TCAD simulations of LGAD devices using Silvaco software

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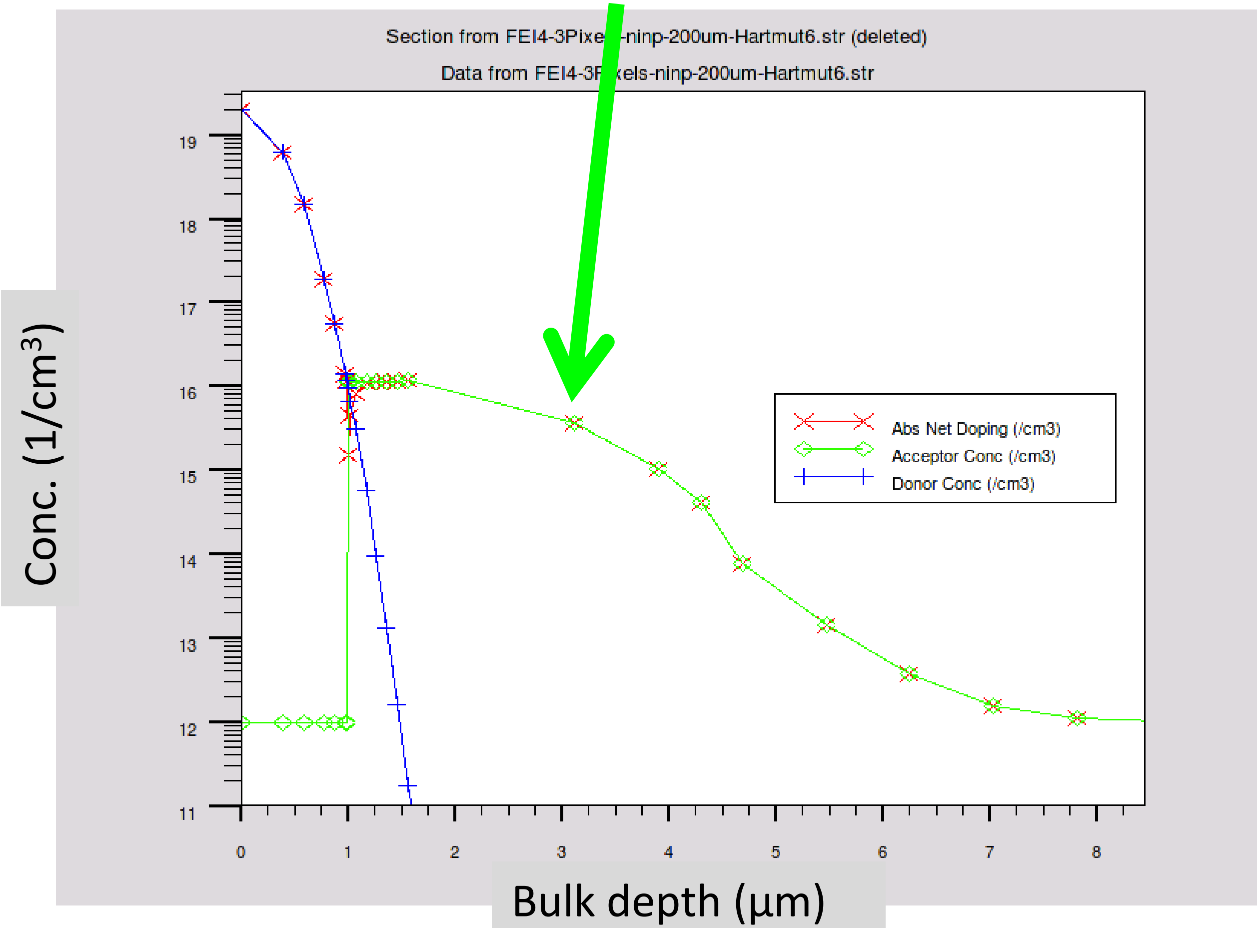
Outline

- Simulated structure & doping profile
- CV & Electric field
- Simulation of alpha particles hitting from the backside
- Simulation of MIPs hitting from the frontside
- Comments & conclusion

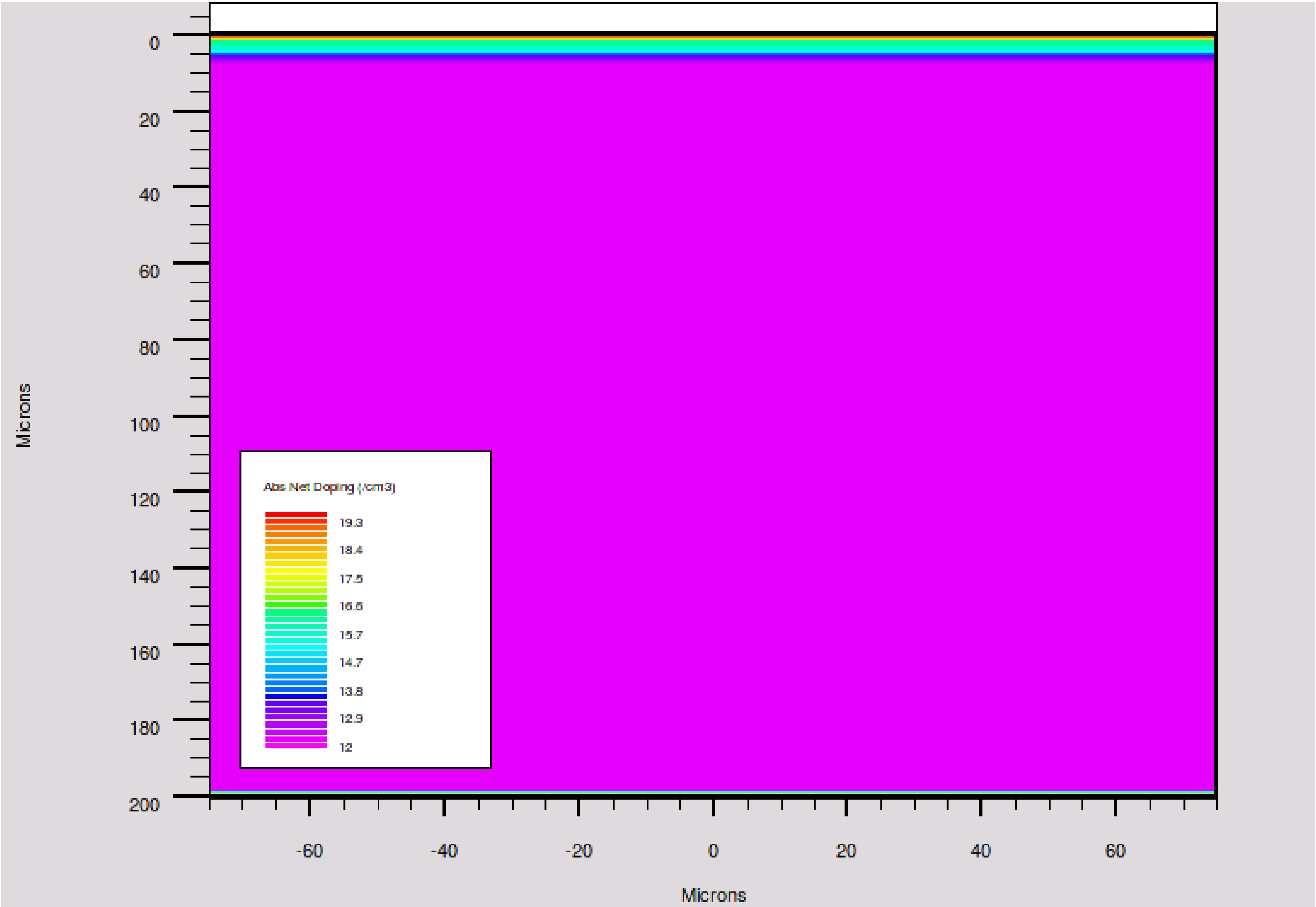
Simulated structure & doping profile

- 2D simulation of a 200 µm thick n-on-p diode, 150 µm wide
- Bulk doping conc. = 1×10^{12} /cm^3
- 2 versions studied: with and without multiplication implant
- Profile from real data*
- Peak @ 1µm
- Plateau 0.5 µm wide



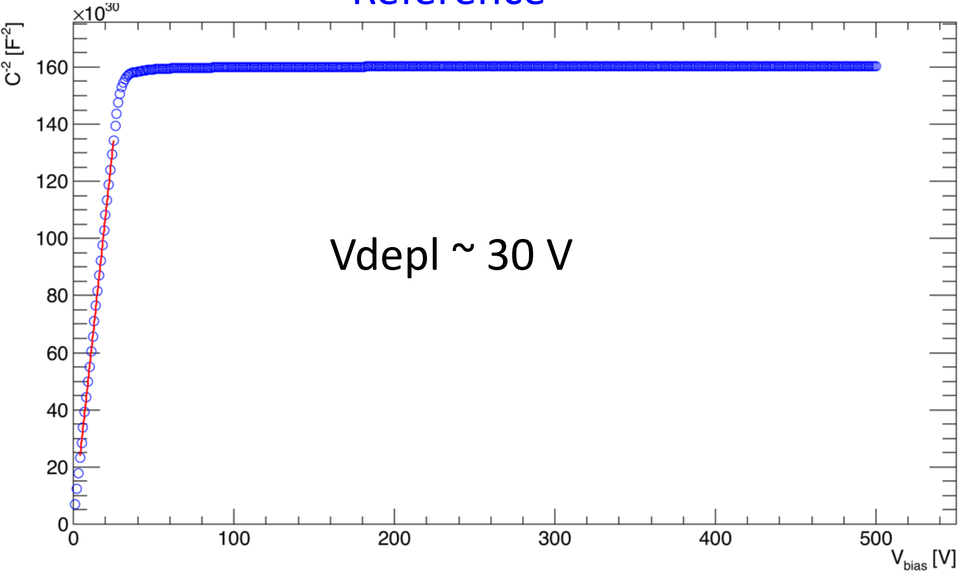
* Profile provided by H. Sadrozinski (from CV on a low-gain diode)

The 2D simulated structure

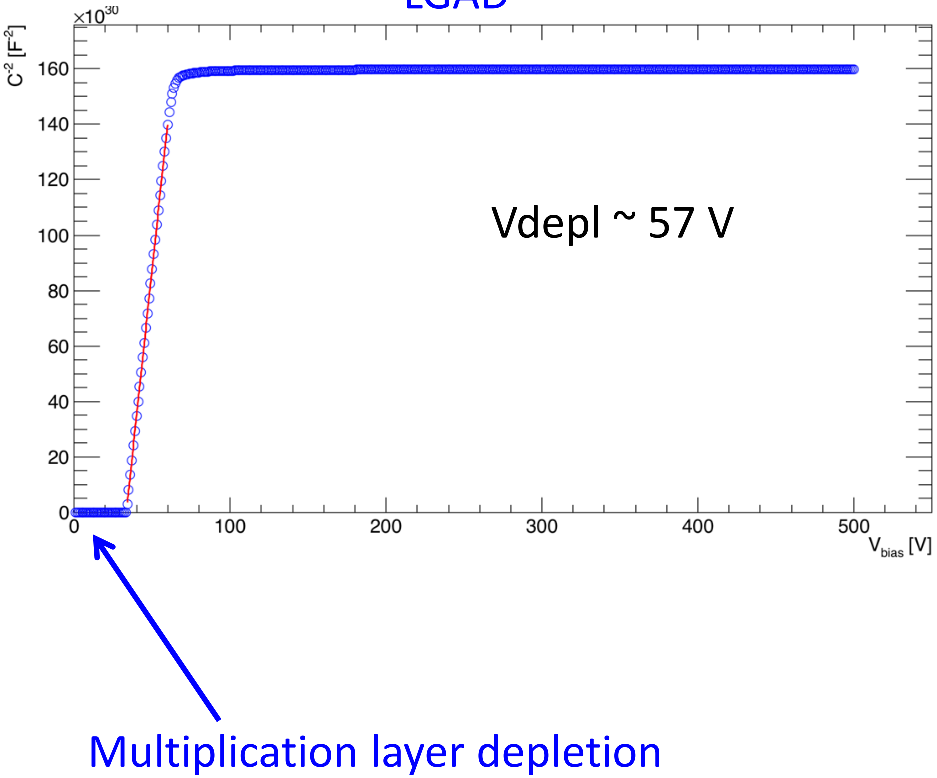


Depletion voltage, reference vs LGAD

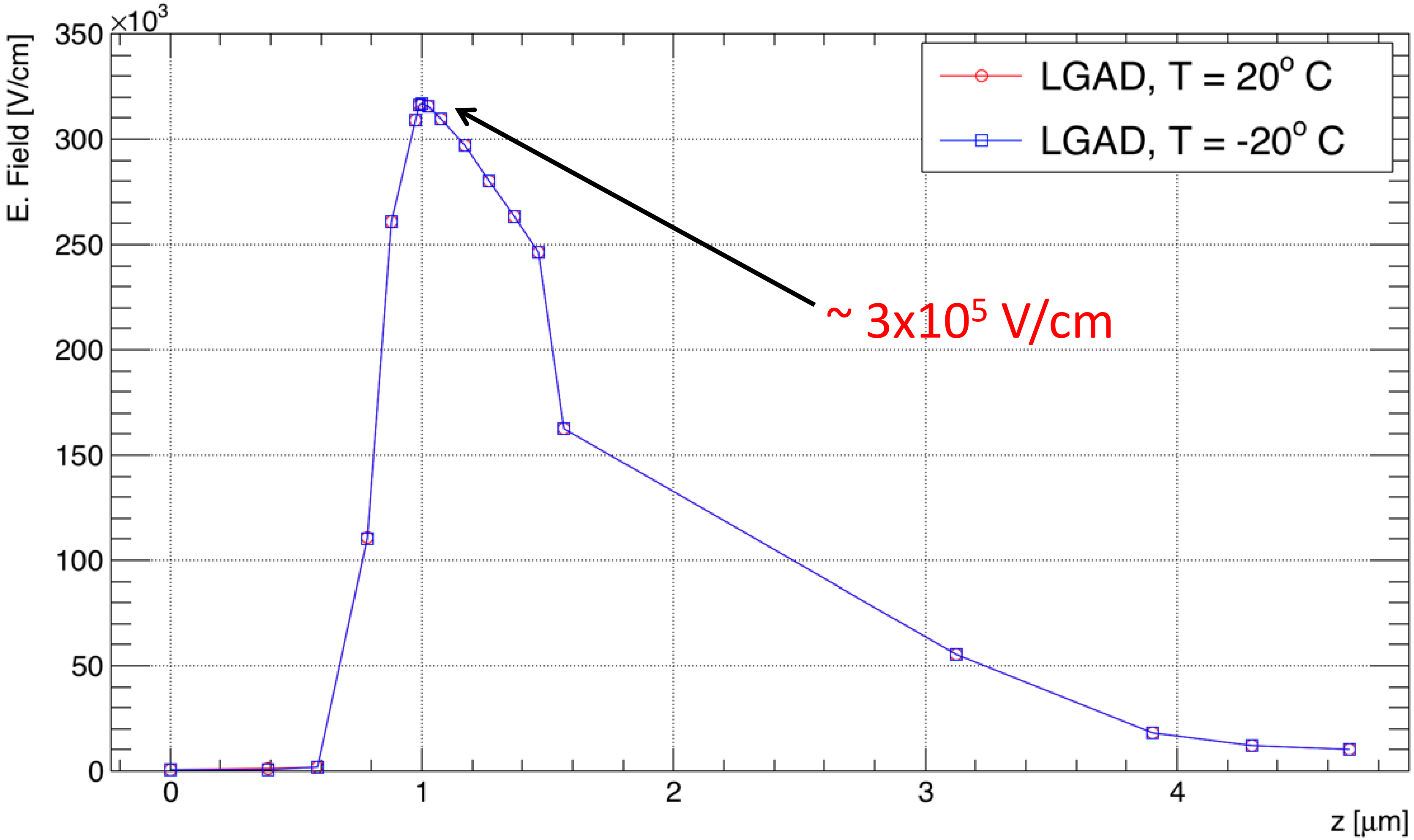
Reference



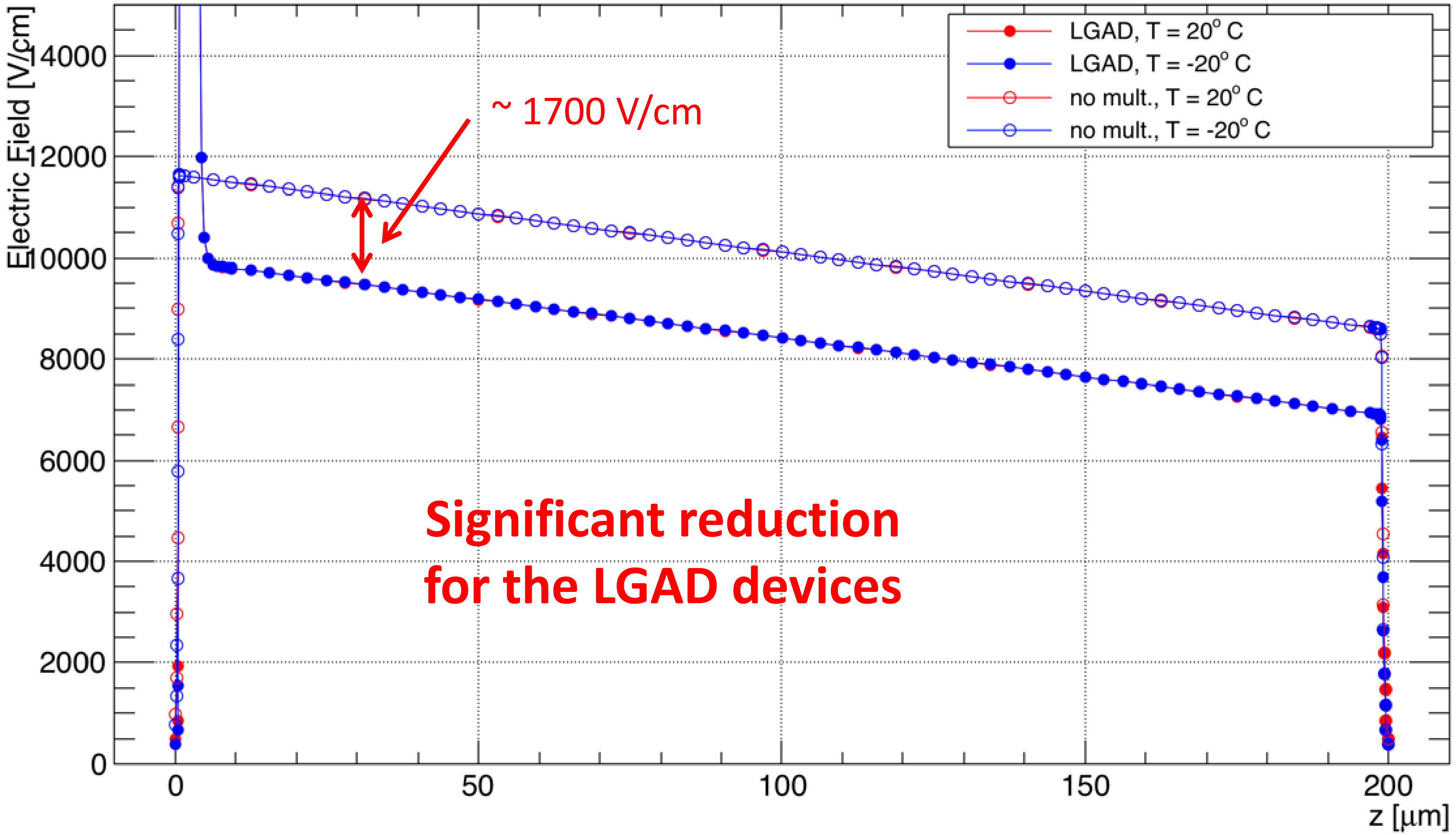
LGAD



Electric field – mult. zone



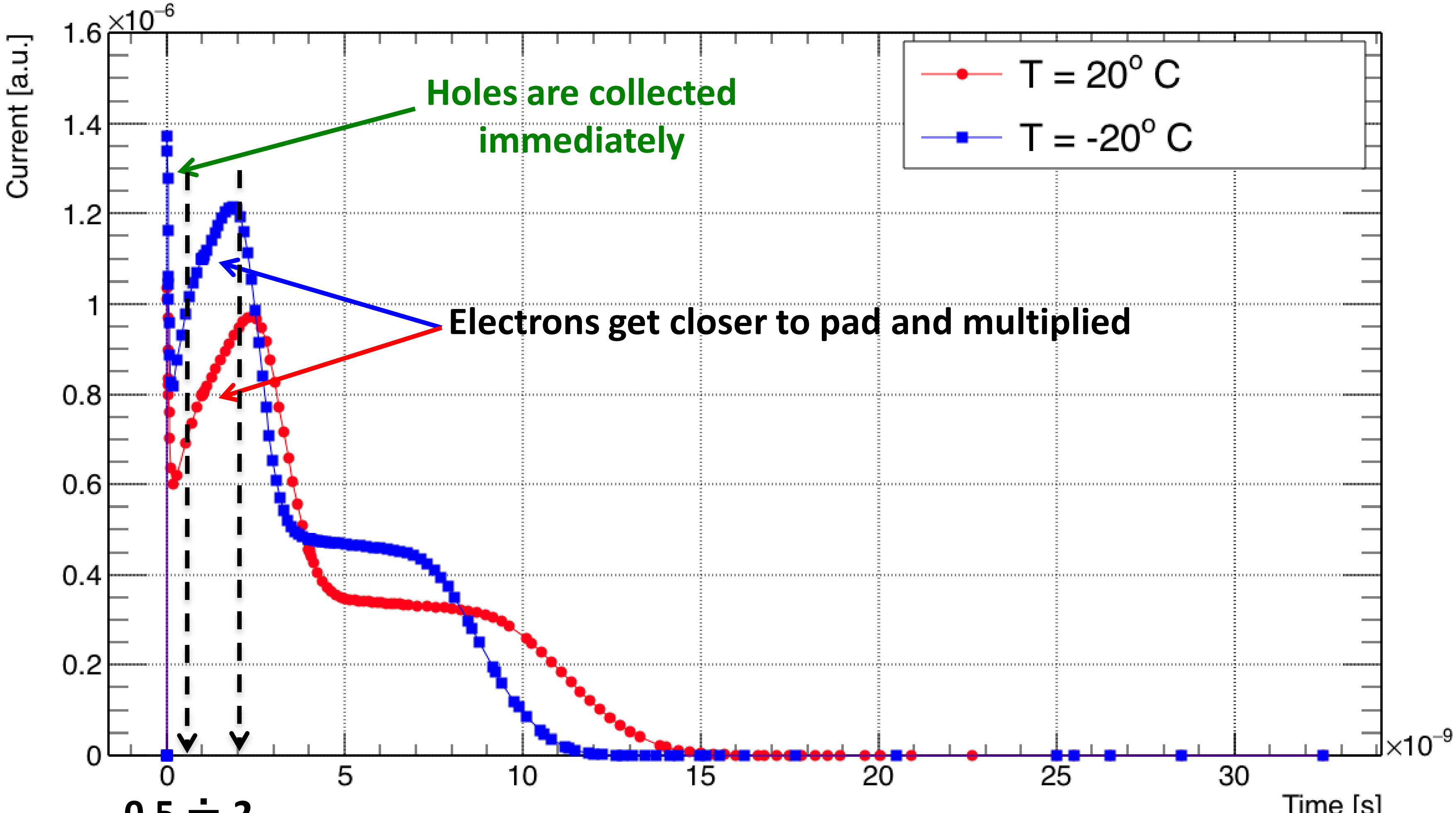
Electric field – bulk



Alpha's simulations

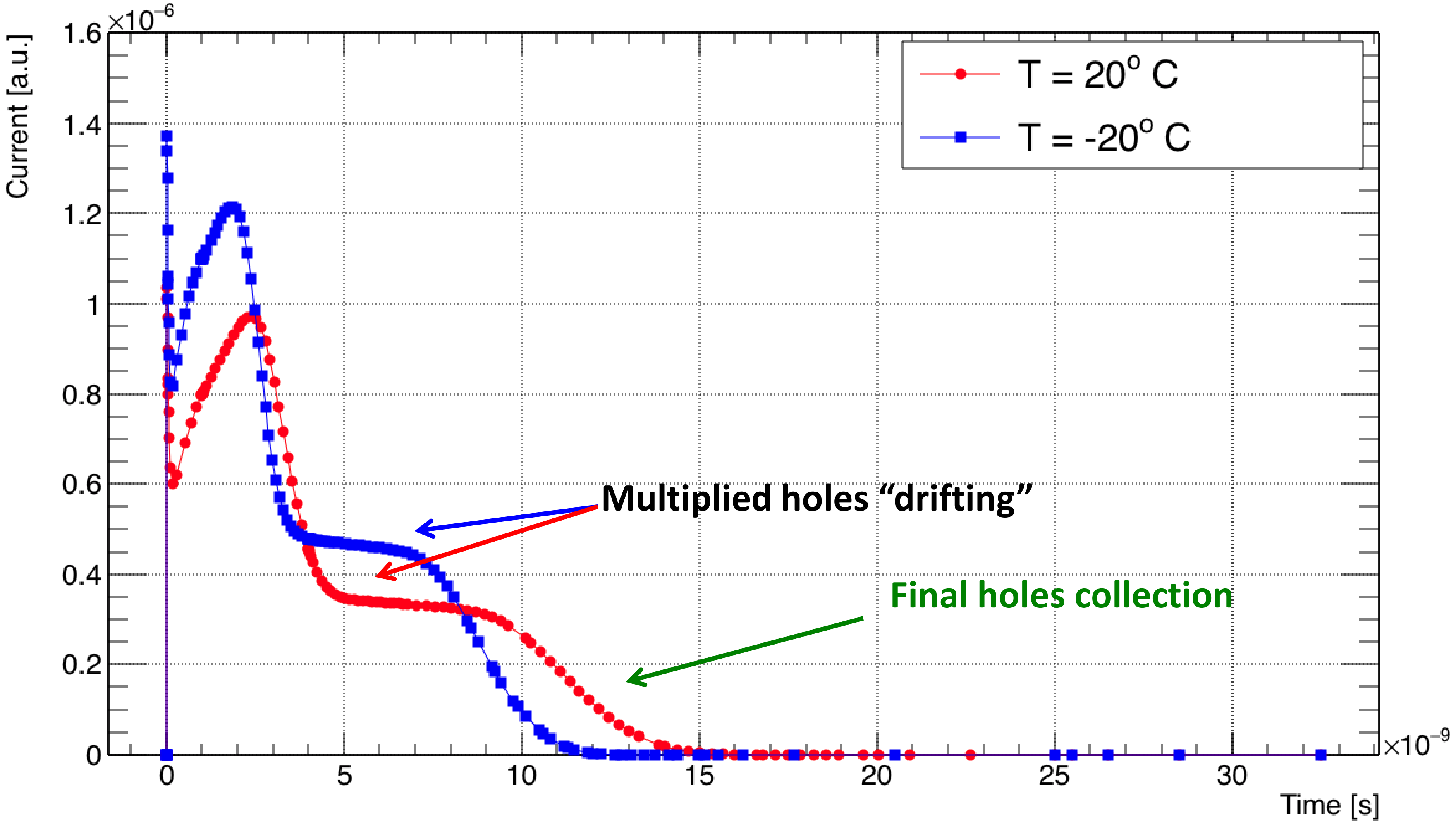
- Alpha impinging from the back
  - Range: 5 μm
  - Energy ~ 1 MIP in 200 μm
- 200 μm thick devices
- V_{bias} = 50, 100, 150 & 200 V
- $\Phi = 0$
- T = from -35° C to +20° C
- Observables: signal, electric field and gain

