

# Comparative investigation of irradiated small-pitch 3D strip detectors

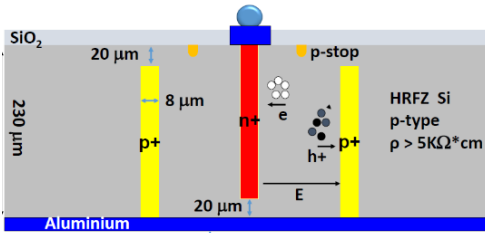
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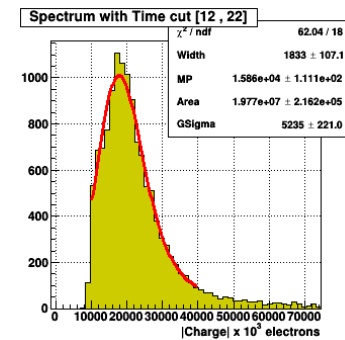
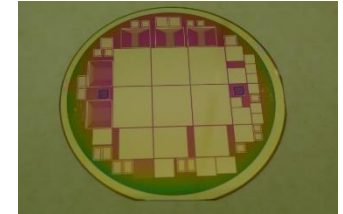
32<sup>nd</sup> RD50 Workshop, Hamburg

# Introduction

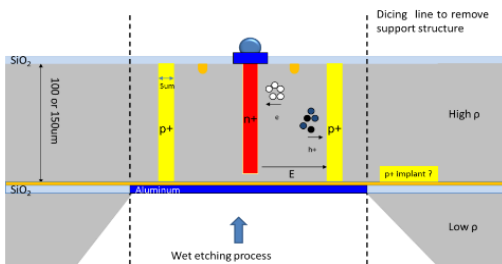
- Radiation hardness study of small-pitch 3D strip sensors



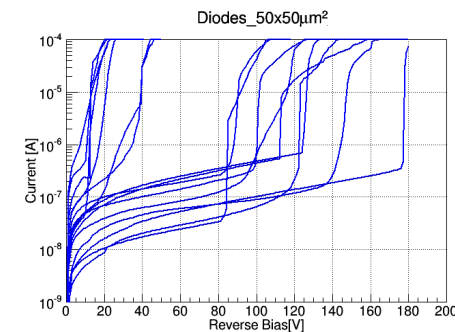
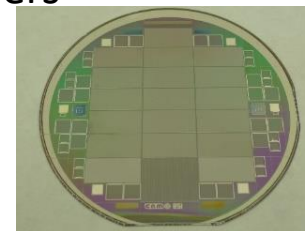
- ✓ Double sided fabrication process
- ✓ 230 μm thick wafers
- ✓ Charge collection of irradiated sensors



- First measurements of new RD53A 3D sensors

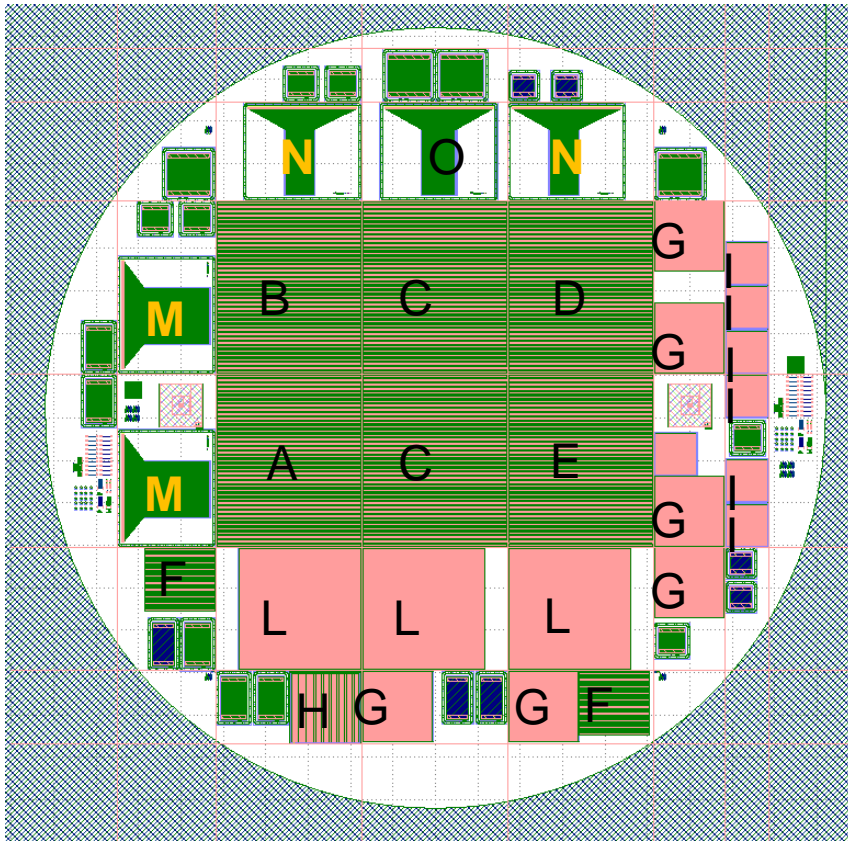


- ✓ Single sided fabrication process
- ✓ 150 μm thick SOI wafers
- ✓ IVs on wafer level



## Mask layout

- Run 7781 - first batch with small pixel size:  $50 \times 50 \mu\text{m}^2$  and  $25 \times 100 \mu\text{m}^2$
- Double sided process,  $230 \mu\text{m}$  thick wafers,  $8 \mu\text{m}$  column diameter



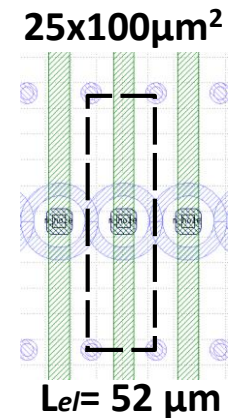
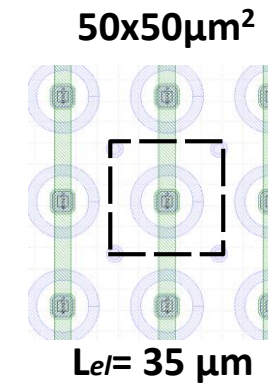
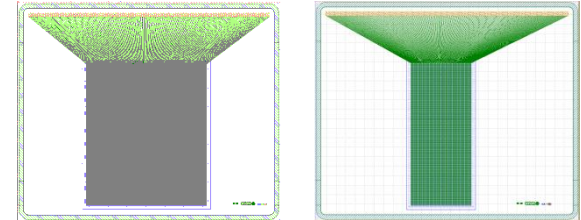
### Mask: CNM745

