Operational voltage of silicon heavily irradiated strip detectors utilizing avalanche multiplication effect

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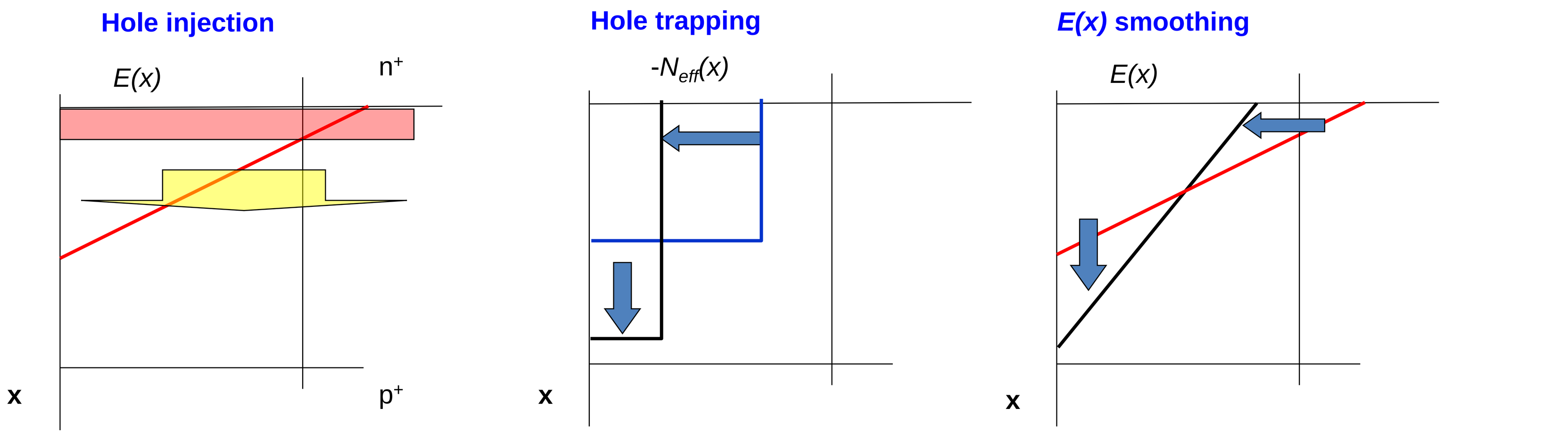
Recent results on the collected charge Q_c in heavily irradiated Si detectors, which are developed by CERN-RD50 collaboration "Radiation hard semiconductor devices for very high luminosity colliders" showed an abnormal Q_c enhancement if detectors were operated at the bias voltage beyond 1000 V. Our earlier investigations (*V. Eremin , et al., "Avalanche effect in Si heavily irradiated detectors: physical model and perspectives for application", doi:10.1016/j.nima.2011.05.002*) showed that this enhancement arises from a fundamental effect of carrier avalanche multiplication in high electric field of n+-p junction.

The model developed in PTI considers:

- the competition of the reduction of the collected charge due to carrier trapping to the deep levels of radiation induced defects and charge increase arisen from avalanche multiplication,
- formation of Double Peak electric field profile *E(x)* in heavily irradiated detectors (*E. Verbitskaya, et al., NIM A 583 (2007) 77*);
- focusing of the electric field and current near the collecting strips;
- avalanche hole generation near the strips, the hole injection into the detector bulk, and the hole trapping to the deep levels of radiation induced defects that gives rise to the negative feedback, which stabilizes the avalanche multiplication.

Calculations of the electric field profile *E(x)* and collected charge Q_c are carried out with variable parameters: detector bias voltage *V*, temperature *T* in the range typical for LHC, irradiation fluence *F*, concentration ratio of deep levels – midgap donors and acceptors, strip detector geometry (strip width).

