Science & Technology Facilities Council

First results on irradiated OVERMOS1 HR CMOS for HEP applications

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on behalf of OVERMOS project collaboration

Overview

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

OVERMOS description

OVERMOS features DPW originally proposed for ILC

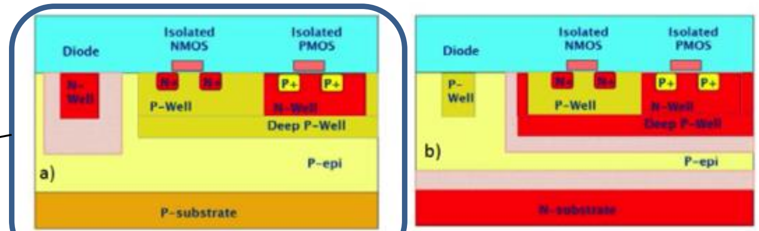


Figure 3. a) Original deep P-well pixel designed for TPAC as well as for ALICE and b) proposed new pixel architecture

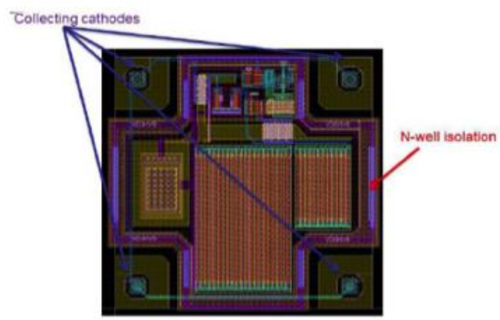
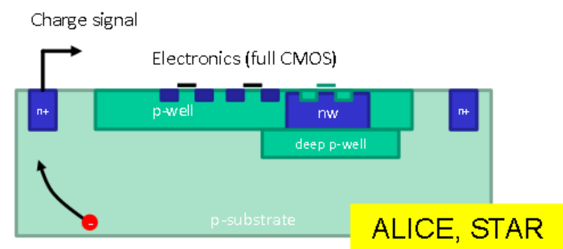


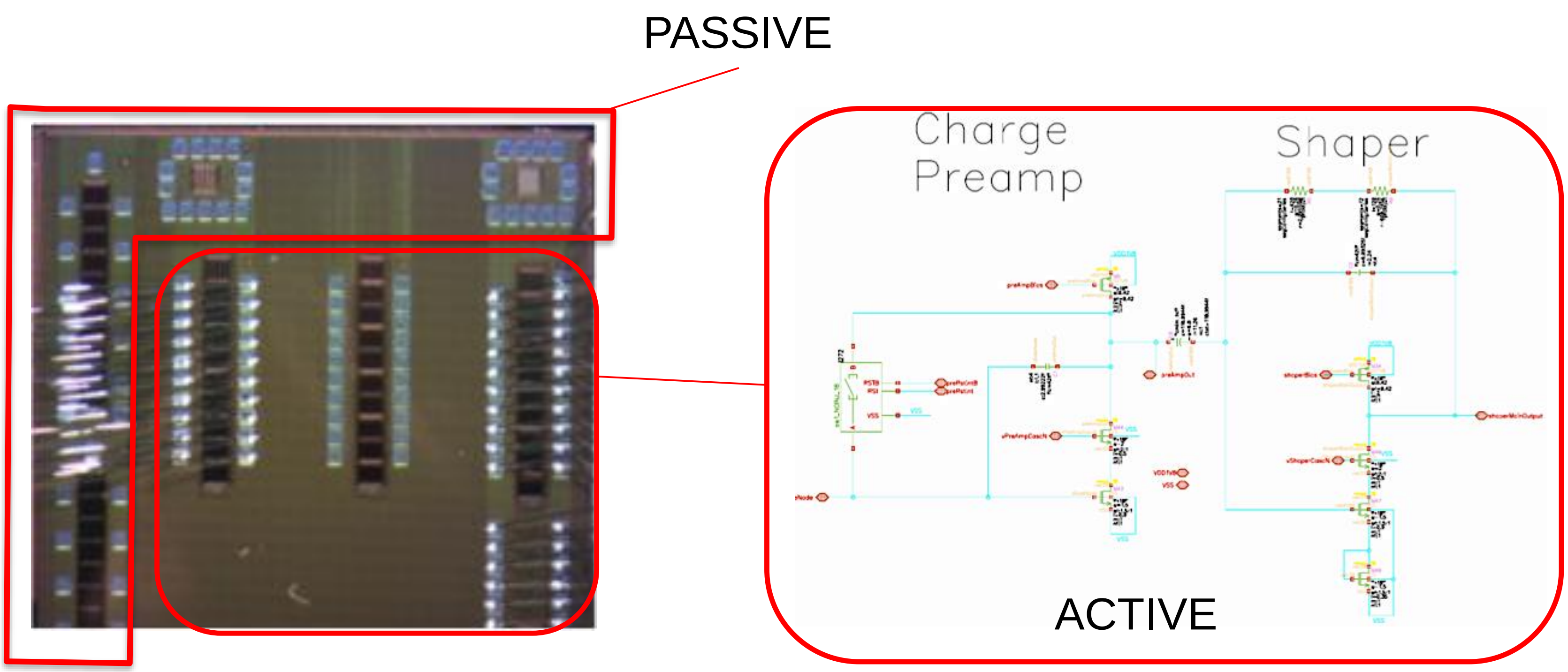
Figure 4 Example Pixel Circuit in ToweJazz 180 HR-CMOS



Electronics **outside** charge collection well
- Very **small sensor capacitance** → low power
- Potentially less rad. hard (longer drift lengths)
- Full CMOS with additional deep-p implant

MAPS imagers / detectors normally suffer from poor radiation tolerance due to slow charge collection
OVERMOS is a MAPS project demonstrator fabricated using TJ 180 nm Hi-res

OVERMOS1 description



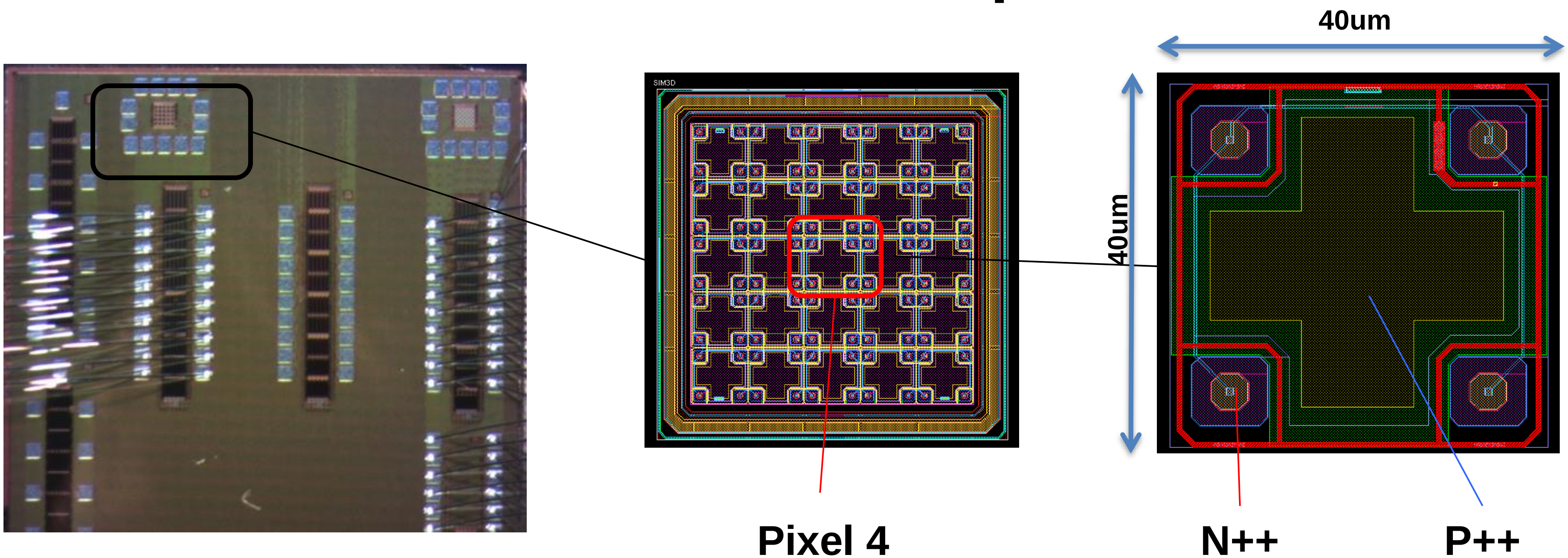
- The OVERMOS1 ASIC was fabricated using TowerJazz HR CMOS 180 nm P-type wafer , 18 um epitaxial layer
- Current OVERMOS1 addresses some previous issues found in OVERMOS
- The ASIC logically consists of PASSIVE and ACTIVE pixels, i.e. without and with in-pixel electronics respectively;

