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edge-Transient Current Technique in single crystal CVD diamonds

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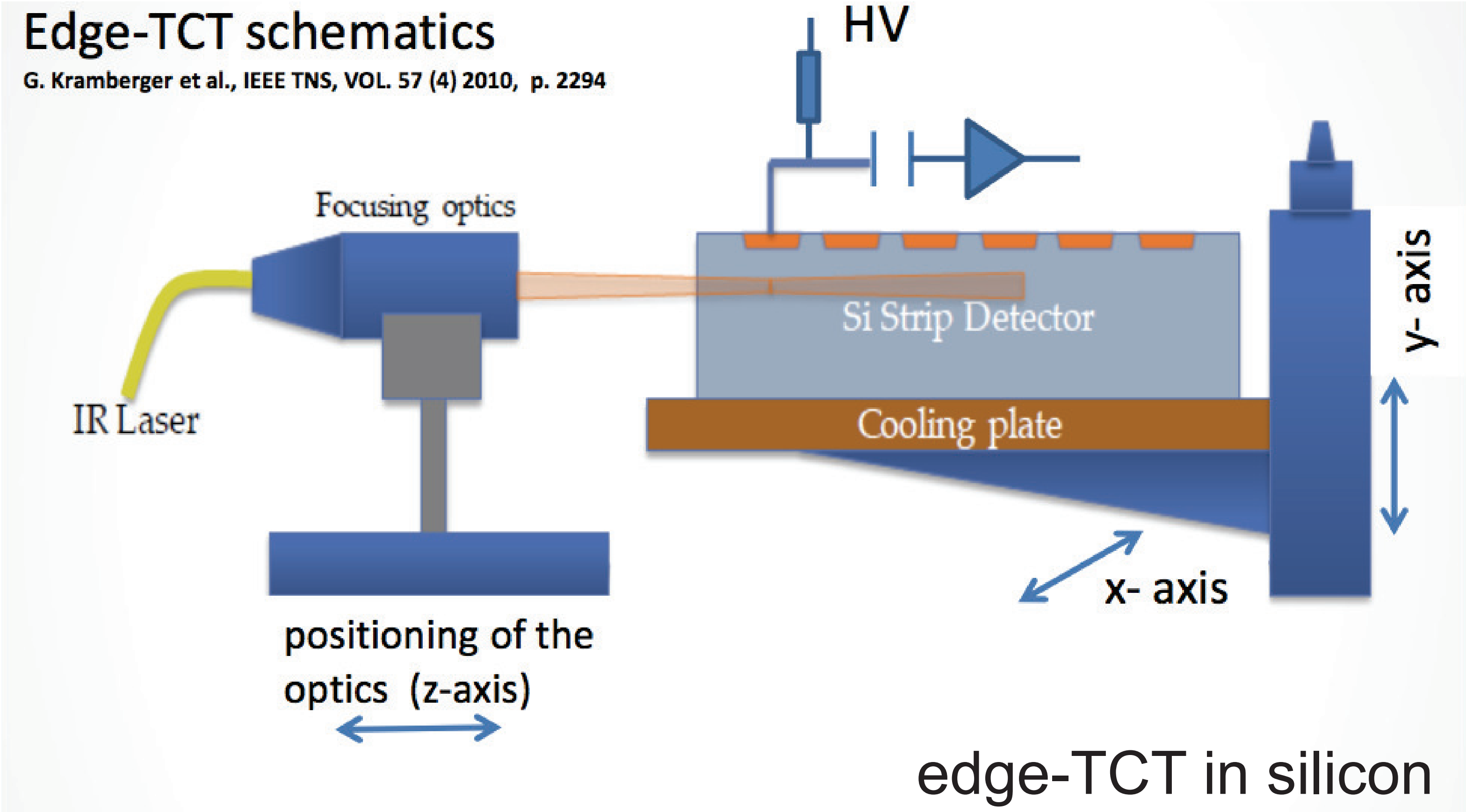
ETH Institute for Particle Physics

Outline

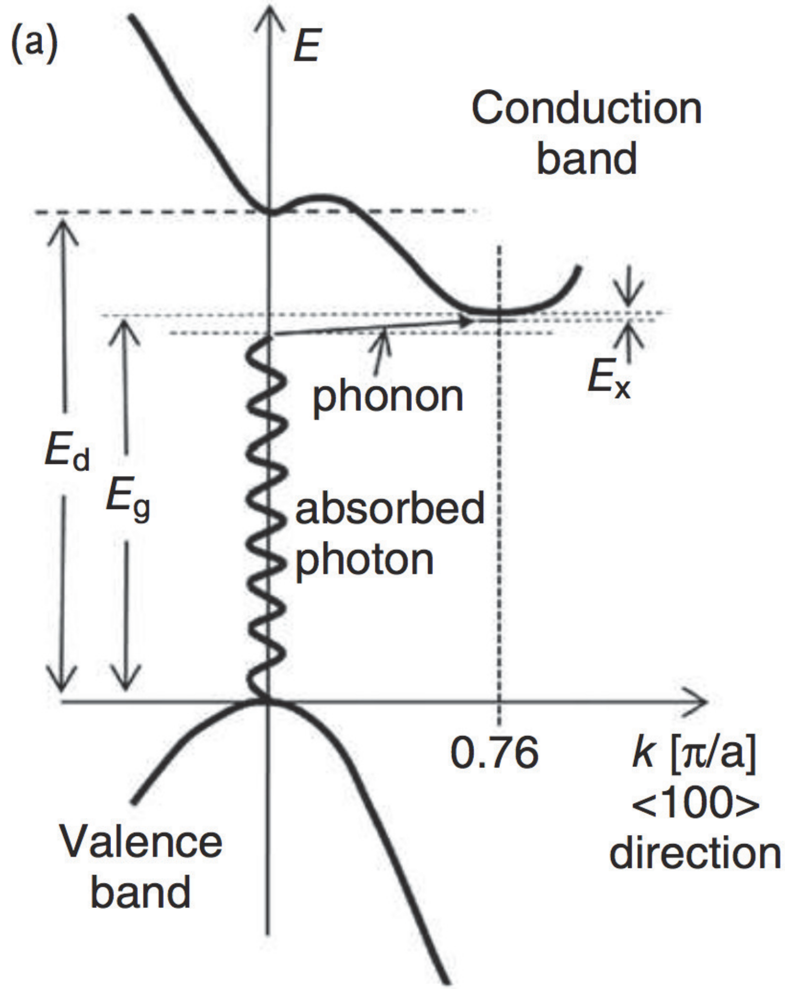
- Background
- Experimental setup
- Results
- Analysis
- Simulation
- Conclusions

edge-TCT (concept)



- Powerful tool to demystify the charge transport properties of (irradiated and unirradiated) sCVD diamond:
  - electric field (independently of trapping) —> space charge
  - trapping times
  - saturated velocity
  - mobility electrons and holes

Electronic band gap of diamond



Electronic band diagram of diamond showing photon absorption by the indirect band gap.

Indirect Bandgap

required energy ≈ 5.47 eV / 226 nm
(minus phonon contribution and exciton energy)
1-photon absorption
2-photon absorption: $E_\gamma \approx 2.74$ eV / 453 nm

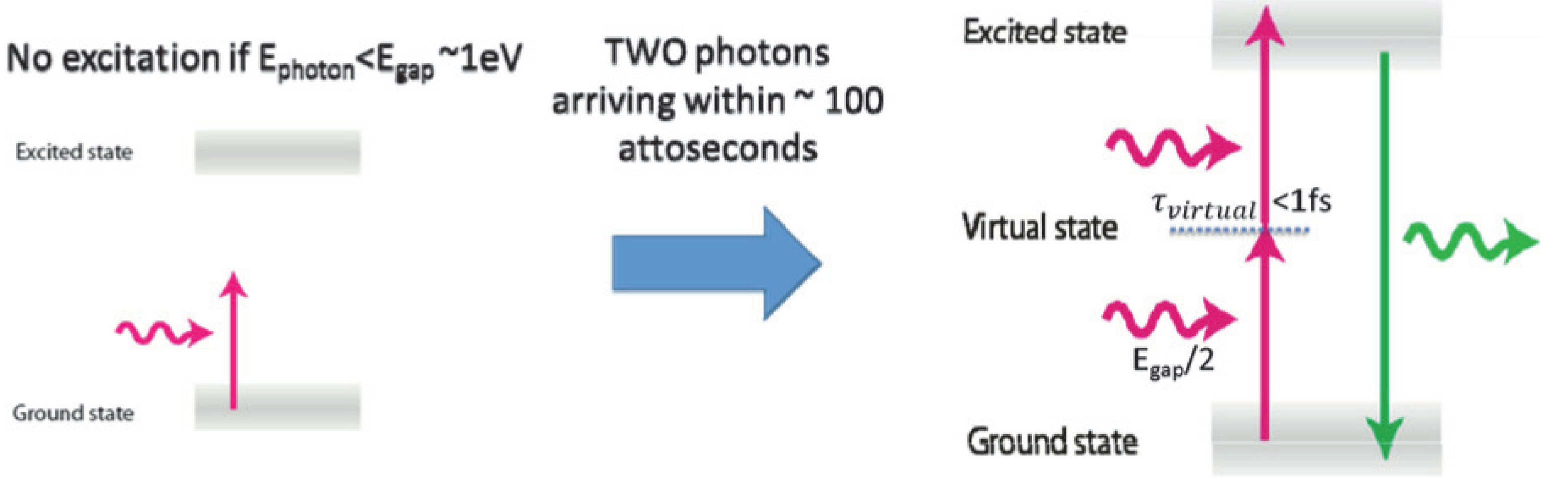
Direct Bandgap

required energy = 7.3 eV / 170 nm
1-photon absorption
2-photon absorption: $E_\gamma = 3.65$ eV / 340 nm
3-photon absorption: $E_\gamma = 2.43$ eV / 510 nm

Attoline Laser

- ~ 25 fs
- 0.1 – 5 nJ pulse energy, equivalent to $2 \cdot 10^8 - 10^{10}$ photons/pulse
- photon energy of 3.1 eV (400 nm)

