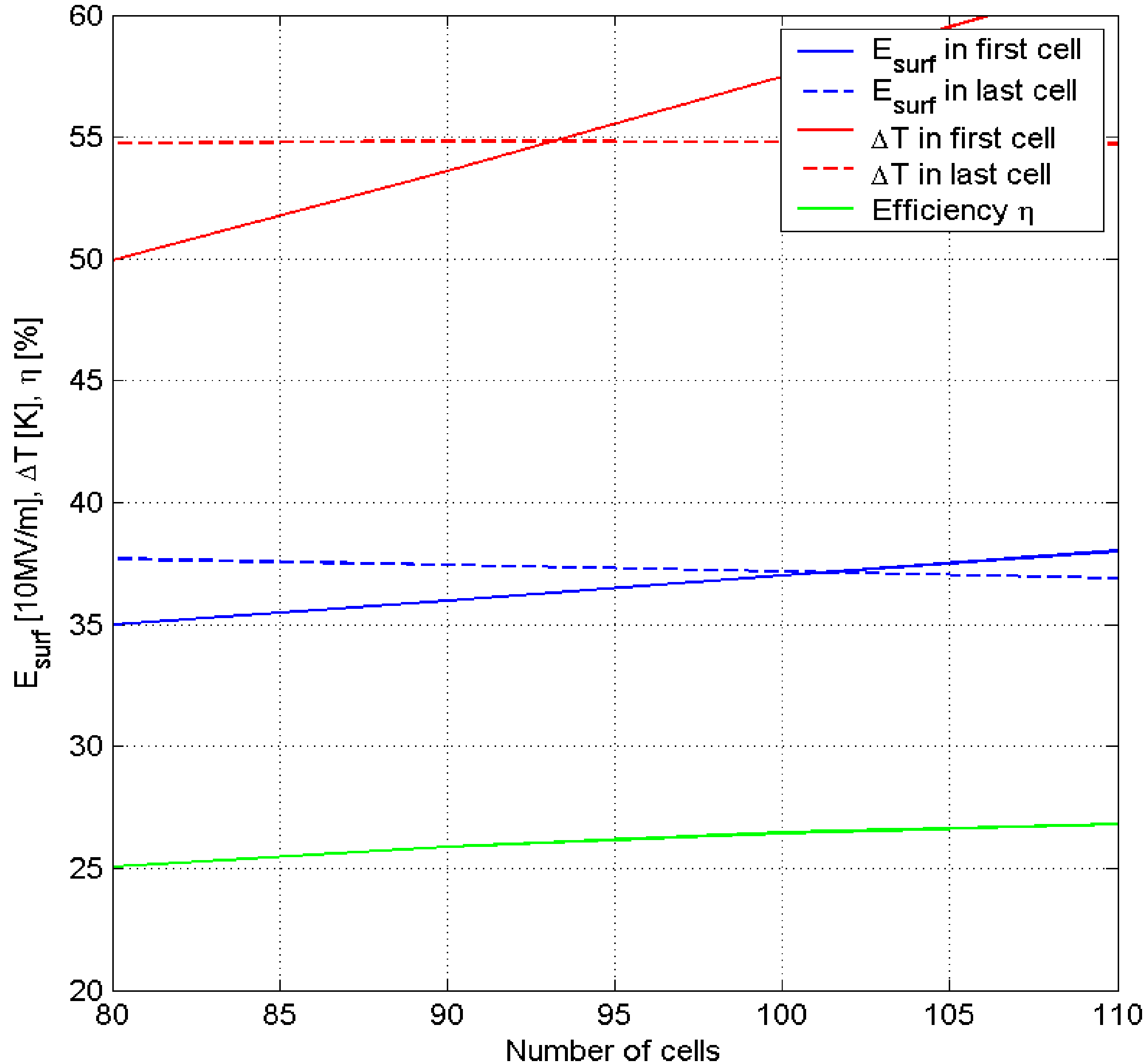
Given N, N_b, N_{cycles}

$$\left\langle E_{acc}^{load} \right\rangle = 150 \ {}^{MV}\!/_{m}$$

and $Q, v_g, r/Q$

$$E_{surf}/E_{acc},\ H_{surf}/E_{acc}$$

for first and last cells



Structure parameters are calculated for different number of cells

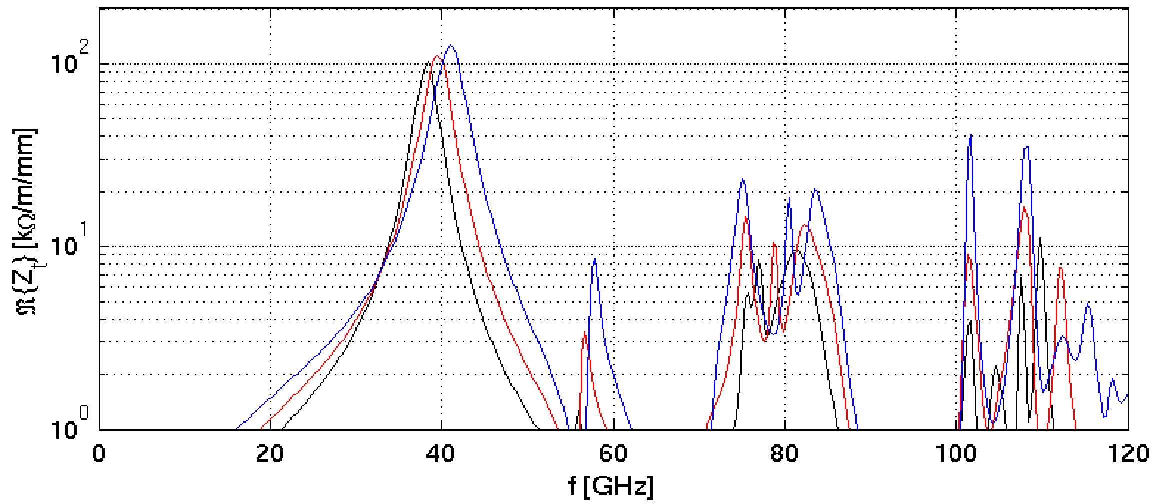
