E-TCT and charge collection studies with irradiated HV-CMOS detectors

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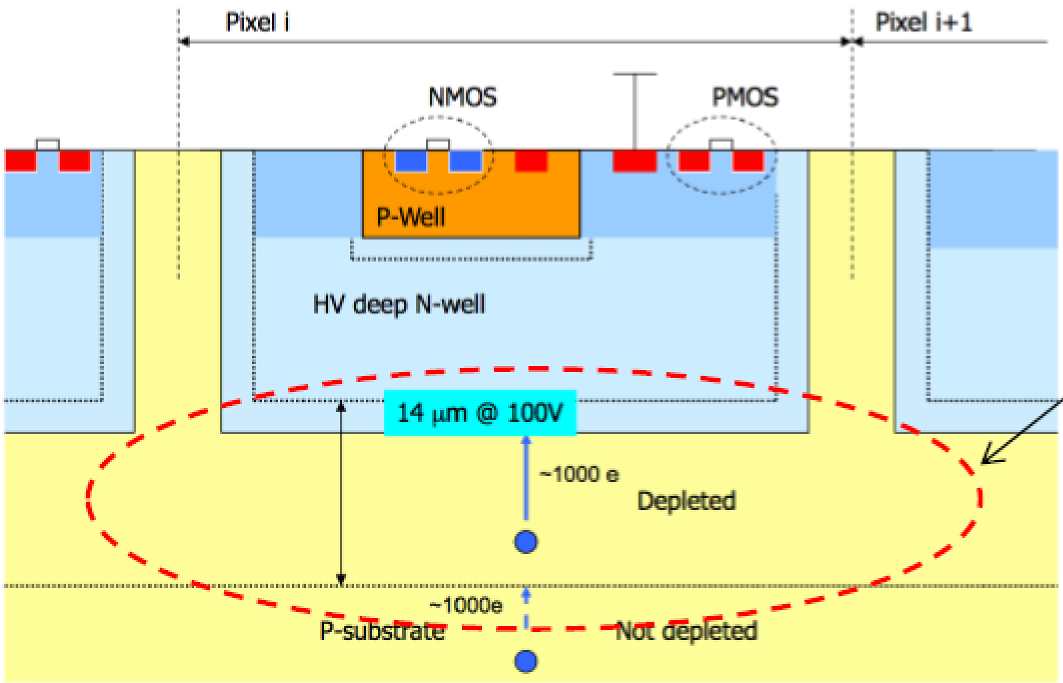
et al.

HV-CMOS detectors

- charge collecting electrode n-well in p-type substrate, resistivity 10 or 20 Ωcm
- depletion layer ~16um thick at 120 V bias (at 20 Ωcm)
- CMOS circuitry is implemented in the n-well



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

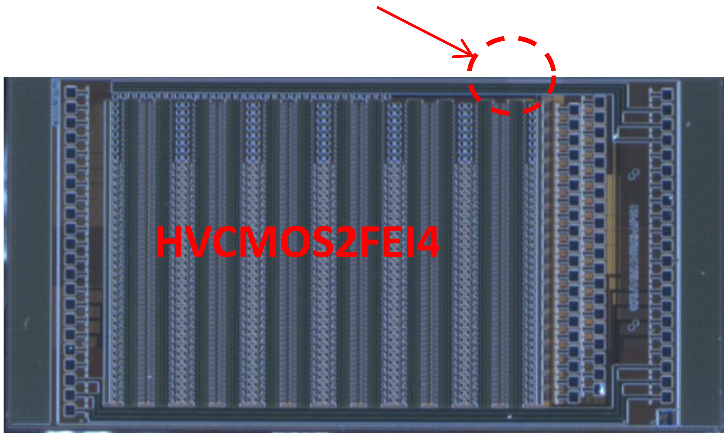
Charge collection from n-well - substrate junction

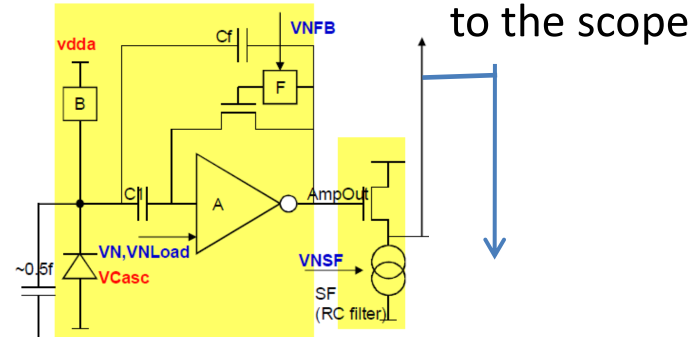
Samples

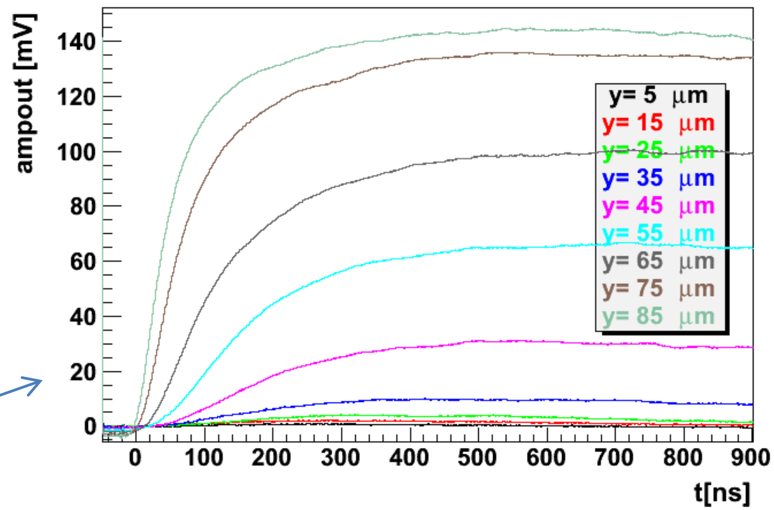
CCPDv2 (HV2FEI4) chip (*HV CMOS pixels studies*): 180 nm, AMS, 10 Ωcm, 60 V max bias,
Active pixels: output of the amplifier monitored on the scope

Single cell charge sensitive amplifier:

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







Charge: max. amplitude of the output

Samples

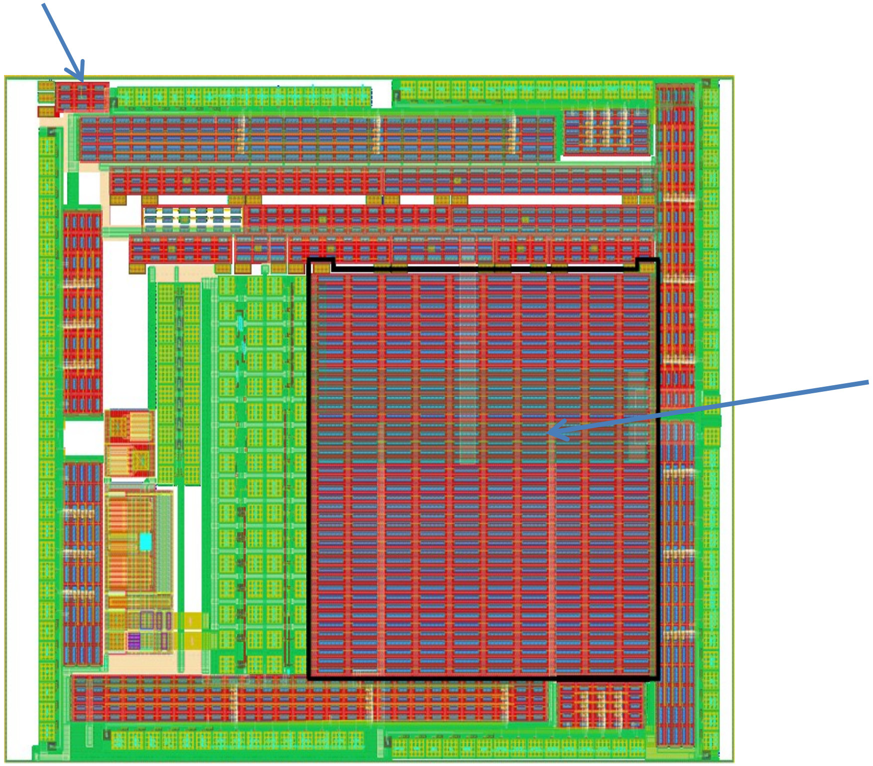
CHESS1 chip made by *Strips CMOS collaboration:*

350 nm AMS, 20 Ωcm, 120 V max bias

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

E-TCT

- 100 x 45 μm^2 pixels
- passive pixel ➔ induced current directly observed on the scope



