Characterization of CNM's 3D pixel sensors for the CMS Phase-2 upgrade

Francisca J. Muñoz Sánchez

Instituto de Física de Cantabria

"9th TRENTO WORKSHOP ON ADVANCED SILICON RADIATION DETECTORS"

Genova. 27th February, 2014

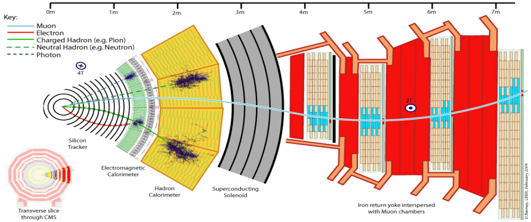
M. Lozano
G. Pellegrini
D. Quirion

E. Currás, M. Fernández
G.Gómez, R. Jaramillo
F.J. Muñoz, I. Vila

T. Rohe

Contents

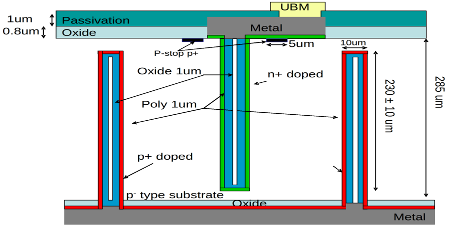
Motivation. From LHC to HL-LHC



- Luminosity: $10^{34} \cdot cm^{-2} \cdot s^{-1} \rightarrow 5{\times}10^{34} \cdot cm^{-2} \cdot s^{-1}$
- Particle fluences:$6{\times}10^{14}$ $n_{eq} \cdot cm^{-2} \rightarrow 2{\times}10^{16}$ $n_{eq} \cdot cm^{-2}$
- CMS inner Radius: 4.4 cm $\rightarrow$ 3.3 cm
- Planar n-on-on sensors $\rightarrow$ New Radiation Hard Technology

Description of the technology

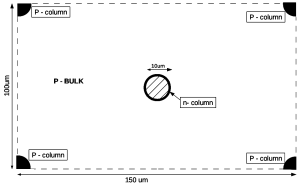
- Sensors fabricated at CNM-Barcelona
- Double side configuration
- Simpler process. Photolitography to define metal contacts only in one side
- HV-bias in the back side by simple wire bonding



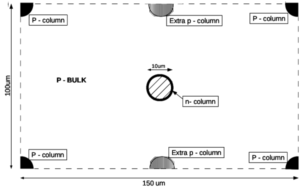
Proposed by G. Pellegrini in 2006

Description of the different layouts

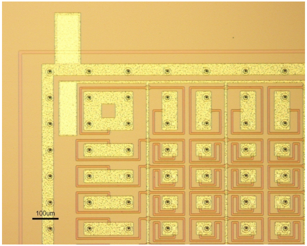
Sparse pattern



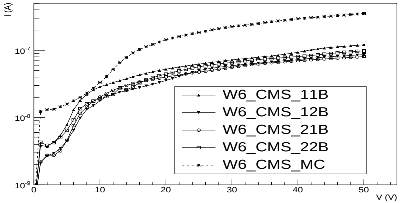
Dense pattern

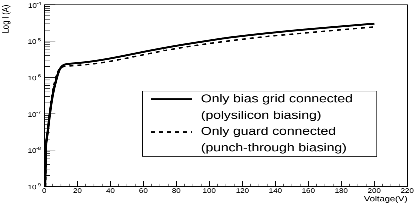


One wafer includes a polysilicon bias grid to bias one to one every pixel unit cell:



Electrical Characterization I





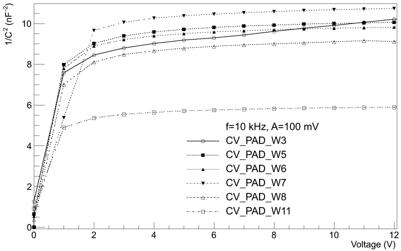
- High Homogeneity and a higher current for the Multi-Chip (MC) sensor (16 single-chips)
- Biasing studies: biasing through the guard ring or through the bias grid

