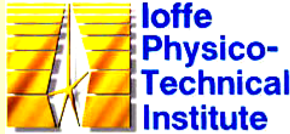

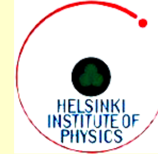

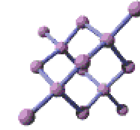

Long term annealing of neutron irradiated detectors evaluated at LHC operational temperatures

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Marko Mikuž, Vladimir Cindro
Jožef Stefan Institute, Ljubljana

Chris Parkes
Glasgow University

8 RD50 Collaboration Workshop
Prague, June 25-28, 2006

Technotest

Goal of the project:

Finding correlations and comparison of radiation hardness with respect to:

Type of Si

Processing

Radiation

characteristics of heavily irradiated detectors

Technotest

Participants

Detector processing:

- Ioffe Physico-Technical Institute (PTI)
  + Research Institute of Material Science and Technology (RIMST)
- BNL
- Helsinki Institute of Physics (HIP)

Irradiation:

- CERN (protons 24 GeV/c)
- Iosef Stefan Institute, Ljubljana (neutrons 1 MeV)

Evaluation

- Ioffe Physico-Technical Institute
- BNL
- HIP
- Iosef Stefan Institute
- Glasgow University

Status of the work

Experiments carried out:

- **detectors processed at three institutions**
- **irradiated by 1 MeV neutrons, $F_n = 1\cdot10^{10}$- $5\cdot10^{15}$ cm^{-2}**
- **irradiated by 24 GeV/c protons, $F_p = 1\cdot10^{14}$ and $1\cdot10^{15}$ cm^{-2}**

1 MeV neutrons: *pres. 5 RD50 Workshop, Florence*

I-V characteristics, TCT signal

24 GeV protons: *pres. 7 RD50 Workshop, CERN*

SCSI in detectors from MCZ Si; V_{fd} and $N_{eff\ in}$ in long term annealing

Current study in 2006

1 MeV neutrons: studies of annealing (initial stage)

- **detectors processed from MCZ and FZ n-type Si**
- **annealing at 80°C**

Experimental samples

F_n (cm-2)	FZ		CZ		
5E+13	PTI-n1-b11	HIP-w-57	PTI-Cz-c12	HIP-CZ-34	BNL-n-131
5E+14	PTI-n2-c13	HIP-w-7	PTI-Cz-d11	HIP-Cz-66	BNL-Cz-98

Resistivity, kΩ·cm
n-Si FZ: 4-6
n-Si MCZ: 1

Manufacturing procedure

	PTI	BNL	HIP
Oxidation	1100C/6h	1100C/6h	**done after implantation**
p+	50 keV/ 3e14 cm-2	45 keV/2e14cm-2	20 keV/1e15cm-2
n+	80 keV/9e14 cm-2	80 keV/6e14cm-2	70 keV/1e15cm-2
Annealing	700C/40min	700C/30min	1100/4h
Al sintering	430C/7min	430C/5min	**370C/40min (no TD)**

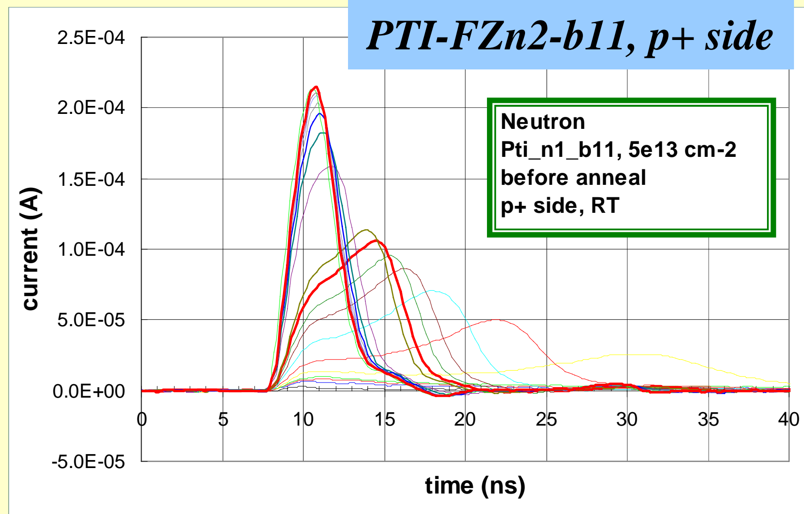
Experimental

- annealings: 80°C, steps with variable time
- TCT using 840 nm laser pulse generation of free carriers,
  p+ side, n+ side
- **Current pulse response is measured at RT and -15°C (ATLAS)**
- **All measurements: range of bias voltage 20/50-900 V**

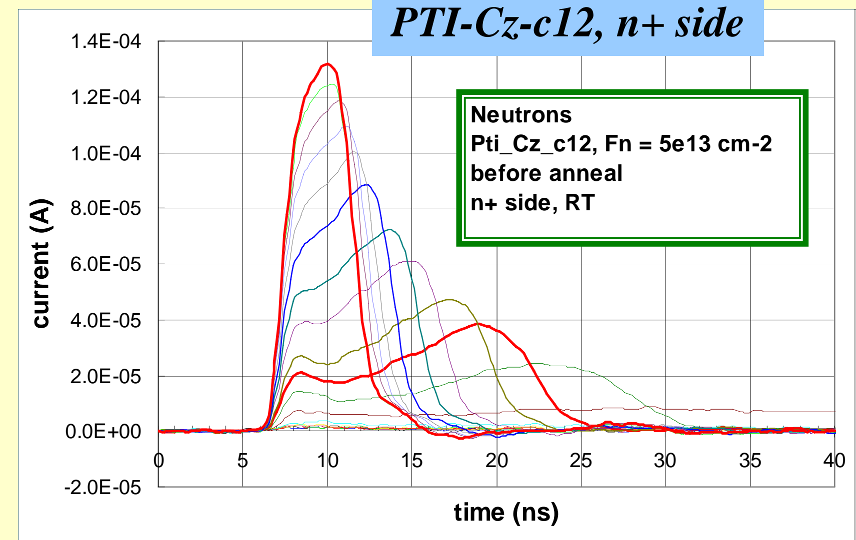
Current pulse response, n-Si, $F_n = 5 \cdot 10^{13}$ cm^{-2}

