Gamma Radiation Induced Space Charge Sign Re-inversion in Proton Irradiated High Resistivity CZ Si Detectors

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OUTLINE

- **Introduction**
- **Experimental**
  - **Samples**
  - **Radiation source**
  - **Measurements**
- **Results and discussions**
- **Summary**

Introduction

- **[O] in CZ Si: in the 10^{18}'s /cm^3**
  - **Comes naturally from wafer manufacture process**
  - **Resistivity ≤100 Ω-cm**
  - **Thermal donor (TD) a problem**
- **Magnetic CZ technology now available:**
  - **High [O]**
  - **High resistivity ≥1000 Ω-cm : almost detector grade**
- **SCSI (from + to -) still observed in proton irradiated MCZ Si Detectors, although at much higher fluence**
- **Positive space charge induced in MCZ Si detectors after gamma radiation (+ to ++)**
- **Can space charge sign re-invert (SCSRI) back to positive with gamma radiation on p-irradiated, SCSI MCZ Si detectors From – to +)?**
- **What is field distribution (will DJ/DP still preserve)?**

Experimental

- **Samples**

  Control FZ (CFZ) samples and some MCZ samples processed together by Univ. of Helsinki, and some MCZ samples were processed by BNL

  Oxidation: 8+5 hours in O_2 at 1050 ^oC, all diodes are $p^+/n/n^+$ junctions

Wafer #	Type	Resistivity (Ω-cm)	Thickness (μm)
1	CFZ	3000	520
A, B, 3	MCZ	1200	380

Various square diodes of 0.36 cm^2 each from each wafer were used

- **Radiation**

  Neutrons: <E>=1 MeV; fluence: 0 to 2.9×10^{14} n/cm^2

  Protons: 10 MeV and 20 MeV; fluence: 0 to 1.2×10^{14} p/cm^2

  60Co gamma: E = 1.25 MeV; Dose rate: 0.5 Mrad/hr; Dose range: 0-1.2 Grad

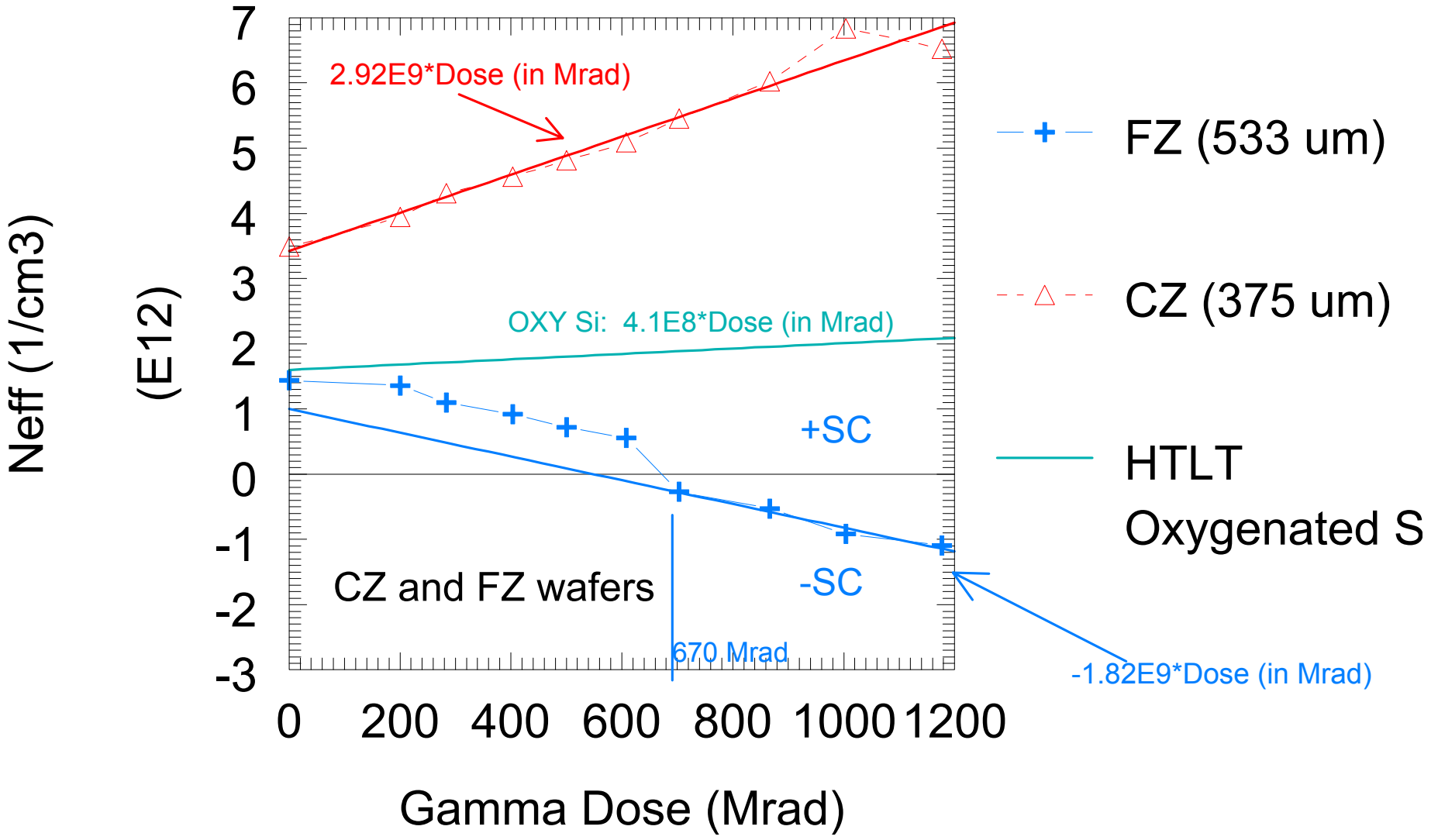
- **Measurements**

  TCT measurements using a red laser

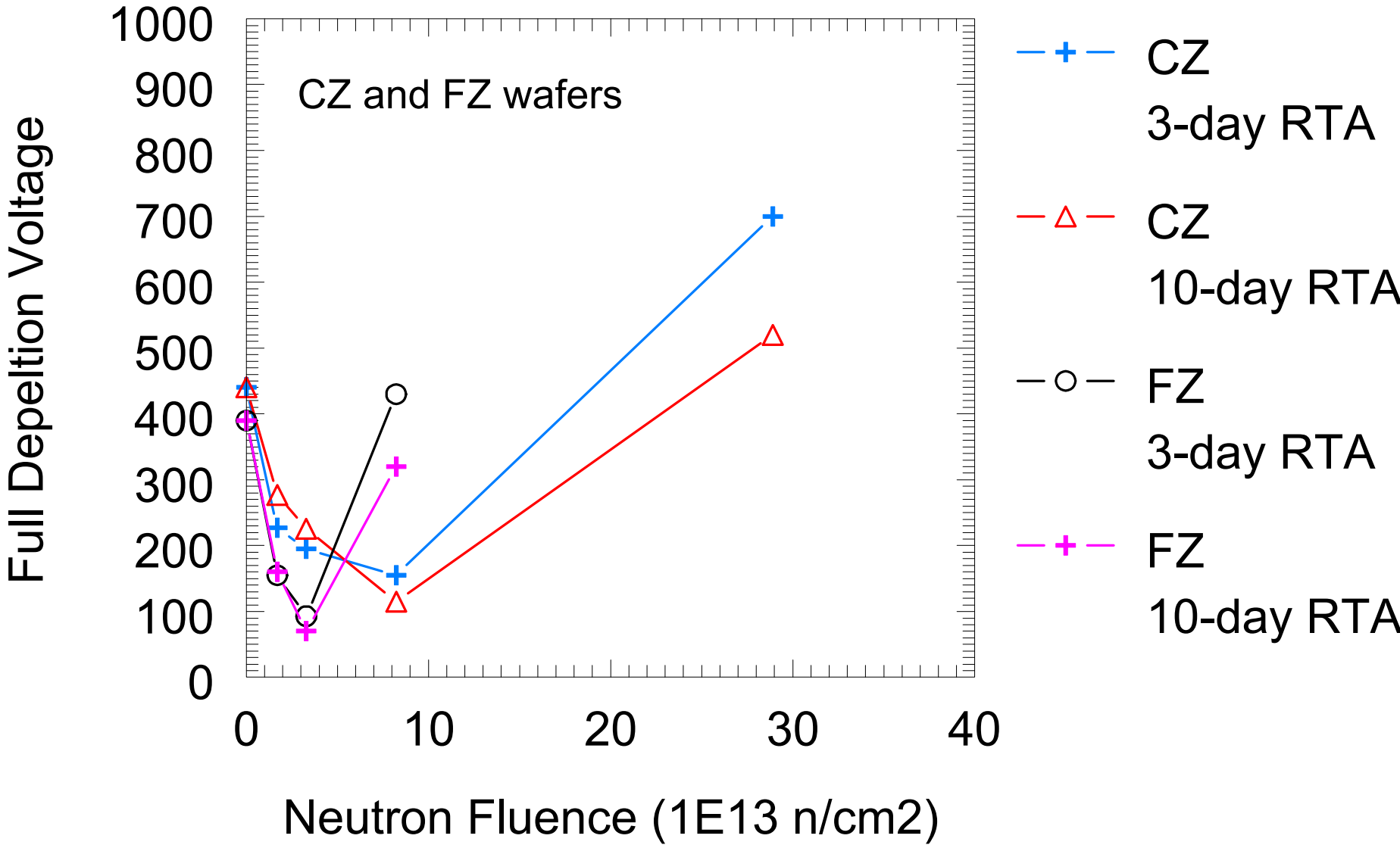
Negative SC build-up for control FZ Si detectors is: -1.82x10^9 x Dose

