Spectroscopic Analysis of DC and RF Breakdowns

The spectroscopy is part of a framework of experiments for breakdown research at CERN

Activity goals:

Experimental approach to understand the RF breakdown in comparison with the DC breakdown phenomena and its relevance to NC RF accelerating structures

- Discover the sequence of effects (trigger model) which lead to breakdown
- Discover the processes during a breakdown
- Give an explanation for commonly observed but not yet understood effects e.g.
    1. What is conditioning ?
    2. What causes damages on structures ?
    3. Is there a dependency on materials and processing techniques?
    4. Is there a observable precursor before the breakdown ?
    5. What is the gradient-limiting effect?

The spectroscopy itself will help to answer more detailed questions

What kind of plasma is produced during a breakdown,

how does it develop with time?

Optical spectroscopy can reveal properties of these plasmas and its development over time:

Time-resolved spectroscopy is a very efficient way to discover the processes during a breakdown!

It can be done for DC and RF with minor changes in the setup which leads to a very good comparability!

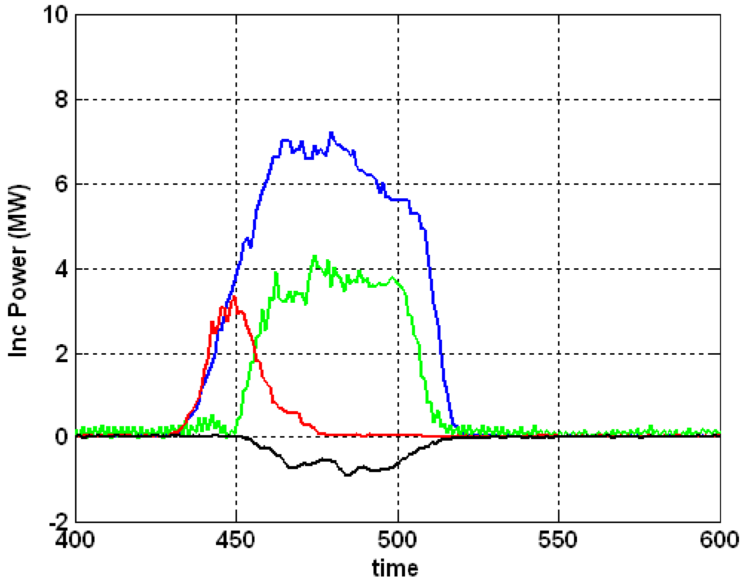
The spectroscopy itself will help to answer more detailed questions

Why is the plasma diagnostic so important?

There is a lot of energy absorbed during a breakdown. This energy is converted into heating of the surface which causes damages and fatigue. How can a plasma absorb these huge amounts of energy (~1Joule) on such a small scale? What are the conductance properties of such a plasma?

There is also some part of that energy converted into electromagnetic radiation…

This light will help to find out the properties of that plasma!



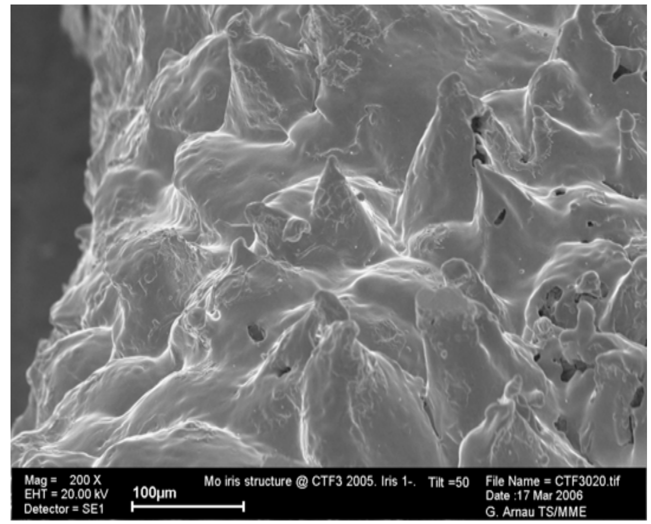
The spectroscopy itself will help to answer more detailed questions

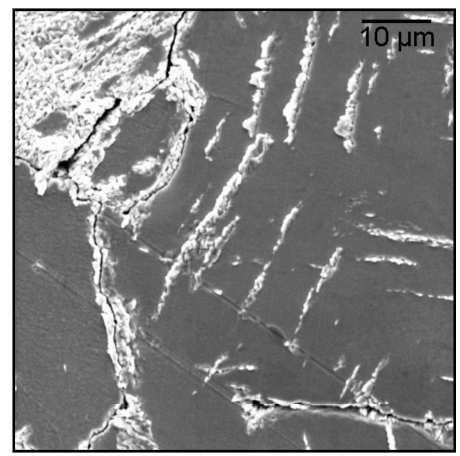
What can be measured? Conclusion?

1. 'Classical' spectroscopy: What lines resp. elements are involved in the process? How do they develop in time?

- If there are light elements (H,C,N,O) involved, they must be caused by outgassing from cracks (fatigue, is the spectrum the same before and after a long time of running?) or from impurities in or on the surface (spectrum before and after conditioning).

Do these lines play a significant role in the breakdown or is it a side-effect? (check appearance and intensity of these lines during a breakdown)





The spectroscopy itself will help to answer more detailed questions

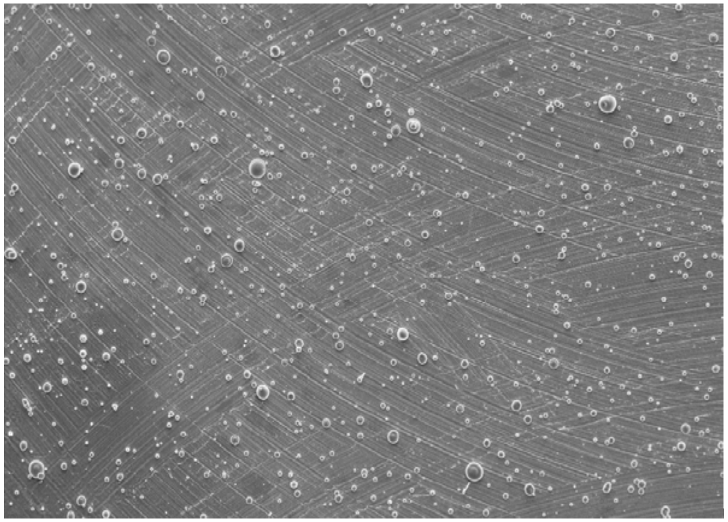
What can be measured? Conclusion?

2. Is there a blackbody background? Does it change with time?

- Measure the temperature of the surface and macroscopic hot particles (Cu clusters)

- The cooling-down (Wien-shift of blackbody radiation) allows an estimation of the size of the clusters

- There are ions ejected at about 50km/s (see M. Johnsons talk) from RF structures, does that cause visible Doppler-effects?