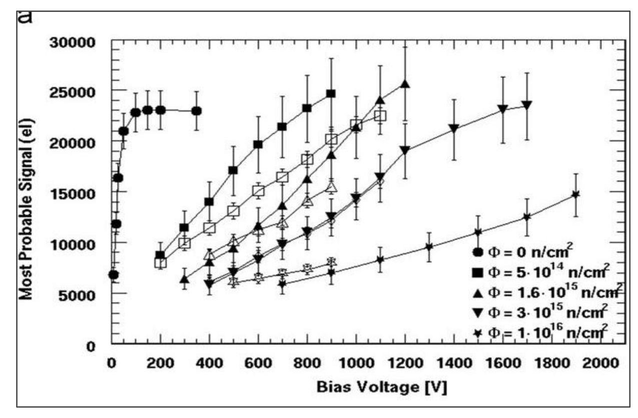
PTI model for stabilization of avalanche multiplication by deep levels



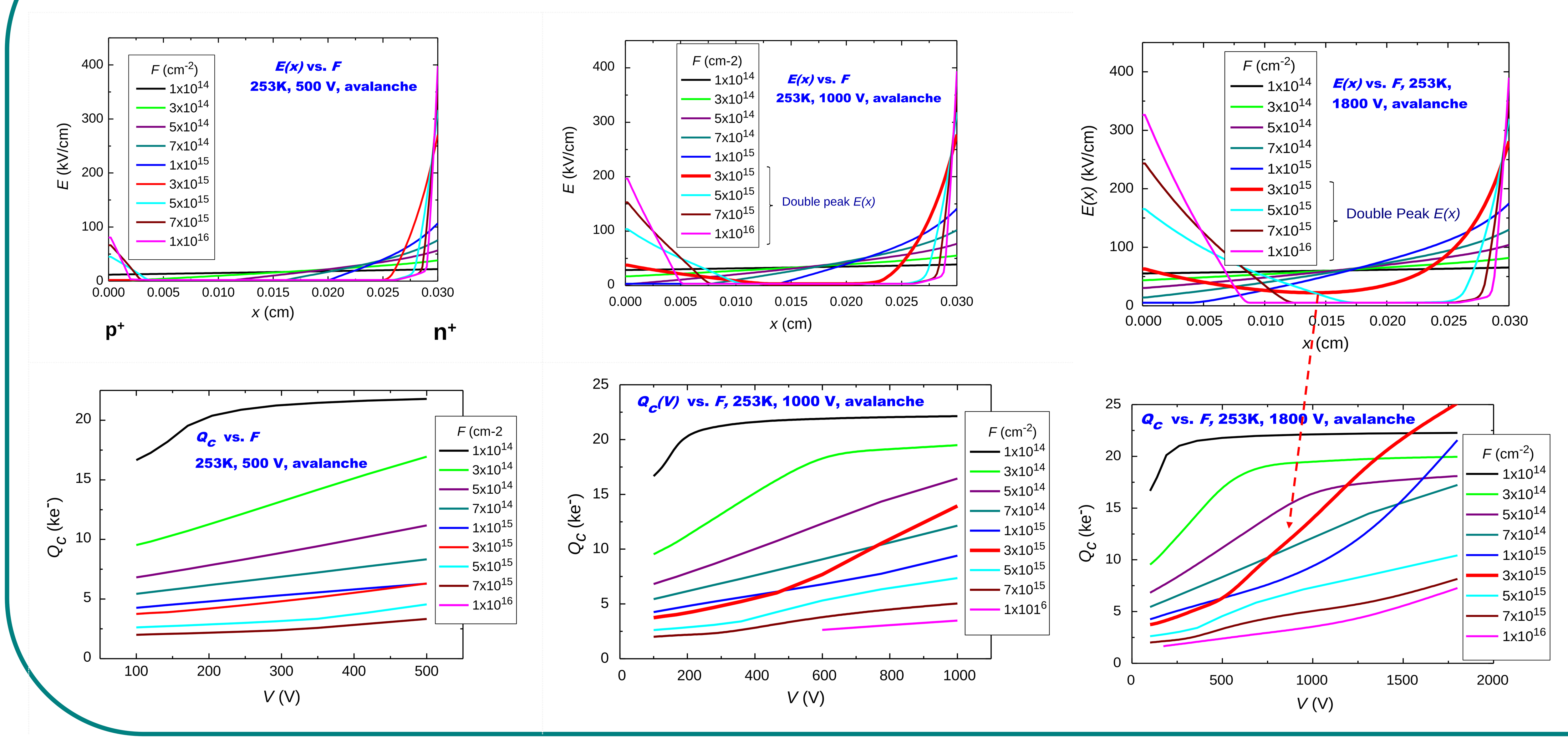
Parameters for simulation

- One-dimensional model
- n-on-p strip detector, d = 300 mm
- Trapping midgap energy levels:
  - deep donors DD $E_v + 0.48$ eV,
  - deep acceptors DA $E_c - 0.53$ eV
  - Current generation level $E_a = 0.65$ eV
- $g = 0.02\ cm^{-1}$
- $\beta_e = 3.2\times10^{-16}\ cm^2s^{-1}$, $\beta_h = 3.7\times10^{-16}\ cm^2s^{-1}$
- Avalanche parameters (*B. J. Baliga*):
  - $A_e = 8.026\cdot10^5\ cm^{-1}$, $B_e = 1.1989\cdot10^6$ V/cm
  - $A_h = 4.8015\cdot10^6\ cm^{-1}$, $B_h = 2.1769\cdot10^6$ V/cm

Experimental results (*I.Mandic, et al., NIM A 612 (2010) 474*)