Signal, V = 150 V

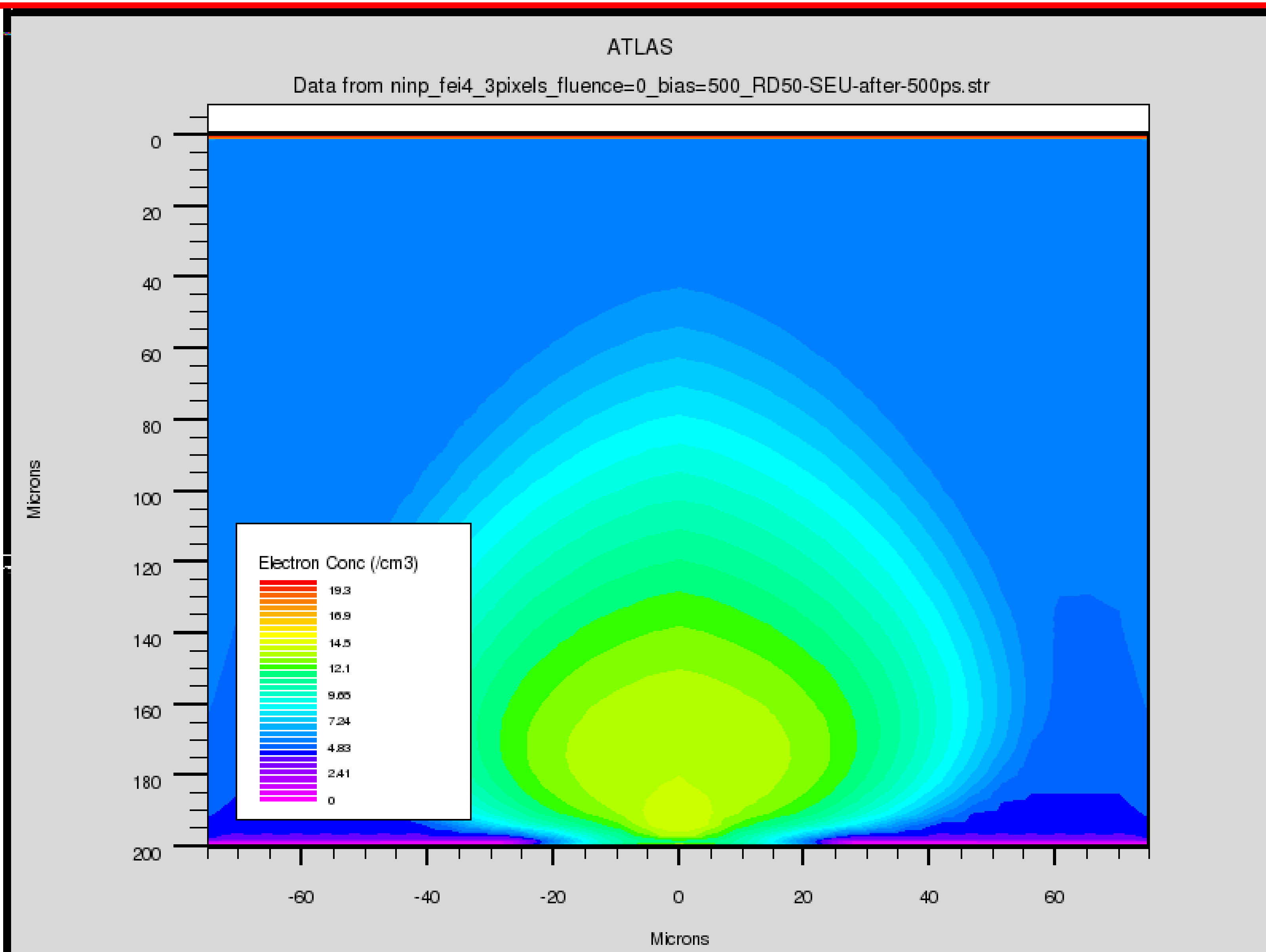


0.5 ÷ 2 ns

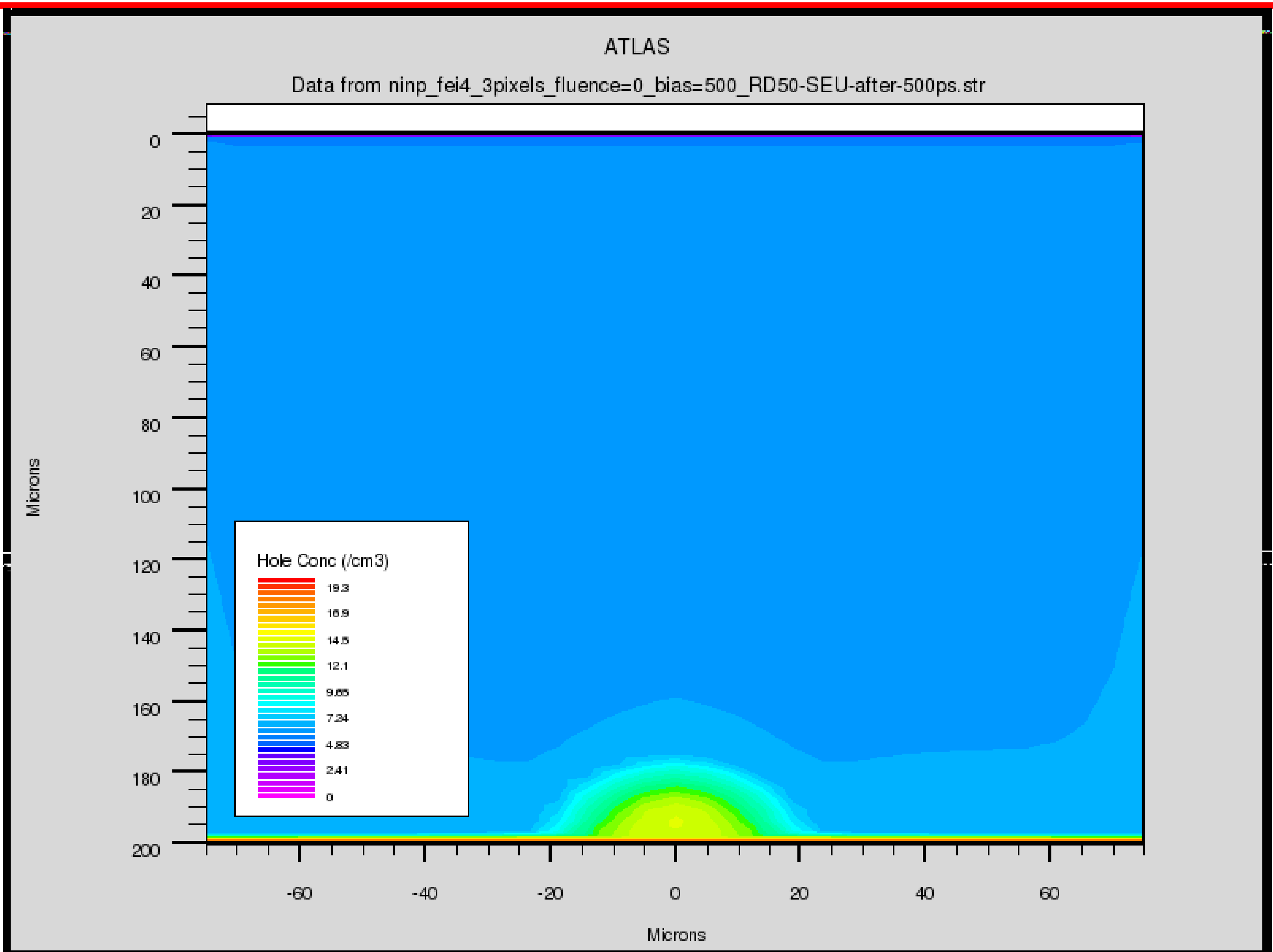
Signal, V = 150 V



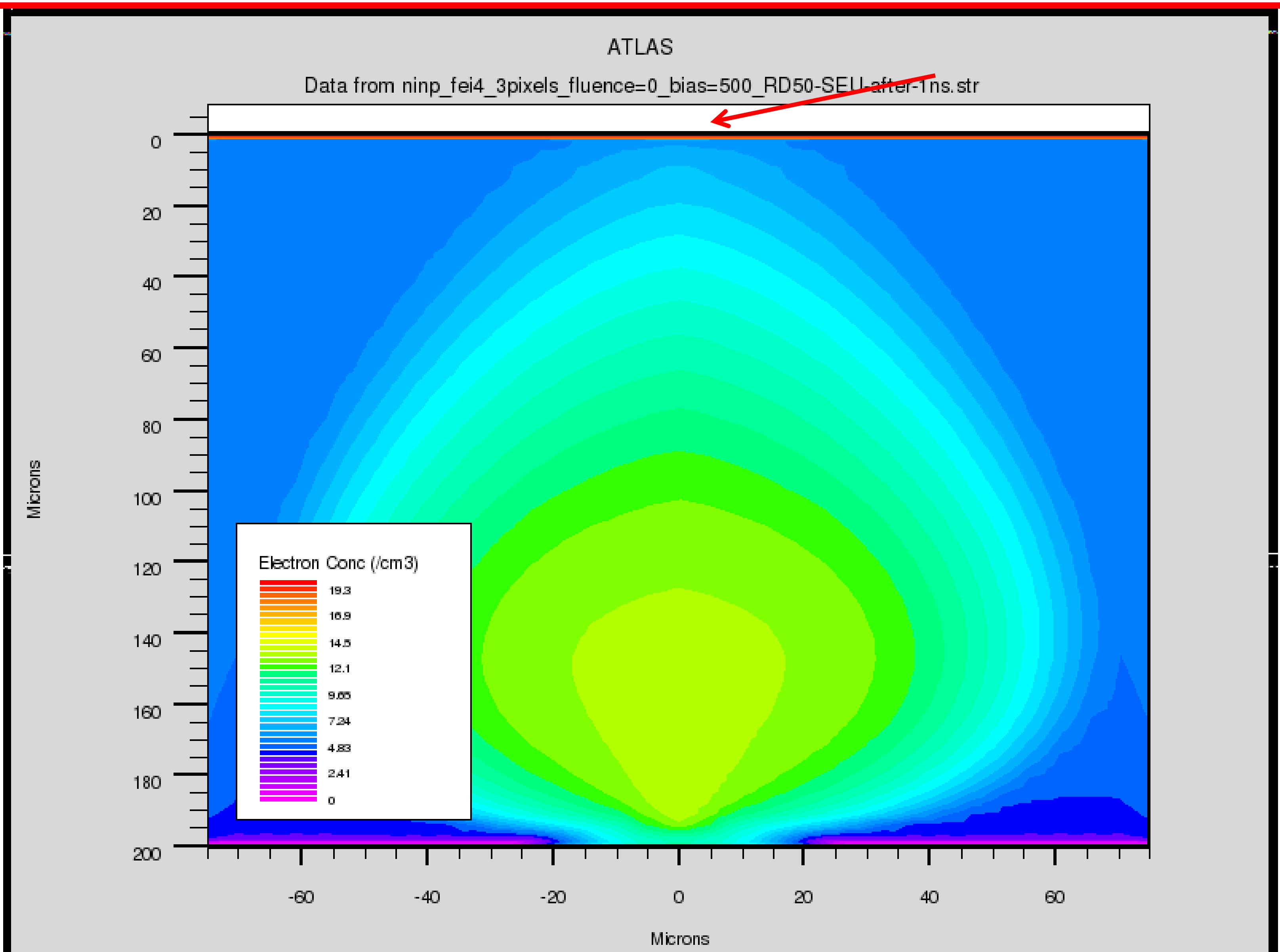
Elec. Conc. – 150 V, 500 ps after particle strike



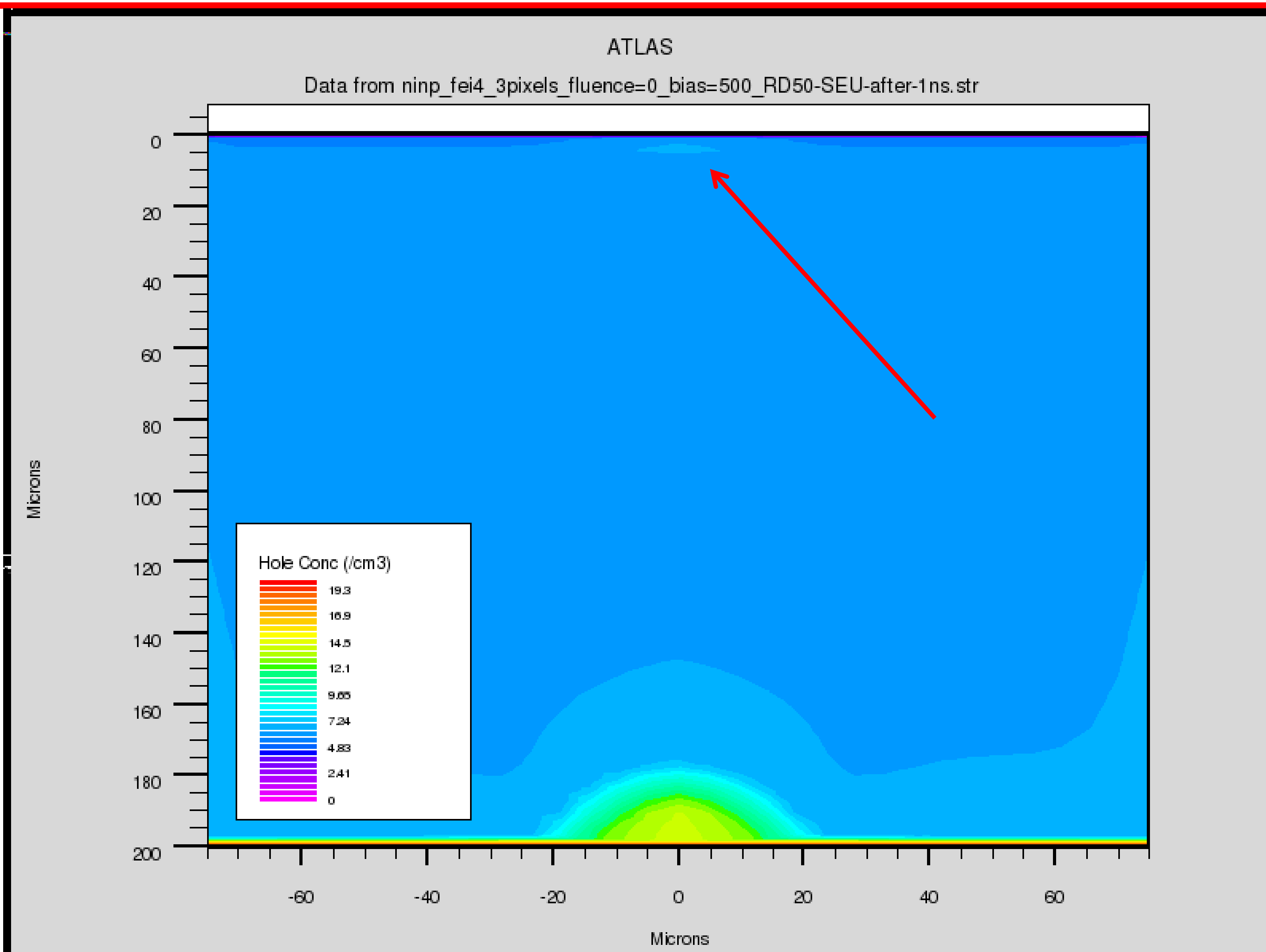
Hole Conc. – 150 V, 500 ps after particle strike



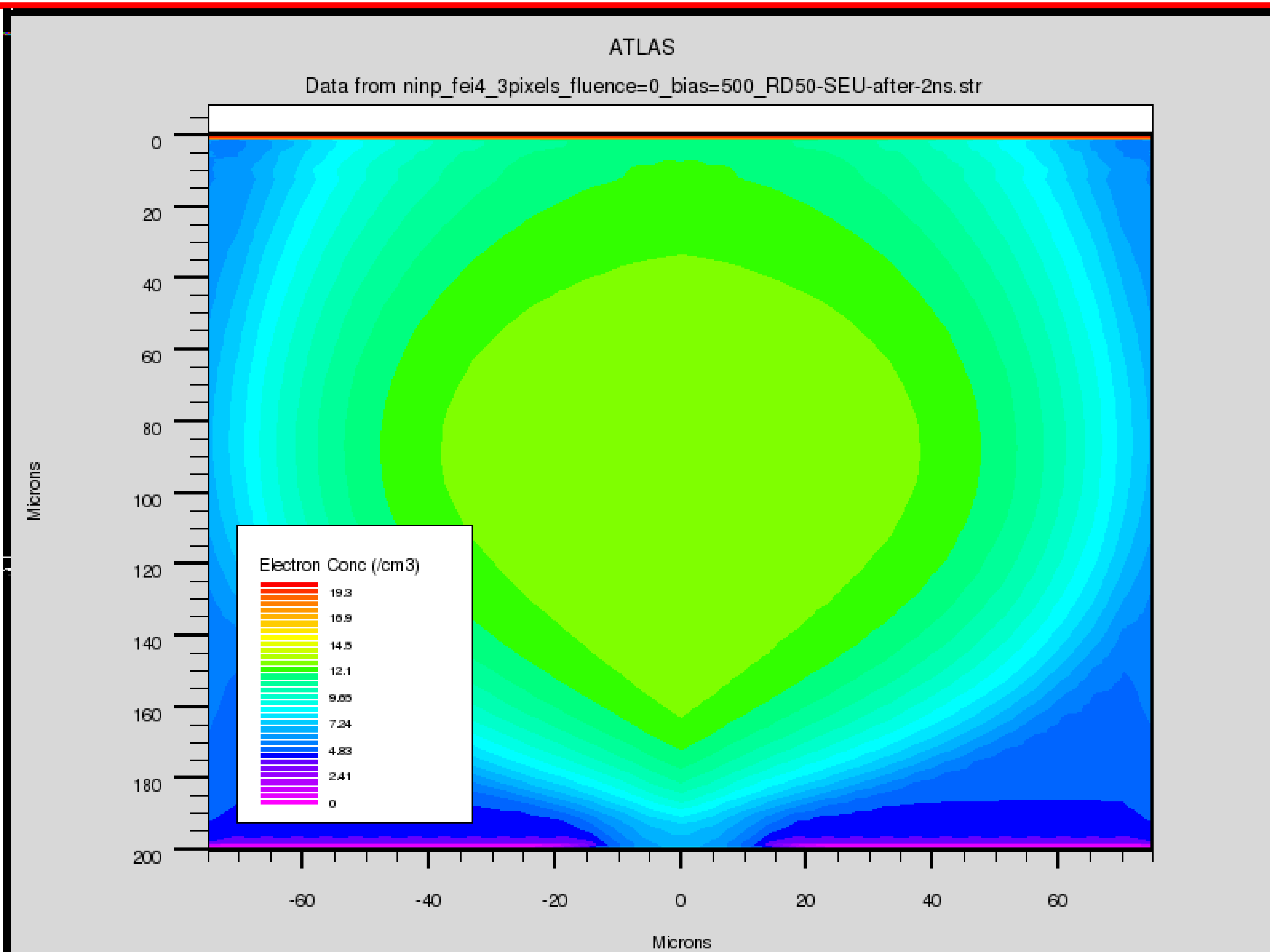
Elec. Conc. – 150 V, 1 ns after particle strike



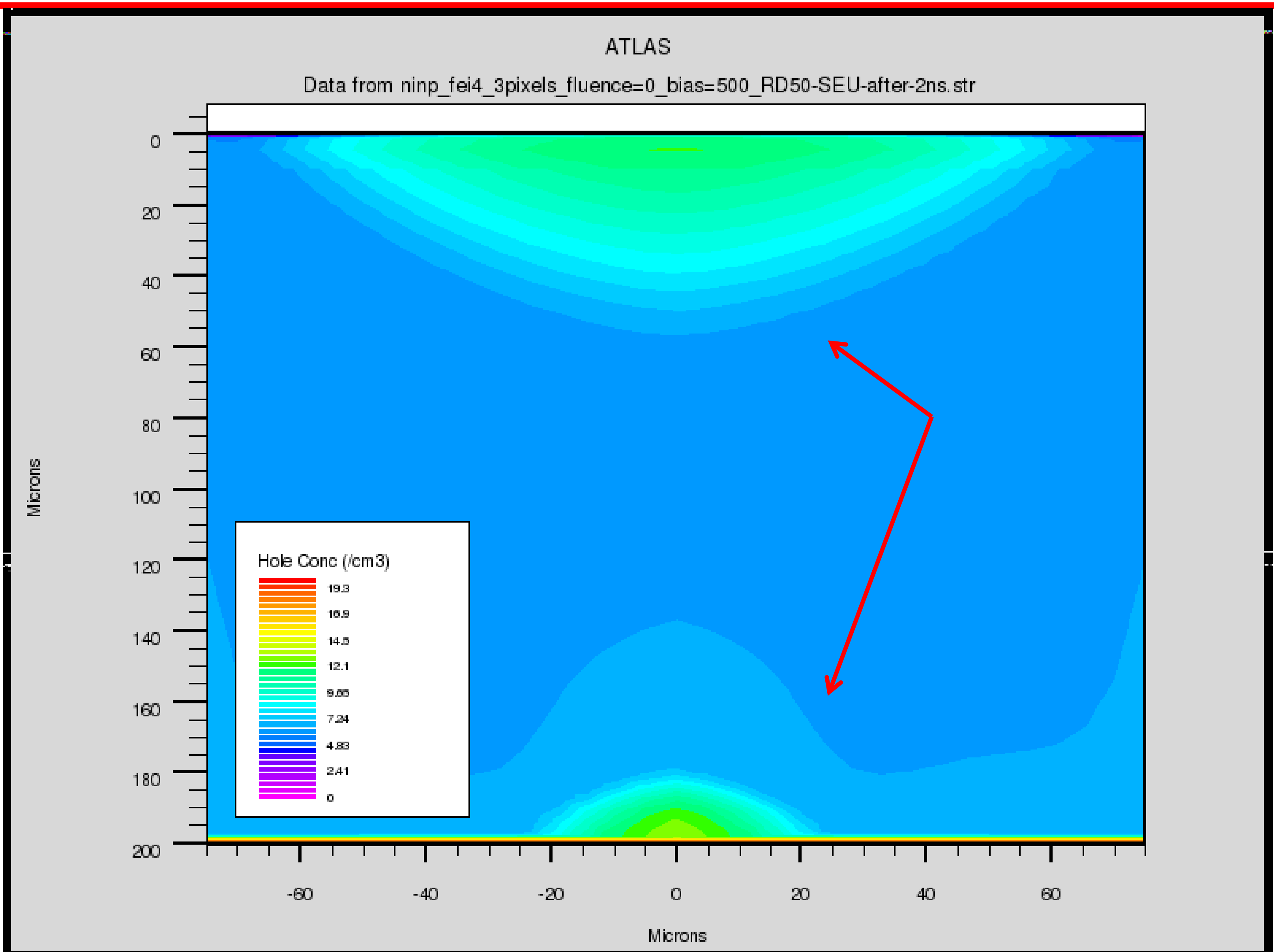
Hole Conc. – 150 V, 1 ns after particle strike



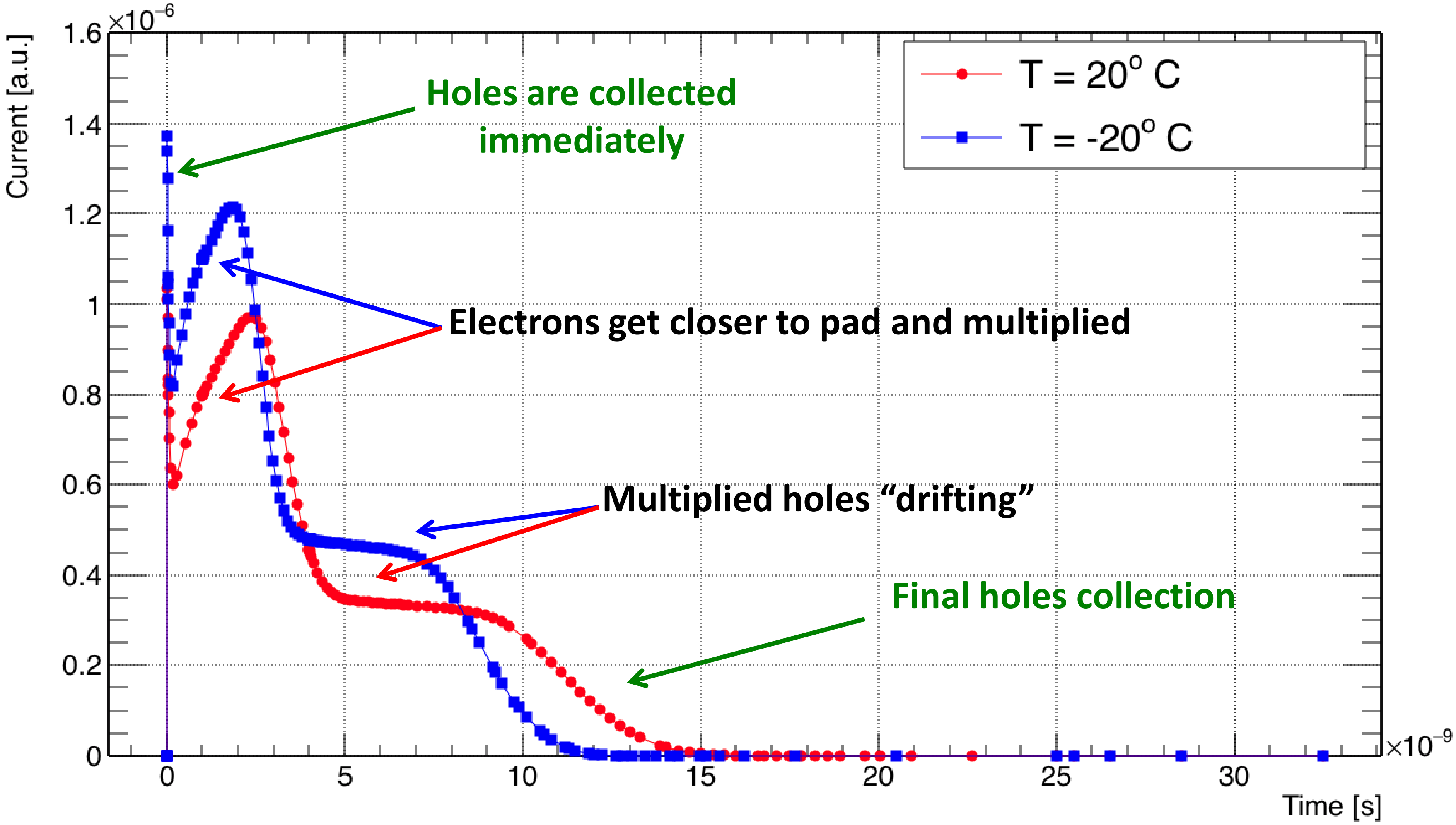
Elec. Conc. – 150 V, 2 ns after particle strike



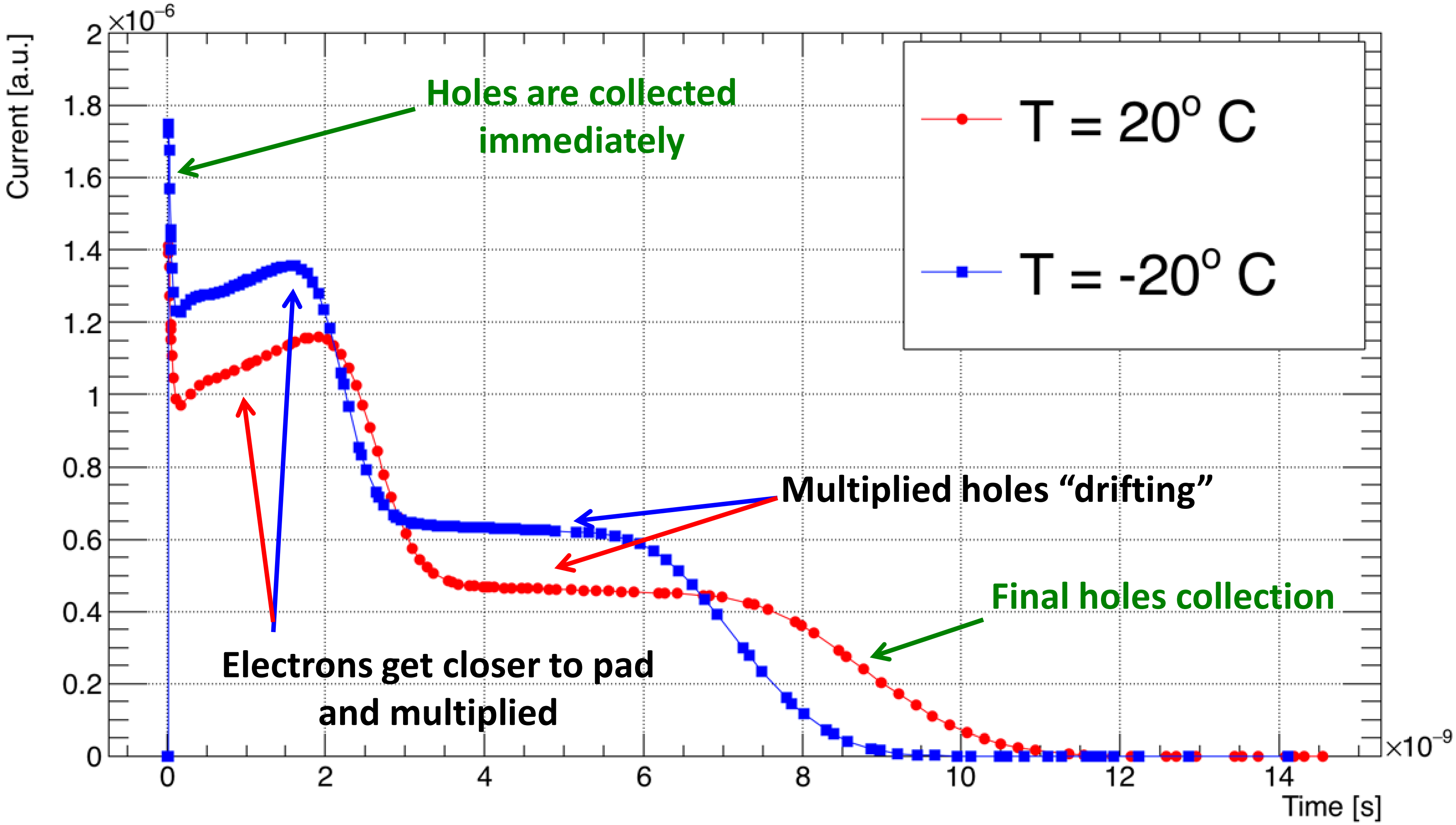
Hole Conc. – 150 V, 2 ns after particle strike



