CLIC Structure R&D

W. Wuensch

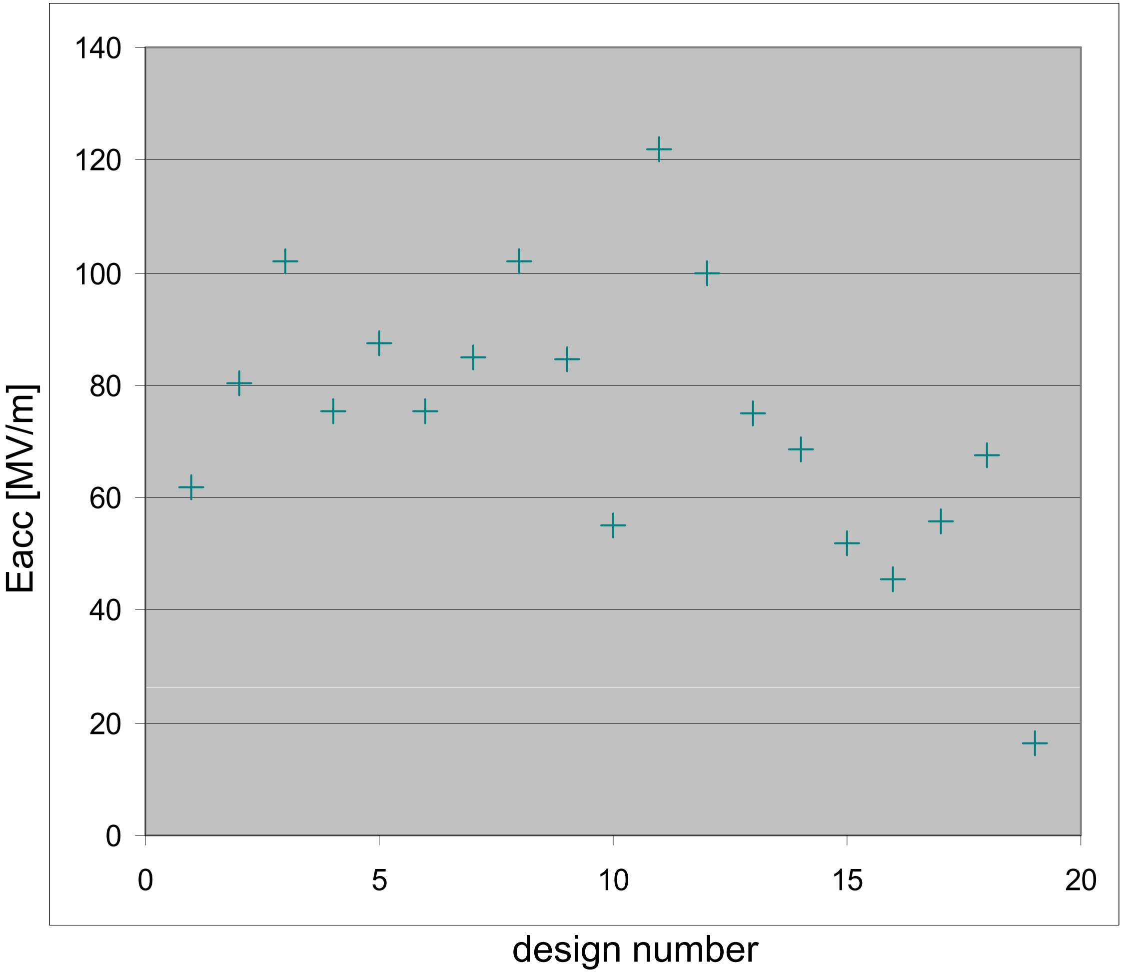
CLIC workshop

16-10-2007

1. What is the status of demonstrating 100 MV/m?

2. Overview of the structure development effort.

Compilation of most measured NLC/JLC/CLIC X-band and 30 GHz accelerating gradients



First cell unloaded, scaled to 100 ns, 10^{-6} breakdown rate, copper

A. Grudiev

This data contains > 100 MV/m but not a structure with all of the necessary characteristics.

To get a full structure we need to understand what is going on.

Part of the variation in the data is due to geometry and part is due preparation, surface, conditioning etc.

The development program: Extract the underlying scalings and dependencies. Design and test structures which give reasonable overall machine efficiency - optimization. Make experiments to validate scaling and dependencies. Make experiments to validate preparation etc. Search for fundamental improvements.

New data from this year

Where we are: Geometrical scaling of gradient and optimization procedure leads us to relatively low aperture, low group velocity structures

We cannot make these structures at 30 GHz due to excessively tight tolerances (this is basically why we went to X-band) so the results from the two 30 GHz structures we have tested so far this year 52 MV/m (100 ns, 10^{-6}, undamped) and 67 MV/m (100 ns, 10^{-6}, damped) do not themselves give high gradients. But they do agree quite well with our geometrical scaling of gradient and the latter structure is heavily damped.

A retest of an old low-ish aperture NLC structure gave 102 MV/m (100 ns, 10^{-6}, undamped) – again good agreement with our model and a step in the right direction. But no damping and just taking this point the loaded gradient would be below 100 MV/m.

Summary: We start to be able to predict rather well the gradient a (copper) structure will achieve – we need to now use this knowledge to actually build a 100 MV/m structure.

So our urgent priority is to produce X-band test structures based on optimized X-band designs. This process started in earnest in late spring and the first structures should be arriving towards the end of the year.

To speed up this process, and to benefit from all the development work made by NLC/JLC, SLAC and KEK are also producing test structures.

In the coming year, all testing which could lead to a feasibility demonstration will occur at SLAC and KEK. The two-beam test stand in CTF3 will be coming on line but will likely be mainly occupied with power production issues.

We hope that our colleagues at SLAC and KEK get good support from their management!

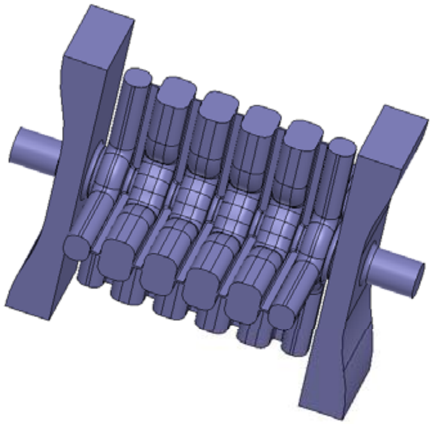
Basic scaling tests, effect of damping, cleaning surface, effect of machining technique and more exotic stuff will be made at X-band and 30 GHz.

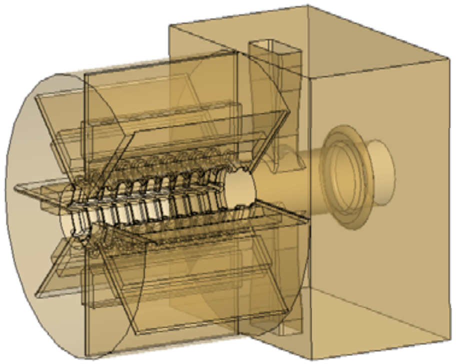
1. What is the status of demonstrating 100 MV/m?