2-Photon Absorption

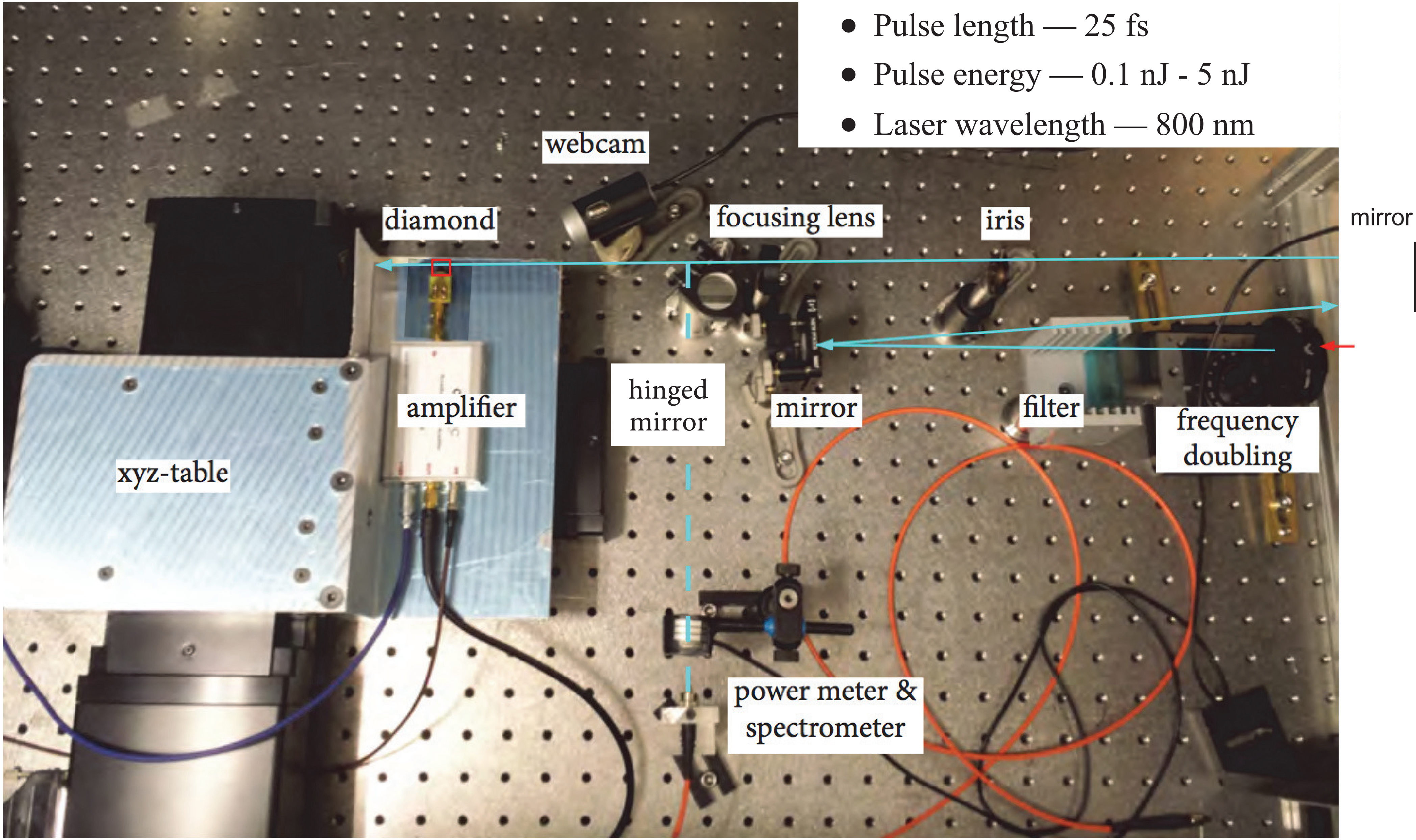


$$\tau_{virtual} \sim \frac{\hbar}{E_{gap}/2} \sim 0.1x10^{-15}s$$

- Theoretically predicted in 1931 by Maria Goppert Mayer in her Ph.D. thesis at Göttingen
- Experimentally observed in $CaF_2:Eu^{2+}$ by Kaiser and Garret at Bell Labs in 1961

Setup

- Pulse length — 25 fs
- Pulse energy — 0.1 nJ - 5 nJ
- Laser wavelength — 800 nm



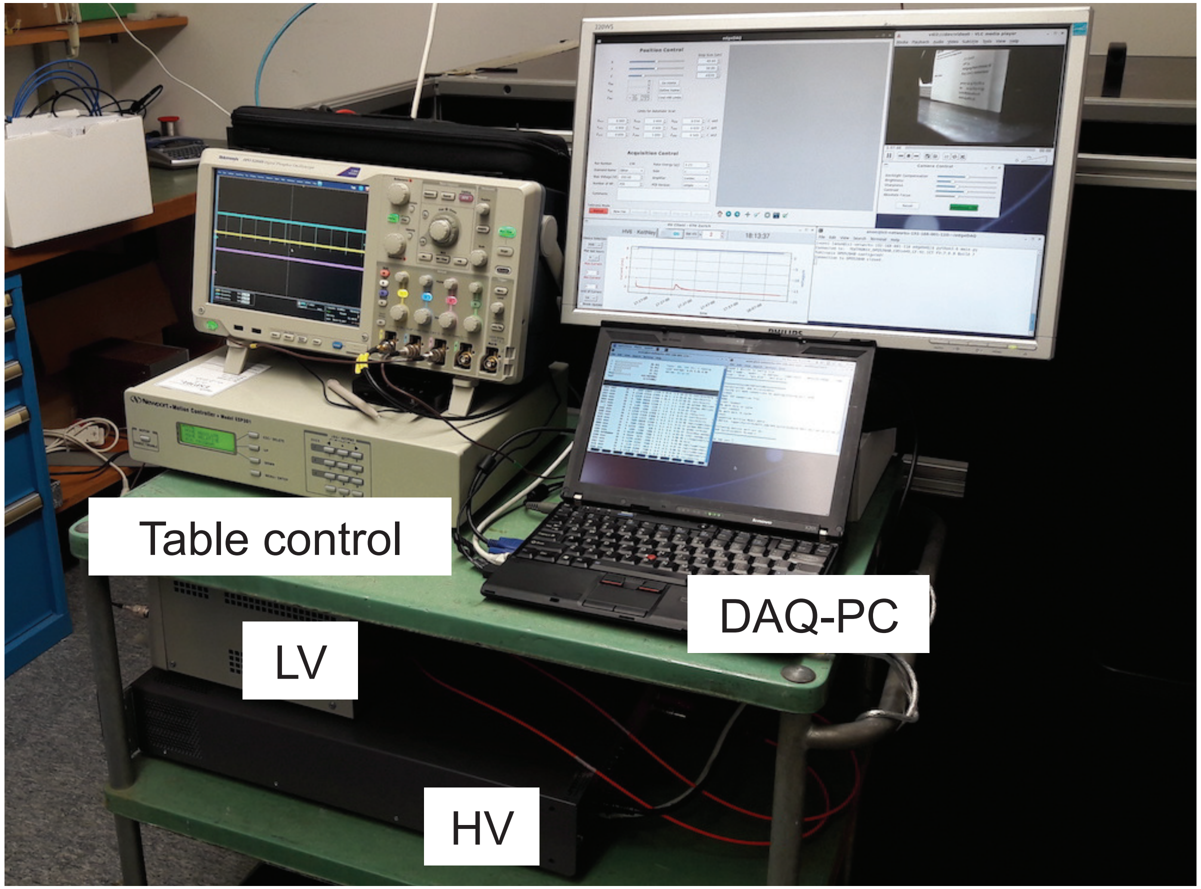
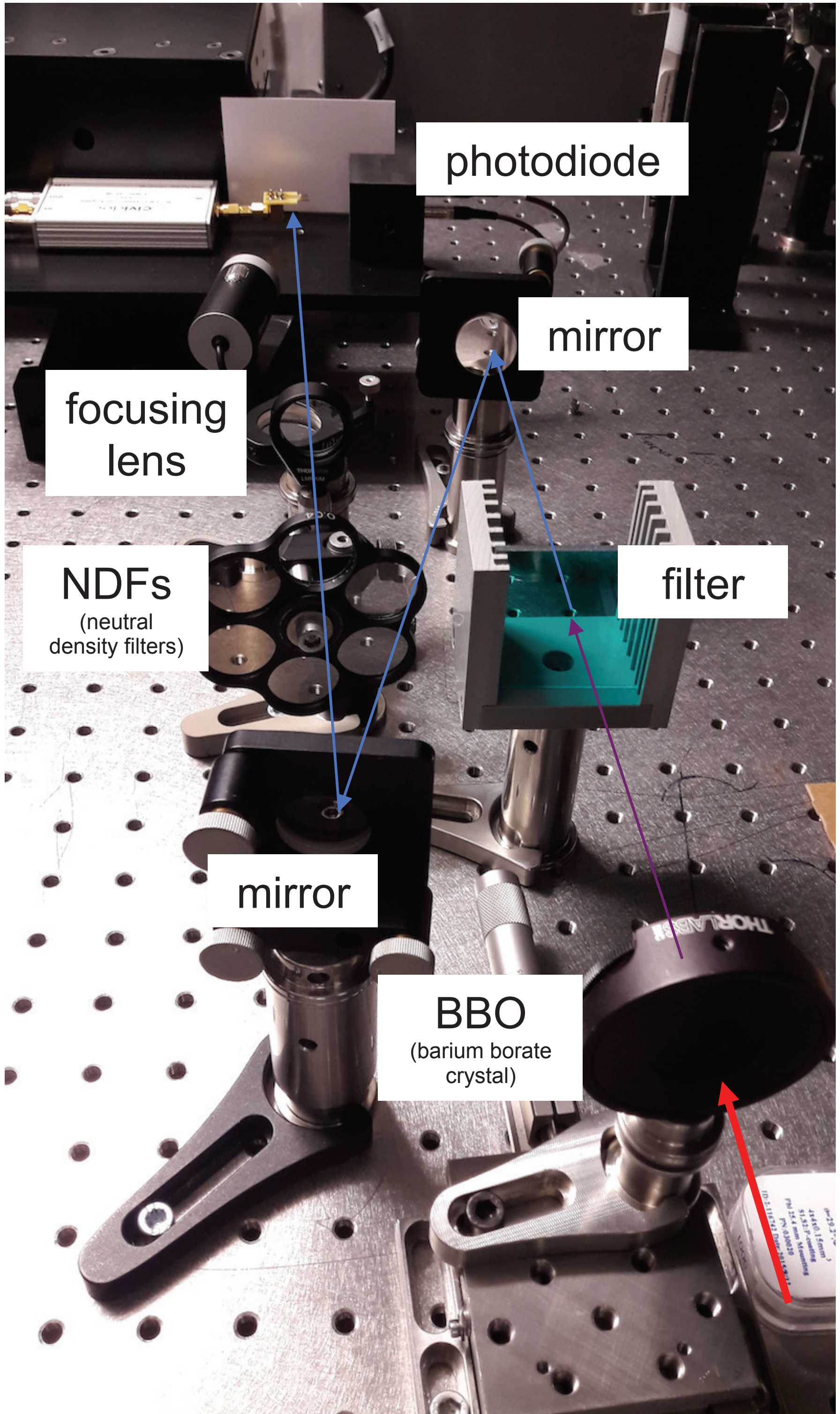
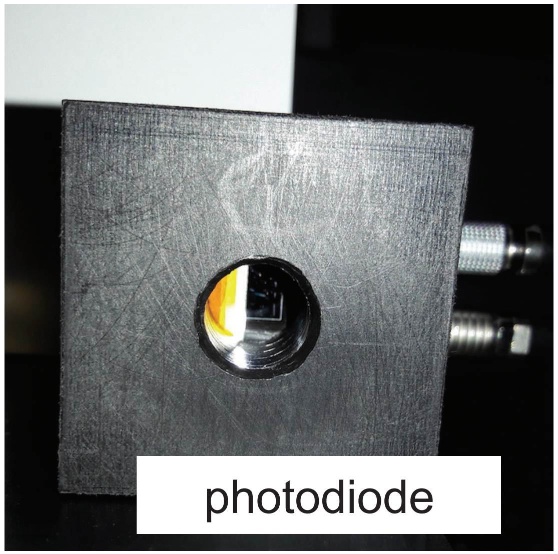
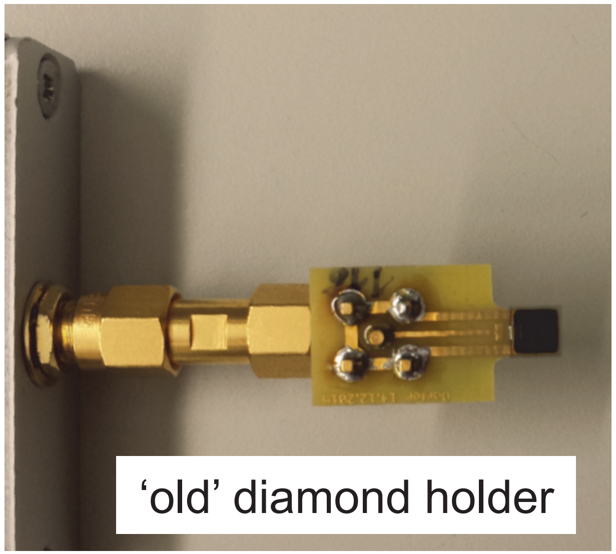


