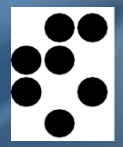
Timing measurements on neutron-irradiated LGADs in epitaxial wafers



Jožef Stefan Institute

The 39th RD50 Workshop

16-19 November 2021

J. Villegas, A. Doblas, O. Ferrer, S. Hidalgo,
G. Kramberger, N. Moffat, G. Pellegrini

Motivation

- LGADs were neutron-irradiated at fluencies ranging between 10^{14} and $5 \cdot 10^{15}$ n_{eq}/cm^2

- Time resolution, gain, collected charge and acceptor removal were measured with a TCT setup before and after irradiation

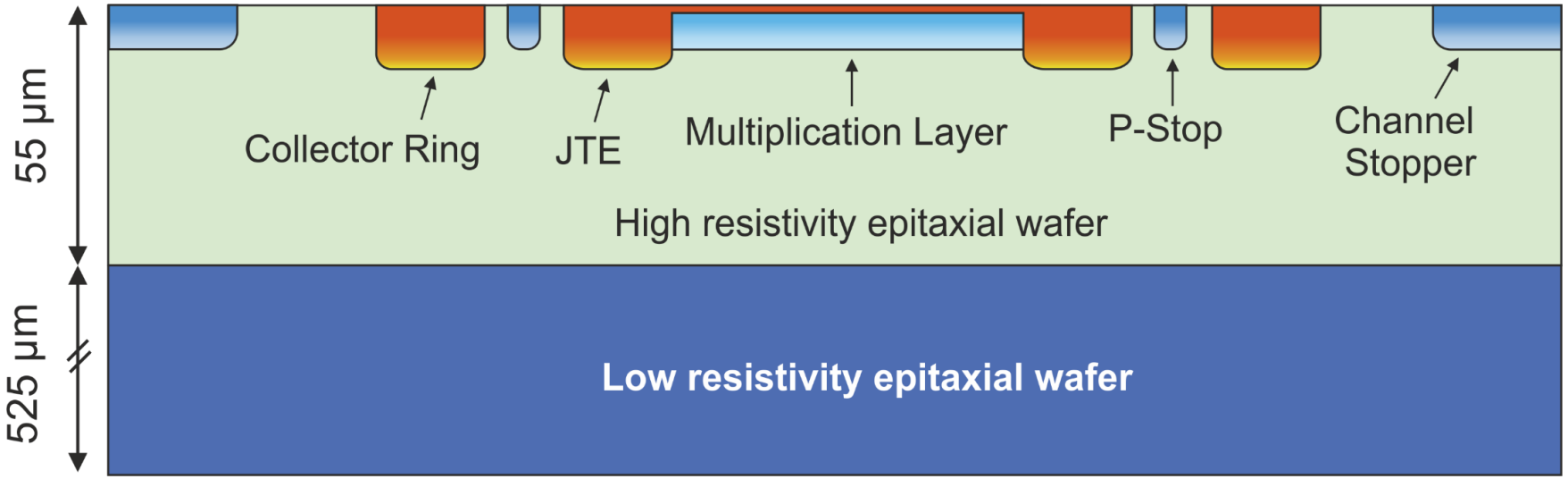
- Comply with the CMS and ATLAS market survey requirements:

CMS : 8fC & 50ps at $1.5 \cdot 10^{15}$ n_{eq}/cm^2 at (max) 600V
ATLAS : 4fC & 70ps at $2.5 \cdot 10^{15}$ n_{eq}/cm^2 at (max) 800V

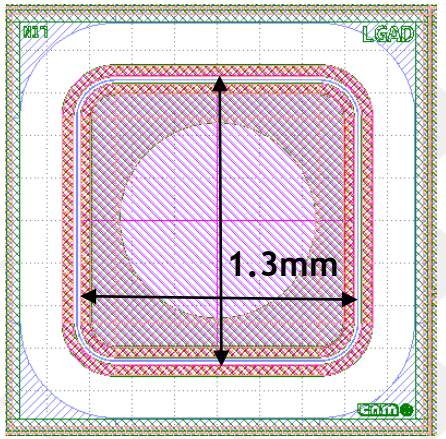
Run 13002: 6-inch LGAD in Epitaxial Wafers (6LG3)

- **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).

