Comparison of charge collection efficiency of segmented silicon detectors made with FZ and MCZ p-type silicon substrates

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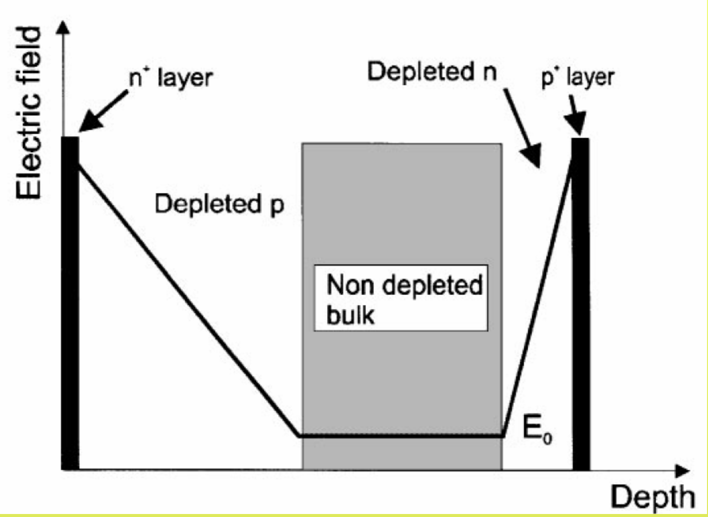
OUTLINE:

- Motivation for using p-type silicon substrate
- Results after heavy (SLHC levels) irradiation
- Motivations for Magnetic Czochralski) MCz substrate instead of FZ
- Comparison of charge collection efficiency after 5x101^{4} n cm^{-2}
- Conclusions

Why p-type substrate for tracking in high radiation environments?

Schematic changes
of Electric field
after irradiation



Effect of trapping on
the Charge Collection
Efficiency (CCE)

$$Q_{tc} \cong Q_0 \exp(-t_c/\tau_{tr}),\ 1/\tau_{tr} = \beta\Phi.$$

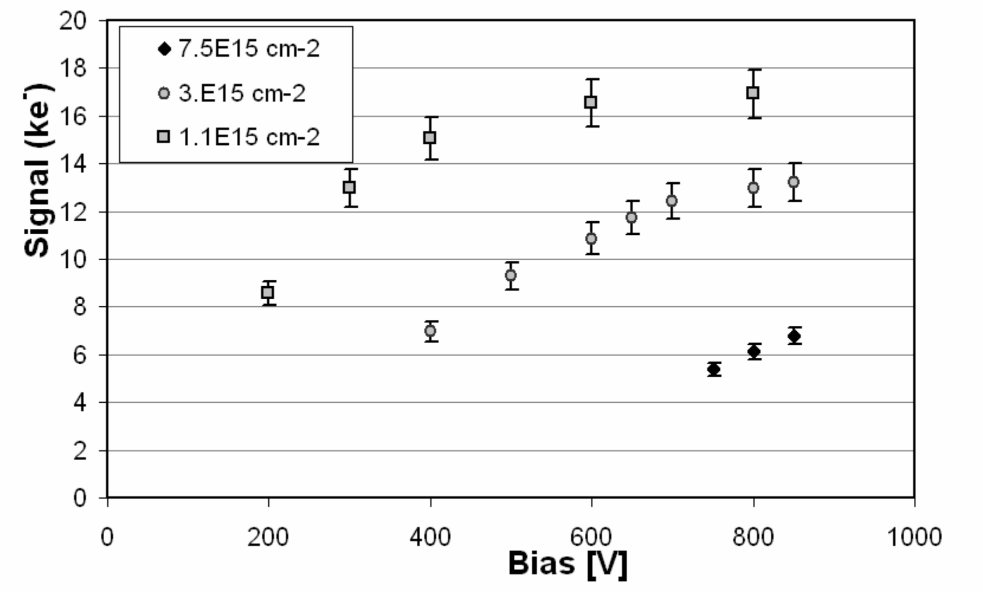
Collecting electrons provide a sensitive advantage with respect to holes due to a much shorter t_c. P-type detectors are the most natural solution for *e* collection on the segmented side.

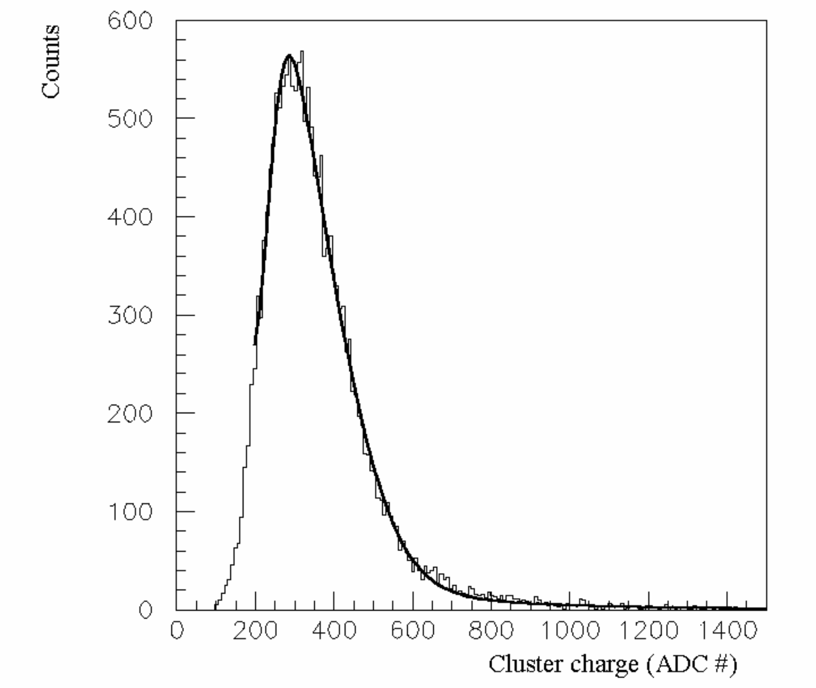
Expected changes in the CCE: high resistivity FZ

Measurements performed with miniature detectors, 1x1 cm^2, ~80 µm strip pitch. Charge collection measurements made with 40MHz analogue electronics, signal induced by fast electrons from ^{106}Ru or ^{90}Sr sources (mip equivalent charge deposition). Calibration performed with non-irradiated 300µm thick Si detectors.

