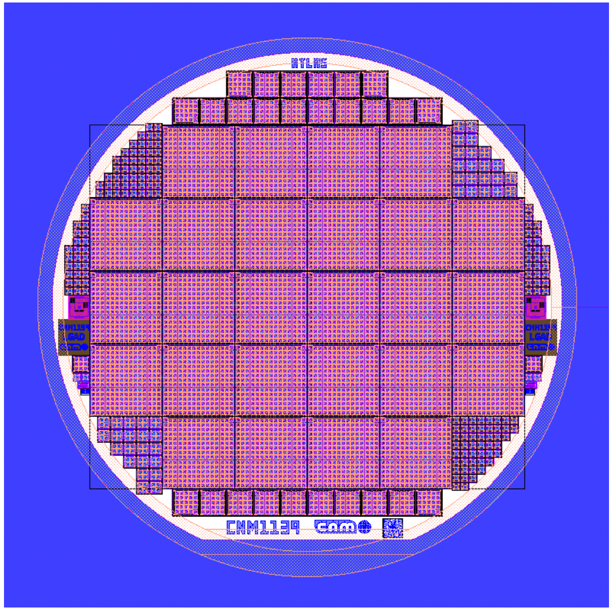
Radiation Tolerance Study of CNM-IMB RUN15973



Last (43rd) RD50 Workshop on Radiation Hard Semiconductor Devices

E. Navarrete, I. Vila, J. González, M. Fernández, R. Jaramillo, J. Campderros.

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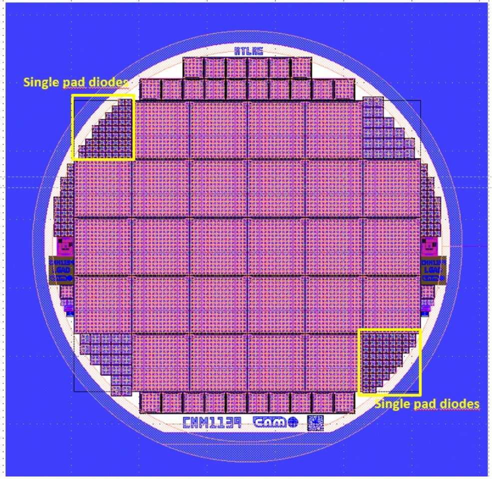
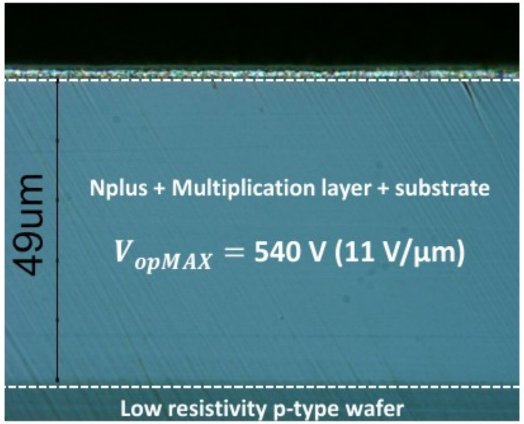
Samples Description

CNM RUN15973 – See talk yesterday by J. Villegas (43rd RD50)



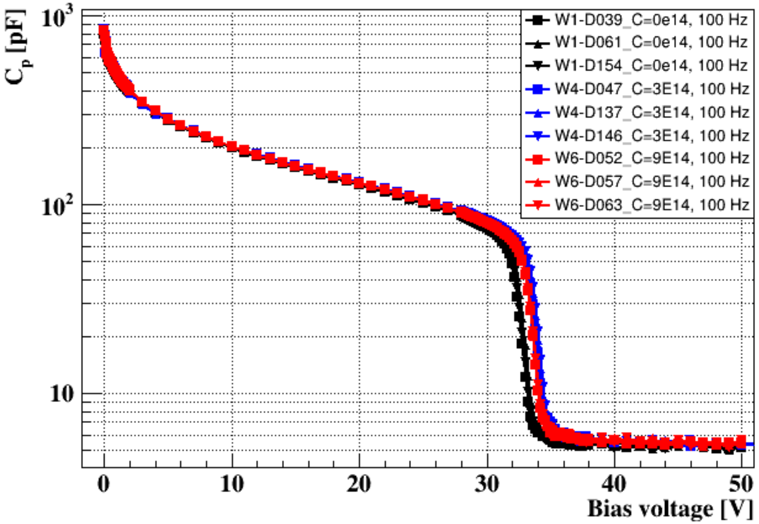
Wafer	Boron dose Boron Energy	Carbon dose/Energy
8 (Run15246)	1.9e13/cm² 100keV	1e14/cm² / 150keV
1		0
4		3e14/cm² / 150keV
6		9e14/cm² / 150keV

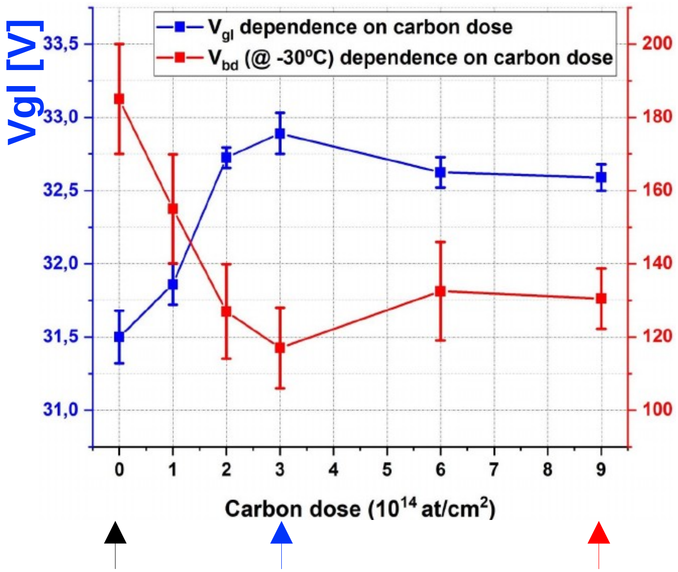


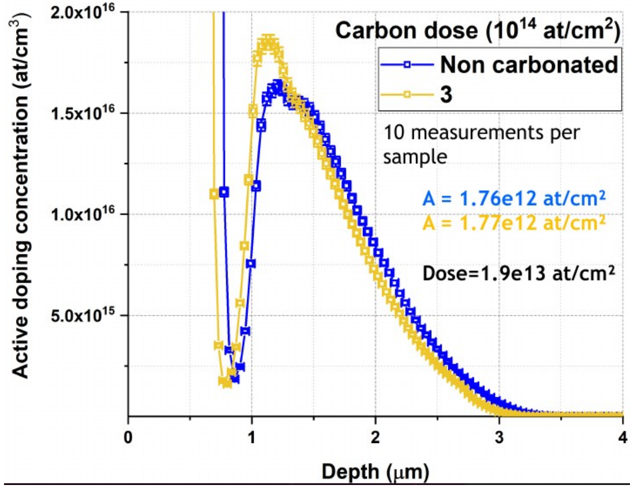
- Goal of this run is to optimize C dose for radiation hardness. Rest of parameters as in 15246 (41st RD50, Sevilla). Three doses characterized: (0, 3, 9)×10^{14} cm^{-2}.
- **Shallow** gain-layer implantation profile
- **Interpad** distance of 47 µm (23.5 µm from gain-layer to p-stop center), "ATLAS mask"
- **Thickness** 49 µm → 540 V maximum bias to avoid **S**ingle **E**vent **B**urnouts
- **Irradiated** with neutrons at JSI Triga II reactor: 0, 4×10^{14}, 8×10^{14}, 1.5×10^{15},2.5×10^{15} n_{eq}/cm^2
- **Annealed** 80 min at 60°C.

Non-irrad, gain depletion voltage (V_{gl})

J. Villegas, 43rd RD50







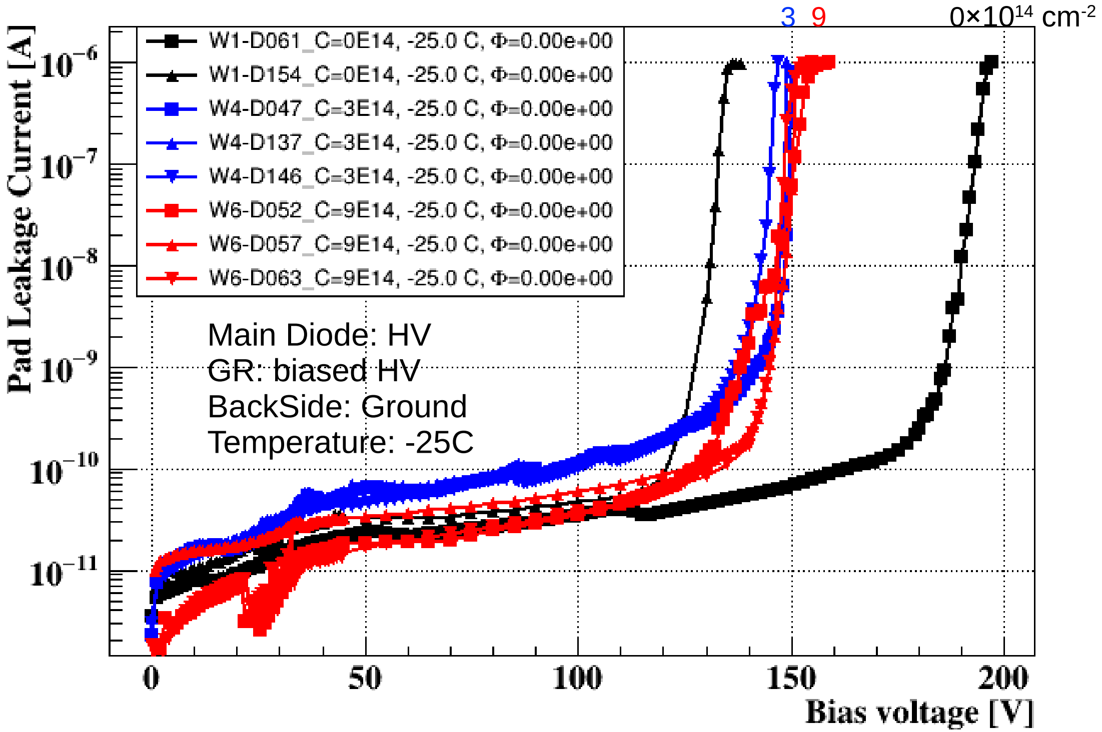
Spreading resistance measurements

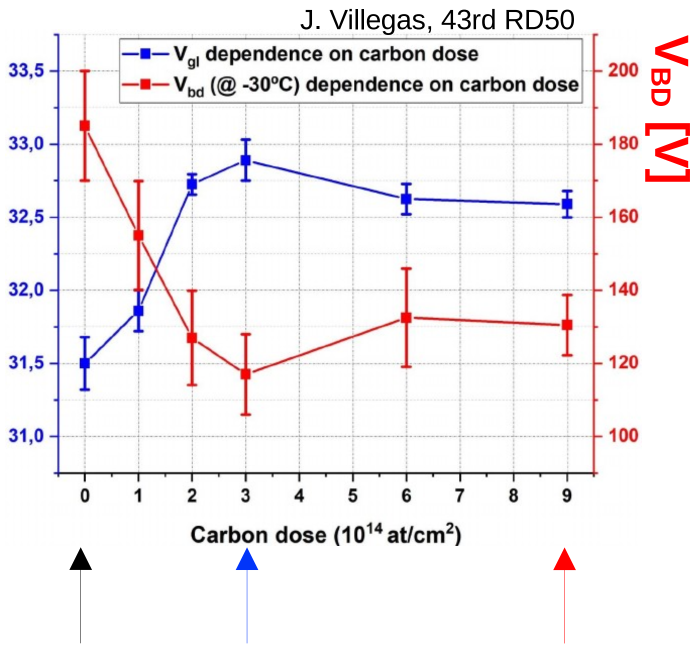
Main Diode: HV
GR: biased HV
BackSide: Ground
Temperature: **RT**
Frequency: **100 Hz**

V_{gl} increases with C-dose up to 3×10^{14} [C]/cm², then stabilises

Diffusion of B and P is reduced in presence of C → more shallow implant → higher Neff → higher gain

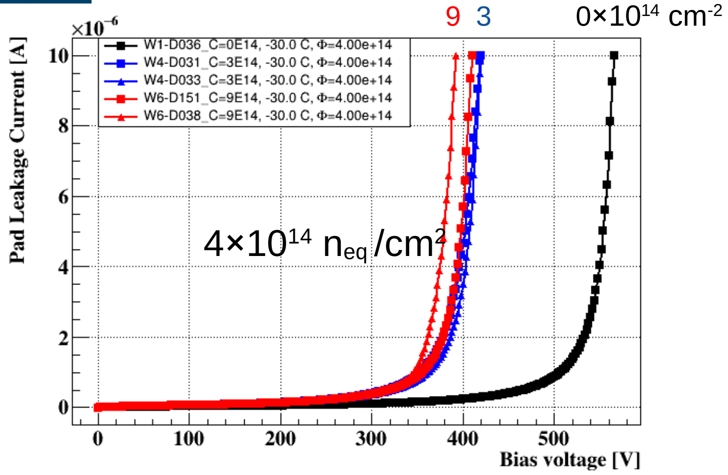
Non-irrad, IV & breakdown voltage

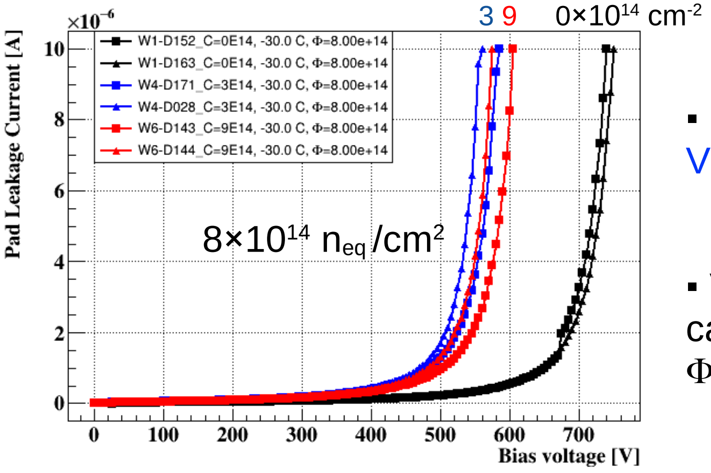




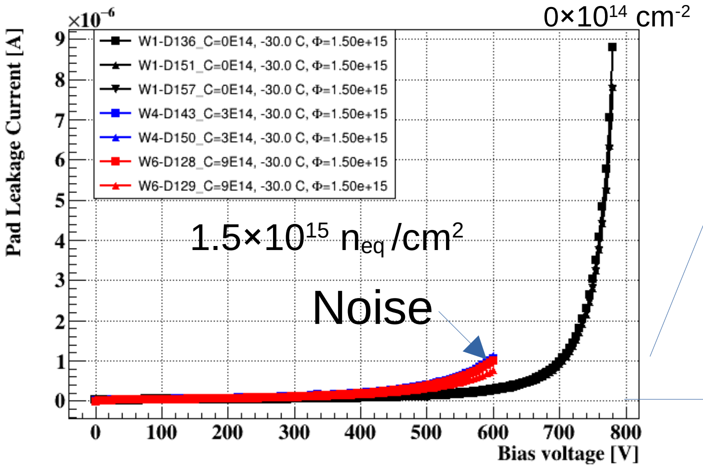
- Breakdown voltage decreases as C dose increases. For dose ≥ 3×10^{14} [C]/cm² it grows slightly and seems to flat out.
- Correlation between V_{gl}, gain and breakdown: higher V_{gl} → higher gain → earlier BD

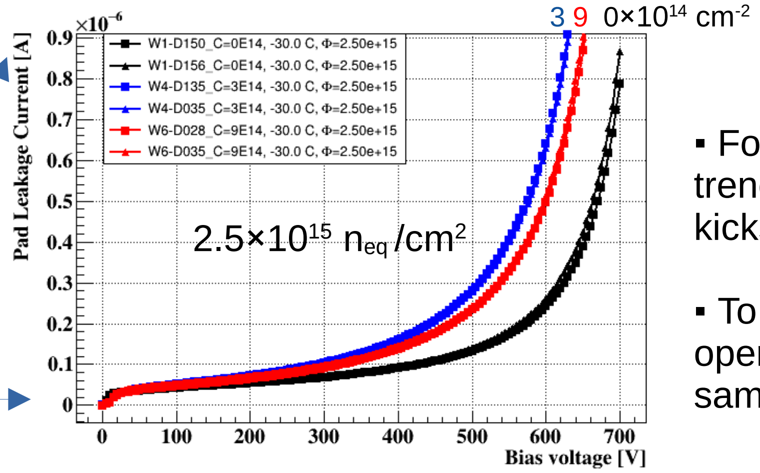
IV Irradiated





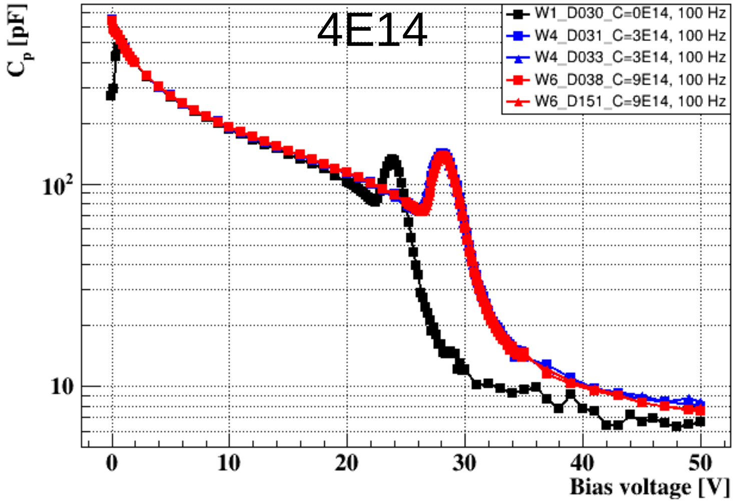
- Non-irrad: $V_{BD}(C=3)<V_{BD}(C=9)<V_{BD}(C=0)$
- V_{BD} grows with fluence (non-carbonated and carbonated) for $\Phi \leq 8\times10^{14}$ n_{eq}/cm^2

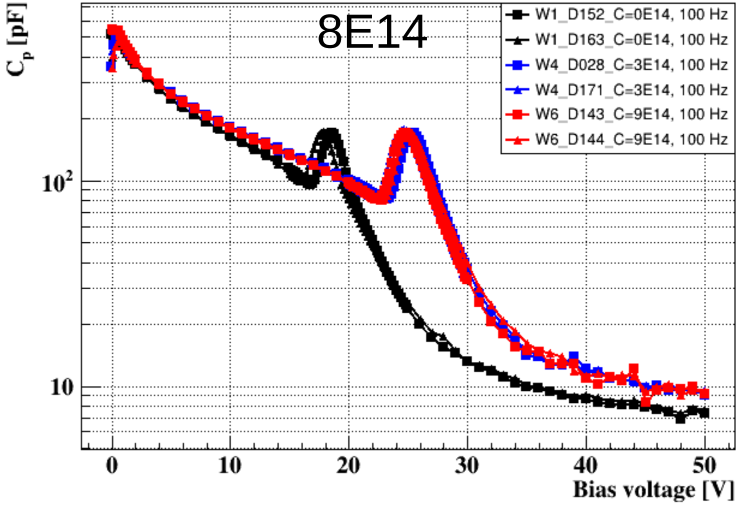


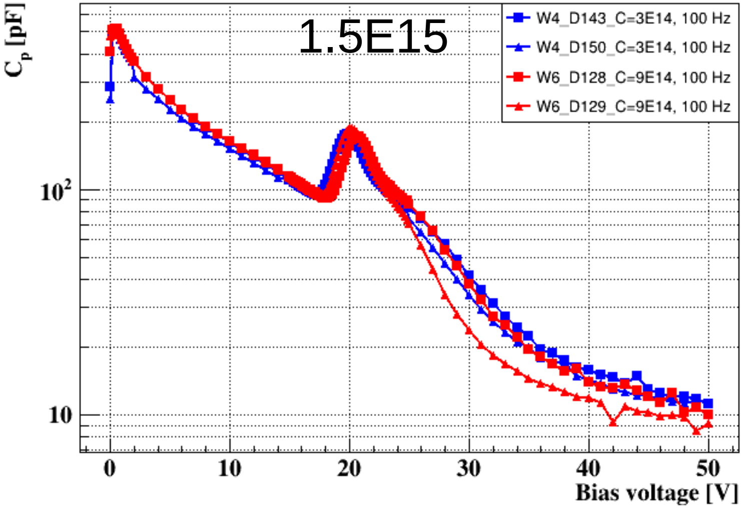


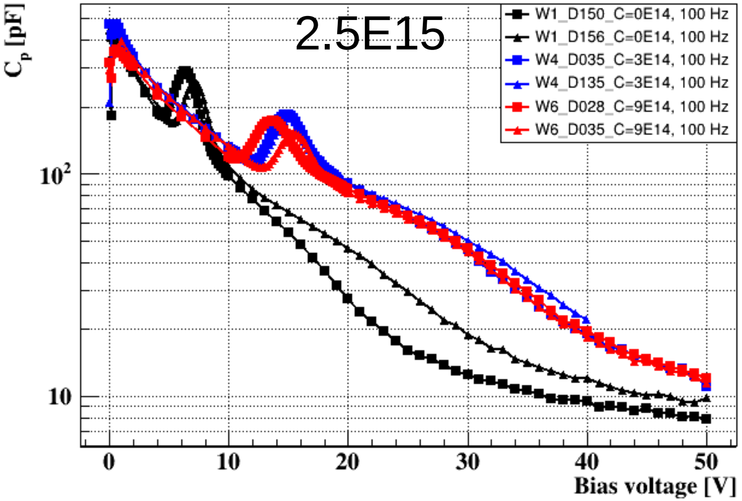
- For $\Phi \geq 1.5e15$ n_{eq}/cm^2 same trend is observed, but noise kicks in at 600 V.
- To avoid SEBs the maximum operating voltage for these samples is 540 V.