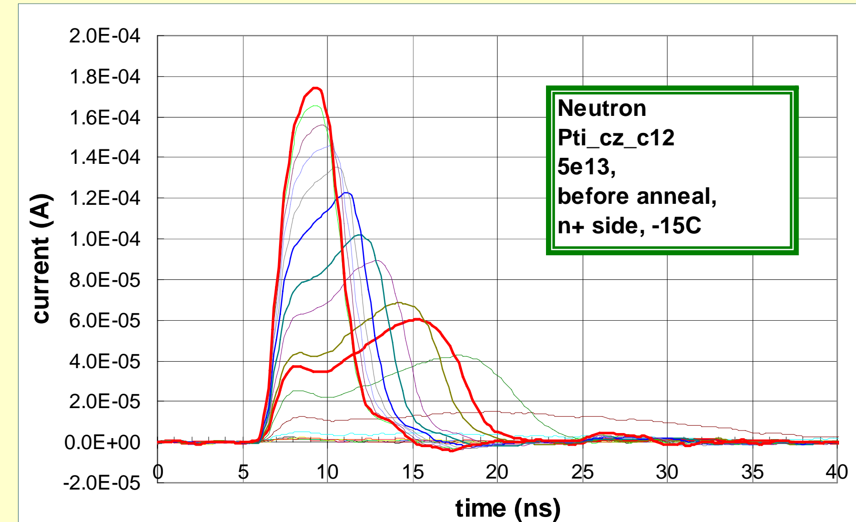
Before annealing

PTI-FZn2-b11, p+ side



PTI-Cz-c12, n+ side

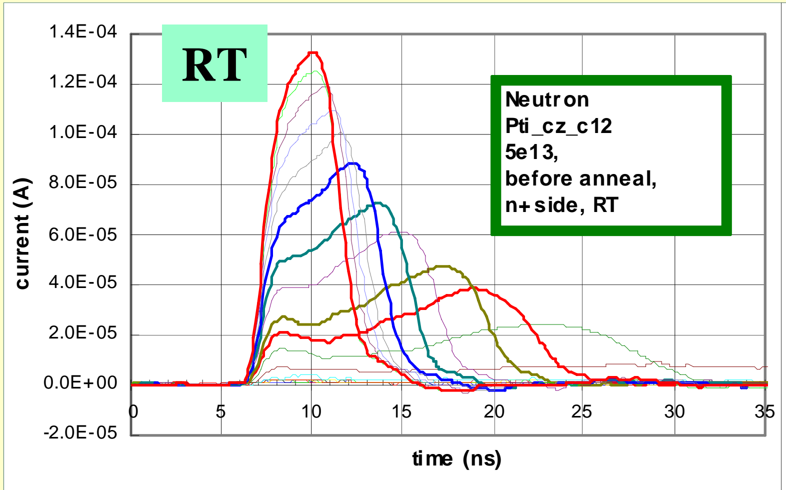


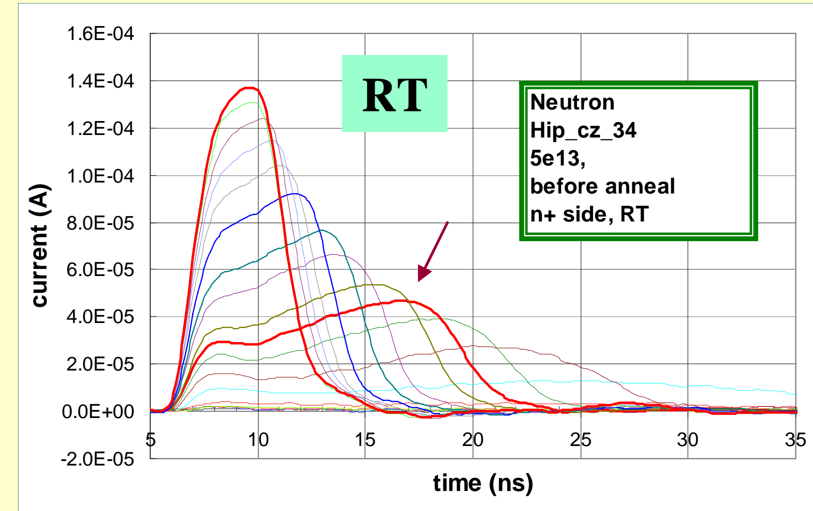


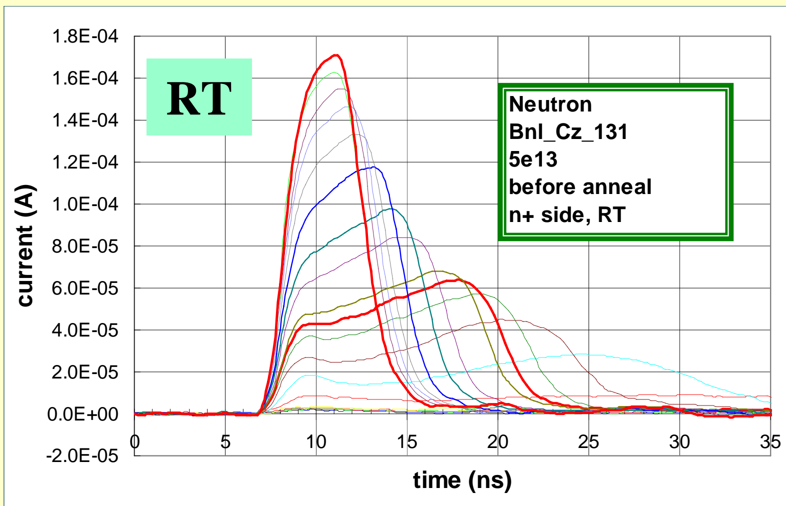
Before annealing:
FZ Si: SCSI (-SC)
MCZ Si : no SCSI (all samples)
- evaluation of response from n+ side, hole collection

