Progress and Plans on Warm Cavity Technology

Sergio Calatroni – CERN

On behalf of the CLIC Structures Team

Outline: four main lines of development

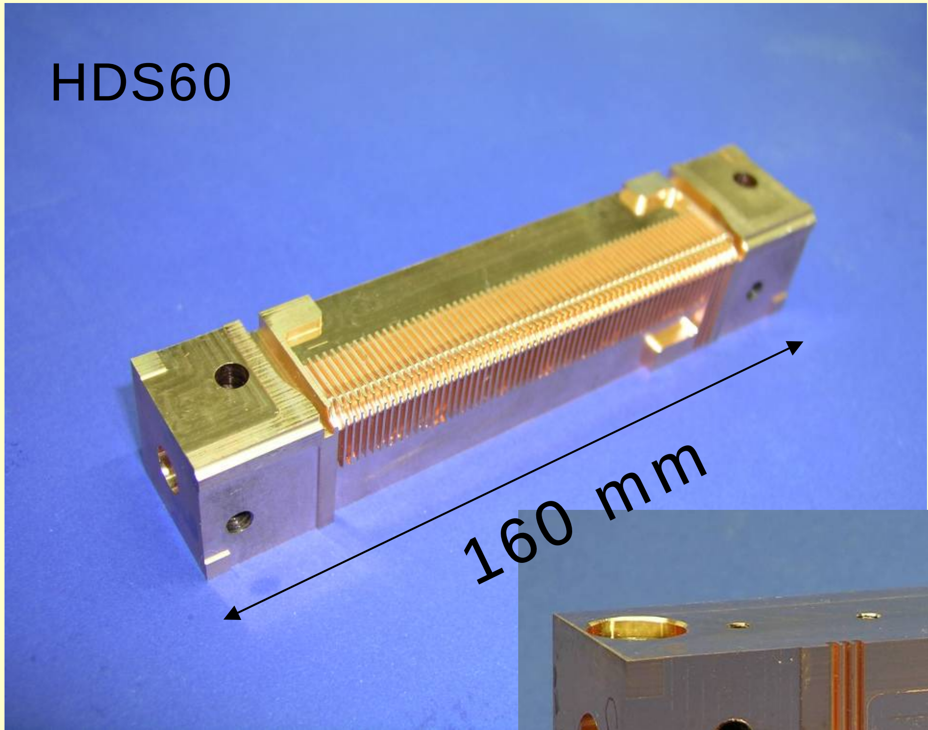
- RF design optimisation for low E_{surf}, H_{surf} and short pulses :
  - Present design: HDS and its rationale

- Material optimisation to withstand pulsed heating and repeated RF breakdown :
  - Pulsed heating & fatigue
  - Laser testing, ultrasound testing, CuZr and other candidate materials
  - CTF2 high gradient tests and comparison with DC spark tests
  - Search for optimum material and treatments
  - CTF3 tests: ultimate gradient and study of breakdown rate – Mo vs Cu
  - Best conditioning strategy?

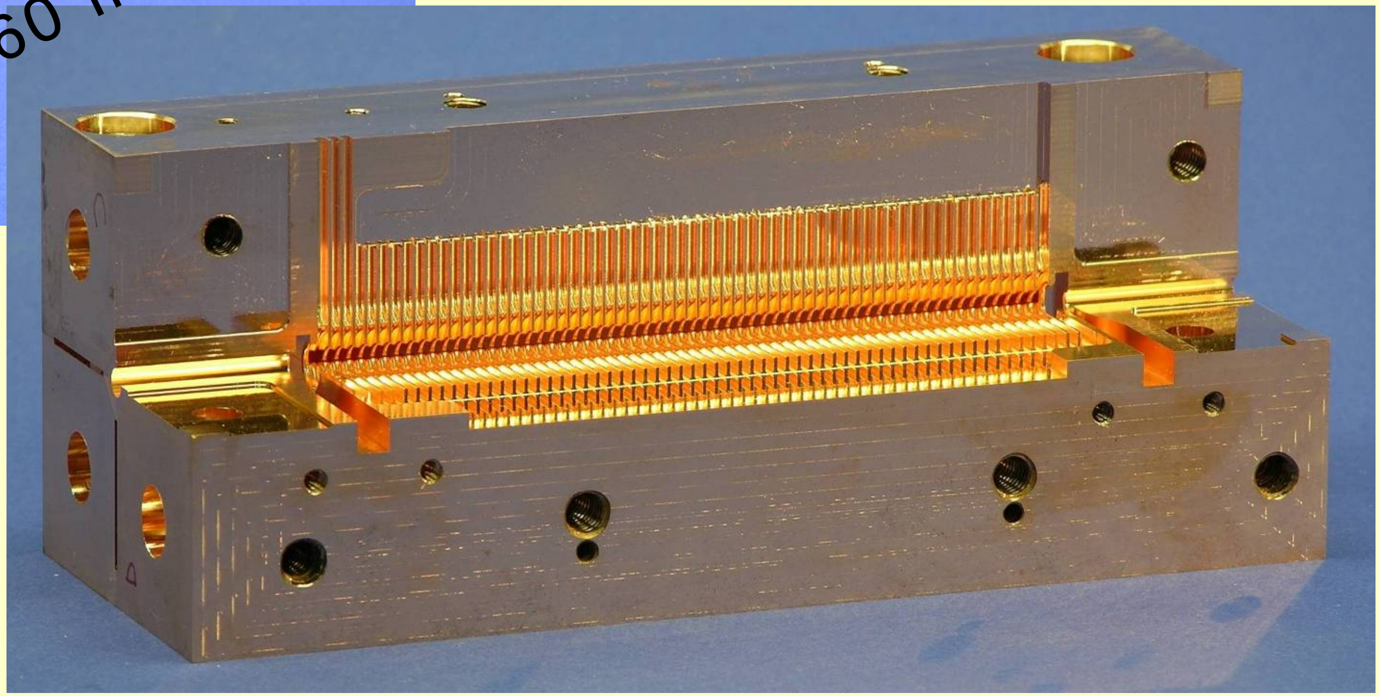
- Integrated parameter optimisation
  - Scaling of breakdown limit
  - Parameter optimization

- How to make a structure?

Hybrid Damped Structure (HDS) structures: to be tested soon

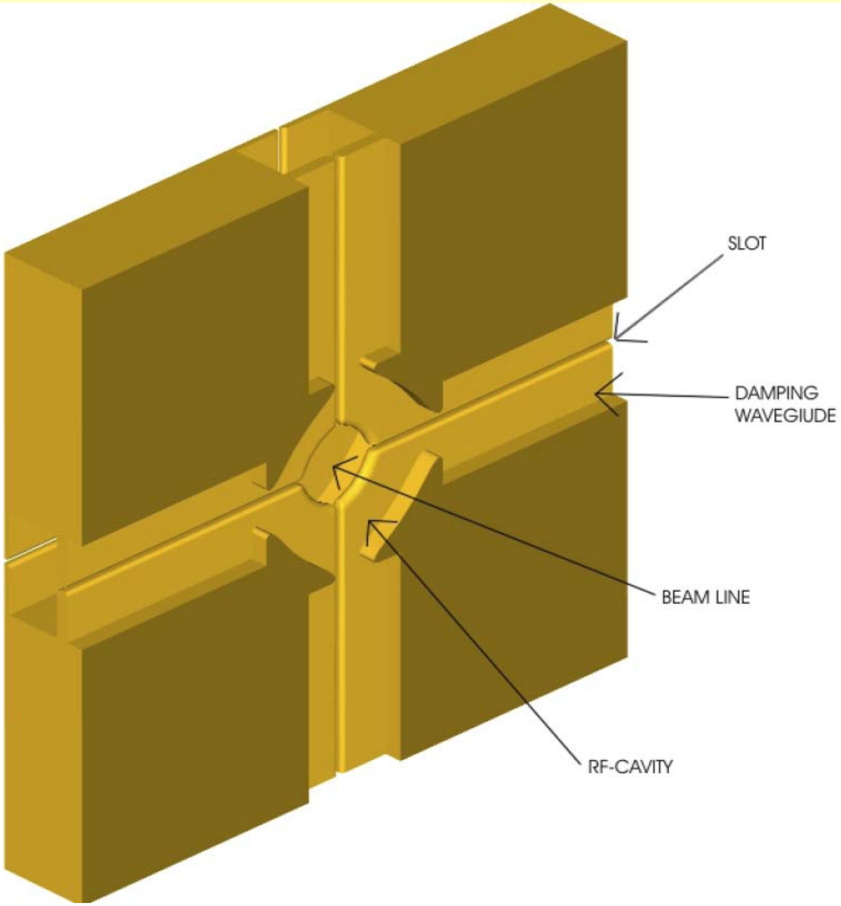


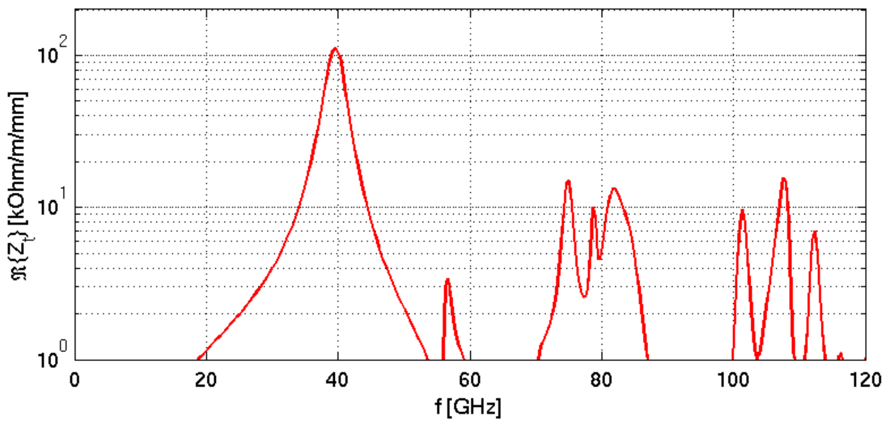
High-speed 3D milling of the fully profiled surface with 10-µm precision

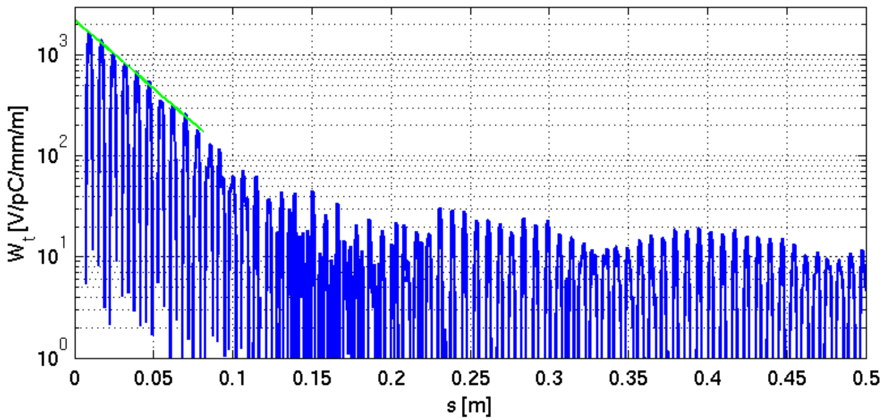


HDS: RF design

Combination of slotted iris and radial waveguide (hybrid) damping results in low Q-factor of the first dipole mode: ~ **10**. Damping by more than a factor 100 is achieved after only eight RF periods

