The CLIC High-Gradient Research Program

AAC06
10 July 2006
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Overview

The CLIC study is investigating ways to obtain high accelerating gradients using normal conducting rf cavities.

The current parameters: 30 GHz, 150 MV/m

Clear mandate: demonstrate the CLIC accelerating gradient in an efficient prototype structure with nominal pulse length, sufficiently low breakdown rate - realistic operating conditions. By 2010!

Also show solutions to pulsed surface heating and micron tolerance fabrication and assembly. Have an idea about cost.

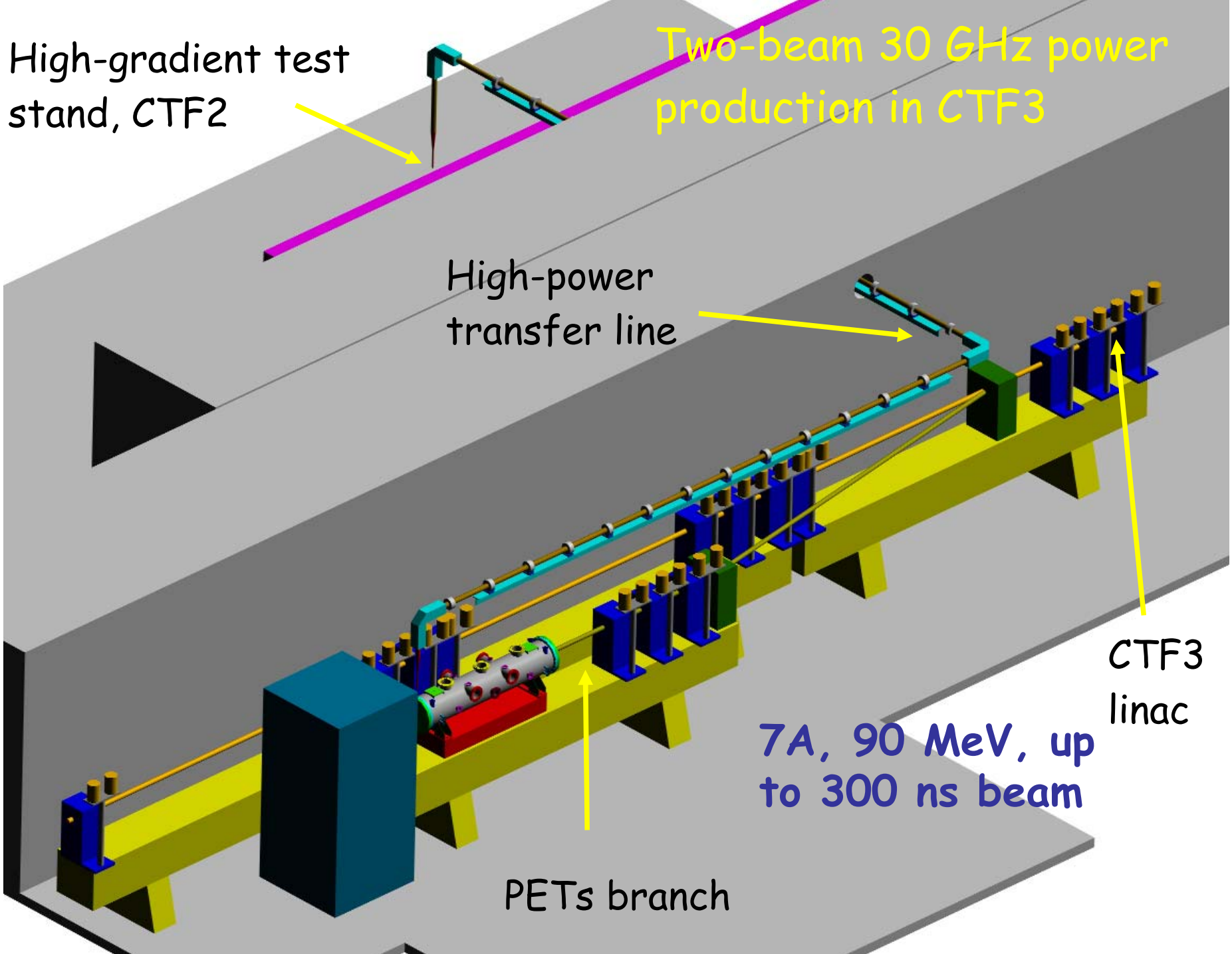
Balance on the fine line between the exotic and the accessible

Subjects of our program

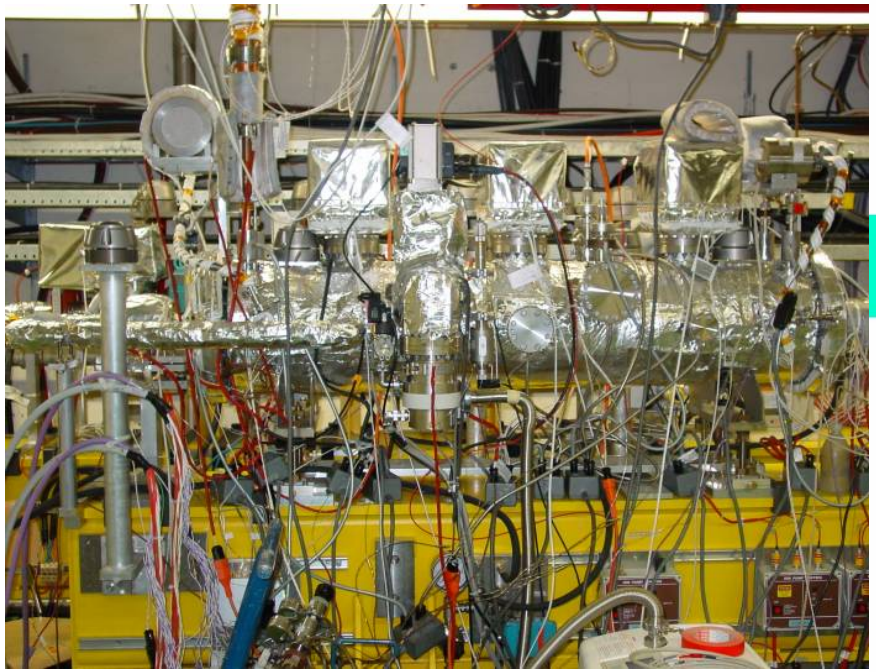
- rf design
- rf testing
- dc spark
- ultrasonic
- laser fatigue
- material studies
- machining studies

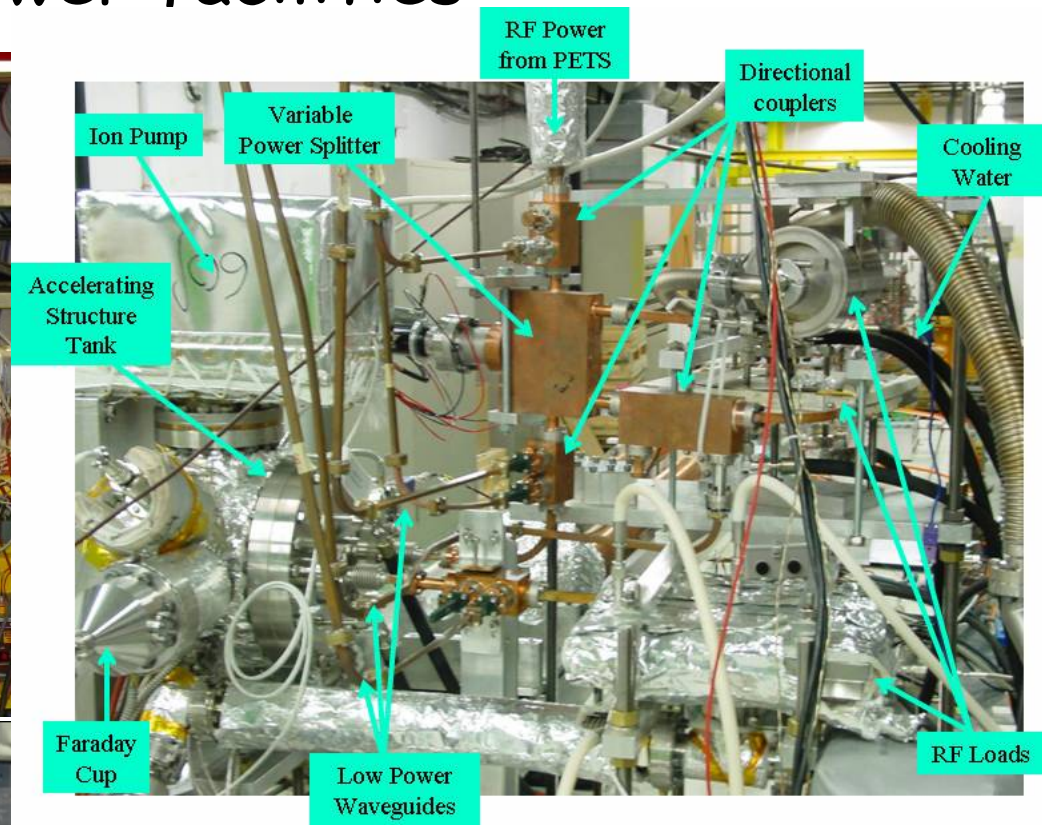
rf testing

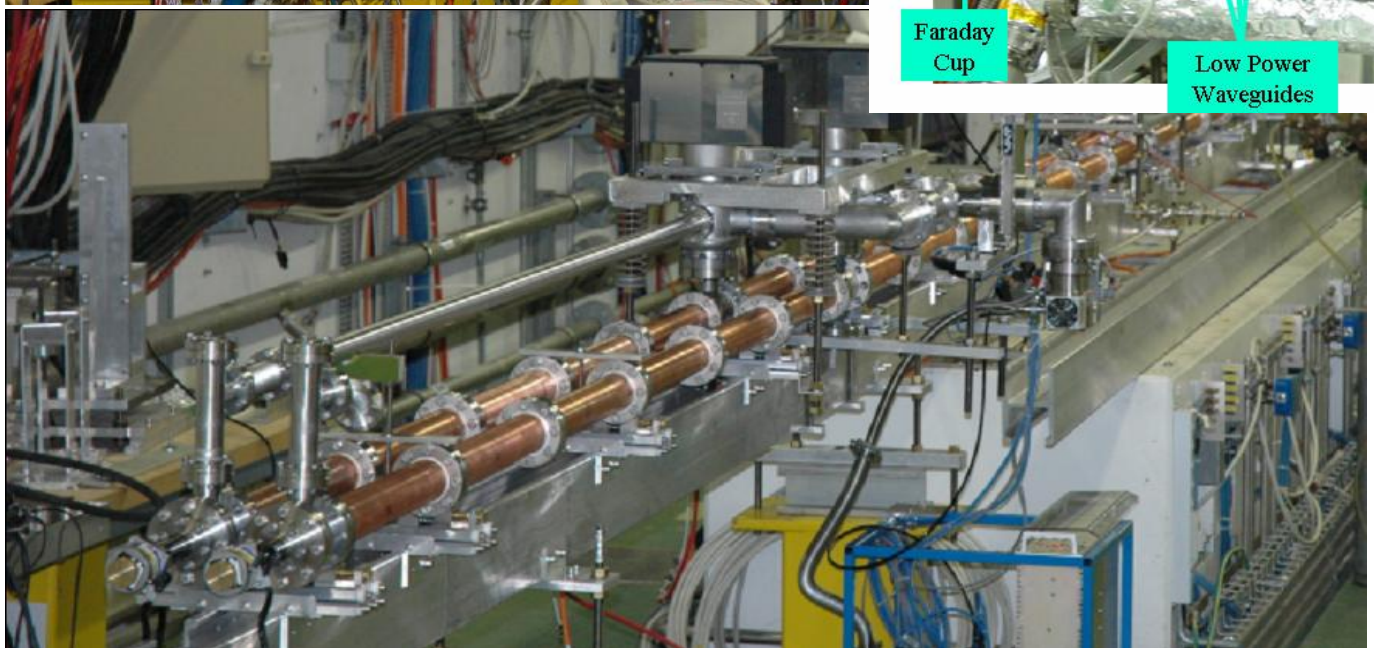
- Extend previous results to the CLIC pulse length, 70 ns, and beyond
- Address all relevant practical issues such as conditioning rate/strategy, breakdown probability, onset of damage, etc.
- Investigate the high-power/gradient rf properties of different materials
- Demonstrate the high-power/gradient performance of heavily damped structures – efficient structures
- Demonstrate design gradient in a prototype structure
- CTF3 for 30 GHz experiments, NLCTA for X-band experiments


High-gradient test stand, CTF2
Two-beam 30 GHz power production in CTF3
High-power transfer line
CTF3 linac
7A, 90 MeV, up to 300 ns beam
PETs branch

30 GHz rf power facilities



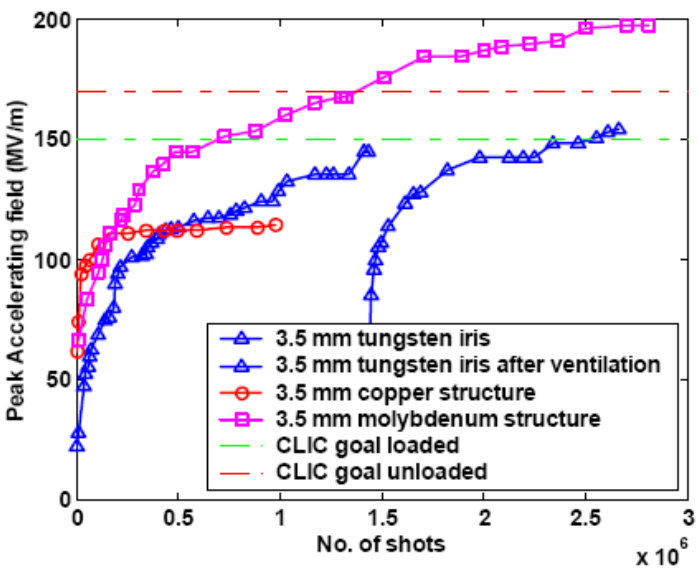




100 MW produced,
65 MW delivered
30 GHz power
10 (50) Hz
repetition rate
6 months per year

Material testing with rf

Previously reported high-gradient tests (2002): 30 GHz, 16 (30) ns Cu, W-iris and Mo-iris structures



