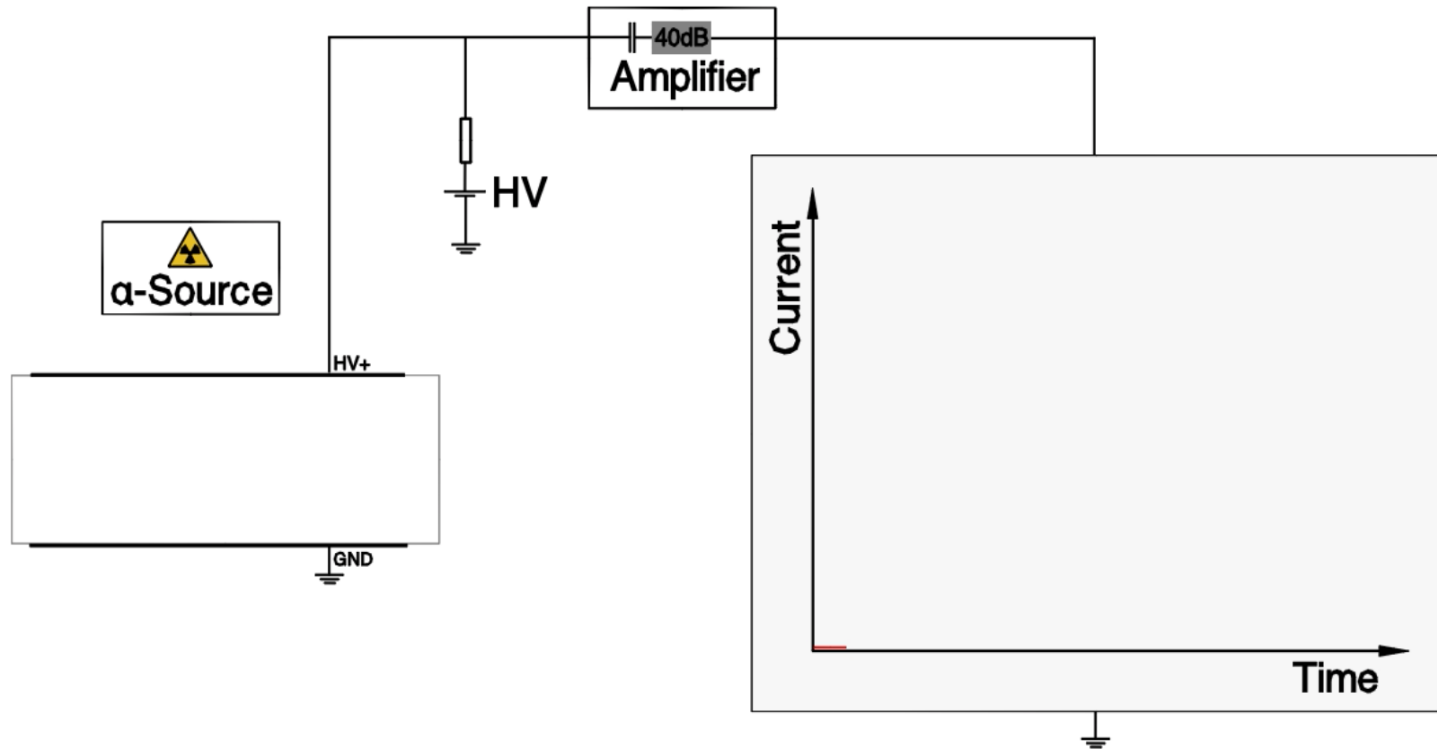


A novel Transient-Current-Technique based on 2-Photon Absorption in Diamond

Christian Dorfer, ETH Zurich
Zurich PhD Seminar, 8-9th March 2018

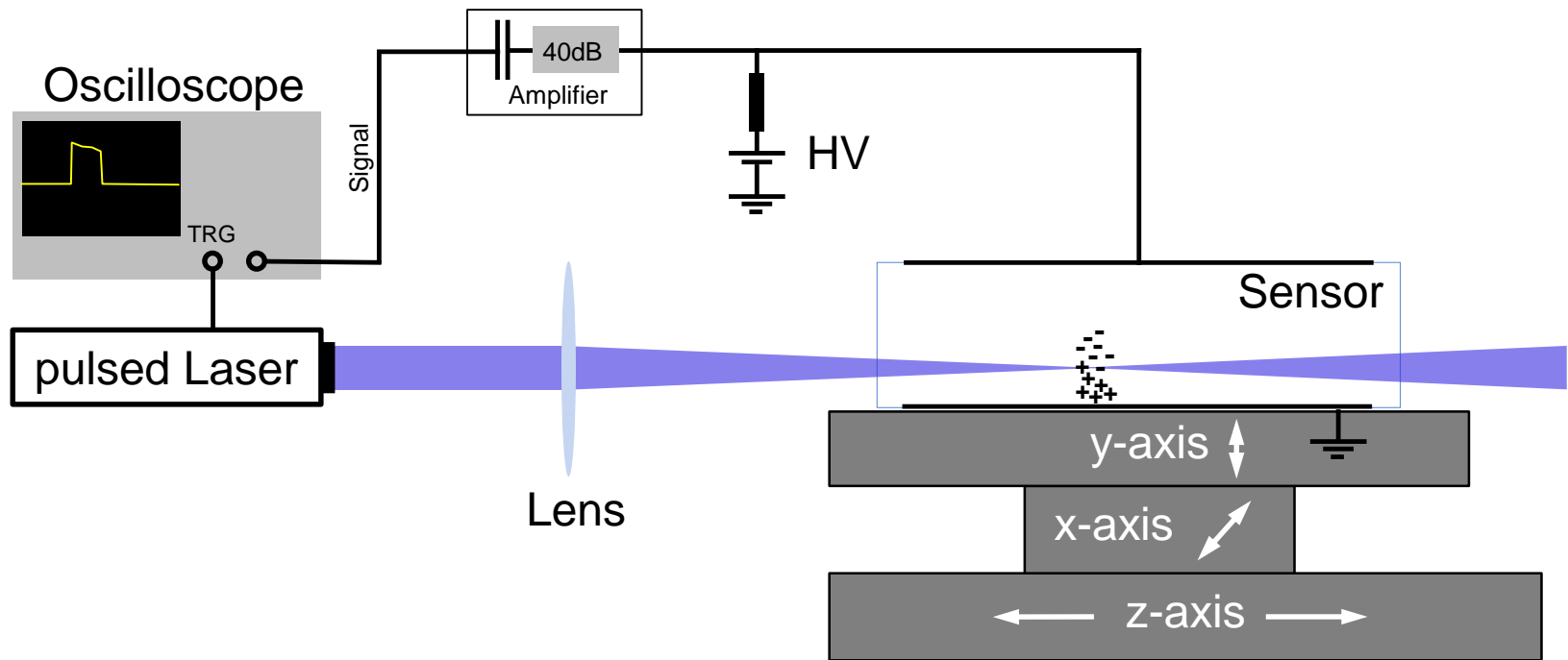
A novel **Transient-Current-Technique** based on 2-Photon Absorption in Diamond *What is that?*



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?

