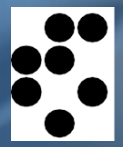
Timing measurements on neutron-irradiated LGADs in epitaxial wafers



Jožef Stefan Institute

The 38th RD50 Workshop

21-23 June 2021

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Motivation

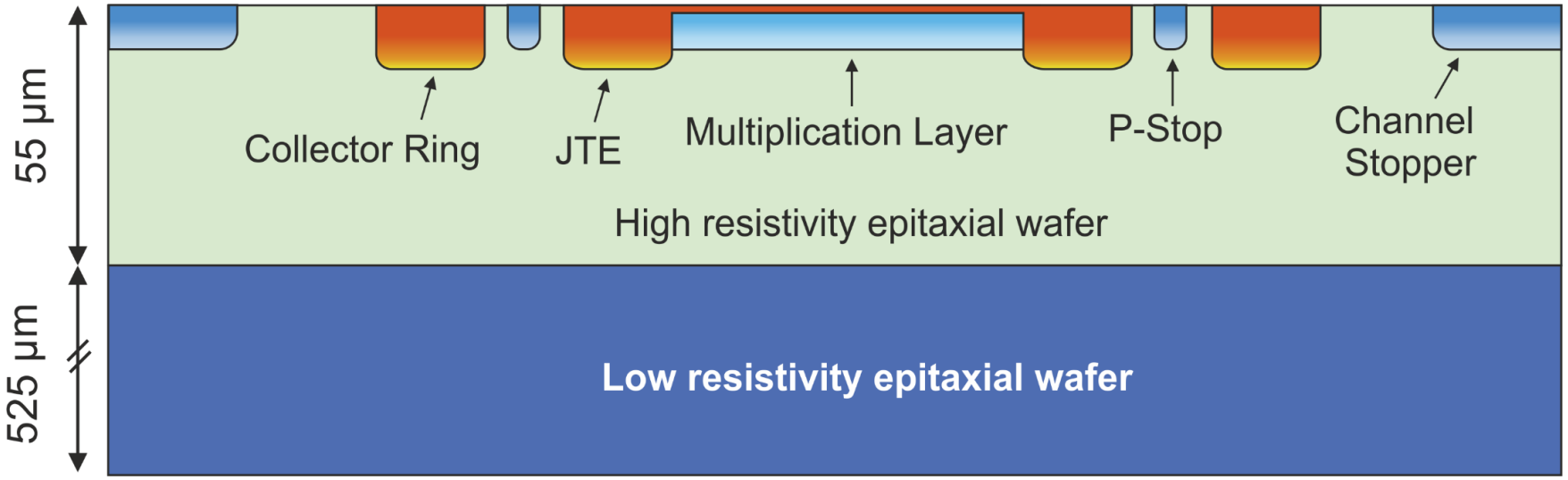
- LGADs were neutron-irradiated at fluencies ranging between 10^{14} and 10^{16} $1/cm^2$
- Time resolution, gain, collected charge and acceptor removal were measured before and after irradiation
- Comply with the CMS and ATLAS requirements:

CMS : 10fC at $1.5 \cdot 10^{15}$ /cm² at (max) 600V
ATLAS : 4fC at $2.5 \cdot 10^{15}$ /cm² at (max) 600V

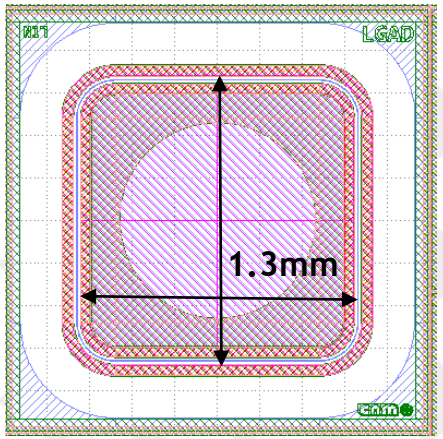
Run 13002: 6-inch LGAD in Epitaxial Wafers (6LG3)

- **4 wafers (3 LGAD + 1 PiN).**
- 6-inch 50-60/525 µm **epitaxial** wafers.
  - Handle wafer resistivity = 0.001-1 Ohm-cm
  - Substrate resistivity > 200 Ohm-cm (measured = 1-10 kOhm-cm).

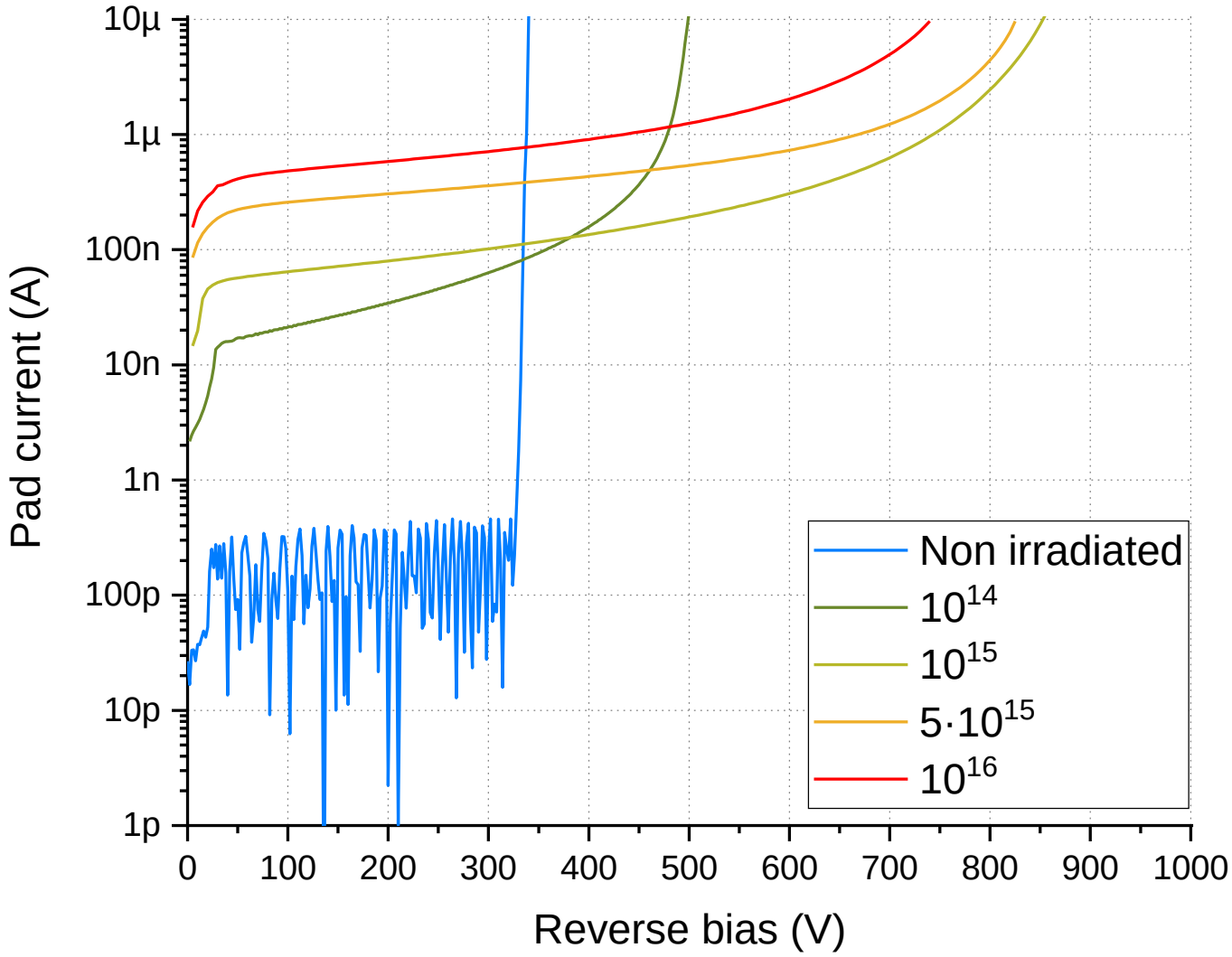
Wafer	Dose	Energy
1	-	-
2	D1 (medium)	E
3	D2 (medium-high)	E
4	**D3 (high)**	**E**