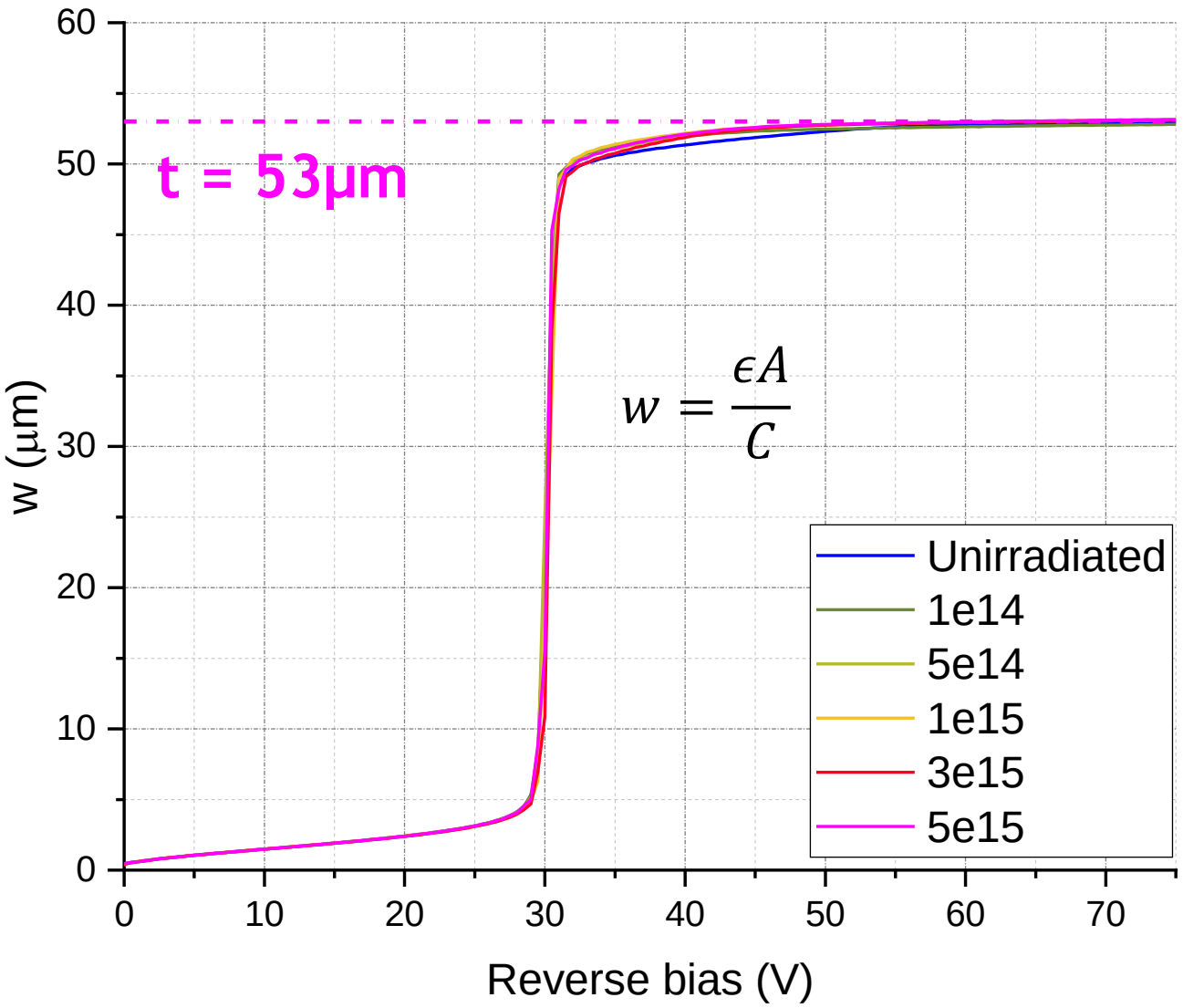
Wafer	Dose (1/cm²)	Energy (keV)
1	-	-
2	$1.9 \cdot 10^{13}$	100
3	$1.95 \cdot 10^{13}$	100
4	**$2 \cdot 10^{13}$**	**100**



