TCT and test beam results of irradiated magnetic Czochralski silicon (MCz-Si) detectors

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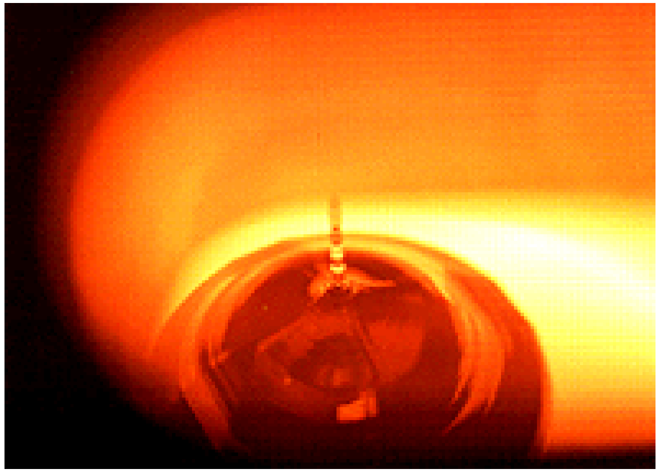
Outline

- Motivation
- Experimental setups
- Transient Current Technique (TCT) measurements on diodes
- Test beam results
- Conclusions

Background

Why Magnetic Czochralski silicon (Mcz-Si) is an attractive sensor material for high luminosity applications ?

- MCz-Si contains oxygen (5-10×10^{17} cm^{-3})
  → improved radiation hardness
- MCz-Si is commonly used material in microelectronics industry
- Available in large wafer sizes and quantities
- Possibly cost-effective material



- The difference between MCz-Si and Cz-Si is the magnetic field during the crystal growth. Magnetic field improves the controllability of the silicon melt thus improving the dopant/impurity concentration of resulting wafers.

Motivation

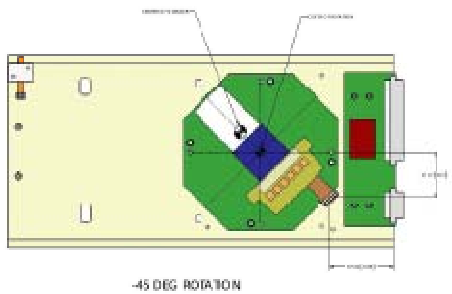
- There is no clear consensus whether MCz-Si type inverts (Space Charge Sign Inversion, SCSI) after certain fluence.
- SCSI / *E(x)* can be studied by TCT method ($i(t) \propto E(x)e^{-time/\tau\, trap}$)
- The problem: the possible SCSI in MCz-Si takes place at such a high fluence ($>1\times10^{14}\ cm^{-2}$) that one has to take trapping ($\tau_{trapping}$) into account, i.e., SCSI is not apparent in *as-measured* signal at high fluencies.

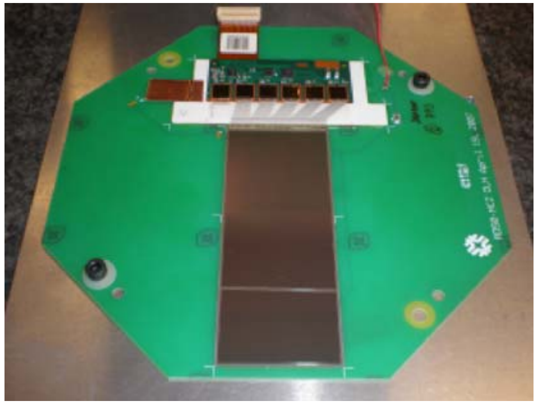
How possible SCSI affects the cluster resolution ?
How sensor segmentation influences the CCE and resolution ?

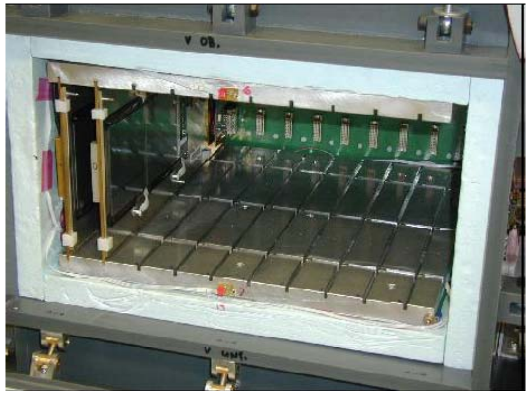
Beam tests on segmented strip detectors needed!

