# CCE in irradiated silicon detectors considering the avalanche effect

by

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# Outline

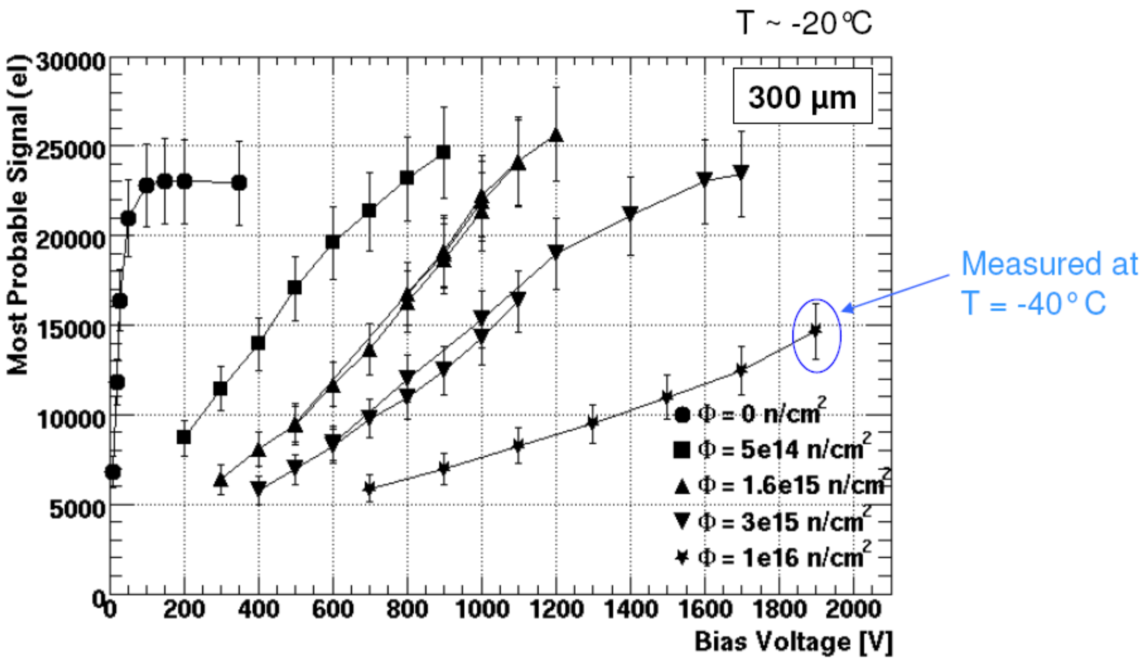
- *Model*
- *The effect simulation*
- *CCE(V) profile*
- *CCE(F) profile*
- *Summary*

# Experimental evidence of the gain

**Signal vs. Bias Voltage**

- highest voltage limited by breakdown

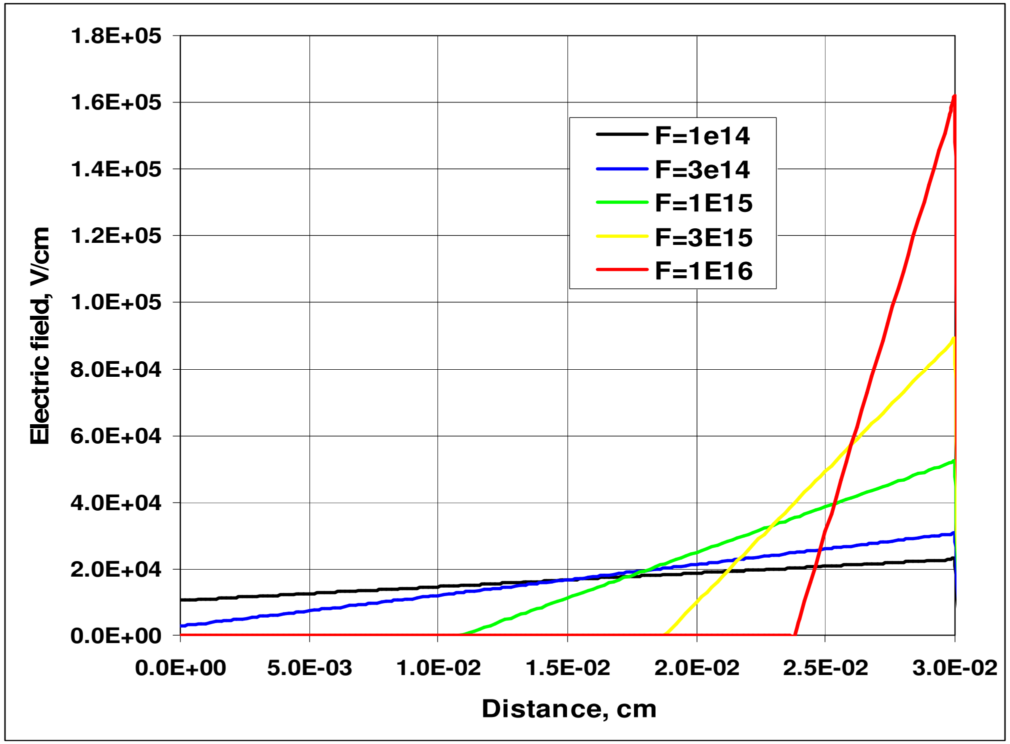
➔ 100 % CEE seen also after $3 \times 10^{15}$ n/cm$^2$
➔ 15000 electrons after $1 \times 10^{16}$ n/cm$^2$