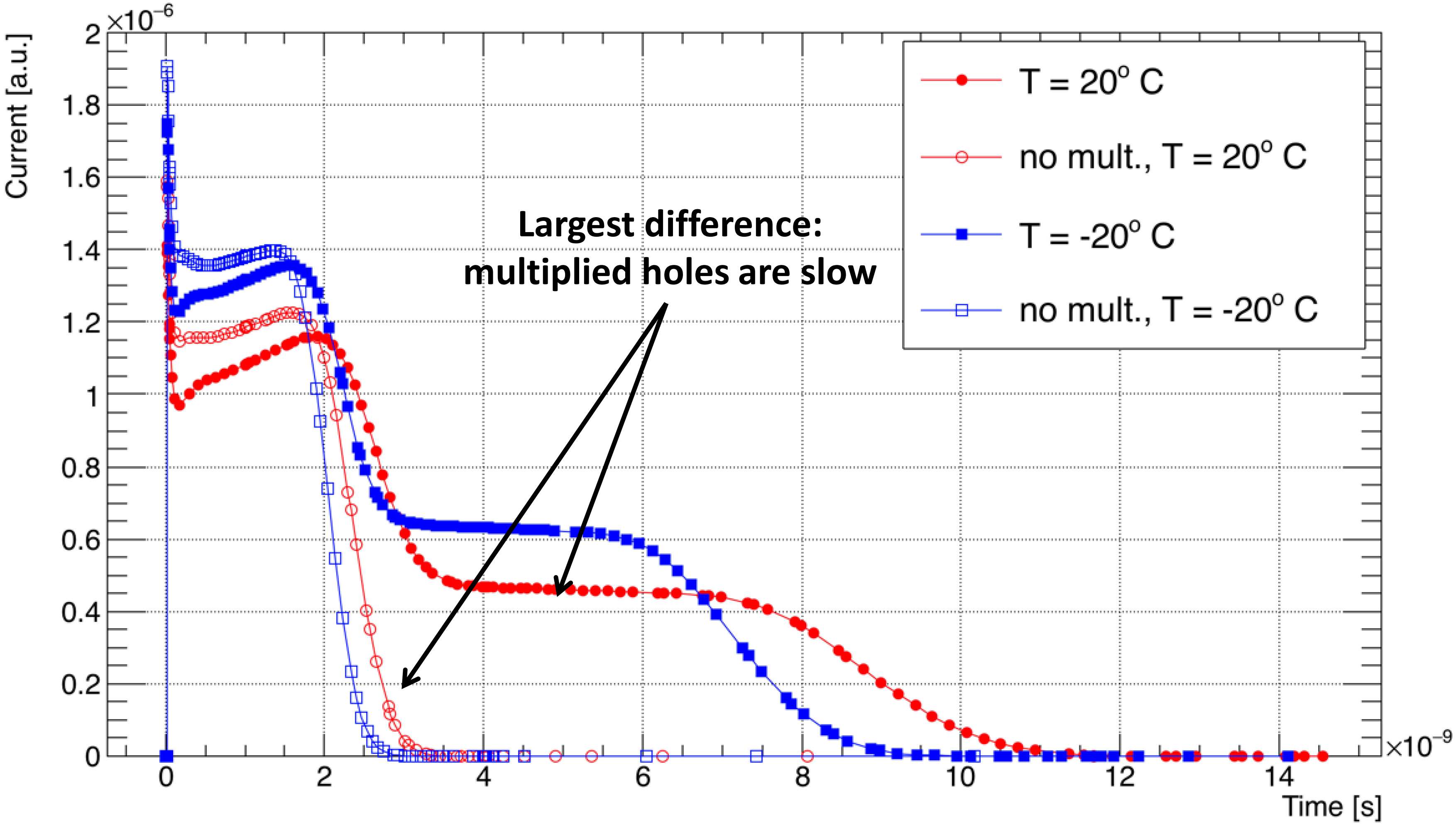
Signal, V = 150 V



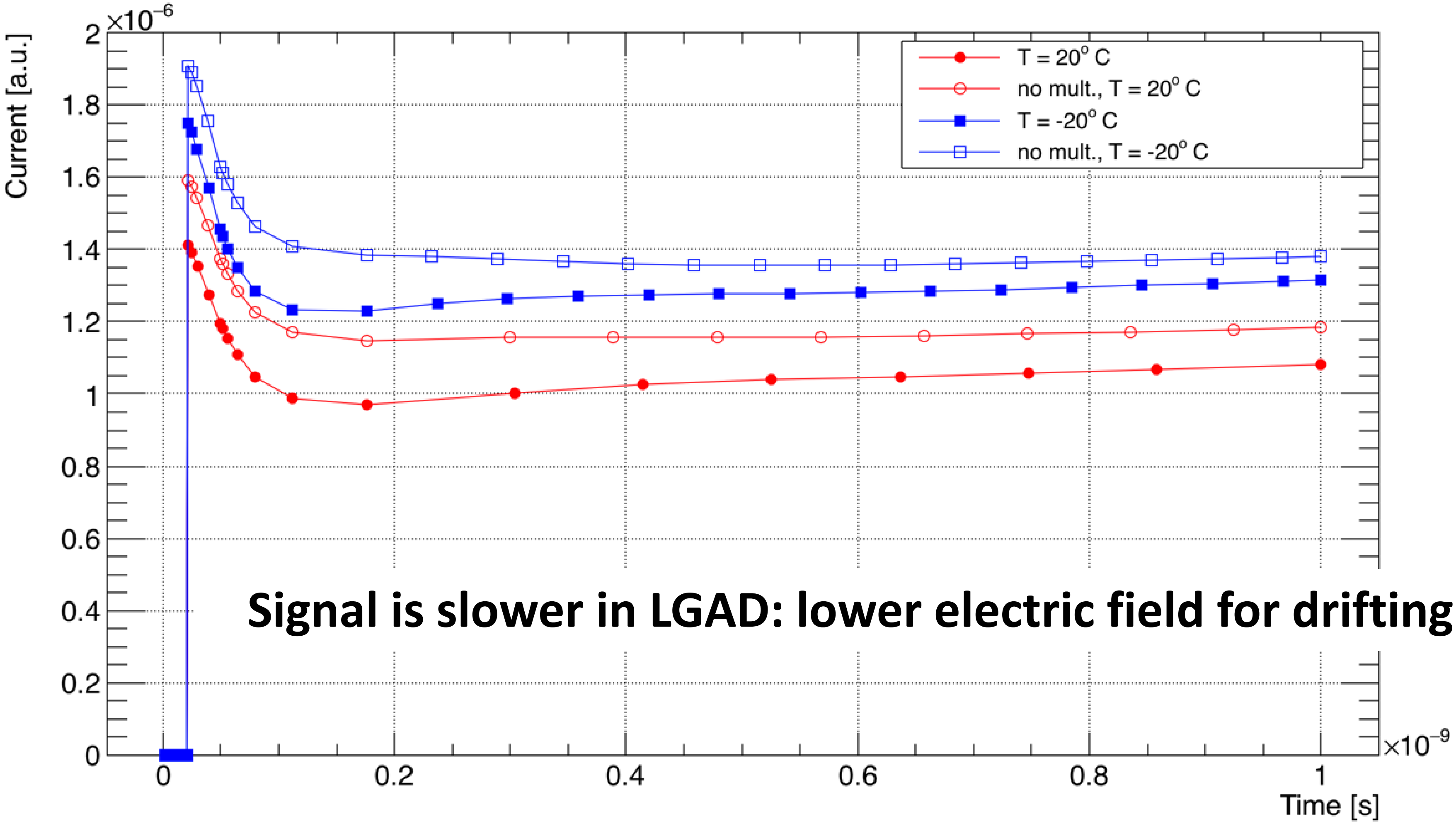
Signal, V = 200 V



LGAD vs reference – 200 V

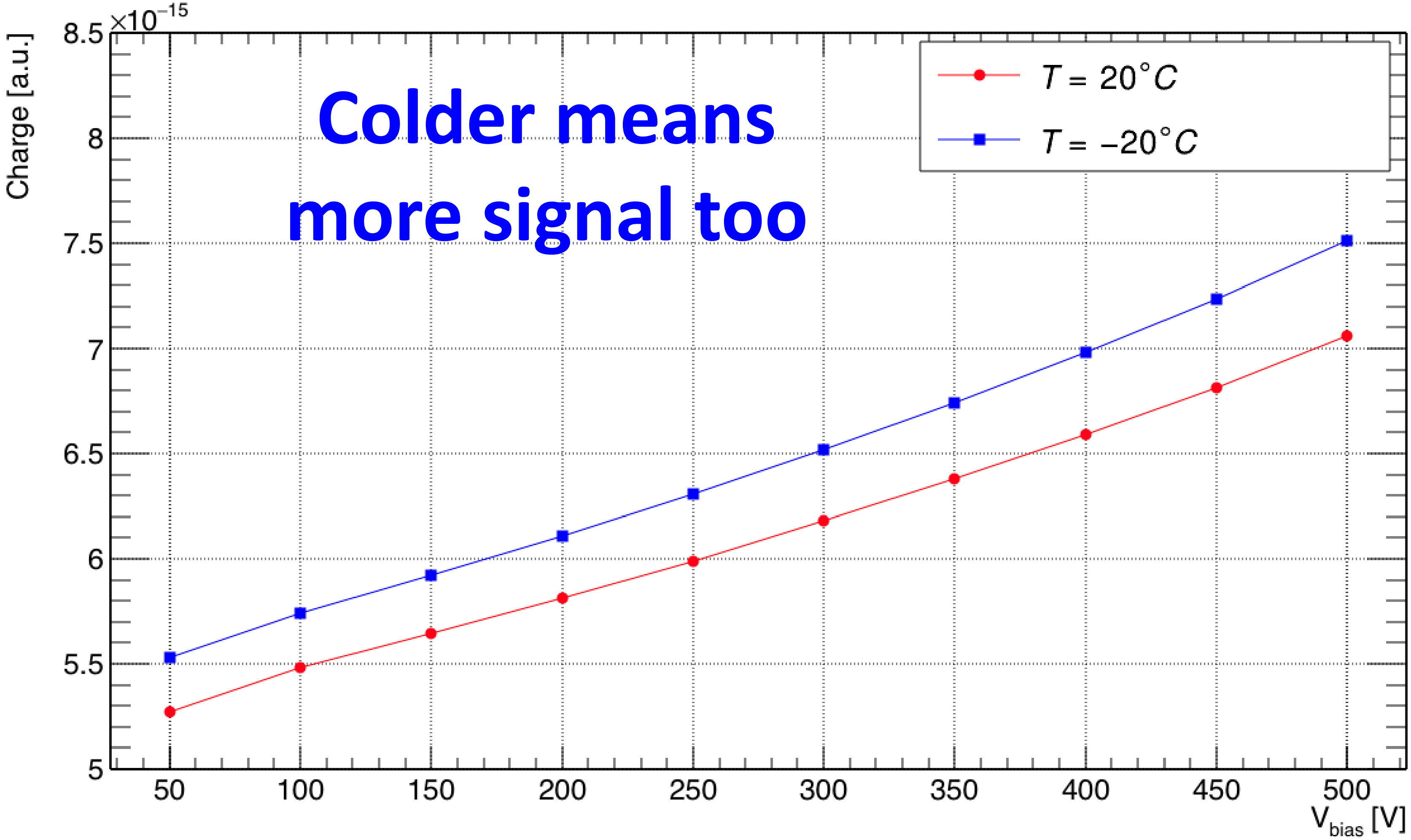


LGAD vs reference – 200 V - zoom

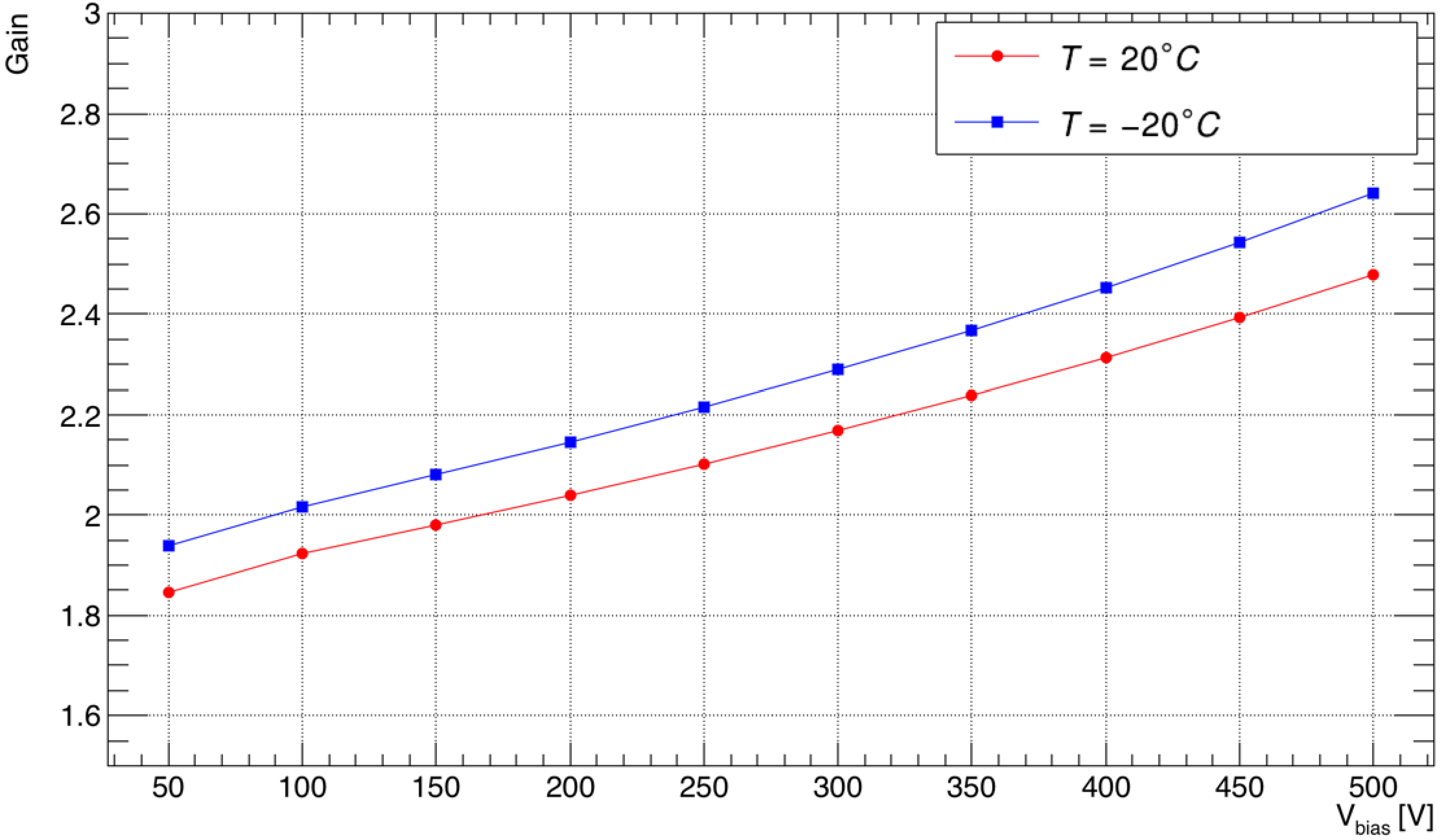


Signal is slower in LGAD: lower electric field for drifting

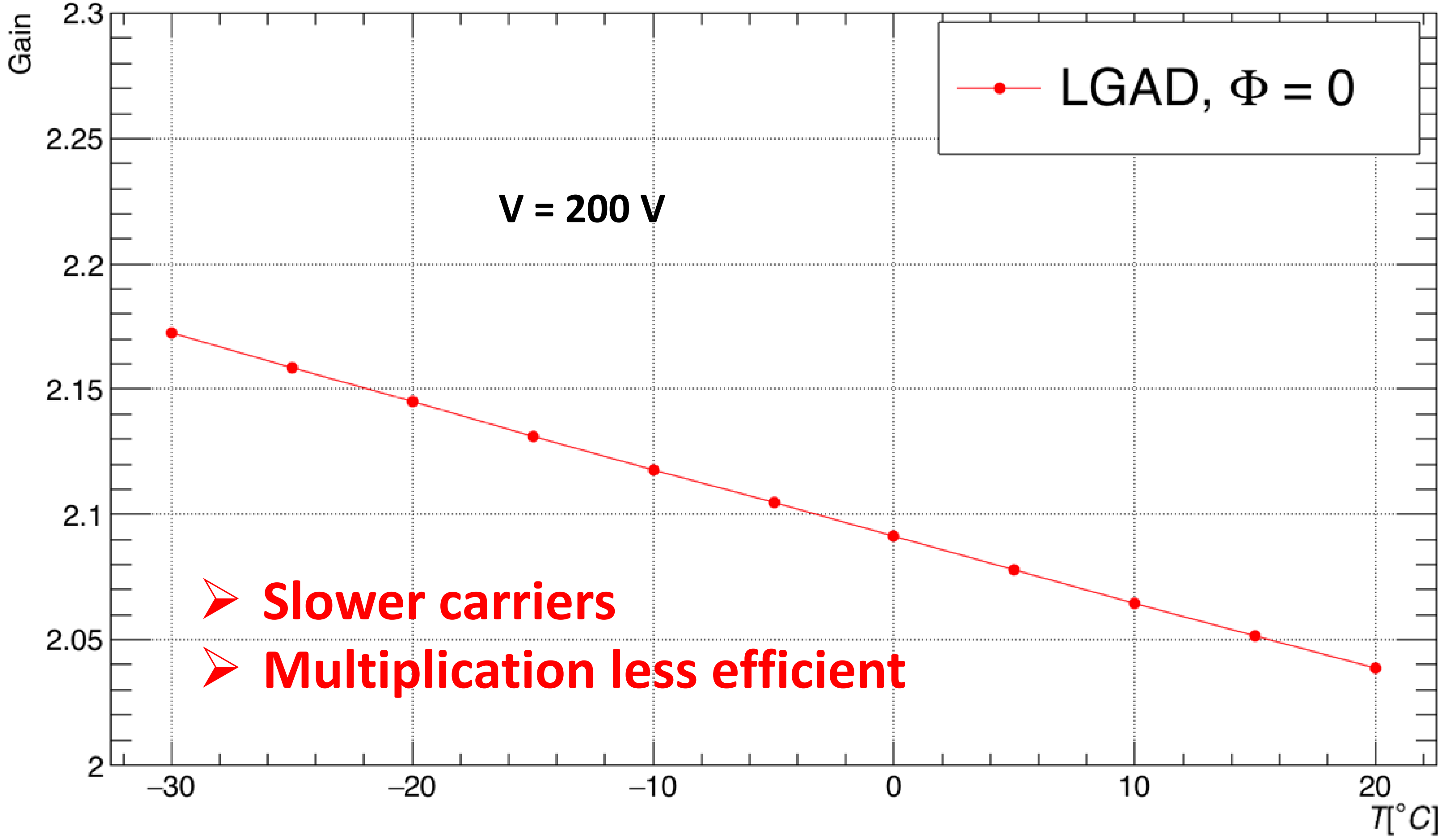
Charge: comparison



Gain for Fluence = 0



Gain vs temperature



MIPs simulations

- MIP impinging from the front
- 50, 100, 200 & 300 µm thick devices
- V_{bias} = from 50 to 1000 V
- $\Phi = 0, 1x10^{15}, 3x10^{15}$ & $1x10^{16}$
  - Model: Moscatelli et al. 2015 – NSS 2015
  - and Passeri et al. 2015 - Nucl. Instr. Meth. A (in press)
    - Bulk damage only (*N.B.* no acceptor removal, only trapping)
- Observables: signal, IV, electric field and gain

Passeri et al. 2015

Modeling of radiation damage effects in silicon detectors at high fluences HL-LHC with Sentaurus TCAD

D. Passeri [a,b,*], F. Moscatelli [c,b], A. Morozzi [a,b], G.M. Bilei [b]

Table 1

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

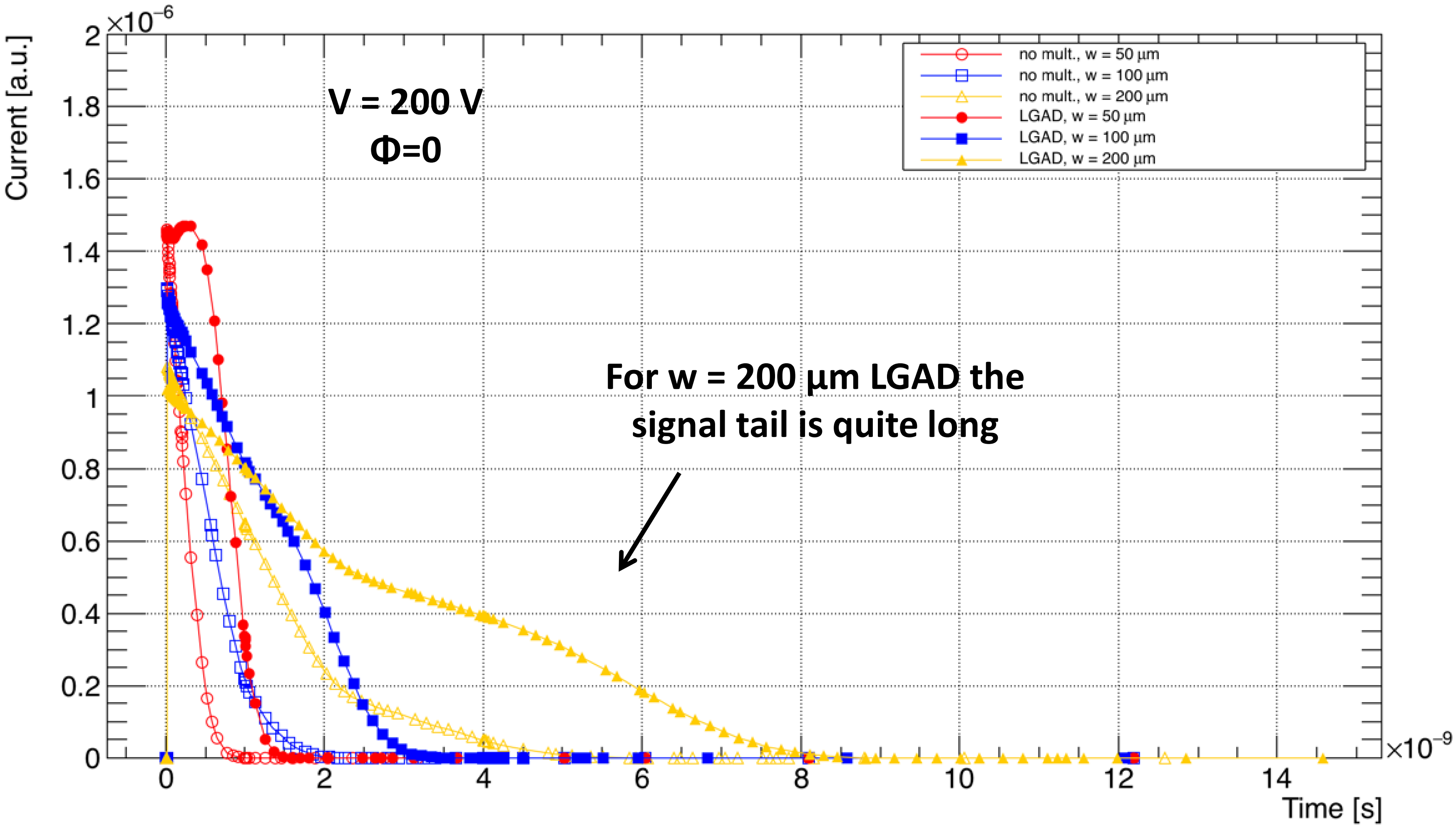
Defect	E (eV)	σ_e (cm^{-2})	σ_n (cm^{-2})	η
Acceptor	$E_c - 0.42$	1.00×10^{-15}	1.00×10^{-14}	1.6
Acceptor	$E_c - 0.46$	7.00×10^{-15}	7.00×10^{-14}	0.9
Donor	$E_v + 0.36$	3.23×10^{-13}	3.23×10^{-14}	0.9

Table 2

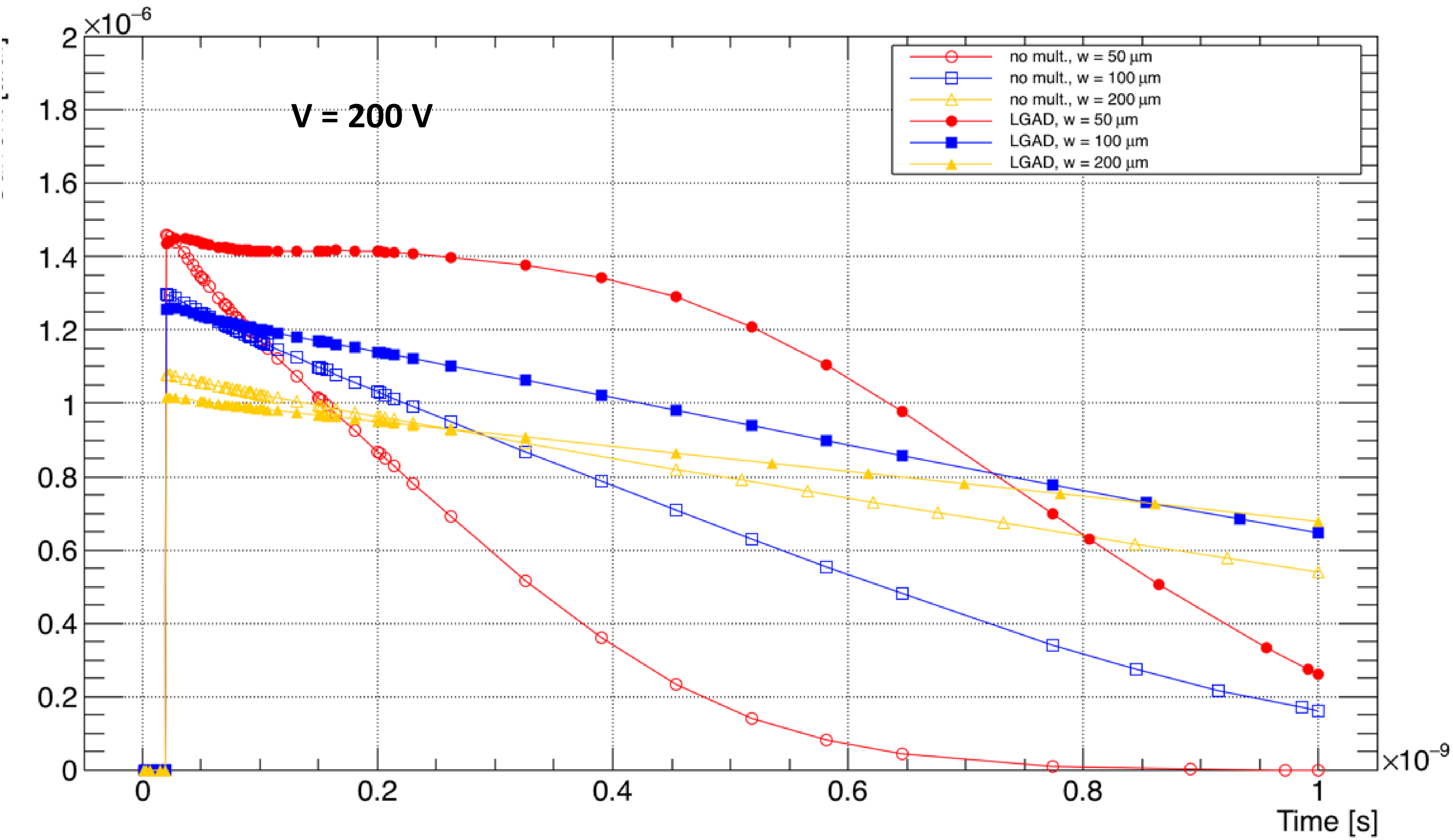
Parameters for fluences within 7×10^{15} n/cm^2 and 2.2×10^{16} n/cm^2.