Telescope setup

- The telescope reference planes + detectors under test are housed inside a cold chamber, in which the temperature can be adjusted by two water cooled 350 W Peltier elements.
- Reference planes are installed to ±45 degrees (due to the height limitation)
- Reference detectors are D0 Run IIb HPK sensors with:
  - 60 micron pitch and intermediate strips
  - size 4 cm x 9 cm
  - 639 channels
- Readout electronics: CMS 6-APV chip Tracker Outer Barrel hybrids (5 chips bonded)
- DAQ software: a modified version of the CMS Tracker data acquisition software XDAQ

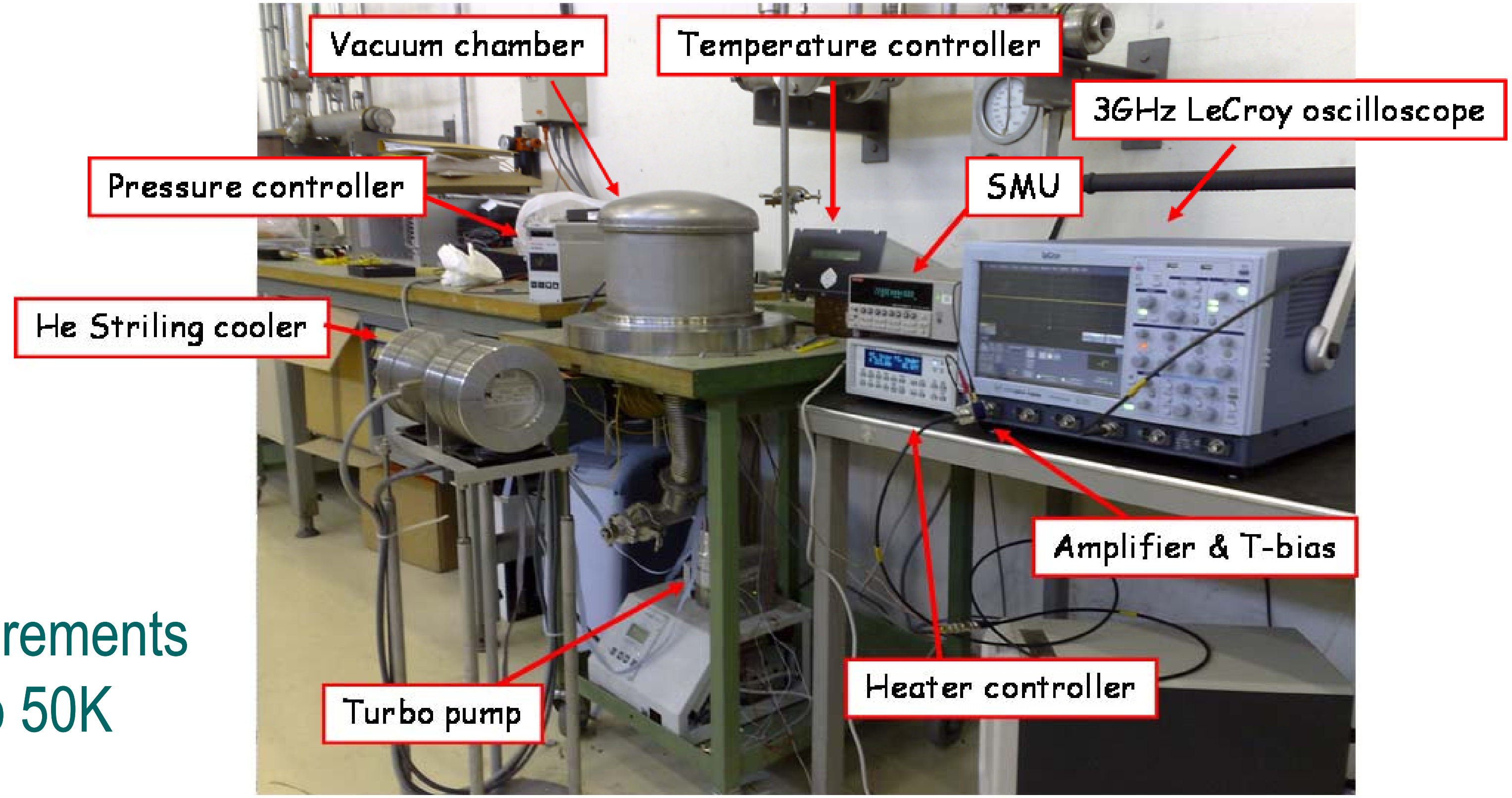






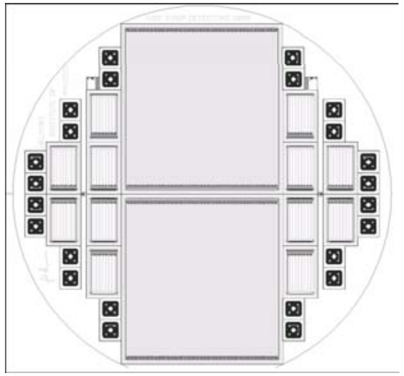
RD39 Collaboration TCT setup

