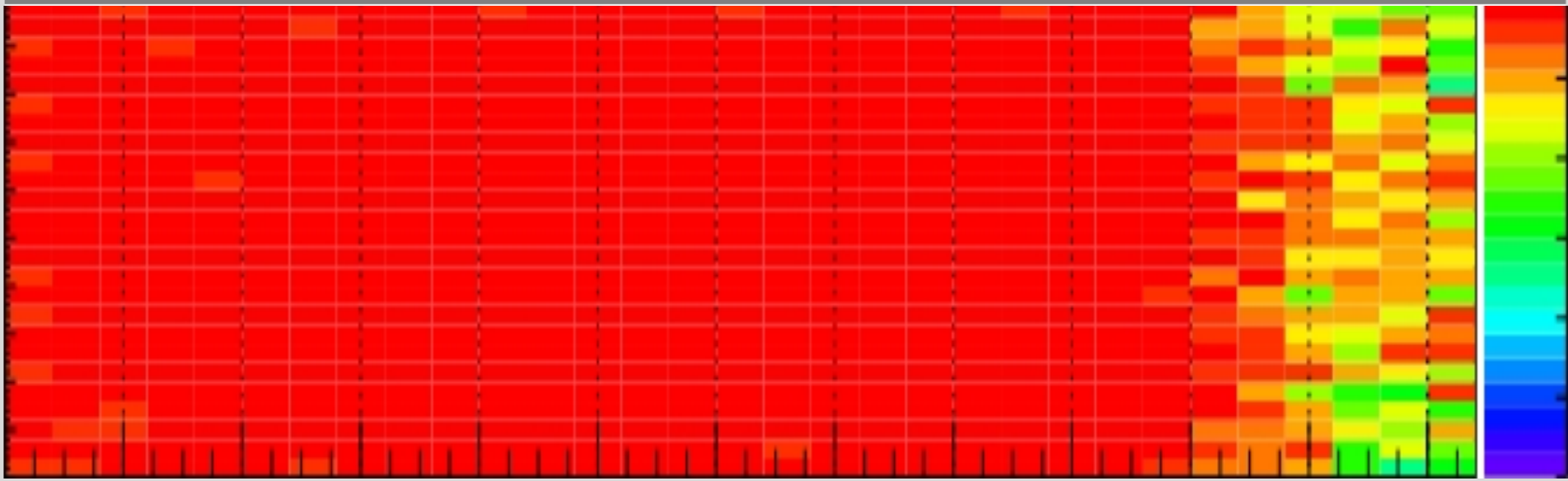
Charge collection & electric field properties of irradiated thin n-in p planar pixel sensors

Natascha Savić[1], J. Beyer[1], A. La Rosa[1], A. Macchiolo[1], R. Nisius[1],
B. Hiti[2], G. Kramberger[2], I. Mandić[2], M. Petek[2]
[1]Max-Planck Institute, [2]Jožef-Stefan Institute

30th RD50 Workshop, Krakow, June 5th-7th 2017

MAX-PLANCK-GESELLSCHAFT

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

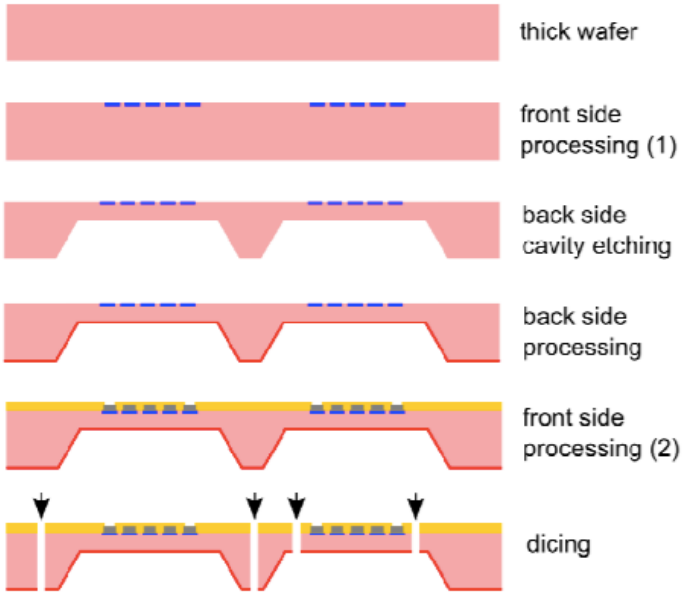


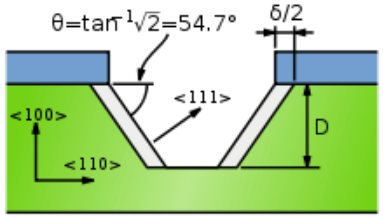
Overview

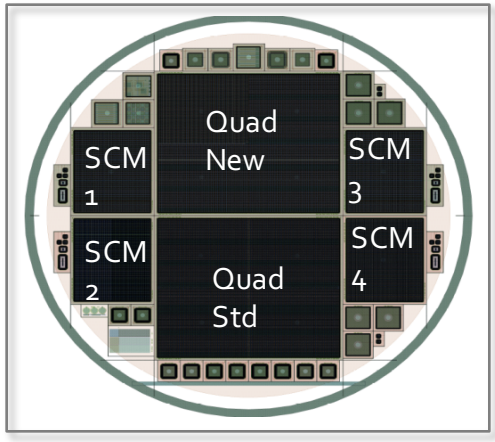
- **Charge collection of CIS n-in-p pixel sensors**
  i. TCT studies with (un-)irradiated sensors with a thicknesses of 100 and 150 µm
     i. Irradiation level up to $1x10^{16}$ n_{eq}/cm^2
     ii. Standard 50x250 μm^2 pixel cell and 50x50 μm^2 pixel implants
  ii. Comparison to source scan and test beam measurements
- **Electric field properties of CIS n-in-p pixel sensors**

CIS Production

- Thin production on 4" wafers for 100 and 150 µm thick sensors
- Thinning technology without using support/handling wafer by anisotropic wet etching (KOH)

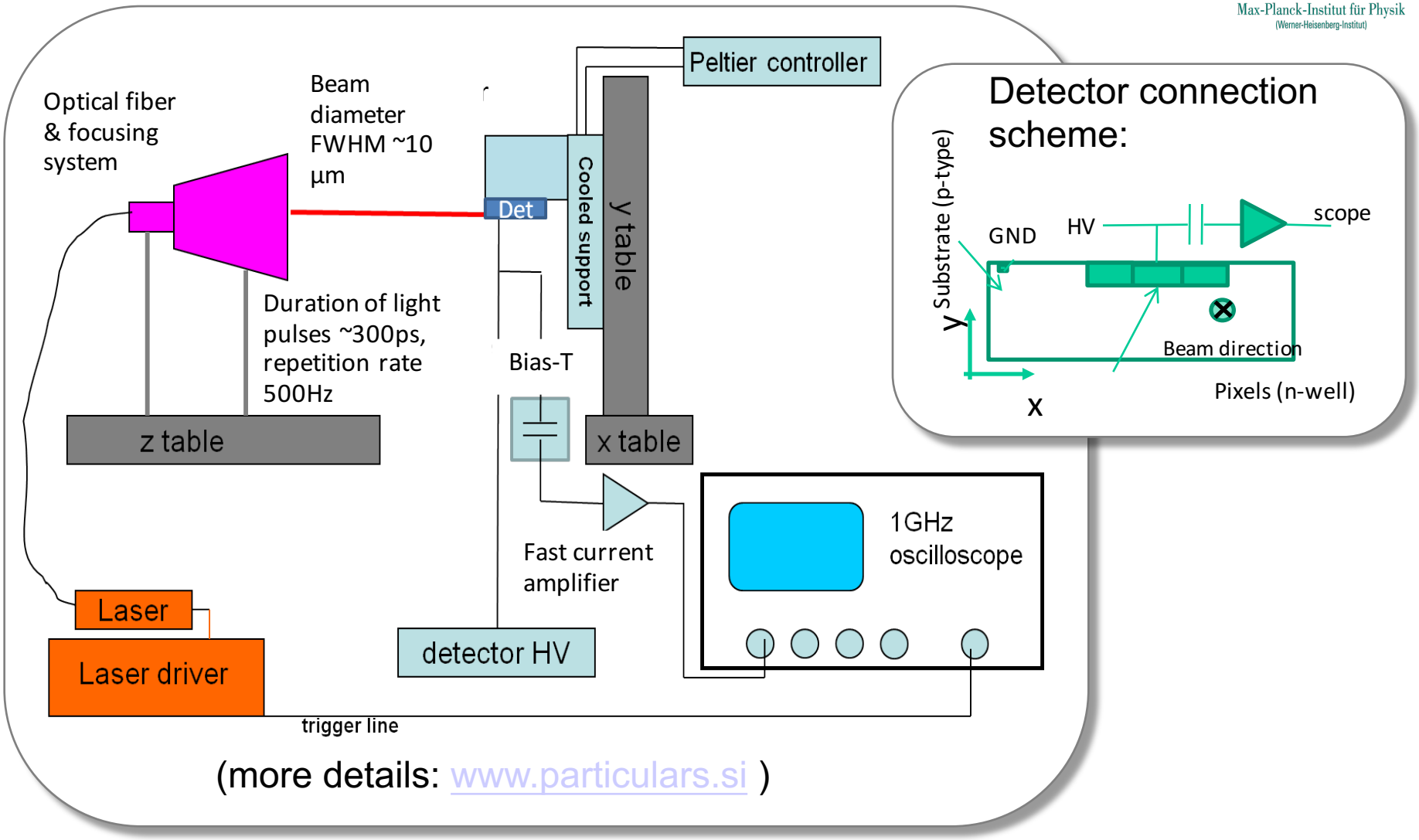






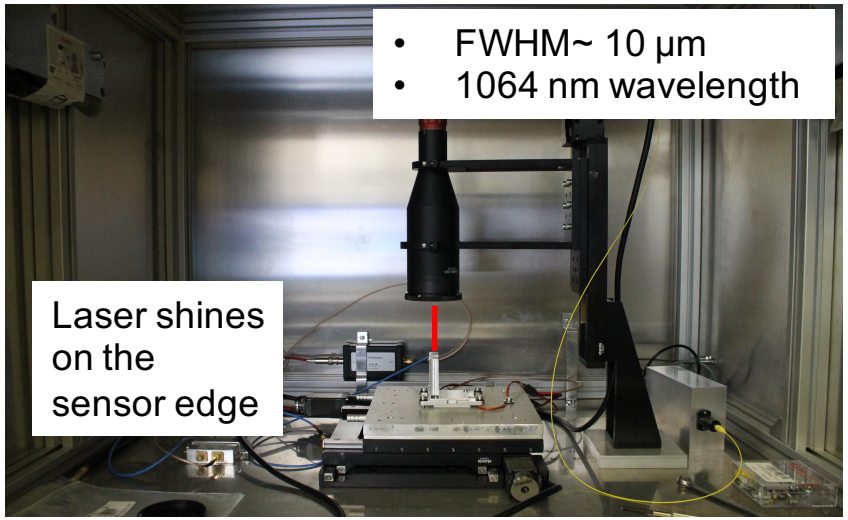
- **CiS4** standard FE-I4 pitch
  i. Pixel size : 50x250 µm²
  ii. Pixel matrix : 80x336
- **CiS4** with 50x50 µm² implants
  i. Pixel size : 50x250 µm²
  ii. Pixel matrix : 80x336