- A:  $25 \times 250 \mu\text{m}^2$  2E - standard FE-I4
- B:  $25 \times 500 \mu\text{m}^2$  5E – i.e. 5x "25x100" 1E, with 3DGR
- C:  $50 \times 50 \mu\text{m}^2$  1E with the rest connected to GND with 3DGR
- D:  $25 \times 100 \mu\text{m}^2$  2E with the rest connected to GND
- E:  $50 \times 50 \mu\text{m}^2$  with the rest connected to GND without 3DGR
- F : FEI3 device:  $50 \times 50 \mu\text{m}^2$  with rest to GND with 3D GR
- G: ROC4sens  $50 \times 50 \mu\text{m}^2$
- H: PSI46dig
- I: FERMILAB RD ROC  $30 \times 100 \mu\text{m}^2$
- L: Velopix  $55 \times 55 \mu\text{m}^2$
- **M: Strip  $50 \times 50 \mu\text{m}^2$**
- **N: Strip  $25 \times 100 \mu\text{m}^2$**
- O: Strip  $30 \times 100 \mu\text{m}^2$
- P: Pad diodes  $25 \times 25$ ,  $25 \times 50$ ,  $30 \times 50$ ,  $50 \times 50 \mu\text{m}^2$

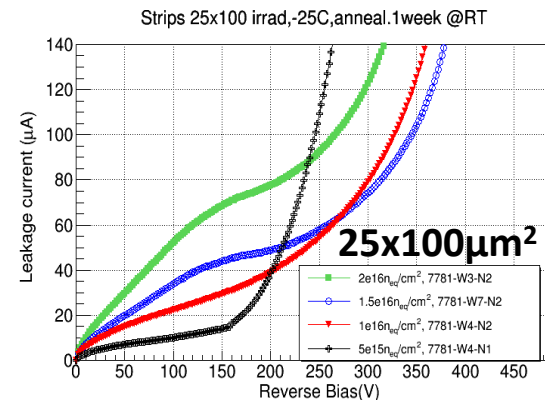
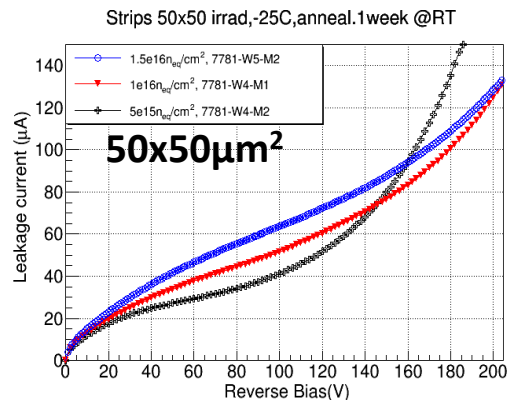
## 3D strip sensors

- 3D strip detectors irradiated at different fluences with neutrons at JSI Ljubljana:

Strip detector	Pixel cell ( $\mu\text{m}^2$ )	Electrode distance ( $\mu\text{m}$ )	Fluence ( $n_{\text{eq}}/\text{cm}^2$ ) $\times 10^{16}$
7781-8-M2	50x50 1E	35	-
7781-4-M1	50x50 1E	35	0.5
7781-4-N1	25x100 1E	52	0.5
7781-4-M2	50x50 1E	35	1.0
7781-5-M2	50x50 1E	35	1.5
7781-7-N2	25x100 1E	52	1.5
7781-3-N2	25x100 1E	52	2.0

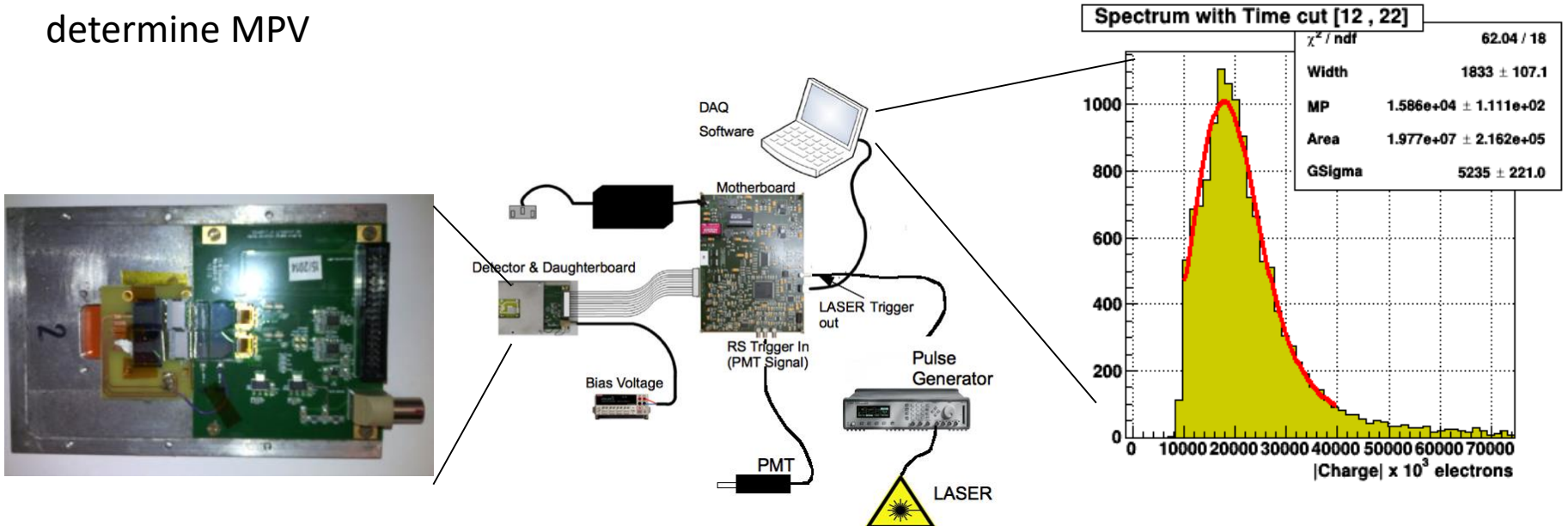
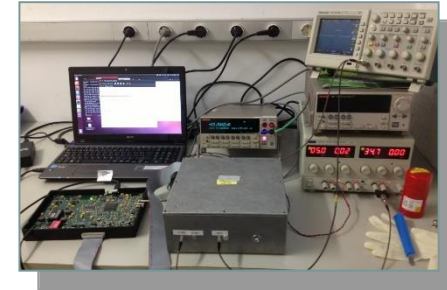


