

Negative feedback in Si detectors with avalanche multiplication

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Motivation

- 1. The effect of negative feedback in heavily irradiated p⁺-i-n⁺ Si detectors plays a key role in detector performance**
- 2. The analytical approach in the effect description may clarify the profit in exploiting the effect in the detectors for future developments**
- 3. The analytical approach can advance understanding the effect in detectors with different structures (such as LGAD) and geometrically enhanced multiplication (strip and pixels)**

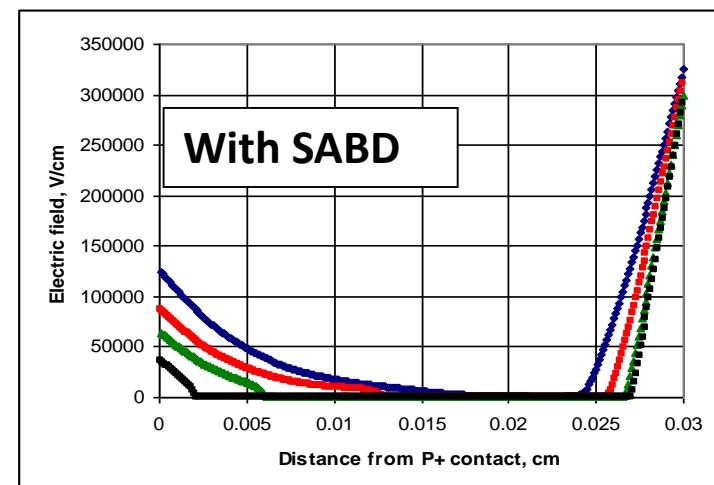
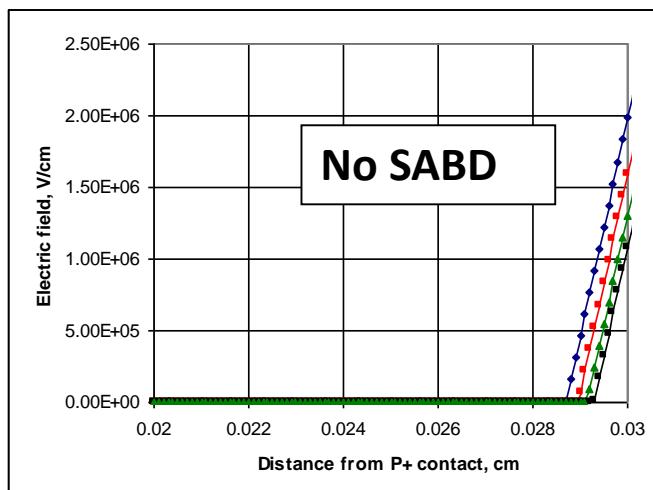
The first systematic study of trapping related negative feed back

(14 RD50 meeting, Freiberg, 2009)

Numerical calculation of the electric field in heavily irradiated Si detectors



$$F_n = 1e16 \text{ cm}^{-2}, V = 1500, 1000, 700, 500 \text{ V}$$



SABD – soft avalanche breakdown

Analytical approach for the electric field calculation

Numerical approach (process simulation)

- Two trapping centers uniformly distributed in the detector bulk
- Statistics of deep levels occupation (Shockley – Read - Hall theory)
- Drift velocity dependent on electric field
- 1D Poisson equation

Analytical approach (calculation)

- Two trapping centers uniformly distributed in the detector bulk
- Rate equations for trapped electrons and holes
- Saturated drift velocity in the detector space charge region
- 1D Poisson equation
- No electrically neutral region

