

Fitting the LGAD simulation

F.R. Palomo¹, M.Moll², S.Otero², S.Hidalgo³, I.Vila⁴

rogelio@zipi.us.es

¹Dept. Ingeniería Electrónica, Escuela Superior de Ingenieros

Universidad de Sevilla, Spain

²PH-DT/SSD, CERN

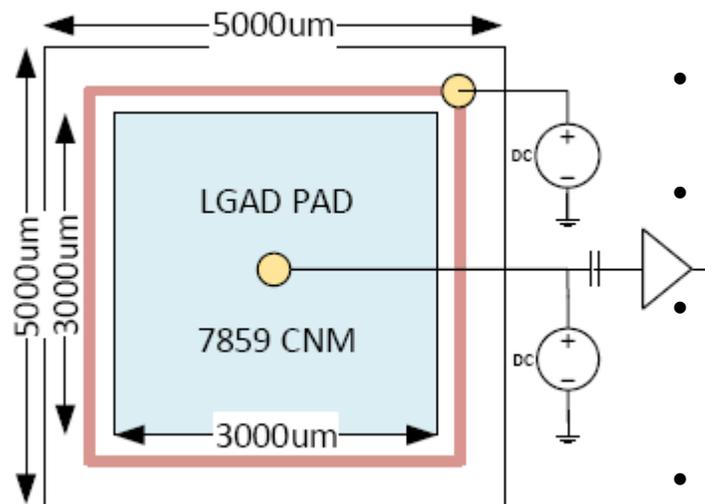
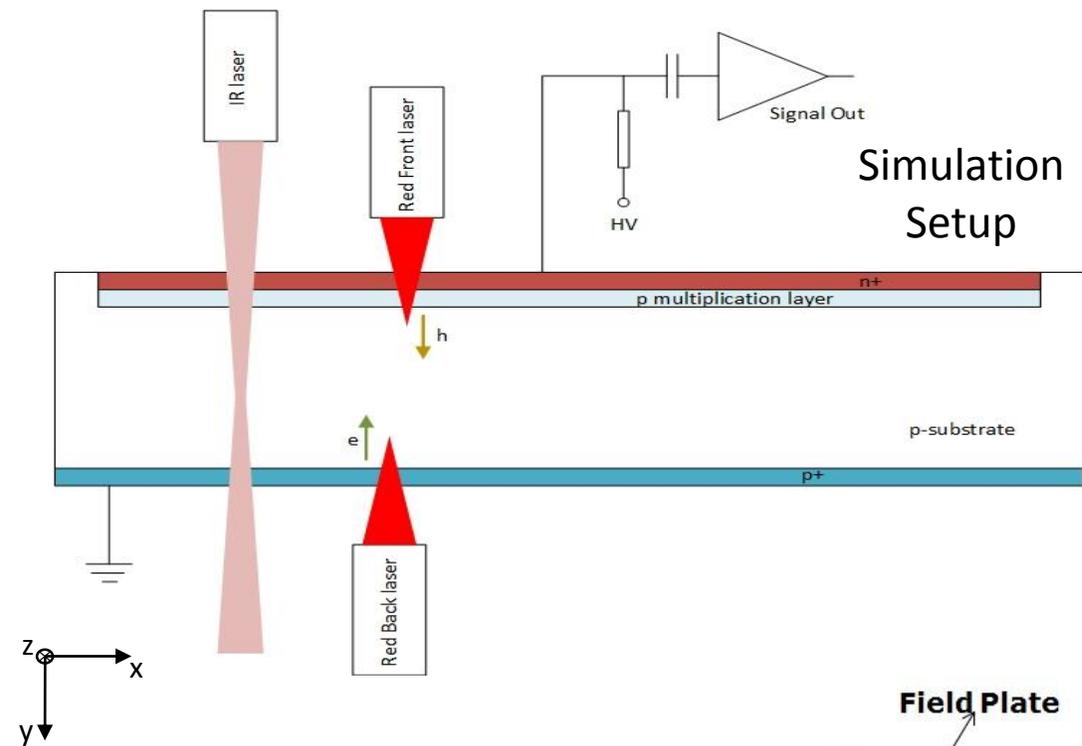
³CNM-IMB Barcelona, Spain

⁴IFCA Santander, Spain

Introduction

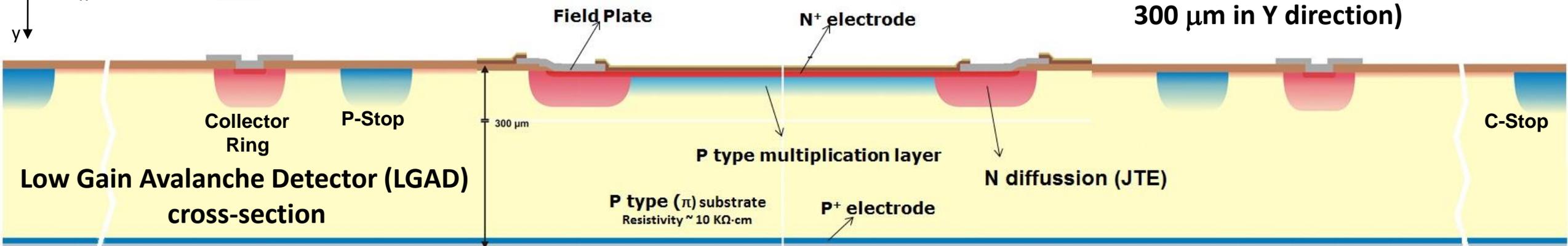
1. Development of several LGAD models to test gain variation with bias and n+/pwell doping
2. Improvement in the LGAD models compared with experimental data
3. Analisis of radiation effects in LGAD
4. Work in progress: dopant removal simulation
5. Work in progress: 50um LGAD with traps

Sentaurus TCAD Simulation SetUp



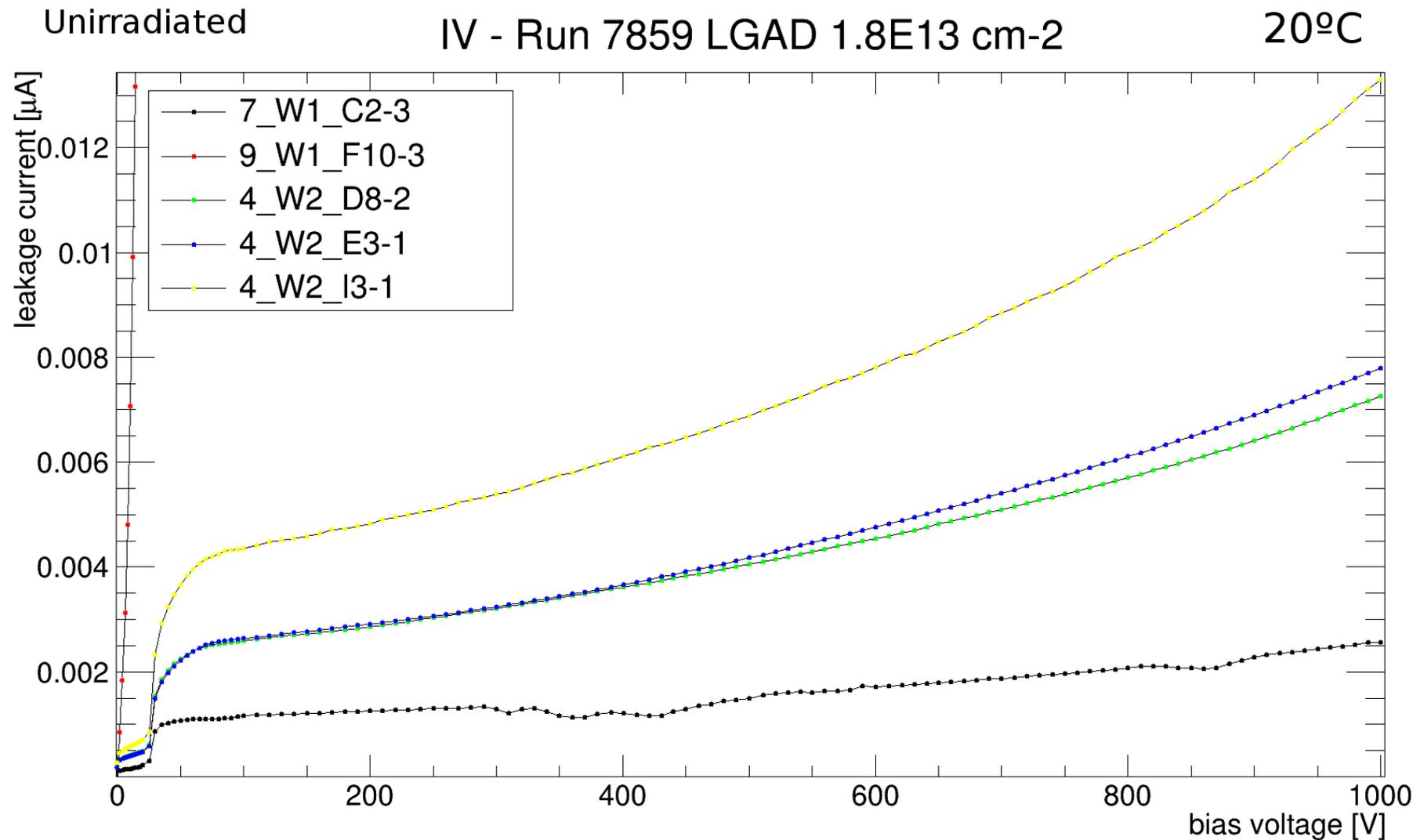
Simulation Setup:

- Red Pulsed Laser: 670 nm, 10 μm spot, 50W/cm², 200 ps,
- Backillumination at Device Center
- Frontillumination at Device Center
- IR Pulsed Laser: 1064nm, 30W/cm², 10 mm spot, 30W/cm², 200 ps at Device center
- 2D detector model: 1 μm in Z direction, 5 mm in X direction, 300 μm in Y direction)