Expected changes in the CCE: high resistivity FZ

Protons: CNM miniature detectors
(~10kΩ, initial V_{FD} ~ 60V)

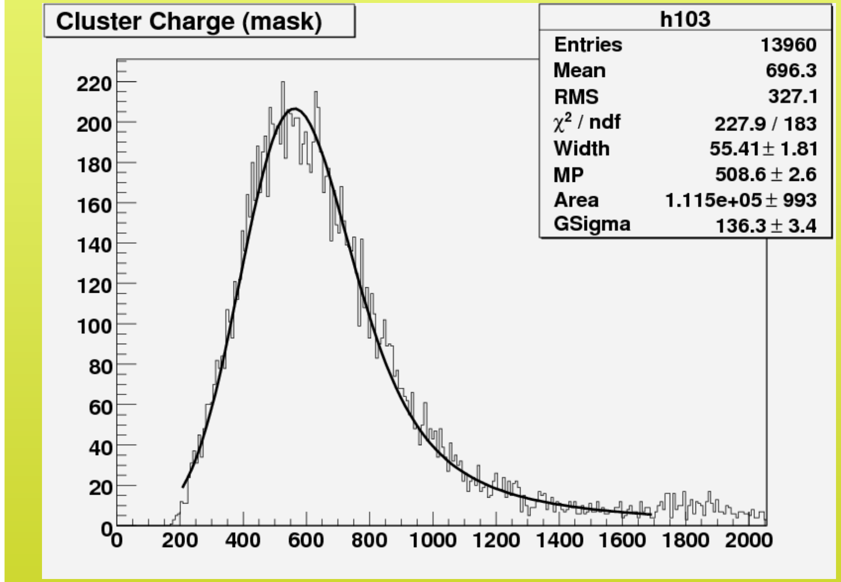


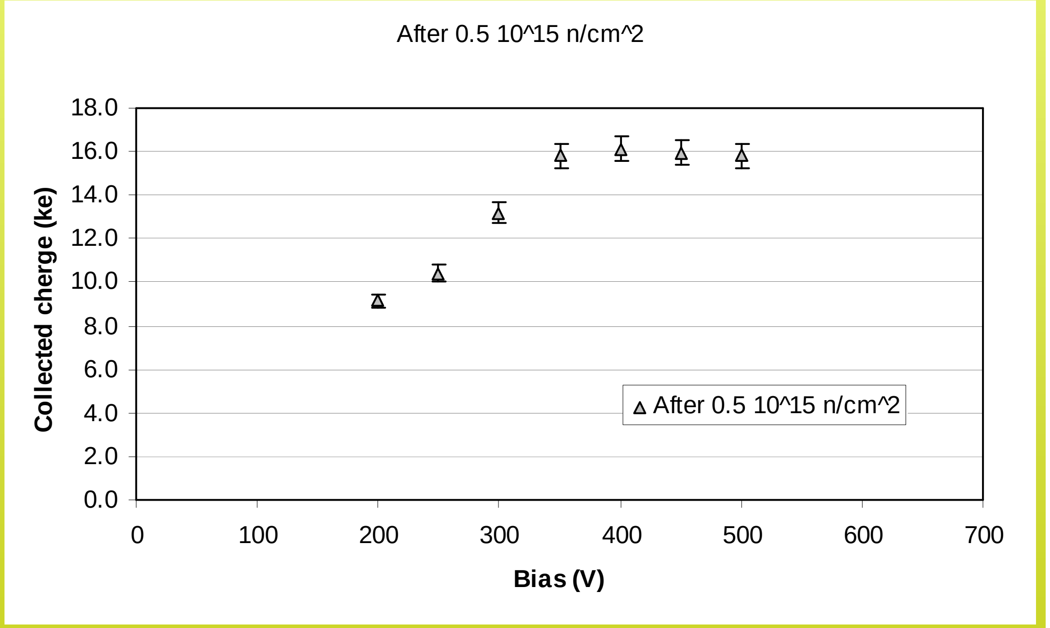


Expected changes in the CCE: high resistivity FZ

Neutrons: Micron miniature detectors (~10kΩ, initial V_{FD} ~ 60V)