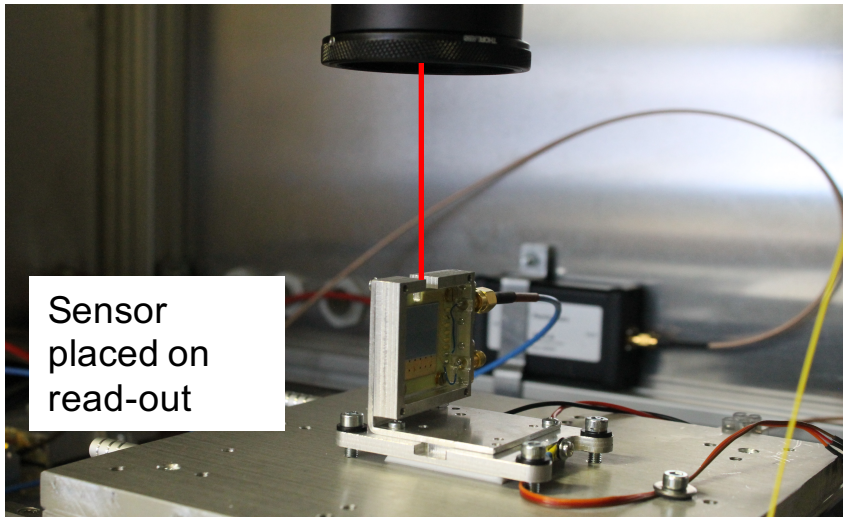
Edge-TCT: The measurement set-up

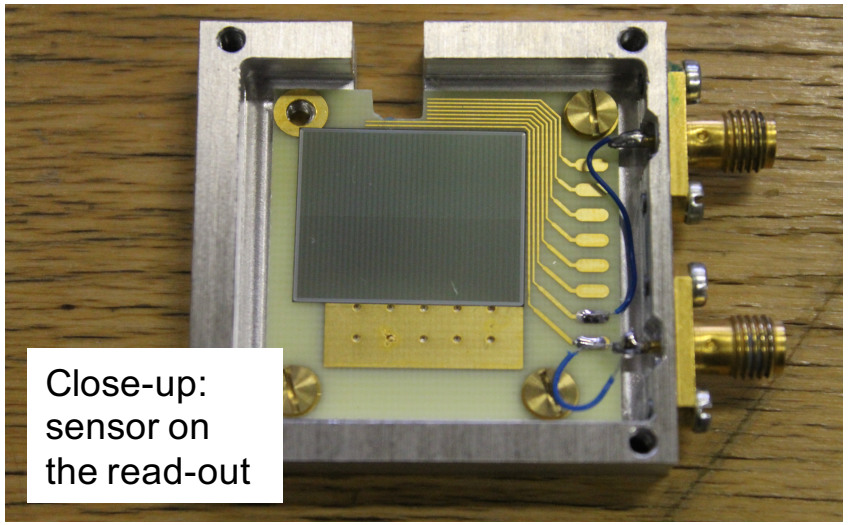


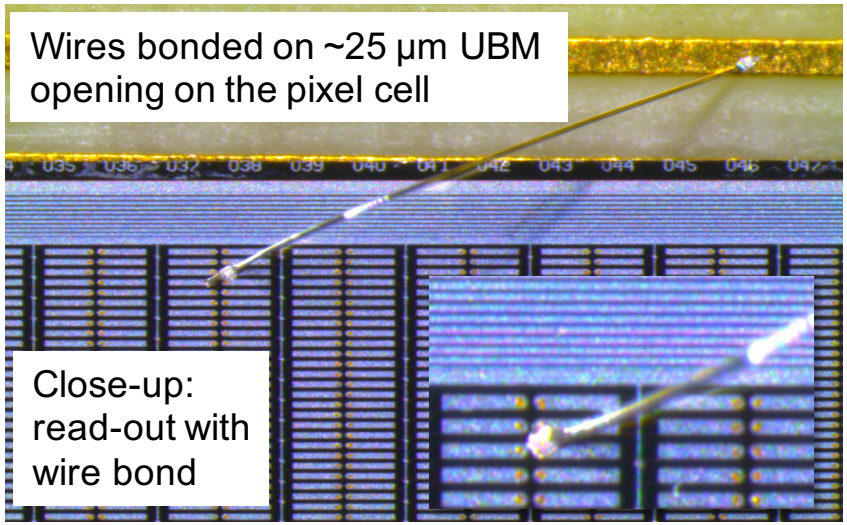
Edge-TCT: The measurement set-up

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)









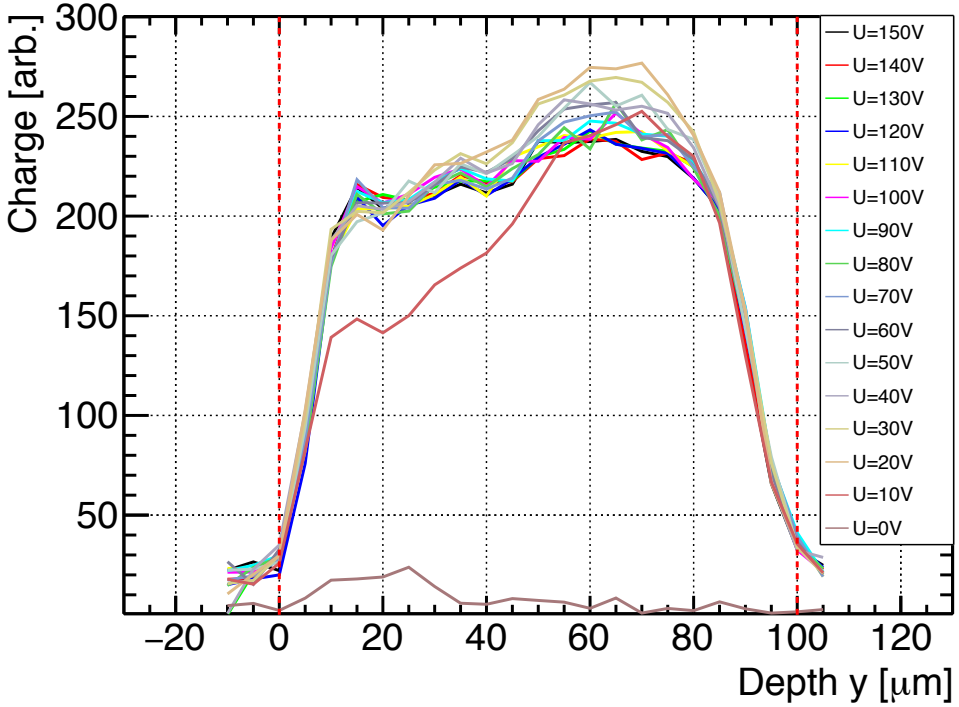
Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

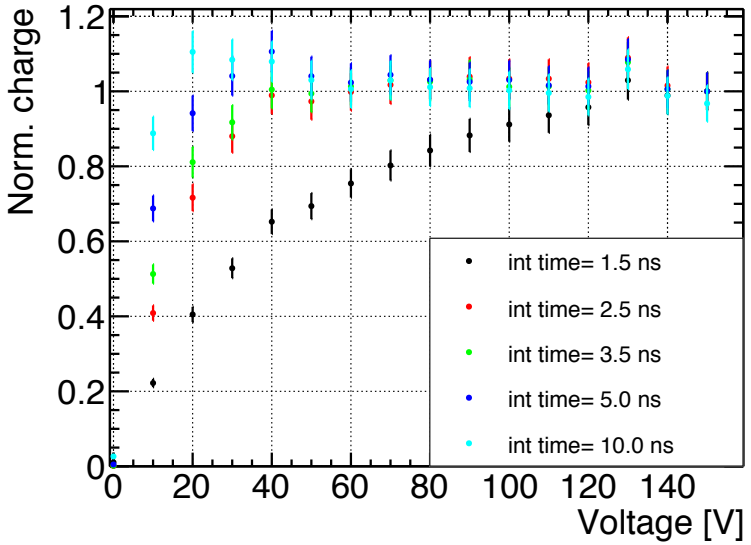
Results of a standard 50x250 μm^2 pixel cell in 100 and 150 μm thick sensors

Charge vs depth at no irradiation

100 µm

Max-Planck-Institut für Physik





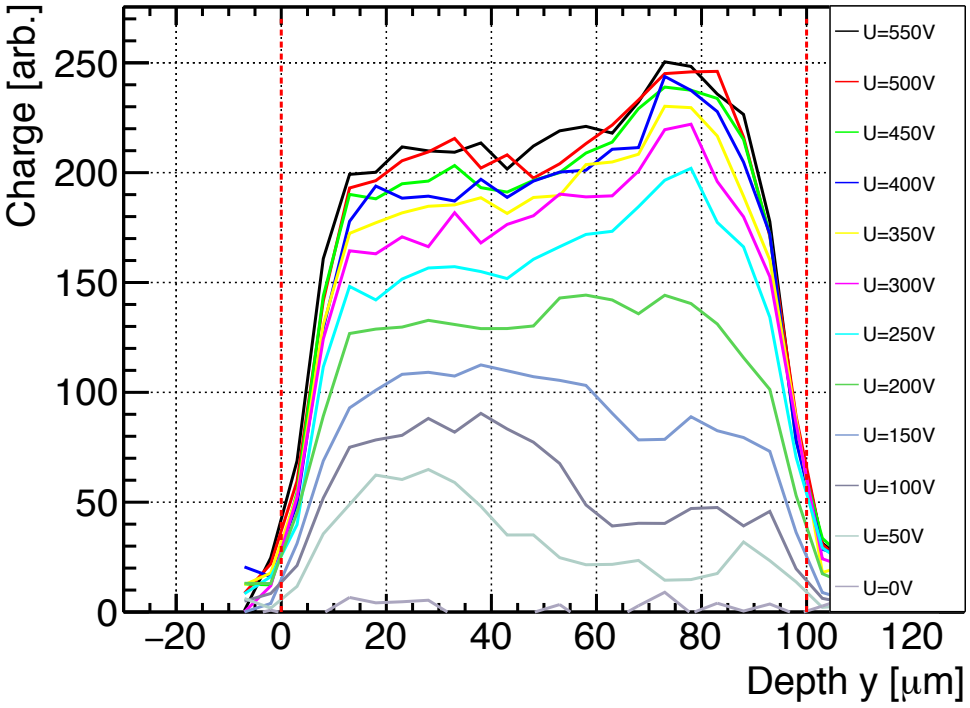
- Depletion voltage of around 20V fits well to expectations
- Depletion voltage changes artificially with integration time
  - Integration time t=10ns is chosen to be the most appropriate one

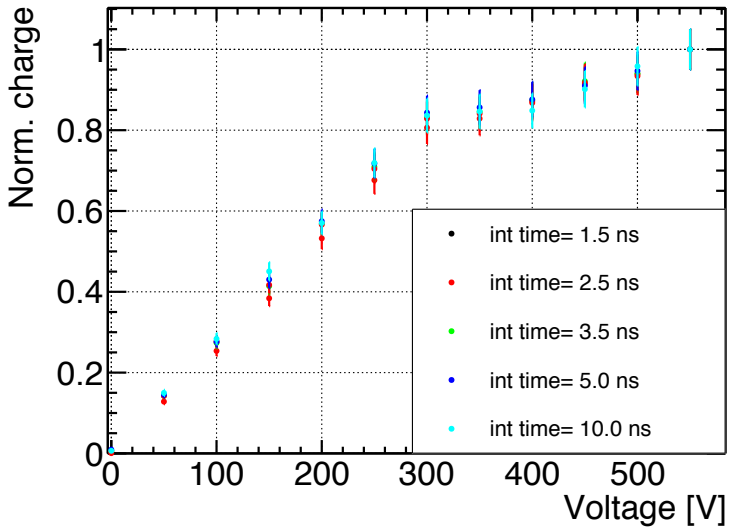
not irradiated

Charge vs depth at 5x10^{15} n_{neq}/cm^2

100 µm

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)





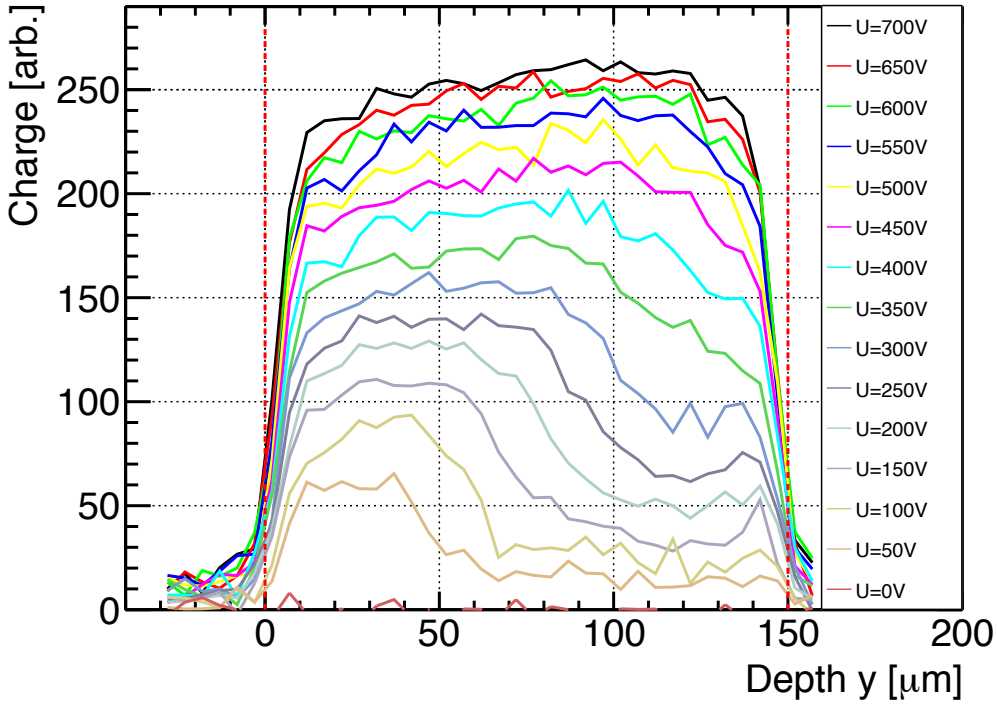
- Depletion voltage around 300V is in agreement with data from test beam measurements
- Comparison of different integration times shows similar charge collection behaviour

