Measurements on last IMB-CNM LGADs production

Centro Nacional de Microelectrónica IMB CSIC Consejo Superior de Investigaciones Científicas RDG Radiation Detectors Group IFCA

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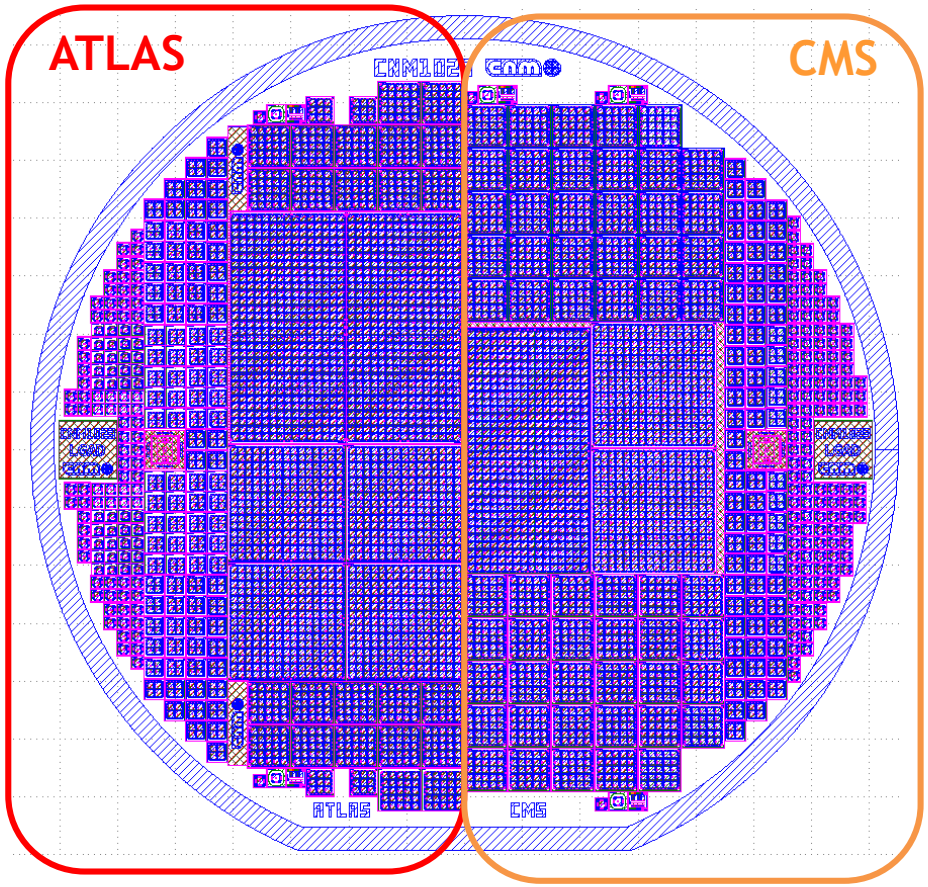
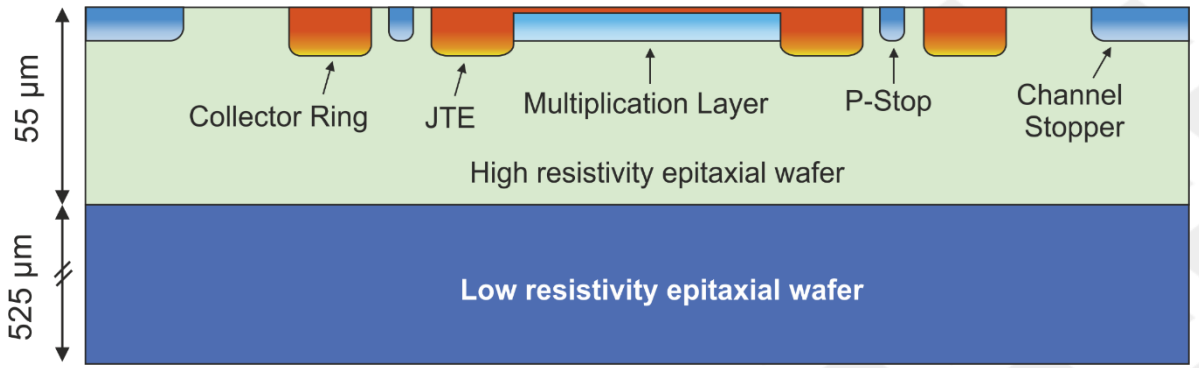
1. Overview ATLAS-CMS Engineering Run: CNM-6LG3-2

Run15246: 6” ATLAS-CMS Common Run (CNM-6LG3-2)



Devices (ATLAS) : 1x1, 2x2, 5x5, 15x15 & 15x30 pixels of 1.3x1.3mm²
Devices (CMS) : 1x1, 2x2, 5x5, 16x16 & 16x32 pixels of 1.3x1.3mm²

- 10 LGAD wafers
- Some of them carbonated
- 6-inch 55/525 µm **epitaxial** wafers
  - Handle wafer resistivity = 0.001-1 Ohm-cm
  - Substrate resistivity > 200 Ohm-cm
- Same technological process as first CNM LGAD Run on epitaxial wafers: Run13002 (CNM-6LG3-1)
- **Engineering Runs**: New diffusion furnaces



Overview CNM-6LG3-2

Wafer	1	2	3	4	5	6	7	8	9	10
Gain layer depletion V	$V_{GL} \approx 12V$	$V_{GL} \approx 13V$	$V_{GL} \approx 15V$	$V_{GL} \approx 31V$	$V_{GL} \approx 33V$	$V_{GL} \approx 34V$	$V_{GL} \approx 15V$	$V_{GL} \approx 30V$	$V_{GL} \approx 20V$	$V_{GL} \approx 30V$
Boron dose (1e13/cm²)	1.7	1.8	1.9	2	2.1	2.2	1.9			
Carbon dose (1e13/cm²)	-						5	10	-	
Dry oxidation time DOT (min)	30			180			30	180	90	180

