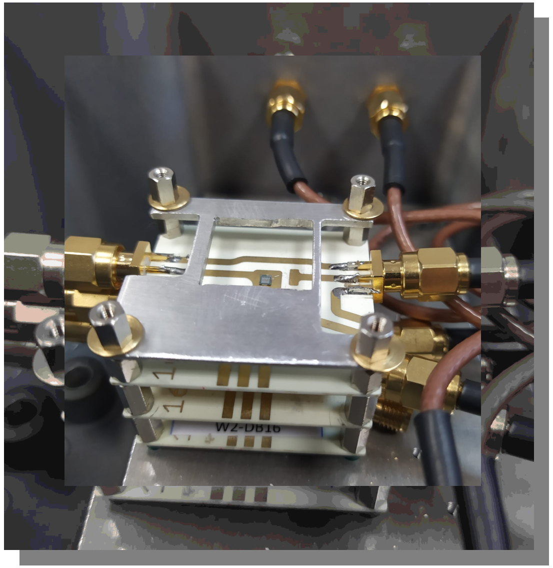
Radiation Tolerance Study of CNM-IMB Run #15246



The 41st RD50 Workshop
December 1st 2022

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Contents

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Samples Description

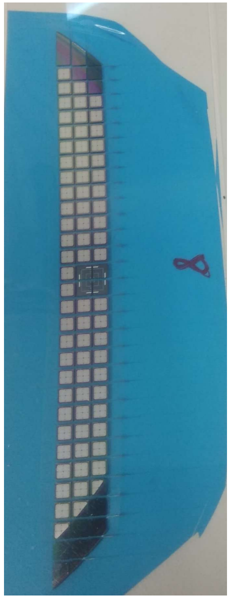
CNM-IMB Run 15246: 6” ATLAS-CMS.

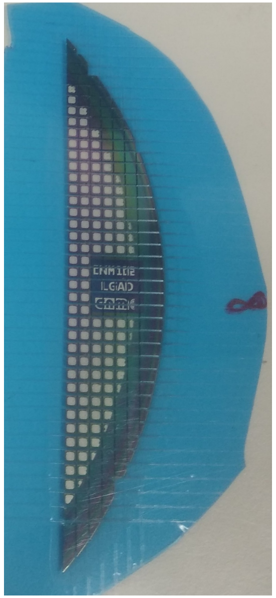
Common Run (CNM-6LG3-2), **Epitaxial** Wafers, some **carbonated**.

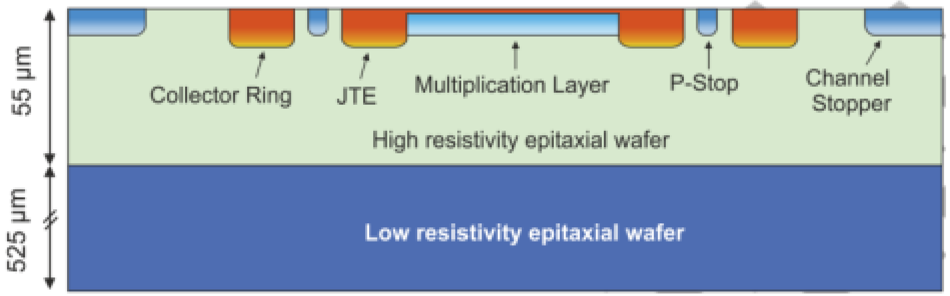
Type of devices CMS: **1x1, 2x2**, 5x5, 16x16 & 16x32 of 1.3x1.3mm^2

Arrived from CNM in June 2022.

Arrived from **irradiation** (0.6E15, 1E15 & 1.5E15 [n_{eq}/cm^2].) at **Ljubljana** in August 22.







Electric Characterization (Fresh)

IV Mapping Single pad diodes

Carbonated

D326					
D325					
D323	D324P				
D321	D322P				
D318	D319P	D320			
D315	D316P	D317			
D311	D312P	D313	D314		
D307	D308P	D309	D310		
D302	D303P	D304	D305	D306	
D297	D298P	D299	D300	D301	
D292	D293P	D294	D295	D296	
D287	D288P	D289	D290	D291	
D281	D282P	D283	D284	D285	D286
D275	D276P	D277	D278	D279	D280
D269	D270P	D271	D272	D273	D274
D267	D268P				
D265	D266P				
D263	D364P				
D261	D262P				
D259	D260P				
D253	D254P	D255	D256	D257	D258
D247	D248P	**D249**	D250	D251	D252
D241	D242P	D243	D244	D245	D246
D236	D237P	D238	D239	D240	
D231	D232P	**D233**	D234	D235	
D226	D227P	D228	D229	D230	
D221	D222P	D223	D224	D225	
D217	D218P	D219	D220		
D213	D214P	D215	D216		
D210	D211P	D212			
D207	D208P	D209			
D205	D206P				
D203	D204P				
D202					
D201					

27 measured

Standard

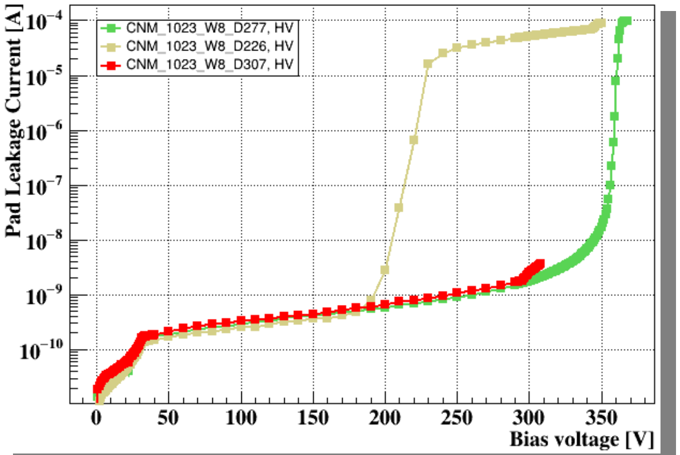
D326					
D325					
D323	D324P				
D321	D322P				
D318	D319P	D320			
D315	D316P	D317			
D311	D312P	D313	D314		
D307	D308P	D309	D310		
D302	D303P	D304	D305	D306	
D297	D298P	D299	D300	D301	
D292	D293P	D294	D295	D296	
D287	D288P	D289	D290	D291	
D281	D282P	D283	D284	D285	D286
D275	D276P	D277	D278	D279	D280
D269	D270P	D271	D272	D273	D274
D267	D268P				
D265	D266P				
D263	D364P				
D261	D262P				
D259	D260P				
D253	D254P	D255	D256	D257	D258
D247	D248P	D249	D250	D251	D252
D241	D242P	D243	D244	D245	D246
D236	D237P	D238	D239	D240	
D231	D232P	D233	D234	D235	
D226	D227P	D228	D229	D230	
D221	D222P	D223	D224	D225	
D217	D218P	D219	D220		
D213	D214P	D215	D216		
D210	D211P	D212			
D207	D208P	D209			
D205	D206P				
D203	D204P				
D202					
D201					

22 measured

GOOD — 33/49

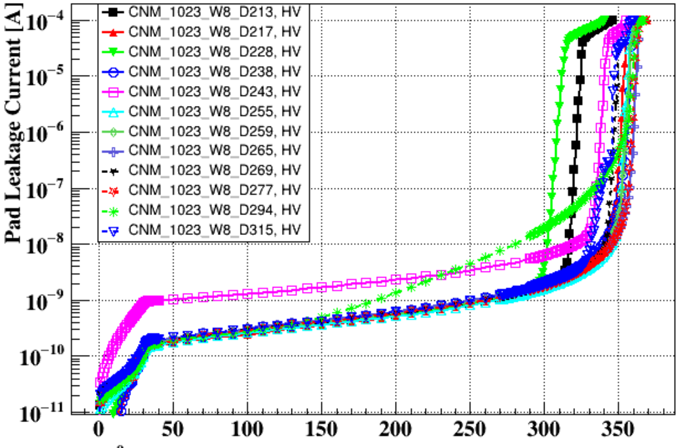
OK but step on IV before breakdown — 15/49

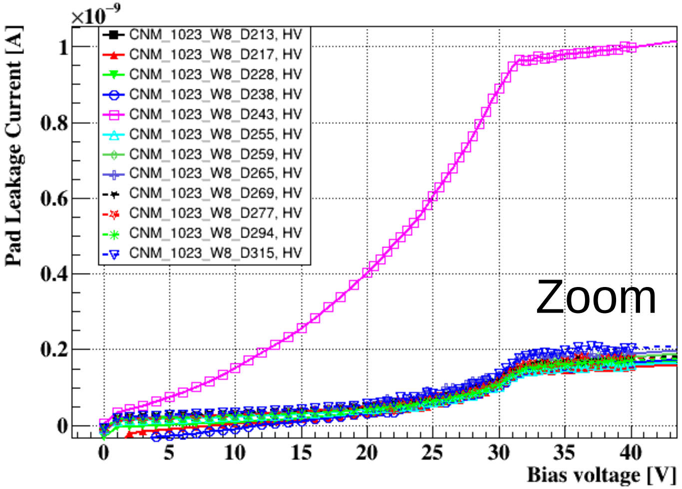
Early breakdown in GR — 1/49



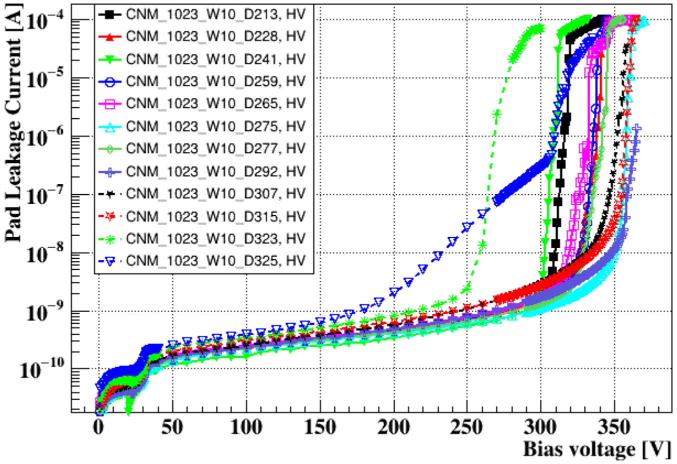
Electric Characterization, IV curves (Fresh)