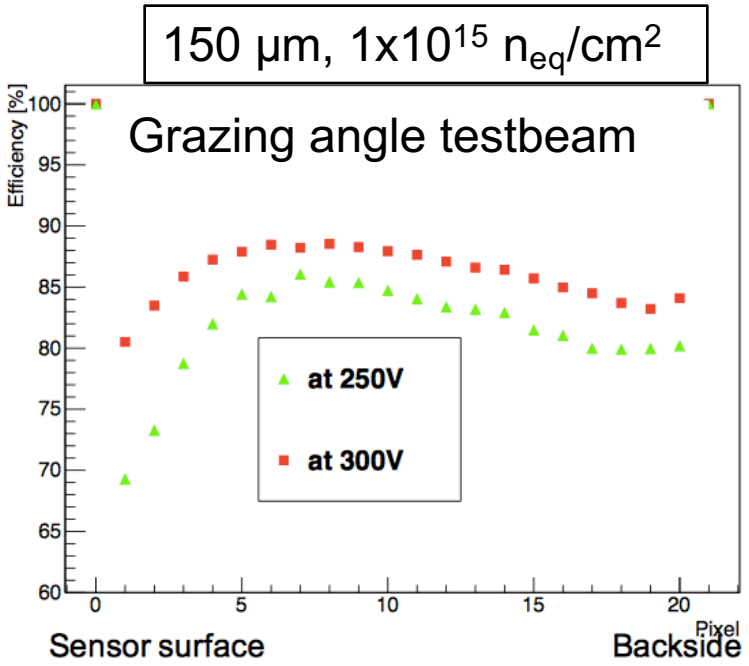
Irradiated to 5x10^{15} n_{eq}/cm^2

Charge vs depth at 5x10^{15} n$_{neq}$/cm^2

150 µm

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)





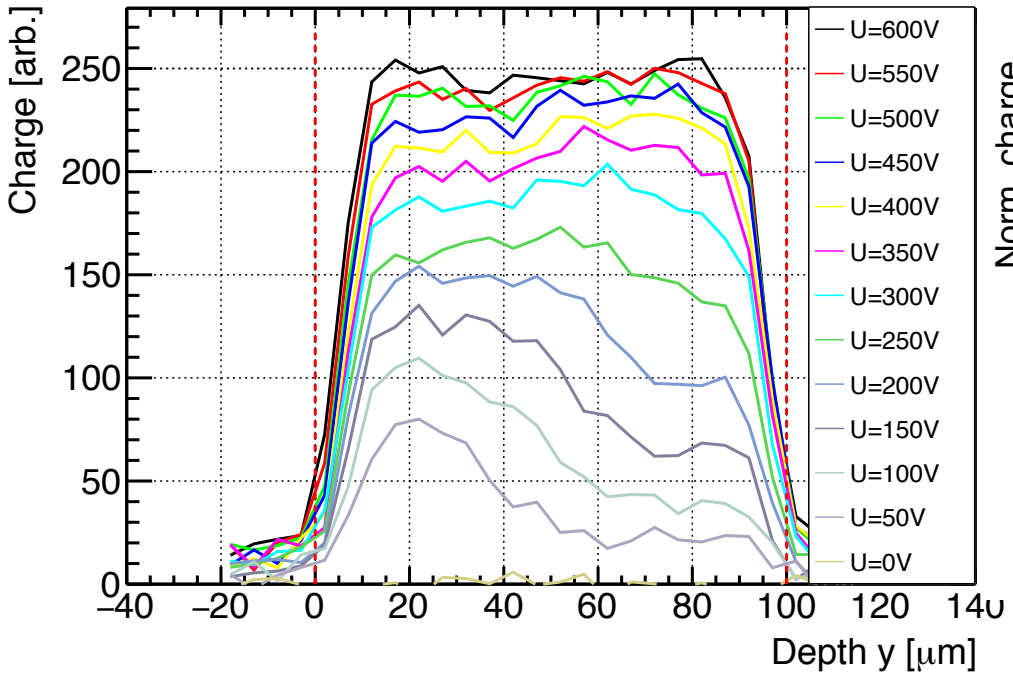
- Depletion around 500V (from the charge profile)
- Depletion voltage agree with test beam measurements
- Double peak also visible in test beam measurements at high incidence angle

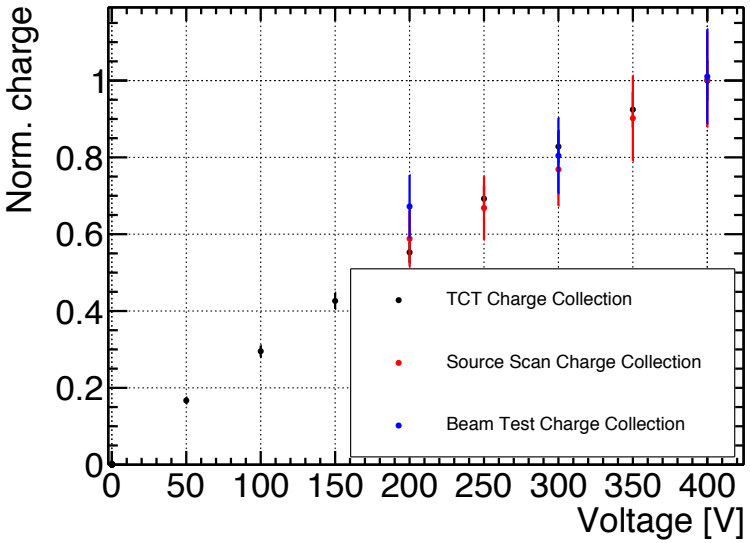
Irradiated to 5x10^{15} n$_{eq}$/cm^2

Charge vs depth 1x10^{16} n_{neq}/cm^2

100 µm

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)



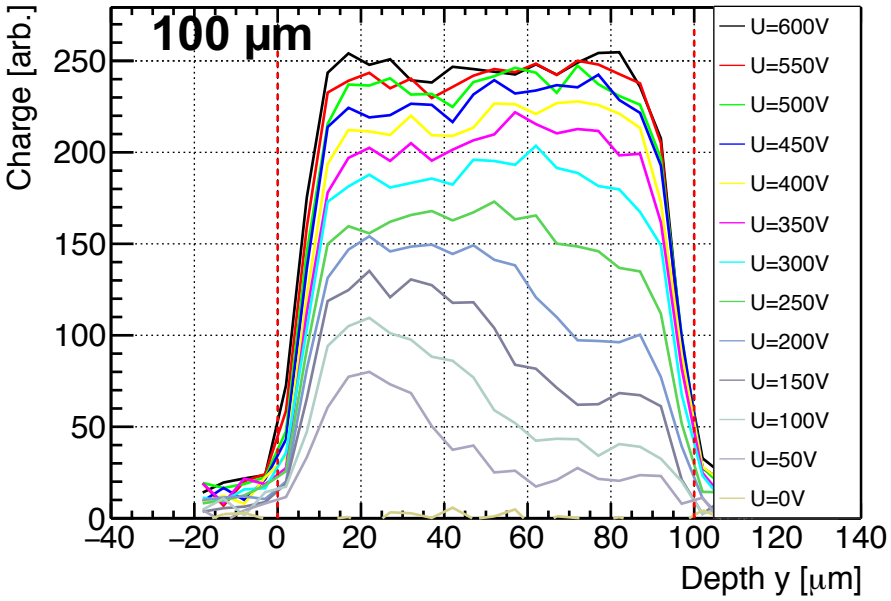


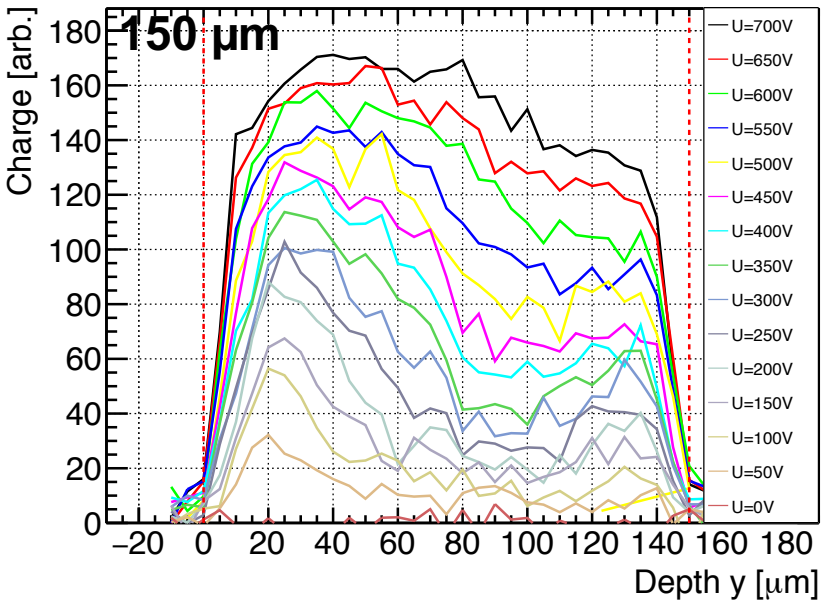
- Depletion voltage around 450V
- Flat charge collection throughout the sensor at higher voltages
- Comparison of normalized charge values of TCT, source scan and test beam measurements shows similar charge collection behaviour

Irradiated to 1x10^{16} n_{eq}/cm^2

Charge vs depth 1x10^{16} n_{neq}/cm^2

100 and 150 µm





- Comparison of charge collection of 100 and 150 µm thick sensors
- 150 µm thick sensor is not fully depleted at 700V, but higher voltages were not possible due to high currents
- Depletion voltage is around 800-900V (taken from test beam results)

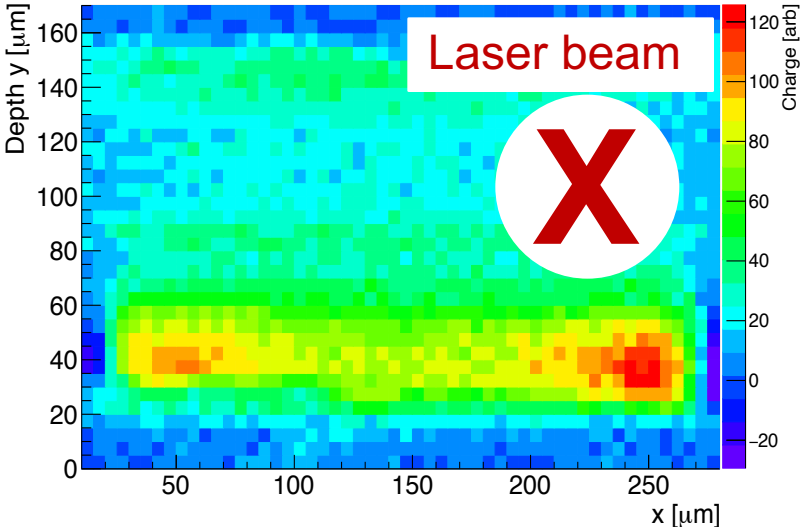
Irradiated to 1x10^{16} n_{eq}/cm^2

2D Charge profile

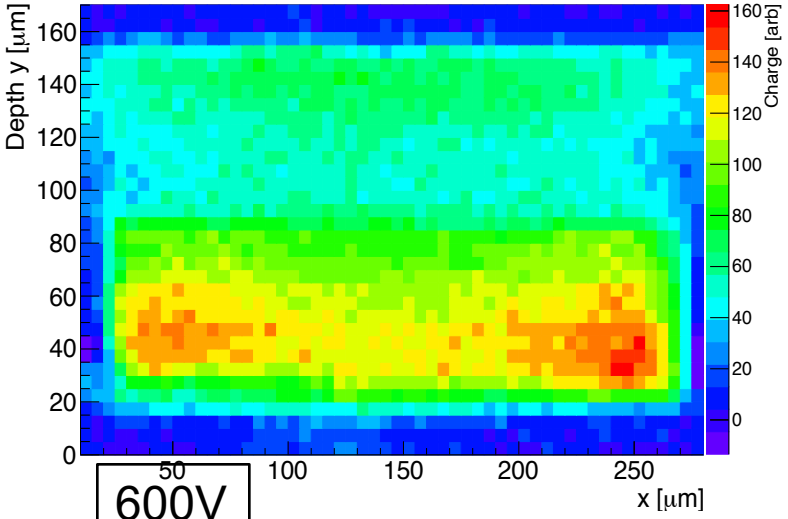
Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

