Trench detectors for enhanced charge multiplication

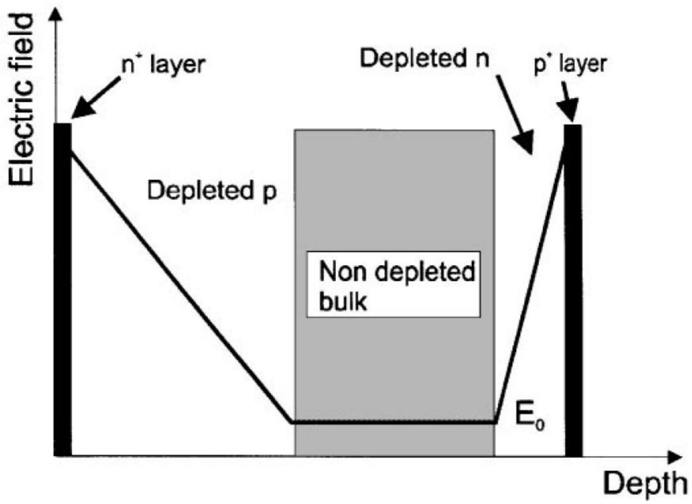
G. Casse, D. Forshaw, M. Lozano, G. Pellegrini

Outline

- Radiation hardness for the innermost layer: charge multiplication (CM)
- Enhancing/optimising CM ?
- Planar pixel for the HL-LHC
- Possible different geometries in the forward region
- Large area devices for the outer layers

N-side read-out can make planar segmented Si detectors suitable for tracking in extreme (SLHC levels: 1×10^{16} cm^{-2}) radiation environments.

Schematic changes of Electric field after irradiation



Effect of trapping on the Charge Collection Efficiency (CCE)

$$Q_{tc} \cong Q_0 \exp(-t_c/\tau_{tr}),\ 1/\tau_{tr} = \beta\Phi.$$

Collecting electrons provide a sensitive advantage with respect to holes due to a much shorter t_c. P-type detectors are the most natural solution for *e* collection on the segmented side.

N-side read out to keep lower t_c

Effect of trapping on the Charge Collection Distance

$$Q_{tc} \cong Q_0 \exp(-t_c/\tau_{tr}),\ 1/\tau_{tr} = \beta\Phi.$$

$$v_{sat,e} \times \tau_{tr} = \lambda_{av}$$

$\beta_e = 4.2E{-}16$ cm^{-2}/ns

$\beta_h = 6.1E{-}16$ cm^{-2}/ns

G. Kramberger et al., NIMA 476(2002), 645-651.

After heavy irradiation the charge collection distance (CCD) of thin detectors should have a similar (better?) charge collection efficiency (CCE) as thicker ones.

$$\lambda_{Max,n}\ (\Phi=1e14) \cong 2400\mu m$$

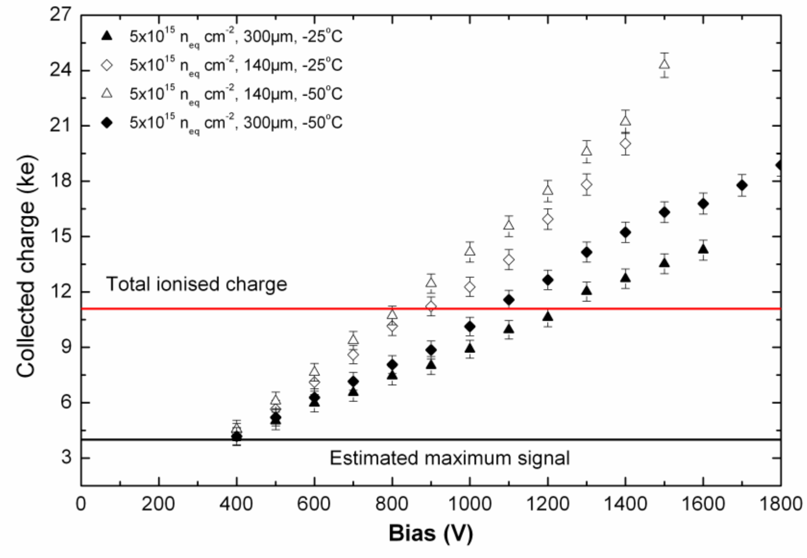
$$\lambda_{Max,n}\ (\Phi=1e16) \cong 24\mu m$$

$$\lambda_{Max,p}\ (\Phi=1e14) \cong 1600\mu m$$

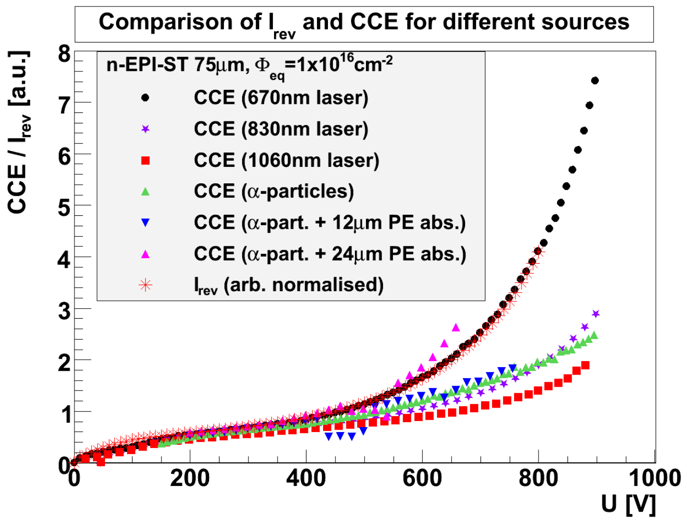
$$\lambda_{Max,p}\ (\Phi=1e16) \cong 16\mu m$$

The reverse current is proportional to the depleted volume in irradiated detectors. Do thin sensors offer an advantage in term of reduced reverse current compared to thicker ones (this aspect is particularly important for the inner layer detectors of SLHC, where significant contribution to power consuption is expected from the sensors themselves)?

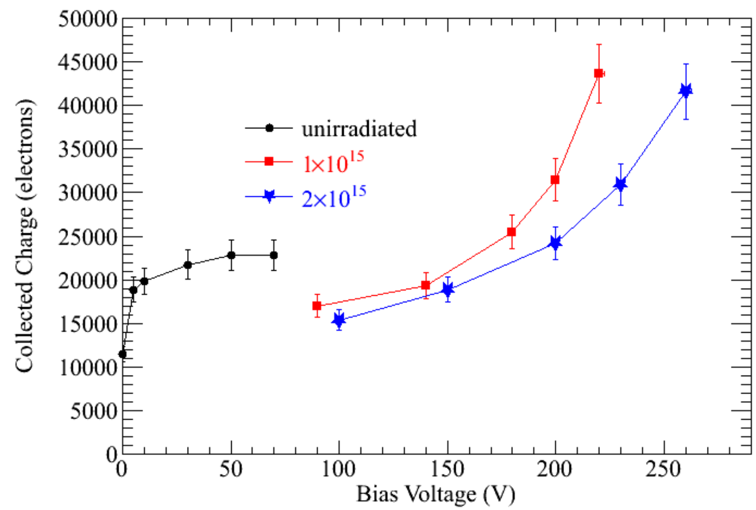
140 and 300 µm n-in-p Micron sensors after 5×10^{15} n_{eq} 26MeV p



Evidence of a charge multiplication effect: not only the whole charge is recovered, but increased by f = 1.75



