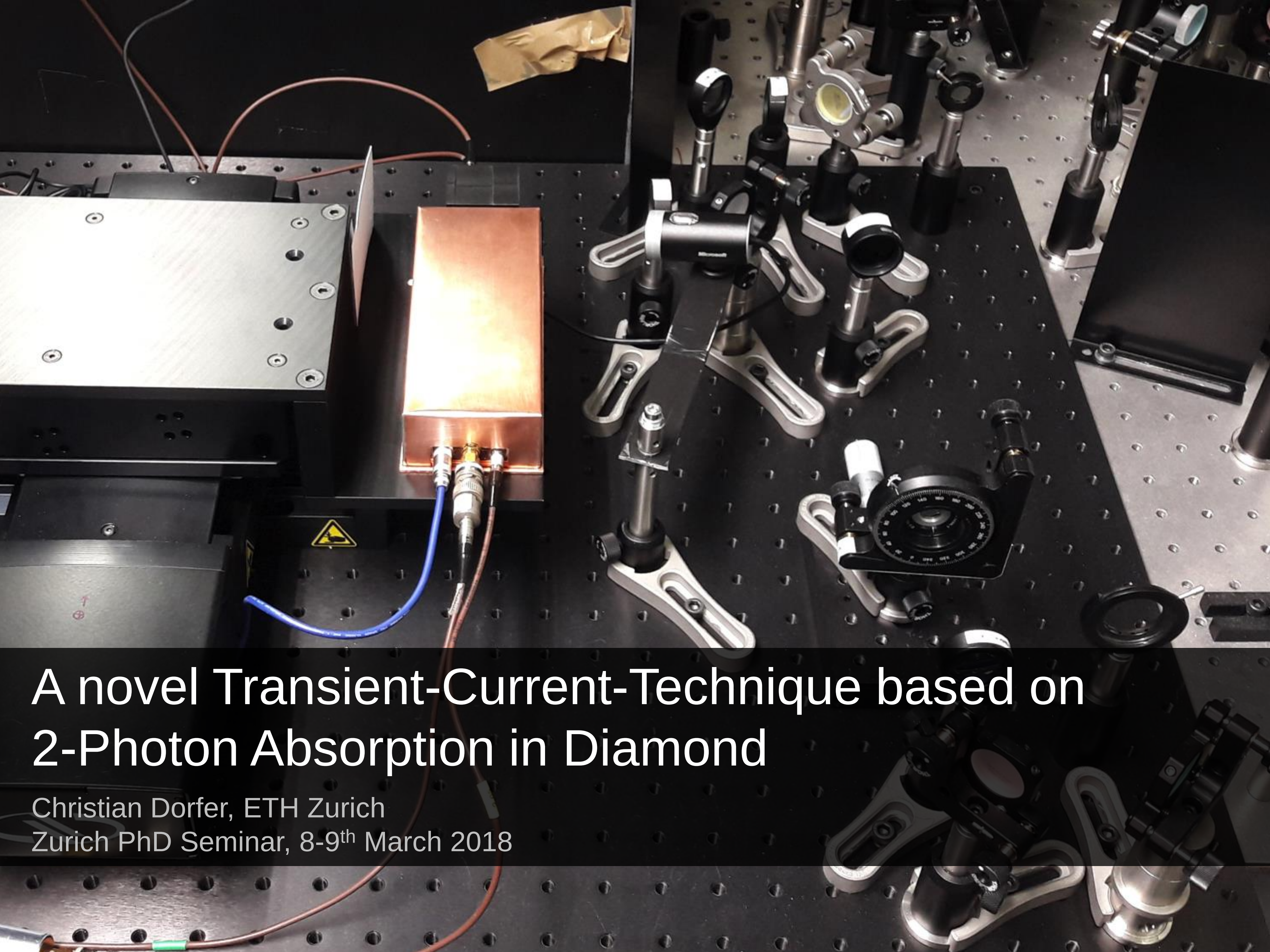


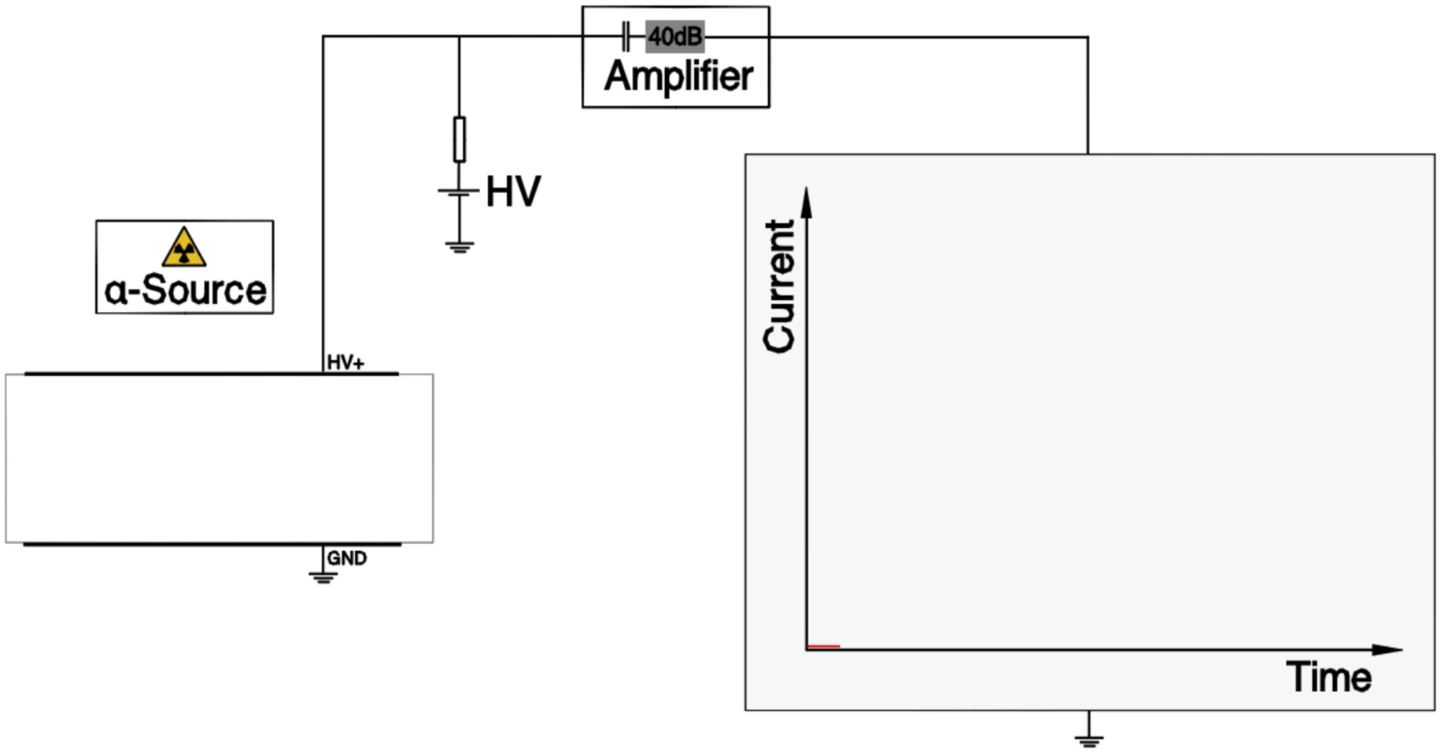
A novel Transient-Current-Technique based on 2-Photon Absorption in Diamond

Christian Dorfer, ETH Zurich

Zurich PhD Seminar, 8-9th March 2018

A novel Transient-Current-Technique based on 2-Photon Absorption in Diamond

What is that?