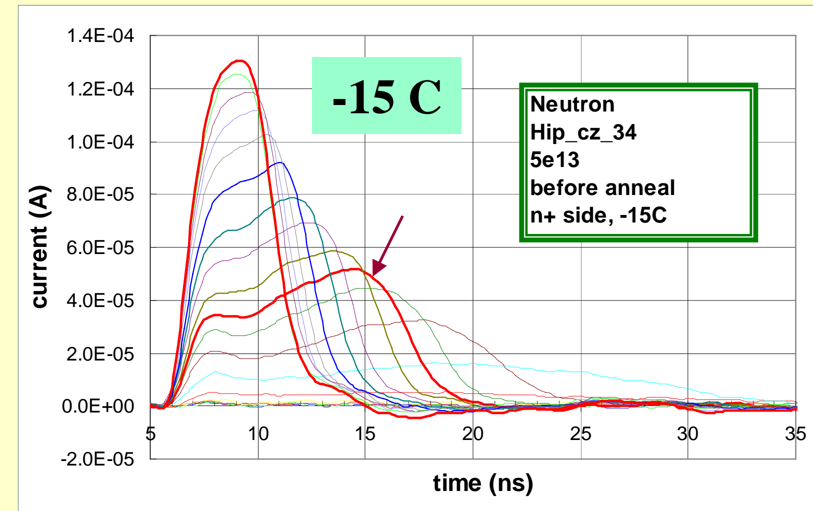
V: 10-900 V

$MCZ\ Si,\ F_n = 5\cdot10^{13}\ cm^{-2}$: different processing



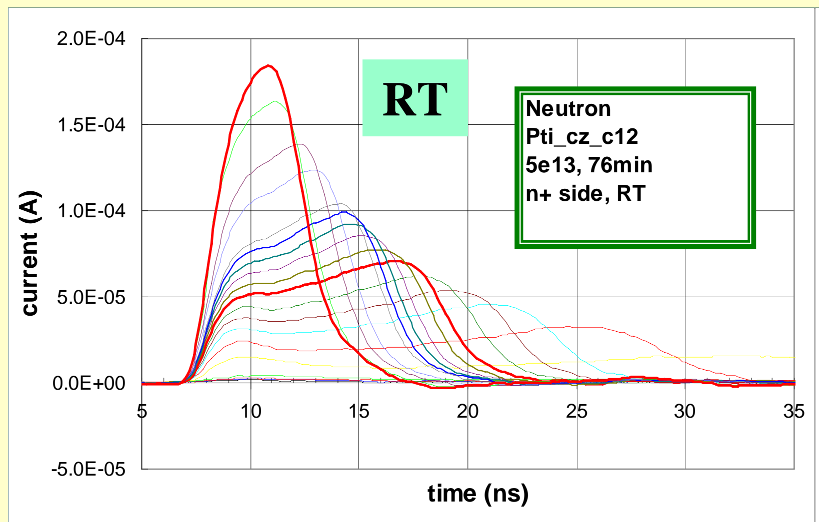


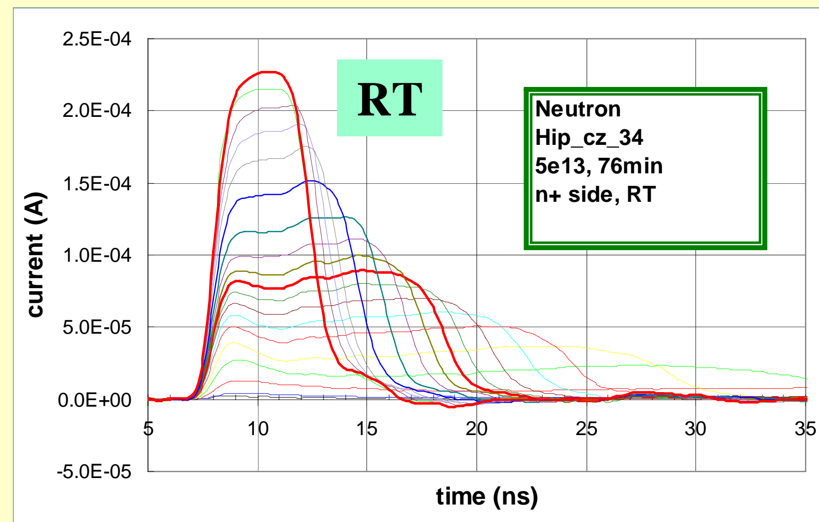


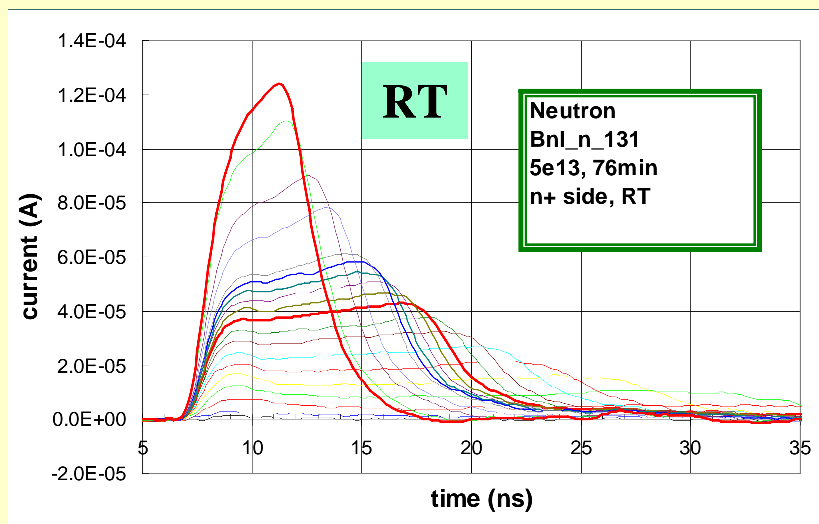


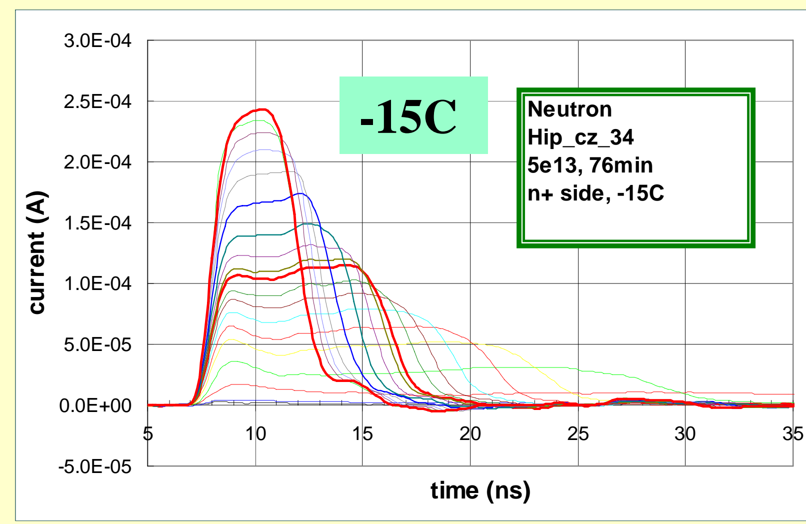
t_{coll} is smaller at -15°C

$F_n = 5\ e13\ cm^{-2}$, $t_{ann} = 76$ min

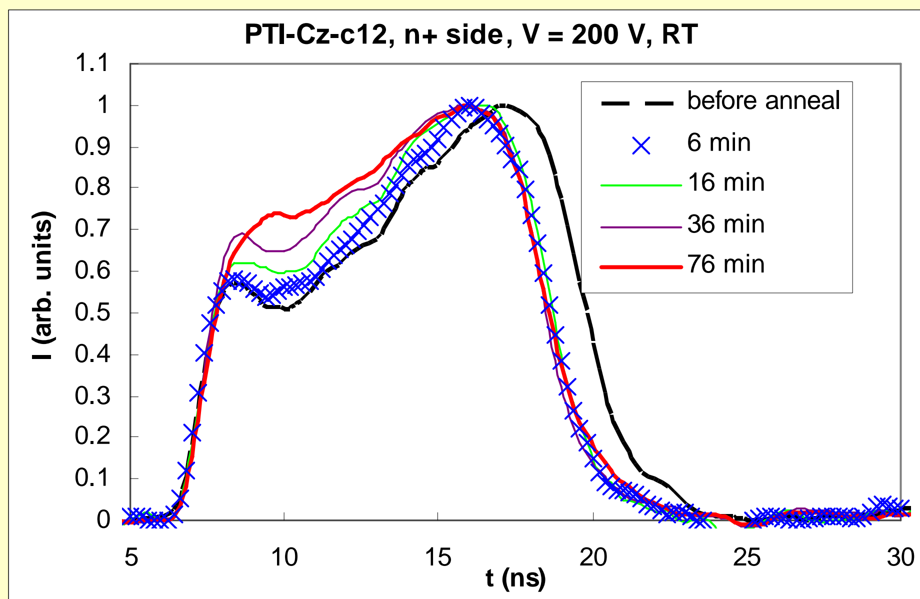








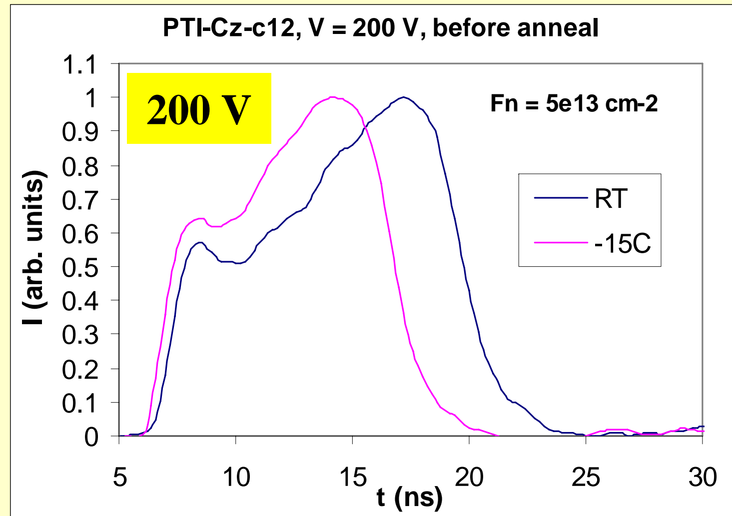
Evolution of response under annealing,
MCZ Si, $F_n = 5\cdot10^{13}$ cm^{-2}, V = 200 V, hole collection

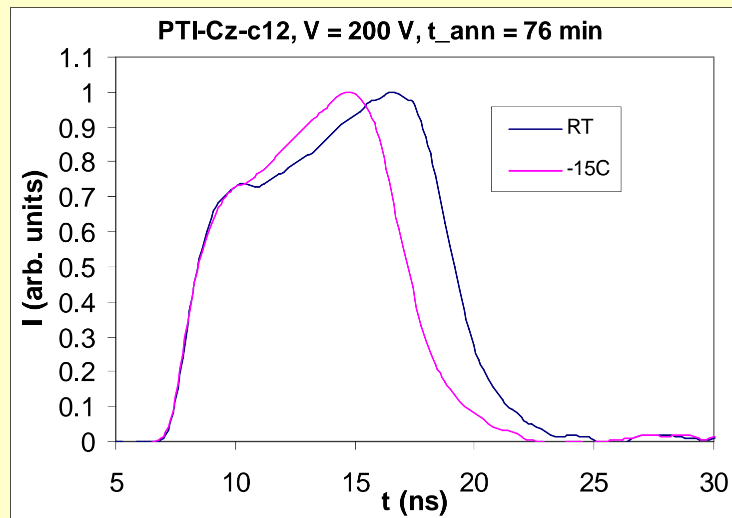


$$i(t) = \frac{Q_o \mu E}{d} e^{-t/\tau_{eff}}$$

RT: detector is fully depleted,
+N_{eff} decreases –
E becomes more uniform

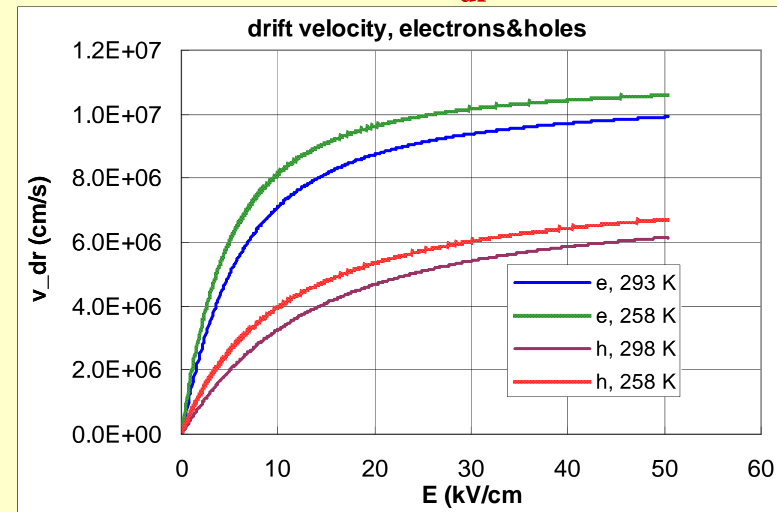
Evolution of response under annealing





$$i(t) = \frac{Q_o v_{dr}}{d} e^{-t/\tau_{eff}}$$

Dependence of v_{dr} vs. E and T

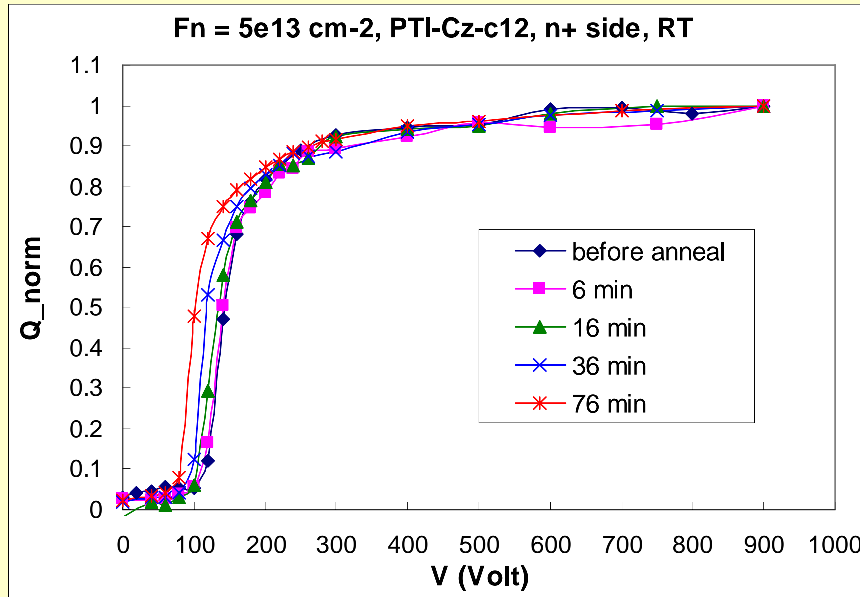


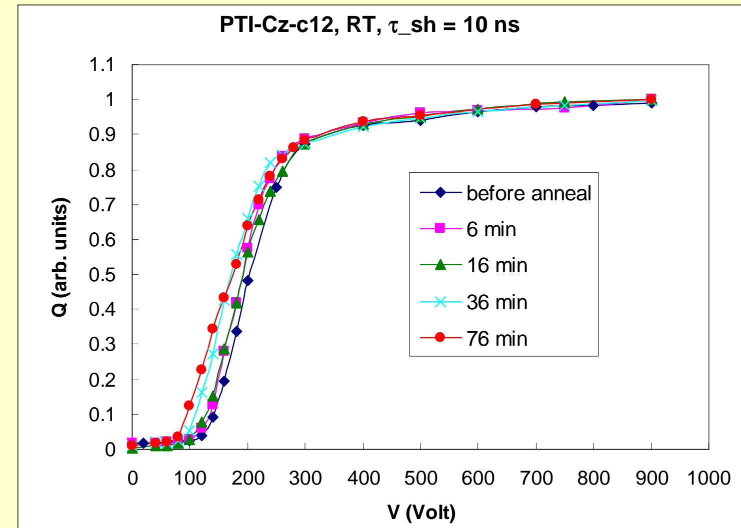
Pulse width: depends on v_{dr}(T)
Difference:
Low E: e – 30%, h – 50%
High E: e, h – 10%

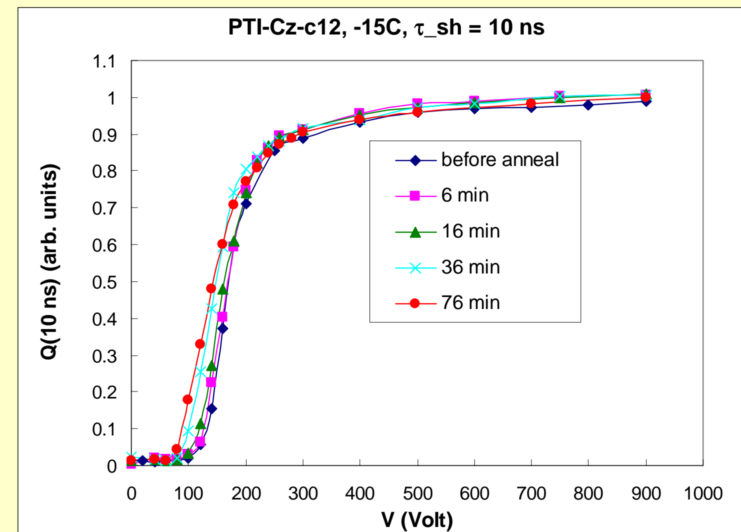
Q vs. V and τ_{sh} , MCZ n-Si, $F_n = 5\cdot10^{13}$ cm^{-2}