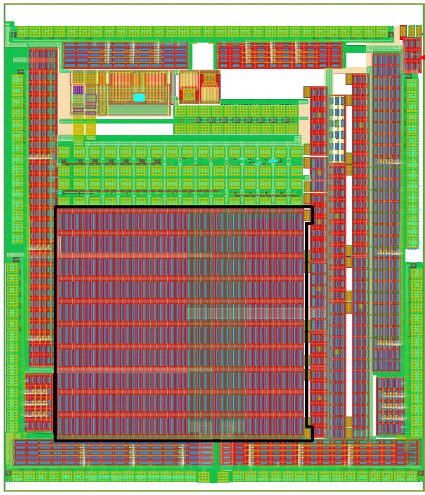
CC measurement with MIPs from Sr^{90} source

- 2 x 2 mm^2 total area
- 440 pixels ~ 45 x 200 μm^2 tied together

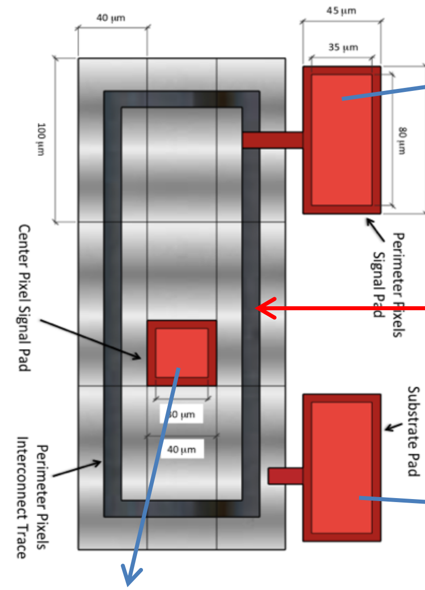
Edge-TCT

Chess1

- passive pixel array in the corner

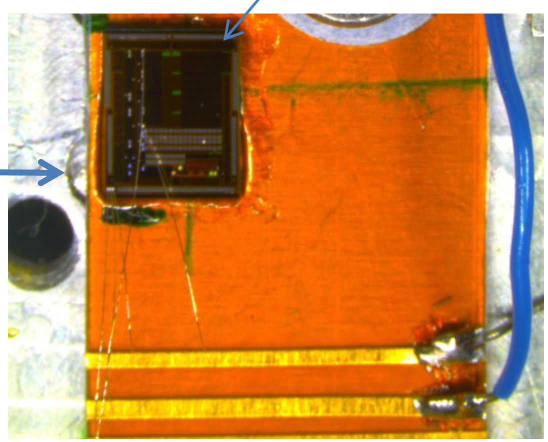


Beam direction



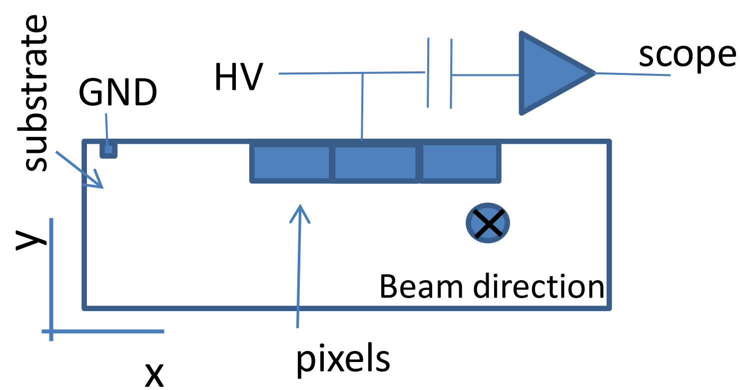
- perimeter to HV
- to ground
- signal to high voltage and readout (via Bias-T)

CHESS1



Beam direction

Detector connection scheme:



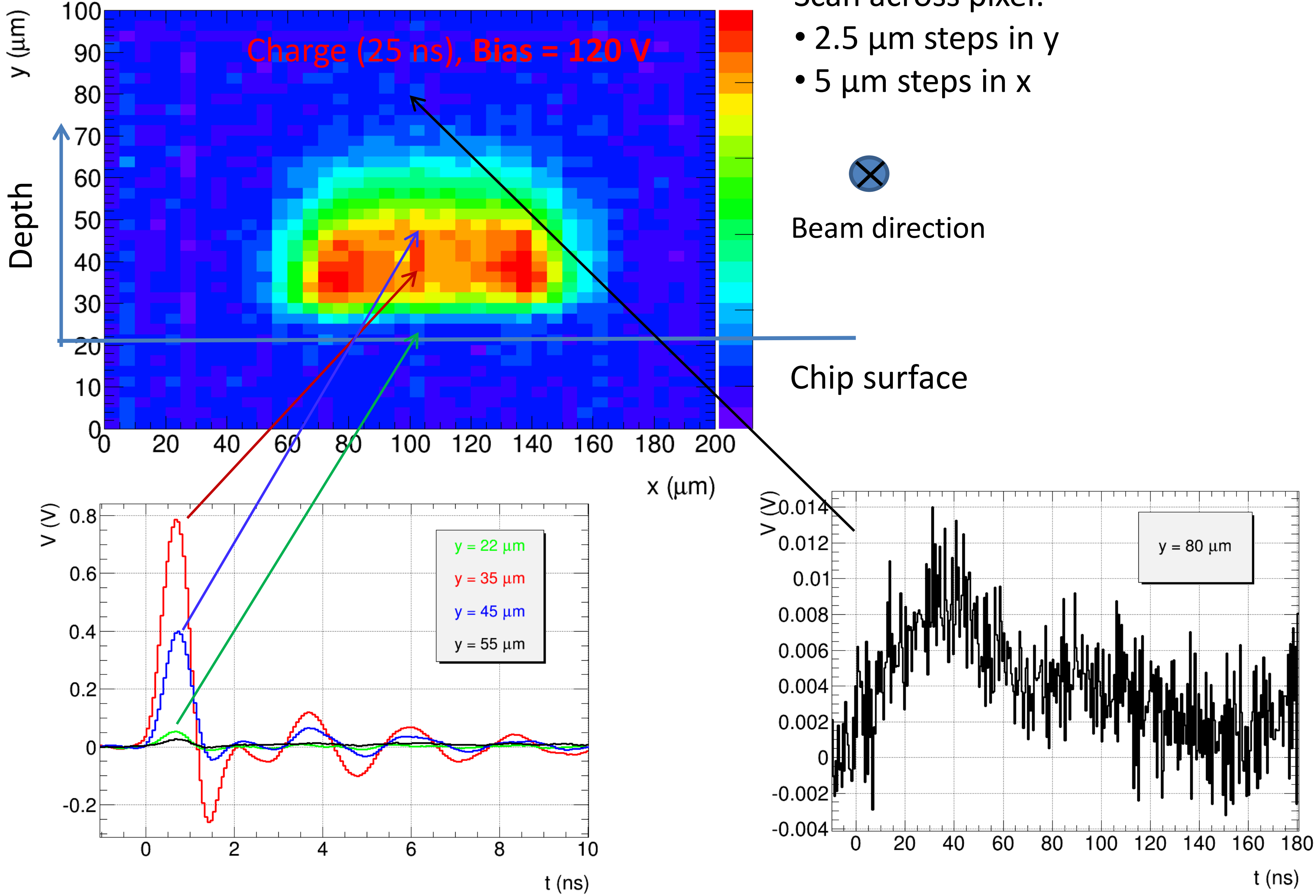
Edge-TCT

Chess1, not irradiated, pixel 100 µm x 45 µm

Scan across pixel:
- 2.5 µm steps in y
- 5 µm steps in x

Beam direction

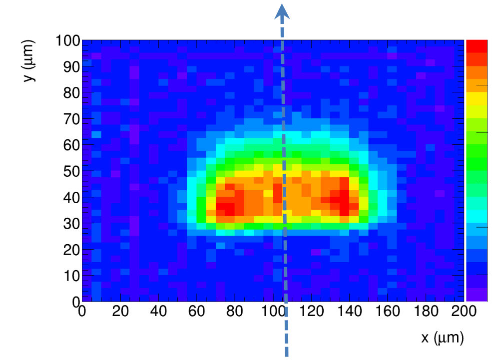
Chip surface



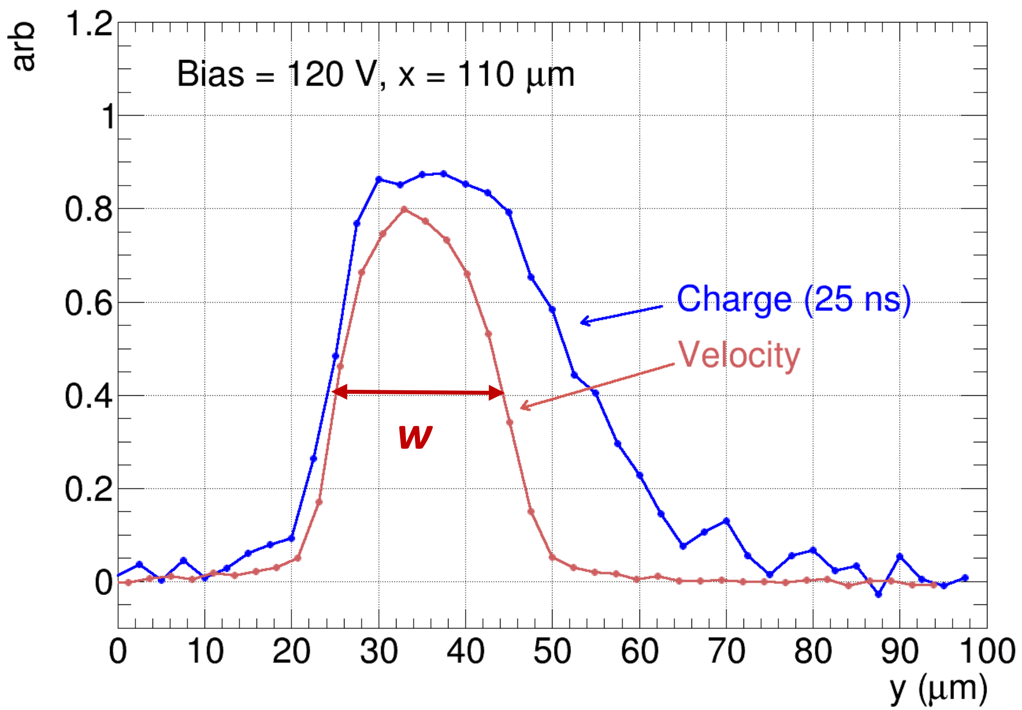
Edge-TCT

Chess1, not irradiated

1) **charge: time** integral of induced current pulse (25 ns)
2) **velocity** (in E-TCT): induced current immediately after the laser pulse



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

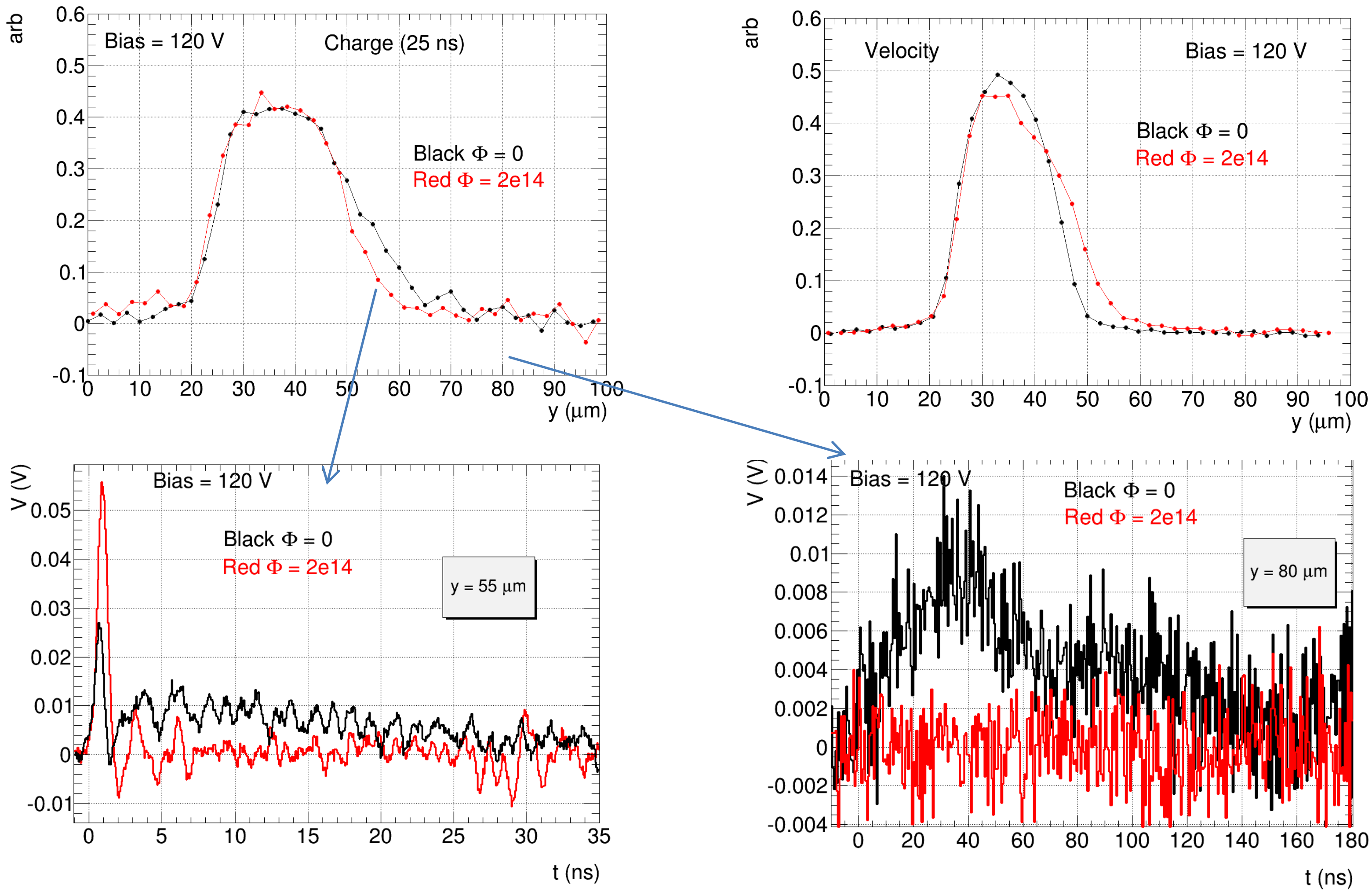


- **high velocity → electric field → depleted region**
- charge collection region wider (diffusion)
  - ➔ take into account non zero laser beam width (~ 10 µm)

Edge-TCT

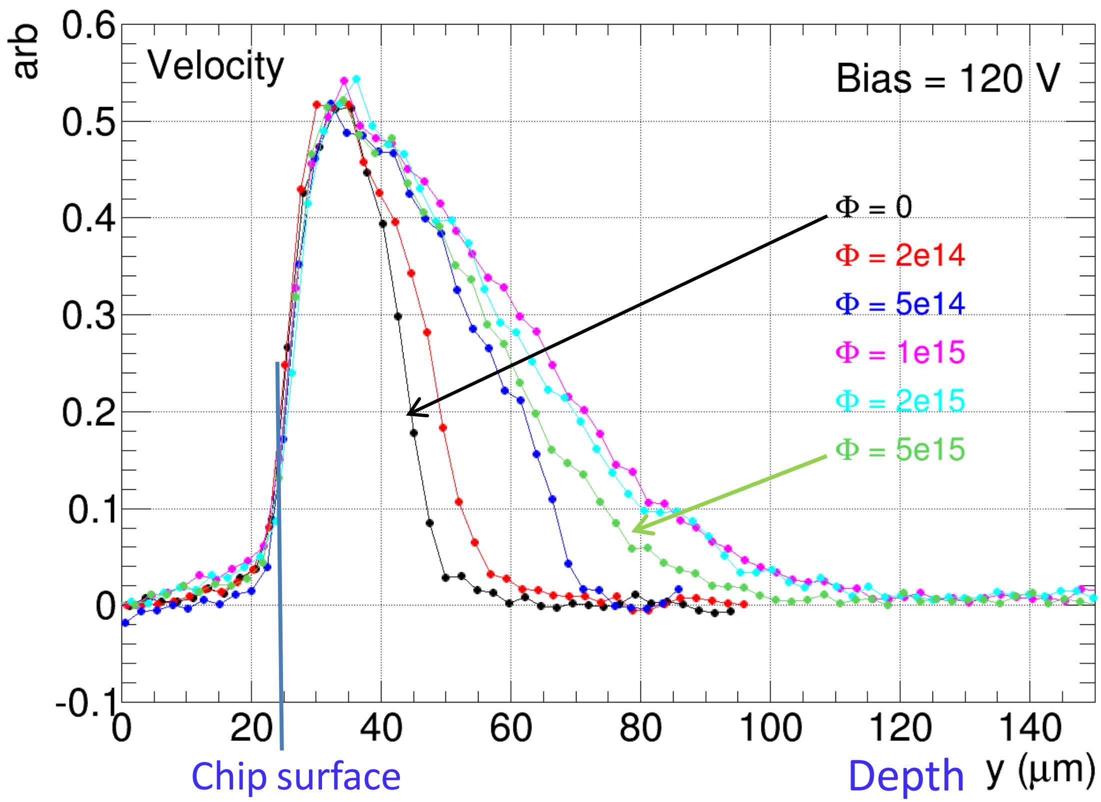
Chess1, irradiated with neutrons to 2e14 n/cm² in reactor in Ljubljana

