

# ***TCT study of silicon epitaxial and MCZ detectors***

***V. Eremin<sup>1</sup>, M. Boscardin<sup>2</sup>, M. Bruzzi<sup>3</sup>, D. Creanza<sup>4</sup>,  
A. Macchiolo<sup>5</sup>, D. Menichelli<sup>3</sup>, C. Piemonte<sup>2</sup>, E. Verbitskaya<sup>1</sup>***

- 1. Physico Technical Institute - St.Petersburg,***
- 2. IRST-Trento***
- 3. Dip. Energetica- INFN Firenze***
- 4. Dip. Interateneo Fisica – INFN Bari***
- 5. Dip. Fisica – INFN Firenze***

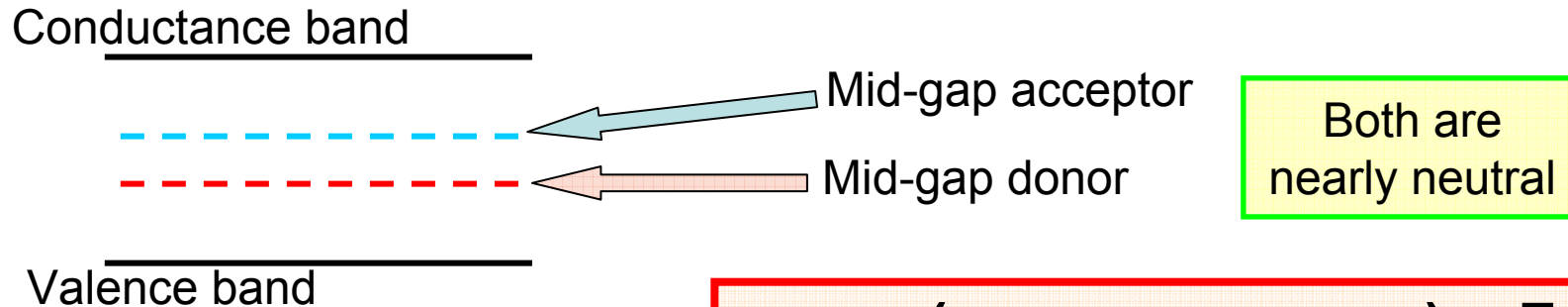
CERN, October 16 -18, 2006

# Outline

1. ***Samples and experiment***
2. ***Input data for TCT response treatment***
3. ***TCT response in bulk and epi detectors***
4. ***Electric field reconstruction***
5.  ***$E(x)$  in cooled detectors***
6. ***Long term annealing effect***
7. ***Conclusions***

# Operation effective deep levels in irradiated detectors

**Mid gap levels (MGL) – Current generation, space charge introduction**



$$J_{\text{gen}} \sim \sum (N_{\text{mgl}} * \sigma * \exp(-E_{\text{mgl}}/kT)) \sim F$$

$$1/\tau \sim \sum N_{\text{dl}} \sim F$$

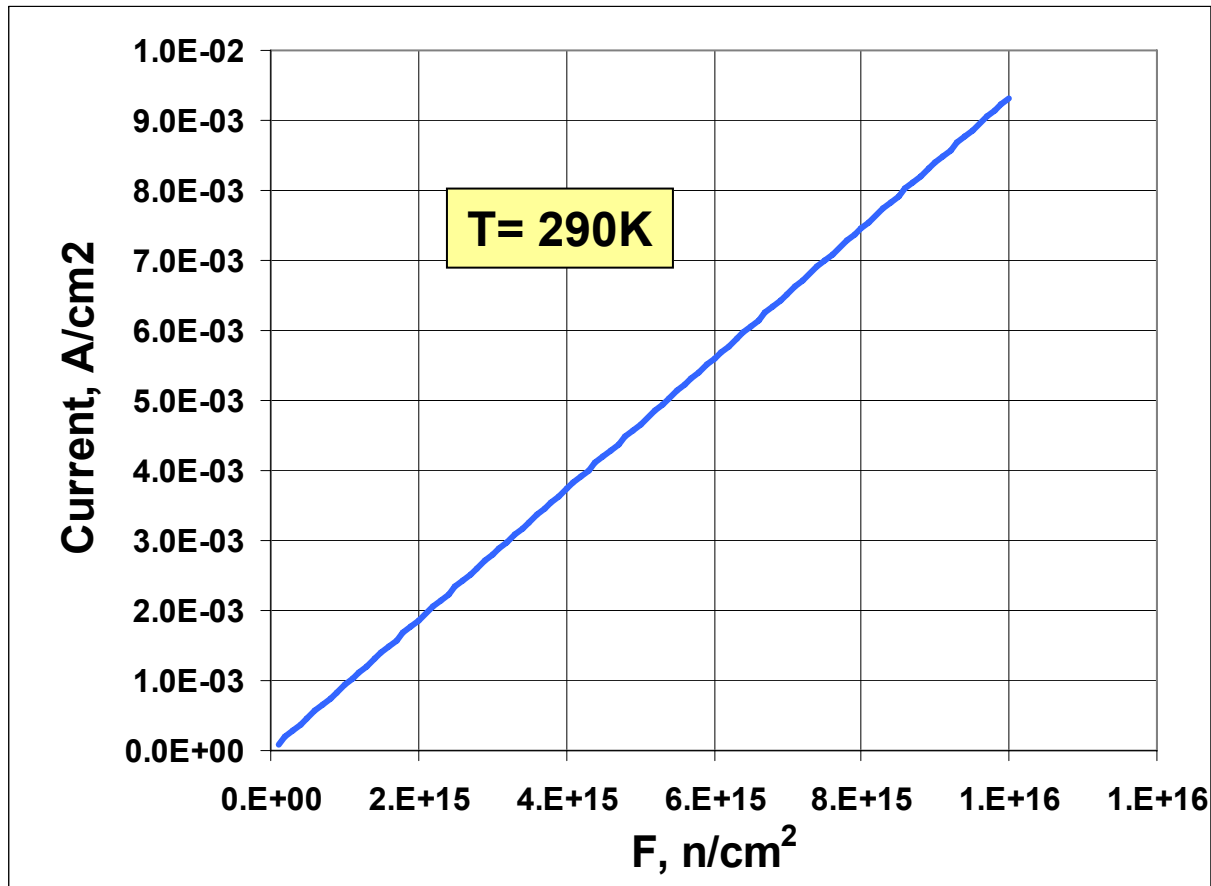
$$N_{\text{eff}} = \sum(N_{\text{DD}^+}) - \sum(N_{\text{DA}^-})$$

**Parameters of MGL**

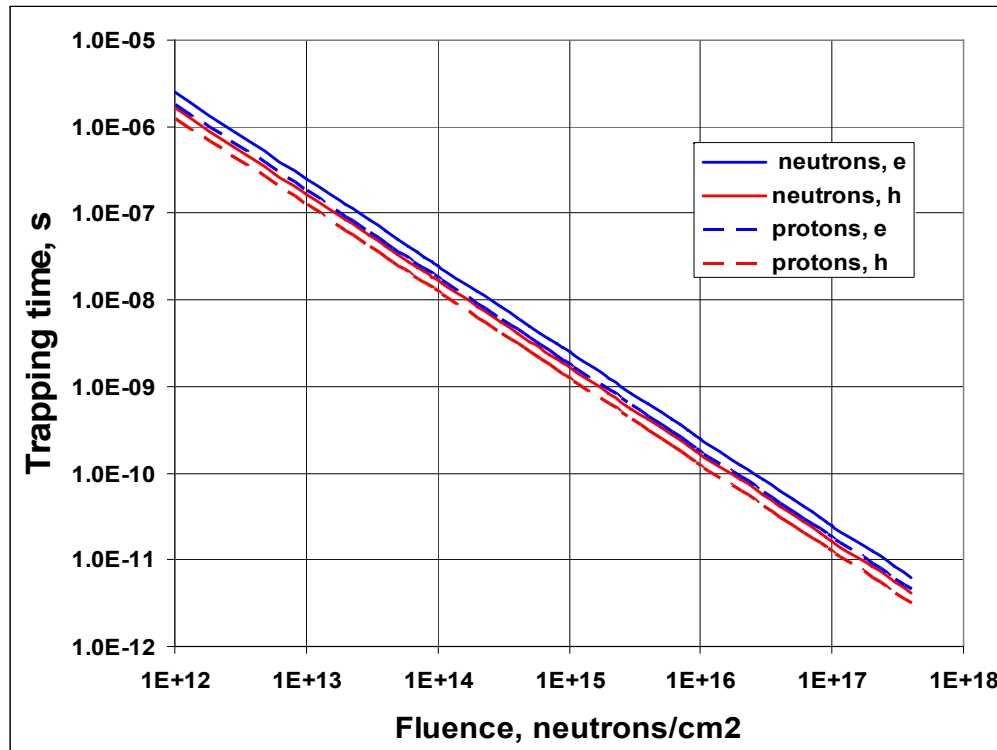
**MGL1 : donor**  
 $E_t - E_v = 0.48\text{eV}$   
 $\sigma = 1 * 10^{-15} \text{ cm}^2$

**MGL2: acceptor**  
 $E_t - E_v = 0.56\text{eV}$   
 $\sigma = 1 * 10^{-15} \text{ cm}^2$

# Generation current in Si PIN detectors



# Life time degradation in Si



$$\tau(\phi) = (1 / \tau_0 + \gamma\phi)^{-1}$$

Trapping probability (protons)	
$t_e^0$	$1 \times 10^3$
$\gamma_e$	$5.5 \times 10^3$
$t_h^0$	$1 \times 10^3$
$\gamma_h$	$8 \times 10^3$

Parameterization for data of G. Gramburger ....

# Samples and technique

Sample #	Material	Radiation	Fluence eq.n.	Annealing		Measurement
				T, C	Time, min	T, K
13-SMG-15	epi	neutrons	8.50E+14	no		293
12-SMG-15	epi	neutrons	8.50E+14	80	60	293
12-SMG-19	epi	neutrons	1.70E+15	80	30	293, 263
12-SMG-22	epi	protons		80	60	293, 263
187-SMG-9	MCZ	neutrons	4.20E+14	no		293, 263
187-SMG-2	MCZ	neutrons	4.20E+14	80	12	293

## ***Technique:***

***TCT setup at PTI***

***TCT setup response***                      ***0.8 ns***

***Temperature range***                        ***77 – 373K***

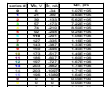
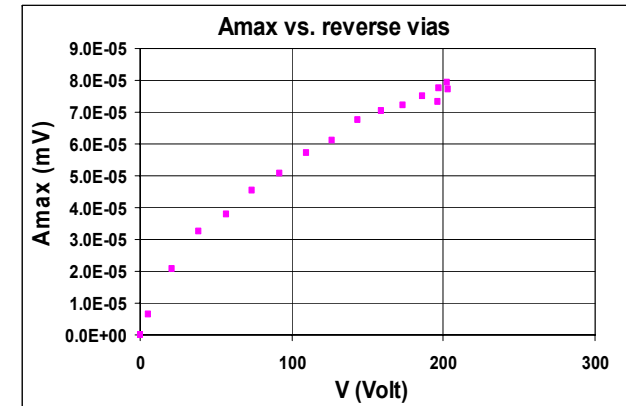
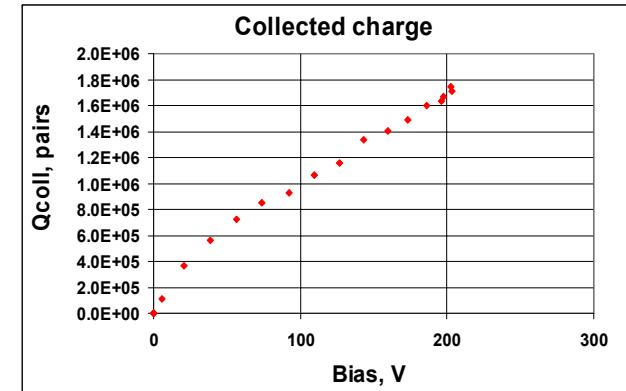
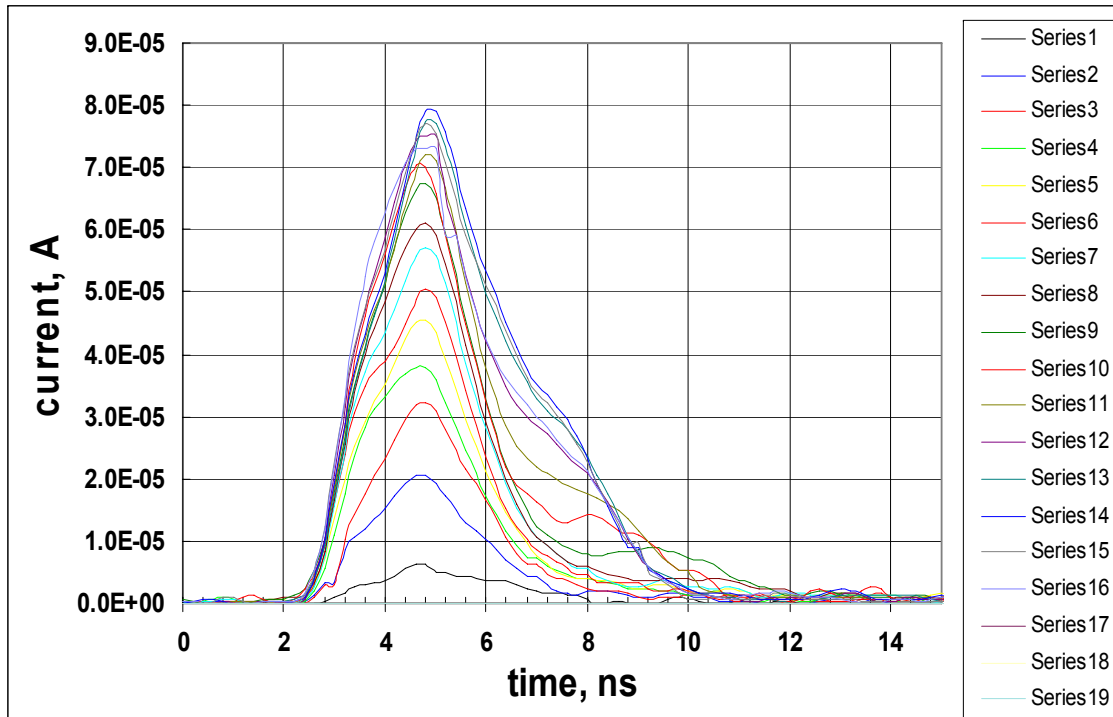
***Laser wavelength***                        ***830um***

