The RD50 testbeam and the related simulations studies

M. Bomben[1] & I. Rubinskyi[2]

[1]LPNHE, Paris [2]DESY

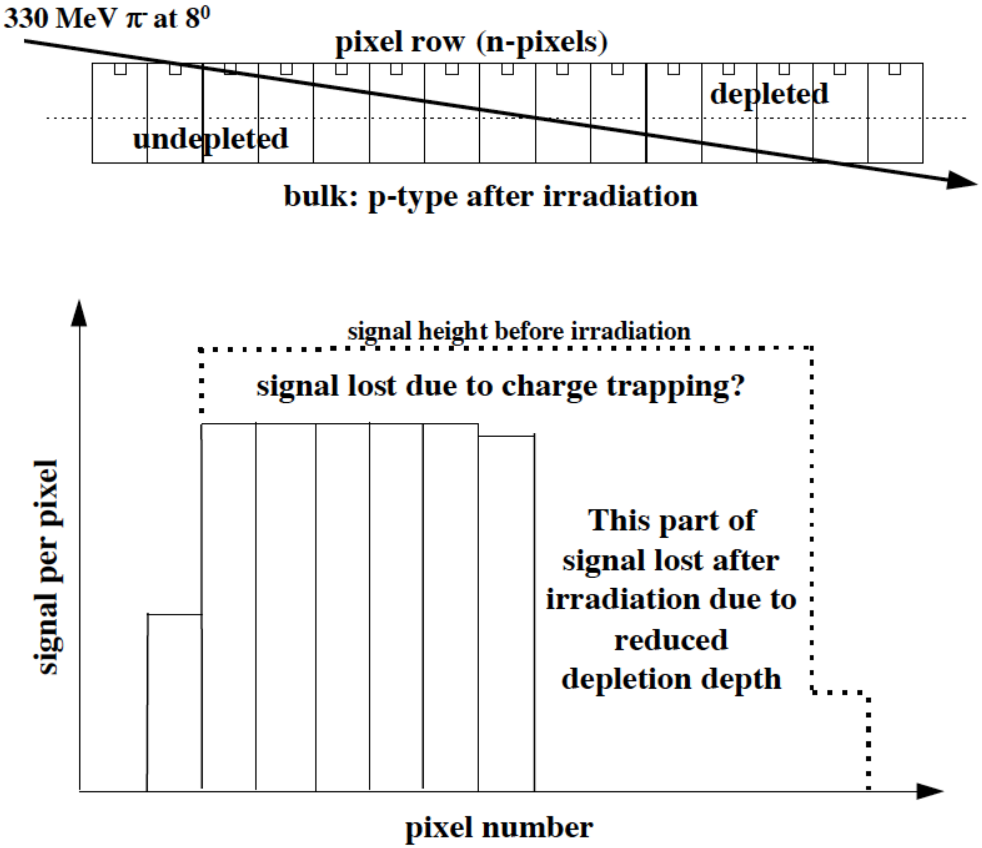
Outline

- The project
- The testbeam
- The simulation studies
- Conclusions & Outlook

THE PROJECT

Grazing angle technique

- Technique developed by Henrich, Bertl, Gabathuler & Horisberger (CMS note 1997/021)



- Tracks enter at shallow angle wrt to the detector surface
- Charge collection efficiency as a function of the bulk depth
  - (Analog readout)

The project

"Simulation of Heavily Irradiated Silicon Pixel Sensors and Comparison with Test Beam Measurements"
V. Chiochia et al., Nuclear Science, IEEE Transactions on , vol.52, no.4, pp. 1067- 1075, Aug. 2005

- Use this technique to perform ~ 1 µm resolved charge collection profiles

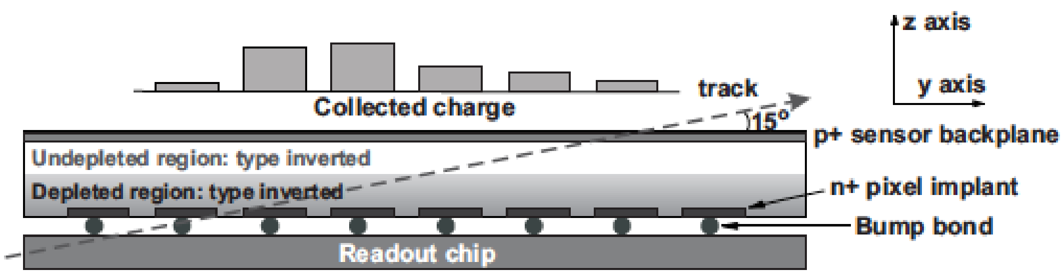
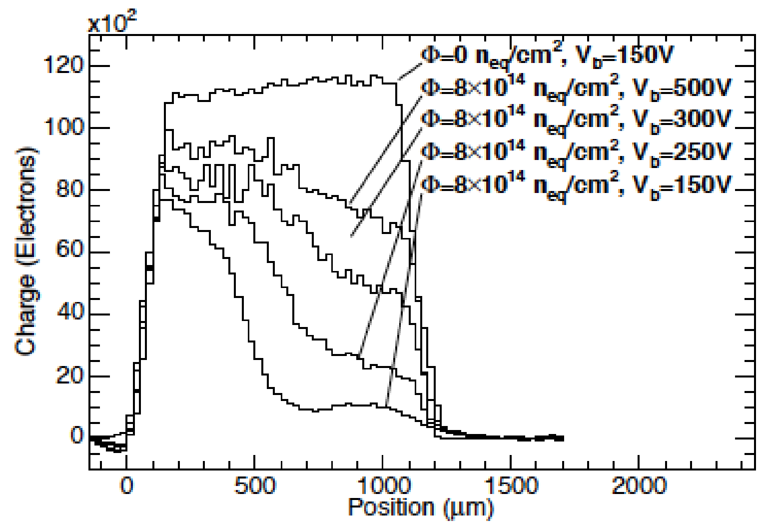


Fig. 2

THE GRAZING ANGLE TECHNIQUE FOR DETERMINING CHARGE COLLECTION PROFILES. THE CLUSTER LENGTH IS PROPORTIONAL TO THE DEPTH OVER WHICH CHARGE IS COLLECTED.



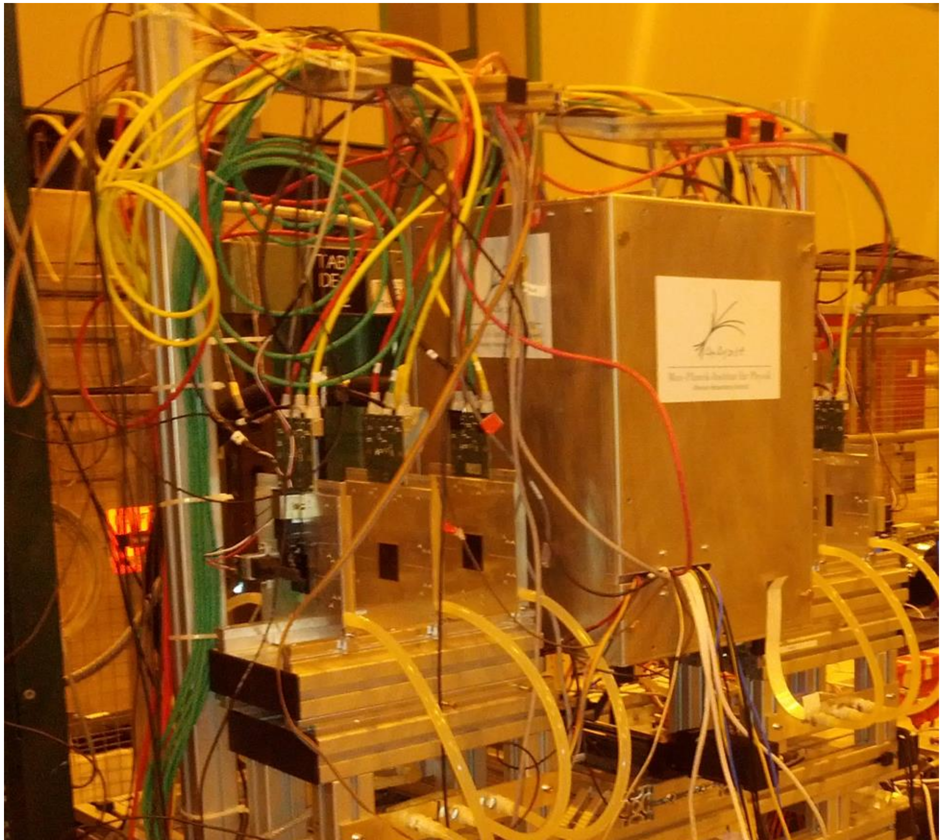
•Parameterization of the Electric Field in simulations
•Comparison data/simulation (next slides)

Fig. 3

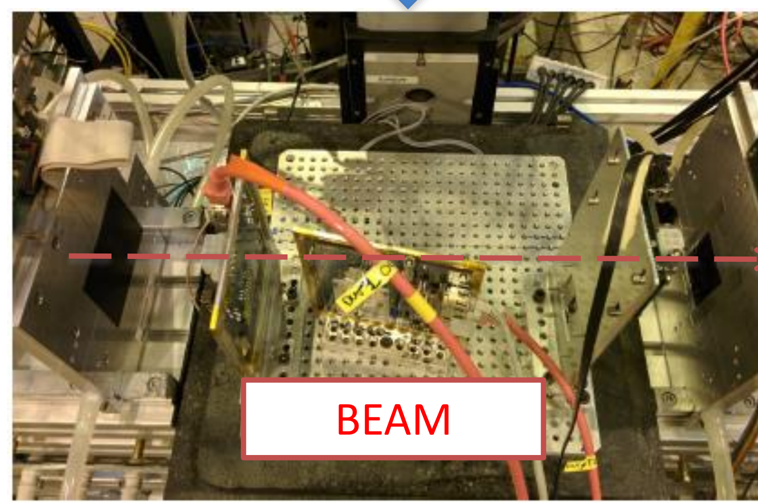
CHARGE COLLECTION PROFILES FOR AN IRRADIATED ($\Phi = 8 \times 10^{14}$ N$_{eq}$/cm^2) AND AN UNIRRADIATED SENSOR ($\Phi = 0$ N$_{eq}$/cm^2) OPERATED AT SEVERAL BIAS VOLTAGES.

THE TESTBEAM

The testbeam: 20-27/10/2014



- CERN SPS H6B experimental hall
- 120 GeV π
- Eudet/Aida telescope
- 2 Devices Under Test in the box



Testbeam report

Telescope moved from PS to SPS only few days before the testbeam start

- not fully unpacked/cabled
- had to finalize telescope setup, incl. network

Beam setup

- long stops for problems (mainly in PS) plus long MD/TS (2d) in 2nd week
- beamfile was wrong → beam pointing downward by ~10^{-2} rad → low trigger rate for 1.5d

Plus some unexpected problems

- LV cables for DCS system didn't work → needed to find enough PS channels
- parts of the mechanics missing → had to adapt schedule → lost one day
- USBPix behaved differently from lab tests, i.e. didn't work
- Several power-cuts in the experimental area
- Unexpected network resets

Almost no data taken ☹ (maybe some data from a parasitic run later this month)

THE SIMULATIONS STUDIES

Simulation studies

- In parallel with the testbeam preparation and running (!) the program of simulation was carried on
- MPI and TU Dortmund had a total of 5 samples to be measured
- Several radiation damage models have been tested

Samples

type	Name (and group)	Thickness (µm)	Irradiation type & Fluence (10^{15} n_{eq}/cm^2)
N-on-p	MPI_VTT-AM4-NP1-8-E4 (MPI)	100	KIT p's - 5
N-on-p	MPI_VTT-NP2-20-E4 (MPI)	200	LUB n's - 6
N-on-p	MPI_VTT-NP1-4-E5 (MPI)	100	LUB n's - 2
N-on-n	DO_FZ (TU DO)	200	PSI π's - 0.416
N-on-n	DO_MCz (TU DO)	285	PSI π's - 0.416

P-bulk: irradiation models

Petasecca p-bulk

Type	Energy (eV)	Defect	$\sigma_e(\mathrm{cm}^2)$	$\sigma_h(\mathrm{cm}^2)$	$\eta(\mathrm{cm}^{-1})$
Acceptor	E_C -0.42	VV	2.0×10^{-15}	2.0×10^{-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_iO_i	2.5×10^{-14}	2.5×10^{-15}	0.9

Pennicard p-bulk

Type	Energy (eV)	Defect	$\sigma_e(\mathrm{cm}^2)$	$\sigma_h(\mathrm{cm}^2)$	$\eta(\mathrm{cm}^{-1})$
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Donor	E_V +0.36	C_iO_i	3.23×10^{-13}	3.23×10^{-14}	0.9

N-bulk irradiation models

Petasecca model for N-type

Level	Ass.	$\sigma_{n,p}$ (cm^2) Exp.[2,9]	σ_n (cm^2)	σ_p (cm^2)	η (cm^{-1})
Ec-0.42eV	$VV^{(-/0)}$	2×10^{-15}	2×10^{-15}	1.2×10^{-14}	13
Ec-0.50eV	VVO(?)	5×10^{-15}	5×10^{-15}	3.5×10^{-14}	0.08
Ev+0.36eV	C_iO_i	2.5×10^{-15}	2×10^{-18}	2.5×10^{-15}	1.1

EVL model for N-type

Plus: fluence dependent carrier lifetime

Trap	E (eV)	g_{int} (cm^{-1})	σ_e (cm^2)	σ_h (cm^2)
Donor	$E_V + 0.48$	6	1×10^{-15}	1×10^{-15}
Acceptor	$E_C - 0.525$	3.7	1×10^{-15}	1×10^{-15}

Chiochia model for N-type

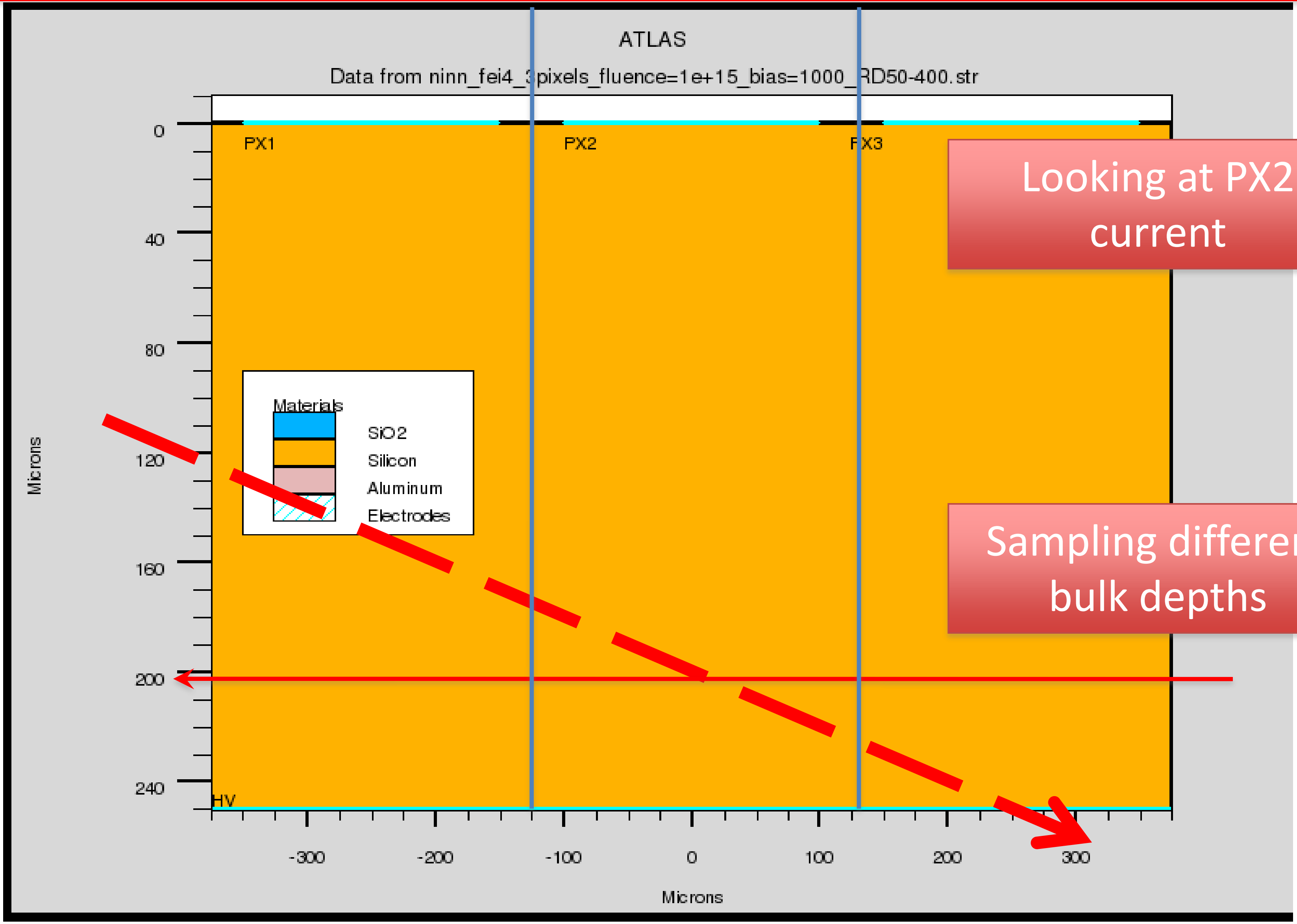
Same levels as EVL model

Φ (n$_{eq}$/cm^2) (×10^{14})	N_A(cm^{-3}) (×10^{15})	N_D(cm^{-3}) (×10^{15})	$\sigma_e^{A/D}$(cm^2) (×10^{-15})	σ_h^A(cm^2) (×10^{-15})	(cm^2) σ_h^D (×10^{-15})
0.5	0.19	0.25	6.60	1.65	6.60
2	0.68	1.0	6.60	1.65	6.60
5.9	1.60	4.0	6.60	1.65	1.65

Charge profile simulations

- Tracks impinging at 15° wrt to the sensor's surface
- Scan along the surface in 10 μm steps