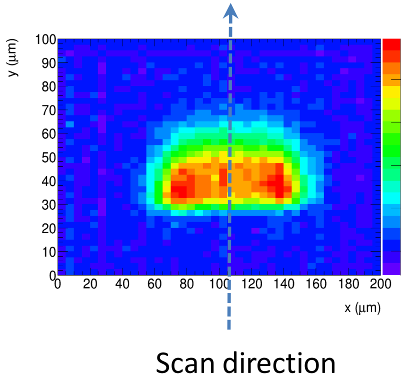
- charge collection region narrower
- field region (velocity) increases ➔ acceptor removal
- no long tails of induced current pulses ➔ trapping, less diffusion



Edge-TCT

Chess1, irradiated with neutrons up to 5e15 n/cm2
Fluence steps: 2e14, 5e14, 1e15, 2e15, 5e15



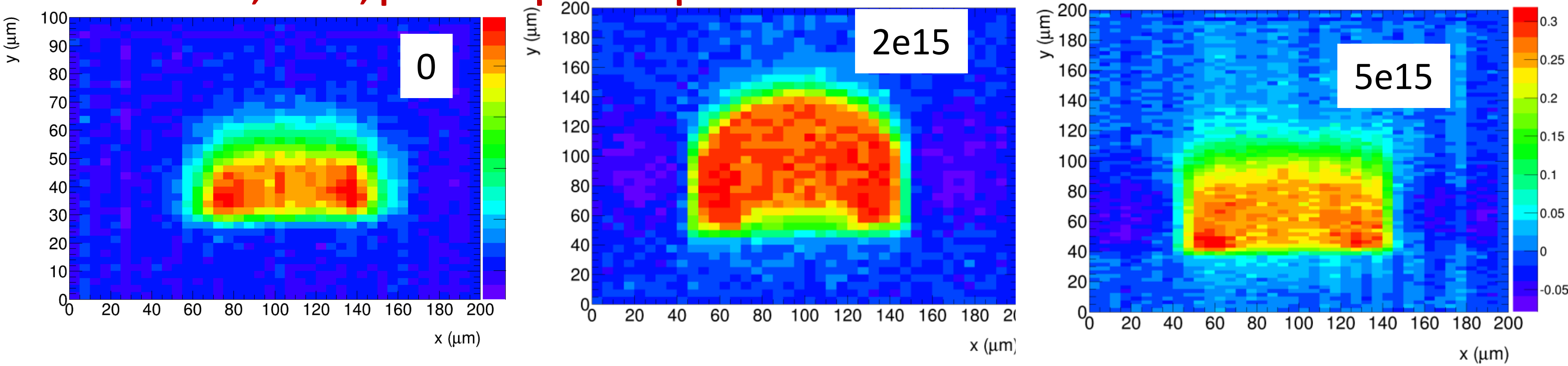


- the depth with electric field (depleted depth) increases with fluence up to ~ 1e15
  - ➔ concentration of initial acceptors falls with irradiation faster than new acceptors are introduced → space charge conc. falls
- depleted depth smaller at 5e15 than at 2e15
  - ➔ acceptor removal finished, space charge concentration increases with irradiation
- **after 5e15 depleted depth still much larger than before irradiation**

Edge-TCT

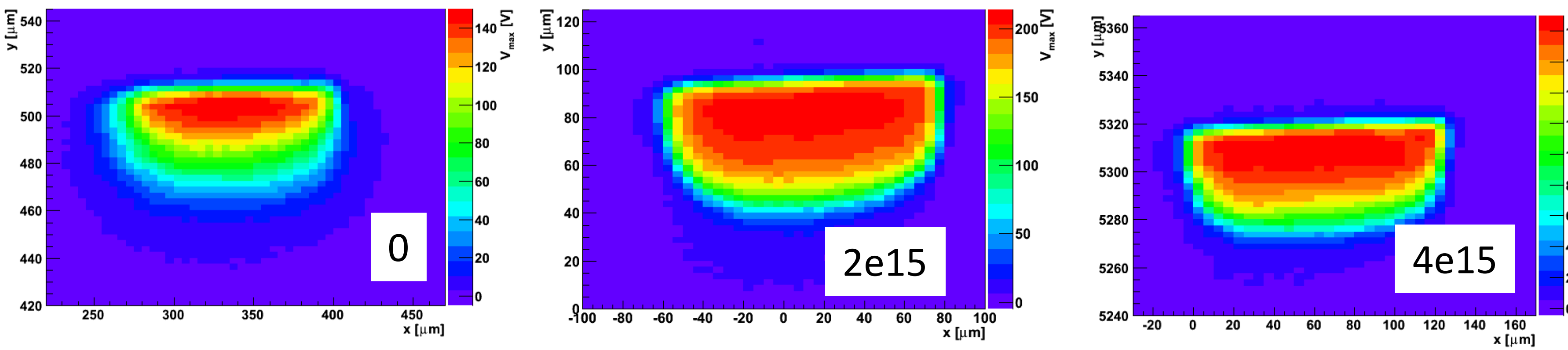
Irradiatied with neutrons

CHESS1, 120 V, pixel 125 µm x 33 µm



V sub =-60 V

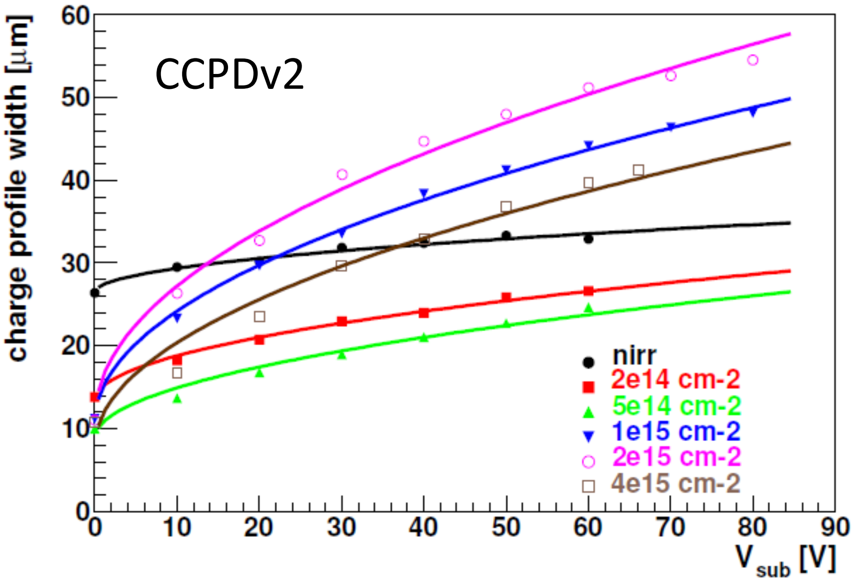
CCPDv2 (HV2FEI4), 60 V, pixel 125 µm x 33 µm

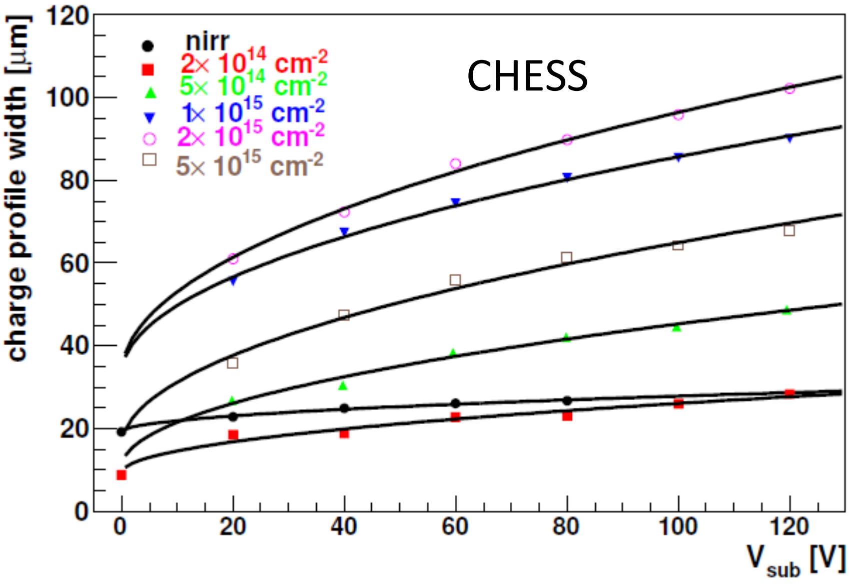


- charge collection region at 5e15 (4e15) smaller than after 2e15 but still much larger than before irradiation