# TCT data for silicon epi as irradiated detector

Detector W13-SMG-15  
epi, 150um  
Neutron irradiated:  $F_{eq} = 8.5 \text{ E}14 \text{ cm}^{-2}$   
Annealing: no

Operational parameters:  
 $T = 293\text{K}$

Extracted values  
 $\tau_{tr} = 3\text{ns}$   
 $V_{fd} = 180\text{V}$

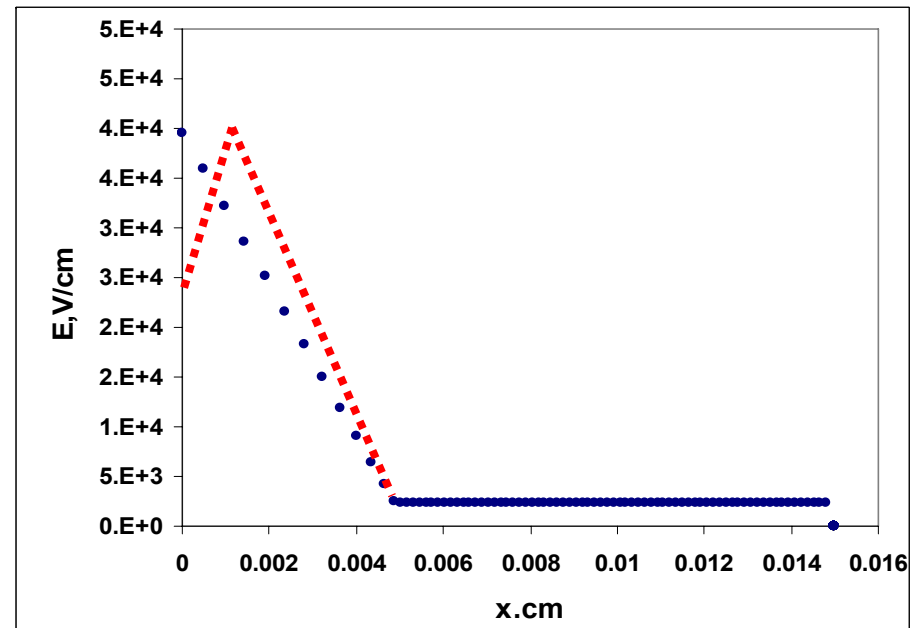
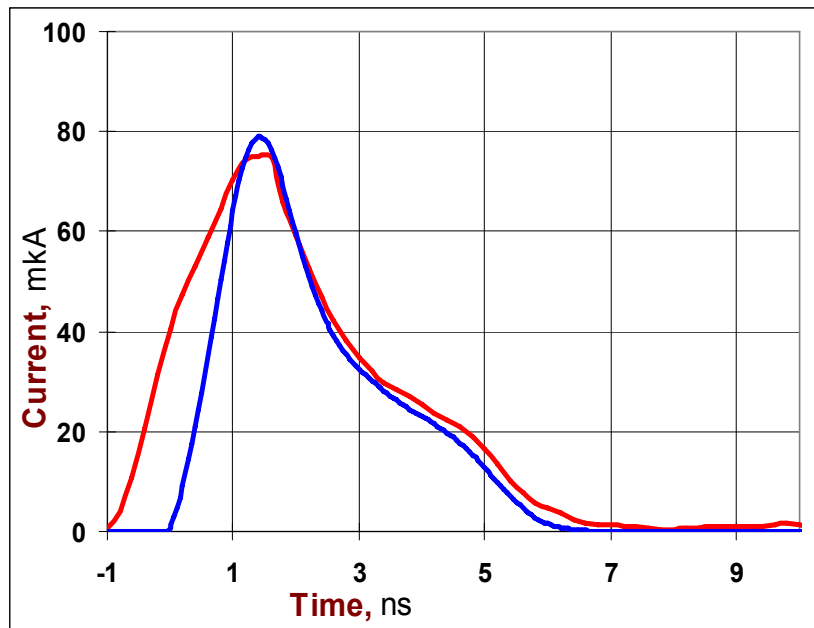


# $E(x)$ reconstruction for silicon epi as irradiated detector

Detector W13-SMG-15  
epi, 150 $\mu$ m  
Neutron irradiated:  $F_{eq} = 8.5 \text{ E}14 \text{ cm}^{-2}$   
Annealing: no

Operational parameters:  
 $V = 186 \text{ V}$   
 $T = 293 \text{ K}$

Extracted values  
 $\text{Tau tr} = 3 \text{ ns}$   
 $V_{fd} = 180 \text{ V}$



Sample parameters		Calculated values	
W1, cm	0.005	E1, V/cm	2800
Eb, V/cm	2100	W1, cm	0.005
Wb, cm	0.01	Eb, V/cm	2100
E2, V/cm	1.77E+20	Wb, cm	0.01
W2, cm	0	E2, V/cm	1.77E+20
		W2, cm	0

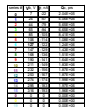
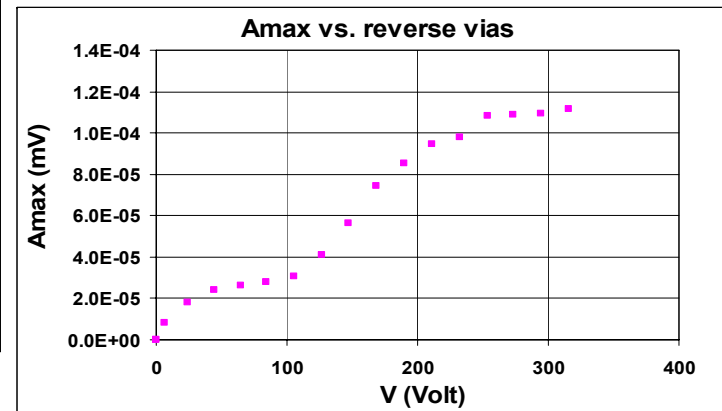
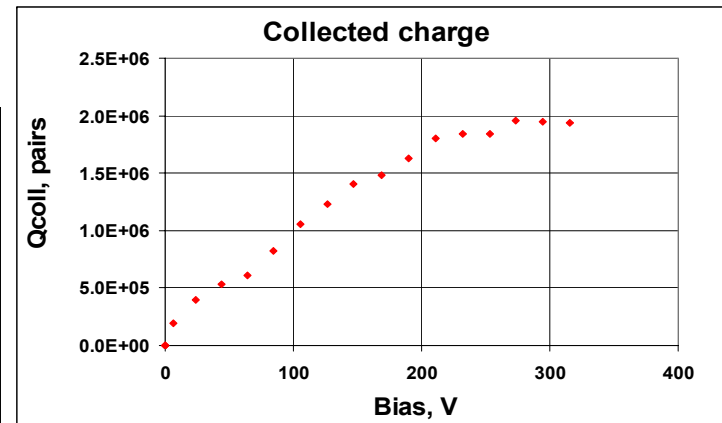
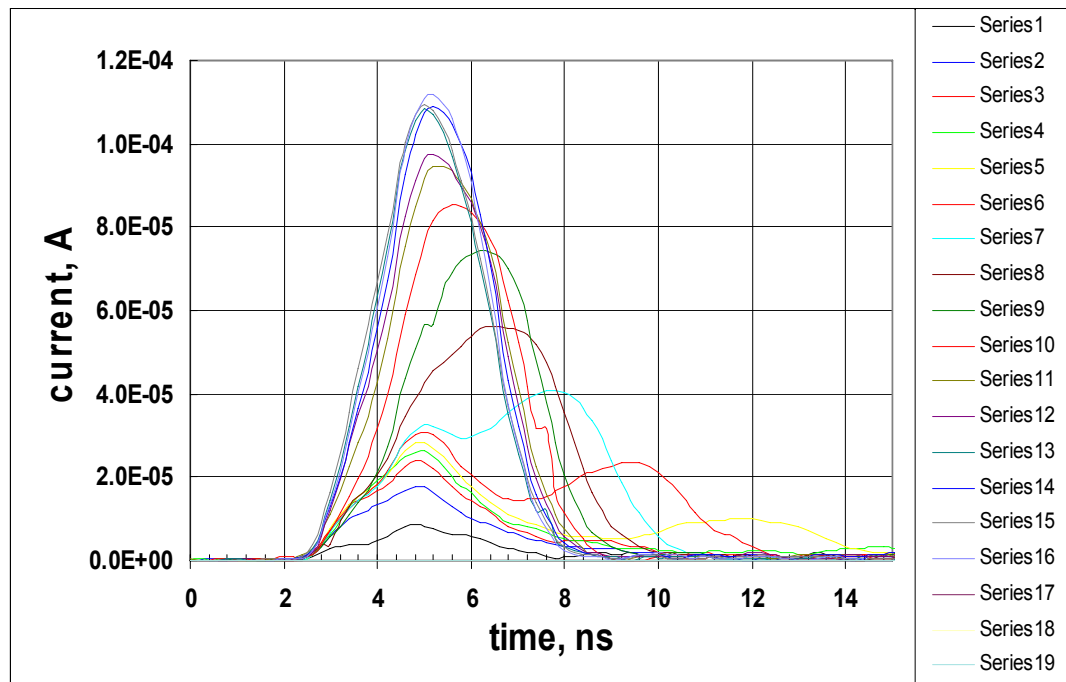


# TCT data for silicon epi annealed detector

Detector W12-SMG-15  
epi, 150um  
Neutron irradiated:  $F_{eq} = 8.5 \text{ E}14 \text{ cm}^{-2}$   
Annealing: 80C@60min

Operational parameters:  
 $T = 293\text{K}$

Extracted values  
 $V_{fd} = 150\text{V}$

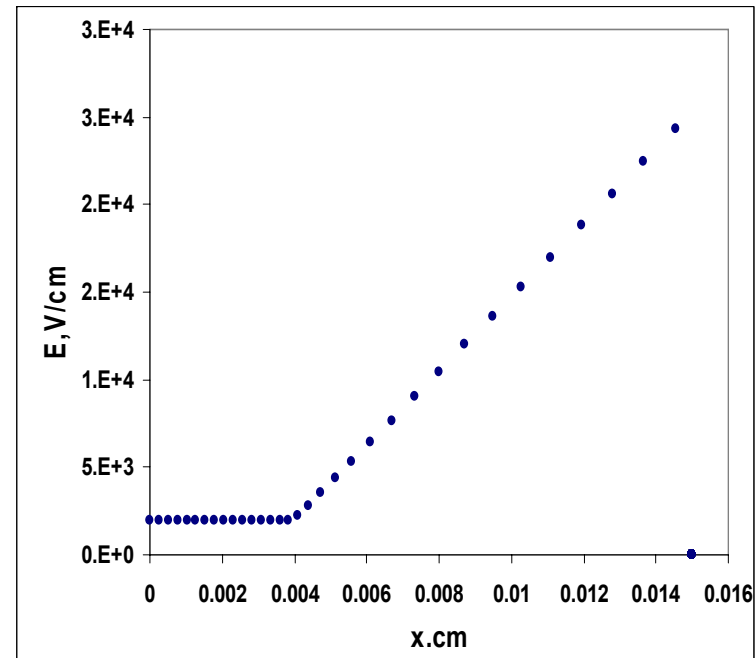
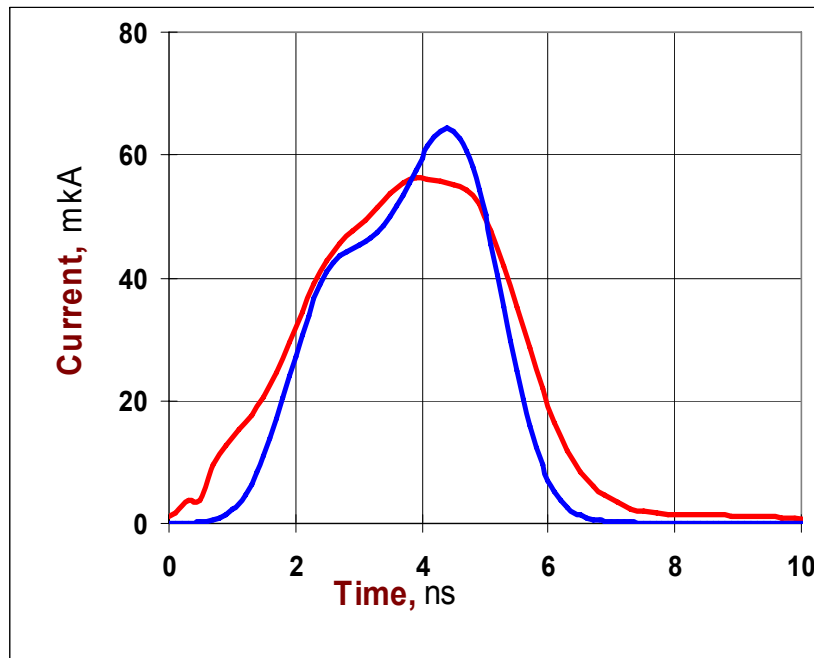


# *E(x) reconstruction for silicon epi annealed detector*

Detector W12-SMG-15  
 MCZ, 150um  
 Neutron irradiated:  $F_{eq} = 8.5 \text{ E}14 \text{ cm}^{-2}$   
 Annealing: 80C@60min