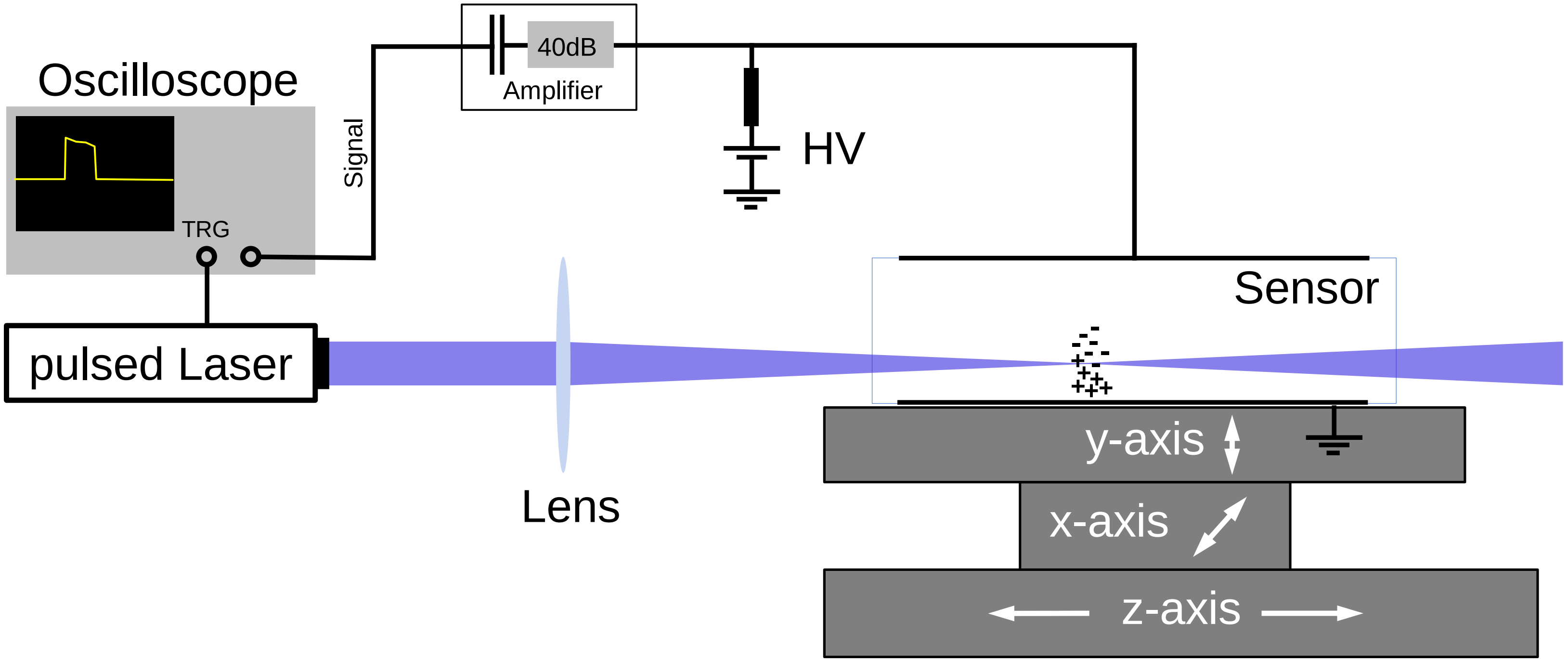


Such setup is able to measure:

- total collected charge vs injected charge → charge collection efficiency
- drift speed and mobility of electrons and holes
- charge carrier lifetimes

A novel Transient-Current-Technique based on 2-Photon Absorption in Diamond

Why novel?

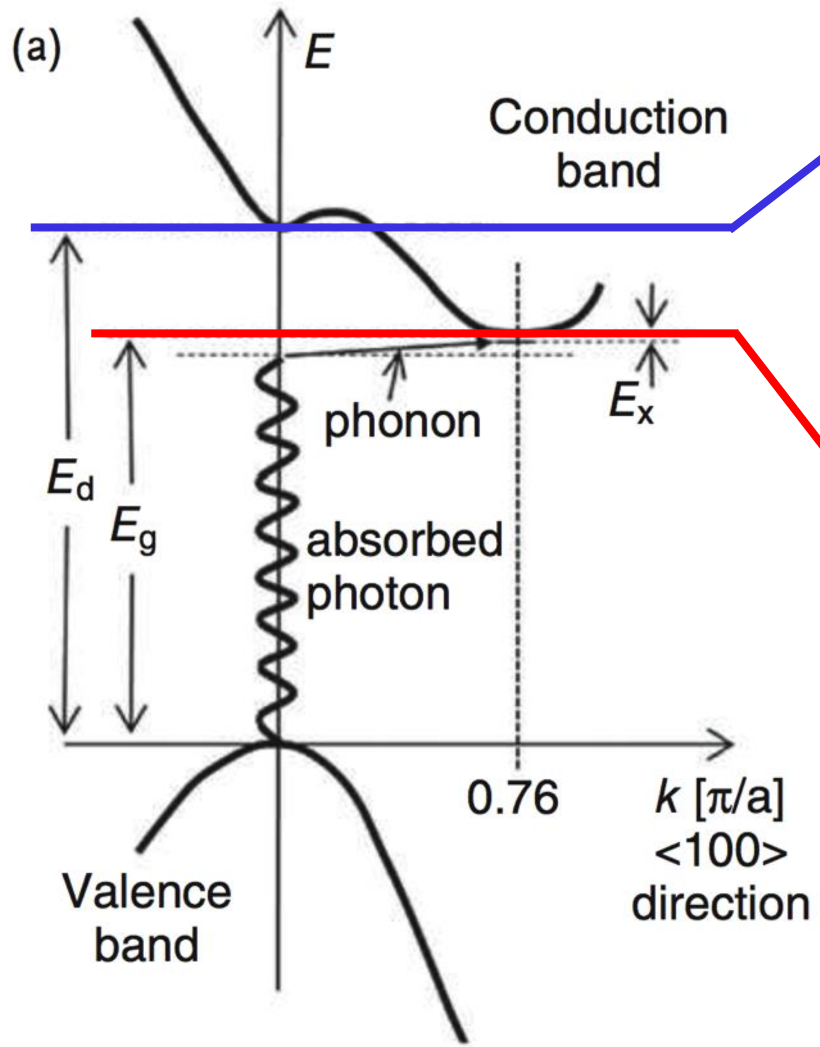


Instead of a source we use a laser beam. This allows to:

- ✓ generate charges in a selected position with sub-micrometer precision
- ✓ control the amount of injected charge through varying laser pulse energy
- ✓ directly measure the electric field (assumption in case of α, β-TCT)
- ✓ trigger directly on the laser pulse
- ✓ do 3D scans of the sensor bulk
- ✓ in addition to all measurements possible with α, β-TCT

A novel Transient-Current-Technique based on 2-Photon Absorption in Diamond What is that?

Let's first have a look how much energy we need to 'set an electron-hole pair free'.



Direct Bandgap

required energy = 7.3 eV / 170 nm

1-photon absorption

2-photon absorption: E_γ = 3.65 eV / 340 nm

3-photon absorption: E_γ = 2.43 eV / 510 nm

Indirect Bandgap

required energy ≈ 5.47 eV / 226 nm

(minus phonon contribution and exciton energy)

1-photon absorption

2-photon absorption: E_γ ≈ 2.74 eV / 453 nm

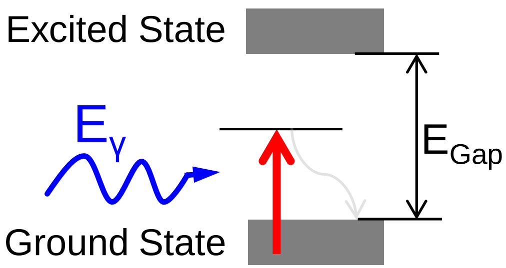
Attoline Laser

- photon energy **3.1 eV** (400 nm)
- ~25 fs
- 0.1-5 nJ pulse energy eq. to $2 \cdot 10^8$ – 10^{10} photons/pulse
- 1 kHz repetition rate

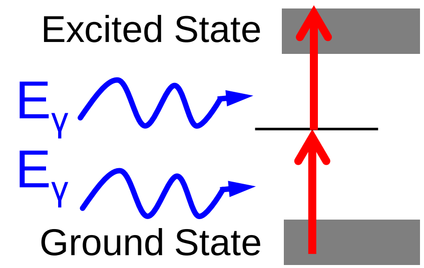
A novel Transient-Current-Technique based on 2-Photon Absorption in Diamond

What is that?

$E_\gamma < E_{Gap}$

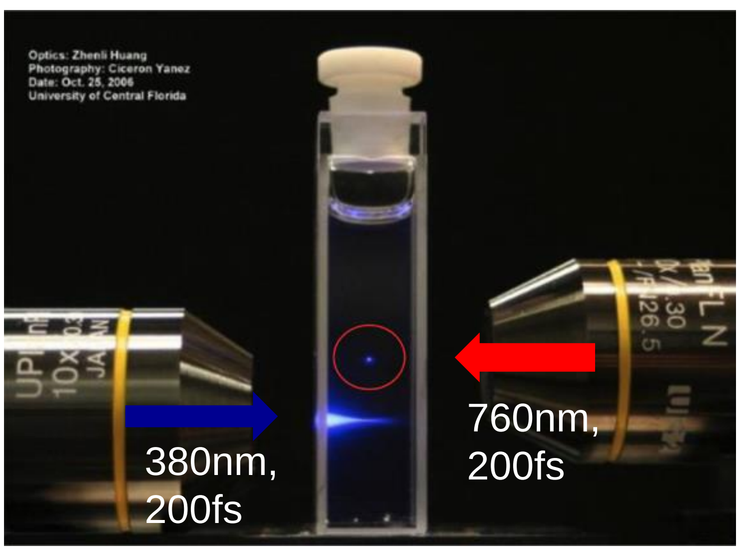


TWO Photons arriving within ~100 attoseconds



Very dense spatial and timed packing of photons required to have two photons ‘in the same place at the same time’!