150 µm

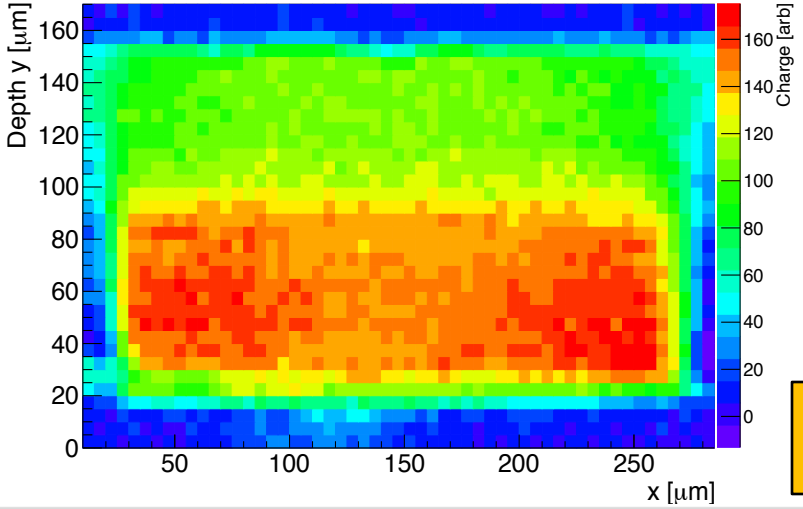
200V



400V



600V

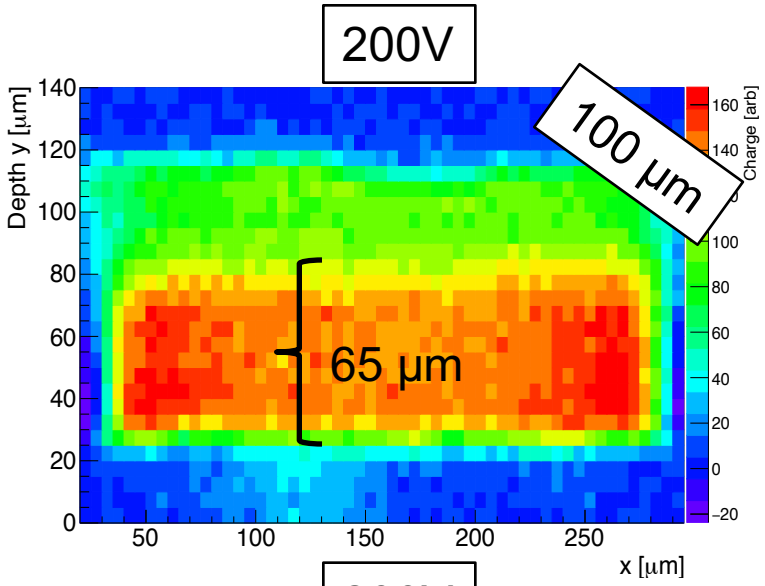


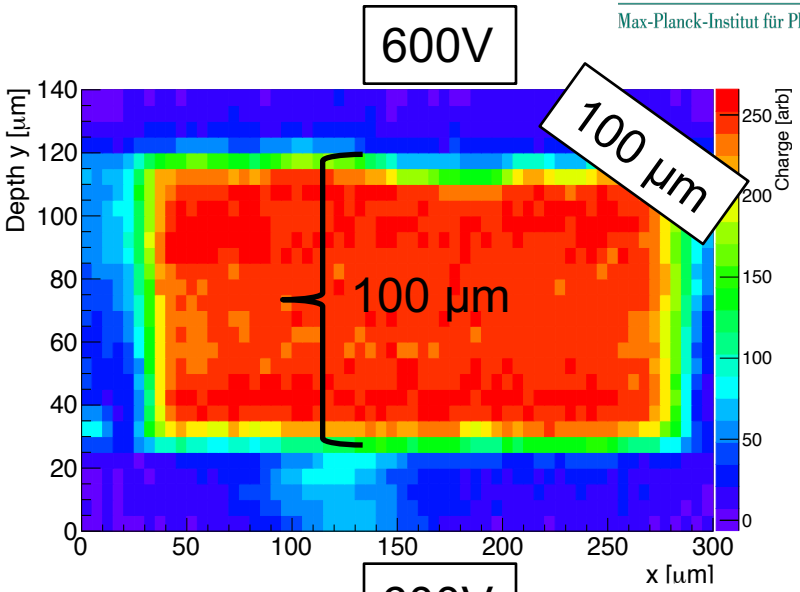
Sensor front side with
Pixel size in x = 250 µm

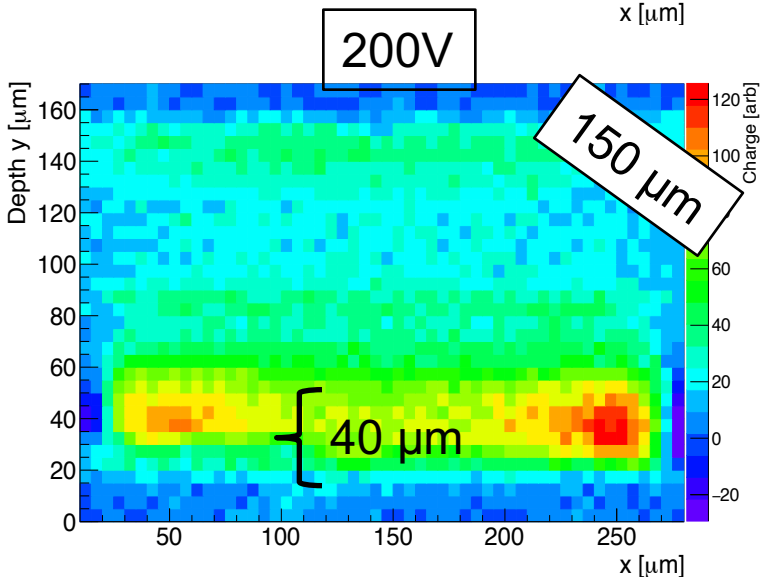
Irradiated to 1×10^{16} n_{eq}/cm^2

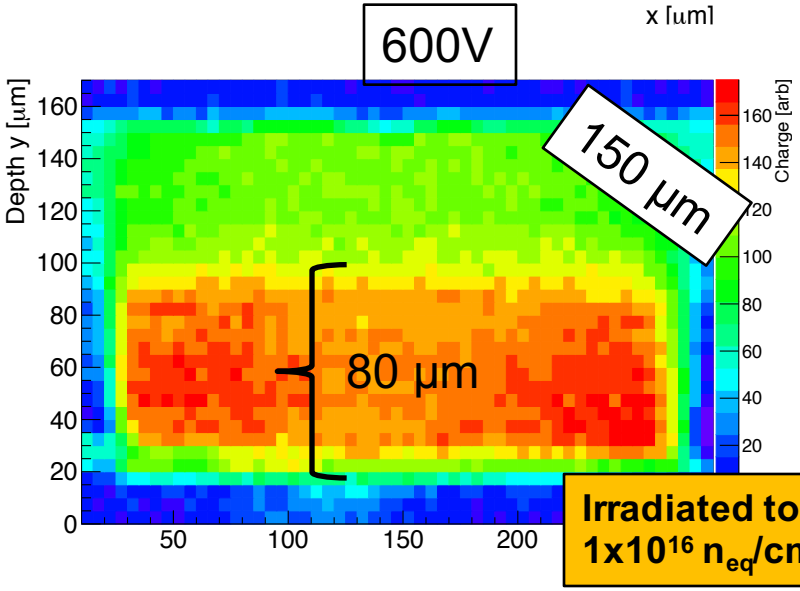
Depletion regions in 100 and 150 µm

Max-Planck-Institut für Physik



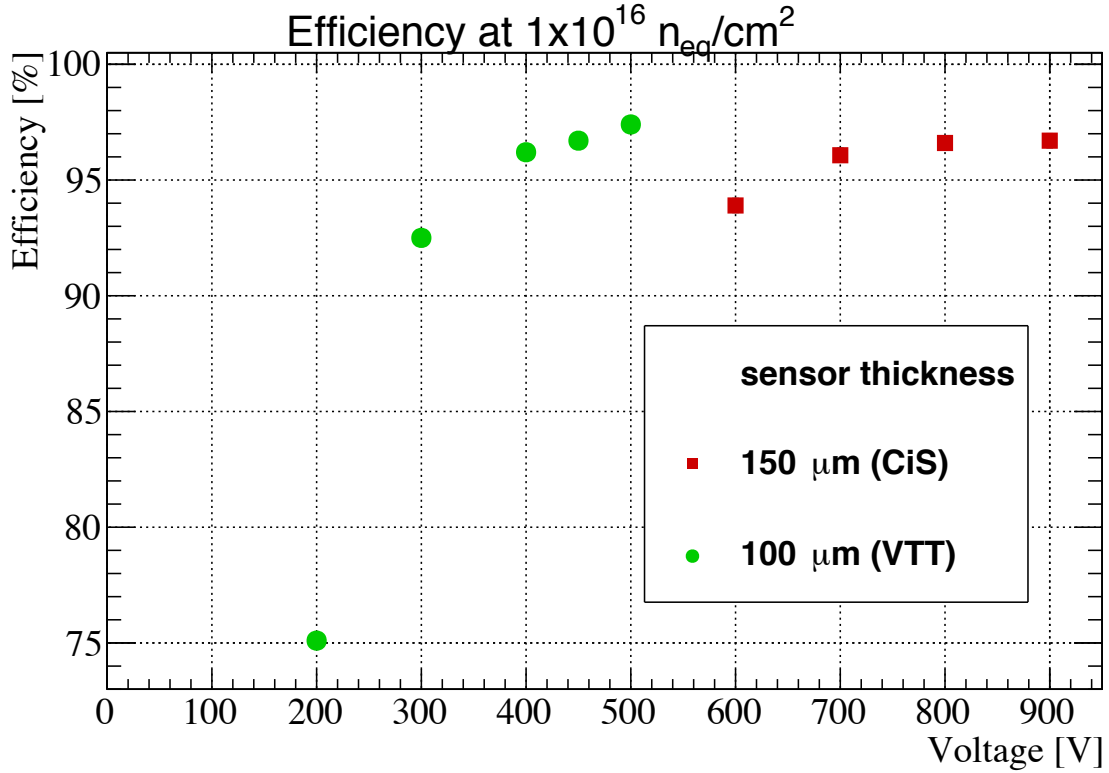






Irradiated to 1×10^{16} n_{eq}/cm^2

Hit efficiency of 100 and 150 µm thick sensors

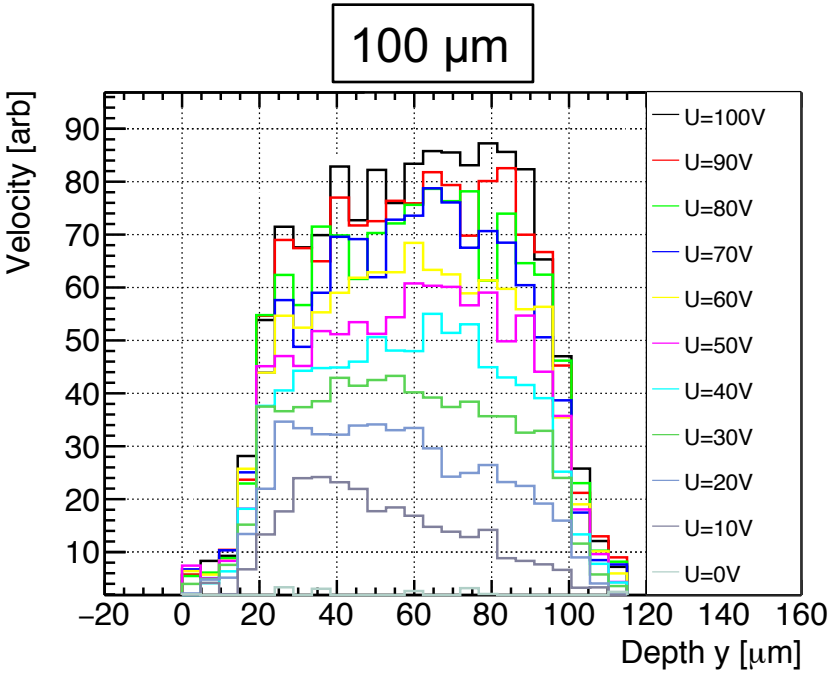


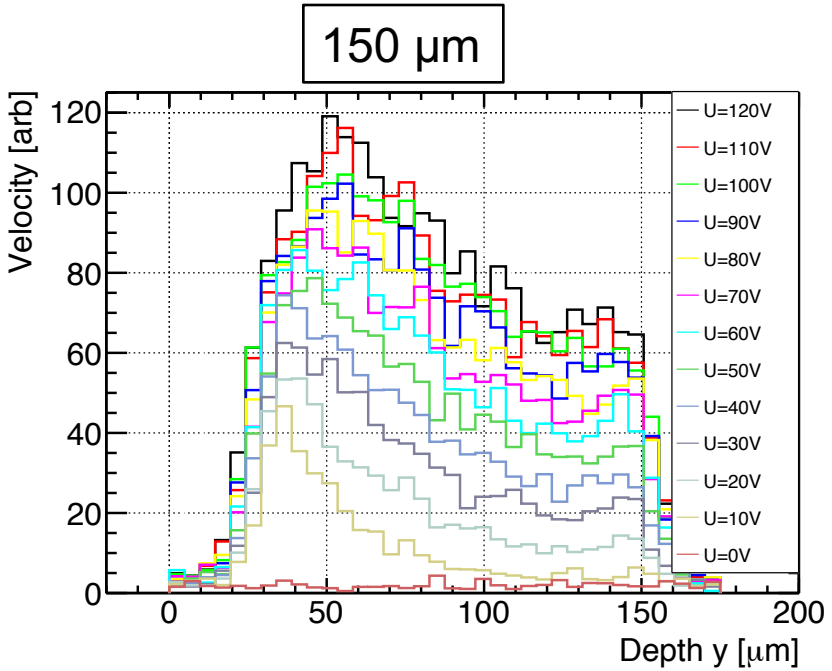
- Comparison of hit efficiencies shows a higher hit efficiency for the module with a 100 µm thick sensor compared to the module with the 150 µm thick sensor
- Results support the charge collection results obtained from the TCT measurements

