Instituto de Física de Cantabria

Edge-TCT characterization of irradiated HV-CMOSv3 sensors

Christian Gallrapp, Michael Moll, Hannes Neugebauer, Constantin Weisser
CERN PH-DT-SSD

Marcos Fernández García
IFCA-CSIC-Universidad de Cantabria,
visiting scientist at CERN PH-DT-SSD

Daniel Muenstermann
University of Geneva

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Outline

Introduction and background information

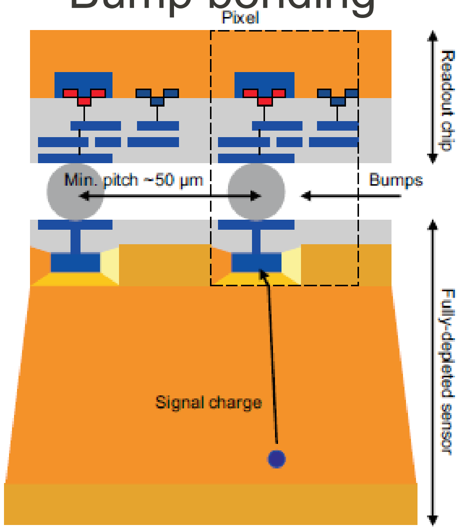
Edge-TCT measurements on HVCMOSv3

Radiation hardness up to 2×10^{16} n_{eq}/cm^2

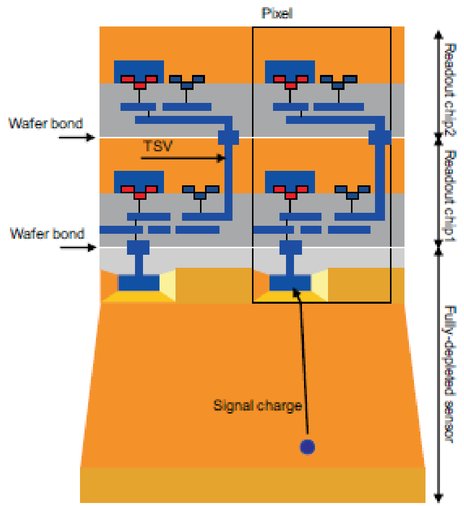
Introduction to HVCMOS

Hybrid pixels

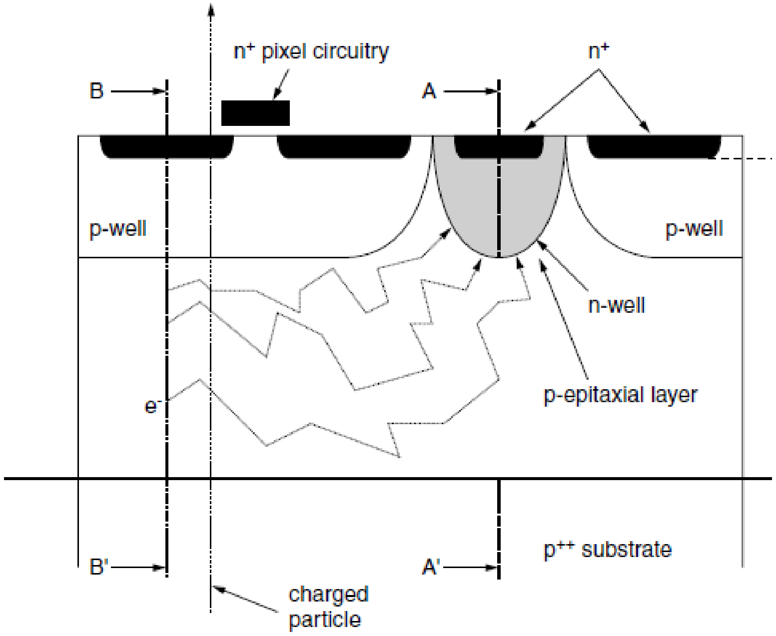
Bump bonding



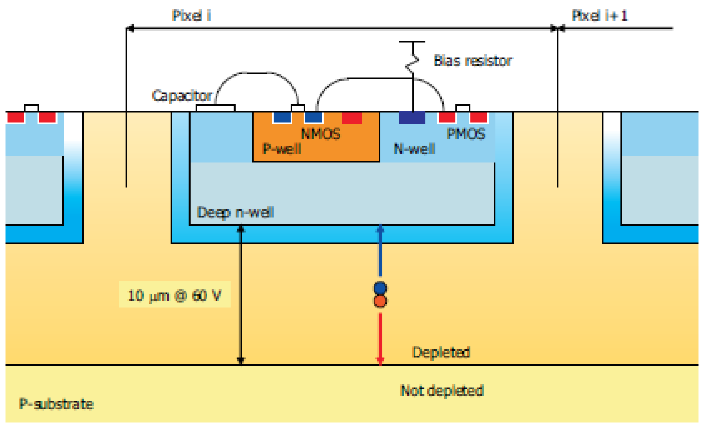
3D integration



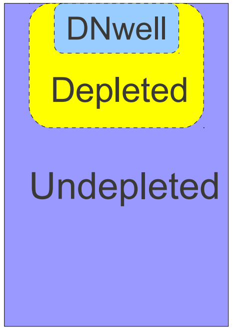
Monolithic CMOS



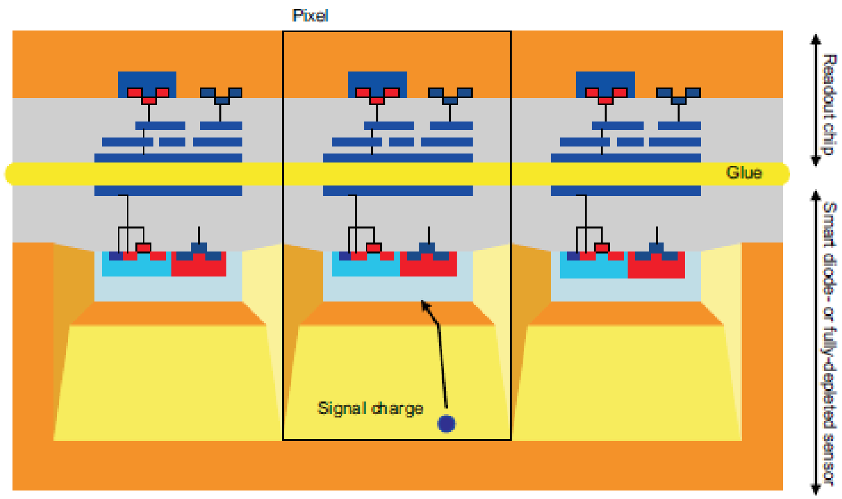
R.Turchetta, NIMA 458, 677-689 (2001)



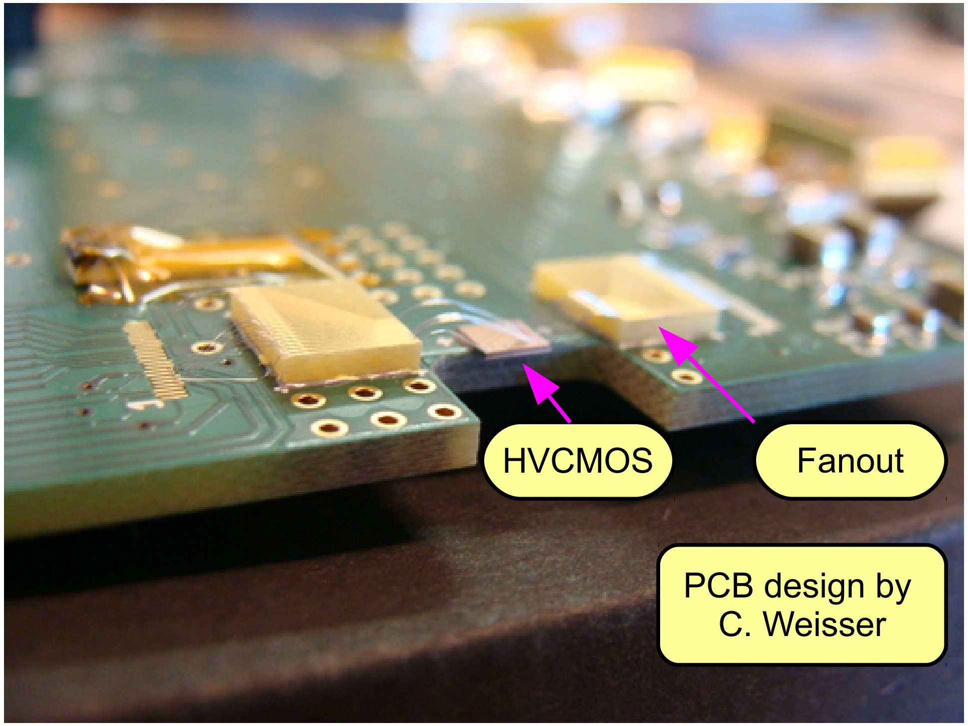
Unconfirmed guesses:
DNwell~1×10^{20} cm^{-3} ? , 5 µm depth (n-type)
Bulk 10 Ω.cm=1.4×10^{15} cm^{-3} (p-type)



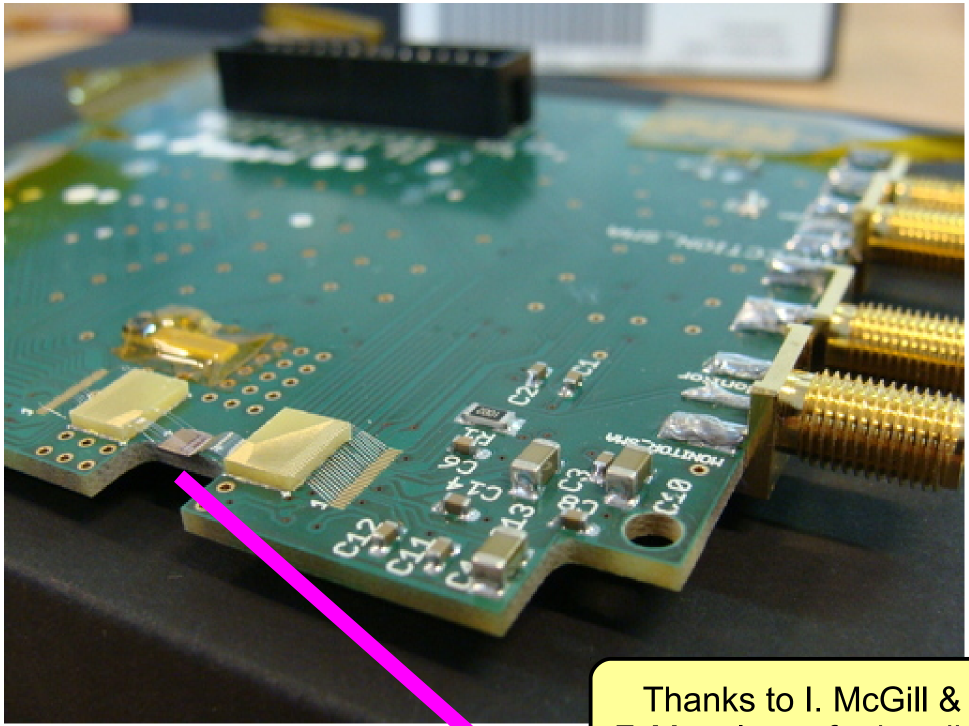
"PowerPoint HVCMOS"
(next slides)



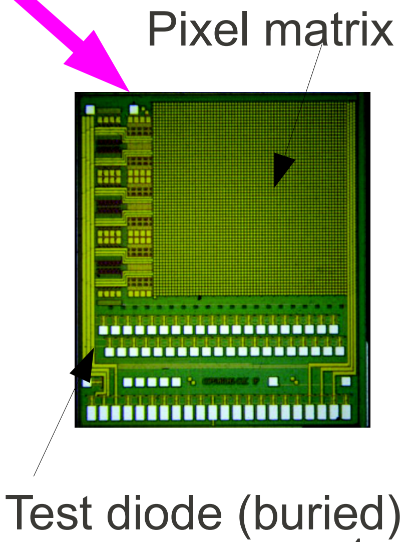
HVCMOS sketches from I. Peric

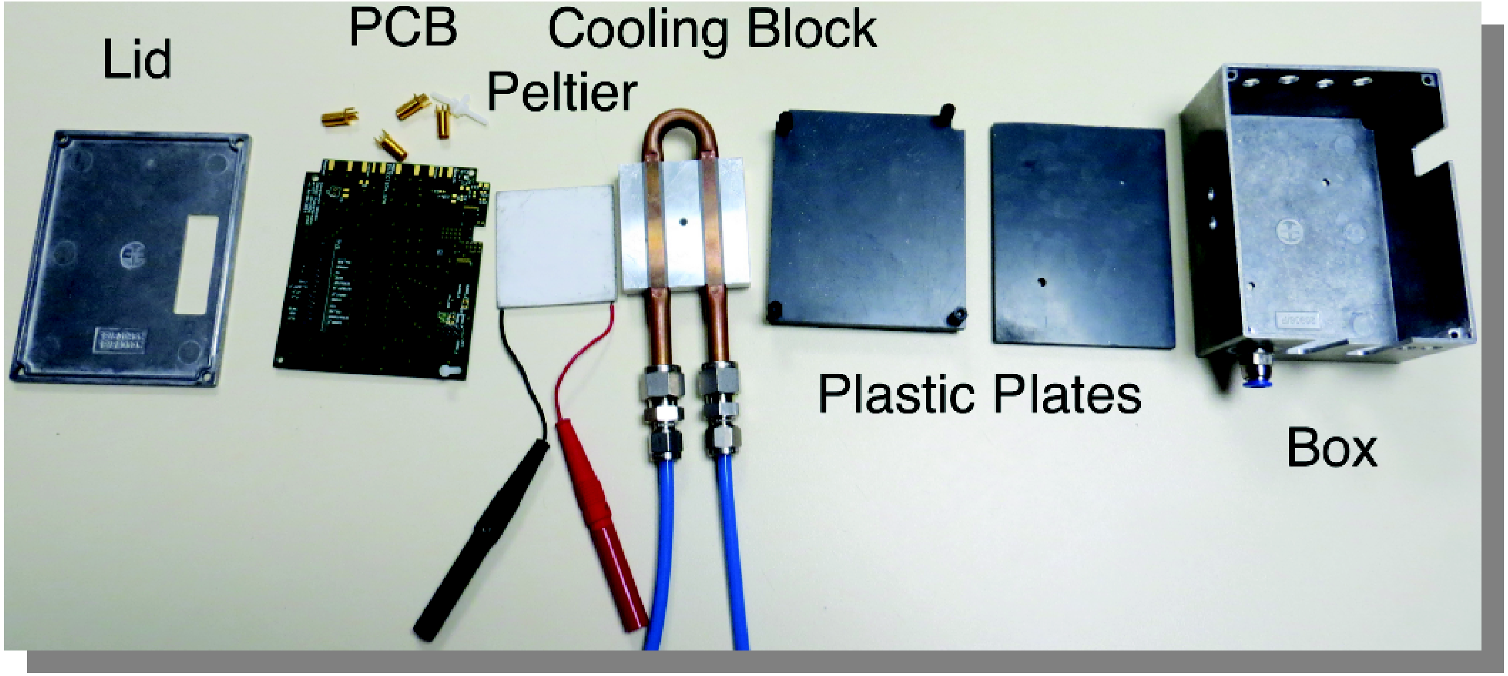


PCB design by C. Weisser

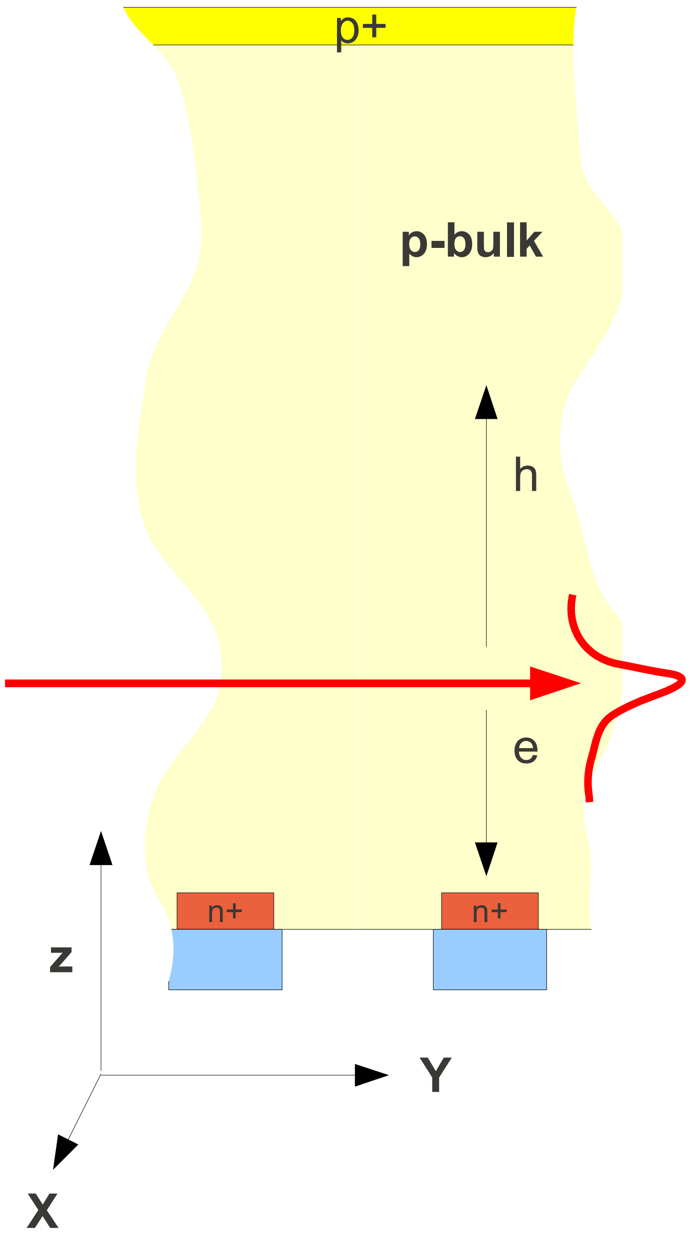


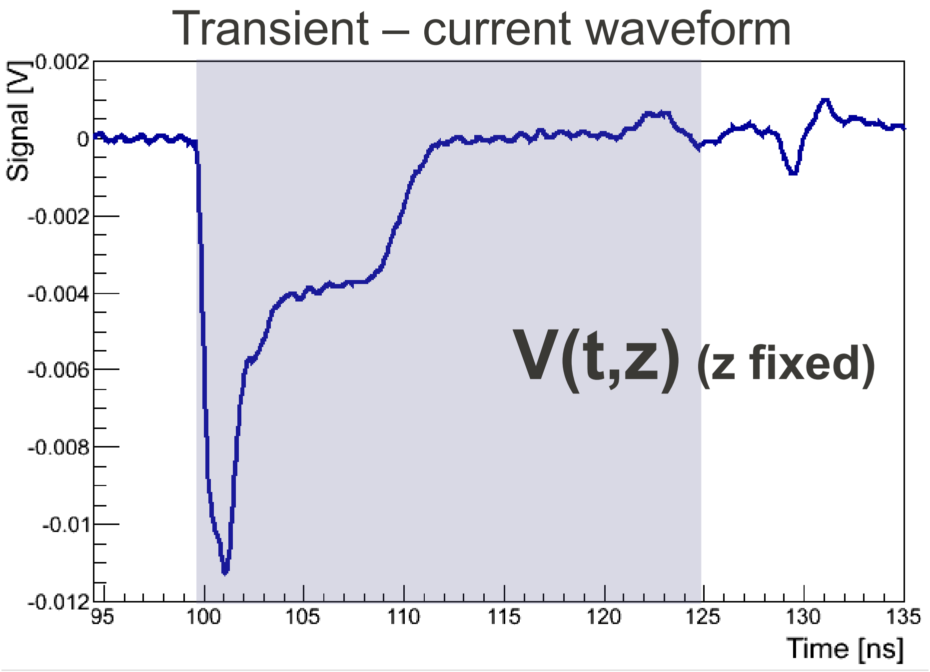
Thanks to I. McGill & F. Manolescu for bonding





Some eTCT jergon





Signal maps:
2D scan

I(t ; z) z variable

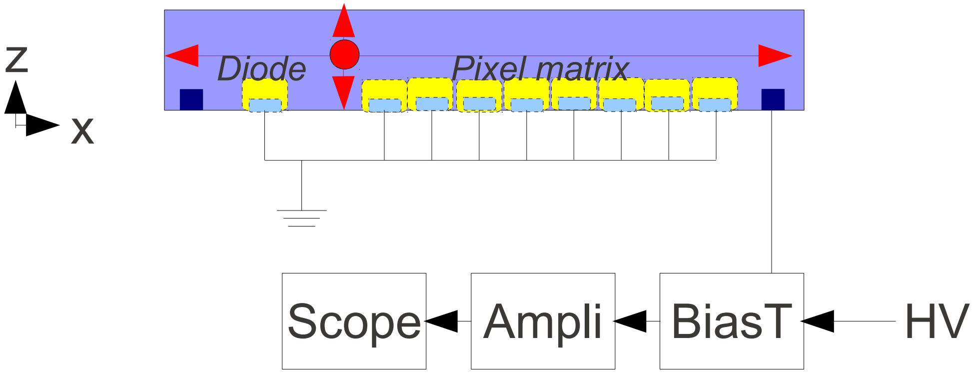
Charge profile
1D scan

$$Q(z) = \int_{0}^{25\,ns} I(t,z)\,dt$$

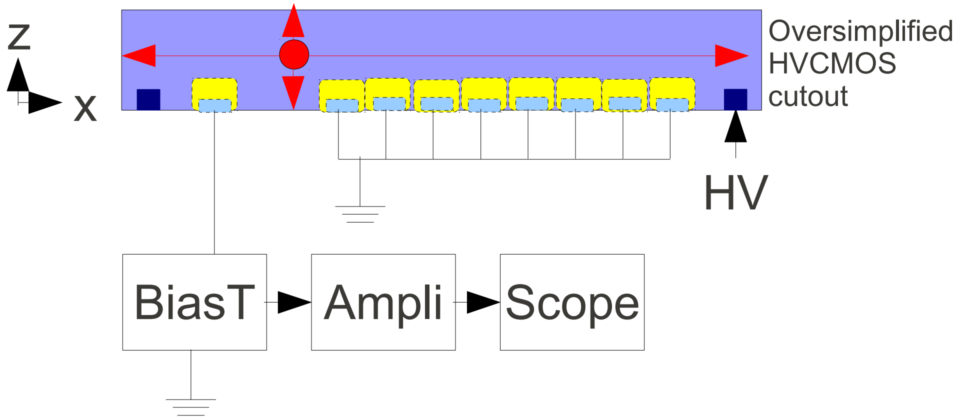
Charge maps:
2D scan

$$Q(x,z) = \int_{0}^{25\,ns} I(t;x,z)\,dt$$

HVCMOSv3: 2 biasing configurations

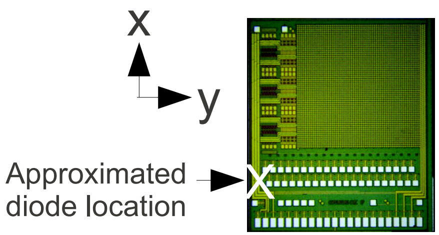


Full chip readout, *a.k.a.* "**configuration 1**"



Diode readout, *a.k.a.* "**configuration 2**"

Good to "find" the detector [~2 mm wide]



Coments:

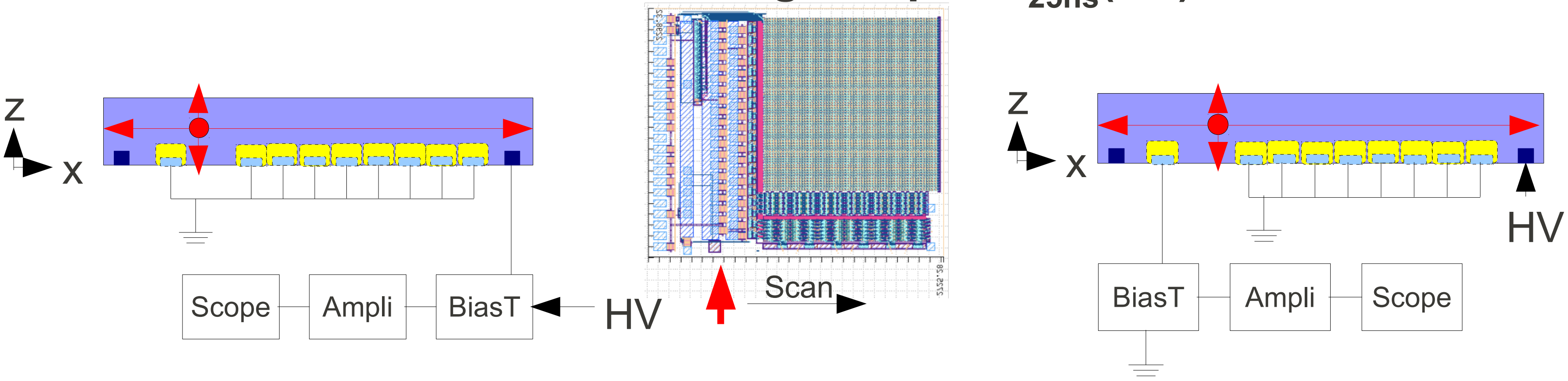
1) **PCB** gives **mechanical support** and allows, if needed, to **access the pixel matrix**. This feature was not used in these measurements.