τ_{sh} = 10 ns

Total charge, RT







τ_{sh} – shaping time

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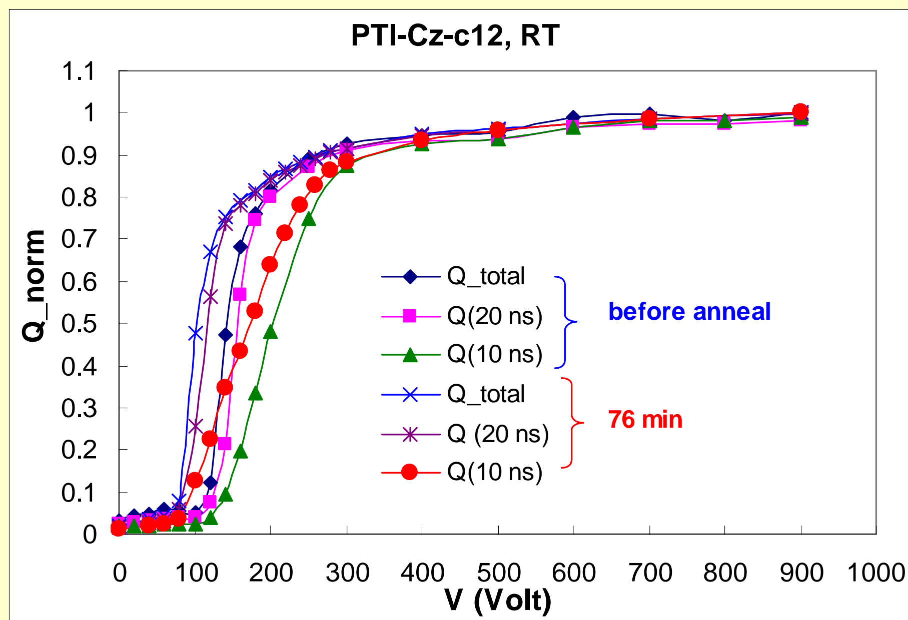
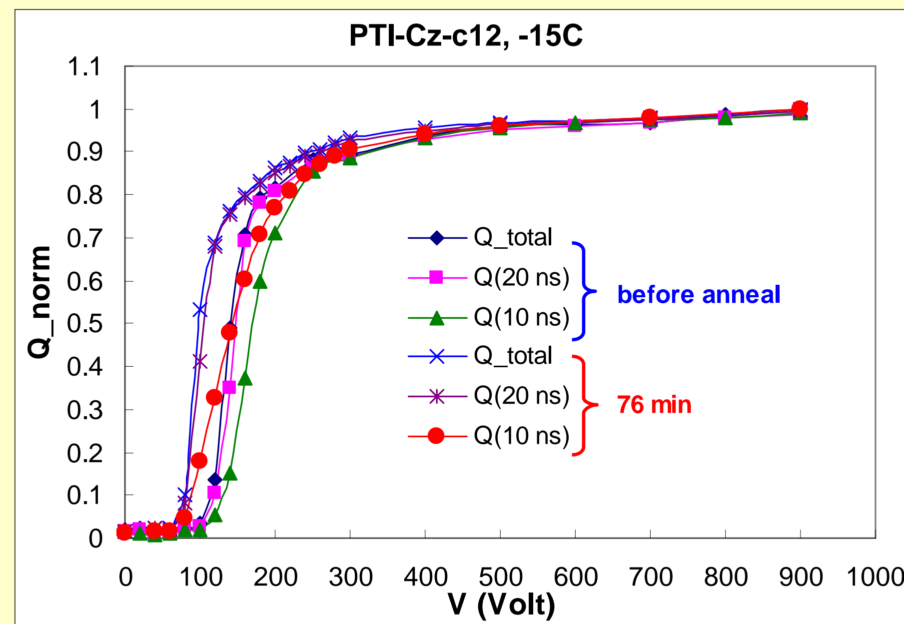
Q vs. V and τ_{sh} , MCZ n-Si, $F_n = 5 \cdot 10^{13}$ cm^{-2}

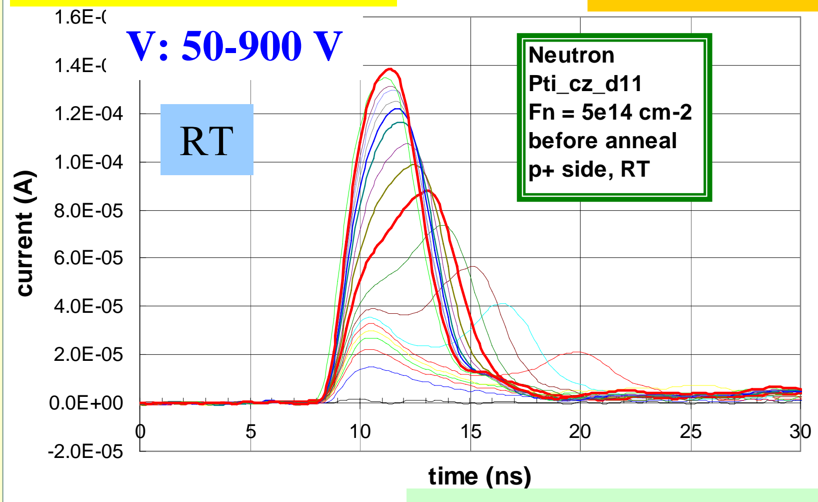


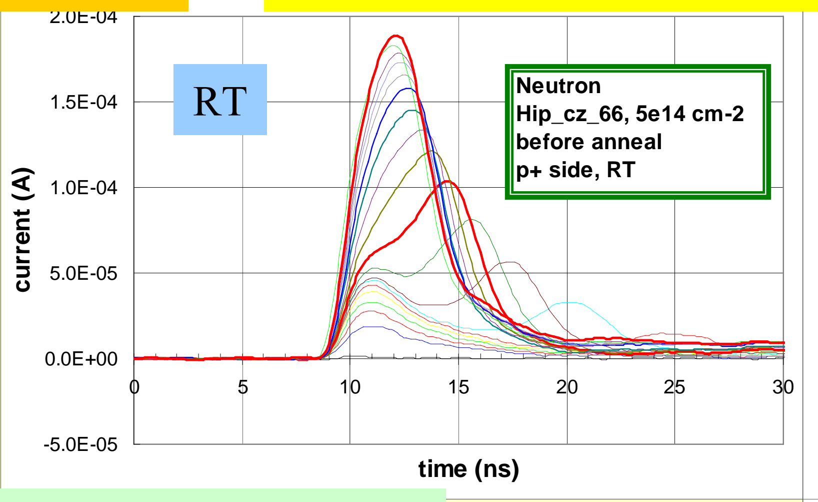


Current pulse response, MCZ n-Si, $F_n = 5\cdot10^{14}$ cm^{-2}

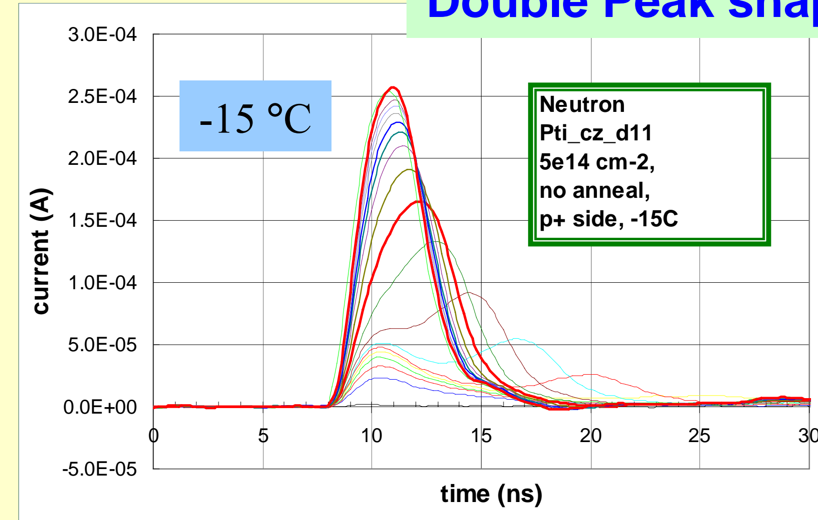
Before annealing | **Different processing** | **p+ side, electron collection**

