

# First measurements of irradiated CNM LGADs with carbon enriched gain layer

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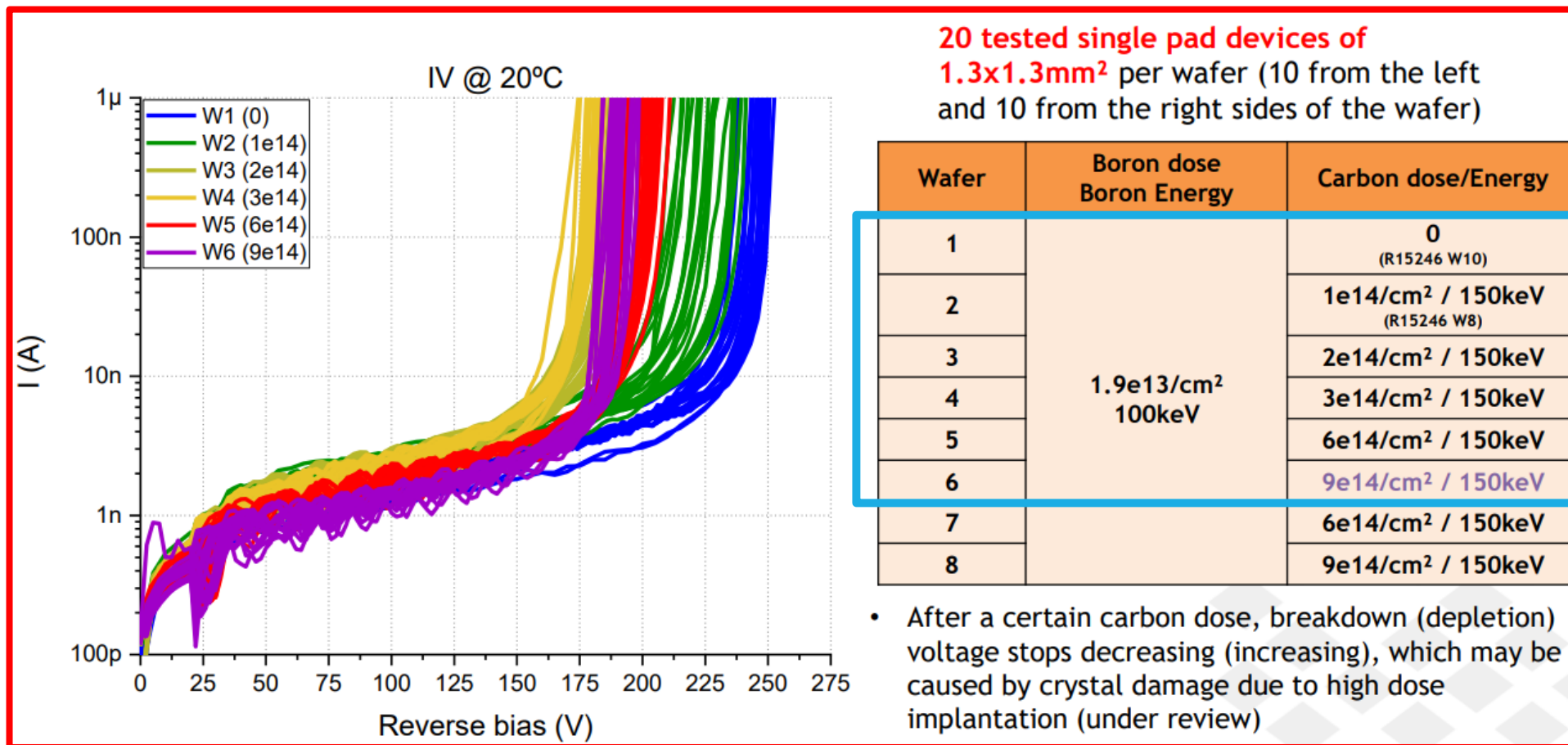
# Previous CNM run (15246)

Long time annealing for both Carbon and Mult Layers 3h @ 1100°C.

Wafer	Boron dose Boron Energy	Carbon dose/Energy	Acceptor removal constant (1e-16/cm <sup>2</sup> )
8	1.9e13 /cm <sup>2</sup>	0	8.25±0.08*
10	100keV	1e14/cm <sup>2</sup> / 150keV	4.95±0.06*

- ATLAS and CMS upgrades require sensors to withstand up to  $\phi_{eq}=2.5E15 \text{ cm}^{-2}$  and TID 2 MGy-> significant decrease of gain
- Previous CNM run (15246) showed good performance in terms of breakdown and depletion voltage, but poor radiation hardness for non carbon enriched sensors
- Carbon enrichment mitigates degradation of gain layer
  - Latest CNM run varies carbon concentration

# ATLAS CNM run 15973



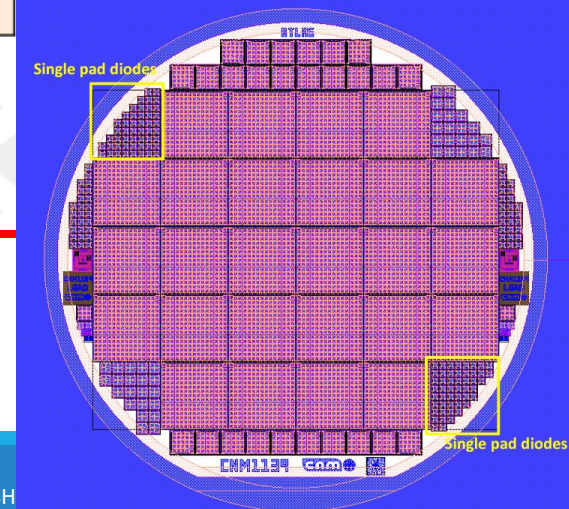
2-3 samples from wafers 1-6 irradiated to:

- $2.5 \text{E}15$
- $1.5 \text{E}15$
- $8 \text{E}14$
- $4 \text{E}14$

and had CV/IV and timing/CC measured

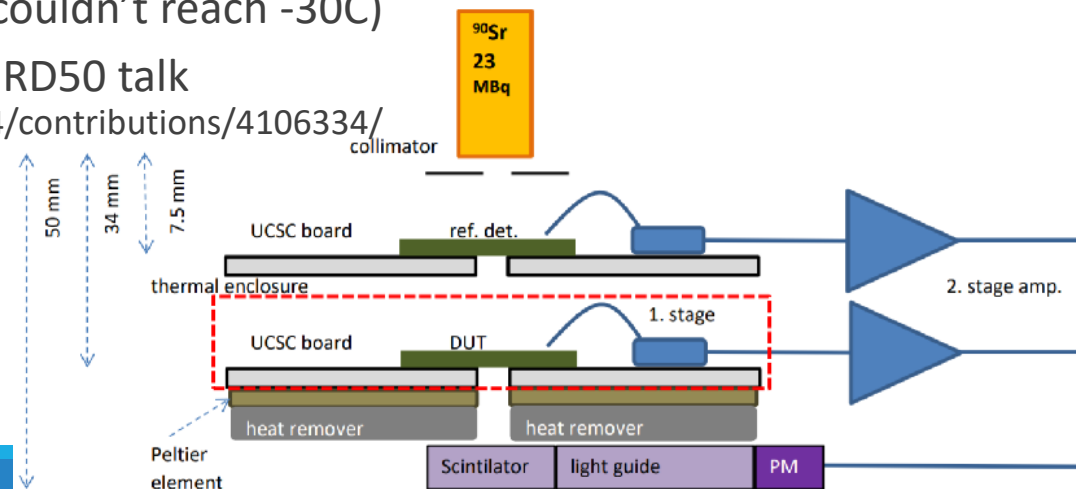
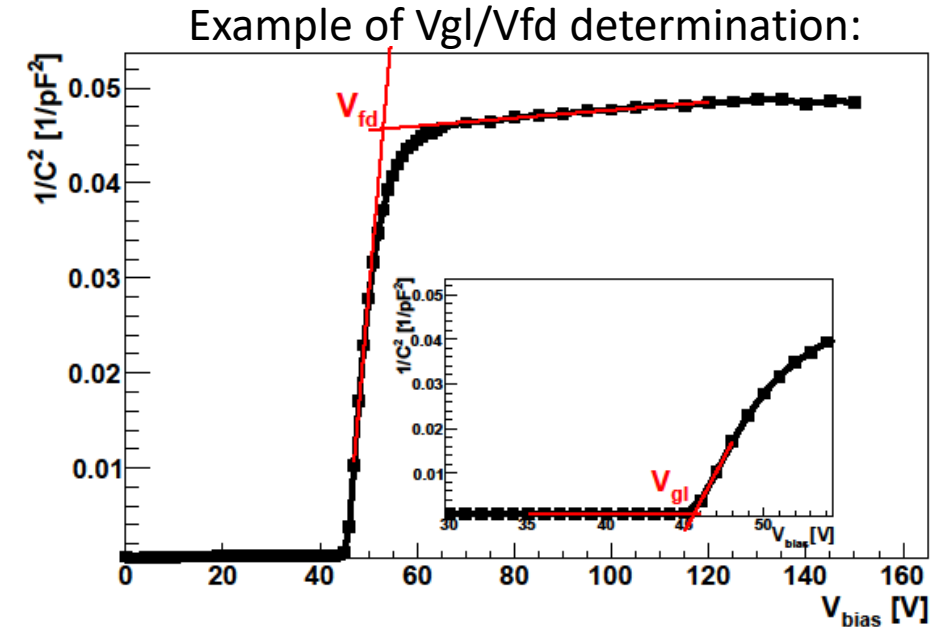
See Jairo's talk at HGTD week

[https://indico.cern.ch/event/1197867/contributions/5393946/attachments/2644911/4/577908/20230510\\_CN\\_M\\_ATLAS\\_Run15973\\_FirstResults.pdf](https://indico.cern.ch/event/1197867/contributions/5393946/attachments/2644911/4/577908/20230510_CN_M_ATLAS_Run15973_FirstResults.pdf)