→ Focal Point of Femtosecond Laser

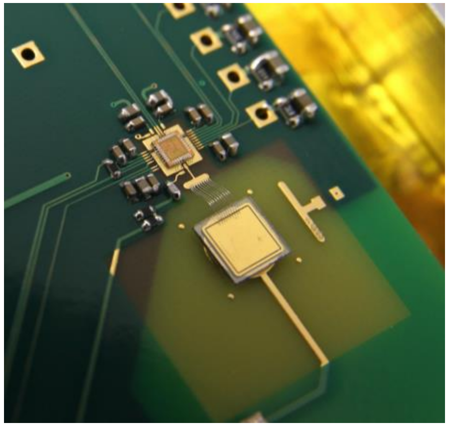


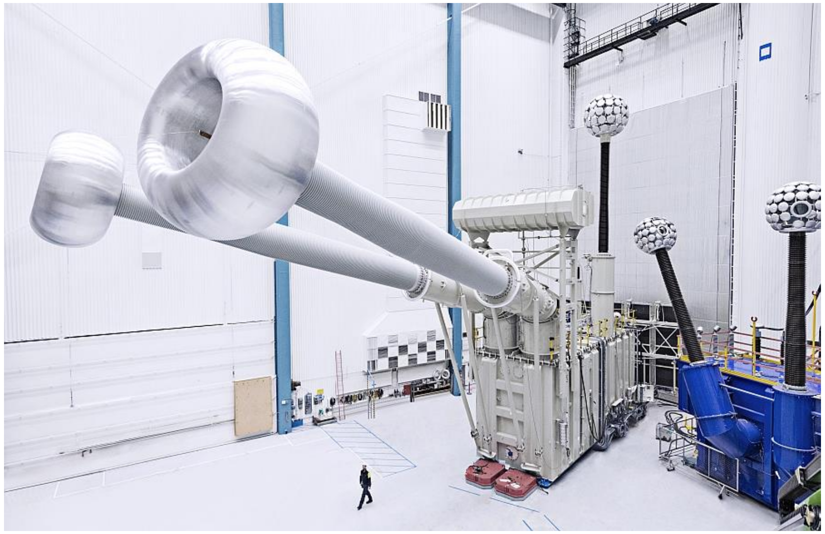
A novel Transient-Current-Technique based on 2-Photon Absorption in Diamond Why diamond?

~~*Because evaporating gold onto silicon is not expensive enough ;)*~~

In Particle Physics:

- highly radiation hard particle detectors
  charge loss due to irradiation is a factor of 7-10 smaller than in silicon
- fast response
- operation at room temperature is no problem
- high resistivity → low detector noise





Outside of Particle Physics:

- One of the LEADING CONTENDERS for future high power semiconductors
  → massive size reductions possible

Now we ideally know what

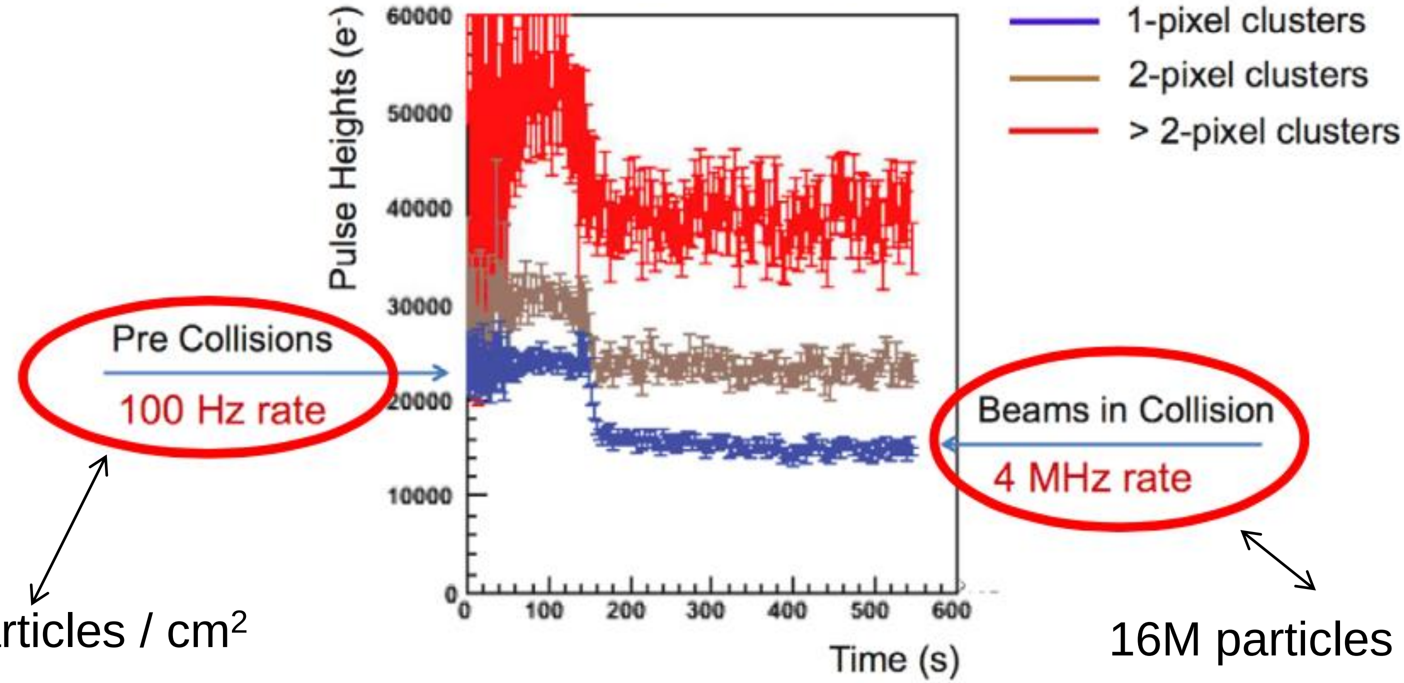
A novel Transient-Current-Technique based on
2-Photon Absorption in Diamond

is about.

The motivation for my thesis

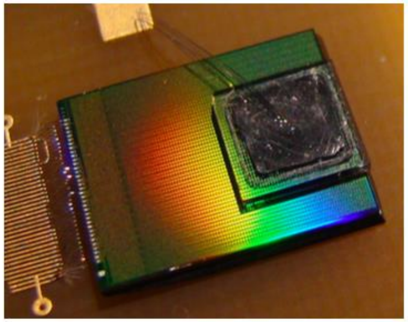
Single-crystalline CVD diamond has shown some unexpected behavior in the past:

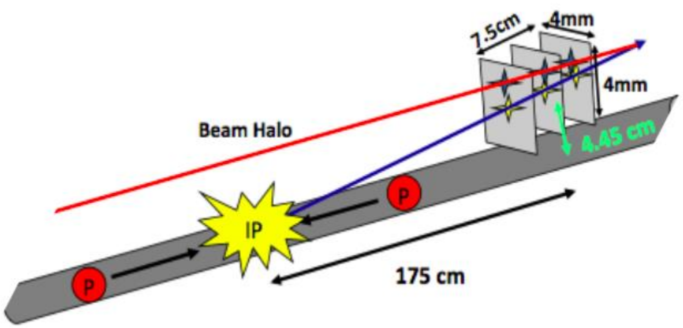
Average Signal from Detector



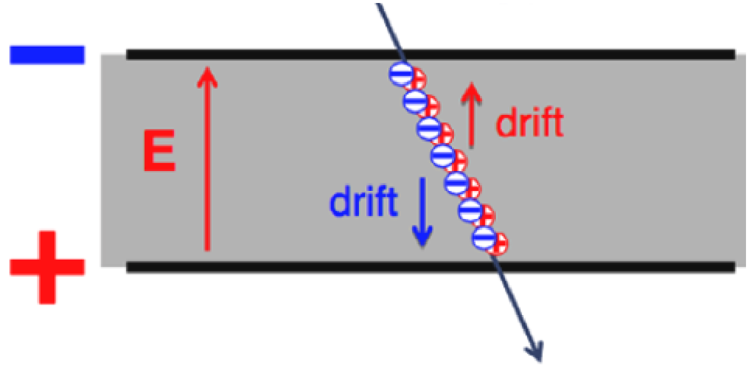
400 particles / cm^2

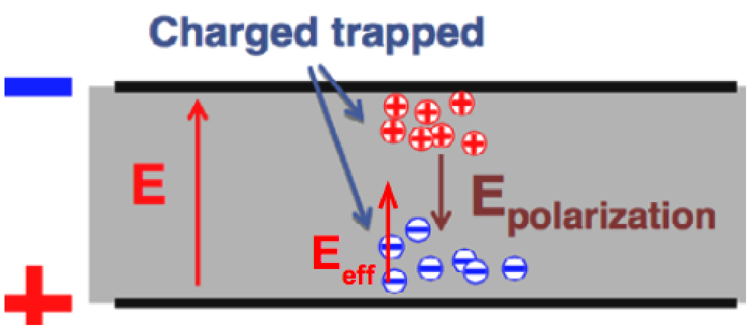
16M particles / cm^2





Many theories ..