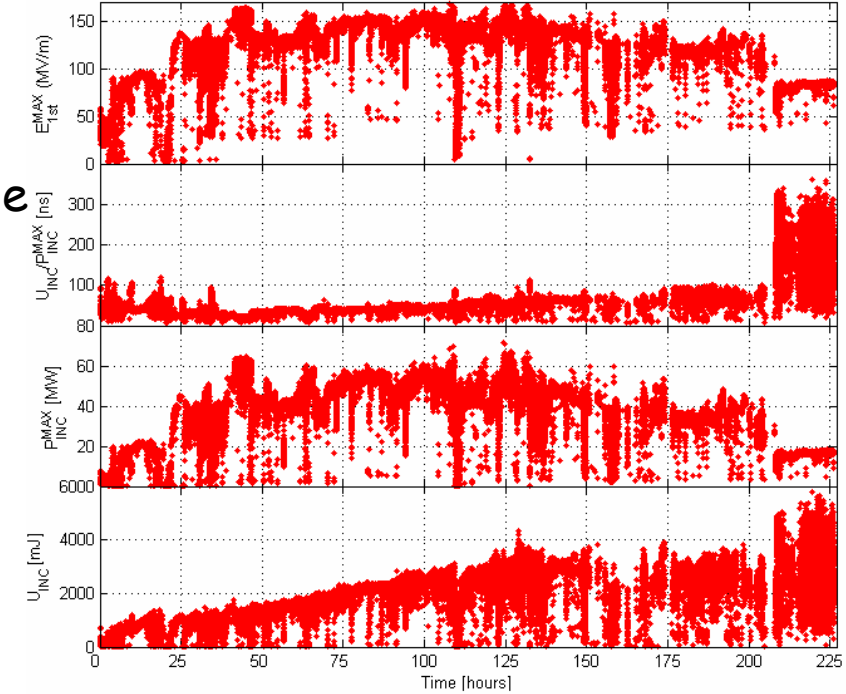
Frequency	29.984 GHz
Number of cells	30
Phase advance	2π/3
Beam aperture	3.5 mm
Group velocity	4.6% of c
Fill time	8.3 ns
E_{SURF} / E_{ACC}	2.2
Power needed for E_{ACC} = 150 MV/m	54 MW

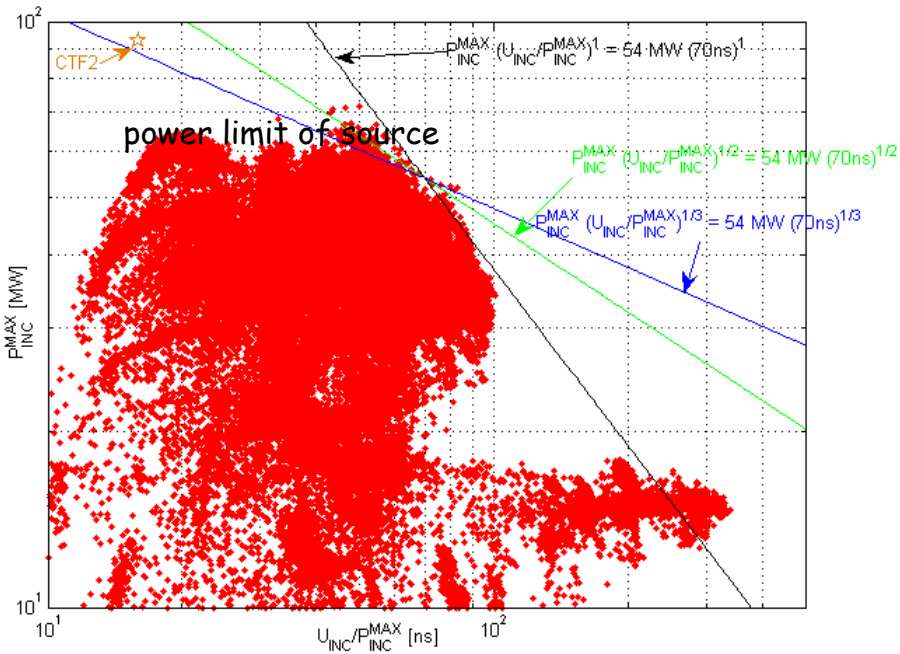
30 GHz Mo-iris structure

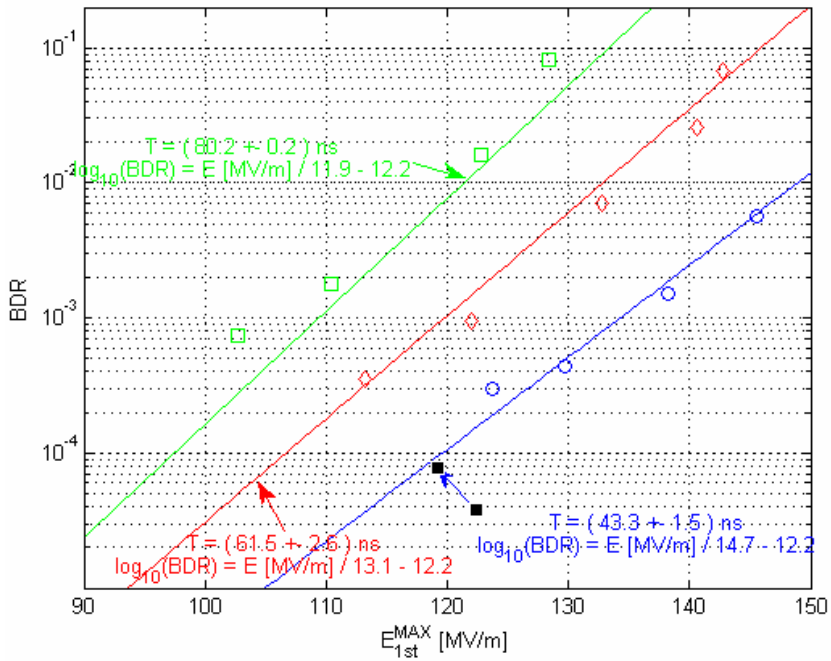
Conditioned to 140 MV/m, 70 ns, 52 MW

Breakdown probability slope 12 MV/m/decade

Presented at EPAC

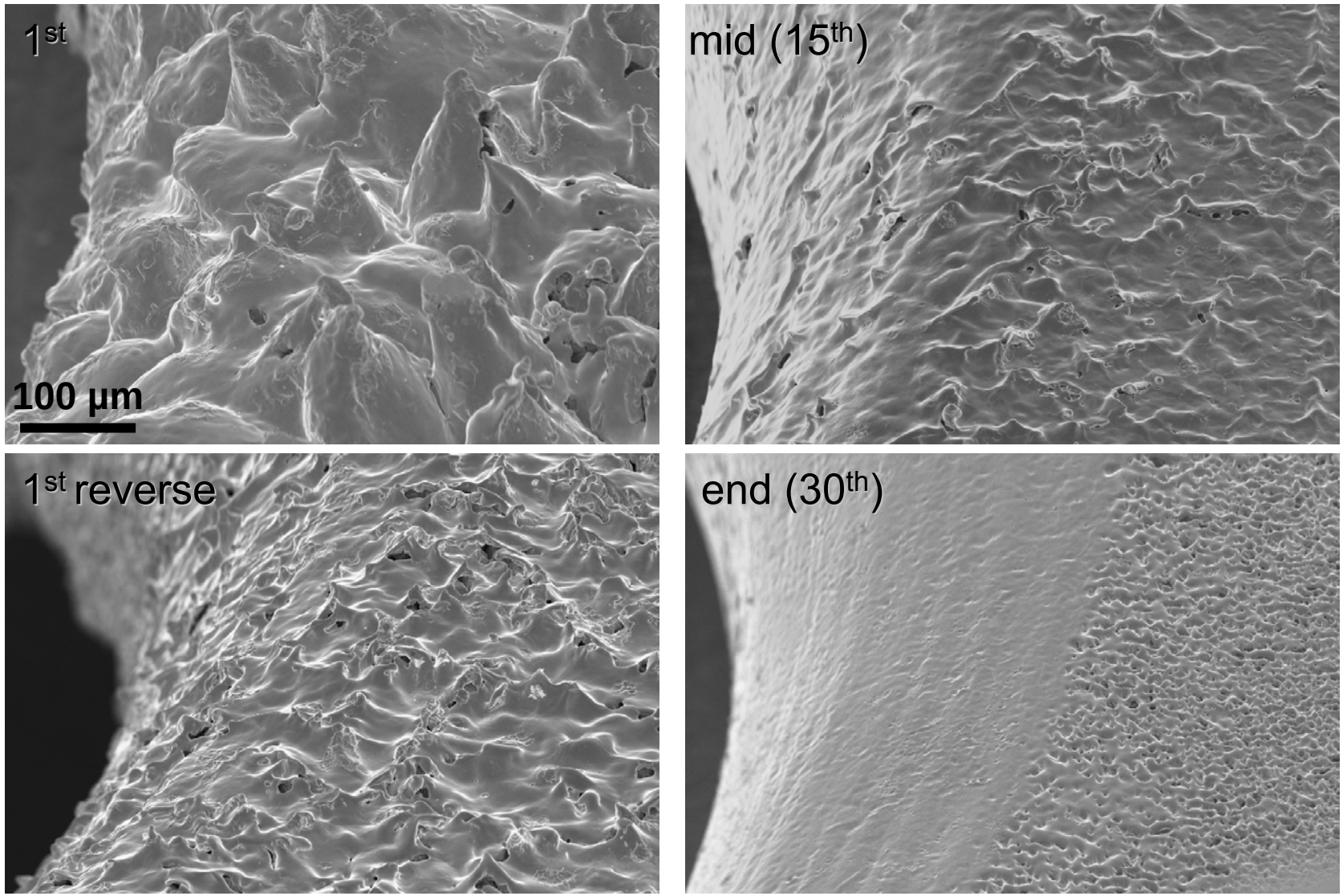




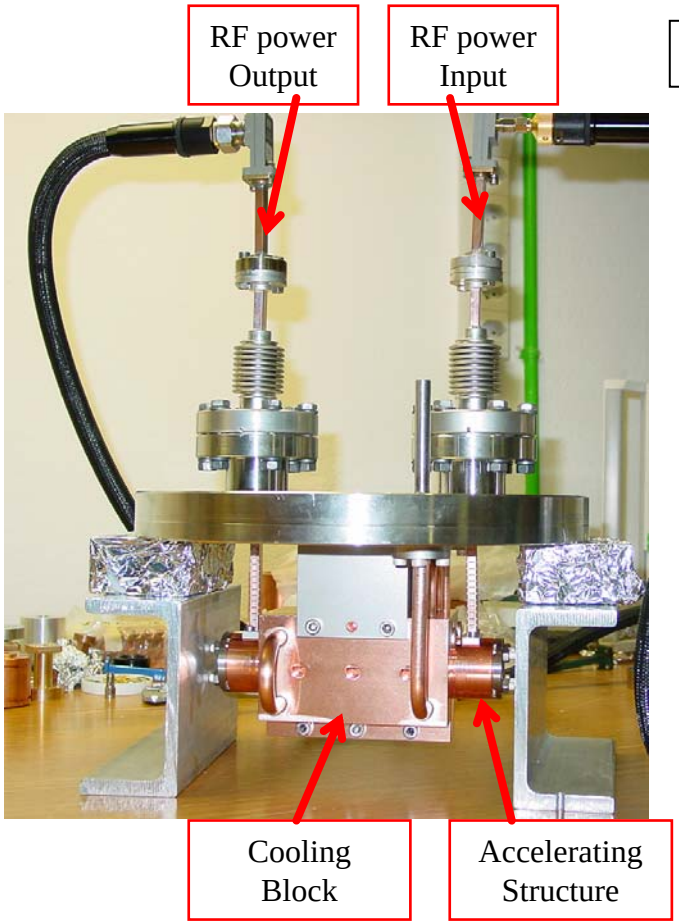


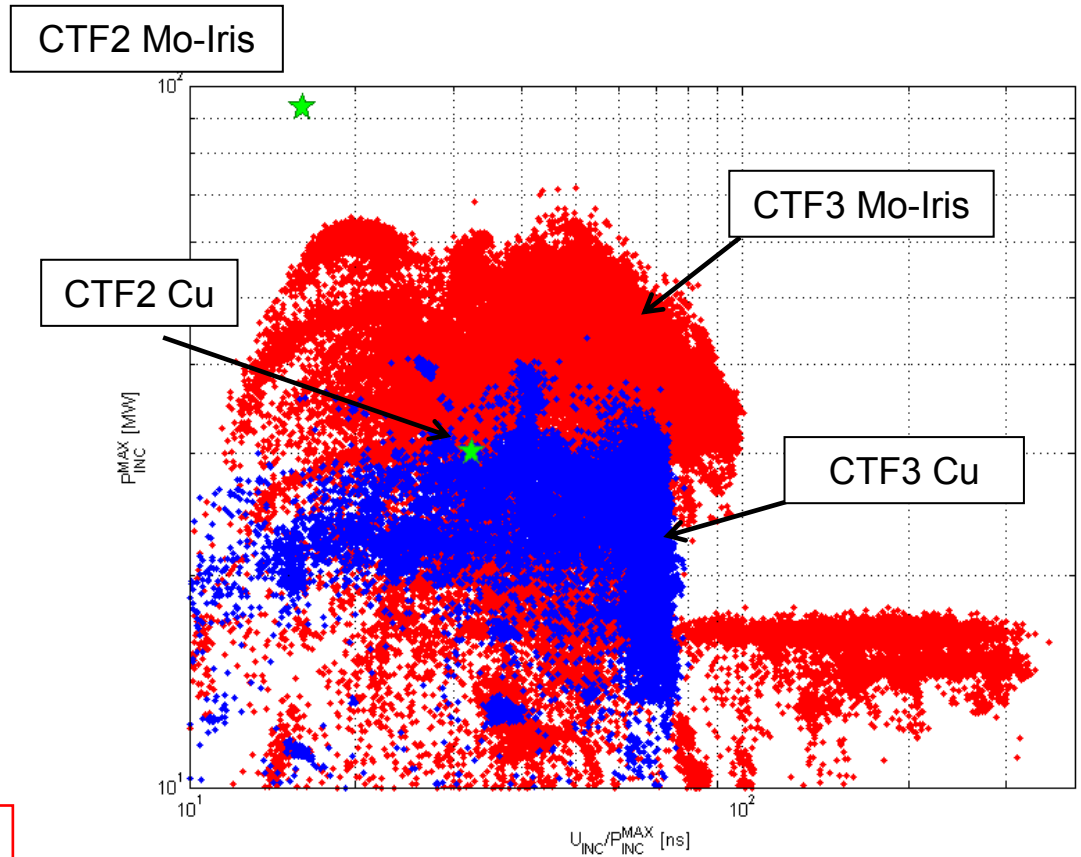
Surface modifications of Mo-iris structure – lesson learned!

