Breakdown experiments

CLIC09 workshop

15.10.2009

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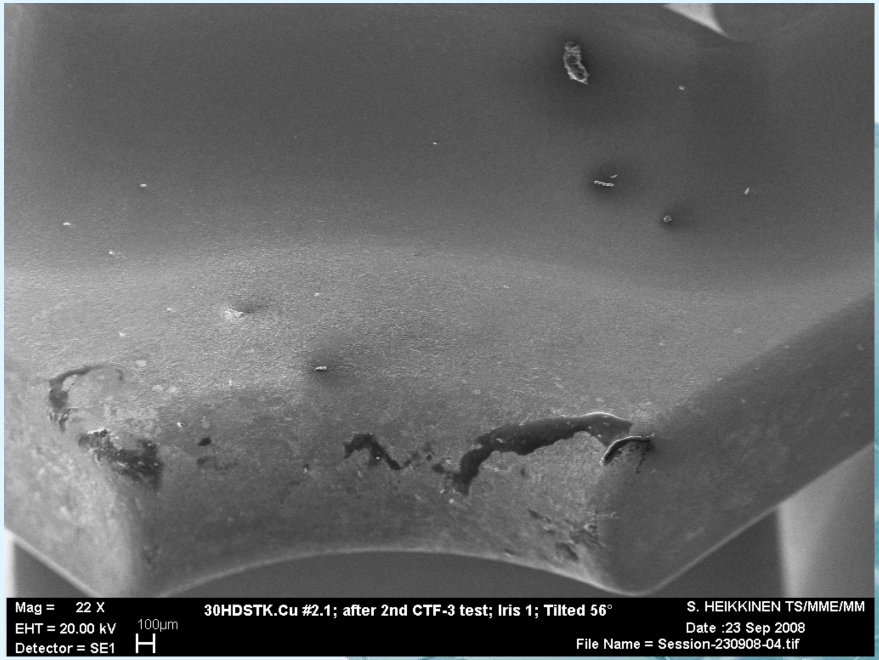
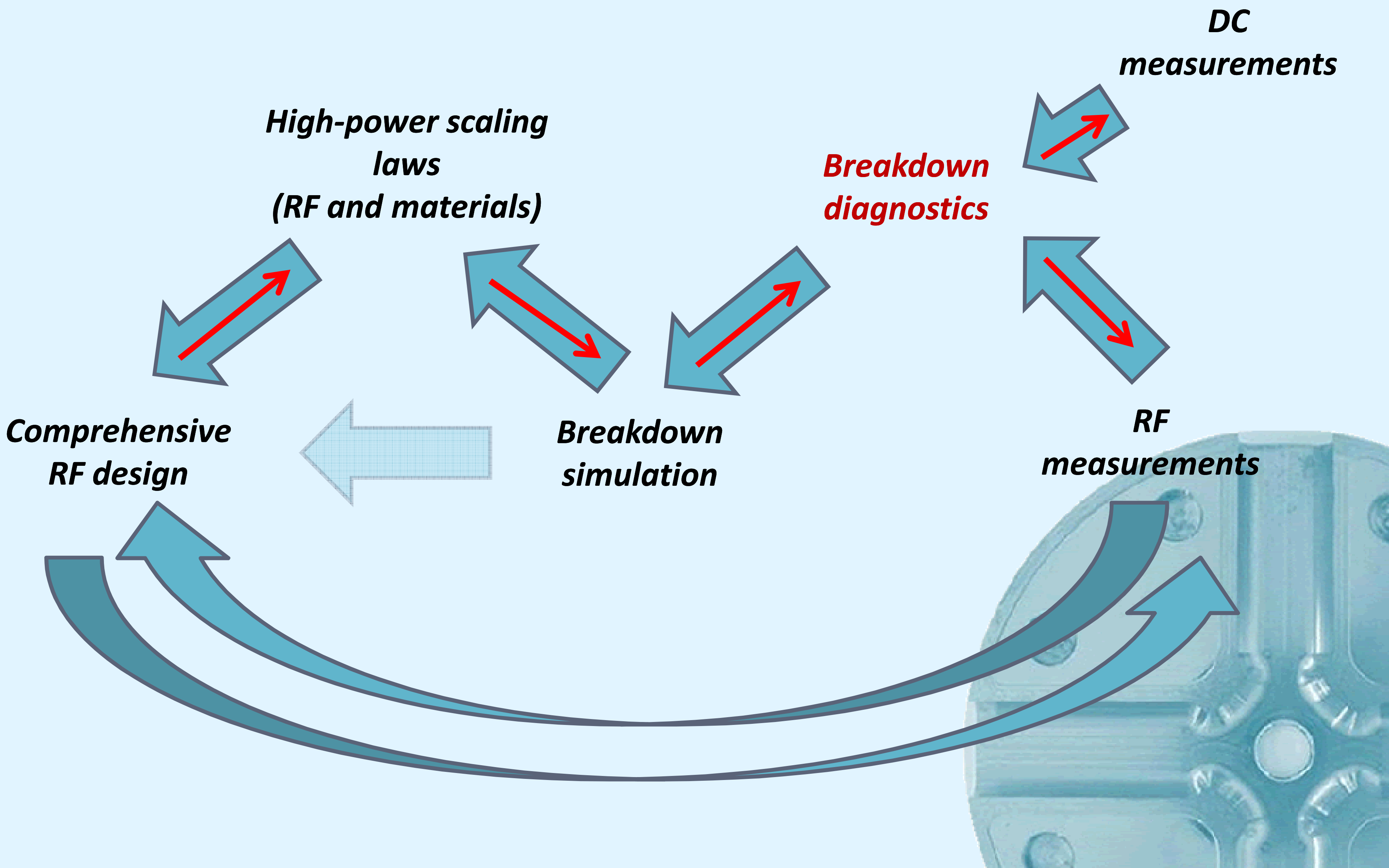
Outline

1. The quantitative approach to high gradients, an introduction
2. Which diagnostic methods are used?
3. Overview of measurable parameters
4. Results from comparative RF and DC breakdown studies
5. Details from optical breakdown spectroscopy
6. A proposal for RF breakdown detection
7. The DC breakdown movie
8. Summary

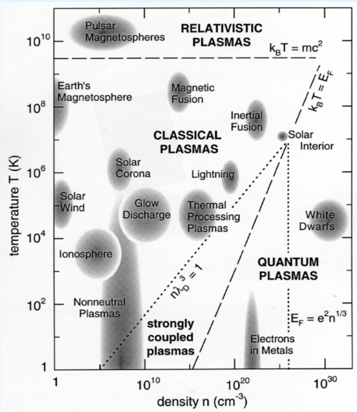


The quantitative approach to high gradients



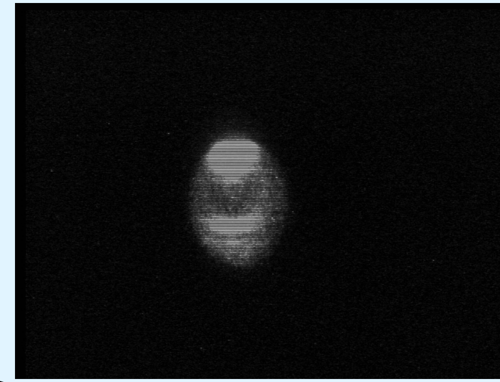
The quantitative … igh gradients

- Breakdown source identification



Plasma parameters → **simulation input**

Spectroscopy

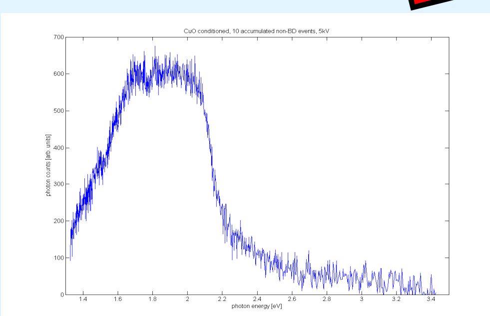


Plasma size/position → **simulation and design input**

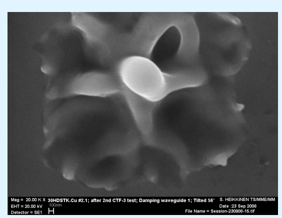
BREAKDOWN DIAGNOSTICS

RF measurements, FC, XRAY →

-Machine protection
- Conditioning

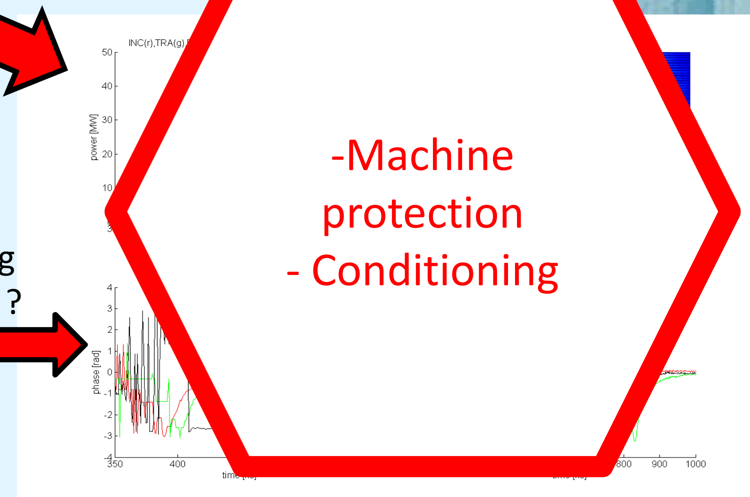


OTR in nominal pulses → **simulation and machine parameter input**



SEM → **simulation and design input**

Missing energy ?

