An overview of CLIC accelerating and transfer structure development

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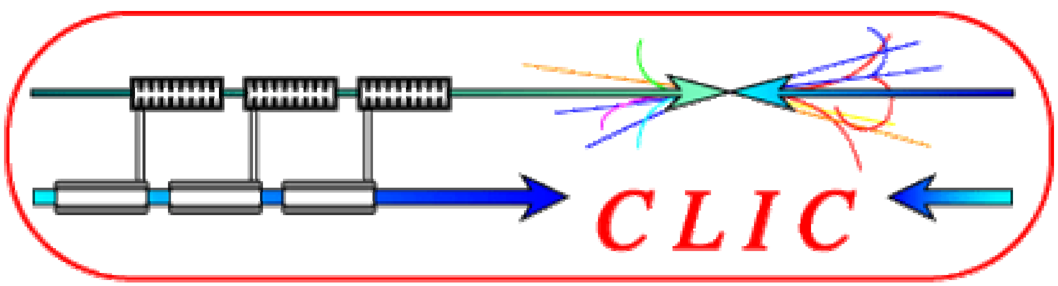
Outline

- Introduction
- Transfer structure
- Accelerating structure
  - New materials
  - New design
  - Optimization
- Summary

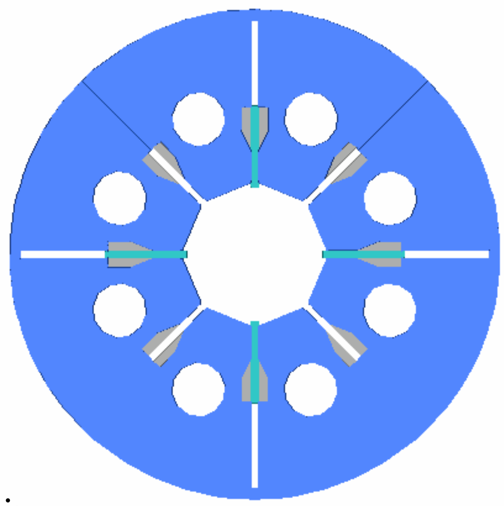
Introduction

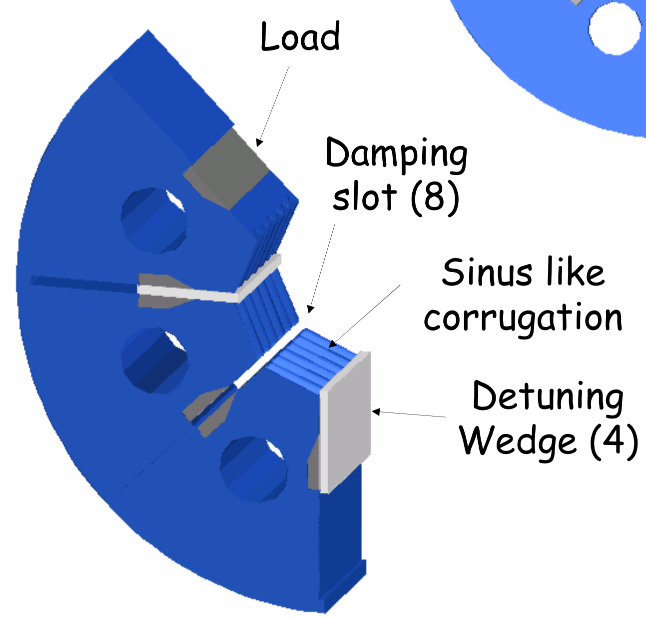
- Compact LInear Colider in the multi-TeV range
- Cost and geography: length < 50 km =>
- Very high gradient: 150 MV/m =>
- Power and gradient: 30 GHz =>
- Two beam acceleration scheme

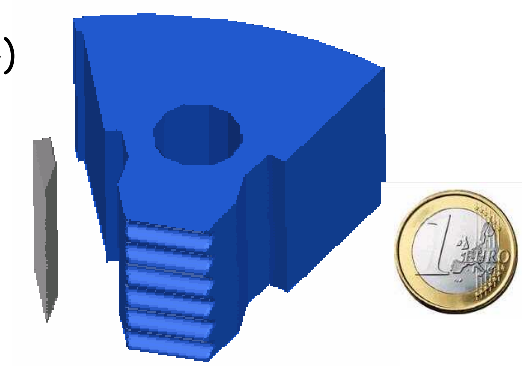


Transfer structure

CLIC transfer structure views



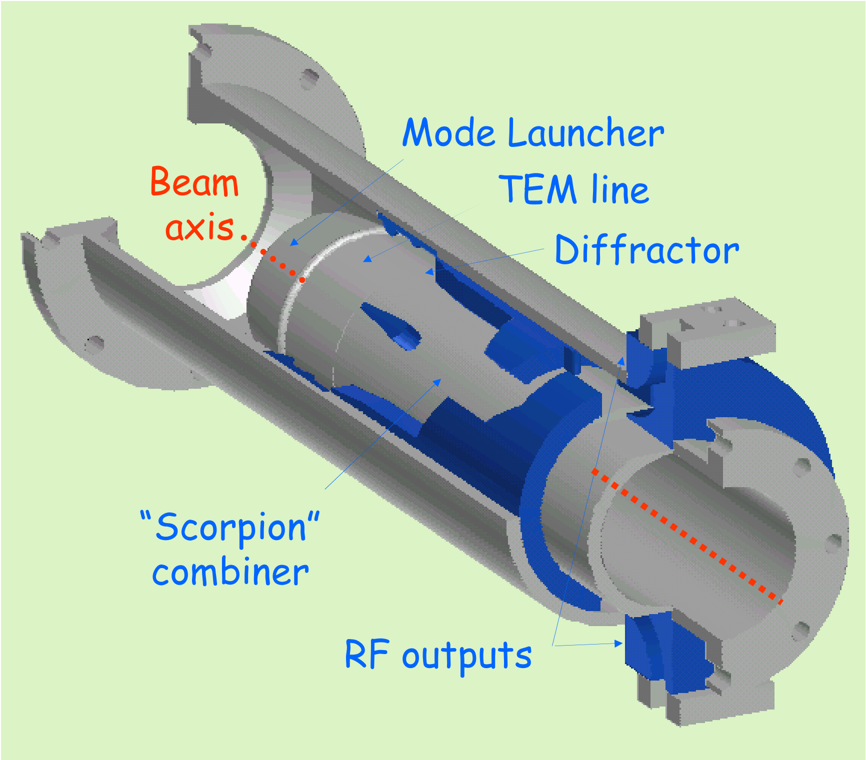




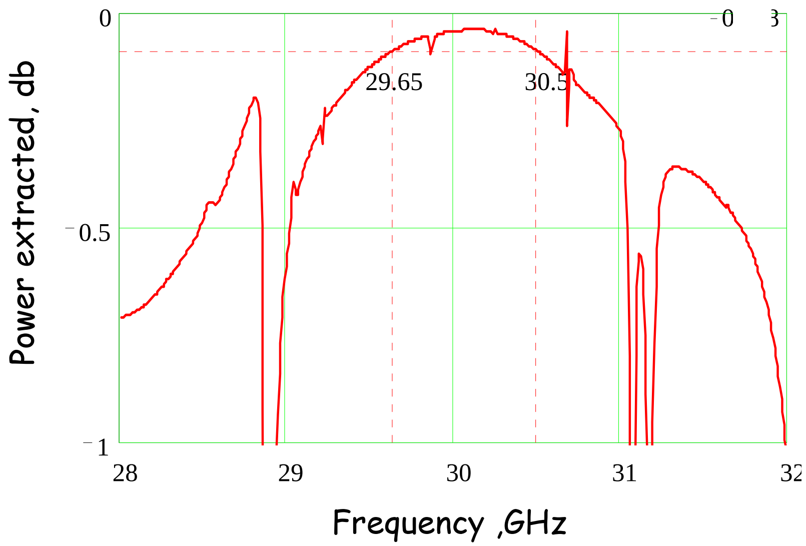
25 mm aperture
transfer structure parameters:

120^0/cell
L=3.283 mm
2a=25.0 mm
$F_{sync.}$ = 30.45 GHz
β_{GR} = 0.8624 C
R/Q = 219.3 Ω/m
Depth = 1.222 mm
Structure Length 0.8 m
Cells number: 244
E_{surf} = 98 MV/m
Beam current: 163 A
Power: 130(HDS)x4/0.95= 560MW

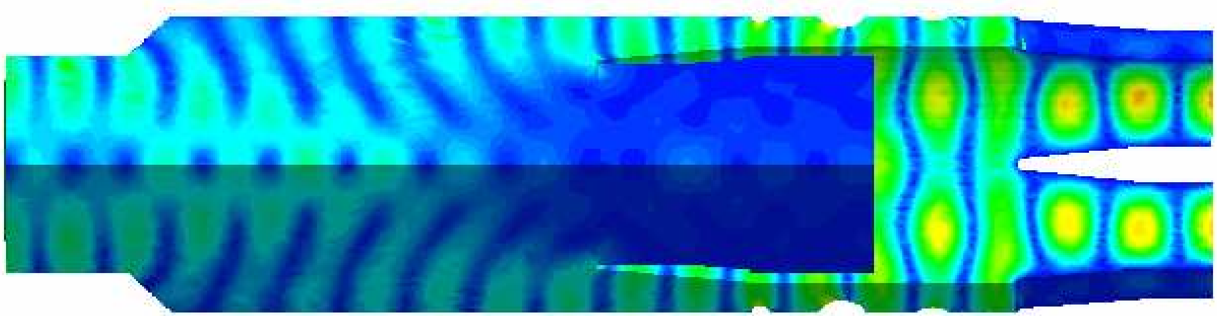
Power extractor for transfer structure



Power extraction efficiency

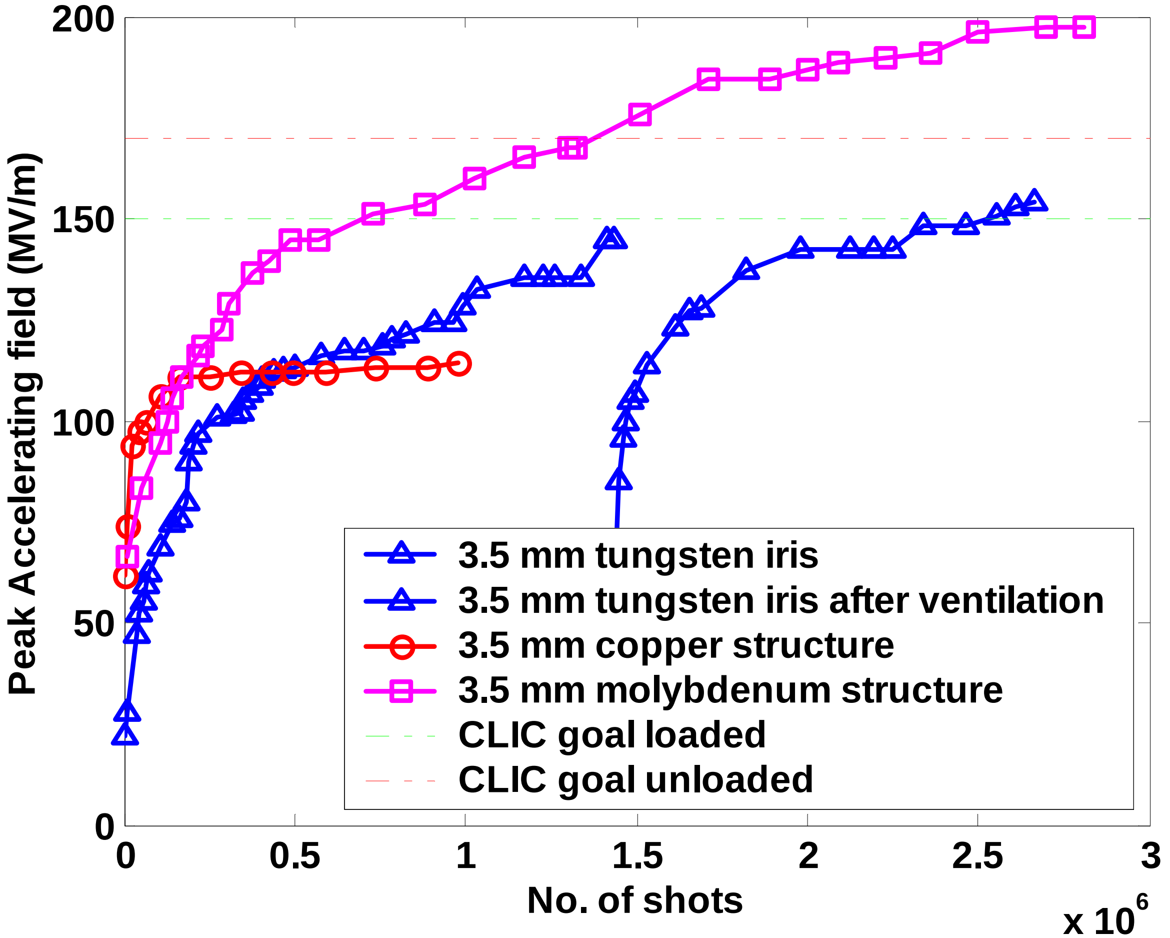


Electric fields in extractor



New materials

Copper, tungsten iris and molybdenum iris accelerating structures



30 GHz

16 ns

New materials

CLIC lifetime: 20y x 9m/y x 30d/m x 24h/d x 100Hz = 5×10^{10} cycles could be limited by fatigue due to pulsed surface heating

Comparison of Cupper alloys

Alloy name	Cu OFE	Cu Cr	Cu Cd	Cu Zr
ΔT [°C] (HDS Structure)	71	88	80	77
$\sigma_{Thermal}$ (Thermal Stress of HDS Structure) [MPa]	234	305	244	263
$\sigma_{Fatigue}$ (Fatigue Strength at 10^8 cycles) [MPa]	117	193	205	241
$\sigma_{Thermal}$ / $\sigma_{Fatigue}$	2	1.58	1.19	1.09

CLIC main linac parameters

- Average loaded accelerating gradient $\langle E_{acc}^{load} \rangle = 150\ {}^{MV}\!/_{m}$
- Frequency $f = 29.985\,GHz$
- Number of particles in the bunch $N = 4\times10^{9}$
- 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