- 670nm and 1060nm lasers for TCT and CCE

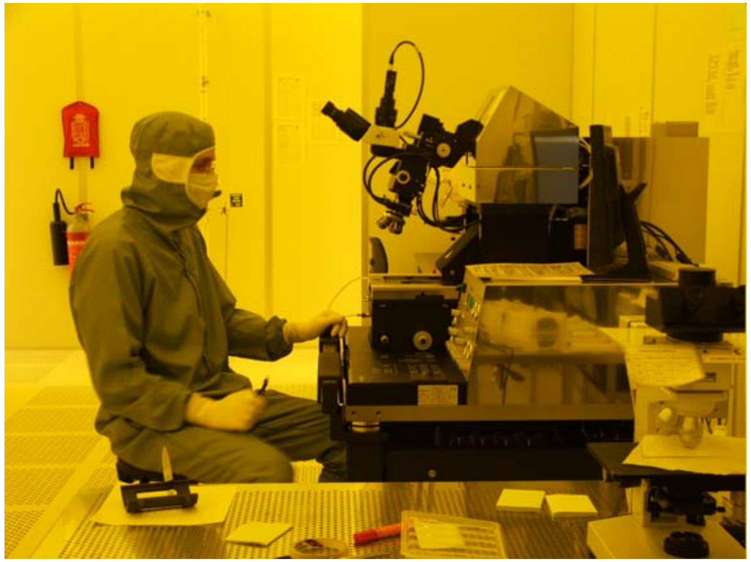


- Measurements down to 50K

MCz-Si detectors

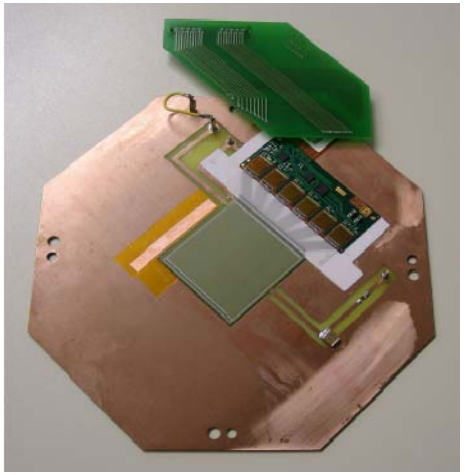


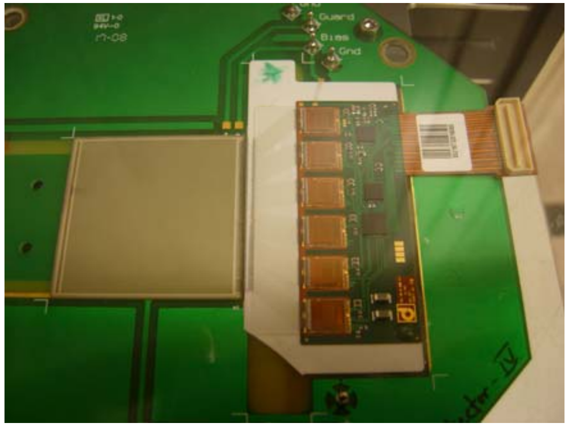
- Detector processing was done at the clean room of Helsinki University of Technology (TKK) Micro and Nanofabrication Centre (MINFAB)
  - Material: n-type Magnetic Czochralski (Okmetic Ltd., Finland) wafers
  - Large detectors:
    - 4.1×4.1 cm^2 area
    - 50 µm pitch
    - strip width 10 µm, strip length 3.9 cm
    - 768 strips per detector (=6*128)
  - Pad detectors:
    - 5 x 5 mm^2 p^+ implanted area
    - 2 x 2 mm^2 opening in the front metallization for TCT measurements.



