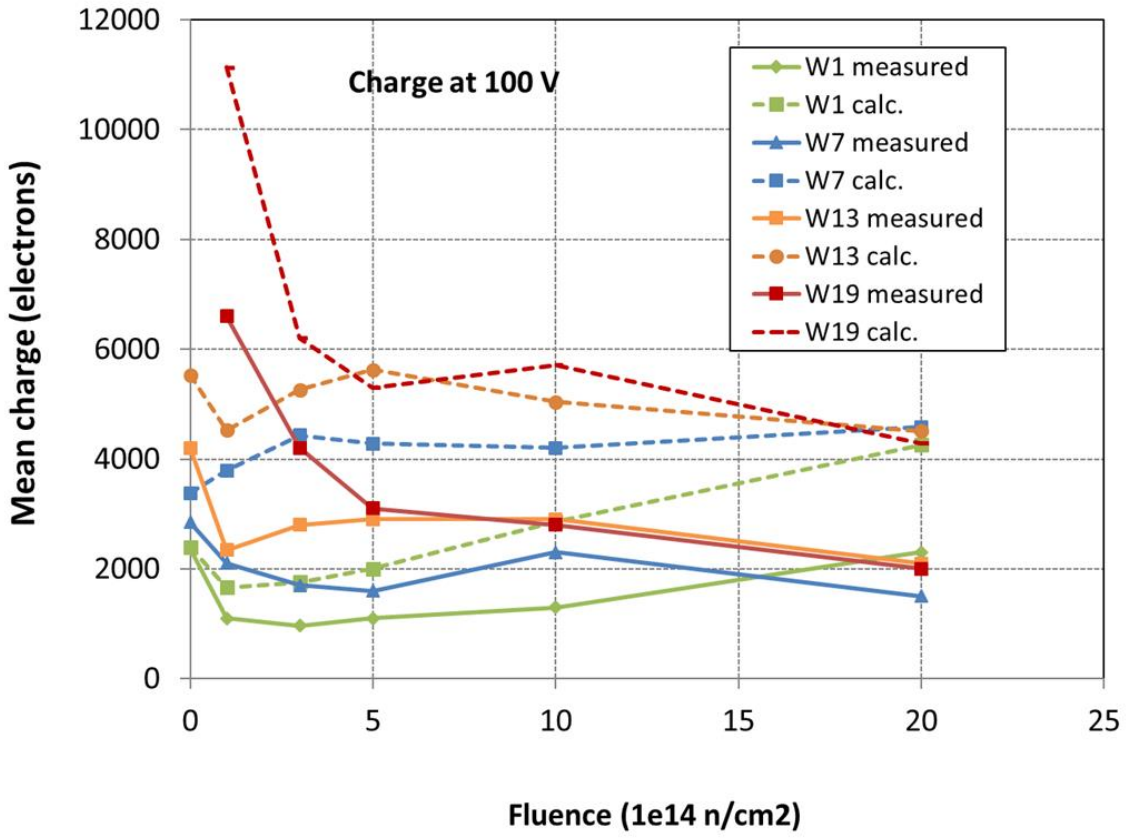
Influence of back plane on charge collection properties of irradiated CMOS detectors

Reminder about measurements with AMS CHESS2 chip

- Initial resistivities: W1: 20 Ω·cm, W7: 50 Ω·cm, W13: 200 Ω·cm, W19: 1 kΩ·cm
- bias from top, no back plane processing
- thickness 250 um



- much smaller collected charge than deposited in depleted region estimated with E-TCT by a MIP (with trapping loss taken into account)
- for more info about measurements with chess2 chips see B. Hiti et al. at TREDI 2017:
  https://indico.cern.ch/event/587631/contributions/2471700/attachments/1415576/2167163/20170221_hiti.pdf

Samples

- Measured with structures from LFoundry demonstrator submission
- 150 nm HR-CMOS technology
- resistivity of p-type substrate > 2 kΩcm
- breakdown voltage from 175 V to over 400 V, depending on the test structure

- Two sets:

  ➔ not thinned (700 um), no back plane, substrate biased over implant on top
  ➔ thinned to 200 um, back plane processed, bias through the BP