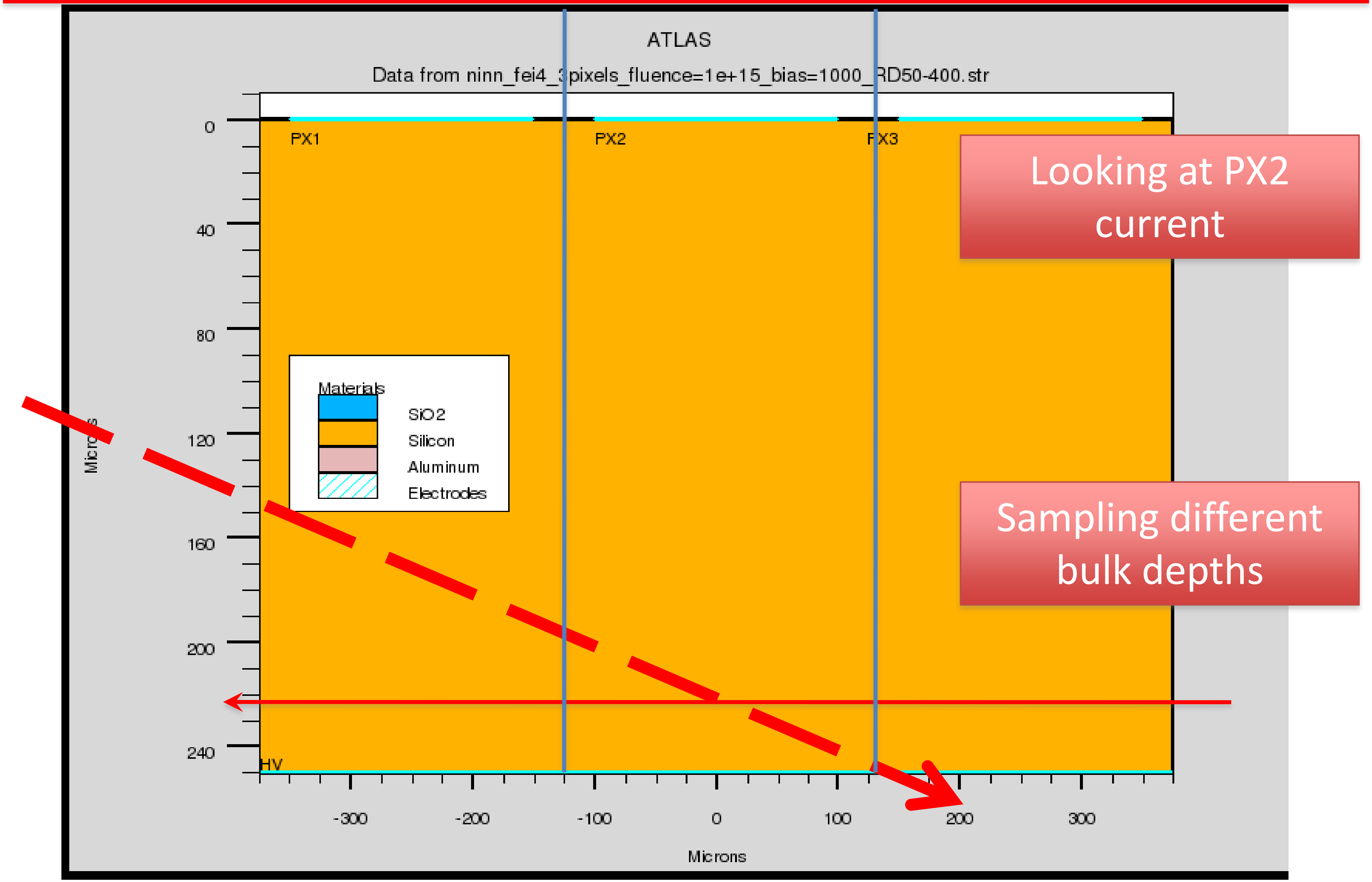
Scanning the bulk depth



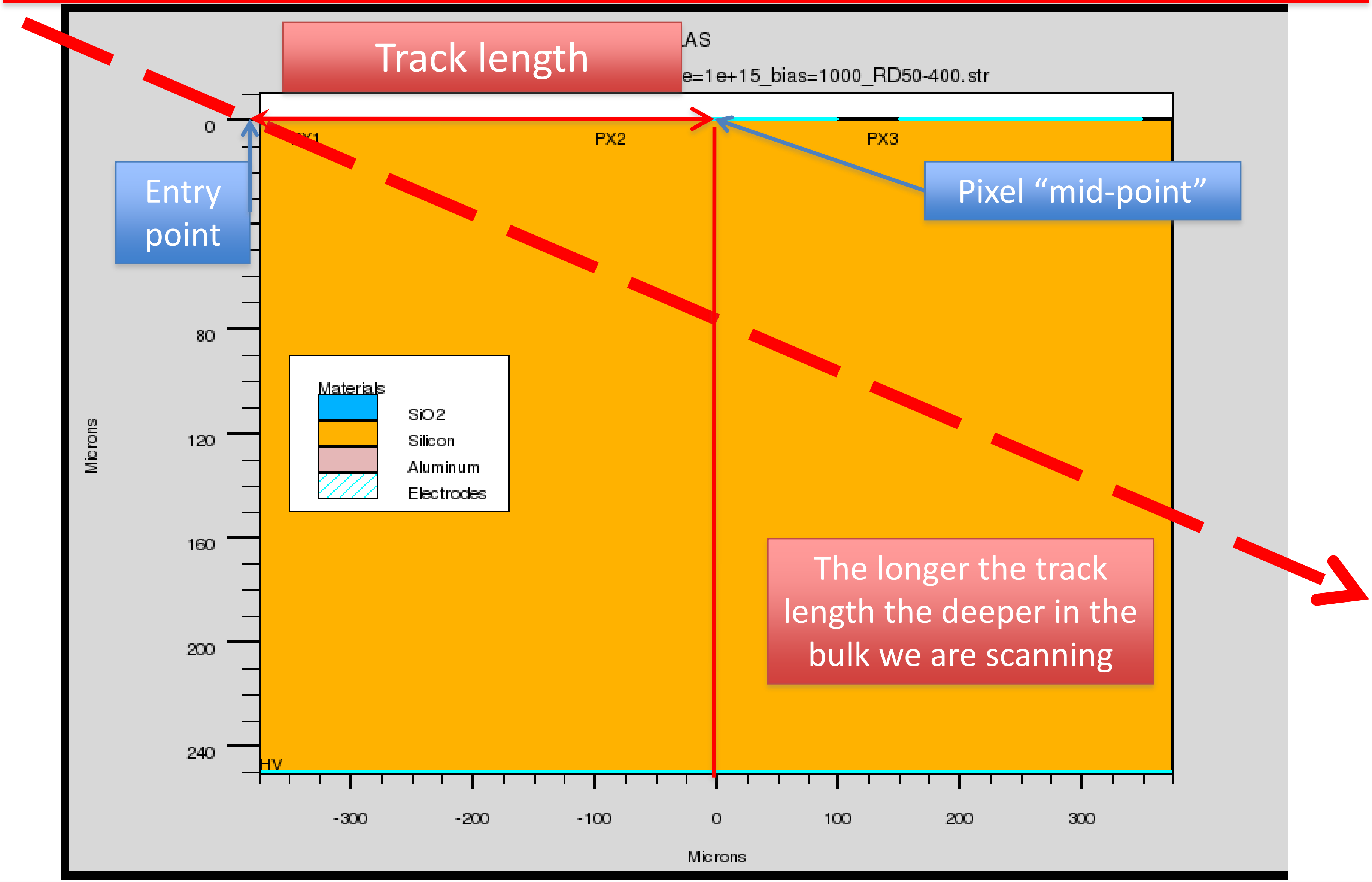
Looking at PX2 current

Sampling different bulk depths

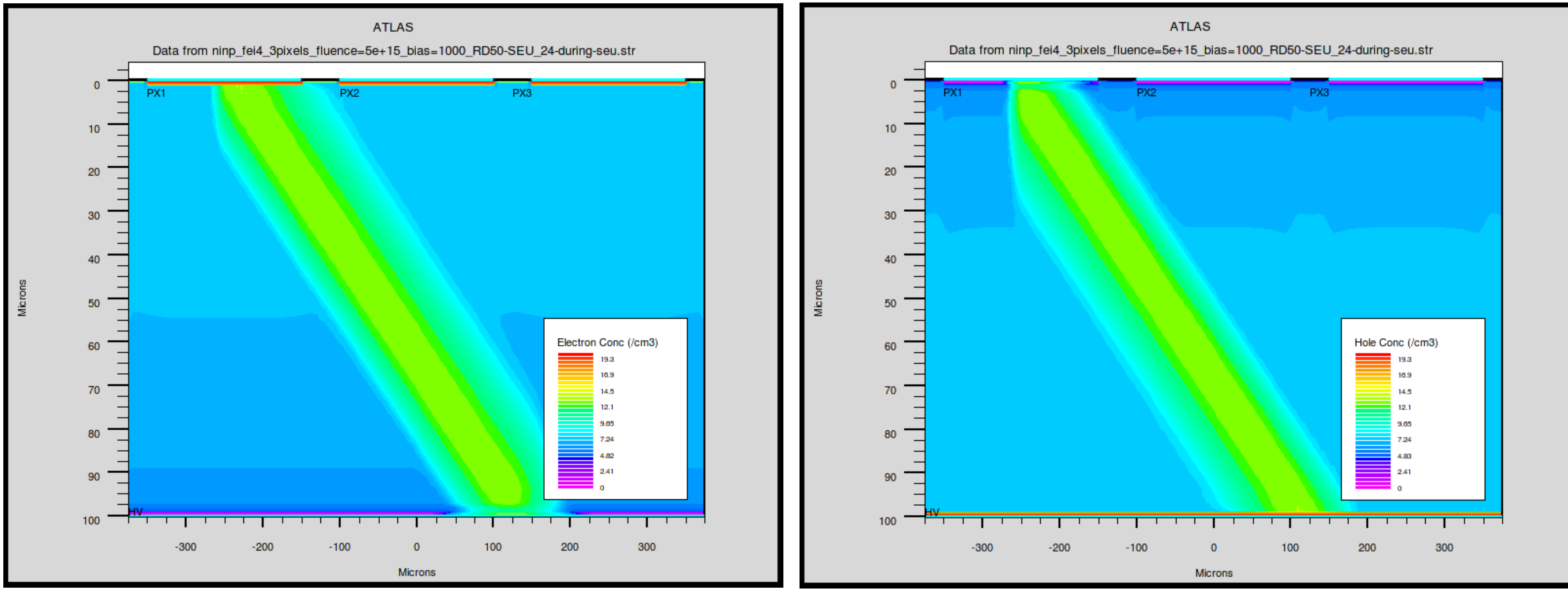
Scanning the bulk depth



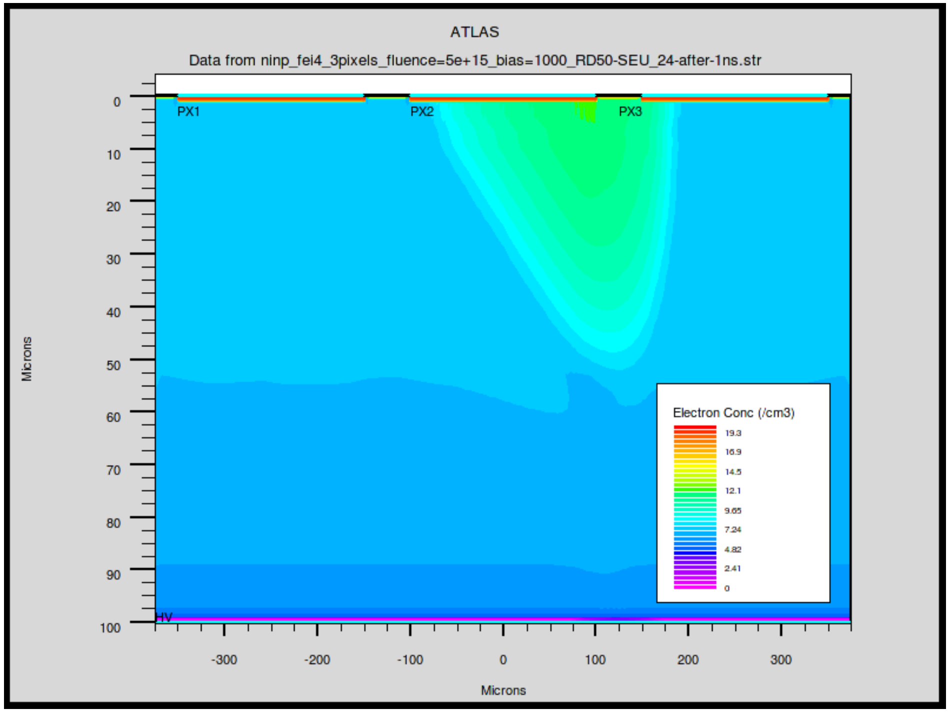
Scanning the bulk depth

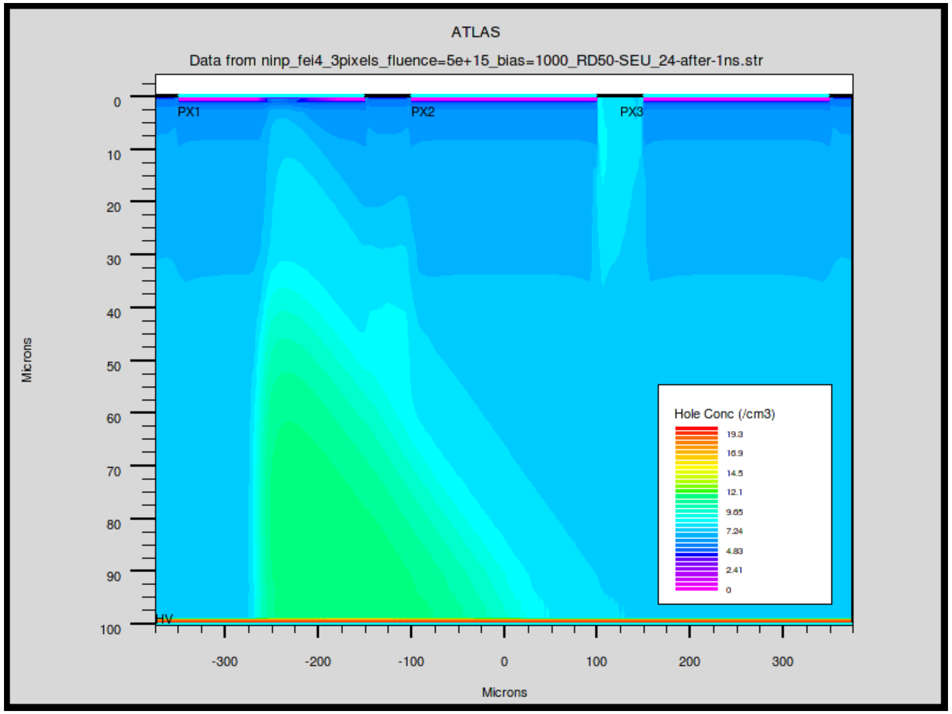


Carrier concentration during the hit



Carrier concentration 1 ns after the hit





N-ON-P RESULTS

N-on-p samples

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N-on-p	MPI_VTT-NP1-4-E5 (MPI)	100	LUB n's - 2
N-on-n	DO_FZ (TU DO)	200	PSI π's - 0.416
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Reminder: P-bulk irradiation models

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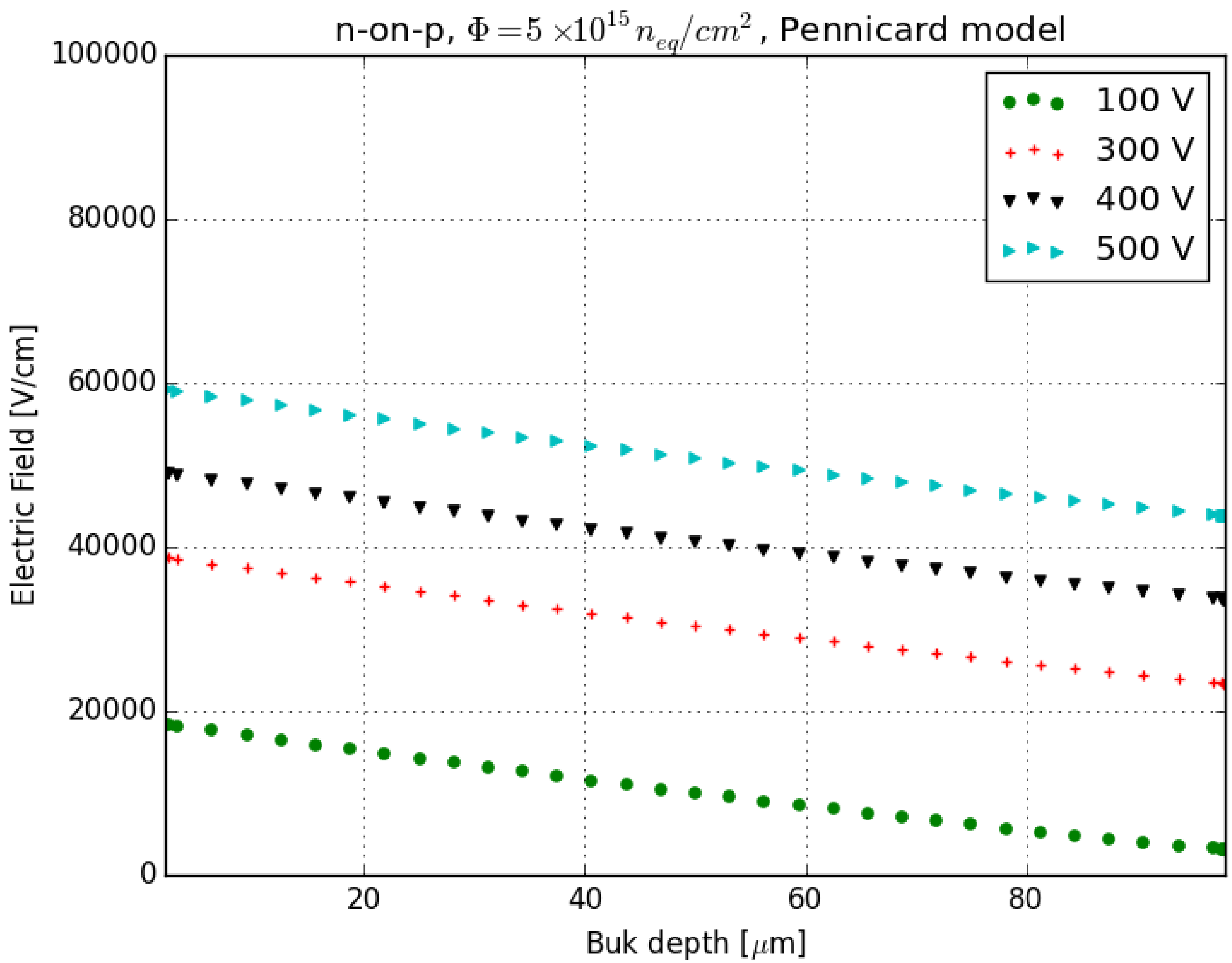
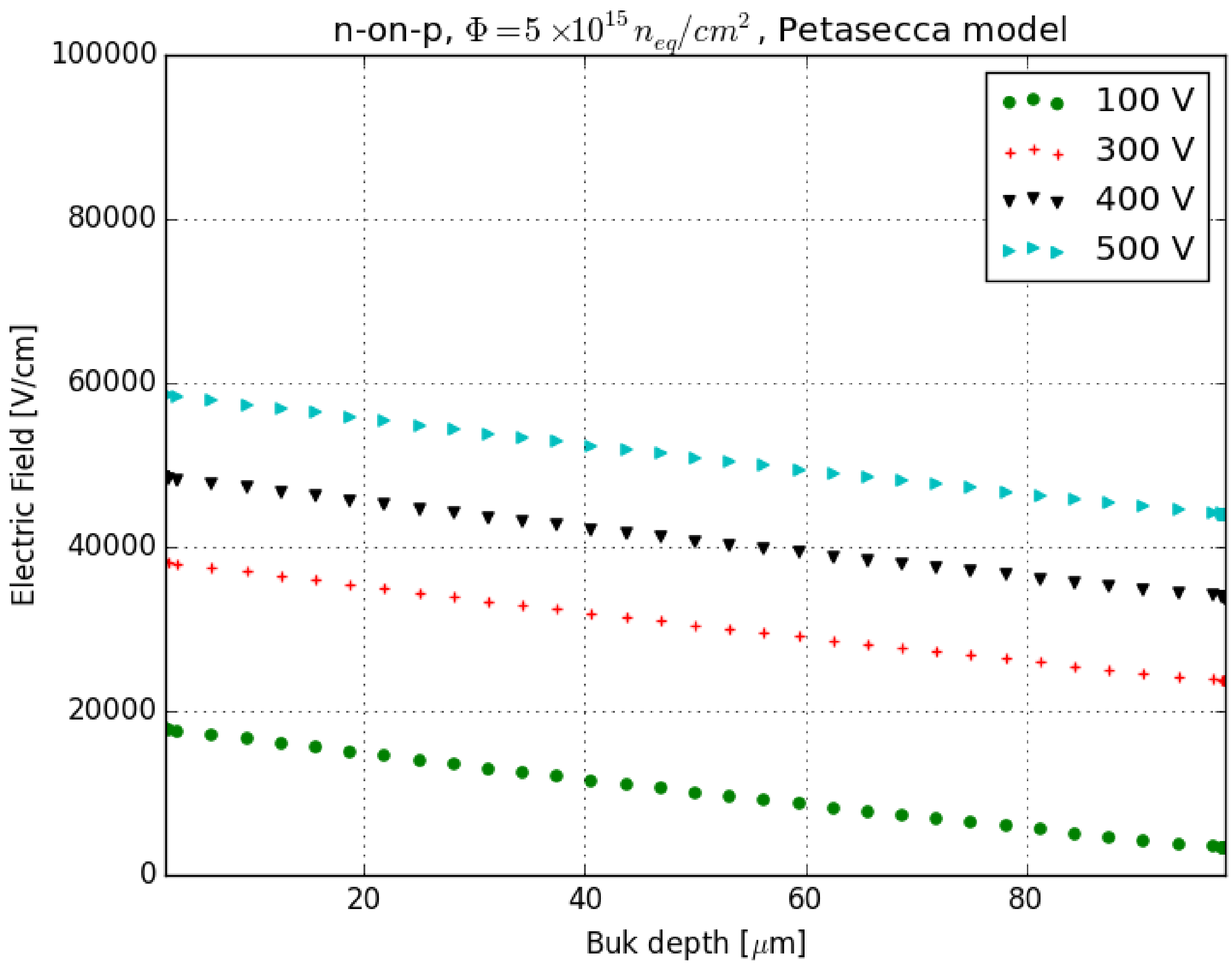
THIN N-ON-P SENSOR

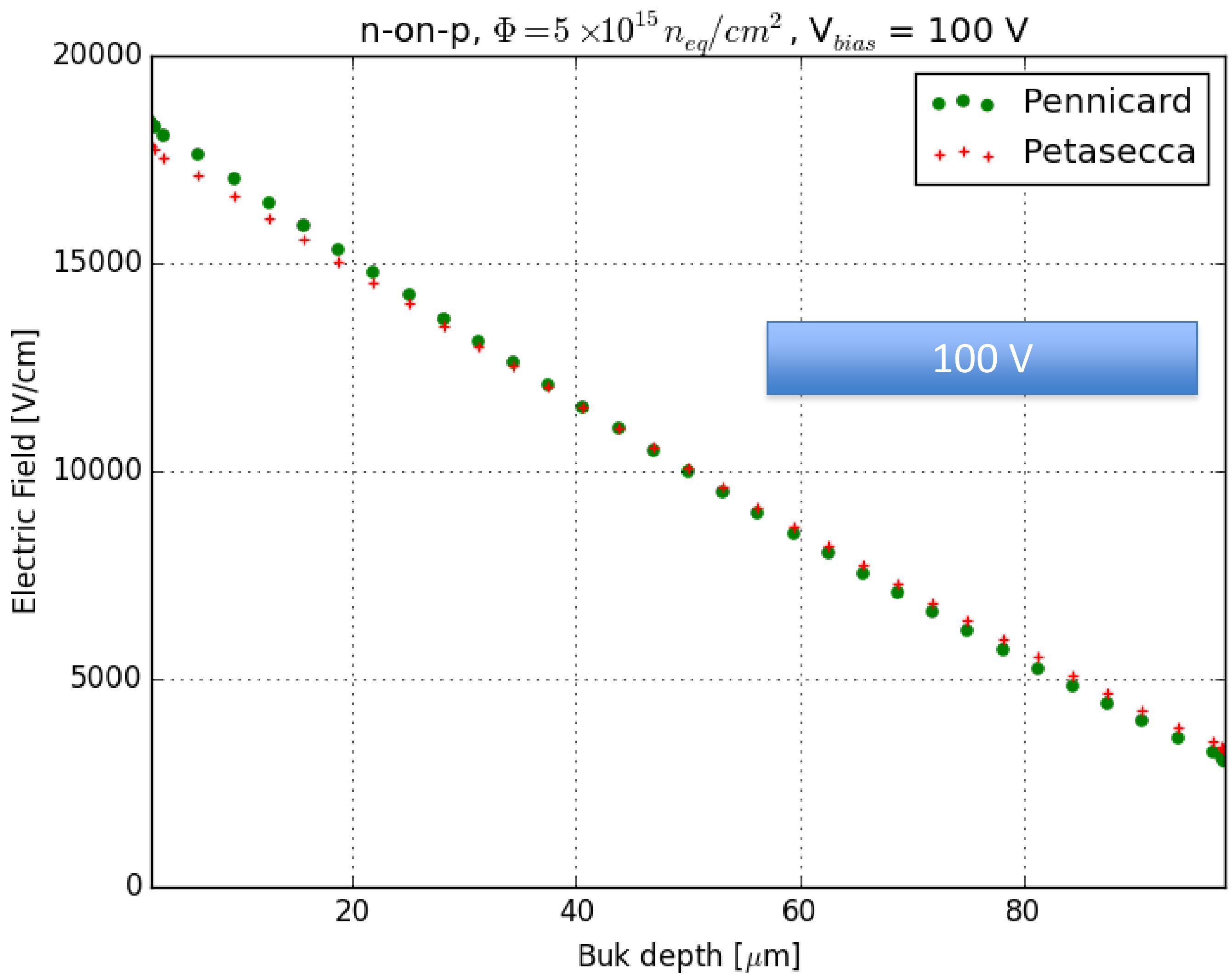
MPI_VTT-AM4-NP1-8-E4 - Electric field profile



