UNIVERSITY OF LIVERPOOL

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Status of Silicon Strip Sensor Measurements at Liverpool

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Overview

- Activation energy (E_g) and current related damage rate (α) determination through IV measurements of irradiated HPK and Micron sensors with fluences up to $2\times10^{16}\ n_{eq}/cm^2$

- TCT and eTCT measurements of RD50 charge multiplication sensors (Micron)

IV Study

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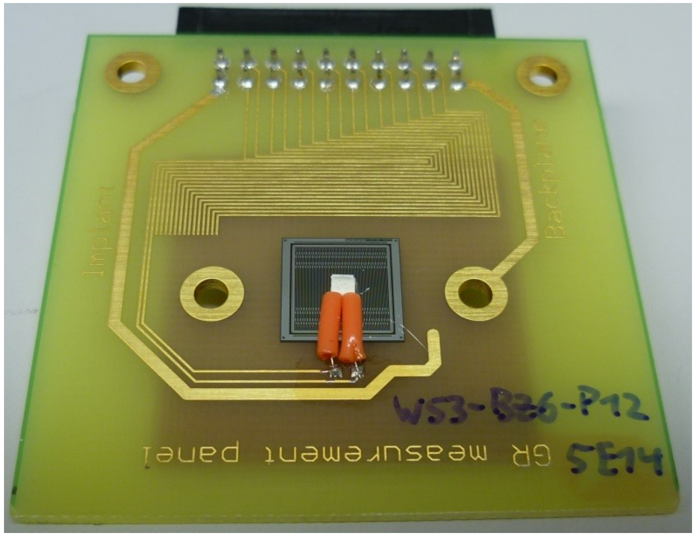
Sensors/Measurements

- Silicon sensors irradiated to different fluences
  - **ATLAS07 MINI**: 1×10^{12}, 5×10^{12}, 1×10^{13}, 5×10^{13}, 1×10^{14}, 5×10^{14}, 1×10^{15}, 5×10^{15}, 1×10^{16}, 1.5×10^{16}, 2×10^{16} $[n_{eq}/cm^2]$
  - **Micron 2437 (143µm)**: 5×10^{15}, 1×10^{16}, 2×10^{16} $[n_{eq}/cm^2]$
  - **Micron 2923 (108µm)**: 5×10^{15}, 1×10^{16}, 2×10^{16} $[n_{eq}/cm^2]$

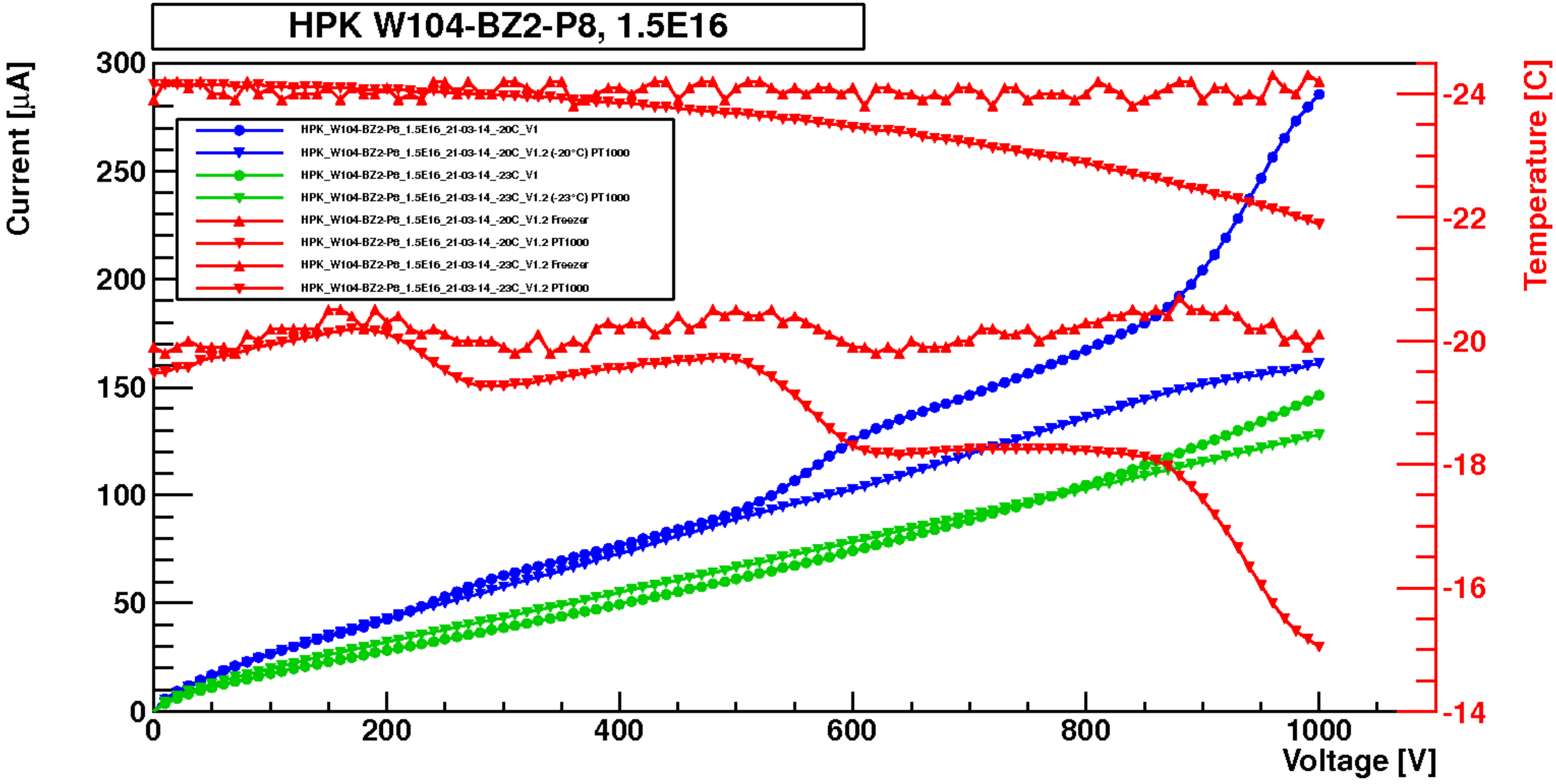
- One set of sensors measured at Liverpool, second set send to Lancaster

- PT1000 temperature sensor glued on silicon
- IV measurements in freezer at different temperatures from -23°C to -15°C (at least 2 per sensor)

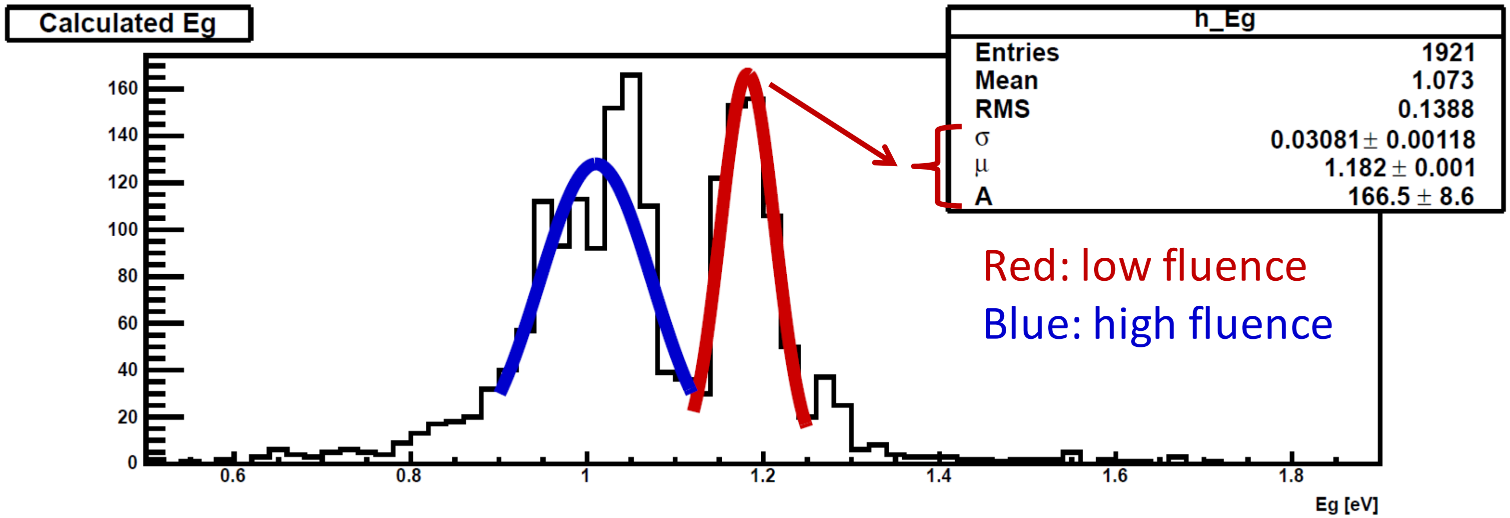


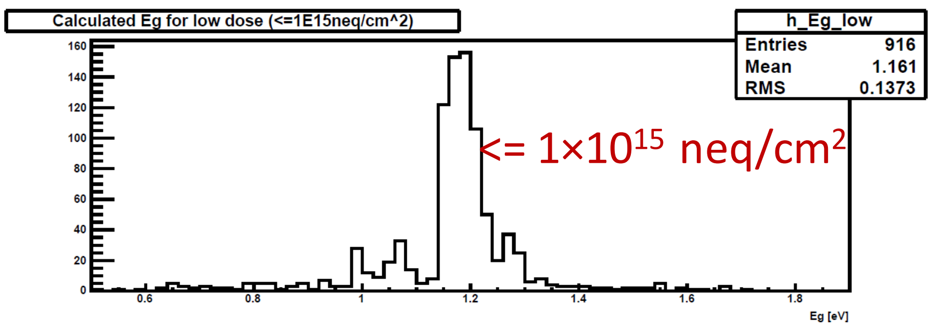
Self-Heating

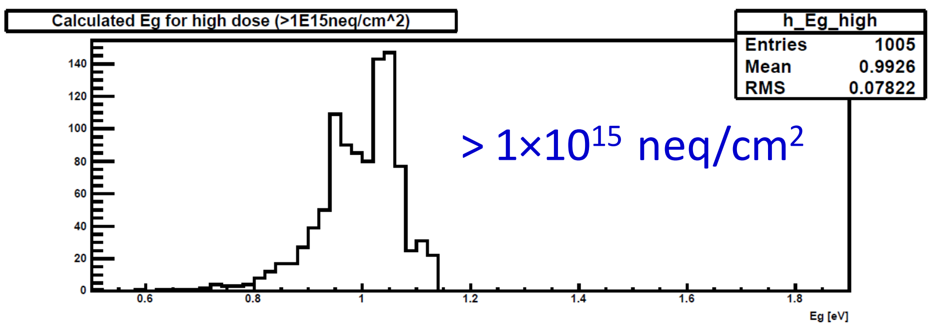
For samples irradiated to more than $1\times10^{15}\ n_{eq}/cm^2$, the temperature increase of the sensor due to high current at higher voltages is clearly visible.