Positive SC build-up for Oxy Si detectors is: 4.1 x10^8 Dose

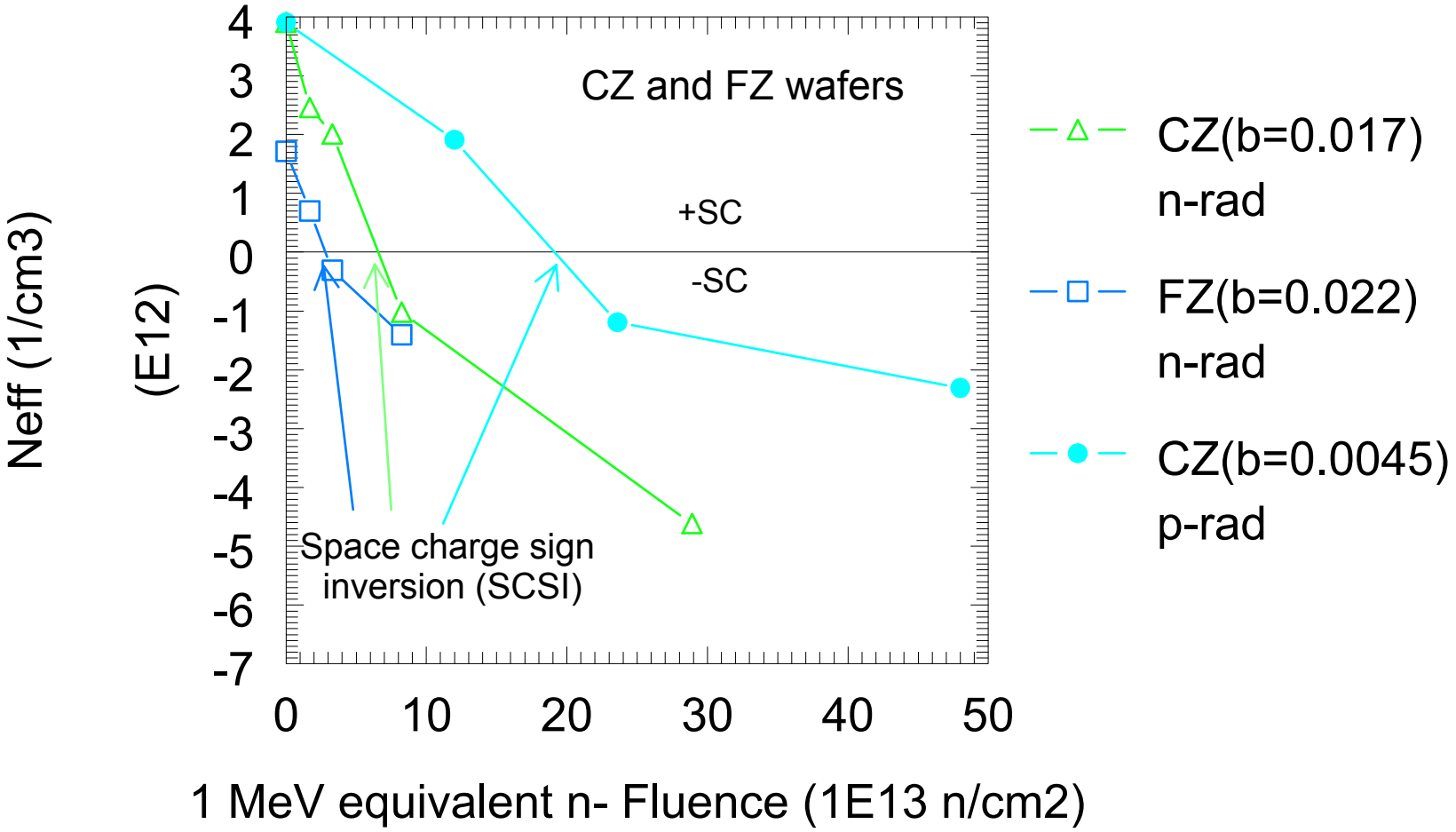
Positive SC build-up for MCZ Si detectors is: 2.9 x10^9 x Dose, about 8 times higher



Full depletion voltage vs. n-fluence



Comparison of N_{eff} vs. 1 MeV equivalent n-fluence between neutron and proton radiations



- CZ Si detectors are slightly more rad-hard than FZ ones with n-rad
  - β_{CZ} (b in the figure) is about 23% less than β_{FZ}
- CZ Si detectors are much more rad-hard than FZ ones with p-rad
  - β_{CZ} is about 1/5 of β_{FZ} and is about ½ of β_{OXY}
  - SCSI fluence is 3 time higher than that of FZ

Comparison and summary of radiation induced detects

ntroduction rate of stable defects

$N_{eff} = \beta_{\gamma,n,\mathrm{n_{eq}}} \cdot \Phi_{\gamma,n,or\,\mathrm{n_{eq}}}$, ($\Phi_\gamma$ in Mrad, Φ_n and $\Phi_{\mathrm{n_{eq}}}$ in $\mathrm{n_{eq}/cm^2}$)

Detector Type	Gamma β_γ (1/Mrad-cm^3)	n (1 MeV) β_n (1/n_{eq}-cm)	Proton $\beta_{n_{eq}}$ (1/ n_{eq}-cm)	Normalized Rad-hard factor
CFZ	-1.82x10^9	-0.022	-----	1
MCZ	**2.92x10^9**	-0.017	**-0.0045**	5
(old) FZ	-8.0x10^9	-0.023	-0.022	1
HTLT oxygenated	**4.1x10^8**	-0.023	**-0.0094**	2.4

Introduction rate of reverse anneal generated defects

$N_{eff}^{rev} = \beta_{rev,n\,or\,\mathrm{n_{eq}}} \cdot \Phi_{n\,or\,\mathrm{n_{eq}}}$, ($\Phi_n$ and $\Phi_{\mathrm{n_{eq}}}$ in $\mathrm{n_{eq}/cm^2}$)

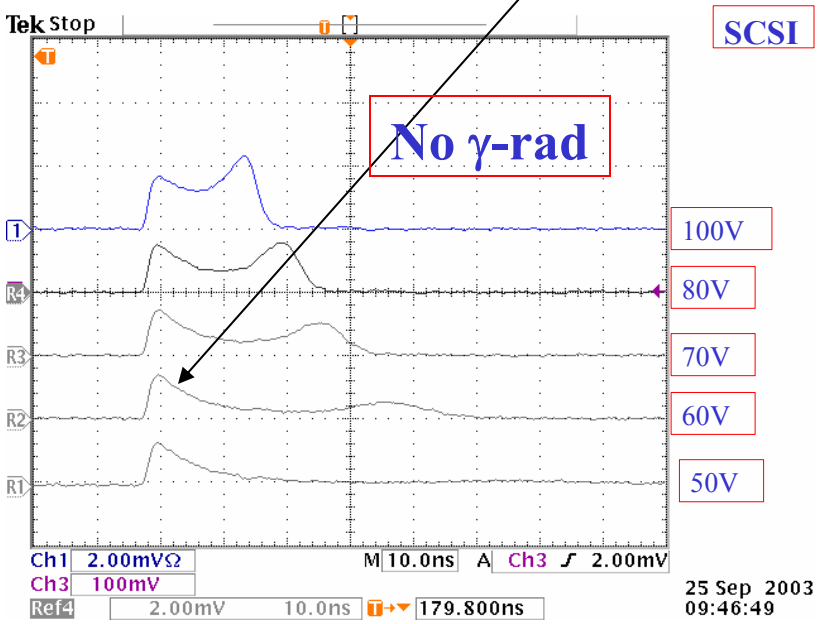
Detector Type	n (1 MeV) β_n^{rev} (1/n_{eq}-cm)	Proton $\beta_{n_{eq}}^{rev}$ (1/ n_{eq} -cm)	Normalized Rad-hard factor
CFZ	-0.062		1
MCZ	-0.050	**-0.0096**	5-7
(old) FZ	-0.073		1

- **With higher [O], MCZ Si has more un-activated TD's**
  - **Produced during the TD killing process**
- **Gamma radiation activates those un-activated TD's, giving rise to the higher positive SC build-up rate**
- **This positive SC build-up may also happen in charged particle irradiated MCZ Si detectors, giving possibility of compensating regular negative SC ---- improvement of rad-hardness**
- **The degree of this improvement in rad-hardness may depend type of particle radiation**
- **MCZ Si detectors are also more rad-hard than CFZ Si detectors in reverse annealing**