Electrical Characterization II

Coaxial Formula

$$V_{fd} = \frac{Nq}{2\epsilon}\left[r_1^2 Ln\frac{r_2}{r_1} - \frac{1}{2}\left(r_2^2 - r_1^2\right)\right]$$

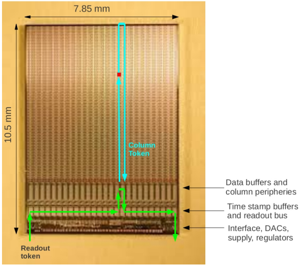
$r_1 \rightarrow$ column radius.
$r_2 \rightarrow$ n+ and p+ columns distance.

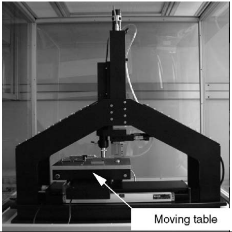


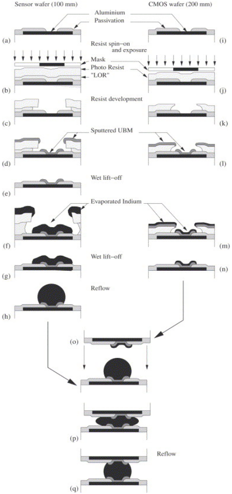
V$_{FD}$ was measured in diodes and analytically assessed in pixel sensors.

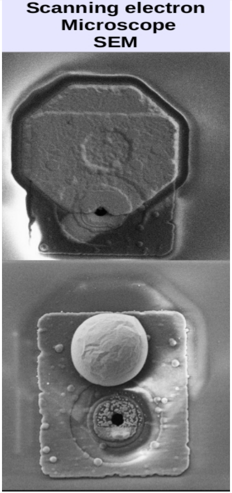
$$\boxed{V_{FD,sensor} \sim 6 \cdot V_{FD,diode}}$$