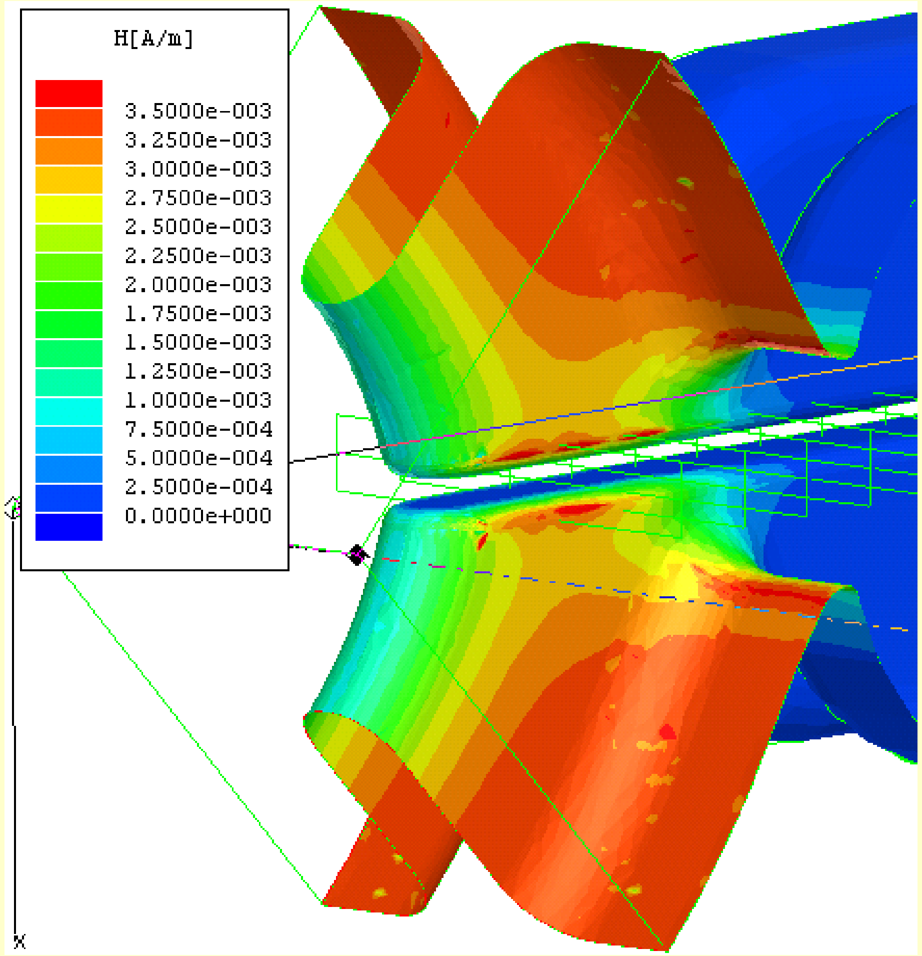




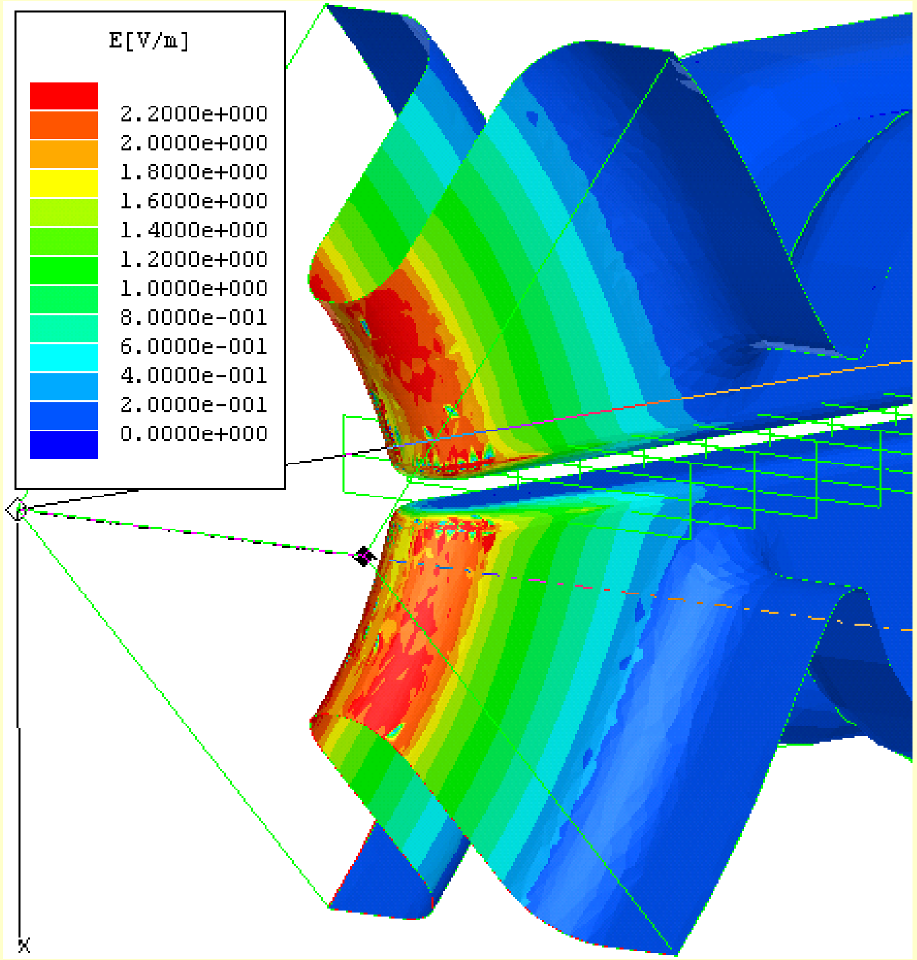


HDS: cell RF design

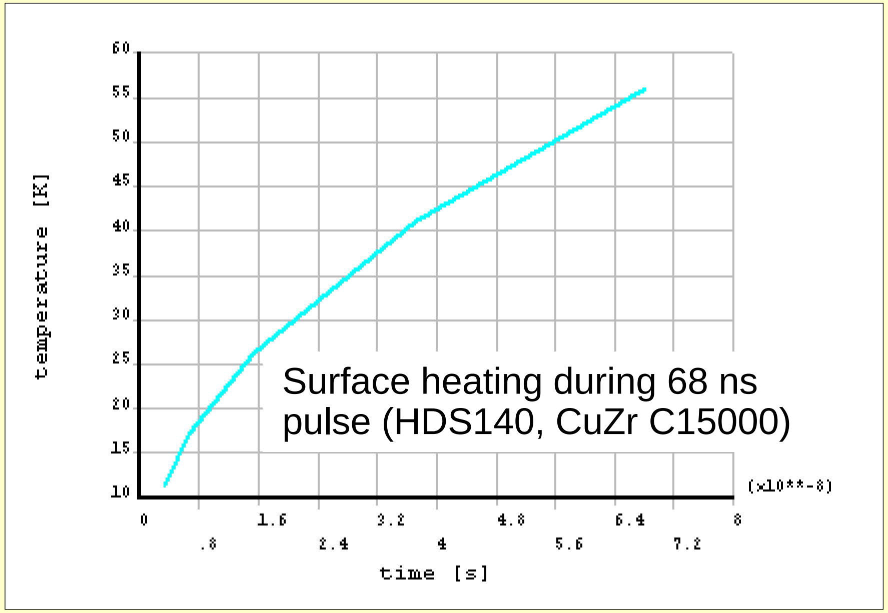
Surface magnetic field

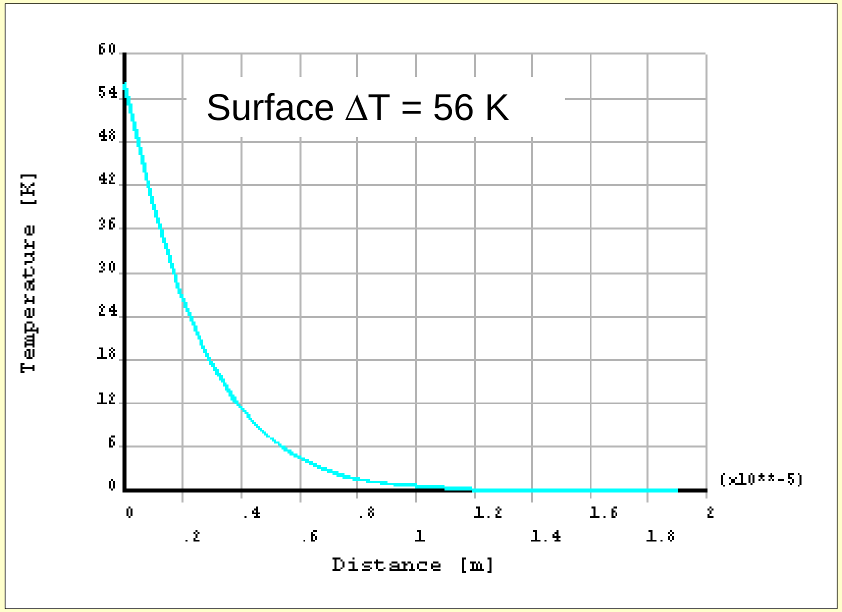


Surface electric field



Material research: surface heating

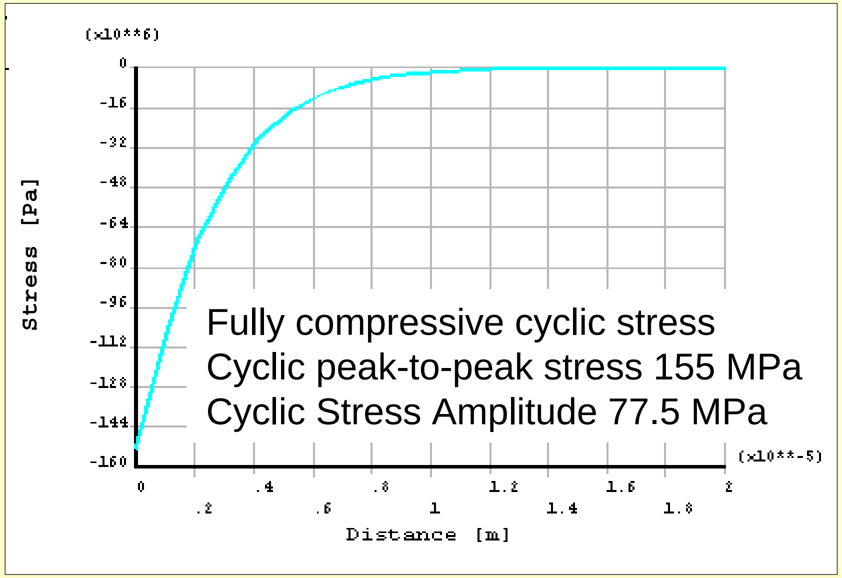




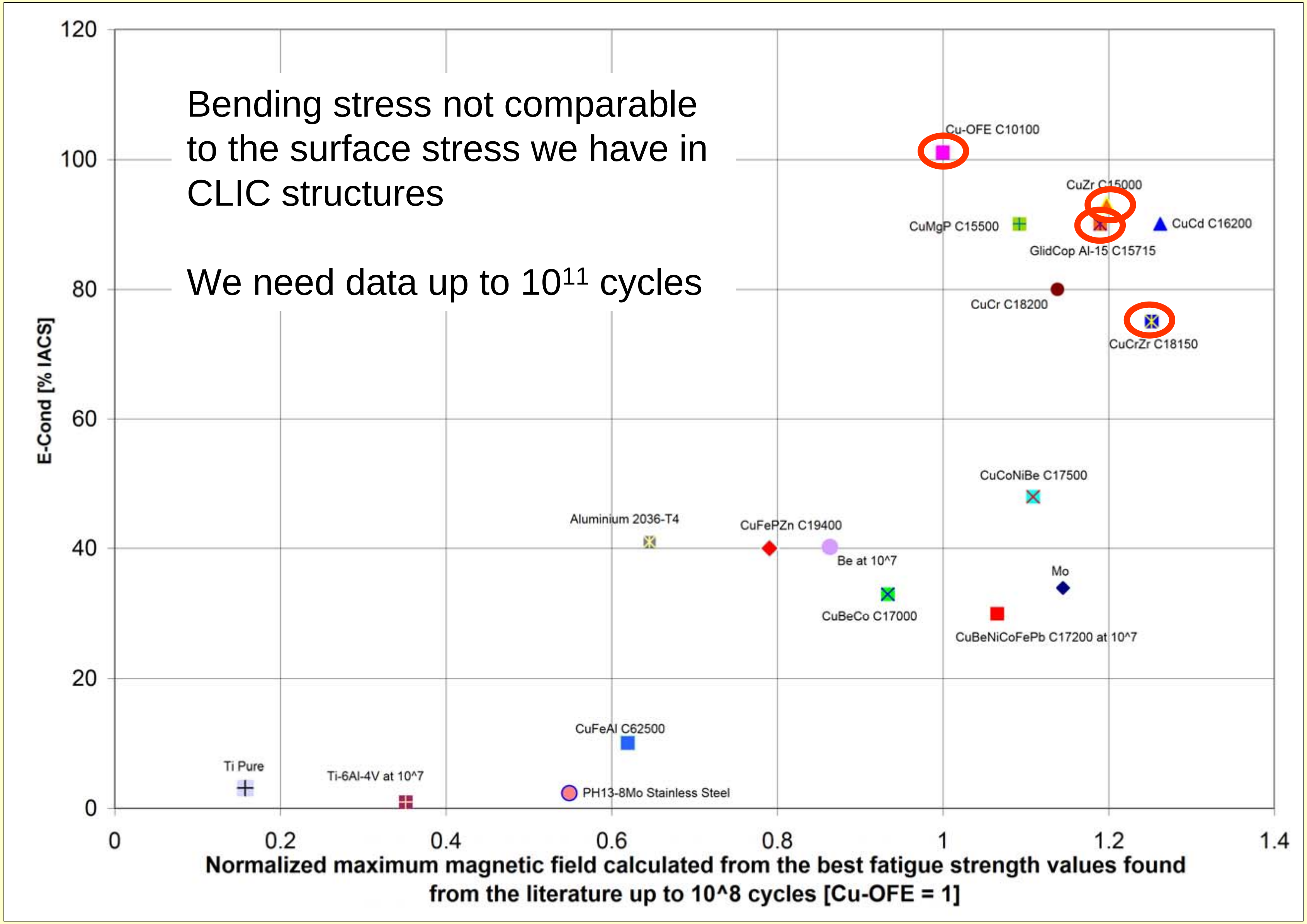
High peak surface magnetic field

⇒ High thermo-mechanical stress over the ~10^{11} RF pulses foreseen in the CLIC lifetime

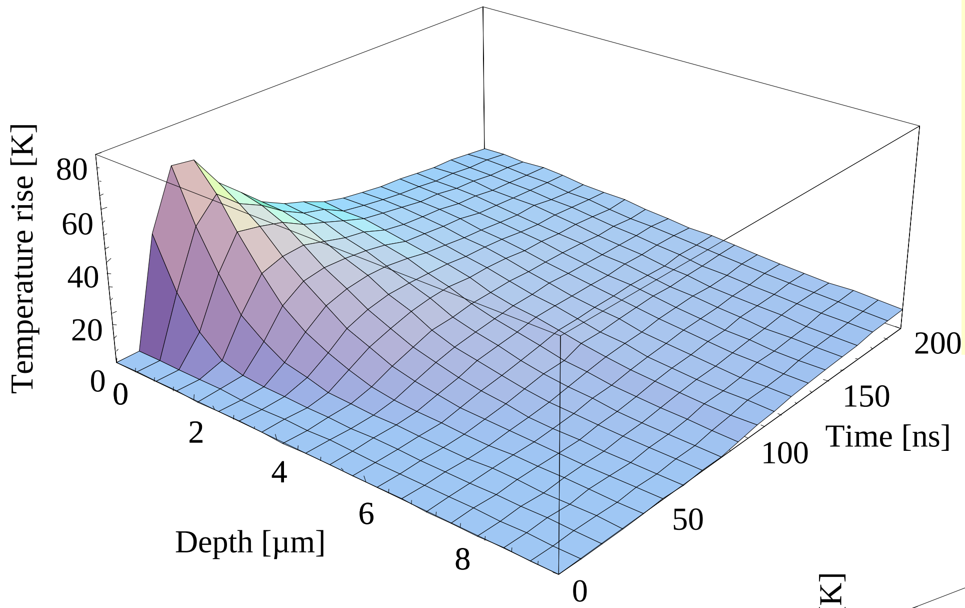
⇒ Breakup by “fatigue”