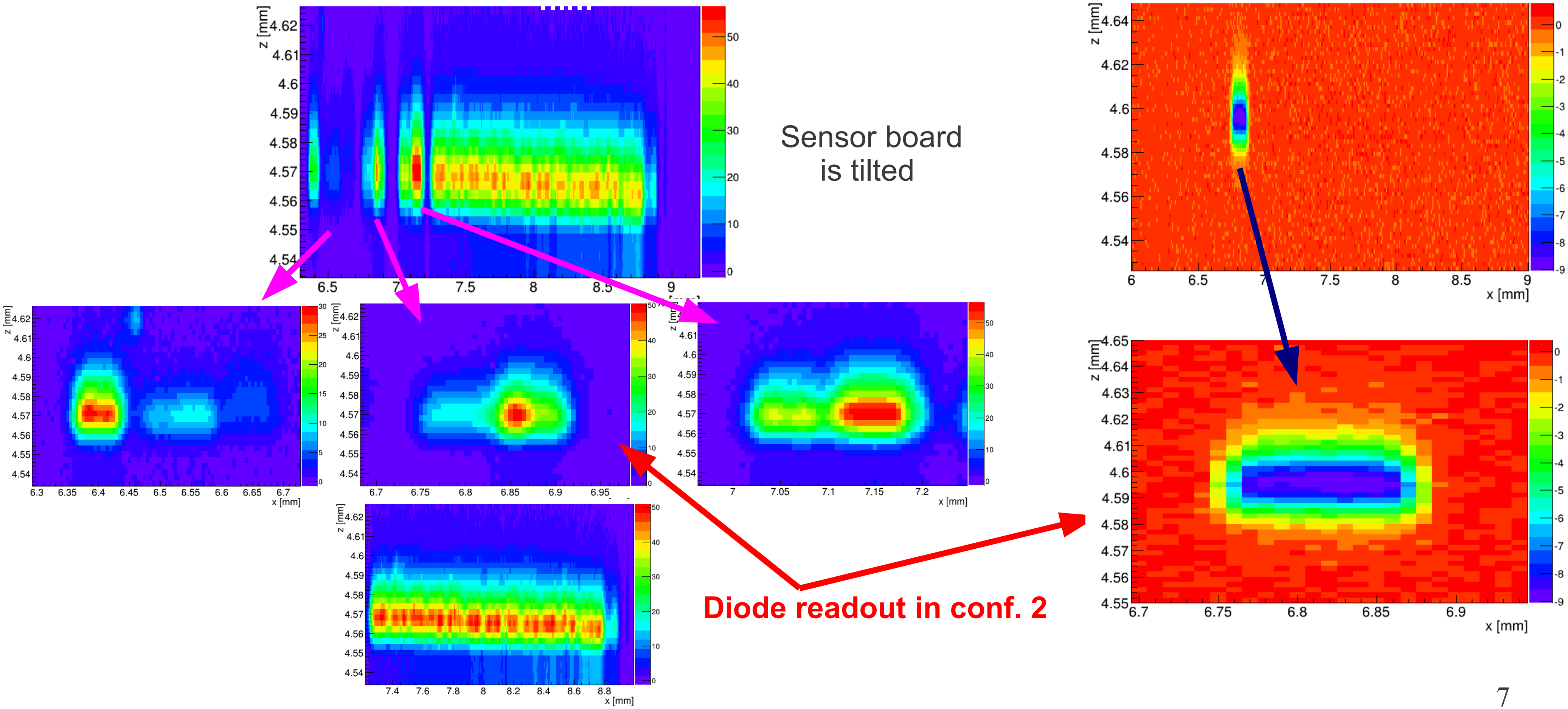
2) In both configurations, we use the detector as a "monolithic **passive** pixel", (we do not use the active part (preamp) at all). Analog waveform is picked at the PCB, amplified and displayed in the scope.

3) In edge-TCT **illumination** is produced **uniformly** along the light path (over several mm). Carriers produced before/after the measured "feature" can still be picked via **capacitive coupling**. In low res., they **will appear as diffusion**.

4) Measurements shown in this talk were taken at the same laser power (± 0.5 μW)

Unirradiated HVCMOS – Charge maps: $Q_{25ns}(x,z)$





Sensor board
is tilted

Diode readout in conf. 2

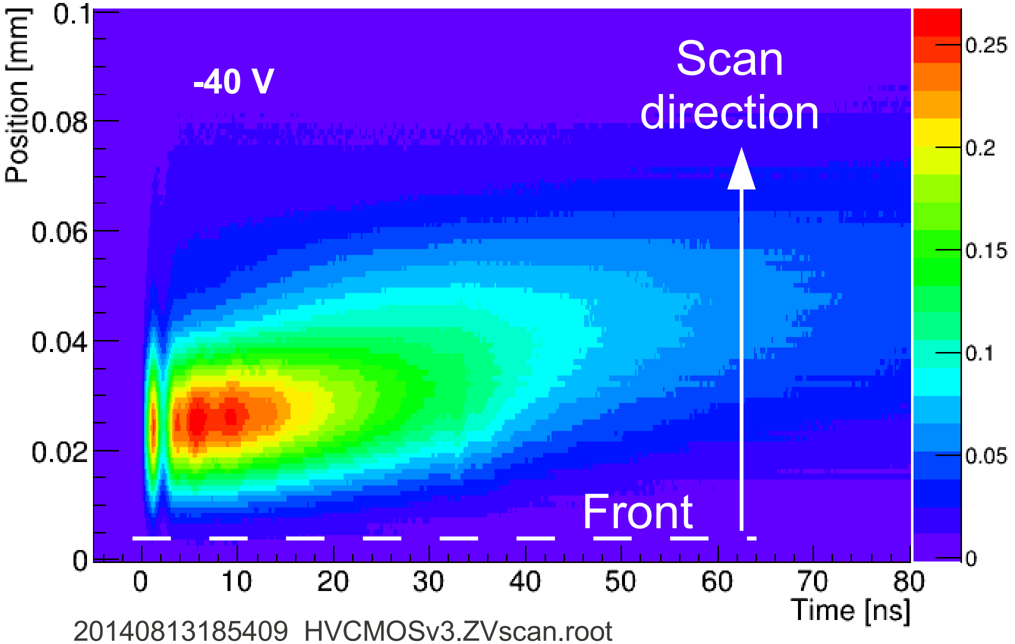
(Δx=10,Δz=5) µm resolution

Signal maps for non-irradiated and 2×10^{16}

Effect of trapping on diffusion

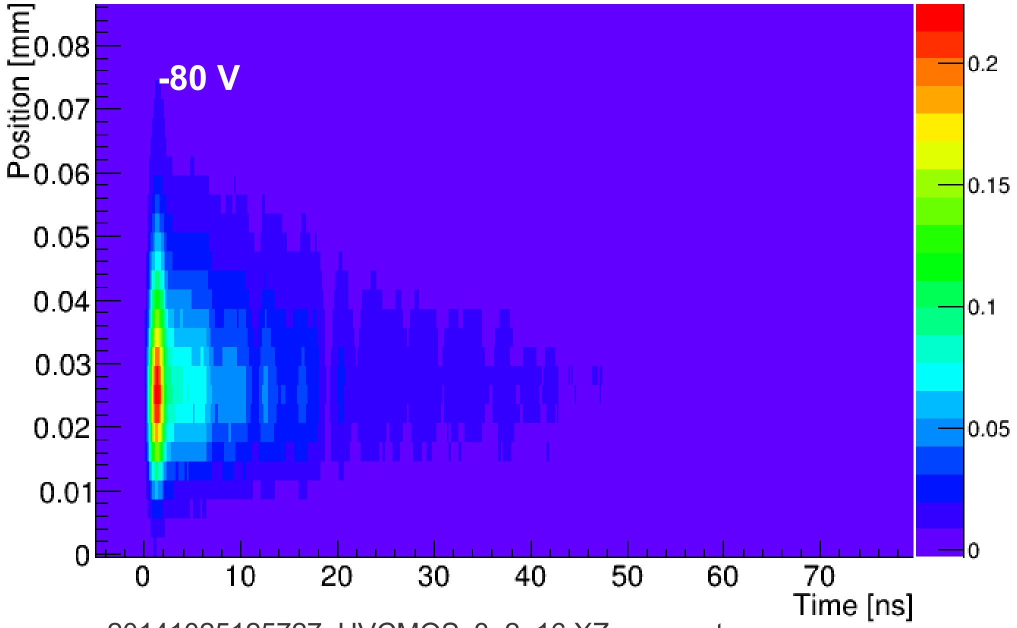
- Comparison of **full chip readout** (conf 1) non-irradiated and 2×10^{16}
- Showing **signal maps**: **V(waveform time,laser position) [V≡scope signal]**

Unirradiated



20140813185409_HVCMOSv3.ZVscan.root

2e16



20141025125727_HVCMOSv3_2e16.XZscan.root

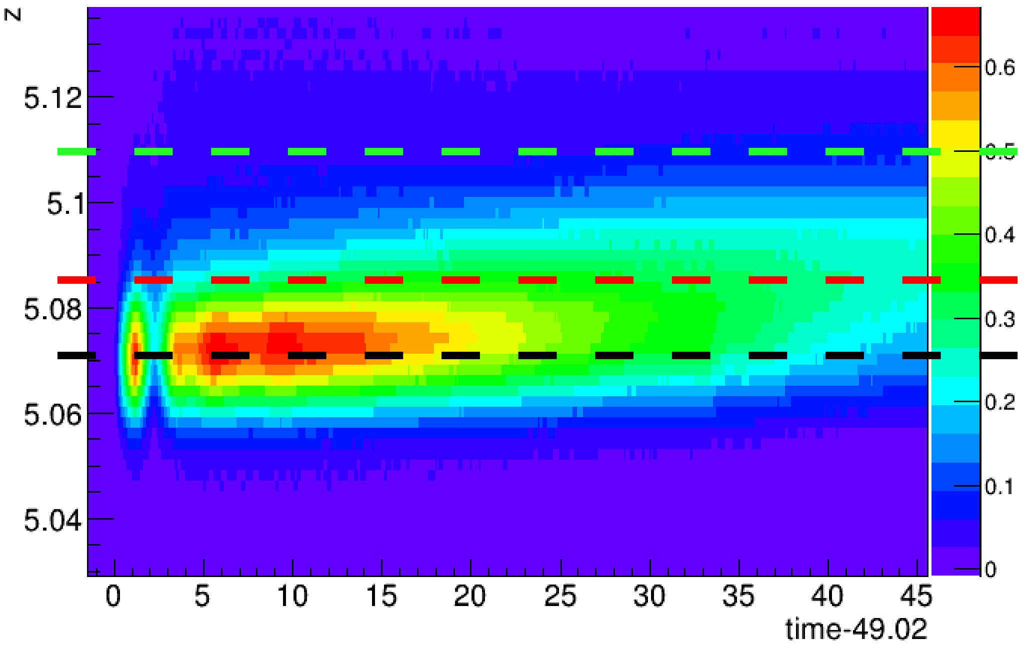
- Drift (time<2 ns spot) and diffusion (time>2 ns) clearly seen.

- Drift and diffusion amplitude decrease as beam moves away from the surface. After ~50 μm drift disappears while diffusion still survives, though amplitude reduces and shifts to longer times.

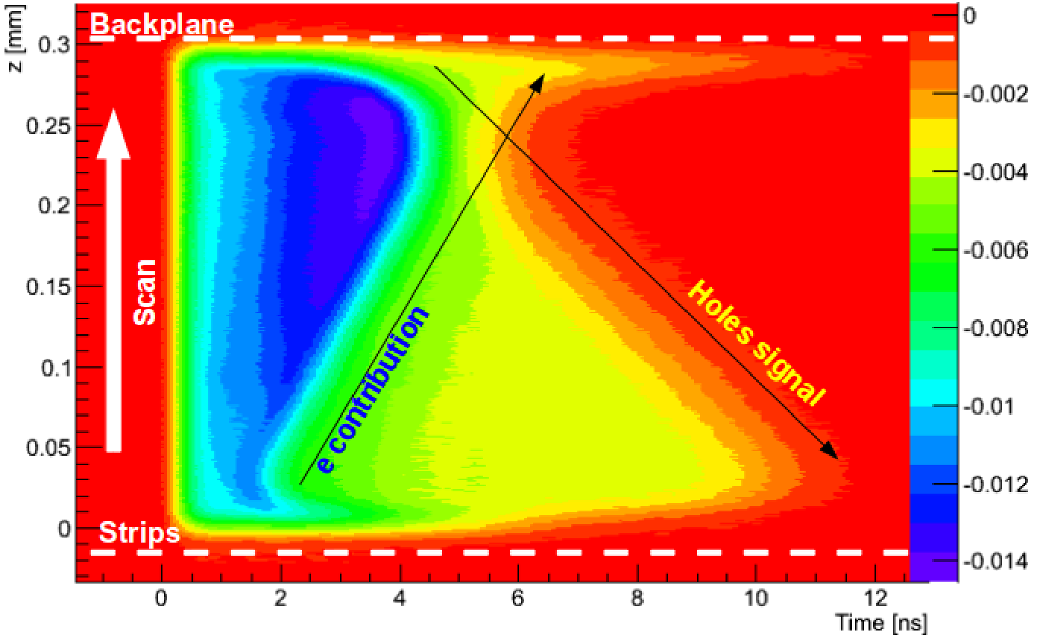
- Diffusion contribution is much smaller. Fast contribution still present.

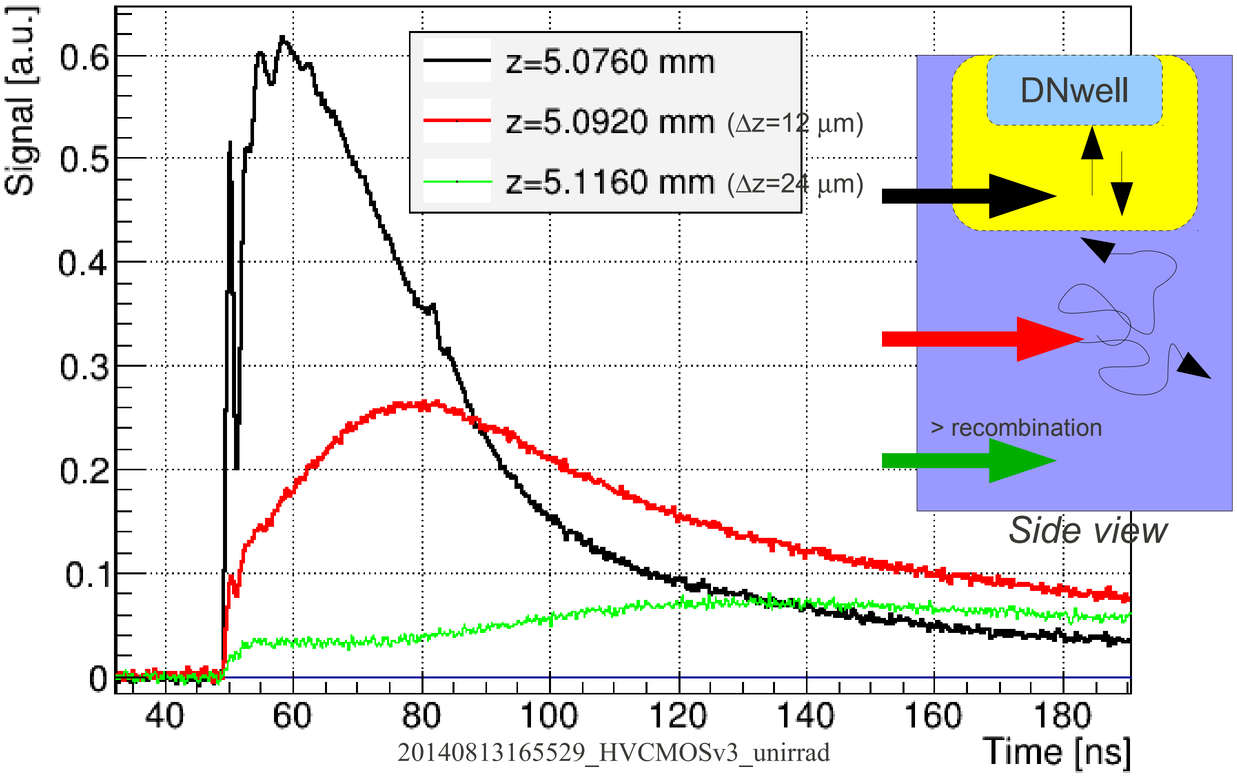
Full chip readout: signal maps

HVCMOSv3



Microstrip detector [for comparison] (Micron)





- Fast peak will be assimilated to drift, slower to diffusion.

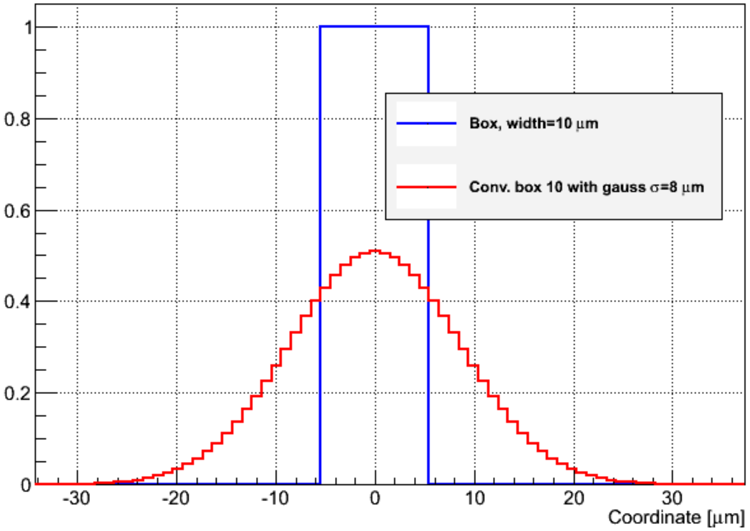
- Diffusion maximum decreases in amplitude and shifts towards longer times as injection moves away from depleted region. Laser tails overlapping the depleted region may still produce direct drift.

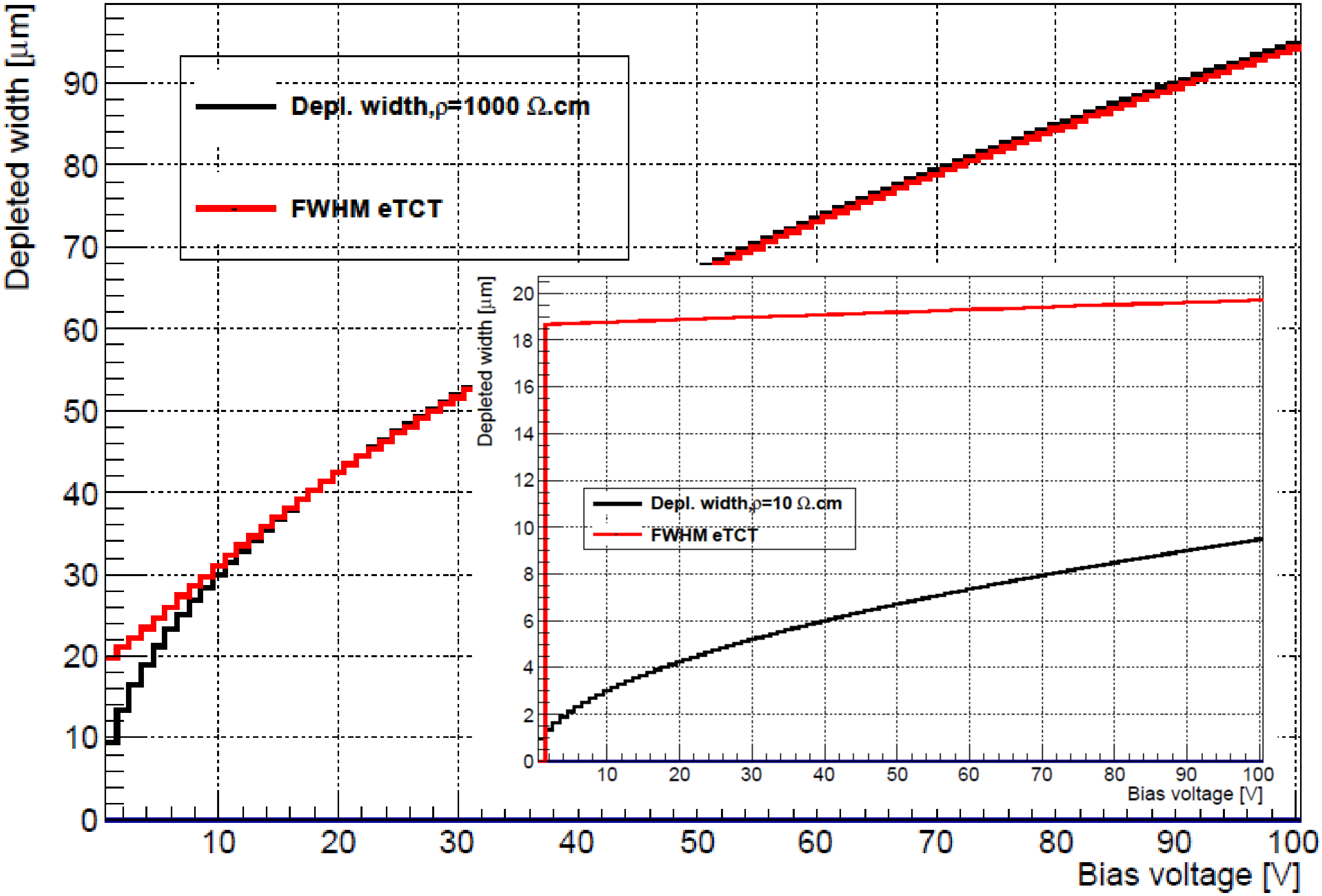
- Drift peak inside the depleted bulk does not move

Limiting spatial resolution in edge-TCT

Spatial resolution in edge-TCT is limited by laser beam gaussian width~ 8 μm.

Assume a real depleted region 10 μm wide. **Measured depleted region** is the result of the convolution of the beam with the real **depleted "box"**.



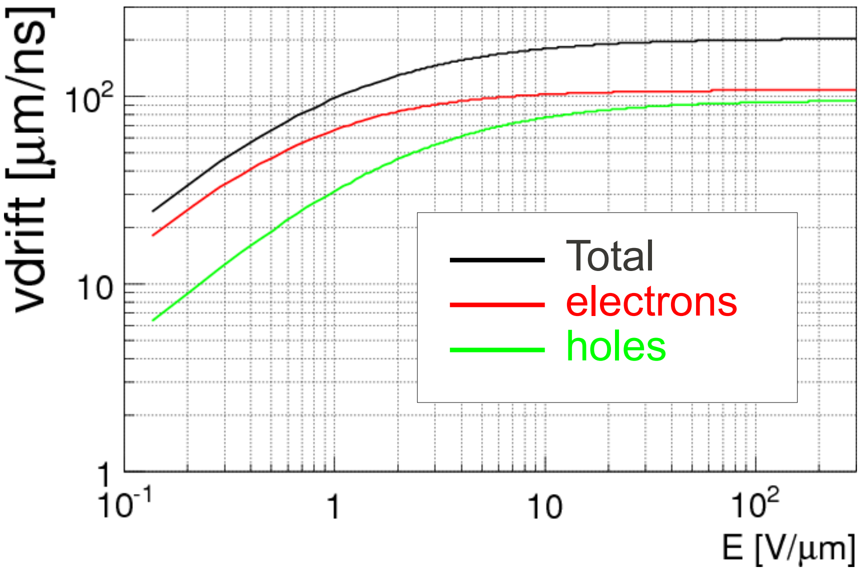


At 90V, for ρ=10 Ω.cm, a depletion region of ~10 μm (see inset) is expected. The apparent width measured will be FWHM~20 μm (4σ=35 μm).

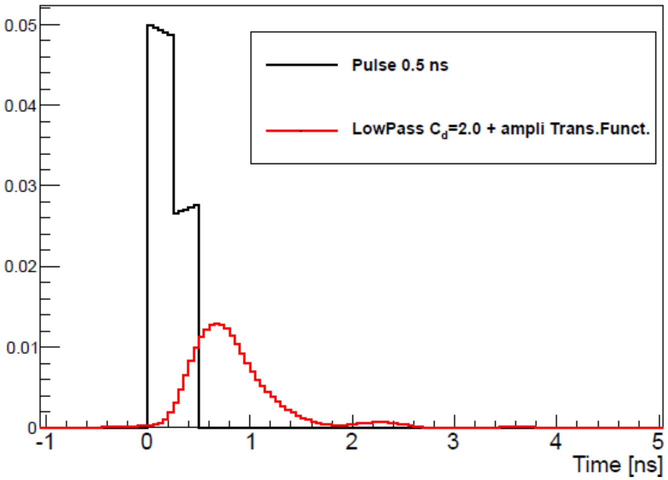
Real depleted width and edge-TCT measured (σ=8 μm) coincide for real thickness>10 μm.

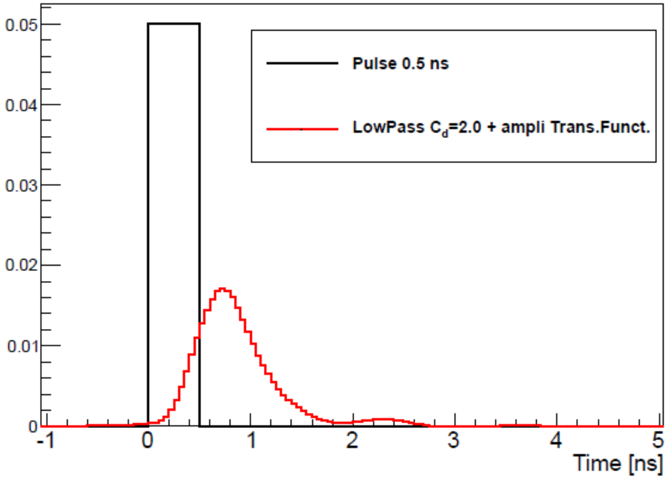
Drift velocity saturation in HVCMOS

90V bias over 10 µm → drift velocity saturation. Depleted region is crossed in (much) less than 1 ns, even at 10 V. Assumed, in this talk, that drift velocity in low resistivity silicon same as in high res.

