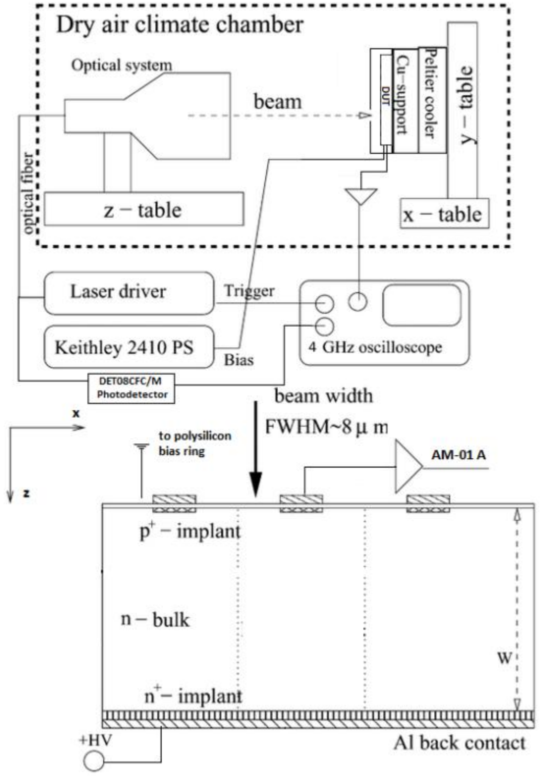
TCT - Measurements

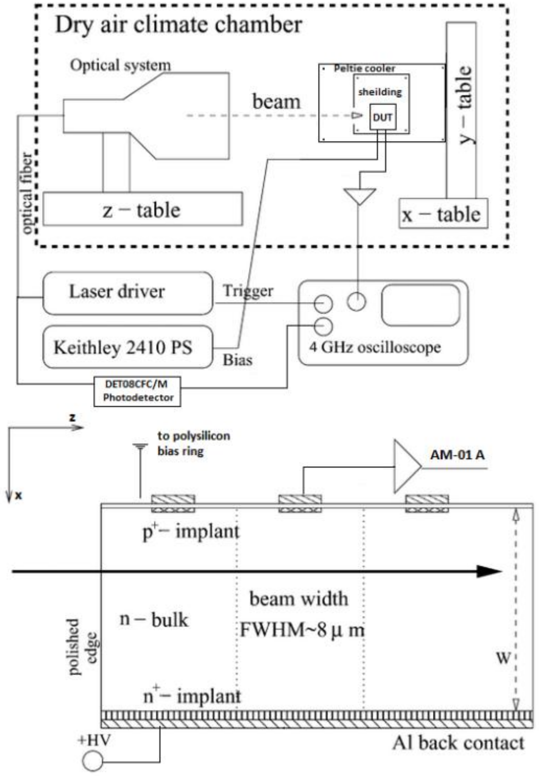
by ZengHao

2018/04/20

Experimental Setup



(a) Top-TCT Configuration

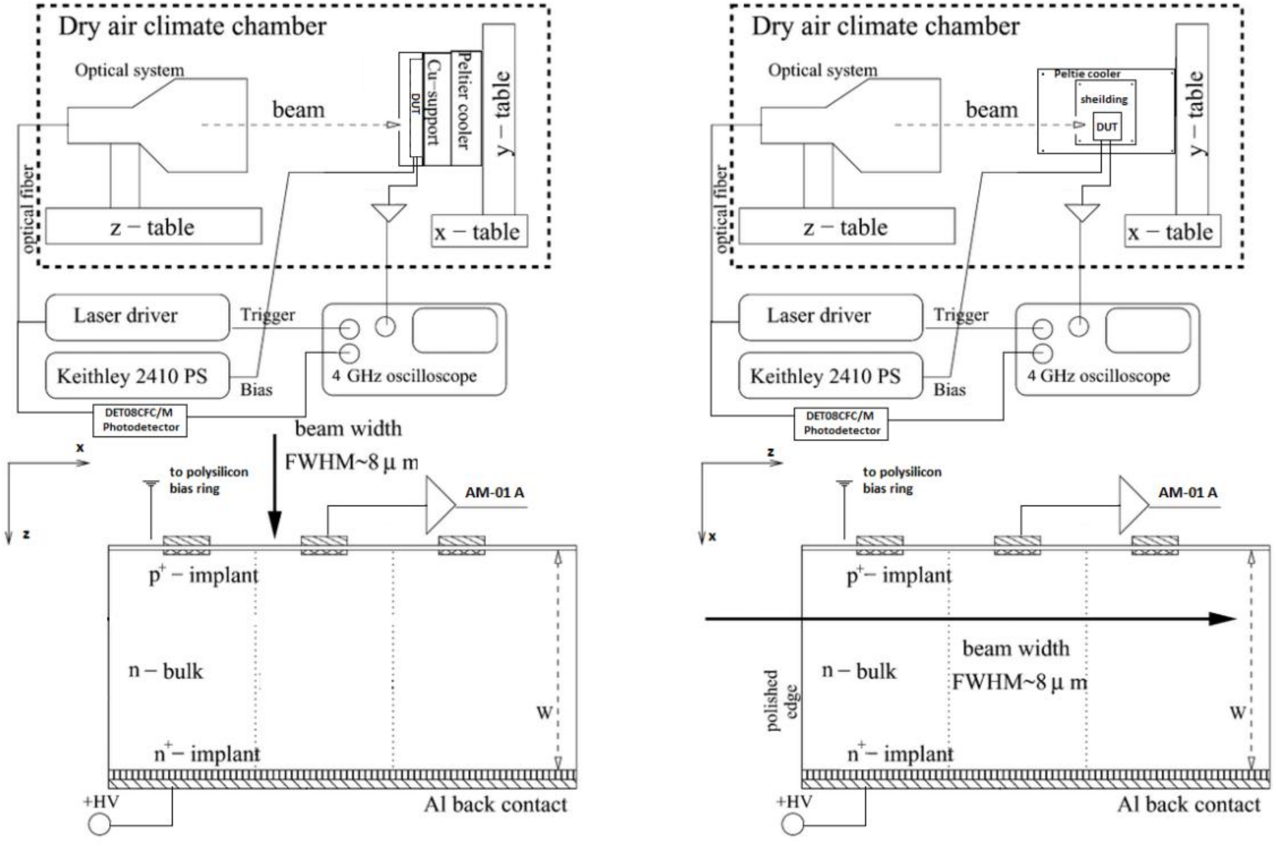


(b) Edge-TCT Configuration

Schematic view of the experimental setup

Top-TCT:
sensor was connected to a high voltage supply through a bias-T.
backside of the sensor was connected to the high voltage line
two of the AC-coupled readout strips close to the edge were directly connected to the wide band amplifiers
Amplifiers were connected to a power supply.
The induced current pulses were digitized and stored using the oscilloscope.

Experimental Setup



(a) Top-TCT Configuration

(b) Edge-TCT Configuration

Schematic view of the experimental setup

The second configuration can be used for both edge- and topTCT measurements

After laser pulse shot onto the detector edge or top side (that is the difference between edge- and top- TCT), electron-hole pairs are created in the bulk.
Charges start to drift in the electric field.
The electrical current is observed on the strips.