Fatigue resistance: literature data & choice of material candidates

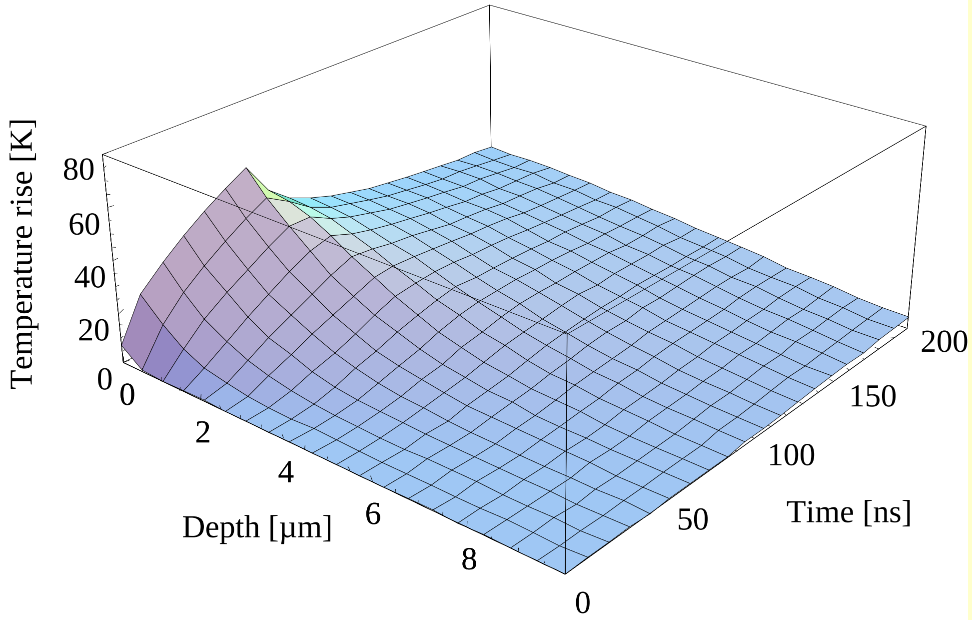


Low cycle fatigue: UV excimer laser (308 nm) pulsed heating



← Laser pulse

RF pulse ↓

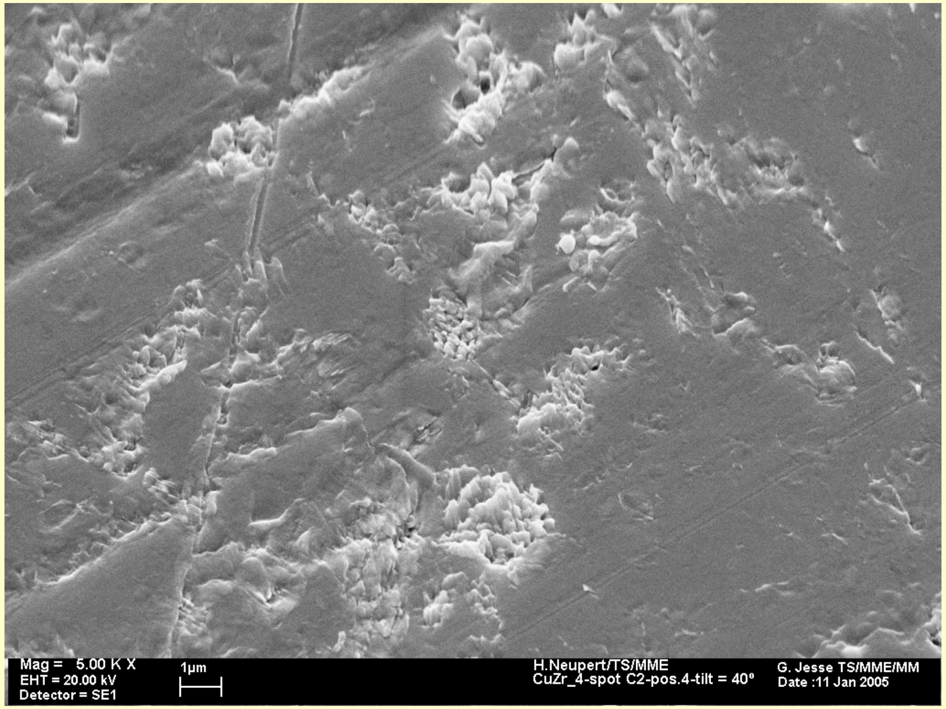


The pulse shapes correspond.
In particular the temperature profile at the peak is very similar, and results in similar stress level.

$$\sigma = \frac{\Delta T * E * \lambda}{(1-\nu)}$$

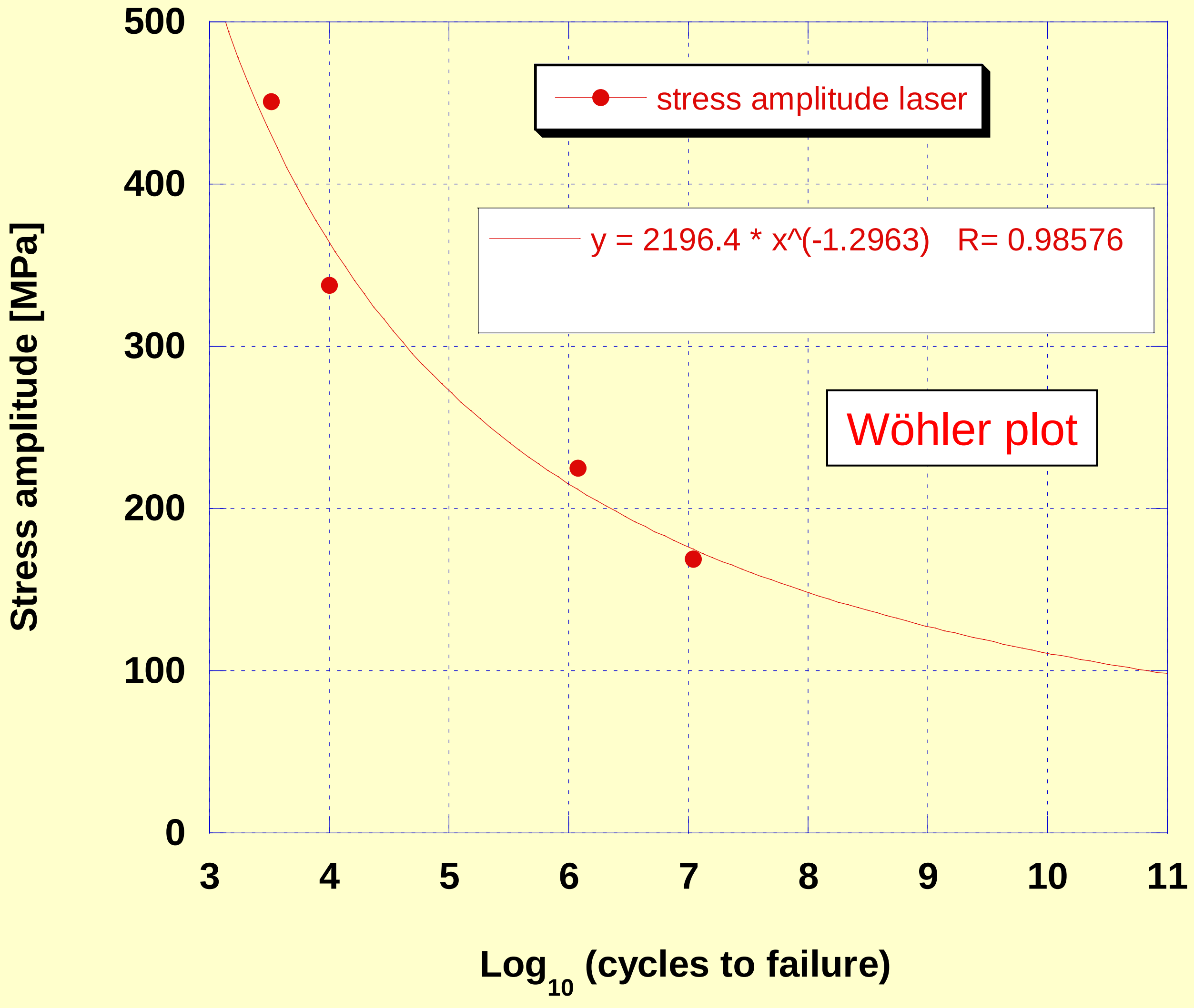
Laser fatigue: surface modification ($\rightarrow$ roughness change)