- Samples irradiated to 1e13, 5e13, 1e14, 5e14,1e15 and 2e15 with neutrons in TRIGA reactor in Ljubljana

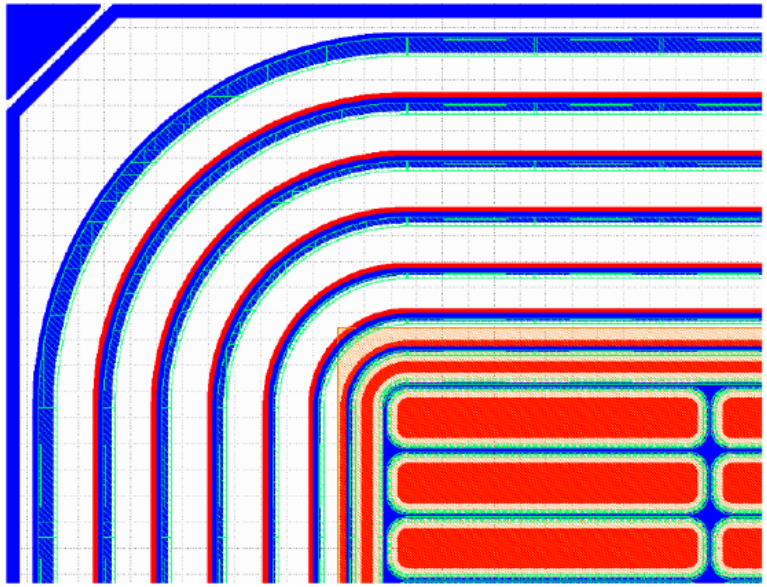
- E-TCT and Sr90 charge collection measurements

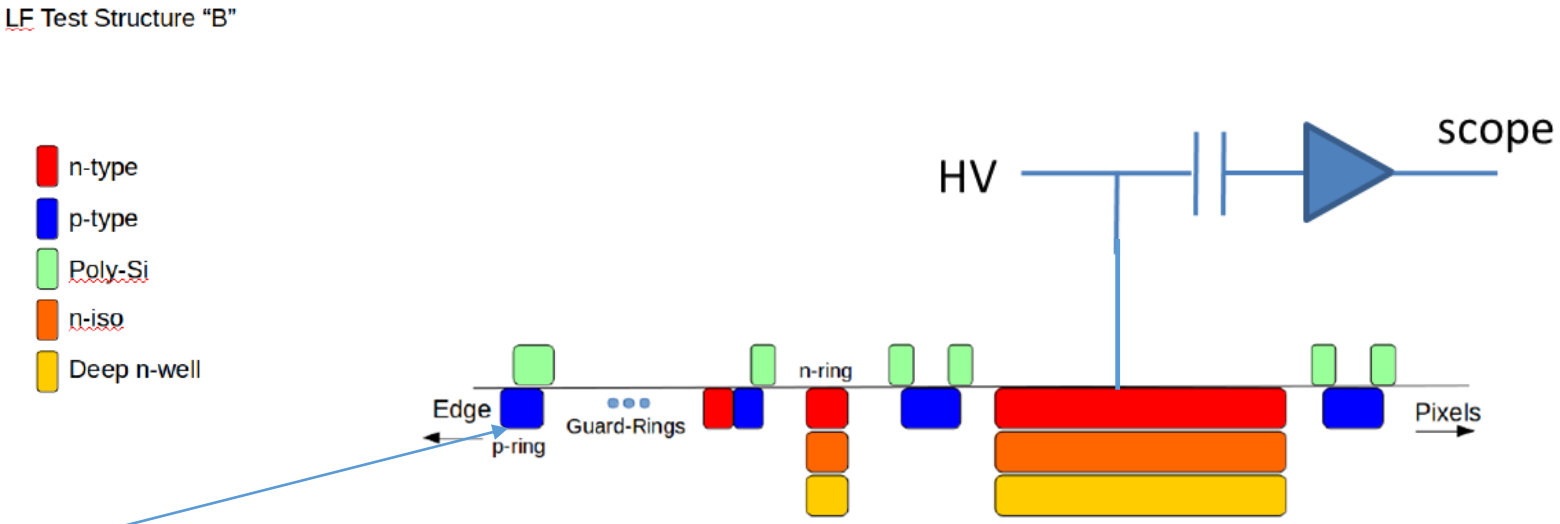
- Moore details in slides from RD50 workshop in Krakow in June 2017:

  https://indico.cern.ch/event/637212/contributions/2608669/attachments/1471691/2277507/RD50_June_2017_IM.pdf