CV Irradiated



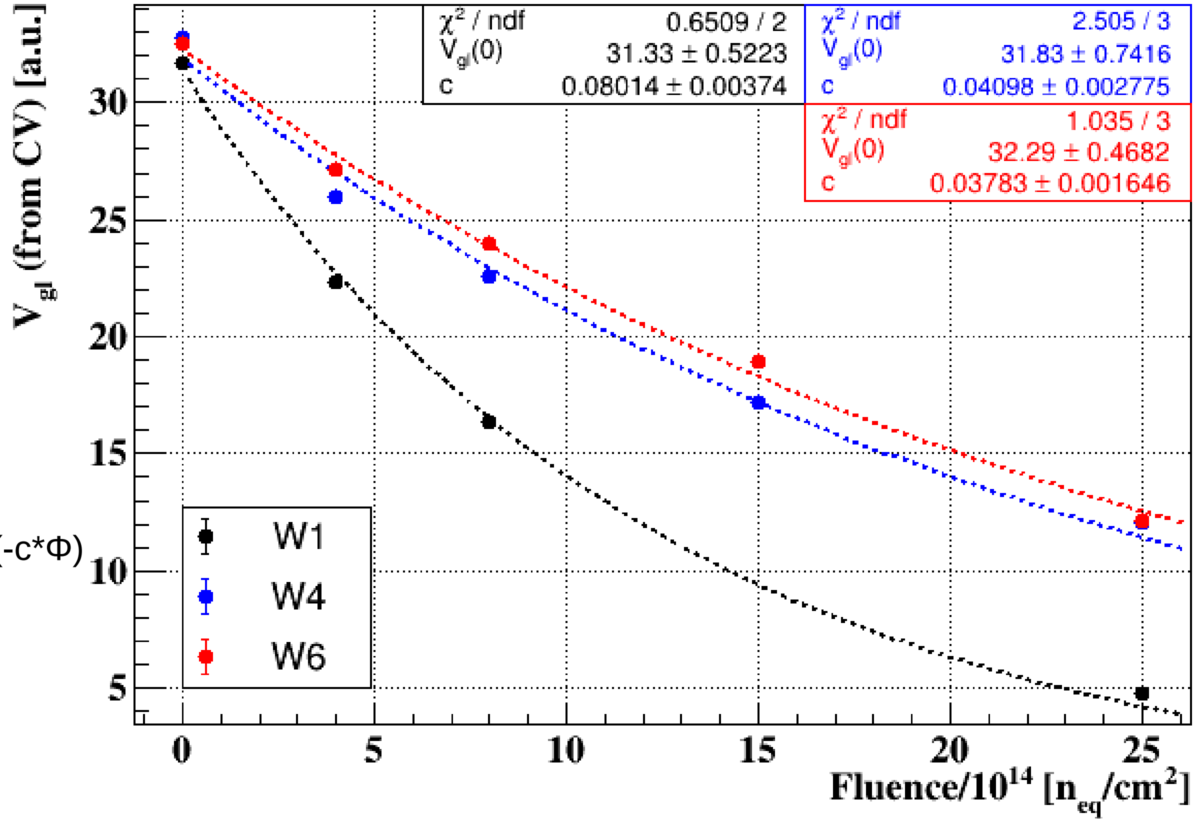






Main Diode: HV
GR: biased HV
BackSide: Ground
Temperature: RT
Frequency: 100 Hz

Acceptor removal estimation from CV



Fits to:
$V_{gl}(\Phi)=V_{gl}(\Phi=0)\exp(-c*\Phi)$

$[C]=9\times10^{14}$ cm^{-2}
$[C]=3\times10^{14}$ cm^{-2}
$[C]=0$ cm^{-2}

Wafer	W1, C=0E14	W4, C=3E14	W6, C=9E14
$c[10^{-16}cm^2]$	8.0	4.1	3.8
c[10^{-16} cm²] (Lbj)	7.08	3.66	3.76

c=3.8±0.3 from previous Run15246 (W8)

See: A. Howard, 42nd RD50

Radioactive Source Characterization

Radioactive Source Setup

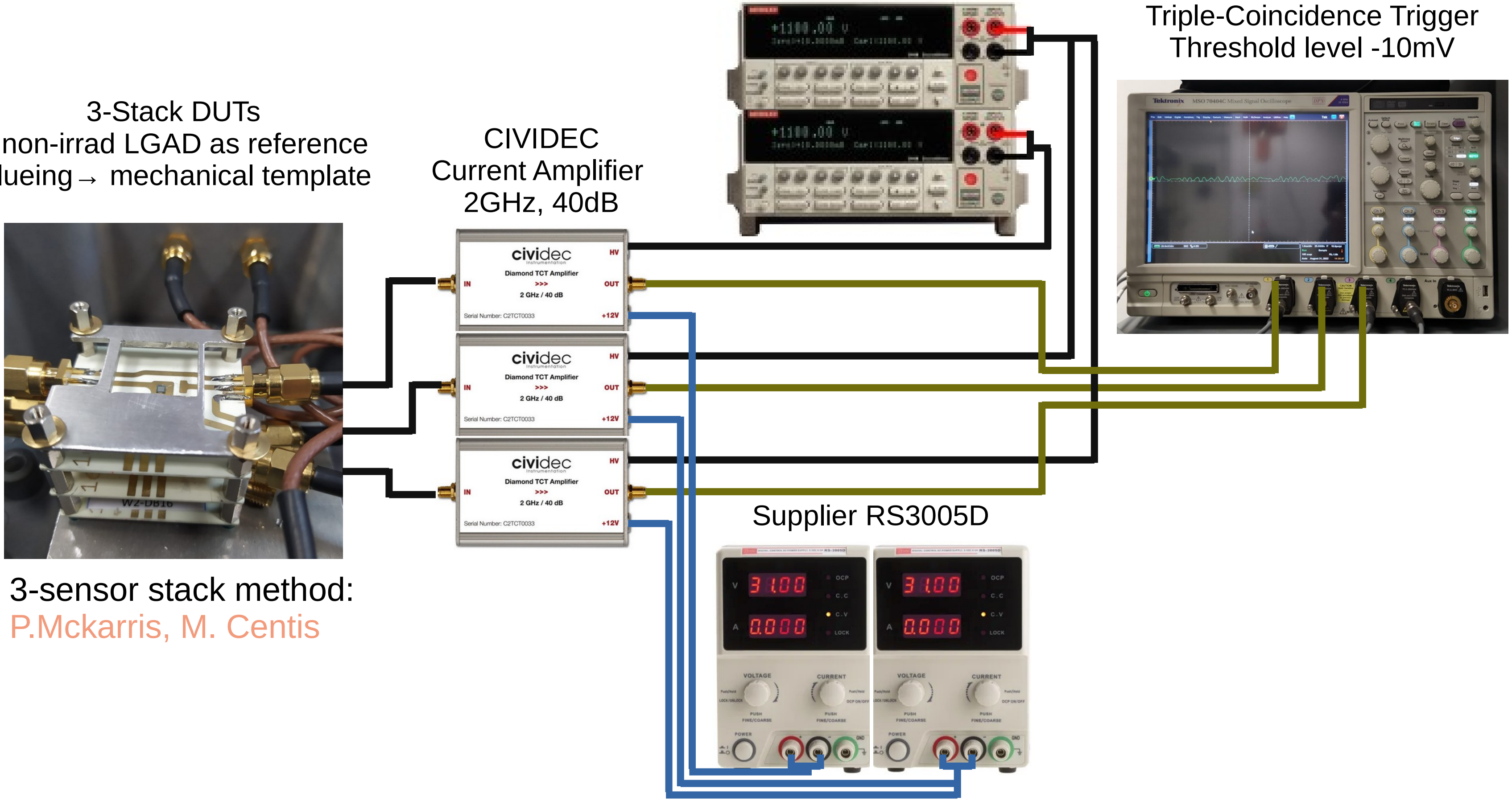
3-Stack DUTs
1 non-irrad LGAD as reference
Glueing→ mechanical template

CIVIDEC
Current Amplifier
2GHz, 40dB

SourceMeter Keithley 2410

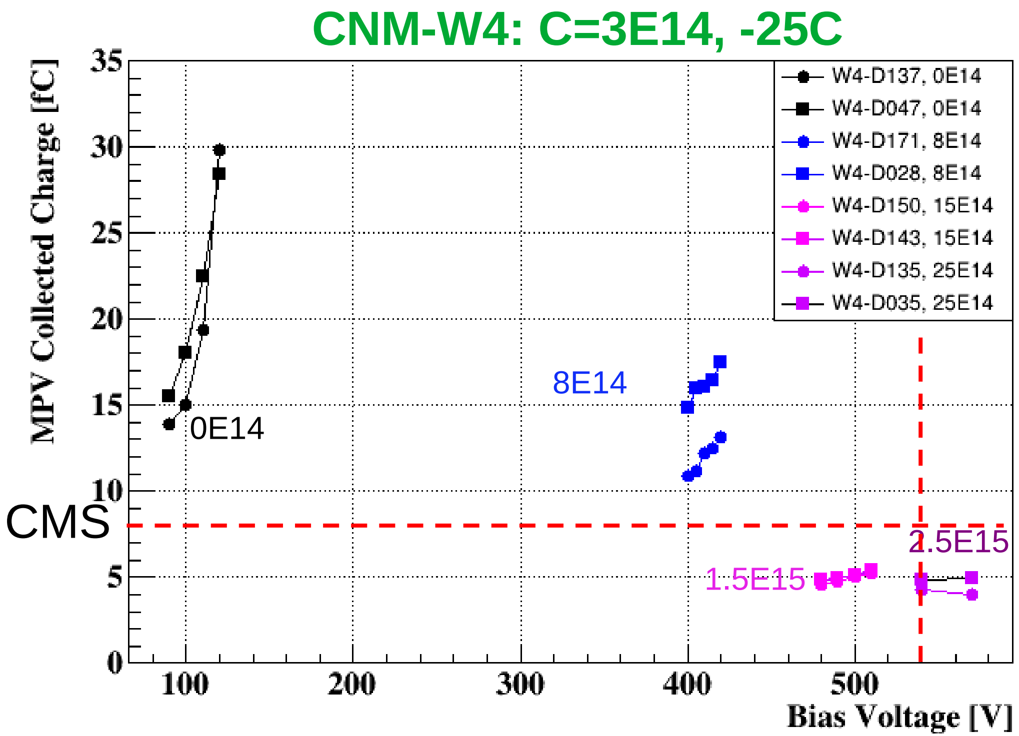
Oscilloscope Tektronix MSO 7404C
25GS/s, BW=4GHz,
Triple-Coincidence Trigger
Threshold level -10mV

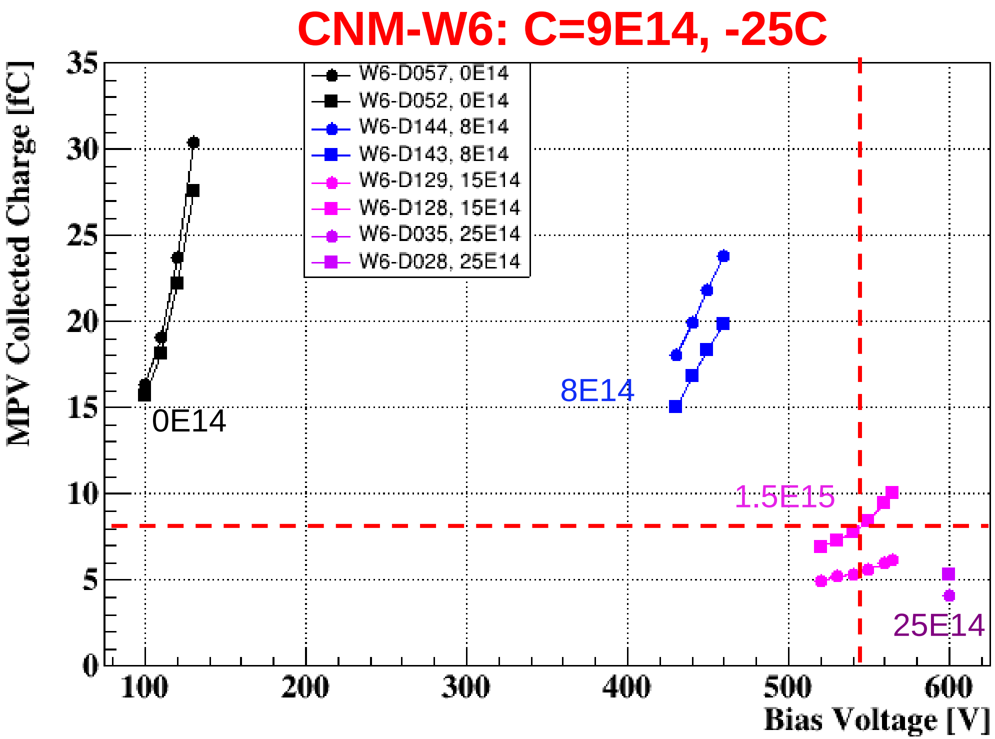
Supplier RS3005D



3-sensor stack method:
P.Mckarris, M. Centis

Charge Collection

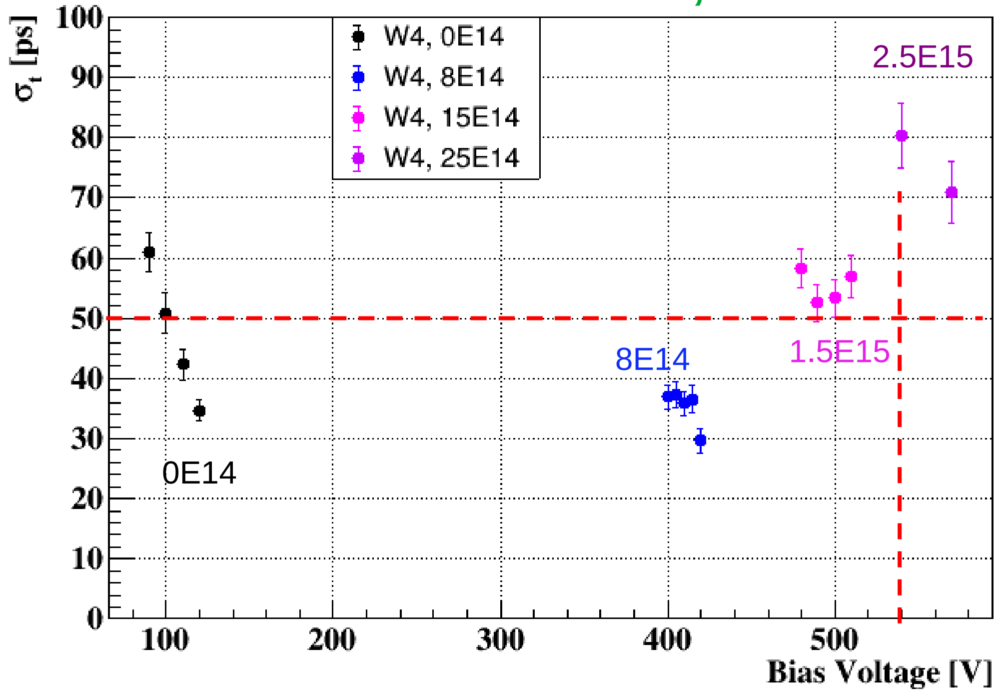




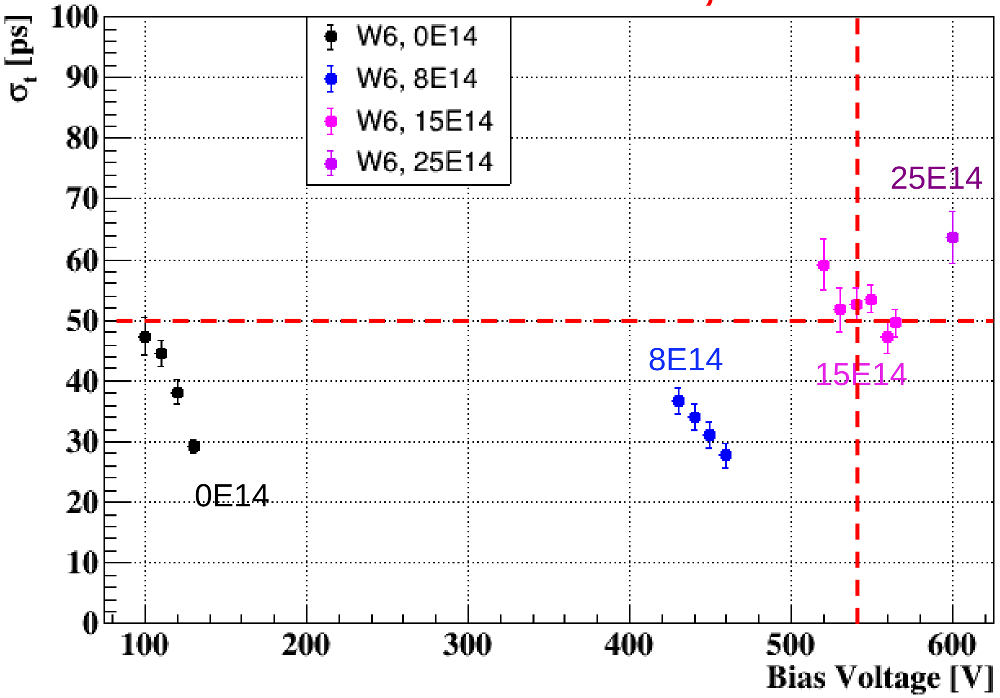
- Higher carbon dose irradiated (W6) can be operated at higher voltage than W4.
- Highest neutron fluence (2.5×10^{15} n_{eq}) does not comply with CMS requirements.
- Highest carbon dose (W6: 9×10^{14} [C]/cm^2) qualifies up to **$\Phi=1.5\times10^{15}$ n_{eq}** "at the limit".