Doping profiles under confidentiality rules

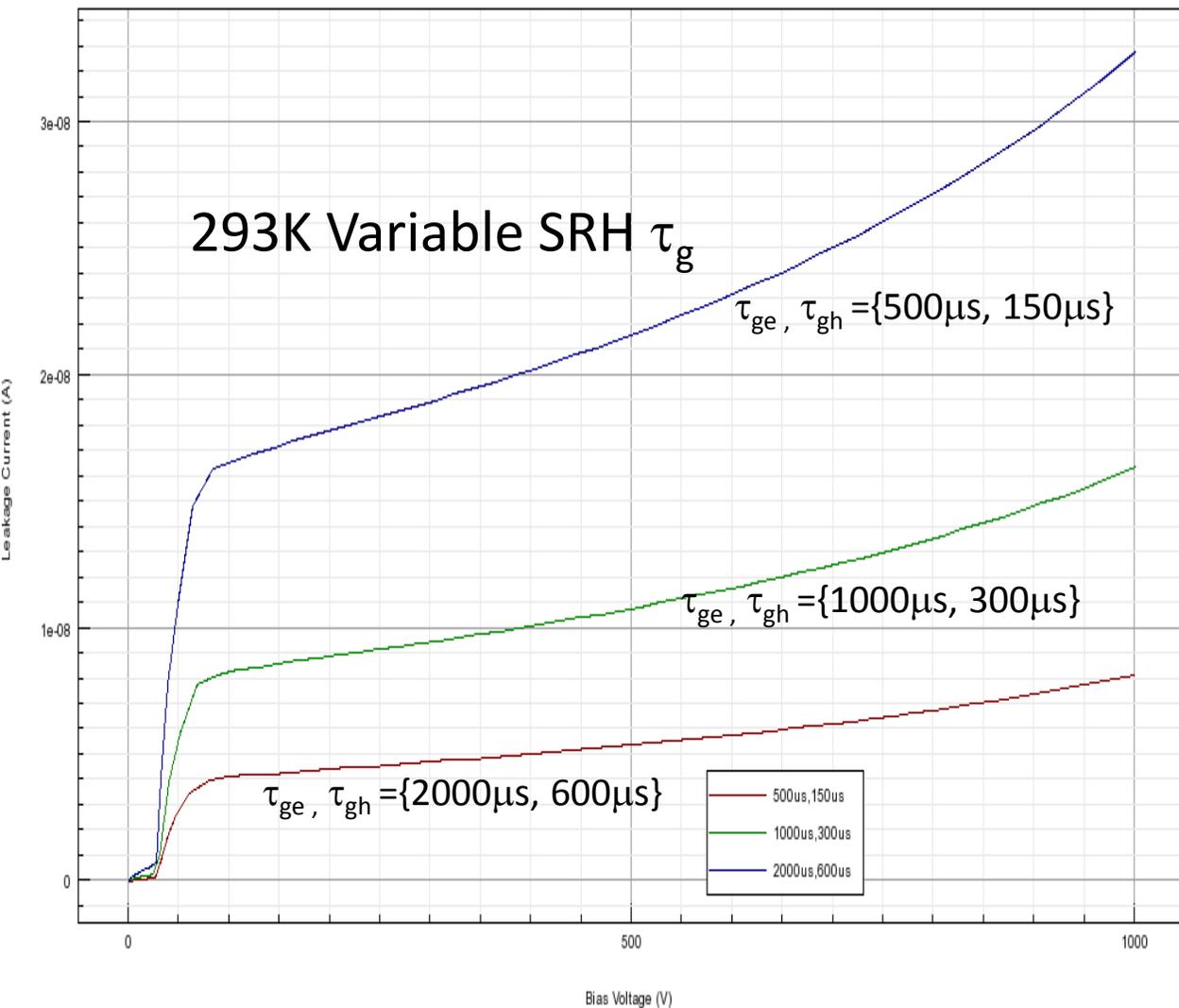
LGAD IV Experimental



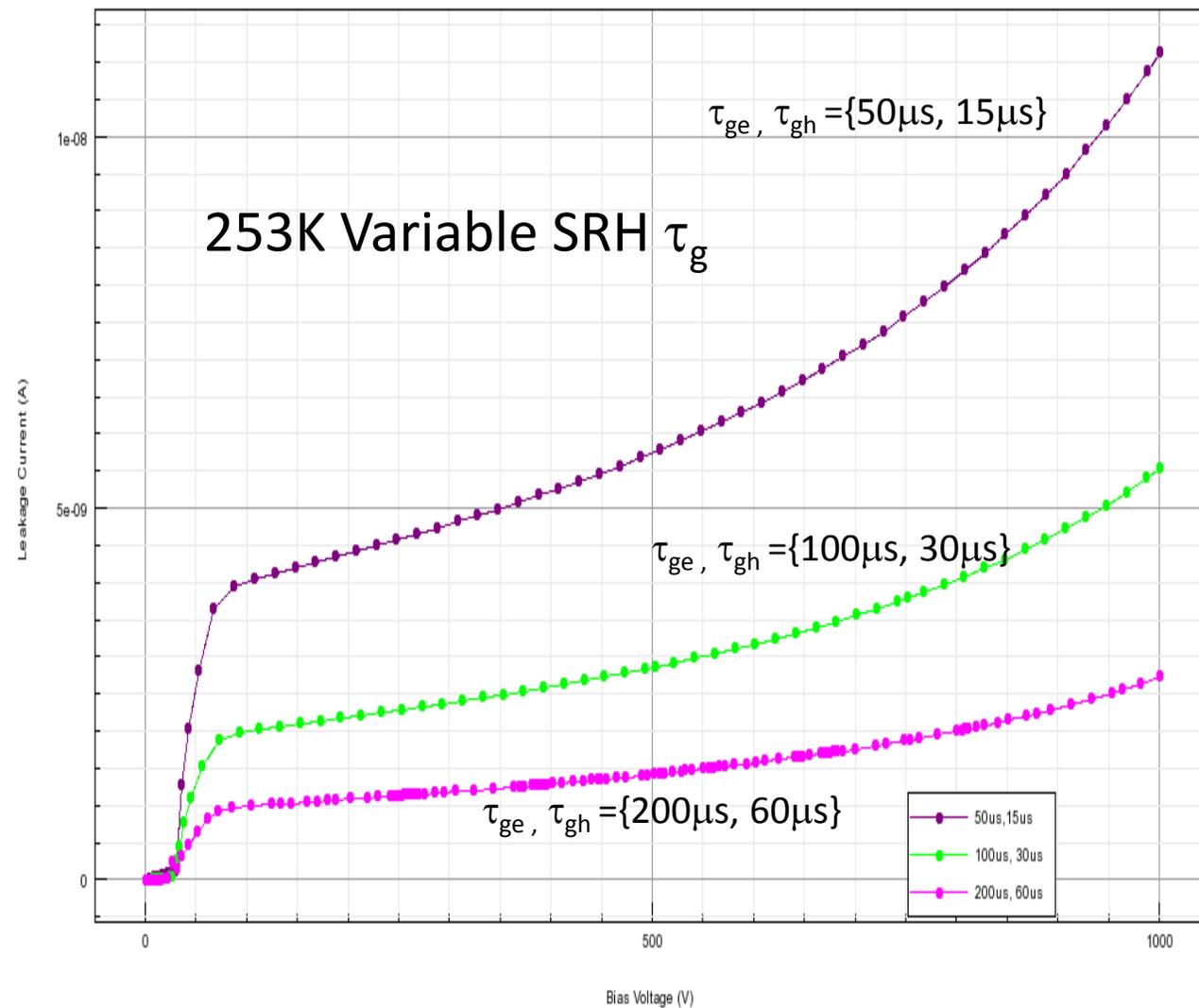
Sofia Otero Ugobono, SSD, CERN

LGAD IV

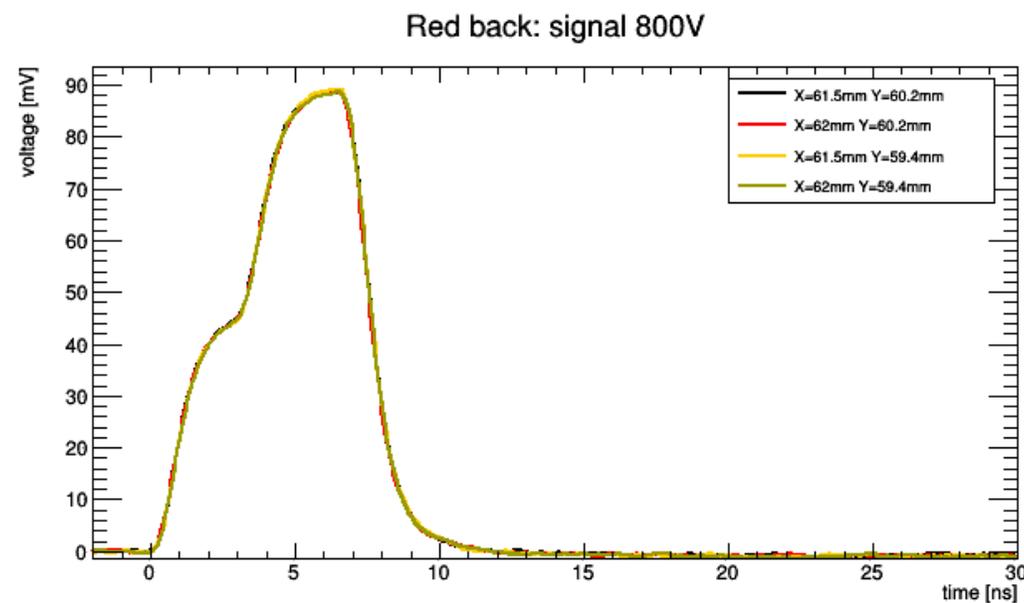
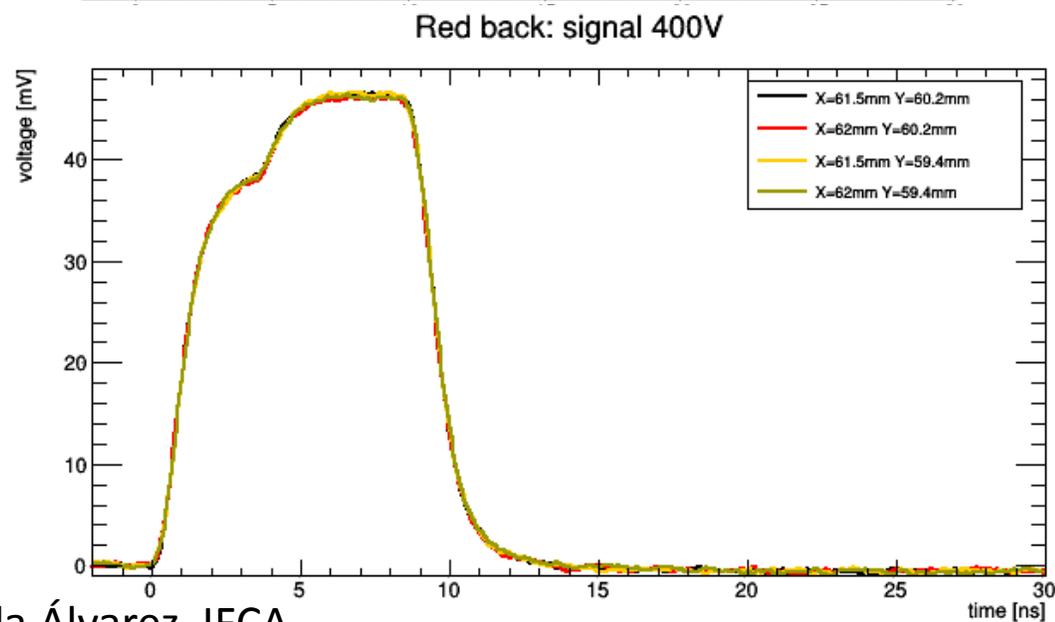
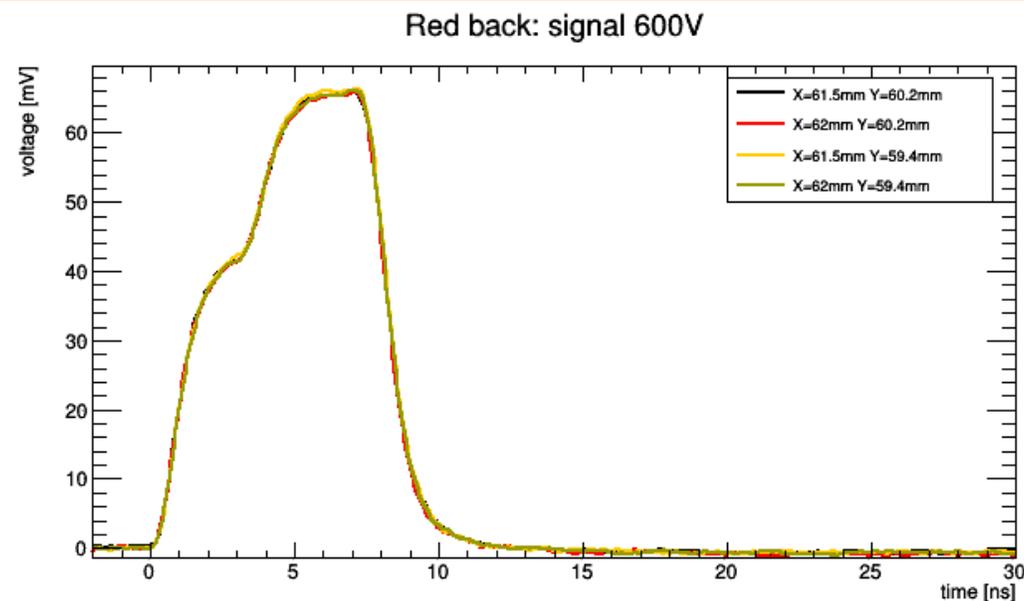
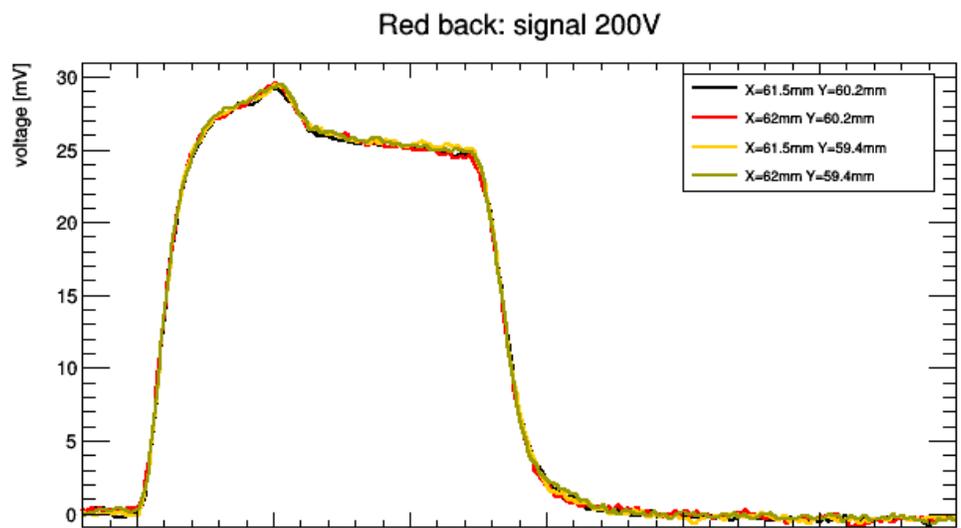
293K LGAD7859D3



253K LGAD7859D3



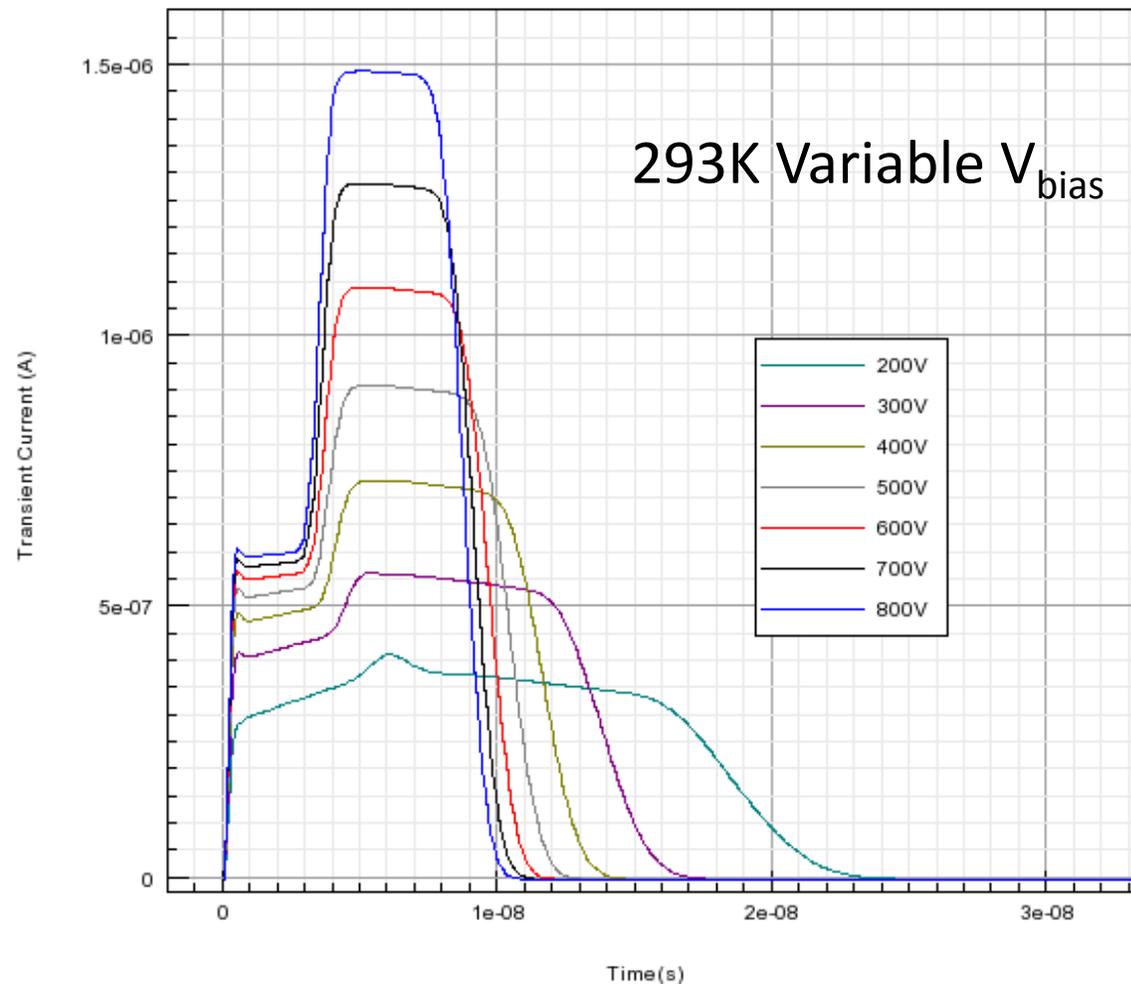
LGAD Red Laser Back Transient Experimental 293K



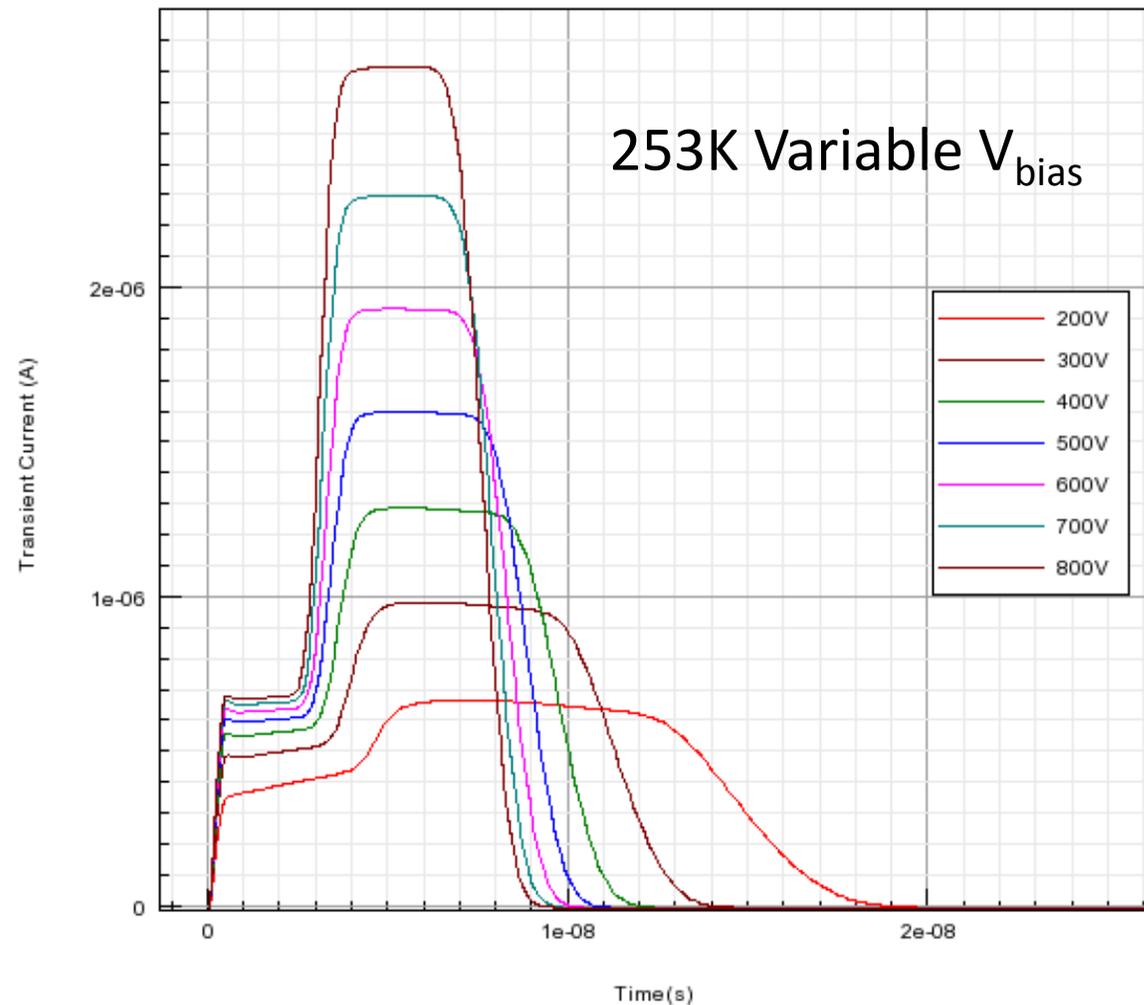
Iván Vila Álvarez, IFCA

LGAD Red Laser Back Transient (area factor 1.2 in all laser slides)