3-cells calculation of wakefields

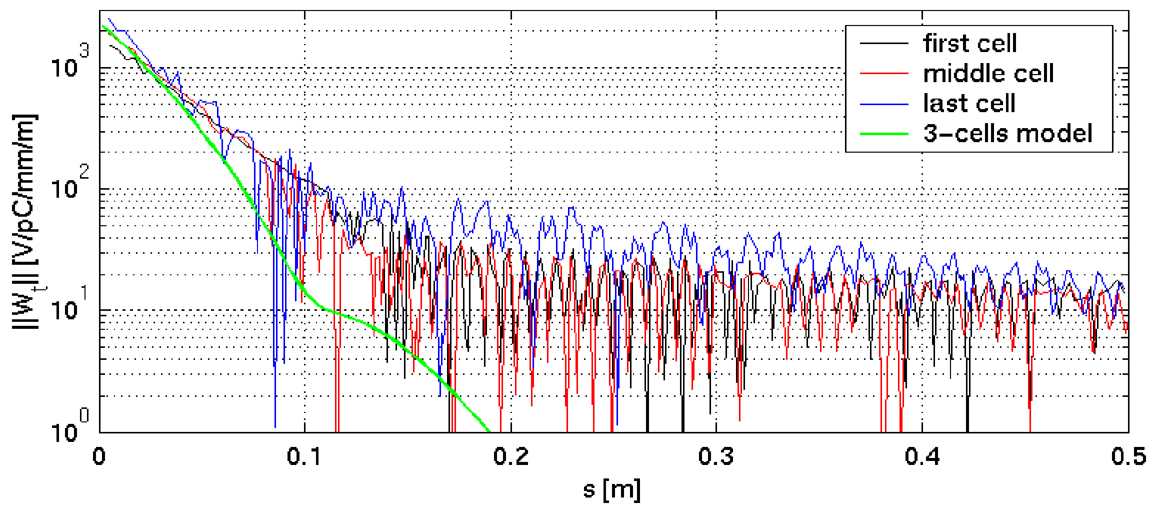
A_1, f_1, Q_1 for each cell are interpolated from its values in the first, middle and last cells and then the structure wakefields are calculated using:

$$W_t = \sum_{i=1}^{N_{cells}} A'_{1i}\, e^{-\frac{\omega_{1i} t}{2Q_{1i}}} \sin(\omega_{1i} t)$$