Table control
DAQ-PC
LV
HV

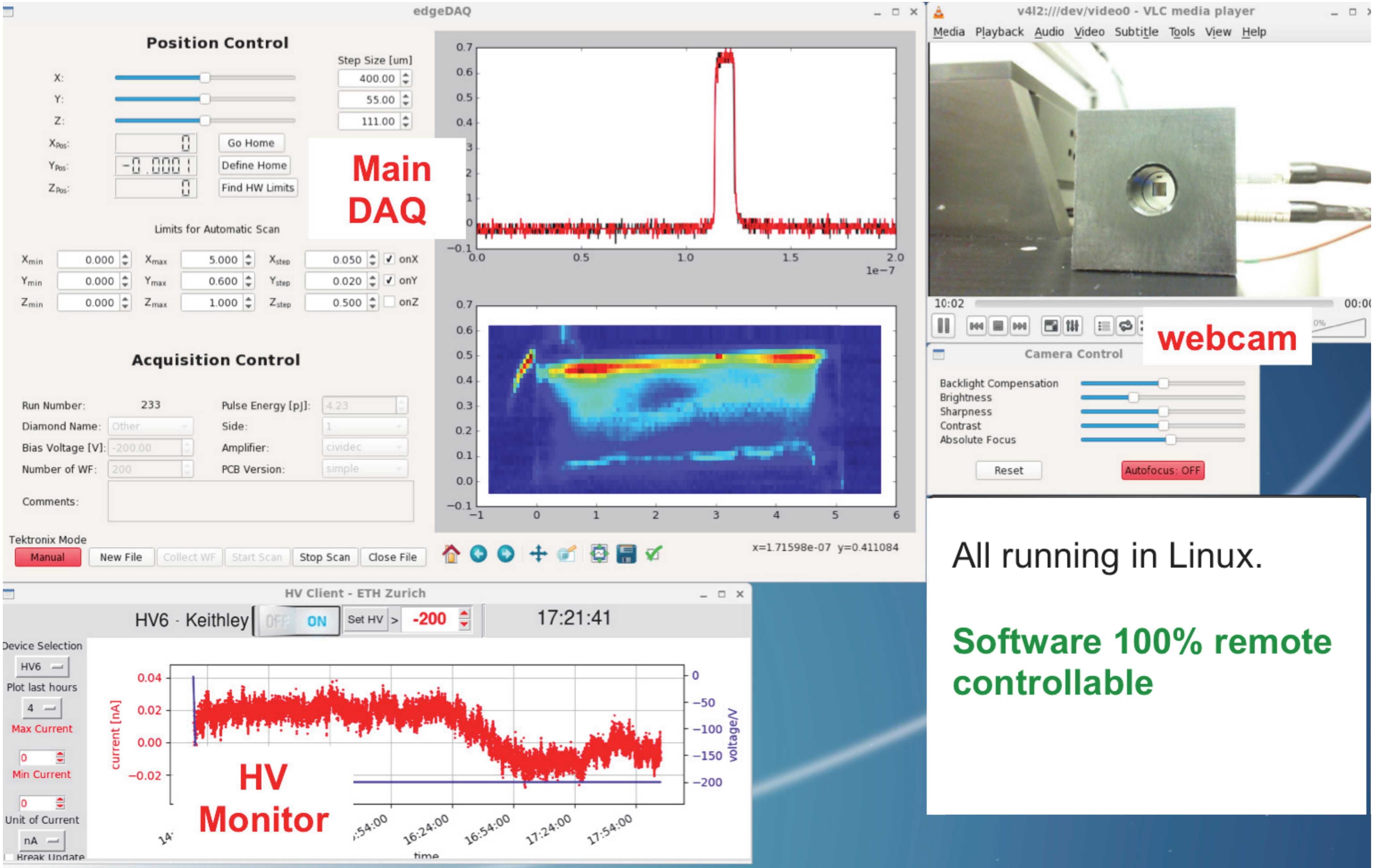

photodiode
mirror
focusing
lens
NDFs
(neutral
density filters)
filter
mirror
BBO
(barium borate
crystal)


photodiode


'old' diamond holder

April 2017

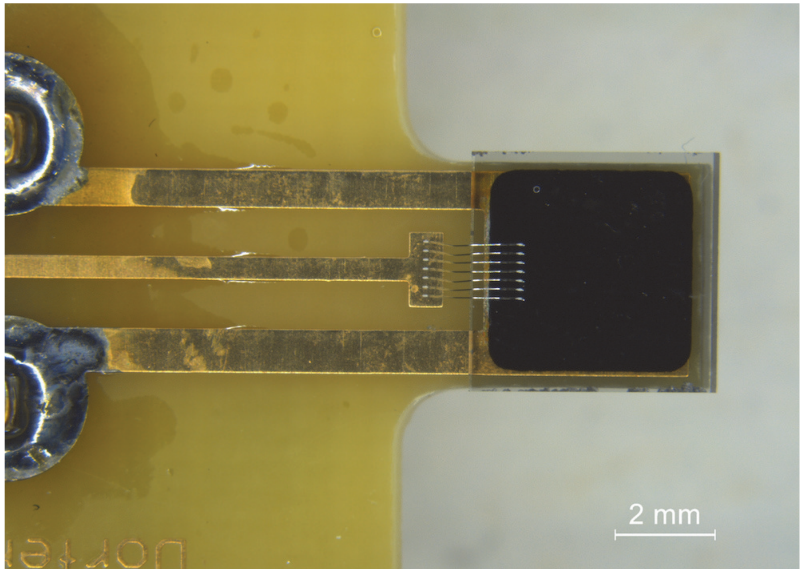
DAQ screenshot

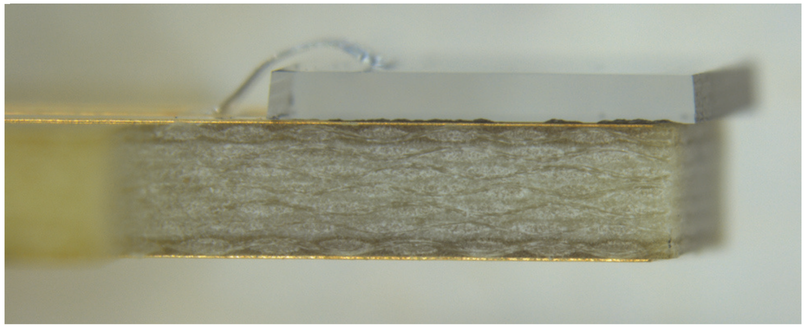


All running in Linux.

Software 100% remote controllable

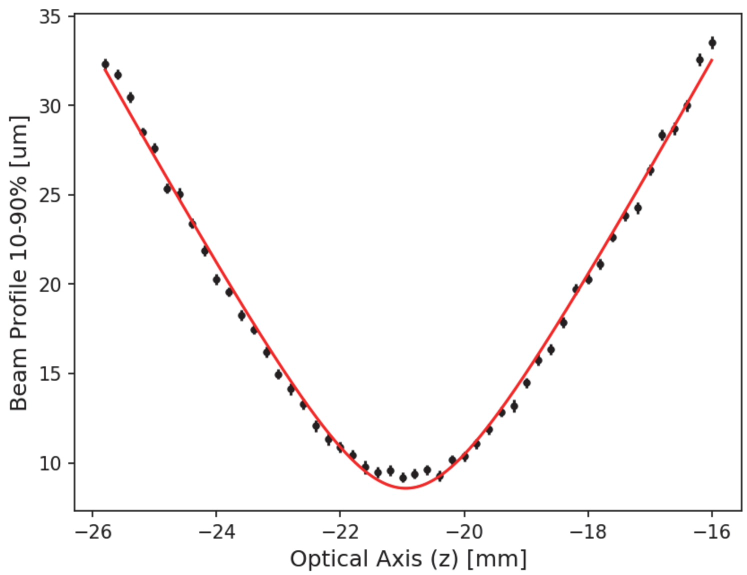
scCVD sample



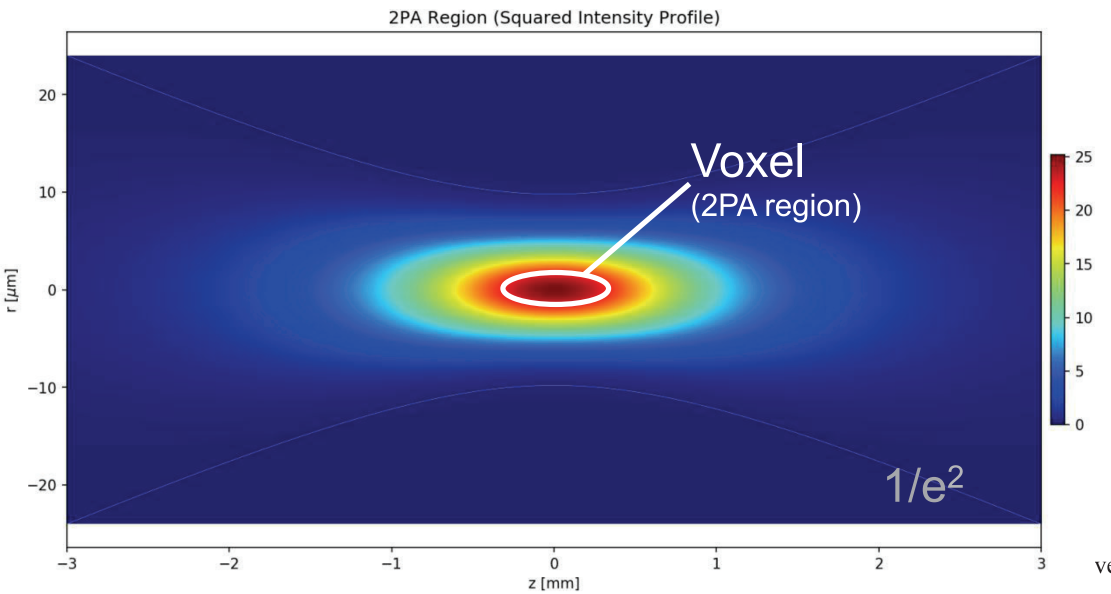


- bought from Element 6 (through DDL)
- Not used in PLT due to poor CCD performance
  - requires high field to collect full charge
- thickness — 566 um
- Not irradiated
- pad metallized by Rutgers University (TiW sputtered with shadow mask)
- metallization distance from edge ≈400 μm
- 2 edges polished

Beam profile



- Beam profile from the knife edge scan
  - in air, not accounting for aberration in diamond
  - 2.0 mm => 4.8 mm



- The charge profile is proportional to intensity squared for 2 photon absorption

