Effect of thinning and backplane processing on charge collection properties of irradiated CMOS detectors

V. Cindro, A. Gorišek, B. Hiti, G. Kramberger, I. Mandić, M. Mikuž, M. Zavrtanik et al.

Jožef Stefan Institute, Ljubljana, Slovenia
University of Ljubljana, Slovenia

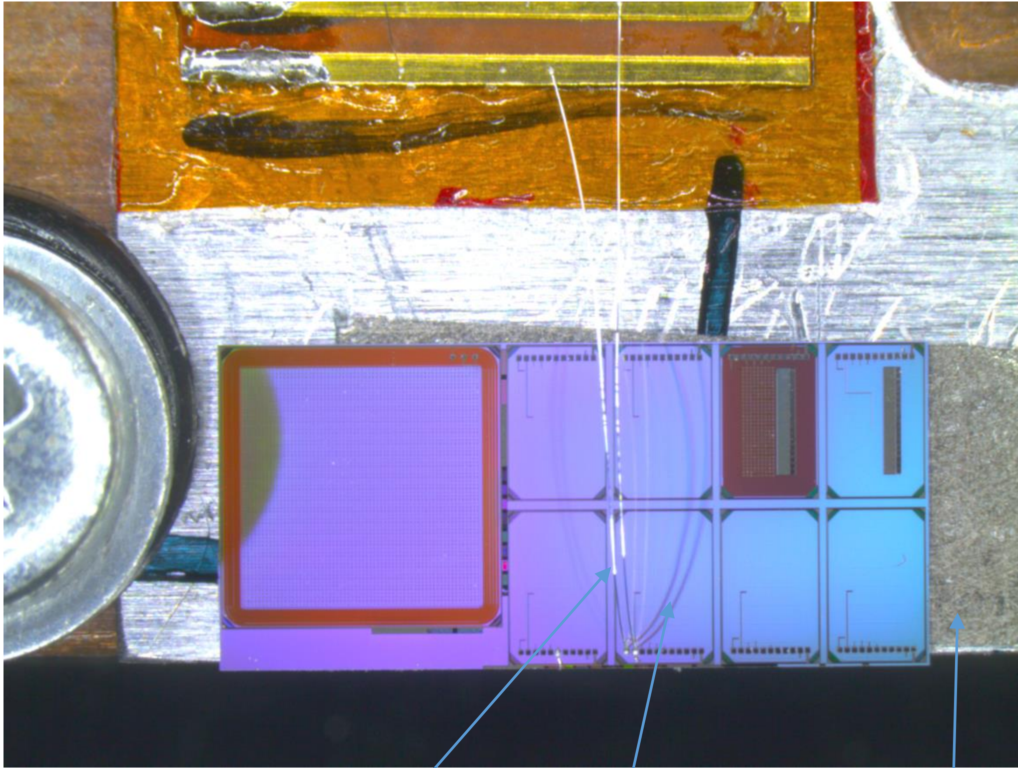
Samples

- test structures from LFoundry demonstrator submission designed by University of Bonn:
  - ❑ Piotr RYMASZEWSKI et al., *Prototype Active Silicon Sensor in 150nm HR-CMOS technology for ATLAS Inner Detector Upgrade,* 2016 JINST 11 C02045
  - ❑ T. Wang et al., *Development of a Depleted Monolithic CMOS Sensor in a 150 nm CMOS Technology for the ATLAS Inner Tracker Upgrade,* 2017 JINST 12 C01039
- 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
- measurements shown here with passive pixel array
- 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 with neutrons in TRIGA reactor in Ljubljana
- E-TCT and Sr-90 charge collection measurements

LFoundry passive test structure B



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

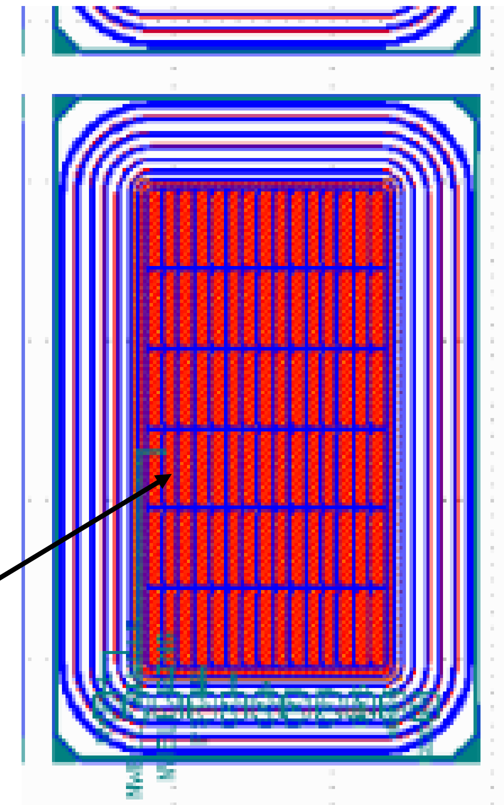
Structure B

Conductive glue (at GND)