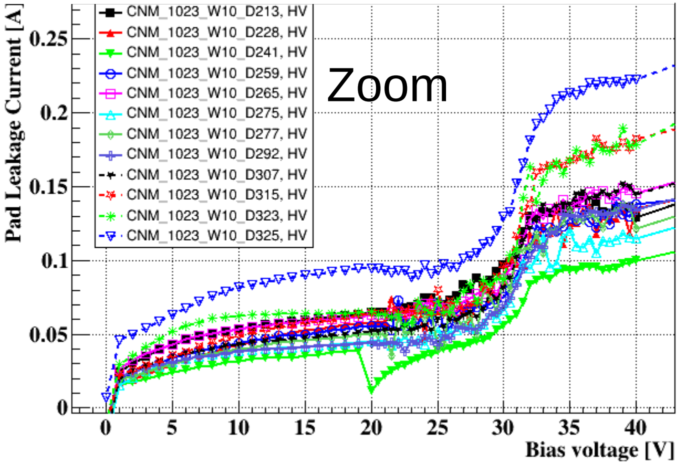
Carbonated, CNM, RT





Standard, CNM, RT

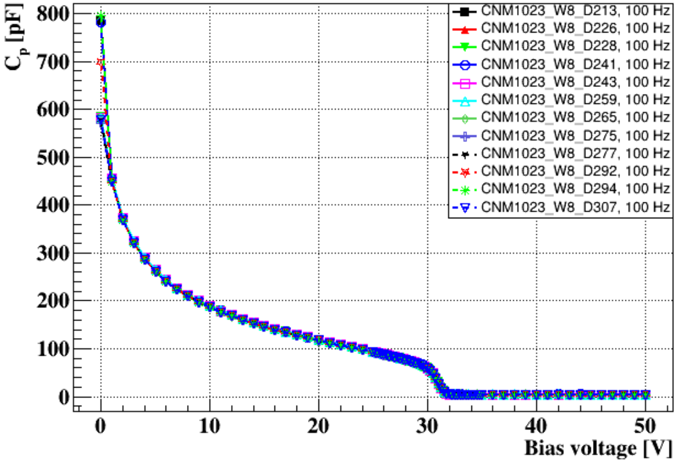


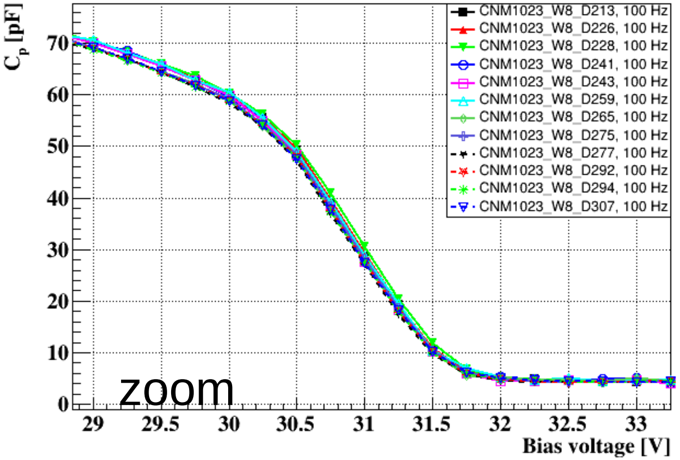


Main Diode: HV
GR: Connected HV
BackSide: Ground
Temperature: RT
Compliance: 100 uA

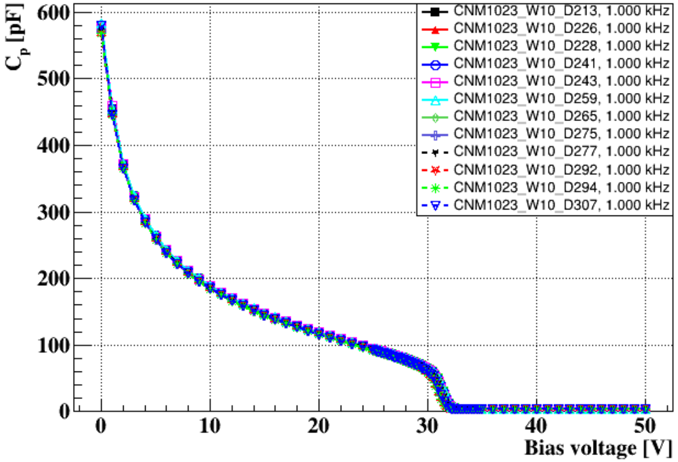
Electric Characterization, CV curves (Fresh)

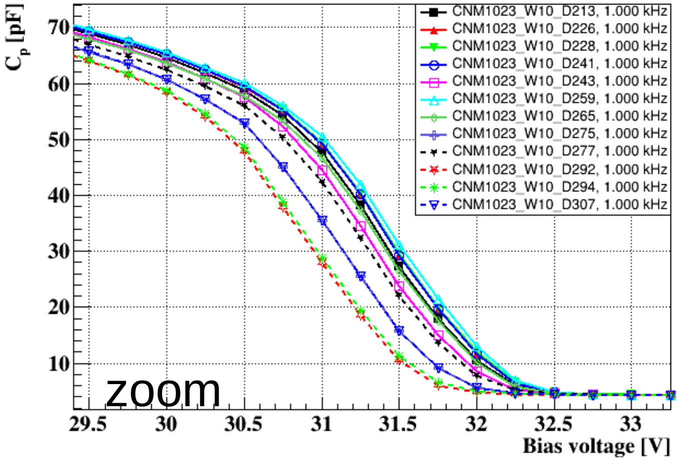
Carbonated, CNM, RT





Standard, CNM, RT





Main Diode: HV
GR: Connected HV
BackSide: Ground
Temperature: RT
Frequency: 1000 Hz

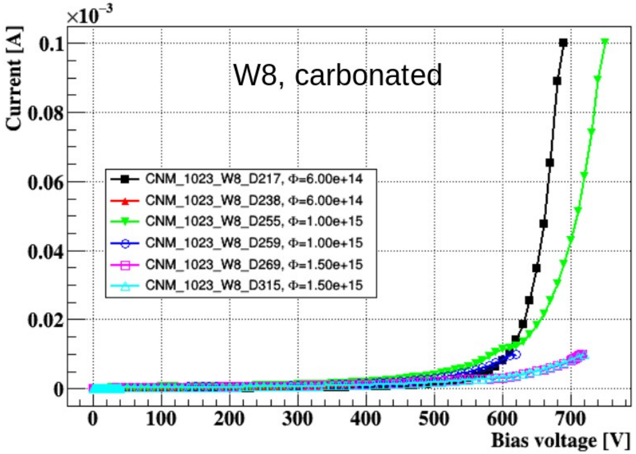
Electric Characterization

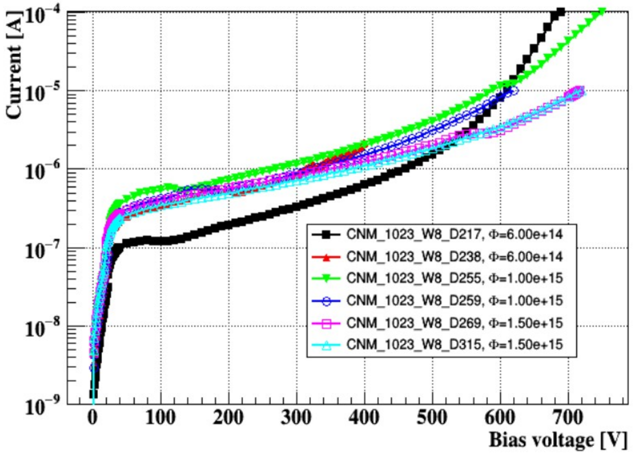
Characterization summary (88 sensors measured fresh)

	CV		IV	
	W8	**W10**	**W8**	**W10**
Single sensors	12	12	27	22
2X2 sensors	12	13	**9+7+1**	**16+3+3**
Total:	24	25	44	44

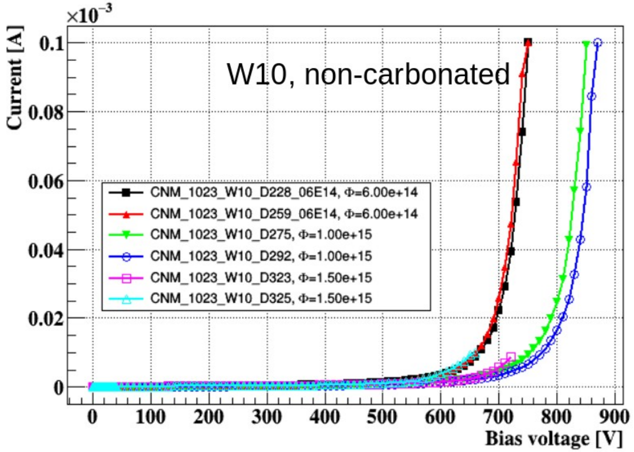
Electric Characterization, IV (Irradiated)