200x



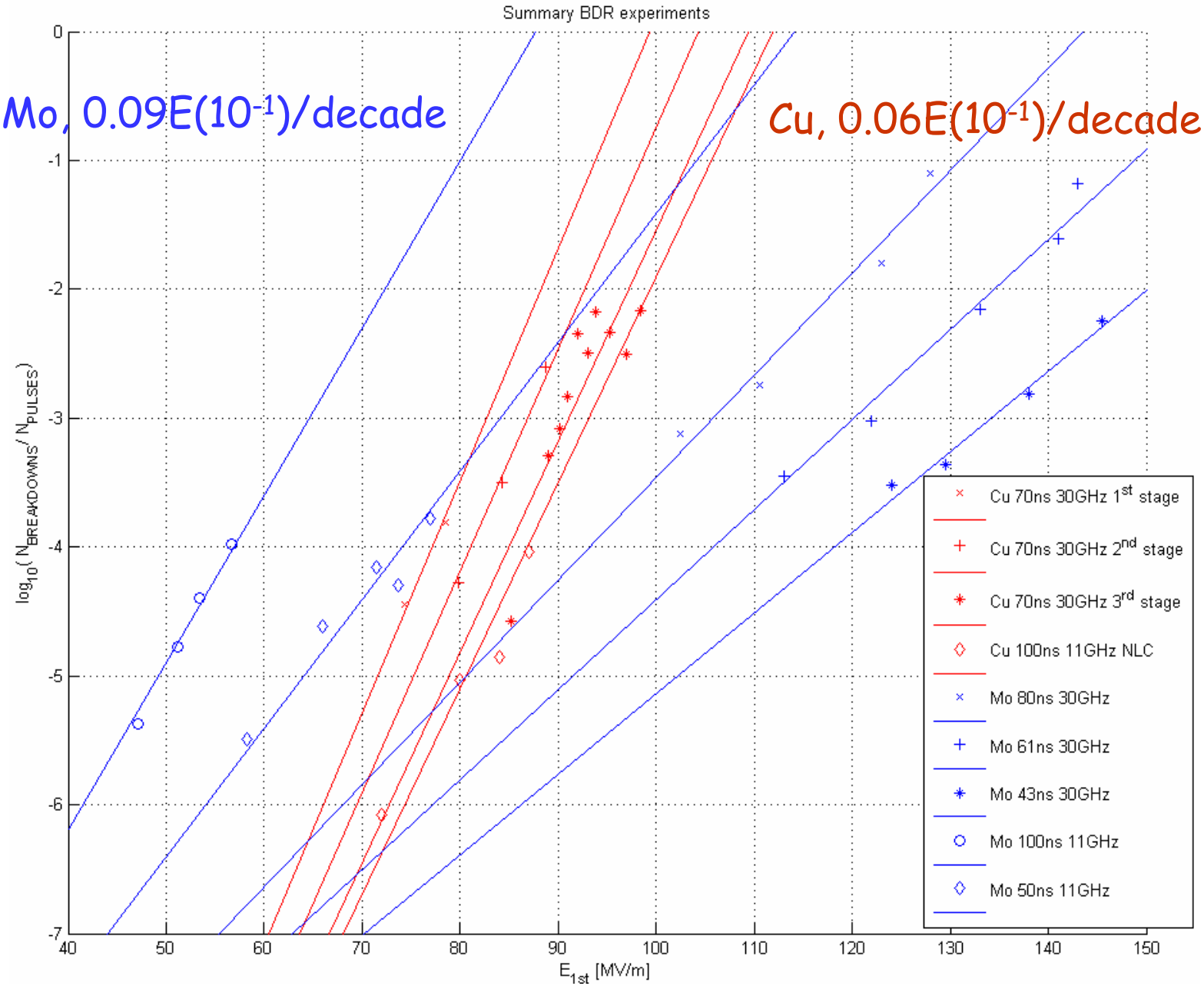
30 GHz copper 2π/3 structure





Peak gradient 110 MV/m, 70 ns

Breakdown probability – material dependence

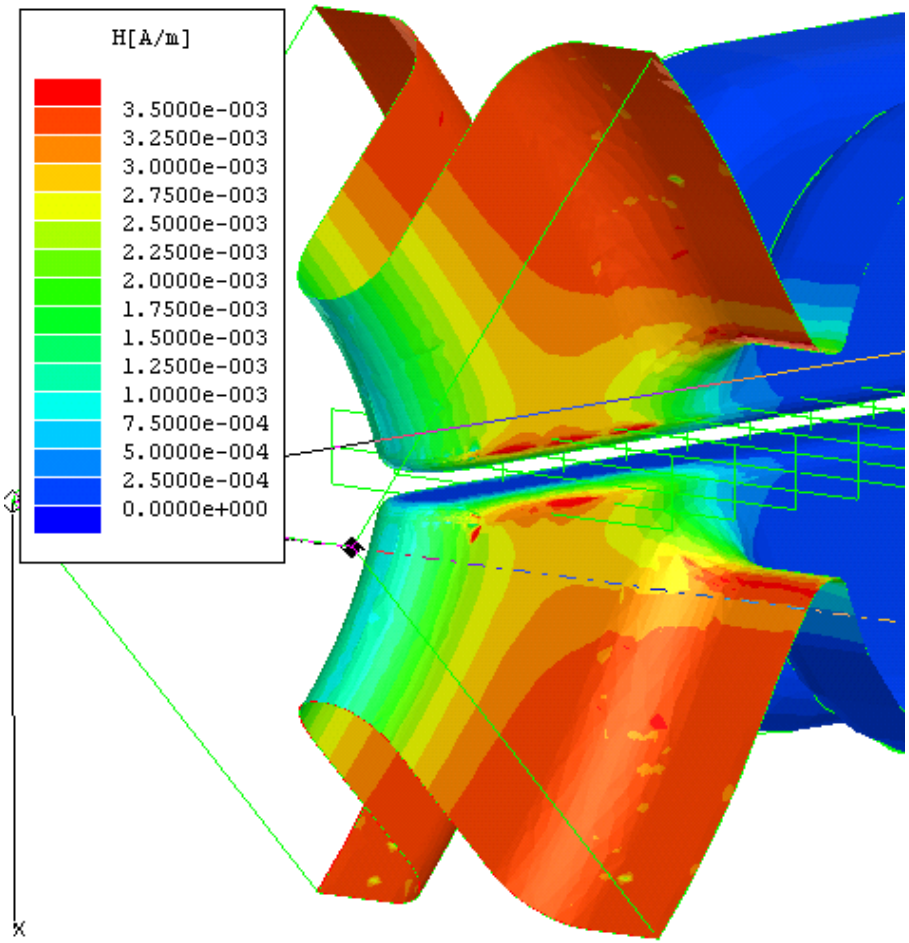


Heavily-damped structure testing

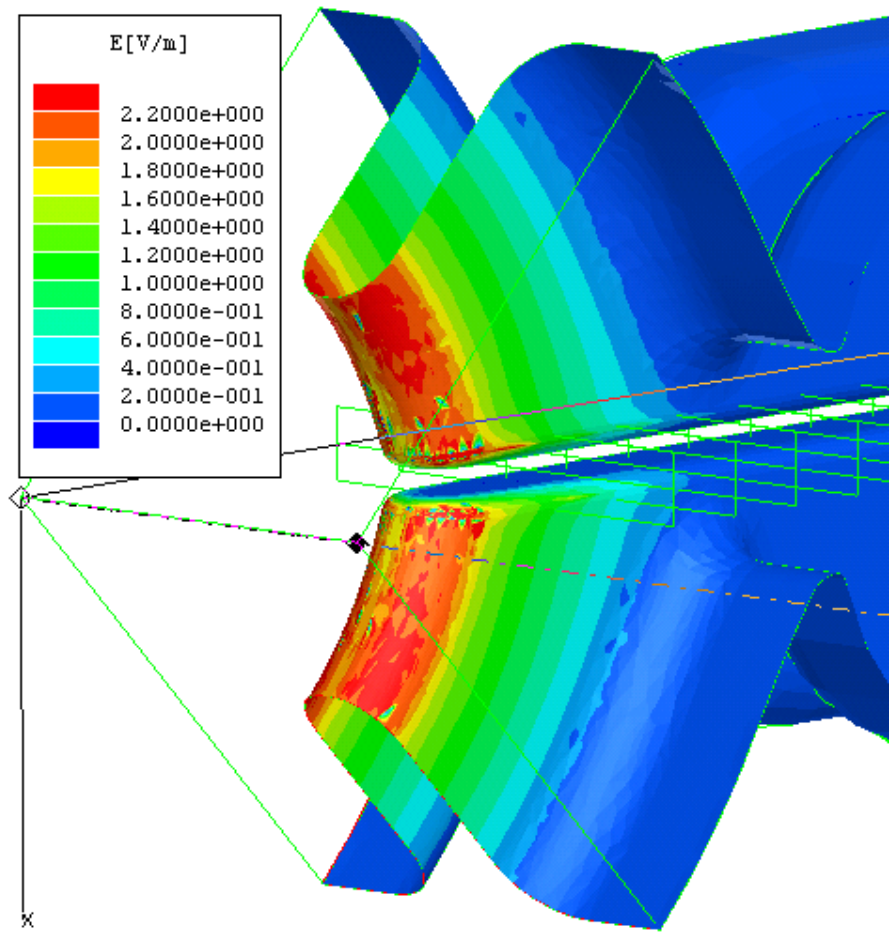
short rf pulses give high gradients

HDS cell design

Surface magnetic field

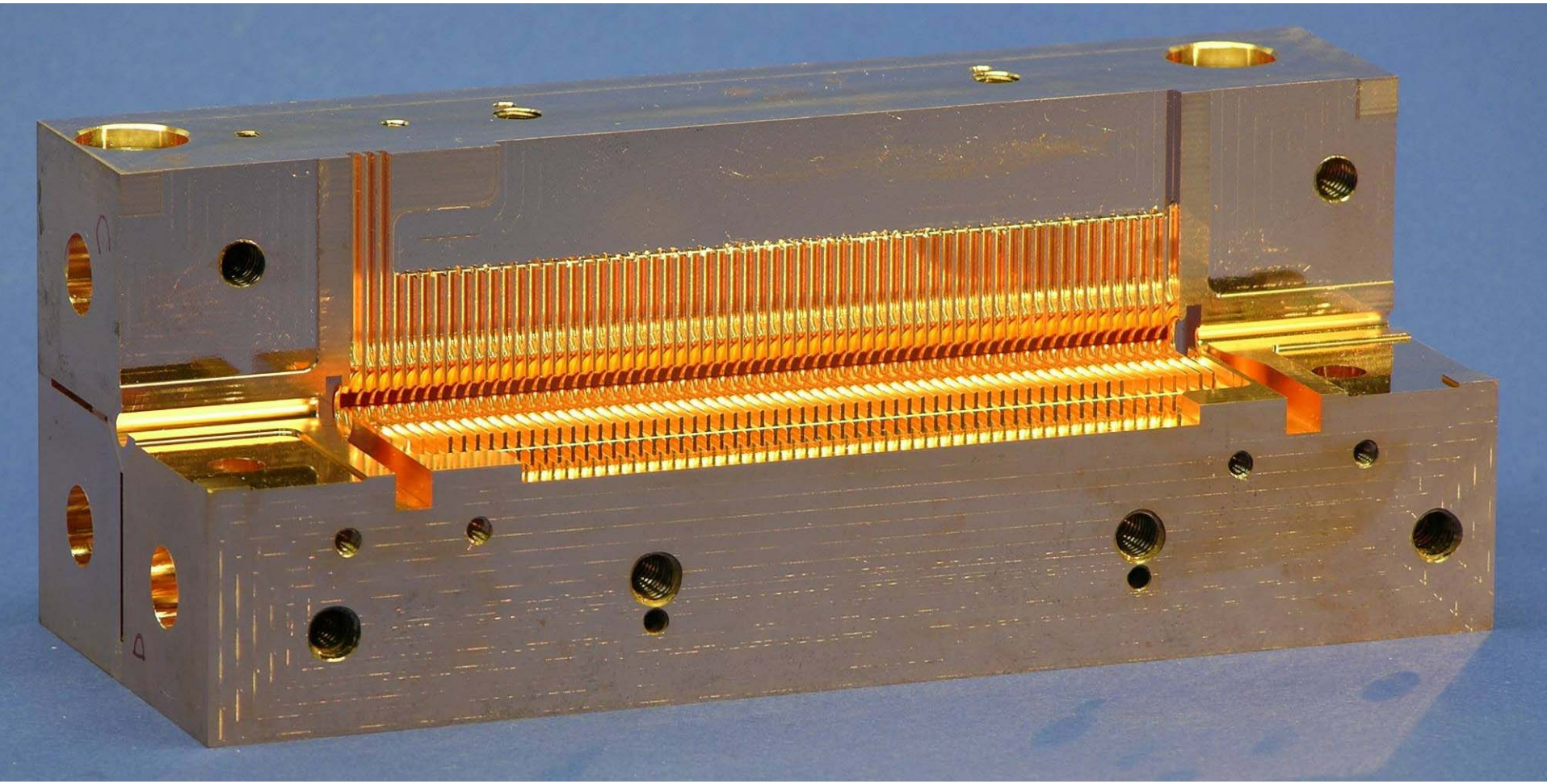


Surface electric field



+ strong HOM damping allows short rf pulses

HDS 60-cell Cu prototype



Test underway: HDS OK at high power! 25 MW, 70 ns, 79 MV/m average, 83 MV/m peak so far…