293K LGAD7859 RedLaserBack 50Wcm-2 10um 200ps

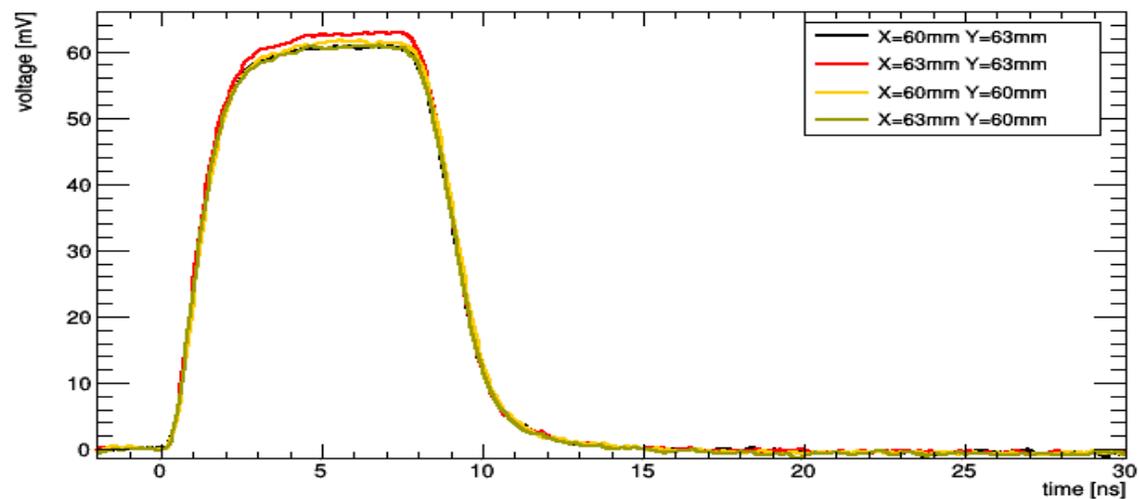


253K LGAD7859 RedLaserBack 50Wcm-2 10um 200ps

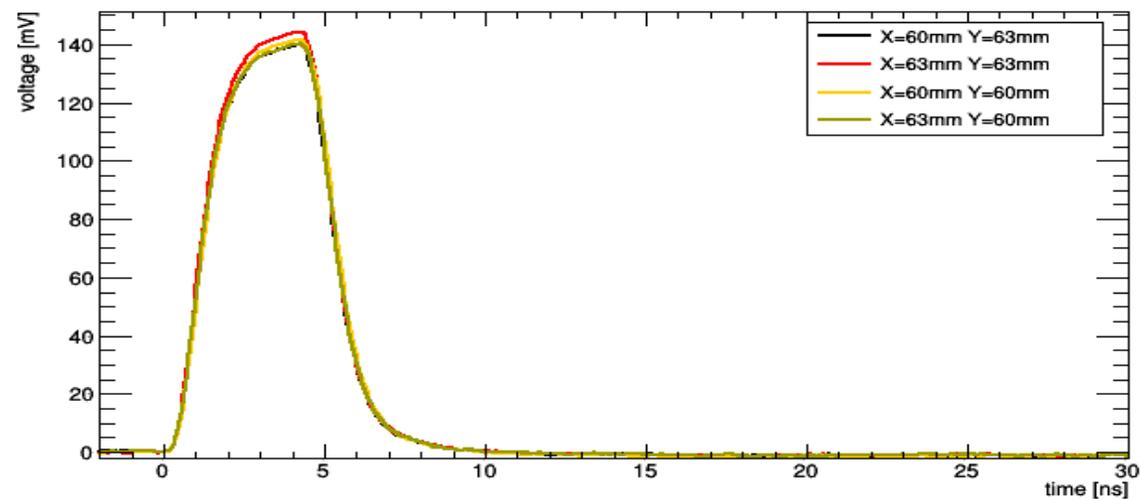


LGAD Red Laser Front Experimental

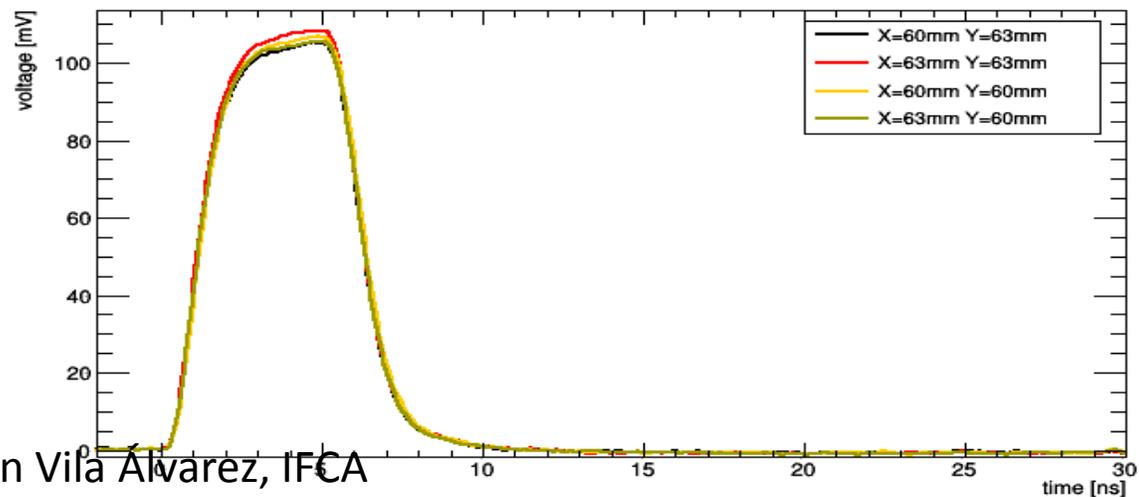
Red front: signal 200V



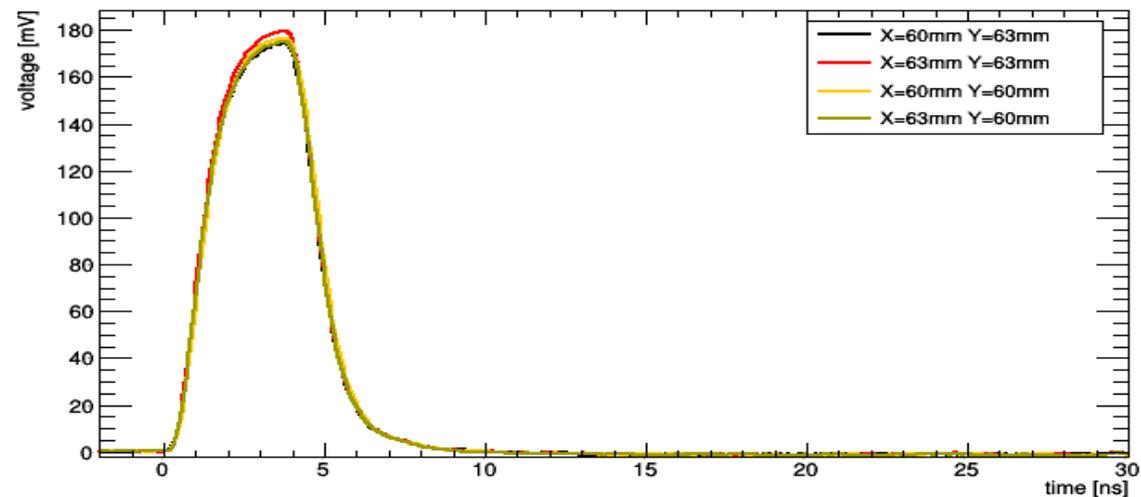
Red front: signal 600V



Red front: signal 400V



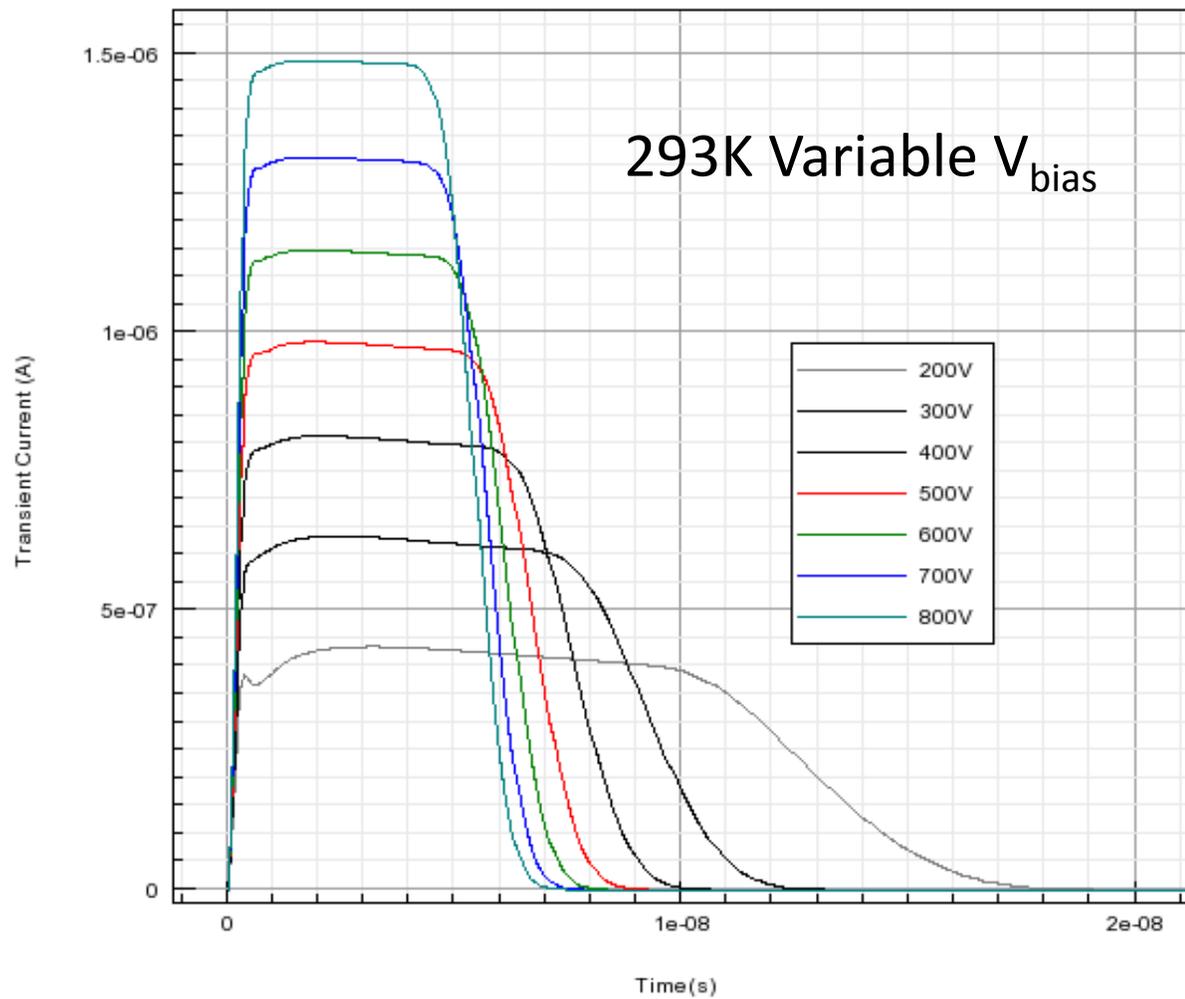
Red front: signal 800V



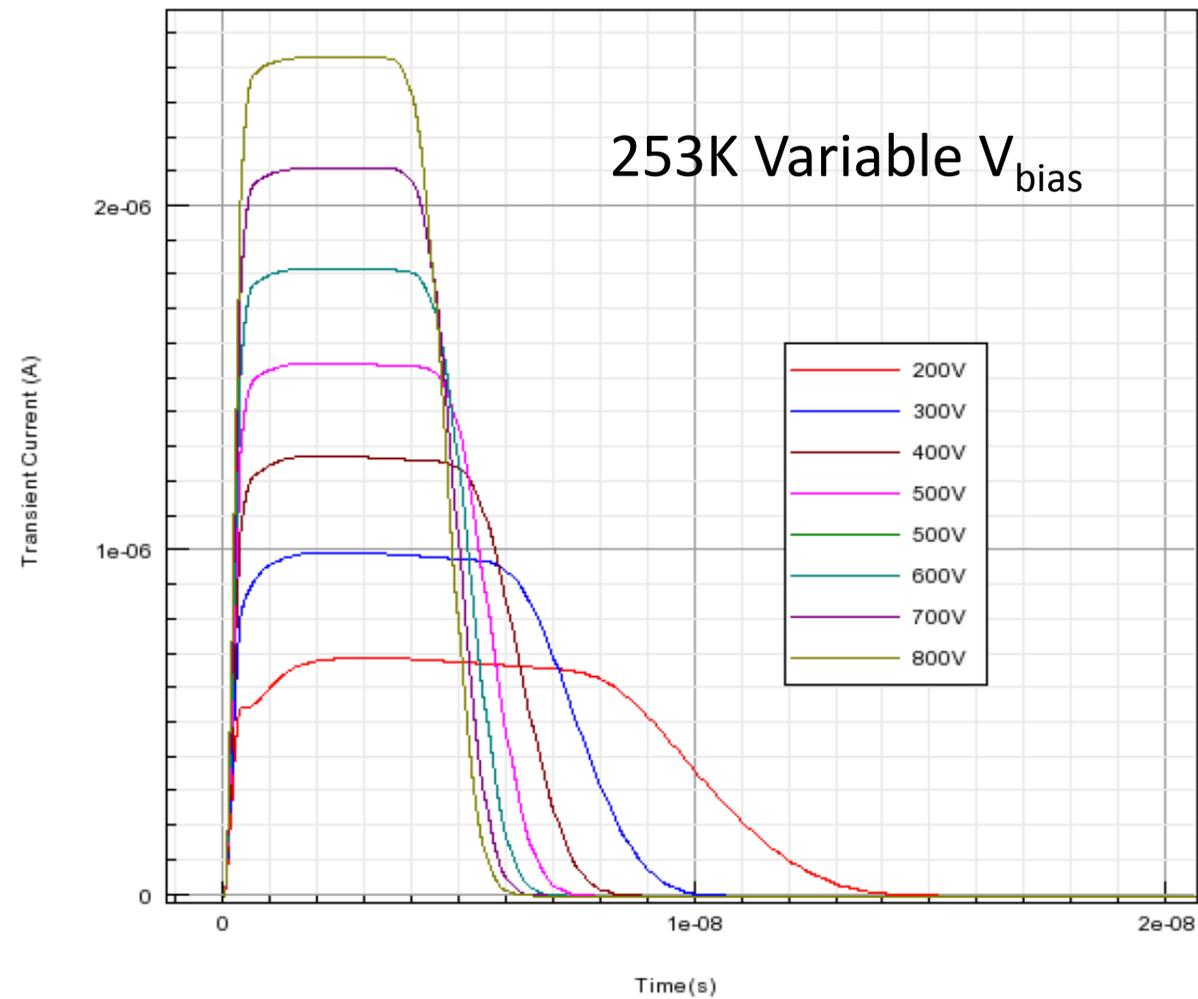
Iván Vila Álvarez, IFCA

LGAD Red Laser Front

293K LGAD7859 RedLaserFront 50Wcm-2 10um 200ps

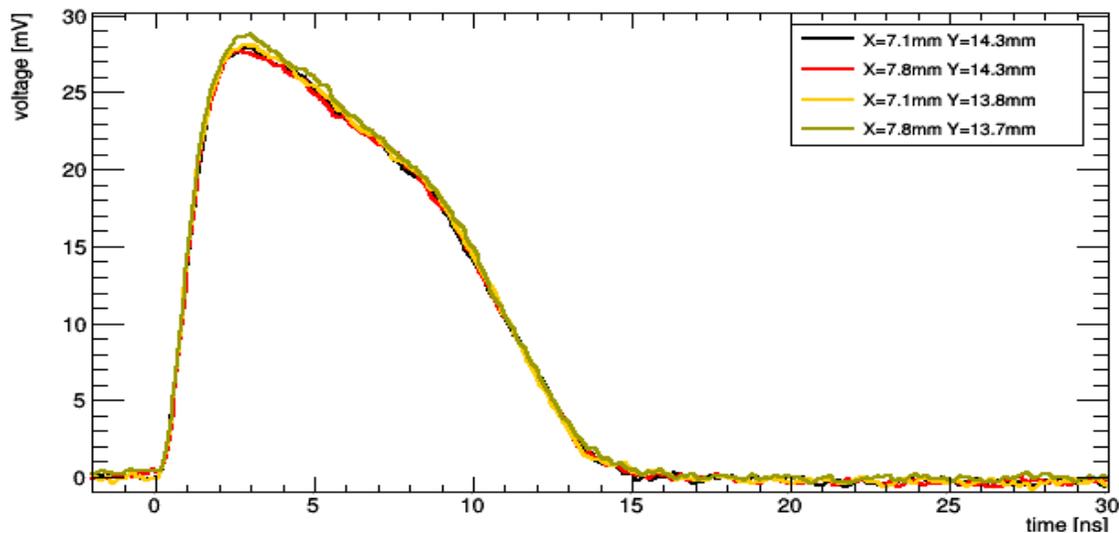


253K LGAD7859 RedLaserFront 50Wcm-2 10um 200ps

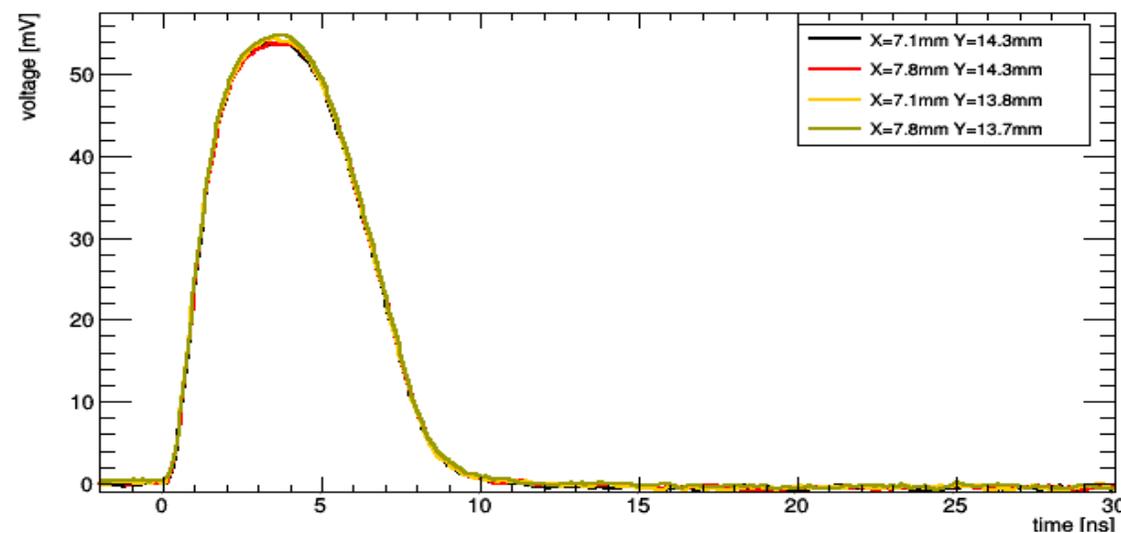


LGAD IR Laser Experimental

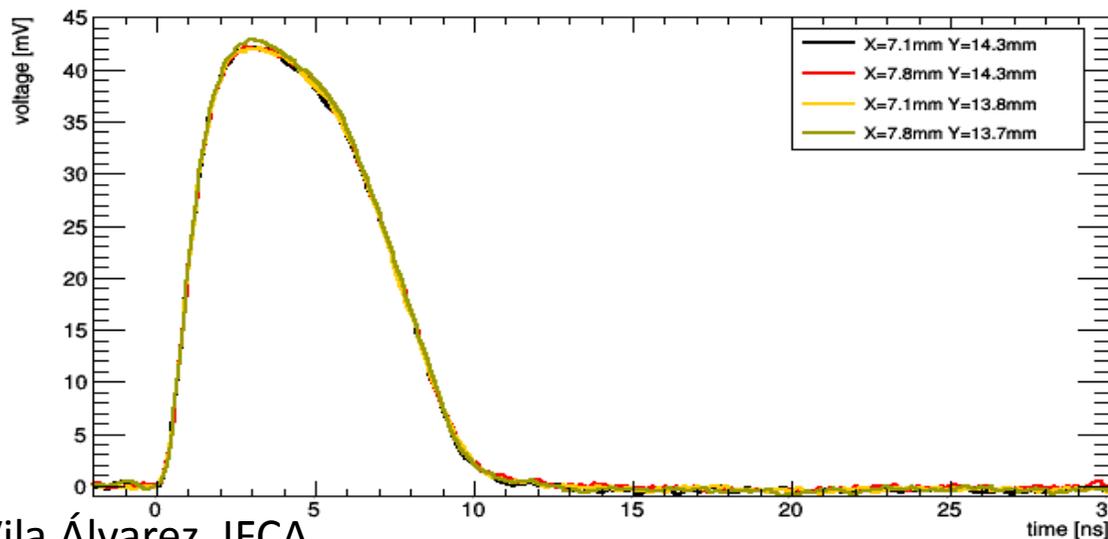
IR front: signal 200V



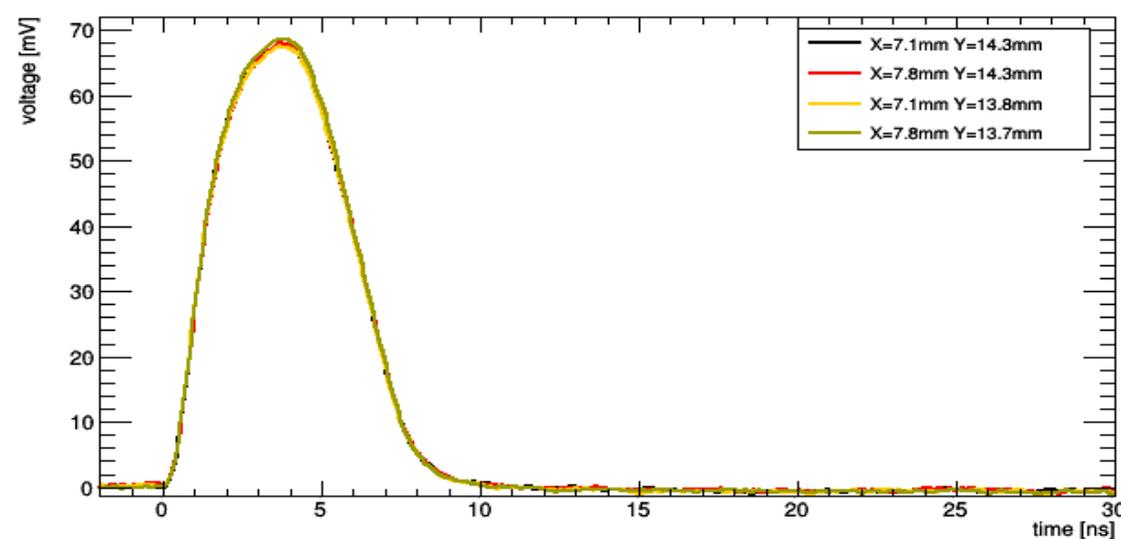
IR front: signal 600V



IR front: signal 400V



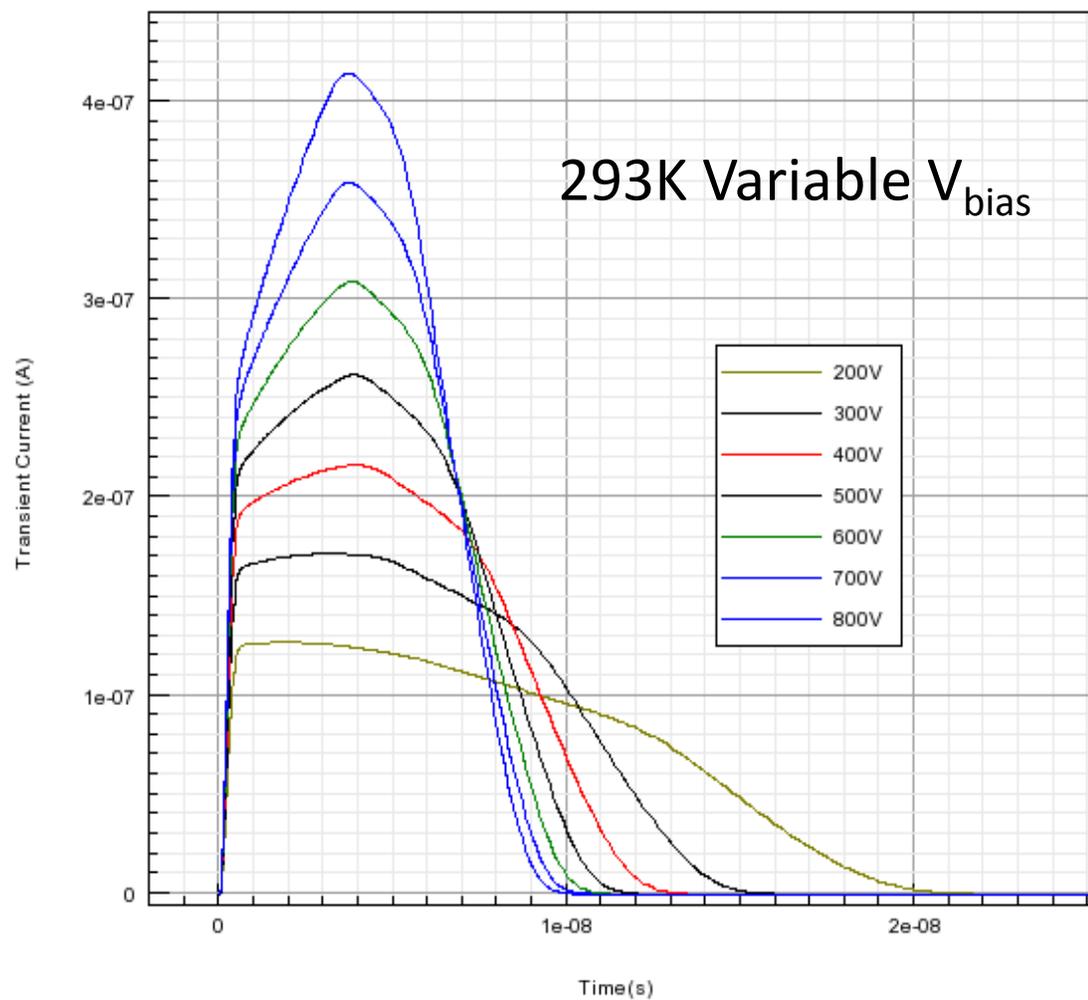
IR front: signal 800V



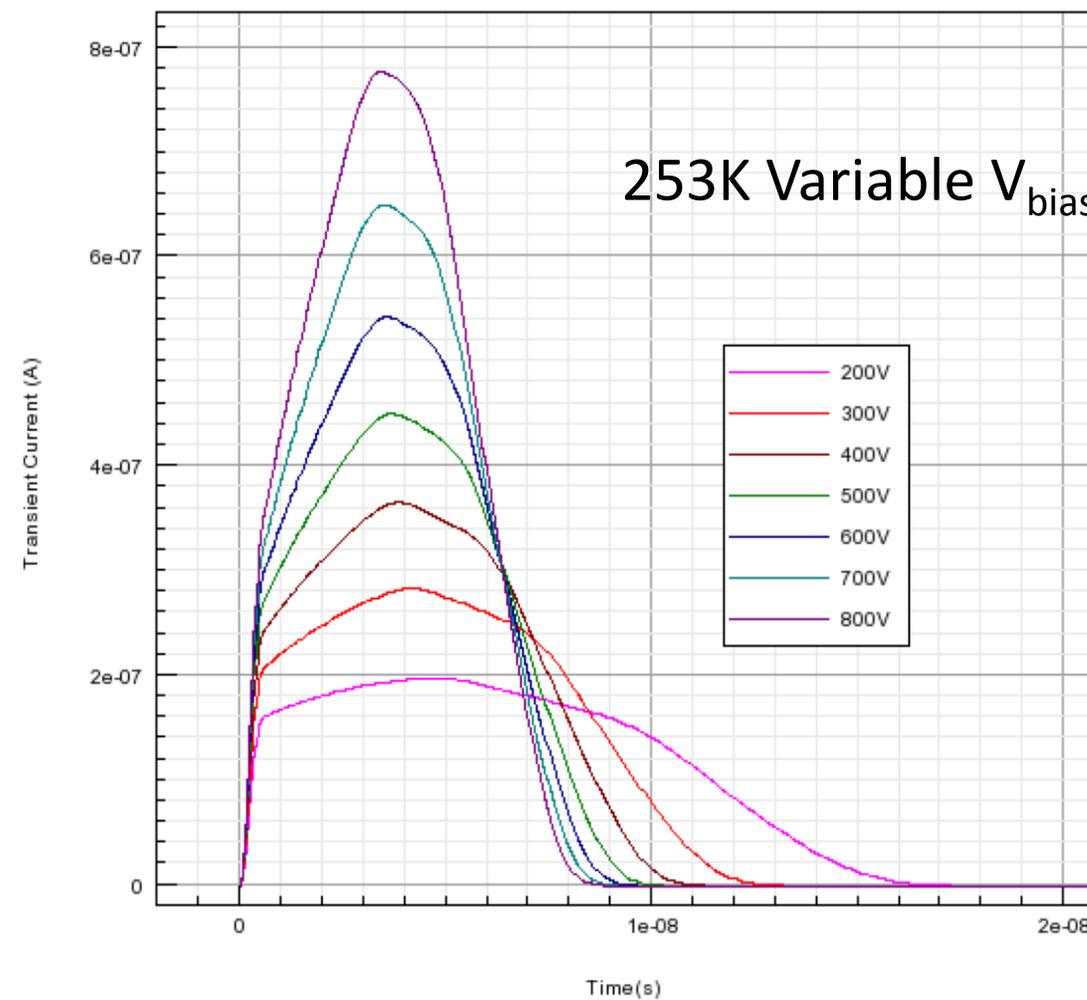
Iván Vila Álvarez, IFCA

LGAD IR Láser

293K LGAD7859 IRLaser 30Wcm-2 10um 200ps



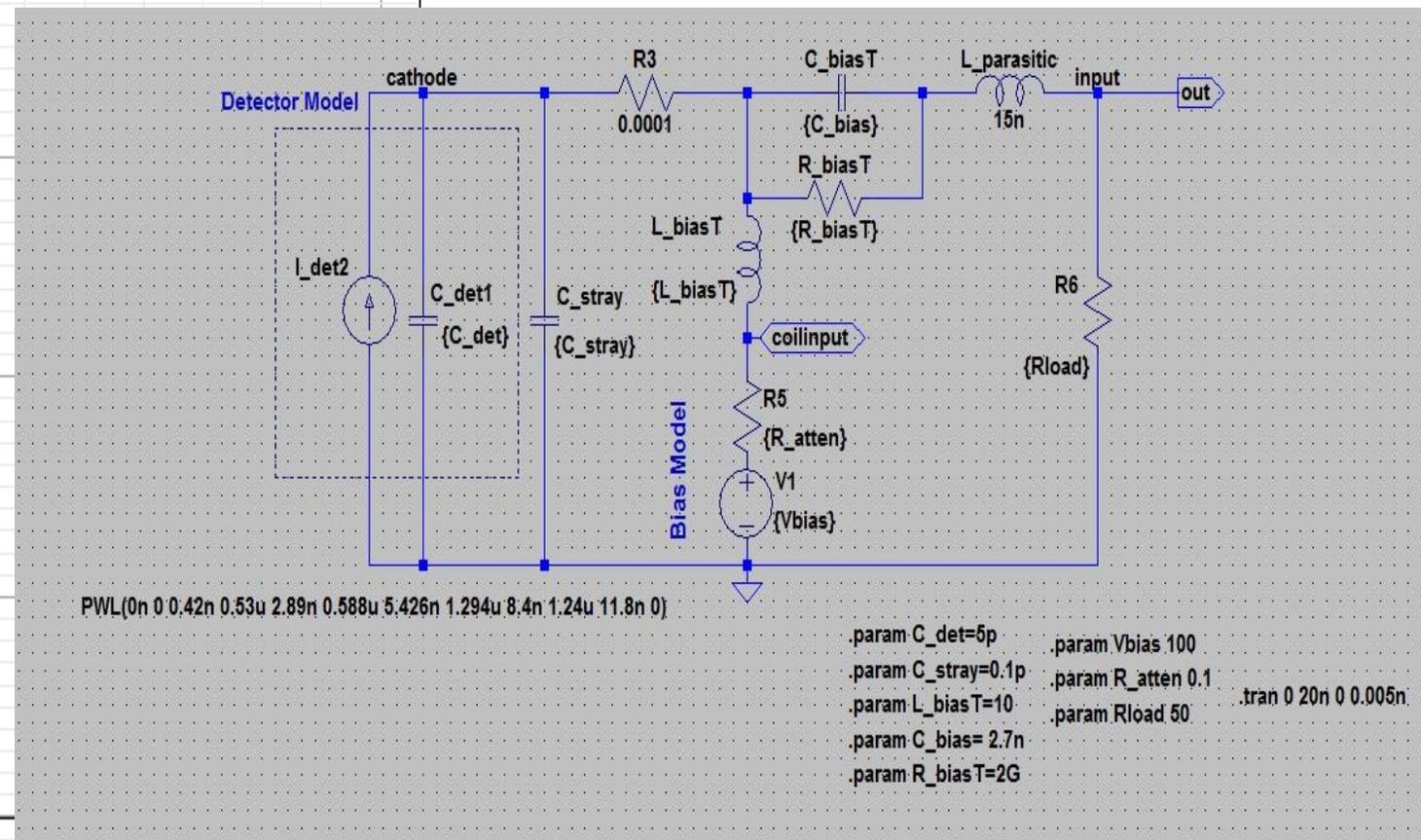
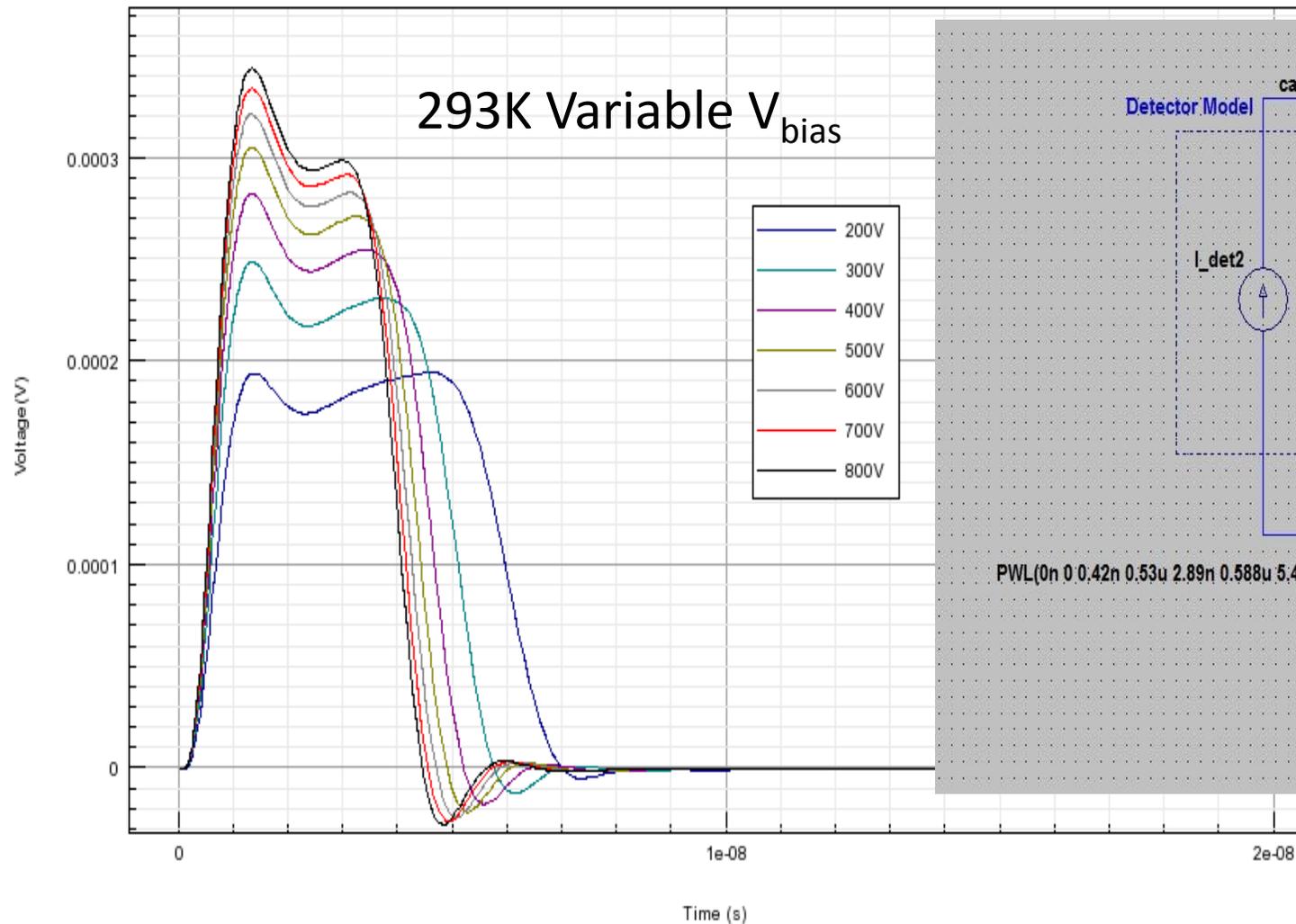
253K LGAD7859 IRLaser 30Wcm-2 10um 200ps



Parasitic Effects of Signal Conditioning

PINLGAD7859 RedLaserBack 670nm 50W/cm2 200ps 10um 293K ROCircuitOutput