2. Overview of the structure development effort.

Accelerating structure design

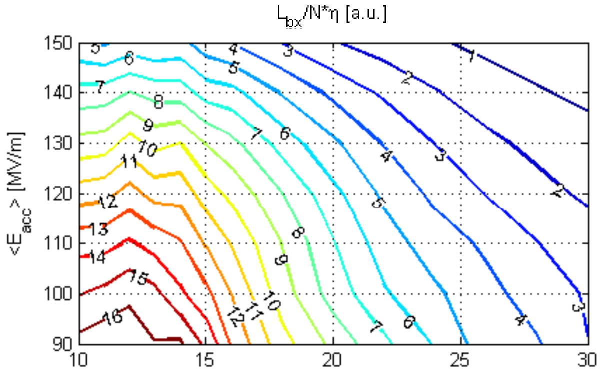
PETS design

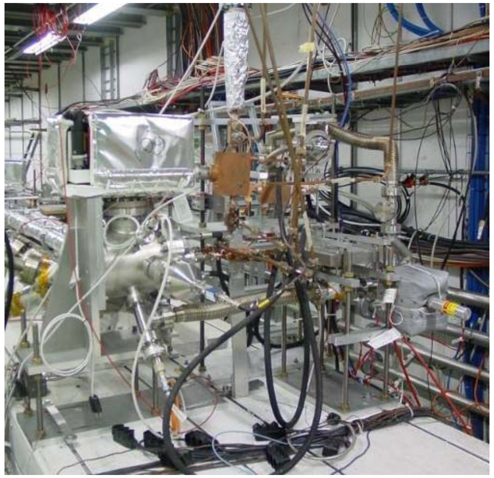




Structure-machine optimization

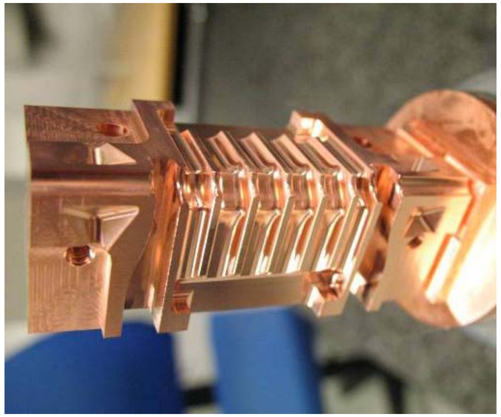
rf testing



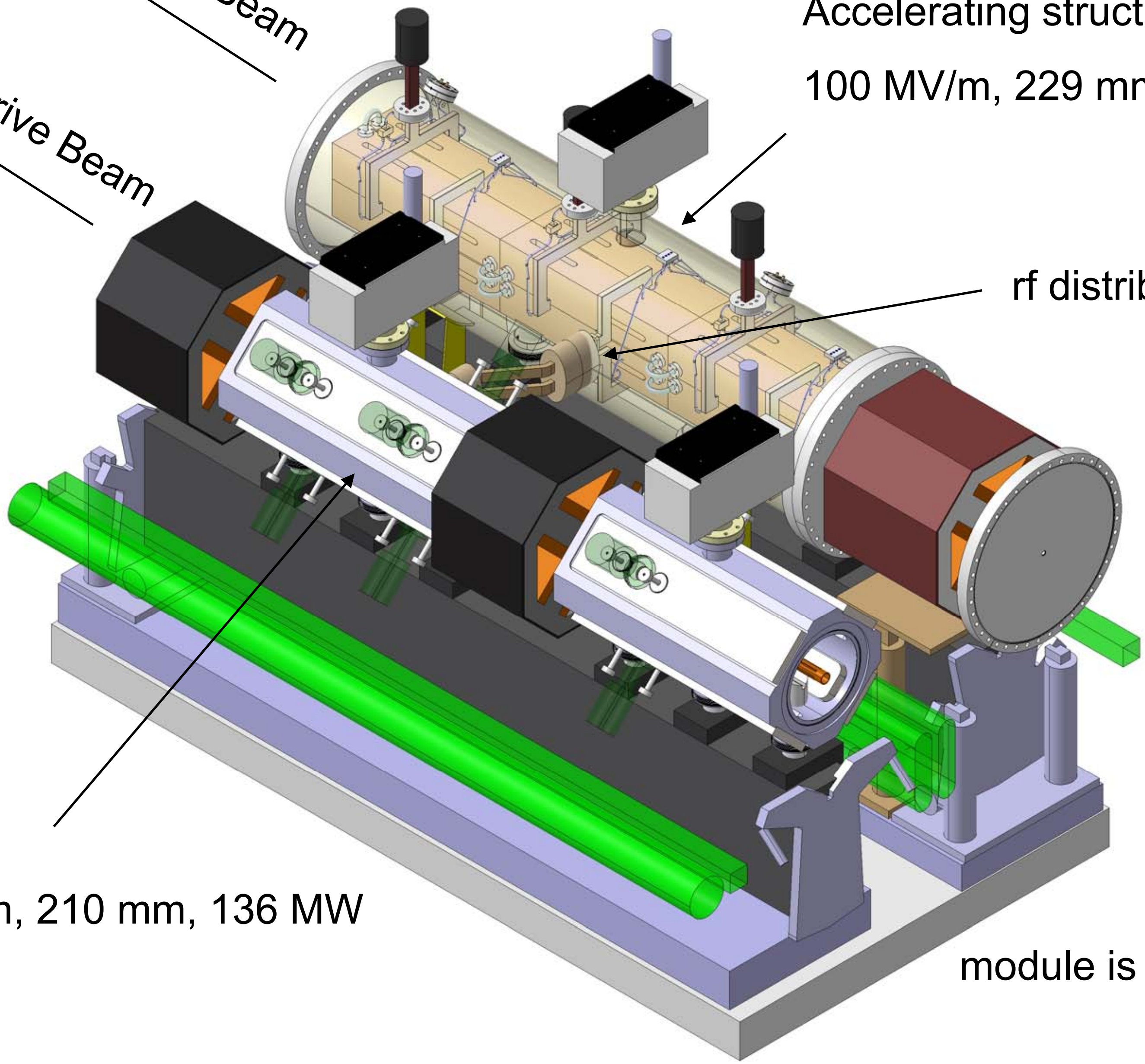


Study of high-power limits, breakdown and pulsed surface heating

Technology, fabrication materials and integration



CLIC module



Main Beam

Drive Beam

Accelerating structure

100 MV/m, 229 mm, 64 MW

rf distribution

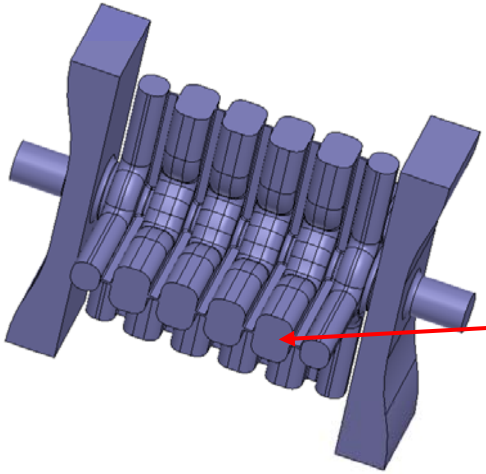
PETS

-6.5 MV/m, 210 mm, 136 MW

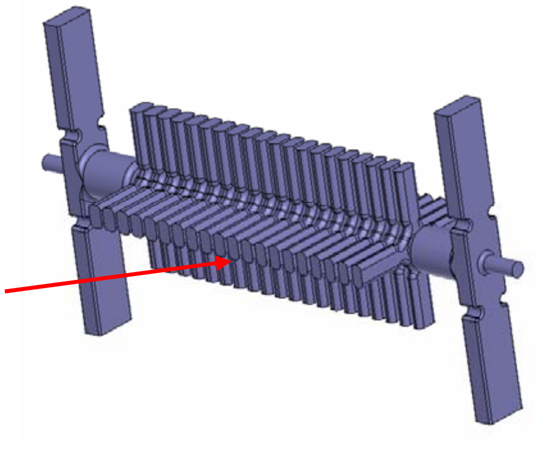
module is 2 m long