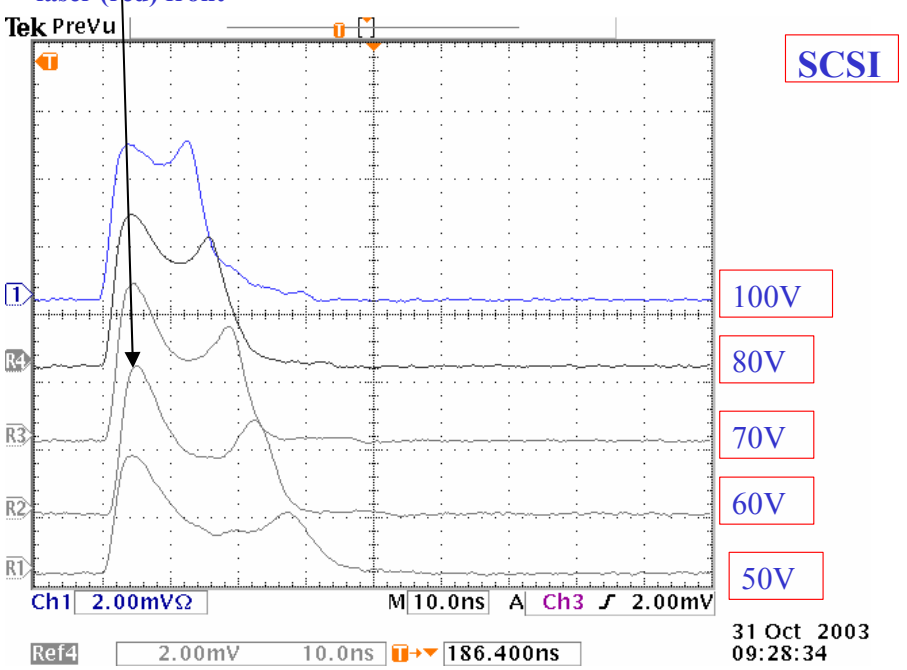
Proton radiation + gamma radiation in MCZ Si detectors

Increase in the field of the front junction clearly observed
Double peak field still exists
---- space charge moving toward positive direction

#A-3-15, MCZ, 380 μm, 5.9x10^{13} p/cm^2 (10 MeV), 9 month RTA
laser (red) front



#A-3-15, MCZ, 380 μm, 5.9x10^{13} p/cm^2 (10 MeV), 9 month RTA + gamma radiation (210 Mrad)
laser (red) front



Proton radiation + gamma radiation in MCZ Si detectors

Increase in the field of the front junction clearly observed
Double peak field still exists, but back peak smaller
--- space charge almost becomes positive (expect to see SCSRI at next dose of 450 Mrad)

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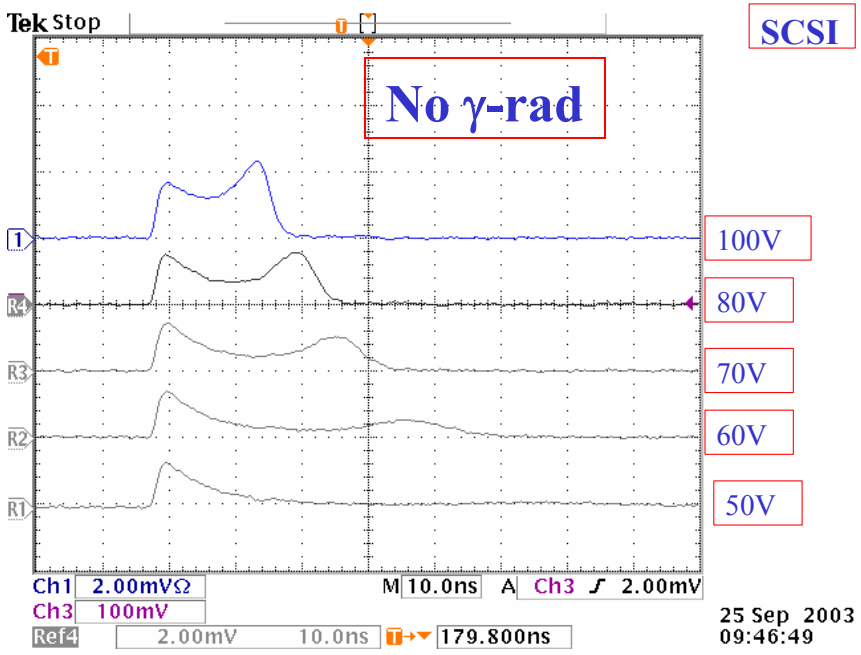
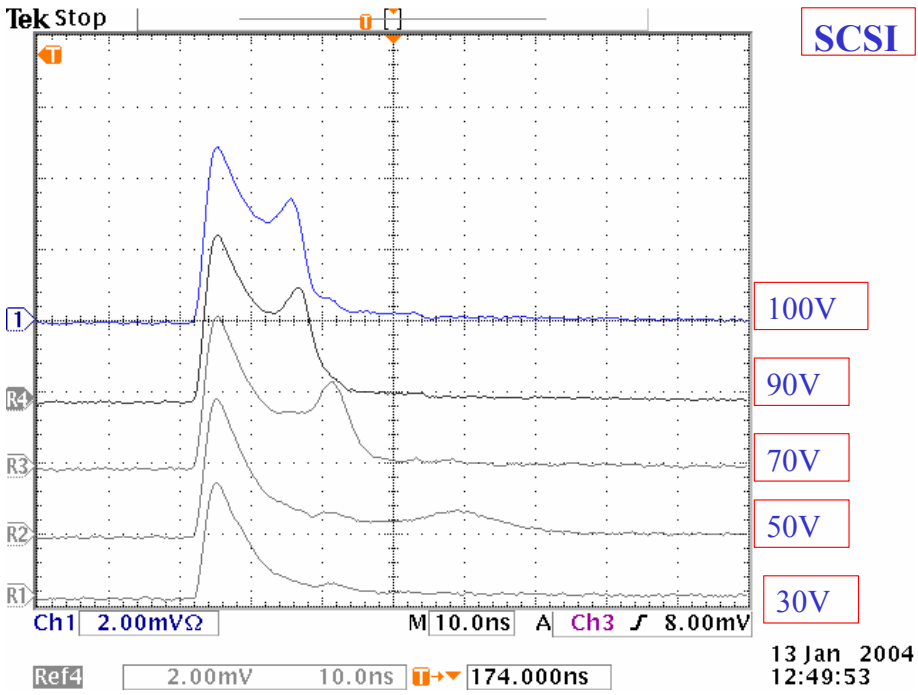
laser (red) front



#A-3-15, MCZ, 380 µm, 5.9x10^{13} p/cm^2 (10 MeV), 9 month RTA + gamma radiation (310 Mrad)
laser (red) front



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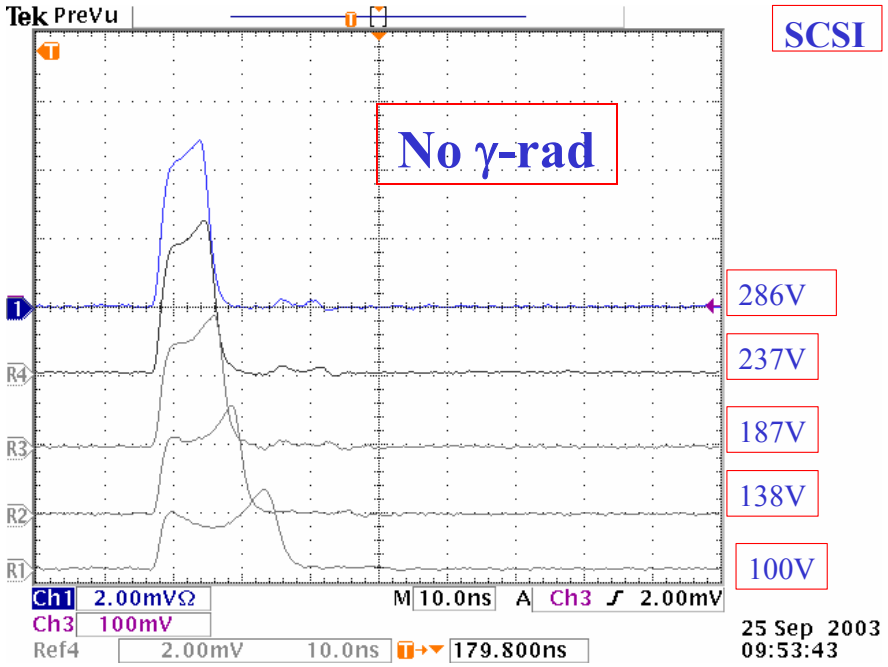