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

Signal vs time, different thicknesses – 200 V

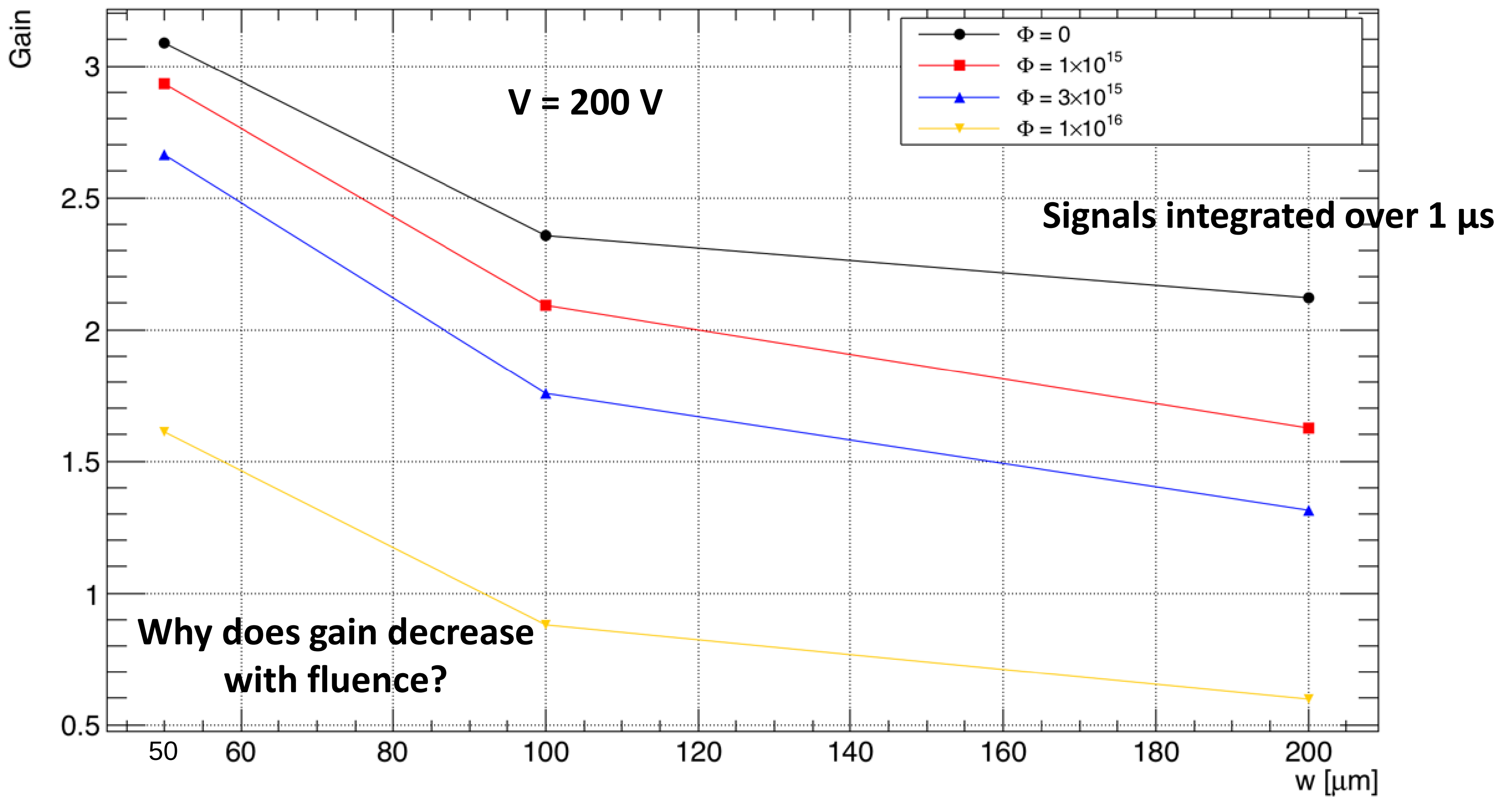


Signal of irr. samples – $\Phi = 1x10^{15}$



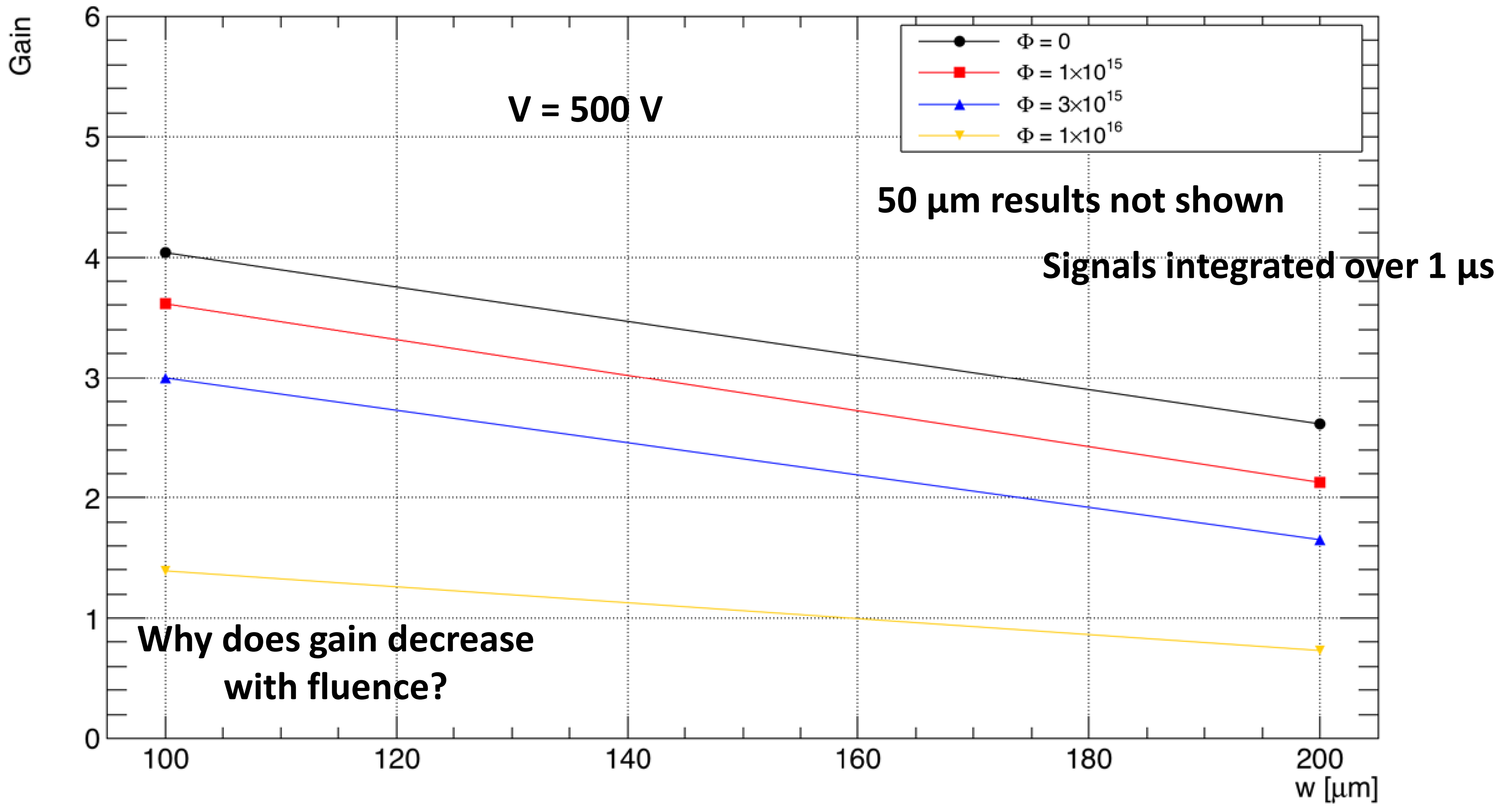
Gain vs different thicknesses – 200 V

Gain = charge normalised to a non-LGAD device at the same fluence and voltage

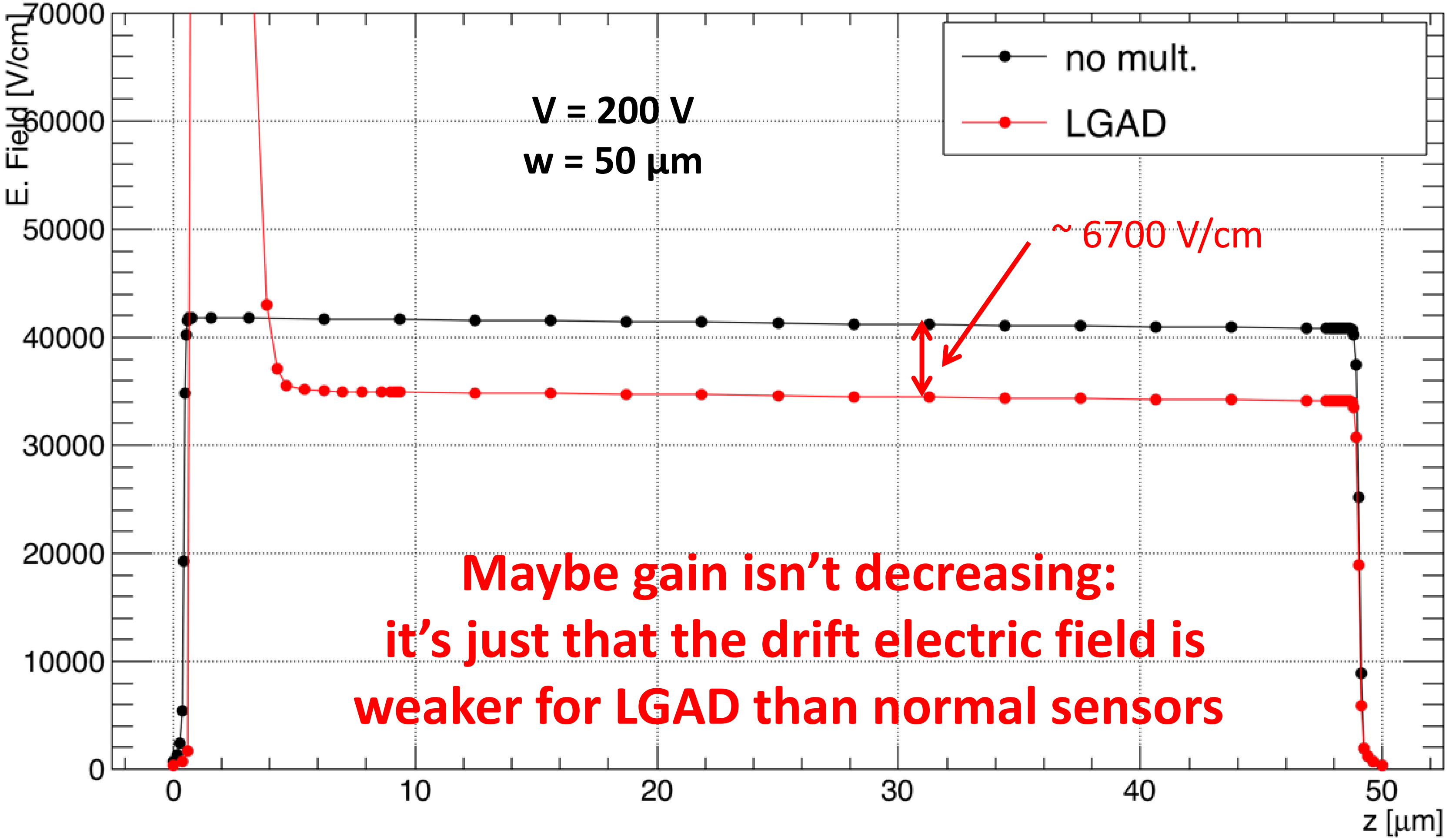


Gain vs different thicknesses – 500 V

Gain = charge normalised to a non-LGAD device at the same fluence and voltage

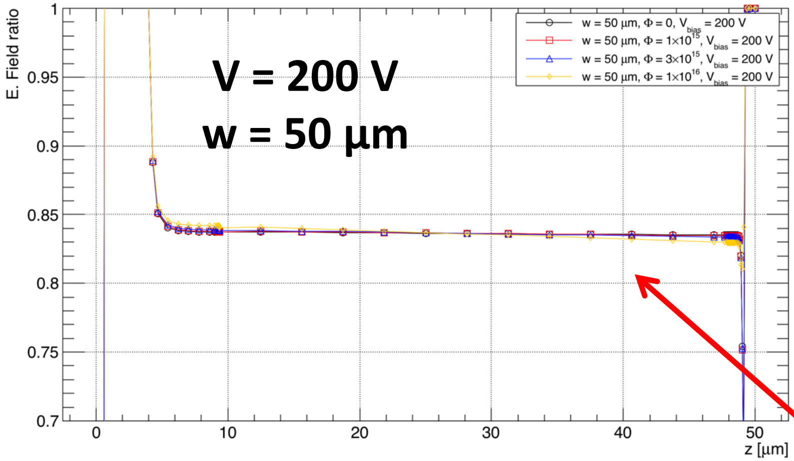


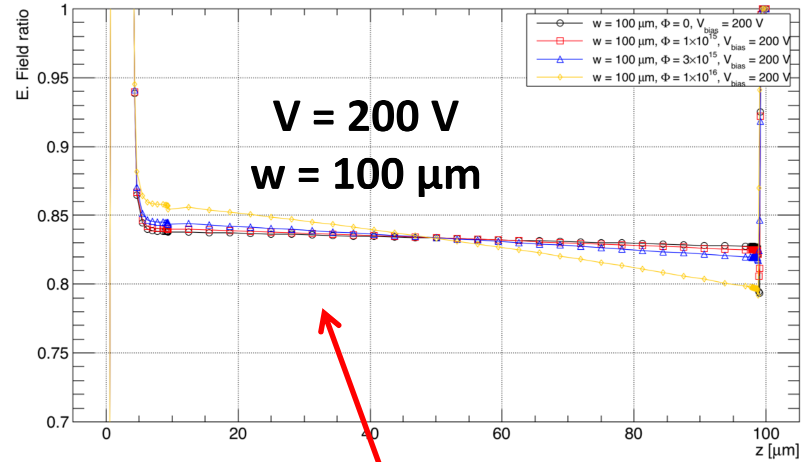
Electric field for $\Phi = 1x10^{15}$

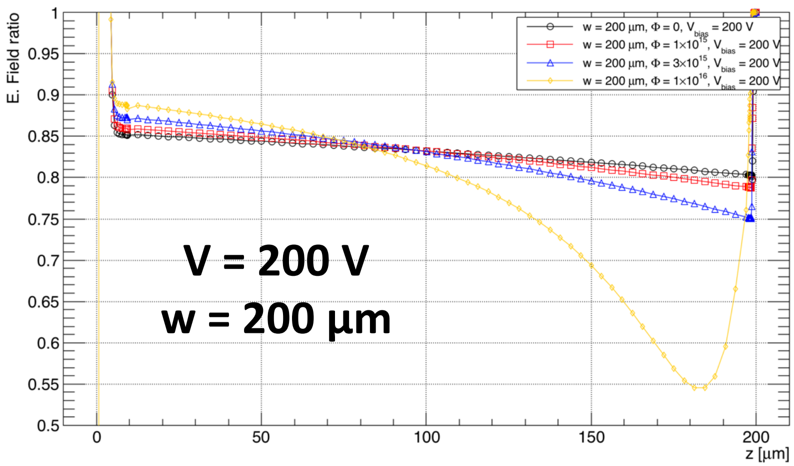


Electric field ratio

Electric field normalized to the reference detector



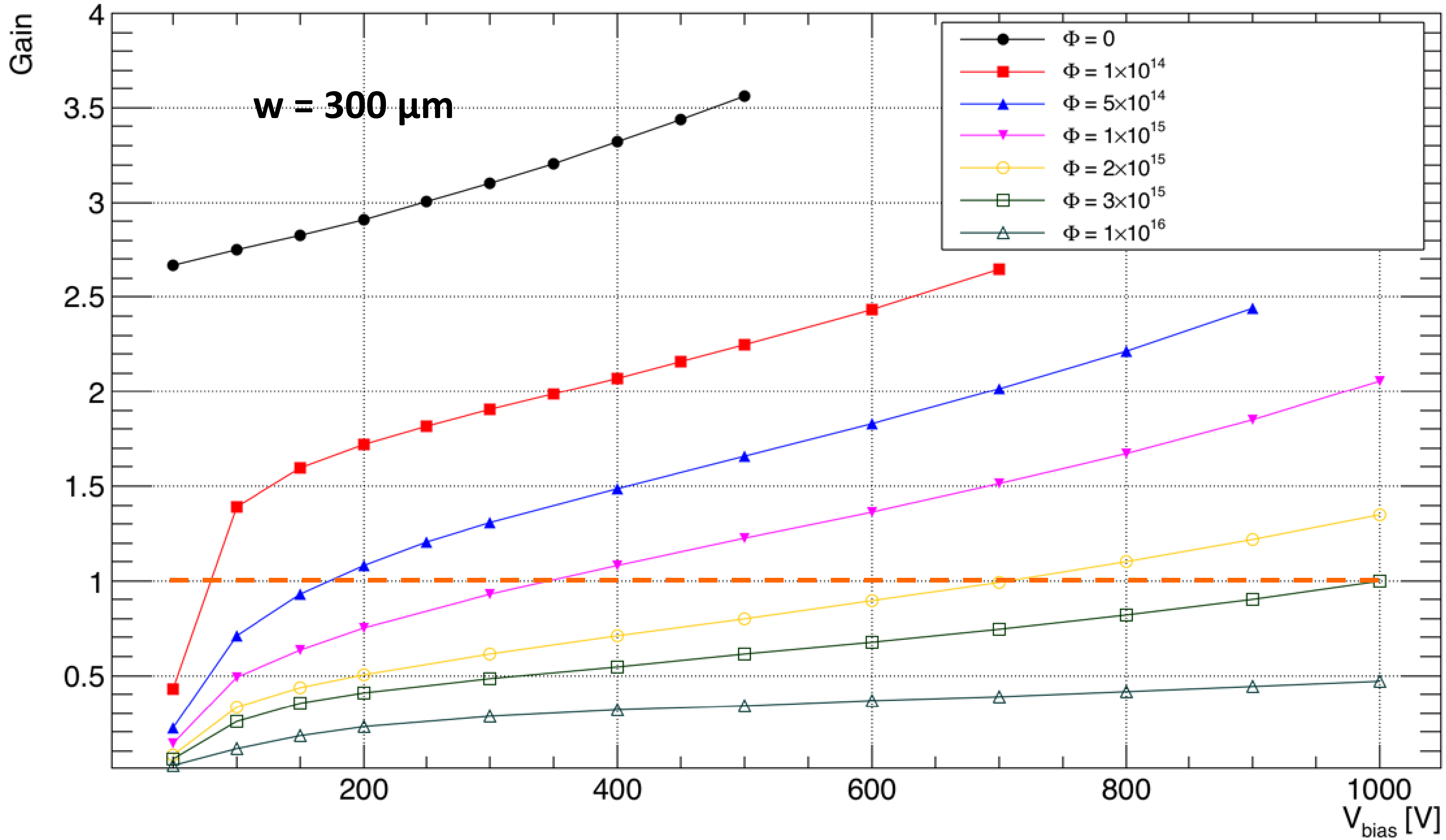




Bulk field significantly lower

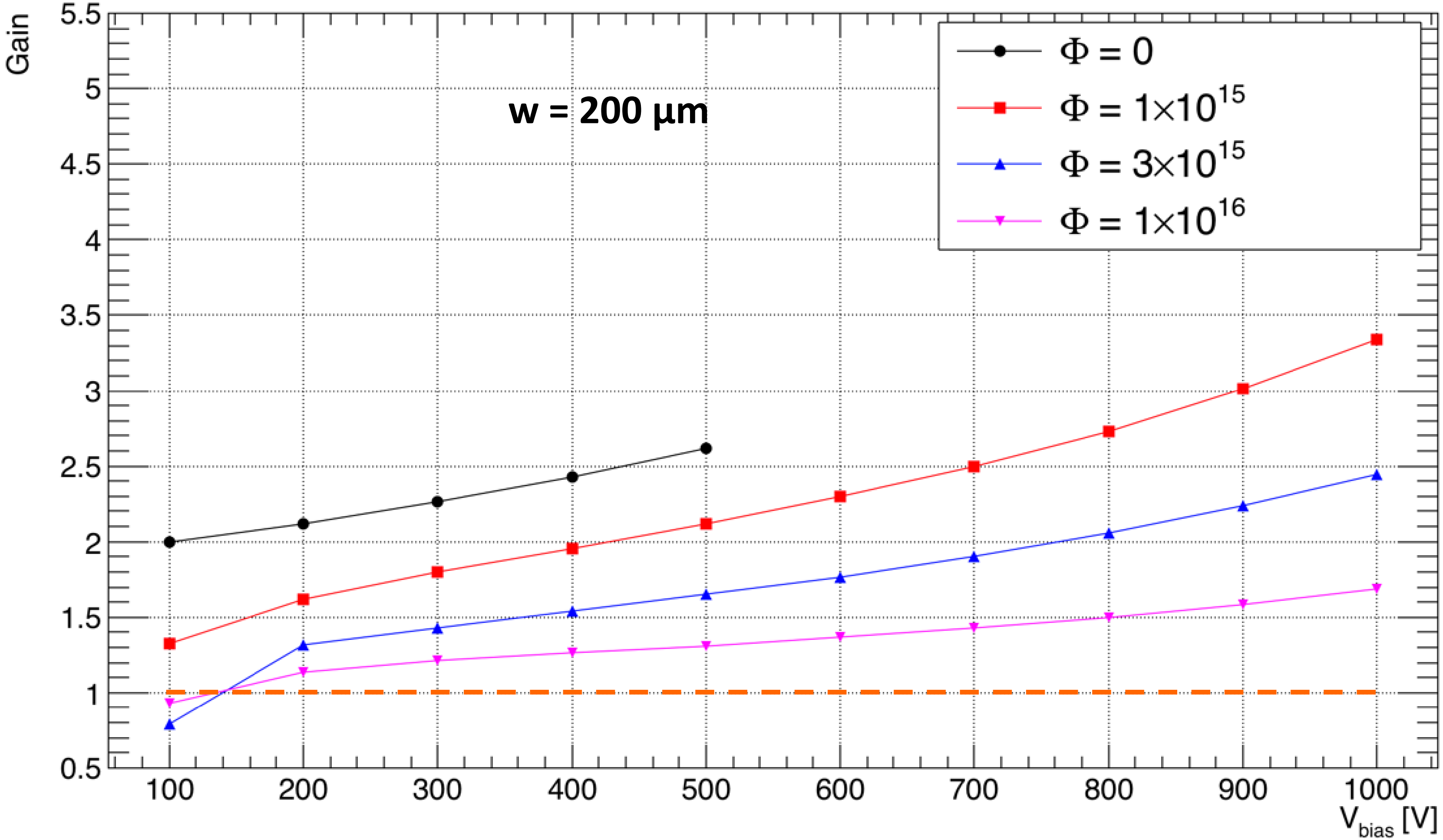
Gain vs bias voltage – w = 300 μm

Charge normalized to the reference detector at the zero fluence

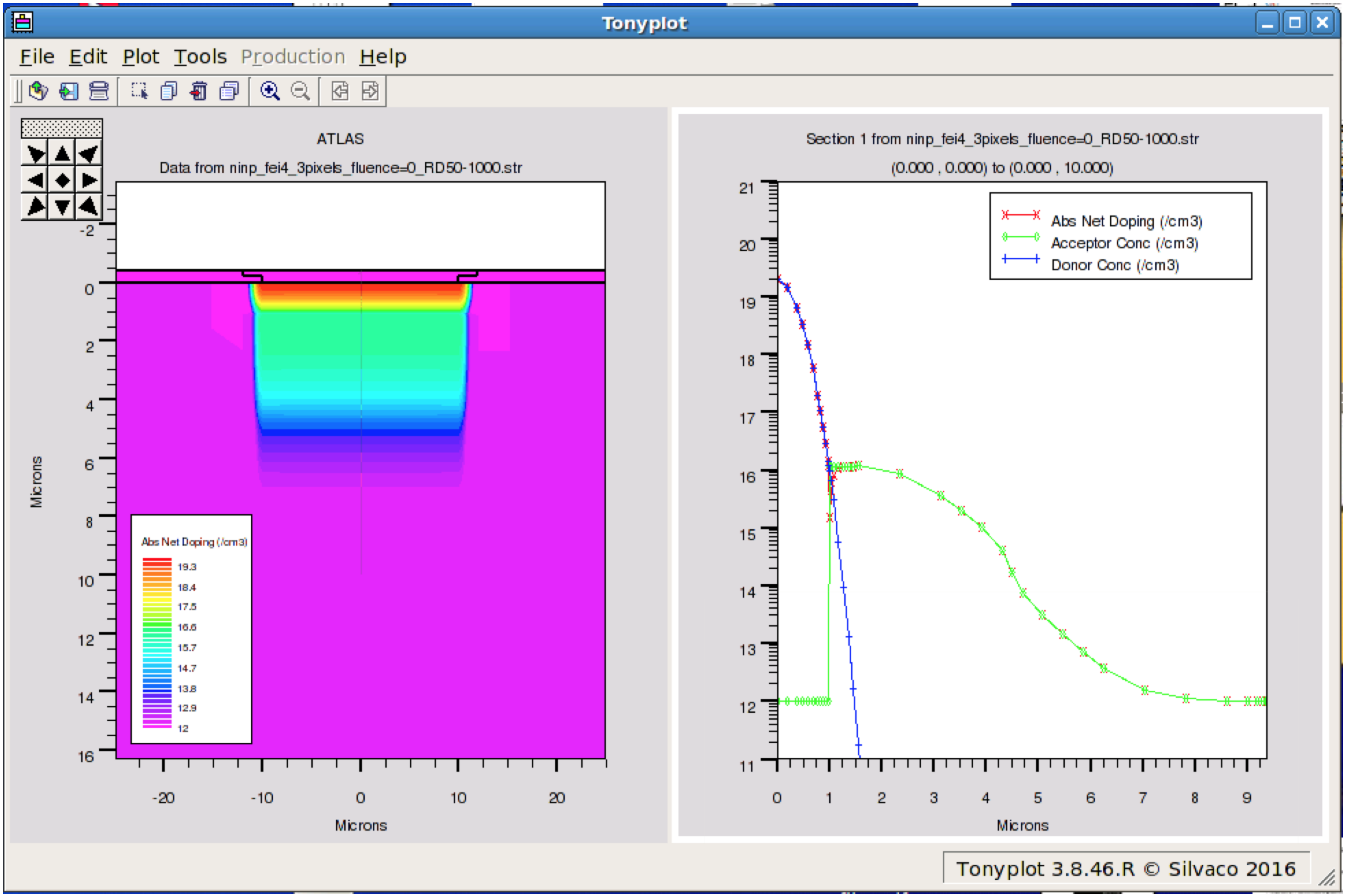


Gain vs bias voltage – w = 200 μm

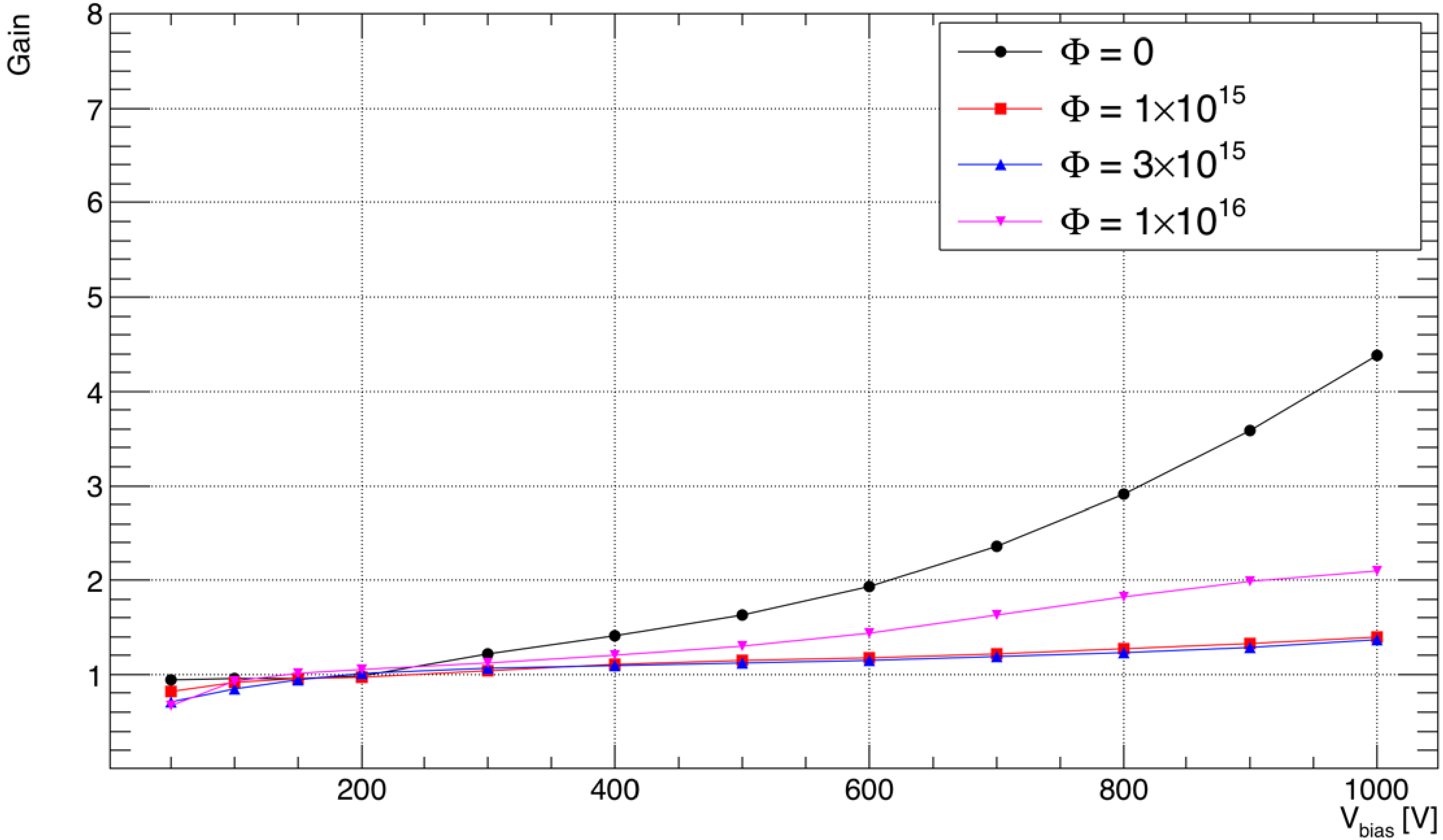
Charge normalized to the reference detector at the same fluence



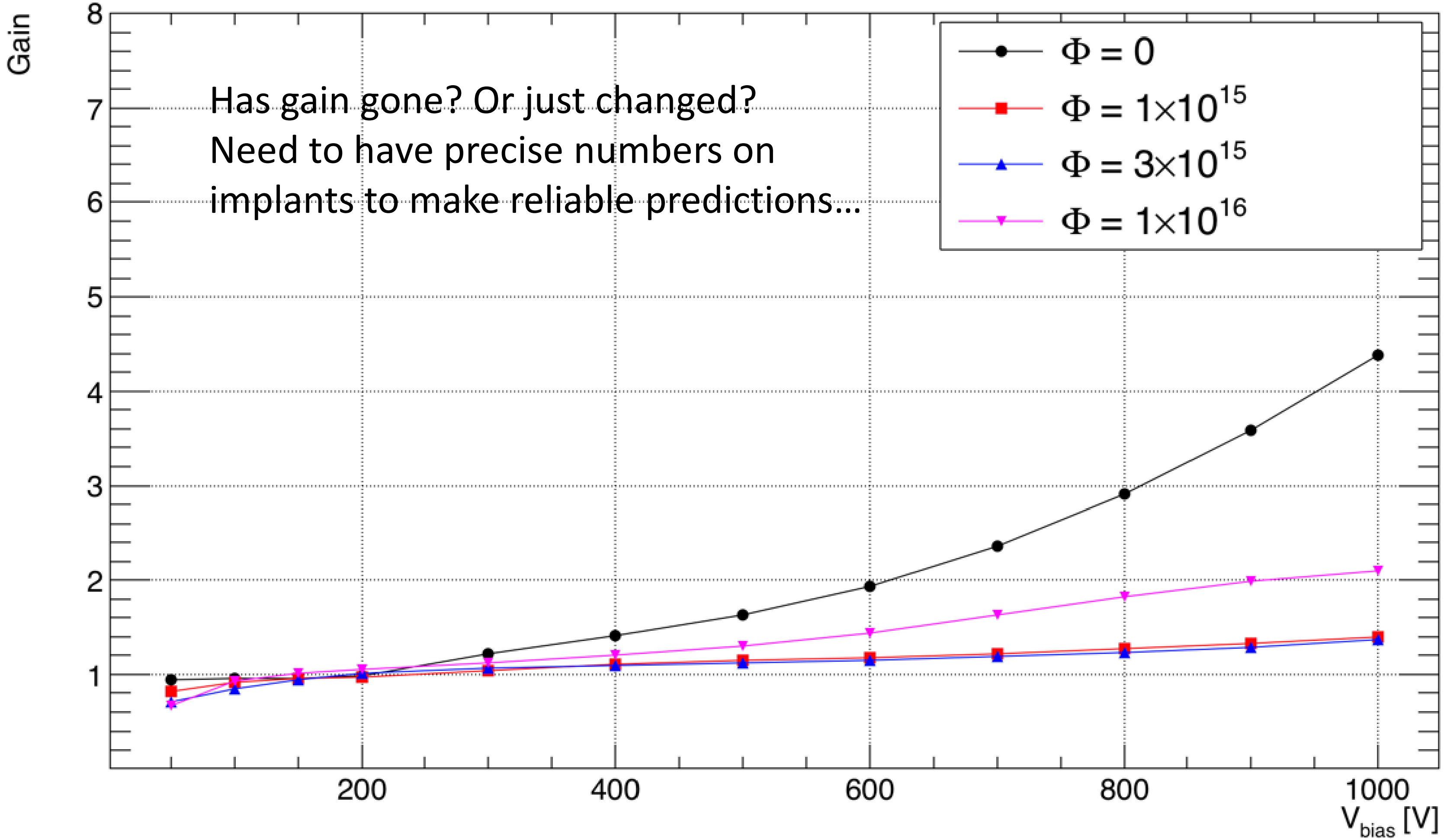
More realistic structure



Very preliminary results on the new structure

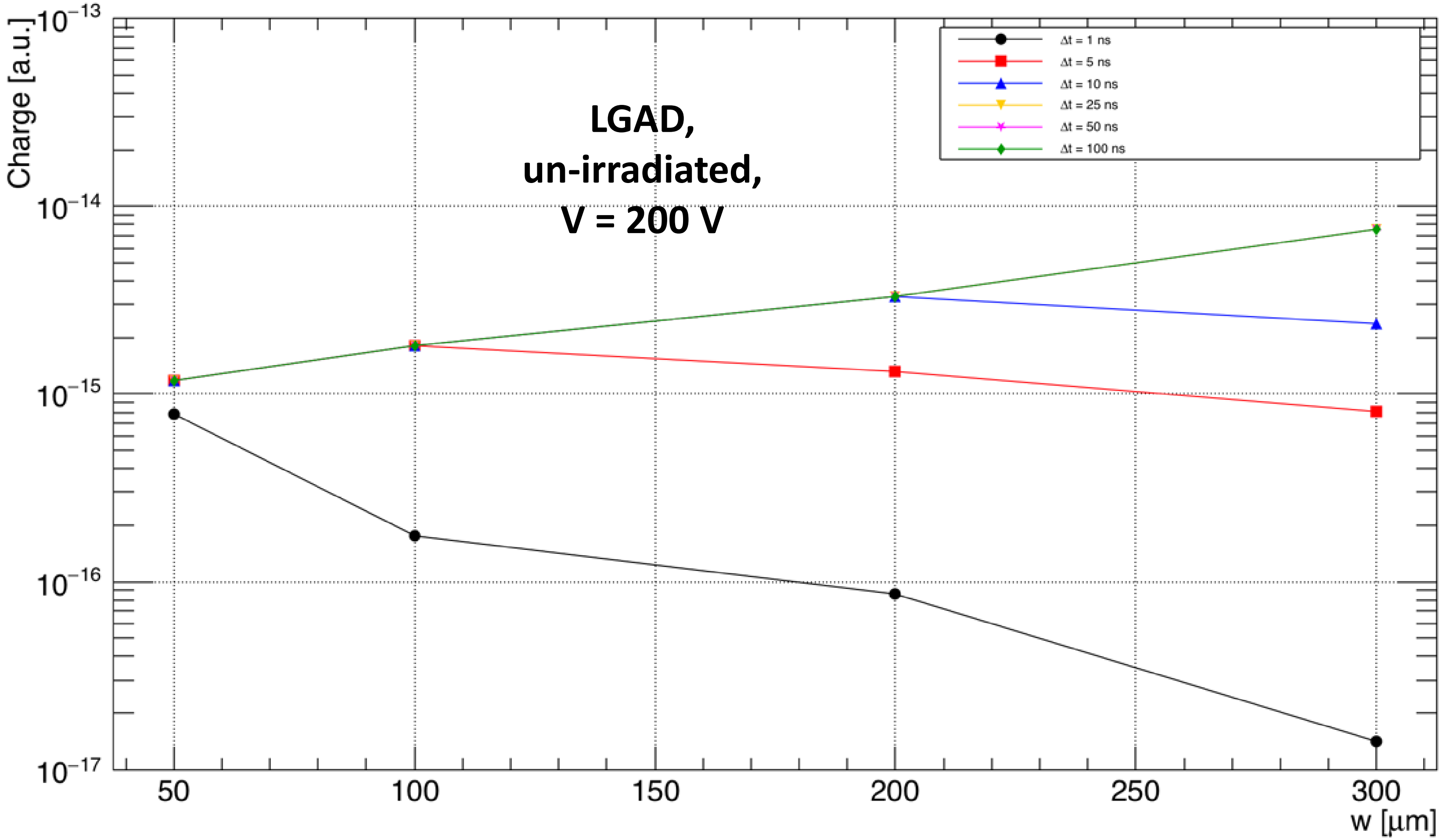


Very preliminary results on the new structure



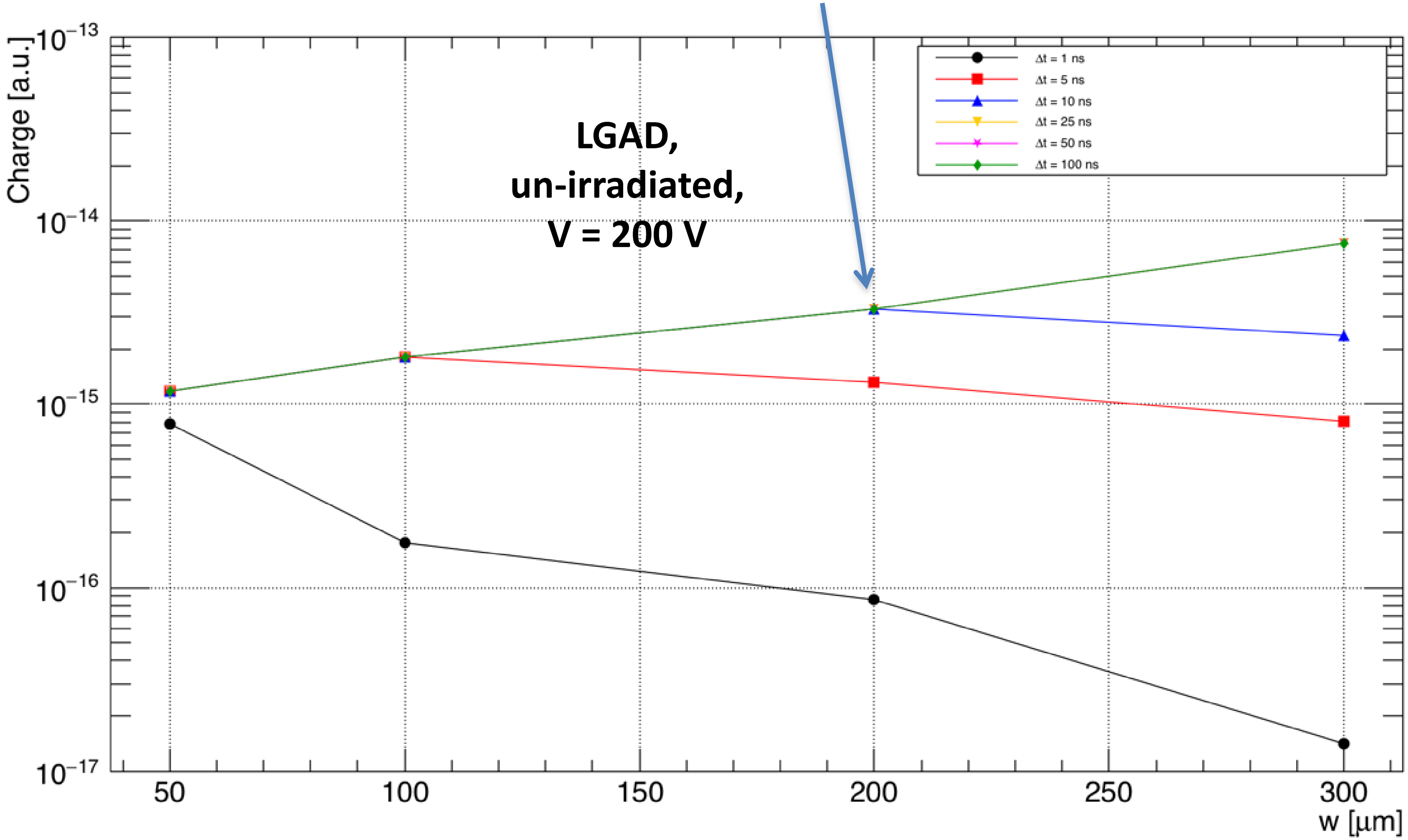
Has gain gone? Or just changed?
Need to have precise numbers on implants to make reliable predictions…

How long do I have to wait for my signal?