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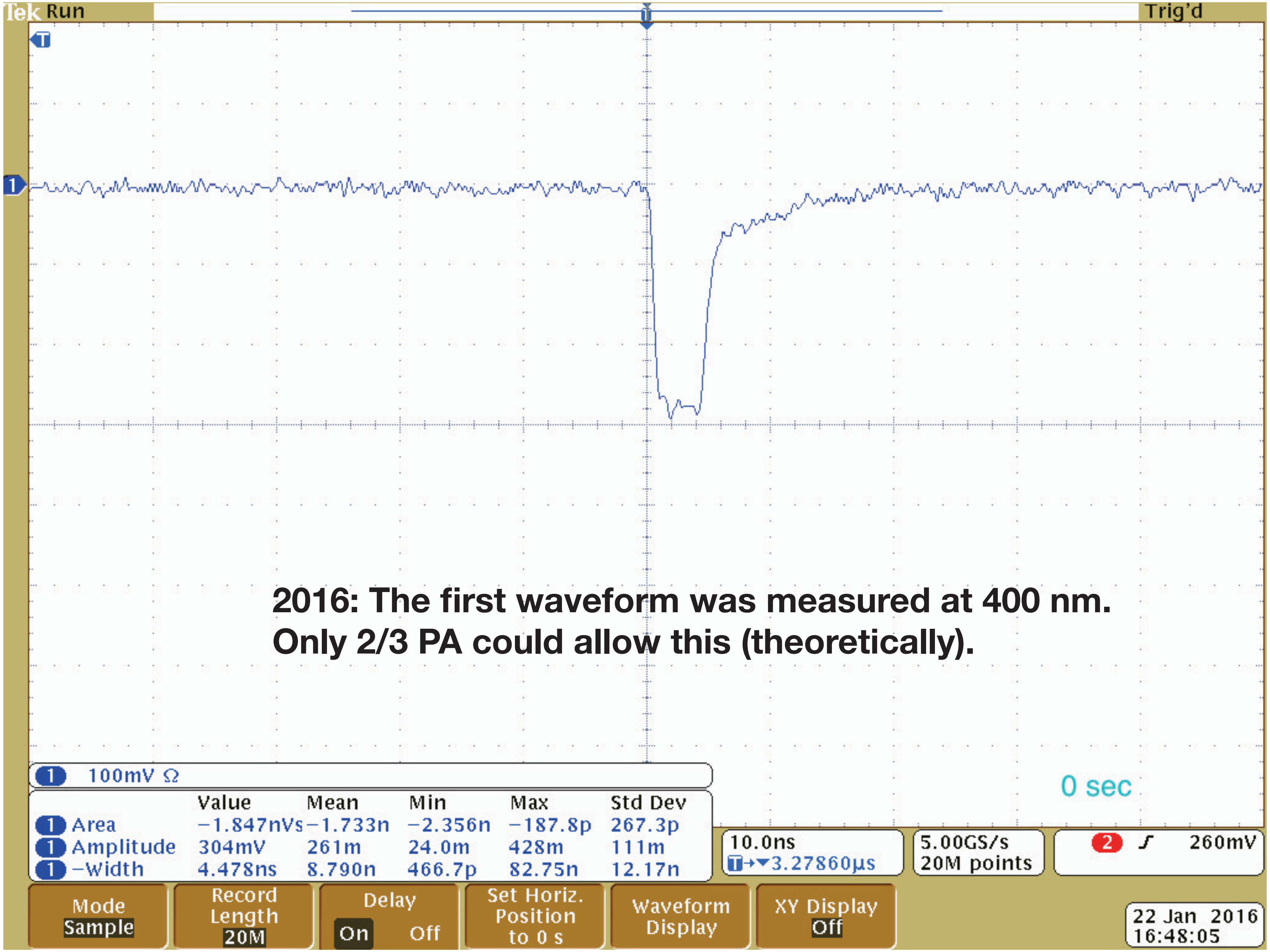
First Signal!



2016: The first waveform was measured at 400 nm.
Only 2/3 PA could allow this (theoretically).

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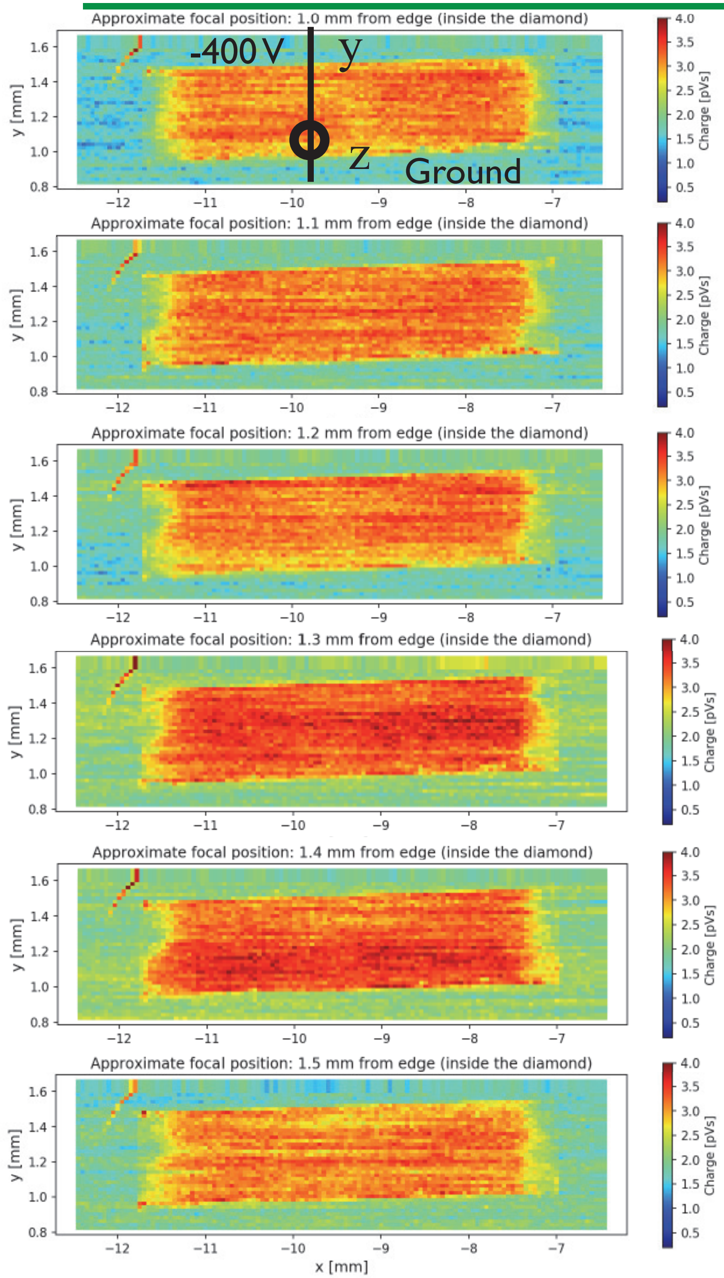
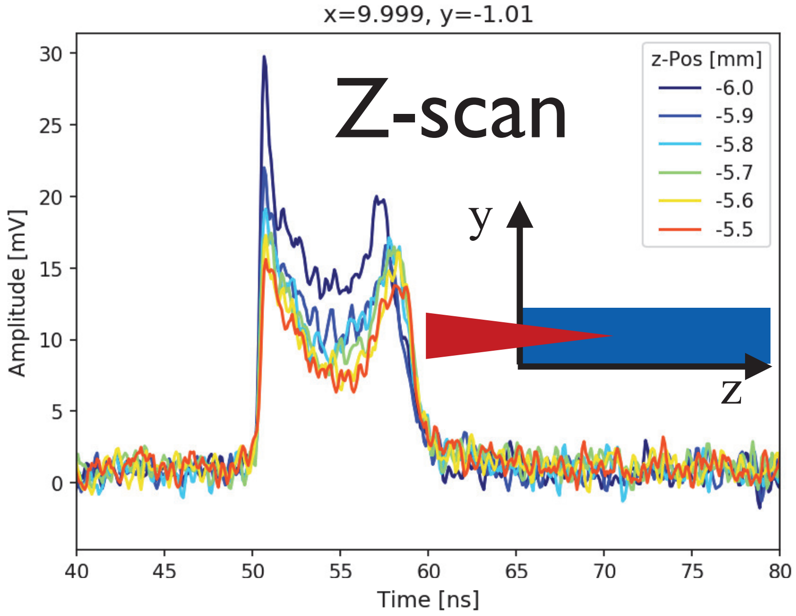
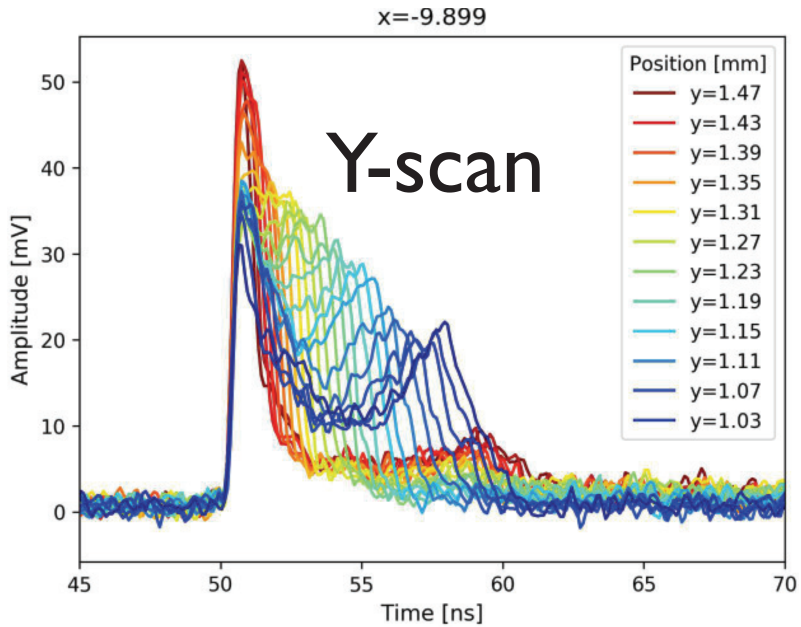
1st 3D scan







- Test parameters:
  - Bias voltage: -400V (0.7 V/µm)
  - 50 waveform averaging, 3993 scan points (~0.4s each)
  - Laser pulse energy: 0.2 nJ
- Parameters to extract:
  - drift speed
  - electrical field configuration
    - space charge
  - trapping rate

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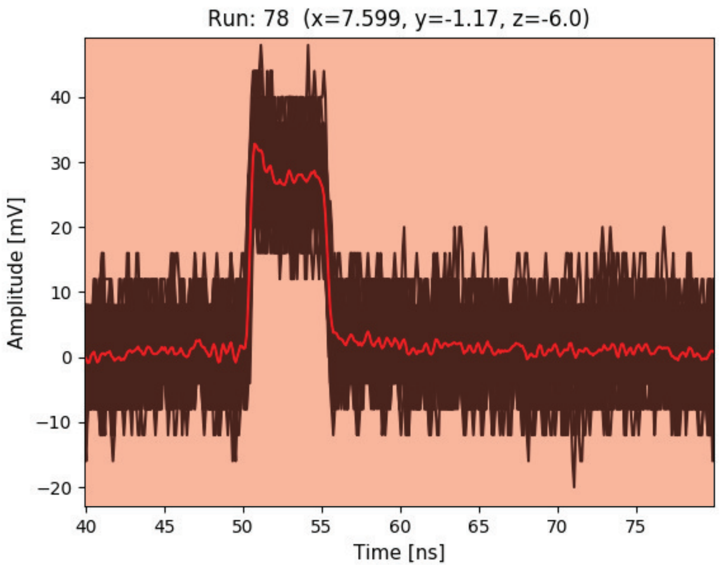
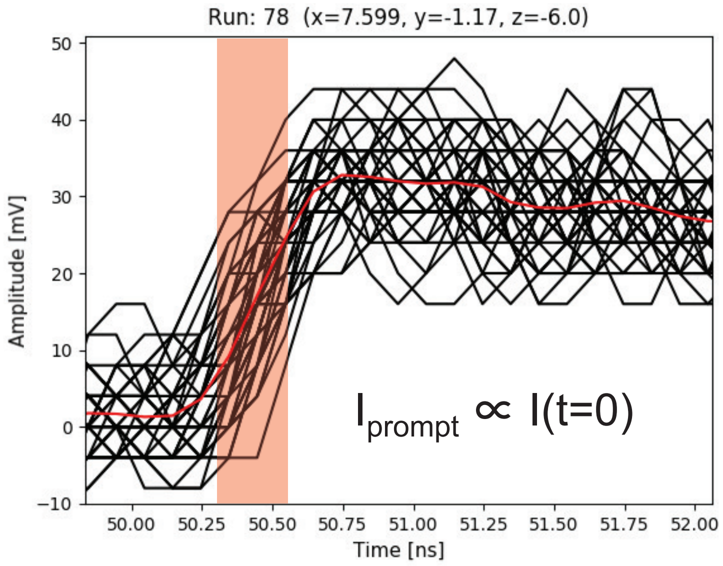
Waveform analysis