Experimental Setup

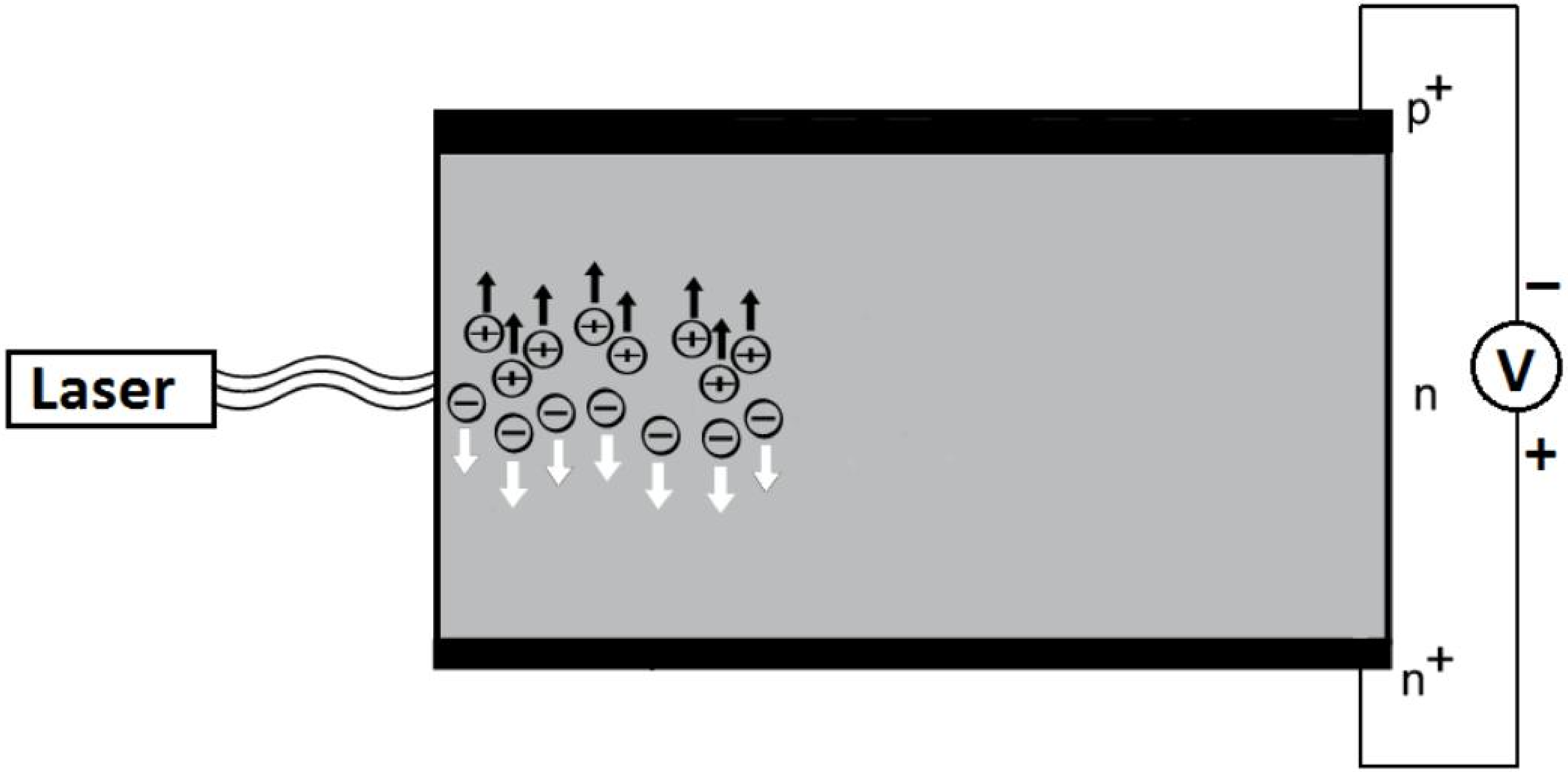
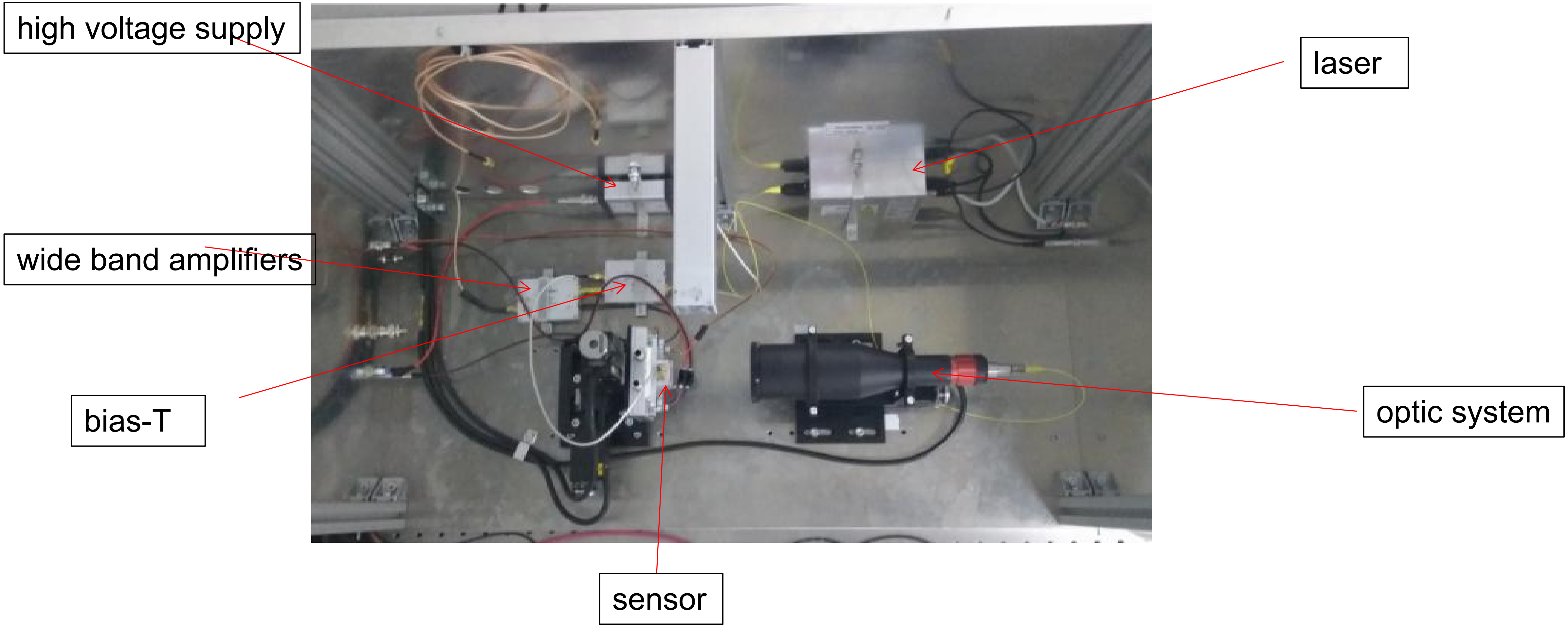


Figure 3: Schematic view of the charge creation process, Edge-TCT.

Experimental Setup



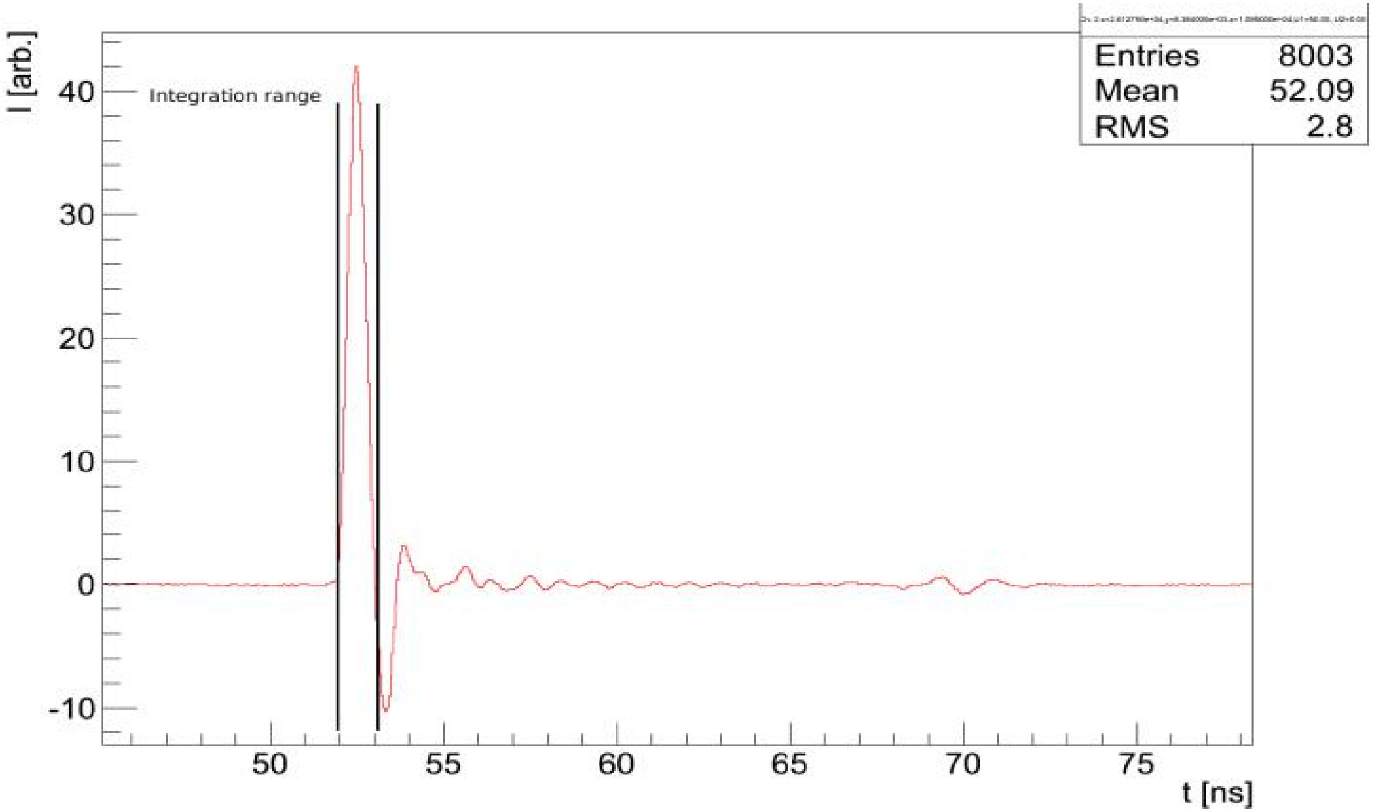
Lasers

Figure 4: Schematic view of the light splitter.

Two lasers produced by Particulars were used to create free electron-hole pairs in the sensor: an infra-red (1060 nm) fibre-coupled laser (LA-01 IR (FC)) and a red (640 nm)fibre-coupled laser (LA-01 R (FC)).

Light from the lasers transports through the fibers, passing the lightsplitter, which splits the light with fraction 10% to 90%. Successfully, 90% of the light aimed to the sensor and the 10% aimed to the photodetector

Red Laser



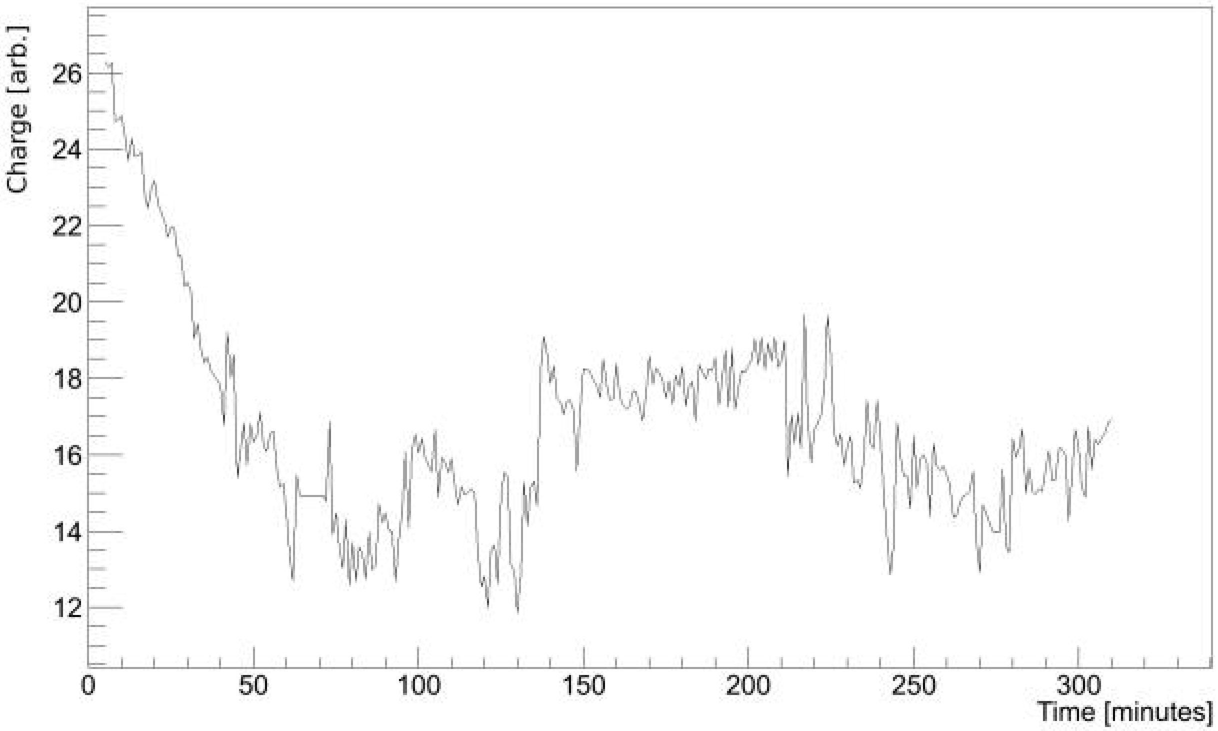
Signal from the photodetector, red laser (640 nm). Averaged over 50 waveforms

The charge in arbitrary units is extracted by integrating the signal in a fixed time range, which is shown with black lines in the figure

Question from Maoqiang:I don't understand what is "arbitrary units”?

answer:I think it is just the meaning of optional units,as long as the unit is directly proportional to the laser intensity.It can be the charge or the voltage.Maybe in this figure it is the electrics current I.

