TCT study of H35Demo test structures

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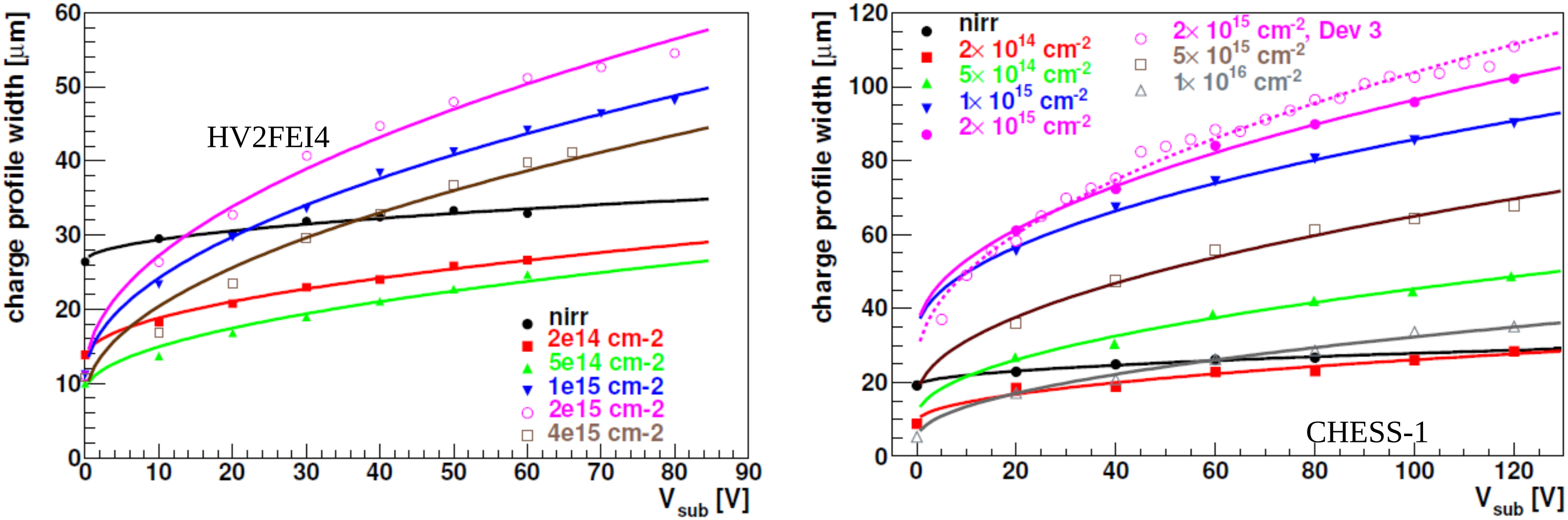
HV-CMOS in HEP

Several productions from different foundries have been made
Each with its production technology and wafer resistivity:

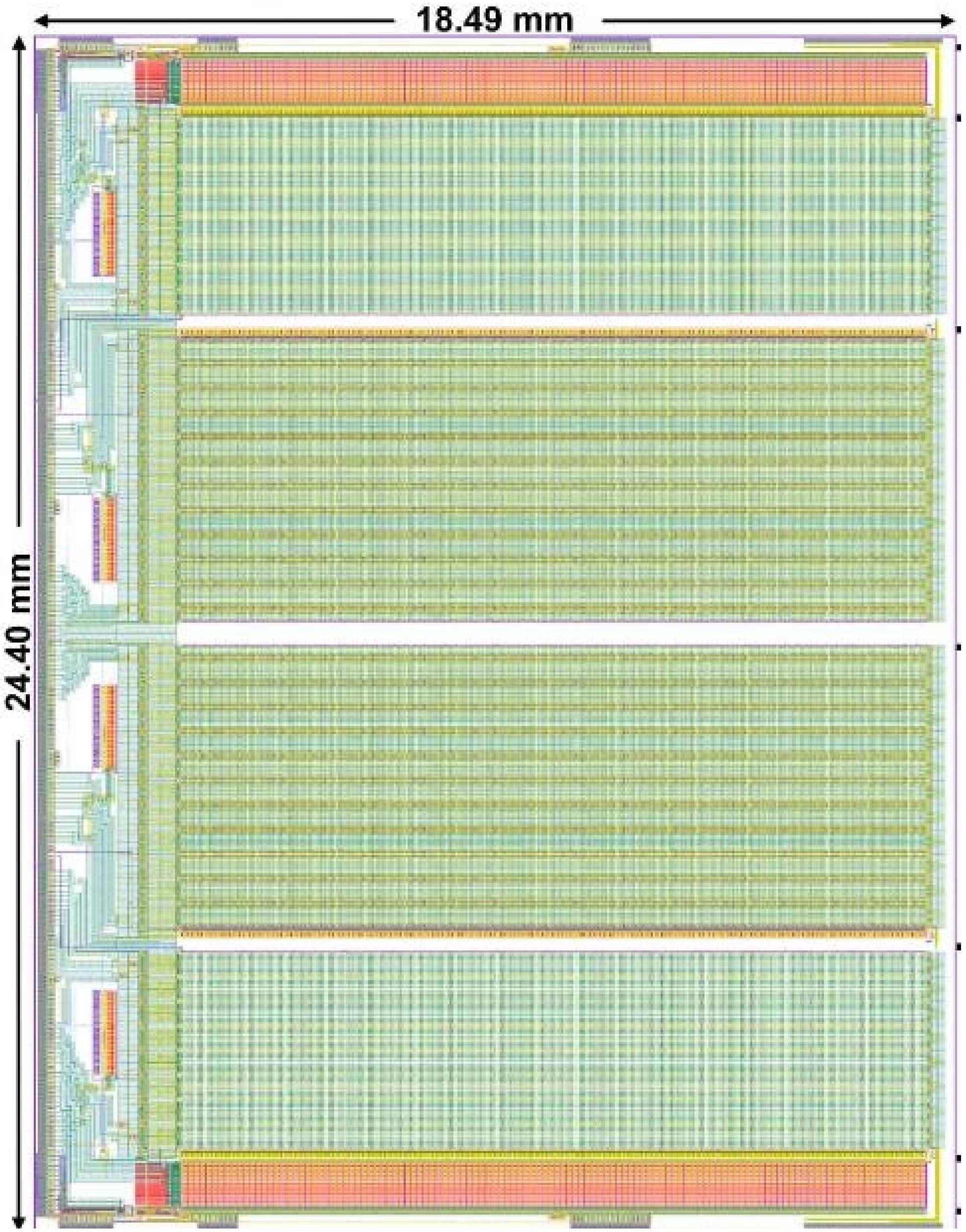
- AMS 350nm, ρ = 20Ω·cm (CHESS-1)
- AMS 180nm, ρ = 10Ω·cm (HV2FEI4)
- LFoundry 150nm, ρ = 2kΩ·cm
- X-FAB 180 nm, ρ = 100Ω·cm

Interesting results have been obtained but it is hard to compare devices from different foundries because of different technologies, substrate doping and well properties



G Kramberger, 27th RD50 Workshop

H35Demo Chip



Main features:

- Different substrate resistivities:
  20Ω·cm (standard), 80Ω·cm, 200Ω·cm, 1kΩ·cm
- AMS 0.35 μm High Voltage CMOS (H35)

Areas (from top to bottom):

- Standalone nMOS matrix
  Digital pixels with in pixel nMOS comparator
  Standalone readout
- Analog matrix (2 identical arrays)
  Different flavors in terms of gain and speed
- Standalone CMOS matrix
  Analog pixels with off pixel CMOS comparator
  Standalone readout