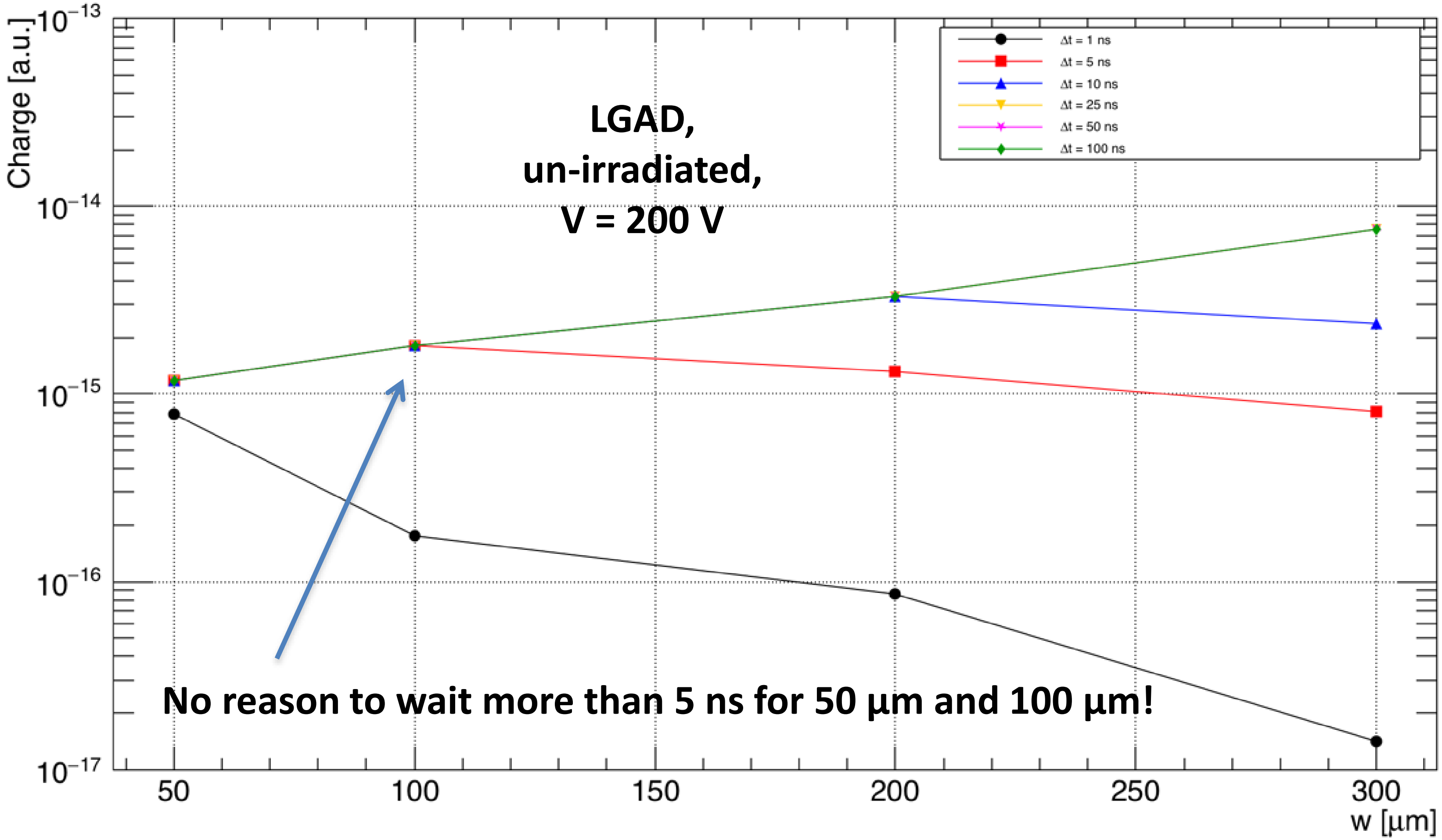


How long do I have to wait for my signal?

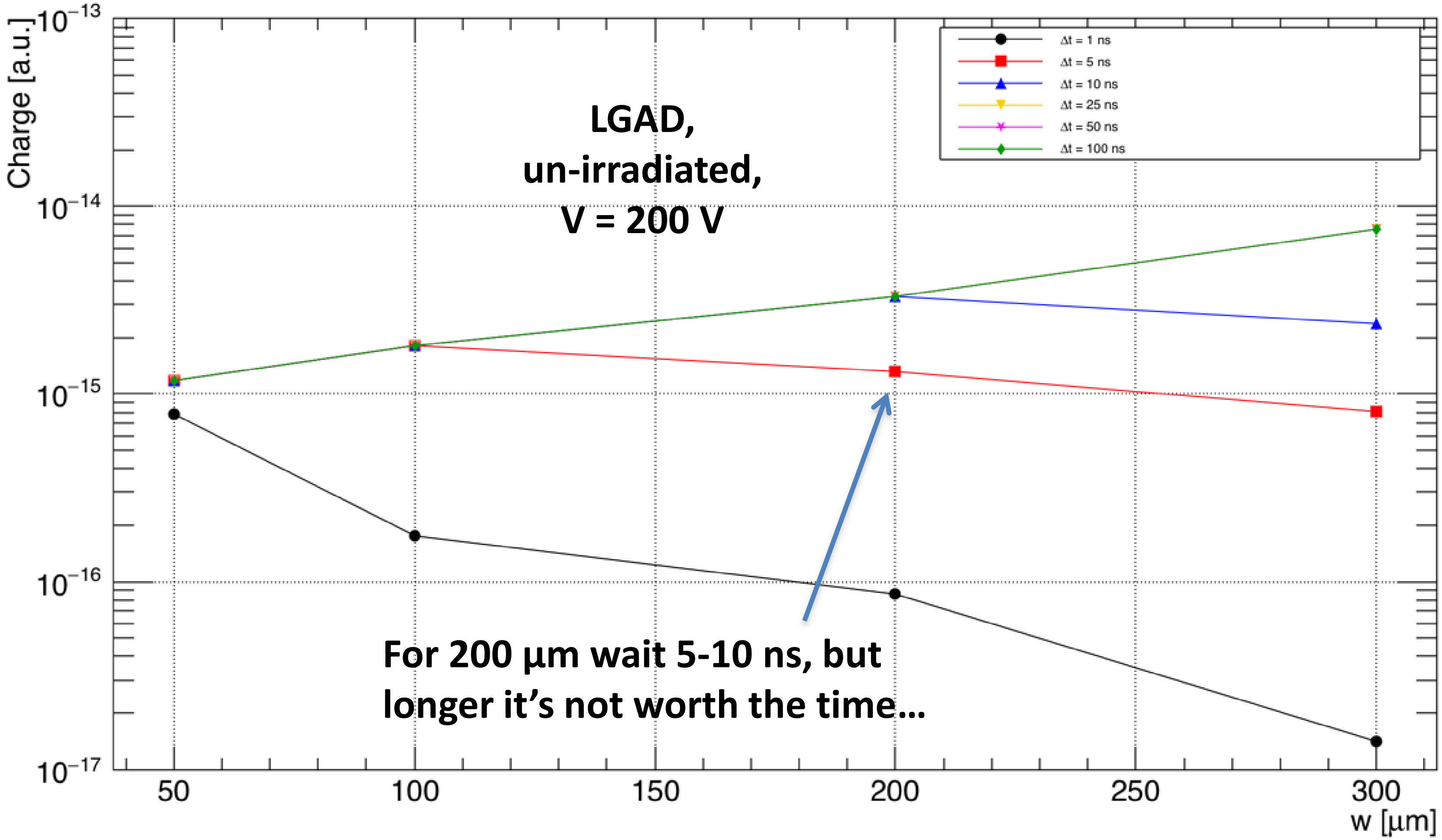
After 10 ns it doesn't make a lot of difference, but…



How long do I have to wait for my signal?



How long do I have to wait for my signal?

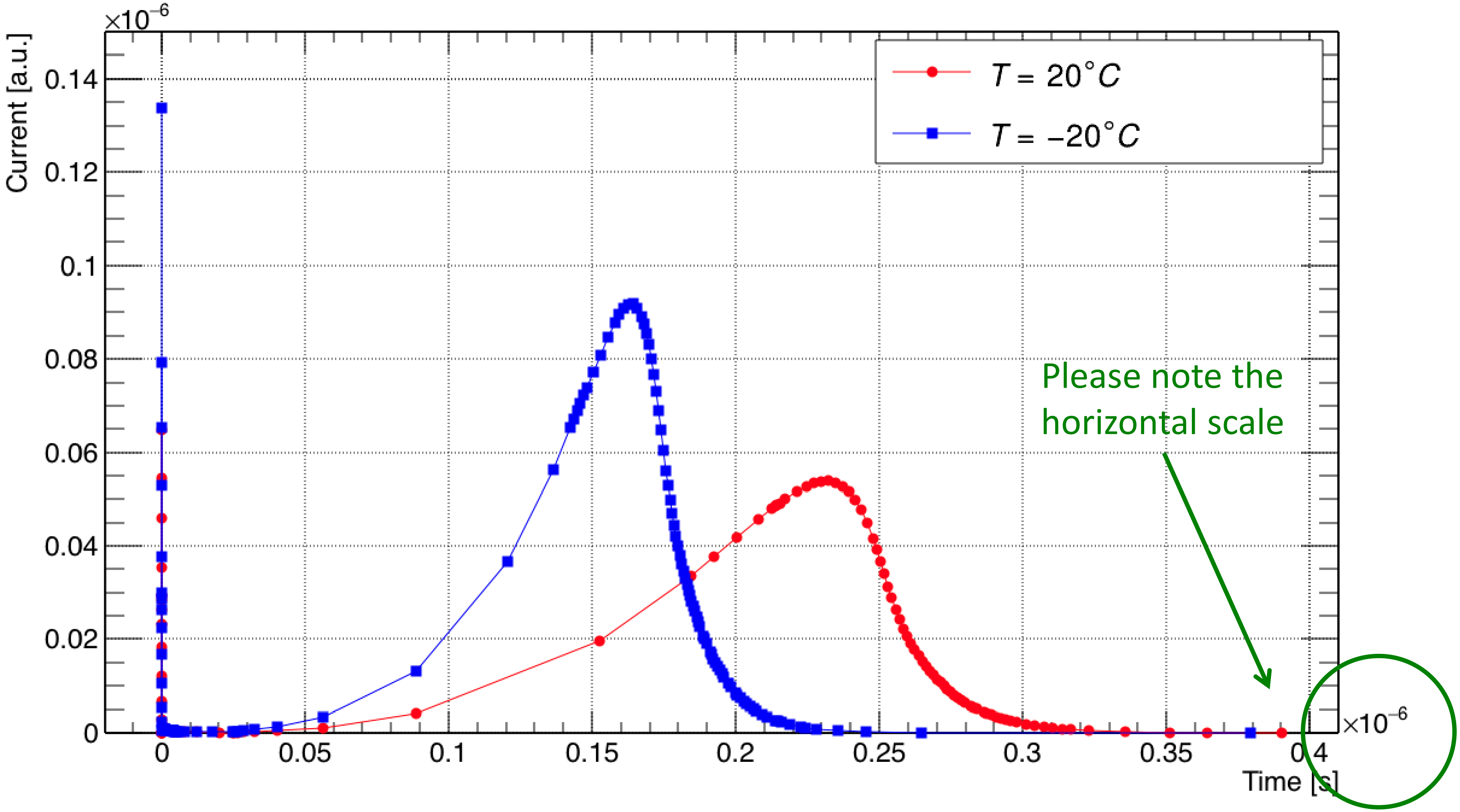


Conclusions & outlook

- Signal properties in LGAD have been studied
  - Both alpha from backside and MIPs
- Alpha studies show that the holes are multiplied
- Colder device is faster (expected) and gives rise to more charge
  - Reason: impact ionization is more effective (longer mean free path)
- MIP studies confirms that signal “takes” longer for LGAD
  - But response at t=0 is the same as for non-LGAD (expected)
  - Hence: the front-end will make the difference for timing
  - Anyway, interesting timing studies can be carried out
- Lower gain after irradiation could be apparent: an important difference could be linked to the electric field strength
- Gain for w = 200 µm goes from 1 to 1.7 from 0 to 1000V at $\Phi=1\times10^{16}$
- Next: *more realistic detectors* (**based on real numbers**), new doping profiles, surface damage effects

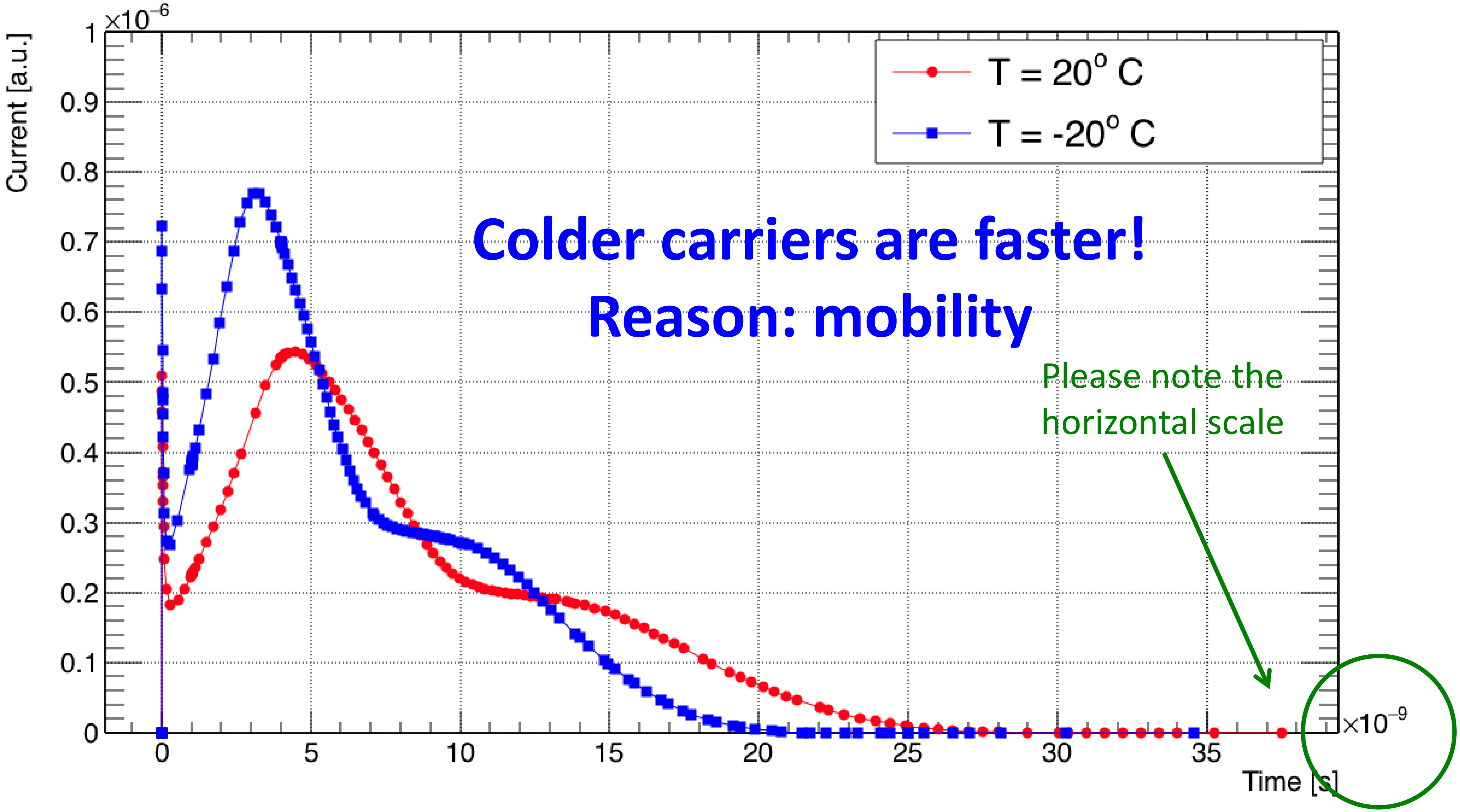
Backup

Signal, V = 50 V

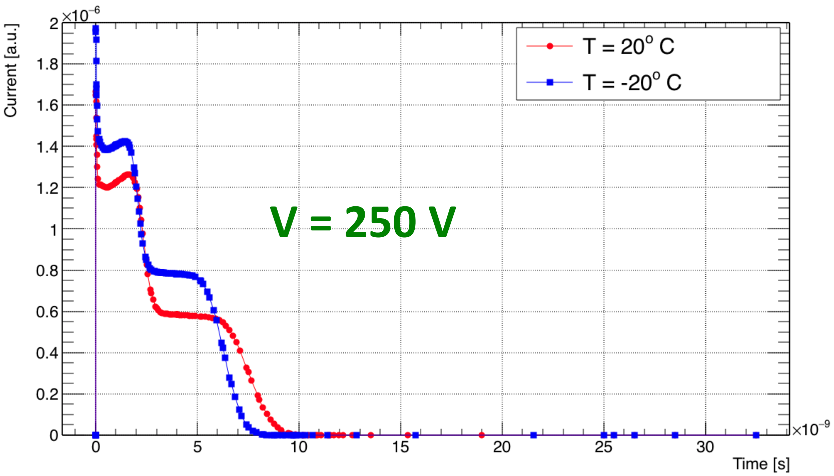


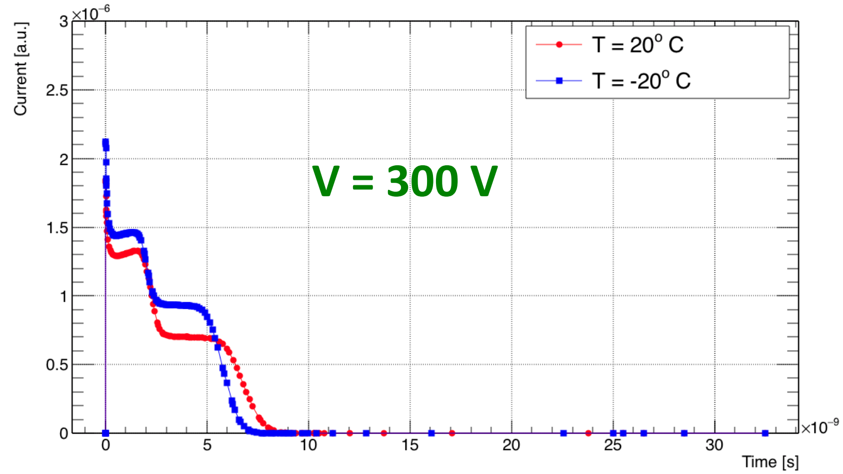
×10⁻⁶
Current [a.u.]
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
×10⁻⁶
Time [s]
T = 20°C
T = −20°C
Please note the horizontal scale

Signal, V = 100 V

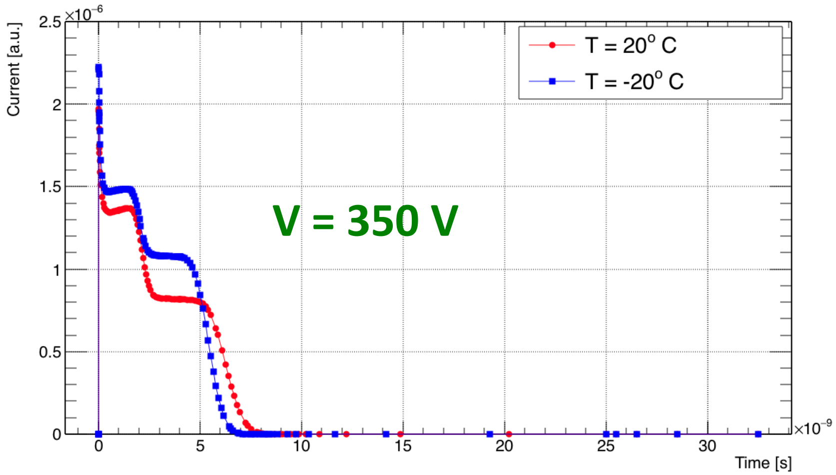


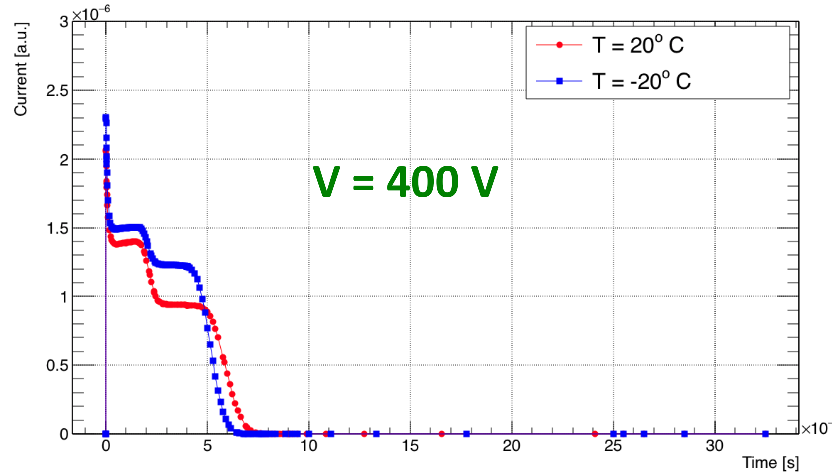
More bias points (I)





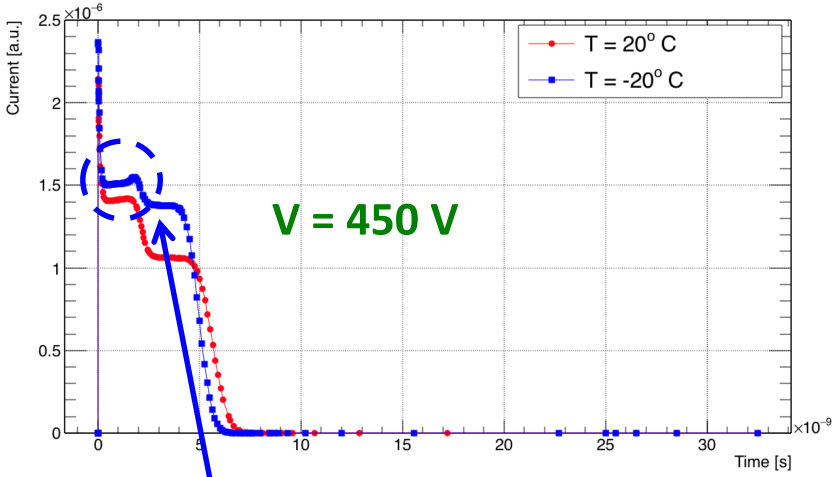
Same horizontal scale for all





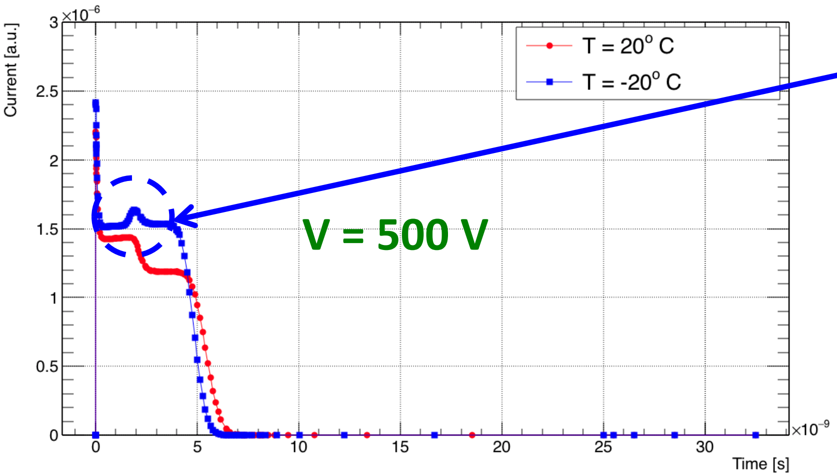
More bias points (II)

As before: colder means faster… and more signal too?

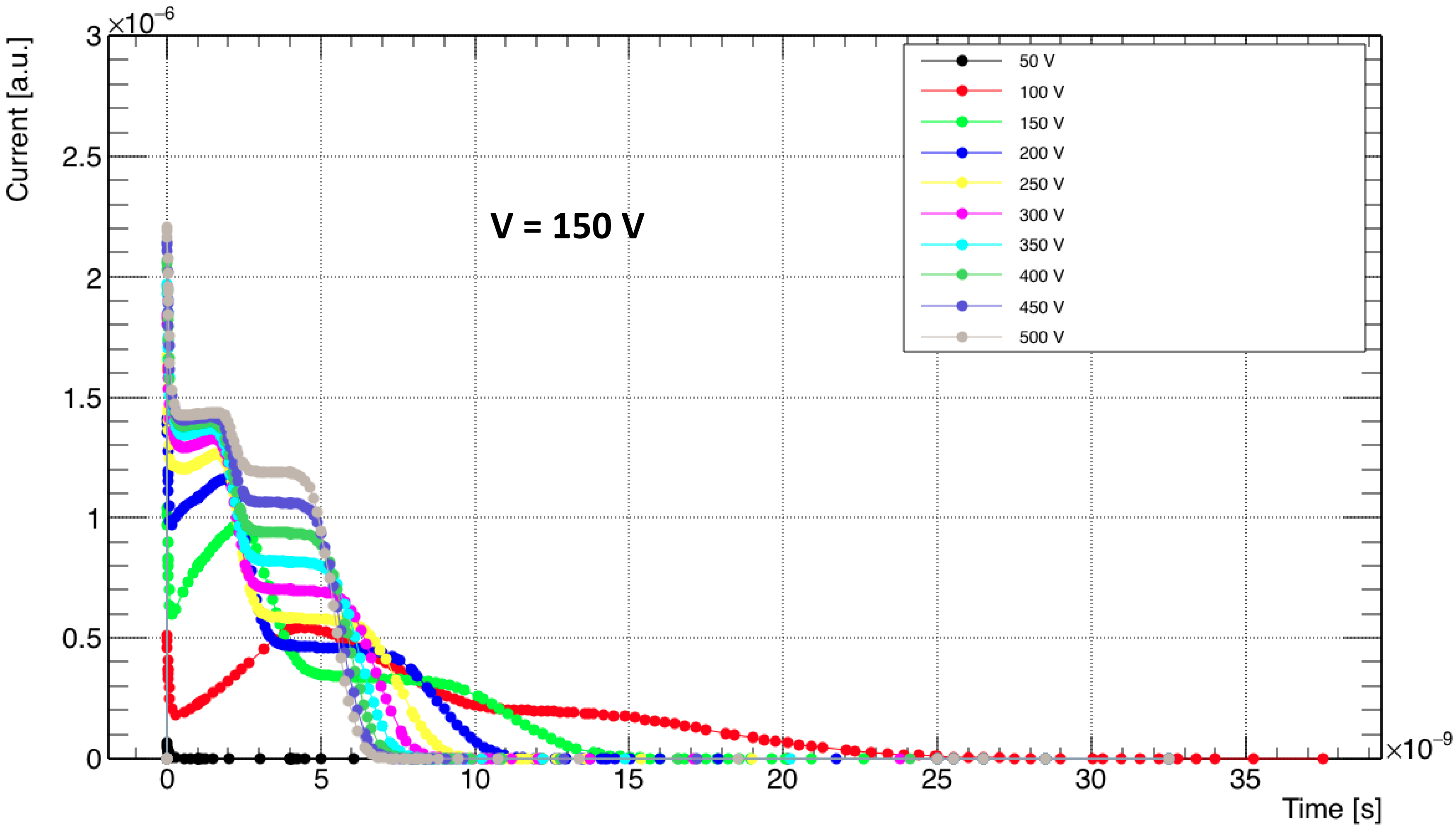


Same horizontal scale for all

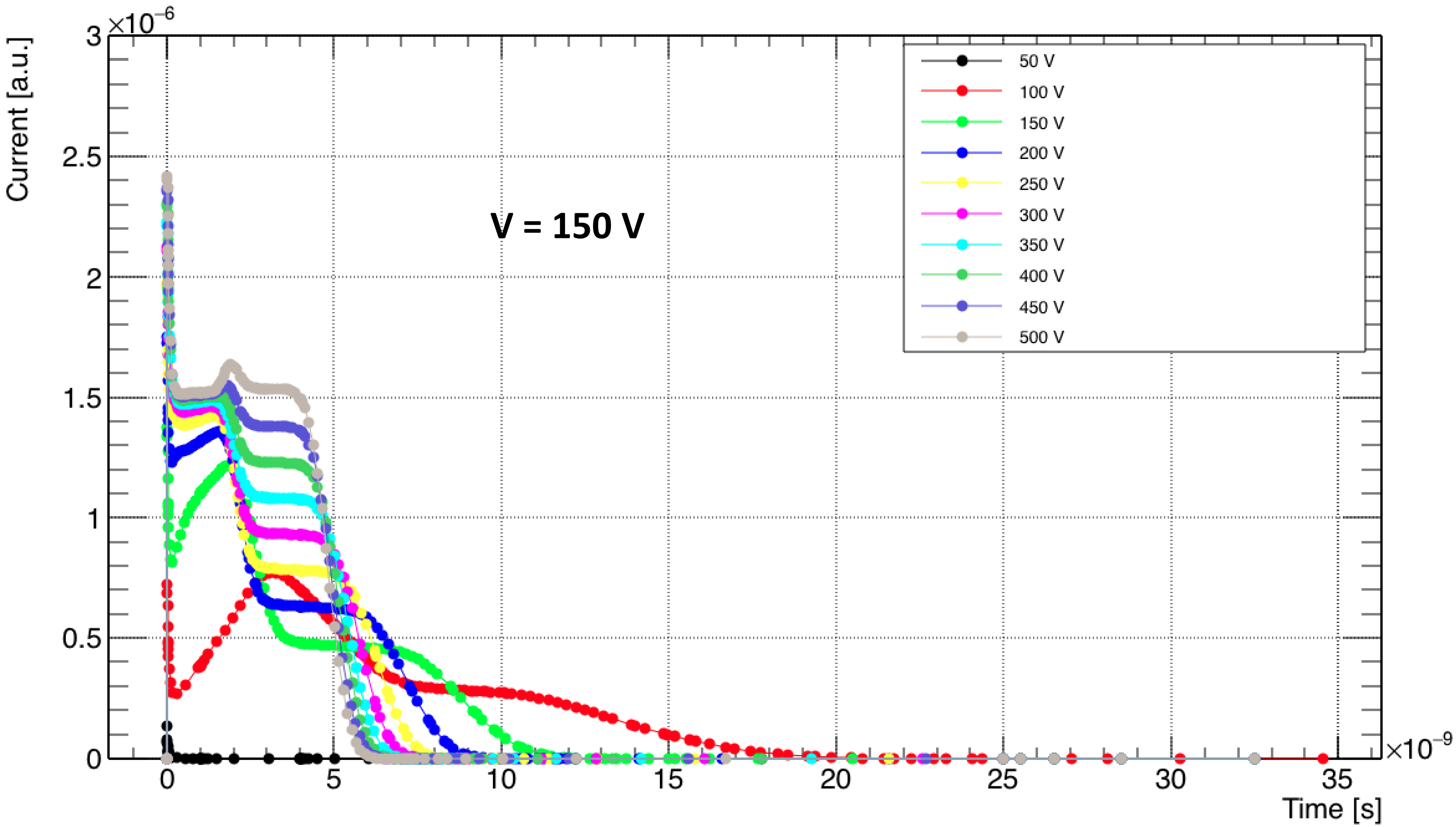
Ridge?