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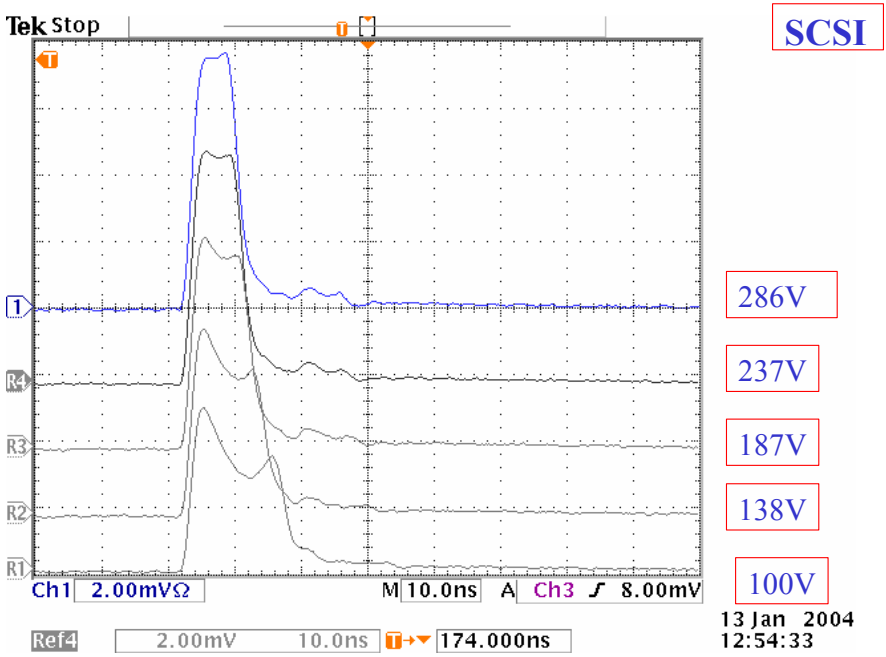

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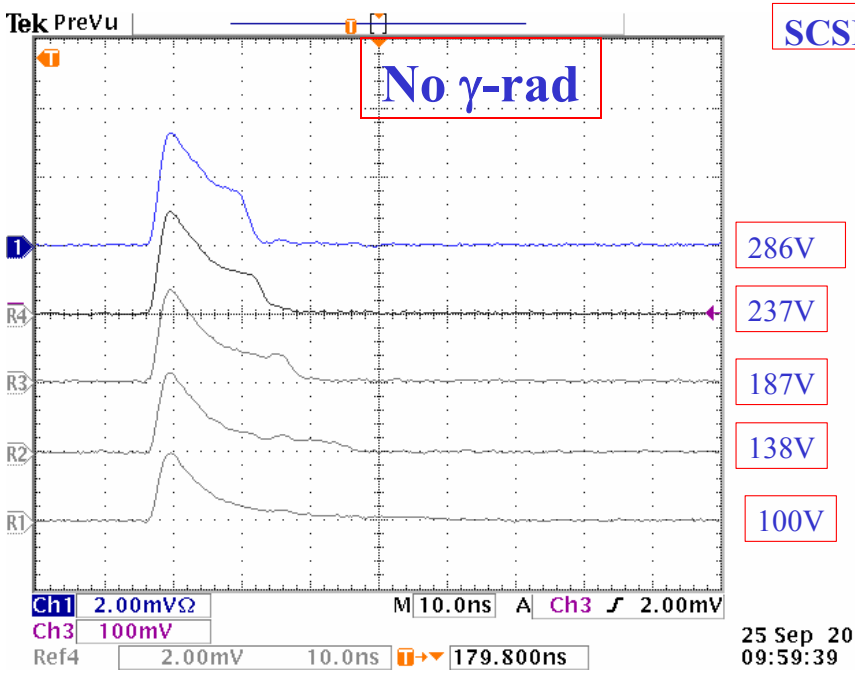
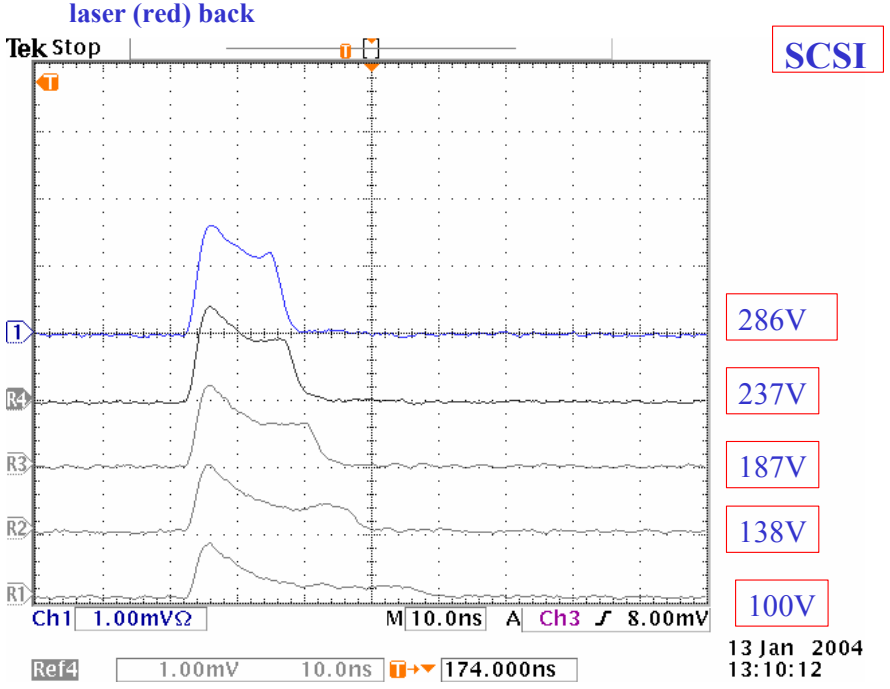
laser (red) back



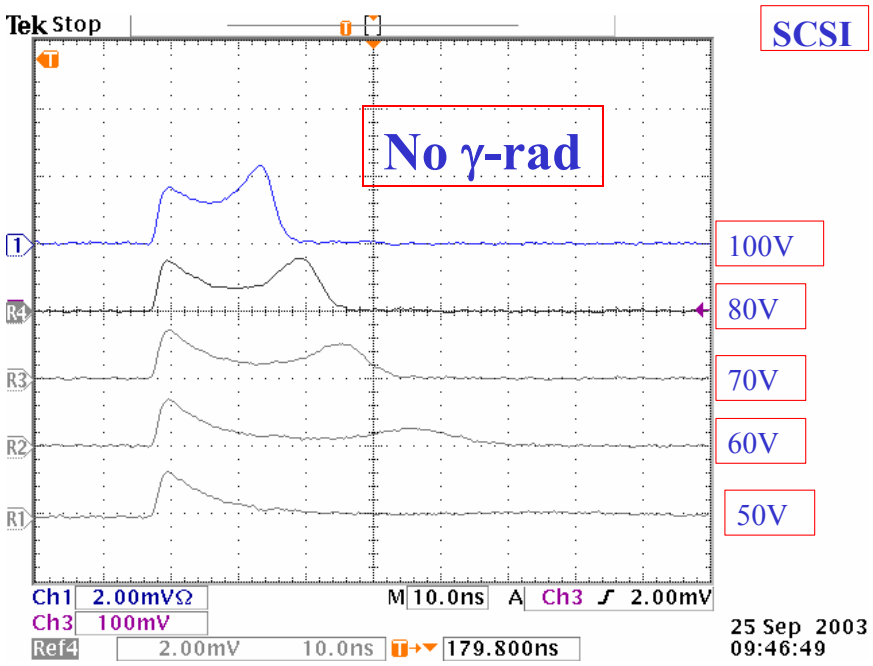
#A-3-15, MCZ, 380 μm, 5.9×10^{13} p/cm^2 (10 MeV), 9 month RTA + gamma radiation (310 Mrad)
laser (red) back



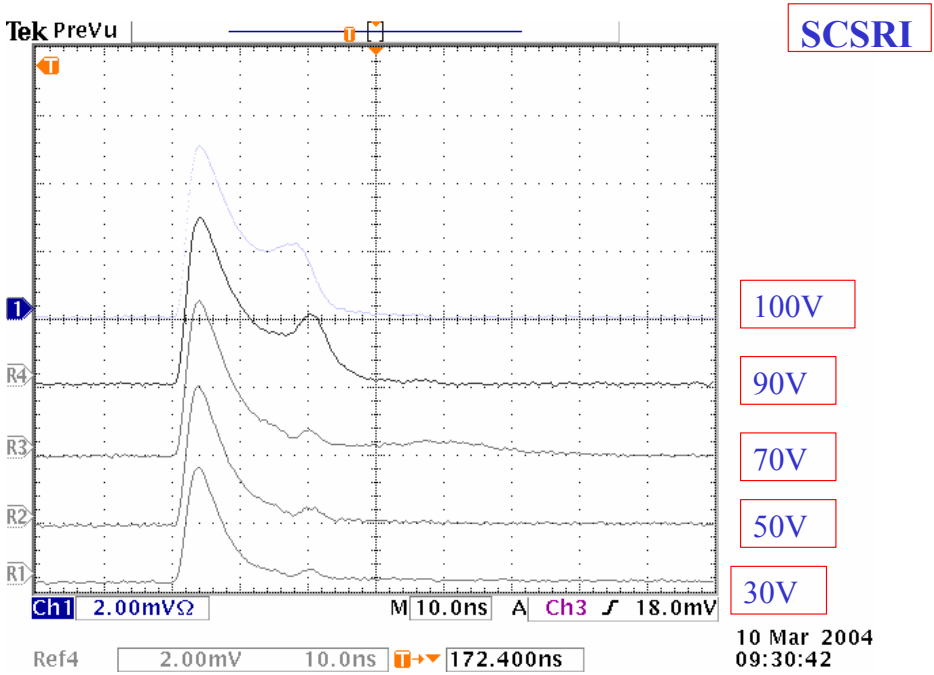
Proton radiation + gamma radiation in MCZ Si detectors