Time Resolution

CNM-W4: C=3E14, -25C

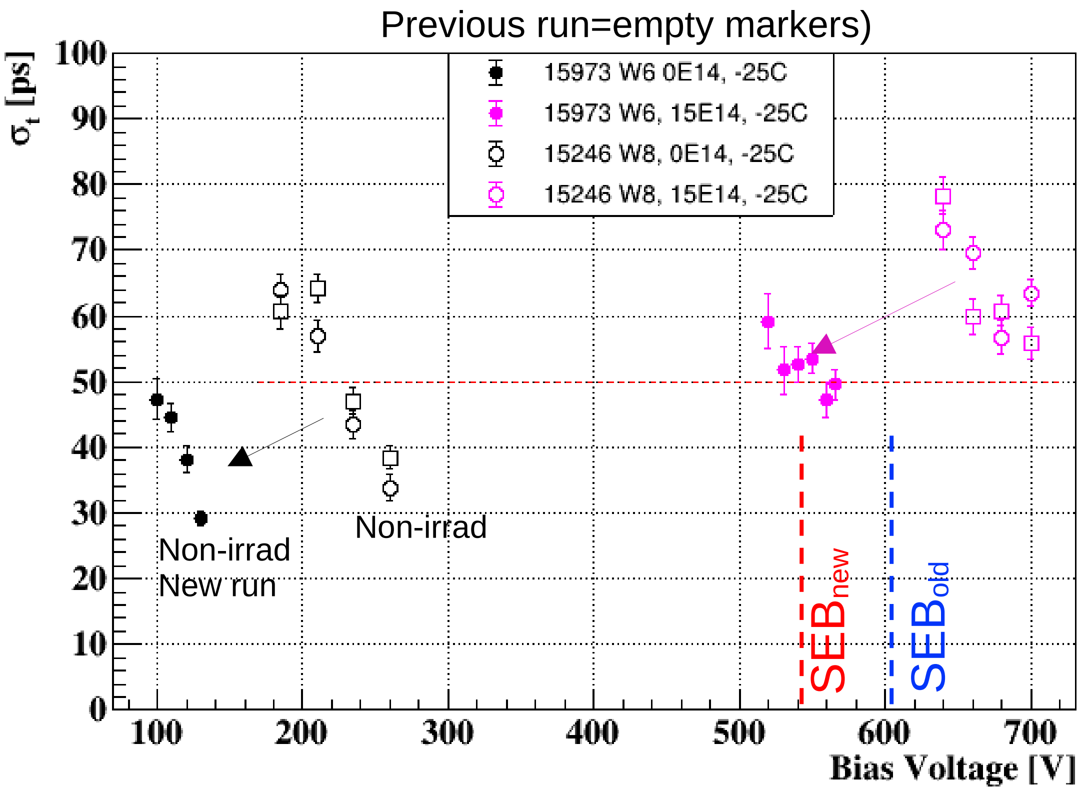


CNM-W6: C=9E14, -25C



- Both wafers (W4 & W6) qualify up to **Φ=1.5×10^{15} n$_{eq}$** (last fluence point “at the limit”)

Comparison with former run



New run: 15973, 47 μm thick
W6=9×10^{14} [C]/cm²

Old run: 15246, 55 μm thick
W8=6×10^{14} [C]/cm²

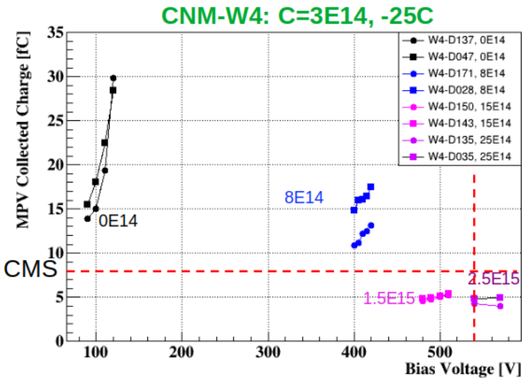
Improved time resolution at lower voltages for both unirradiated and 1.5×10^{15} n_{eq}/cm^2

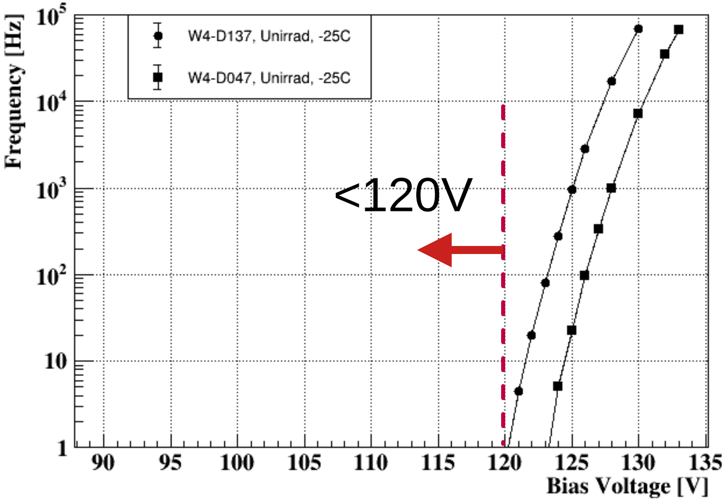
Noise Study

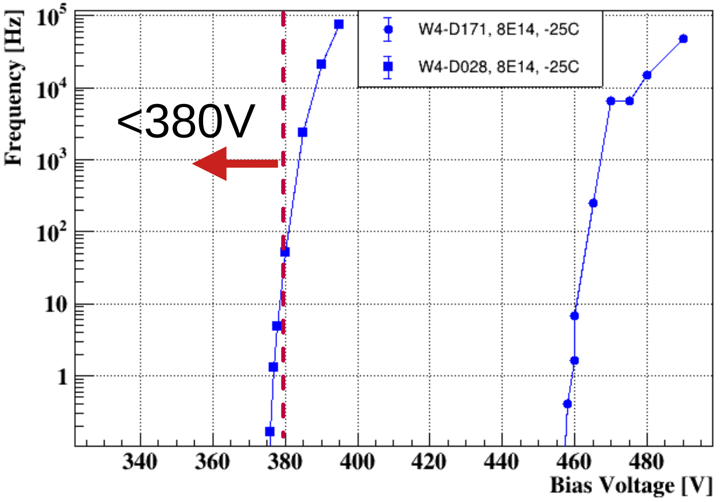
- A measurement of the frequency of spurious pulses, using NIM electronics modules.

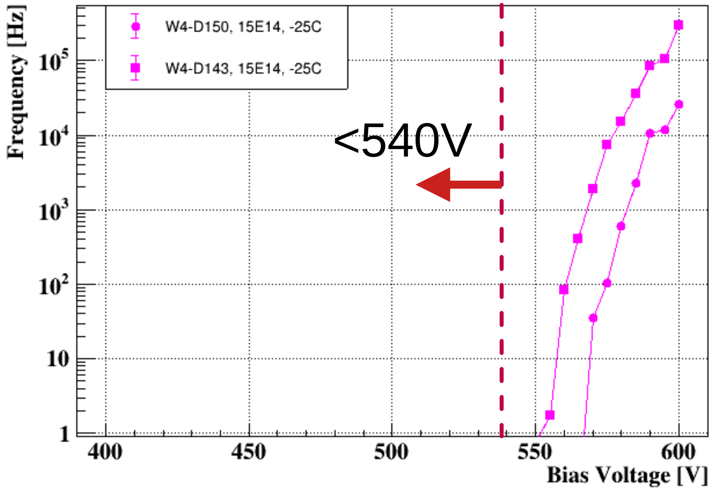
- No radioactive source was employed for the measurements.

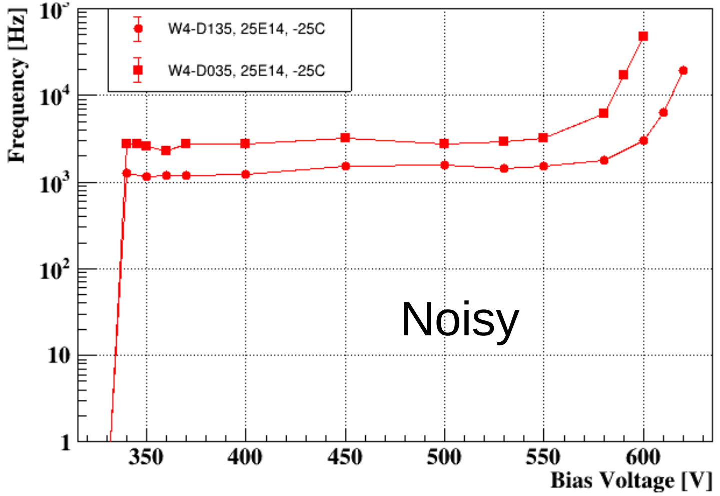
W4 Spurious Pulse Rate (th=-25mV)



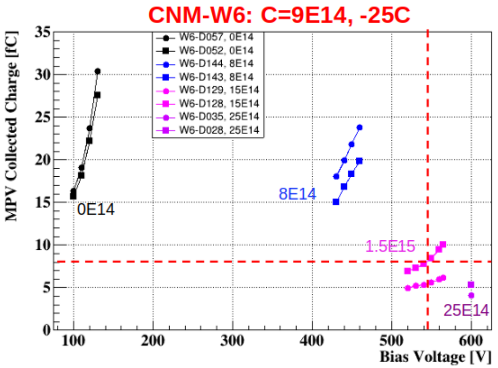


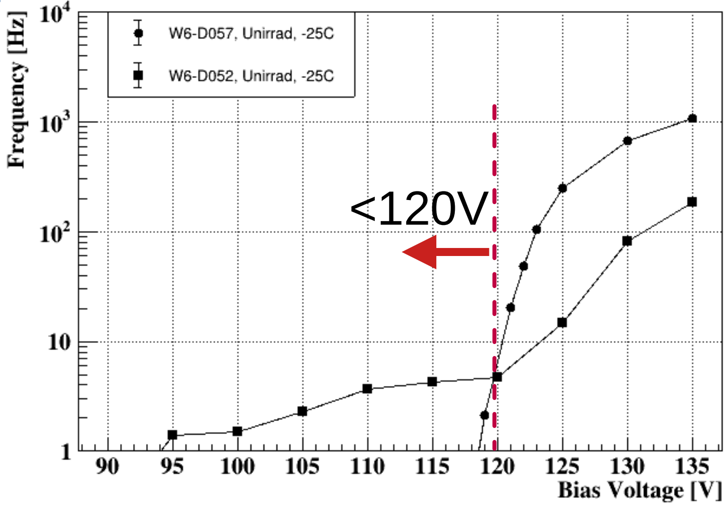


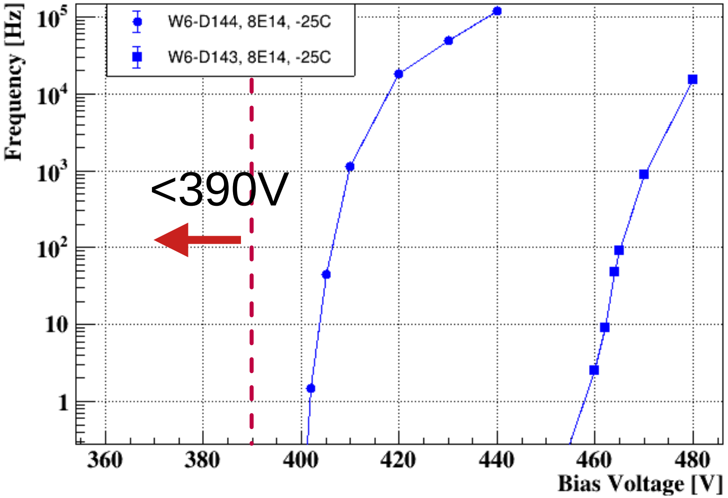


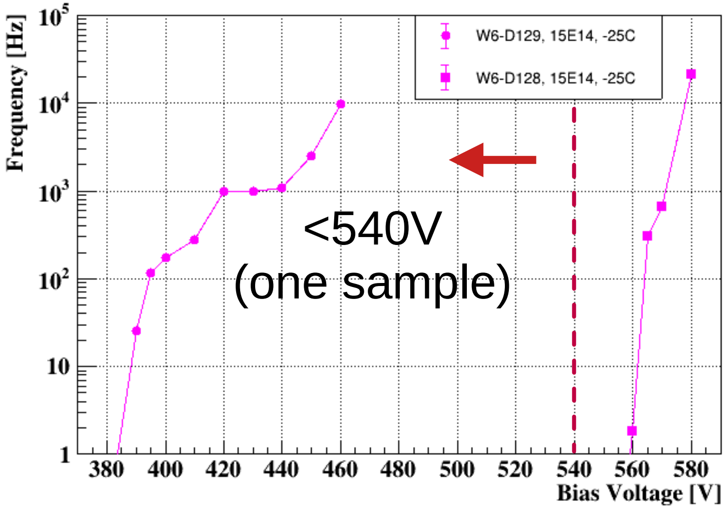


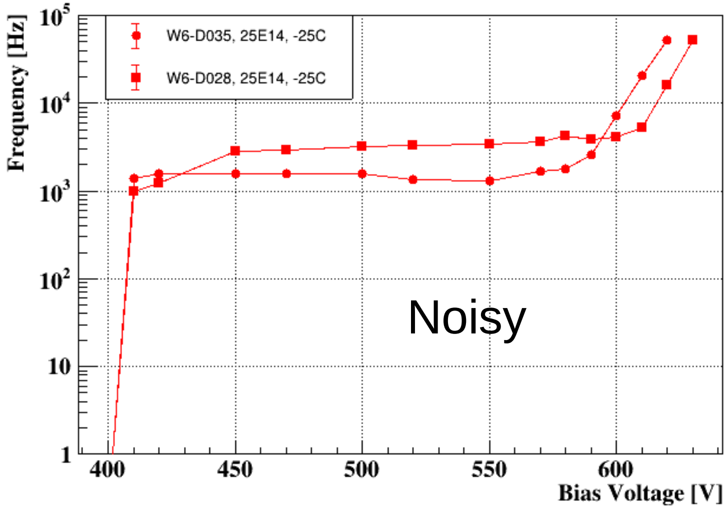
W6 Spurious Pulse Rate (th=-25mV)







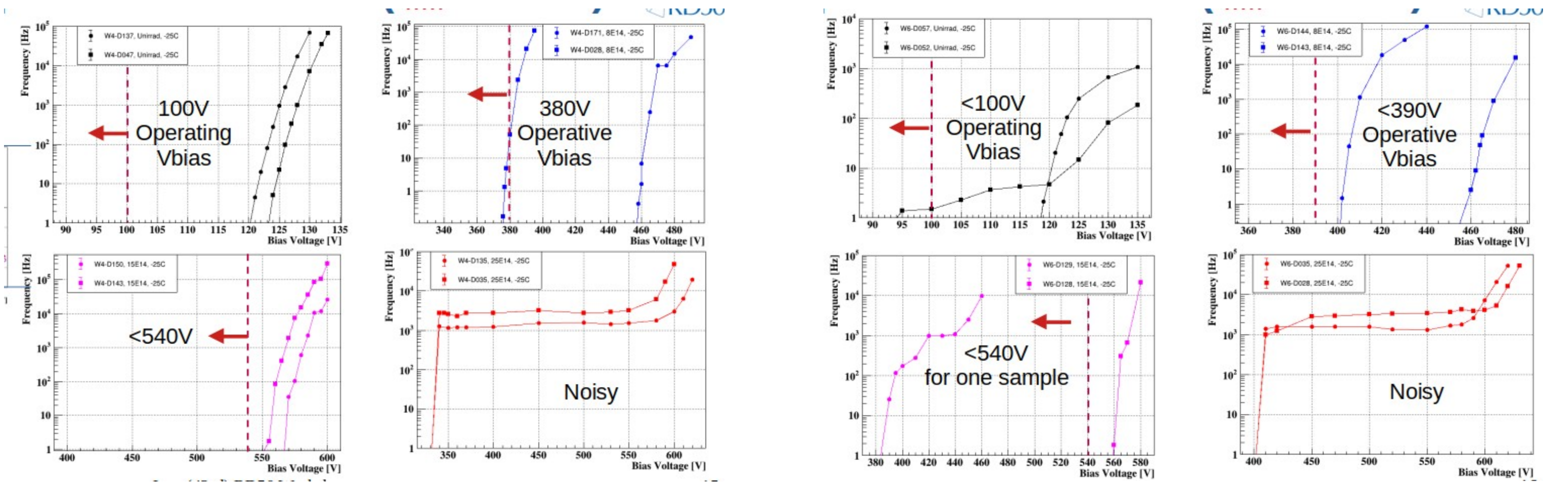


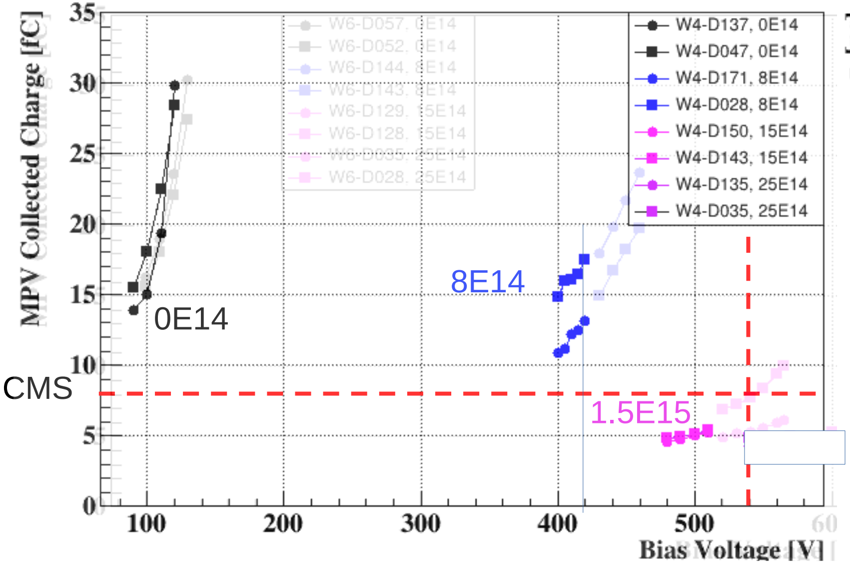


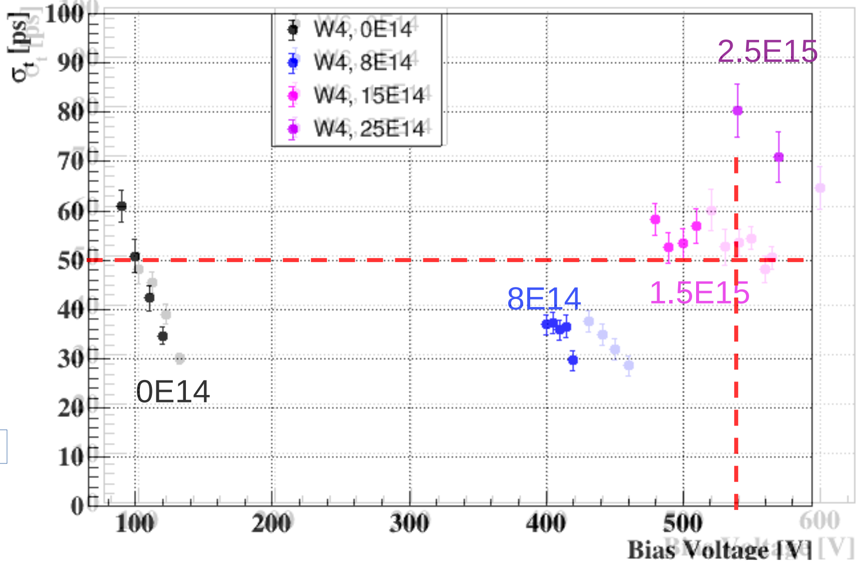
Conclusions

- Characterization of new CNM run15973, same parameters as run15246, focused on optimizing the C dose.
- Operation voltage for irradiated samples reduced by 100V compared to its predecessor.
- The highest C-dose:
  - leads to the smallest acceptor removal coefficient
  - qualifies up to $1.5x10^{15}$ n_{eq}/cm^2 (CMS criteria: Q≥8 pC, σ_t≤50 ps) for one detector → **Promising** but **more statistics** is needed.