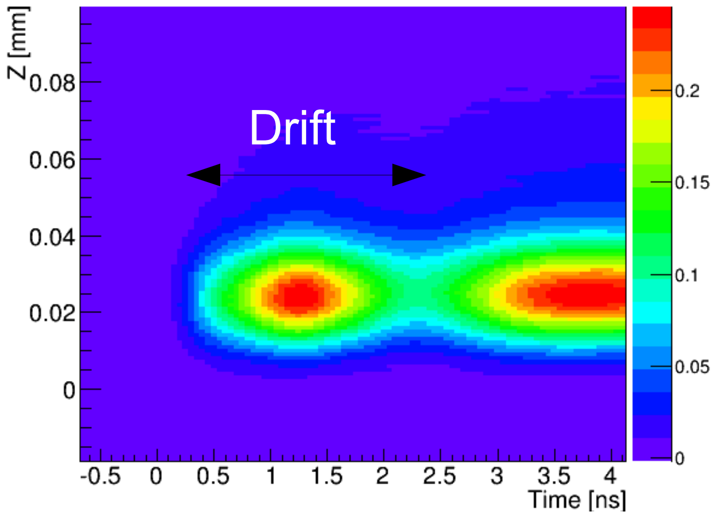


Calculated time response of Low Pass filtered (2pF) and amplified to various assumed HVCMOS-like signal. Output signal does not resolve electron/holes drift features (as we are used to see in thick sensors)

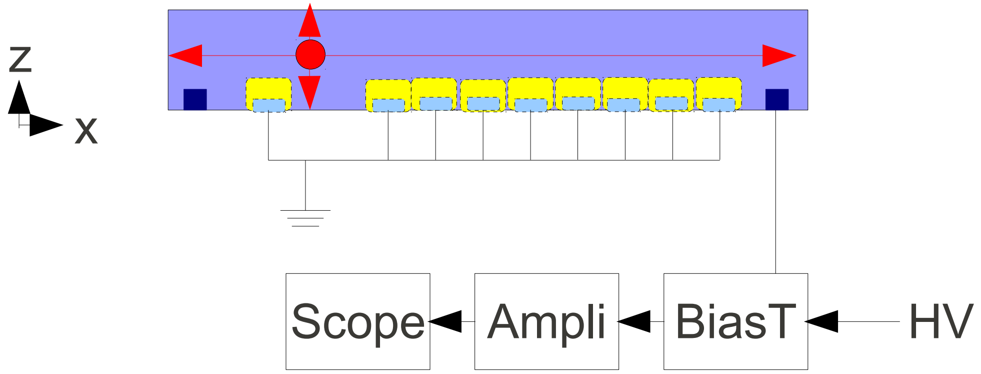




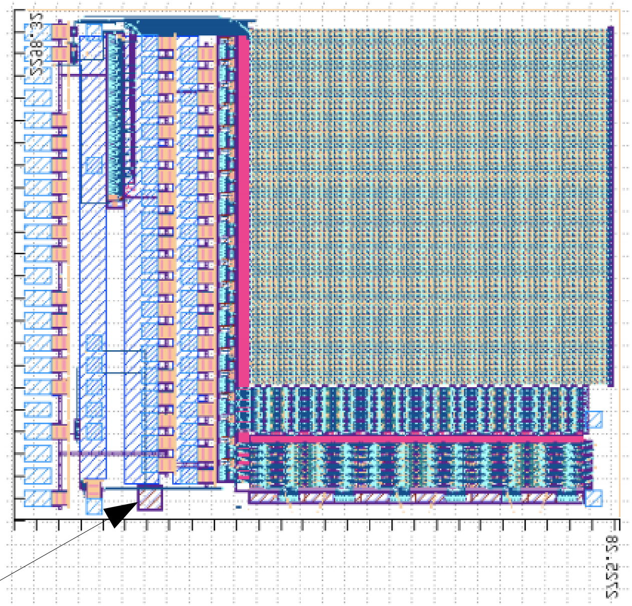
Zoom on “fast” signal



Full detector readout (configuration 1)

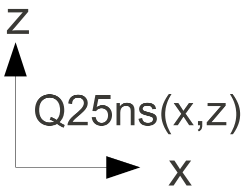


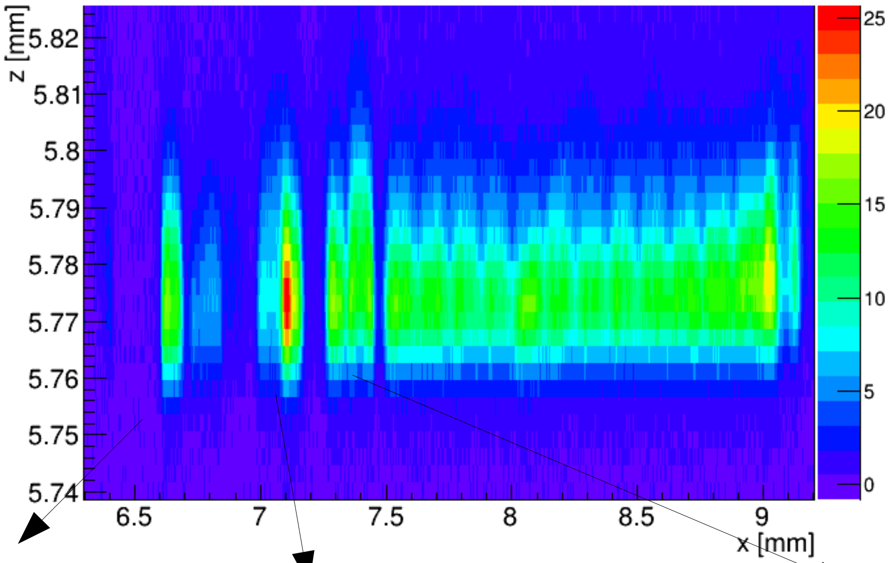
Scope ◄ Ampli ◄ BiasT ◄ HV

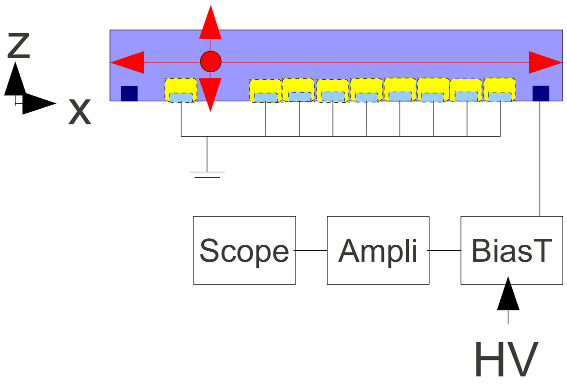


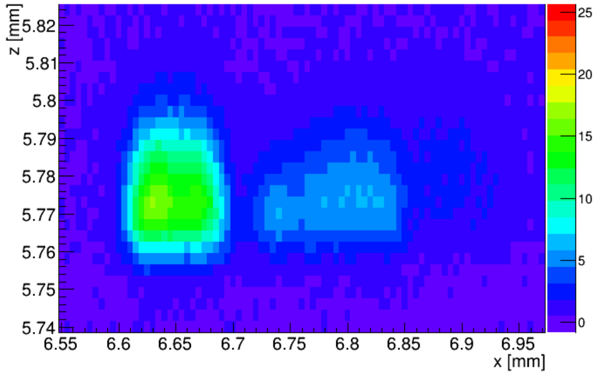
Diode

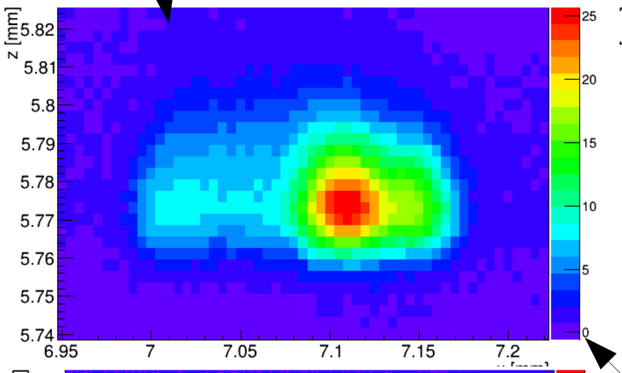
2e16 HVCMOS, full chip readout scan $Q_{25ns} = Q(x,z)$

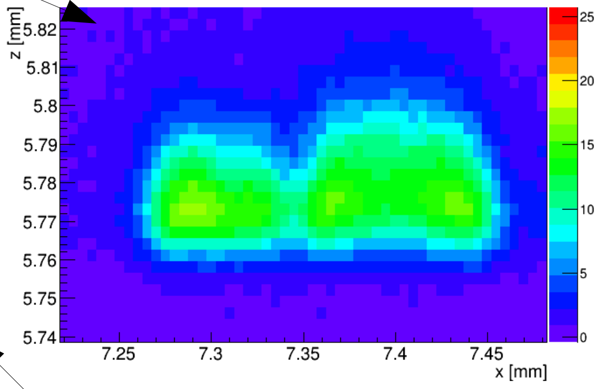


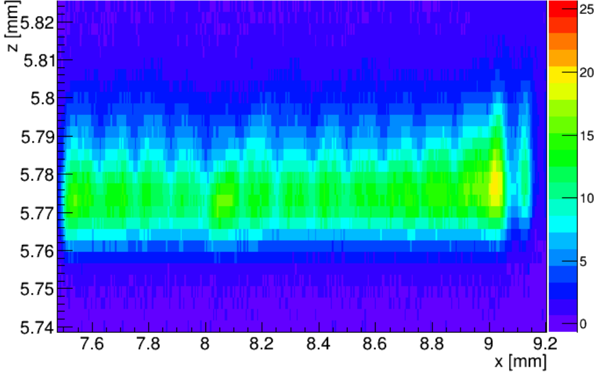








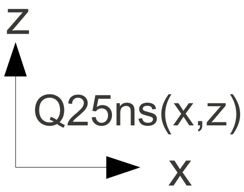


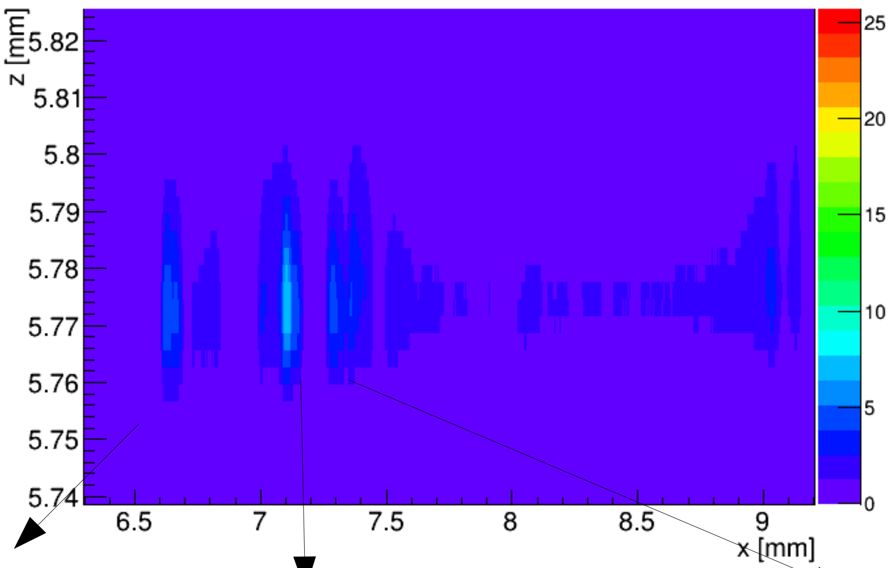


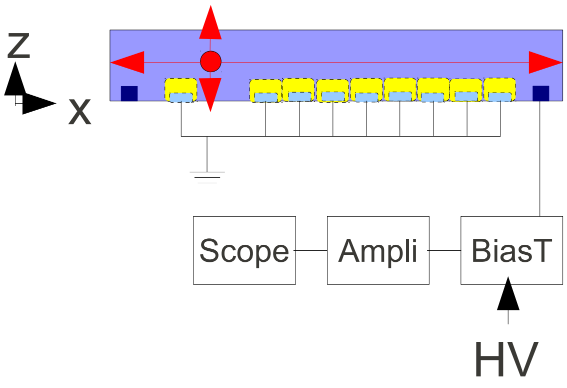
Diode looks asymmetric in conf 1

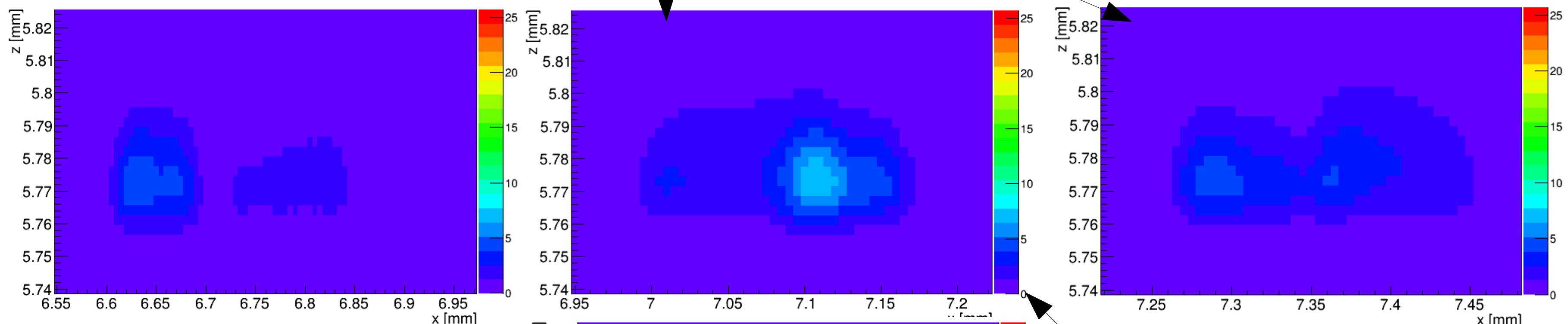
(Δx=10,Δz=5) μm resolution

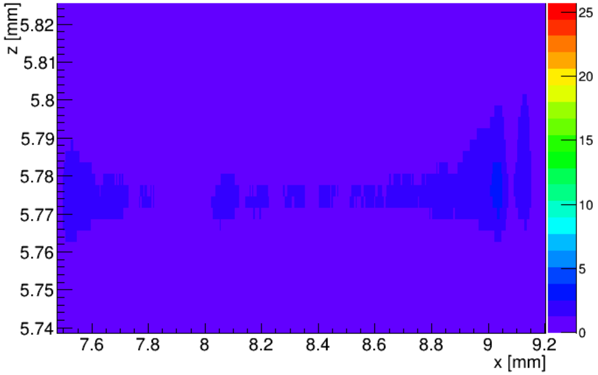
2e16 HVCMOS, full chip readout scan, only drift, Q(t<2.5 ns)









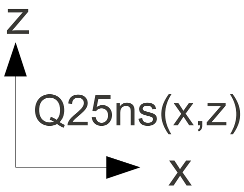


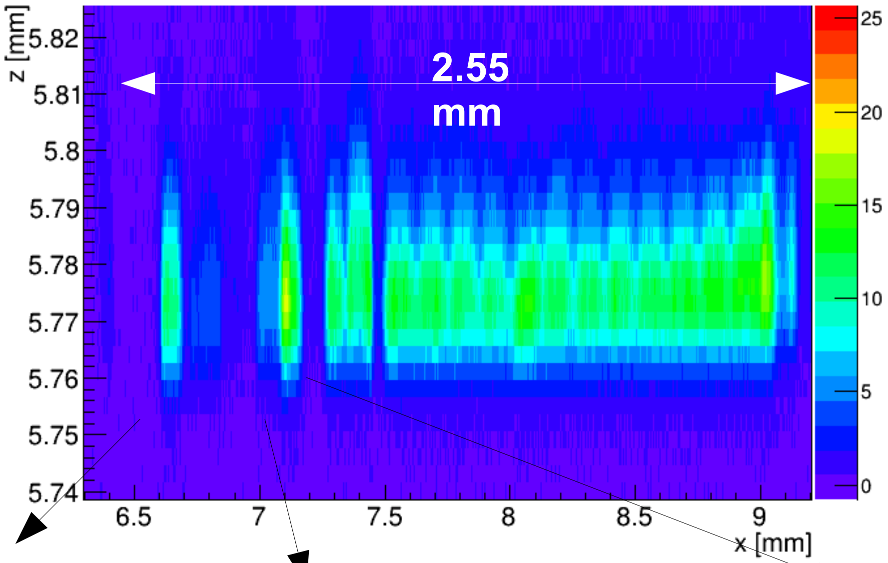
Diode looks asymmetric in conf 1

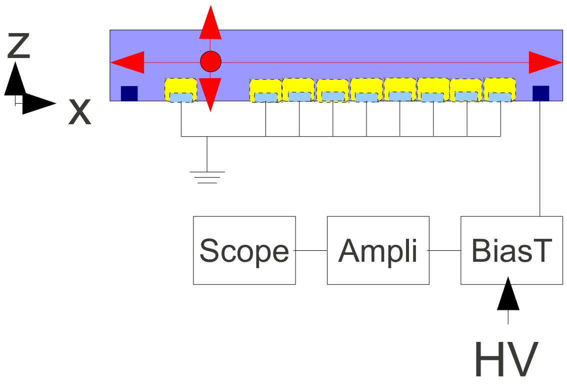
Full chip readout (=conf. 1)

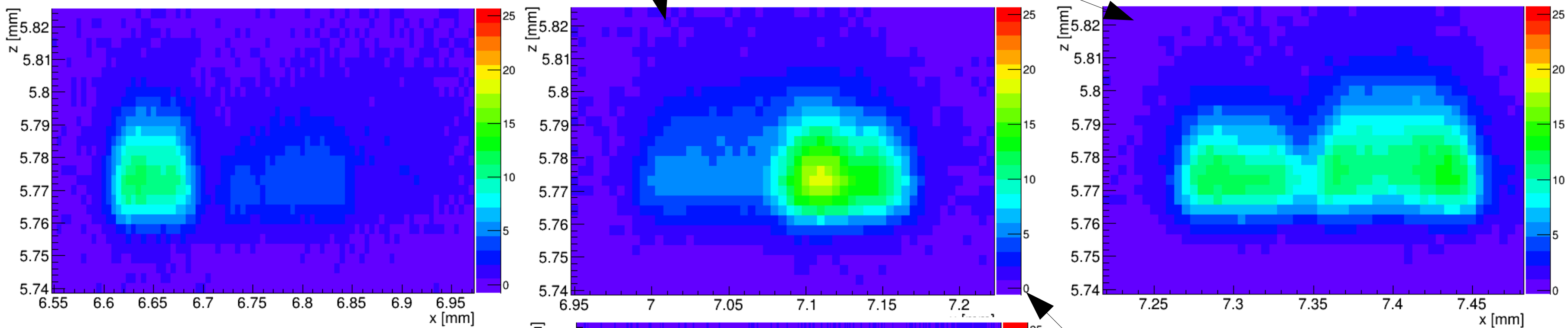
(Δx=10,Δz=5) μm resolution

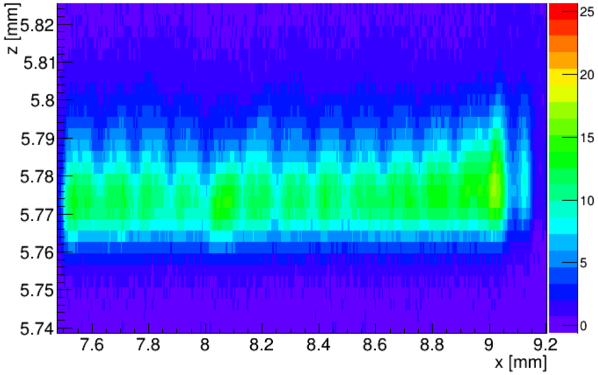
2e16 HVCMOS, full chip readout scan, only diffusion, Q(t in [2.5,25] ns)











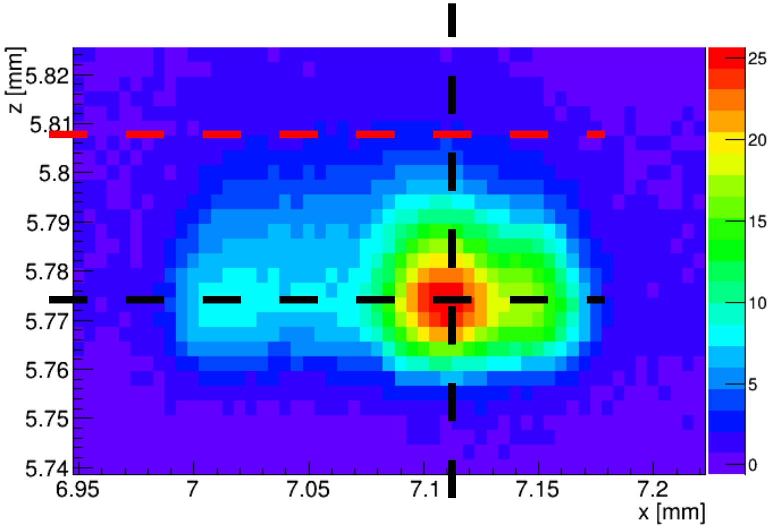
Full chip readout (=conf. 1)

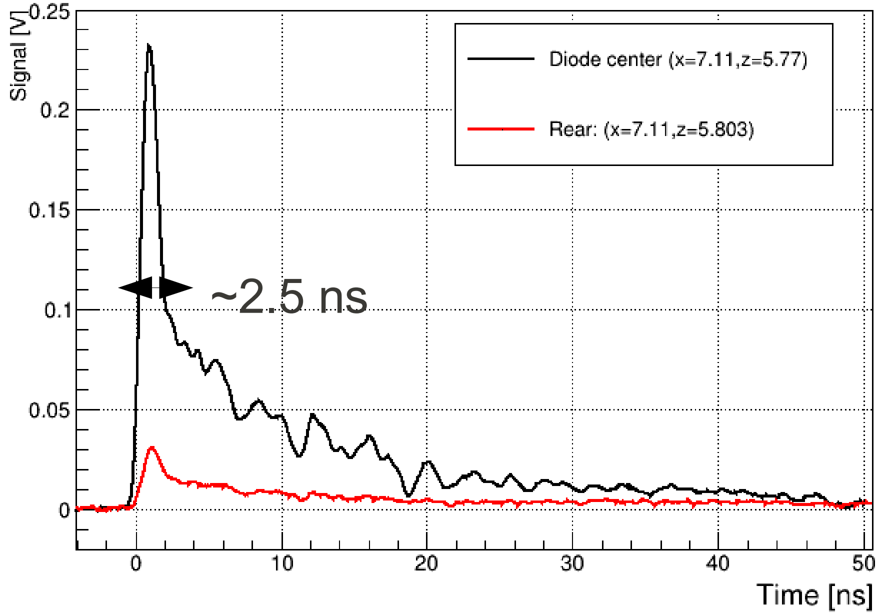
Diode looks asymmetric in conf 1

Conf 1, higher contribution by diffusion

(Δx=10,Δz=5) μm resolution

2e16 HVCMOS, zoom on diode in full detector readout



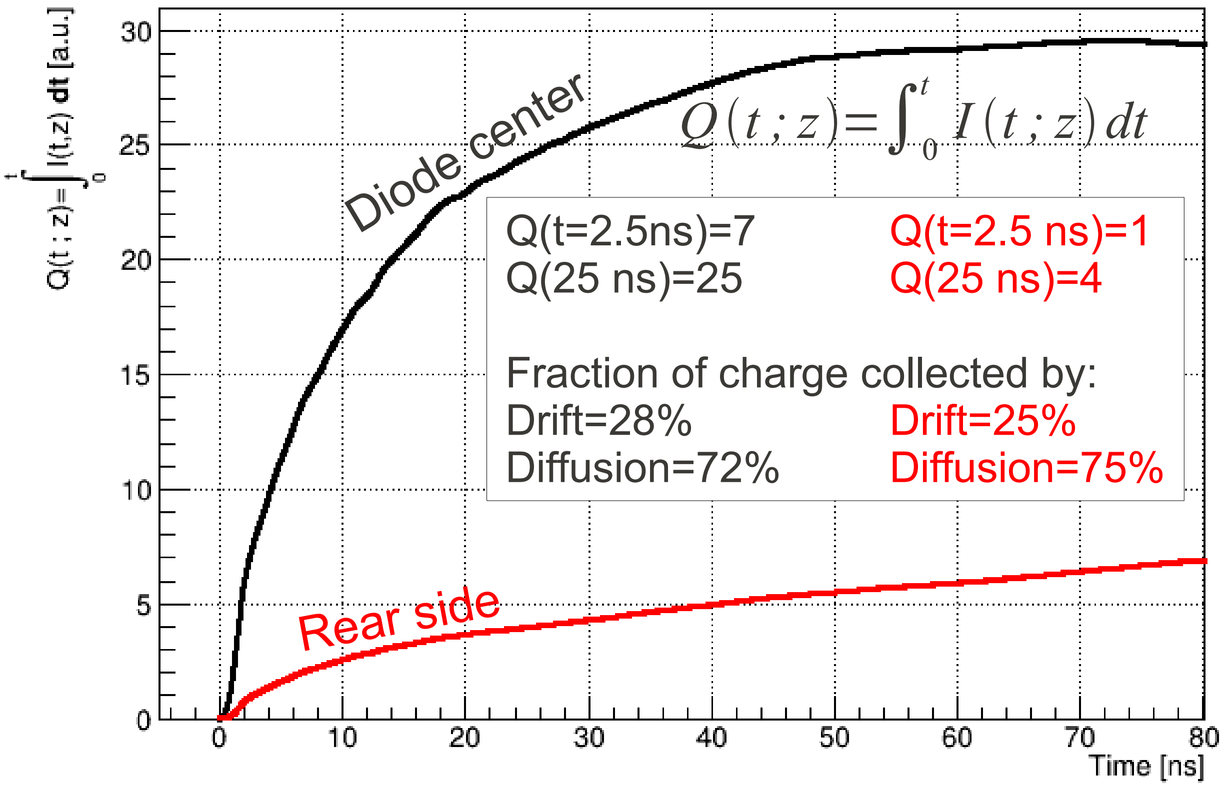


Distinctive long pulses due to diffusion have been washed out.

Very fast peak ~2.5 ns wide associated to drift (as in the case of the unirradiated detector).