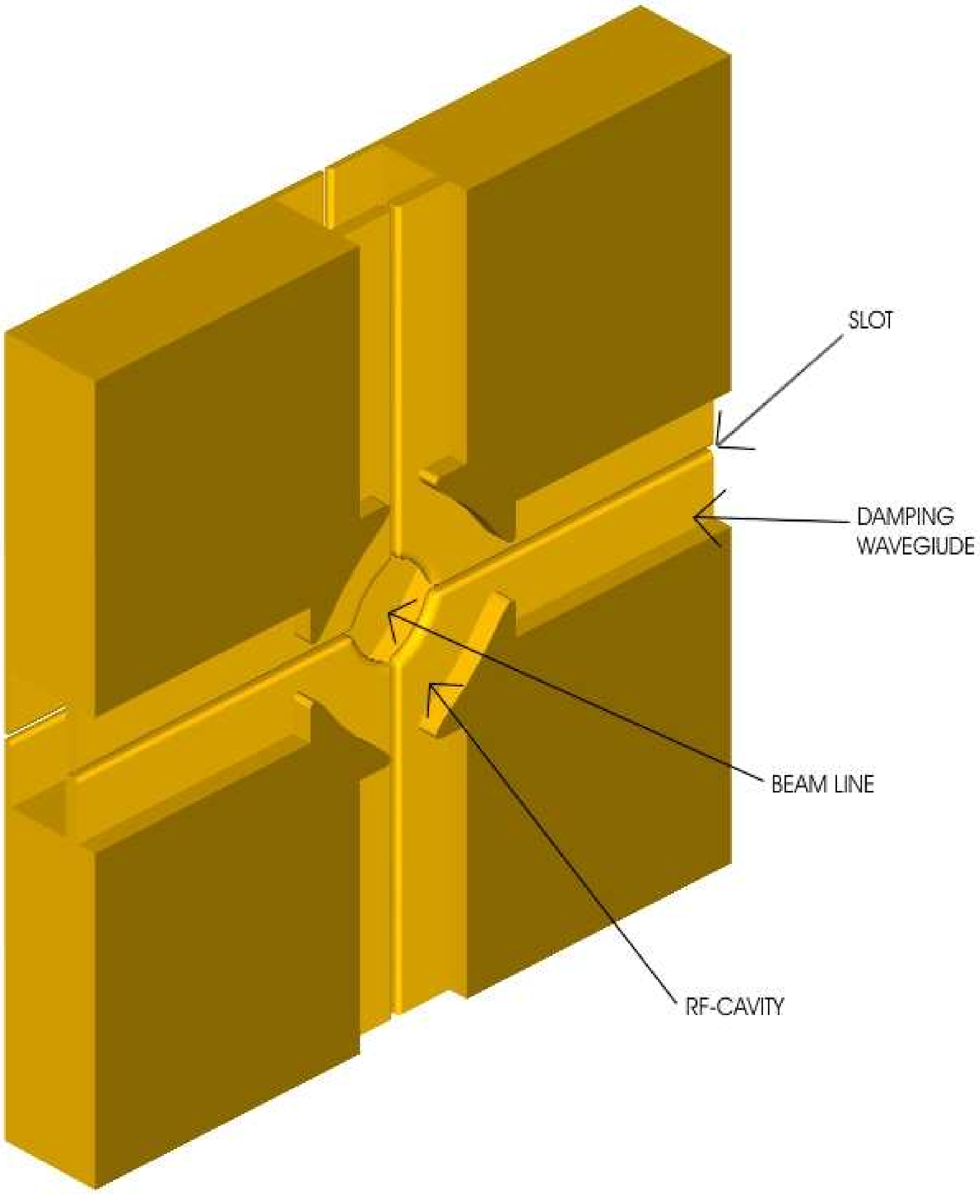
$$E_{surf}^{\max} = 347 \, {}^{MV}\!/_{m}$$