E_g Histogram

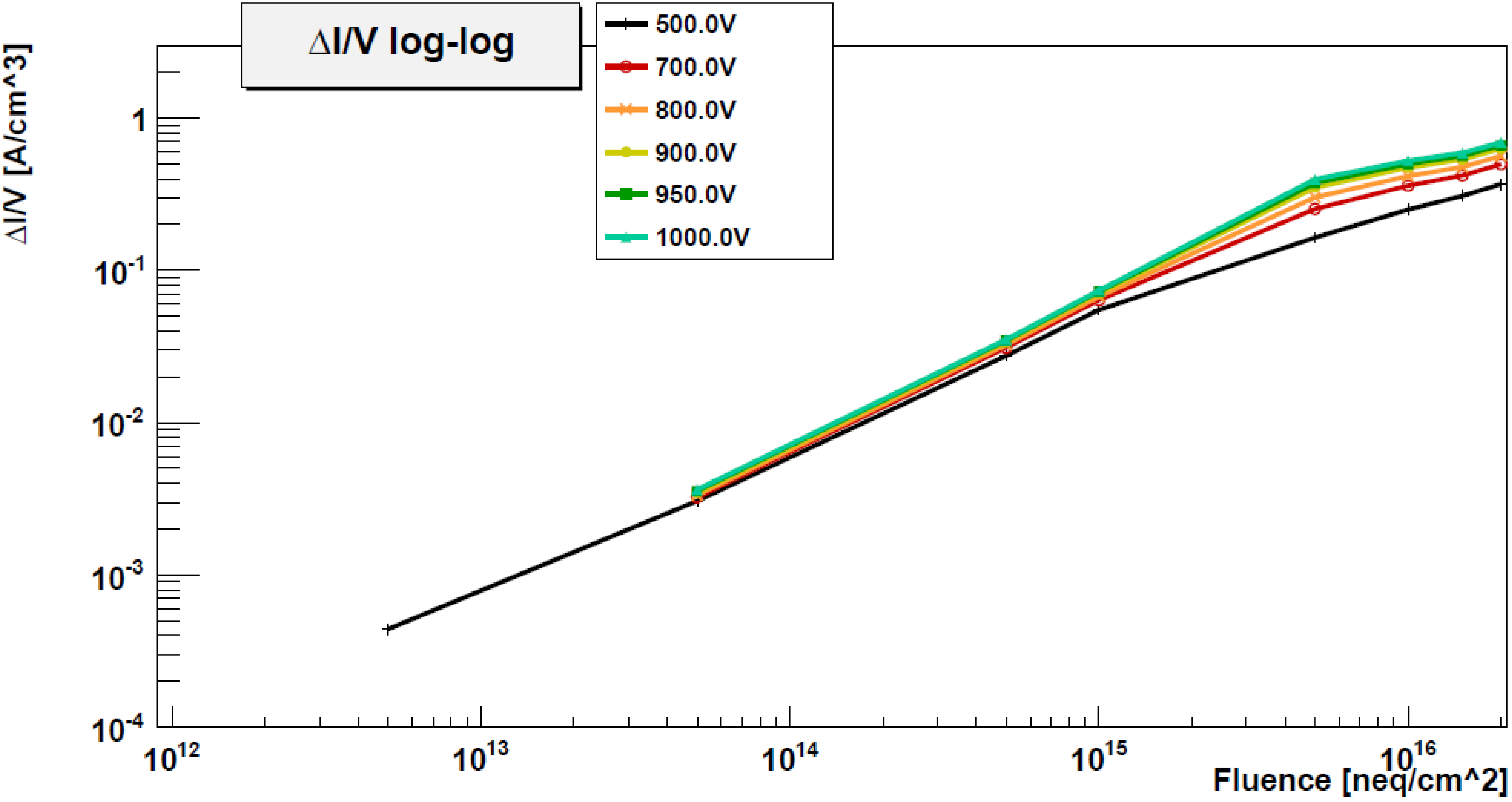






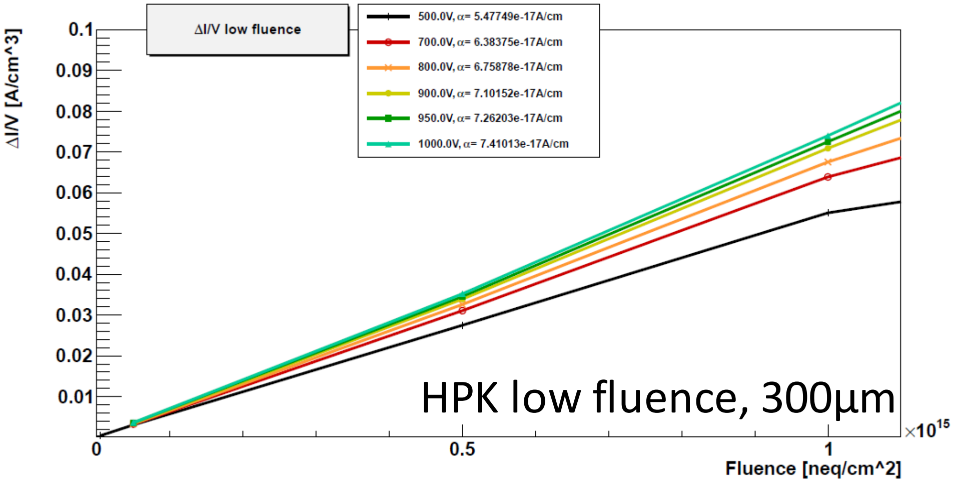
- E_g from Gauss fit for low fluence: **(1.18±0.03)eV** in good agreement with literature value (1.214±0.014)eV
- But: for higher fluences E_g significantly smaller **(1.01±0.06)eV**

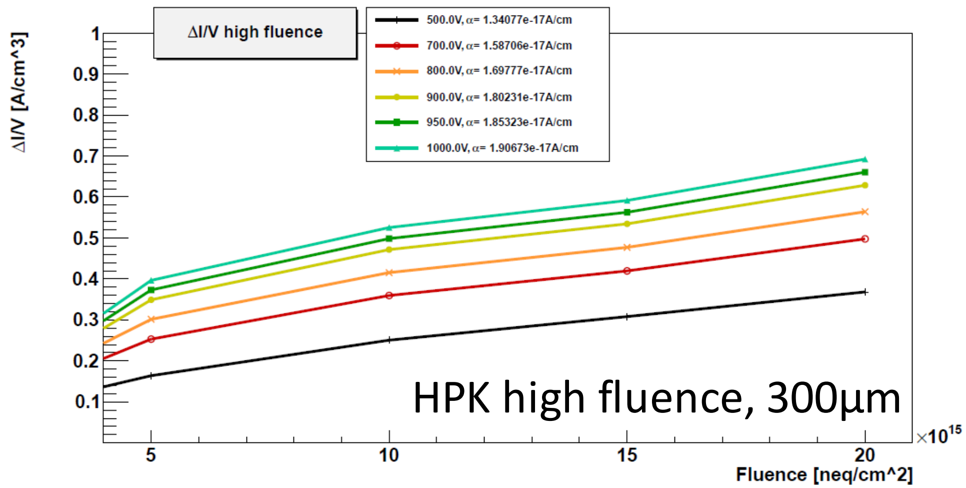
HPK



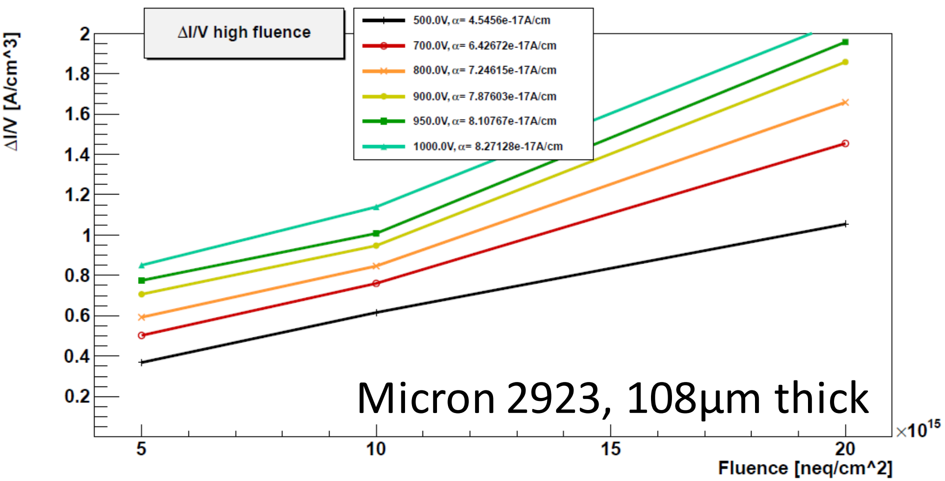
ΔI/V log-log
500.0V
700.0V
800.0V
900.0V
950.0V
1000.0V
ΔI/V [A/cm^3]
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{12}
10^{13}
10^{14}
10^{15}
10^{16}
Fluence [neq/cm^2]

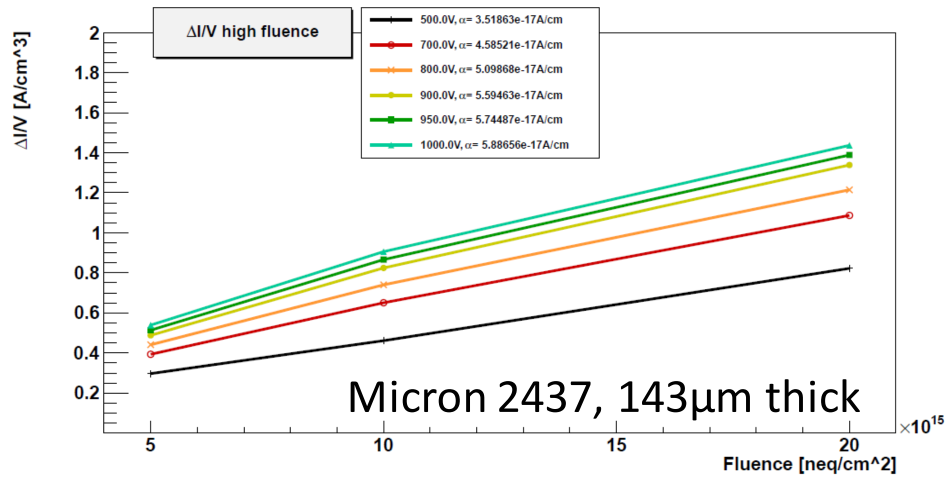
Volume Current (linear)





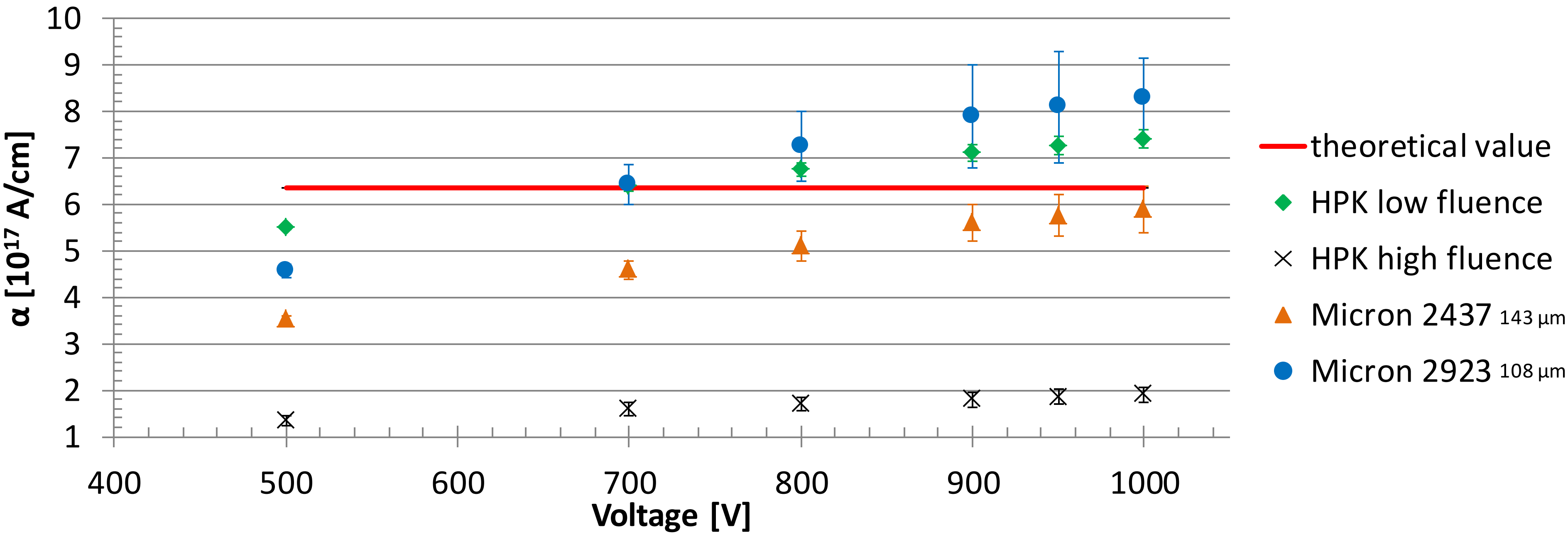
Fit straight line to graphs for α determination





Alpha Values

- Theoretical Value (420min annealing at 21°C): **6.371×10^{-17}A/cm**
- Literature value for E_g for temperature scaling of current
- Used “depleted” area:
  - HPK: $(0.8348\times0.86)cm^2$, 293µm thickness
  - Micron: $(1.0985\times1.0973)\ cm^2$, 143/108 µm thickness (Micron 2437/2923)



Problem: Alpha depends on current and current depends on E_g => which E_g value for alpha calculation?