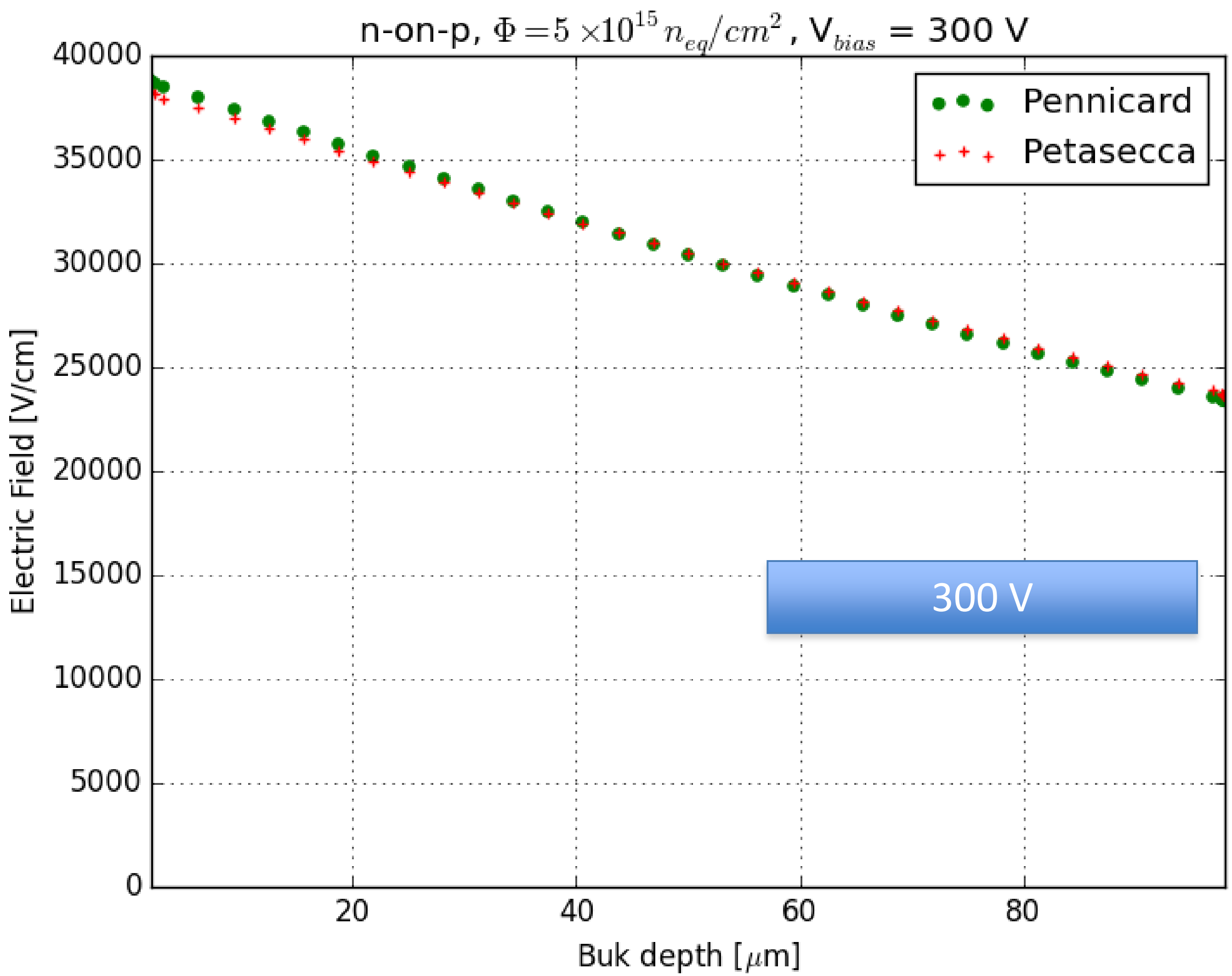
MPI_VTT-AM4-NP1-8-E4 - Electric field profile