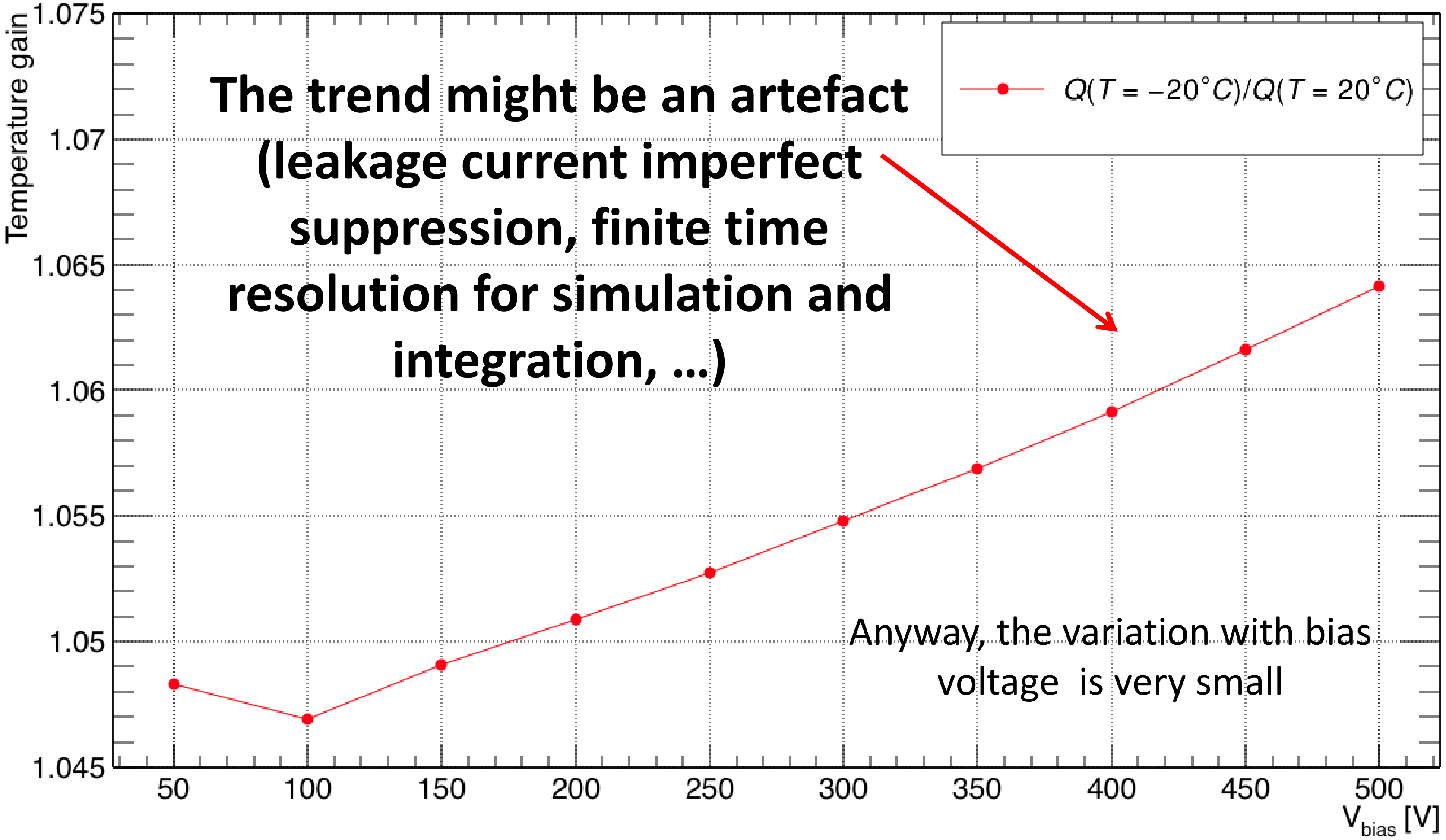
Summary plot for T = 20° C



Summary plot for T = -20^o C



“Temperature” gain

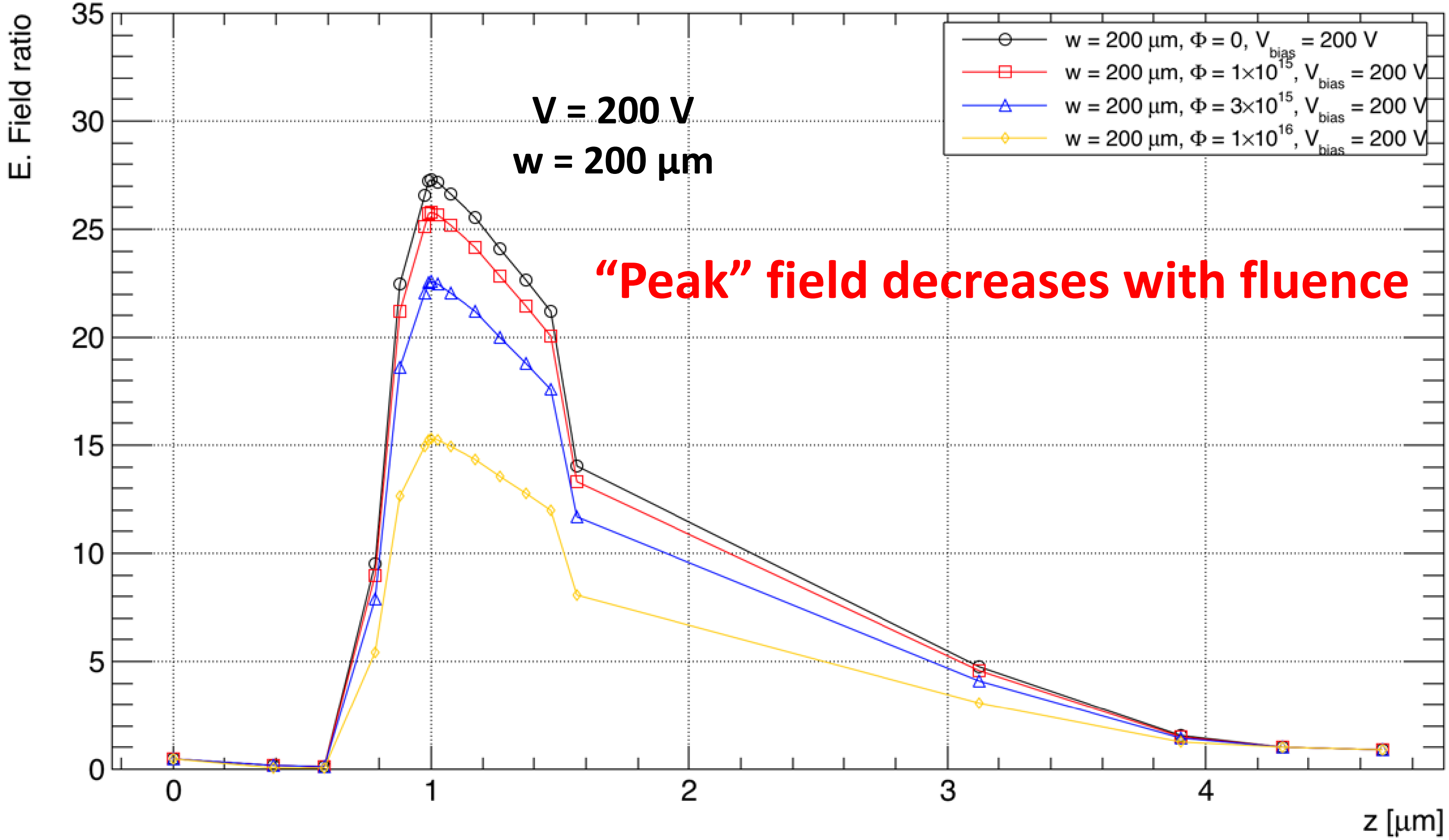


The trend might be an artefact (leakage current imperfect suppression, finite time resolution for simulation and integration, …)

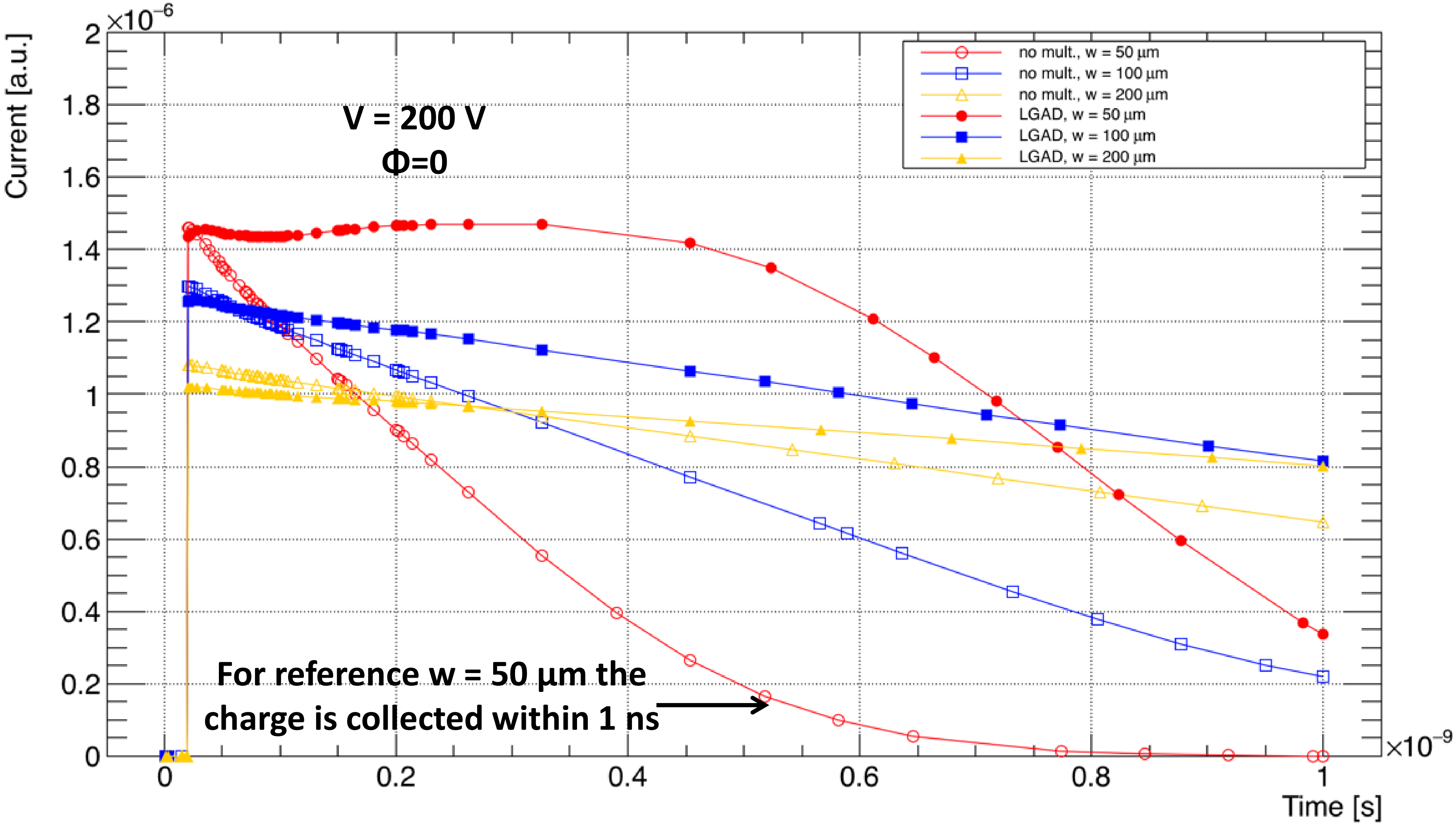
Anyway, the variation with bias voltage is very small

Electric field ratio

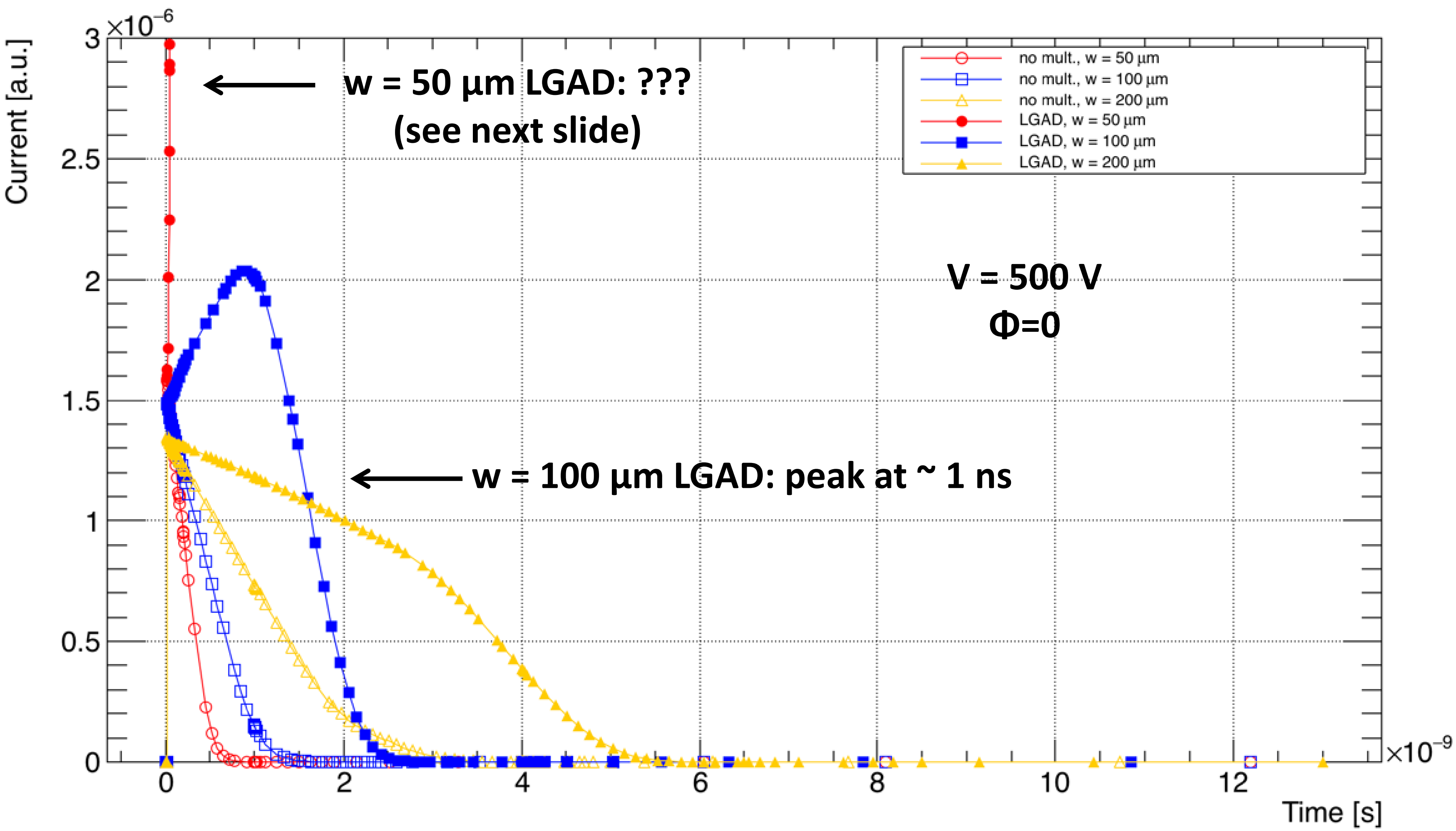
Electric field normalized to the reference detector



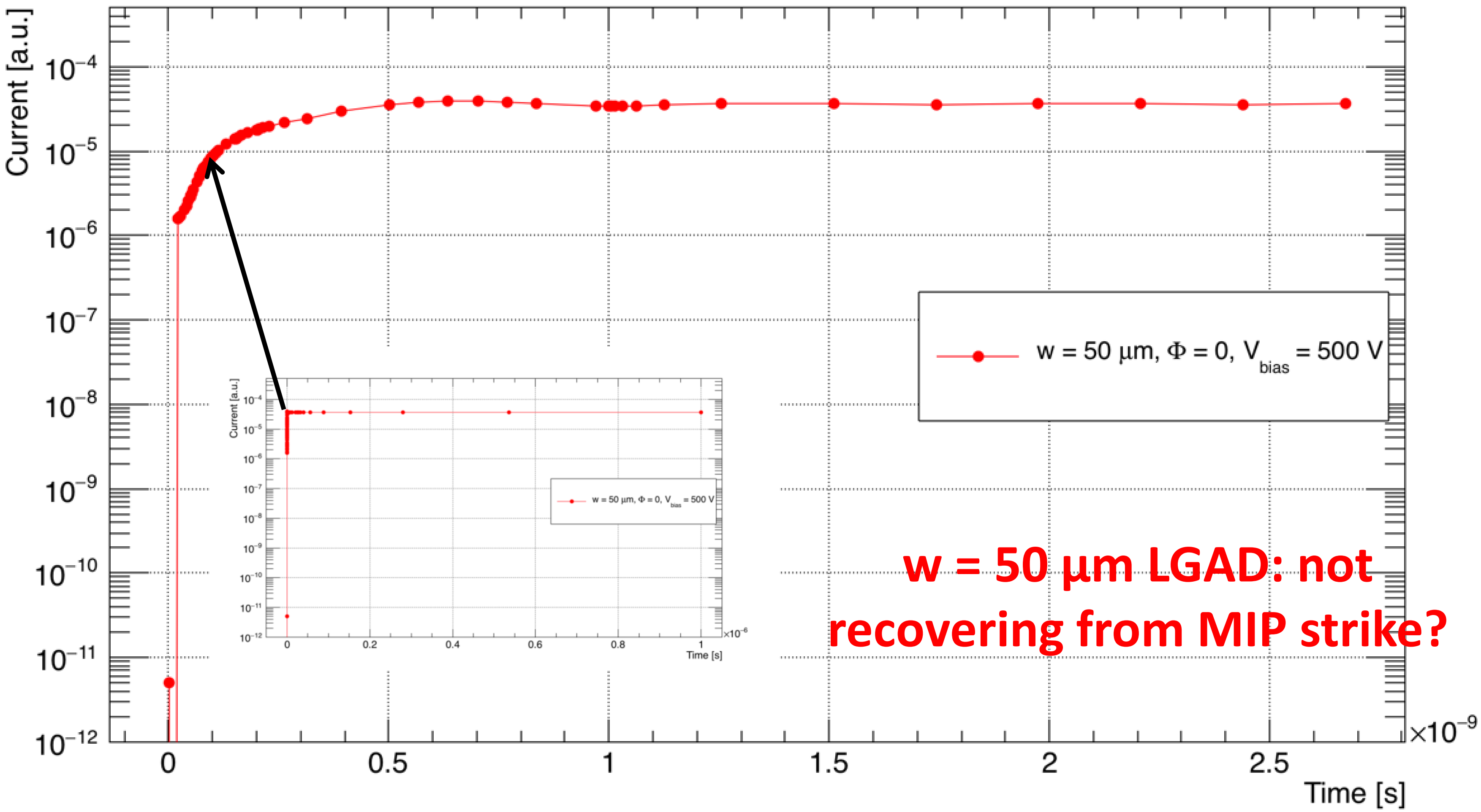
Signal vs time, different thicknesses – 200 V



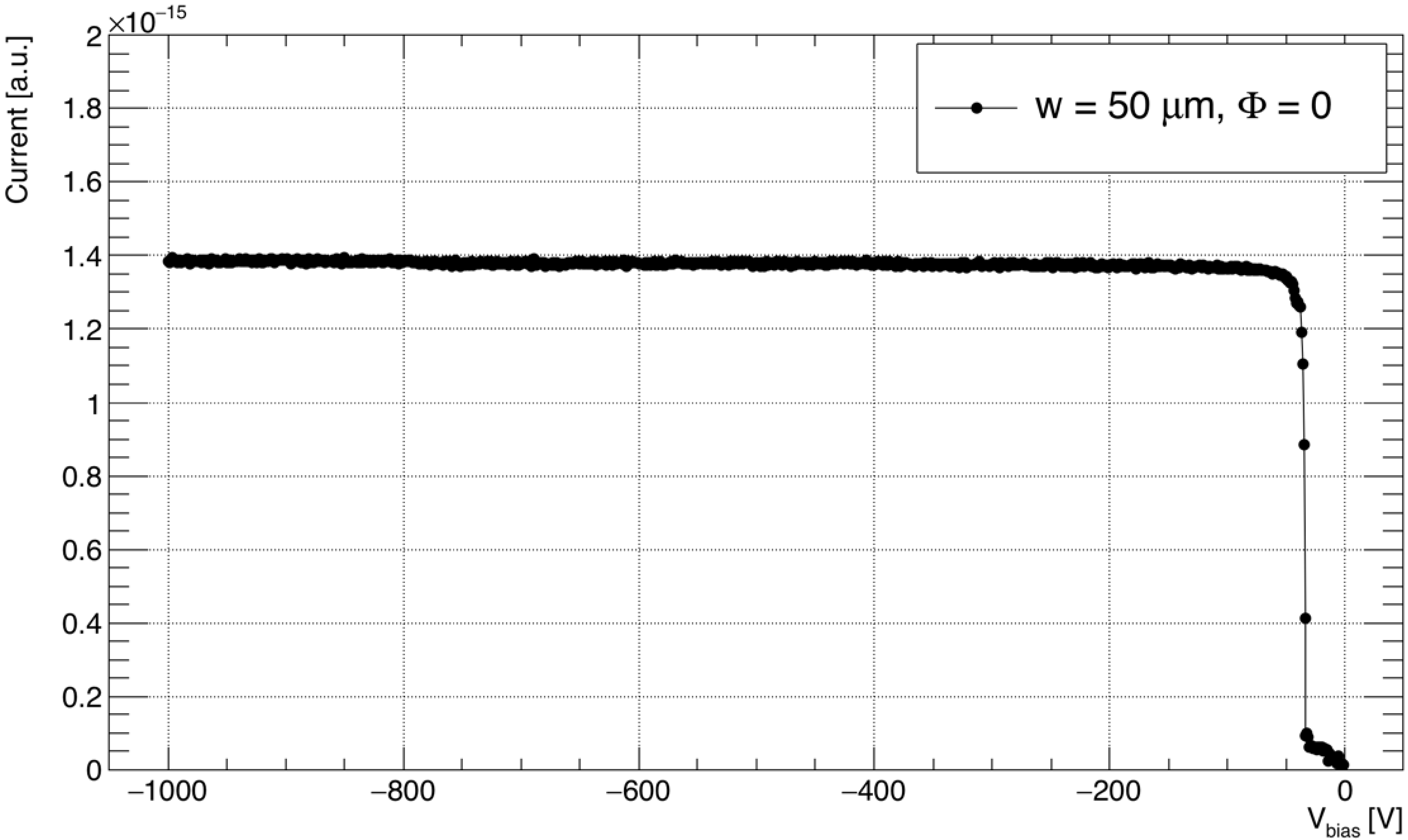
Signal vs time, different thicknesses – 500V



Signal vs time, w = 50 μm, un-irr. – 500 V



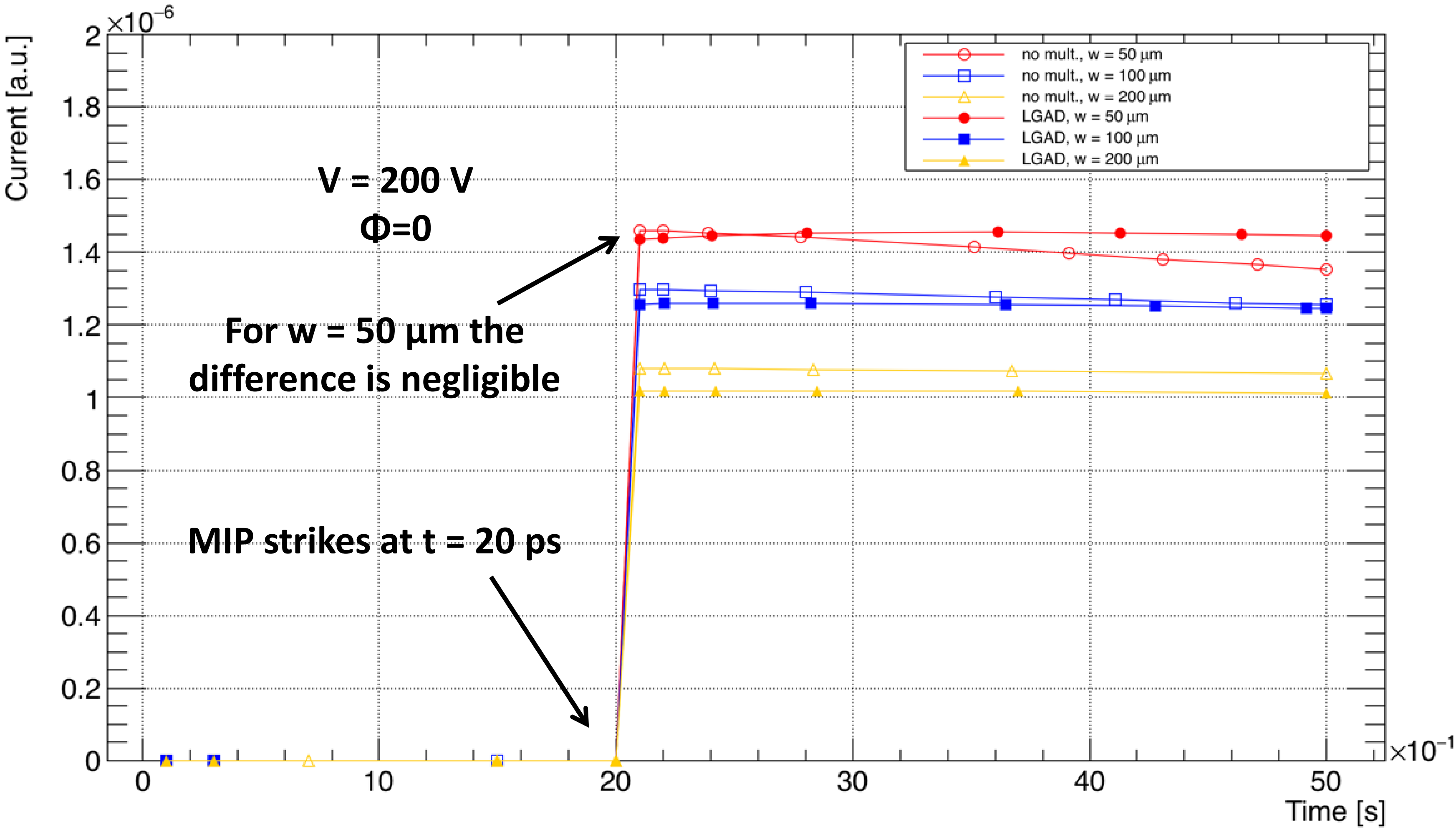
No breakdown in thin un-irr. till 1000 V



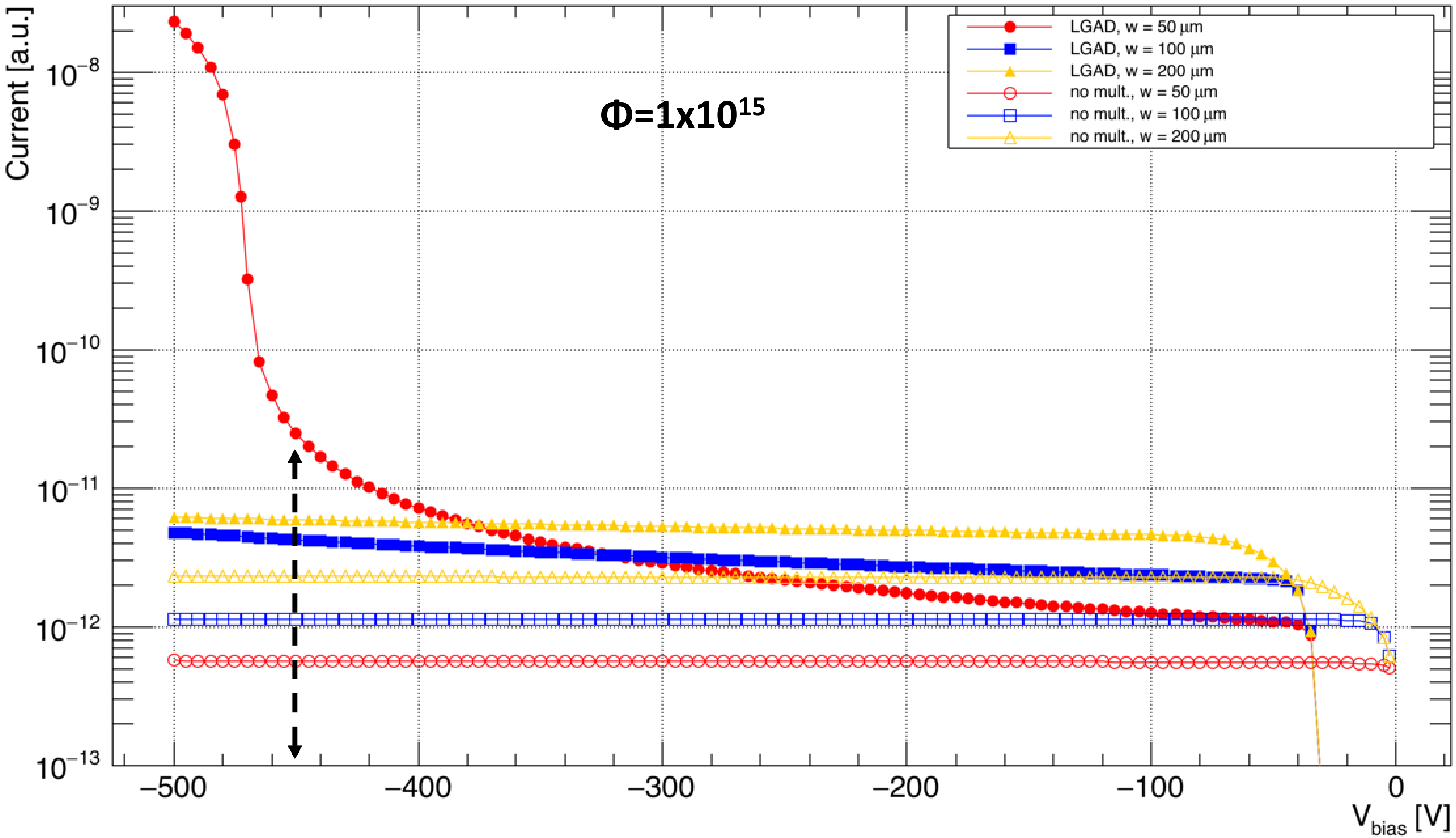
Break down voltage summary for irr. LGAD