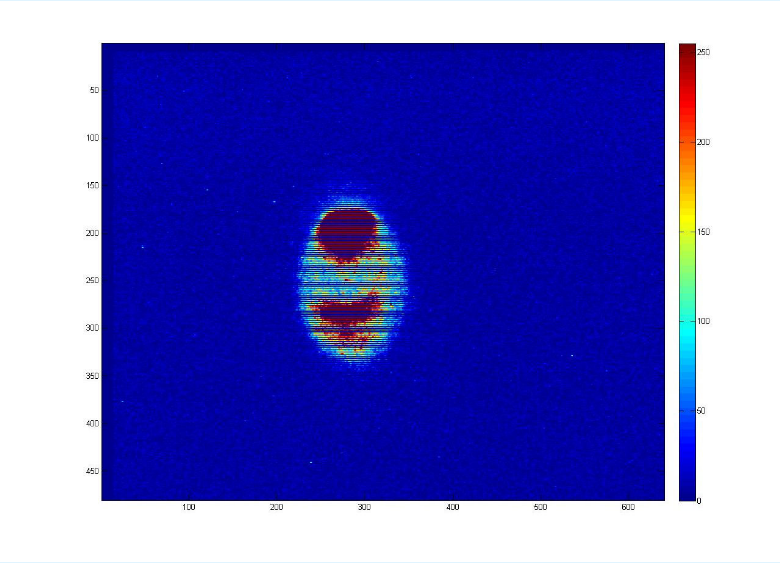


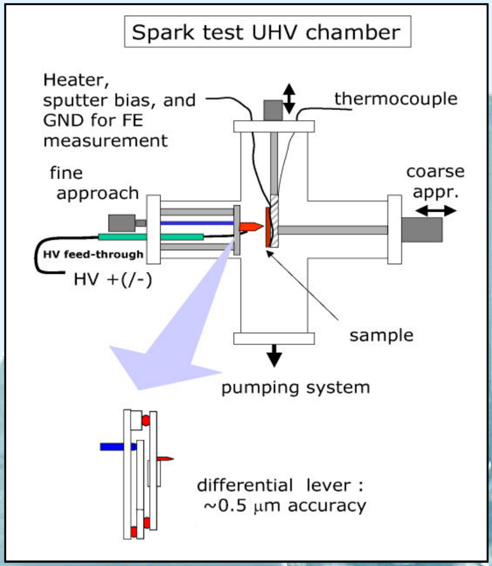
The connection between simulation and experiment

Emitted currents
-Dark current spectrum
-OTR
-X-rays
-Trigger mechanism
-Missing energy
-Breakdown rate
-Ion currents
-Fowler-Nordheim distribution

Plasma characteristics
-Time structure
-Physical dimension (imaging)
-Ion species (opt. spectroscopy)
-Ion currents
-Vacuum behaviour

Surfaces
-Crater morphology
-Material diagnostics
-Fatigue process

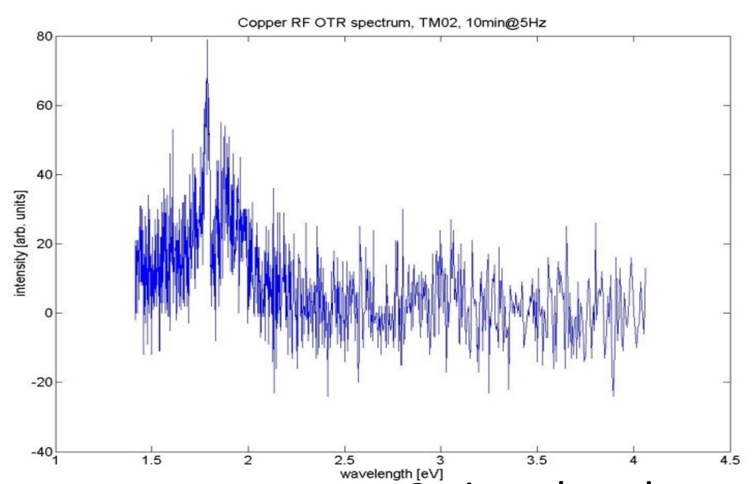


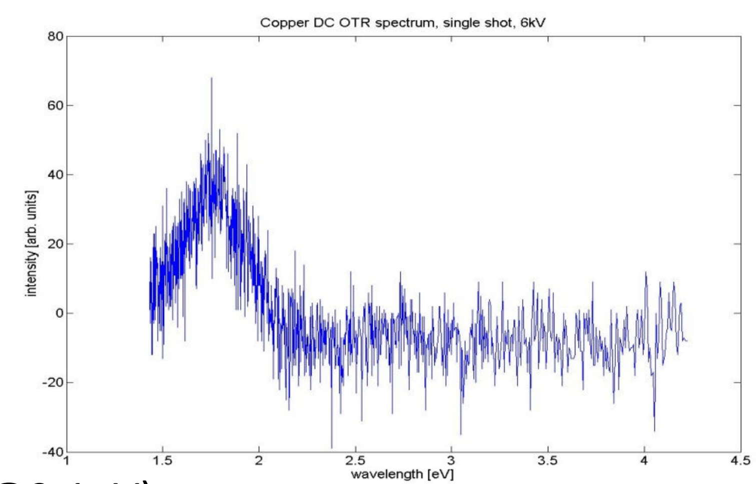


RF and DC diagnostics: some results

RF	DC

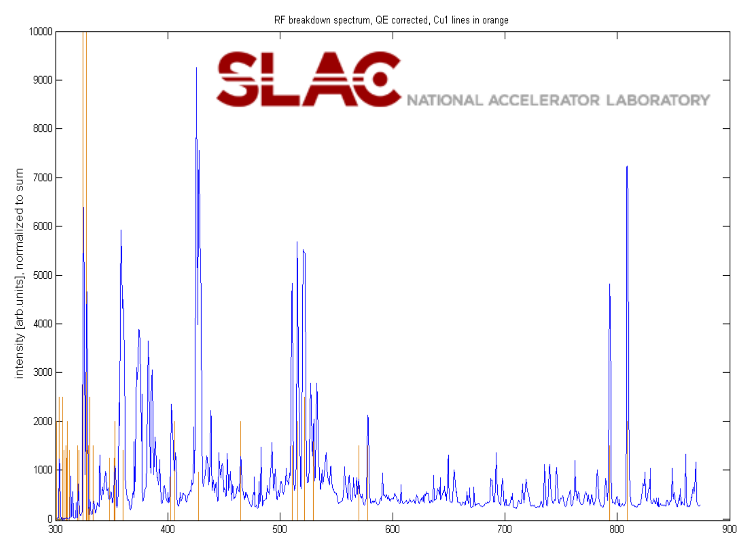
OTR (Cu), ***no BD***

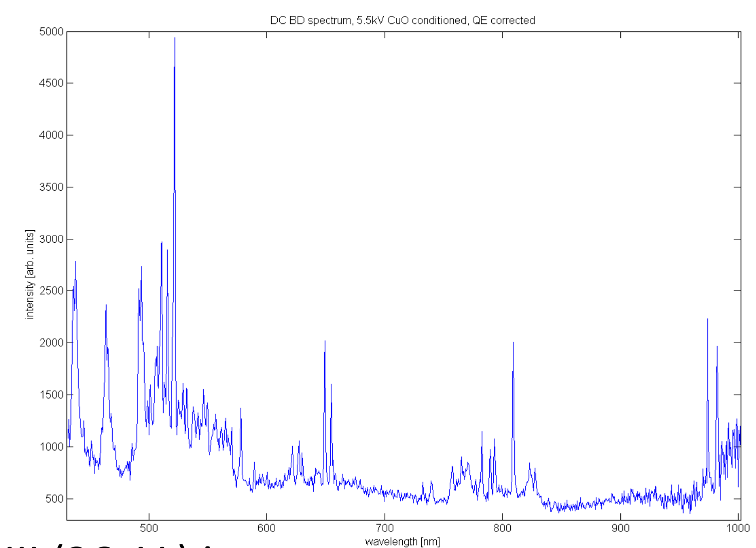




Cu interband transition (@2.1eV) spectrum

Opt. ***BD*** spectroscopy

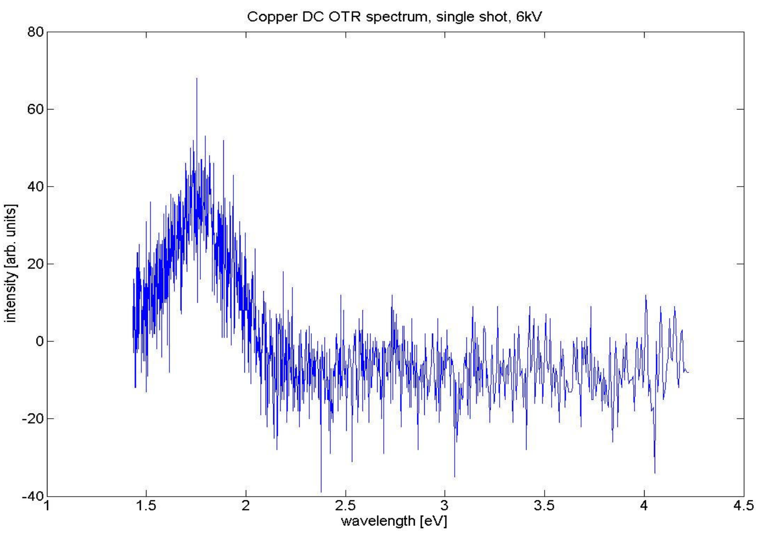




Cu I (7.7eV), Cu II (20eV), Cu III (36eV) ions

RF and DC diagnostics: some results

OTR (Cu), *no BD*



➔ Spectrum typical for OTR in Cu (interband transition @ 2.1eV)