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

$$W_{t,2} = 23 \, {}^{V}\!/_{pC\cdot mm\cdot m}$$

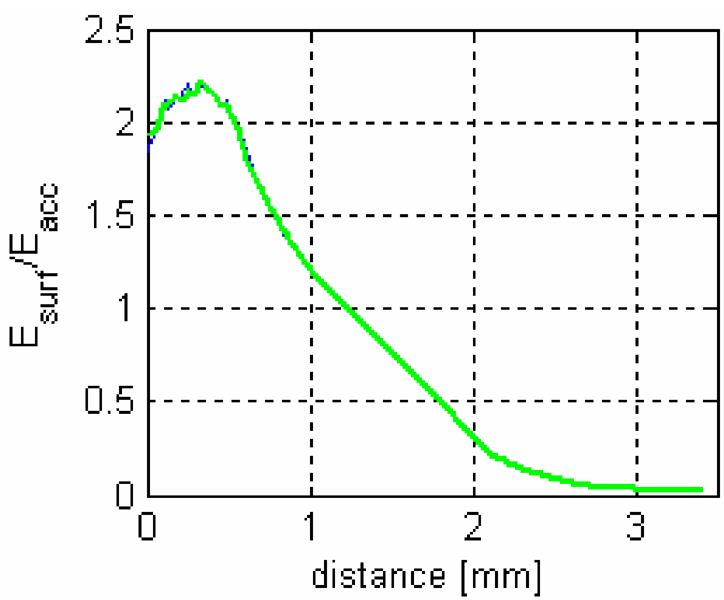
$$P_{in} = 125\,MW$$

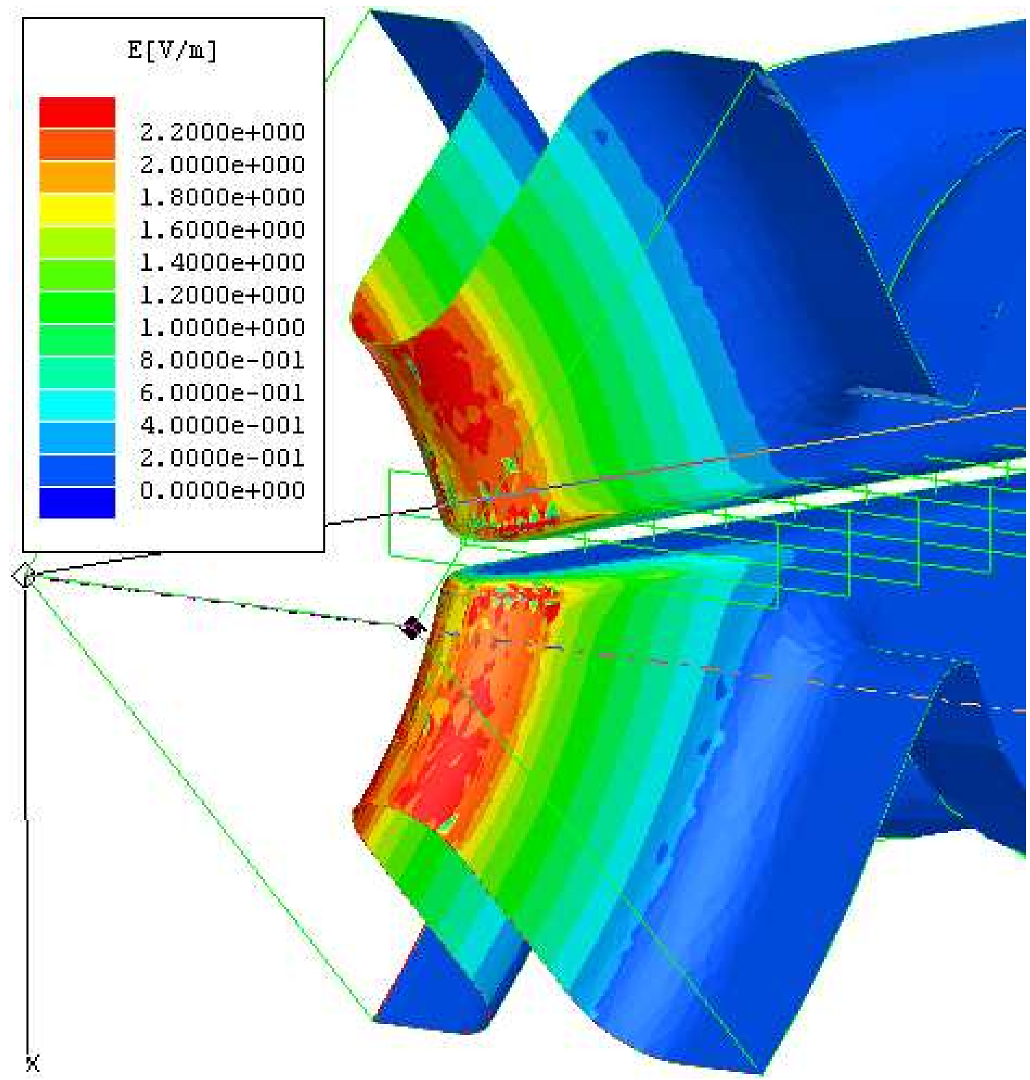
Geometry of HDS cell



Surface electric field in HDS cell

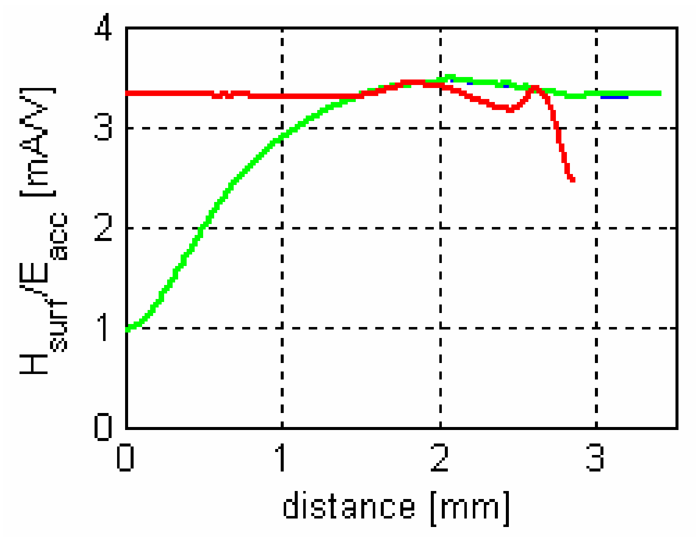
$$E_{surf} / E_{acc} = 2.2$$

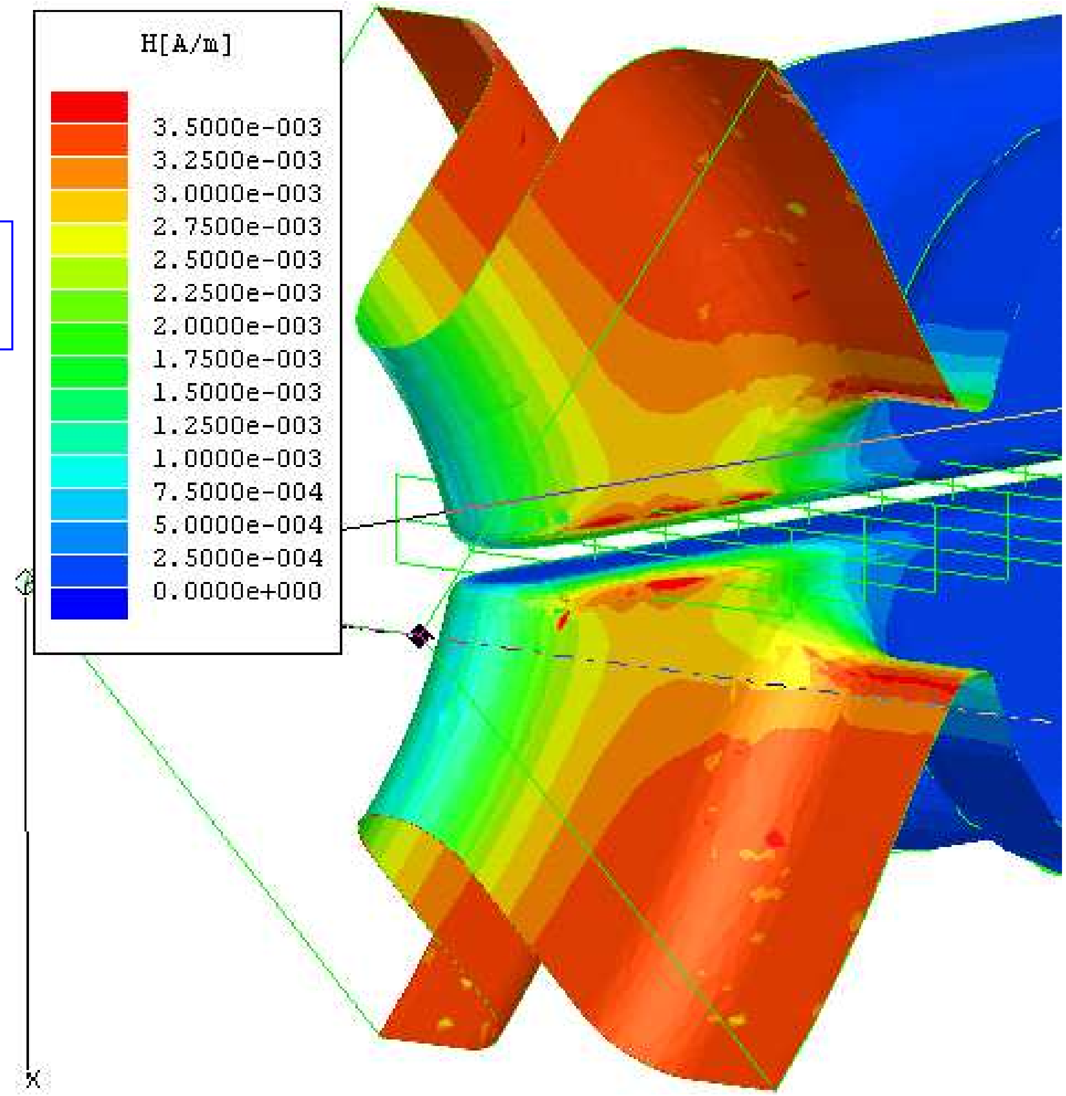




Surface magnetic field in HDS cell

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





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%)