After 454 Mrad, Space charge Sign re-inverted
Double peak field still exists

#A-3-15, MCZ, 380 μm, 5.9x10^{13} p/cm^2 (10 MeV), 9 month RTA
laser (red) front



After gamma radiation (454 Mrad)



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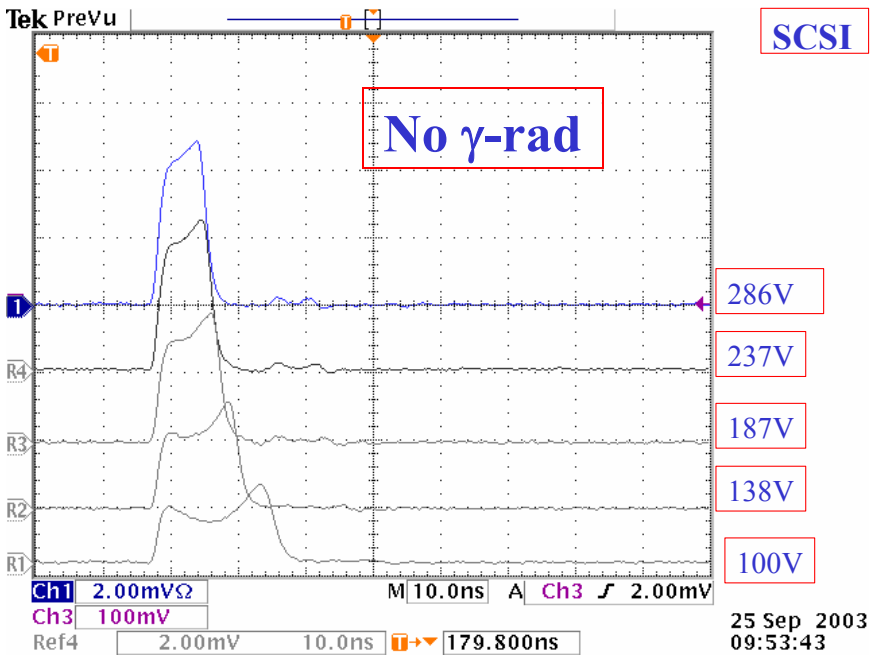

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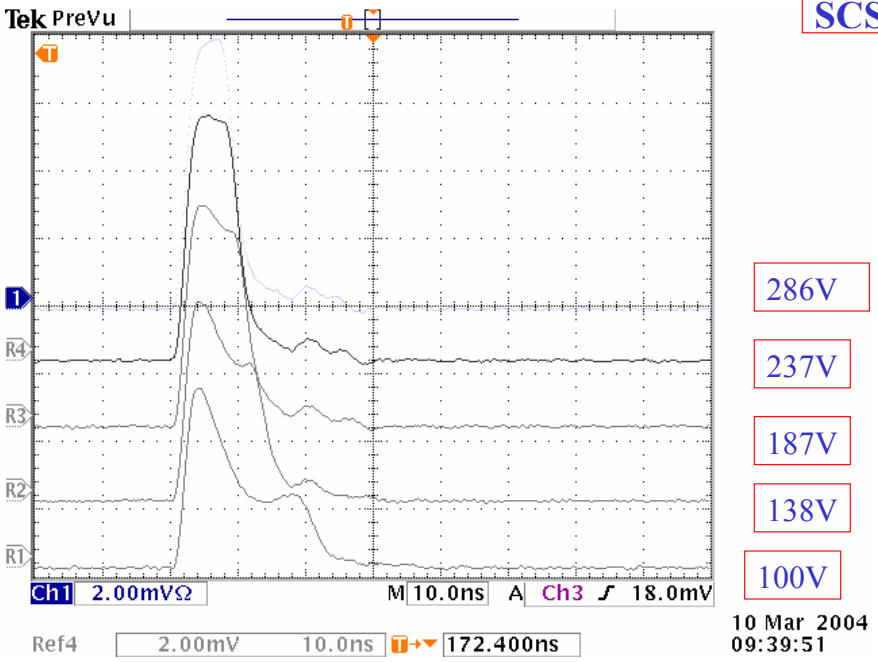

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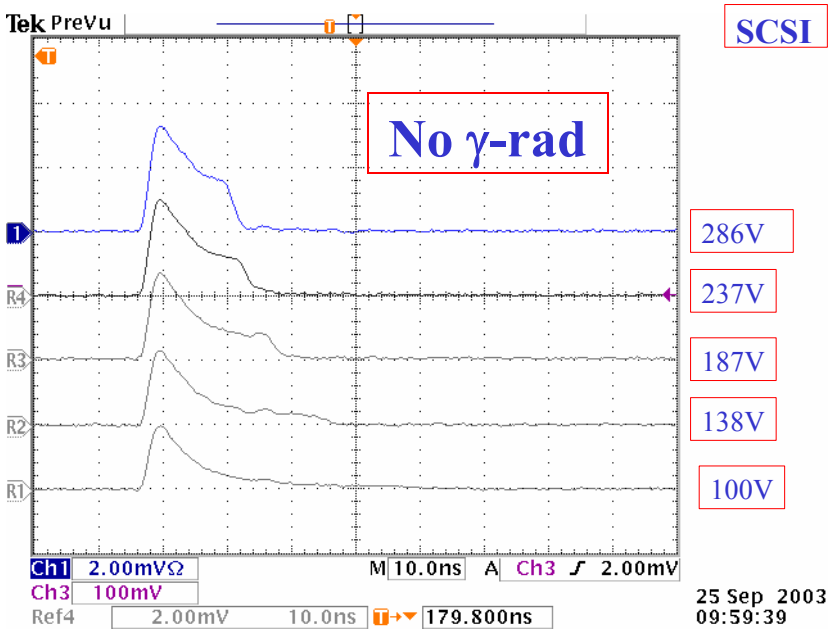
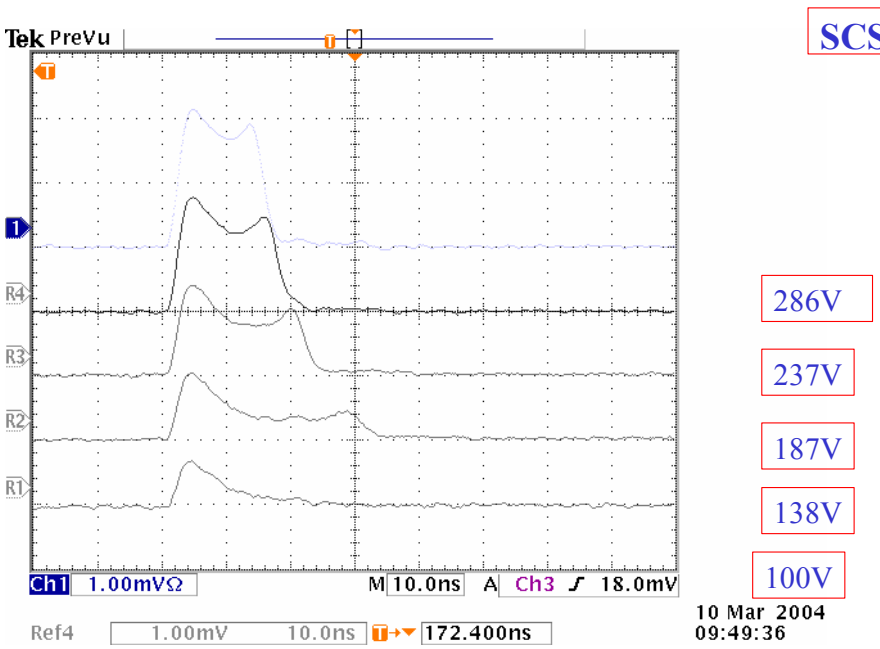
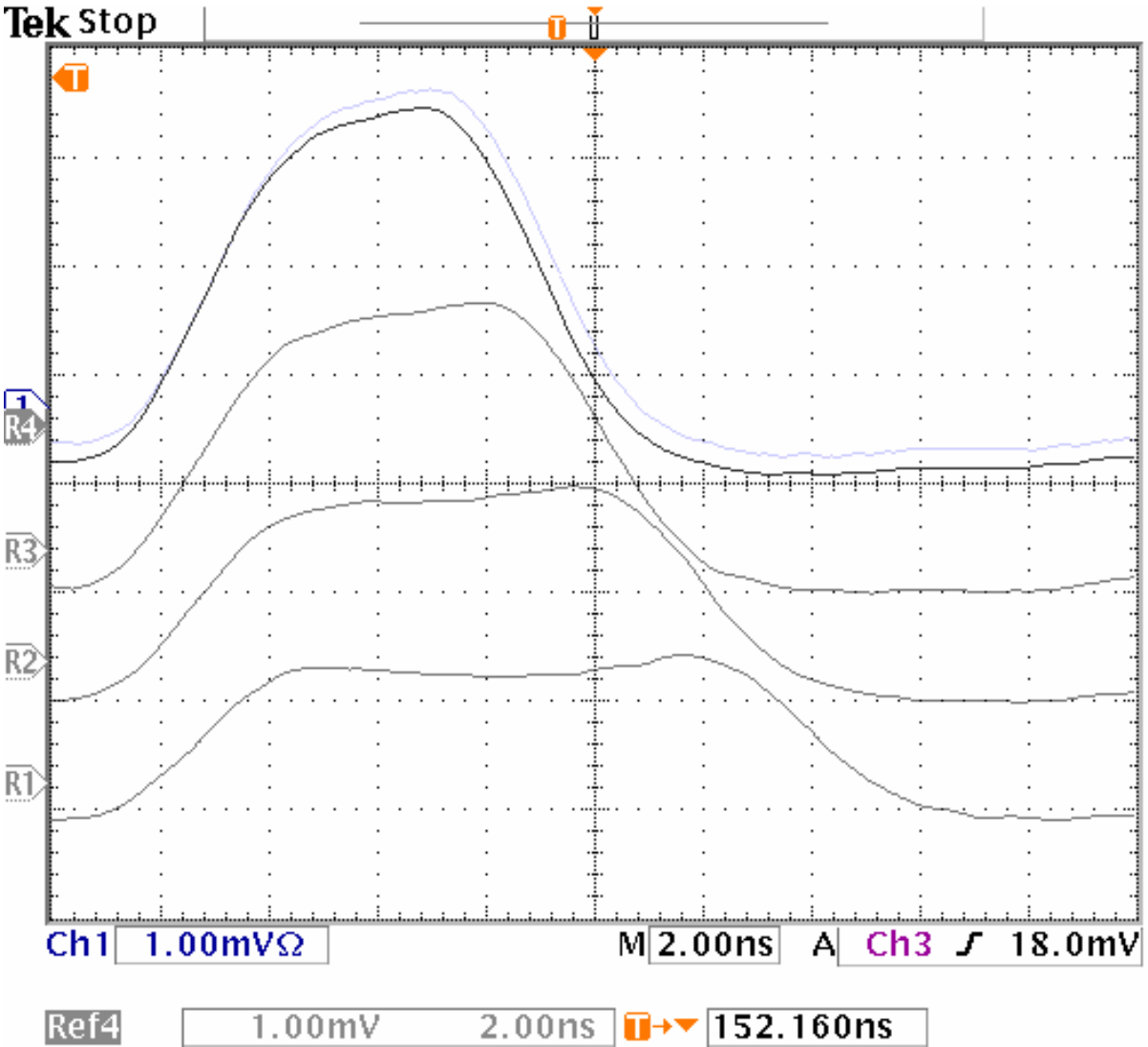