- All detectors annealed for 1 week at room temperature
- IVs carried out in probe station



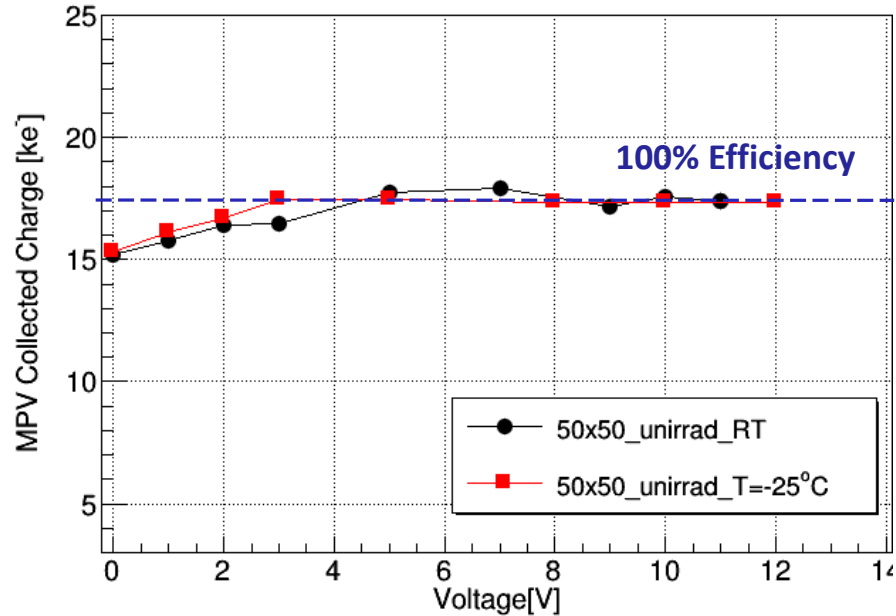
## ALiBaVa System

- Charge Collection done by ALiBaVa readout system at CNM-IMB-CSIC
- Measurements done in a fridge at  $T=-25^{\circ}\text{C}$
- MIPs from a  $^{90}\text{Sr}$  source used to perform charge collection
- AC pitch adapters employed
- Analysis of data with *sin\_preguntas* script on ROOT framework
- Resulting spectrum fitted with a convolution of a Gaussian and Landau distribution to determine MPV



# Non-irradiated 3D strip sensors

Non-irradiated strips sensors

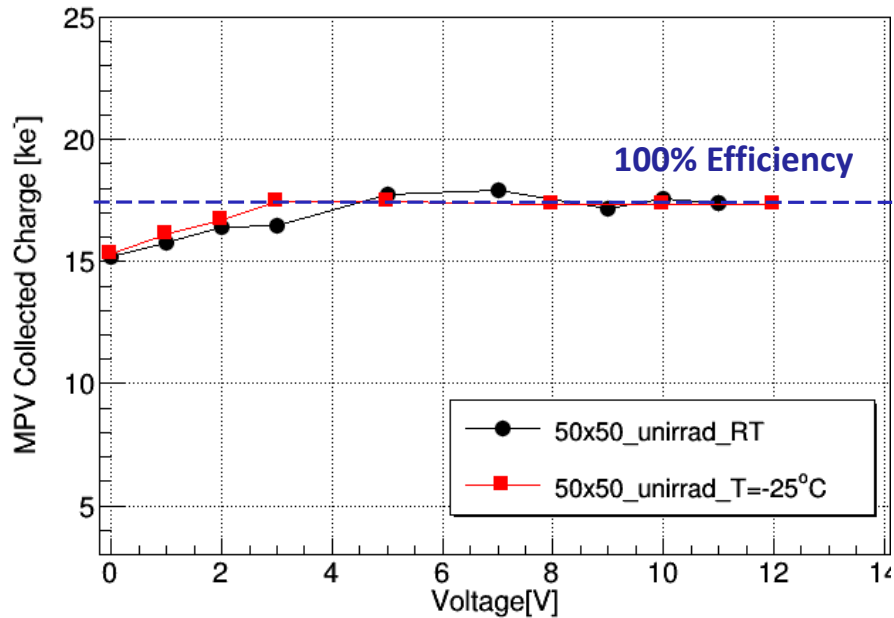


- 50x50  $\mu\text{m}^2$  active at 0V with 15ke<sup>-</sup> collected charge
- 100% charge collected at full depletion (~5V )
- Estimated uncertainties of ~6% (not included in the graph)
- Maximum value of CC (17.2ke<sup>-</sup>) similar to the FEI4 sensors(16.8ke<sup>-</sup>)\*

\*D.Vazquez Furelos et al., JINST 12 (2017) C01026

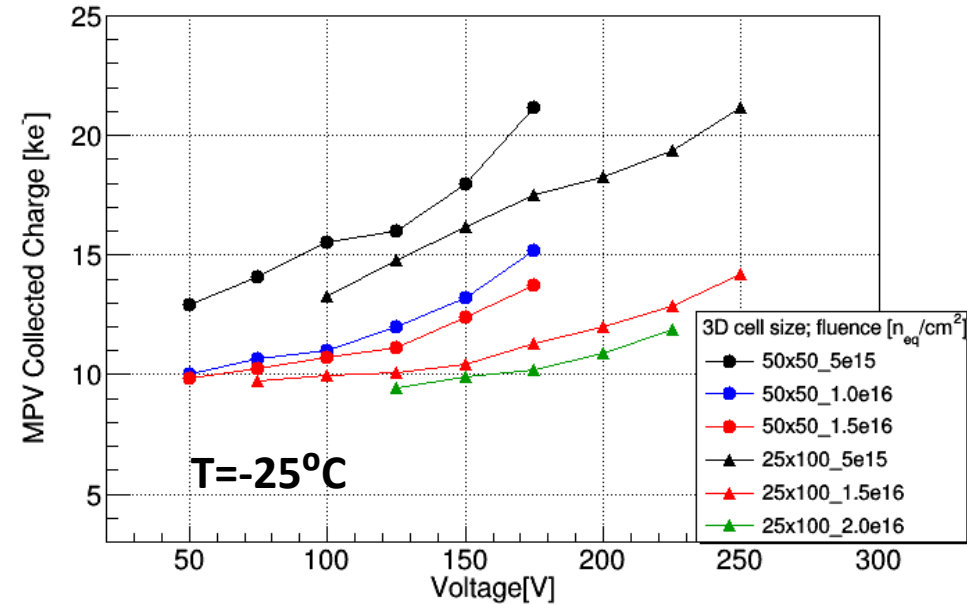
# Irradiated 3D strip sensors

Non-irradiated strips sensors



- 50x50  $\mu\text{m}^2$  active at 0V with 15ke<sup>-</sup> collected charge
- 100% charge collected at full depletion (~5V)
- Estimated uncertainties of ~6% (not included in the graph)
- Maximum value of CC (17.2ke<sup>-</sup>) similar to the FEI4 sensors(16.8ke<sup>-</sup>)\*