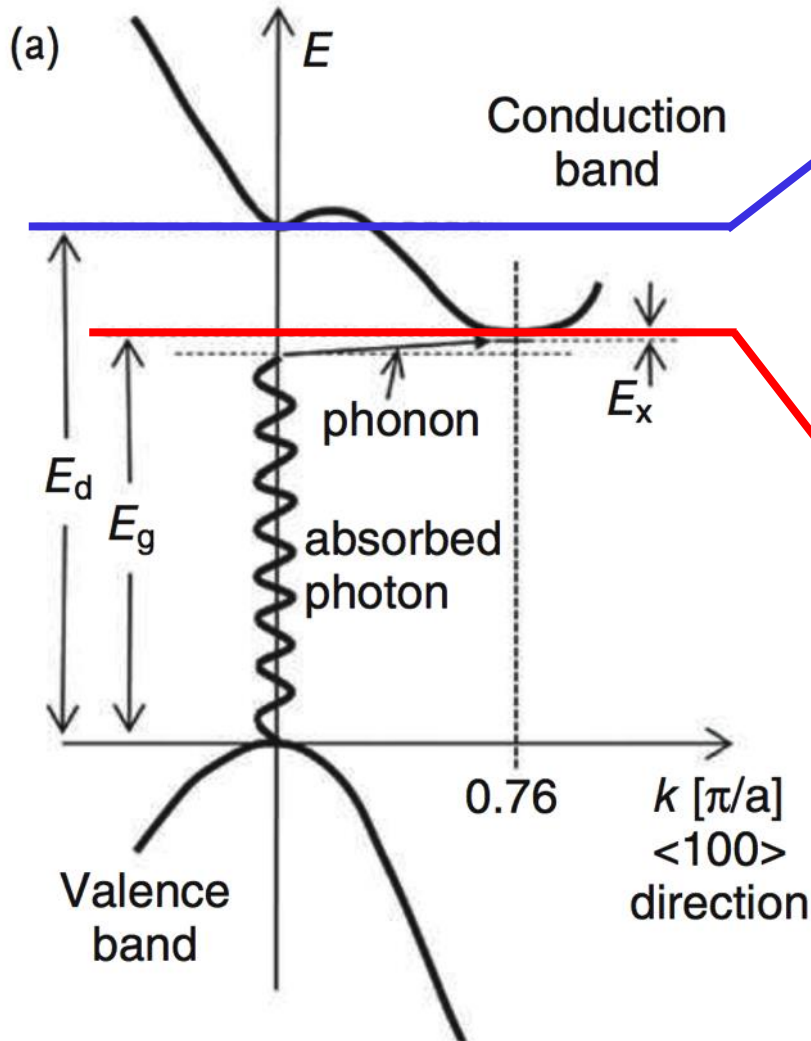


Instead of a source we use a laser beam. This allows to:

- ✓ 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: $E_V = 3.65$ eV / 340 nm

3-photon absorption: $E_V = 2.43$ eV / 510 nm

Indirect Bandgap

required energy \approx **5.47 eV** / **226 nm**

(minus phonon contribution and exciton energy)

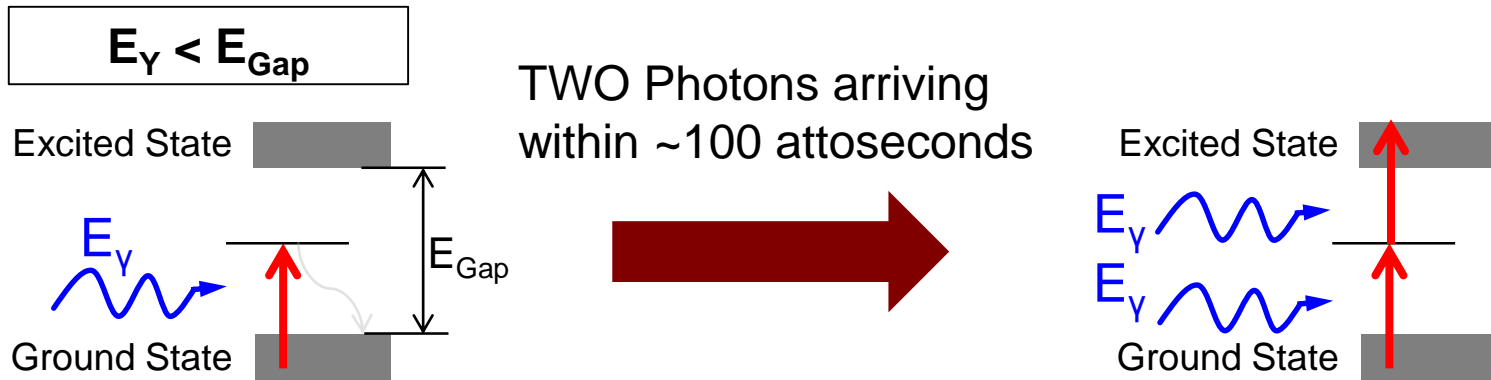
1-photon absorption

2-photon absorption: $E_V \approx 2.74$ eV / 453 nm

Attoline Laser

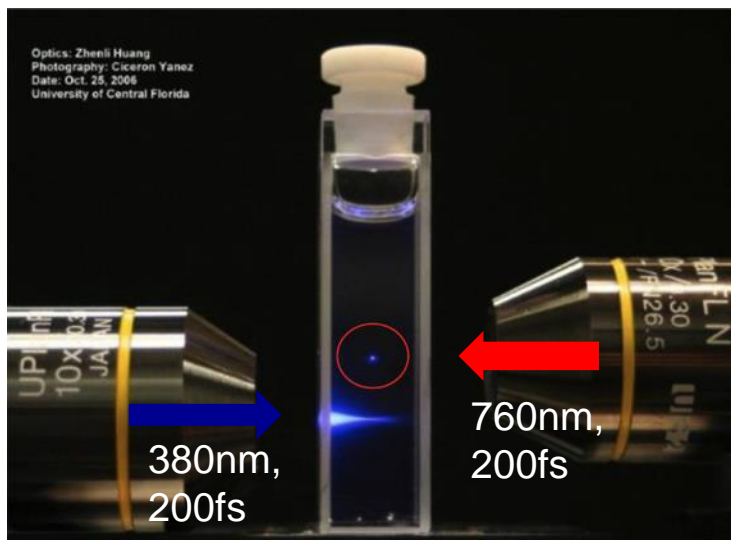
- photon energy **3.1 eV** (400 nm)
- ~ 25 fs
- 0.1-5 nJ pulse energy eq. to $2 \cdot 10^8 - 10^{10}$ photons/pulse
- 1 kHz repetition rate

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



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

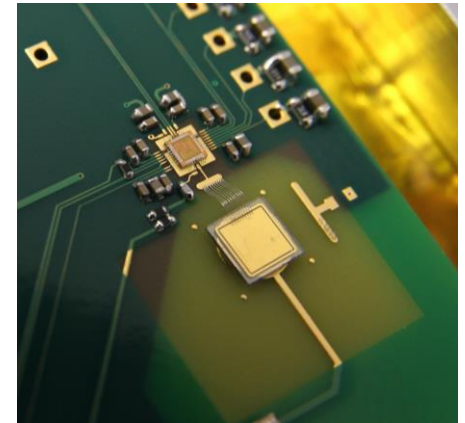


A novel Transient-Current-Technique based on 2-Photon Absorption in **Diamond** *Why diamond?*

~~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

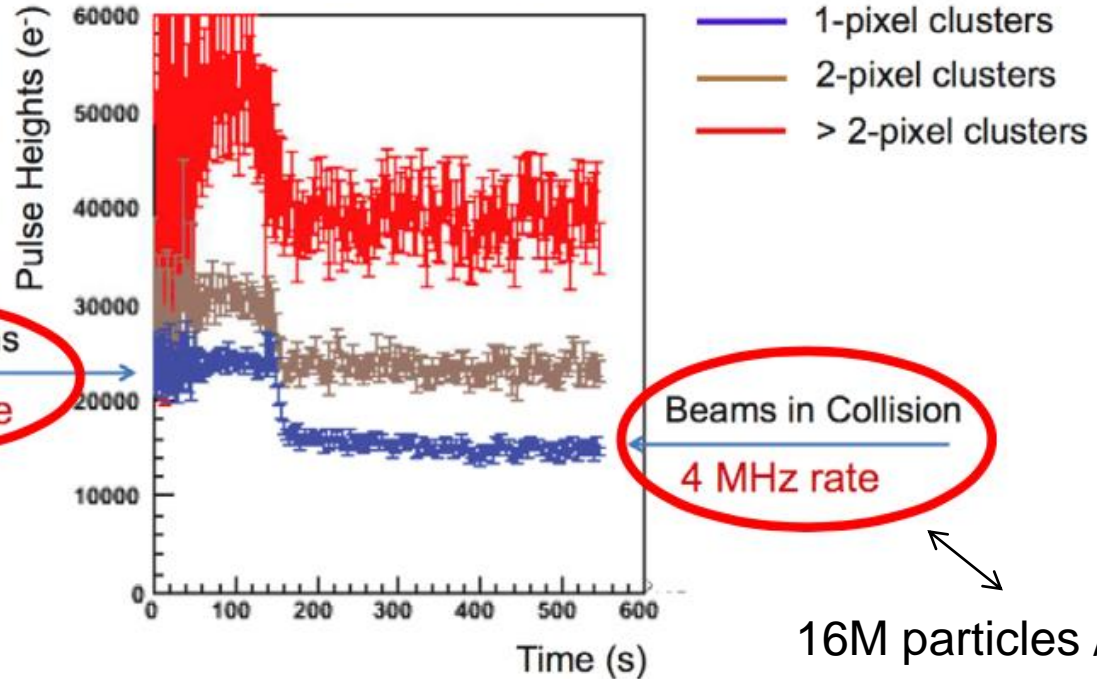
A novel Transient-Current-Technique based on
2-Photon Absorption in Diamond