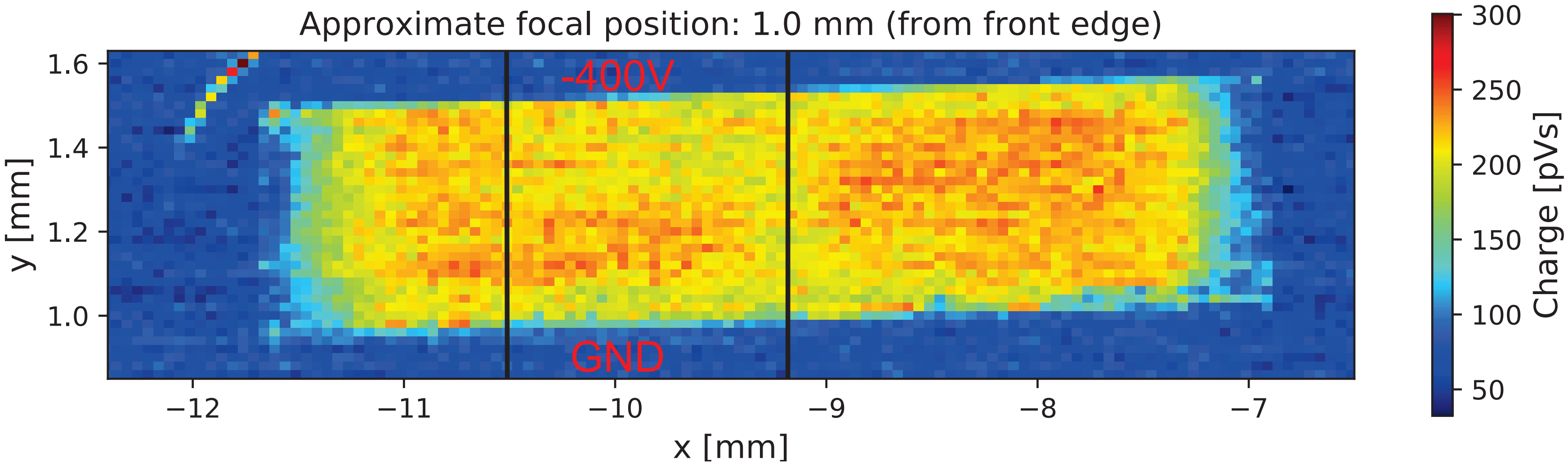


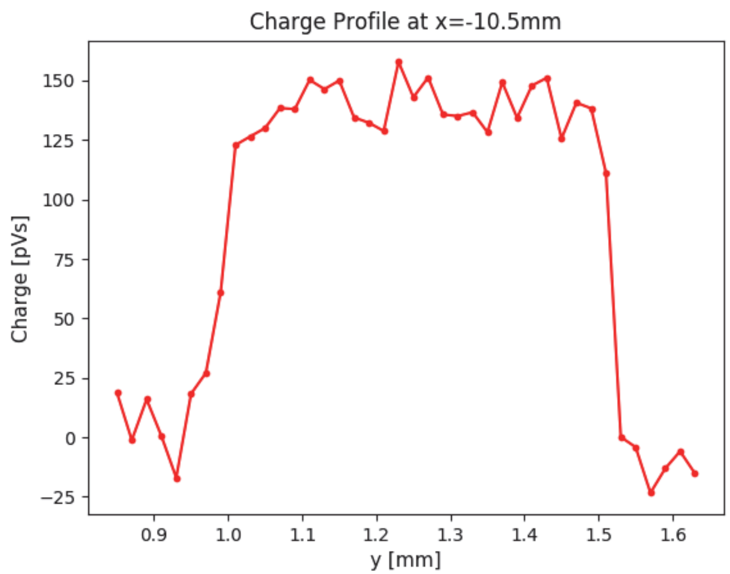


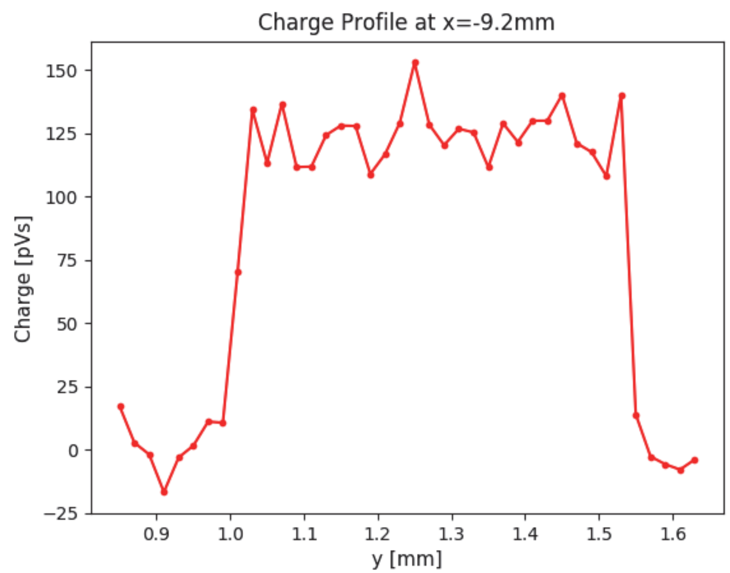
- Total charge
  - Integral of the complete baseline corrected waveform

- Prompt current
  - 0.3 ns-Integral around the center of the rising edge
- Prompt current is proportional to the electric field at the focal point
  - Possible to extract space charge distribution

Total charge







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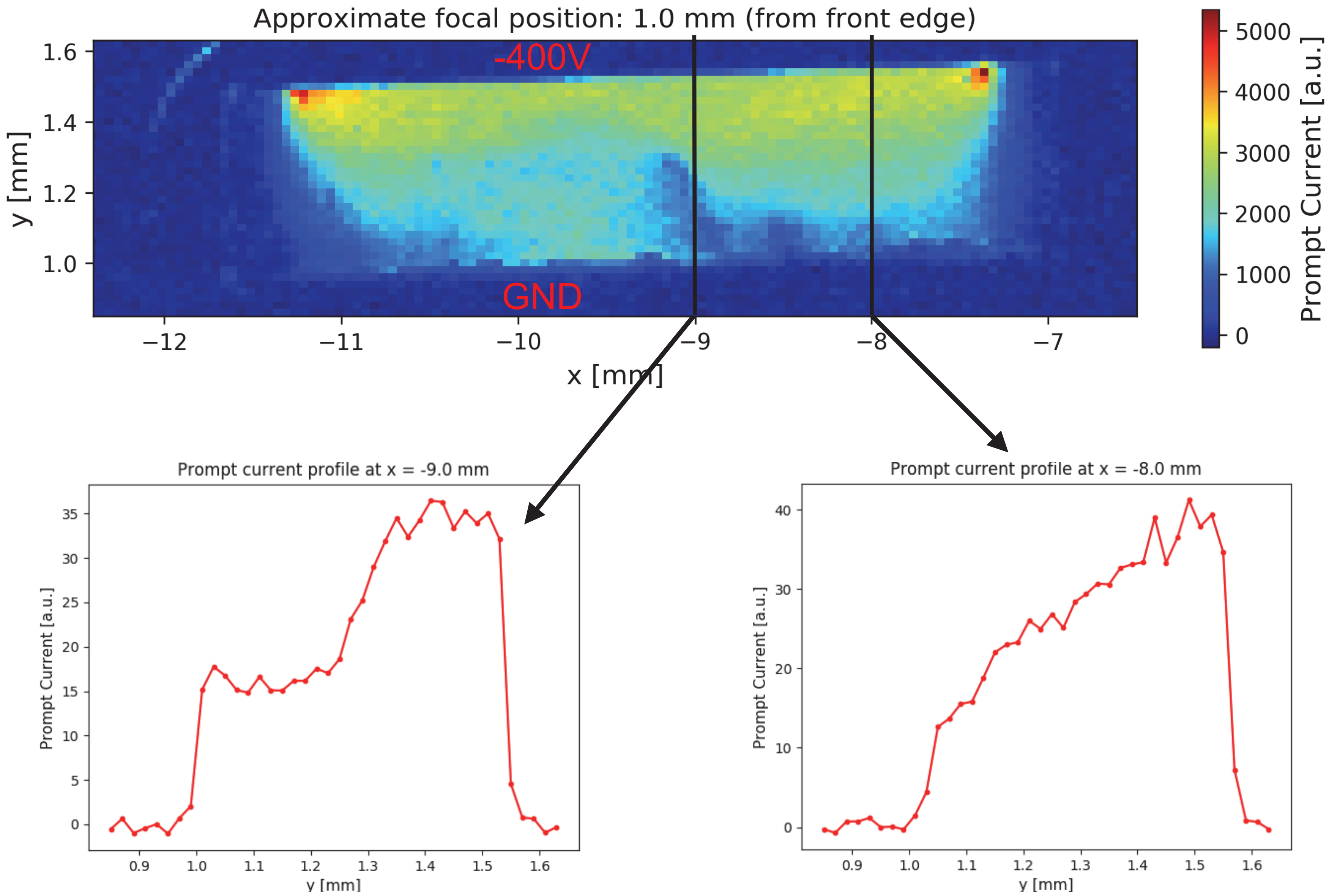
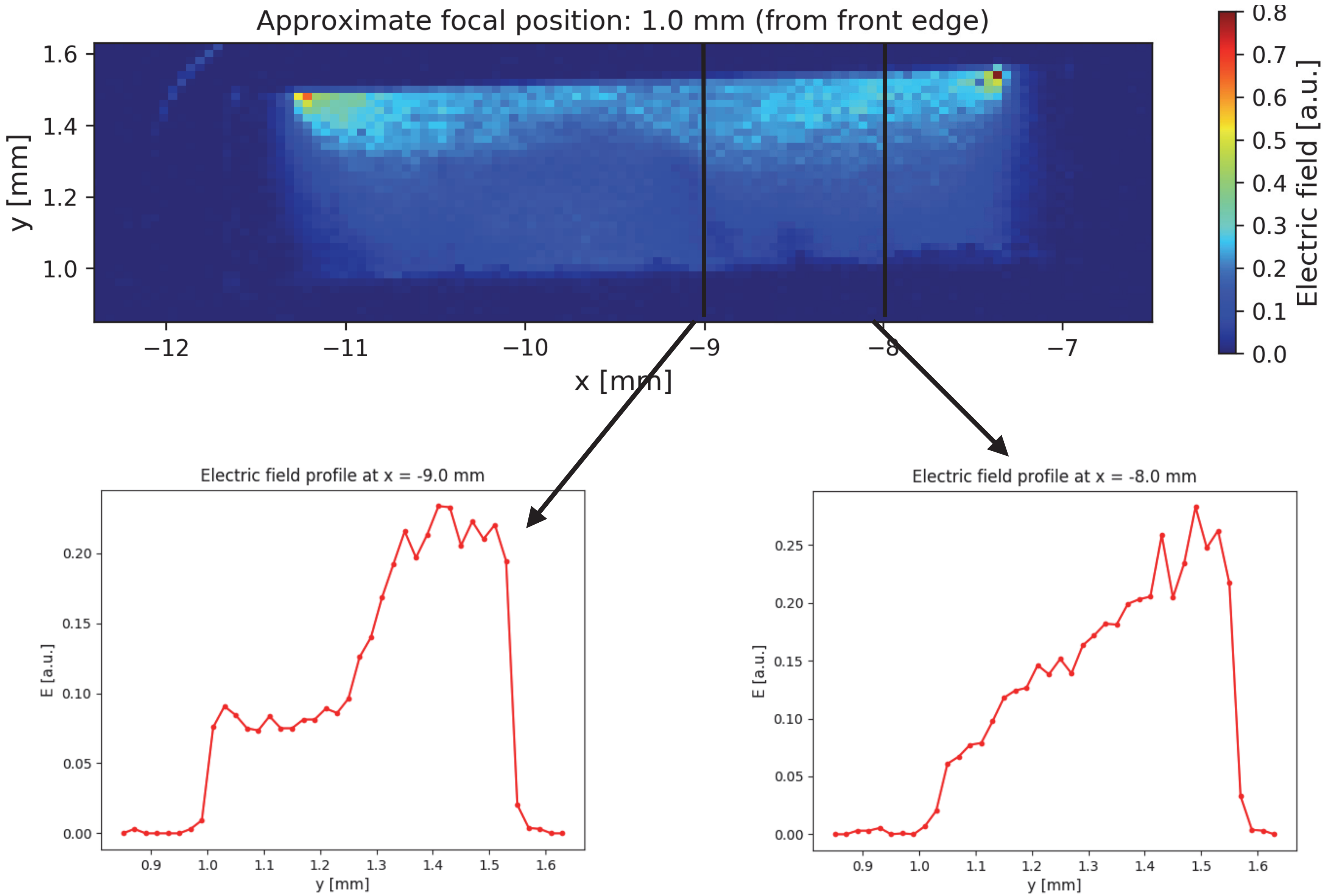
Prompt current