CuZr C15000 reference surface



CuZr C15000, 10 Mshots, 0.15 J/cm^2, ΔT = 120 K, σ = 170 MPa

Surface roughness as a function of fluence and number of shots: CuZr

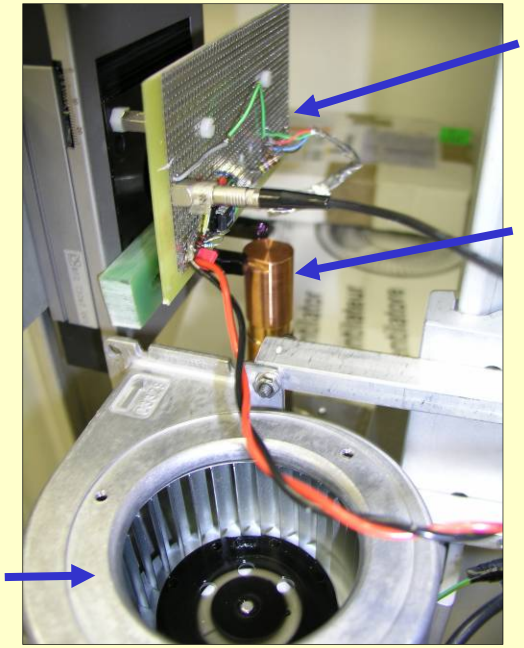


The value of 0.02 µm has been chosen as the first measurable departure from the reference surface (flat, diamond turned).

This is thought to be the most important phenomenon. The further increase of roughness is only crack propagation.

High cycle fatigue data: ultrasonic testing

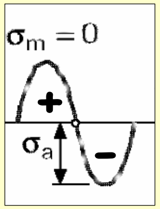
- **Cyclic mechanical stressing of material at frequency of 24 kHz.**
- **High cycle fatigue data within a reasonable testing time. CLIC lifetime 7×10^{10} cycles in 30 days.**
- **Will be used to extend the laser fatigue data up to high cycle region.**
- **Tests for Cu-OFE, CuZr, CuCr1Zr & GlidCop Al-15 under way.**



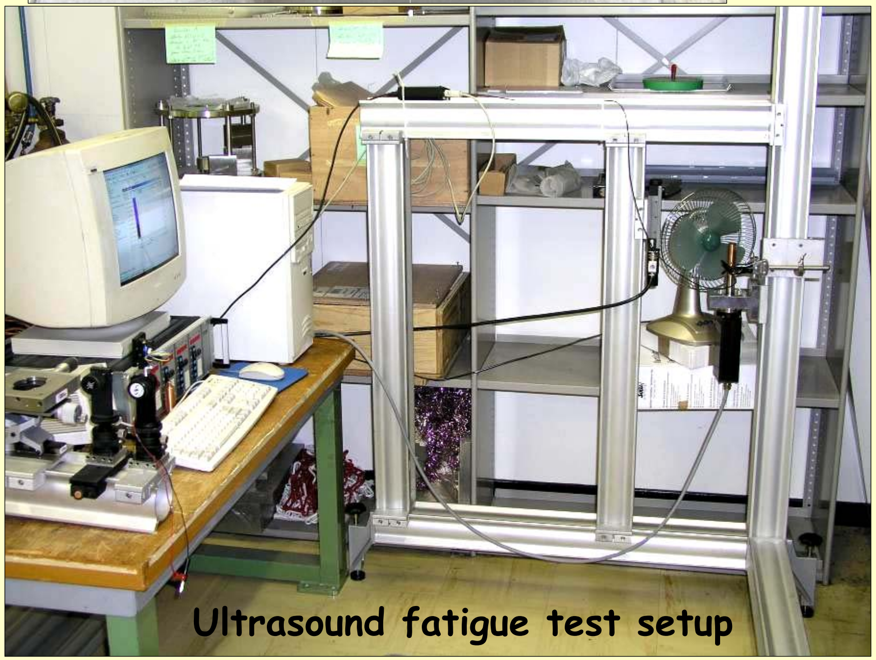
Calibration card measures the displacement amplitude of the specimen's tip

Fatigue test specimen

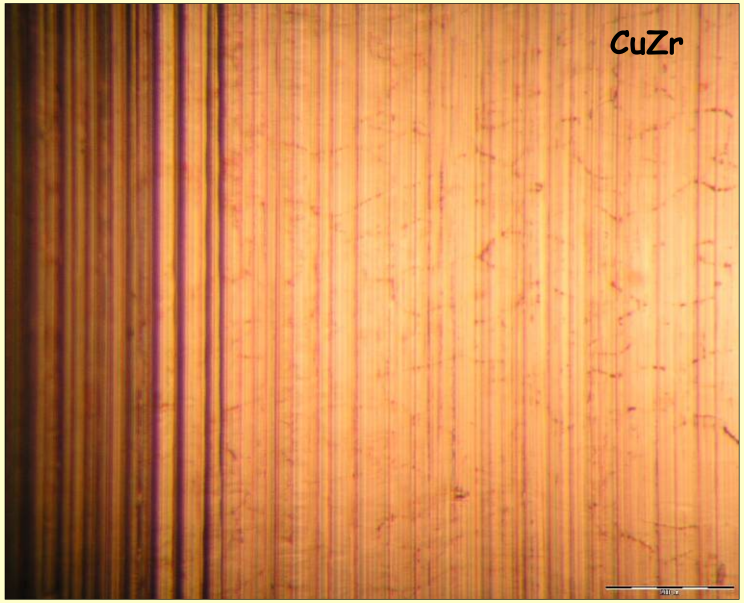
Air Cooling



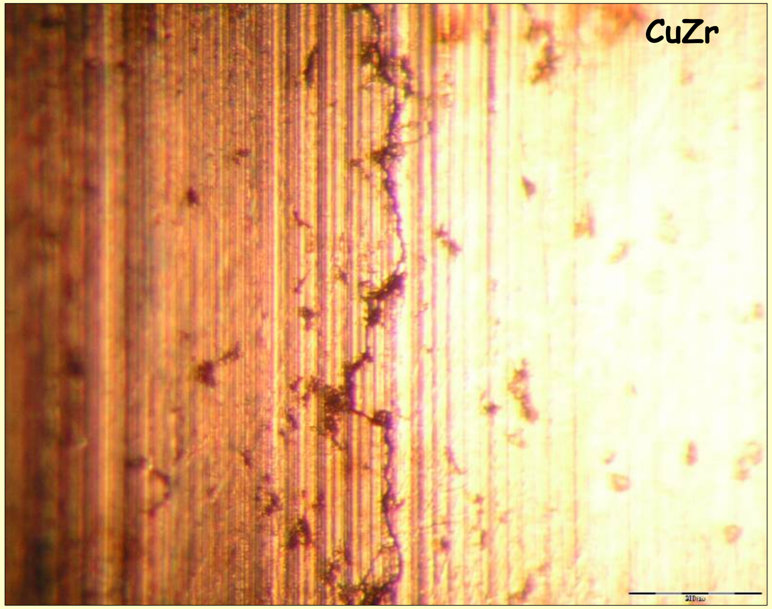
Reversed stress condition



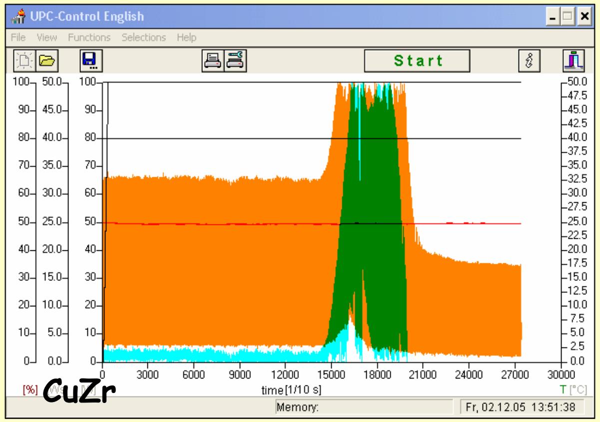
Ultrasonic fatigue: surface crack initiation