Equation for $E(x)$ distribution in heavily irradiated Si detectors

M - magnification coefficient

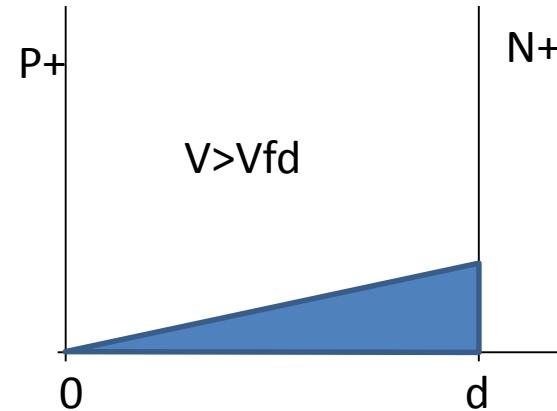
η^h - hole accumulation efficiency

η^n - electron accumulation efficiency

G - bulk current generation rate

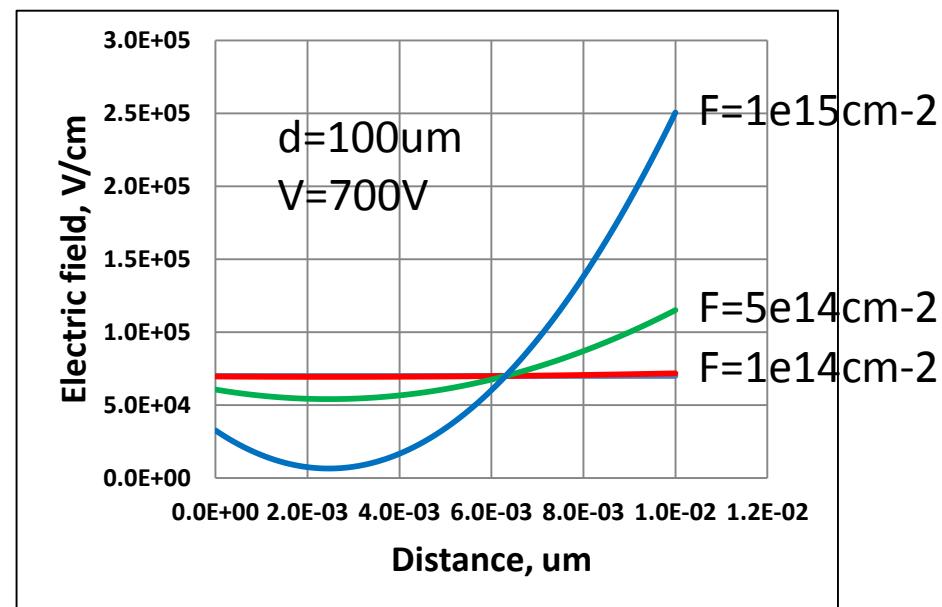
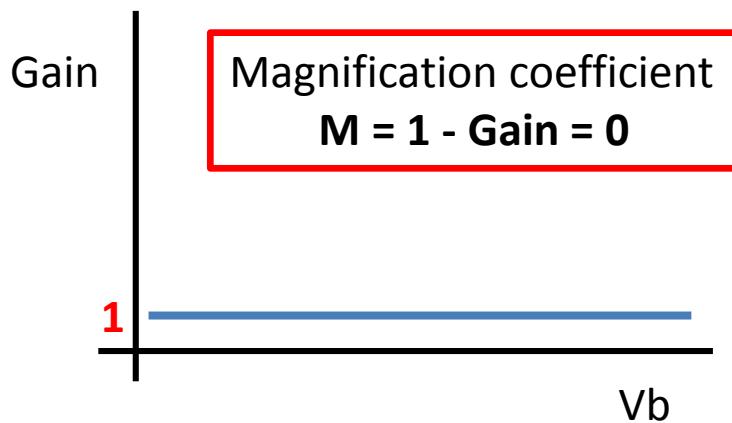
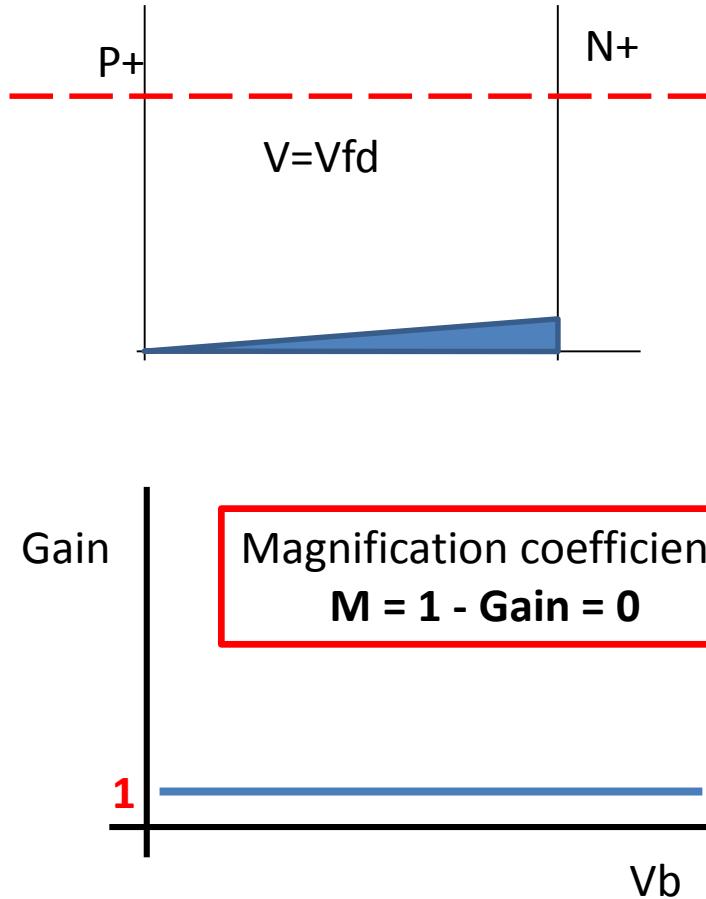
d - detector thickness