After gamma radiation (454 Mrad)



#A-3-15, MCZ, 380 μm, 5.9x10^{13} p/cm^2 (10 MeV), 9 month RTA + gamma radiation (454 Mrad)
laser (red) back

SCSRI



1000V

700V

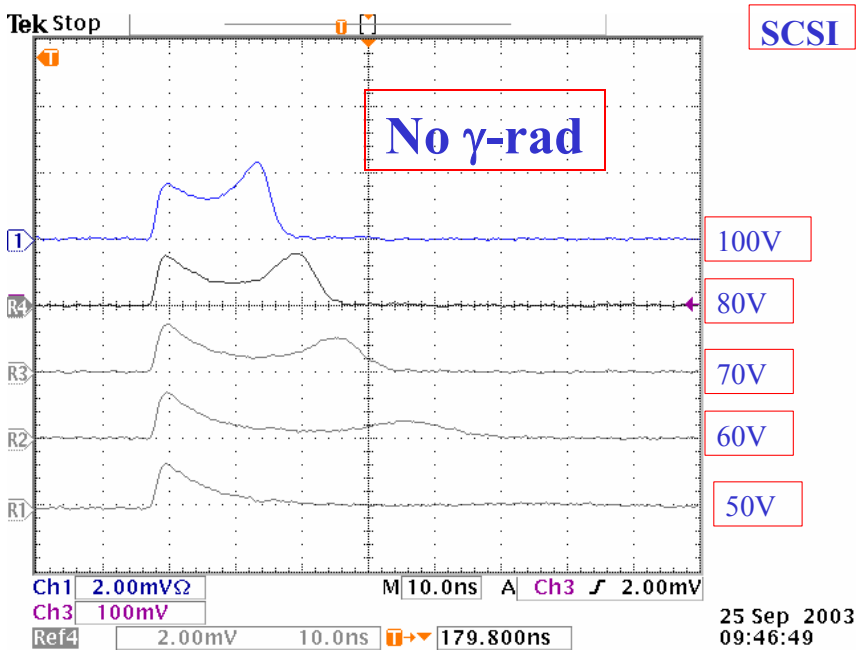
500V

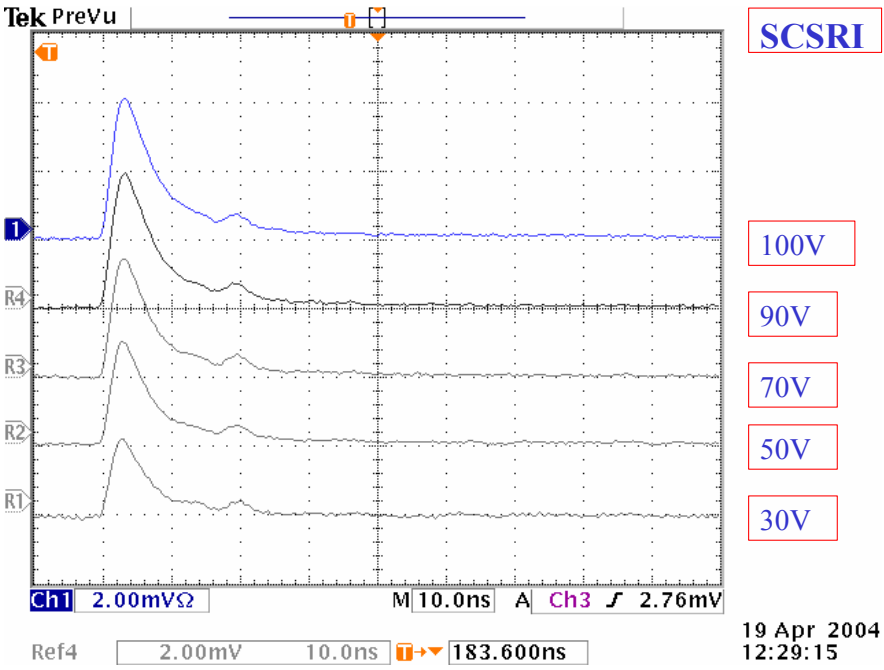
300V

Proton radiation + gamma radiation in MCZ Si detectors

After 662 Mrad, Space charge Sign re-inverted clearly seen

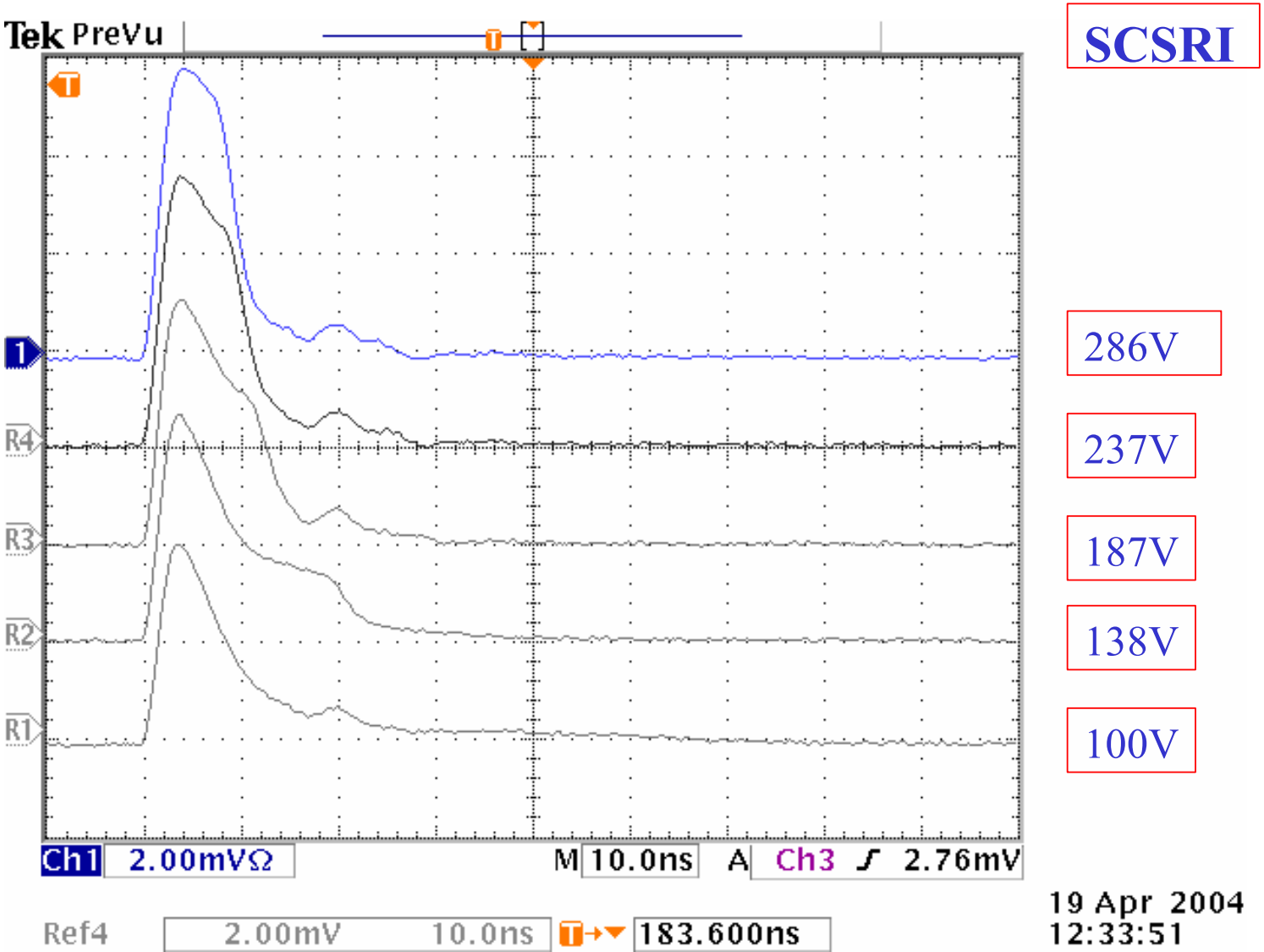
#A-3-15, MCZ, 380 μm, 5.9x10^{13} p/cm^2 (10 MeV), 9 month RTA
laser (red) front





