Science & Technology Facilities Council

OVERMOS
CMOS HR detector for HEP applications

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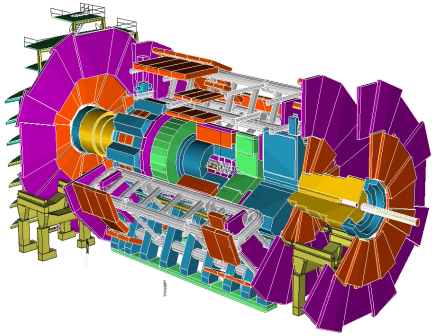
on behalf of OVERMOS project collaboration

Overview

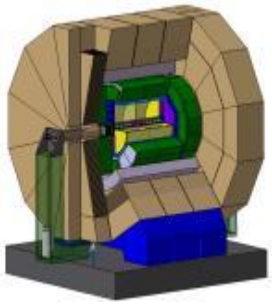
- OVERMOS1 description
- First test results of irradiated / non –irradiated OVERMOS1
- TCAD simulation
- Conclusions and next steps

Introduction – CMOS MAPS & HEP

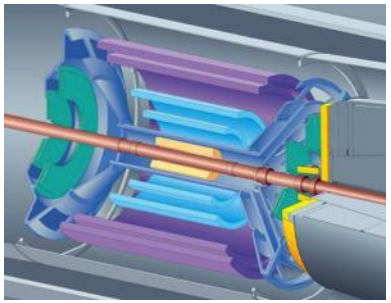
ATLAS



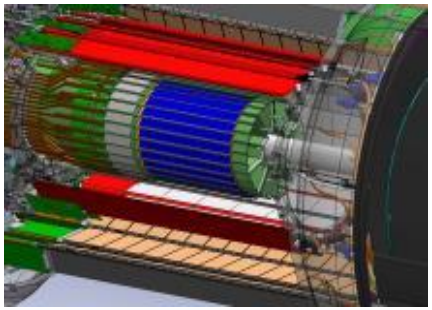
ILC



ALICE-LHC



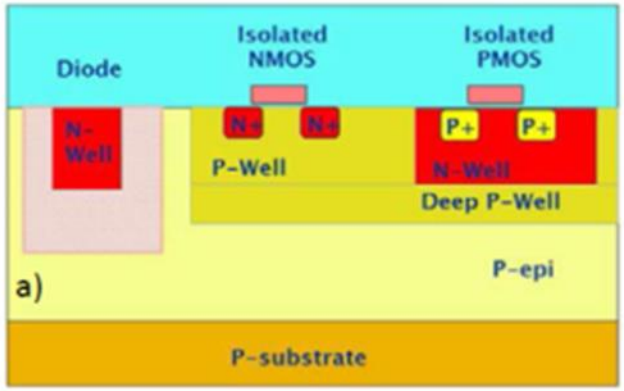
STAR at RICH



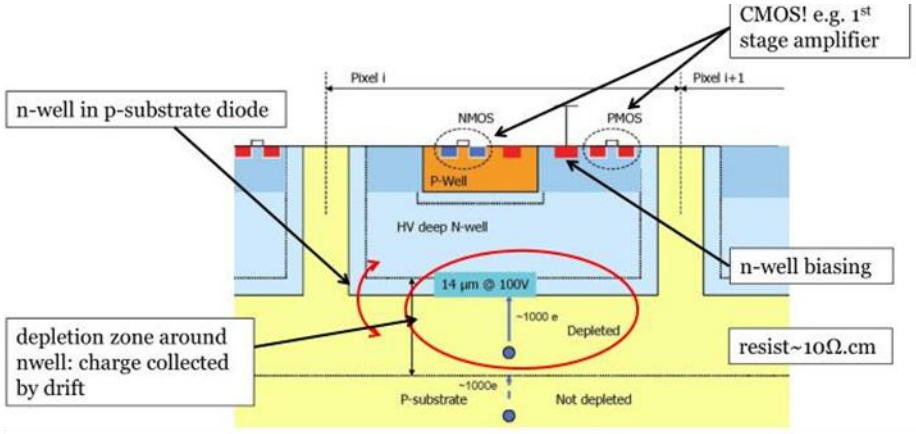
	ATLAS HL LHC	ATLAS	ILC	ALICE	STAR
TID[Mrad]	10^3	80	0.4	0.7	0.3
Fluence[n_{eq} cm^{-2}]	10^{16}	10^{15}	10^{12}	10^{13}	10^{12}
P.Rate[kHz mm^{-2}	10^4	10^3	$2.5 \bullet 10^2$	15	10^2
Timing[ns]	25	25	350	$2 \bullet 10^4$	$2 \bullet 10^5$

CMOS MAPS detectors solutions are and are going implemented in HEP
Further improvements needed for more challenging HEP use

Introduction – CMOS MAPS & HEP



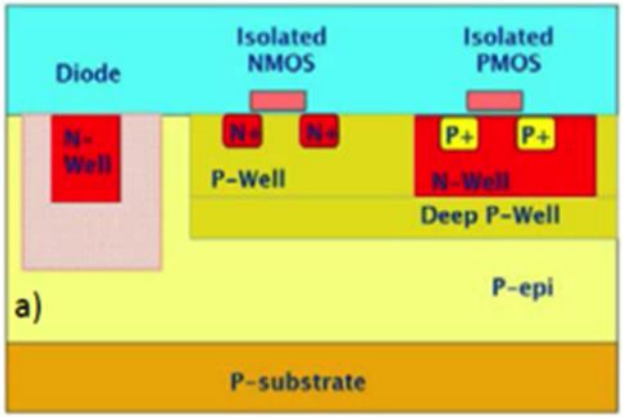
Small collection well
Small capacitance = low noise, low power
Electronics shielded by DPW,
Longer drift distance and relatively low field region

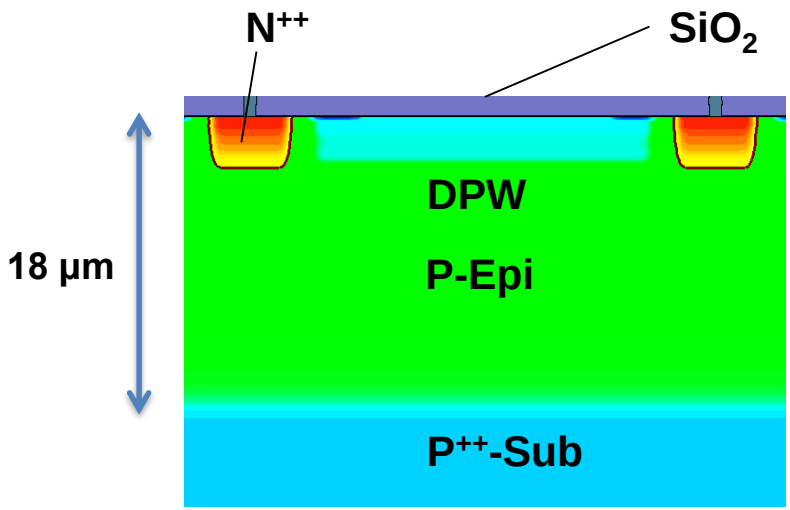


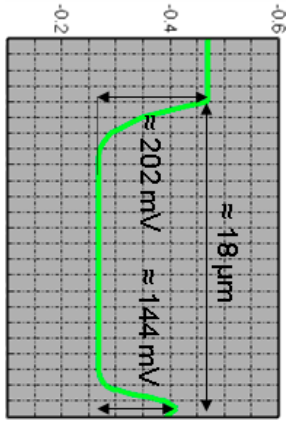
Large collection well
Larger capacitance = higher noise, higher power
Short drift distances, high field
Possible Xtalk from RO to sensor, as electronics inside the DNW

- **To improve the CMOS MAPS radiation hardness a drift component needs adding, as the diffusion based charge collection drastically reduces their CCE past ~ 10^{13} cm^{-2} 1 MeV n_{eq}**
- **As the depletion region ~ $\sqrt{\rho V_{bias}}$ one can either increase the resistivity ρ (HR CMOS) and / or the biasing V_{bias} (HV CMOS)**
- **Ultimately the sought end result is the same, i.e. a depleted CMOS MAPS (DMAPS)**