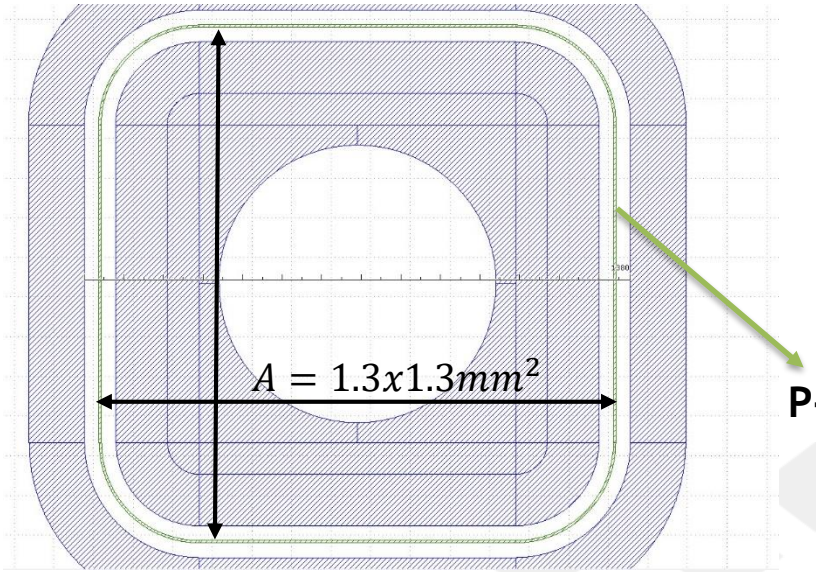
Pad device



Run13002 : active sensor thickness

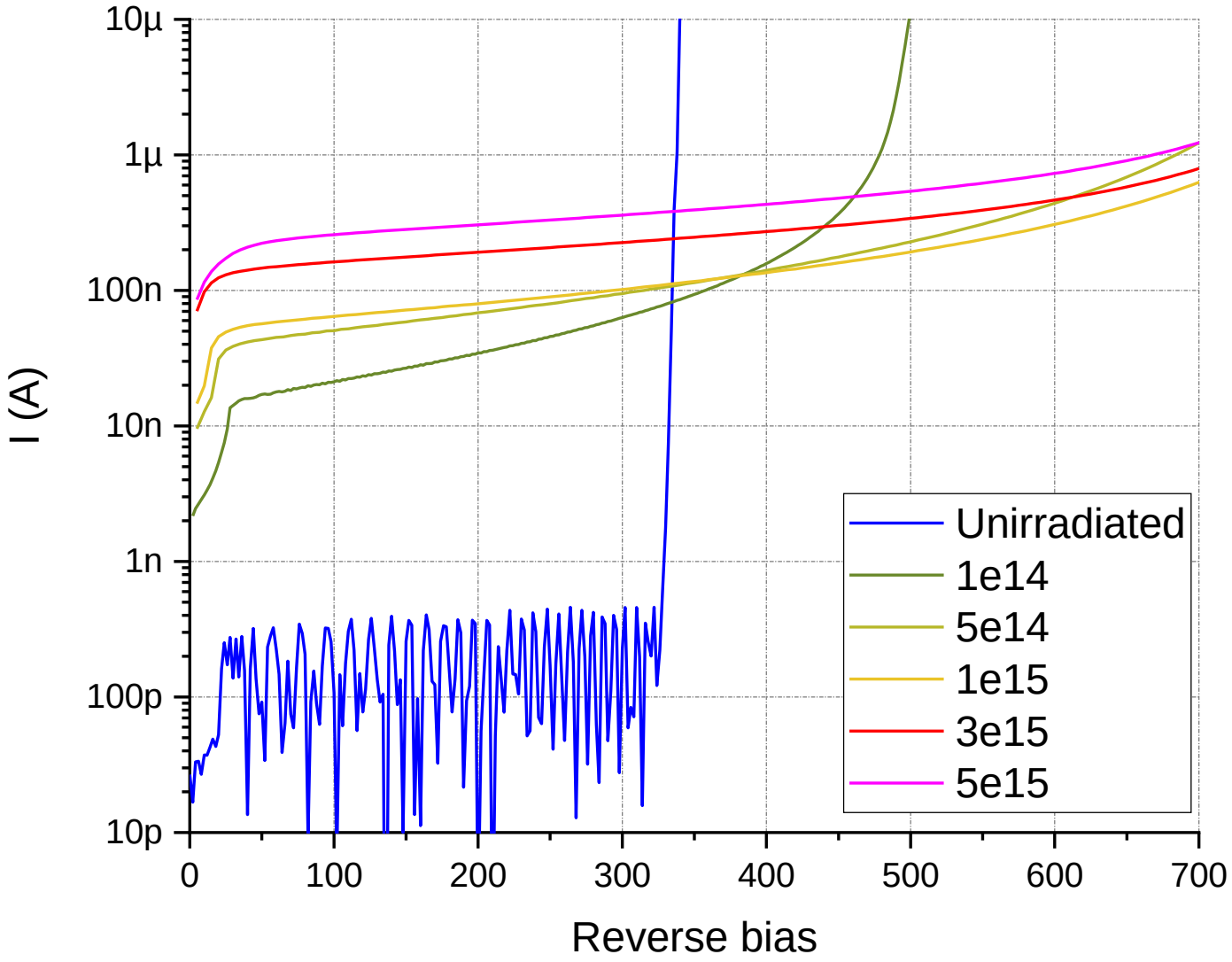


CV measurements taken before irradiation at room temperature



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