After $0.5 \cdot 10^{15}$ n cm^{-2}

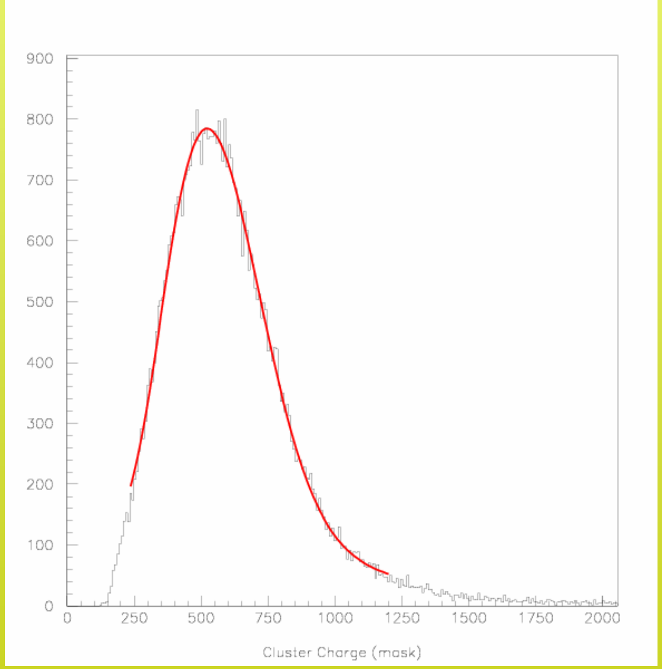


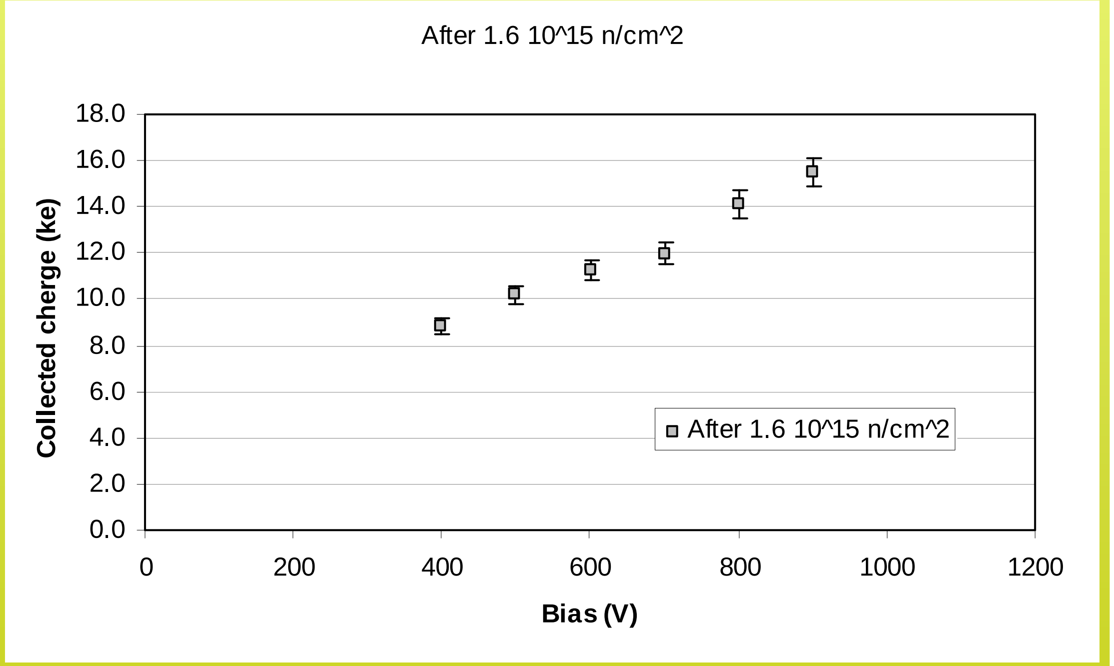


Expected changes in the CCE: high resistivity FZ

Neutrons: Micron miniature detectors (~10kΩ, initial V_{FD} ~ 60V)

After $1.6\cdot10^{15}$ n cm^{-2}

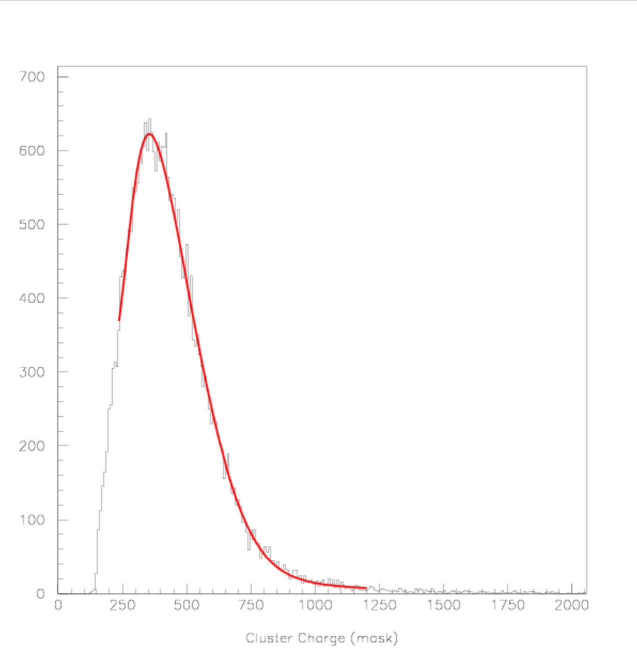


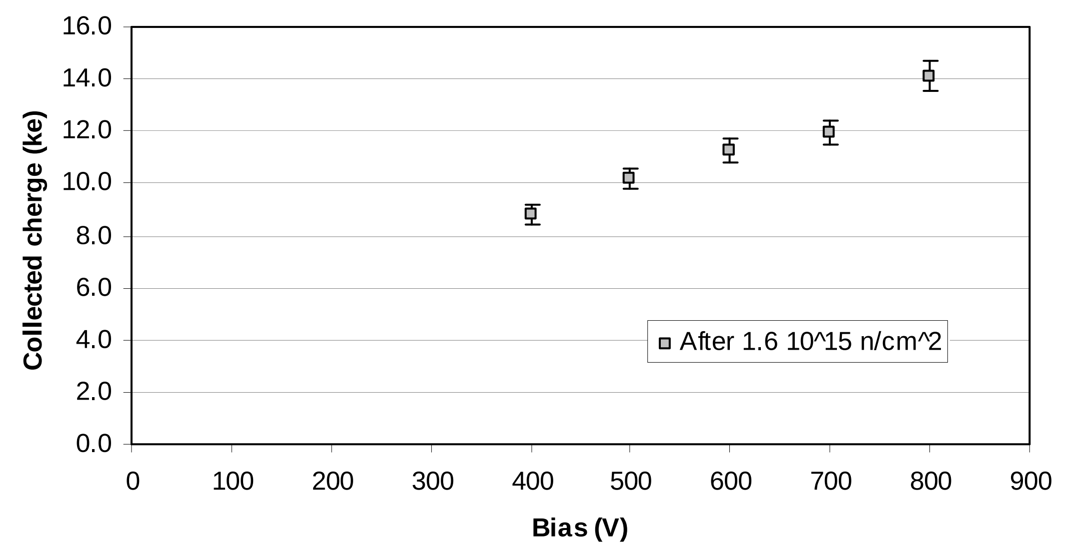


Expected changes in the CCE: high resistivity FZ

After 3 ·10^{15} n cm^{-2}

Neutrons: Micron miniature detectors (~10kΩ, initial V_{FD} ~ 60V)

