E-TCT measurements with passive CMOS pixel detectors on RD50-MPW1 chips from LFoundry

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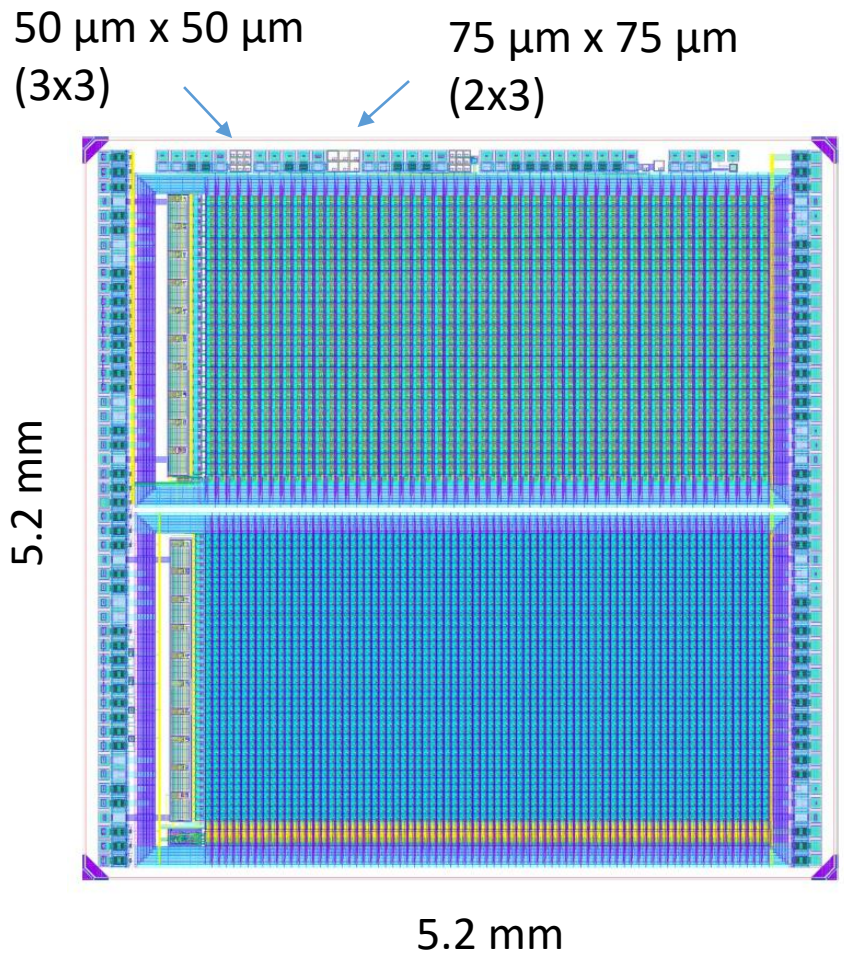
Introduction

- RD50 submitted CMOS pixel detector prototype chip *RD50-MPW1* in 150 nm LFoundry process
- designed by E. Vilella (University of Liverpool) and R. Casanova (IFAE Bacelona)
- chips were produced on p-type wafers in 2 different initial resistivities:
  ~ 500 Ωcm and ~ 2000 Ωcm
- chips were irradiated in reactor in Ljubljana to several different fluences ranging from
  1e13 n/cm² to 2e15 n/cm²
- passive pixel arrays are placed near the edge of the chip for E-TCT measurements
- depletion depth at different bias voltages was measured with E-TCT
- N_{eff} estimated from depletion depth and studied as a function of neutron fluence

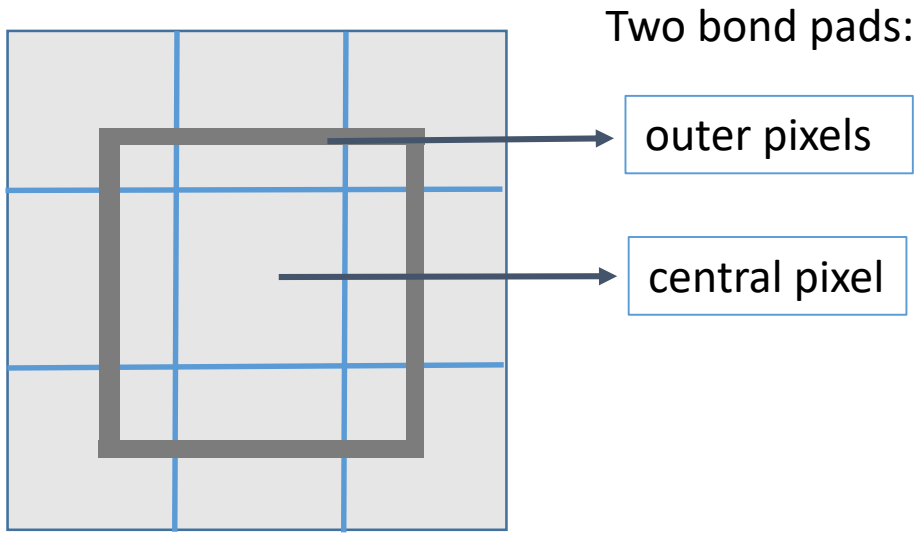
RD50-MPW1 CMOS chip

Passive pixel arrays for E-TCT



Measurements made with:

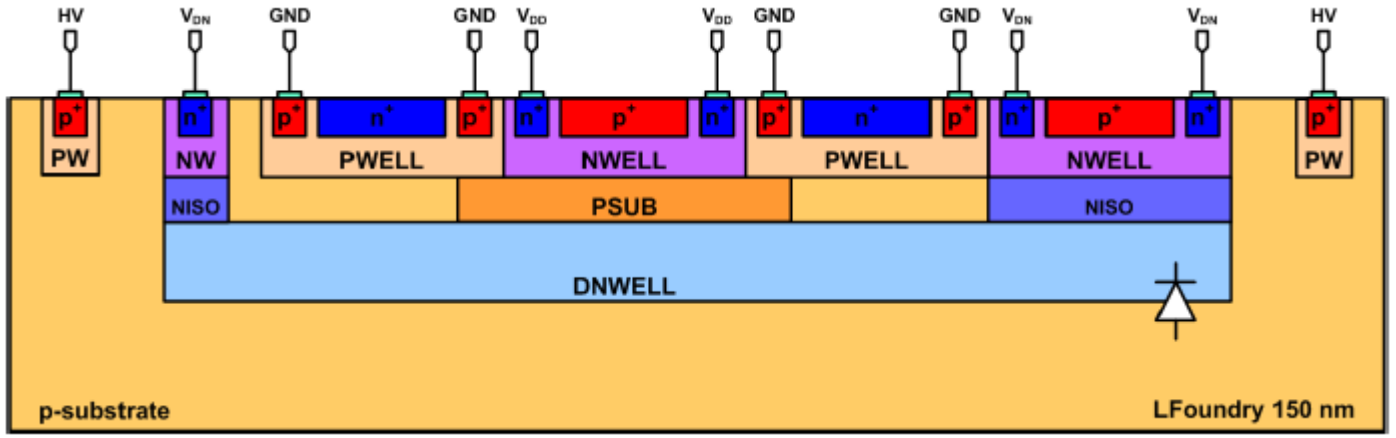
- 3x3 pixel array of 50 µm x 50 µm pixels
- central pixel to read out
- Outer pixels connected together