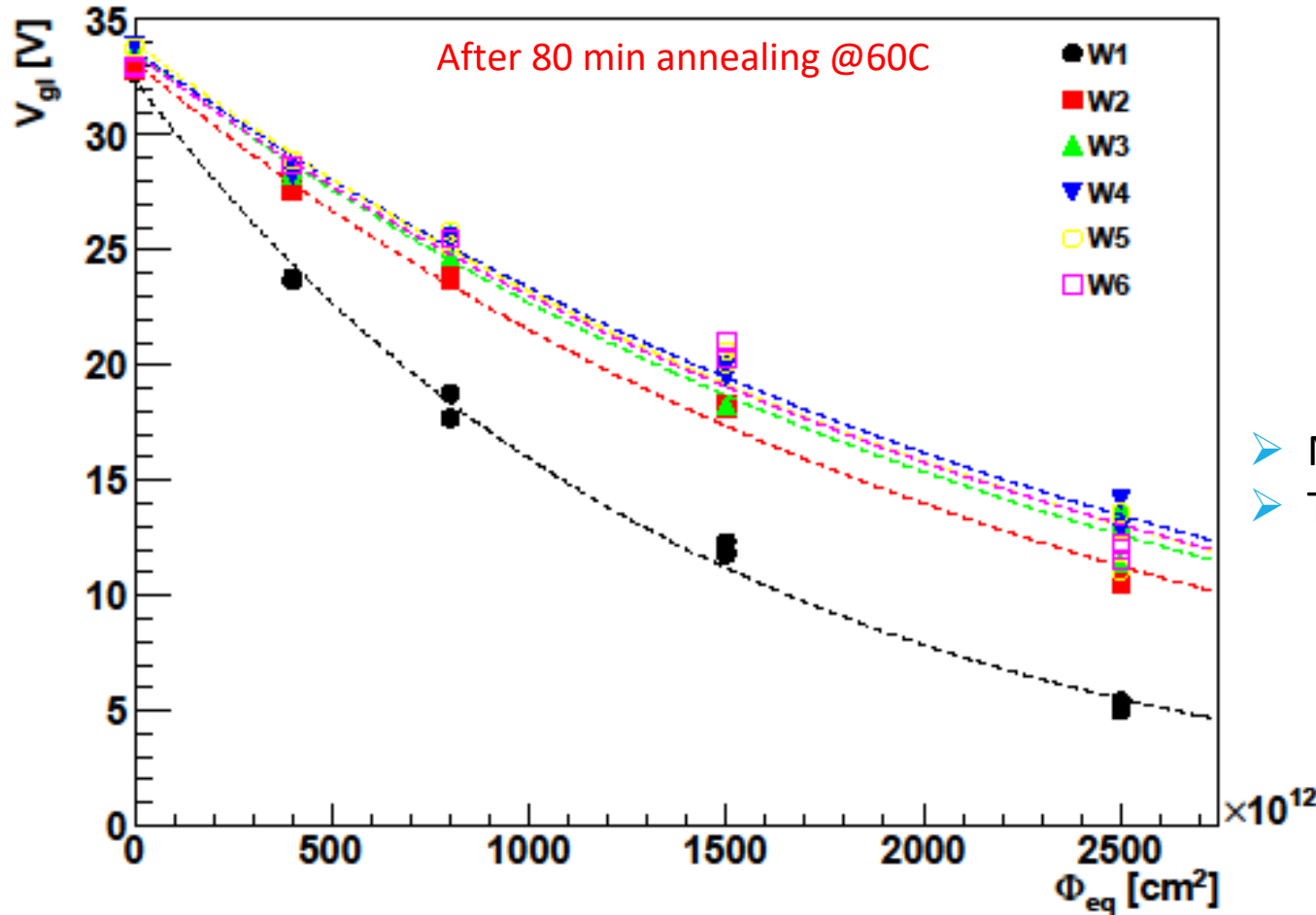


# Experimental Procedure

- Irradiated with neutrons (at JSI Triga II reactor)
- Annealed for 80 mins @ 60°C and kept cold
  - CV/IV measured before and after annealing
- CVIV:
  - 20°C/500mV/10kHz
  - $V_{gl}/V_{fd}$  determined from CV
- Timing/CC :
  - $^{90}\text{Sr}$  source
  - ~-24C (cooling problems so couldn't reach -30C)
  - For details see Gregor's 37<sup>th</sup> RD50 talk  
<https://indico.cern.ch/event/896954/contributions/4106334/>



# Acceptor Removal

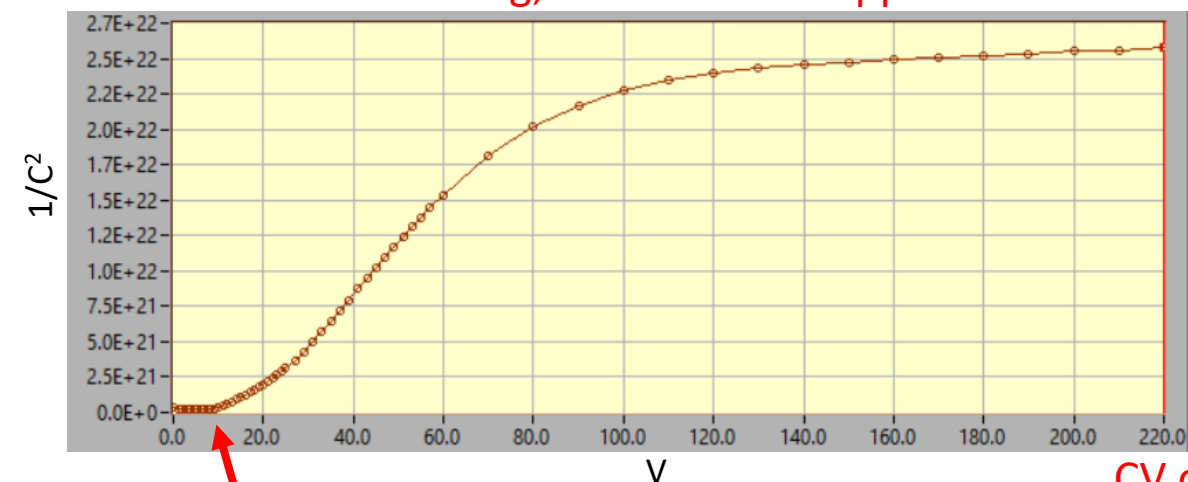


Wafer #	c [ $10^{-16} \text{ cm}^2$ ] (no annealing)	c [ $10^{-16} \text{ cm}^2$ ] (80 min @ 60C)
W1	6.40	7.08
W2	4.07	4.31
W3	3.55	3.91
W4	3.45	3.66
W5	3.53	3.82
W6	3.51	3.76