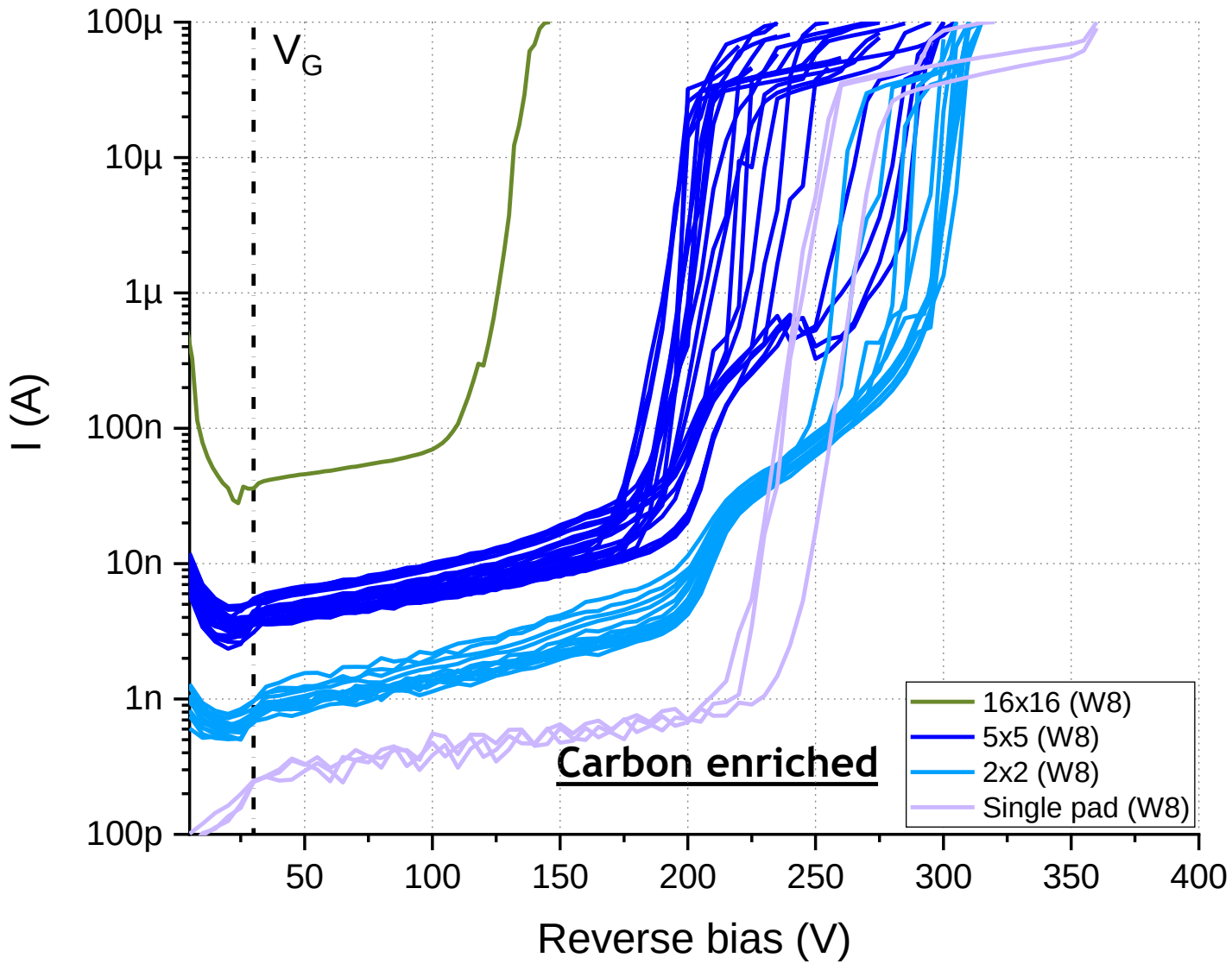
Implantation energies : 100keV (B) & 150keV (C)

Wide experiment window → Commissioning run to calibrate new diffusion furnaces
Experiment1 → W1,W2,W3,W4,W5 & W6: increasing Boron dose at 2 different DOTs
Experiment2 → W3, W9 & W10: fixed Boron dose (1.9) and increasing DOT
Experiment3 → W7 & W8: fixed Boron dose (1.9) and different carbon doses and DOTs

W8 & W10 are equal to CNM-6LG3-1 W4 (having W8 carbon enrichment)
& the ones more suitable for the ATLAS/CMS timing detectors

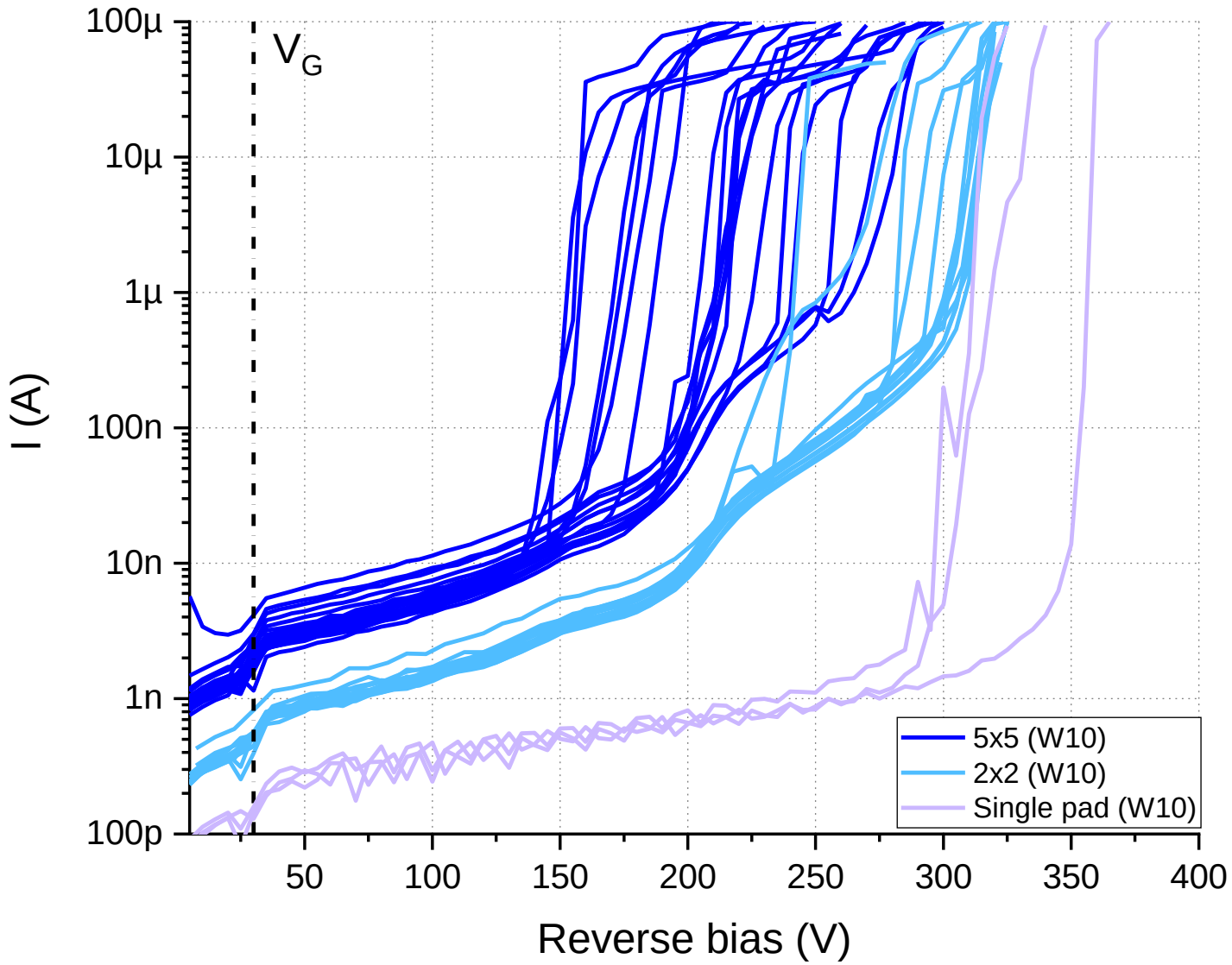
2. IV measurements at room temperature & Yield