Tested LGADs : Pad current at T=-20°C

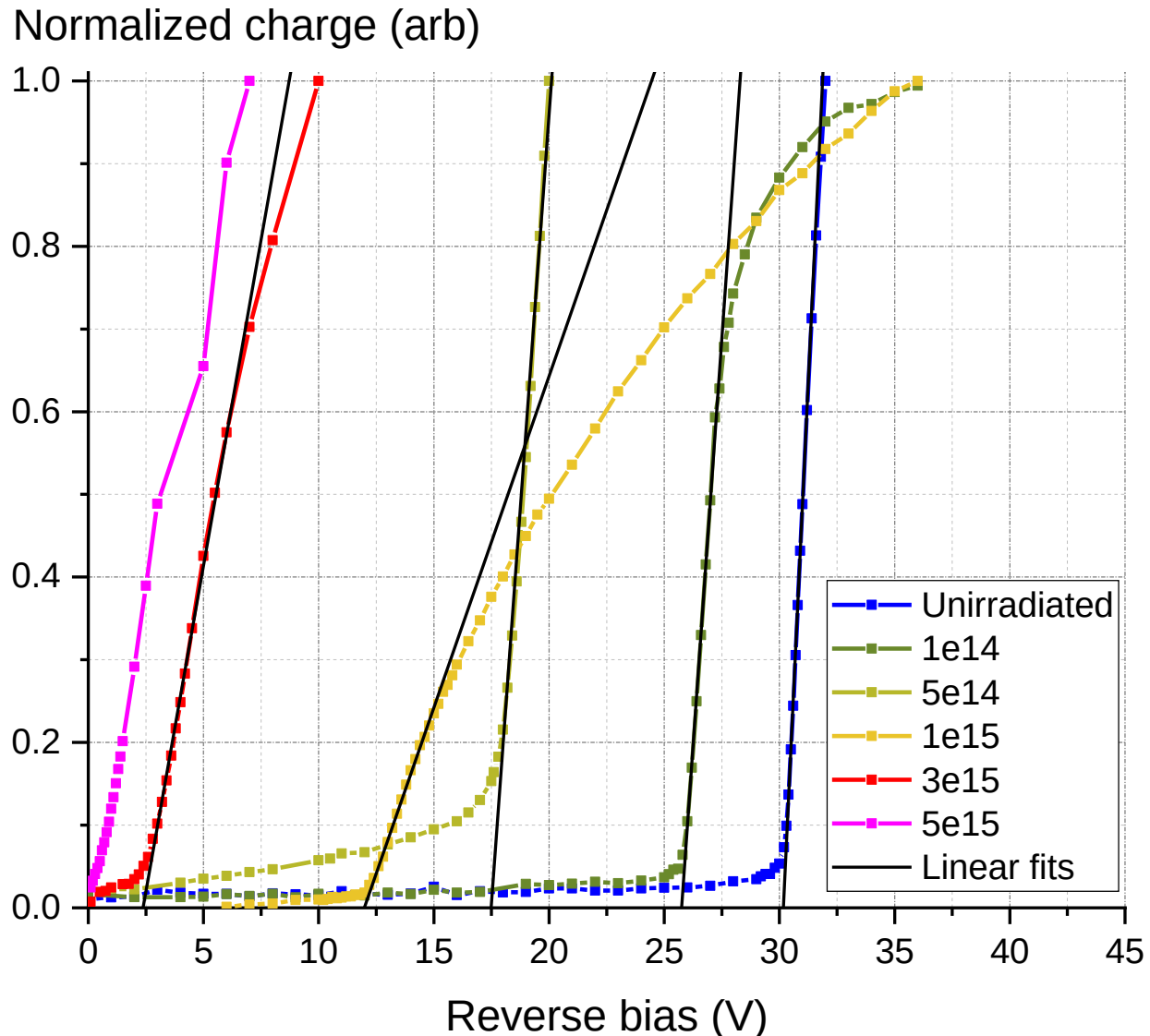


Annealing at 60°C for 80min

Φ_{eq} (n_{eq}/cm²)	Breakdown voltage (V)
-	325
10^{14}	500
$5 \cdot 10^{14}$	720*
10^{15}	780*
$3 \cdot 10^{15}$	>800*
$5 \cdot 10^{15}$	>800