RD50 CMOS chip

Scheme of a pixel

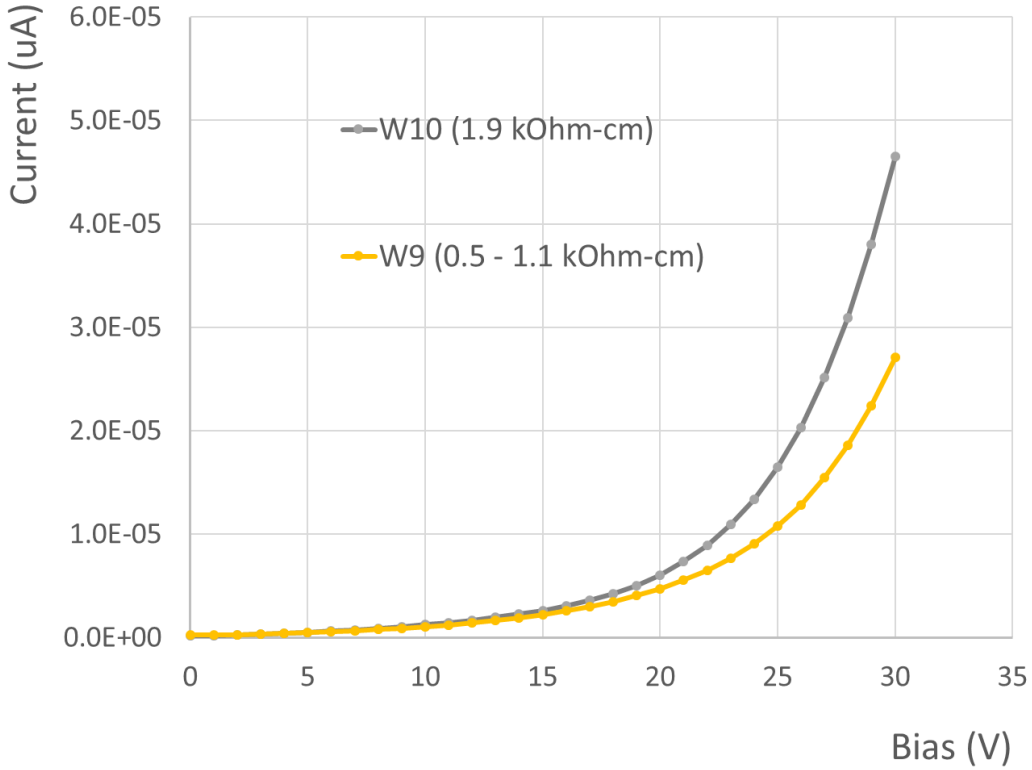
- Passive pixel: same scheme except there is no transistors in the wells
- Dnwell connected to bias voltage and to the amplifier
- P-substrate connected to ground

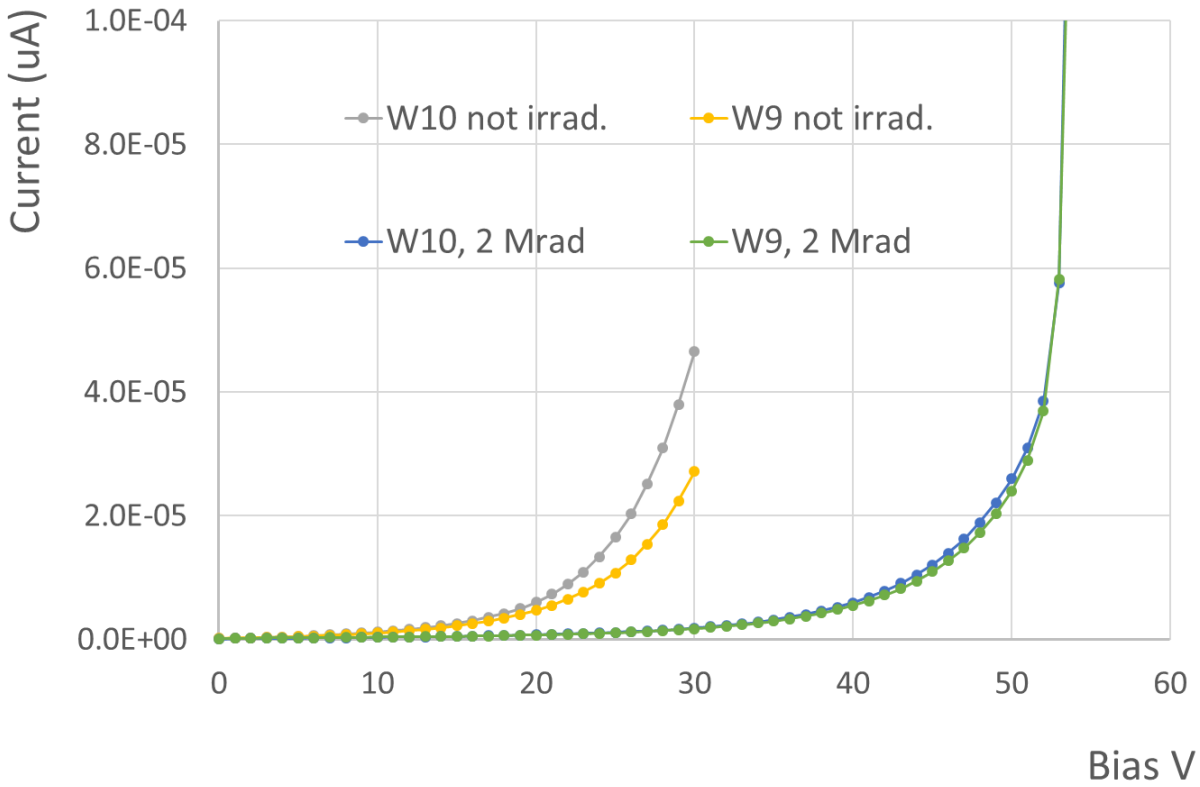


Chips are not thinned, back plane not processed, substrate biased through the implants on top