Upcoming tests

Cu, Al, stainless steel 30 GHz test structures

Mo and Ti also finished + X-band Cu. X-band Mo under fabrication

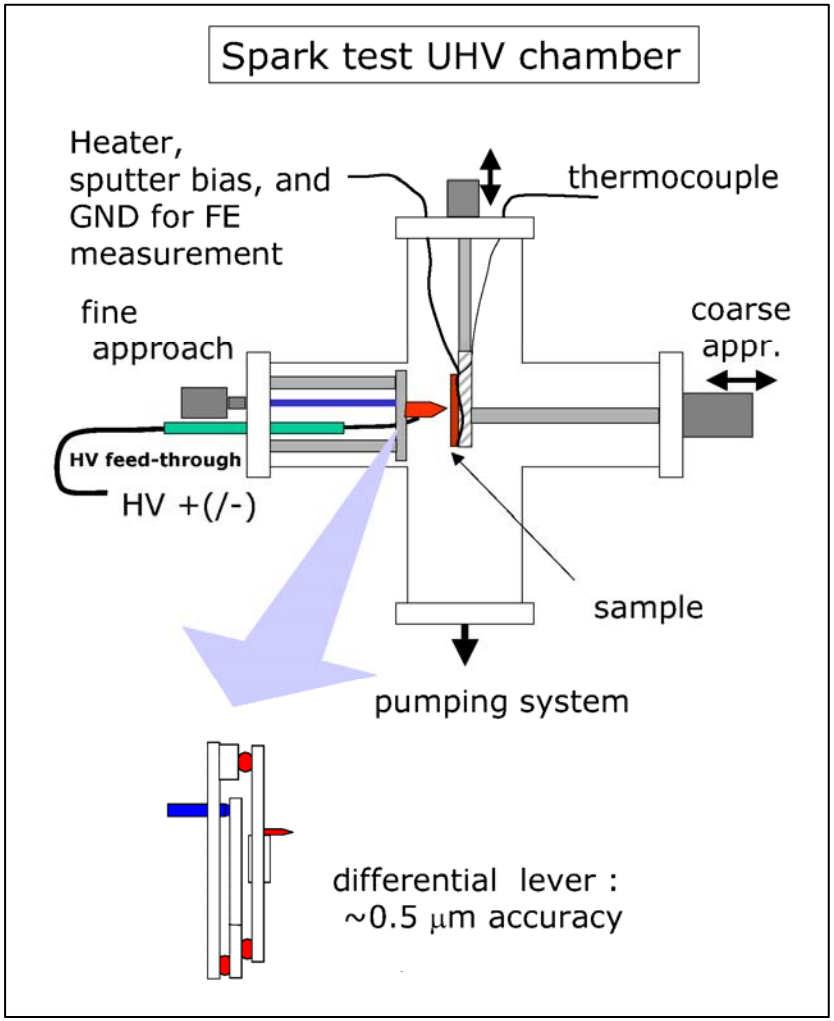
Technology development

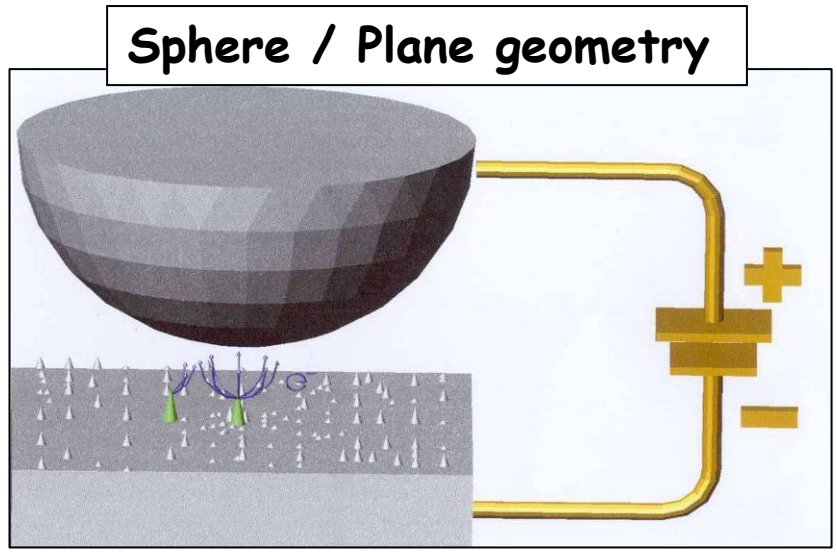
- spark resistant and low breakdown-rate materials
- pulsed surface heating resistant materials
- precision 3-d machining
- bimetallic structures
- surface preparation and preparation
- dc spark
- laser and ultrasonic fatigue

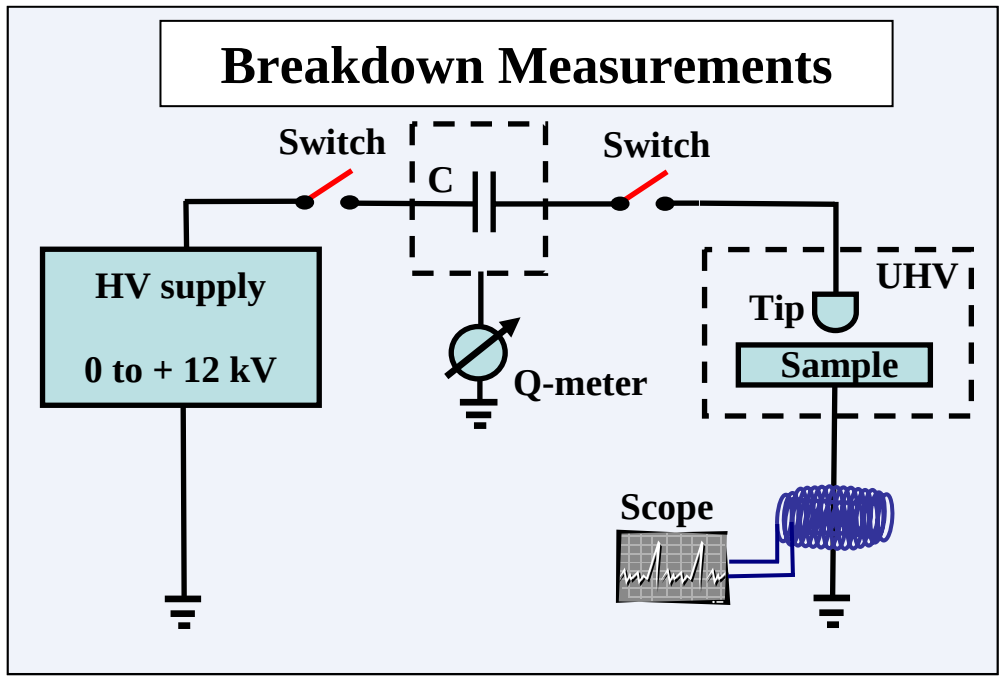
dc spark

Been done many times, but here we reproduce rf procedures and types of measurements.

Experimental Setup

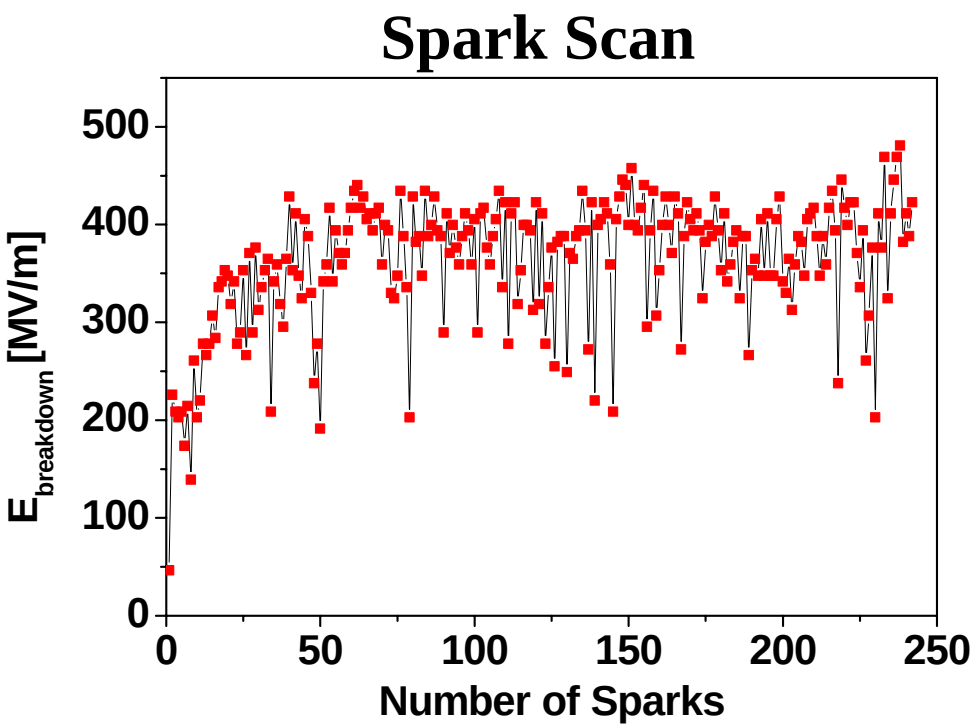


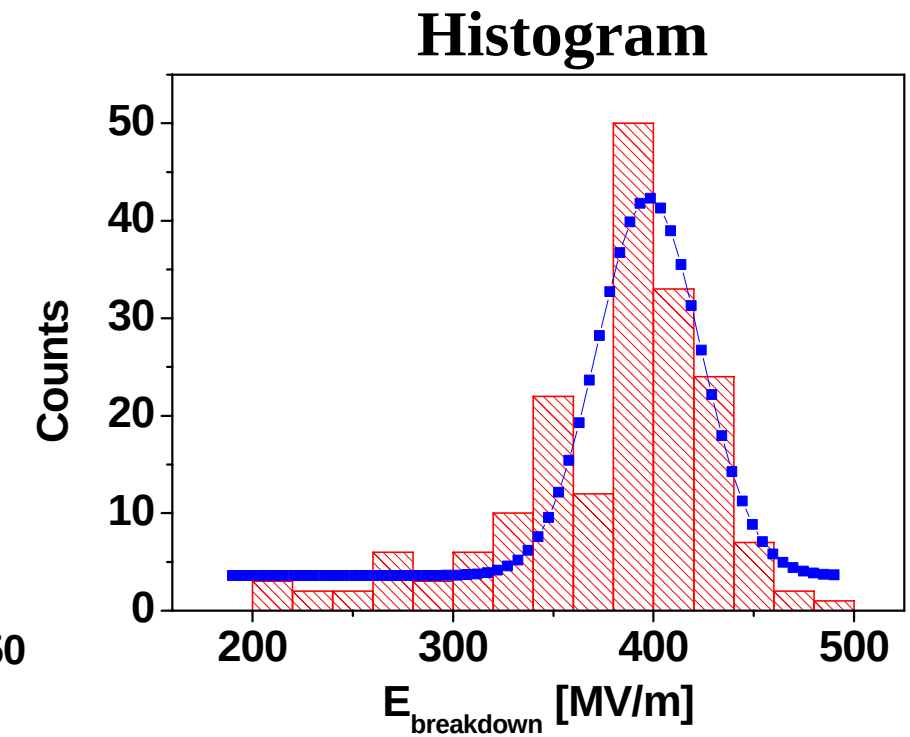




Automatic Spark Conditioning

Molybdenum (Mo) – Tip and Sample

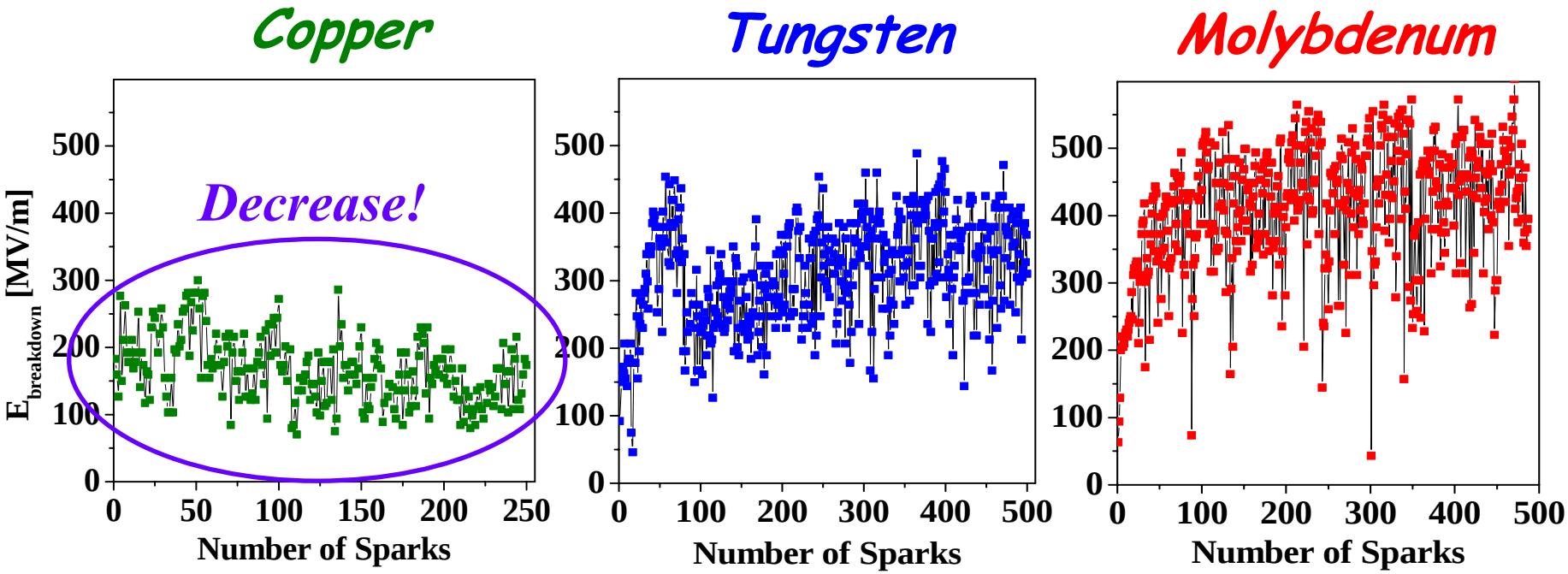




$$E_{breakdown}^{sat} \cong (398 \pm 4)\ MV/m \text{ at } \sim 4 \times 10^{-8}\ mbar$$