Current working theory:

+) charge carriers get trapped →
+) electric field gets weakened →
+) worse charge carrier collection →
+) less signal

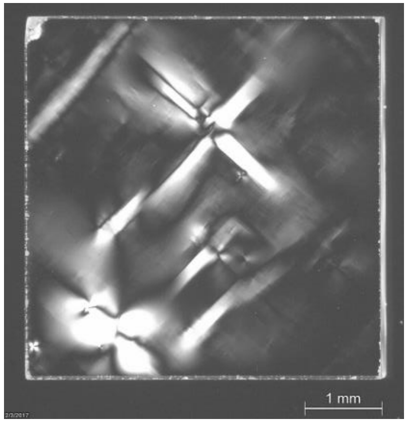
.. not proven experimentally yet.

In edge-TCT we can directly measure:

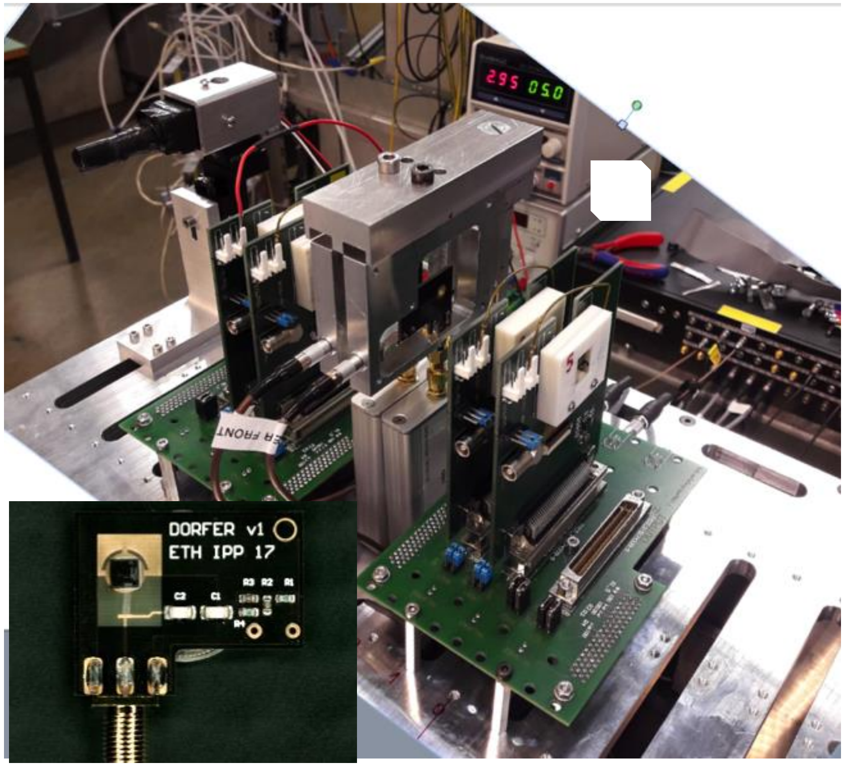
- electric field (independently of trapping) → thus trapped charge
- trapping times

Steps to solve the mystery

We have 15+ diamond samples which are characterized by different means

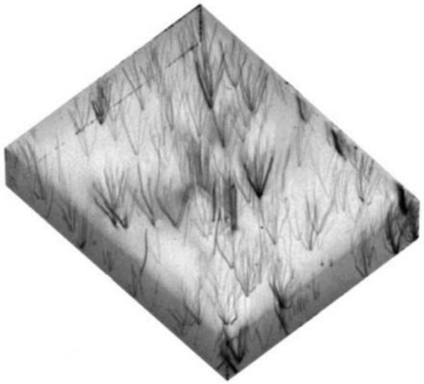


cross-polarization images



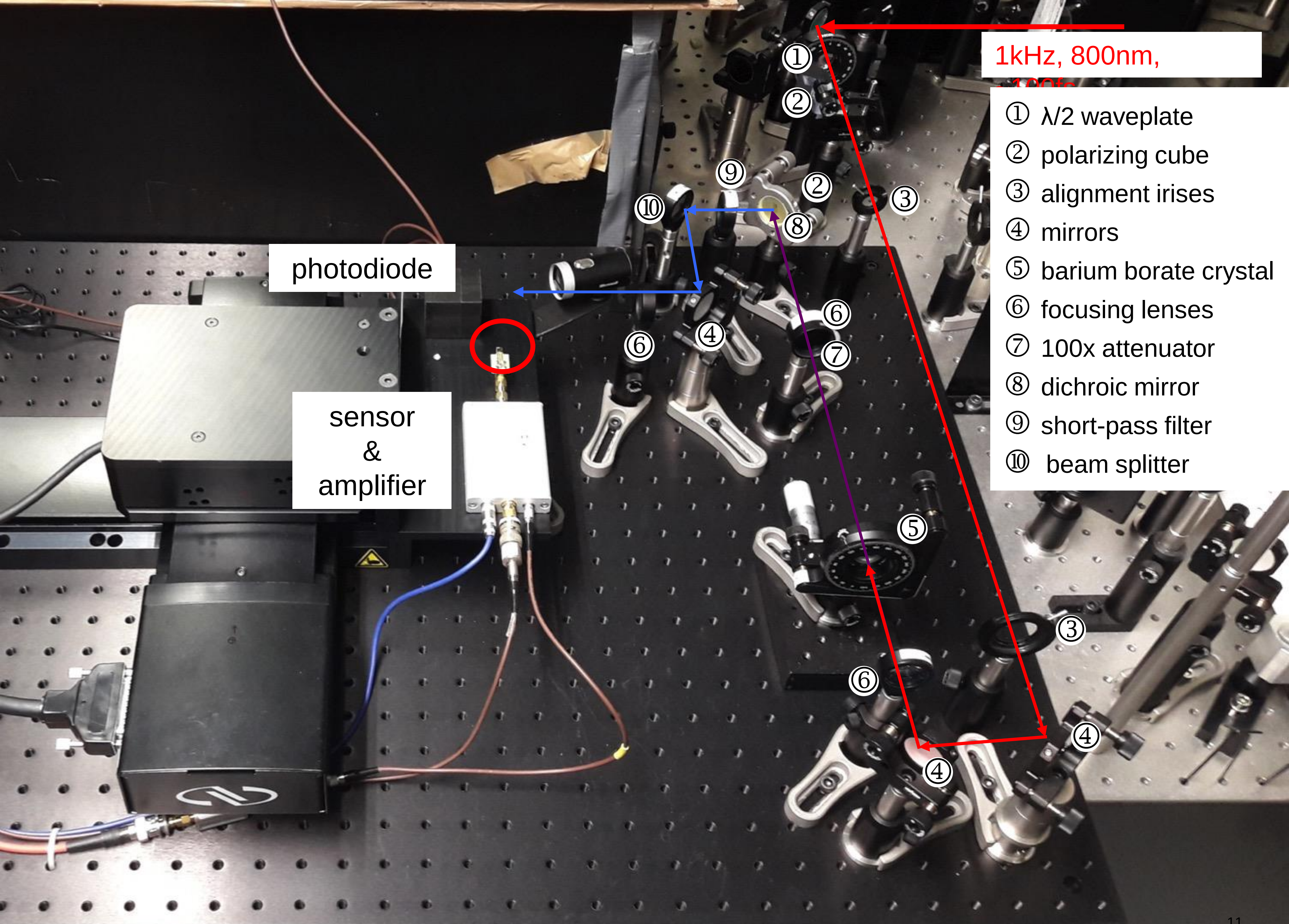
high rate beam tests at PSI
(3 kHz/cm^2 – 10 MHz/cm^2)

