Studies of non-irradiated and irradiated HV-CMOS detectors

I. Mandić, G. Kramberger, V. Cindro, A. Gorišek, M. Mikuž, M. Zavrtanik et al.,
Jožef Stefan Institute ,Ljubljana, Slovenia

work done in the framework of ATLAS CMOS pixels
and ATLAS CMOS strips collaborations

Motivation

- HV-CMOS technology is a very interesting option for detectors at upgraded LHC
  - → reduced cost
  - → improved granularity and spatial resolution

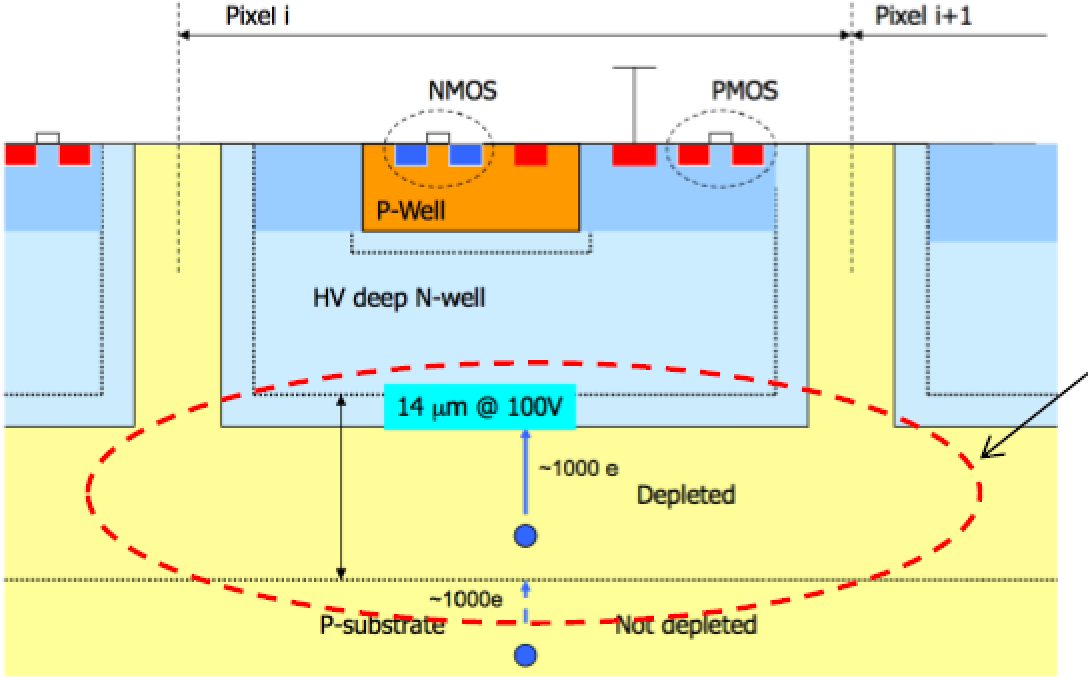
- essential to understand charge collection properties especially after irradiation and at LHC readout speed
  - → very thin depleted layers compared to usual detectors
  - → low resistivity silicon compared to usual detector material

- Edge-TCT and CCE measurements with ^{90}Sr are ideal tools for such studies

- charge collection studies with HV-CMOS sensors (two types of samples CCPDv2, CHESS1) before and after irradiation will be presented here

HV-CMOS detectors

- charge collecting electrode n-well in p-type substrate, resistivity ~ 20 Ωcm
- depletion layer ~14 um thick at 100 V bias
- CMOS circuitry is implemented in the n-well



Daniel Muenstermann | TWEPP 2012 | Oxford | September 19th, 2012

Interested in charge collection from n-well - substrate junction

Samples

1) CHESS1 chip (ATLAS CMOS strips studies):
350 nm AMS, 20 Ωcm, 120 V max bias

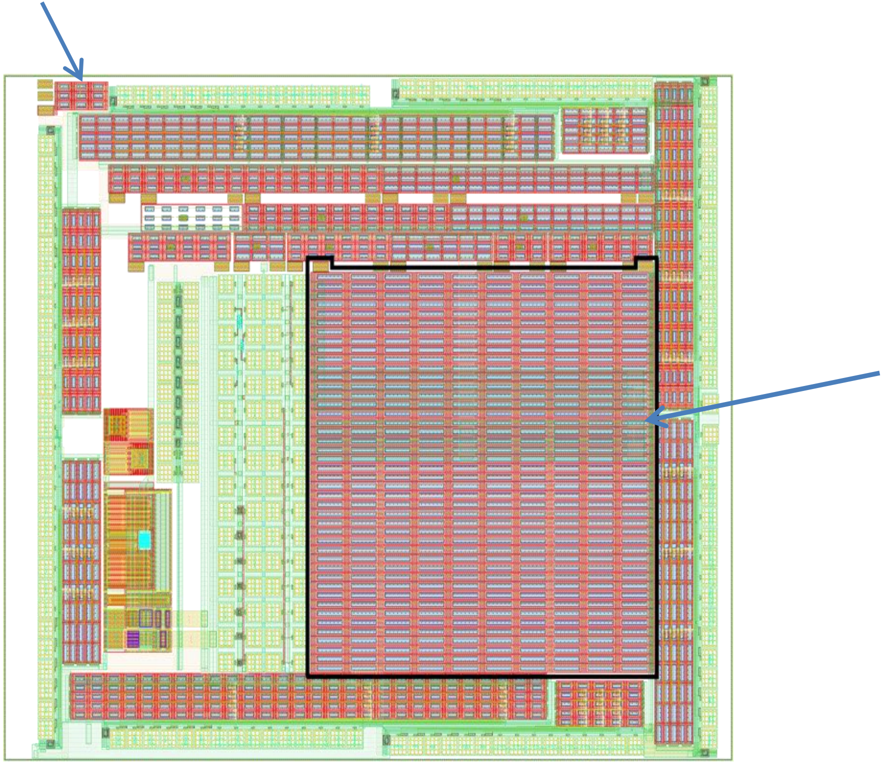
(see. Zhijun's talk earlier today)

Passive pixels: no amplifier in n-well, n-well connected directly to readout (as in standard diode)

E-TCT

- 100 x 45 μm² pixels
- passive pixel

➔ induced current directly observed on the scope

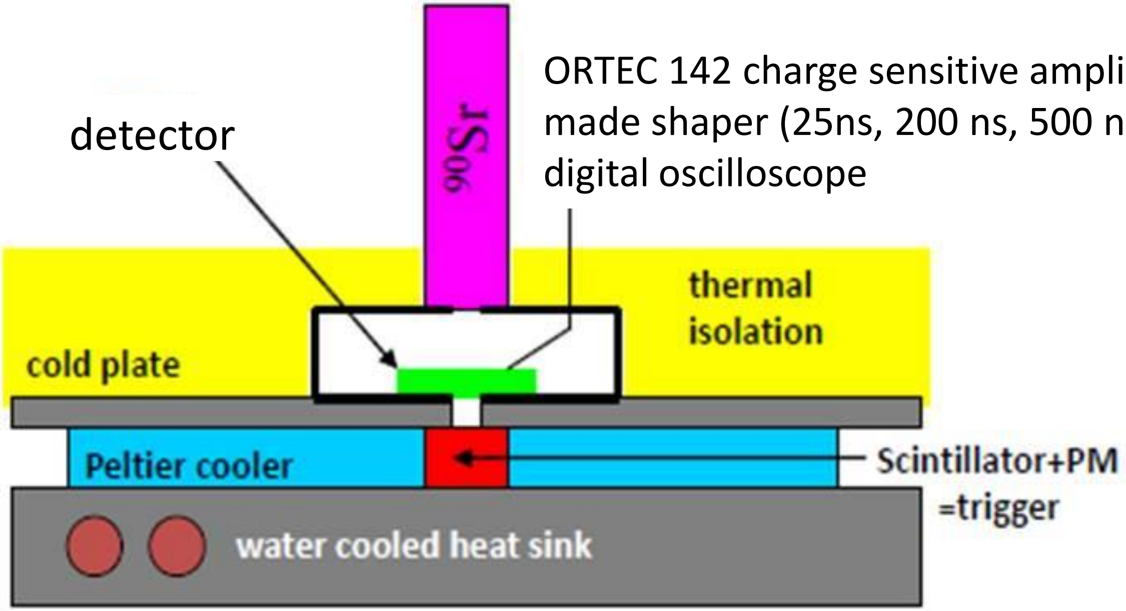


CCE measurement with MIPs from Sr^{90} source

- 2 x 2 mm² total area
- 880 passive pixels (45 x 200 μm²) tied together

➔Large structure needed for good collimation and sufficient event rate

MIP CCE measurement setup


detector

ORTEC 142 charge sensitive amplifier + custom made shaper (25ns, 200 ns, 500 ns)
digital oscilloscope