Irradiations

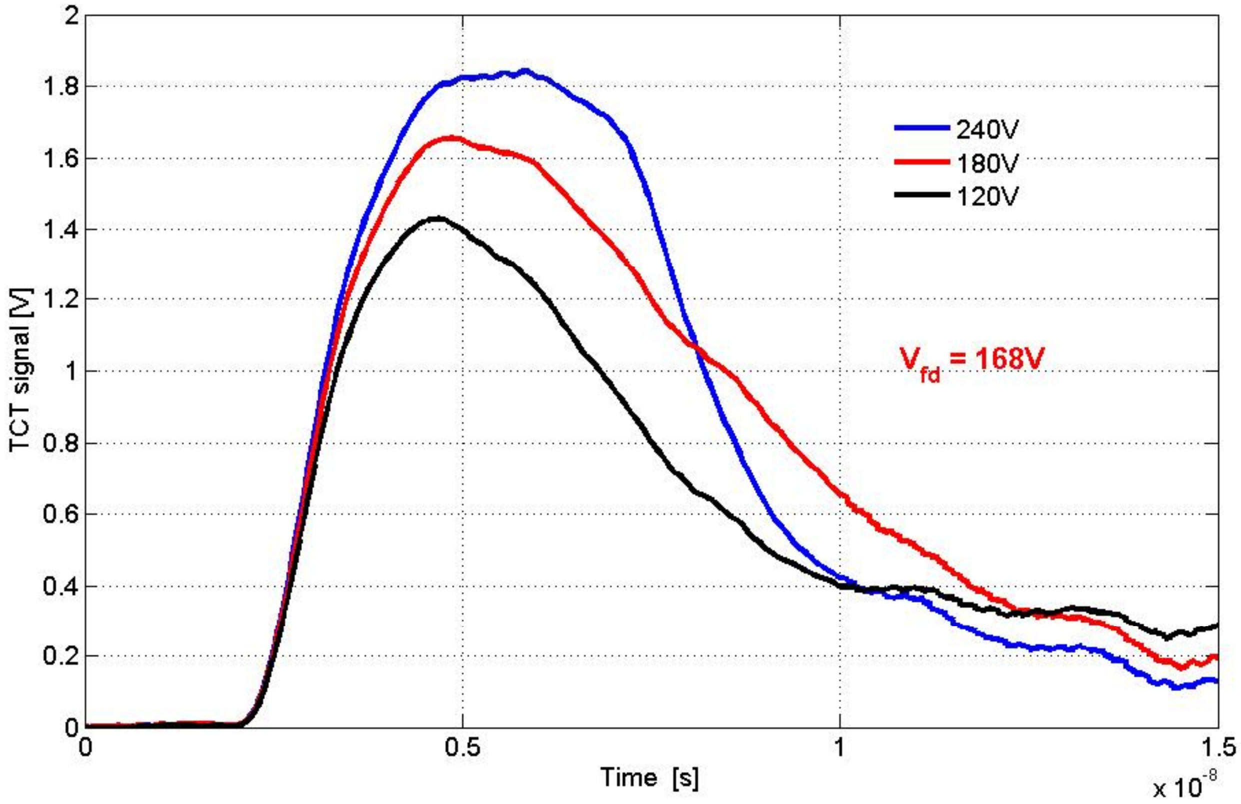
- Two of the large detectors were irradiated to the fluences of 1×10^{14} 1 MeV n_{eq}/cm^2, and 5×10^{14} 1 MeV n_{eq}/cm^2 with 26 MeV protons (Karlsruhe)
- One was left as s non-irradiated reference
- The pad detectors were irradiated with 24 GeV protons (CERN PS) to several different neutron equivalent fluences.
- The devices were not annealed prior to their characterization with the beam telescope or the TCT setup.