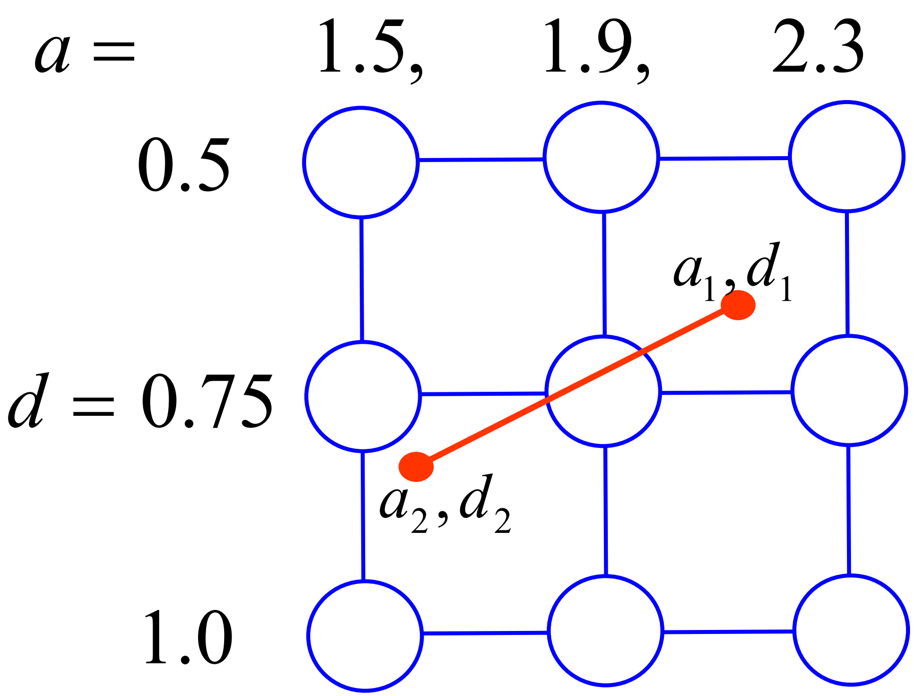
where $$A' = Ae^{\left(\frac{\omega\sigma}{c}\right)^2}$$

$$\sigma = 0.6\,mm$$





9-cells interpolation scheme



For each structure,

$$Q, v_g, r/Q, \quad A_1, f_1, Q_1$$

$$E_{surf}/E_{acc}, H_{surf}/E_{acc}$$

of the first and last cells and also A_1, f_1, Q_1 of the middle cell are interpolated

and

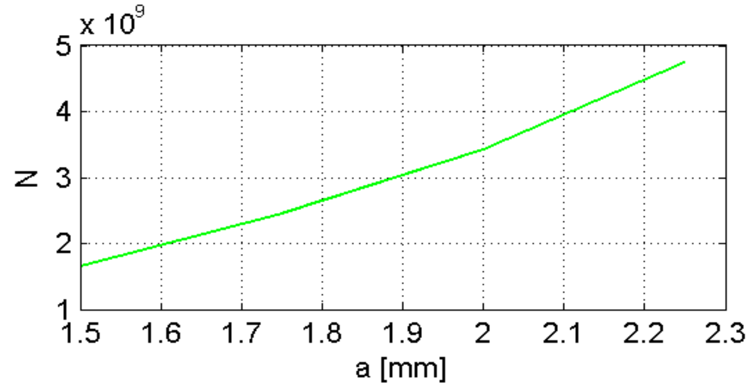
N_b is varied from 1 to 300

11 x 11 x 32 x 32 = 123904 structures have been analyzed

Beam dynamic constraints

For each structure:

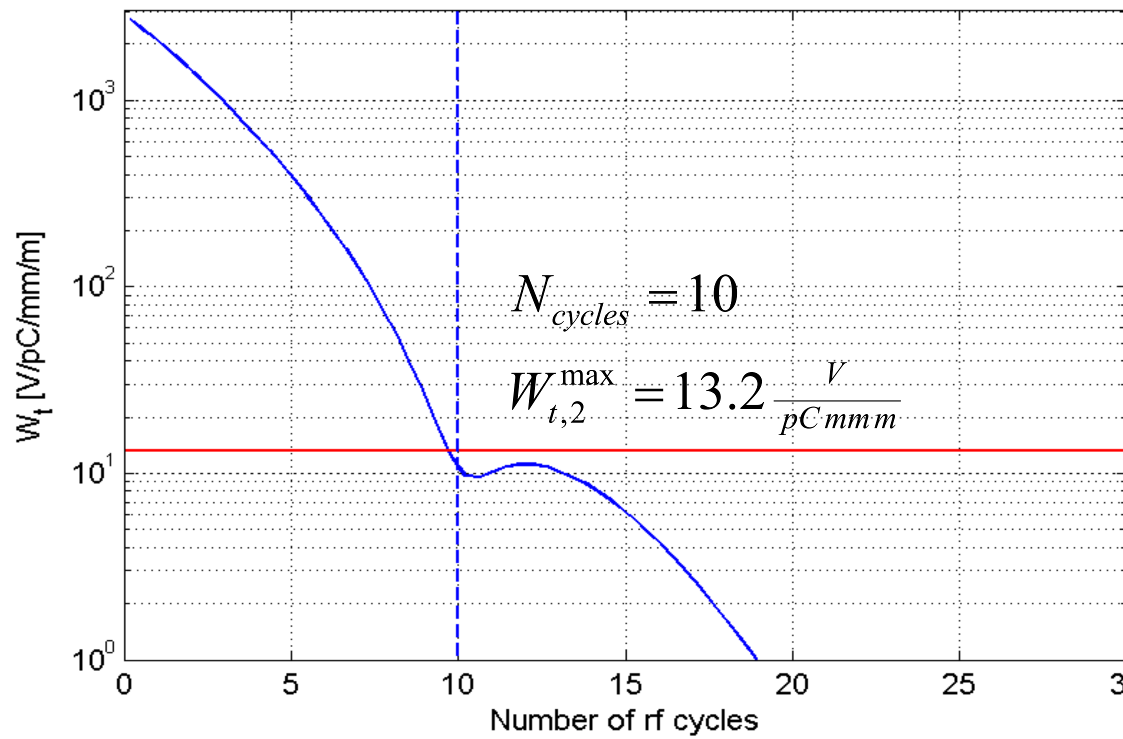
- N is constrained by short-range wakefields