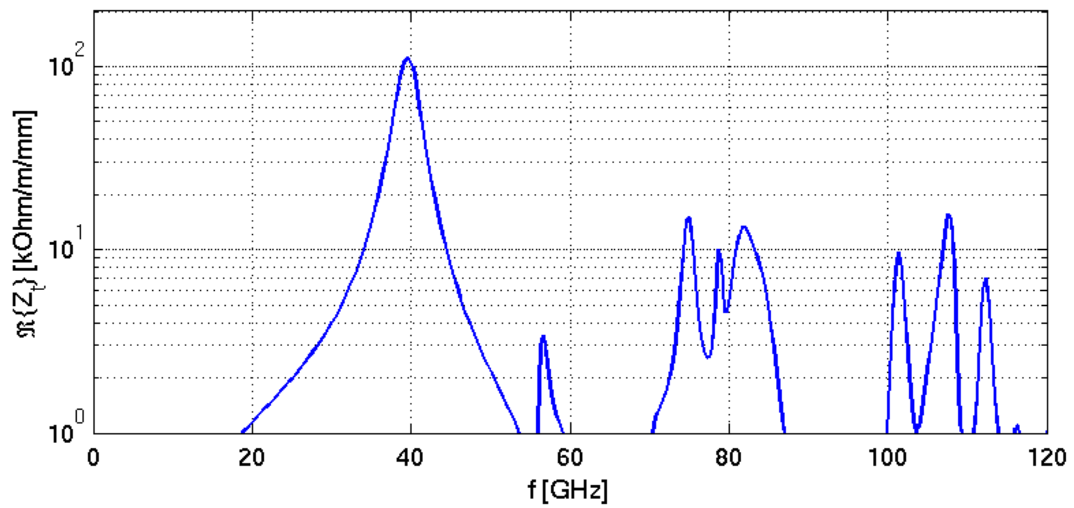
Transverse wakefields calculation

GdfidL in time-domain

$$A_1 = 1120\ V / pC\, mm\, m$$

$$f_1 = 39.66\ GHz$$

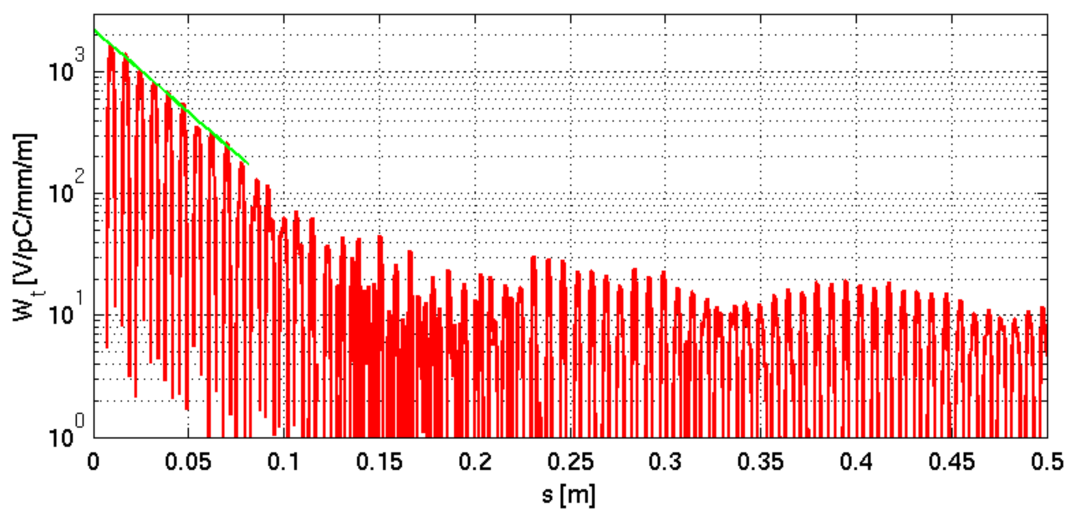
$$Q_1 = 12.6$$



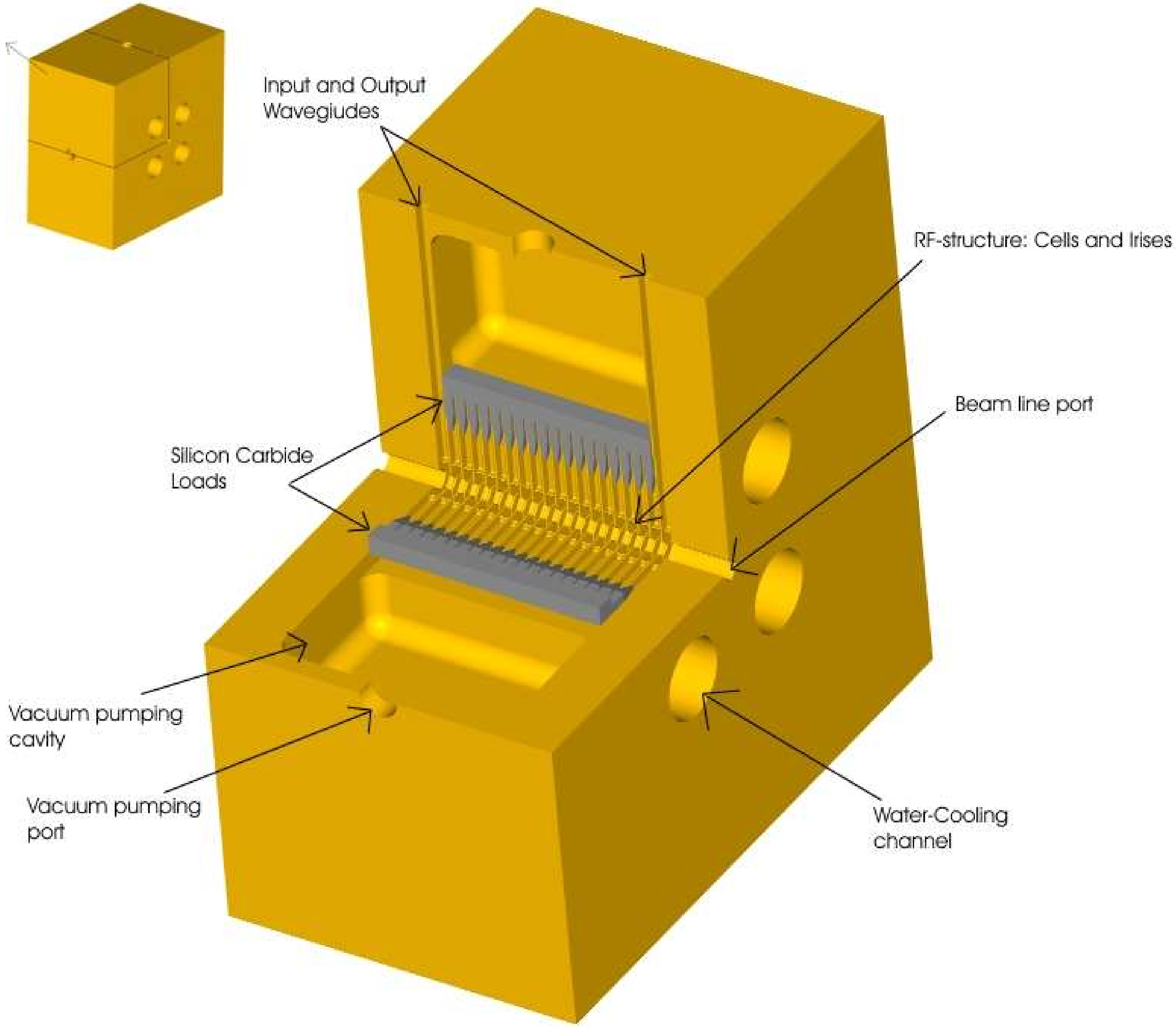
HFSS in frequency-domain

$$f_1 = 39.66\ GHz$$

$$Q_1 = 12.2$$



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

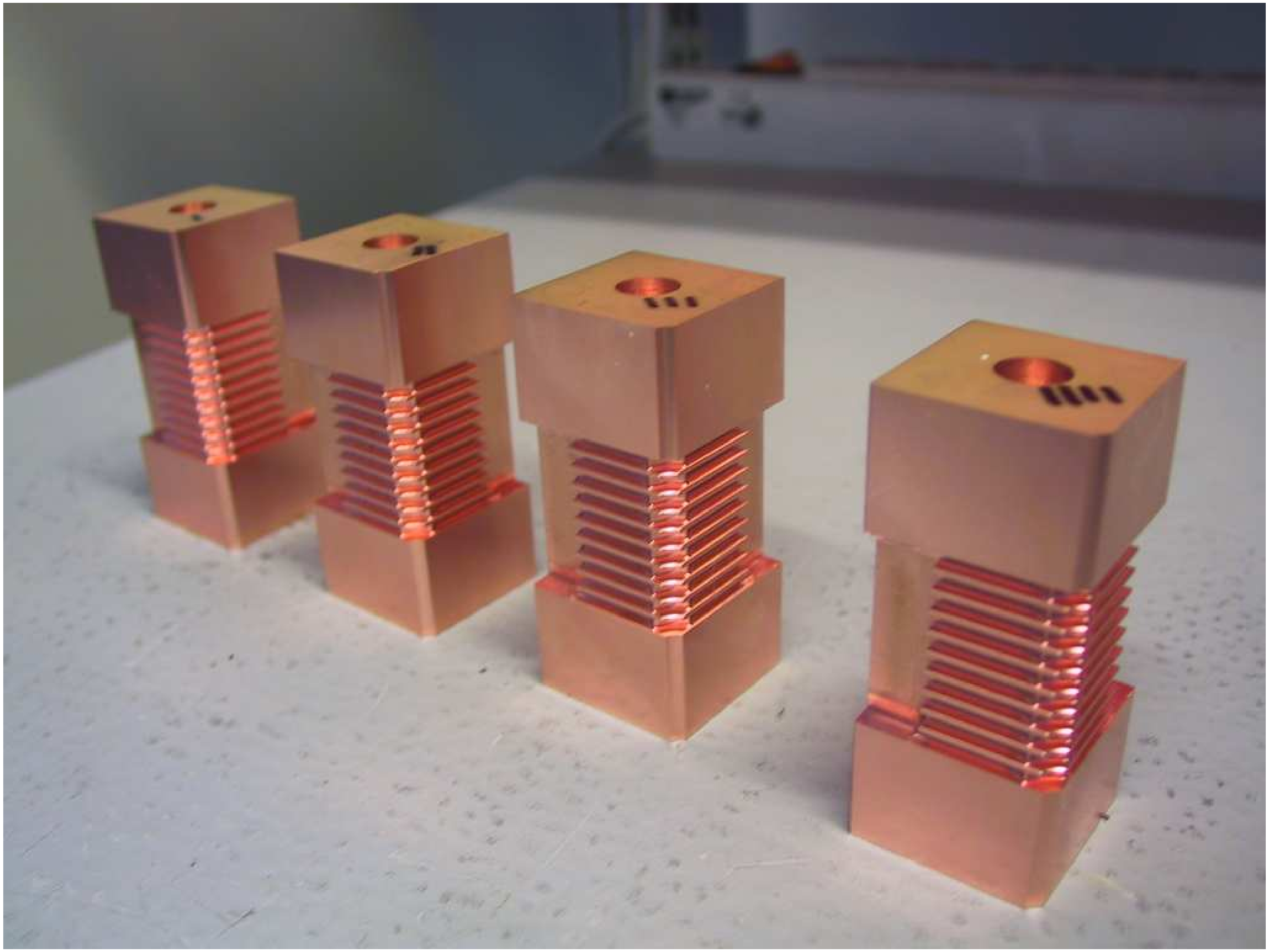