is about.

The motivation for my thesis

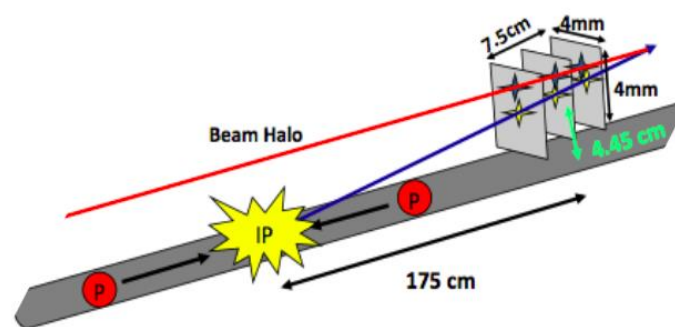
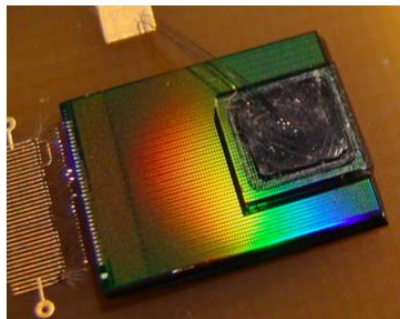
Single-crystalline CVD diamond has shown some unexpected behavior in the past:

Average Signal from Detector

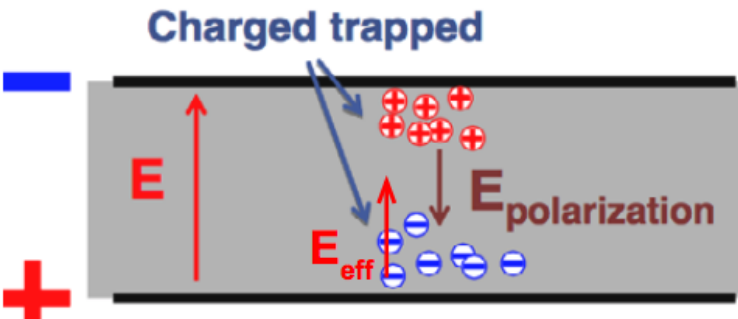
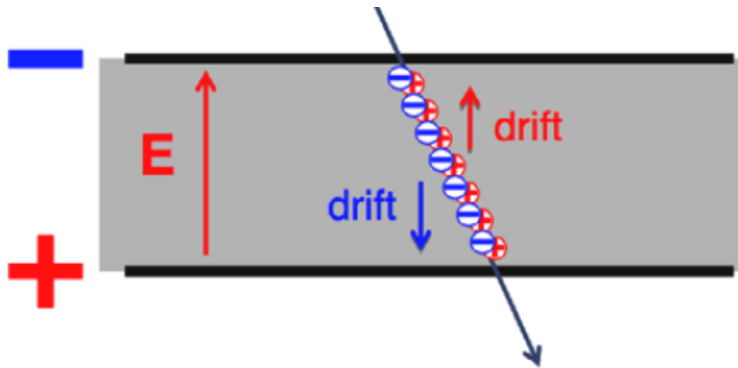


400 particles / cm^2

16M particles / cm^2



Many theories ..



Current working theory:

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

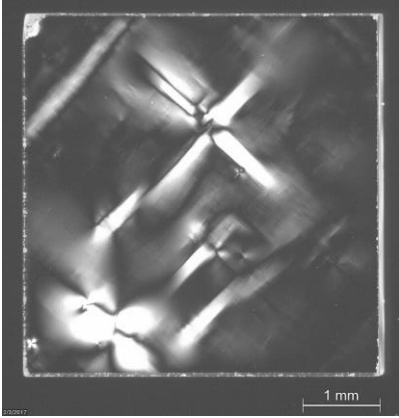
.. not proven experimentally yet.

In edge-TCT we can directly measure:

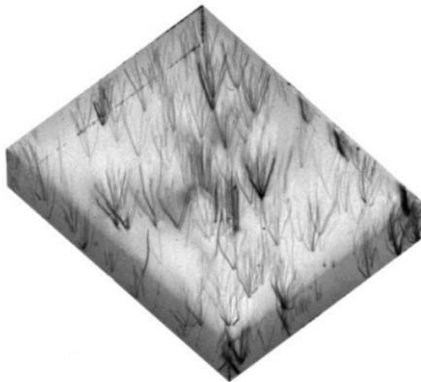
- electric field (independently of trapping) → thus trapped charge
- trapping times

Steps to solve the mystery

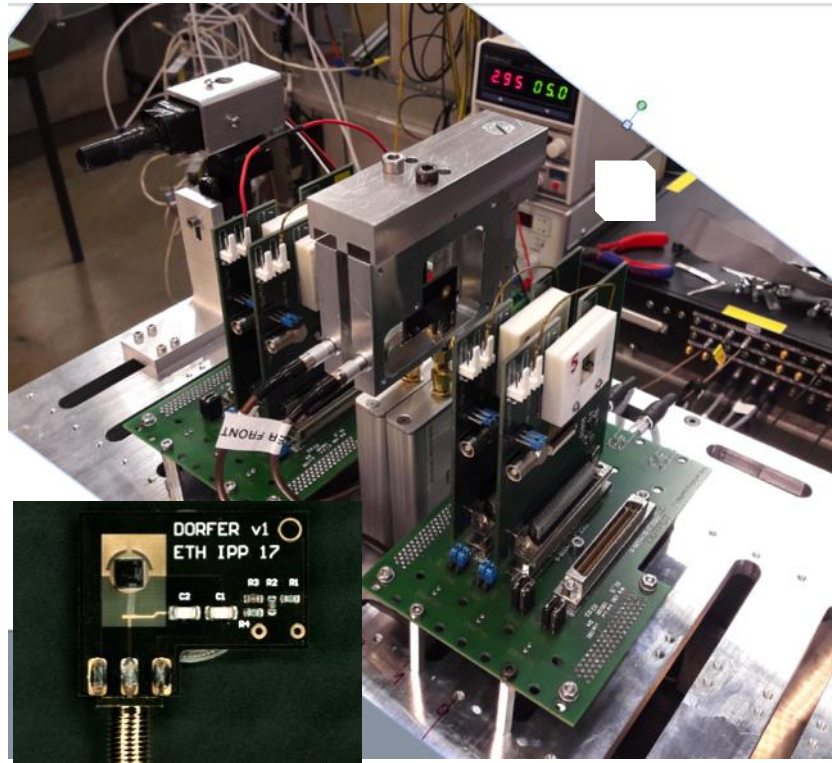
We have 15+ diamond samples which are characterized by different means