➔ related to the charge collection measurements with CHESS chips (“missing charge”)

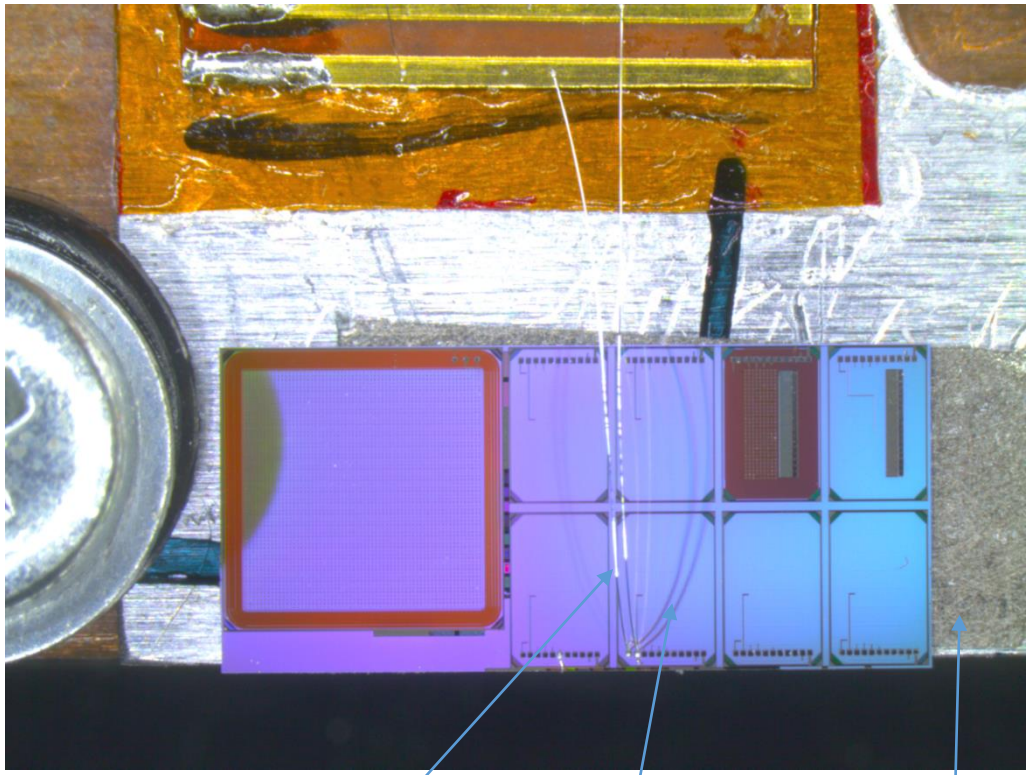
Passive test structure B





- Bias ring at 0 V (or not connected if biased through the back plane)
- n-wells (pixels) connected to HV and amplifier (via bias-T)

Passive test structure B



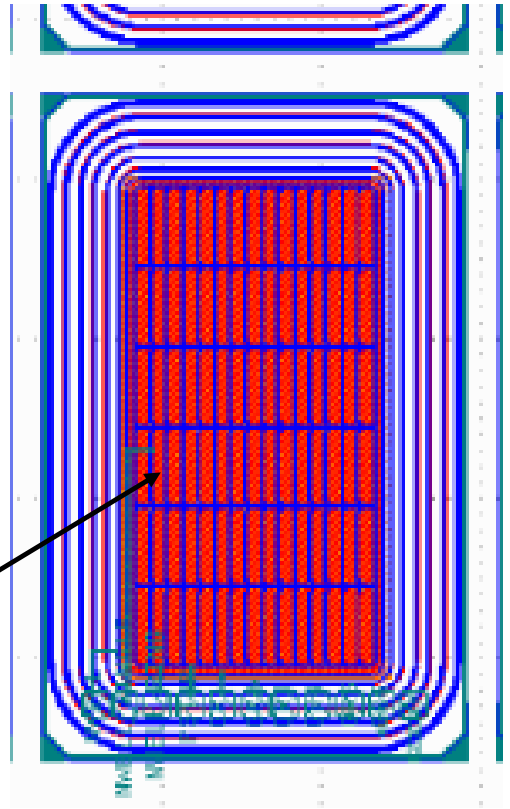
Bond wires to n-wells
(to readout and +HV)