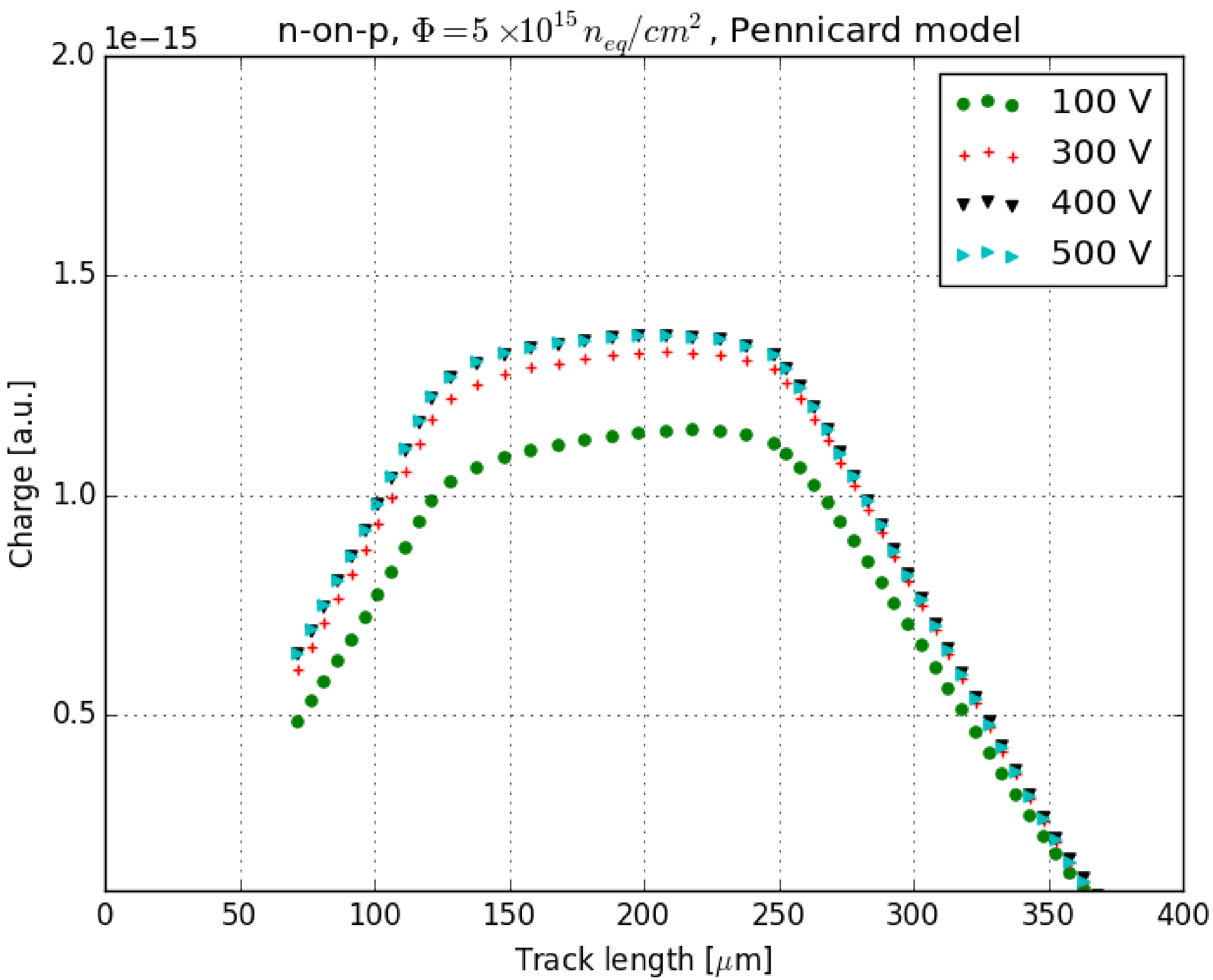
MPI_VTT-AM4-NP1-8-E4 – electric field



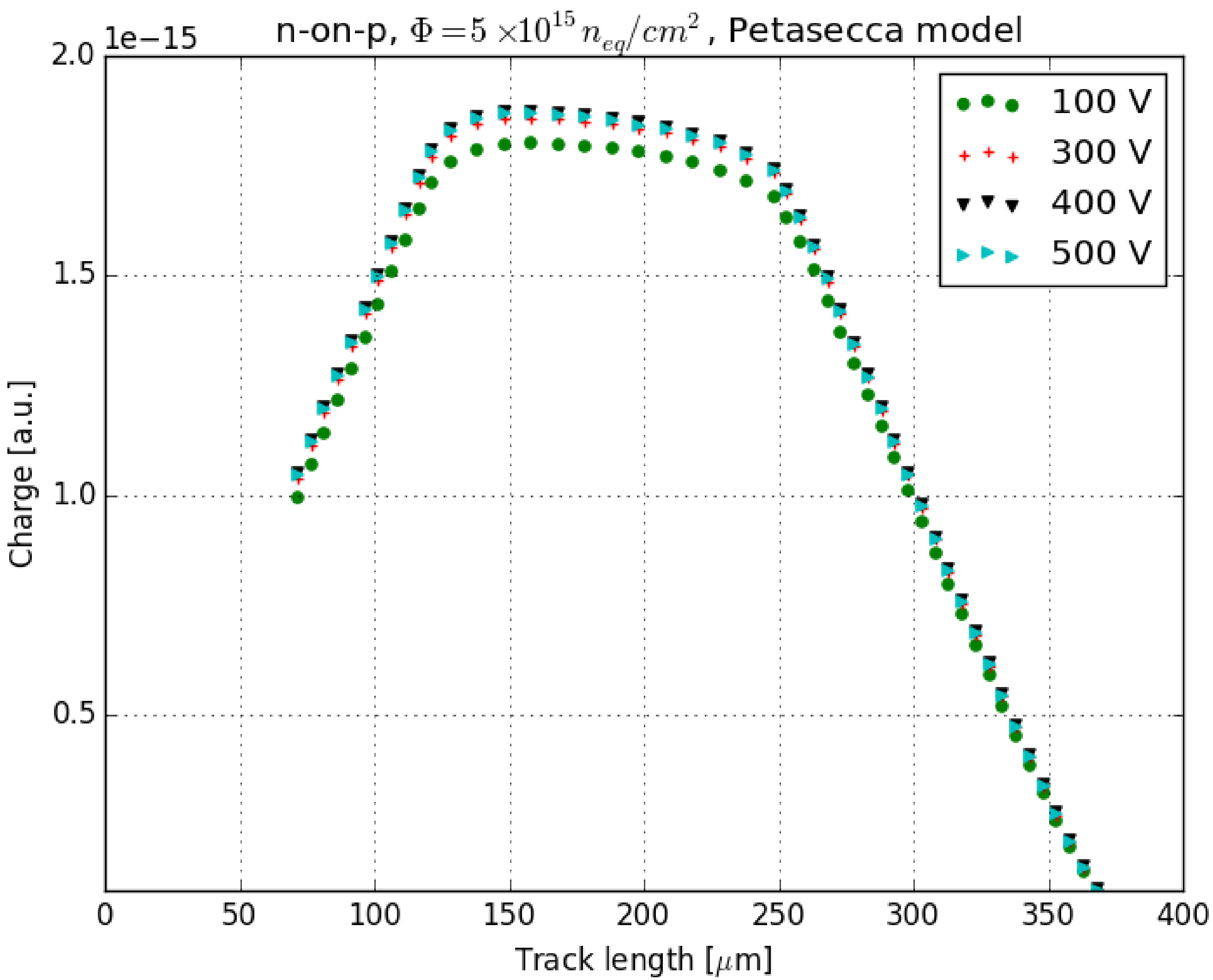
MPI_VTT-AM4-NP1-8-E4 – electric field



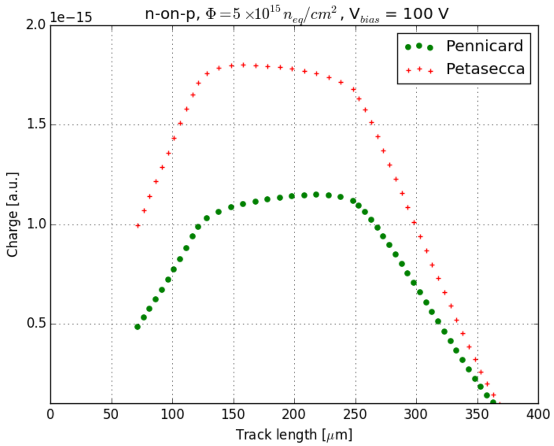
MPI_VTT-AM4-NP1-8-E4 - charge profile



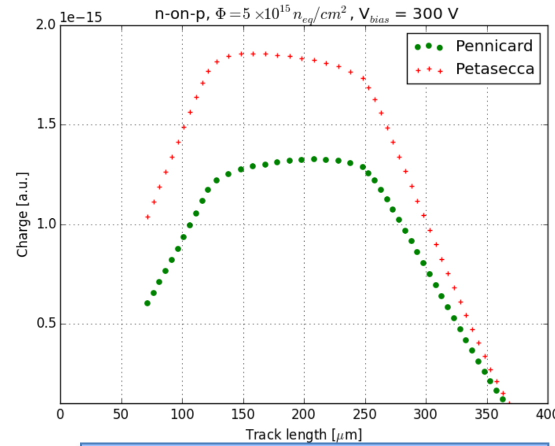
MPI_VTT-AM4-NP1-8-E4 - charge profile



MPI_VTT-AM4-NP1-8-E4 – charge vs bias

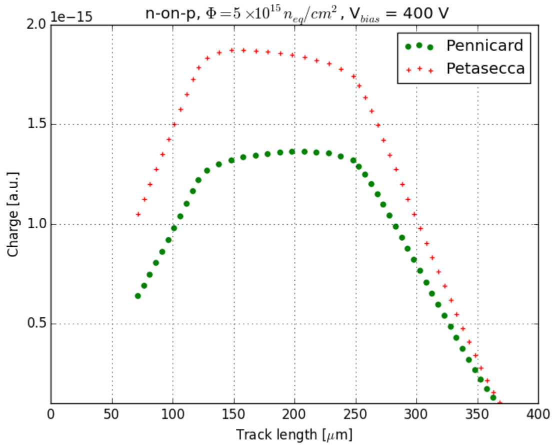


100 V

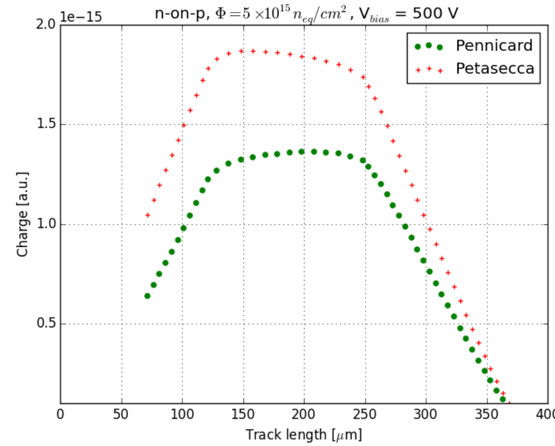


300 V

• Pennicard
+ Petasecca



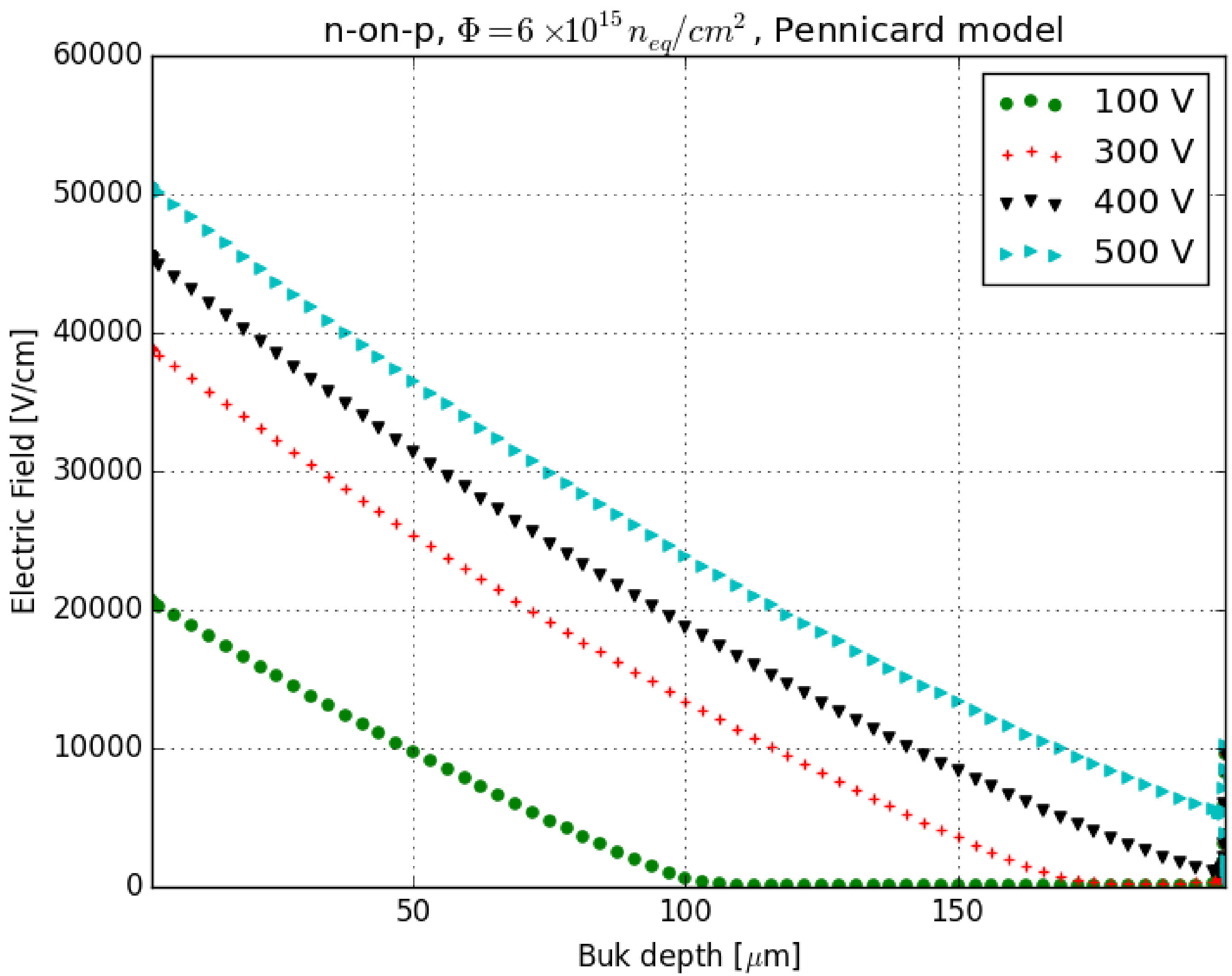
400 V



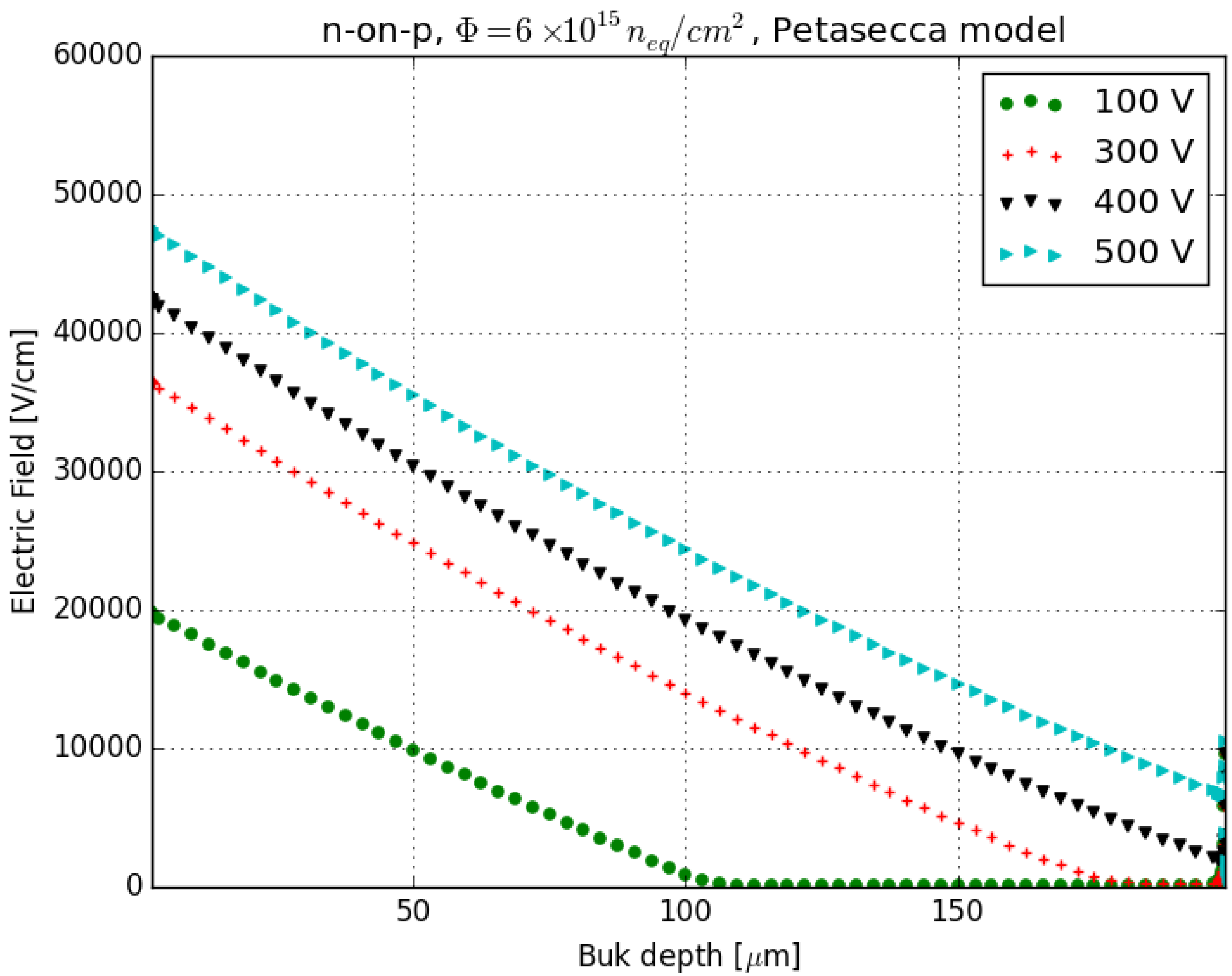
500 V

THICK N-ON-P SENSOR

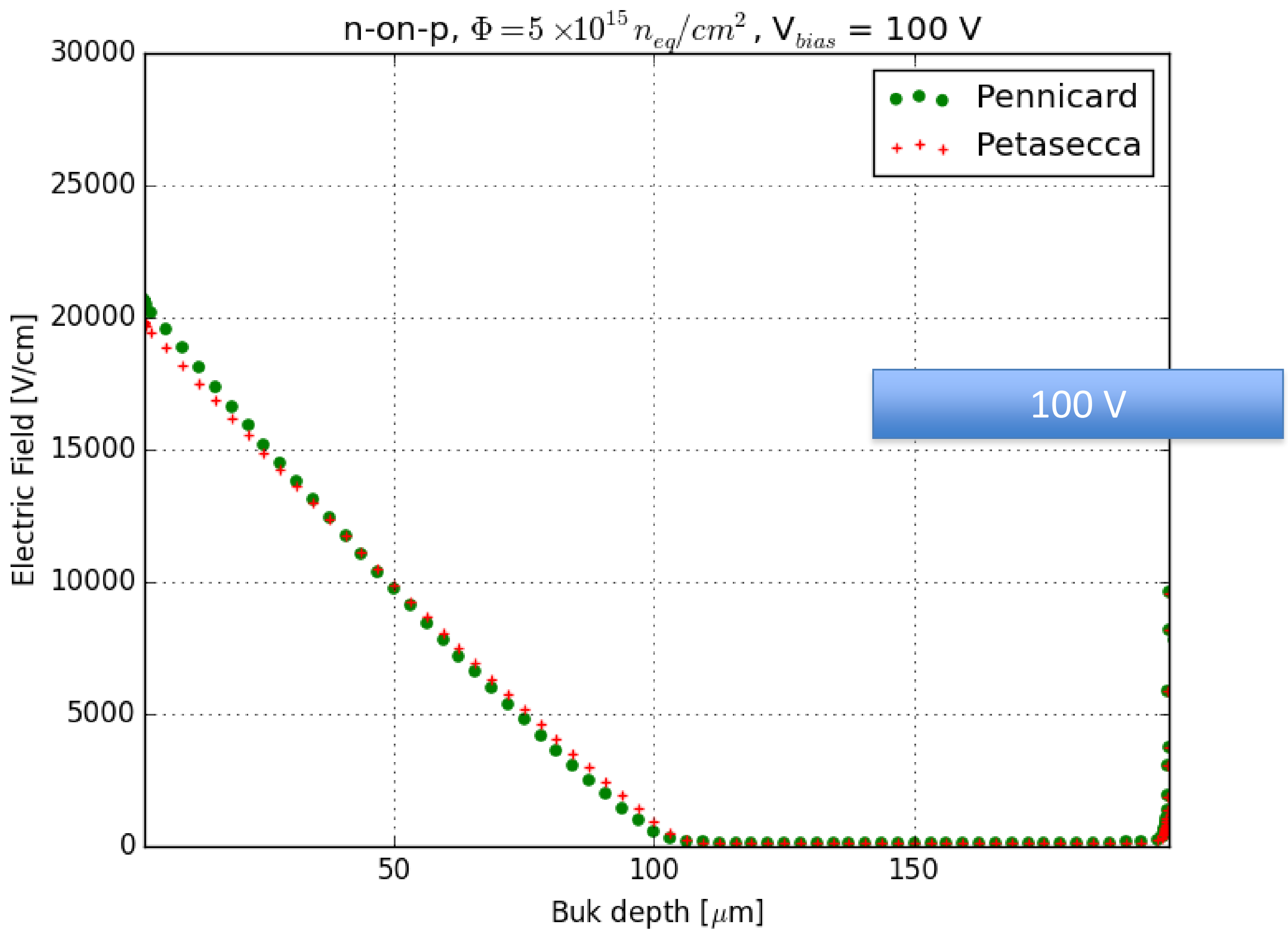
MPI_VTT-NP2-20-E4 - Electric field profile



MPI_VTT-NP2-20-E4 - Electric field profile



MPI_VTT-NP2-20-E4 - Electric field comparison



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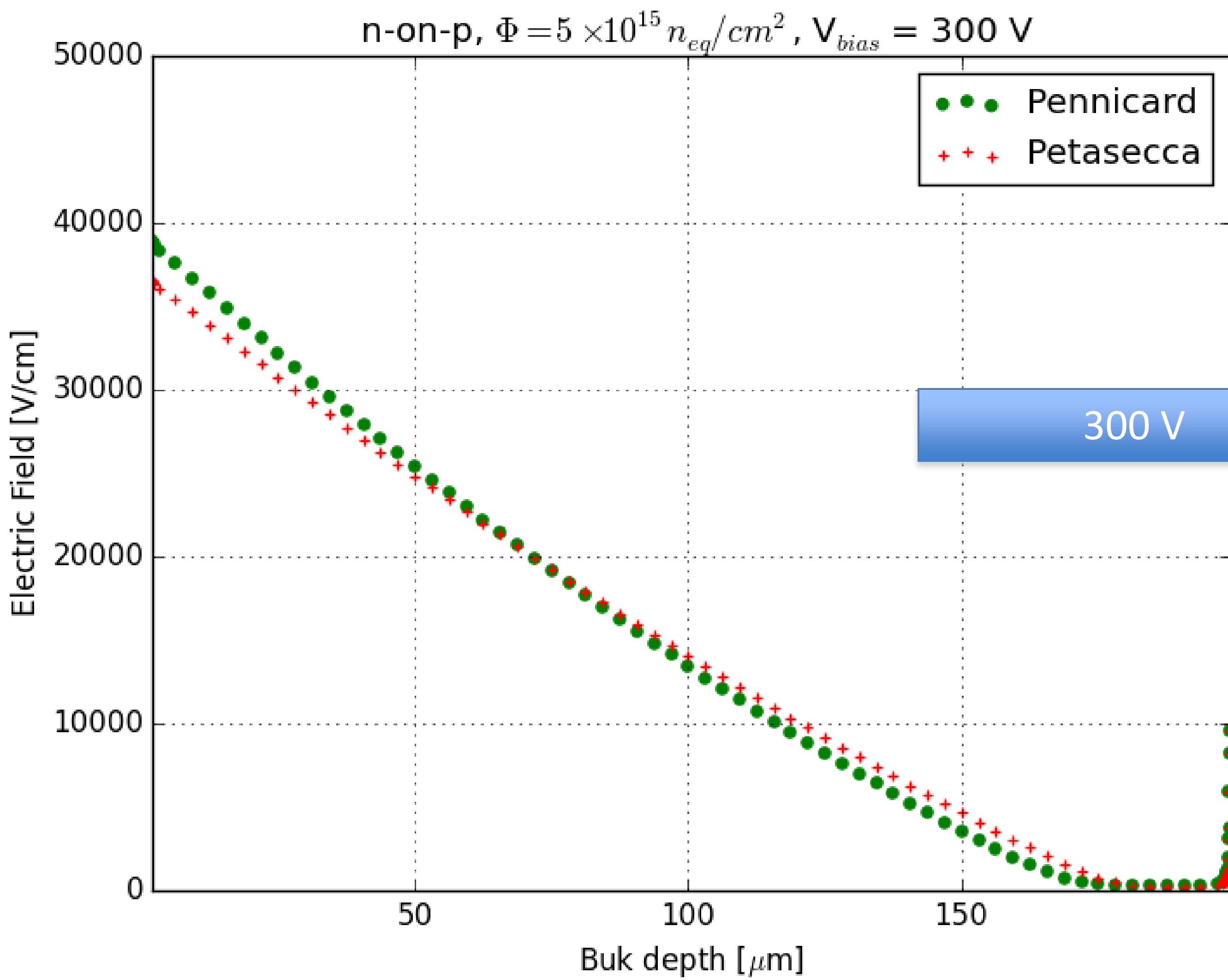
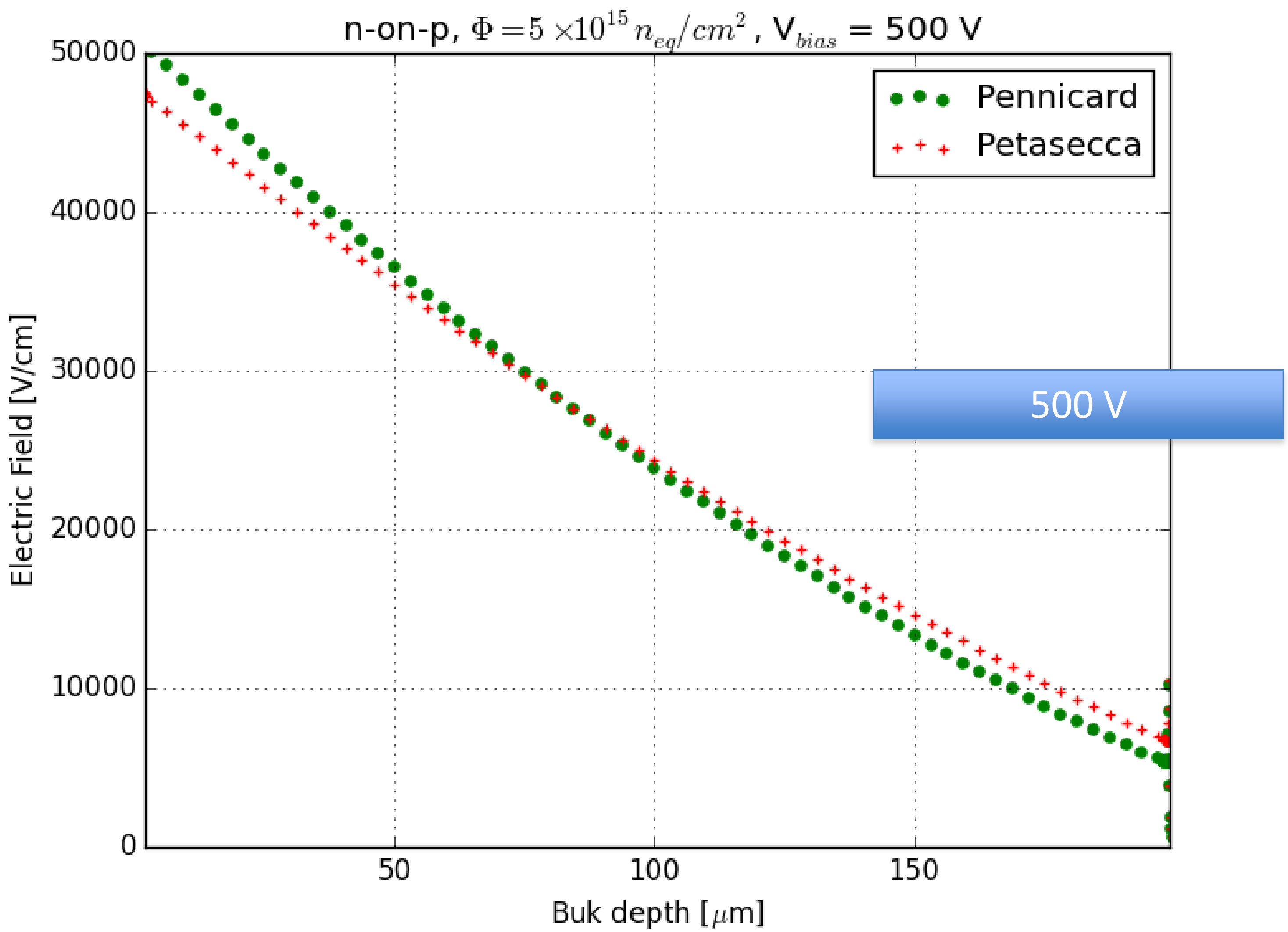
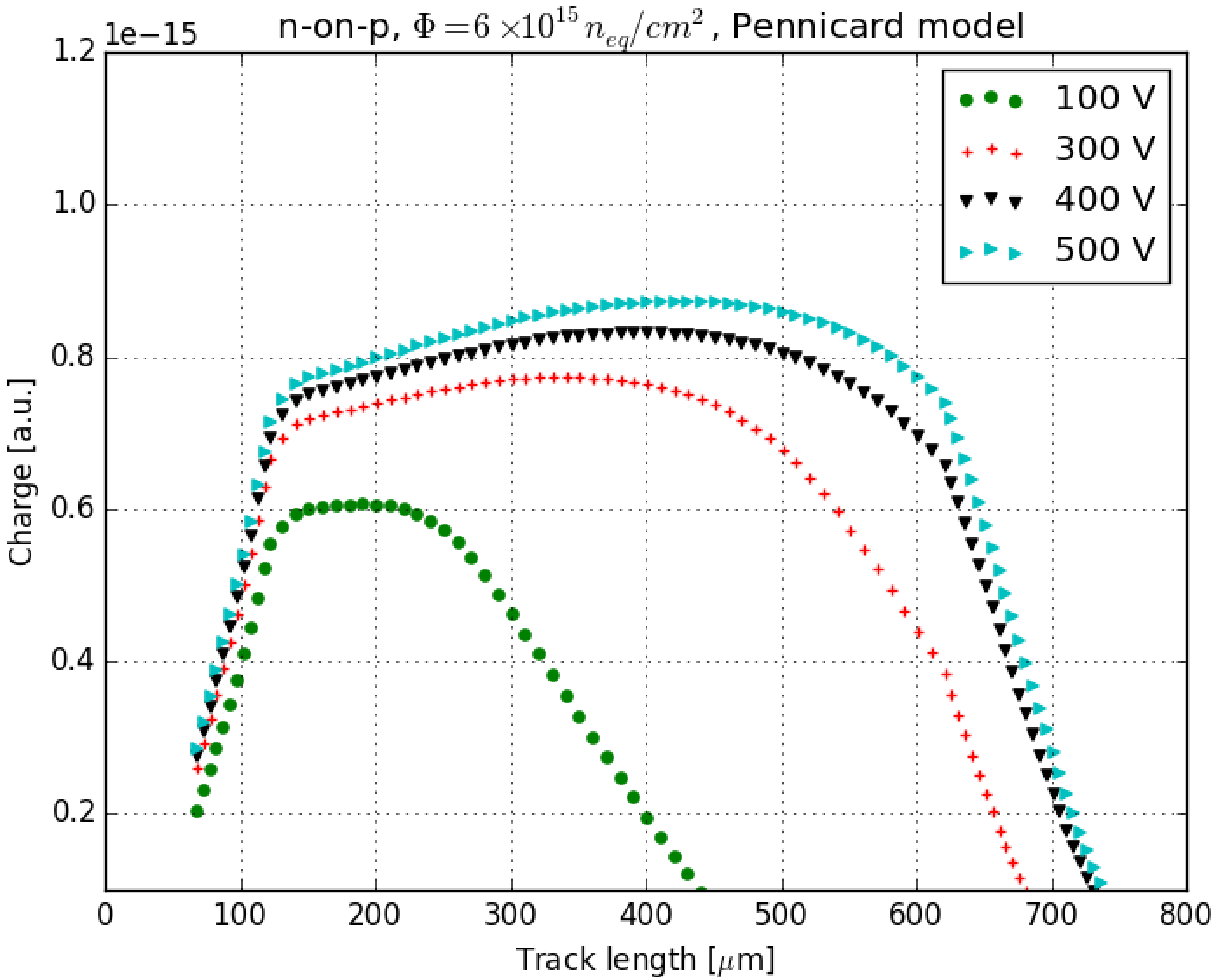


300 V

MPI_VTT-NP2-20-E4 - Electric field comparison



MPI_VTT-NP2-20-E4 – Charge profile



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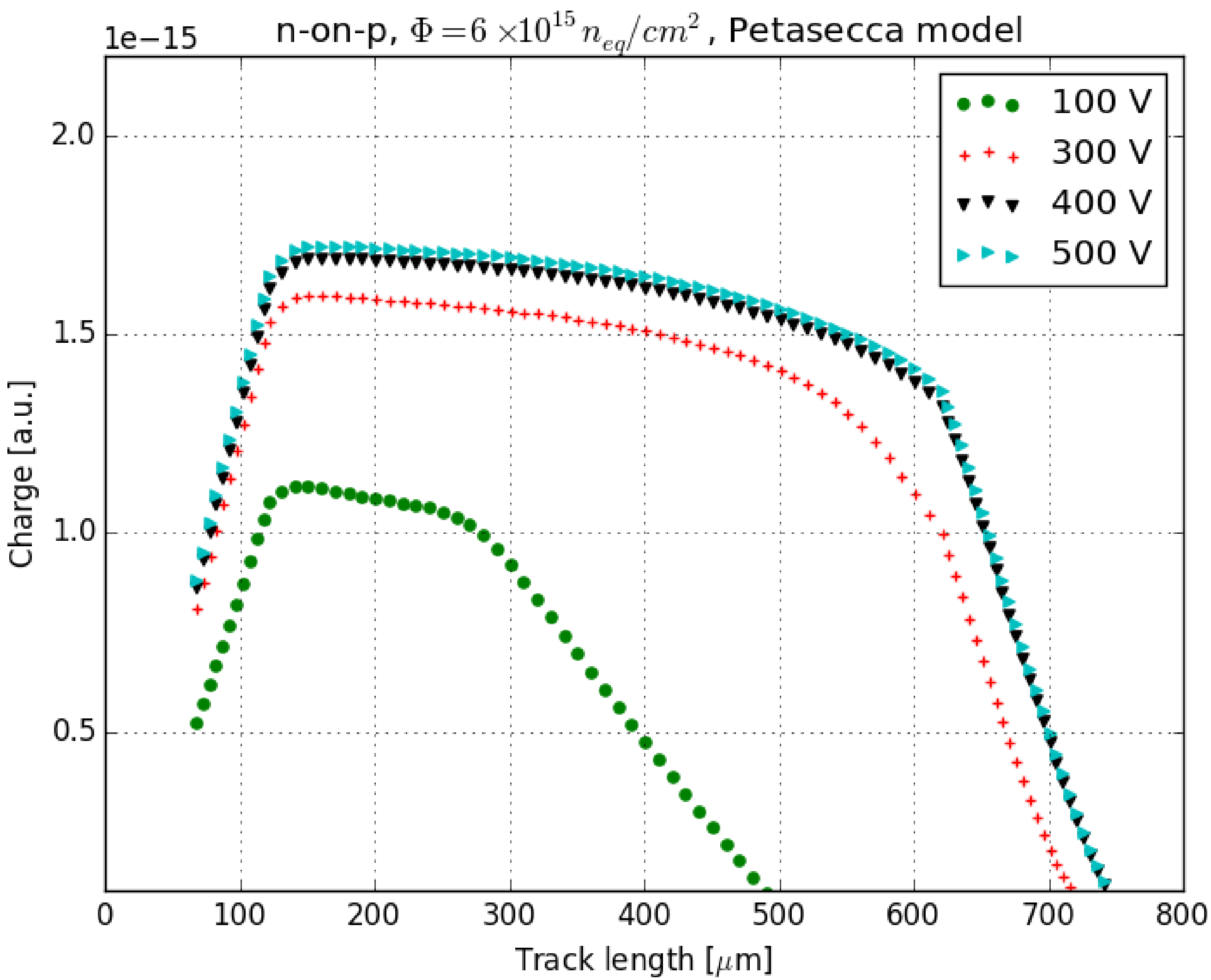