cross-polarization
images



white-beam X-ray
topography

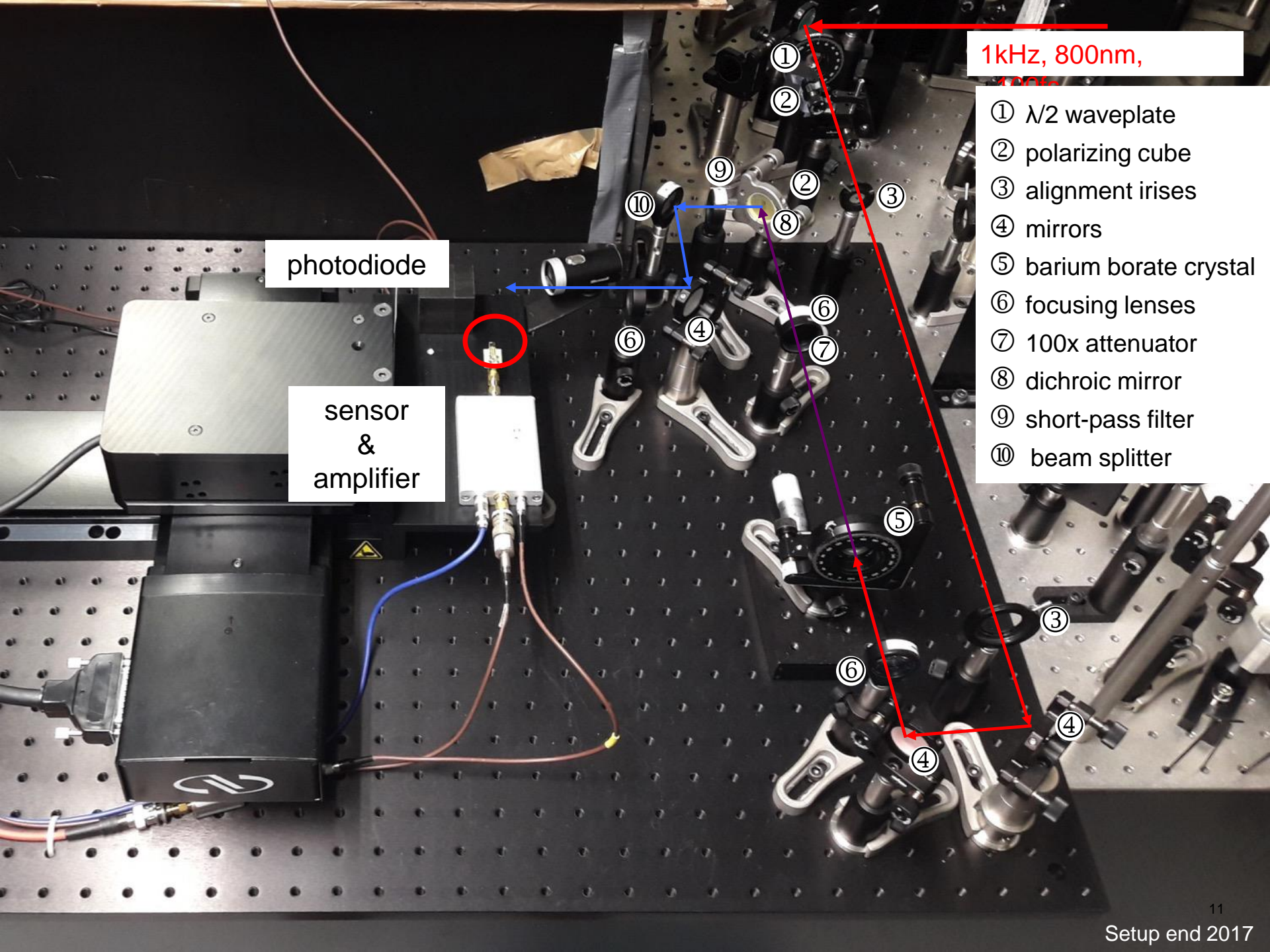


high rate beam tests at PSI
(3 kHz/cm² – 10 MHz/cm²)



⁹⁰Sr measurements

to later be tested in edge-TCT

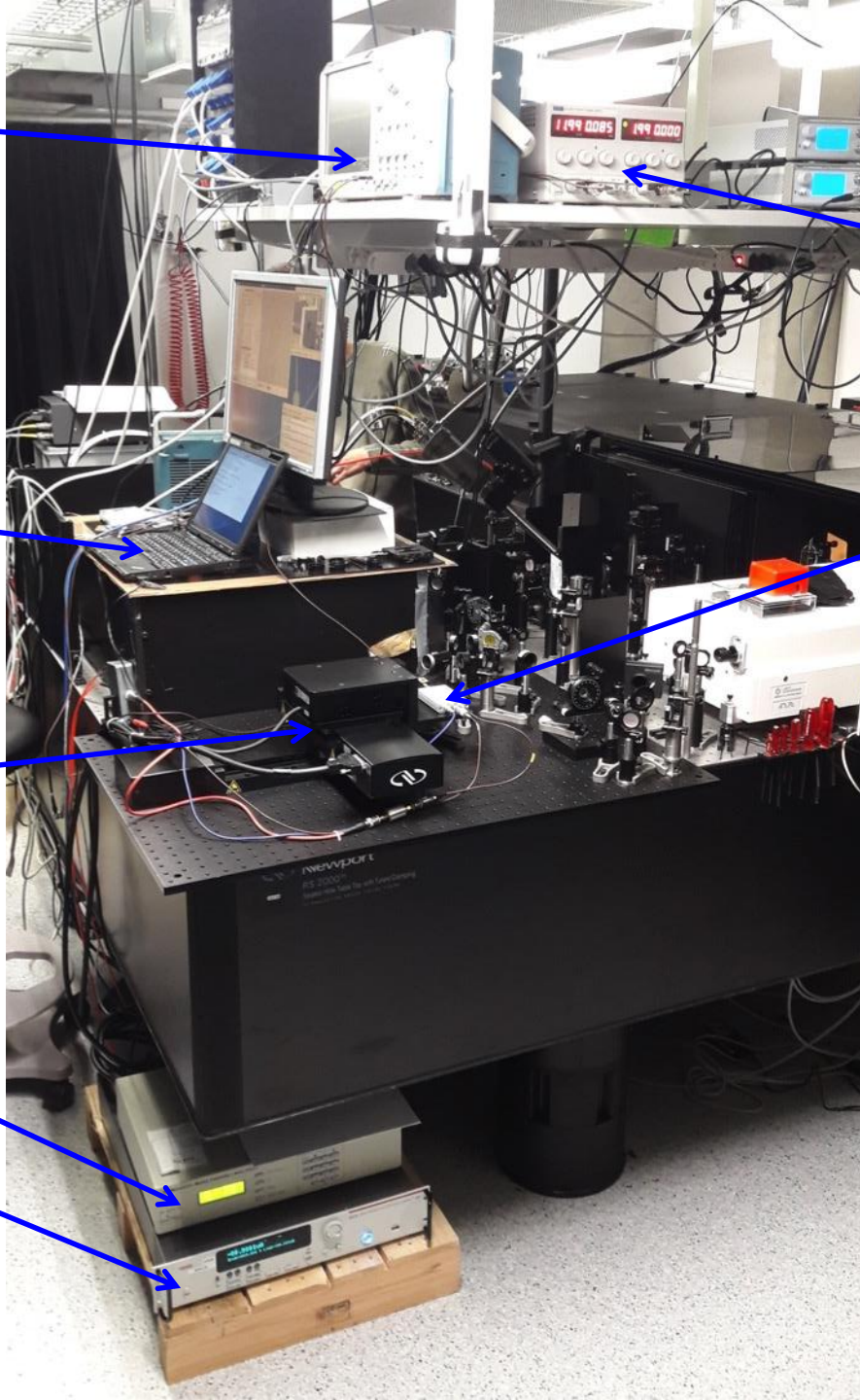


1kHz, 800nm,

photodiode

sensor & amplifier

- ① $\lambda/2$ waveplate
- ② polarizing cube
- ③ alignment irises
- ④ mirrors
- ⑤ barium borate crystal
- ⑥ focusing lenses
- ⑦ 100x attenuator
- ⑧ dichroic mirror
- ⑨ short-pass filter
- ⑩ beam splitter



Oscilloscope

LV supply

DAQ PC

Amplifier

xyz-stage

xyz-stage control

high voltage supply

DAQ Software Screenshot

The screenshot shows the edgeDAQ software interface. On the left, there are controls for Position Control (X, Y, Z sliders and fields) and Acquisition Control (Run Number, Pulse Energy, Bias Voltage, etc.). The main area contains two plots: a line graph showing a sharp peak at approximately 1.1×10^{-7} and a heatmap showing a horizontal band of high intensity. A red box with the text "Main DAQ" is overlaid on the top plot.