Accelerating structures

Geometry of CLIC accelerating structures

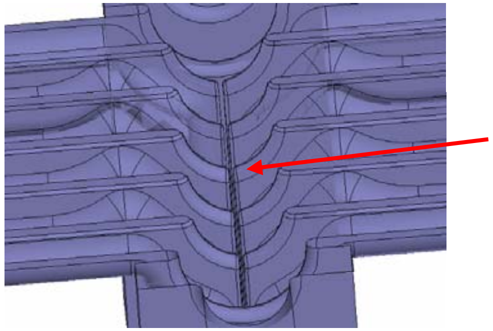


Higher order mode damping waveguides necessary for beam stability

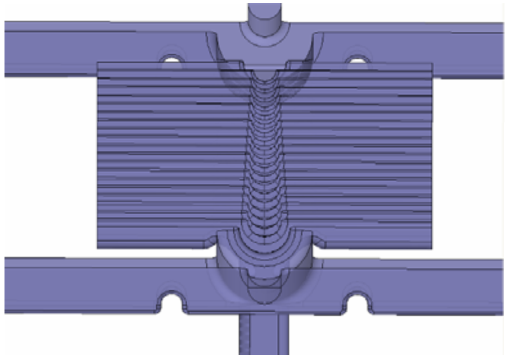


HDS – slot and waveguide

WDS – waveguide only



damping slot for stronger damping



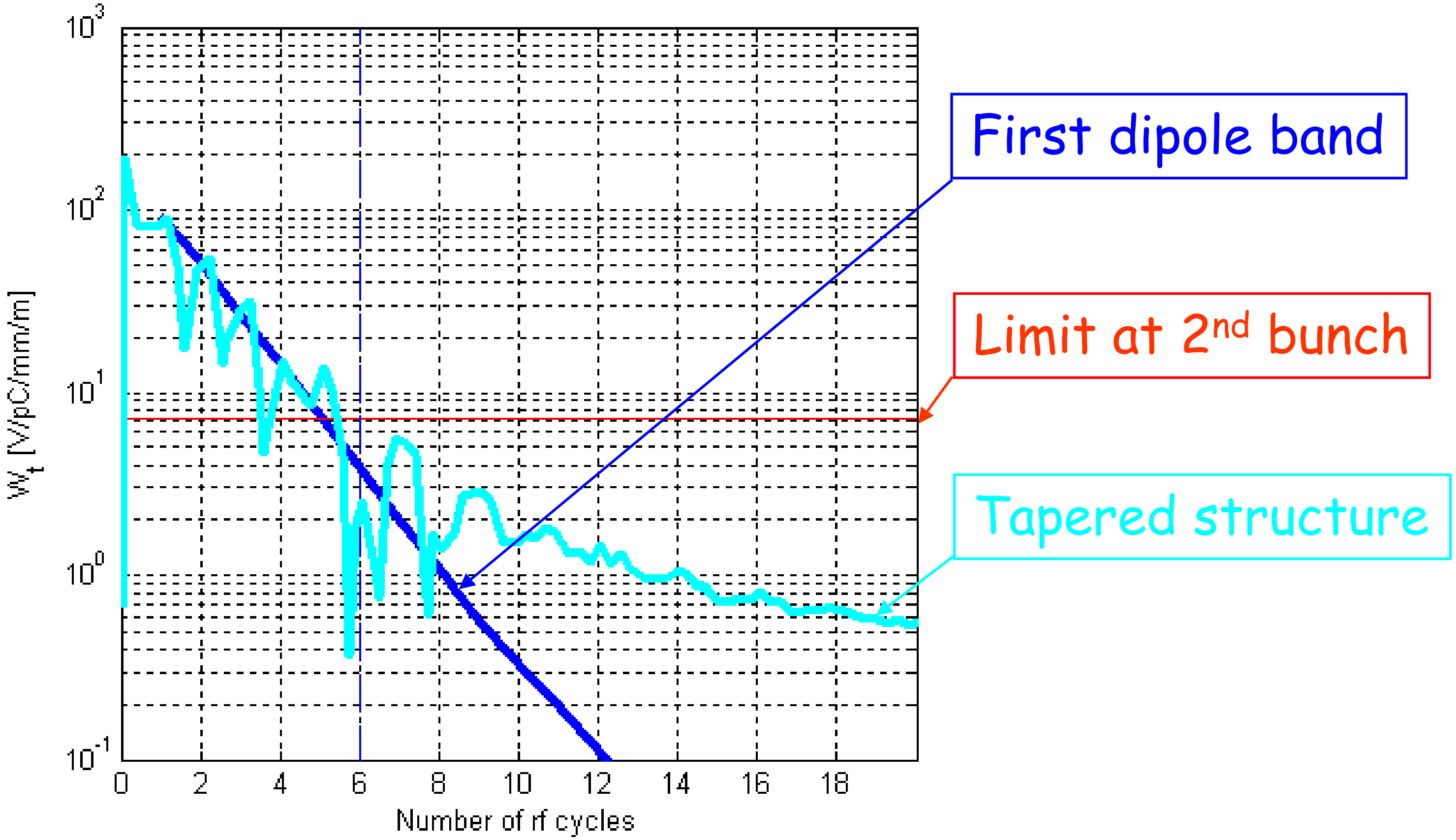
Must be milled quadrants. These can be clamped so exotic alloys, bimetallic possible.

Technology

Can be milled quadrants or turned and milled disks. Disks must be brazed so are restricted to annealed copper.

Transverse long-range wakes in CLIC_G

cell	first	middle	last
Q_1	10	7.7	6.3
A_1 [V/pC/mm/m]	117	140	156
f_1 [GHz]	16.74	17.21	17.67