V - bias voltage

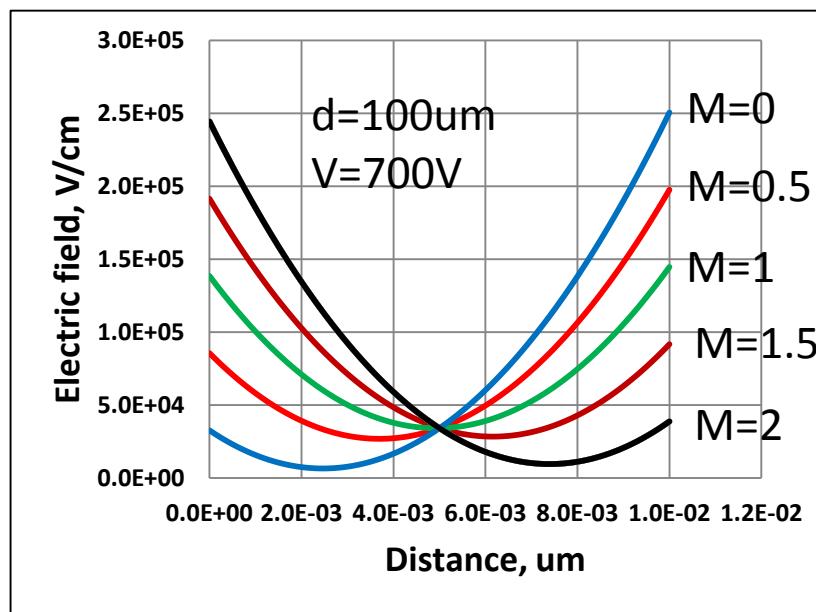
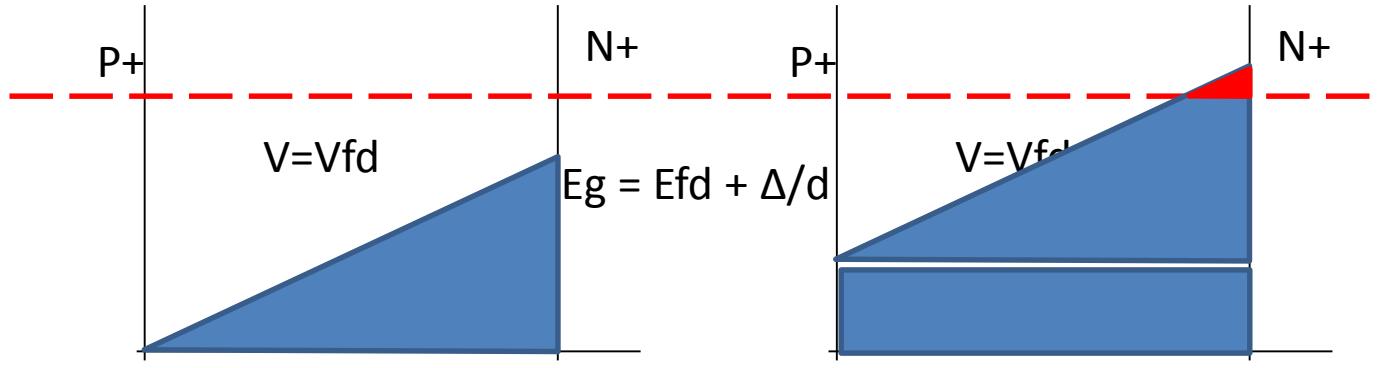