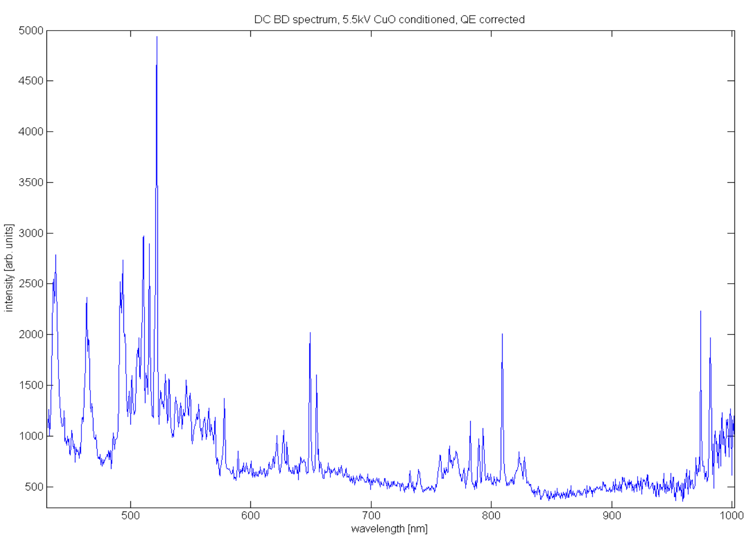
➔Beta measurements possible close to the breakdown limit (~105)

➔ OTR sometimes seems to rise before a breakdown

➔ Oxide layers suppress OTR

➔ An estimation of the energy absorbed by electrons in 30GHz structures: 0.1MW @ 14MW RF input power

Opt. *BD* spectroscopy



➔ found very little traces of O,H,C,S probably no contribution to breakdown physics in this sample

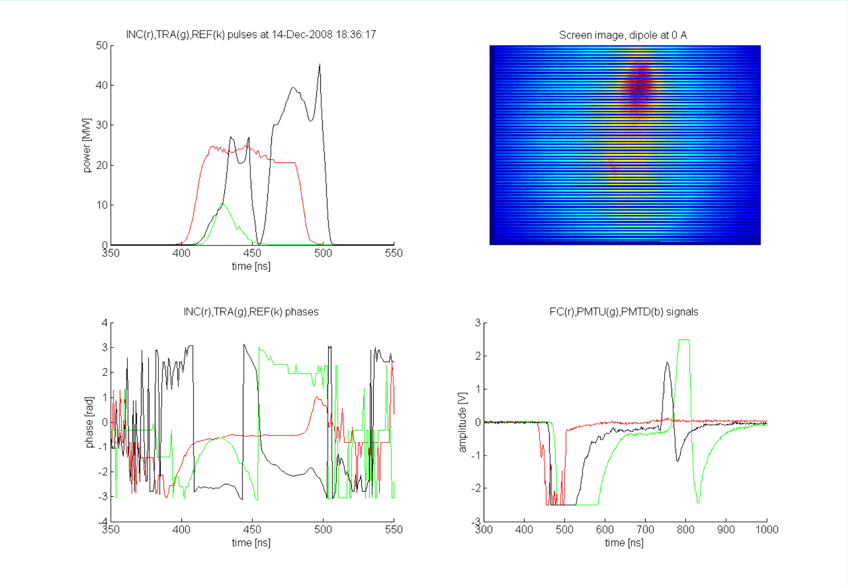
➔ Estimated temperature from two-line-method: 1-5eV, but Cu III (T>36eV) seen, plasma is a non-LTE plasma!

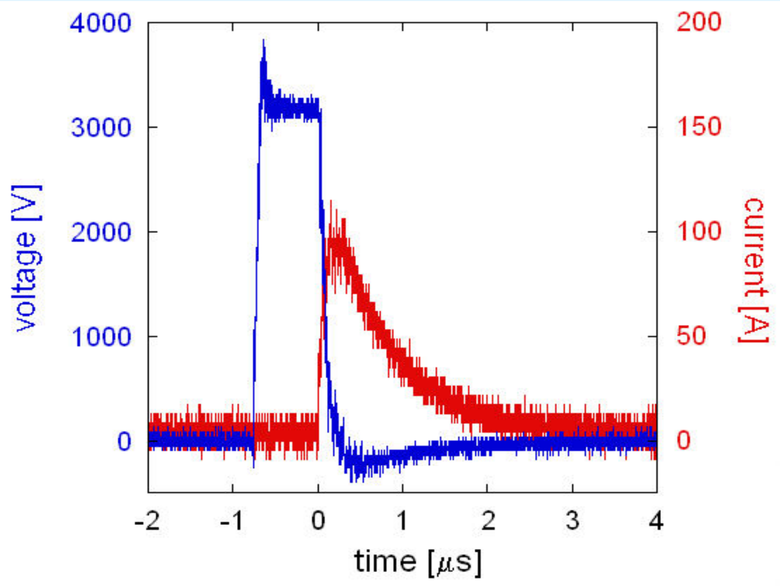
➔ Intensity waveform for different lines highly non-reproducible (clusters? Different plasma? just geometry?)