But diffusion still present even after 2×10^{16}.

At 2e16, diffusion accounts for 75% of the collected signal (in 25 ns). It was 94% in the unirradiated detector.



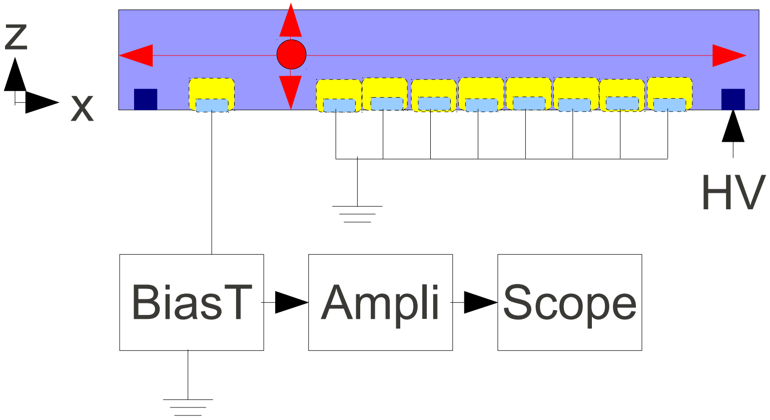
$$Q(t;z)=\int_0^t I(t;z)\,dt$$

Q(t=2.5ns)=7	Q(t=2.5 ns)=1
Q(25 ns)=25	Q(25 ns)=4

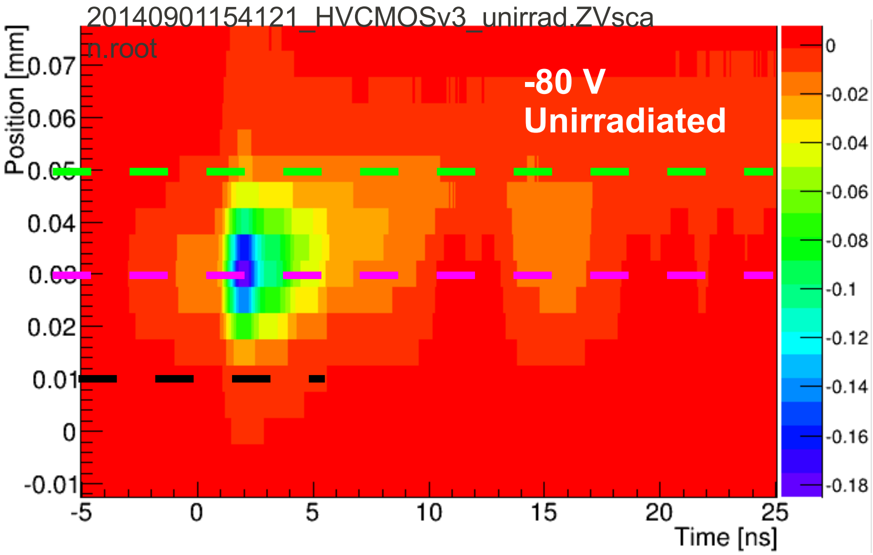
Fraction of charge collected by:

Drift=28%	Drift=25%
Diffusion=72%	Diffusion=75%

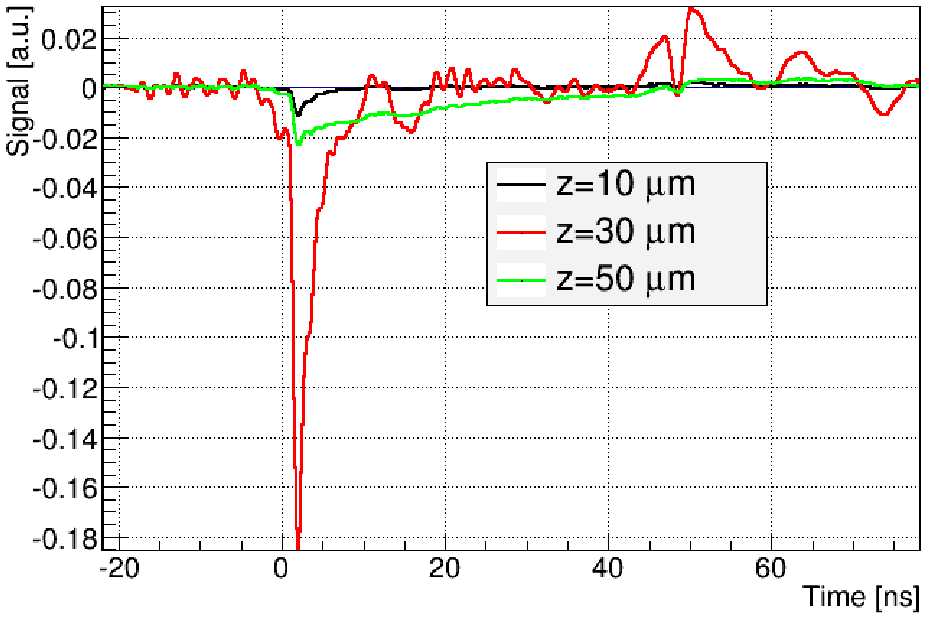
Diode only readout (configuration 2)

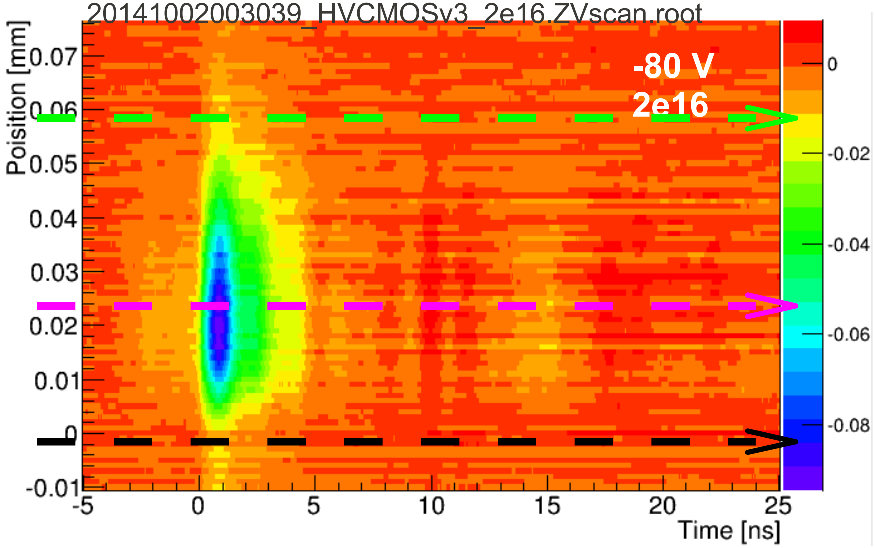


Diode readout (conf. 2) signal maps: V(z,t)

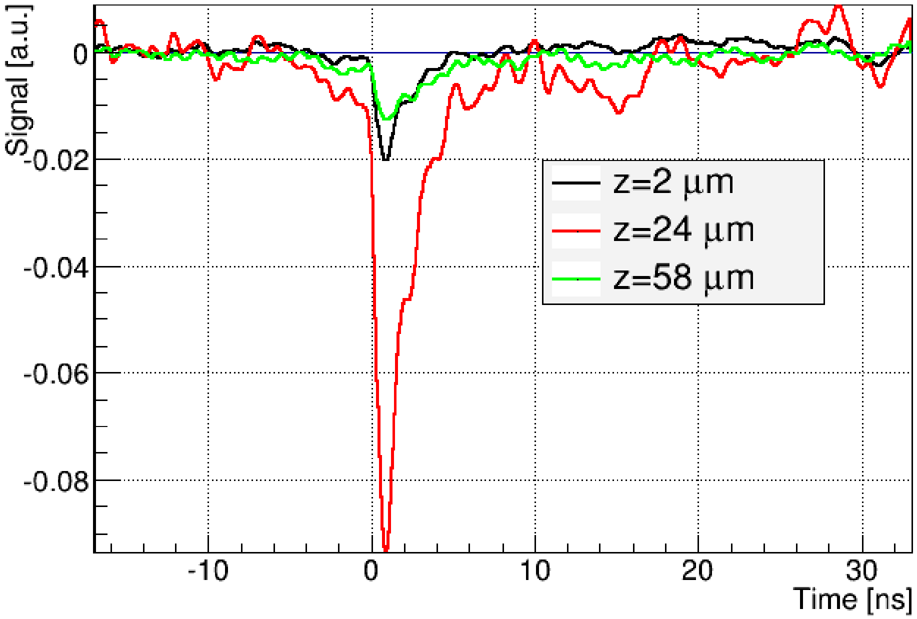


Difficult to **assign** drift and diffusion tags. Some diffusion still visible (see **z=50 µm**), but mainly fast signal (from drift). Fast peak is wider. **Arbitrarily taking 5 ns now as drift peak width,**

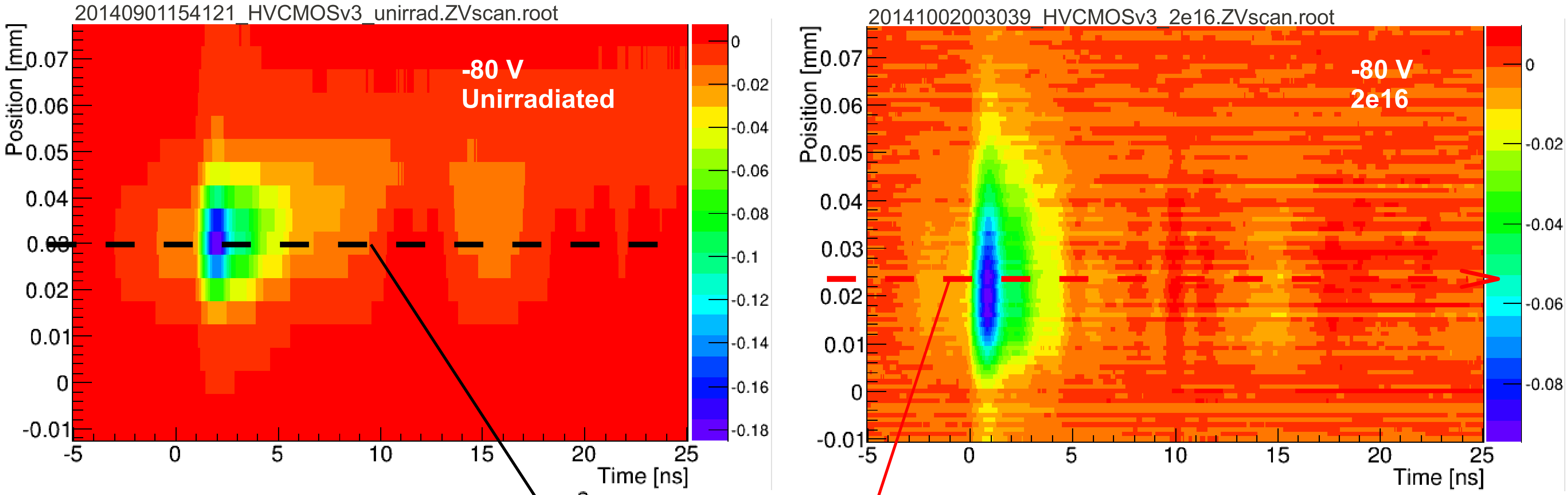




Efficient region for charge creation at 2e16 seems **wider**.

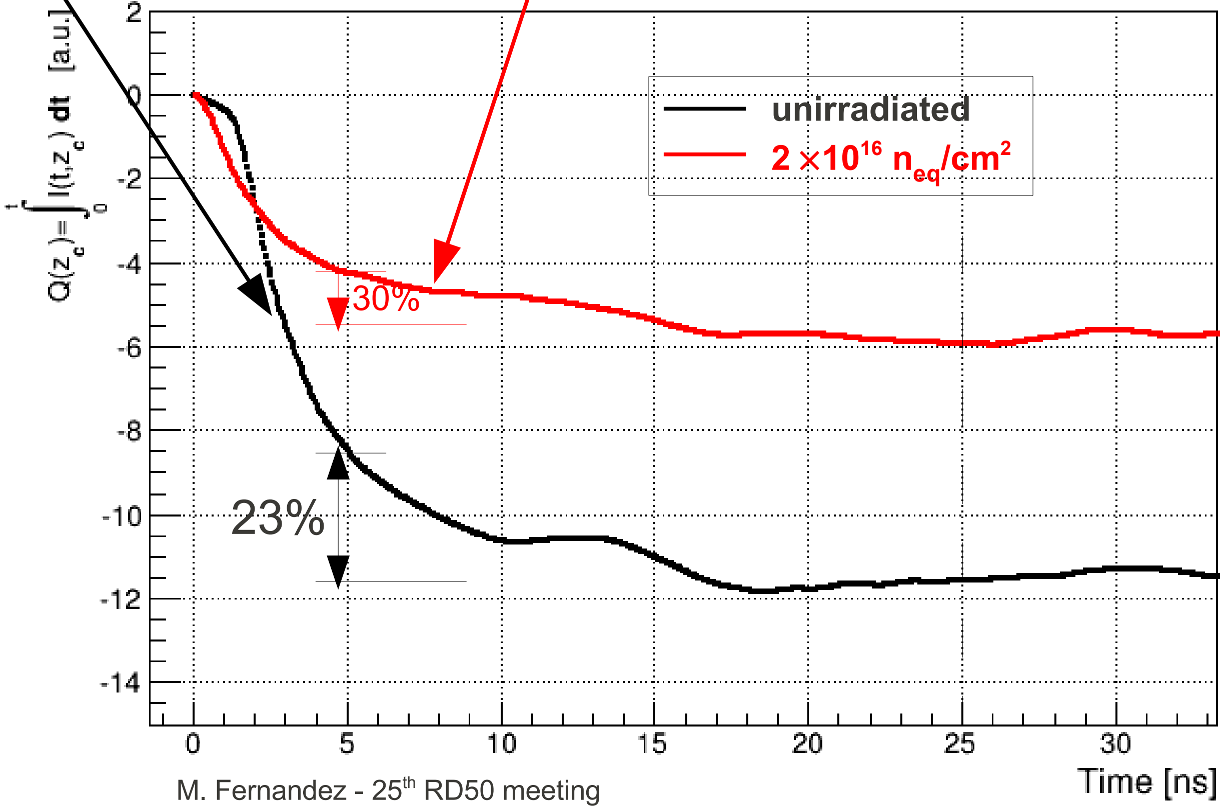


Diode readout (conf. 2), integrated charge



Shown to the right the charge as a function of integration time, at the center of the depleted region (z_c):

$$Q(t)=\int_0^t I(t)\,dt$$

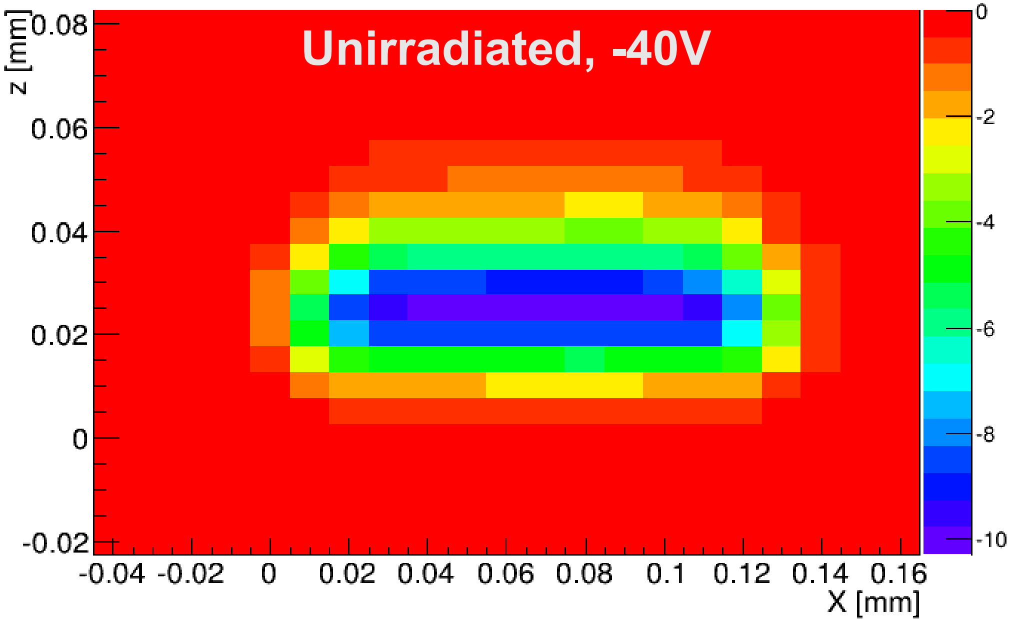


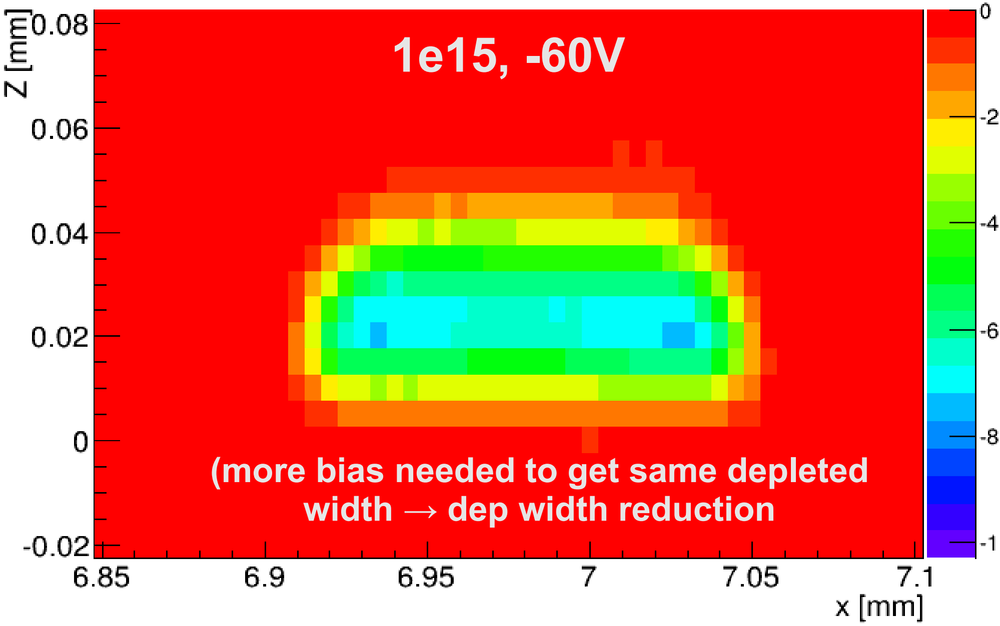
At t=5 ns, the **2×10^{16}** detector collects half the charge of the unirradiated (drift)

.

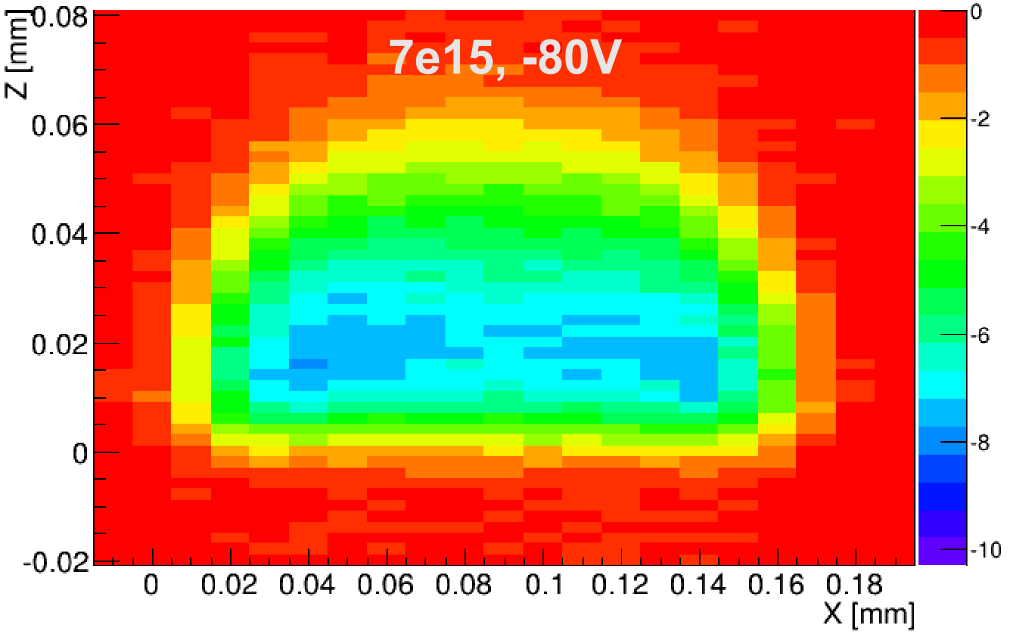
Diffusion (t>5ns) contributes:
30 % for **2×10^{16}**
23% for unirradiated

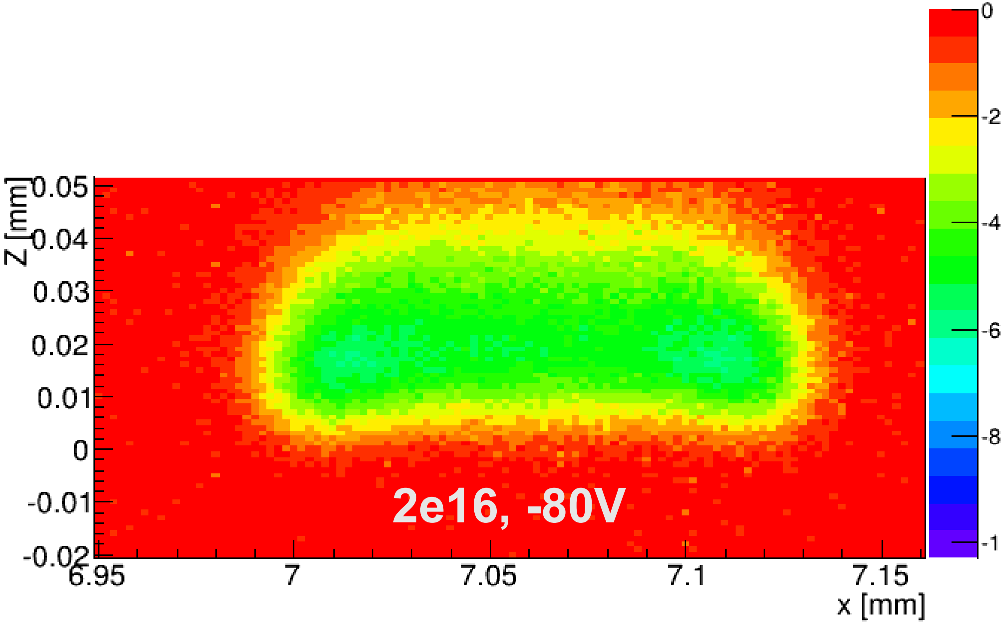
Diode readout, charge maps (various voltages)



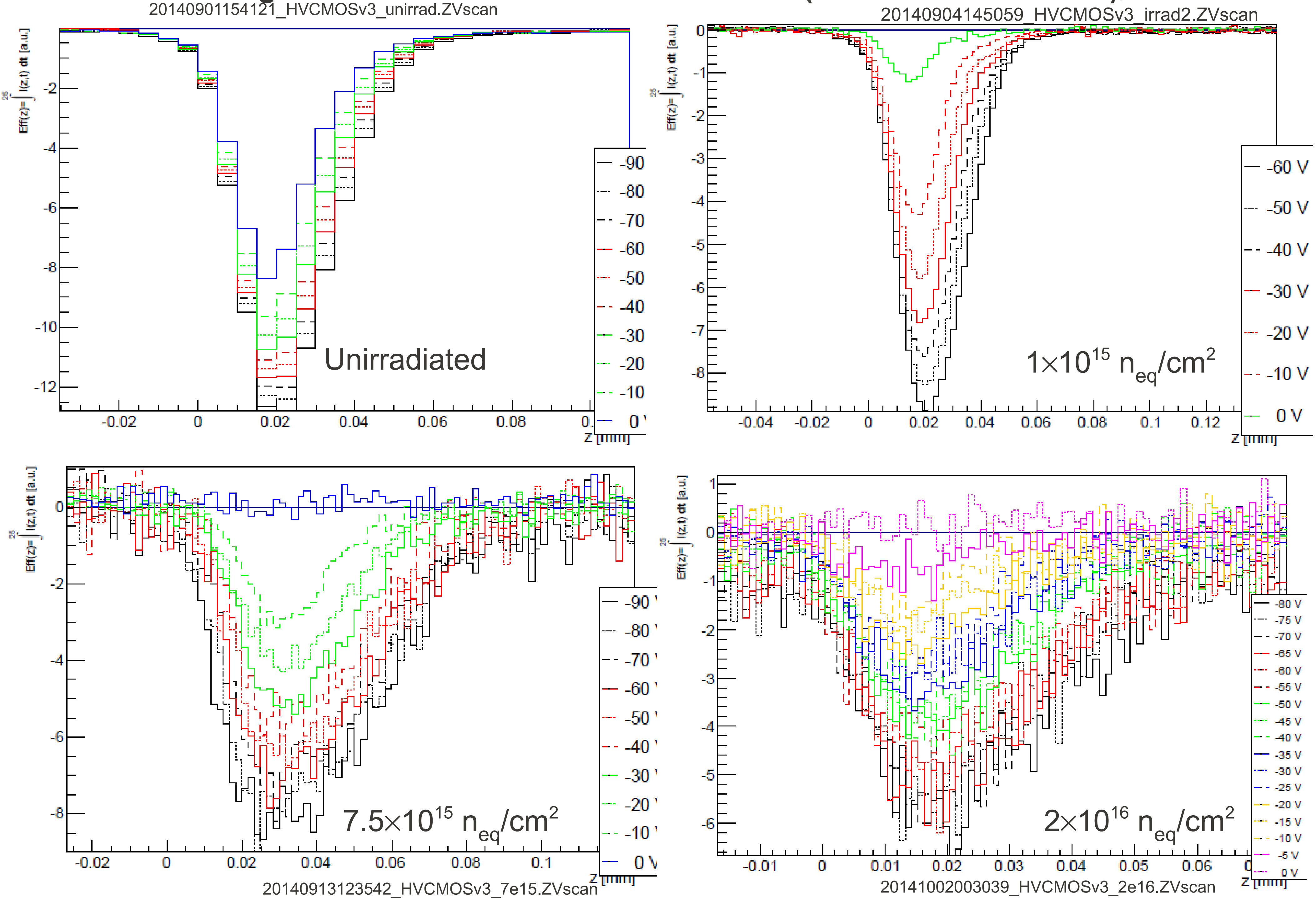


(more bias needed to get same depleted width → dep width reduction)