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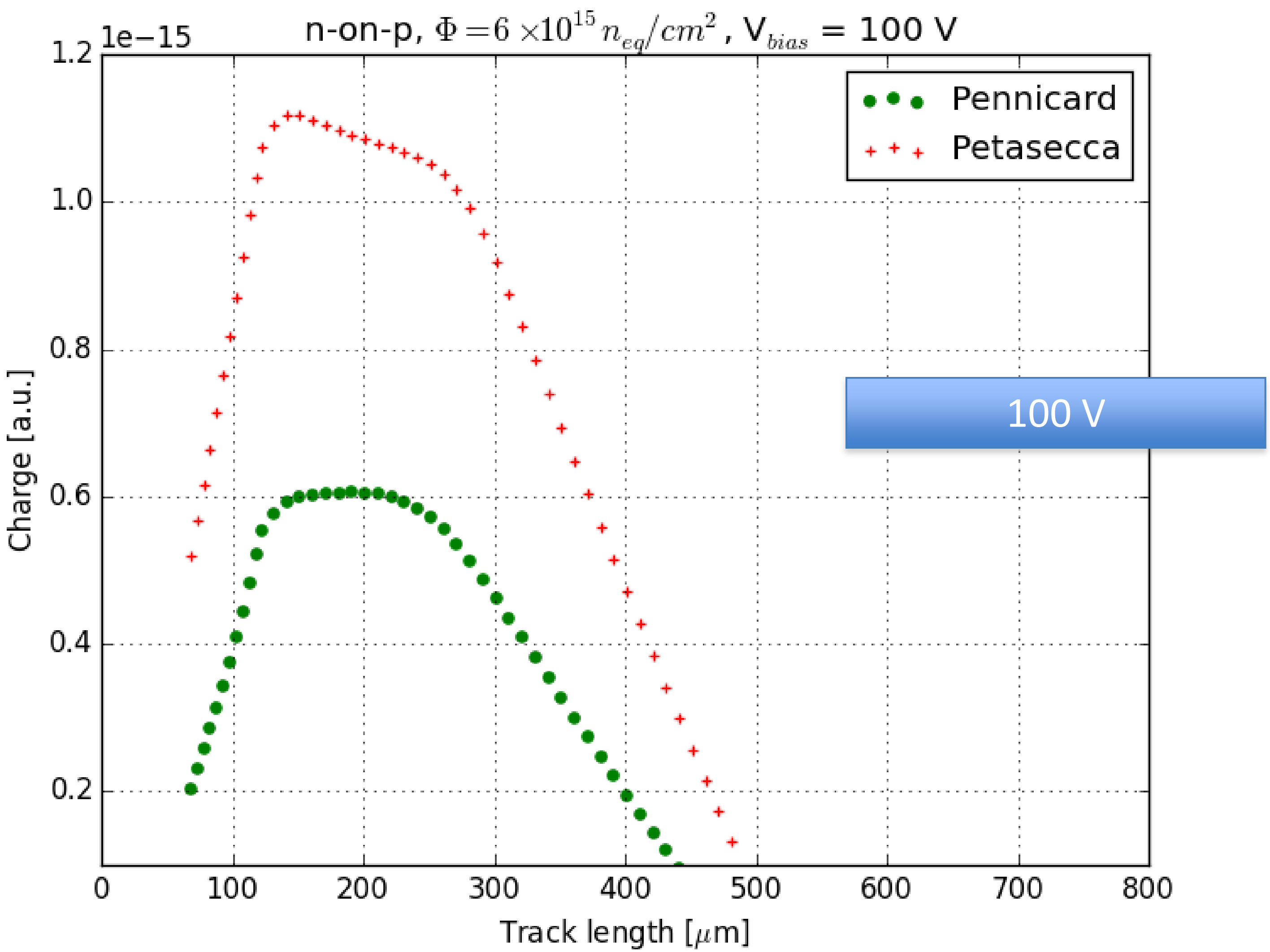
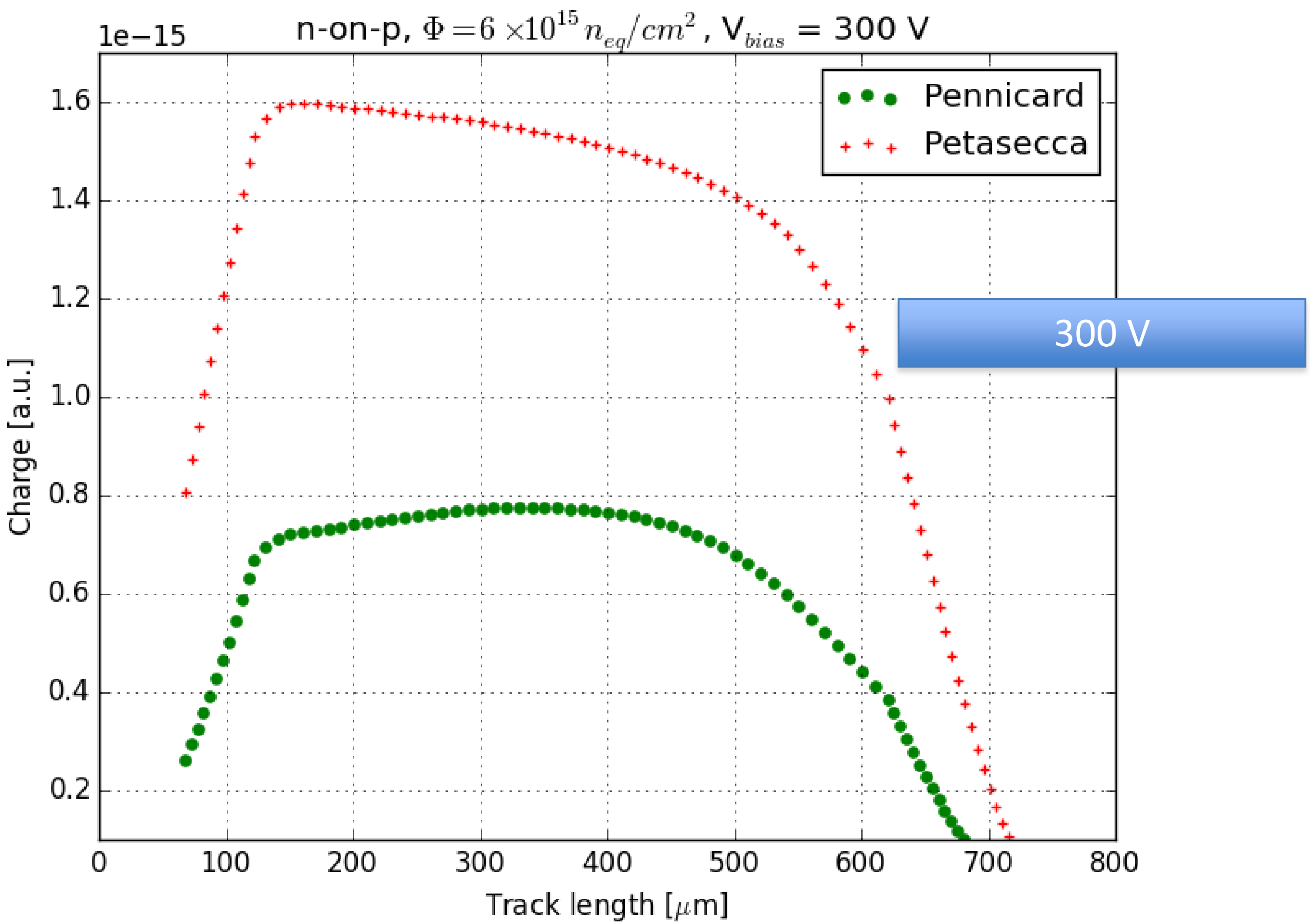


MPI_VTT-NP2-20-E4 – Charge profile comparison



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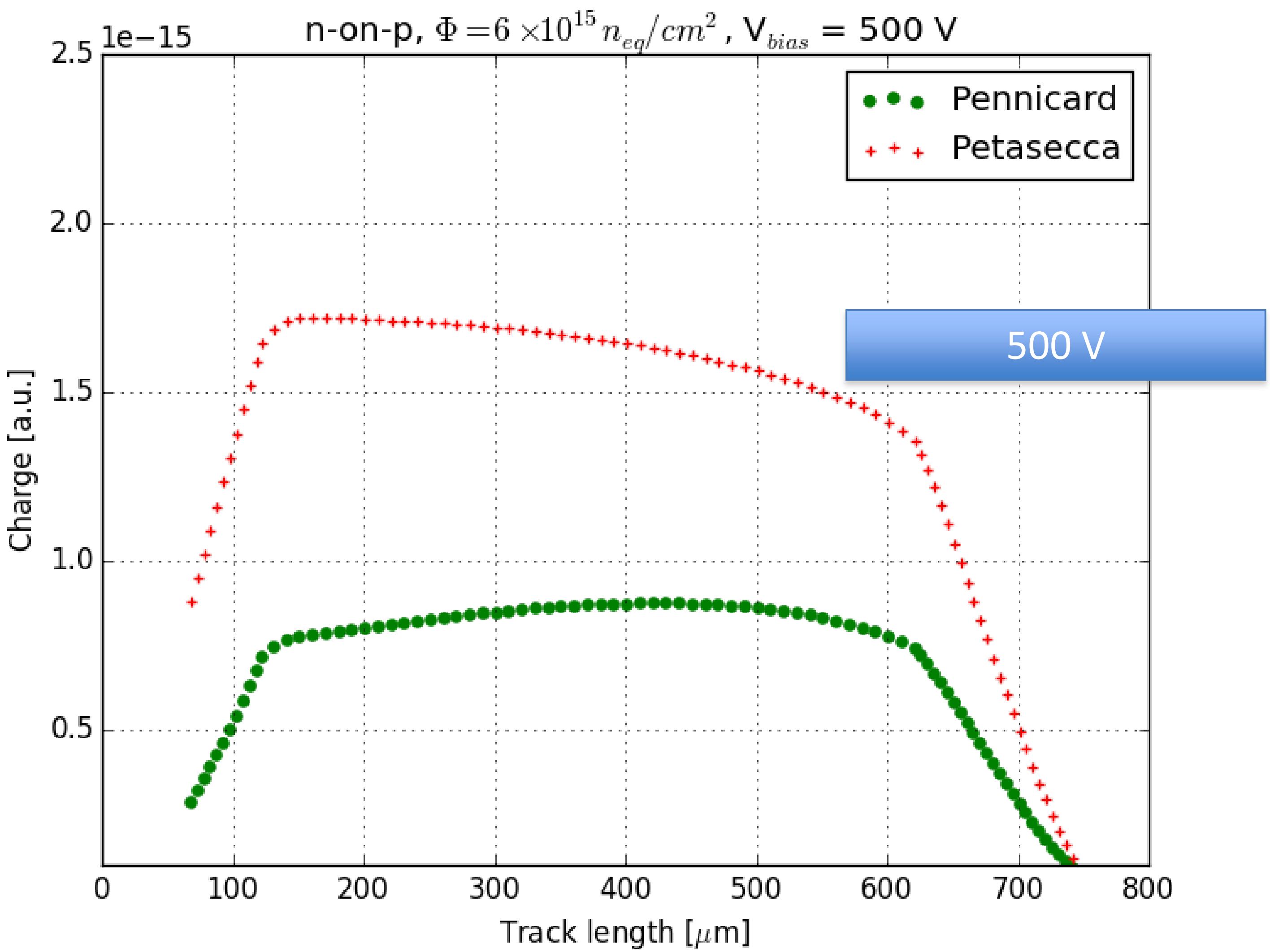

Discussion of n-on-p results

- The two models predict very similar electric field profiles
- On the contrary the two models predict different charge profiles
- The reason for this is apparently the different values for (some of the) emission/capture cross-section
- To confirm/discard a model good charge calibration for data and simulation are needed!

N-ON-N RESULTS

N-on-n samples

type	Name (and group)	Thickness (μm)	Irradiation type & Fluence (10^{15} n_{eq}/cm^{2})
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Reminder: N-bulk irradiation models

Petasecca model for N-type

Level	Ass.	$\sigma_{n,p}$ (cm^2) Exp.[2,9]	σ_n (cm^2)	σ_p (cm^2)	η (cm^{-1})
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Ev+0.36eV	C_iO_i	2.5×10^{-15}	2×10^{-18}	2.5×10^{-15}	1.1

EVL model for N-type

Plus: fluence dependent carrier lifetime

Trap	E (eV)	g_{int} (cm^{-1})	σ_e (cm^2)	σ_h (cm^2)
Donor	$E_V + 0.48$	6	1×10^{-15}	1×10^{-15}
Acceptor	$E_C - 0.525$	3.7	1×10^{-15}	1×10^{-15}

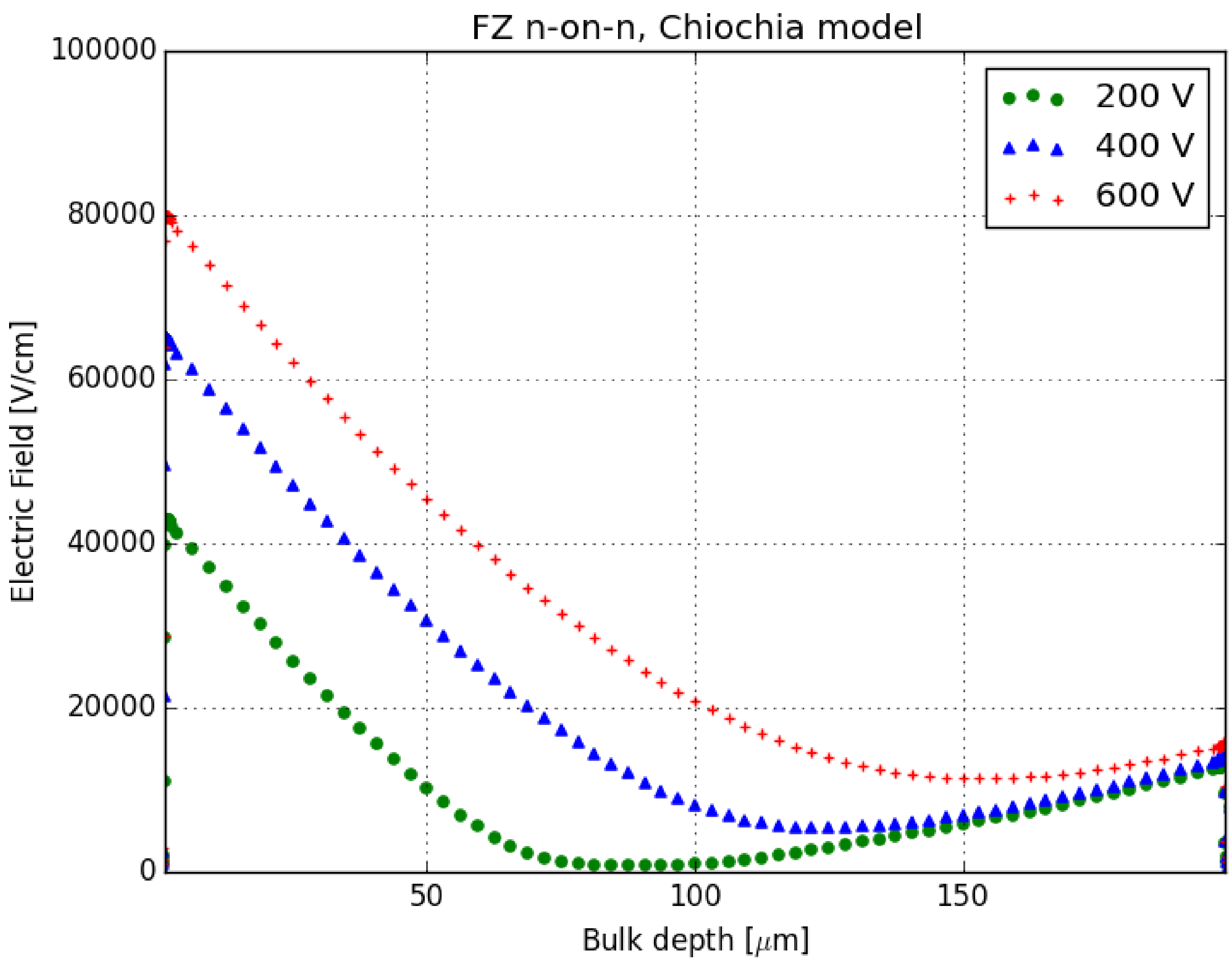
Chiochia model for N-type

Same levels as EVL model

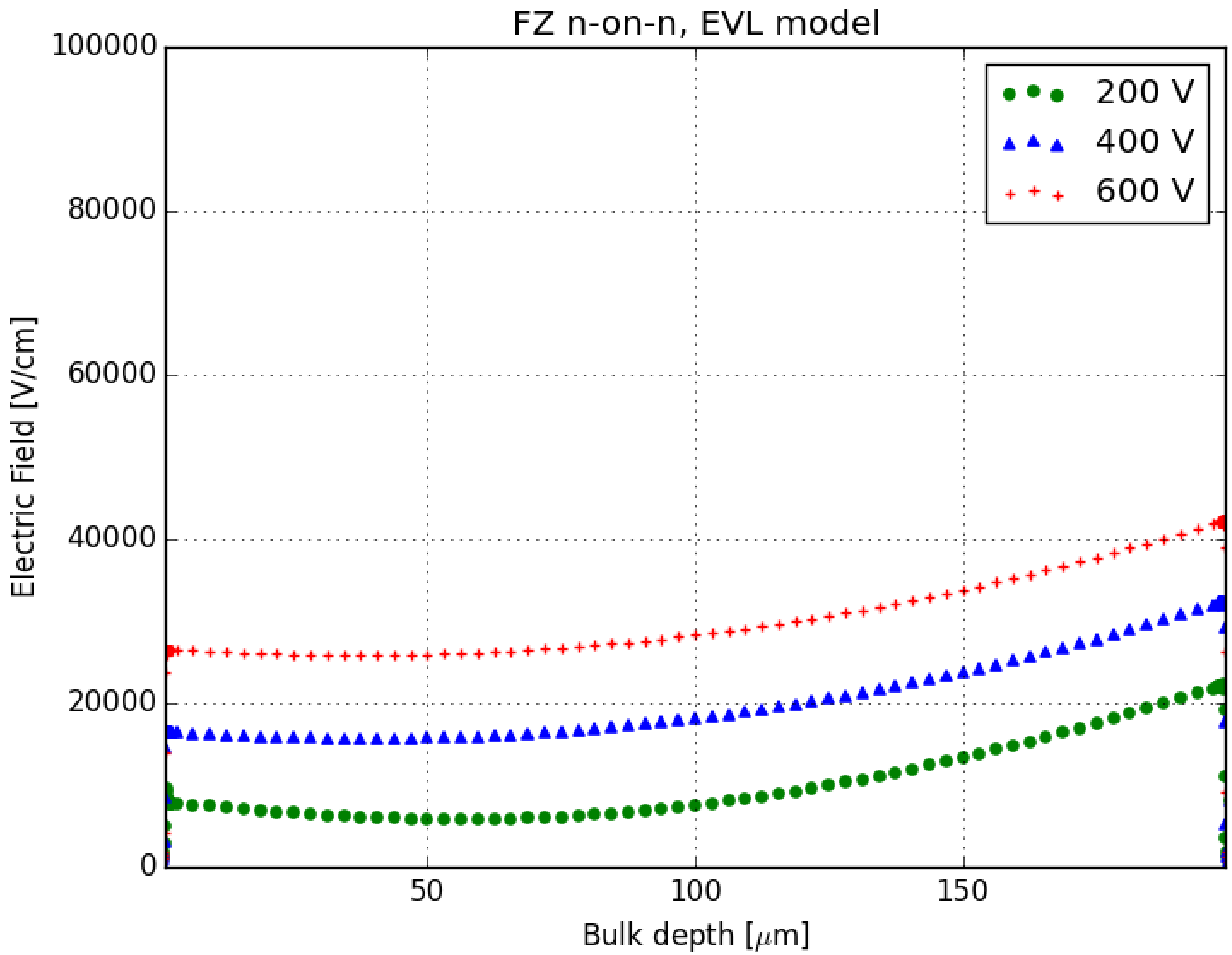
Φ (n_{eq}/cm^2) ($\times10^{14}$)	N_A(cm^{-3}) ($\times10^{15}$)	N_D(cm^{-3}) ($\times10^{15}$)	$\sigma_e^{A/D}$(cm^2) ($\times10^{-15}$)	σ_h^A(cm^2) ($\times10^{-15}$)	(cm^2) σ_h^D ($\times10^{-15}$)
0.5	0.19	0.25	6.60	1.65	6.60
2	0.68	1.0	6.60	1.65	6.60
5.9	1.60	4.0	6.60	1.65	1.65