Proton radiation + gamma radiation in MCZ Si detectors

After 662 Mrad, Space charge Sign re-inverted clearly seen
Double peak field still barely exists

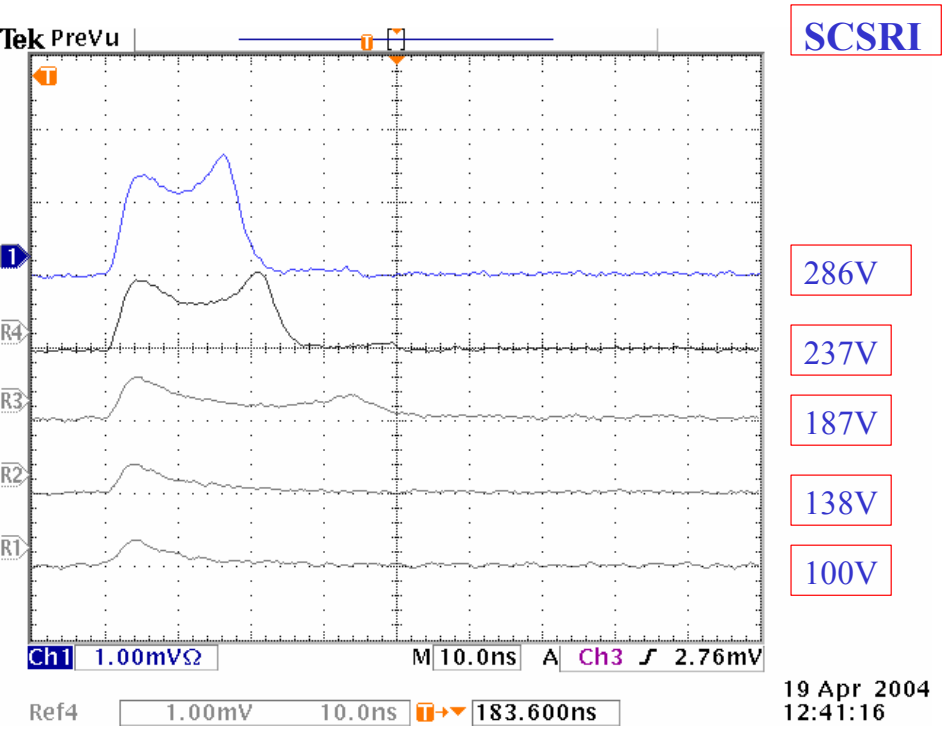


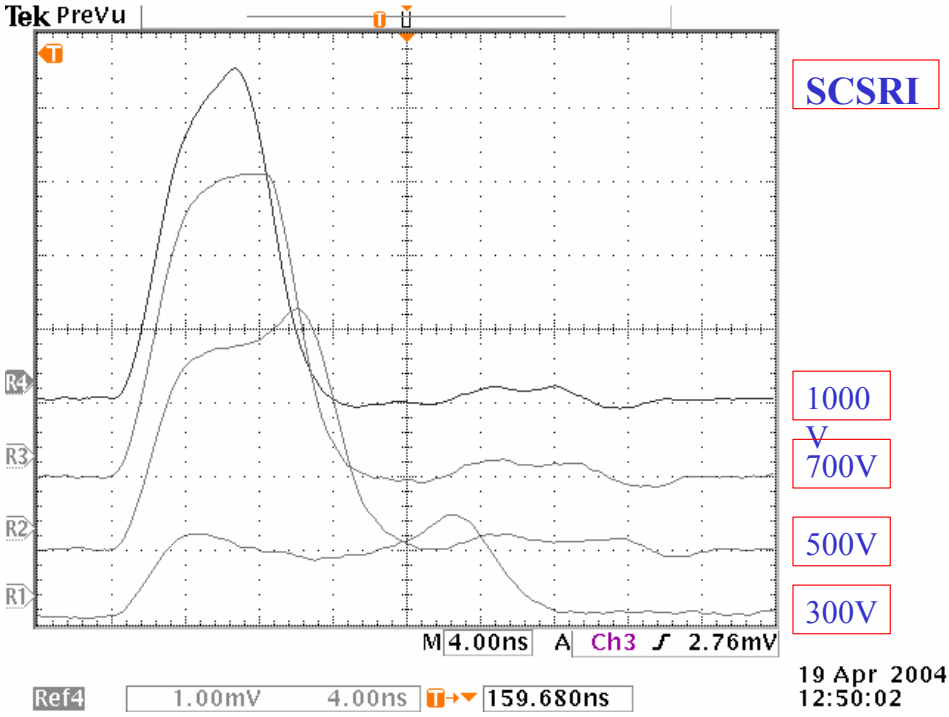
#A-3-15, MCZ, 380 μm, 5.9x10^{13} p/cm^2 (10 MeV), 9 month RTA + gamma radiation (662 Mrad)

laser (red) back

After 662 Mrad, Space charge Sign re-inverted clearly seen

Double peak field still exists

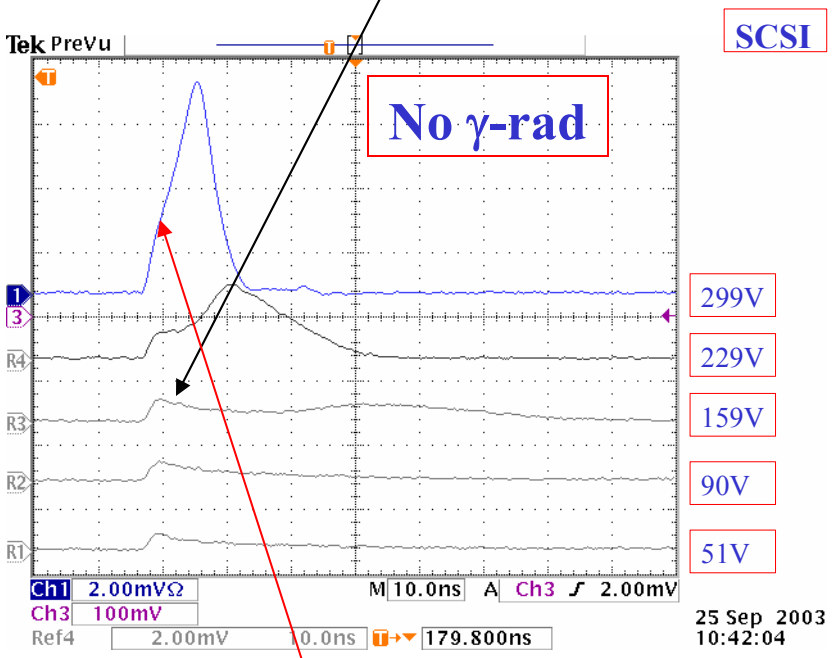




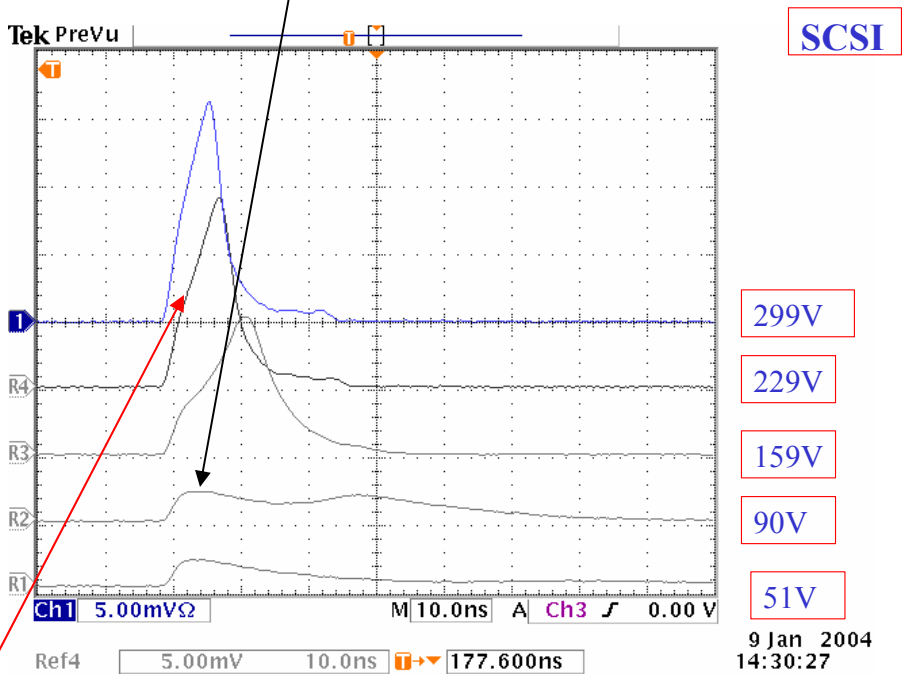
Neutron radiation + gamma radiation in MCZ Si detectors