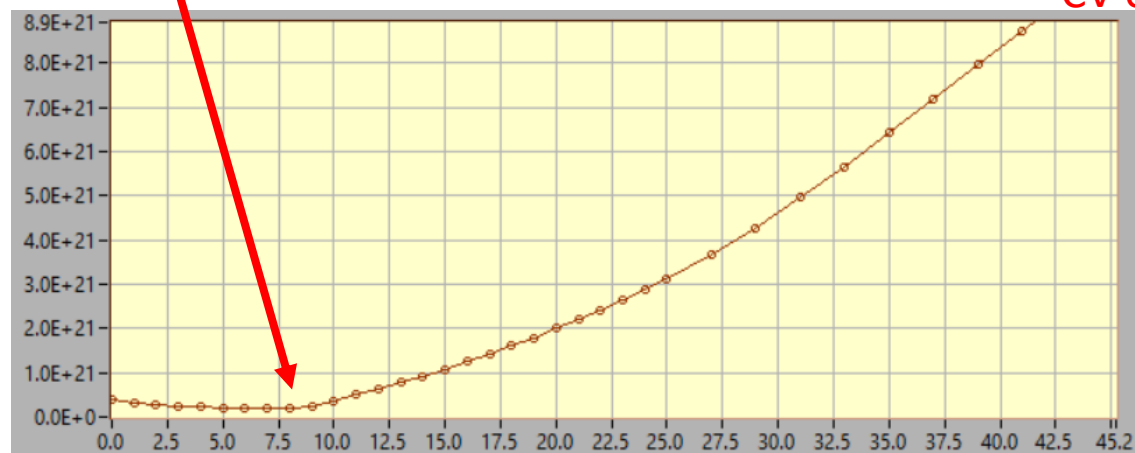
- Measured 2-3 samples per wafer per fluence
- The first results of the acceptor removal values show:
  - no significant difference between wafers 3, 4, 5 or 6.
  - values are higher than hoped – but all this has to be crosschecked with higher statistics, different locations on the wafer, labs and of course with signals
  - c is around 5-10% lower before annealing
    - in agreement with what was seen with HPK non carbonated sensors

# First measurement after irradiation

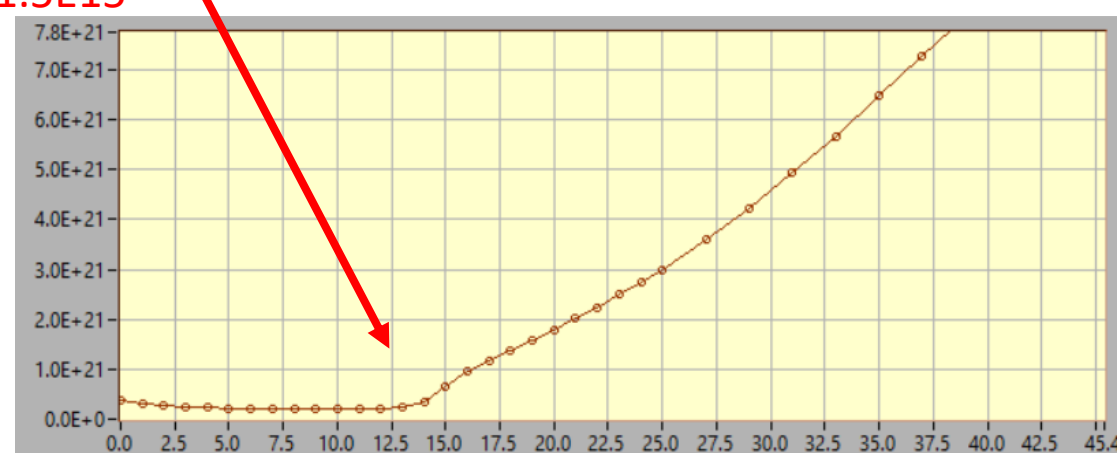
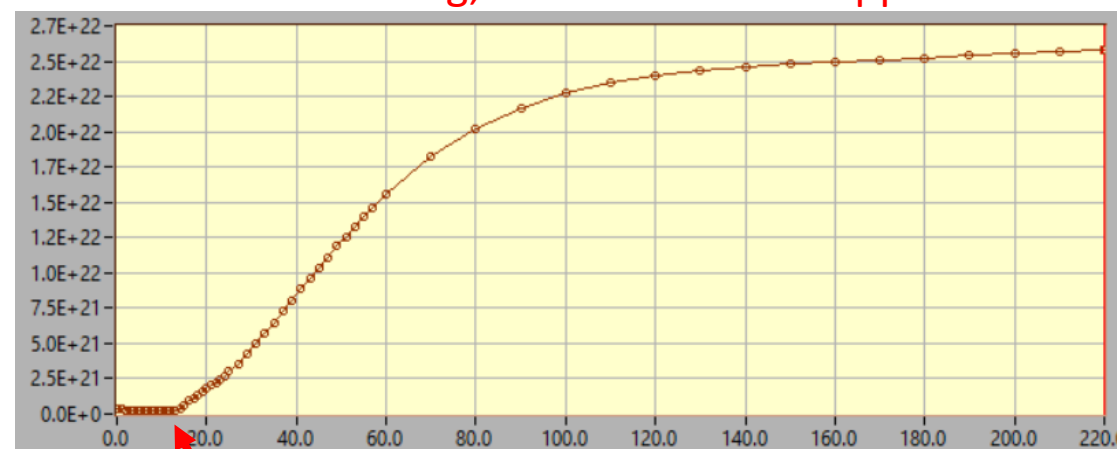
No annealing, first time bias applied