Irradiated to $1x10^{16}$ n_{eq}/cm^2

Velocity profiles for 100 and 150 µm

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)





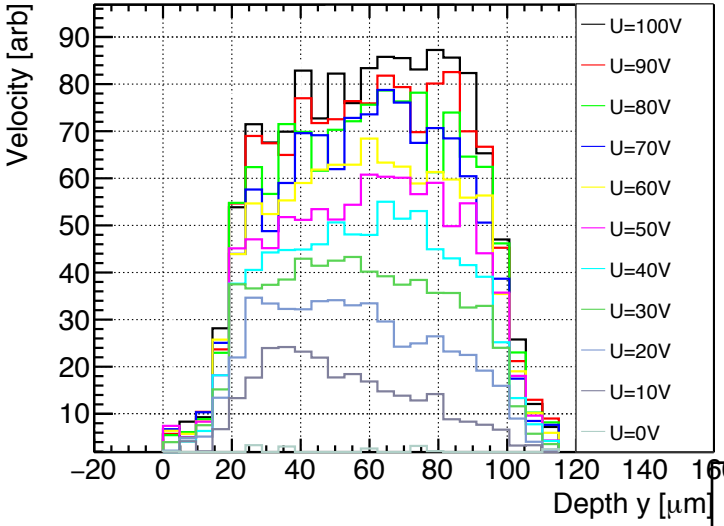
- Velocity profile does not get flat for a 150 µm thick sensor (in line with literature)
- Electric field of 100 µm thick sensor more uniform which is visible in the saturation of the velocity of the charge carriers

not irradiated

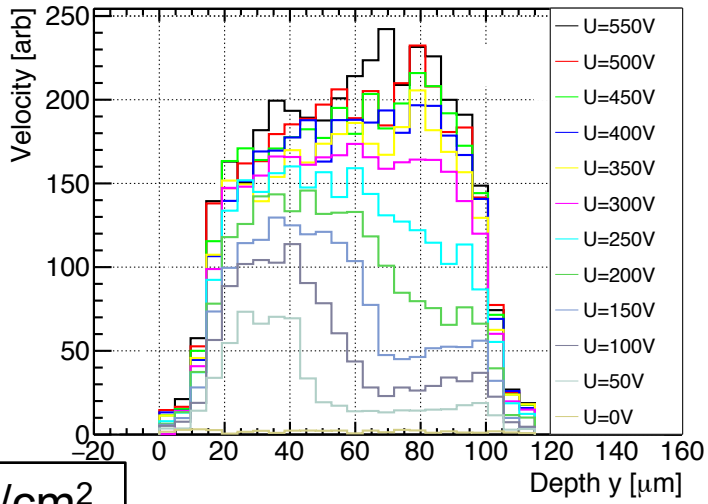
Comparison velocity profiles for 100 µm

100 µm

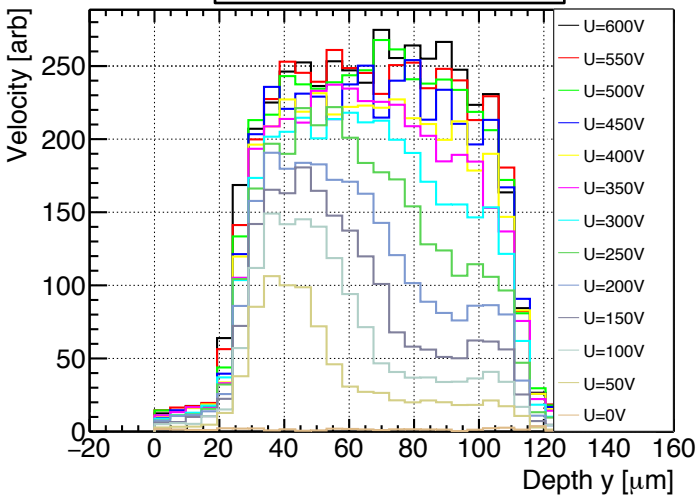
unirradiated



$5x10^{15}n_{eq}/cm^2$



$1x10^{16}n_{eq}/cm^2$



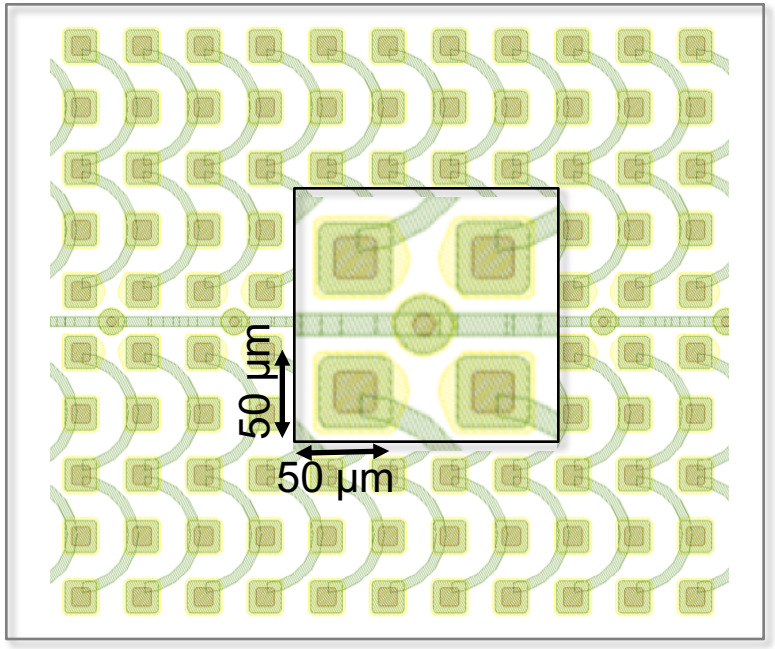
Indication of double peak visible after irradiation!

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Results of a modified 50x250 μm^2 pixel cell with 50x50 μm^2 implants

CIS production

- Sensor layout with 50x50 μm^2 pixel implants
- 5 pixel cells of 50 μm pitch are connected with a metal rail
  - to allow for a readout with the standard FE-I4 chip with 50x250 μm^2 pixel cells



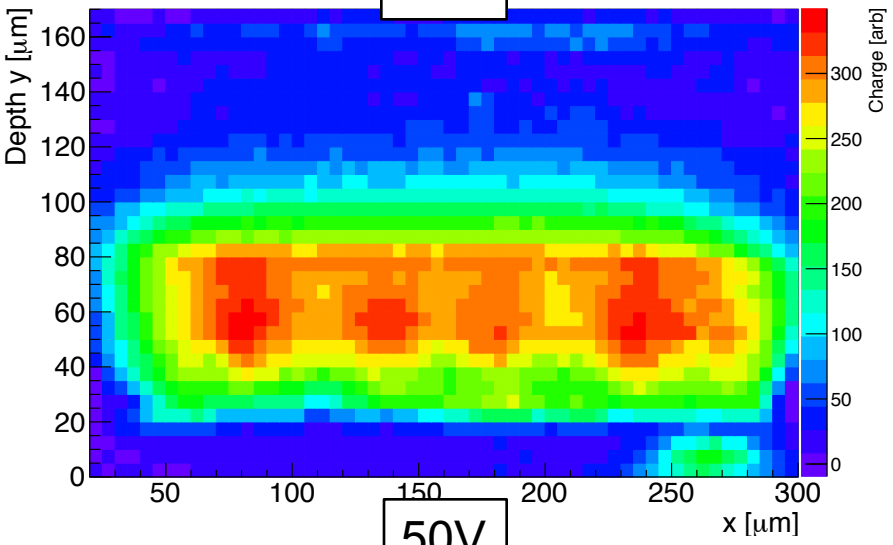
2D charge profile

150 µm

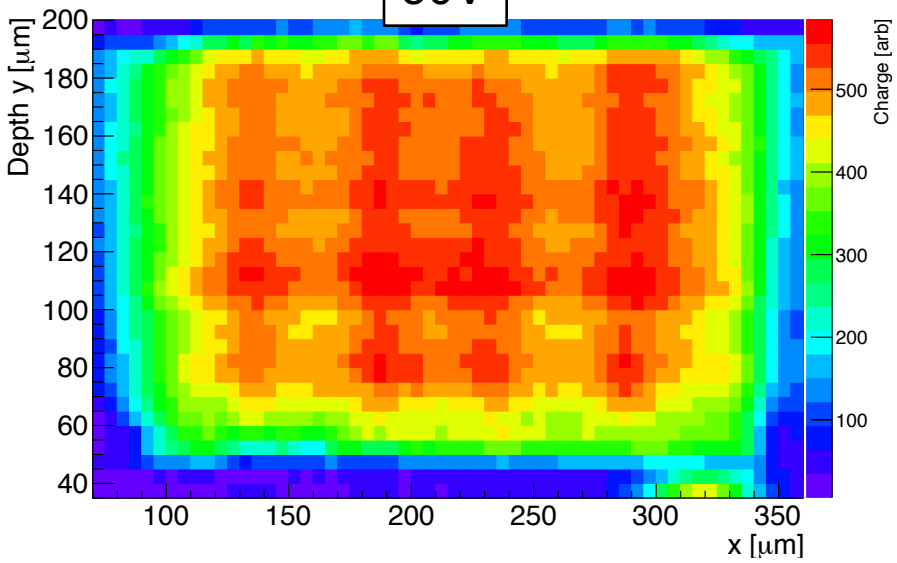
Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

- Higher charge regions could be the inter-pixel regions
  - This could be caused by the geometry of the TCT (laser traverses the sensor parallel to the pixel cells) measurements and the modified pixel cell