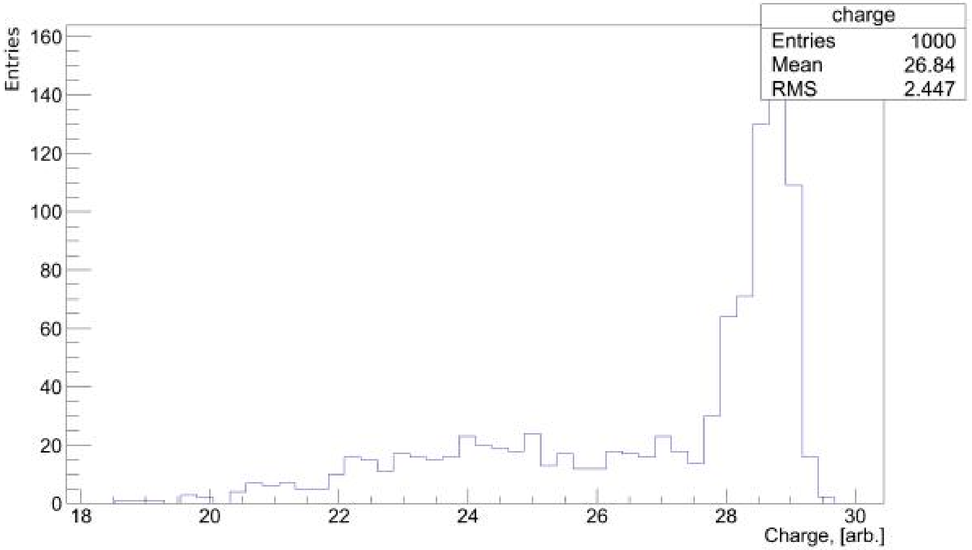
Red Laser



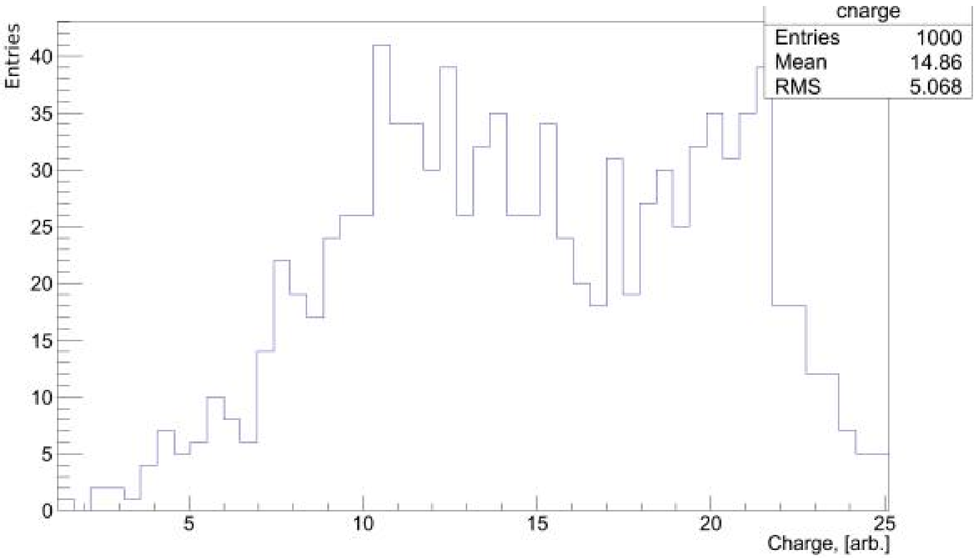
Red laser charge vs time, each point averaged over 100 waveforms

One of the most important problems for the red laser - high power decreasement in time, what is shown in the left figure: laser power decreases by factor of 2 during the first two hours of operation. Later the power still decreases but with smaller slope

Red Laser



(a) Beginning of the operation (3 minutes)

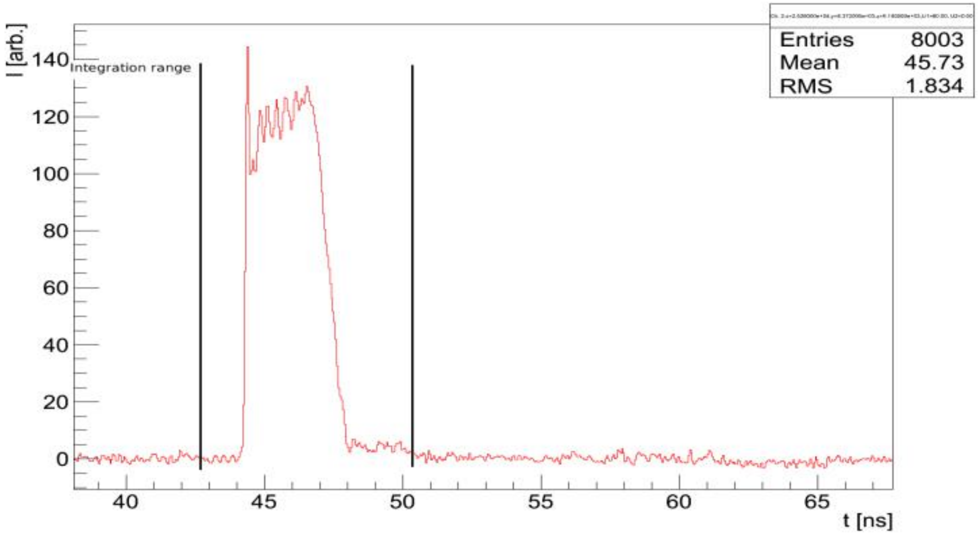


(b) After stabilization (5.7 hours)

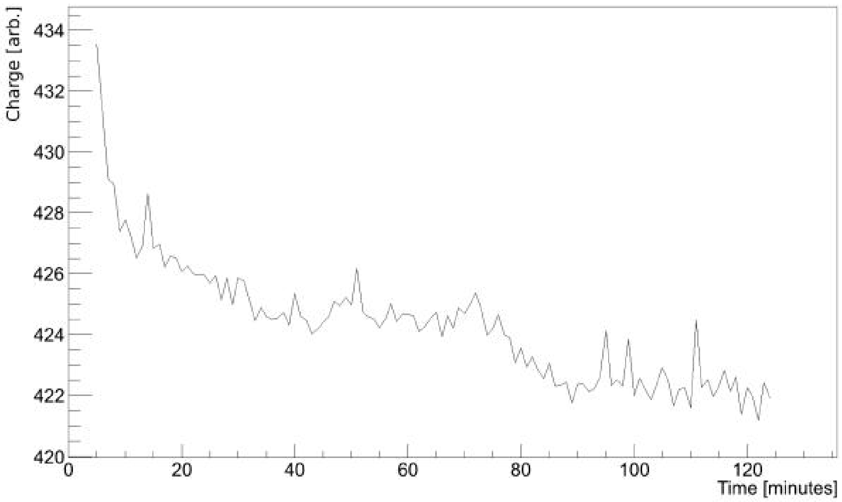
The RMS of the measured charge in the small time range (less than 2 minutes) was taken at the beginning of the operation and after 5.7 hours . The RMS is still 30% even after stabilization, the data has to be normalized by the amount of light measured using the photodetector.

Infra-red Laser

the same mesurement was done to the infra-red laser:



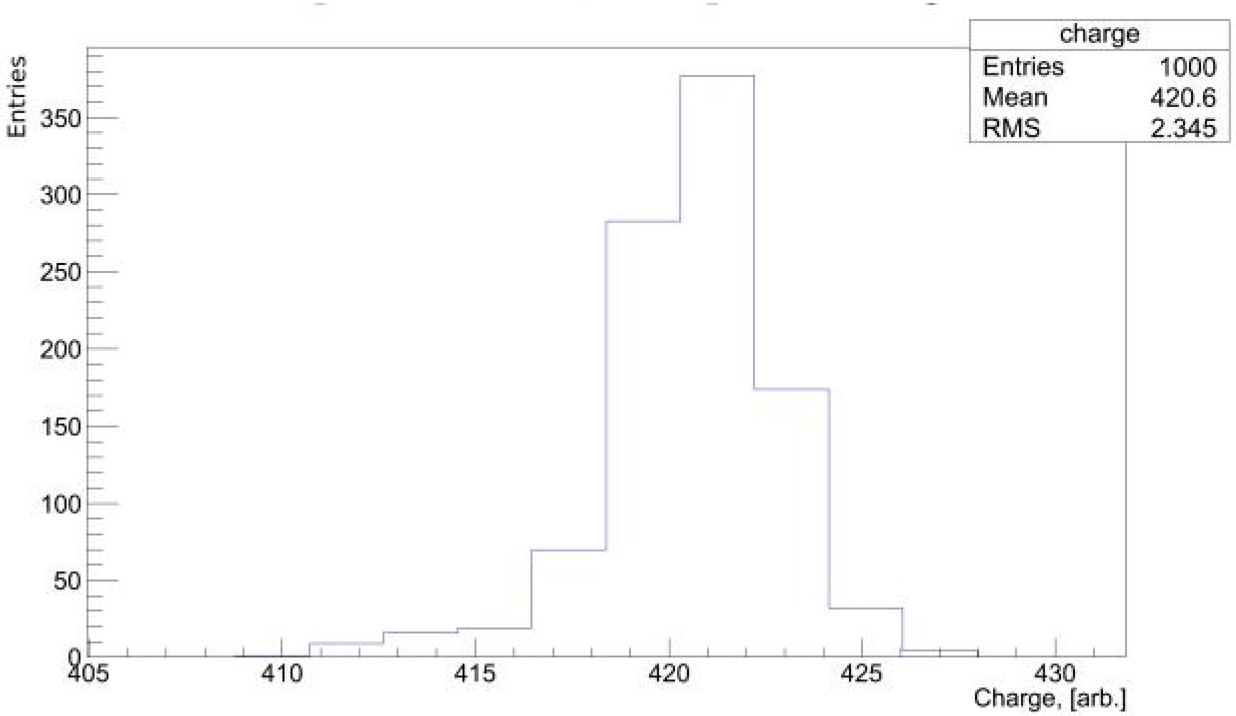
Signal from the photodetector, infra-red laser (1060 nm). Averaged over 50 waveforms