# Electric field evolution with fluence in PAD detectors (single peak model)

The electric field in PAD N on P silicon detector

d = 300um
V = 500V
g = 1.7e-2 $cm^{-1}$

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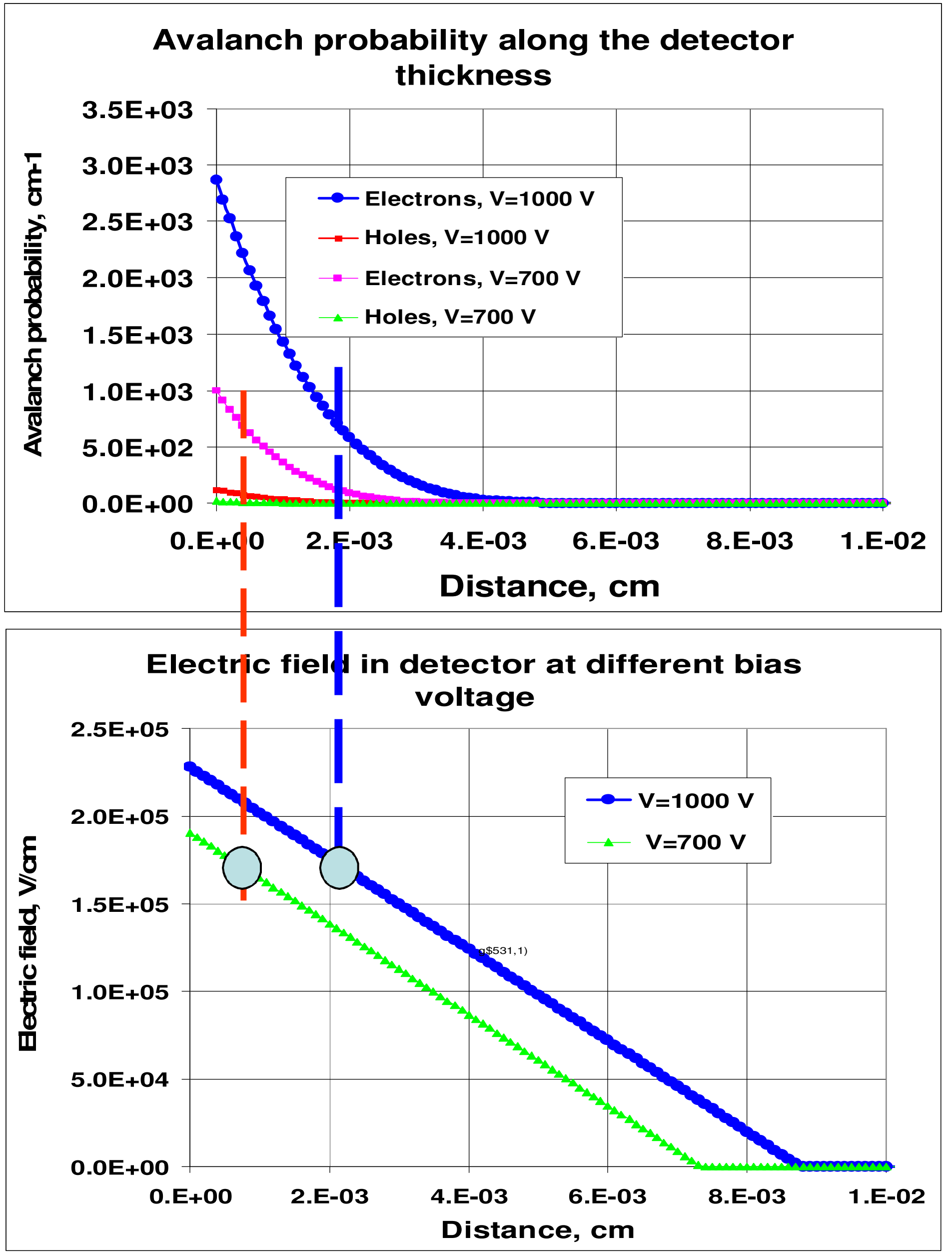
# Depth profile of multiplication probability