Back-Up



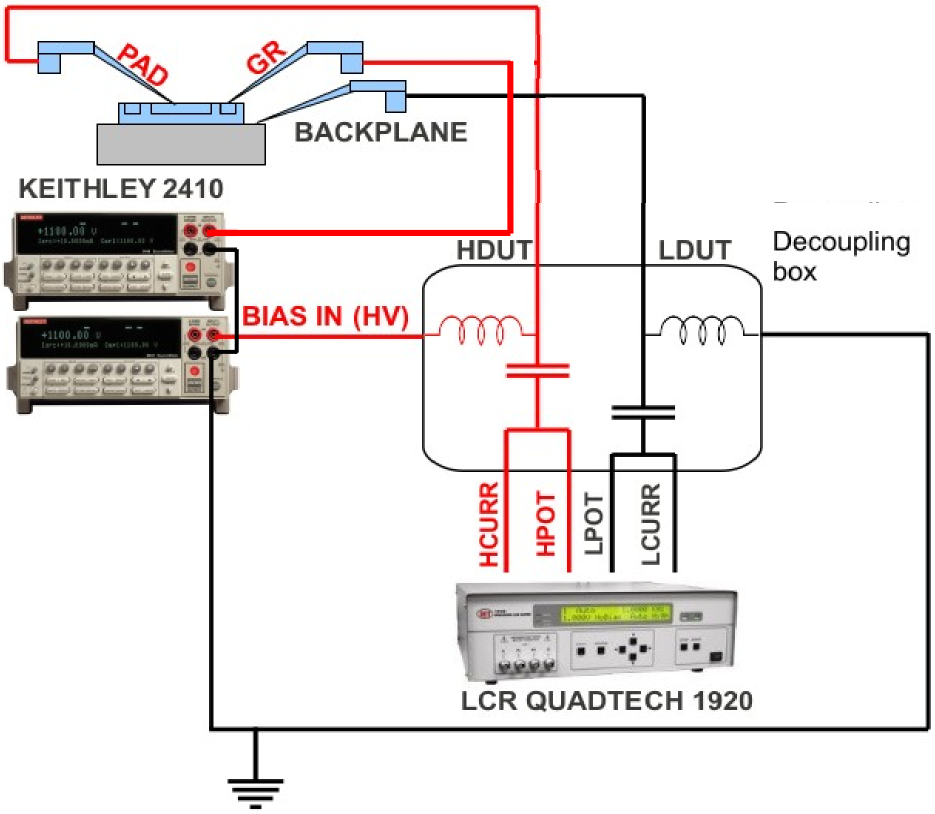


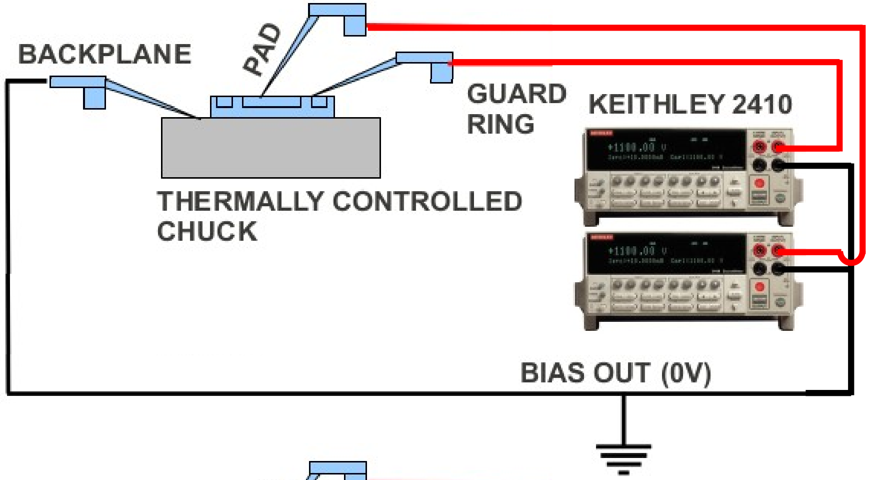


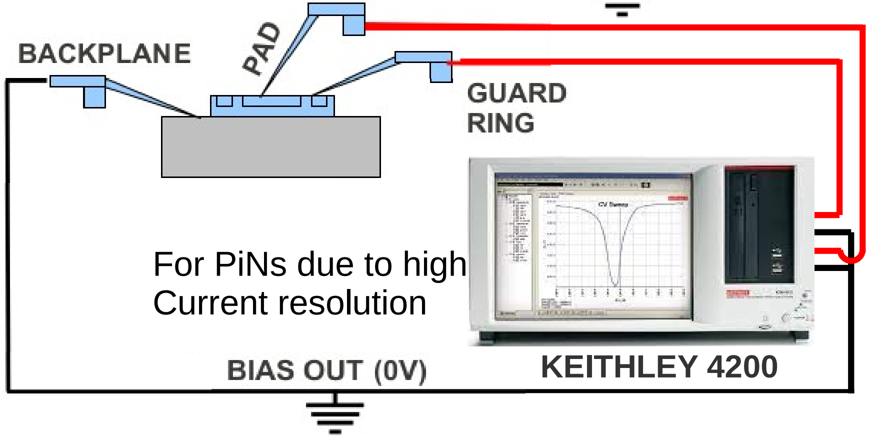
W4 and W6 (=plot behind,faint colors) seem to have very similar gain. One of the detectors W4,8e14 has been measured with huge noise in the noise 400-420V, accorgding to the noise studies
Both W4,1.5e15 resist 540 V for noise but they were measured only up to 510V. Why????
Only one detector W6,1.5e15 can be measured up to 540V. **We are basing this study in one detector only!!**

CV Setup

IV Setup







For PiNs due to high Current resolution

A. Himmerlich, N. Castello-Mor, E.C. Rivera et al.

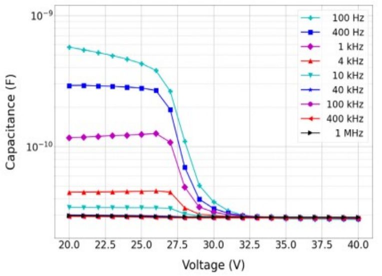


Fig. 1. *C–V* measurements performed on a CNM LGAD, neutron irradiated with 1×10^{14} n_{eq}/cm^2. The measurements were performed at a temperature of -20 °C at different frequencies from 100 Hz up to 1 MHz.

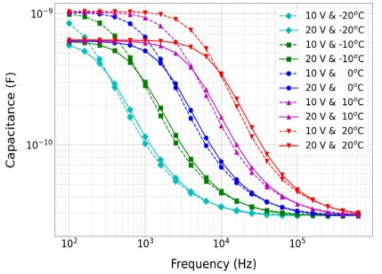
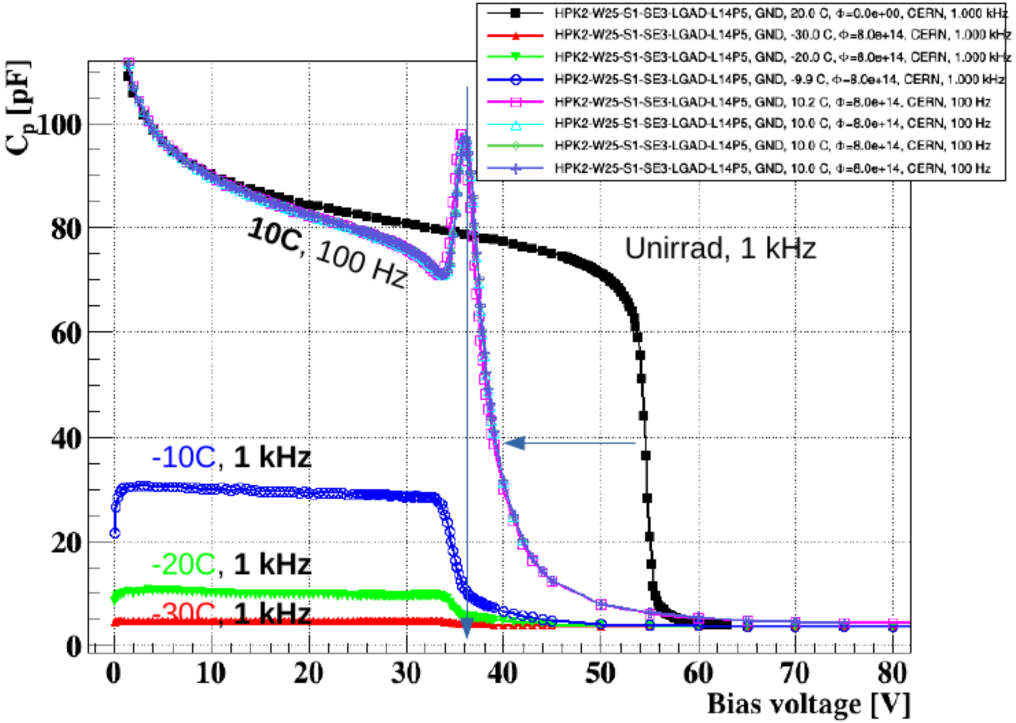


Fig. 2. Capacitance measured at certain bias voltages and temperatures in dependency of the frequency. The measurement were performed on a CNM LGAD neutron irradiated with 1×10^{14} n_{eq}/cm^2.

(standard: 10 kHz). For high frequencies the measured capacitance of the gain layer region significantly drops. This effect becomes even more pronounced when decreasing the temperature as shown in Fig. 2. Here the capacitance values at a certain bias below V_{GL} are plotted against the measurement frequencies. The data are taken in the temperature range of −20 °C to +20 °C.

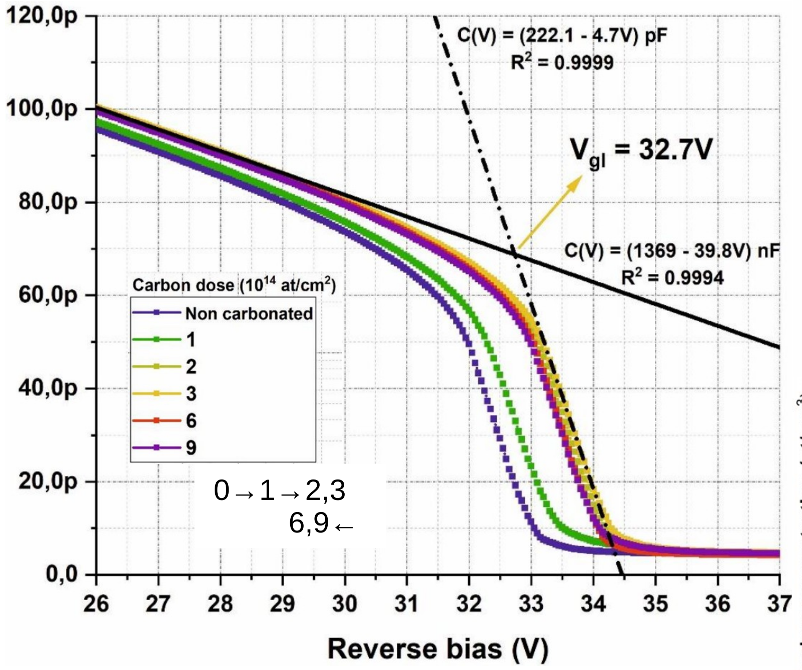
HPK2-W25, 8e14, CV at different freq and temperatures

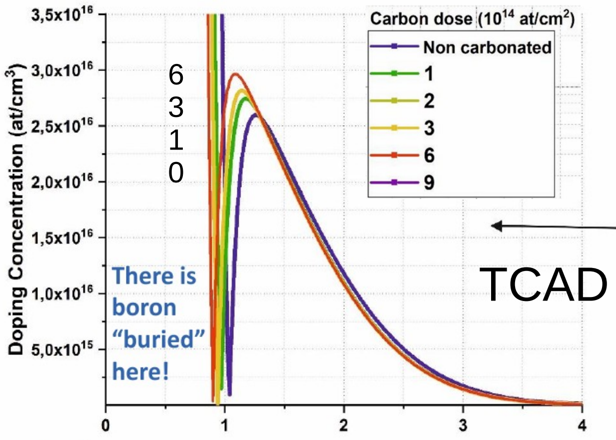


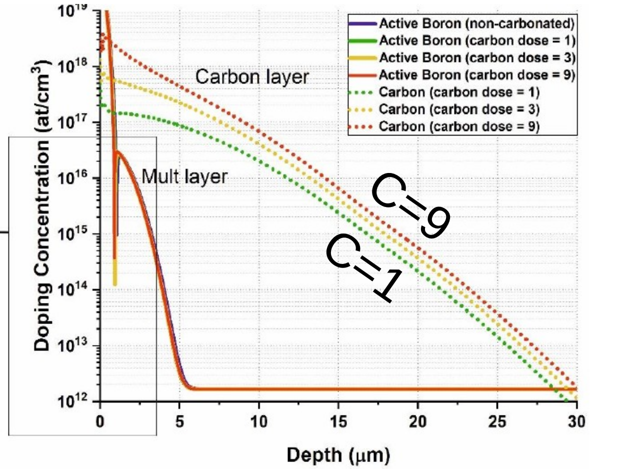
C(1 kHz, Φ=0, 20C ; 0V)=C(100 Hz, 8e14, 10C : 0V)
Cp(1 kHz, 0V) depends on T

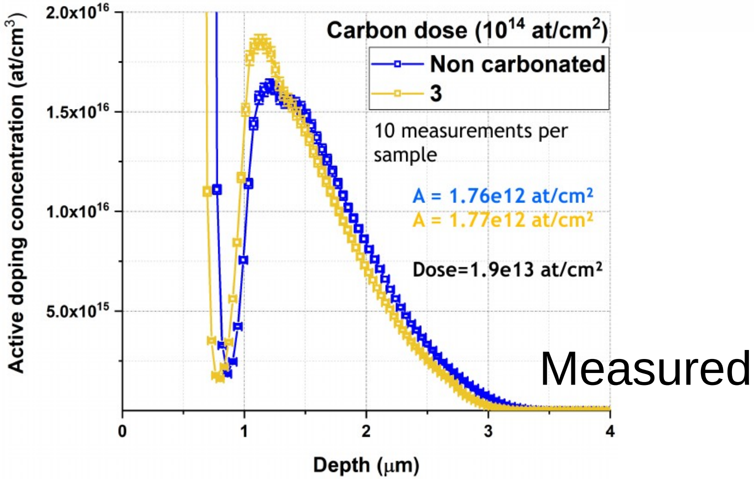
Marcos Fernandez, Tredi 2021

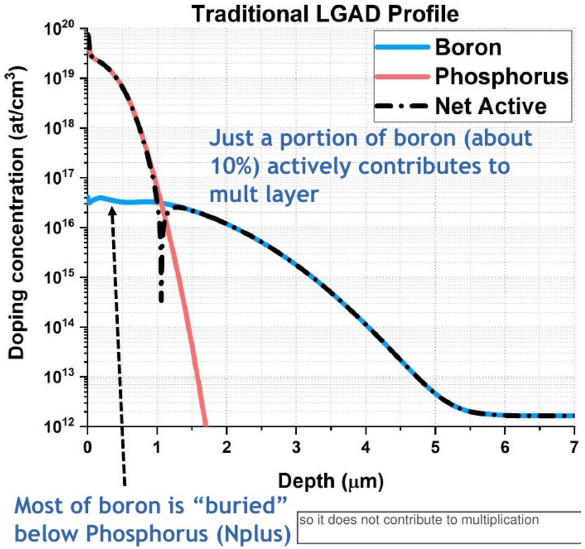
The higher C dose, the higher [B]
More boron that was buried gets activated by the C
Device have more gain

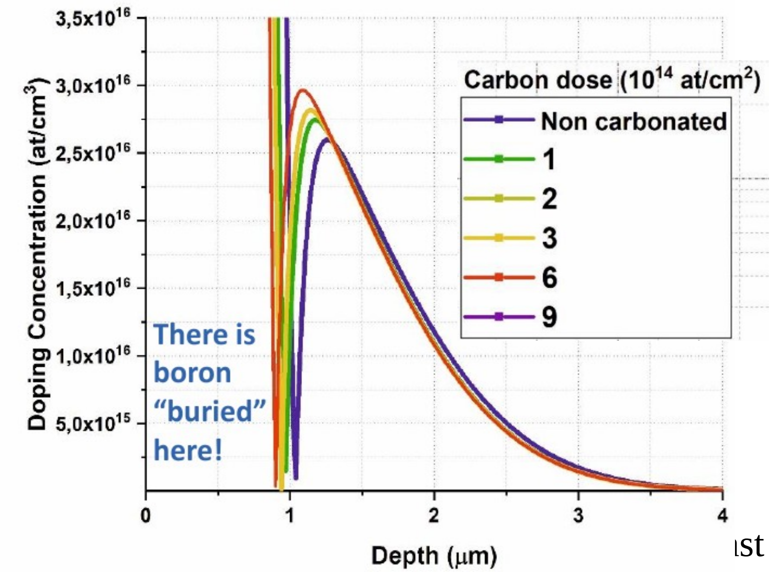









Traditional LGAD Profile
Boron
Phosphorus
Net Active
Just a portion of boron (about 10%) actively contributes to mult layer
Doping concentration (at/cm³)
Depth (μm)
Most of boron is "buried" below Phosphorus (Nplus)
so it does not contribute to multiplication


Carbon dose (10¹⁴ at/cm²)
Non carbonated
1
2
3
6
9
There is boron "buried" here!
Doping Concentration (at/cm³)
Depth (μm)

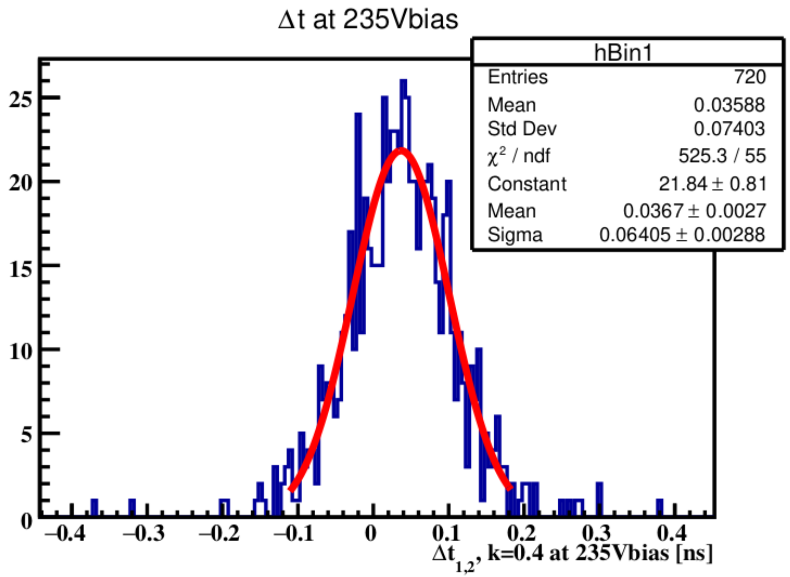
Time Resolution

Constant Fraction Discrimination (40%).

Compute the Time of arrival difference between the three sensors: **$\Delta t_{1,2}$, $\Delta t_{1,3}$ & $\Delta t_{2,3}$**

Fit the Width of the difference distributions:
$\sigma_{1,2}$, $\sigma_{1,3}$ & $\sigma_{2,3}$

The time resolution and its errors[2] are determined by:



$$\sigma_1 = \left(\frac{1}{2}\left(\sigma_{21}^2 + \sigma_{13}^2 - \sigma_{32}^2\right)\right)^{\frac{1}{2}}, \quad \sigma_2 = \left(\frac{1}{2}\left(\sigma_{21}^2 - \sigma_{13}^2 + \sigma_{32}^2\right)\right)^{\frac{1}{2}}, \quad \sigma_3 = \left(\frac{1}{2}\left(-\sigma_{21}^2 + \sigma_{13}^2 + \sigma_{32}^2\right)\right)^{\frac{1}{2}}$$

$$\delta_1 = \frac{\left((\sigma_{21}\delta_{21})^2 + (\sigma_{13}\delta_{13})^2 + (\sigma_{32}\delta_{32})^2\right)^{\frac{1}{2}}}{2\sigma_1},$$

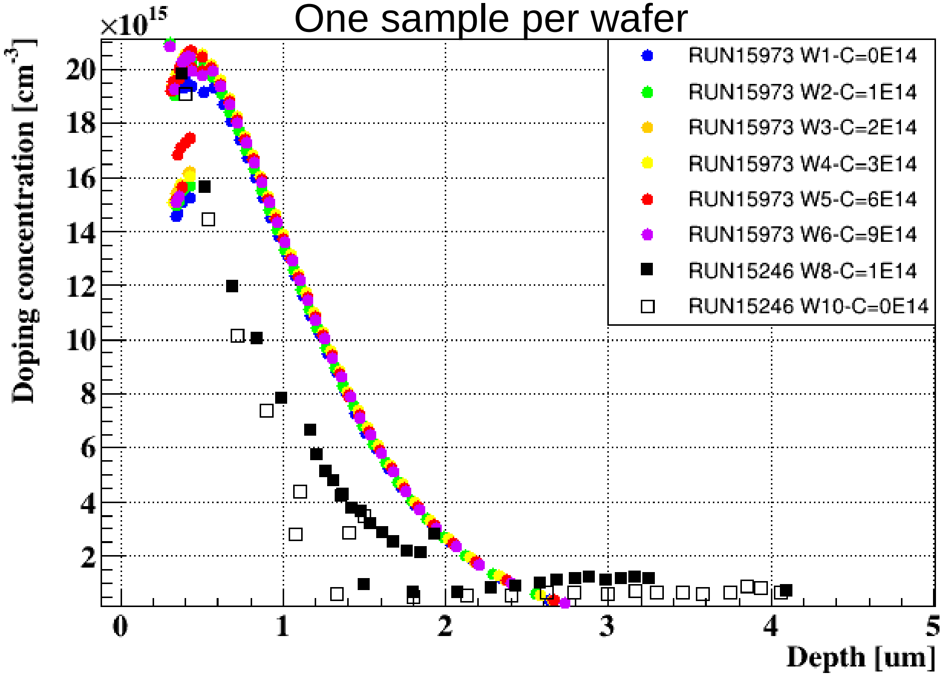
$$\delta_2 = \frac{\left((\sigma_{21}\delta_{21})^2 + (\sigma_{13}\delta_{13})^2 + (\sigma_{32}\delta_{32})^2\right)^{\frac{1}{2}}}{2\sigma_2},$$

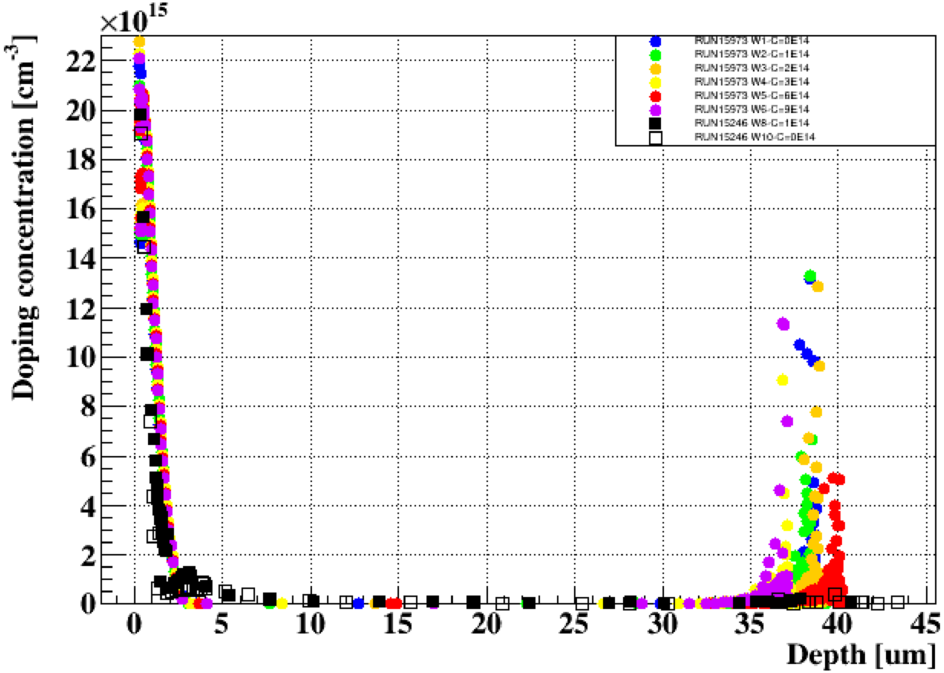
$$\delta_3 = \frac{\left((\sigma_{21}\delta_{21})^2 + (\sigma_{13}\delta_{13})^2 + (\sigma_{32}\delta_{32})^2\right)^{\frac{1}{2}}}{2\sigma_3}.$$