293K Variable V_{bias}



Radiation Damage Models

Four damage models

1. Pennicard Model $\phi = 1e12$ up to $1e14$ n_{eq}/cm^2
2. CMS Proton and Neutron model $\phi = 1e14-1e15$ n_{eq}/cm^2
3. Two Level Model Proton $\phi = 1e14-1e15$ n_{eq}/cm^2
4. New Perugia Model $\phi = 1e12$ up to $2e16$ n_{eq}/cm^2

Parameters for fluences up to 7×10^{15} n/cm^2 . New Perugia

Defect	E (eV)	σ_e (cm ⁻²)	σ_n (cm ⁻²)	η
Acceptor	$E_c - 0.42$	1.00×10^{-15}	1.00×10^{-14}	1.6
Acceptor	$E_c - 0.46$	7.00×10^{-15}	7.00×10^{-14}	0.9
Donor	$E_v + 0.36$	3.23×10^{-13}	3.23×10^{-14}	0.9

Parameters for fluences within 7×10^{15} n/cm^2 and 2.2×10^{16} n/cm^2 .

Defect	E (eV)	σ_e (cm ⁻²)	σ_n (cm ⁻²)	η
Acceptor	$E_c - 0.42$	1.00×10^{-15}	1.00×10^{-14}	1.6
Acceptor	$E_c - 0.46$	3.00×10^{-15}	3.00×10^{-14}	0.9
Donor	$E_v + 0.36$	3.23×10^{-13}	3.23×10^{-14}	0.9

Modeling of radiation damage effects in silicon detectors at high fluences HL-LHC with Sentaurus TCAD, D.Passeri et al, NIMA 824 (2016), 443-445

CMS Proton Model

Defect	Energy (eV)	σ_e (cm ²)	σ_h (cm ²)	η (cm ⁻¹)	Concentration (cm ⁻³)
Acceptor	$E_c - 0.525$	10^{-14}	10^{-14}	—	$1.189 \times \Phi + 6.454 \times 10^{13}$
Donor	$E_v + 0.48$	10^{-14}	10^{-14}	—	$5.598 \times \Phi - 3.959 \times 10^{14}$

CMS Neutron Model

Defect	Energy (eV)	σ_e (cm ²)	σ_h (cm ²)	η (cm ⁻¹)	Concentration (cm ⁻³)