OVERMOS description

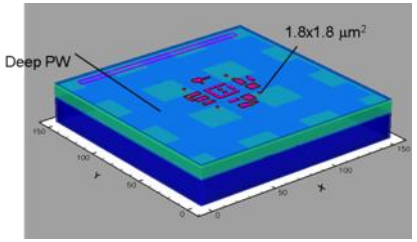






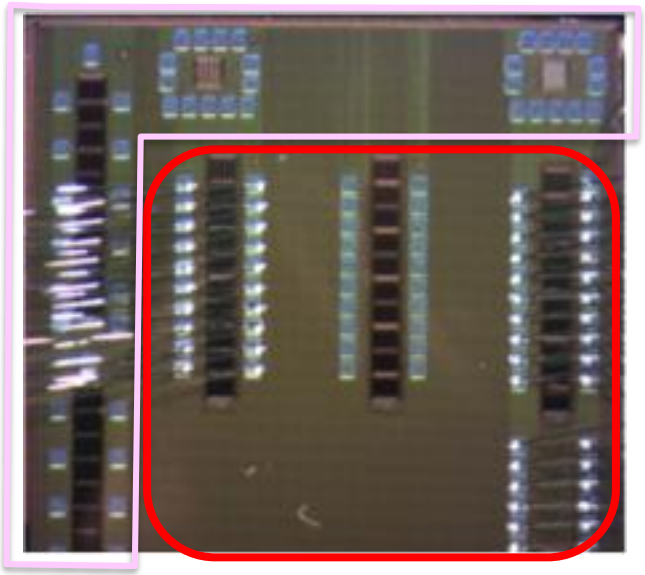
OVERMOS is a RAL project, in collaboration with IHEP, aimed at investigating and modelling performances of HR CMOS MAPS fabricated using:

- TJ 180 nm Hi-res 18 µm thick epitaxial layer 1kOhm –cm
- Small (4 x 4 μm^2) 4 collecting nodes within each pixel
- CMOS DPW or INMAPS, originally proposed TPAC for DECAL of ILC



OVERMOS1 description

PASSIVE



ACTIVE

- The ASIC logically consists of PASSIVE and ACTIVE structures, i.e. without and with in-pixel electronics respectively;

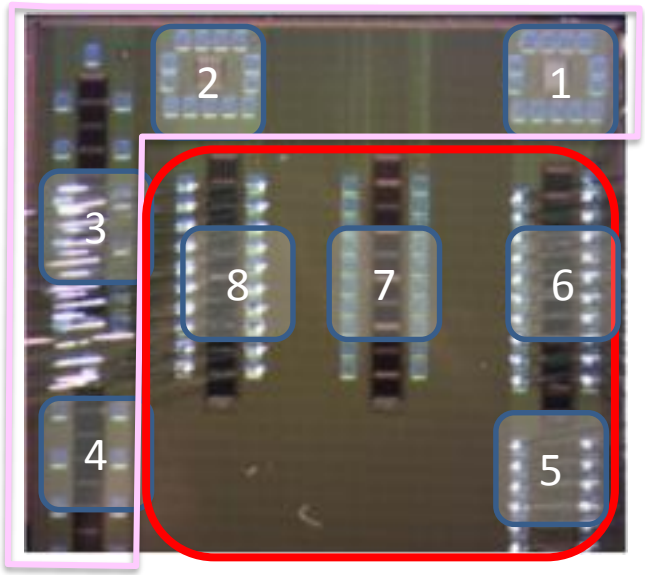
OVERMOS1 description

2: Basic Passive: 5x5 of 40 x 40 um

3: Basic Passive Large: 5x5 of 40 x 400 um merged

4: Basic Passive Large: 5x5 of 40 x 400 um

PASSIVE



1: Symmetric Passive: 5x5 of 40 x 40 um

8: Basic Active Large 5x5 of 40 x 400 um

7: Basic Active Large Merged 5x5 of 40 x 400 um

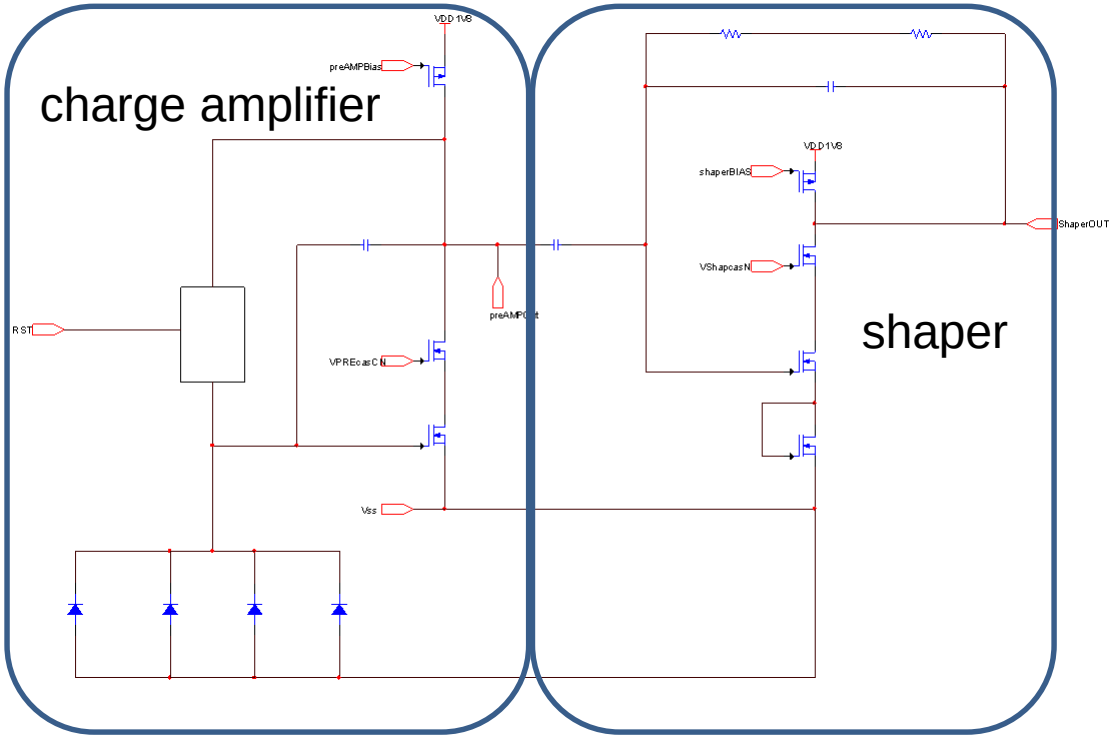
6: Basic Active AC Large 5x5 of 40 x 400 um independent diode biasing AC coupled

5: Basic Active: 5x5 of 40 x 40 um

ACTIVE

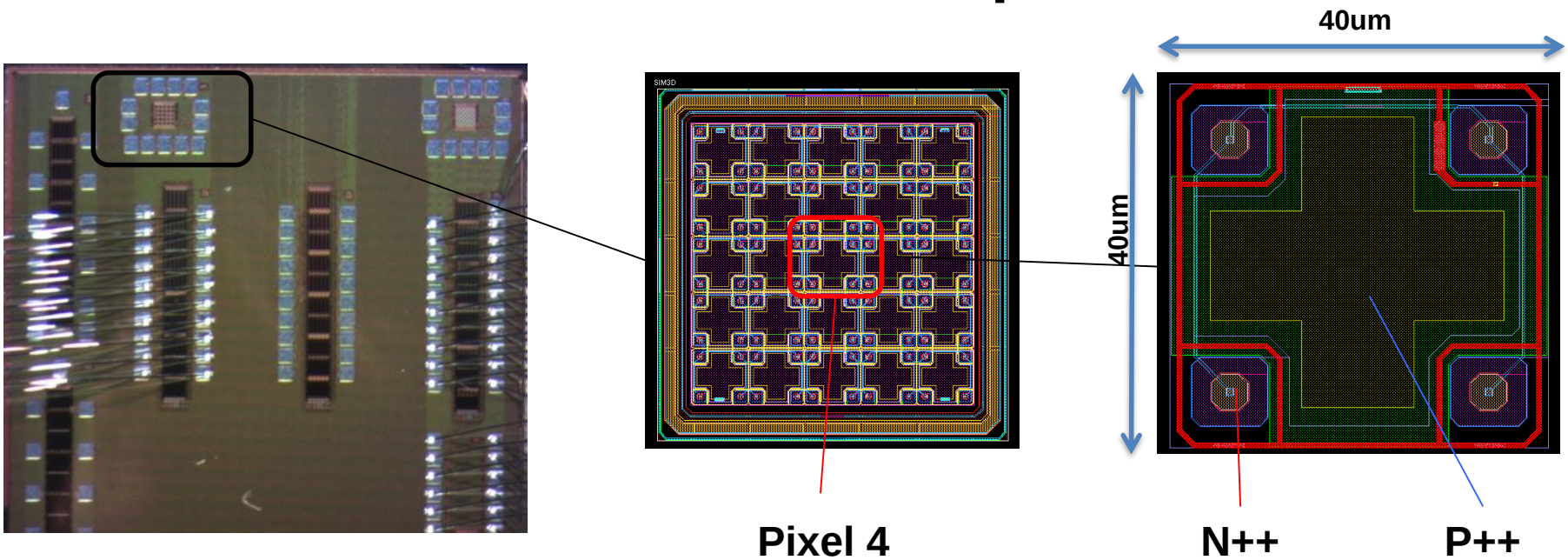
- The PASSIVE pixels consist of arrays of pixels with different arrangements of the 4 collecting nodes (of the same size) within each pixel
- The ACTIVE pixels, i.e. with in-pixel electronics, all allow analogue readout of the pixels