Resitivity 3 kΩcm
Designed by Bonn

15x6 array of
50x250 um^2 pixels

Two signal contacts:
- single pixel
- all (89) other pixels

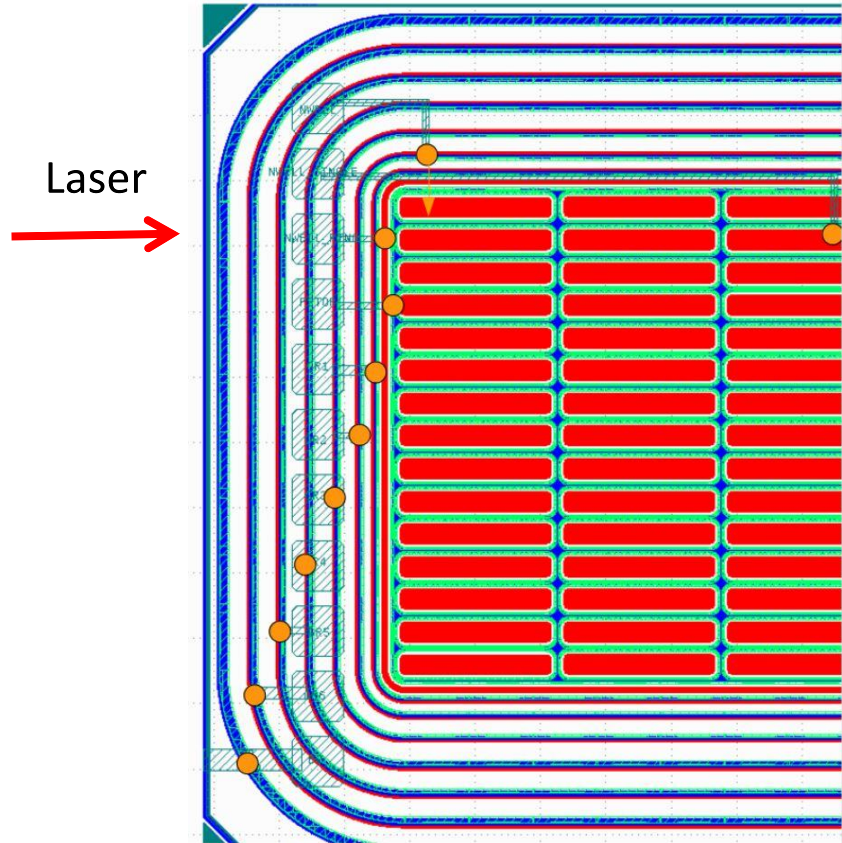


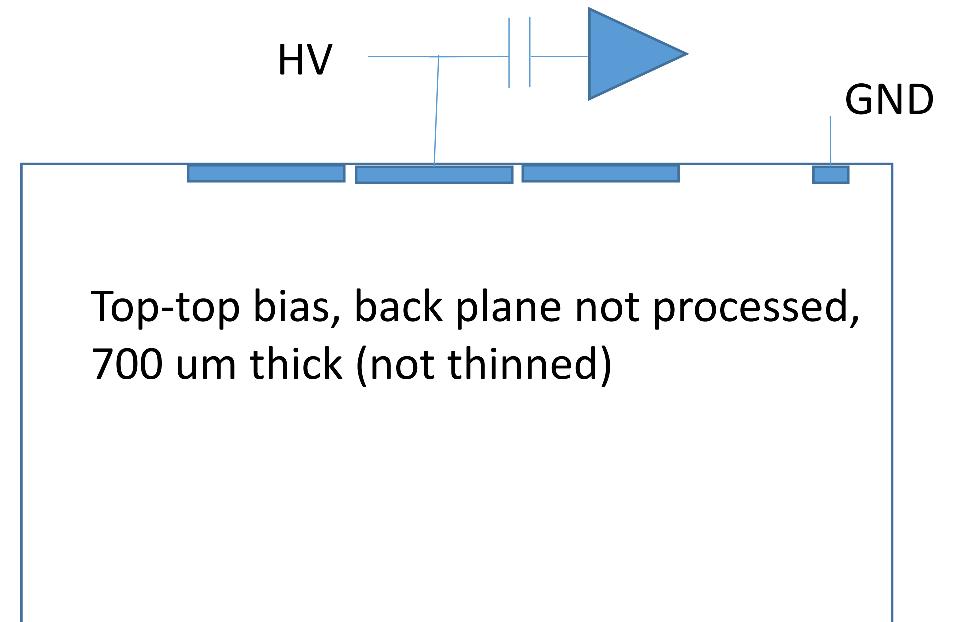
IR laser beam

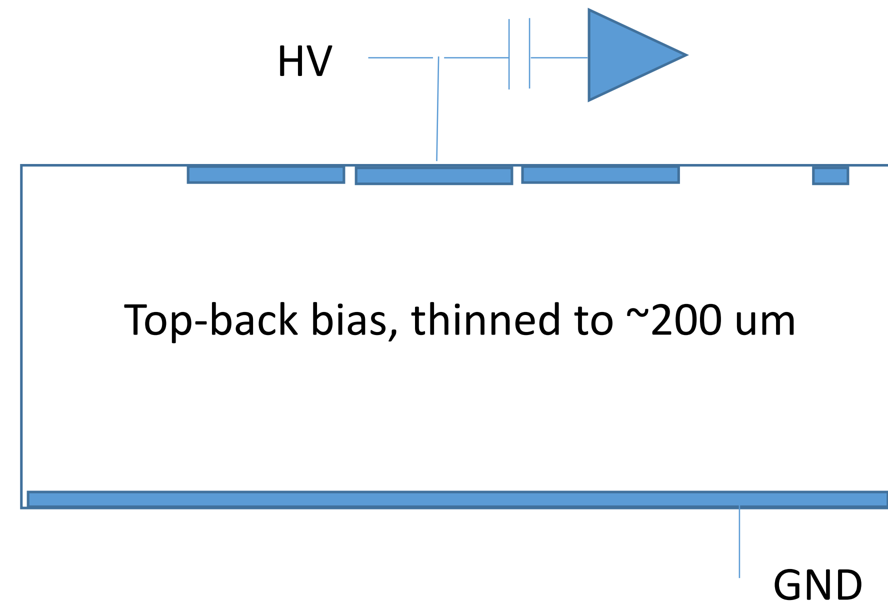
⊙ y-scan

↔ x @ pixel ~centre

LFoundry passive test structure B



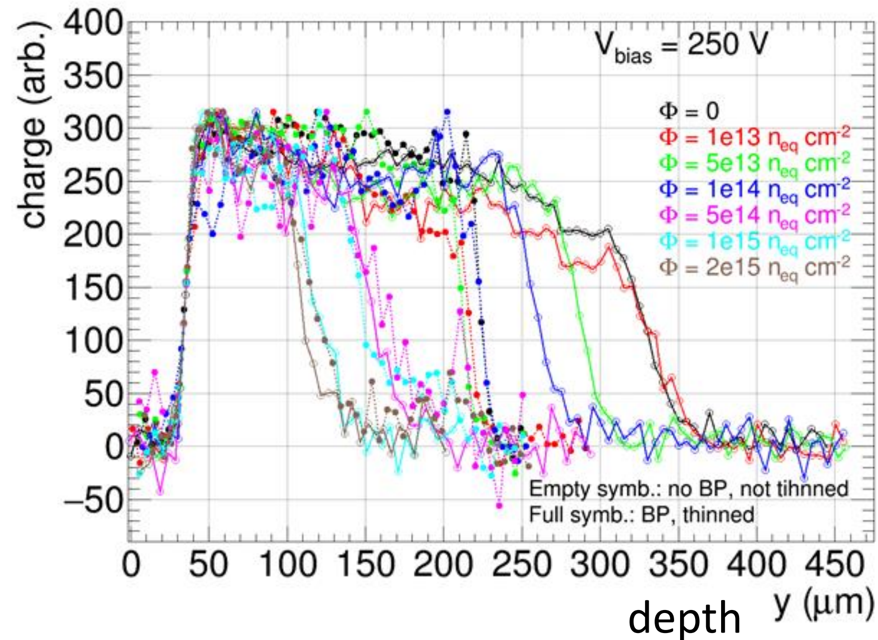


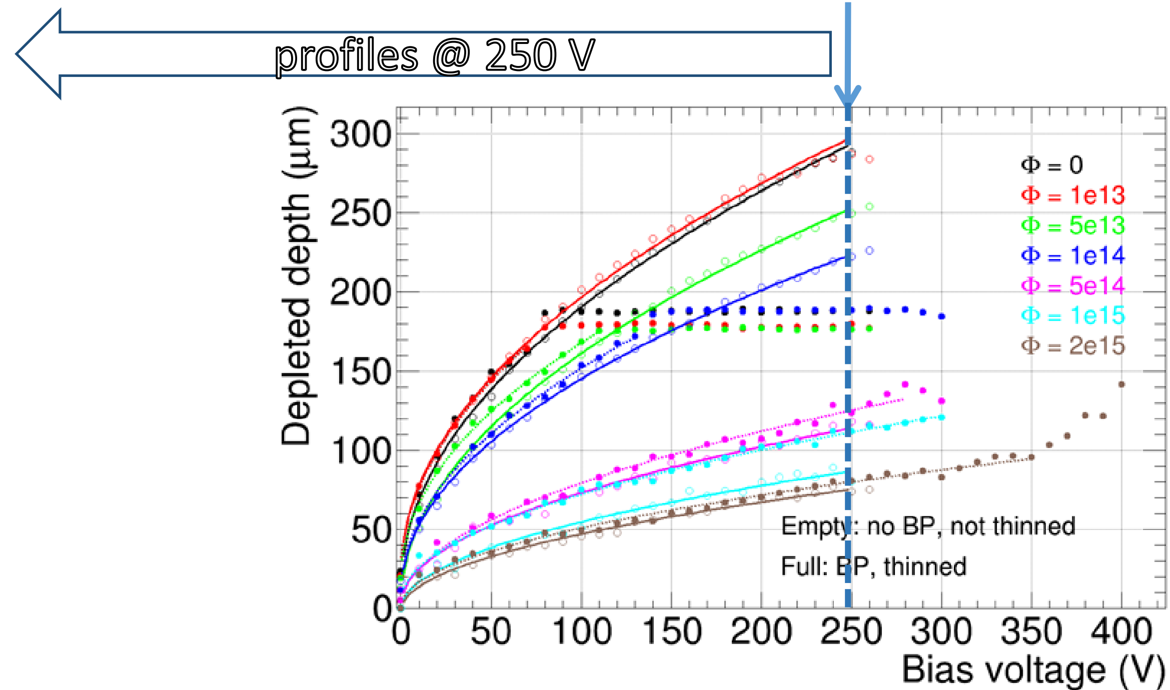


Edge – TCT measurements

- http://arxiv.org/abs/1801.03671 , submitted to NIM A
- RD50 workshop in Krakow
https://indico.cern.ch/event/637212/contributions/2608669/attachments/1471691/2277507/RD50_June_2017_IM.pdf