Φ[neq/cm^2] w[µm]	$1x10^{15}$	$3x10^{15}$	$1x10^{16}$
50	450	450	450
100	> 500	900	900
200	> 500	> 1000	> 1000

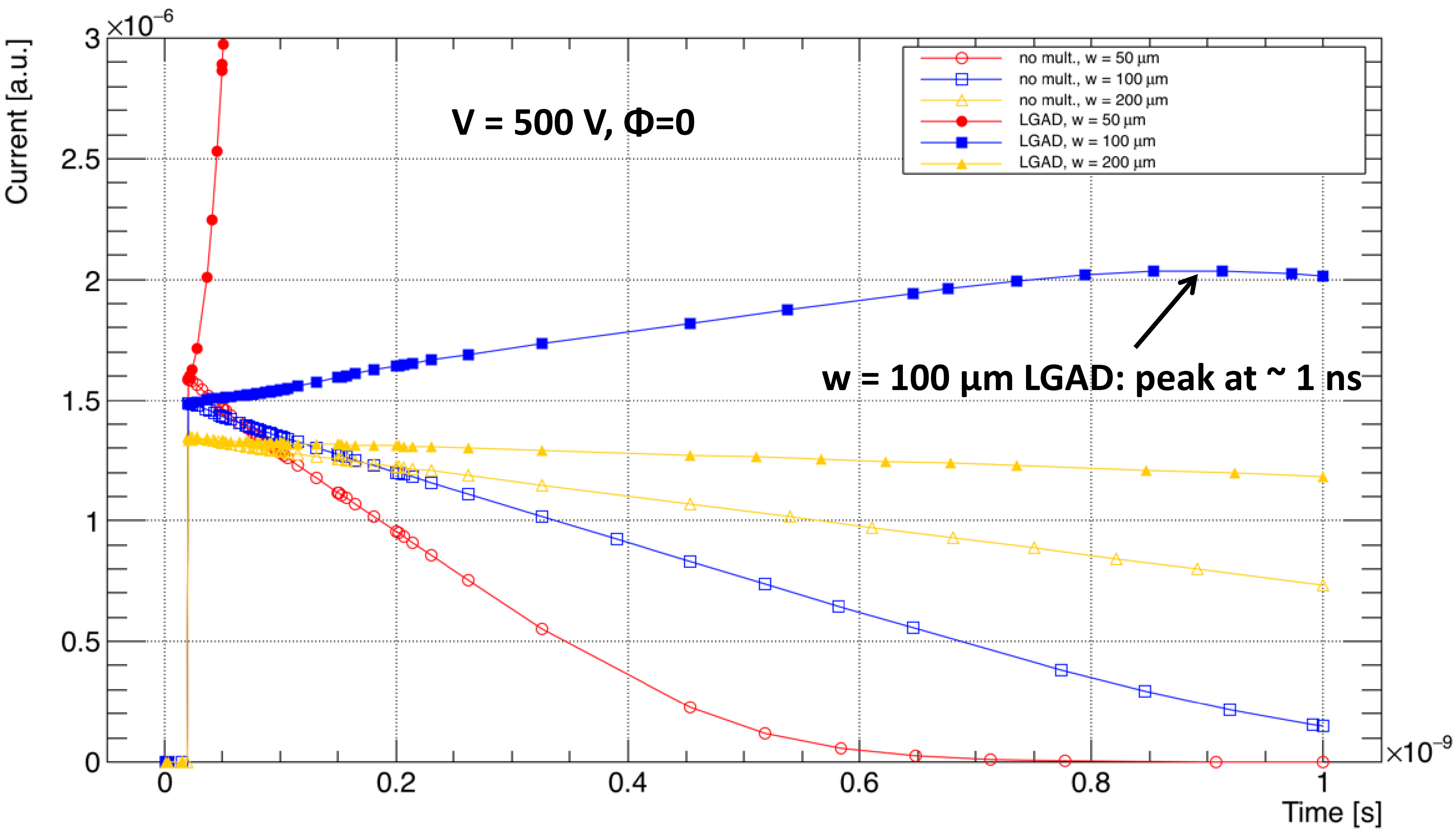
Signal vs time, different thicknesses – 200 V



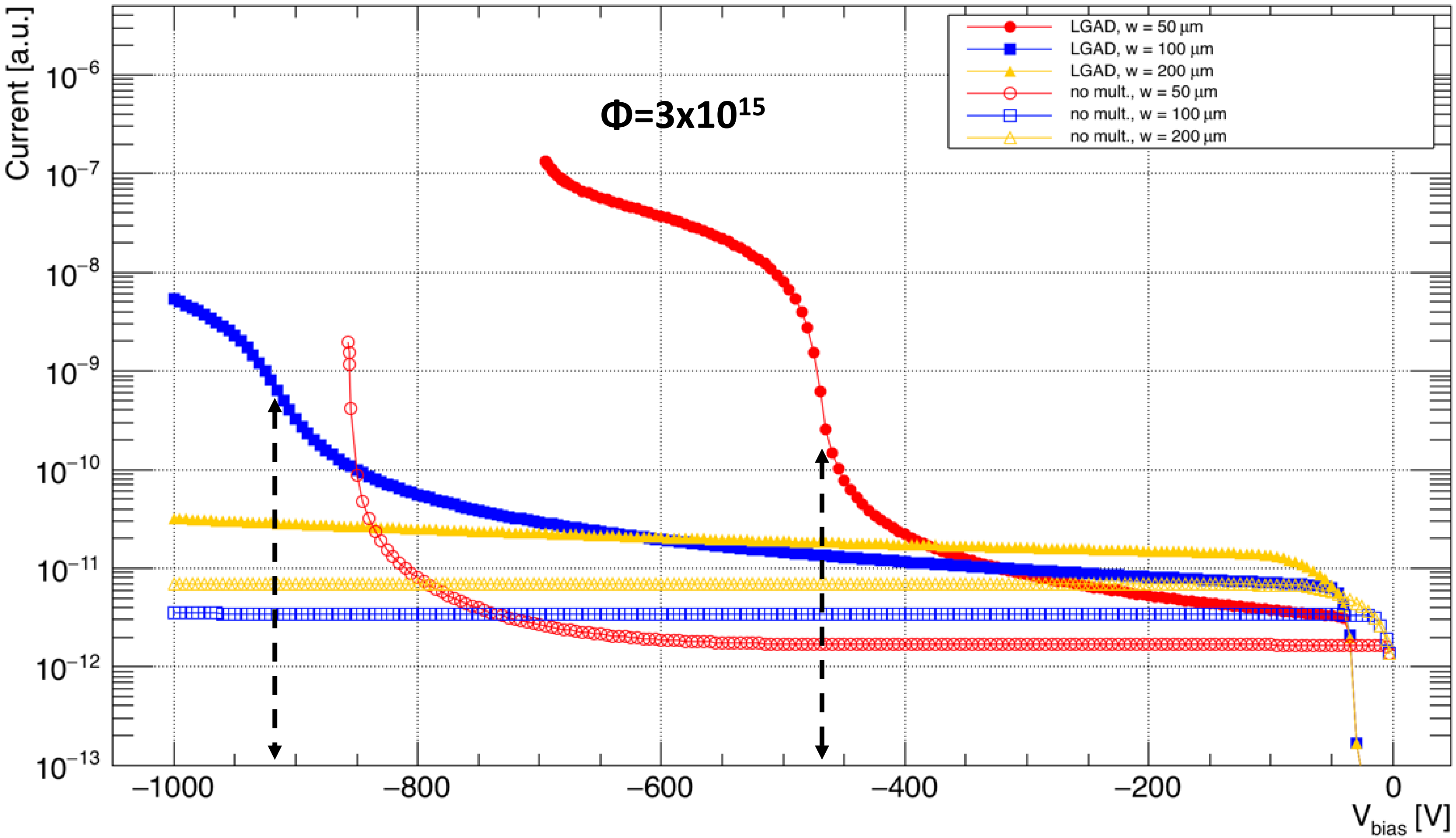
Breakdown in thin irr. LGAD and ref.



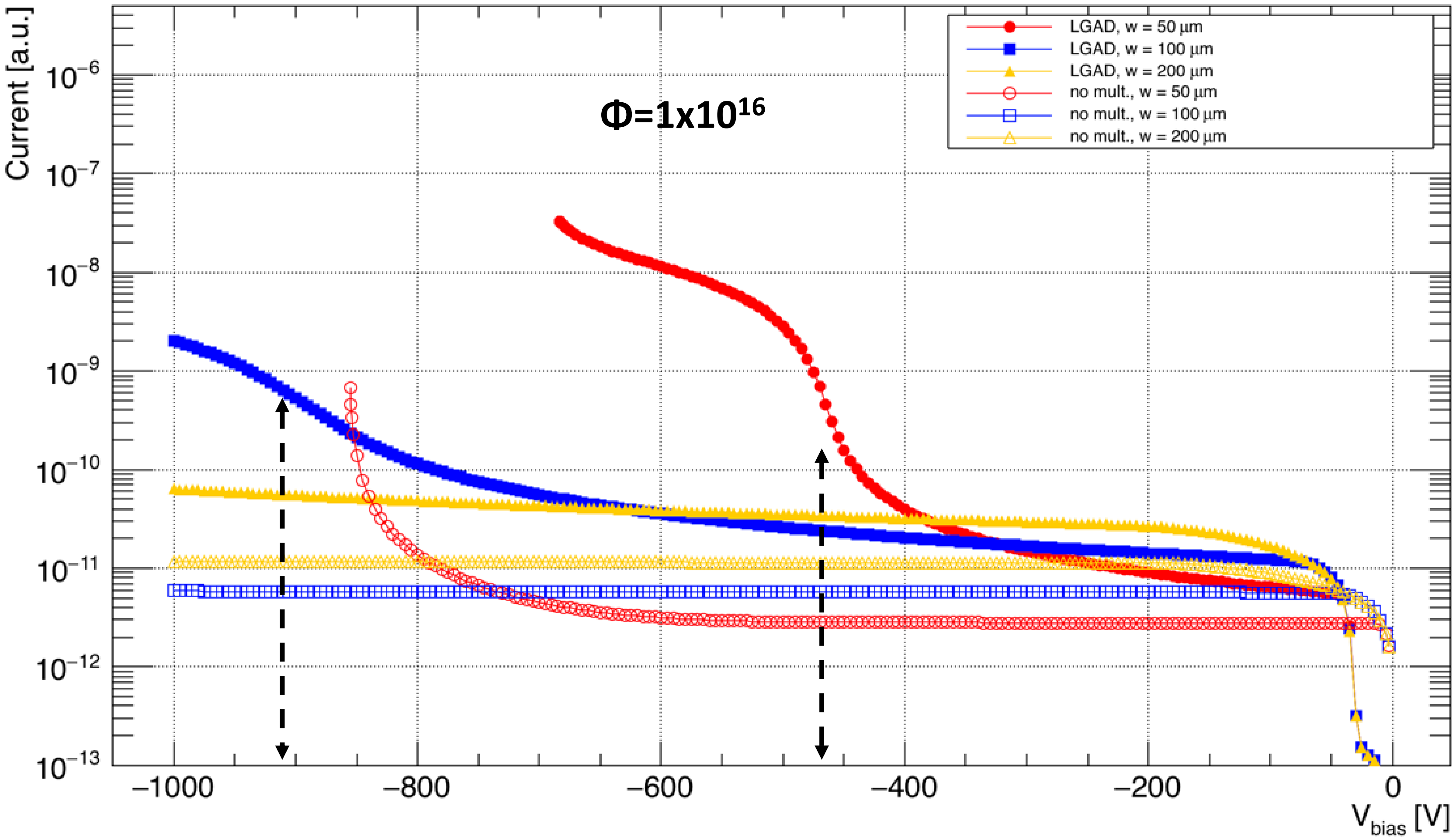
Signal vs time, different thicknesses



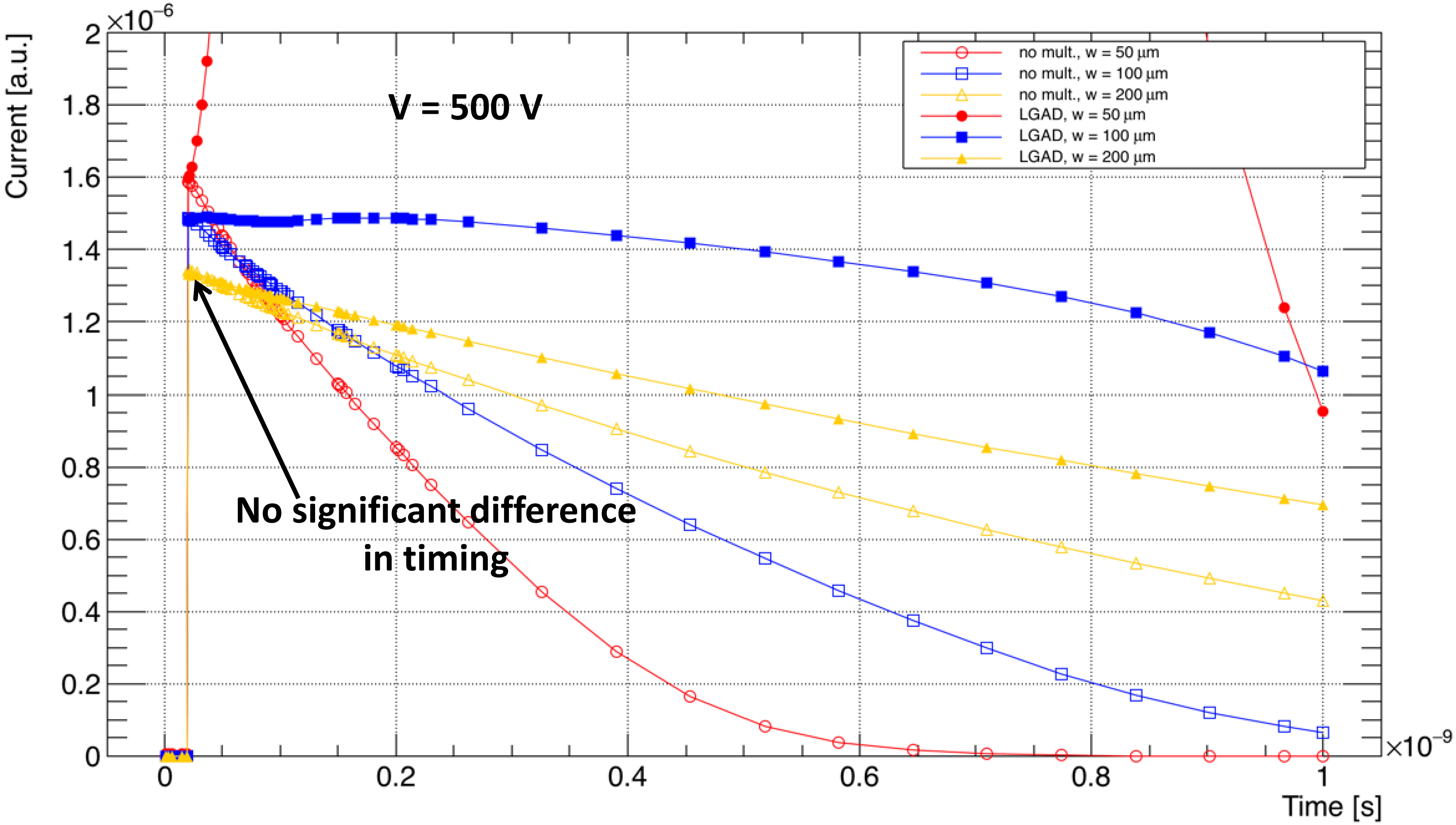
Breakdown in thin irr. LGAD and ref.



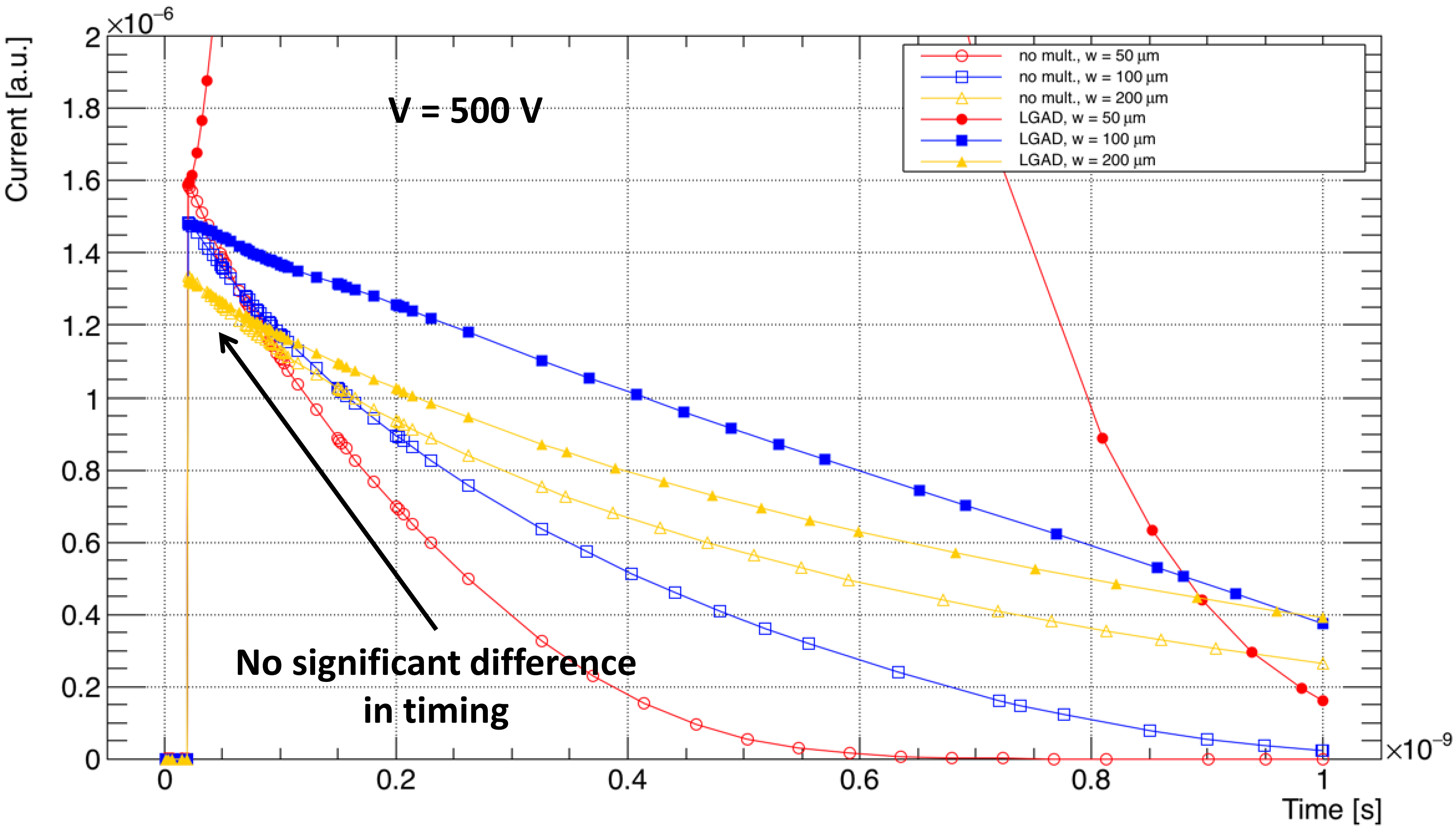
Breakdown in thin irr. LGAD and ref.



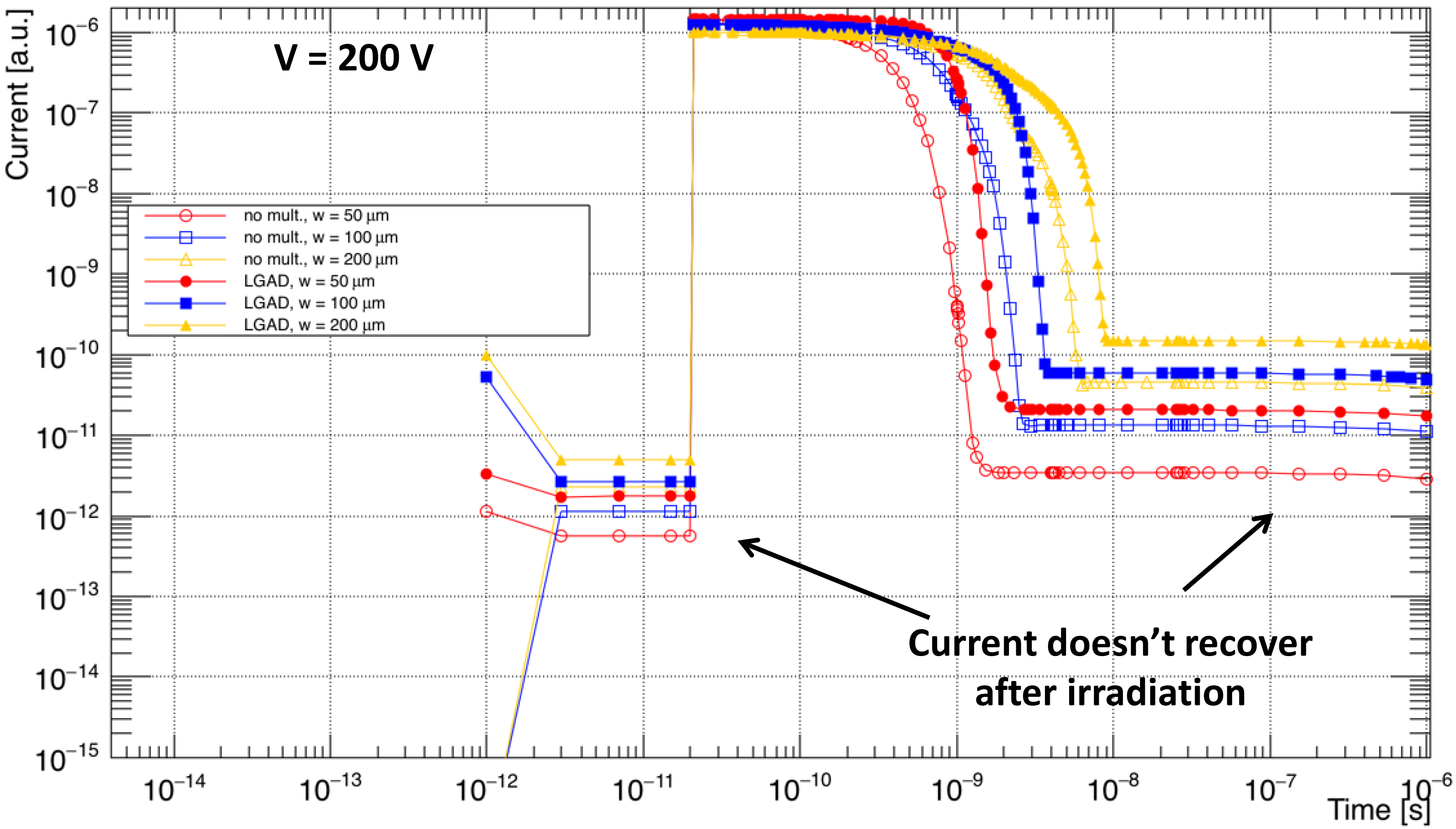
Simulation of irr. samples – $\Phi = 3x10^{15}$



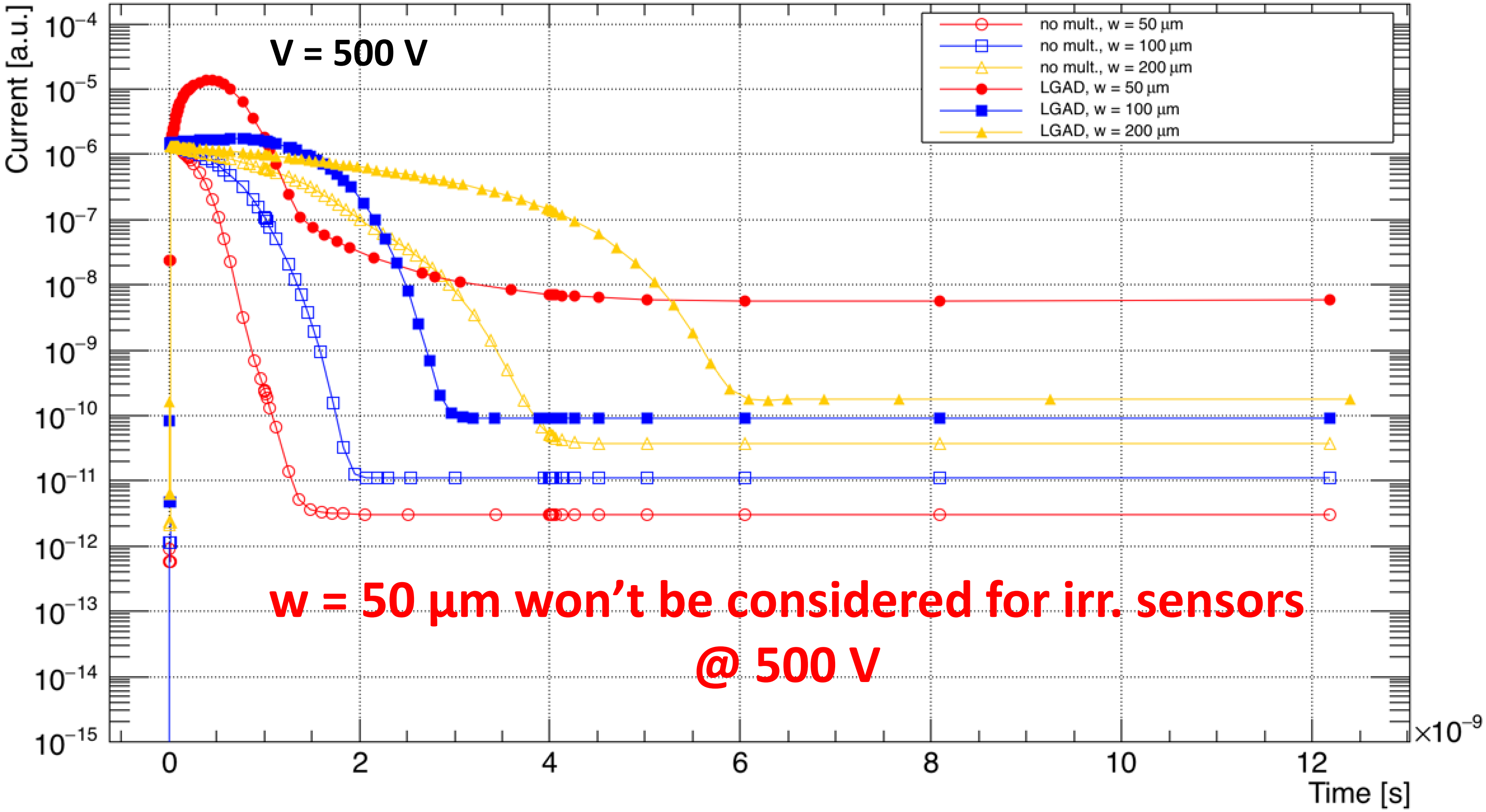
Simulation of irr. samples – $\Phi = 1x10^{16}$