Infra-red laser power vs time, each point averaged over 100 waveforms

The power decreasement of the infra-red laser even at the beginning of operation is small - power drops only by 3% during the first two hours of operation.

Infra-red Laser



Infra-red laser power deviation measured in a small time window after 2.2 hours of operation.

The same is for the RMS: after 2.2 hours of operation infra-red laser shows the deviation of 0.5% comparing to 1% (not shown) at the beginning of operation.

Laser

Question from Lingteng: why we need two kinds of lasers?

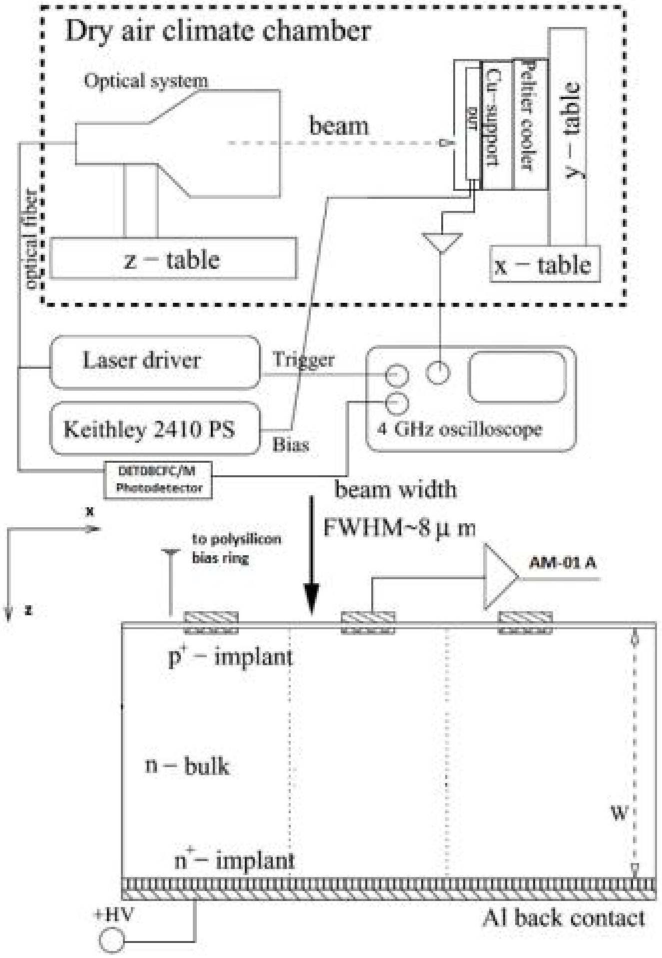
My answer：

Because different laser can shot the sensor in different depth.

$E = hc/\lambda$

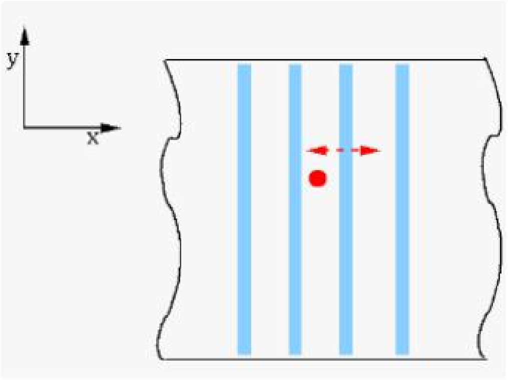
in this experiment, the infra-red can only shot in the surface of the sensor, but the red-laser can shot deeper.

Top-TCT

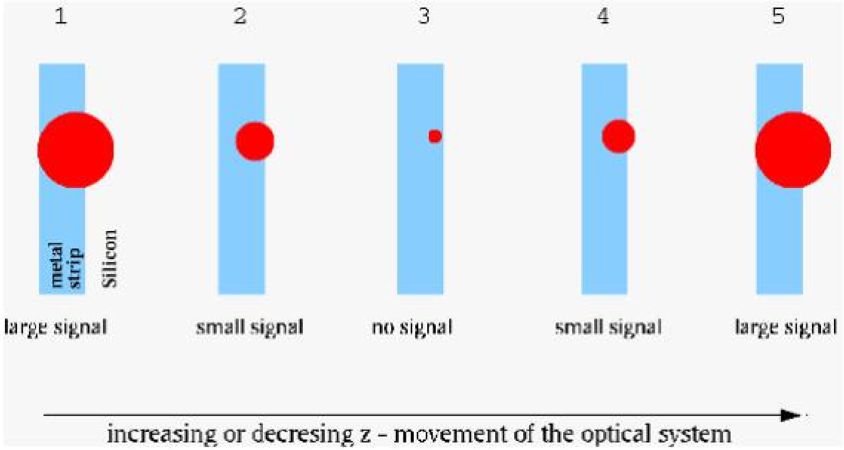


- Top-TCT is defined by illuminating of the sensor top surface. Top-TCT is used to extract such quantities as the depletion voltage, velocity of the charge carriers, which is used for calculation of the mobilities of electrons and holes.

Top-TCT Focus Search



(a) Scan along X axis.



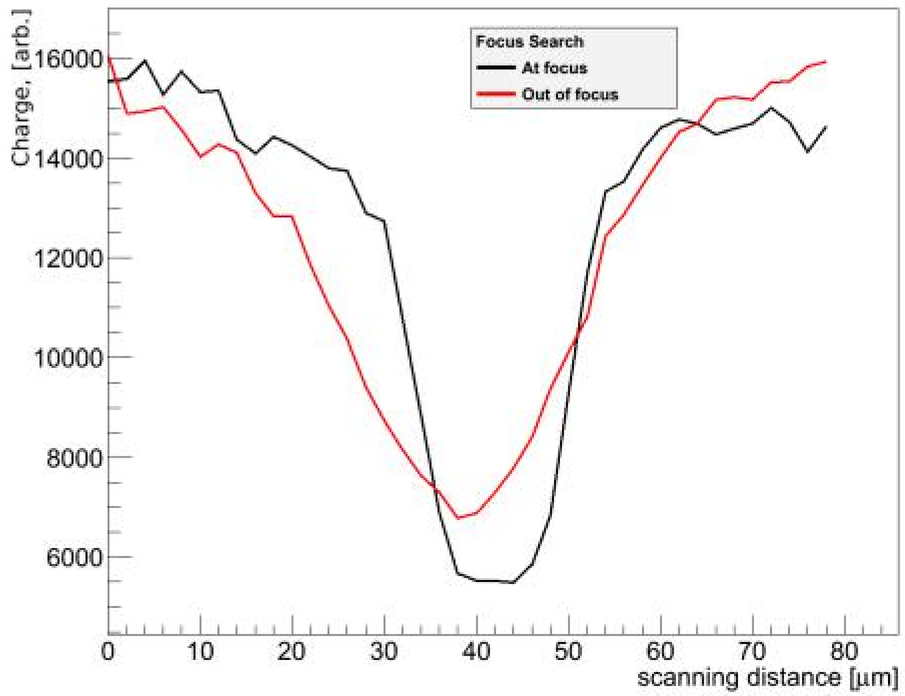
(b) Changing of the beam spot size due to the different optical distances.

Schematic representation of the focus search method for a strip detector

when moving the beam spot along the X axis, less charge will be observed at the strip region- part of light will be reflected from the strip.
Then, by changing the optical distance,the size of the beam spot can be changed(Figure(b))

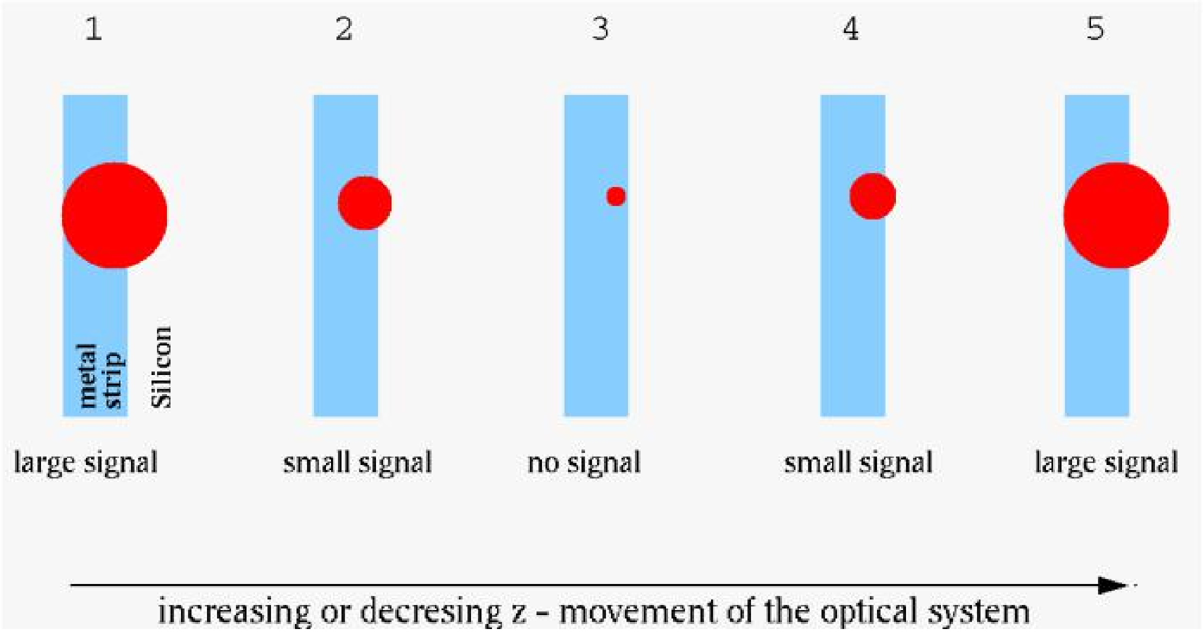
Question from Xin:Why “less charge will be observed at the strip region” and why “the size of the beam spot can be changed”?
Answer:the strip is metal, the second question,bacuase the laser beam is not absolutely linear, the beam spot has some distribution, this is why should we find the focus.The beam spot is more smaller, the laser is more stronger.