Pad device

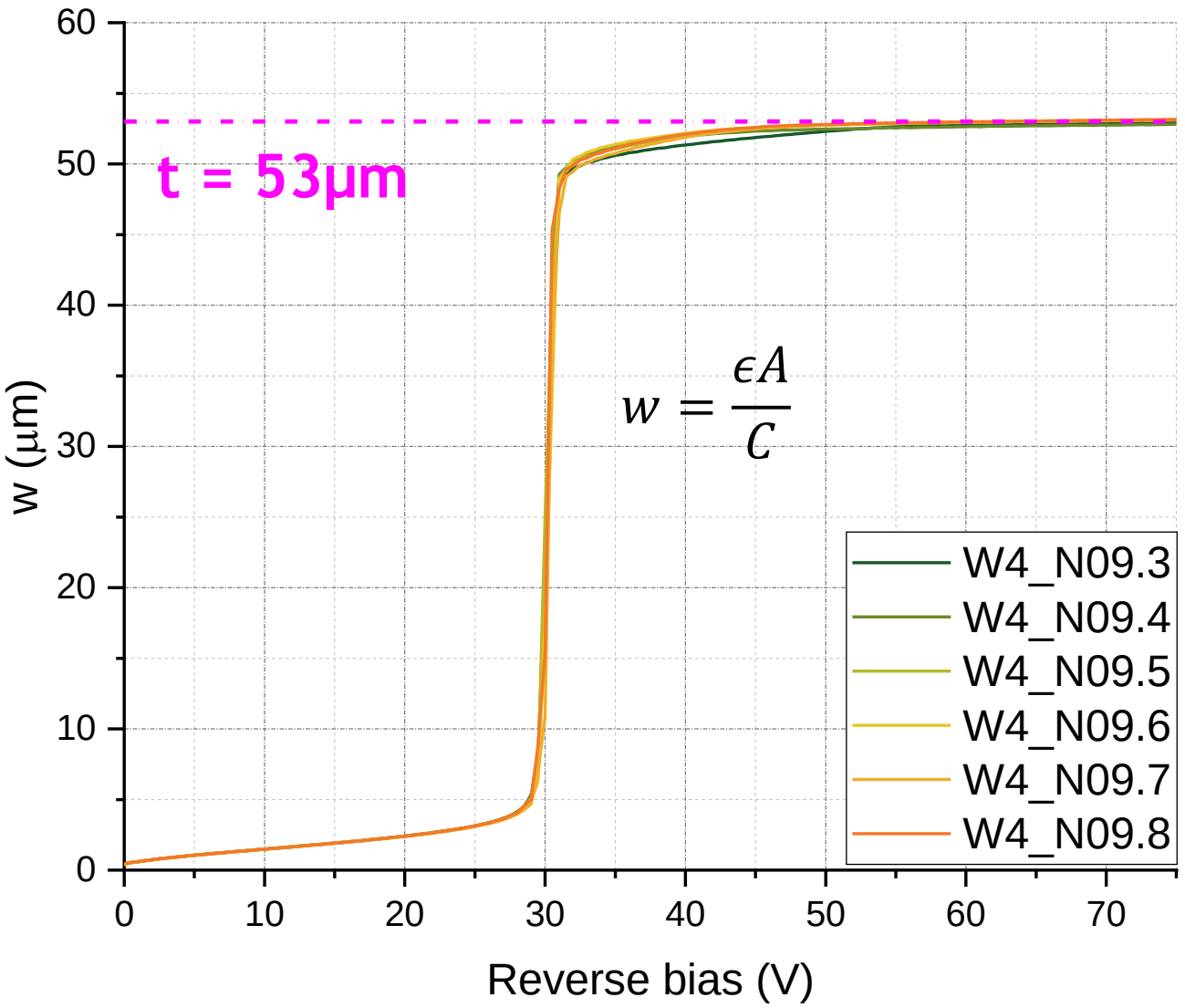


Tested LGADs : Pad current at T=-20°C

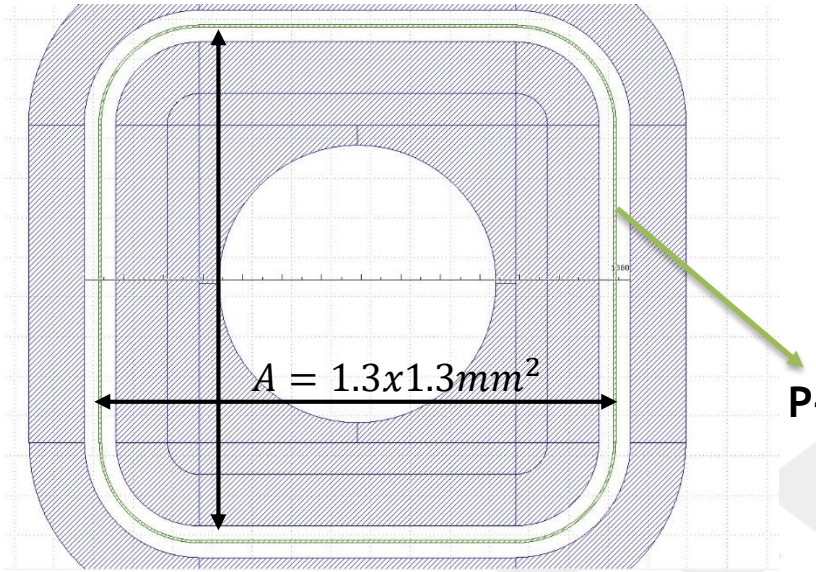


Device	Φ_{eq} (1/cm²)	Breakdown voltage (V)
W4_N18.6	-	325
W4_N09.4	10^{14}	500
W4_N09.3	10^{15}	>800
W4_N09.6	$5 \cdot 10^{15}$	>800
W4_N09.5	10^{16}	>750