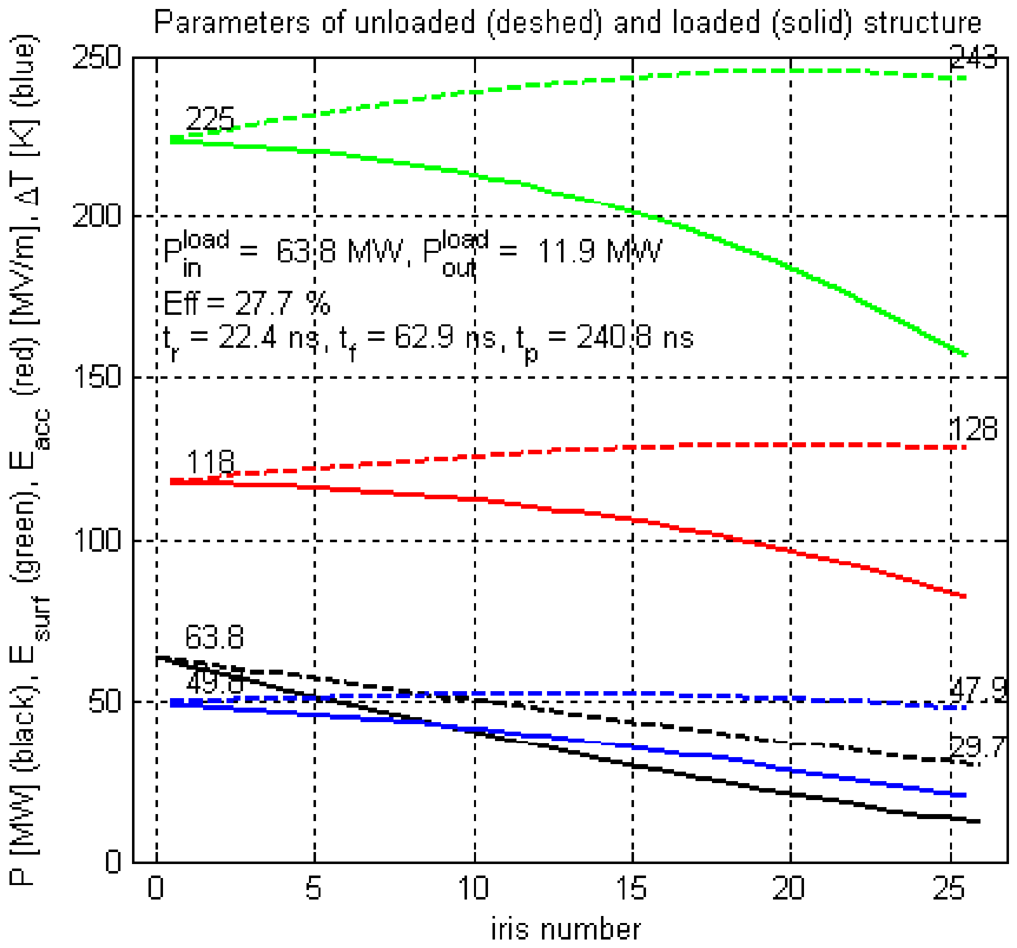


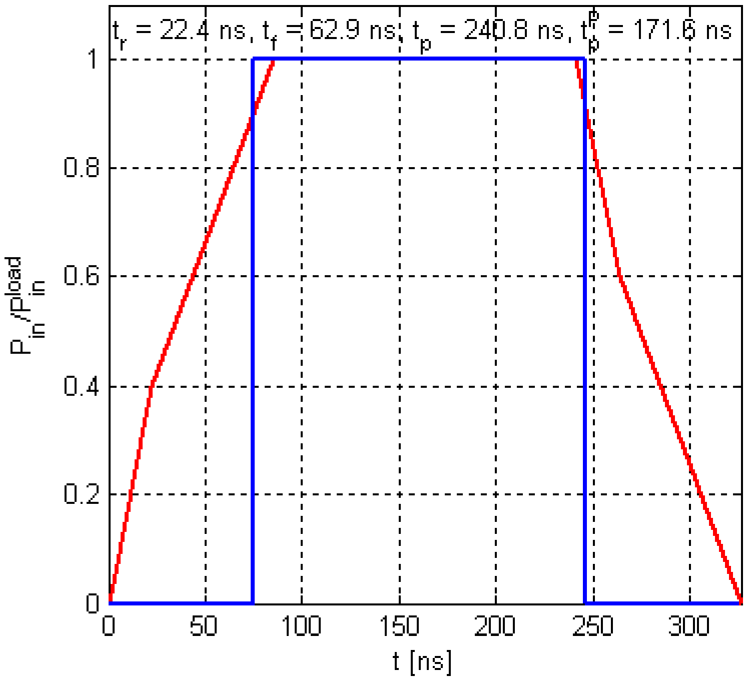
Parameters of new structure

Structure	CLIC_G
Frequency: f [GHz]	12
Average iris radius/wavelength: $\langle a \rangle/\lambda$	0.11
Input/Output iris radii: $a_{1,2}$ [mm]	3.15, 2.35
Input/Output iris thickness: $d_{1,2}$ [mm]	1.67, 1.00
N. of reg. cells, str. length: N_c, l [mm]	24, 229
Bunch separation: N_s [rf cycles]	6
Luminosity per bunch X-ing: $L_{b\times}$ [m^{-2}]	1.22×10^{34}
Bunch population: N	3.72×10^{9}
Number of bunches in a train: N_b	312
Filling time, rise time: τ_f, τ_r [ns]	62.9, 22.4
Pulse length: τ_p [ns]	240.8
Input power: P_{in} [MW]	63.8
$P_{in}/C t^{P}{}_{p}{}^{1/3}$[MW/mm ns$^{1/3}$]	18
Max. surface field: E_{surf}^{max} [MV/m]	245
Max. temperature rise: ΔT^{max} [K]	53
Efficiency: η [%]	27.7
Figure of merit: $\eta L_{b\times}/N$ [a.u.]	9.1

High power constraints

CLIC_G structure parameters

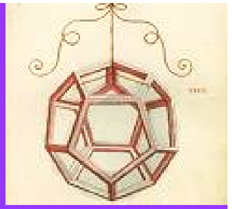




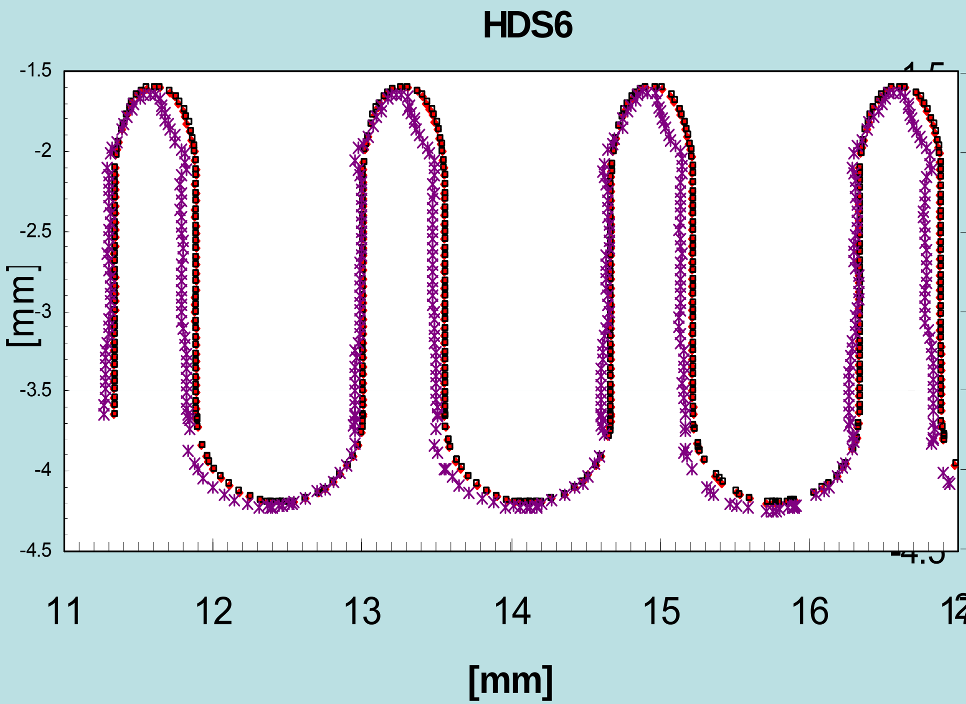
Accuracy:

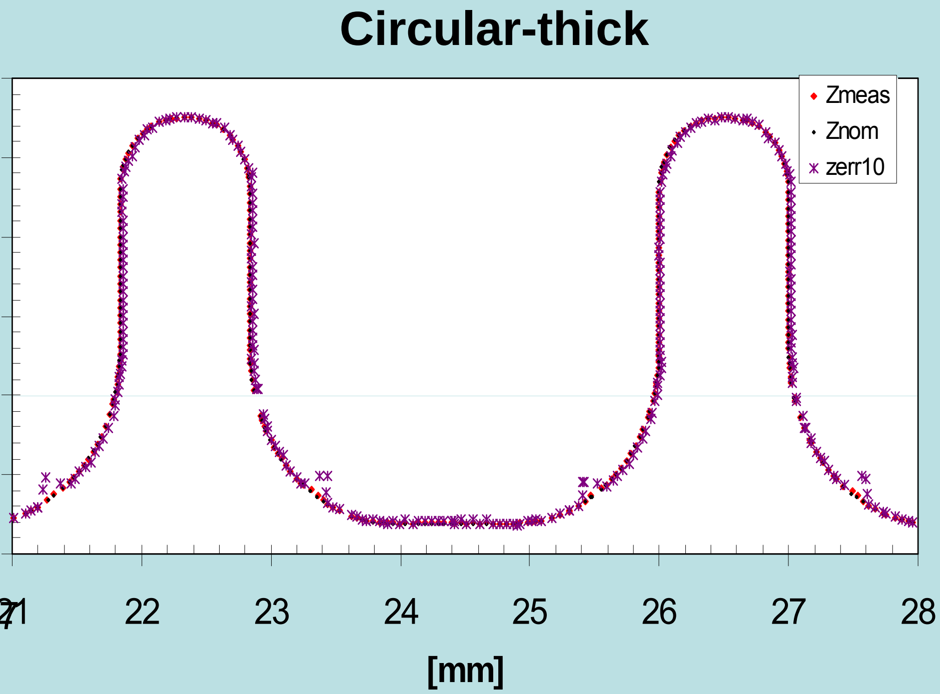
Present specifications: 5 µm shape tolerance
(…..the best that can be done)

Metrology on copper quadrants



Measurement: coordinate measuring machine, contact with 0.1N force, accuracy +/-3 µm (at CERN), scan pt. by pt. on the surface ....in parallel with RF low power control



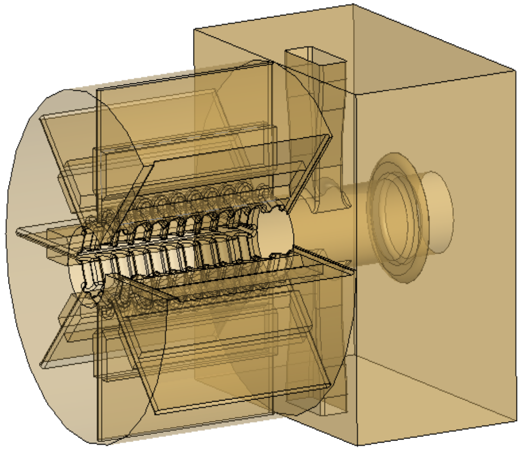


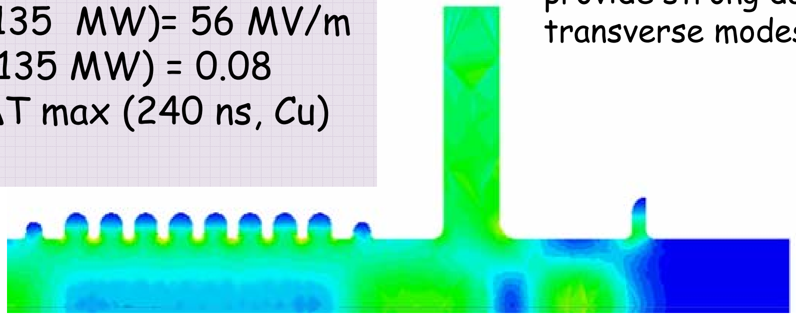
PETS

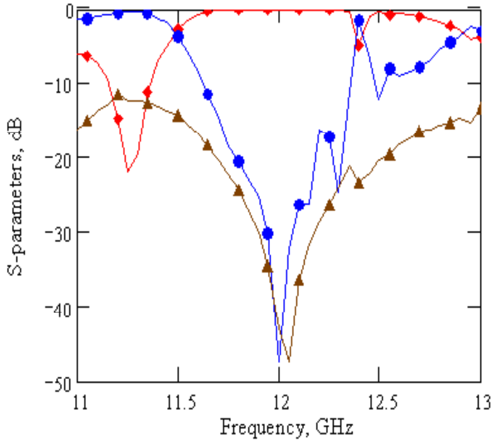
CLIC Power Extraction and Transfer Structure (PETS)