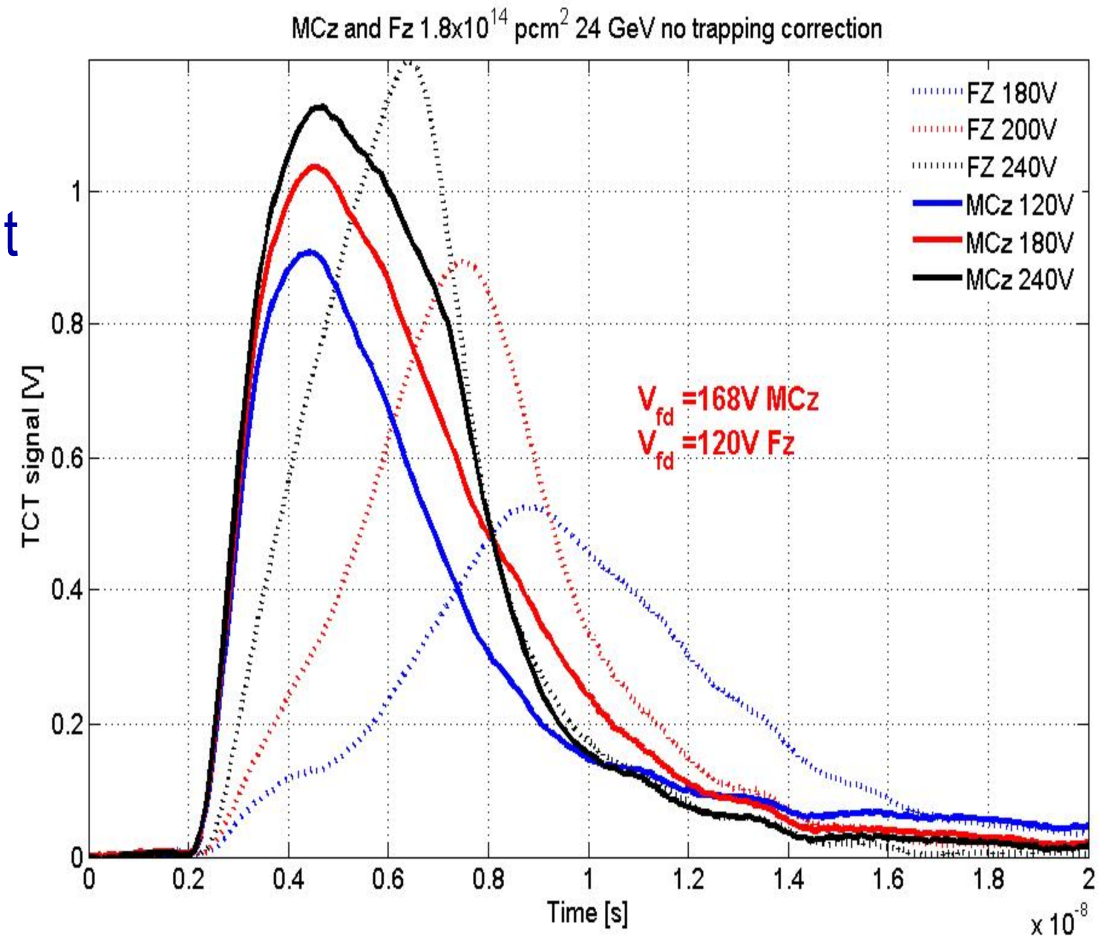
TCT results on diodes

- MCz-Si 1×10^{14} 1 MeV n_{eq}/cm^2
- Decreasing transient → no SCSI
- Red laser, front illumination



TCT results on diodes II

- MCz-Si and Fz-Si 1×10^{14} 1 MeV n_{eq}/cm^2
- MCz-Si decreasing transient → no SCSI
- Fz-Si clearly increasing transient → SCSI has occured
- Trapping correction not needed at this fluence