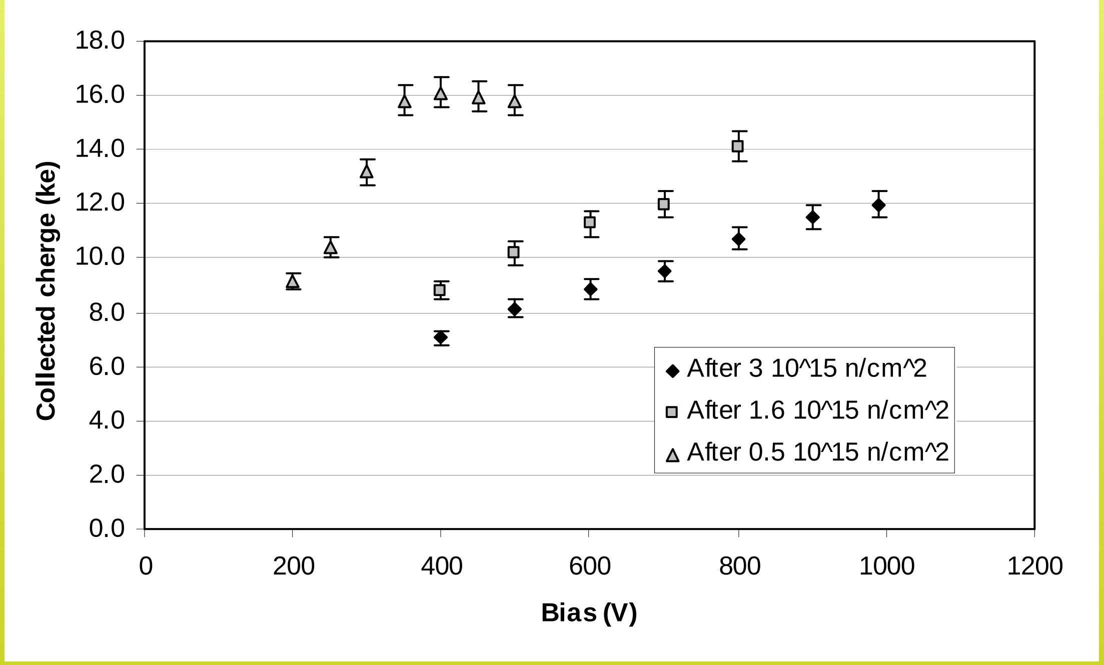




Expected changes in the CCE: high resistivity FZ

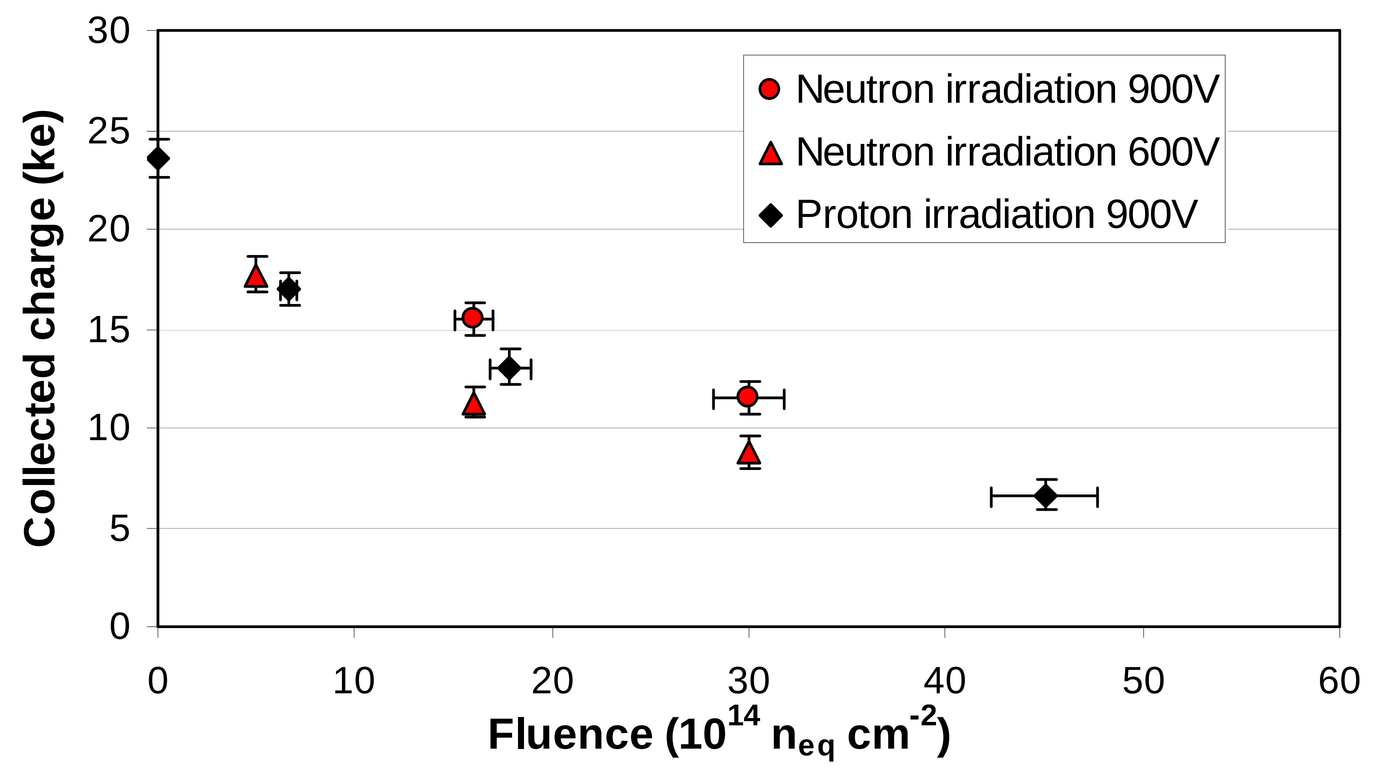
Neutrons: Micron miniature detectors

Summary before annealing



Expected changes in the CCE: high resistivity FZ

CCE as a function of fluence:



Is MCz substrate giving advantages with respect to FZ?

Fz p-type substrate was proven extremely rad-hard. Recent developments in Si crystal manufacturing technology has provided Cz wafers with higher resistivity (MCz). MCz wafers are cheaper than FZ and could be available in bigger sizes.

C-V measurements performed with n-type MCz have hinted a possible reduced degradation of this type of substrate compared to FZ. Is the effect due to the different initial resistivity? Moreover, is the trend measured with the C-V method reflected in the CCE measurements? Is the p-type substrate following the same trend?

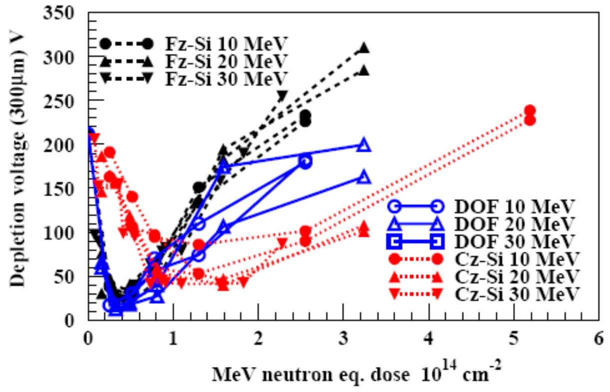


Fig. 1. Evolution of the detector depletion voltage as a function of the irradiation dose.