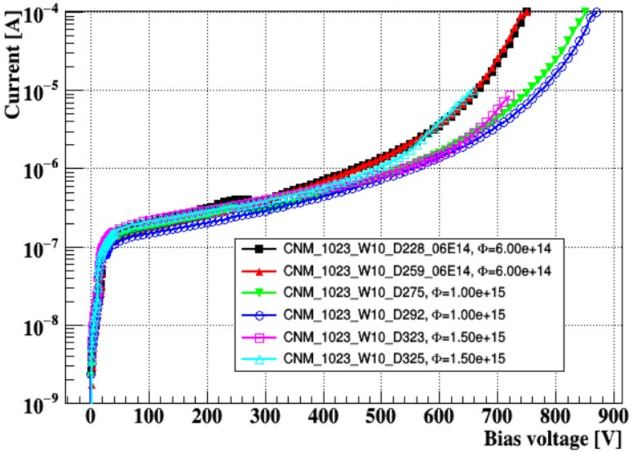
Carbonated, CNM, -25º C





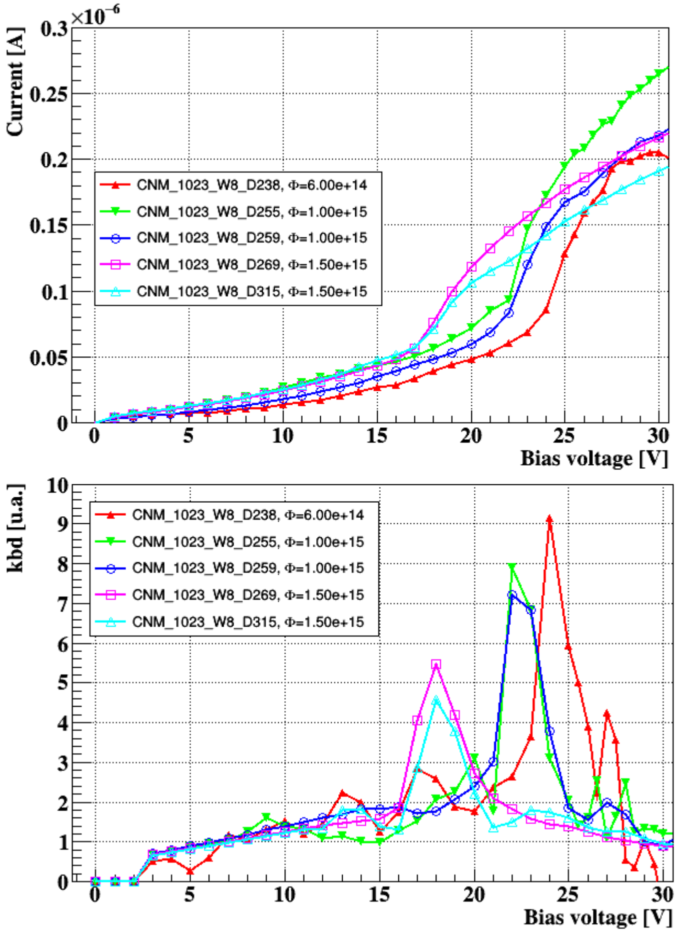
Standard, CNM, -25º C



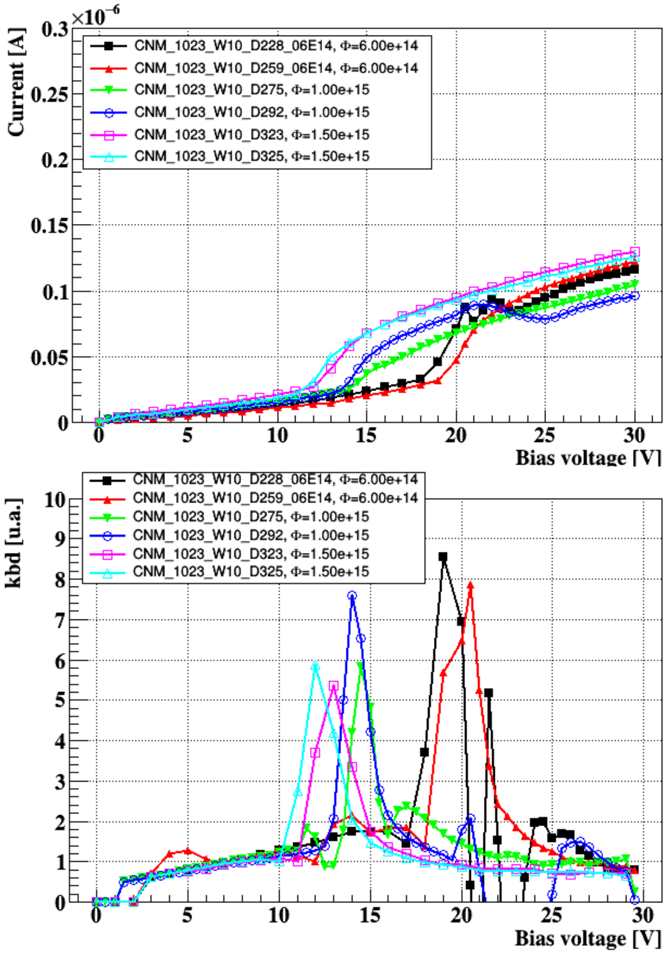


Electric Characterization, IV (Irradiated)

Carbonated, CNM, -25º C



Standard, CNM, -25º C



Vgl calculation

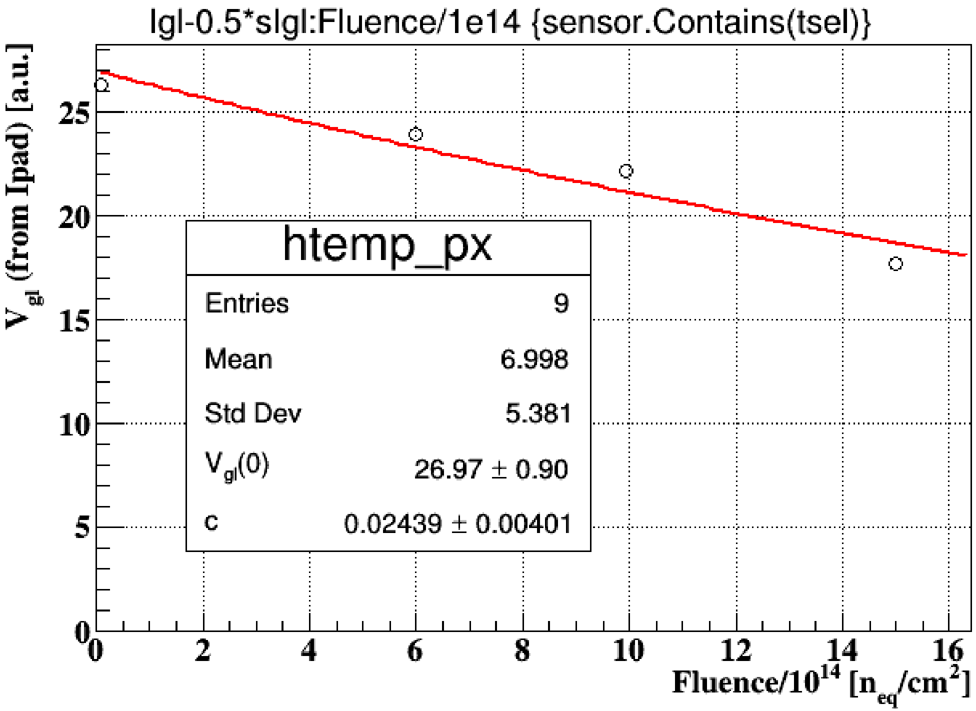
Using "automatic" variable **kbd**[1], based on the derivative of current[2], to identify depletion transition from gain layer to bulk. (See BackUp).

$$K(I,V)=\frac{dI}{dV}\frac{V}{I}$$

[1] Marcos Fernandez 16th Trento Workshop on Advanced Silicon Radiation Detectors, 17th Feb 2021
[2] N. Bachetta et al. https://doi.org/10.1016/S0168-9002(00)01207-9
Other methods to calculate Vgl, see: V. Gkougkousis, 35th RD50 workshop, 2019.