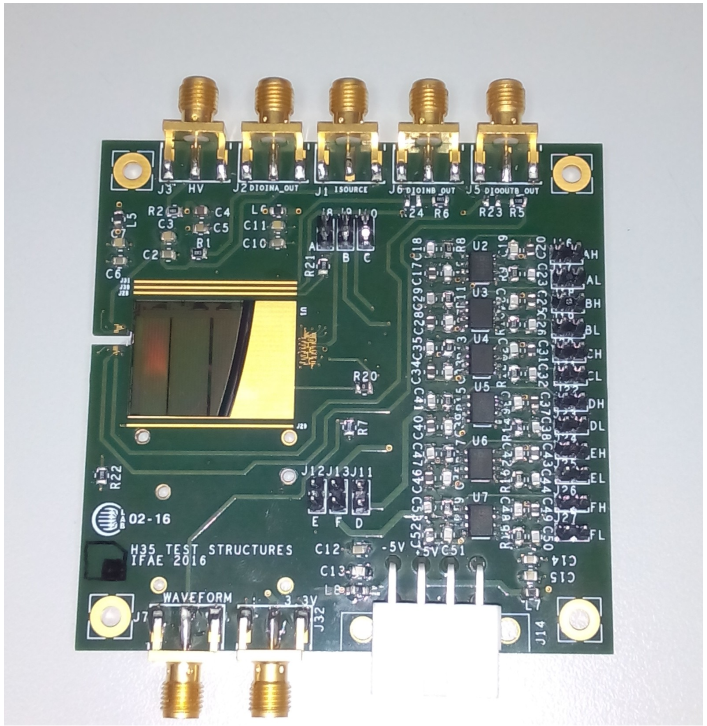
Test structures:

- Central pixel w/ 8 neighbor + output buffer
- **Central pixel w/ 8 neighbor**

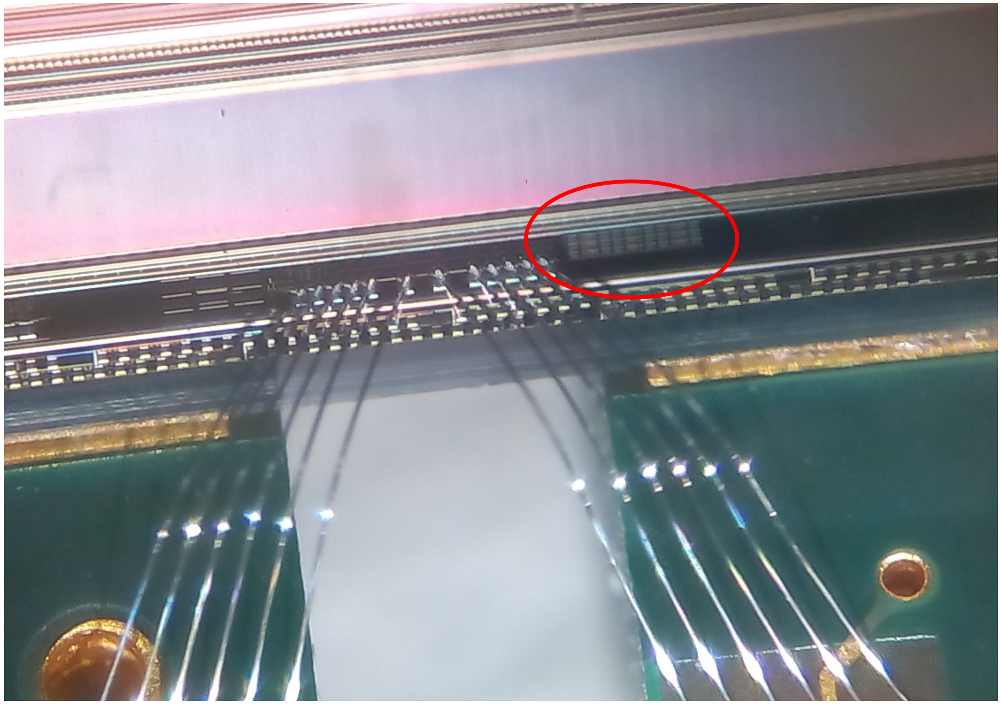
H35Demo test structure

The test structures are on the side of the chip

→ Incomplete chips on the periphery of the wafer can be used



H35Demo chip on the PCB
Designed by C. Puigdengoles



Detail of the test structures

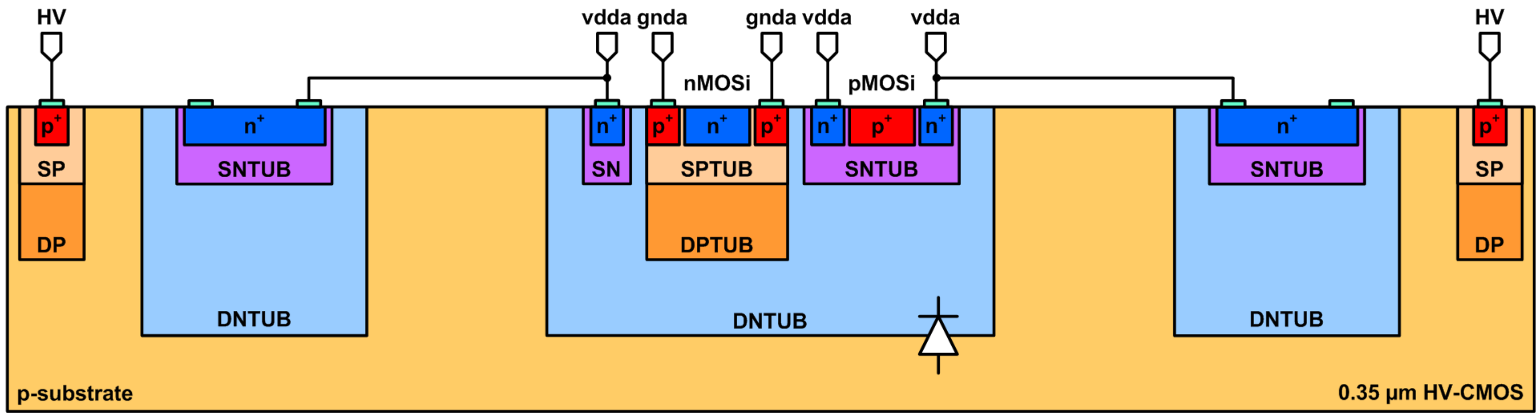
Tested devices

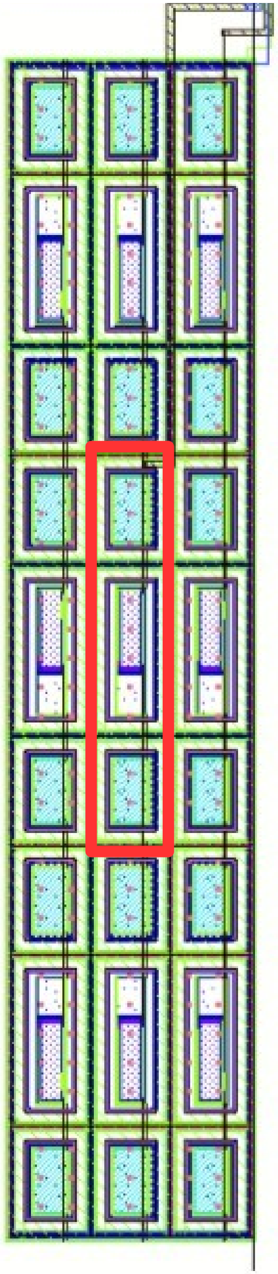
Name	S1	S2	S3
Origin	UNIGE	IFAE	KIT
Nominal ρ [Ωcm]	200	200	1000