OVERMOS1 description



- The ACTIVE pixels include a charge amplifier, shaper and Voltage follower with each output being routed out
- Some flavours feature AC coupling to the RO, allowing for relatively high voltage biasing to the pixels

OVERMOS1 description



- All the pixels in the OVERMOS1 include an p++ region around each diode to isolate them from neighbouring ones, an issue that plagued previous version of OVERMOS
- The OVERMOS1 ASIC ‘basic passive’ has been tested before and after n-irradiation for DC and charge collection

OVERMOS1 irradiation

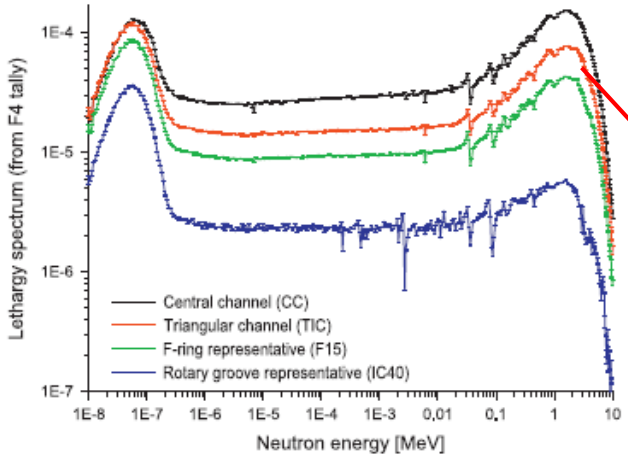


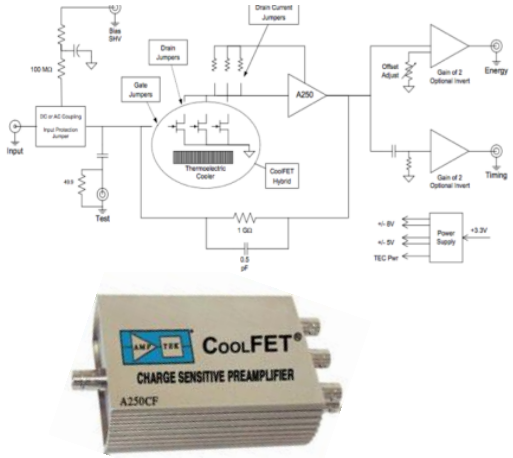
Fig. 4. Lethargy neutron spectrum in representative irradiation channels in core 189 of the TRIGA reactor. Normalization per source neutron.

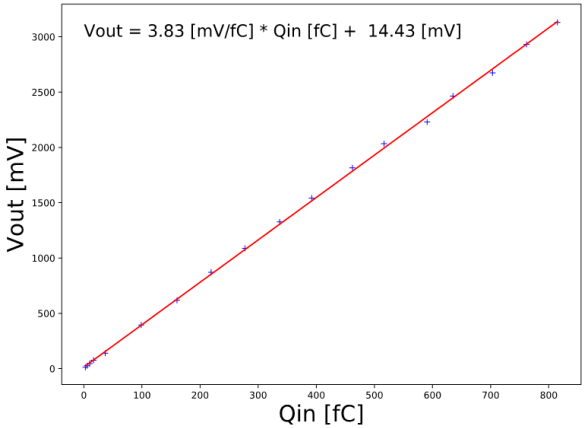
Fractions of thermal (<0.625 eV), epithermal (0.625 eV–0.1 MeV), and fast (> 0.1 MeV) neutron fluxes in TRIGA (core 189) irradiation channels.

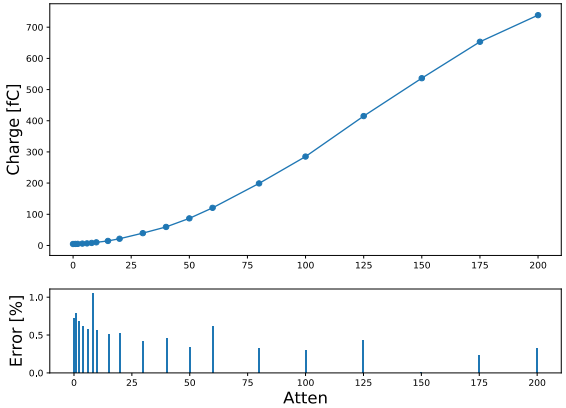
Irradiation channel	**Thermal** (%)	**Epithermal** (%)	**Fast** (%)
CC	26.6	33.9	39.5
ThCol	79.0	14.4	6.6
RPP	57.2	23.9	18.9
RBP	83.3	12.2	4.5
TangCh	57.8	24.9	17.3
F15	42.6	28.5	28.8
F19	50.0	25.3	24.6
F22	47.8	26.2	26.0
F24	47.4	26.5	26.1
F26	48.4	25.9	25.7
IC40	60.4	25.1	14.5
TIC	37.9	29.4	32.7

- OVERMOS devices have been irradiated at Ljubljana in October 2017 to 1E13, 5E13,1E14 and 5E14 n fluence
- Estimated around 30% of fluence consisting of high energy neutrons (> 100keV)

OVERMOS1 Charge collection





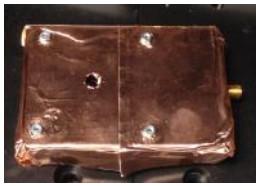


Charge collection studies performed using Laser injection:

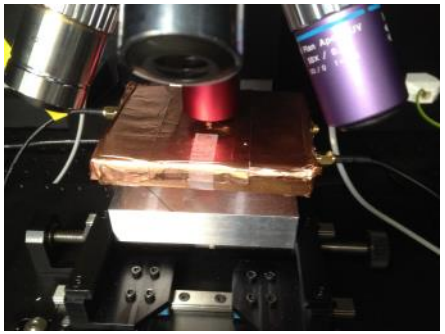
1: Amptek A250CF calibrated using mV voltage pulses injected through (measured) 1.2 pF capacitor to get V(Q). RMS Noise ≈ 76 e- @ OVERMOS capacitance

2: Trilite Laser 1064 nm calibration using a 300 um Si sensor, 1um top passivation. Laser beam size 5 x 5 um2 (measured with beam profiler), 4.1 ns FWHM (measured with FEMTO 2 GHz optoreceiver), 50 Hz repetition rate. Up to 5 points measured on sensor to calculate average injected charge