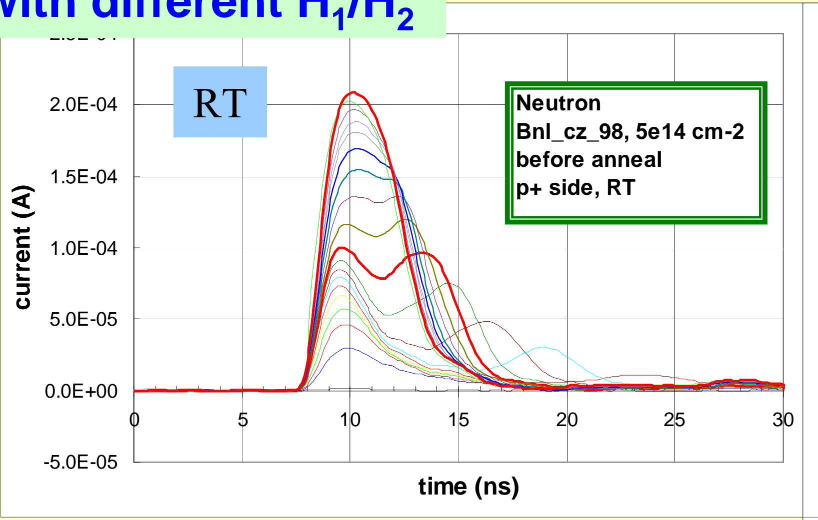
V: 50-900 V





Double Peak shape with different H_1/H_2





SCSI for all detectors, at RT and -15 °C

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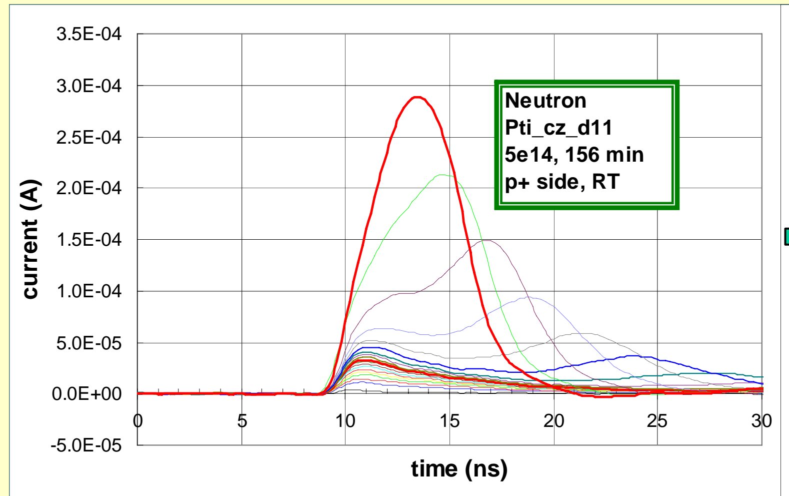
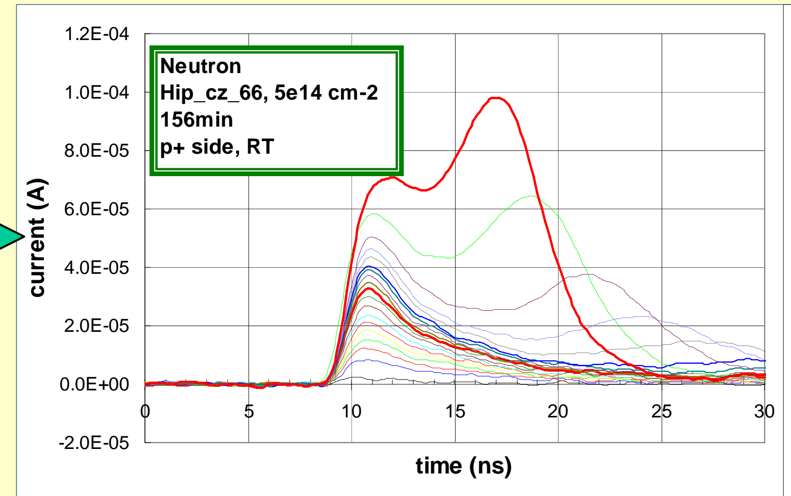
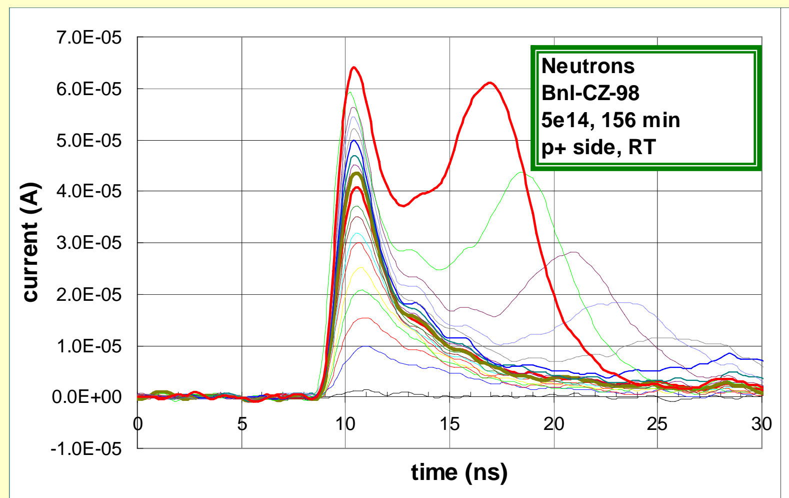
Fn = 5 e14 cm^{-2}, t_{ann} = 156 min, RT







H_1/H_2 ratio in DP is different:
E(x) is different

Practical aspect:
t_{coll} is sensitive to technology

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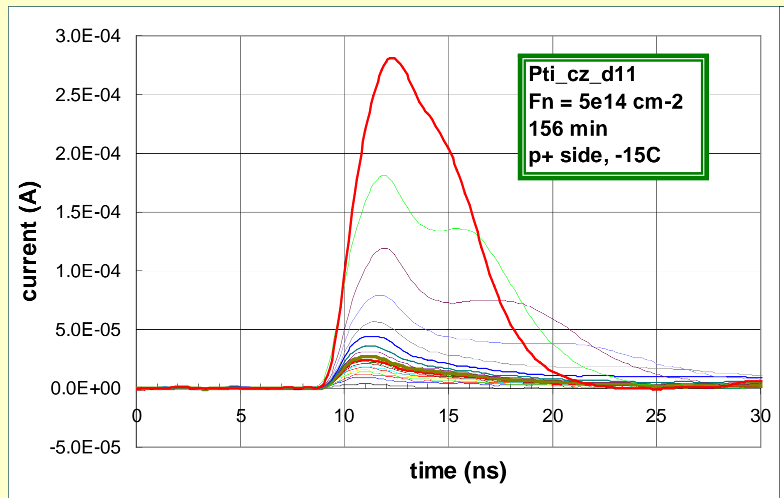
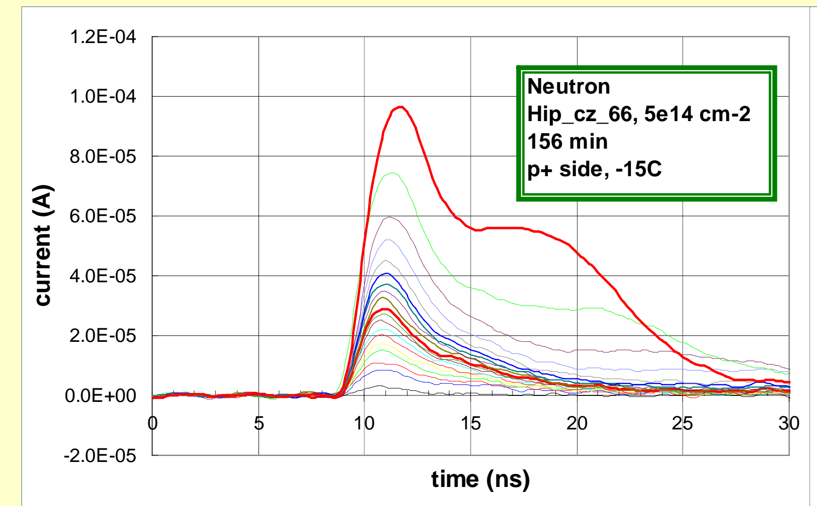
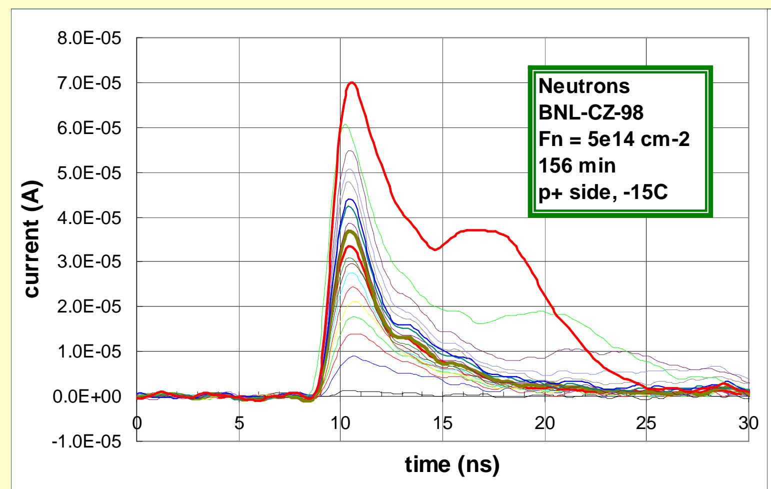
Fn = *5e14 cm*$^{-2}$, t_{ann} = 156 min, -15°C







At -15°C:

Pronounced DP with $H_1/H_2>1$ even at 900 V

- <u>reduction of E at n+ side</u>

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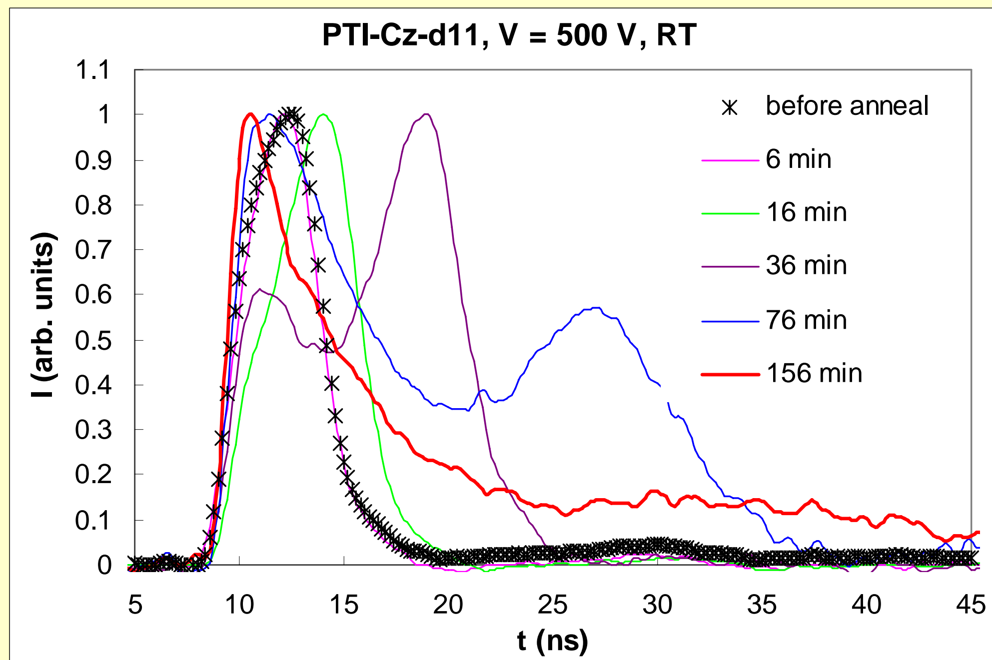
Evolution of response under annealing