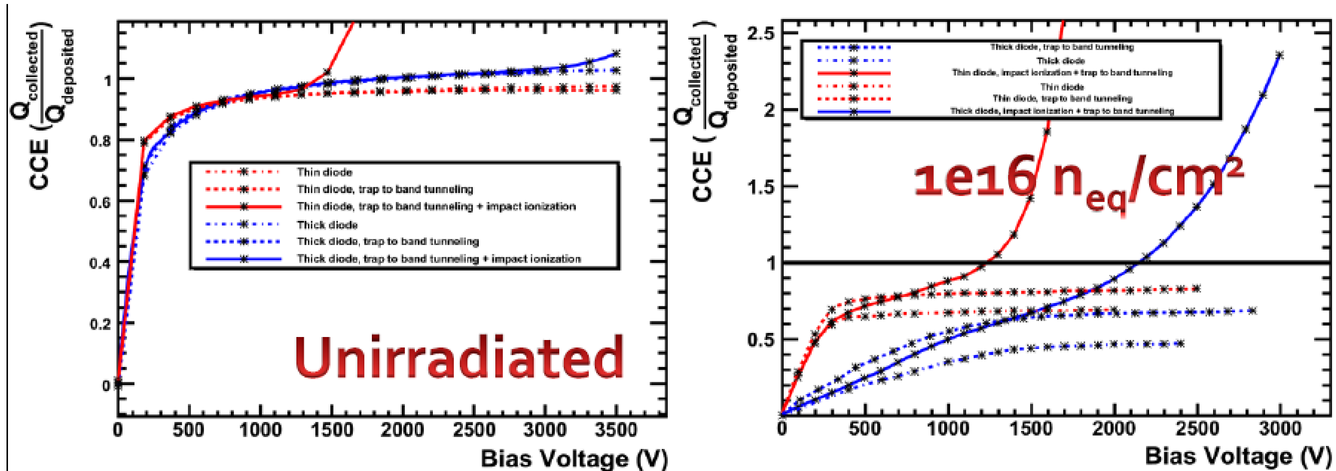
Also CM in diodes (J. Lange, 15th RD50 workshop).



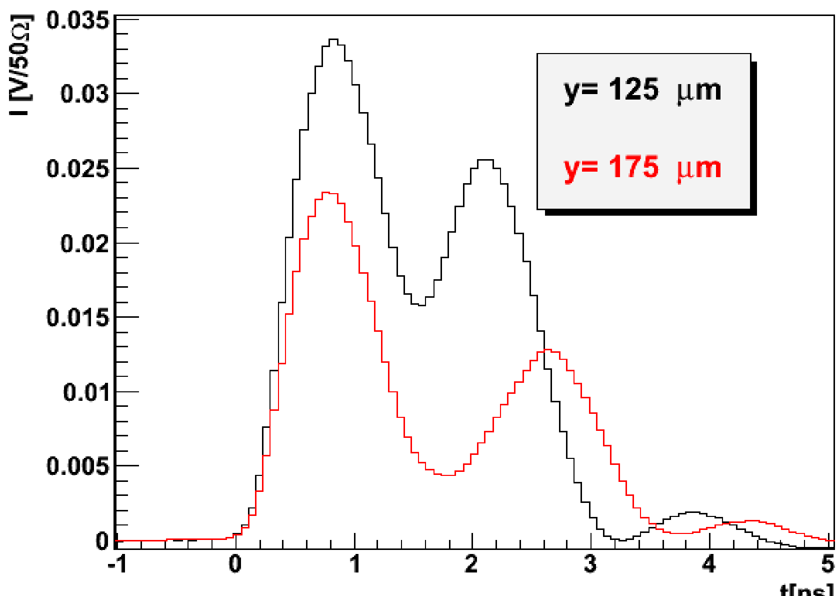
M. Koehler et al., Test Beam and Laser Measurements of Irradiated 3D Silicon Strip Detectors, 16thRD50 Workshop, Barcelona

CM is a well documented effect, but we are not mastering it yet

We can qualitatively understand it. We are investigating it from various perspectives.



ISE TCAD, M. Benoit et al., presented at the ATLAS Upgrade meeting, DESY, Hamburg, 19/04/2010



TCT studies

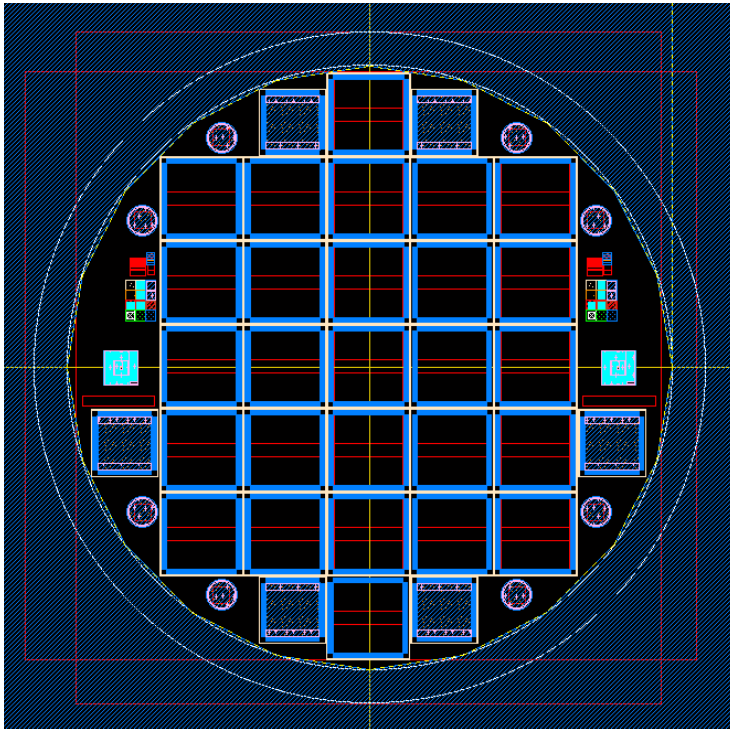
2nd peak due to avalanche multiplication

the difference in peak amplitude for different y is due to electrons trapped

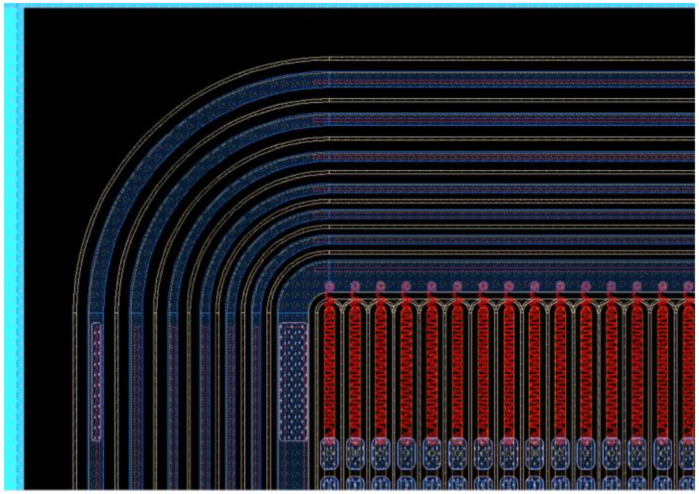
G. Kramberger wt al., 18th RD50 workshop.

Can we manipulate/optiise CM ?

- Charge multiplication after irradiation
- The idea: manipulation of the electric field
- The processing method
- Results before and after irradiation

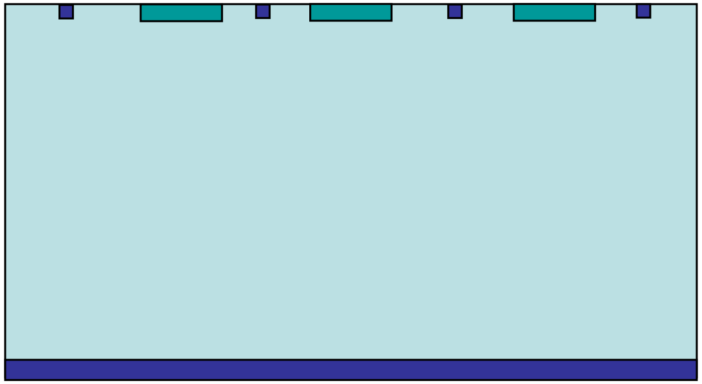


Attempt to manipulate the electric field for inducing CM (RD50 project)



NinP type strip detectors with trenched electrodes
Single chip - 1cm^2 area
Strip pitch 80um with p-stop isolation structures
Device Simulation and fabricated done by CNM