Focus Search

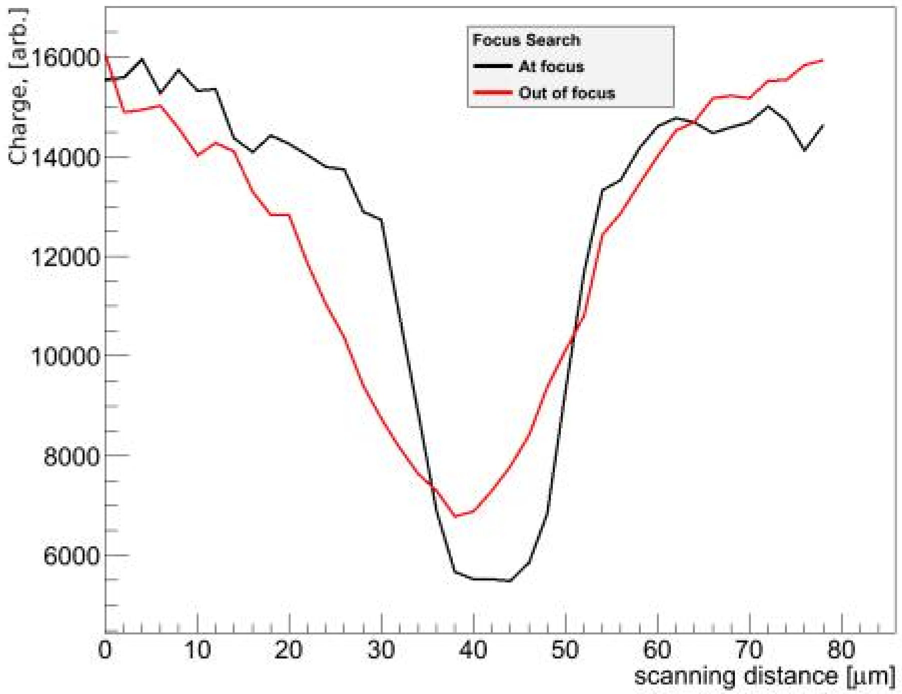


Scans for focused and un-focused beam, Top-TCT

Question from Tao:why the beam at focus decreases quickly,while the beam out of focus decreased slowly?
Answer:Because this means that the focused beam spot is smaller than un-focused beam spot. The un-focused beam spot need move longer distance from the metal strip to the silicon-region.

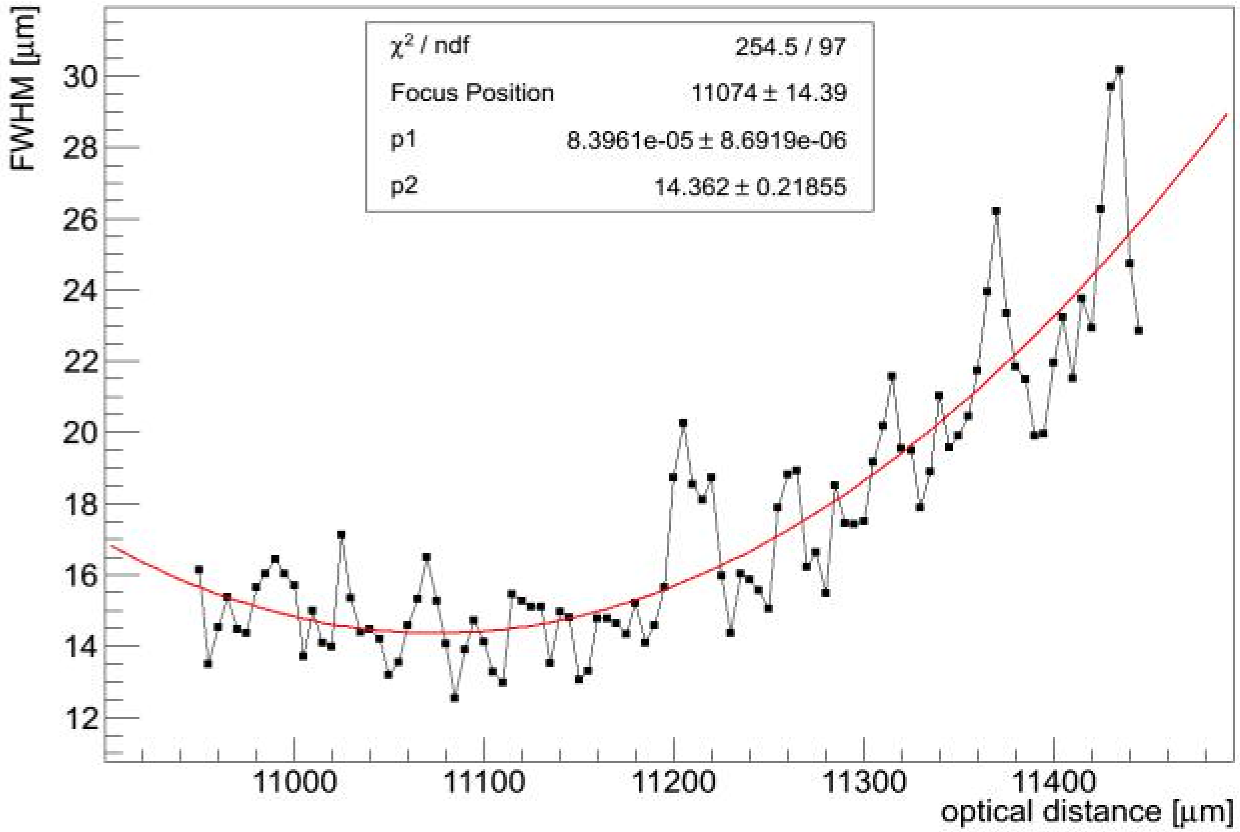


Focus Find



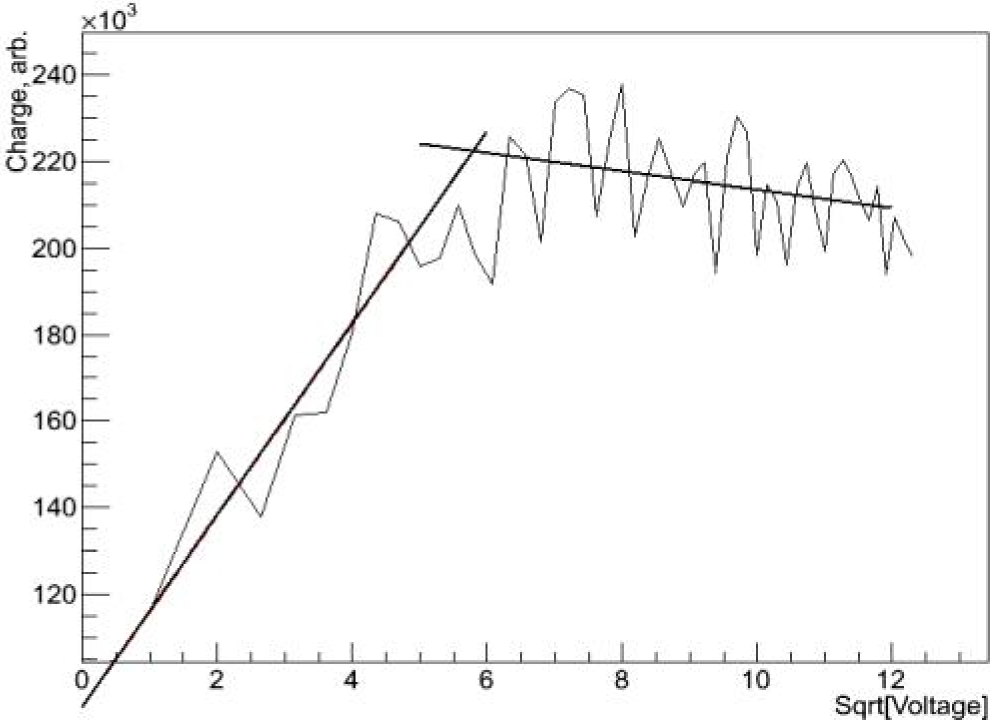
- This curve could be fitted using the error function, and the FWHM value can be extracted from the fit. When the beam spot gets smaller, the same happens to the FWHM value.

Focus Find



The FWHM is plotted for different optical distances and fitted with the second-order polynomial.
The position with the smallest value of the FWHM is defined to be a focus position.