***observed with the TCT setup**

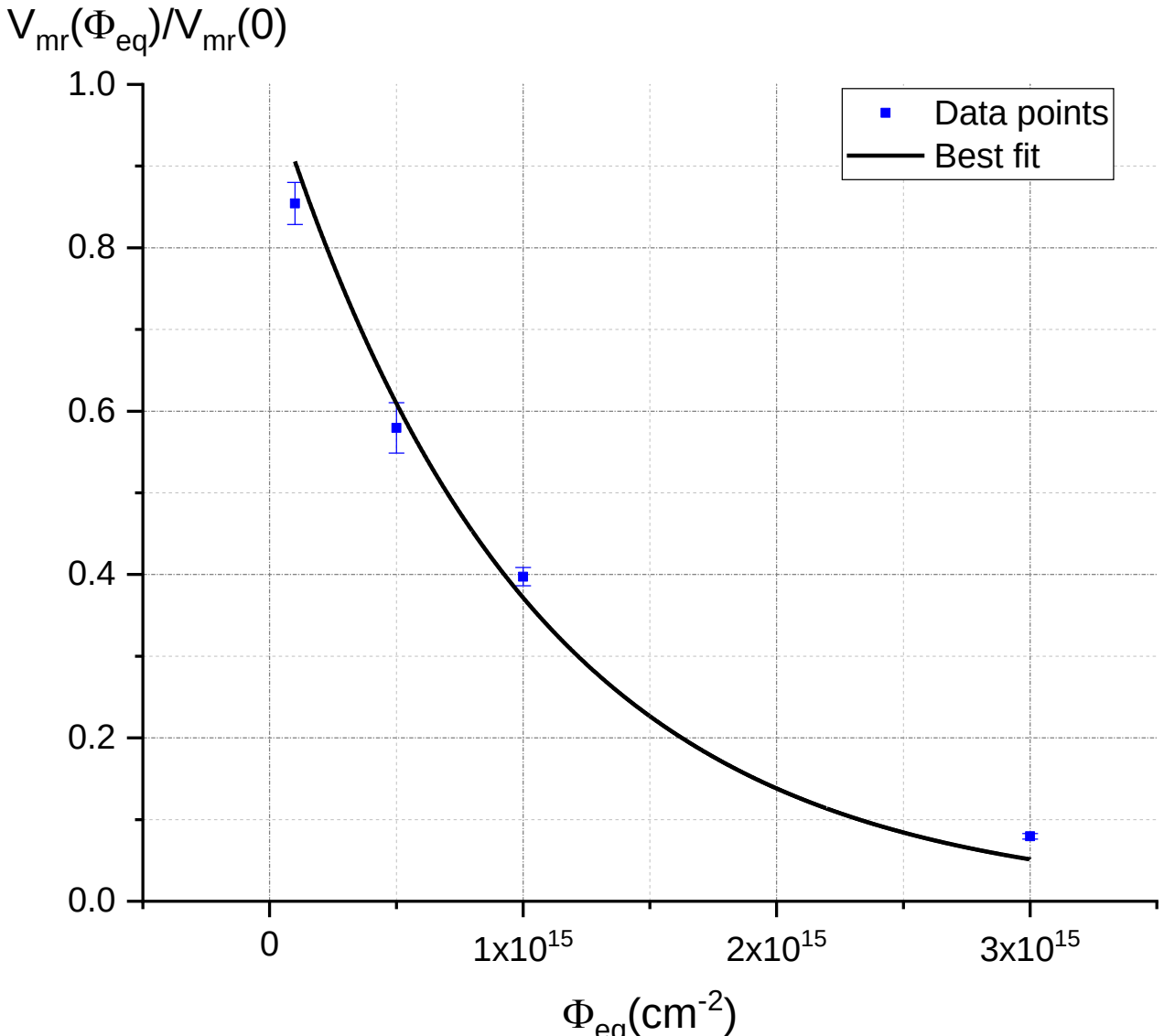
TCT measurements : Acceptor removal



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

Φ_{eq} (n_{eq}/cm^2)	V_{mr}(V)
-	30.2±0.4
10^{14}	25.8±0.7
$5{\cdot}10^{14}$	17.5±0.9
10^{15}	12.0±0.3
$3{\cdot}10^{15}$	2.4±0.1
$5{\cdot}10^{15}$	-

TCT measurements : Acceptor removal (-20°C)



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

Φ_{eq} (n_{eq}/cm²)	$\frac{V_{mr}(V)}{V_{mr}(0)}$
10^{14}	25.8±0.7
$5 \cdot 10^{14}$	17.5±0.3
10^{15}	12.0±0.2
$3 \cdot 10^{15}$	2.4±0.1

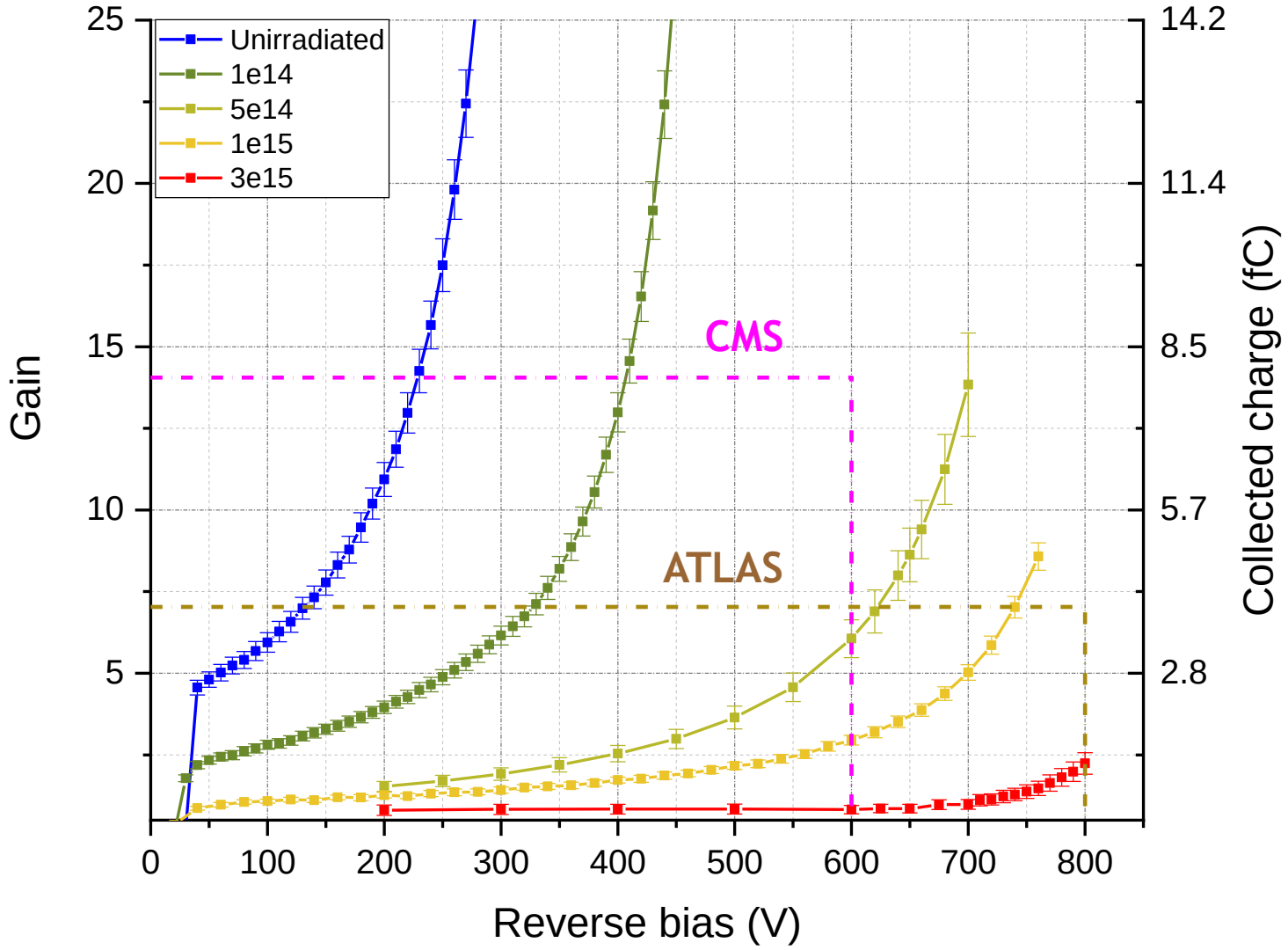
Best fit :