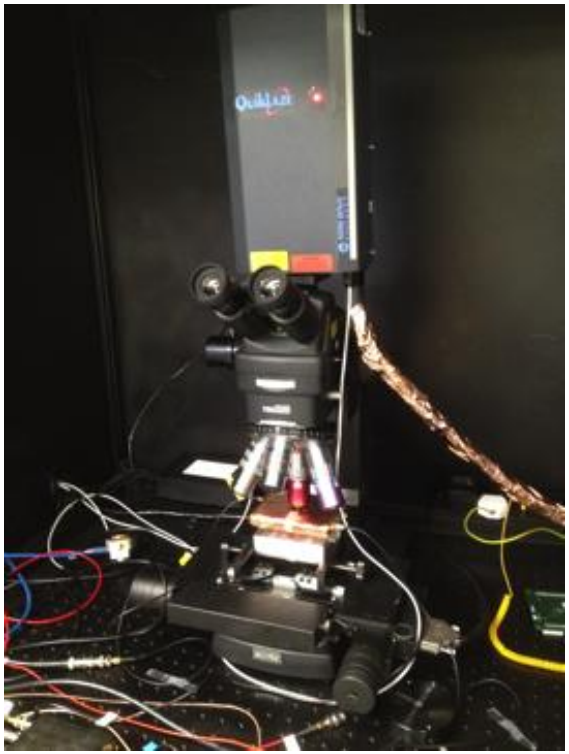
OVERMOS1 Charge collection

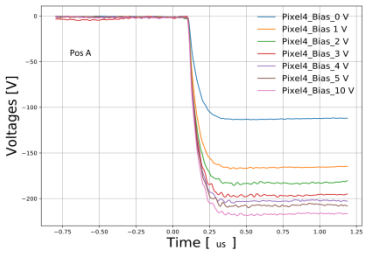


OVERMOS
In metal box
to reduce EMP noise



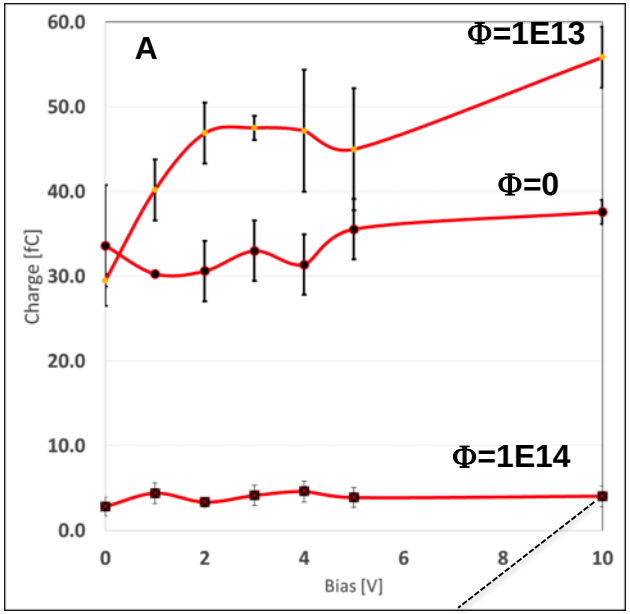
OVERMOS
Under Laser 100x optics



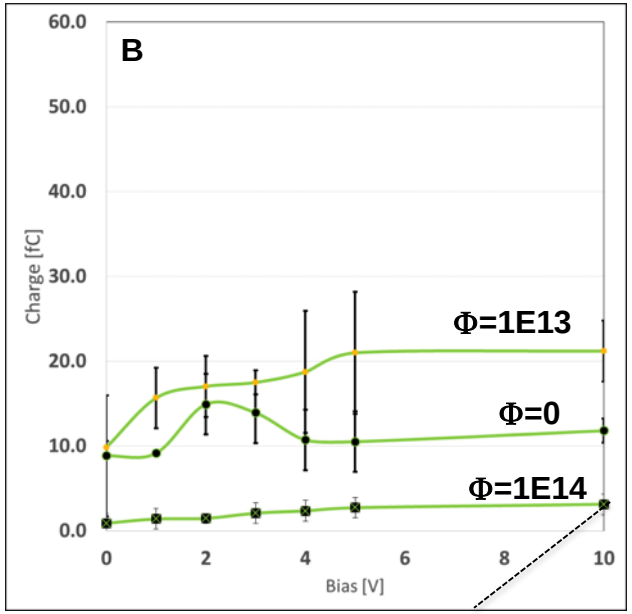


3: the calibrated Laser was used to inject <Q injected> = 541.66 fC or 1.805 fC/um (corresponding to the Laser attenuation settings which gave the minimum error %)
(not taking into account IR reflection on ASIC's top)

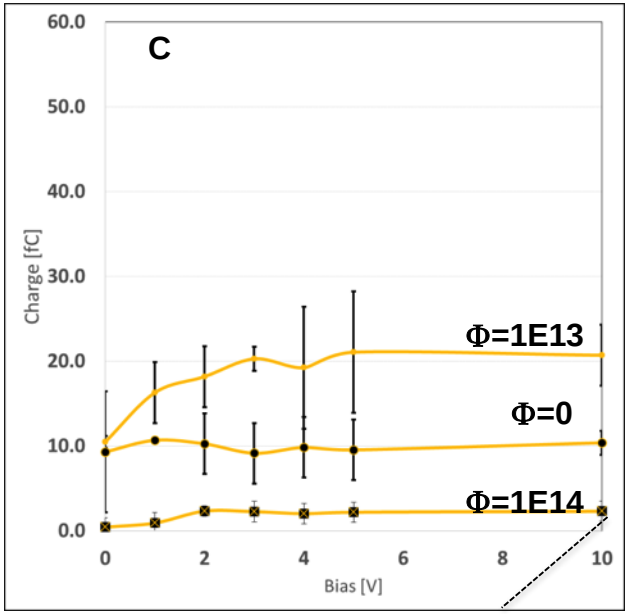
OVERMOS1 Charge collection



4.04fC
±29.7%

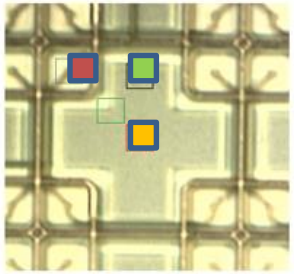


3.14fC
±36.3%



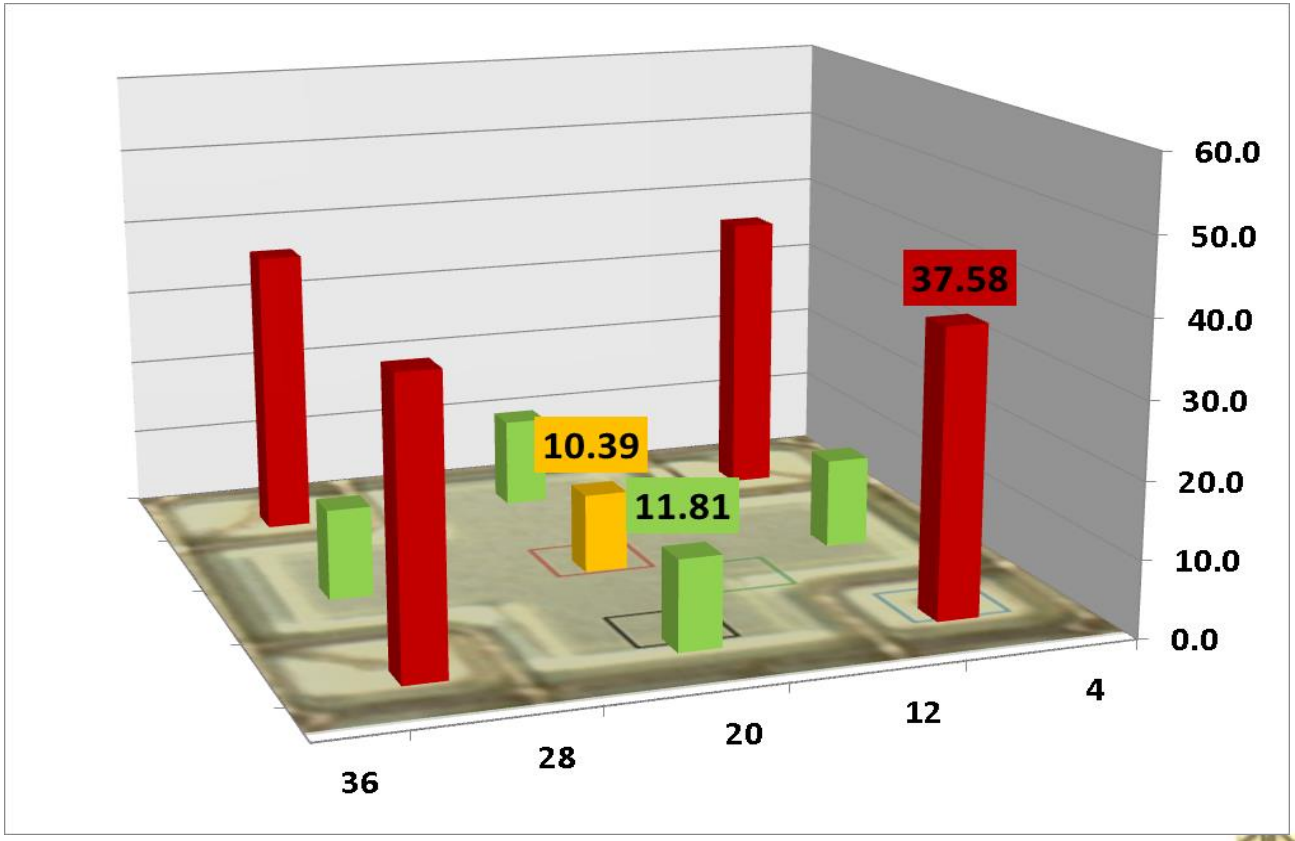
2.31fC ±5.4%

- Total collected charge vs. Vbias , points A,B,C. Integration time 400 ns
- <Q injected> = 1.805 fC/um
- HVbias =10V provided through the A250CF, via a 400 Meg resistor chain
- T = 21C in all tests