Interconnection Process at PSI





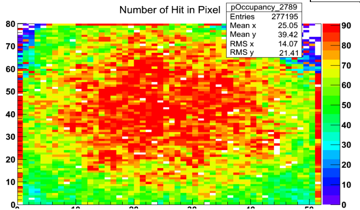


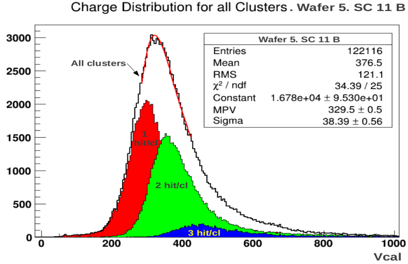


^{90}Sr Characterization. Unirradiated sensors

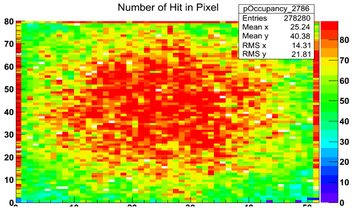
$$Vbias = 20V$$

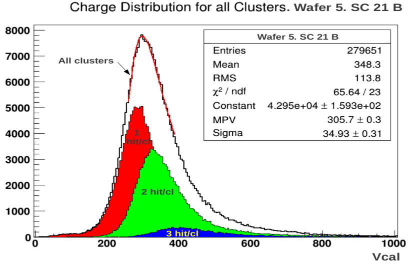
Sparse





Dense





^{90}Sr Characterization. Irradiated sensors

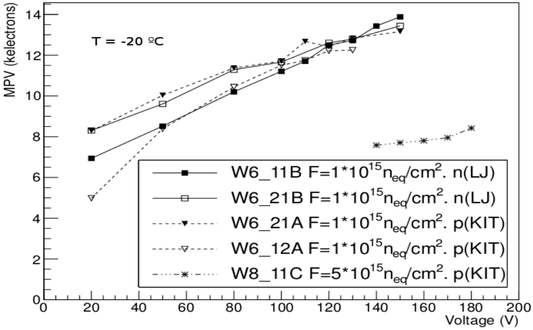
- Protons irradiation up to $5 \cdot 10^{15}\ n_{eq} \cdot cm^{-2}$. KIT.
- Neutrons irradiation up to $1 \cdot 10^{16}\ n_{eq} \cdot cm^{-2}$. Ljubljana.
- Charge collection efficiency
- Full Depletion Voltage
  - Depletion Area grows vertically
  - Relative Efficiency

$$E_r = \frac{Number\ of\ hits}{Number\ of\ Triggers}$$

  - E_r Saturation implies that the maximal area has been depleted

^{90}Sr Characterization. Irradiated sensors I

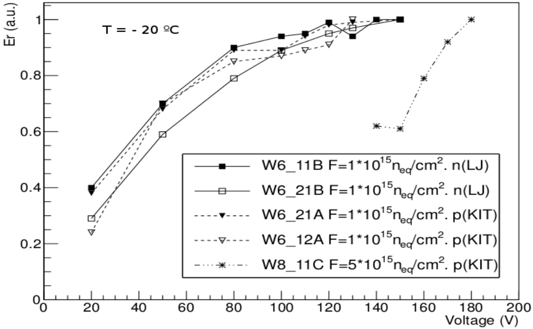
MPV vs V$_{bias}$



NIM A:http://dx.doi.org/10.1016/j.nima.2013.05.121

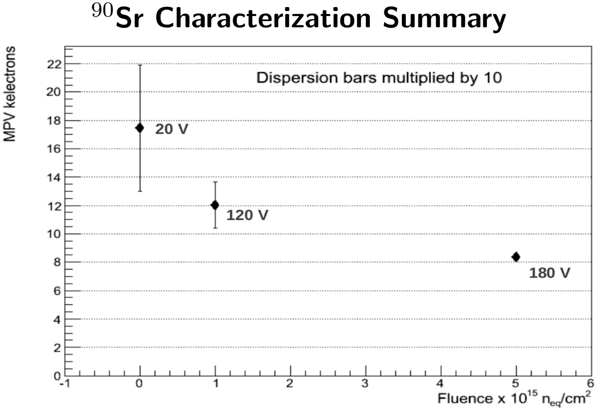
^{90}Sr Characterization. Irradiated sensors II

E$_r$ vs V$_{bias}$



NIM A:http://dx.doi.org/10.1016/j.nima.2013.05.121

^{90}Sr Characterization. Irradiated sensors III

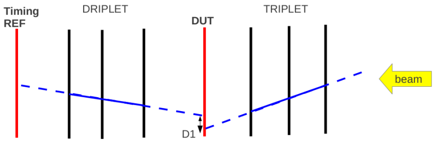


NIM A:http://dx.doi.org/10.1016/j.nima.2013.05.121

Test beam Characterization at DESY

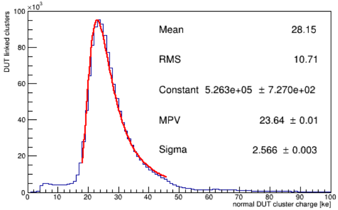
- Positron beam of momentum 6 GeV
- Datura Telescope. Mimosa-based pixel telescope.
  $\sigma = 4 - 5\ \mu m$, readout $\sim$ 100 μs

To avoid telescope pile-ups, a timing reference sensor is needed

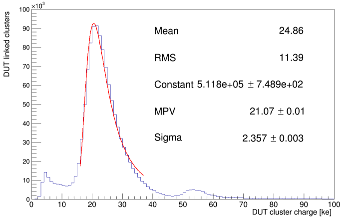


Test beam Results I. Unirradiated

Sparse



Dense

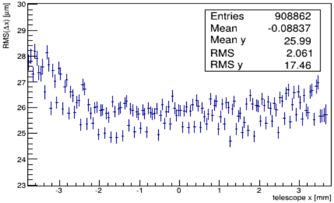


- Charge distribution differences aren't necessary due to the different pattern
- ROC calibration uncertainties are about 15 %

