Reverse current of heavily irradiated Si detectors operated in the avalanche mode

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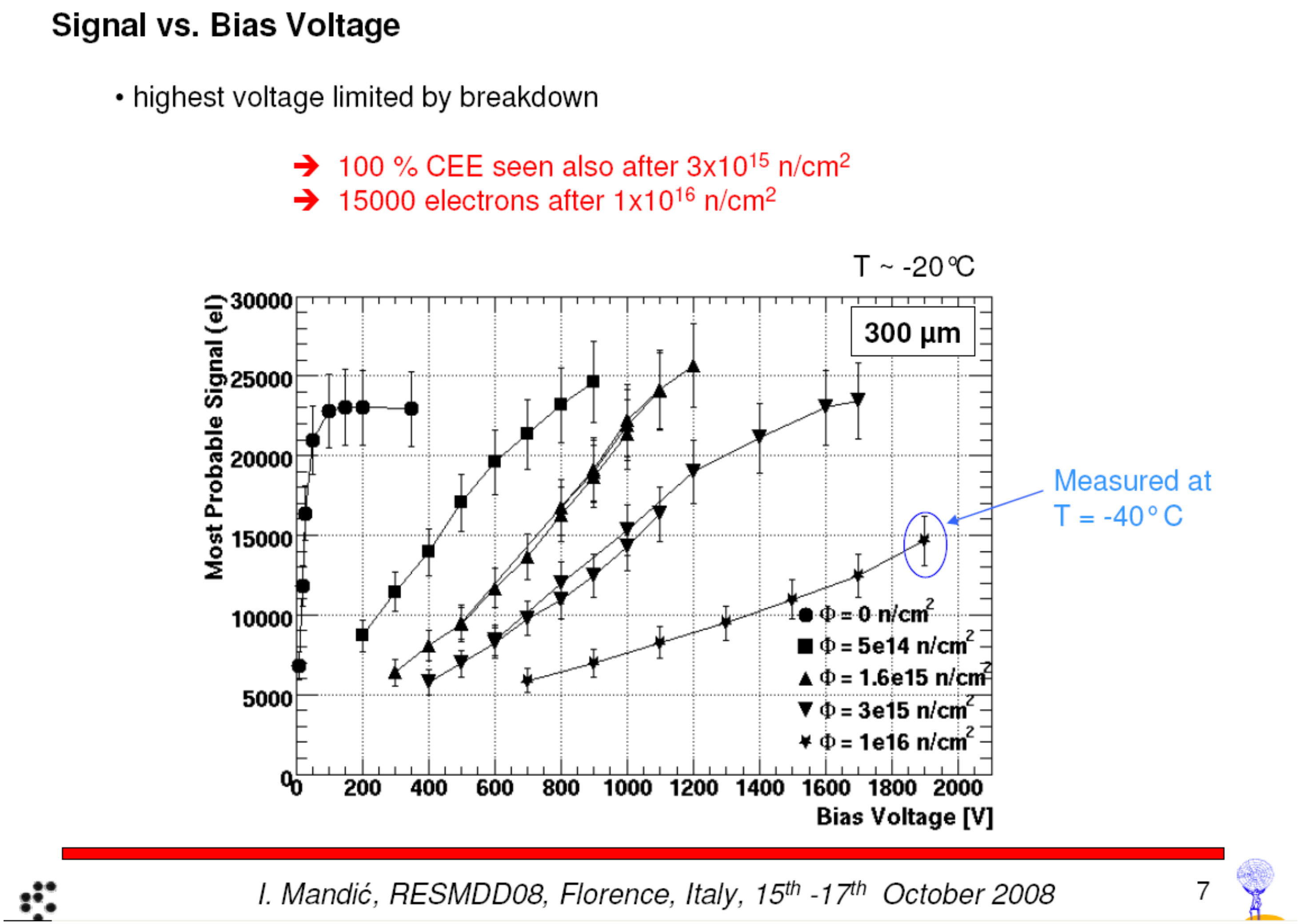
RD-50, CERN, 17 – 19 November, 2010

Experimental evidence of the gain



Signal vs. Bias Voltage

- highest voltage limited by breakdown

➔ 100 % CEE seen also after 3x10^{15} n/cm^2
➔ 15000 electrons after 1x10^{16} n/cm^2

T ~ -20℃

Measured at
T = -40 ° C

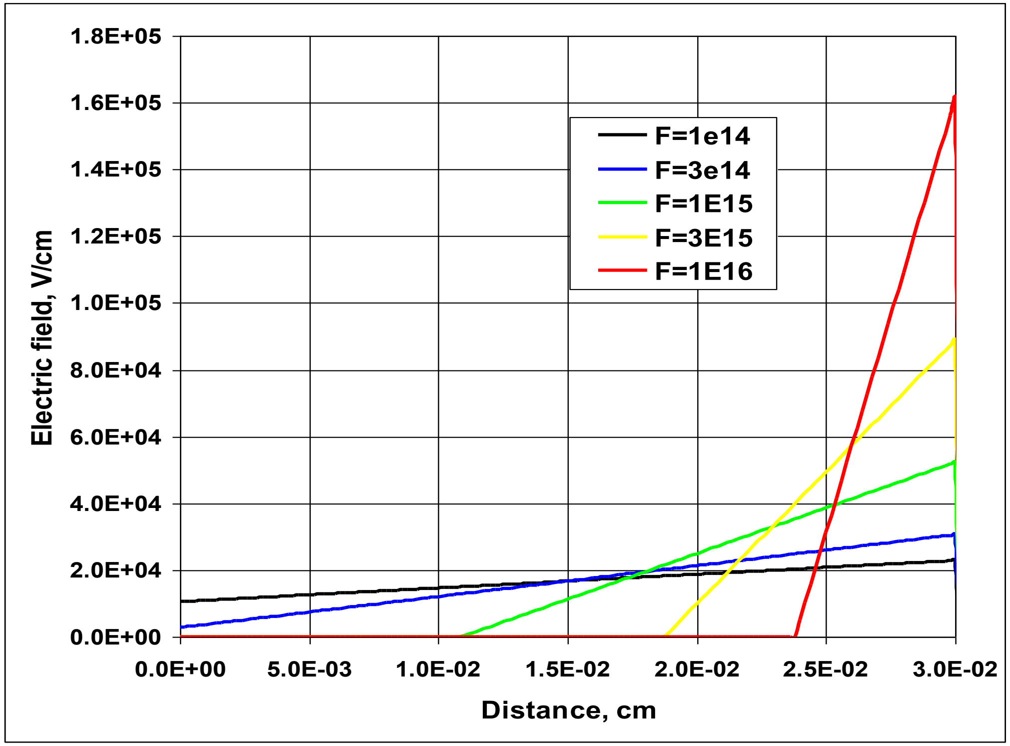
I. Mandić, RESMDD08, Florence, Italy, 15th -17th October 2008