The **N on P** detector operates at:
RT
The detector thickness - 300um
Fluence 1e16 neq/cm$^2$

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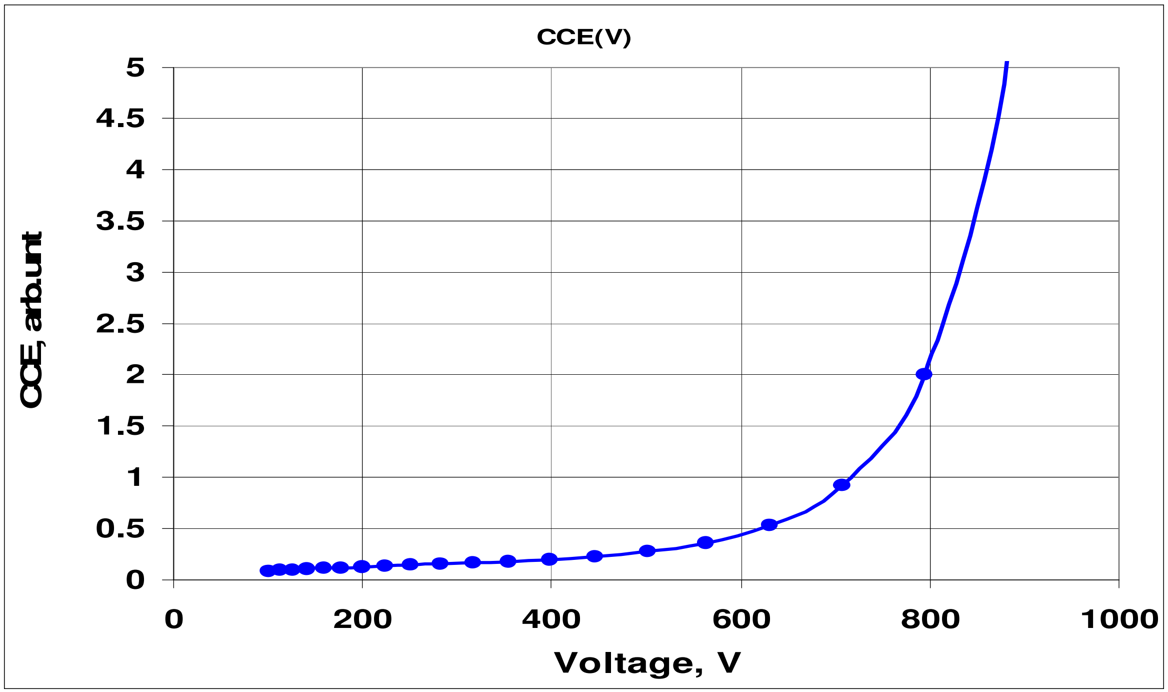
# Voltage dependence of the CCE

**The detector operates at RT.**
**The detector thickness is 300um.**
**Fluence 1e16neq/cm2**
**The trapping time: $\tau_e = \tau_p = 2.5e\text{-}10$ s,**
**Electron collection to the $n^+$ side**