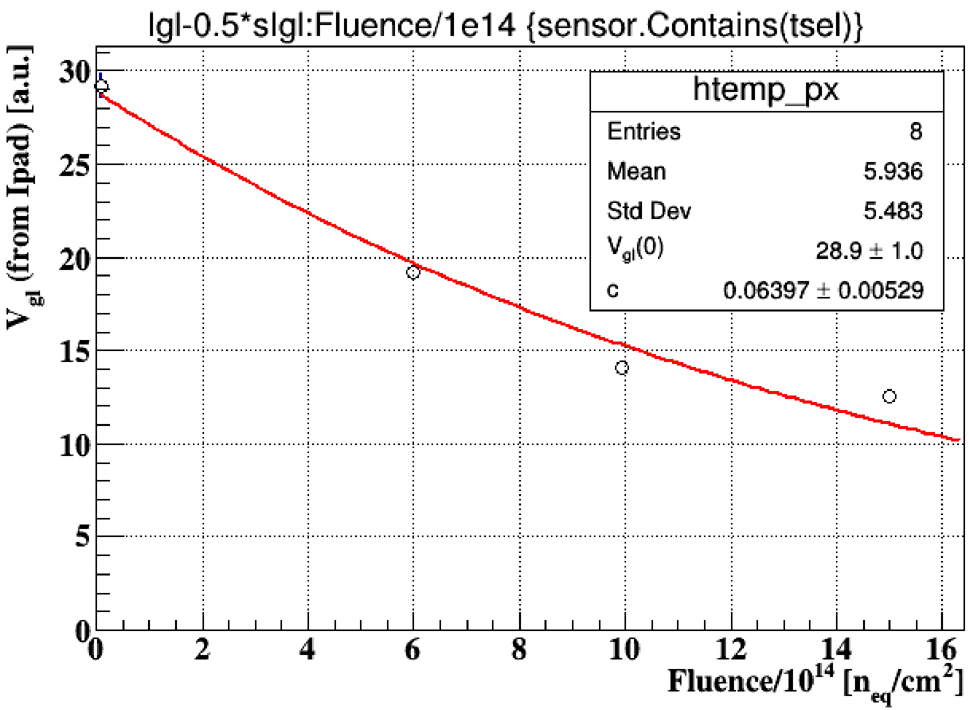
Acceptor Removal Constant

Carbonated, CNM, -25º C



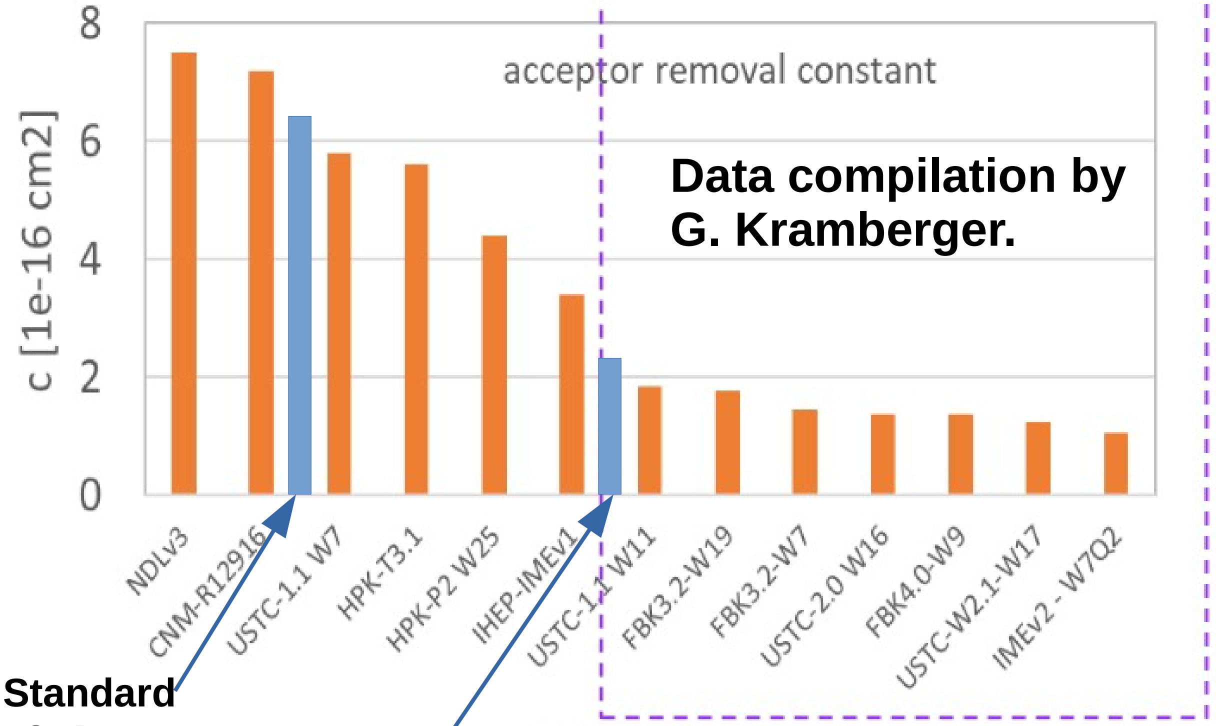
c [10^{-16} cm^2]=**2.4**

Standard, CNM, -25º C



c [10^{-16} cm^2]=**6.4**

Acceptor Removal Constant



CNM-Run #15246 Standard

c [10^{-16} cm^2]=**6.4**

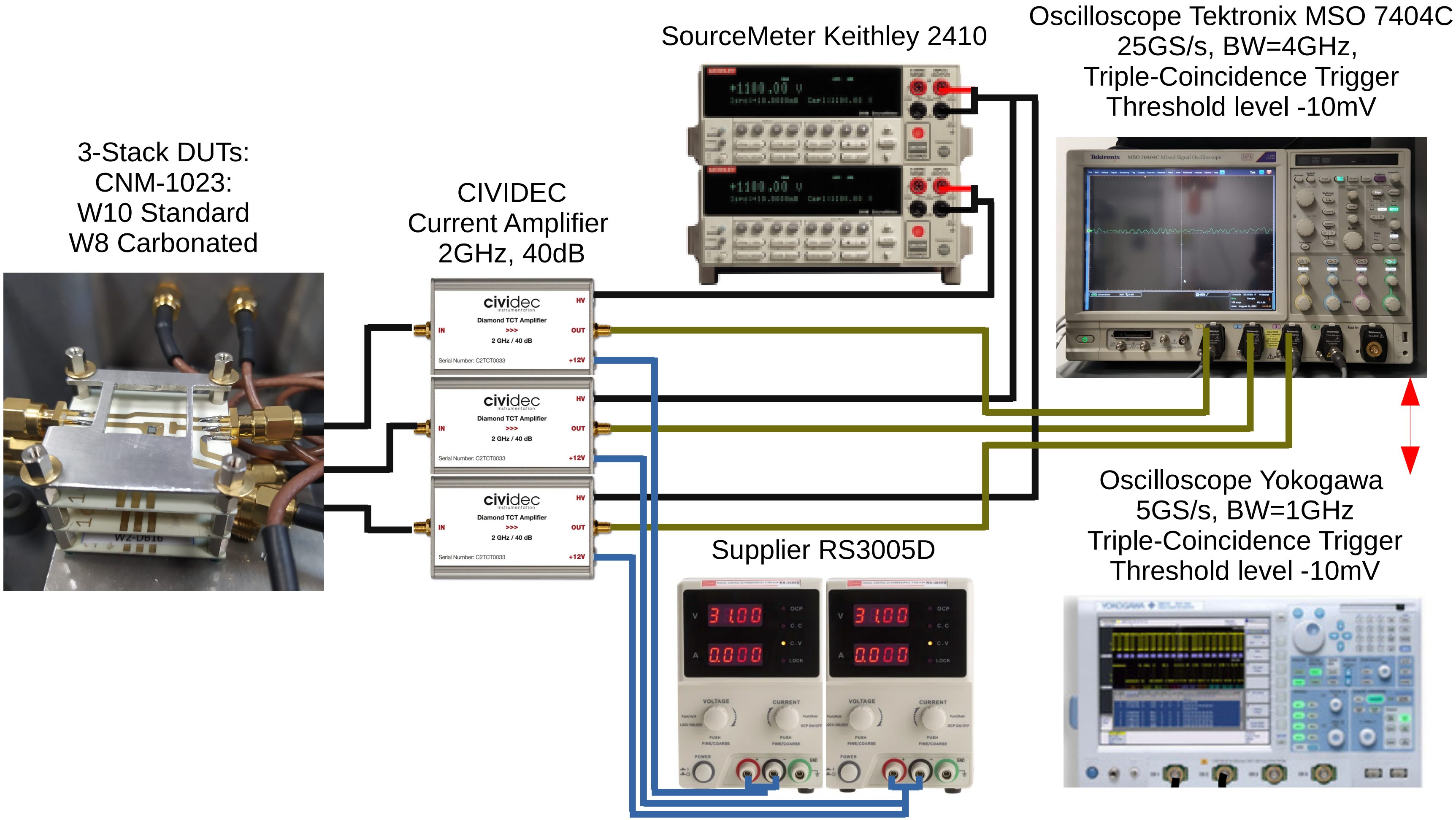
CNM-Run #15246 Carbonated

c [10^{-16} cm^2]=**2.4**

huge improvement for the C-enriched GL

Caveat:
No all C-constants were calculated with the same method

Radioactive Source Setup

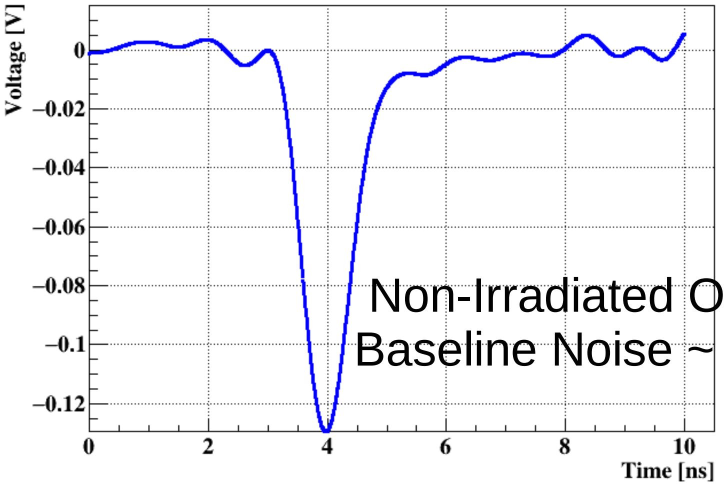


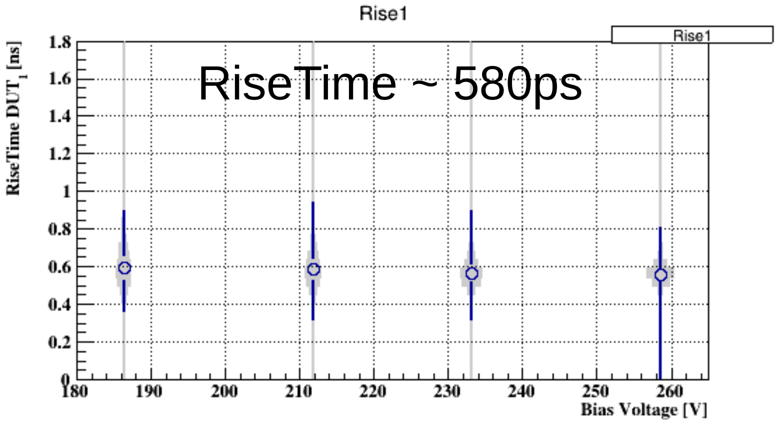
Devices Under Test (RS-Setup)

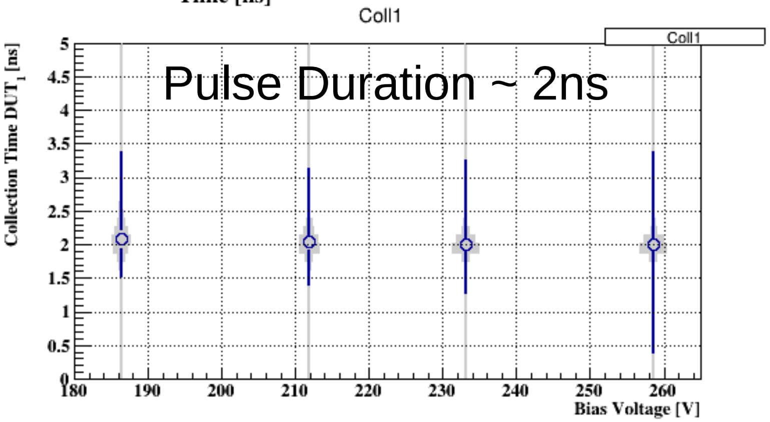
Irradiation [n_{eq}/cm^2]	**W8 Carbonated** (Single diodes)	**W10 Standard** (Single diodes)
Non-Irradiated	**2**	**3**
0.6e15	**2+2**	**2+2**
1.0e15	**2+2**	**2+2**
1.5e15	**2+2**	**4**