V.Eremin, RD50, Nov 2010

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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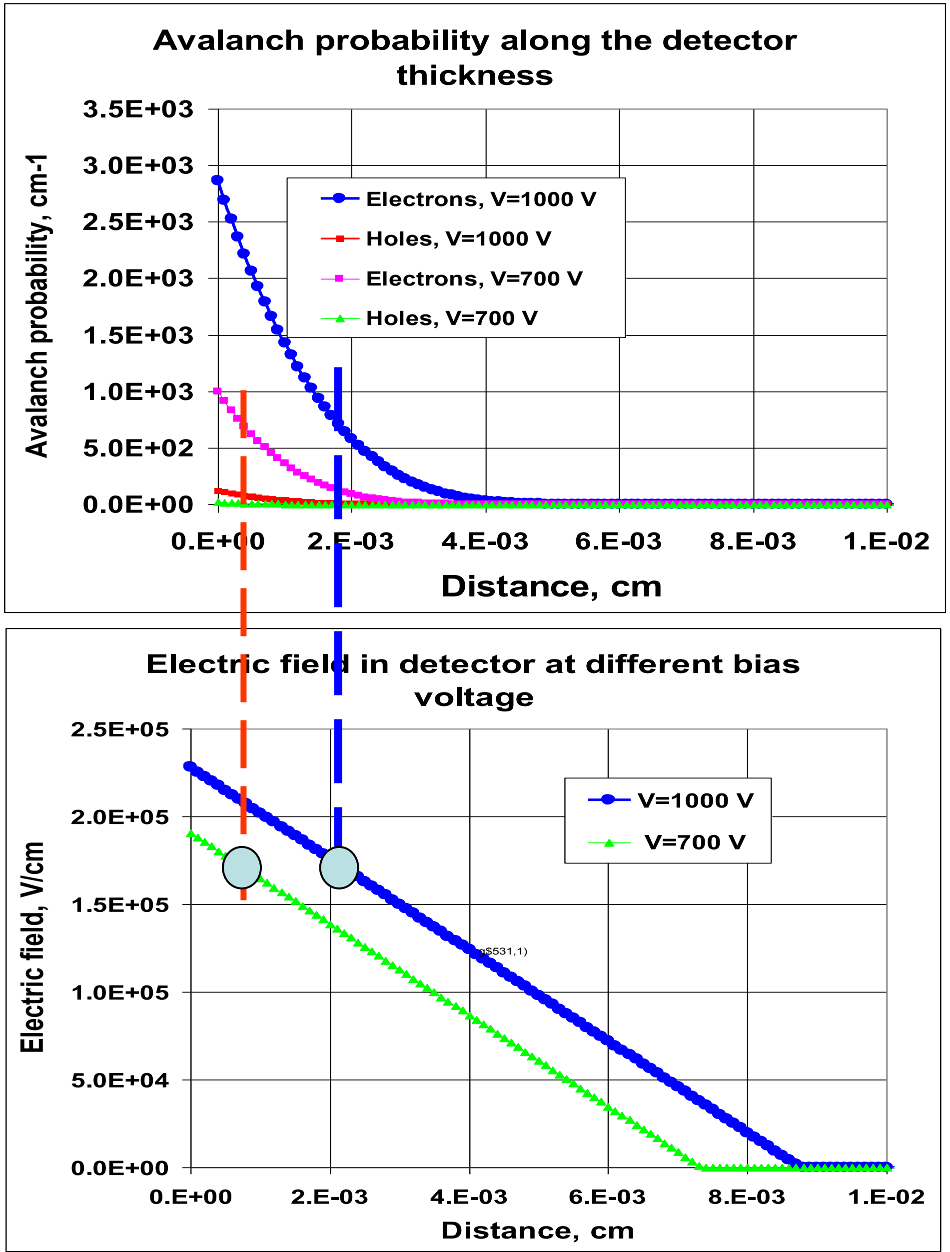
Depth profile of multiplication probability



The **N on P** detector operates at: RT
The detector thickness - 300um
Fluence - 1e16 n_{eq}/cm^2

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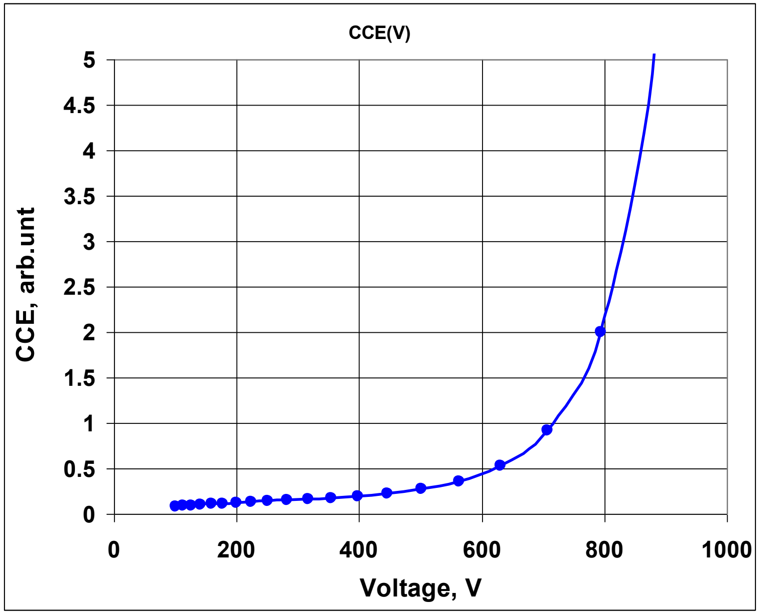
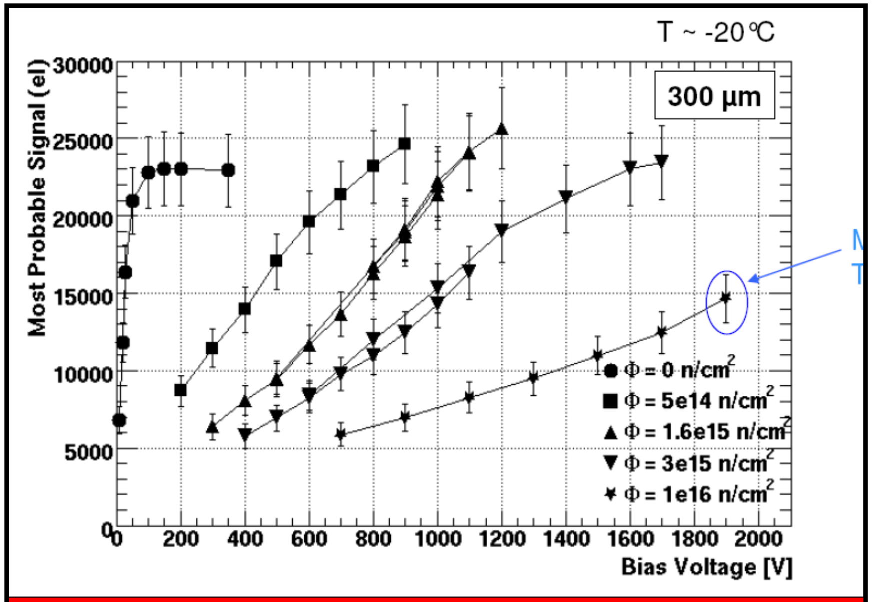
Voltage dependence of the CCE

The detector operates at RT.
The detector thickness is 300um.
Fluence 1e16n_{eq}/cm2
The trapping time: $|_e = \tau_p = 2.5e\text{-}10$ s,
Electron collection to the n^+ side