THIN N-ON-N SENSORS

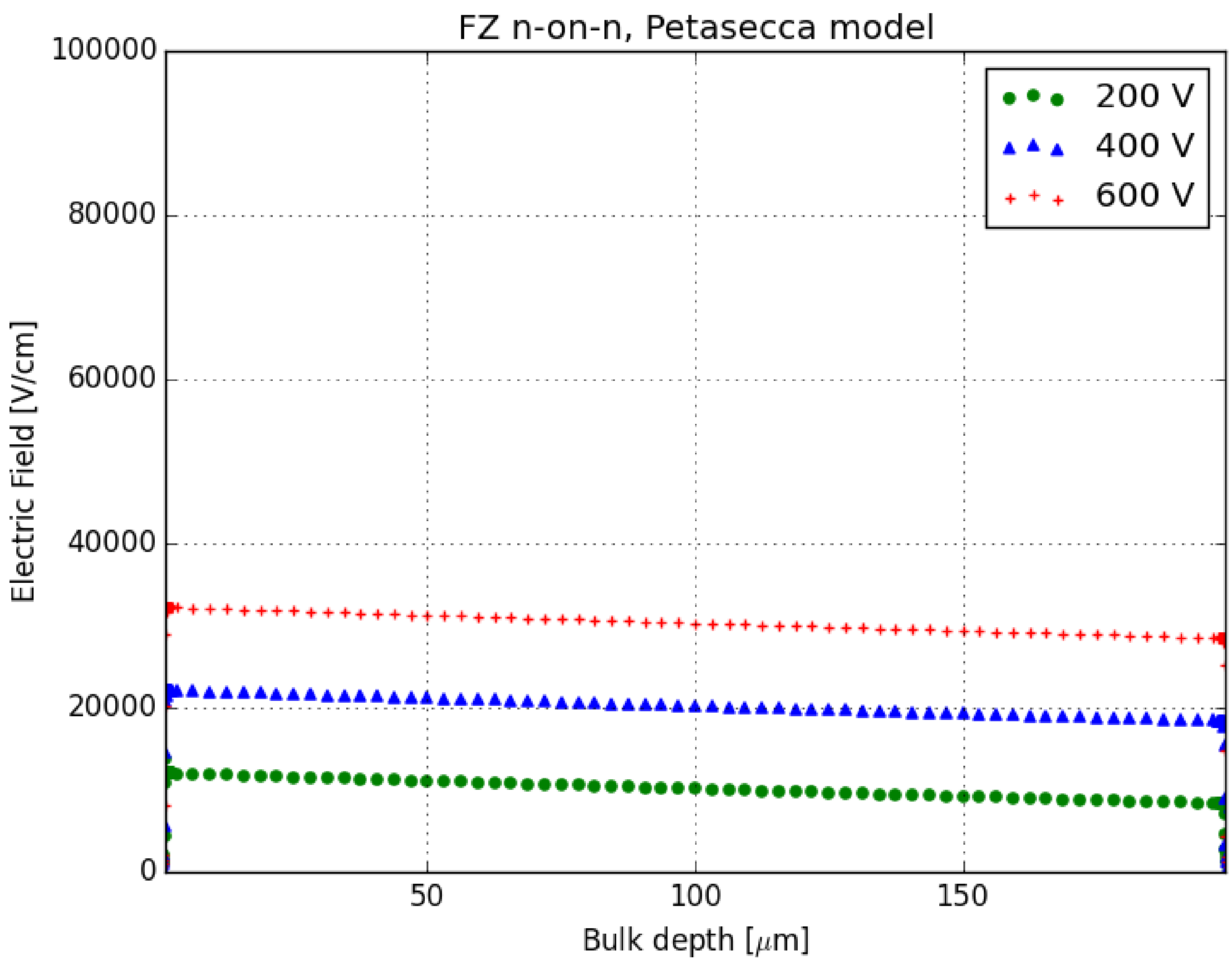
DO_FZ – Electric field profile



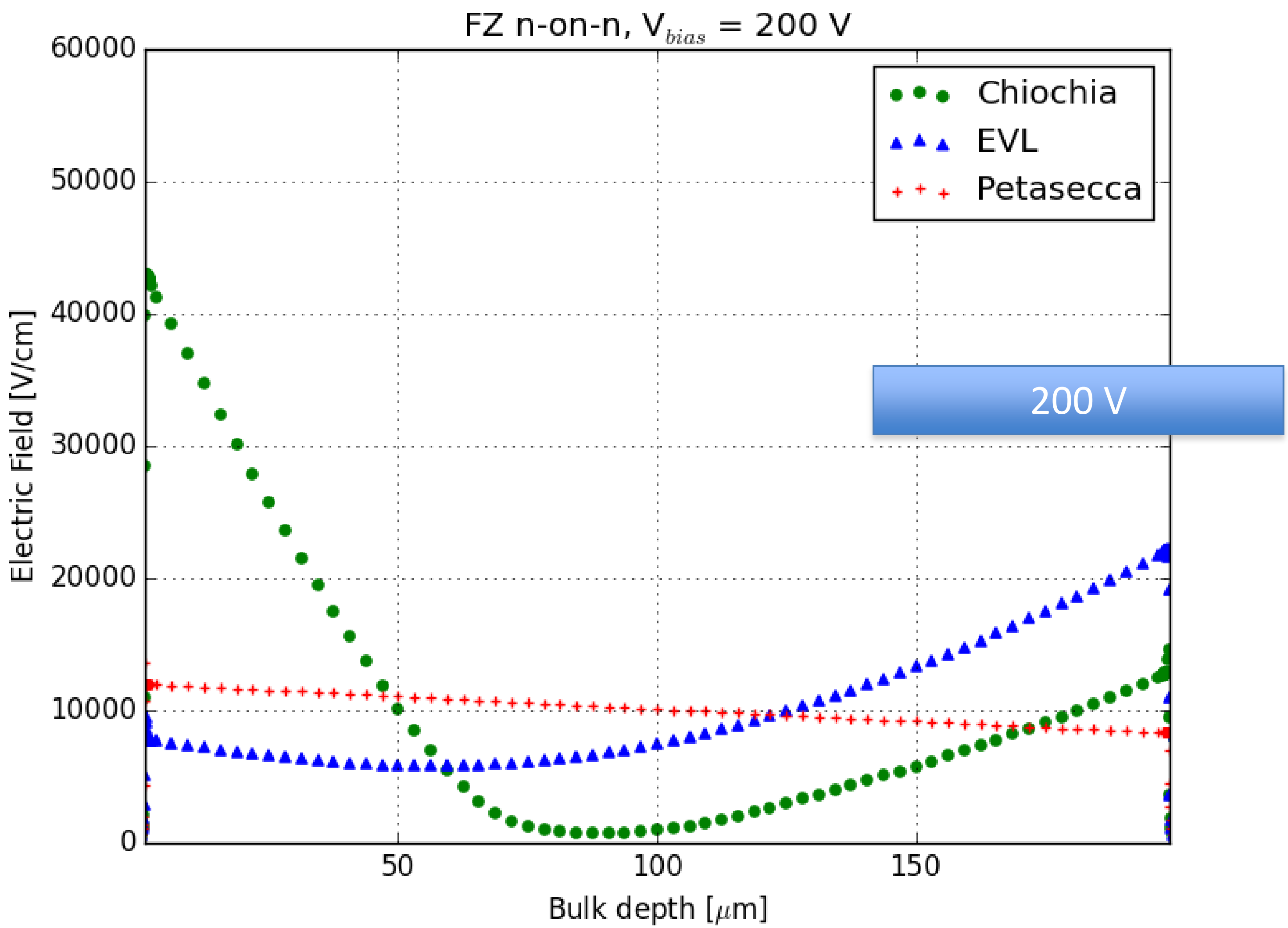
DO_FZ – Electric field profile



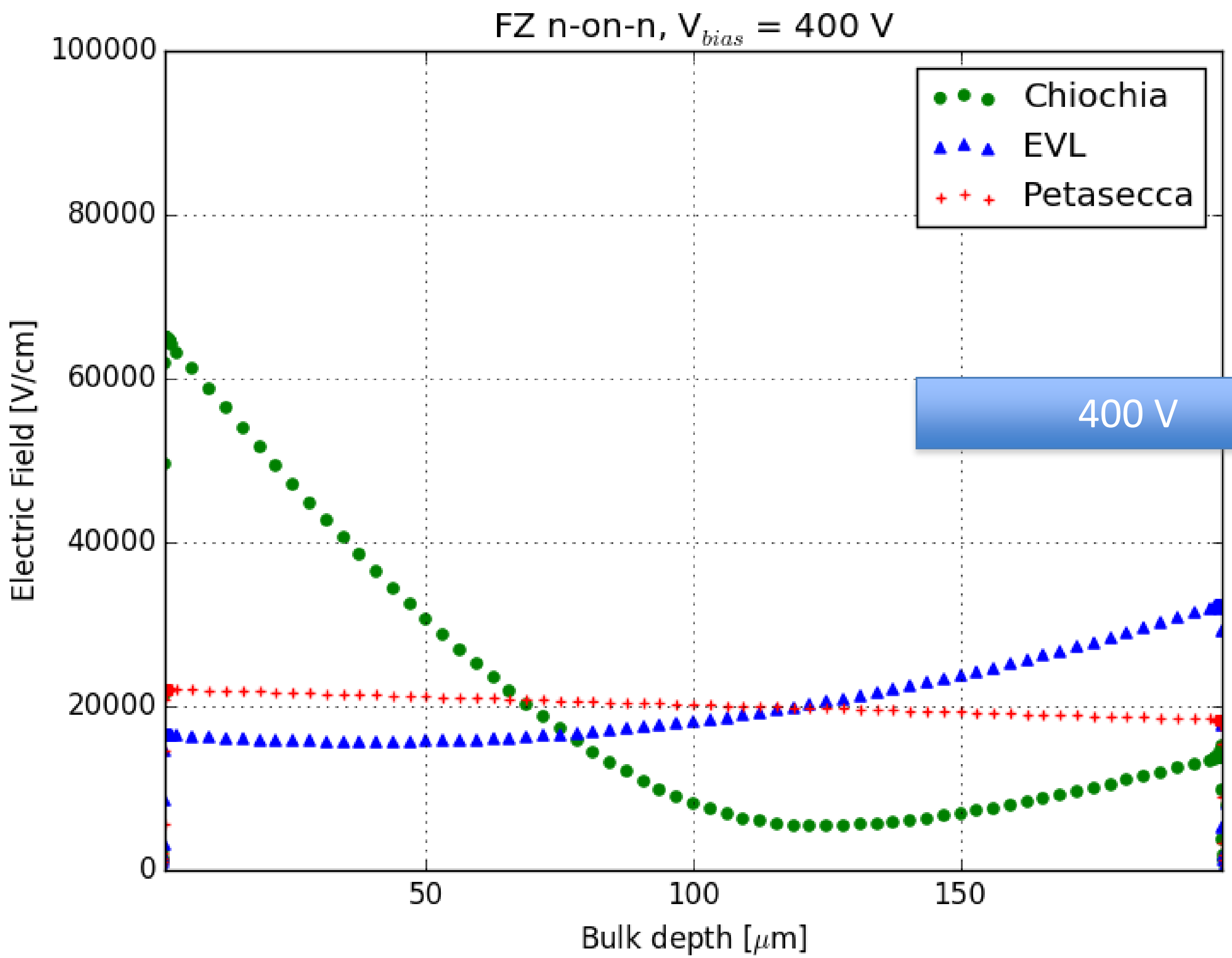
DO_FZ – Electric field profile



DO_FZ – Electric field profile comparison

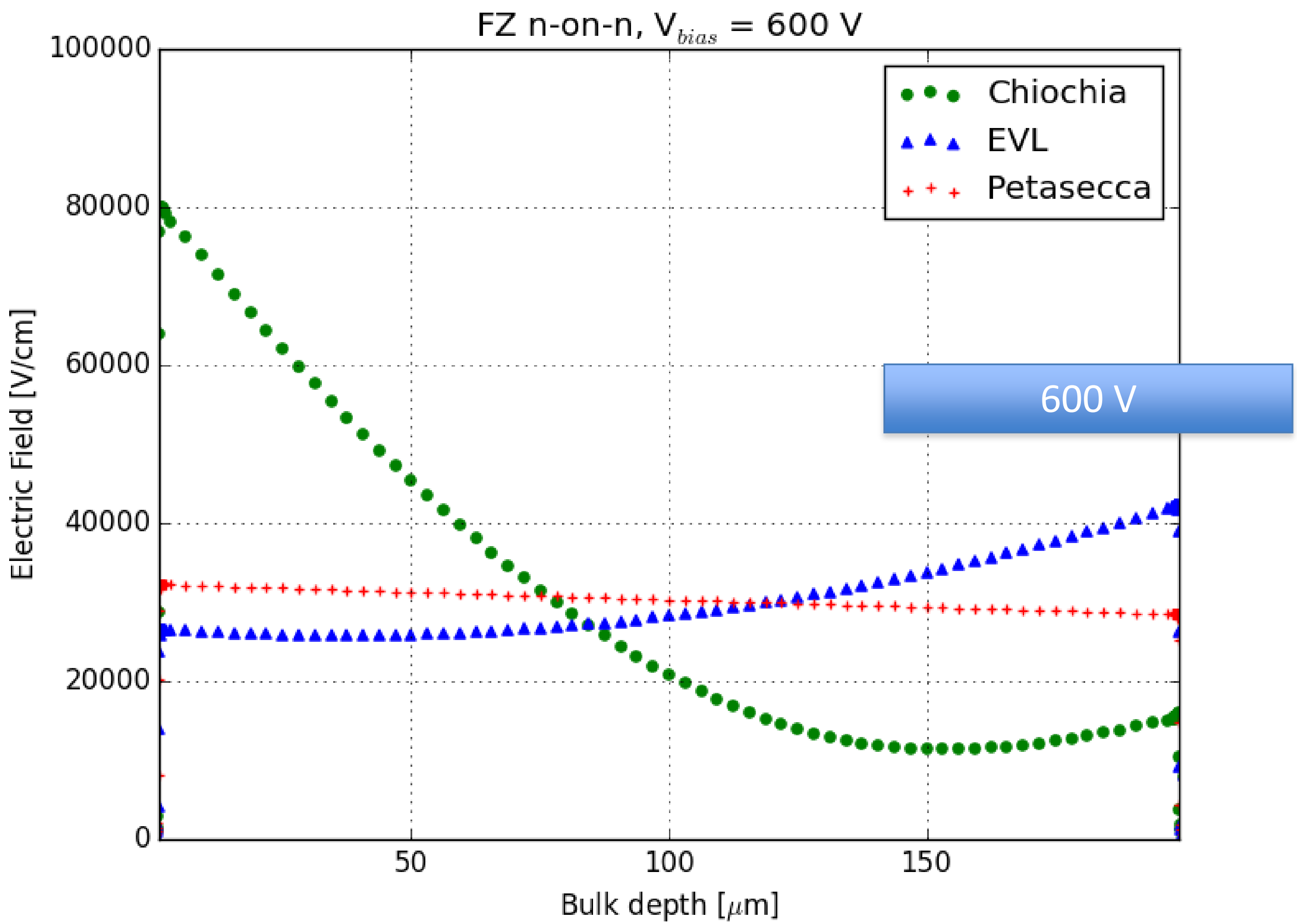


DO_FZ – Electric field profile comparison

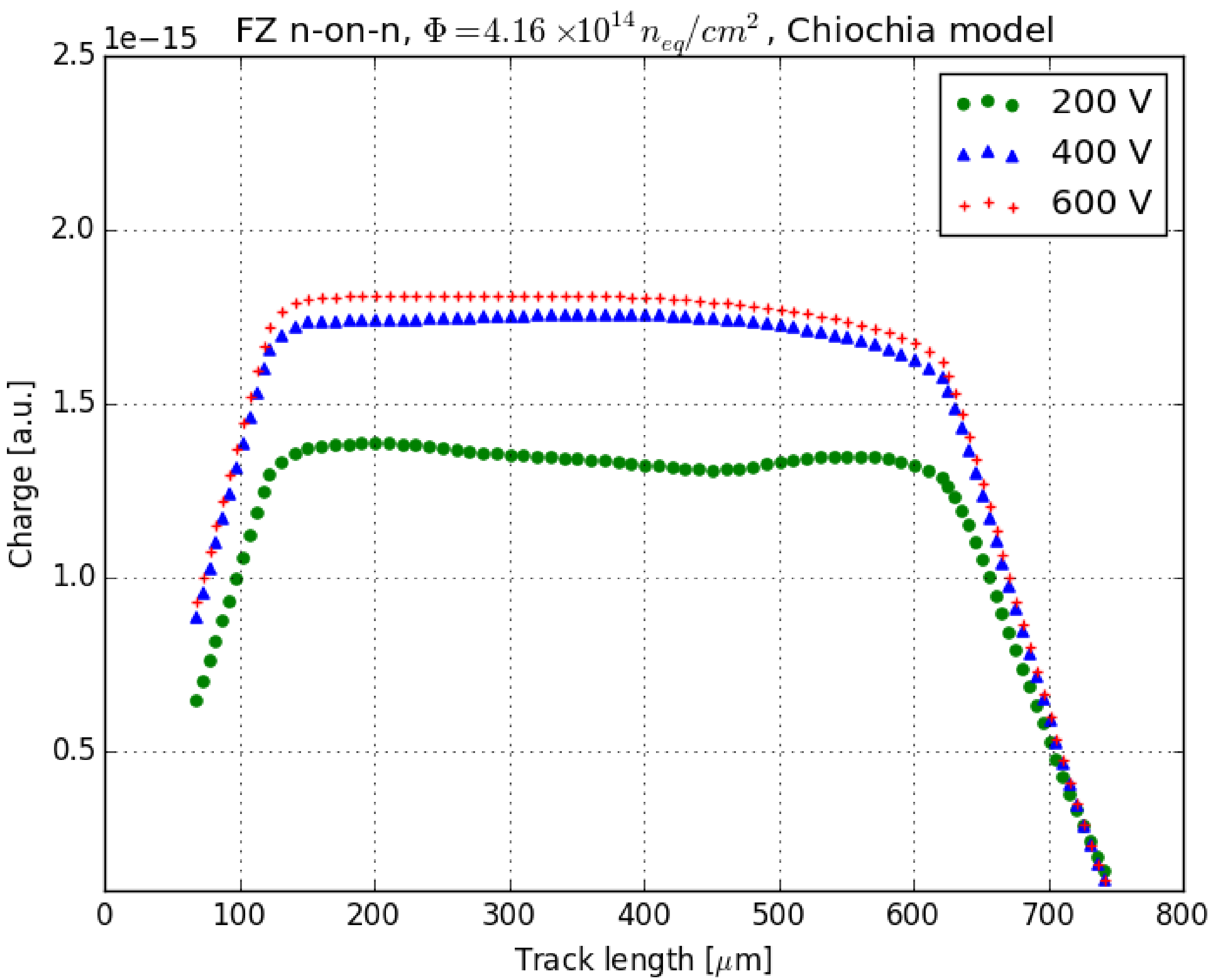


400 V

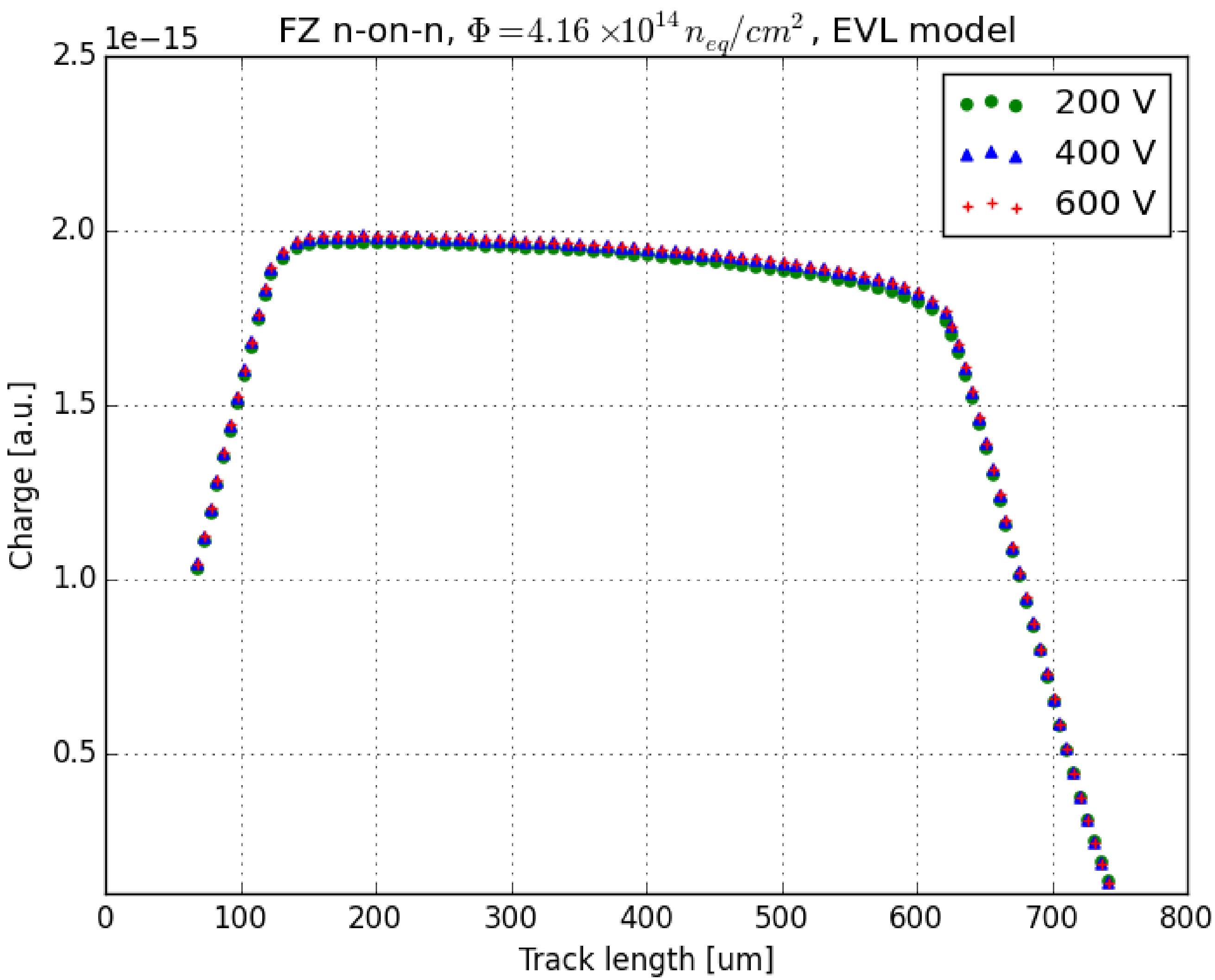
DO_FZ – Electric field profile comparison



