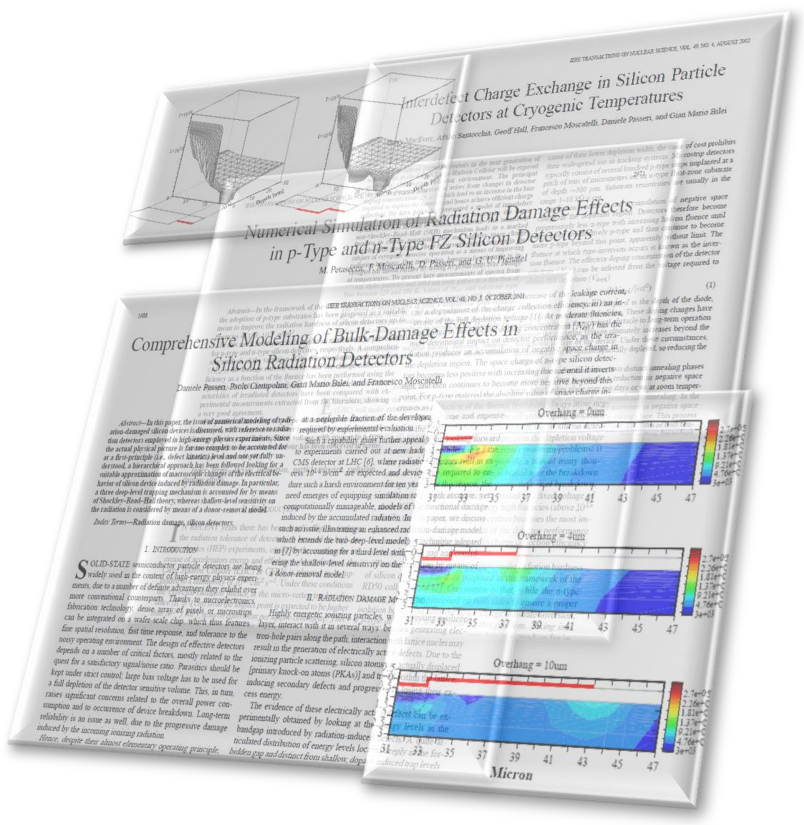
Modeling of Radiation Damage Effects in Silicon Detectors at High Fluences HL LHC with Sentaurus TCAD

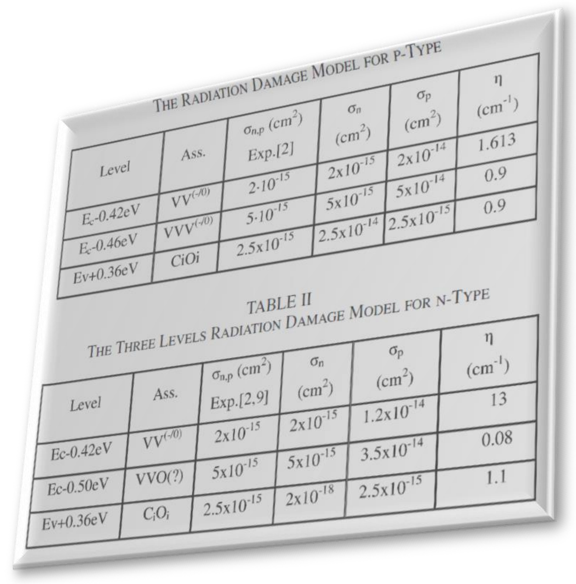
D. Passeri[(1,2,*)], F. Moscatelli[(3)], A. Morozzi[(1,2)], G.M. Bilei[(2)]

1) Dipartimento di Ingegneria, Università di Perugia, via Duranti 93, 06125 Perugia, Italy.
2) Istituto Nazionale di Fisica Nucleare, via Pascoli 1, 06123 Perugia, Italy.
3) Istituto per la Microelettronica e Microsistemi, CNR Bologna, Italy.