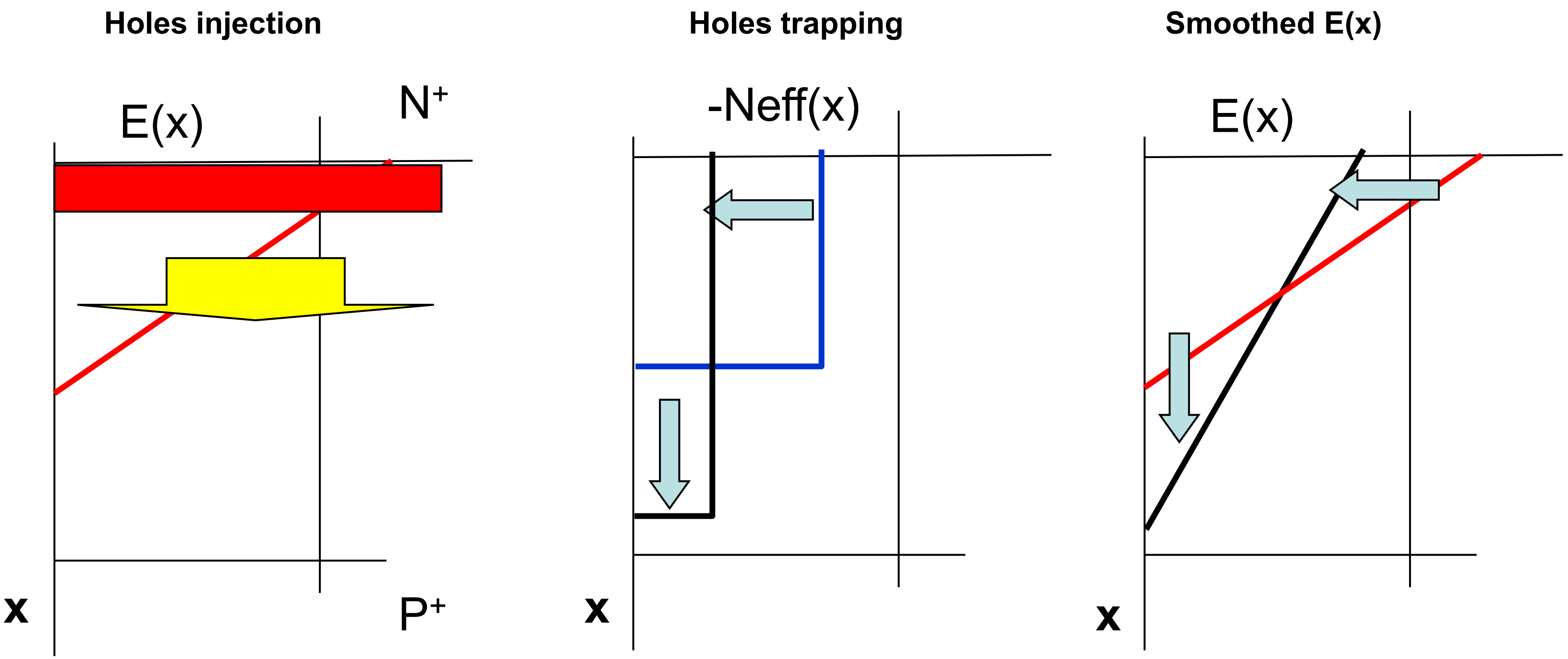




I. Mandić, RESMDD08, Florence, Italy, 15th -17th October 2008

Calculation with trivial SP detector model

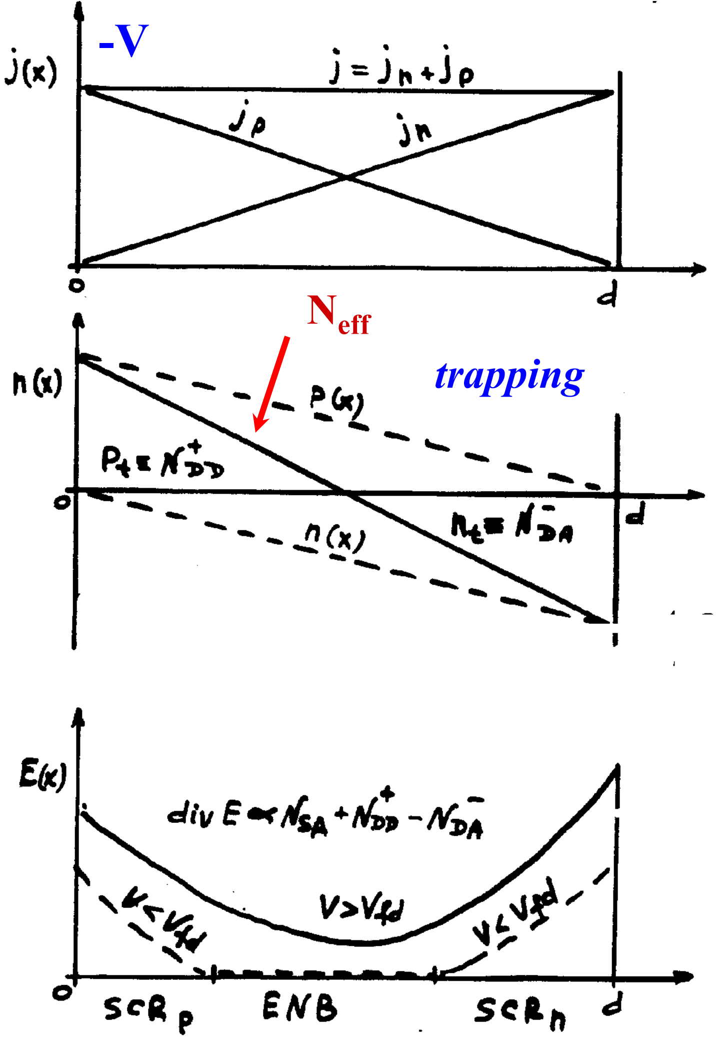
PTI model for stabilization of avalanche multiplication by deep levels



The approach is based on the explanation of high breakdown voltage for 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 (1997), 350.)