Acceptor	$E_c - 0.525$	1.2×10^{-14}	1.2×10^{-14}	1.55	$1.55 \times \Phi$
Donor	$E_v + 0.48$	1.2×10^{-14}	1.2×10^{-14}	1.395	$1.395 \times \Phi$

Simulation of Silicon Devices for the CMS Phase II Tracker Upgrade CMS Note 250887

Pennicard Model			$N(\text{cm}^{-3}) = \eta_{\text{int}} \times \phi$		
Type	Energy (eV)	Defect	σ_e (cm ²)	σ_h (cm ²)	η (cm ⁻¹)
Acceptor	$E_C - 0.42$	VV	$*9.5 \times 10^{-15}$	$*9.5 \times 10^{-14}$	1.613
Acceptor	$E_C - 0.46$	VVV	5.0×10^{-15}	5.0×10^{-14}	0.9
Donor	$E_V + 0.36$	C _i O _i	$*3.23 \times 10^{-13}$	$*3.23 \times 10^{-14}$	0.9

Simulations of radiation-damaged 3D detectors for the Super-LHC, D.Pennicard et al. NIMA 592(1-2), 2008, pp16-25

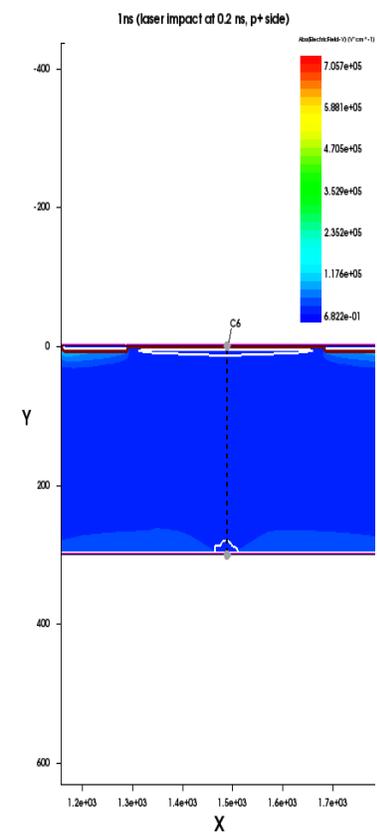
Eremin et al two level model* $N(\text{cm}^{-3}) = g_{\text{int}} \times \phi$

No.	Trap	Energy Level	g_{int} (cm ⁻¹)	σ_e (cm ⁻²)	σ_h (cm ⁻²)
1.	Acceptor	$E_c - 0.525$ eV	0.8	4×10^{-14}	4×10^{-14}
2.	Donor	$E_v + 0.48$ eV	0.8	4×10^{-14}	4×10^{-14}

Combined effect of bulk and Surface damage on strip insulation properties of proton irradiated n+-p silicon strip sensors, R.Dalal et al. JINST 2014 9 P04007
 *The origin of double peak electric field distribution in heavily irradiated silicon detectors, V.Eremin, E.Verbitskaya, Z.Li, NIMA 476 (2002) 556-564