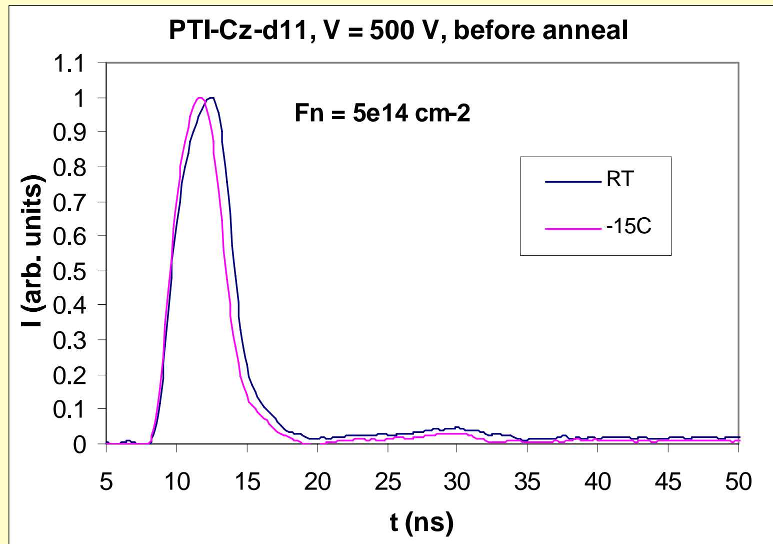
MCZ Si, $F_n = 5{\cdot}10^{14}$ cm^{-2} V = 500 V, RT

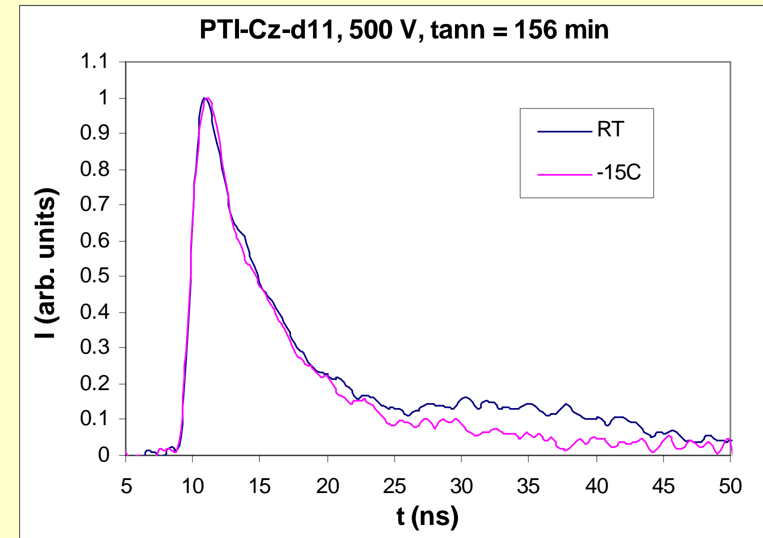
Electron collection



E(x) changes from full depletion to partial depletion at RT and -15°C

Evolution of response under annealing,
MCZ Si, $F_n = 5{\cdot}10^{14}$ cm^{-2}, V = 500 V



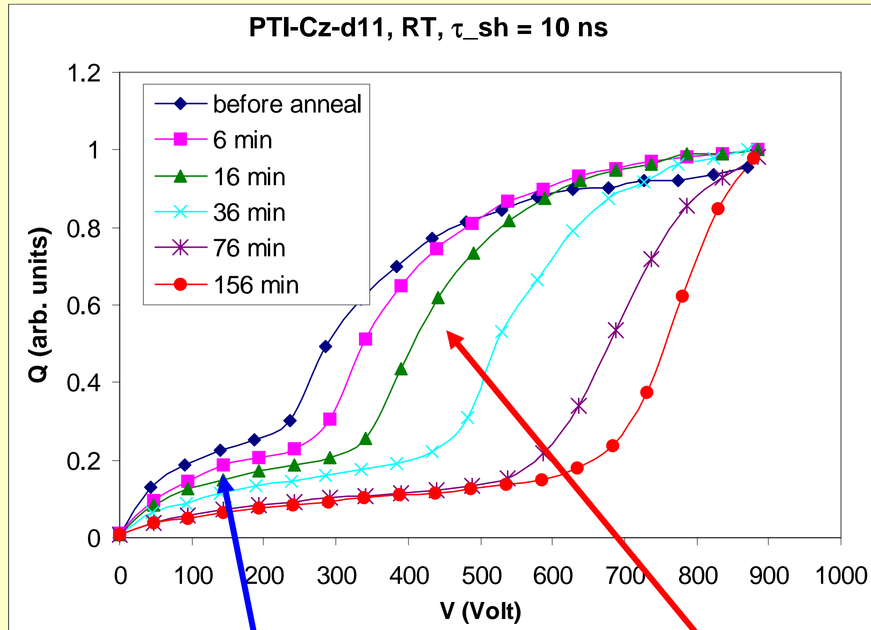


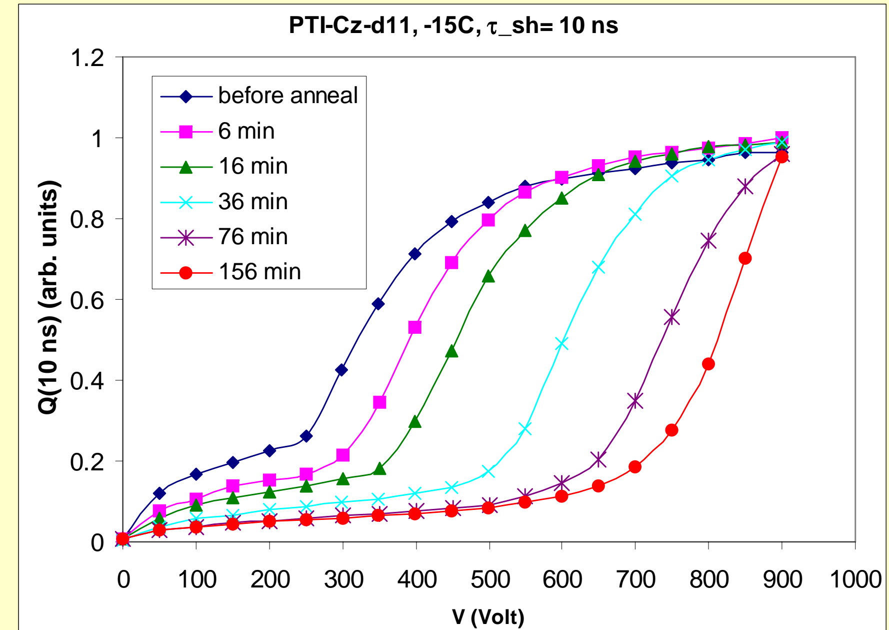
τ is the same at RT and –15°C

τ = 6 ns

- lowest value!

Q vs. V under annealing
MCZ n-Si, $F_n = 5 \cdot 10^{14}$ cm^{-2}





Single peak ↑ **Double peak ↑**

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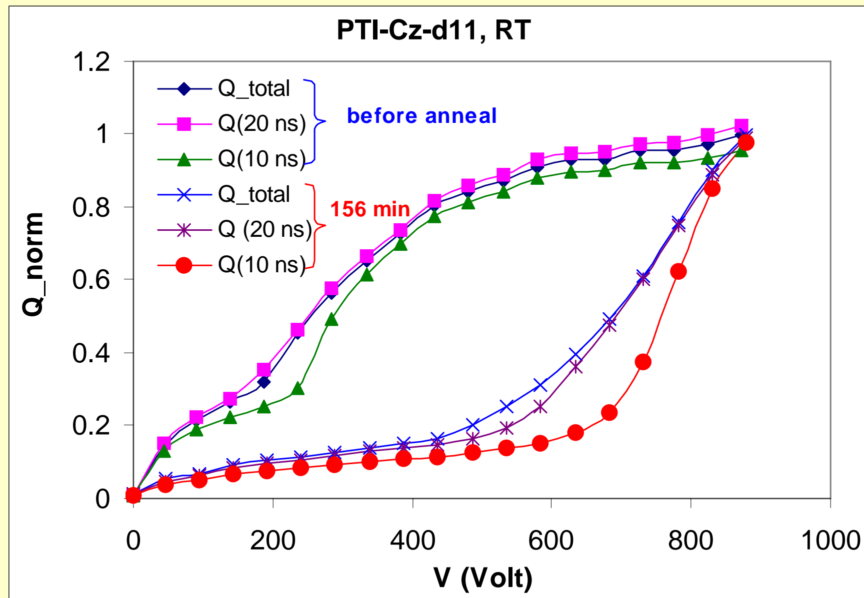
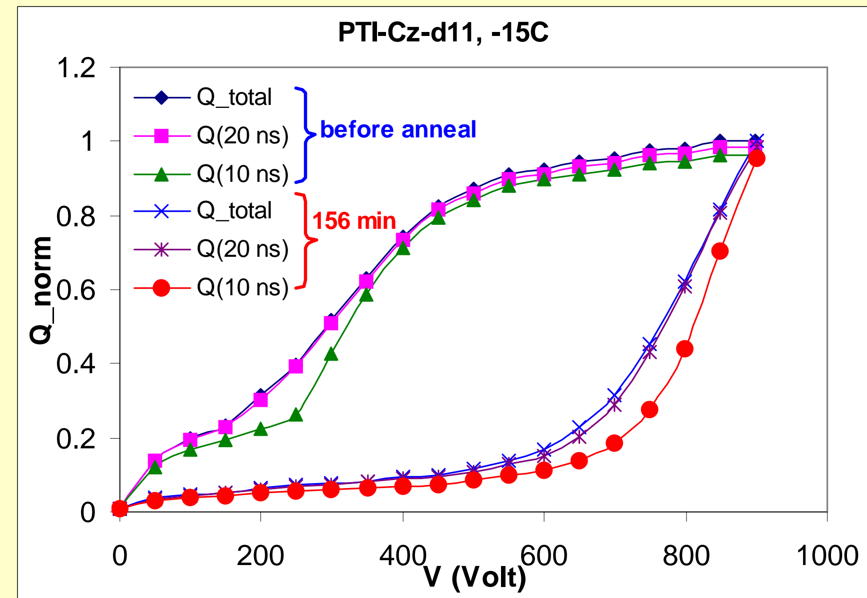
Q vs. V and τ_{sh} at RT and –15 ℃