TCT and eTCT measurements

PRELIMINARY RESULTS

Charge Multiplication Sensors

- Measure dedicated charge multiplication sensors, produced by Micron Semiconductor Ltd (UK)
- 1cm x 1cm, n-in-p FZ strip detectors
- Various strip pitch (P) and width (W)
- Irradiated to two different fluences
  - 1×10^{15} n_{eq}/cm^2
  - 5×10^{15} n_{eq}/cm^2

More details on sensors see:

- U. Parzefall; *A Long Term Study of Charge Multiplication*; 24th RD50 Workshop
- C. Betancout; *Charge Collection Measurements on Dedicated RD50 Charge Multiplication SSDs*; 23rd RD50 Workshop
- S. Wonsak; *Combined Measurement Results of dedicated RD50 Charge Multiplication Sensors*; 22nd RD50 Workshop

TCT & eTCT

Two **T**ransient **C**urrent **T**echnique setups at CERN:

- TCT+
  - TCT top/bottom with red (660nm) and IR (1064nm) laser
  - eTCT with IR laser
- eTCT
  - eTCT with IR laser

- Read-out of 5th strip
- Edge scans from top (strip implants) to bottom (backside) of sensor

For more details see talk:

- C. Gallrapp; *TCT, eTCT and I-DLTS measurement setups at the CERN SSD Lab*; 24th RD50 Workshop

Sensor List

- First set of sensors measured with TCT+ and eTCT setup at CERN
  - No initial annealing
  - Liv-2488-7-1-15-H: more collected charge in ALiBaVa measurement than other sensors

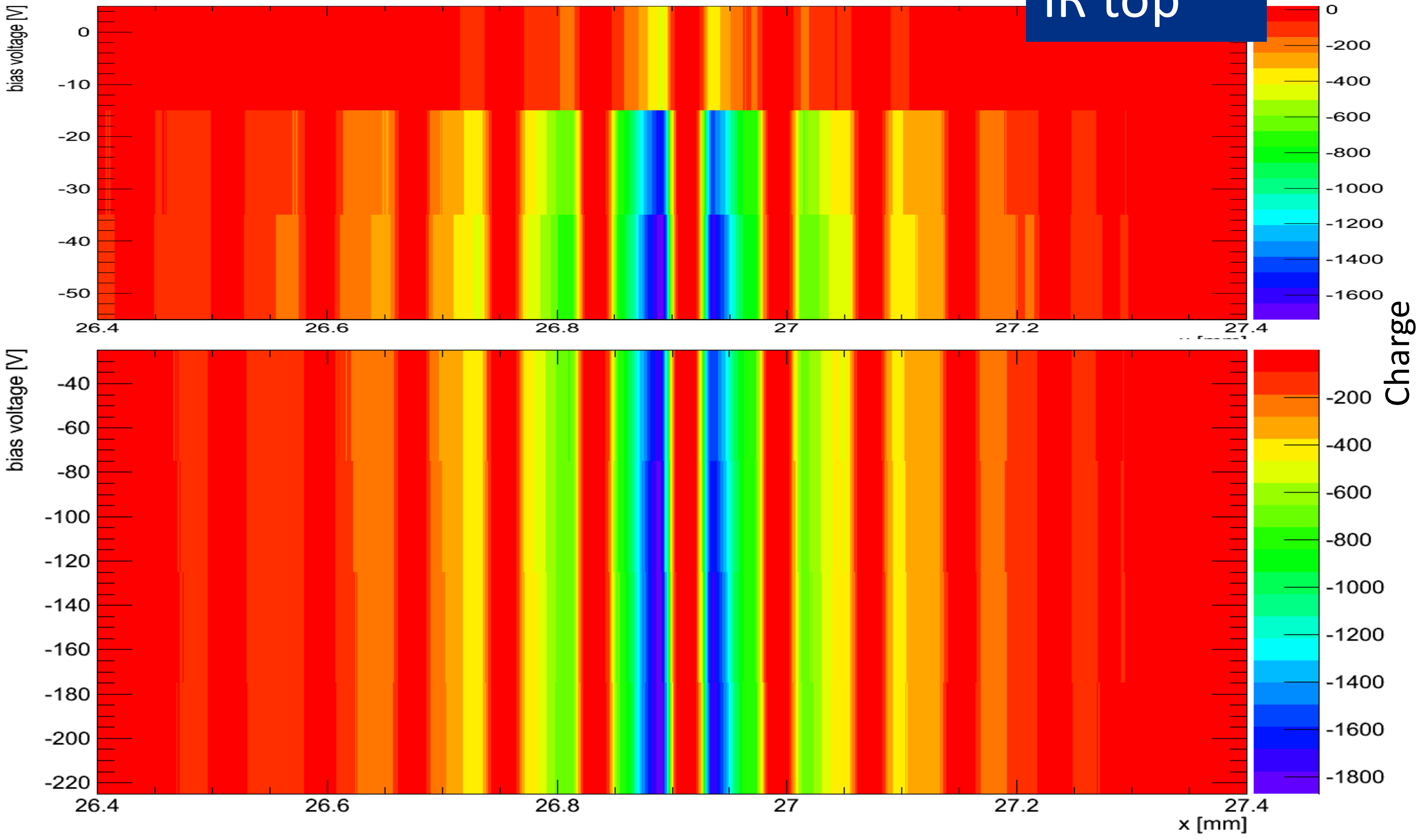
Name	W-P [µm]	Dose [n_{eq}/cm^2]	TCT	eTCT
2328-16-CERN *	P80-W32	-	red, **IR**	TCT+
Liv-2935-7-1-15-L	P80-W6	1.00E+015	IR	**TCT+**
Liv-2935-7-1-15-H	P80-W6	5.00E+015		**eTCT**
Liv-2488-7-1-15-H	P80-W6	5.00E+015	**IR**	**eTCT, TCT+**
Liv-2935-7-3-1-L	P40-W15-I15 **	1.00E+015		**eTCT**