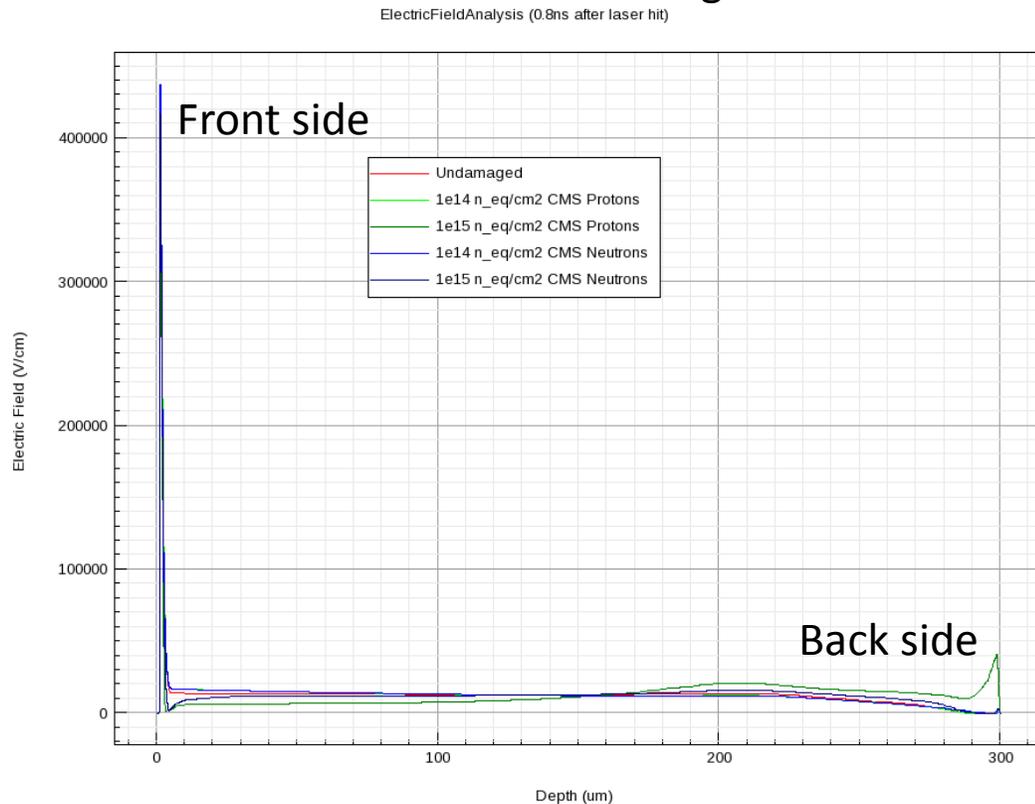
LGAD

All Models show a similar panorama, for example: CMS Model

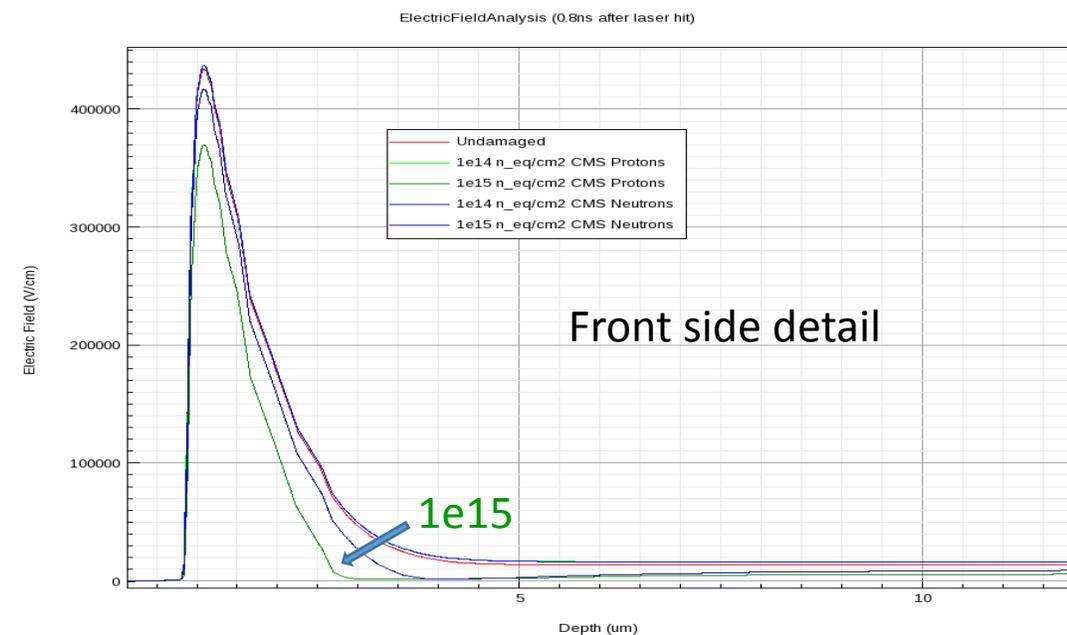
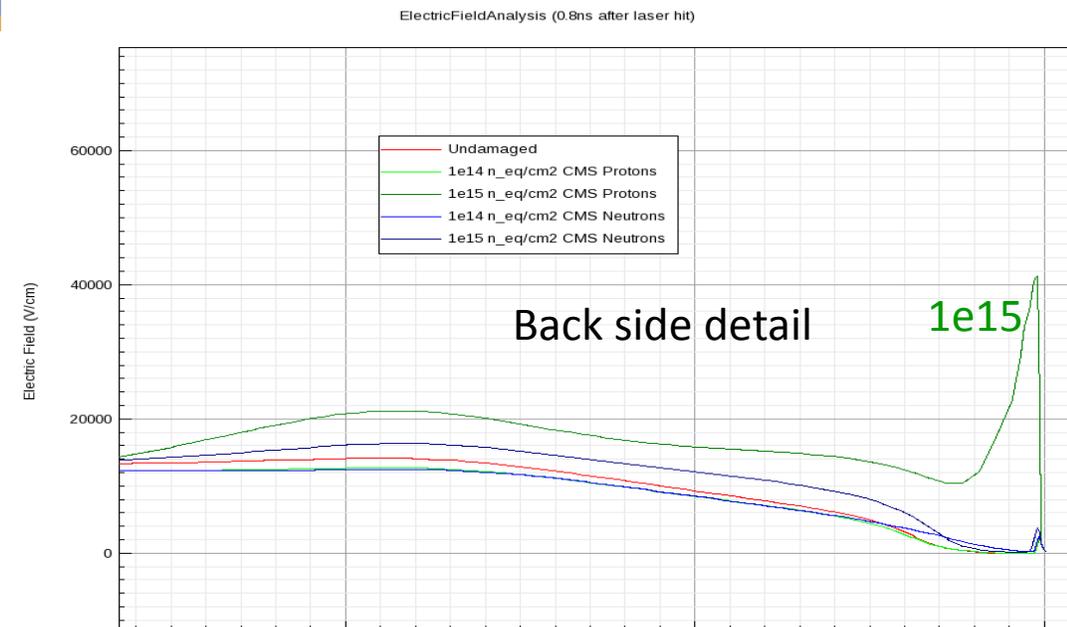


Electric Field Profiling

Electric Field along Y axis

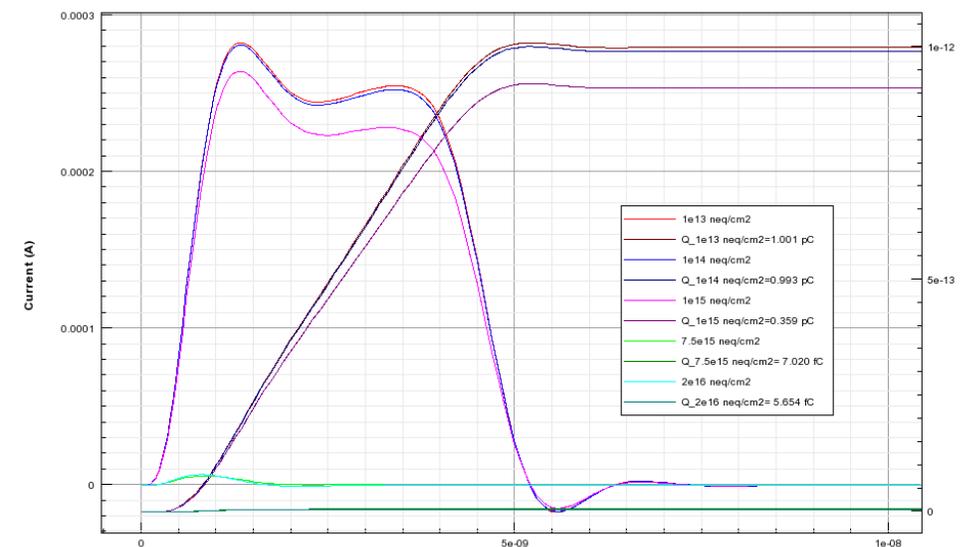


At 1e15 a double junction appears at P+ volumen (device back side)

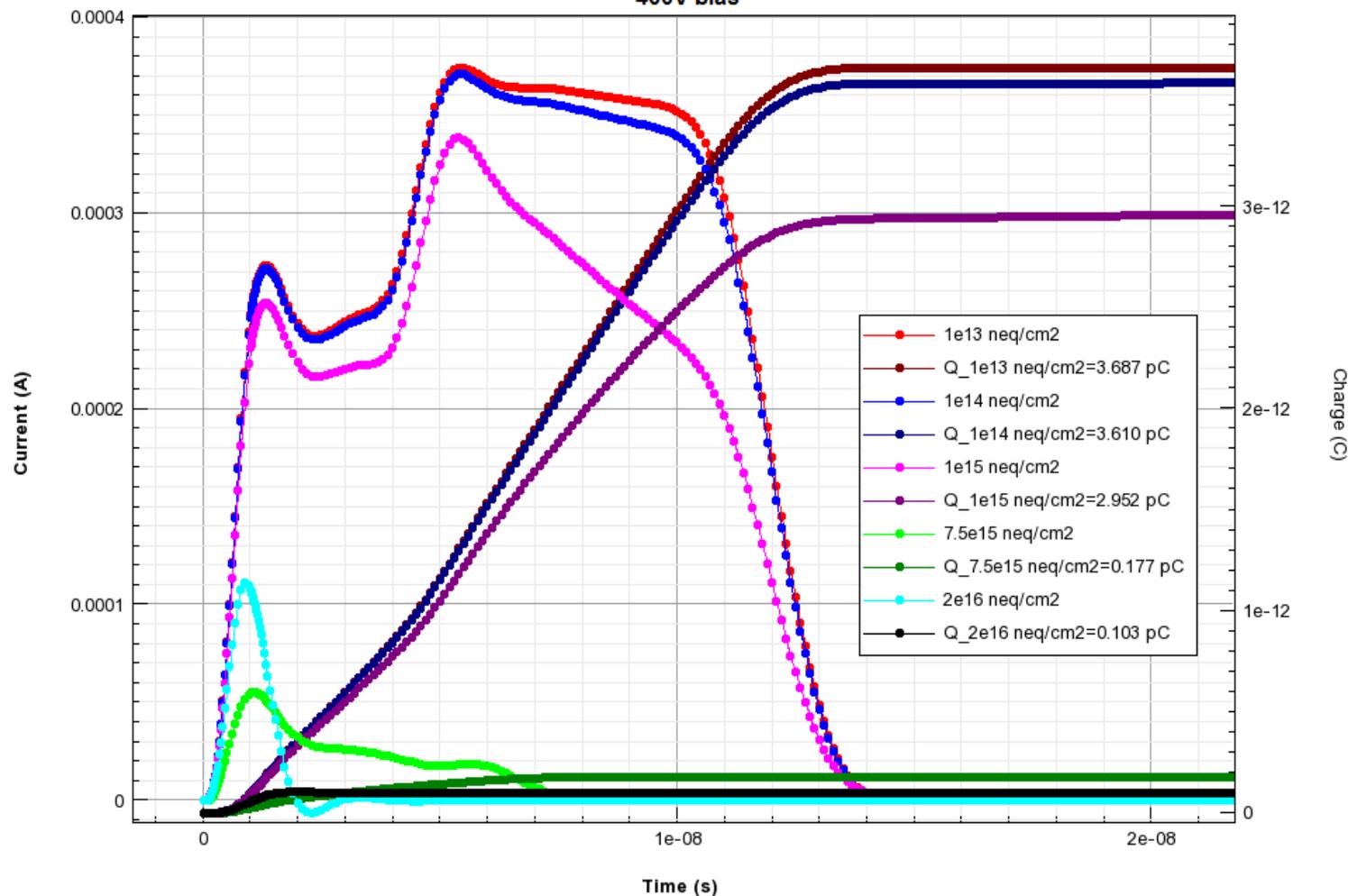


LGAD 300 um RedLaserBack 293K New Perugia

PINLGAD 300um 293K RedLaserBack(670 nm 50W/cm2 200ps 10um) New Perugia Trap Model Read Out Electronics 400V bias



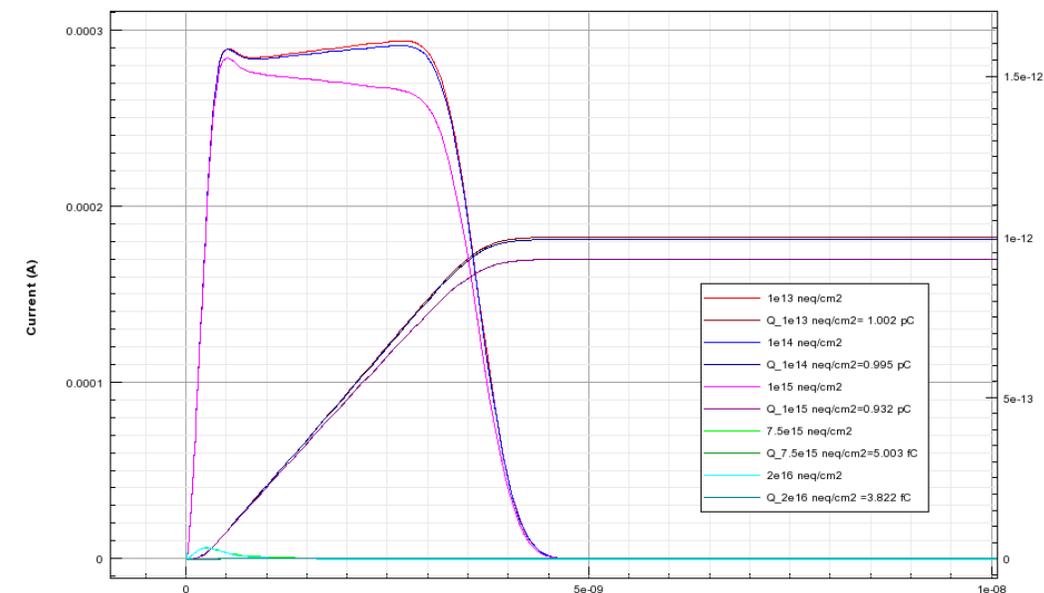
LGAD 300um (293K) LaserBack (670nm 50W/cm2 200ps 10um) New Perugia Trap Model ReadOut Electronics 400V bias



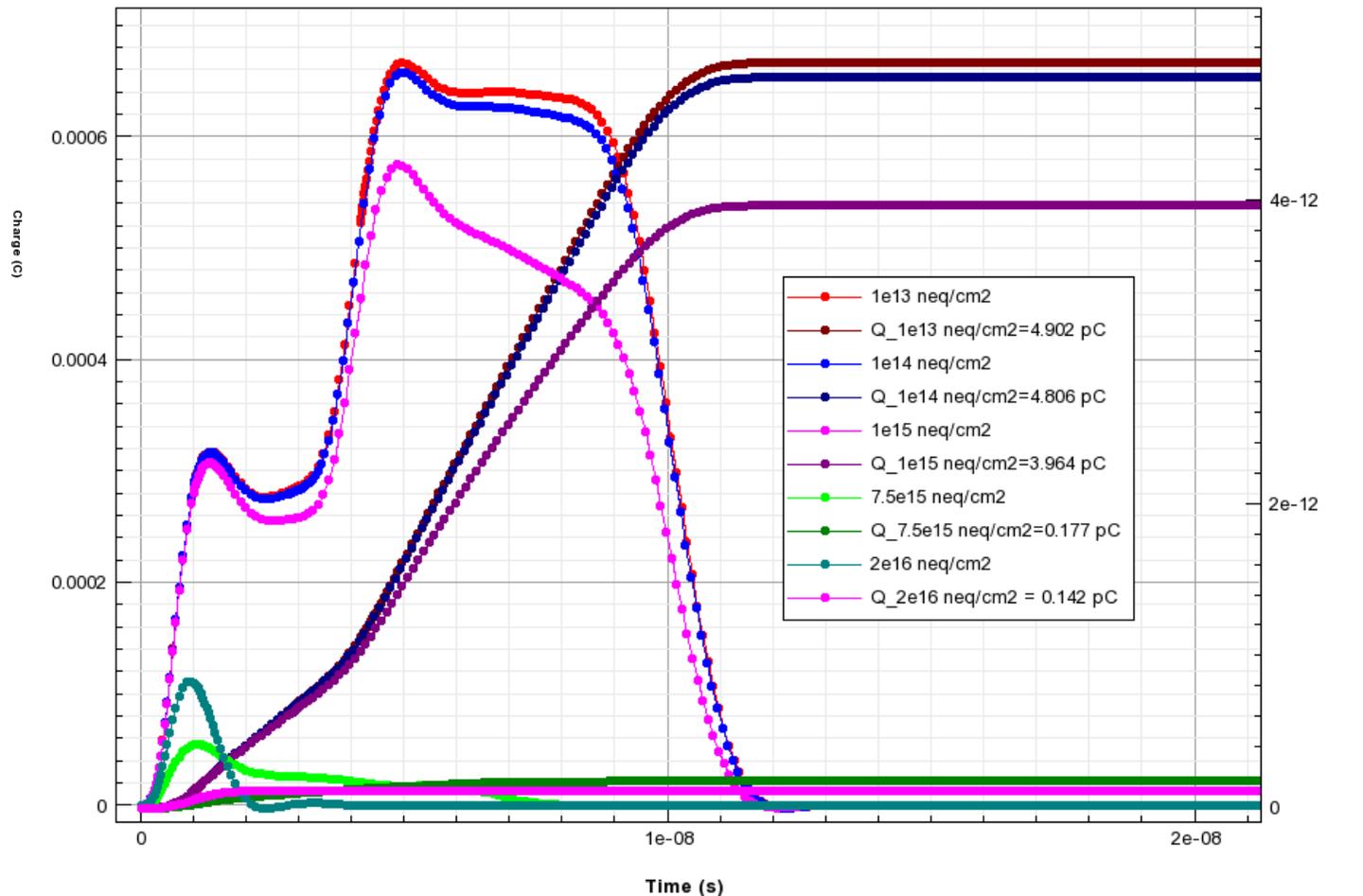
Fluence n/cm ²	Charge LGAD (pC)	Charge PIN (pC)	Gain Q _{lgad} /Q _{pin}
1e13	3,687	1,001	3,68
1e14	3,610	0,993	3,63
1e15	2,952	0,359	8,22
7,5e15	0,177	0,007	25,28
2e16	0,103	0,005	20,6