**Operational parameters:**  
 $V = 147\text{V}$   
 $T = 293\text{K}$

**Extracted values**  
 $\text{Tau tr} = 3 \text{ ns}$   
 $V_{fd} = 150\text{V}$



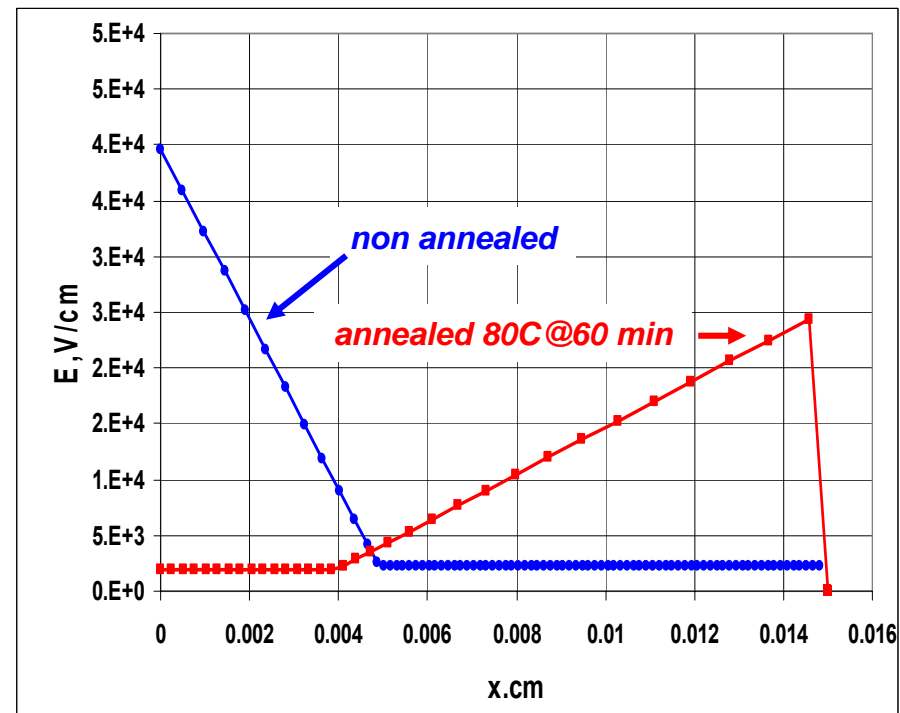
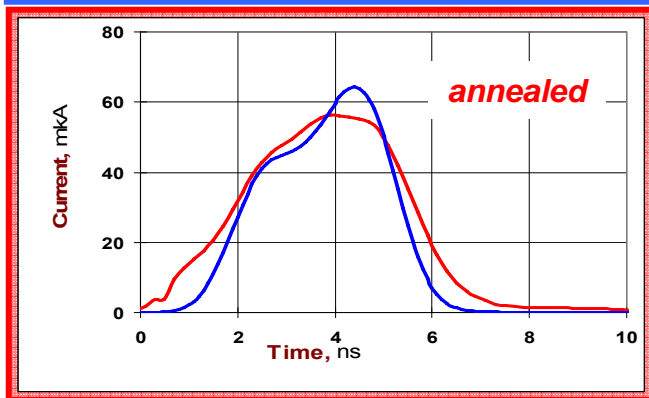
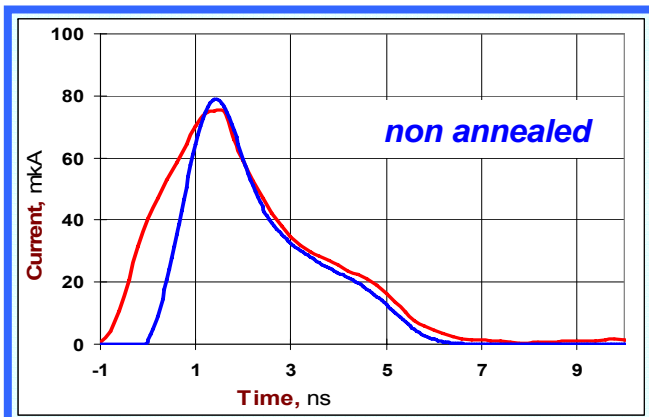
Sample parameters		Calculated values	
d (cm)	1.50E-02	E1-V/cm	2000
W (cm)	1	W1, cm	0
Wep (cm)	0.00E+00	Eh-V/cm	2000
Wep2 (cm)	0.00E+00	Wb, cm	0.004
Wep3 (cm)	0.00E+00	Ez-V/cm	23272.727
Wep4 (cm)	0.00E+00	Wz, cm	0.011
ICF mode			
Wep (cm)	2.23E+00		
Wep2 (cm)	1.41		
Wep3 (cm)	5.64E+00		
Wep4 (cm)	290		
Wep5 (cm)	0.1		

# Annealing effect in silicon epi detectors

epi, 150um  
 Neutron irradiated:  $F_{eq} = 8.5 \text{ E}14 \text{ cm}^{-2}$   
 W13-SMG-15: non annealed  
 W12-SMG-15: annealed 80C@60 min

Operational parameters:  
 $T = 293\text{K}$

Extracted values  
 $\tau = 3 \text{ ns}$



Sample parameters	
d [cm]	3.00E-02
Uc[V]	0
Neut [1/cm <sup>2</sup> ]	0.00E+00
tau[n]	5.00E-09
tau[n]	5.00E-09
ICT mode	
beta=1	2.80E+06
beta IV	184
beta cm	5.64E+03
Temper. [K]	293
beta [cm]	0.1

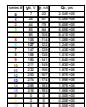
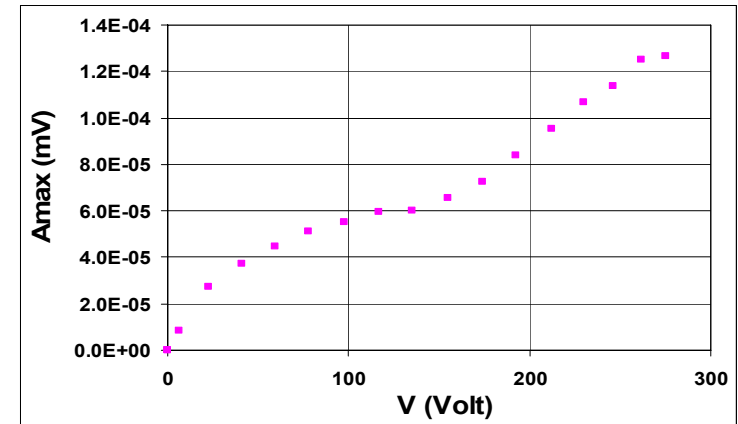
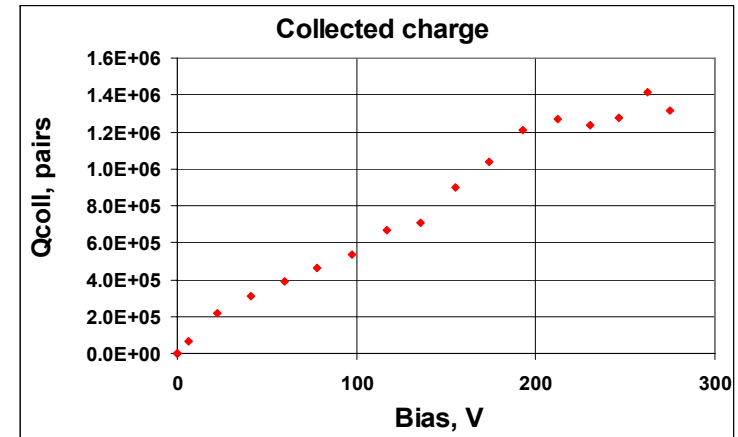
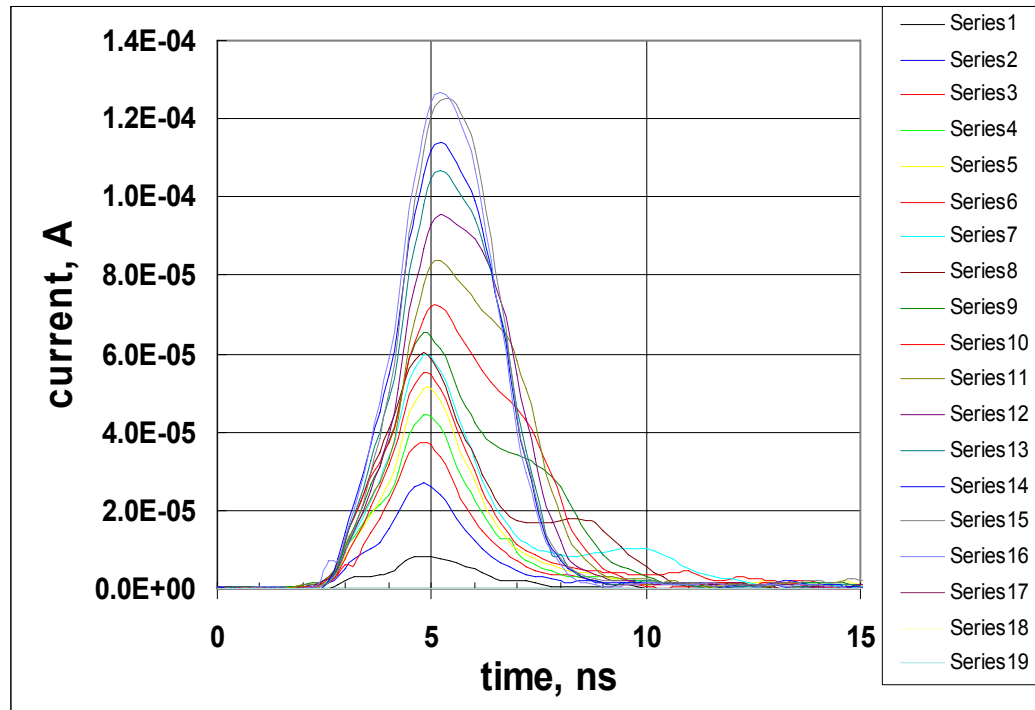
Calculated values	
E1 [V/cm]	5200
E2 [V/cm]	6200
E3 [V/cm]	2200
E4 [V/cm]	0.015
E5 [V/cm]	3168.886
E6 [V/cm]	0.0115

# TCT data for silicon epi annealed detector

Detector W12-SMG-19  
 epi, 150um  
 Neutron irradiated:  $F_{eq} = 1.7 \text{ E}15 \text{ cm}^{-2}$   
 Annealing: 80C@30min

Operational parameters:  
 $T = 293\text{K}$

Extracted values  
 $\tau_{tr} = 1.5 \text{ ns}$   
 $V_{fd} = 190\text{V}$

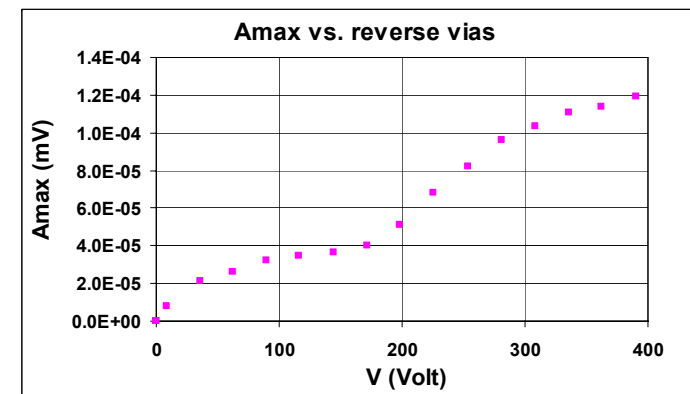
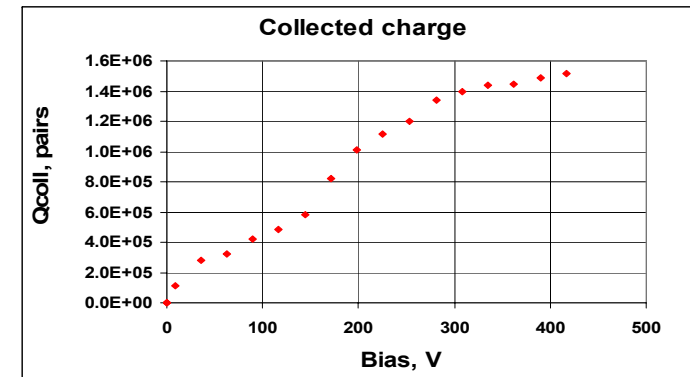
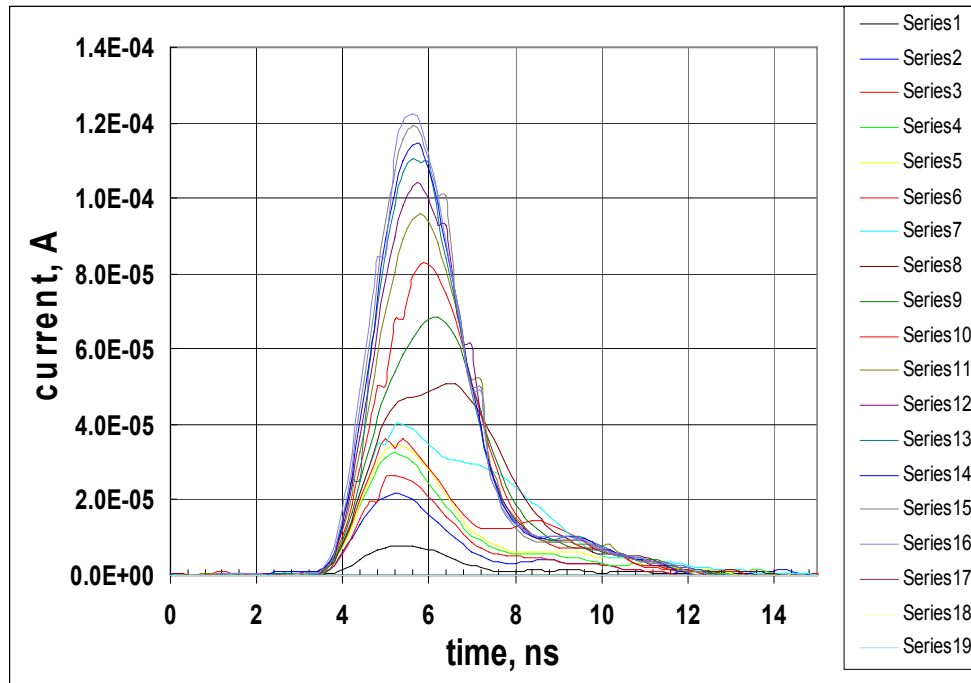


# TCT data for silicon epi annealed and cooled detector

Detector W12-SMG-19-10  
epi, 150um  
Neutron irradiated:  $F_{eq} = 1.7 \text{ E}15 \text{ cm}^{-2}$   
Annealing: 80C@30min

Operational parameters:  
 $T = 263\text{K}$

Extracted values  
 $T_{Au} \text{ tr} = 1.5 \text{ ns}$   
 $V_{fd} = 198\text{V}$