RF and DC additional diagnostics

RF	DC

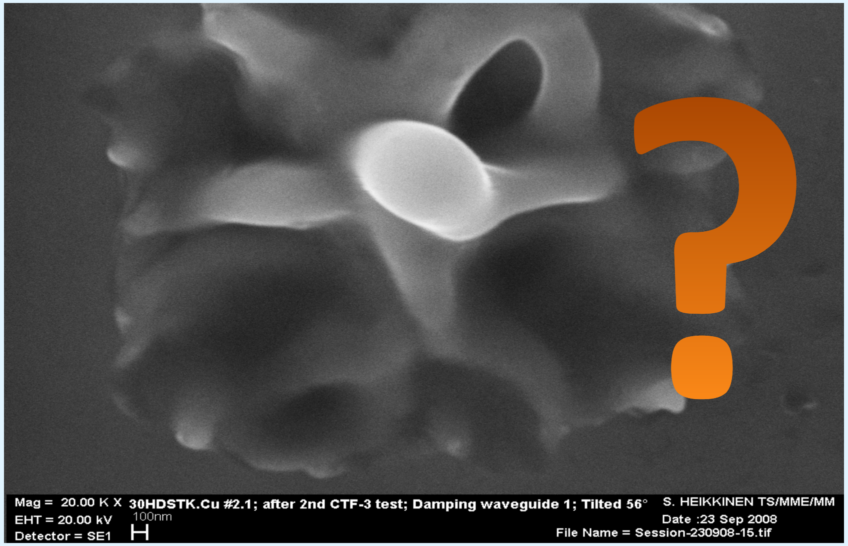
RF (I,Q), Xray, FC @30GHz

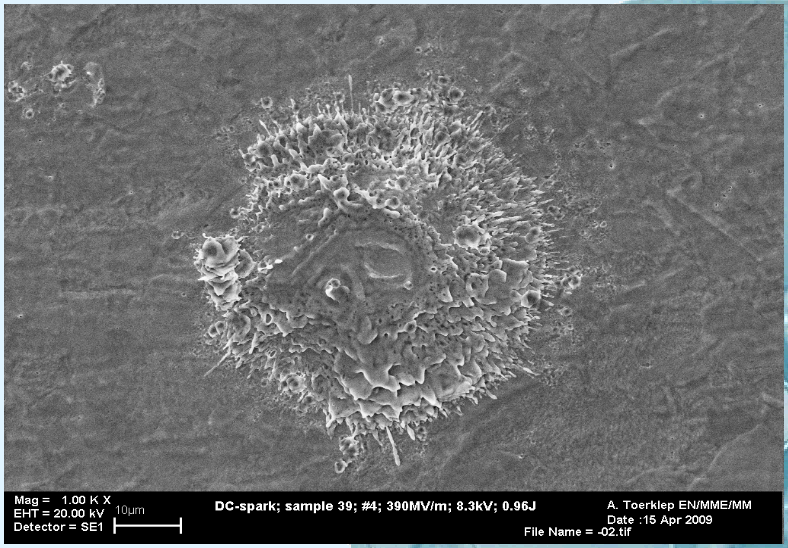




Current, voltage and delay

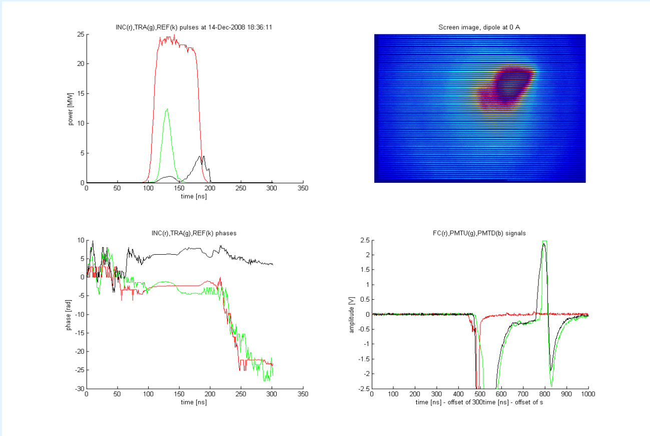
SEM of single breakdowns

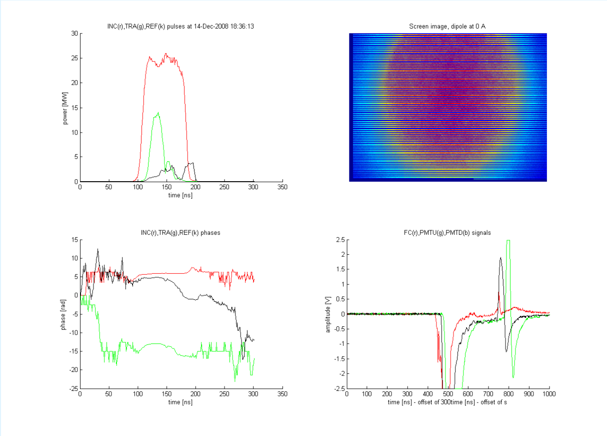




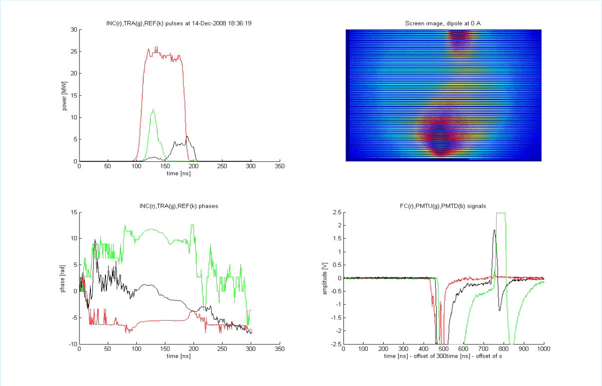
SEM of single breakdowns

RF and DC diagnostics: BDs are never the same





30GHz speedbump structure



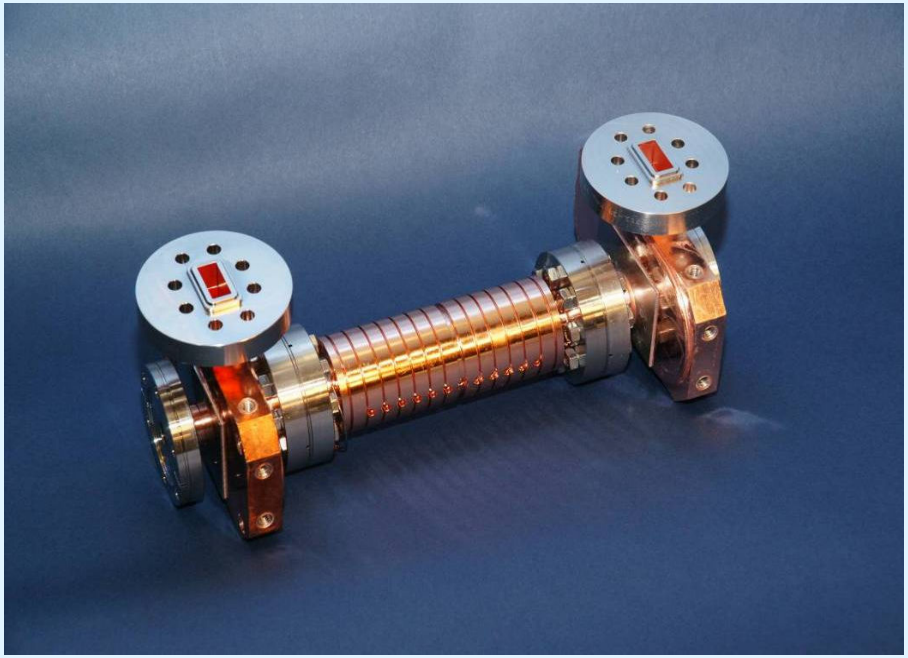
➔ BDs are very fast (~ns) transient phenomena
➔ BD parameters change over orders of magnitude (e.g. dark current vs. BD current)
➔ BDs are never the same (in RF!)
➔ BDs affect S-parameters (RF) / current and voltage (DC)
➔ random BD current emission (RF)

➔ working on BD-plane formalism for position dependent missing E calculation
➔ optimization of DC setup for fast transients ongoing
➔ development of high dynamic range diagnostic tools (LogAmps etc.)
➔ fast single-shot multi-channel equipment necessary

Optical spectroscopy in RF and DC

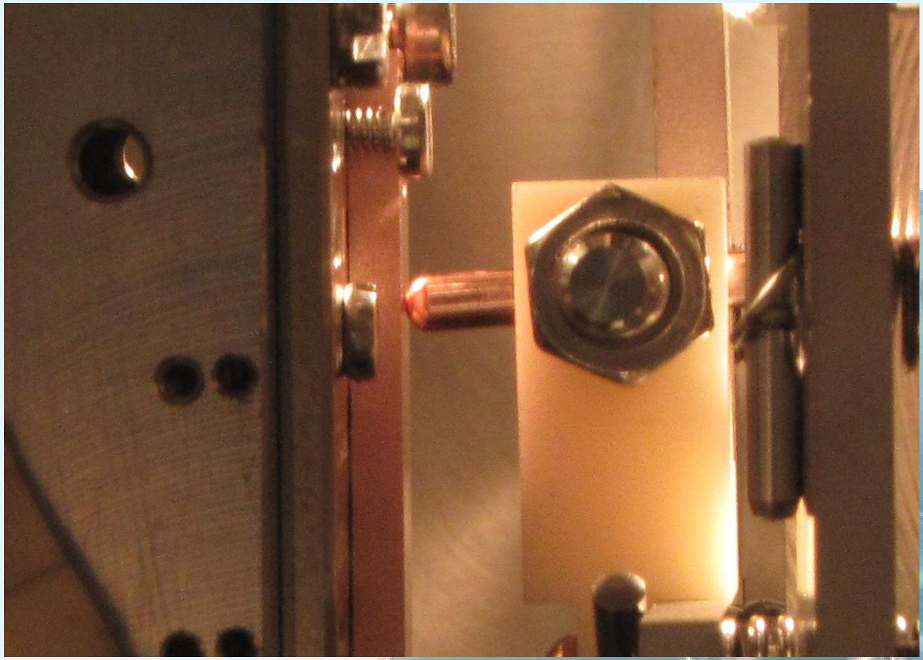
RF

SLAC C10 (vg 1.35) structure in ASTA, running at 100MV/m (@48MW), 200ns pulse length