Detector current before irradiation

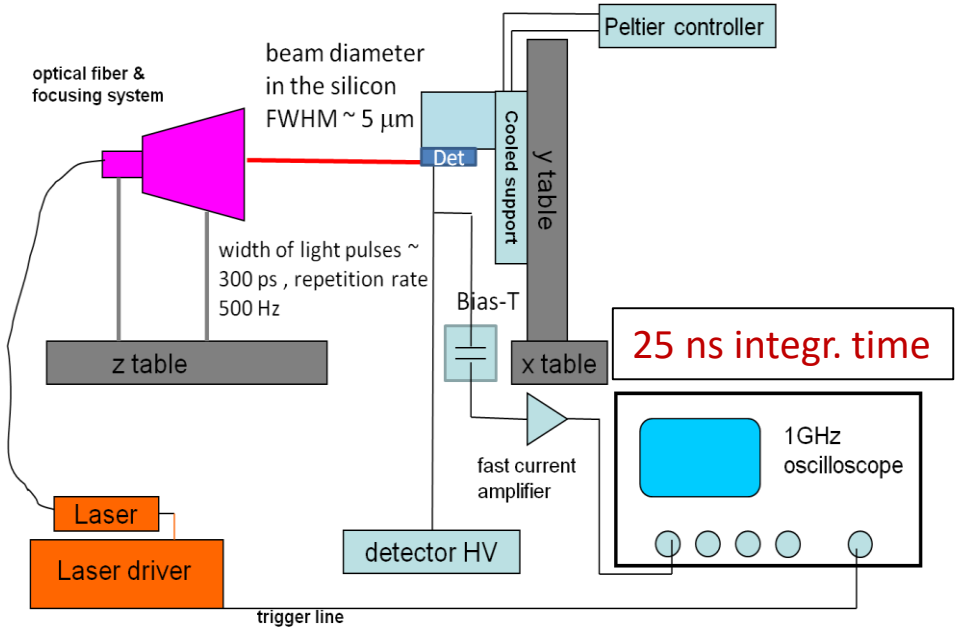
Current measured on outer 8 pixels of 3x3 pixel array (50x50 um² pixel)

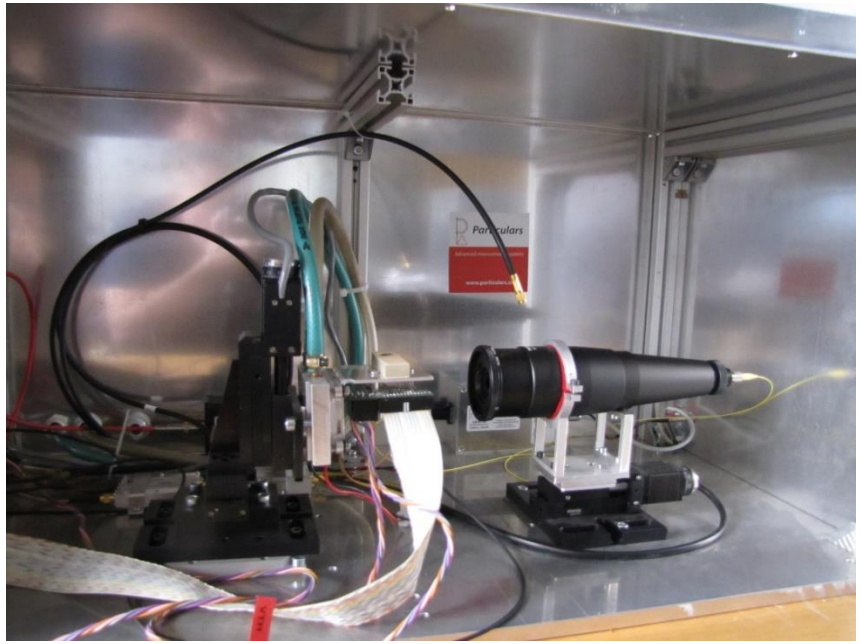




- high current before irradiation ➔ several reasons in the design for this
- E-TCT measurements made up to ~ 50 uA
- chips were exposed to 2 Mrad TID from background radiation in the reactor:
  ➔ at 0 W reactor power there is no neutrons, only photons
  ➔ current dropped after gamma irradiation ➔ high current before irradiation related to surface effects