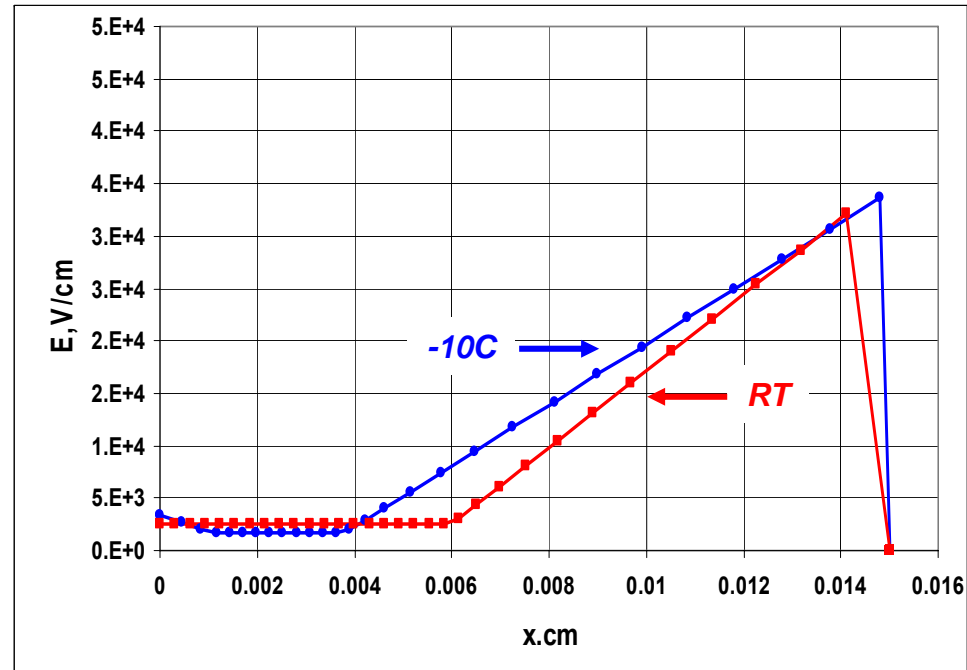
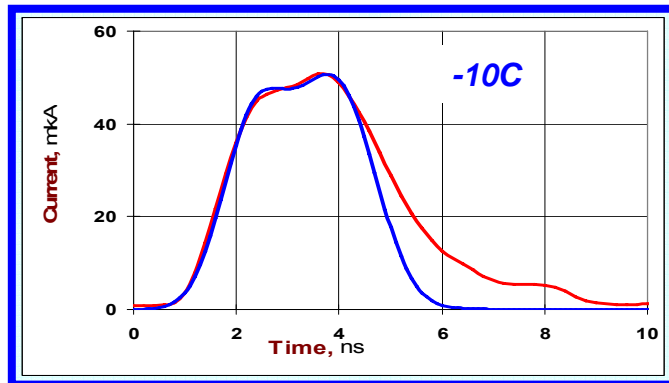
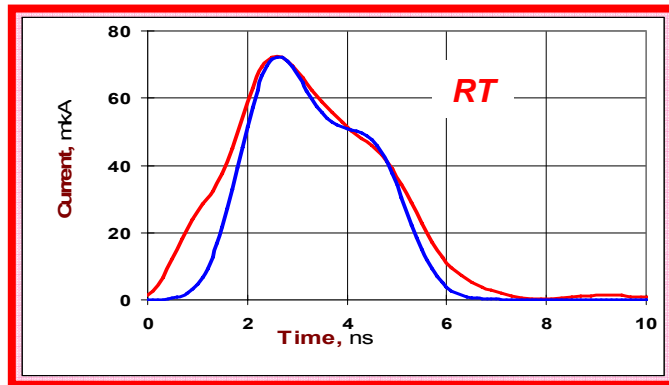
Series	V (V)	Qcoll (pairs)	Amax (mV)
Series1	0	0	0
Series1	100	4.0E+05	3.0E-05
Series1	200	8.0E+05	6.0E-05
Series1	300	1.2E+06	9.0E-05
Series1	400	1.5E+06	1.2E-04
Series2	0	0	0
Series2	100	3.5E+05	2.5E-05
Series2	200	7.0E+05	5.0E-05
Series2	300	1.0E+06	7.5E-05
Series2	400	1.3E+06	1.0E-04
Series3	0	0	0
Series3	100	3.0E+05	2.0E-05
Series3	200	6.0E+05	4.0E-05
Series3	300	9.0E+05	6.0E-05
Series3	400	1.2E+06	8.0E-05
Series4	0	0	0
Series4	100	2.5E+05	1.5E-05
Series4	200	5.0E+05	3.0E-05
Series4	300	7.5E+05	4.5E-05
Series4	400	1.0E+06	6.0E-05
Series5	0	0	0
Series5	100	2.0E+05	1.0E-05
Series5	200	4.0E+05	2.0E-05
Series5	300	6.0E+05	3.0E-05
Series5	400	8.0E+05	4.0E-05
Series6	0	0	0
Series6	100	1.5E+05	7.5E-06
Series6	200	3.0E+05	1.5E-05
Series6	300	4.5E+05	2.2E-05
Series6	400	6.0E+05	3.0E-05
Series7	0	0	0
Series7	100	1.0E+05	5.0E-06
Series7	200	2.0E+05	1.0E-05
Series7	300	3.0E+05	1.5E-05
Series7	400	4.0E+05	2.0E-05
Series8	0	0	0
Series8	100	5.0E+04	2.5E-06
Series8	200	1.0E+05	5.0E-06
Series8	300	1.5E+05	7.5E-06
Series8	400	2.0E+05	1.0E-05
Series9	0	0	0
Series9	100	3.0E+04	1.5E-06
Series9	200	6.0E+04	3.0E-06
Series9	300	9.0E+04	4.5E-06
Series9	400	1.2E+05	6.0E-06
Series10	0	0	0
Series10	100	2.0E+04	1.0E-06
Series10	200	4.0E+04	2.0E-06
Series10	300	6.0E+04	3.0E-06
Series10	400	8.0E+04	4.0E-06
Series11	0	0	0
Series11	100	1.5E+04	7.5E-07
Series11	200	3.0E+04	1.5E-06
Series11	300	4.5E+04	2.2E-06
Series11	400	6.0E+04	3.0E-06
Series12	0	0	0
Series12	100	1.0E+04	5.0E-07
Series12	200	2.0E+04	1.0E-06
Series12	300	3.0E+04	1.5E-06
Series12	400	4.0E+04	2.0E-06
Series13	0	0	0
Series13	100	5.0E+03	2.5E-07
Series13	200	1.0E+04	5.0E-07
Series13	300	1.5E+04	7.5E-07
Series13	400	2.0E+04	1.0E-06
Series14	0	0	0
Series14	100	3.0E+03	1.5E-07
Series14	200	6.0E+03	3.0E-07
Series14	300	9.0E+03	4.5E-07
Series14	400	1.2E+04	6.0E-07
Series15	0	0	0
Series15	100	2.0E+03	1.0E-07
Series15	200	4.0E+03	2.0E-07
Series15	300	6.0E+03	3.0E-07
Series15	400	8.0E+03	4.0E-07
Series16	0	0	0
Series16	100	1.5E+03	7.5E-08
Series16	200	3.0E+03	1.5E-07
Series16	300	4.5E+03	2.2E-07
Series16	400	6.0E+03	3.0E-07
Series17	0	0	0
Series17	100	1.0E+03	5.0E-08
Series17	200	2.0E+03	1.0E-07
Series17	300	3.0E+03	1.5E-07
Series17	400	4.0E+03	2.0E-07
Series18	0	0	0
Series18	100	5.0E+02	2.5E-08
Series18	200	1.0E+03	5.0E-08
Series18	300	1.5E+03	7.5E-08
Series18	400	2.0E+03	1.0E-07
Series19	0	0	0
Series19	100	3.0E+02	1.5E-08
Series19	200	6.0E+02	3.0E-08
Series19	300	9.0E+02	4.5E-08
Series19	400	1.2E+03	6.0E-08

# Cooling effect in silicon irradiated epi detectors

Detector W12-SMG-19  
 epi, 150um  
 Neutron irradiated:  $F_{eq} = 1.7 \text{ E}15 \text{ cm}^{-2}$   
 annealed 80C @30 min  
 RT; -10C

Operational parameters:  
 $V = 174\text{V}$

Extracted values  
 $\text{Tau tr} = 1.5 \text{ ns}$



Sample parameters	
d (cm)	3.00E-02
Uc(V)	0
Neff (1/cm <sup>3</sup> )	0.00E+00
tau(n)	5.00E-09
tau(p)	5.00E-09
TCF mode	
beta=1	2.80E+06
beta IVI	184
beta (cm)	5.64E+03
Temper. (K)	293
Base (cm)	0.1

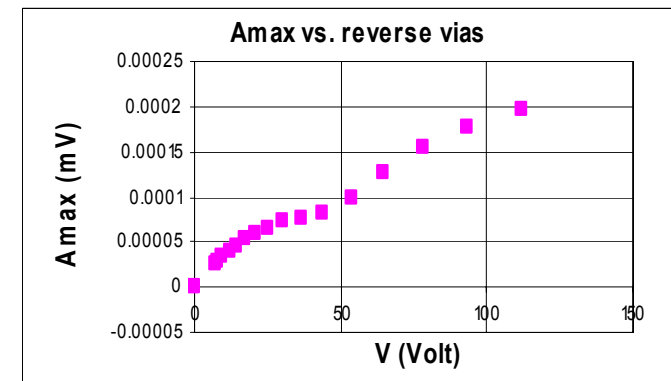
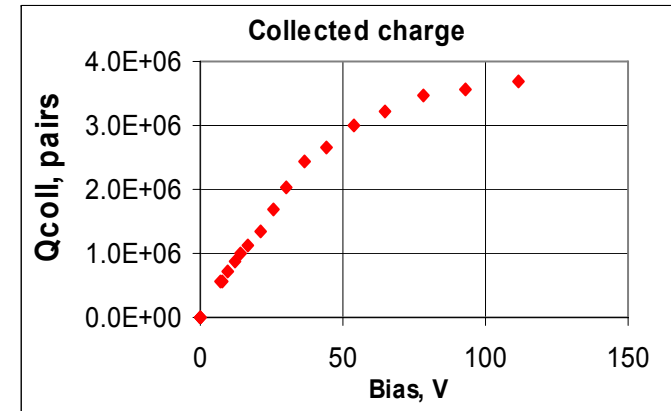
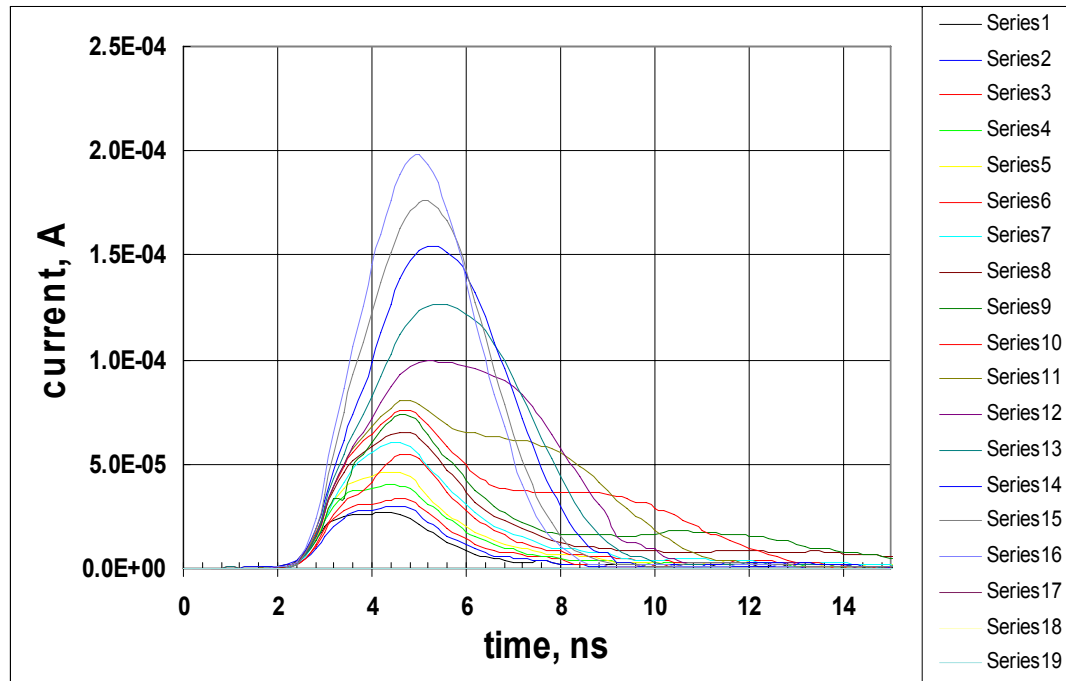
Calculated values	
E1, V/cm	5200
E2, V/cm	0.0035
E3, V/cm	2200
Wb, cm	0.015
E2, V/cm	3168.886
W2, cm	0.0115

# TCT data for proton irradiated silicon epi detector

Detector W12-SMG-22  
 epi, 150um  
 Proton irradiated:  $F_{eq} = 7 \text{ E}14 \text{ cm}^{-2}$   
 Annealing: 80C@60min