- Charge profiles at different fluences
- Depletion depth estimated from width of the profile



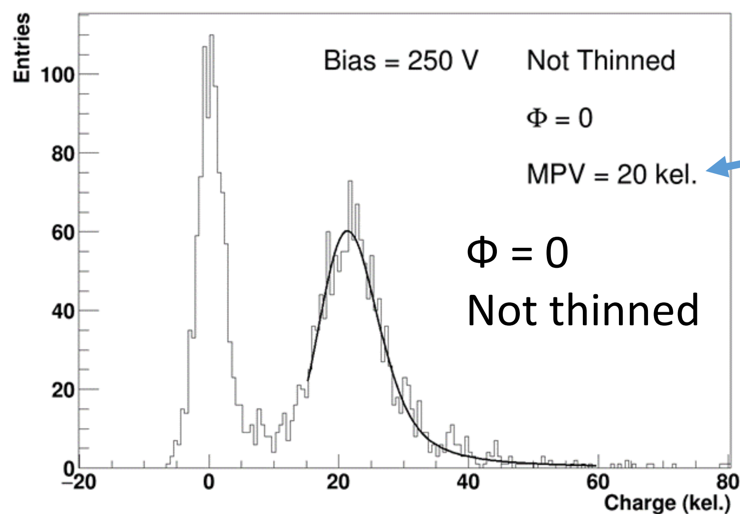


- Charge profiles normalized to same maximum (laser beam monitor not used) !

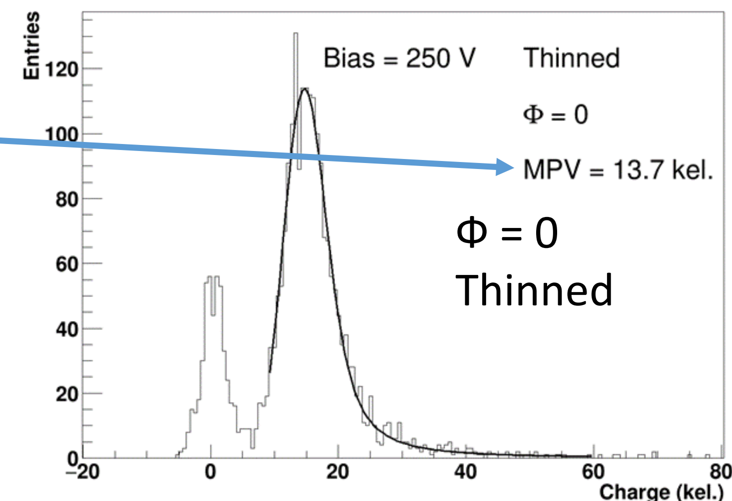
Charge collection measurements with Sr-90
Ortec 142 + 25 ns shaper

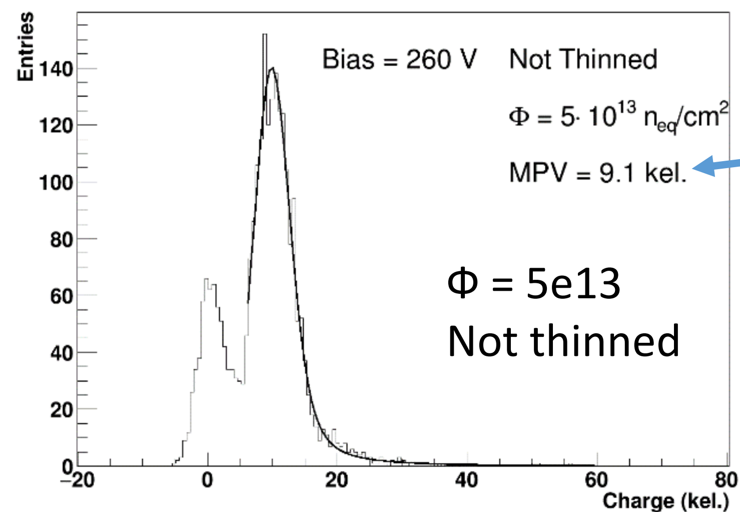
More detail in: http://arxiv.org/abs/1801.03671

➔ large drop of collected charge after irradiation in non-thinned samples

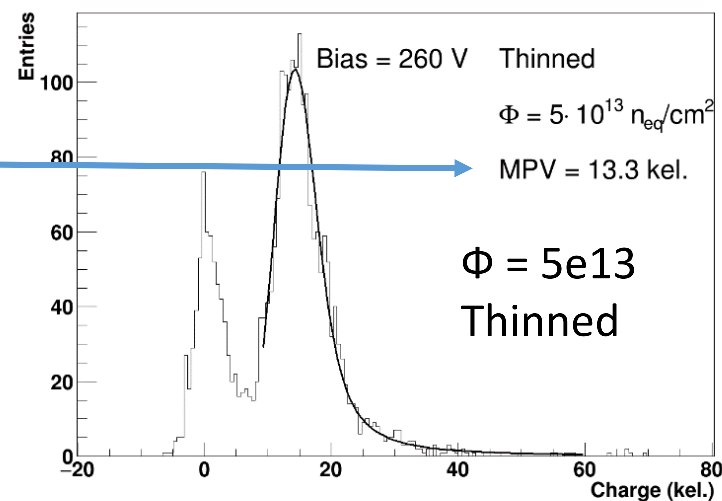


Before irradiation:
charge as expected from depletion depth for both samples





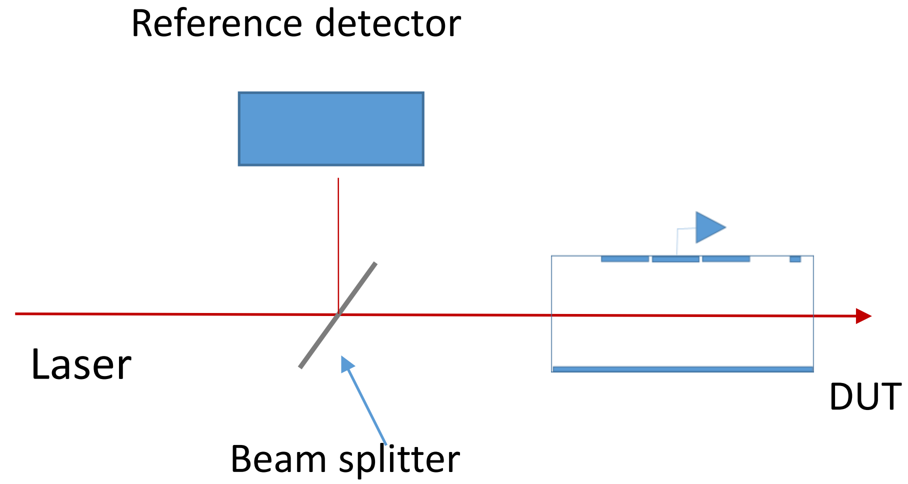
After irradiation:
smaller charge in non-thinned sample although larger depletion depth !



fully depleted ~180 µm thick

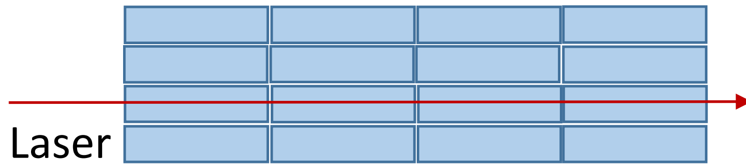
E-TCT: beam monitor

1) use beam monitor:
   → can compare signals between detectors
   → but still don't know the charge



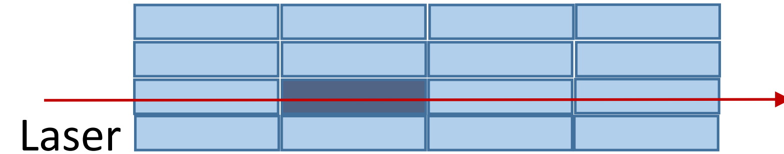
2) Two readout configurations:

•all pixels connected together to the readout amp



Weighting field as in Sr-90 measurements
➔ similar to pad detector

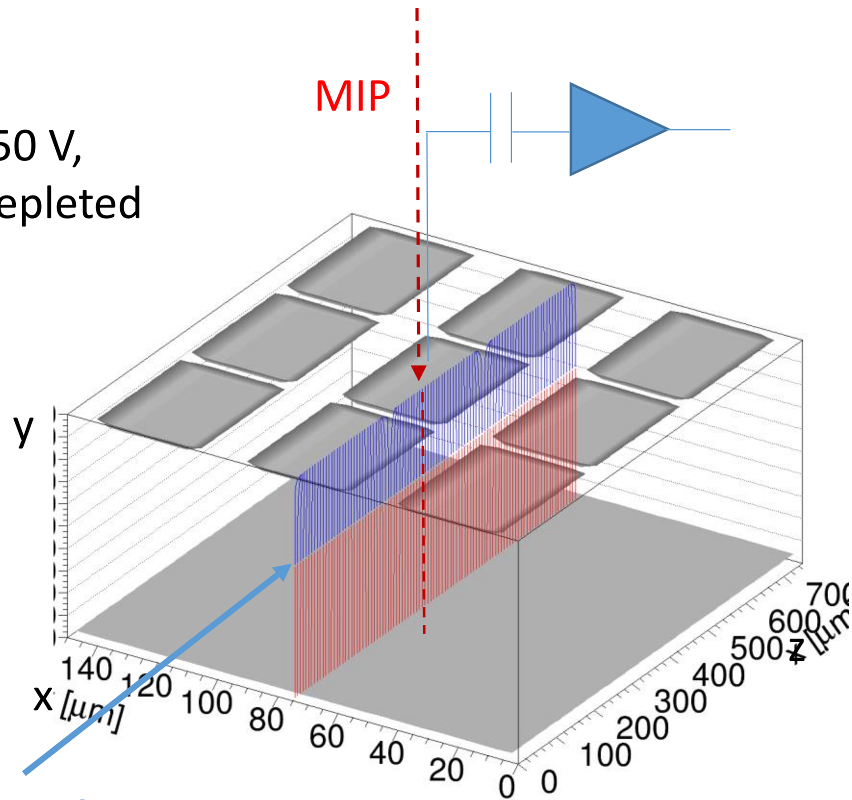
•single pixel
(remaining pixels on same potential but not connected to readout)



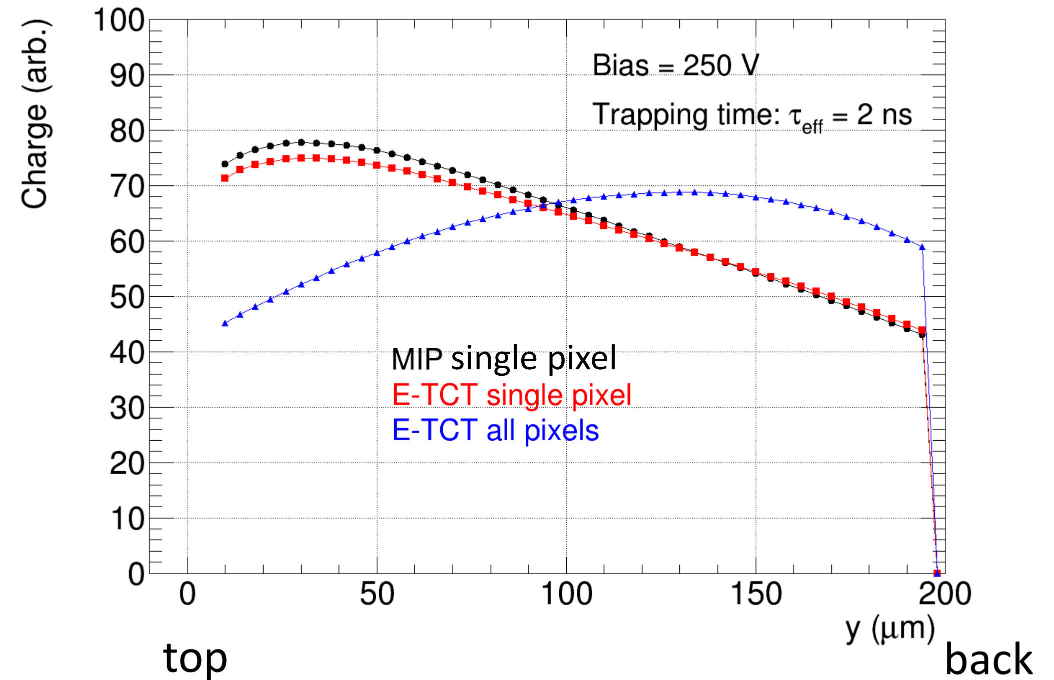
More similar to pixel detector in tracking application but:
→ charge generated and drifting also bellow neighbor pixels affects the induced current pulse on the readout pixel

KDetSim simulation (kdetsim.org)