The screenshot shows a VLC media player window displaying a webcam feed of a diamond sample. The video title is "v4l2:///dev/video0 - VLC media player". Below the video, there is a "Camera Control" panel with sliders for Backlight Compensation, Brightness, Sharpness, Contrast, and Absolute Focus. A red box with the text "webcam" is overlaid on the video feed.

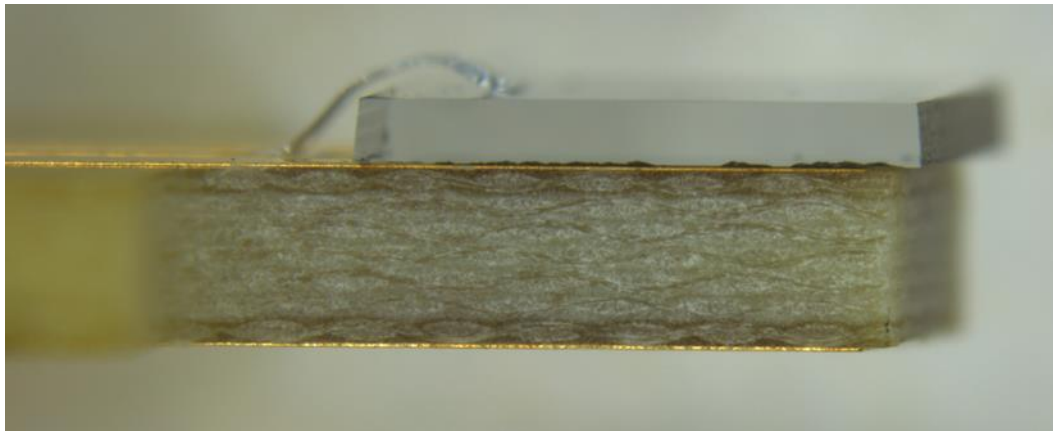
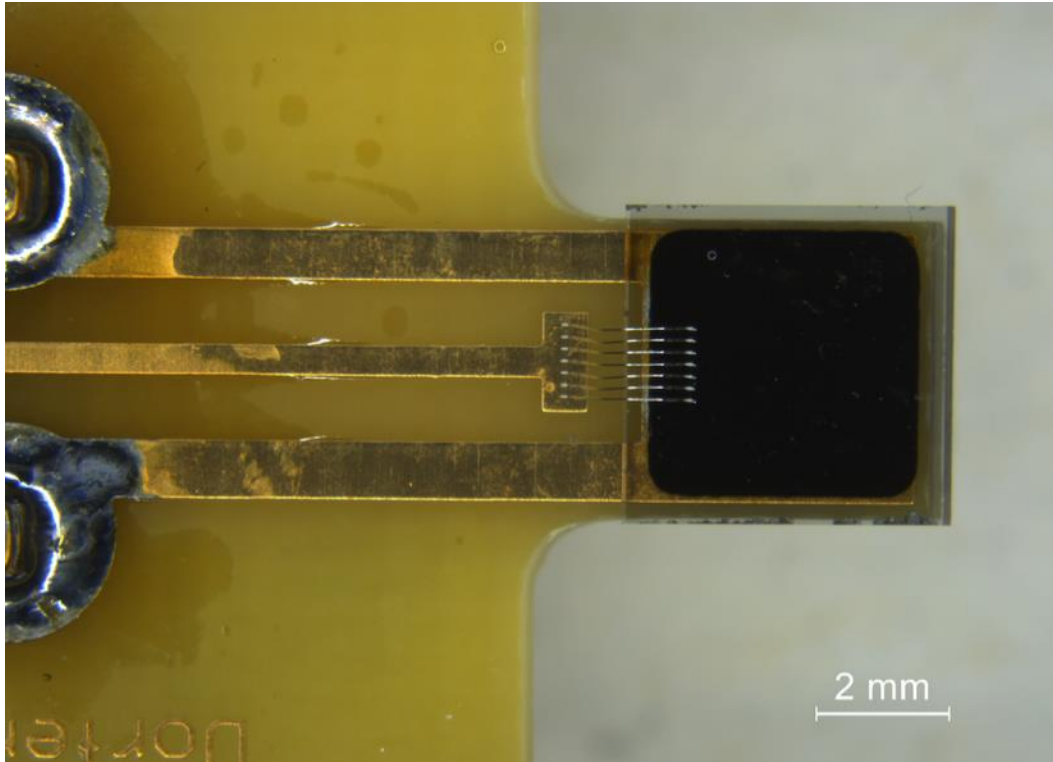
The screenshot shows the HV Client - ETH Zurich software interface. It displays a graph of current [nA] and voltage [V] over time. The current is shown in red and the voltage in blue. The current fluctuates around 0.02 nA, while the voltage is constant at -200 V. A red box with the text "HV Monitor" is overlaid on the graph.

All running on Linux.

Setup 100% remote controllable

Selected sCVD Diamond Sample

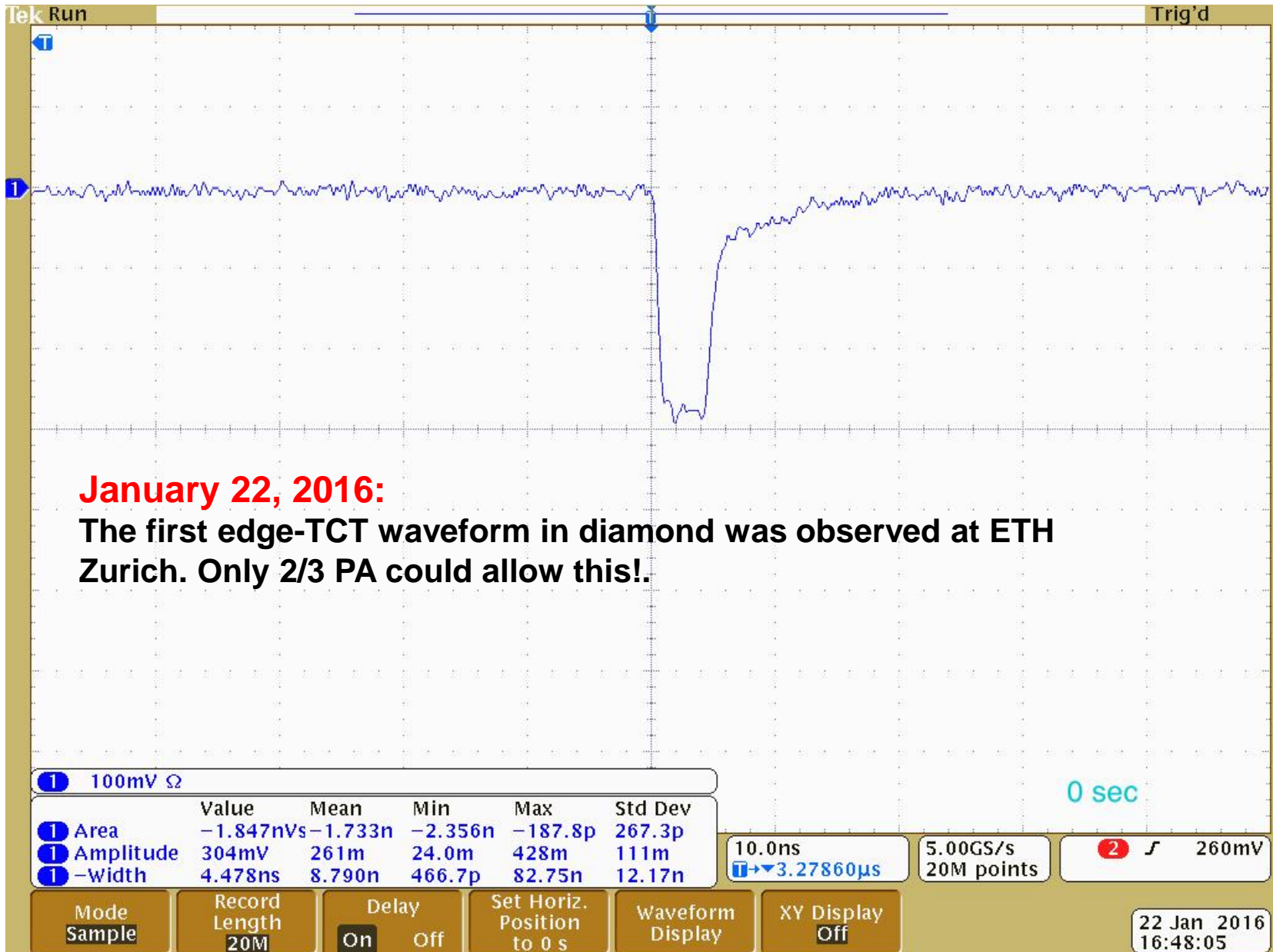
The results shown in the following slides stem from data of this diamond