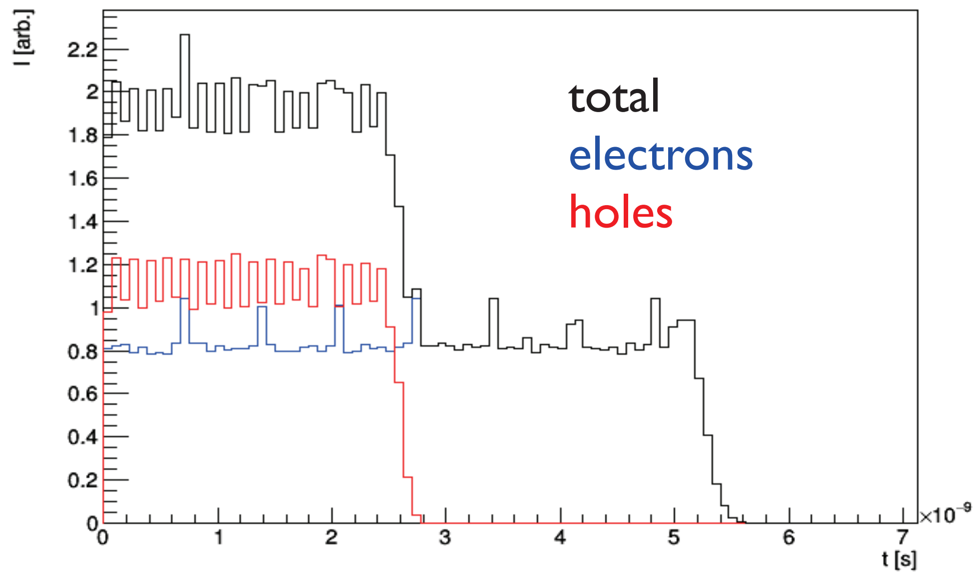


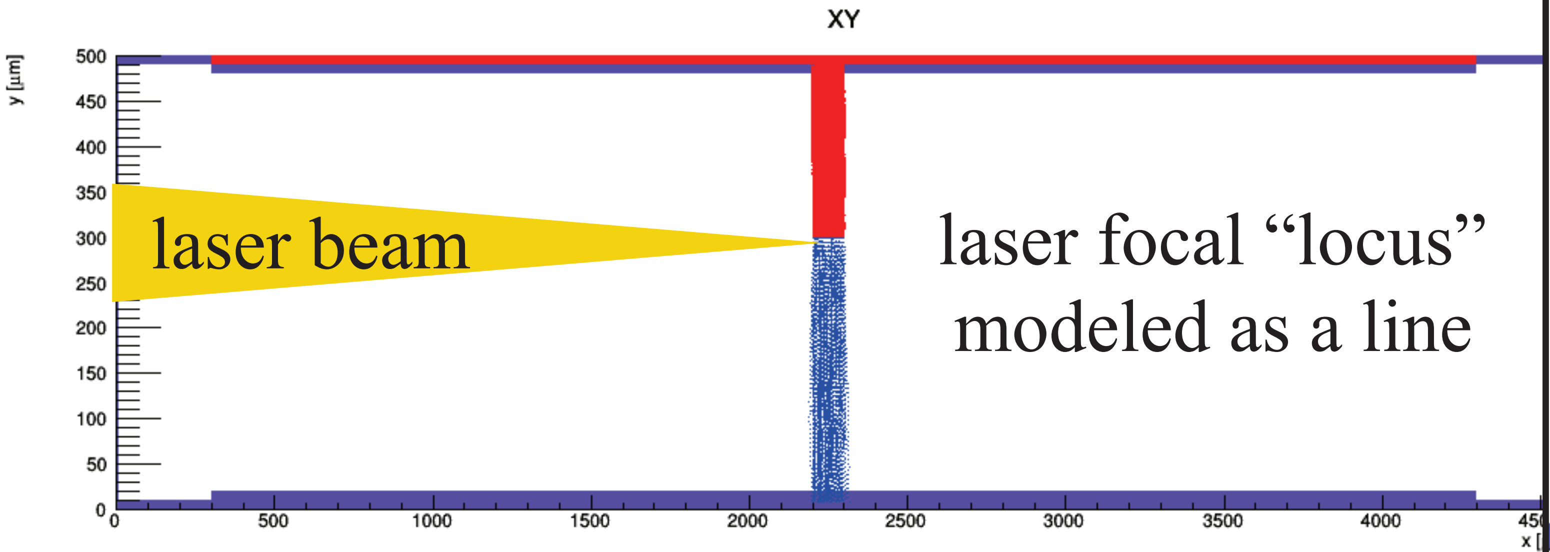
Electric field

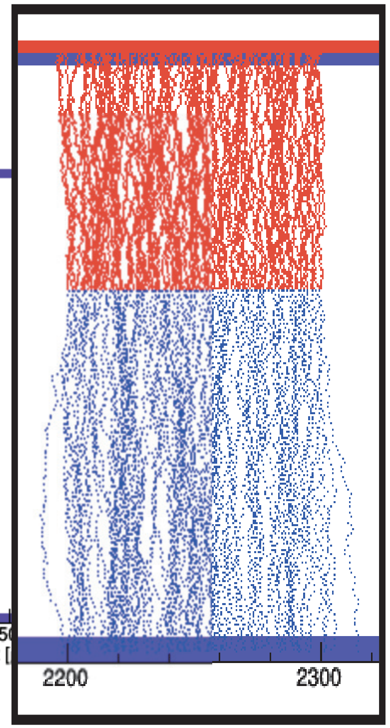


Detector simulation with KDetSim

- Simulation allows to model signal's shape
- Injection along a laser beam line
- No space charge
- Difusion = on
- No RC filter, no trapping
- holes ≈ 7.7 µm/ns
- electrons ≈ 5.8 µm/ns







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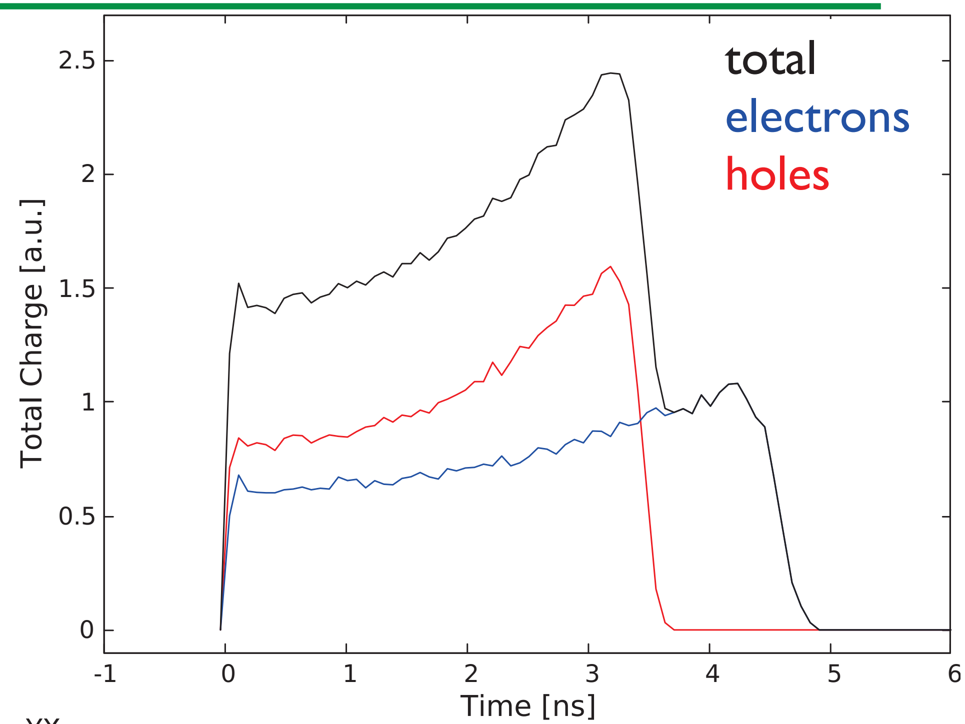

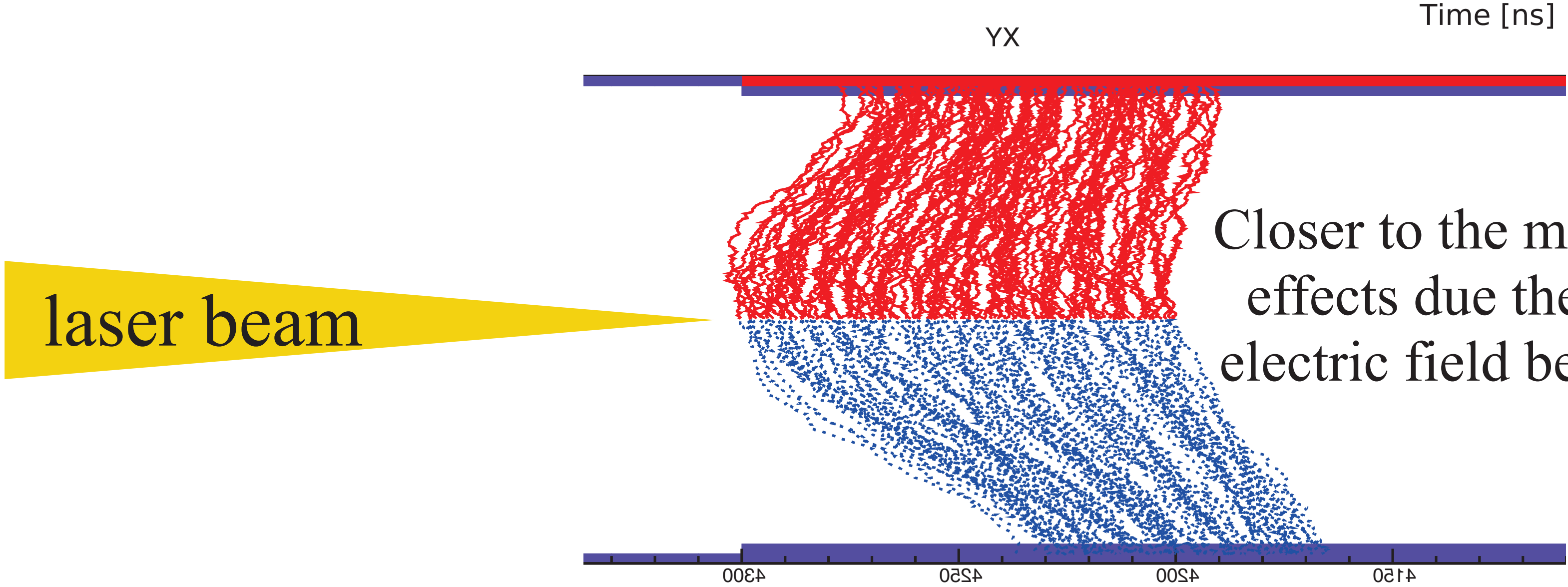

Closer to the metallization end effects due the non-uniform electric field become apparent