Structure B

Conductive glue (at GND)

15x6 array of
50x250 um² pixels

Contacts:
- single pixel
- all other pixels

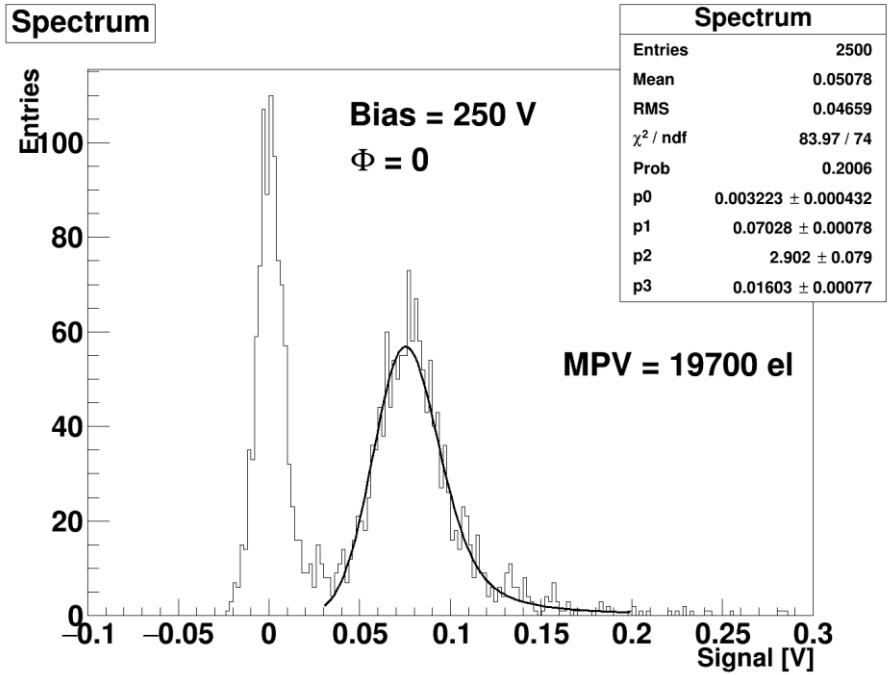


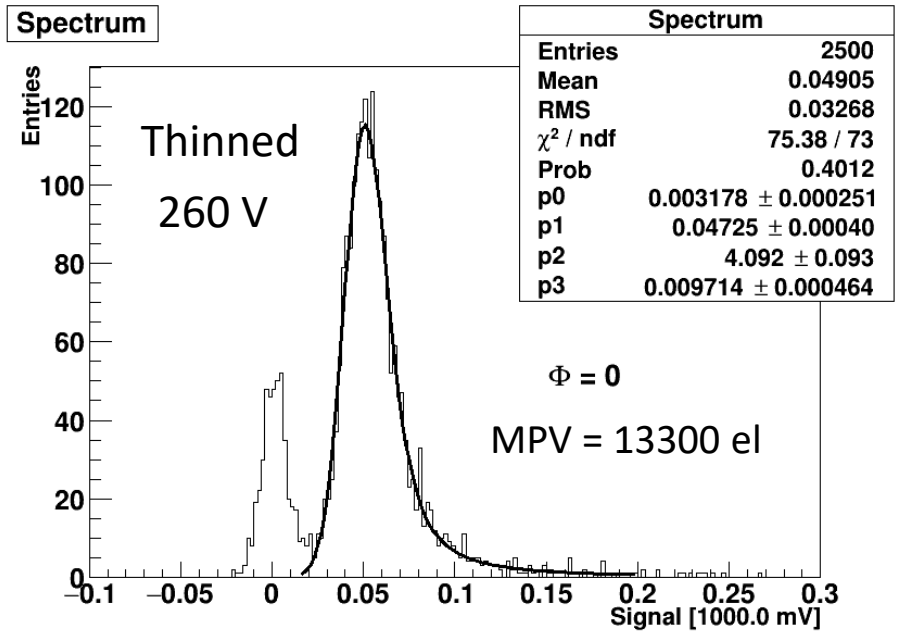
IR laser beam

Thinned: substrate contacted via back plane
Not thinned: substrate contact from top via bond-wire