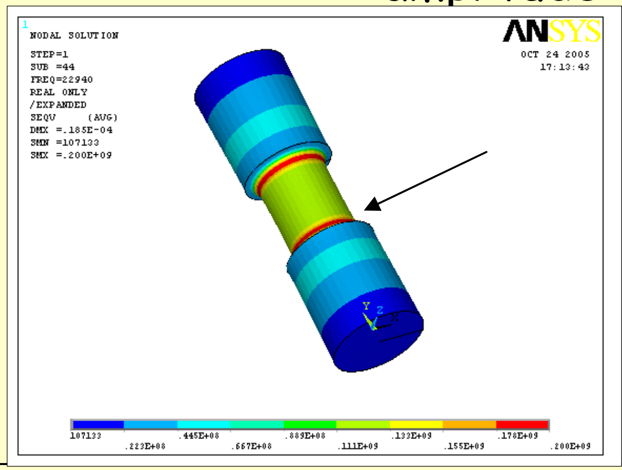


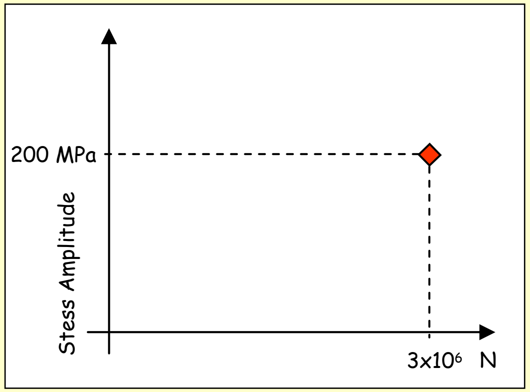
Diamond turned specimen before



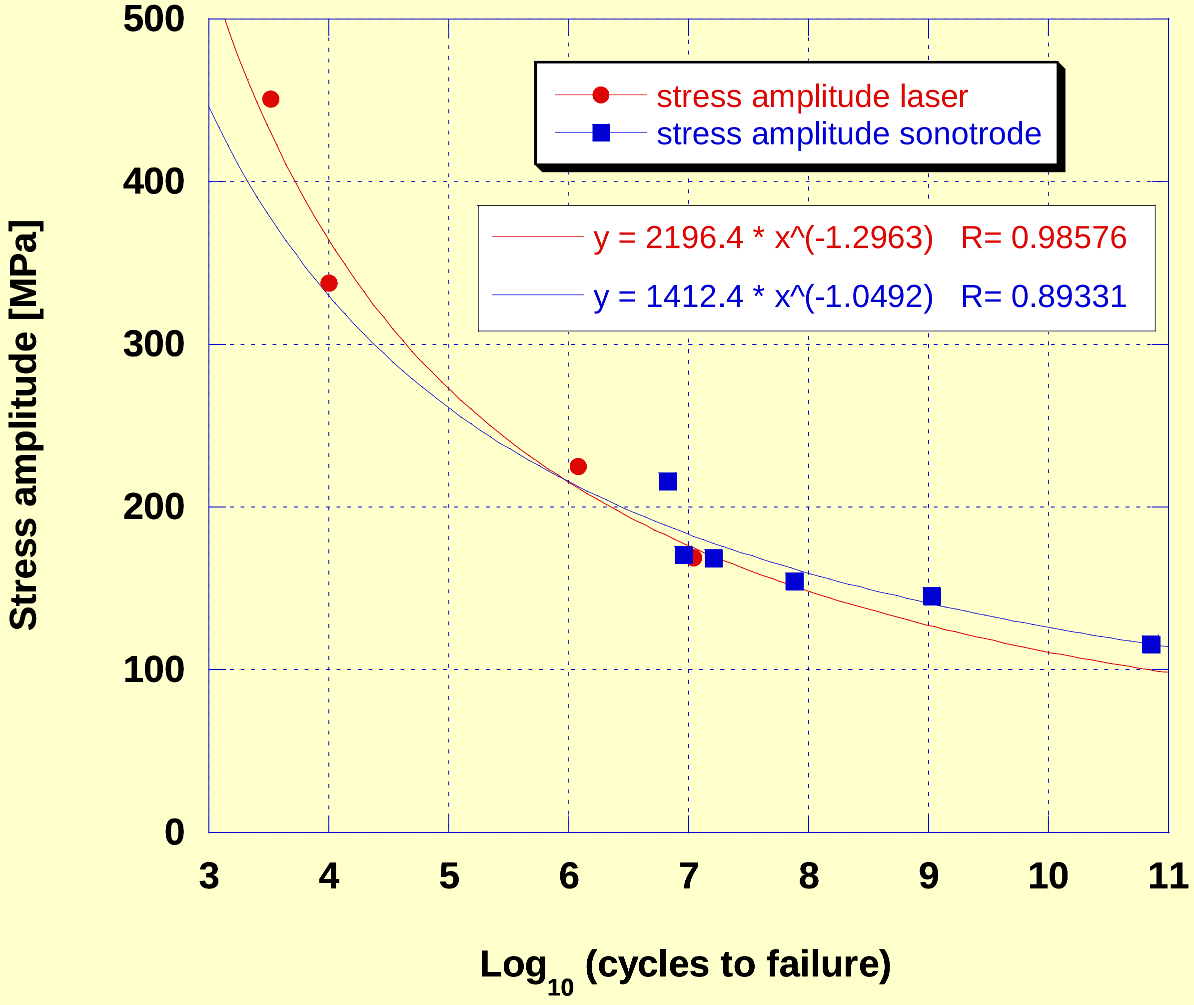
After 3*10^6 cycles at stress amplitude 200 MPa





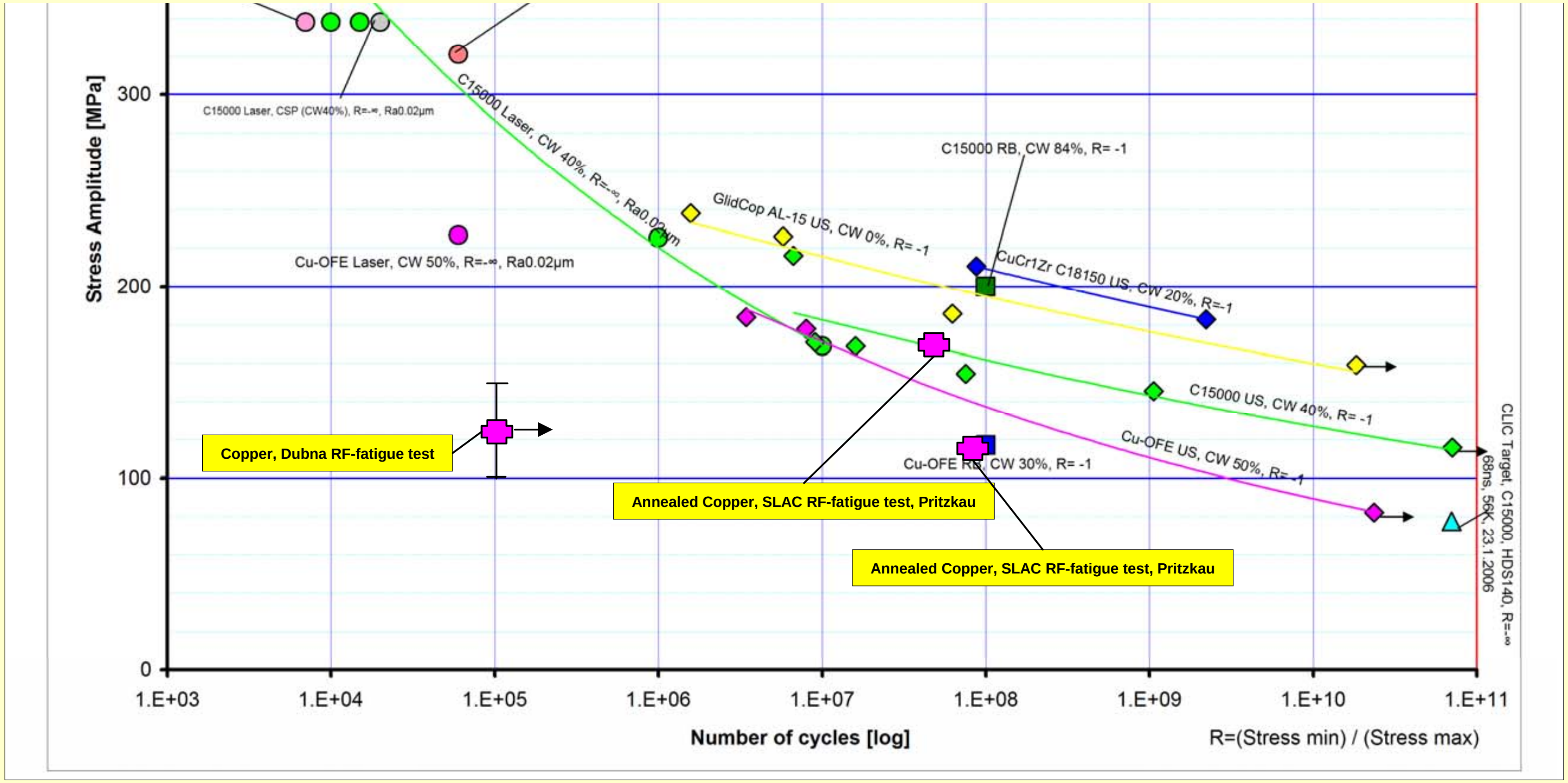


Fatigue limit: laser & ultrasound data for CuZr C15000 40% cold worked



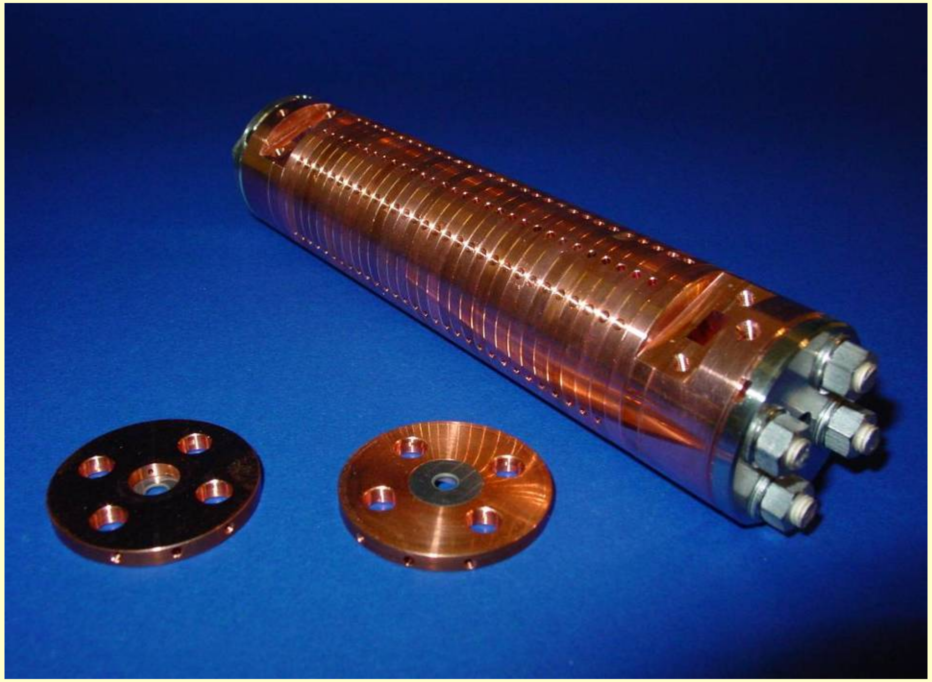
Laser & Ultrasound fatigue data combined

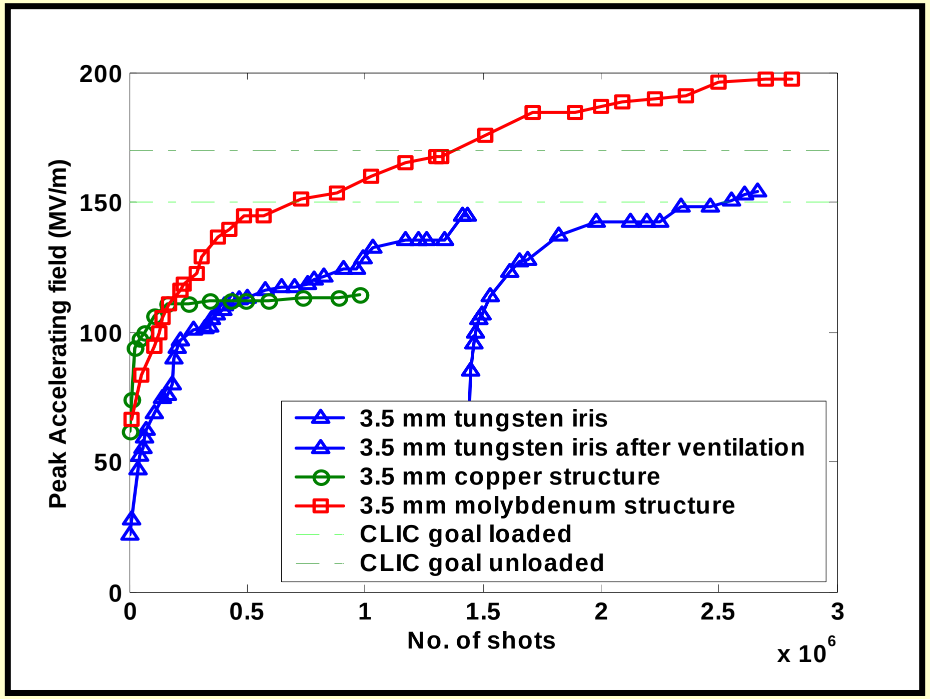
- RF testing at high pulse number in order to validate these data is of the highest priority. Operating at 50 Hz, it would allow 10^7 cycles in less than 2.5 days
- RF design of a dedicated test structure is done, and mechanical design and fabrication are under way.
- It is hoped to get it operational by end 2006 – early 2007, operating in parallel with the existing high-gradient test stand.