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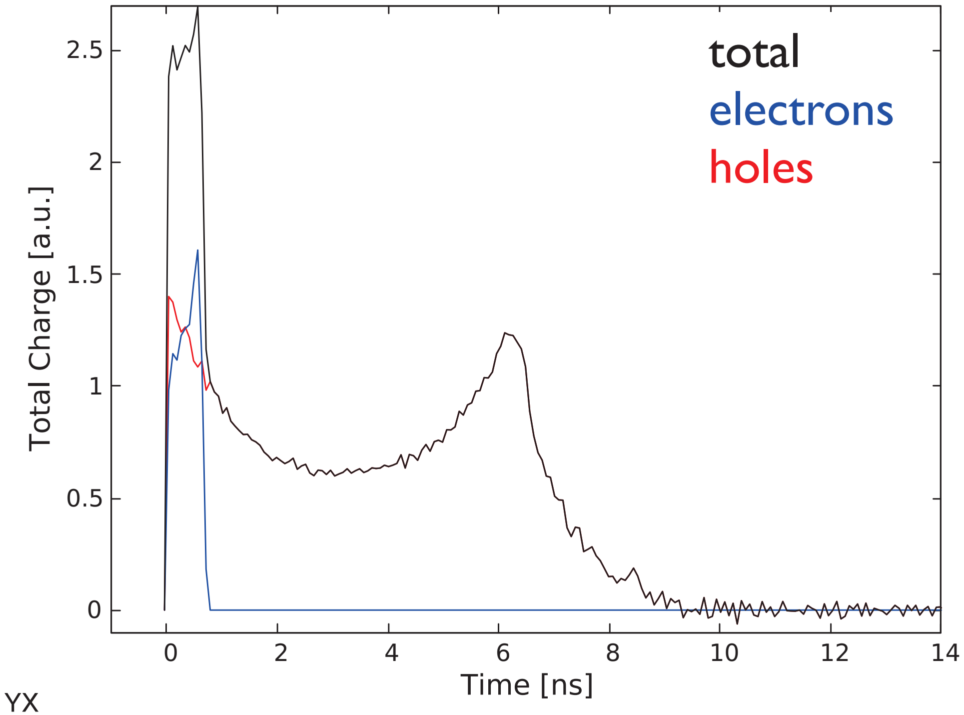
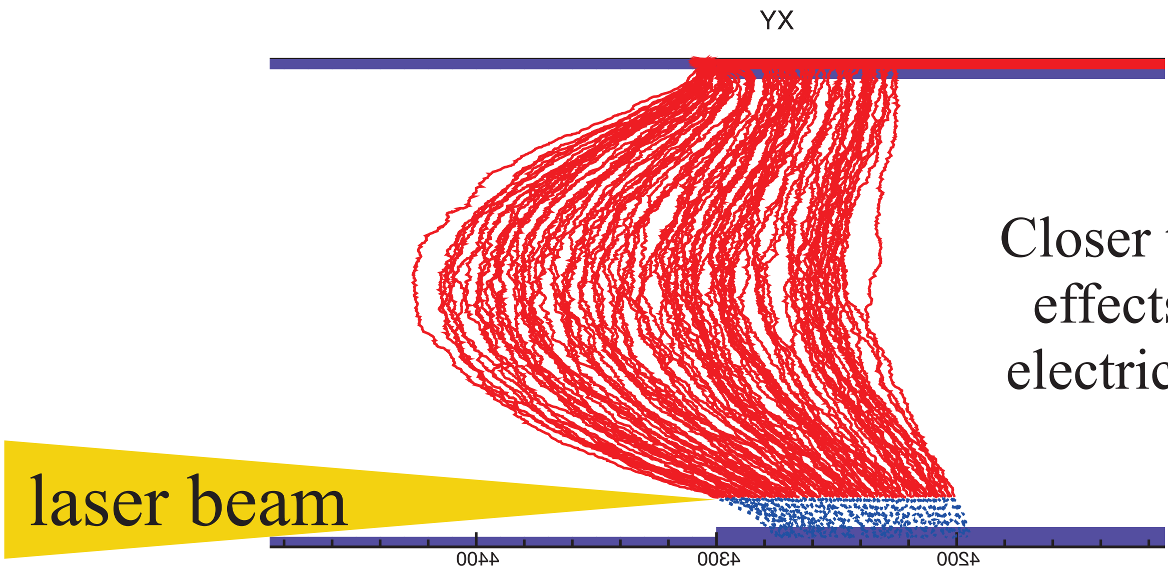
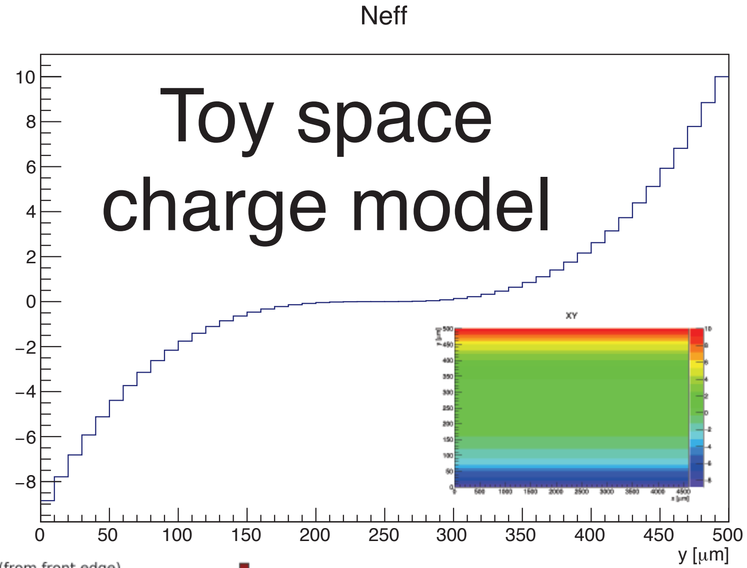


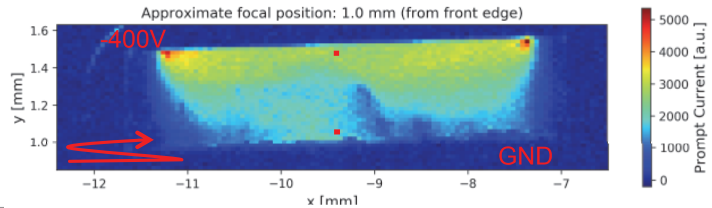


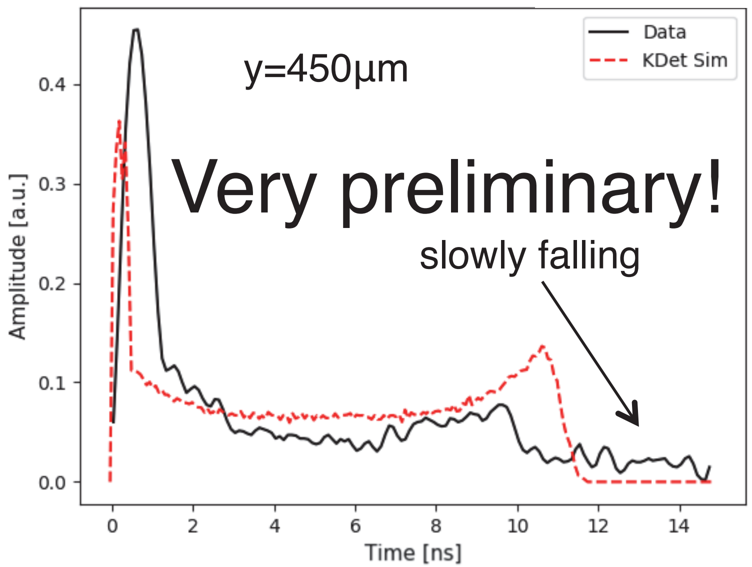
Closer to the metallization end effects due the non-uniform electric field become apparent

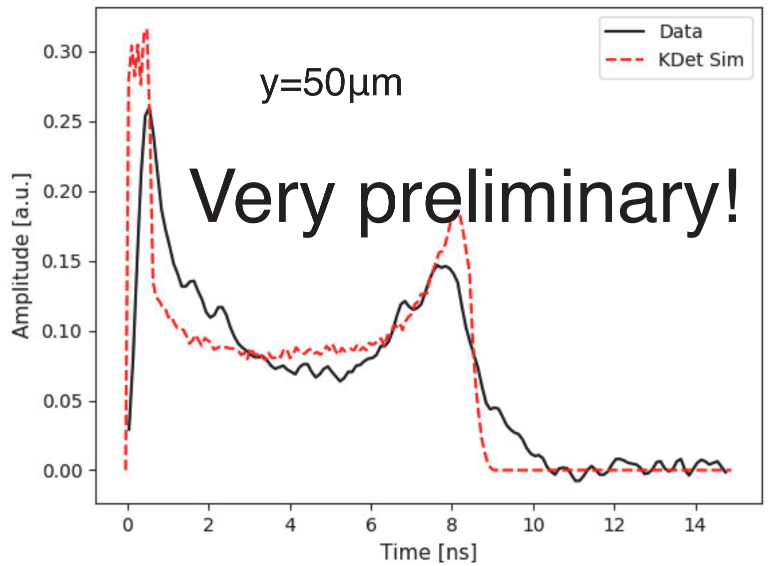
Detector simulation with KDetSim

- Another way to modify the signal shape is with the space charge
- Cubic space charge distribution
- Injection along a line
- Difusion = on
- No RC filter, no trapping