H35Demo test structure

The tested structure is a matrix of 3x3 pixels of 50·250 um^2 each

- 3 deep N wells in each pixel
  - central 50·110 um^2
  - external 50·70 um^2
- no electronics inside the pixels
- deep P well inside the deep N well of the central N well
- deep N wells covered by a layer of polysilicon in the external N wells
- central pixel (marked in red in the drawing) is read out individually
- signals of the 8 external pixels are shorted together





Pixel cross section and schematic drawing of the tested structure*

**from Eva Vilella*

TCT Setup

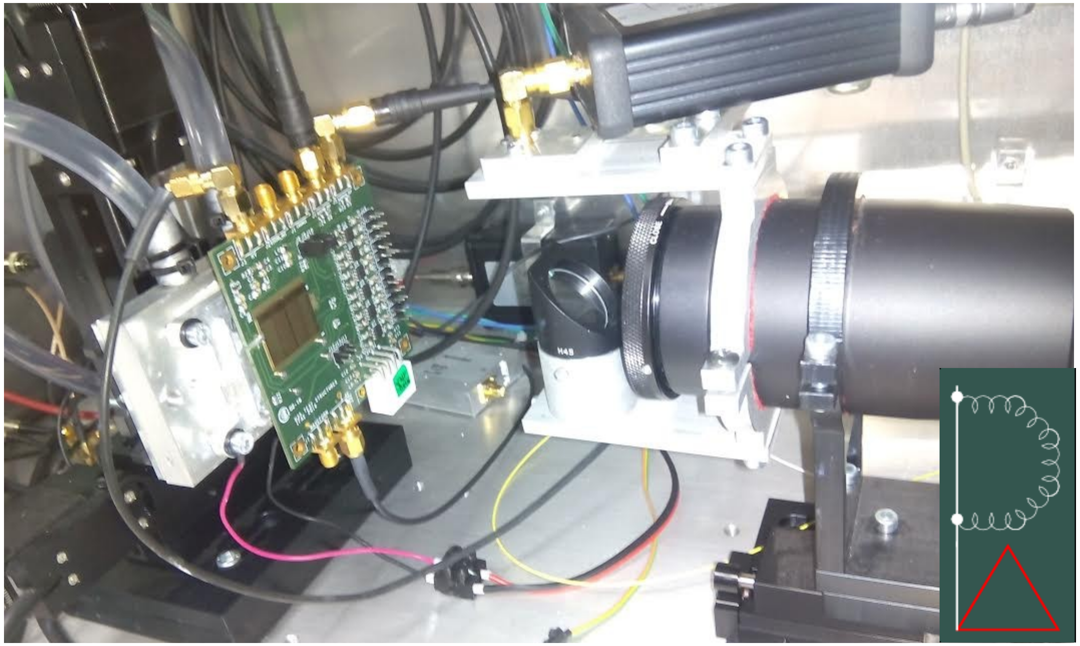
Scanning TCT from Particulars

Laser properties

- Red or IR laser (640 nm and 1064 nm) available
  - all results shown have been obtained with the IR laser beam
- Beam spot ~10 um FWHM
- Laser pulses of ~500 ps

Readout through DRS4 evaluation board

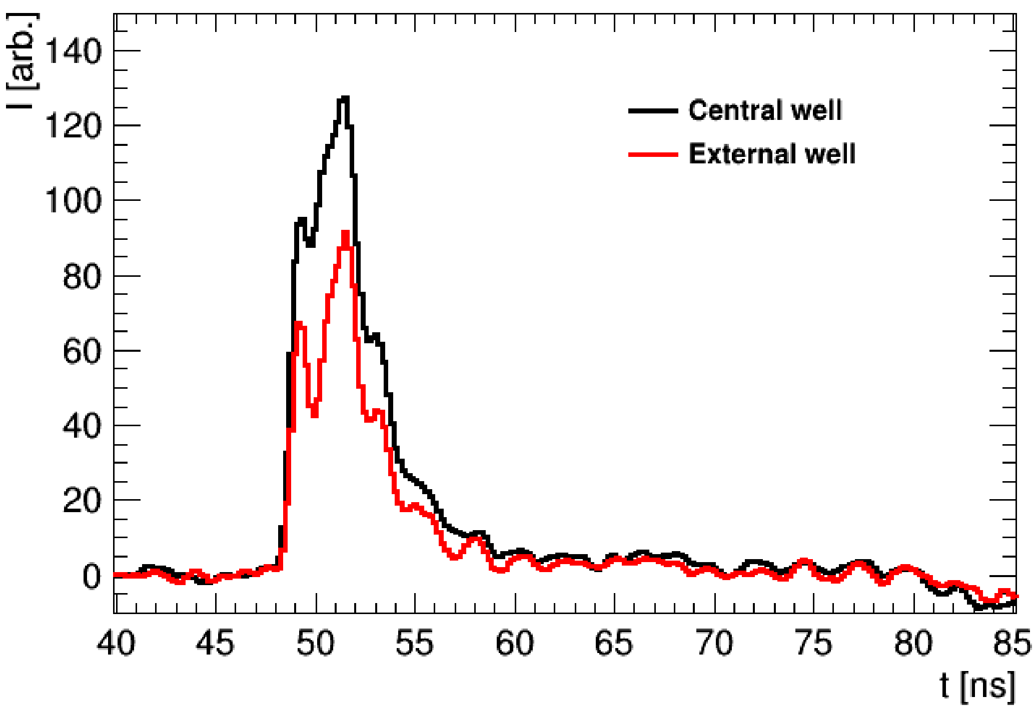
- 700 MHz bandwidth
- 5 GSPS
- 200 ns sampling depth
- 4 channels
  - 1 for trigger
  - 1 for beam monitor
  - 2 readout channels

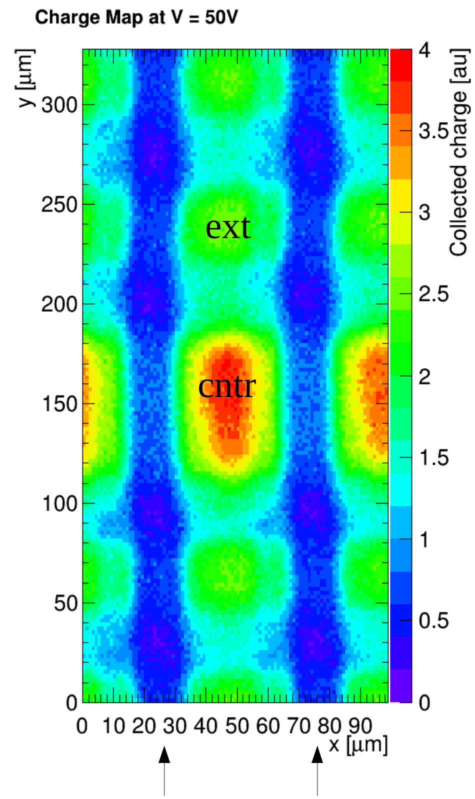


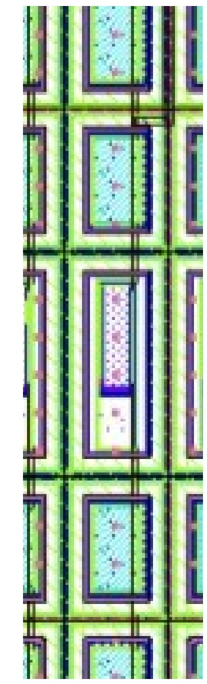
S1 - Top TCT

This sample has been kindly provided to us by M. Benoit, Geneva University

Each waveform is integrated in a 25 ns wide time interval (45-70 ns)
to obtain the charge collected by the pixel