- HV-CMOS: thin → small signals, large noise → S/N bad
  ➔ must have clean sample
  ➔ need large detector for reasonable trigger rate and good collimation, small scintillator

MIP CCE measurement

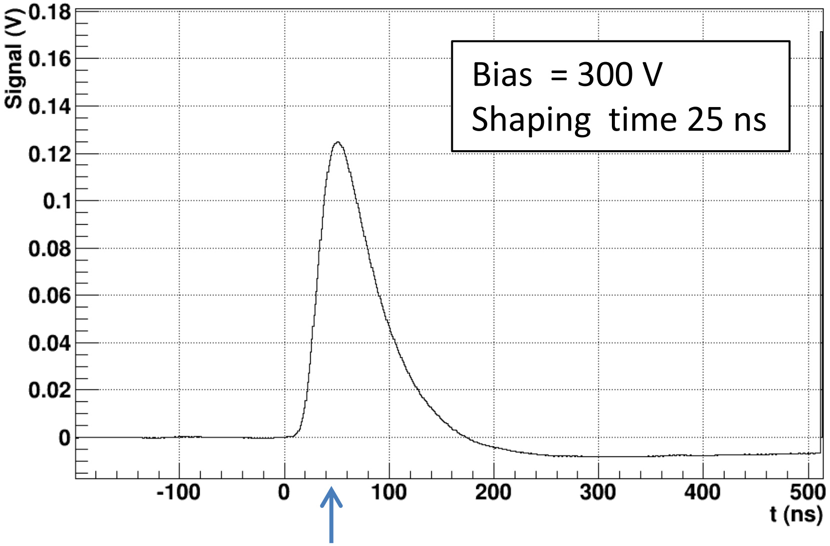
Calibration

- Sr^{90} with 300 µm thick FZ p-type silicon diode, V_{fd} = 70 V
  ➔ calibration at 25 ns shaping time : **230 electrons (mean)/mV**

- confirmed with Am241 source, 59.5 keV photon peak in 300 µm thick detector

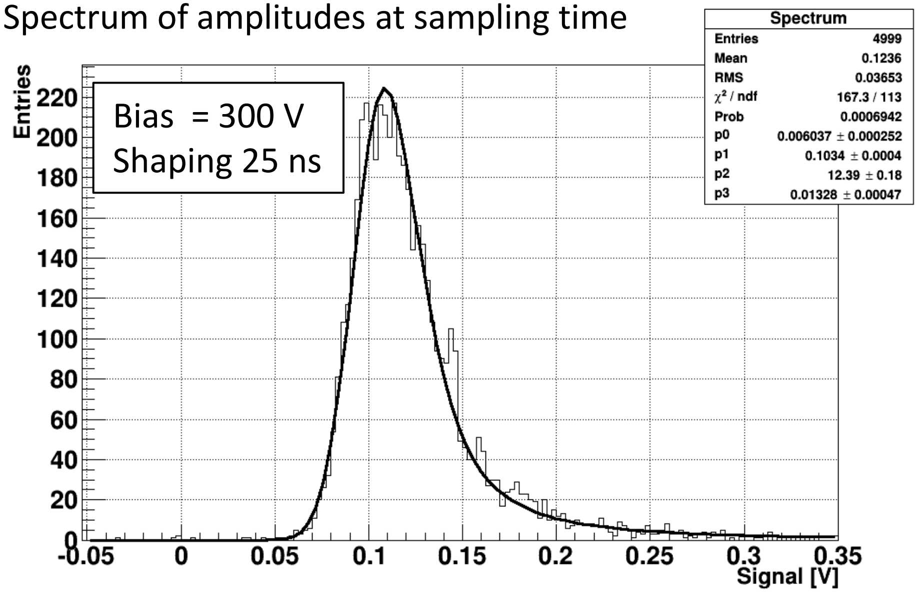
FZ p-type silicon diode, 300 µm thick , V_{fd} = 70 V:

Averaged 5000 waveforms



Sampling time

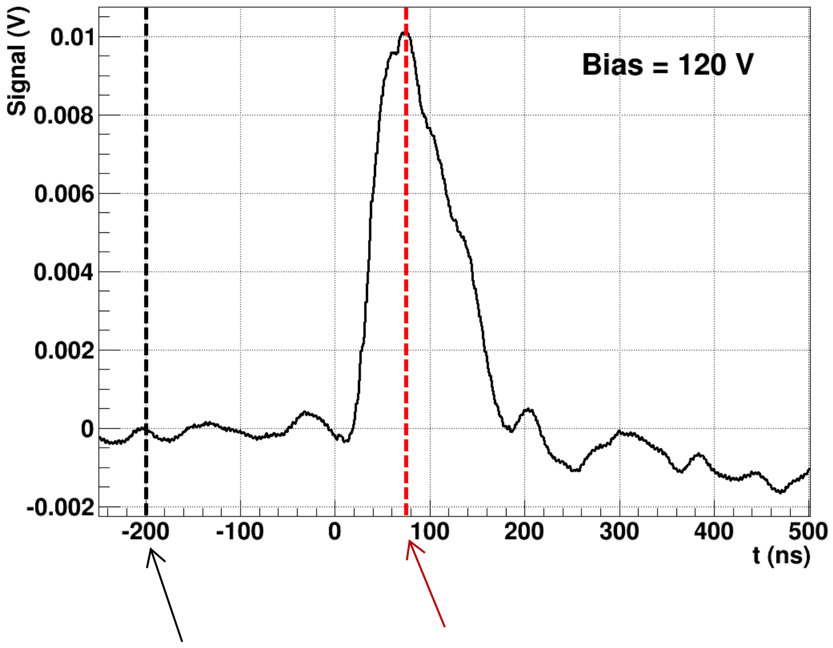
Spectrum of amplitudes at sampling time



MIP CCE measurement

CHESS1 large passive HV-CMOS array

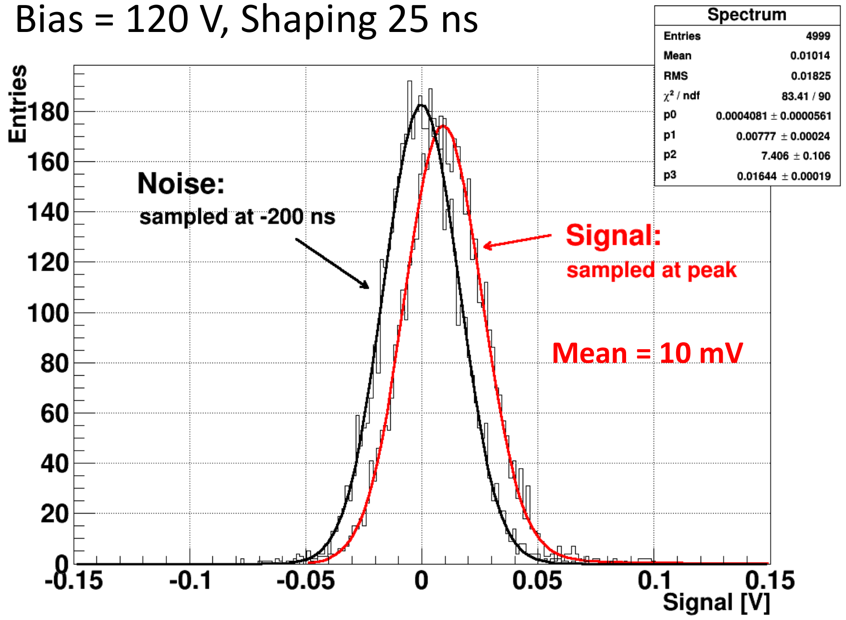
Averaged waveform (5000 samples)