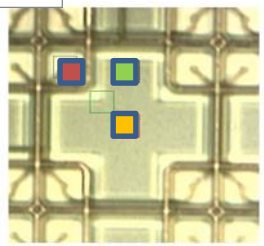


OVERMOS1 Charge collection

Φ=0

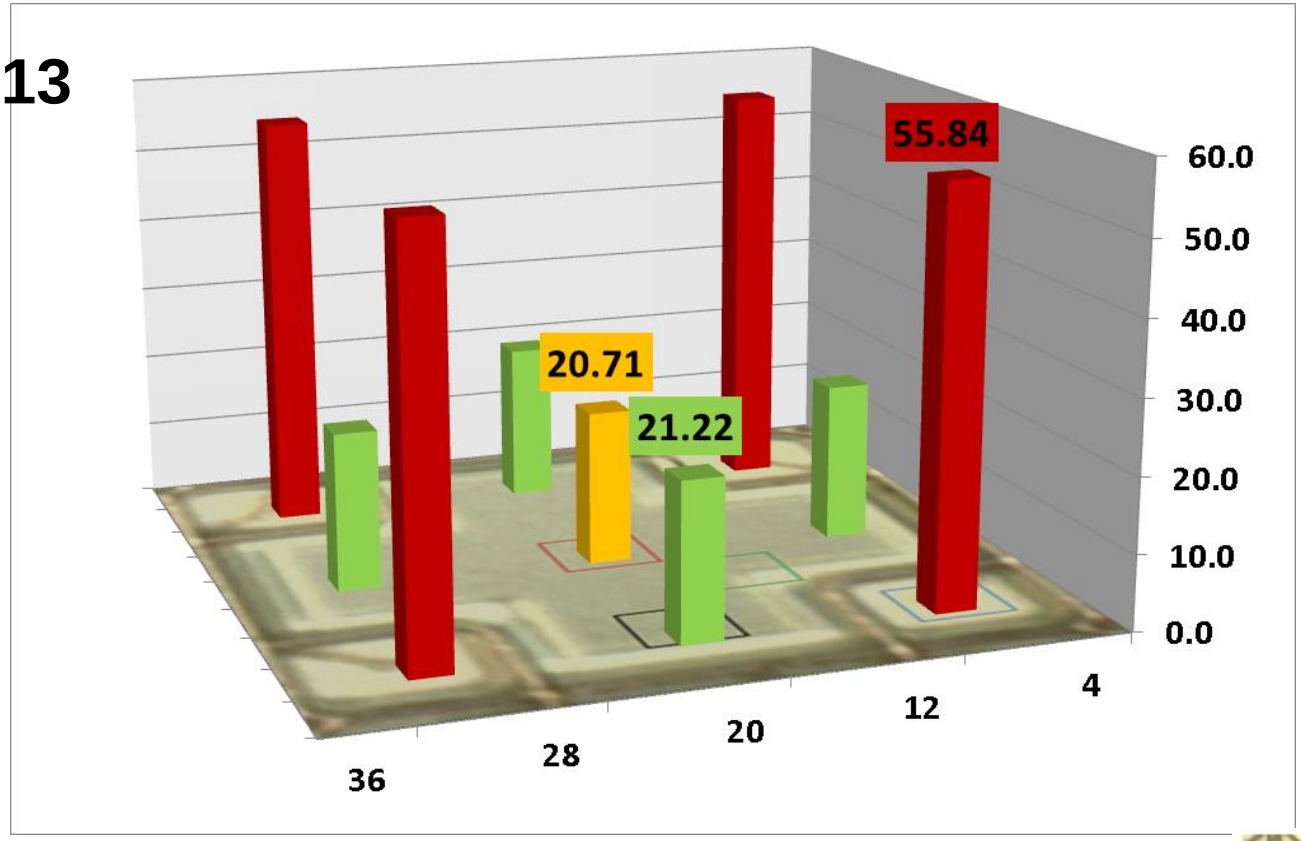


Laser injection test results (1064 nm, 5 x 5 um2 beam size)
Vbias = 10V
<Q injected> = 1.805 fC/um



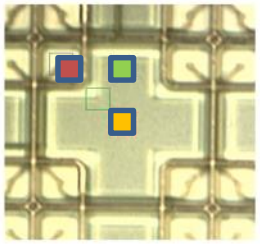
OVERMOS1 Charge collection

Φ=1E13



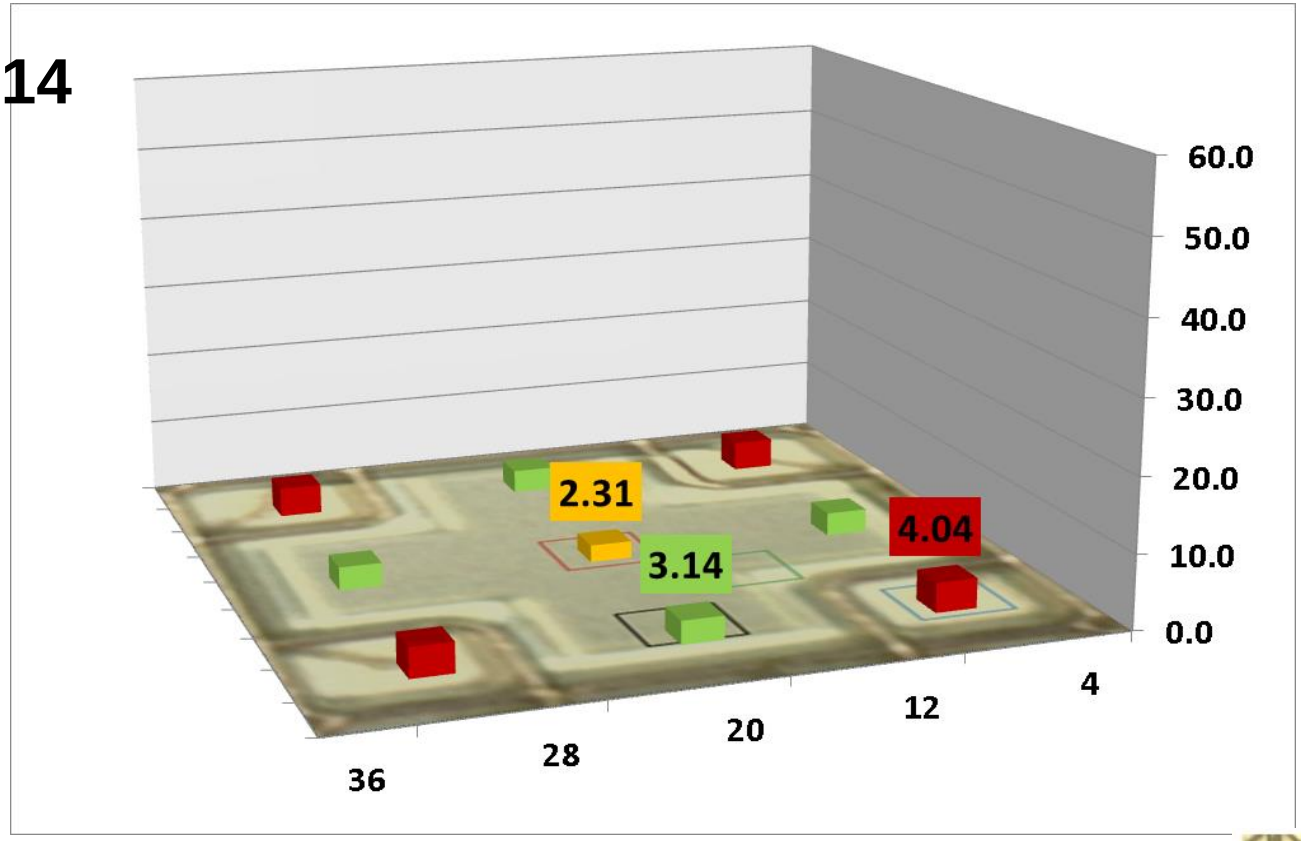
Q[fC]

Laser injection test results (1064 nm, 5 x 5 um2 beam size)
Vbias = 10V
<Q injected> = 1.805 fC/um