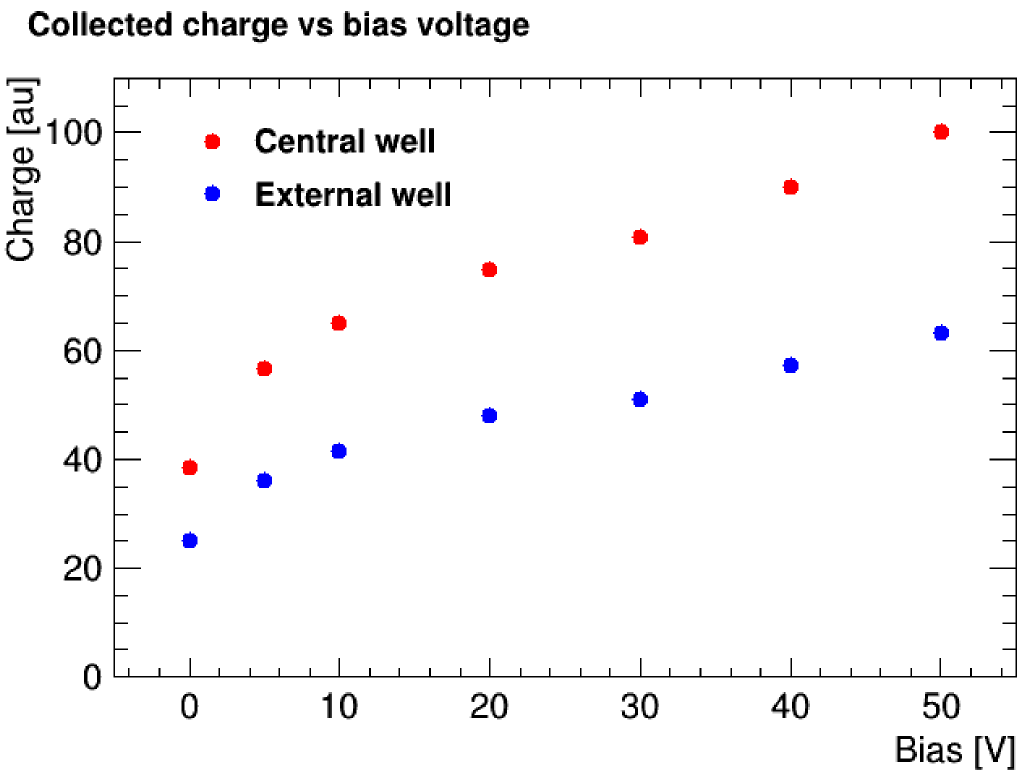


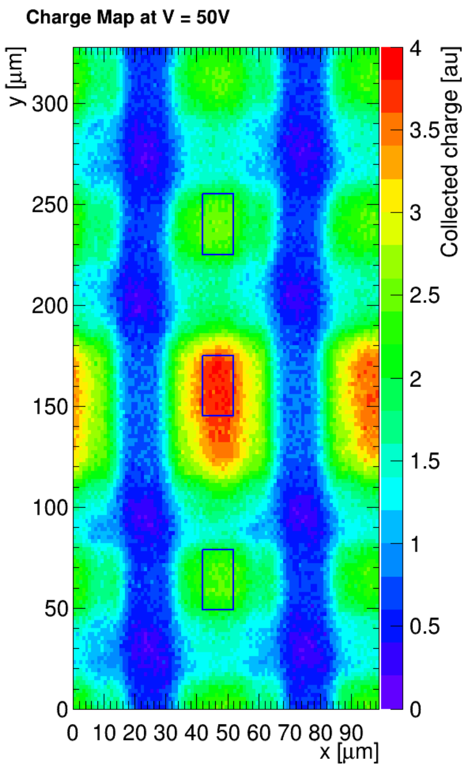
Metal lines on surface

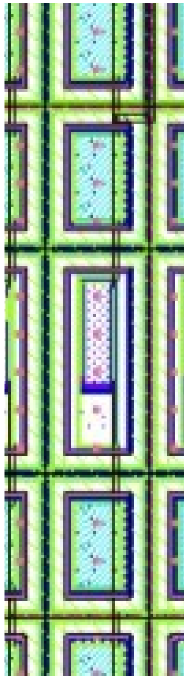
The sub-structures of the pixel are visible
The low value regions correspond to the metal lines on the pixels
The region with the highest collected charge corresponds with the deep P well

S1 - Top TCT

I selected three regions of 10 μm · 30 μm to compute the average collected charge in the structure with deep P well inside the deep N well and in the structure with the only deep N well





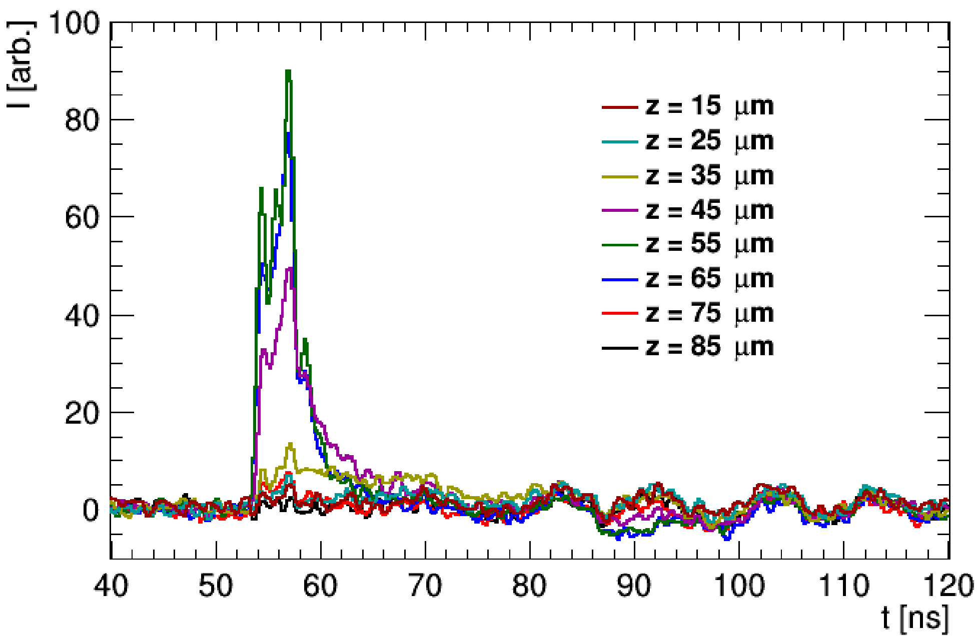


The external wells collect ~ 64% of the central one at any voltage
Two possible explanations:
- The olisicon layer on top of the external well reflects+adsorbs part of the light
- The central well efficiency is higher than external one