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.*

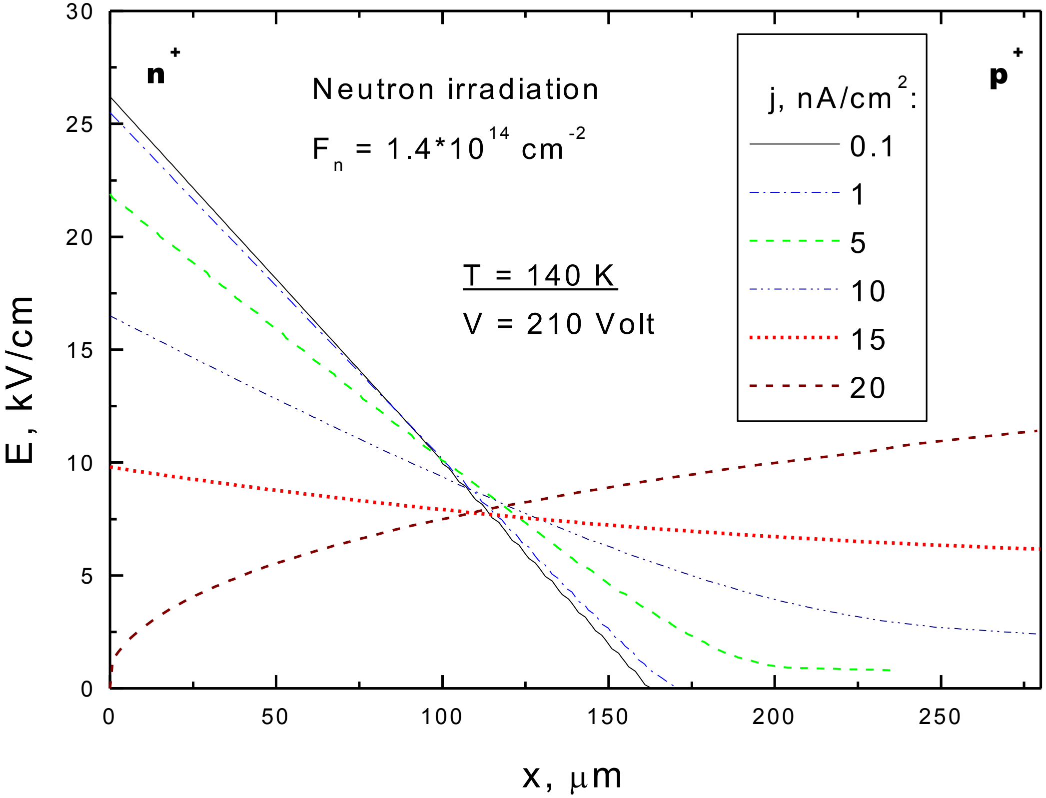


Trapping of free carriers from detector reverse current to midgap energy levels of radiation induced defects leads to DP E(x)

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

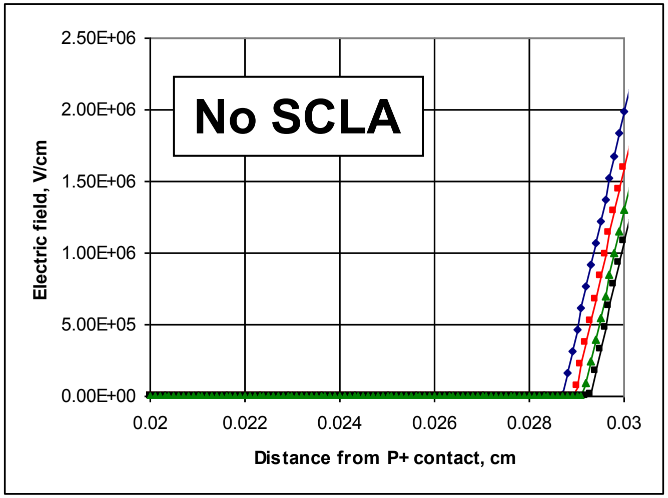


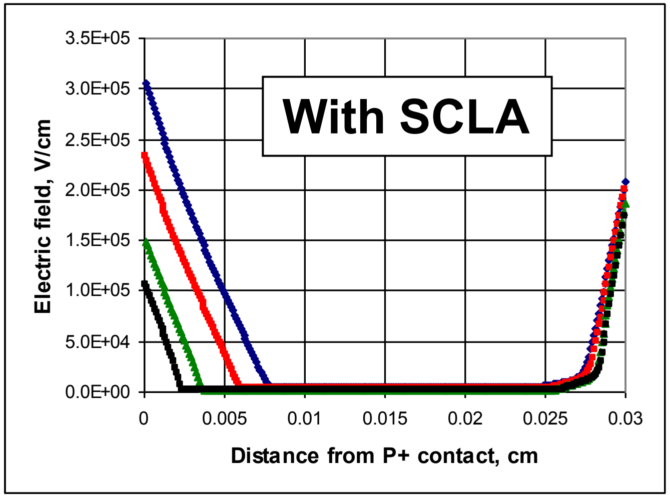
E.Verbitskaya et al., “Optimization of electric field distribution by free carriers injection ….” IEEE trans., NS-49 (2002), p. 258.

Calculation of the Electric field with PTI model of "Space Charge Limited Avalanche"

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		4.00E+15		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.prob	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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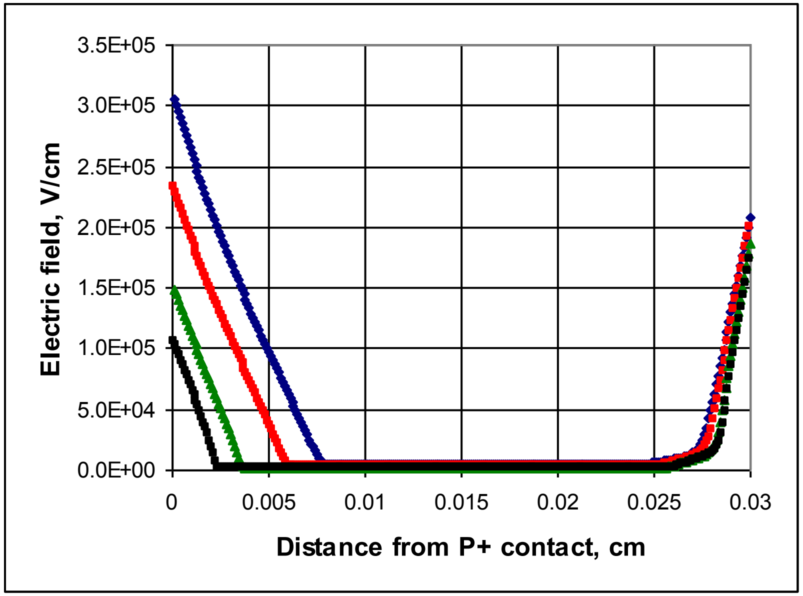
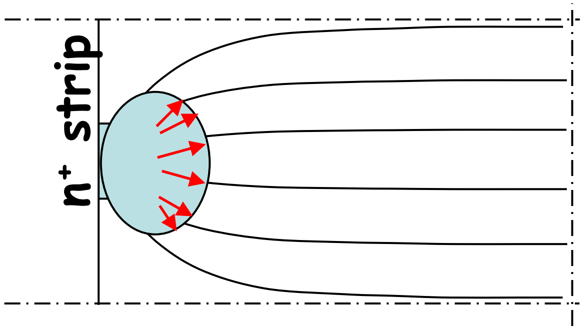
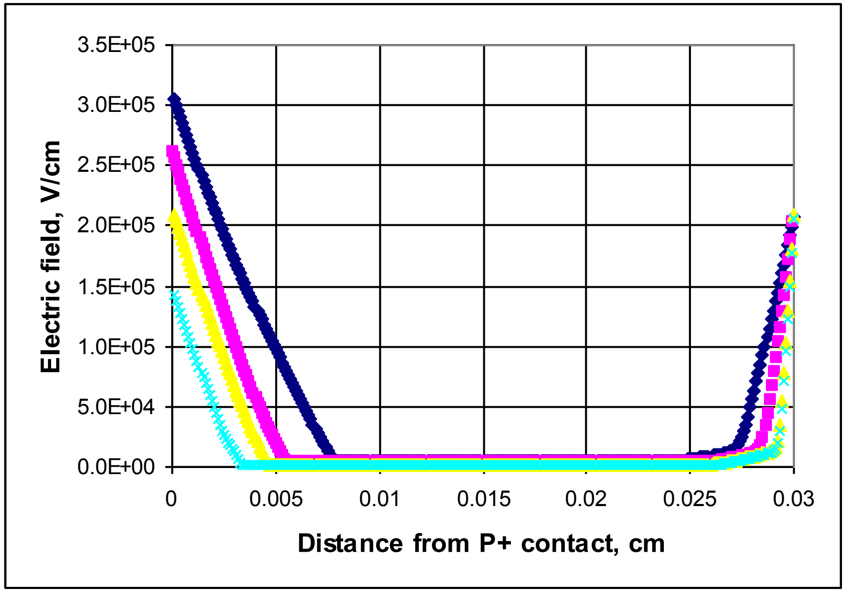
Current focusing effect in detectors with SCLA