Edge-TCT

- from E-TCT measurements extract the charge collection width vs. Bias voltage





- fit with: $$Width(V_{bias}) = Width(0) + \sqrt{\frac{2\varepsilon\varepsilon_0}{e_0 N_{eff}} V_{bias}}$$

N_{eff} : effective acceptor concentration - free parameter

➔ get N_{eff} dependence on neutron fluence

Evolution of N_{eff} with fluence

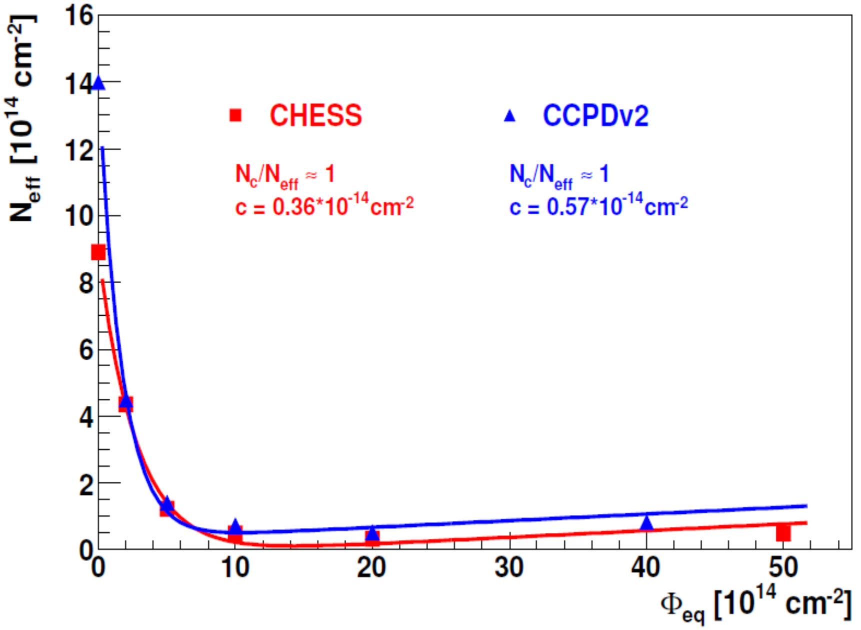
$$N_{eff} = N_{eff\,0} - N_c \cdot (1 - \exp(-c \cdot \Phi_{eq})) + g \cdot \Phi_{eq}$$

acceptor removal

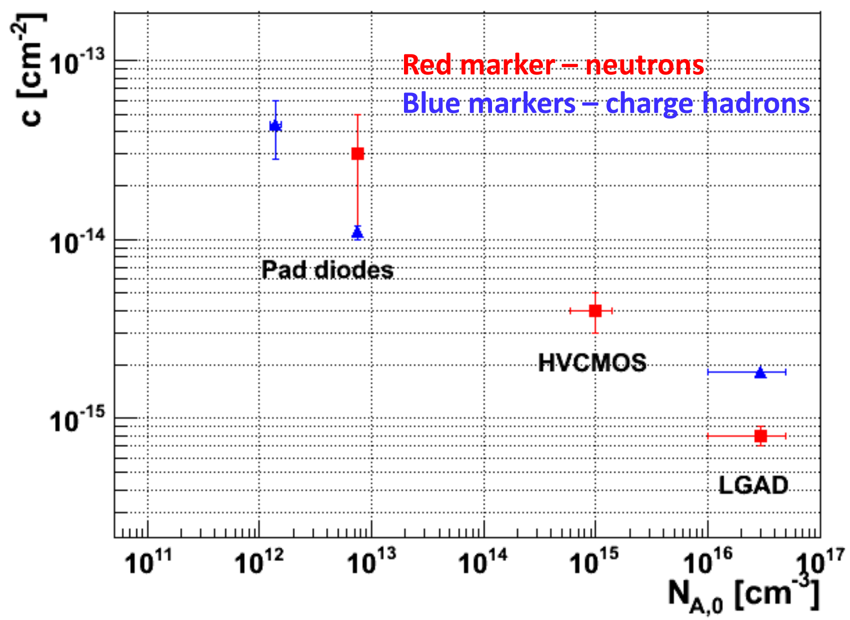
Radiation introduced deep acceptors (stable damage): g = 0.02 cm^{-1} (fixed)

Initial concentration

N_{eff} vs. fluence



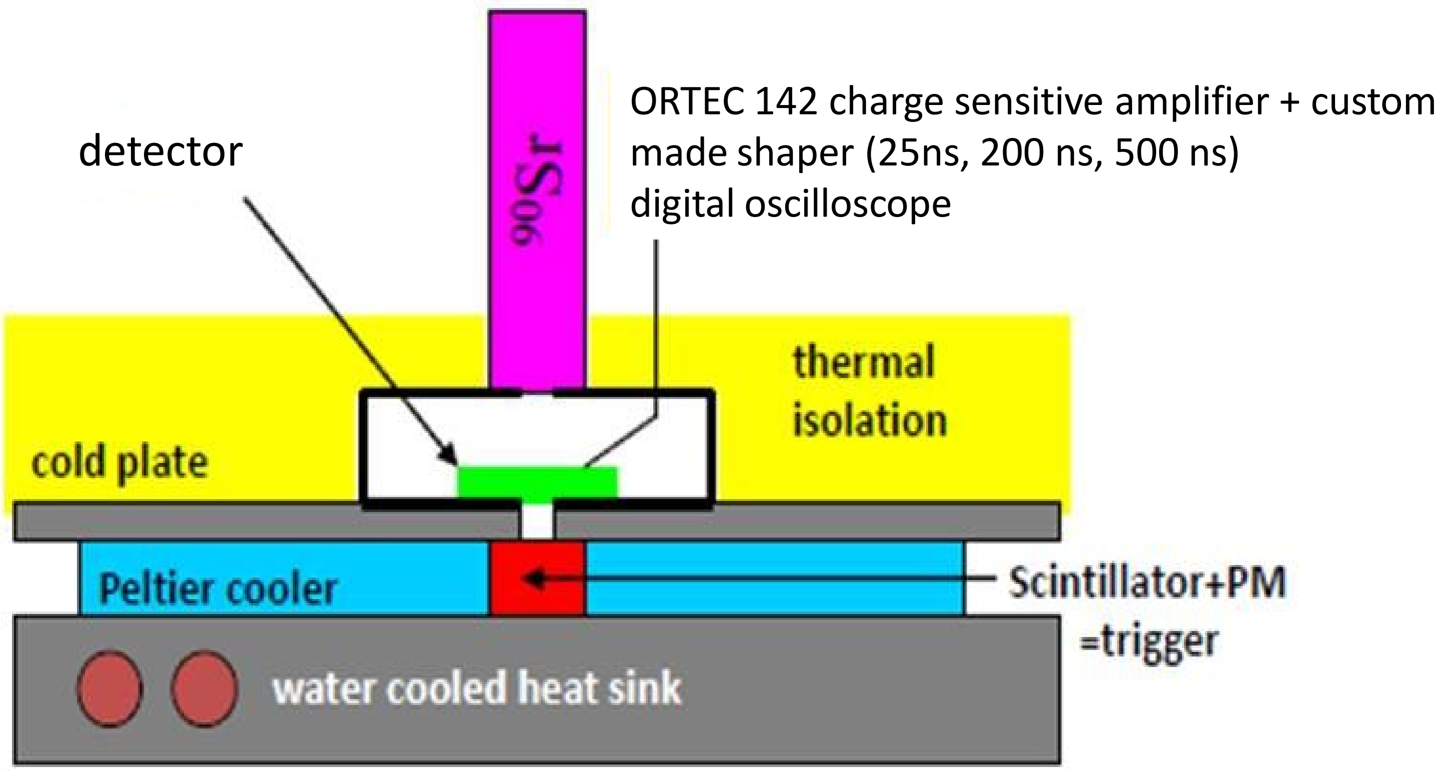
Removal rate *c* depends on initial space charge concentration



G. Kramberger, 10th Trento workshop

http://indico.cern.ch/event/351695/session/4/contribution/4/material/slides/0.pdf