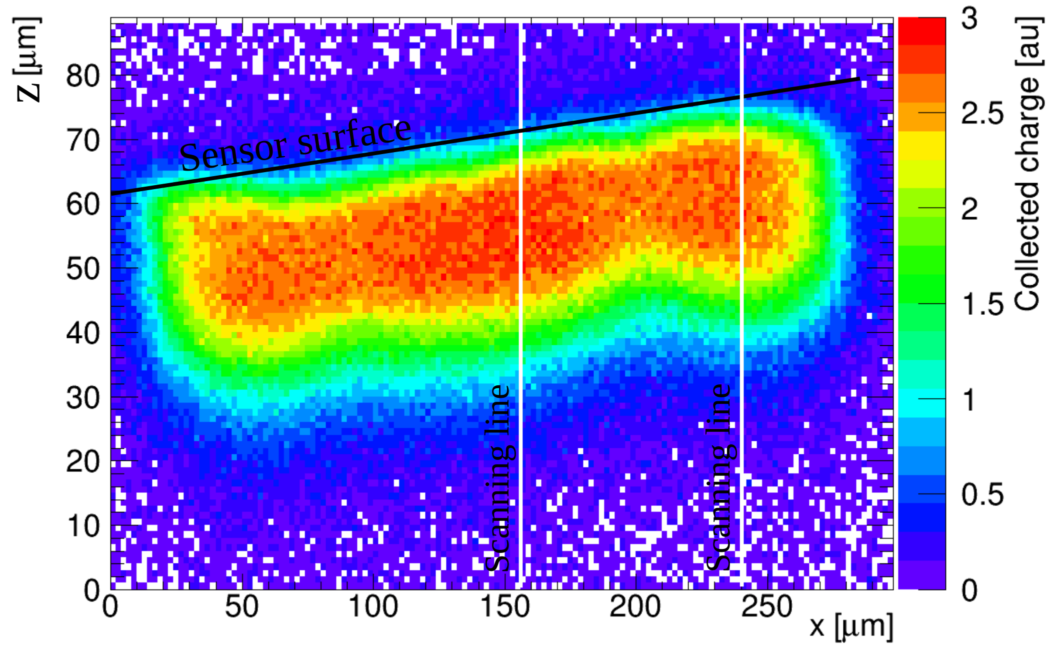
S1 – Edge TCT

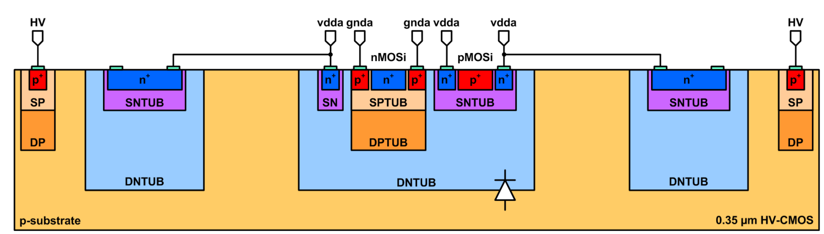
Collected charge obtained by the waveform integral over a 25 ns time interval

Sample waveform @ x = 165µm, V = 50V



Charge collection map @ V = 50V





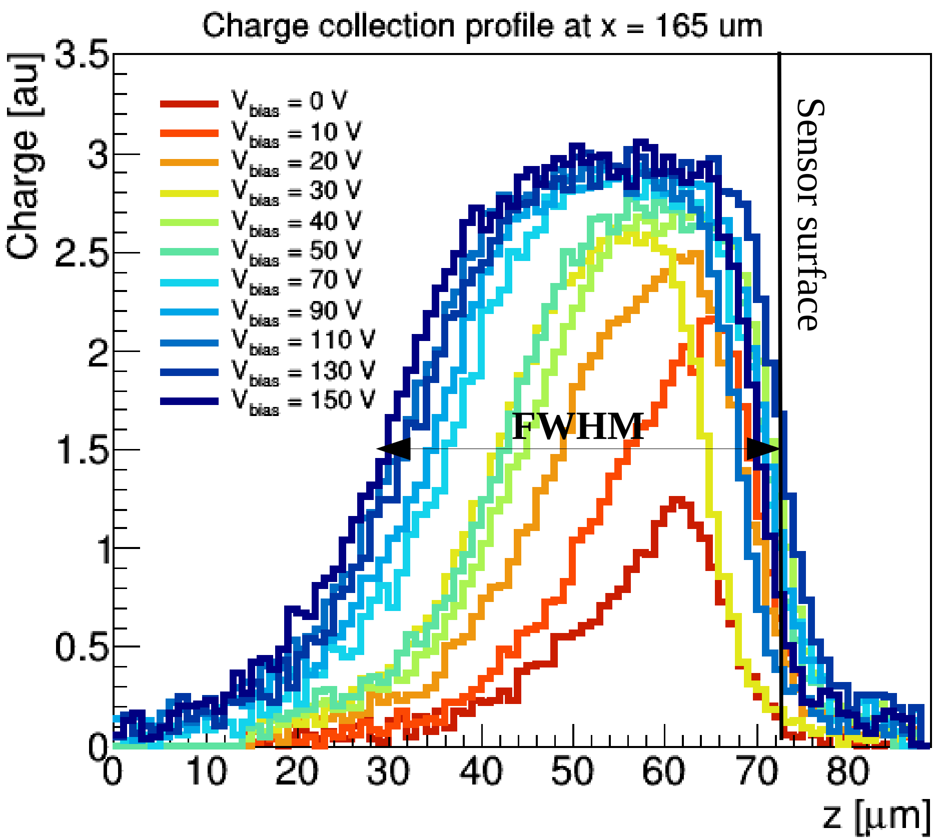
The separation of the three deep N wells is slightly visible in the charge collection map

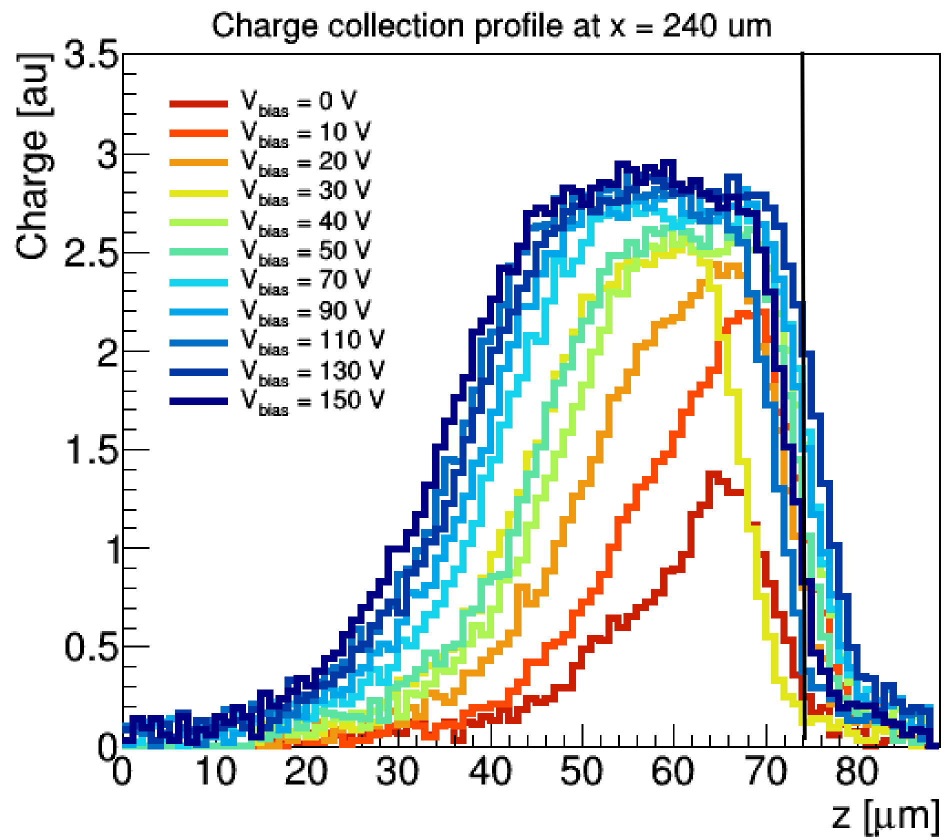
The design distance between the central and the lateral N wells is 20 µm

S1 – Edge TCT

The y profile of the 2D map shows the evolution of the depletion depth with the bias voltage

- At x = 165 μm, at the position of the deep p-well inside the n-well
- At x = 240 μm, at the center of the external structure w/o p-well