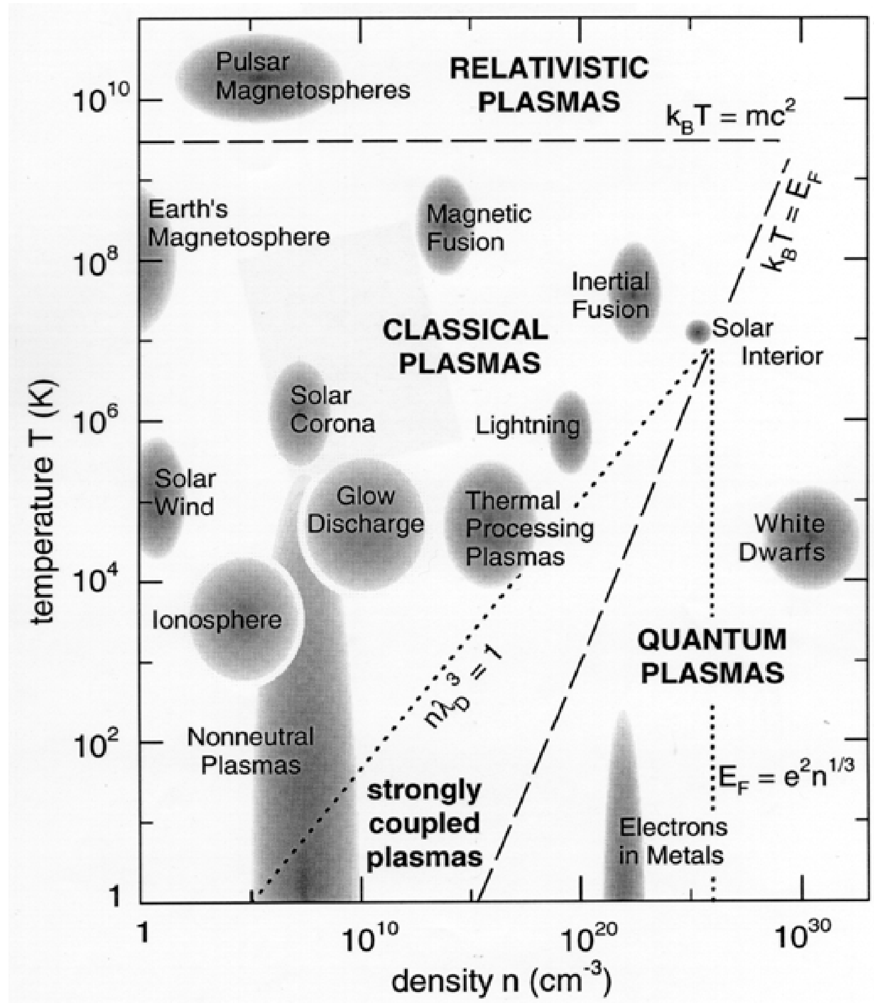
The spectroscopy itself will help to answer more detailed questions

What can be measured? Conclusion?

3. Estimation of plasma parameters:

- Measure the plasma temperature by the two-line-method

- Estimate the electron density with the help of a line profile (if there is no light-element line, a simulation of the broadening effects in Cu lines would be very helpful)



The spectroscopy itself will help to answer more detailed questions

All these measurements will be done at the beginning of the conditioning, at the end of the conditioning (where we suppose to run at constant breakdown-rate), and for breakdowns during breakdown-rate measurement mode.

It will be possible to distinguish if there is an observable difference between breakdowns during conditioning and normal operation.

The spectroscopy itself will help to answer more detailed questions

There will be for sure more things to measure and conclude,

especially the unexpected effects!

Since there has never been a time resolved spectroscopy of light emitted by RF breakdowns and no fully understood plasma model, there will for sure be some surprising effects which reveal with increasing optical resolution.

One of the most interesting questions:

Is there a precursor to a breakdown

(e.g. IR radiation from pulsed surface heating)?

Can it help to protect the structure?

The first trials

Since there was no clue what to expect from time-resolved spectroscopy, the first approach was done with a self-designed simple spectrometer

Some specifications

- Motor, scope (PMT readout) and linear gauge readout are controlled by a standard PC
- ~10nm resolution (higher resolution decreases intensity)
- LabView based software for calibration, alignment an spectroscopy operation
- Scope acts as ADC for the PMT(s), 4GHz bandwidth and up to 20GSa/s
- System takes data autonomous (~6h to take full spectrum in DC setup)
- Two PMTs for white and dispersed light (normalization)
- Fiber or free path optical input
- HeAr-reference light source for calibration

The first trials

The spectrometer

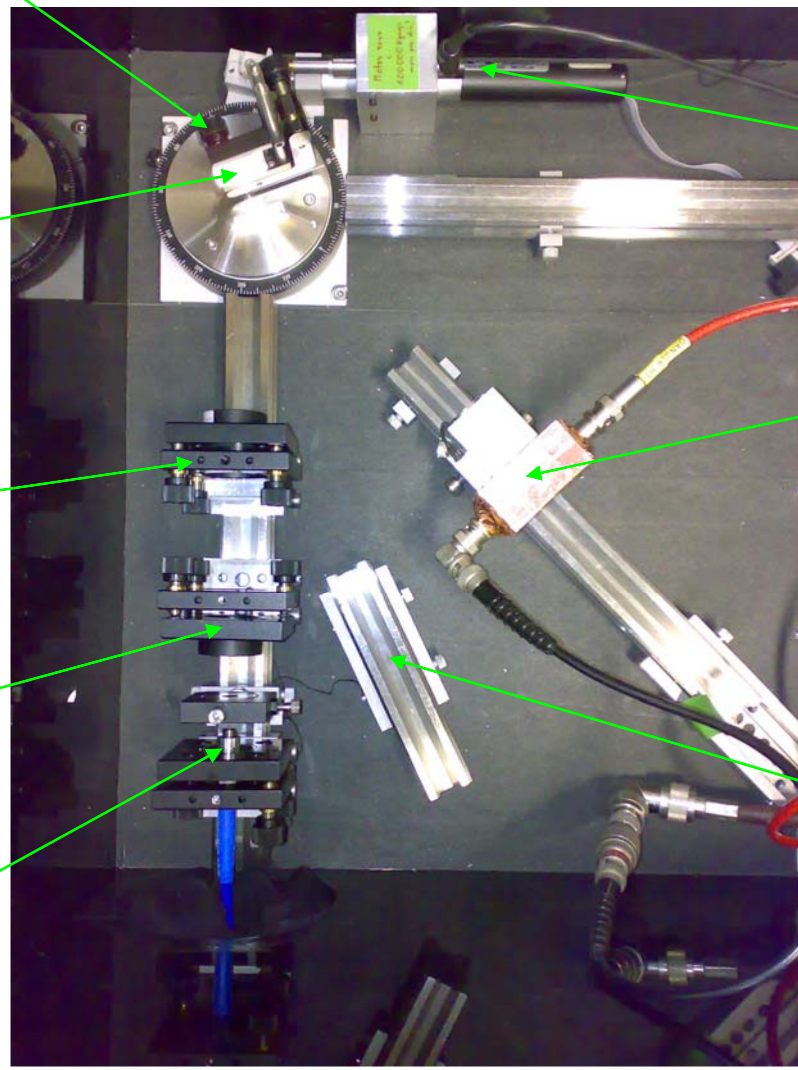
Rotational stage, servo controlled, 250steps/nm