MIP Charge Collection measurement setup



MIP CCE measurement

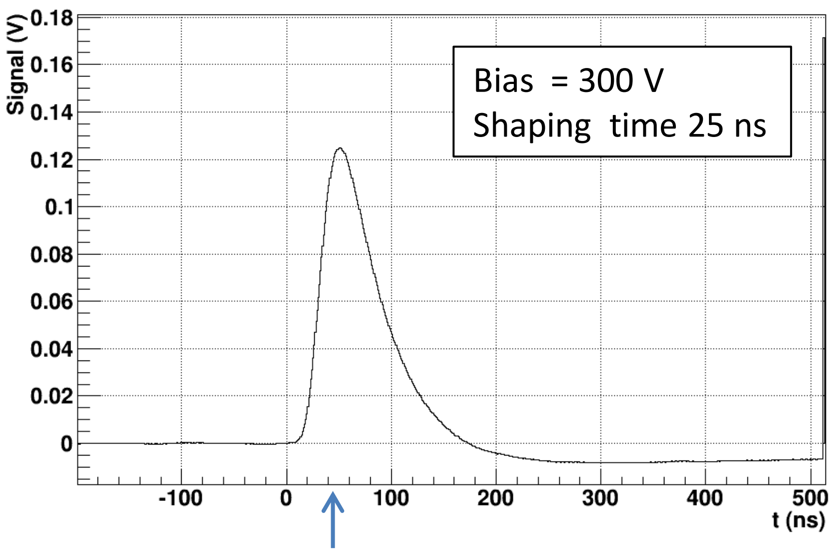
Calibration

- Sr^{90} with 300 µm thick FZ p-type silicon pad 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

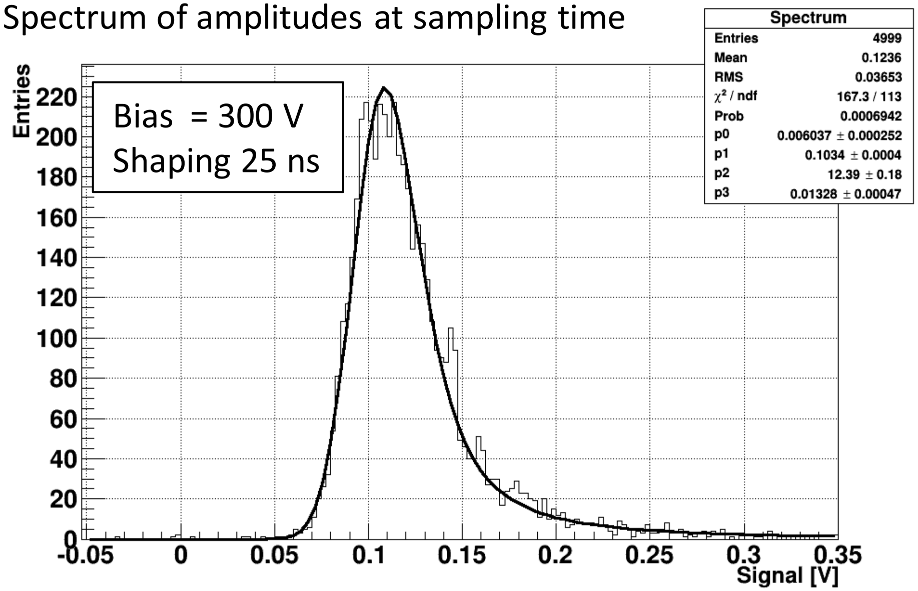
FZ p-type silicon diode, 300 µm thick , V_{fd} = 70 V:

Averaged 5000 waveforms



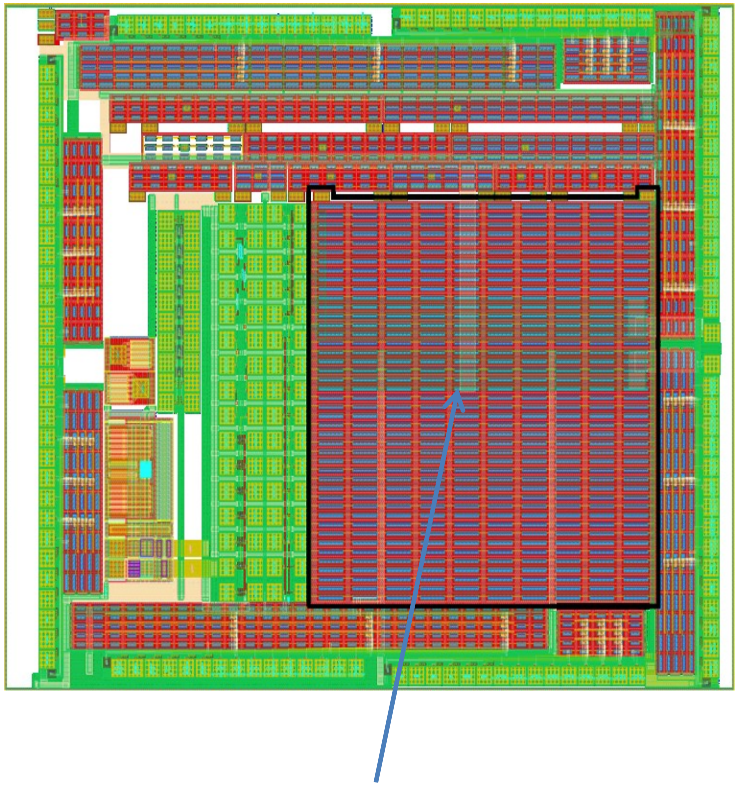
Sampling time

Spectrum of amplitudes at sampling time



MIP CC measurements

Chess1, large passive array (2 mm x 2 mm)



- HV-CMOS: thin → small signals, large noise → S/N bad

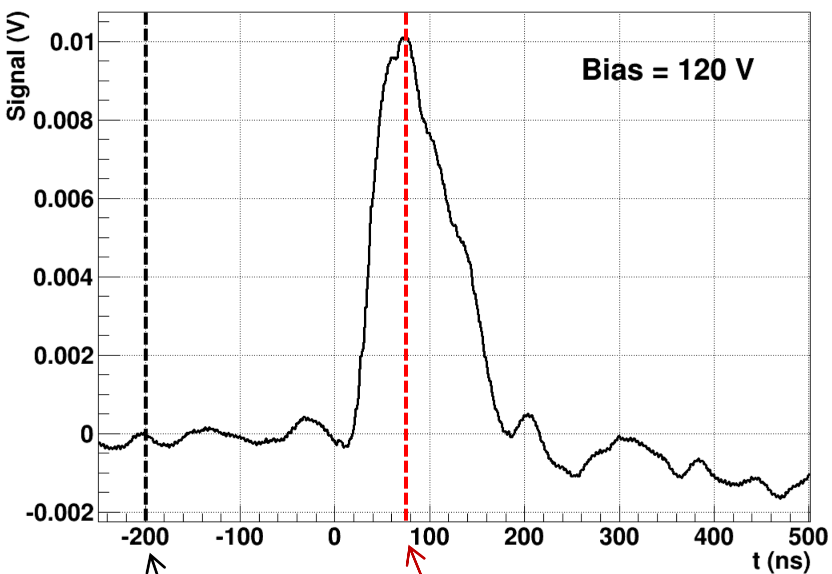
  ➔ must have clean sample

  ➔ need large detector for good collimationand reasonable trigger rate

MIP CC measurement

CHESS1 large passive HV-CMOS array

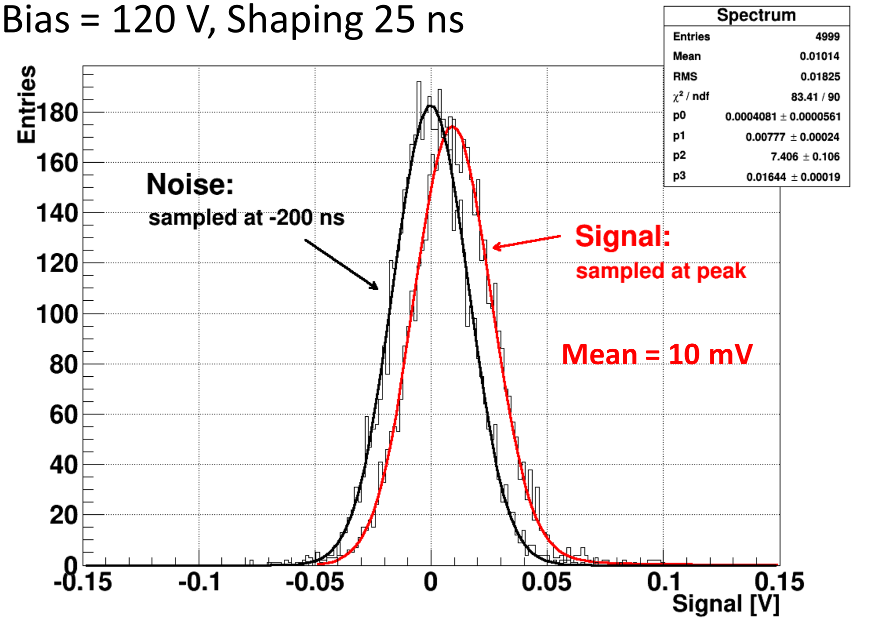
Averaged waveform (5000 samples)