Bias 250 V,
fully depleted



E-TCT Laser beam

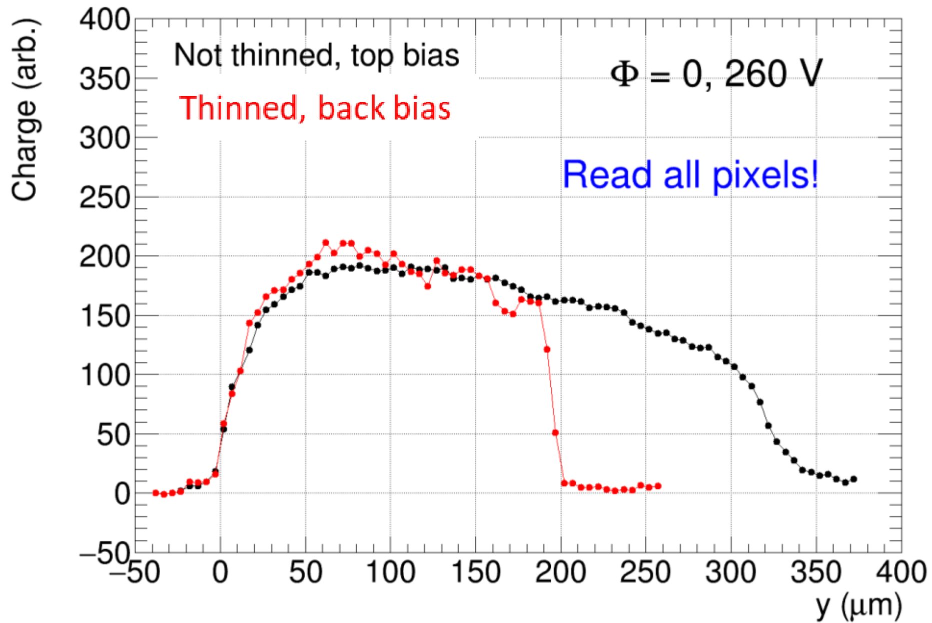


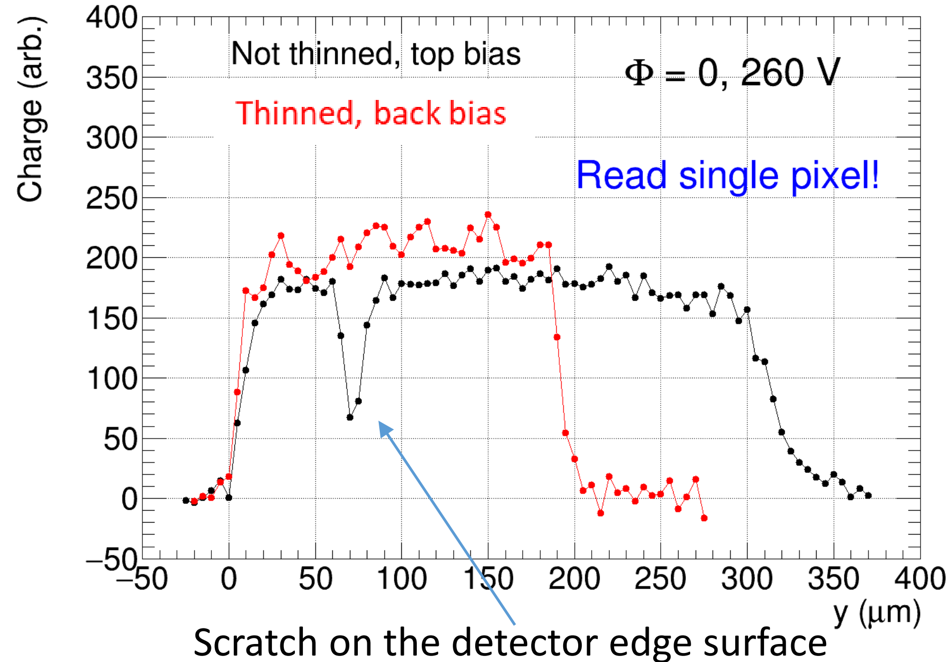
- ➔ MIP – vertical impact through the center of readout pixel
- ➔ E-TCT – charge carriers drift under several pixels

- charge profile in irradiated detector depends on readout configuration (weighting field)
- E-TCT with single pixel readout similar to MIP profile
  → charge drifting to neighbour pixels doesn't contribute much

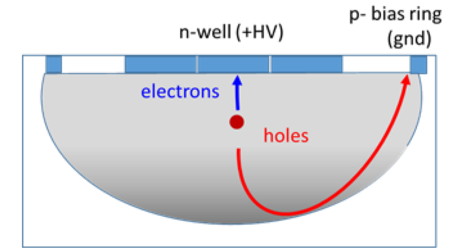
E-TCT measurement before irradiation

Charge measured with different samples (i.e. red and black in same plot) normalized to same laser power ➔ possible because of laser beam monitor

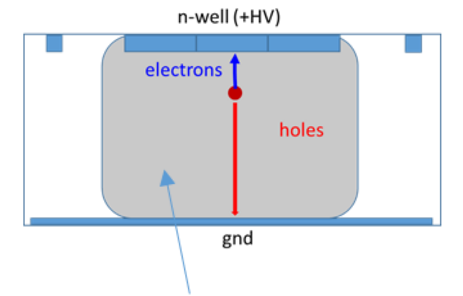




Not thinned top bias:



Thinned back bias:



depletion

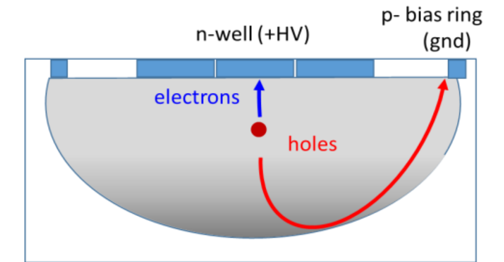
- same response at same depth for thinned and not thinned (up to the thickness of thin sample)
- all charge collected in 25 ns at all ***y*** in both sample
  → carriers must drift across whole weighting field → obvious in thinned fully depleted sample with back bias
  → not thinned top bias: ohmic conductivity of undepleted substrate sufficient to bring low weighting potential near depletion region

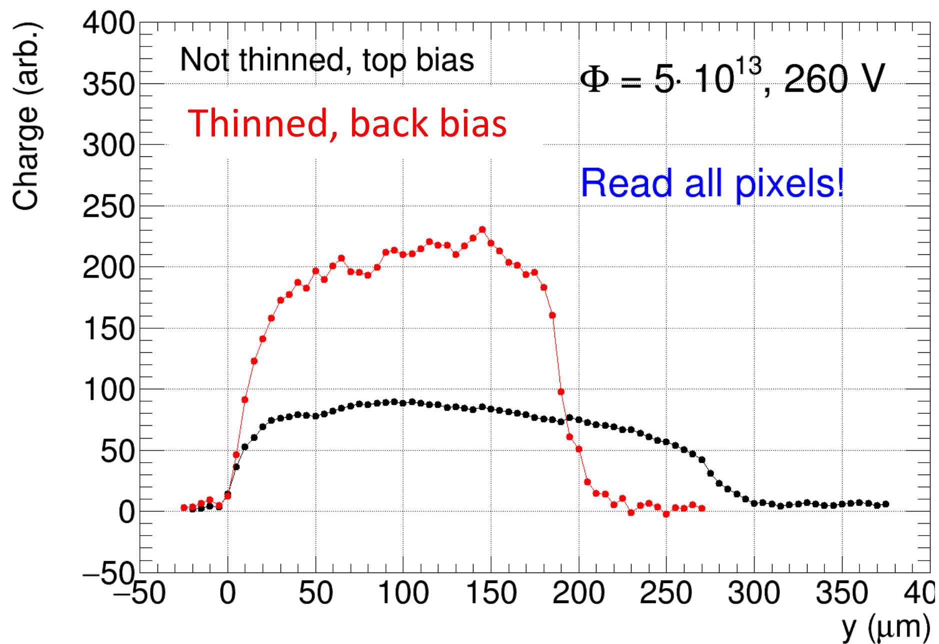
E-TCT measurement after irradiation:

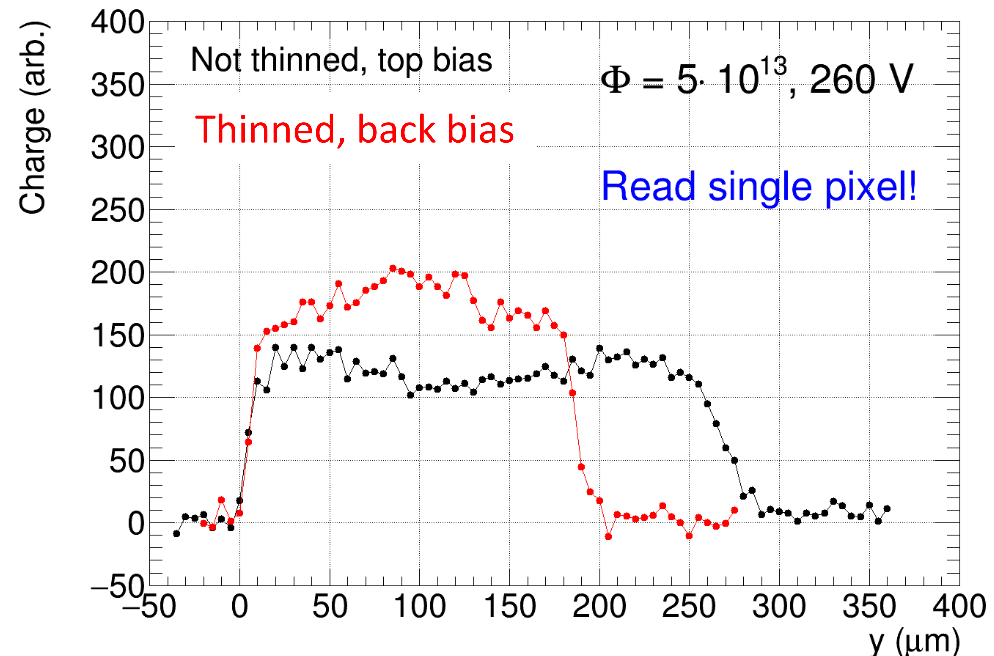
- more charge collected in thinned back-biased sample
  ➔ in top bias case charge doesn't traverse all weighting field
    → trapped in the low field region

- difference looks smaller in **single pixel** case
  ➔ weighting field peaked near the pixel,
    drift close to n-well contributes more to collected charge