Irradiated strip sensors

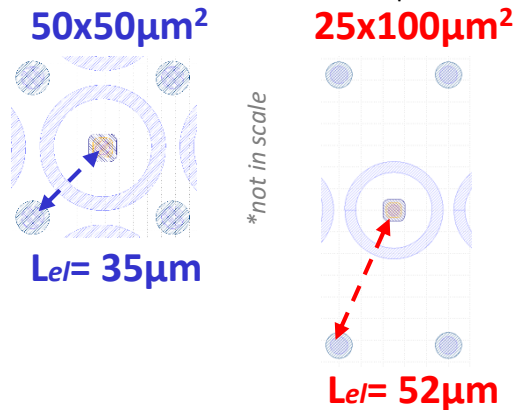


- 50x50  $\mu\text{m}^2$  collects more charge than 25x100  $\mu\text{m}^2$  for the same fluence; clear for  $V > 125\text{V}$
- 25x100  $\mu\text{m}^2$  also collects  $>10\text{ke}^-$  charge at high fluences
- 50x50  $\mu\text{m}^2$  collects similar charge for higher fluences
- Charge multiplication effects for  $V > 150\text{V}$  in 50x50  $\mu\text{m}^2$  at  $0.5 \times 10^{16} n_{\text{eq}} \text{cm}^{-2}$
- In graph, minimum CC  $\sim 10\text{ke}^-$  (probably an artifact)

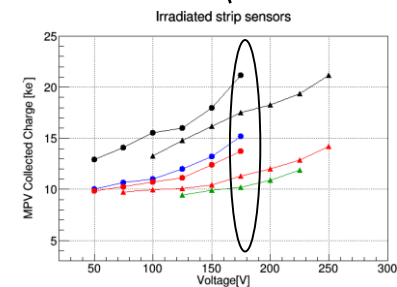
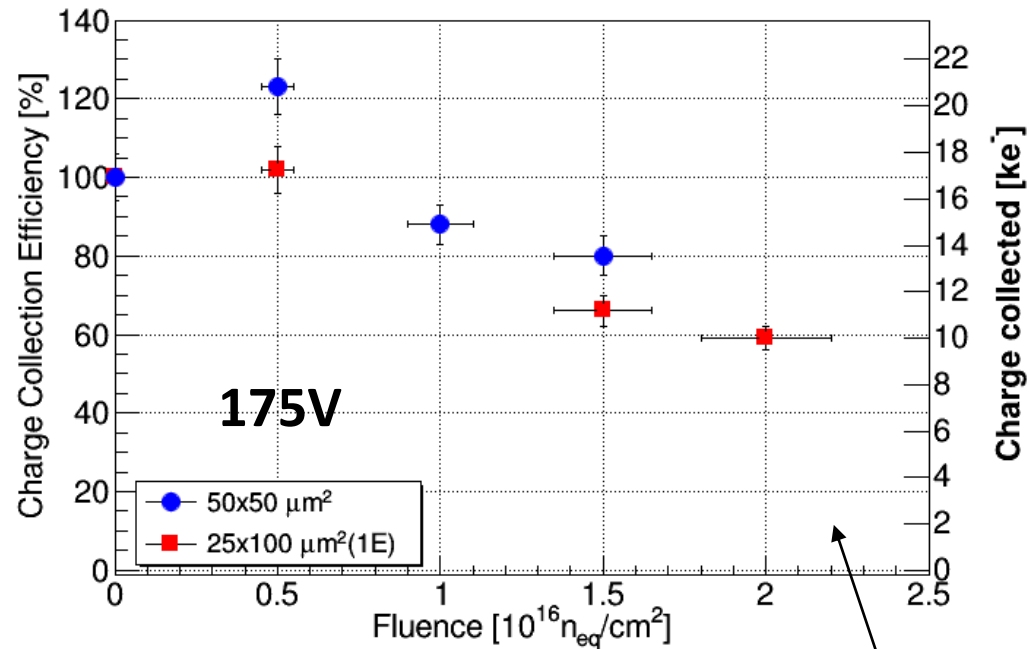
\*D.Vazquez Furelos et al., JINST 12 (2017) C01026

## Summary and conclusion

- Charge collection characterisation of double sided 3D strip sensors
- Two pixel cell geometry:
  - 50x50 $\mu\text{m}^2$  and 25x100 $\mu\text{m}^2$
- Non-irradiated: 100% efficiency at 5V
- Irradiated up to  $2.0 \times 10^{16} n_{\text{eq}} \text{cm}^{-2}$



- CCE improves as electrode distance decreases
- At  $1.5 \times 10^{16} n_{\text{eq}} \text{cm}^{-2}$ , 50x50  $\mu\text{m}^2$  achieves 80% of efficiency, 25x100 $\mu\text{m}^2$ , 65%
- At  $2.0 \times 10^{16} n_{\text{eq}} \text{cm}^{-2}$ , 25x100 $\mu\text{m}^2$  shows 60% of efficiency
- 50x50  $\mu\text{m}^2$  radiation hardness better than 25x100 $\mu\text{m}^2$  but further studies needed