$$c = (9.9 \pm 0.7) \cdot 10^{-16}\text{cm}^2$$

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

Nuclear Inst. and Methods in Physics Research, A 891 (2018) 68-77

TCT measurements : gain and estimated CC for a MIP (-20°C)



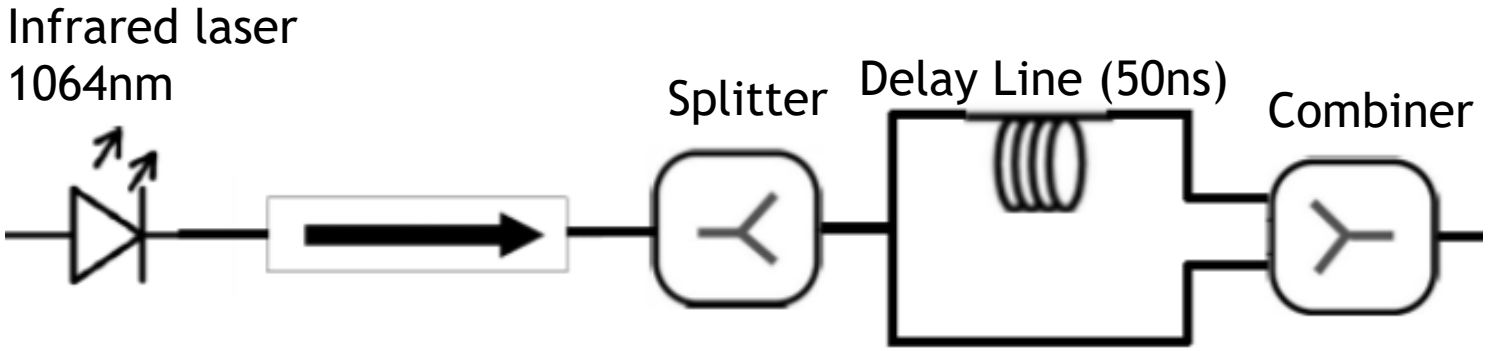
Gain=Q(LGAD)/Q(PiN)

Infrared laser (1064nm)
Signal corresponding to ~15MIPs
(no gain attenuation observed for this lgads)

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

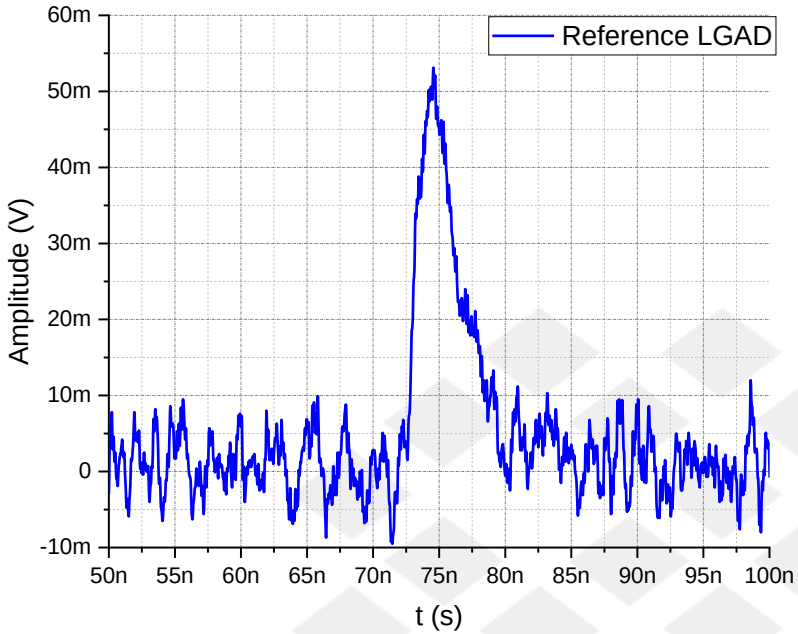
CMS : 8fC at $1.5 \cdot 10^{15}$ n_{eq}/cm² at (max) 600V
ATLAS : 4fC at $2.5 \cdot 10^{15}$ n_{eq}/cm² at (max) 800V