Operational parameters:  
 $T = 293\text{K}$

Extracted values  
 $V_{fd} = 54\text{V}$



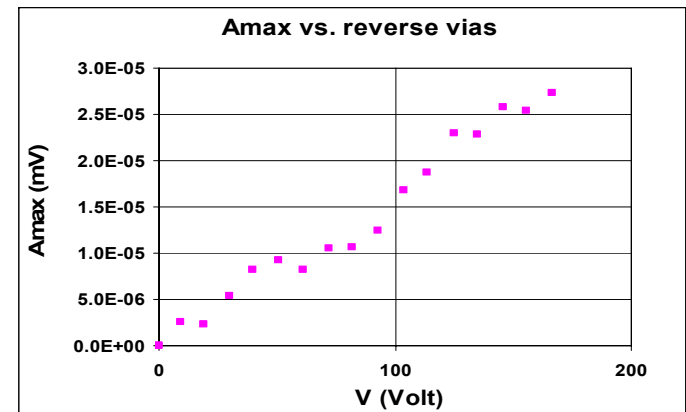
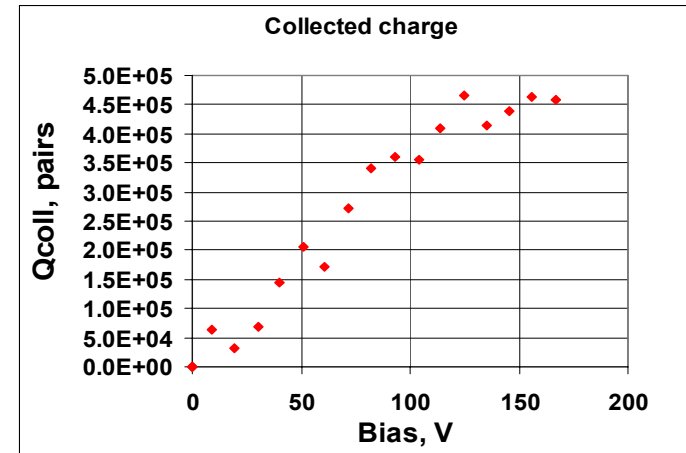
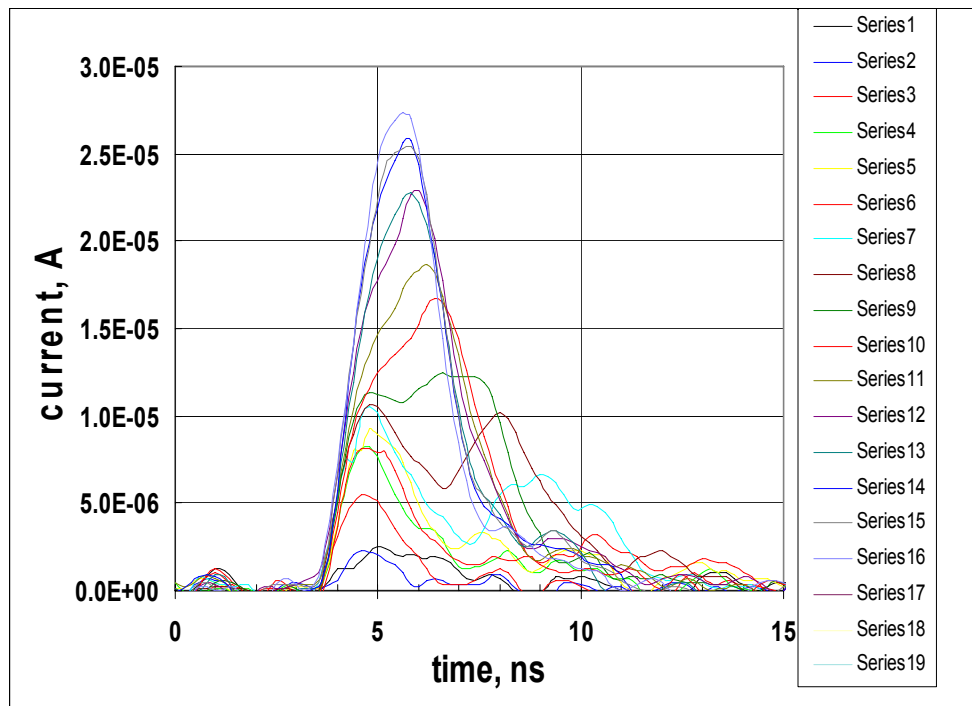
Series	V (V)	Qcoll (pairs)	Amax (mV)
1	0	0	0
2	10	1000000	0.00005
3	20	2000000	0.0001
4	30	3000000	0.00015
5	40	4000000	0.0002
6	50	5000000	0.00025
7	60	6000000	0.0003
8	70	7000000	0.00035
9	80	8000000	0.0004
10	90	9000000	0.00045
11	100	10000000	0.0005
12	110	11000000	0.00055
13	120	12000000	0.0006
14	130	13000000	0.00065
15	140	14000000	0.0007
16	150	15000000	0.00075
17	160	16000000	0.0008
18	170	17000000	0.00085
19	180	18000000	0.0009

# TCT data for silicon epi annealed detector

Detector W12-SMG-22-10  
 epi, 150um  
 Proton irradiated:  $F_{eq} = 7 \text{ E}14 \text{ cm}^{-2}$   
 Annealing: 80C@60min

Operational parameters:  
 $T = 263\text{K}$

Extracted values  
 $V_{fd} = 92\text{V}$



Series	Peak Current (A)	Peak Time (ns)
Series 1	~1.0E-05	~5.5
Series 2	~2.7E-05	~5.5
Series 3	~1.5E-05	~5.5
Series 4	~1.0E-05	~5.5
Series 5	~1.0E-05	~5.5
Series 6	~1.0E-05	~5.5
Series 7	~1.0E-05	~5.5
Series 8	~1.0E-05	~5.5
Series 9	~1.0E-05	~5.5
Series 10	~1.0E-05	~5.5
Series 11	~1.0E-05	~5.5
Series 12	~1.0E-05	~5.5
Series 13	~1.0E-05	~5.5
Series 14	~1.0E-05	~5.5
Series 15	~1.0E-05	~5.5
Series 16	~1.0E-05	~5.5
Series 17	~1.0E-05	~5.5
Series 18	~1.0E-05	~5.5
Series 19	~1.0E-05	~5.5

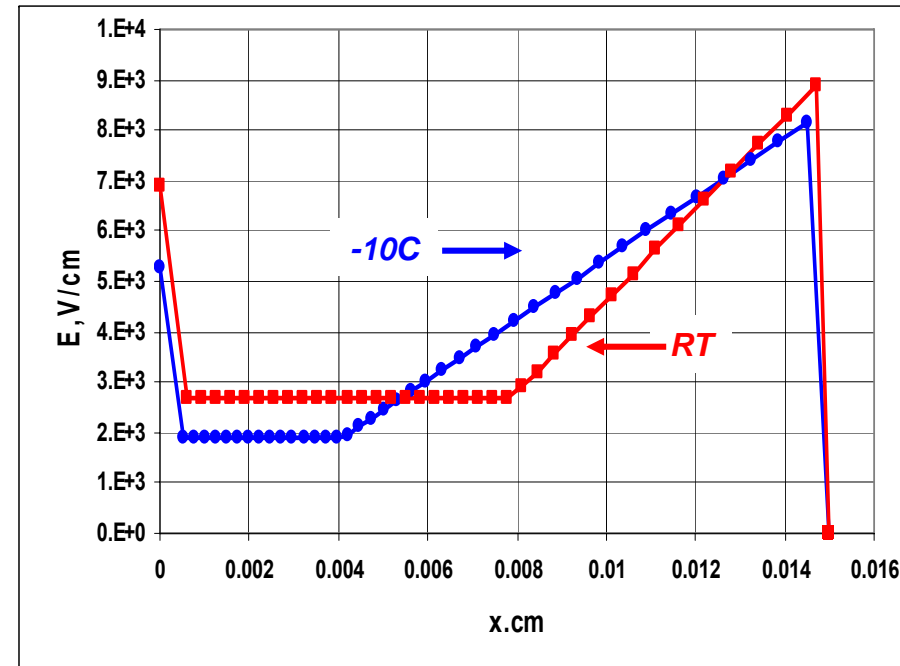
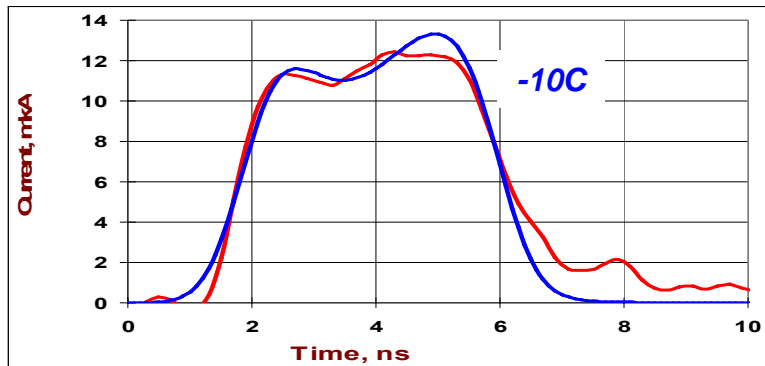
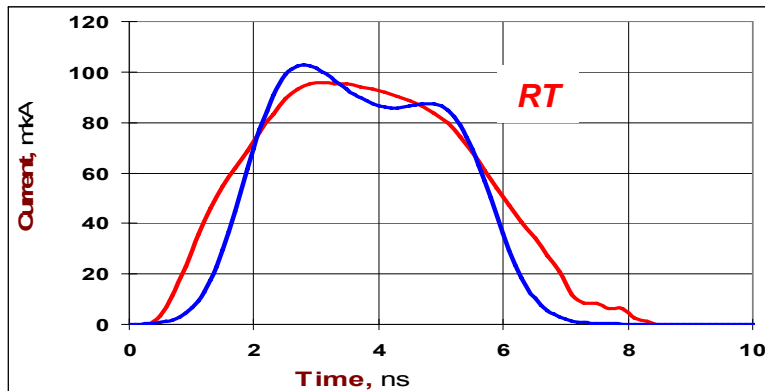


# Cooling effect in proton irradiated epi silicon detectors

Detector W12-SMG-22  
 epi, 150um  
 Proton irradiated:  $F_{eq} = 7 \text{ E}14 \text{ cm}^{-2}$   
 annealed 80C @30 min  
 RT; -10C

Operational parameters:  
 $V = 92 \text{ V}$

Extracted values  
 $\text{Tau tr} = 4 \text{ ns}$



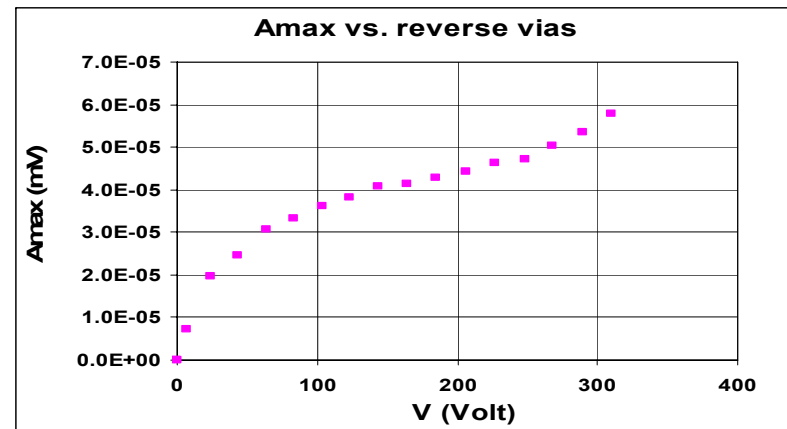
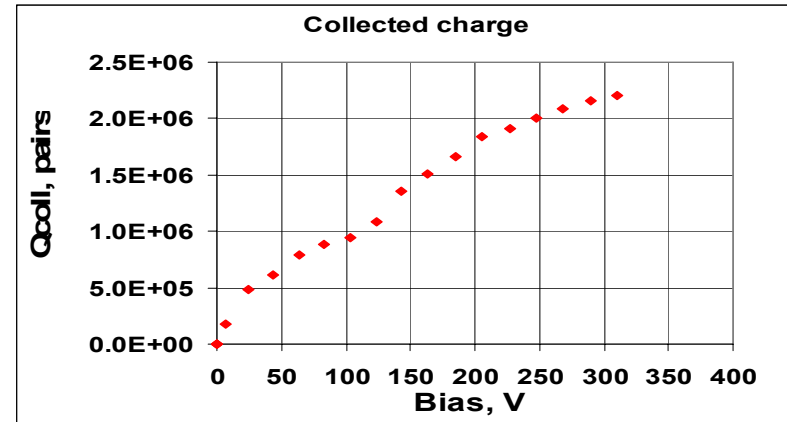
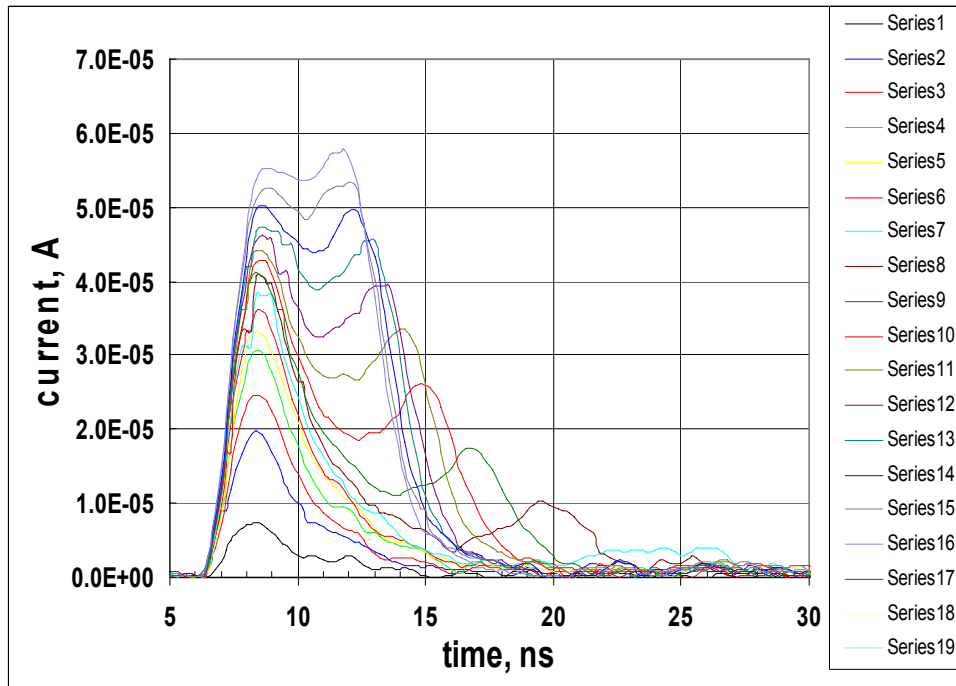
Sample parameters		Calculated values	
d (cm)	3.00E-02	E1, V/cm	5200
delta	0	E2, V/cm	0.0038
neff (1/cm)	0.00E+00	Eb, V/cm	2200
tau (ns)	6.00E-09	Wb, cm	0.015
tau0 (ns)	5.00E-09	E2, V/cm	31000.000
TCF mode		VZ, cm	0.0115
beta (cm)	0.20E+00		
beta0 (cm)	0.00E+00		
beta1 (cm)	0.00E+00		
beta2 (cm)	0.00E+00		
beta3 (cm)	0.00E+00		
beta4 (cm)	0.00E+00		
beta5 (cm)	0.00E+00		
beta6 (cm)	0.00E+00		
beta7 (cm)	0.00E+00		
beta8 (cm)	0.00E+00		
beta9 (cm)	0.00E+00		
beta10 (cm)	0.00E+00		
beta11 (cm)	0.00E+00		
beta12 (cm)	0.00E+00		
beta13 (cm)	0.00E+00		
beta14 (cm)	0.00E+00		
beta15 (cm)	0.00E+00		
beta16 (cm)	0.00E+00		
beta17 (cm)	0.00E+00		
beta18 (cm)	0.00E+00		
beta19 (cm)	0.00E+00		
beta20 (cm)	0.00E+00		
beta21 (cm)	0.00E+00		
beta22 (cm)	0.00E+00		
beta23 (cm)	0.00E+00		
beta24 (cm)	0.00E+00		
beta25 (cm)	0.00E+00		
beta26 (cm)	0.00E+00		
beta27 (cm)	0.00E+00		
beta28 (cm)	0.00E+00		
beta29 (cm)	0.00E+00		
beta30 (cm)	0.00E+00		
beta31 (cm)	0.00E+00		
beta32 (cm)	0.00E+00		
beta33 (cm)	0.00E+00		
beta34 (cm)	0.00E+00		
beta35 (cm)	0.00E+00		
beta36 (cm)	0.00E+00		
beta37 (cm)	0.00E+00		
beta38 (cm)	0.00E+00		
beta39 (cm)	0.00E+00		
beta40 (cm)	0.00E+00		
beta41 (cm)	0.00E+00		
beta42 (cm)	0.00E+00		
beta43 (cm)	0.00E+00		
beta44 (cm)	0.00E+00		
beta45 (cm)	0.00E+00		
beta46 (cm)	0.00E+00		
beta47 (cm)	0.00E+00		
beta48 (cm)	0.00E+00		
beta49 (cm)	0.00E+00		
beta50 (cm)	0.00E+00		
beta51 (cm)	0.00E+00		
beta52 (cm)	0.00E+00		
beta53 (cm)	0.00E+00		
beta54 (cm)	0.00E+00		
beta55 (cm)	0.00E+00		
beta56 (cm)	0.00E+00		
beta57 (cm)	0.00E+00		
beta58 (cm)	0.00E+00		
beta59 (cm)	0.00E+00		
beta60 (cm)	0.00E+00		
beta61 (cm)	0.00E+00		
beta62 (cm)	0.00E+00		
beta63 (cm)	0.00E+00		
beta64 (cm)	0.00E+00		
beta65 (cm)	0.00E+00		
beta66 (cm)	0.00E+00		
beta67 (cm)	0.00E+00		
beta68 (cm)	0.00E+00		
beta69 (cm)	0.00E+00		
beta70 (cm)	0.00E+00		
beta71 (cm)	0.00E+00		
beta72 (cm)	0.00E+00		
beta73 (cm)	0.00E+00		
beta74 (cm)	0.00E+00		
beta75 (cm)	0.00E+00		
beta76 (cm)	0.00E+00		
beta77 (cm)	0.00E+00		
beta78 (cm)	0.00E+00		
beta79 (cm)	0.00E+00		
beta80 (cm)	0.00E+00		
beta81 (cm)	0.00E+00		
beta82 (cm)	0.00E+00		
beta83 (cm)	0.00E+00		
beta84 (cm)	0.00E+00		
beta85 (cm)	0.00E+00		
beta86 (cm)	0.00E+00		
beta87 (cm)	0.00E+00		
beta88 (cm)	0.00E+00		
beta89 (cm)	0.00E+00		
beta90 (cm)	0.00E+00		
beta91 (cm)	0.00E+00		
beta92 (cm)	0.00E+00		
beta93 (cm)	0.00E+00		
beta94 (cm)	0.00E+00		
beta95 (cm)	0.00E+00		
beta96 (cm)	0.00E+00		
beta97 (cm)	0.00E+00		
beta98 (cm)	0.00E+00		
beta99 (cm)	0.00E+00		
beta100 (cm)	0.00E+00		

