TCAD simulations of LGAD devices

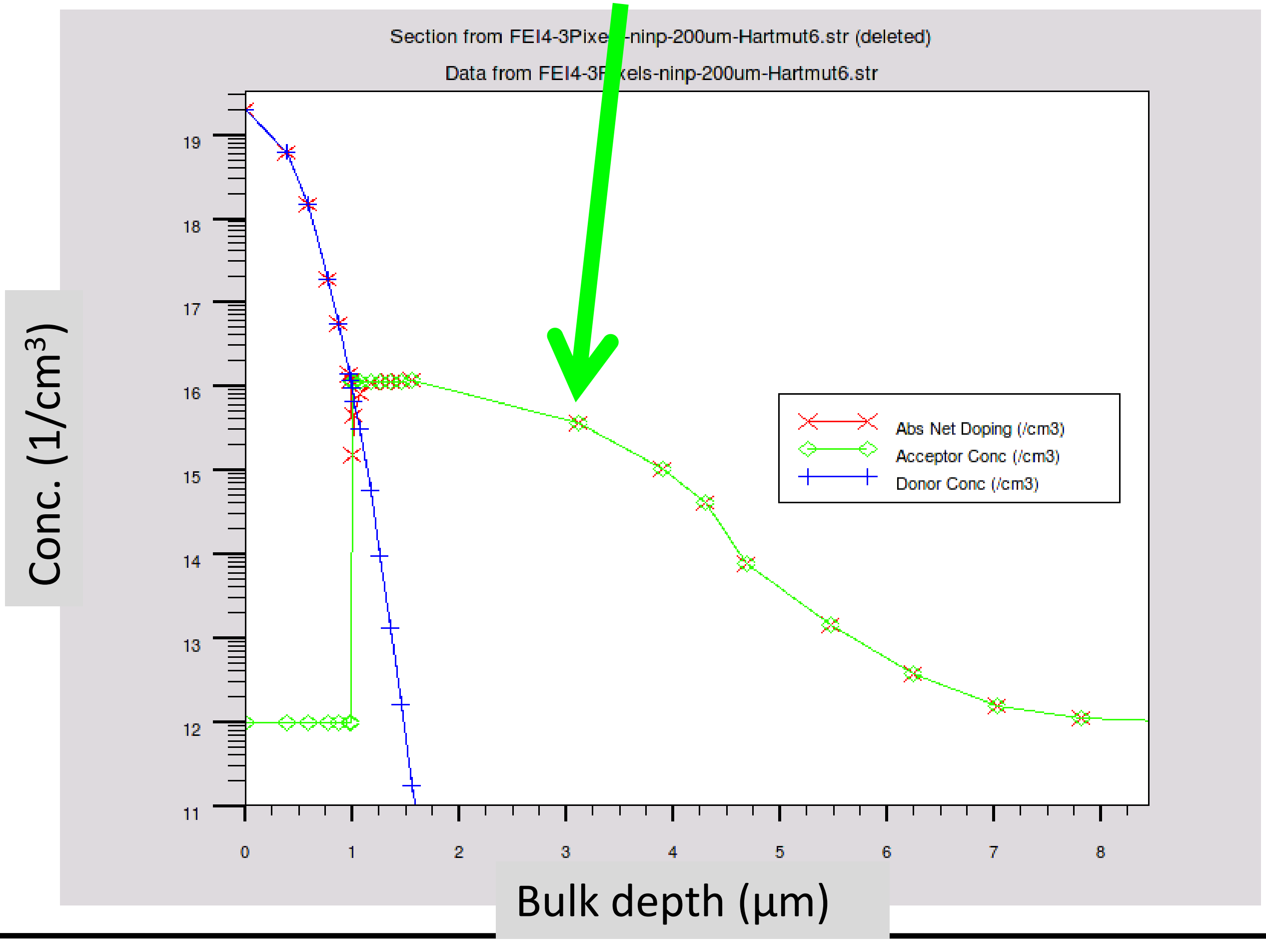
M. Bomben - LPNHE & UPD, Paris

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

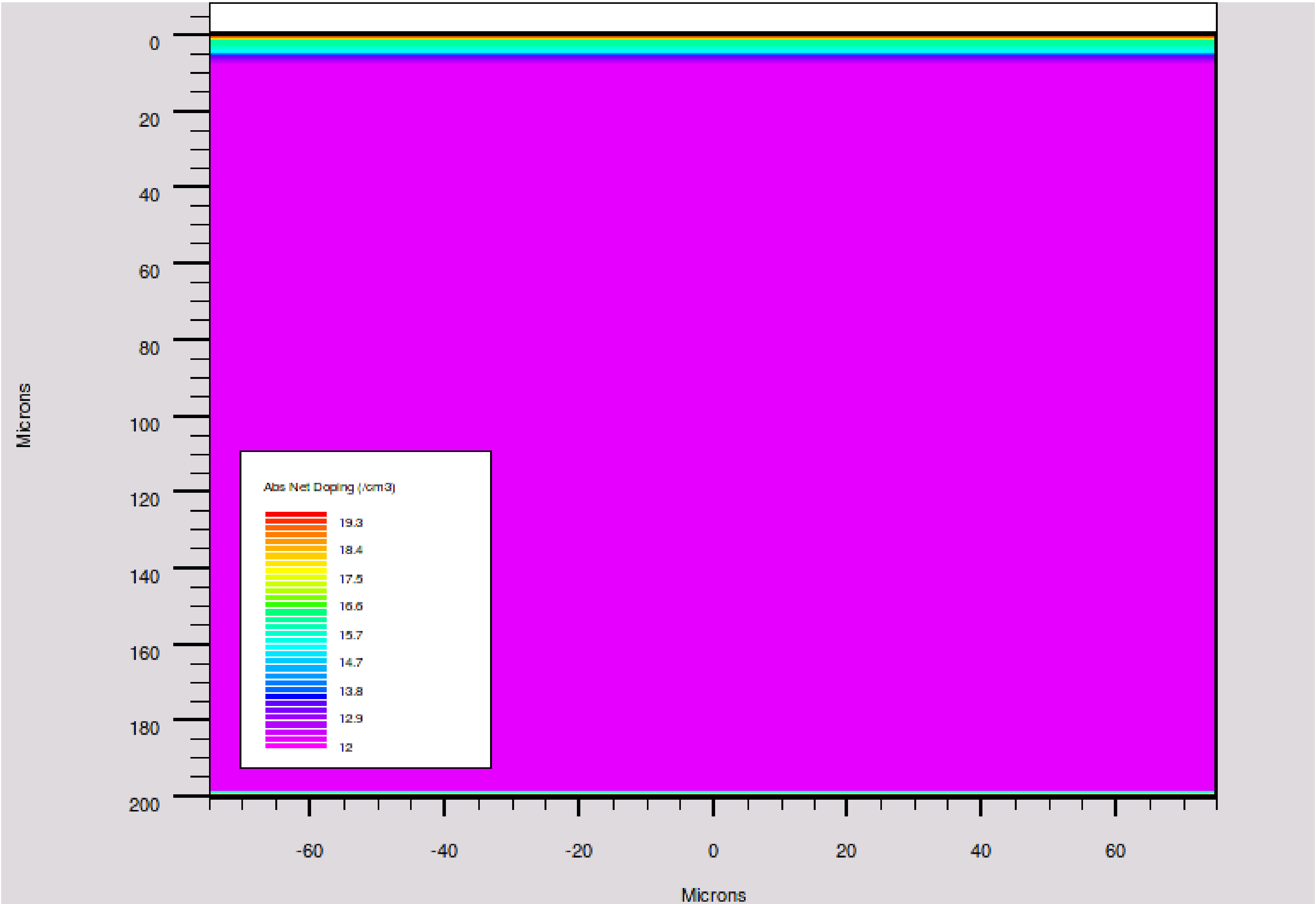
Simulated structure & doping profile

- 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



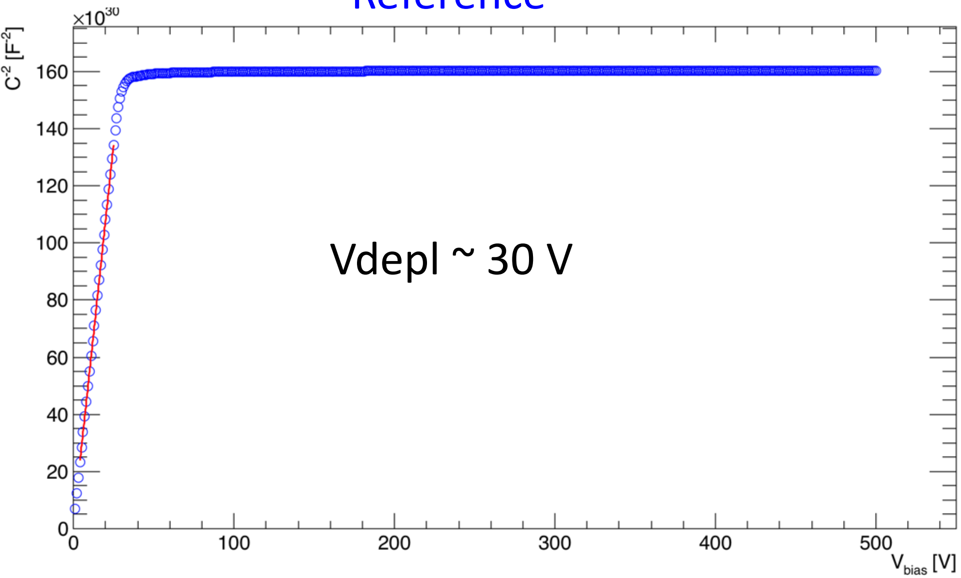
* Profile provided by H. Sadrozinski (from CV on a low-gain diode)

The 2D simulated structure

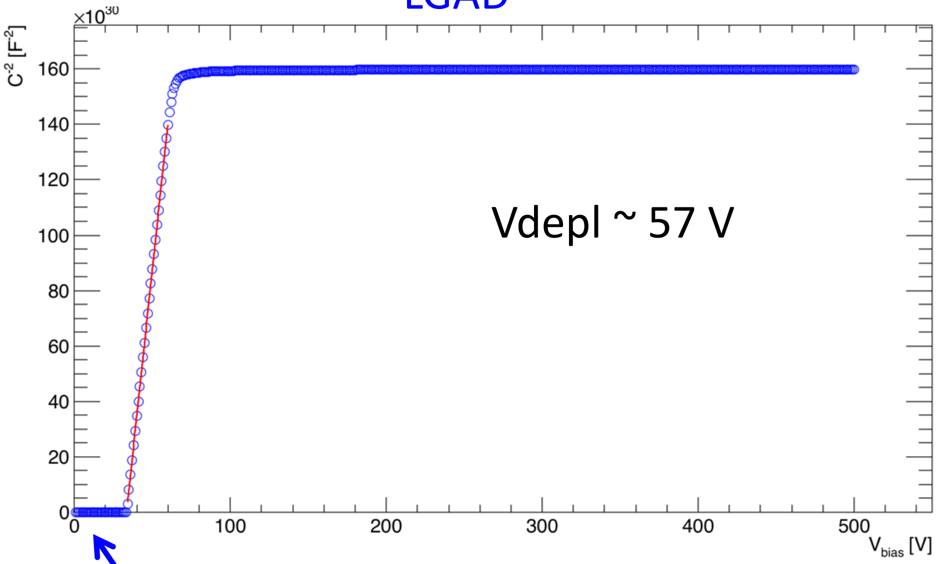


Depletion voltage, reference vs LGAD

Reference

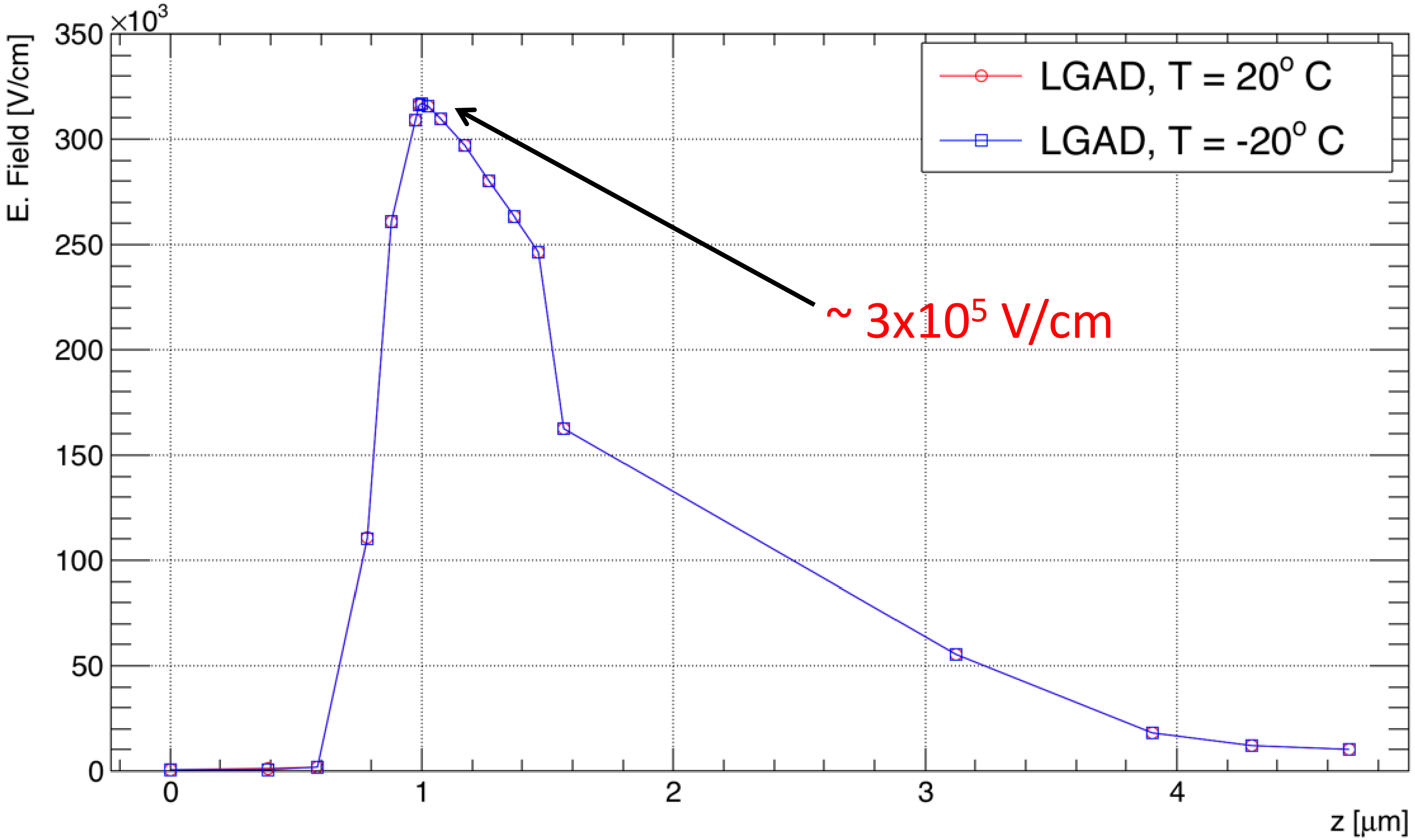


LGAD

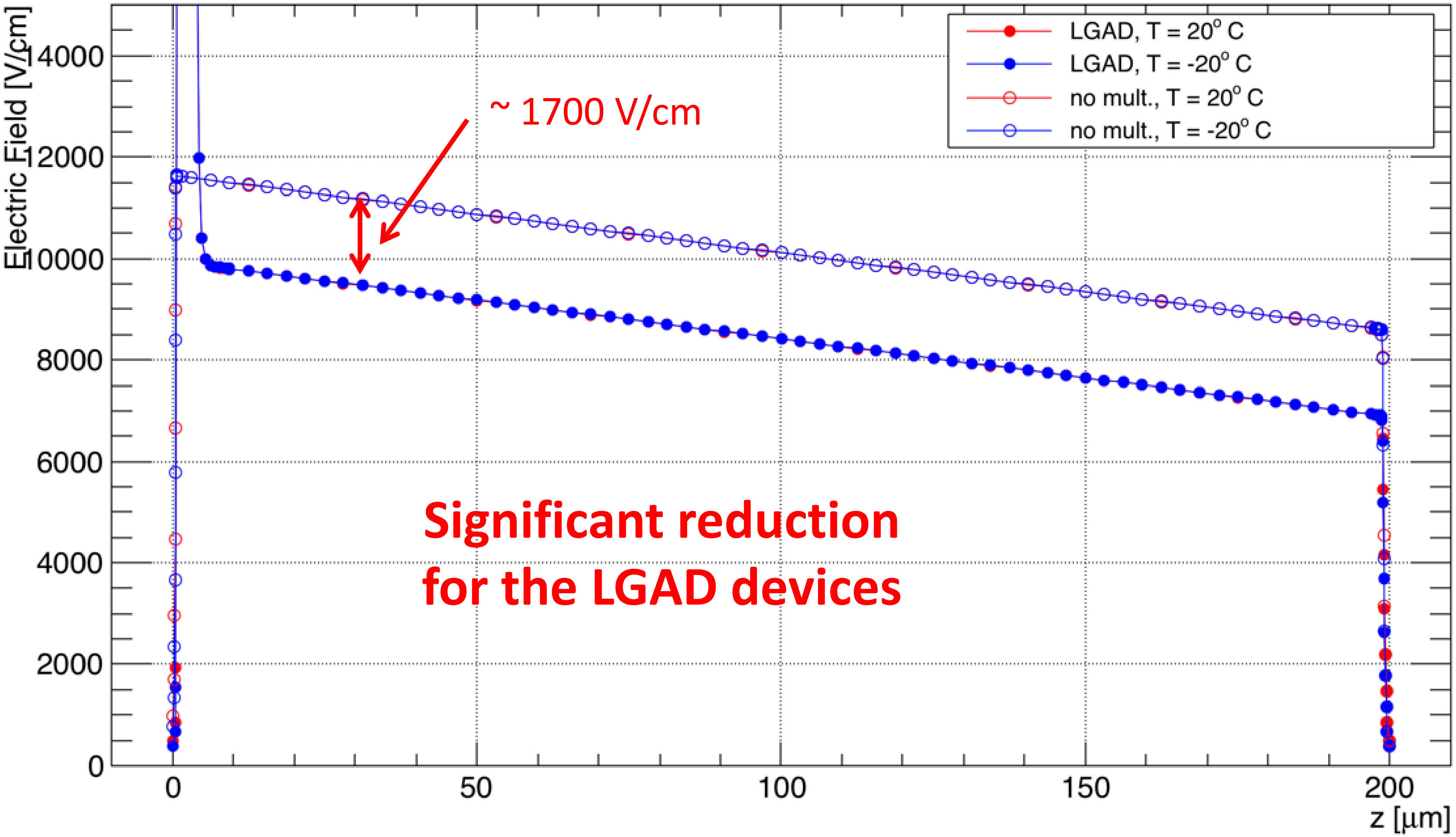


Multiplication layer depletion

Electric field – mult. zone



Electric field – bulk

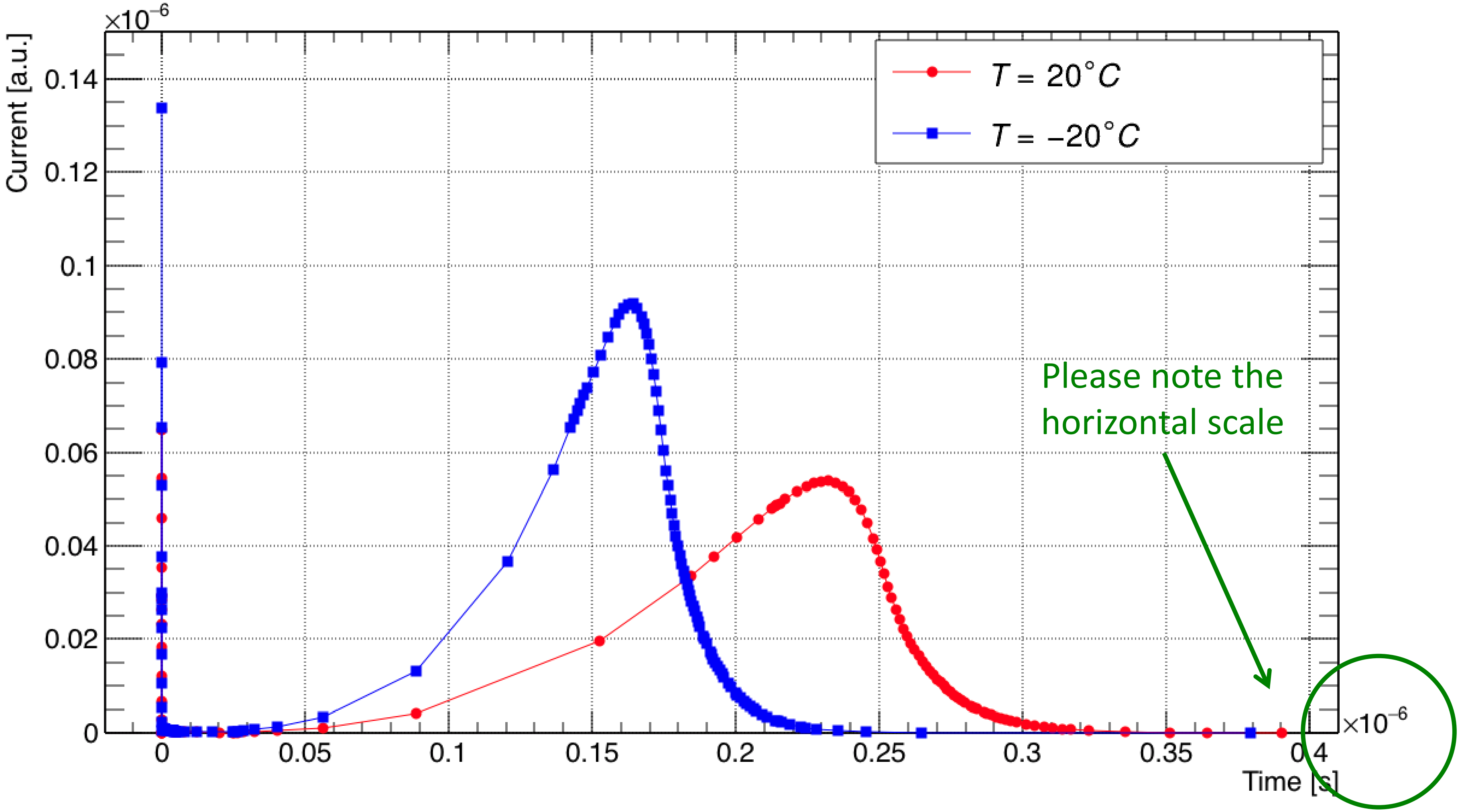


Significant reduction for the LGAD devices

Alpha’s simulations

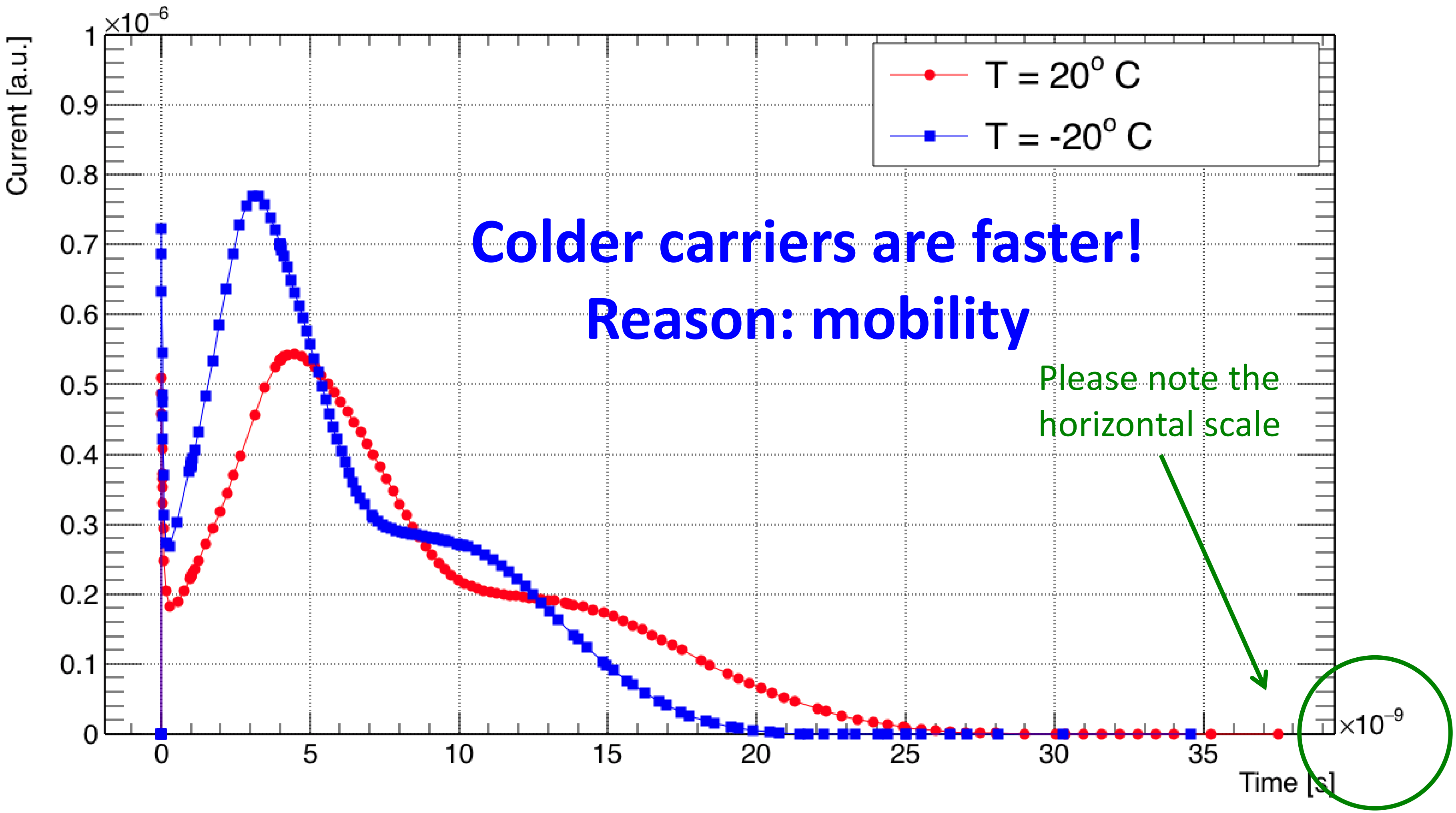
- Alpha impinging from the back
  - Range: 5 μm
  - Energy ~ 1 MIP in 200 μm
- 200 μm thick devices
- V_{bias} = 50, 100, 150 & 200 V
- $\Phi = 0$
- T = from -35° C to +20° C
- Observables: signal, electric field and gain