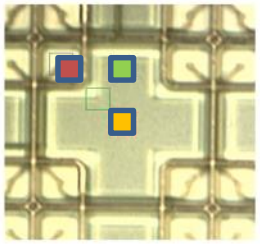


OVERMOS1 Charge collection

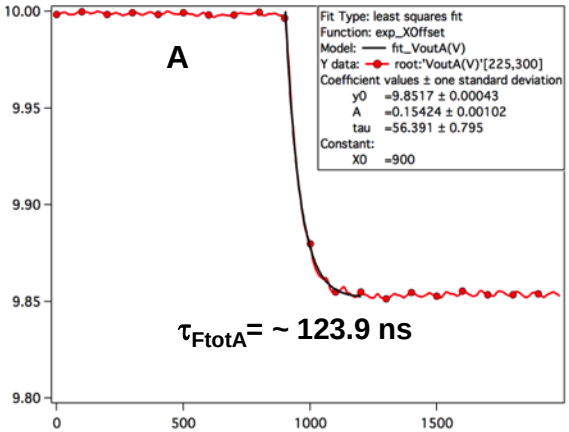
Φ=1E14

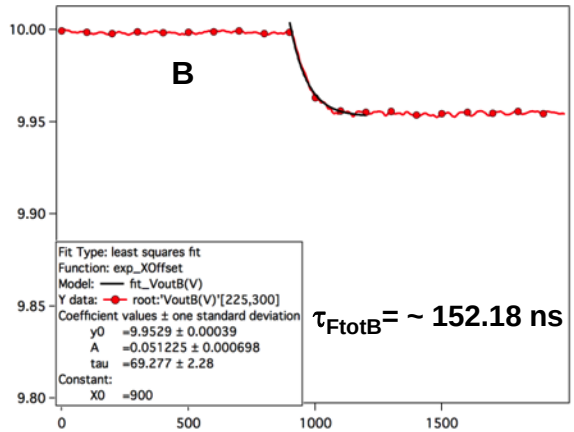


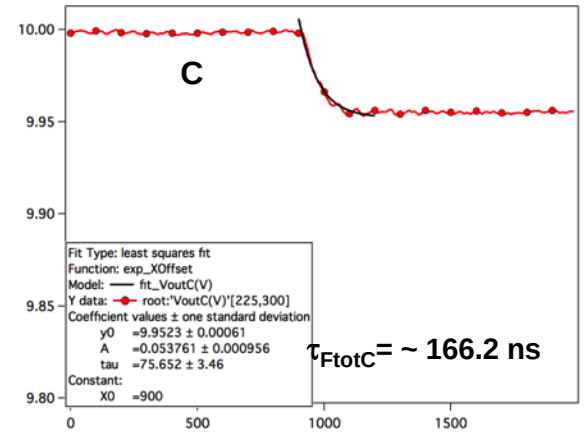
Laser injection test results (1064 nm, 5 x 5 um2 beam size)
Vbias = 10V
<Q injected> = 1.805 fC/um



OVERMOS1 collection time





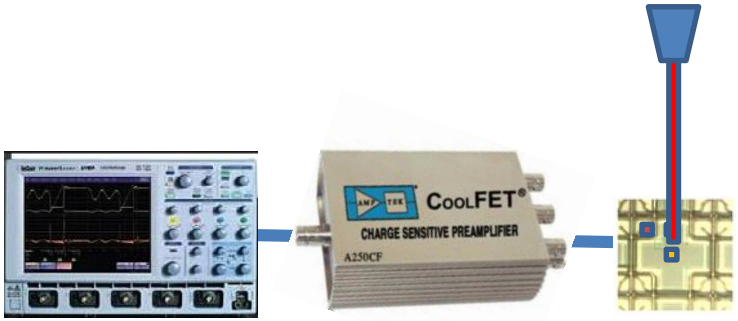


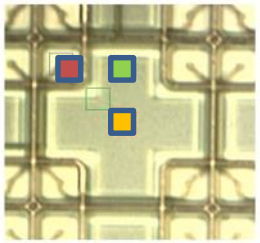
Collected charge vs. time, points A,B,C Vbias = 10V, $\underline{\Phi = 0}$
<Q injected> = 1.805 fC/um

AMPTEK A250CF
τ_{RAMP}= 15 ns

τ_{Fs} ~ sqrt((τ_{Ftot})^2 - (τ_{RAMP})^2) ~

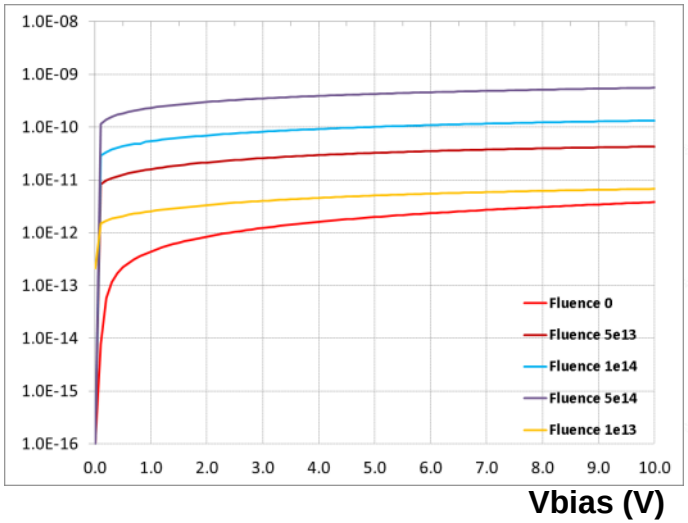
A: 123 ns
B: 151.4 ns
C: 165.5 ns

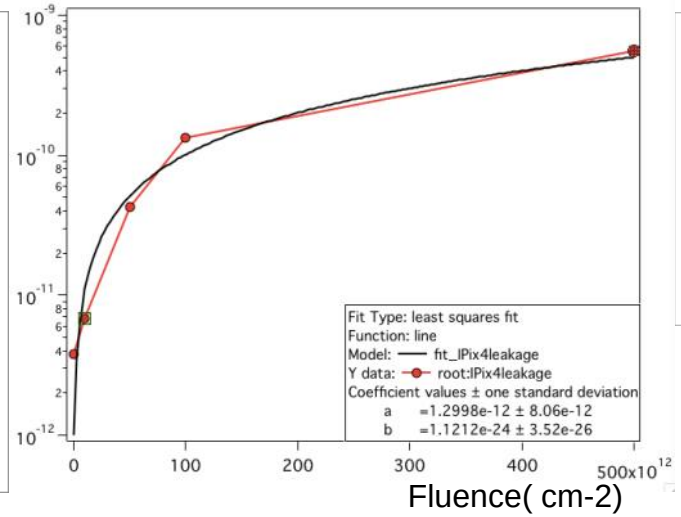


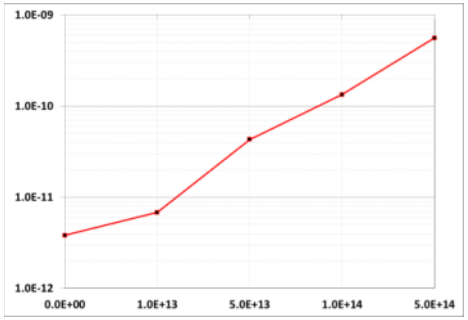


OVERMOS1 DC test

Ipix4 (A)