+ Good vacuum pumping capabilities

CONTRA

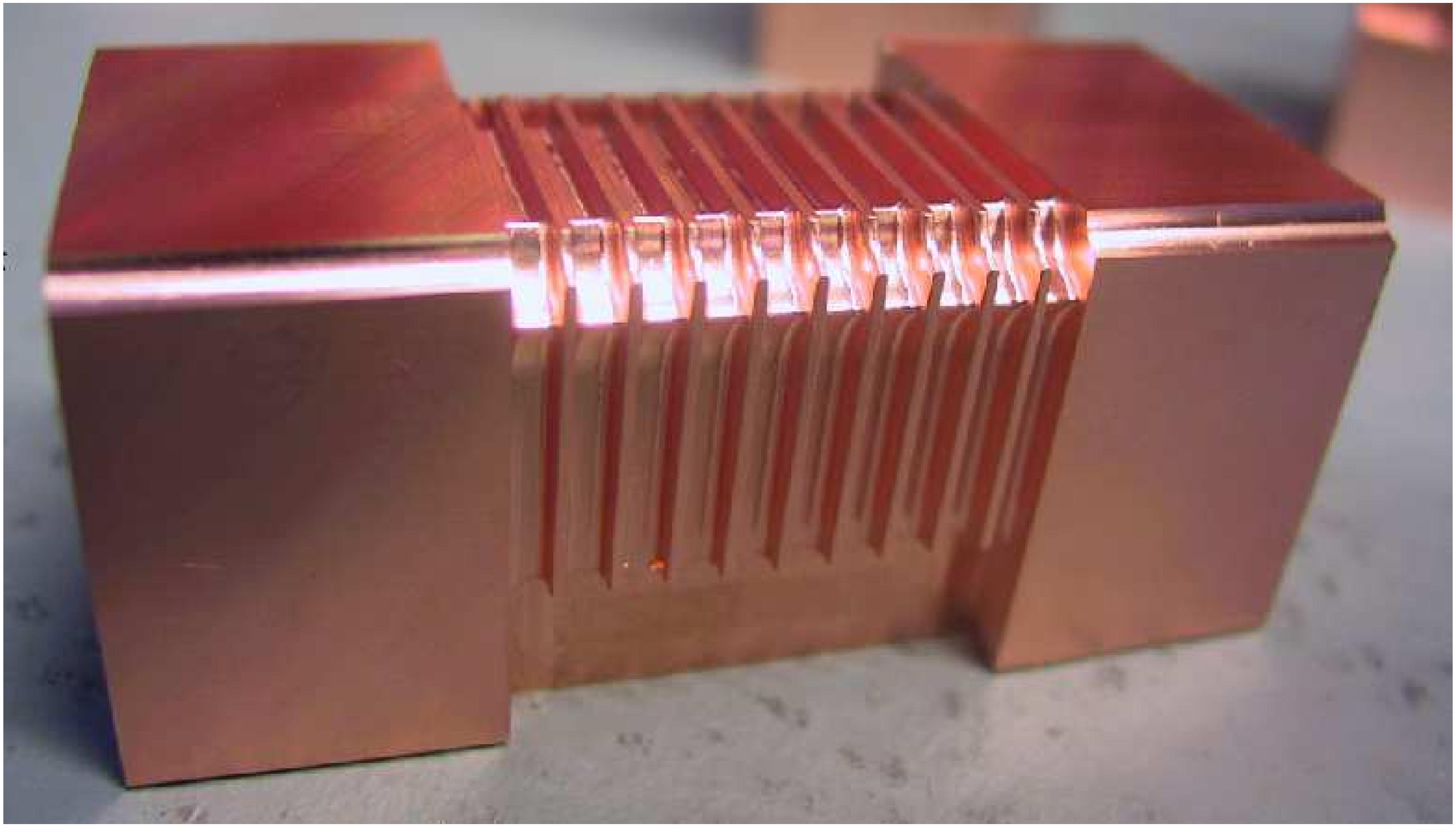
- new technology needs to be shown (machinability, tolerances, etc.)

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

5 micron machining test: 4 x1/4



5 micron machining test: 1/4



2-cells calculation of the structure

Given N, N_b, N_{cycles}

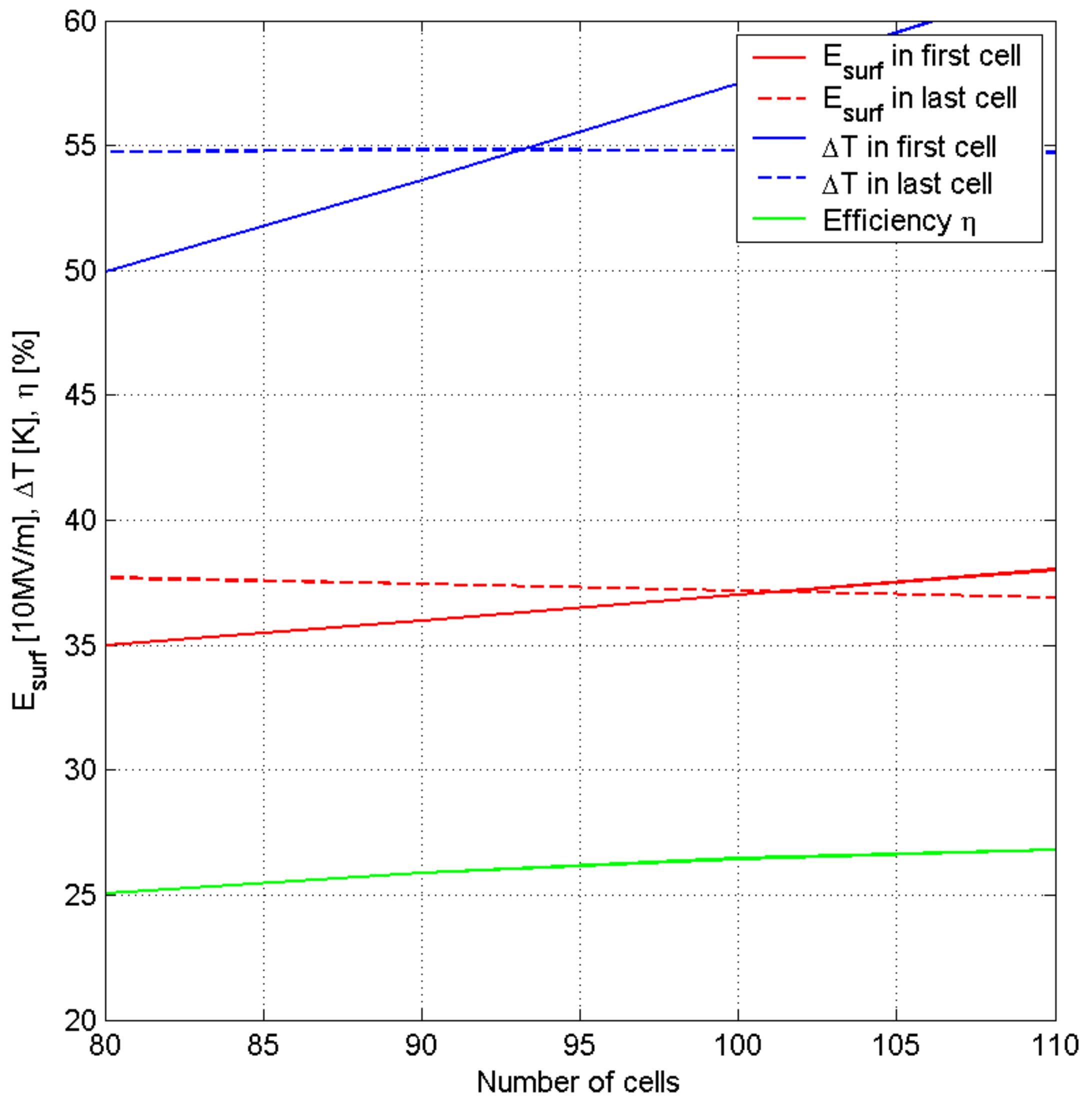
$$\left\langle E_{acc}^{load} \right\rangle = 150 \ ^{MV}\!/_{m}$$