- **Visible CCE reduction at τ_{sh} = 10 ns**
- **Reduction is less at –15°C (v_{dr})**

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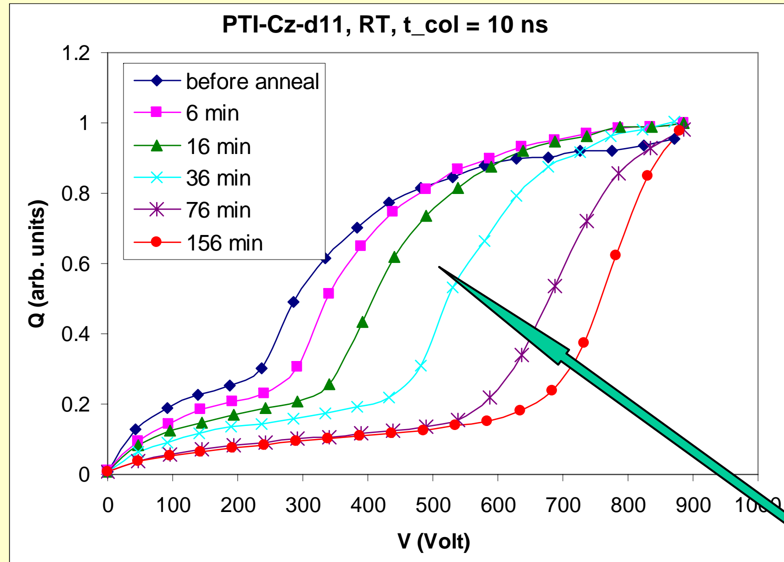
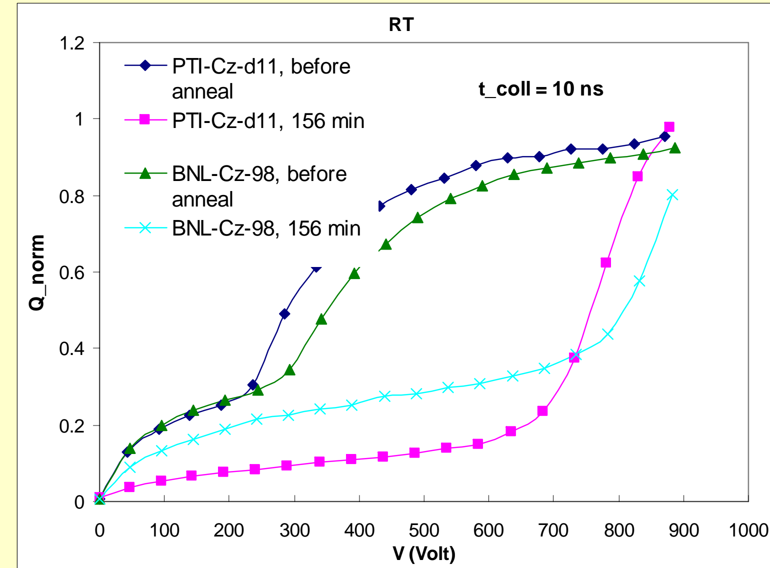
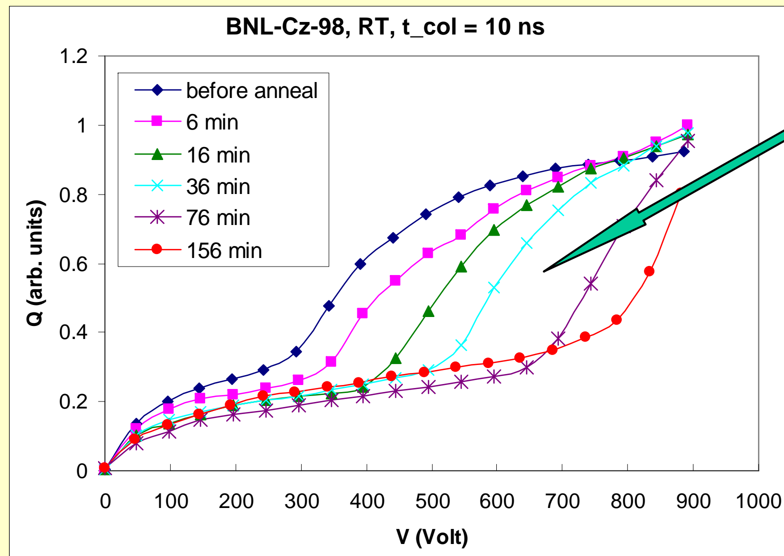
Different processing, Q vs. V at RT







Difference in H_1/H_2

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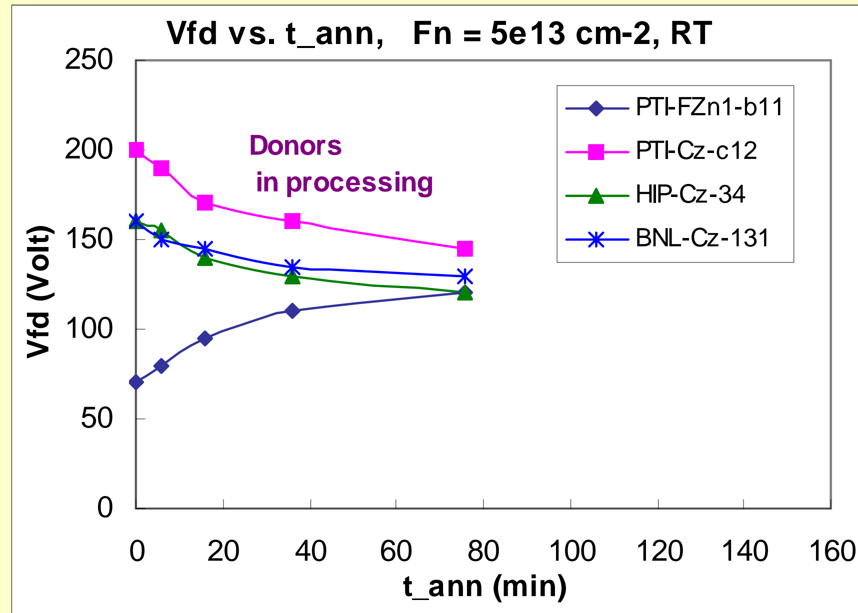
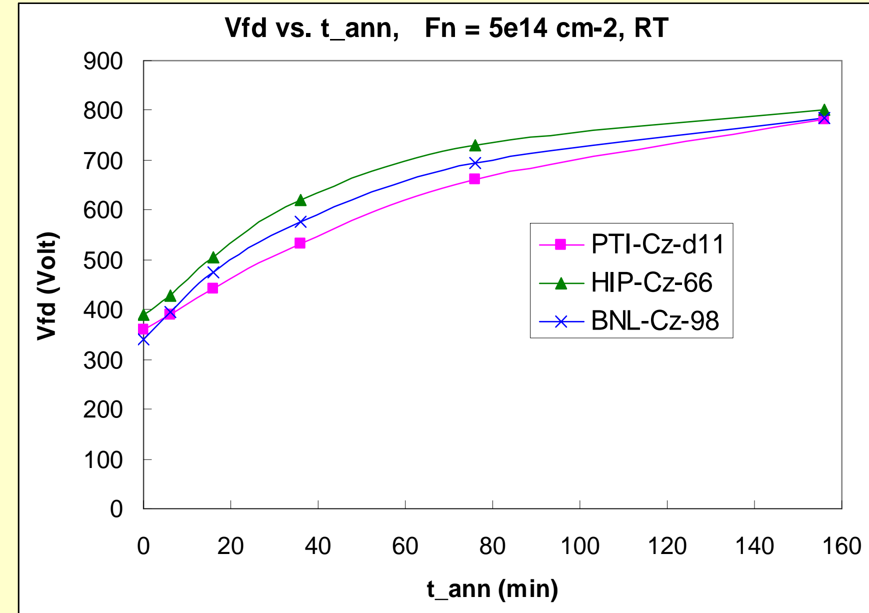
V_{fd} and N_{eff} evaluated from pulse response