CV of W1  $1.5E15$



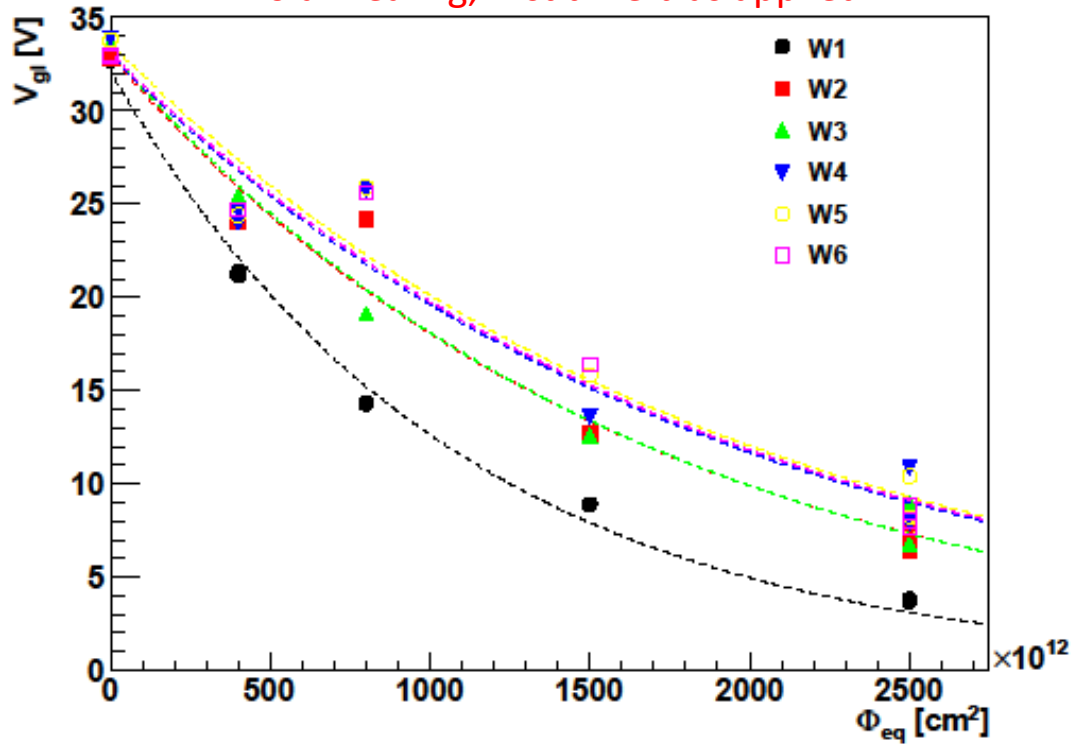
No annealing, second time bias applied



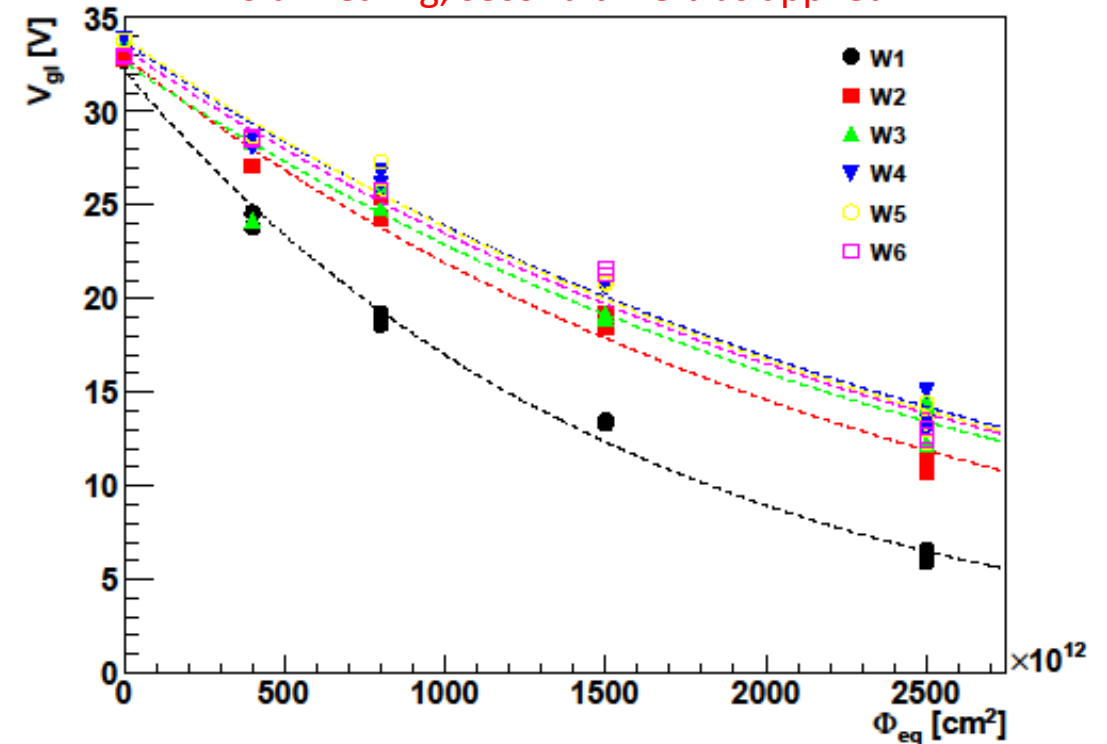


# First measurement after irradiation

No annealing, first time bias applied



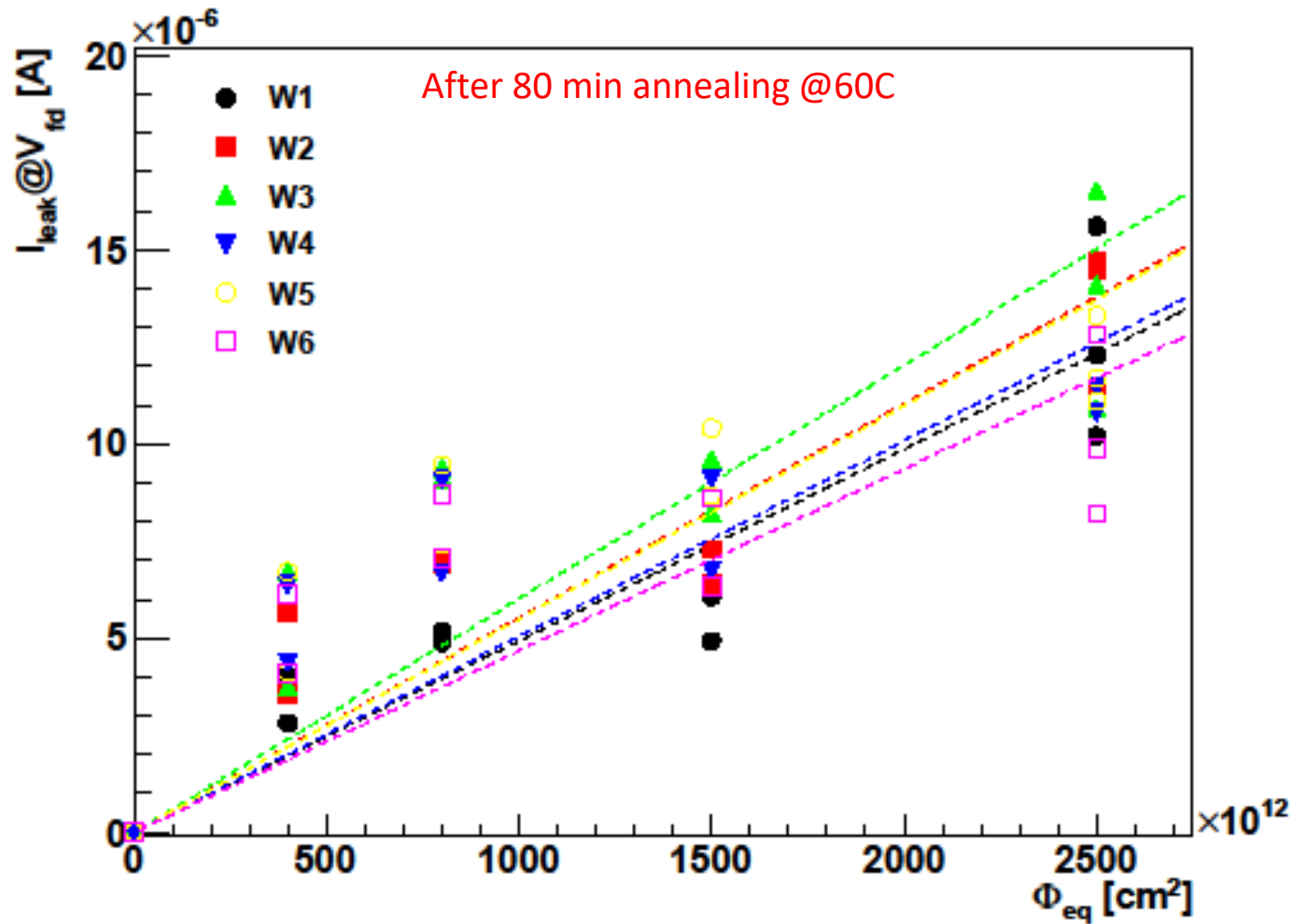
No annealing, second time bias applied



- CV/IV before annealing first time bias is applied is different to second time bias is applied
  - $V_{gl}$  values improves and stabilises
- Not specific to CNM, same is observed in sensors from other producers