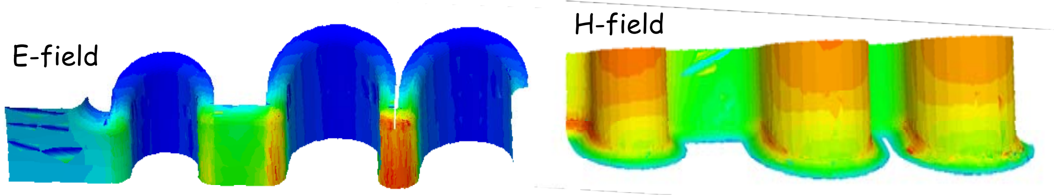
PETS parameters:
- Aperture = 23 mm
- Period = 6.253 mm (90^0/cell)
- Iris thickness = 2 mm
- R/Q = 2258 Ω
- V group= 0.453
- Q = 7200
- P/C = 13.4
- E surf. (135 MW)= 56 MV/m
- H surf. (135 MW) = 0.08 MA/m (ΔT max (240 ns, Cu) = 1.8 C^0)

In its final configuration, PETS comprises eight octants separated by the damping slots. Each of the slots is equipped with HOM damping loads. This arrangement follows the need to provide strong damping of the transverse modes.





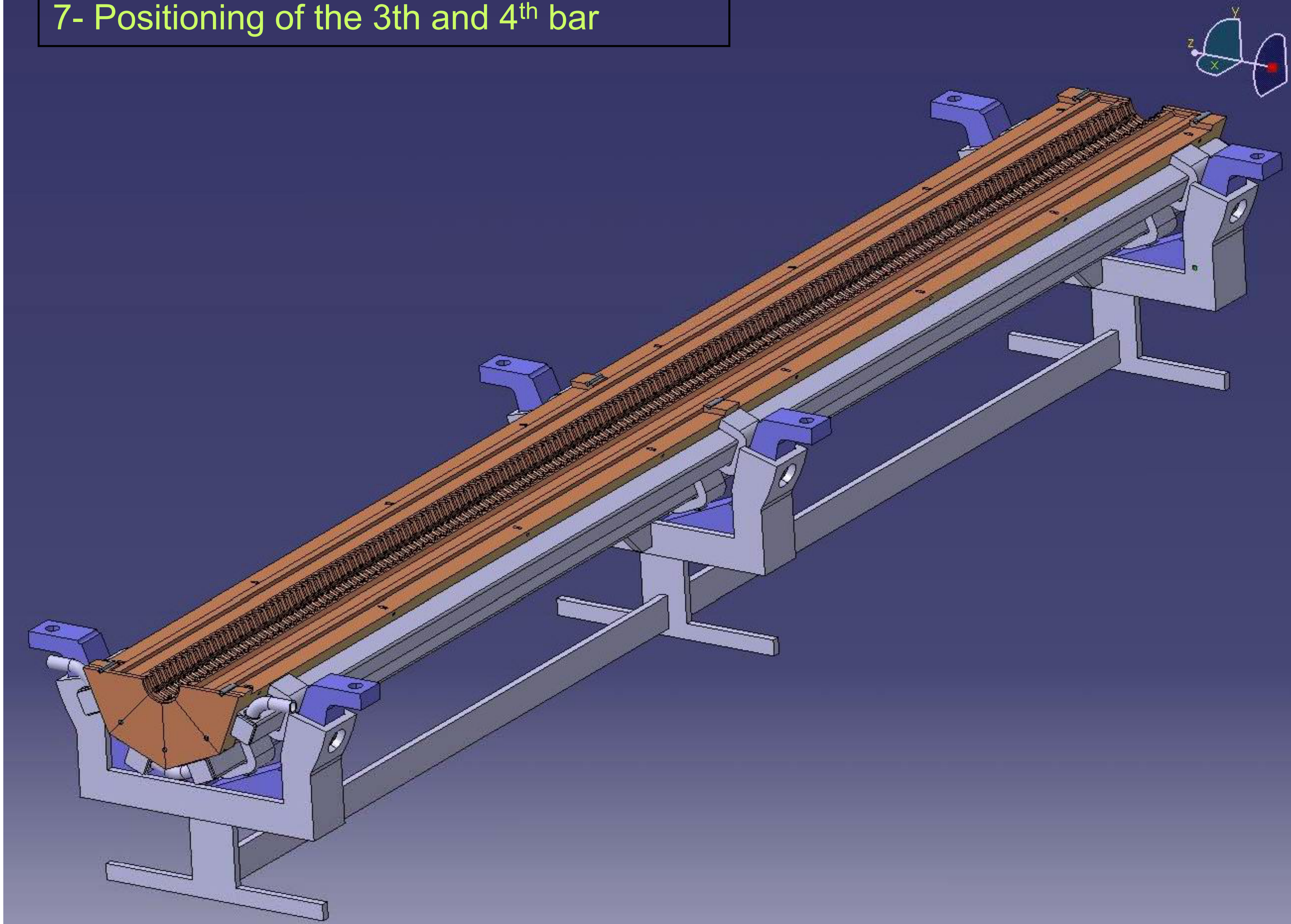




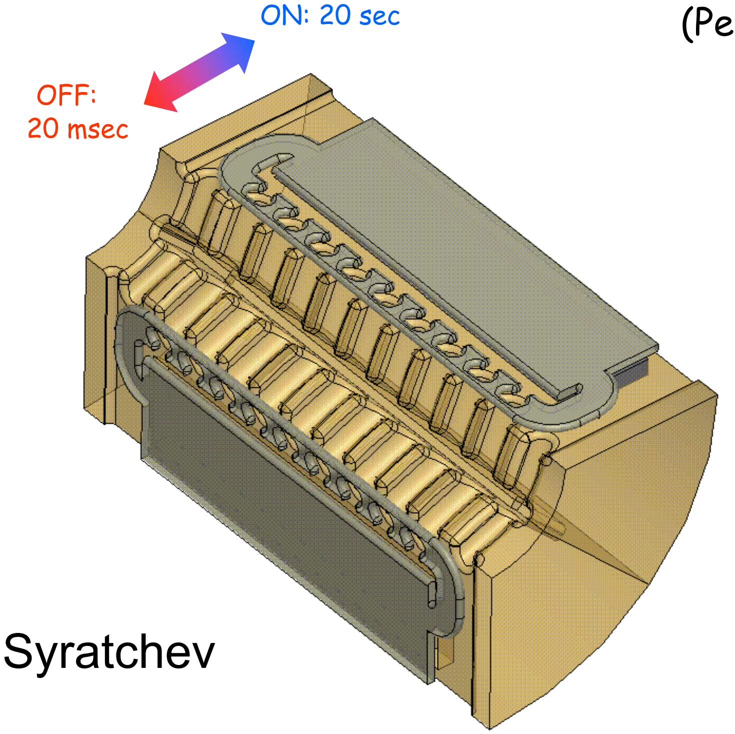
To reduce the surface field concentration in the presence of the damping slot, the special profiling of the iris was adopted.