Well known 6 Guard Ring structure used.
AC coupled

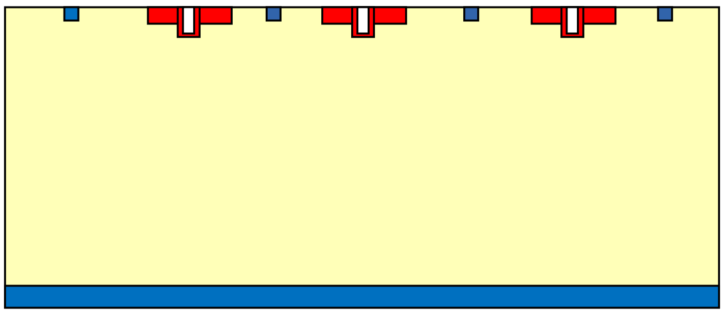


1 standard P-stop design used a reference

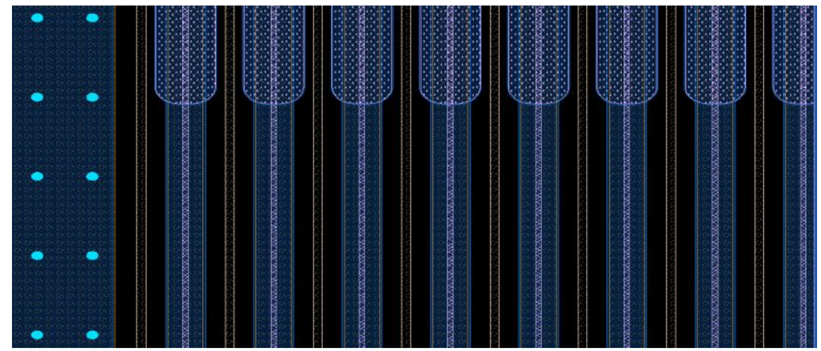
5 trench structures simulated → Fabricated → Measured

Trenched detector design

Poly trench

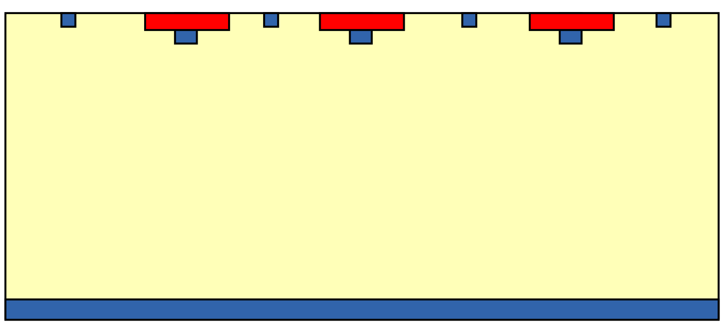


Trench 5, 10 50um deep
All 5um wide in center of N+ electrode



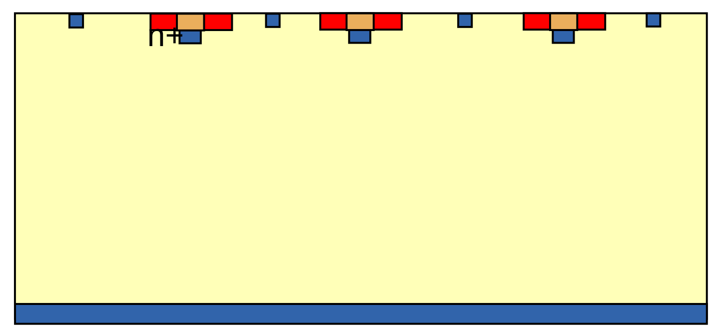
P+ implant under N electrode
Centered, 5um wide

P-type diffusion



Same as P-type diffusion but with trench through N+

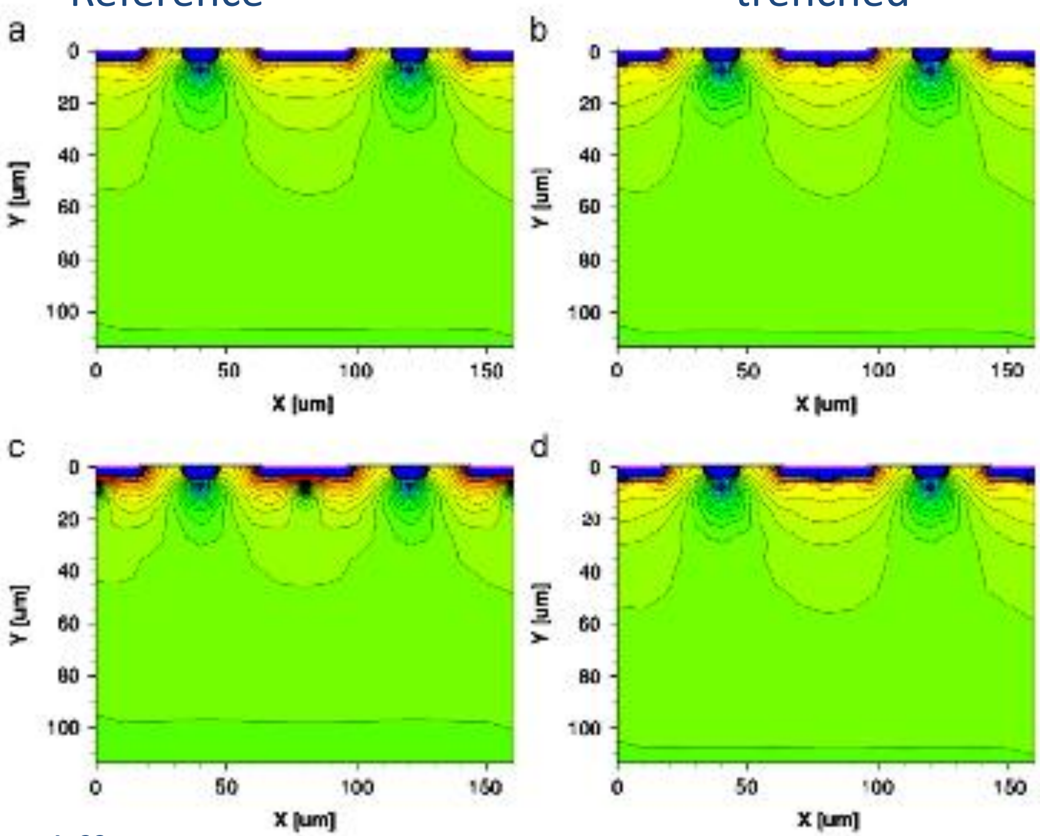
Oxide trench

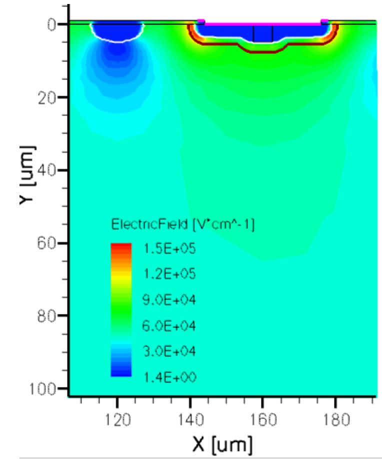


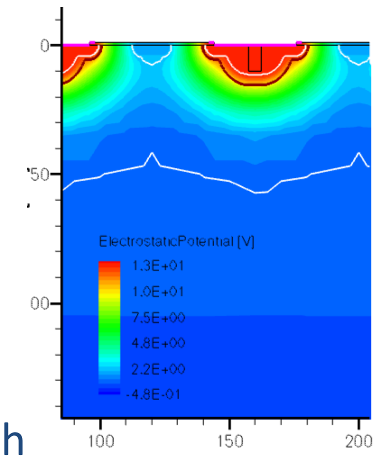
TCAD simulations

Reference

trenched





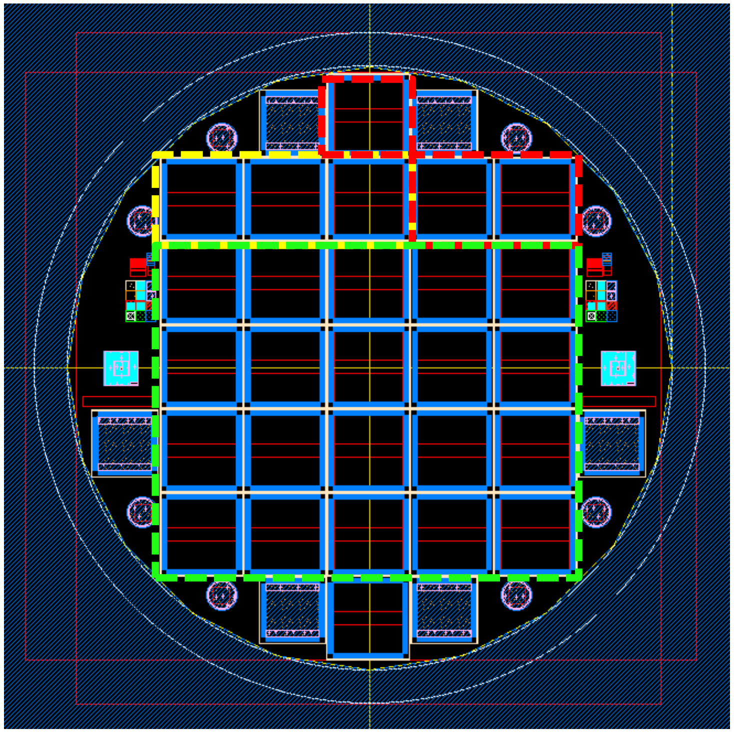


P+ diffusion

P+ diffusion with oxide filled trench

See NIMA53508 - Simulation of new p-type strip detectors with trench to enhance the charge multiplication effect in the n-type electrodes, P. Fernández-Martínez et al.