Ruled diffraction grating, 300 lines/mm, blazed at 500nm

BK7 biconvex lens, 100mm focus length

350micron input slit

Fiber input with collimator



Linear gauge, 1micron resolution, absolute position

PMT, Hamamatsu R7400U-01, 350-650nm, 0.78ns rise time, 350micron input slit

White light PMT stays here during DC setup operation

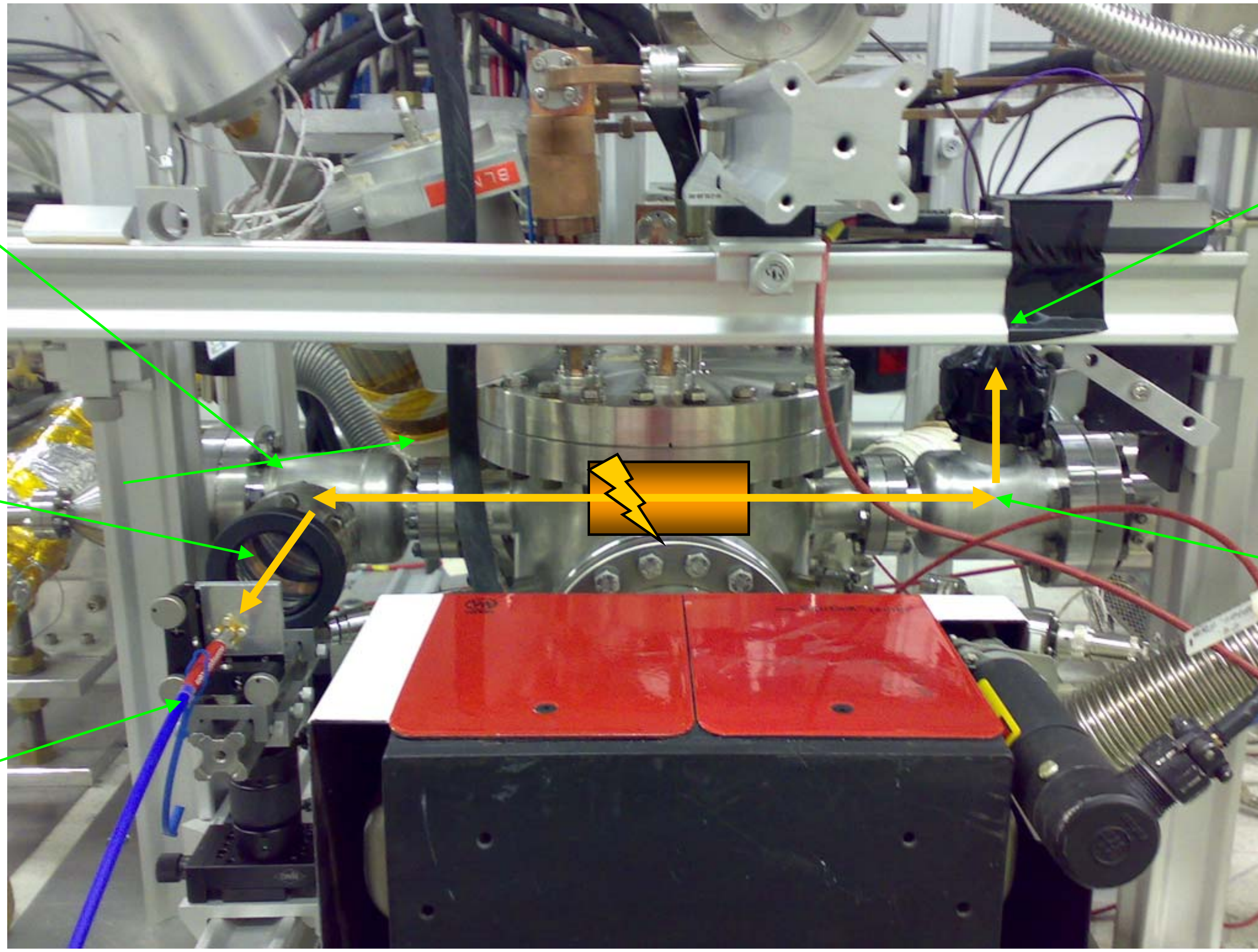
The first trials

The optics in the RF setup

Faraday cup with mirror and window

Light collimation lens

1 mm optical fiber

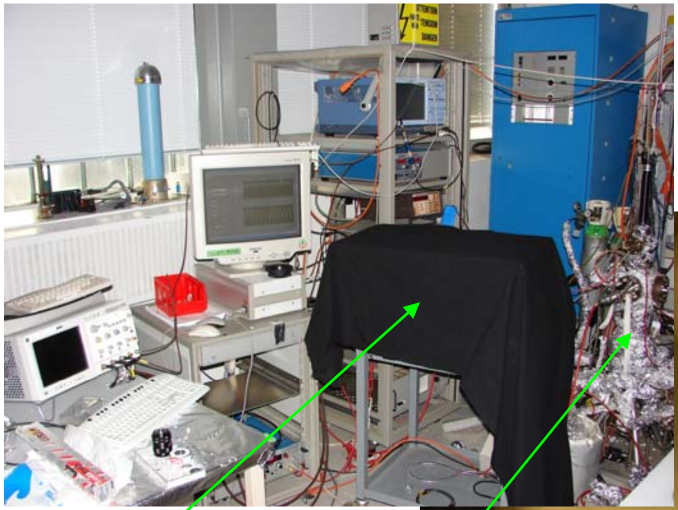


White light PMT

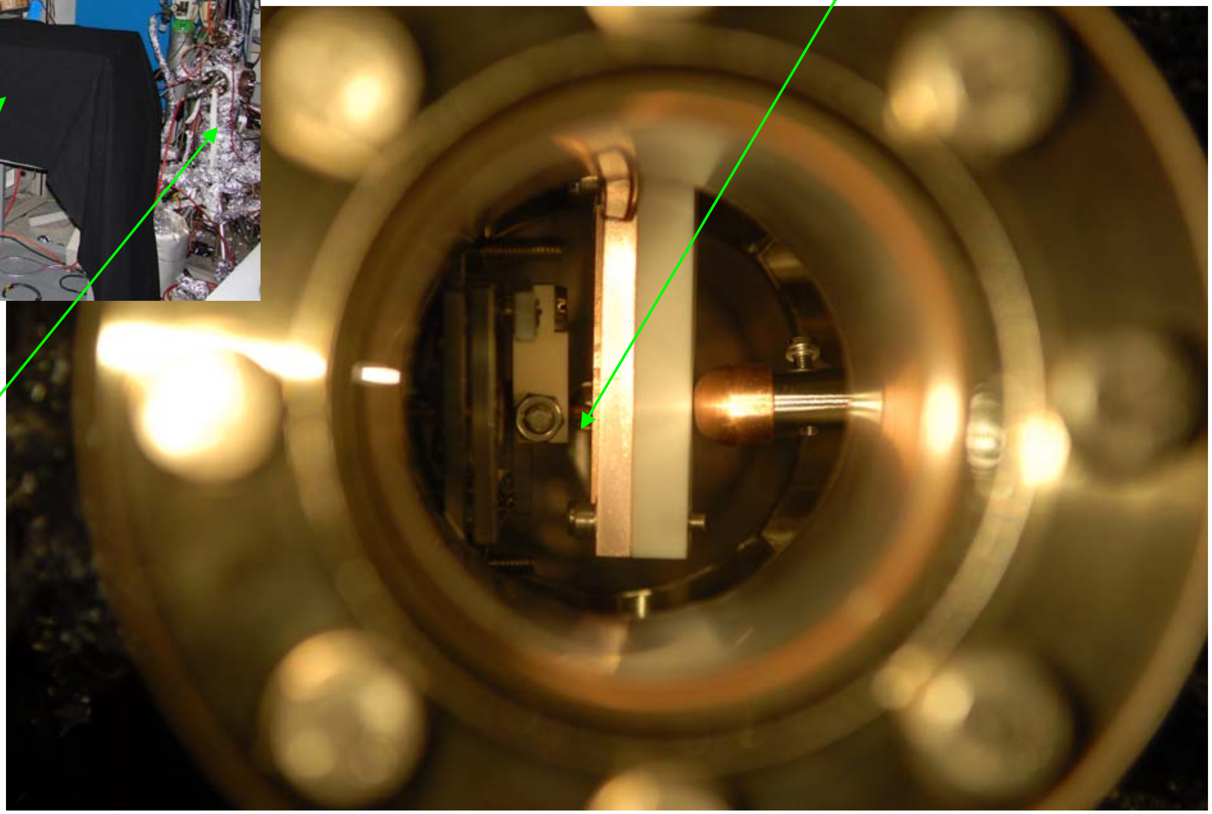
Faraday cup with mirror and window

The first trials

The spectrometer in the DC setup



1mm optical fiber without collimation optics



spectrometer

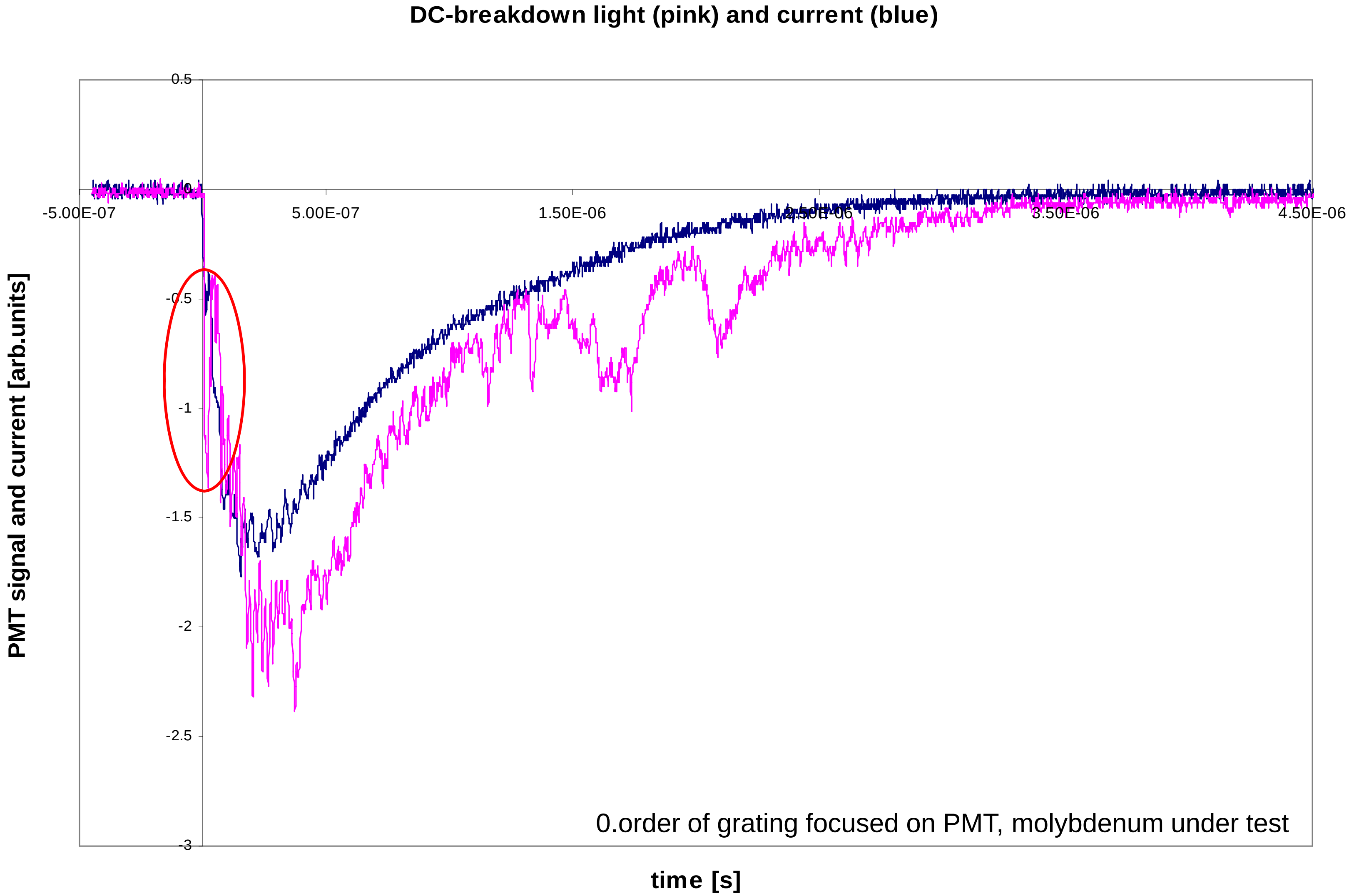
DC sparc setup

Problems and difficulties

- The amount of light is very low, in the RF case its only a few photons after the grating (in time resolved operation)
- The pulses are very short (low integrated intensity)
- The sensitivity of the PMTs is rather low, integration is not possible
- Low intensity and low sensitivity can only be compensated by lower resolution (that is a wider input slit)
- The collimation into the fiber is very challenging and extremely sensitive to misalignments
- The emission size is around a few 10microns but the distance of the optics is around 10mm (in DC) to about 50cm (in RF) due to the vacuum chamber
- The repetition rate (around 0.1Hz in DC and even less in RF) does not allow integration with standard CCD or similar due to noise
- Each breakdown is different in pulse shape and intensity