Introduction and background

- ✓ TCAD radiation damage: historical perspective (University of Perugia model).
- ✓ Hierarchical approach based on increasing number of deep-level recombination centres / trap states.
- ✓ Comprehensive modelling of device behaviour with fluence:
  - depletion voltage, leakage current (α), "double peak" shaped electric field, charge collection efficiency,…
- ✓ Meaningful and physically sounded parametrization.
- ✓ Three levels with donor removal and increased introduction rate (to cope with direct inter-defect charge exchange numerical issues…).
- ✓ n type and p type substrate.
- ✓ Suitable for fluences up to 10^{15} cm^{-2} 1 MeV neutrons.





[1] D. Passeri, P. Ciampolini, G.M. Bilei, and F. Moscatelli, *Comprehensive Modeling of Bulk-Damage Effects in Silicon Radiation Detectors*, IEEE Trans. on Nuclear Science, vol. 48, no. 5, October 2001.

[2] M. Petasecca, F. Moscatelli, D. Passeri, and G. U. Pignatel, *Numerical Simulation of Radiation Damage Effects in p-Type and n-Type FZ Silicon Detectors*, IEEE Trans. on Nuclear Science, vol. 53, no. 5, October 2006.

The "new" University of Perugia model

- ✓ Extend the predictive capabilities to HF HL-LHC radiation damage levels (e.g. fluences > 2.0×10^{16} cm^{-2} 1 MeV neutrons).
- ✓ Keep low the number of traps (e.g. fitting parameters).
- ✓ New effects (e.g. charge multiplication <- avalanche effects).
- ✓ Physically grounded approach, no over-specific modelling.
- ✓ Capture cross-section variations (σ_n, σ_p), keeping the same (already characterized) defects: energy levels, introduction rates, …
- ✓ Predictive capabilities V_{dep}, $I_{leakage}$ (α), "double peak" shaped electric field.
- ✓ Charge collection @Φ, @T, @V_{bias}, … (e.g. device independent).

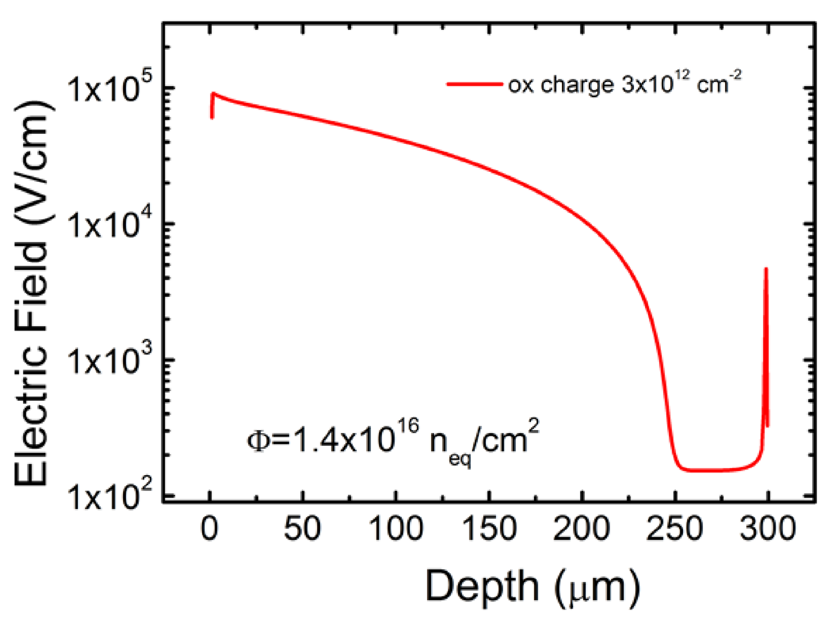
THE RADIATION DAMAGE MODEL FOR P-TYPE SUBSTRATE