Signal, V = 50 V

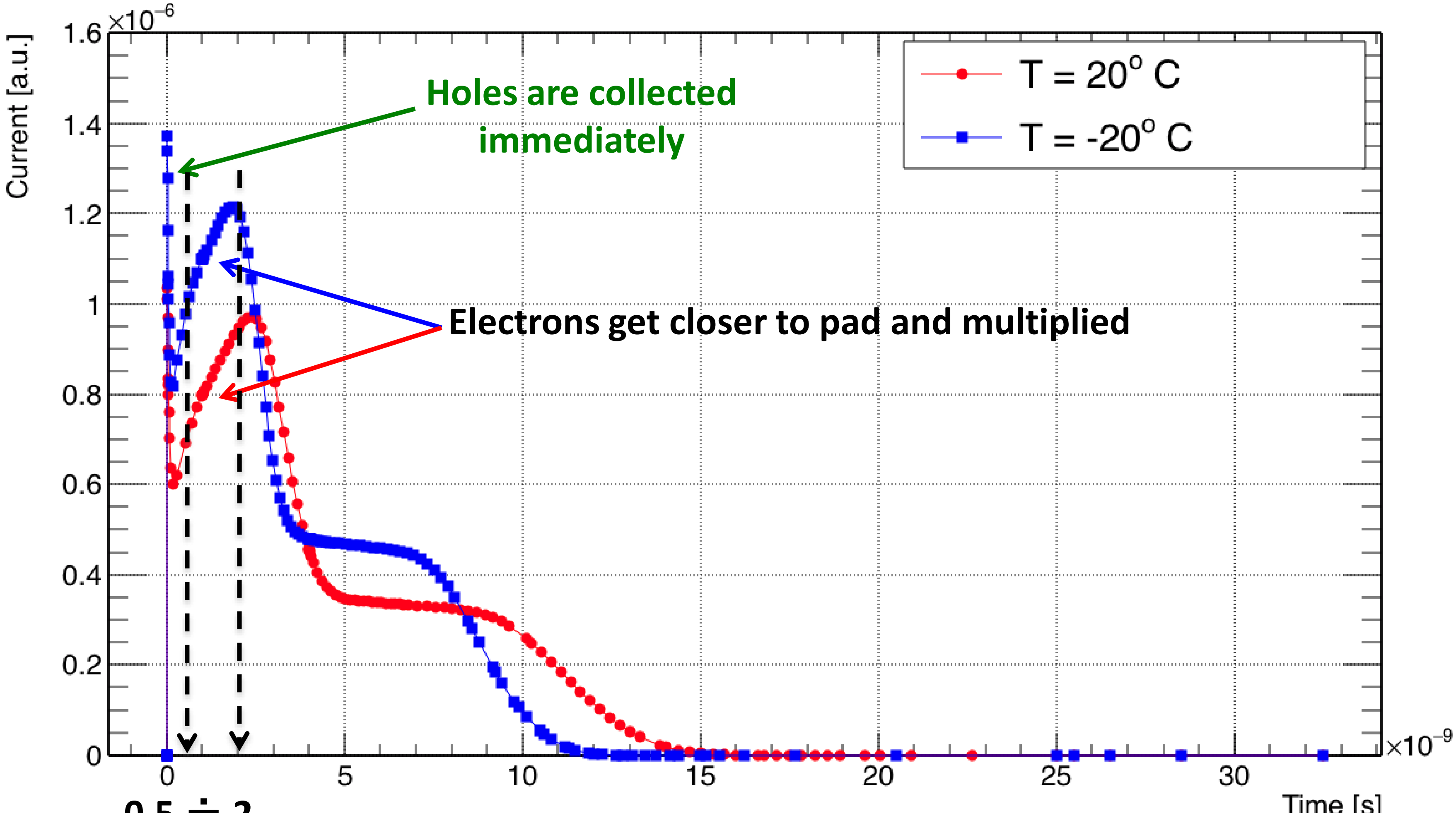


$\times10^{-6}$
Current [a.u.]
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
$\times10^{-6}$
Time [s]
$T = 20^{\circ}C$
$T = -20^{\circ}C$
Please note the horizontal scale

Signal, V = 100 V

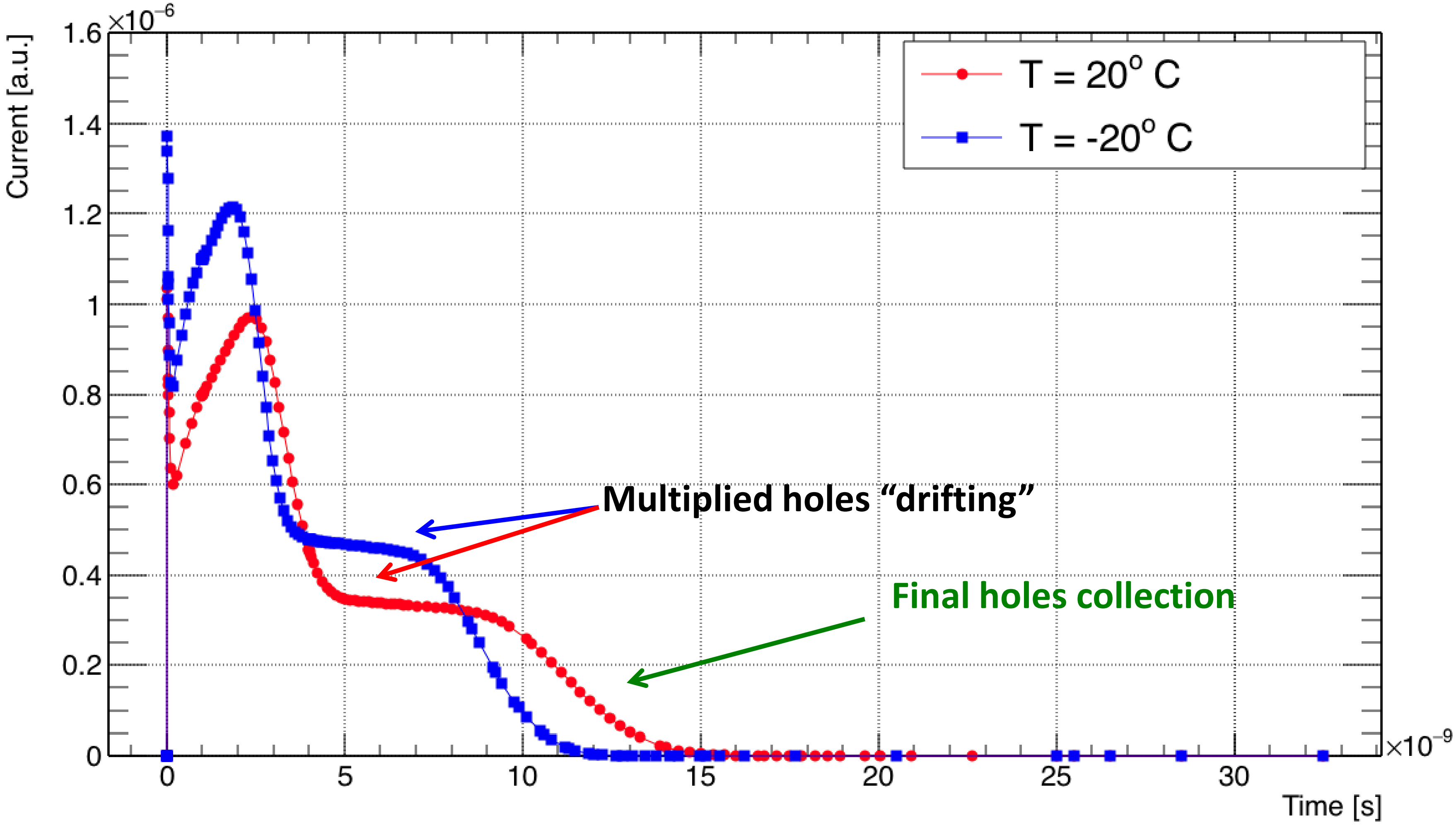


Signal, V = 150 V

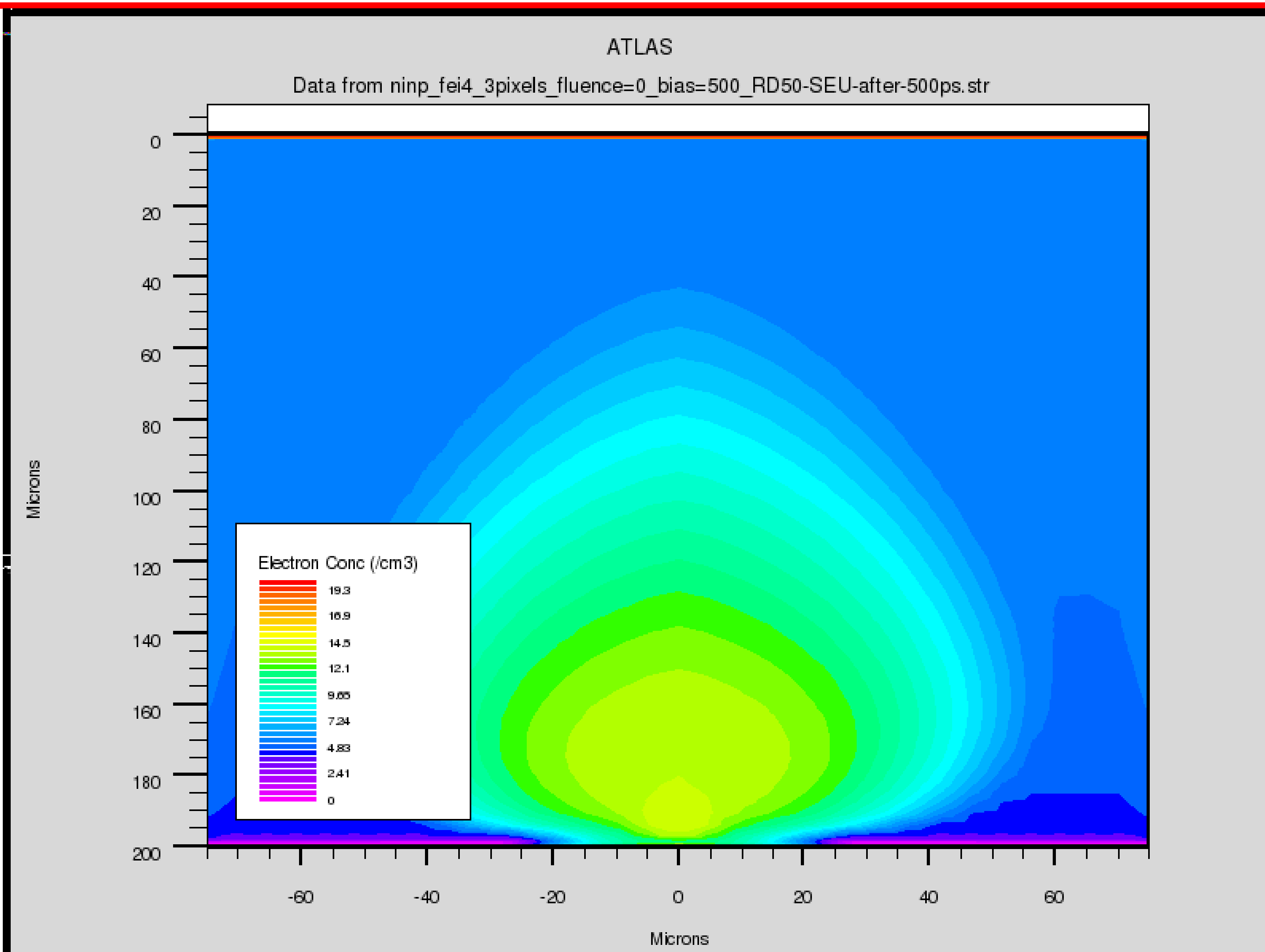


0.5 ÷ 2 ns

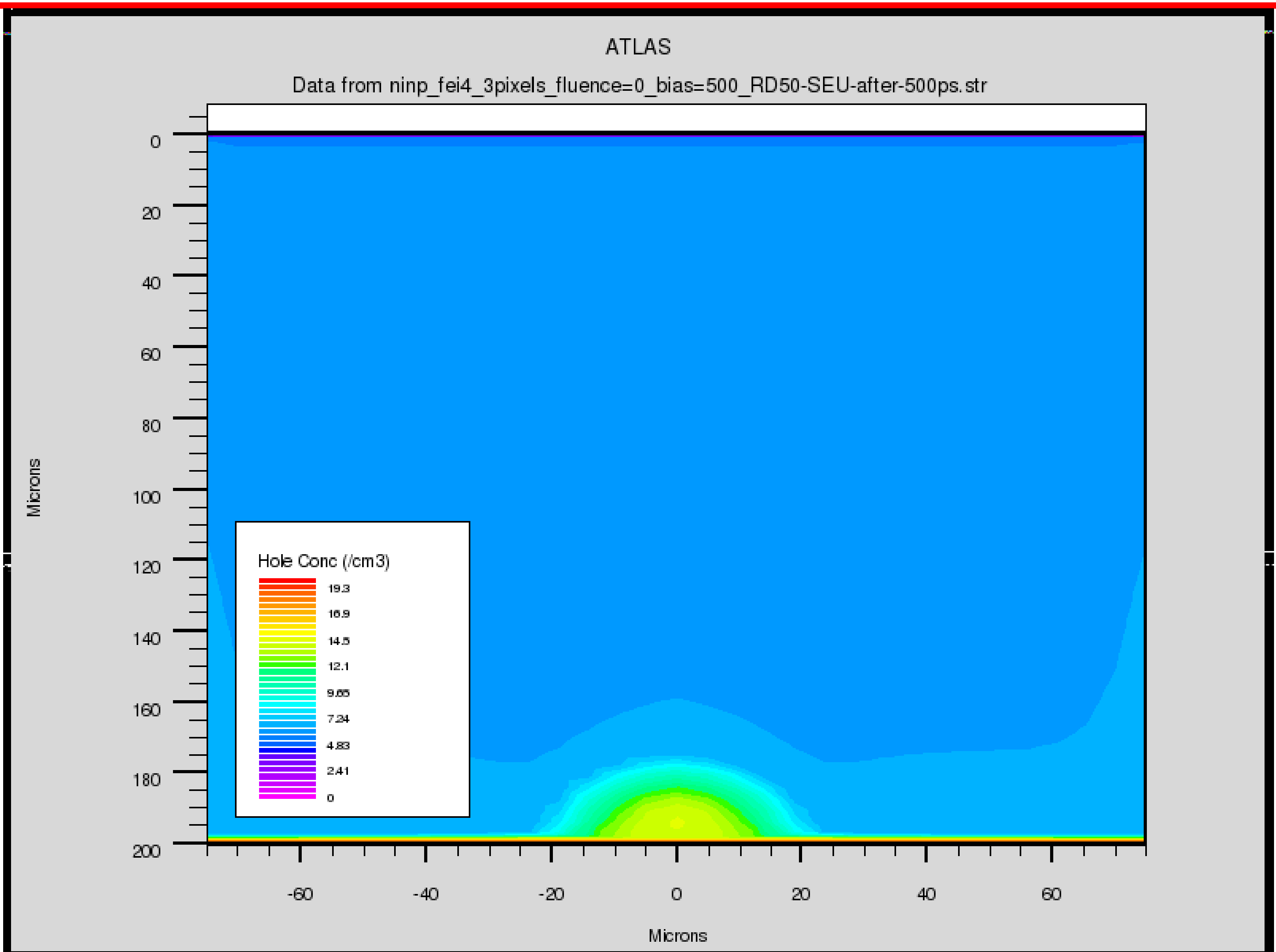
Signal, V = 150 V



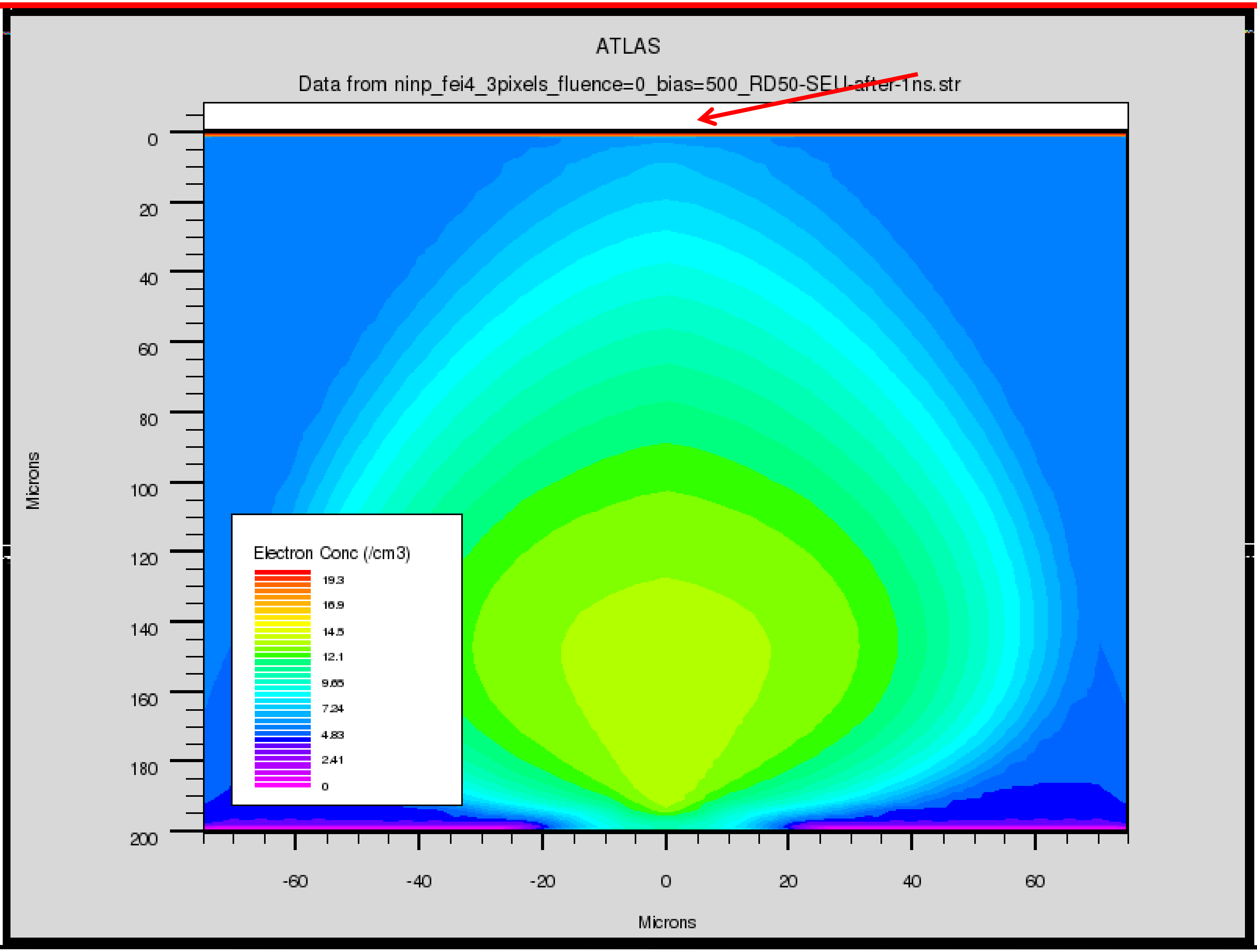
Elec. Conc. – 150 V, 500 ps after particle strike



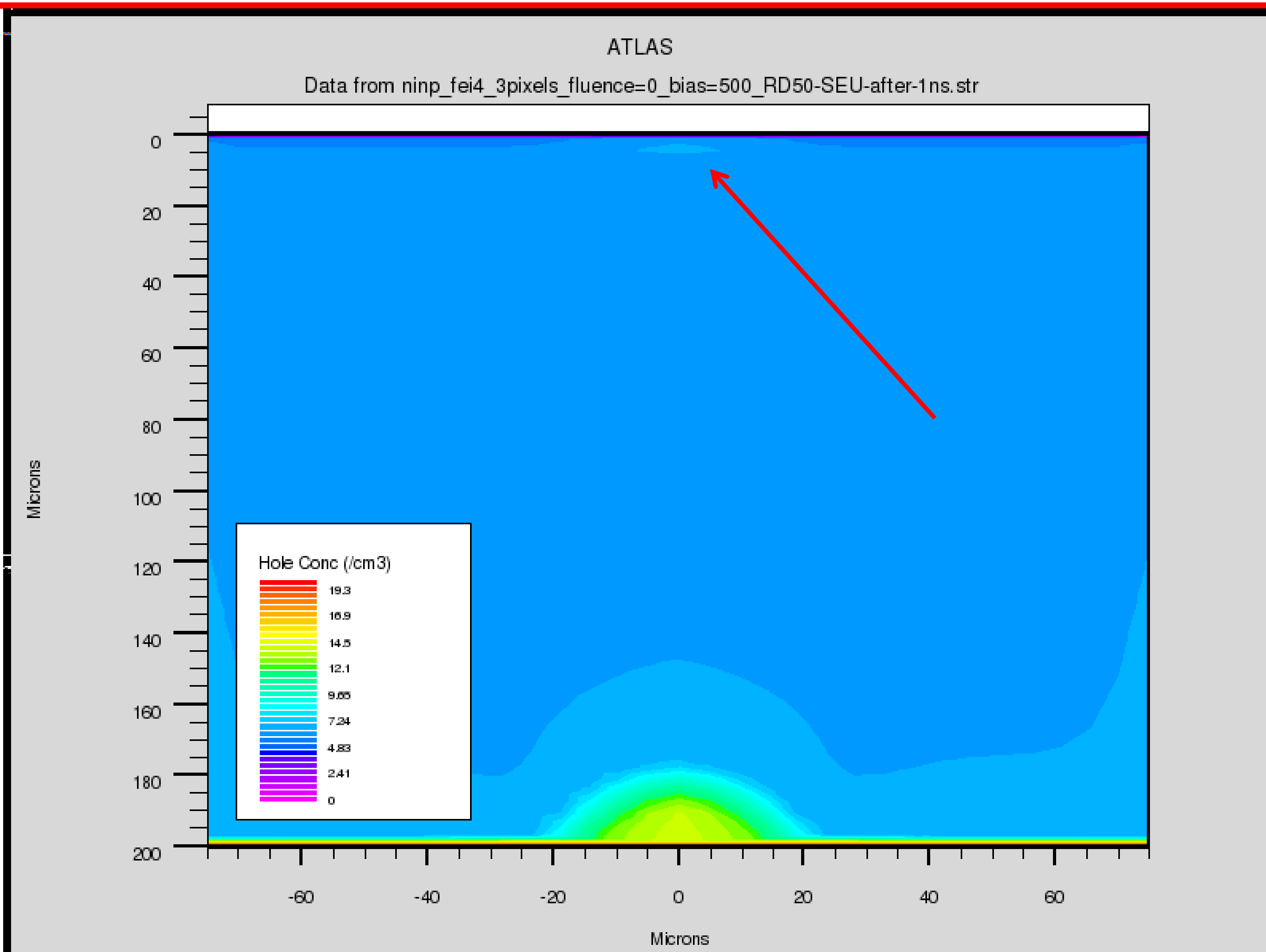
Hole Conc. – 150 V, 500 ps after particle strike



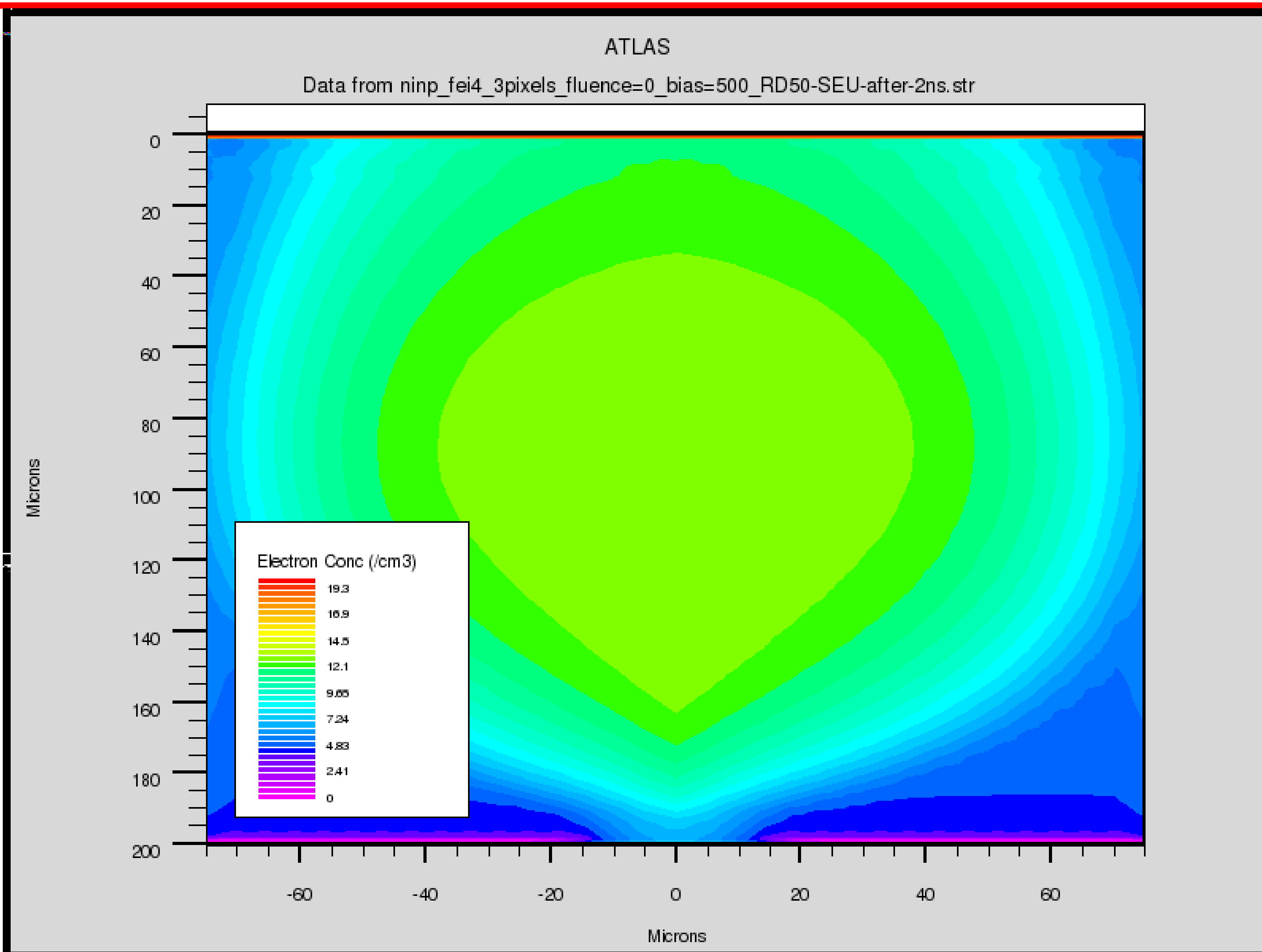
Elec. Conc. – 150 V, 1 ns after particle strike