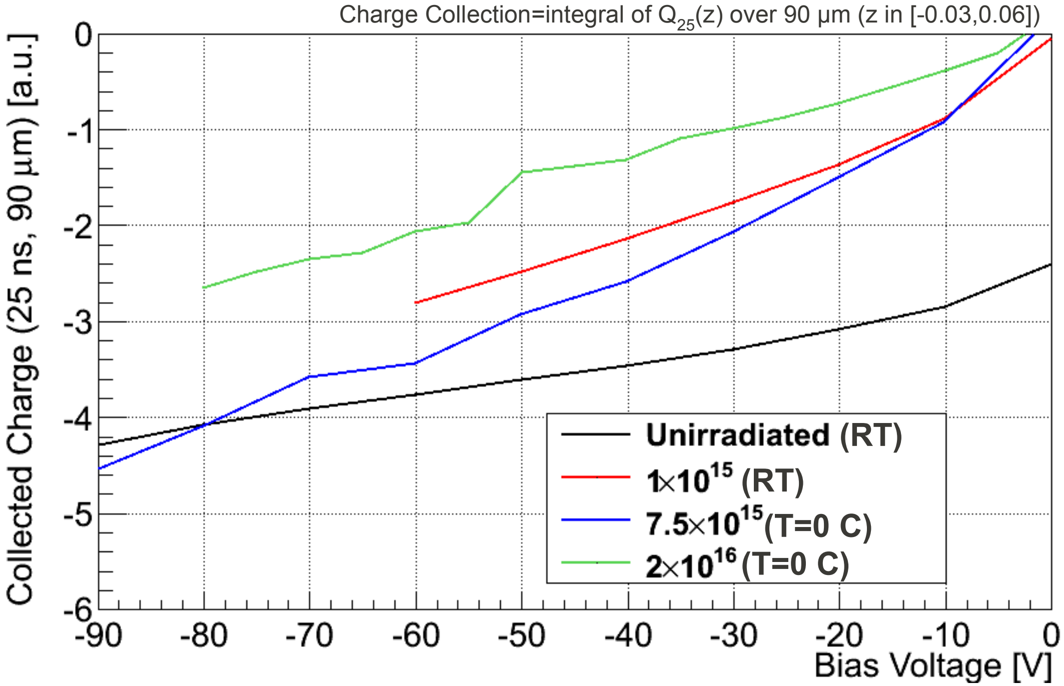


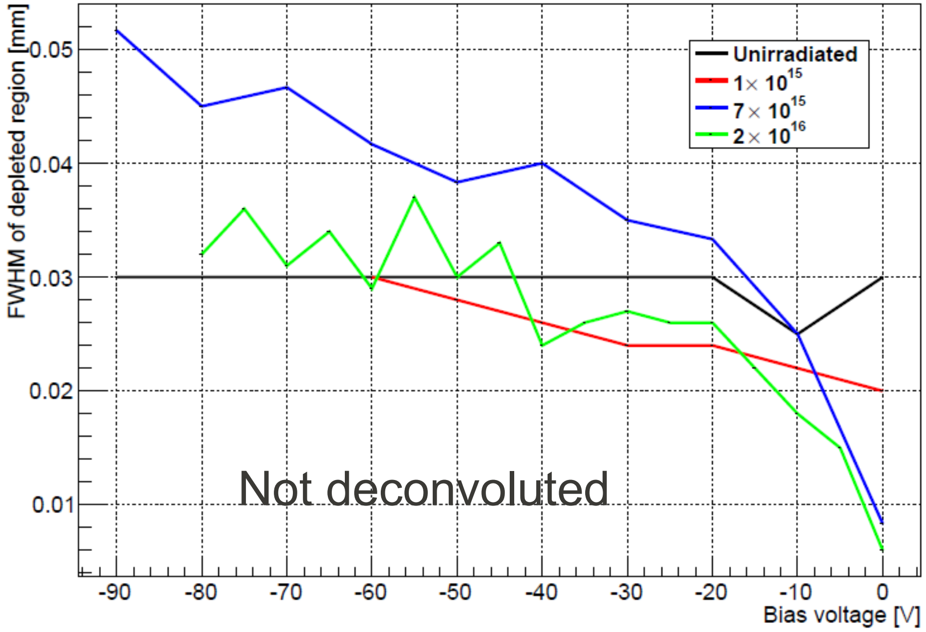


Charge in 25 ns at the center of the diodes (mind different X-axis)



HVCMOSv3, radiation hardness





Note measurements at different T! Absorption in Si decreases with decreasing T → less signal produced at lower T→ CCV of 7×10^{15}, 2×10^{16} are probably underestimated.

Interpretation:

$$w = 0.3\ \ [\mu\mathrm{m}] \times \sqrt{\rho(V_b + V_{bi})}$$

$$V_{dp} = 11 \left[\frac{\Omega\cdot\mathrm{cm}}{(\mu\mathrm{m})^2}\right]\cdot\frac{d^2}{\rho_p} - V_{bi}$$

1×10^{15}: Depth of depleted region decreases ↔ ρ decrease ↔ V_{dep} increase. Less charge collected for the same voltage across the detector → drop of collected charge.

7×10^{15}: Depleted width increases, we collect more charge for the same voltage. For bias>80V it seems to overcome the unirradiated value

2×10^{16}: depletion width as unirradiated. However less charge collected → trapping

Depletion width looks bigger than expected due to contribution of diffusion in 25 ns!!

Conclusions

- Tested 4 HVCMOSv3 to 4 different fluences: 0, 1×10^{15},7×10^{15},2×10^{16} n_{eq}/cm^2
- Only analog readout, no amplified signal from pixel matrix was used
- Full sensor readout (conf. 1) shows high contribution from diffusion, reducing after irradiation. For configuration 2 (diode only), drift dominates
- Different relative contributions to collected charge from drift and diffusion:

Q contribution conf.1	Unirradiated		2×10^{16}	
@drift max	Drift [2.5 ns]	diff [2.5-25 ns]	Drift [5 ns]	diff. [5-25 ns]
	6%	94%	25%	75%
Bias voltage [V]	-40		-80	

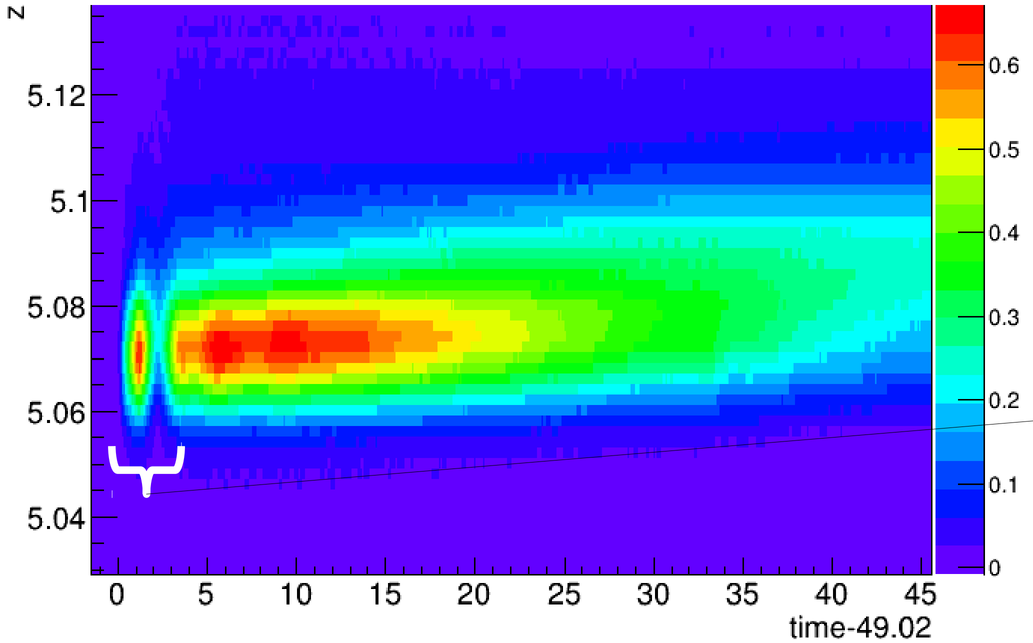
Q contribution conf.2	Unirradiated		2×10^{16}	
@drift max	Drift [5 ns]	diff [5-25 ns]	Drift [5 ns]	diff. [5-25 ns]
	77%	23%	70%	30%
Bias voltage [V]	-80		-80	

- Region efficient for charge creation reduces for 1×10^{15}, increases for 7×10^{15} and recovers the unirradiated level at 2×10^{16}.
- At 1×10^{15} the detector could be operated without cooling. Collected charge generally decreases down to 50% at -60V and 2×10^{16}.

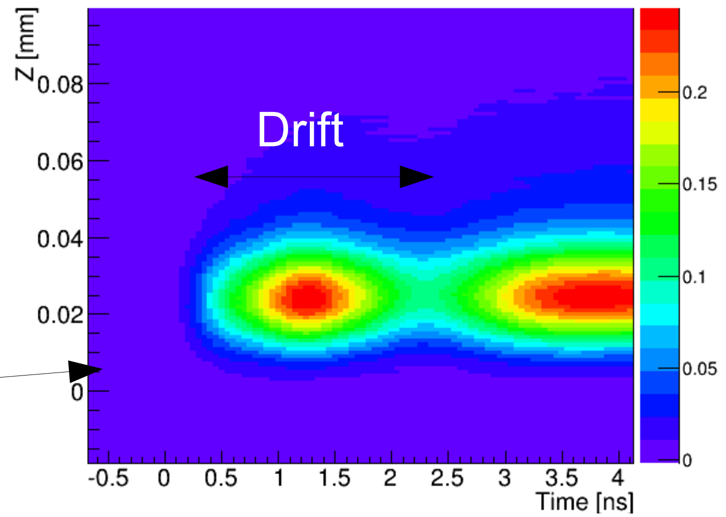
ⓘ Many things can be improved in next measurements: PCB and mechanics. We need also more statistics as well.

BACKUP

Full chip readout: charge profiles Q(z)

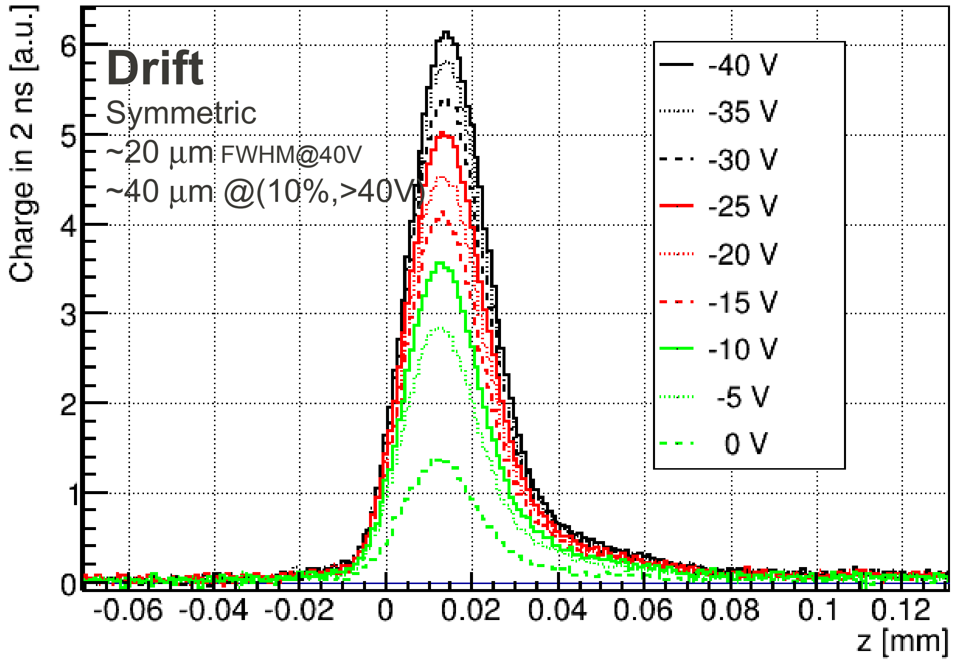


Zoom on “fast” signal



Drift peak does not shift with depth (see strip edge-TCT before for comparison)

Diffusion⇒ charge profile c.o.g. is shifted

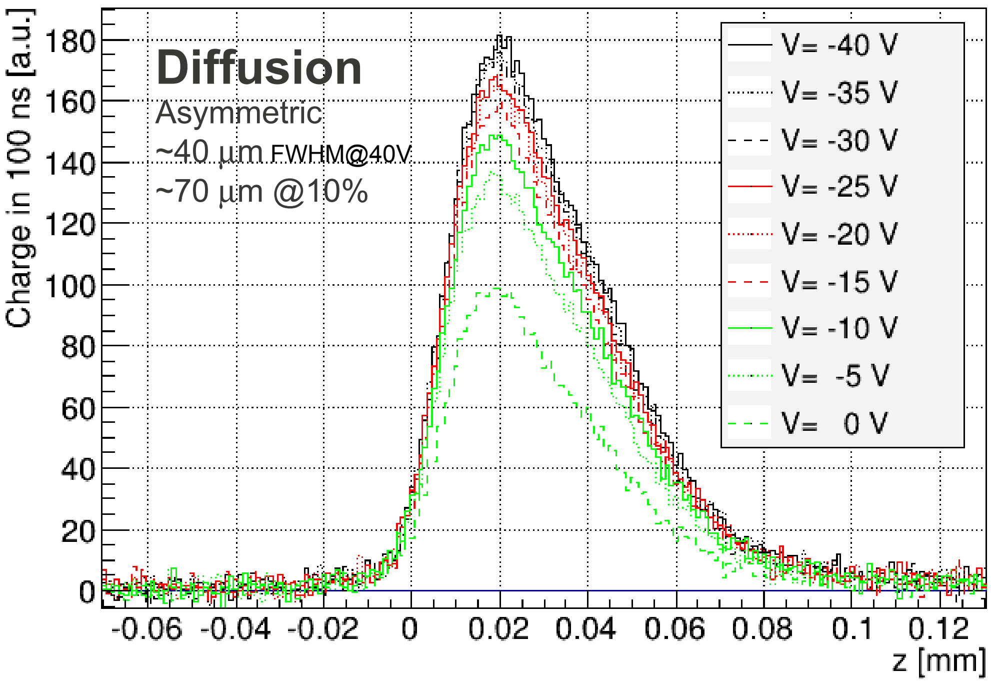


Drift

Symmetric

~20 µm FWHM@40V

~40 µm @(10%,>40V)



Diffusion

Asymmetric

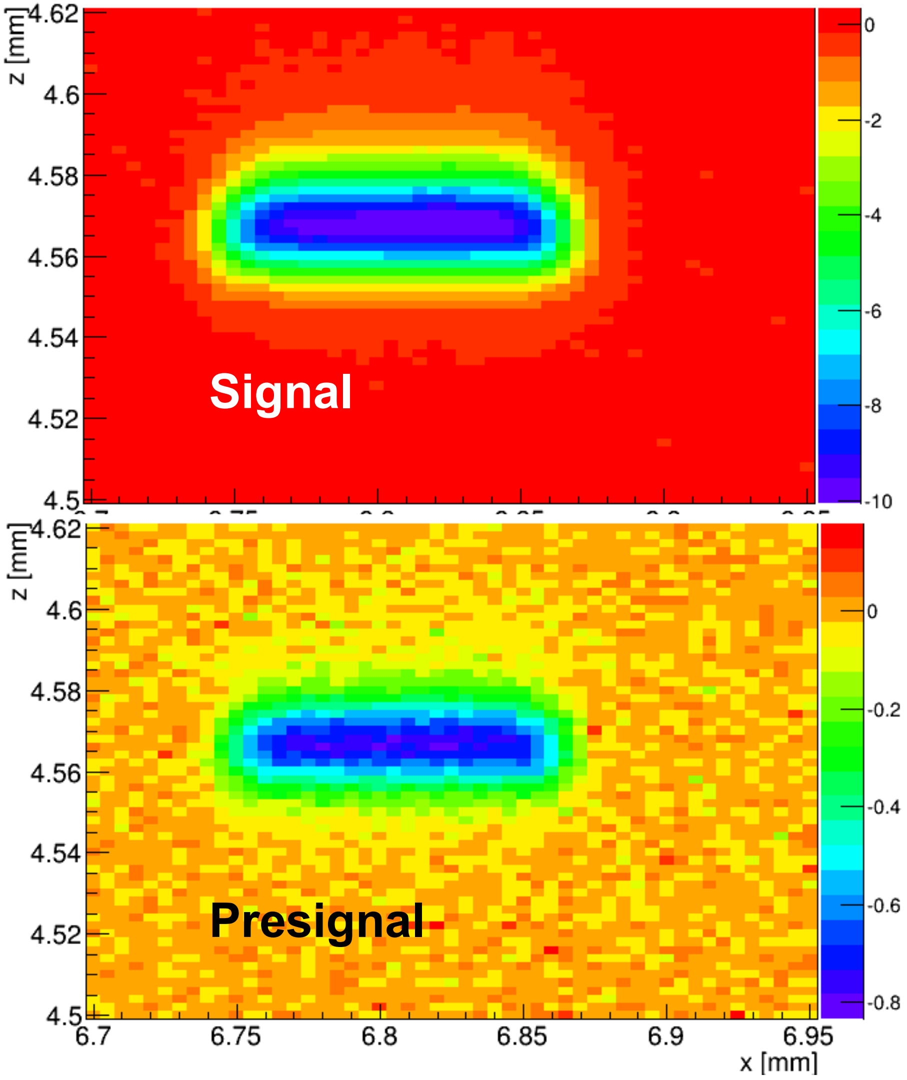
~40 µm FWHM@40V

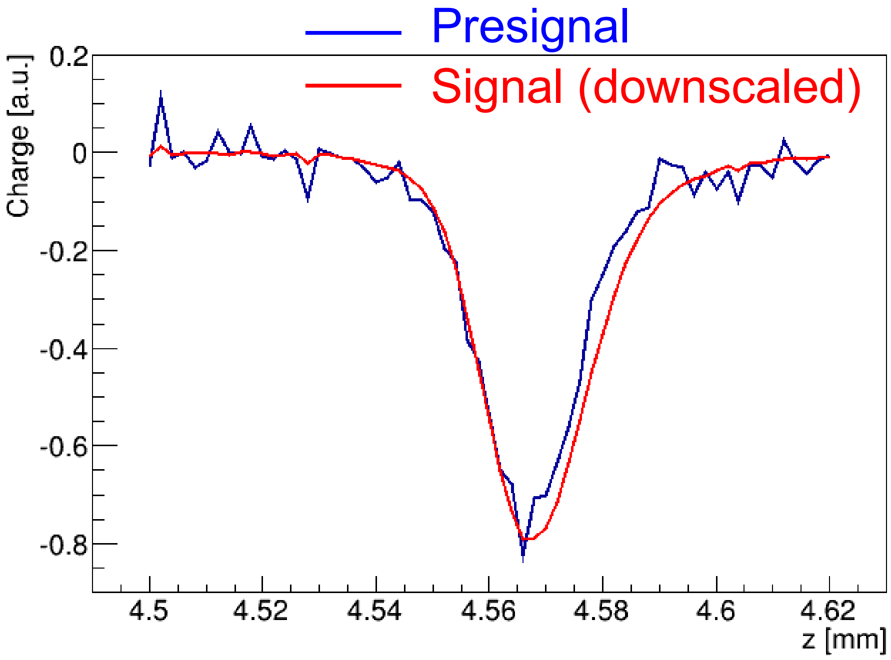
~70 µm @10%

20140813185409_HVCMOSv3

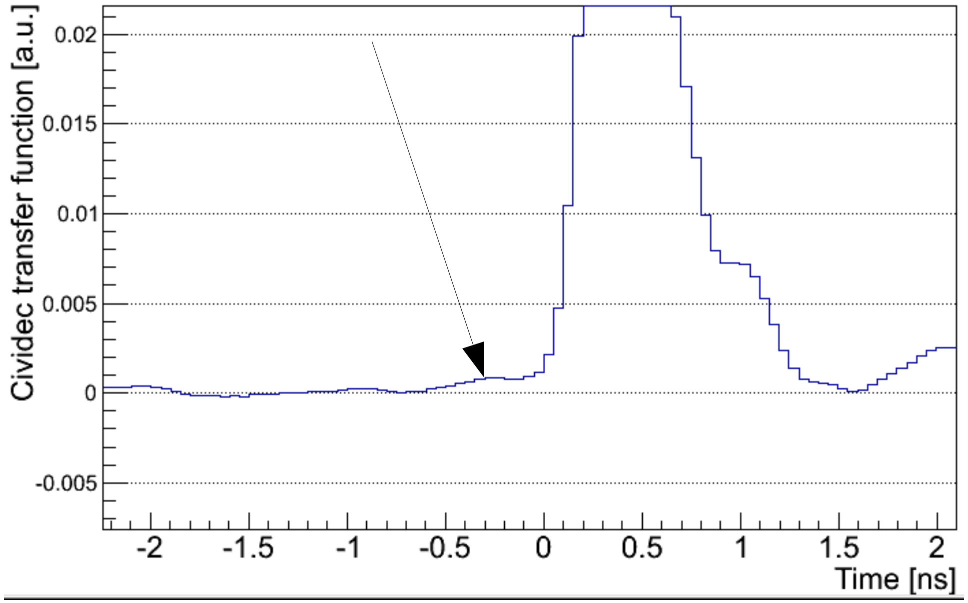
Presignal:

Seen in conf 2 (diode), not in conf 1



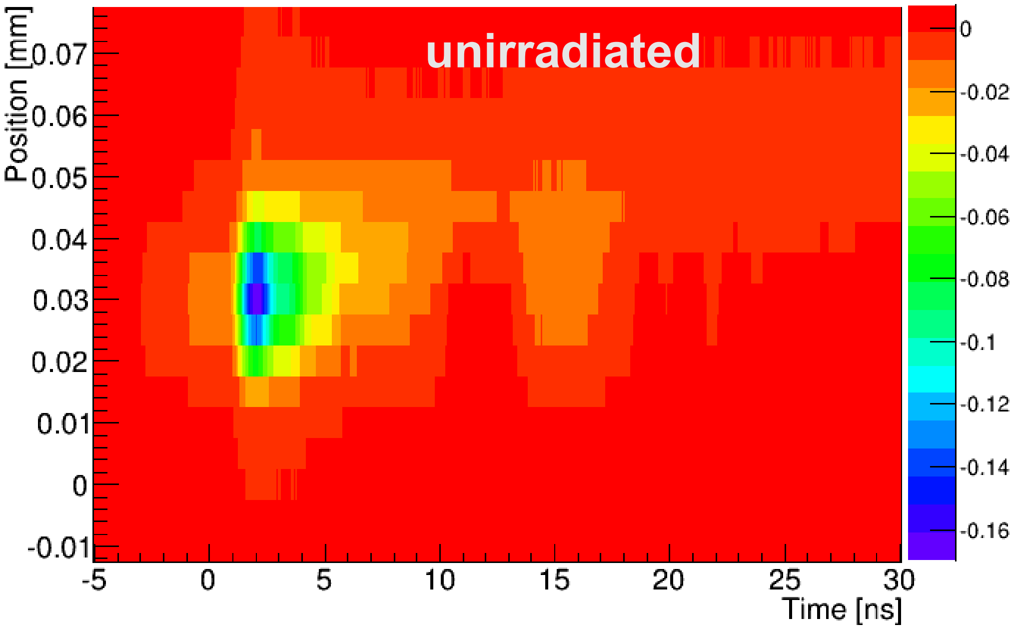


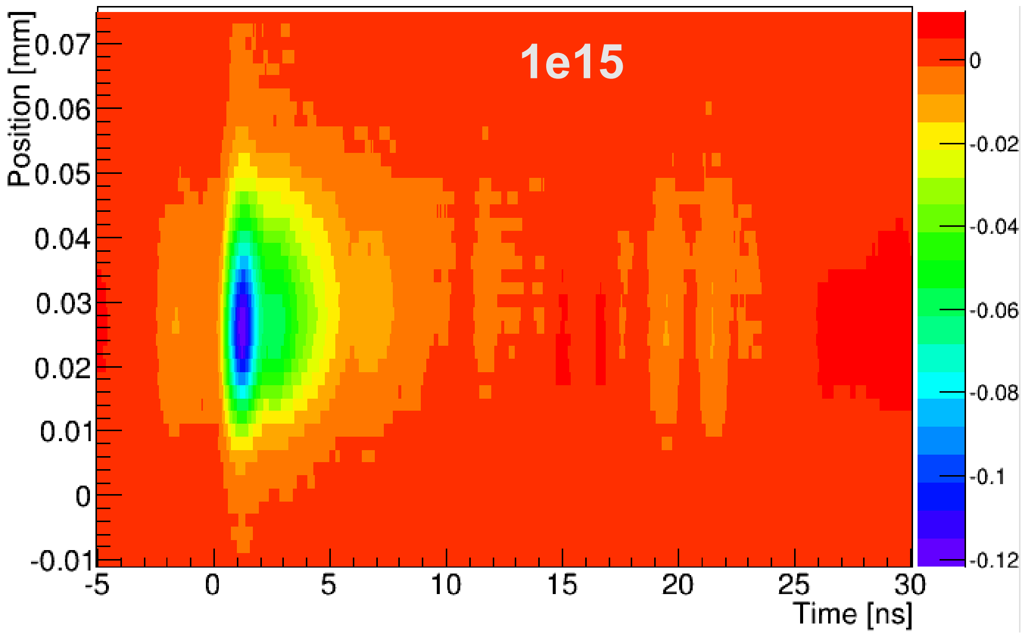
Seems as “feature” of the amplifier.