- N_{cycles} is limited by long-range wakefields

$$N \times W_{t,2}^{\max} =$$

$$4 \cdot 10^{9} \times 10 \frac{V}{pC\,mm\,m}$$



Optimization constraints

Given parameters of the first and last cells and N, N_b, N_{cycles}

$E_{surf}^{max}, \Delta T^{max}, P_{in}, t_p$ are calculated for each structure

- rf breakdown limits for Mo

$$E_{surf}^{max} < 420 \times 0.9 = 378 \, {}^{MV}\!/_{m}$$

and

$$P_{in} < \sqrt{150ns / t_p} \cdot 100\, MW$$

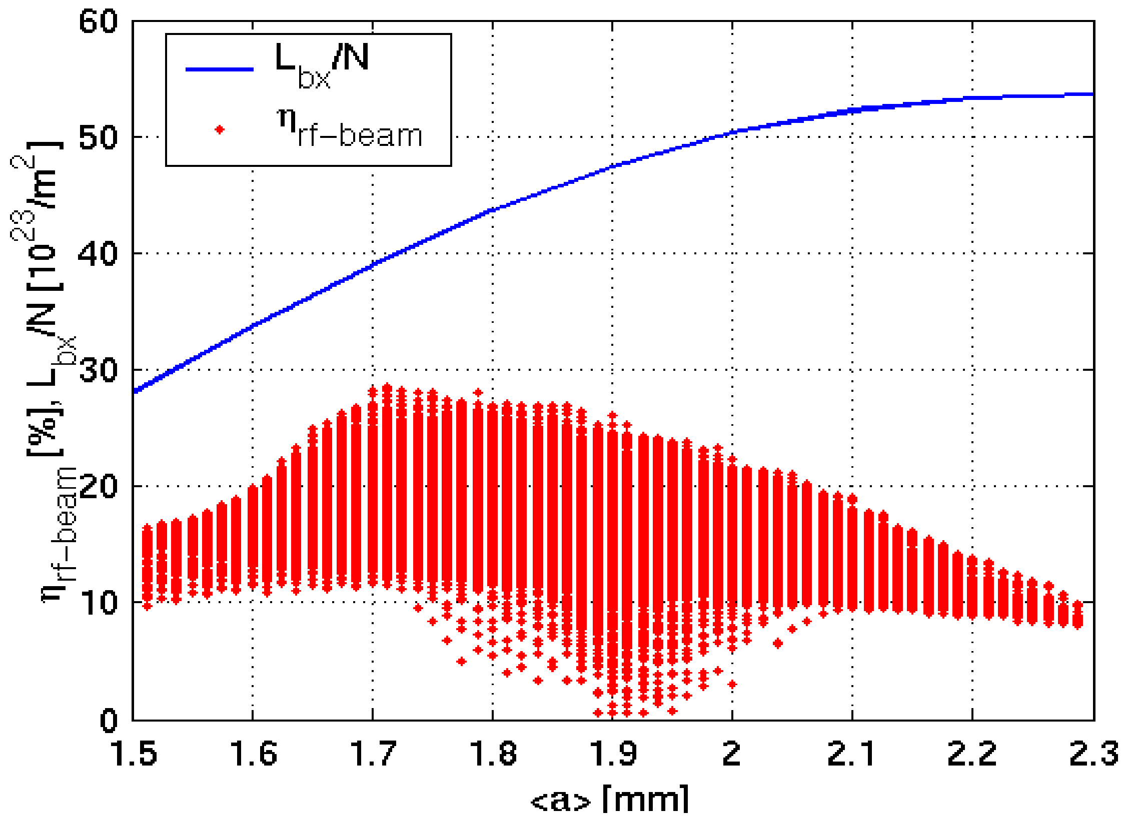
- pulsed surface heating limits for CuZr alloy

$$\Delta T^{max} < 70 \times 0.8 = 56\, K$$

72932 (59%) structures satisfy these conditions

Optimization criteria

$$\max\left\{\frac{\int L\,dt}{\int P\,dt}\right\} \sim \max\left\{\frac{L_{b\times}}{N}\cdot\eta_{rf\rightarrow beam}\right\}$$



Optimal structure parameters

$$a = 2.125 \div 1.675,\ d = 0.8 \div 0.75\,mm, \quad N_{cells} = 93, \quad l = 28.5\,cm$$