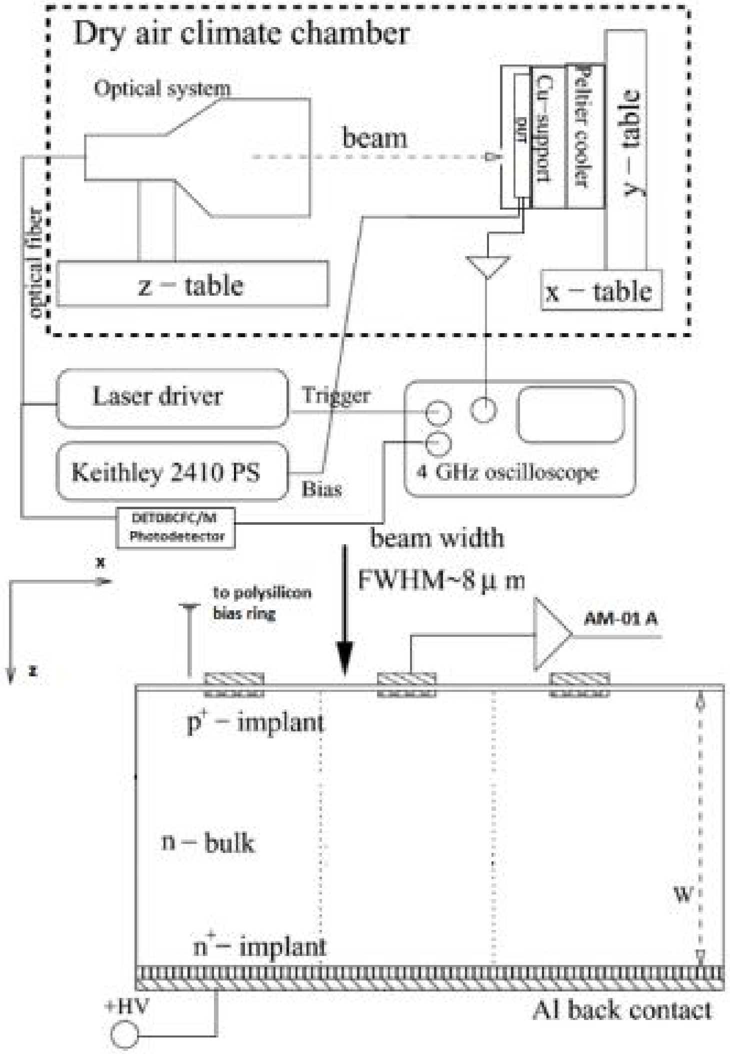
Depletion Voltage



To find the depletion voltage, the charge collected at certain position between strips for the different bias voltages has to be integrated. After reaching the depletion voltage charge stops to increase and becomes constant. Plotting the charge with square root of voltage, the dependency can be obtained, which has to be fitted with two lines - one fits the rising part, second one - the constant part, when all charge is collected (detector is fully depleted). The intersection of these curves gives the value of the full depletion voltage.

Depletion voltage search, Top-TCT

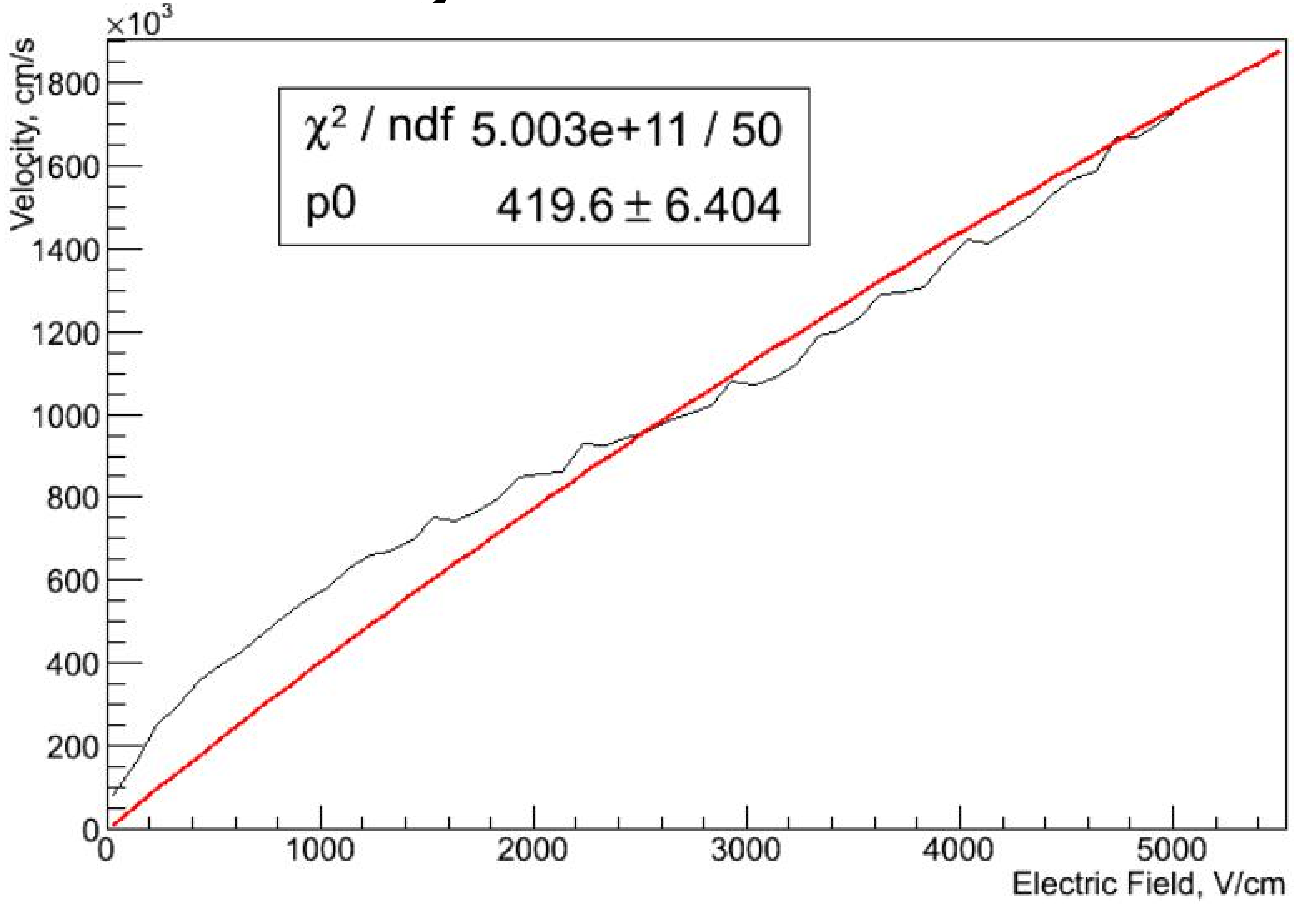
Mobility



The TCT is used to calculate the charge carrier mobility.

The 80% of the red light is absorbed after 5 μm of silicon - this is used to measure the charge carrier mobility of different type.
After applying positive voltage to the strips (p-type bulk sensor from Particulars) and negative to the back side, holes drifting to the back side and electrons to the strips. Shooting from the top side: electrons are collected immediately, and the transit time is the time of the hole drift.

Mobility



The average hole drift velocity for p-type sensor from Particulars

he average hole drift velocity through the sensor is given by $\frac{W}{t_{transit}}$, where $t_{transit}$ is the duration of the signal, W is the thickness of the sensor.

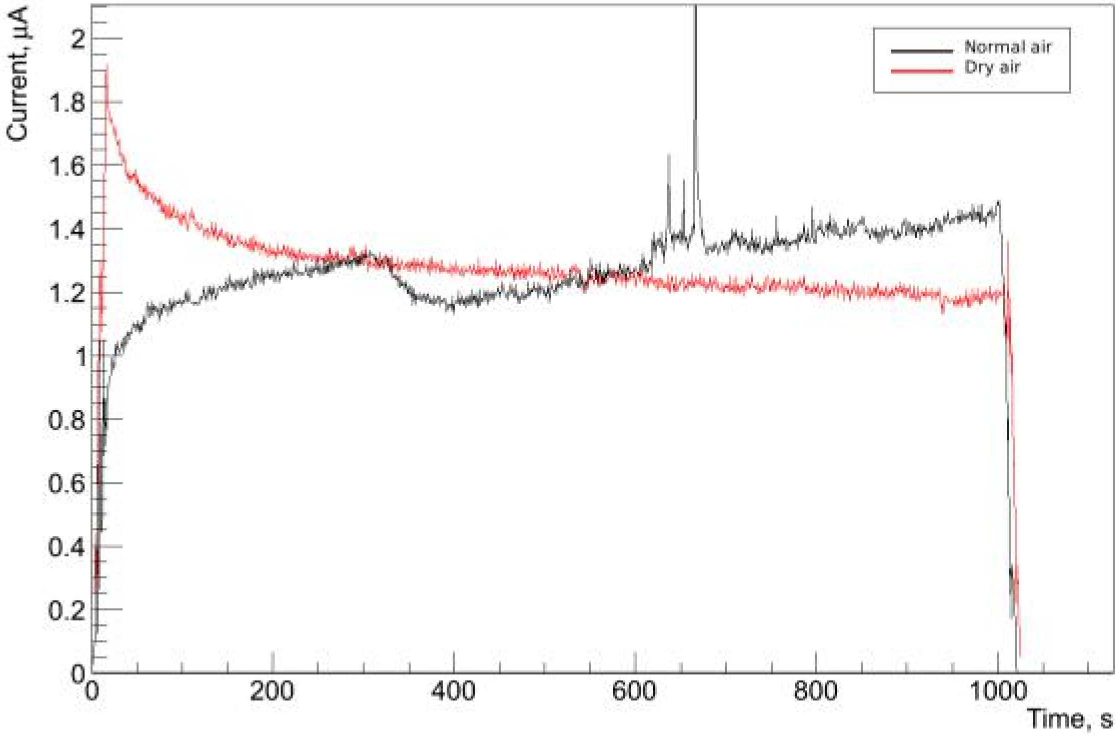
For the sample sensor from Particulars the average hole drift velocity is shown in left figure. The fit function is given by (1), according to the (2), where v_{sat} is the holes saturation velocity, μ_0 is the low-field mobility, E is the electric field.