OVERMOS1 description

Pixel Types:

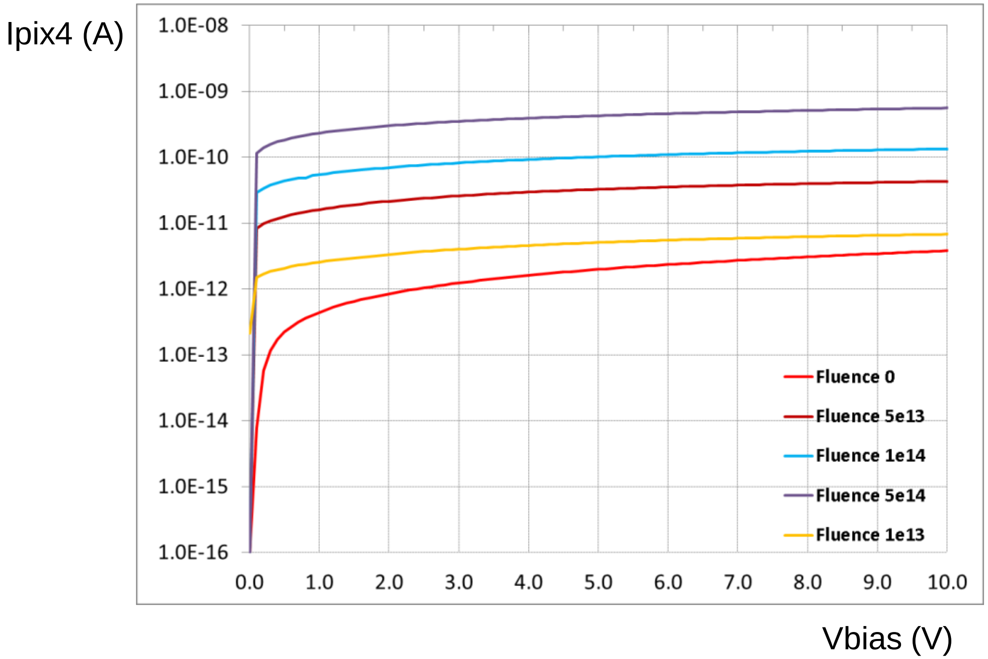
- Basic Passive: Basic diode (40u x 40u). 5x5 array. No in-pixel electronics. Inner 9 pixels individually accessible. Outer 14 jointly connected.
- Basic Active: Basic diode (40u x 40u).. 5x5 array. In-pixel electronics. Inner 9 pixels individually accessible. Outer 14 jointly connected.
- Basic Active AC: Basic diode (40u x 40u).. 5x5 array. In-pixel electronics. Inner 9 pixels individually accessible. Outer 14 jointly connected. Diode AC coupled to electronics with independent diode biasing.
- Symmetric Passive: Symmetric diode (40u x 40u).. 5x5 array. No in-pixel electronics. Inner 9 pixels individually accessible. Outer 14 jointly connected.
- Basic Passive Large: Basic diode (40u x 400u). 5x5 array. No in-pixel electronics. Inner 9 pixels individually accessible. Outer 14 jointly connected.
- Basic Active Large: Basic diode (40u x 400u). 5x5 array. In-pixel electronics. Inner 9 pixels individually accessible. Outer 14 jointly connected.

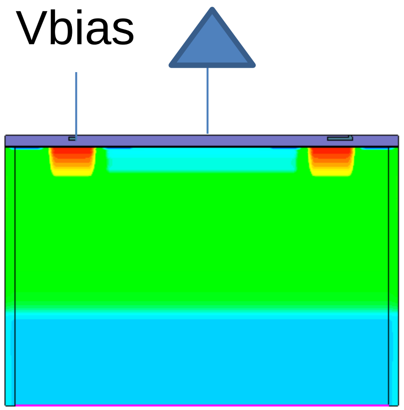
OVERMOS1 description



- All the pixels in the OVERMOS1 include an p++ region around each diode to isolate them from neighbouring ones, an issue that plagued the previous version of OVERMOS
- Diodes size 4.5 x 4.5 um2
- The OVERMOS1 ASIC 'basic passive' has been tested before and after n-irradiation for DC and charge collection

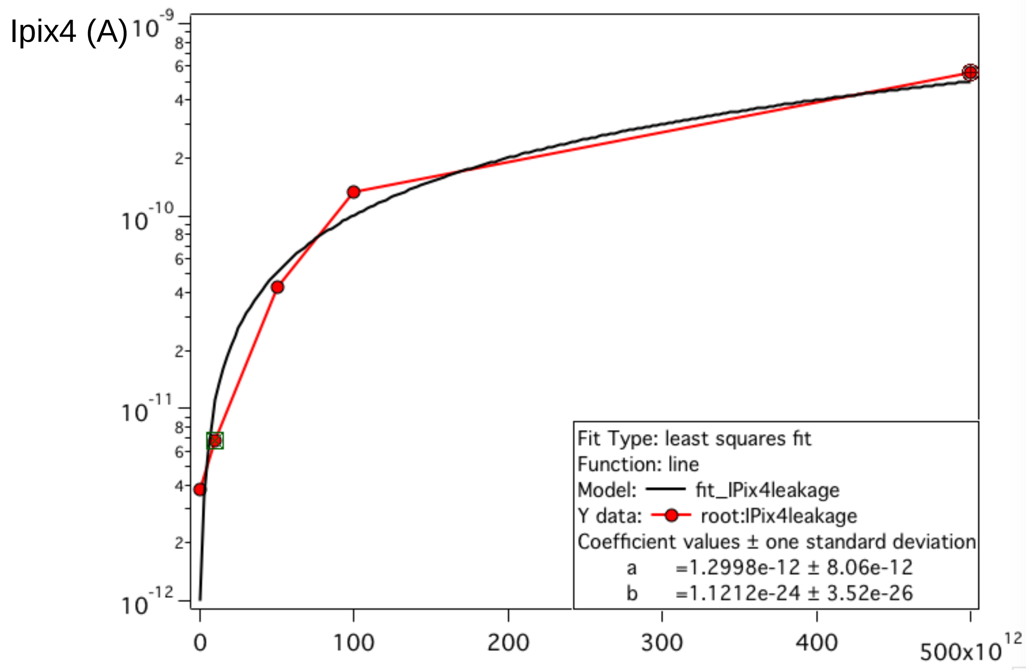
Single pixel leakage currents



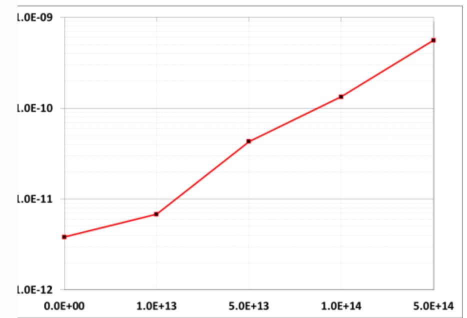


- **OVERMOS1 irradiated at Ljubljana in October 2017**
- **1E13, 5E13,1E14 and 5E14 n fluence**
- **The OVERMOS was glued onto a carrier and wirebonded**
- **Leakage currents test results of single pixel 4 with substrate and other pixels floating**