Run13002 : 1.3x1.3mm sensor thickness

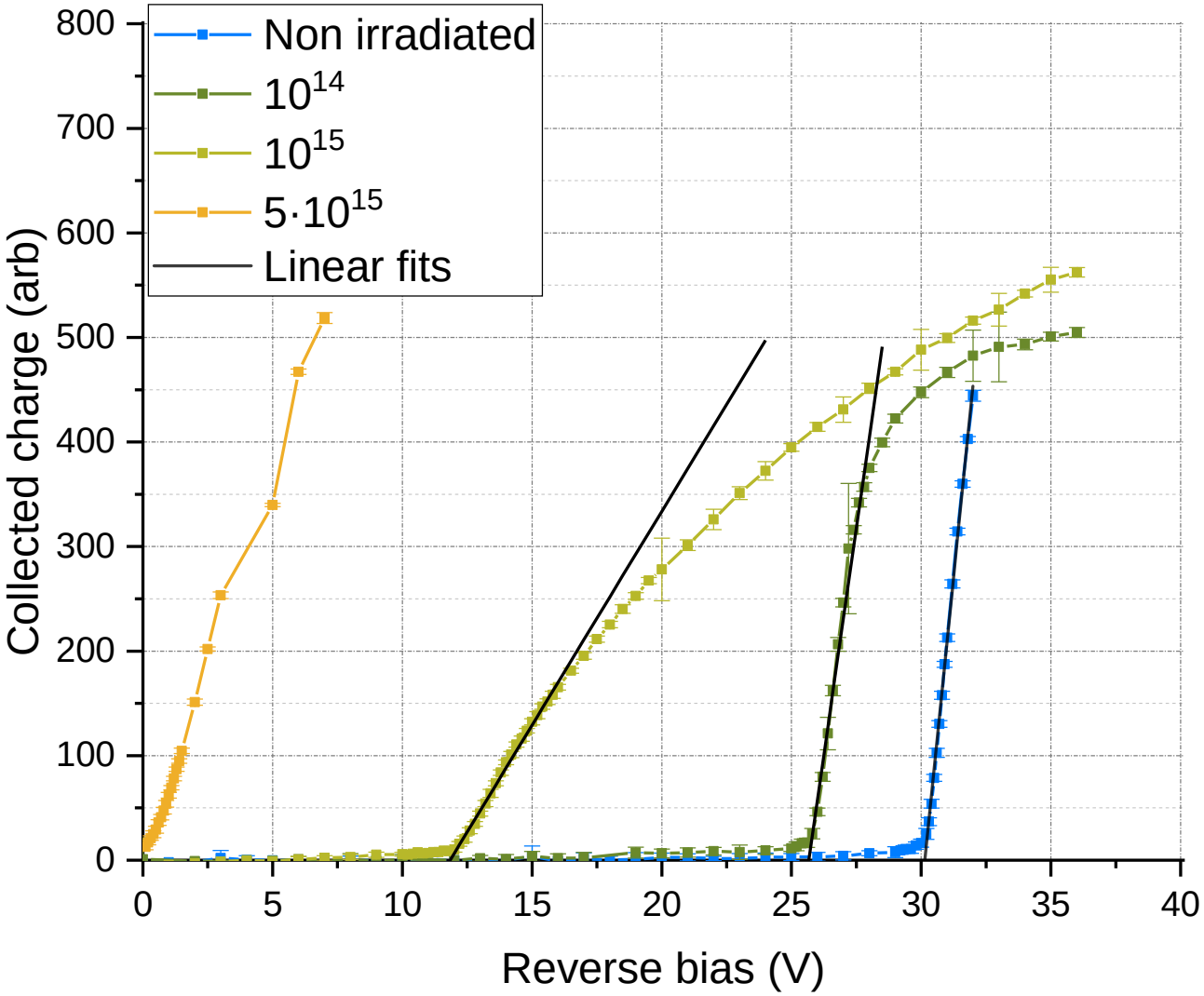


CV measurements taken before irradiation at room temperature



$$t = \frac{\epsilon A}{C_{FD}} \approx 53\mu m$$

TCT measurements : Acceptor removal

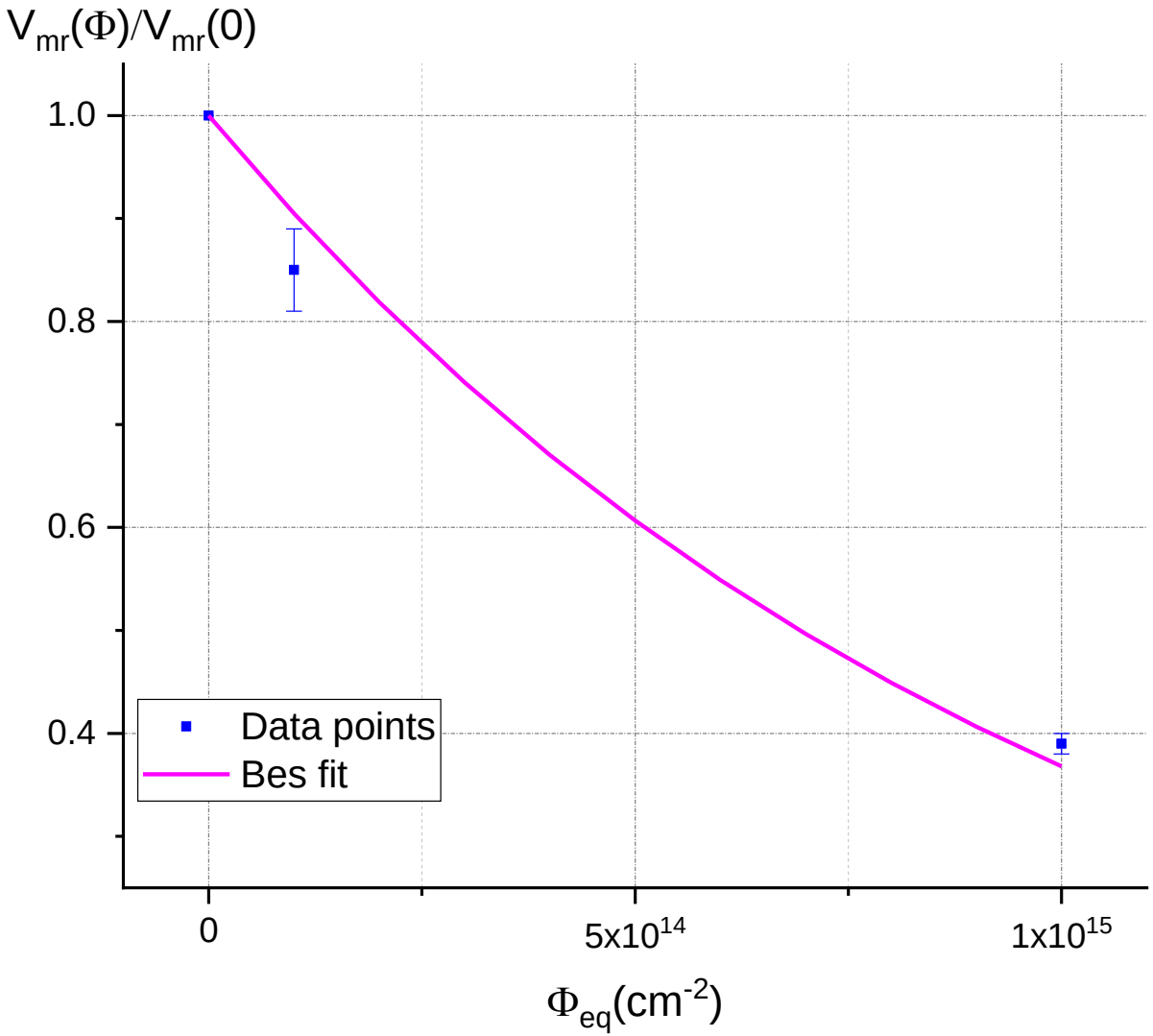


$$V_{mr}(\Phi_{eq}) \approx V_{mr}(0)e^{-c\Phi_{eq}}$$

Device	Φ_{eq} (1/cm²)	T (°C)	V_{mr} (V)
W4_N18.6	-	20	30.1±0.4
W4_N09.4	10^{14}	0	25.7±1.4
W4_N09.3	10^{15}	0	11.8±0.3
W4_N09.6	$5\cdot10^{15}$	0	-

Infrared laser (1064nm)
Laser pulse width : variable for each device to get a signal large enough

TCT measurements : Acceptor removal (-20°C)



$$V_{mr}(\Phi_{eq}) \approx V_{mr}(0)e^{-c\Phi_{eq}}$$

Device	Φ_{eq} (1/cm²)	$\frac{V_{mr}(V)}{V_{mr}(0)}$
W4_N18.6	-	1
W4_N09.4	10^{14}	0.85±0.04
W4_N09.3	10^{15}	0.39±0.01

Best fit :

$$c = (10 \pm 1) \cdot 10^{-16}\text{cm}^2$$

Reference: $c = (9.5) \cdot 10^{-16}\text{cm}^2$

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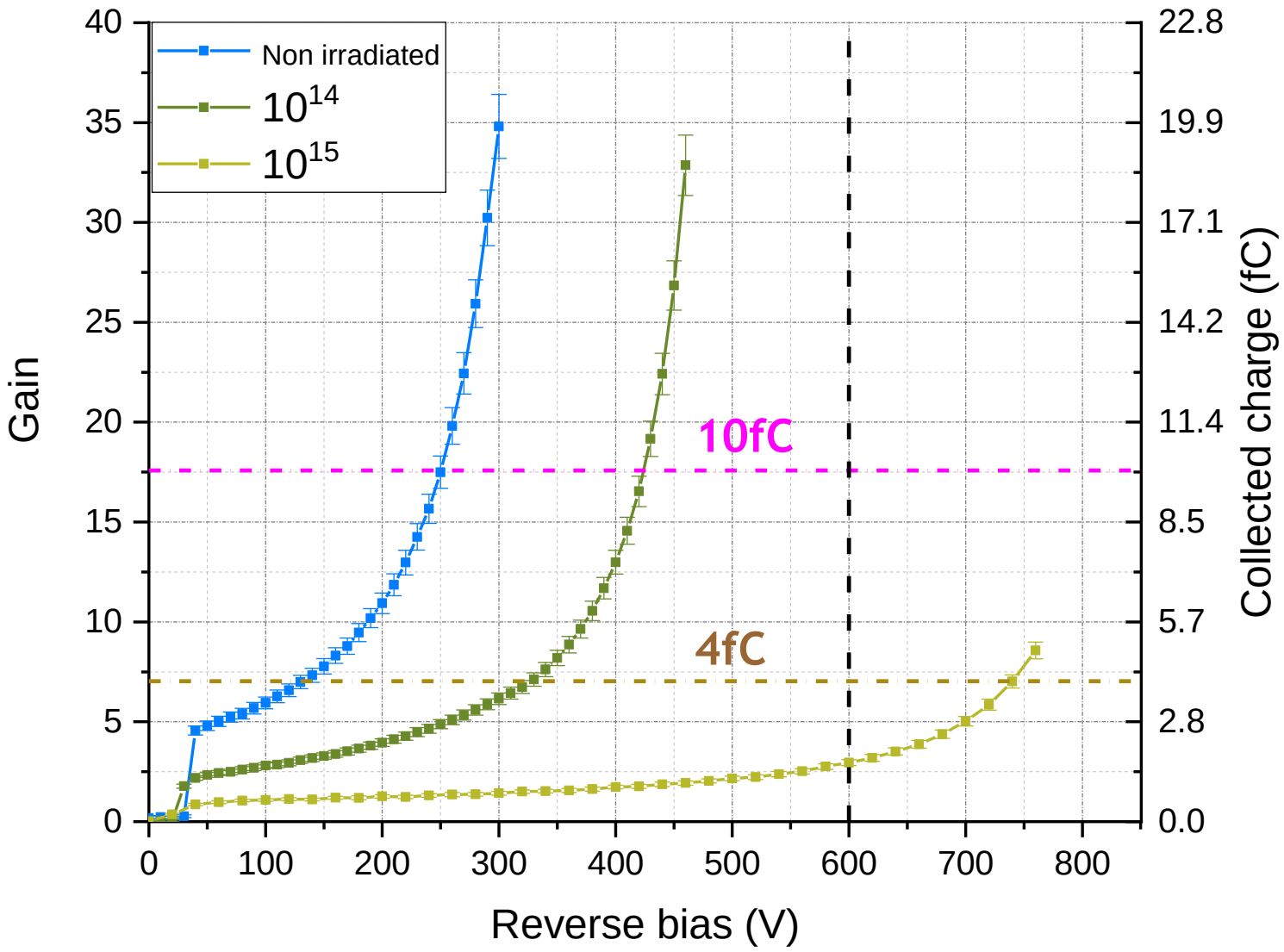
TCT measurements : gain and collected charge for a MIP (-20ºC)



Device	Φ_{eq} (1/cm²)	Breakdown voltage (V)
W4_N18.6	-	325
W4_N09.4	10^{14}	500
W4_N09.3	10^{15}	>800

