High-Frequency, High-Gradient, **RF Breakdown**

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EPAC2002

Normal conducting linear-collider design principle #1,

“High frequencies give high gradients”

Is this really true?

In fact, tests have shown that RF breakdown is an exceedingly tricky issue for NLC/JLC, CLIC.

Damage observed, gradients were not obtained.

Substantial efforts to address RF breakdown issues have been launched within the linear collider studies.

This presentation attempts to summarize our understanding of the physics of breakdown and the development of techniques for higher gradients

Selected Linear-Collider RF Parameters

NLC/JLC 500 GeV	**11.424 GHz** 55 MV/m loaded accelerating gradient 85 MW section input power 267 ns RF flat top 23 J total RF pulse energy
CLIC 500 GeV and 3 TeV	**29.985 GHz** 150 MV/m loaded accelerating gradient 240 MW section input power 100 ns RF flat top 25 J total RF pulse energy

Conclusion: We're not doing too badly.

NLC/JLC have made long-run-time tests at the 70 MV/m level and now worry about conditioning times and trip rates.

CLIC built 11 GHz structures have supported over 120 MV/m accelerating gradients, 150 ns pulses.

30 GHz levels I'll come back to at the end of the talk.

It appears that the character of RF breakdown at high-frequency and high-gradient is different than at lower frequencies.

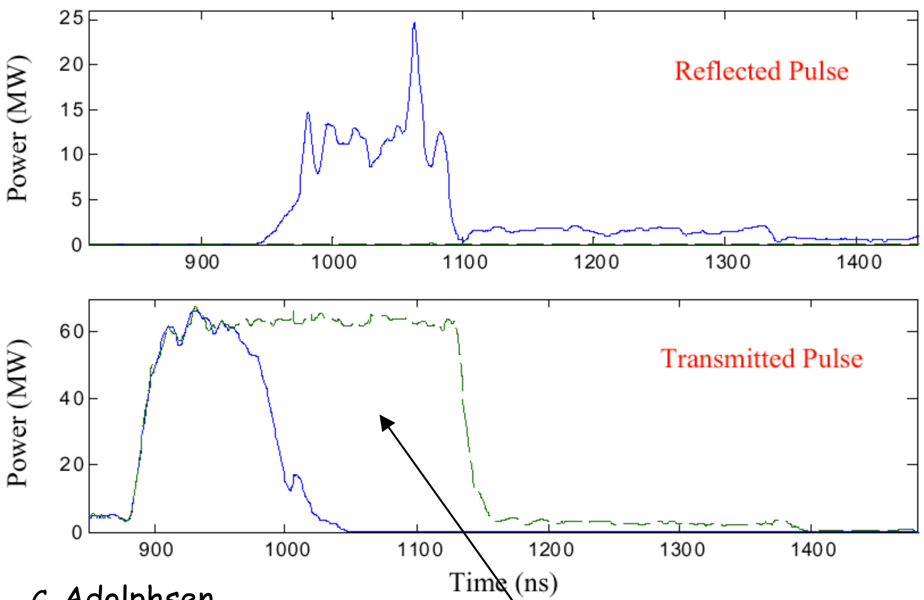
Progress in gradient will come from an understanding of RF breakdown.

Experimental results from NLCTA (11 GHz) and CTF2 (30 GHz).

General features

RF signature

11 GHz

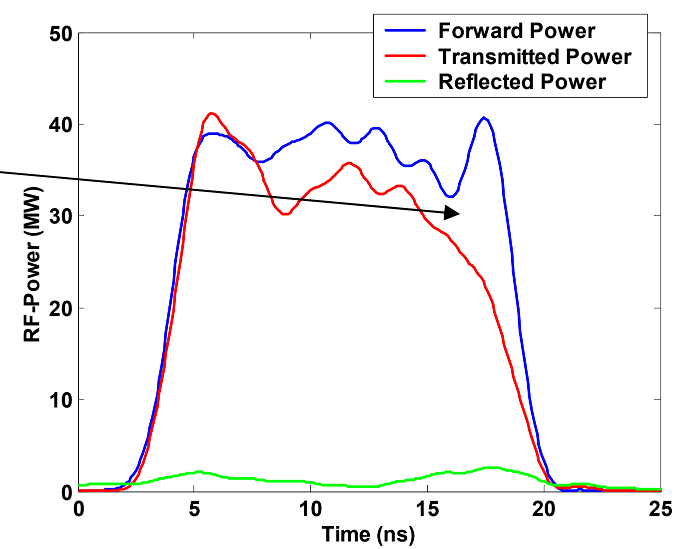


C. Adolphsen

Easily 50% of incoming power can go missing, > 50 MW.

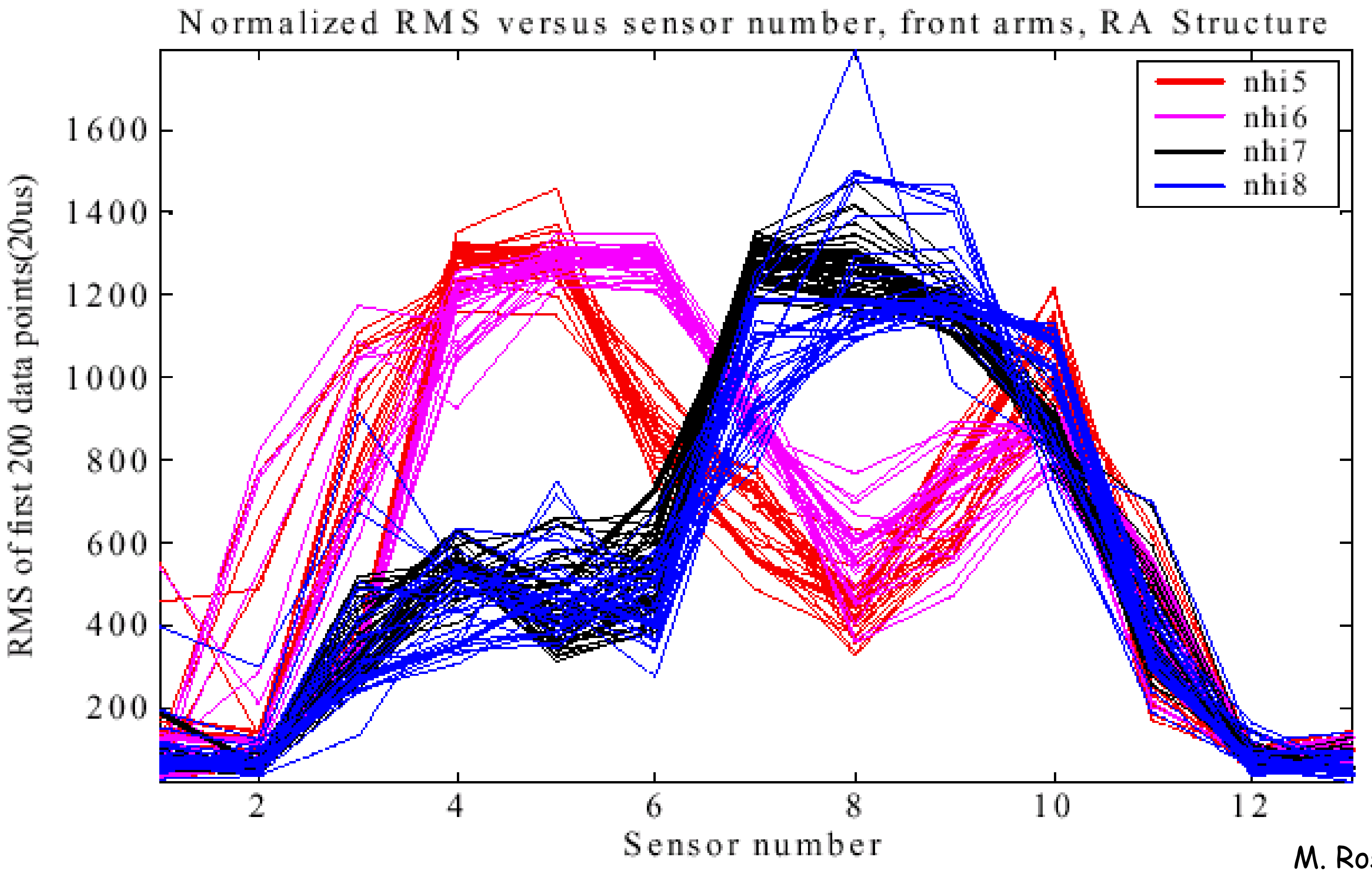
30 GHz

Missing energy



1 J can liquefy $\frac{1}{4}$ mm^3,
Enough to produce any observed damage in just a few shots.

Breakdowns go 'bang'