Increase in the field of the front junction clearly observed
Double peak field still exists
---- space charge moving toward positive direction

#3-3-1, MCZ, 380 μm, 8.23x10^{13} n/cm^2, 9 month RTA, laser (red) front



#3-3-1, MCZ, 380 μm, 8.23x10^{13} n/cm^2, 9 month RTA, laser (red) + gamma radiation (310 Mrad)
front

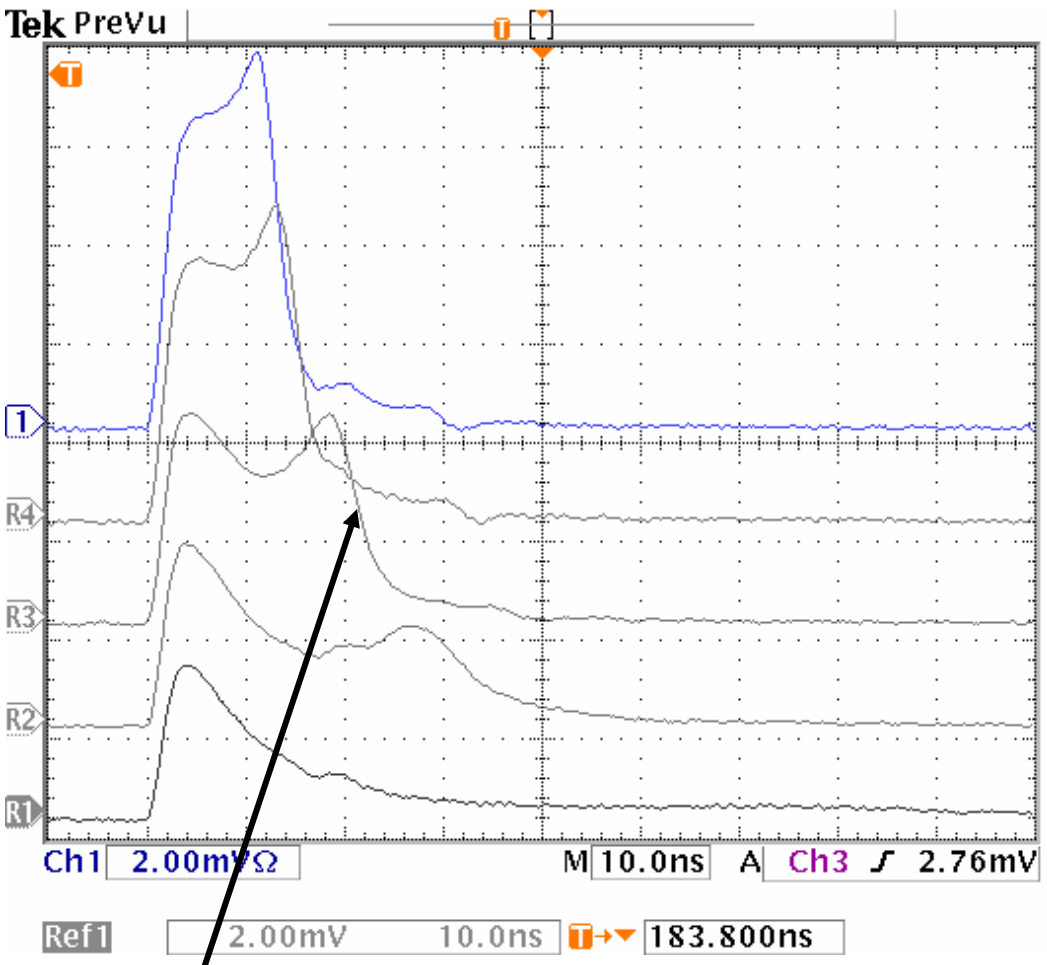


Depletion at lower bias after gamma radiation

Neutron radiation + gamma radiation in MCZ Si detectors

#3-3-1, MCZ, 380 μm, 8.23×10^{13} n/cm^2 , 9 month RTA + gamma radiation (662 Mrad)

laser (red) back



SCSI

139V

120V

90V

70V

50V

Increase in the field of the front junction clearly observed, Double peak field still exists

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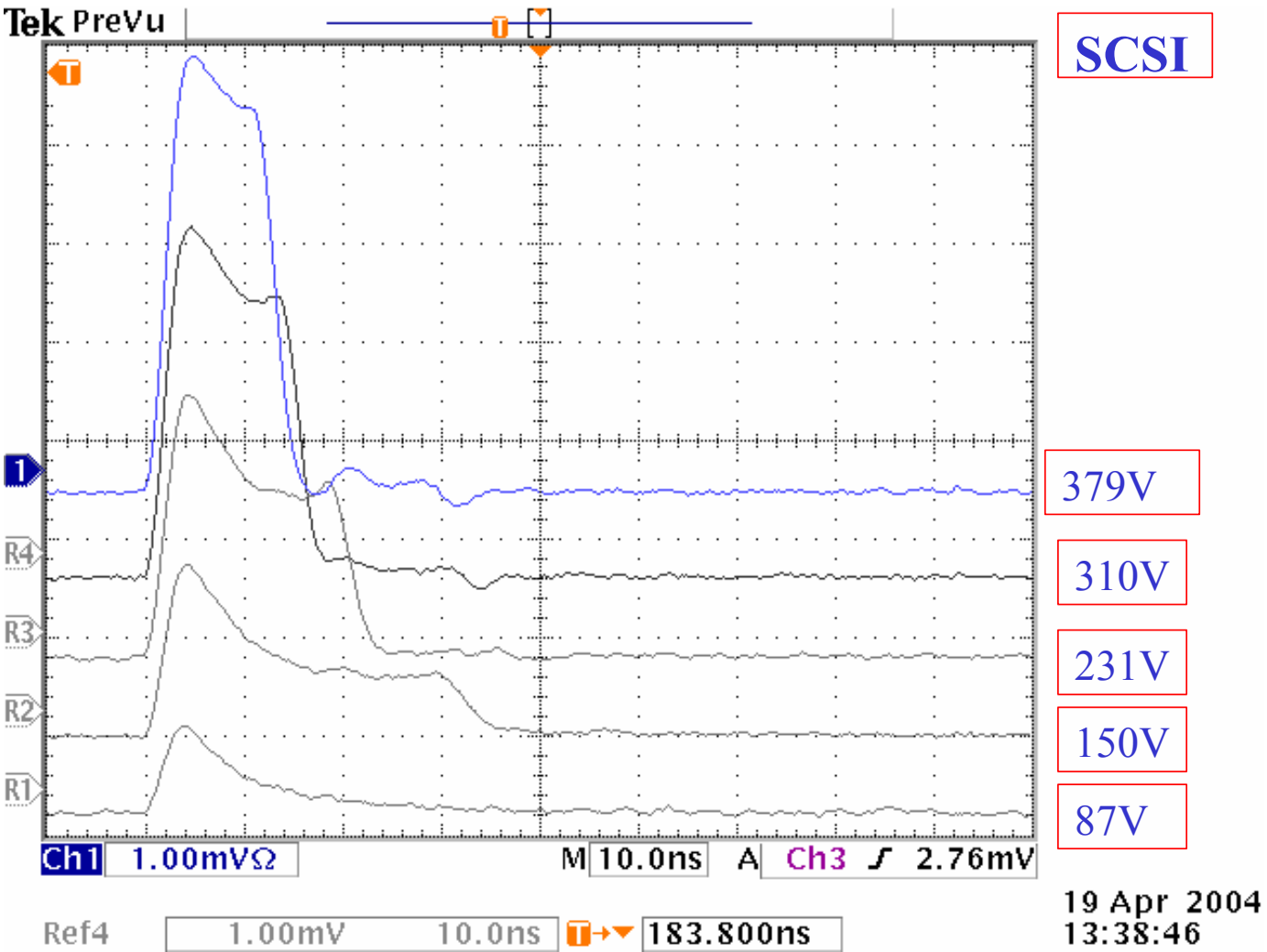
Depletion at lower bias after gamma radiation

Neutron radiation + gamma radiation in MCZ Si detectors

#3-3-1, MCZ, 380 μm, 8.23×10^{13} n/cm^2 , 9 month RTA + gamma radiation (662 Mrad)

laser (red) back



Summary

- **Positive space charge built-up observed in p and n – irradiated MCZ Si detectors after gamma radiation**

- **SCSRI was achieved at the high dose 454 Mrad in a low fluence proton irradiated MCZ Si detector**

- **No SCSRI yet for low fluence n-irradiated MCZ Si detector at the highest dose in this study, but positive space charge is building-up, SCSRI expected at higher doses**

- **Up to the highest dose in this study, the DJ/DP field distribution is still preserved**

- **No SCSRI observed in control FZ Si detectors**