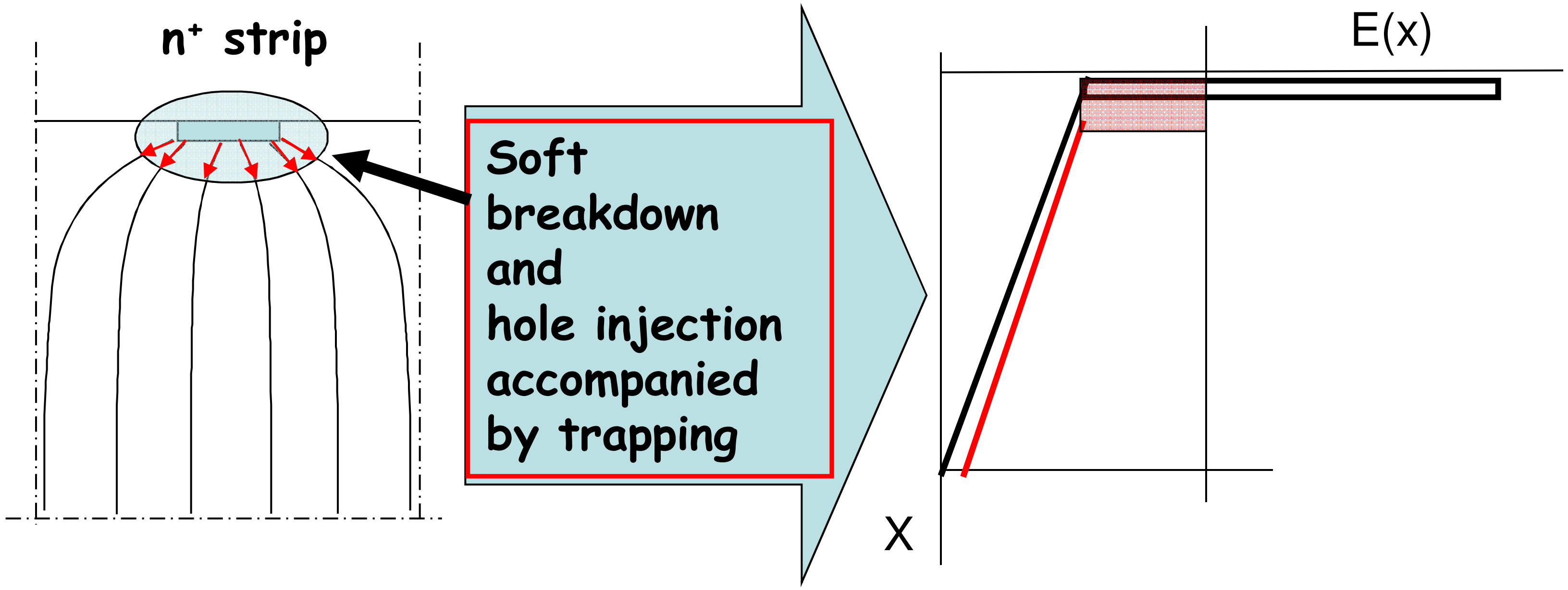



**Calculations are based on trivial SP detector model.**
**What is in a real strip detector ?**

# Current stabilization and electric field smoothing around strip

**The approach is based on explanation of the high breakdown voltage for the heavily irradiated P on N silicon detectors via the electric field suppression by the local current injection.**

**(V. Eremin et. al., "Scanning Transient Current Study of the I-V Stabilization Phenomenon in Silicon Detectors Irradiated by Fast Neutrons", NIM A, 388 (1977), 350.)**



# Extractions

from the "Conclusions" of the talk
"The Avalanche Effect in Operation of Heavily Irradiated Si p-i-n Detectors"
V. Eremin (Friburg, 2009).