Single pixel leakage currents



Fluence(cm-2)



$$I = I_0 + K\Phi$$

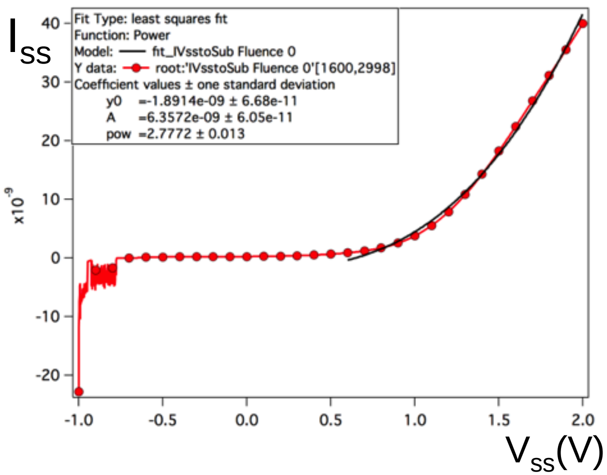
K = 1.121e-24 ± 3.52e-26

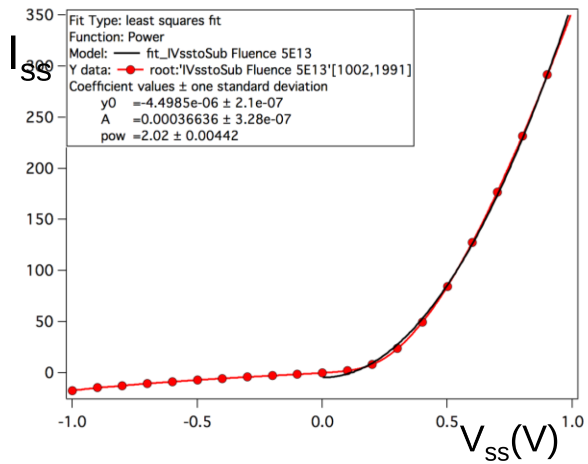
I_{leak} vs. Fluence @ V_{bias} = 10 V

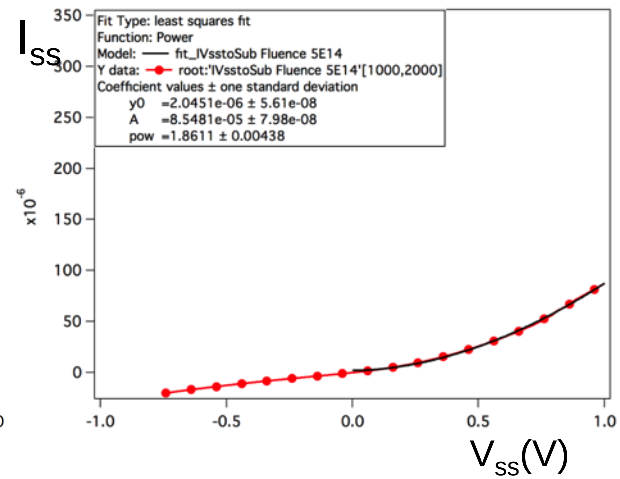
(Substrate floating, all other pixels left floating)

Leakage currents

Φ=0 **Φ=5E13** **Φ=5E14**



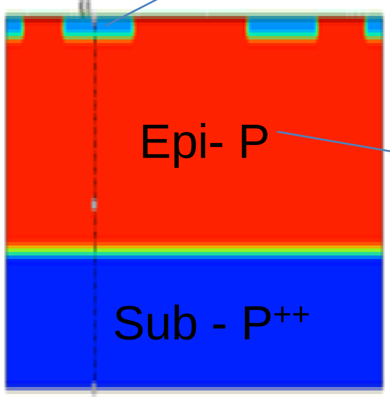




Φ=0: I∝$V^{2.72}$ **Φ=5E13: I∝$V^{2.02}$** **Φ=5E14: I∝$V^{1.86}$**

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

Mott-Gurney currents



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

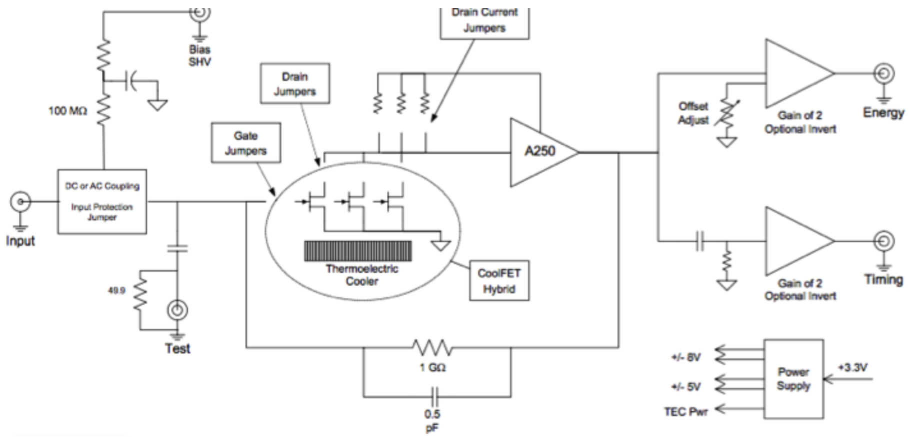
Leakage current is measured between P wells (top and substrate)
For constant current and assuming only drift component

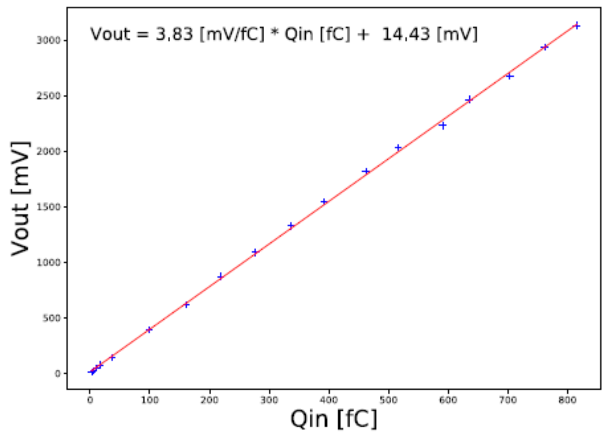
$$j = q\,p\,\mu_p F \longrightarrow p = \frac{j}{q\,\mu_p F} \longrightarrow \frac{\partial}{\partial x} F = \frac{j}{\varepsilon\,\varepsilon_0\,\mu_p F}$$

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

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

Charge collection

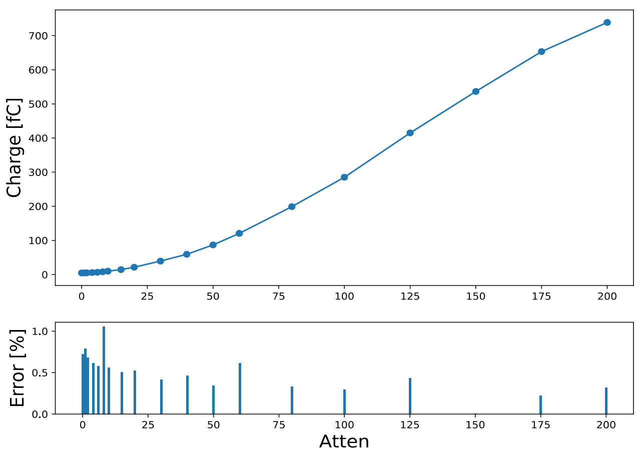




Charge collection studies performed using Laser injection:

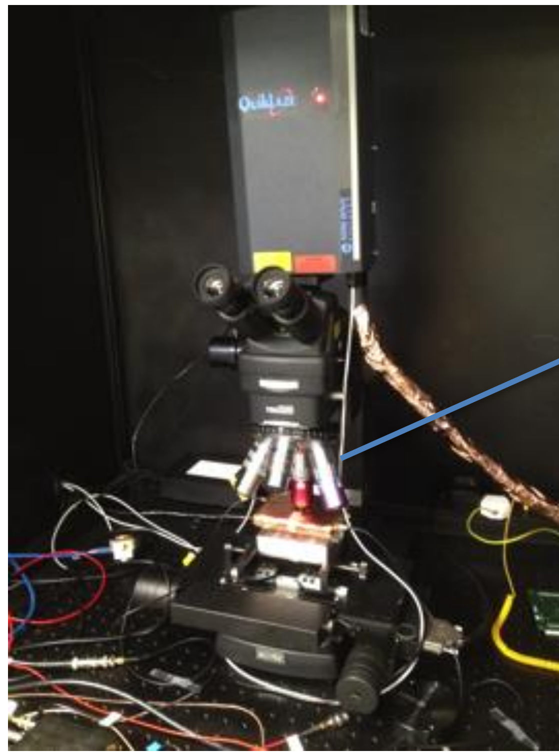
1:Amptek A250CF calibrated using mV voltage pulses injected through (measured) 1.2 pF capacitor to get V(Q). RMS Noise ≈ 76 e- @ OVERMOS capacitance