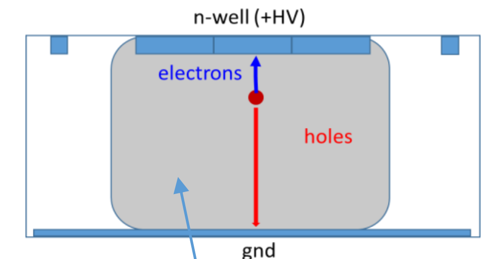
Not thinned top bias:





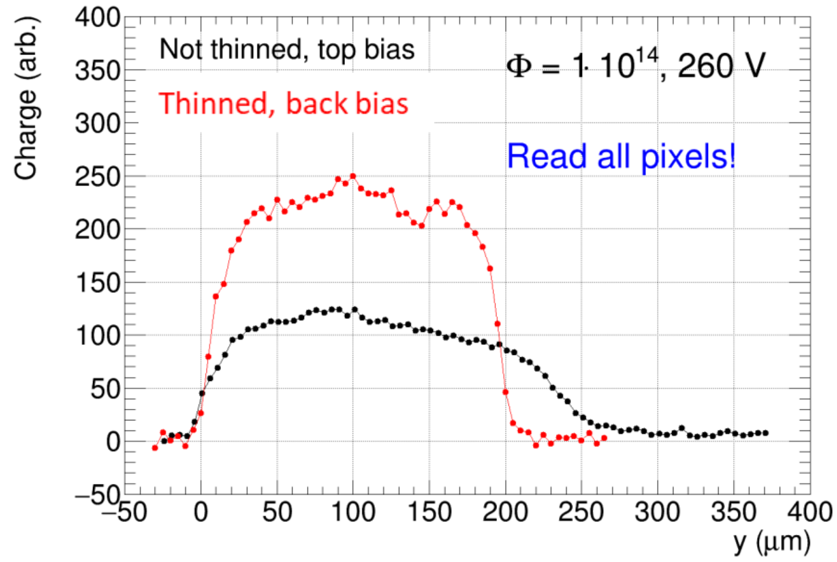


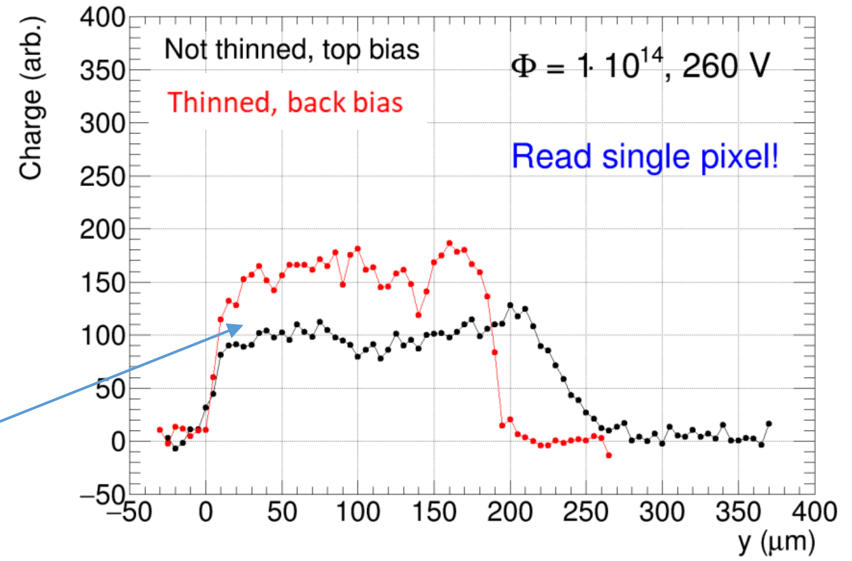
Thinned back bias:



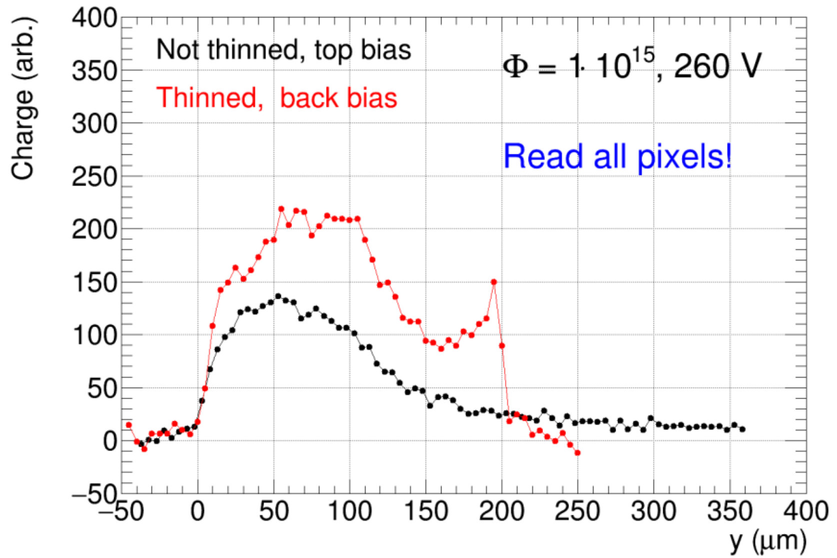
depletion

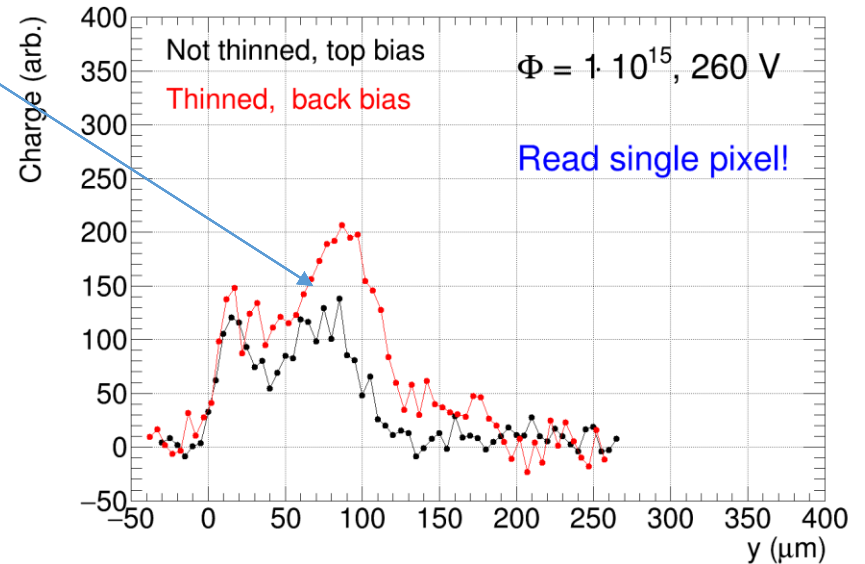
E-TCT, higher fluences





Smaller difference
Between black and red
in single pixel readout!