*: sensor for ALiBaVa calibration

**: I15: biased intermediate strip with 15µm width

P80-W32, unirradiated

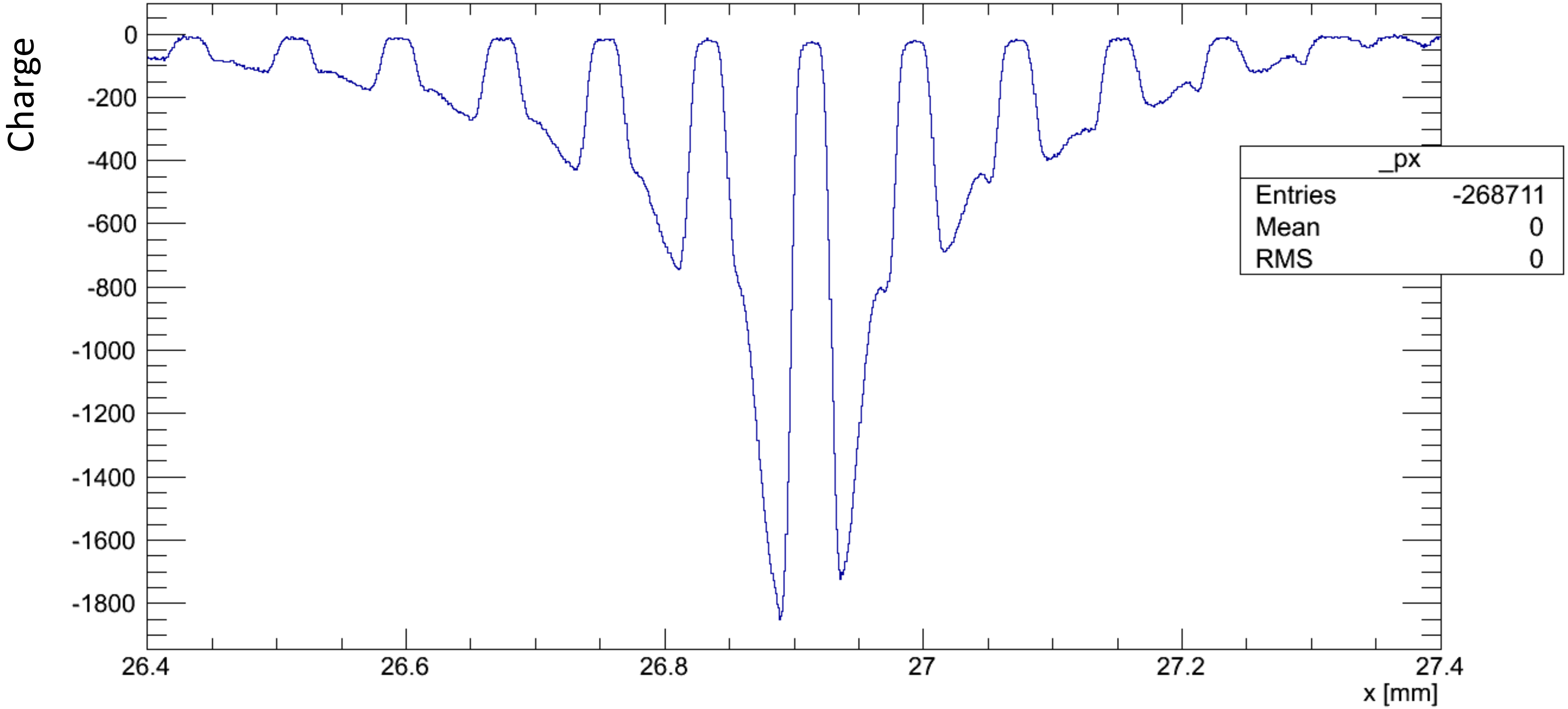
IR top



P80-W32, unirradiated

IR top

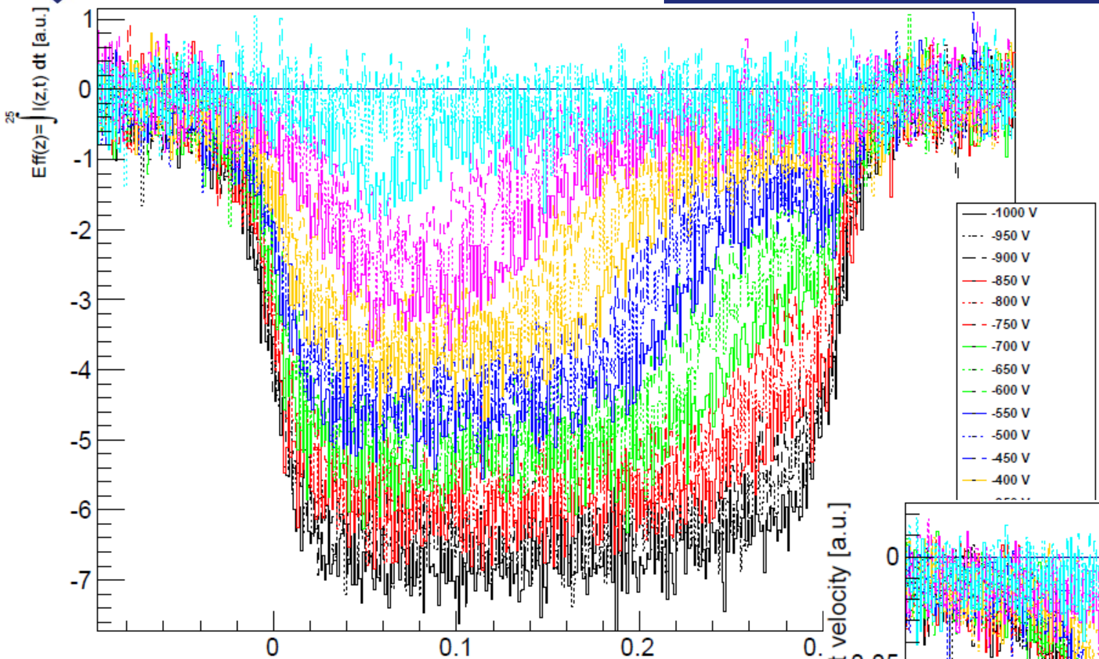
-200V

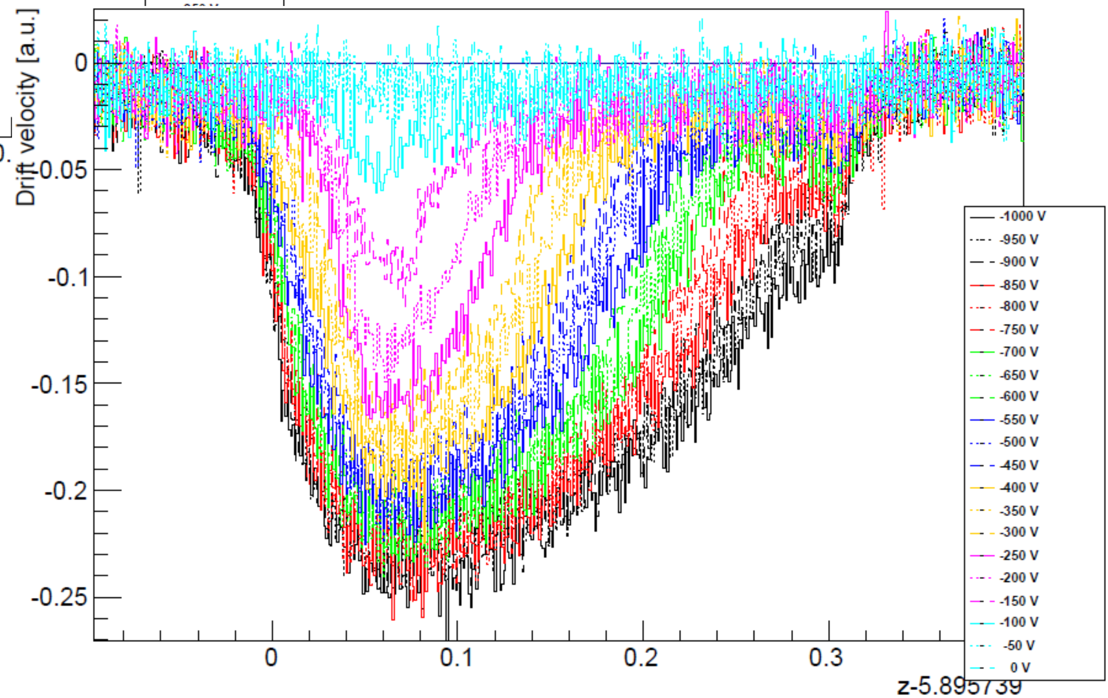


P80-W6, $1\times10^{15}\ n_{eq}/cm^2$

edge

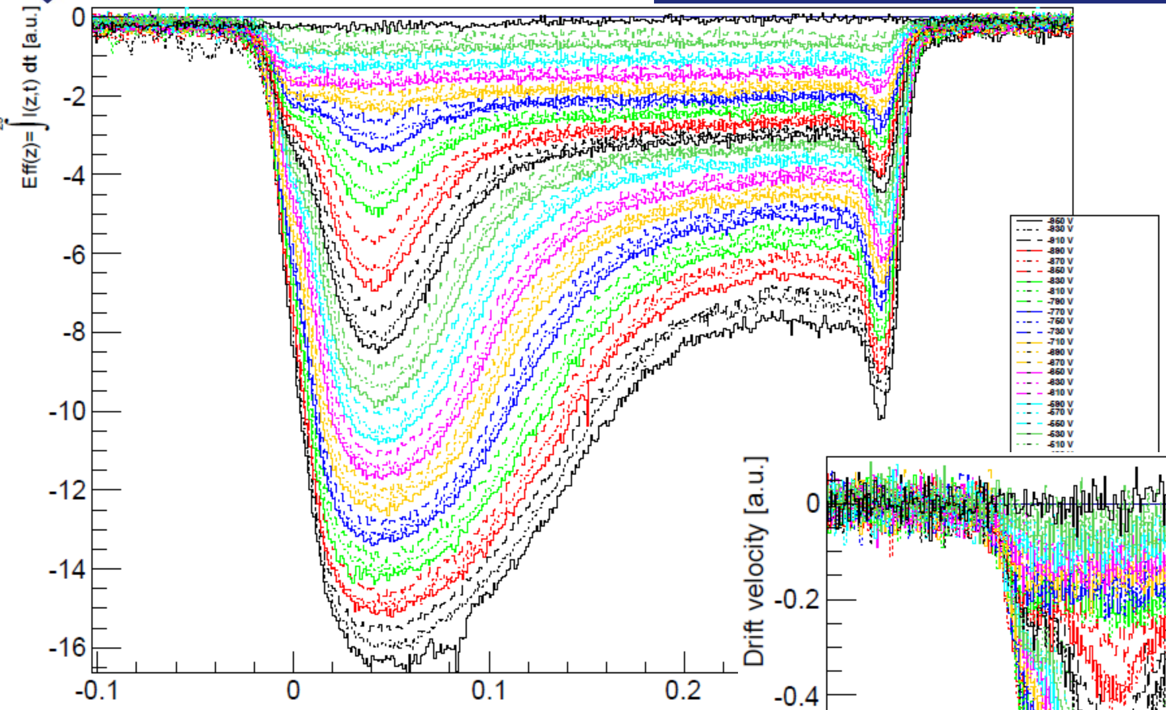
with TCT+