Type	E (eV)	Defect	σ_e (cm^{-2})	σ_h (cm^{-2})	η (cm^{-1})
Acceptor	Ec-0.42	VV	1.0×10^{-15}	1.0×10^{-14}	1.6
Acceptor	Ec-0.46	VVV	7.0×10^{-15}	7.0×10^{-14}	0.9
Donor	Ev+0.36	C_iO_i	3.23×10^{-13}	3.23×10^{-14}	0.9

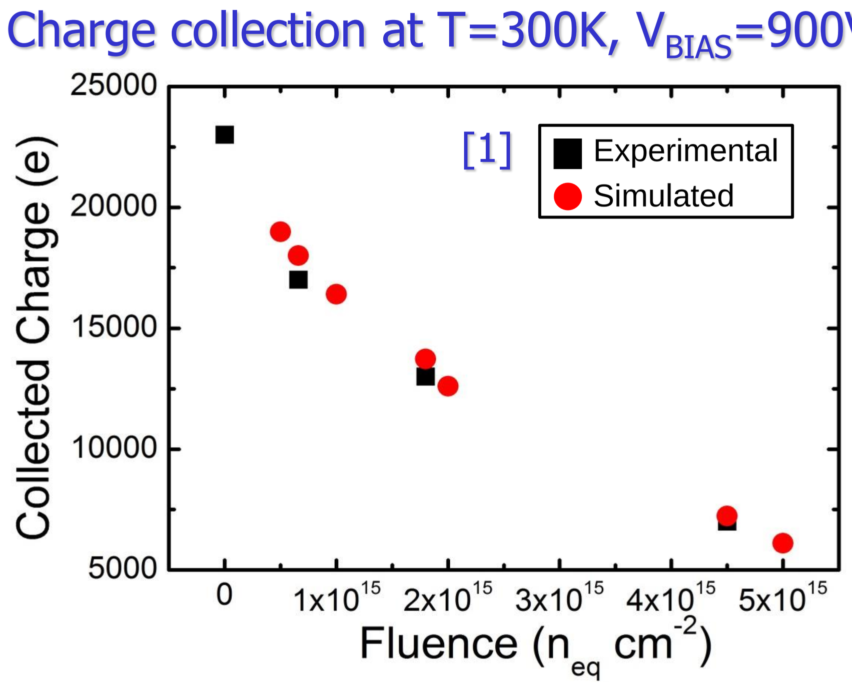
(up to 7×10^{15} n/cm^2)

Type	E (eV)	Defect	σ_e (cm^{-2})	σ_h (cm^{-2})	η (cm^{-1})
Acceptor	Ec-0.42	VV	1.0×10^{-15}	1.0×10^{-14}	1.6
Acceptor	Ec-0.46	VVV	3.0×10^{-15}	3.0×10^{-14}	0.9
Donor	Ev+0.36	C_iO_i	3.23×10^{-13}	3.23×10^{-14}	0.9