$$N = 3.04 \times 10^9$$

$$N_{cycles} = 10$$

$$N_b = 108$$

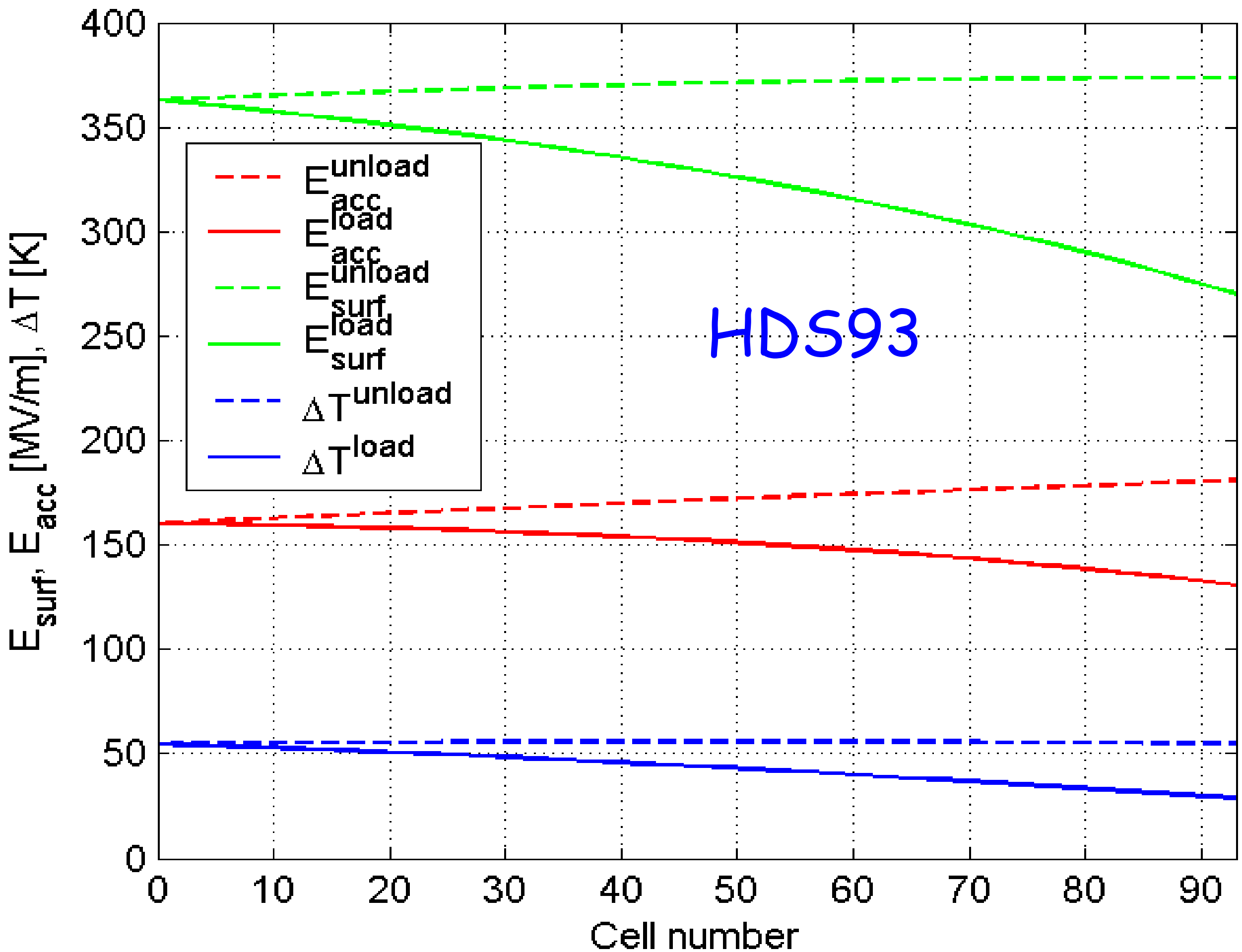
$$t_p = 48.4\,ns$$

$$E_{surf}^{max} = 374\,{}^{MV}/_{m}$$

$$\Delta T^{max} = 54.7\,K$$

$$\eta_{rf \to beam} = 26\%$$

$$P_{in} = 176\,MW$$