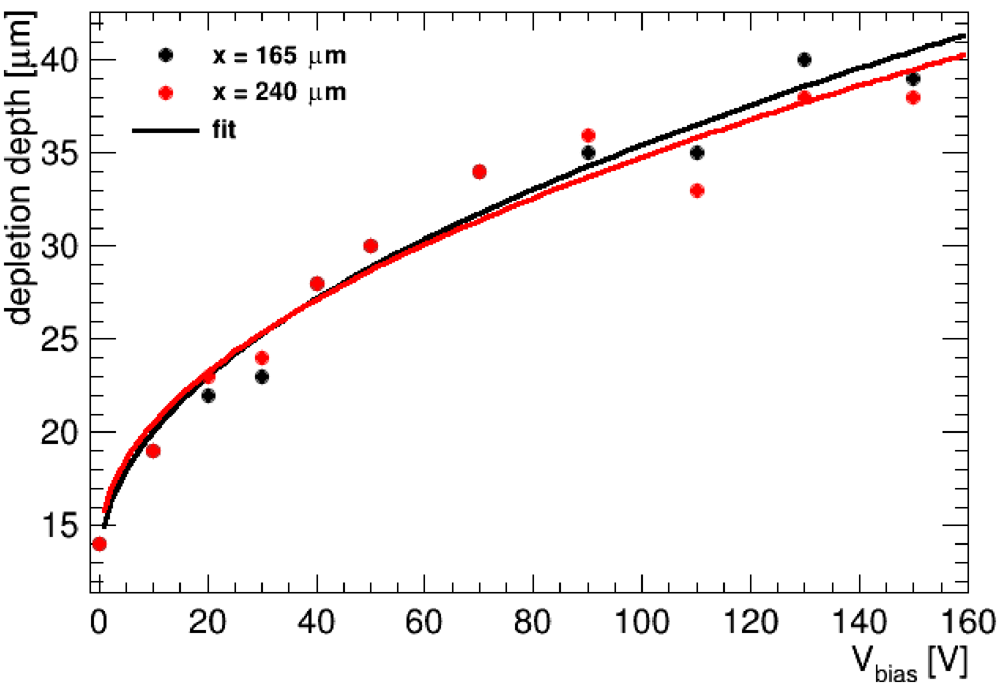




The difference of collected charge between the wells observed with Top TCT is not present in this case

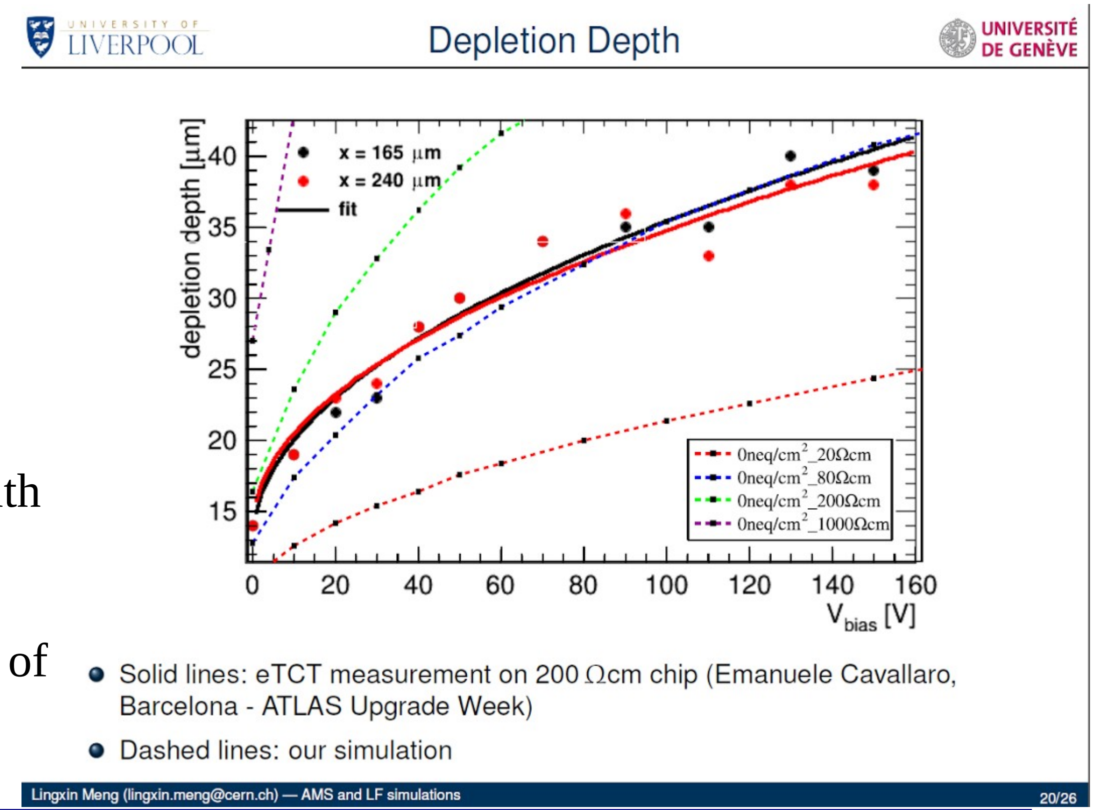
S1 – Depletion depth

The depletion depth is given by the formula: $$d = d_0 + \sqrt{2\frac{\varepsilon_{Si}\varepsilon_0 V}{qN_{eff}}} = d_0 + \alpha\sqrt{\rho V}$$



The measurement points are given by the full width half maximum of the charge collection profile

The fit returns a resistivity of ρ_{meas} ~ 50 Ω·cm that is significantly smaller than the nominal value



Simulations by Lingxin show that this data fits with the 80 Ω·cm simulation

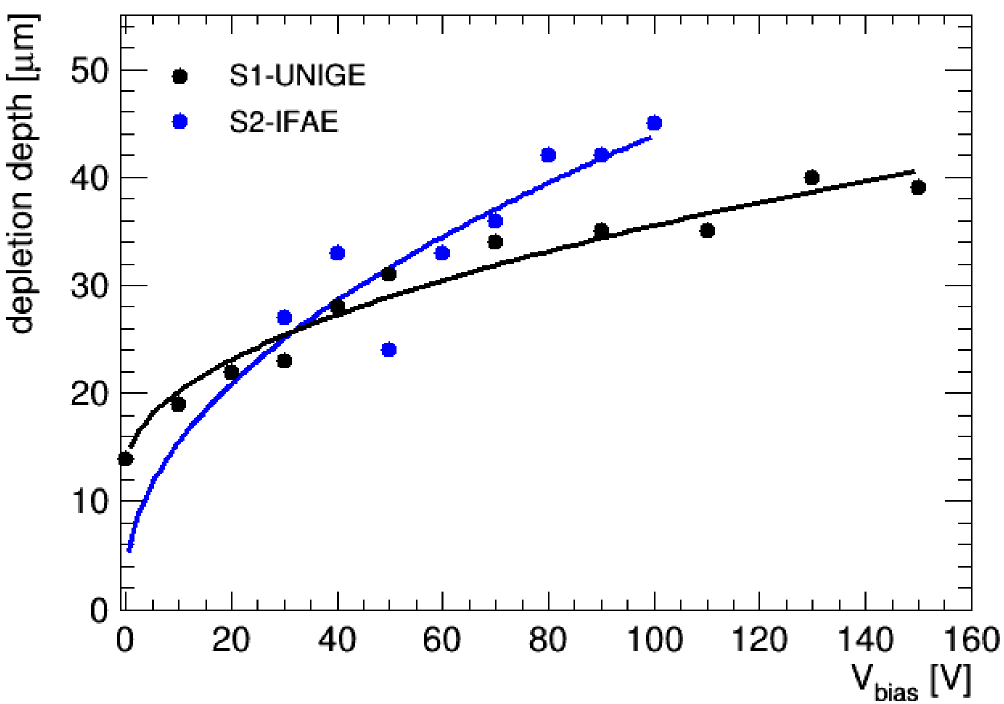
I repeated the measurements with another sample of nominal resistivity 200 Ω·cm