^{90}Sr measurements

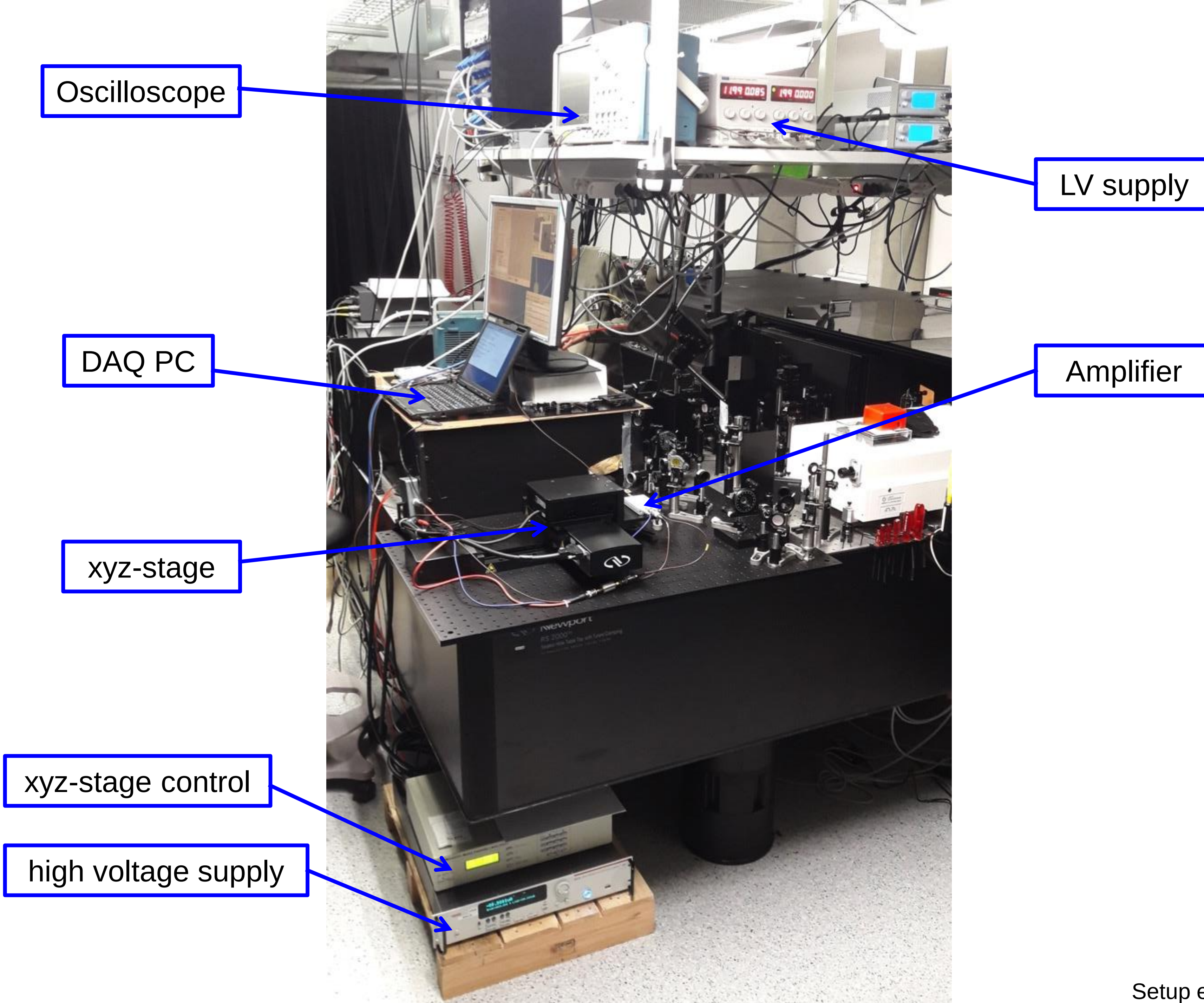


white-beam X-ray topography

to later be tested in edge-TCT

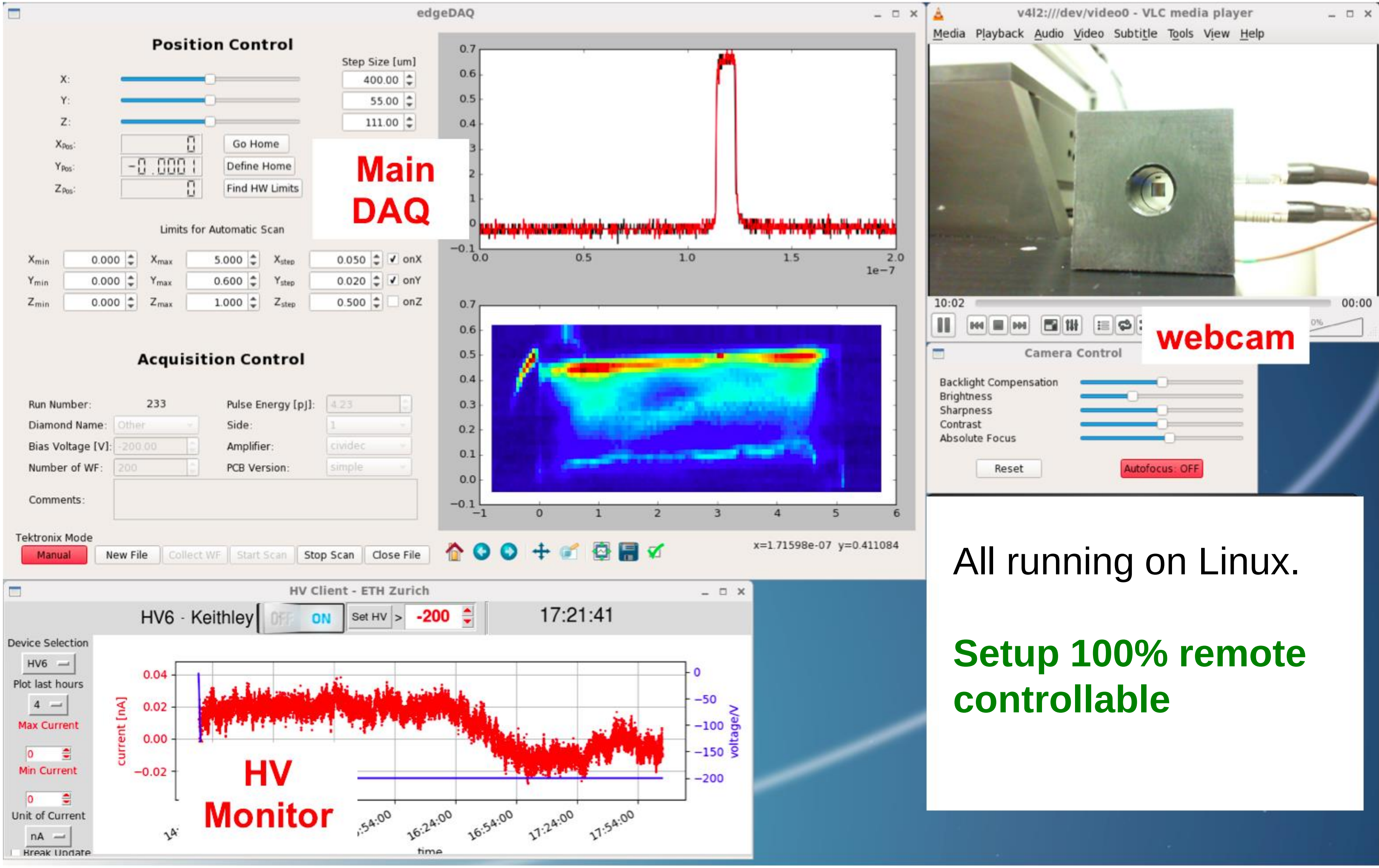


Setup end 2017



Setup end 2017

DAQ Software Screenshot

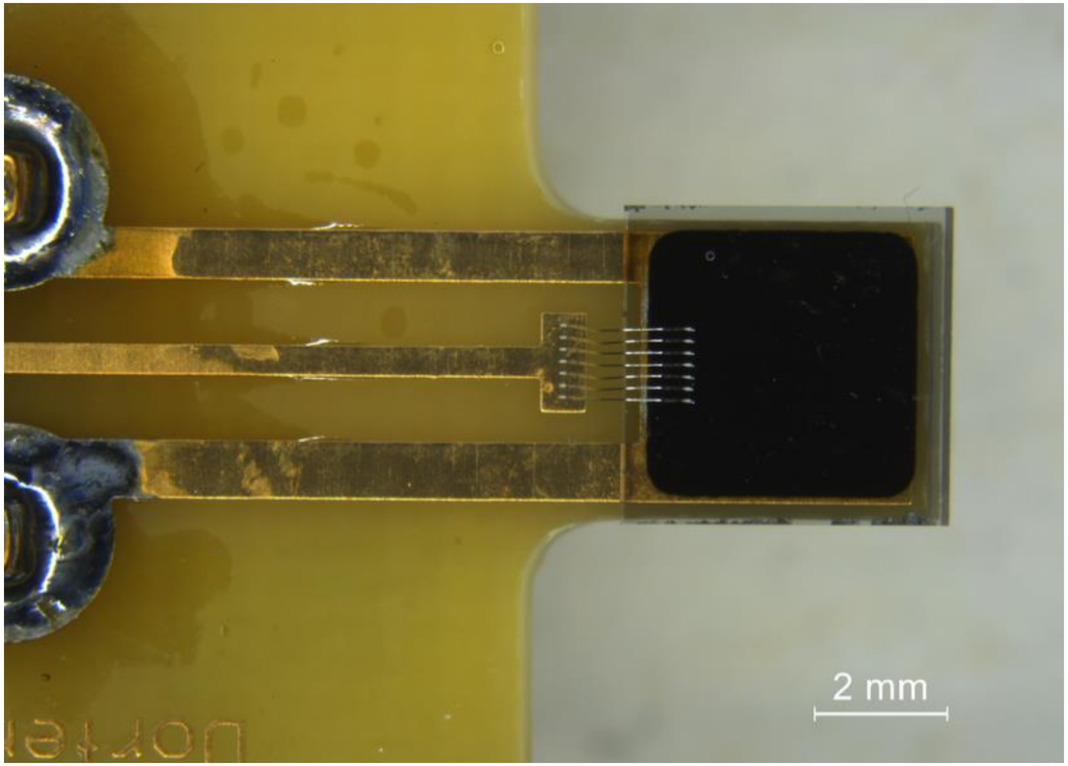


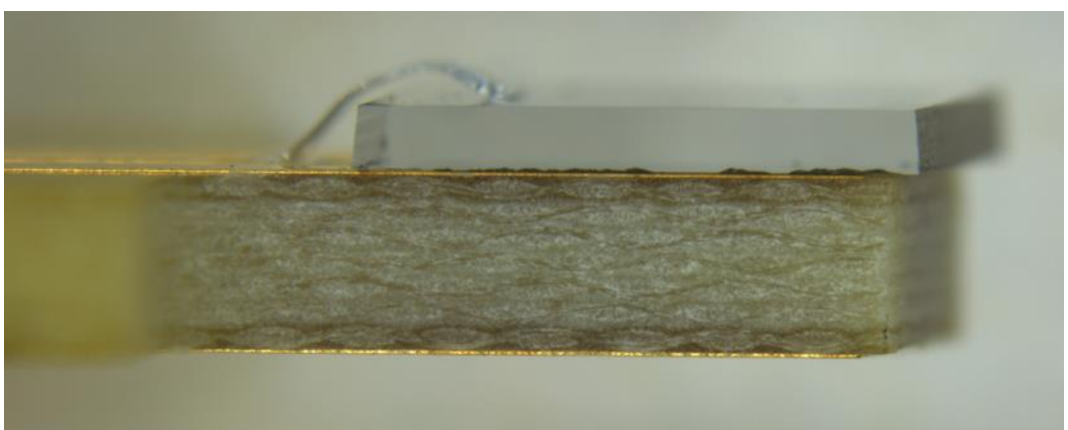
All running on Linux.

Setup 100% remote controllable

Selected sCVD Diamond Sample