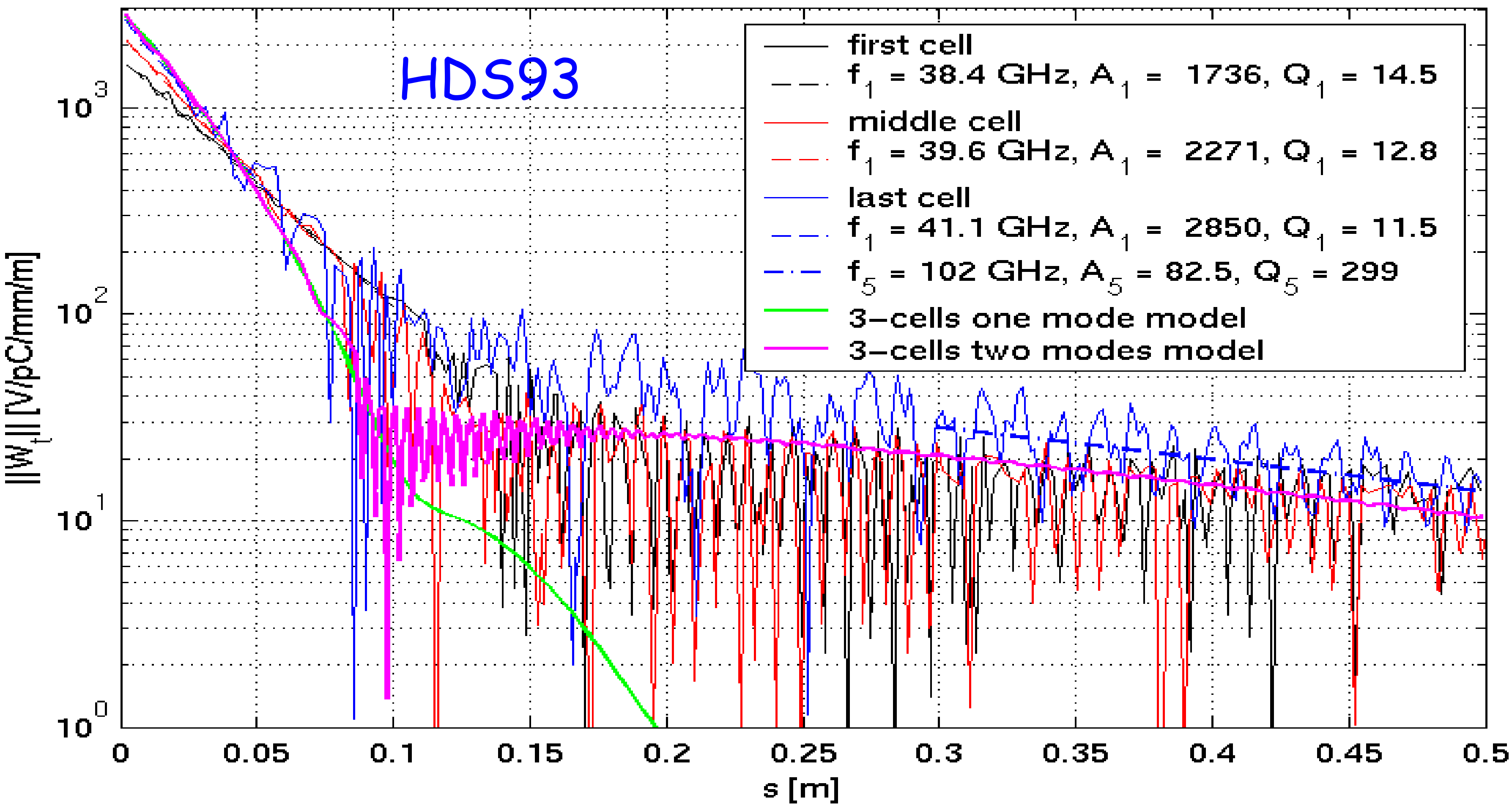
Efficiency issue

TDS nominal bunch spacing 20 rf cycles	XDS nominal bunch spacing 20 rf cycles	HDS nominal bunch spacing 20 rf cycles	HDS optimal bunch spacing 10 rf cycles
24% 21%	24% 15%	16%	26%