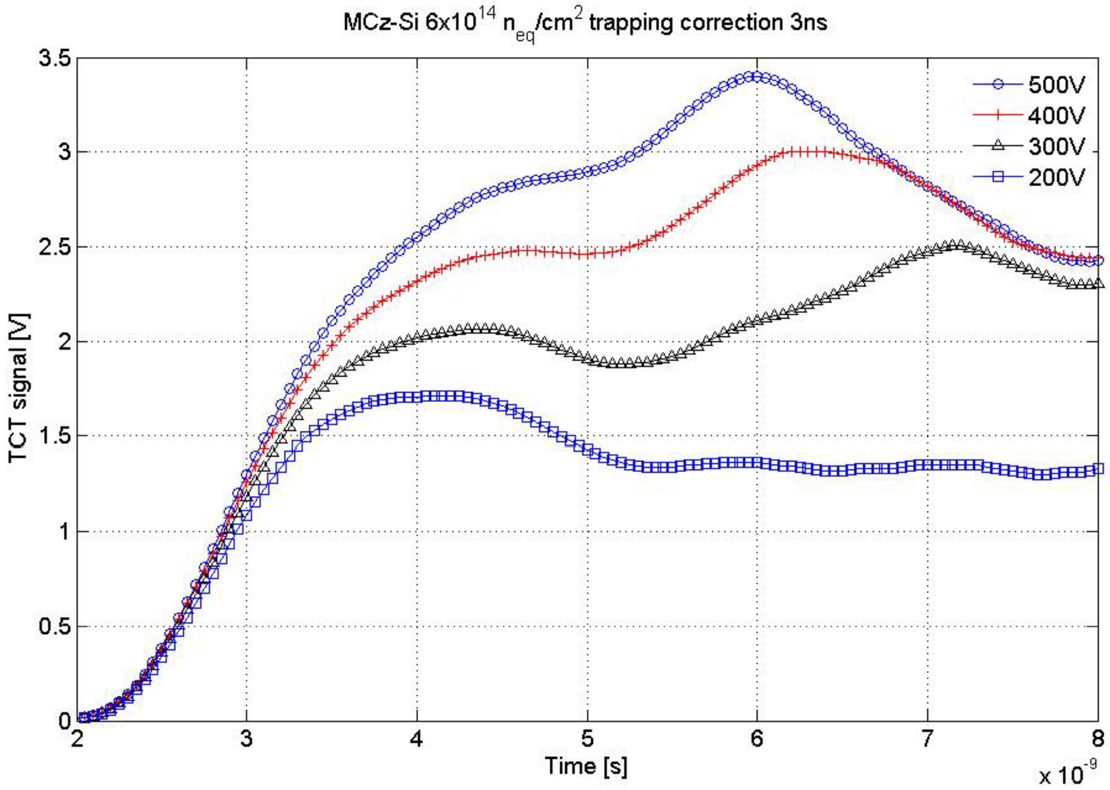
TCT results on diodes III

- MCz-Si 6×10^{14} 1 MeV n_{eq}/cm^2

  - Clearly increasing transient → higher electric field closer to the back contact = SCSI has occured

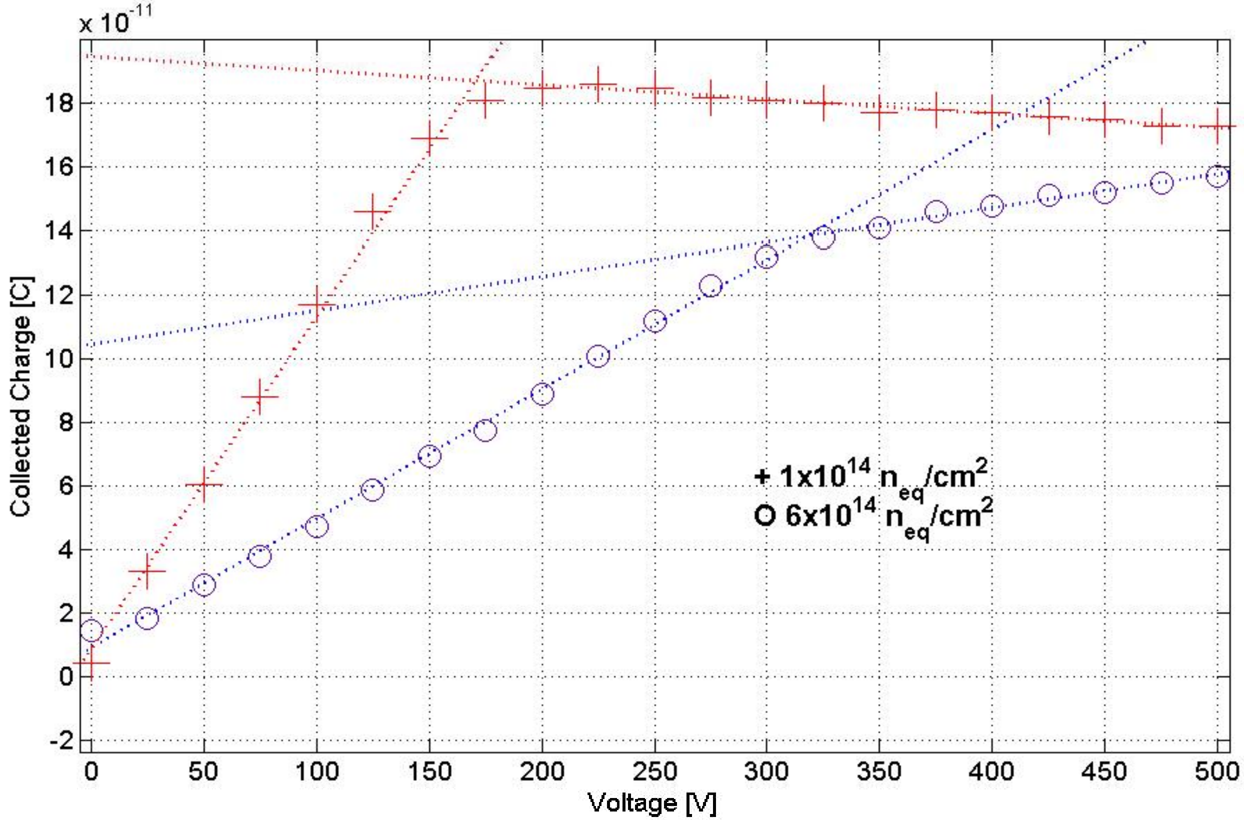
- Trapping correction 3ns i.e., measured signal multiplied