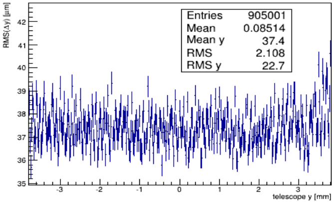
$$\boxed{V_{bias} = 20V, Room\ Temperature}$$

Test beam Results II. Unirradiated

Sparse

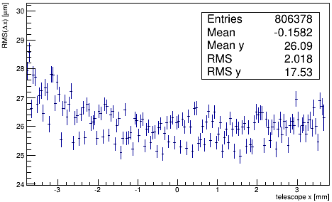


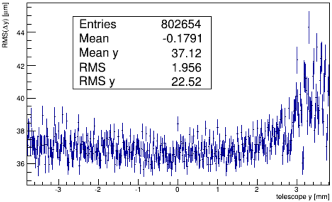
$$p_x/\sqrt{12} = 28\mu m$$



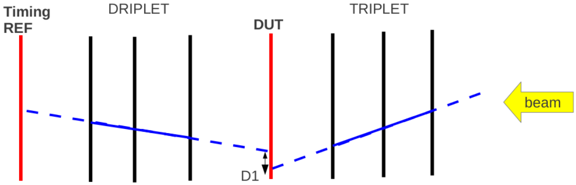
$$p_x/\sqrt{12} = 43\mu m$$

Dense





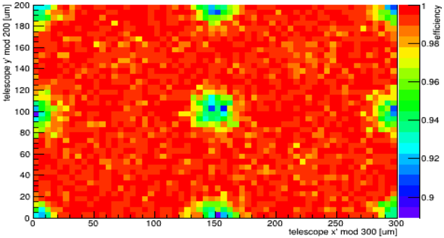
Efficiency tracks selection



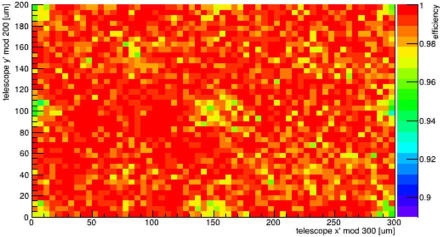
- Driplet linked to DUT and Reference sensor
- Triplet linked to DUT
- D1 $< 500\ \mu$m

Test beam Results III. Unirradiated

Sparse



Dense



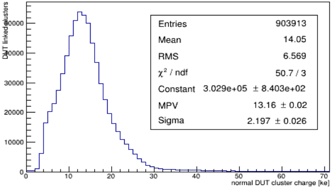
- The sensor including the dense column pattern shows higher homogeneity
- Sparse and Dense drop 6 and 2 %, respectively in the worst case. Normal incidence
- Pn-junction columns don't show a significant efficiency drop