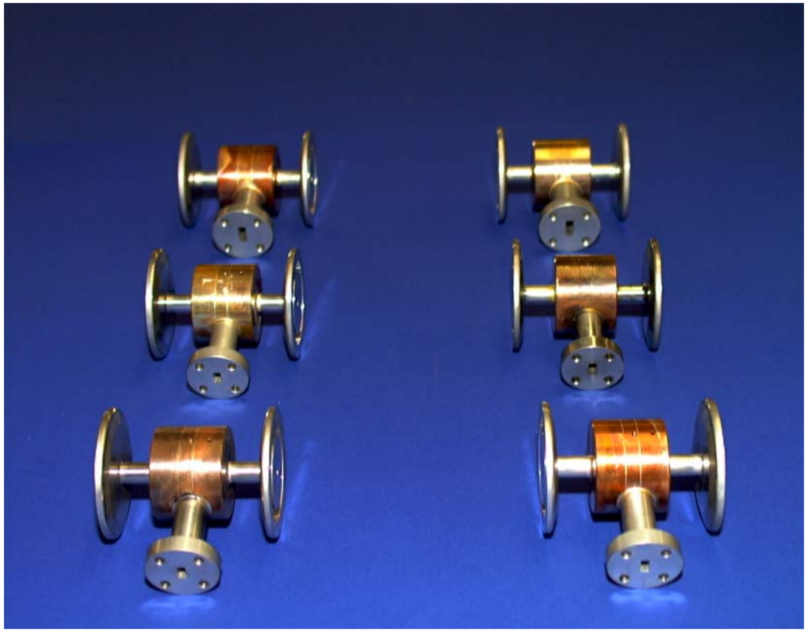


11 GHz

M. Ross

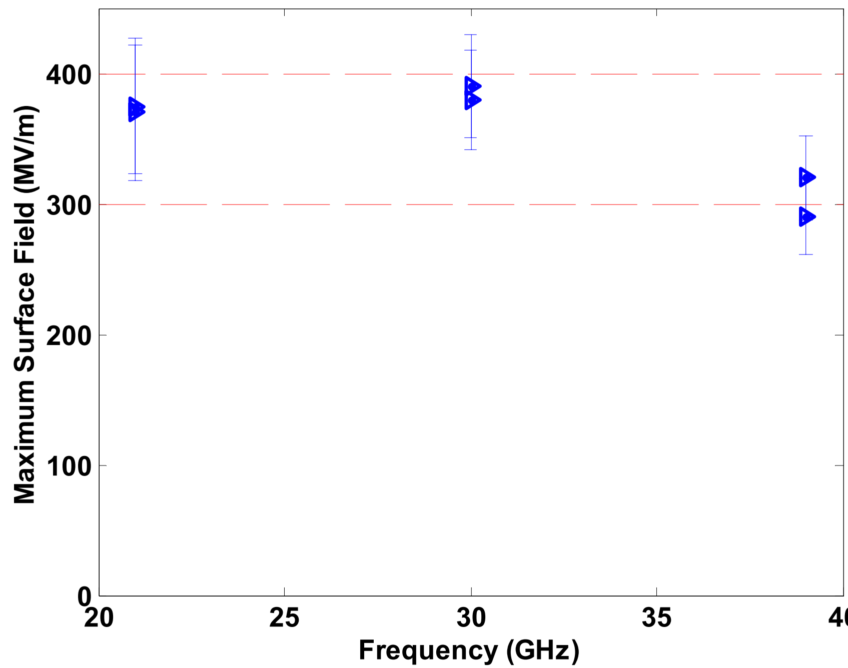
Shot by shot position of breakdown using acoustic sensors.

Maximum gradient independent of f and T



The cavities

The results



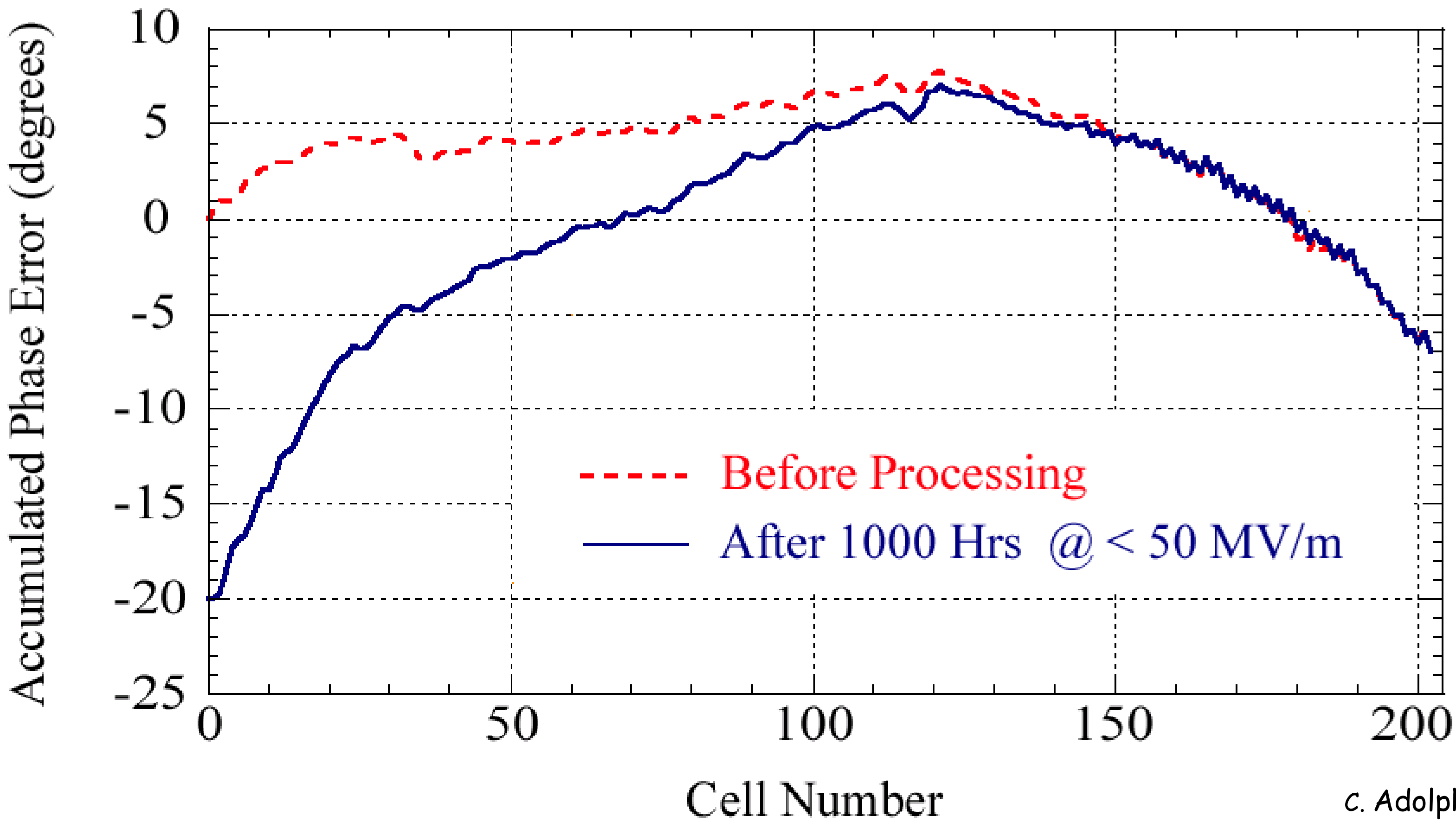
70° K to 500 ° K
no change either.