First results from spectroscopy

The pulse shape of the white light emitted by a breakdown in the DC setup



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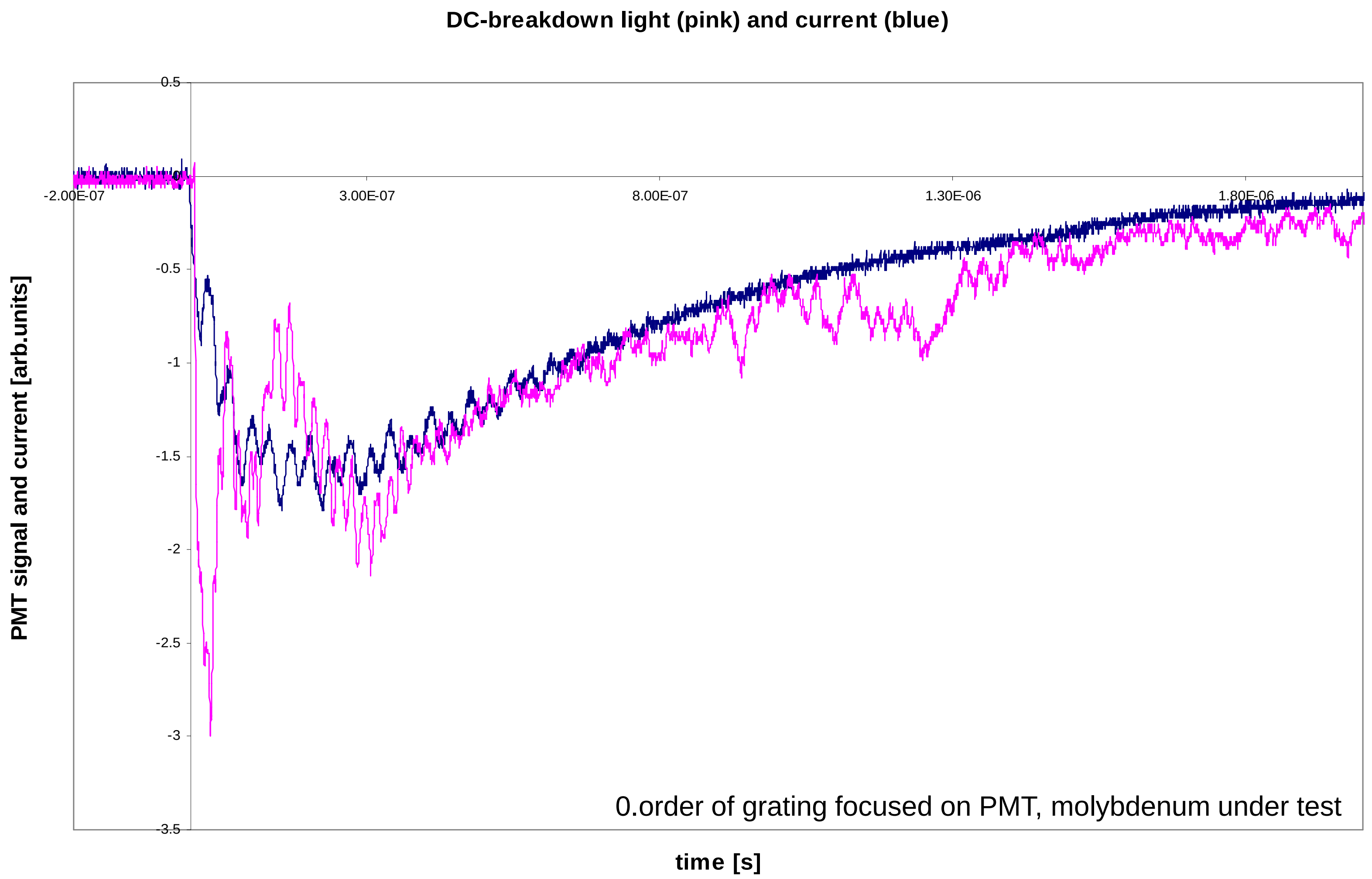

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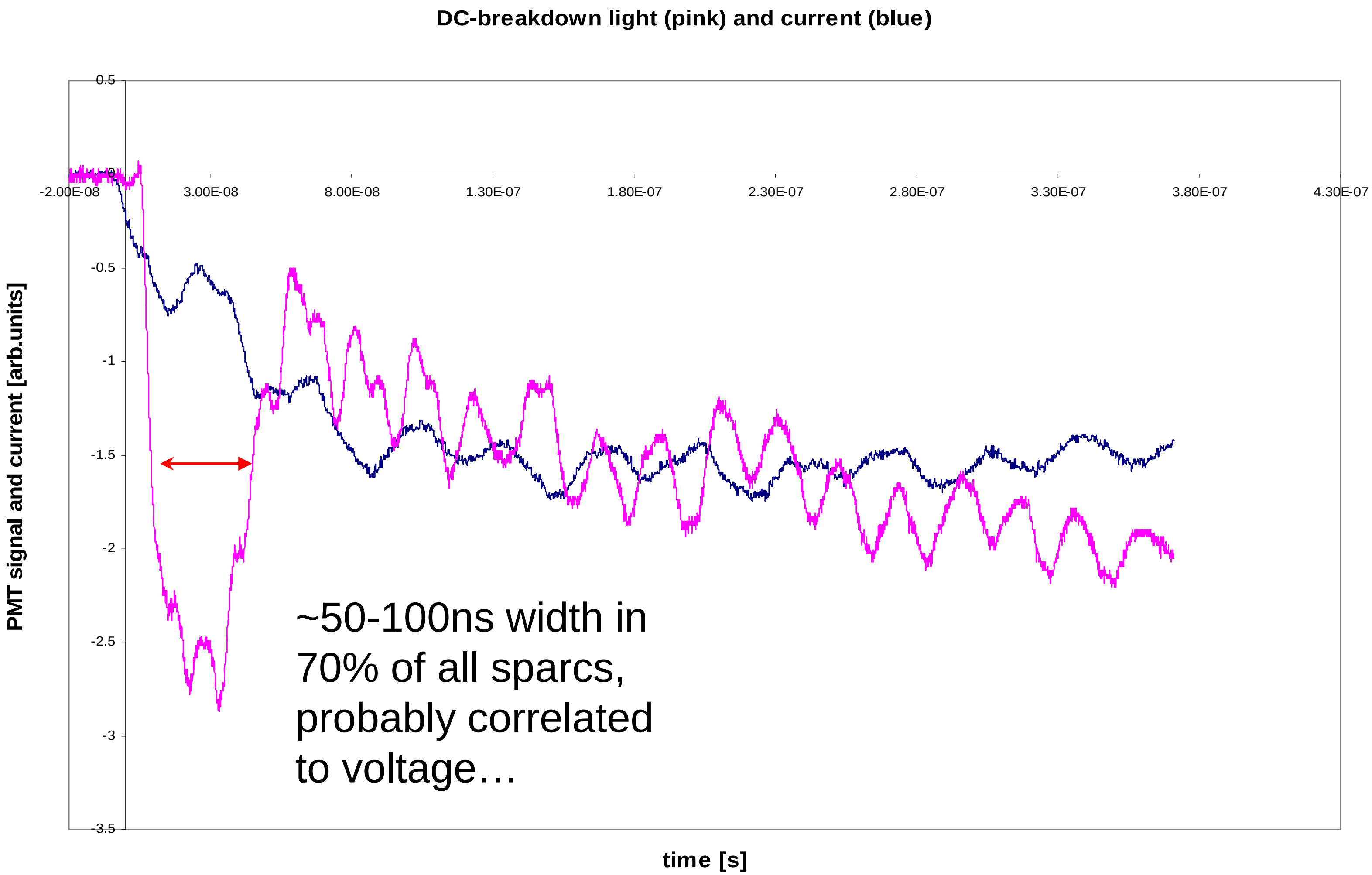
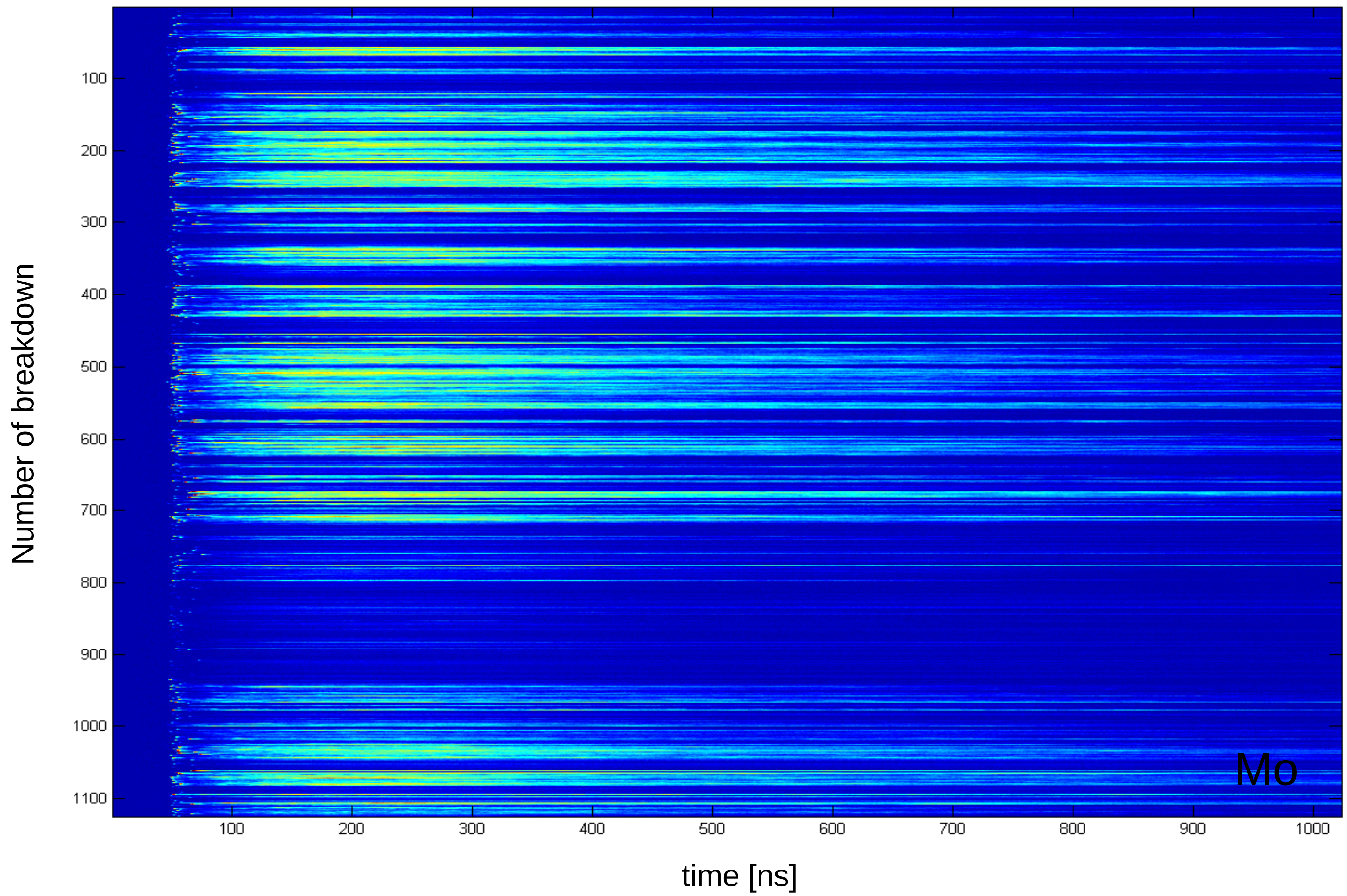