Edge TCT setup

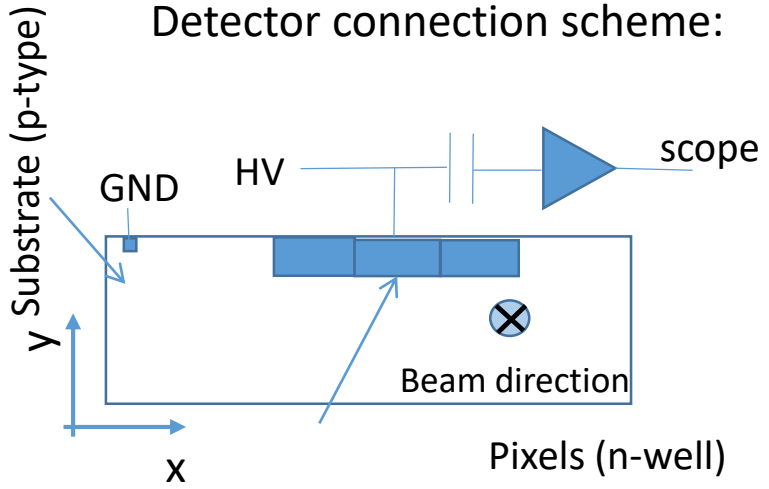




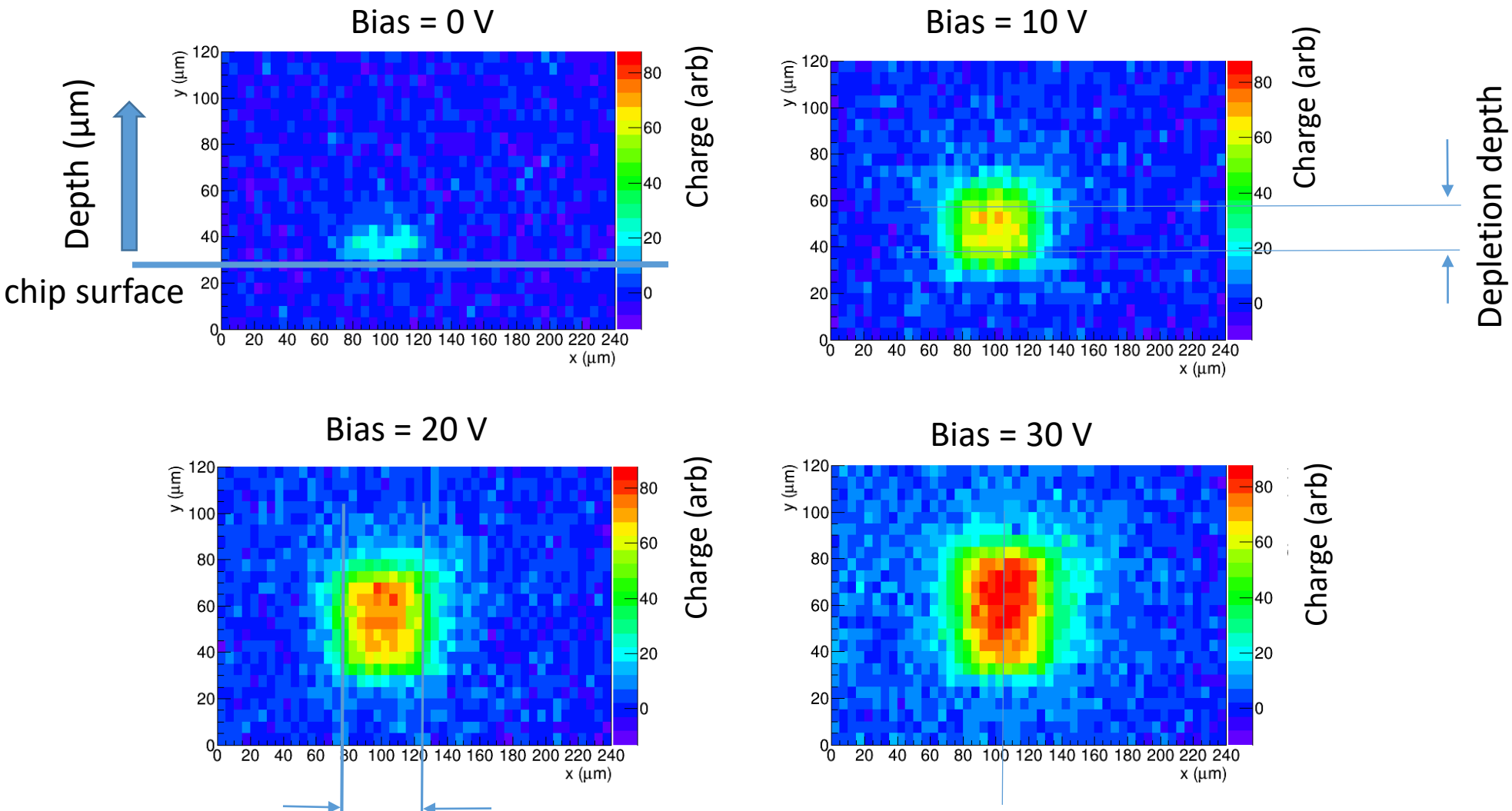
(more details: www.particulars.si)

TCT measurements with passive pixels (no amplifier in the n-well)
➔ collecting electrode connected to the amplifier

Detector connection scheme:



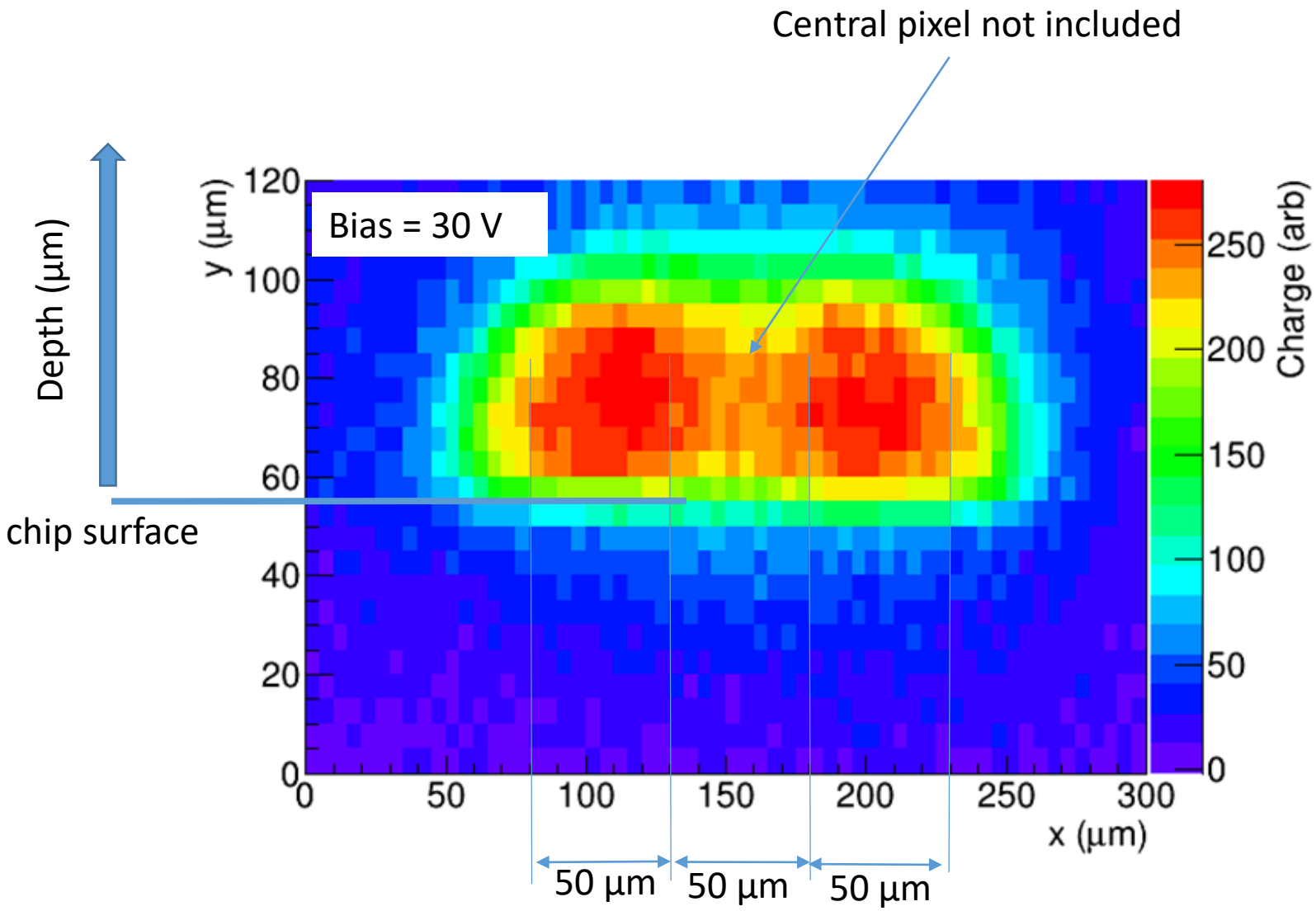
Before irradiation

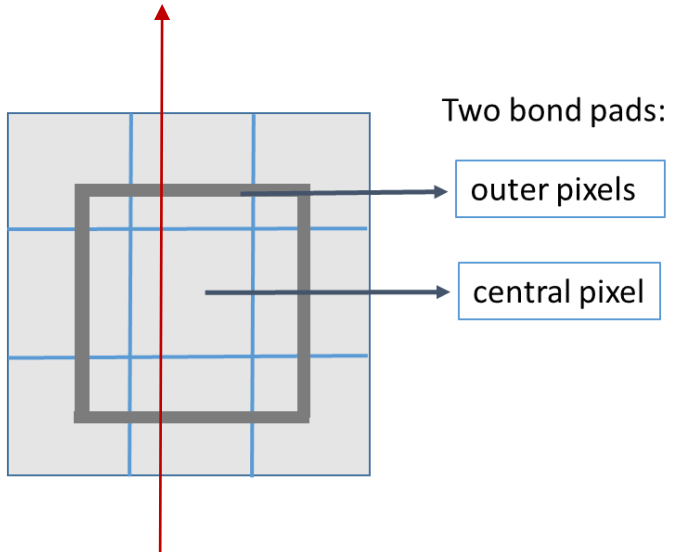


Pixel width 50 µm

Depletion depth: FWHM of the charge profile across the centre of the pixel

Charge profile, outer pixels





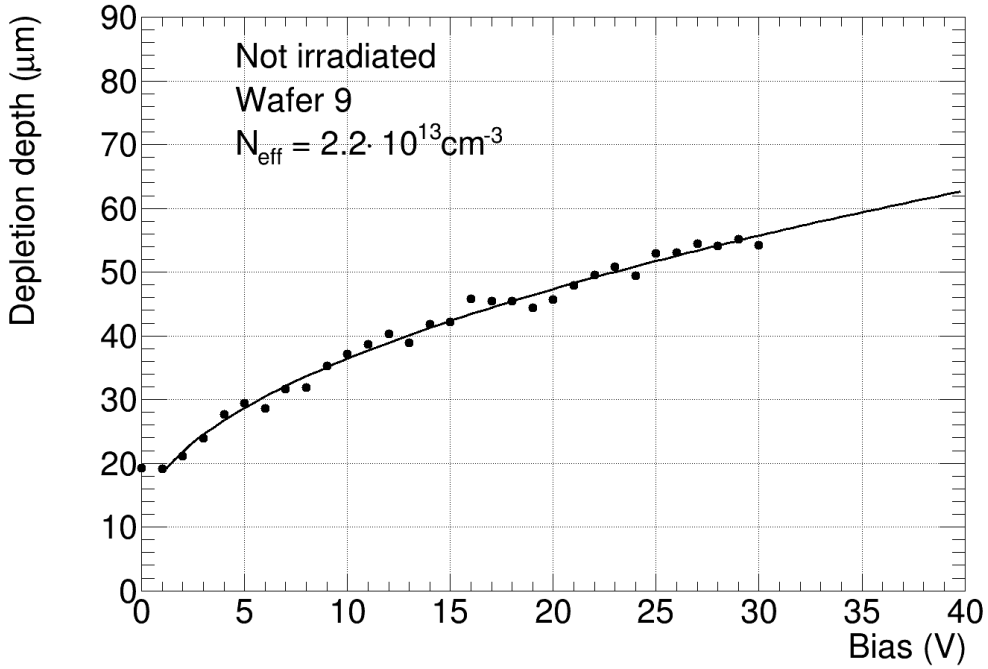
IR laser direction in E-TCT

- if only outer pixels read out
charge under central pixel not included

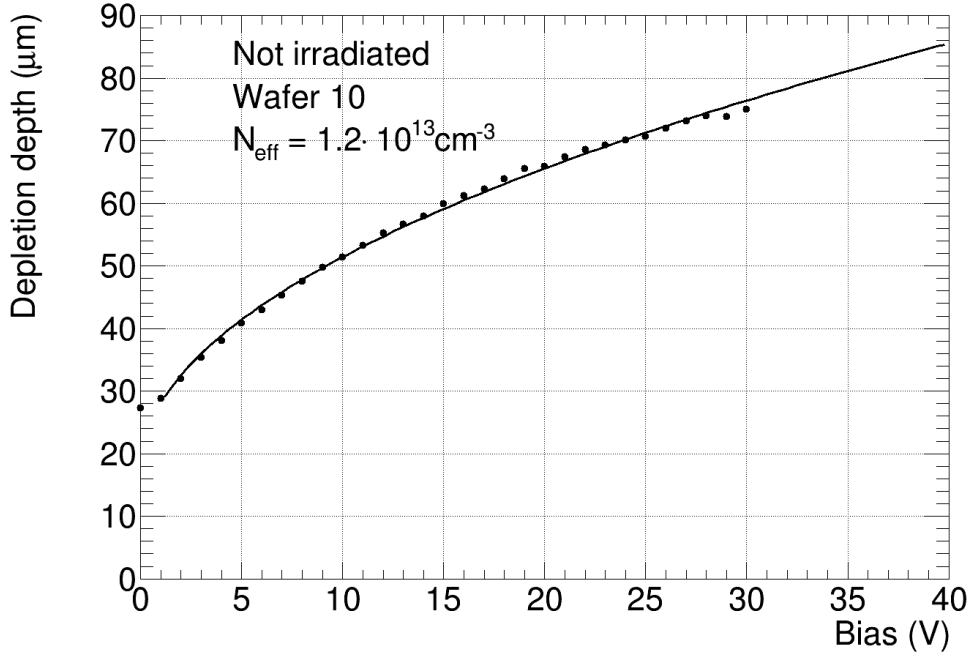
Before irradiation

Charge profile measured across the middle of central pixel

Fit: $d = d_0 + \sqrt{\frac{2\varepsilon\varepsilon_0}{e_0 N_{eff}} \cdot V_{sub}}$ ➡ extract N_{eff}