Other features

• Currents: Several hundred mA to A bursts emitted from beam-pipe. Very sensitive measure of breakdown.
• Light: Persists for several hundreds of ns after RF is gone. Copper vapor?
•Vacuum: Strong signal at beginning of conditioning, later it fades…

Damage

RF signature

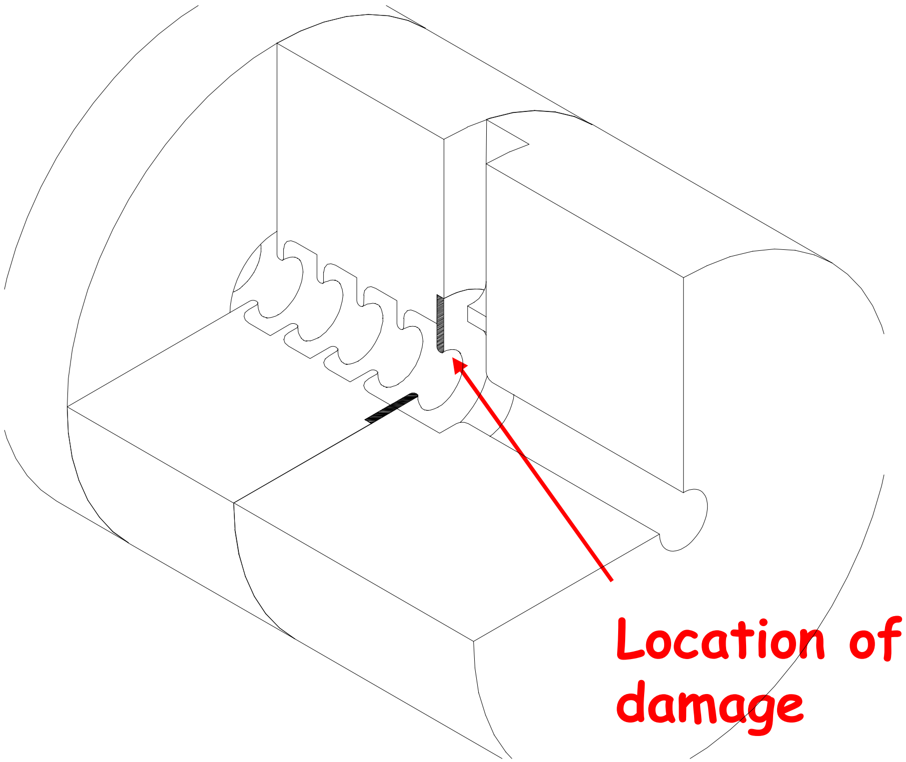


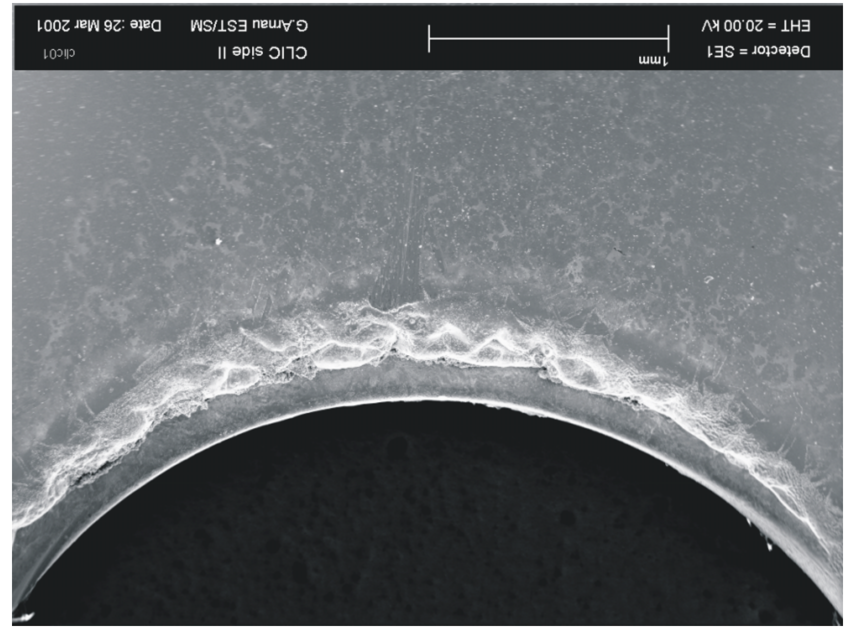
C. Adolphsen

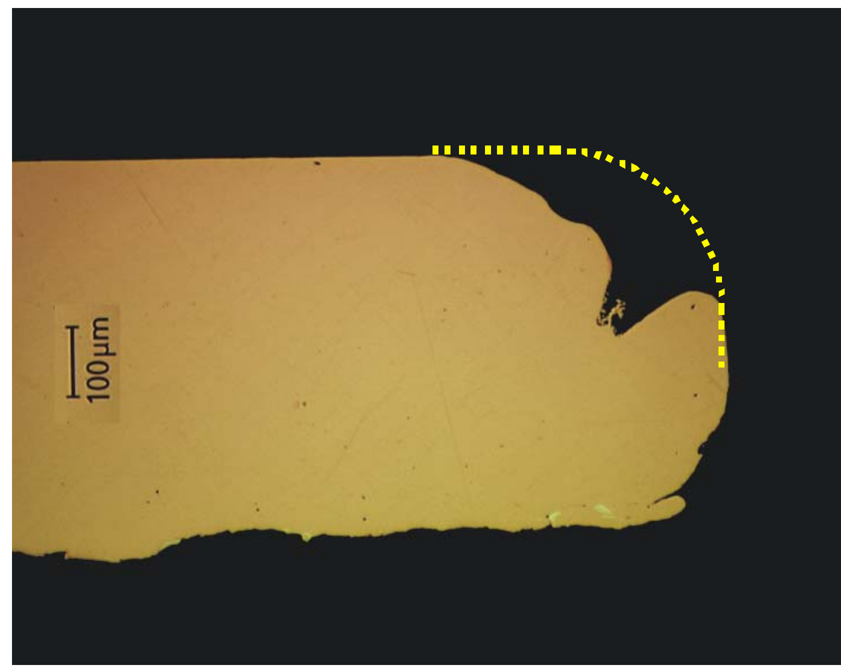
Material removed from iris tips.