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

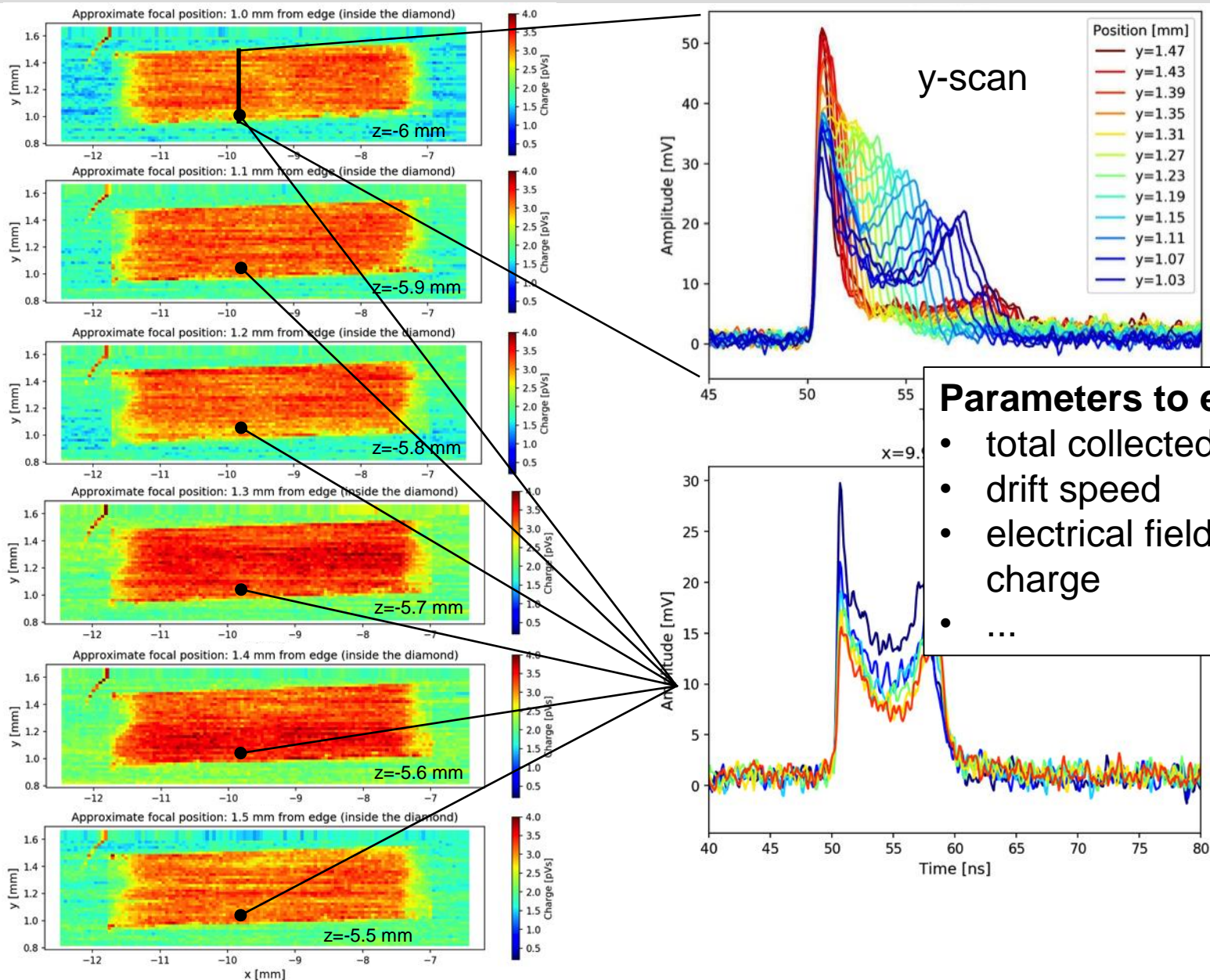
First Signal!

Confirmation of multi-photon absorption in sCVD diamond



First 3D Scan

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



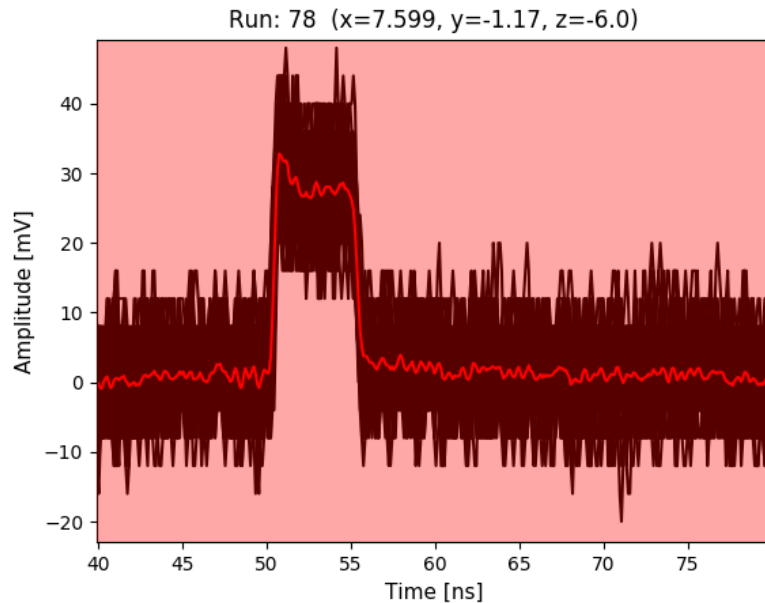
Parameters to extract:

- total collected charge
- drift speed
- electrical field \rightarrow space charge
- ...