$e^{time/3ns}$

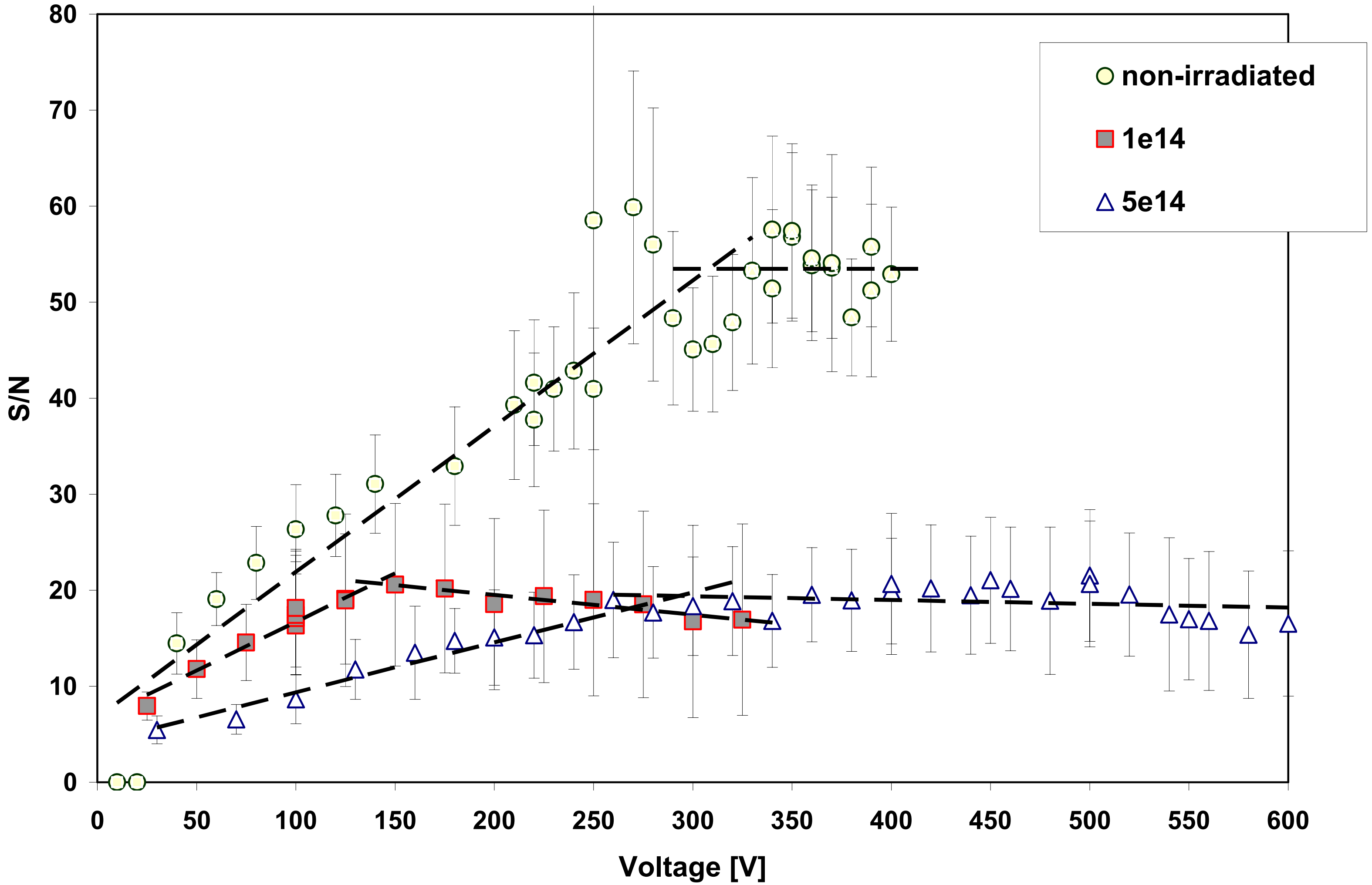


MCz Full Depletion Voltage (V_{fd})