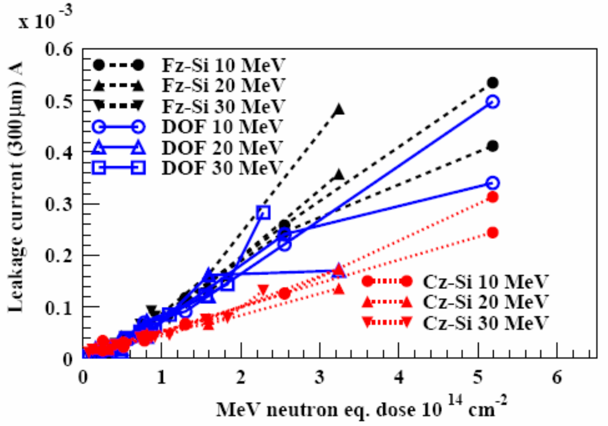


Fig. 2. Leakage current of oxygenated Fz-Si, Fz-Si and Cz-Si as a function of fluence.

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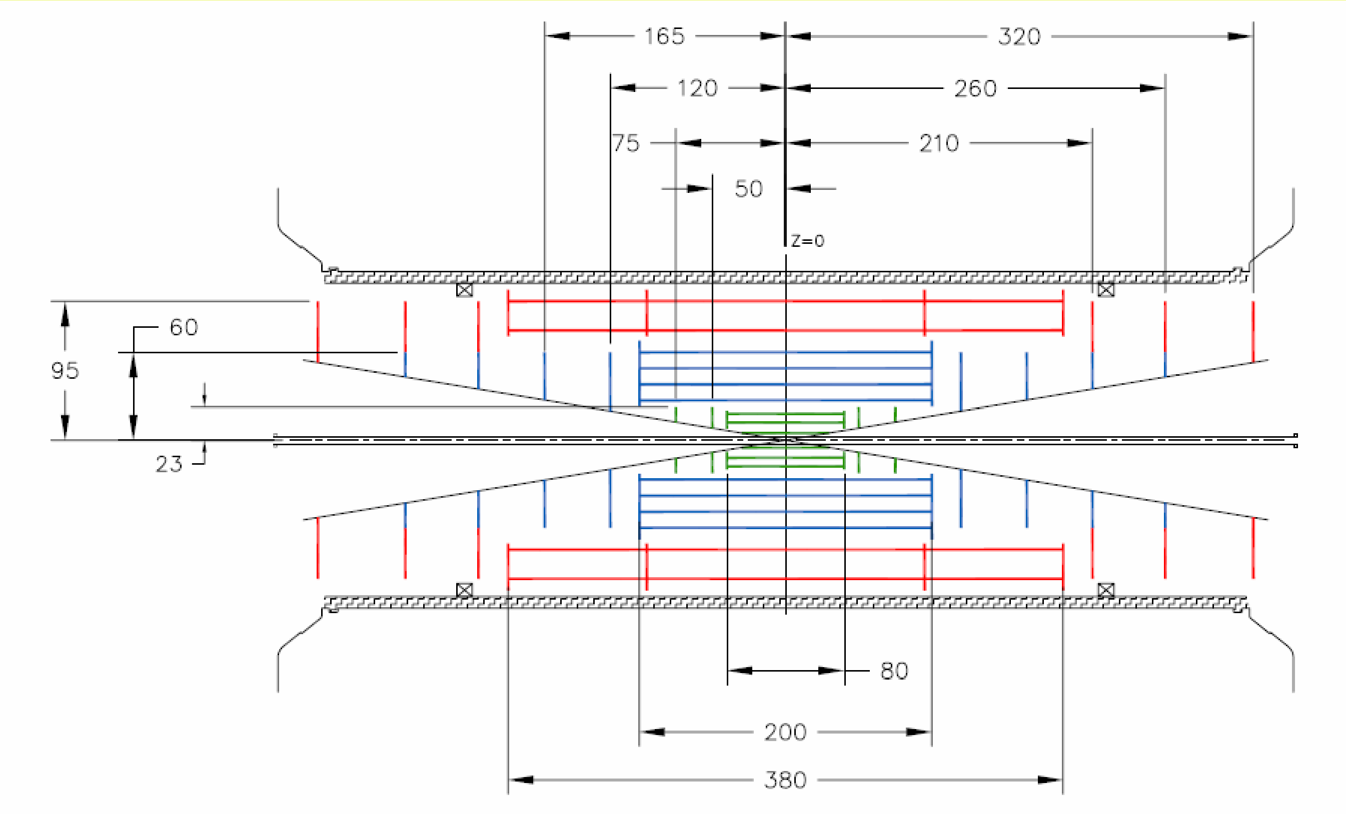
Experimental method

To answer the previous questions concerning the FZ/MCz comparison, a systematic study involving a significant number of detectors should be carried out. Our interest was though concentrated on the measure of the CCE performances by FZ and MCz detectors after irradiation.

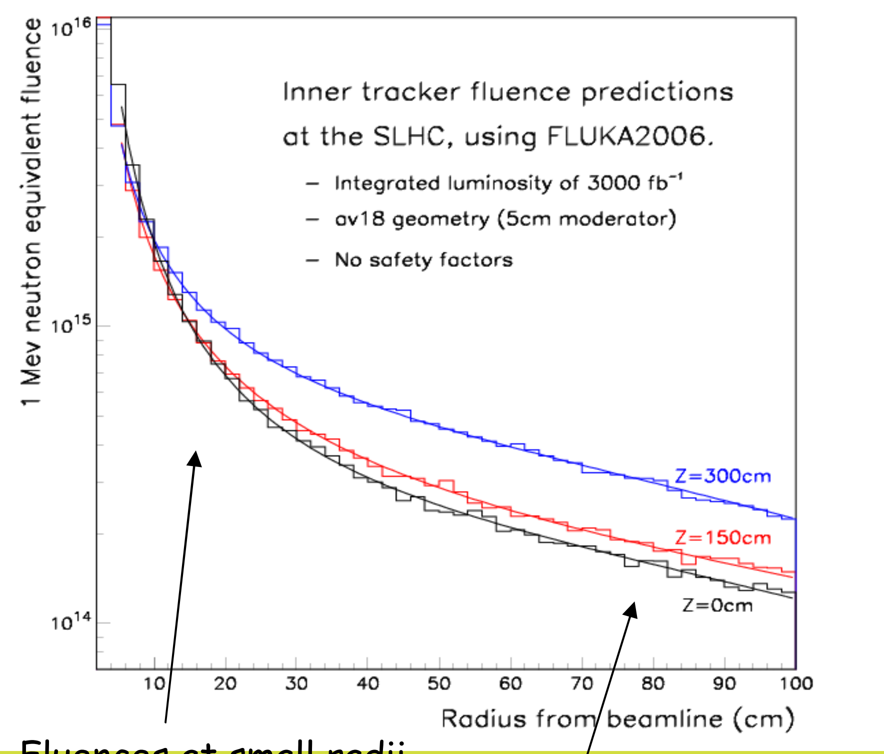
In particular, we wanted to test the devices after the dose expected in the innermost microstrip layer of the upgraded ATLAS tracker detector. The radiation damage in SLHC will be due to particles emerging from the interactions and to backscattered neutrons. For the anticipated layout of the upgraded ATLAS detector, the radius at which the two contributions are equal is about 25 cm. For further radii the neutron contribution becomes dominating (the neutron contribution is about 53% at 27cm and 87% at 100cm radii). The target dose is 5×10^{14} n_{eq} cm^{-2}, corresponding to the final simulated dose after 3000 fb^{-1} integrated luminosity.