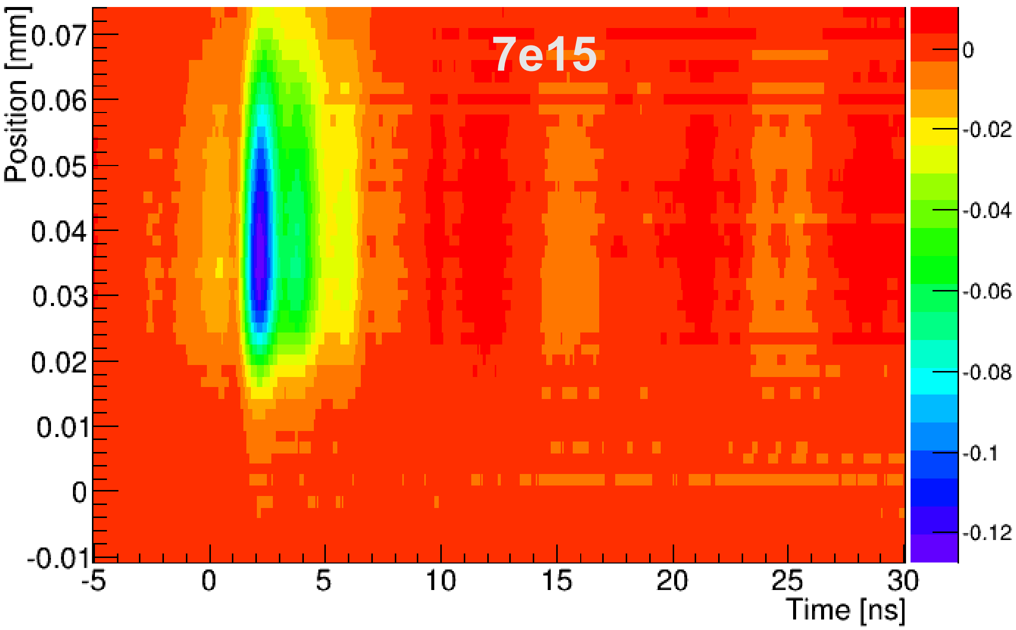


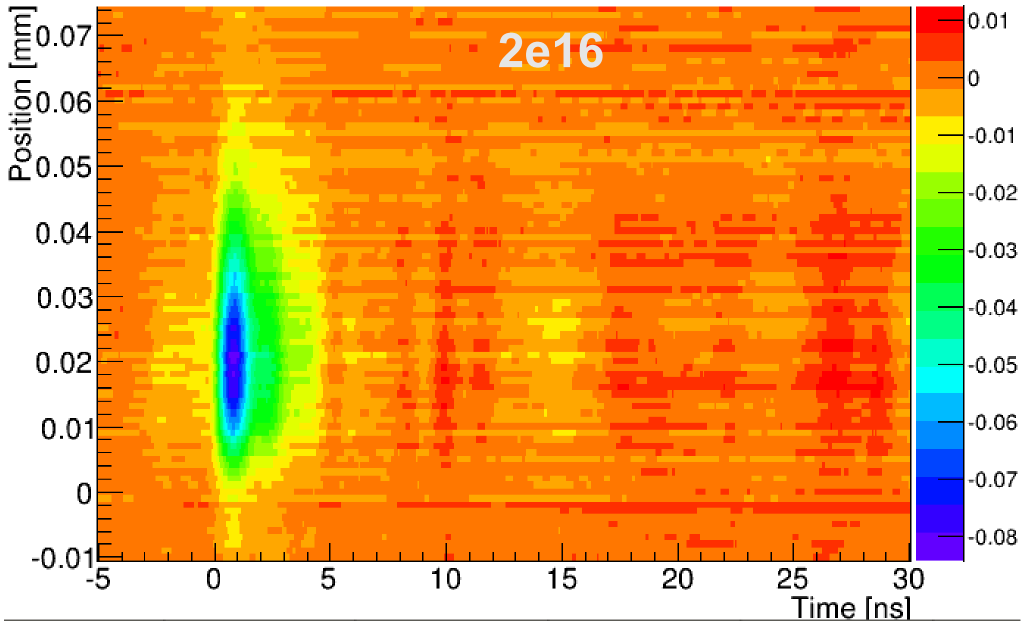
Bulk~10 Ohm.cm
Implant~

Diode readout, -60V, signal maps



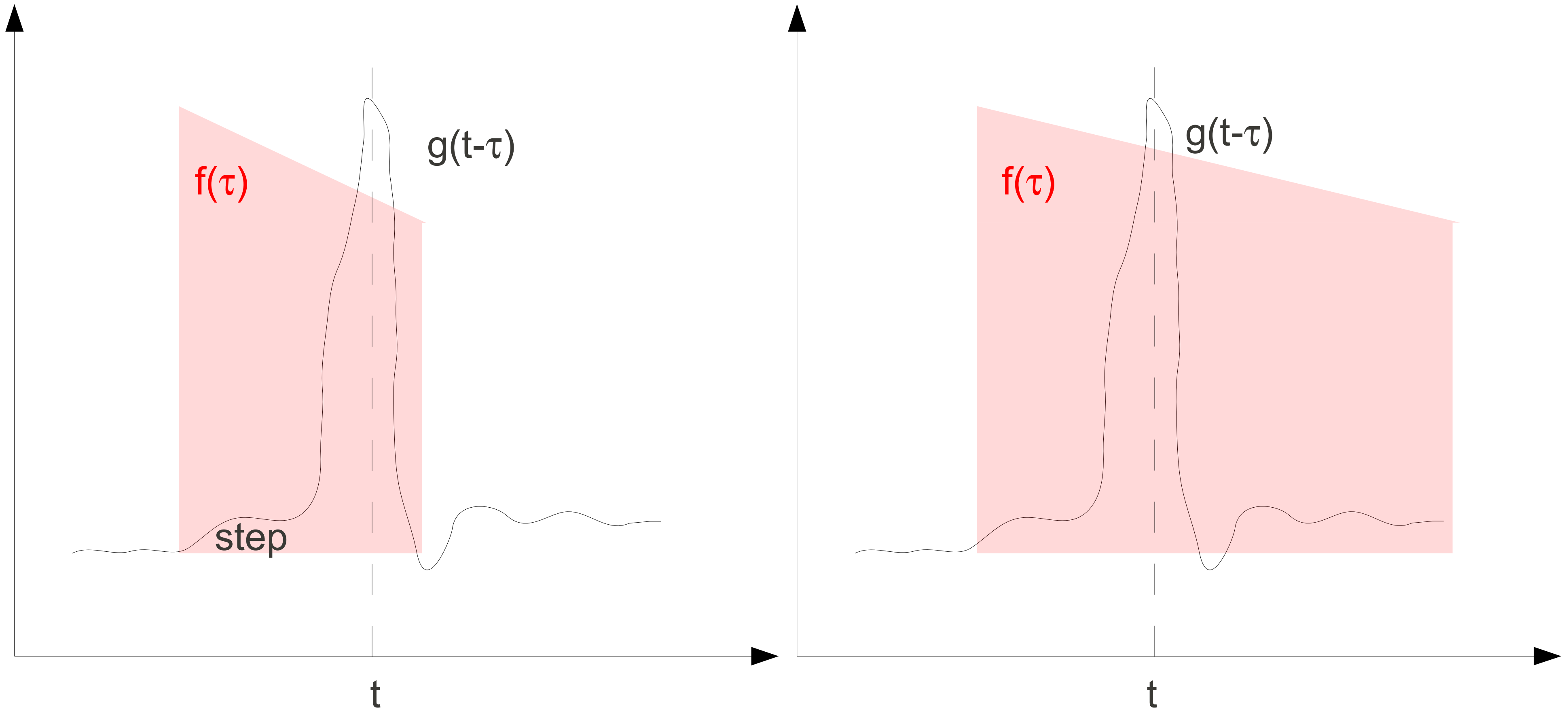






$$(f * g)(t) \overset{\text{def}}{=} \int_{-\infty}^{\infty} f(\tau)\, g(t-\tau)\, d\tau$$

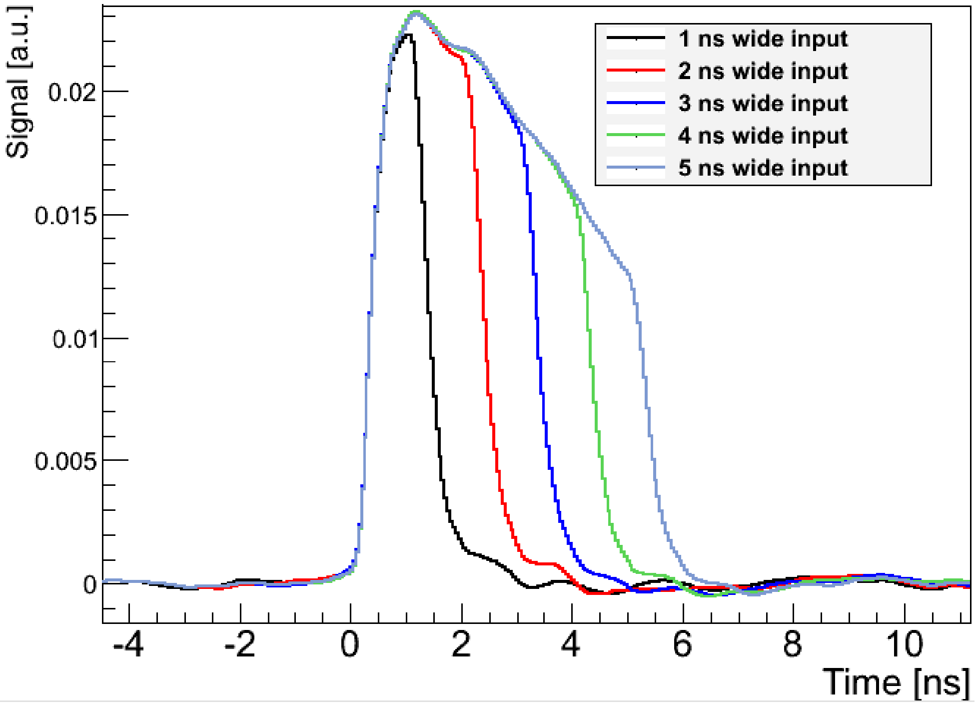
f≡Ideal signal, g≡System Transfer Function

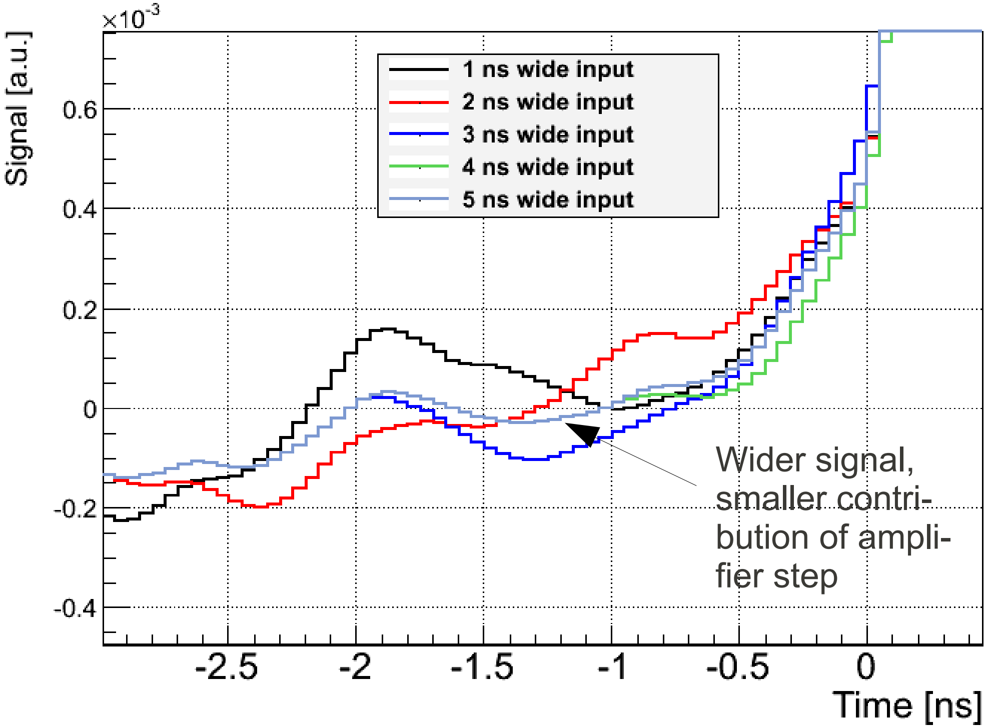


Convolution integral expands from (-∞,∞)
Narrow signals: relative contribution of amplifier step, at point "t", is higher for small signals
Wide signals: at the same position, the integral from (-∞,∞) adds up more signal, and the step contribution is smaller

$$(f * g)(t) \stackrel{\text{def}}{=} \int_{-\infty}^{\infty} f(\tau)\, g(t-\tau)\, d\tau$$

f≡Ideal signal, g≡System Transfer Function

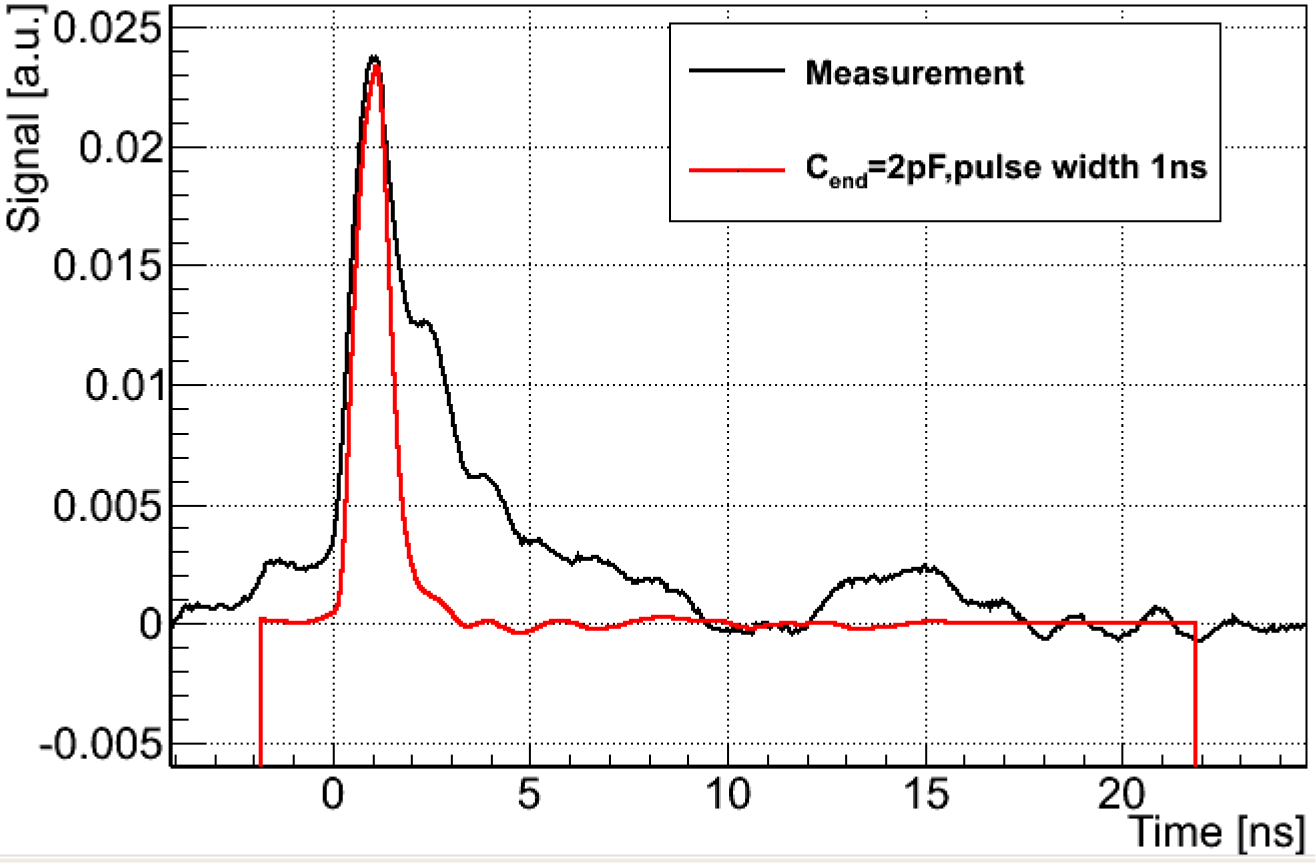




Wider signal, smaller contribution of amplifier step

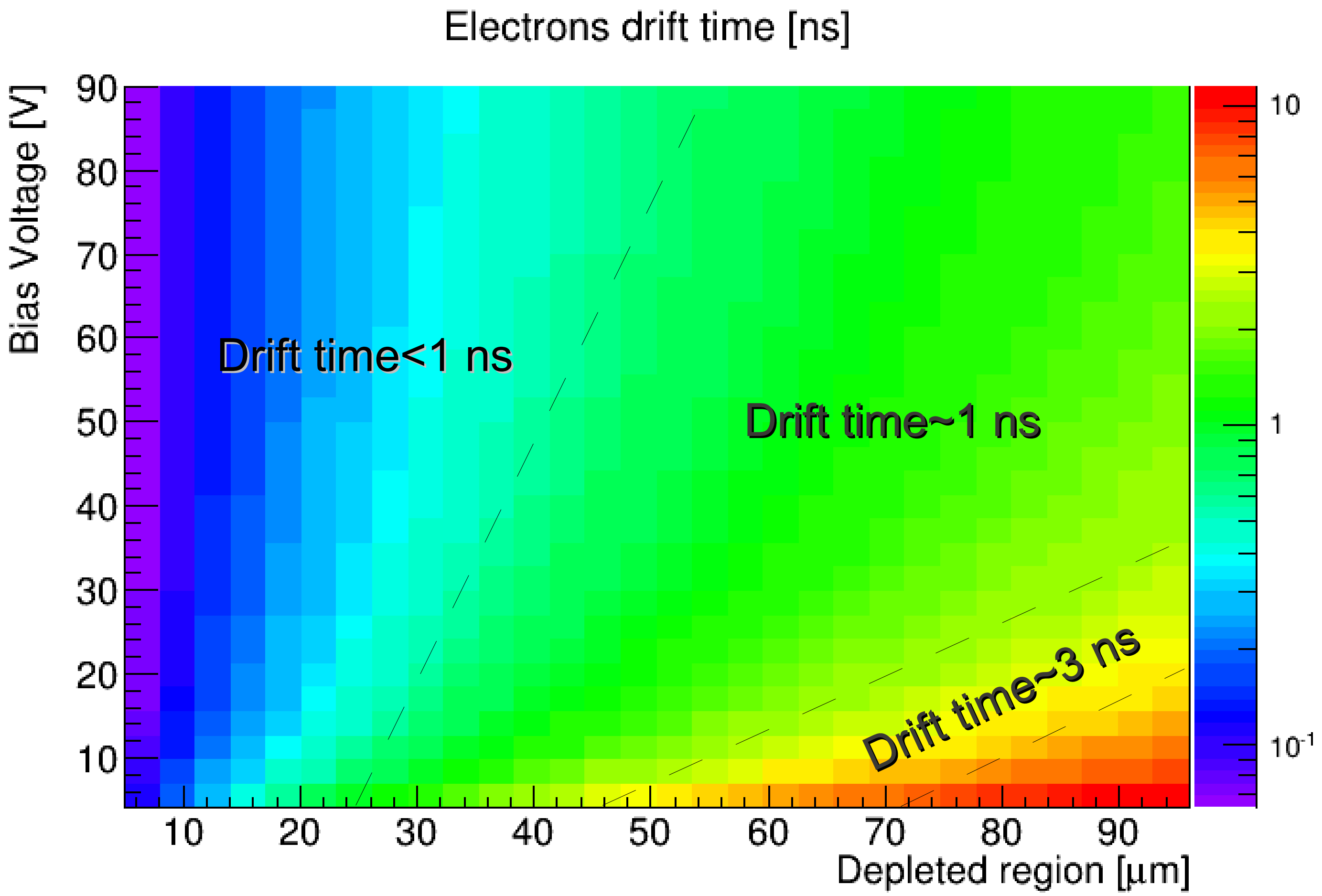
Convolution integral expands from (-∞,∞)
Narrow signals: relative contribution of amplifier step, at point "t", is higher for small signals
Wide signals: at the same position, the integral from (-∞,∞) adds up more signal, and the step contribution is smaller

Comparison calculated signal vs measured (conf 2)



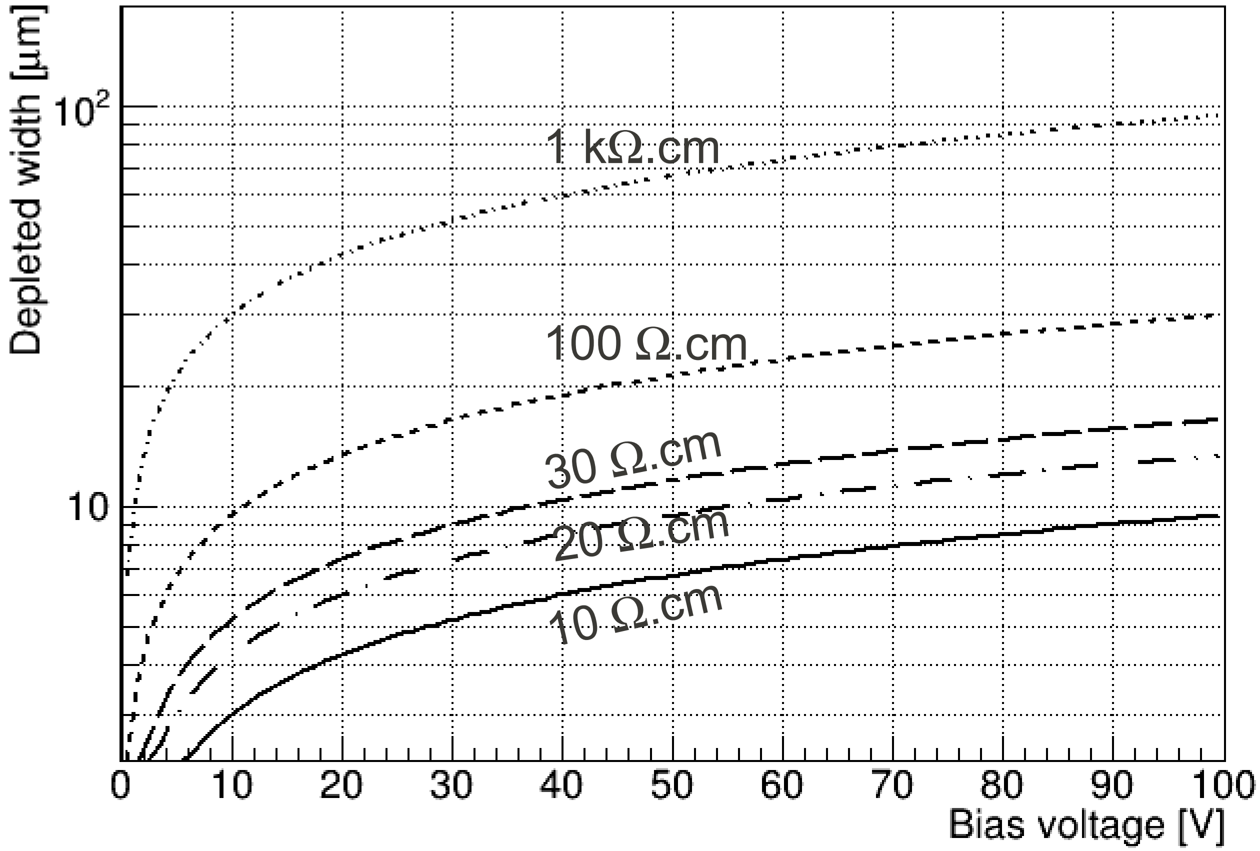
Capacitance is a second order effect in the width of the pulse.
Oscillations coming from the PCB

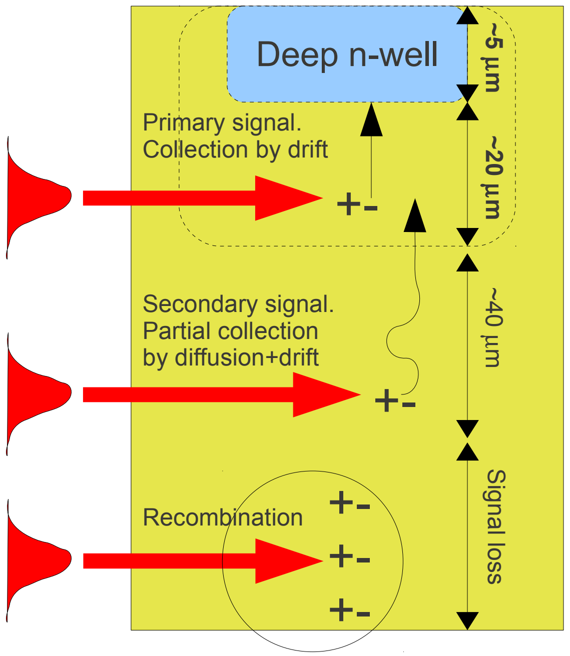
Collection time needed for electrons to traverse X µm of depleted region at given bias voltage



tdrift.C

Depletion width in p-type material (formula from Spieler, page 66)