[2] See Paul McKarris' Talk:
https://indico.cern.ch/event/840877/

Doped profile
Common-Run vs ATLAS-Run

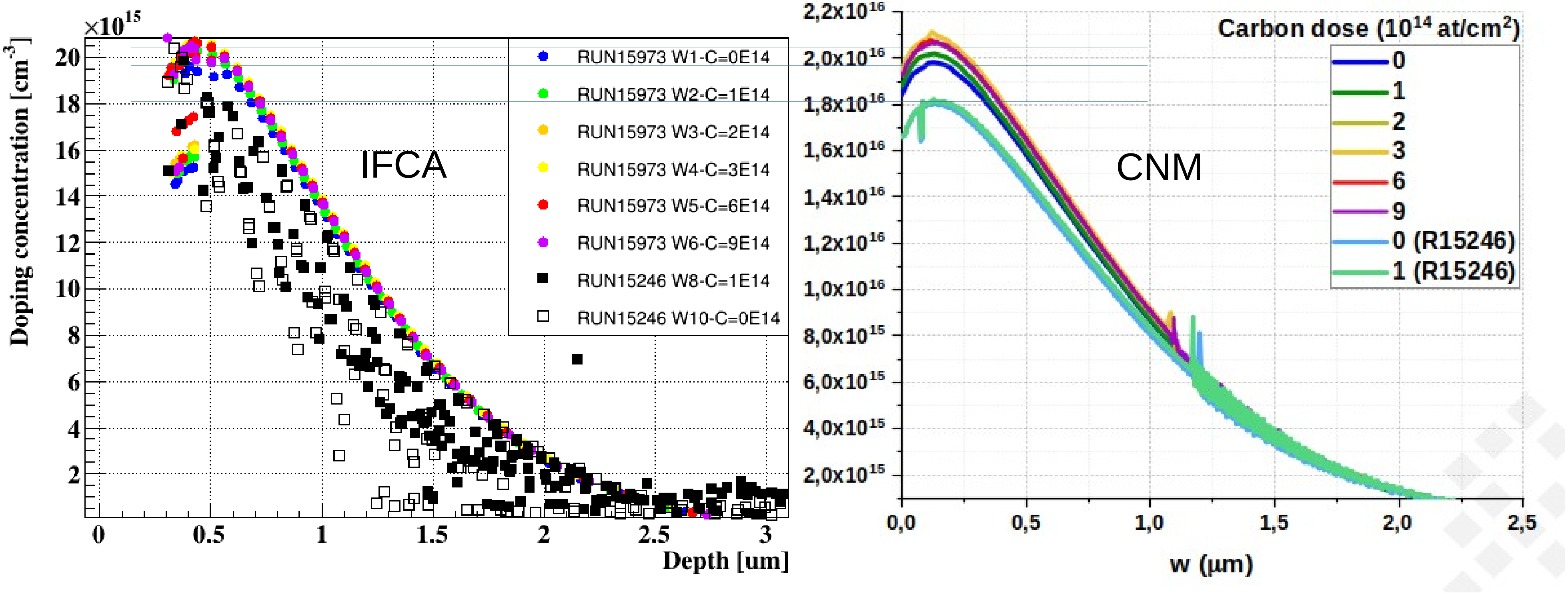
One sample per wafer



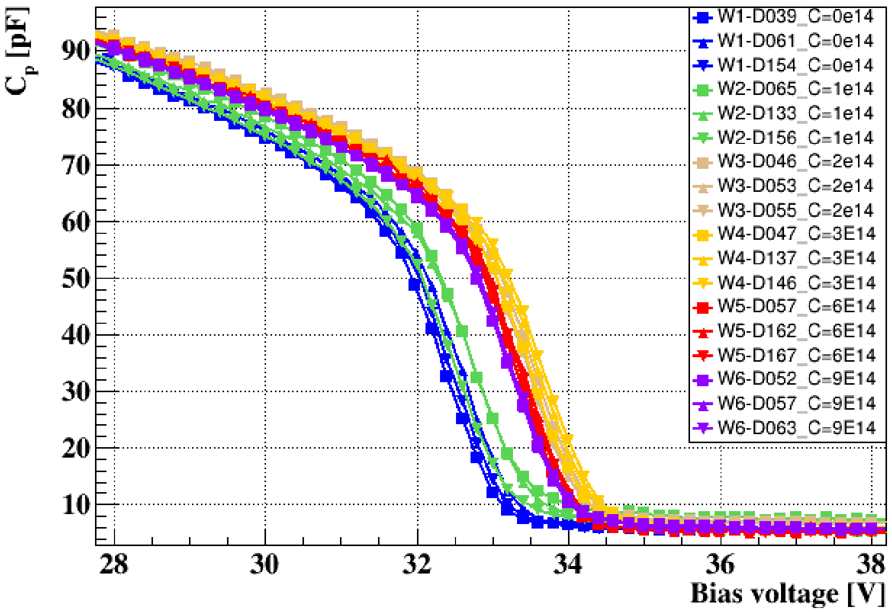


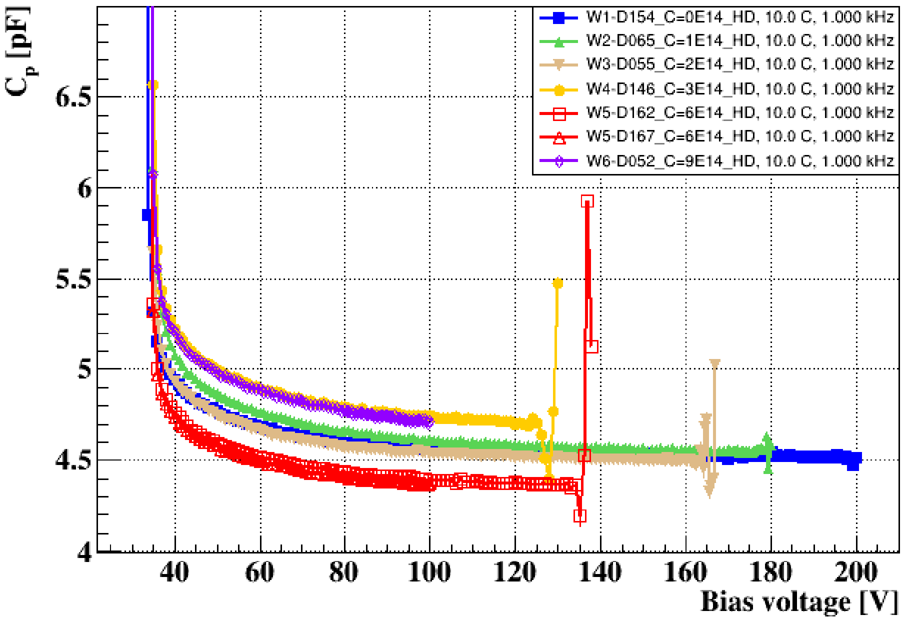
"
- Los sensores son más finos (42um en lugar de 52um), lo que hace que rompan antes.
- Algunas recetas de oxidación/difusión adaptadas a los nuevos hornos del CNM hicieron que los perfiles de dopaje cambiaran ligeramente. Muy poco, pero lo suficiente como para que los sensores del nuevo run tengan más ganancia.
"