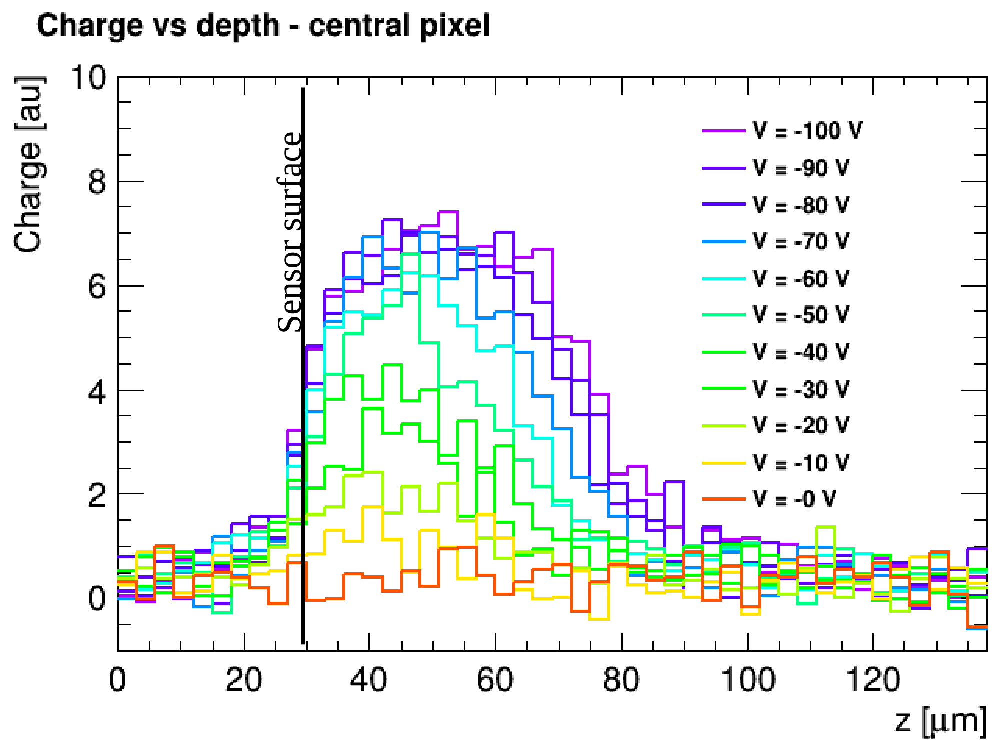
S2 – Depletion depth

This sample comes from the IFAE wafer with nominal resistivity 200 Ω·cm

The depletion depth vs V_{bias} plots do not overlap with the one of sensor S1

The measured resistivity is ρ_{meas} ~180 Ω·cm

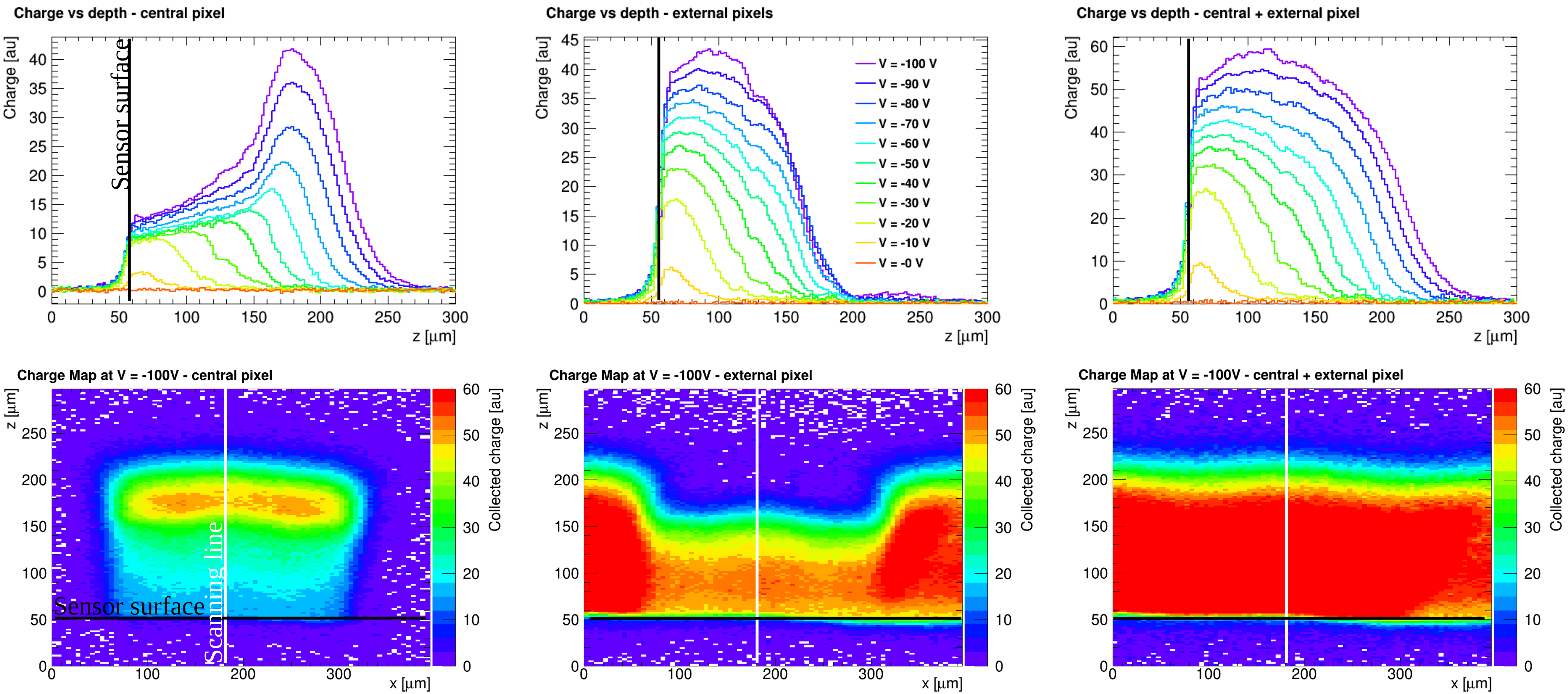




Measurements on other devices with nominal resistivity 80 Ω·cm and 200 Ω·cm should be done to investigate this inconsistency

S3 – Edge TCT

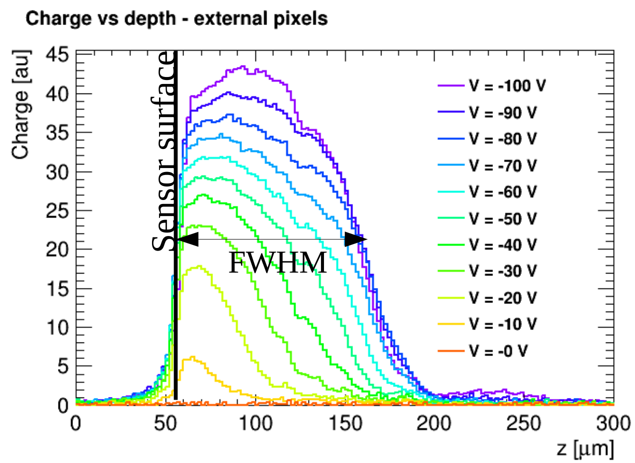
This sample has been kindly provided to us by I. Peric, KIT