Wafer 8 (CMS part): IV & Yield (20°C) with temporary metal on wafer



Wafer	8	10
Gain layer depletion V	$V_{GL} \approx 30V$	
Boron dose (1e13/cm²)	1.9	
Carbon dose (1e13/cm²)	10	-
DOT (min)	180	
Size	Yield (breakdown > Vgl+50V)	
16x32	0/1 0%	0/1 0%
16x16	1/2 50%	0/2 0%
5x5	58/75 77%	53/74 74%
2x2	38/41 93%	38/41 93%
Single pad	18/18 100%	18/18 100%

Wafer 10 (CMS part) : IV & Yield (20°C) with temporary metal on wafer



Wafer	8	10
Gain layer depletion V	$V_{GL} \approx 30V$	
Boron dose (1e13/cm²)	1.9	
Carbon dose (1e13/cm²)	10	-
DOT (min)	180	
Size	Yield	
16x32	0/1 0%	0/1 0%
16x16	1/2 50%	0/2 0%
5x5	58/75 77%	53/74 74%
2x2	38/41 93%	38/41 93%
Single pad	18/18 100%	18/18 100%

Diced single pad diodes : IV mapping at IFCA (CMS side)

W8 (single pad)

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					

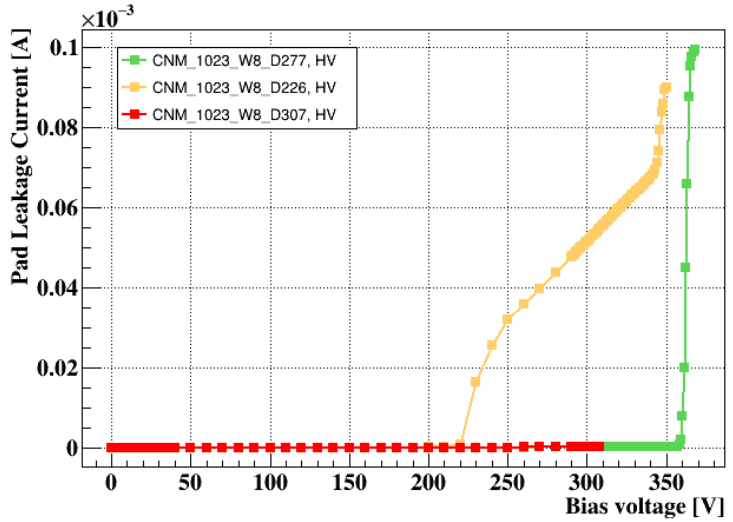
W10 (single pad)

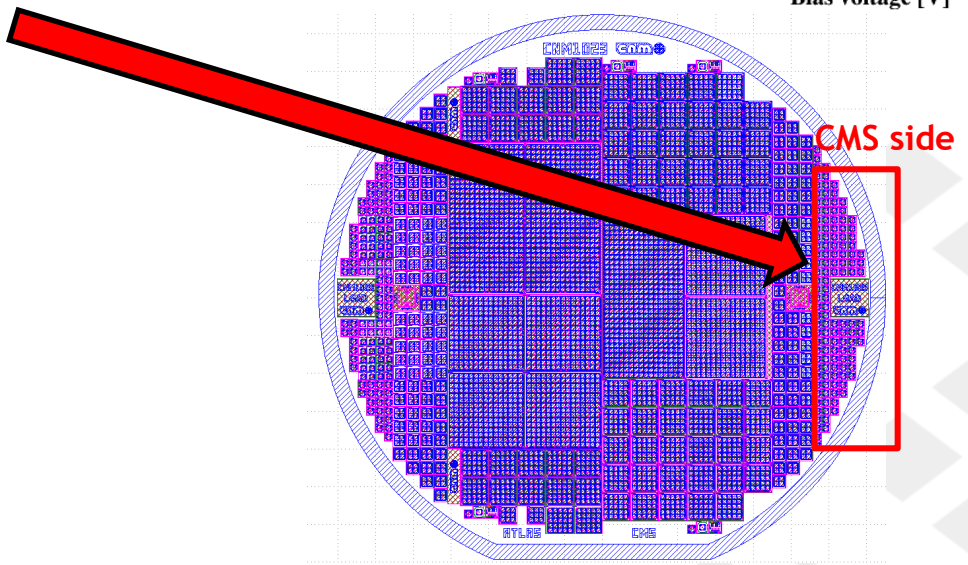
D326					
D325					
D323	D324P				
D321	D322P				
D318	D319P	D320			
D315	D316P	D317			
D311	D312P	D313	D314		
D307	D308P	D309	D310		
D302	D303P	D304	D305	D306	
D297	D298P	D299	D300	D301	
D292	D293P	D294	D295	D296	
D287	D288P	D289	D290	D291	
D281	D282P	D283	D284	D285	D286
D275	D276P	D277	D278	D279	D280
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					