Design Variation's

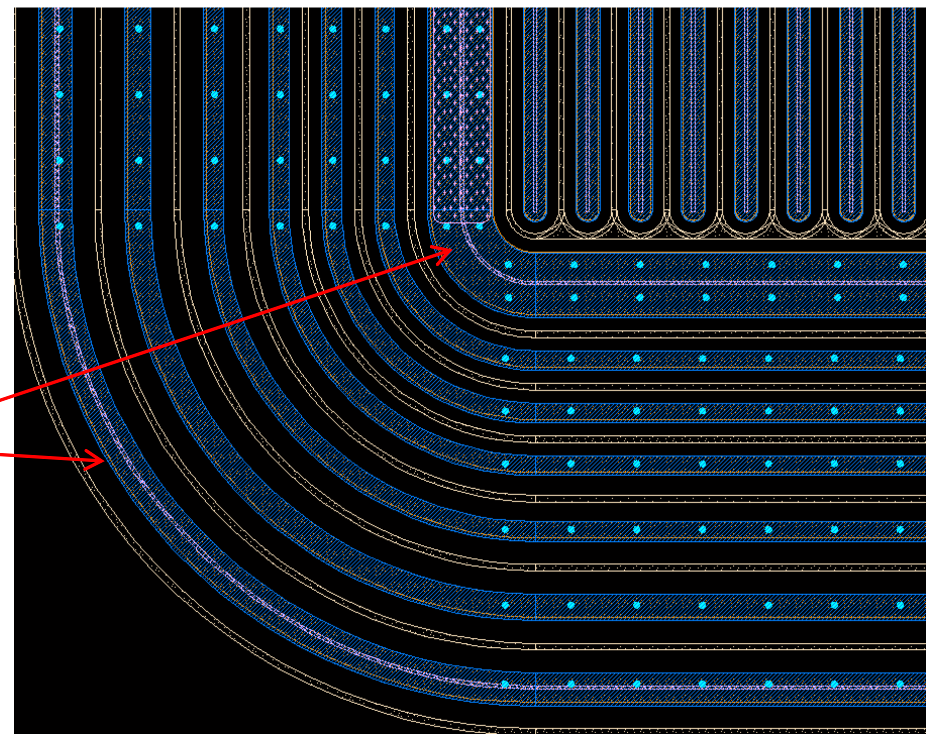


Each wafer featured a couple of variations on trench placement

Det A1- trench structure only in active strips

Det A2 – trench structure extended to Bias rail

Det A3 – trench structure extended to Bias rail and last GR



Trench, Bias ring and final GR

Note, Only type A1 dets sent for irradiation

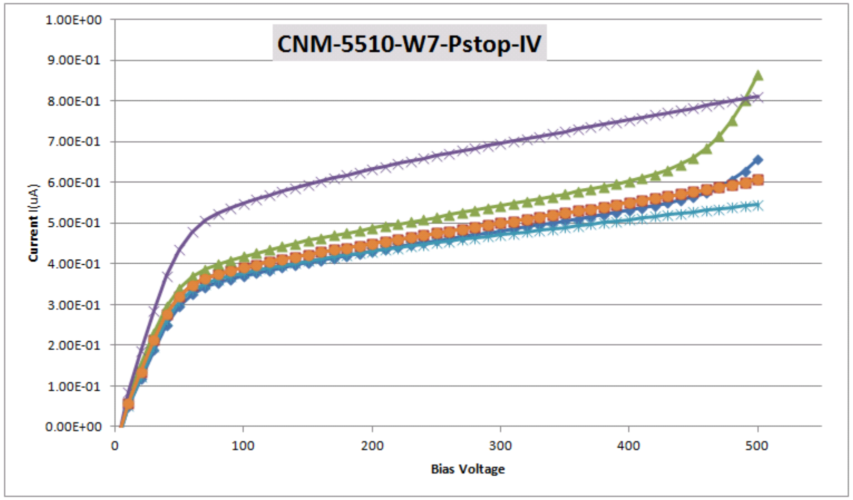
Wafer information/ Irradiation

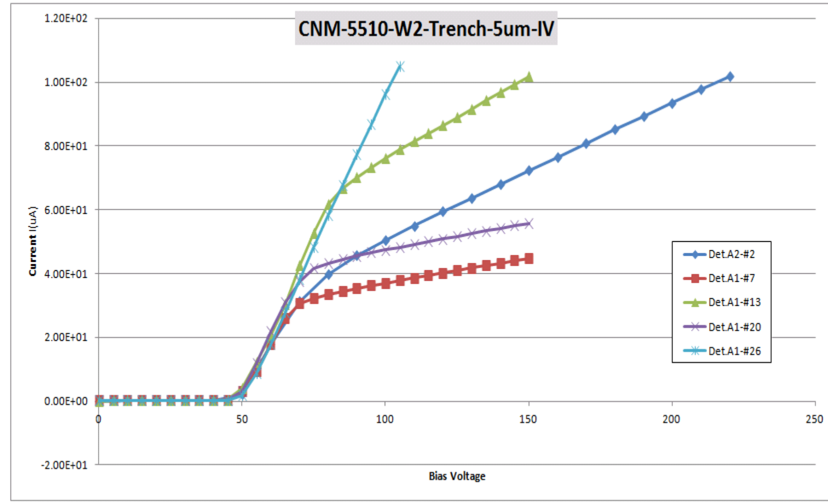
W2 – 5um trench through centre of electrodes
W3 – 10um trench through centre of electrodes
W5 – 50um trench through centre of electrodes (poor metallisation)
W7 – reference, standard N electrodes with P-stops
W16 – P^+ implant under N electrode, 5um wide
W18 – W16 structure with wide p^+ implant

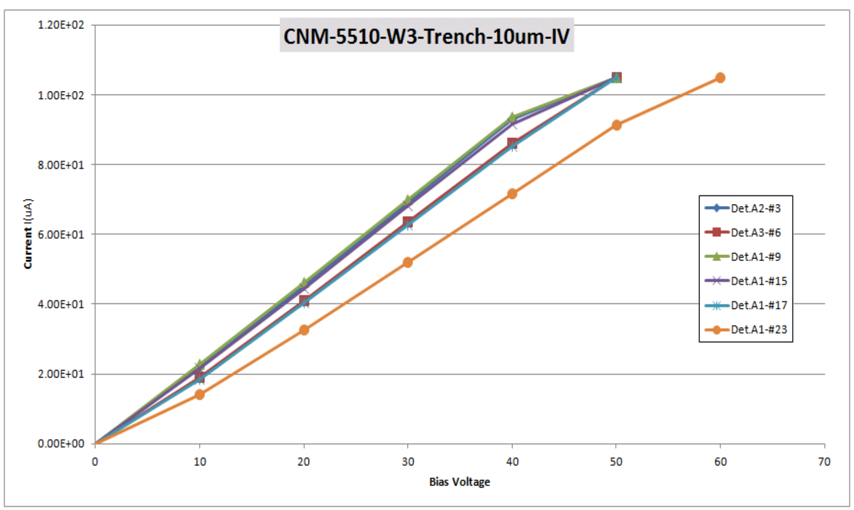
Detectors sent for neutron irradiation to JSI Ljubljana, Doses -