Noise sampling point

Signal sampling point

Bias = 120 V, Shaping 25 ns

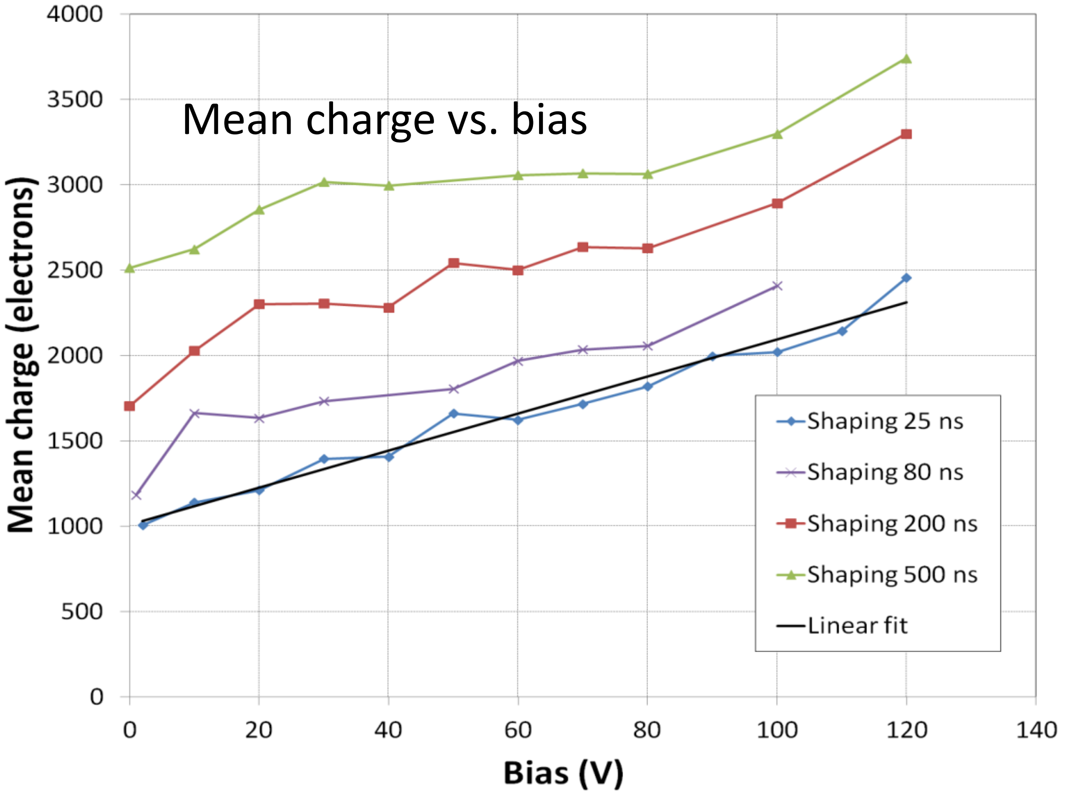


Signal spectrum mean: 10 mV

➔mean charge: 2300 electrons

MIP CCE measurement

CHESS1 large passive HV-CMOS array



25 ns shaping: **Mean charge = 1010 el + 11 el/V**

- charge increases with shaping time → diffusion

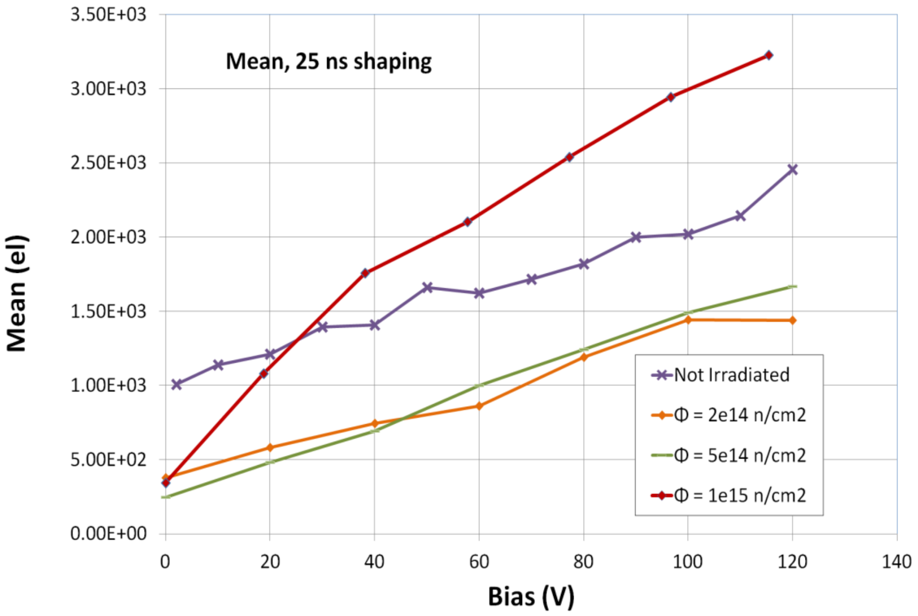
- charge ~ 1000 el at 0 V due to diffusion

➔if at 100 V depleted layer 14 μm thick: **~ 1400 el** expected from depleted layer:
measured: **2100 el** ➔ **~ 700 el** from diffusion (~ consistent)

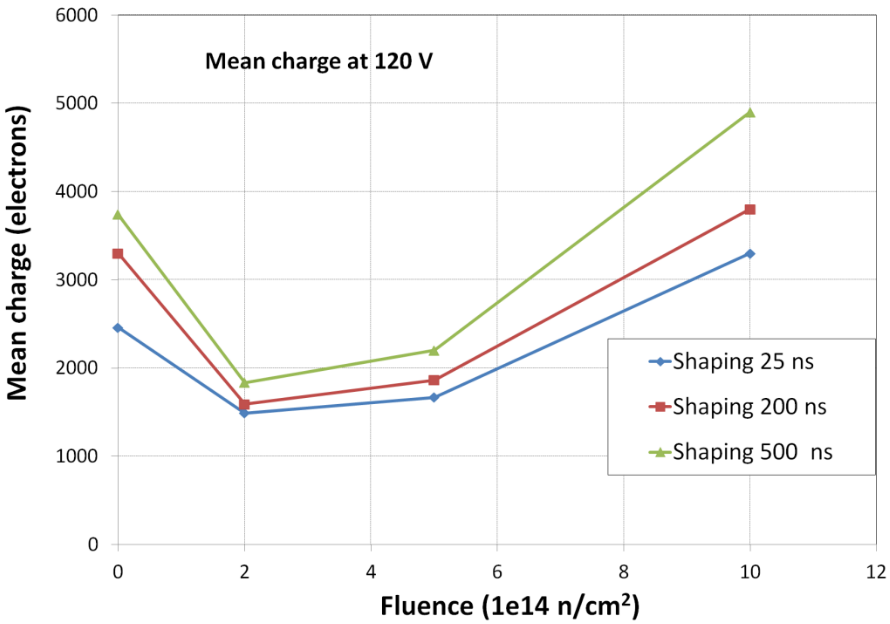
MIP CCE measurement

CHESS1 large passive HV-CMOS array – **irradiated** with neutrons in reactor in Ljubljana

Charge vs. bias



Charge at 120 V vs. fluence



- charge drops after first irradiation step, small influence of shaping time: **small diffusion contribution**
- charge increases with more irradiation ➔ **depleted region increases due to acceptor removal**