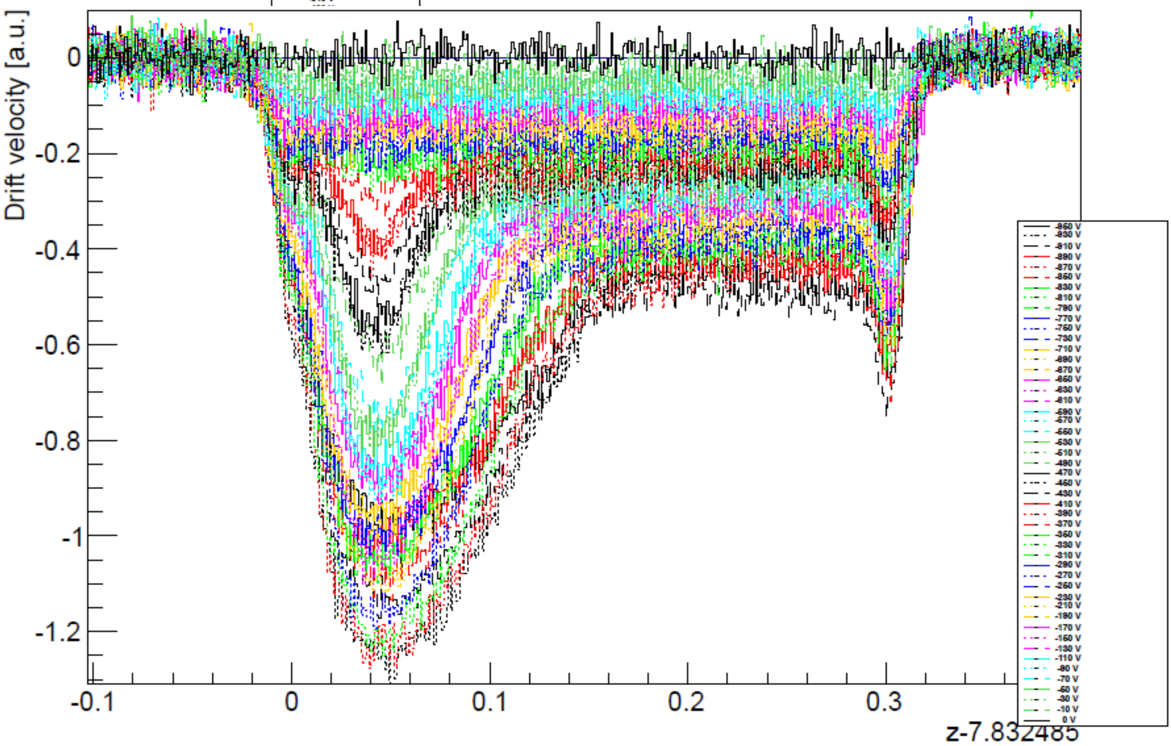




P80-W6, 5×10^{15} n_{eq}/cm^2

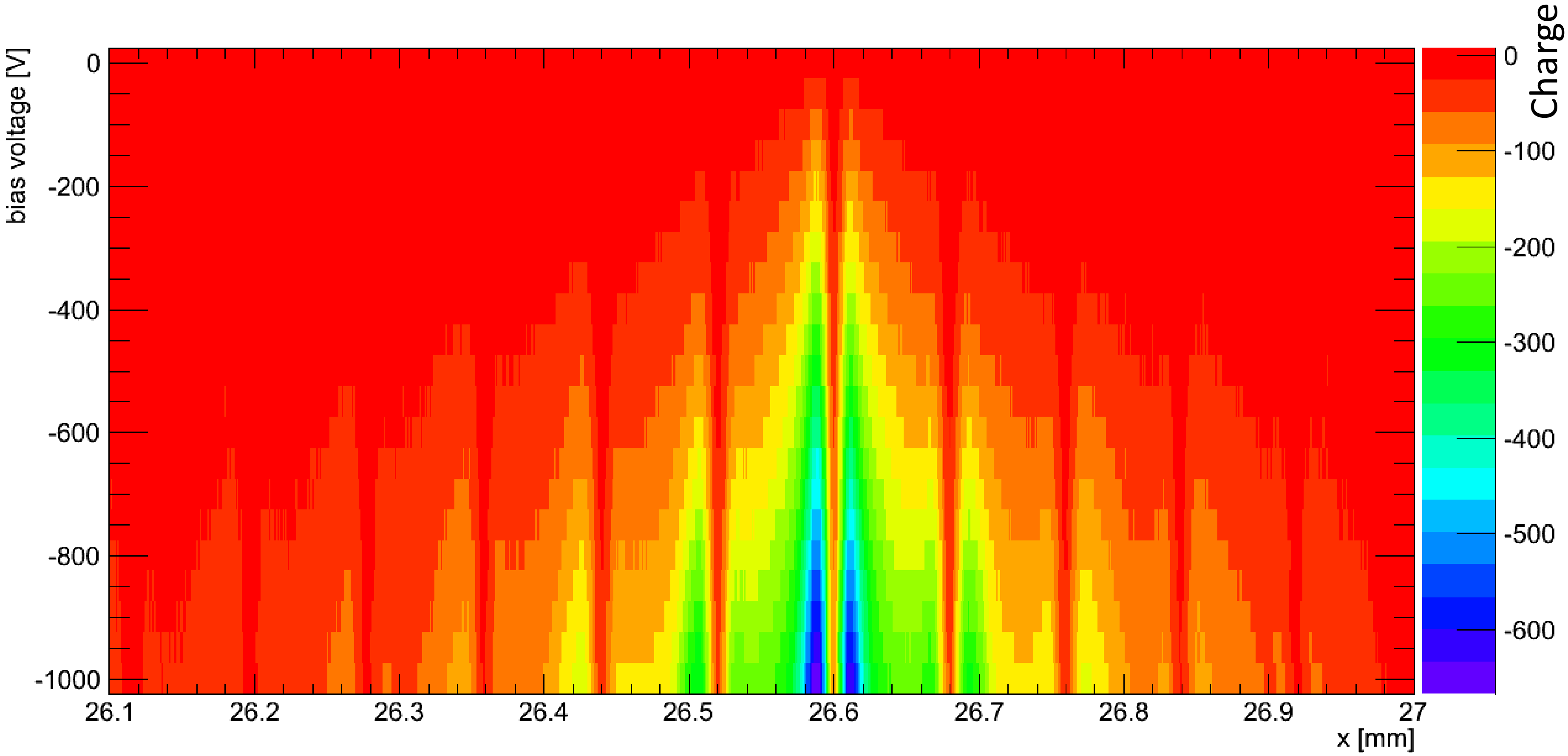
edge





P80-W6, 5×10^{15} n_{eq}/cm^2

IR top

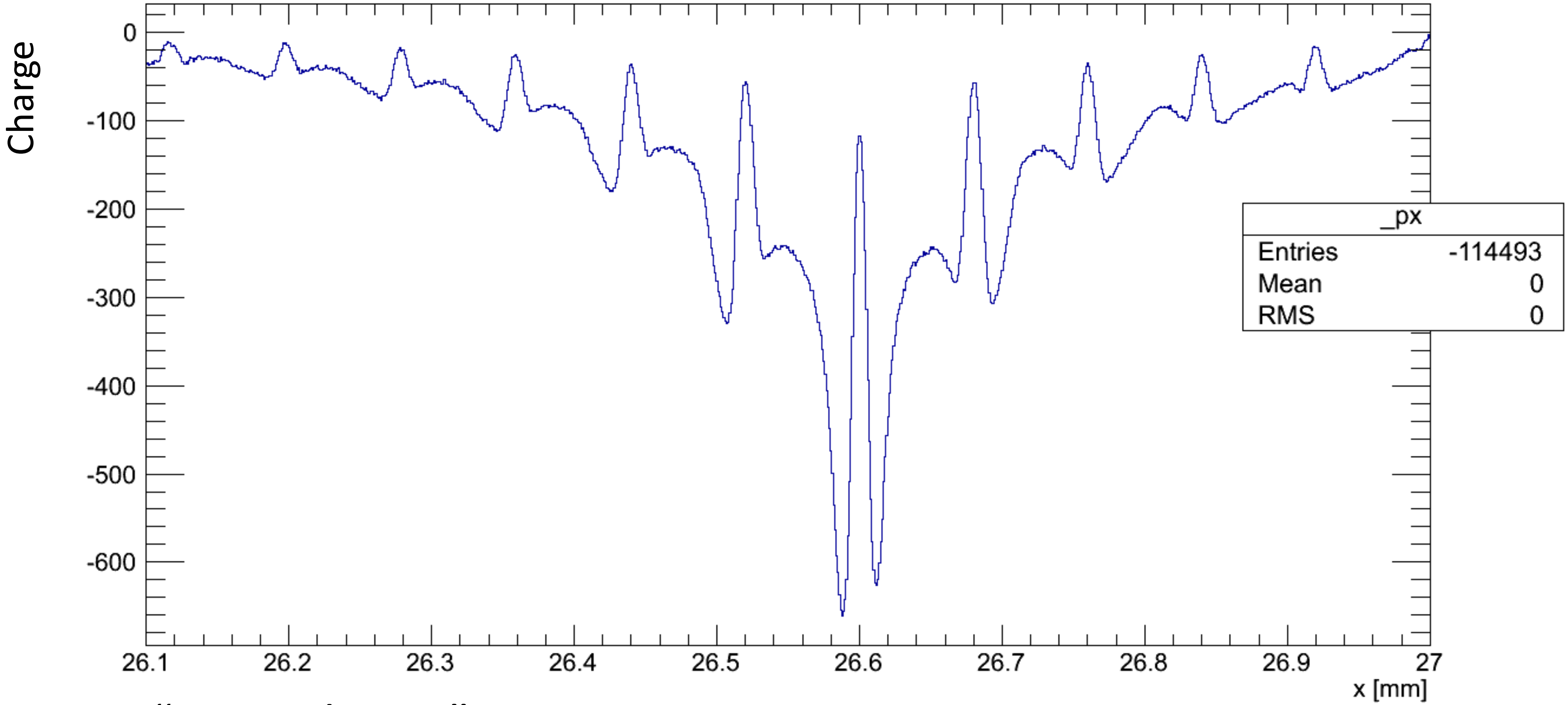


"more charge"

P80-W6, $5\times10^{15}\ n_{eq}/cm^2$

IR top

-1000V

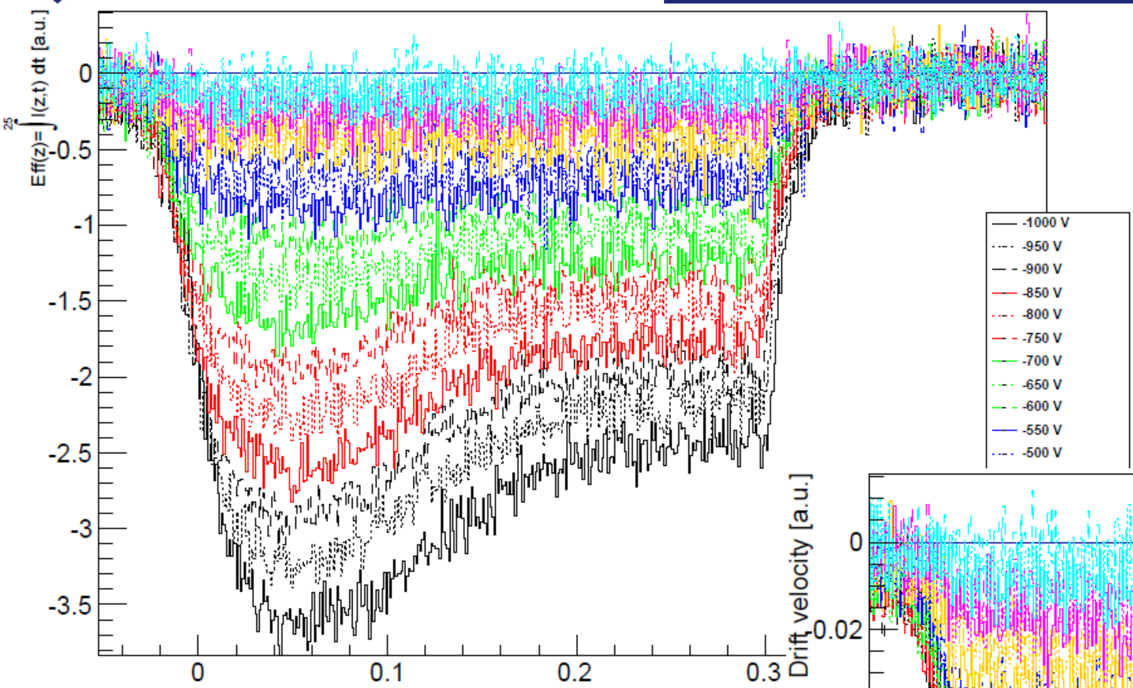


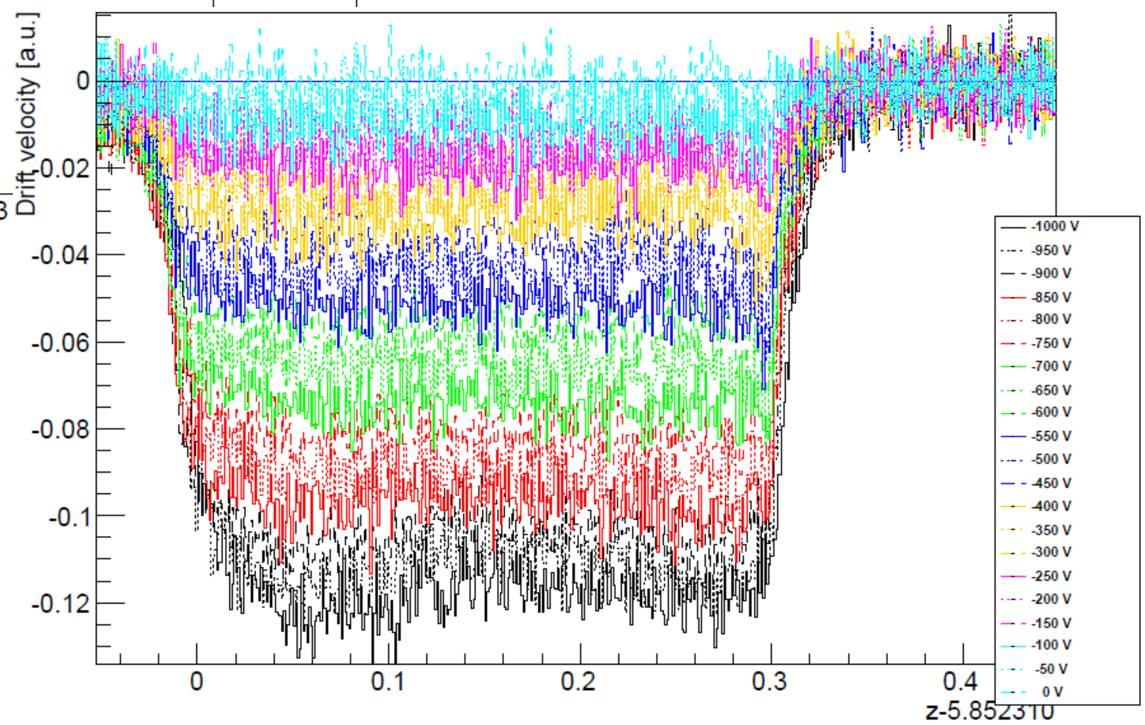
“more charge”