11 GHz

Mechanical signature

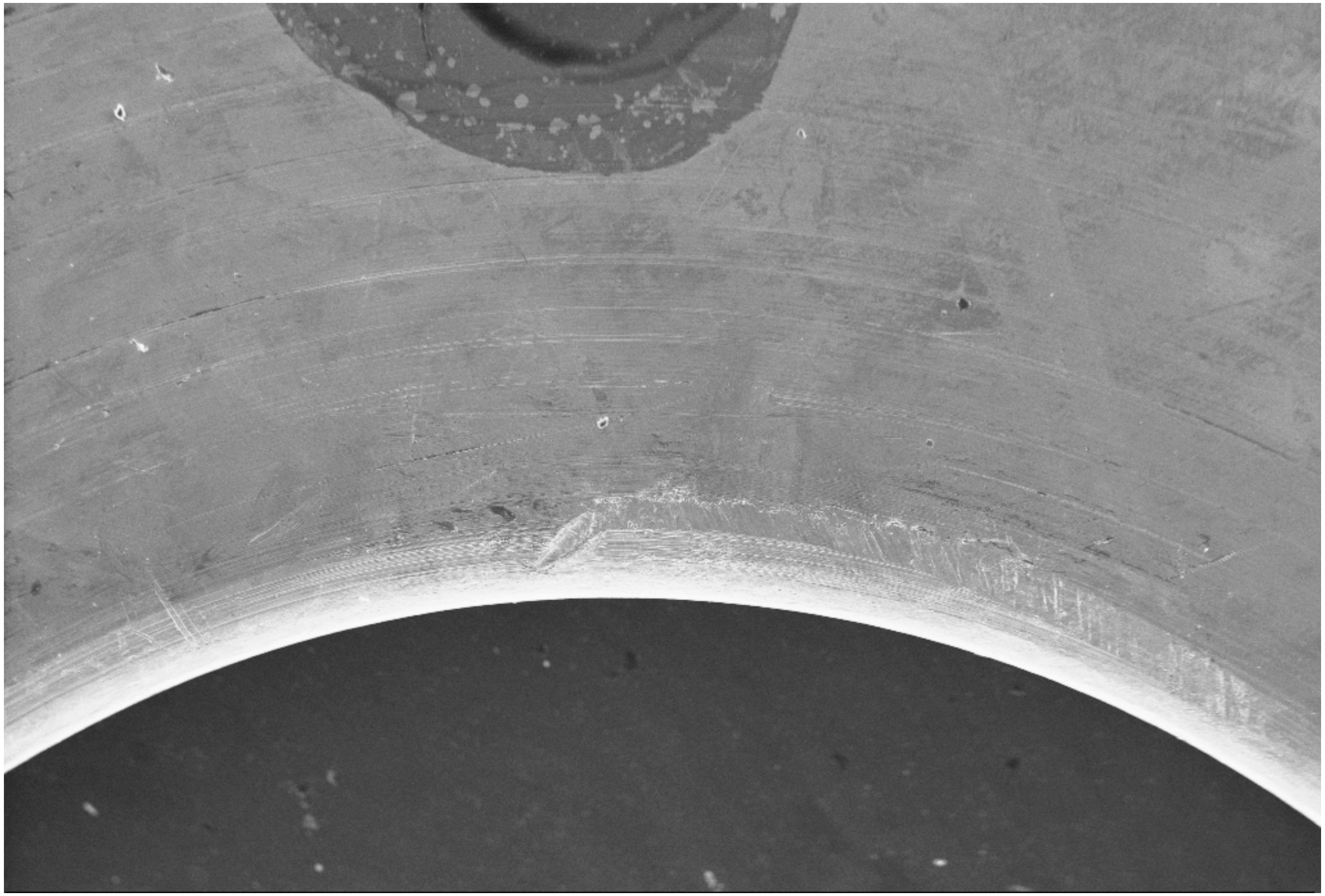






Single feed power coupler
30 GHz, 16 ns,
66 MV/m local
accelerating gradient

But at 4 ns, 160 MV/m accelerating - no damage



30 GHz

Physics of breakdown and damage

Breakdown trigger

Early conditioning:
Seems to be dirt and desorbed gas.

Late conditioning :
All copper CLIC structures have conditioned to surface fields of 300 to 400 MV/m.
β values of typically 30 are observed.
Implies 10 GV/m, melting due to field emission currents, exceeds tensile strength, atomic binding potential.
Ultimate limit?

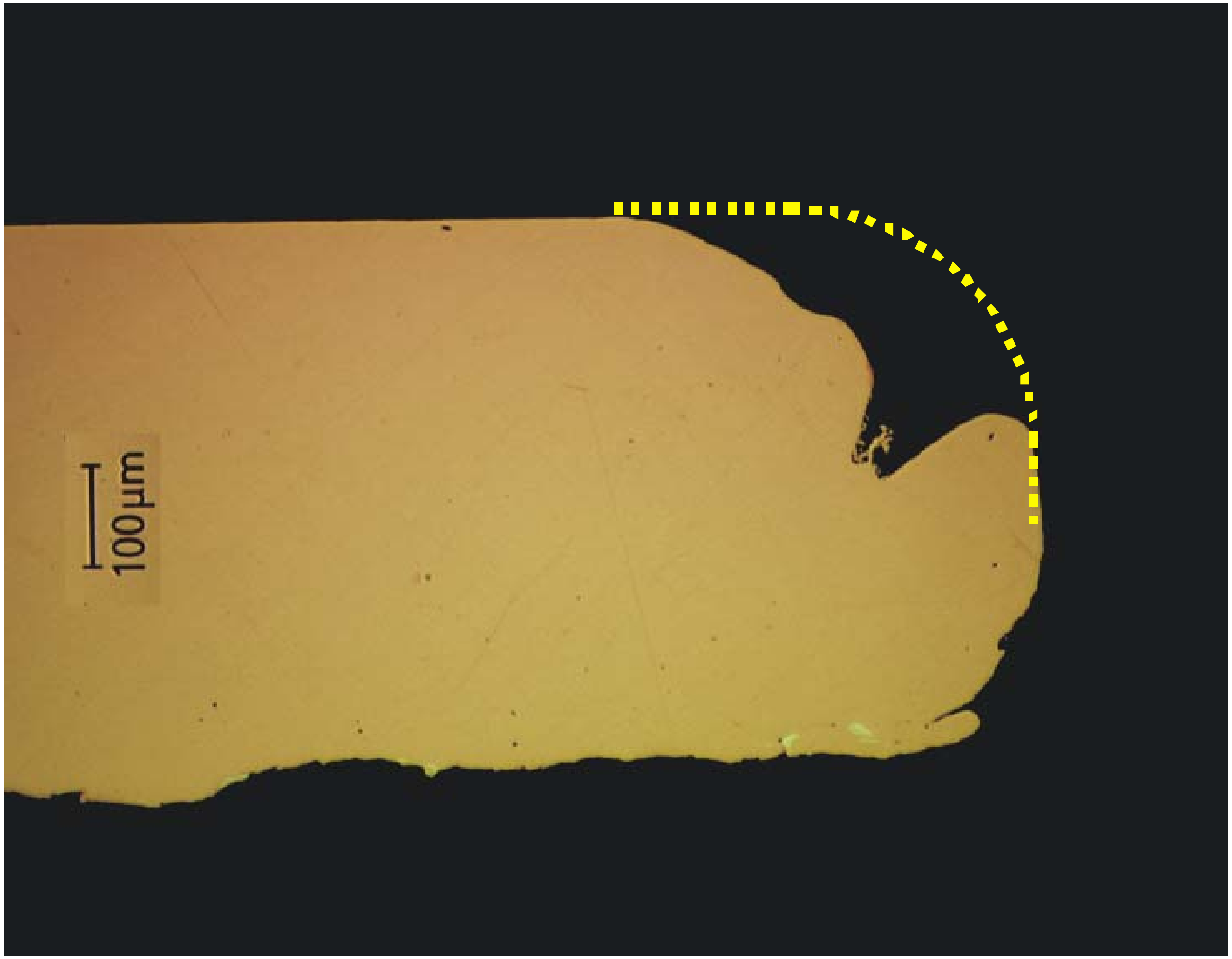
Discharge

Absorbs huge powers with little reflection.
Impedance matching characteristics of a gas discharge?