N_{eff} = 2.2 · 10^{13} cm^{-3}
Resistivity: 600 Ωcm

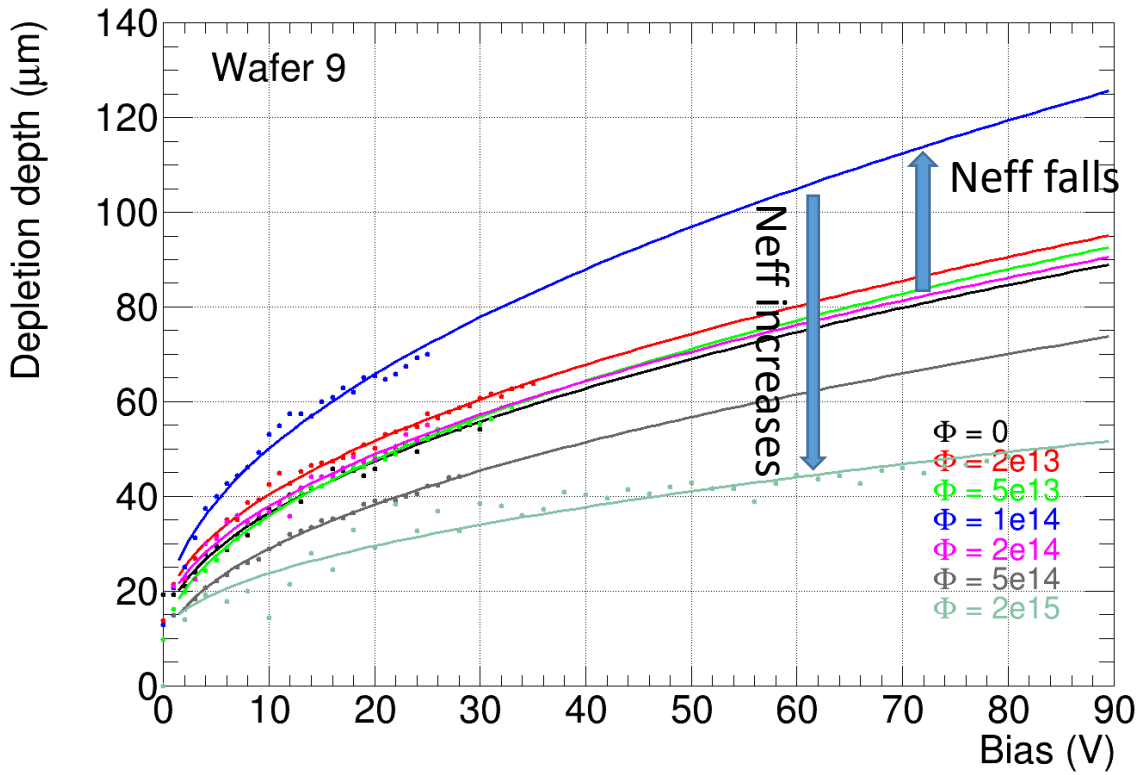


N_{eff} = 1.2 · 10^{13} cm^{-3}
Resistivity: 1100 Ωcm

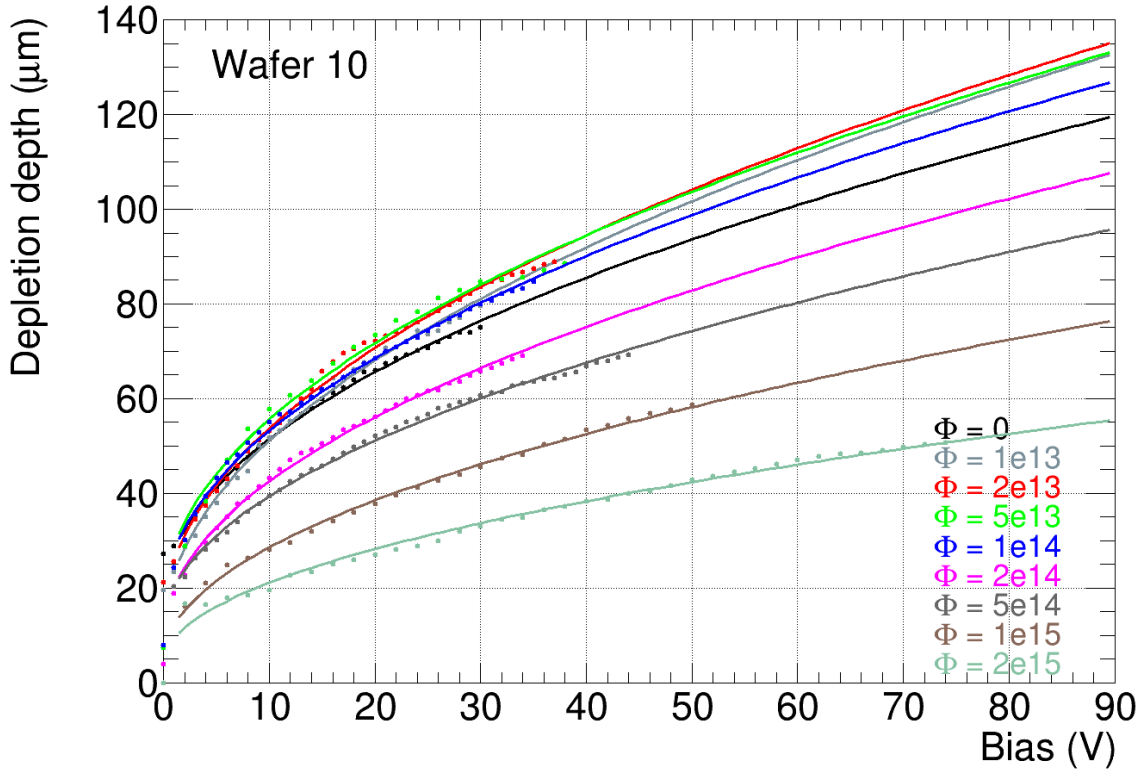
➔ resistivity smaller than nominal (1.9 kΩcm)

After irradiation with neutrons

W9 (600 Ohm cm)



W10 (1.1 kOhm-cm)



- depletion depth changes with irradiation
- acceptor removal effects seen

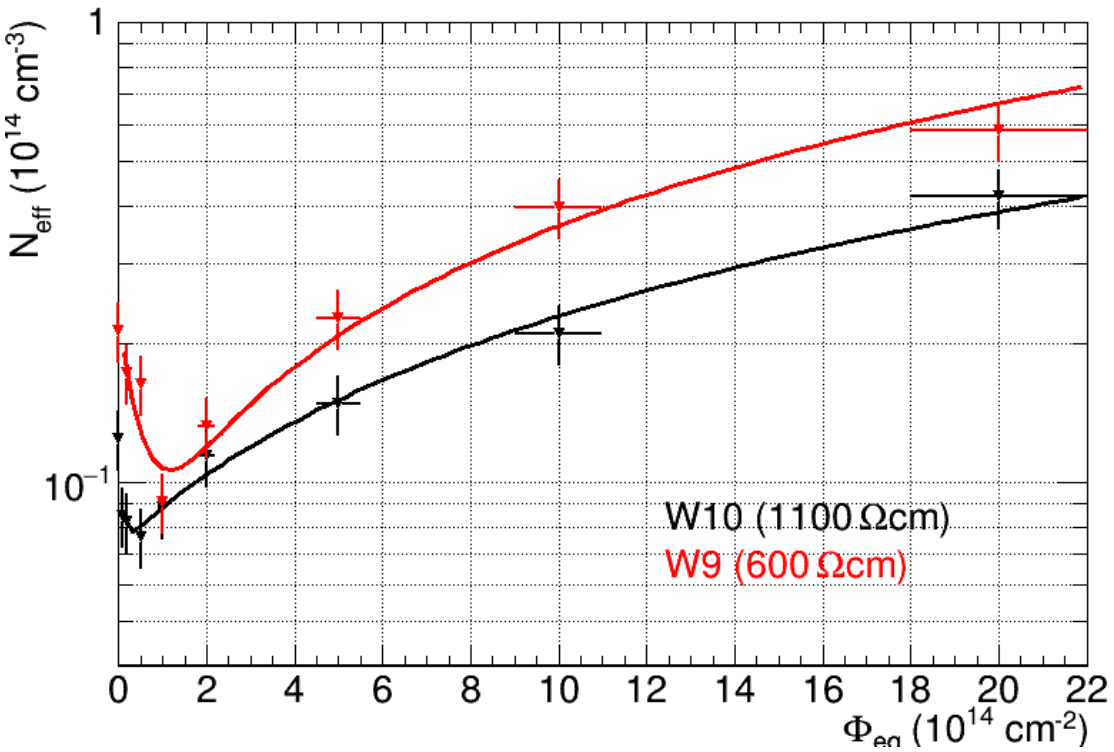
Fit: $$N_{\text{eff}} = N_{\text{eff0}} - N_{\text{c}} \cdot (1 - \exp(-c \cdot \Phi_{\text{eq}})) + g_{\text{C}} \cdot \Phi_{\text{eq}}$$