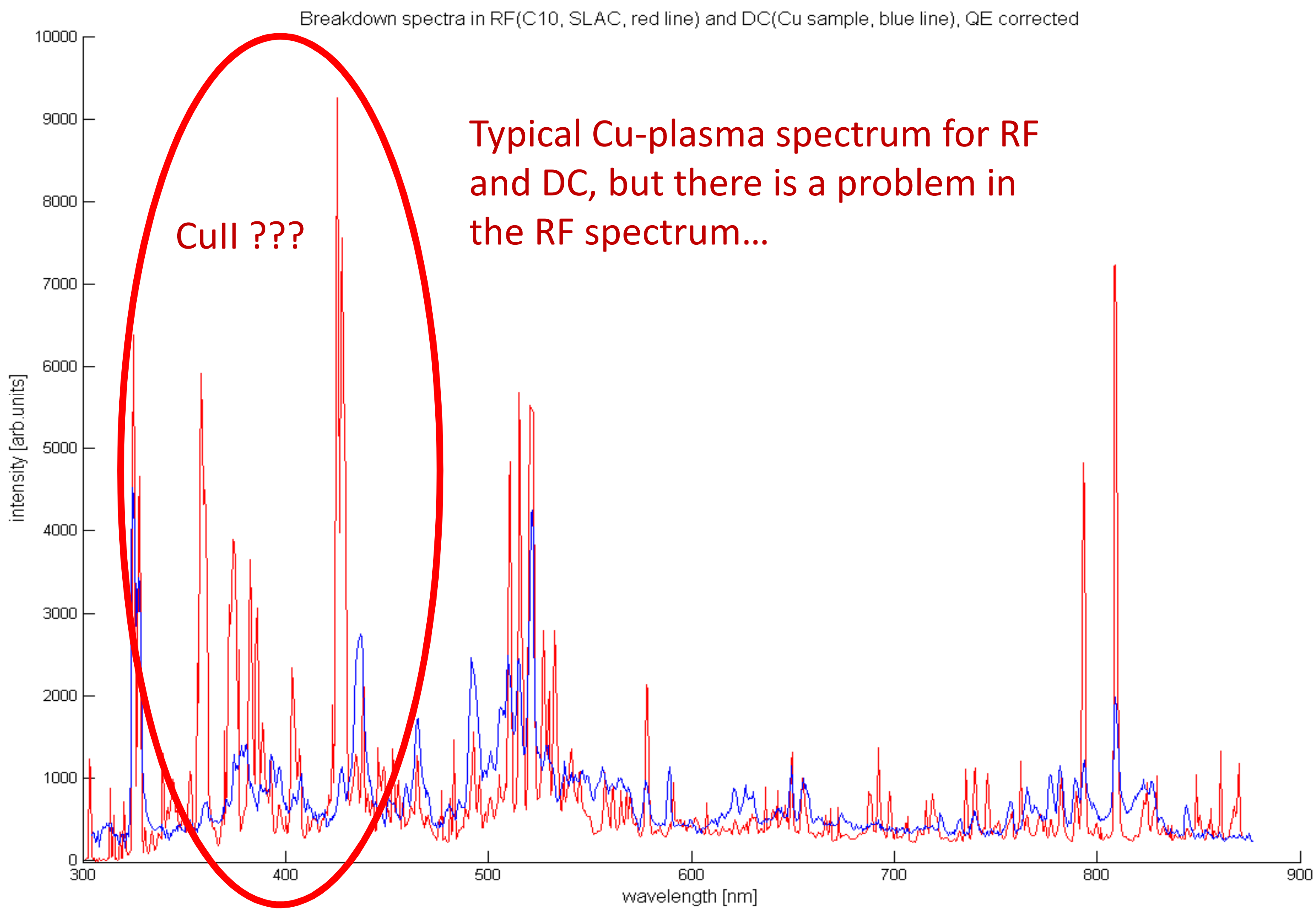


DC

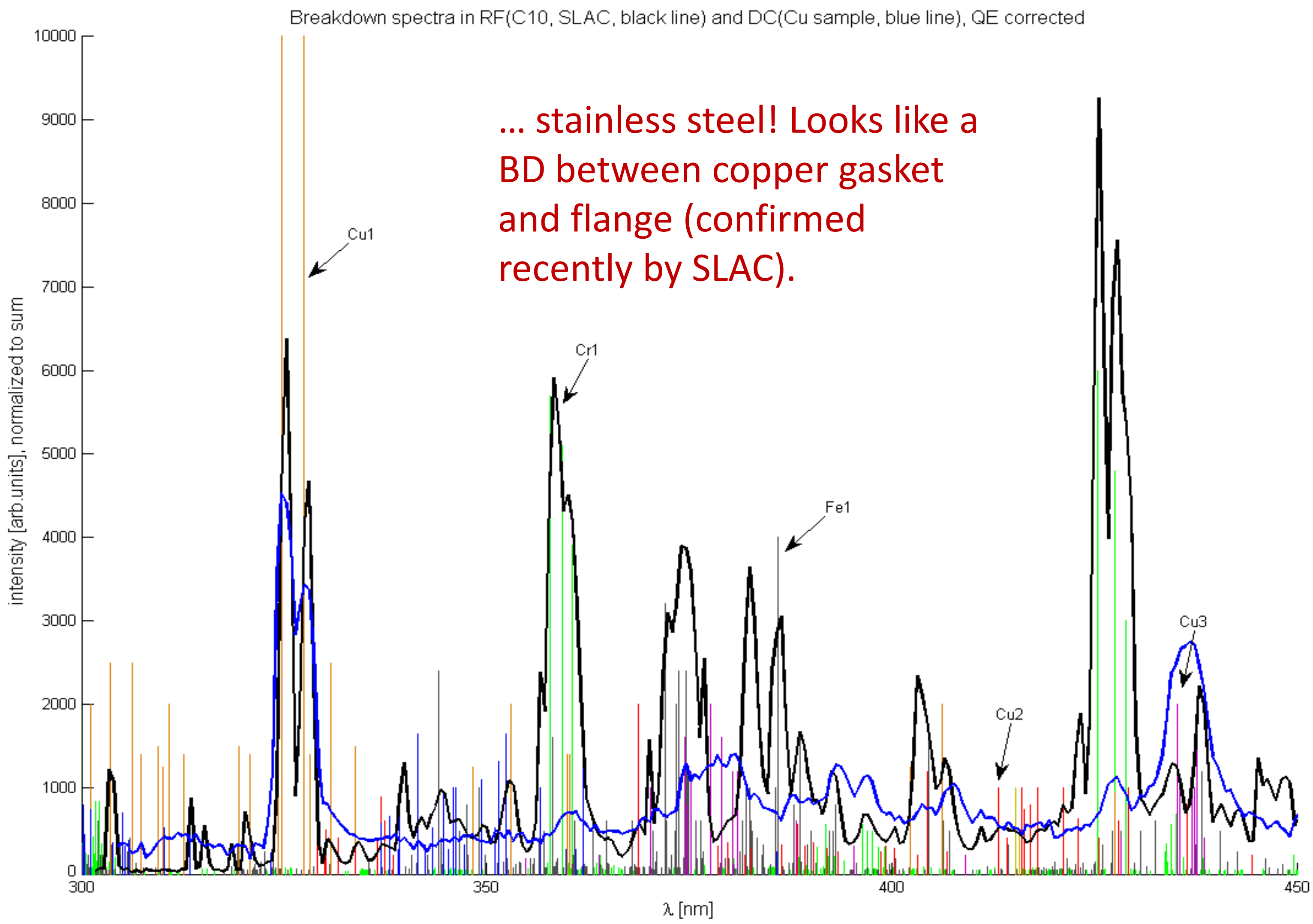
CERN DC test stand, 6kV DC, OFE Cu sample, 300MV/m surface field