Use of Mo reduces efficiency by ~1%

Optimal structure wakefields

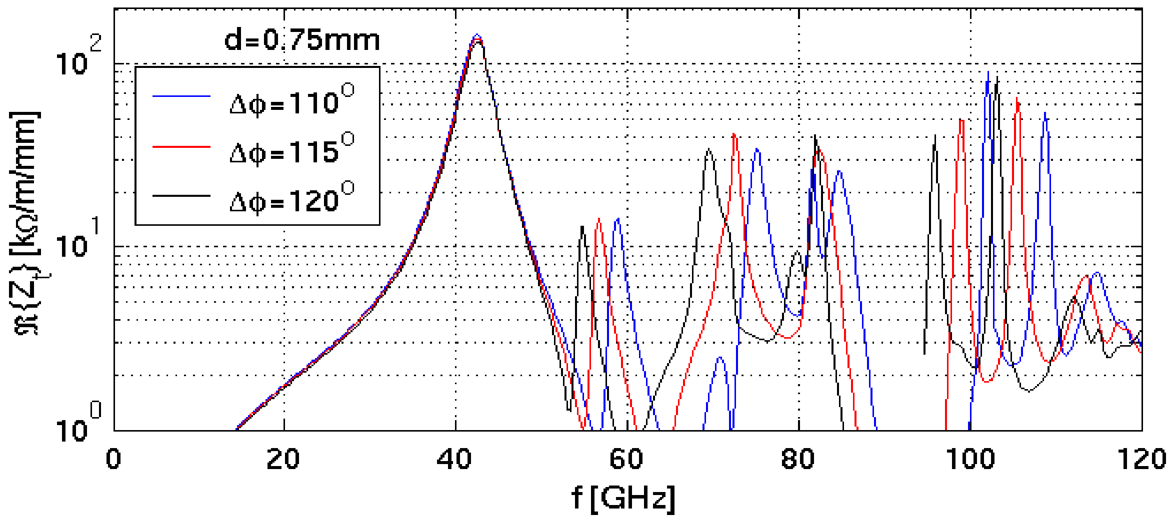
$$W_t = \sum_{i=1}^{N_{cells}} A'_{1i}\, e^{-\frac{\omega_{1i} t}{2Q_{1i}}} \sin(\omega_{1i} t) + A'_{5i}\, e^{-\frac{\omega_{5i} t}{2Q_{5i}}} \sin(\omega_{5i} t)$$

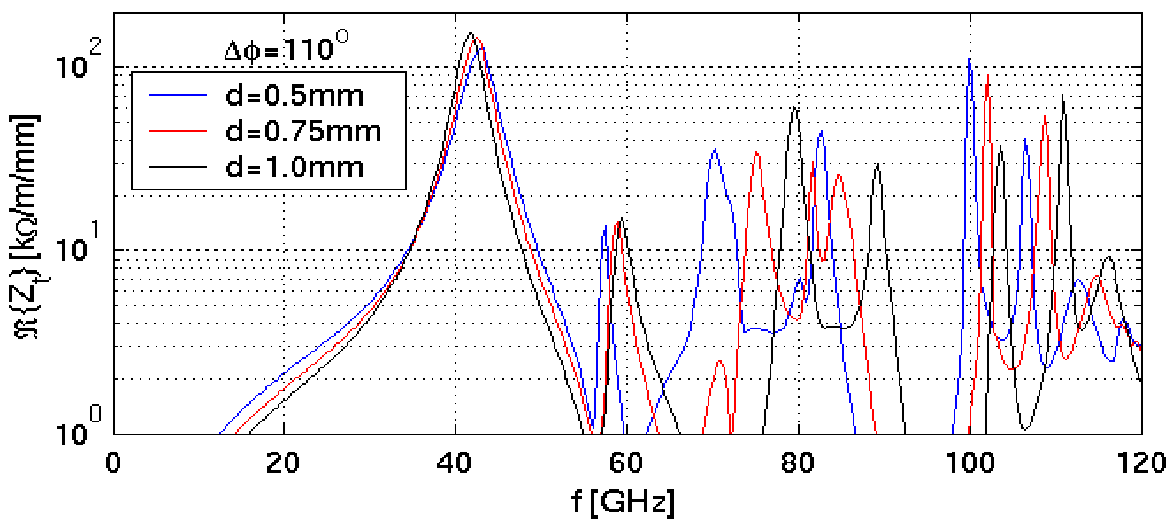


Higher order dipole modes detuning

Relative change in %
per GHz of detuning

by	$\Delta\phi$	d
Q	1	3
v_g	1	10
r/Q	0.5	3
$\frac{E_{surf}}{E_{acc}}$	0.6	6
$\frac{H_{surf}}{E_{acc}}$	0	4





Outlook

- Optimization for 120 degree phase advance
- GdfidL simulation of complete HDS
- Design of couplers and damping loads for HDS
- Asset test at SLAC