CV,IV & RS Measured, **Only CV & IV**

Typical Waveform



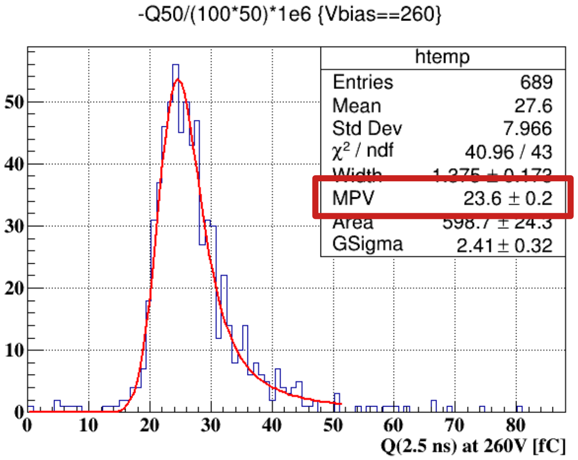




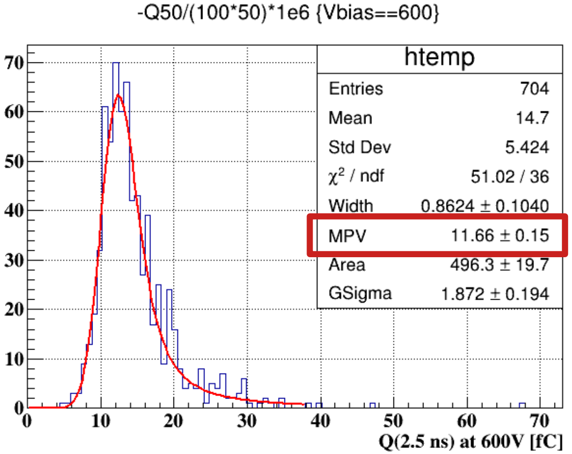
Charge Collection

Carbonated, CNM, -25º C

Non-irradiated

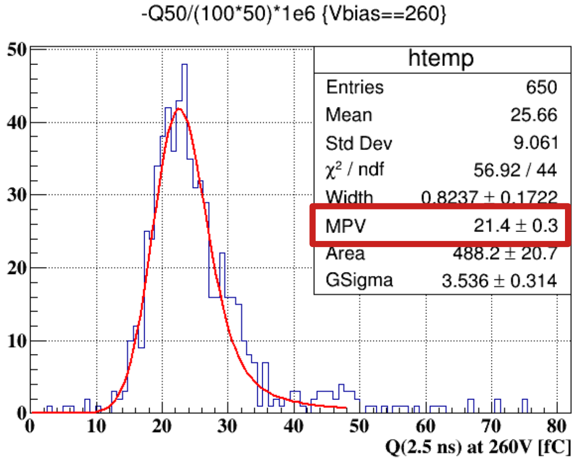


Irradiated 1E15

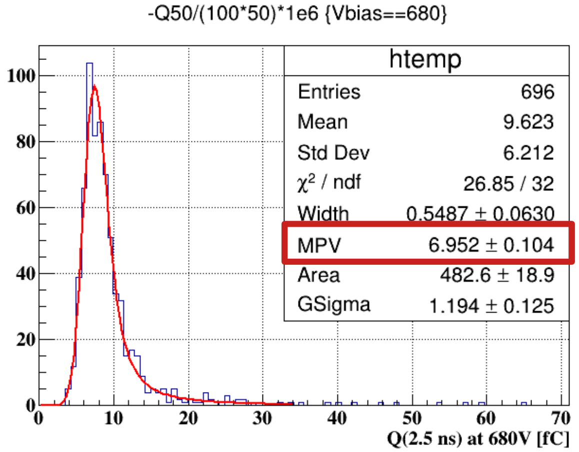


Standard, CNM, -25º C

Non-irradiated



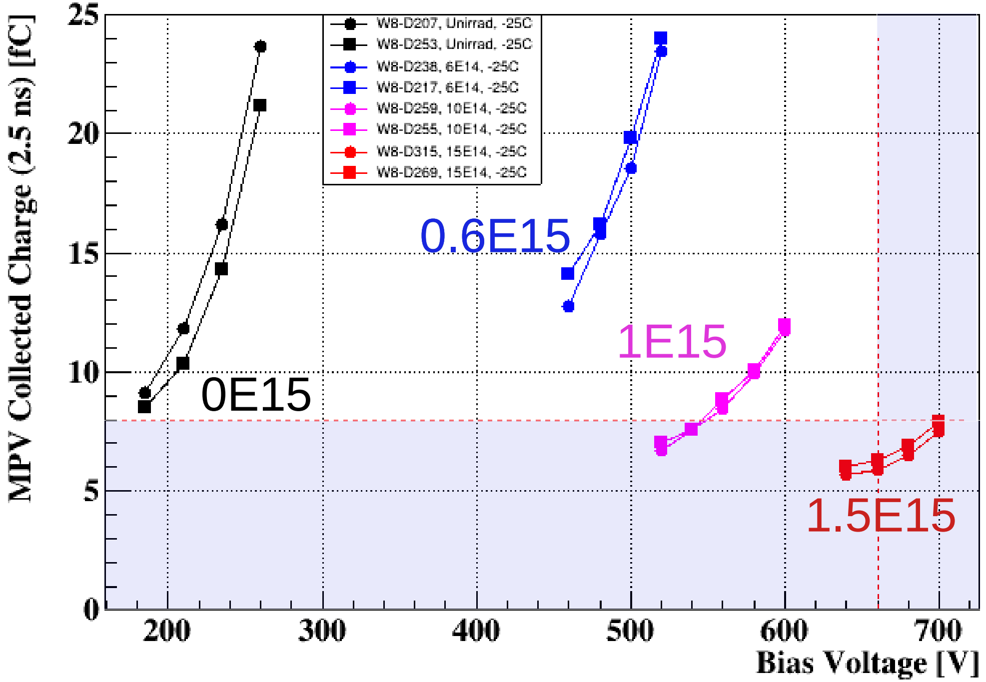
Irradiated 1E15



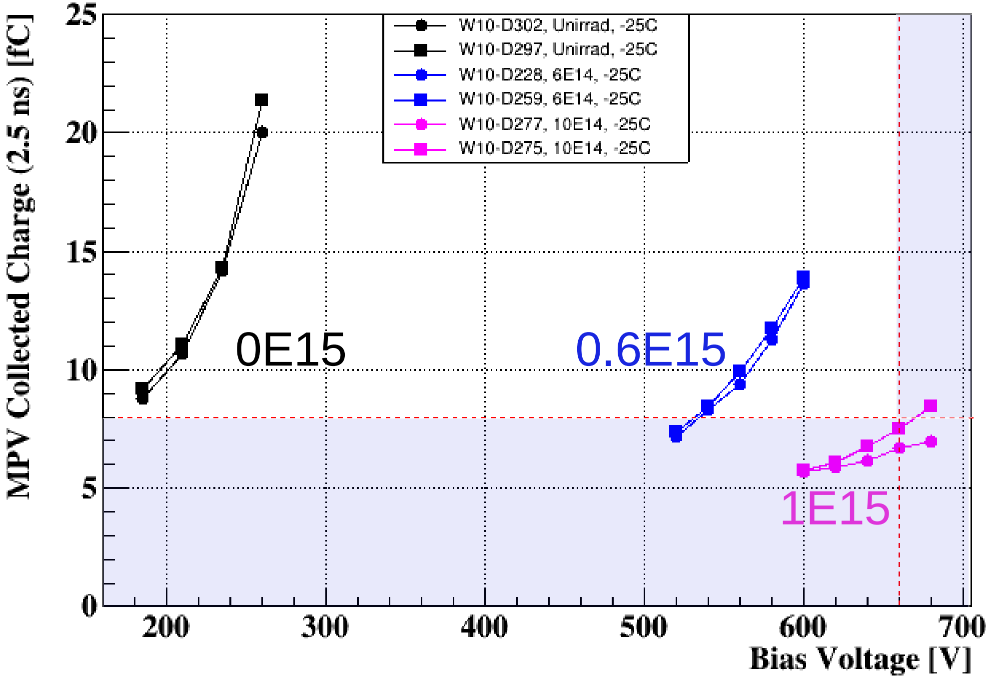
Collected charge: Integral of the Waveforms.
Most Probable Value Of **Landau+Gaus** Fit.