$$\boxed{V_{bias} = 20V, Room\ Temperature}$$

Test beam Results IV. Irradiated up to $1 \cdot 10^{15} n_{eq} \cdot cm^{-2}$

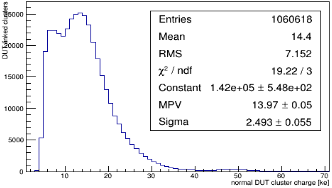
Charge distributions at -15 C

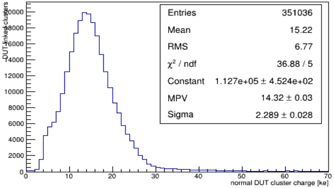
Sparse



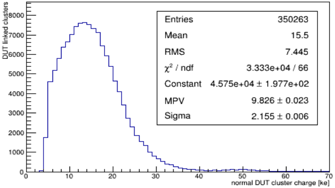
$V_{bias} = 120V$

Dense



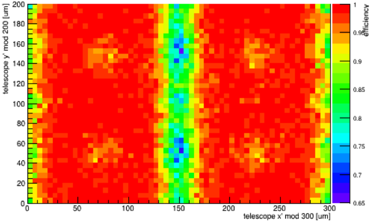


$V_{bias} = 140V$

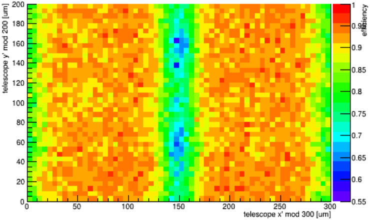


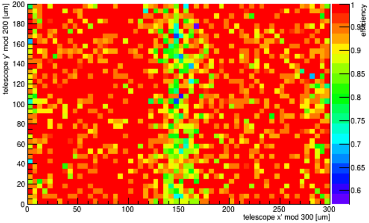
Test beam Results V. Irradiated up to $1 \cdot 10^{15} n_{eq} \cdot cm^{-2}$

Sparse **Efficiency Maps at -15 C** **Dense**

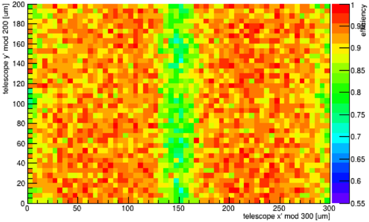


$V_{bias} = 120V$





$V_{bias} = 140V$



- Electrical Characterization
  - Sensor biasing by the bias grid and by punch-through are in good agreement
- After the ^{90}Sr characterization:
  - Sensors up to irradiation fluences of $5 \times 10^{15} n_{eq} \cdot cm^2$
  - Sensors show a good performance and applying bias voltages below 200 V
  - Results are compatible with ATLAS-IBL results
- In test beam measurements:
  - Unirradiated dense pattern show a more homogeneous performance in terms of efficiency
  - Irradiated samples need a deeper study
  - Charge distributions $\rightarrow$ PSI46 performance after high irradiation fluences

Acknowledgements

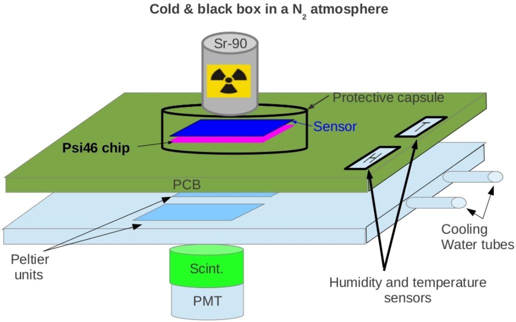
- PSI, ETH and DESY CMS-pixel Teams
- Specially:
  - Hans Christian Kaetsli
  - Andrei Starodumov
  - Dmitry Hits
  - Marco Rossini
  - Daniel Pitzl
  - Simon Spannagel
- Irradiation Facilities: Ljubljana and KIT
- AIDA project


Thank you
for your Attention!

BACKUP

Strontium-90 characterization

- ^{90}Sr is a pure electron emitter
- MIP. Particle which kinetic energy $\geq 2 \times$ rest mass

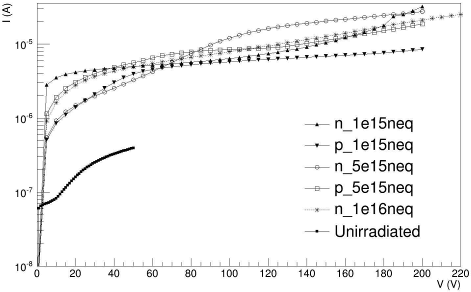


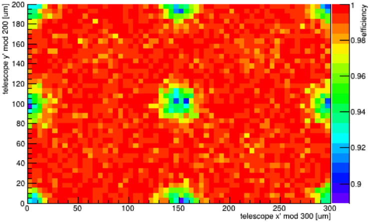
Irradiation Facilities

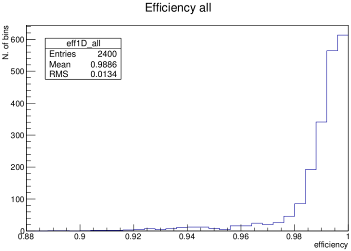
Radiation resistance of 3D pixel sensors was also characterized