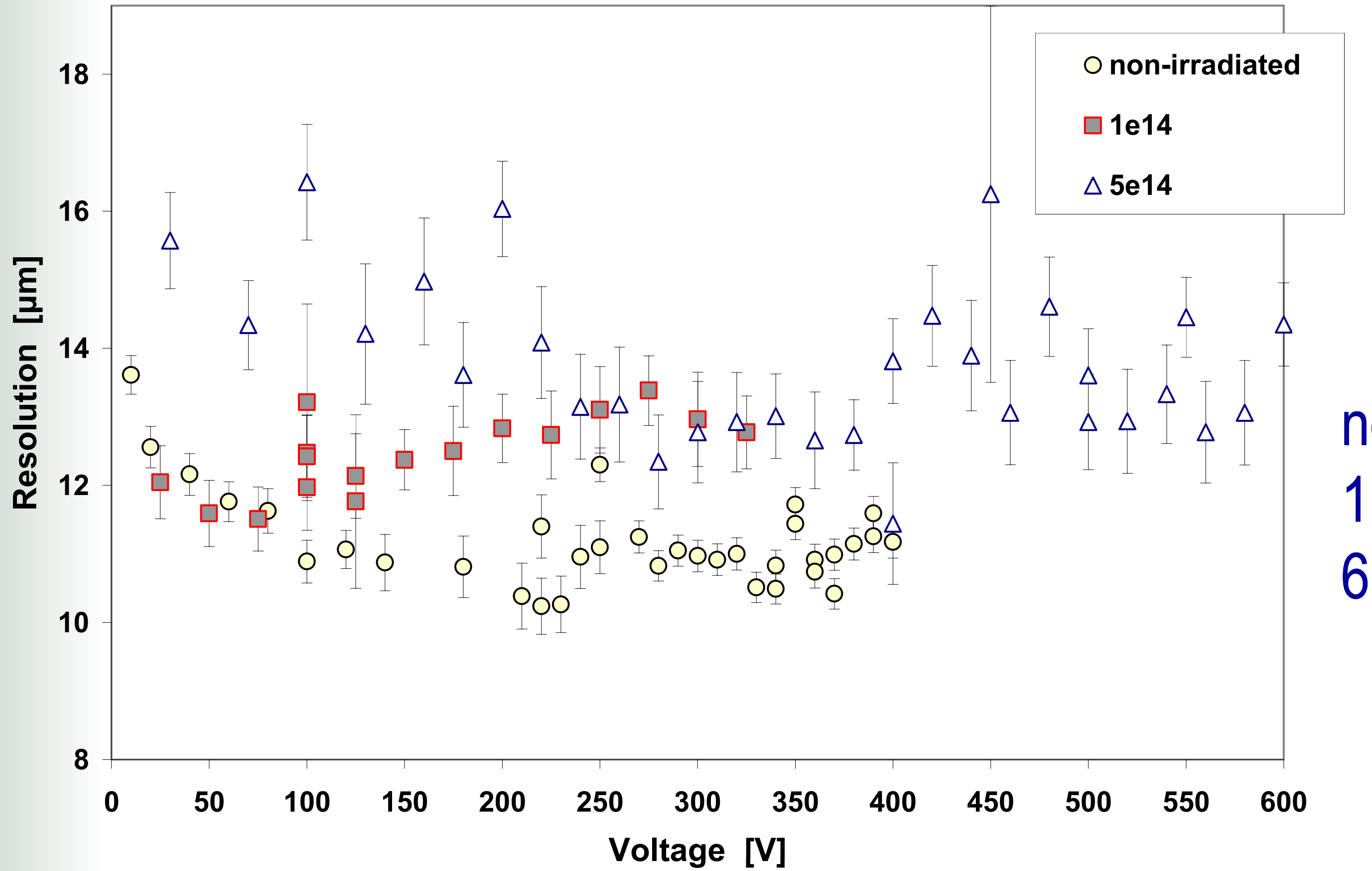
Measurements done with IR laser



Test beam results - S/N



Test Beam results - resolution



non-irrad ≈ 11 µm

1×10^{14} ≈ 12 µm

6×10^{14} ≈ 13 µm

Conclusions

- TCT measurements with trapping correction indicate that in MCz-Si the dominating electric field has shifted to the back side of the sensor after 6×10^{14} 1 MeV n_{eq}/cm^2 fluence.
- Beam test data from summer 2007 shows that the cluster resolution of MCz-Si detectors is only slightly affected by the irradiation and SCSI.
- This most probably due to the Double Junction (DJ) effect, i.e., high electric field existing on both p+ and n+ sides of the detector
- Measured diode full depletion voltages obtained by the CCE measurement with an infrared laser are consistent with the data from the beam tests.
- Beam tests on MCz-Si sensors were continued in summer 2008 in order to study the properties of MCz-Si detectors irradiated up to the fluences of 3×10^{15} 1 MeV n_{eq}/cm^2
- Data analysis is currently going on and results will be reported at 08 RESSMD conference in Florence and at RD50 Workshop, CERN.