Signal of irr. samples – $\Phi = 1x10^{15}$

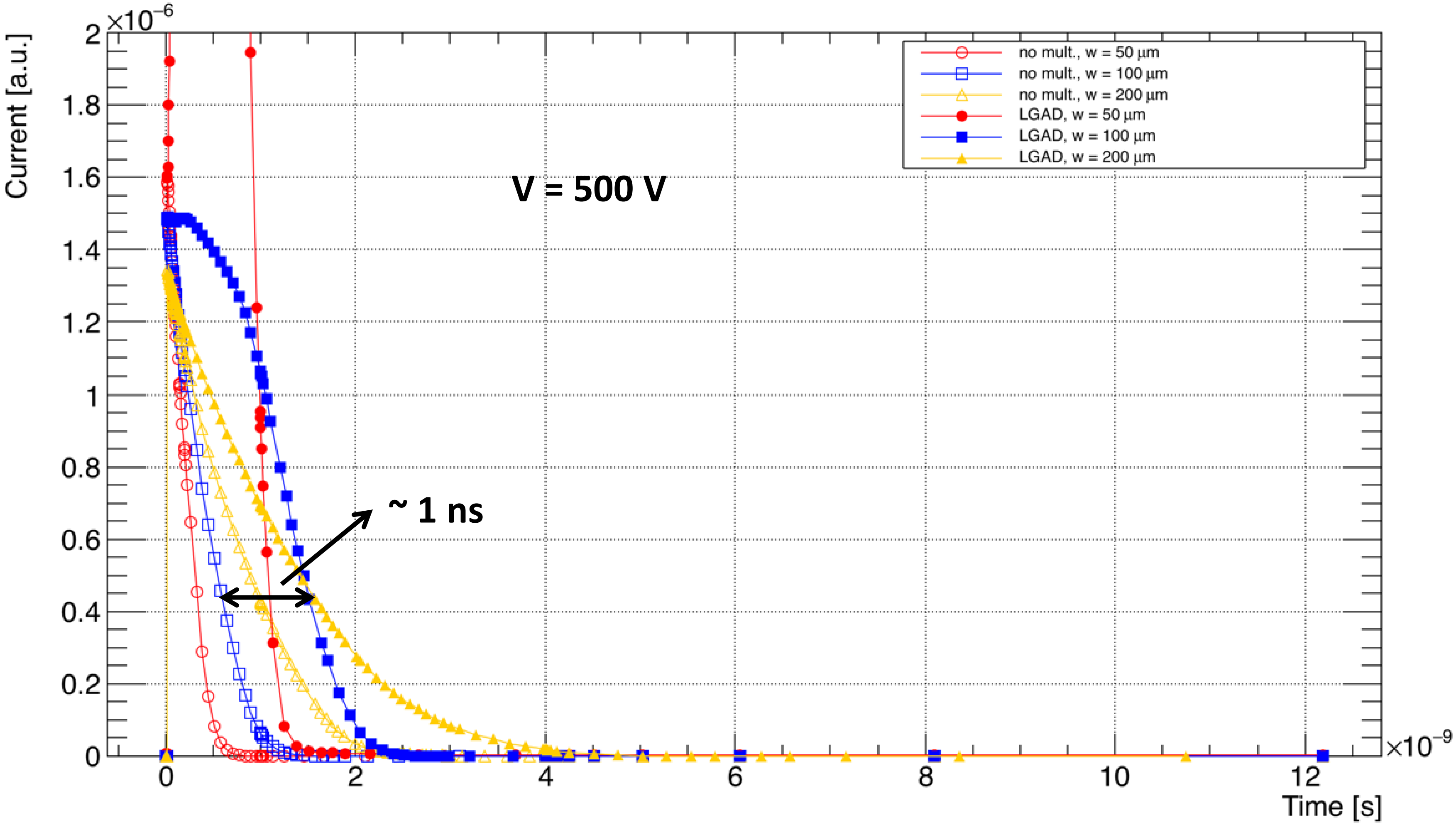


Simulation of irr. samples – $\Phi = 1\text{x}10^{15}$

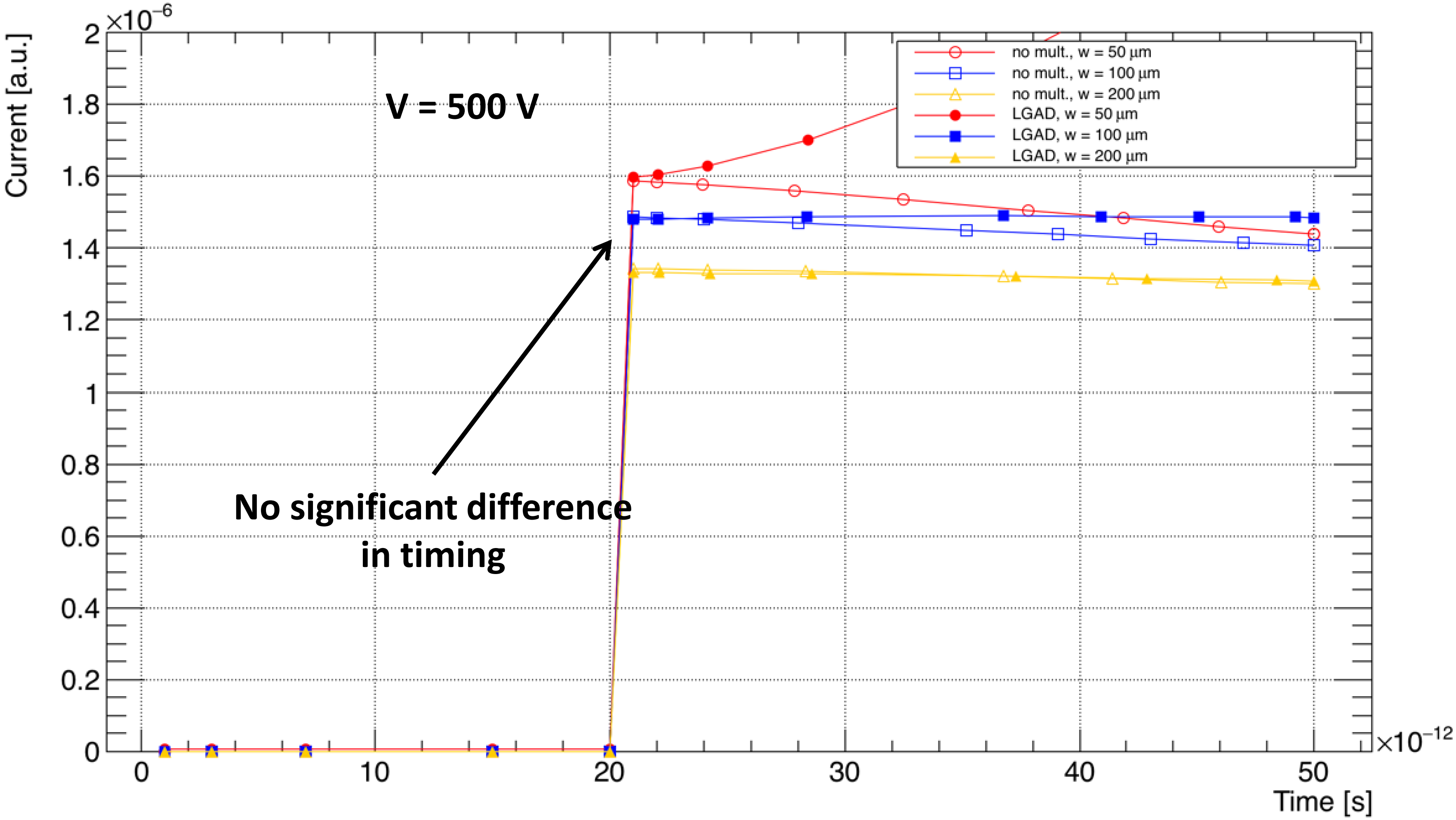


w = 50 µm won't be considered for irr. sensors @ 500 V

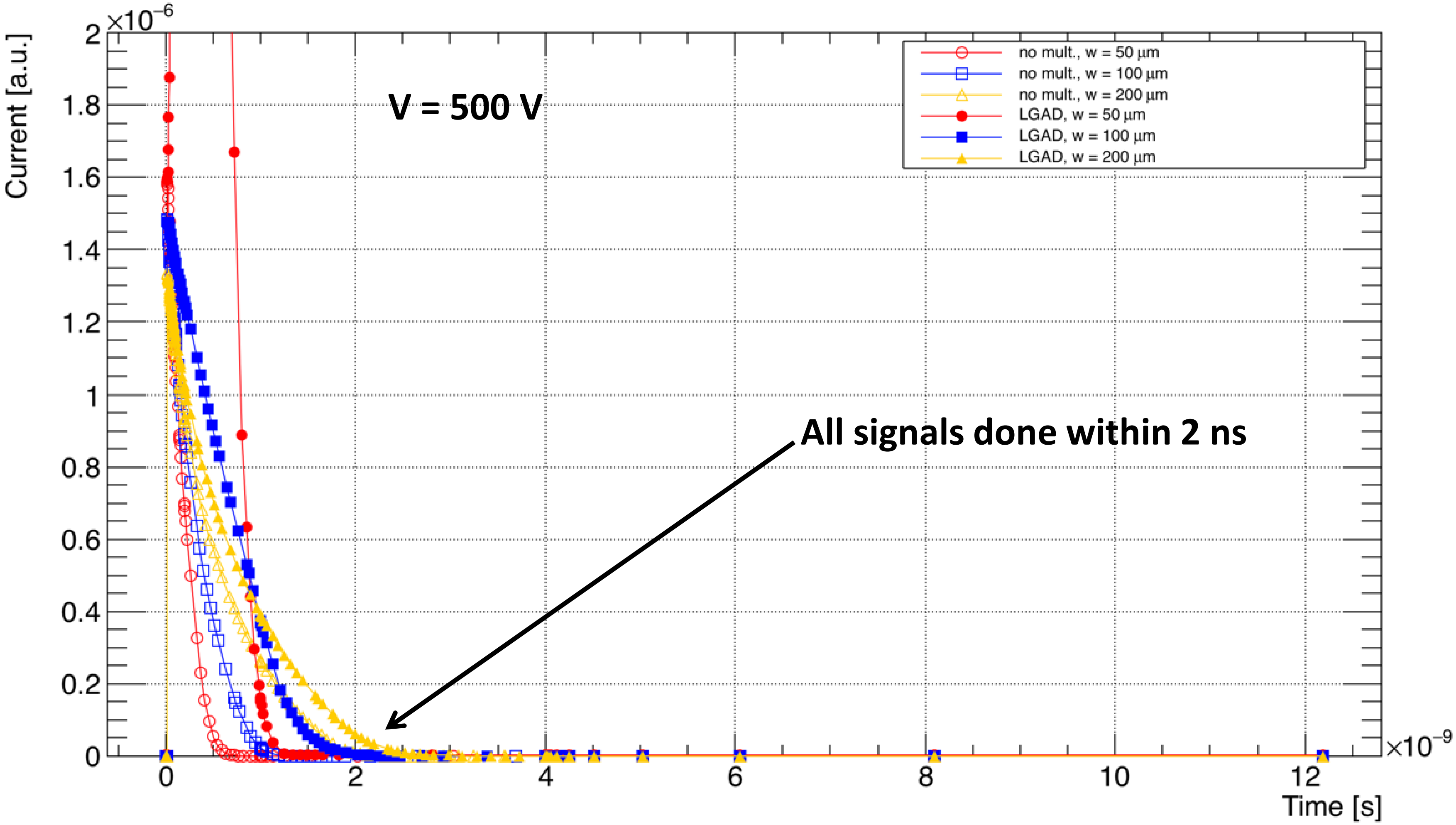
Simulation of irr. samples – $\Phi = 3x10^{15}$



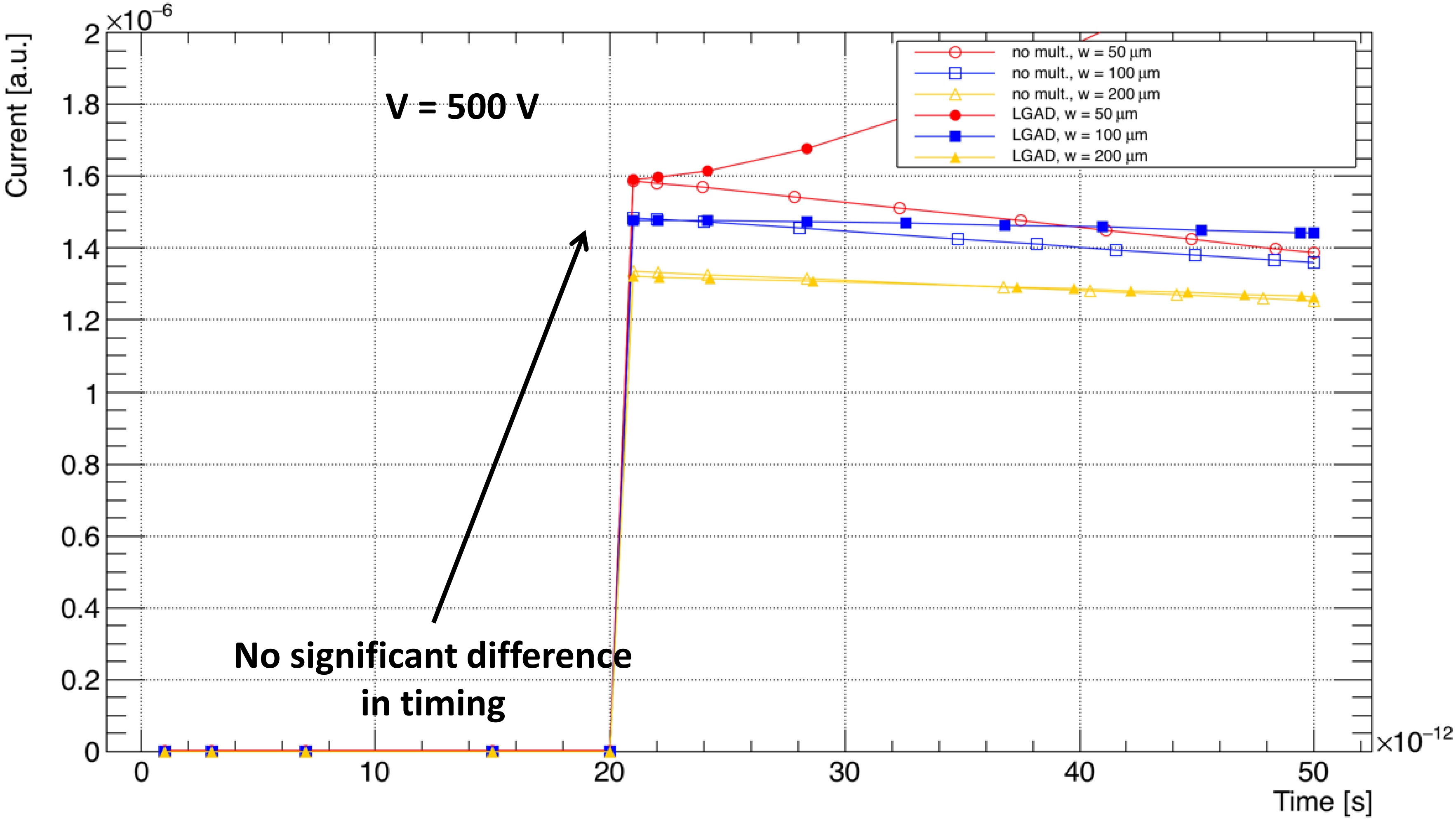
Simulation of irr. samples – $\Phi = 3x10^{15}$



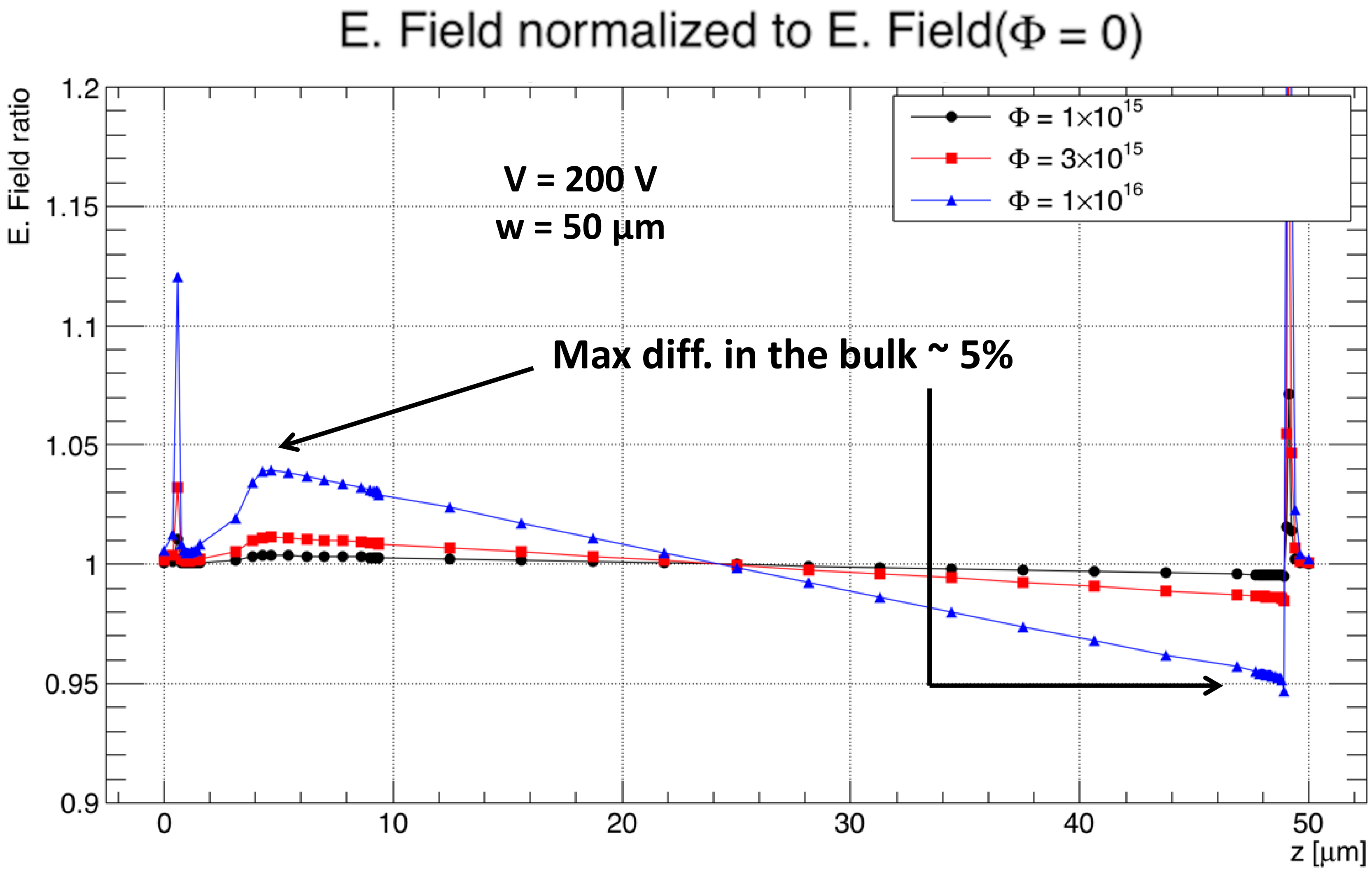
Simulation of irr. samples – $\Phi = 1x10^{16}$



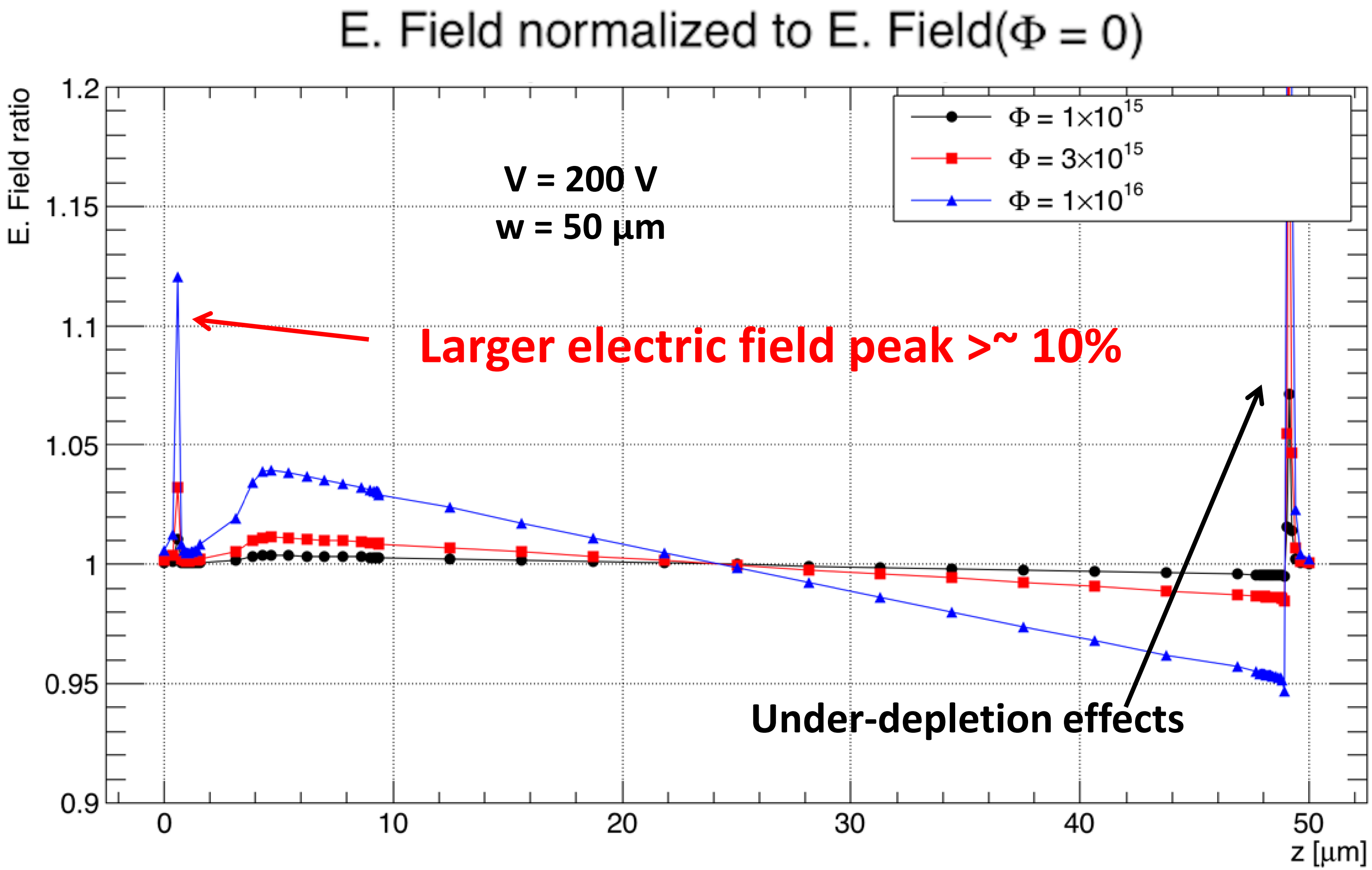
Simulation of irr. samples – $\Phi = 1x10^{16}$



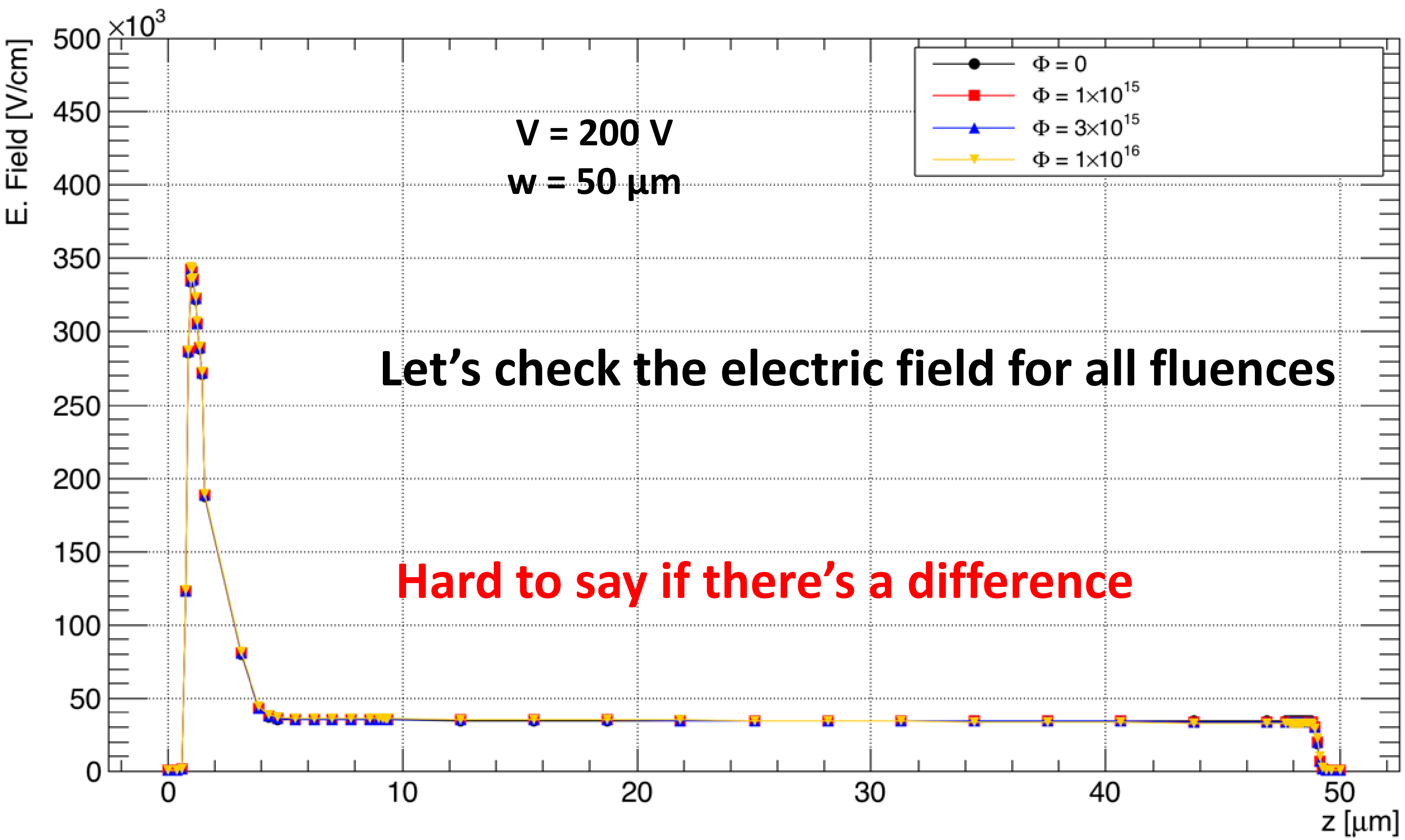
Ratio of electric field – LGAD only



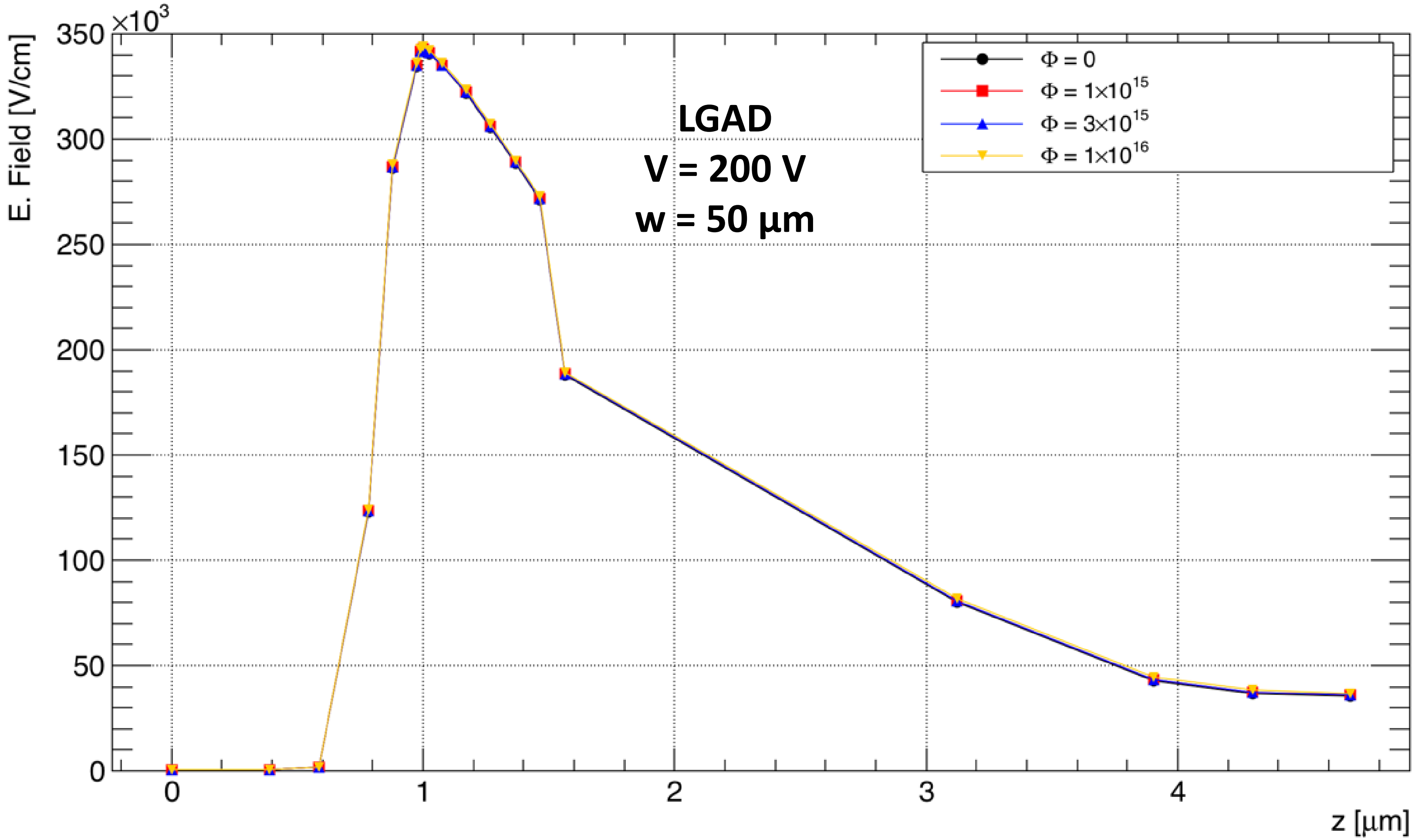
Ratio of electric field – LGAD only



Electric field for all fluences

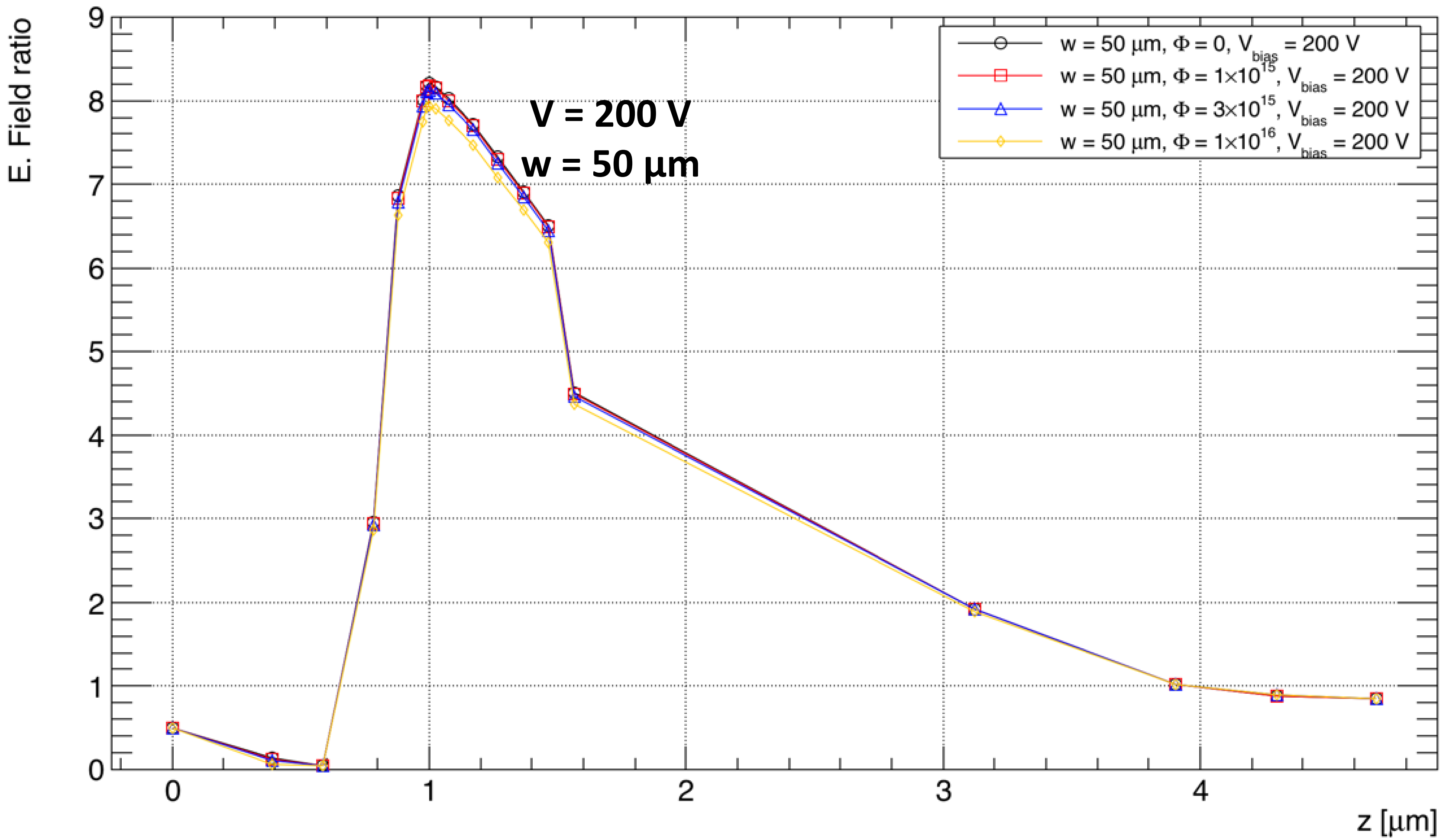


Electric field for all fluences



Electric field ratio

Electric field normalized to the reference detector



Electric field ratio

Electric field normalized to the reference detector