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



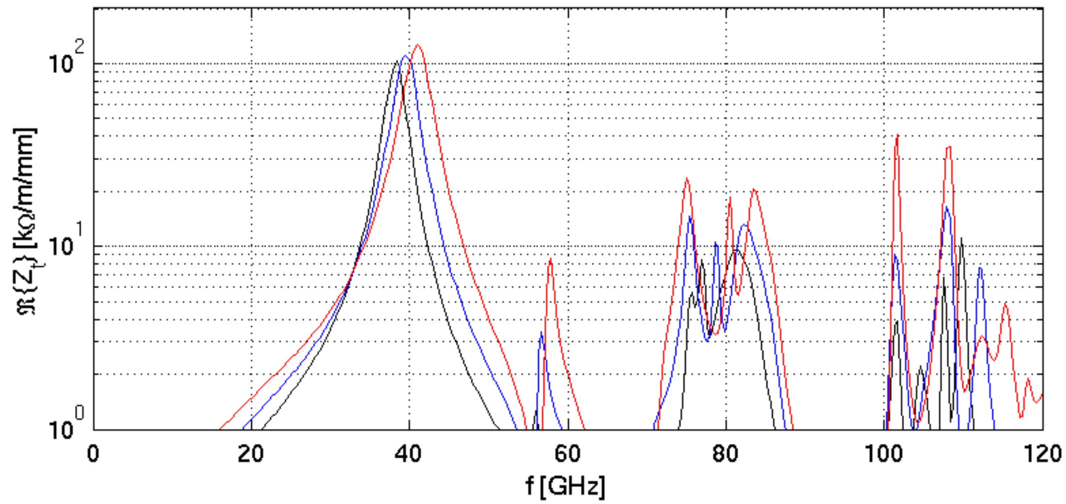
3-cells calculation of wakefields

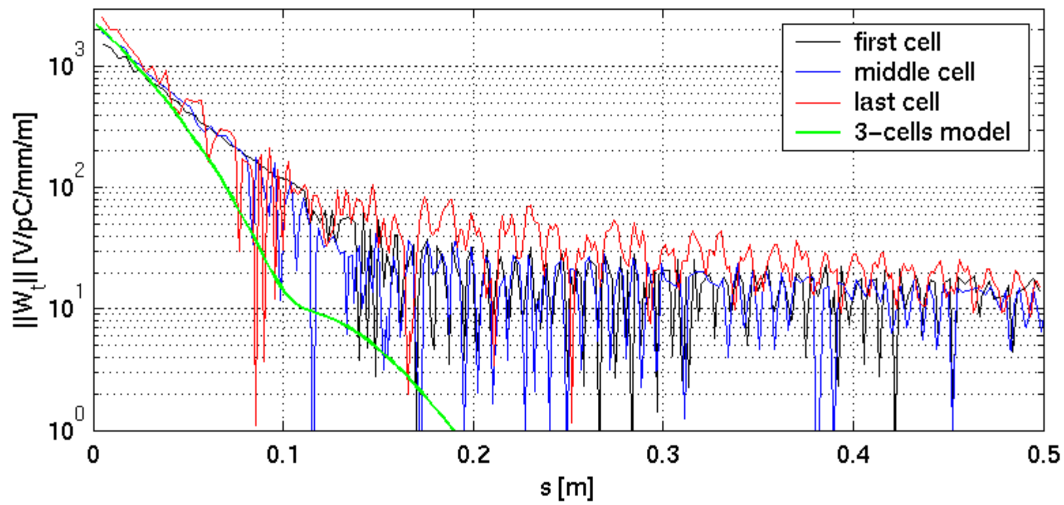
A_1, f_1, Q_1 for each cell are interpolated from its values in the first, middle and last cells and then the structure wakefields are calculated using:

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

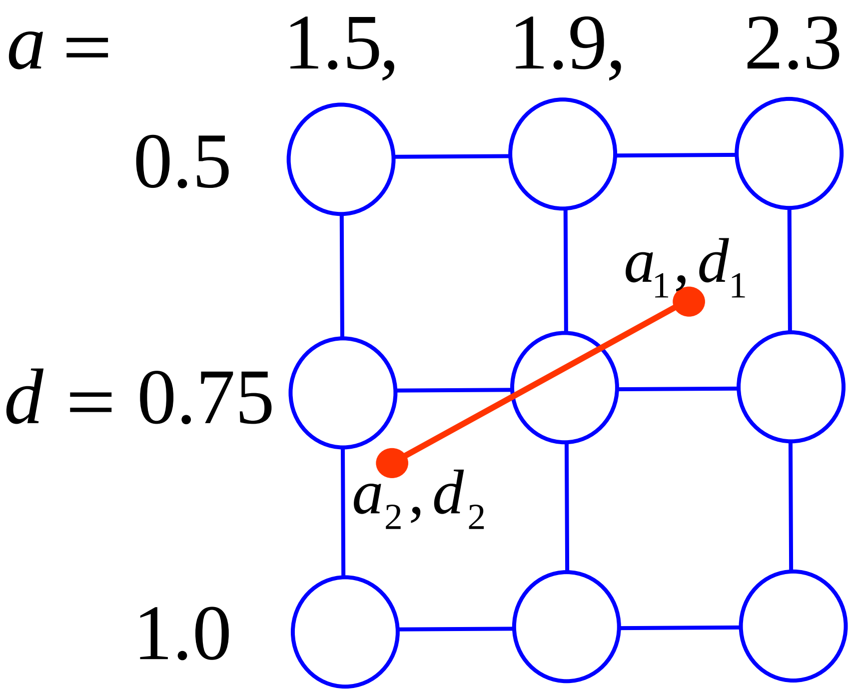
where $$A' = A e^{\frac{\omega^2 \sigma^2}{2c^2}}$$

$$\sigma = 0.6\, mm$$





9-cells interpolation scheme



For each structure,

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

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

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

and

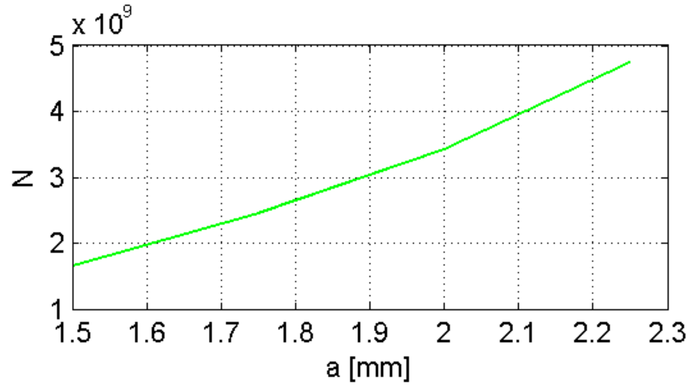
N_b is varied from 1 to 300

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

Beam dynamic constraints

For each structure:

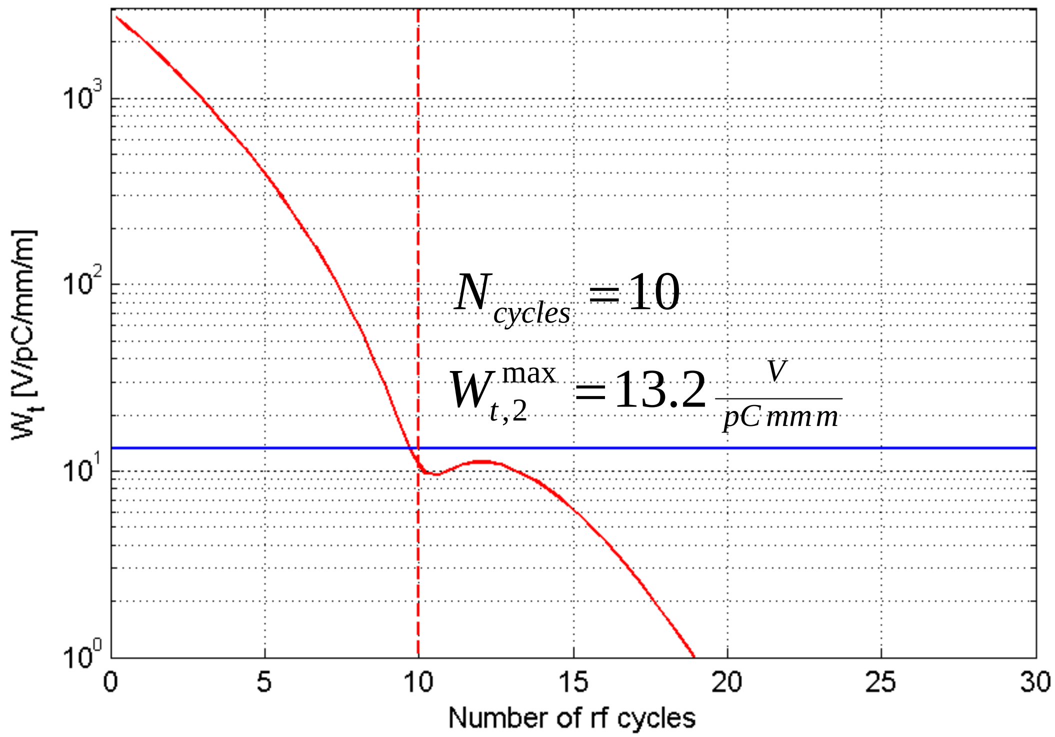
- N is constrained by short-range wakefields



- 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

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

and

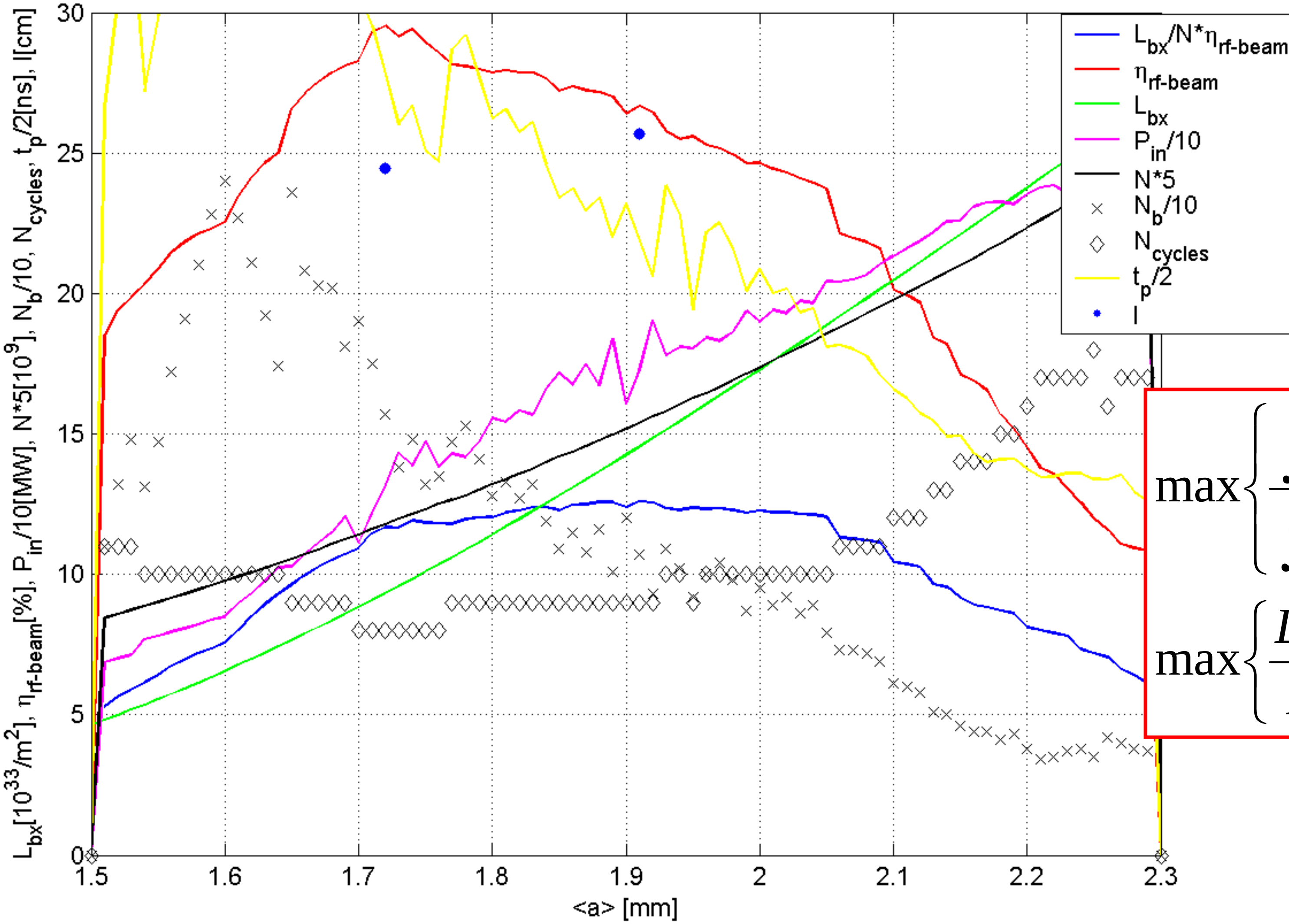
$$\boxed{P_{in} < \sqrt{150ns / t_p} \cdot 100 \, MW}$$

- pulsed surface heating limit for CuZr alloy

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

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

	HDS84 max(L/N*Eff)	HDS80 max(Eff)
$a\,[mm]$	$2.14 \div 1.68$	$1.94 \div 1.5$
$l\,[mm]$	257	244
N_{cycles}	9	8
N_b	107	157
$t_p\,[ns]$	43.8	55.6
$P_{in}\,[MW]$	173	132
N	3.08×10^{9}	2.36×10^{9}
$L_{bx}\,[m^{-2}]$	1.45×10^{34}	0.93×10^{34}
$\eta_{rf-beam}[\%]$	26.7	29.5
$L_{bx}/N\times\eta_{rf-beam}[a.u.]$	12.6	11.7

Efficiency comparison

	DDS	HDS
f [GHz]	11.424	29.985
E_{loaded} [MV/m]	55	150
Efficiency [%]	33	29.5
Bunch spacing [rf cycles]	16	8

Use of Mo iris tips reduces efficiency by ~1%

Outlook

- Optimization of accelerating structure
  - rf phase advance
  - rf frequency
- Investigation of material properties
  - Laser and ultrasound induced fatigue tests
  - DC spark experiments
- Commissioning 30 GHz rf power source in CTF3 for accelerating structure development