High gradient testing in CTF2 for iris material selection/characterisation

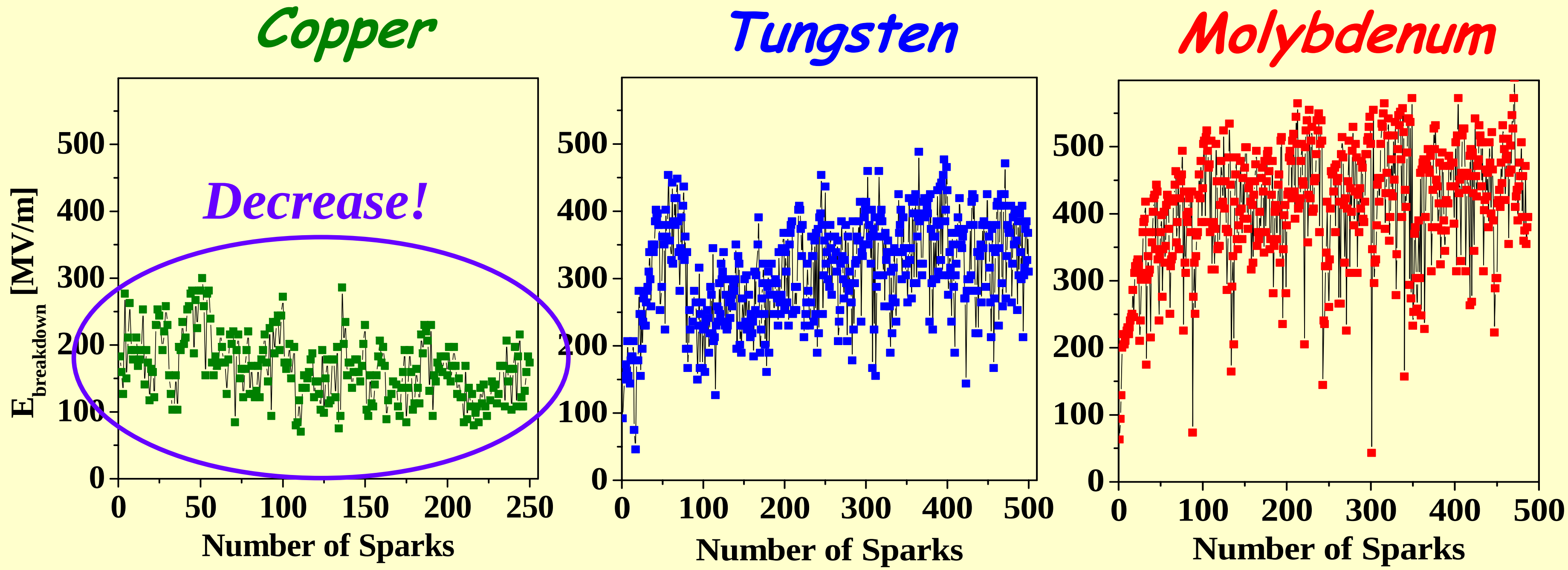
The aim is to select the iris material which offers the best compromise among: resistance to breakdown, rapidity of conditioning, breakdown rate, RF losses, easiness of machining and structure fabrication, etc. etc. etc.…





Circular structures, 30 GHz, 2/3π, clamped irises, 16 ns pulse length in CTF2
Tested materials: Cu, Mo and W iris (longer pulses available now with CTF3)

DC spark testing: comparison of selected materials

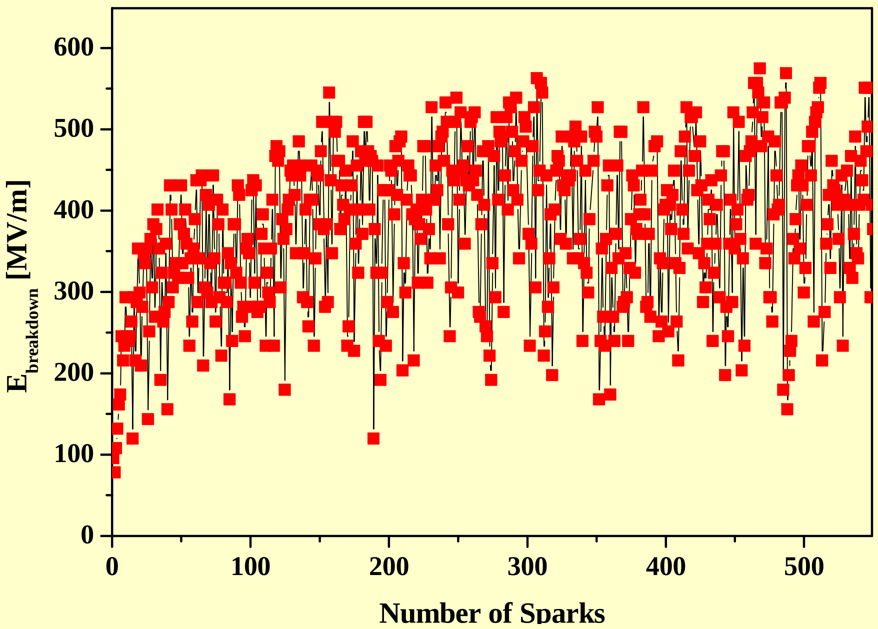


	E_{breakd}^{sat} *(DC)* *[MV/m]*	*Max. surface field in RF [MV/m]*
Cu	**160**	**241**
W	**349**	**329**
Mo	**430**	**420**

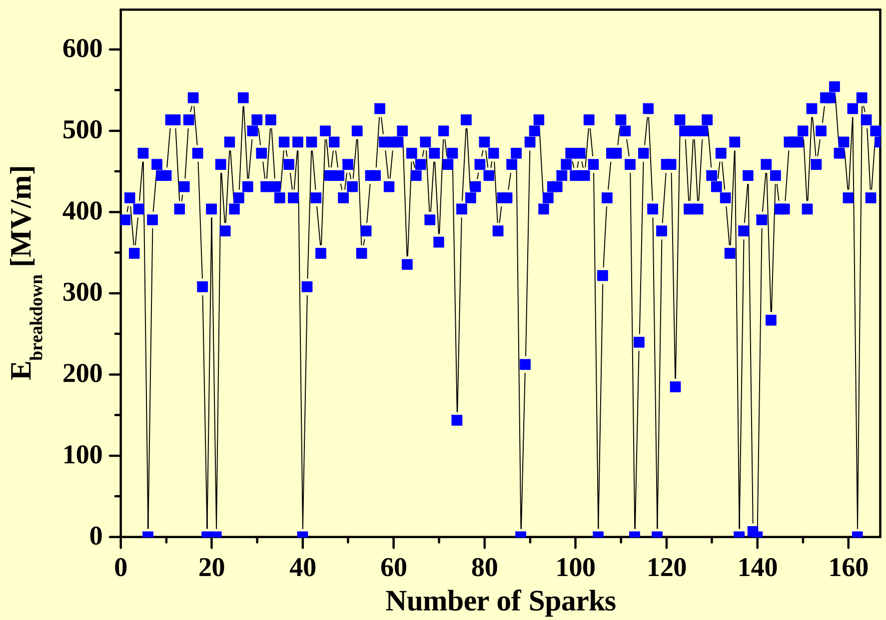
DC and RF breakdown measurements give similar breakdown fields for Mo and W

Superior behavior of both Mo and W with respect to Cu.