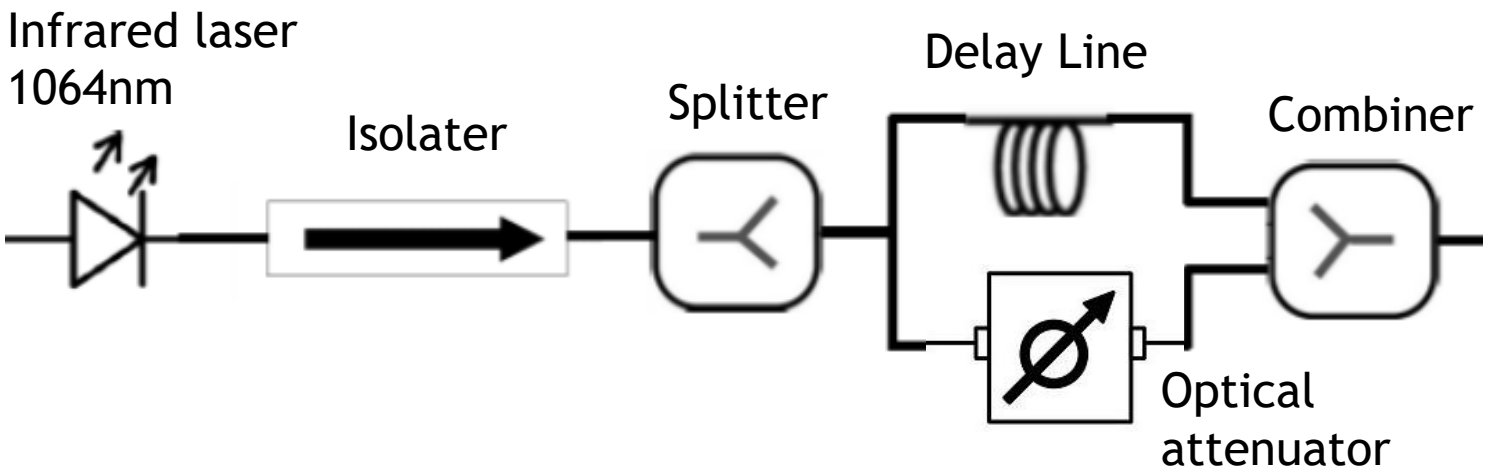
Gain=Q(LGAD)/Q(PiN)

Infrared laser (1064nm)
Laser pulse width : 1.52ns
40µm FWHM & ~15MIPs

CMS : 10fC at $1.5 \cdot 10^{15}$ /cm² at (max) 600V
ATLAS : 4fC at $2.5 \cdot 10^{15}$ /cm² at (max) 600V

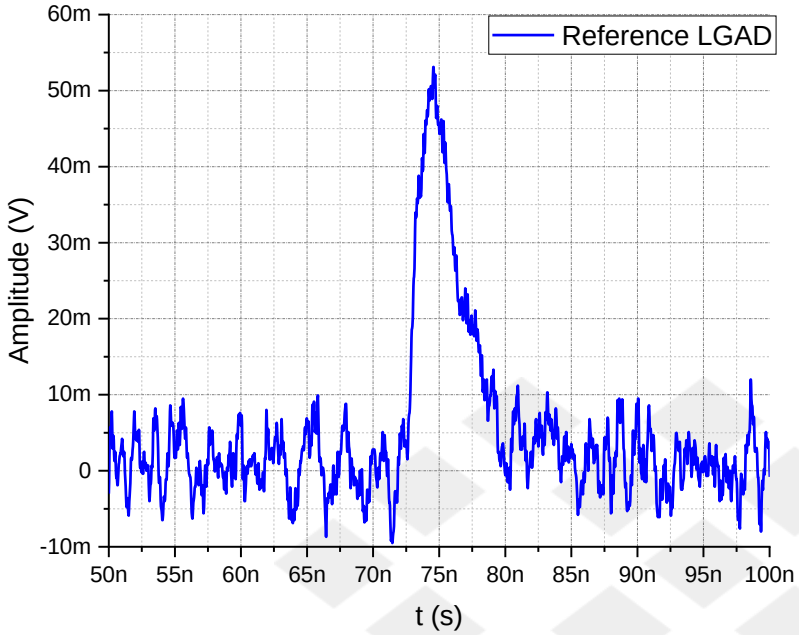
Gain 1 = 0.569fC (MIP → 67e/h pairs per µm in silicon low doped x 53 µm)

TCT measurements : Timing setup



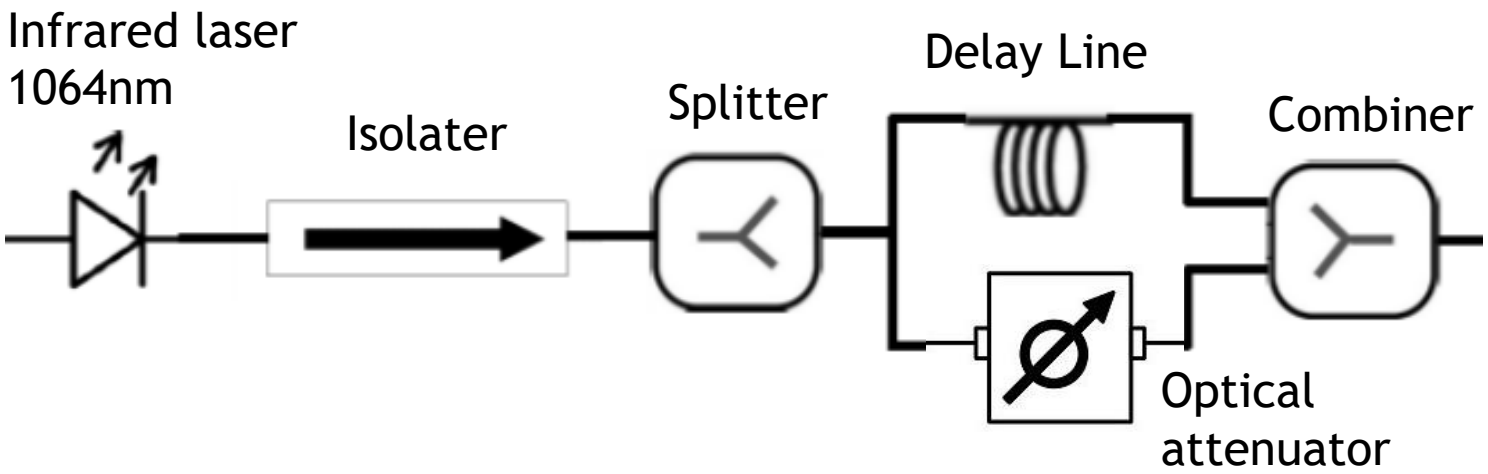
- Calibration with 90-Sr → MPV MIP peak signal = 40-45mV
- Two signals delayed 50ns
- Time difference between signals is calculated at different CFD fractions for 1000 waveforms
- Time resolution is defined as the lowest value of the Gaussian's fit sigma of the Time difference data (Generally got for CFD > 40-50%)

Ref. LGAD (from same wafer)
T=20°C
V=300V

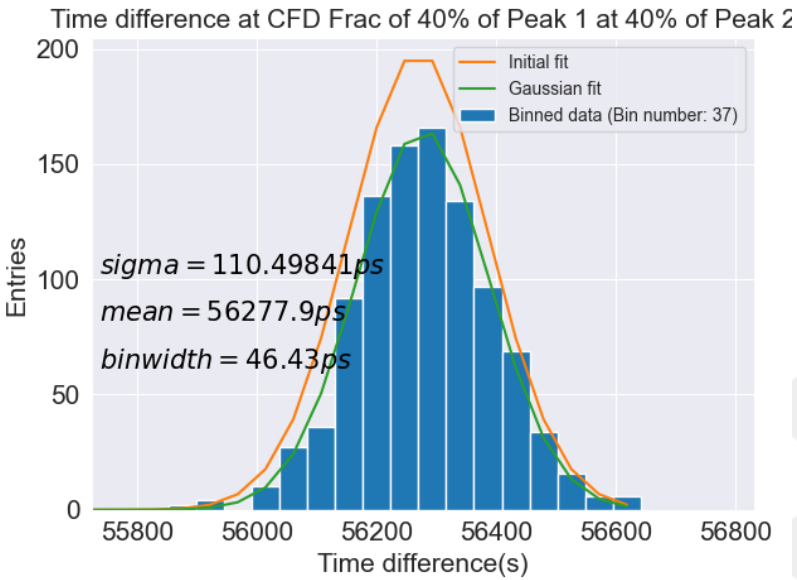


(Binwidth = 25ps → $\sigma_{TDC} = 7.2ps$)