TCT measurements : Timing setup

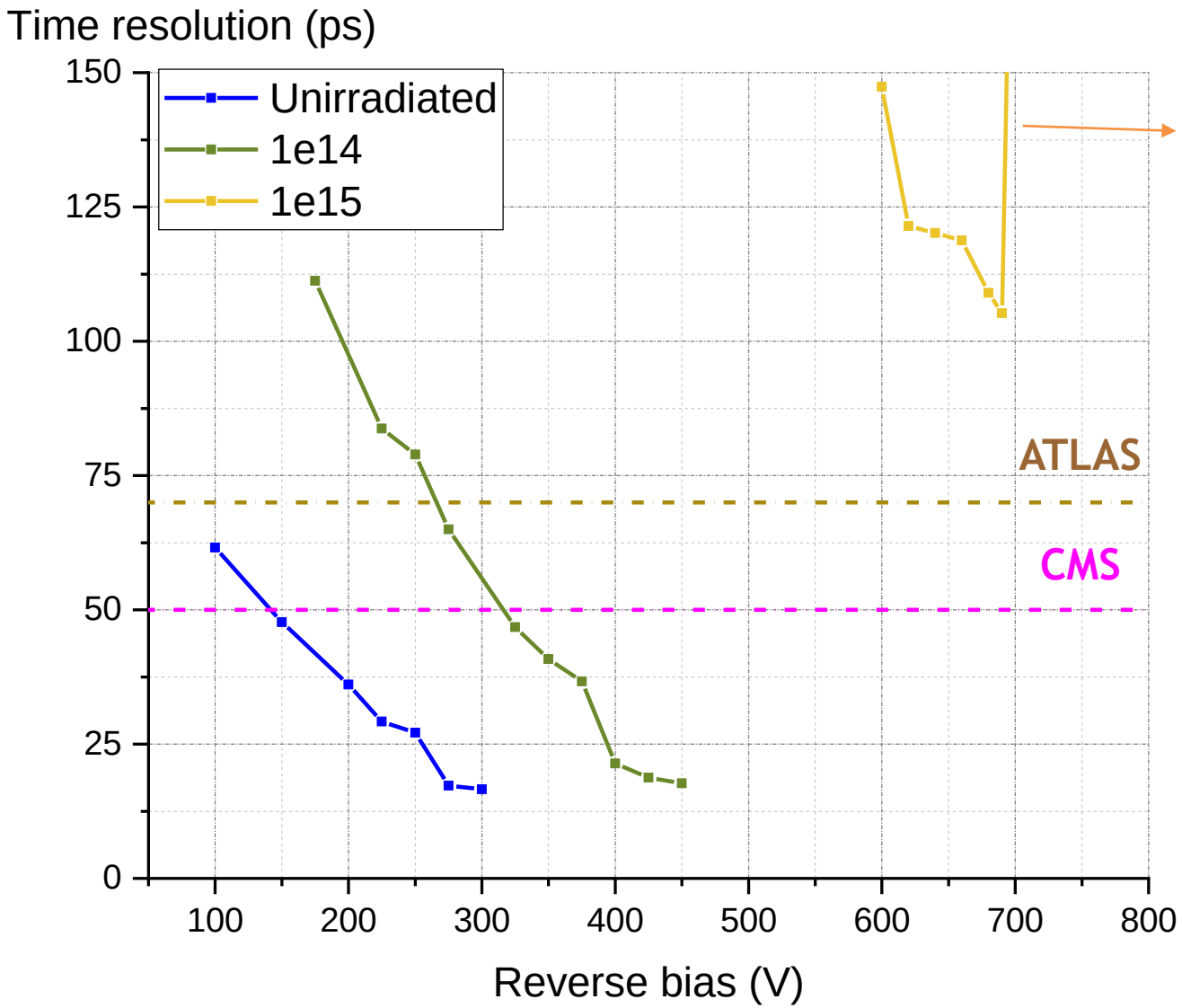


- Calibration with 90-Sr → MPV MIP peak signal = 50mV
- Time difference between signals is calculated at different CFD fractions
- Time resolution is defined as the lowest value of the Gaussian's fit sigma of the Time difference data (Generally got for CFD = 40-50%)
- Setup → Particulars ()