GOOD

OK but step on IV before breakdown

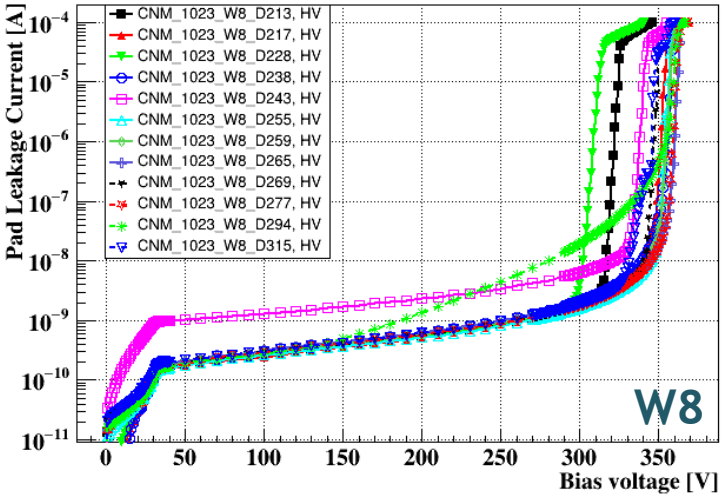
Early breakdown in GR

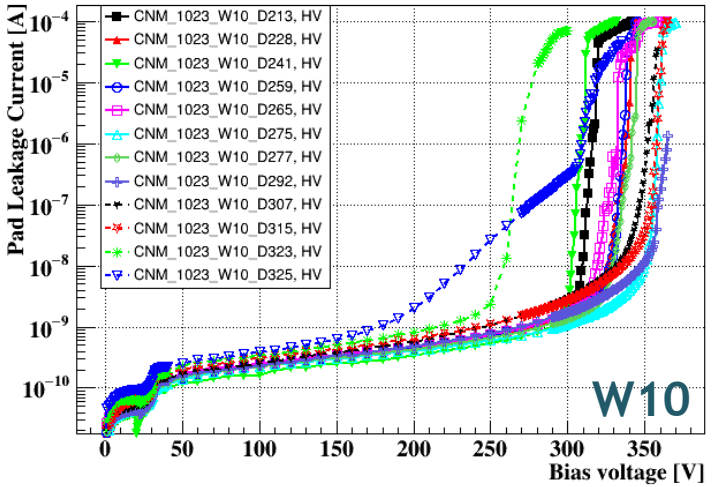




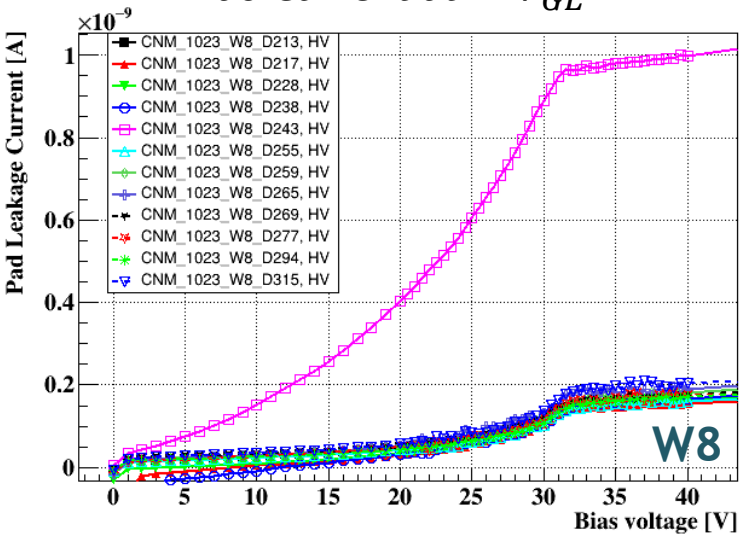
Diced single pad diodes : IV mapping at IFCA (CMS side)

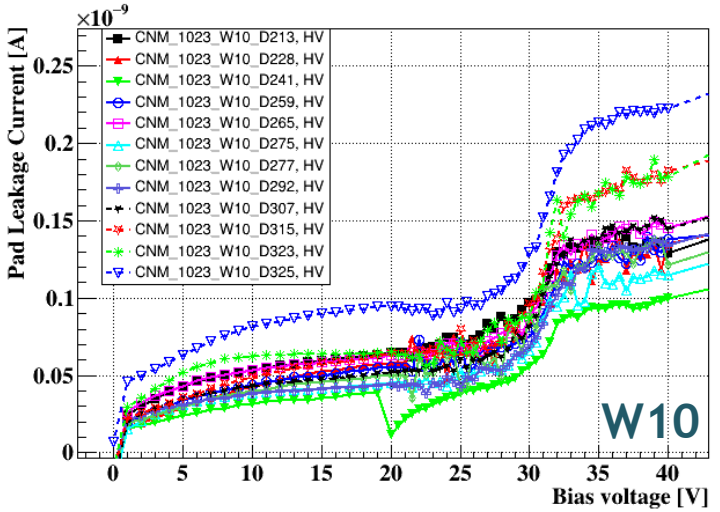
Pad current up to breakdown





Pad current at $\approx V_{GL}$

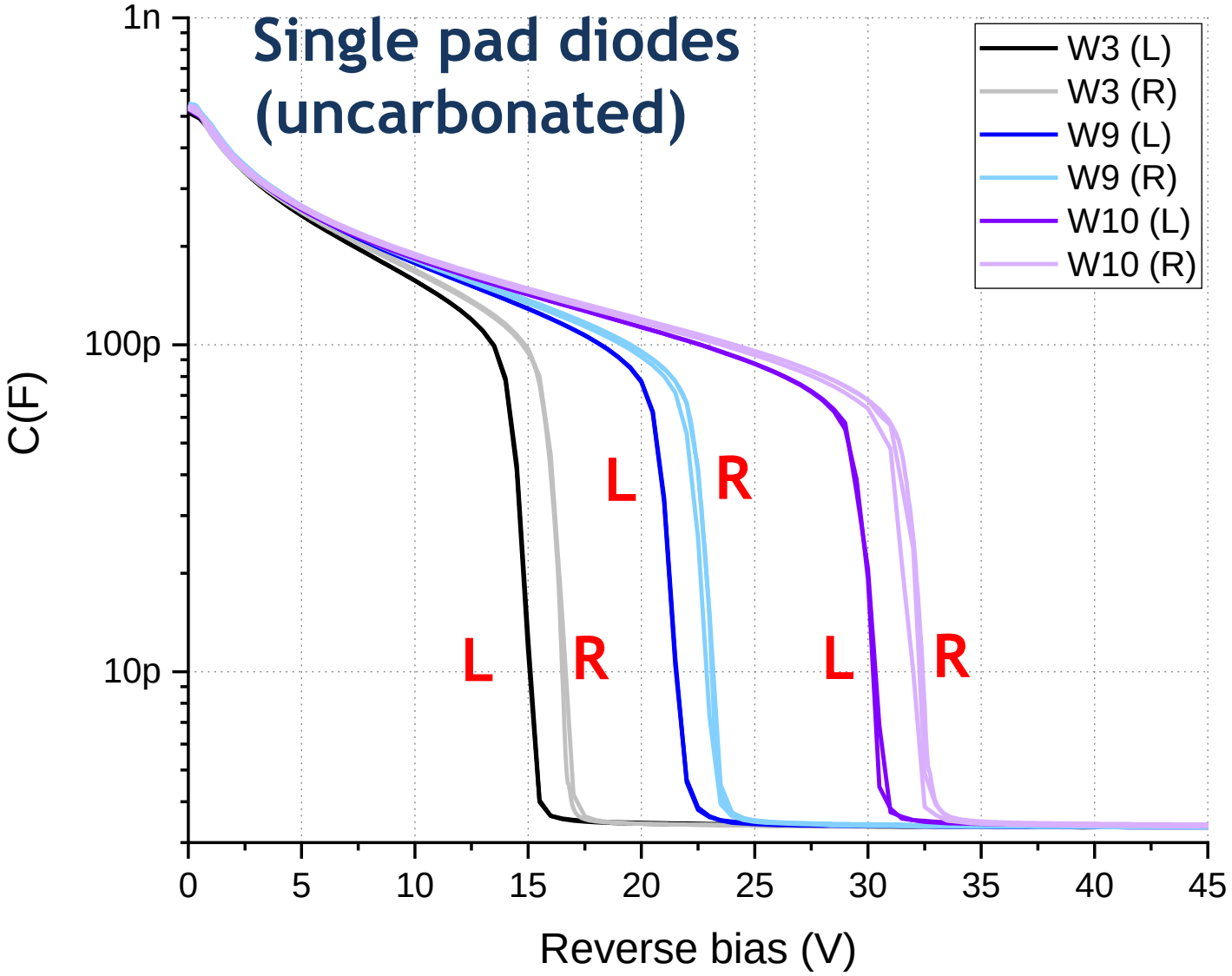




	W8 (Carbonated)	W10 (Non-Carbonated)
	V_{BD}	
Mean [V]	344.1	331.6
RMS [V]	16.93	23.86