Charge collection



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

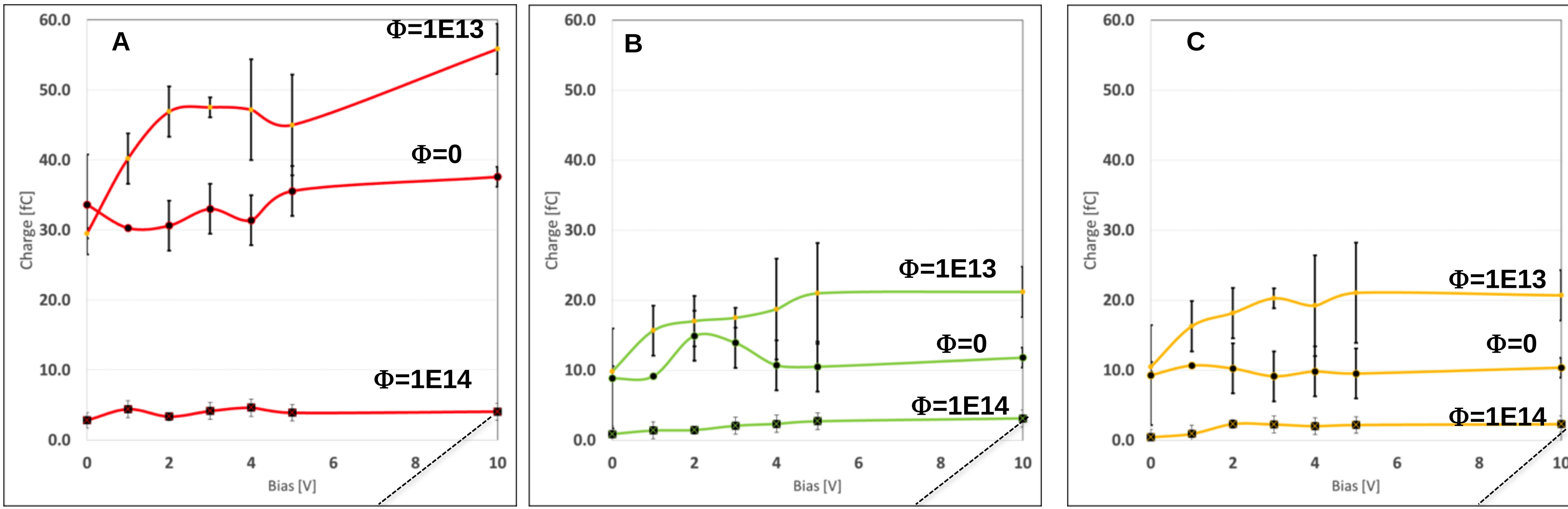
Charge collection



OVERMOS
In metal box to reduce EMP noise

3: the calibrated Laser was used to inject <Q injected> = 541.66 or 1.805 fC/um
(corresponding to ≈ 150 Laser attenuation, which gave the minimum error %)
(not taking into account IR reflection on ASIC’s top)