The results shown in the following slides stem from data of this diamond

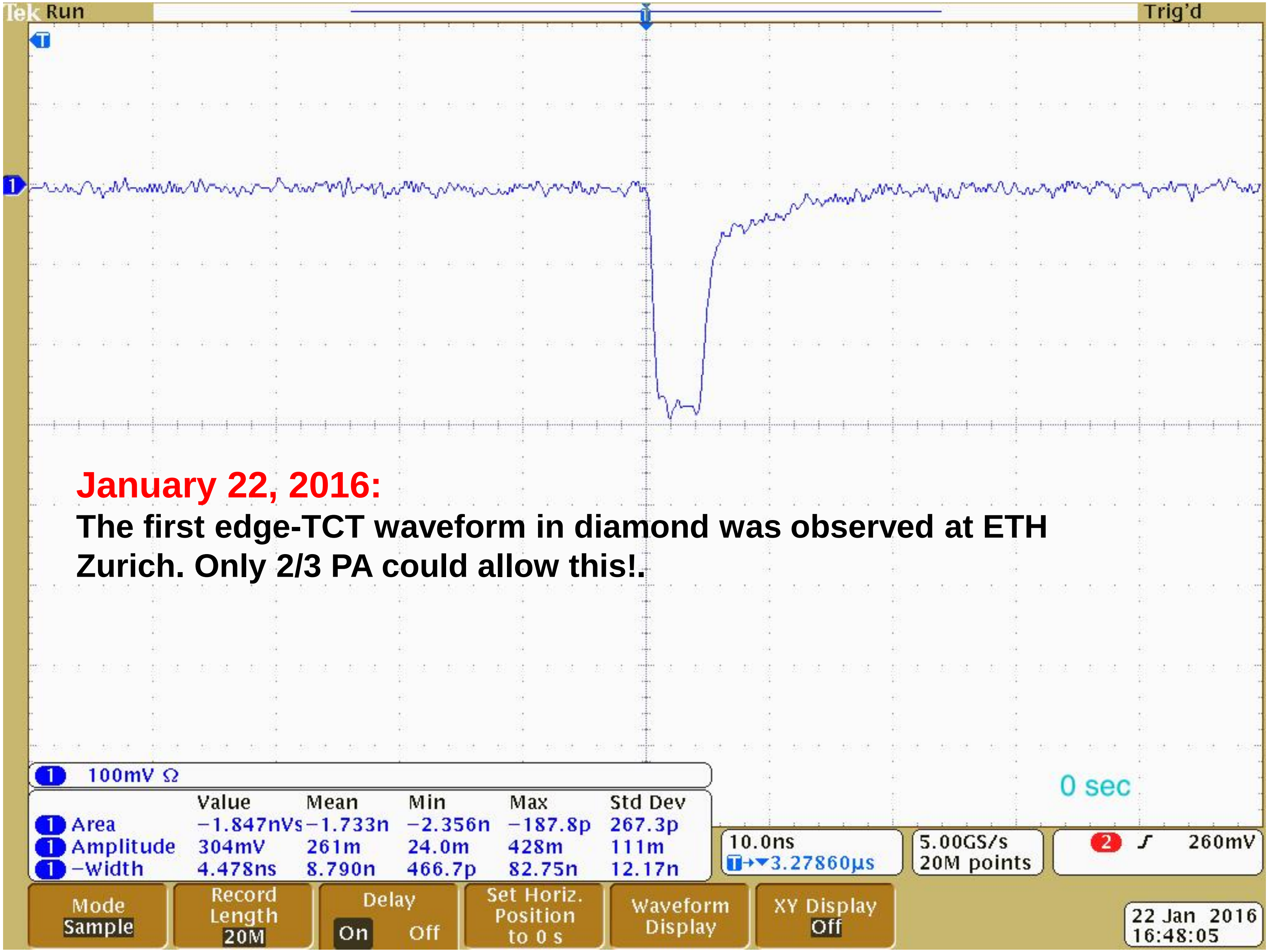




- bought from Element 6 (through DDL)
- Poor CCD performance
  - requires high field to collect full charge
- thickness – 545 um
- Not irradiated
- pad metallized by Rutgers University (TiW sputtered with shadow mask)
- metallization distance from edge ≈400 μm
- 2 edges polished

First Signal!