# TCT data for silicon MCZ as irradiated detector

Detector W187-SMG-9  
MCZ, 300um  
Proton irradiated: 26 MeV, Feq = 4.2 E14 cm-2  
Annealing: no

Operational parameters:  
T = 293K

Extracted values  
Vfd = 206V



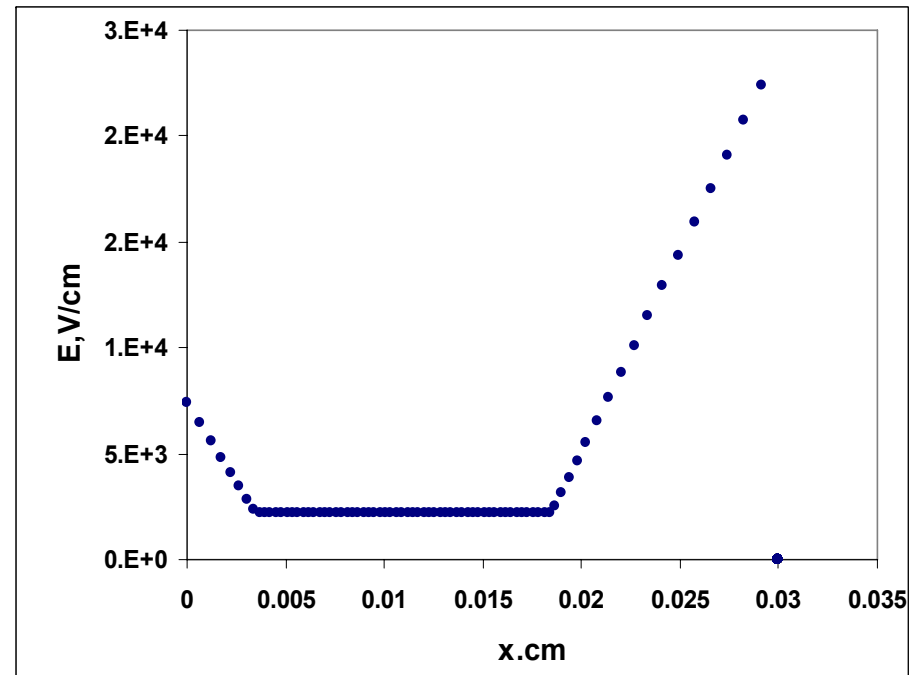
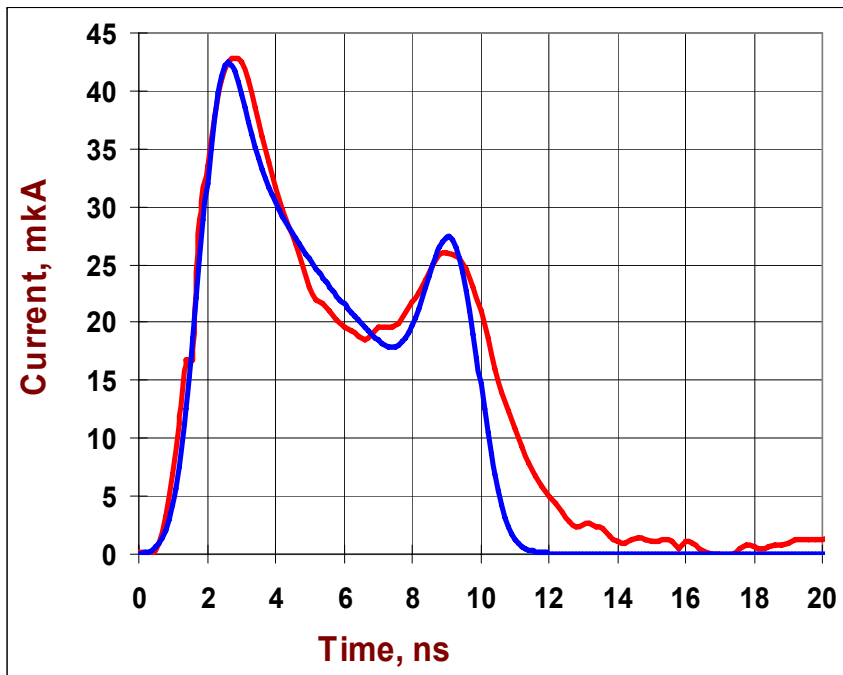
Series	Peak Current (A)	Peak Time (ns)
Series1	~1.0E-05	~10
Series2	~2.0E-05	~8
Series3	~3.0E-05	~8
Series4	~4.0E-05	~8
Series5	~5.0E-05	~8
Series6	~6.0E-05	~8
Series7	~7.0E-05	~8
Series8	~5.0E-05	~10
Series9	~4.0E-05	~10
Series10	~3.0E-05	~10
Series11	~2.0E-05	~10
Series12	~1.0E-05	~10
Series13	~0.5E-05	~10
Series14	~0.2E-05	~10
Series15	~0.1E-05	~10
Series16	~0.05E-05	~10
Series17	~0.02E-05	~10
Series18	~0.01E-05	~10
Series19	~0.005E-05	~10

# $E(x)$ reconstruction for silicon MCZ as irradiated detector

Detector W187-SMG-9  
MCZ, 300um  
Proton irradiated: 26 MeV, Feq = 4.2 E14 cm-2  
Annealing: no

Operational parameters:  
 $V = 184$  V  
 $T = 293$  K

Extracted values  
 $\tau_{tr} = 6$  ns  
 $V_{fd} = 180$  V



Sample parameters	
d (cm)	3.00E-02
Uc(V)	0
Wd1 (1/cm)	0.00E+00
Wd2 (1/cm)	6.00E-09
tau(n) (s)	5.00E-09
tau(p) (s)	5.00E-09
ICT mode	
Uc=1	2.80E+06
Ub (V)	184
Uc (V)	5.64E+03
Temper (K)	293
Base (aw)	0.1

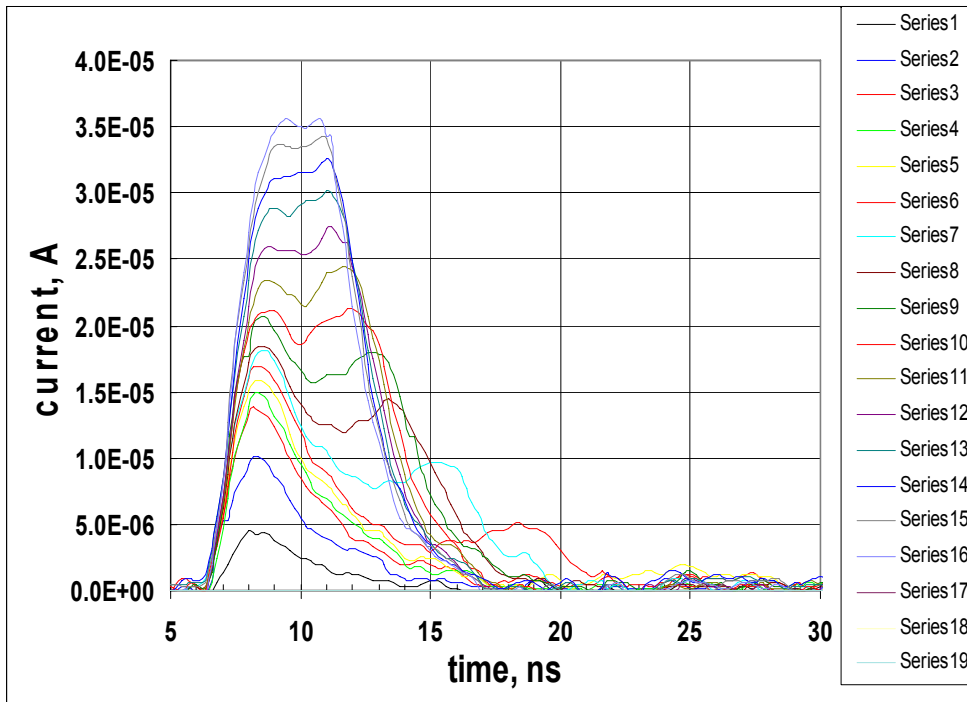
Calculated values	
E1 (V/cm)	5200
E2 (V/cm)	6.00E+03
E3 (V/cm)	2200
E4 (V/cm)	0.015
E5 (V/cm)	2.00E+06
E6 (V/cm)	0.0115

# TCT data for silicon MCZ as irradiated cooled detector

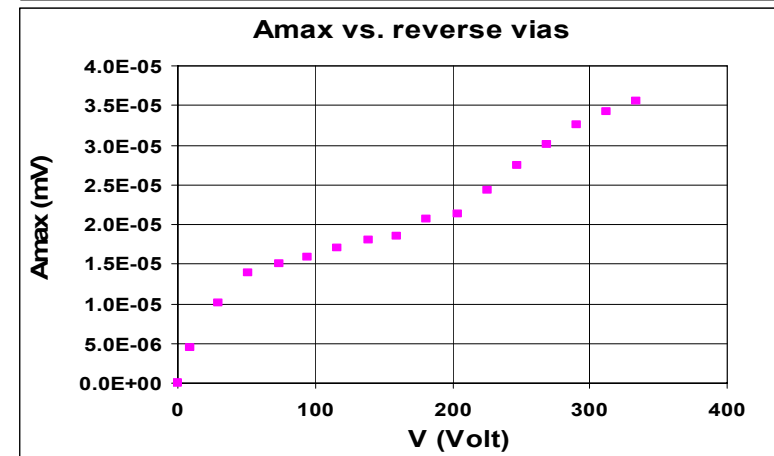
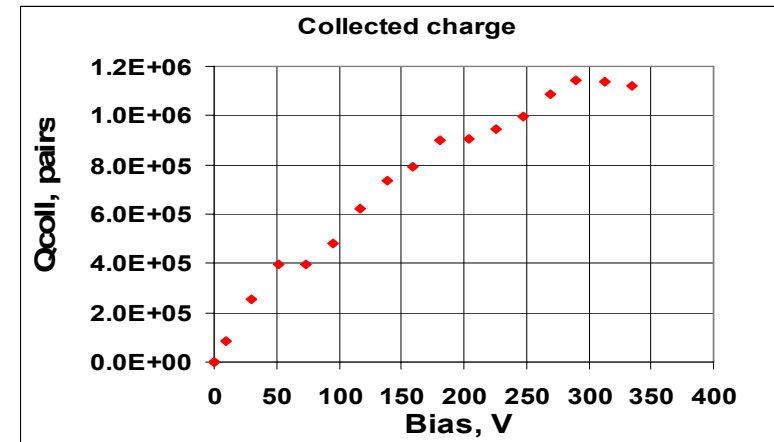
Detector W187-SMG-9  
MCZ, 300um  
Proton irradiated: 26 MeV, Feq = 4.2 E14 cm-2  
Annealing: no

Operational parameters:  
T = 263K

Extracted values  
Vfd = 180V



Series	V (V)	Qcoll (pairs)	Amax (mV)
1	0	0	0
2	25	2.5E+05	1.0E-05
3	50	4.0E+05	1.5E-05
4	75	4.5E+05	1.8E-05
5	100	5.0E+05	2.0E-05
6	125	6.5E+05	2.2E-05
7	150	8.0E+05	2.5E-05
8	175	9.0E+05	2.8E-05
9	200	9.5E+05	3.0E-05
10	225	1.0E+06	3.2E-05
11	250	1.1E+06	3.5E-05
12	275	1.15E+06	3.8E-05
13	300	1.18E+06	4.0E-05
14	325	1.15E+06	3.8E-05
15	350	1.1E+06	3.5E-05
16	375	1.05E+06	3.2E-05
17	400	1.0E+06	3.0E-05
18	425	9.5E+05	2.8E-05
19	450	9.0E+05	2.5E-05