Collected charge

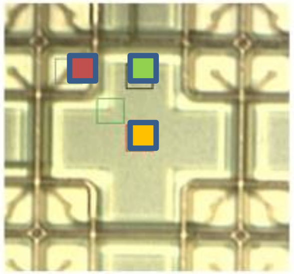


4.04fC ±29.7%

3.14fC ±36.3%

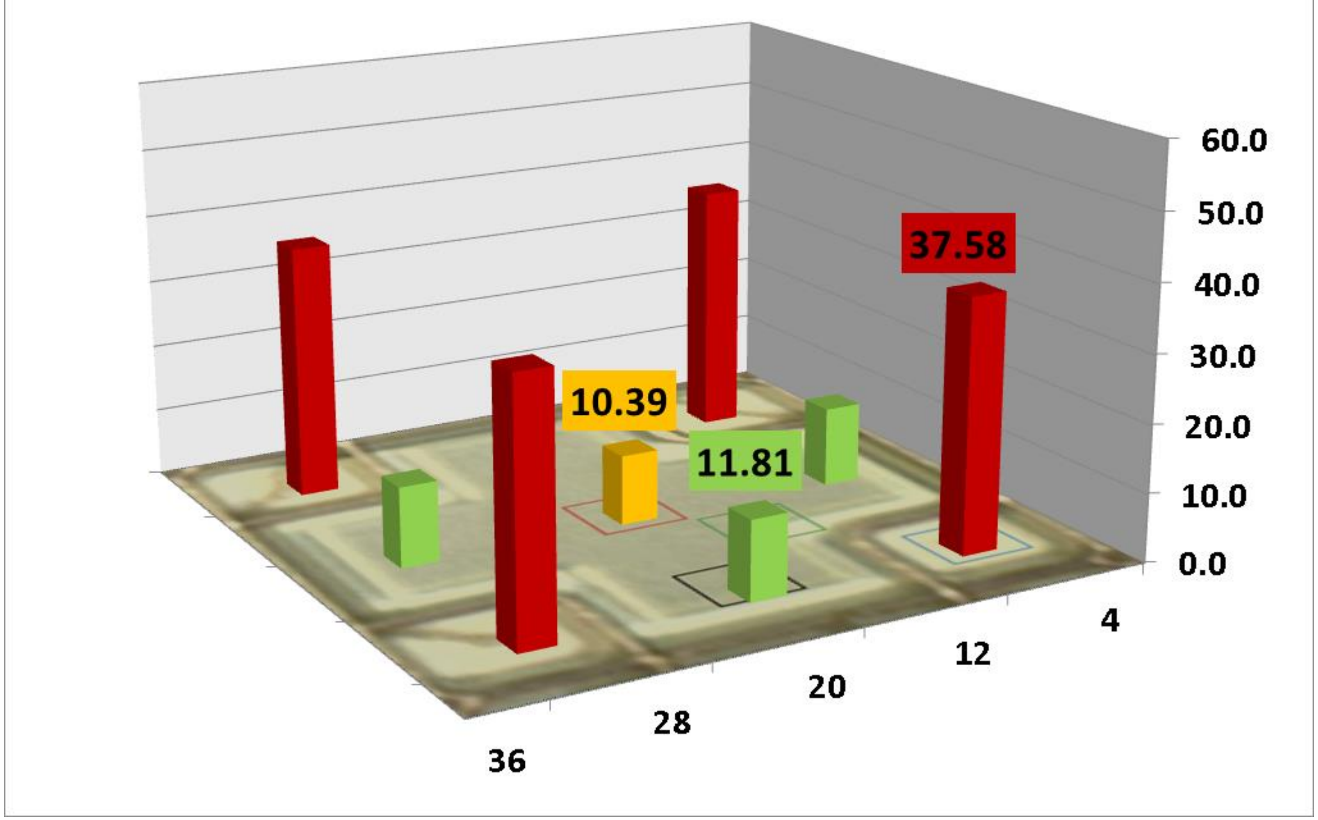
2.31fC ±5.4%

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

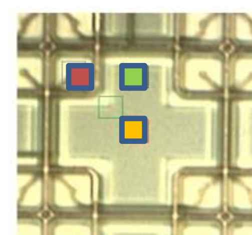


Collected charge

Φ=0

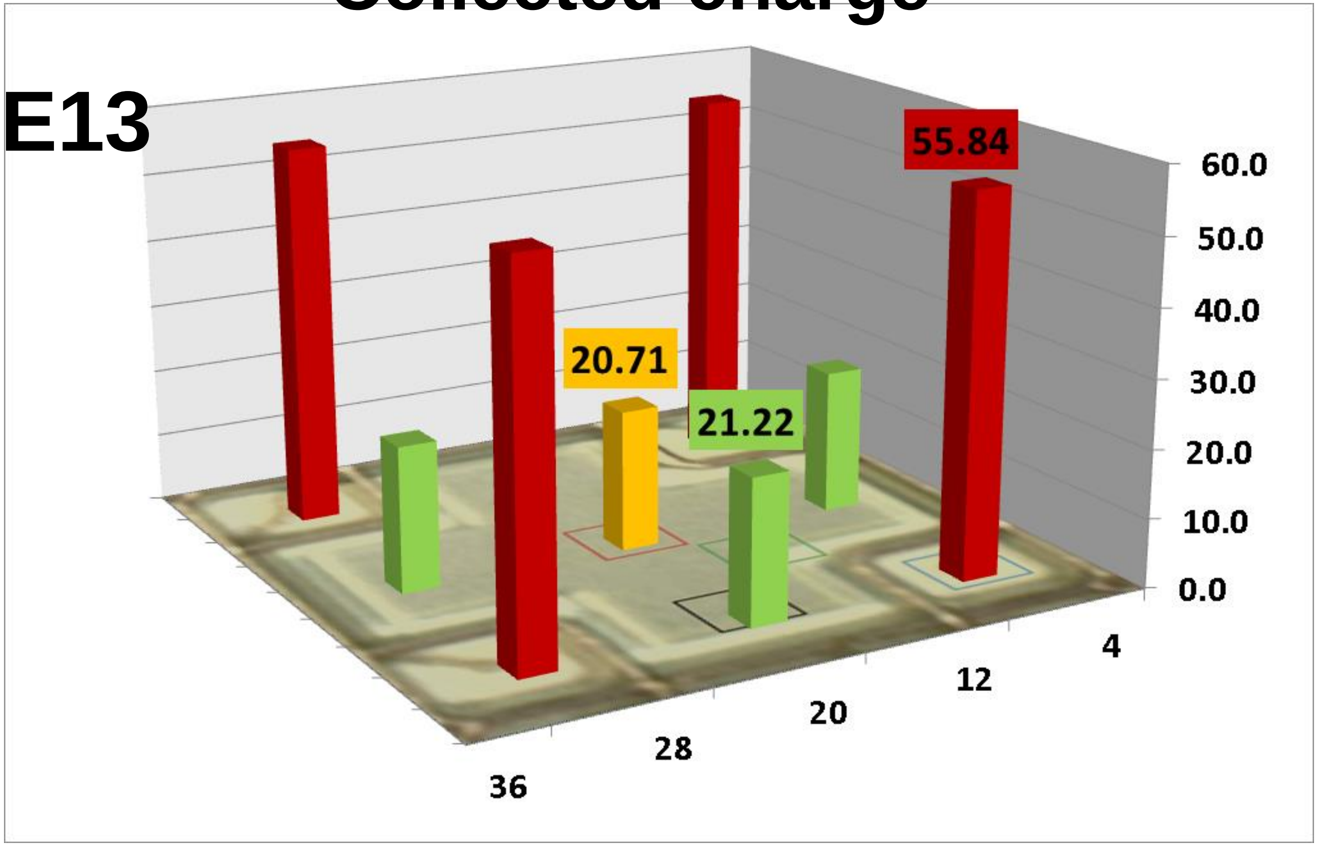


Laser injection test results (1064 nm, 5 x 5 um2 beam size)
Vbias = 10V
<Q injected> = 1.805 fC/um

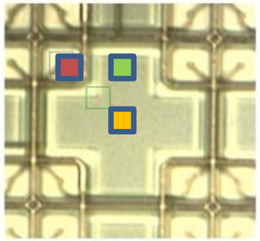


Collected charge

Φ=1E13

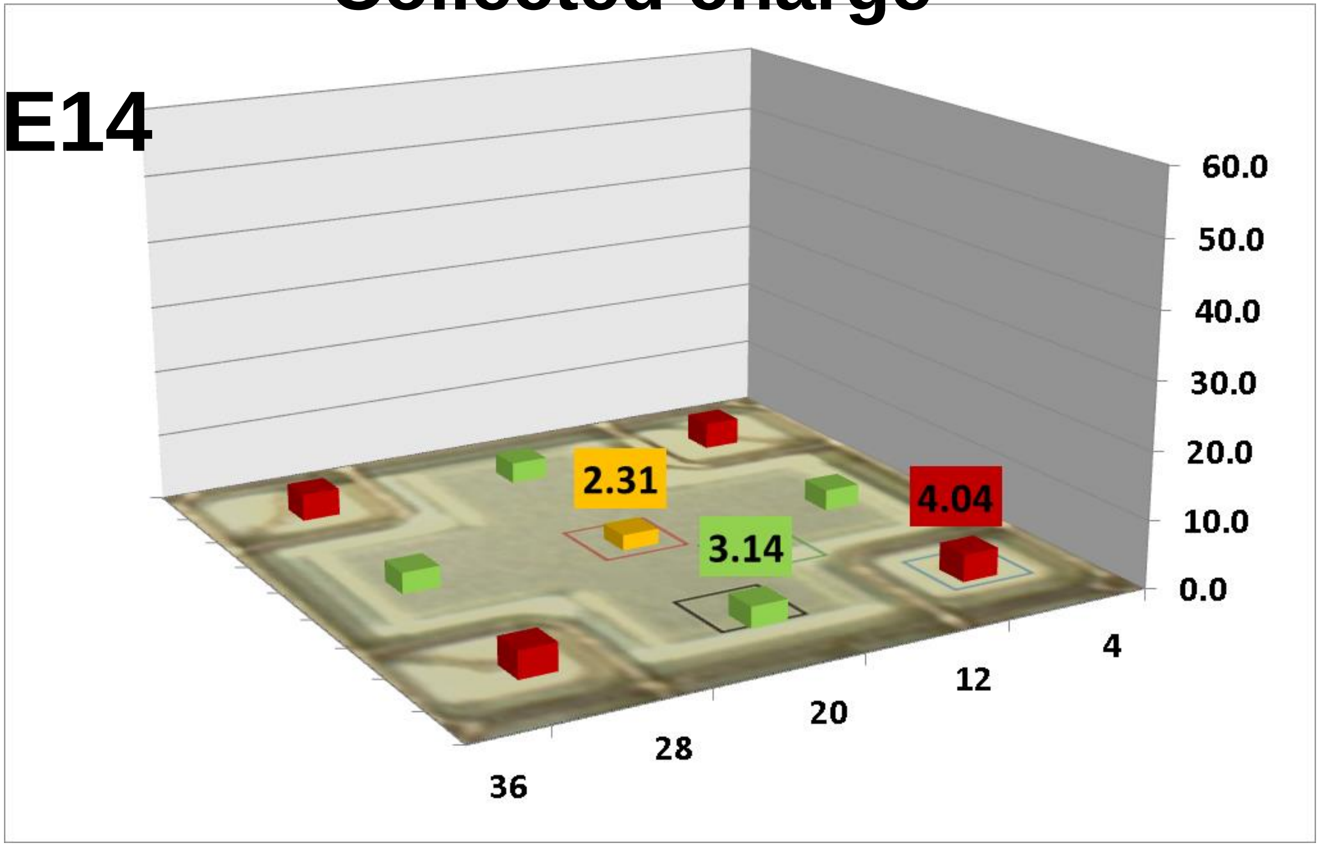


Laser injection test results (1064 nm, 5 x 5 um2 beam size)
Vbias = 10V
<Q injected> = 1.805 fC/um