$$f(E) = \frac{p_0 E}{1 + \frac{p_0 E}{v_{sat}}}. \tag{1}$$

$$v_h(E) = \frac{\mu_0 E}{1 + \frac{\mu_0 E}{v_{sat}}}. \tag{2}$$

Edge-TCT

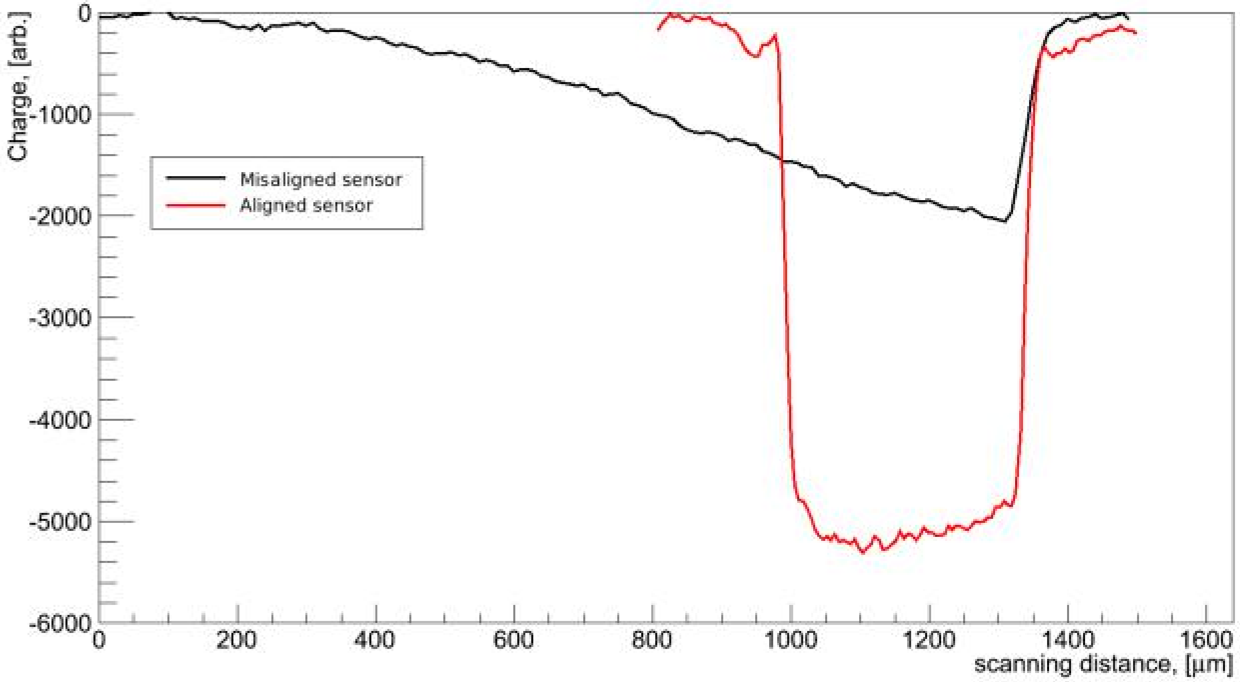
- Leakage Current



Leakage current of the test sensor CE2339 as a function of time in different conditions, Ubias = 90 V.

The part before 300 seconds differs due to the different starting conditions, but the following data shows several small breakdowns for normal conditions, which could be explained by the presence of dust and water molecules

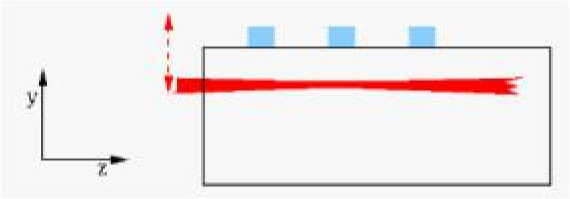
Alignment



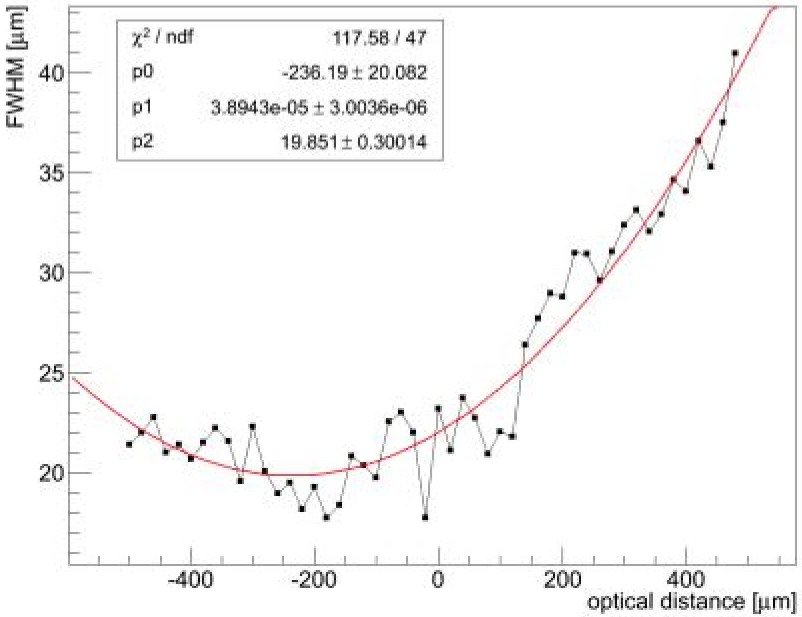
Edge-TCT scan for aligned and misaligned sensor.
Sensor thickness is 280 μm

The misalignment appears as the different thickness of the detector, which should be constant (280 μm for CE2339 sample). The amplitude is smaller due to the fact that less light absorbed when sample is misaligned.

Edge-TCT Focus Search



(a) Schematics

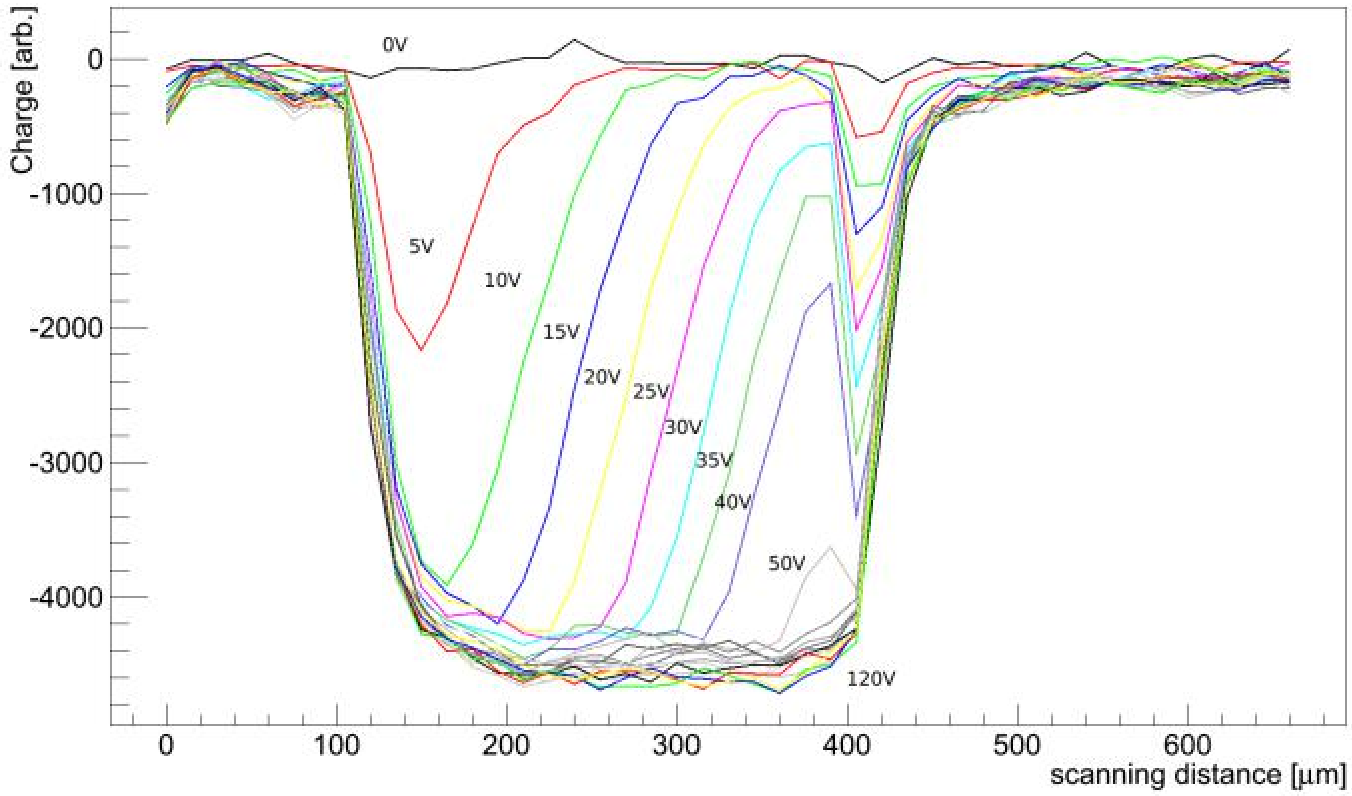


(b) FWHM as a function of optical distance, Edge-TCT.

Edge-TCT laser beam focusing

To find the focus with Edge-TCT the same approach is used as for the Top-TCT measurements. Instead of scanning and passing the strips, scan is done along the entire detector thickness.