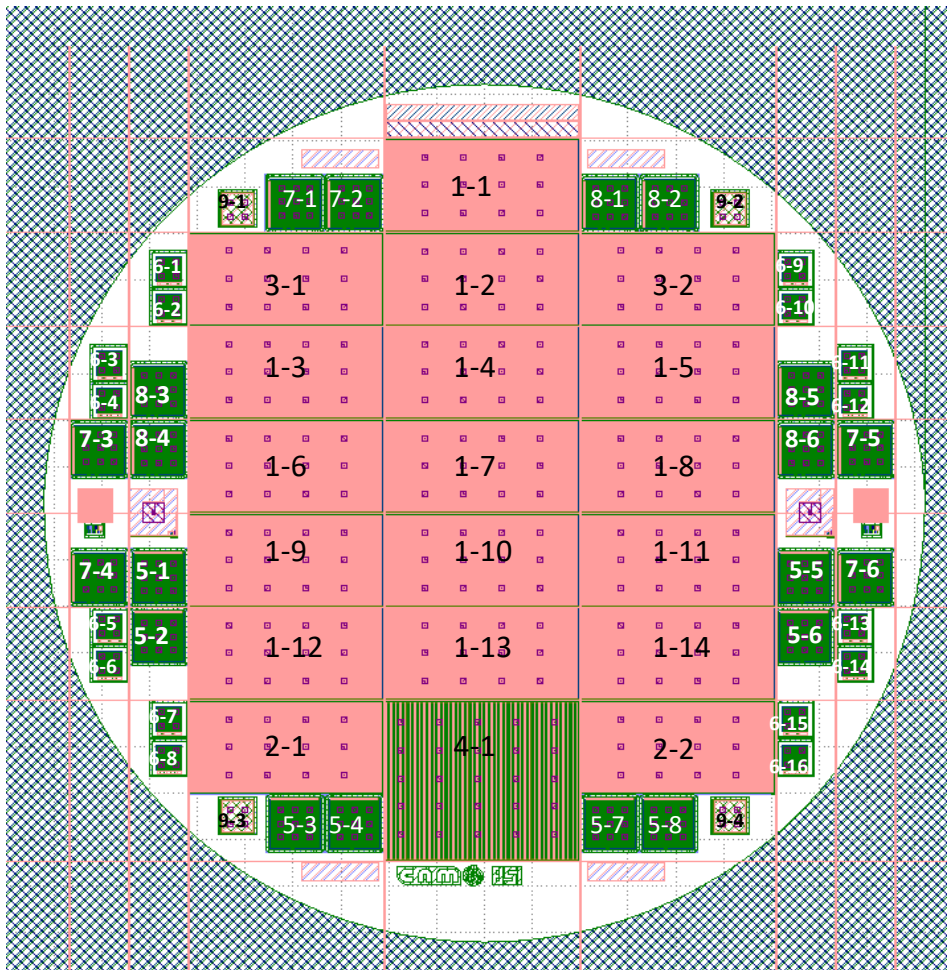
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# 3D single sided detectors

## New production

# Mask layout

- Run 9761- first run with RD53A pixel design



## Mask:CNM851

- 1-x RD53A  $50 \times 50 \mu\text{m}^2$
- 2-x RD53A  $25 \times 100 \mu\text{m}^2$  (2E)
- 3-x RD53A  $25 \times 100 \mu\text{m}^2$  (1E)
- 4-1 FEI4 ( $50 \times 50 \mu\text{m}^2$ )

## Diodes

- 5-x  $50 \times 50 \mu\text{m}^2$  100x100 electrodes
- 6-x  $50 \times 50 \mu\text{m}^2$  50x50 electrodes
- 7-x  $25 \times 50 \mu\text{m}^2$  100x100 electrodes
- 8-x  $25 \times 100 \mu\text{m}^2$  200x50 electrodes

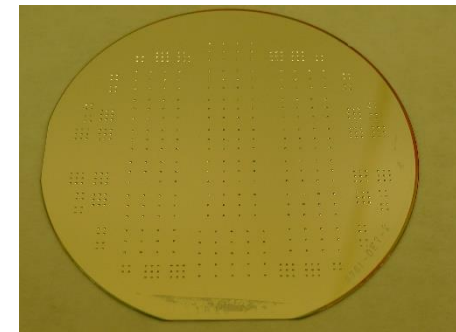
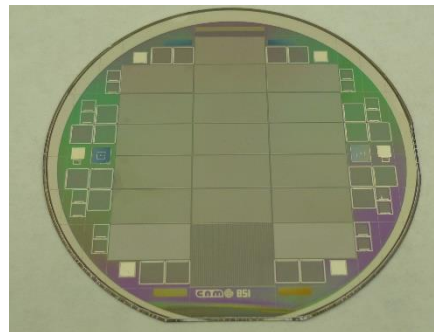
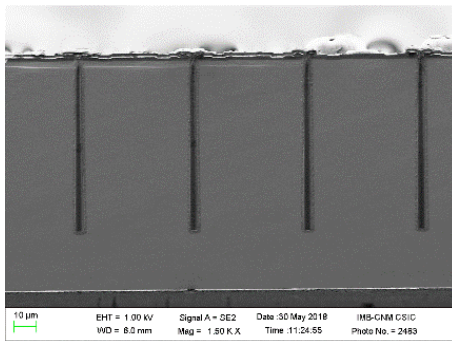
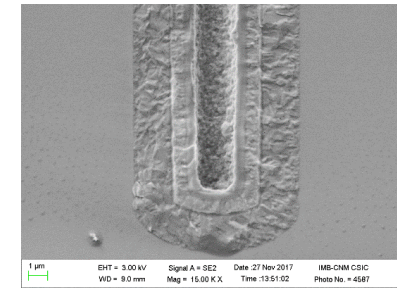
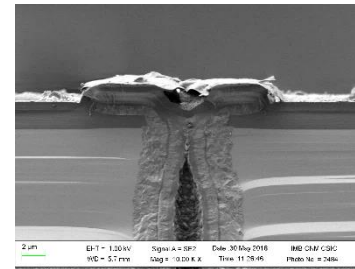
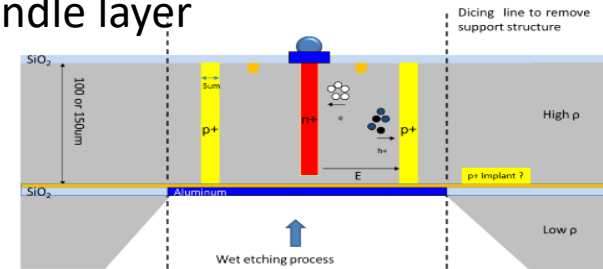
## MOS

- 9-x  $3500 \times 3500 \mu\text{m}^2$

# Technology

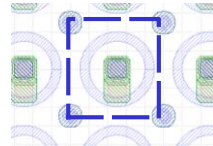
- 7 wafers produced and concluded the last week
- SOI wafers 150  $\mu\text{m}$  and 100  $\mu\text{m}$  active thickness with 300 $\mu\text{m}$  handle layer
- Single-on-sided process
  - Both p- and n-columns etched from same side (front)

- N+ column depth: 130  $\mu\text{m}$  and 80  $\mu\text{m}$
- 8  $\mu\text{m}$  holes diameter
- P+ columns filled with undoped polysilicon
- Thinning and biasing on the backside
- Temporary metal deposited to perform IVs and removed before the UBM process at CNM