Improving conditioning rate: DC spark tests



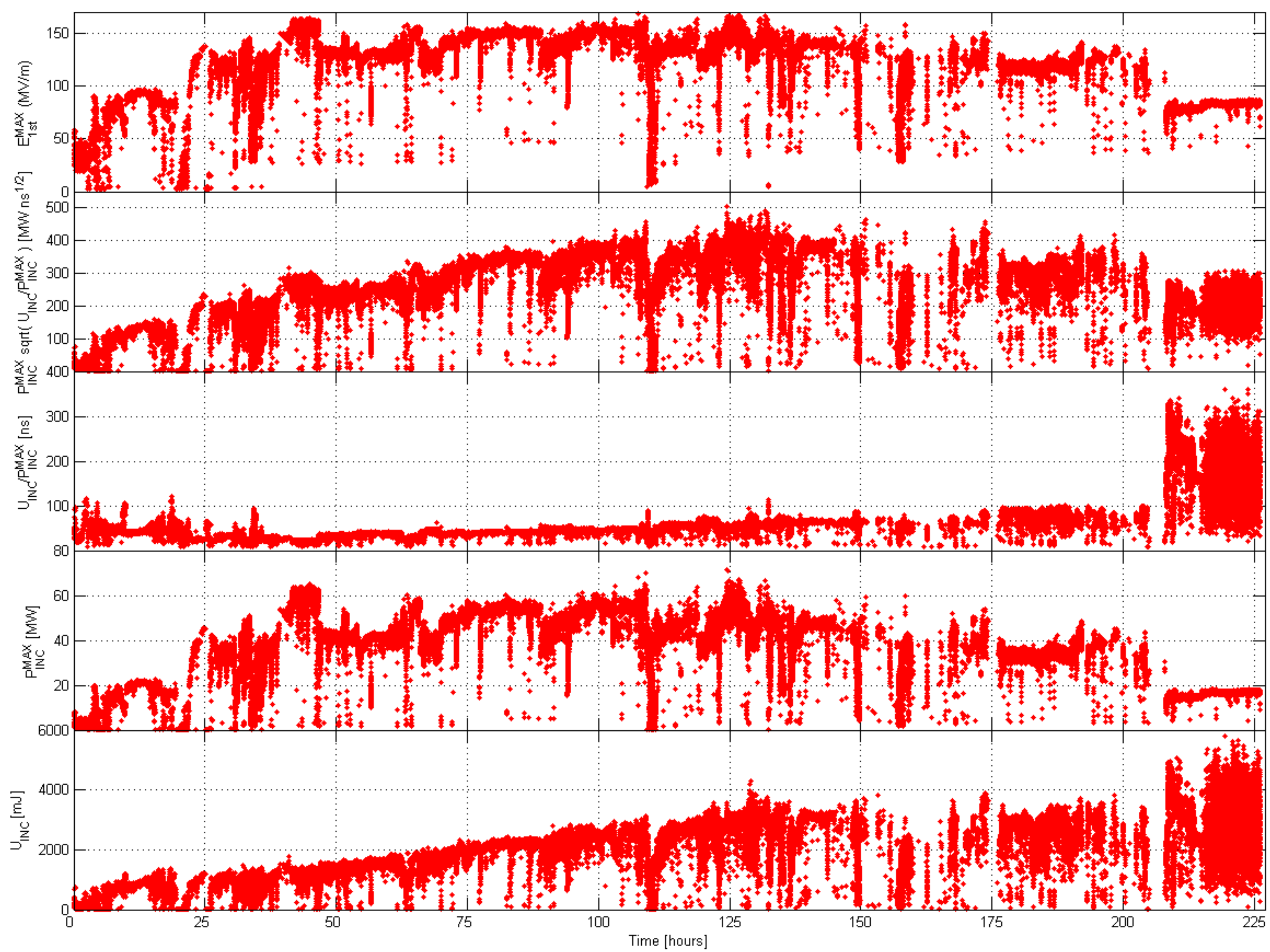
conditioning rate of standard sample



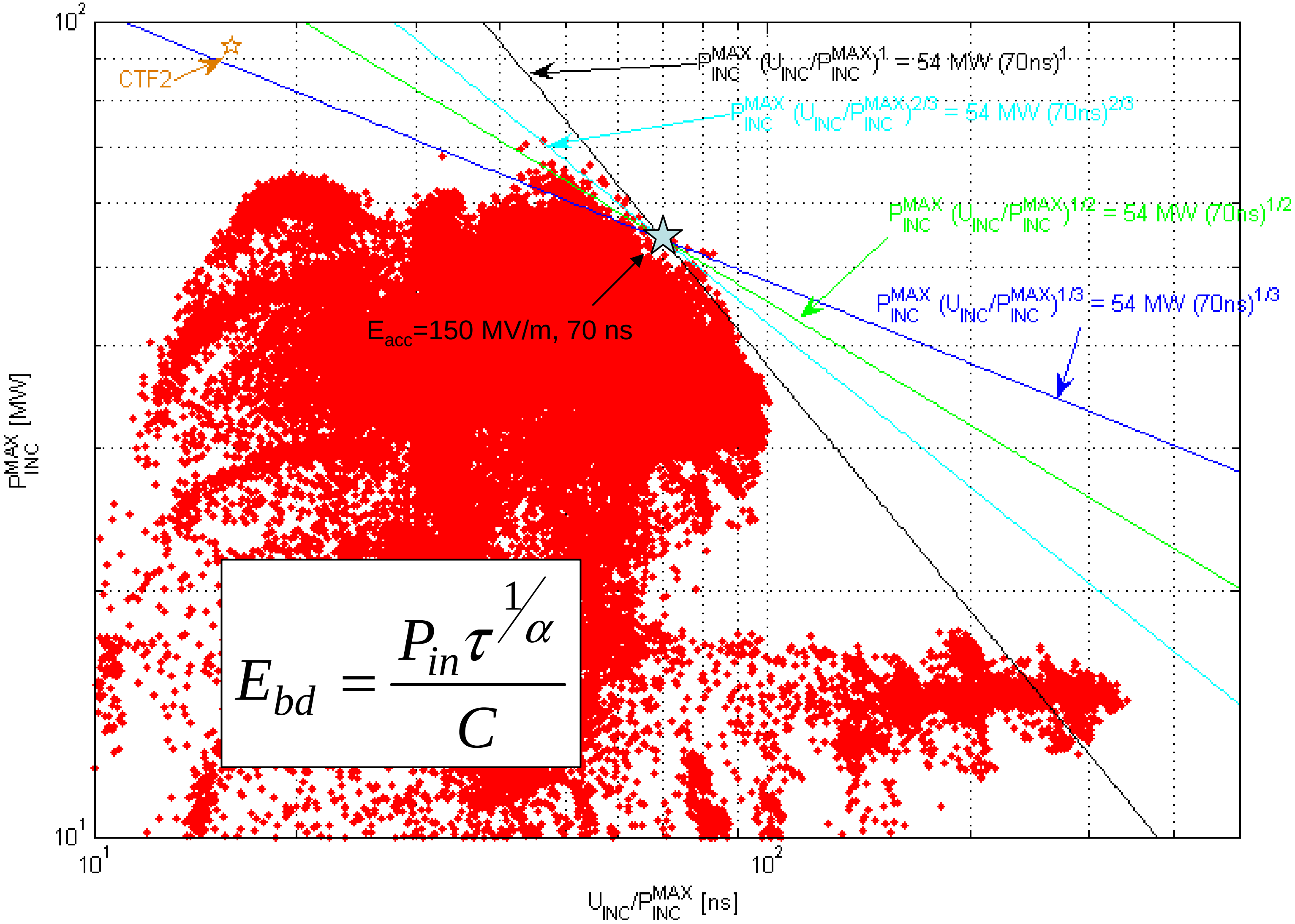
conditioning rate of high-temperature vacuum treated sample

The understanding of the underlying mechanism is in progress, as well as possible implementations in a real RF device

30 GHz Mo-iris (30 cells) structure in CTF3: RF conditioning rate



30 GHz Mo-Iris structure (30 cells): breakdown limit and scaling



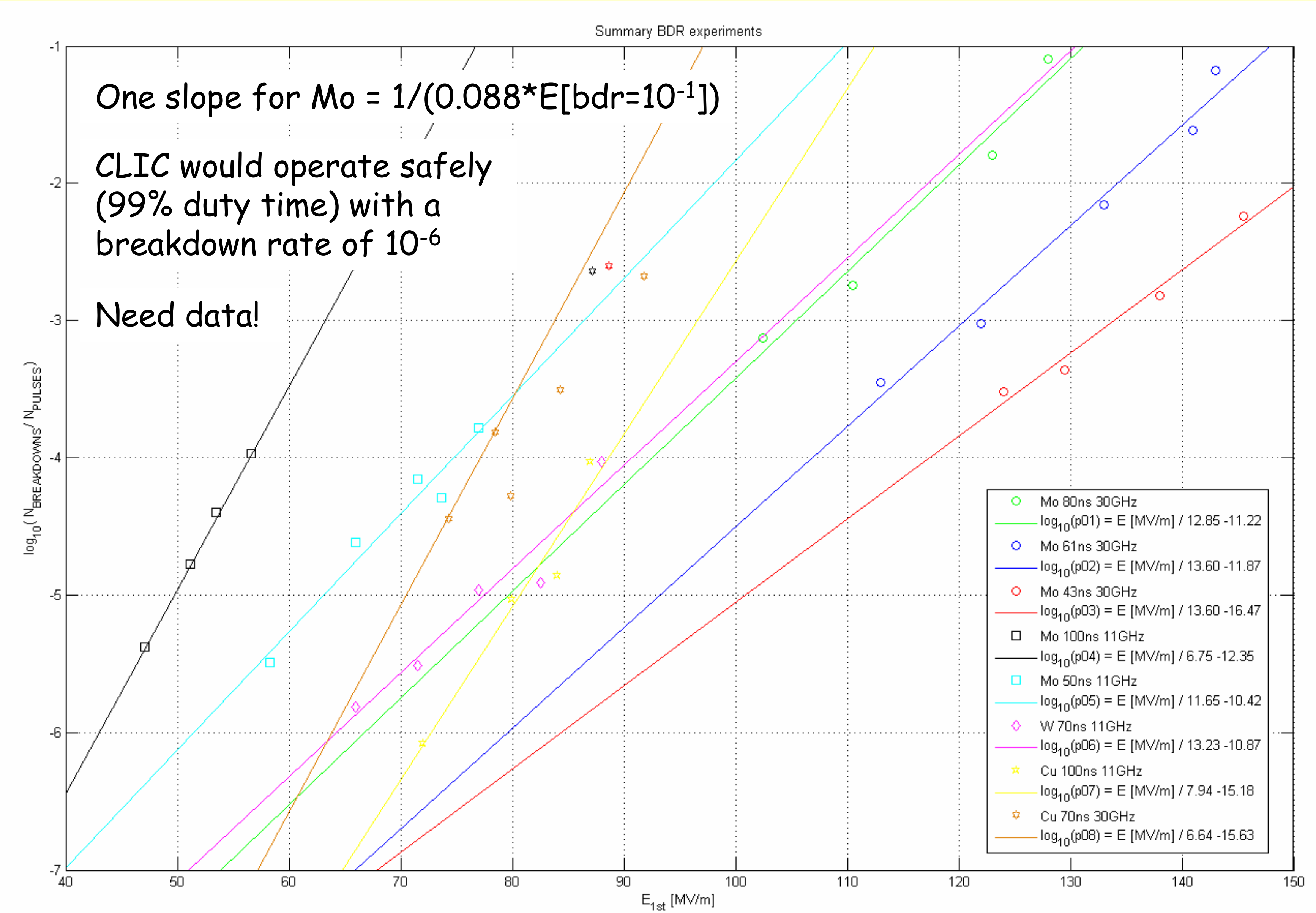
$$E_{bd} = \frac{P_{in}\tau^{1/\alpha}}{C}$$

LATEST NEWS! Breakdown rate of Mo vs. Cu at 30 GHz

One slope for Mo = 1/(0.088*E[bdr=10^{-1}])

CLIC would operate safely (99% duty time) with a breakdown rate of 10^{-6}

Need data!



Structure optimisation

All structure parameters are variable:

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

f = 12 – 30 GHz,

$\Delta\varphi$ = 50 - 130°,

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

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

d_1/λ = 0.025 - 0.1, $d_2 > d_1$

N_{cells} = 15 – 300.

N structures:

7

10

9

24

60

61

4

221.356.800

Beam dynamics constraints:

N, $L_{b\times}$ depend on $\langle a\rangle/\lambda$, $\Delta a/\langle a\rangle$, f and $\langle E_{acc}\rangle$ and come from D. Schulte

N_{cycles} is determined by condition: $W_{t,2}$ = 10 V/pC/mm/m for N = 4x10^9

rf breakdown and pulsed surface heating (rf) constraints:

$E_{surf}^{max} < 380$ MV/m & $\Delta T^{max} < 56$ K (or 40K) & $P_{in} t_p^{1/2} < 1200$ MWns$^{1/2}$

or $P_{in} t_p^{1/3} < 442$ MWns$^{1/3}$

or $P_{in} t_p^{1/3}/C < 20$ MWns$^{1/3}$/mm

or $P_{in} t_p^{1/3}/C < 16$ MWns$^{1/3}$/mm

or $P_{in} t_p^{1/2}/C < 42$ MWns$^{1/2}$/mm

or $P_{in} t_p^{1/2}/C < 30$ MWns$^{1/2}$/mm

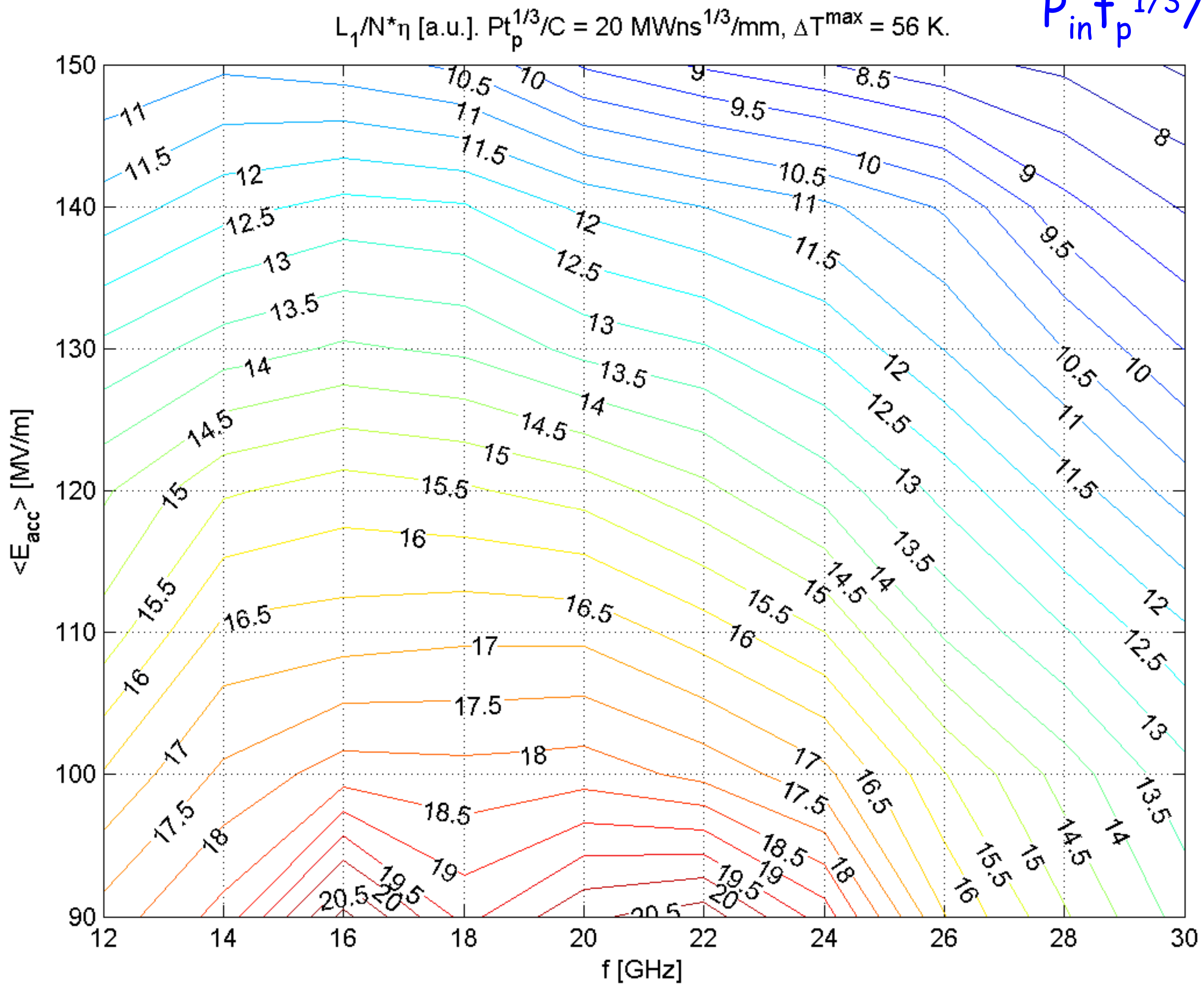
Optimization figure of merit

Luminosity per linac input power:

$$\int L dt / \int P dt \sim L_{b\times}/N\eta$$

Cost is not taken into account… yet!