P80-W6, 5×10^{15} n_{eq}/cm^2

edge

with TCT+

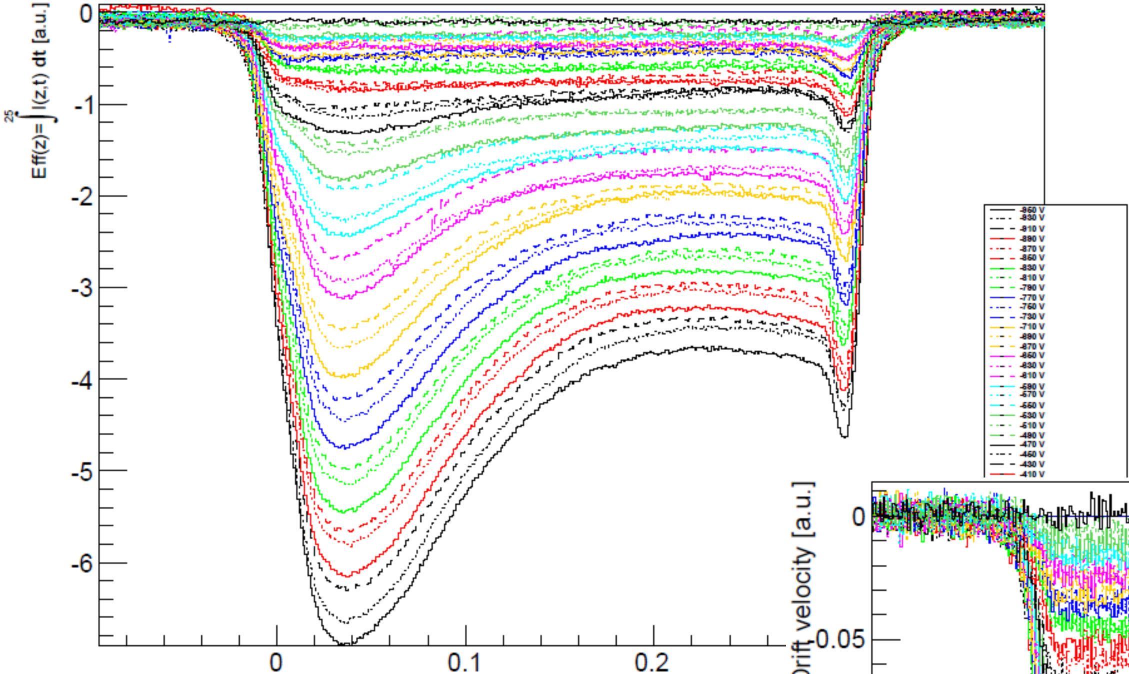


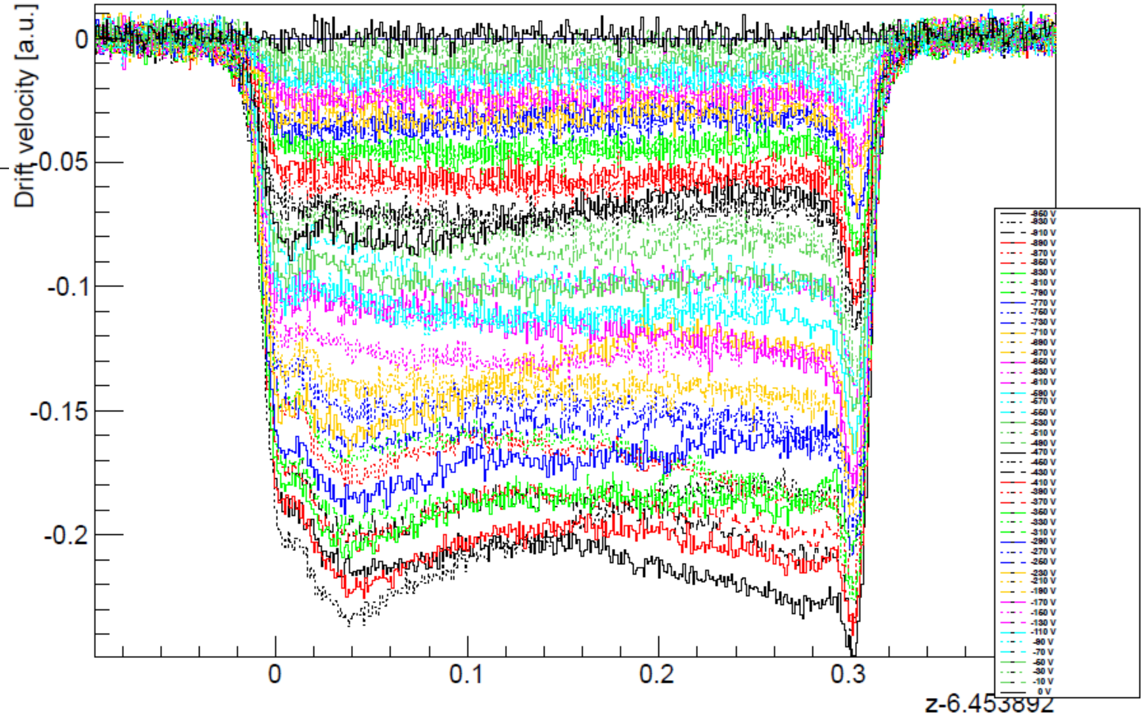


“more charge”

P80-W6, $5\times10^{15}\ n_{eq}/cm^2$

edge



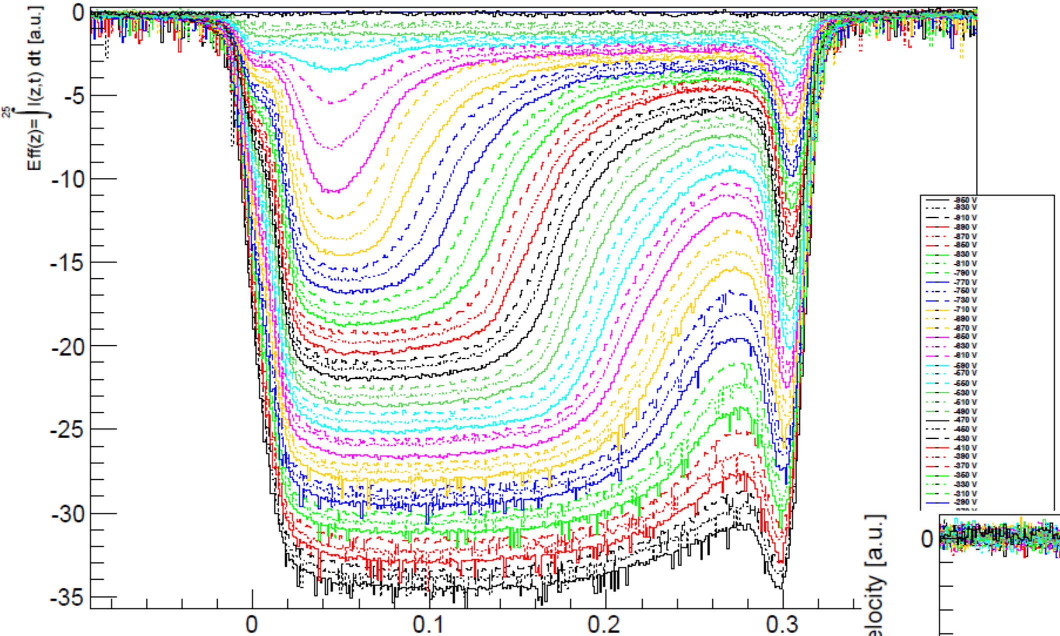


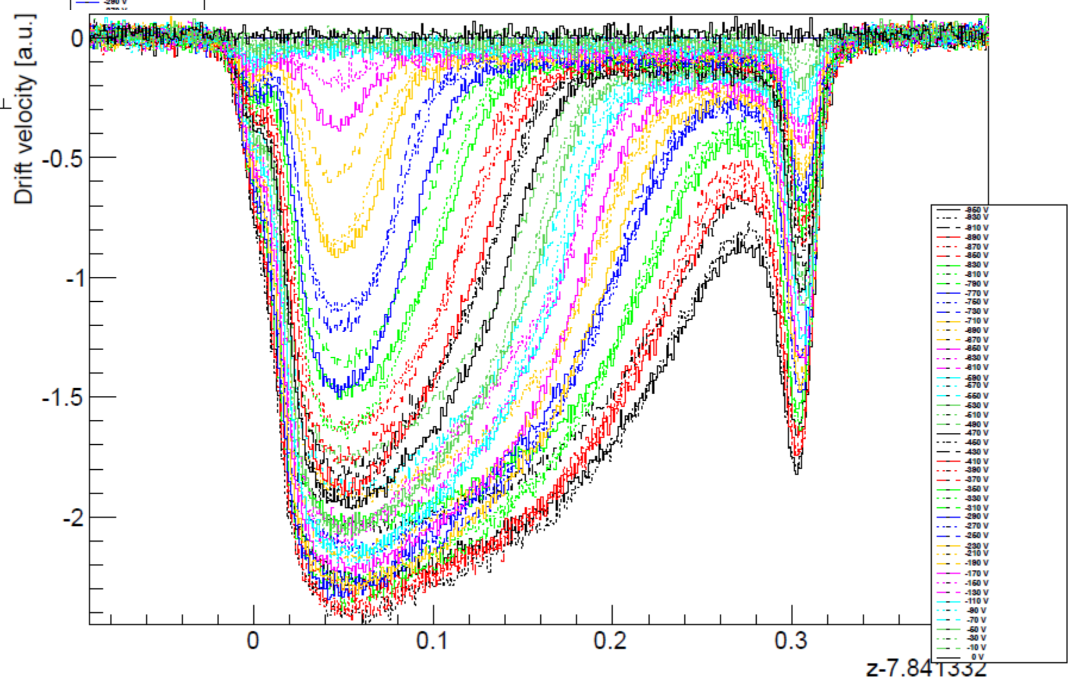
No homogeneous efficiency along sensor side:
Efficiency increase with distance to pads

"more charge"

P40-W15-I15, 1×10^{15} n_{eq}/cm^2

edge





Summary

- First IV measurements show a decrease in E_g for sensors irradiated with a fluence higher than $1\times10^{15}\,n_{eq}/cm^2$
- Current related damage rage α:
  - HPK: factor 4 difference between low and high fluence; high fluence significant lower than expected
    HPK low fluence 3σ agreement with expected value at 700V and 800V, but no saturation
  - 3σ agreement of Micron sensors (≥900V) with expected value, no saturation
- Need verification of results with second set of sensors
- Continue study with annealing of sensors

- First TCT/eTCT measurements of RD50 charge multiplication sensors are promising
- More measurements will follow

Acknowledgements

- I would like to thank the irradiation teams at Ljubljana and Birmingham.

- Special thanks go to Christian, Marcos, Hannes and Michael at CERN for helping with the TCT measurements and sharing their setups.

Backup

IV Measurement Aim

- IV scaling:

$$\frac{I(T_2)}{I(T_1)} = \left(\frac{T_2}{T_1}\right)^2 exp\left(\frac{-\boldsymbol{E_g}}{2k_B}\frac{T_1 - T_2}{T_1 T_2}\right)$$

E_g: activation energy (1.214±0.014eV [1]); T_1: measurement temperature, T_2: scaling temperature; k_B: Boltzmann constant

Use for scaling of current to different temperatures, determination of E_g from measurement

- Investigate behaviour of current for irradiated sensors

$$\frac{I(\Phi_{eq}) - I(\Phi_0)}{V} = \boldsymbol{\alpha}\Phi_{eq}$$

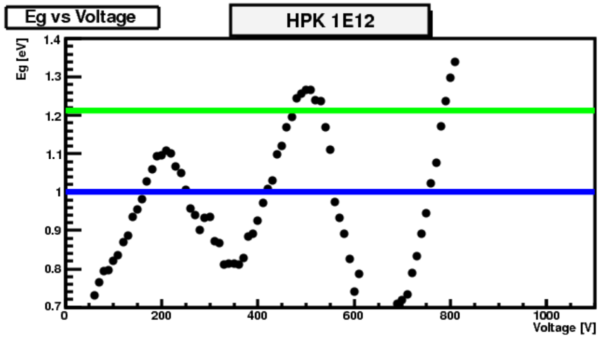
Only valid up to ~1×10^{15} n_{eq}/cm^2

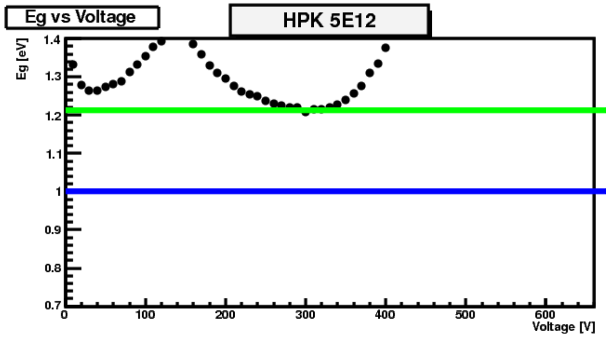
V: depleted volume; Φ_{eq}: equivalent fluence; $I(\Phi_0)$: nonirradiated current ; α: current related damage rate