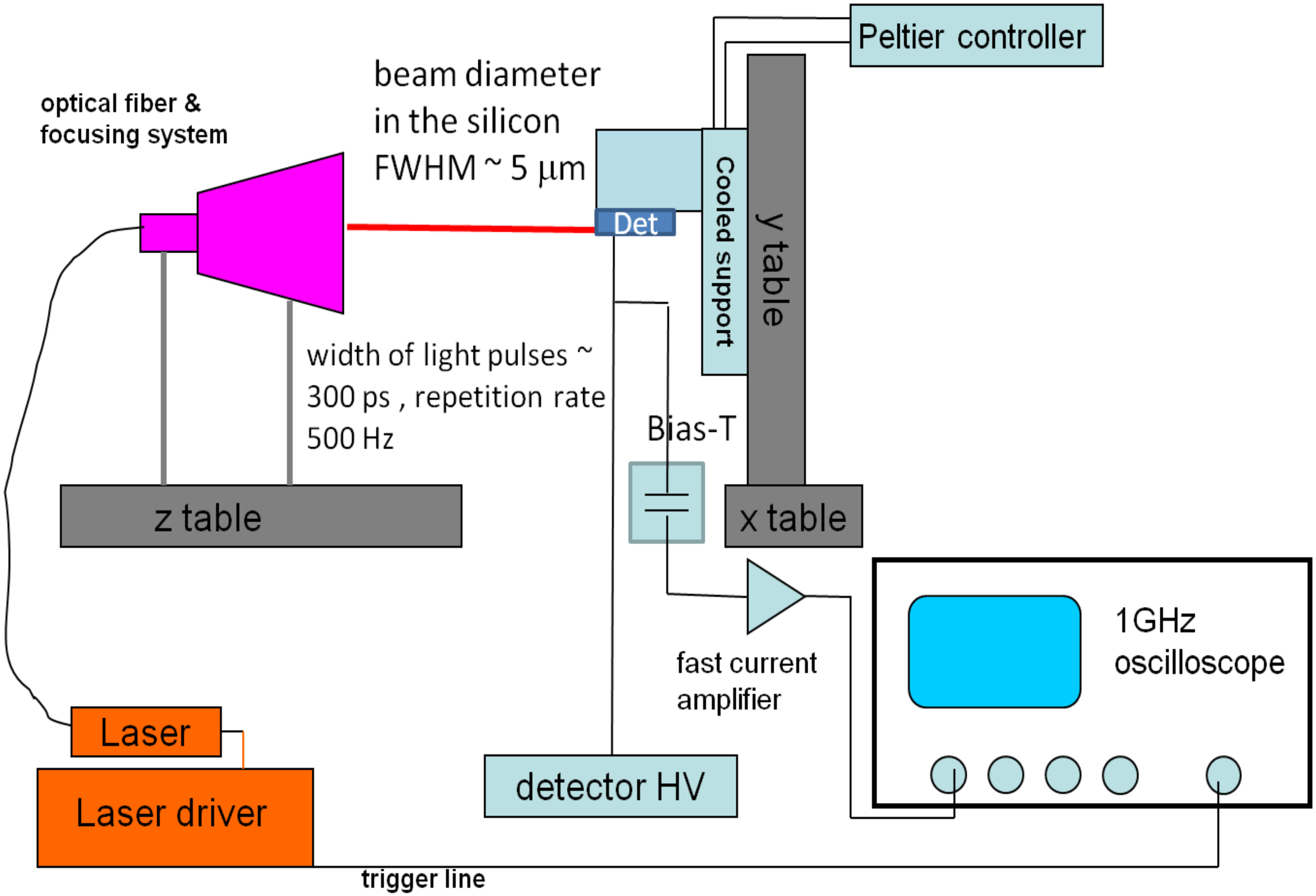
→ see talk by G. Kramberger

- larger charge at 500 ns shaping at 1e15 n/cm^2 : detrapping?

➔ τ_{d1} ~ **500 ns** for holes measured (however for 20% of the trapped holes),

see: *G. Kramberger et al., 2012 JINST 7 P04006*

Edge TCT



optical fiber & focusing system

beam diameter in the silicon FWHM ~ 5 μm

Peltier controller

Det

Cooled support

y table

width of light pulses ~ 300 ps , repetition rate 500 Hz

Bias-T

z table

x table

fast current amplifier

1GHz oscilloscope

Laser

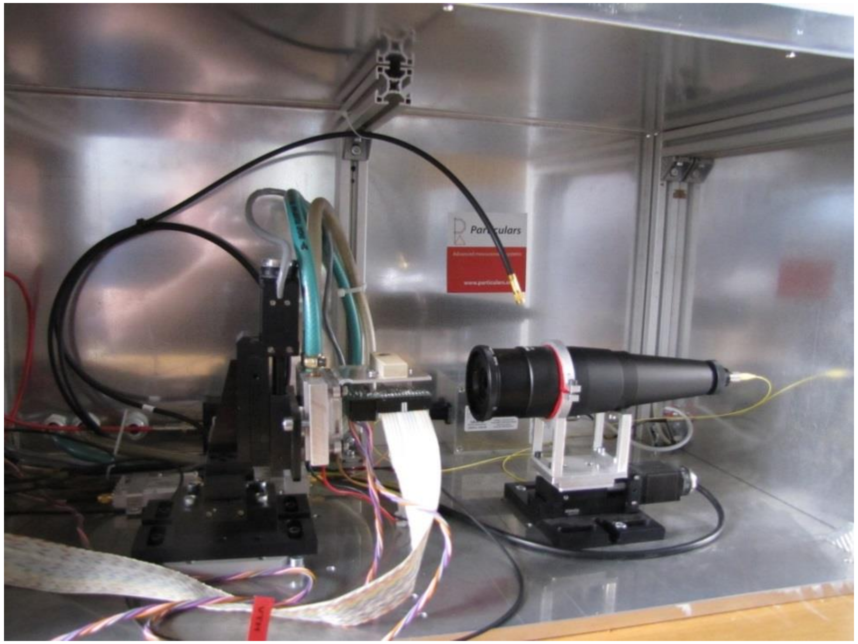
Laser driver

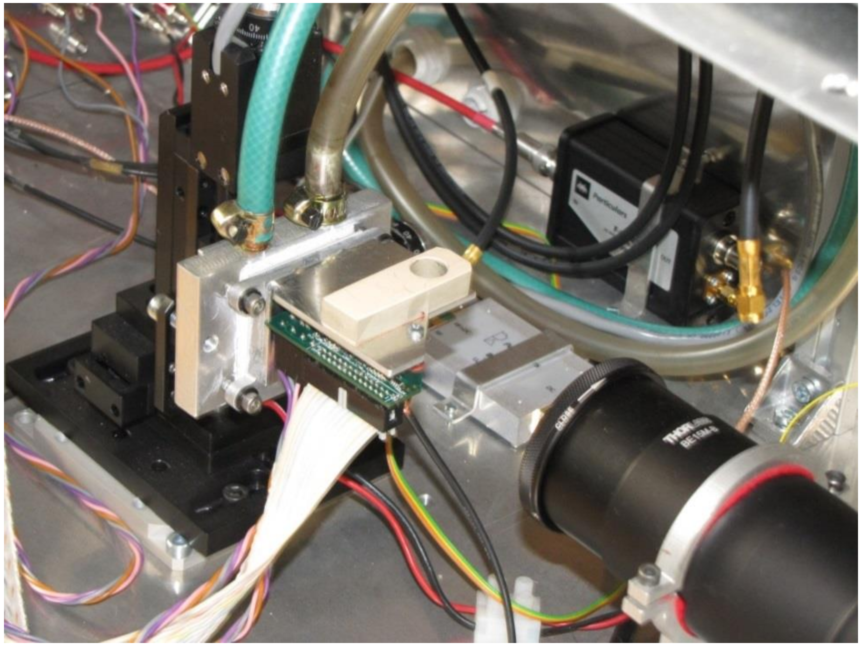
detector HV

trigger line

Edge-TCT

Photos of the setup (more details: www.particluars.si)