ATLAS tracker strawman layout



***Layout options*, A. Seiden, ATLAS Tracker Upgrade Workshop, Liverpool 06-08 December 2006.**

Parameterisation of 1MeV-n_{eq} fluences



Fluences at small radii dominated by particles from interaction point.

Fluences at larger radii dominated by neutron-albedo, greatest near endcaps.

***Radiation Simulations and Irradiation Facilities*, I. Dawson, ATLAS Tracker Upgrade Workshop, Liverpool 06-08 December 2006.**

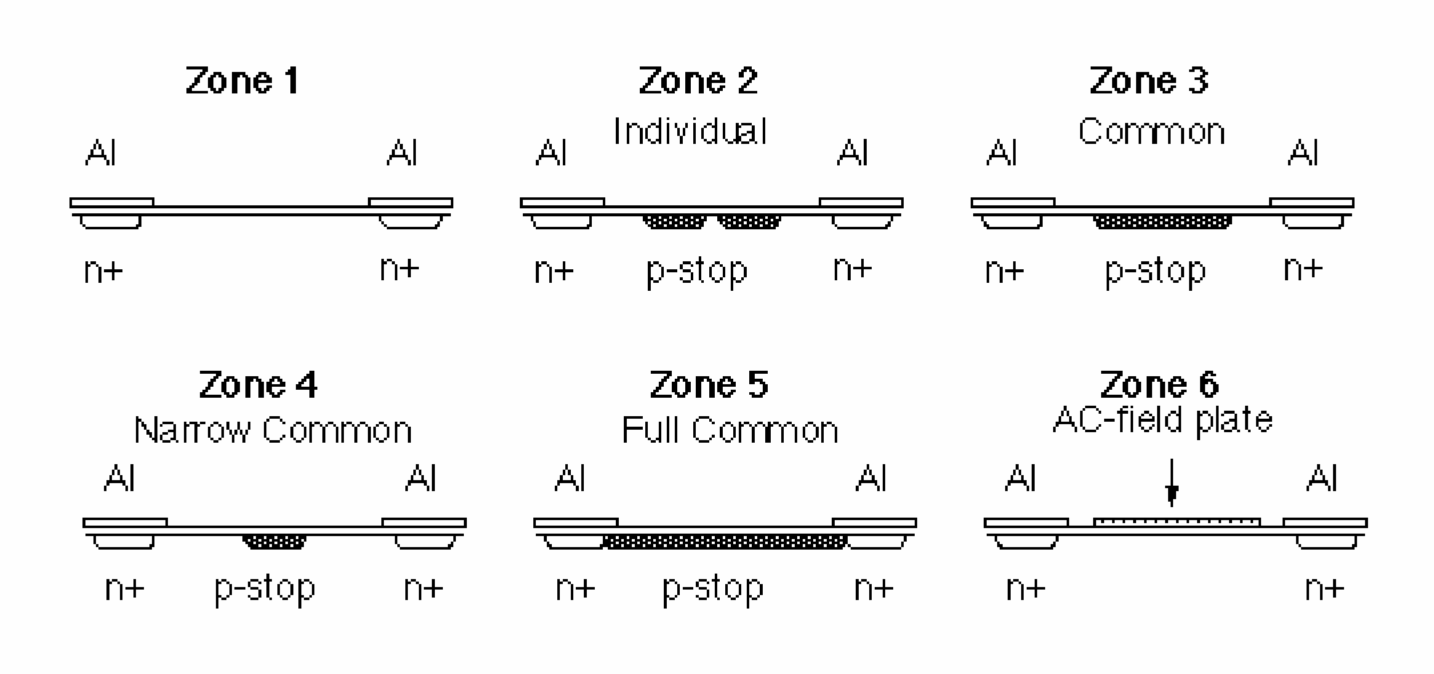
$$\Phi(r) = \frac{a_1}{r^2} + \frac{a_2}{r} + a_3 + a_4 \cdot r$$

Z(cm)	a_1	a_2	a_3	a_4
0	1.4×10^{17}	3.7×10^{15}	1.7×10^{14}	-1.0×10^{12}
150	7.0×10^{16}	9.5×10^{15}	9.7×10^{13}	-5.7×10^{11}
300	4.9×10^{16}	1.2×10^{16}	3.0×10^{14}	-2.0×10^{12}

Directly test detector CCE performances after $5\text{x}10^{14}$ n_{eq} cm^{-2}.

Sensor’s description

Miniature detectors, 1x1 cm^2, ~75 µm strip pitch produced by HPK with different strip isolation methods on FZ and MCz p-type silicon substrates.