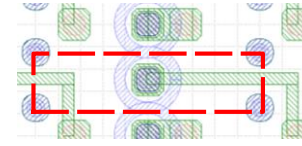


# RD53A - Electrical characterisation

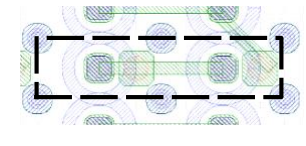
- 150  $\mu\text{m}$  active thickness



50x50  $\mu\text{m}^2$



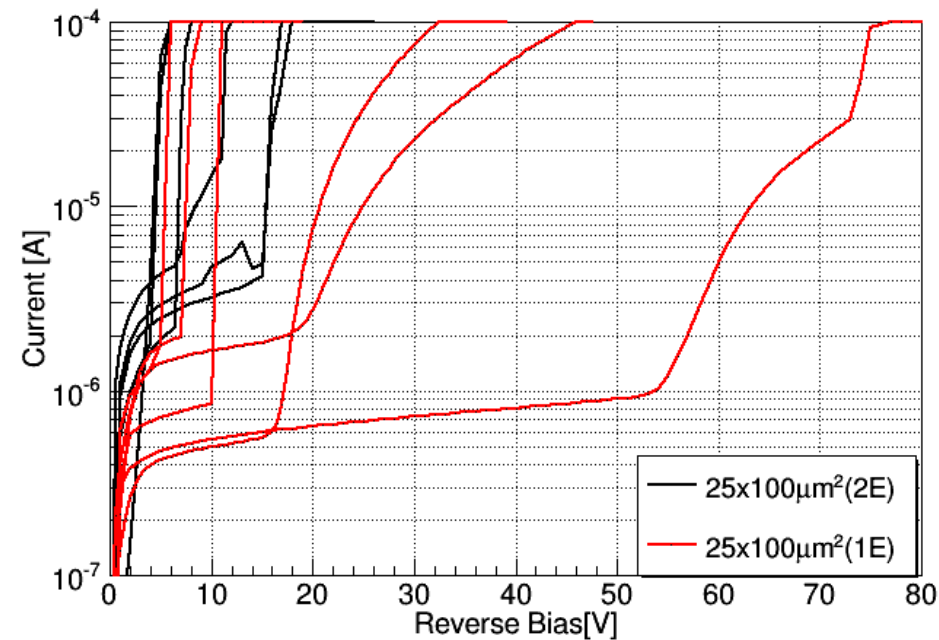
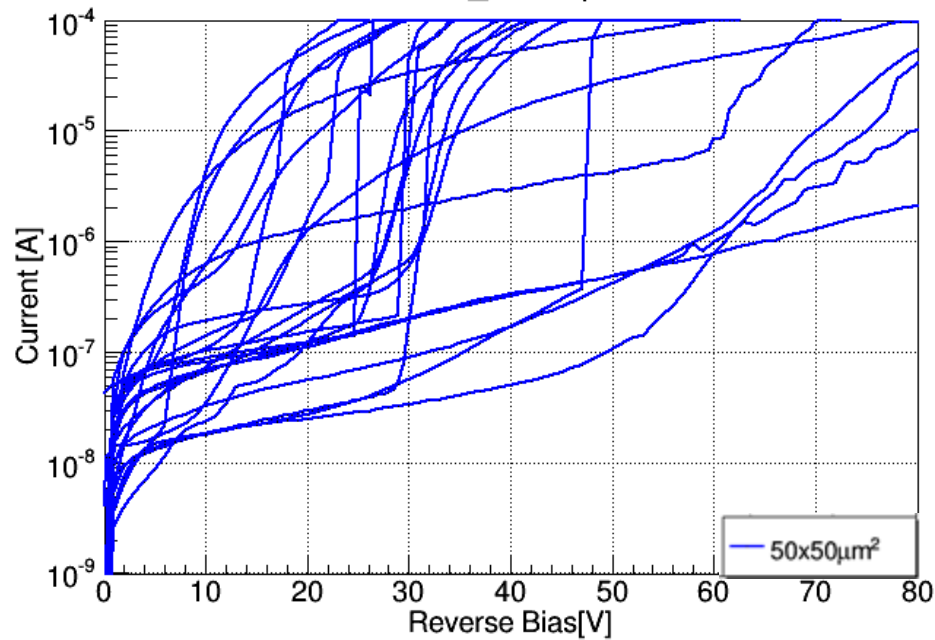
25x100  $\mu\text{m}^2$  1E



25x100  $\mu\text{m}^2$  2E

RD53A\_50x50 $\mu\text{m}^2$

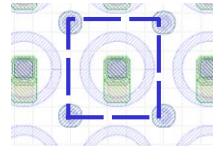
RD53A\_25x100 $\mu\text{m}^2$



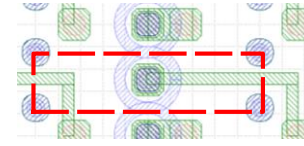
- Some 50x50  $\mu\text{m}^2$  sensors have low leakage current with soft breakdown voltage
- 25x100  $\mu\text{m}^2$  (2E) pixel geometry problematic for ITk requirements