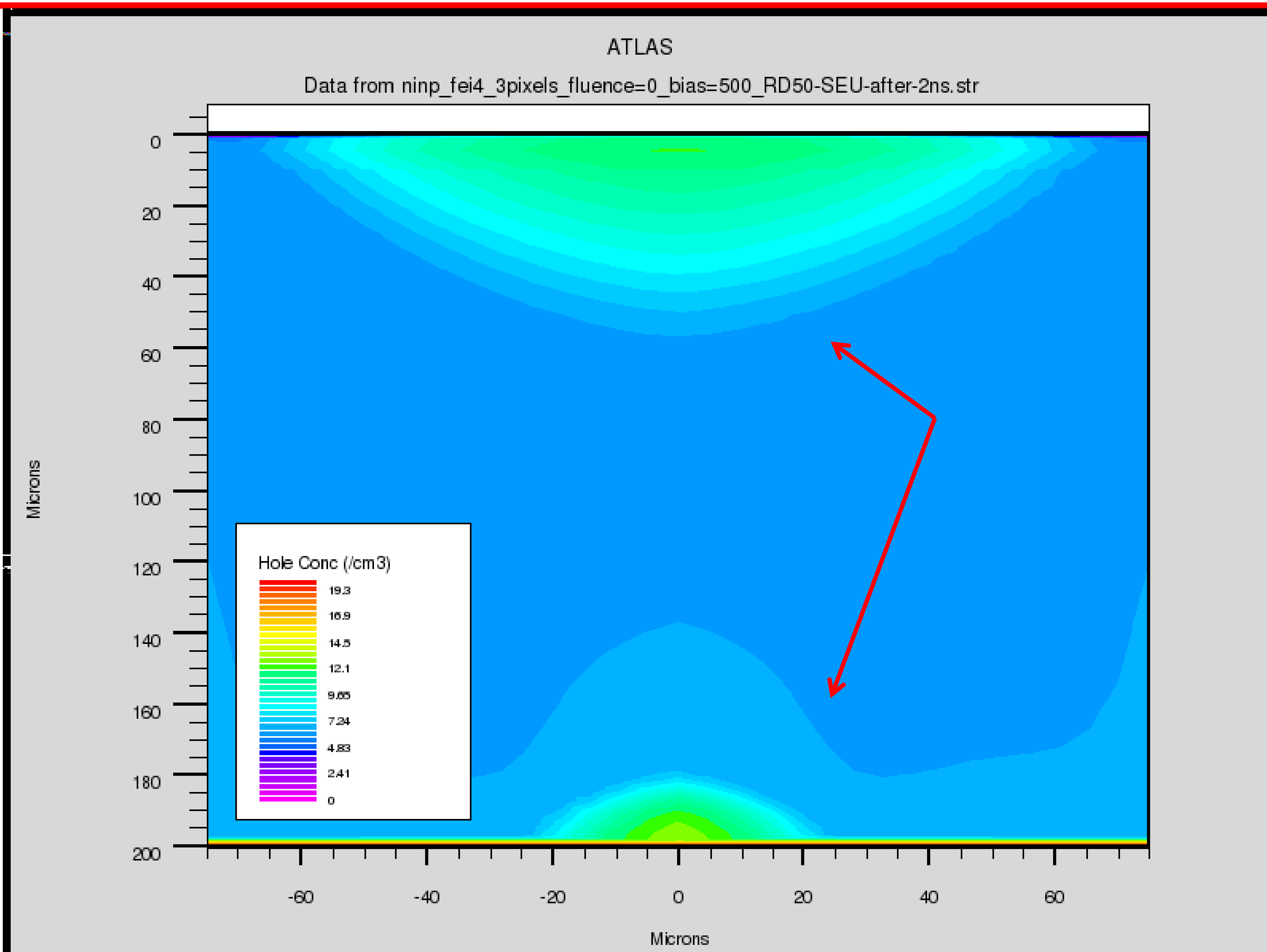
Hole Conc. – 150 V, 1 ns after particle strike



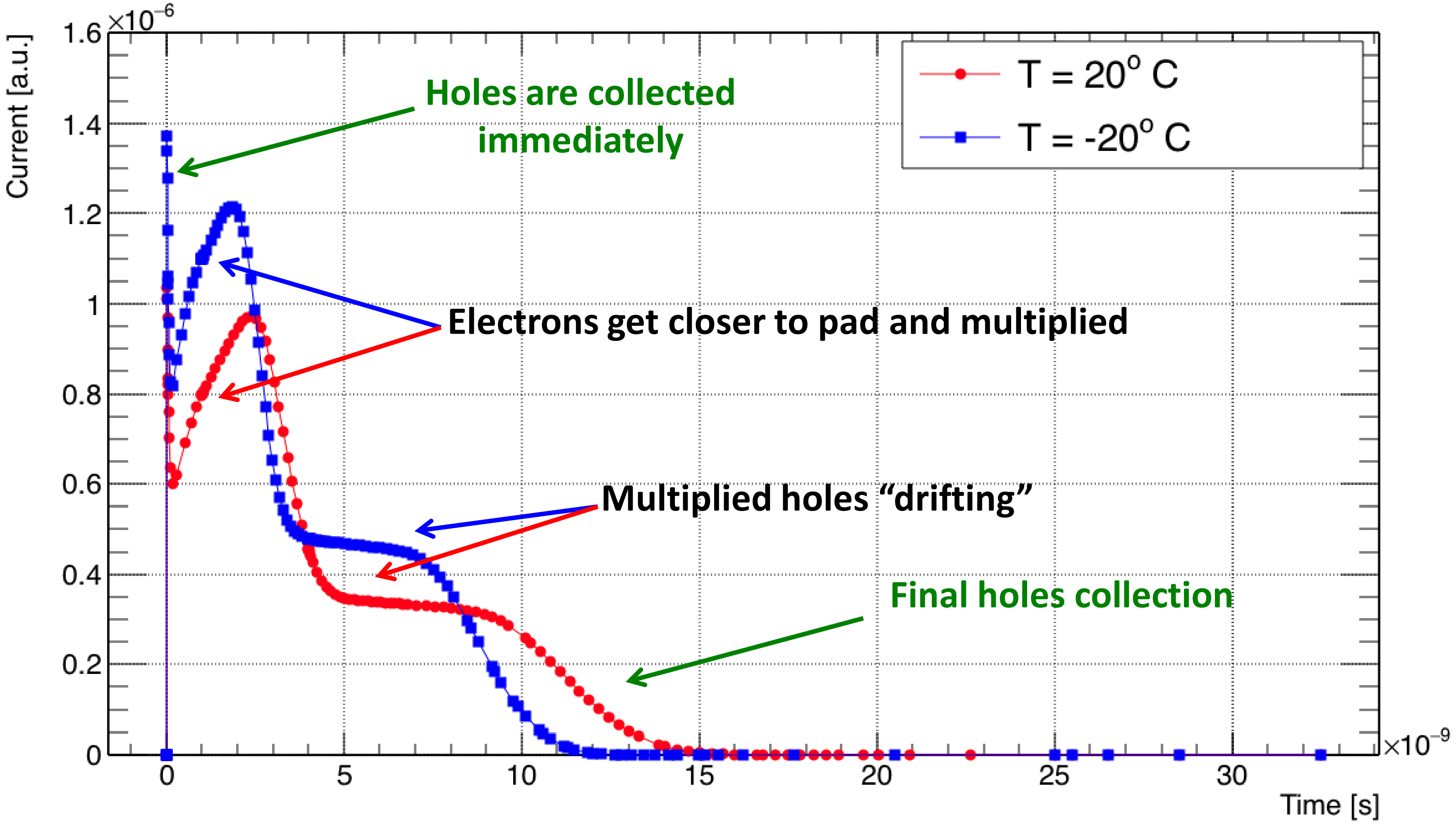
Elec. Conc. – 150 V, 2 ns after particle strike



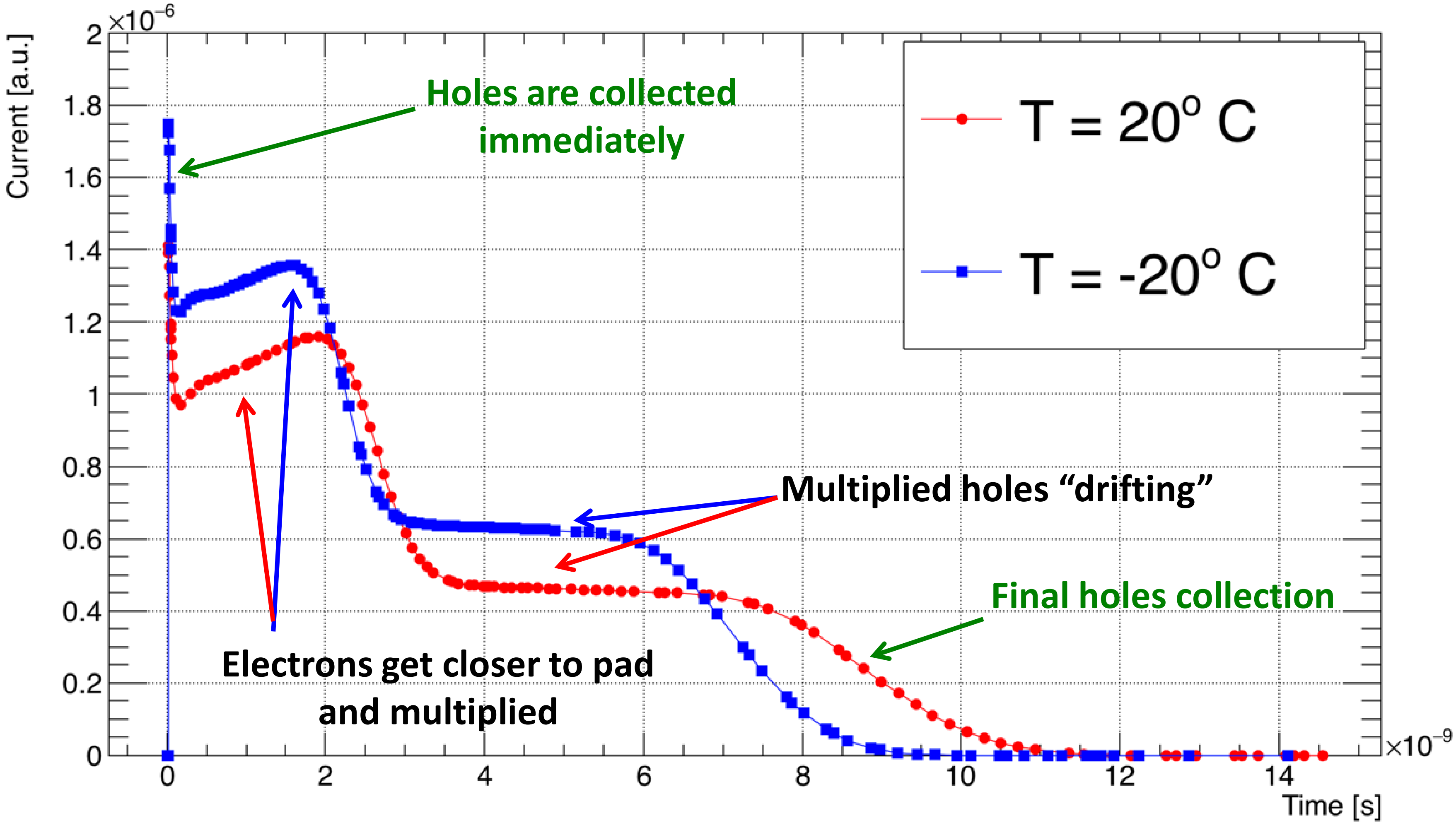
Hole Conc. – 150 V, 2 ns after particle strike