TCT measurements : Timing setup

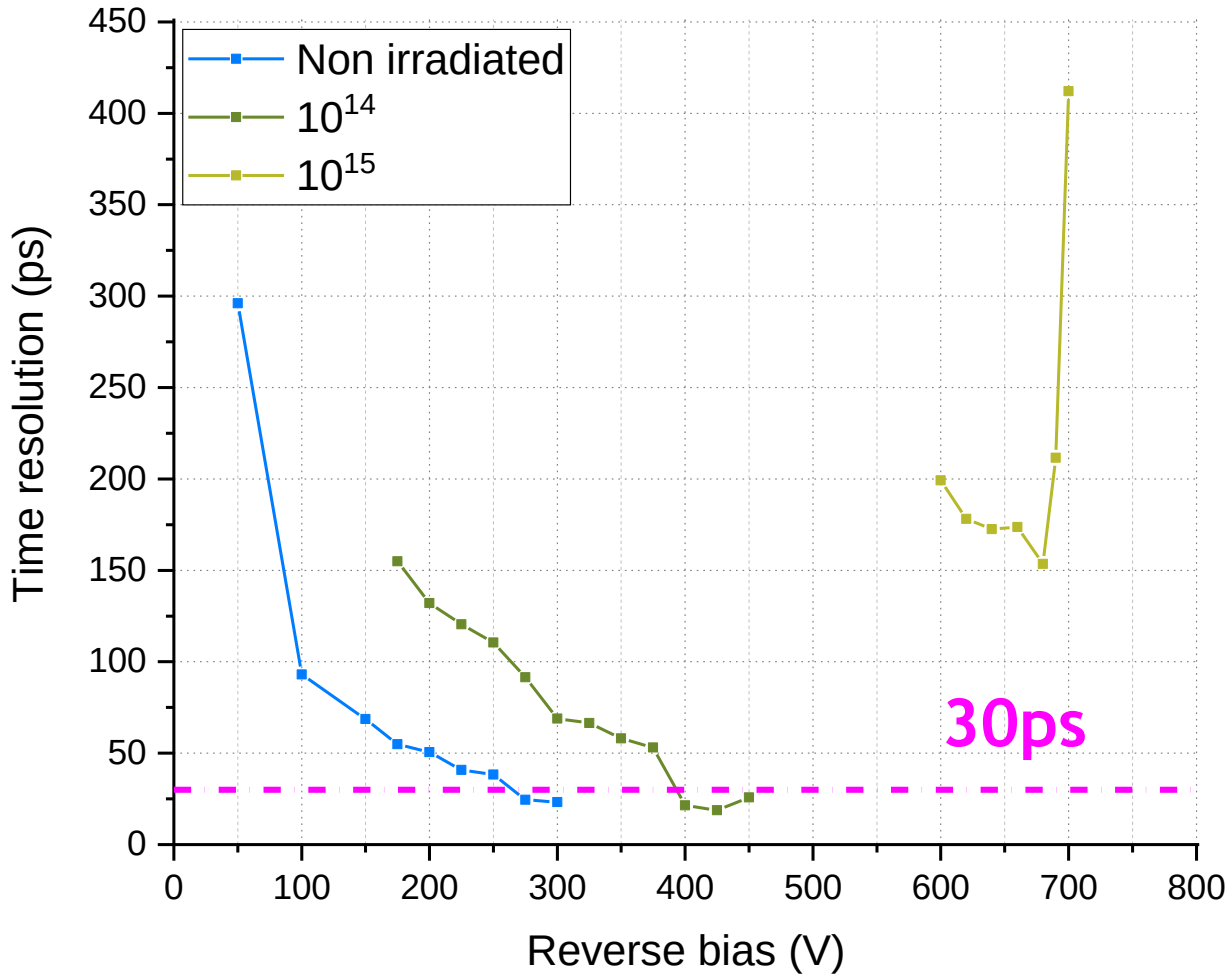


$\Phi_{eq} = 10^{14}\text{cm}^{-2}$
V=250V



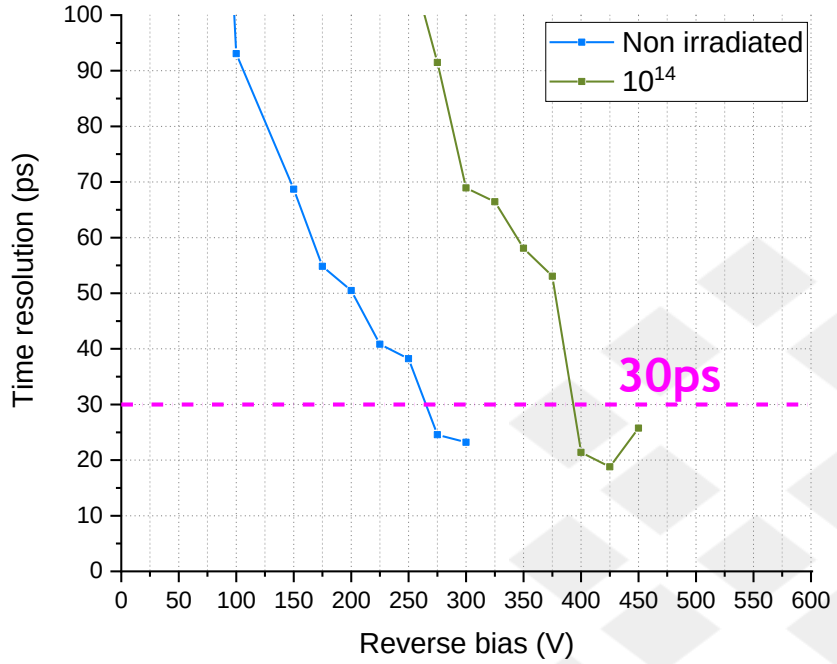
- **Calibration with 90-Sr → MPV MIP peak signal = 40-45mV**
- **Two signals delayed 50ns**
- **Time difference between signals is calculated at different CFD fractions for 1000 waveforms**
- **Time resolution is defined as the lowest value of the Gaussian's fit sigma of the time difference data (Generally got for CFD > 40-50%)**

TCT measurements : Time resolution for ~ 1MIP (-20°C)

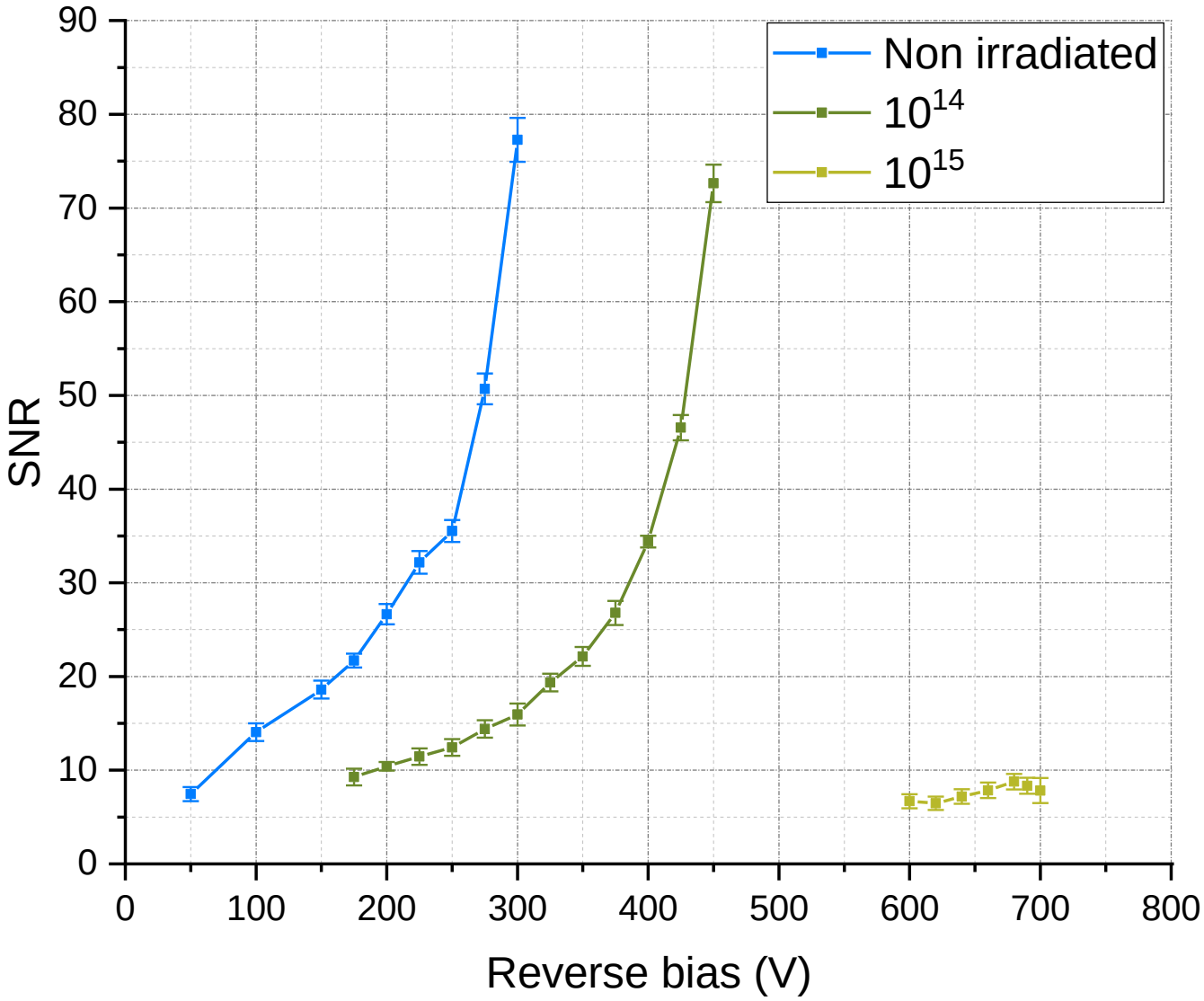


Device	Φ_{eq} (1/cm²)	Breakdown voltage (V)
W4_N18.6	-	325
W4_N09.4	10^{14}	500
W4_N09.3	10^{15}	>800
W4_N09.6	$5 \cdot 10^{15}$	>800