I. Syratchev

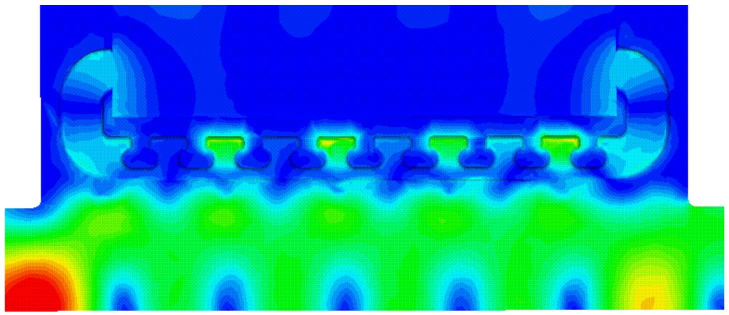
7- Positioning of the 3th and 4th bar

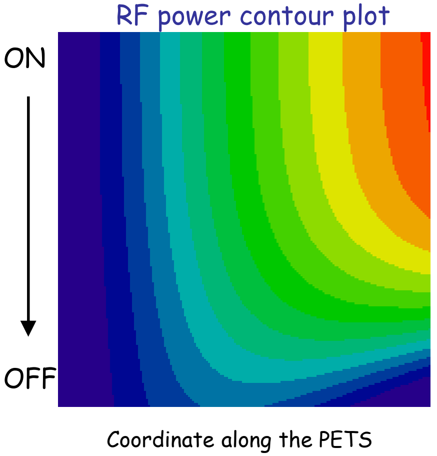


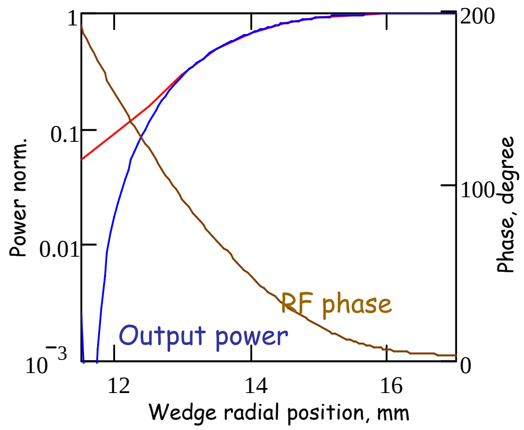
Local termination of the RF power production in the PETS (Petsonov)

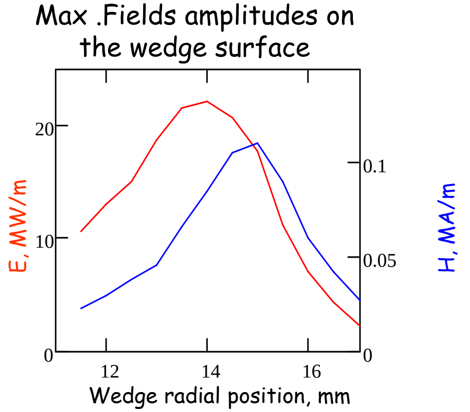


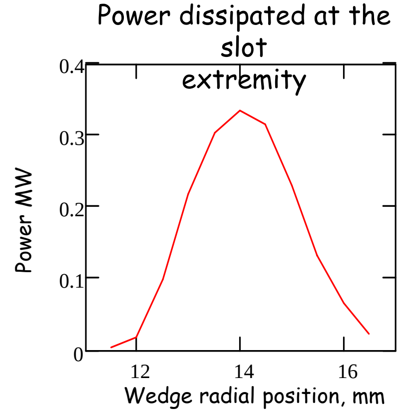
I. Syratchev

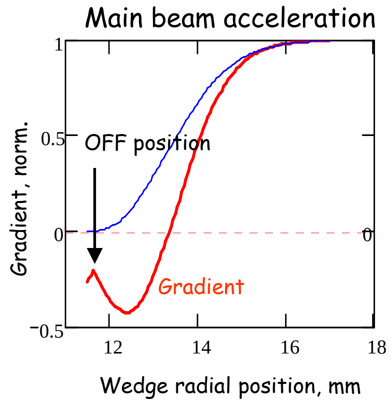












The net RF power generated by the beam at the end of the constant impedance structure will be zero if the structure synchronous frequency is detuned by amount ±β*c*/(1-β)*L*, where β – Vg /c and *L* - length of the structure. We have found that such a strong detuning can be achieved by inserting four thin wedges through four of the eight damping slots.

High power constraints:

breakdown – sparks in high surface electric field and high power flow regions

pulsed surface heating – surface deterioration from fatigue in high surface magnetic field regions

Quantifying these high power constraints are essential for making a true high-power design and are a basic input to the overall CLIC optimization procedure.

Going beyond designing low power microwave properties and guessing the high-power performance.

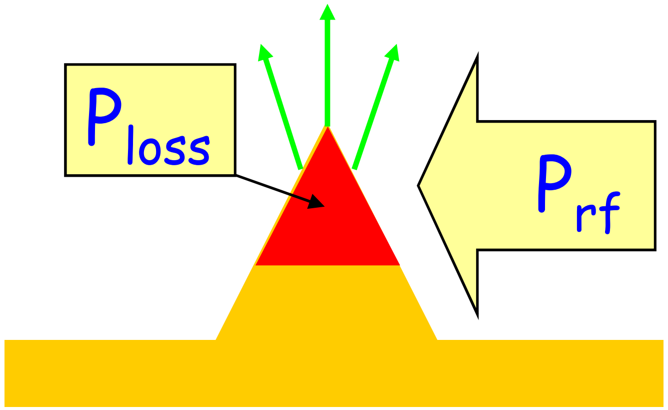
The breakdown limit has been poorly understood until now – requires a reasonable understanding of the origin of breakdown. We believe we have made a significant contribution to this.

The induced stress in pulsed surface heating is easily calculated but appropriate material property data hasn’t available – especially at the high number of cycles needed for CLIC.

Breakdown

Pulsed surface heating

Field emission and rf power flow



$$\Delta T \approx P_{loss} < P_{rf}$$

$$P_{loss} = \int_V J_{FN} \cdot E \, dv$$

$$P_{rf} = \oint_S E \times H \, ds$$

1. Field emission currents J_{FN} heat a (possible) breakdown site up to a temperature rise ΔT on each pulse.
2. After a number of pulses the site is modified so that J_{FN} increases so that ΔT increases above a certain threshold.
3. Breakdown takes place.

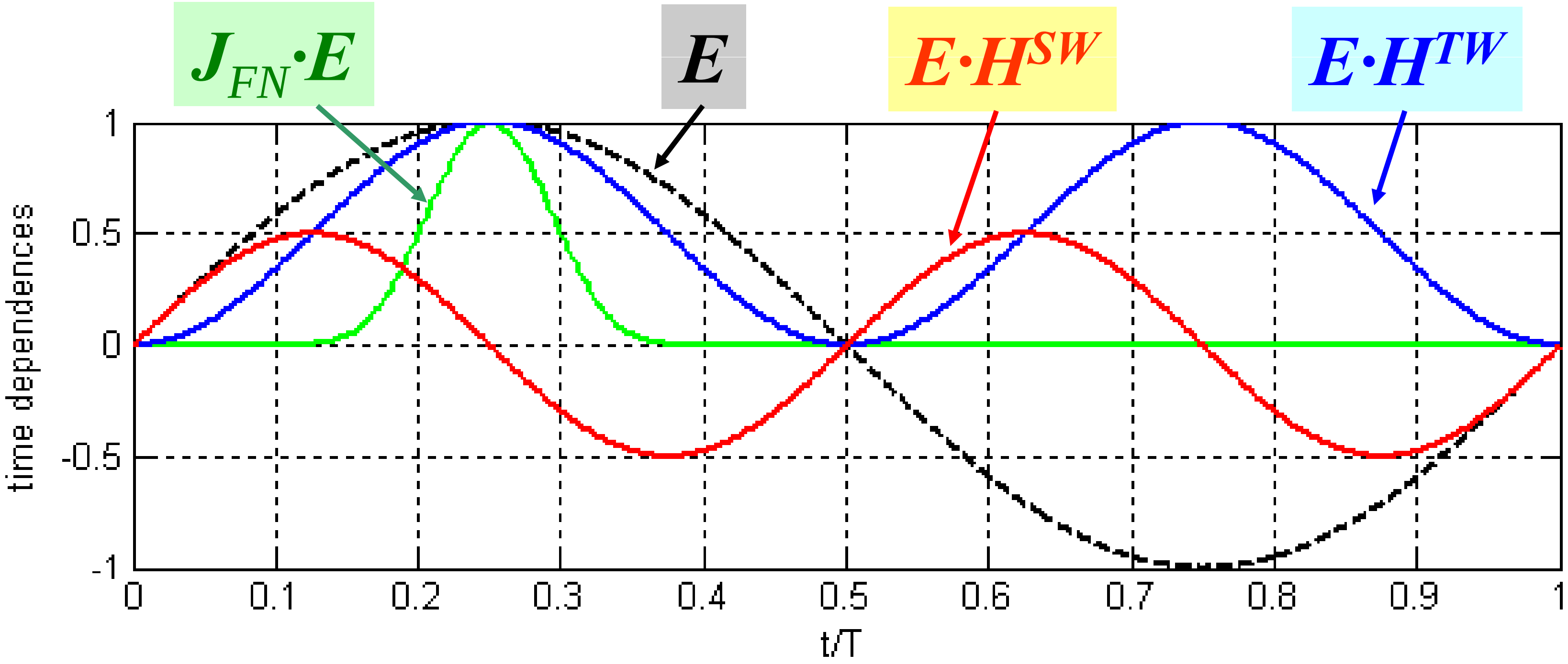
This scenario can explain:

- Dependence of the breakdown rate on the gradient (Fatigue)
- Pulse length dependence of the gradient (1D÷3D heat flow from a point-like source)

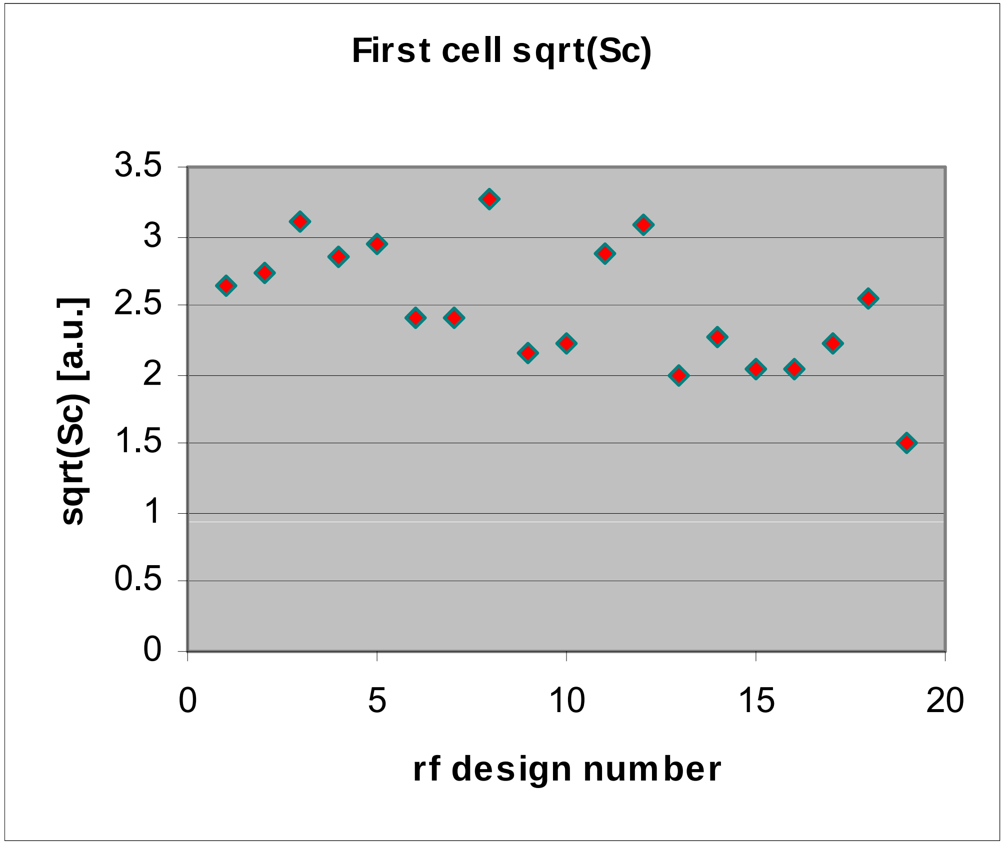
Field emission and power flow

$$E \times H = E_0 \cdot H_0^{TW} \sin^2 \omega t + E_0 \cdot H_0^{SW} \sin \omega t \cos \omega t$$

$$J_{FN} \cdot E = A E_0^3 \sin^3 \omega t \cdot \exp\left(\frac{-62\,GV/m}{\beta E_0 \sin \omega t} \right)$$



New rf breakdown constraint



$$S_c = \mathrm{Re}\{S\} + 0.2 \cdot \mathrm{Im}\{S\}$$

Spread is ~ ±25%

(in linear field scale)

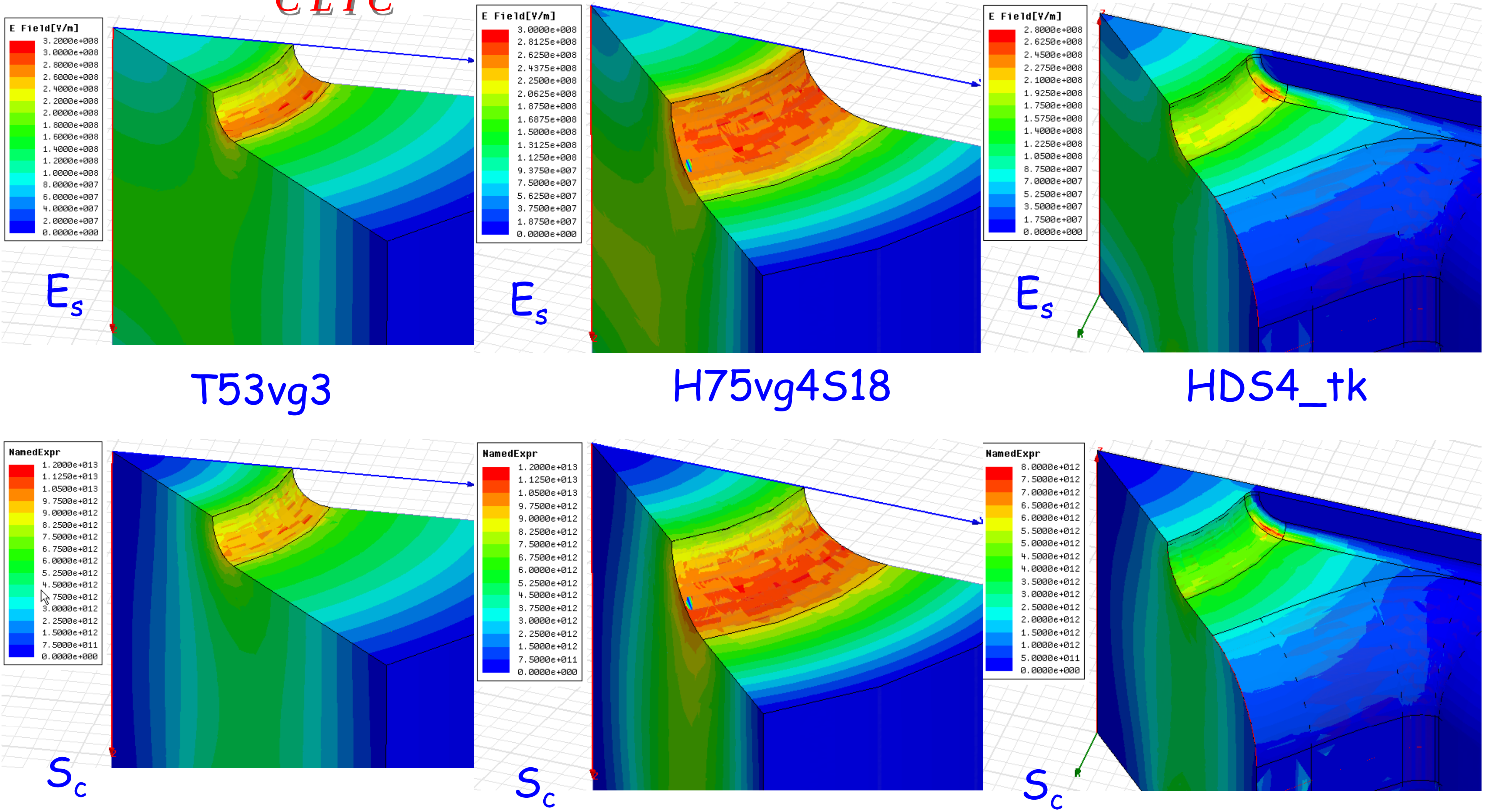
Almost the same as P/C,

but in addition

1. This is a local field quantity f scaling.
2. H75vg4S18 fits.
3. Describes standing wave structures.

Depending on the degree of optimism we can choose $S_c = 5 \div 9$ [MW/mm^2]