Confirmation of multi-photon absorption in sCVD diamond

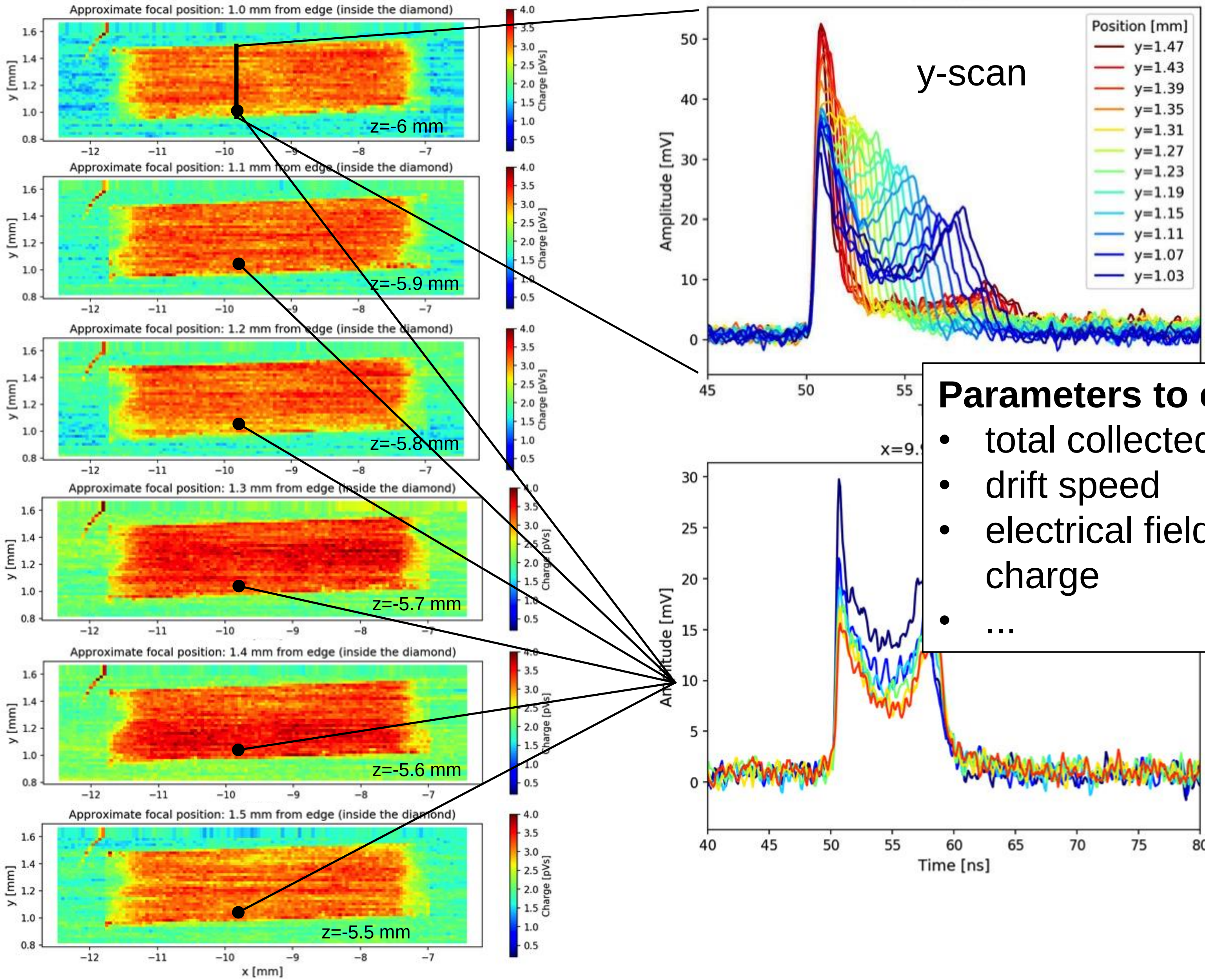


January 22, 2016:

The first edge-TCT waveform in diamond was observed at ETH Zurich. Only 2/3 PA could allow this!.

First 3D Scan

Bias voltage -400V (0.7V/um), 50 waveform averaging, 3993 scan points, 0.2 nJ pulse energy



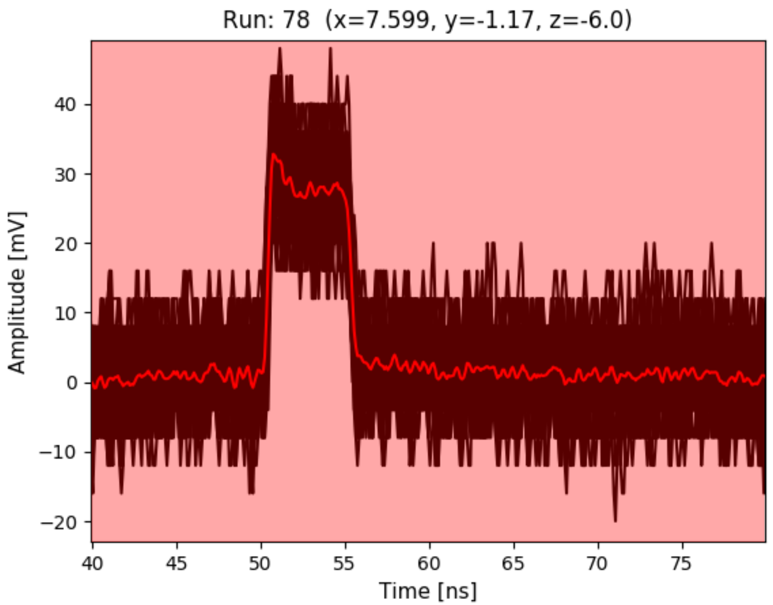
Parameters to extract:

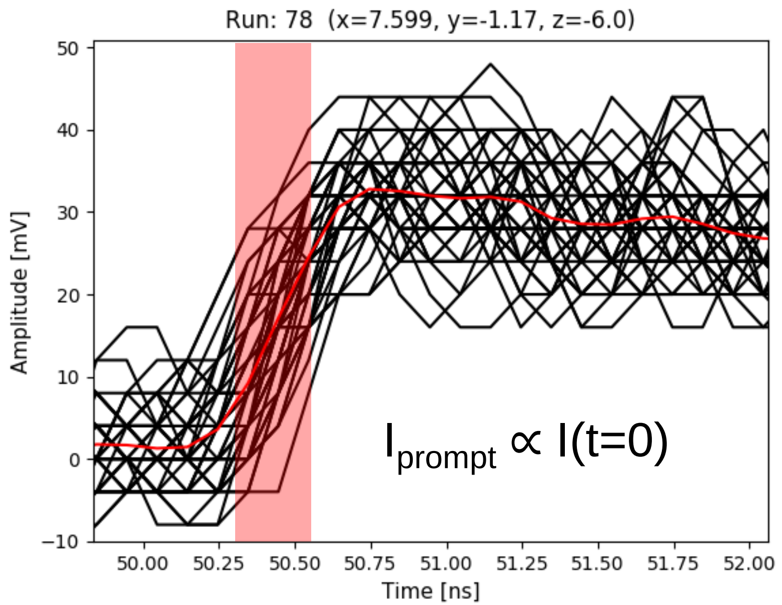
- total collected charge
- drift speed
- electrical field → space charge
- …

Waveform Analysis

Selected examples: *total charge* and *prompt current*

All waveforms are baseline corrected and averaged before further analysis.





Total Charge

Integral of the complete baseline corrected waveform [0-200 ns]

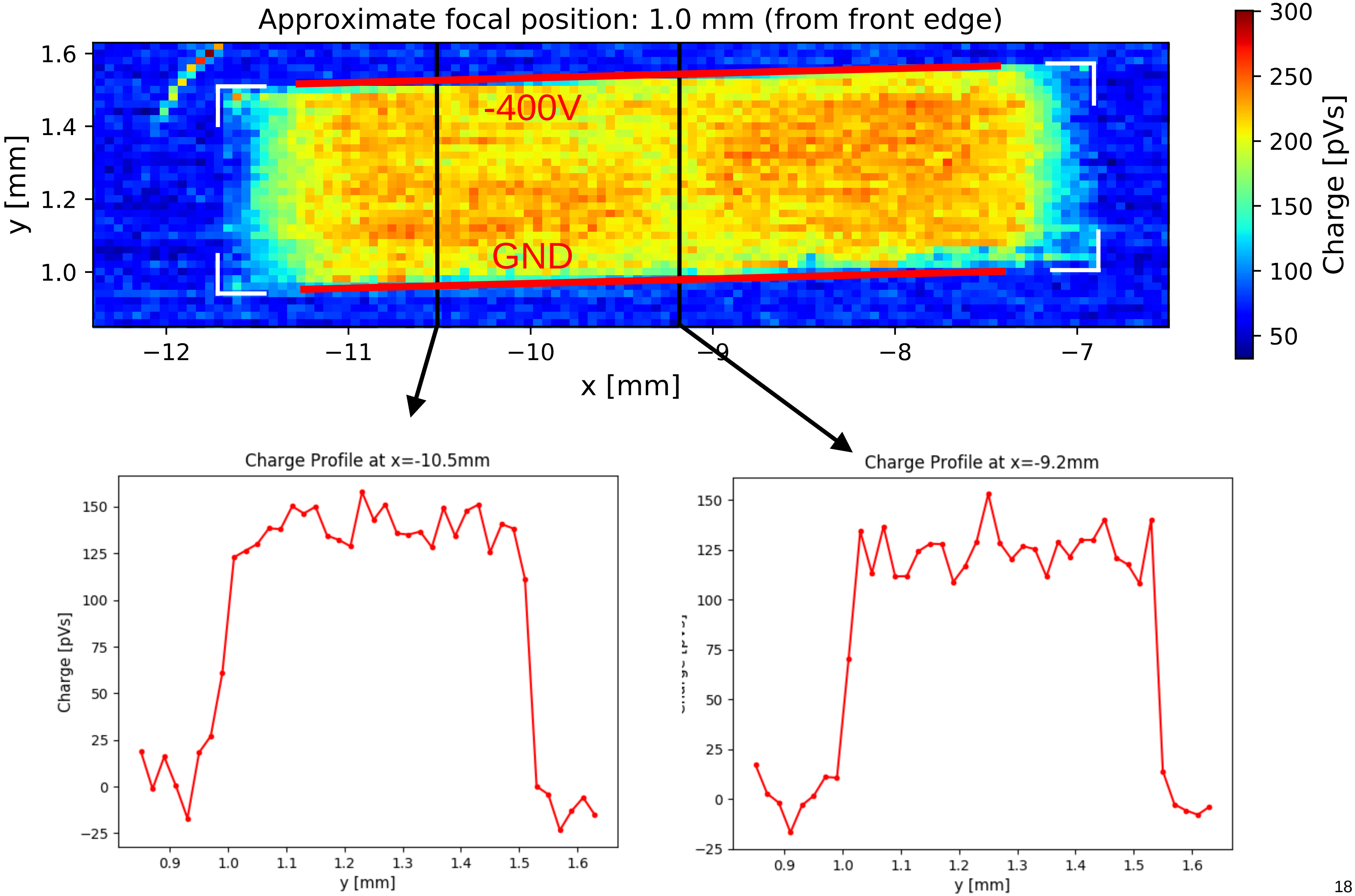
Prompt Current

0.3 ns-Integral around the center of the rising edge.