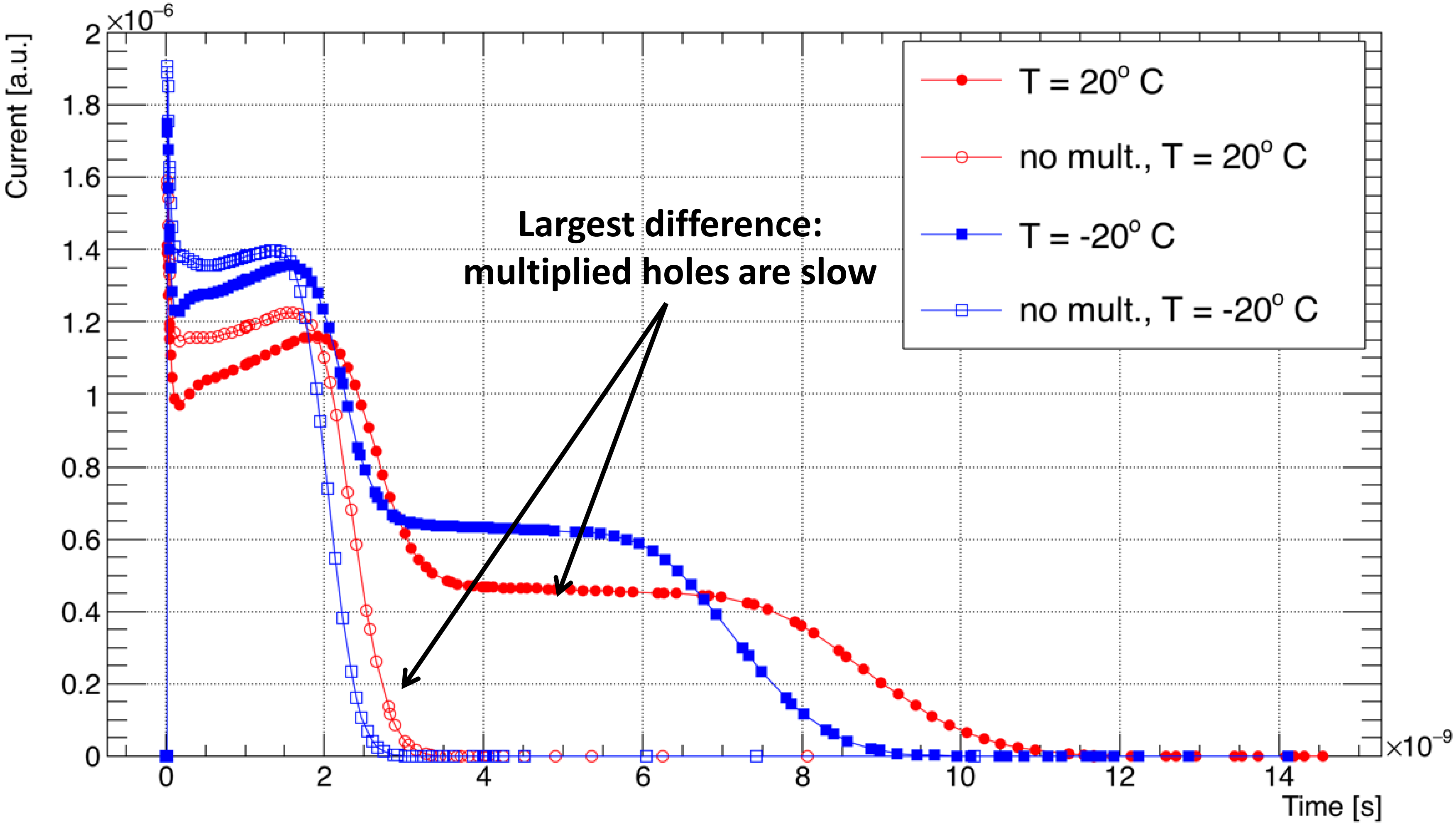
Signal, V = 150 V



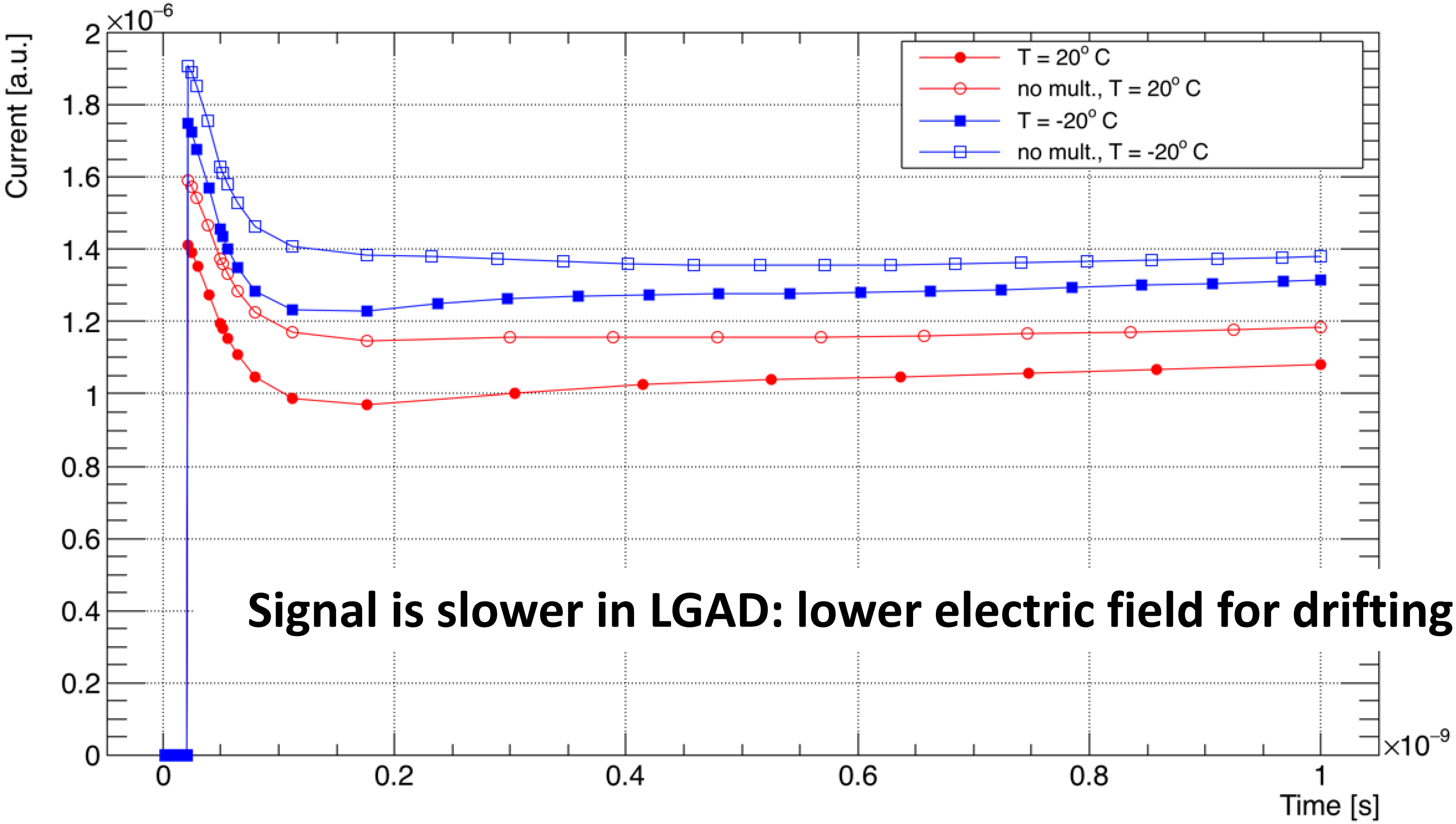
Signal, V = 200 V



LGAD vs reference – 200 V

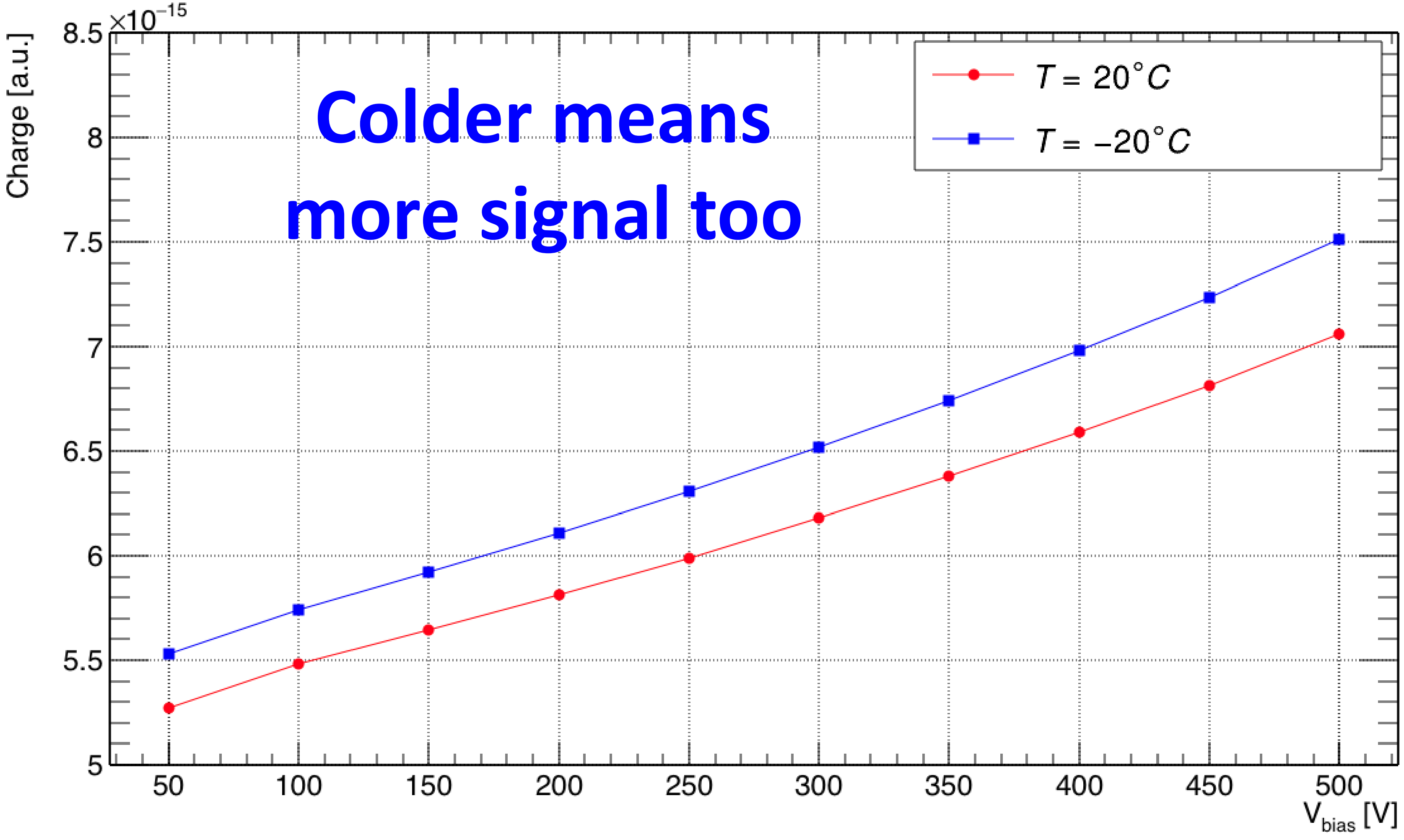


LGAD vs reference – 200 V - zoom

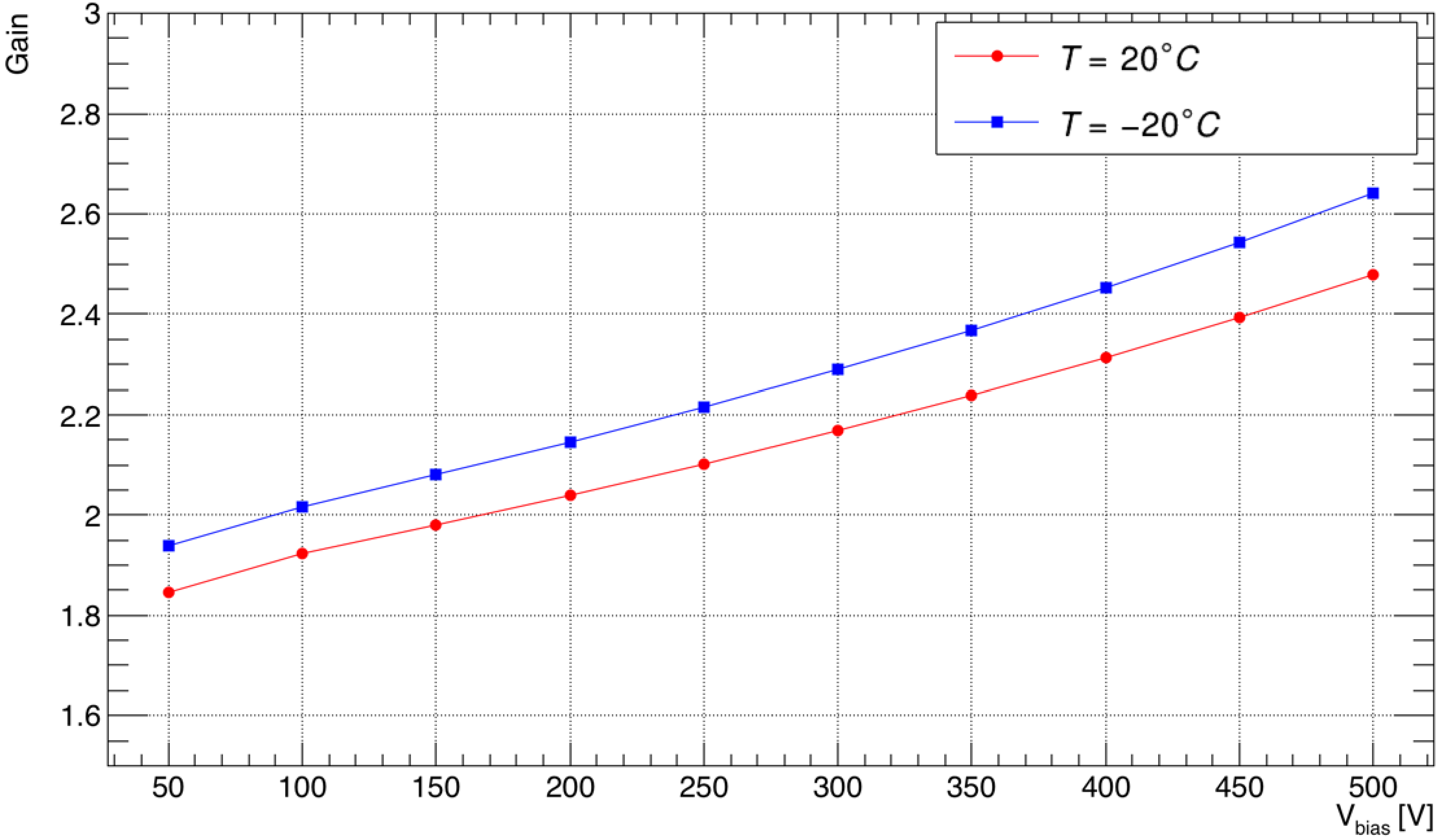


Signal is slower in LGAD: lower electric field for drifting

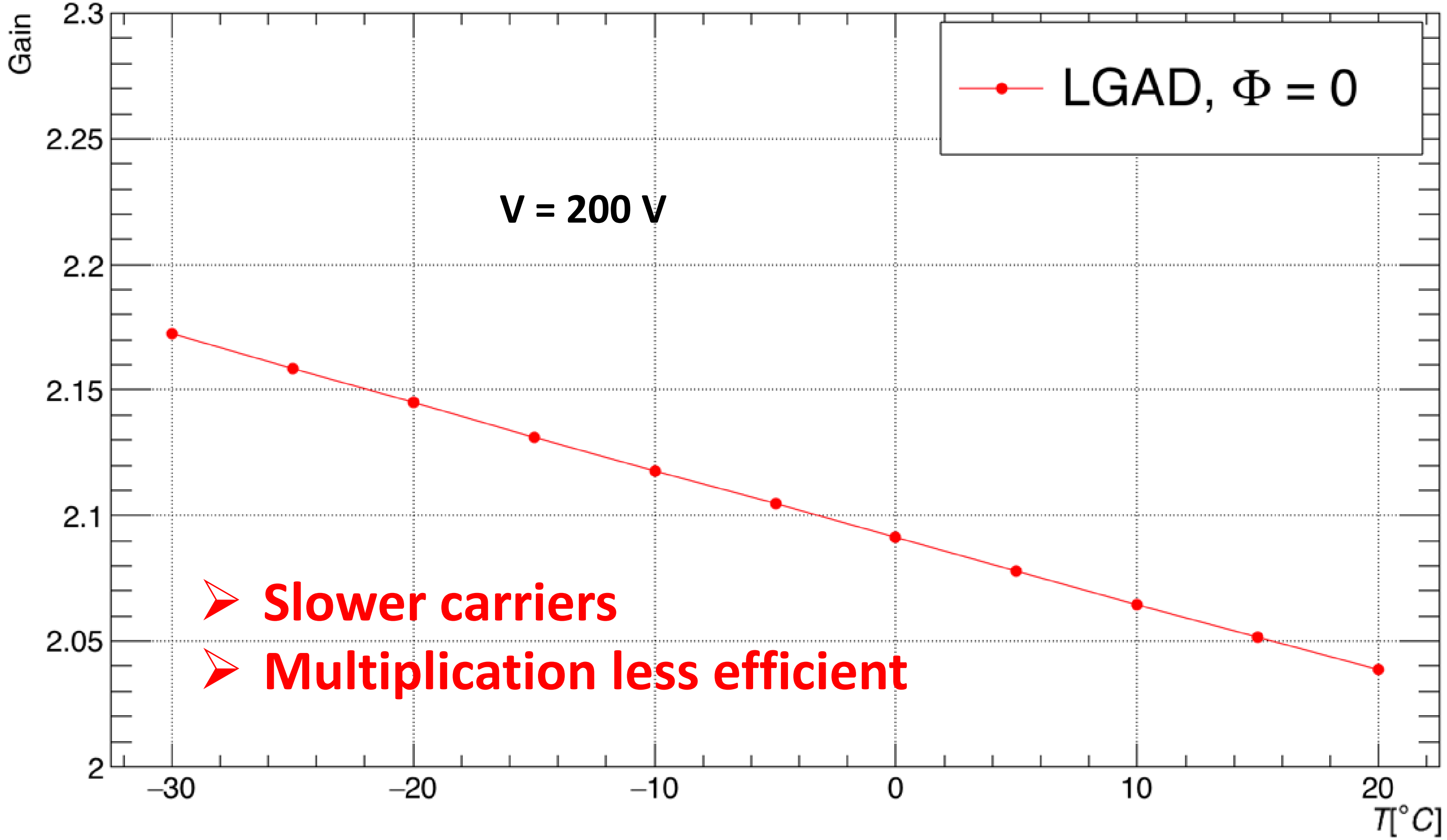
Charge: comparison



Gain for Fluence = 0



Gain vs temperature

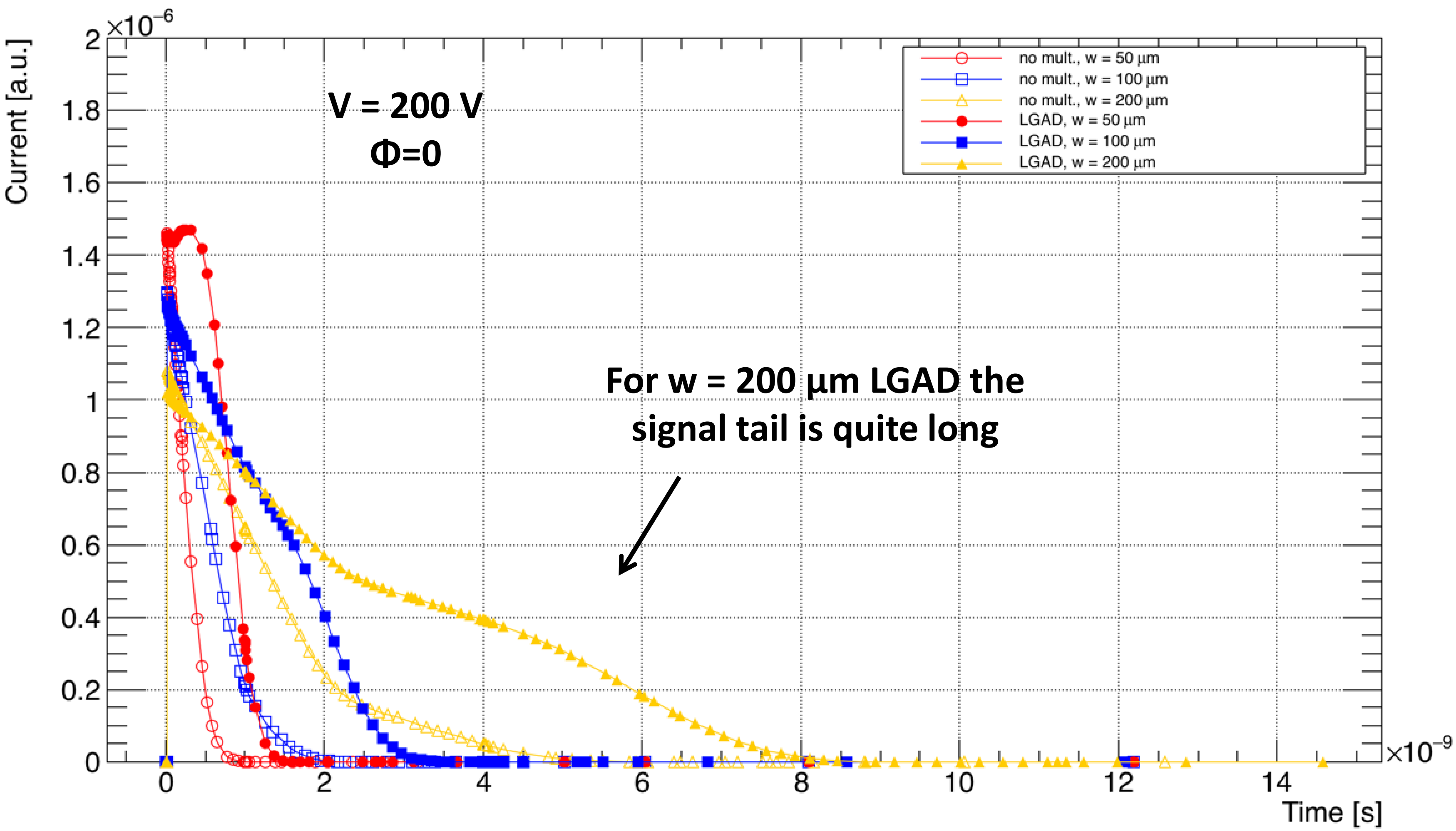


- Slower carriers
- Multiplication less efficient

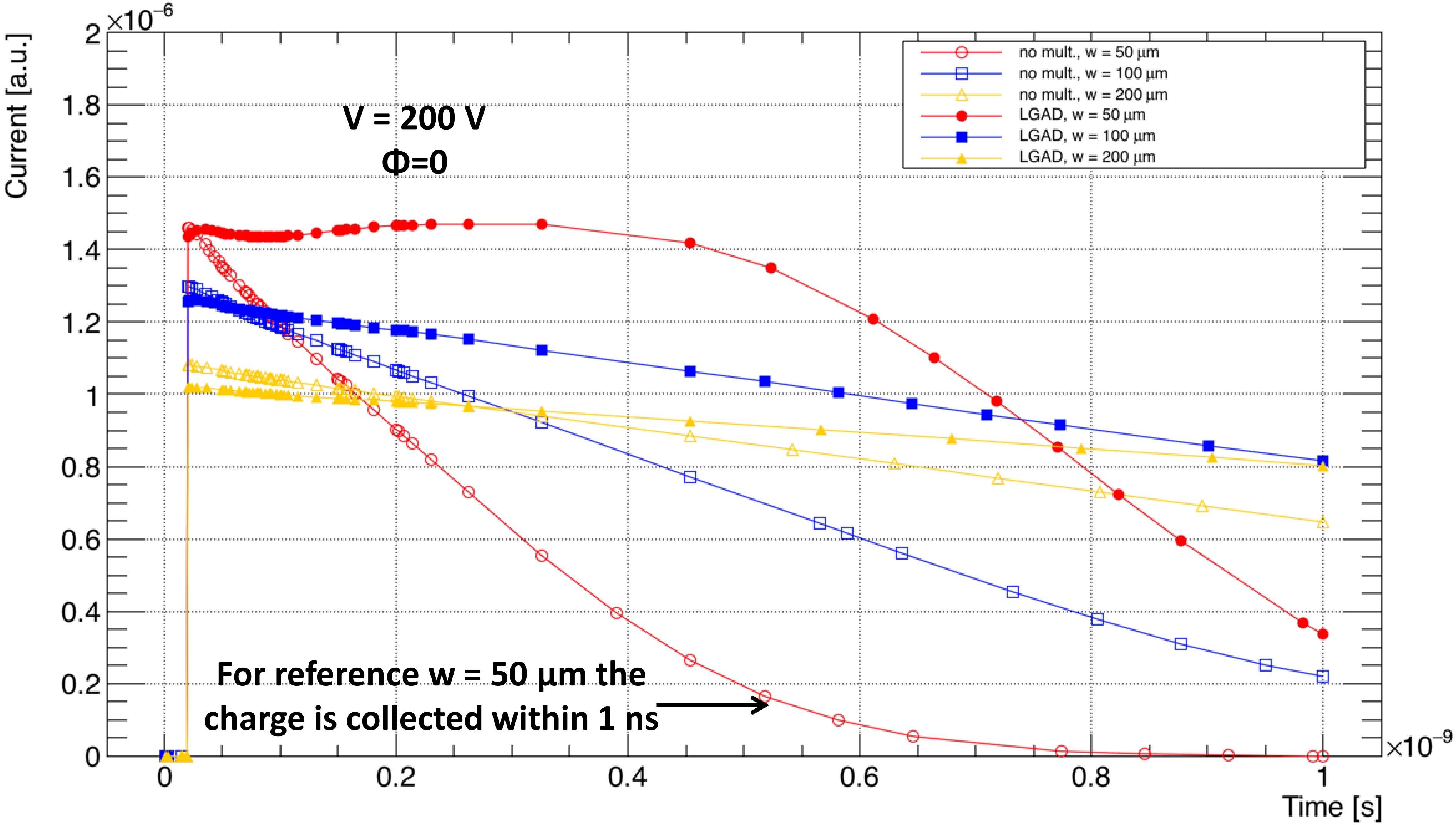
MIPs simulations

- MIP impinging from the front
- 50, 100 & 200 μm thick devices
- V_{bias} = 200 & 500 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

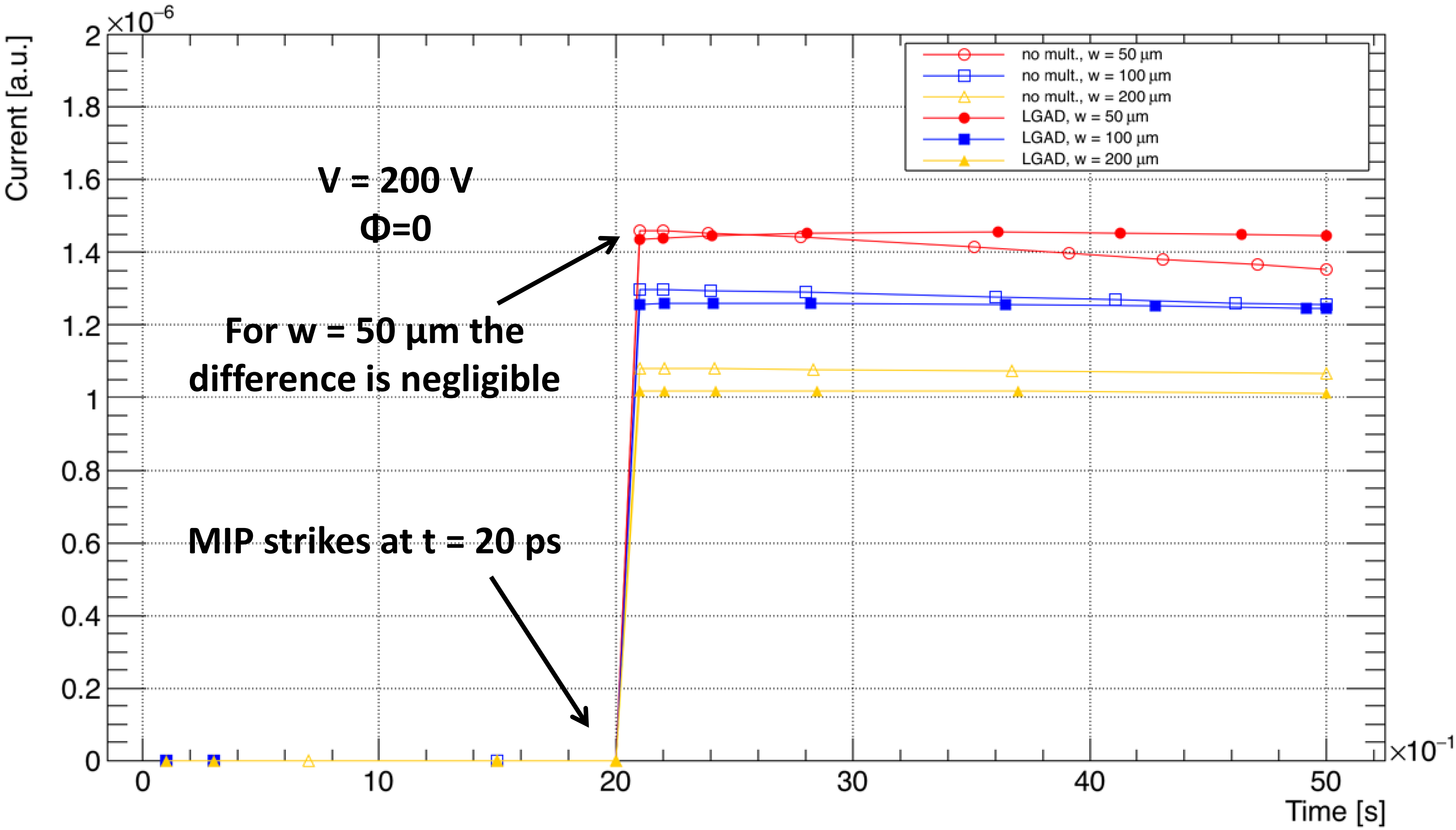
Signal vs time, different thicknesses – 200 V



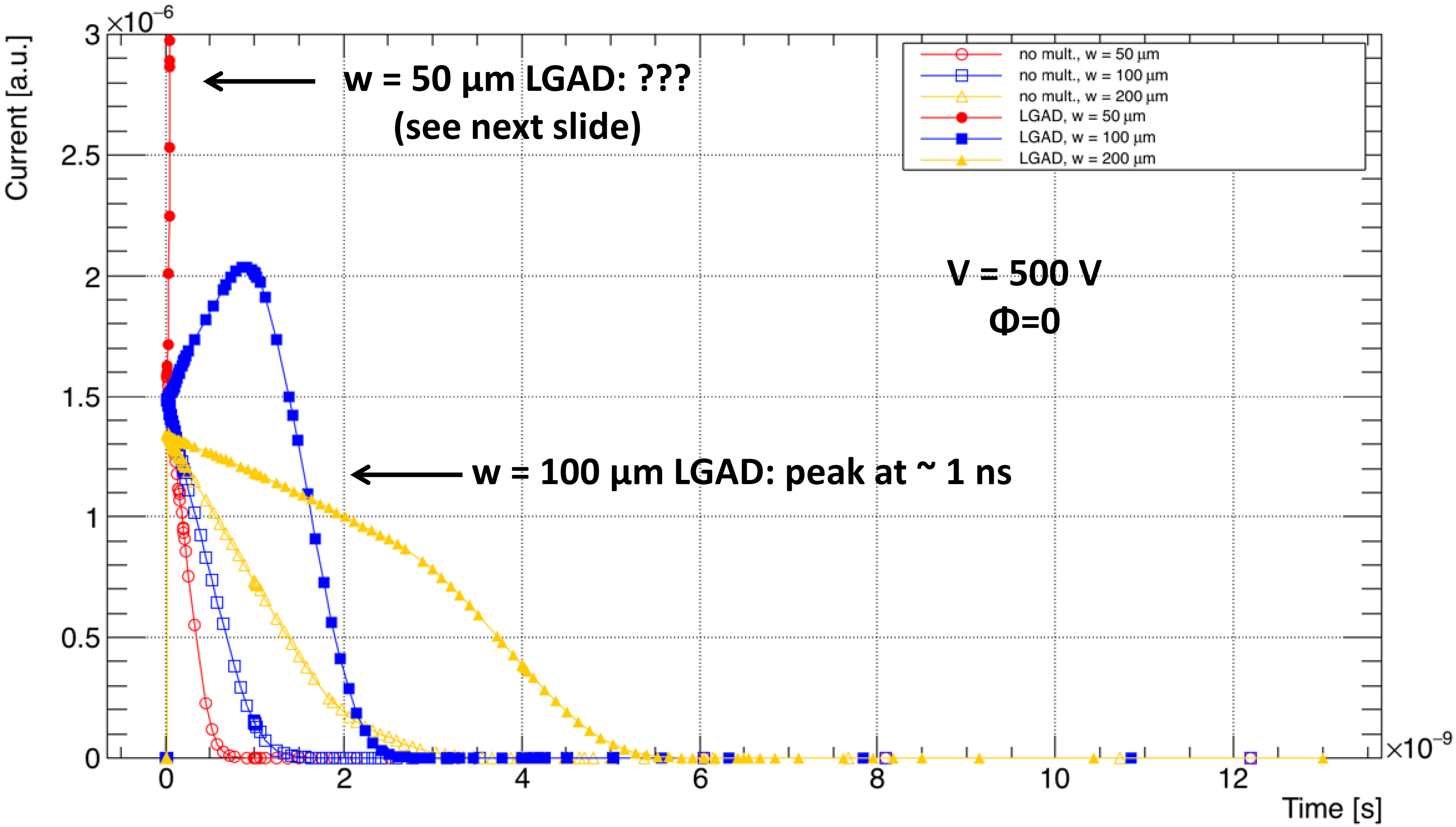
Signal vs time, different thicknesses – 200 V



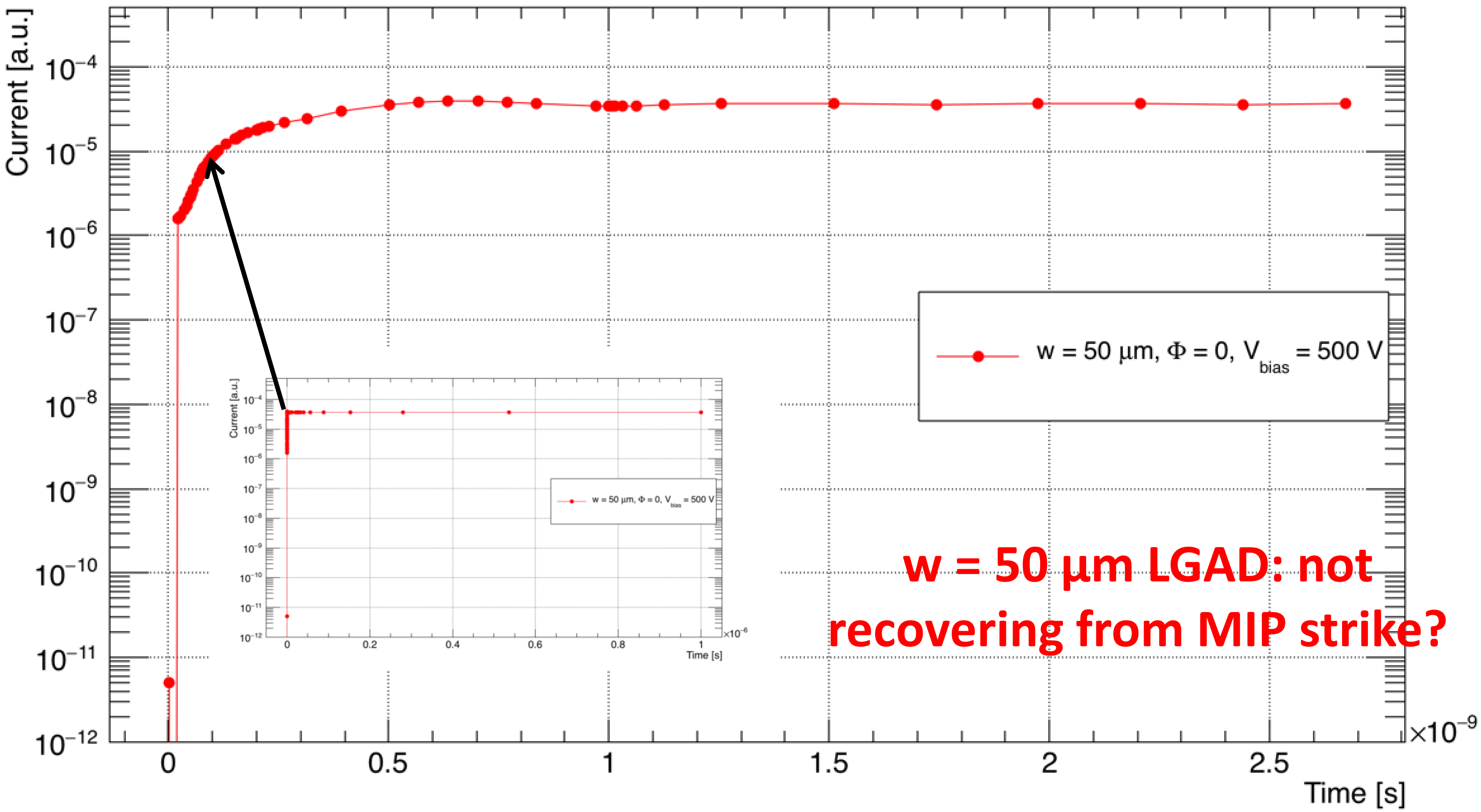
Signal vs time, different thicknesses – 200 V



Signal vs time, different thicknesses – 500V

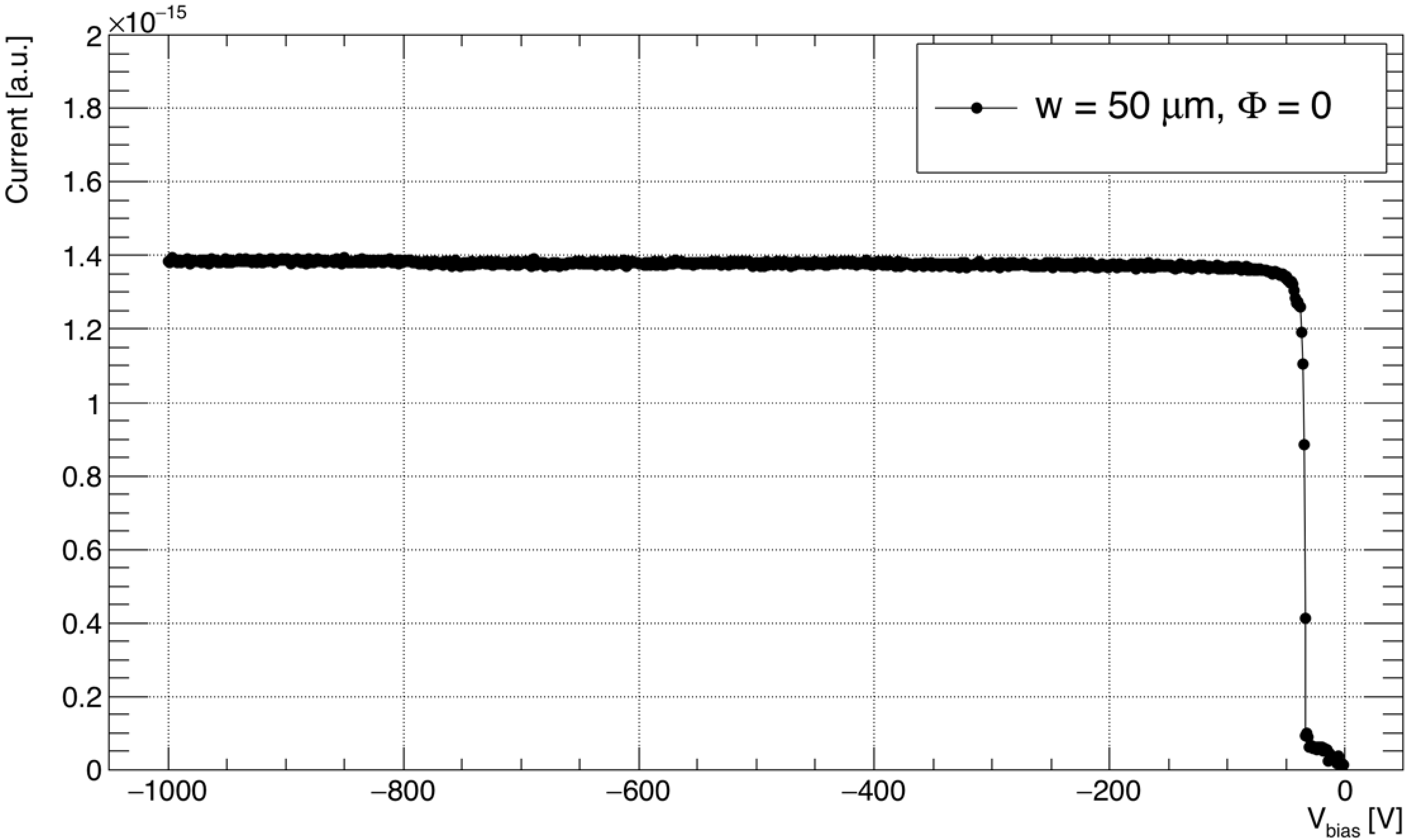


Signal vs time, w = 50 µm, un-irr. – 500 V



w = 50 µm LGAD: not recovering from MIP strike?