LGAD 300 um RedLaserBack 253K New Perugia

PINLGAD 300um 253K RedLaserBack(670 nm 50W/cm2 200ps 10um) New Perugia Trap Model Read Out Electronics 400V bias



LGAD 300um (253K) LaserBack (670nm 50W/cm2 200ps 10um) New Perugia Trap Model ReadOut Electronics 400V bias



Fluence n/cm ²	Charge LGAD (pC)	Charge PIN (pC)	Gain Q _{lgad} /Q _{pin}
1e13	4,902	1,002	4,89
1e14	4,806	0,995	4,83
1e15	3,964	0,932	4,25
7,5e15	0,177	0,005	35,4
2e16	0,142	0,003	47,3

Work in Progress: Acceptor Removal+Trap Model (New Perugia)

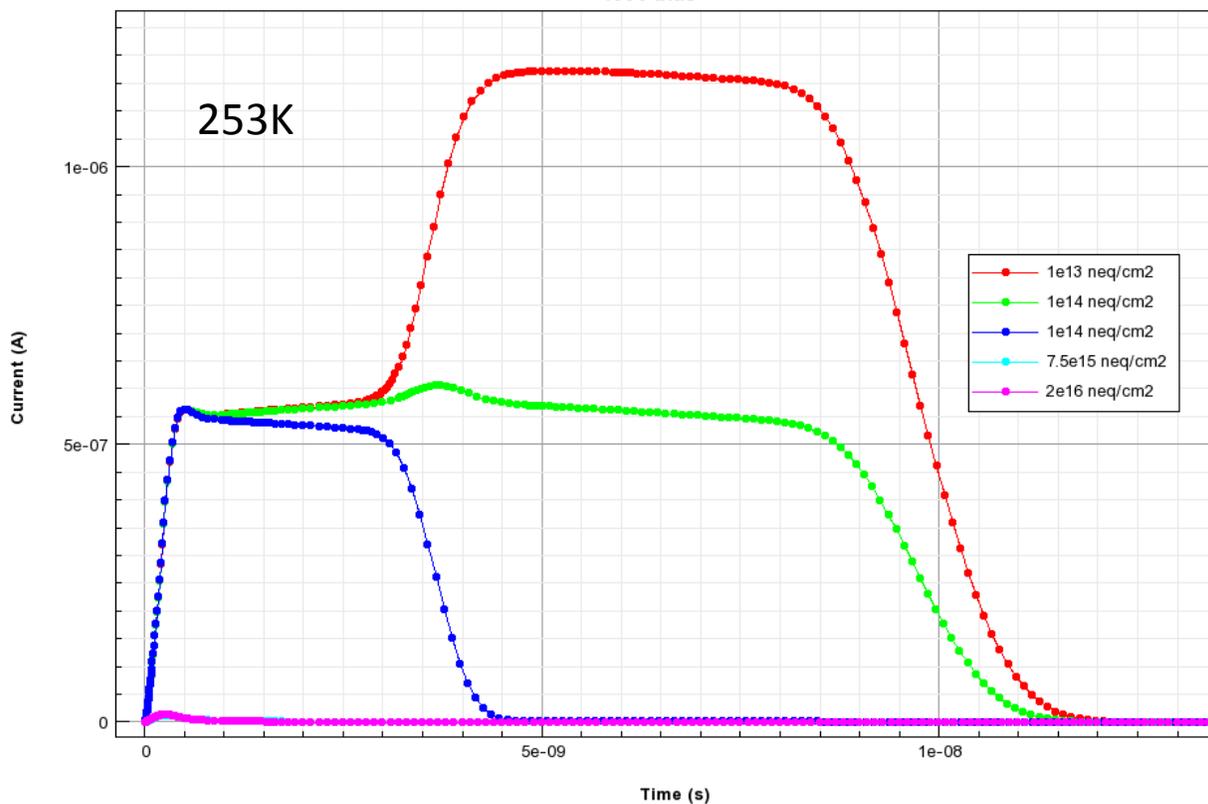
$$N_A = N_{A0} e^{-c\phi}$$

$$c = 10e^{-16} \text{ cm}^{-2}$$

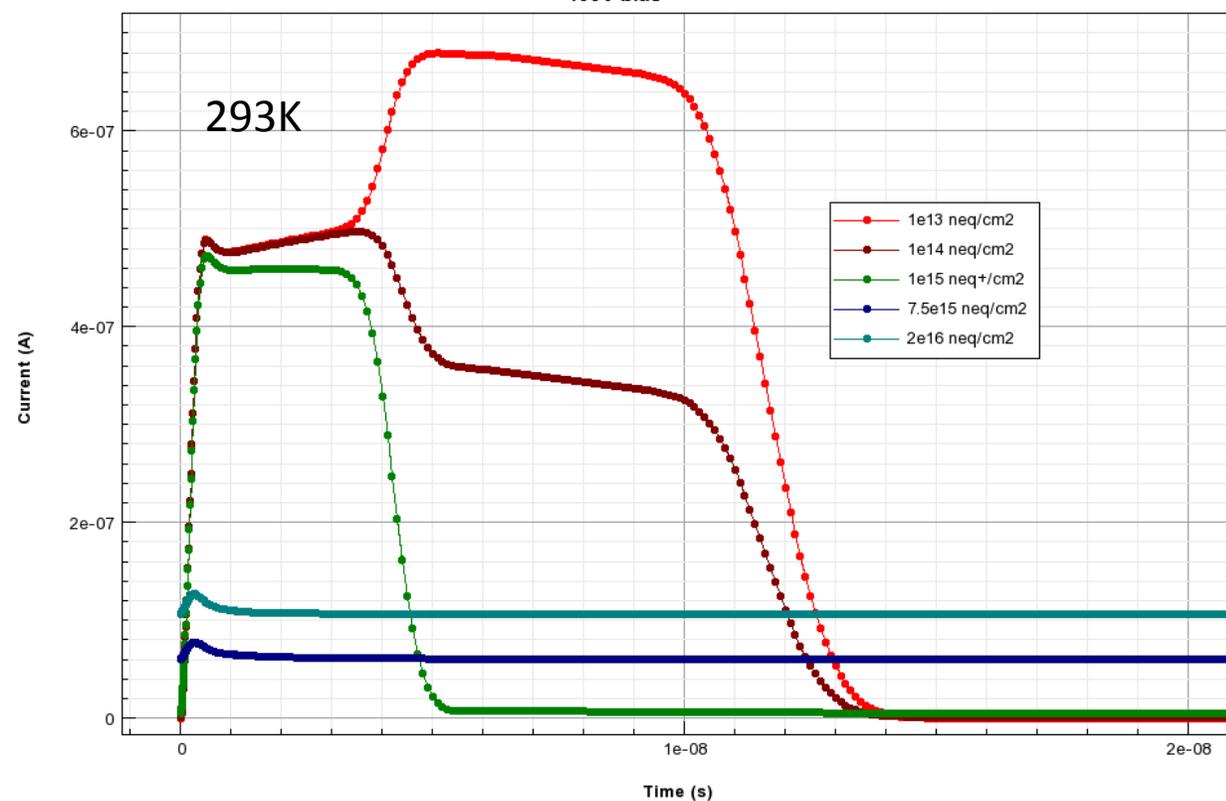
Beyond $1e15 \text{ n}_{eq}/\text{cm}^2$ there is no p mult.layer for all practical purposes,

We have to discuss this model in deep

LGAD 300um (253K) LaserBack (670nm 50W/cm2 200ps 10um) Acceptor Removal+New Perugia Trap Model
400V bias



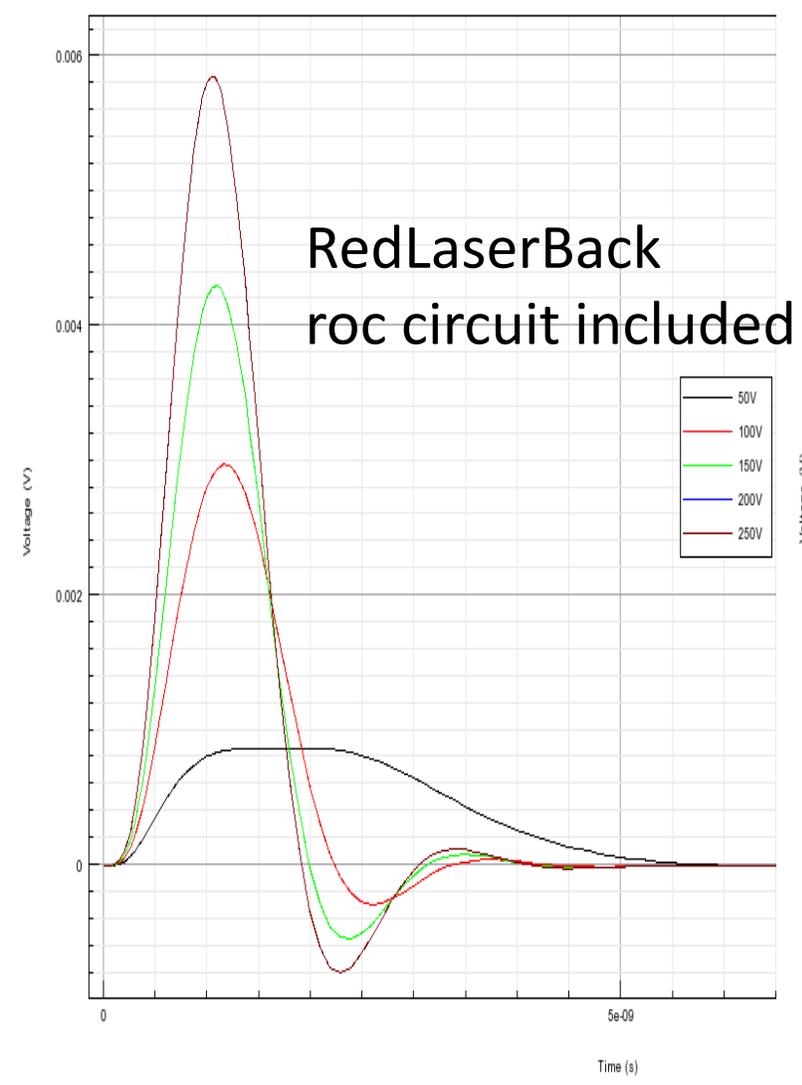
LGAD 300um (293K) LaserBack (670nm 50W/cm2 200ps 10um) Acceptor Removal+New Perugia Trap Model
400V bias



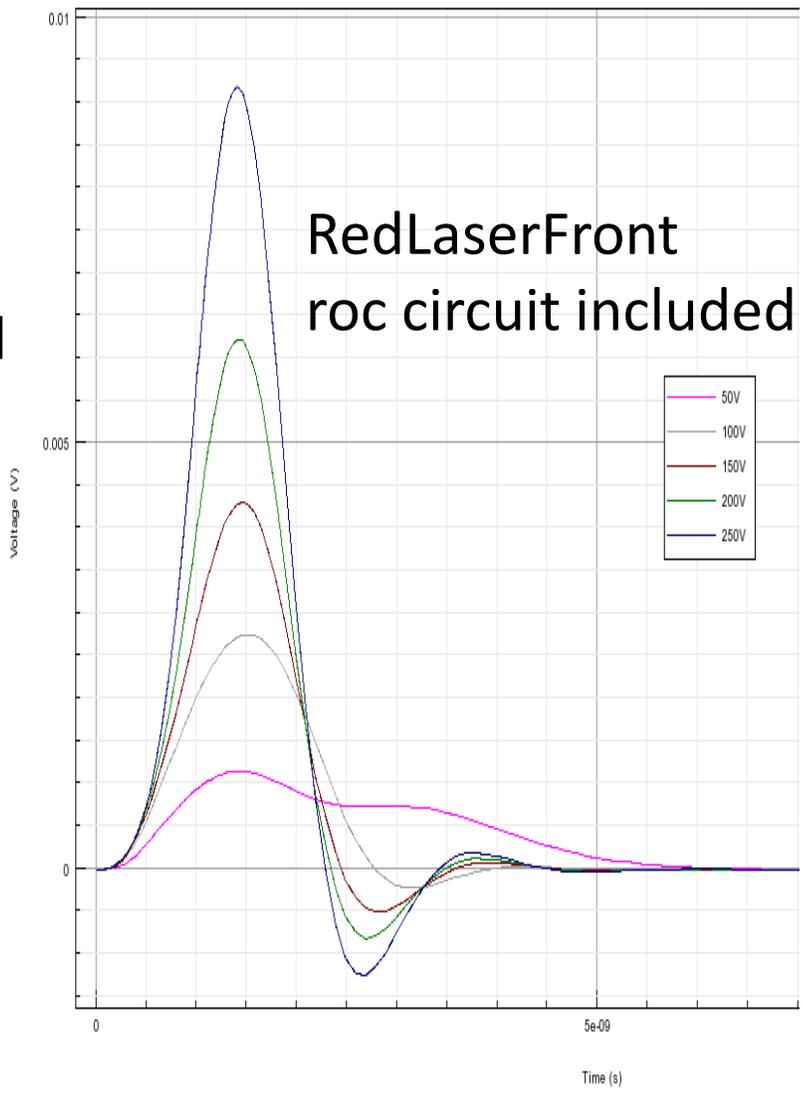
Radiation effects in Low Gain Avalanche Detectors after hadron irradiations, G.Kramberger et al., JINST 2015 10 P07006

LGAD 50um (work in progress)