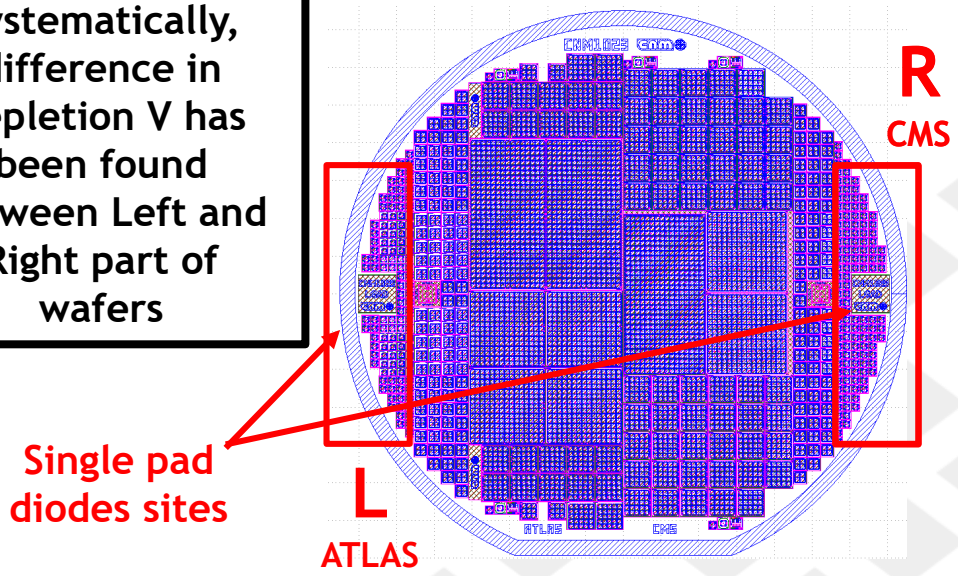
3. CV measurements

Differences between Left & Right sides of the wafers

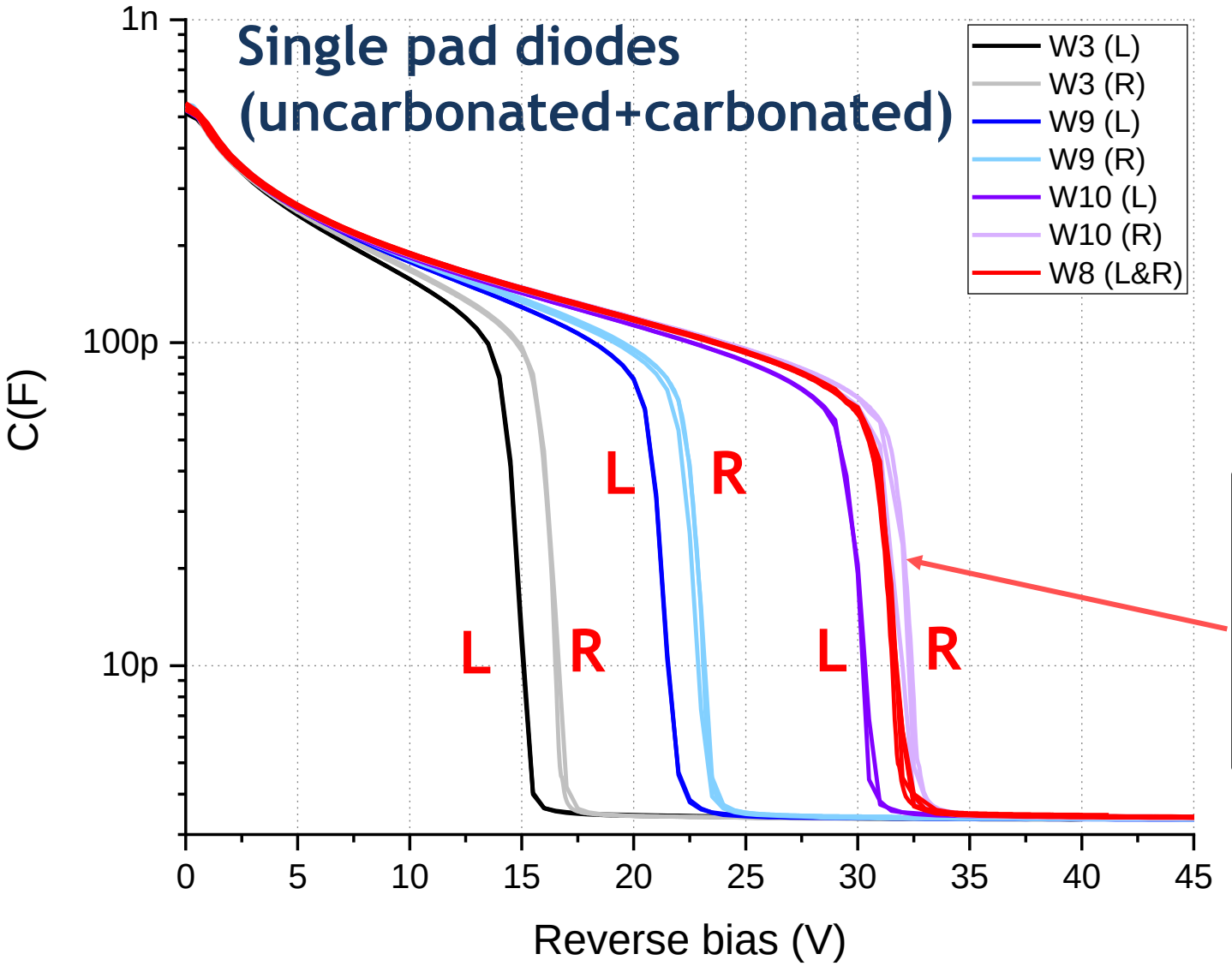


Wafer	3	8	9	10
Boron dose/ Imp. Energy	1.9e13/cm² / 100keV			
Carbon dose/ imp. Energy	-	1e14/cm² / 150keV	-	
DOT (min)	30	180	90	180

Systematically, difference in depletion V has been found between Left and Right part of wafers