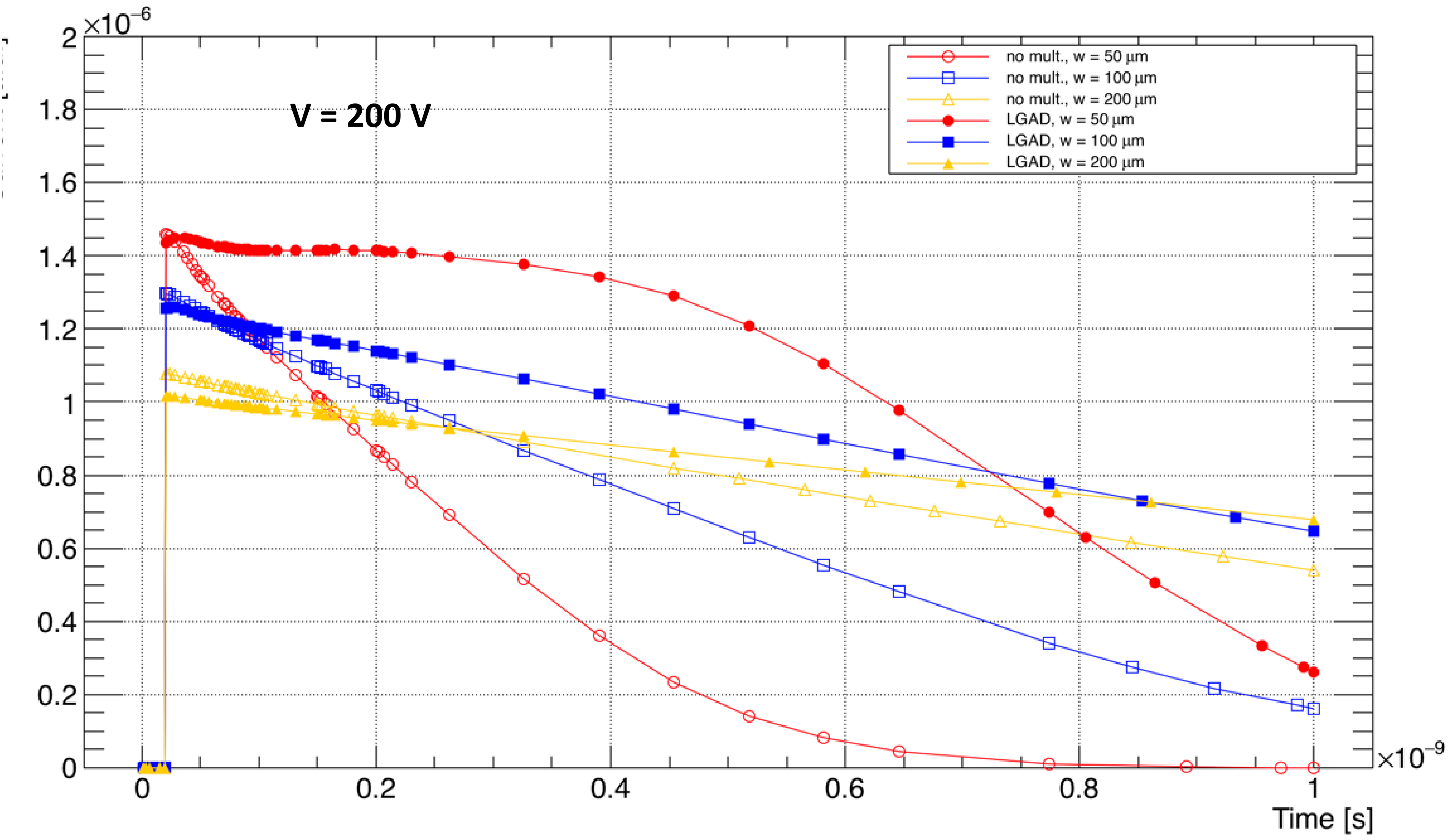
No breakdown in thin un-irr. till 1000 V



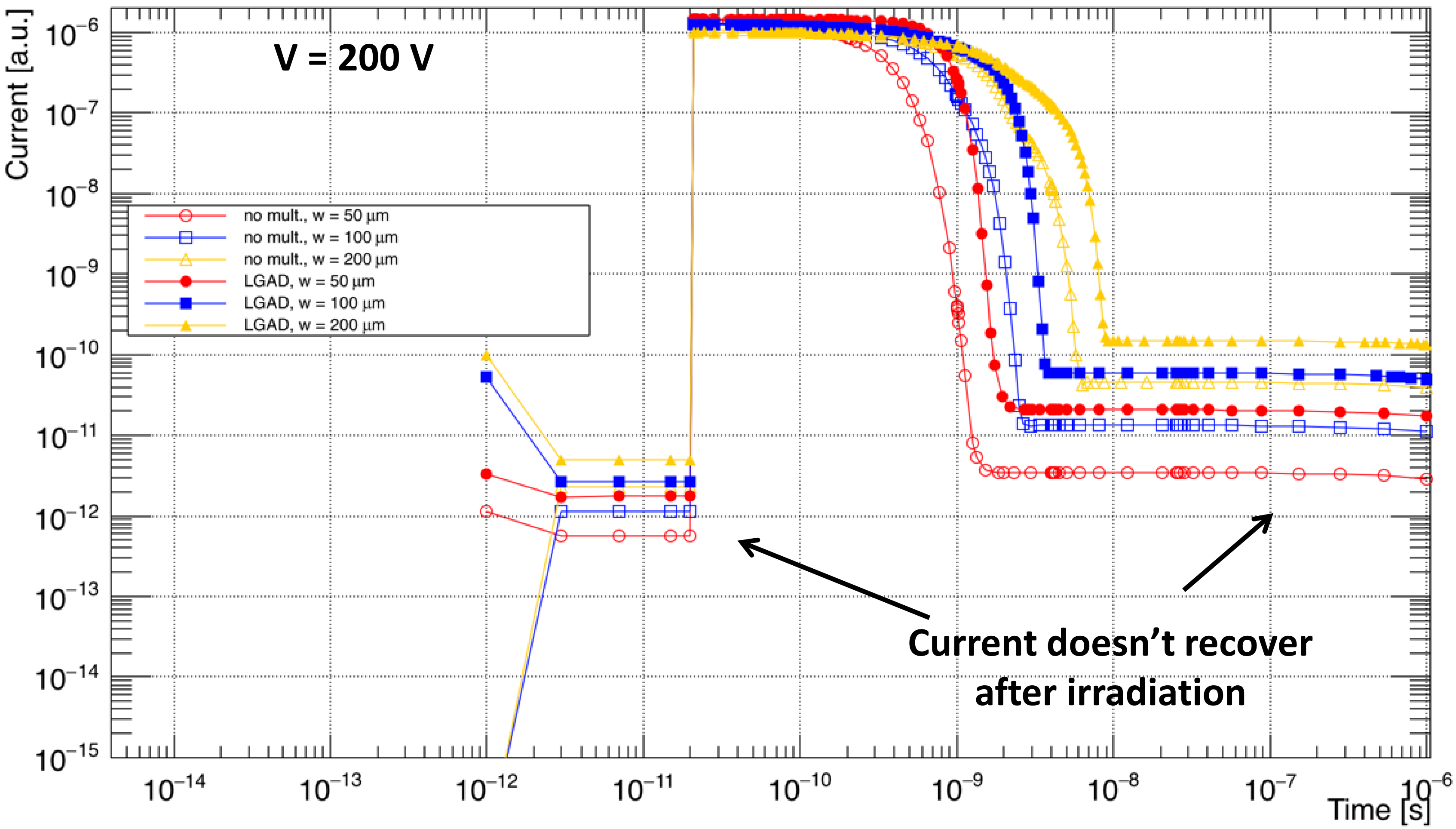
Break down voltage summary for irr. LGAD

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

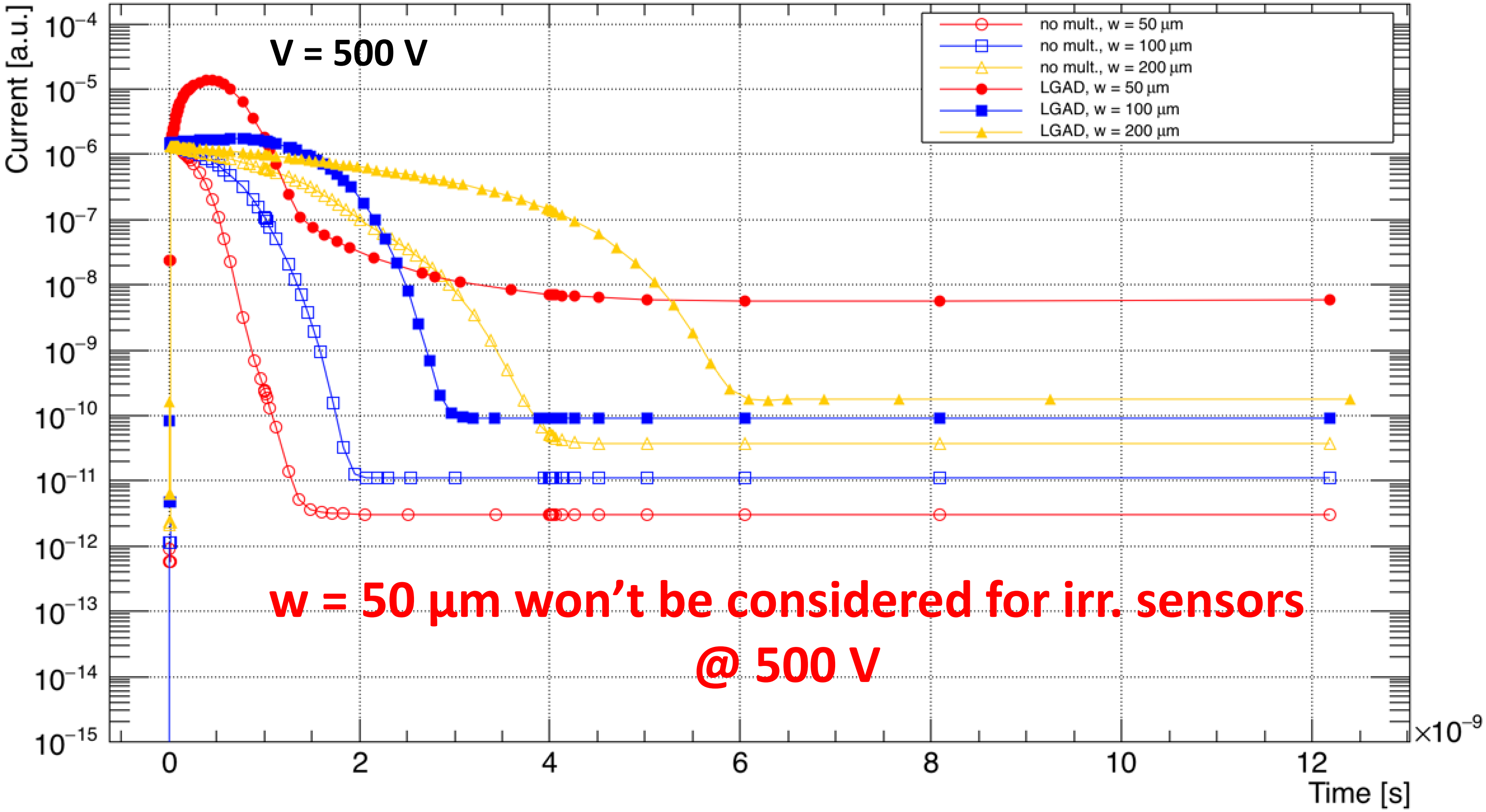
Signal of irr. samples – $\Phi = 1\times10^{15}$



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

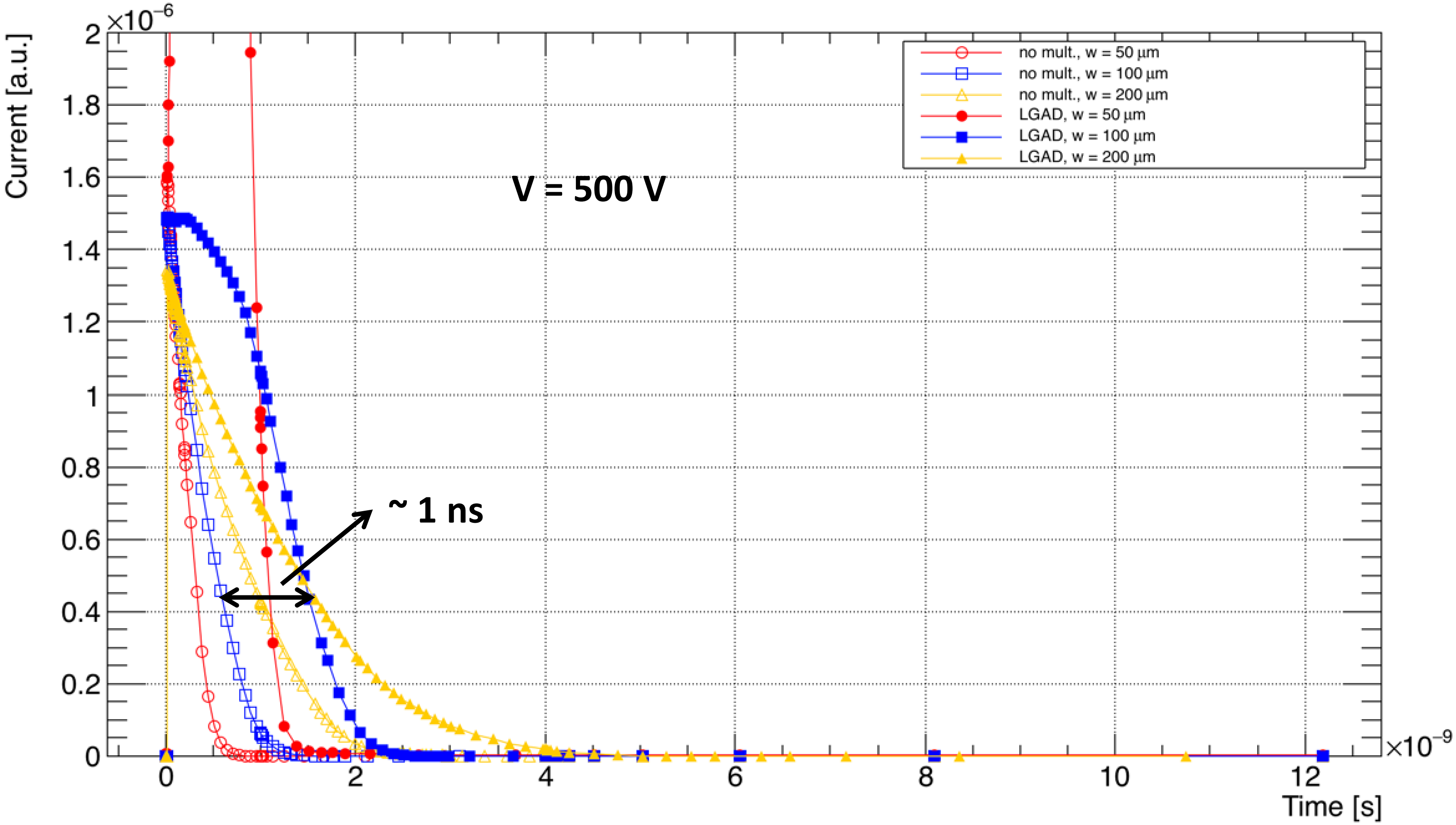


Simulation of irr. samples – $\Phi = 1x10^{15}$

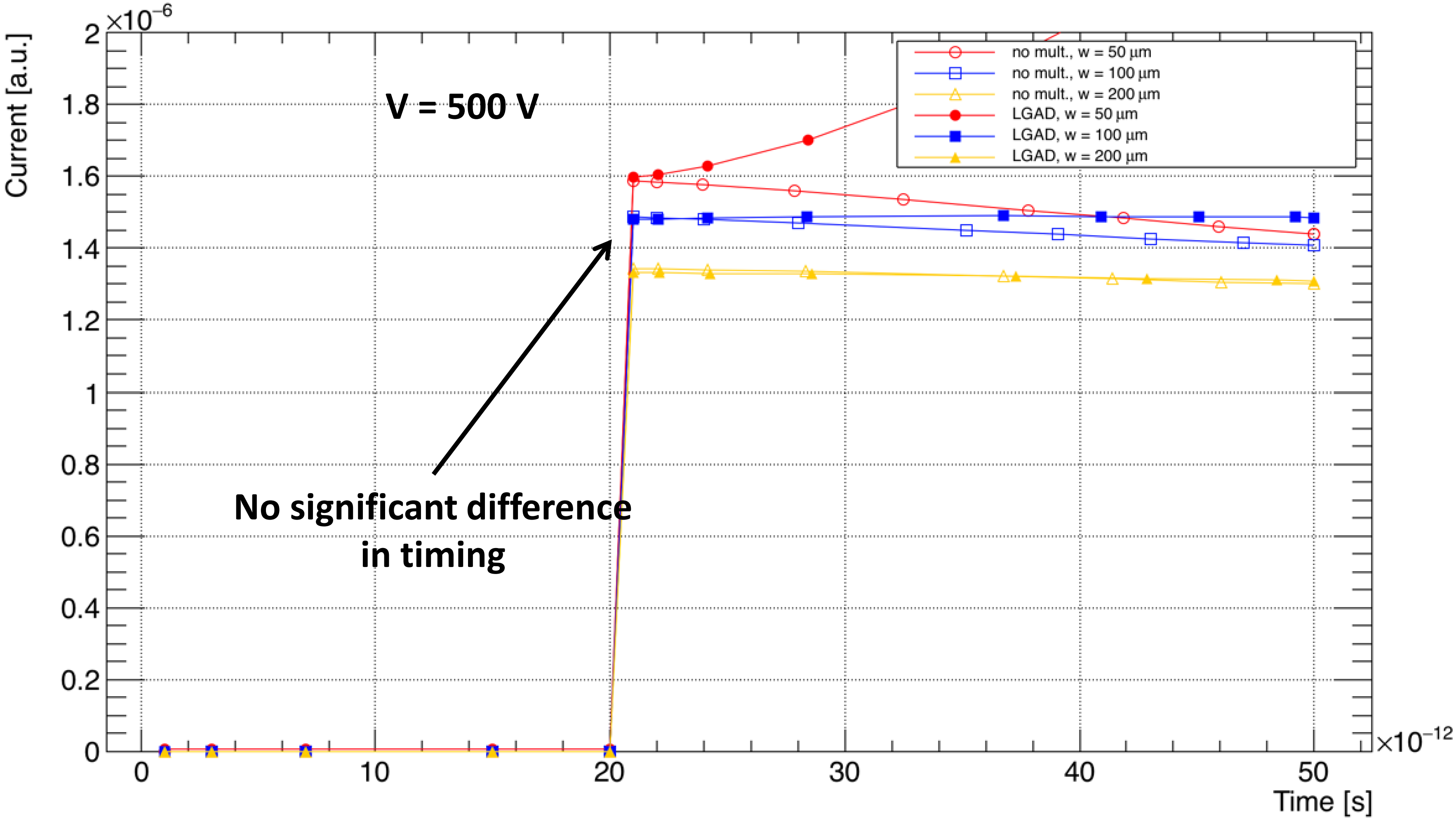


w = 50 μm won't be considered for irr. sensors @ 500 V

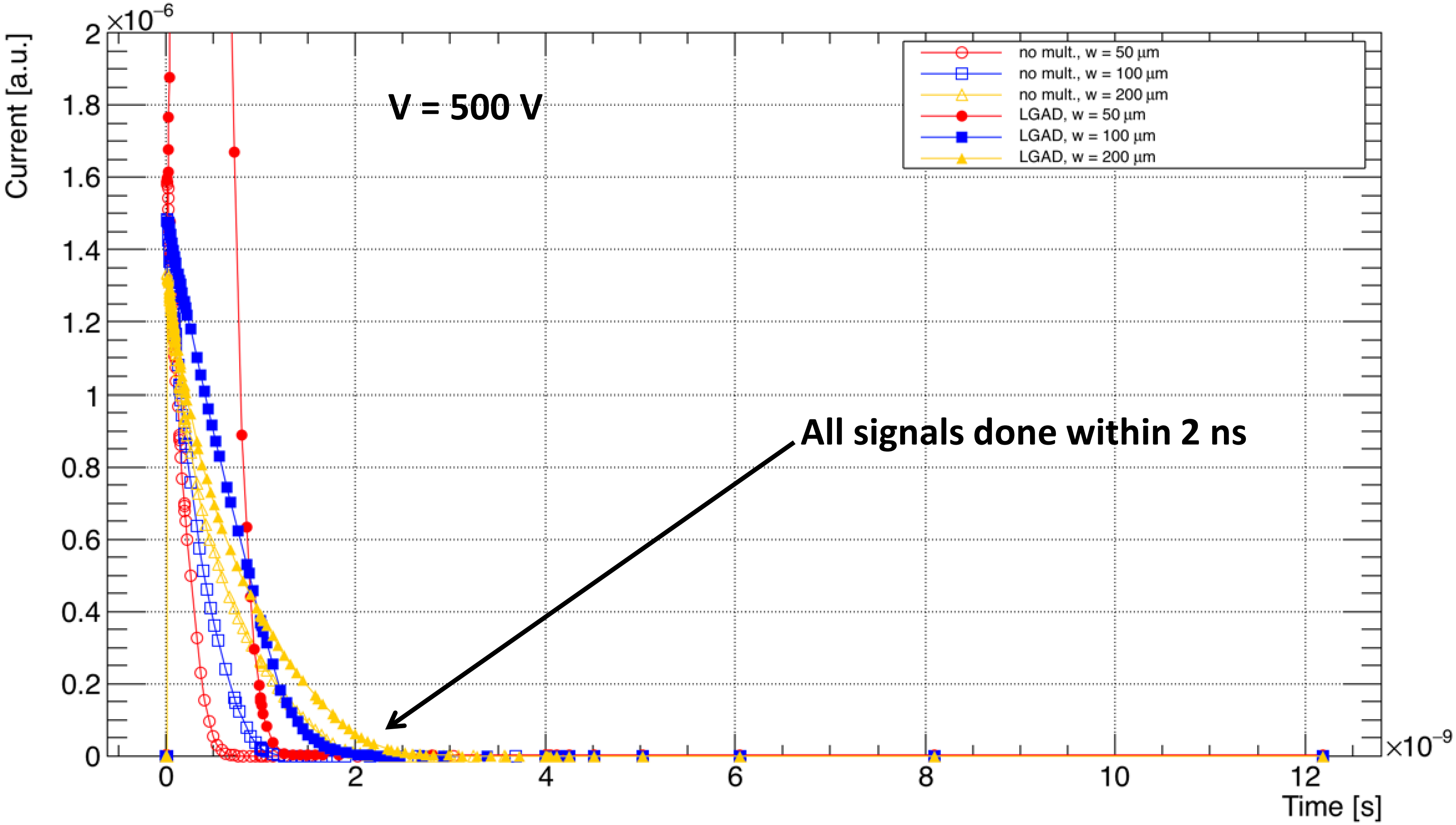
Simulation of irr. samples – $\Phi = 3x10^{15}$



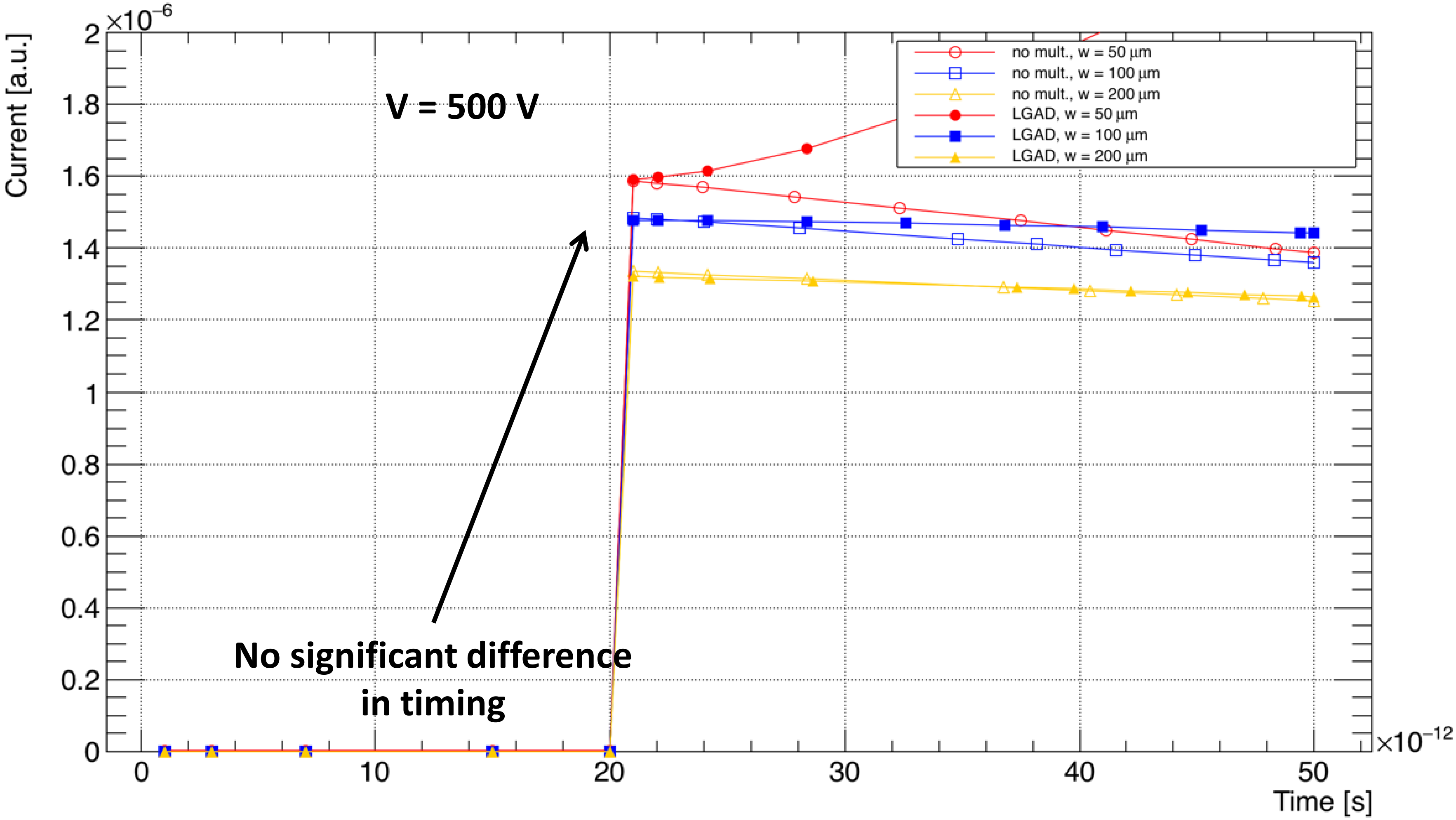
Simulation of irr. samples – $\Phi = 3 \times 10^{15}$