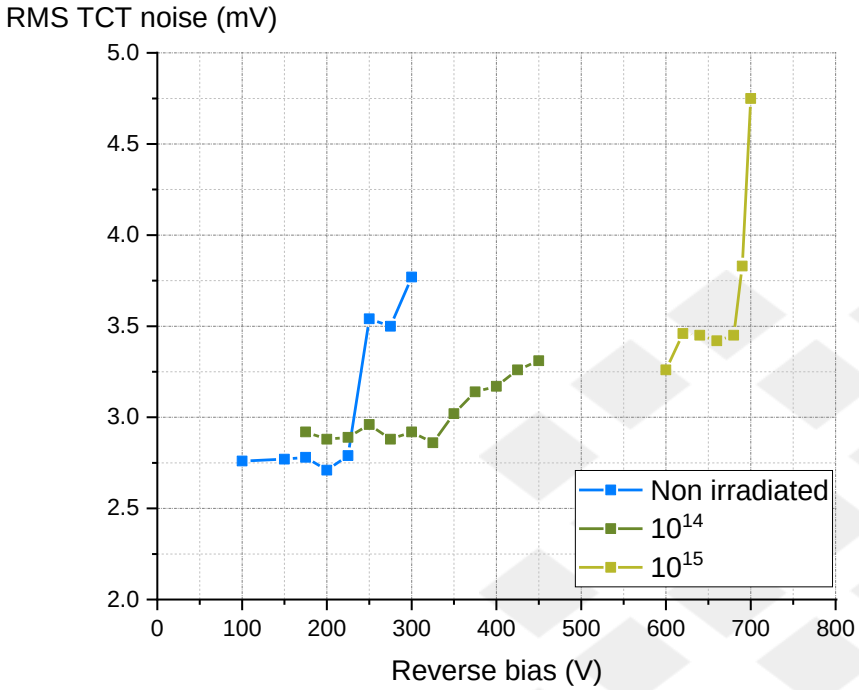
W4_N09.6 couldn't be tested (signal ~ noise)



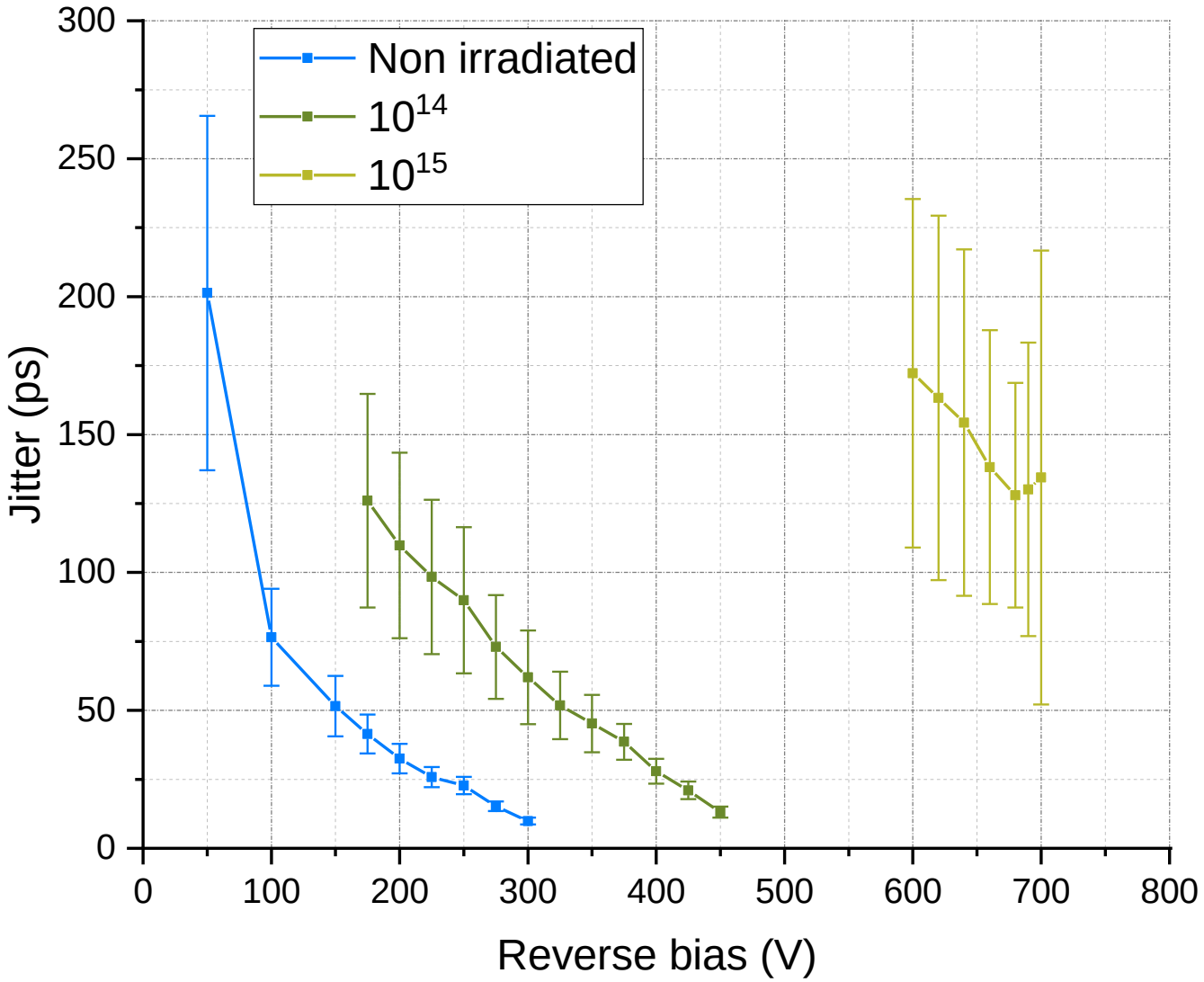
TCT measurements : SNR for ~ 1MIP (-20°C)



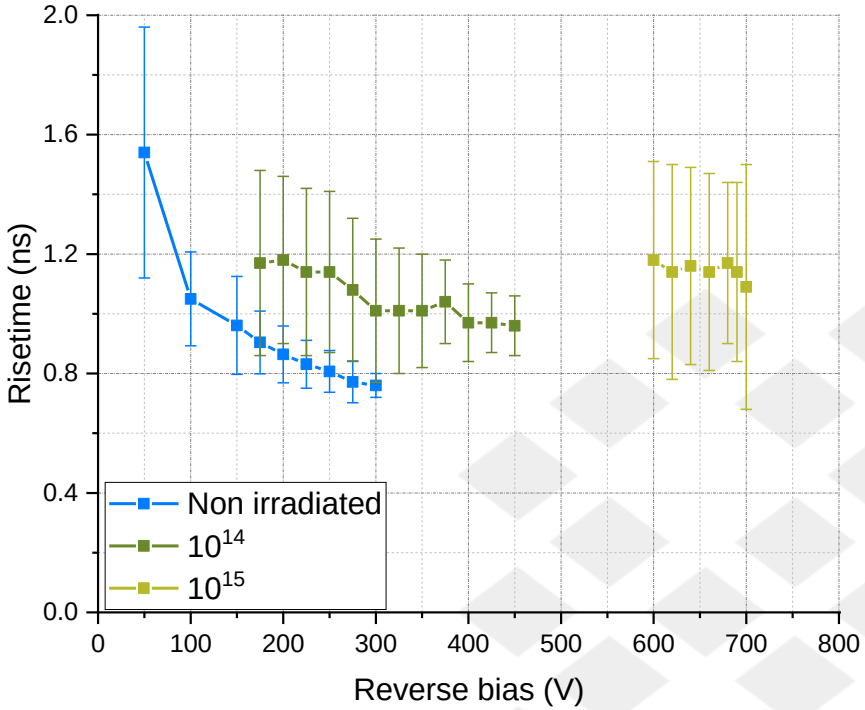
Device	Φ_{eq} (1/cm²)	Breakdown voltage (V)
W4_N18.6	-	325
W4_N09.4	10^{14}	500
W4_N09.3	10^{15}	>800