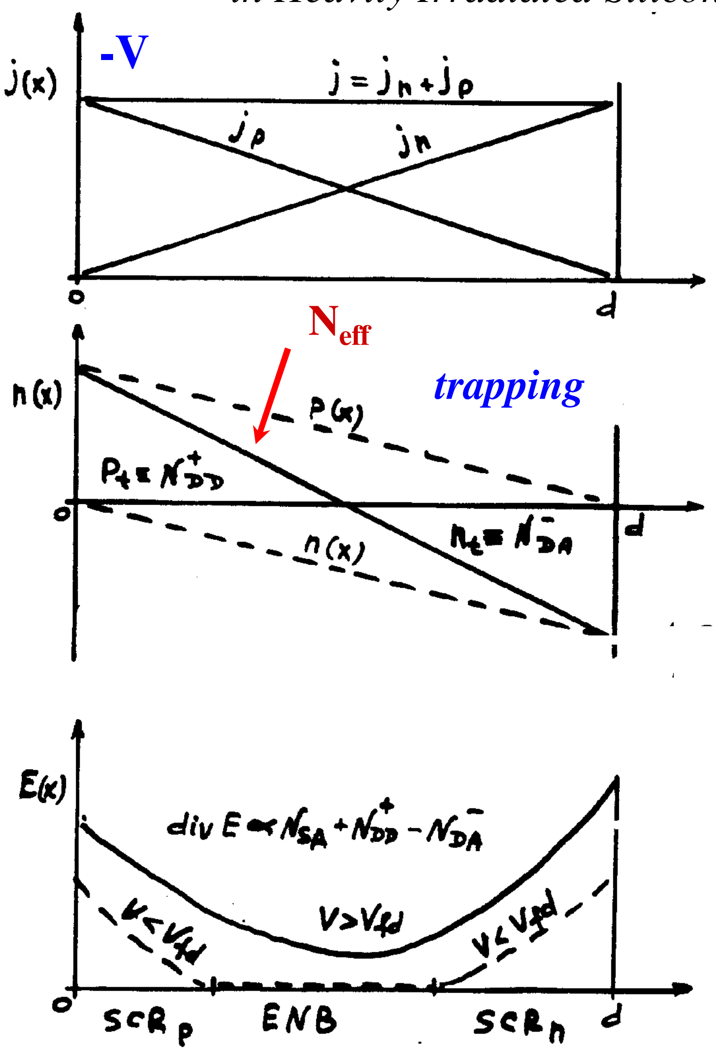
1. The charge multiplication in heavily irradiated detectors is based on two fundamental mechanisms:

- the avalanche multiplication in P-N junctions
- the electric field manipulation by current injection in the deep level dopped semiconductors.

2. The SPB model conceders a "strong feed-back loop" via the current injection that explains the detector stable operation at the high voltage and the smoothed rise of the collected charge up to 100% of CCE.

# PTI model and origin of Double Peak (DP) electric field distribution

*V. Eremin, E. Verbitskaya, Z. Li. "The Origin of Double Peak Electric Field Distribution in Heavily Irradiated Silicon Detectors", NIM A 476 (2002) 556.*

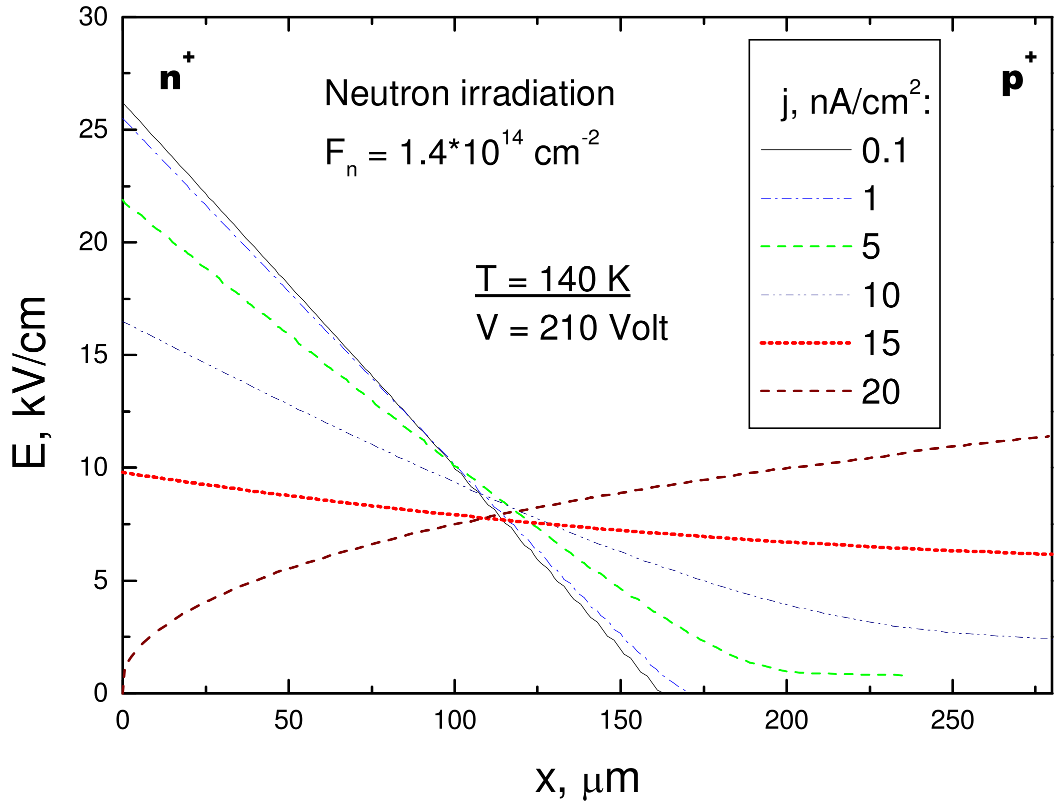



**Trapping of free carriers**
from detector reverse current
to midgap energy levels
of radiation induced defects
leads to DP E(x)