# RD53A - Electrical characterisation

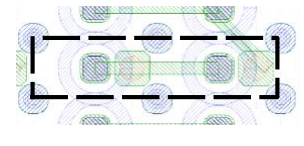
- 100  $\mu\text{m}$  active thickness



50x50  $\mu\text{m}^2$

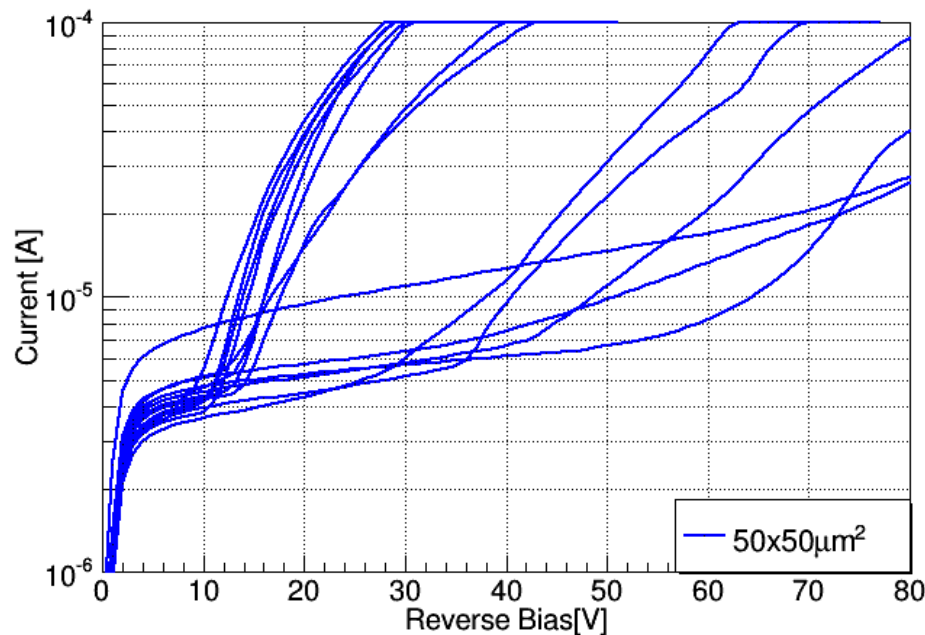


25x100  $\mu\text{m}^2$  1E

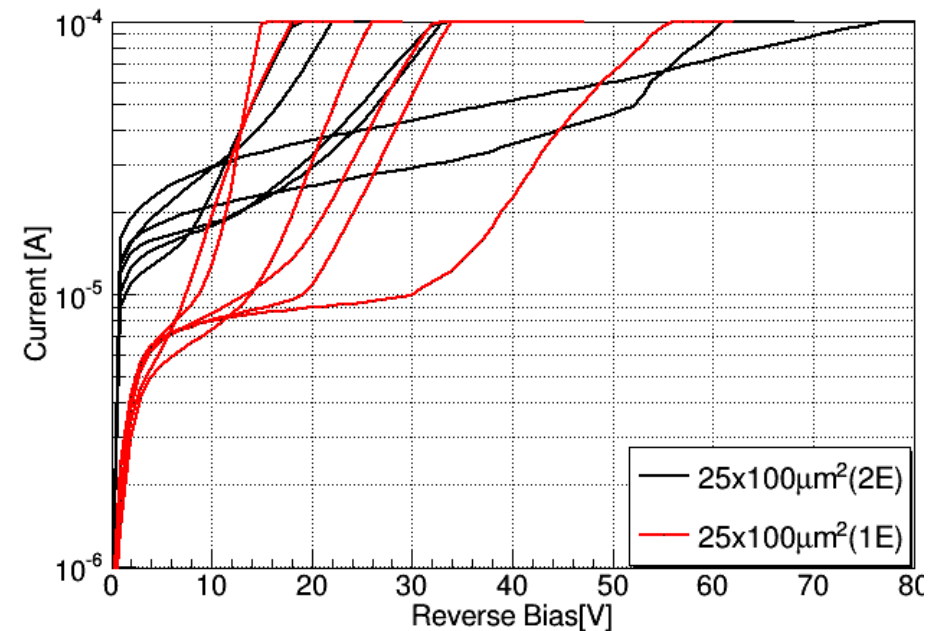


25x100  $\mu\text{m}^2$  2E

RD53A\_50x50 $\mu\text{m}^2$



RD53A\_25x100 $\mu\text{m}^2$

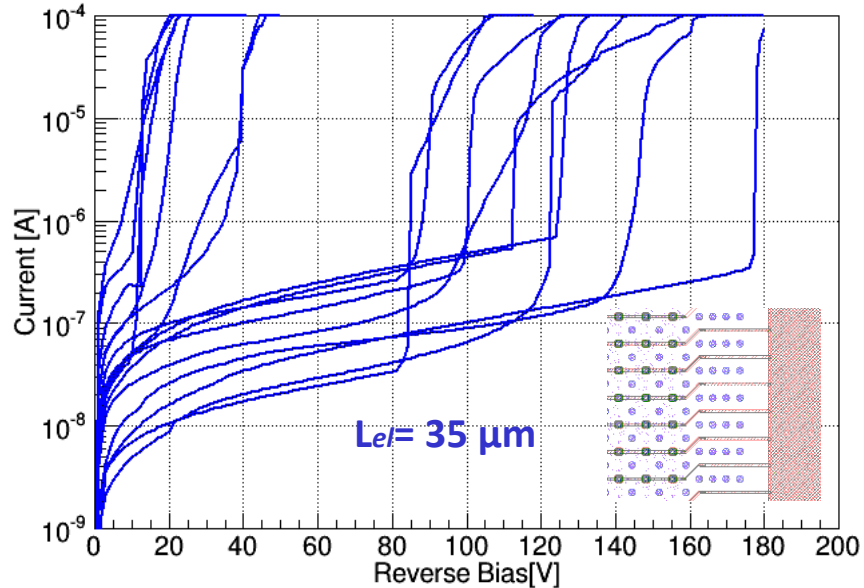


- Several good sensors
- In thinner wafers, higher leakage current (issue under investigation)
- 25x100  $\mu\text{m}^2$  (2E) pixel geometry works