Influence of irradiation fluence *F* on *E(x)* profile and collected charge Q_c

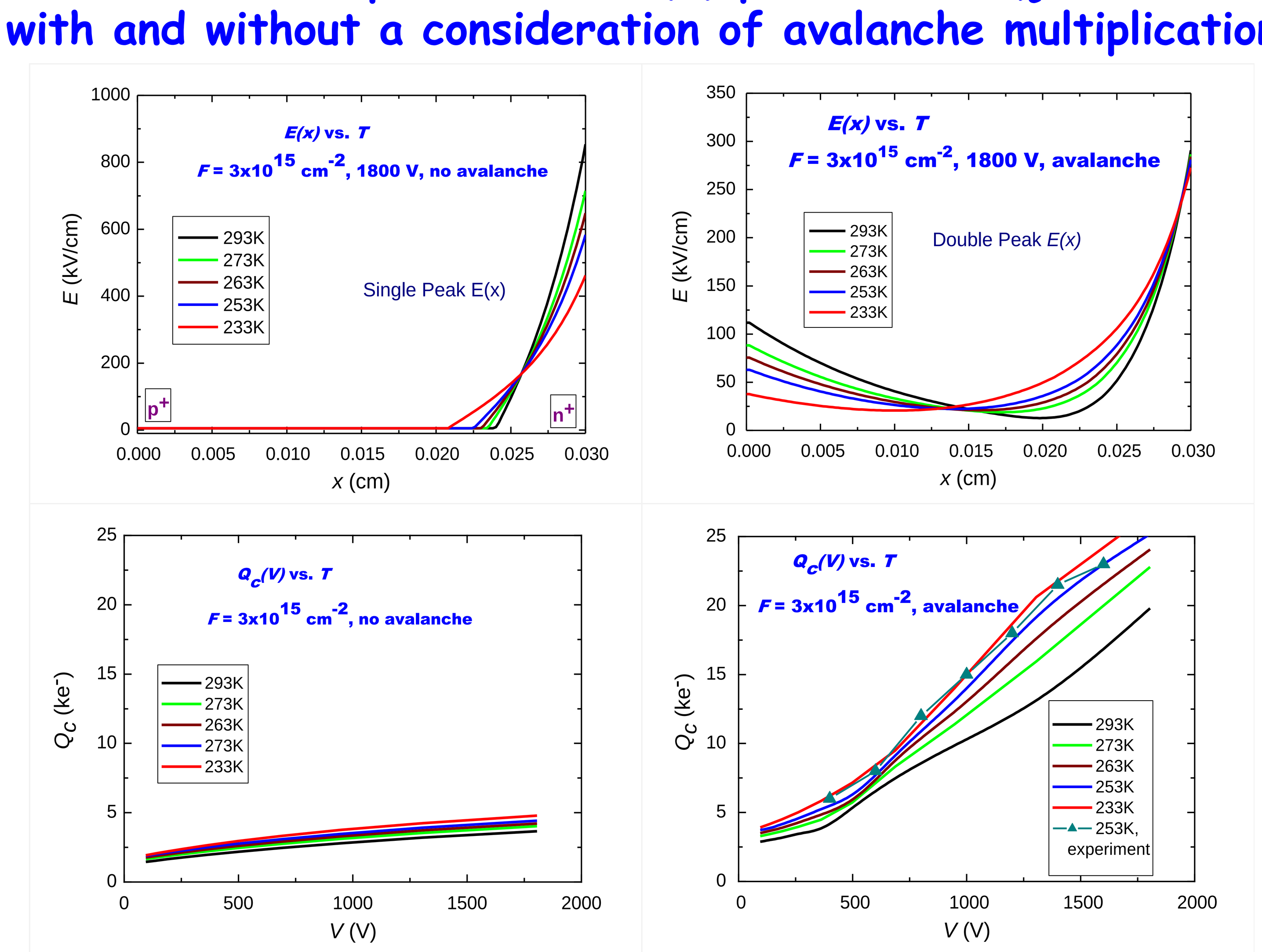


Simulations are carried out for $F = 3\times10^{15}\ cm^{-2}$ at which the experimental collected charge enhancement is maximal.

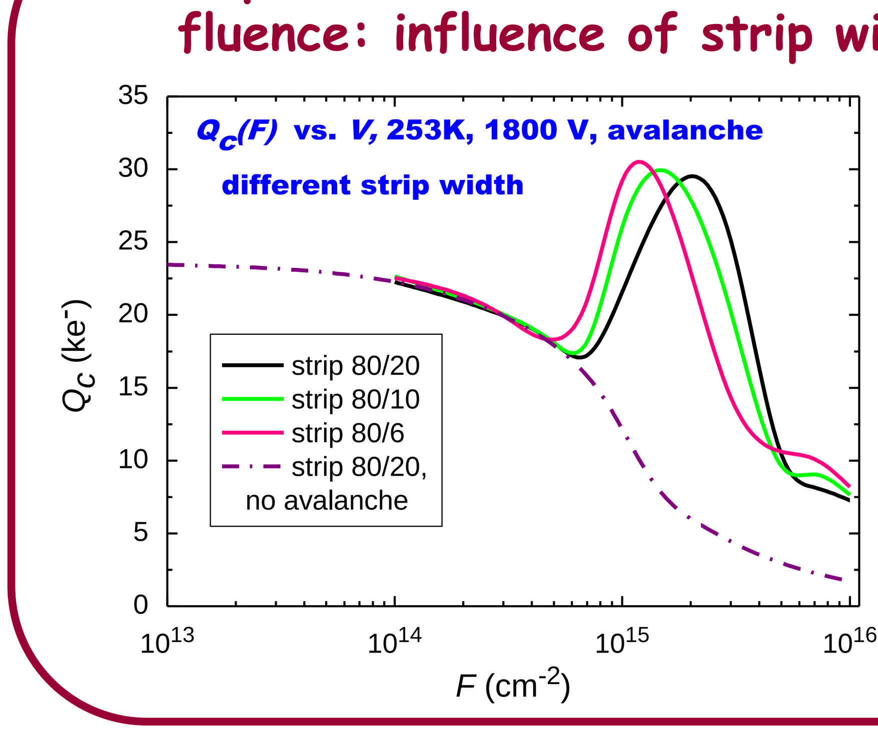
Avalanche multiplication:

- **evolves when the electric field transforms from Single Peak to Double Peak *E(x)*;**
- **starts at *V* = 500 V and is efficient at *V* ≥1000 V;**
- **leads to stabilization of the electric field at n^+ strips**

Influence of temperature on *E(x)* profile and Q_c with and without a consideration of avalanche multiplication



Dependence of collected charge on fluence: influence of strip width



Maximal enhancement of the collected charge occurs at *F* around $10^{15}\ cm^{-2}$.

Focusing effect at smaller strip width leads to Q_c increase at lower *F*

Conclusions

- **Double Peak electric field distribution is still the main feature for heavily irradiated detectors operated in the avalanche multiplication mode.**
- **Enhancement of the collected charge due to avalanche multiplication occurs when *E(x)* profile has Double Peak shape.**
- **Maximal Q_c enhancement occurs at operational voltage *V* ≥1000 V and in the fluence range $(1\text{-}3)\times10^{15}\ cm^{-2}$ and is stimulated by focusing with reduction of strip width.**
- **The electric field near the n^+-strips is stabilized in avalanche mode via voltage drop redistribution and electric field extension towards the p^+ contact. This redistribution depends on the concentration ratio of radiation defects with deep levels, N_{DD}/N_{DA}.**
- **Q_c enhancement with respect to the experimental values may be related with one-dimensional model approach. May be smoothed in real configuration?**

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