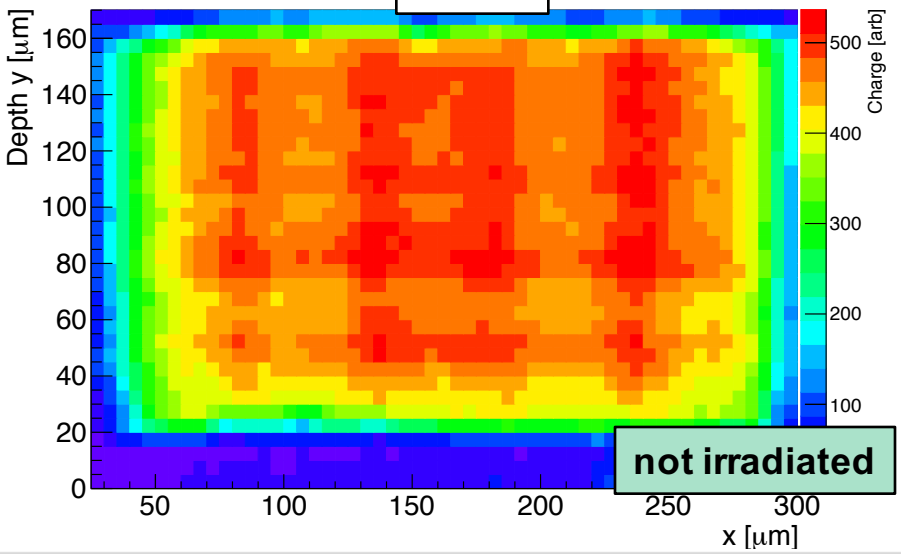
10V



50V



100V

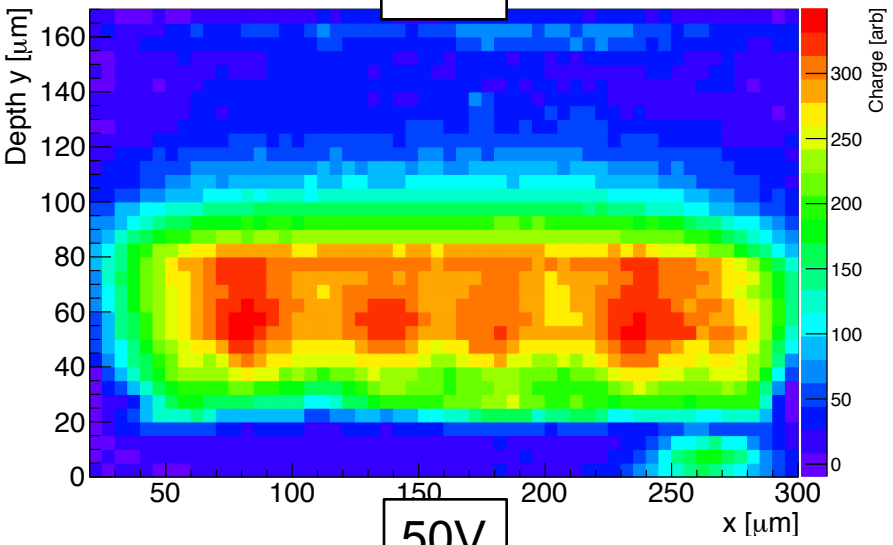


2D charge profile

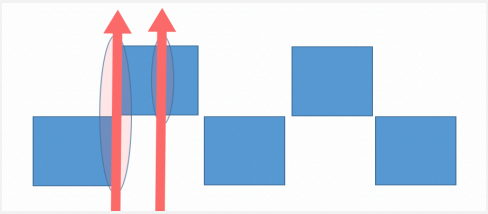
150 µm

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

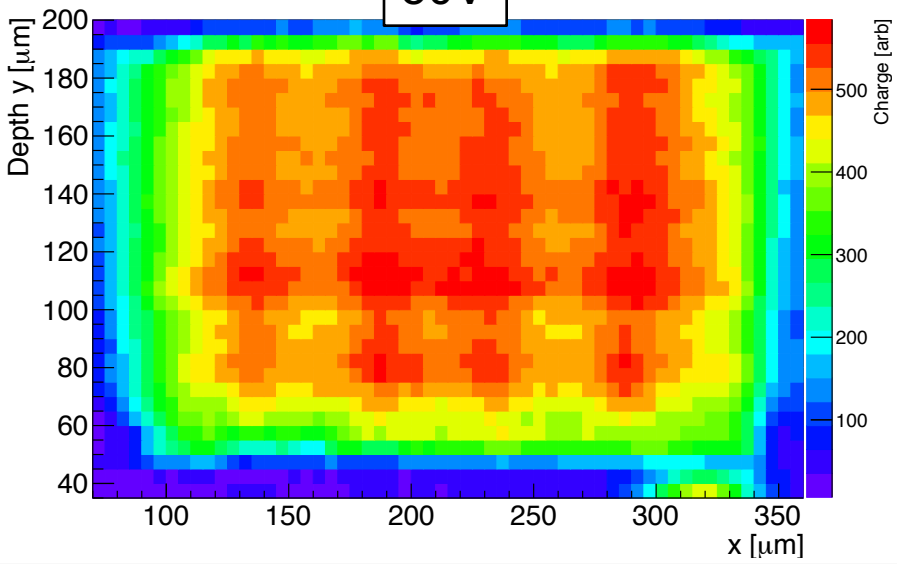
10V



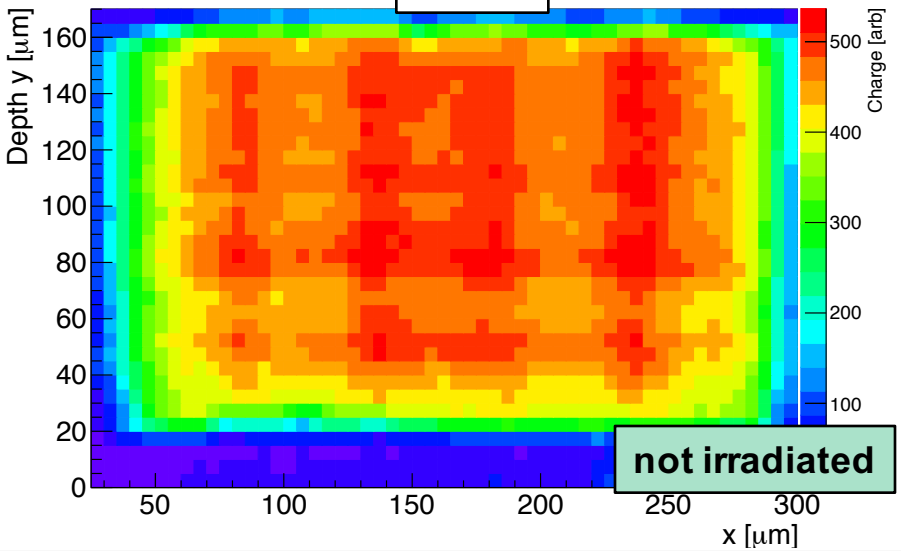
- Charge collected from longer beam stretch could lead to higher charge collection in the inter-pixel regions because of diffusion and laser beam halo



50V

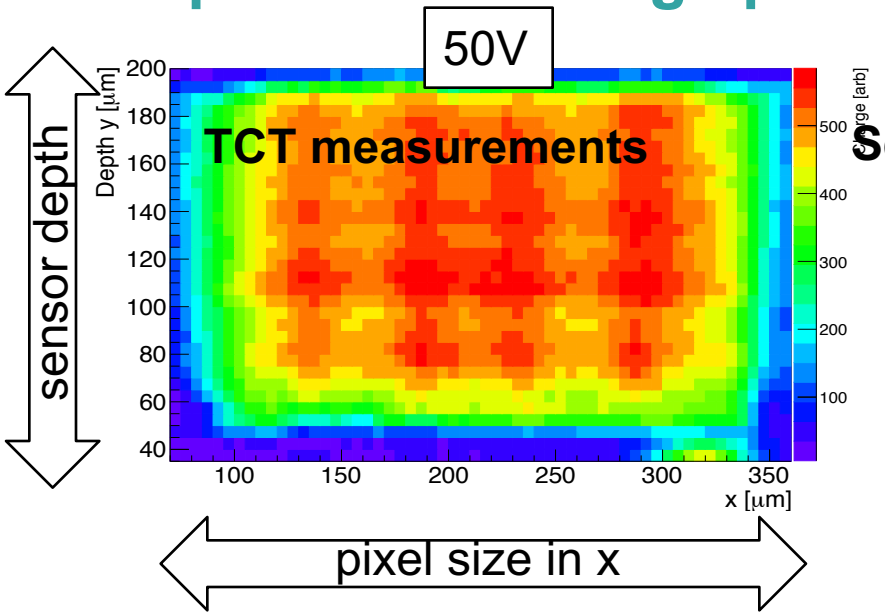


100V



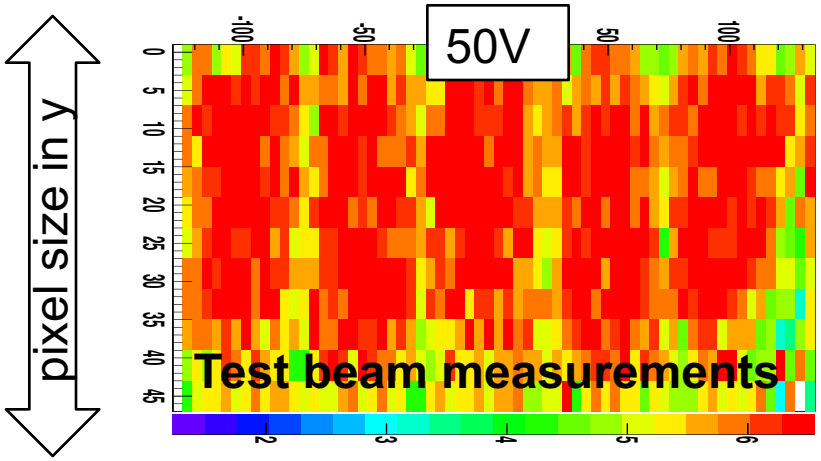
Comparison of charge profiles TCT and test beam

150 µm



Sensor depth vs. x

- The charge collection obtained by test beam measurements shows a higher charge region on the pixel implant itself
  - The beam traverses the sensors perpendicular to the pixel cells (not influenced by the geometry of the modified pixel cell)



Surface of the sensor: y vs. x

not irradiated

Conclusion

- **100 µm and 150 µm thick sensors:**
  - For a 100 µm thick sensor charge collection profiles of all fluences flatten after reaching the depletion voltages
  - The 150 µm thick irradiated sensor does not reach depletion due too low voltages applied (limited by the thermal runaway)
    - Normalised charge of TCT, lab, test beam measurements are in line
  - For a 100 µm thick sensor charge carrier velocities at all fluences are maximal at the front side at lower voltages but flatten out at higher voltages (not the case for the 150 µm thick sensor)
    - Indication of double peak visible after irradiation for both thicknesses
- **50x50 µm^2 pixel implants**
  - With modified pixel design it is possible to make first prediction of the charge sharing of small pixel cells

Outlook

- Confront TCT measurements with further high incidence angle test beam measurements
- Extend TCT measurements to real 50x50 μm^2 pixels cells (from RD53A sensors)
- Compare TCT measurements to TPA (two photon absorption) measurements

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

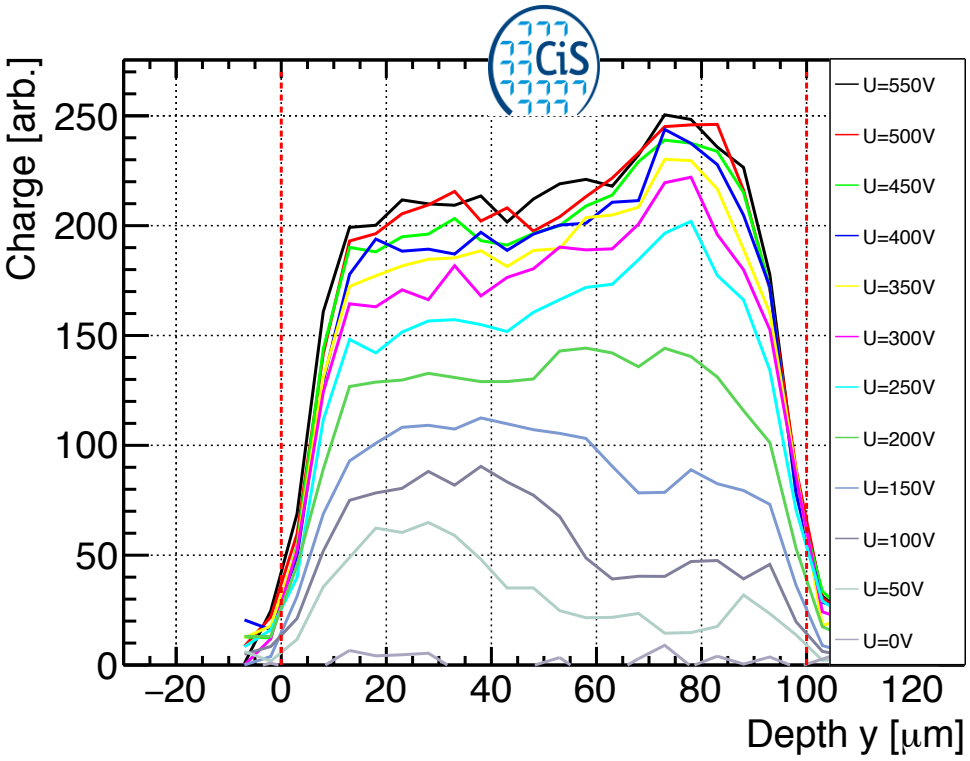
Thank you for your attention!

Special thanks to JSI, above all Igor, Bojan and Gregor!

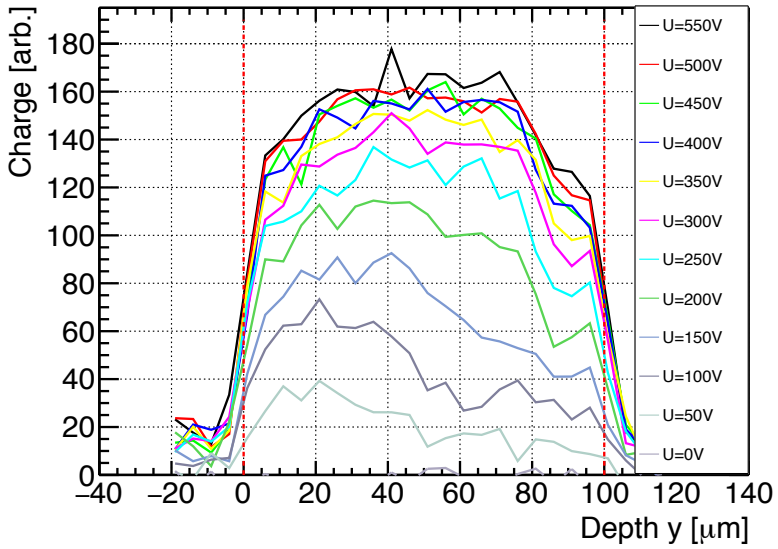
Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Back up

Comparison charge vs depth



100 μm



- Depletion voltage of ~300V for both sensors
- In the 1 dimensional charge profile the lower charge in the last 10 μm are clearly visible

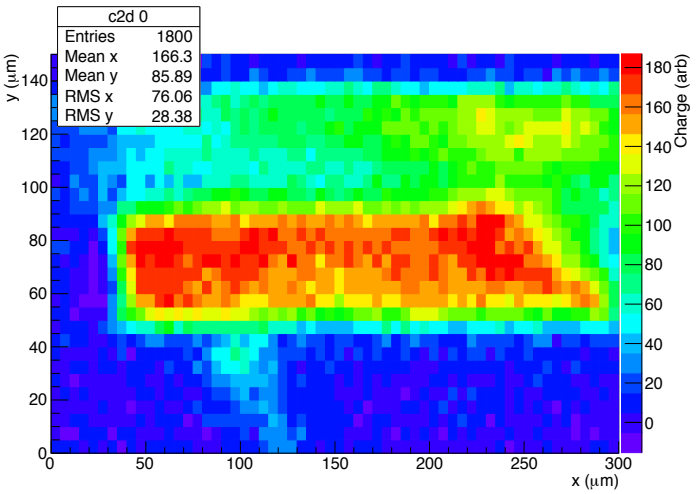
➢ This will be checked with the charge collection scans in the lab