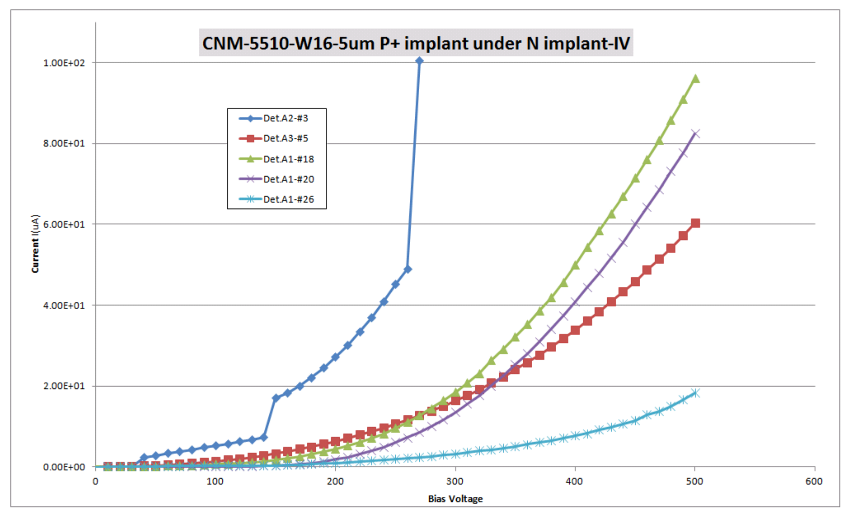
1E15	1MeV neq	Measured
5E15	1MeV neq	Measured
1E16	1MeV neq	Partially Measured
2E16	1MeV neq	Measured
3E16	1MeV neq	W2/5 No signal at 1000v

Initial IV from wafers W2,3,7,16

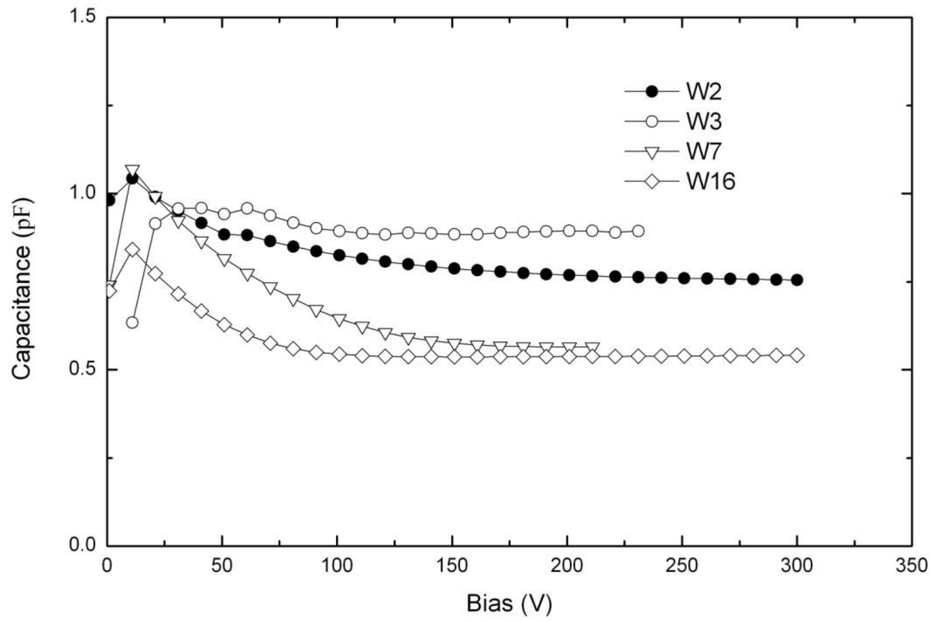






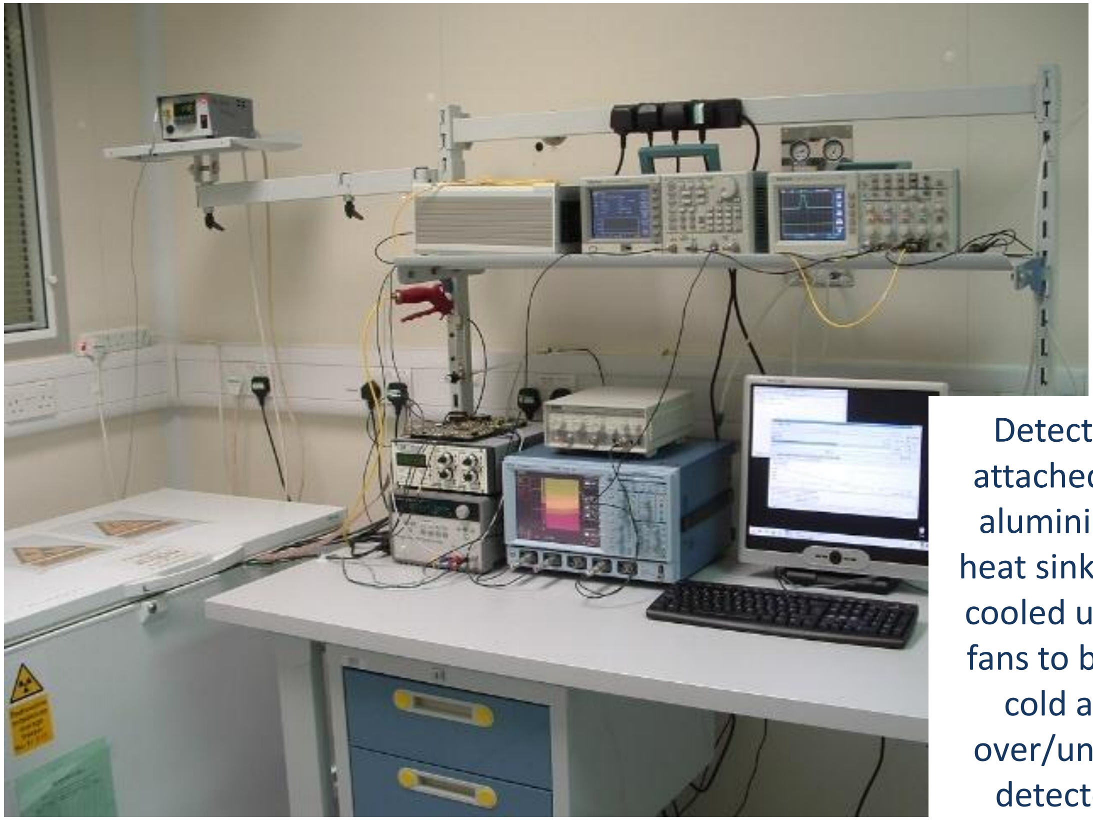


Interstrip capacitance



Alibava Setup

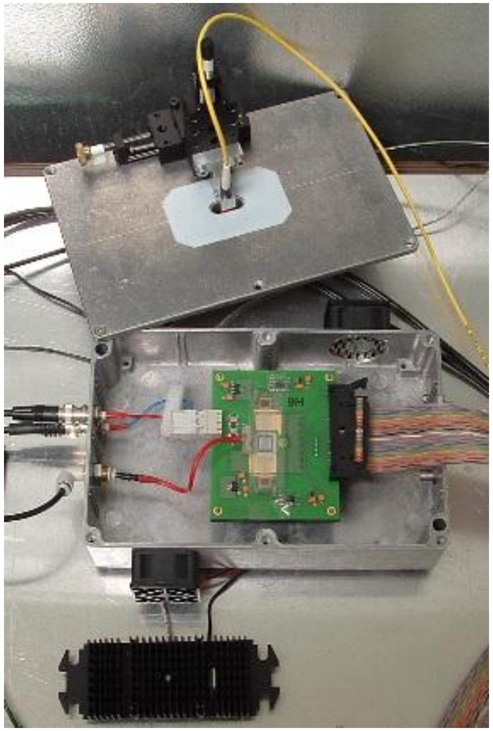
Analogue readout based on the Beetle V1.5 chip
(40 MHz readout speed)



Detector attached to aluminium heat sink and cooled using fans to blow cold air over/under detector