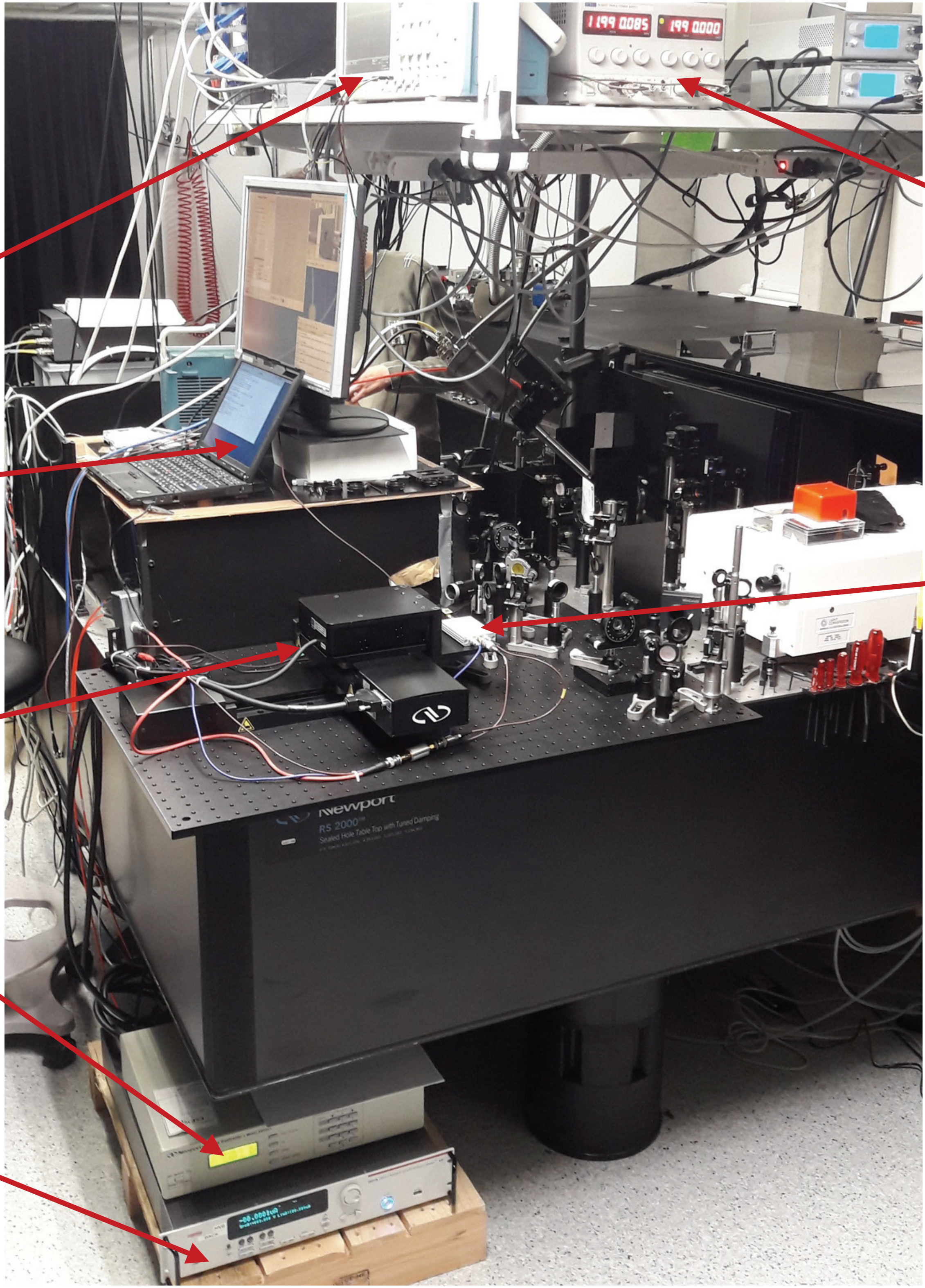
Conclusions

- We have a working edge-TCT setup for investigating charge transport properties in scCVD diamonds
- Clear TCT signals have being observed
- We are making the first steps in the analysis and simulation

Outlook

- Introduce a shutter in the setup for on demand automatic light blocking
  - understand systematics due to light pumping
- Better understand the shape of the focal point in diamond
- Try lenses with different focal strengths
- Measure diamond with strip metallization pattern

New setup in Johnson lab



Oscilloscope

LV supply

DAQ PC

Amplifier

xyz-stage

xyz-stage control

high voltage supply

Electric field calculations

no trapping

$$I_{e,h} = A \cdot e_0 \cdot N_{e,h} \cdot \cancel{e^{-\frac{t}{\tau_{eff}}}} \cdot v_{e,h} \cdot W$$

$$I_{e,h}(t=0) = A \cdot e_0 \cdot N_{e,h} \cdot v_{e,h} \cdot \frac{1}{d}$$

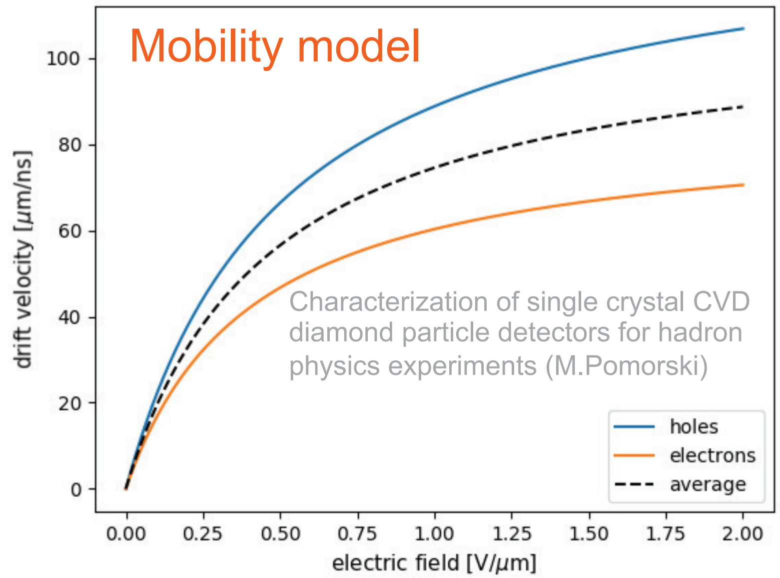
$$I_{e,h}(t=0) = A \cdot e_0 \cdot N_{e,h} \cdot \mu_{e,h}(E) \cdot E \cdot \frac{1}{d}$$

$$I_{e,h}(t=0) = constant \cdot \mu_{e,h}(E) \cdot E$$

$$0 = I_{e,h}(t=0) - constant \cdot \mu_{e,h}(E) \cdot E$$

I_{prompt} from data | scaling | Mobility model

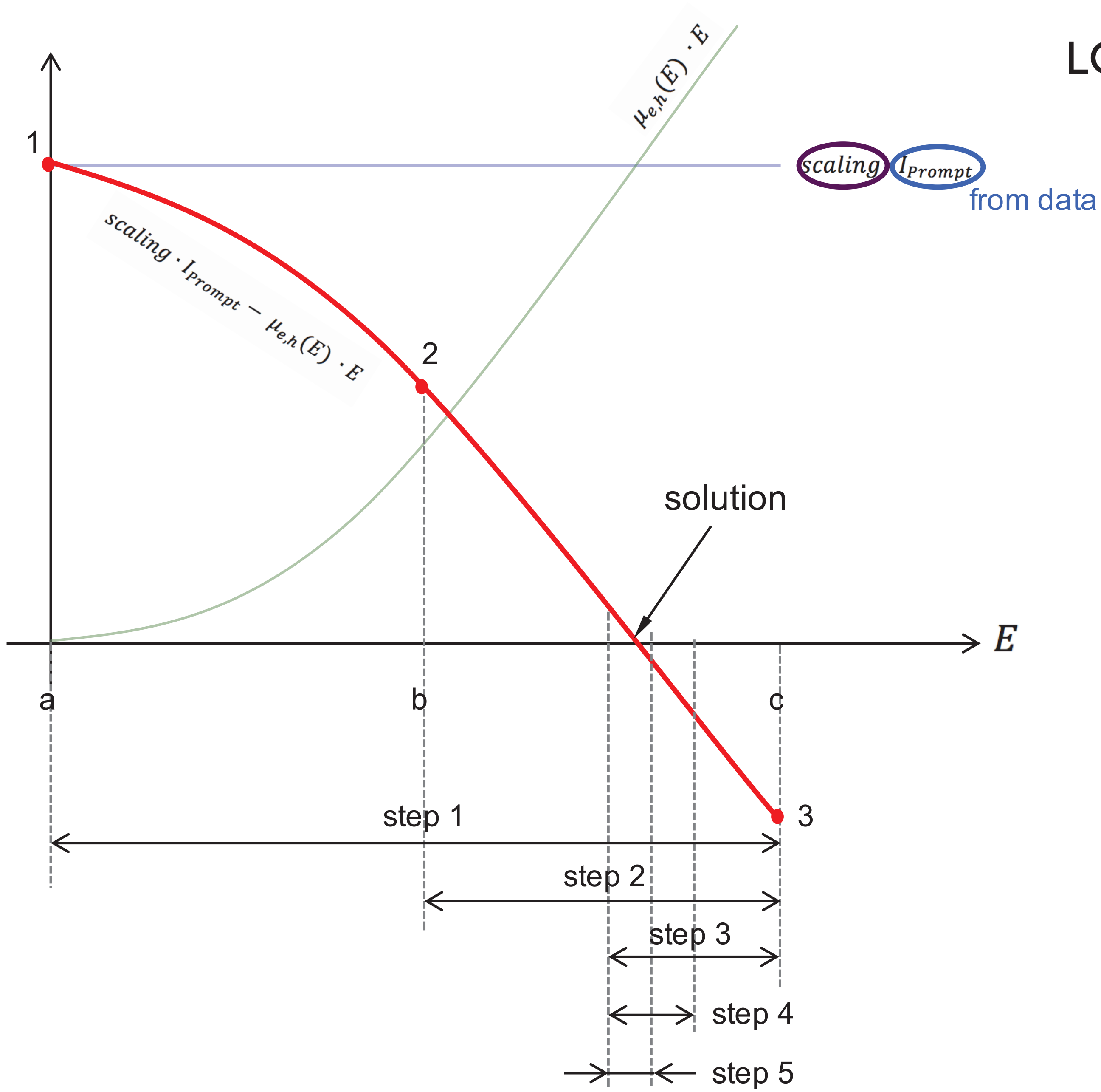
A .. Amplification
e_0 .. electron charge
$N_{e,h}$ .. number of e,h pairs (constant in first order)
$v_{e,h}$ .. avg. drift speed of e&h
W .. weighting field (=1/thickness for 2 parallel infinite 2D electrodes)



Use 'Bisection Method' to solve for **E** with the constraint that:

$$V_{Bias} = \int_0^d E\, dy$$

Bisection method



LOOP

evaluate f(a), f(b), f(c)

if f(a) * f(b) > 0:

a = (a+c)/2

else:

c = (a+c)/2

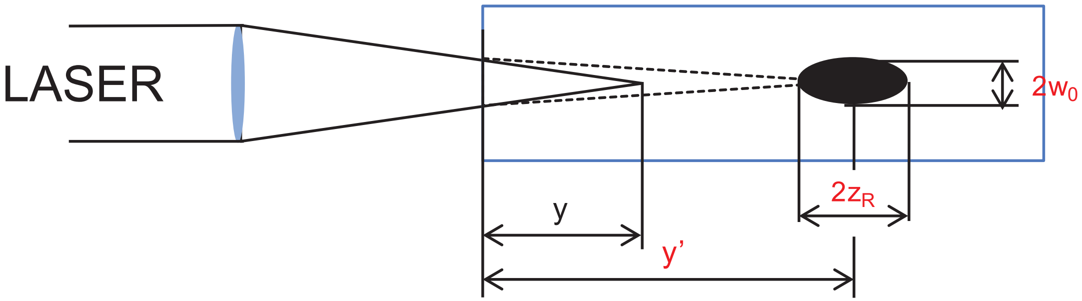
if |a – c| < threshold:

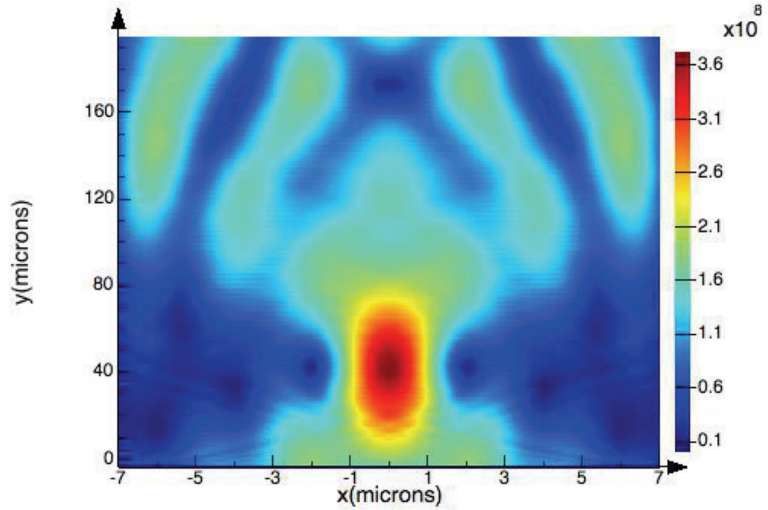
found solution

Understanding Gaussian Optics

LUMERICAL Simulations

- Simulation of focal point in air.
  - Interference patterns due to thin lens approximation.
  - Thin lens filled with beam causes airy discs.





Simulation of focal point in diamond (Intensity)