W9 (600 Ωcm):

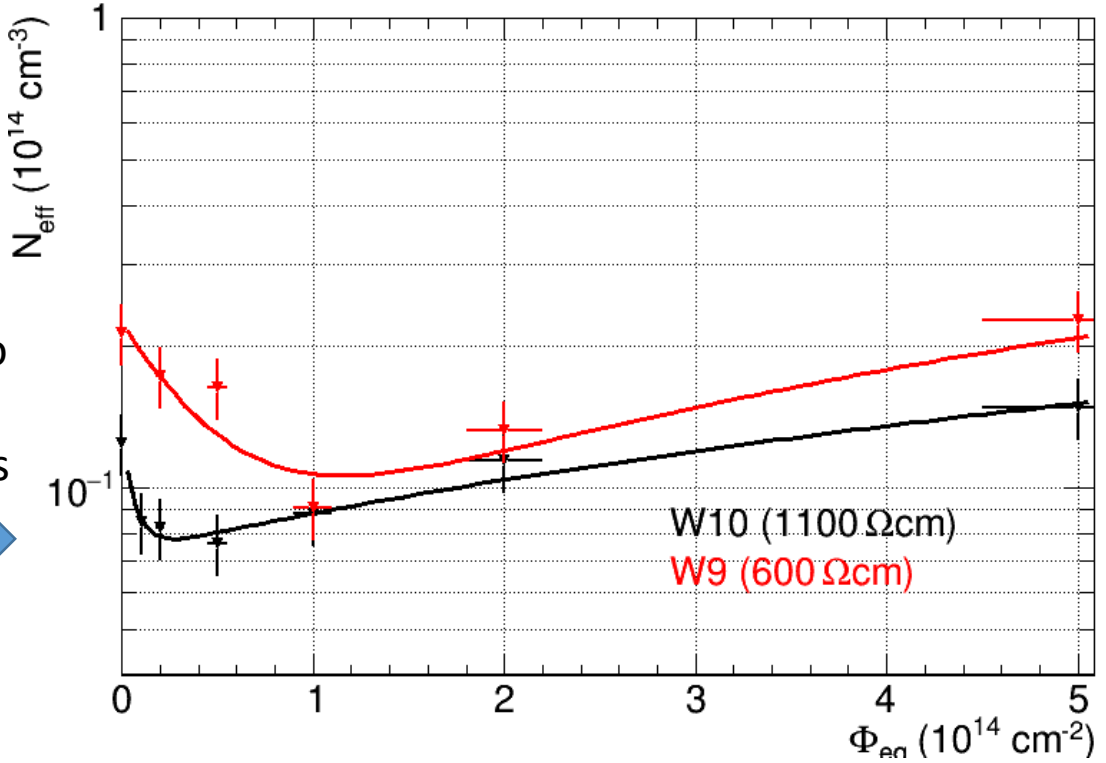
N_{eff0} = 2.2e13 cm^{-3}, N_c/N_{eff0} = 0.75,
c = 2.1e-14 cm^2, g_c = 0.031 cm^{-1}

W10 (1100 Ωcm):

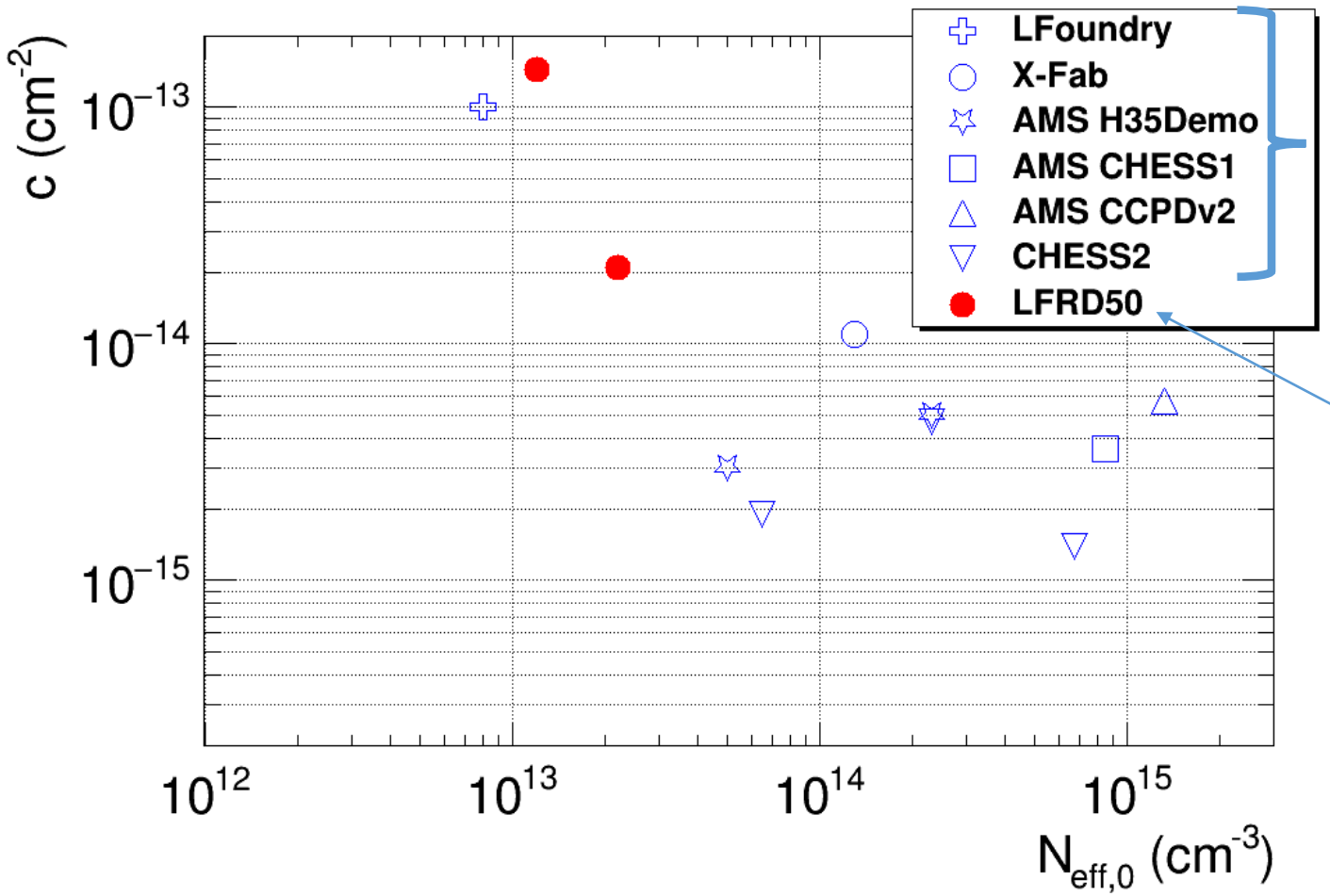
N_{eff0} = 1.2e13 cm^{-3}, N_c/N_{eff0} = 0.41,
c = 14 e-14 cm^2, g_c = 0.016 cm^{-1}