First results from spectroscopy

There is another effect of the white light pulse shapes…

Clustering?



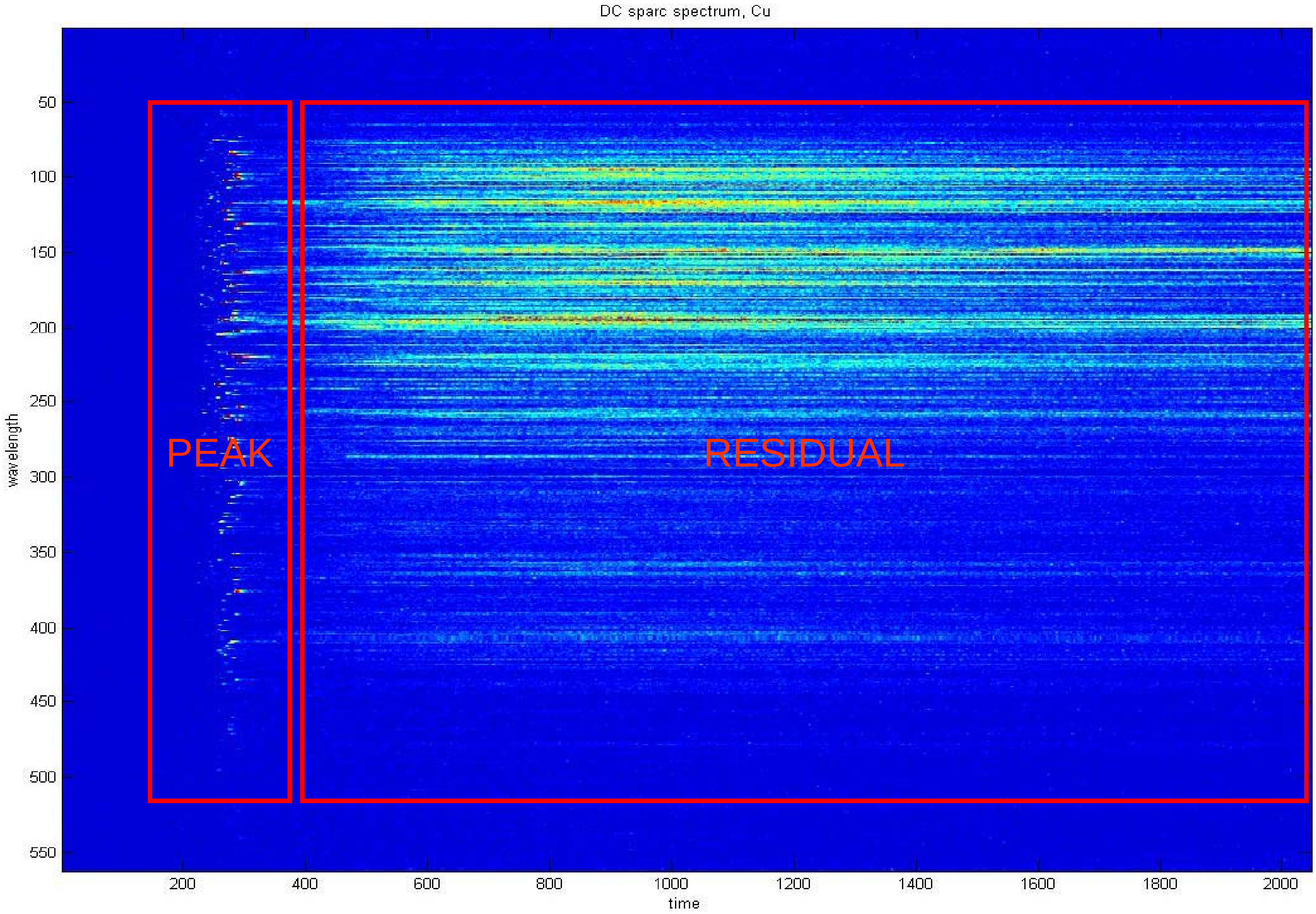
First results from spectroscopy

The pulse shape of the dispersed light emitted by a breakdown in the DC setup

Is it something like a plasma ignition process?
Does the appearance of the peak depend on the gradient?
Is it a line- or a continuous spectrum?