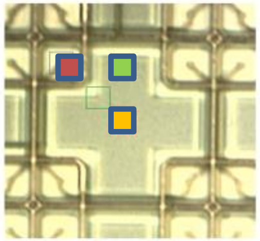


Collected charge

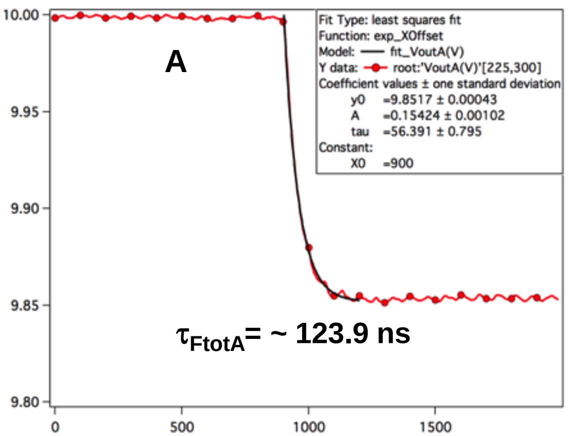
Φ=1E14

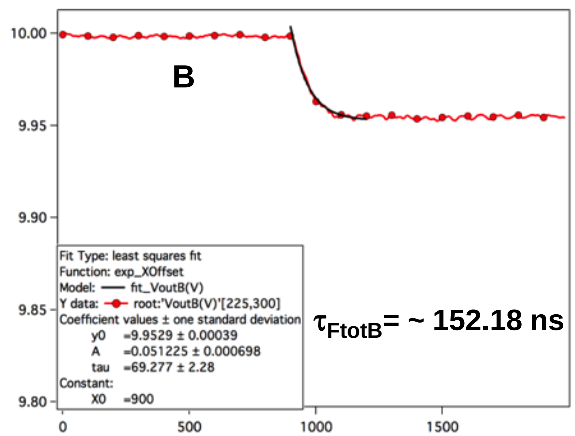


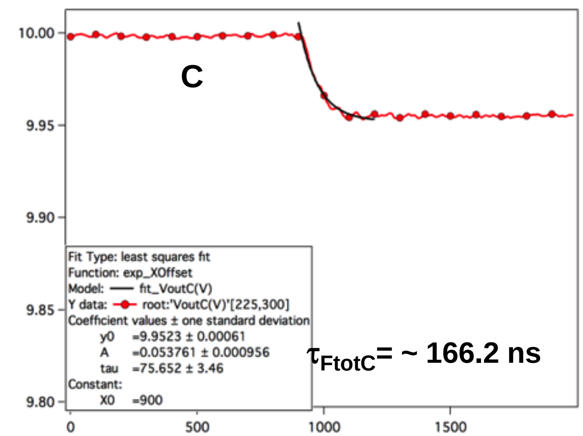
Laser injection test results (1064 nm, 5 x 5 um2 beam size)
Vbias = 10V
<Q injected> = 1.805 fC/um



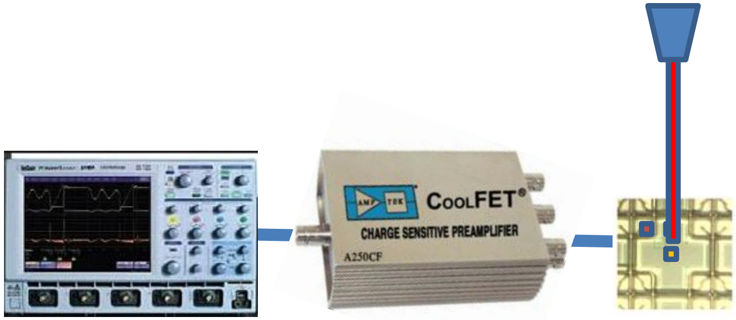
Collected charge transient







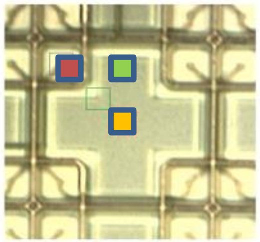
Collected charge vs. time, points A,B,C Vbias = 10V, $\Phi = 0$
<Q injected> = 1.805 fC/um