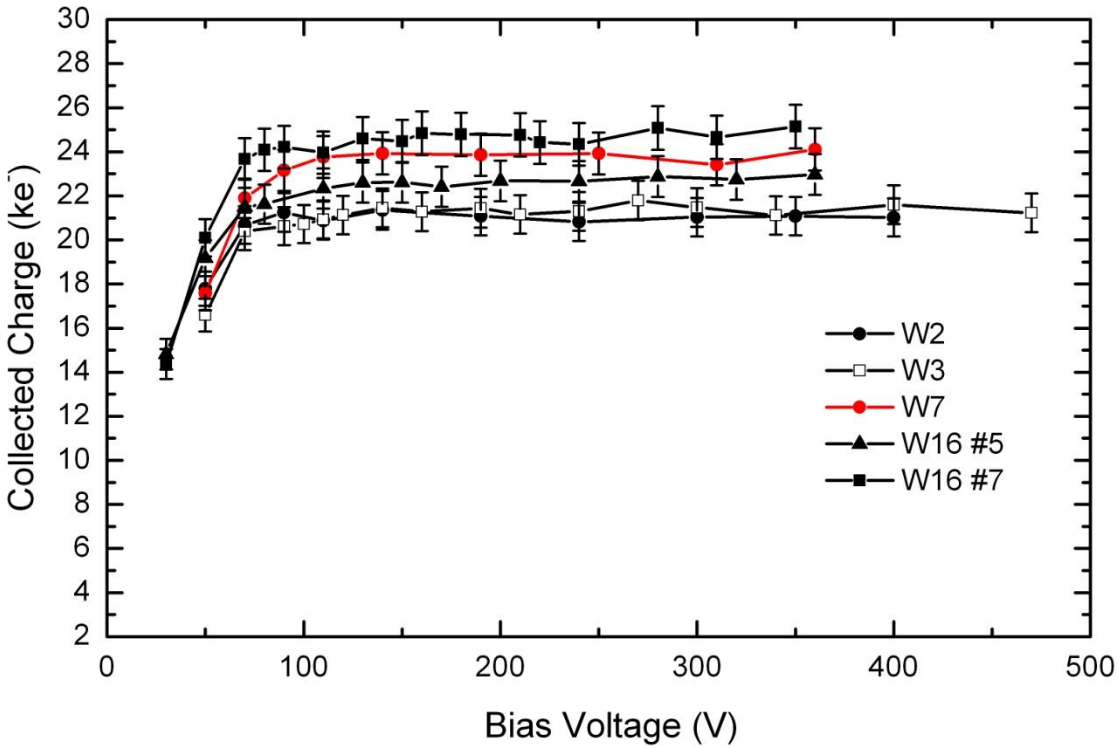
Cooling down to - 45 deg.C (ElCold EL11LT), 1deg.C hysteresis loop

Signal generation with 370 Mbq 90Sr fast beta source or IR Laser (980/1060 nm) for charge collection & sharing studies



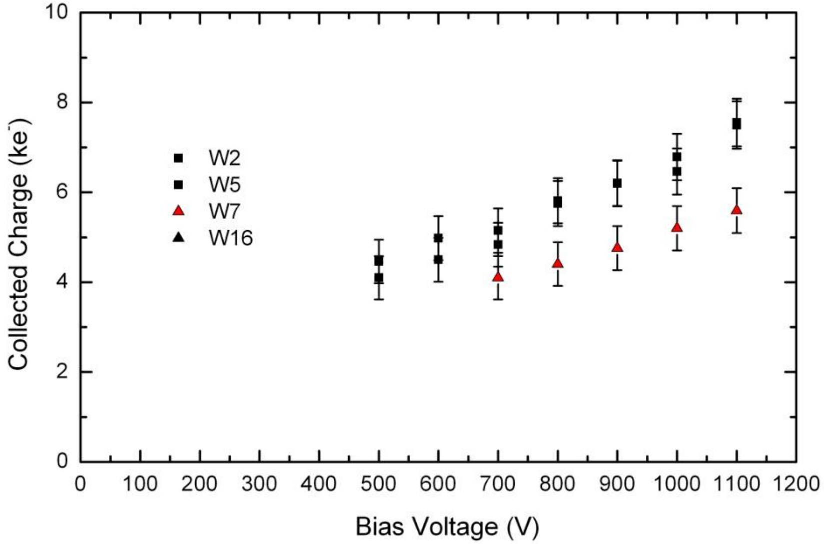
Scintilator/s placed under/ontop daughter board for single or coincidence trigger

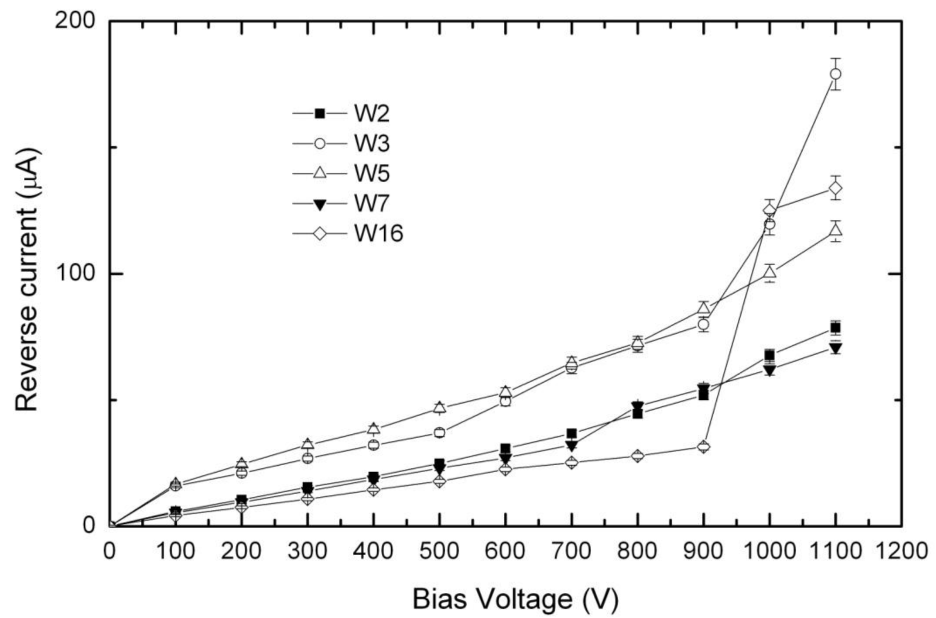
Charge collection as a function of bias voltage – CC(V): non-irradiated sensors