Presented at EPAC

Comparison Cu – W - Mo



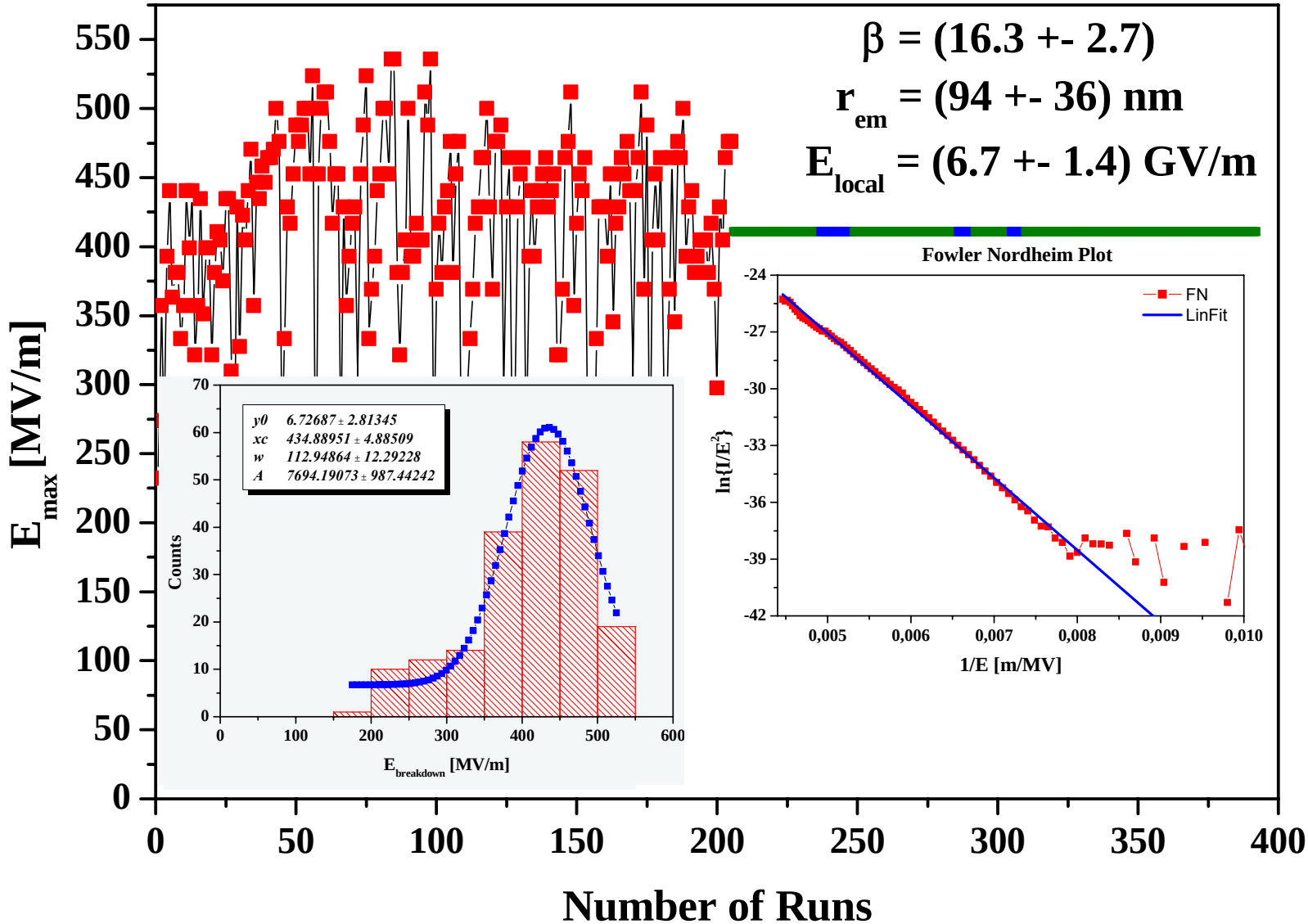
Cu: $E^{sat}_{breakdown} \cong (159 \pm 3)$ MV/m at ~ 7×10^{-10} mbar

W: $E^{sat}_{breakdown} \cong (349 \pm 6)$ MV/m at ~ 2×10^{-08} mbar

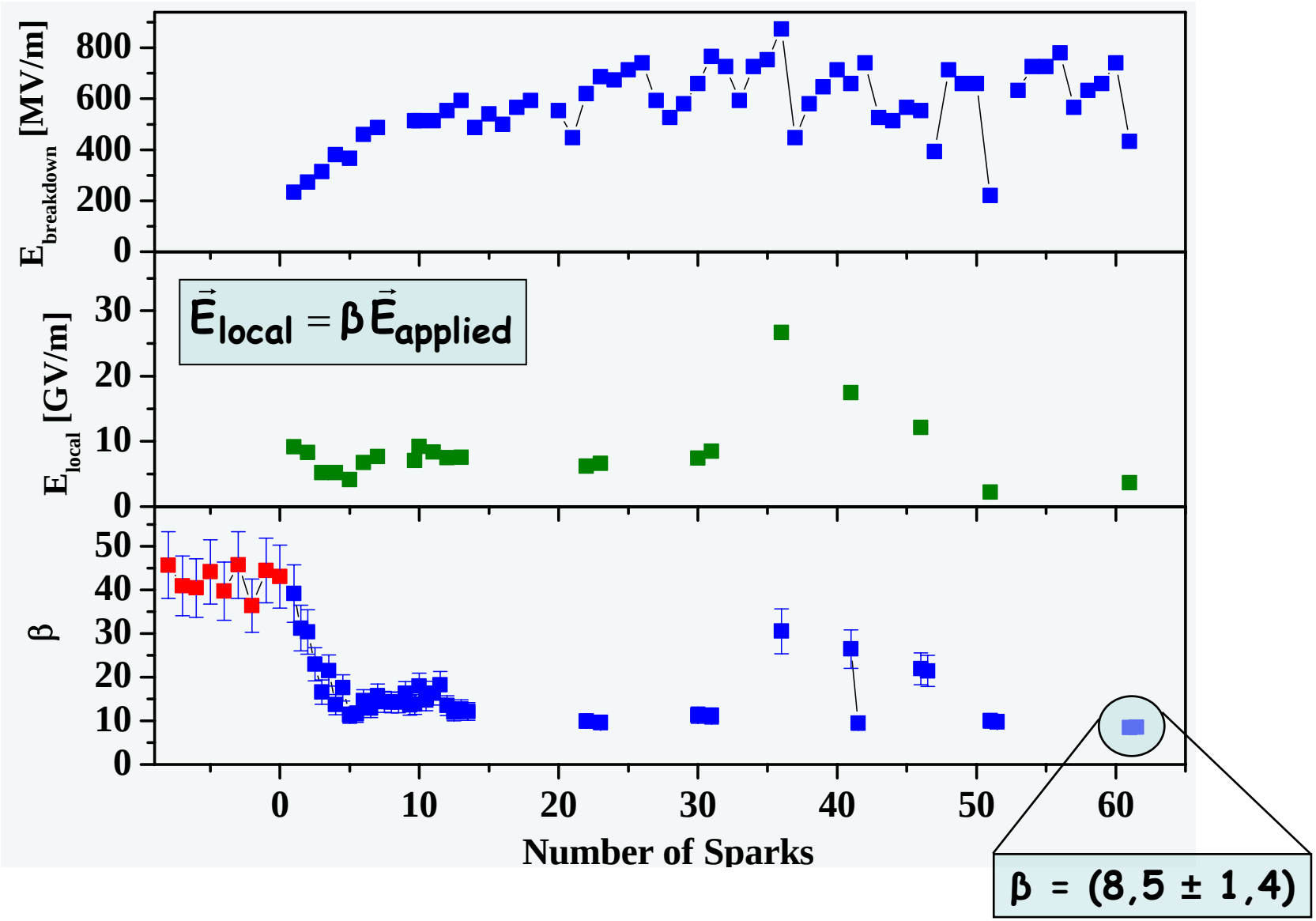
Mo: $E^{sat}_{breakdown} \cong (431 \pm 7)$ MV/m at ~ 2×10^{-09} mbar