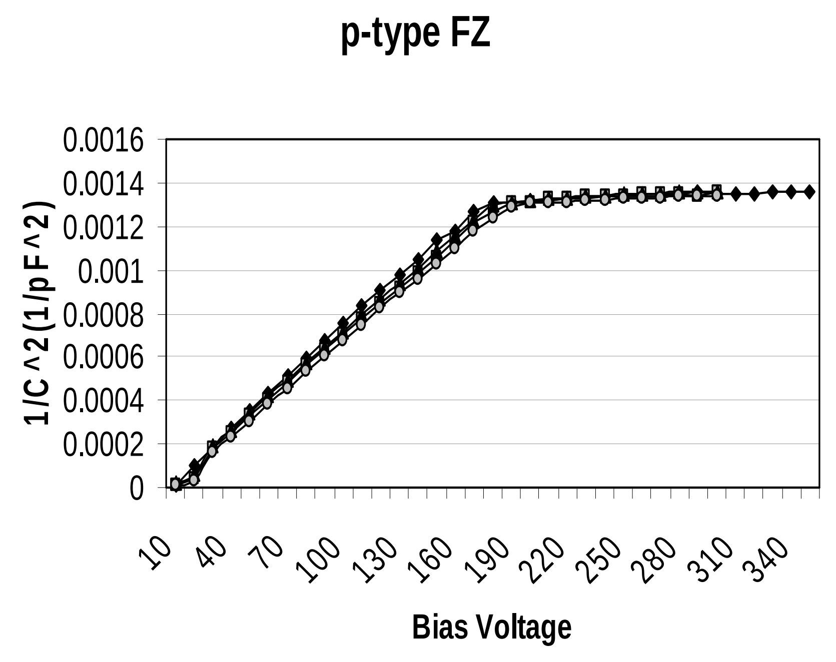


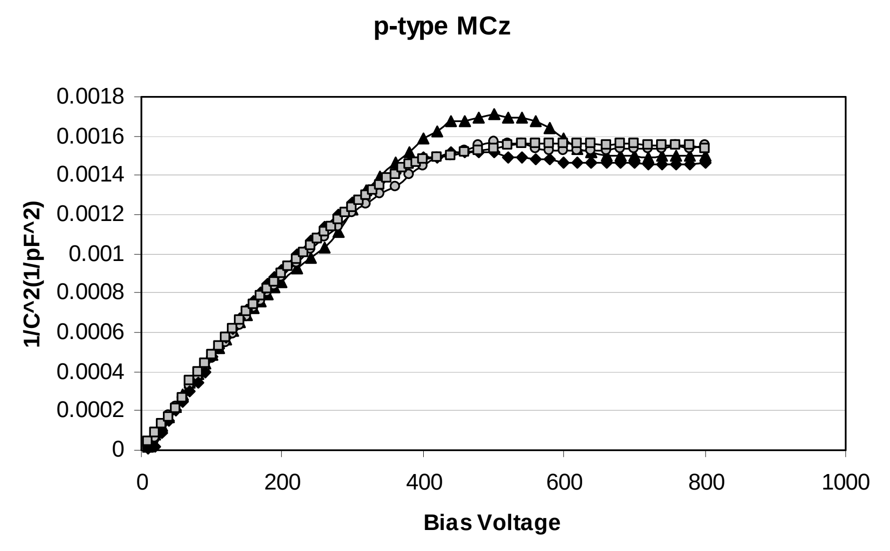
Lower resistivity FZ and MCz detectors

CV measurements show lower initial resistivity.

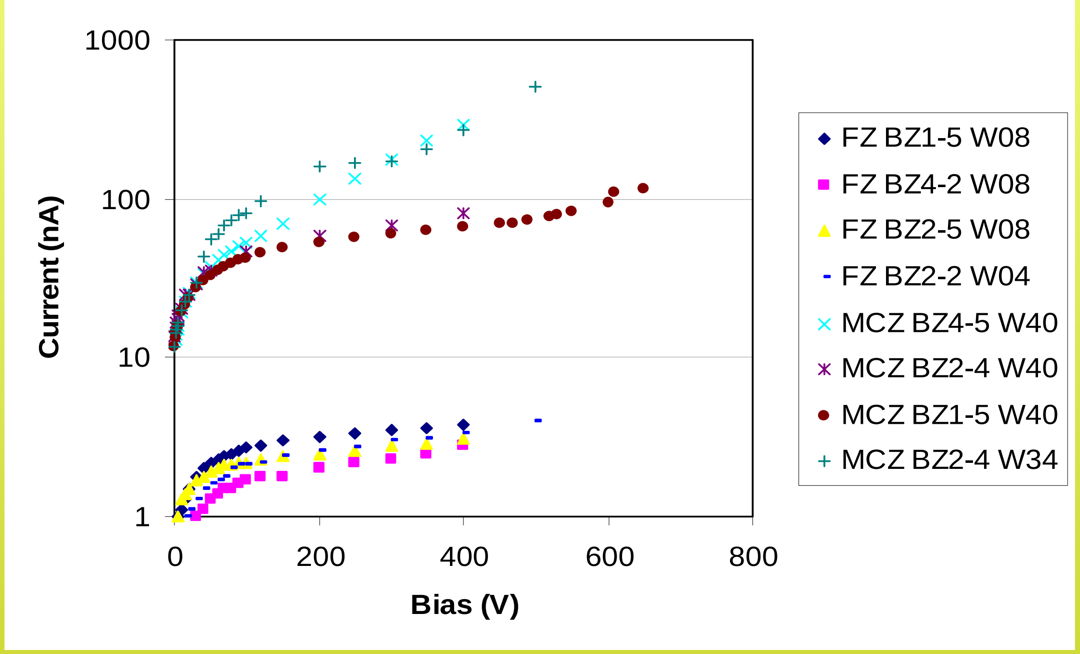
Resistivity of FZ p-type wafers ~ 5kΩ

Resistivity of MCz p-type wafers ~ 2kΩ





I-V/C-V measurements



High grade FZ detectors show lower current than MCz detectors. This reflect the better grade possibly achievable with FZ. Note though that low currents are not particularly relevant for devices that will undergo heavy hadron irradiation.