$$E(d) = -\frac{q}{\epsilon \epsilon_0} \left[\frac{1}{2} (1 + M) \eta^h G d^2 \right] - \left[\frac{1}{3} (\eta^h + \eta^n) G d^2 + \frac{\epsilon \epsilon_0 V}{qd} \right]$$

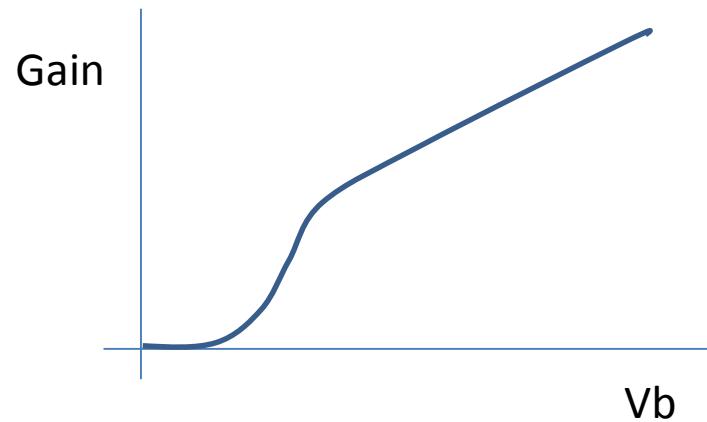
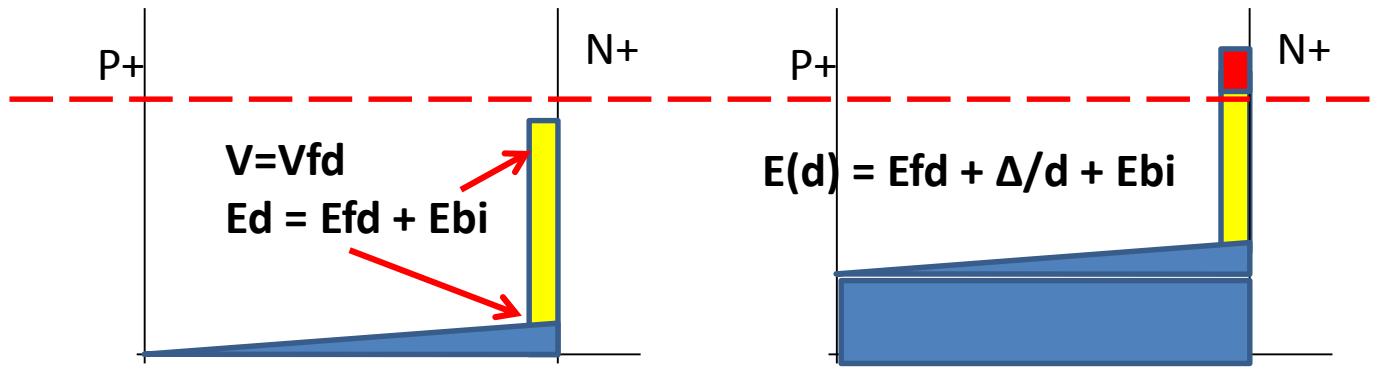
Irradiated P-I-N detector (no trapping related feed back)