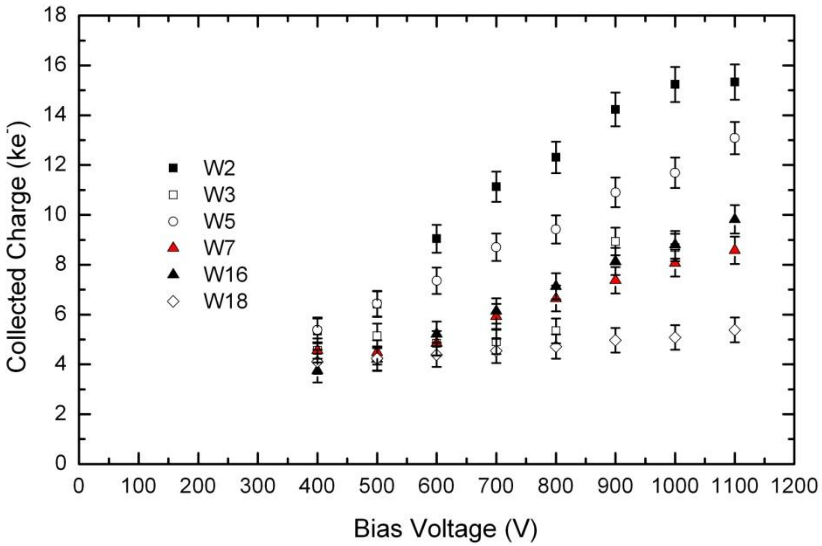
W5 wouldn't Bias, >1ma at 10V

CC(V) and IV after 1E15 n_{eq} cm^{-2}



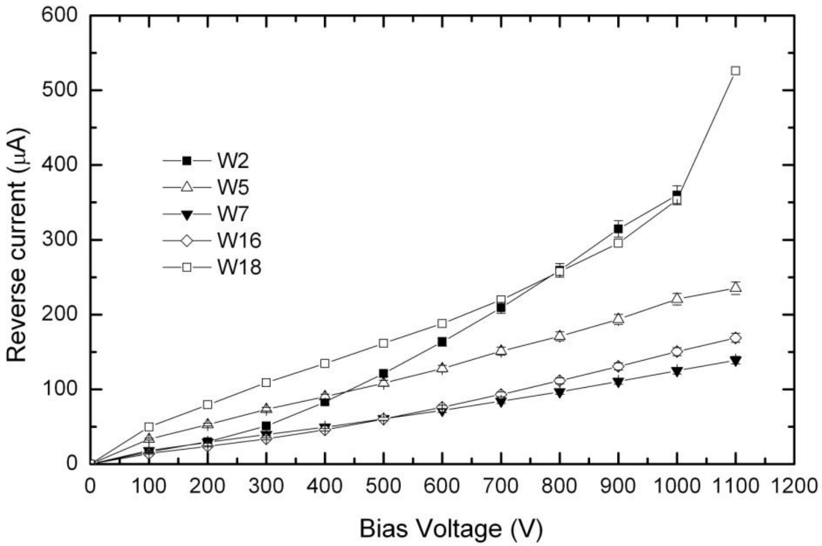


CC(V) and IV after 5E15 n_{eq} cm^{-2}

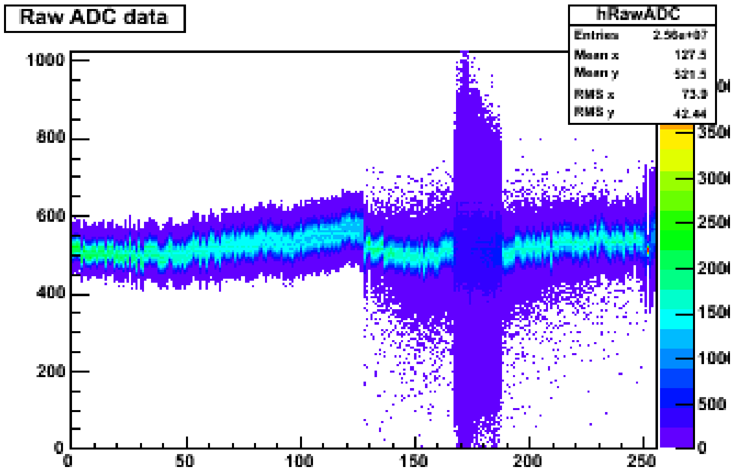


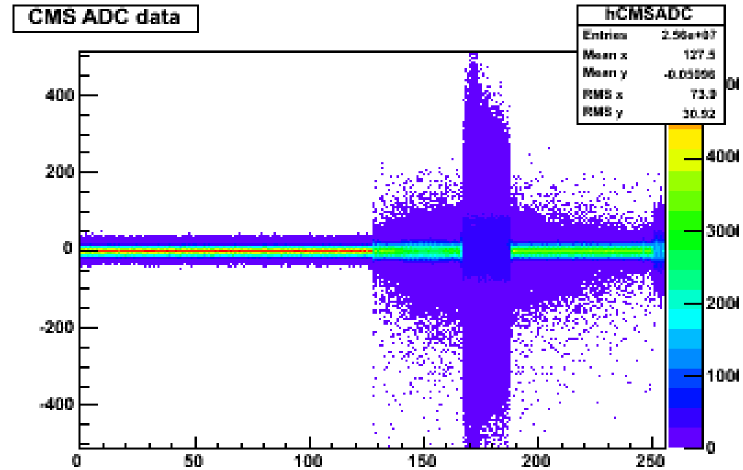
More evidence that trenched detectors have enhanced CC(V) compared to reference

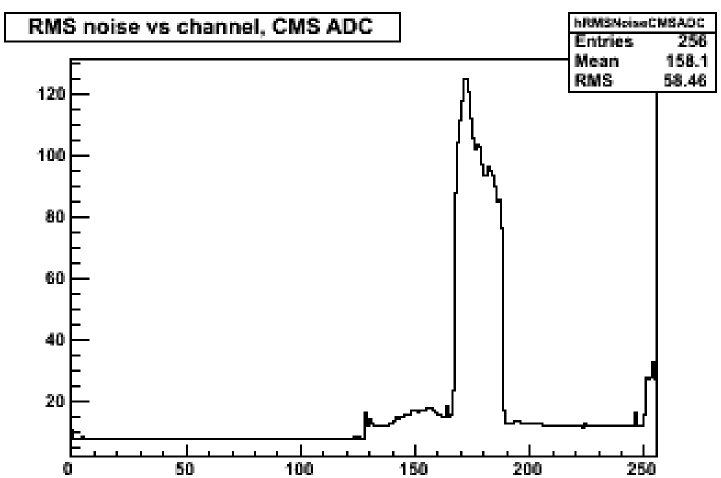
All sensors have higher currents than reference

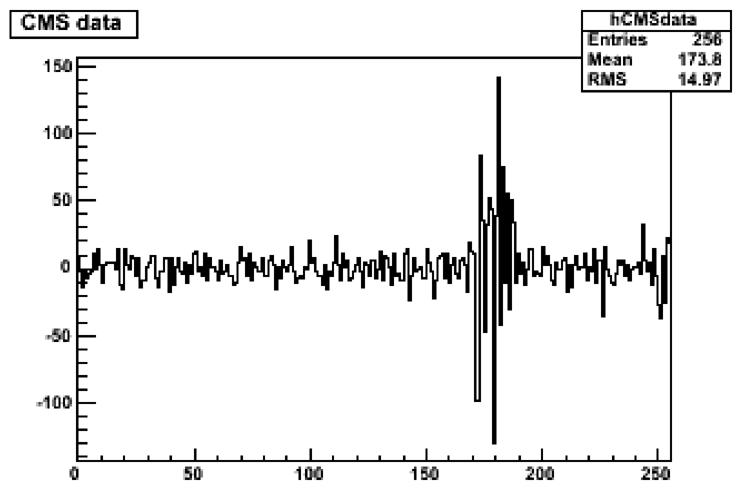


Problems with strip isolation......