RF and DC BD spectroscopy in detail



RF and DC BD spectroscopy in detail



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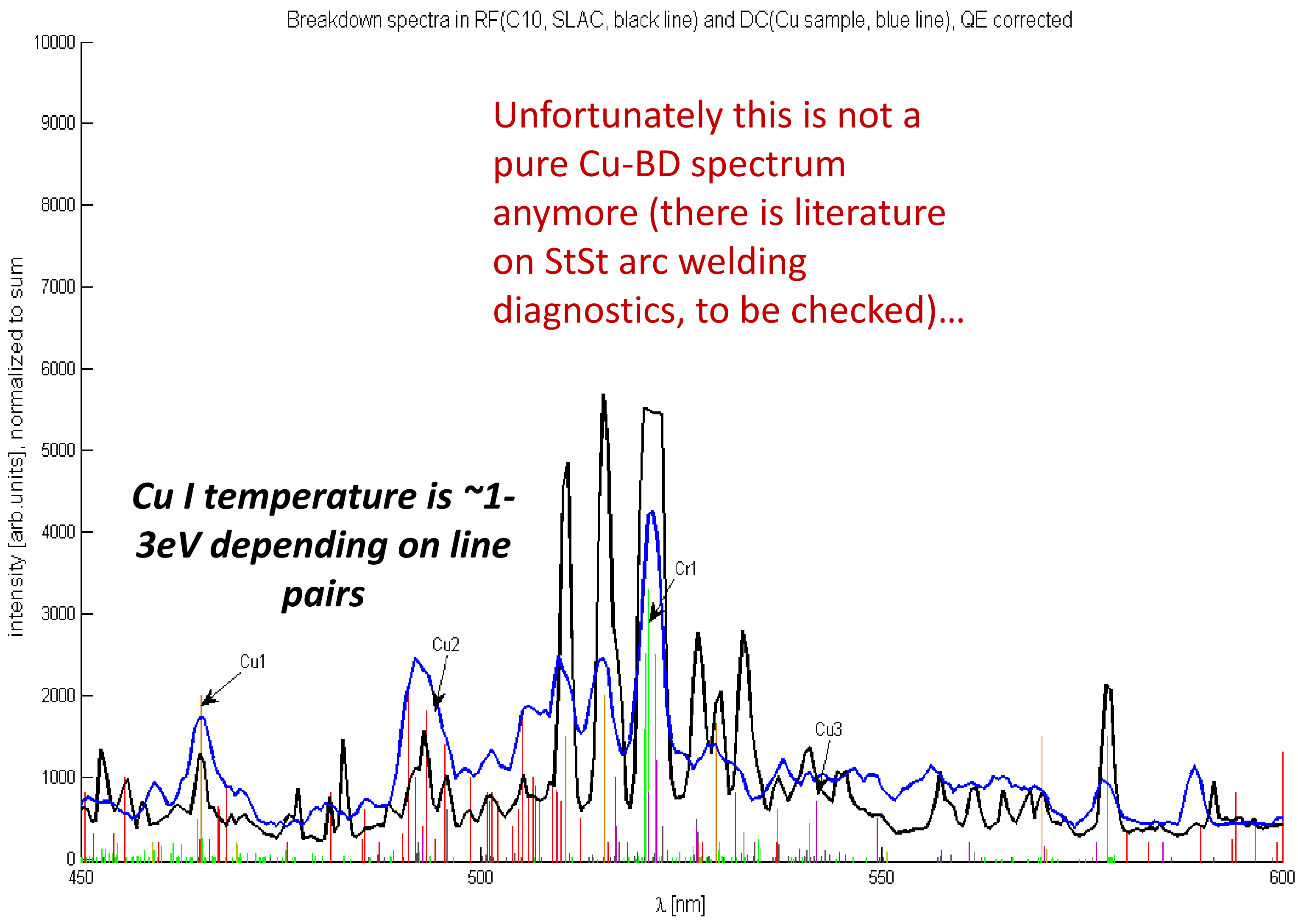
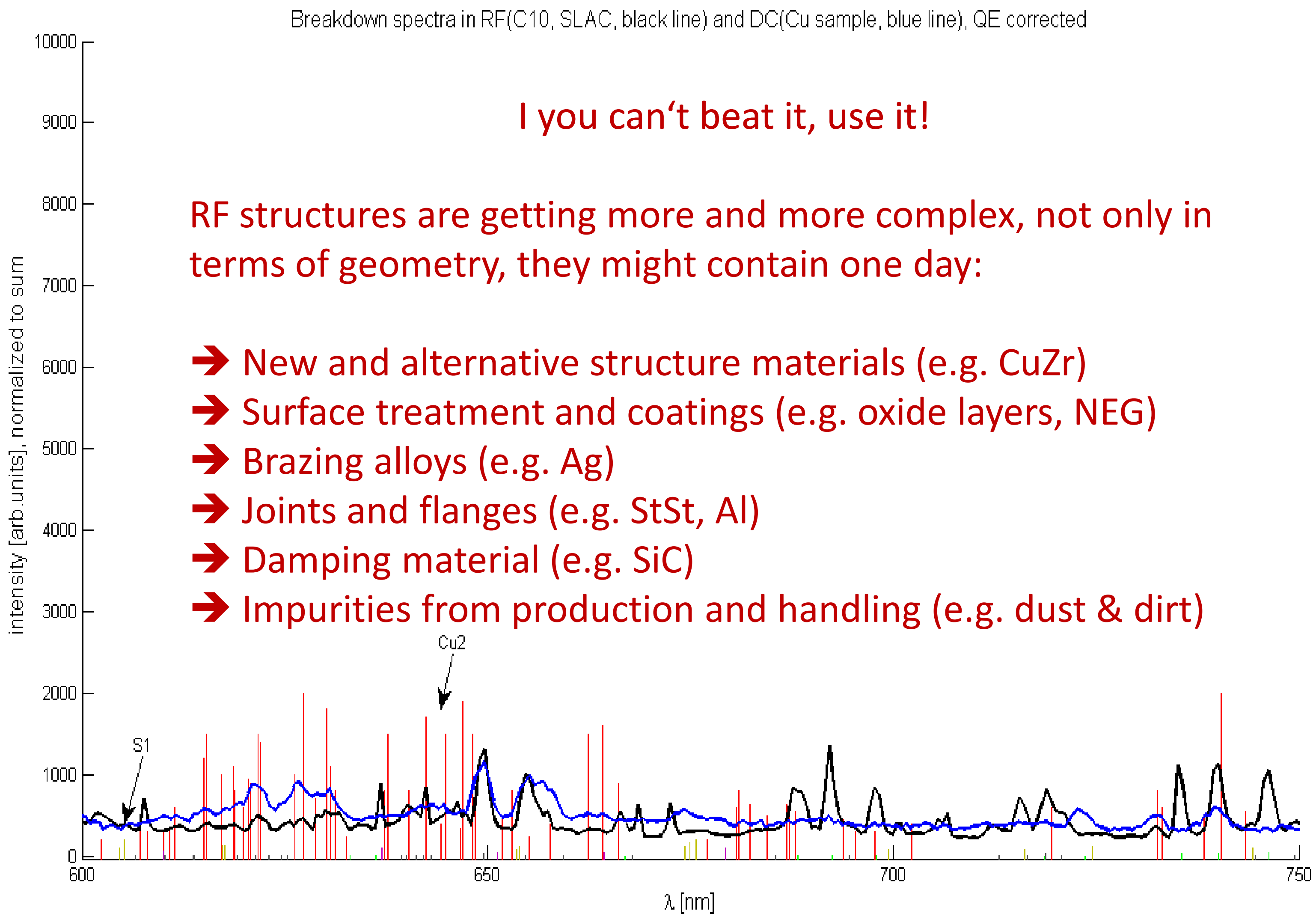


RF and DC BD spectroscopy in detail



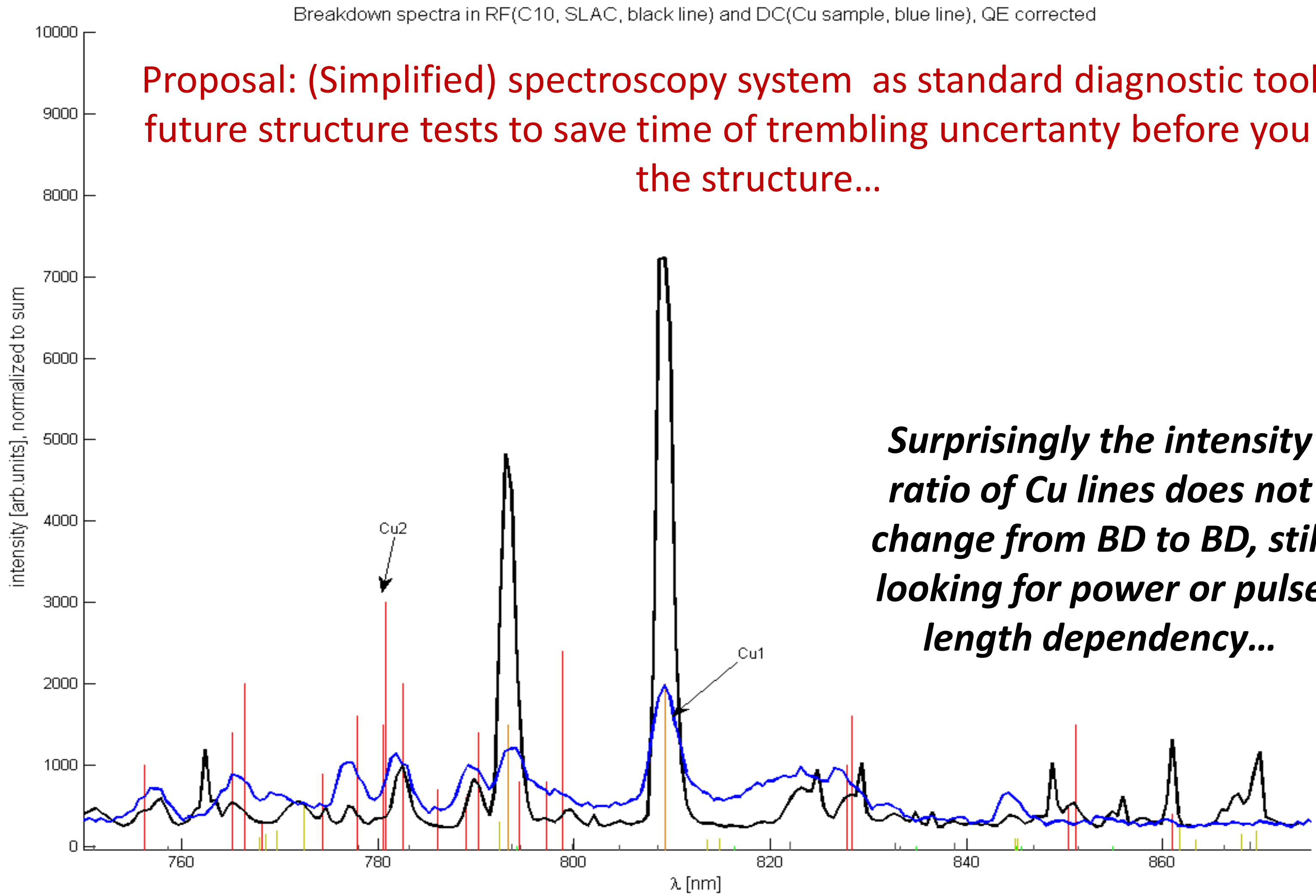
I you can‘t beat it, use it!

RF structures are getting more and more complex, not only in terms of geometry, they might contain one day:

- ➔ New and alternative structure materials (e.g. CuZr)
- ➔ Surface treatment and coatings (e.g. oxide layers, NEG)
- ➔ Brazing alloys (e.g. Ag)
- ➔ Joints and flanges (e.g. StSt, Al)
- ➔ Damping material (e.g. SiC)
- ➔ Impurities from production and handling (e.g. dust & dirt)