Waveform Analysis

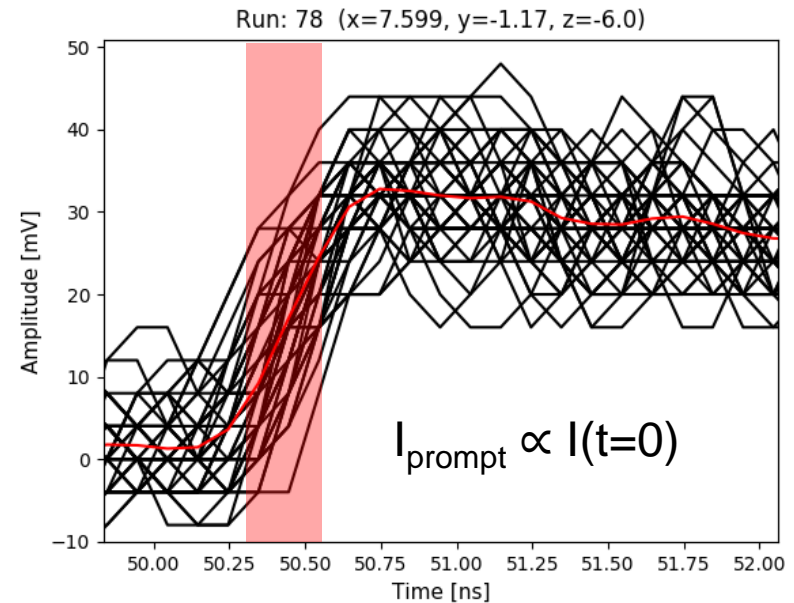
Selected examples: *total charge* and *prompt current*

All waveforms are baseline corrected and averaged before further analysis.



Total Charge

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



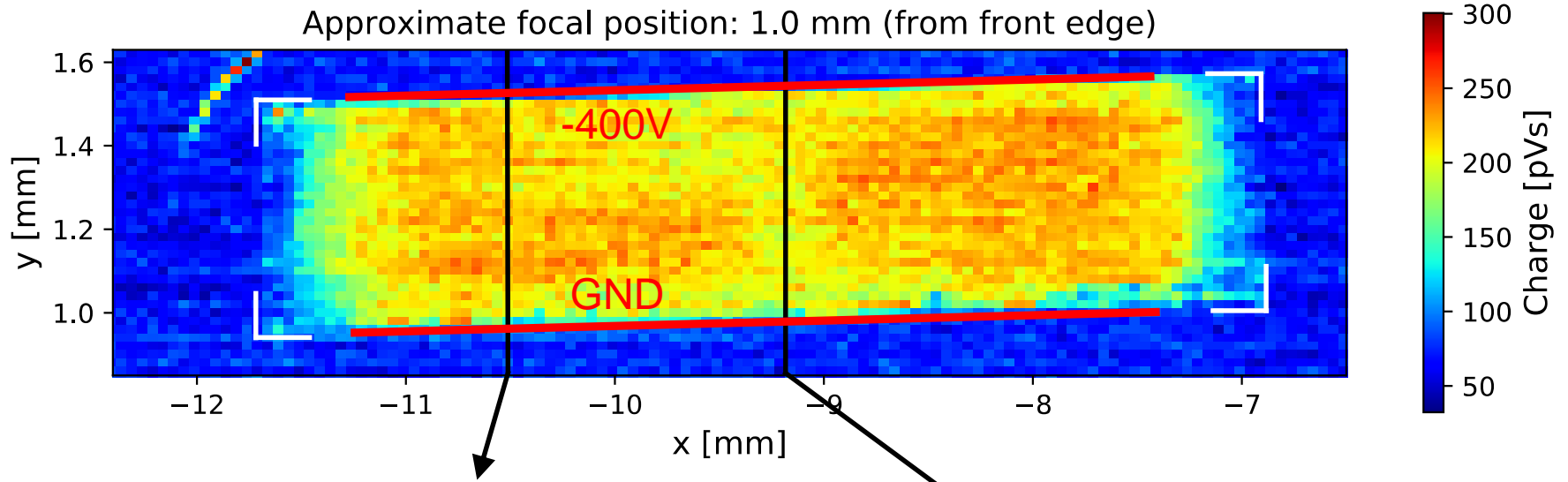
Prompt Current

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

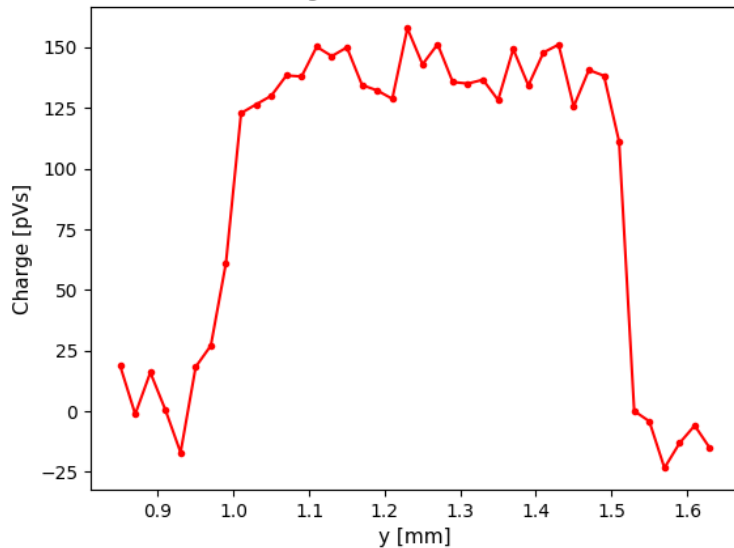
→ The **electric field** can be
calculated from the result of the
prompt current extraction!