Preparation for breakdown probability measurements - Mo

Saturation Field = 435 MV/m **Operation Field = 410 MV/m**

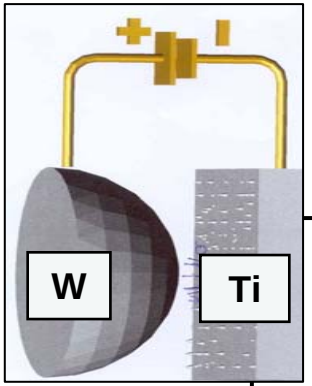


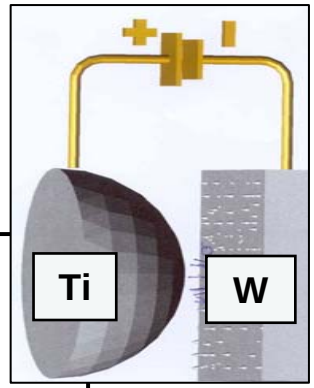
Titanium Anode and Cathode

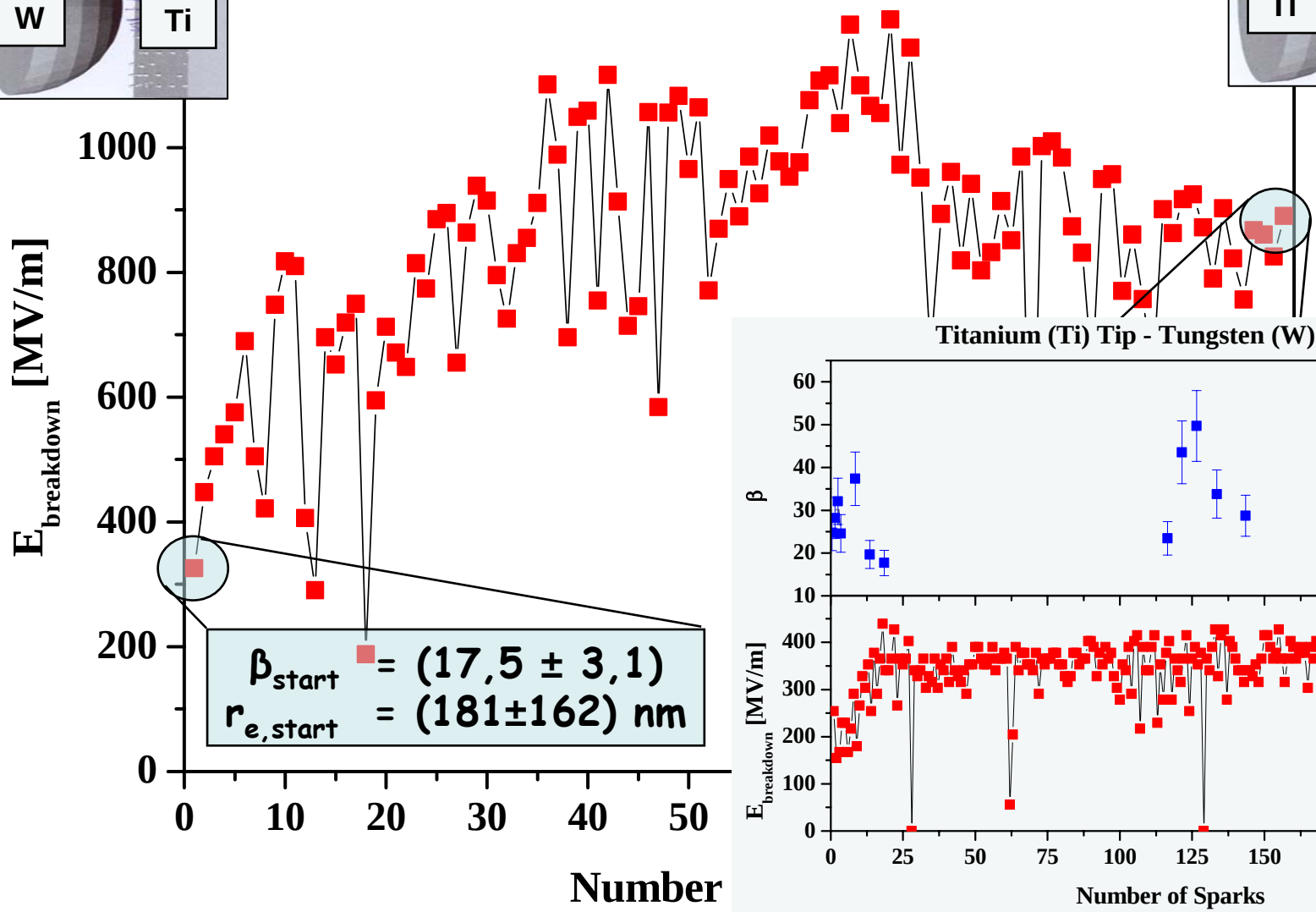


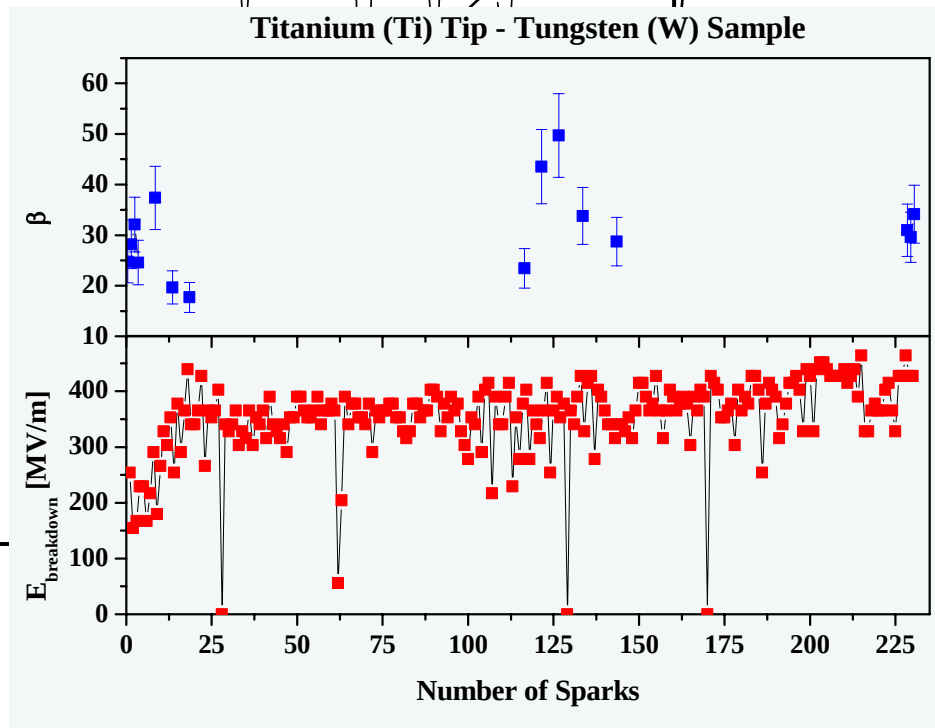
W ↔ Ti / anode ↔ cathode

Tungsten (W) Tip - Titanium (Ti) Sample









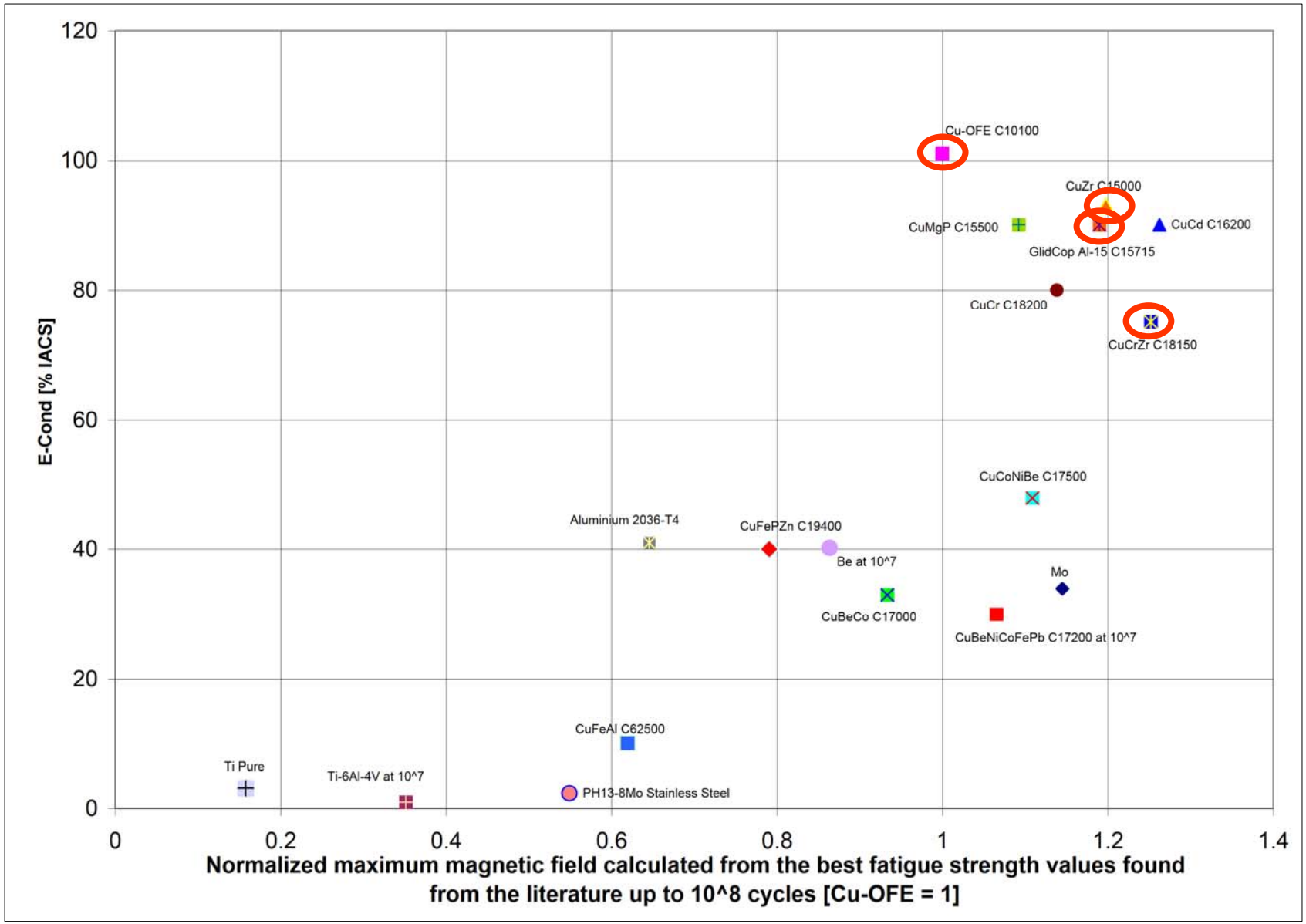
Other dc spark highlights

- Mo vacuum bake parameters optimized for significant reduction in conditioning time
- Effect of static pressure on breakdown field of Mo measured
- GLIDCOP breakdown field/conditioning rate has been compared to copper
- Second system under preparation with higher voltage, variable pulse energy and better breakdown probability capabilities.

Fatigue testing

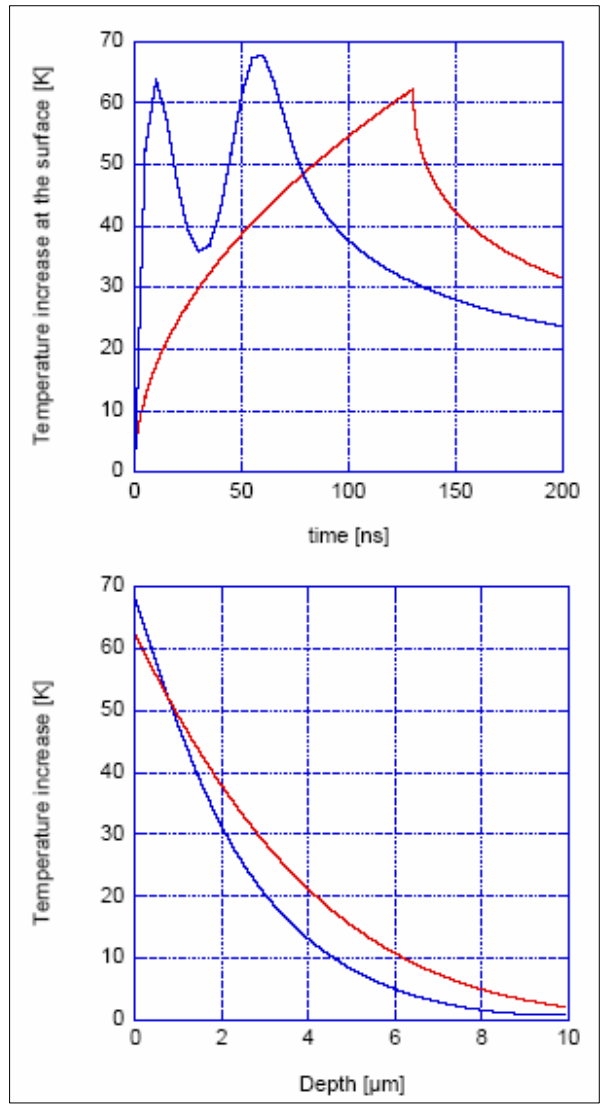
Simulate pulsed surface heating for faster technology development

Presented at EPAC Candidate materials for cell walls

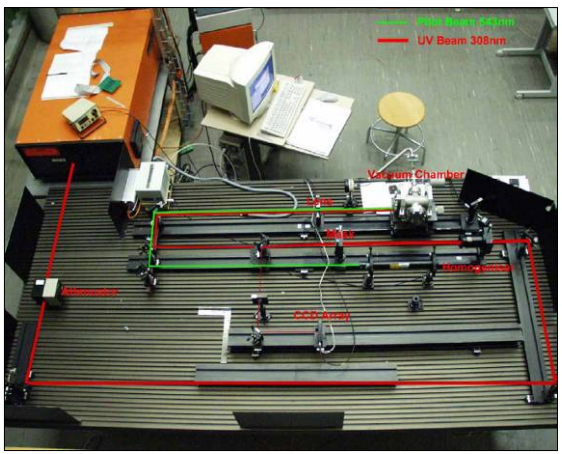


Pulsed Laser Fatigue Tests

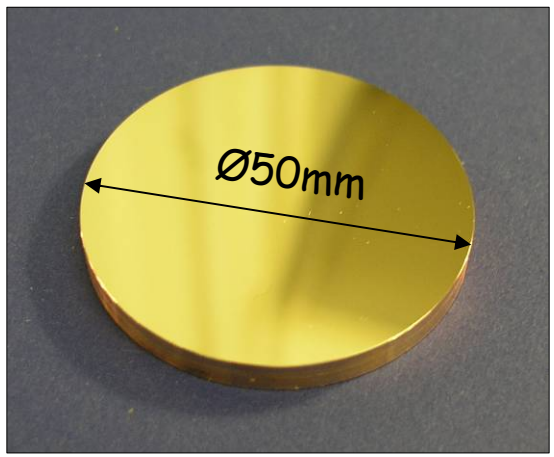
- Surface of test sample is heated with pulsed laser. Between the pulses the heat will be conducted into the bulk.
- The Laser fatigue phenomenon is close to RF fatigue.
- The operating frequency of the pulsed laser is 20 Hz -> low cycle tests.
- Observation of surface damage with electron microscope and by measuring the change in surface roughness.
- Tests for CuZr & GlidCop in different states under way.



Red curve – CLIC RF pulse
Blue curve – Laser pulse



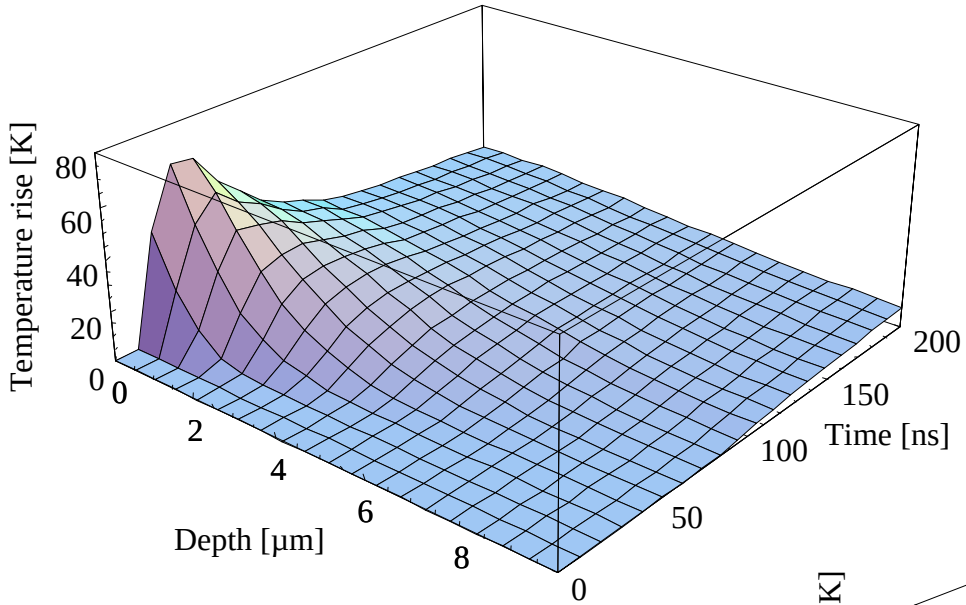
Laser test setup



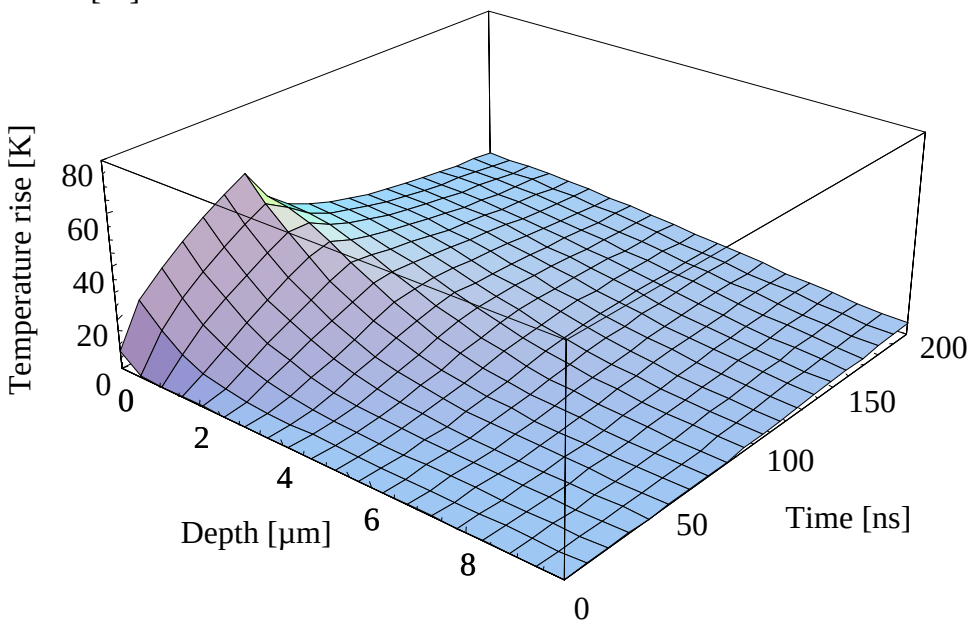
Diamond turned test sample, Ra 0.025µm

Comparison of heating profiles

← Laser pulse



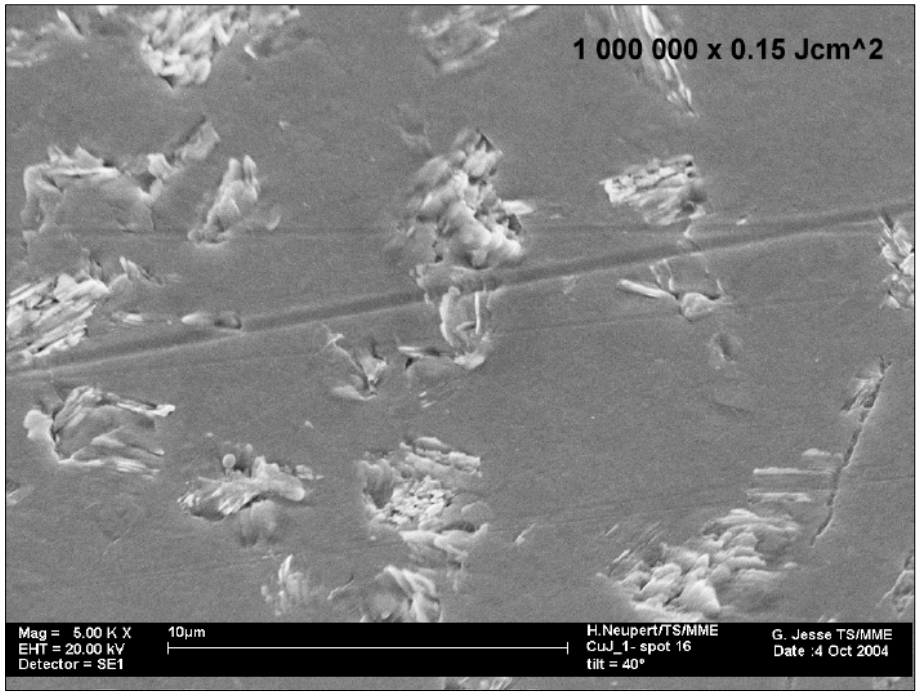
RF pulse ↓



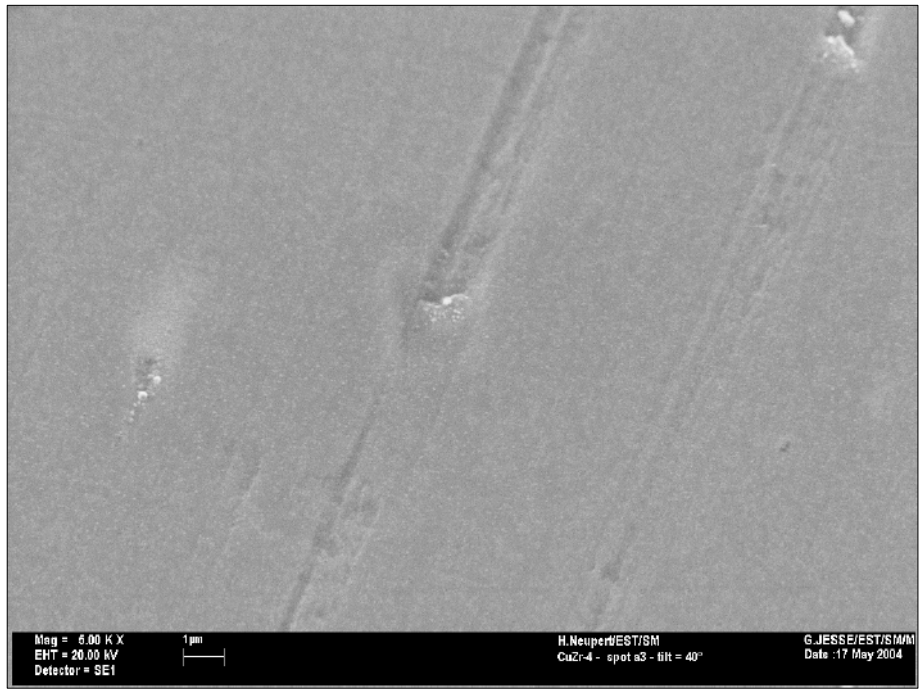
The pulse shapes correspond.
In particular the temperature profile at the peak is very similar, and results in similar stress level.