Sr-90, before irradiation

- all pixels connected to readout (similar to pad detector)
- device small (1.5 mm x 0.75 mm) we can't collimate to measure only events with tracks passing through the detector
  ➔ before irradiation and at low fluences signal and noise peak well separated and Landau could be fit
  (can measure with these devices if MPV > ~ 4000 el)





Not thinned:

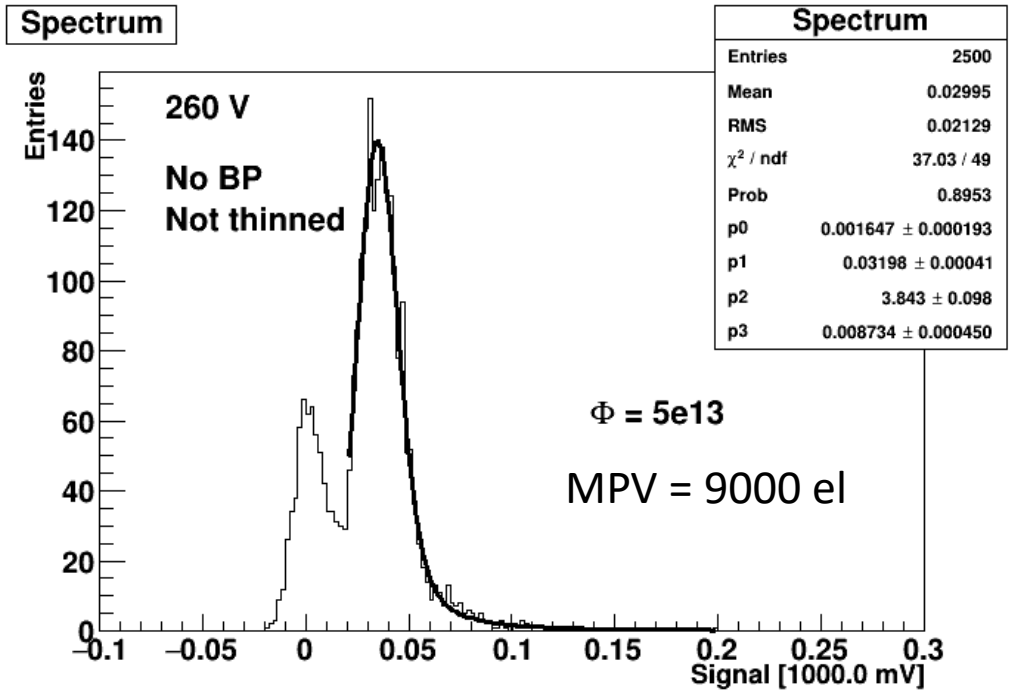
- depleted depth from E-TCT ~ 280 um
  ➔ expected MPV ~ 21000 el