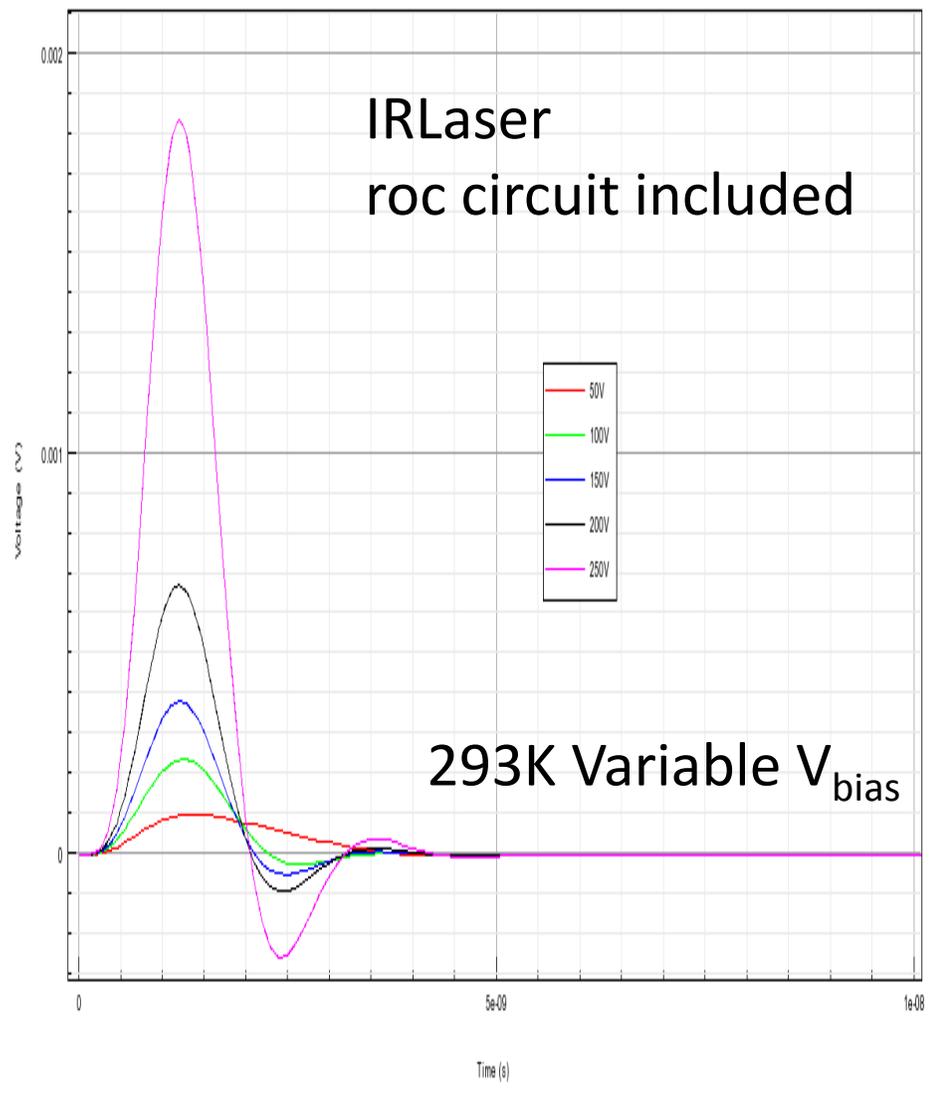
LGAD7859-50um 293K RedLaserFront 670nm 50W/cm2 200ps 10um ROC-15nH



LGAD7859-50um 293K RedLaserBack 670nm 50W/cm2 200ps 10um ROC-15nH



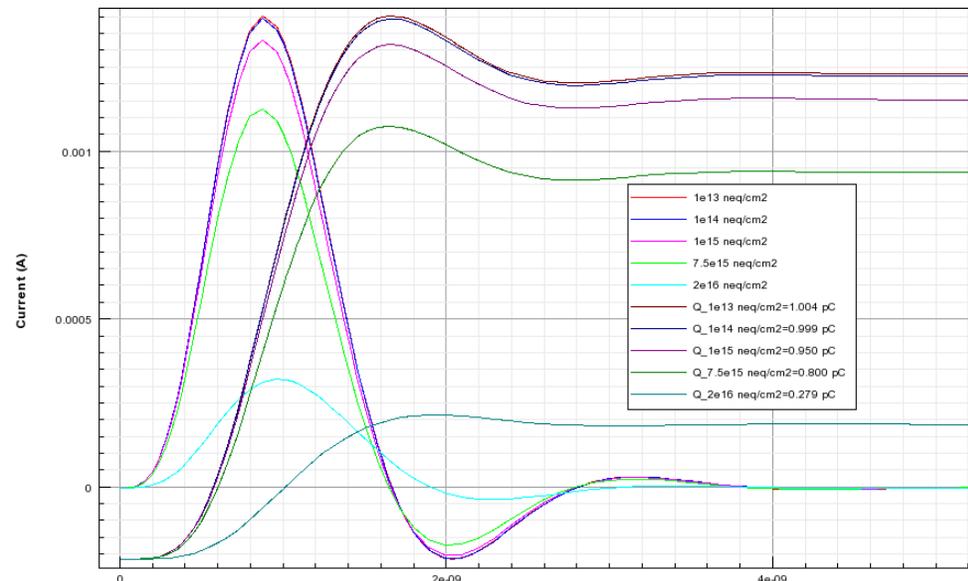
LGAD7859-50um 293K IRLaser 1064nm 30W/cm2 200ps 10um ROC-15nH



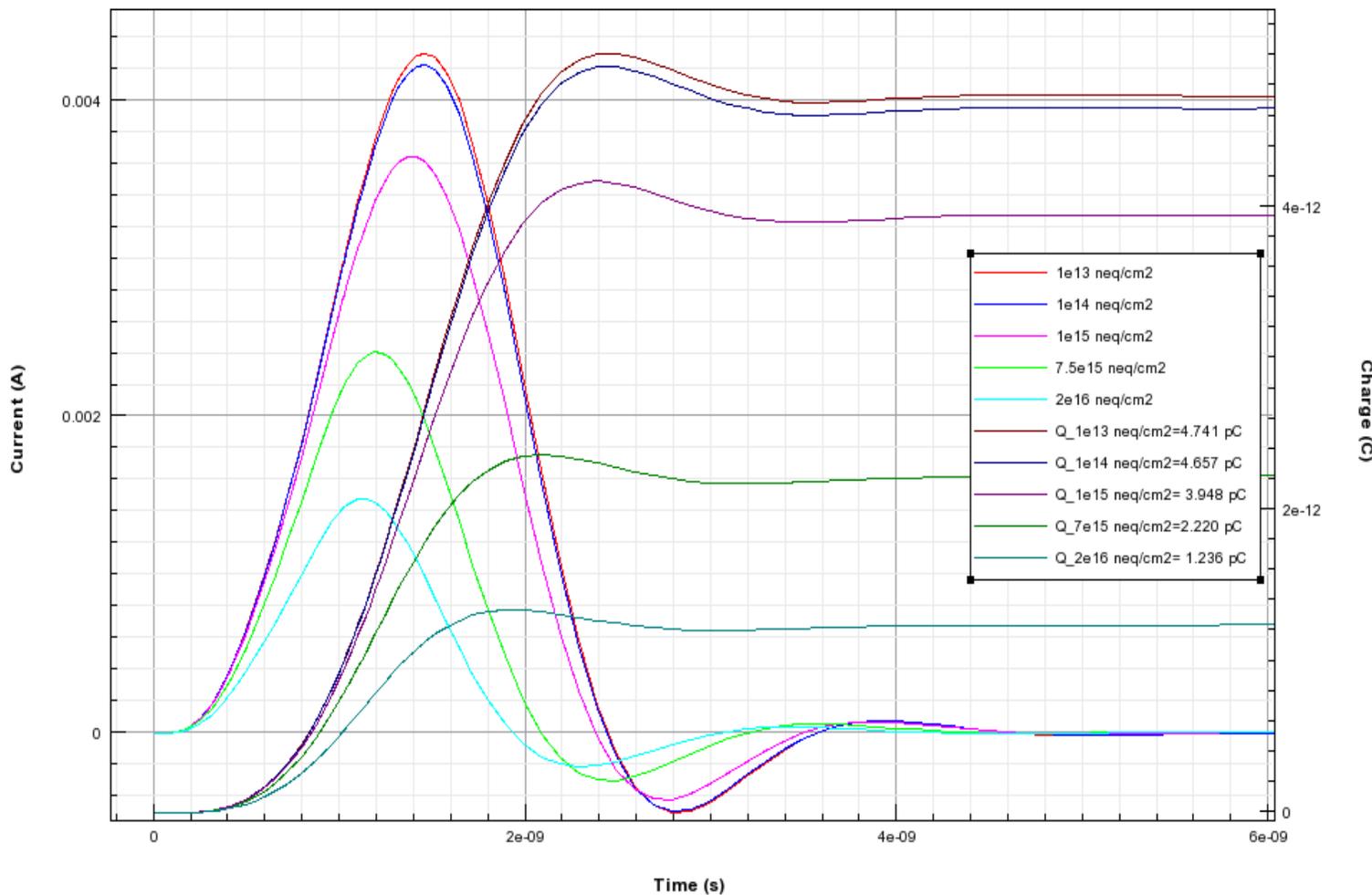
50 um 293K New Perugia RedLaserBack

LGAD 50um 293K RedLaserBack(670 nm 50W/cm2 200ps 10um) New Perugia Trap Model Read Out Electronics 150V bias

PINLGAD 50um 293K RedLaserBack(670 nm 50W/cm2 200ps 10um) New Perugia Trap Model Read Out Electronics 150V bias

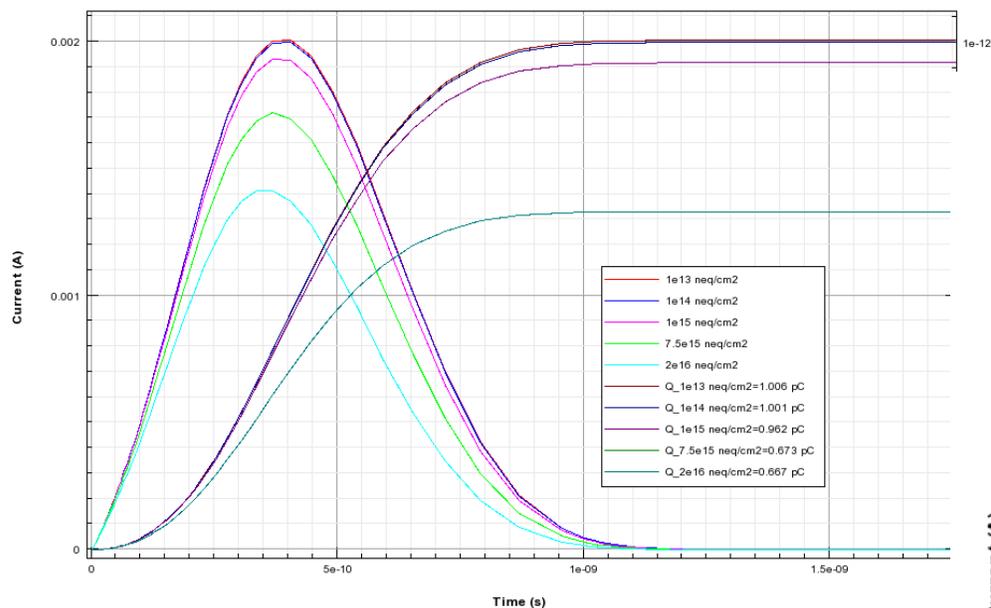


Fluence n/cm ²	Charge LGAD (pC)	Charge PIN (pC)	Gain Q _{lgad} /Q _{pin}
1e13	4,741	1,004	4,72
1e14	4,657	0,999	4,66
1e15	3,948	0,950	4,15
7,5e15	2,220	0,800	2,78
2e16	1,236	0,279	4,43

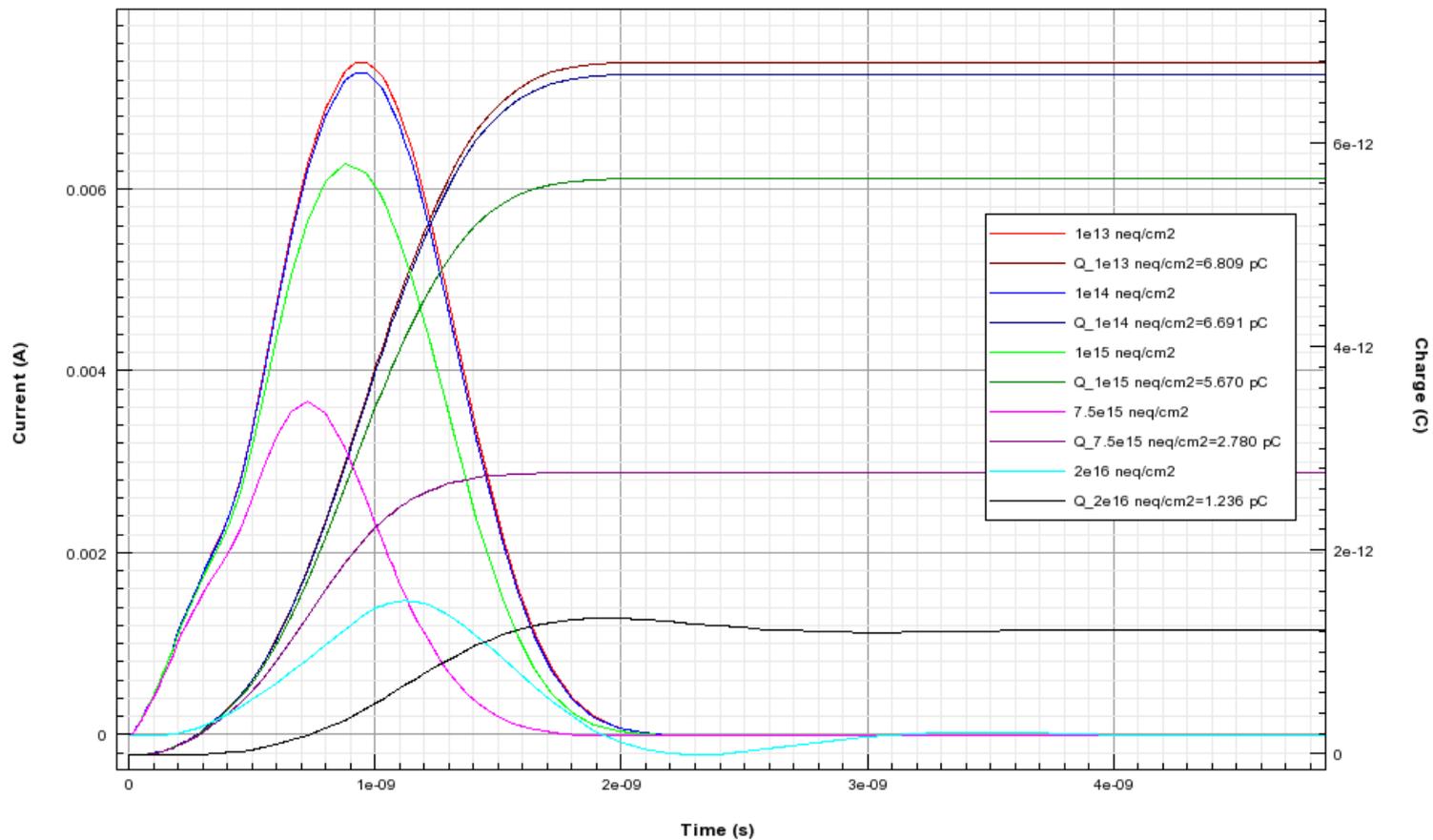


50 um 253K New Perugia RedLaserBack

PINLGAD 50um253K RedLaserBack(670 nm 50W/cm2 200ps 10um) New Perugia Trap Model Read Out Electronics 150V bias



LGAD 50um253K RedLaserBack(670 nm 50W/cm2 200ps 10um) New Perugia Trap Model Read Out Electronics 150V bias



Fluence n/cm ²	Charge LGAD (pC)	Charge PIN (pC)	Gain Q _{lgad} /Q _{pin}
1e13	6,809	1,006	6,77
1e14	6,691	1,001	6,68
1e15	5,870	0,962	6,10
7,5e15	2,278	0,673	3,38
2e16	1,236	0,667	1,85

Conclusions

- LGAD model from CNM, with JTE, guard rings, p-stops and c-stops.
- Now in process of detailed fitting to experimental data
- Waiting for new experimental data
- Starting the modeling of dopant removal

Thanks for your attention
fpalomo@us.es