**DLs responsible for DP E(x) are midgap DLs:**

**DD**: $E_v + 0.48$ eV
**DA:** $E_c - 0.52$ eV

# Electric field manipulation in bulk of heavily irradiated detector by hole injection




**E.Verbitskaya et al., "Optimization of electric field distribution by free carriers injection …." IEEE trans., NS-49 (2002), p. 258.**

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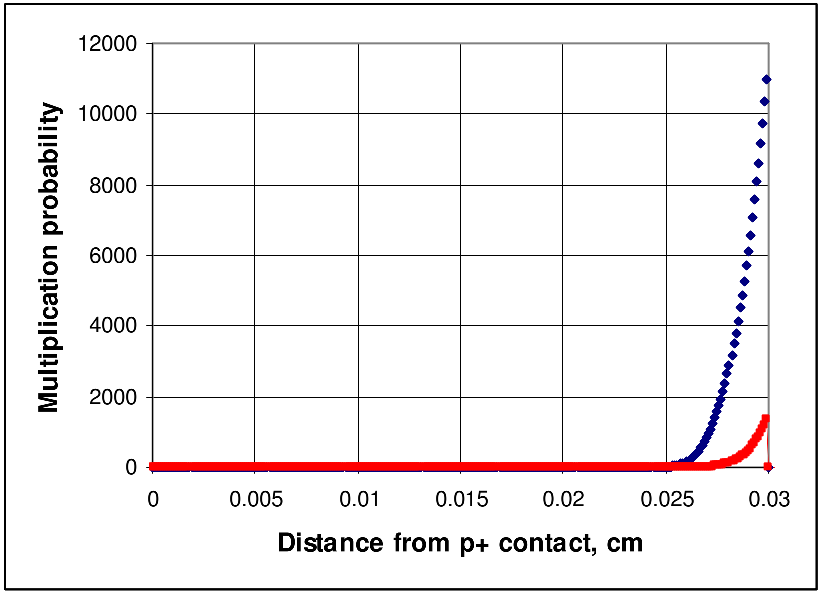
# PTI model of electric field stabilization effect via the "Soft Avalanche Break Down"





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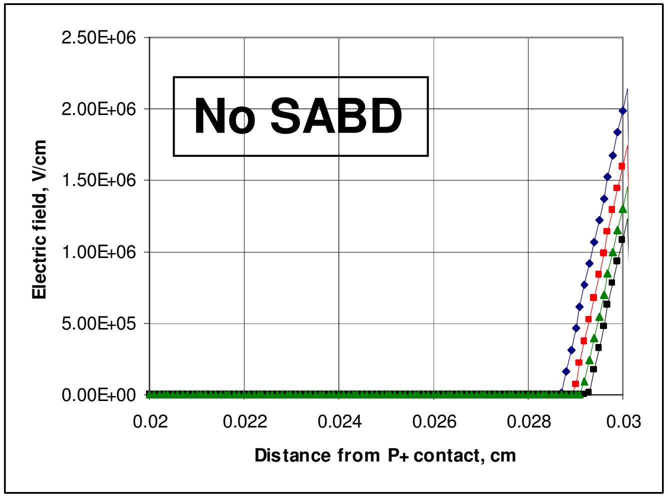
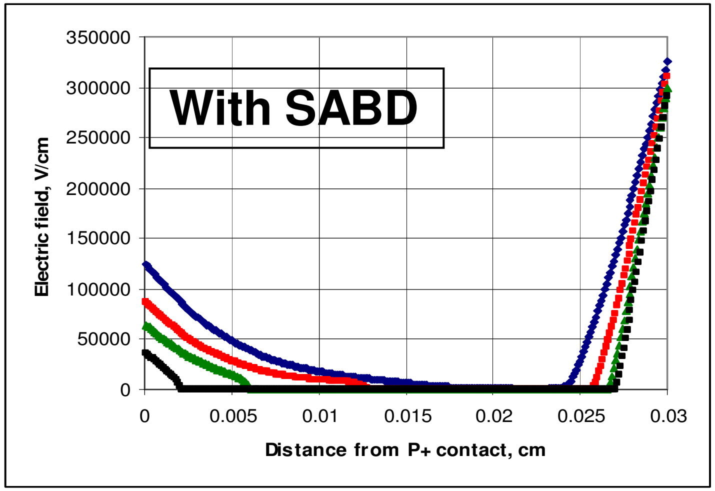
# Calculation of the Electric field with PTI model of "Soft Avalanche Break Down"