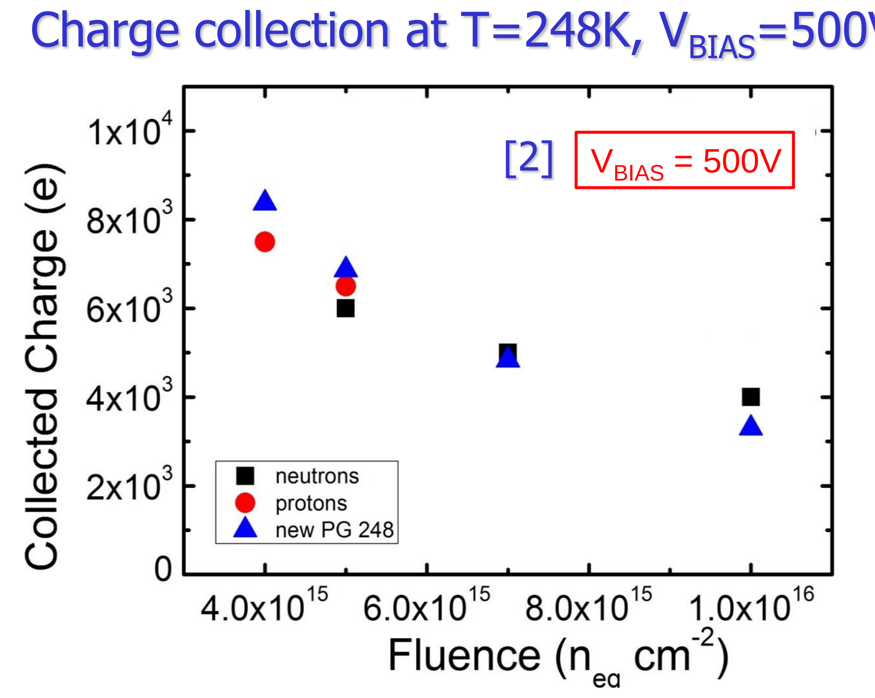
(between 7×10^{15} - 2.2×10^{16} n/cm^2)



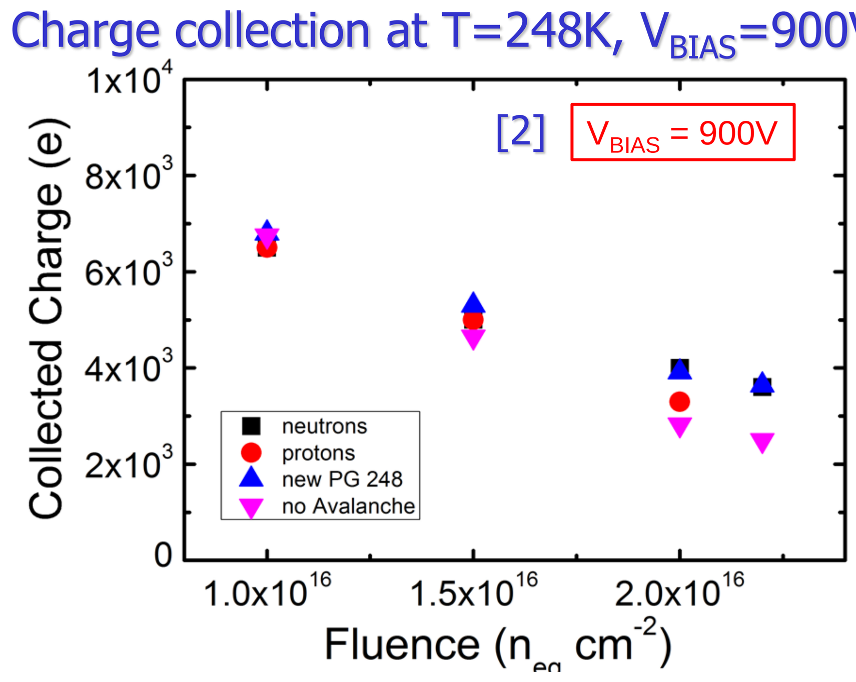
Charge collection at T=300K, V_{BIAS}=900V