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

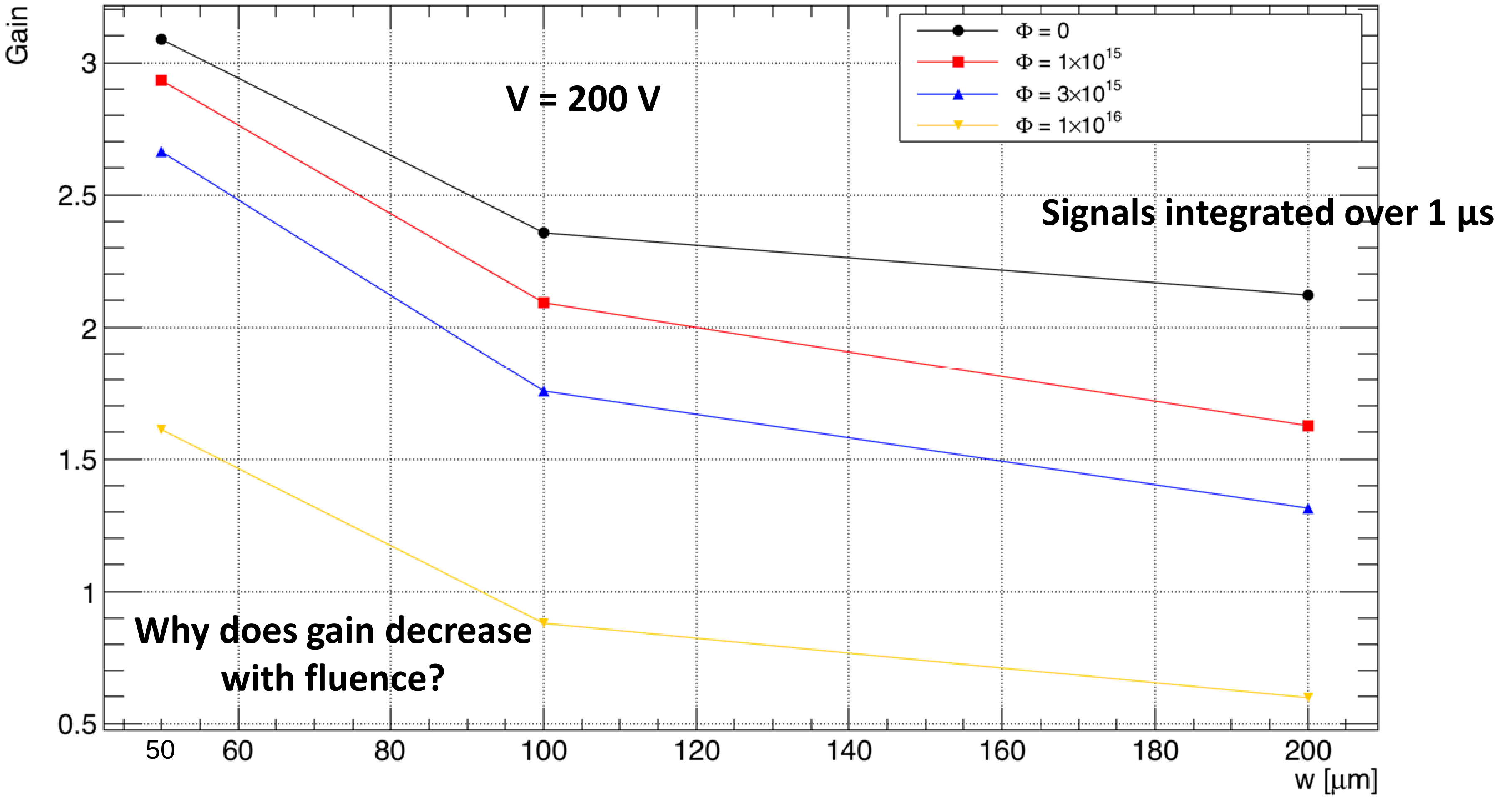


Simulation of irr. samples – $\Phi = 1x10^{16}$



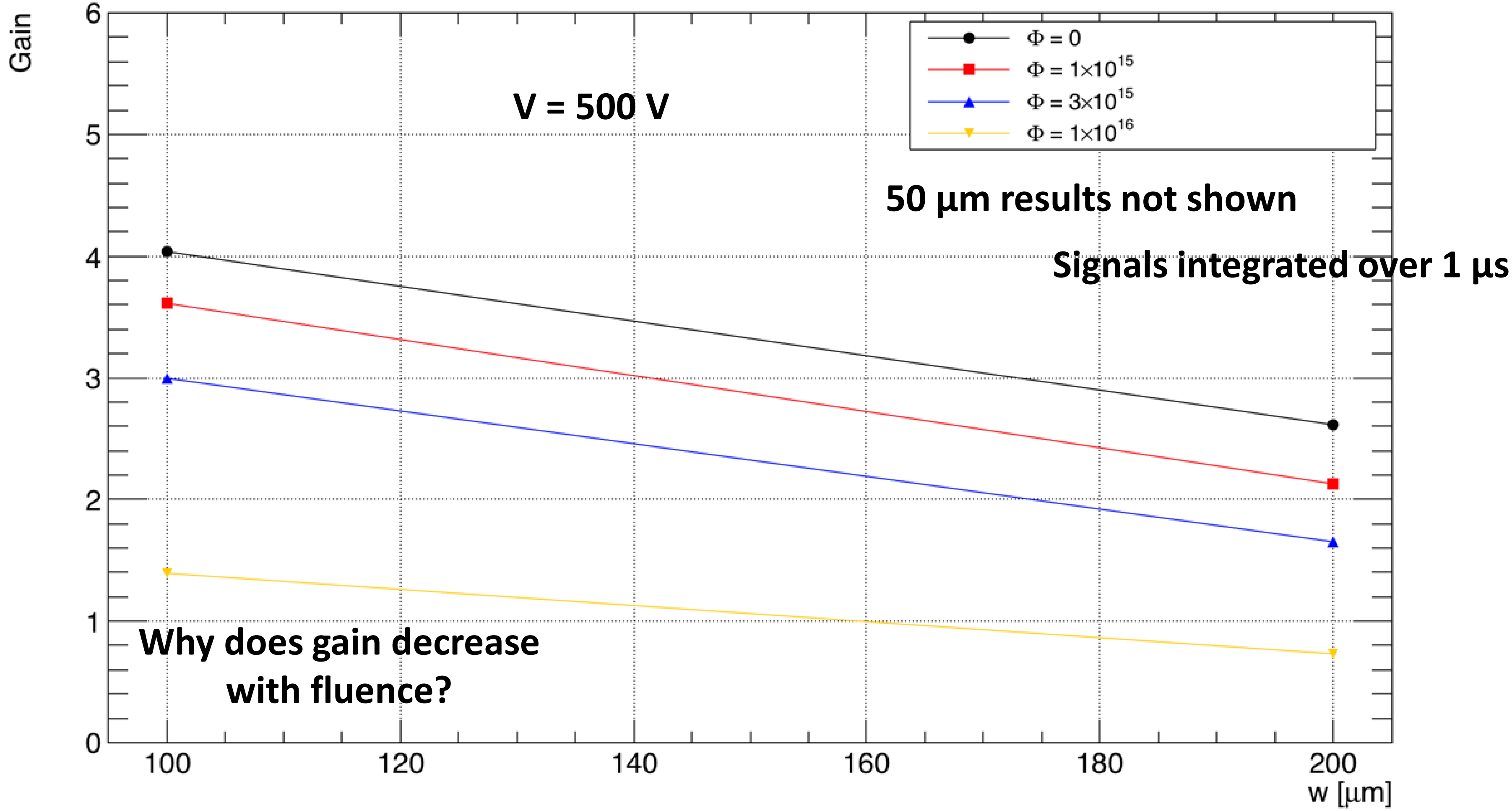
Gain vs different thicknesses – 200 V

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

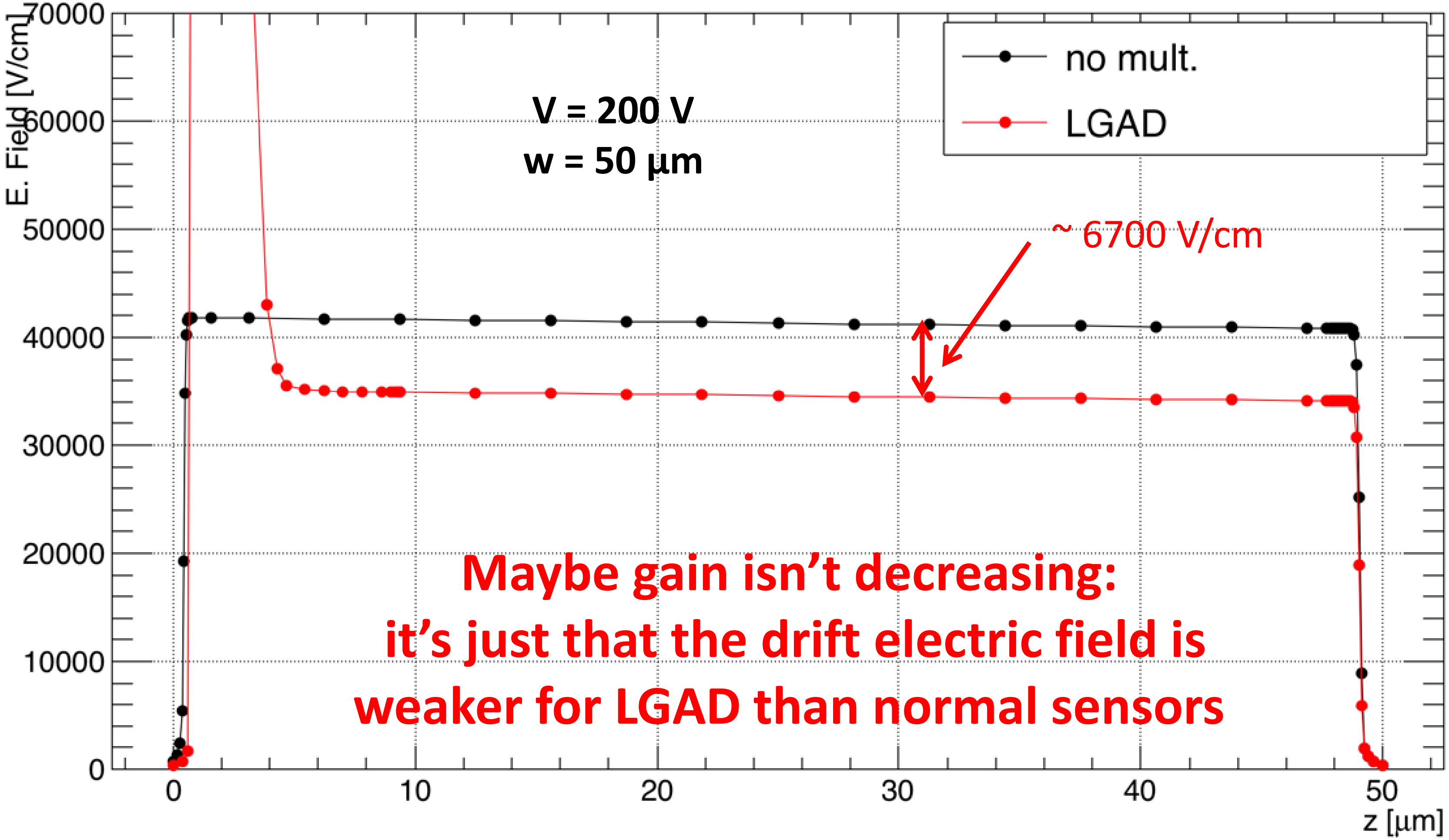


Gain vs different thicknesses – 500 V

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



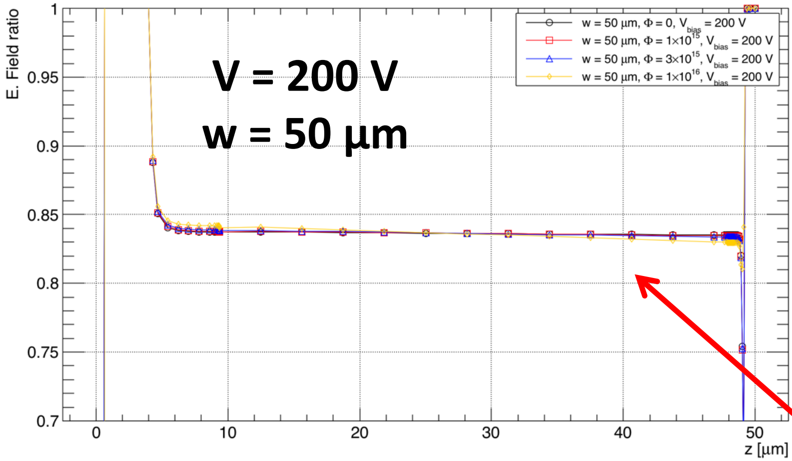
Electric field for $\Phi = 1x10^{15}$

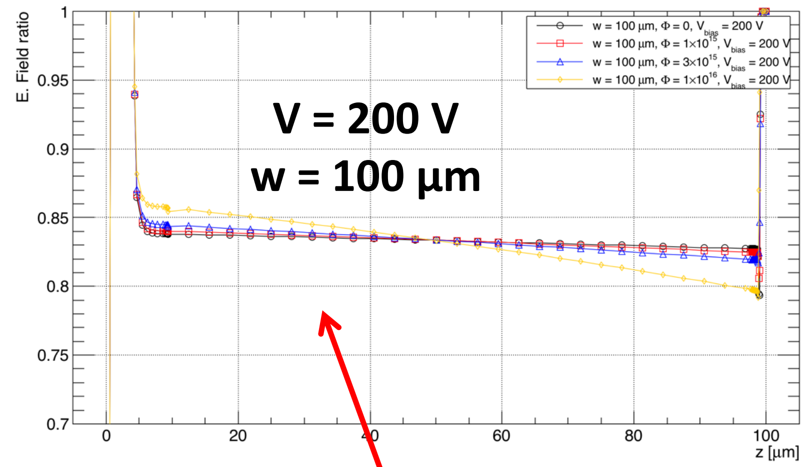


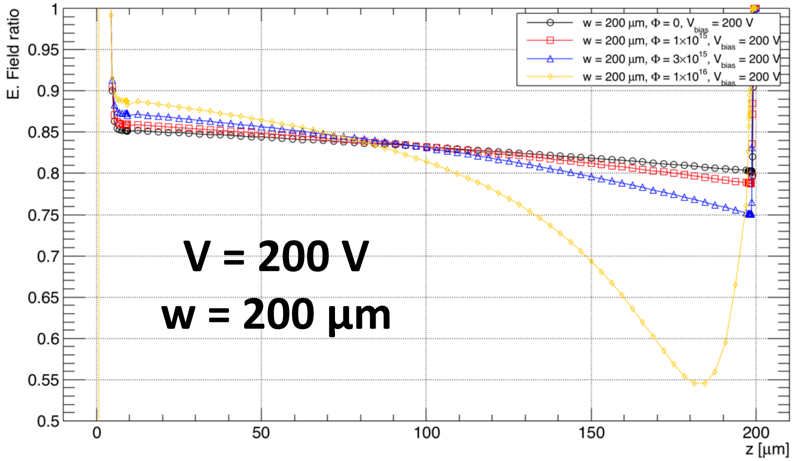
Maybe gain isn't decreasing:
it's just that the drift electric field is weaker for LGAD than normal sensors

Electric field ratio

Electric field normalized to the reference detector



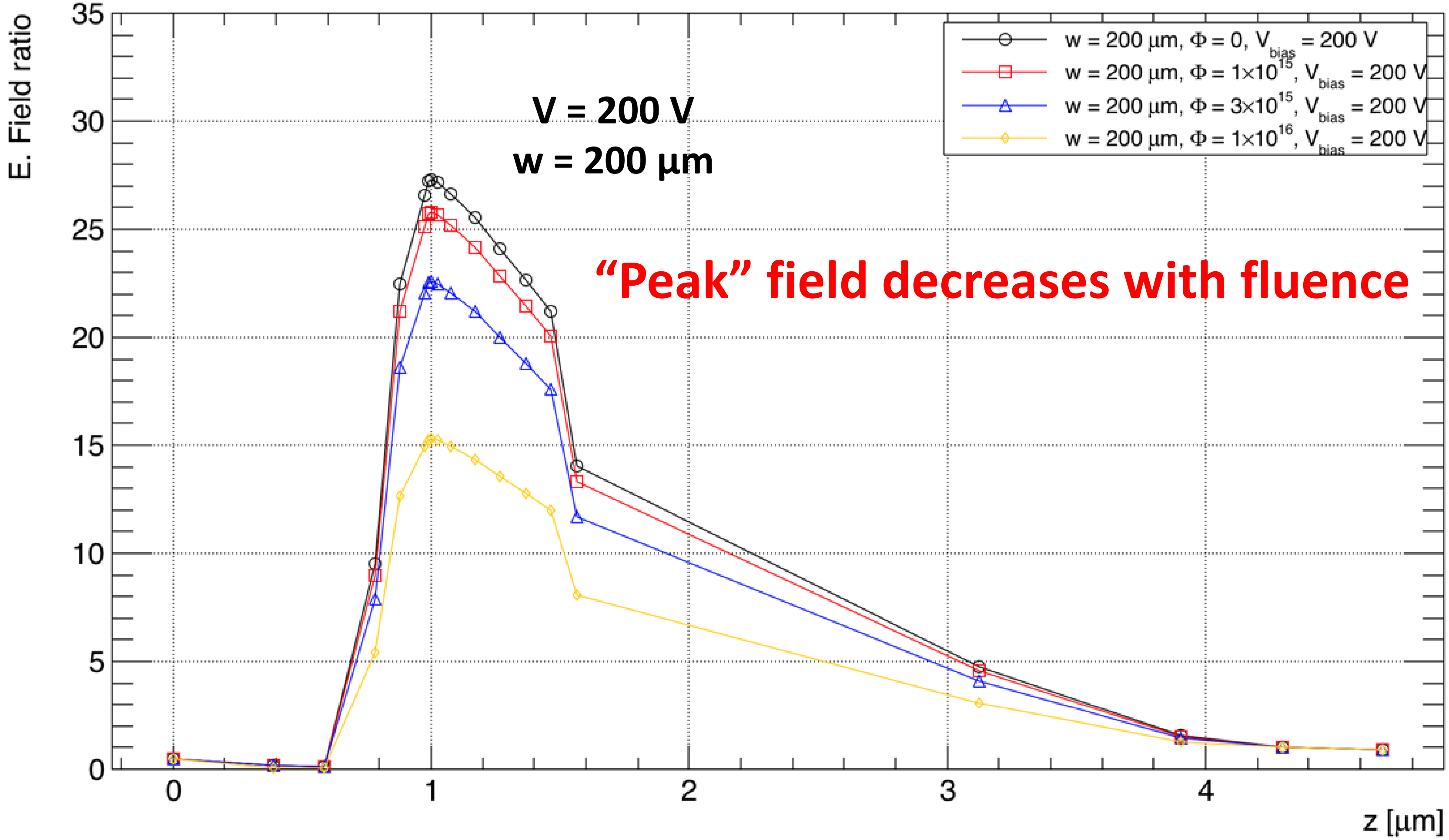




Bulk field significantly lower

Electric field ratio

Electric field normalized to the reference detector

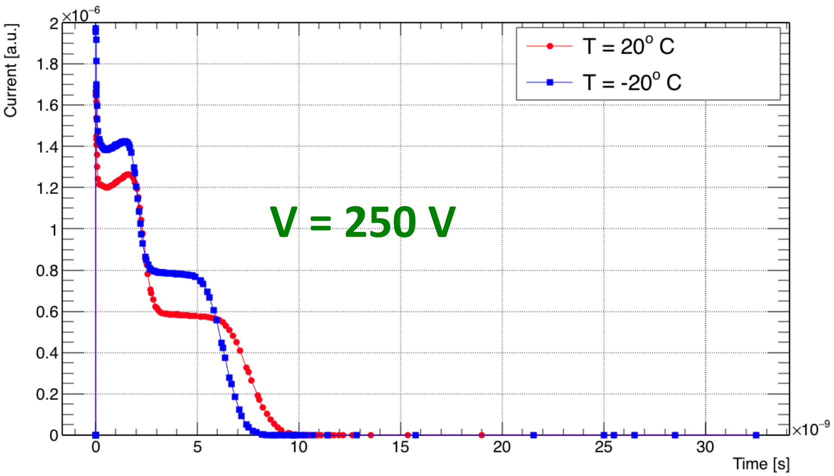


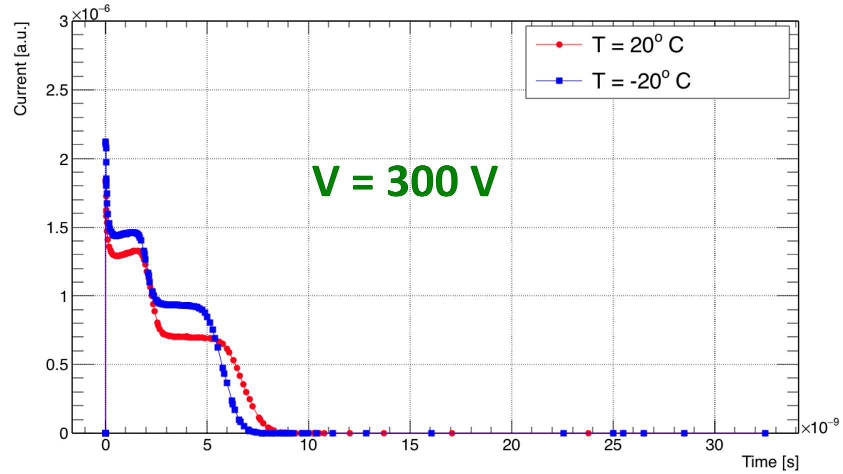
Conclusions & outlook

- Signal properties in LGAD have been studied
  - Both alpha from backside and MIPs
- Alpha studies show that the holes are multiplied
  - and are slowly collected (as expected)
- 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 fe will make the difference for timing
- Lower gain after irradiation could be apparent: an impoertant difference could be linked to the electric field strength
- Gain for w = 100 μm goes from 4 to 1.4 from $\Phi=0$ to $\Phi=1x10^{16}$ (500V)
- Next: new doping profiles, more bias voltages, surface damage effects

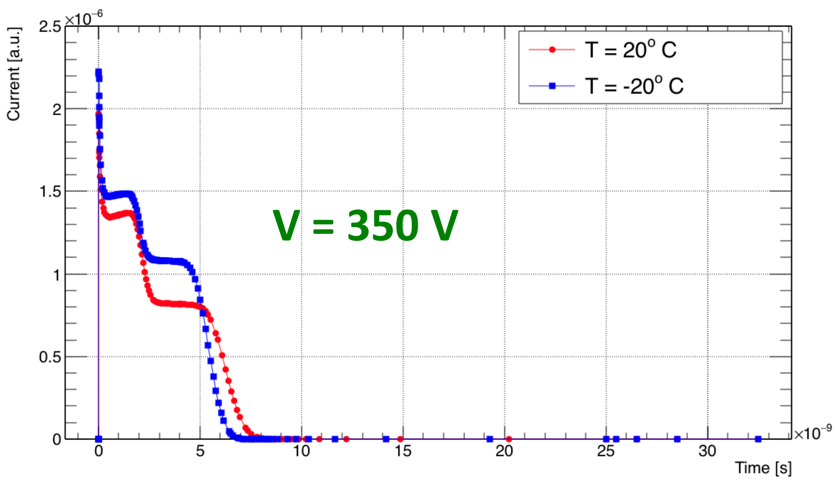
Backup

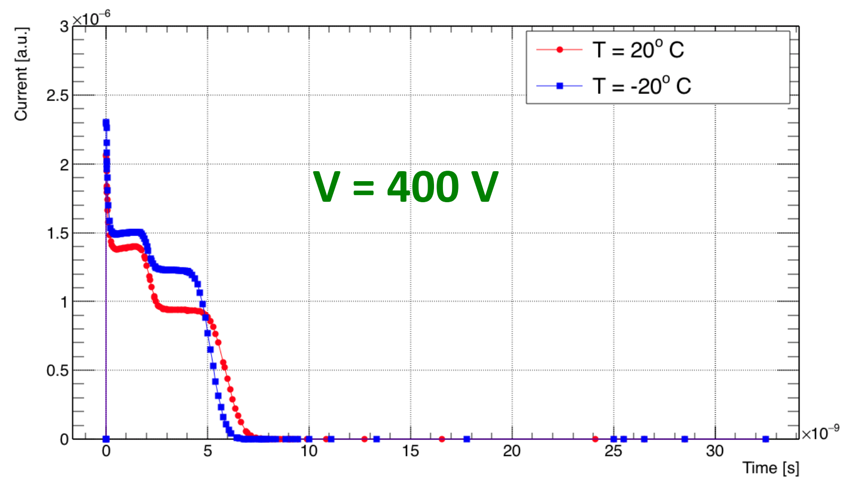
More bias points (I)





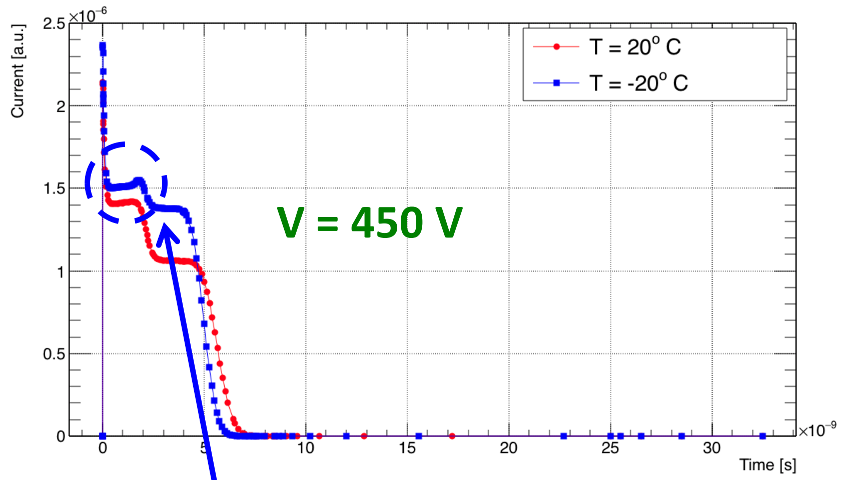
Same horizontal scale for all





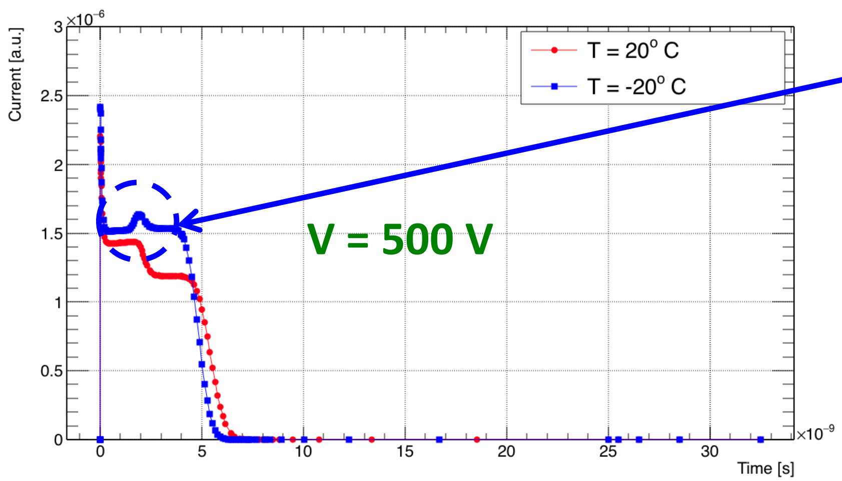
More bias points (II)