RF and DC BD spectroscopy in detail

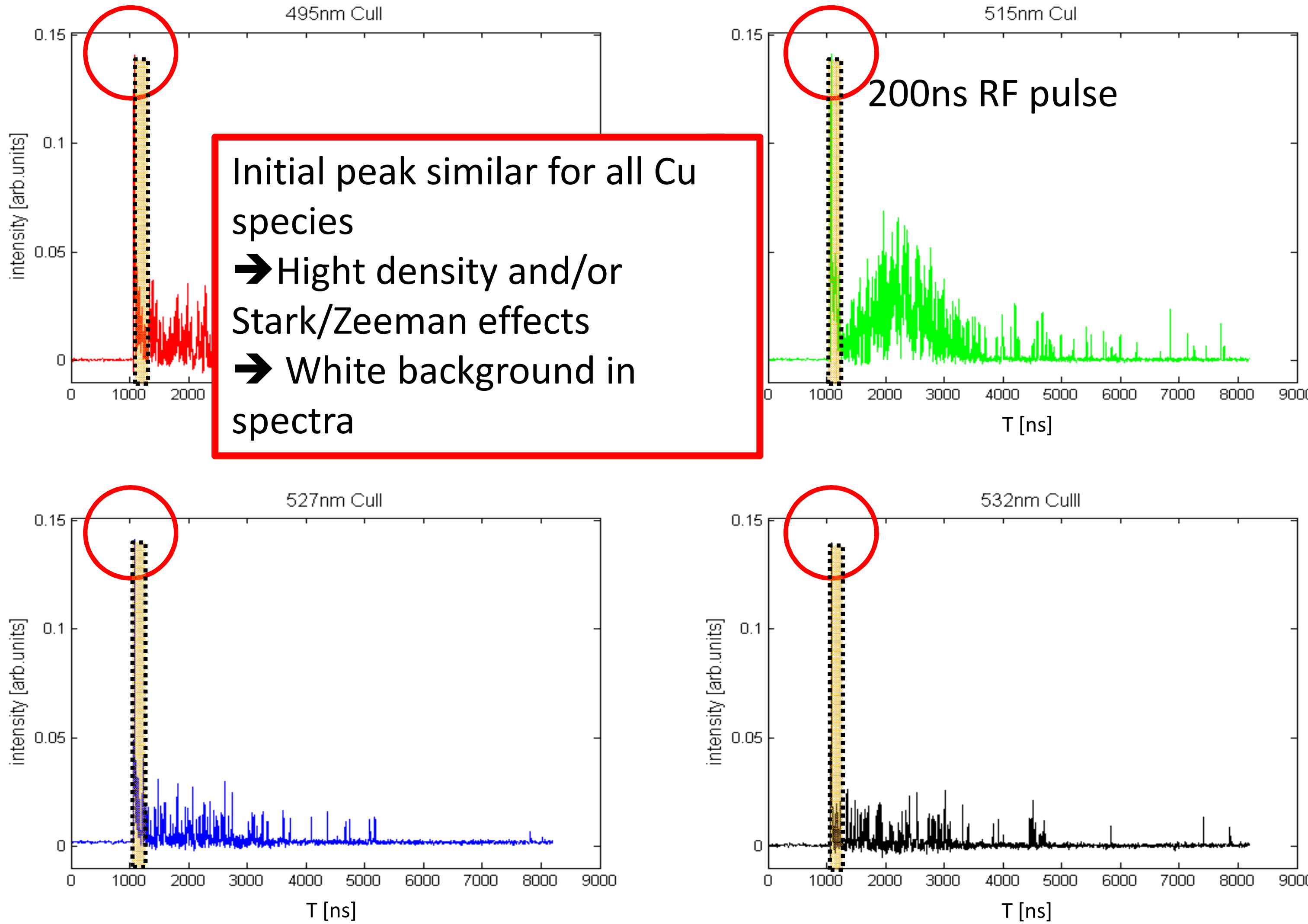
Proposal: (Simplified) spectroscopy system as standard diagnostic tool for future structure tests to save time of trembling uncertanty before you cut the structure…



Surprisingly the intensity ratio of Cu lines does not change from BD to BD, still looking for power or pulse length dependency…

RF and DC BD spectroscopy in detail

Time resolved spectroscopy of selected lines in RF (SLAC C10@100MV/m, 200ns)



Initial peak similar for all Cu species
➔Hight density and/or Stark/Zeeman effects
➔ White background in spectra

RF faraday cup measurements

High currents (5V in 50Ohms, 100mA, 50ns) of electrons hit the FC in each BD event, X-rays are produced by these electrons (30GHz CERN speedbump structure)

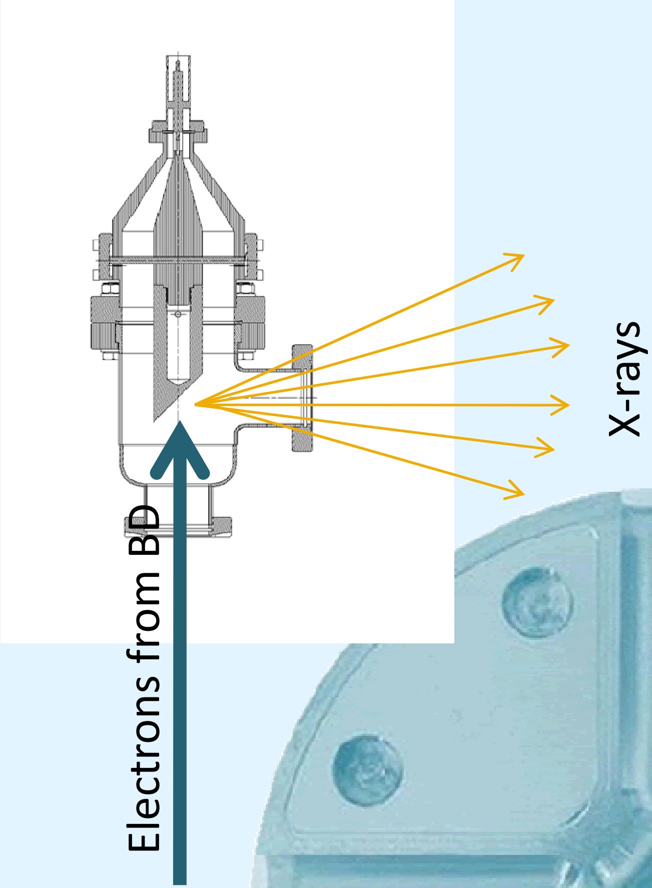
➔FC covers 1/200 of solid angle
➔ approx. 10E13 electrons per BD

X-rays pass vacuum window and Al-foils
➔ at least 10keV to be detectable,
for 10E13 electrons dissipated energy
is around 20mJ

X-rays pass 14mm Cu and 5mm Fe
➔ at least 100keV to be detectable,
for 10E13 electrons dissipated energy
is around 180mJ

In total:

~***200mJ***

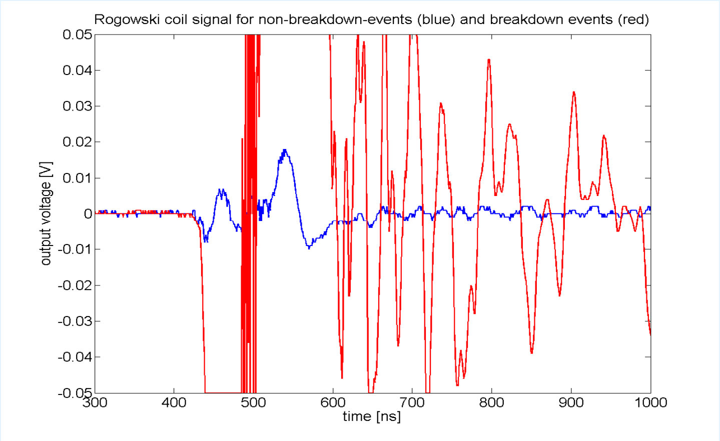


Very similar to measured missing Energy in RF, but no direct correlation!

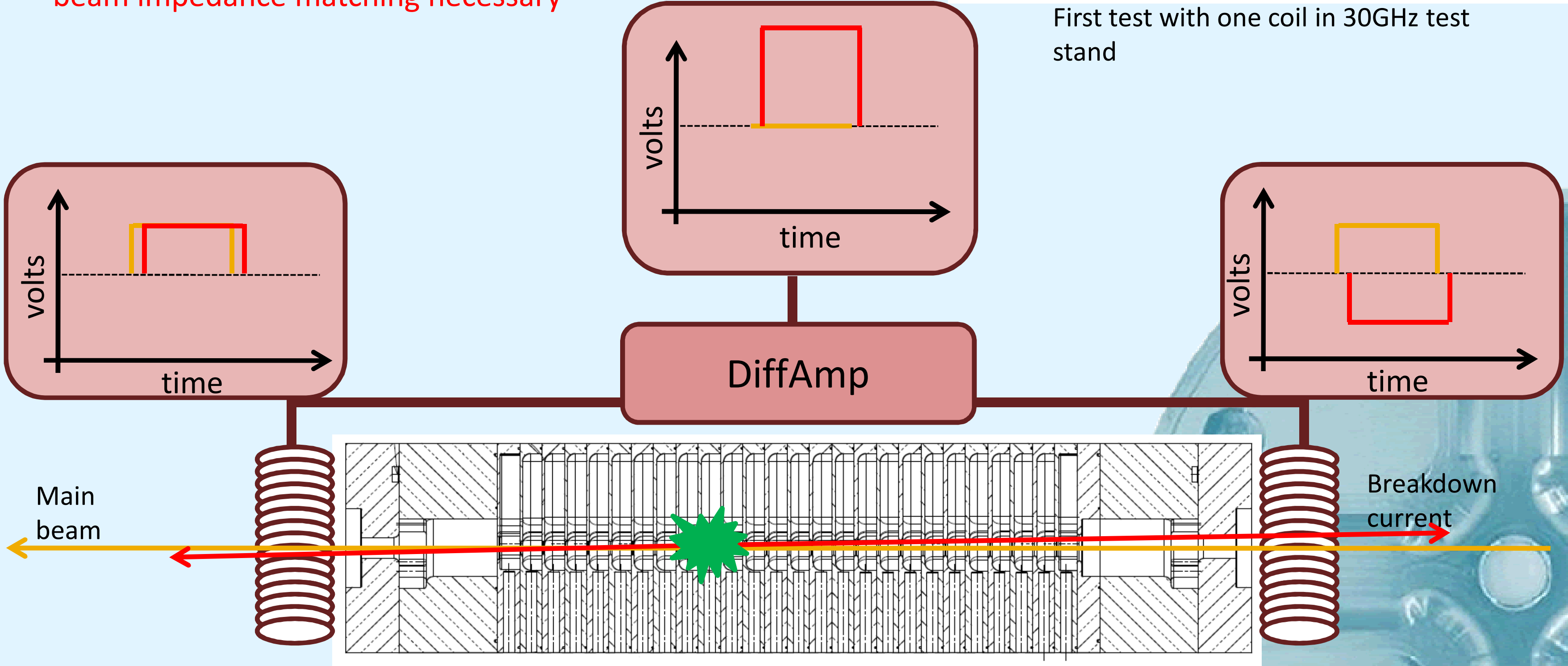
Breakdown detection for CLIC accelerating structures