| DL # | Ci-Oi | | Deep donor | | V-V | | Deep acceptor | |
|---|---|---|---|---|---|---|---|---|
| D/A, 0/1 | 0 | | 0 | | 1 | | 1 | |
| | electrons | holes | electrons | holes | electrons | holes | electrons | holes |
| Et=Edl-Ev | **0.36** | 0.76 | **0.48** | 0.64 | **0.7** | 0.42 | **0.595** | 0.525 |
| sig/e[cm2 | **1.00E-15** | | **1.00E-15** | | **1.00E-15** | | **1.00E-15** | |
| sig/h[cm2] | | **1.00E-15** | | **1.00E-15** | | **1.00E-15** | | **1.00E-15** |
| Ndl[cm-3] | **0.00E+00** | | **2.00E+14** | | **0.00E+00** | | **5.00E+15** | |
| Sig*Vth | 1.93E-08 | 1.47E-08 | 1.93E-08 | 1.47E-08 | 1.93E-08 | 1.47E-08 | 1.93E-08 | 1.47E-08 |
| detrap.prol | 8.31E-04 | 1.42E+04 | 1.76E-01 | 6.73E+01 | 3.23E+03 | 3.66E-03 | 2.98E+01 | 3.97E-01 |

**Fn = 1e16 cm-2, V = 1500, 1000, 700, 500V**

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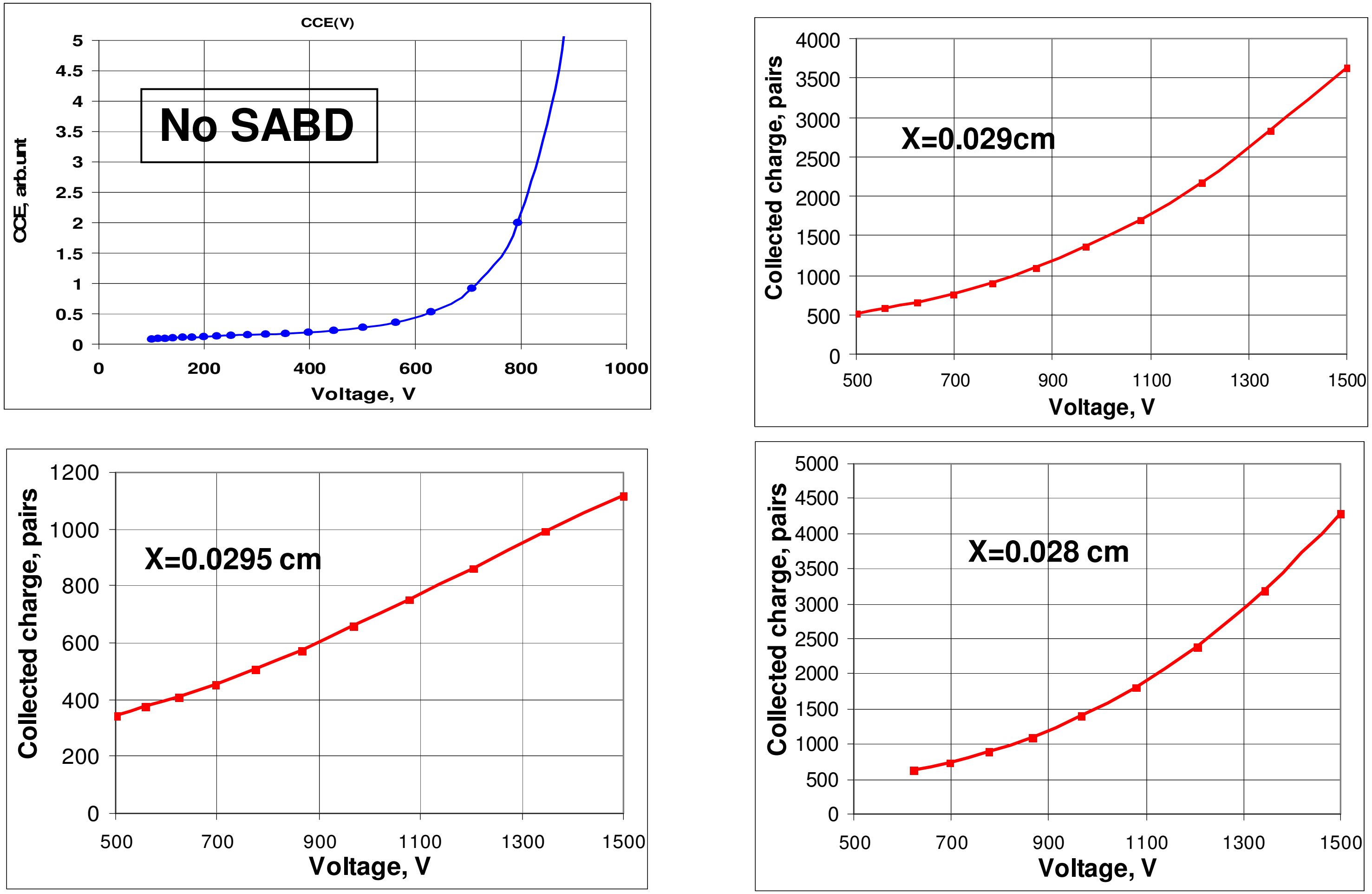
# Voltage dependence of the multiplication effect in detectors