NO current focusing
(PAD configuration)



Current focusing

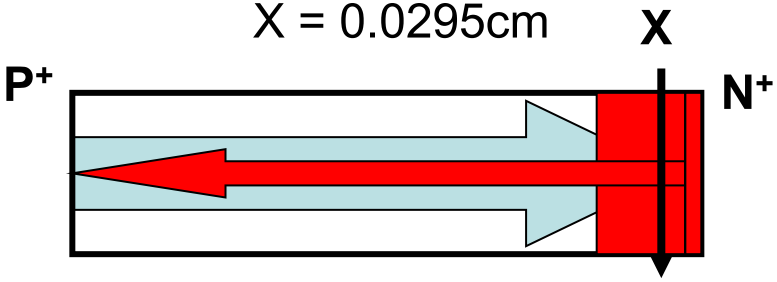


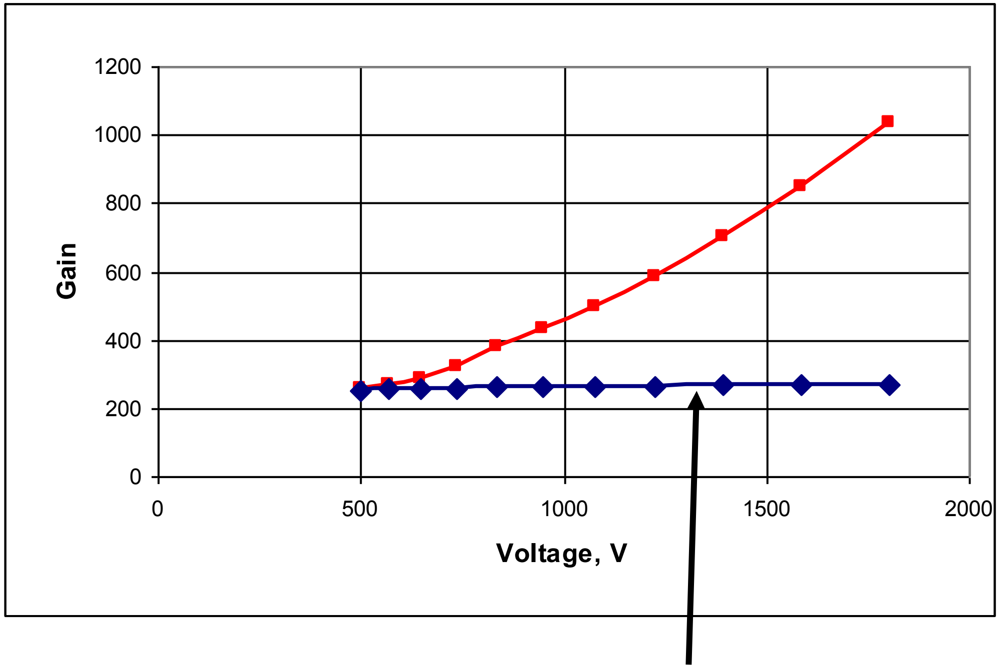


V.Eremin, RD50, Nov 2010

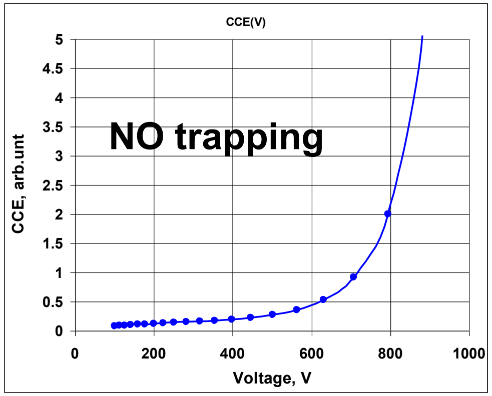
Voltage dependence of the gain in SCLA mode

Fn = 1e16 cm^{-2}
X = 0.0295cm





No Avalanche



NO trapping

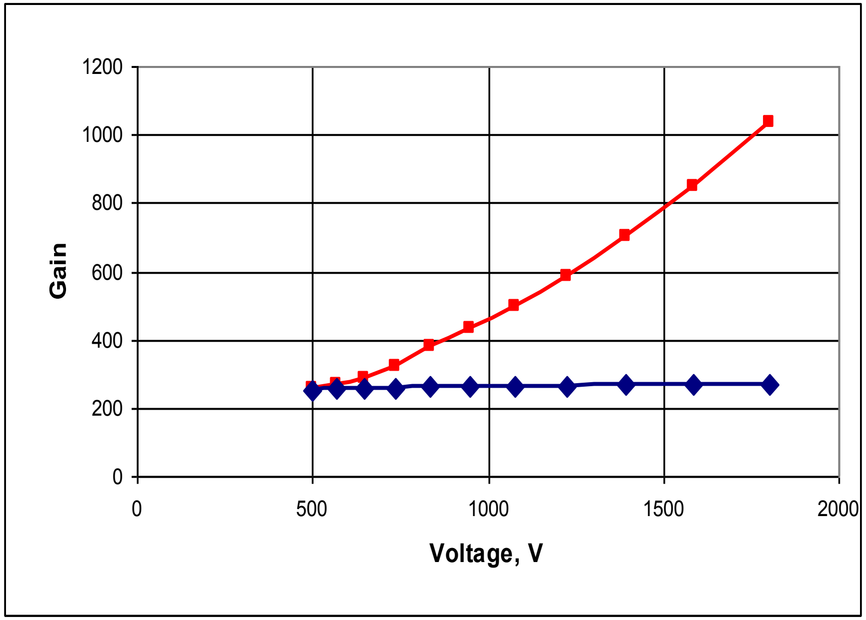
V.Eremin, RD50, Nov 2010

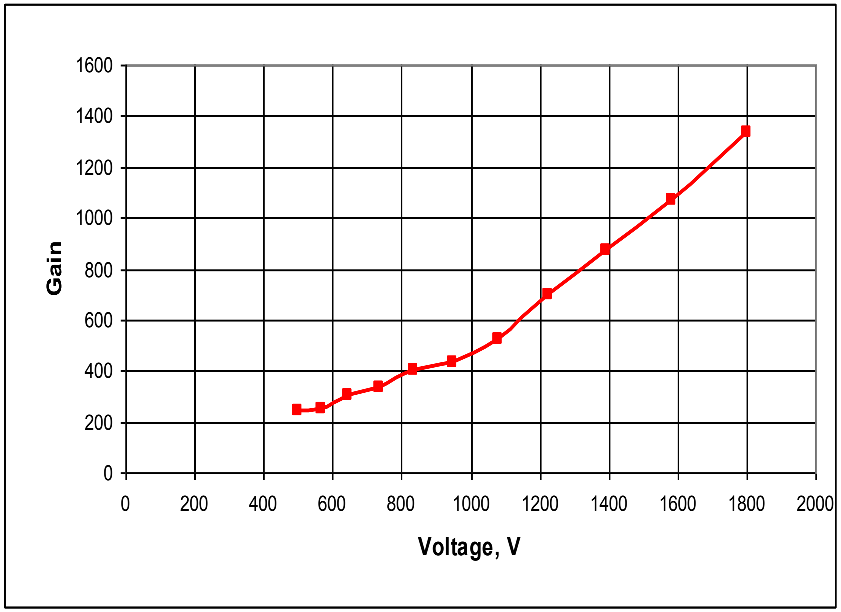
Current focusing effect on the gain in SCLA mode