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

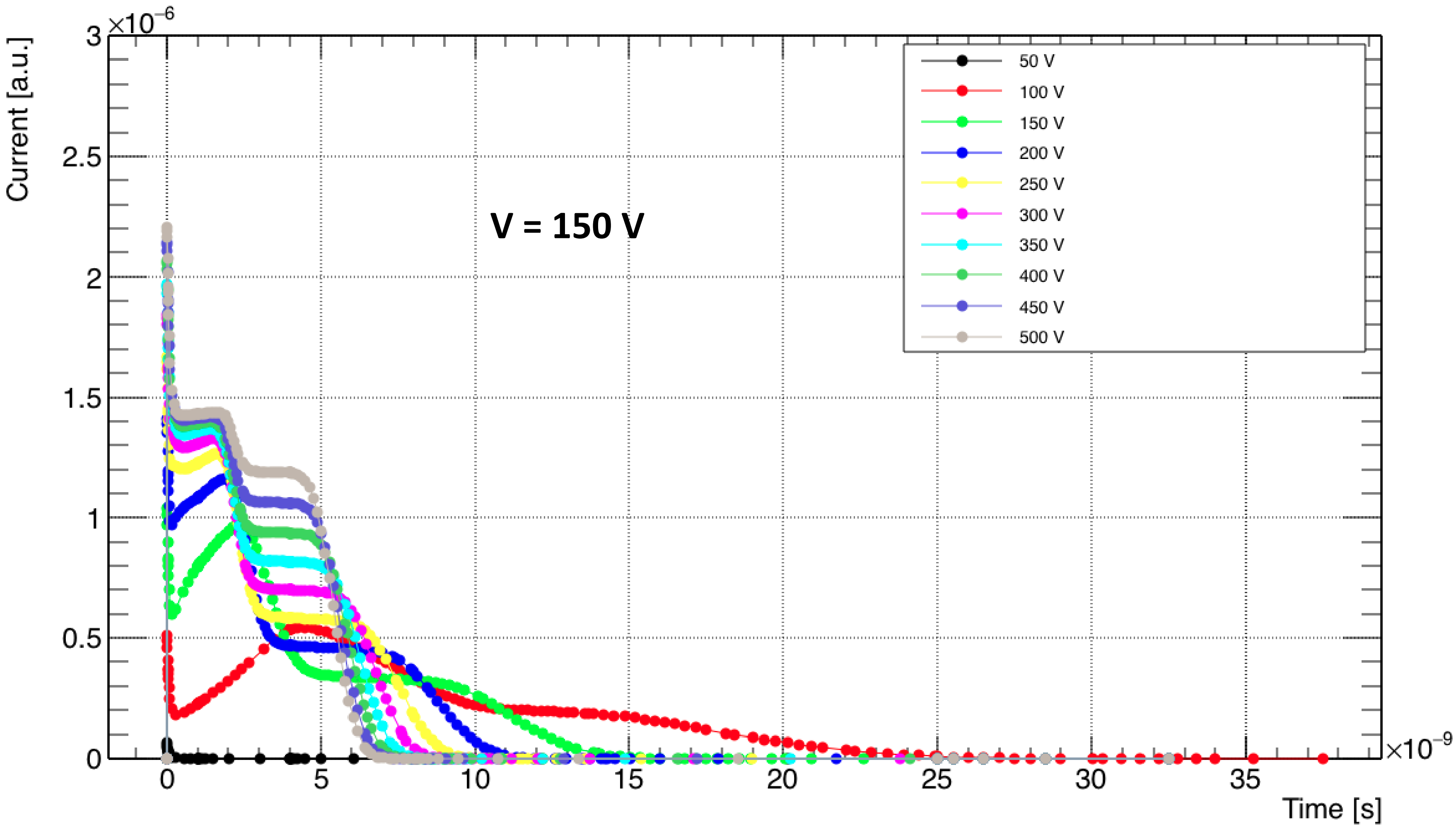


Same horizontal scale for all

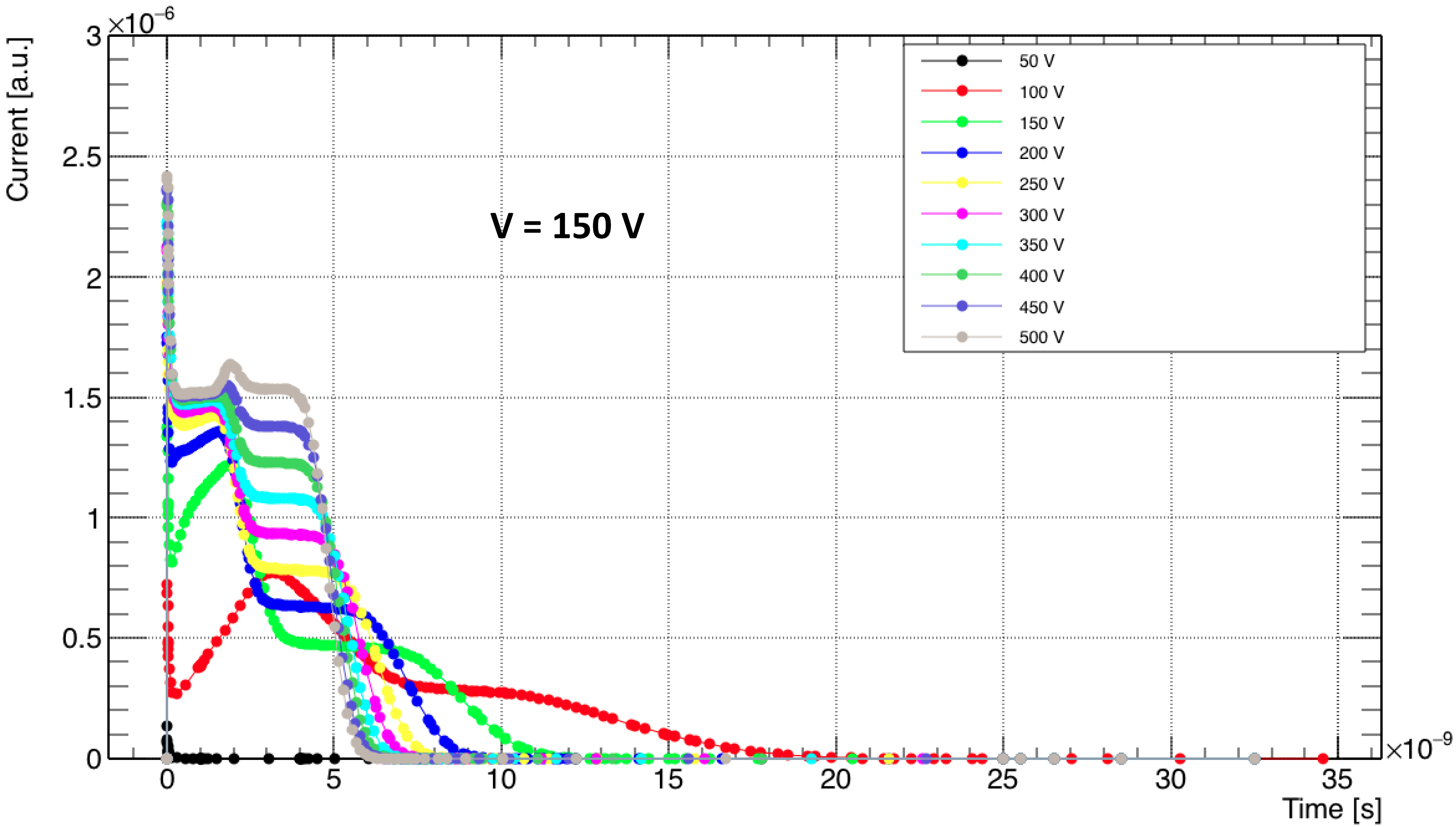
Ridge?



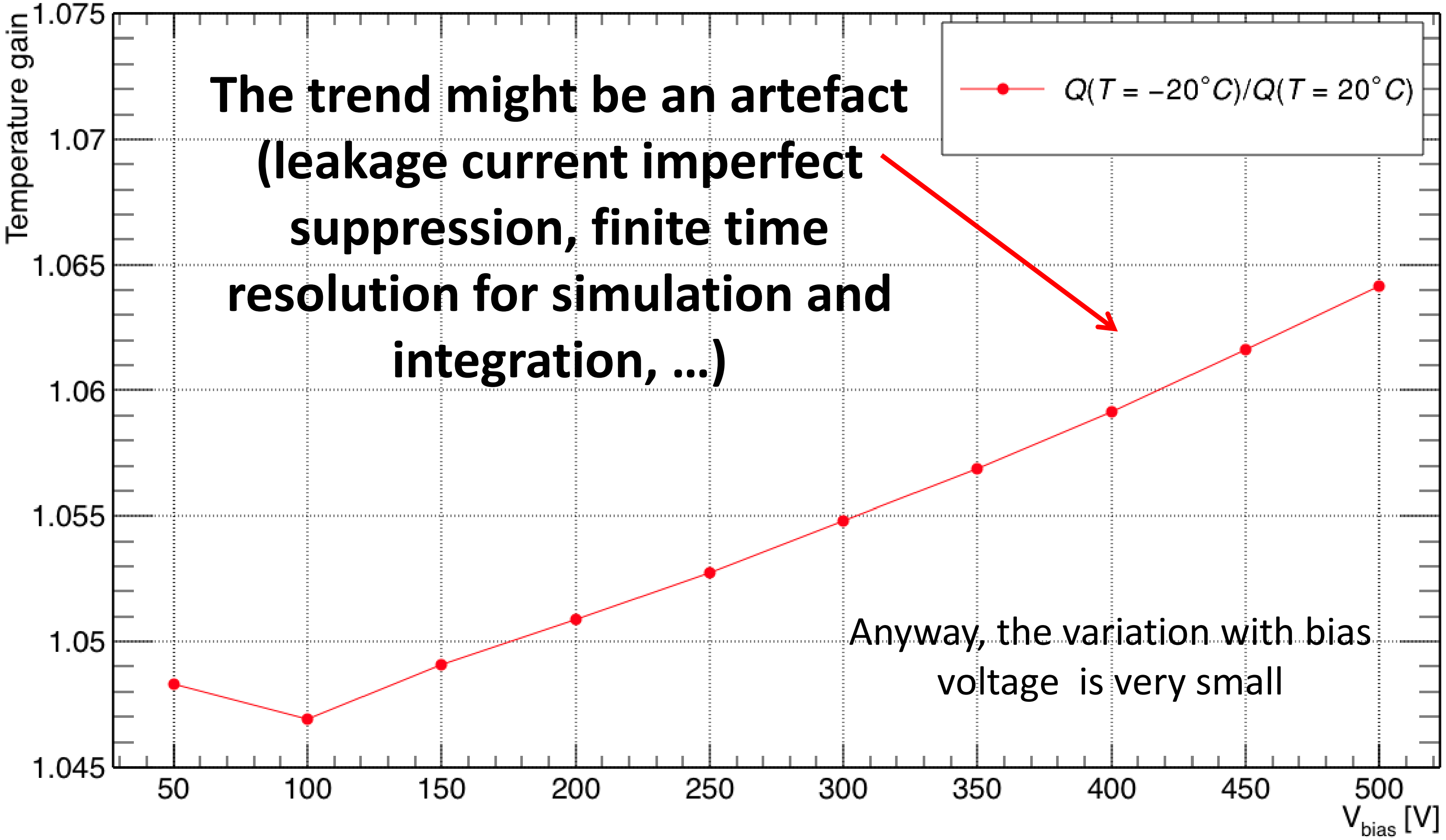
Summary plot for T = 20° C



Summary plot for T = -20° 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

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]

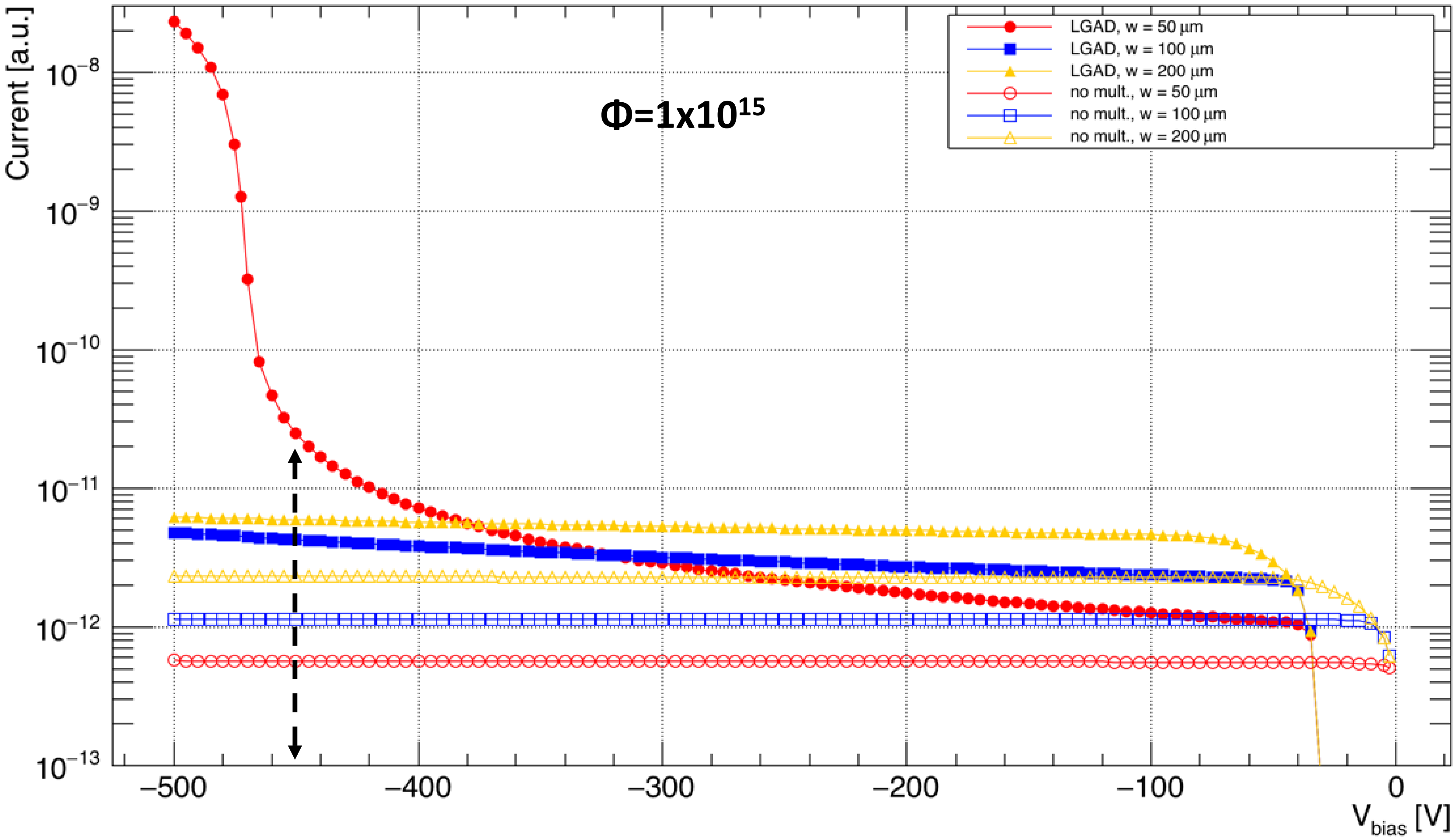
Table 1
Parameters for fluences up to 7×10^{15} n/cm^2.

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

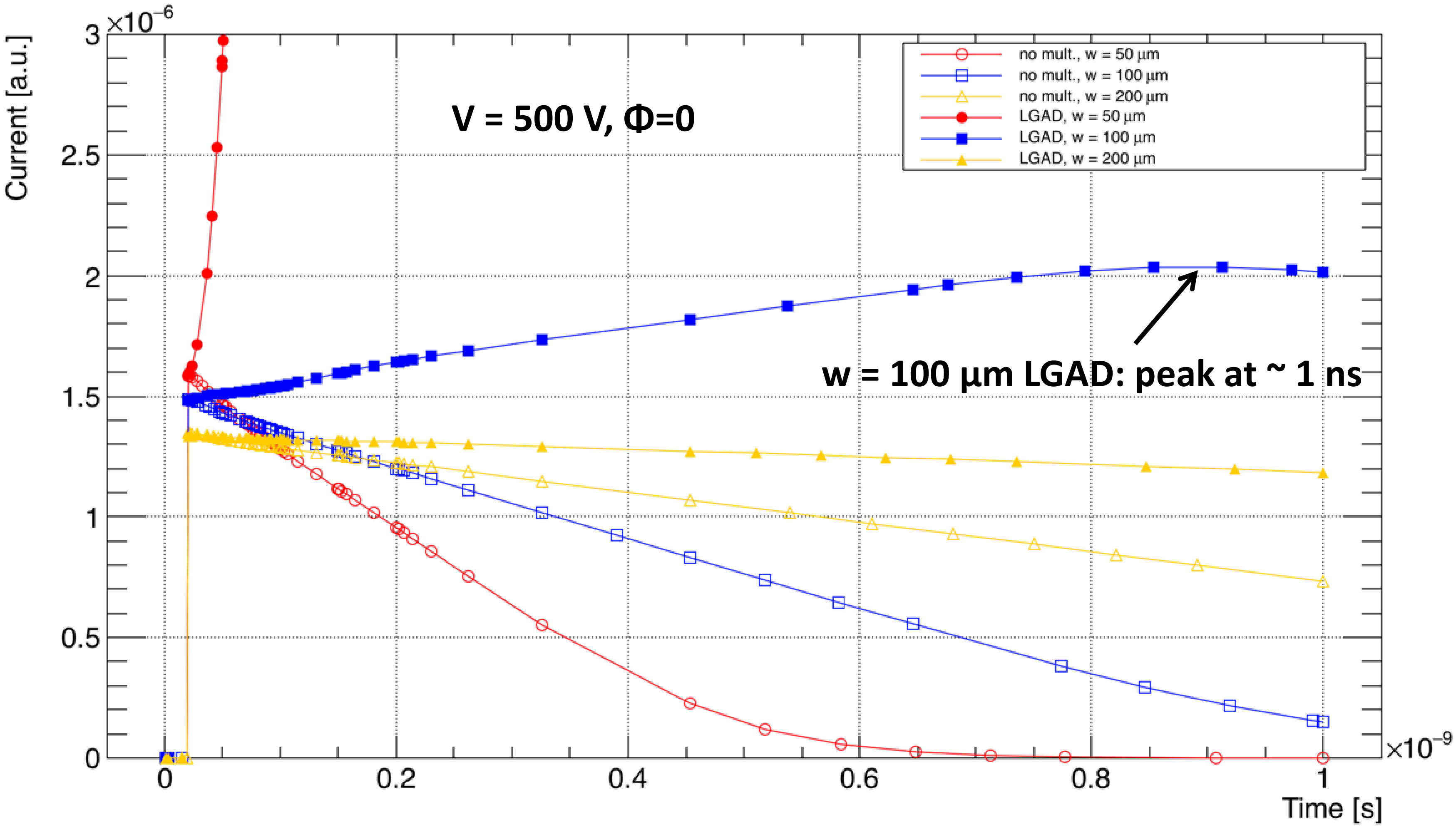
Table 2
Parameters for fluences within 7×10^{15} n/cm^2 and 2.2×10^{16} n/cm^2.

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

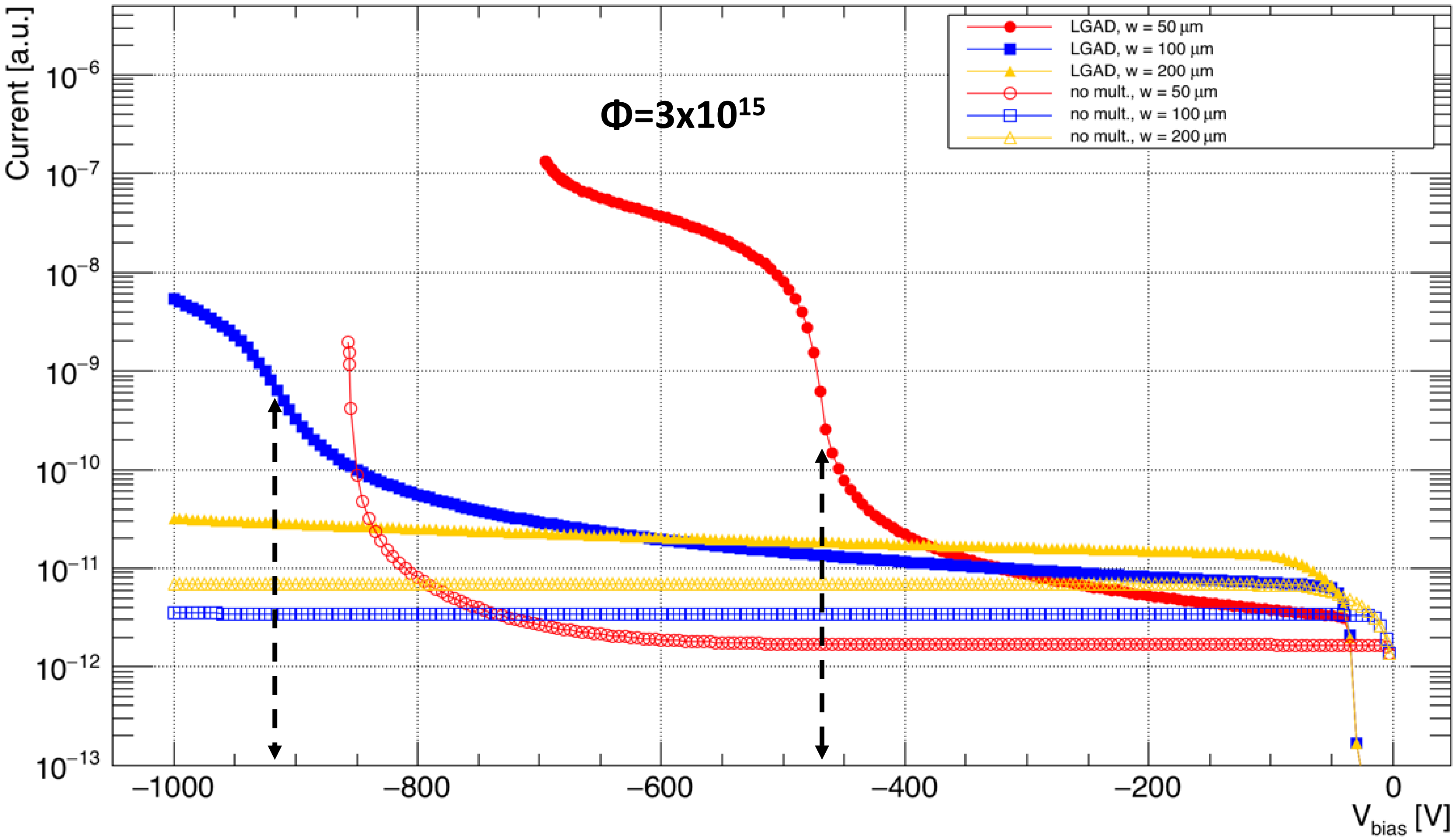
Breakdown in thin irr. LGAD and ref.