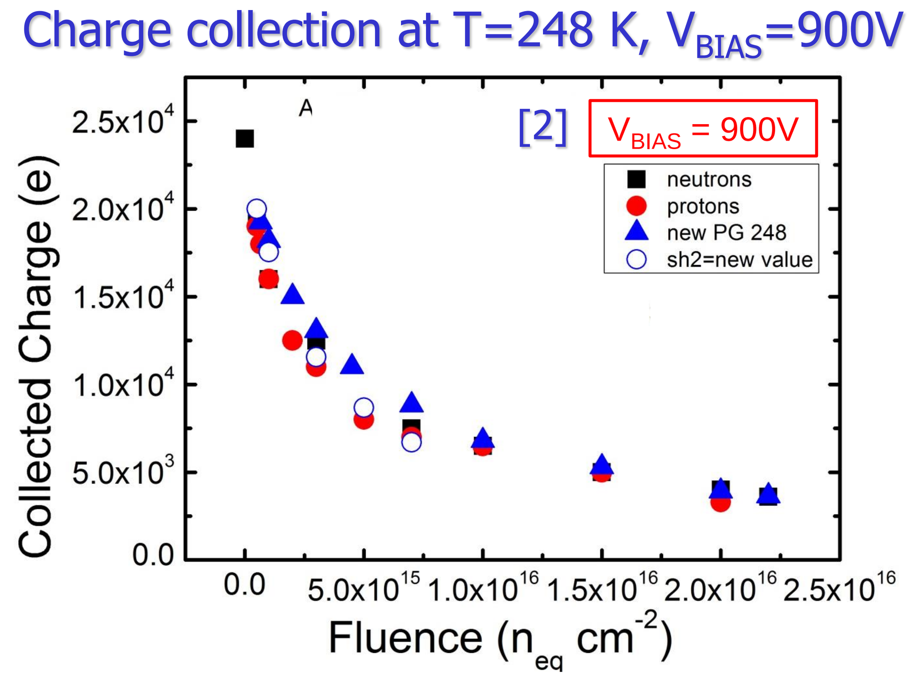
Charge collection at T=248K, V_{BIAS}=500V



Charge collection at T=248K, V_{BIAS}=900V

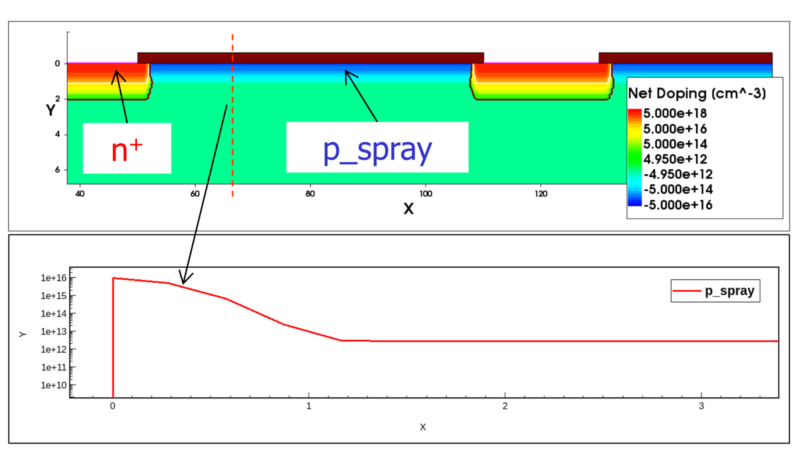


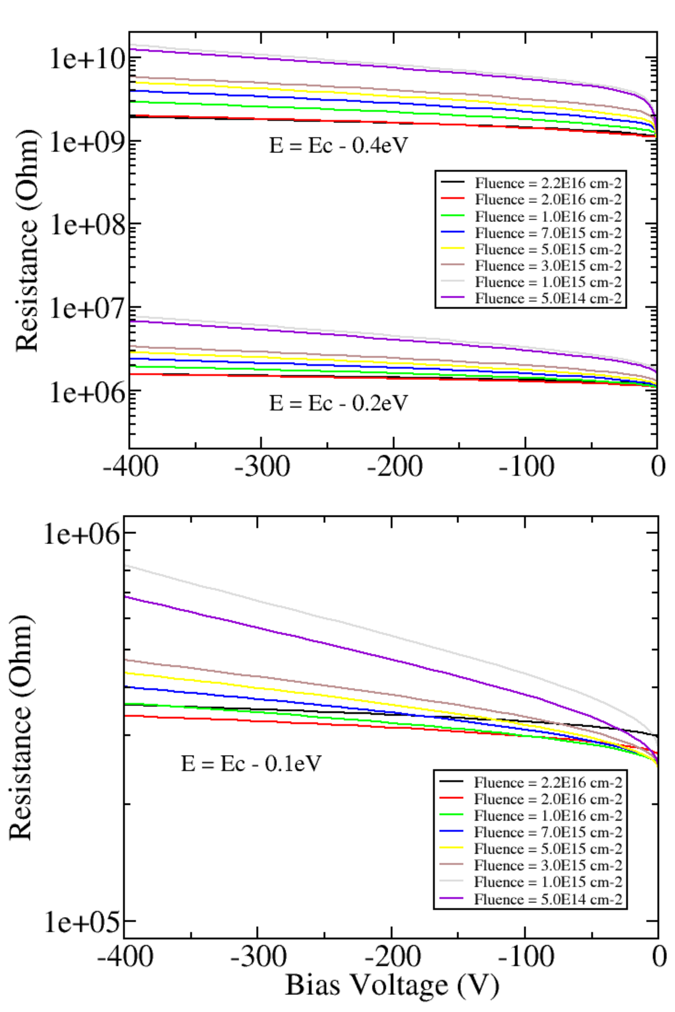
Charge collection at T=248 K, V_{BIAS}=900V