Total Charge

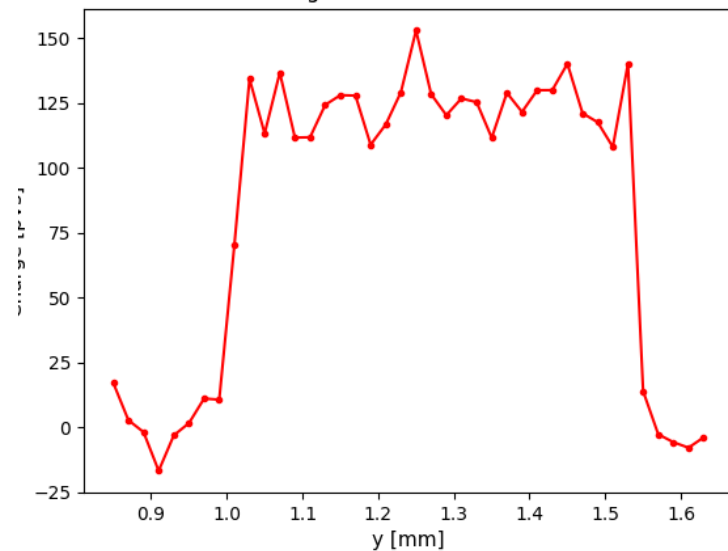
Example of a 2D map and charge profiles



Charge Profile at x=-10.5mm

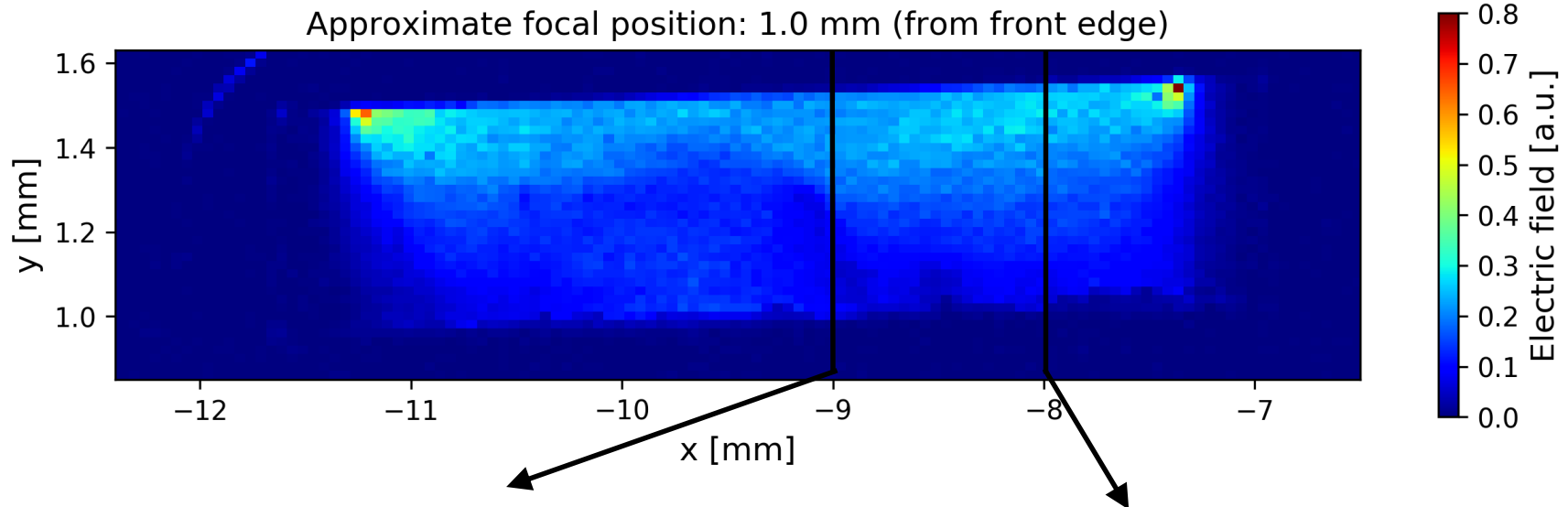


Charge Profile at x=-9.2mm

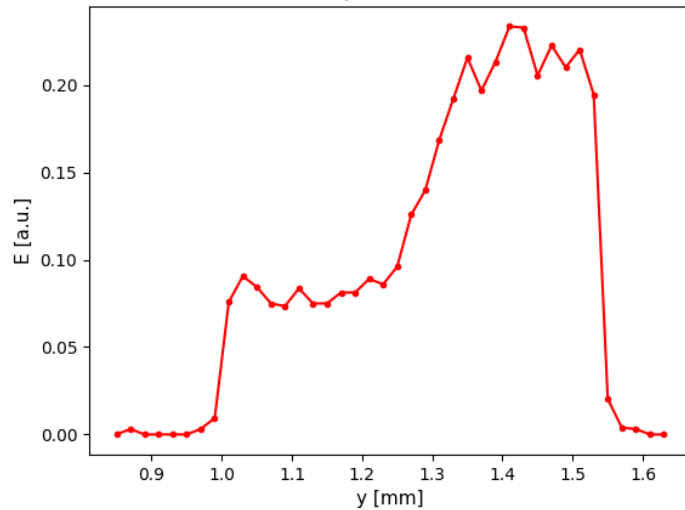


Electric Field

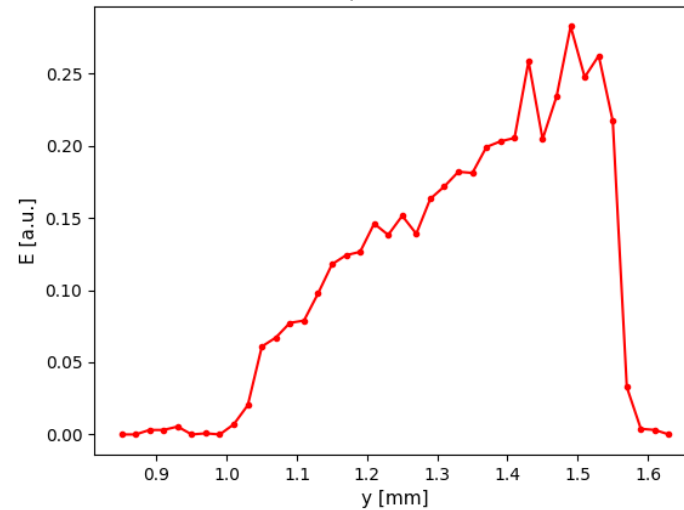
Example of a 2D map and electric field profiles



Electric field profile at x = -9.0 mm



Electric field profile at x = -8.0 mm



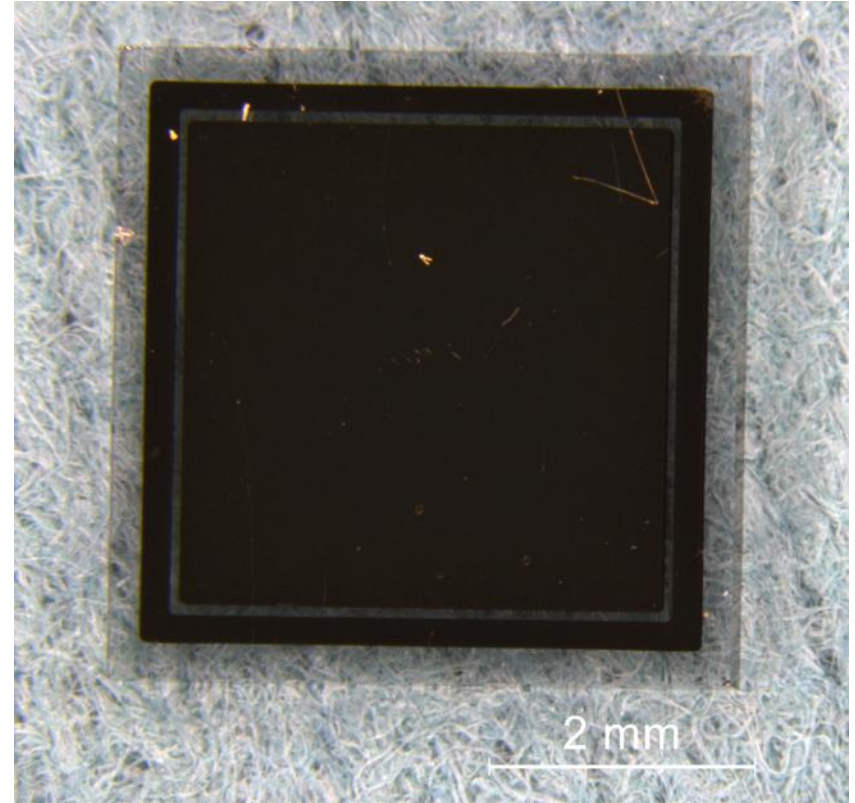
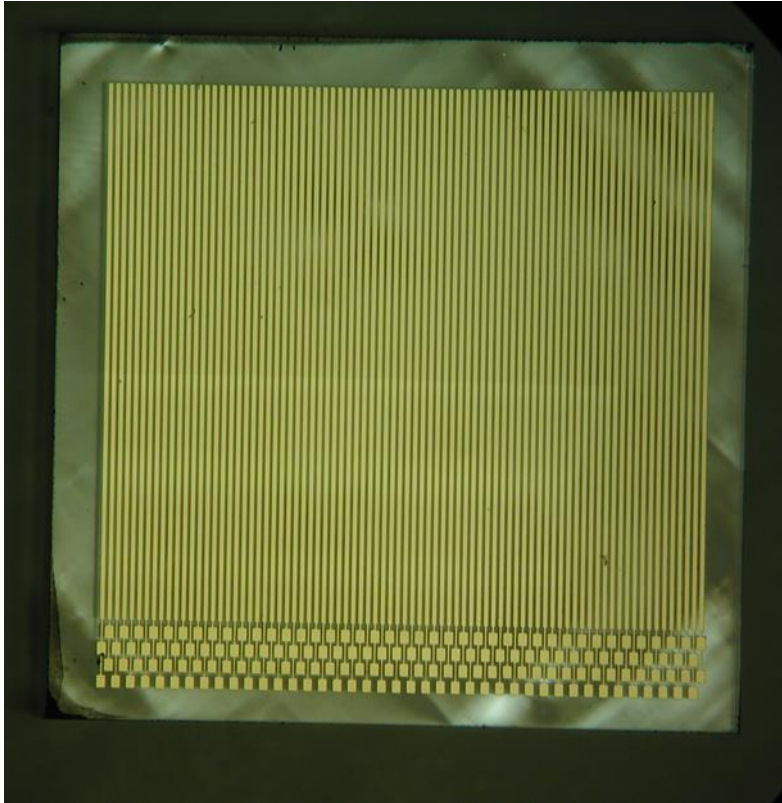
What is coming?

- 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**