- Not just observed at JSI
- Cause unknown

# Leakage current at $V_{fd}$



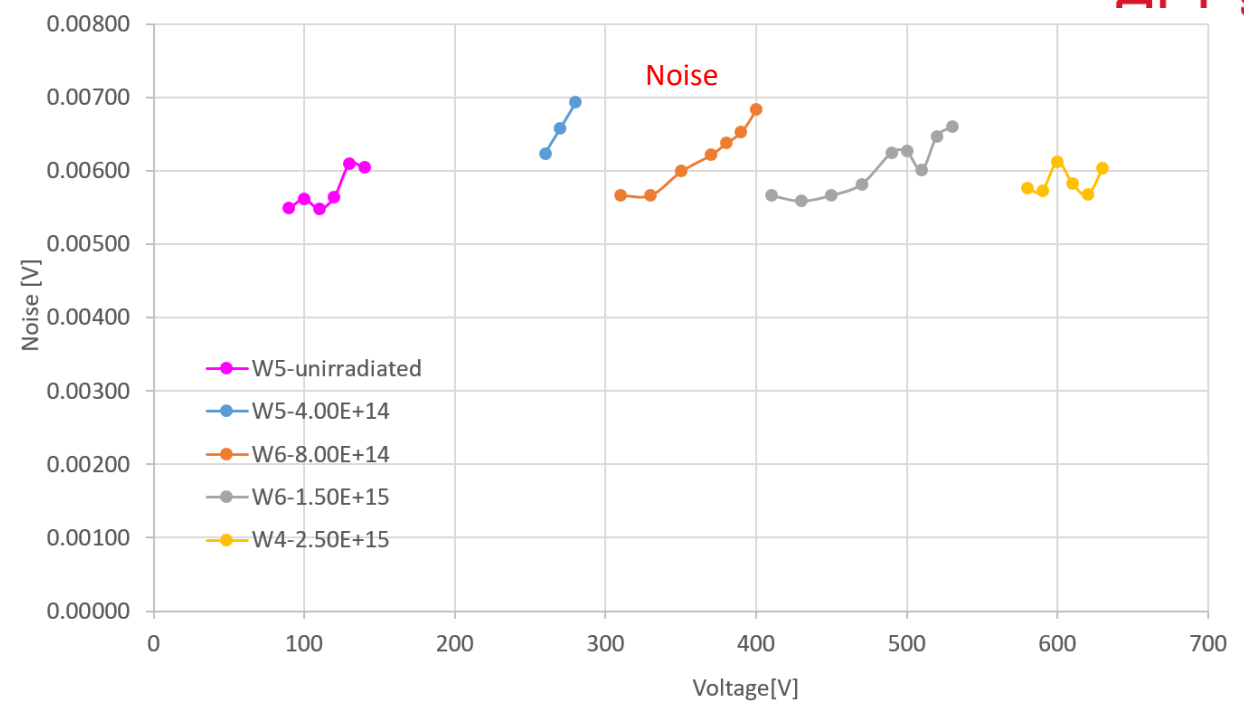
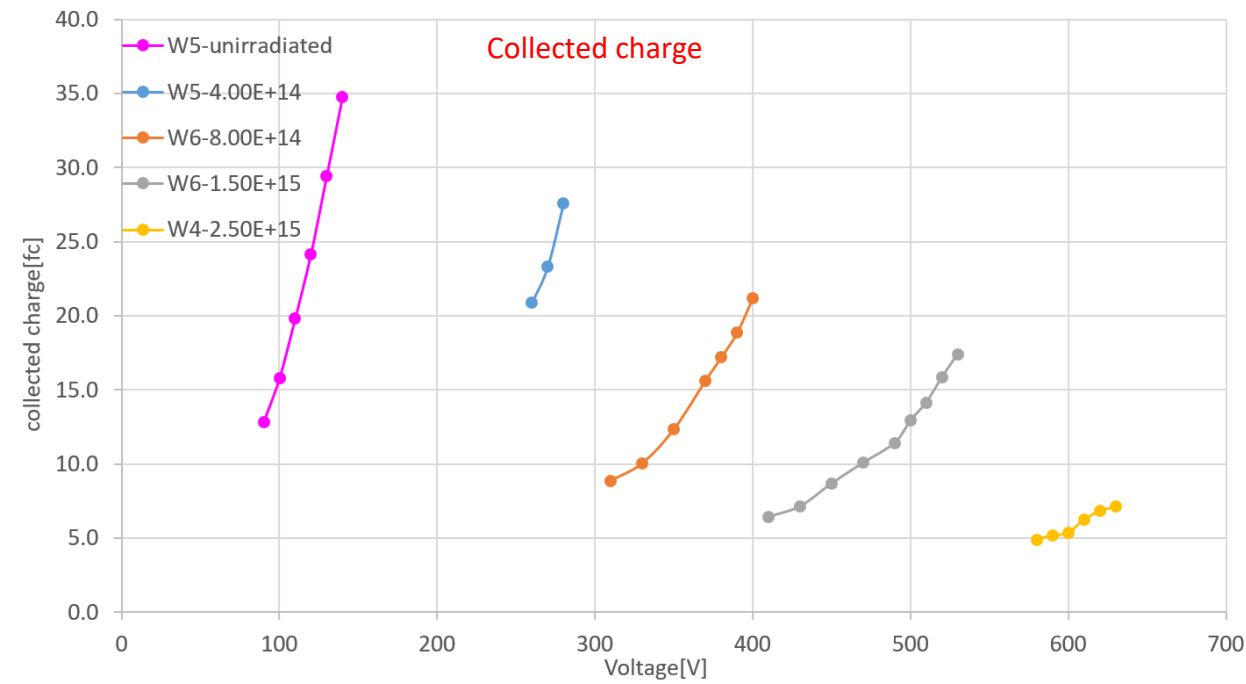
(Not the same as  $\alpha$ )

Wafer #	$\alpha^1$ [ $10^{-17}$ A/cm] (80 min @ 60C)
W1	5.84
W2	6.53
W3	7.11
W4	5.97
W5	6.49
W6	5.54

- Values are compatible with expectations
- Gain at lower fluences pushes the values higher