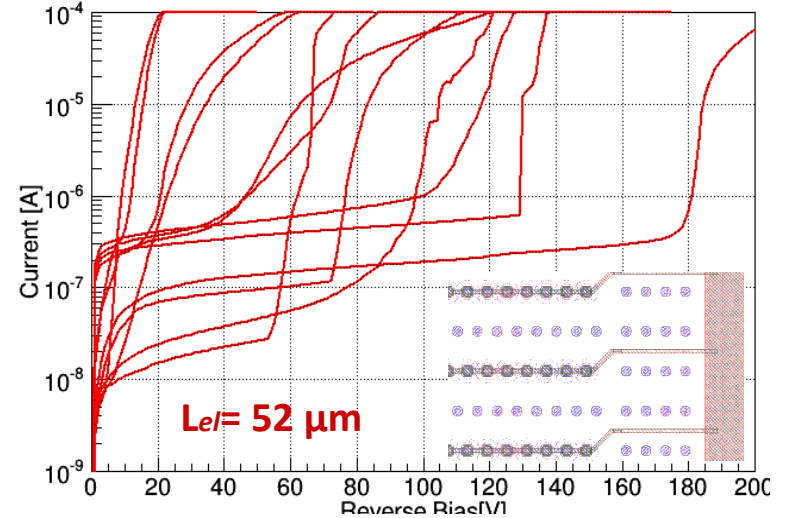
## Diodes - Electrical characterisation

- 150  $\mu\text{m}$  active thickness

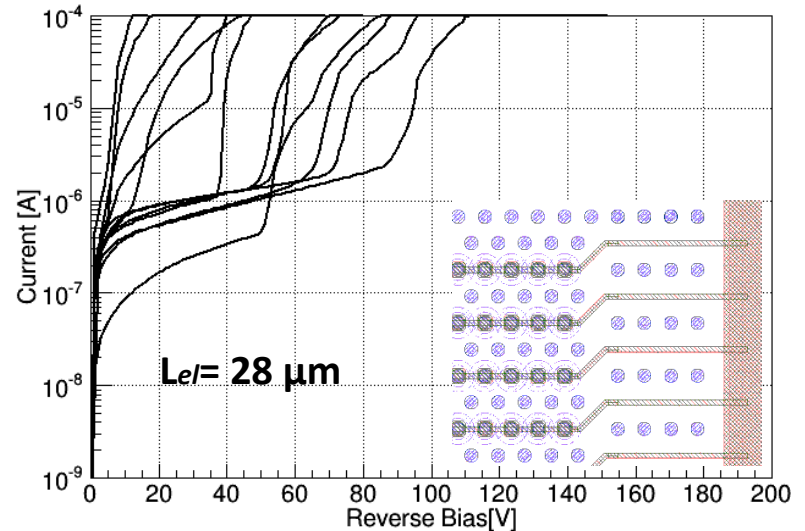
Diodes\_50x50 $\mu\text{m}^2$



Diodes\_25x100 $\mu\text{m}^2$ (1E)



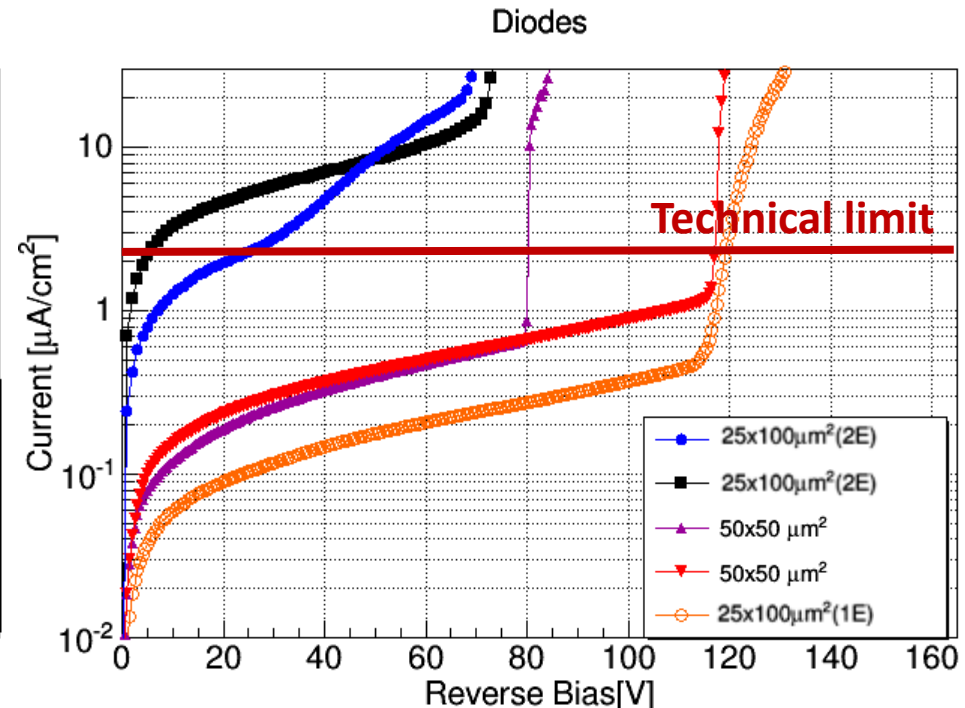
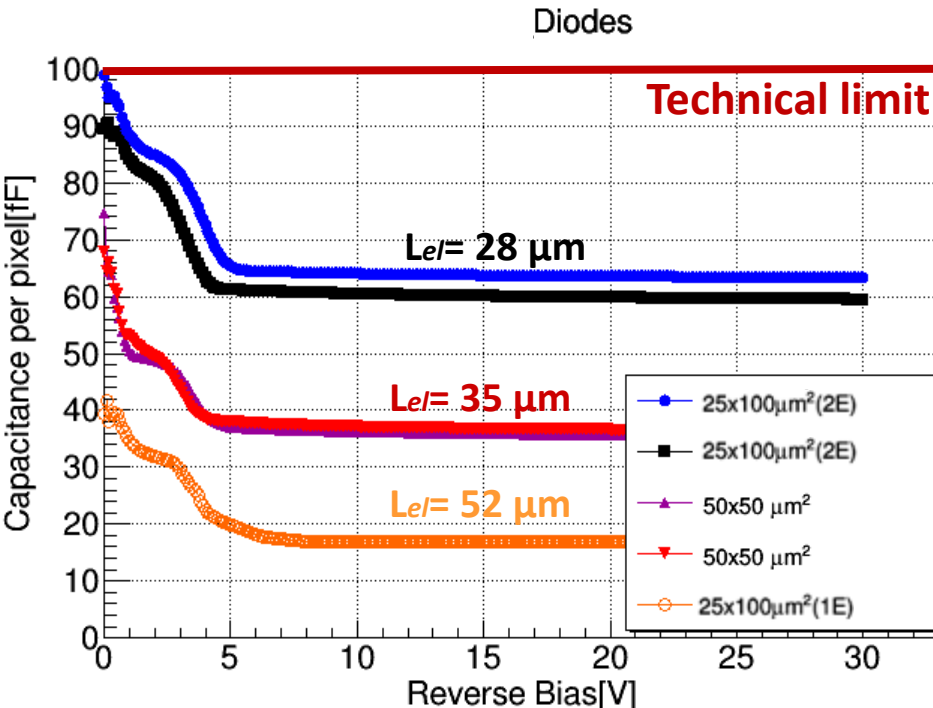
Diodes\_25x100 $\mu\text{m}^2$ (2E)



Leakage current in **50x50  $\mu\text{m}^2$**  and **25x100  $\mu\text{m}^2$  (1E)** lower than **25x100  $\mu\text{m}^2$  (2E)**

## Diodes – CV measurements

- 150  $\mu\text{m}$  active thickness



- The capacitance increases as the electrode distance decreases
- Two sloping intervals: the first for the lateral (2V) and the second for full depletion (5V)
- The leakage current is below the acceptance criteria for  $50 \times 50 \mu\text{m}^2$  and  $25 \times 100 \mu\text{m}^2 (1E)$





# Thank you for your attention!