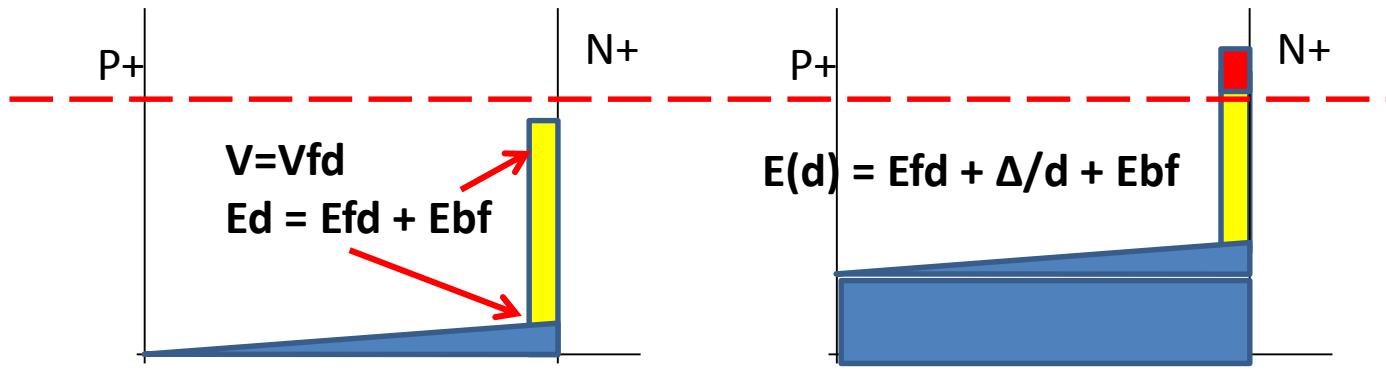
Irradiated P-I-N detector (with trapping-related negative feedback)



Extension on LGAD (non irradiated LGAD)



Extension on LGAD (irradiated LGAD)

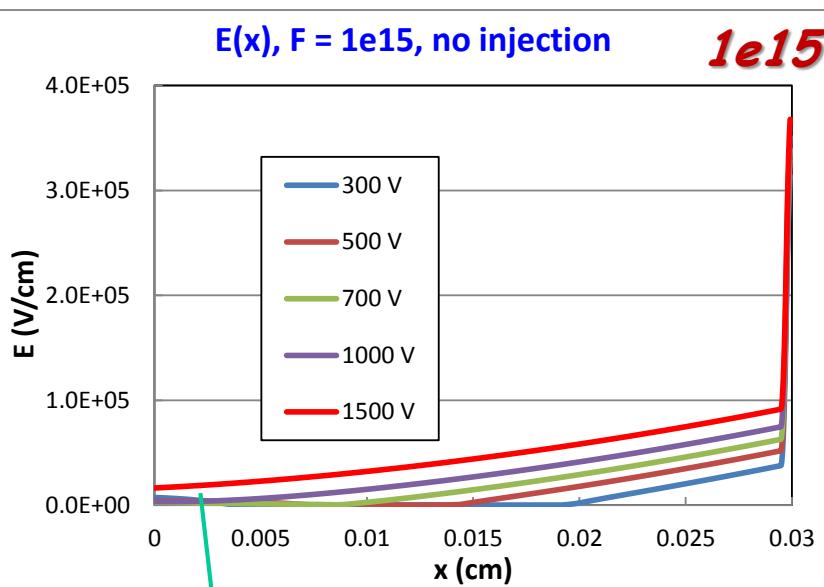


$$E(d) = -\frac{q}{\epsilon\epsilon_0} \left[\frac{1}{2} (1 + M) \eta^h G d^2 \right] - \left[\frac{1}{3} (\eta^h + \eta^n) G d^2 + \frac{\epsilon\epsilon_0 V}{qd} + \frac{\epsilon\epsilon_0}{q} E_{bf} \right]$$