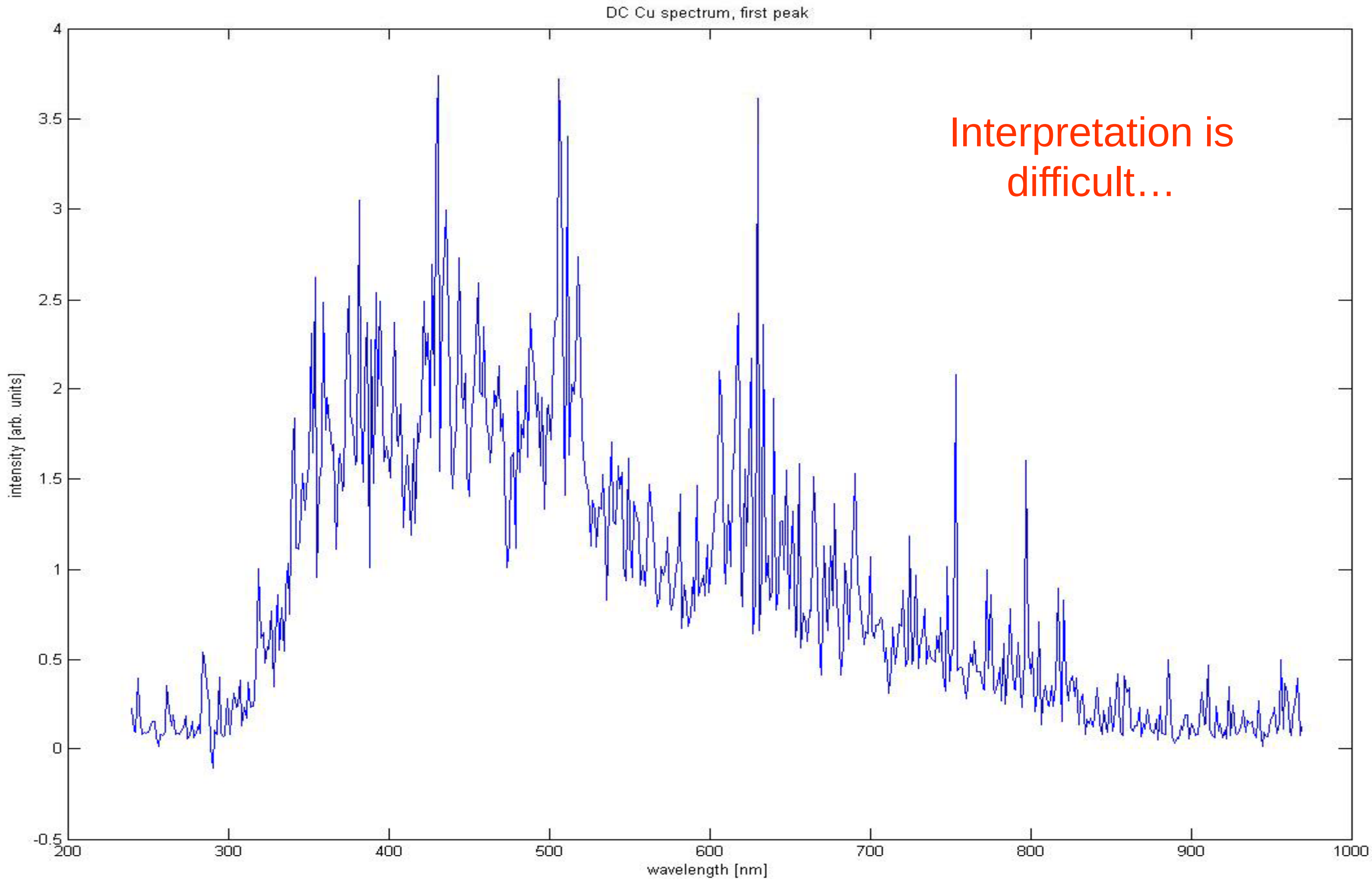
First results from spectroscopy

Time resolved Cu spectrum from the DC sparc setup



First results from spectroscopy

The peak spectrum



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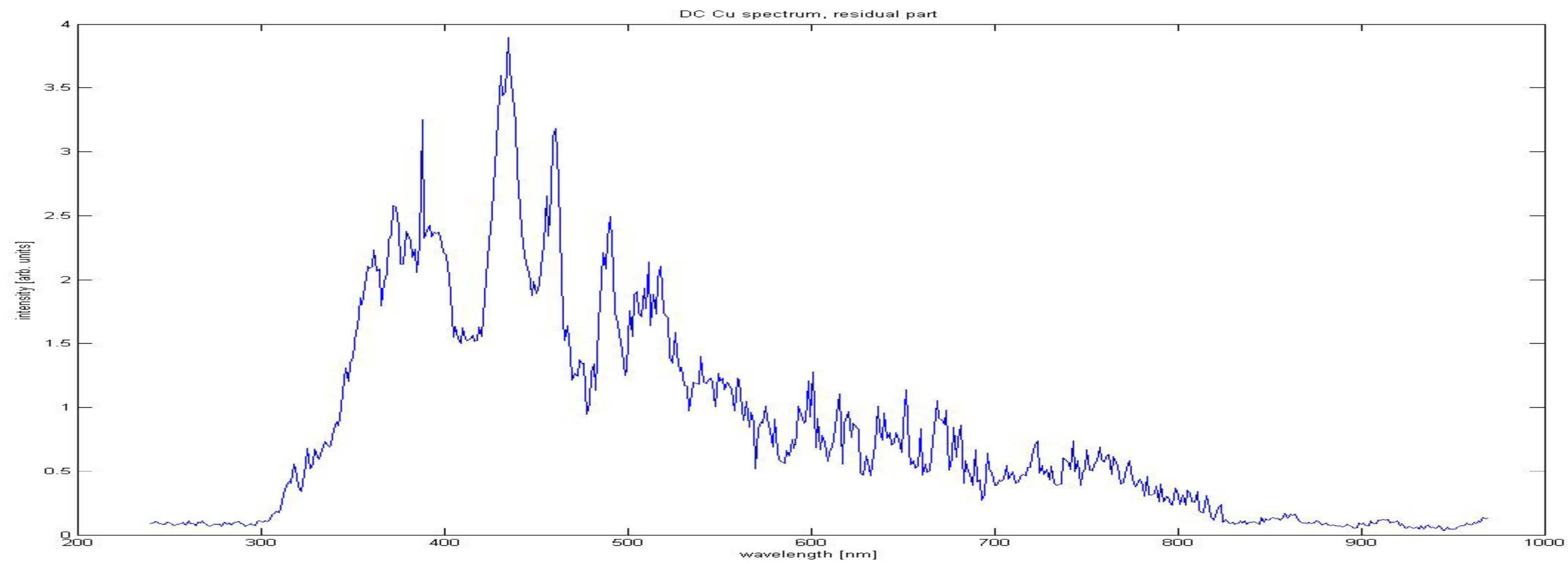