zoom to low fluences



Compare removal parameter ***c*** with other CMOS substrates



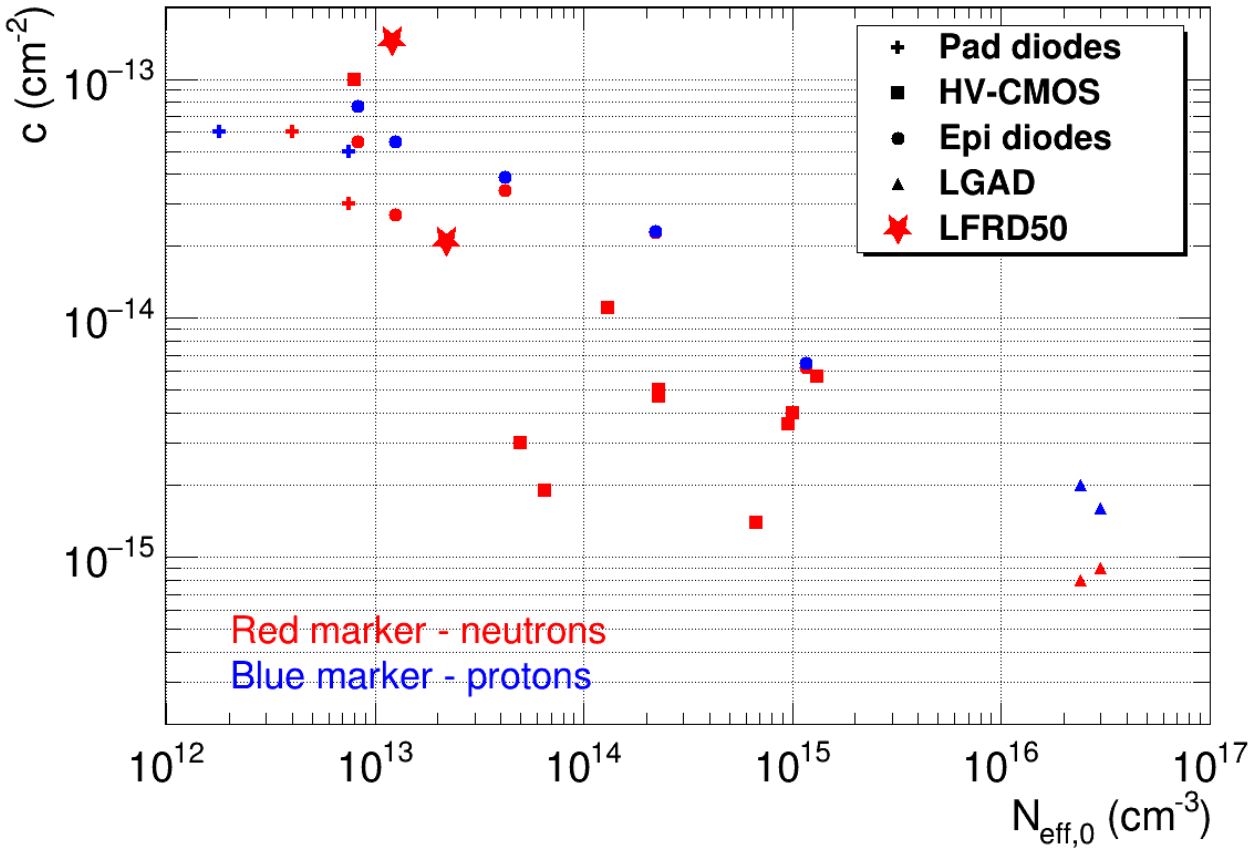
From
B. Hiti et al.,
Charge collection in irradiated HV-CMOS detectors

https://doi.org/10.1016/j.nima.2018.07.022

This measurement

Summary for CMOS, diodes, LGAD, for protons and neutrons

- Fits into the summary plot:
  ➔ *c* drops with increasing N_{eff0}
  ➔ *c* higher after proton irradiation



Epi diodes:

- P. Dias de Almeida, 32nd RD50 Workshop, 2018
- https://indico.cern.ch/event/719814/contributions/3022586/
- K. Kaska http://repositum.tuwien.ac.at/obvutwhs/content/titleinfo/1633435

LGAD:

- G. Kramberger, JINST Vol. 10 (2015) P07006

Pad diodes:

- G. Kramberger, 26th RD50 workshop, Santander, 2015 https://indico.cern.ch/event/381195/contributions/905665/

CMOS:

- A. Affolder et al., JINST 11 P04007 2016
- I. Mandić et al., JINST 12 P02021 2017
- E. Cavallaro et al., JINST 12 C01074 2017
- B. Hiti et al., JINST 12 P10020 2017
- B. Hiti et al, (NIMA) https://doi.org/10.1016/j.nima.2018.07.022

See also:

- M. Moll, IEEE TNS 65 (2018) p.1561 https://doi.org/10.1109/TNS.2018.2819506
- G. Kramberger, HSTD11, Okinawa, 2017 https://indico.cern.ch/event/577879/

Summary

- measurements with irradiated pixel detector structures on *RD50-MPW1* chip by LFoundry, two initial resistivites

- TID irradiation by background radiation in the reactor when chain reaction turned off (no neutrons)
  ➔ smaller detector current measured after irradiation
    - may help to identify the source of the excessive detector current measured before irradiation

- neutron irradiation
  ➔ N_{eff} measured with E-TCT and studied as the function of fluence
    ➔ acceptor removal parameter **c** extracted
      - results consistent with previous measurement
      - acceptor removal constant higher for substrates with lower initial resistivity