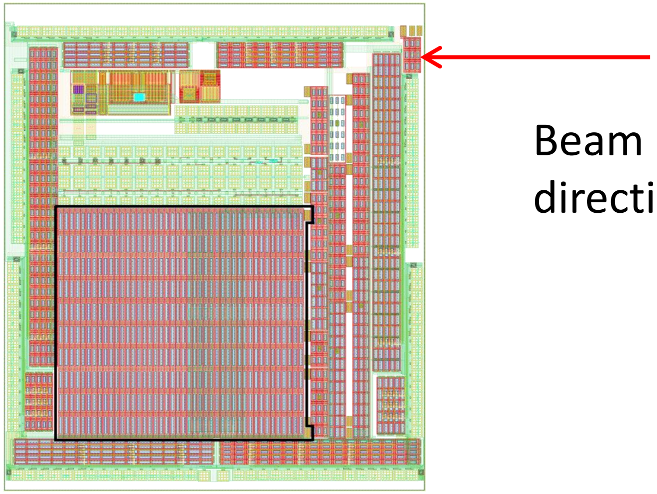




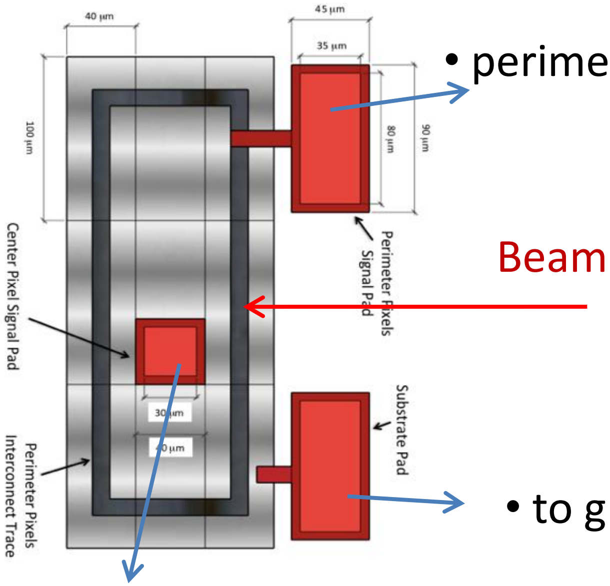
Edge-TCT

Chess1

- passive pixel in the corner

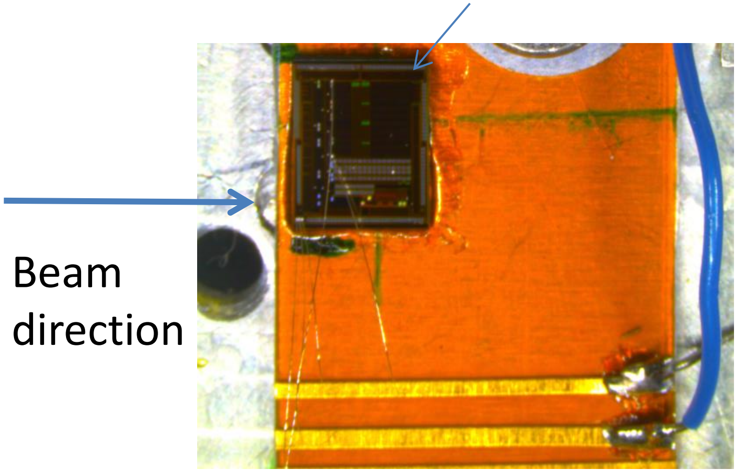


Beam direction



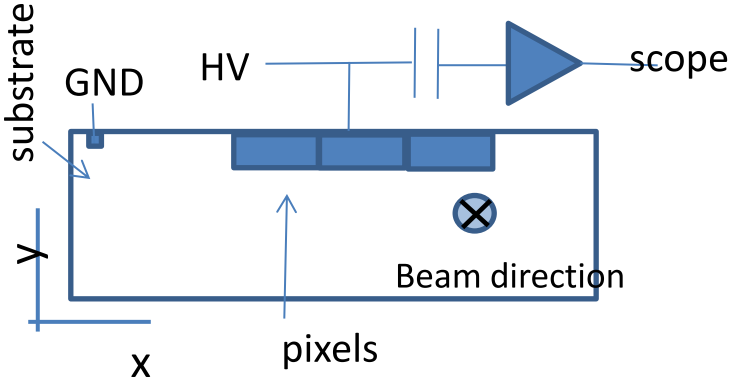
- perimeter to HV
- to ground
- signal to high voltage and readout (via Bias-T)

CHESS1



Beam direction

Detector connection scheme:

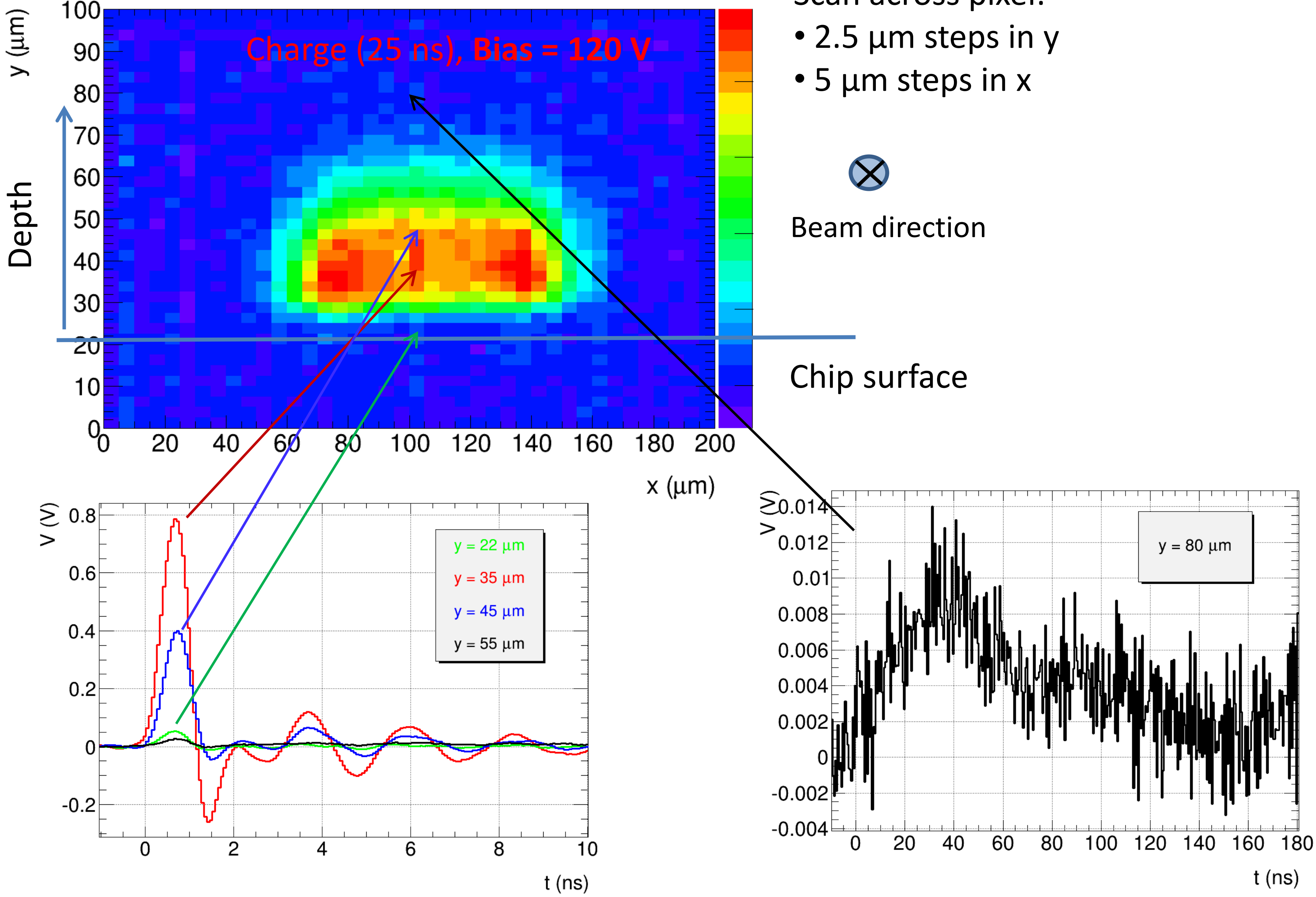


Edge-TCT

Chess1, not irradiated, pixel 100 µm x 45 µm

Scan across pixel:

- 2.5 µm steps in y
- 5 µm steps in x

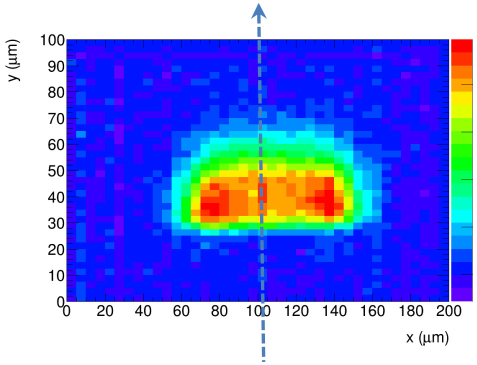


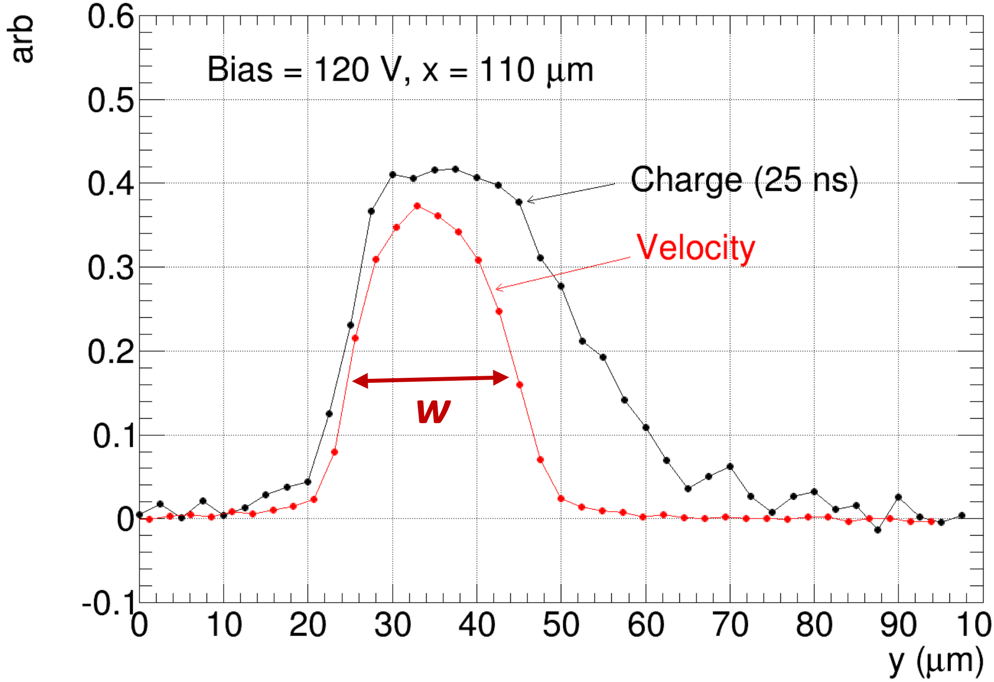
Edge-TCT

Chess1, not irradiated

1) **charge:** integral of induced current pulse
2) **velocity** (in E-TCT): induced current immediately after the laser pulse

$$I(x,y,t\sim 0)\approx qE_w(x,y)\left[\bar{v}_e(x,y)+\bar{v}_h(x,y)\right];\quad \bar{v}_e(x,y)+\bar{v}_h(x,y)\propto E$$