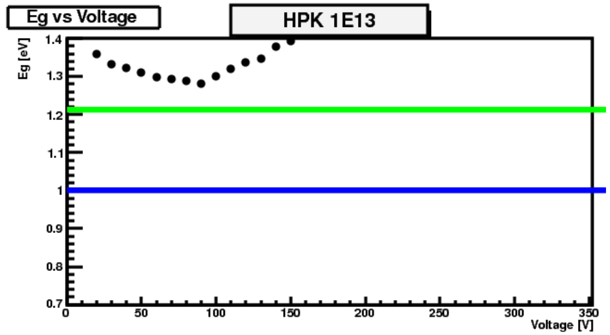
Determination of α from measurements

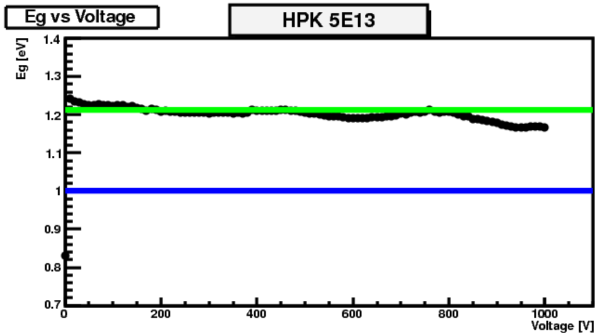
[1]: A. Chilingarov; *Temperature dependence of the current generated in Si bulk*; **2013_JINST_8_P10003**

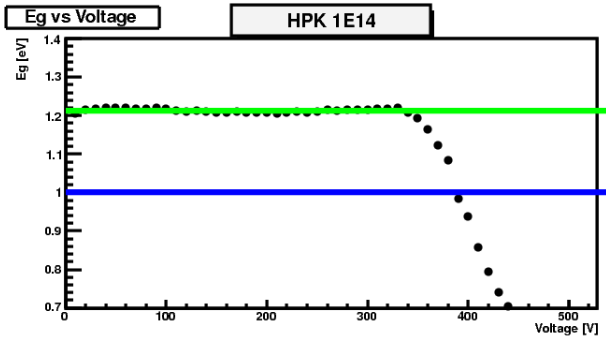
E_g Details I (HPK)



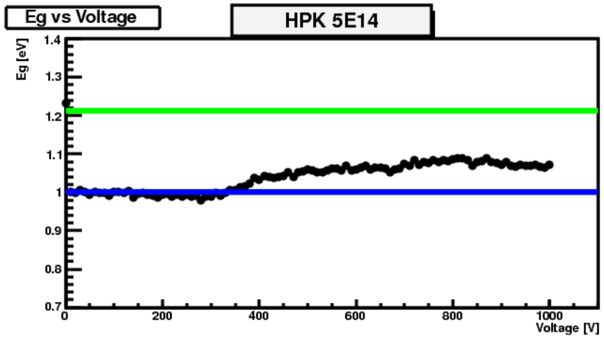


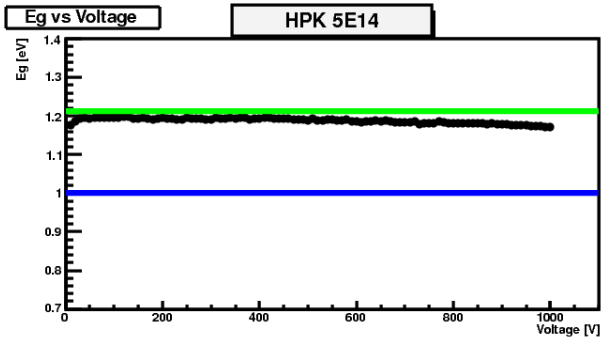


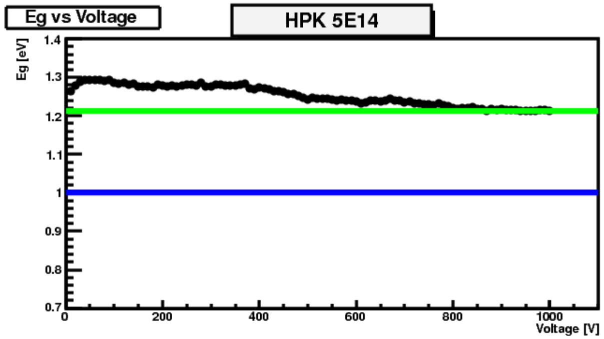




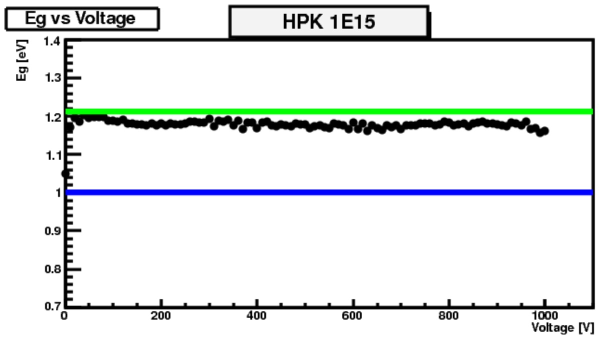
E_g ≈1.2eV (green line) for most sensors (also next slide)

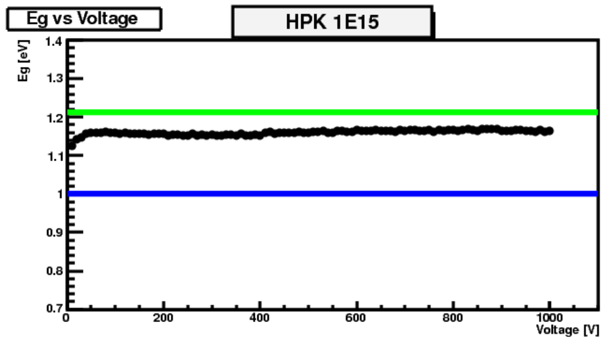


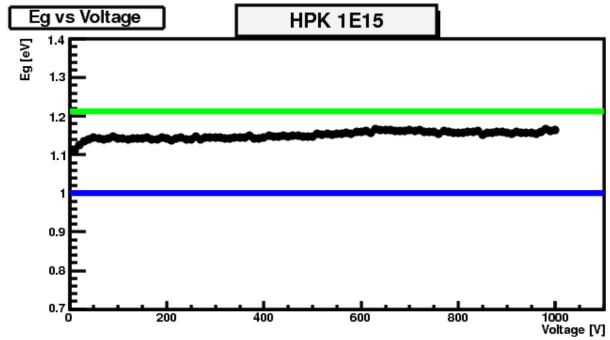


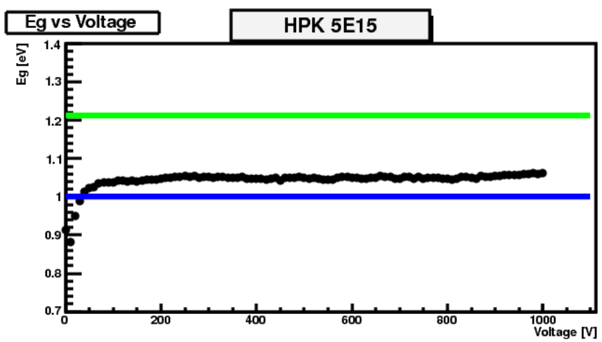


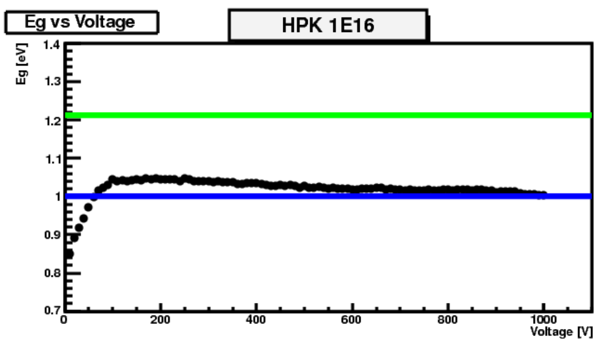
E_g Details II (HPK)

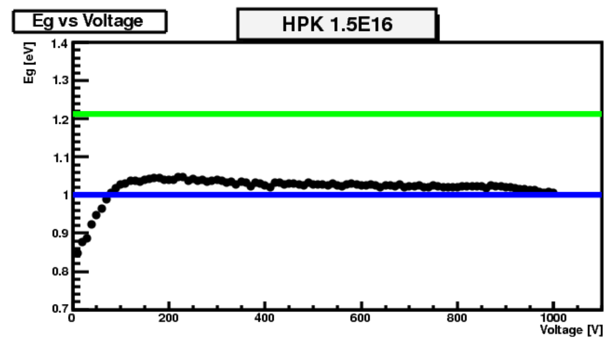


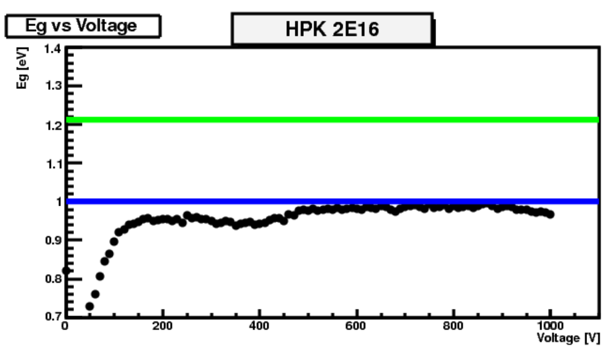






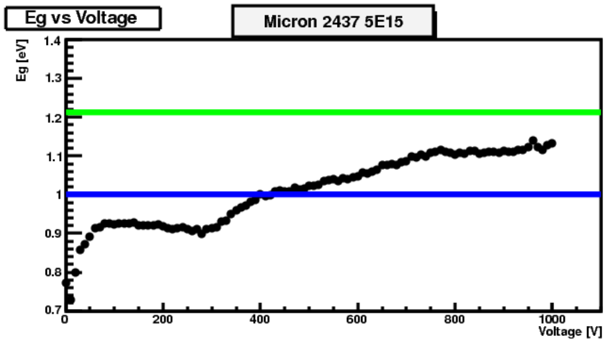


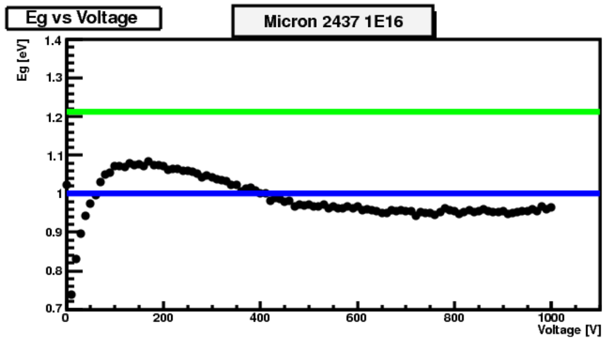


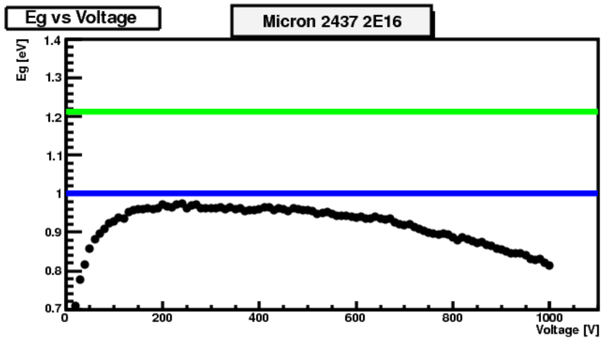


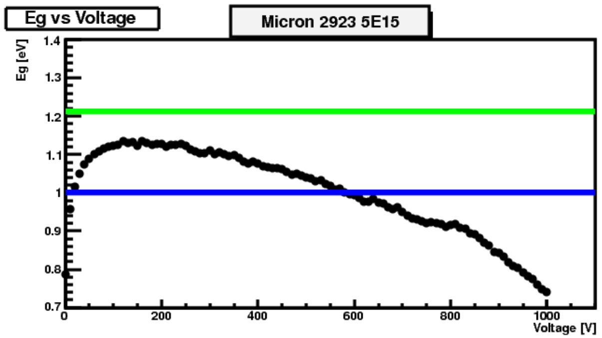
Sensors irradiated to 1×10^{15}, 5×10^{15}, 1×10^{16}, 1.5×10^{16}, 2×10^{16} n_{eq}/cm^2 clearly lower E_g $\approx$1eV (blue line) than lower dose