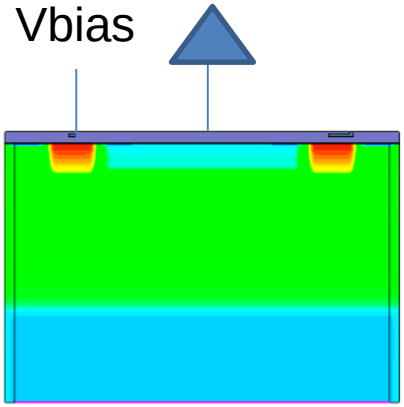






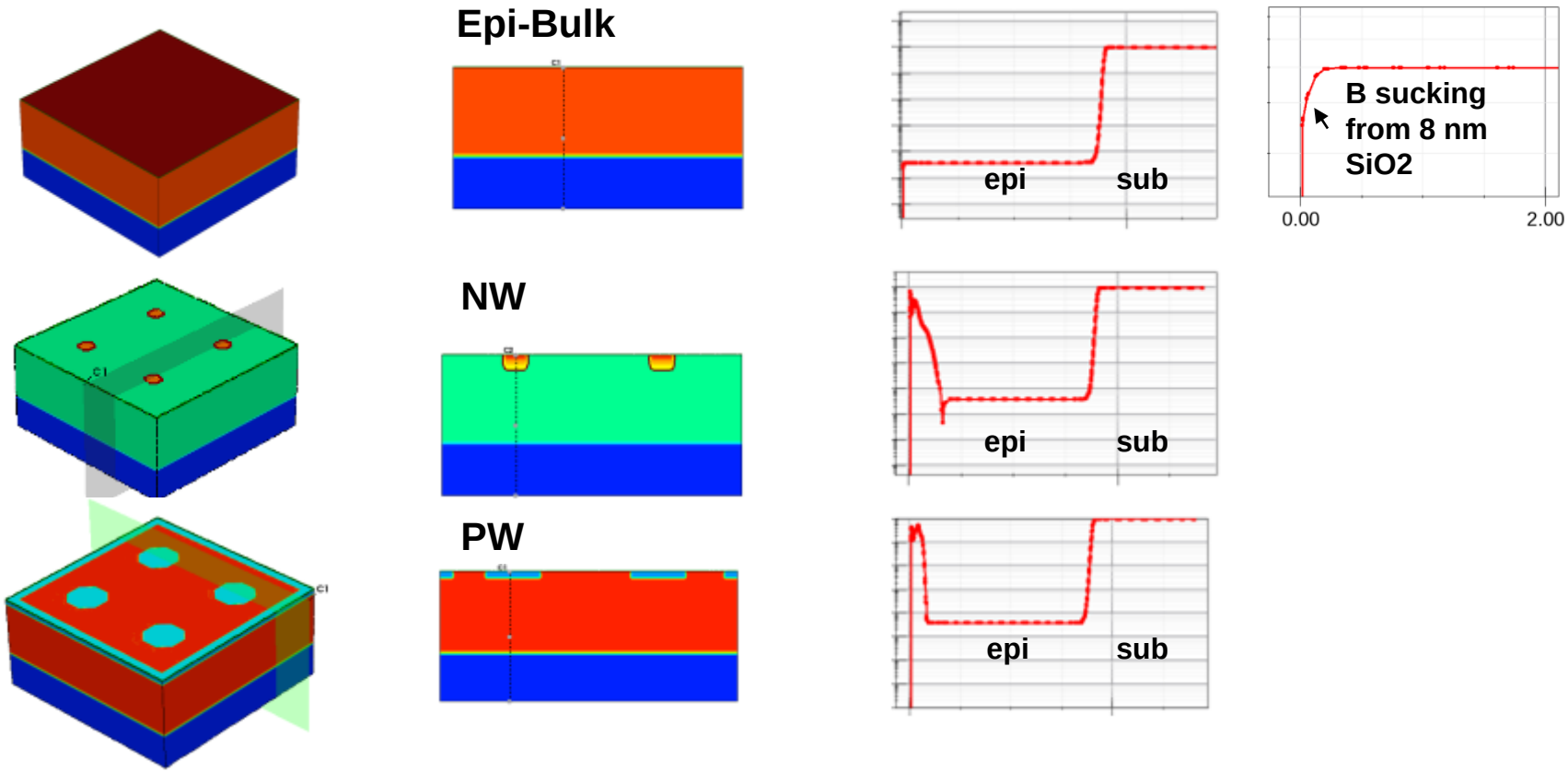
$$I = I_0 + K\Phi$$

K = 1.121e-24 ± 3.52e-26



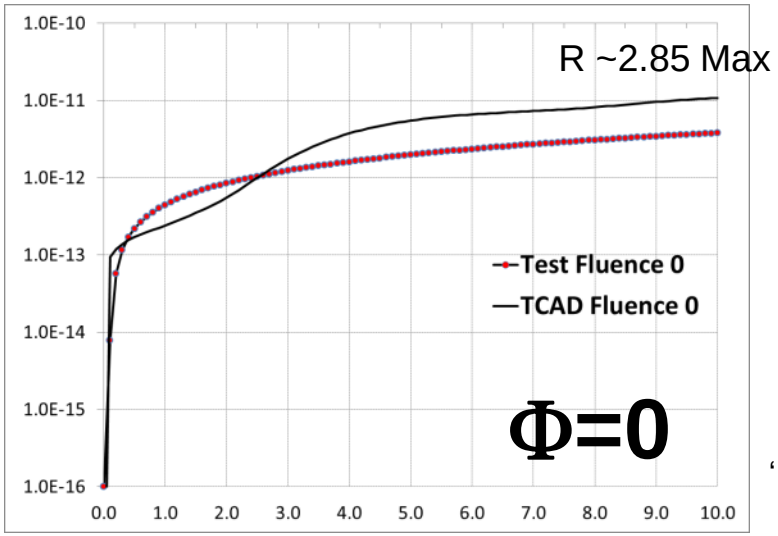
- DC test results of leakage currents test of single pixel 4 with substrate and other pixels floating
- Linear increase with fluence, as expected

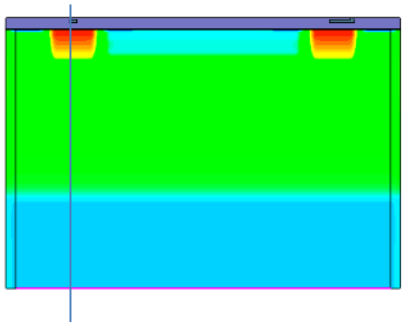
Synopsys TCAD simulations



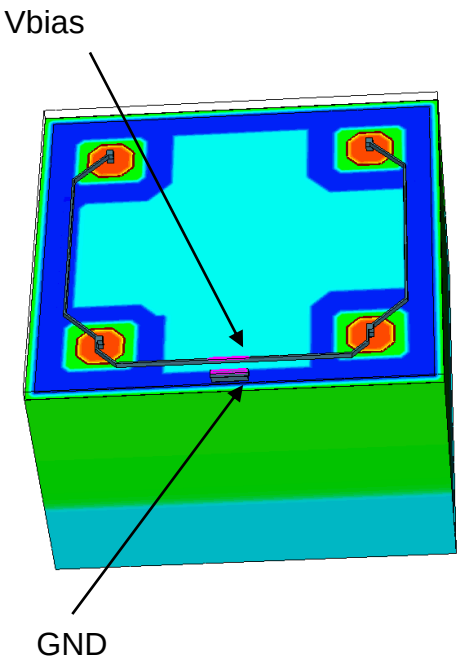
- Individual doping profiles for OVERMOS were obtained using **SPROCESS**, to simulate a (simplified) CMOS fabrication by using TJ foundry process information
- These (1D) doping profiles were then implemented in **SDE**
- Huge reduction in mesh size (O(3e5) points) and computation time

TCAD DC initial results
Leakage currents





'1D' profiles from SPROCESS



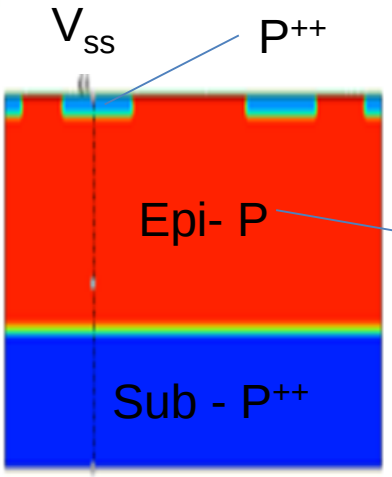
- Leakage current for tested non irradiated pixel and TCAD results differ by ~ 3 max
- Surface Recombination velocity SRV=1e4
- SiO2/Si trap density 1e11

Conclusions and next steps

- First test results of OVERMOS1 basic flavor were presented
- Measured with Laser injection, initial increase in CCE observed for irradiated device
- Charge collection drops by tenfold at **Φ = 1e14 w.r.t Φ = 0**
- DC tests showed expected leakage increase with n-fluence
- Initial TCAD simulations for DC only off by ~ 3
- **Next step: to fully characterise the remaining sensors, both passive and active and TCAD simulations comparisons**

<u>THANK YOU</u>

Backup slides Mott-Gurney currents



$$\frac{\partial}{\partial x} F = \frac{q\left(p - n + N_D - N_A\right)}{\varepsilon\varepsilon_0} \sim \frac{qp}{\varepsilon\,\varepsilon_0}$$

Leakage current is measured between P wells (top and substrate)
For constant current and assuming only drift component

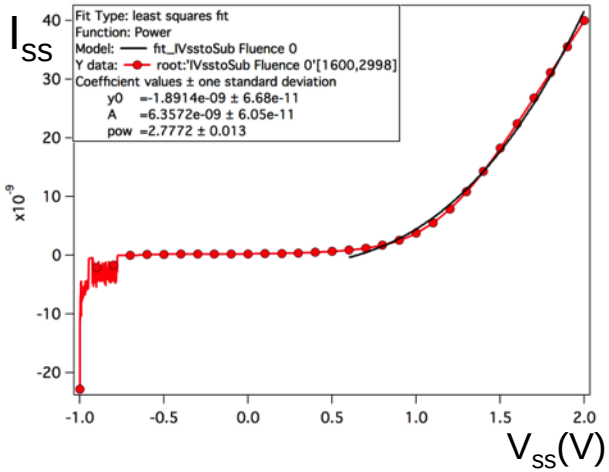
$$j = q p \mu_p F \longrightarrow p = \frac{j}{q \mu_p F} \longrightarrow \frac{\partial}{\partial x} F = \frac{j}{\varepsilon\,\varepsilon_0 \mu_p F}$$

$$\int_0^x F\left(\frac{\partial}{\partial z} F\right) dz = \int_0^x \frac{2j}{\varepsilon\,\varepsilon_0 \mu_p} dz \longrightarrow F^2 = \frac{2jx}{\varepsilon\,\varepsilon_0 \mu_p}$$

$$-\left(\int_0^{Z_{epi}} F\,dx\right) = V_{SS} \longrightarrow j = \frac{9}{8}\frac{\varepsilon\varepsilon_0 \mu_p V_{SS}^2}{Z_{epi}^3}$$