Optimisation of working parameters: there are no sacred cows…



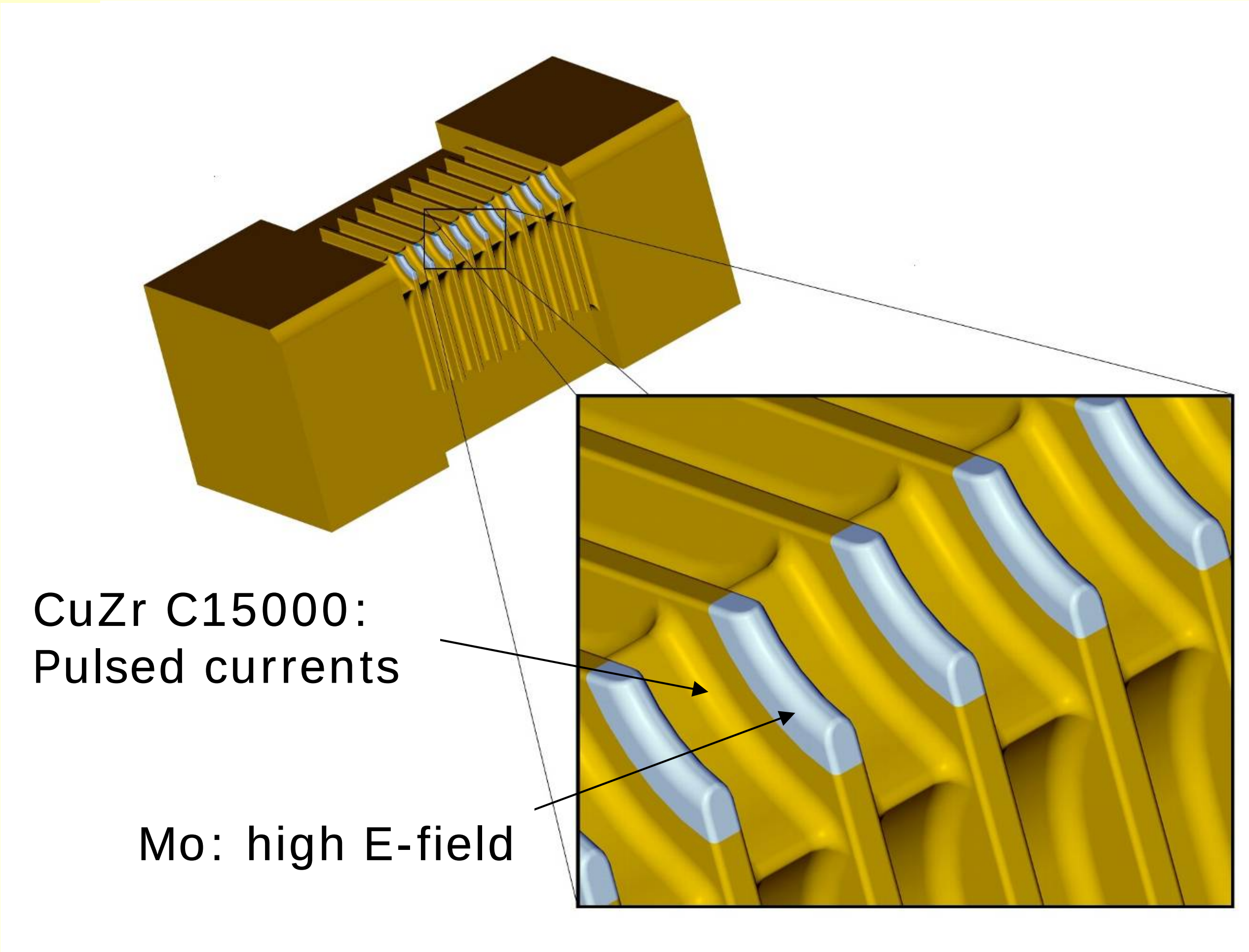
$P_{in}t_p^{1/3}/C < 20\ \mathrm{MWns^{1/3}/mm}$

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

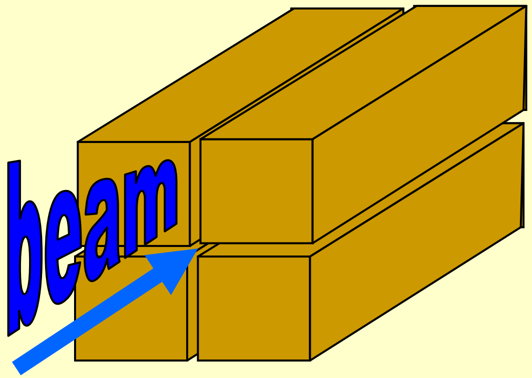
CTF3 (7.11.2005):

$\sim 20\ \mathrm{MWns^{1/3}/mm}$

How to make a bi-metal HDS structure with Mo iris and CuZr body?



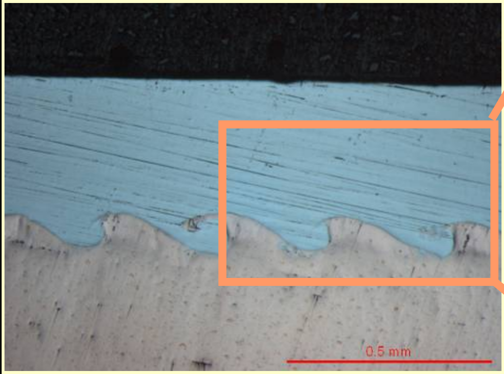
Structure assembly

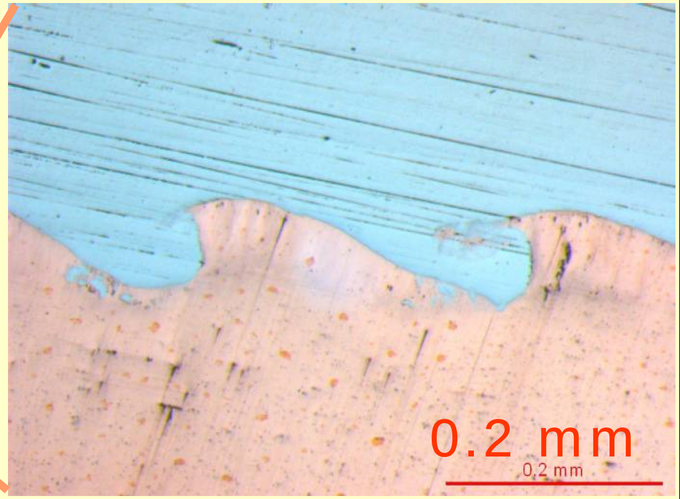


Aim: +/- 1µm accuracy, 0.05µm Ra close to the beam region

CuZr-Mo bimetal – possible manufacturing techniques

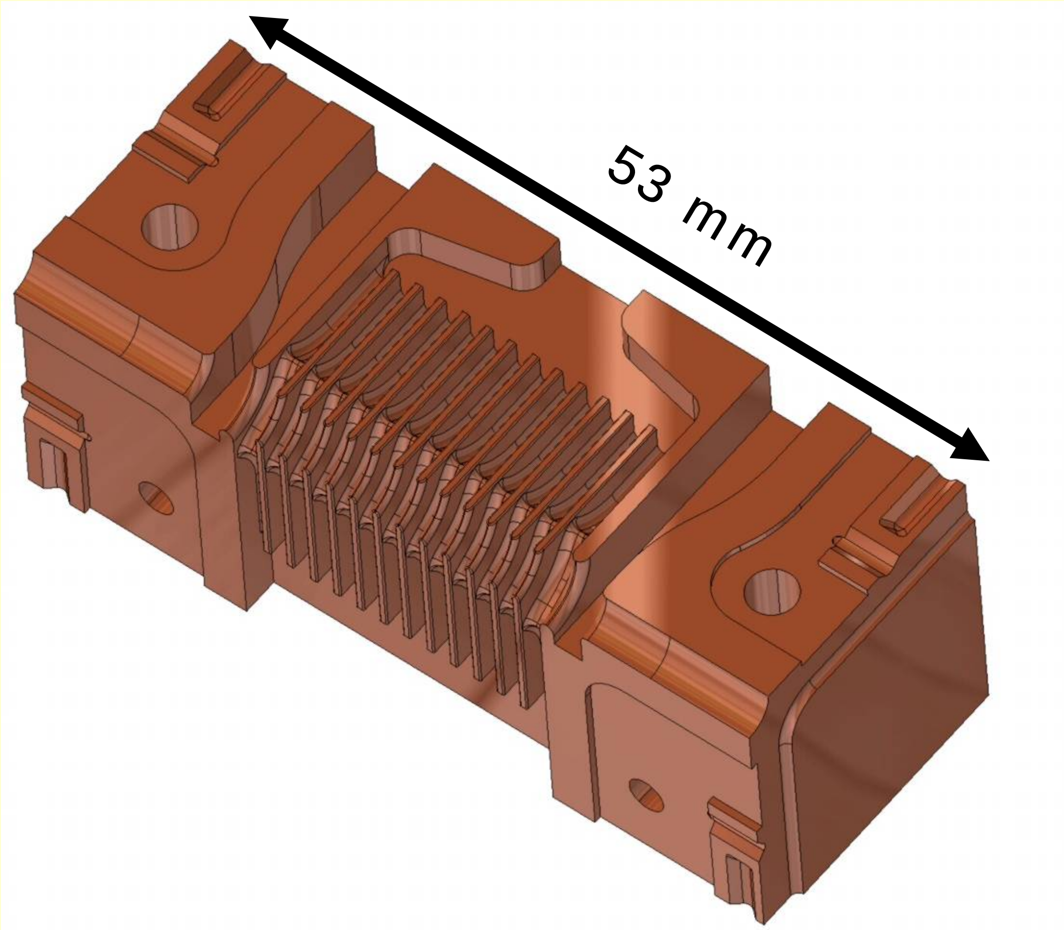
Explosion bonding:





Minsk, R.Stefanovich

HDS: testing program in CTF3 of single-metal structures



HDS60 (60 cells), π/3,
Cu-OFE:
RF test foreseen in June 2006

Next:
HDS11 (11 cells), π/3:
Cu-OFE,
Mo,
stainless steel,
Ti,
Al
(bulk pieces)

Conclusions

- Fatigue problem can probably be overcome, but more data are needed
- Breakdown problem (ultimate gradient, breakdown rate) needs lots of experimental data, both RF and DC, in order to validate material choices and to refine the scaling laws, which are used as an input to the optimisation procedure
- Optimisation is regularly updated with new results, costs need to be implemented
- HDS design is sound, experimental validation in a few days
- Manufacturing techniques for bi-metals are being audited, for the moment no clear winner.
- 2010 is very close! Run, run, run!

Acknowledgements

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