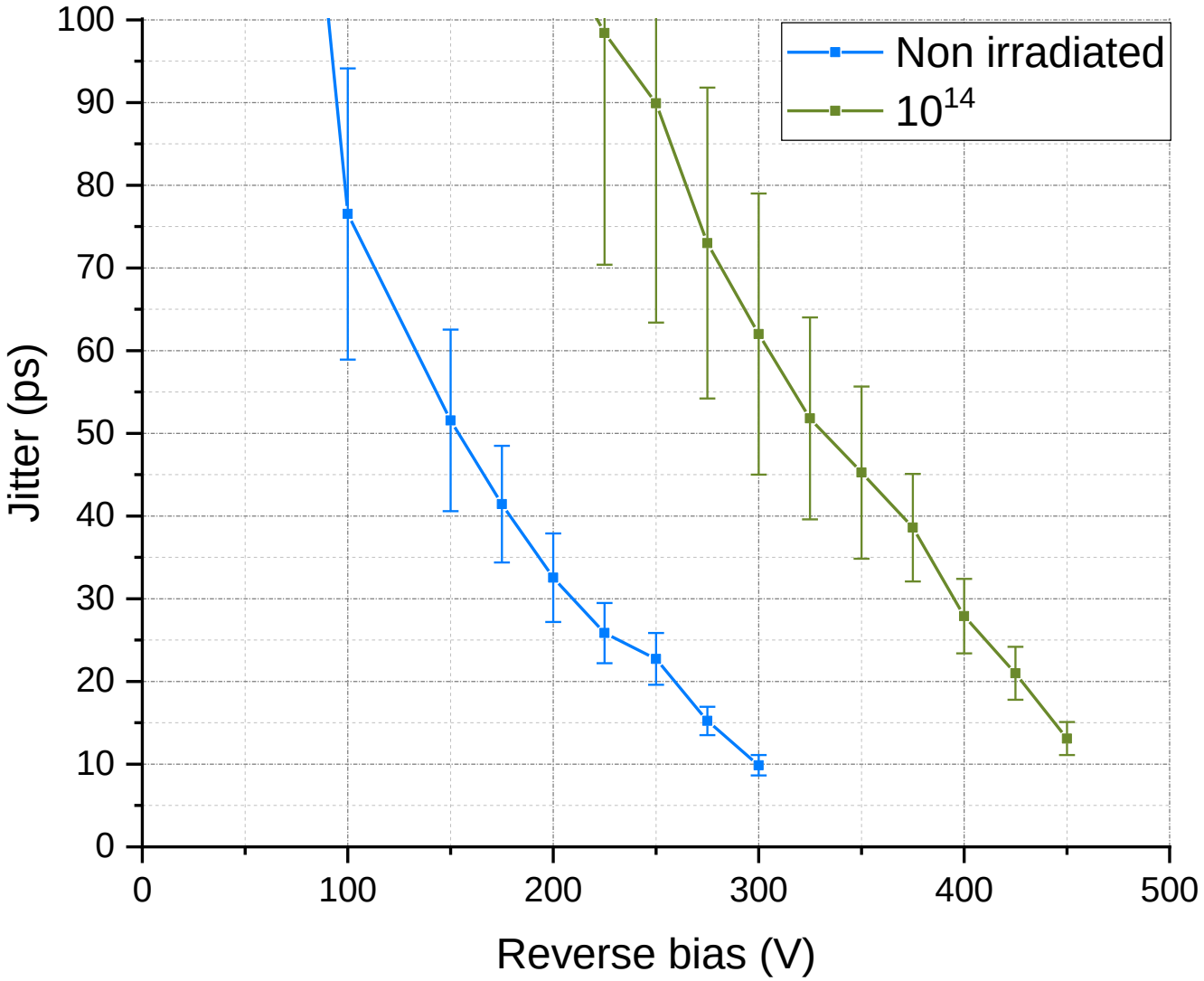
TCT measurements : Jitter (Risetime over SNR) for ~ 1MIP (-20°C)



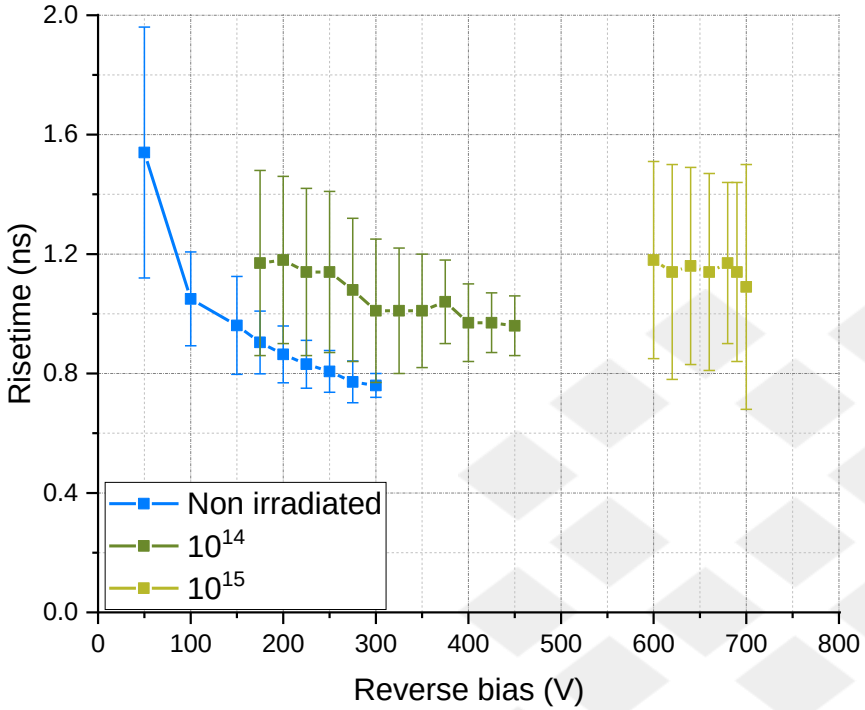
Device	Φ_{eq} (1/cm²)	Breakdown voltage (V)
W4_N18.6	-	325
W4_N09.4	10^{14}	500
W4_N09.3	10^{15}	>800



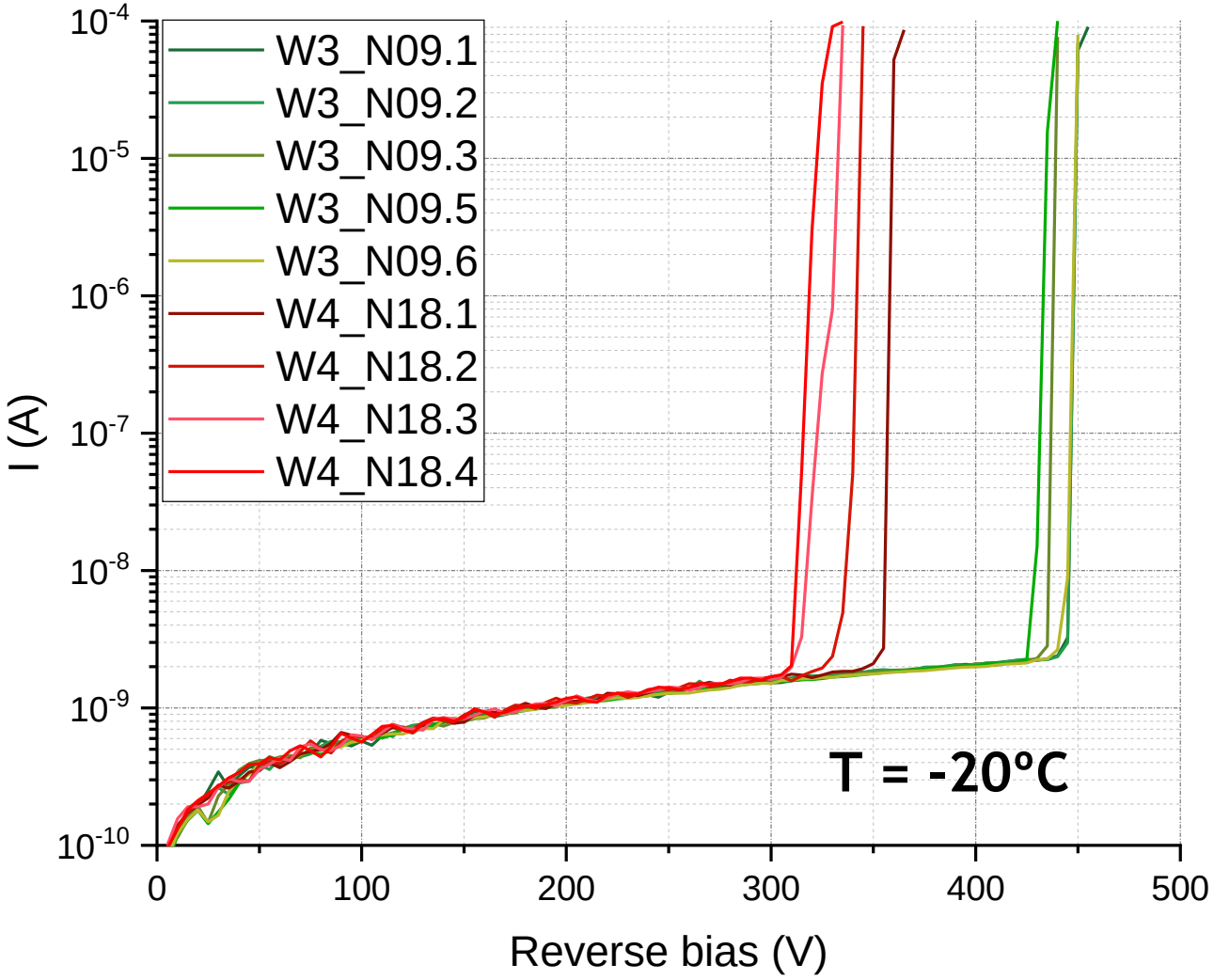
TCT measurements : Jitter (Risetime over SNR) for ~ 1MIP (-20°C)



Device	Φ_{eq} (1/cm²)	Breakdown voltage (V)
W4_N18.6	-	325
W4_N09.4	10^{14}	500
W4_N09.3	10^{15}	>800