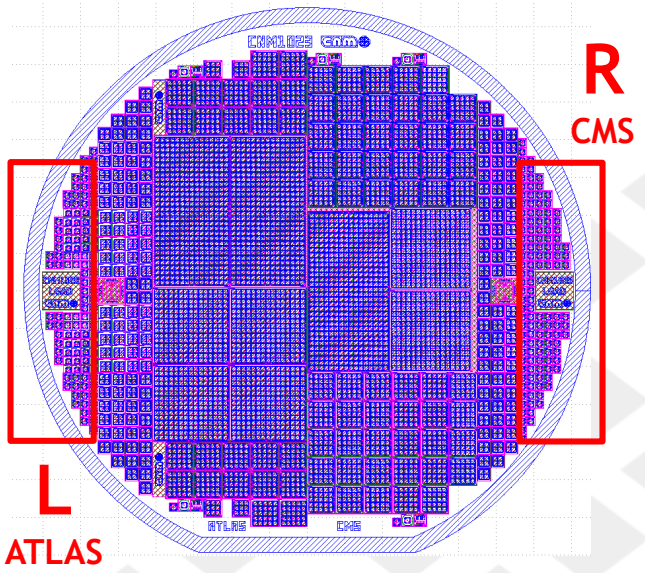


Differences between Left & Right sides of the wafers

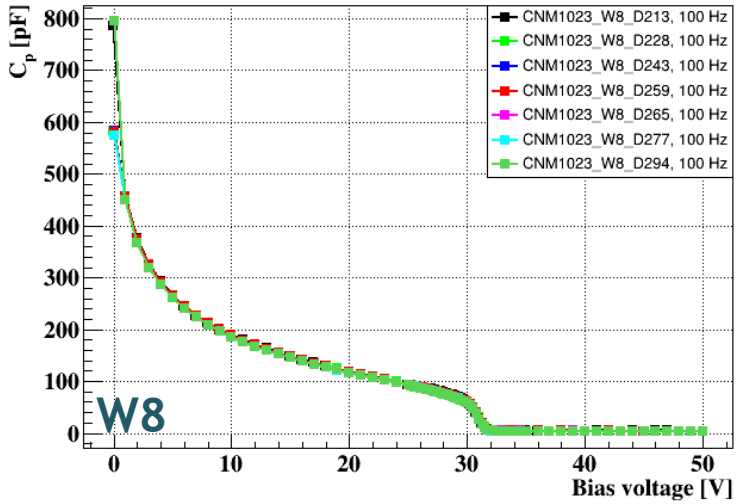


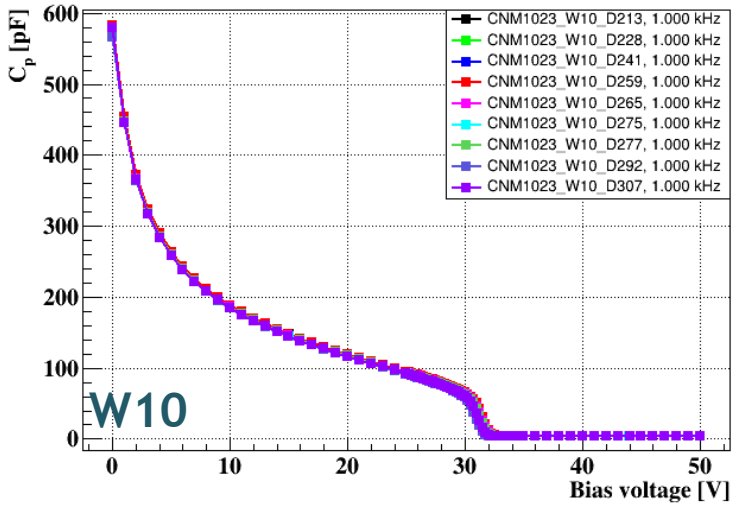
Wafer	3	8	9	10
Boron dose/ Imp. Energy	1.9e13/cm² / 100keV			
Carbon dose/ imp. Energy	-	1e14/cm² / 150keV	-	
DOT (min)	30	180	90	180

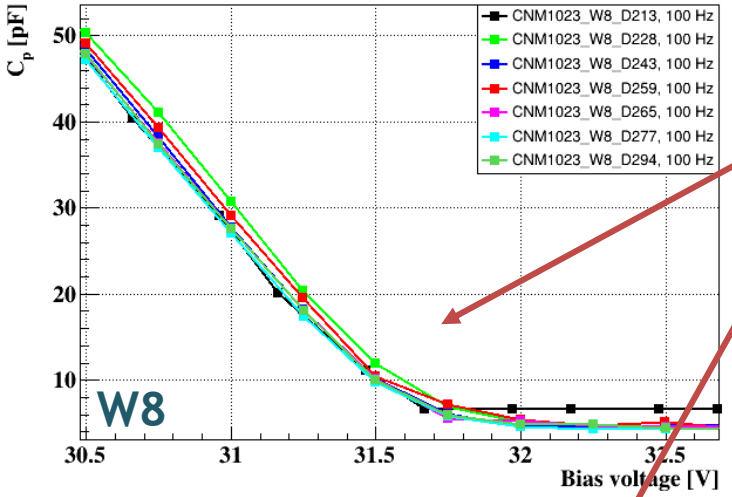
In the presence of C, this difference is not observed

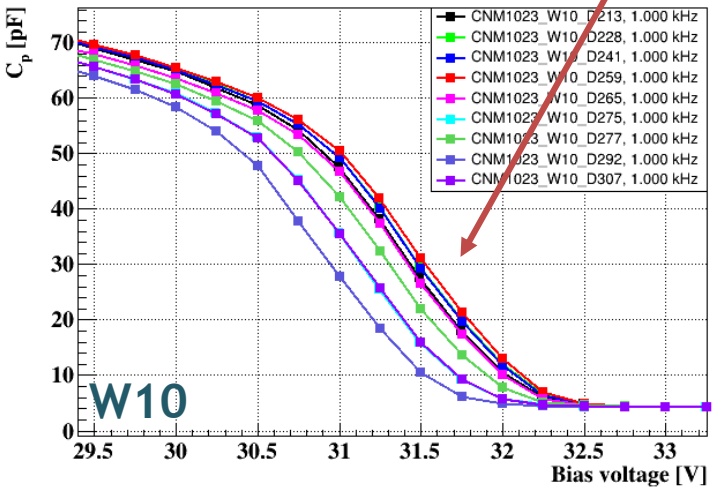


Diced single pad diodes : CV measurements at IFCA (CMS side)









V_{GL} is less dispersive in the presence of carbon

	W8 (Carbonated)	W10 (Non-Carbonated)
	V_{GL}(V)	
Mean [V]	31.15	31.61
RMS [V]	0.018	0.202