Doped profile
Common-Run vs ATLAS-Run

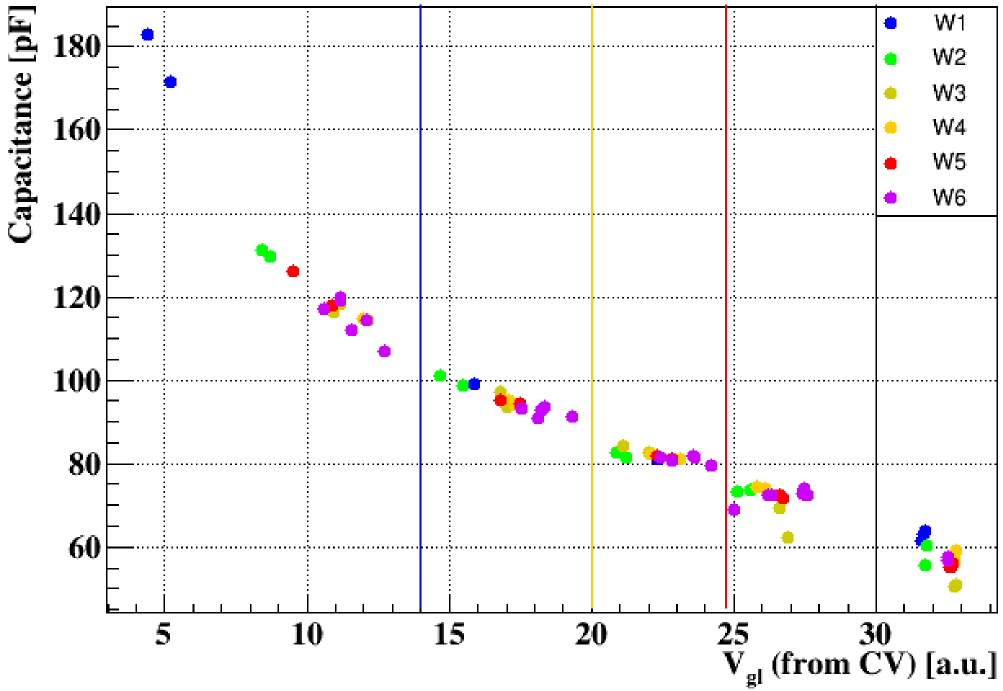


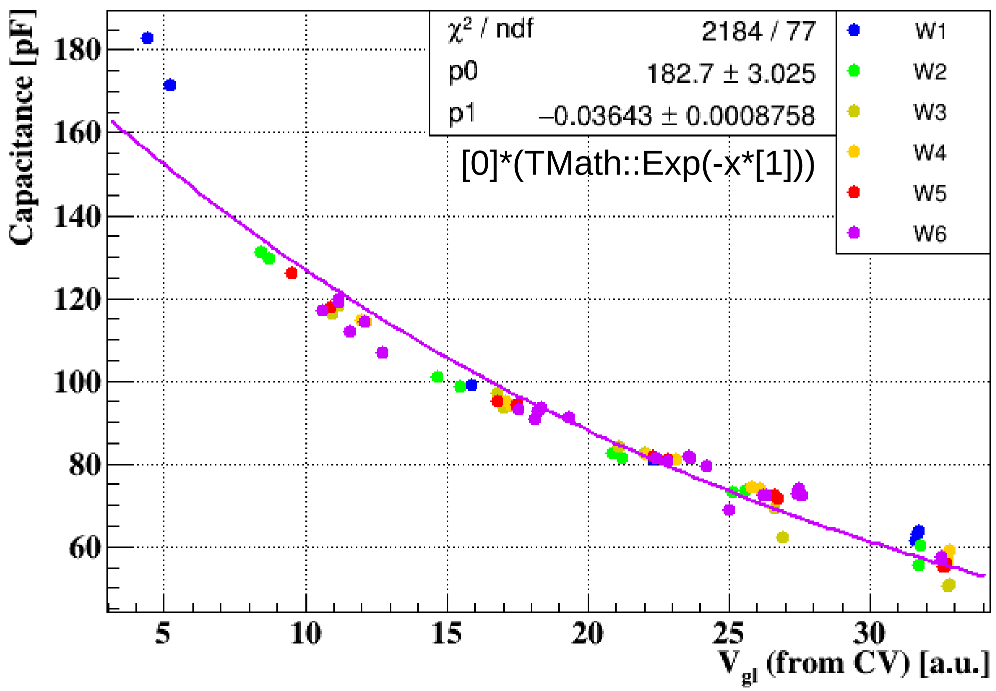
End-Capacitance





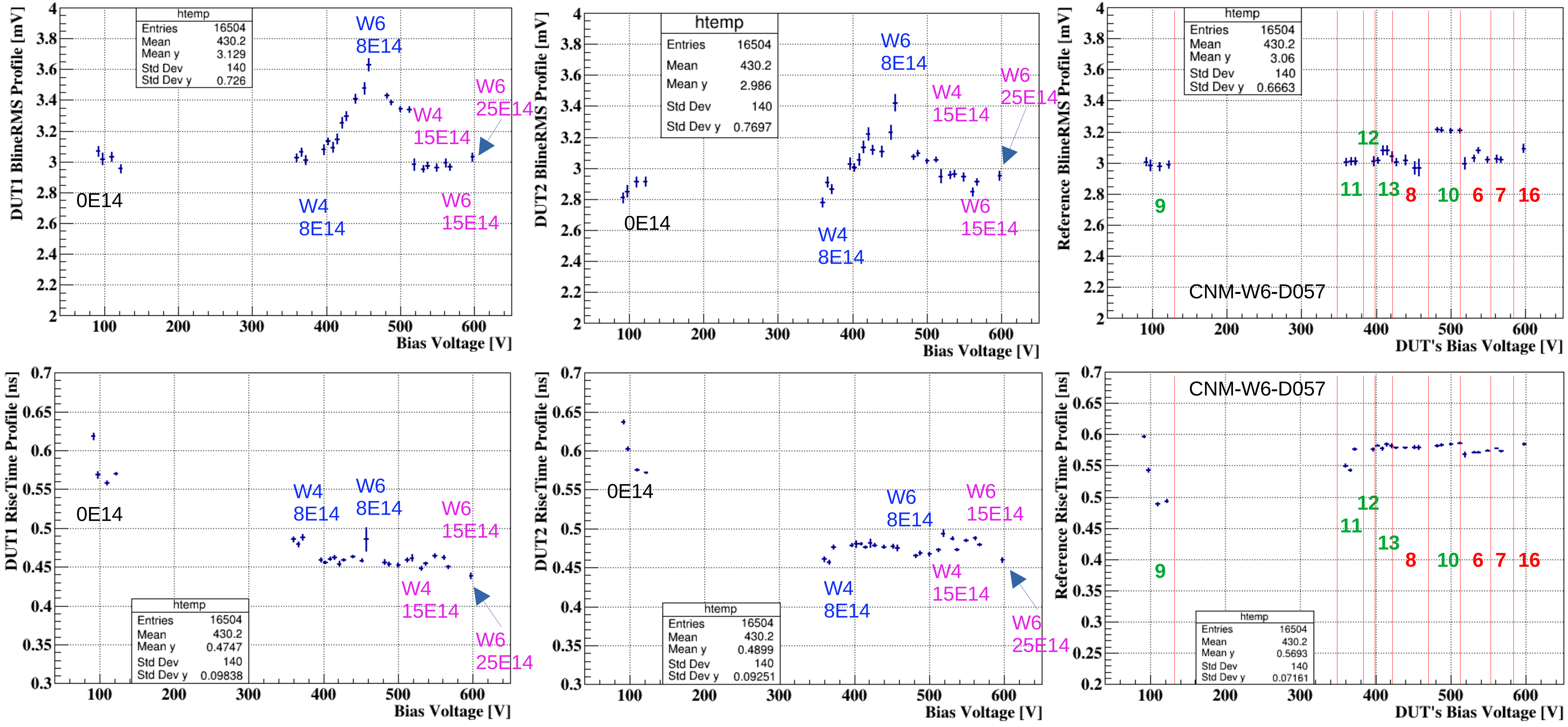
Capacitance vs V_{gl}



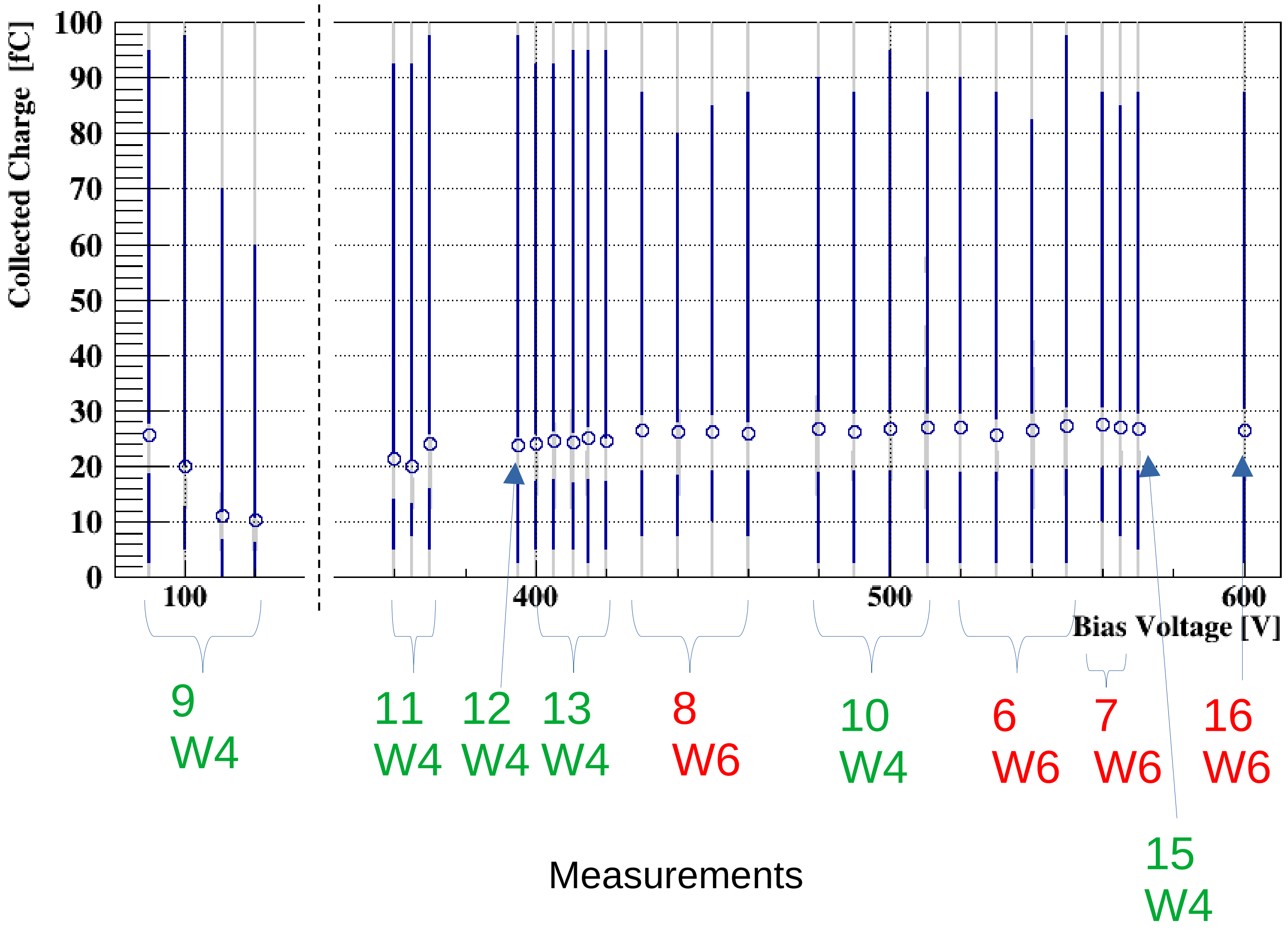


Control plots

DUT1 DUT2 Reference

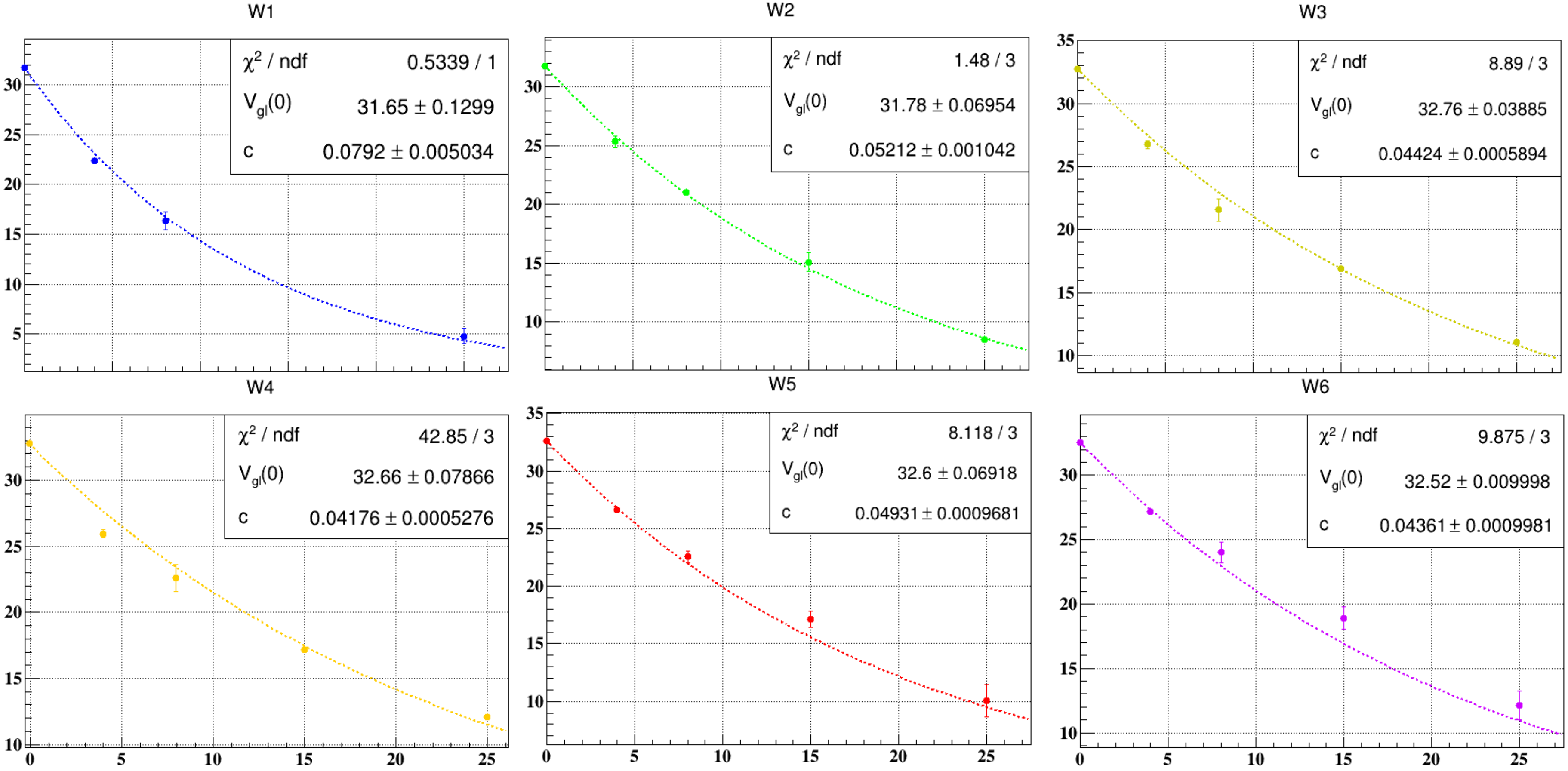


Control plots



Measurements

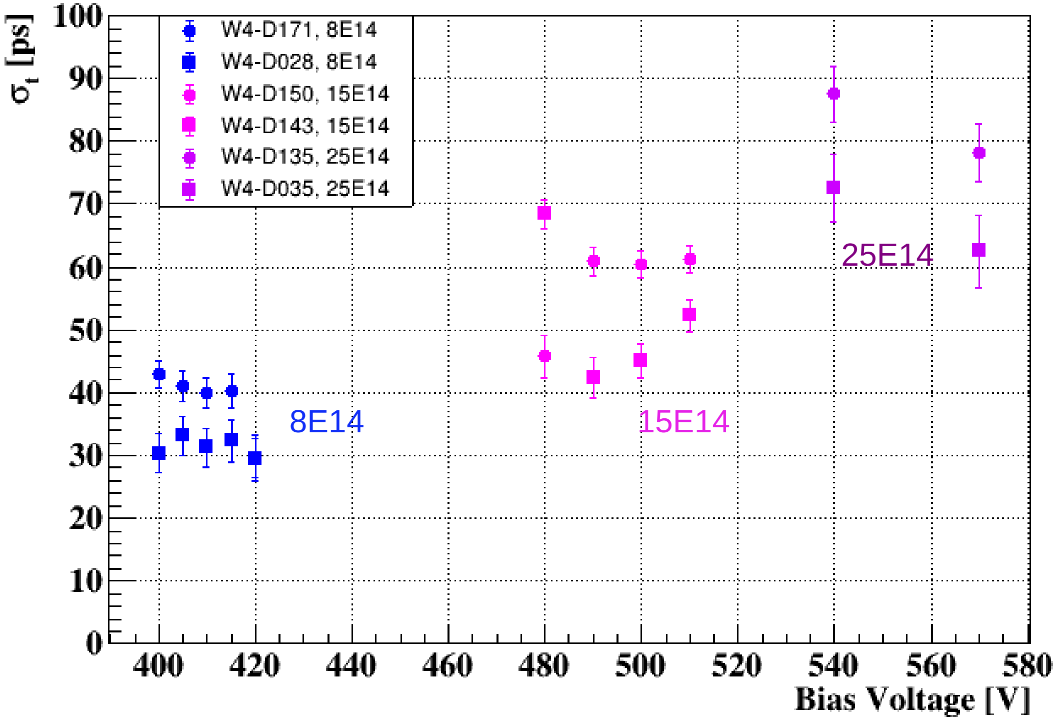
Acceptor removal estimation from CV



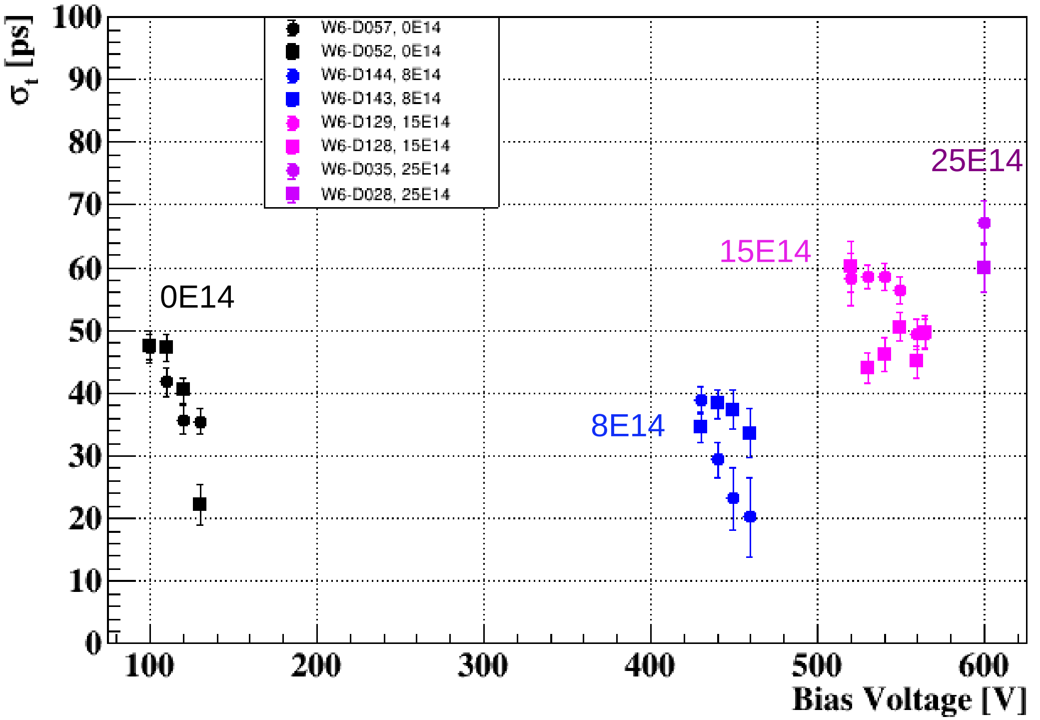
Wafer	W1, C=0E14	W2, C=1E14	W3, C=2E14	W4, C=3E14	W5, C=6E14	W6, C=9E14
$c[10^{-16} cm^2]$	7,9	5.2	4.4	**4.1**	4.9	**4.3**