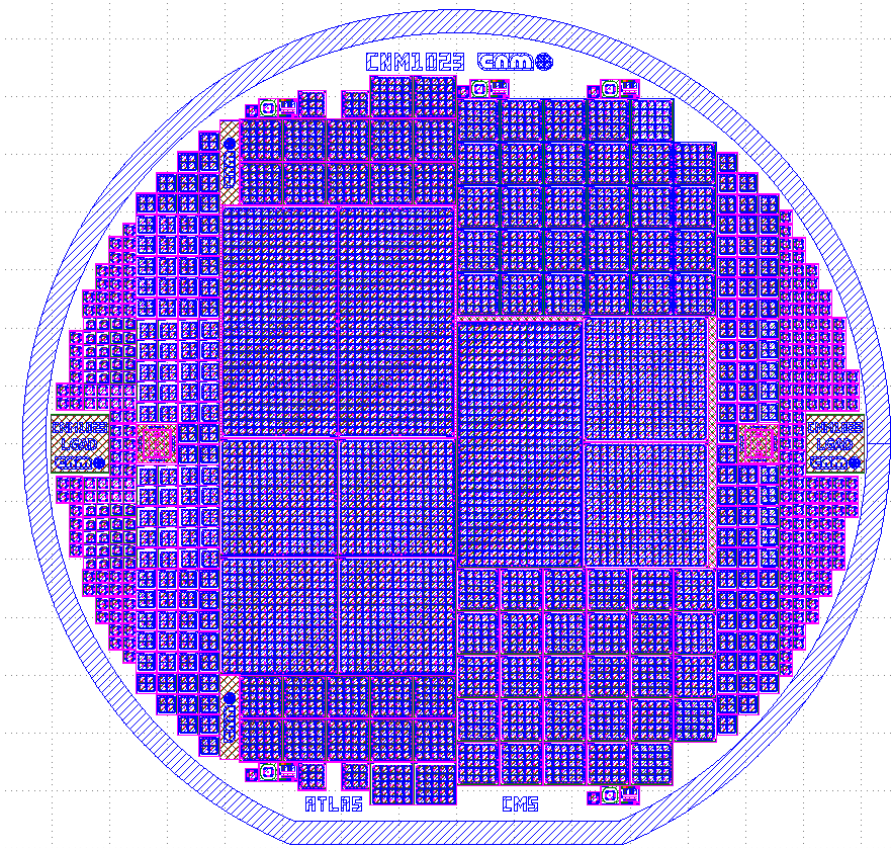


Upcoming measurements Run13002



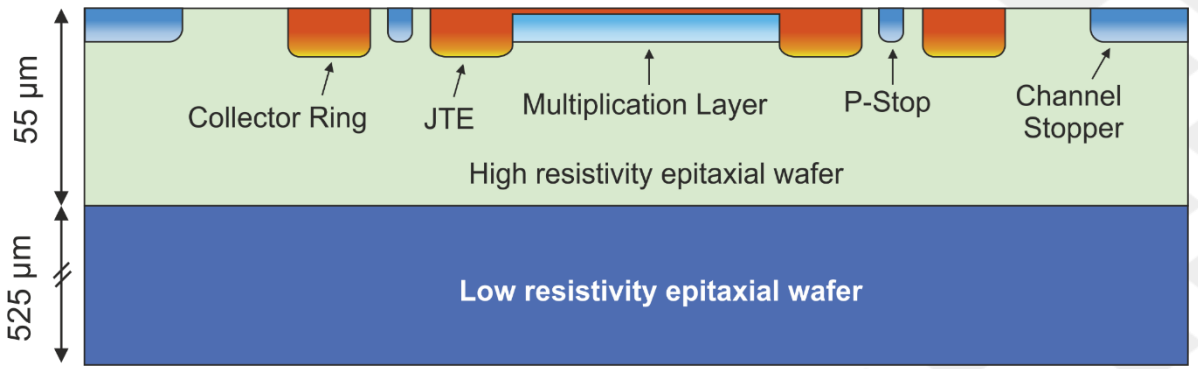
Wafer	Dose	Energy	Φ_{eq} (1/cm²)
3	D2 Medium-high	E	$5 \cdot 10^{14}$
			$8 \cdot 10^{15}$
			10^{15}
			$2 \cdot 10^{15}$
			$3 \cdot 10^{15}$
4	D3 High	E	$5 \cdot 10^{14}$
			$8 \cdot 10^{15}$
			$2 \cdot 10^{15}$
			$3 \cdot 10^{15}$

Run 13840: 6” ATLAS-CMS Common Run (6LG3)

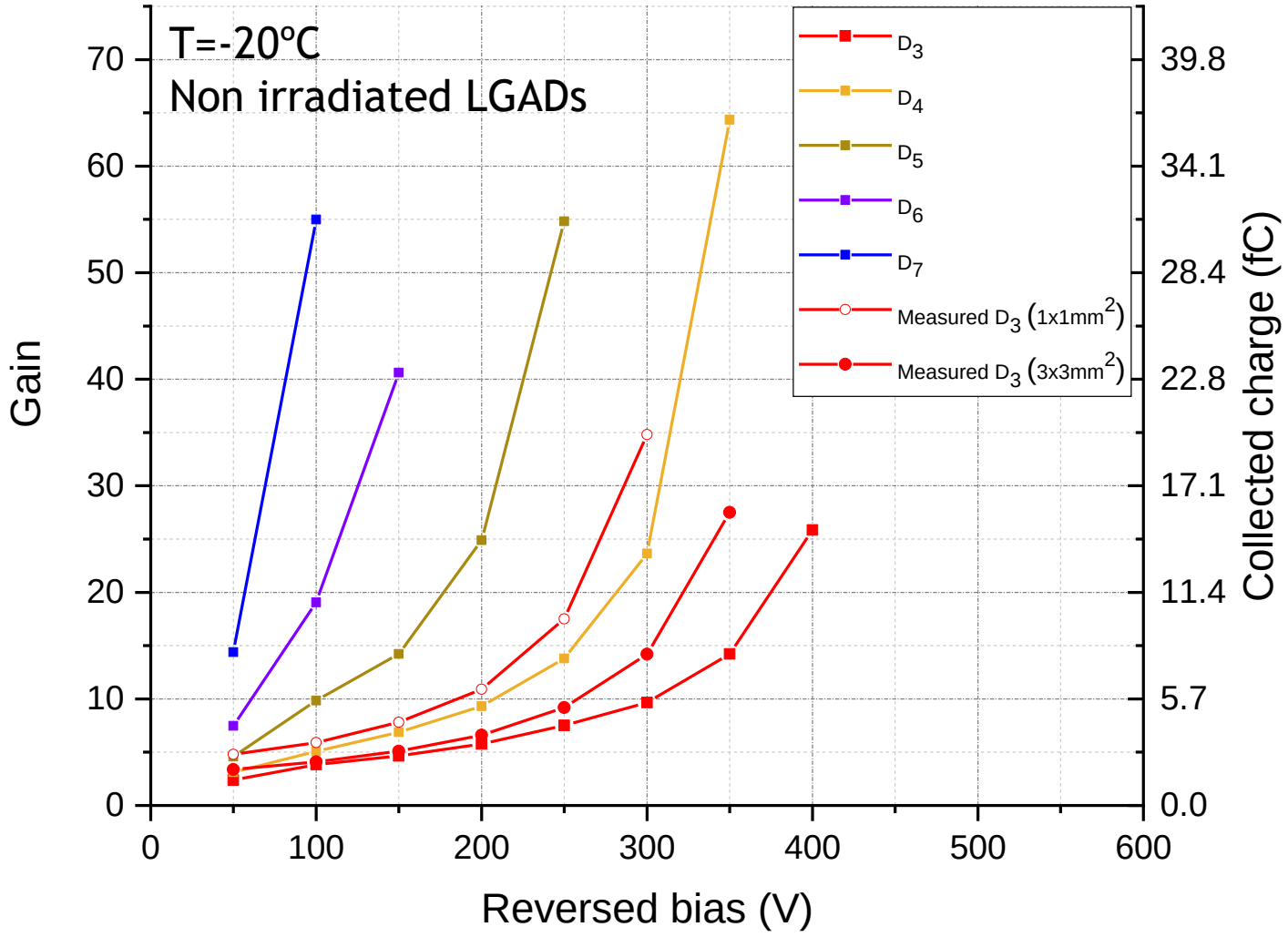


1x1, 2x2, 5x5 & 16x16 mm^2 devices

- 9 LGAD + 1 PiN 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 Run 13002 : 6LG3
- New diffusion furnace → Higher diffusion processes quality and uniformity
- It will be terminated by : forth quarter of 2021
- **Waiting to define optimal dose and implantation E**



Run 13840: Preliminary TCAD 1D Simulation



Dose	Energy
D3 (highest for Run13002)	E
D4>D3	E
D5>D4	E
D6>D5	E
D7>D6	E

Implantation dose will be raised (implantation energy might as well be) to fulfill ATLAS and CMS operation requirements after irradiation:

CMS : 10fC at $1.5 \cdot 10^{15}$ /cm² at (max) 600V
ATLAS : 4fC at $2.5 \cdot 10^{15}$ /cm² at (max) 600V

Thanks for your attention!