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

Pulsed Laser Fatigue Tests



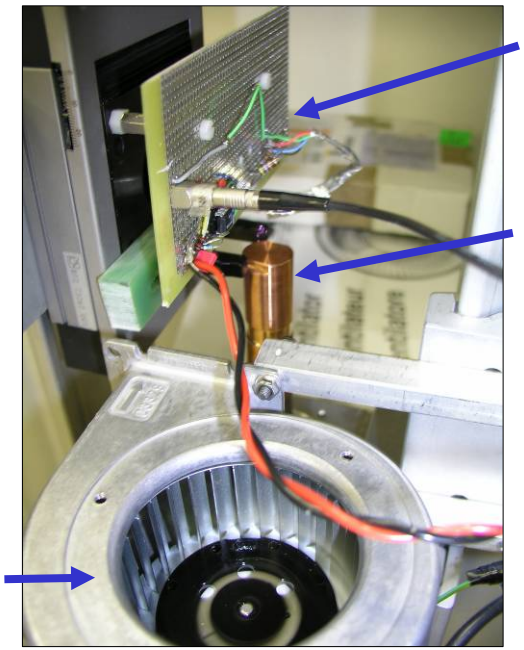
Cu-OFE at 10^6 cycles, $\Delta T=90°C$
Fatigued surface



CuZr at 10^6 cycles, $\Delta T=90°C$
No fatigue.

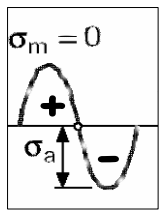
Ultrasonic fatigue experiment

- 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.



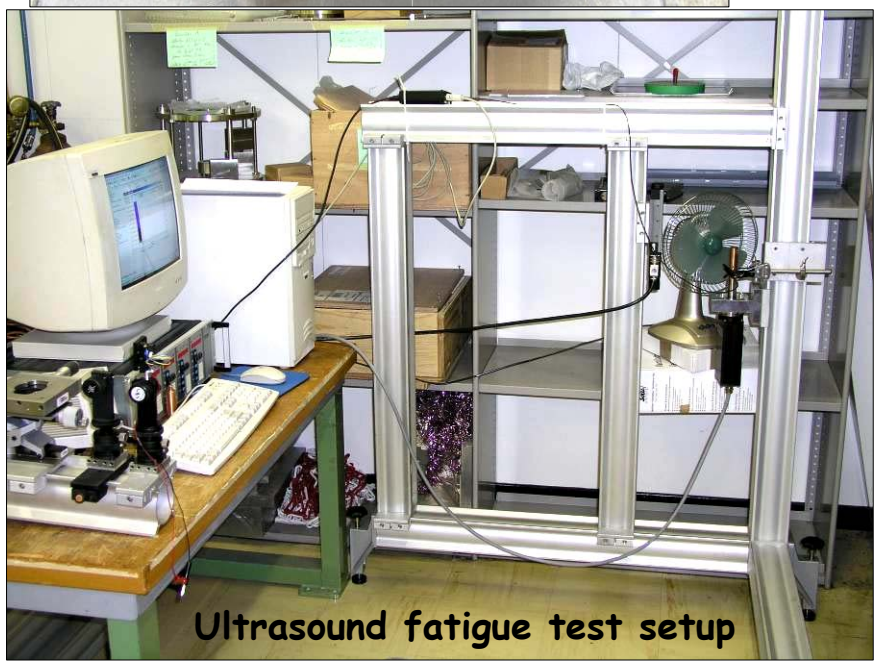
Calibration card measures the displacement amplitude of the specimen's tip

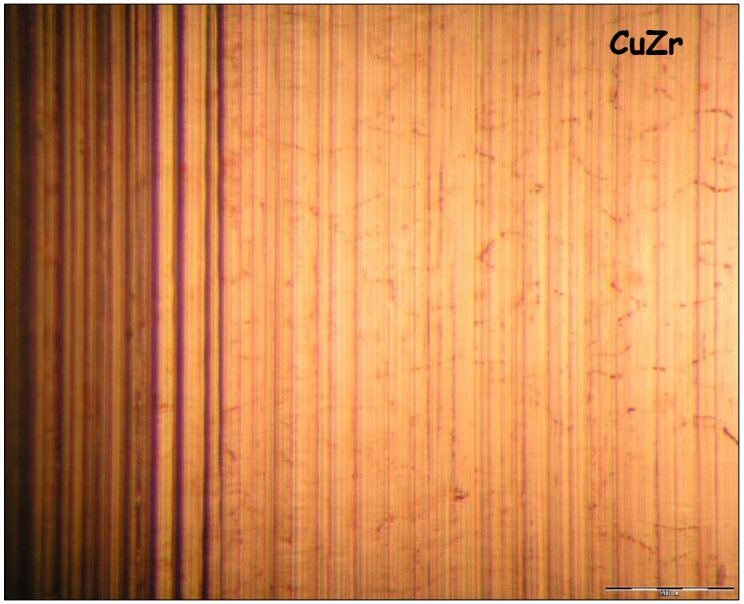
Fatigue test specimen



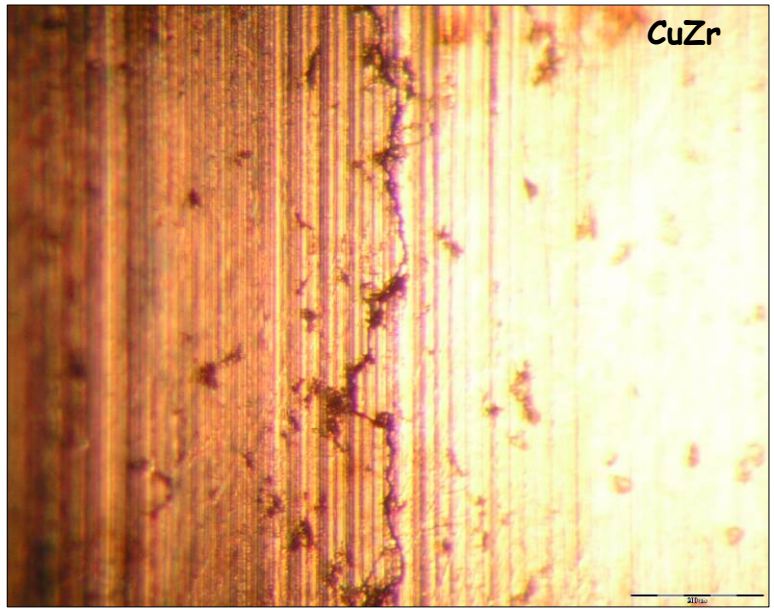
Reversed stress condition

Air Cooling

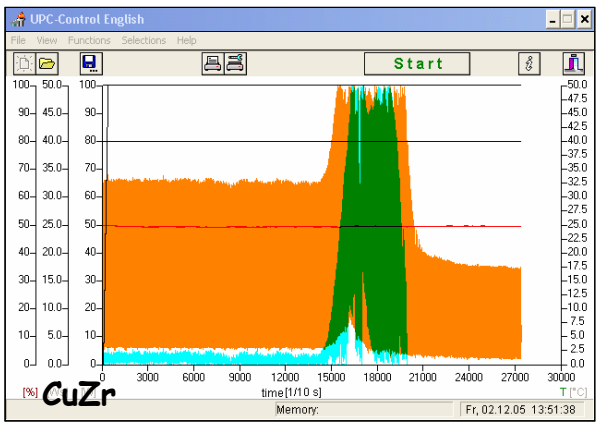


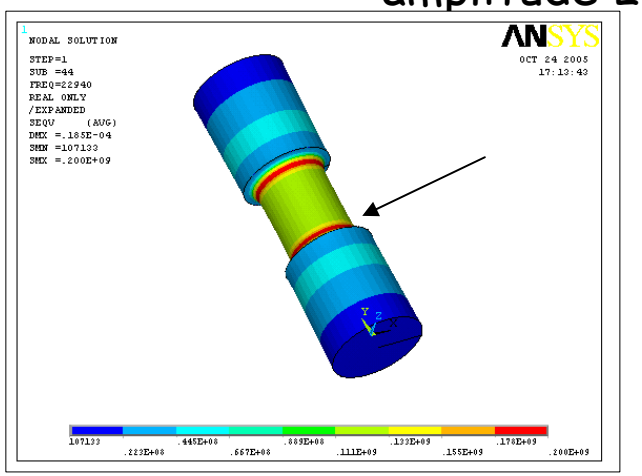


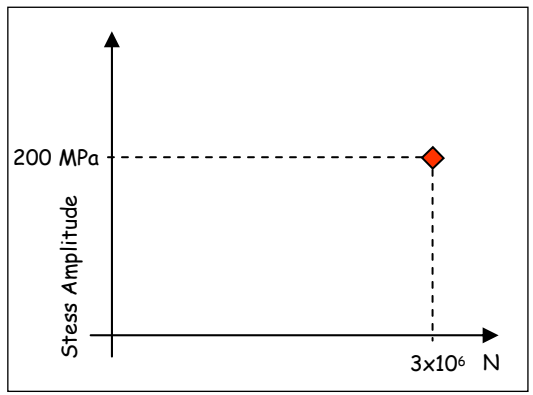
Diamond turned specimen before



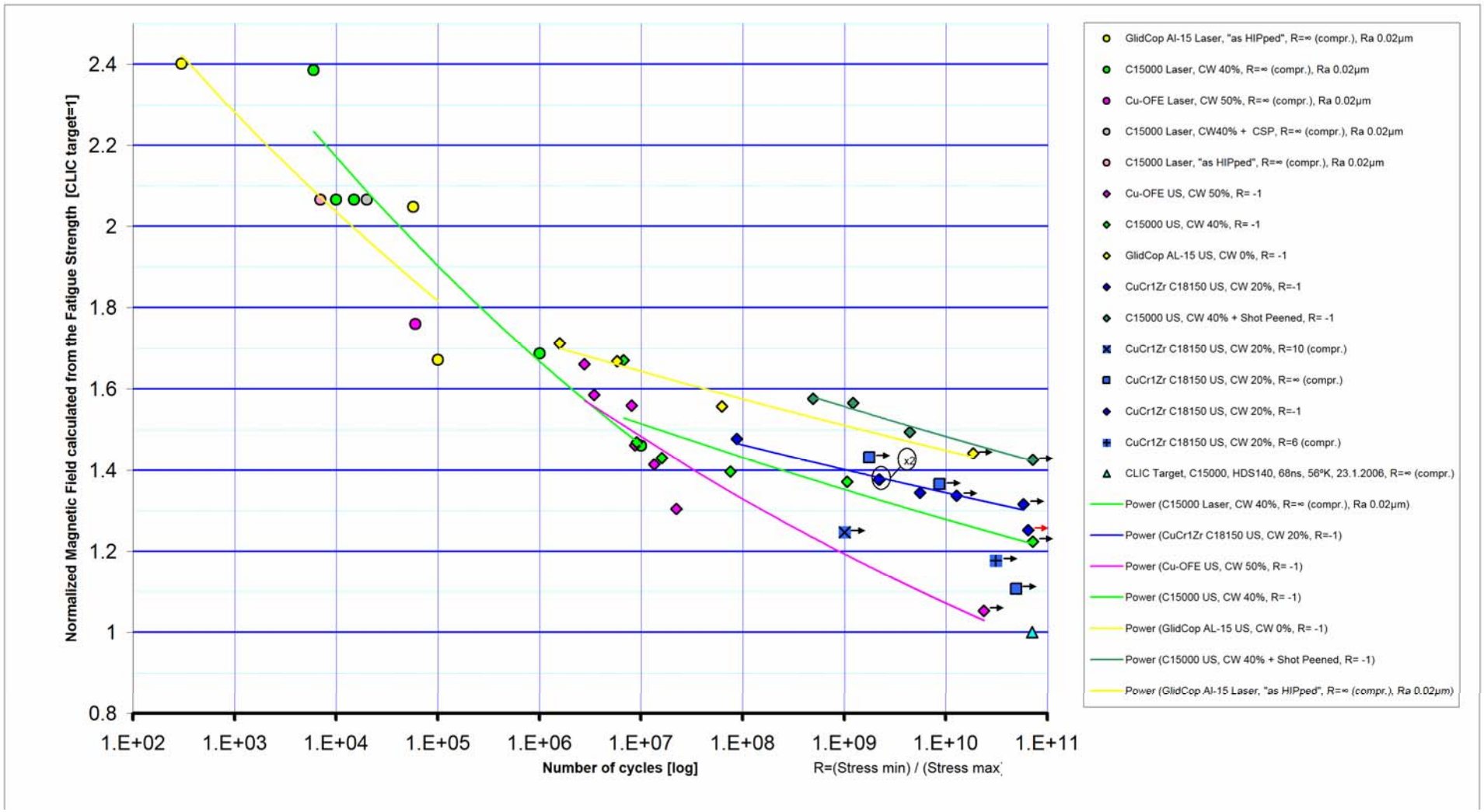
After 3*10⁶ cycles at stress amplitude 200 MPa