Surface distributions for low v_g

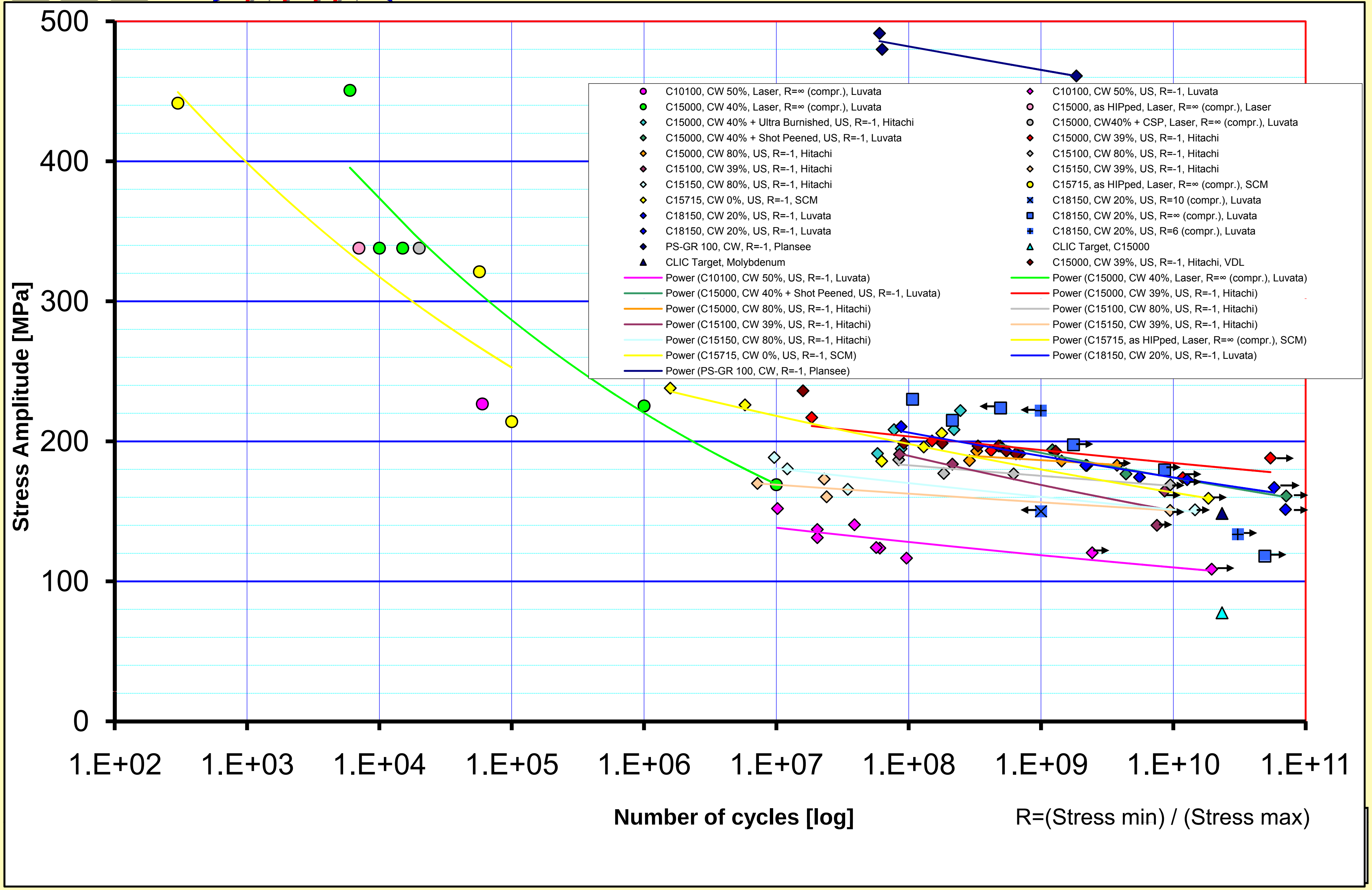


Surface distribution is similar to the electric field one

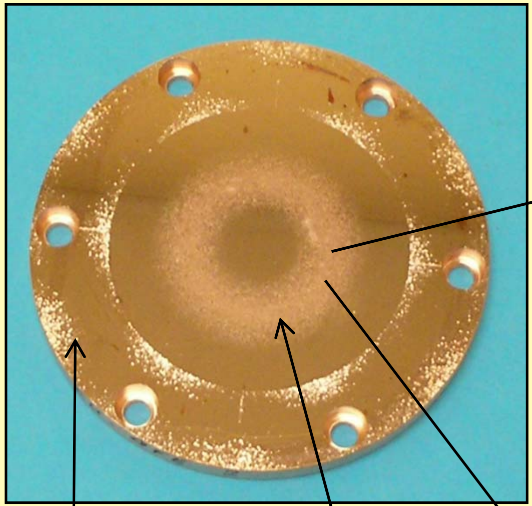
Breakdown

Pulsed surface heating

Wöhler curves of the test results (Stress vs. N)

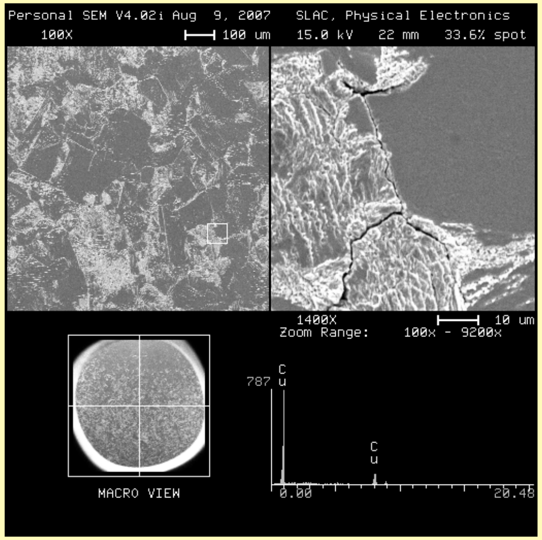


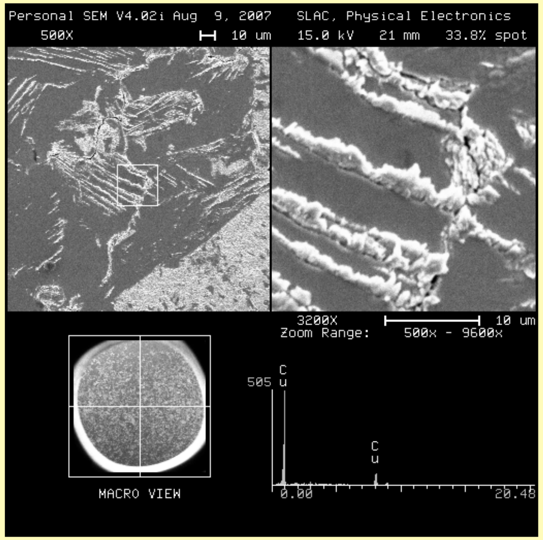
Fatigue by RF experiments

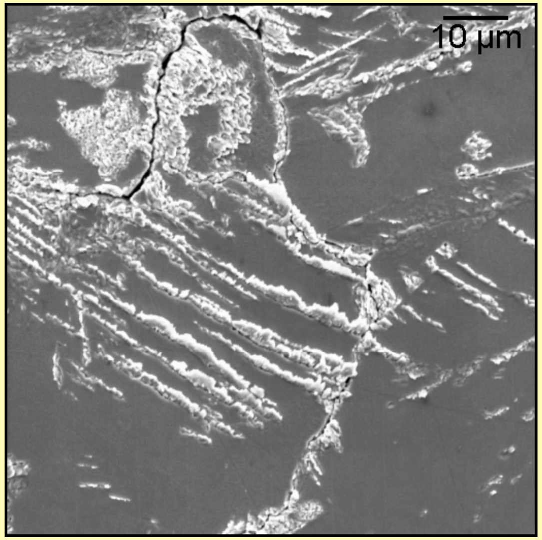


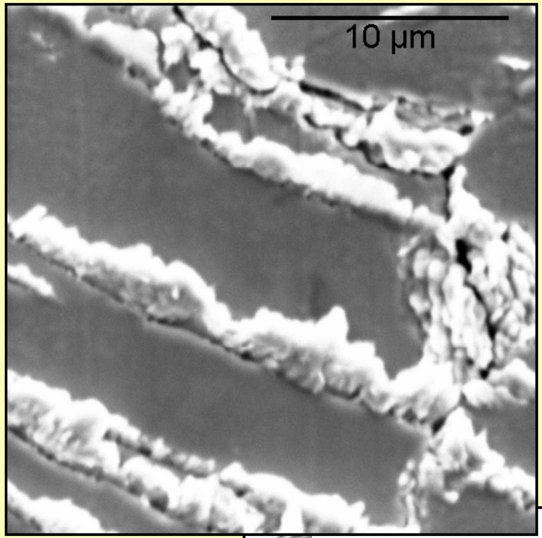
Fatigued zone

RF breakdown zones









Conditioning curves of pure metals