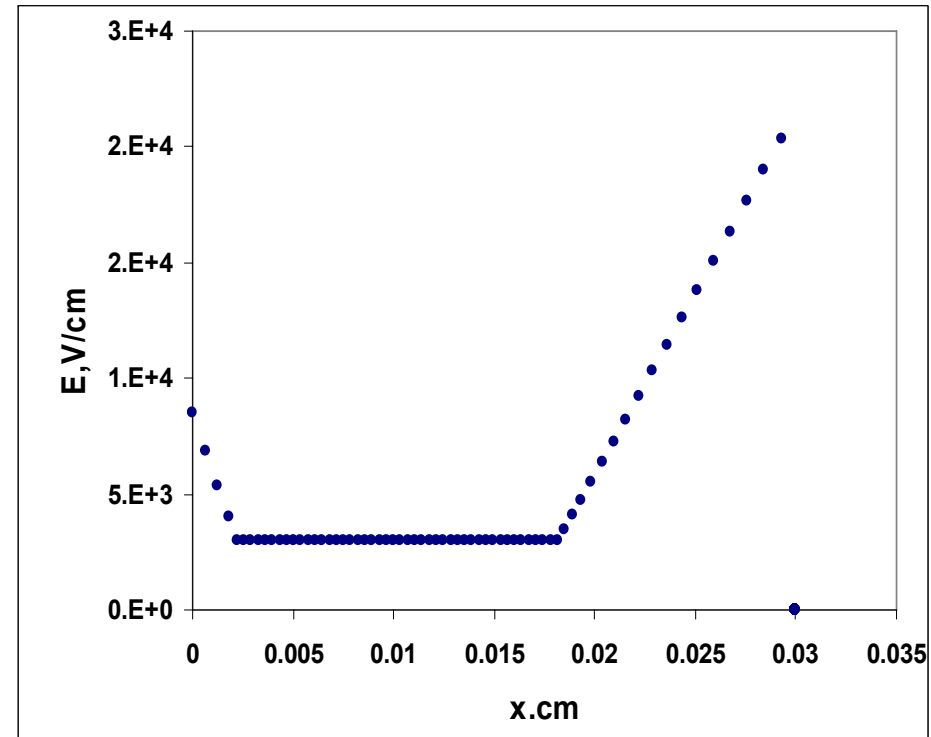
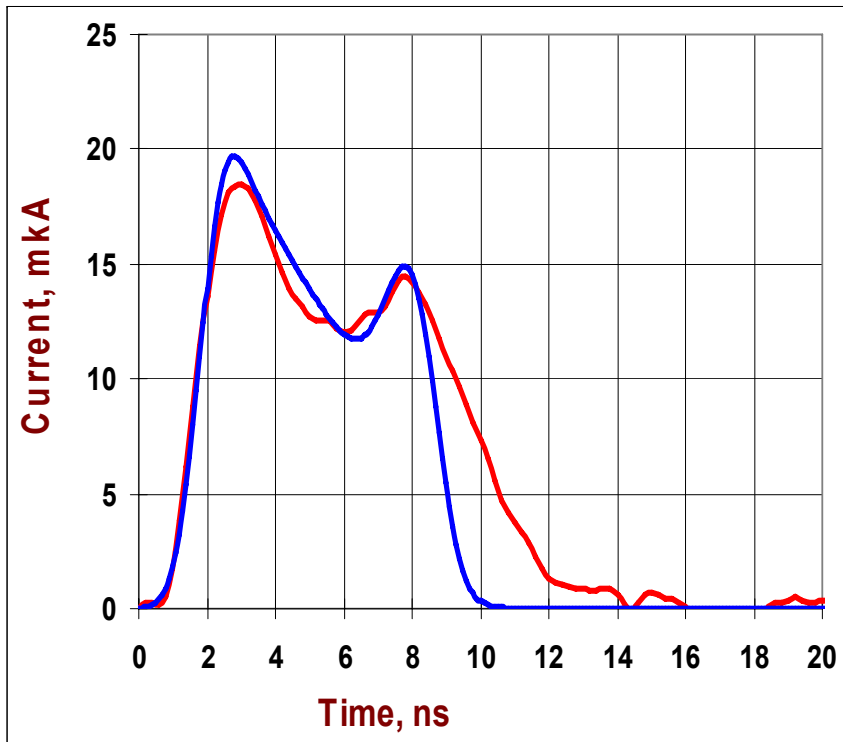


# $E(x)$ reconstruction for silicon MCZ as irradiated cooled detector

Detector W187-SMG-9  
MCZ, 300um  
Proton irradiated: 26 MeV,  $F_{eq} = 4.2 \text{ E}14 \text{ cm}^{-2}$   
Annealing: no

Operational parameters:  
 $V = 184 \text{ V}$   
 $T = 263\text{K}$

Extracted values  
 $\tau_{tr} = 6 \text{ ns}$   
 $V_{fd} = 180\text{V}$



Sample parameters	
W1, cm	0.0022
W2, cm	0.0118
W3, cm	0.0022
W4, cm	0.0022
W5, cm	0.0022
W6, cm	0.0022
W7, cm	0.0022
W8, cm	0.0022
W9, cm	0.0022
W10, cm	0.0022
W11, cm	0.0022
W12, cm	0.0022
W13, cm	0.0022
W14, cm	0.0022
W15, cm	0.0022
W16, cm	0.0022
W17, cm	0.0022
W18, cm	0.0022
W19, cm	0.0022
W20, cm	0.0022
W21, cm	0.0022
W22, cm	0.0022
W23, cm	0.0022
W24, cm	0.0022
W25, cm	0.0022
W26, cm	0.0022
W27, cm	0.0022
W28, cm	0.0022
W29, cm	0.0022
W30, cm	0.0022
W31, cm	0.0022
W32, cm	0.0022
W33, cm	0.0022
W34, cm	0.0022
W35, cm	0.0022
W36, cm	0.0022
W37, cm	0.0022
W38, cm	0.0022
W39, cm	0.0022
W40, cm	0.0022
W41, cm	0.0022
W42, cm	0.0022
W43, cm	0.0022
W44, cm	0.0022
W45, cm	0.0022
W46, cm	0.0022
W47, cm	0.0022
W48, cm	0.0022
W49, cm	0.0022
W50, cm	0.0022
W51, cm	0.0022
W52, cm	0.0022
W53, cm	0.0022
W54, cm	0.0022
W55, cm	0.0022
W56, cm	0.0022
W57, cm	0.0022
W58, cm	0.0022
W59, cm	0.0022
W60, cm	0.0022
W61, cm	0.0022
W62, cm	0.0022
W63, cm	0.0022
W64, cm	0.0022
W65, cm	0.0022
W66, cm	0.0022
W67, cm	0.0022
W68, cm	0.0022
W69, cm	0.0022
W70, cm	0.0022
W71, cm	0.0022
W72, cm	0.0022
W73, cm	0.0022
W74, cm	0.0022
W75, cm	0.0022
W76, cm	0.0022
W77, cm	0.0022
W78, cm	0.0022
W79, cm	0.0022
W80, cm	0.0022
W81, cm	0.0022
W82, cm	0.0022
W83, cm	0.0022
W84, cm	0.0022
W85, cm	0.0022
W86, cm	0.0022
W87, cm	0.0022
W88, cm	0.0022
W89, cm	0.0022
W90, cm	0.0022
W91, cm	0.0022
W92, cm	0.0022
W93, cm	0.0022
W94, cm	0.0022
W95, cm	0.0022
W96, cm	0.0022
W97, cm	0.0022
W98, cm	0.0022
W99, cm	0.0022
W100, cm	0.0022

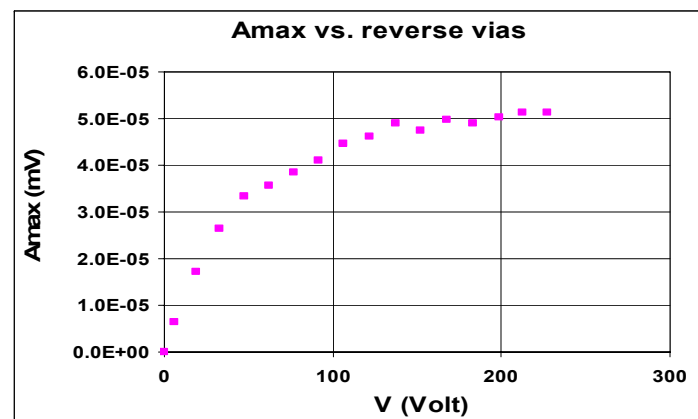
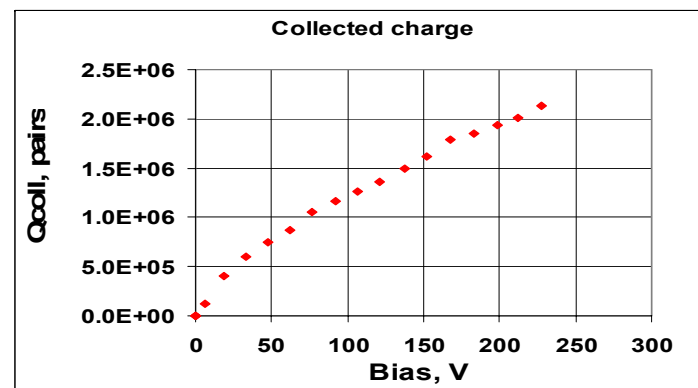
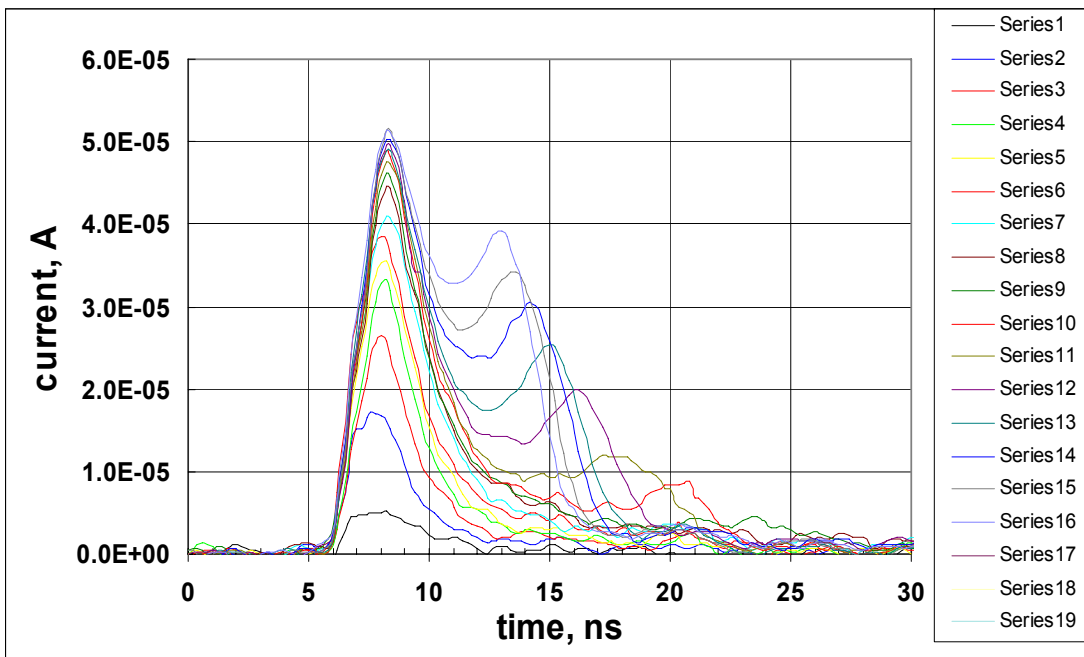
Calculated values	
E1, V/cm	5500
W1, cm	0.0022
Eb, V/cm	3000
Wb, cm	0.016
E2, V/cm	19466.102
W2, cm	0.0118

# TCT data for silicon MCZ annealed detector

Detector W187-SMG-2  
 MCZ, 300um  
 Proton irradiated: 26 MeV, Feq = 4.2 E14 cm-2  
 Annealing: 80C, 12 min

Operational parameters:  
 T = 293K

Extracted values  
 Vfd = 180V



Series	V, V	Q, pairs	Amax, mV
1	0	0.00E+00	0.00E+00
2	10	1.00E+05	1.00E-05
3	20	2.00E+05	2.00E-05
4	30	3.00E+05	3.00E-05
5	40	4.00E+05	4.00E-05
6	50	5.00E+05	5.00E-05
7	60	6.00E+05	6.00E-05
8	70	7.00E+05	7.00E-05
9	80	8.00E+05	8.00E-05
10	90	9.00E+05	9.00E-05
11	100	1.00E+06	1.00E-04
12	110	1.10E+06	1.10E-04
13	120	1.20E+06	1.20E-04
14	130	1.30E+06	1.30E-04
15	140	1.40E+06	1.40E-04
16	150	1.50E+06	1.50E-04
17	160	1.60E+06	1.60E-04
18	170	1.70E+06	1.70E-04
19	180	1.80E+06	1.80E-04
20	190	1.90E+06	1.90E-04
21	200	2.00E+06	2.00E-04
22	210	2.10E+06	2.10E-04
23	220	2.20E+06	2.20E-04
24	230	2.30E+06	2.30E-04
25	240	2.40E+06	2.40E-04
26	250	2.50E+06	2.50E-04
27	260	2.60E+06	2.60E-04
28	270	2.70E+06	2.70E-04
29	280	2.80E+06	2.80E-04
30	290	2.90E+06	2.90E-04
31	300	3.00E+06	3.00E-04

# *E(x) reconstruction for silicon MCZ annealed detector*

Detector W187-SMG-2  
 MCZ, 300um  
 Proton irradiated: 26 MeV, Feq = 4.2 E14 cm-2  
 Annealing: 80C, 12 min