Charge Collection vs Fluence

Carbonated, CNM, -25º C

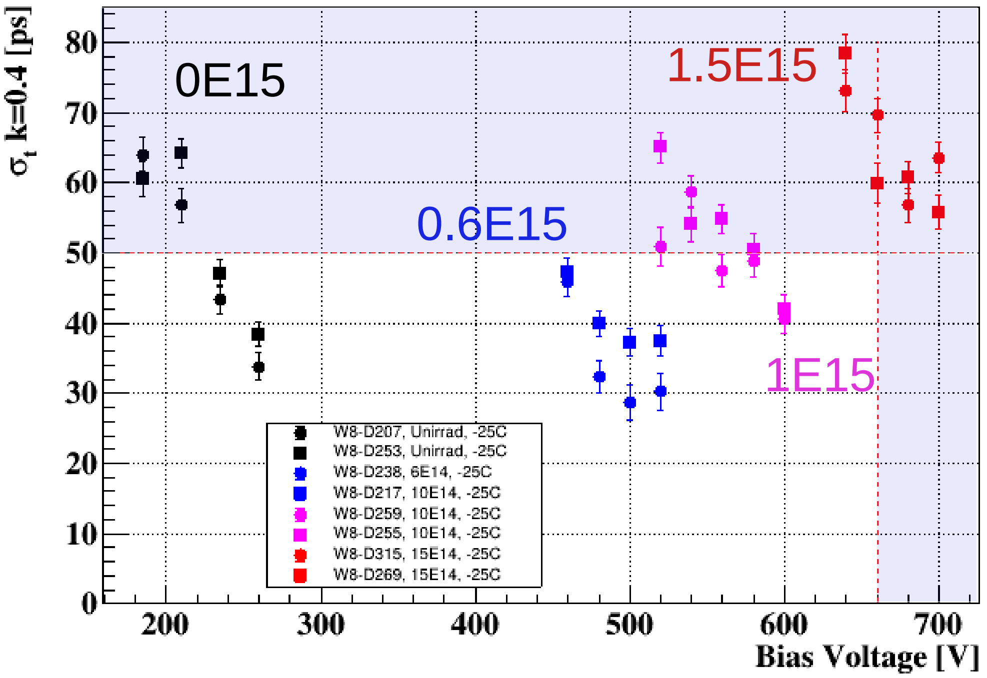


Standard, CNM, -25º C

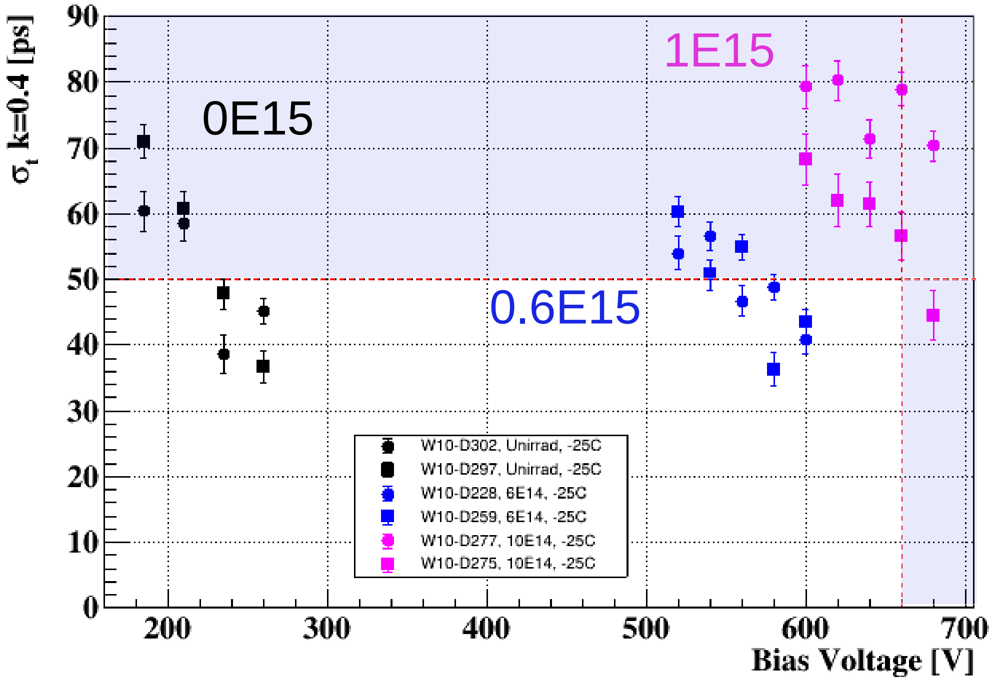


Time Resolution vs Fluence

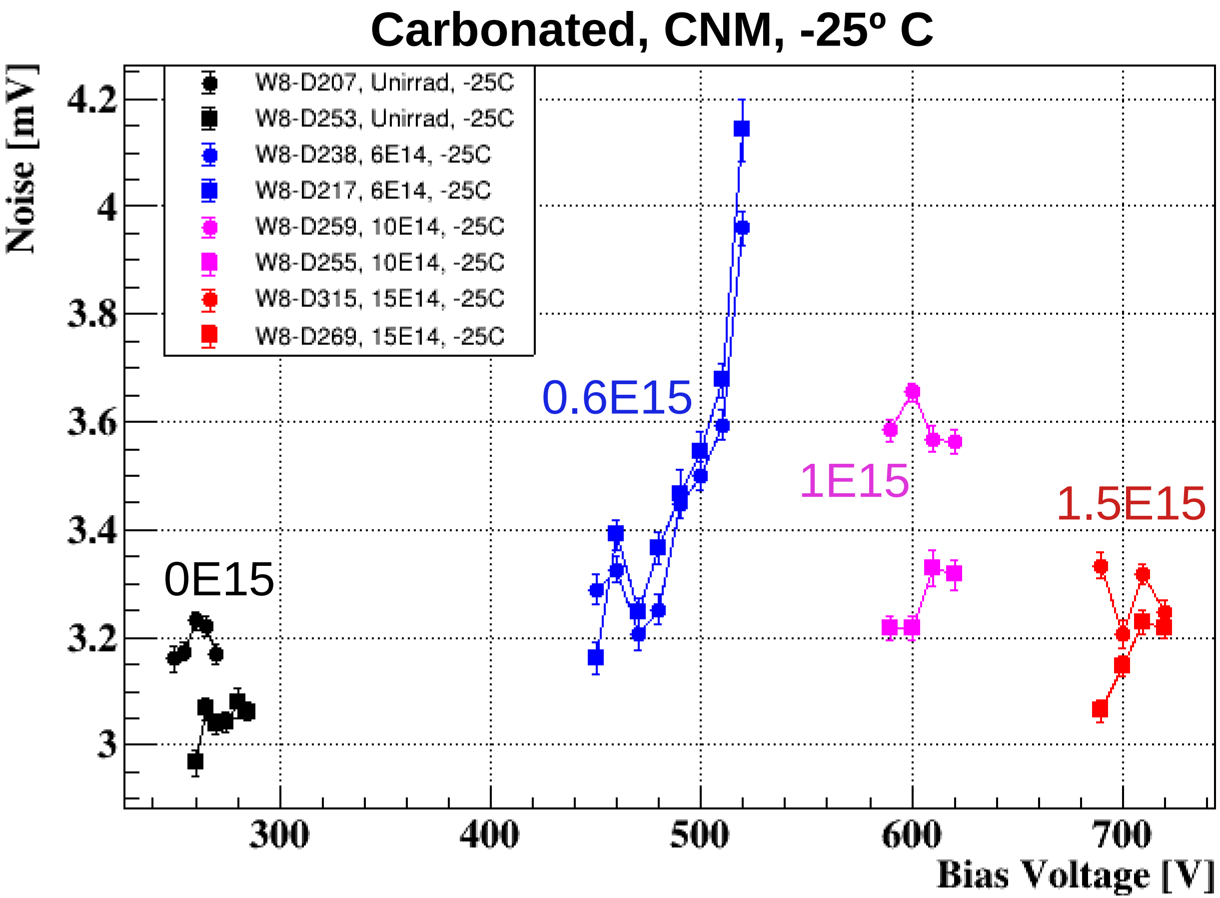
Carbonated, CNM, -25º C

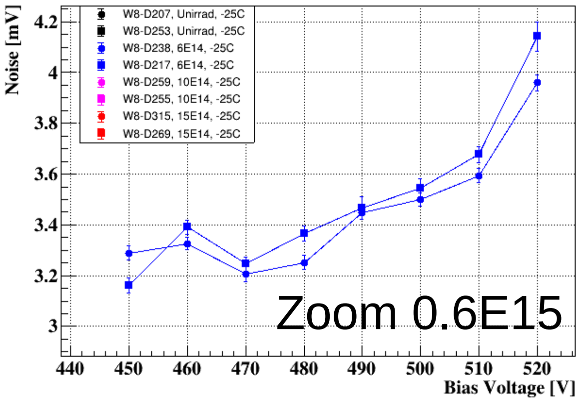


Standard, CNM, -25º C



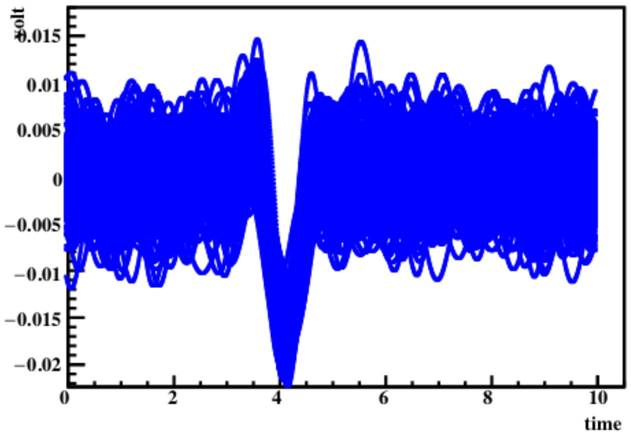
BaseLine Noise Bias Dependence





Spurious Pulse Rate at Operating Vbias

Example of waveforms of thermally triggered Spurious pulses:

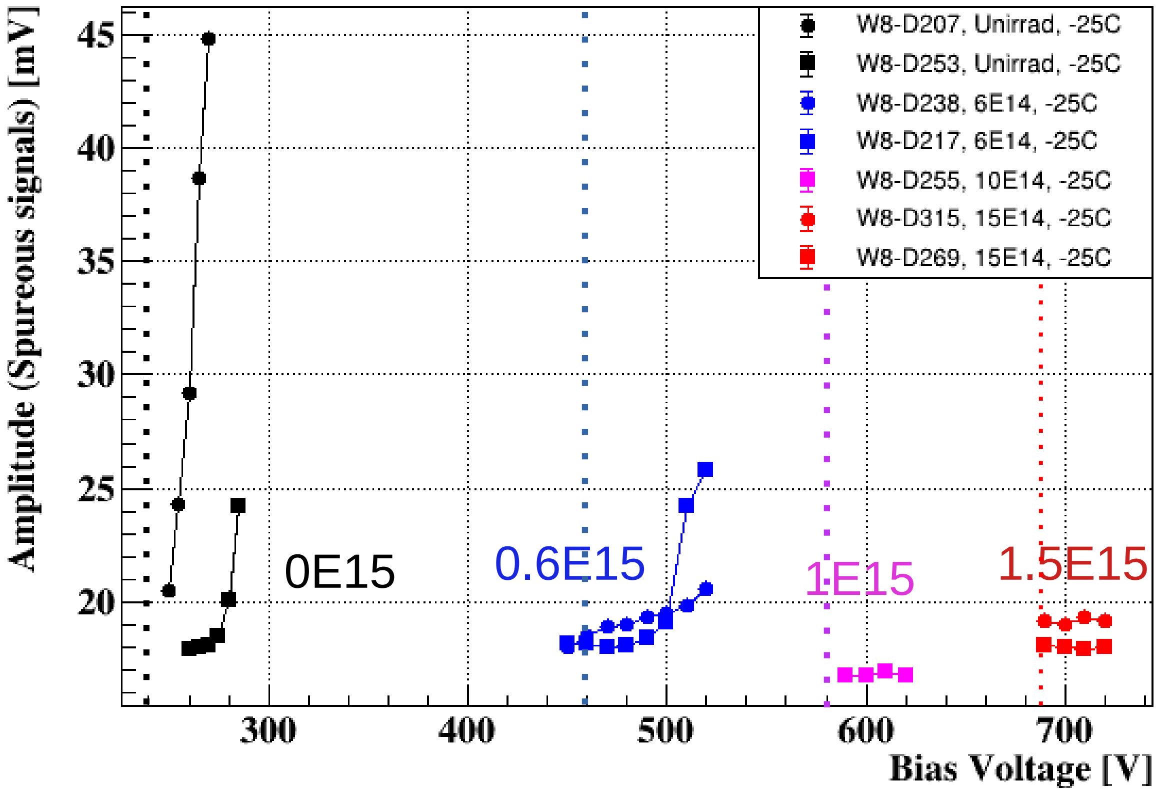


Due to the Aggressive Interpad Distance (IP47)

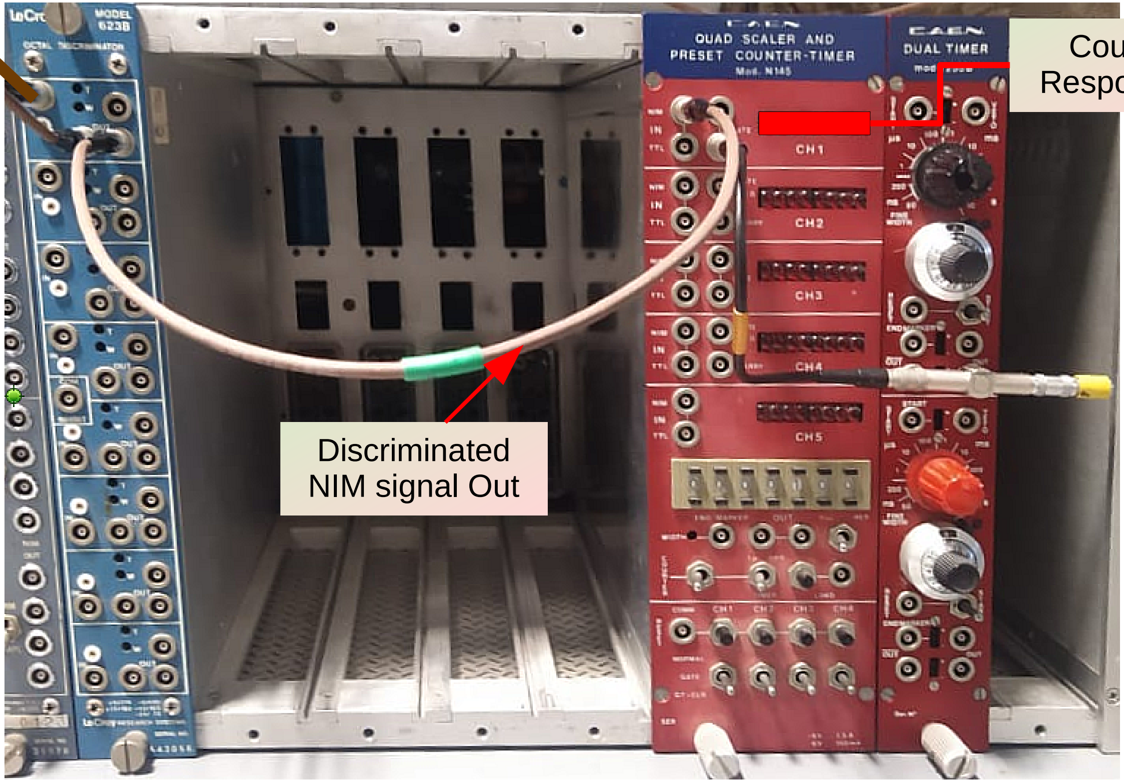
Fluence	Operating voltage (50ps)	Spurious pulse rate (-15mV th)
0E15	240Vbias	2Hz
		7Hz
0.6E15	460Vbias	7Hz
		40Hz
1E15	580Vbias	1Hz
		59Hz

Caveat: Pulse rate may be limited by the digital Scope BandWidth.