Fn = 1e16 cm-2

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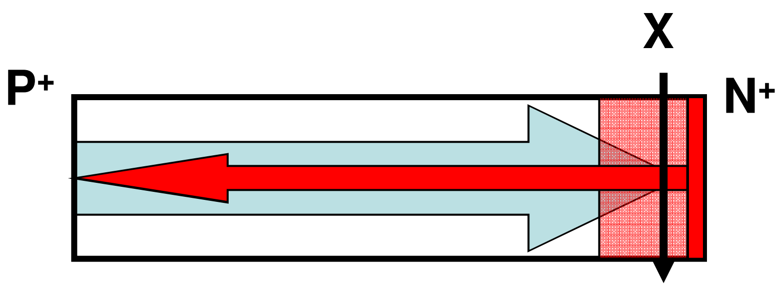
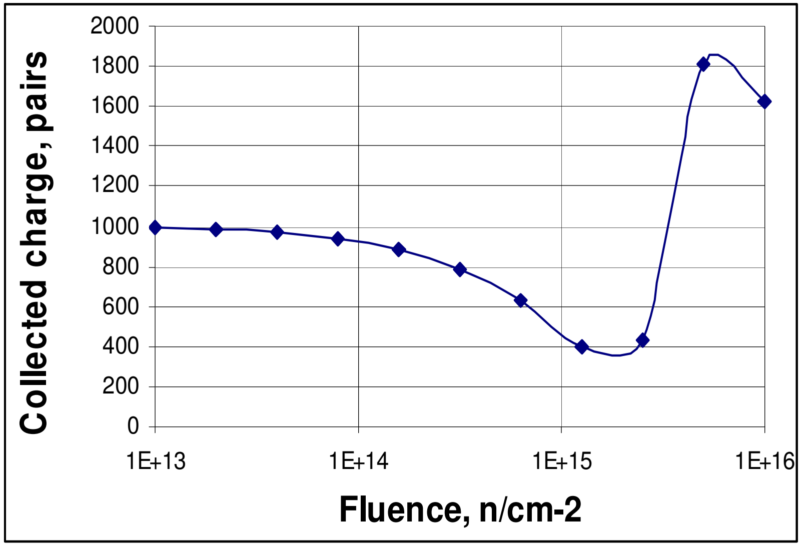
# Fluence dependence of the multiplication effect in detector

V = 1000V
X = 0.028cm




CCD ~ $V_{dr}$*$t_{tr}$ = 10e7*2.5e-10=25um
Q gen = 1000 e (10um of MIP track)
CCE mip = 30/300*10=1

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# Future

- The set of strip detectors with different width of strips will be finished in 2009.
- Irradiation - spring 2010.
- CCE calculation for MIPs with PTI SABD model

# Summary

- Earlier predicted phenomenon of stabilization of the maximal electric field at n+ side of heavily irradiated detectors is proofed.
- The soft CCE(V) characteristics of heavily irradiated detectors were successfully modeled.
- The PTI DP model with effective 2 midgap levels for E(X) distribution in irradiated detectors has got new confirmation.