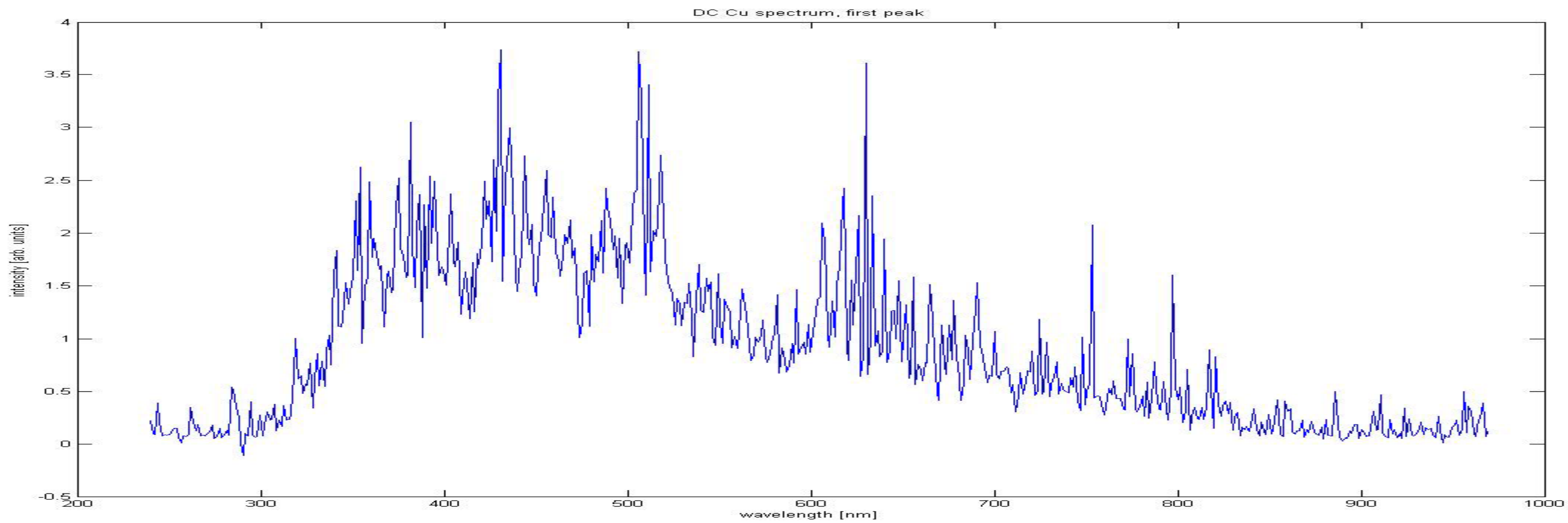

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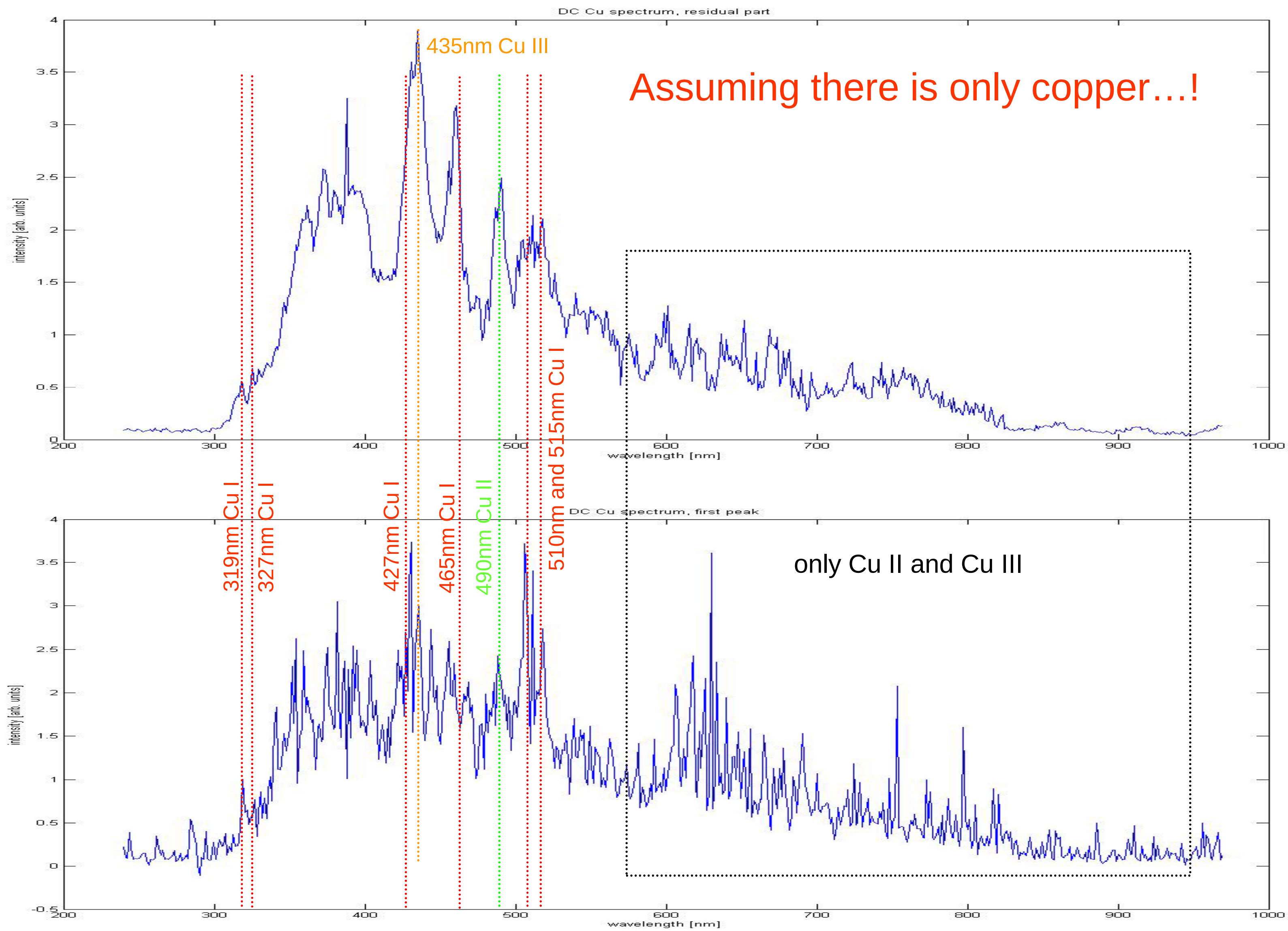

Summary and Outlook

- Time resolved spectroscopy offers a variety of plasma diagnostics characterizing the effects developing during a breakdown
- First time-resolved spectra have been measured revealing a division of the process in two parts, the ignition and the residual
- A line spectrum with a continuous background could have been identified

- Higher resolution and more sensitive detectors are now necessary to continue with more detailed studies of the lines, they are crucial for the clear assignment of lines
- It would be nice to get some help from plasma theorists and plasma simulation experts, spectroscopical effects in copper are not easy to calculate…

The time resolved spectroscopy will reveal interesting facts about the plasma formed during a breakdown and eventually lead to a better understanding and a model of what leads to and happens during a breakdown!

Thank you!