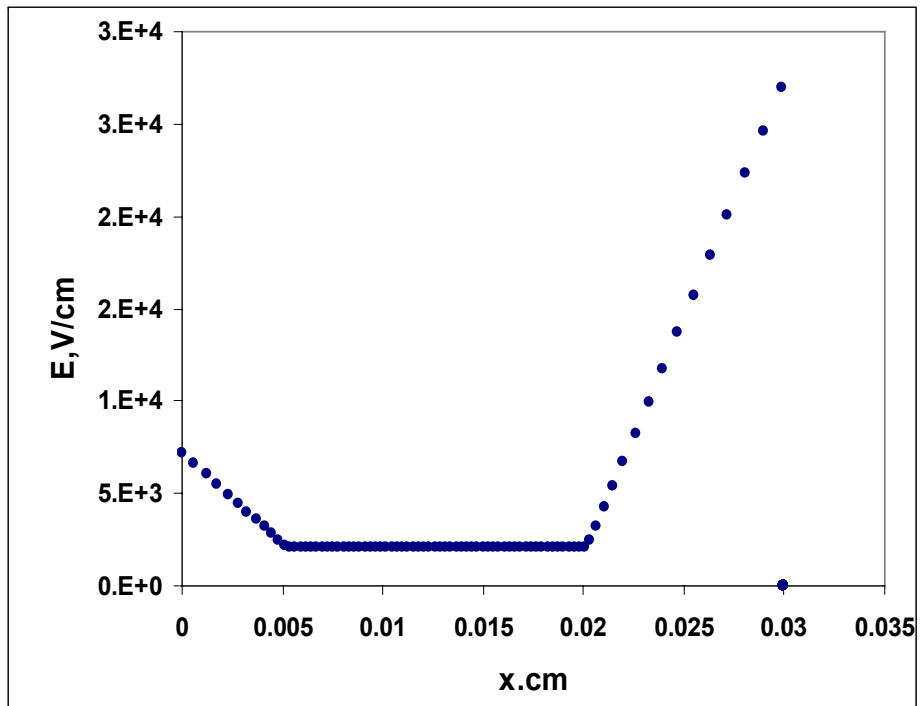
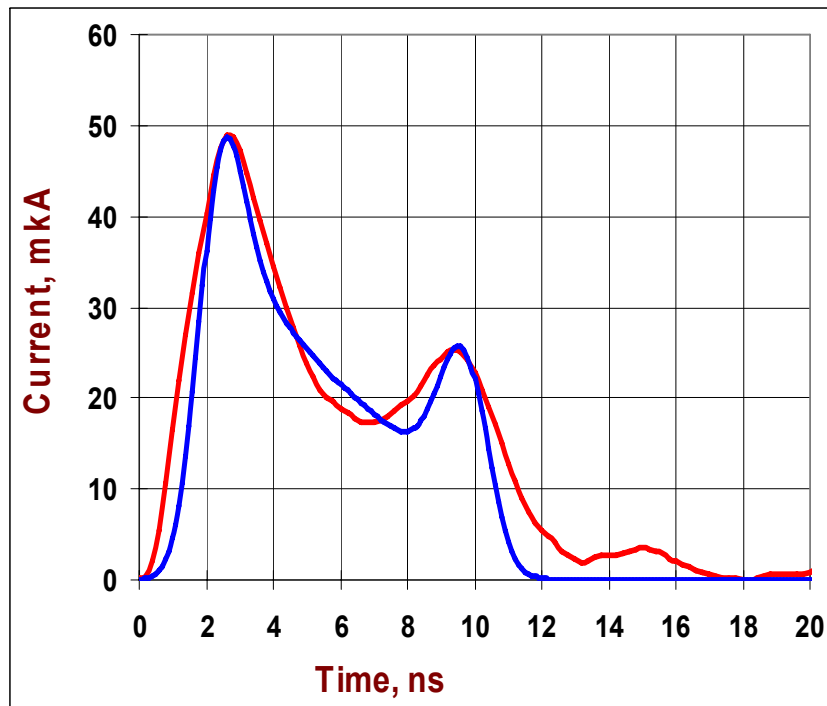
**Operational parameters:**

V = 184V

T = 293K

**Extracted values**

Tau tr = 6 ns



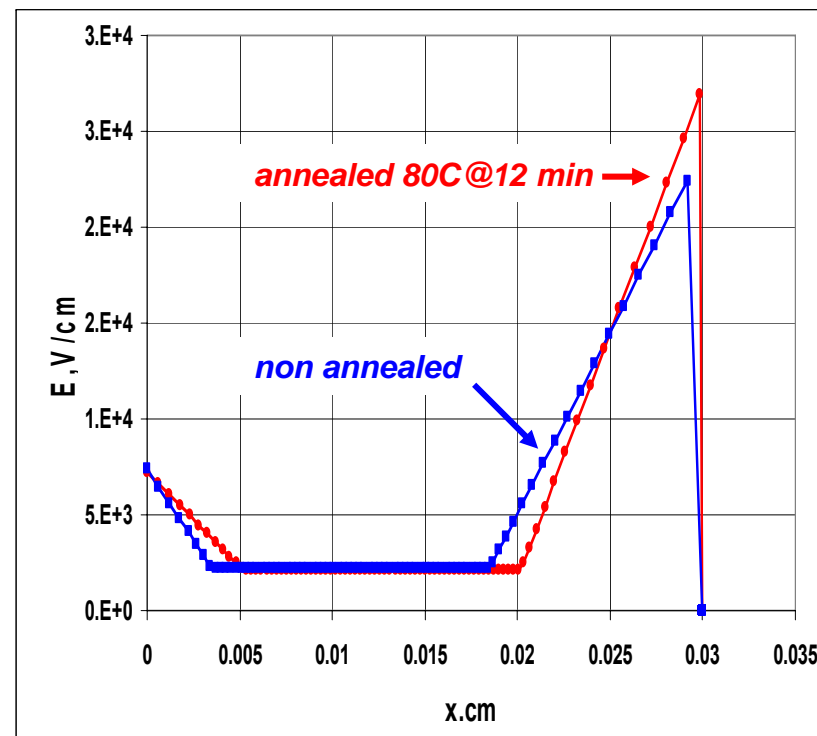
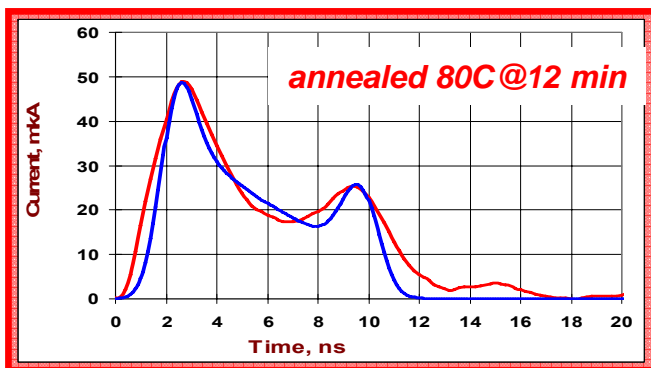
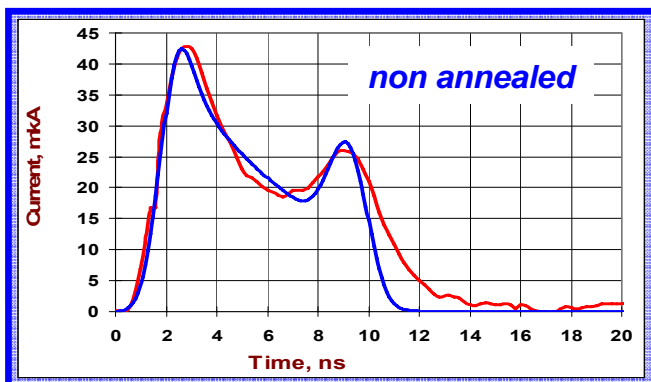
Sample parameters	
W1	0.0000
W2	0.0000
W3	0.0000
W4	0.0000
W5	0.0000
W6	0.0000
W7	0.0000
W8	0.0000
W9	0.0000
W10	0.0000
W11	0.0000
W12	0.0000
W13	0.0000
W14	0.0000
W15	0.0000
W16	0.0000
W17	0.0000
W18	0.0000
W19	0.0000
W20	0.0000
W21	0.0000
W22	0.0000
W23	0.0000
W24	0.0000
W25	0.0000
W26	0.0000
W27	0.0000
W28	0.0000
W29	0.0000
W30	0.0000
W31	0.0000
W32	0.0000
W33	0.0000
W34	0.0000
W35	0.0000
W36	0.0000
W37	0.0000
W38	0.0000
W39	0.0000
W40	0.0000
W41	0.0000
W42	0.0000
W43	0.0000
W44	0.0000
W45	0.0000
W46	0.0000
W47	0.0000
W48	0.0000
W49	0.0000
W50	0.0000
W51	0.0000
W52	0.0000
W53	0.0000
W54	0.0000
W55	0.0000
W56	0.0000
W57	0.0000
W58	0.0000
W59	0.0000
W60	0.0000
W61	0.0000
W62	0.0000
W63	0.0000
W64	0.0000
W65	0.0000
W66	0.0000
W67	0.0000
W68	0.0000
W69	0.0000
W70	0.0000
W71	0.0000
W72	0.0000
W73	0.0000
W74	0.0000
W75	0.0000
W76	0.0000
W77	0.0000
W78	0.0000
W79	0.0000
W80	0.0000
W81	0.0000
W82	0.0000
W83	0.0000
W84	0.0000
W85	0.0000
W86	0.0000
W87	0.0000
W88	0.0000
W89	0.0000
W90	0.0000
W91	0.0000
W92	0.0000
W93	0.0000
W94	0.0000
W95	0.0000
W96	0.0000
W97	0.0000
W98	0.0000
W99	0.0000
W100	0.0000

# Annealing effect in silicon MCZ detectors

MCZ, 300um  
 Proton irradiated: 26 MeV,  $4.2 \text{ E}14 \text{ cm}^{-2}$   
 W187-SMG-9: non annealed  
 W187-SMG-2: annealed 80C@12 min

Operational parameters:  
 $V = 184 \text{ V}$   
 $T = 293\text{K}$

Extracted values  
 $\text{Tau tr} = 6 \text{ ns}$   
 $V_{fd} = 180\text{V}$



Sample parameters	
d (cm)	3.00E-02
Uc(V)	0
Wd1 (1/cm)	0.00E+00
Wd2 (1/cm)	6.00E-09
tau(n)	5.00E-09
tau(p)	5.00E-09
ICT mode	
Uc=1	2.80E+06
Ub (V)	184
Uc (V)	5.64E+03
Temper (K)	293
Base (aw)	0.1

Calculated values	
E1 (V/cm)	5200
W1 (cm)	0.0035
Eb (V/cm)	2200
Wb (cm)	0.015
E2 (V/cm)	3168.886
W2 (cm)	0.0115

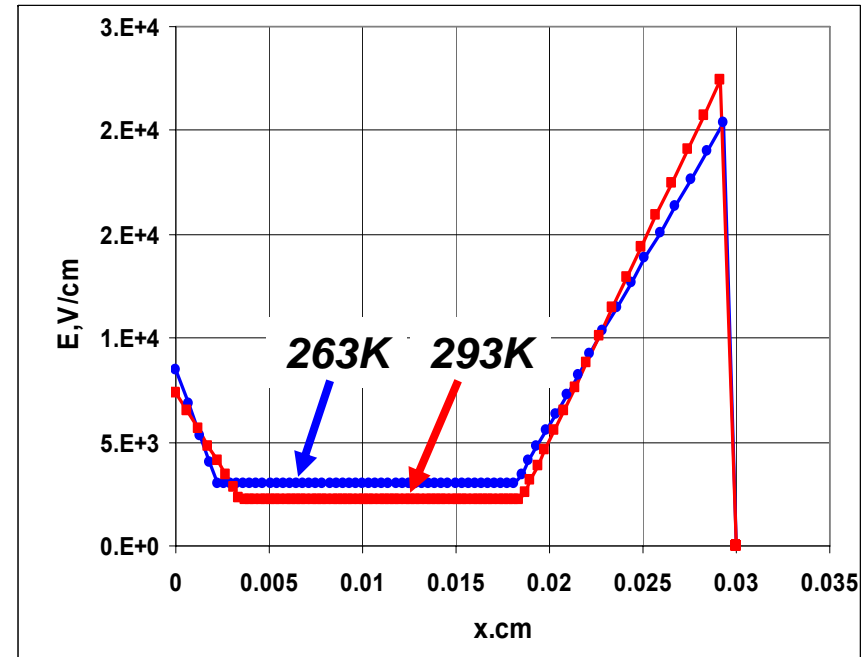
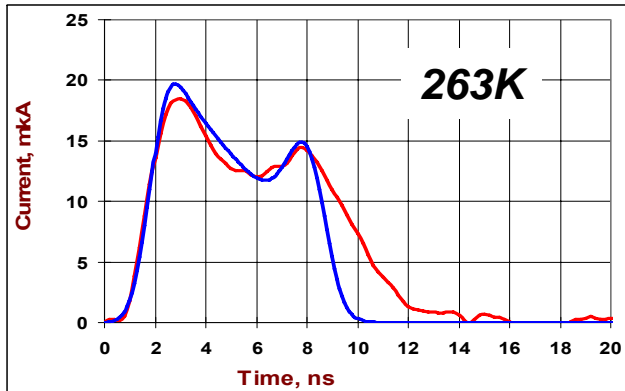
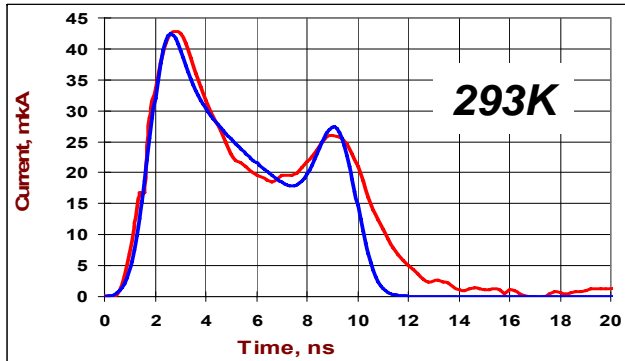


# Effect of MCZ detectors cooling

Detector W187-SMG-9  
 MCZ, 300um  
 Proton irradiated: 26 MeV, Feg = 4.2 E14 cm-2  
 Annealing: no

Operational parameters:  
 V = 184 V

Extracted values  
 Tau tr = 6 ns  
 Vfd = 180V



Sample parameters	
d (cm)	3.00E-02
Uc(V)	0
Wfd (1/cm)	0.00E+00
tau(tr) (s)	6.00E-09
tau(d) (s)	5.00E-09
ICT mode	
Uc=1	2.50E+06
Uc (V)	184
t (1/cm)	5.64E+03
Temper. (K)	293
Base (aw)	0.1

Calculated values	
E1 (V/cm)	5200
E2 (V/cm)	6200
E3 (V/cm)	2200
Wfd (cm)	0.015
E2 (V/cm)	31000.000
V2 (cm)	0.0115

# Conclusions

- 1. The current response of MCZ and epi- silicon based detectors is can be explained in the frame of double peak electric field distribution model with “active” electrically neutral bias region.**
- 2. Epi- detectors exhibit the space charge sign inversion due to high irradiation fluence or reverse annealing with high resistivity base**
- 3. The SCSI is observed for MCZ and epi- based detectors at  $F_{eq} > 4.5e14cm^{-3}$**
- 4. The SCSI is stimulated by the long term annealing in MCZ and epi detectors**
- 4. In MCZ based detectors the long term annealing leads to increase of the electric field at n+ contact and reduction at p+ contact.**
- 5. The electric field in the base region is insensitive to the annealing.**
- 3. The detector cooling redistributes the electric field with a trend of its better uniformity:  
the electric field at the detector contacts reduces  
the field in the thickness of neutral base slightly incre**