Irradiated to 5×10^{15} n_{eq}/cm^2

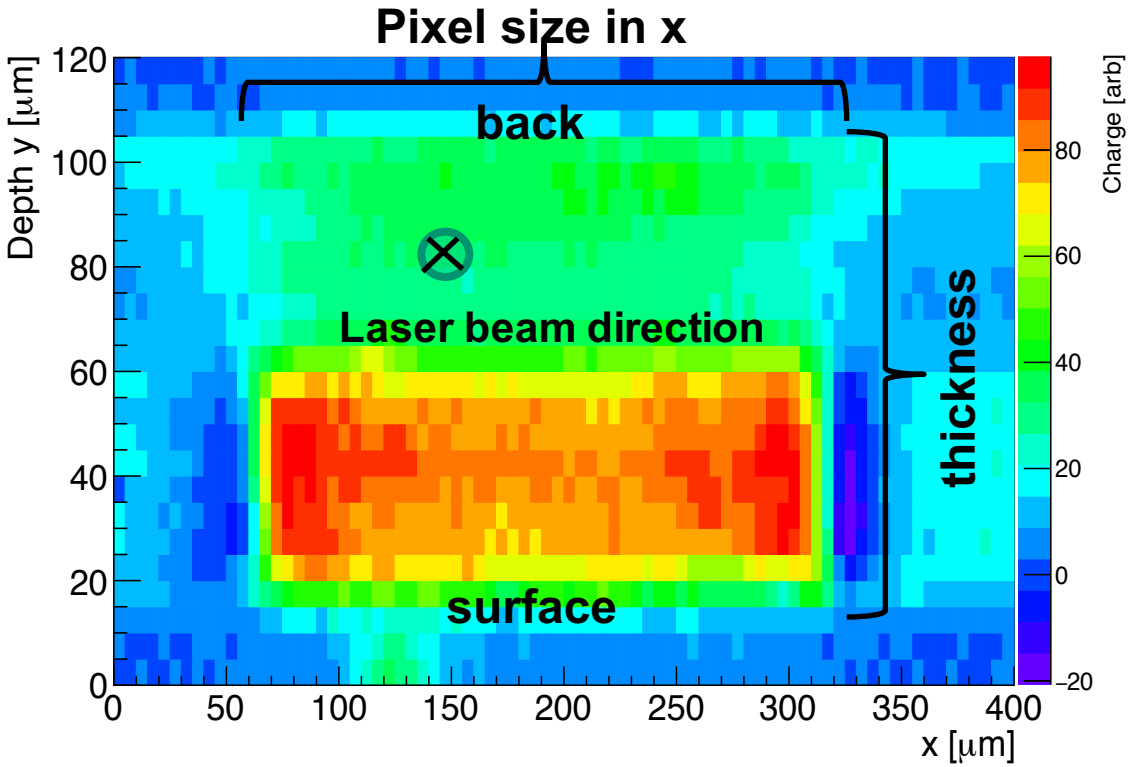
2D Charge profile two measurements

100 µm

Only read-out pixel is biased



All pixels on nearly the same potential



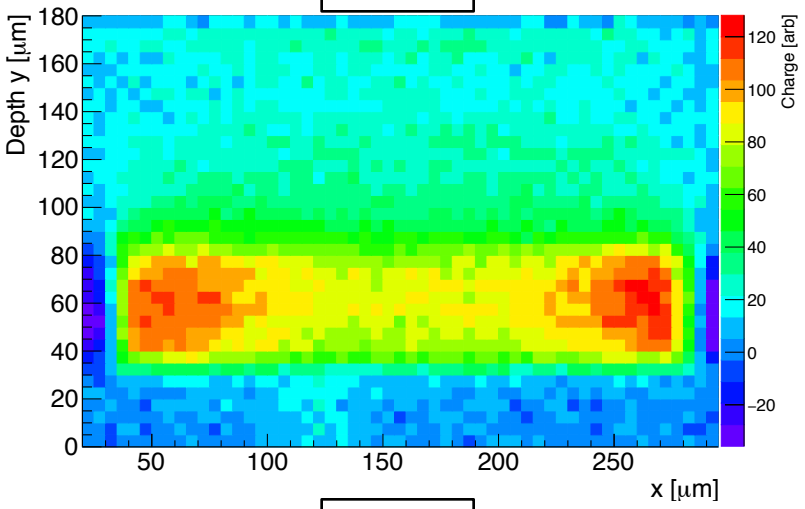
- Only read-out pixel is biased: Bias dot and rail introduce charge loss when being on a different potential
- All pixels are biased: No influence of bias dot and rail