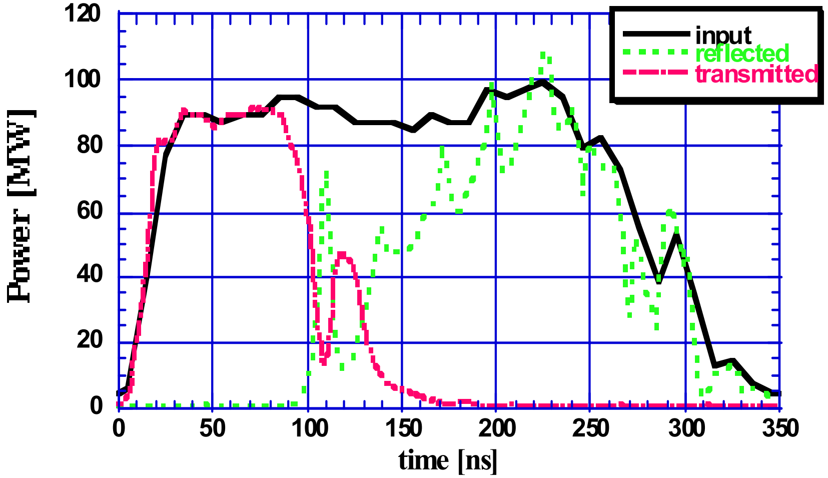
Due to high frequencies, power must be absorbed by electron currents?
Ions play a role in neutralizing space charge?

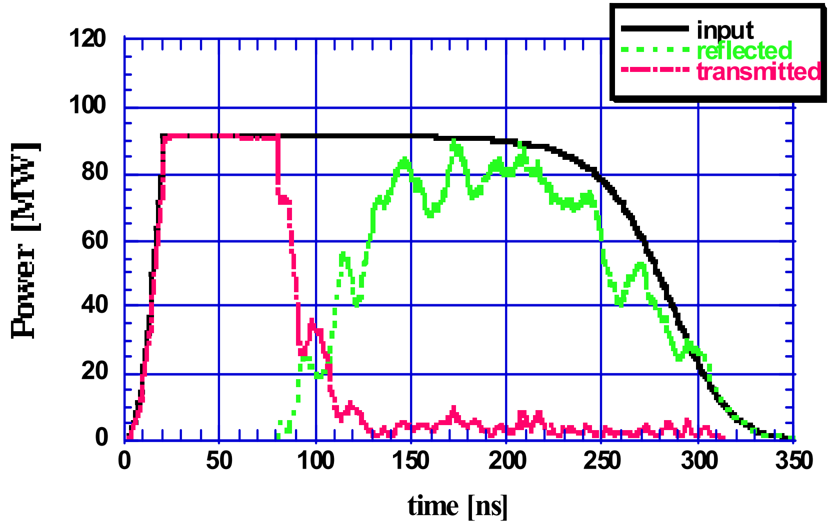
Does group velocity play a role?
Localization of impact of currents causes melting and damage?
Focusing by RF field patterns or ions?

Damage again...



Simulation of a breakdown in a waveguide!