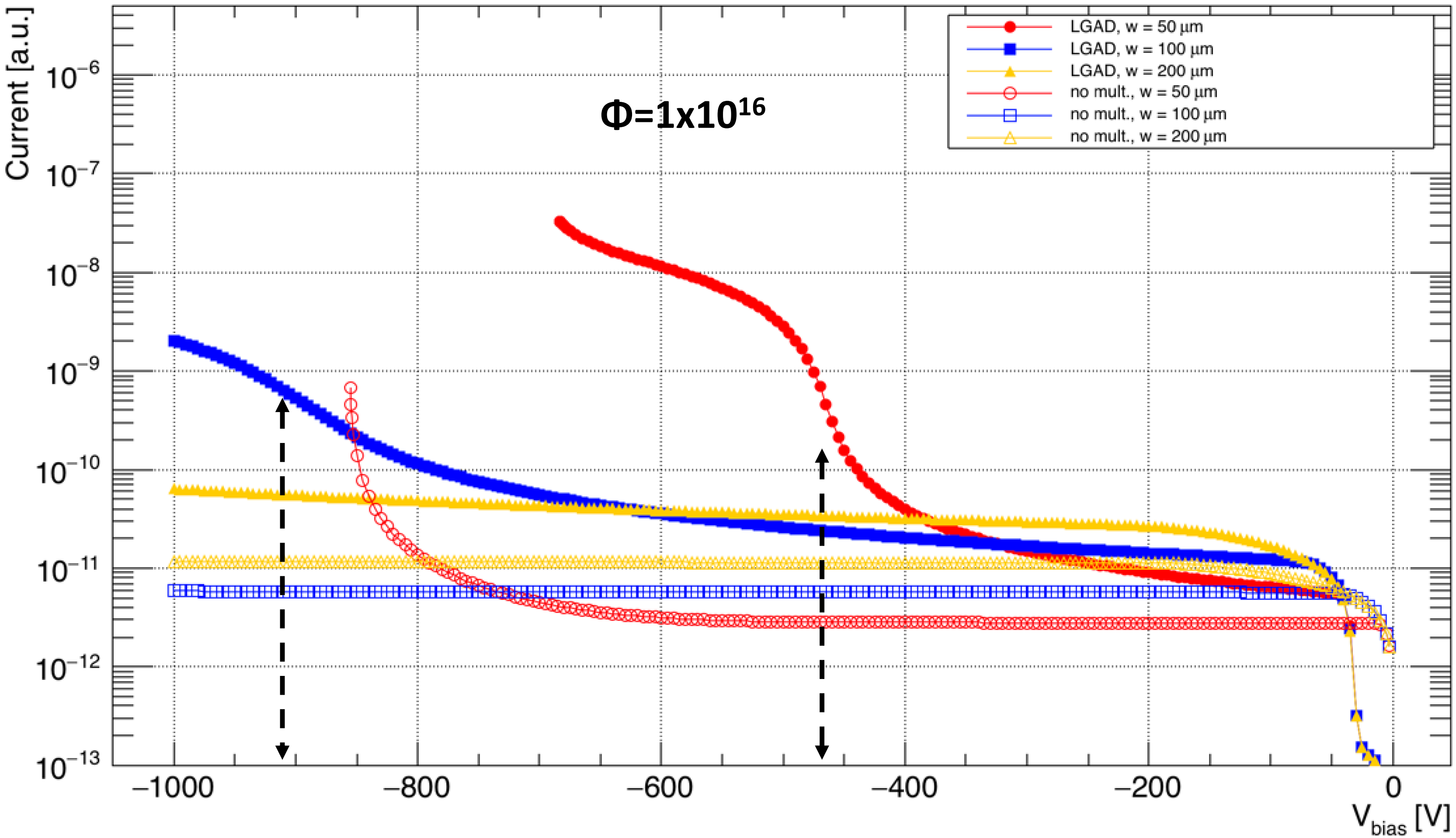
Signal vs time, different thicknesses



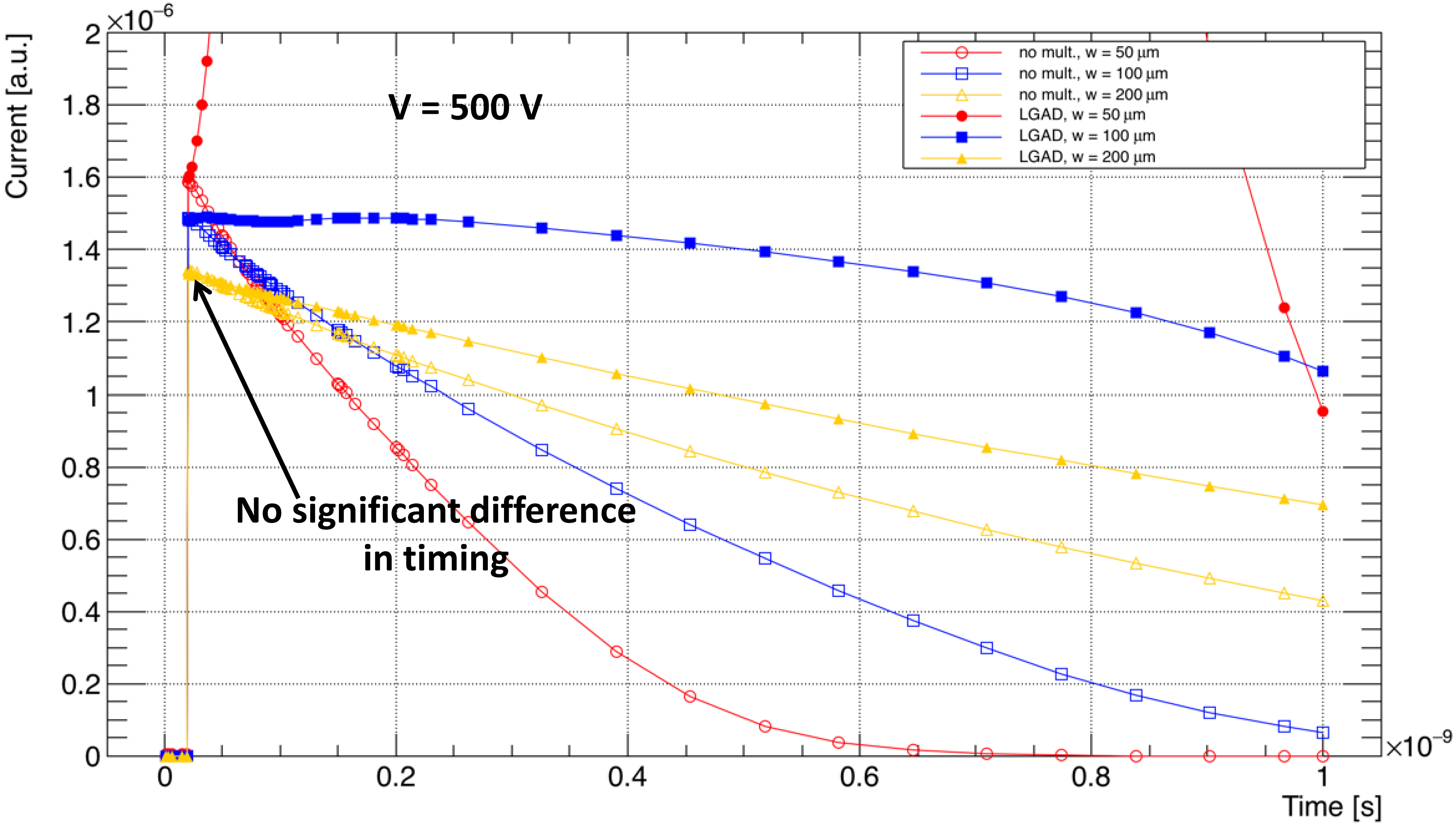
Breakdown in thin irr. LGAD and ref.



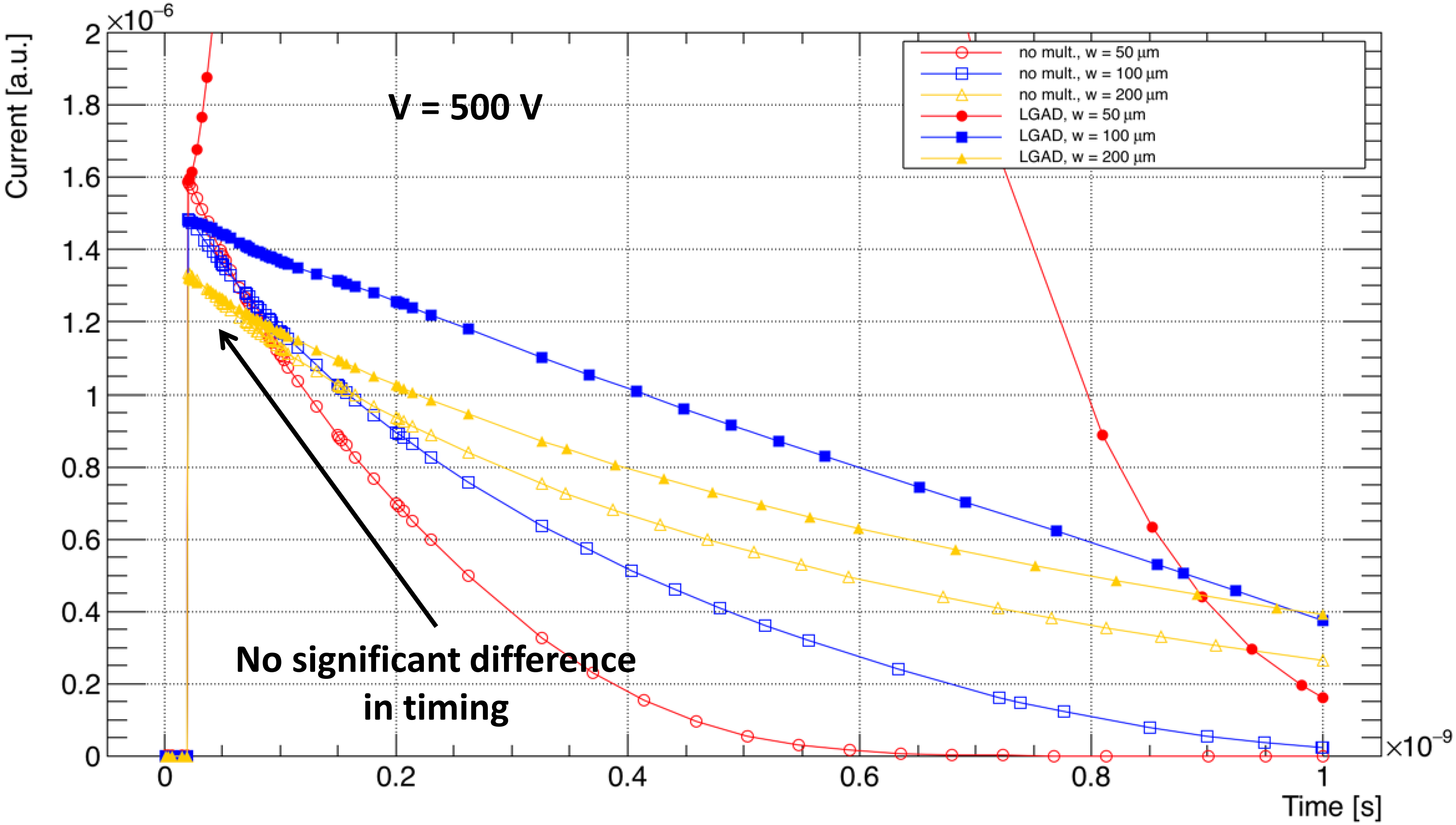
Breakdown in thin irr. LGAD and ref.



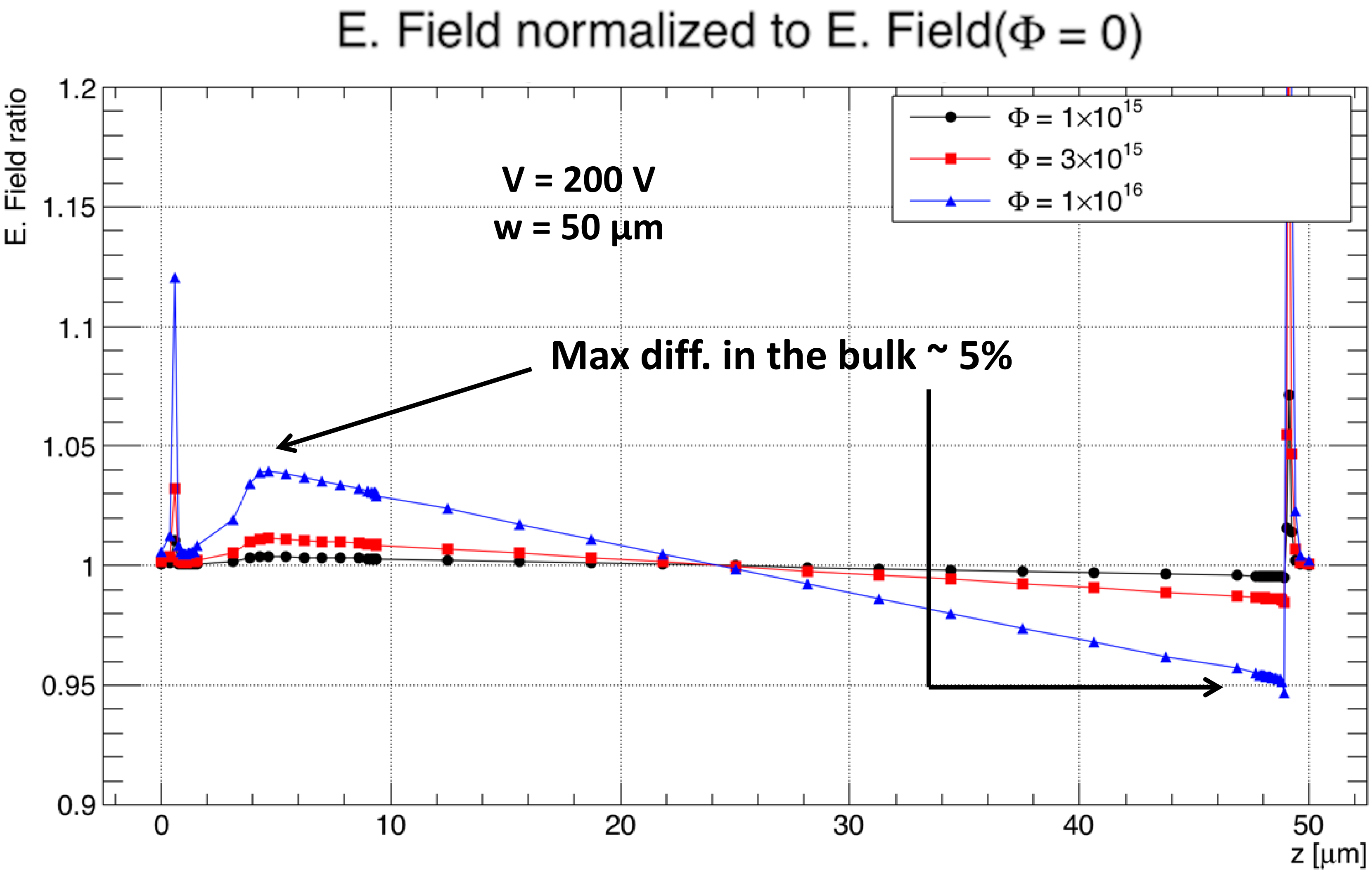
Simulation of irr. samples – $\Phi = 3x10^{15}$



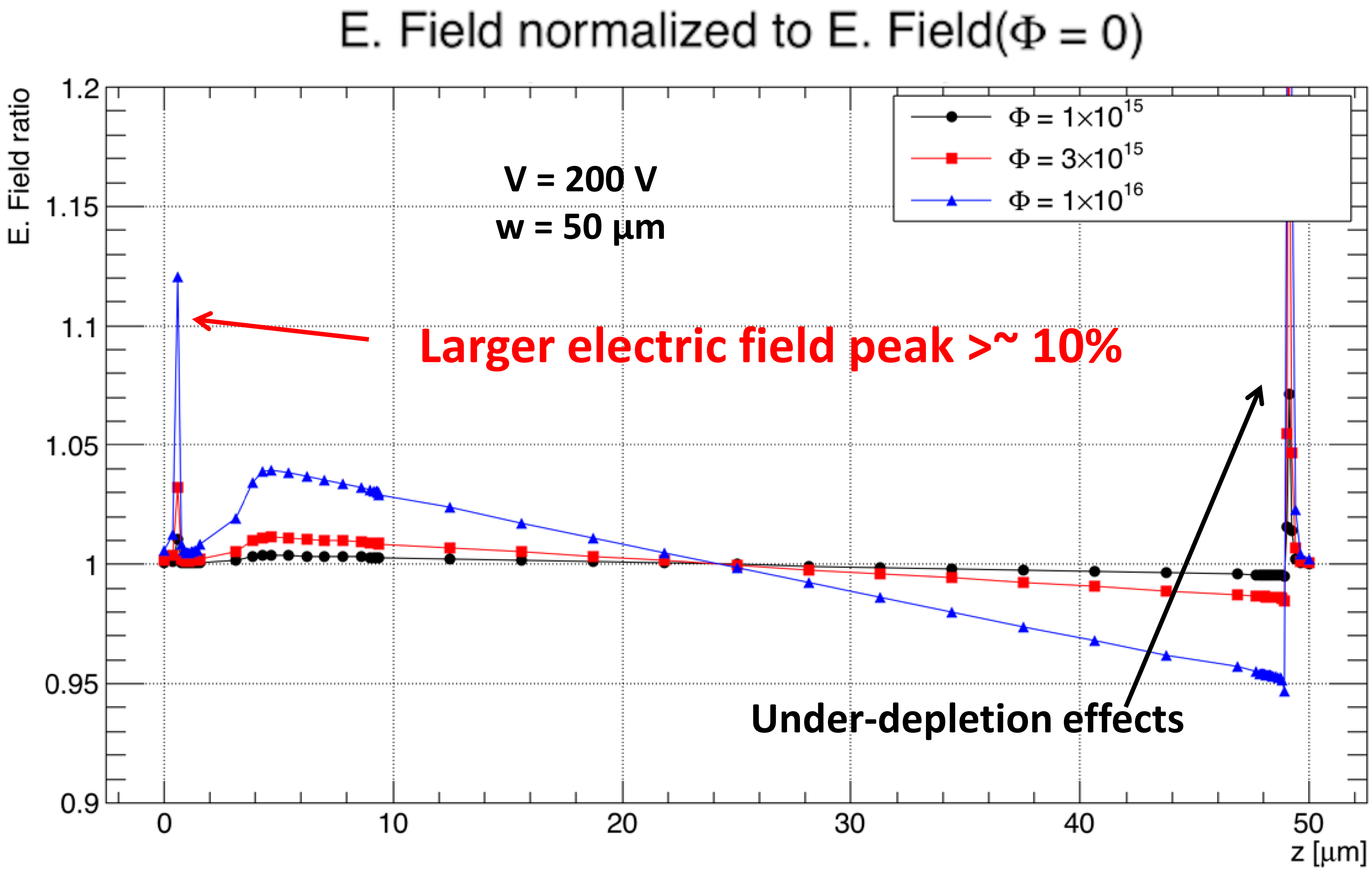
Simulation of irr. samples – $\Phi = 1x10^{16}$



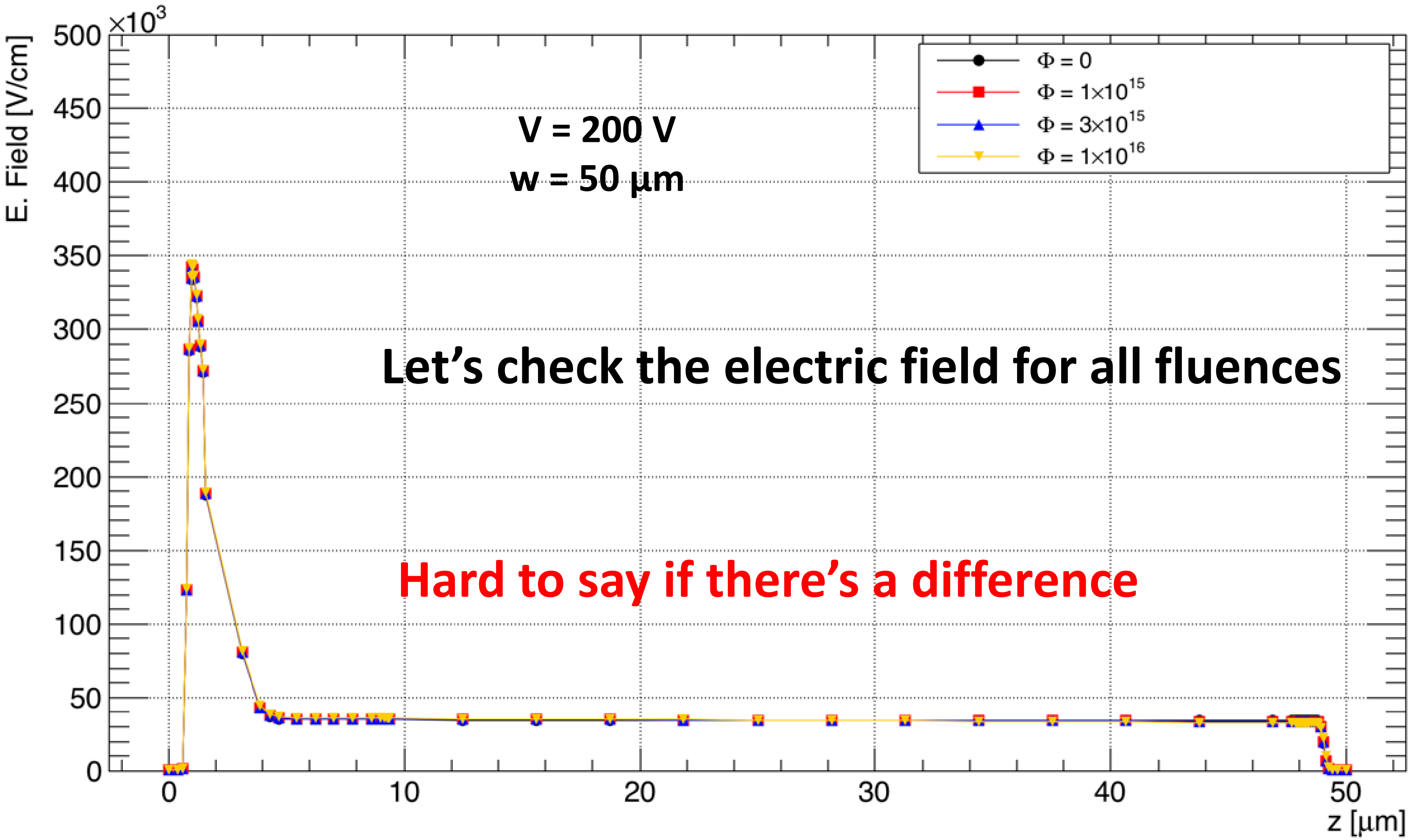
Ratio of electric field – LGAD only



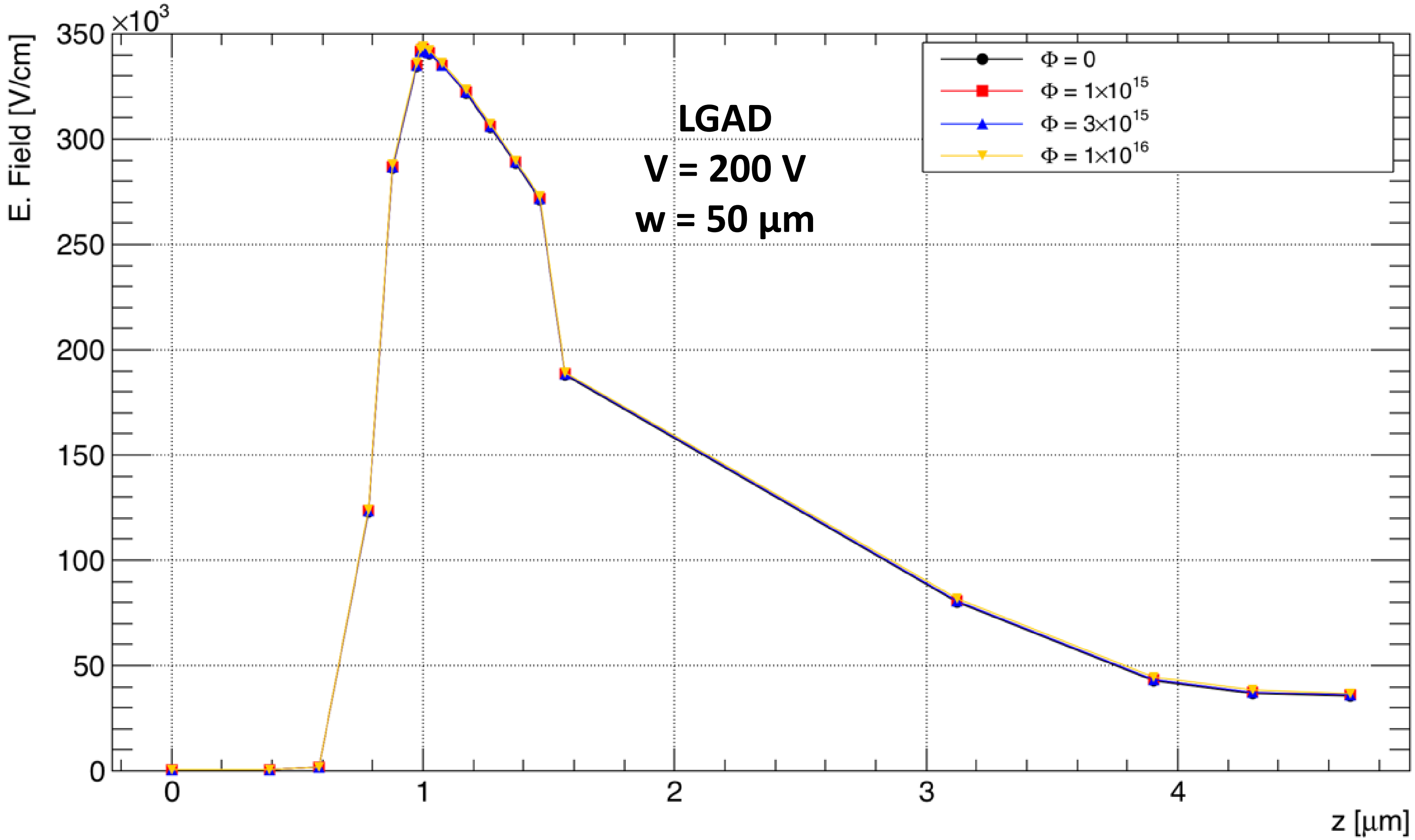
Ratio of electric field – LGAD only



Electric field for all fluences

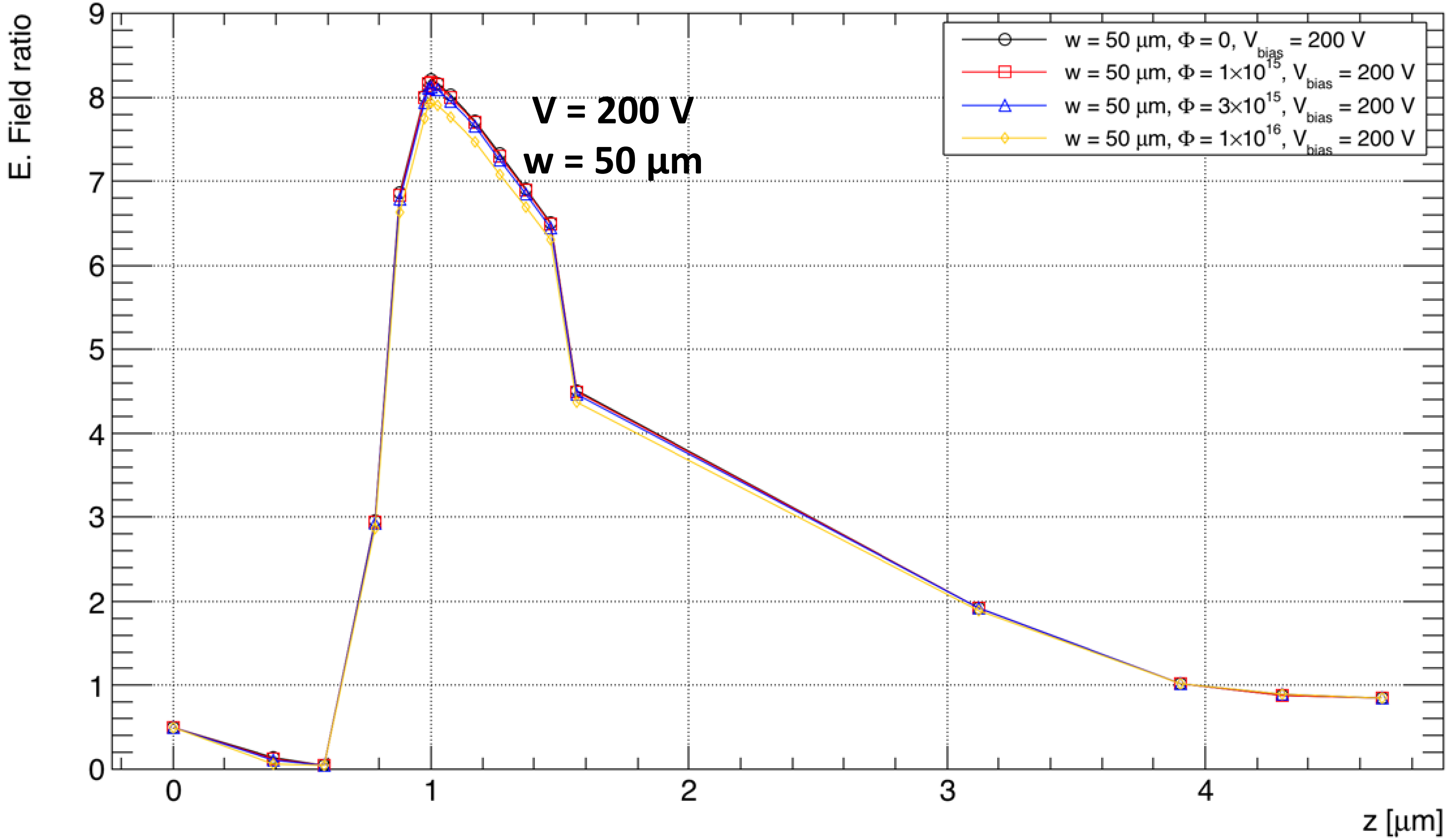


Electric field for all fluences



Electric field ratio

Electric field normalized to the reference detector



Electric field ratio

Electric field normalized to the reference detector