Side view of HVCMOS

For 10 Ω.cm, the expected depletion voltage is V_{dep}~1.1·(thickness[µm])^2

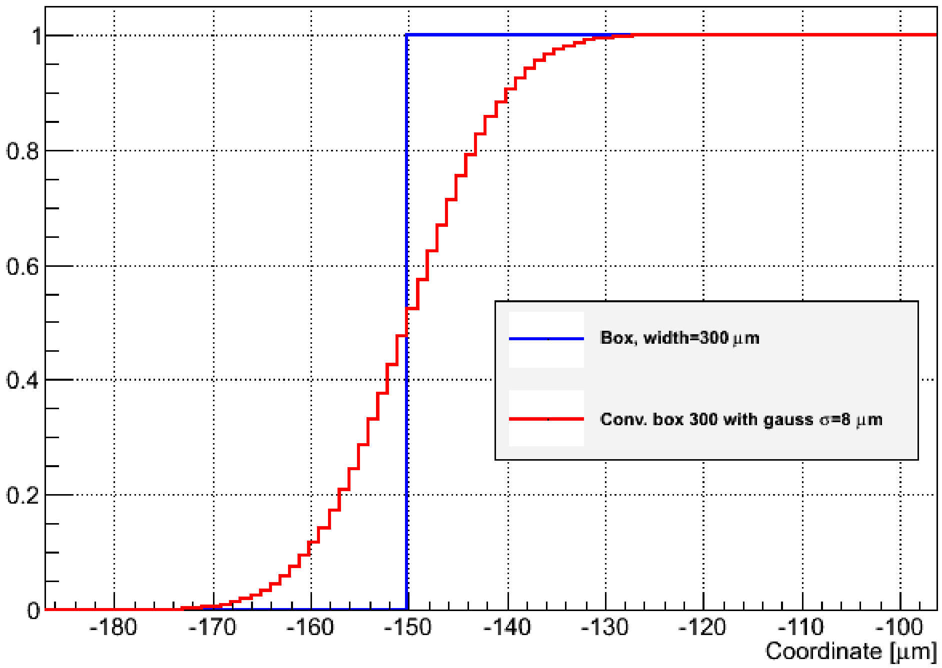
For 10 Ω.cm we expect ~10 µm depleted bulk at 90 V

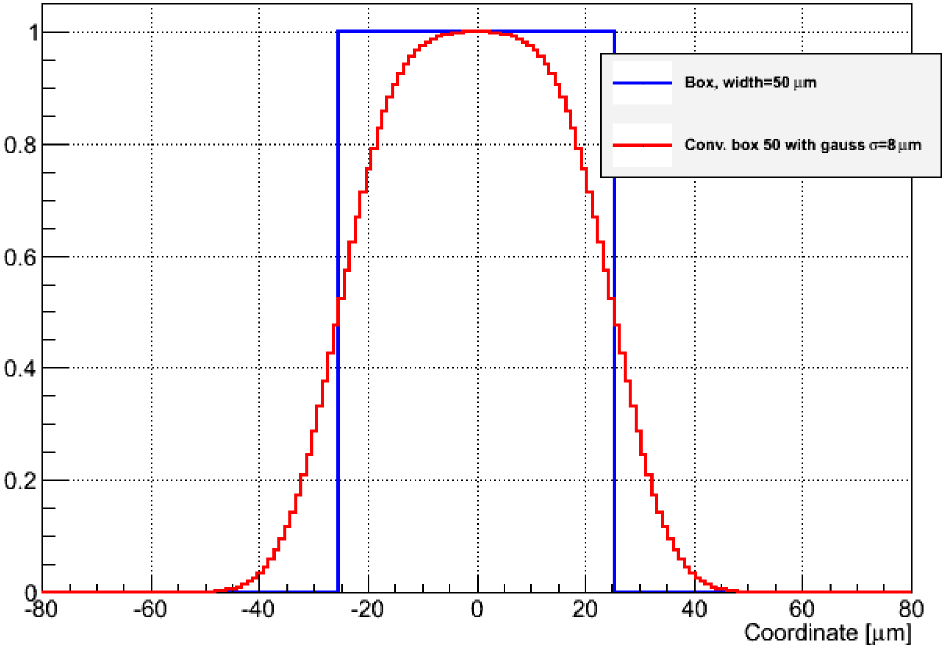
10 Ω.cm=1.4e15 (p-type)

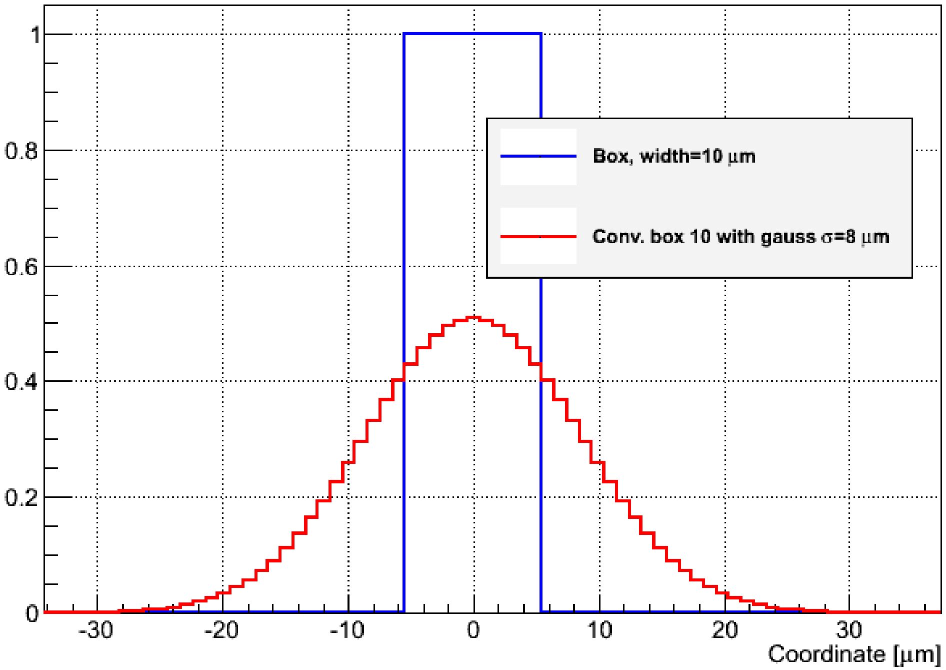
Nbulk		**P bulk**	
cm-3	**Ω.cm**	**cm-3**	**Ω.cm**
1e12	4415.3	1E12	13267.4
1e13	442.0	1E13	1327.5
1e14	44.5	1E14	133.1
1e15	4.6	1E15	13.5
1e16	0.5	1E16	1.45
1e17	0.09	1E17	0.197
1e18	0.023	1E18	0.041
1e19	0.005	1E19	0.009

http://www.cleanroom.byu.edu/ResistivityCal.phtml

Effect of convoluting gaussian signal with depleted box-like region





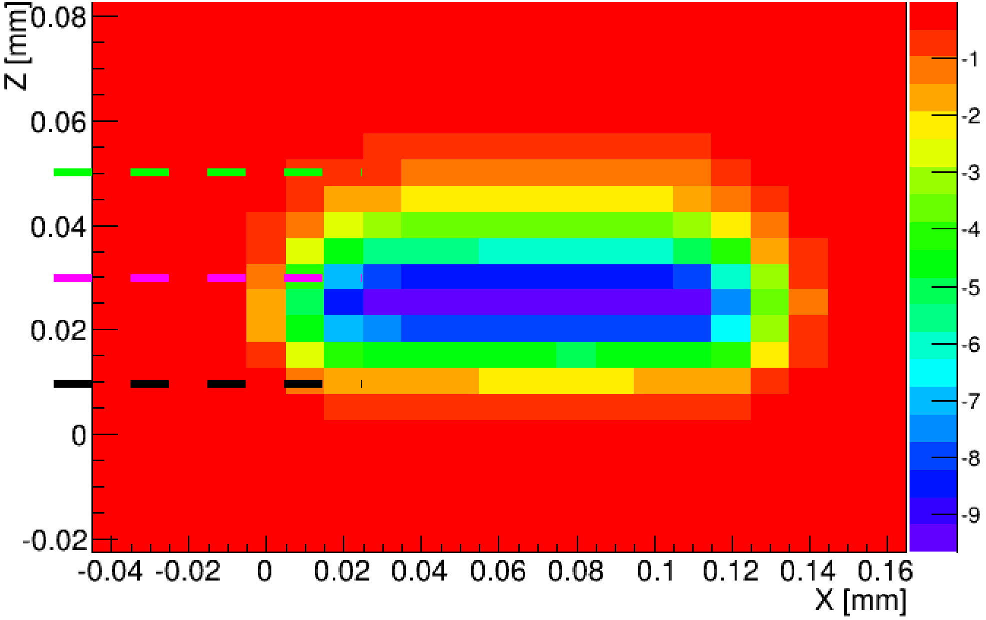


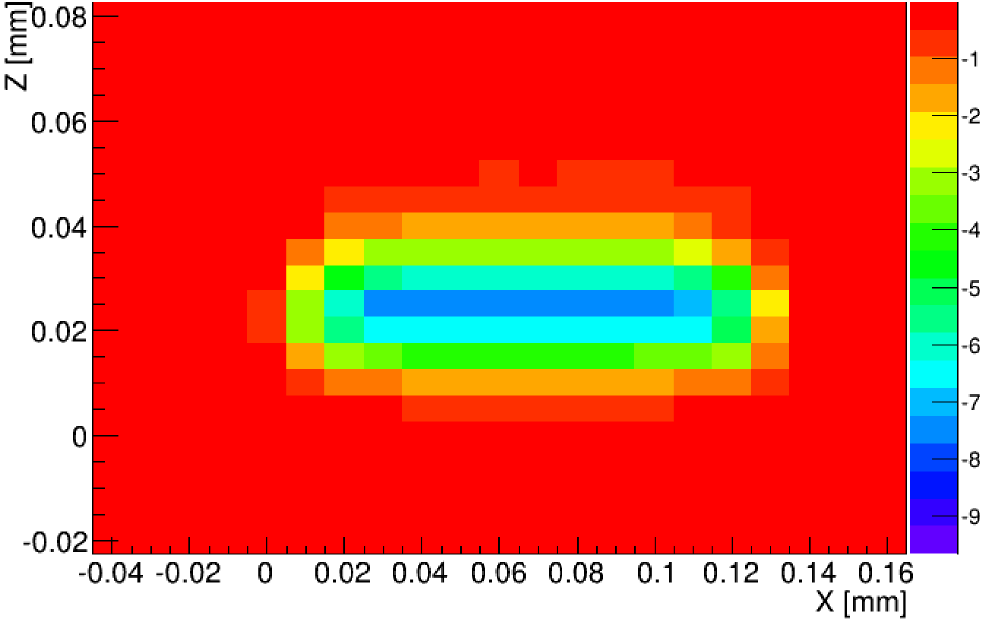
For “thick” detectors (~300 μm), signal is collected already 30 μm before the beam center enters the detector

If thickness<50 μm, signal collection starts ~15 μm before

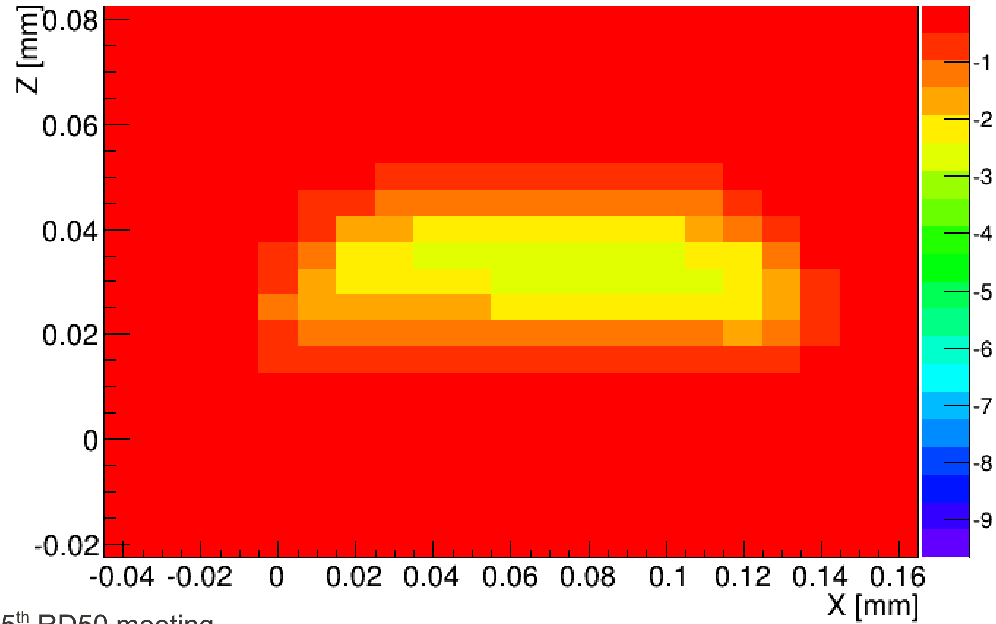
To have an active region~80 (40) μm as measured with the laser, the box thickness is 50(10) μm

Unirradiated HVCMOS, diode readout

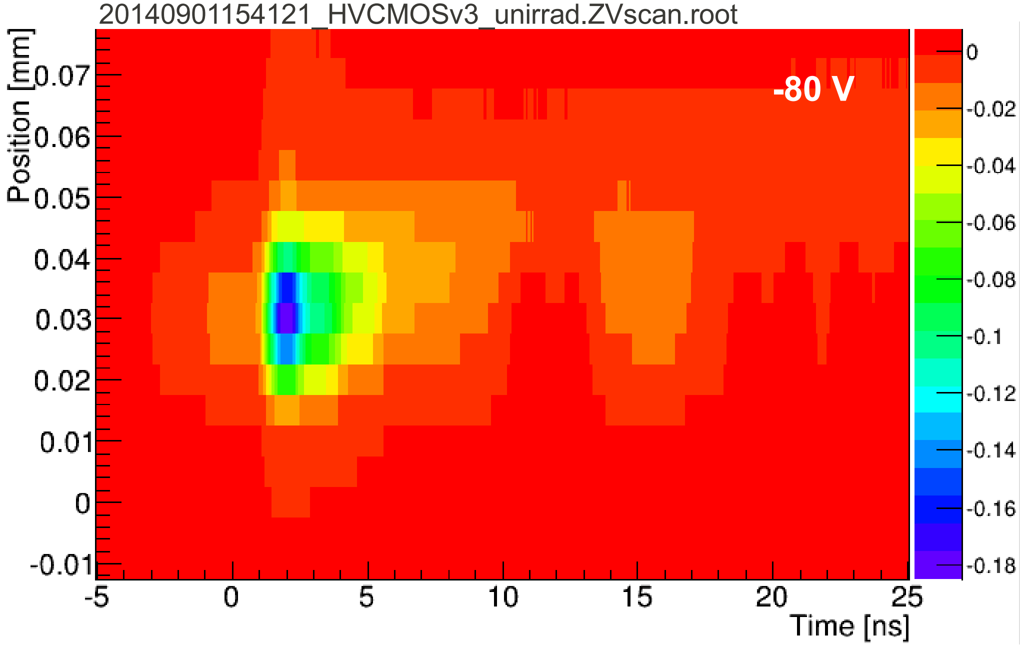

Q(x,z) t<10 ns [drift+”diffusion”]


Q(x,z) t<5 ns [drift]

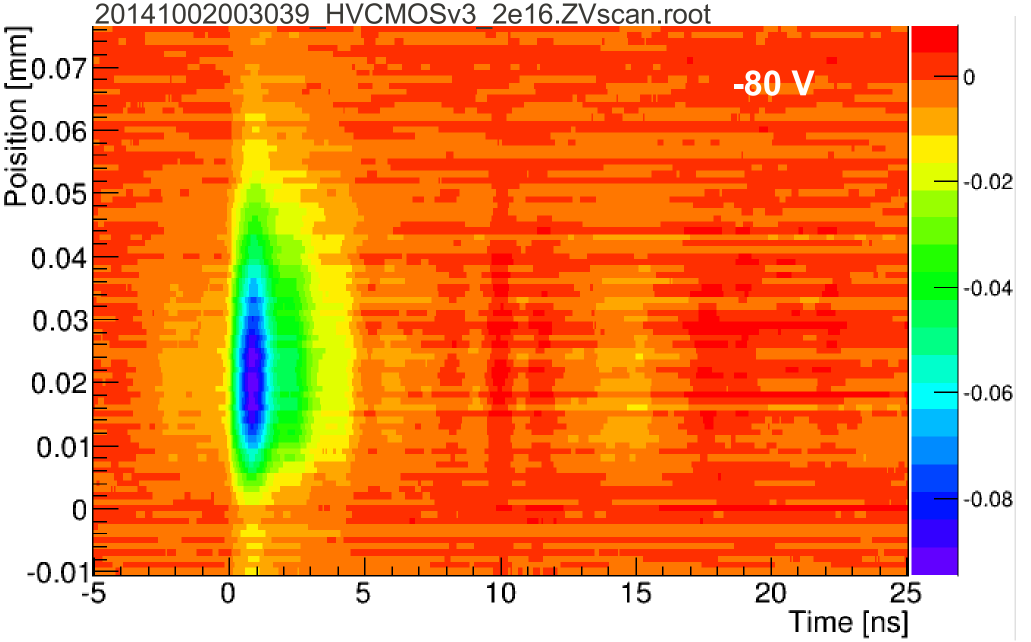
Relative contributions of drift and diffusion depend on the threshold by eye that we set.


Q(x,z) t in [5-10] ns [”diffusion”]

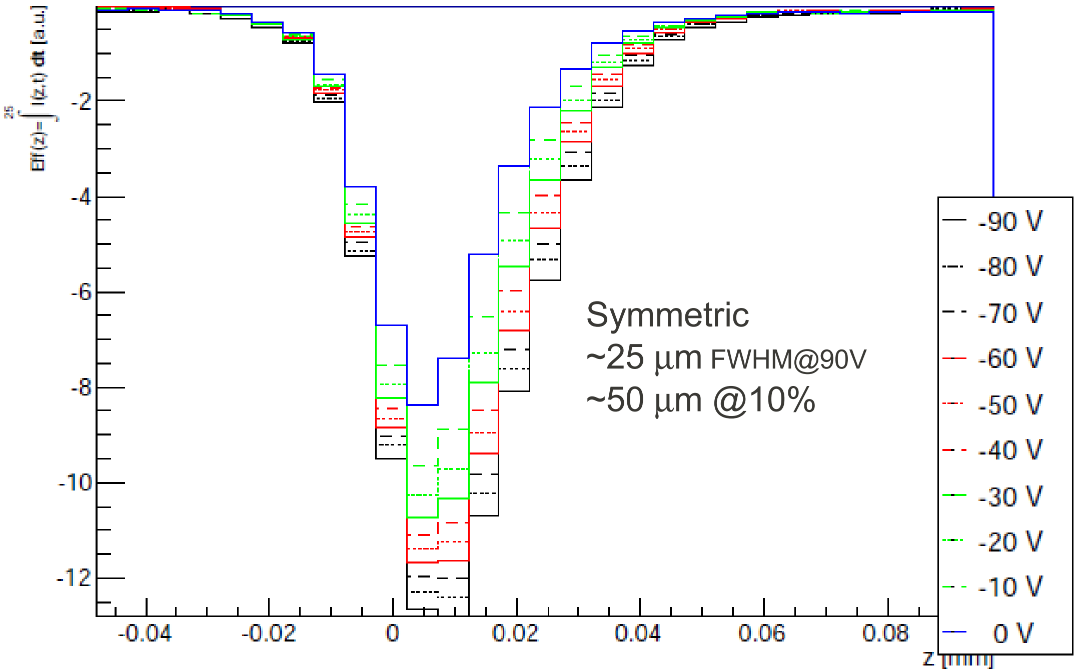
Diode readout (conf. 2): depleted region



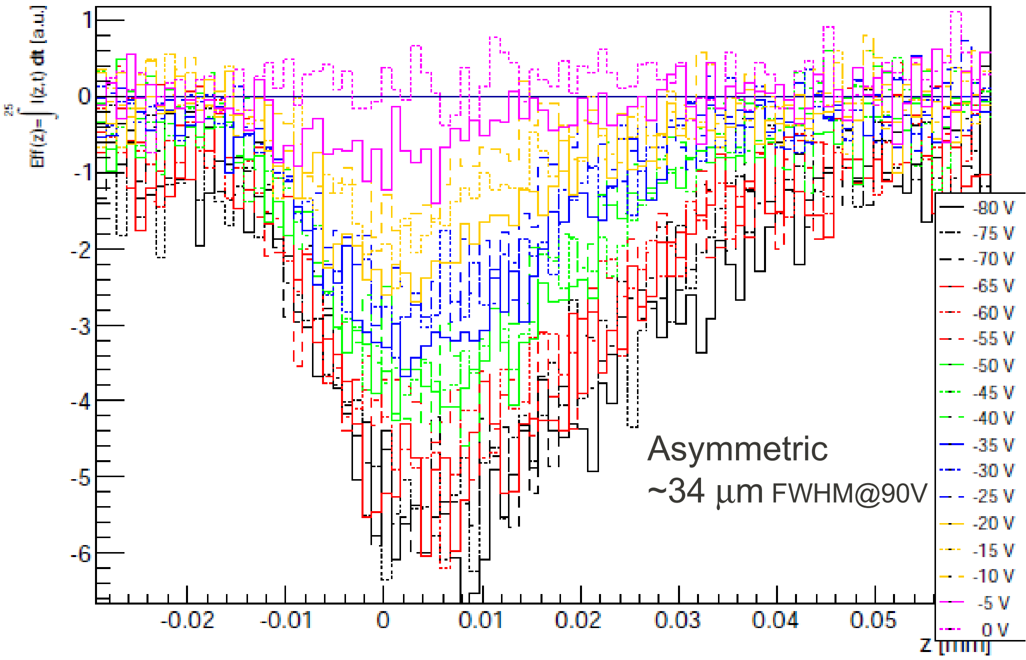
Some diffusion still visible, but mainly signal coming from drift



Diffusion contribution is gone. Efficient region for charge production seems bigger