Depletion Voltage



Charge profiles for different voltages, Edge-TCT

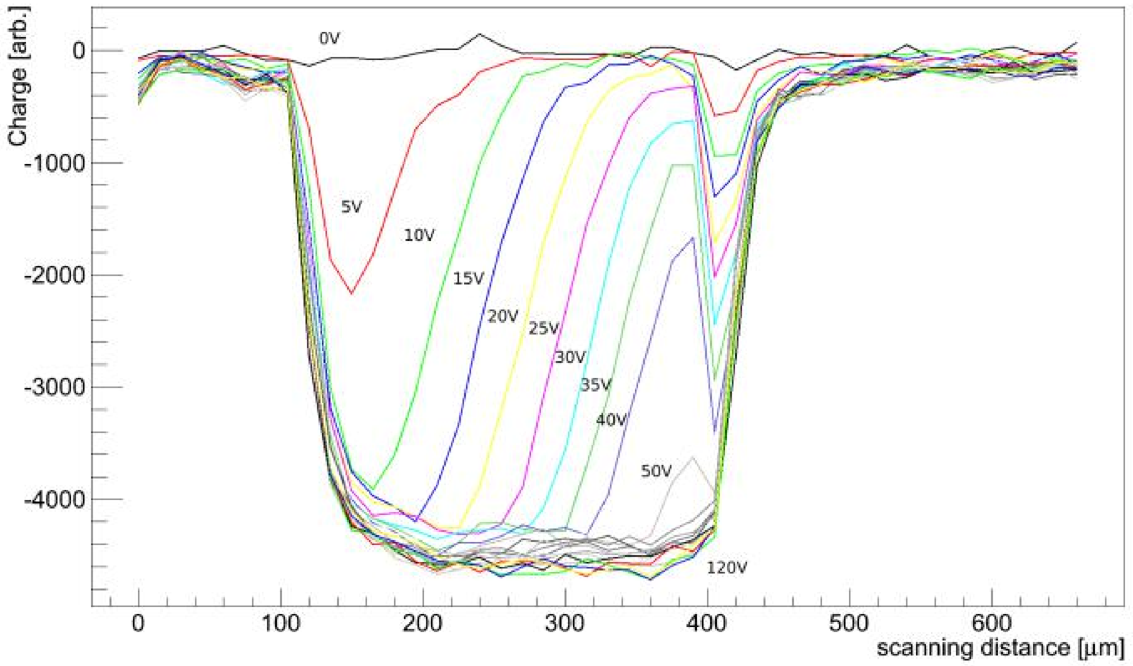
When the detector is not fully depleted the signal near the bottom of the detector still can be observed due to the different doping concentrations in the n and n+ layers

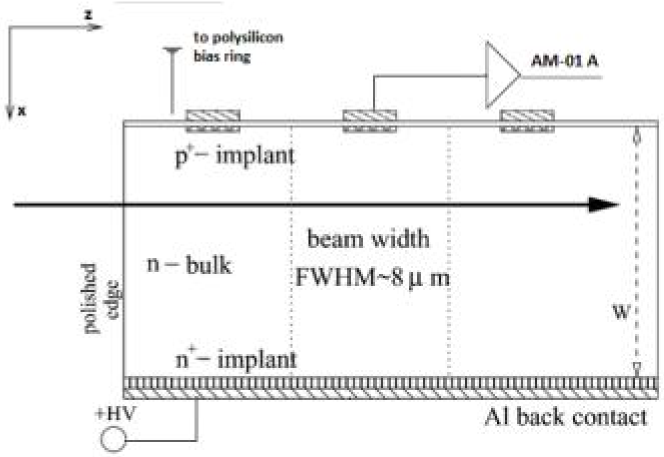
Question from Suyu:1. considering they're studying the effection of irradiation on silicon, why don't they use more powerful laser like violet or ultraviolet laser ?

2. in Figure 21, what causes the second peaks around 400 \mu m?

answer:1.I think more powerful laser will damage the silicon,this isn't we want to see.And our main purpose is the depletion voltage measurement ,mobility and so on.

Depletion Voltage





2.I think because the second peak position is near the negative pole, holes drift to the negative pole and then offset some electrons.

Electric Field Profiles

The induced current in the detector can be expressed by (3), where e_0 is the elementary charge, $N_{e,h}$ is the number of created e-h pairs near the strip, A is the amplifier amplification, $\tau_{eff,e,h}$ is the effective trapping time, $v_{e,h}$ is the drift velocity and E_ω is the weighting field. For simple pad detectors term $\overrightarrow{v}_{e,h}(t) \cdot \overrightarrow{E}_\omega$ is simply $\frac{v_{e,h}}{W}$, where W is the detector thickness.

$$I_{e,h}(t) = Ae_0 N_{e,h} \exp(-\frac{t}{\tau_{eff,e,h}}) \overrightarrow{v}_{e,h}(t) \cdot \overrightarrow{E}_\omega. \qquad (3)$$

The measured current amplitude immediately after charge carrier generation $(\exp(-\frac{t}{\tau_{eff,e,h}}) \approx 1)$ can be expressed as:

$$I(y, t \sim 0) = Ae_0 N_{e,h} \frac{v_e(y) + v_h(y)}{W} = Ae_0 N_{e,h} \frac{\mu_e(y) + \mu_h(y)}{W} E(y). \qquad (4)$$

Electric Field Profiles

From this point there could be two ways: one way to extract the electric field profiles is to use the estimation of the charge carriers number from the laser power, measured using the photodetector. But the problem is that one need precise values of the amplification, $N_{e,h}$ - which is difficult to estimate due to the loses in the optical system, in the silicon, etc. The second way is to use formula (5) as the constraint and to solve numerically the equation (4). That was done using the bisection method[7].

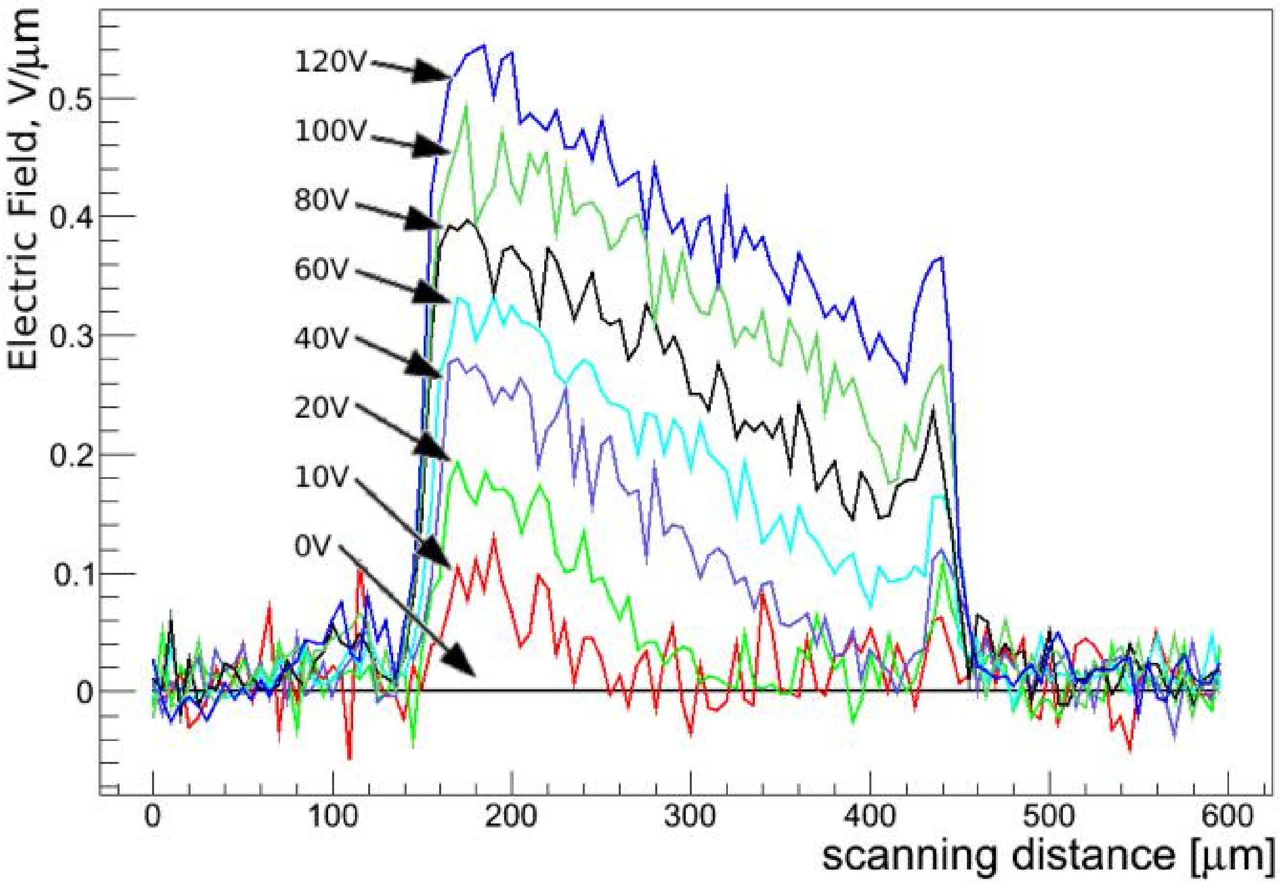
$$V_{bias} = \int_{0}^{W} E(y)dy. \tag{5}$$

As the result the electric field profiles were extracted and are presented In Figure 23.

Also the velocity profiles could be extracted using equation (6), where v_{sat} is the holes saturation velocity, μ_0 is the low-field mobility, E is the electric field.

$$v_h(E) = \frac{\mu_0 E}{1 + \frac{\mu_0 E}{v_{sat}}}. \tag{6}$$

Electric Field Profiles



Field profiles for different voltages, Edge-TCT

Electric Field Profiles

- Question from Ryuta:In section 5.6 (Electric Feild Profiles), there is equation (3).Could you explain a little bit detail about the equation (3),especially, the weighting field ?

The Shockley-Ramo theorem

- The induced charge Q_{qi} on electrode i by a point charge q located at position x_0 is

$$Q_{qi} = -q \cdot \psi_i(\vec{x}_0)$$

- With **weighting potential** ψ_i defined by

$$\nabla^2 \psi_i(\vec{x}) = 0 \qquad \phi|_{S_j} = \delta_{i,j}$$

- The current $I_{qi}(t)$ to electrode i is then given by

$$I_{qi} = \frac{dQ_{qi}}{dt} = -q \cdot \left(\frac{\partial \Psi_i}{\partial x_0}\frac{dx_0}{dt} + \frac{\partial \Psi_i}{\partial y_0}\frac{dy_0}{dt} + \frac{\partial \Psi_i}{\partial z_0}\frac{dz_0}{dt} \right)$$
$$= q\, \vec{E}_{\Psi i}(\vec{x}_0) \cdot \vec{v}_{drift}$$

- The function $\vec{E}_{\Psi i} = -\nabla \Psi_i$ is called the **weighting field**

It's a bit hard to explain this equation, especially in english.you can see more detail from these slides: http://ns.ph.liv.ac.uk/EGAN/files/tuesday/Bruyneel-EGAN-School-P1

We let $v_{collector}$=1, v_{others} =0,than you can get weighting potential and weighting field.

Thank you!