Fn = 1e16 cm-2

No current focusing

Current focusing (ATLAS)

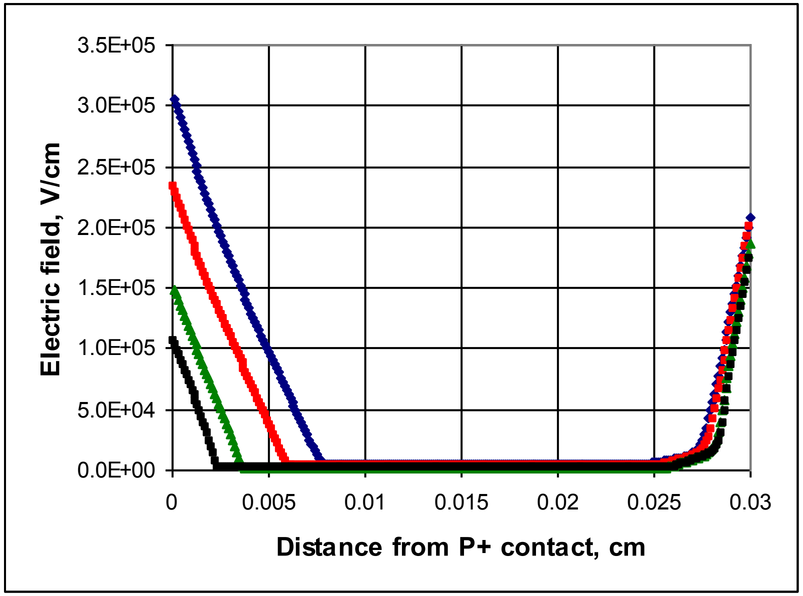




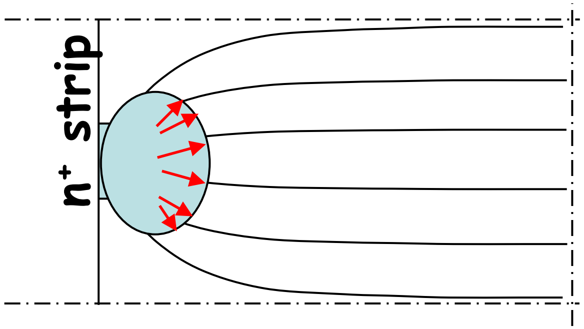
V.Eremin, RD50, Nov 2010

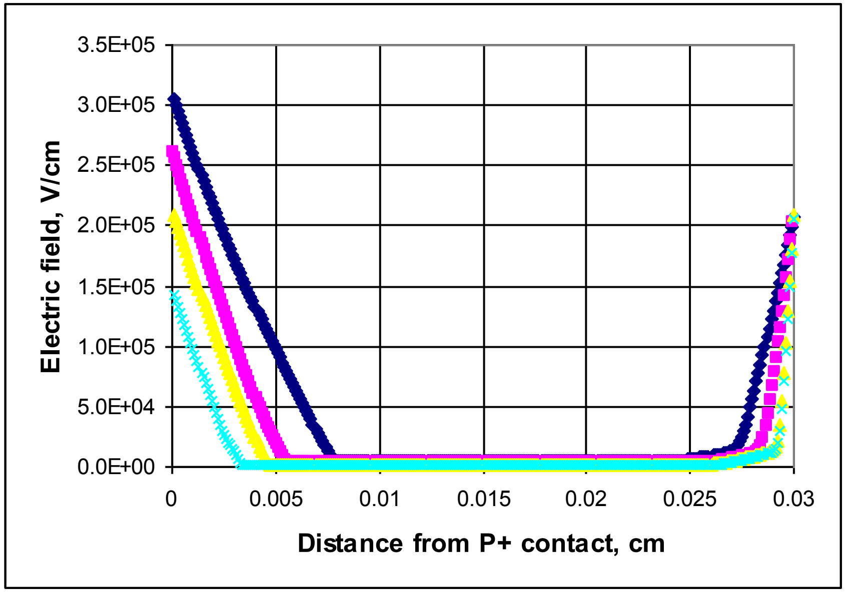
Current focusing effect in detectors with SCLA

NO current focusing
(PAD configuration)



Current focusing





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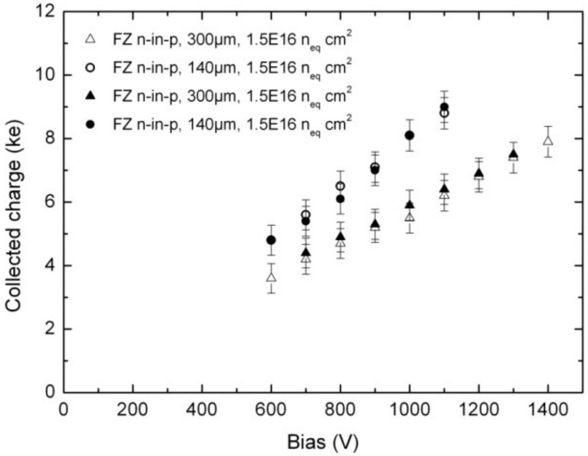
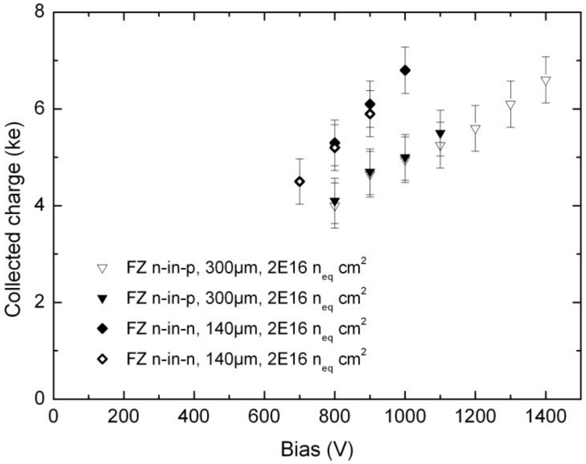
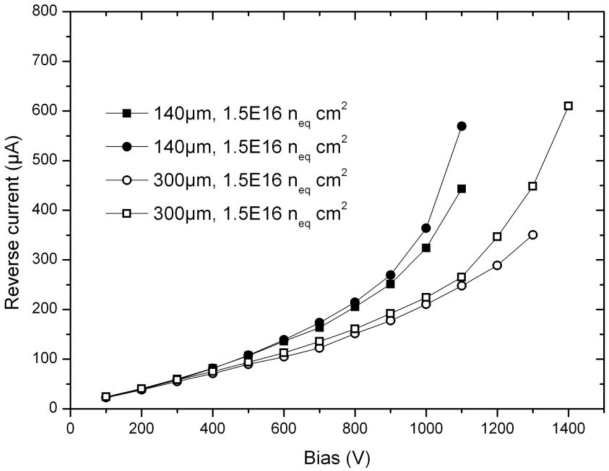
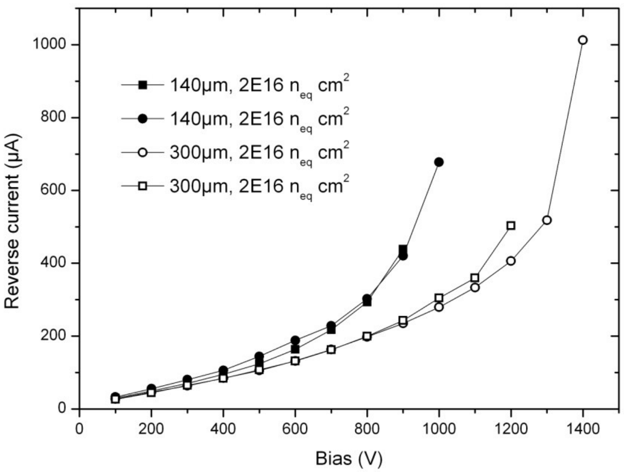
CCE and currents after neutron irradiations