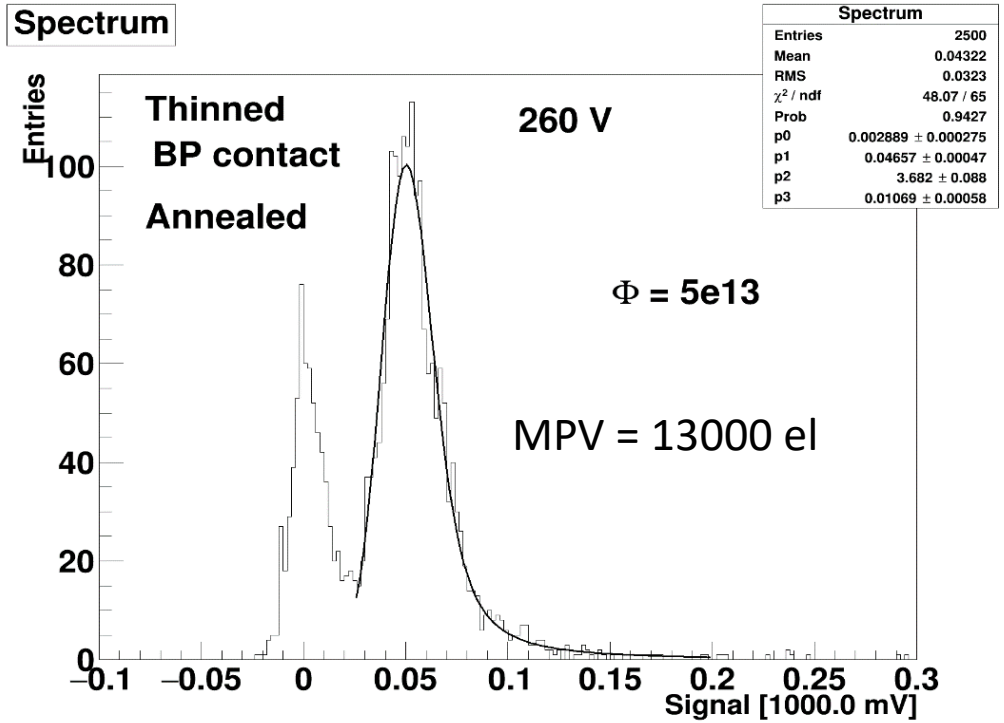
Consistent!

Thinned:

- Depleted depth from E-TCT ~ 190 um
  ➔ expected MPV ~ 13500 el

Sr90, after irradiation to Φ = 5e13 n/cm²





Not thinned, substrate bias from top:

- depleted depth from E-TCT: ~ 260 um
  ➔ expected (full collection) MPV ~ 19000 el
  ➔ **measured MPV ~ 9000 el**

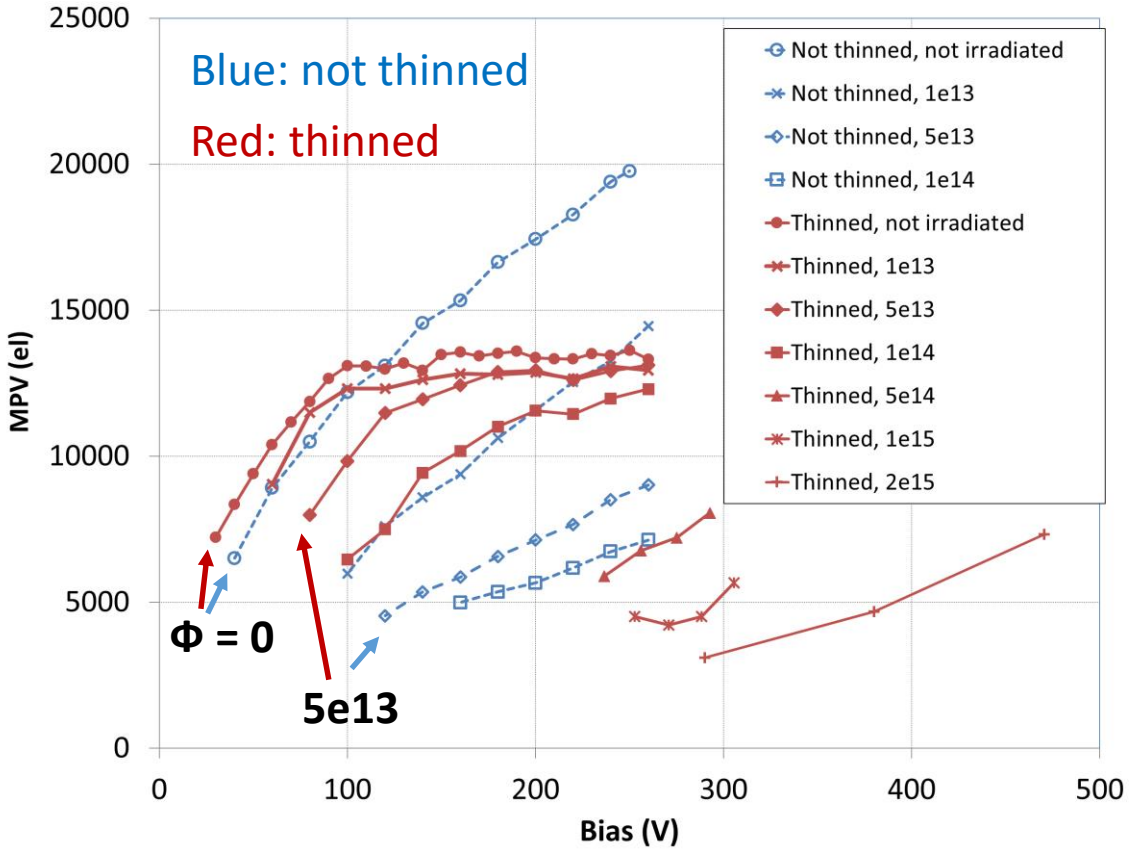
Thinned to ~ 200 um, substrate bias via back plane