Breakdown detection using pairs of Rogowski-coils:

+ easy suppression of main beam signal
+ simple electronics
+ no reference needed
+ can resolve dark current and breakdown current
+ radiation hard
+ cheap feed-throughs
- needs space between structures
- beam impedance matching necessary

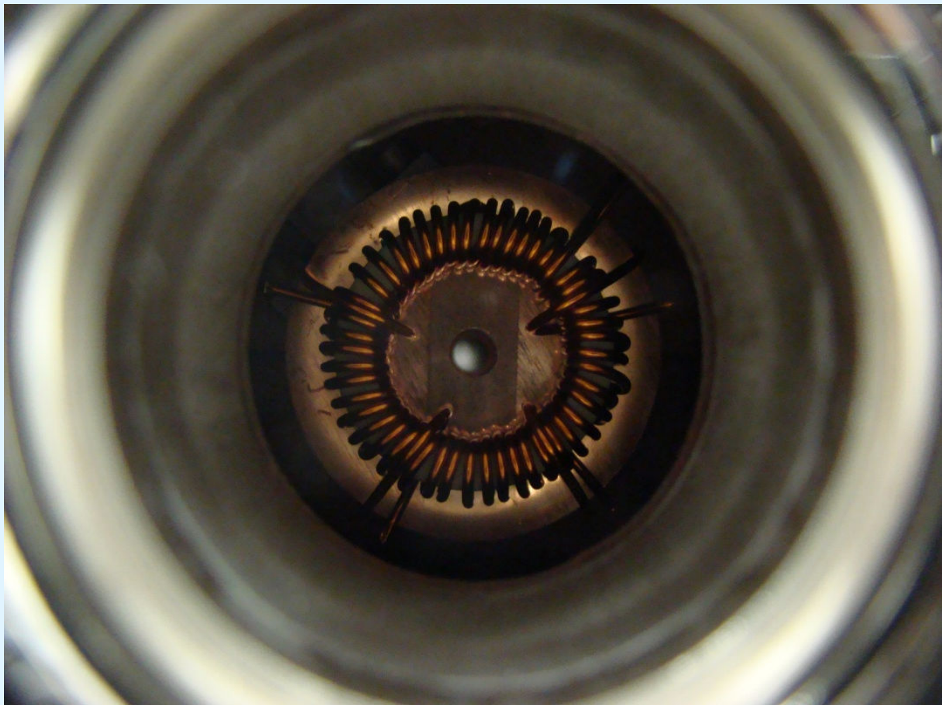


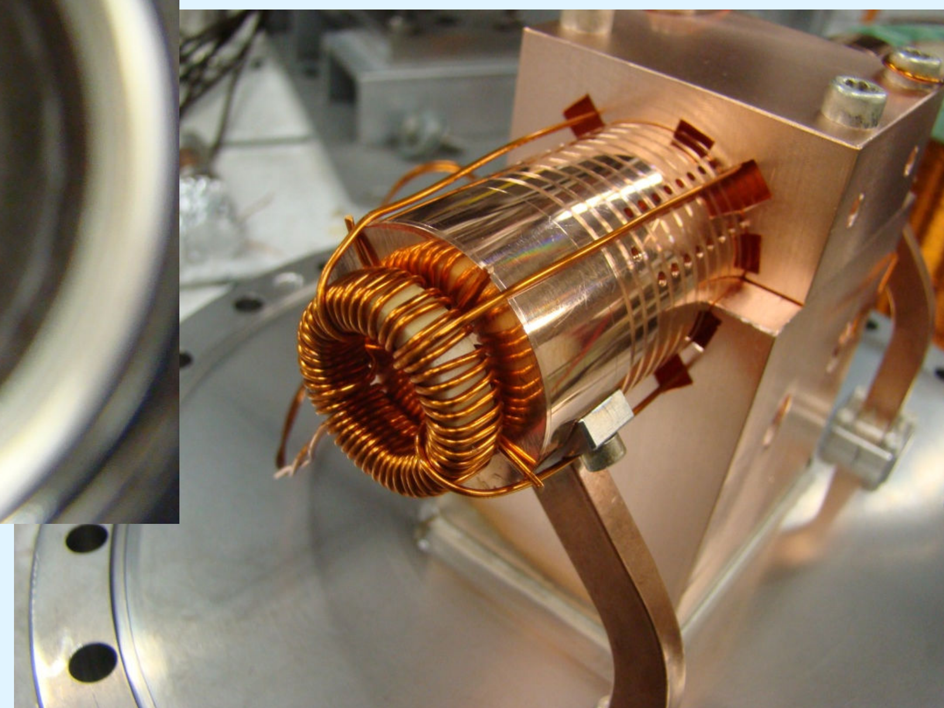
First test with one coil in 30GHz test stand



RF diagnostics spin-off

And how (cheap) it looks like doing the first tests…





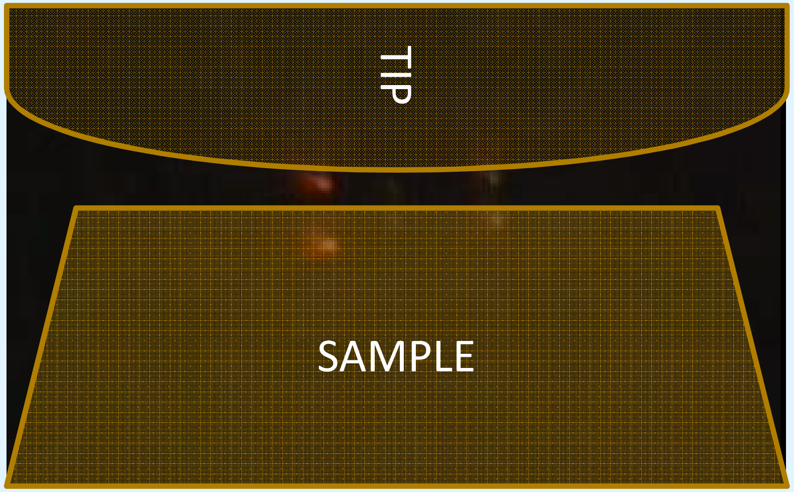
But now coming back to DC again!

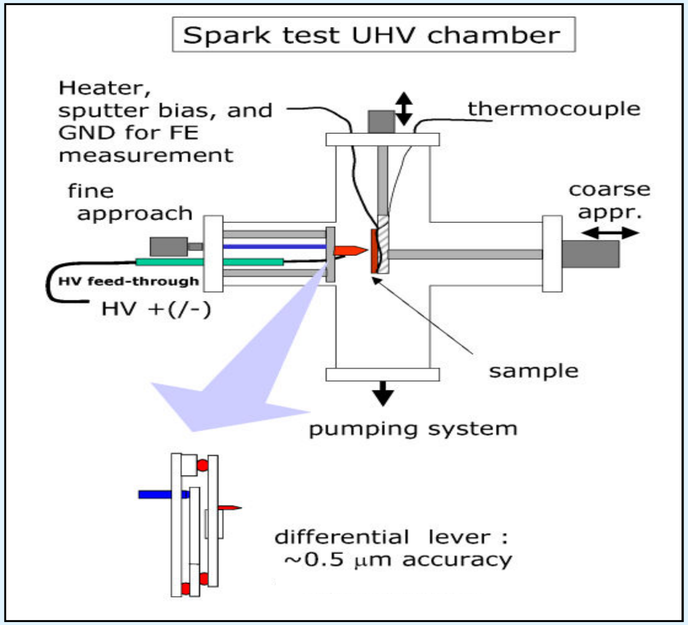
DC breakdown

The motion picture

Featuring: DC breakdown, 12kV, OFE Copper, 20um gap (500MV/m).

Storyline: Capacitor is discharged through the sparc, but the PSU stays connected with high impedance for seconds...





Summary

➔Breakdown diagnostics offer a new way of approaching the understanding of the breakdown mechanism and its possible feedback to high gradient designs

➔ The experiments give input to breakdown simulation (plasma and transient behavior)

➔ Breakdown detection methods besides RF signals and faraday cup were developed (which are under consideration for CLIC now)

➔ Fast diagnostics for abnormal structure BD behavior have been presented and will be implemented in structure test stands

THANK YOU!