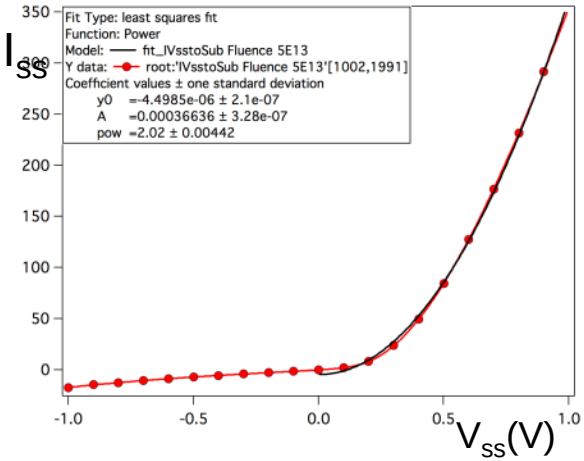
Backup slides - Leakage currents

Φ=0



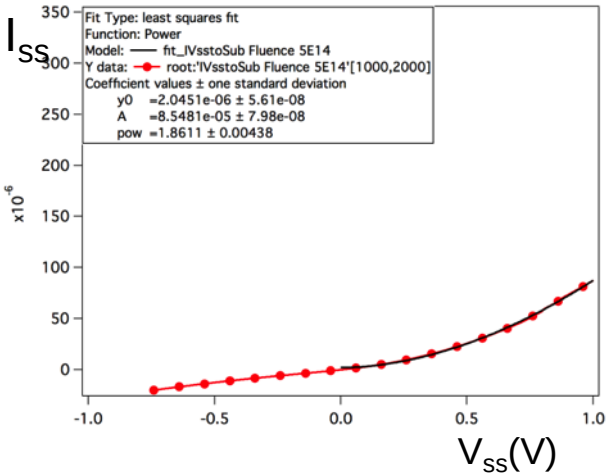
Φ=0: $I \propto V^{2.72}$

Φ=5E13



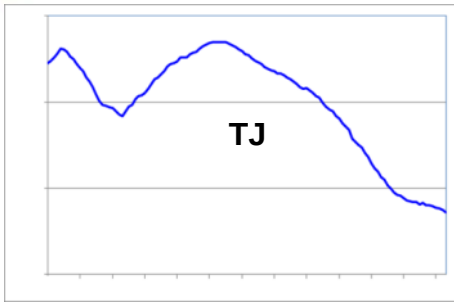
Φ=5E13: $I \propto V^{2.02}$

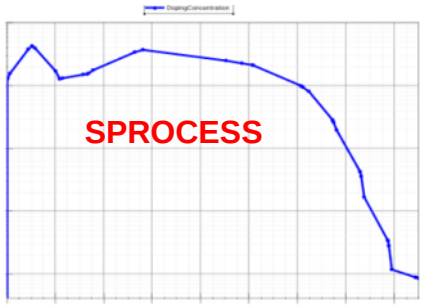
Φ=5E14



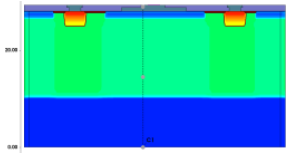
Φ=5E14: $I \propto V^{1.86}$

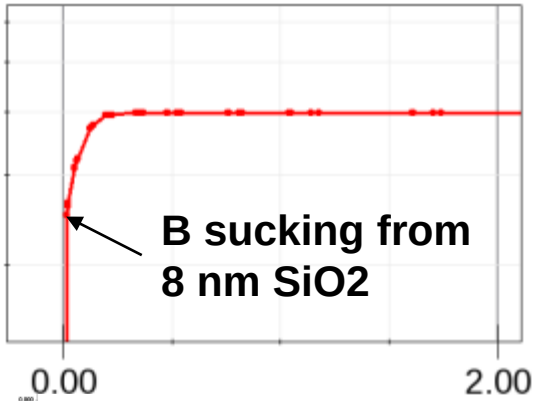
Fitting @ 5E13 shows a nearly ideal V^2 dependence
The power coefficient depends on the fitting
Only one device/ each radiation level
Asymmetry w.r.t. Vss may be due to conductive glue at the substrate

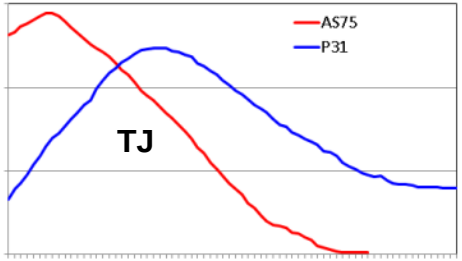




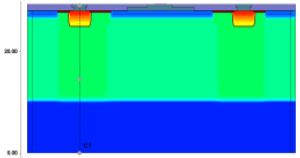
PW

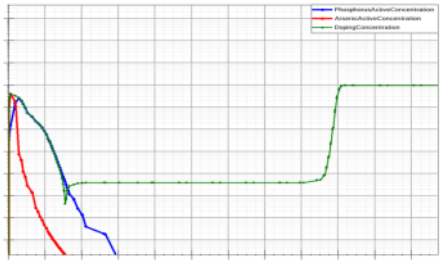




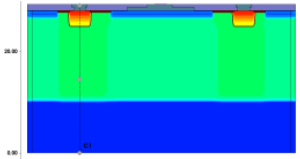


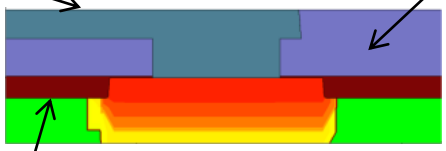
NW





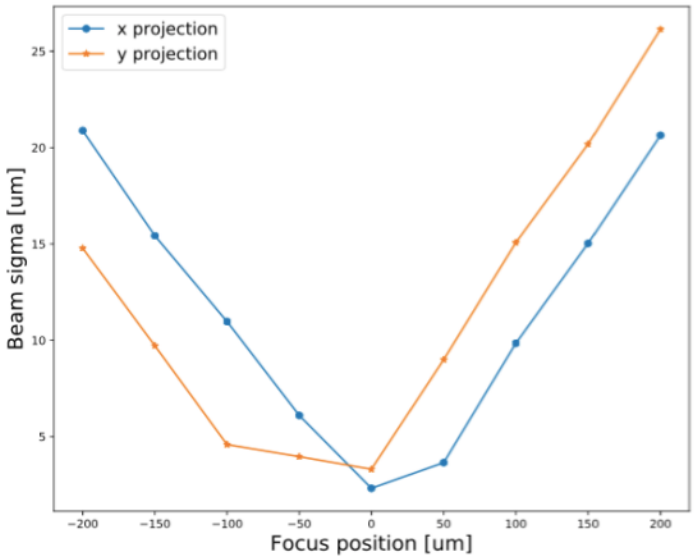
NW

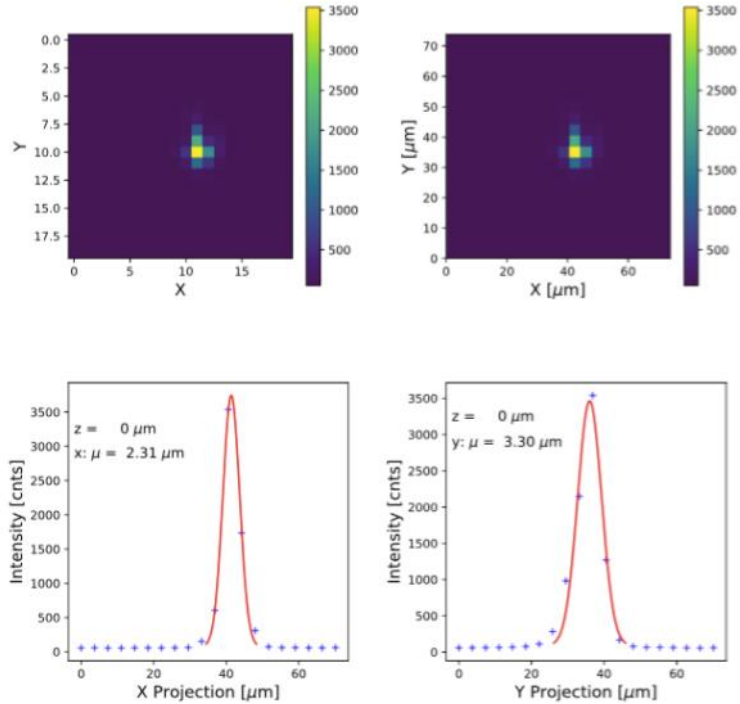




- Some approximations as a result but more affordable for big 3D simulations:
- No B sucking
- No lateral spread doping information
- Coarser doping profiles

BACKUP slides – Laser beam width





Laser beam size vs. focusing – Measured beam size with beam profiler

OVERMOS next steps

Determine Neff by measuring depletion width vs. bias
We use the Trilite Laser (~ 3 um minimum b.w. @ 1064 nm) to sample the OVERMOS1 along the edge