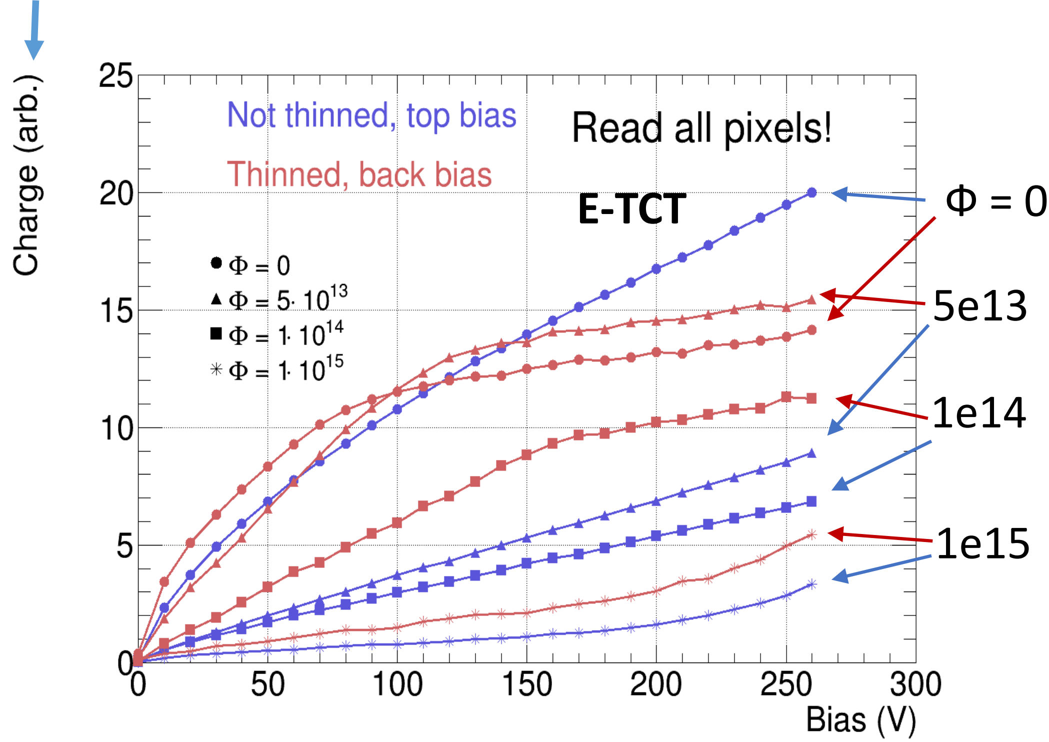




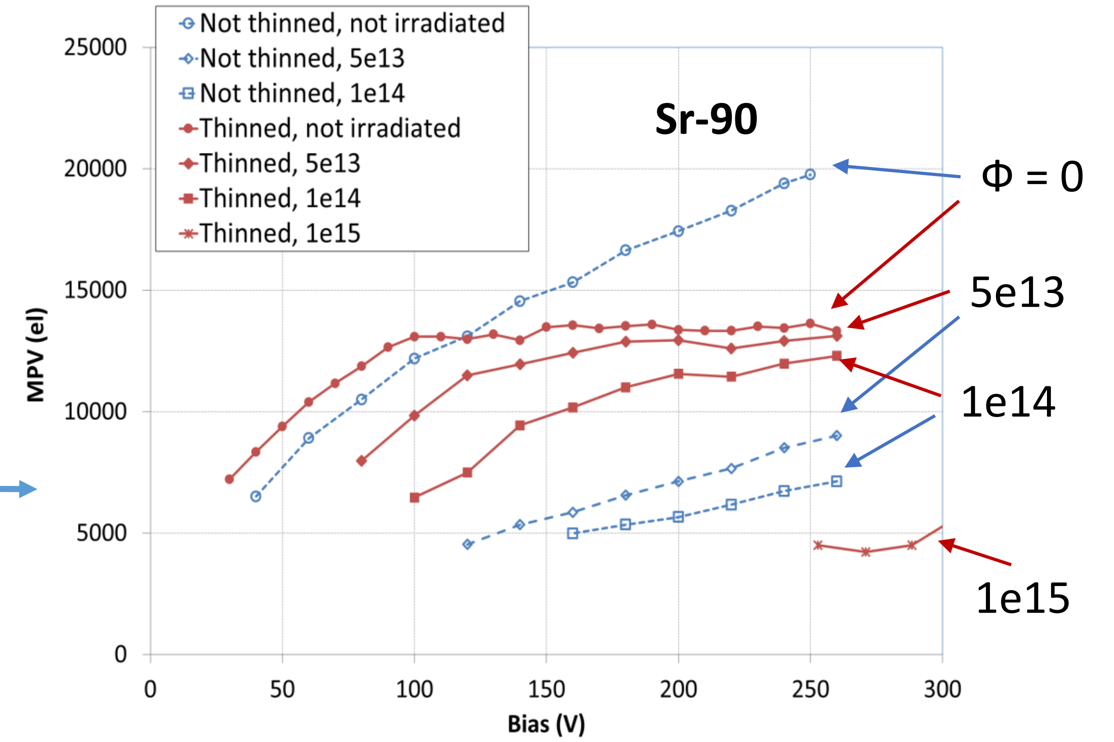
Compare E-TCT with Sr-90 source measurements

- in source measurements charge is generated along the depth of the detector
  ➔ Integrate E-TCT charge profile along ***y*** (depth) to get a value comparable with charge measured with Sr-90

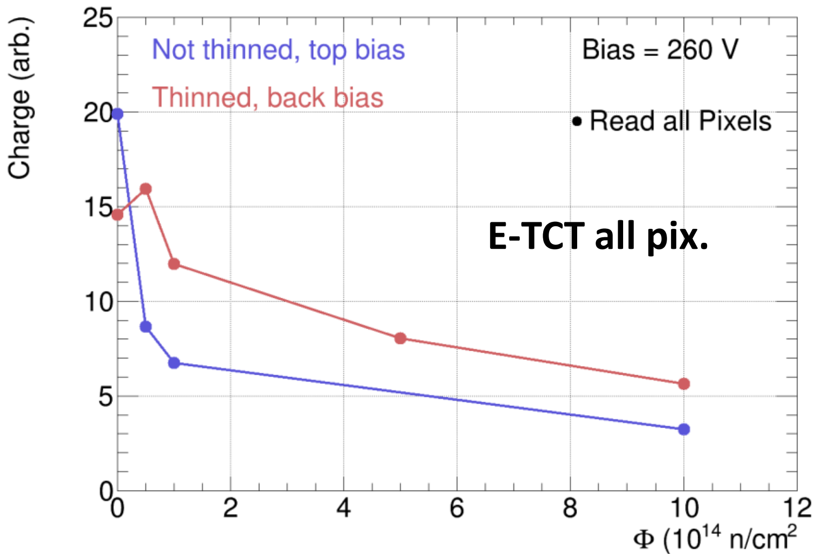
Integral of charge collection profile along *y*



Consistent!