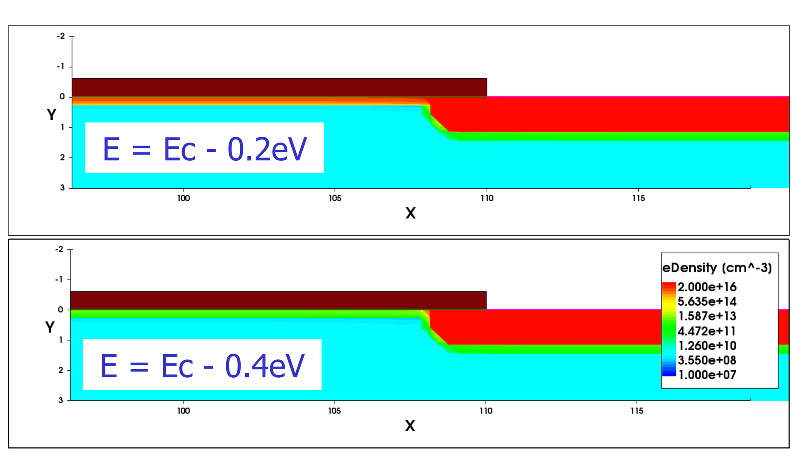
Effect of oxide charge/interface trap states on isolation

- ✓ p_spray isolation capabilities are affected by combined action of oxide charge build-up and interface trap state density increase with fluence.
- ✓ Net doping concentration.





- ✓ Effect of energy level of Si/SiO$_2$ acceptor trap state: the electron conduction (inversion layer) path suppression increases the interstrip resistance ($\Phi=2\times10^{16}$ n/cm^{-2}).



(*) daniele.passeri@unipg.it

Conclusions

- ✓ New University of Perugia Si damage modelling scheme, suitable within commercial TCAD tools.
- ✓ Predictive capabilities extended to high fluences HL-LHC radiation damage levels (e.g. fluences > 2.0×10^{16} cm^{-2} 1 MeV neutrons).
- ✓ Further validation with experimental data comparisons.
- ✓ Study of the effect of the (Si/SiO$_2$) trap states / oxide charges and trap parameter extraction from measurements are under way (combined effect of acceptor and donor states).
- ✓ Future plans: application to the optimization of Si pixel detectors (3D detectors, 2D planar detectors, …).

References

[1] Lozano et al., Comparison of radiation hardness of P-in-N, N-in-N, and N-in-P silicon pad detectors, IEEE Trans. Nucl. Sci. 52 (5) (2005).

[2] Affolder et al., Collected charge of planar silicon detectors after pion and proton irradiations up to 2.2×10^{16} n/cm^2 NIM A, Vol. 623 (2010).