DO_FZ – Charge profile



DO_FZ – Charge profile



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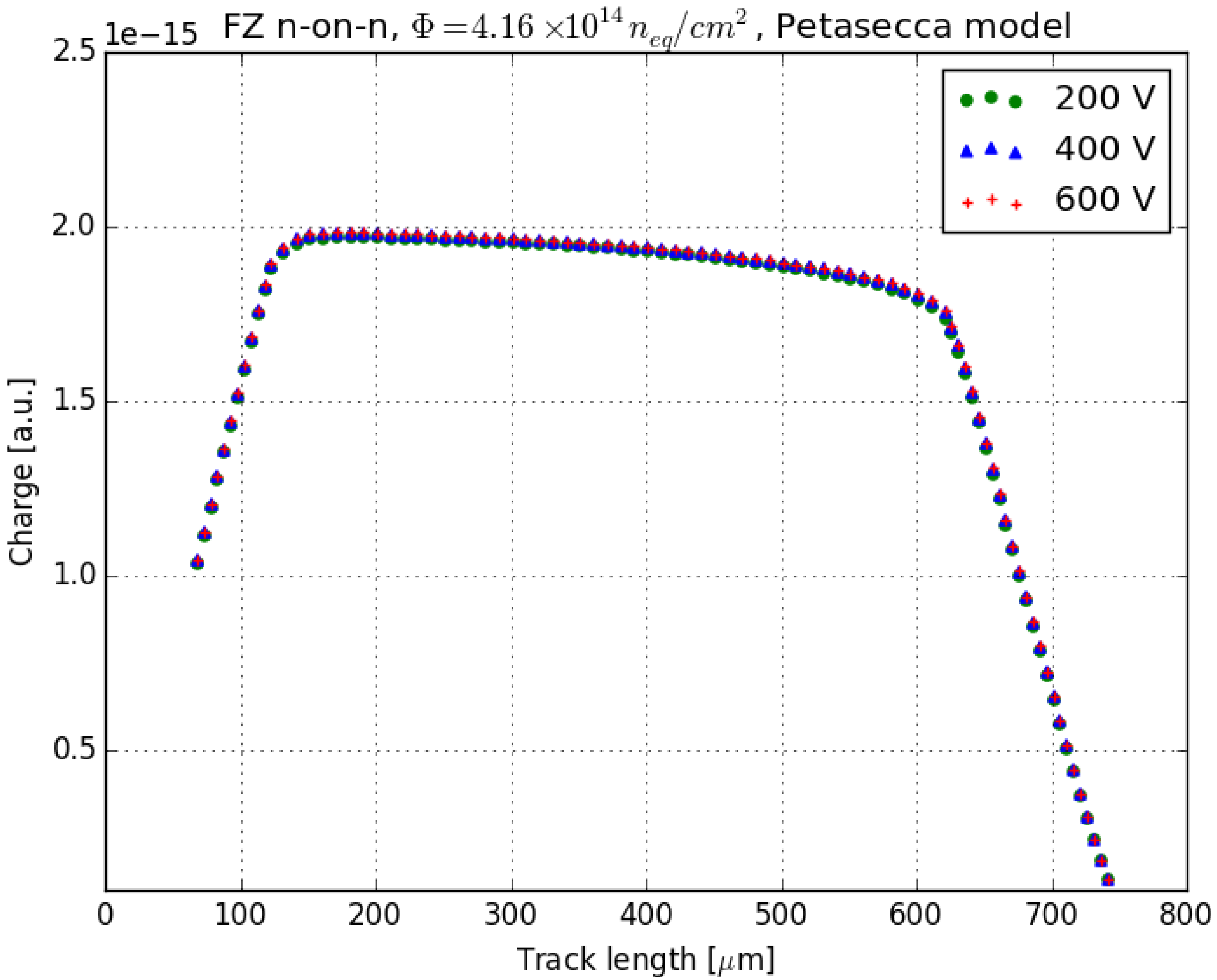

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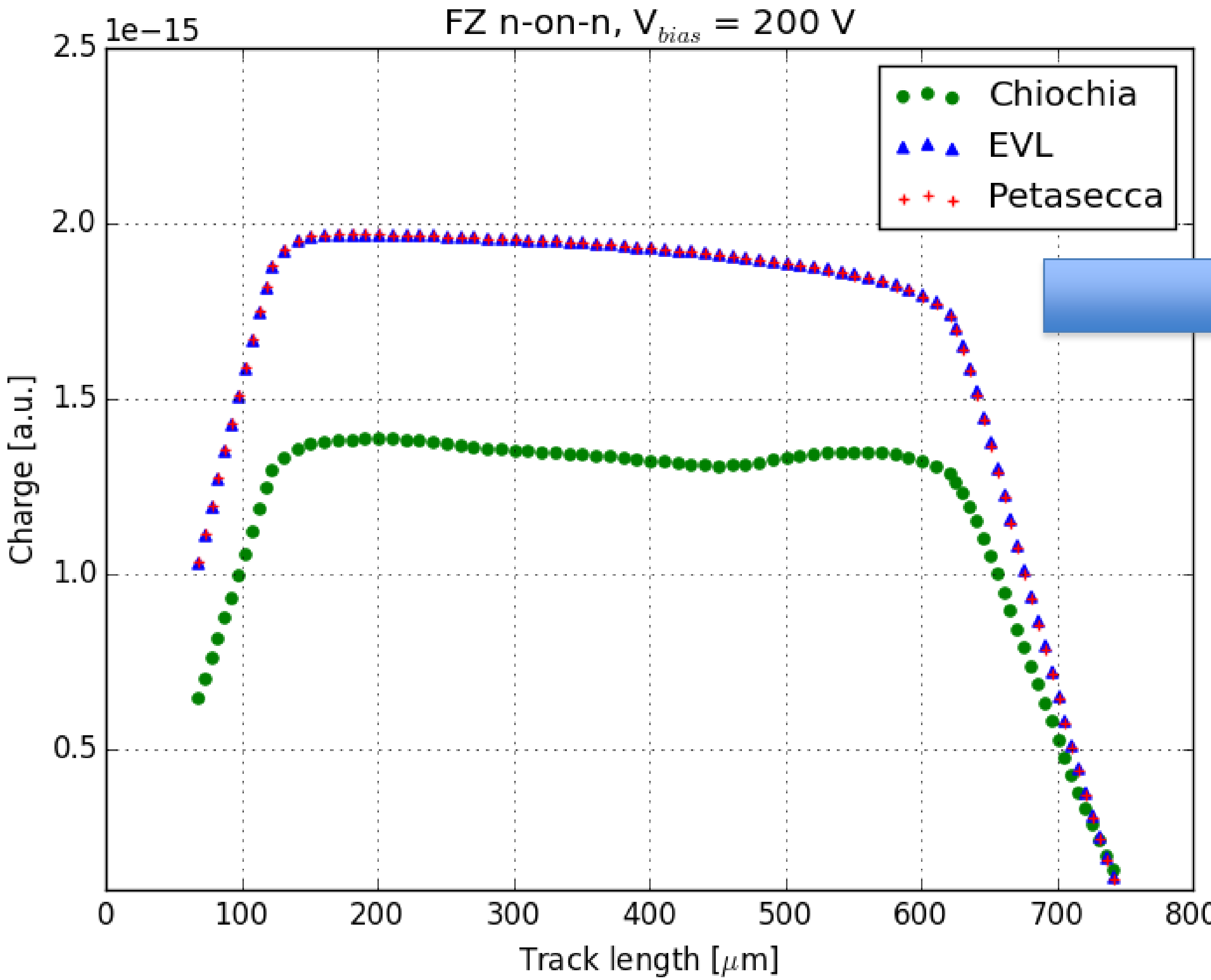
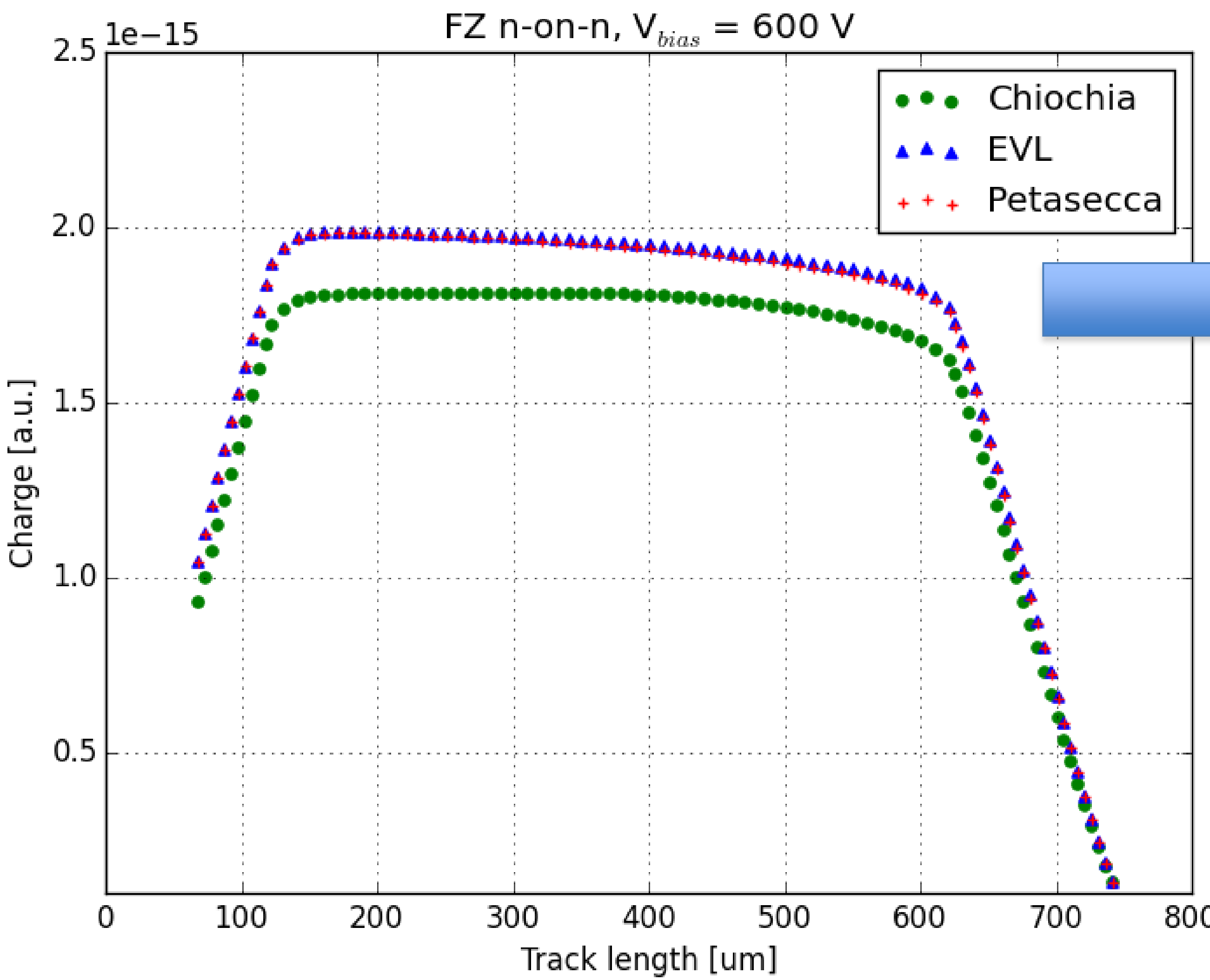