Ref. LGAD (from same wafer)
RT & 300V



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

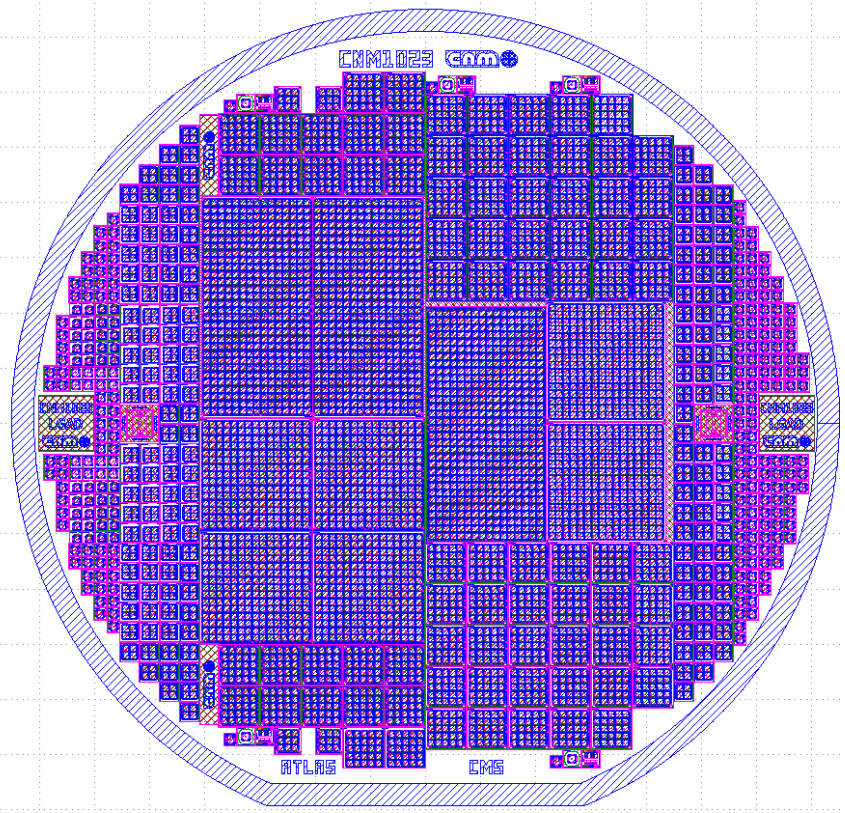


Noise increases at 700V so does time resolution (close to breakdown voltage)

CMS : 50ps at $1.5 \cdot 10^{15}$ n_{eq}/cm² at (max) 600V

ATLAS : 70ps at $2.5 \cdot 10^{15}$ n_{eq}/cm² at (max) 800V

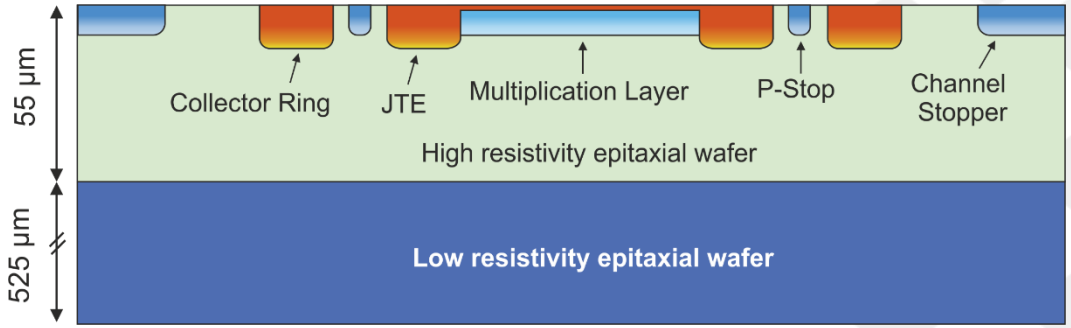
Run13840 & Run14990: 6” ATLAS-CMS Common Run (6LG3 & 6LG2)



1x1, 2x2, 5x5, 15x15 & 15x30 pixels devices of $1.3x1.3mm^2$ (ATLAS)

1x1, 2x2, 5x5, 16x16 & 16x32 pixels devices of $1.3x1.3mm^2$ (CMS)

- 10 LGAD wafers.
- 6-inch 55/525 µm **epitaxial & Si-Si** wafers.
- New diffusion furnace → Higher diffusion processes quality and uniformity
- Some of them carbonated (Epi)
- Increased implantation dose (Epi)
- Deep gain layer (Si-Si)
- Epitaxial one → It will be terminated by the end of 2021
- Si-Si one → Expected termination date : April 2022



Acknowledgements
This work has been financed by the Spanish Ministry of Science and Innovation (MCIN/AEI/10.13039/501100011033/) and by the European Union's FEDER program "a way of making Europe".
Project references: RTI2018-094906-B-C22 and FPA2017-85155-C4-2-R

Thanks for your attention!