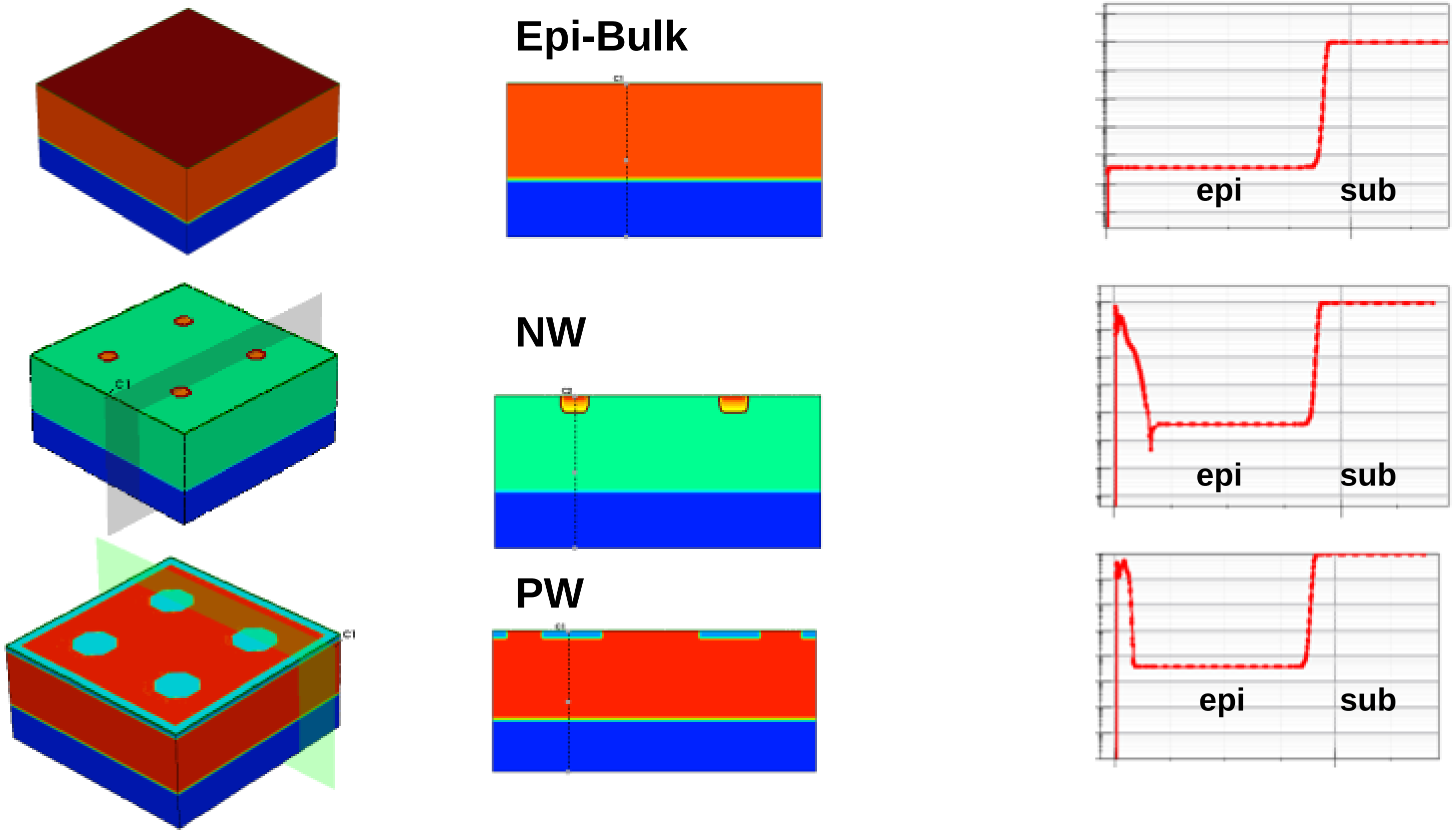
AMPTEK A250CF
τ_{RAMP}= 15 ns

$\tau_{Fs} \sim \sqrt{(\tau_{Ftot})^2 - (\tau_{RAMP})^2} \sim$

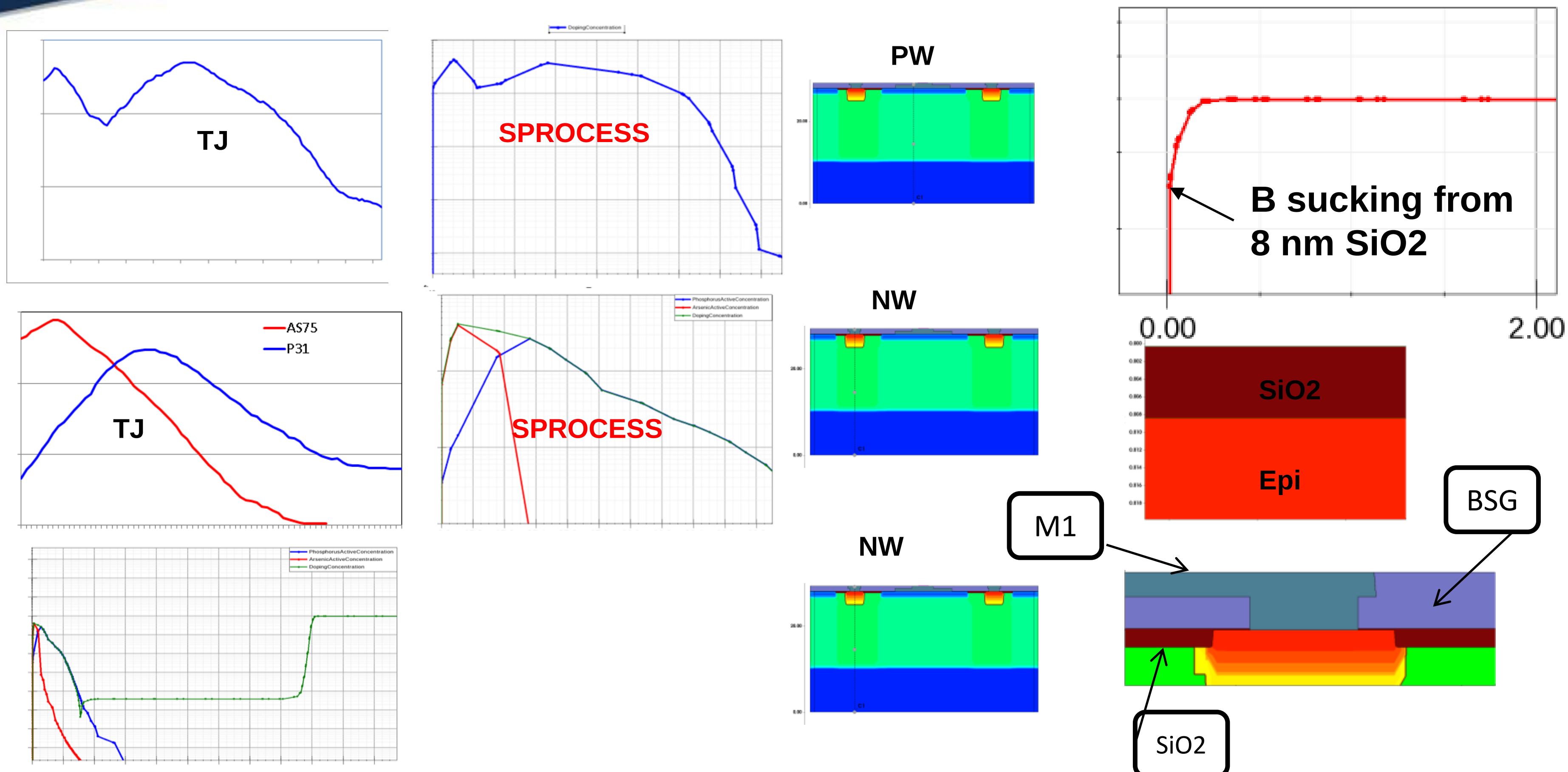
A: 123 ns
B: 151.4 ns
C: 165.5 ns



TCAD simulations

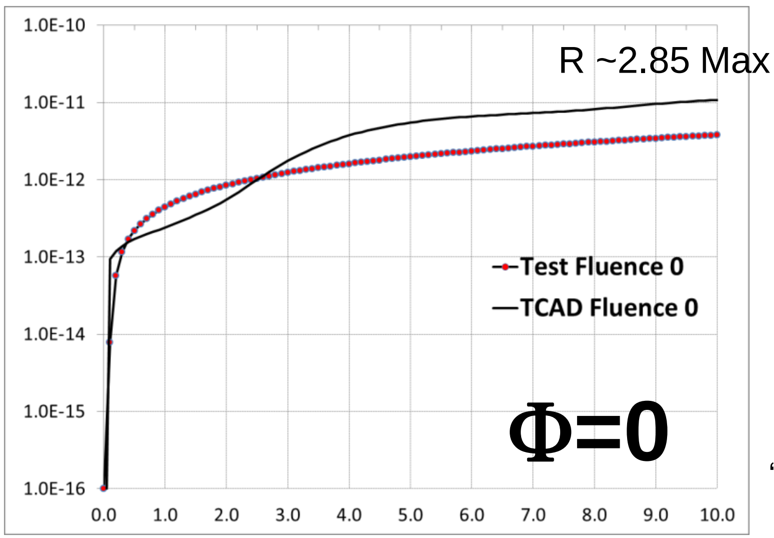


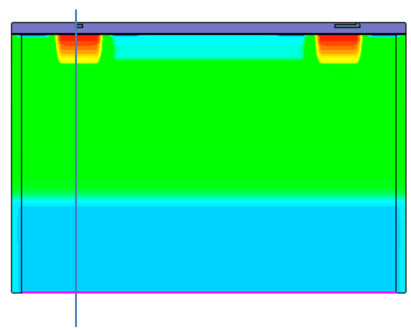
- Individual doping profiles for OVERMOS/DECAL were obtained using SPROCESS, to simulate a (simplified) CMOS fabrication by TowerJazz
- These (1D) doping profiles were then implemented in SDE
- Huge reduction in mesh size and computation time



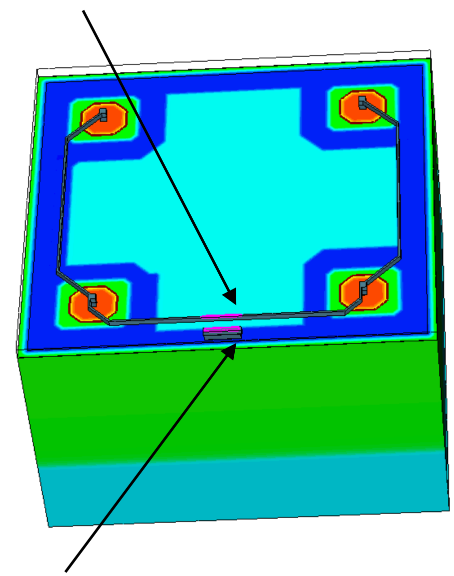
- Some approximations as a result but more affordable for big 3D simulations:
- No B sucking
- No lateral spread doping information
- Coarser doping profiles

TCAD simulation results
Leakage currents





‘1D’ profiles from SPROCESS



From .gds layout SDE to get Cell : 40 x 40 x 29 um3

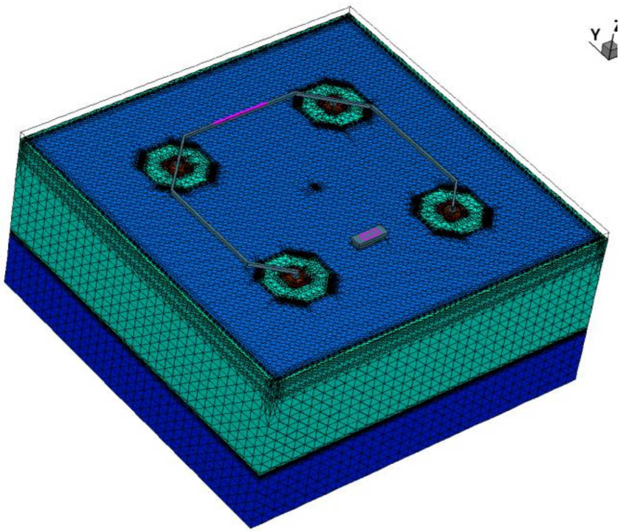
Mesh size: 340974 points
SRV 1e4

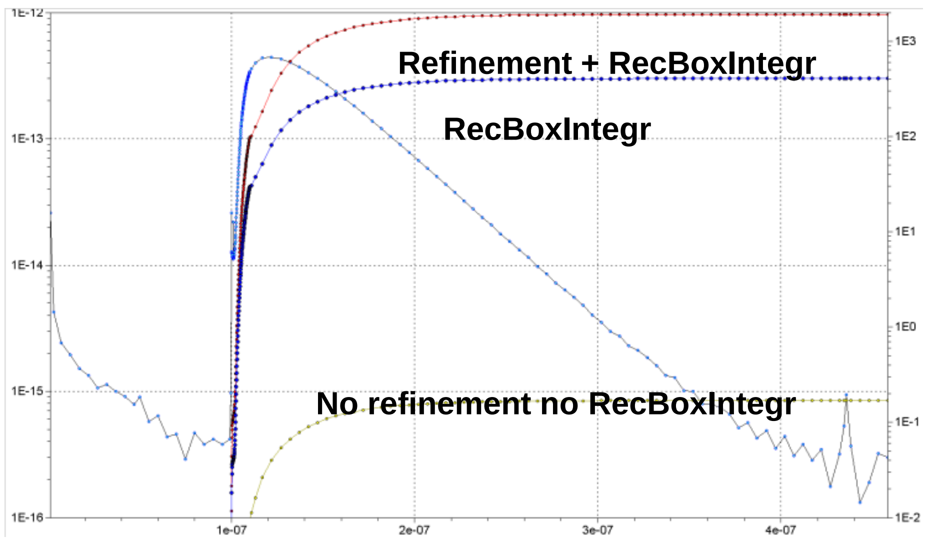
TCAD simulation results
Transient simulation