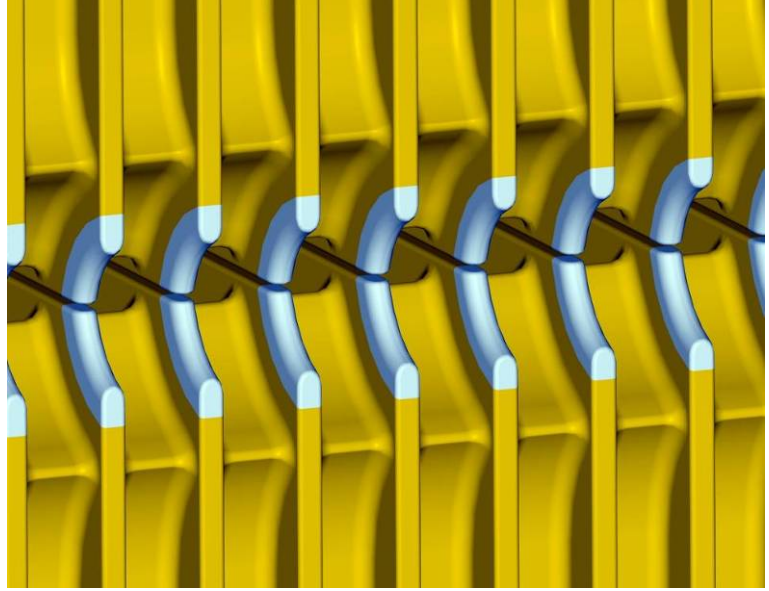
Laser and ultrasonic fatigue results summary

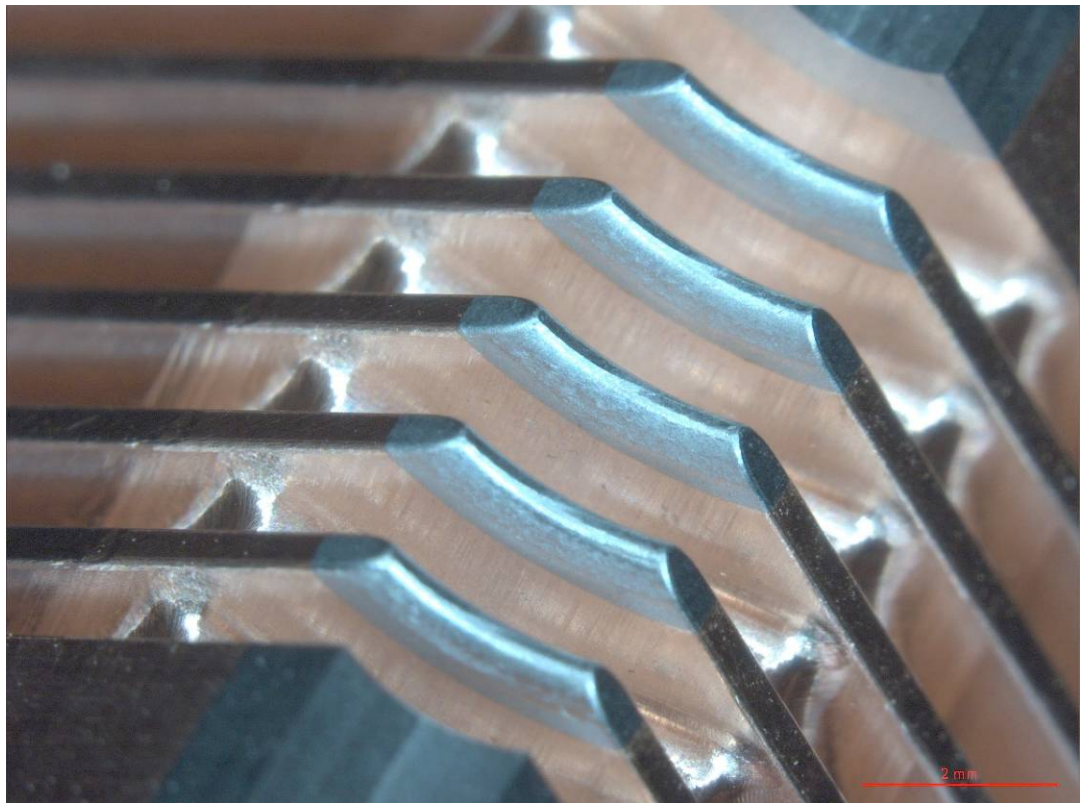


30 GHz and X-band rf benchmark experiments under preparation.
Low cycle 34 GHz experiment under way at Dubna.

Bimetallic structures

Hot isostatic pressing and high-speed milling of CuZr/Mo

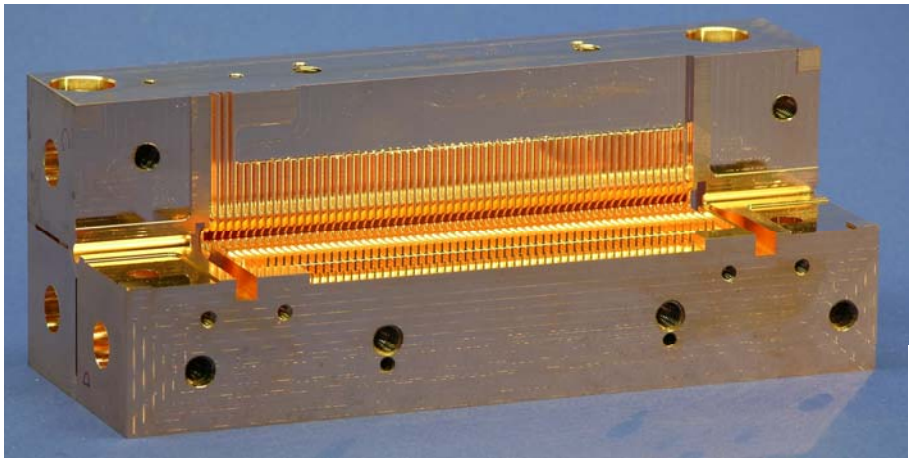




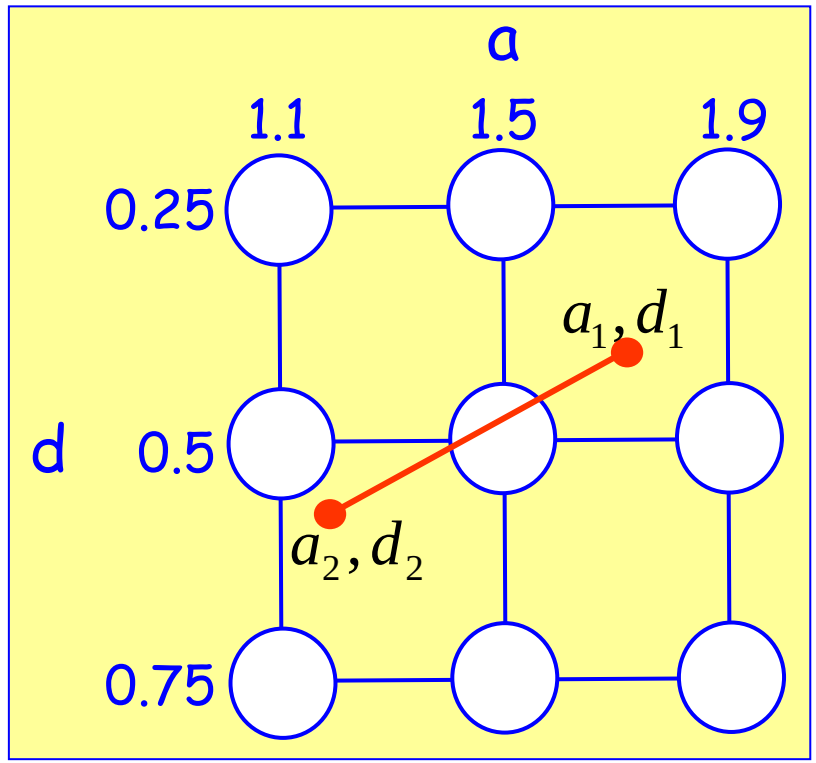
rf design

Try to reconcile the conflict between high gradient and high efficiency

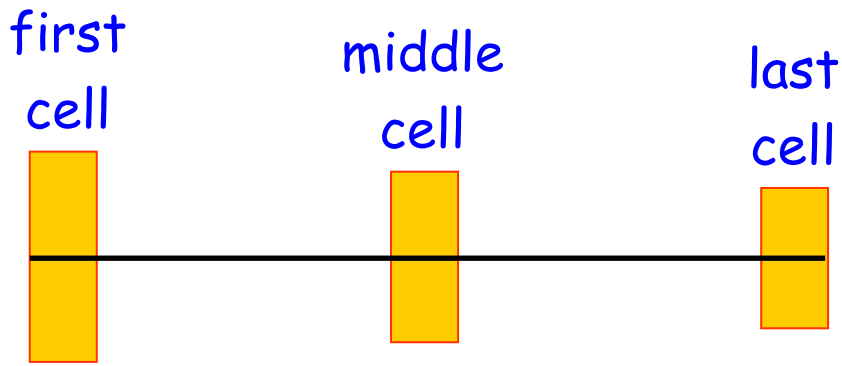
Optimization procedure



Single cell parameter interpolation



Structure parameters are calculated using parameters of the three cells:



Presented at EPAC

Optimization constraints

Beam dynamics constraints:

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

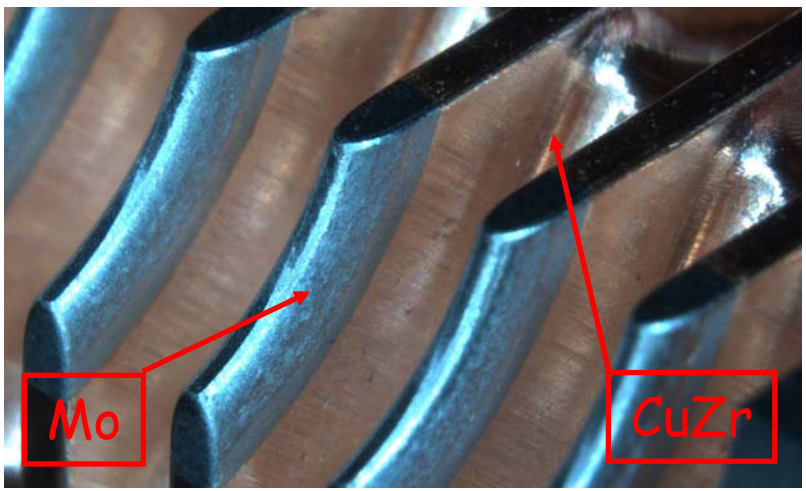
N_s is determined by condition: $W_{t,2}$ = 10 V/pC/mm/m for N = 4×10^9

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 & $\mathbf{D}T^{max} < 56$K

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

Bi-metallic HDS



Posters: MOPLS128; MOPLS103

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

Optimization figure of merit

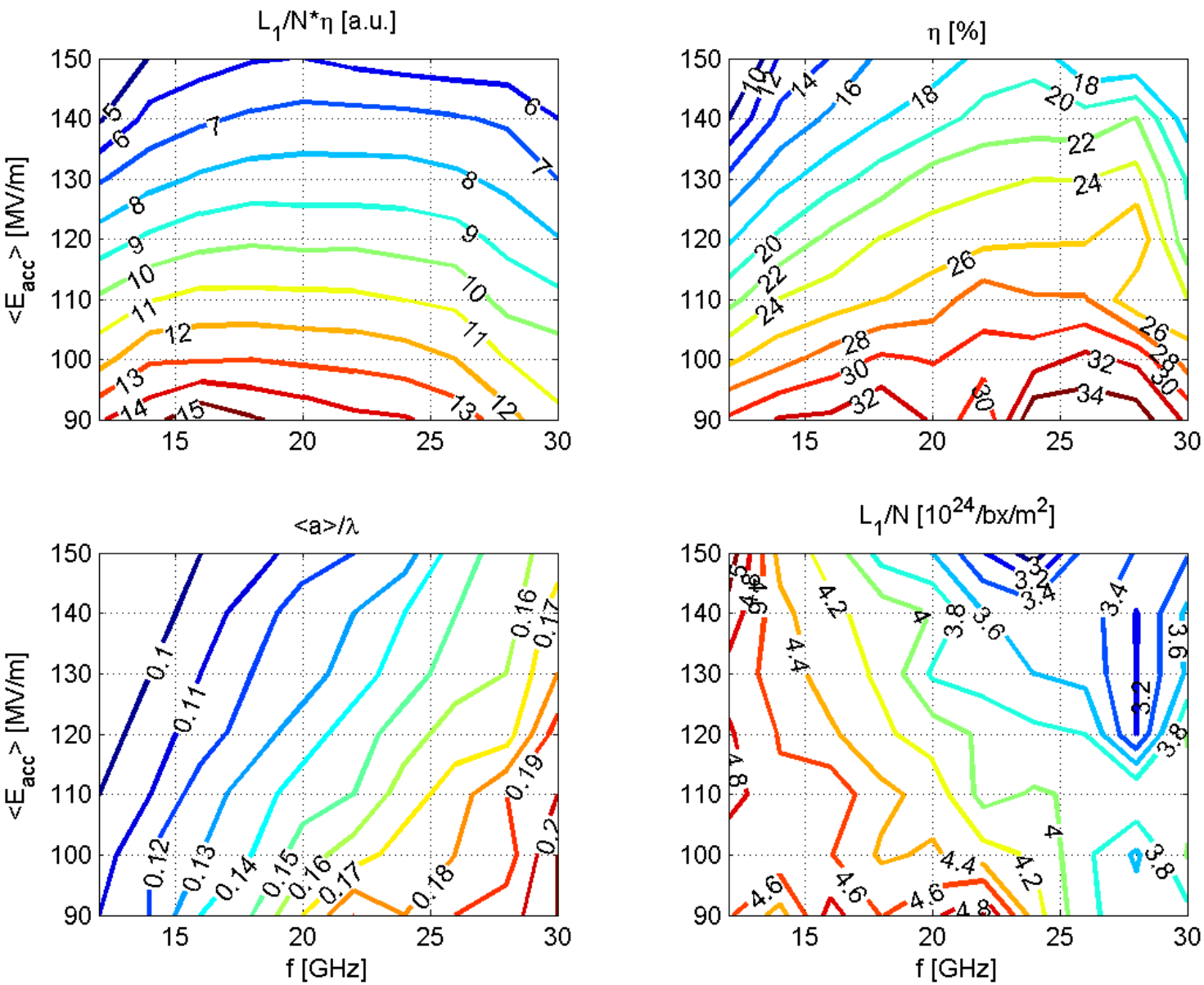
Luminosity per linac input power:

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

Collision energy is constant

Figure of merit

Optimization results



Workshop on High-Gradient RF

CERN, 25 to 27 September 2006

Local Organising Committee

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