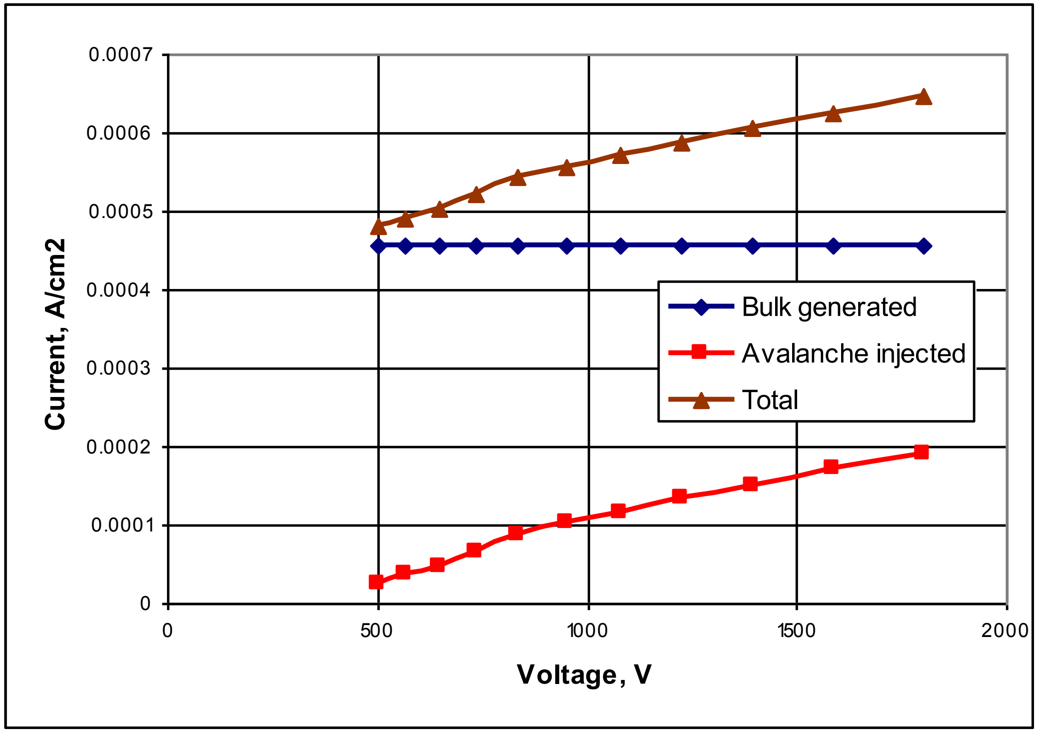




G. Casse, 14th RD50,
Freiburg 5-7 June 2009.

I-V characteristics in SCLA

Fn=1e16 cm-^{2}, T = 260K



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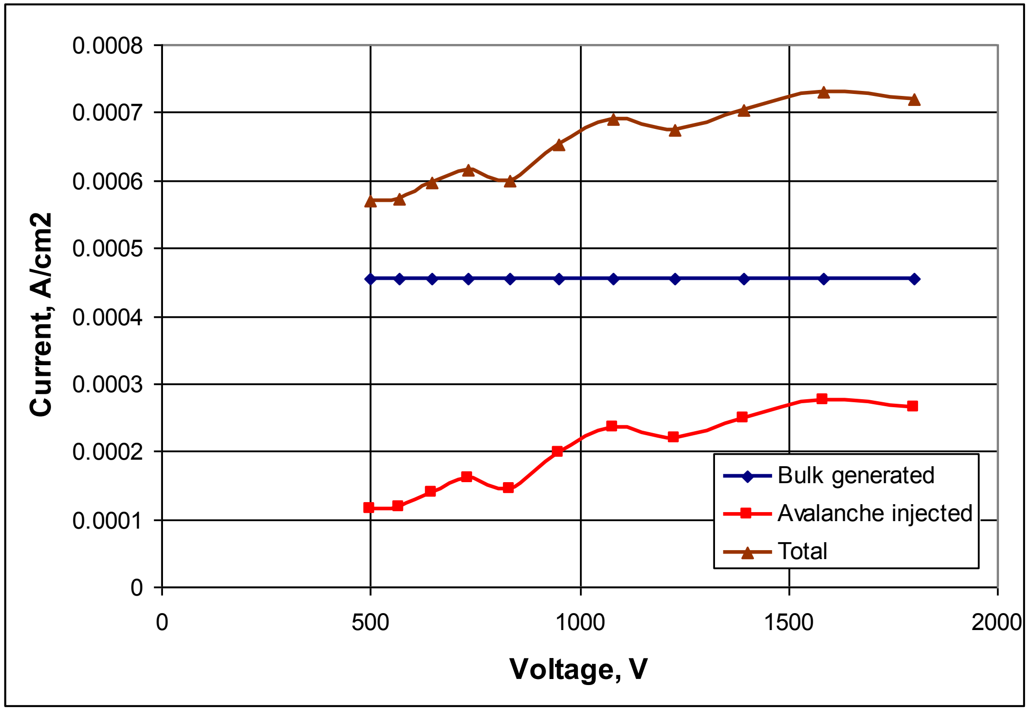
Current focusing effect on the detector leakage current in SCLA mode



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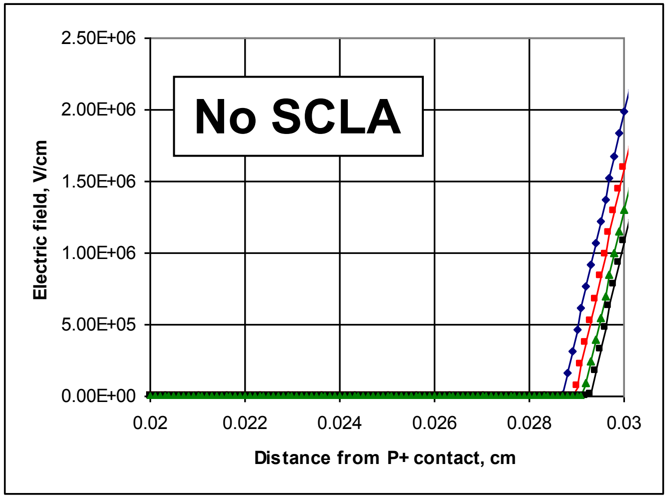
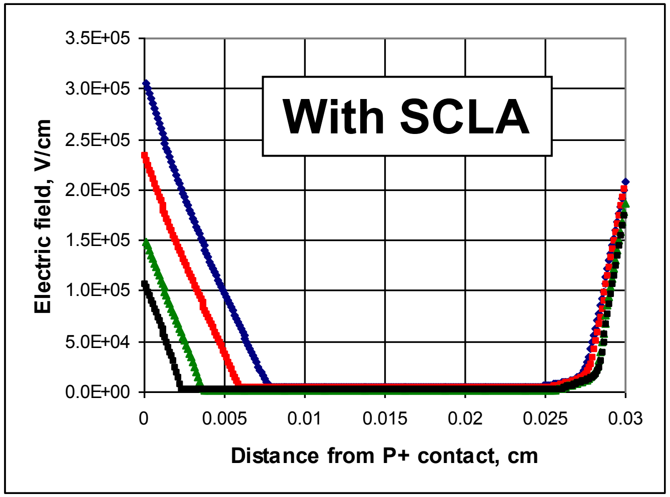
Back side junction breakdown ?