Time Resolution

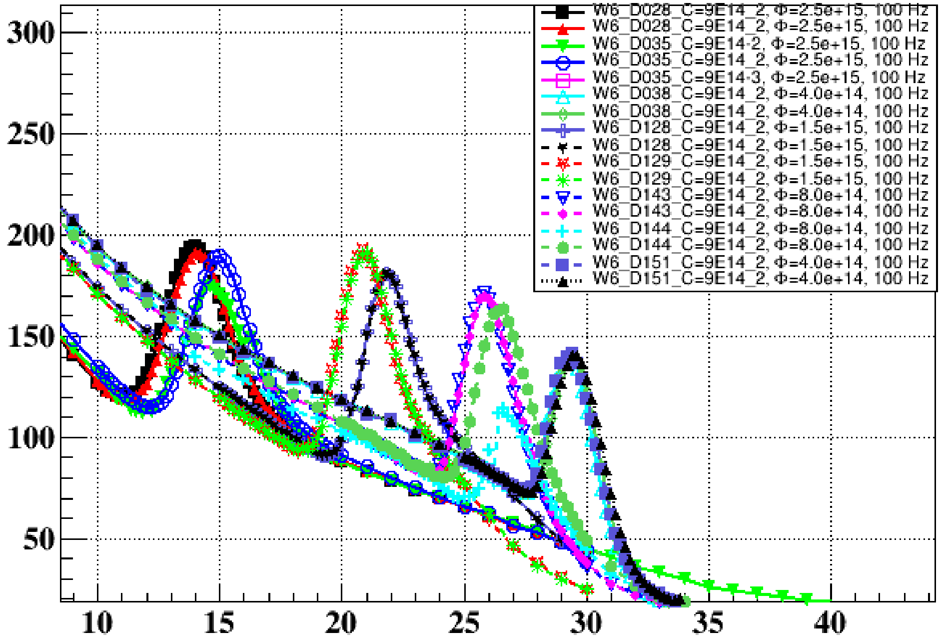
CNM-W4: C=3E14, -25C

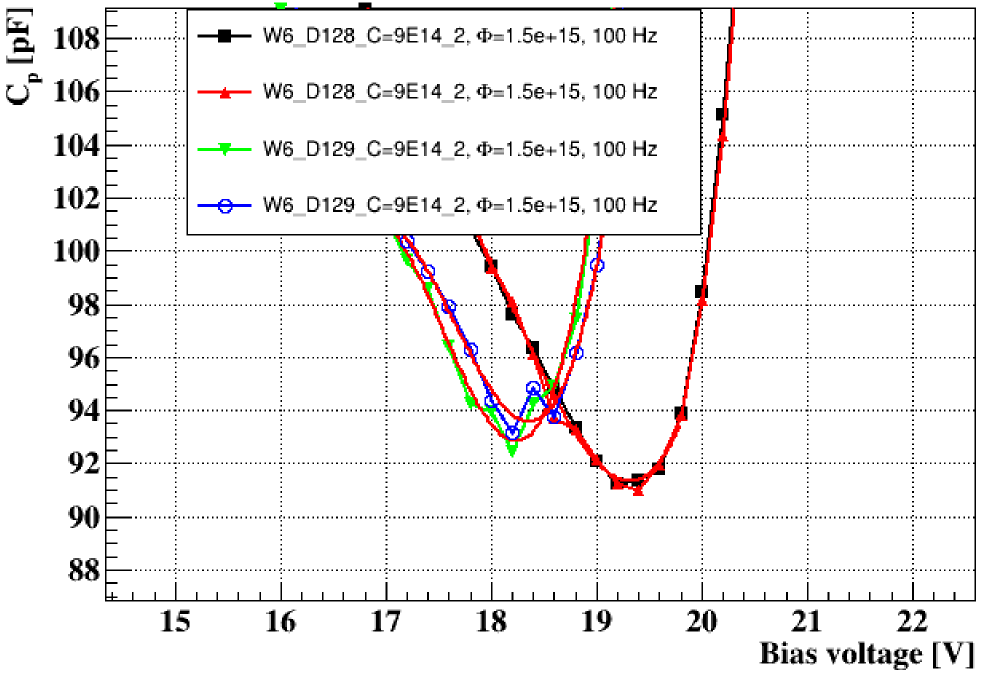


CNM-W6: C=9E14, -25C

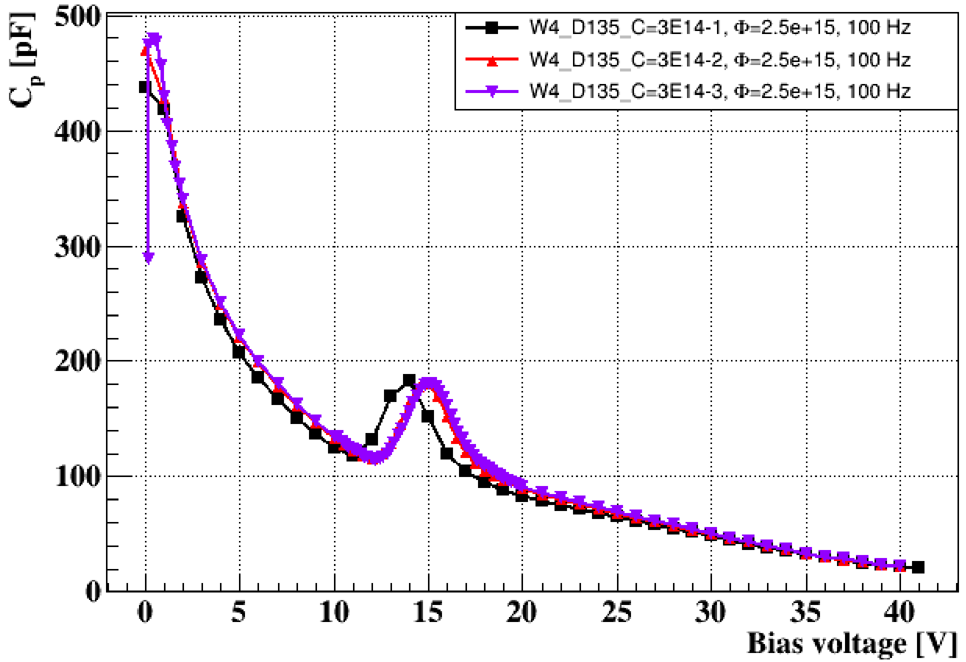


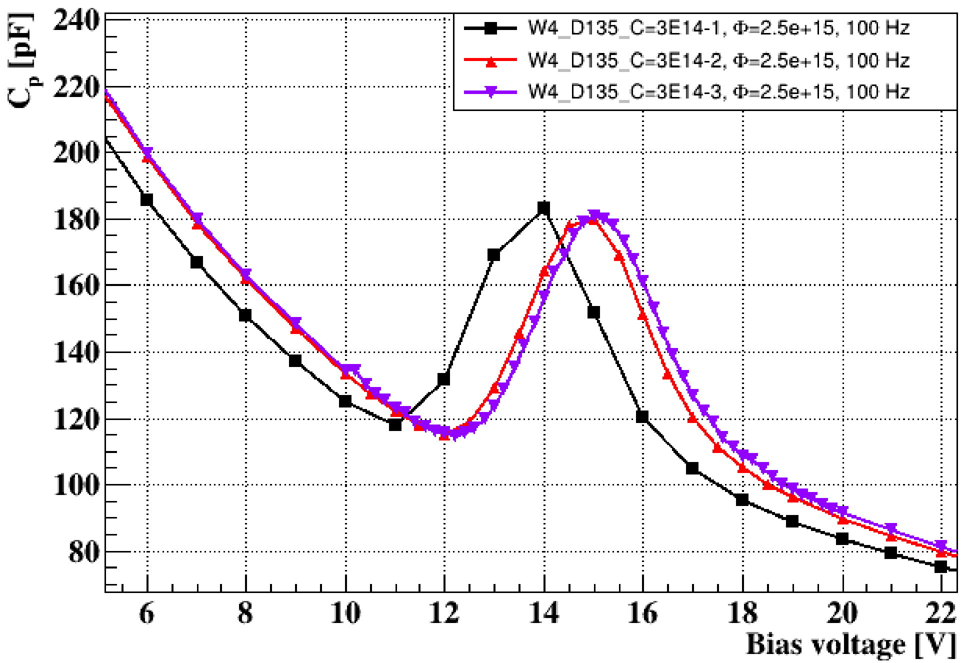
Reproducibility of V_{GL}



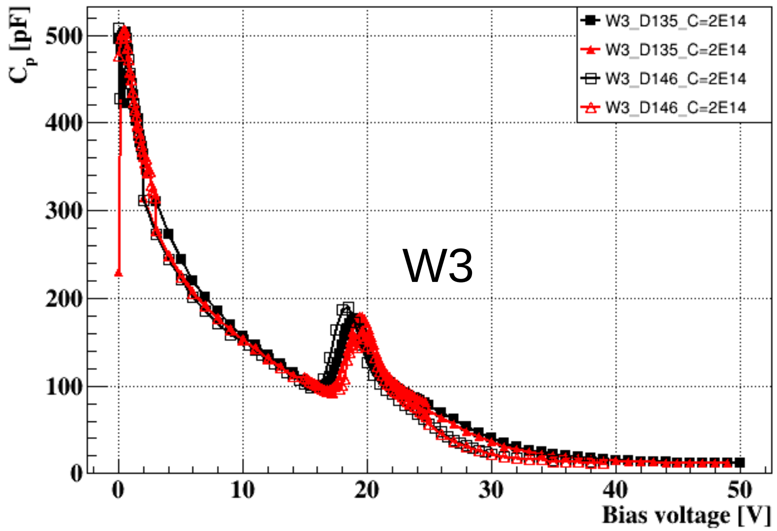


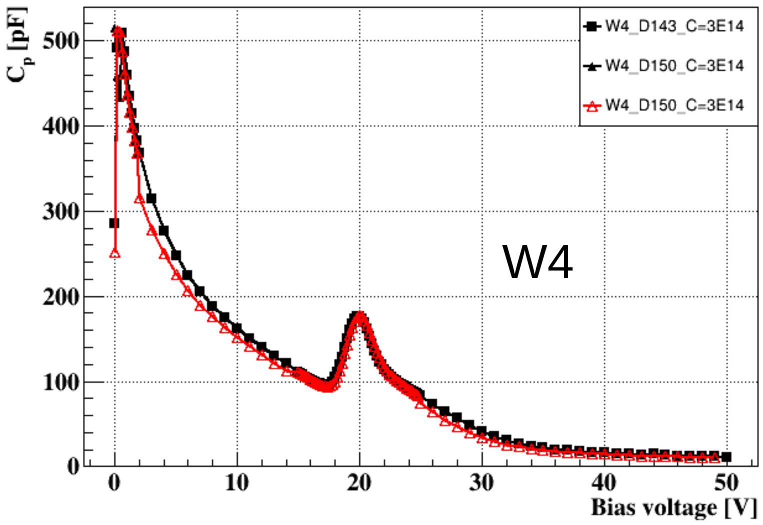
Effect of biasing on Space charge

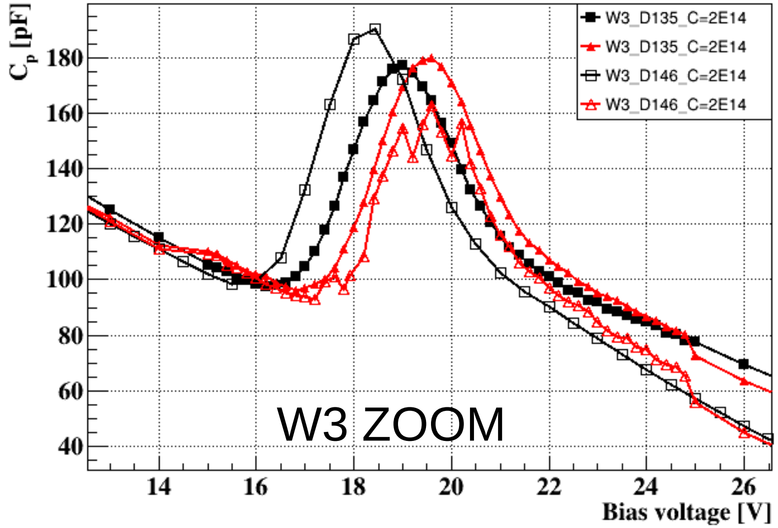


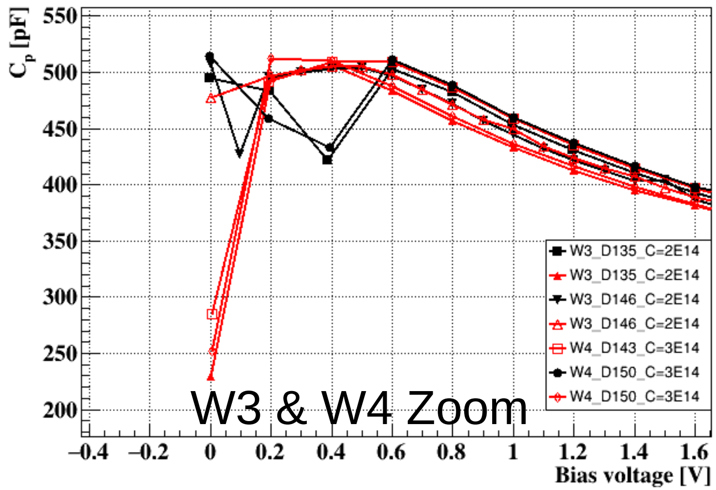


Effect of biasing on Space charge





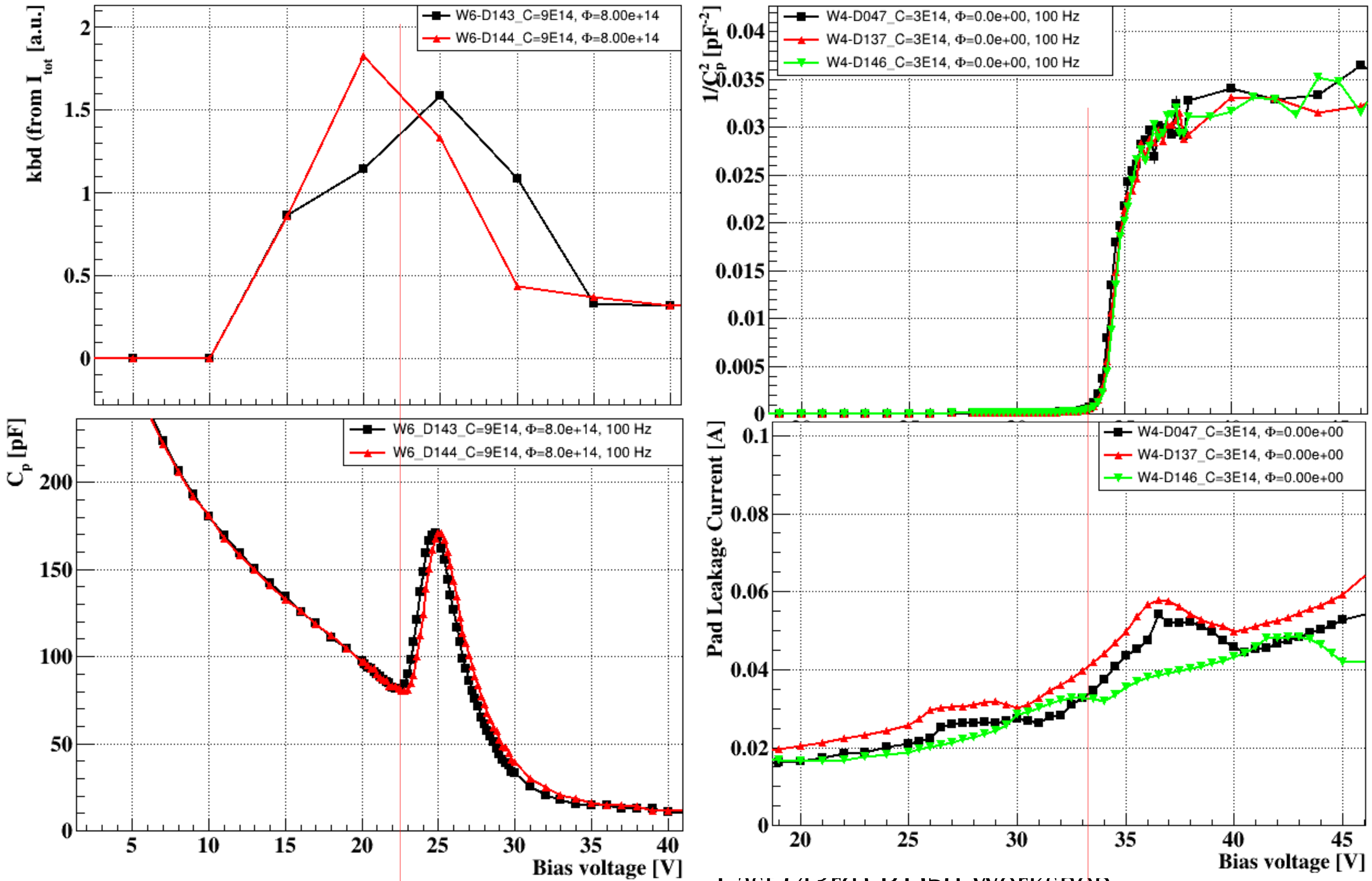




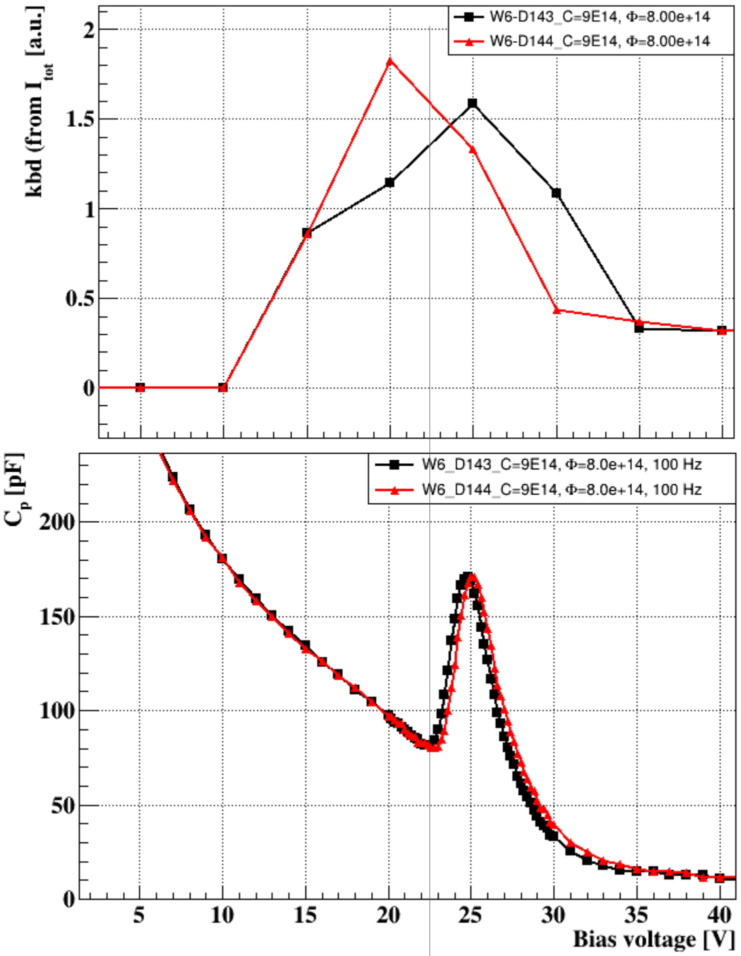
Black: first time biased

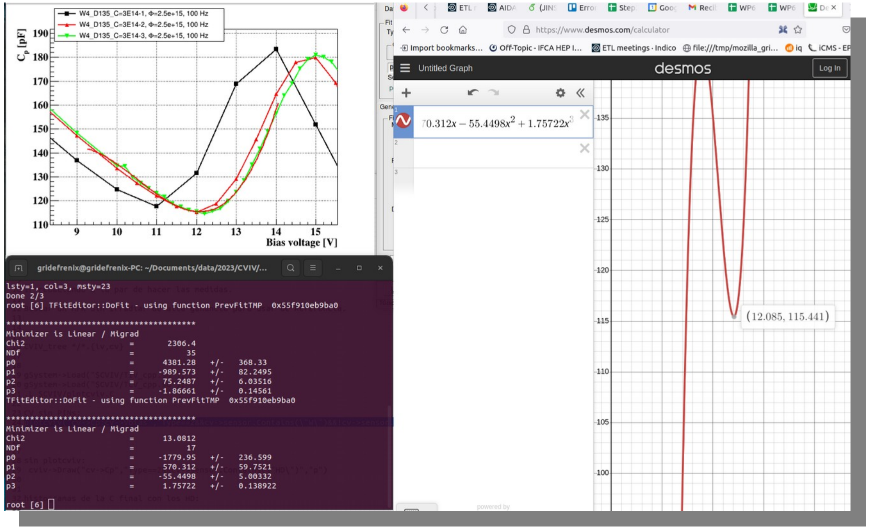
Red: Second time biased

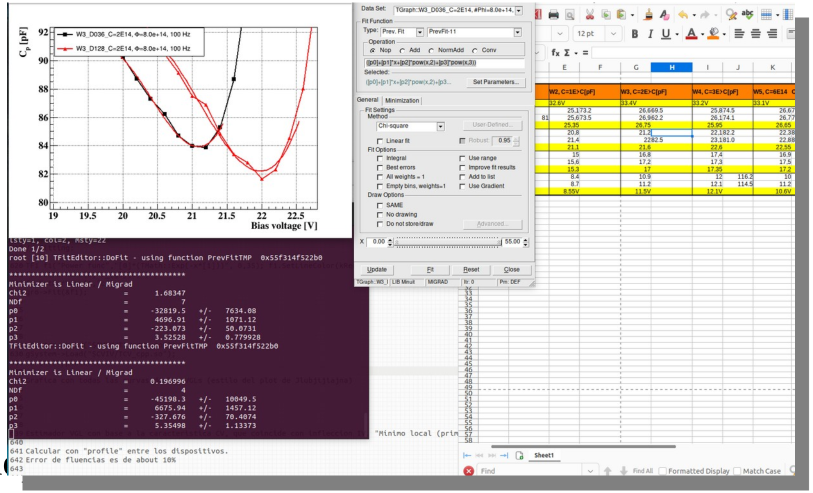
Example of V_{GL} from IV vs CV



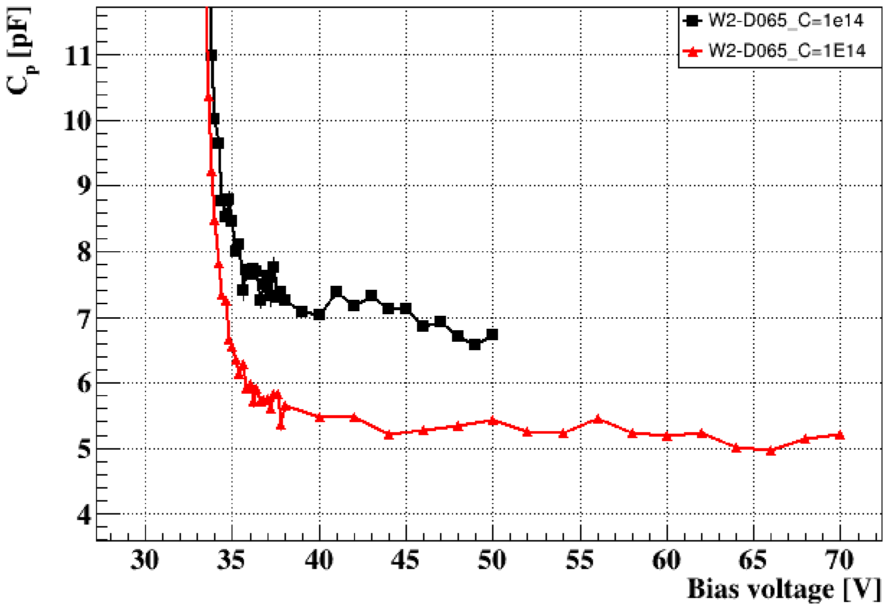
Determination of V_{GL}

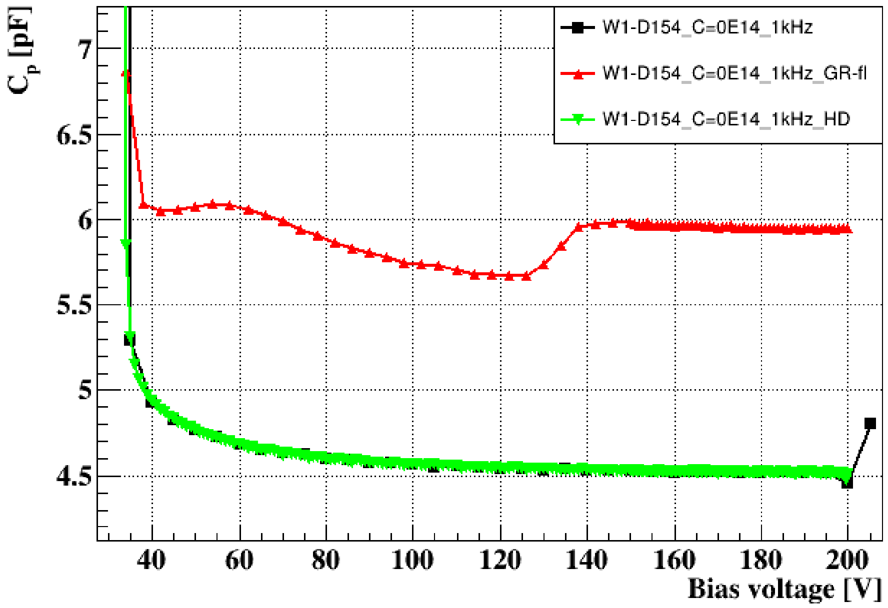




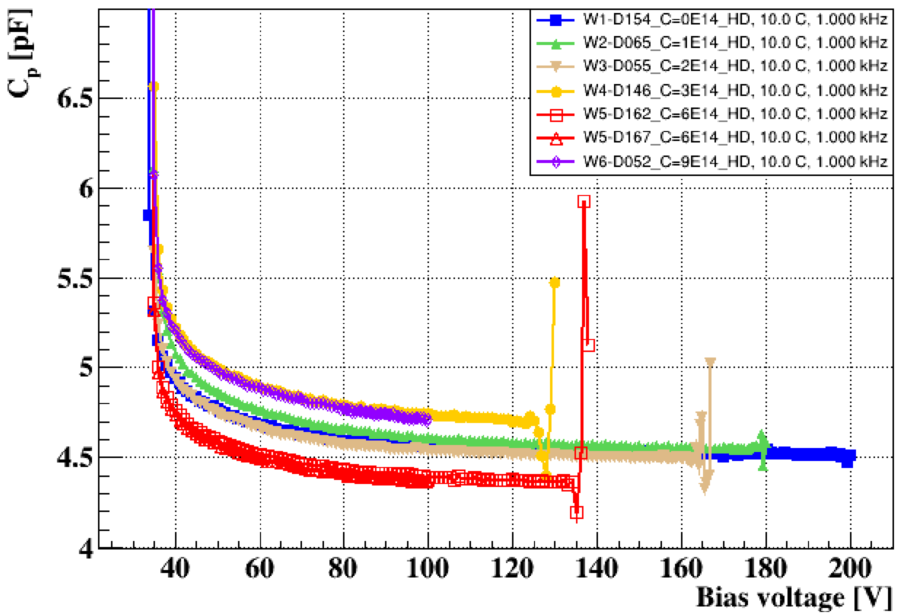


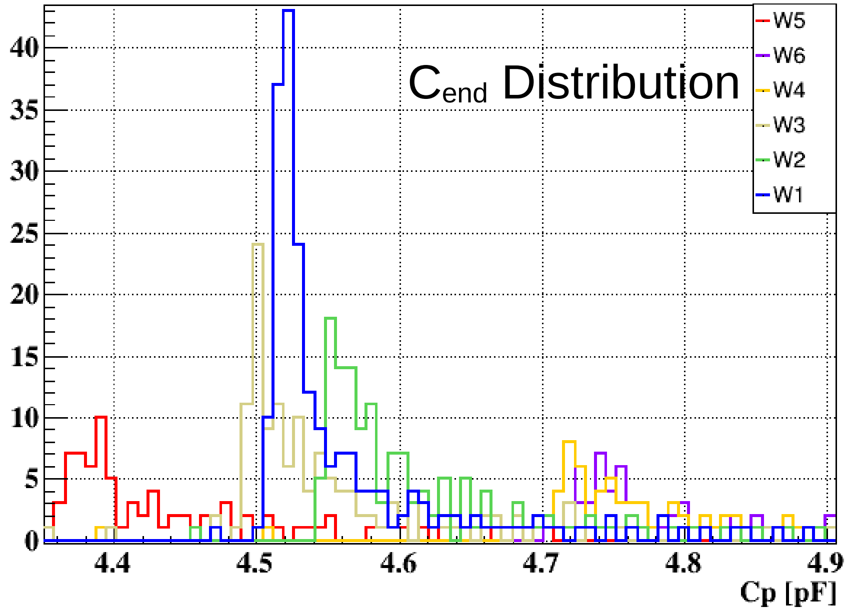
GR connection test