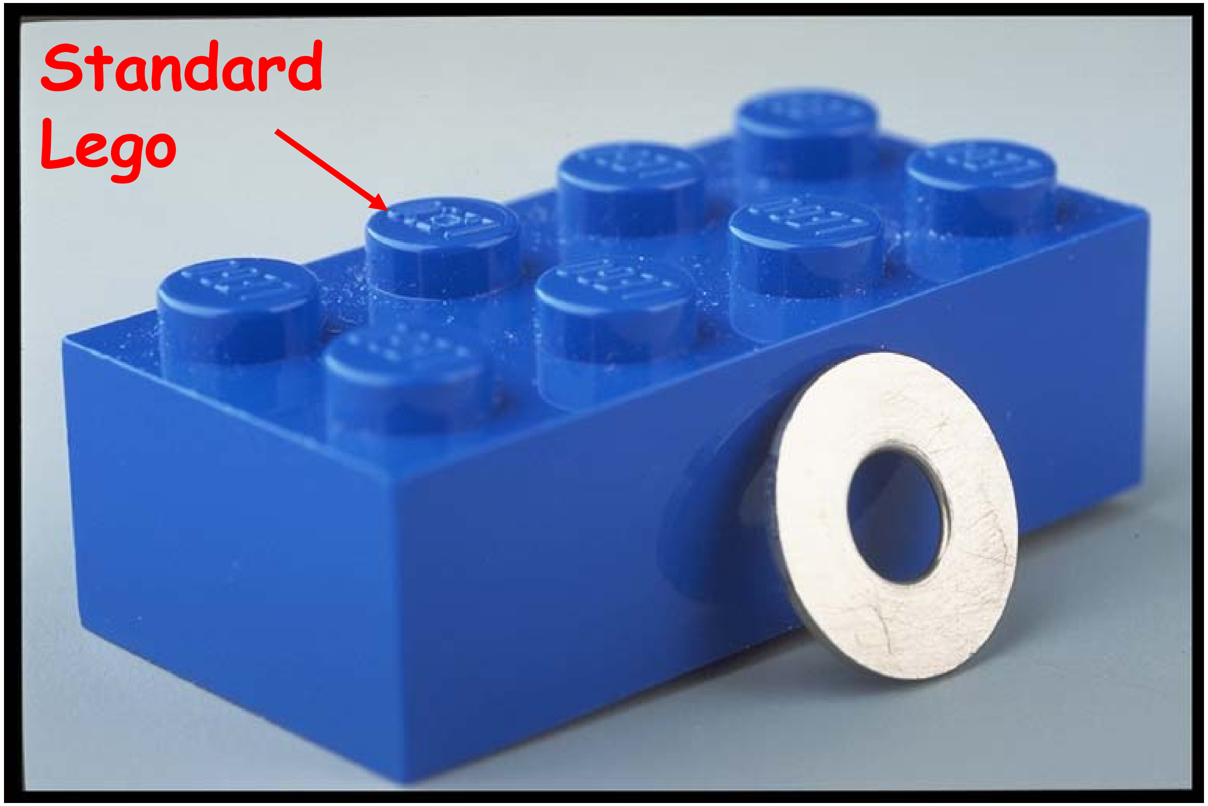
11 GHz

V. Dolgashev, S. Tantawi

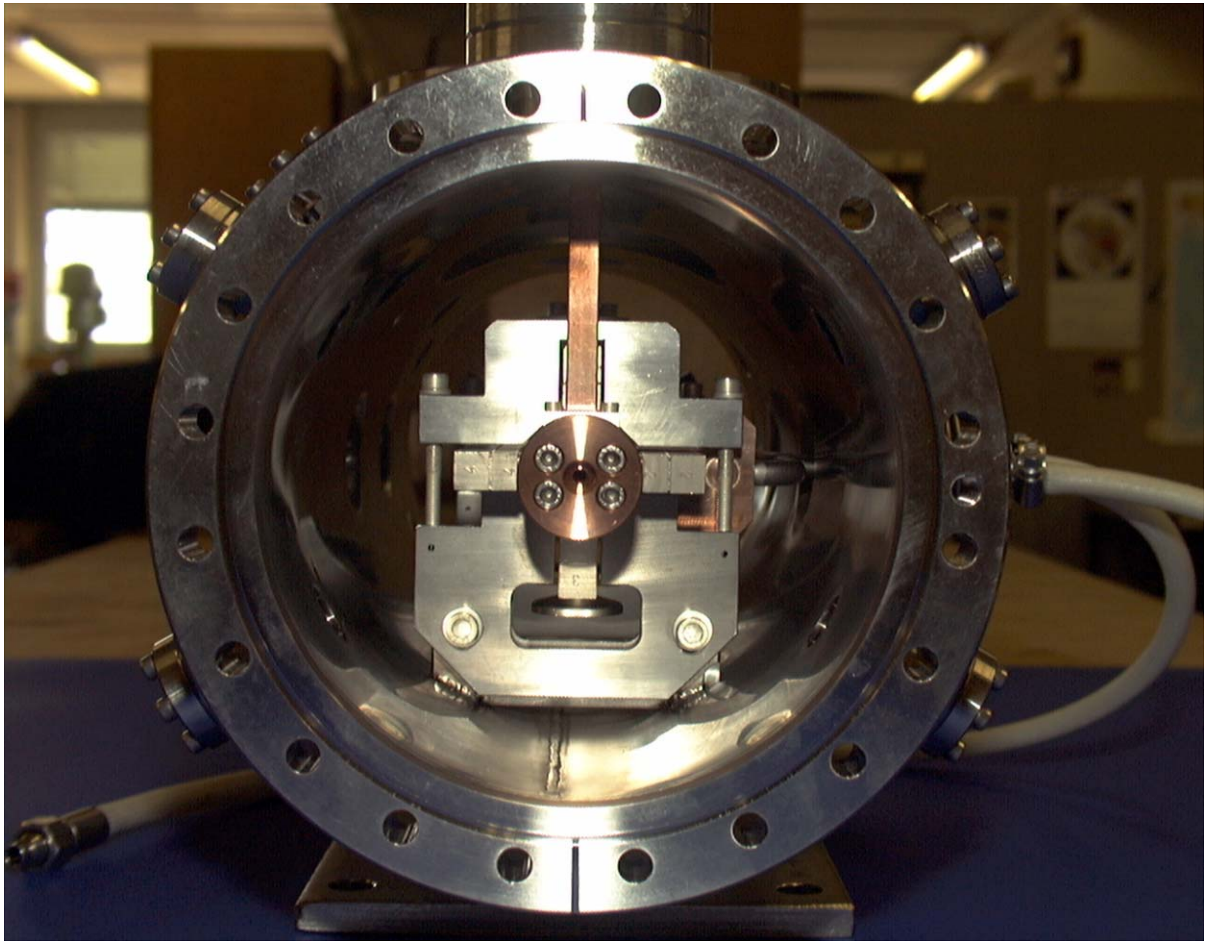
Measurement

Technical solutions for higher gradients

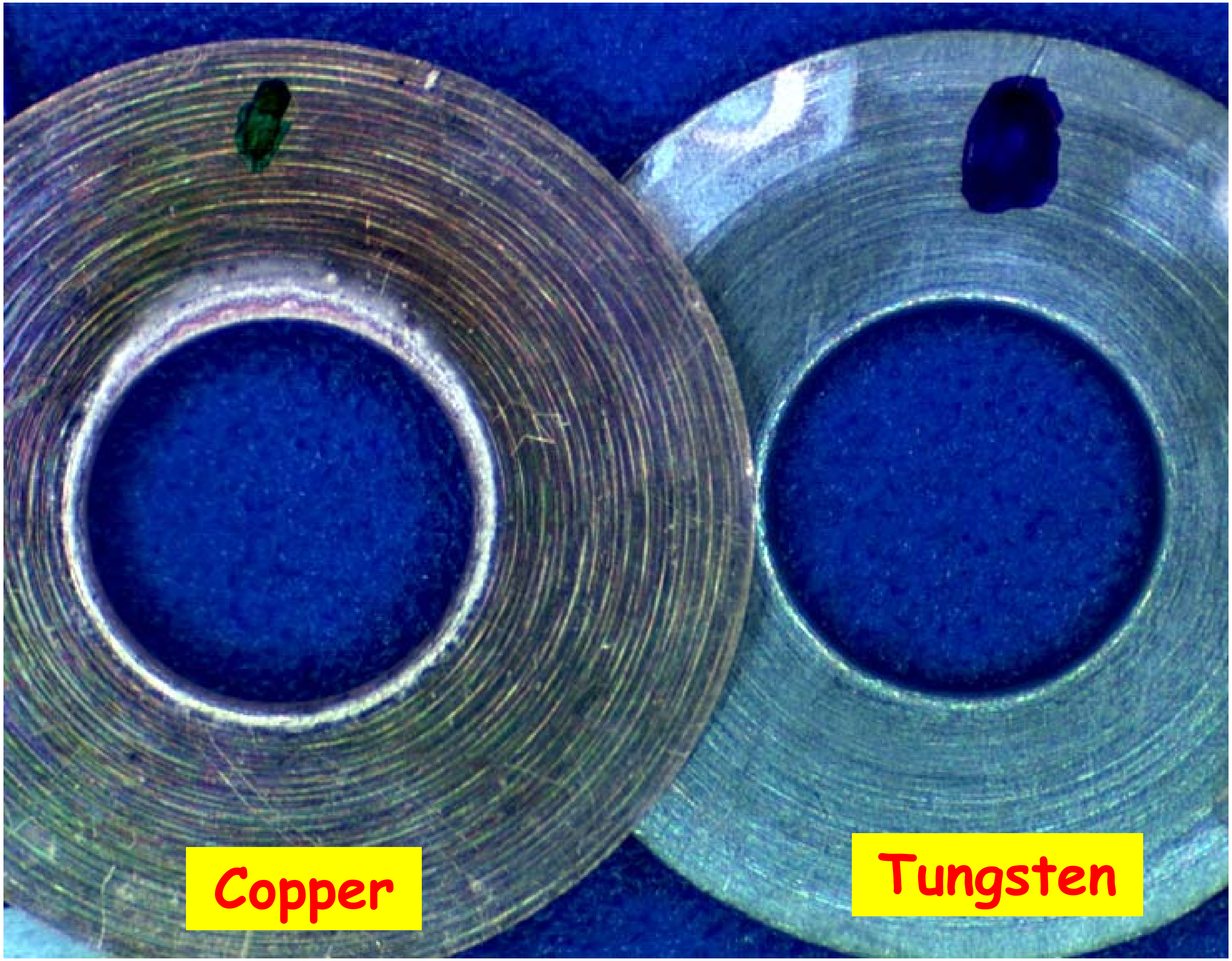
Damage due to large deposit of energy density,
Structure iris viewed as a beam dump,
Choose a material good conductivity and with a high melting point, tungsten!
Clamp into old copper structure to replace damaged coupler iris.