200 V

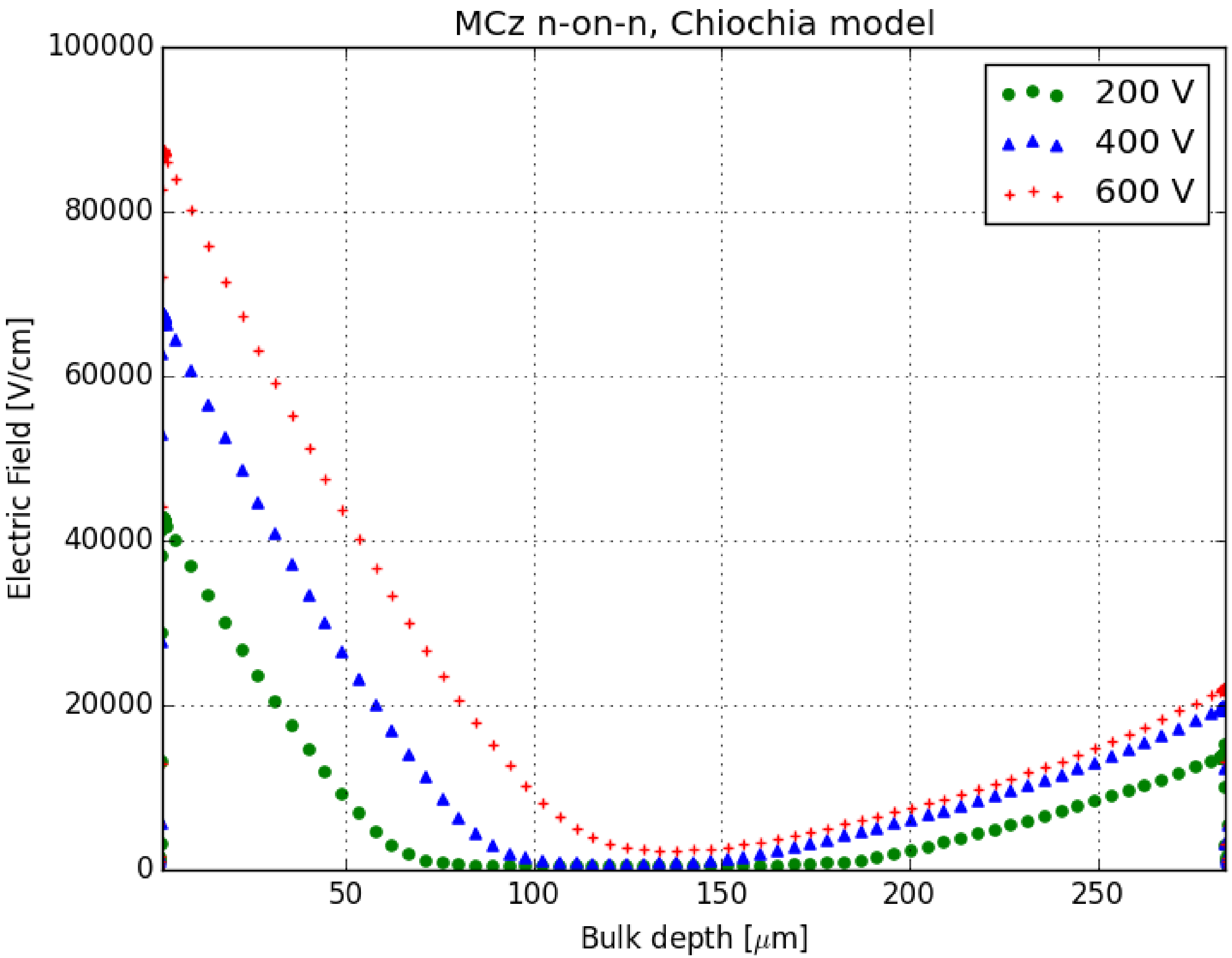
DO_FZ – Charge profile comparison



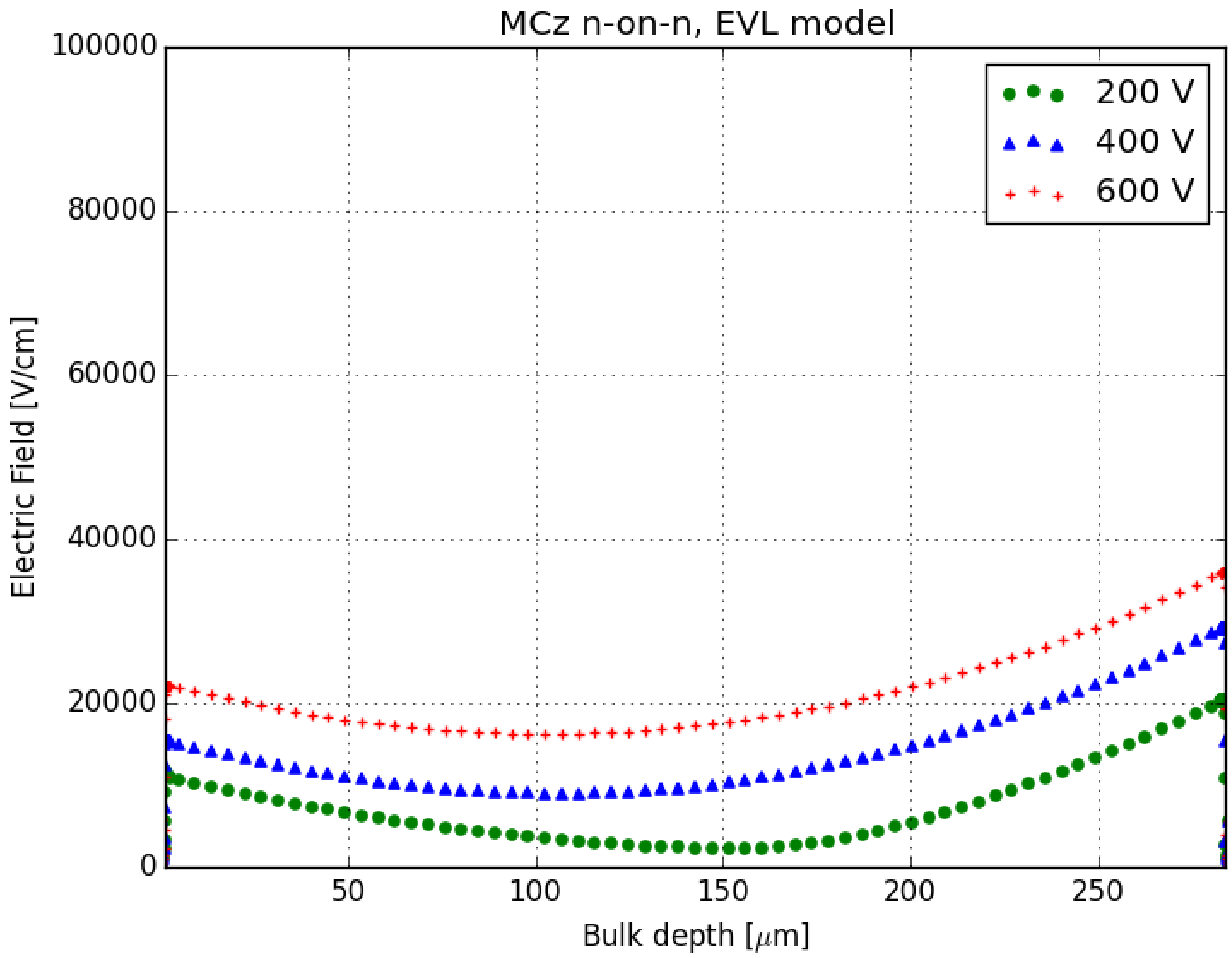
600 V

THICK N-ON-N SENSOR

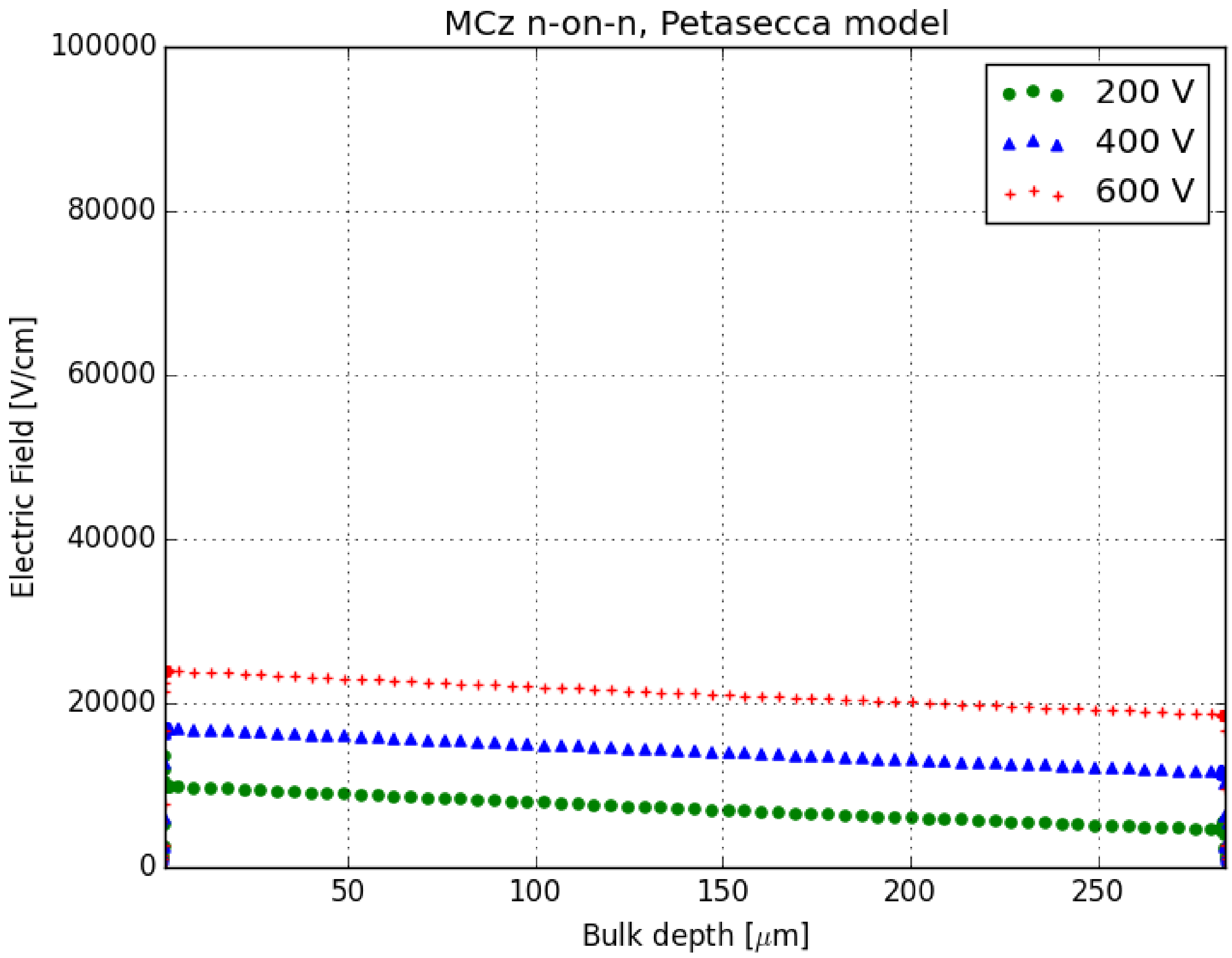
DO_MCz – Electric field profile



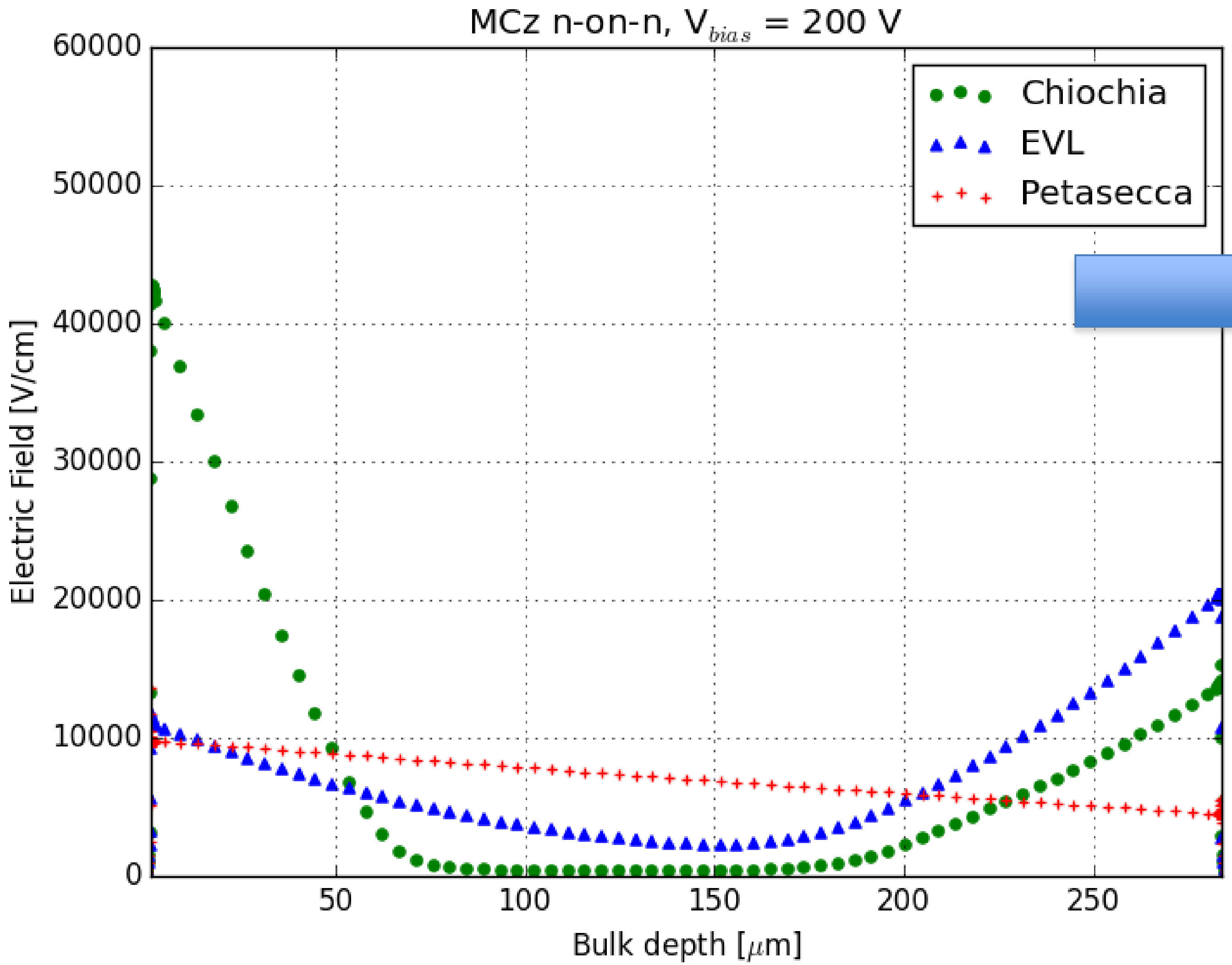
DO_MCz – Electric field profile



DO_MCz – Electric field profile

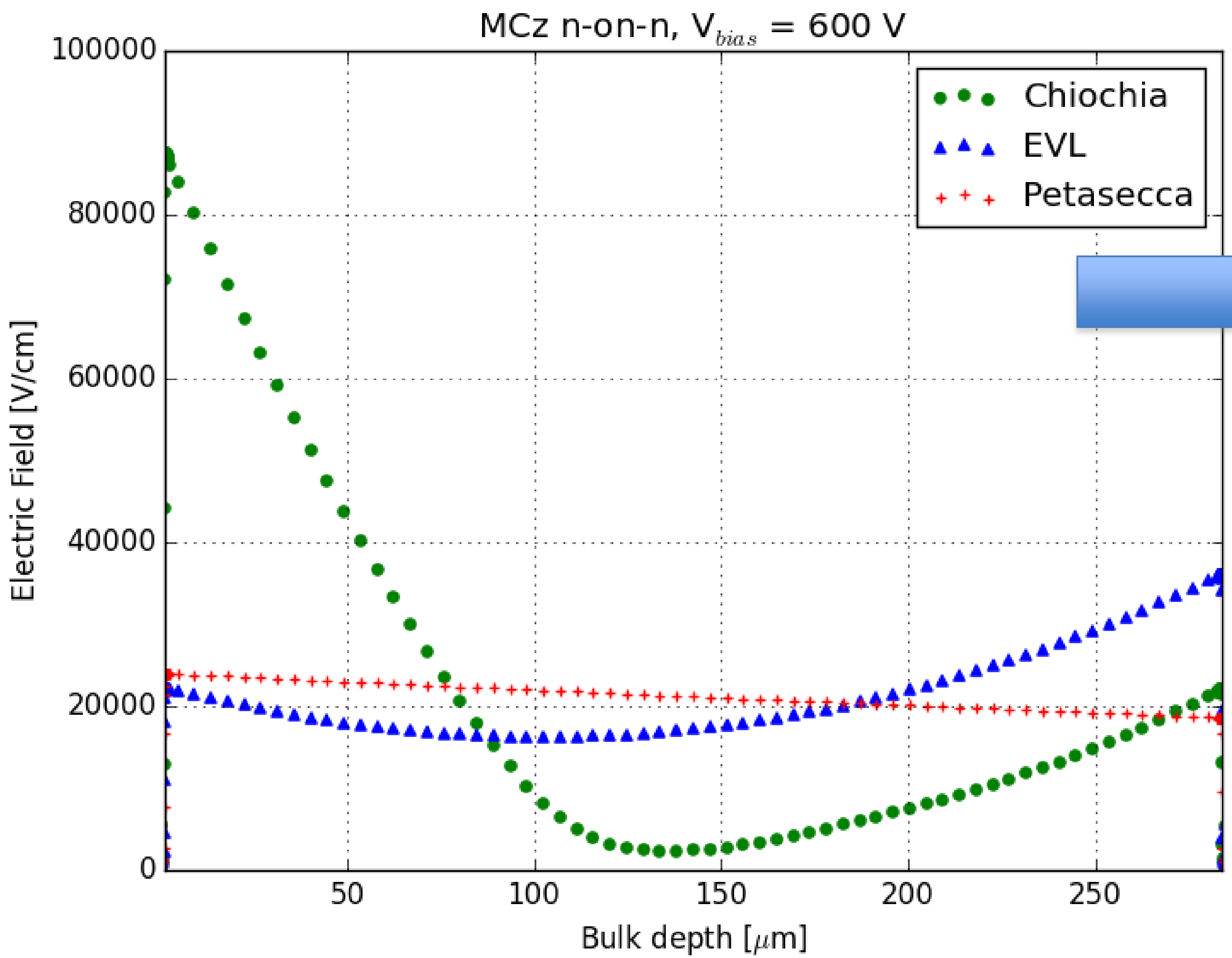


DO_MCz – Electric field profile comparison



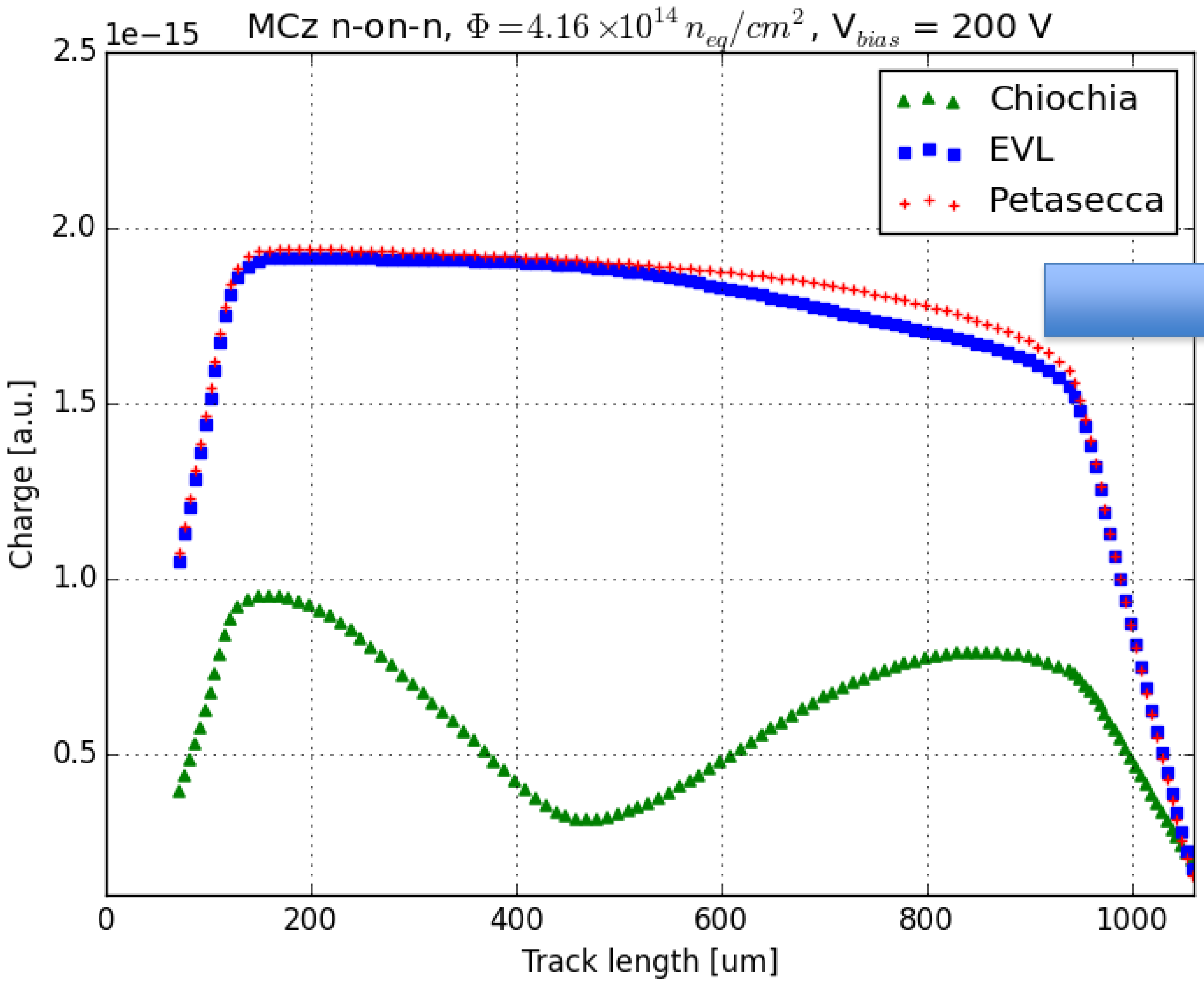
200 V

DO_MCz – Electric field profile comparison



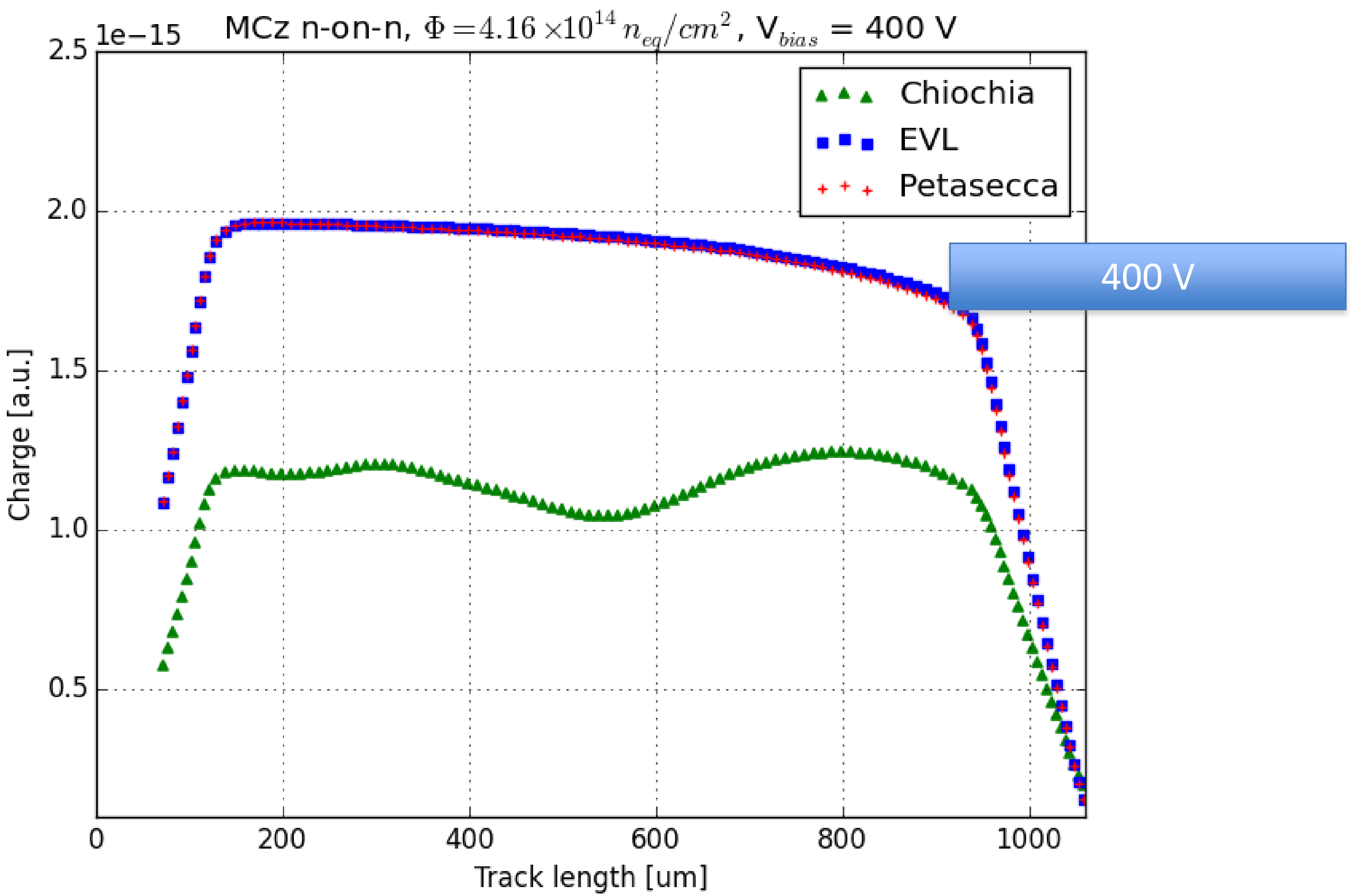
600 V

DO_MCz – Charge profile

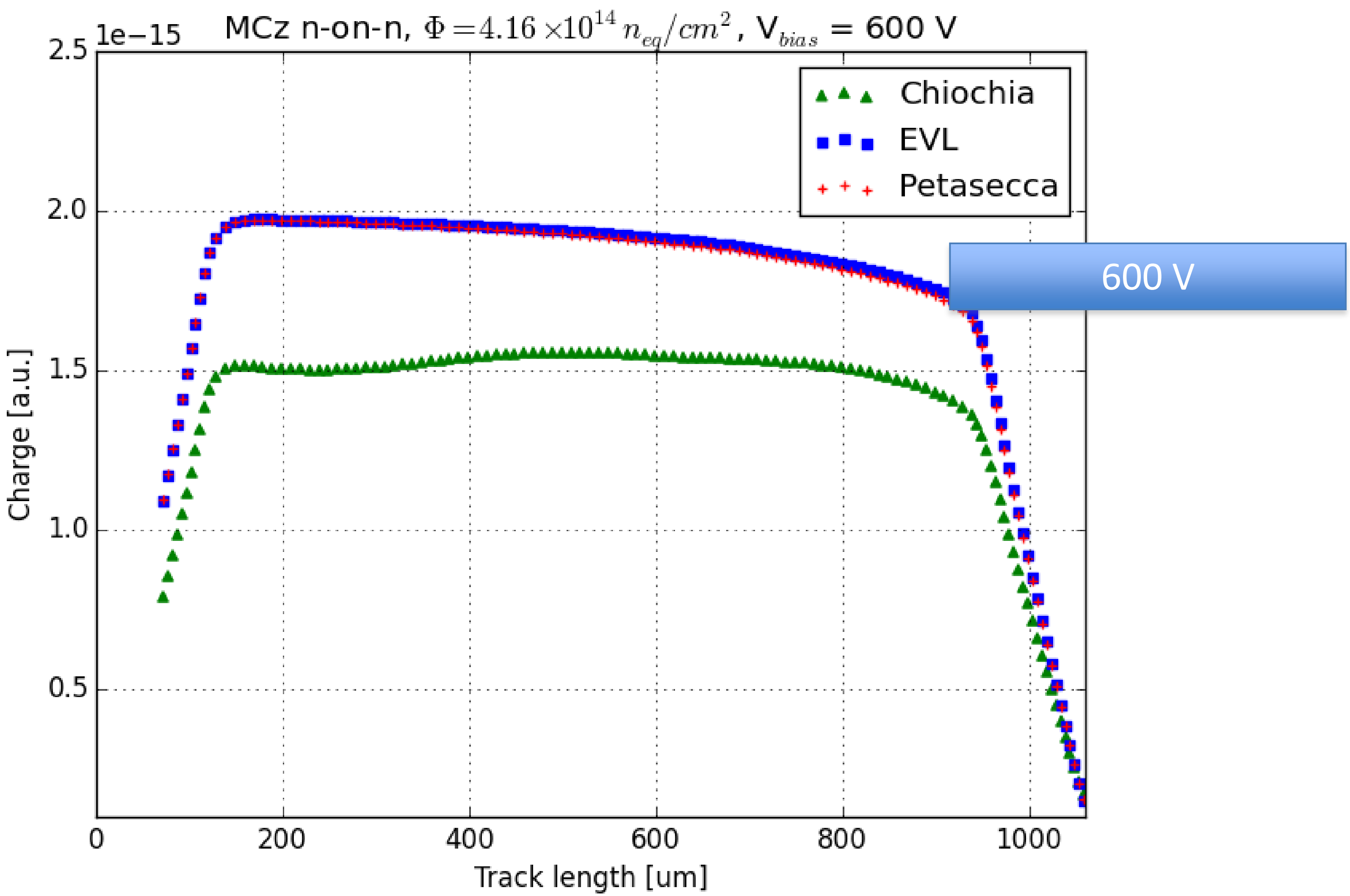


200 V

DO_MCz – Charge profile



DO_MCz – Charge profile



Discussion of n-on-n results

- At very low fluence only the Chiochia model predicts a quite “structured” charge profile
  - But only for small bias voltages
- The test has to be repeated for larger fluences

CONCLUSIONS & OUTLOOK

Conclusions & outlook

- Combining testbeam data & TCAD simulations for irradiated sensors could give access to important sensor properties like:
- The electric field profile
- The trapping constant
- Detailed simulations for a variety of samples and different radiation damage models have been produced
- Looking forward some testbeam data to compare simulations to