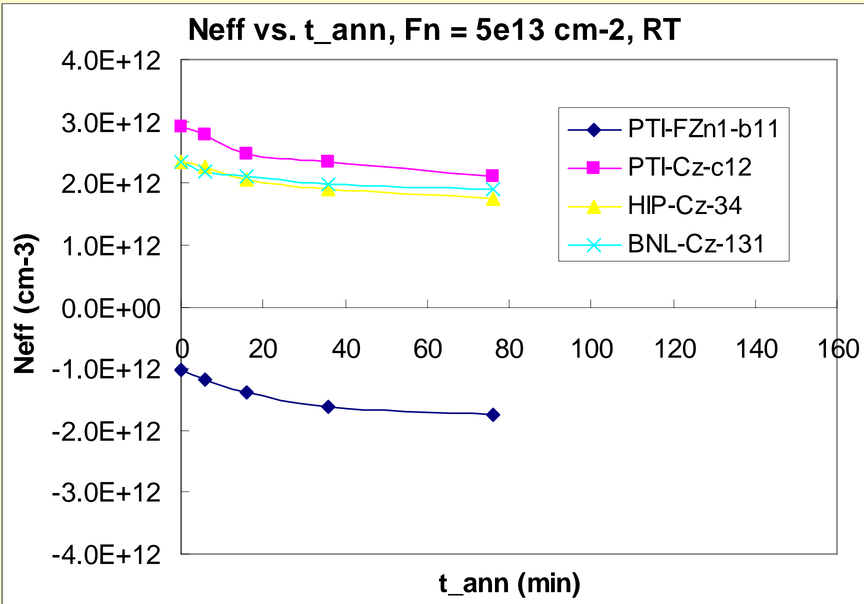
initial annealing stage

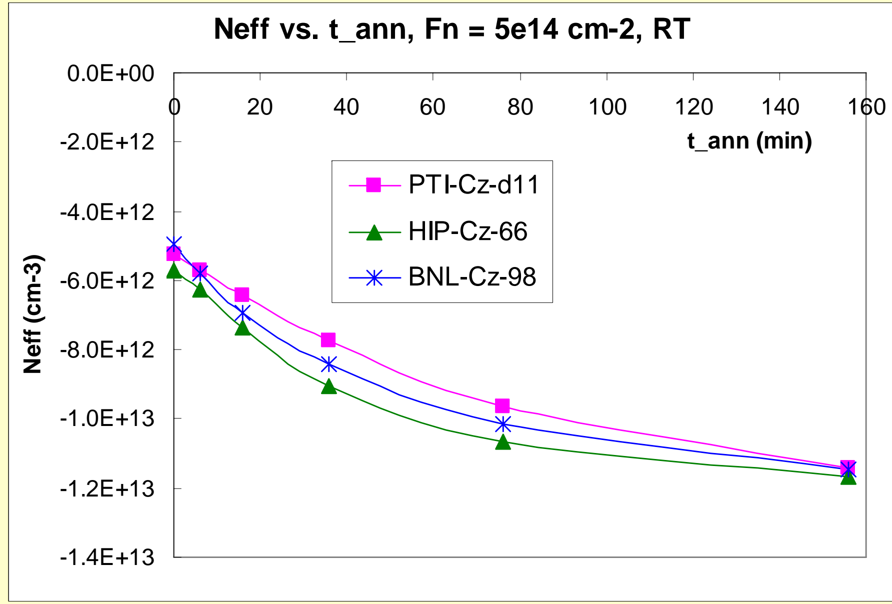
V_{fd}





N_{eff} evaluated from pulse response





Effective macroscopic parameters:

- **As-irradiated MCZ Si detectors:**
  5e13 cm^{-2}: sensitive to processing
  5e14 cm^{-2}: no sensitivity

- **Annealing ≤160 min:**
  reduces sensitivity

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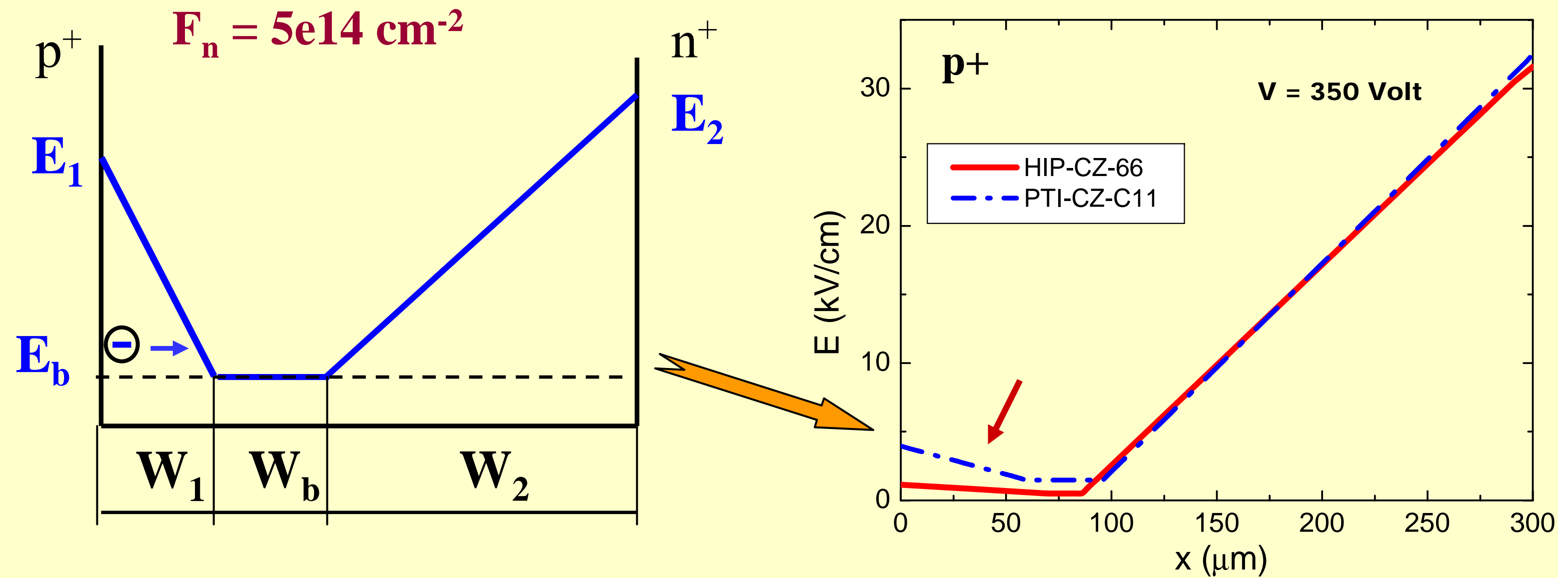
Reconstruction of E(x) from DP response



	HIP-CZ-66	PTI-CZ-C11
tau_e (ns)	4	5
Neff1 (cm-3)	1.41E+11	1.09E+12
Neff2 (cm-3)	9.46E+12	9.51E+12
E_b (V/cm)	500	1500

Electric field gradient dE/dx and N_{eff} in the region adjacent to p^+ contact are different and sensitive to detector processing

difference in balance of DDs and DAs induced by radiation

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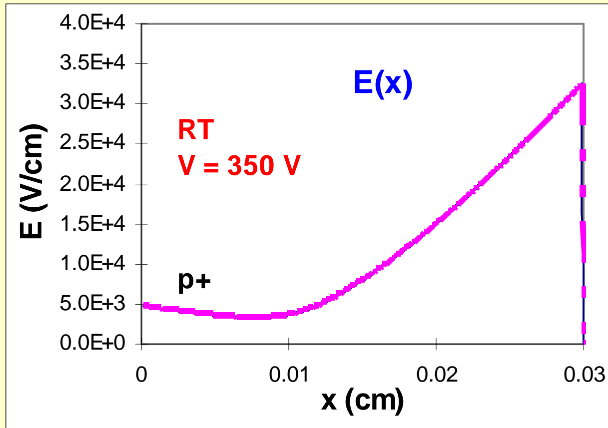
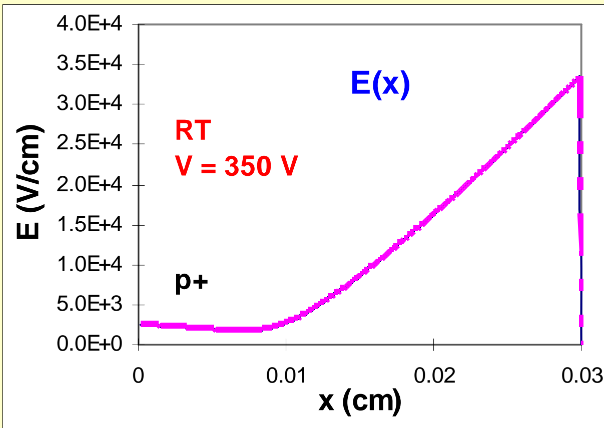
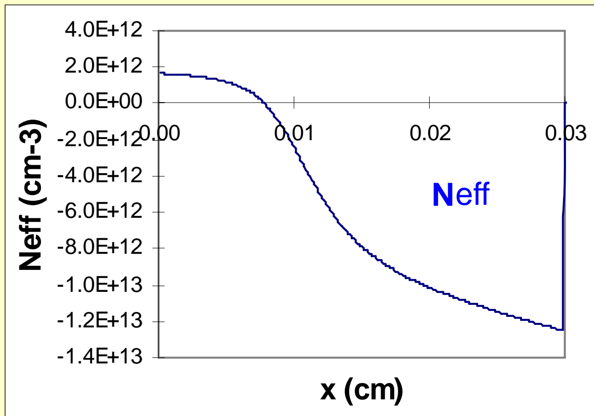
E(x) reconstruction

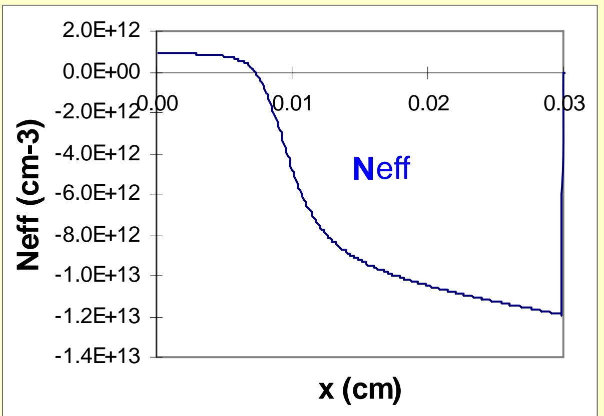
PTI-Cz-d11

HIP-Cz-66









		PTI-Cz-d11	HIP-Cz-66
MGD	Ev + 0.48 eV	2.50E+15	1.40E+15
MGA	Ec - 0.52 eV	1.00E+15	7.50E+14

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Conclusions

Detectors from n-type MCZ silicon irradiated by 1MeV neutrons

- **$F_n = 5\cdot10^{13}$ cm^{-2}**

- Space Charge (+)
- Insignificant difference of pulse response before and after annealing

- **$F_n = 5\cdot10^{14}$ cm^{-2}**

- Space Charge (-)
- DP current pulse shape dominates
- H_1/H_2 is affected by technology and changes under annealing
- Annealing reduces difference in effective macroscopic parameters

Protons, $Fp = 1\cdot10^{15}$ cm^{-2}: influence of technology is still observed!

RT → *–15 °C:*

- **trapping lifetime is the same**
- **reduction of E at n+ side**
- higher drift velocity, reduction of current and dissipated power