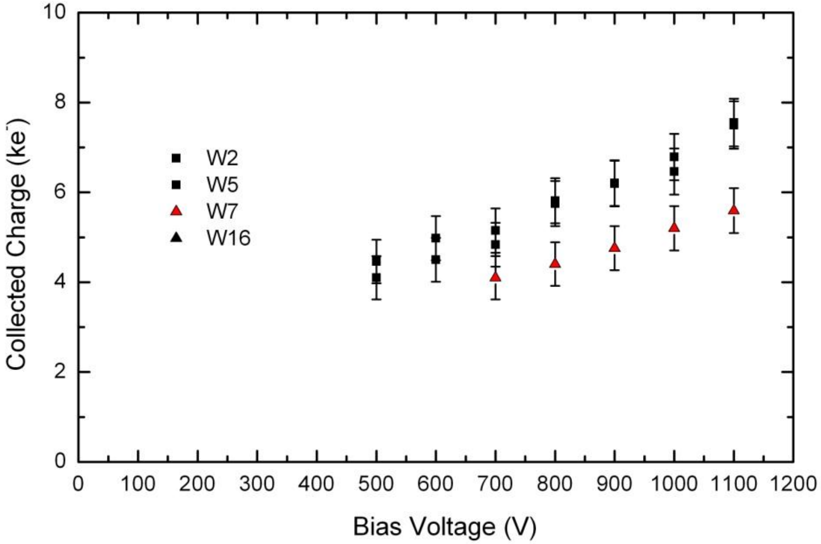




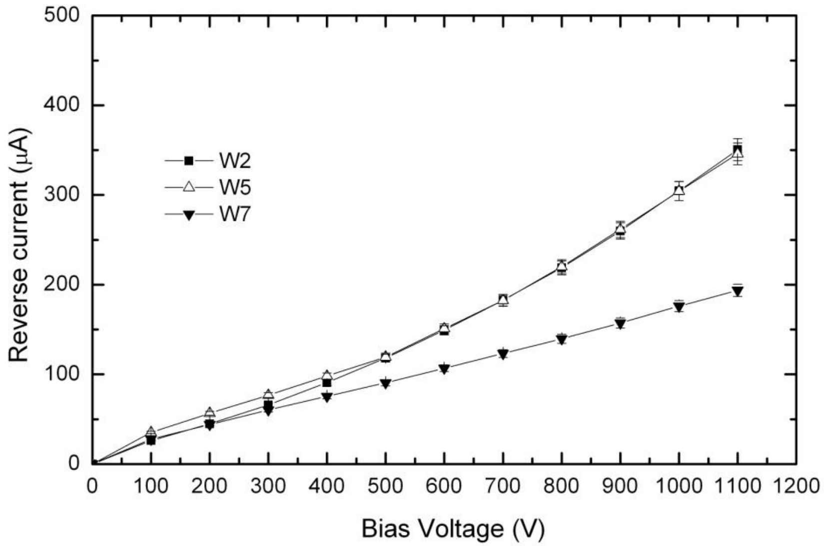




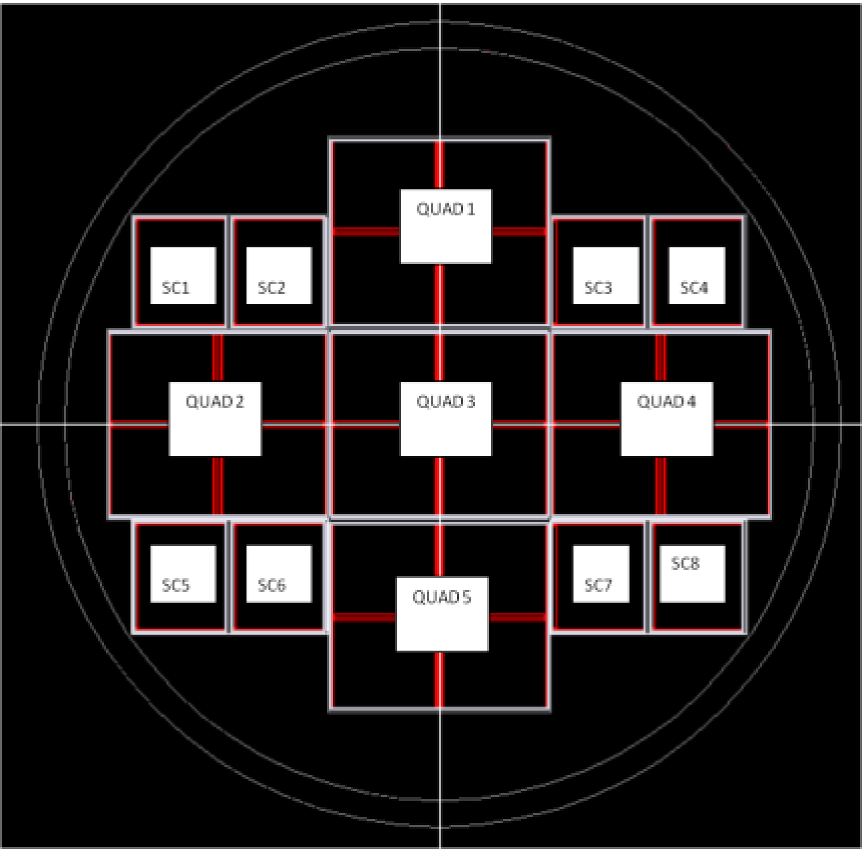
CC(V) and IV after 1E16 n_{eq} cm^{-2}



Trenched detectors with higher charge collection than standard.



Further work is required for understanding and controlling this method for charge collection enhancement. This work is being performed with AC coupled microstrip detectors. The relevant application would be pixel devices. Need to test with a pixel geometry (and DC coupled electronics).



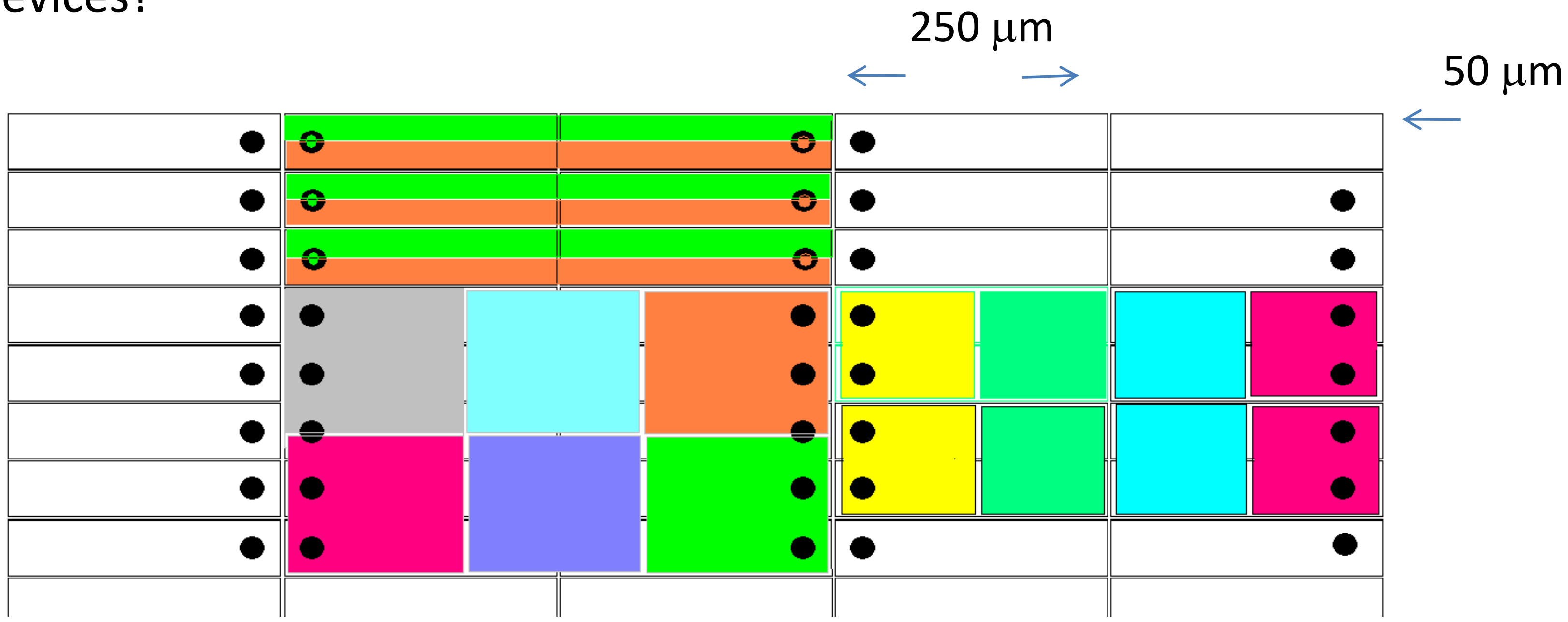
QUAD Mask

Sensor type:
SC1, SC2 – "test" 450 µm edge.
SC3, SC4 – 500x25, 450 µm edge.
SC5 – **SC8** "test", 300 µm edge.
SC6 – **SC7** "production", 300 µm edge.
QUAD1 – "production", 450 µm edge.
QUAD2 – "test", 300 µm edge.
QUAD3 – "test", 450 µm edge.
QUAD4 – "test", 450 µm edge.
QUAD5 – "production" 450 µm.

In pixel layers at higher radii (certainly the 3rd and 4th layers) there will be no need to push the CM for improved signal with respect to standard planar results. Even the second layer will probably need high bias (1000V) with no extra tricks .... Only innermost layer, and possible closer wheel would need a boost ...

Geometries

Possible pixel geometries based around a FE-I4 footprint. Is it possible to manipulate CM with this geometry and DC coupled devices?



Conclusions

Enhanced charge multiplication has been achieved with junction engineering. This is a first evidence that this method could be used for reducing the bias voltage required for a given signal (e.g. required for efficient tracking after very high doses). This might be a route to satisfy the radiation tolerance needs of the innermost layers for HL-LHC.

The development has been performed with microstrip AC coupled sensors. More test (topological characterisation, improvement of the processing, tests with pixel geometries ....) are needed to established if this process has practical applications. Nonetheless it can give insight about how the CM works and contribute to developing an effective parameterisation of the effect for practical uses.

Incidentally, work is being carried out within RD50 to see if CM can be influenced by the junction shape/size in a traditional planar processing.