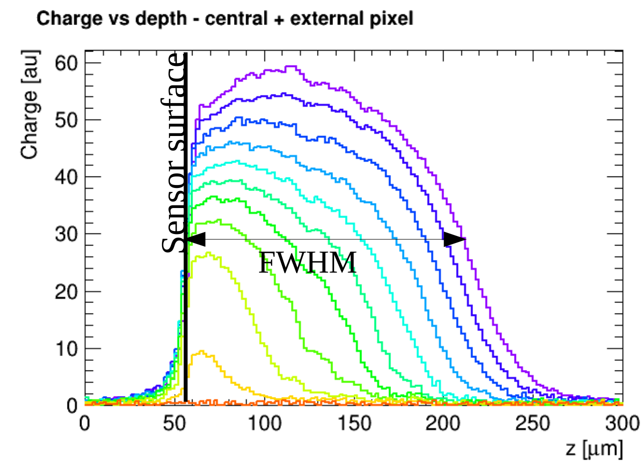


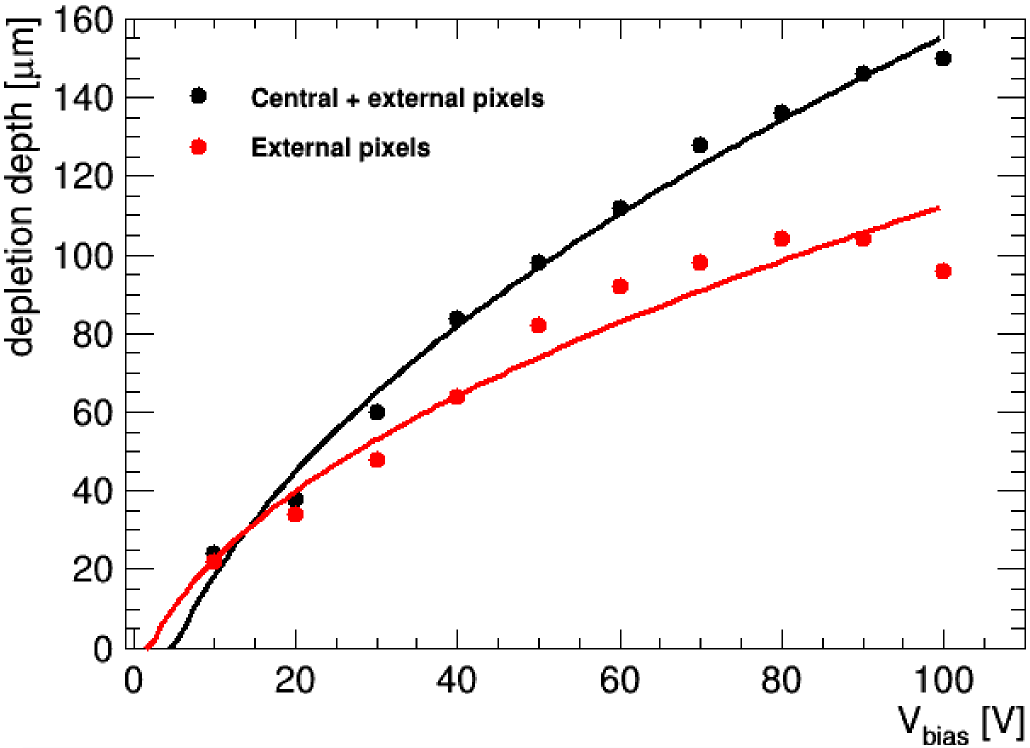
At V_{bias} > 50V and depth >150 µm the central pixel collects charge generated underneath its neighbors on the short pixel direction

S3 – Depletion depth

The FWHM can be taken as measure of the depletion depth for the *external* and *central + external* plots







Fitting with $d = d_0 + \alpha\sqrt{\rho V}$

The resistivities obtained are:

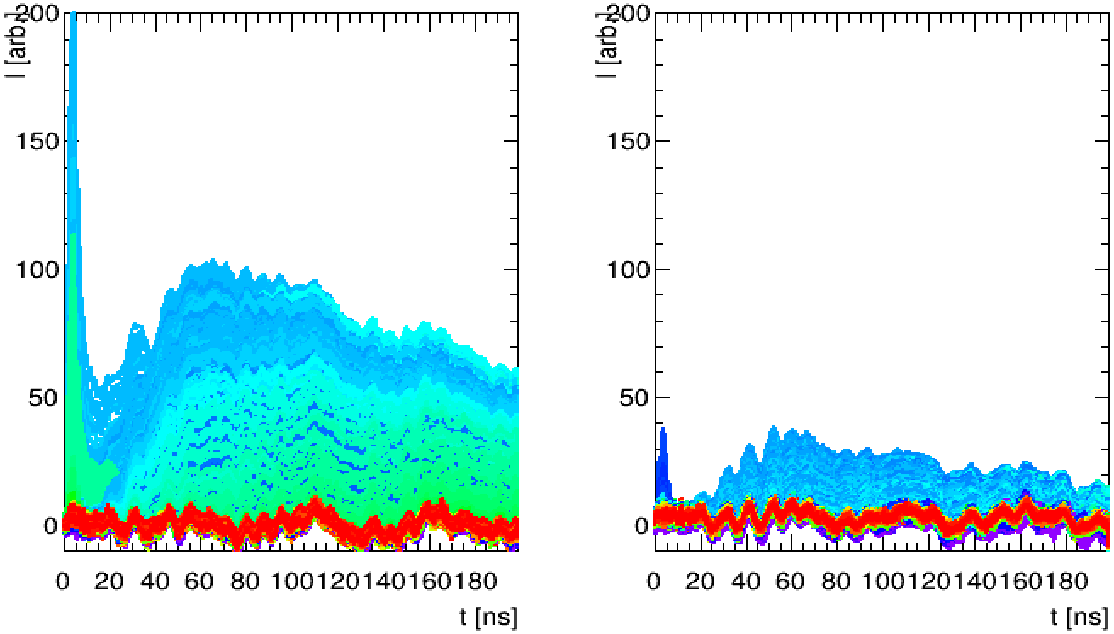
$$\rho^{ext}_{meas} = 1840\,\Omega\cdot\mathrm{cm} \pm 20\%$$

$$\rho^{cntr+ext}_{meas} = 4280\,\Omega\cdot\mathrm{cm} \pm 7\%$$

Problems with other samples

Other three devices with nominal resistivities 20, 80 and 200 Ω·cm have been tested on the edge TCT set-up but the sampled waveforms showed very low current pulses

The waveforms shown here are from the 20 Ω·cm sample biased at 170V and using a laser intensity much higher than usual, lowering the laser intensity the signal would disappear



Integrating the first pulse and drawing a charge collection map just some spots are obtained

Conclusions

- Edge TCT measurements on test structures of nominal resistivity ρ = 200 Ω·cm and ρ = 1000 Ω·cm completed
- The two 200 Ω·cm samples have different behaviors and returns two different values of measured resistivity
- Unexpected behavior observed in the 1k Ω·cm sample

Name	S1	S2	S3
Origin	UNIGE	IFAE	KIT
Nominal ρ [Ωcm]	200	200	1000
Measured ρ [Ωcm]	50	180	4280 / 1840

Outlook

- Measure samples of ρ = 20 Ω·cm
- Increase the statistic of tested devices
- Start an irradiation campaign

In the meantime at IFAE the readout of the stand alone matrices is being developed and the first pulses from a ^{90}Sr source have been detected

Thanks