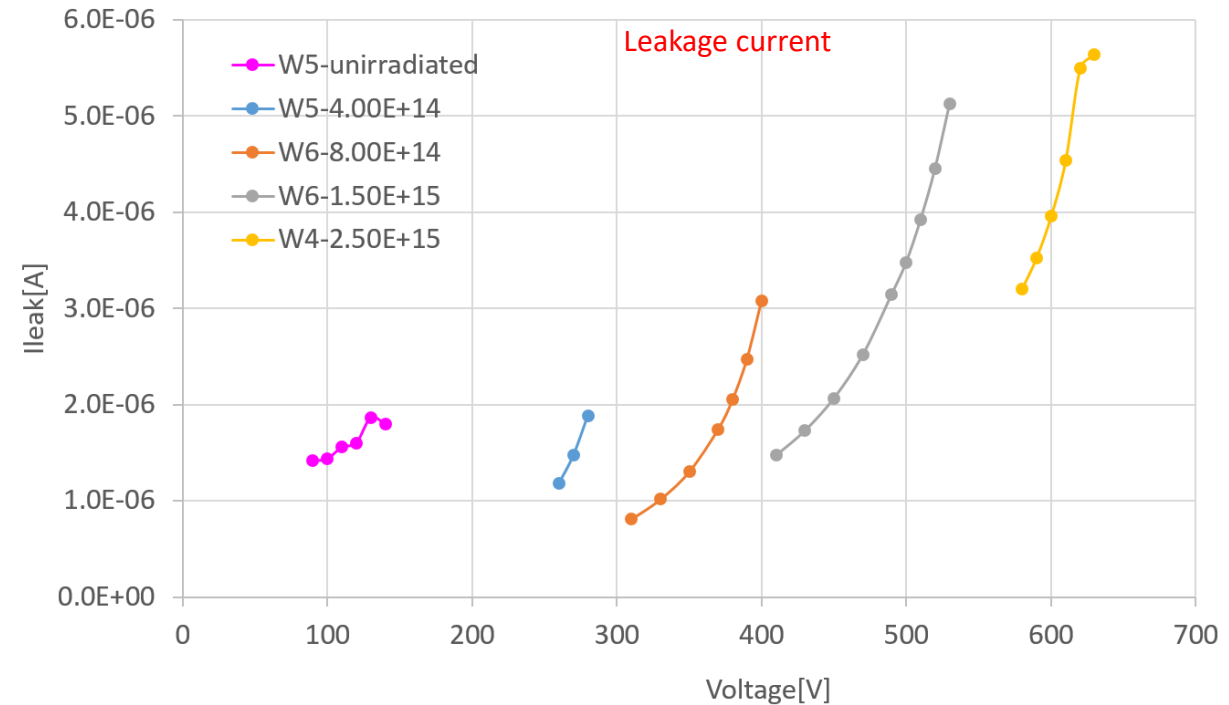
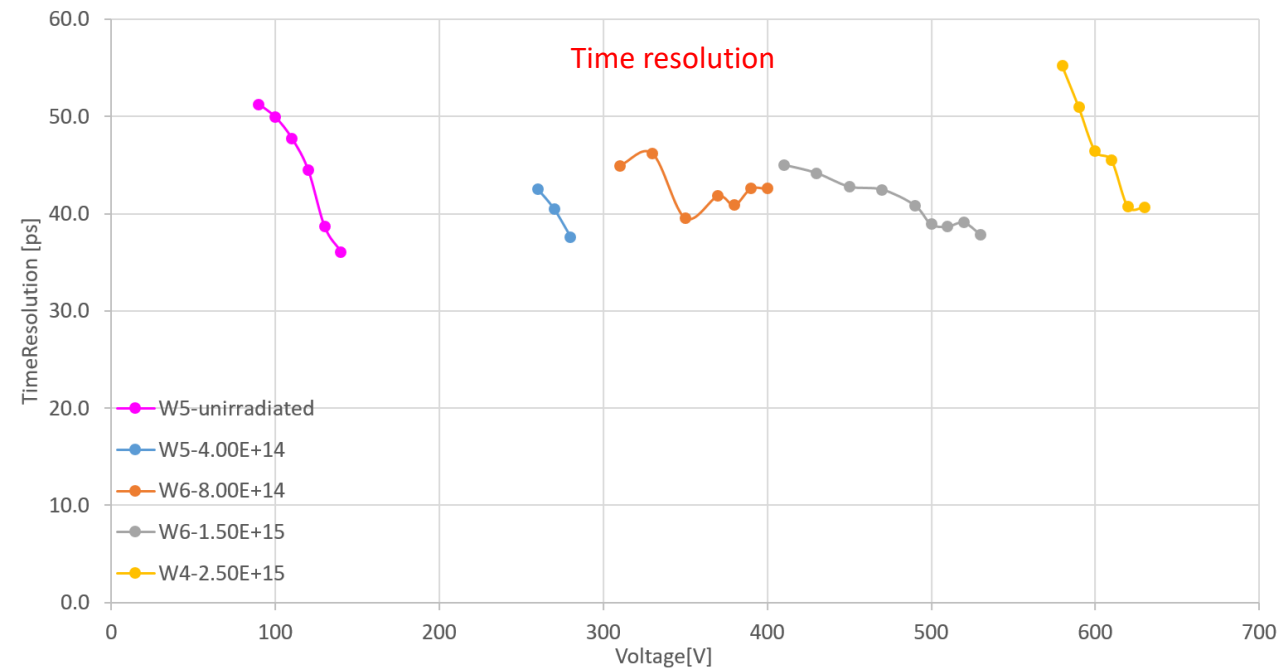
# Timing & Collected Charge



- Tested best samples – one per fluence
- After 2.5E15 irradiation, sensor reaches
  - >4 fC @ 580 V
  - S/N>10

➤ PRELIMINARY

# Timing & Collected Charge



➤ After 2.5E15 irradiation, sensor reaches

➤  $\sigma_t < 50\text{ps}$  @ 600 V,

➤  $I_{leak} < 5\text{ }\mu\text{A}$  up to 610 V (@-24C)

➤ Results so far not in disagreement with results coming from recent testbeam

➤ PRELIMINARY

# Summary

- Previous CNM run had poor radiation hardness for non carbon enriched sensors
  - new run explores different carbon doses
- Samples from wafers 1-6 from latest CNM run had CV/IV measured
  - Acceptor removal is similar among carbon enriched wafers (wafers 2-6)
  - Acceptor removal increases slightly after annealing
  - Unexpected measurements first time bias is applied after irradiation
    - $c$  is initially worse, then improves in second measurement
    - Not specific to CNM - observed among samples from different producers
- Timing/CC measurements done on best sample for each fluence
  - Better performance than expected
  - After irradiation to  $2.5E15$ : 4 fC @ 580 V;  $S/N > 10$ ;  $\sigma_t < 50\text{ps}$  @ 600 V;  $I_{\text{leak}} < 5 \mu\text{m}$  up to 610 V (@-24C)
- Results are preliminary and need to be cross checked across more samples and from other labs