$$M \propto \exp(-E_0/E_d)$$

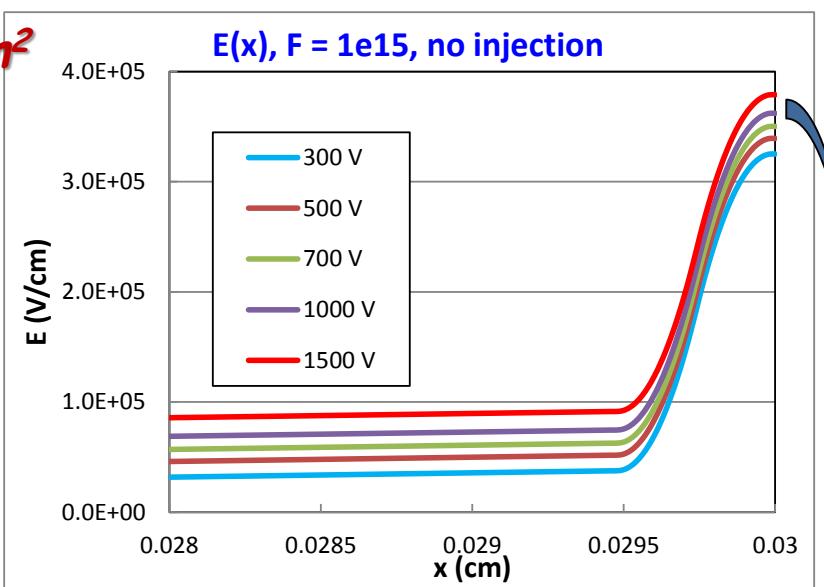
Electric field distribution in irradiated LGAD