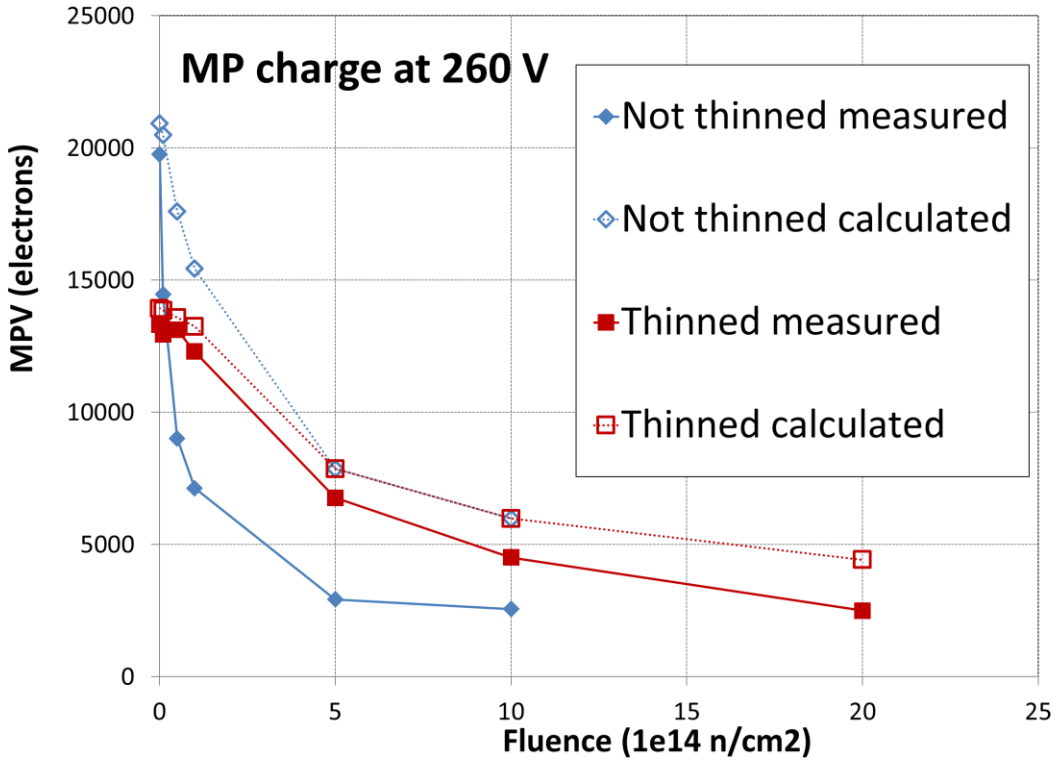
- depleted depth from E-TCT ~ 180 um (fully depleted)
  ➔ expected (full collection) MPV ~ 13500 el
  ➔ **measured MPV ~ 13000 el**

➔ Large difference between samples with and without back plane after irradiation!