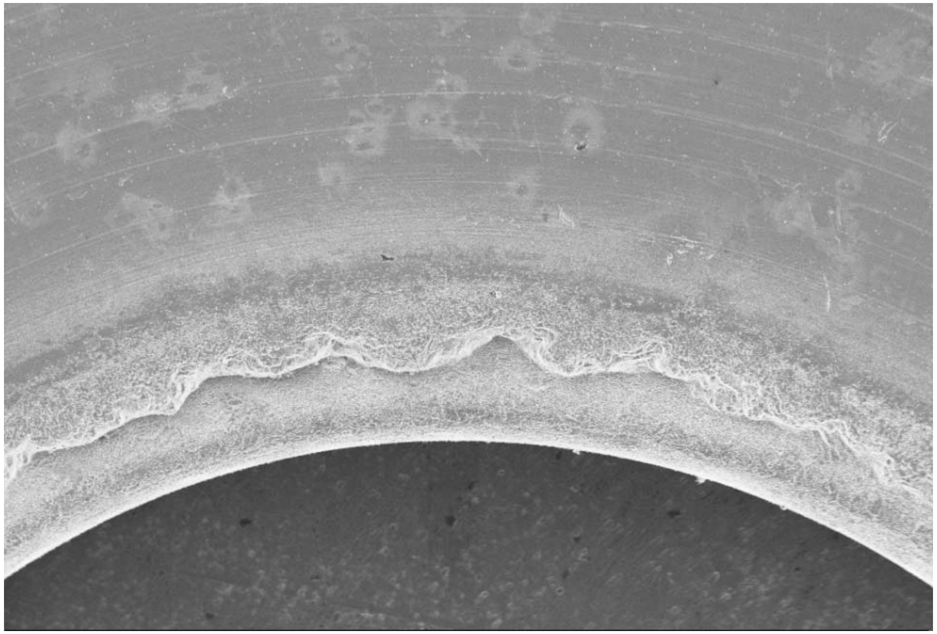
Tungsten coupling iris test set-up



Direct comparison of the arc resistance of Copper and Tungsten

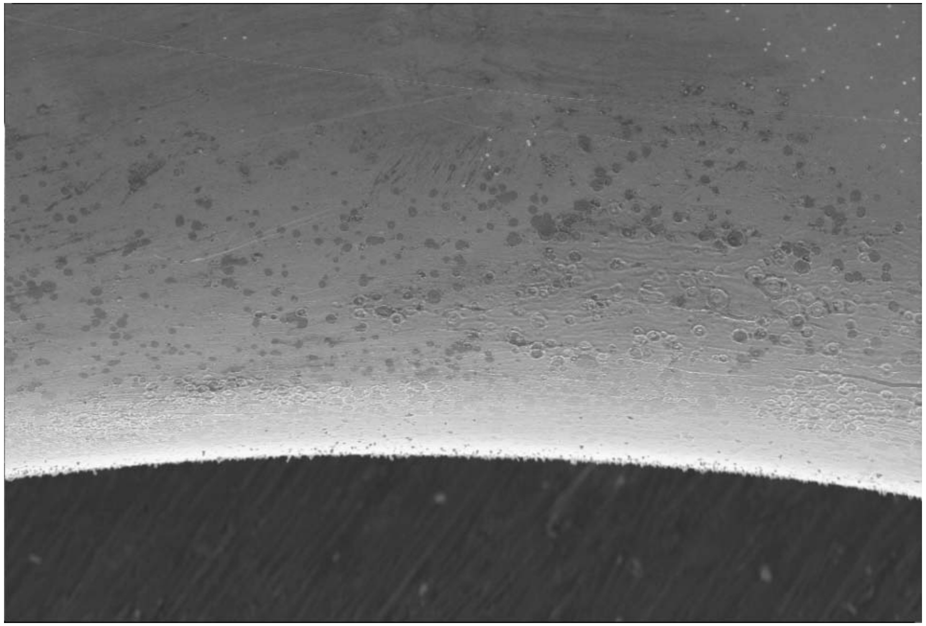


Microscopic comparison

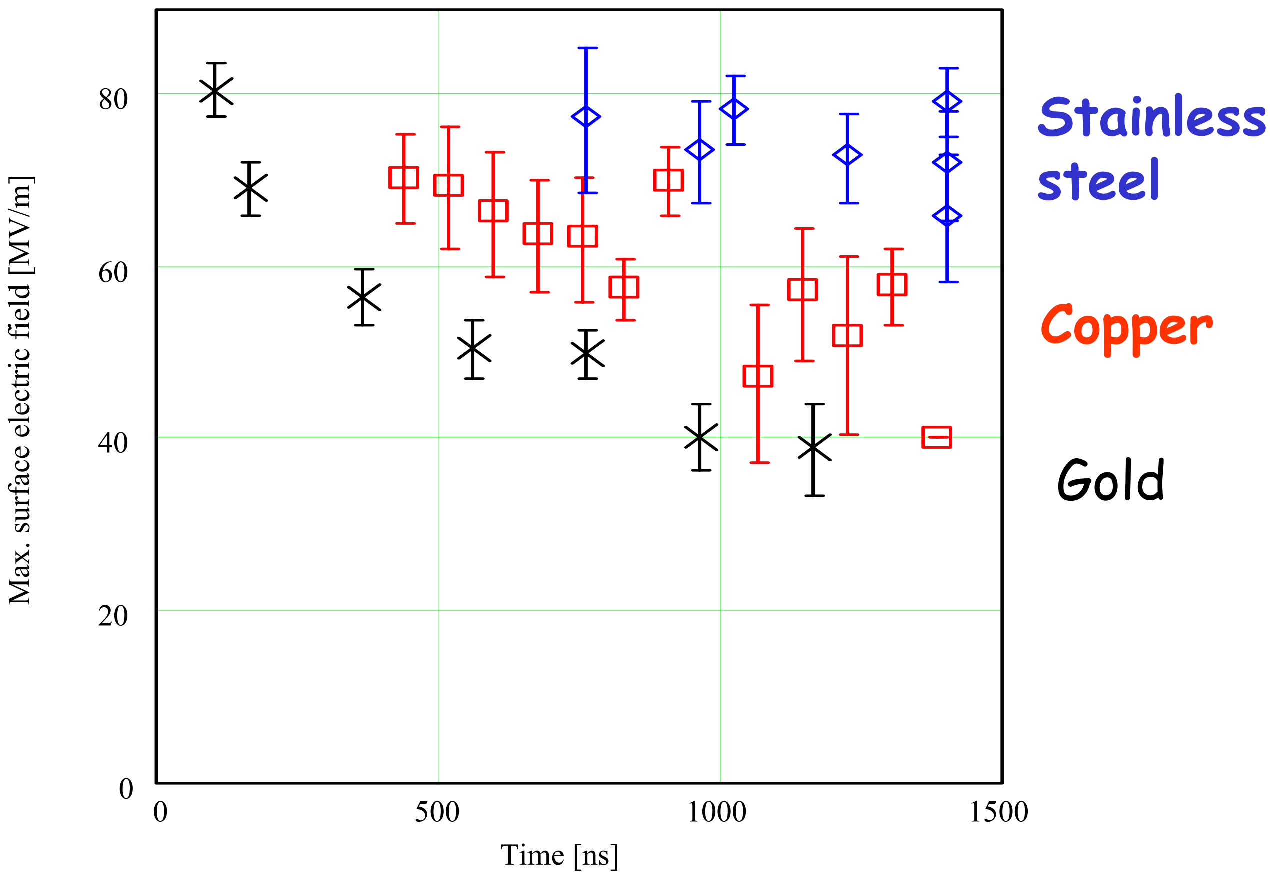


Copper

Tungsten

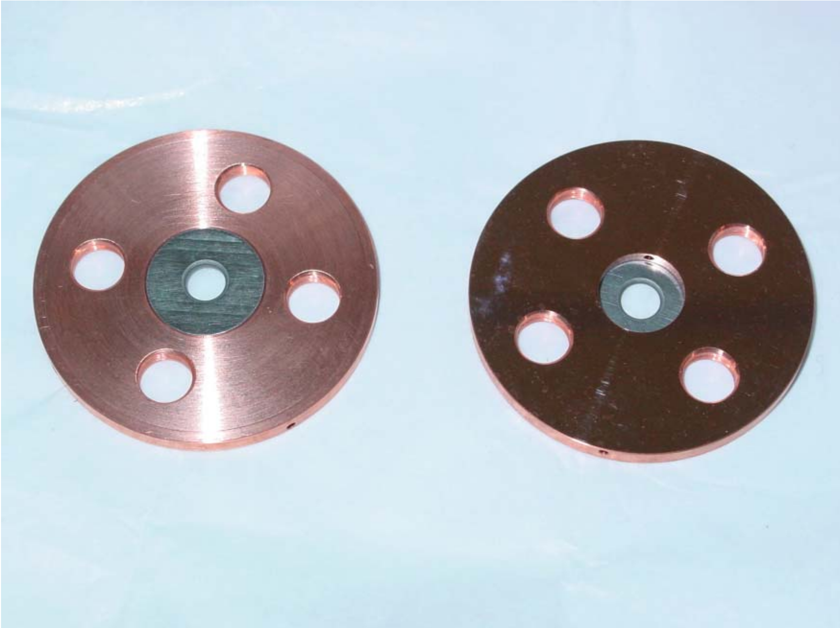


Hint that Tungsten holds a higher surface field, plus 11 GHz waveguide test:



Poster TUPLE098

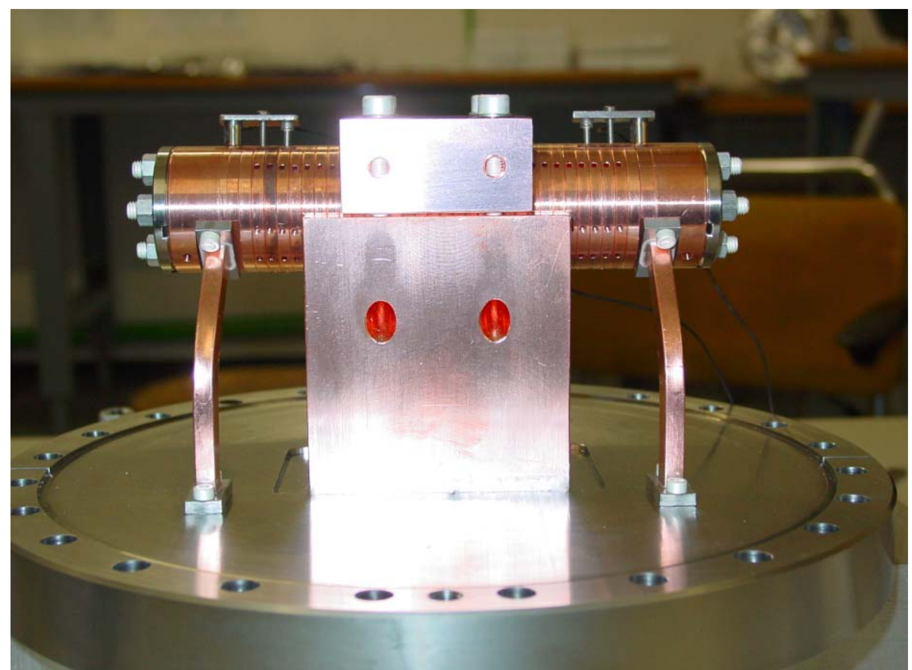