→ The **electric field** can be calculated from the result of the prompt current extraction!

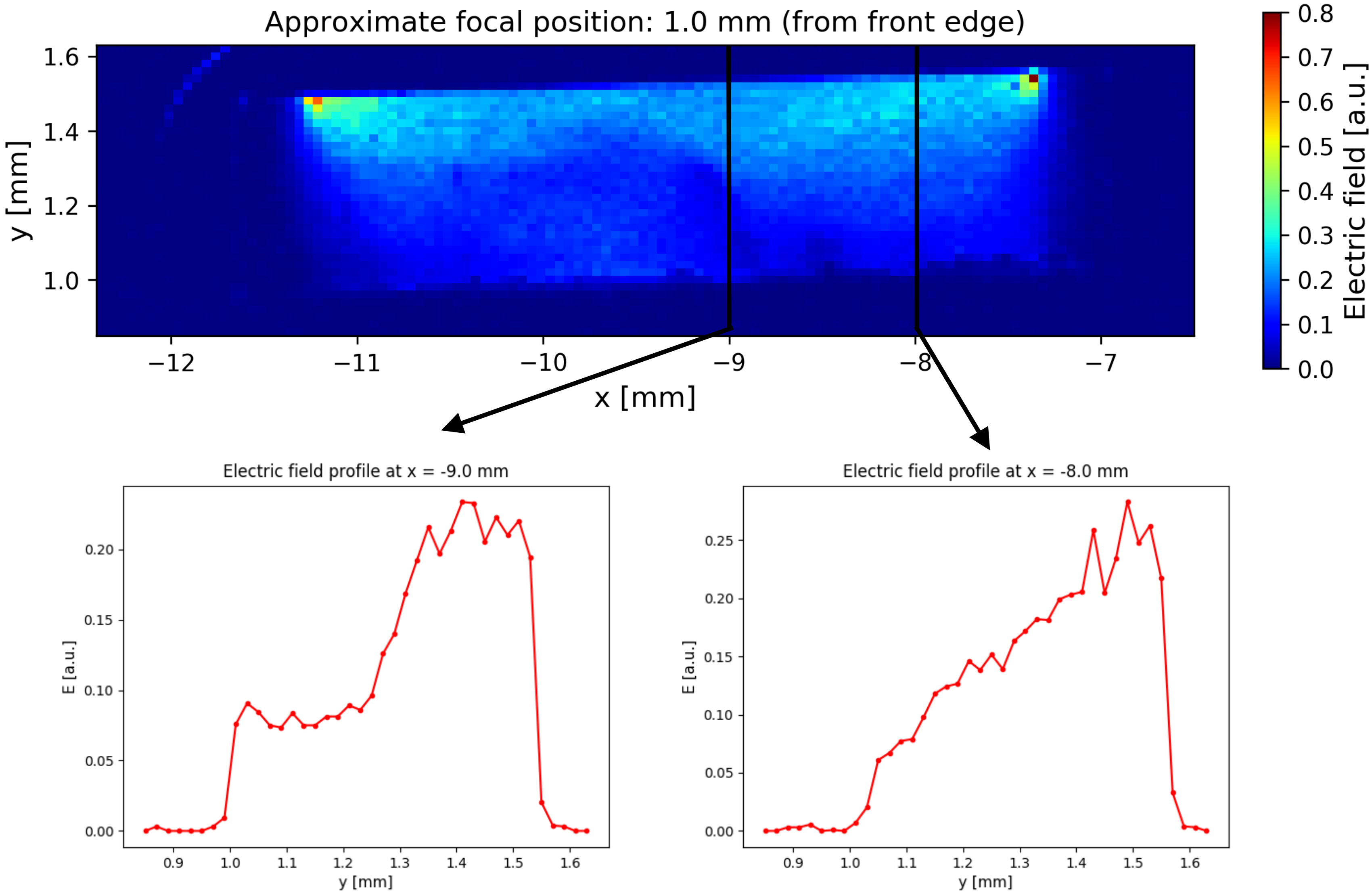
Total Charge

Example of a 2D map and charge profiles



Electric Field

Example of a 2D map and electric field profiles



What is coming?

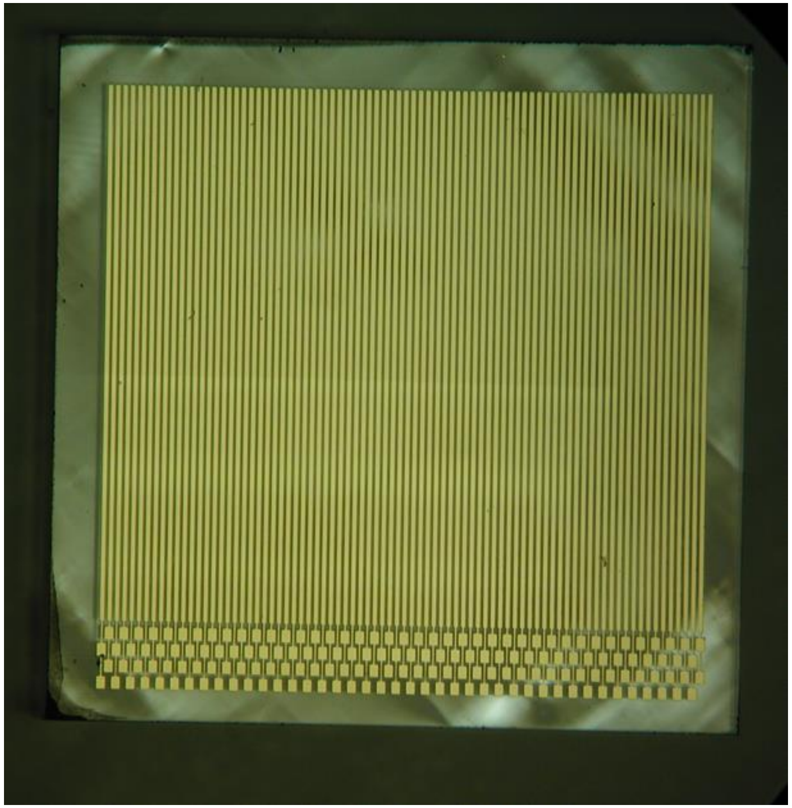
1) The method works → write a paper
   Applied Physics Letter (next month?)

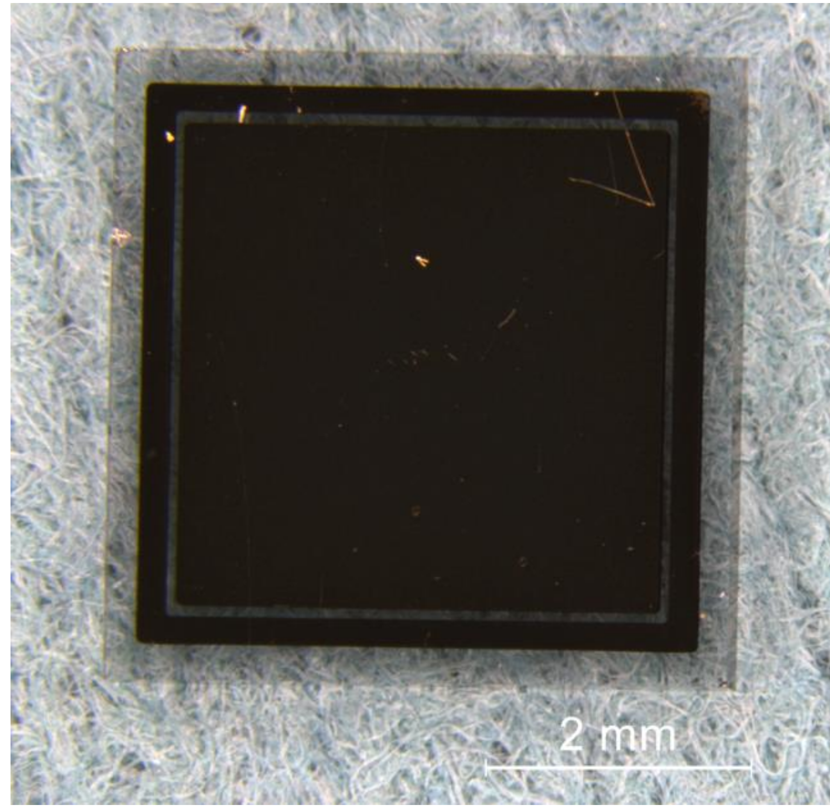
2) Systematic study of >10 diamond samples to find the origin of the polarization effect

Questions?

Other Work Packages

In-House Sensor Making





Procedure for making strip- and pad-detectors developed at ETH’s FIRST cleanroom

Order of Photon Absorption

Purely quadratic dependence between beam power and signal → **2 PA**