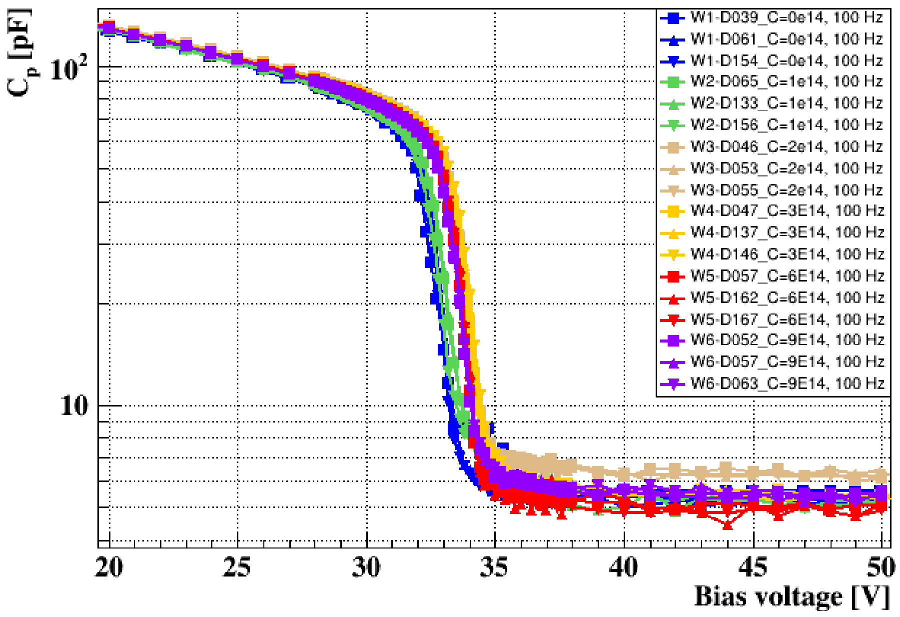


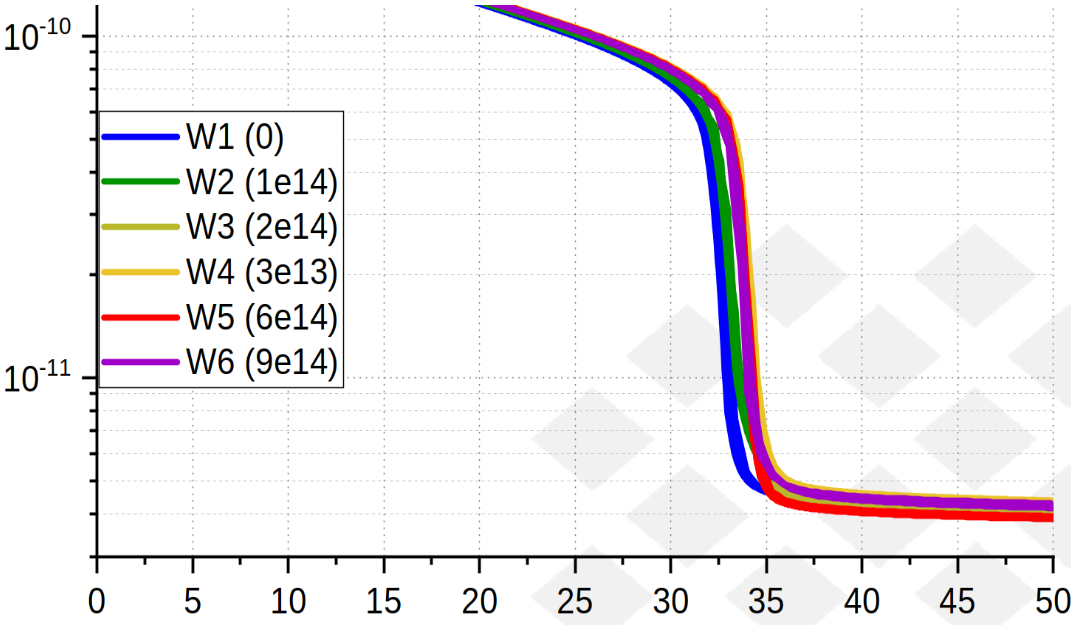
End Capacitance test



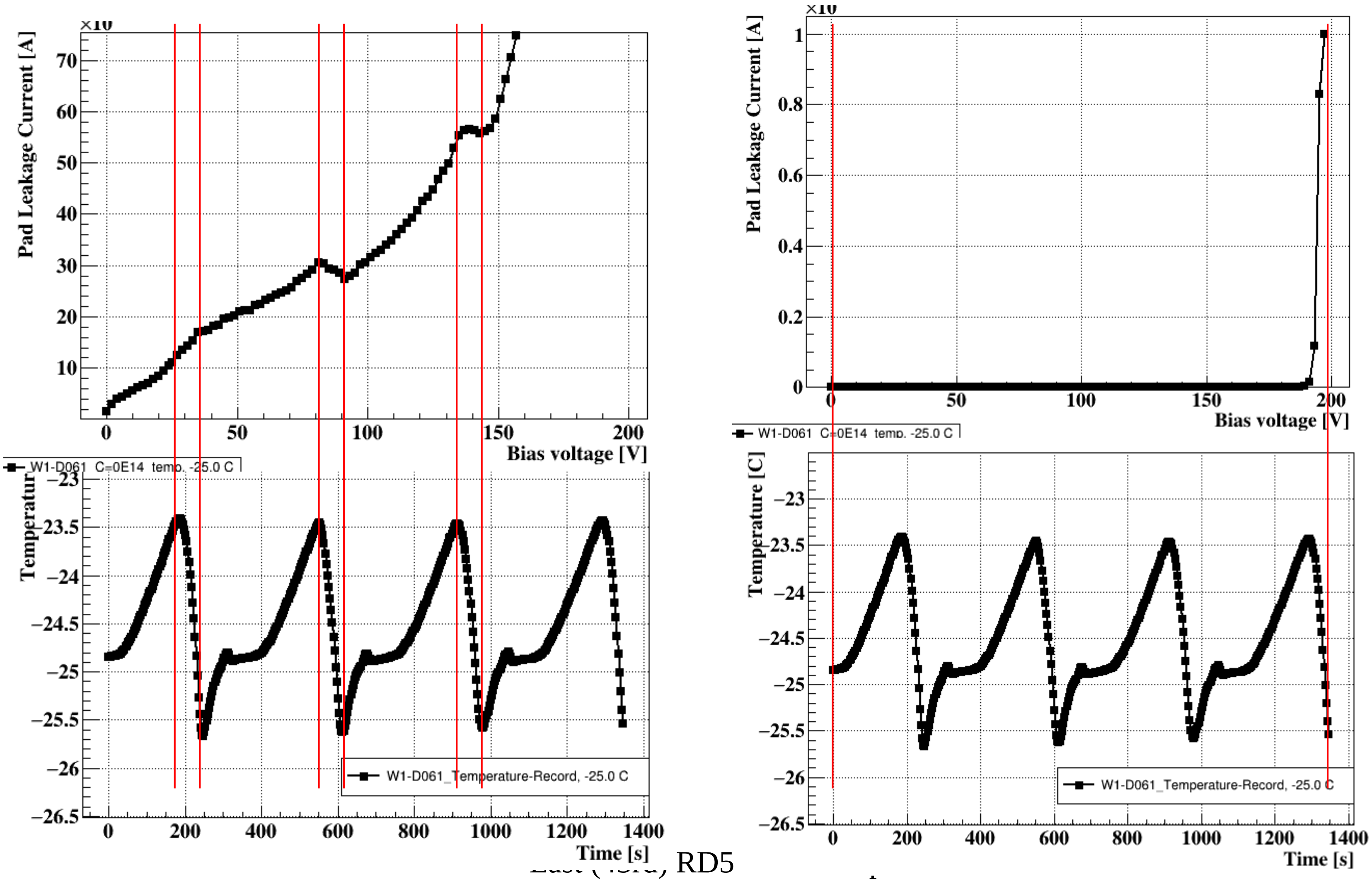


IFCA CNM comparison

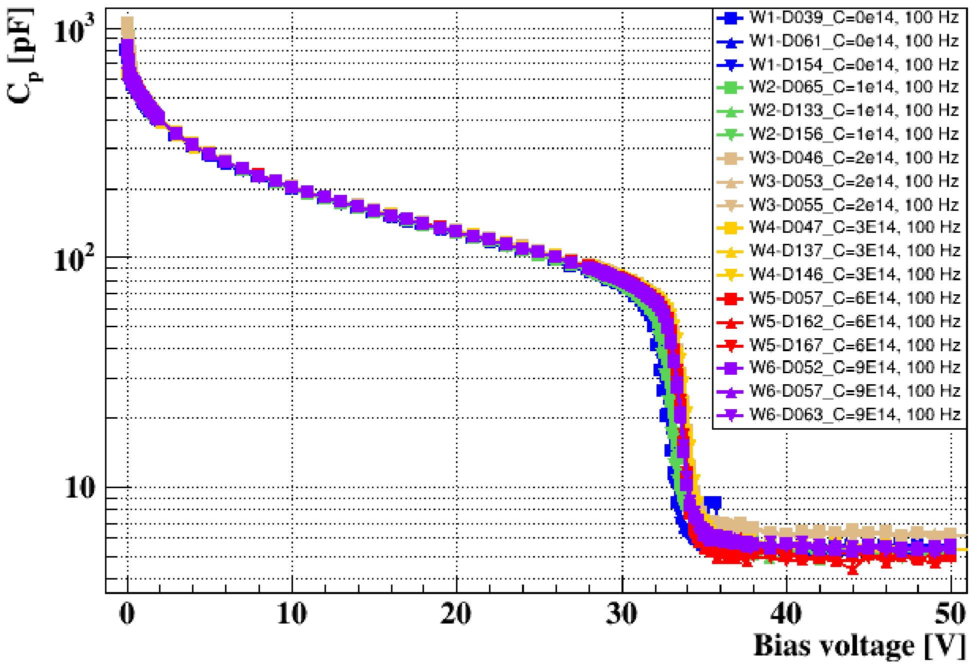


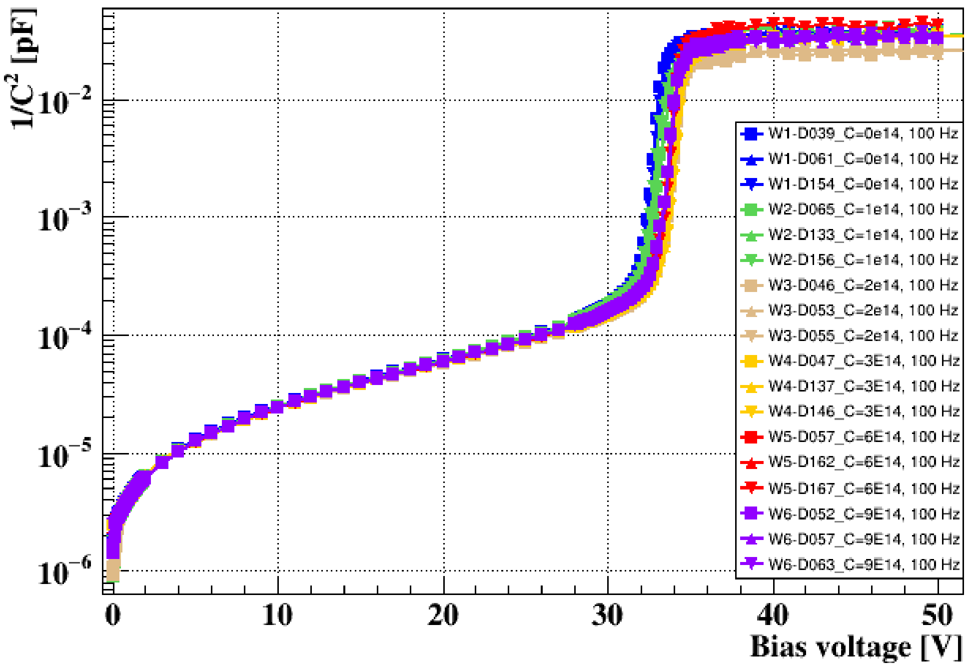


Temperature Test - IV



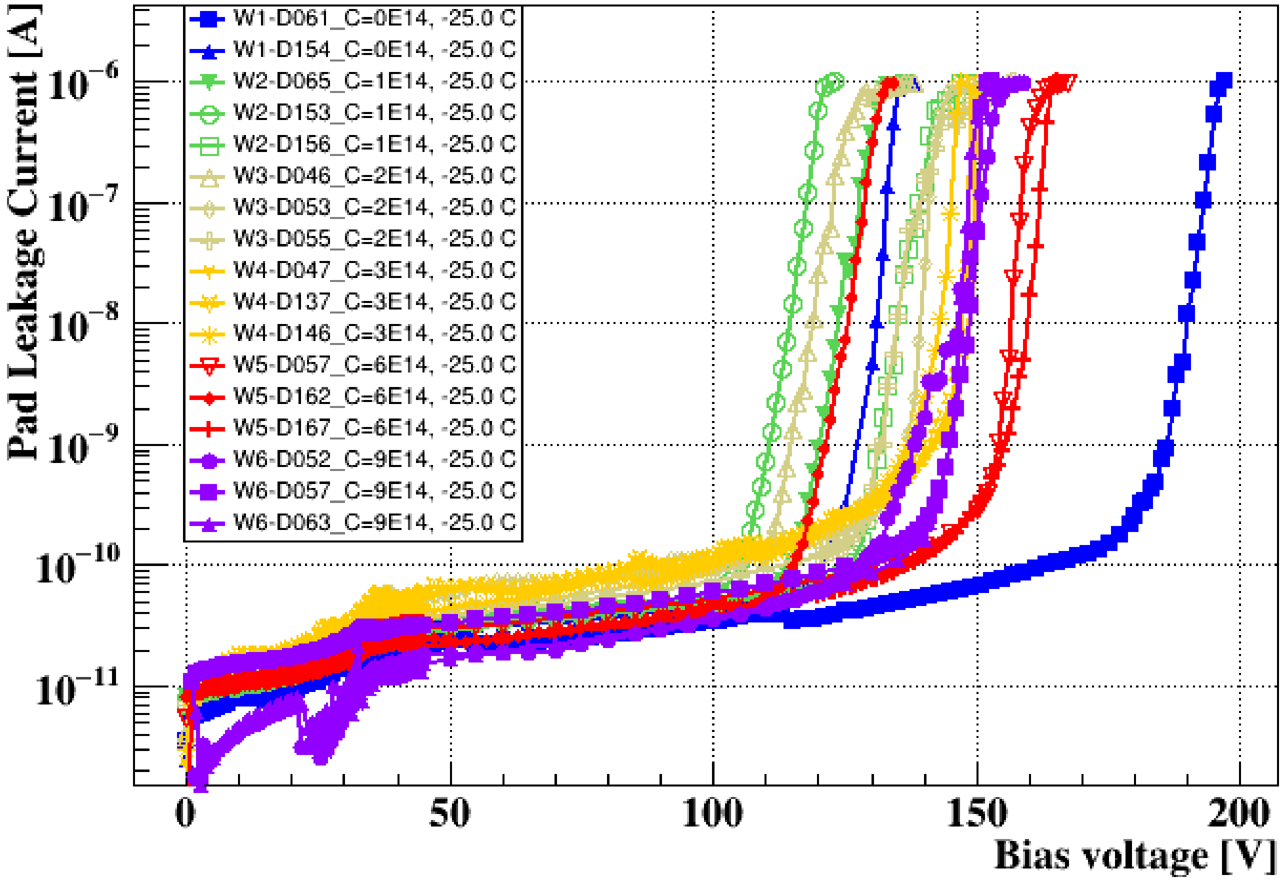
Electric Characterization, CV(Fresh)





Main Diode: HV
GR: biased HV
BackSide: Ground
Temperature: RT
Frequency: 100 Hz

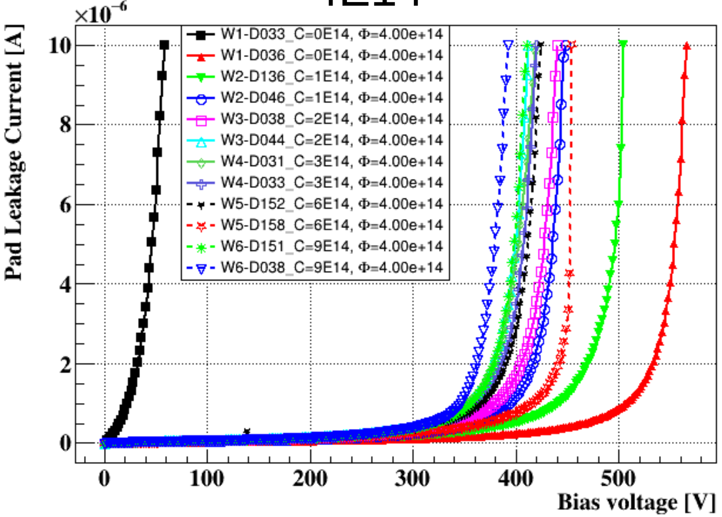
Electric Characterization, IV (Fresh)



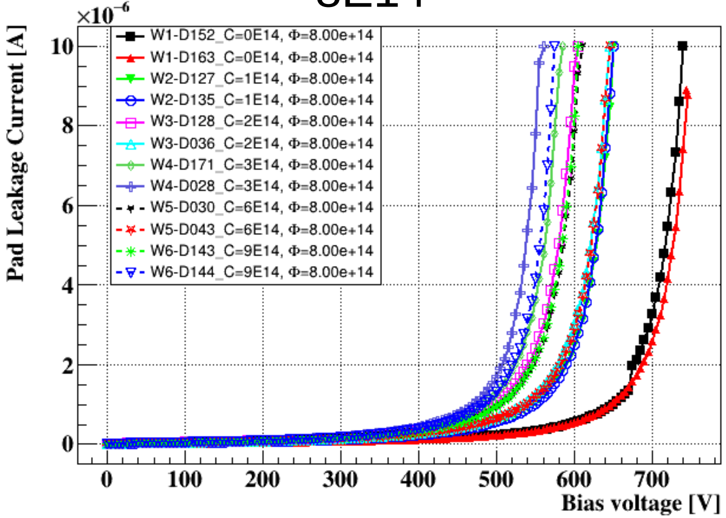
Main Diode: HV
GR: biased HV
BackSide: Ground
Temperature: -25C

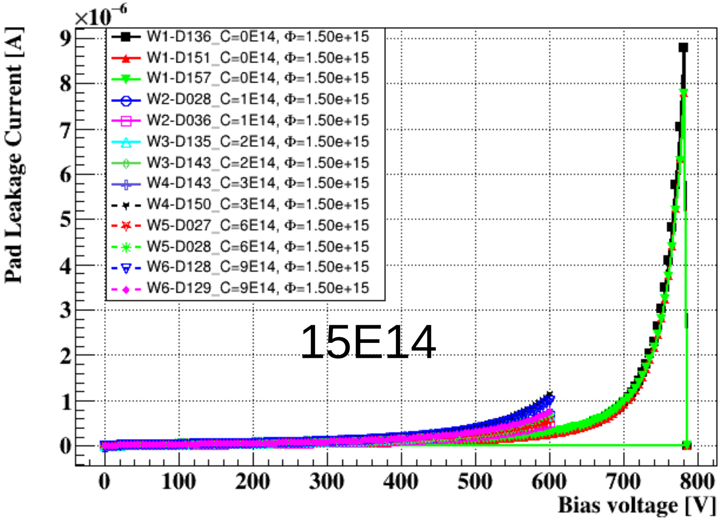
IV Irradiated

4E14

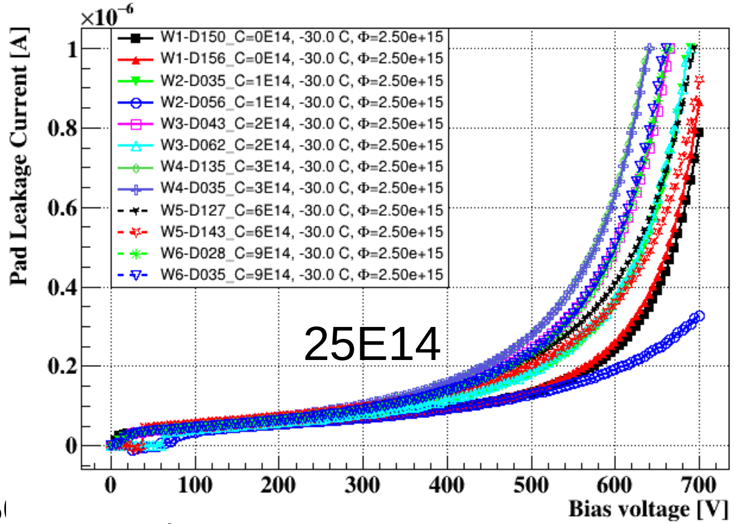


8E14



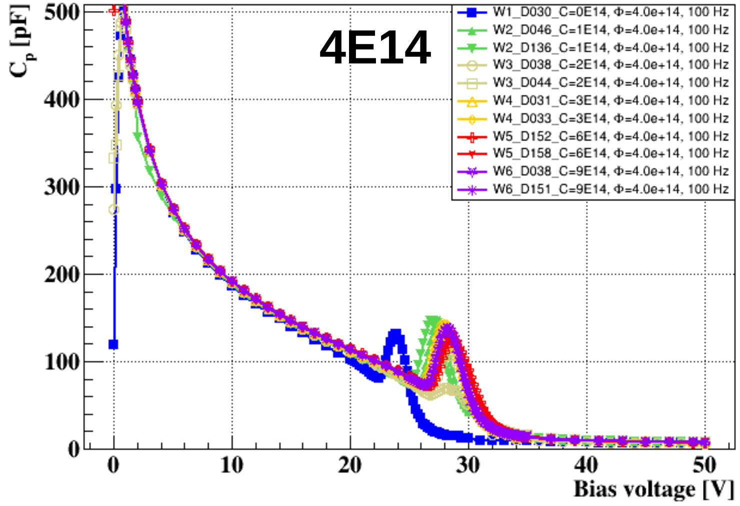


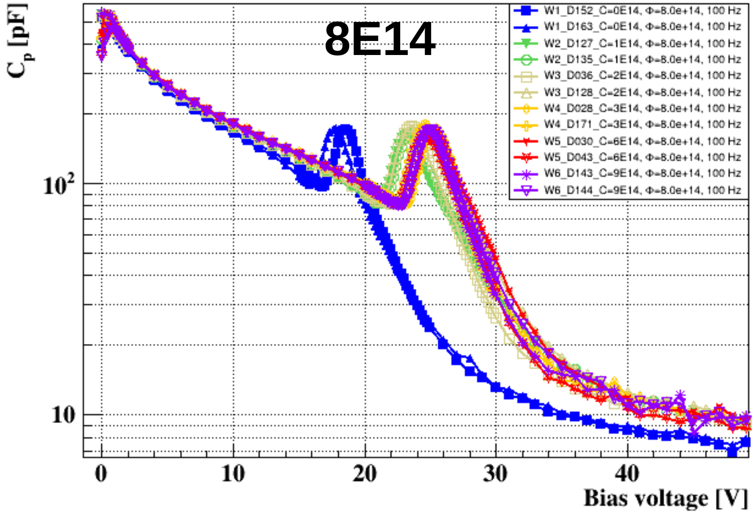
15E14

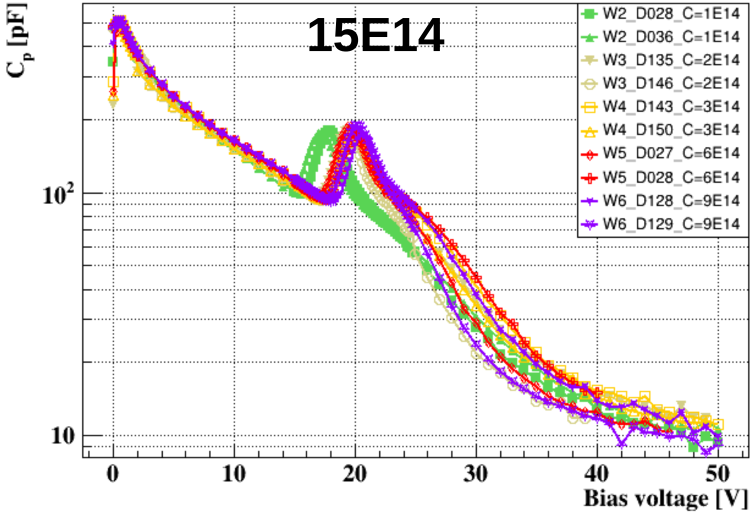


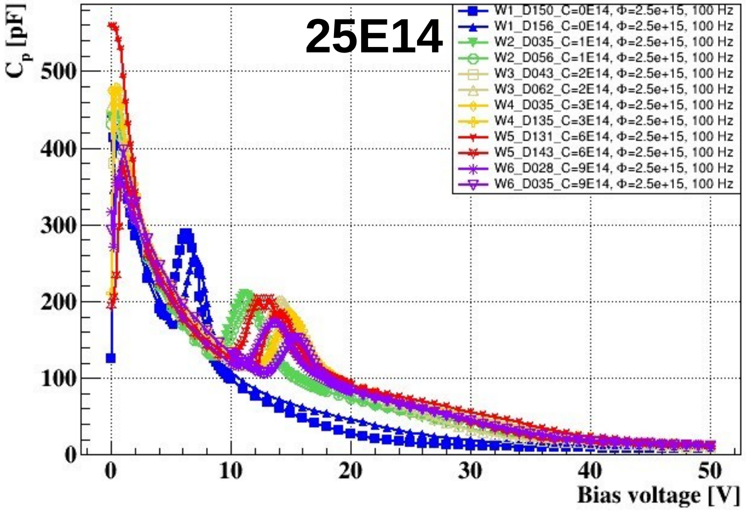
25E14

CV Irradiated









CV Irradiated (Zoom)