Noise sampling point

Signal sampling point

Bias = 120 V, Shaping 25 ns

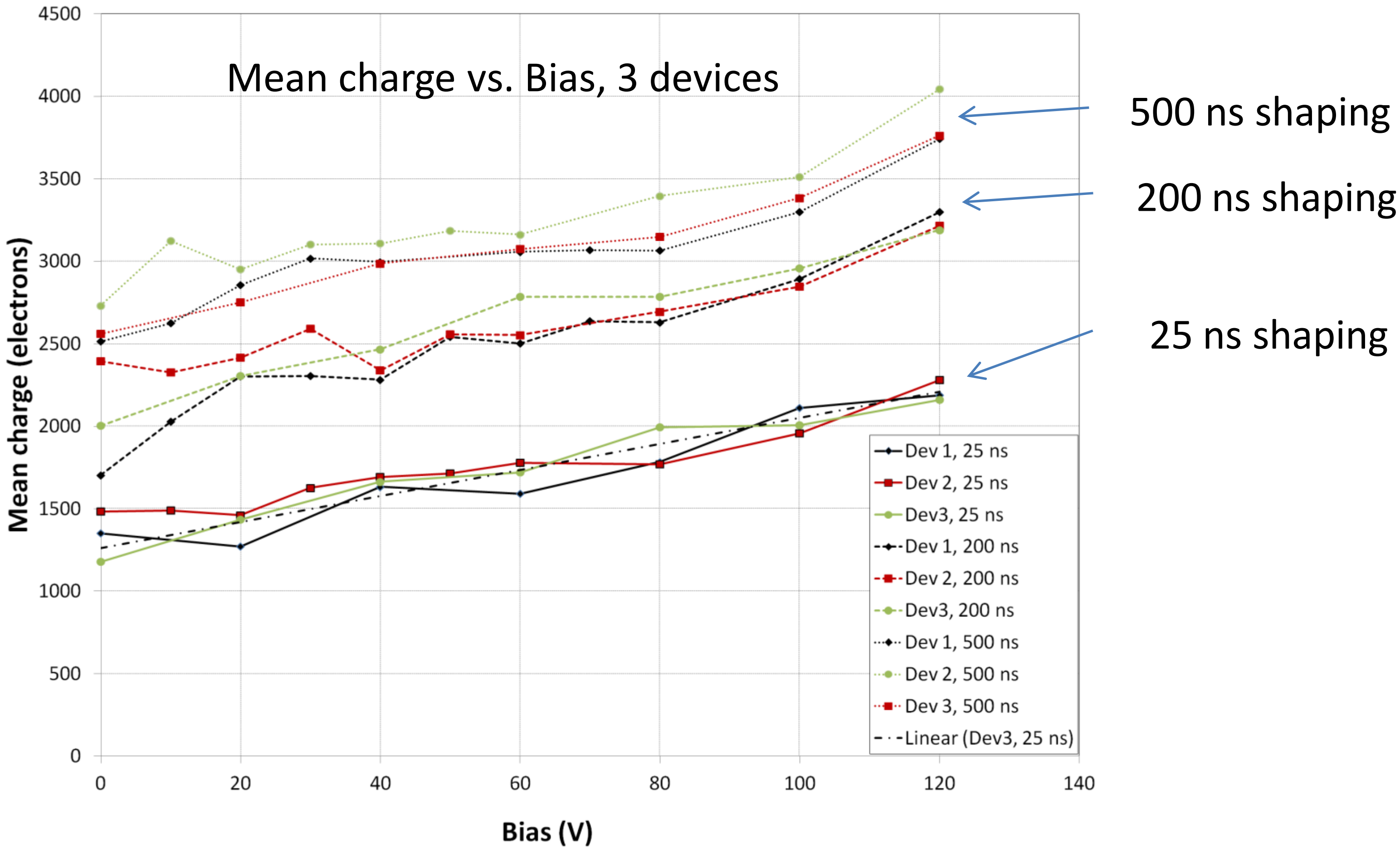


Signal spectrum mean: 10 mV

➔**mean charge: 2300 electrons**

MIP CC measurement

CHESS1 large passive HV-CMOS array – not irradiated



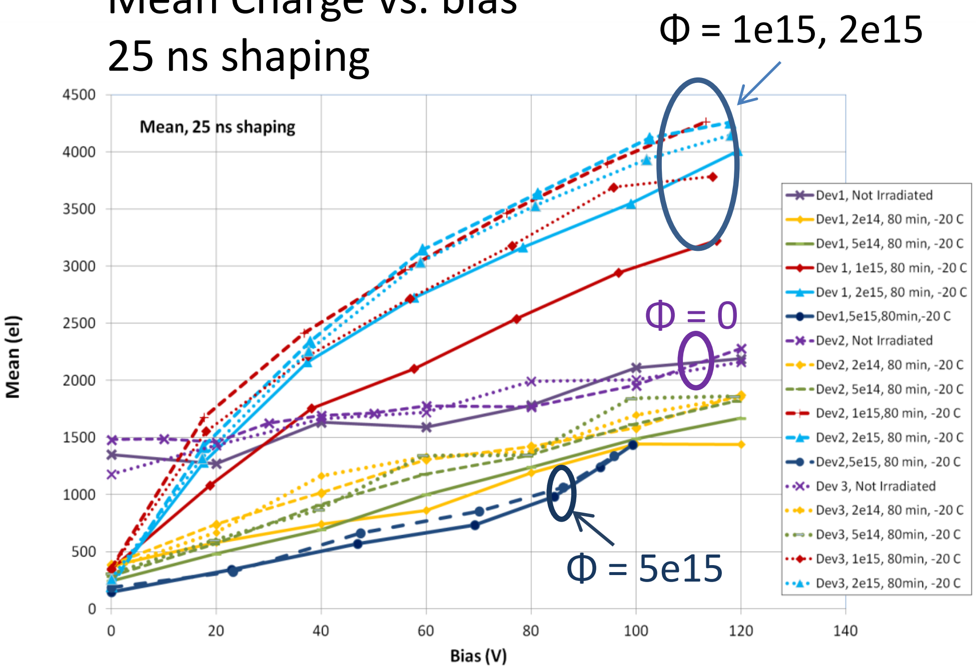
- 25 ns shaping: **Mean charge ~ 1300 el + 80 el/V**
- **diffusion**: ~ charge at 0 V, more charge at longer shaping time

MIP CC measurement

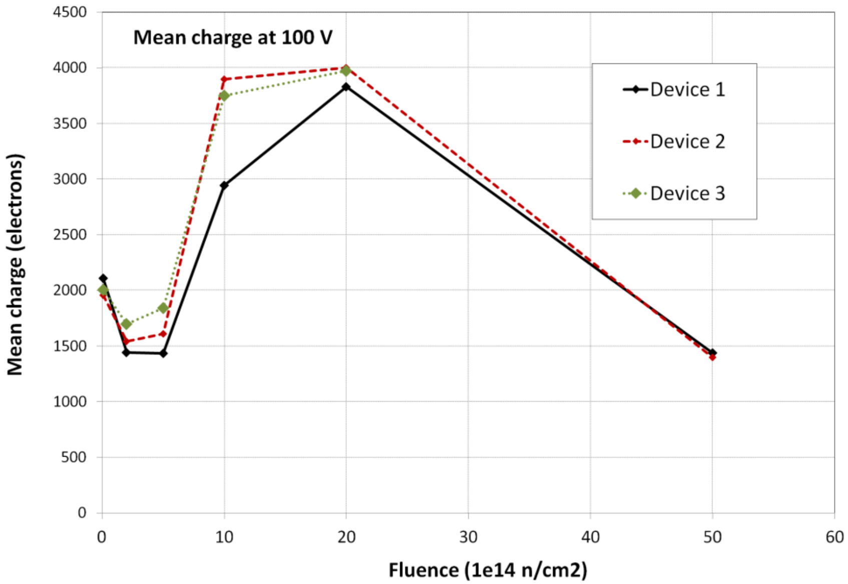
CHESS1 large passive HV-CMOS array – 3 devices irradiated with neutrons

Fluences: 2e14, 5e14, 1e15, 2e15, 5e15

Mean Charge vs. bias
25 ns shaping



Charge vs. fluence



- charge drops after first irradiation steps: **smaller diffusion contribution**
- charge increases with more irradiation ➔ **depleted region increases due to acceptor removal**
- charge drops at higher fluence ➔ **acceptor removal finished, space charge conc. increases with fluence, more charge trapping**