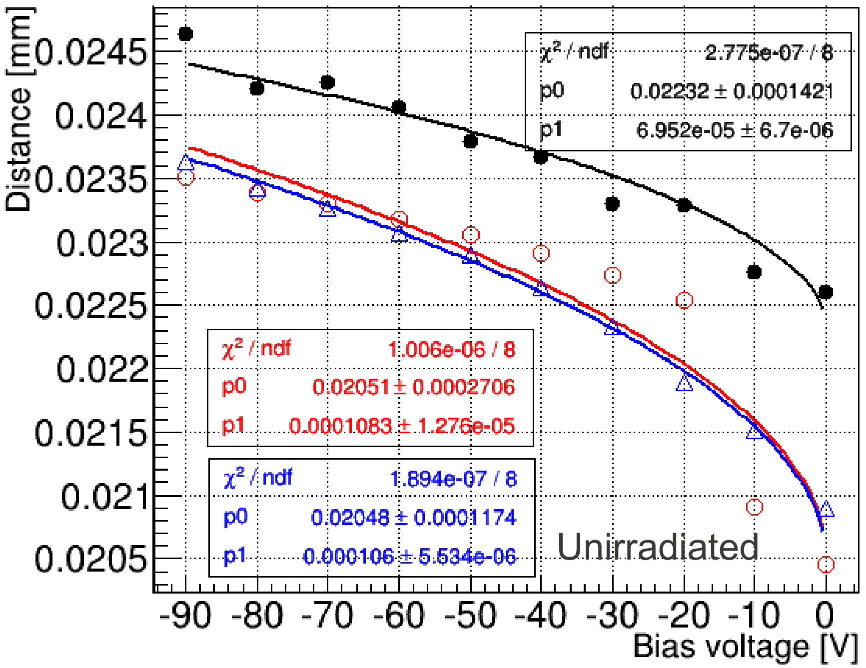
Symmetric
~25 µm FWHM@90V
~50 µm @10%



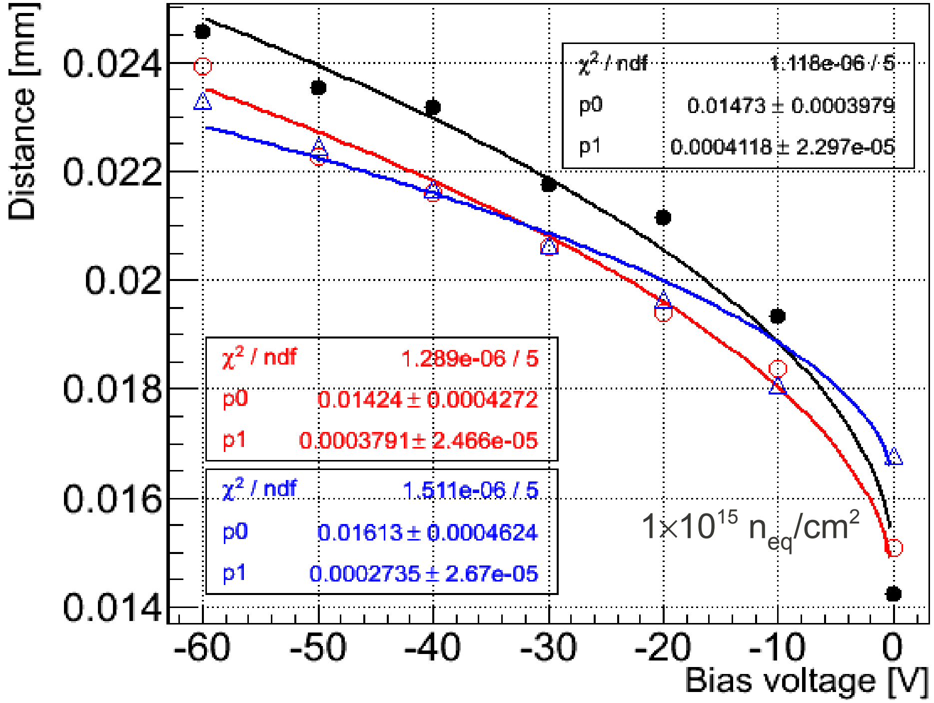
Asymmetric
~34 µm FWHM@90V

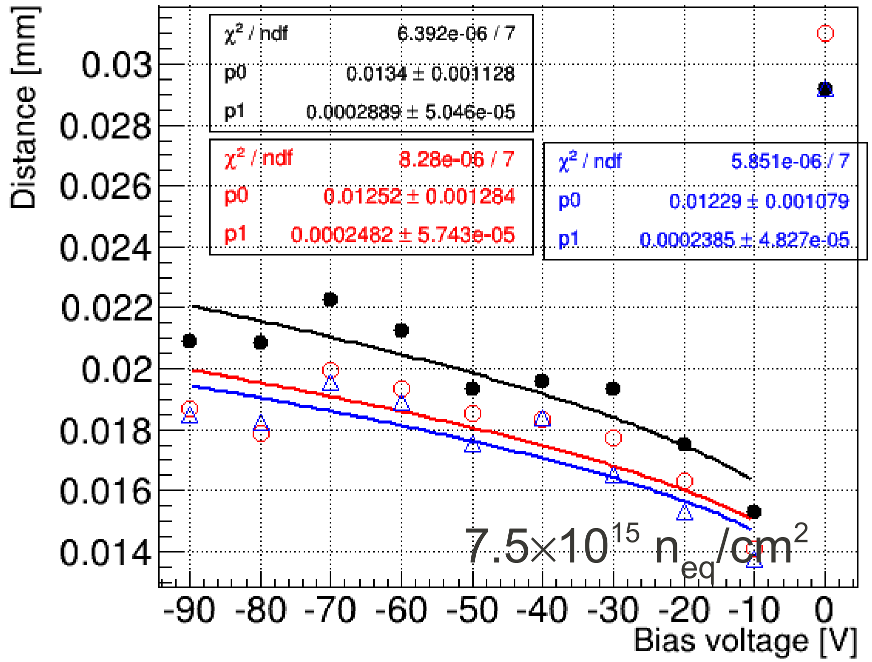
Center of depleted region

20140901154121_HVCMOSv3_unirrad.ZVscan

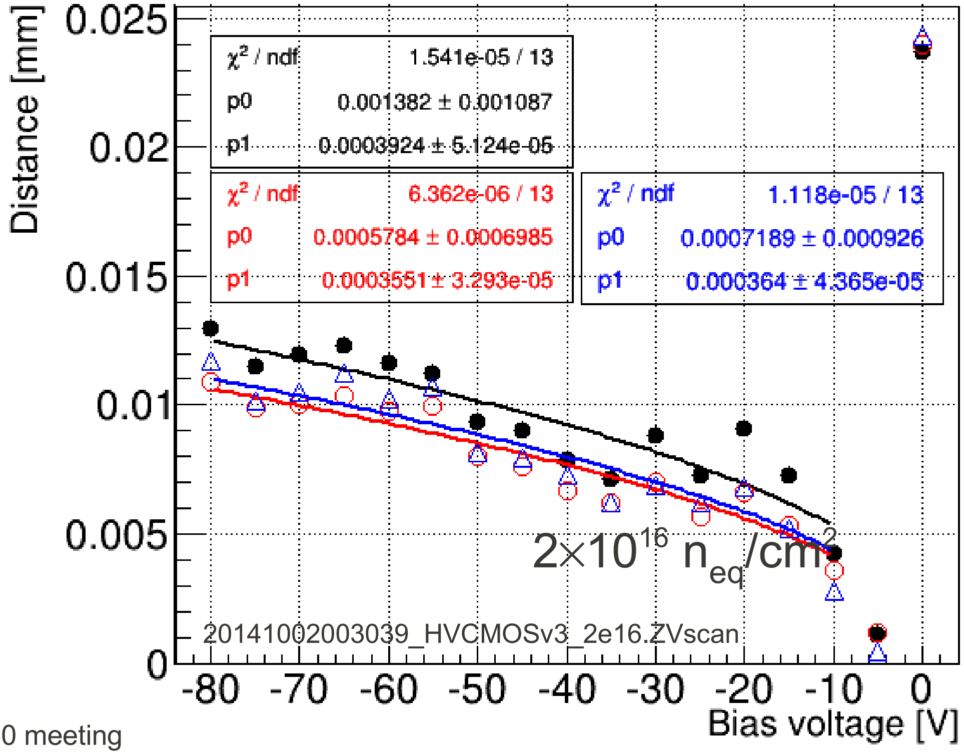


20140904145059_HVCMOSv3_irrad2.ZVscan

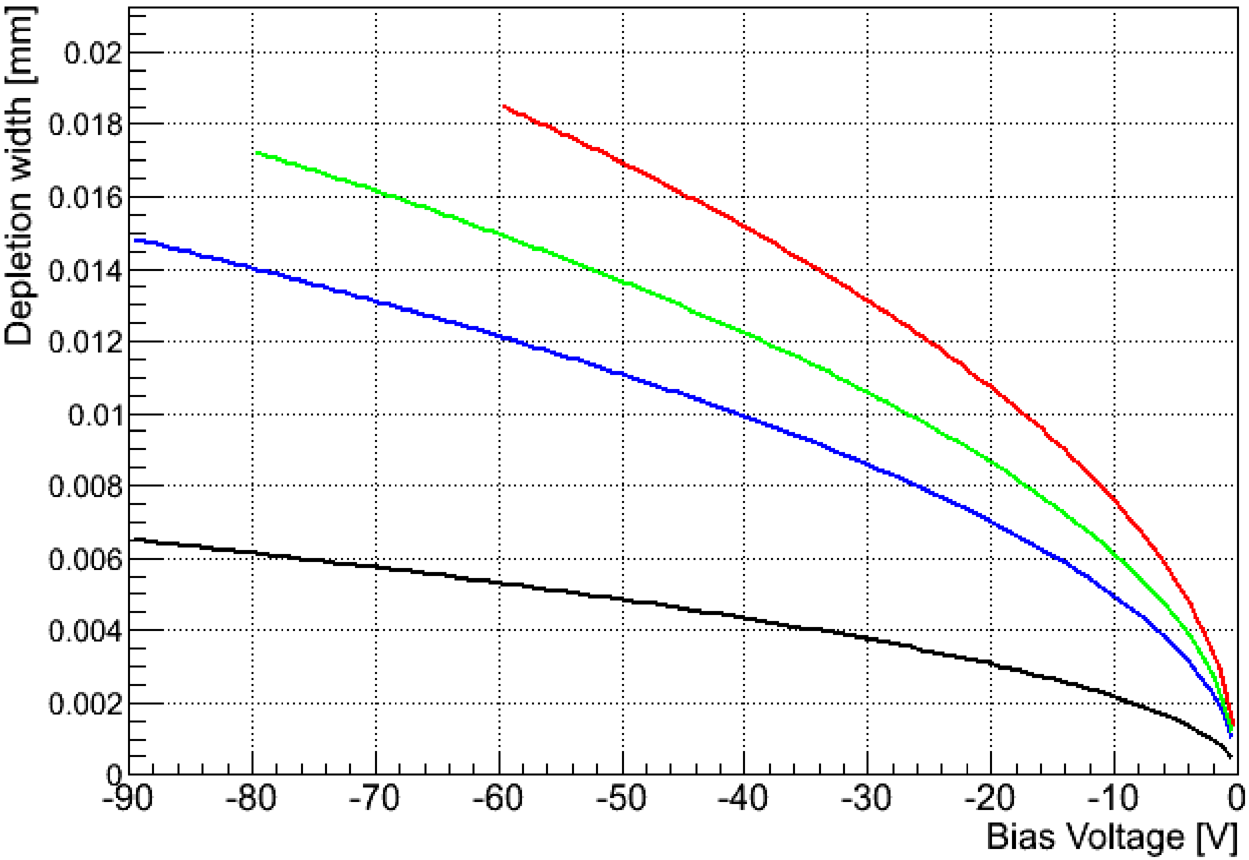




20140913123542_HVCMOSv3_7e15.ZVscan

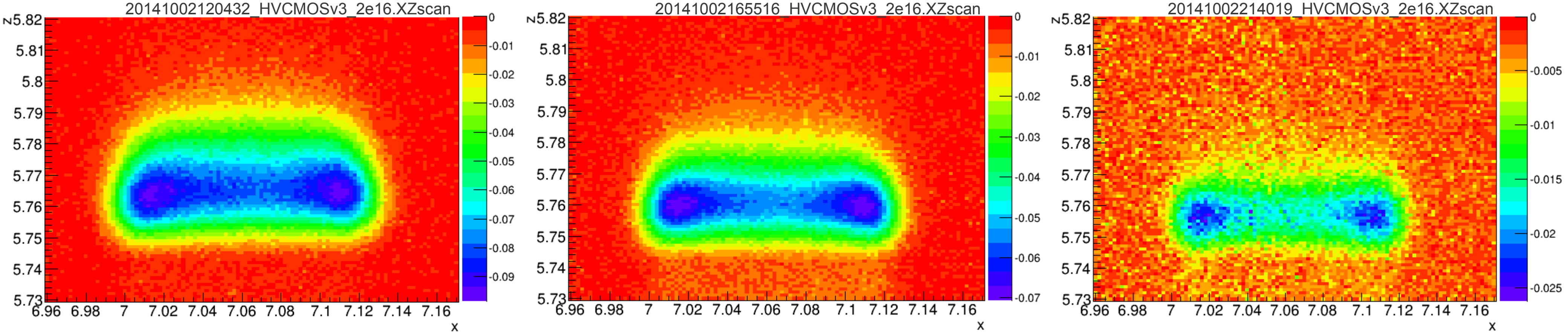


Calculated depletion width from fit to center of depleted region



2D scan (XZ) at different bias voltages, 2e16 neq/cm2, configuration 2

Signal amplitude

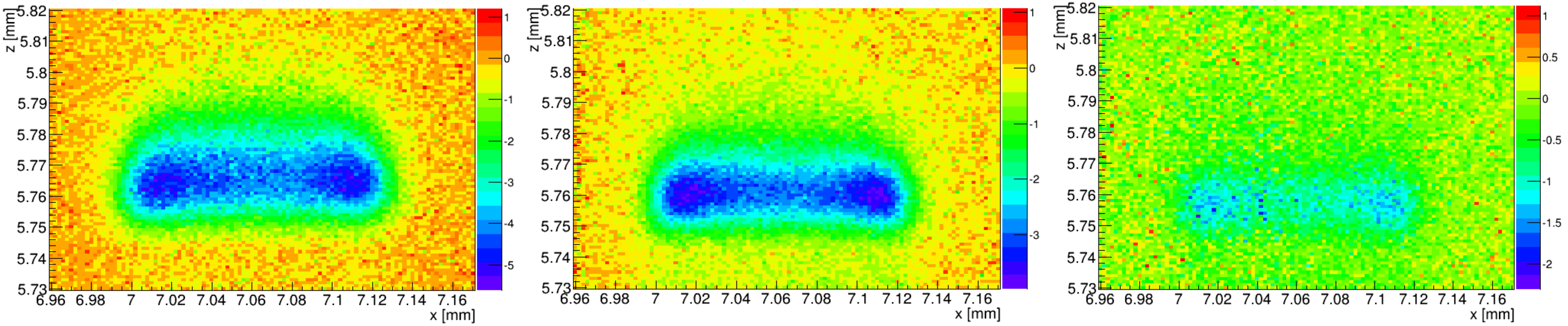


-60 V

-30 V

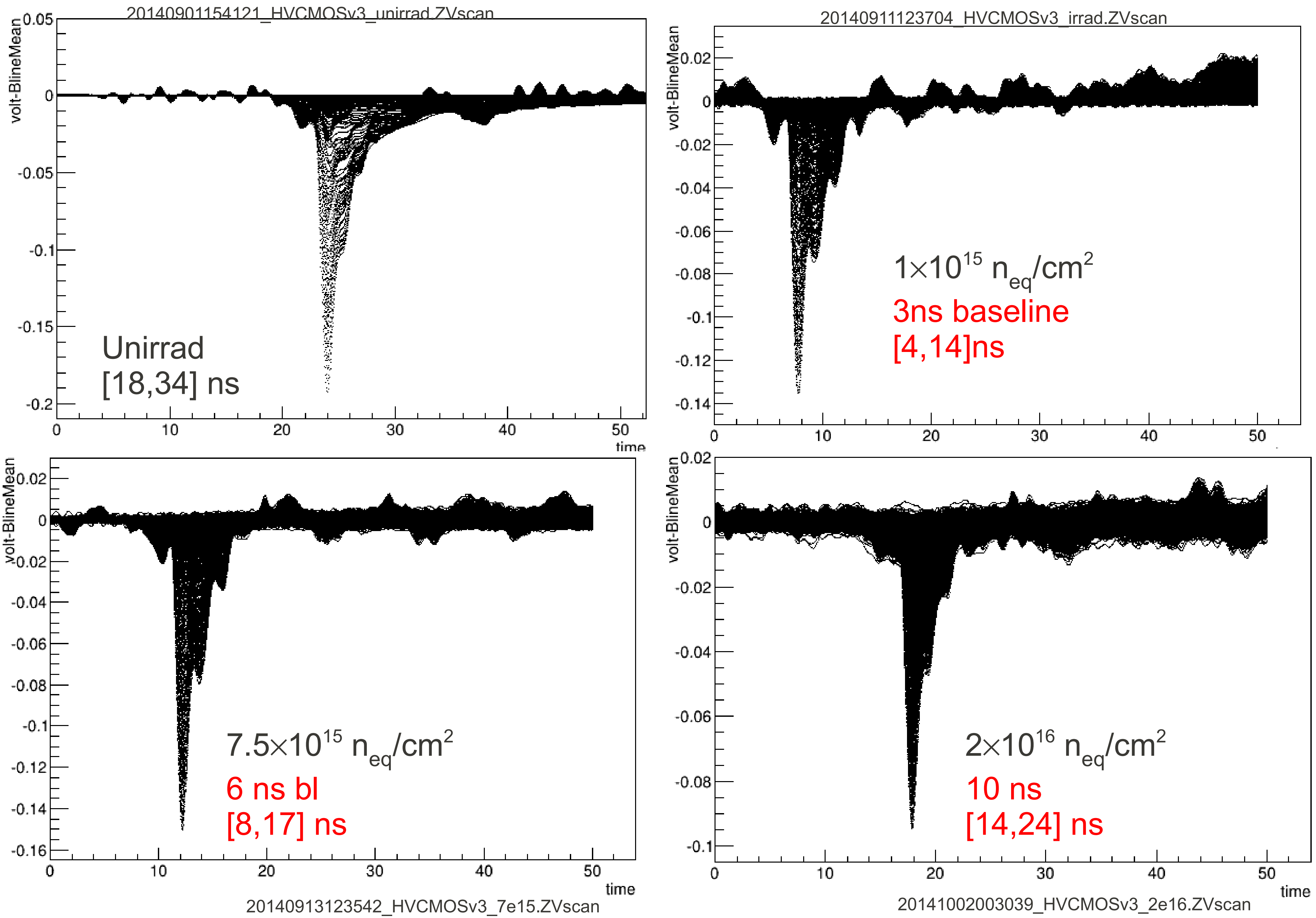
-5 V

Charge in 10 ns



Diode looks symmetric in conf 1

All signals, all voltages [-90,0], conf. 2 (diode)


20140901154121_HVCMOSv3_unirrad.ZVscan

Unirrad
[18,34] ns

20140911123704_HVCMOSv3_irrad.ZVscan

1×10^{15} n_{eq}/cm^2
3ns baseline
[4,14]ns

20140913123542_HVCMOSv3_7e15.ZVscan

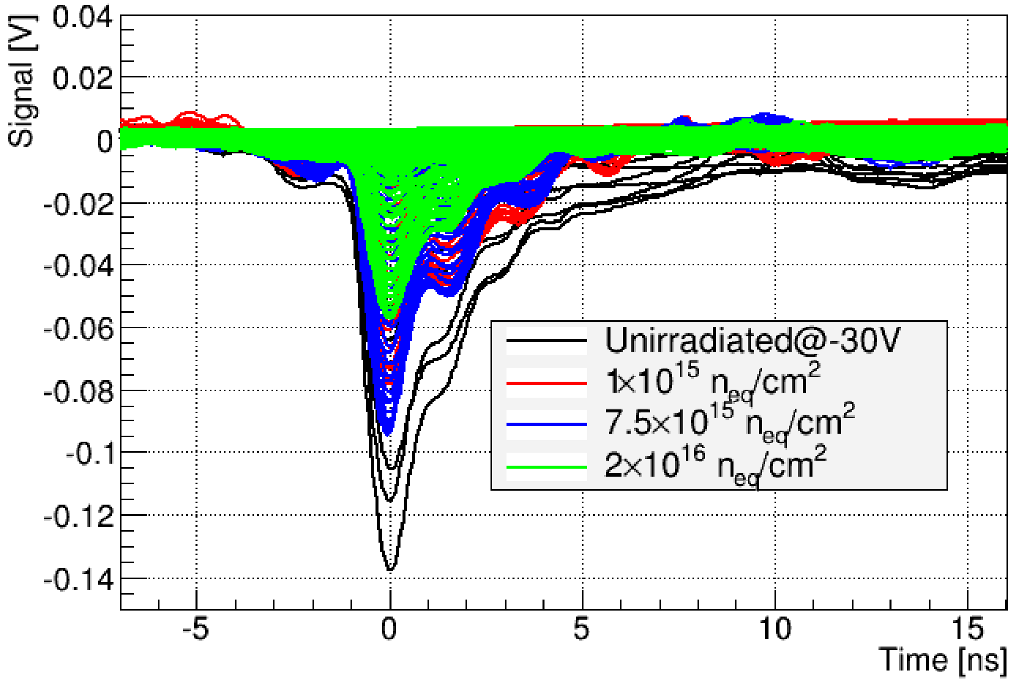
7.5×10^{15} n_{eq}/cm^2
6 ns bl
[8,17] ns

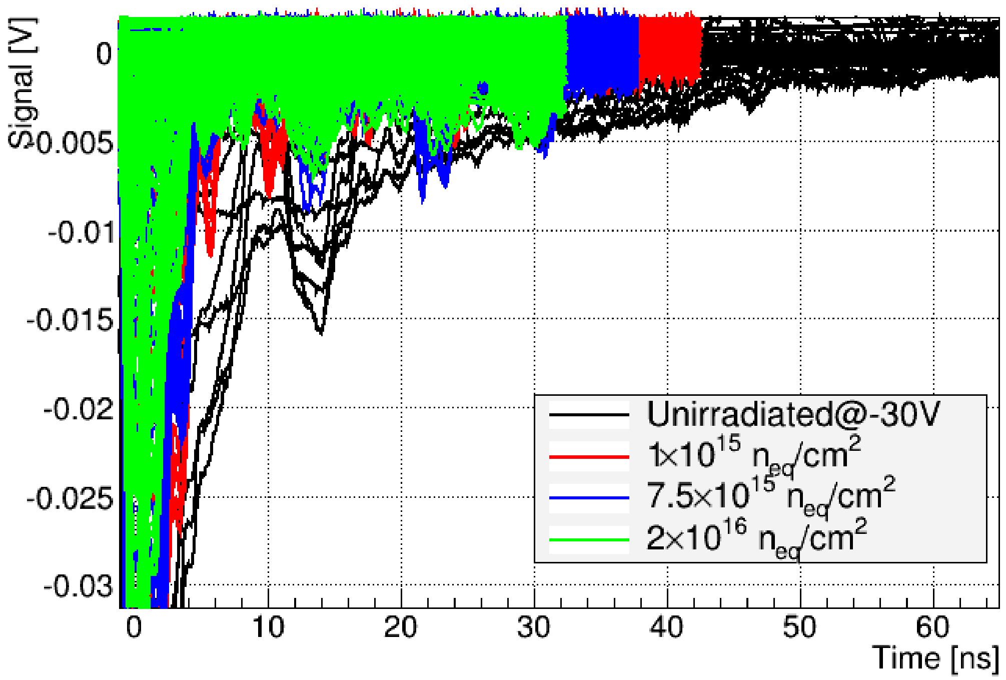
20141002003039_HVCMOSv3_2e16.ZVscan

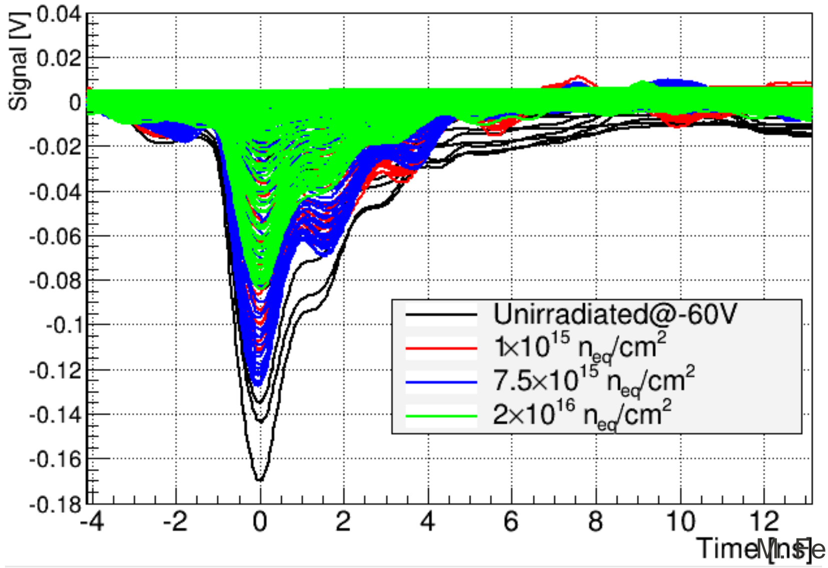
2×10^{16} n_{eq}/cm^2
10 ns
[14,24] ns

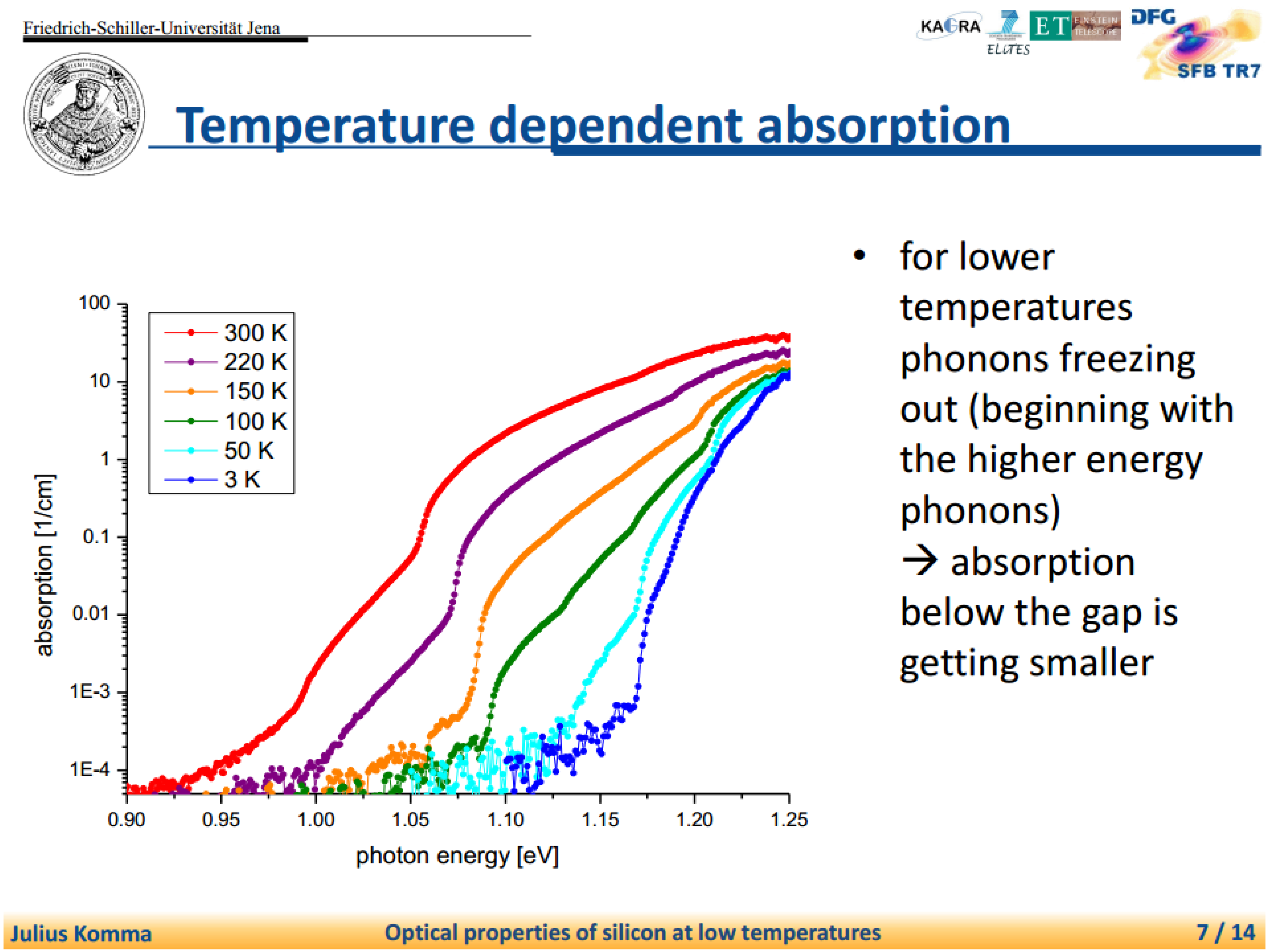
All in one plot (diode configuration)

Diode configuration catches mainly drift. For unirradiated detector diffusion still visible (1 order of magnitude smaller than drift effect)









Friedrich-Schiller-Universität Jena

Temperature dependent absorption

- for lower temperatures phonons freezing out (beginning with the higher energy phonons)
  → absorption below the gap is getting smaller

Julius Komma Optical properties of silicon at low temperatures 7 / 14

$\alpha = \frac{4\pi k}{\lambda}$ ⟶ K decreases → optical absortion decreases → less signal collected