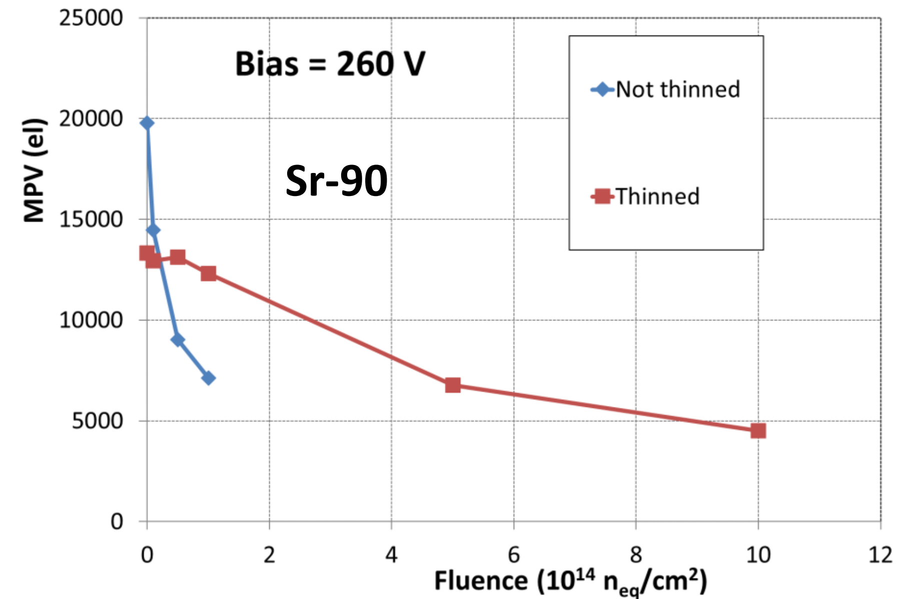


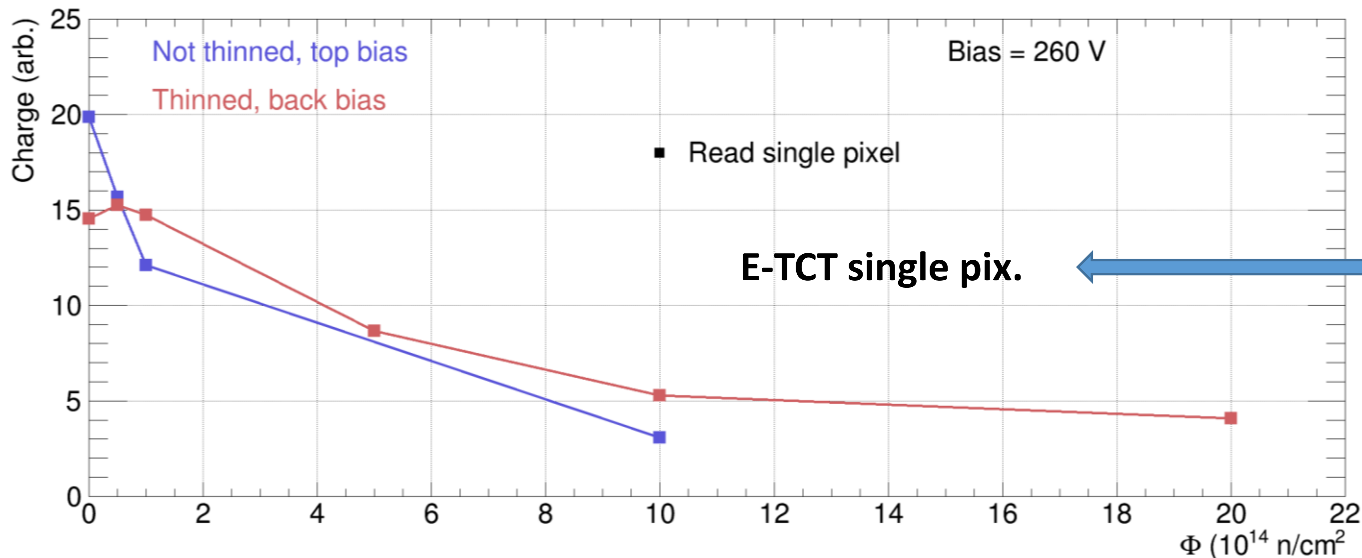
Charge Vs. fluence at 260 V



Similar!

Sr-90 measured with all pixels connected to Readout!

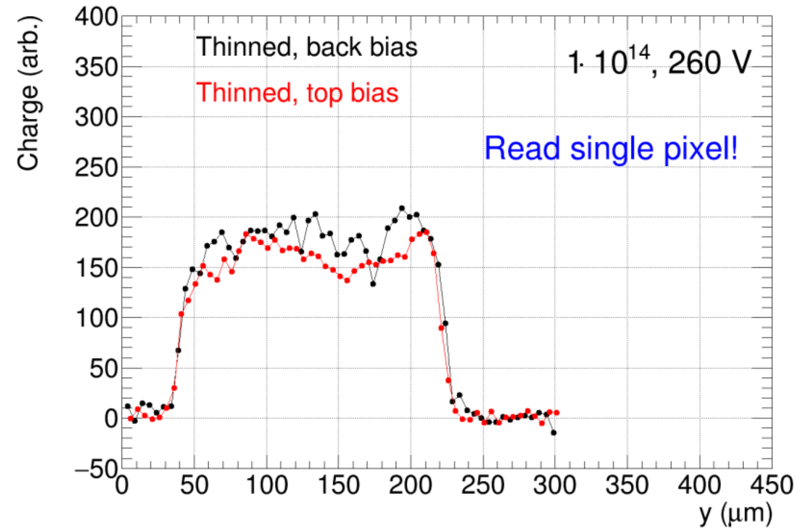


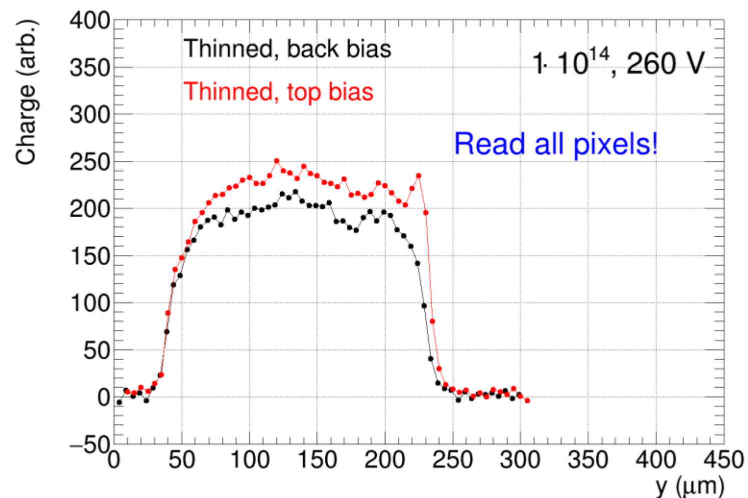


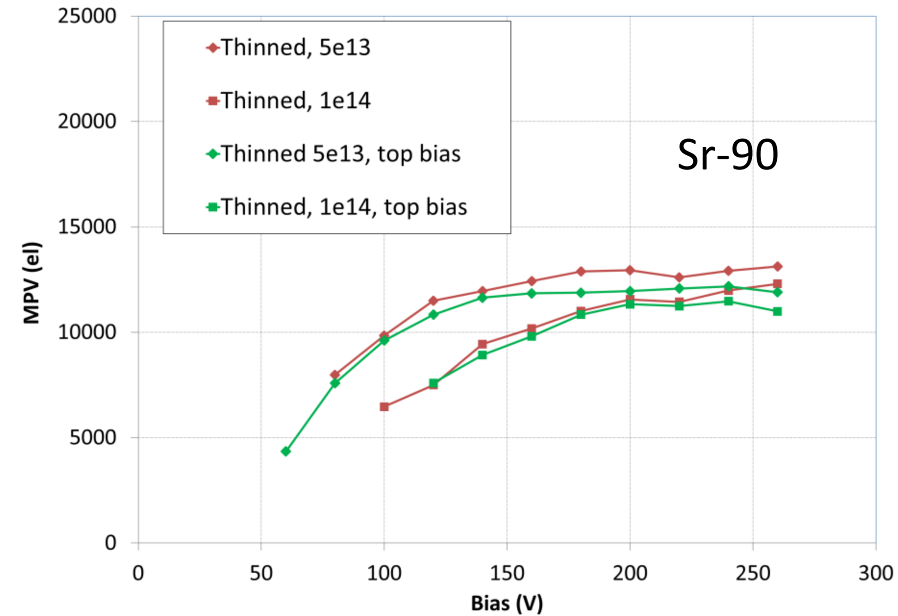
- smaller charge drop in not thinned sample at lower fluences in “single pixel” than in the “all pixel” configuration
- “single pixel” measurement closer to the behavior of real pixel detector in the experiment
  - ➔ single pixel measurements with Sr-90 difficult because pixels are small
  - ➔ test beam needed for MIP response

Backplane but top bias

- Thinn with back plane but **substrate biased via implant on top** as in non-thinned samples (sample mounted on kapton → no contact of backplane with support)







Small difference between top and back bias also when not fully depleted!

- contact with back plane via edge of the device
- equipotential plane at the back
  –> modifies electric and weighting field

Summary

- charge collection properties of depleted CMOS structures studied with E-TCT using beam monitor
  ➔ compare E-TCT measurements with different samples at same laser beam intensity

- study charge collection profiles at different fluences and compare two detector sets and readout configurations

- good agreement of E-TCT and Sr-90 source measurements

➔ thinning and backplane improves charge collection after irradiation
  → better charge collection also if backplane floating and substrate contacted from top

➔ effect less significant in "single pixel" configuration because of weighting field (small pixel effect)

➔ charge collection estimated with E-TCT in "single pixel" readout should give good estimate for tracking application and it is much simpler than test beam measurement