4. Ongoing and future work

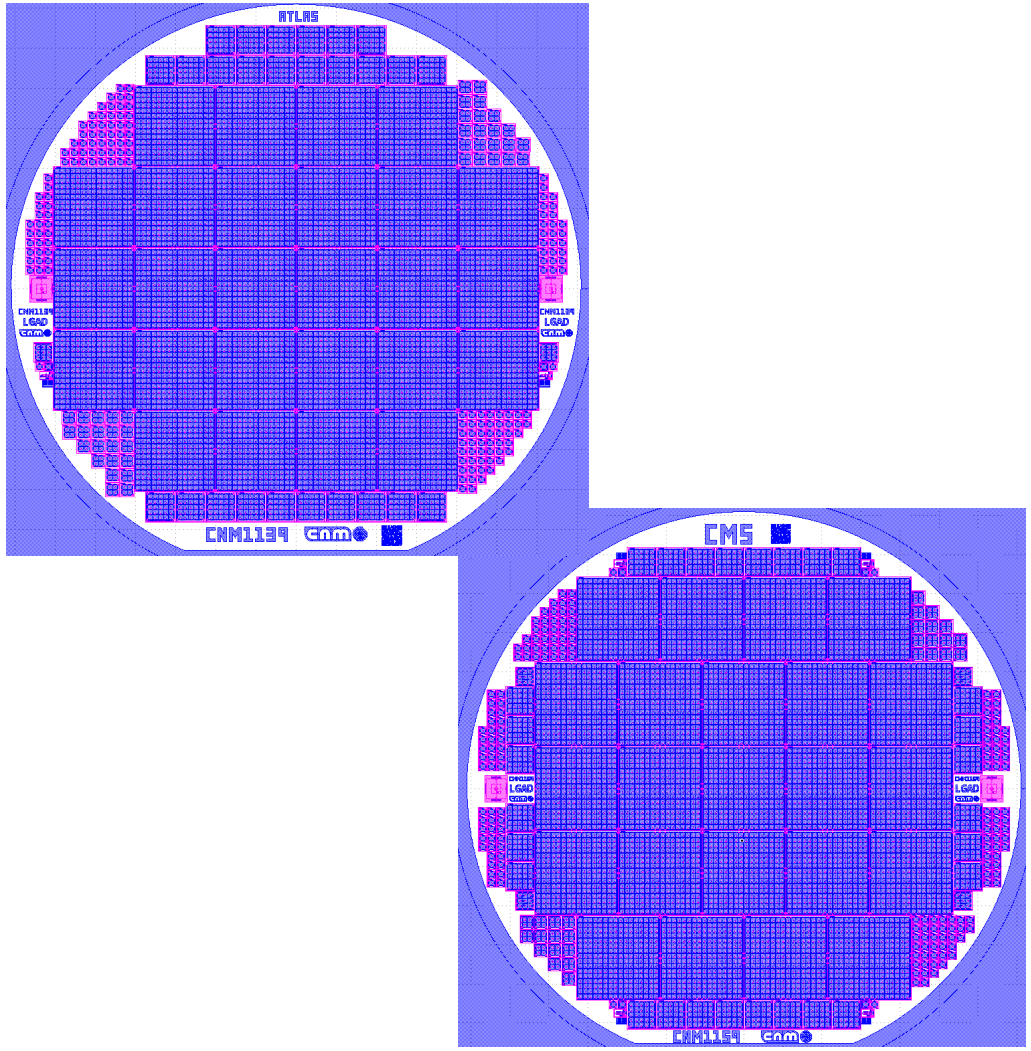
Ongoing work: CNM-6LG3-2

- All wafers are diced

- Irradiation campaign (ATLAS-Left side) ongoing:
  - Single pad & 2x2 devices,
    - **20 single pad** diodes (10 from W8 (Carbonated) & 10 from W10)
    - **20 2x2 pixels** devices (10 from W8 (Carbonated) & 10 from W10)
    - Neutron equivalent fluences **0.4, 0.8, 1.5 & 2.5e15/cm²**
    - **Ready to be tested (TCT & Sr90)**

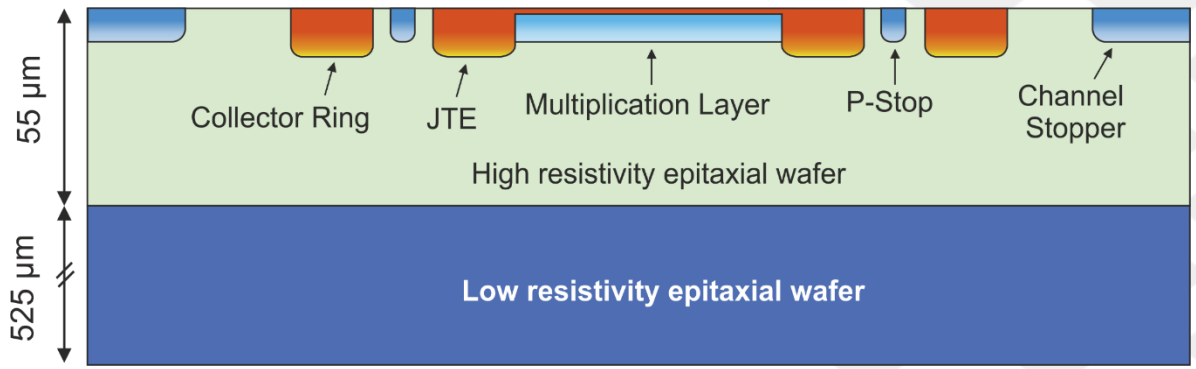
- Irradiation campaign (CMS-Right side) plan:
    - **24 single pad** diodes (12 from W8 (Carbonated) & 12 from W10)
    - **21 2x2 pixels** devices (9 from W8 (Carbonated) & 12 from W10)
    - Neutron equivalent fluences: **0.6, 1 & 1.5e15/cm²**

Future work: ATLAS+CMS Runs (6LG2)

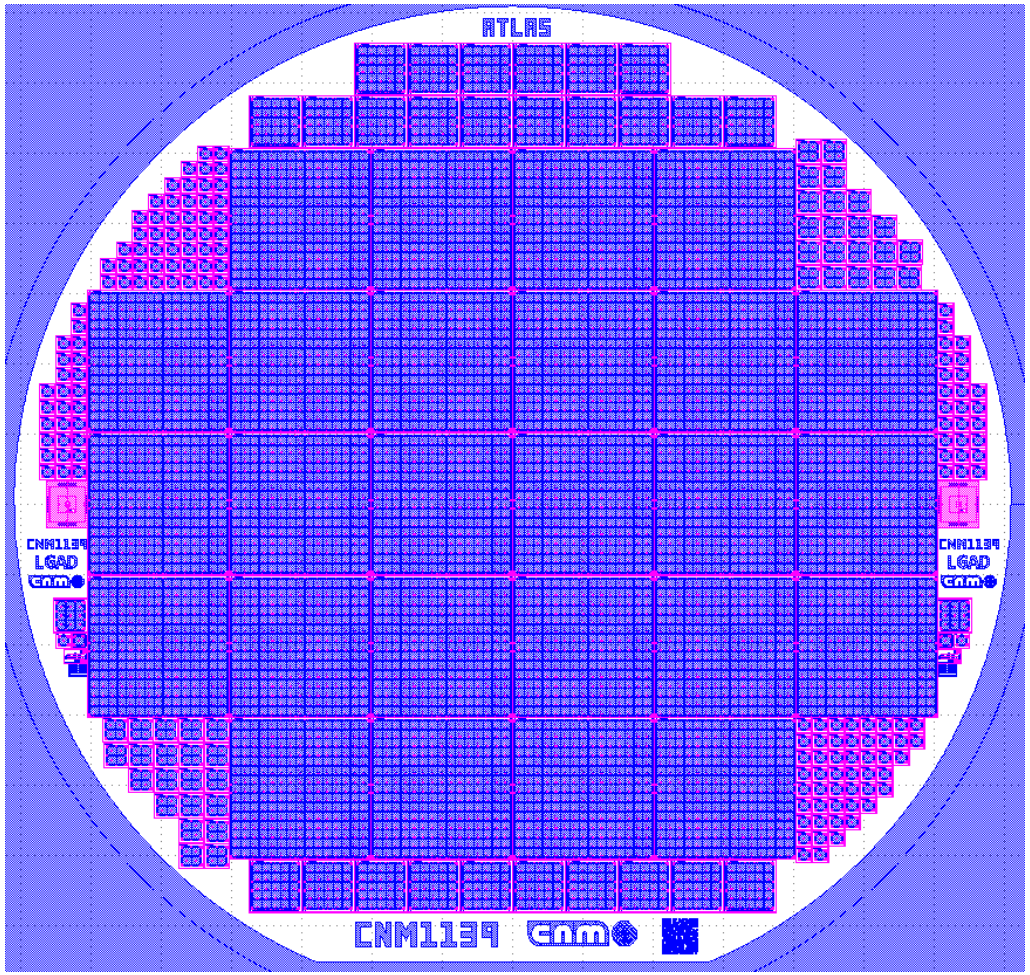


Devices (ATLAS, CMS) : 1x1, 2x2, 5x5, 15x15 & 16x16 pixels of 1.3x1.3 mm²

- 2 Runs (ATLAS, CMS)
- 10 LGAD wafers each run
- 150 mm, 55/525 µm, Si-Si wafers (6LG2)
- Some of them carbonated
- New mask sets: ATLAS (15x15), CMS (16x16) pixel devices
  - ATLAS 15x15: 26 devices, ALTIROC chip compatible
  - CMS 16x16: 23 devices, ETLROC chip compatible
- Gain layer characteristics under review
  - CNM standard multiplication layer, Deep P-layer
- Simulations on deep gain layer (instead of shallow) ongoing