Sr-90, after irradiation

- significantly larger collected charge measured in thinned samples with back plane after irradiation





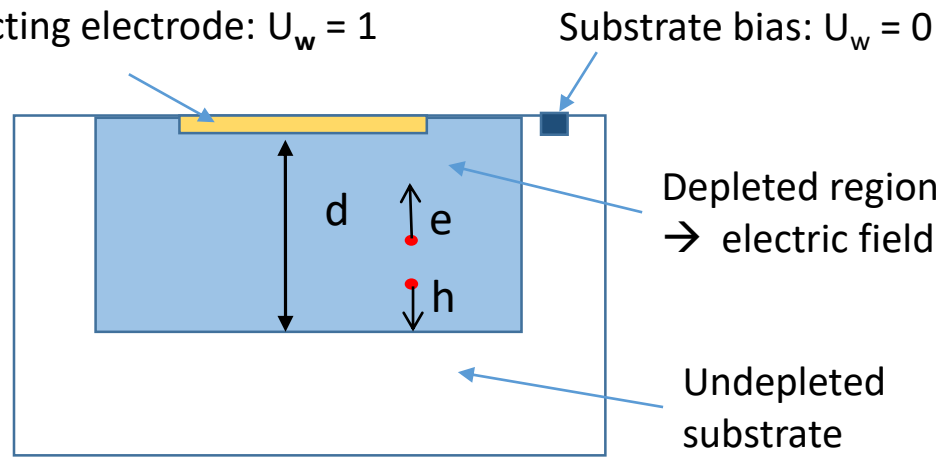
Calculated = Depleted_depth*(75 el/µm)* trapping_loss

➔ larger difference between calculated and measured after irradiation in not thinned samples

➔ good agreement if fully depleted (thinn, Φ < 5e14)

Different weighting field in not thinned top biased devices and thinned devices with back plane after irradiation

No back plane, substrate biased via implant on top



Before irradiation:

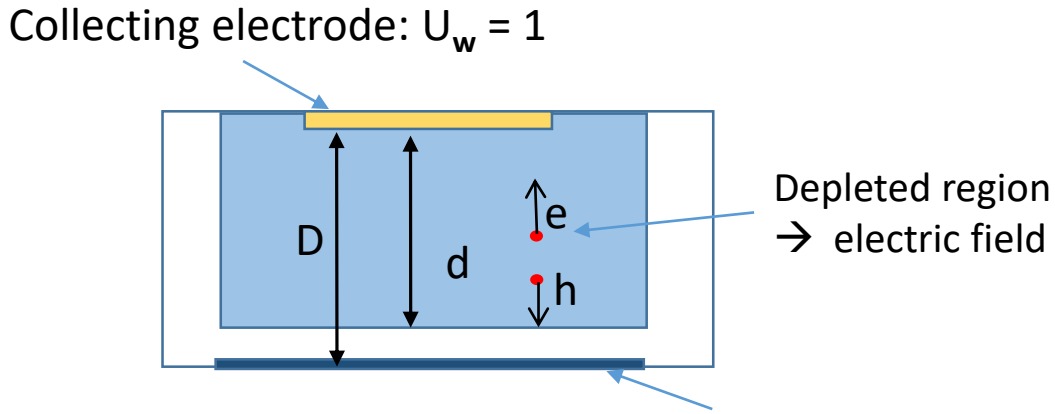
- Undepleted substrate: sufficient conductivity, weighting potential $U_w = 0$ everywhere in the undepleted substrate

➔ carriers drift across whole weighting field: all charge collected

After irradiation:

- substrate conductivity low, $U_w = 0$ at the bias implant on top
  - ➔ carriers trapped in low field at the end of depleted depth, before drifting to the substrate bias electrode
  - ➔ carriers don't drift across all weighting field
  - ➔ partial charge collection

Back plane (and thinned), substrate biased via back plane



Before irradiation:

- Undepleted substrate sufficient conductivity, weighting potential $U_w = 0$

➔ carriers drift across all weighting field: all charge collected

After irradiation:

- substrate conductivity low, $U_w = 0$ at the back plane implant
  - ➔ if fully depleted D = d full charge collection (except trapping loss)
  - ➔ if not fully depleted carriers don't cross all weighting field
    - → charge collection reduced (in pad geometry by a factor **d/D)**
  - ➔ depending on geometry and device thickness this factor can be much larger than in the case of top bias => larger collected charge

Effects of weighting field in irradiated pixel detectors see e.g.: *G. Kramberger, D. Contarato, NIM A 511 (2003) 82–87*

Summary

- “low” collected charge after irradiation measured with LFoundry test structure similar measurements irradiated CHESS
- larger charge measured after irradiation with thinned LFoundry devices with back plane contact

➔ back plane processing (and thinning) should improve charge collection in irradiated devices