$E(x)$, $F = 1e15$, no injection

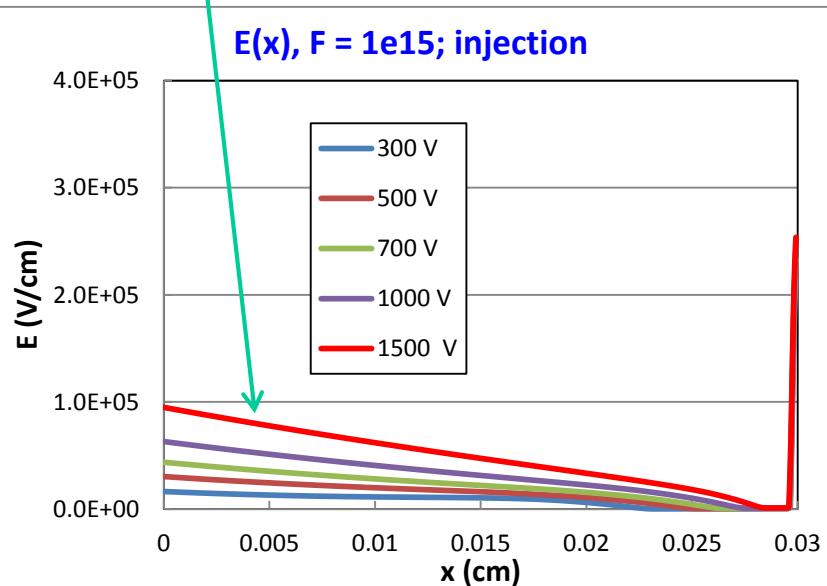


$1e15$ n/cm²

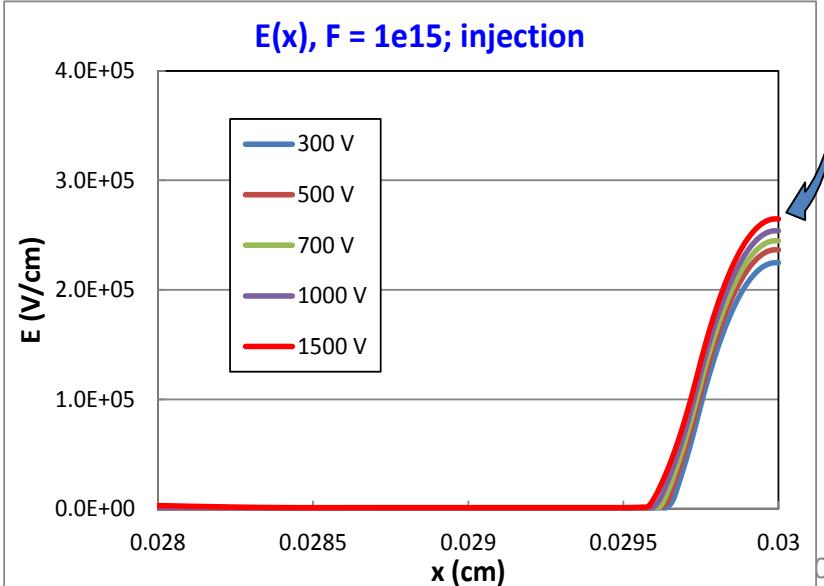
$E(x)$, $F = 1e15$, no injection



$E(x)$, $F = 1e15$; injection

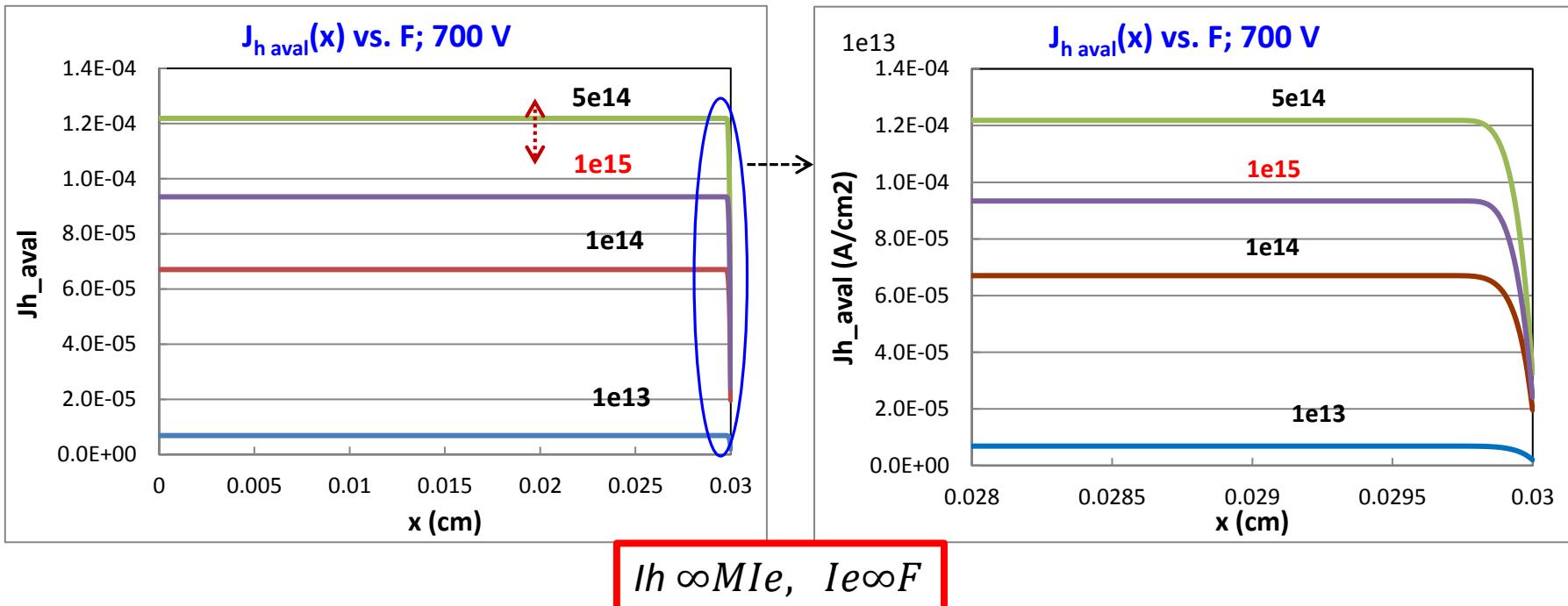


$E(x)$, $F = 1e15$; injection



E
↓

Hole injection current distribution



- Hole injection current – steady-state current of holes originated by impact ionization and drifting towards the back contact
- Holes are trapped on radiation-induces defects, which leads to potential redistribution and reduction of electric field in a built-in p+ layer and current

Conclusions

- 1. Analytical approach expresses the main features of the electric field transformation in the irradiated depleted detector - double peak E(x)**
- 2. It was shown that injection of the hole current from N side of detector leads to a deep electric field redistribution.**
- 3. Due to extremely strong impact of the injected holes on the maximum E in the peak at N+ contact it is possible to expect reduction of the detector gain with fluence**
- 4 Two mechanisms can be considered as candidates which control the signal amplitude:**
 - the gain reduction**
 - the trapping time reduction**
- 5. The analytical approach is under current development at PTI**