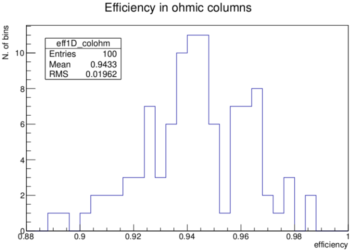
- Continuous energy spectrum of neutrons at TRIGA reactor at JSI (Ljubljana)
- 23 MeV protons at KIT

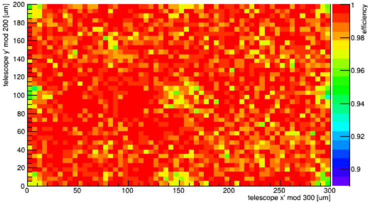
Irradiated samples. IV Curves in pads

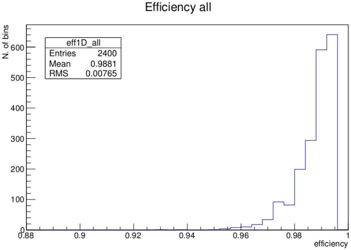


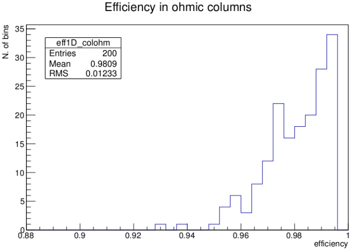

telescope y' mod 200 [um]
telescope x' mod 300 [um]
efficiency
0
50
100
150
200
250
300
0
20
40
60
80
100
120
140
160
180
200
0.9
0.92
0.94
0.96
0.98
1


Efficiency all
eff1D_all
Entries 2400
Mean 0.9886
RMS 0.0134
N. of bins
efficiency
0
100
200
300
400
500
600
0.88
0.9
0.92
0.94
0.96
0.98
1


Efficiency in ohmic columns
eff1D_colohm
Entries 100
Mean 0.9433
RMS 0.01962
N. of bins
efficiency
0
2
4
6
8
10
0.88
0.9
0.92
0.94
0.96
0.98
1

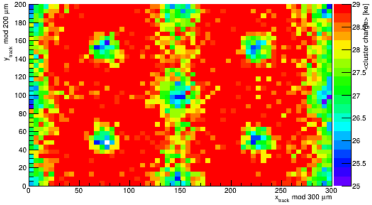

telescope y' mod 200 [um]
telescope x' mod 300 [um]
efficiency
0
50
100
150
200
250
300
20
40
60
80
100
120
140
160
180
200
1
0.98
0.96
0.94
0.92
0.9

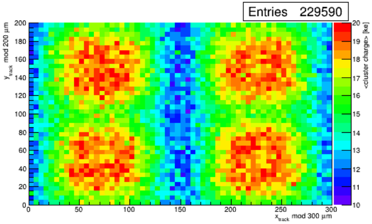

Efficiency all
N. of bins
efficiency
eff1D_all
Entries 2400
Mean 0.9881
RMS 0.00765
0.88
0.9
0.92
0.94
0.96
0.98
1
0
100
200
300
400
500
600


Efficiency in ohmic columns
N. of bins
efficiency
eff1D_colohm
Entries 200
Mean 0.9809
RMS 0.01233
0.88
0.9
0.92
0.94
0.96
0.98
1
0
5
10
15
20
25
30
35

Charge collection Unirradiated (top) and Irradiated (bottom)

Sparse





Dense