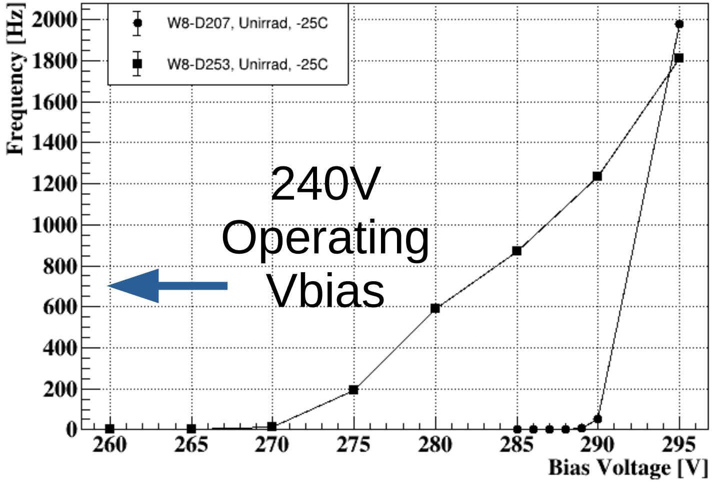
Spurious Pulses Amplitude vs Vbias

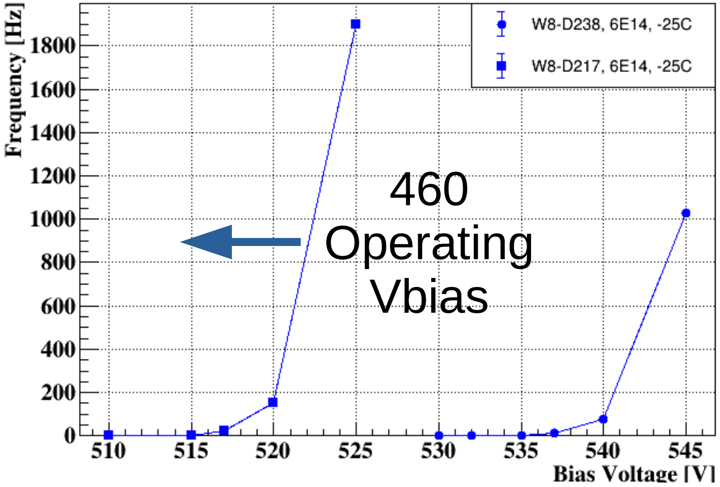


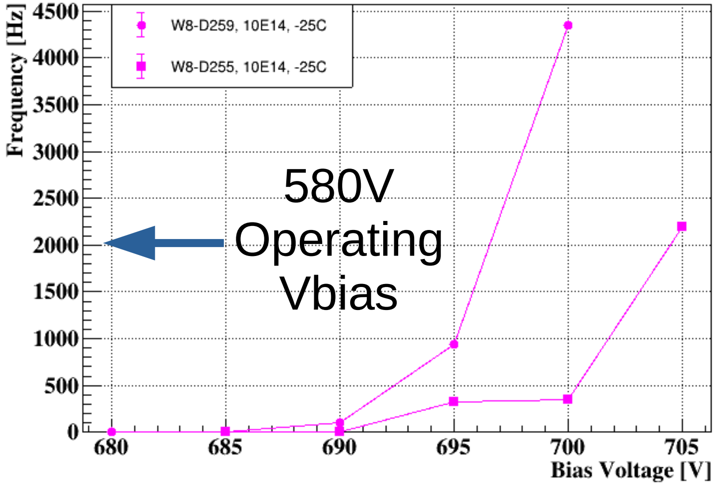
NIM-electronics Setup

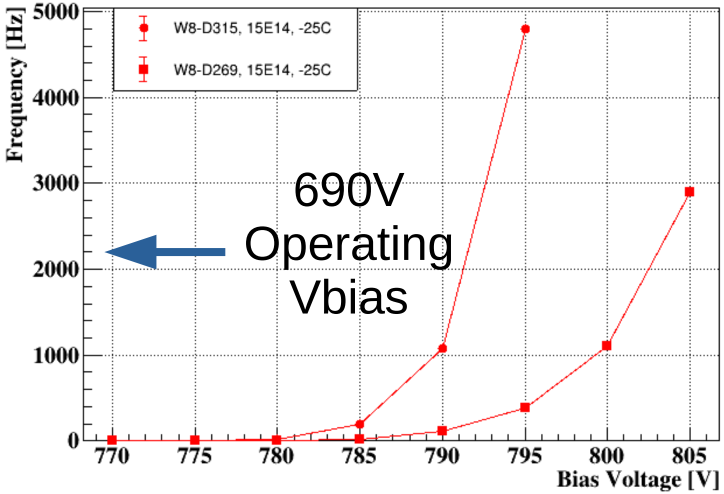


Spurious Pulse Rate (th=-25mV)

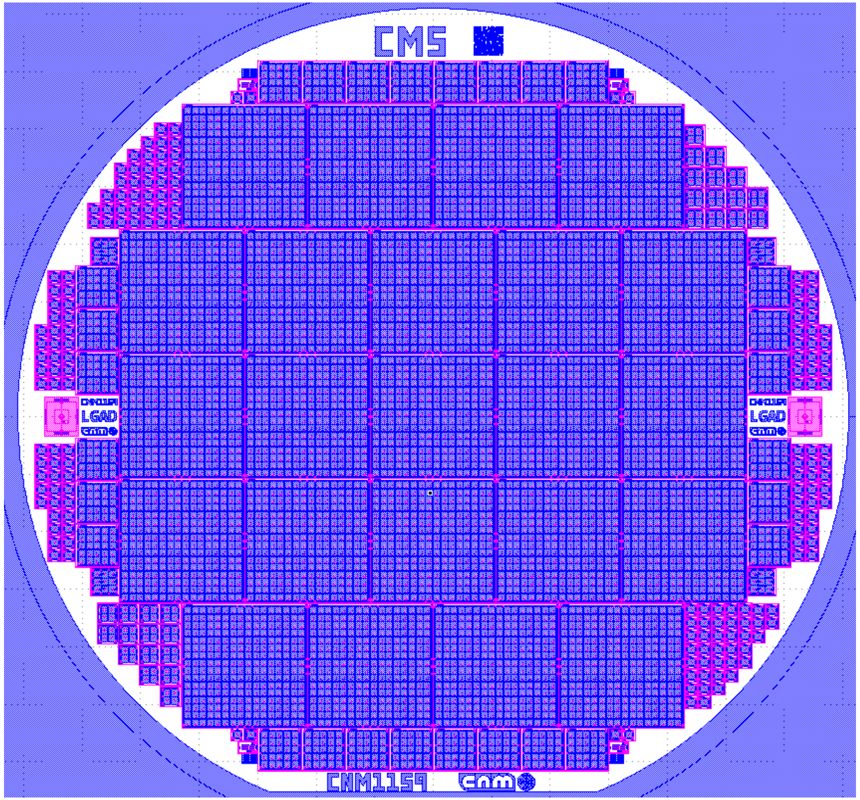








New CMS Run (6LG2)



Devices (**CMS**) : 1x1, 2x2, 5x5 &
16x16 pixels of 1.3x1.3 mm²

To estimate the production yield there will be a dedicated Run

- **10 LGAD wafers**
- 150 mm, 55/525 µm, **Si-Si** wafers (**6LG2**)
- Some of them carbonated
- **Interpad IP60 - IP80**
- Gain layer design
  - CNM standard multiplication layer, as in MS run.
  - Deep P-layer

- **CMS 16x16**: **23** devices
  - **ETLROC** chip compatible (waiting for final layout)
  - **SE3**, 300 µm (500 µm at wire bonding area)
  - **No TCT opening window**
  - Reduced dead area in corners to **improve fill factor**

Conclusions

- Radiation tolerance study completed for **Market Survey CNM** production.
- **Acceptor Removal Constant** of **Carbonated samples** with respect to the Standard samples was **reduced** by more than a factor of two.
- **CNM Carbonated LGADs comply** with **CMS** radiation tolerance requirement at a fluence of **1E15 [n_{eq}/cm^2].**
- For low threshold below 15mV we observe a low Spurious Pulse Rate (about 10Hz) at Operating Voltages. At 20mV threshold, the rate is zero.
- Dedicated Run for evaluating the actual large sensor yield to **start on January.**

THANK YOU

BackUp

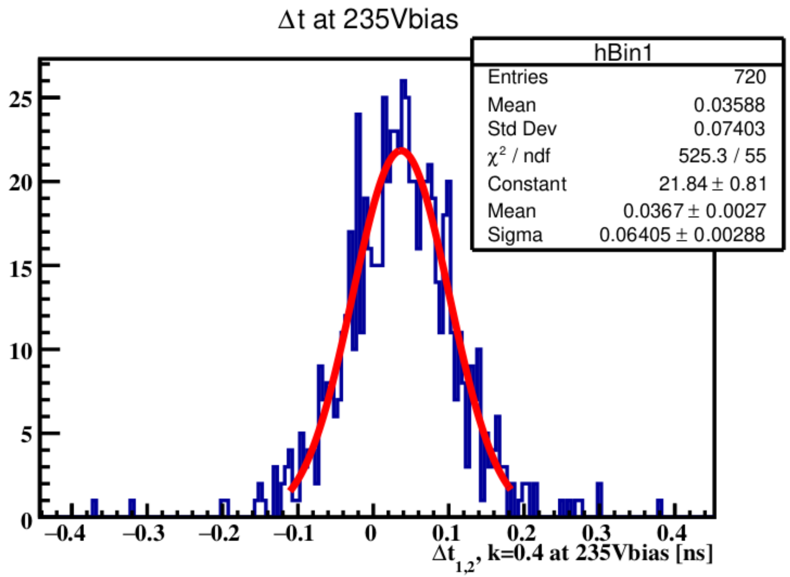
Time Resolution

Constant Fraction Discrimination (40%).

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

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

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



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

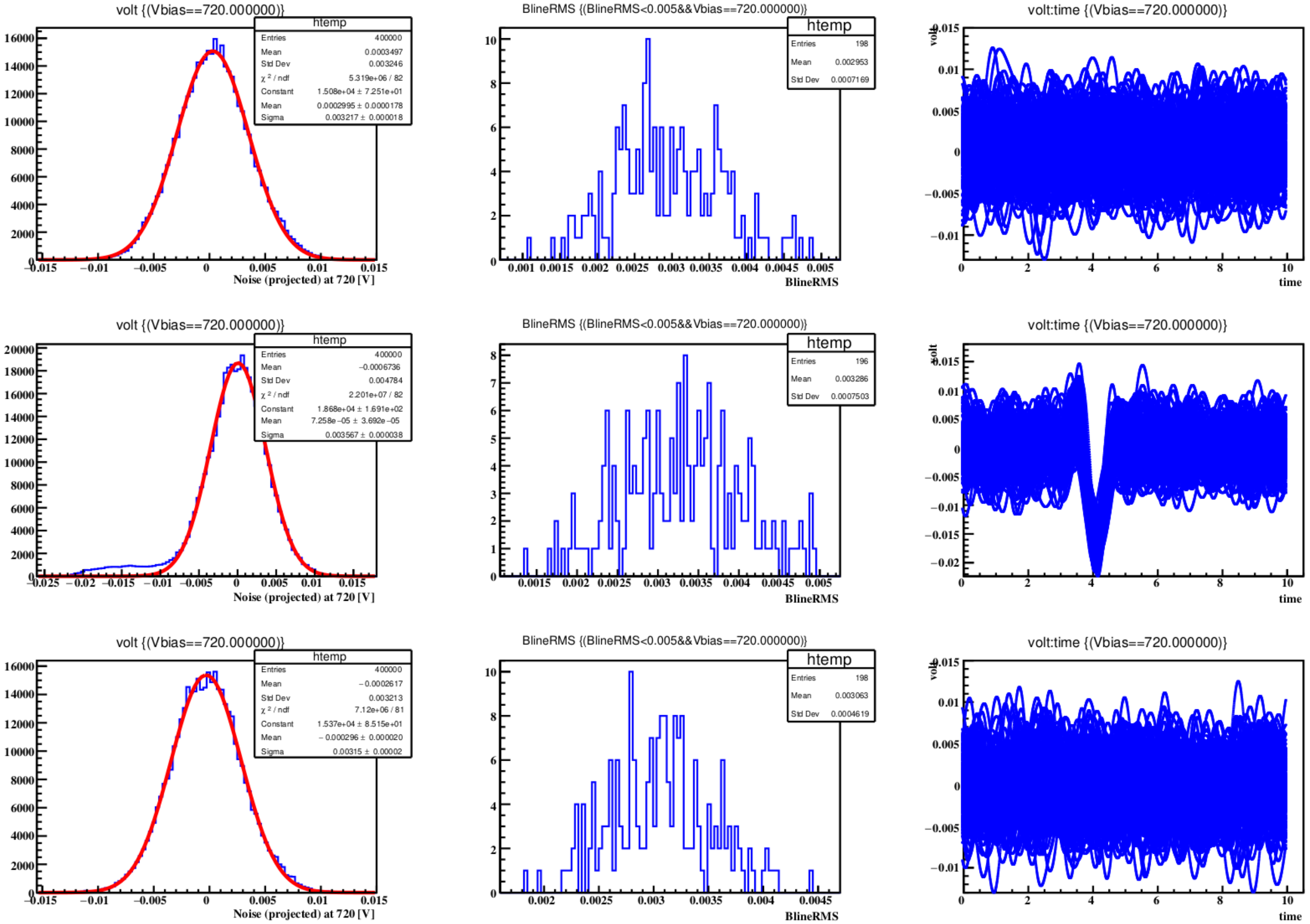
$$\delta_1 = \frac{\left((\sigma_{21}\delta_{21})^2 + (\sigma_{13}\delta_{13})^2 + (\sigma_{32}\delta_{32})^2\right)^{\frac{1}{2}}}{2\sigma_1},$$