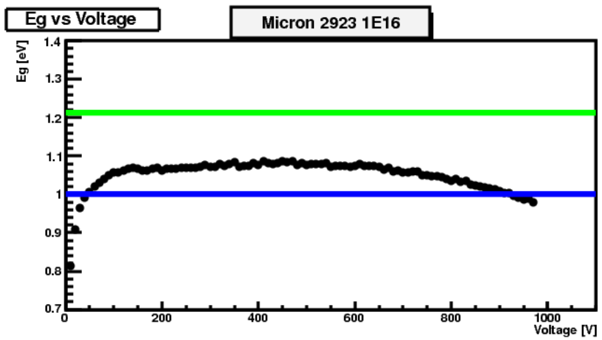
E_g Details III (Micron)

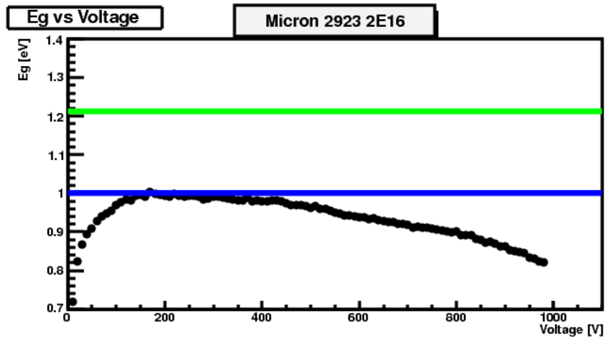












Also for Micron sensors (143µm (upper row) and 108µm (lower row) thick) E_g for higher doses closer to 1eV (blue line) than to 1.2eV (green line)

Alpha Values

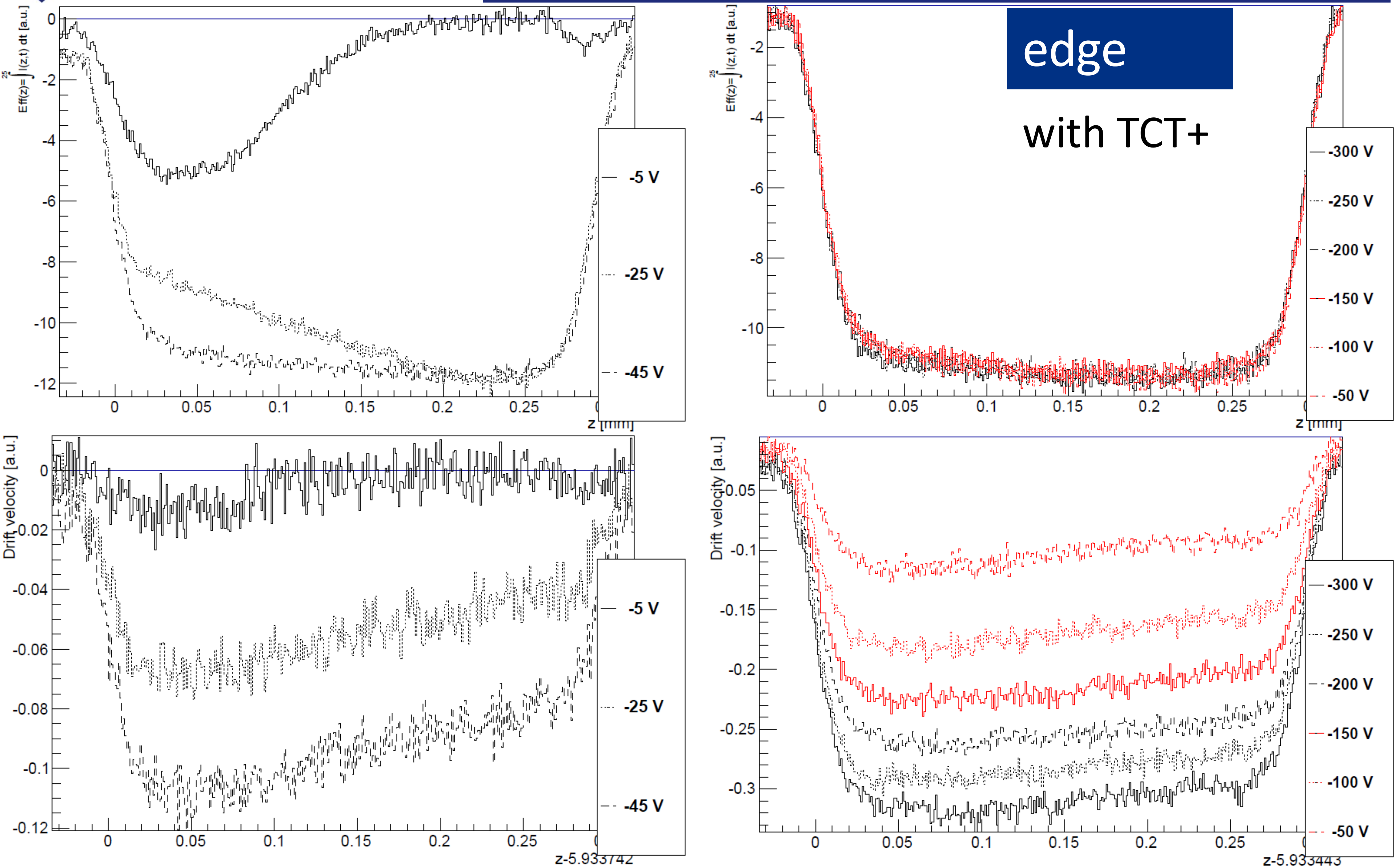
- Theoretical Value (420min annealing at 21°C): **6.371×10^{-17}A/cm**
- Literature value for α for temperature scaling
- Used "depleted" area:
  - HPK: (0.8348×0.86)cm^2, 293μm thickness
  - Micron: (1.0985×1.0973) cm^2, 143/108 μm thickness (Micron 2437/2923)

Voltage [V]	HPK [×10^{17} A/cm]		Micron [×10^{17} A/cm]	
	Low fluence	High fluence	2437	2923
500	5.477±0.015	1.341±0.095	3.519±0.079	4.55±0.14
700	6.38±0.11	1.59±0.13	4.59±0.19	6.43±0.44
800	6.76±0.14	1.70±0.14	5.10±0.31	7.25±0.75
900	7.10±0.18	1.80±0.16	5.60±0.39	7.9±1.1
950	7.26±0.2	1.85±0.16	5.75±0.45	8.1±1.2
1000	7.41±0.21	1.91±0.16	5.89±0.50	8.27±0.86

Green: 3σ agreement with theoretical value

Problem: Alpha depends on current and current depends on E_g => which Eg value for alpha calculation?

P80-W32, unirradiated



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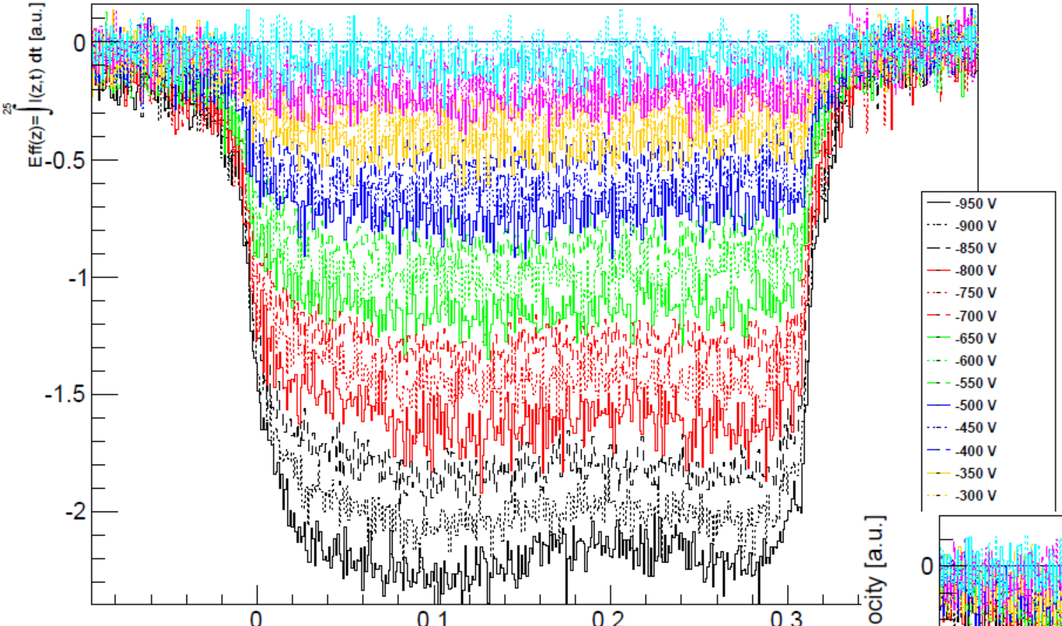
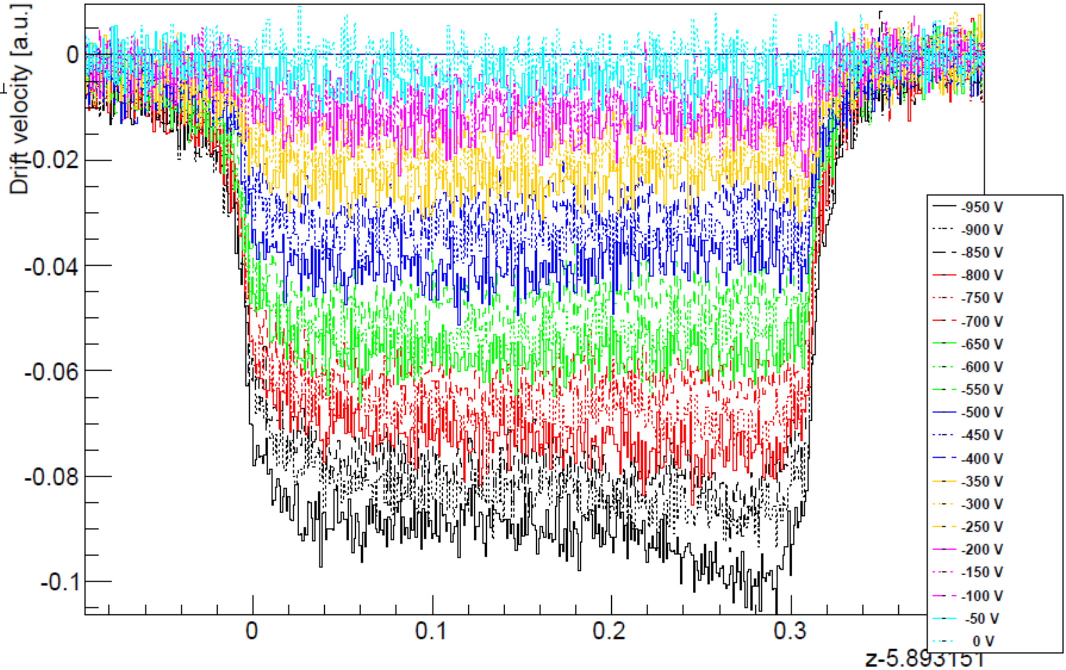
P80-W6, 5×10^{15} n_{eq}/cm^2

edge

with TCT+;
Different
position





"more charge"