V.A.Dolgashev, S. Tantawi



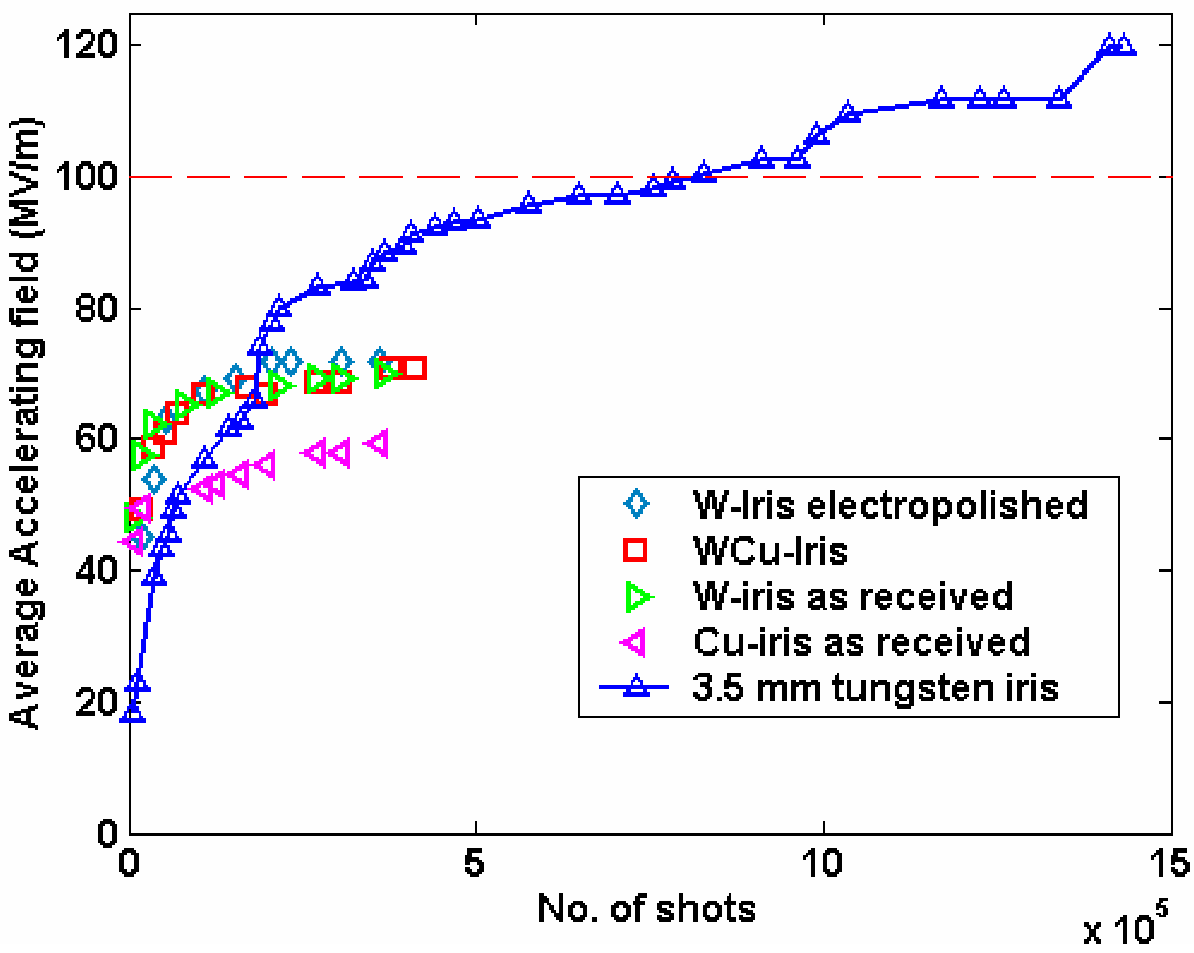
Do these ideas work?
30 cell clamped tungsten-iris structure with reduced surface field cells and coupler.

$2\pi/3$ phase advance
3.5 mm aperture
4.6% v_g/c
T_{fill} 8.3 ns

Couplers: poster TUPLE097



30 cell tungsten-iris structure
Conditioning until just before EPAC.



151 MV/m peak
Accelerating
330 MV/m peak
Surface

30 GHz
16 ns pulse