Initial Charge collection simulation with SRH disabled, to optimize temporal/spatial meshing

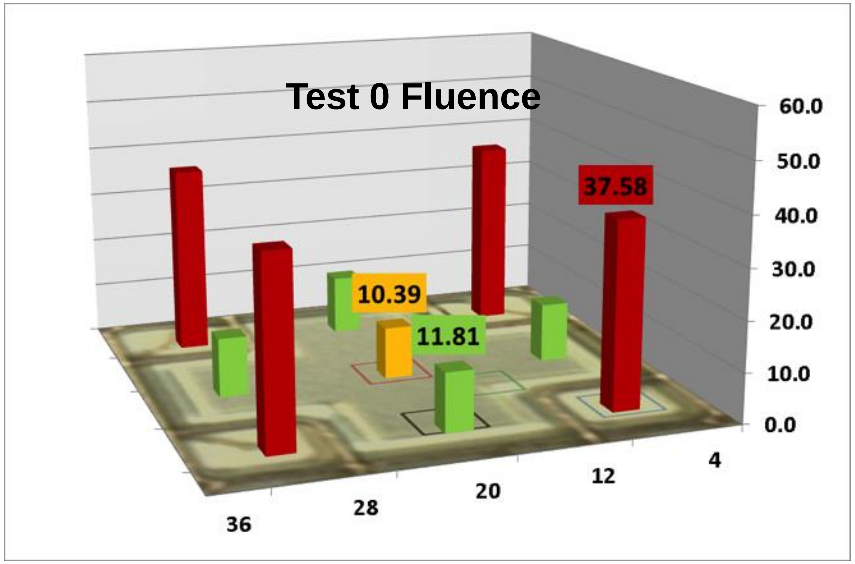
Refinement along the hit track, with refinement that depends on the Debye length~ 1 x Debye length (Epi), ~ 10's x Debye length (Sub)

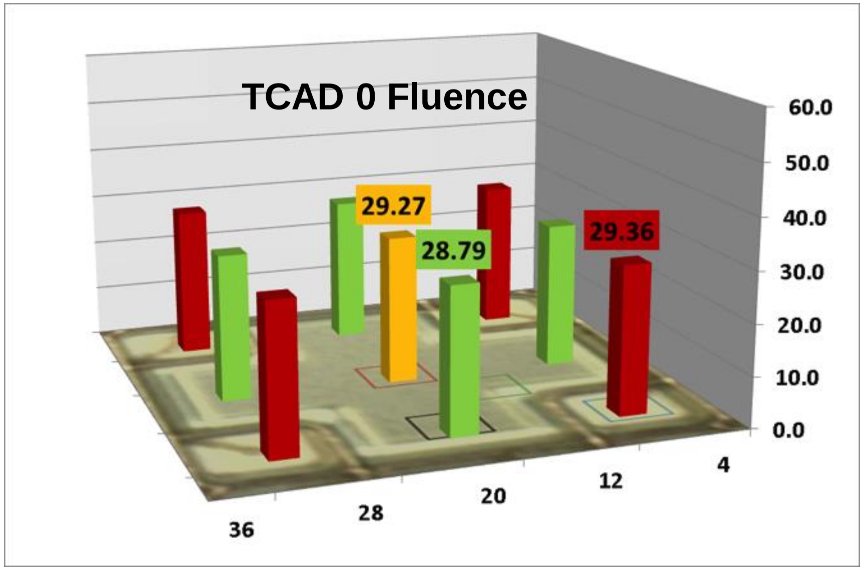
Fermi statistics
customized ILS
Traps density Si/SiO2 1E11
WT_hi = 3um
Sh_i = 1.6 ps
…
Avalanche(Unibo)
…



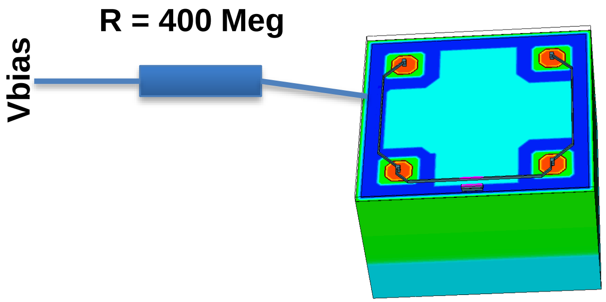


TCAD simulation results
Collected charge





TCAD 0 Fluence
Heavy Ion statement 1.805e-3 pC/um
Vbias = 10V provided through R = 400 Meg



Conclusions and next steps

- First test results of OVERMOS basic flavor were presented: DC tests showed expected leakage increase with n-fluence and initial increase in charge collection, measured with Laser injection
- Charge collection drops by tenfold at **Φ = 1e14**
- **Next: to fully characterise the remaining sensors and TCAD simulations**

THANK YOU

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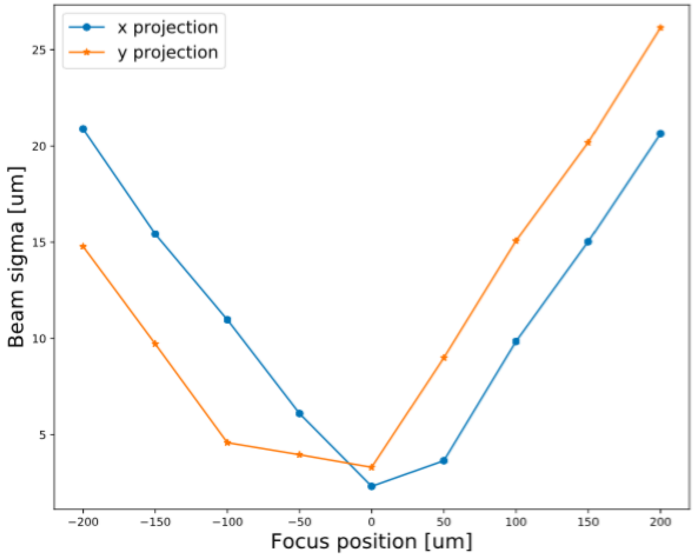
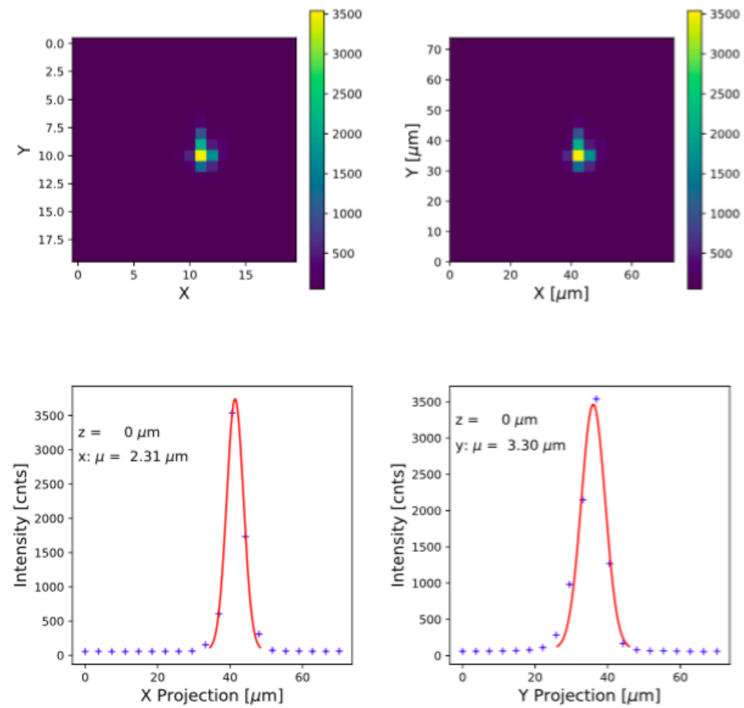
BACKUP





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