Irradiated to 5×10^{15} n_{eq}/cm^2

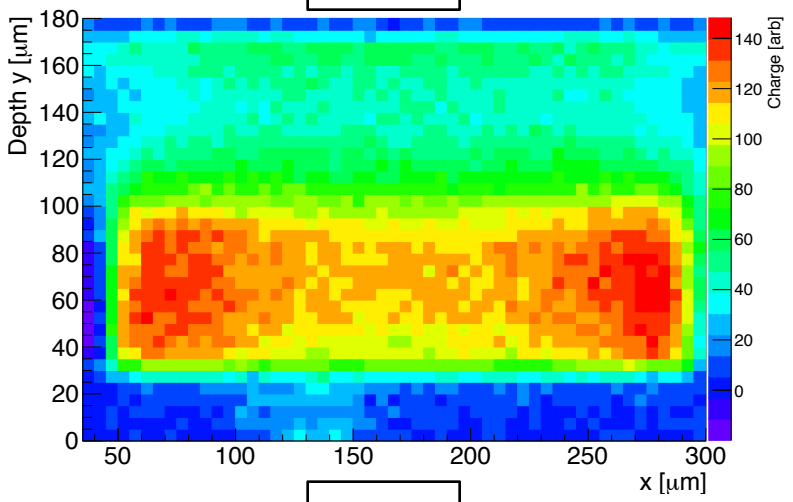
2D-Charge profile

150 µm

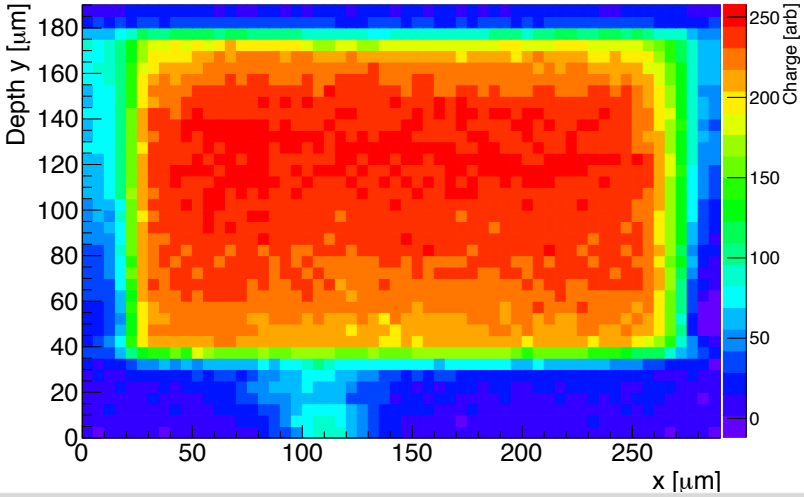
100V



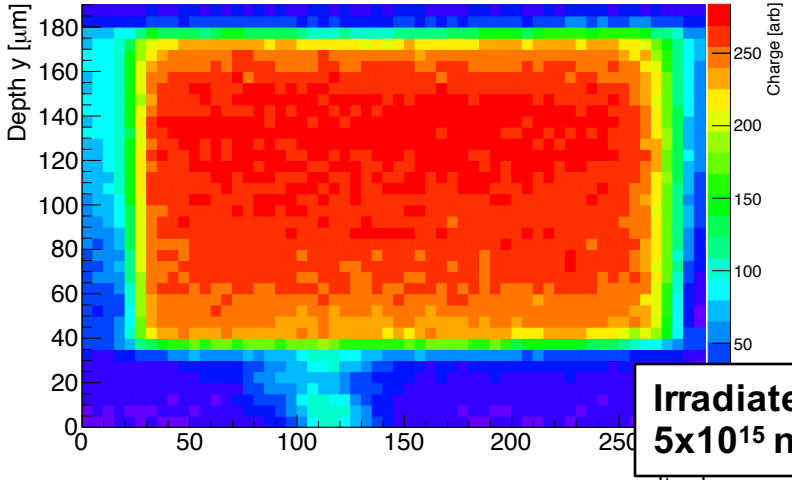
200V



600V

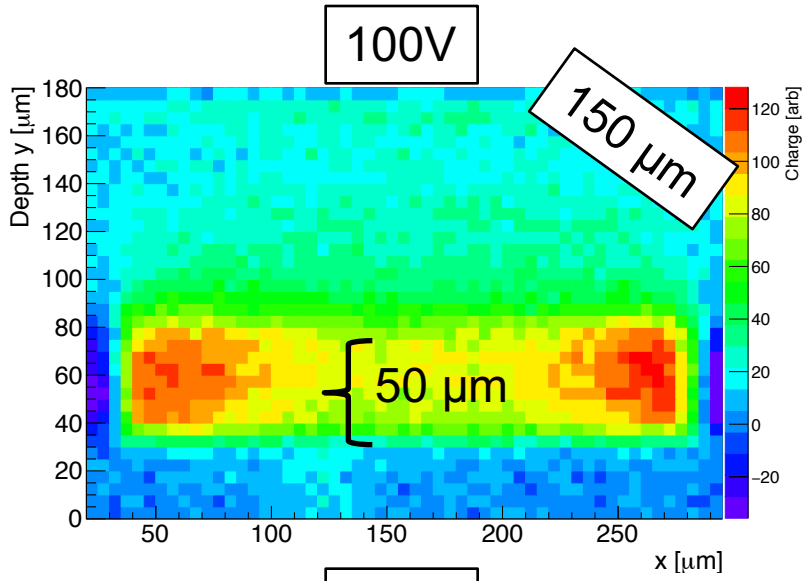


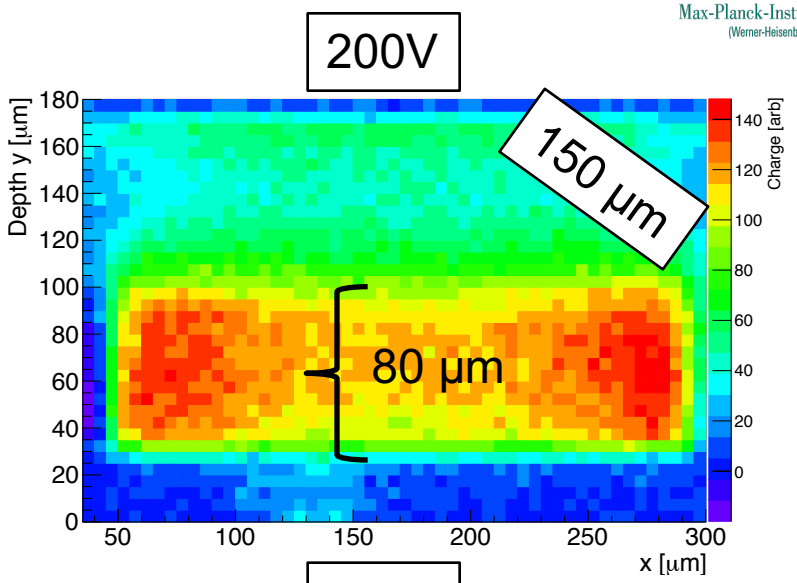
780V

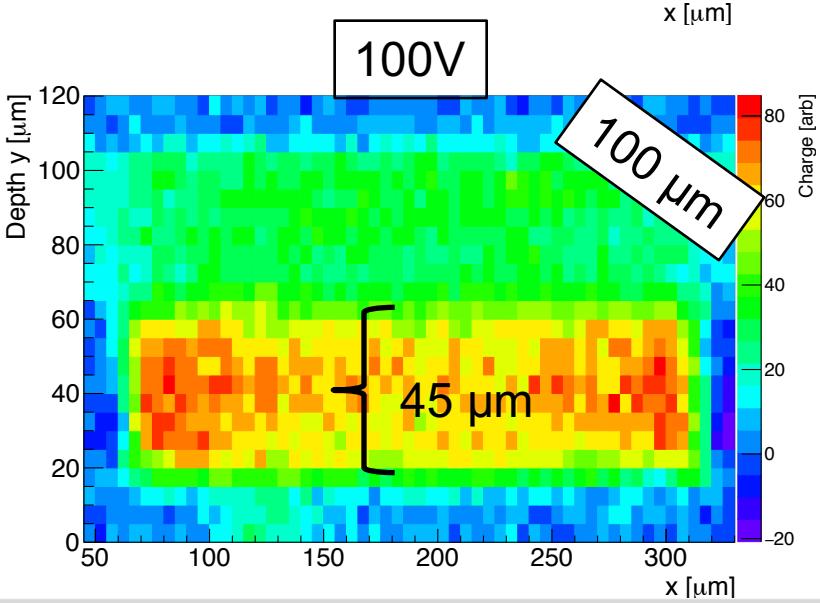


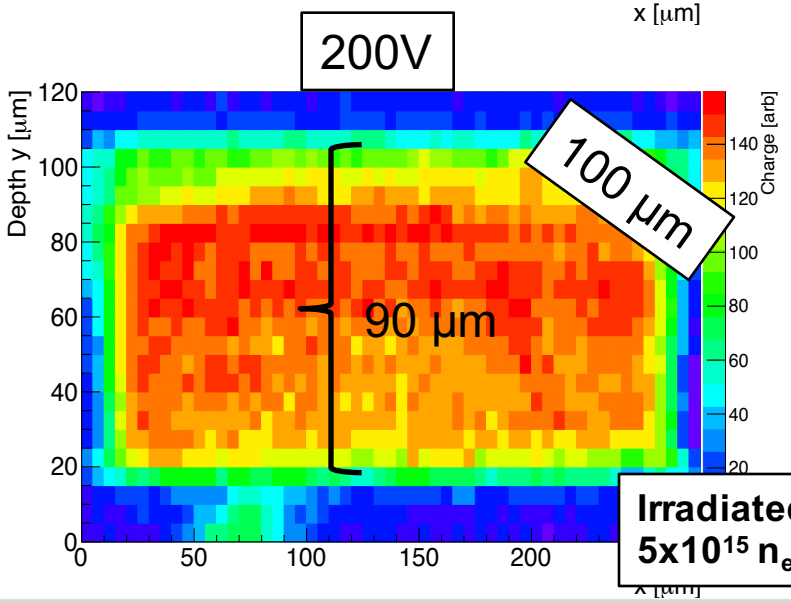
Irradiated to 5×10^{15} n_{eq}/cm^2

Depletion regions in 100 and 150 µm



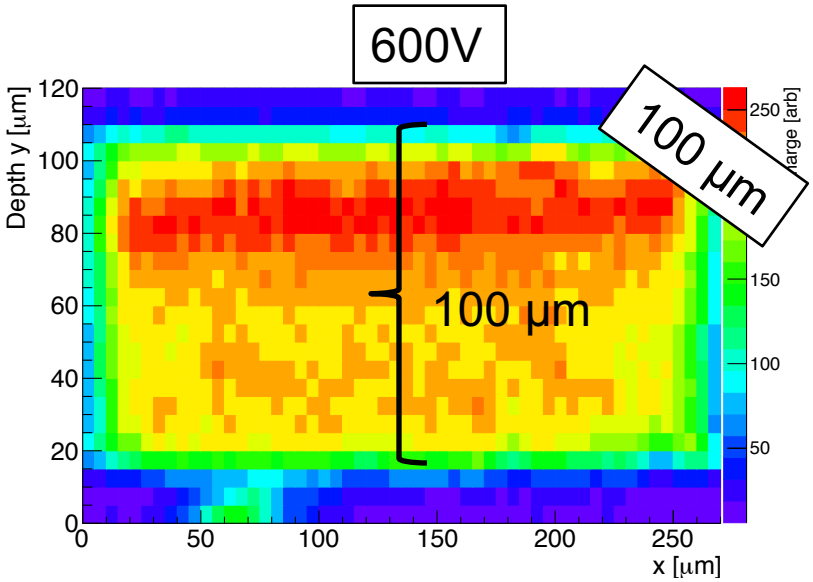




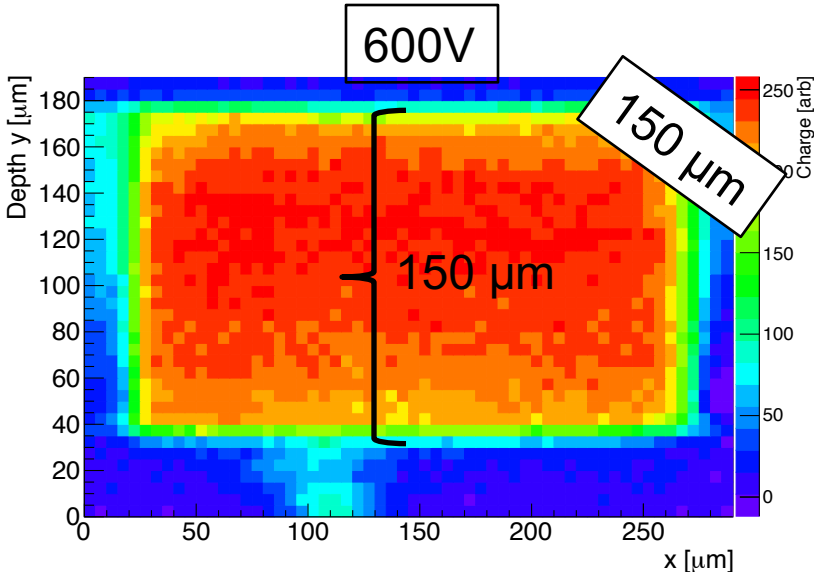


Irradiated to 5×10^{15} n_{eq}/cm^2

Depletion regions in 100 and 150 µm



Depletion was at ~ 300V
(fully over depleted at 600V)



Depletion was at ~ 500V
(slightly over depleted)

- Depletion depths are only slightly larger for the 100 µm sensor up 300V (depletion voltage of 100 µm thick sensor)
- From 300V on the depletion depth of the 150 µm thick sensor starts to get larger than the one of the 100 µm thick sensor (depletion depth limited by the thickness)

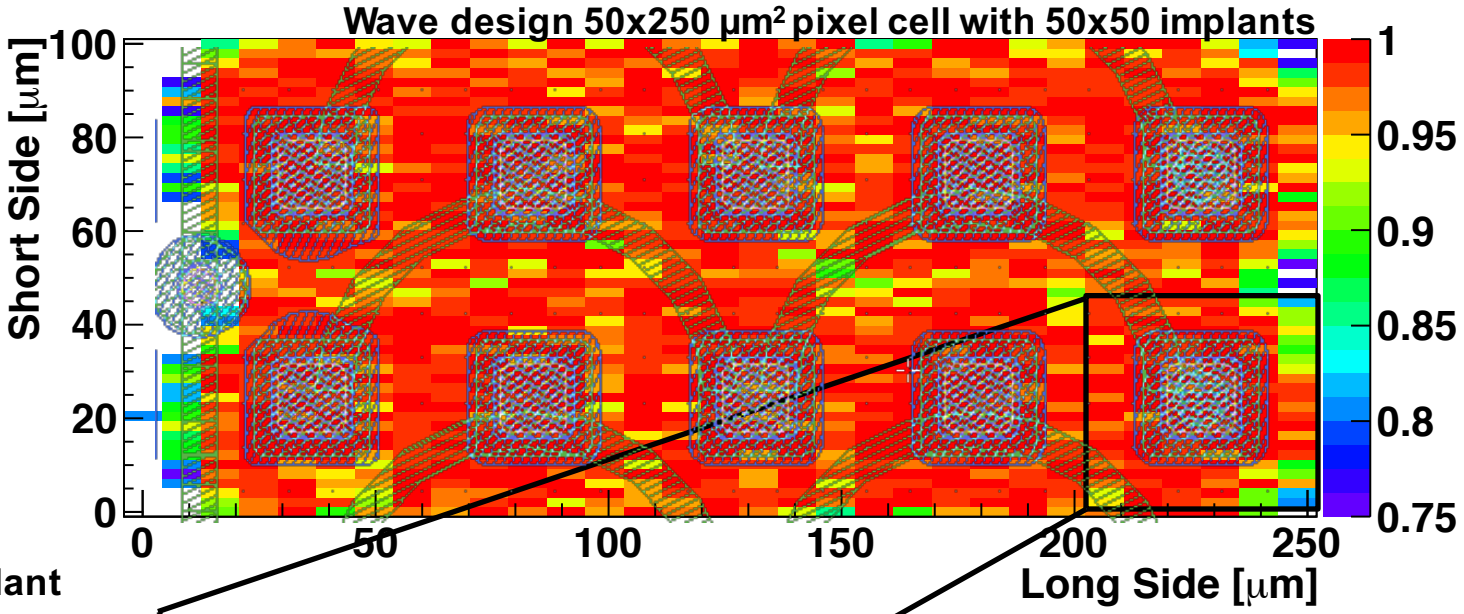
Irradiated to 5×10^{15} n_{eq}/cm^2

In-pixel efficiency at 3x10^{15} n_{eq}/cm^2

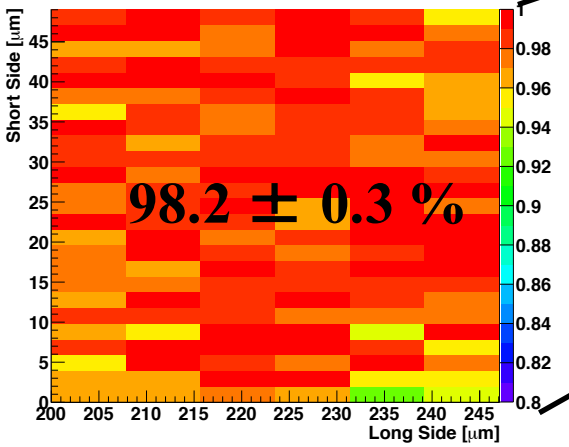
150 µm

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Test beam results



50x50 implant



In-pixel efficiency of the 50x50 µm² implant (implant at the edge) is 98.2% when considering neighboring pixel implants read out by different read-out channels. Efficiency loss due to charge sharing.

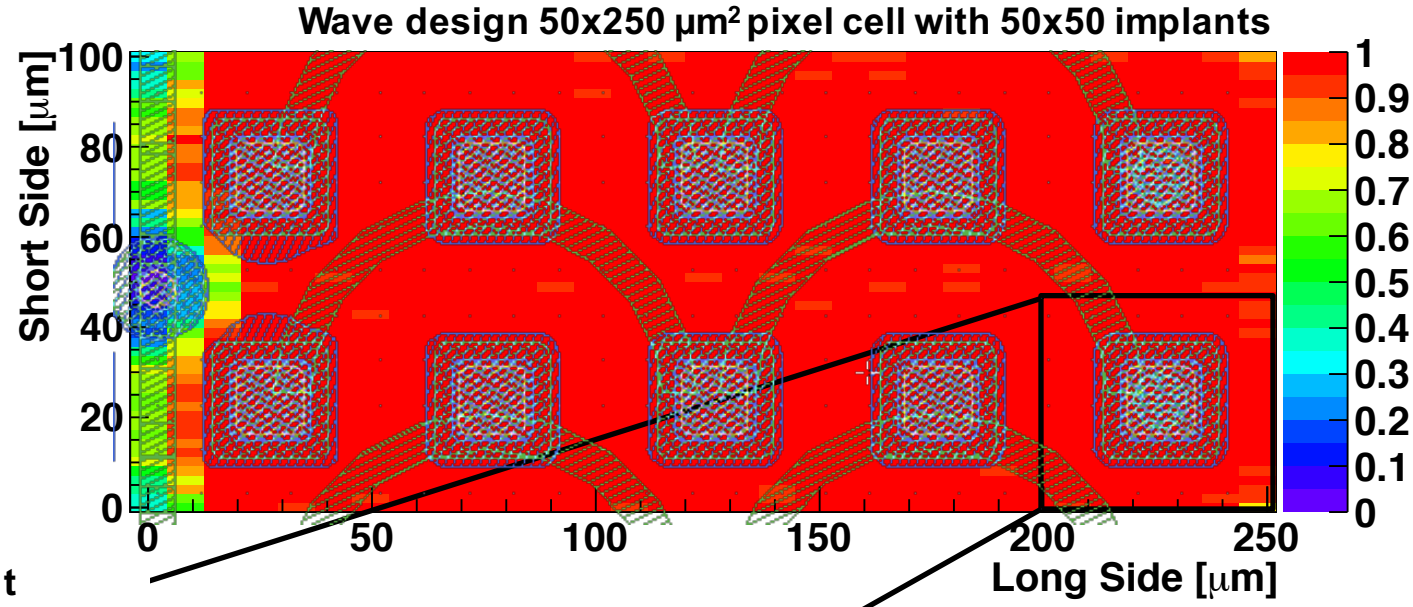
Irradiated to 3x10^{15} n_{eq}/cm^2

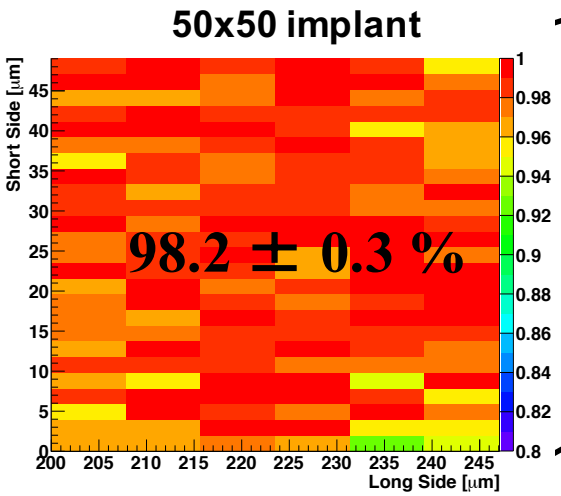
In-pixel efficiency (irradiated to $3x10^{15}$ n_{eq}/cm^2)

150 µm

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Test beam results





Irradiated to $3x10^{15}$ n_{eq}/cm^2