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

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

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

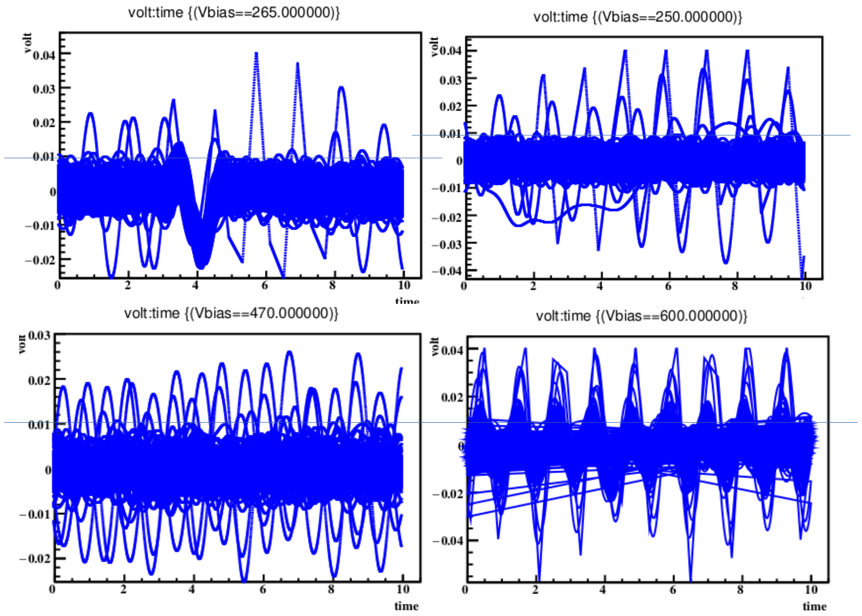
Noise RS Setup

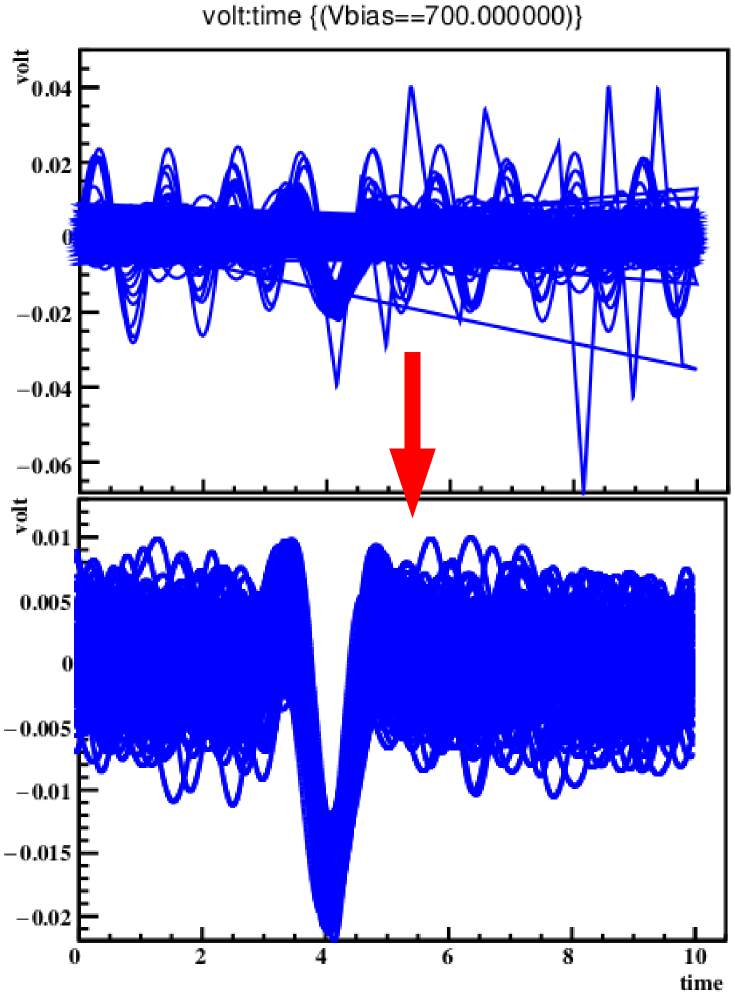


Noise Channel

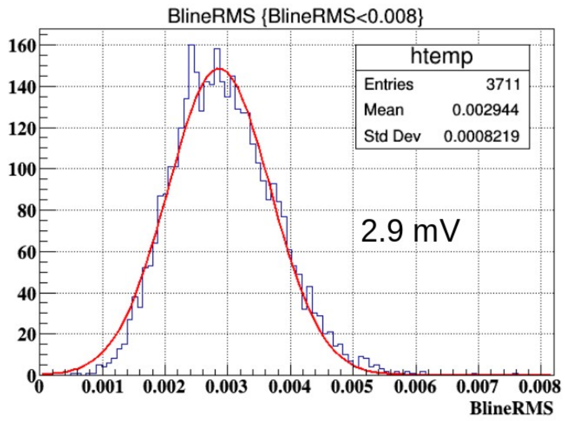
Dark Counts (Trigger)

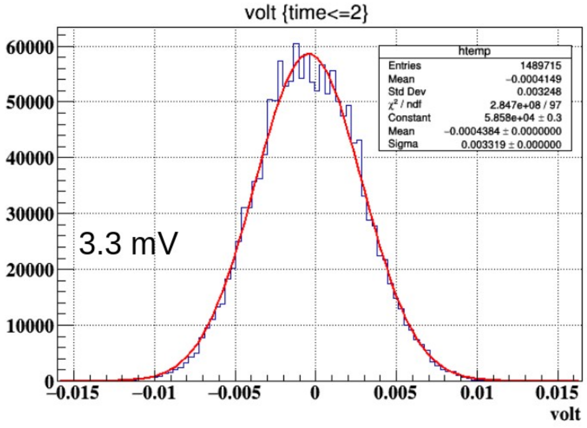
Noise RS Setup



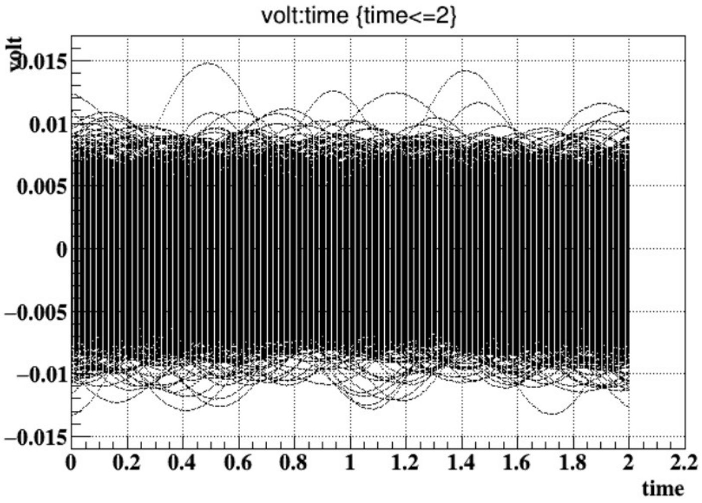


Noise RS Setup



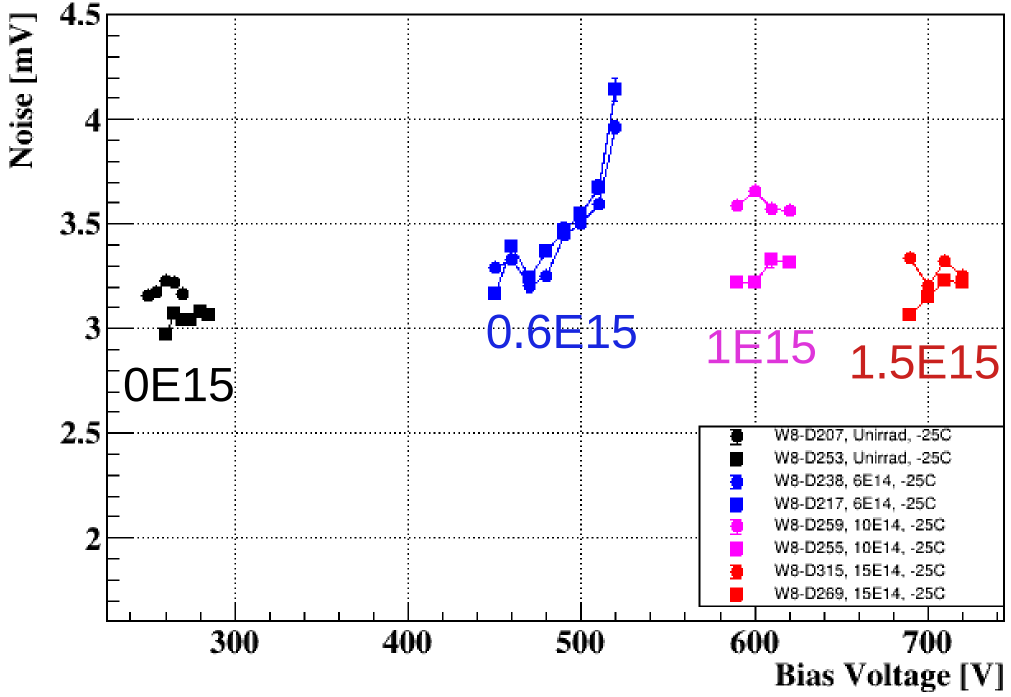


Difference between mean of BlineRMS (left plot) and the RMS of the projection (right plot)



Noise RS Setup

Projection of signals without RS



From BlineRMS calculation