Future work: ATLAS+CMS Runs (6LG2)

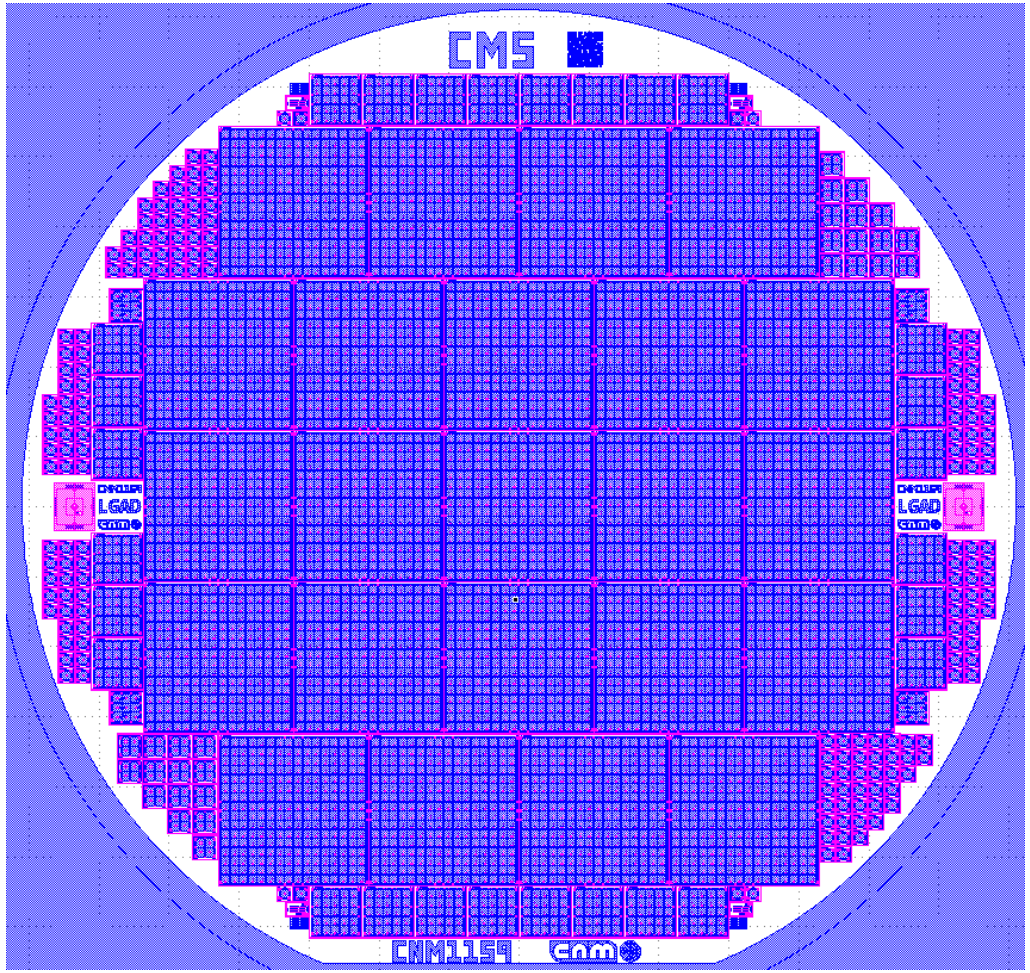


Devices (ATLAS) : 1x1, 2x2, 5x5 & 15x15 pixels of 1.3x1.3 mm^2

- **2 Runs** (ATLAS, CMS)
- **10 LGAD wafers** each run
- 150 mm, 55/525 µm, **Si-Si** wafers (**6LG2**)
- Some of them carbonated
- **New mask sets:** ATLAS (15x15), CMS (16x16) pixel devices
  - **ATLAS 15x15**: **26** devices, **ALTIROC** chip compatible
  - **CMS 16x16**: **23** devices, **ETLROC** chip compatible
- Gain layer characteristics under review
  - CNM standard multiplication layer, Deep P-layer
- Simulations on **deep gain layer** (instead of shallow) ongoing

- **ATLAS 15x15**: **26** devices
  - **ALTIROC** chip compatible
  - **SE3**, 300 µm (400 µm at wire bonding area)
  - **No TCT opening window**
  - Reduced dead area in corners to **improve fill factor**

Future work: ATLAS+CMS Runs (6LG2)



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

- **2 Runs** (ATLAS, CMS)
- **10 LGAD wafers** each run
- 150 mm, 55/525 µm, **Si-Si** wafers (**6LG2**)
- Some of them carbonated
- **New mask sets:** ATLAS (15x15), CMS (16x16) pixel devices
  - **ATLAS 15x15**: **26** devices, **ALTIROC** chip compatible
  - **CMS 16x16**: **23** devices, **ETLROC** chip compatible
- Gain layer characteristics under review
  - CNM standard multiplication layer, Deep P-layer
- Simulations on **deep gain layer** (instead of shallow) ongoing

- **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**

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Project references: RTI2018-094906-B-C22 and PID2020-113705RB-C32

Thanks for your attention!

Overview CNM-6LG3-2

Wafer	1	2	3	4	5	6	7	8	9	10
Gain layer depletion V	$V_{GL} \approx 12V$	$V_{GL} \approx 13V$	$V_{GL} \approx 15V$	$V_{GL} \approx 31V$	$V_{GL} \approx 33V$	$V_{GL} \approx 34V$	$V_{GL} \approx 15V$	$V_{GL} \approx 30V$	$V_{GL} \approx 20V$	$V_{GL} \approx 30V$
Boron dose (1e13/cm²)	1.7	1.8	1.9	2	2.1	2.2	1.9		1.9	
Carbon dose (1e13/cm²)	-						5	10	-	-
DOT (min)	30			180			30	180	90	180
Size	Yield									
16x32 / 15x30	0% / 50%	100% / 50%	100% / 50%	0% / 0%	0% / 0%	0% / 0%	0% / 100%	0% / 50%	0% / 0%	0% / 50%
16x16 / 15x15	50% / 75%	100% / 50%	100% / 75%	0% / 25%	0% / 0%	0% / 0%	100% / 100%	50% / 50%	100% / 50%	0% / 50%
5x5	100% (20/20)	75% (15/20)	90% (18/20)	80% (16/20)	50% (10/20)	5% (1/20)	90% (18/20)	77% (58/75)	90% (18/20)	74% (53/74)
2x2	-*	-*	-*	-*	95% (19/20)	25% (5/20)	-*	93% (38/41)	-*	93% (38/41)

*not measured yet