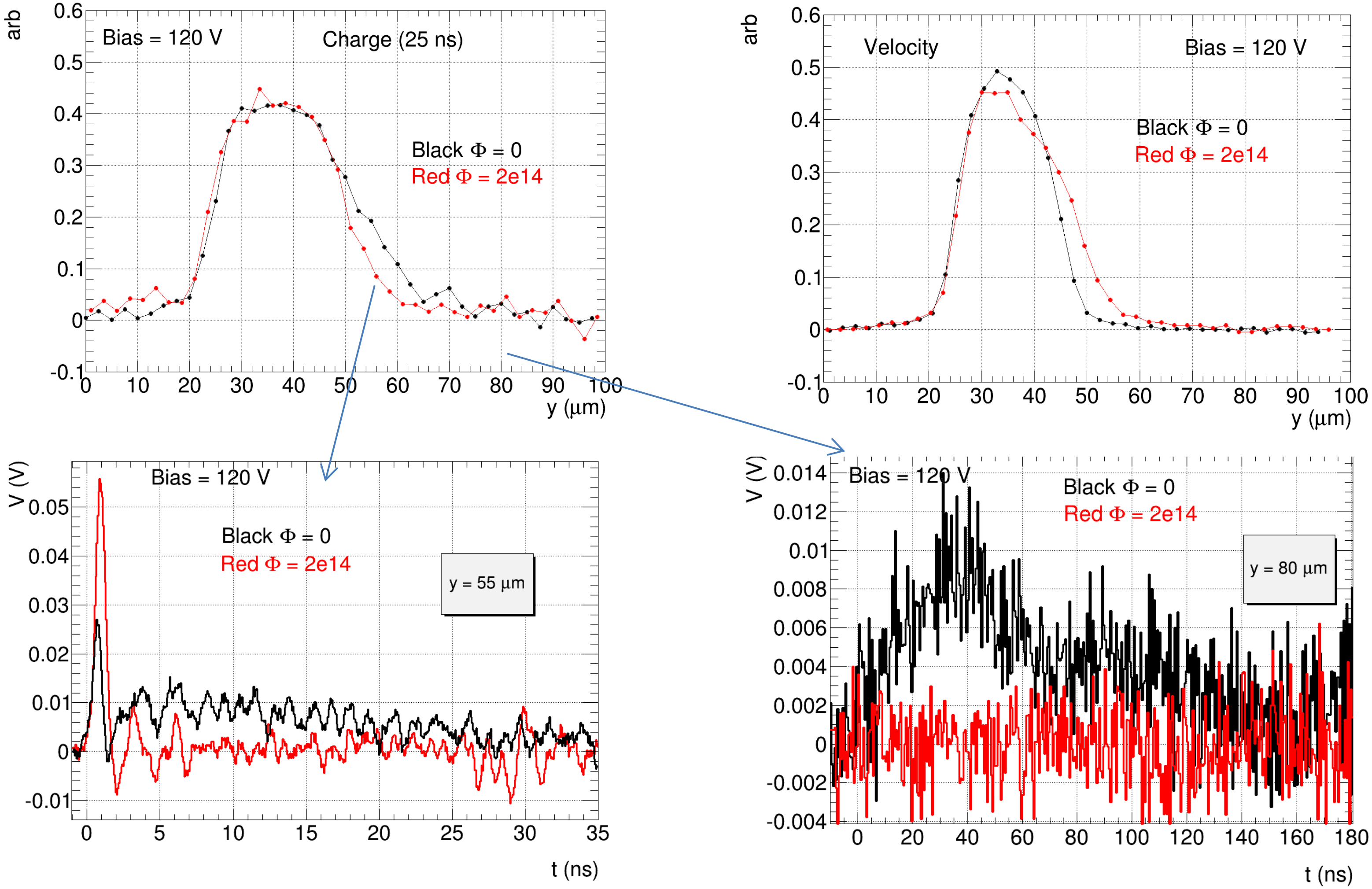


- **high velocity ~ depleted region** ~ 20 µm → about 60% charge within this region
- total charge collection region wider (diffusion) ~ consistent with 2400 el measured with Sr-90
  - → take into account laser beam width

Edge-TCT

Chess1, irradiated with 2e14 n/cm^2

- charge collection region narrower
- field region (velocity) increases ➔ acceptor removal
- no long tails of induced current pulses ➔ less diffusion

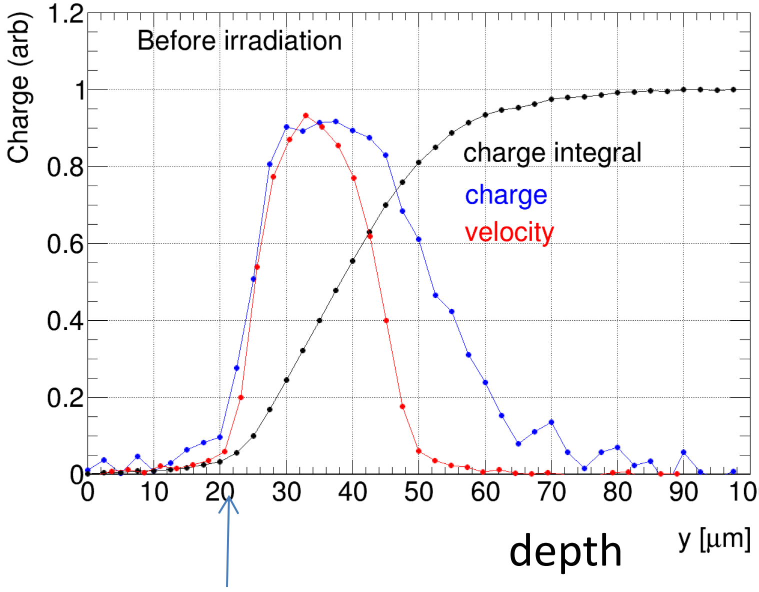


Edge-TCT

Chess1, irradiated with 2e14 n/cm^2

Charge collection and velocity profiles across pixel centre

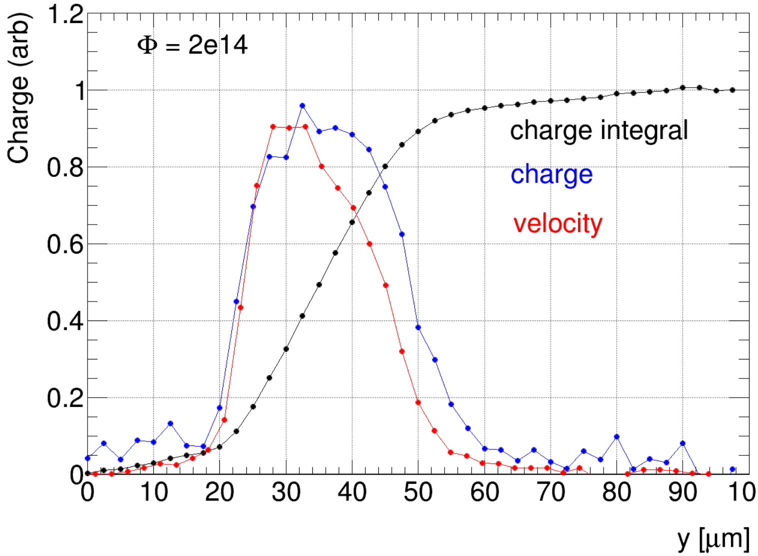
Not irradiated, 120 V



depth

chip surface

Irradiated 2e14, 120 V



After irradiation:

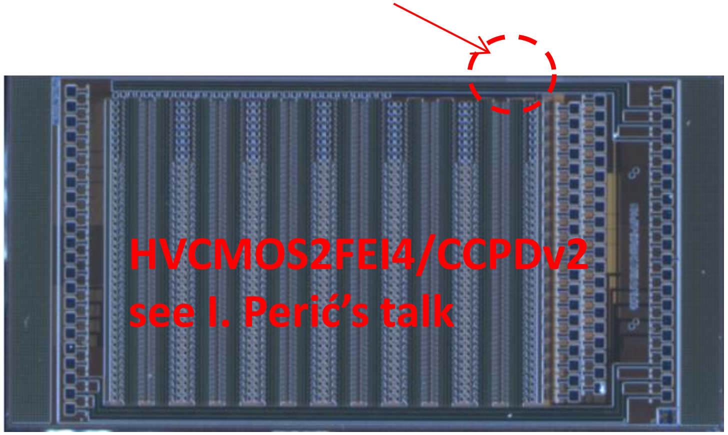
→smaller difference between charge collection and velocity (depleted) region

→charge within depleted region: before irradiation ~60% after irradiation ~90 %

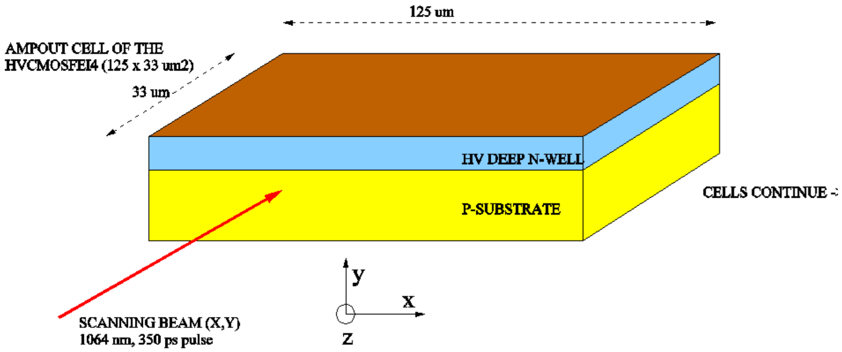
Samples

2) CCPDv2 chip (ATLAS CMOS pixels studies): 180 nm, AMS, ~20 Ωcm, 60 V max bias,
Active pixels: output of the amplifier monitored on the scope

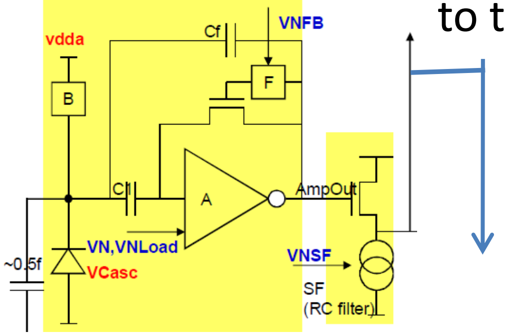
E-TCT on single cell, 125 x 33 μm^2 readout after the charge sensitive amplifier (not observing induced current)



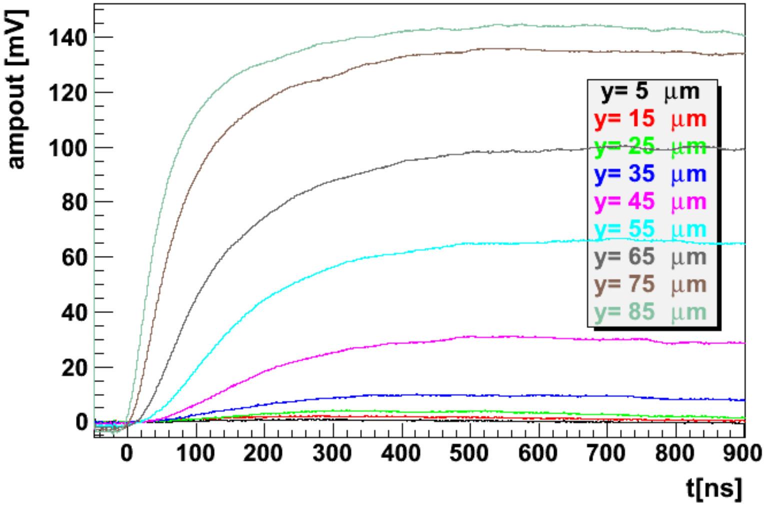
HVCMOS2FEI4/CCPDv2
see I. Perić's talk



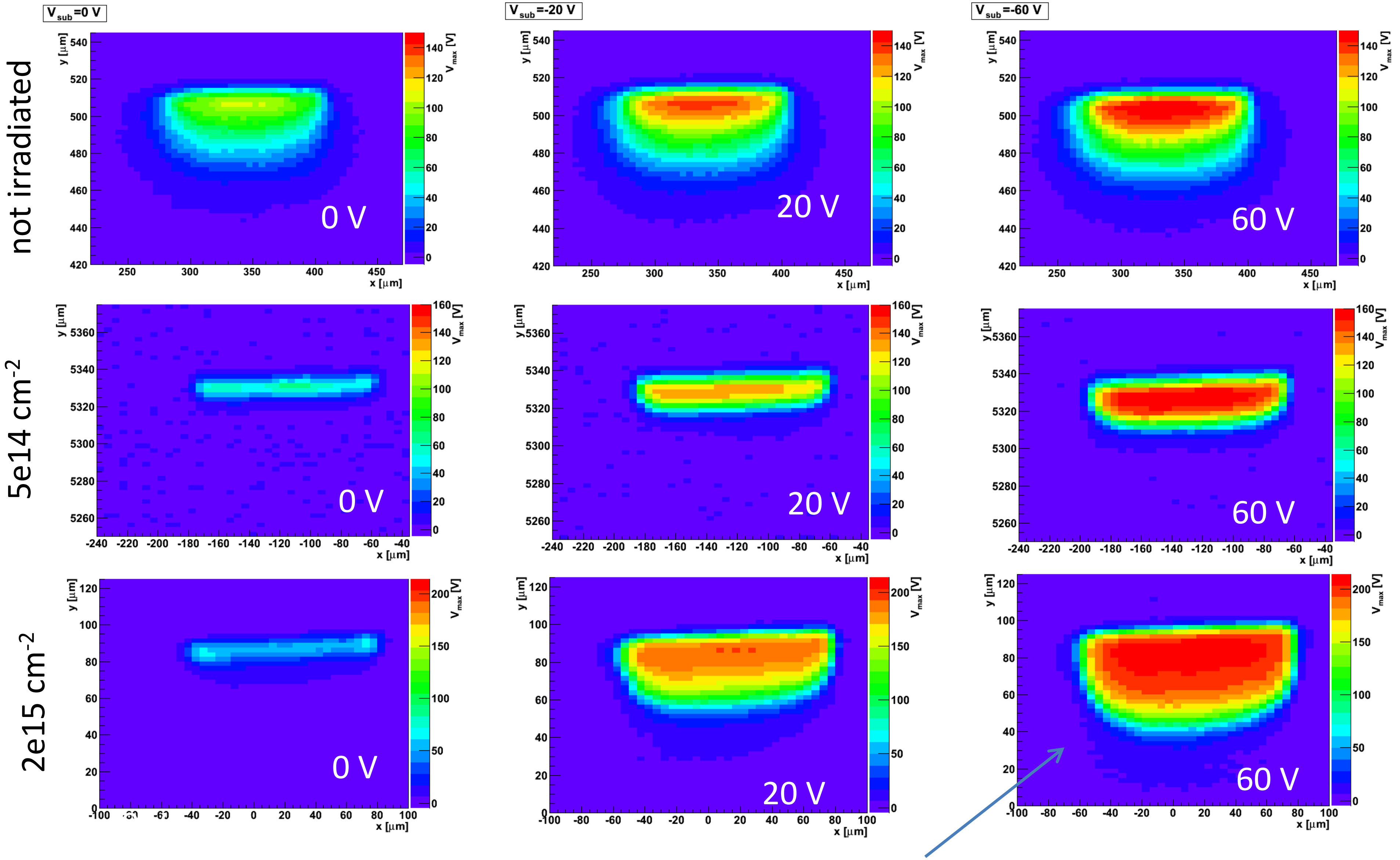
Single cell charge sensitive amplifier:



to the scope

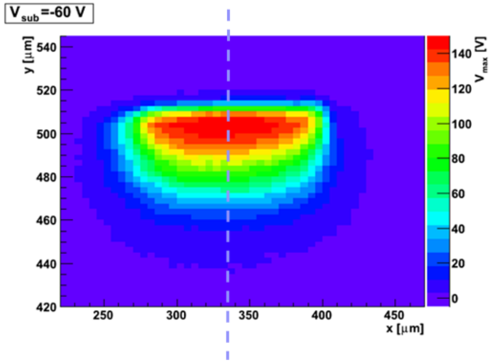


Edge-TCT, HV2FEI4, pixel 125 µm x 33 µm, irradiated with neutrons in Ljubljana

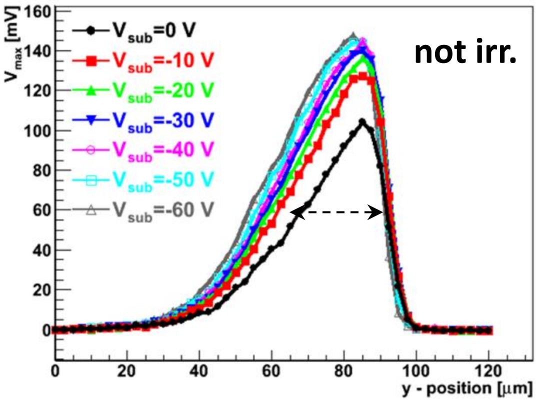


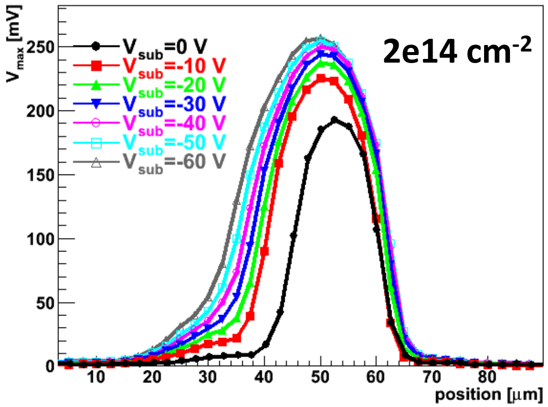
Charge collection region **larger** at high fluence

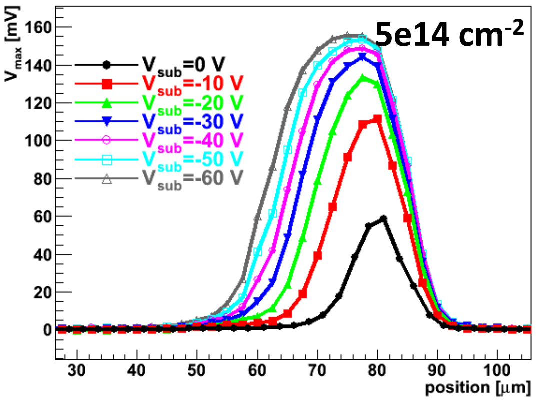
Edge-TCT, HV2FEI4

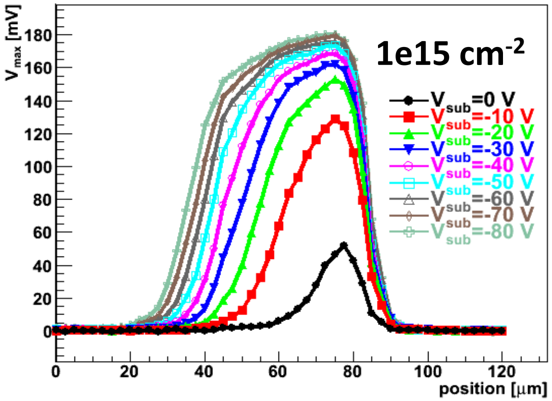


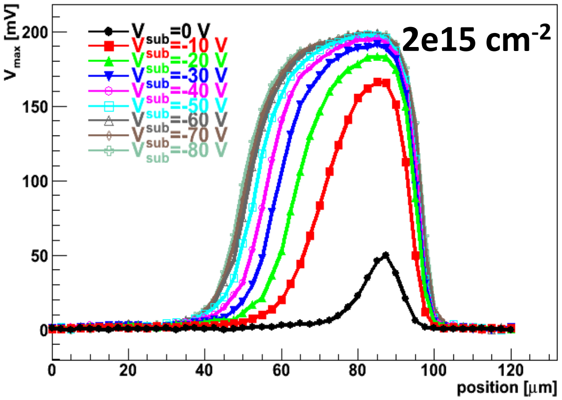
Charge collection profiles across center of the pixel









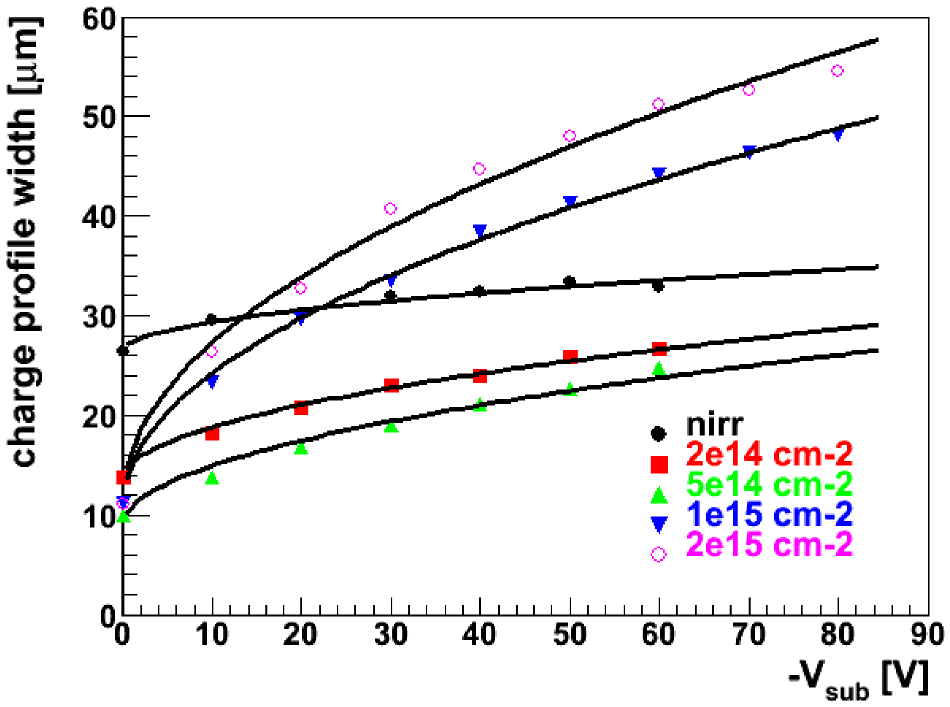


- tail (diffusion) seen before irradiation, almost disappears at 5e14 cm^{-2}

- profile width **(FWHM)** is a measure of charge collection region (drift + diffusion)
  → the width of the laser beam (~ 8 um FWHM) should be taken into account

Edge-TCT, HV2FEI4

Dependence of charge collection region on bias voltage



- at $V_{sub}=0$ V it is assumed that charge is collected by diffusion (note the FWHM of the beam)
- any additional bias increases depletion layer which adds to the diffusion
- effective doping concentration seems to decrease with fluence

  → **depletion region wider after irradiation!**

Points to effective acceptor removal – see talk by G. Kramberger tomorrow

Conclusions:

CCE with MIPs from Sr-90:

- first measurements with passive HV-CMOS devices on CHESS1 chip:

→ before irradiation: **Q = 1010 el + 11 el/V**

→ after irradiation with 2e14 and 5e14 n/cm^2: **Q = 250 el + 11 el/V**

→ after 1e15 n/cm2 larger charge than before irradiation: ~ 3200 el @ 120 V

E-TCT:

- passive pixel (CHESS1) : directly probe field region, charge collecting region, observe induced current pulses, long tails (diffusion).
  After irradiation: → depleted region increases, no tails of induced pulses

- active pixel (HV2FEI4): map charge collection region, diffusion smaller after irradiation
  →significant widening of charge collecting region after 1e15n/cm2

Effective Acceptor removal!

Consistent!

In HVCMOS detectors charge collection increases with irradiation in certain fluence range→ **selection of substrate material important to explore the effect**

Edge-TCT

Chess1, not irradiated

- longer integration, more charge collected deeper in the pixel (diffusion)