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**		**4.00E+15**		**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.prob	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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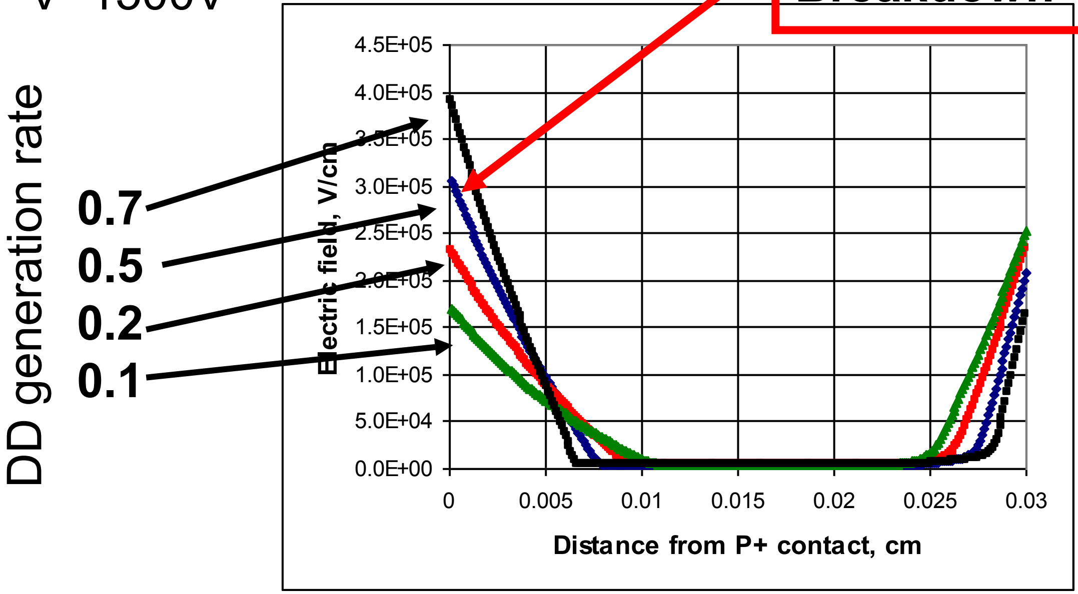
Deep donor generation and the irradiated detector breakdown

Fn=1e16cm-2
T=260K
V=1500V



Double side avalanche injection
Positive feedback
Breakdown

The approach is based on explanation of the high break down 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.)

Conclusions

- The PTI model of Space Charge Limited Avalanche (SCLA) in heavily irradiated detectors explains the major effect – the smoothed rising of CCE with the applied voltage without breakdown.
- The new limitation for the detector operational voltage - the sharp rise of the reverse current could be related with the back side junction breakdown.
- This back side junction breakdown could come from the high density of deep donors and it simulation requires more details on the introduction rate of deep donors.

Acknowledgement

This work was made in the framework of RD50 collaboration and supported in part by:

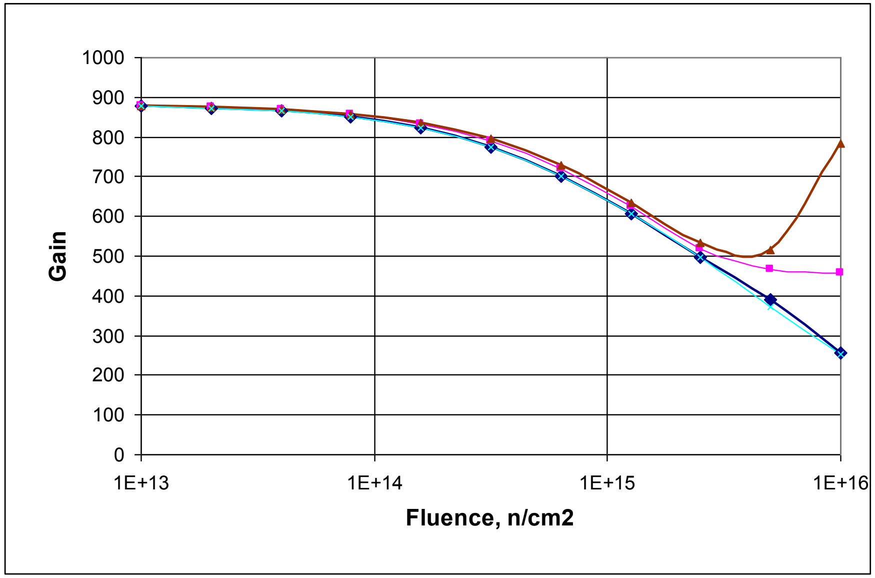
- RF President Grant # 2951.2008.2
- Fundamental Program of Russian Academy of Science on Collaboration with CERN

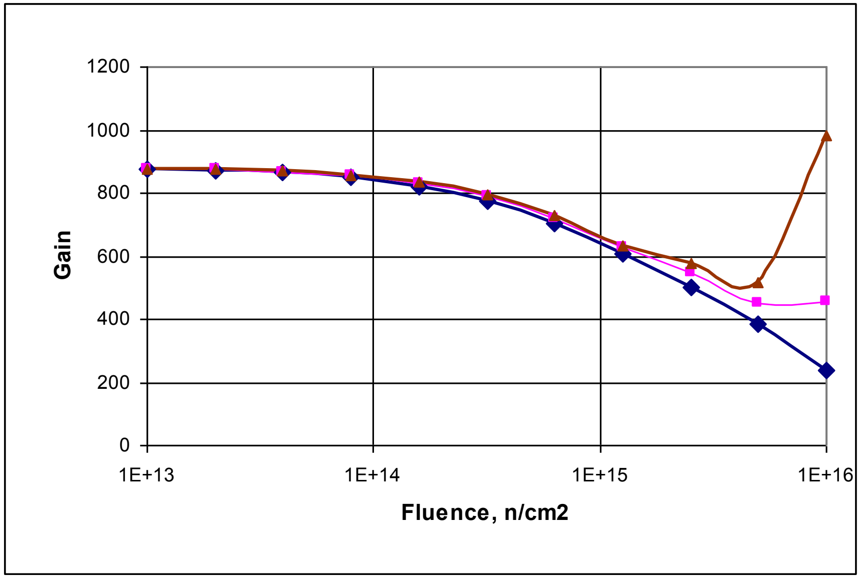
Thank you for attention

Fluence dependence of the gain

V = 500, 1000, 1500V
X = 0.0295cm
No current focusing

Current focusing (ATLAS)





V.Eremin, RESMDD 10