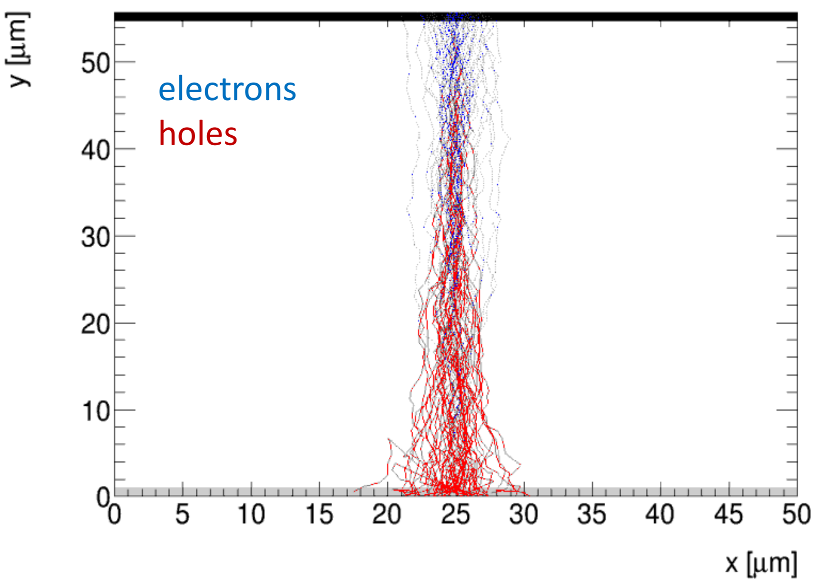
Calculate CC vs. fluence

1. calculate depleted depth using $N_{eff} = N_{eff0} - N_c \cdot (1 - \exp(-c \cdot \Phi_{eq})) + g \cdot \Phi_{eq}$
   g = 0.02 cm^{-1}, pad detector geometry, Bias = 120 V

2. detector thickness same as depleted depth (no influence of weighting field in irradiated detector)

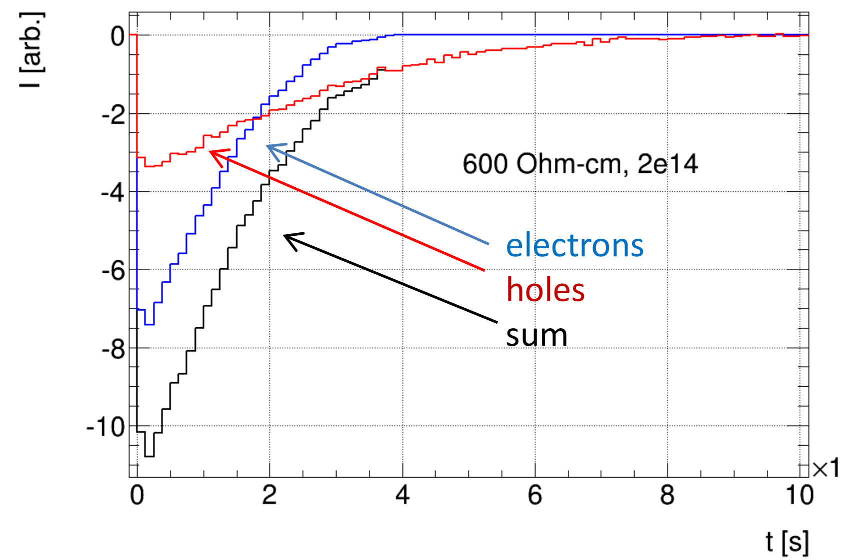
3. calculate trapping loss at given depth and Φ using $\beta = 4e\text{-}16\ ns^{-1}cm^2$

Passage of a MIP



- buckets of charge treated as point charge
- (http://www-f9.ijs.si/~gregor/KDetSim/)

Induced currents (example):



-multiply with $I(t) = I_0(t) \cdot e^{-t/\tau_{eff}}$
to estimate trapping loss at given depth and Φ

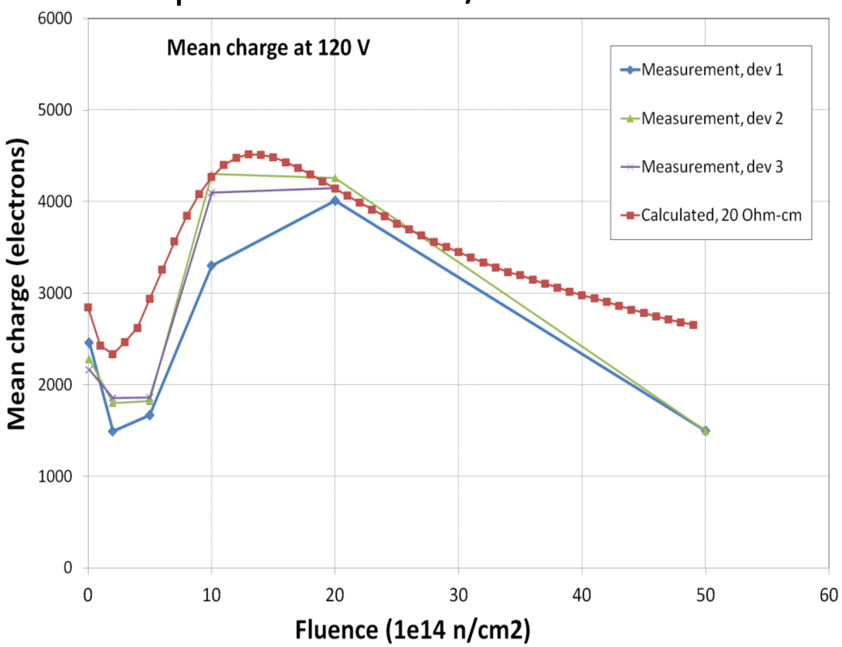
Calculate CC for different resistivites:

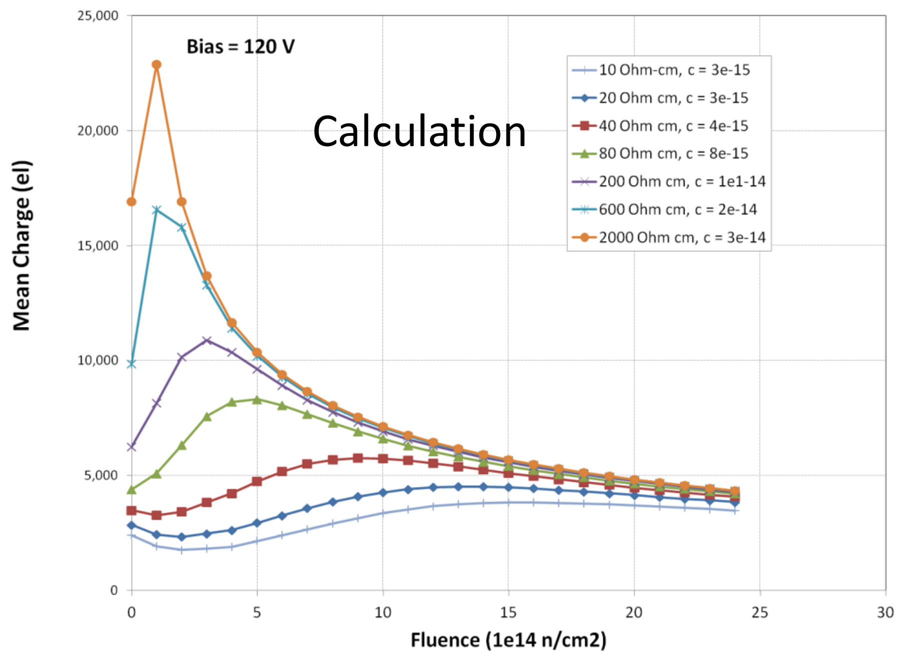
➔ Mean Charge = depletion(μm)* 100 el/μm * trapping_loss +

- 1300 el at Φ = 0
- 650 el at Φ = 1e14
- ..
- 0 el at Φ > 4e14

Diffusion (mostly gues)

Compare measured/calculated





- higher resistivity → more charge
- possible to stay above initial charge in certain fluence range

Summary

E-TCT with detectors made of 10 Ω-cm and 20 Ω-cm material:

- depleted region increases with fluence up to ~2e15 n/cm^2, smaller at higher fluence
  → initial acceptor removal!

CC with MIPs from Sr-90 with large passive array:

- direct measurement of collected charge with large passive array on CHESS1 chip
- at 120 V bias, 25 ns shaping time:
  → before irradiation: Q = 2300 electrons, from diffusion (charge at 0 V) ~ 1300 el
  → after irradiation with 2e14 n/cm^2 charge drops to Q = 1700 electrons (diffusion)
  → largest charge after irradiation with 2e15 n/cm^2: Q = 4100 electrons (acceptor removal)
  → large drop of collected charge after 5e15 n/cm^2: Q ~ 1500 electrons (at 100 V)
- fluence dependence in agreement with E-TCT
- CC at 5e15 might be higher for pixels because of different weighting field

Calculation:

→ higher substrate resistivity → more charge
→ at ~ 100 Ω-cm CC always above initial up to 2e15 n/cm^2 (for neutron irradiation)