Comparison:

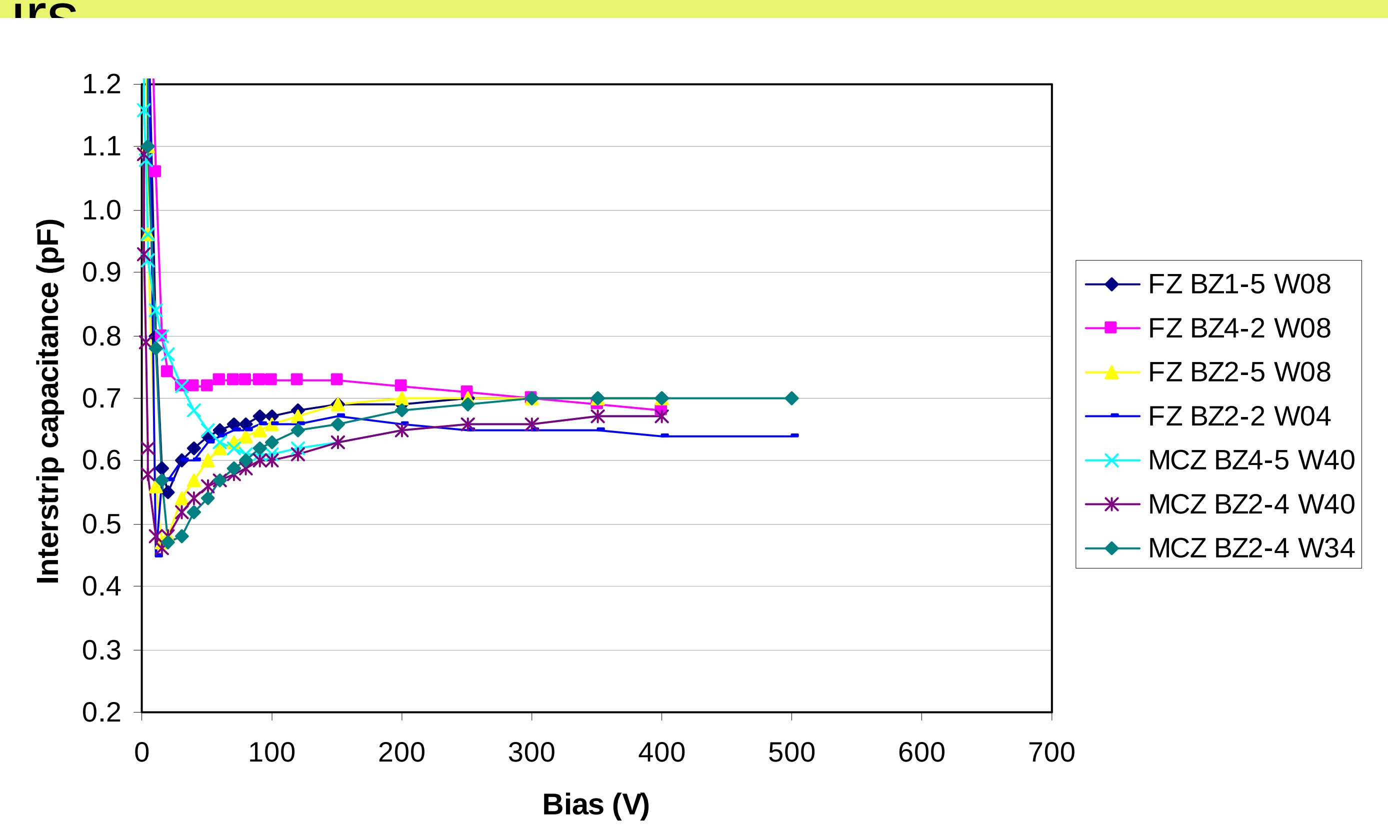
FZ: W08-BZ1-5(570), W04-BZ2-2(510),W08-BZ2-5(450), W08-BZ4-2(470)
MCZ: W40-BZ1-5(680),W34-BZ2-4(320) ,W40-BZ2-4(450), W40-BZ4-5(570)

Interstrip capacitance measurements

Compared interstrip measurements with 2 and 4 nearest neighbours, found difference between 3% to 10%. Report here only measurements with 2 nearest neighbours

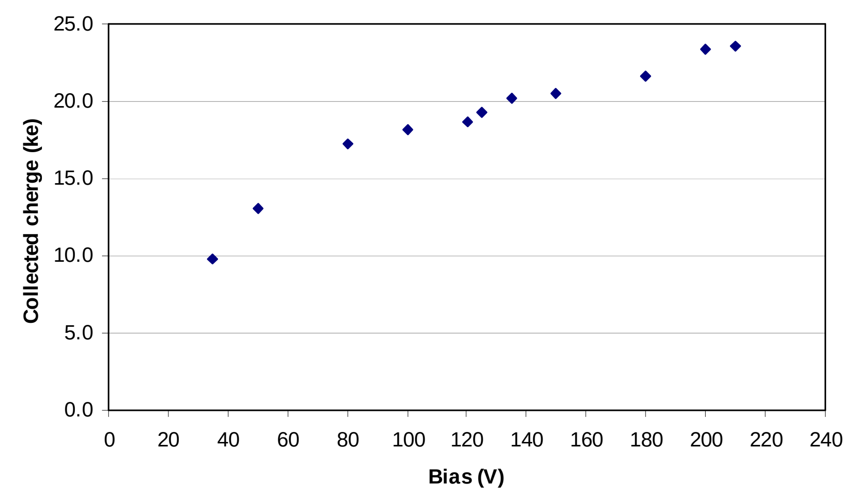
Reference

~ 0.7 pF/cm

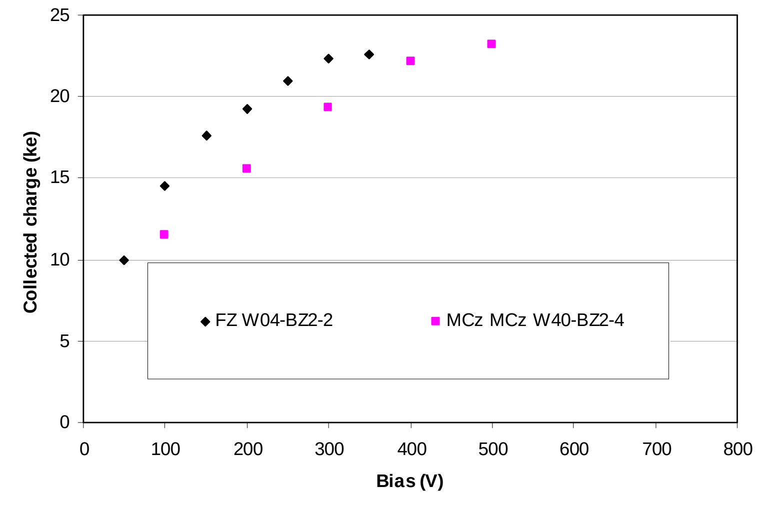


HPK and Micron detectors before irradiation

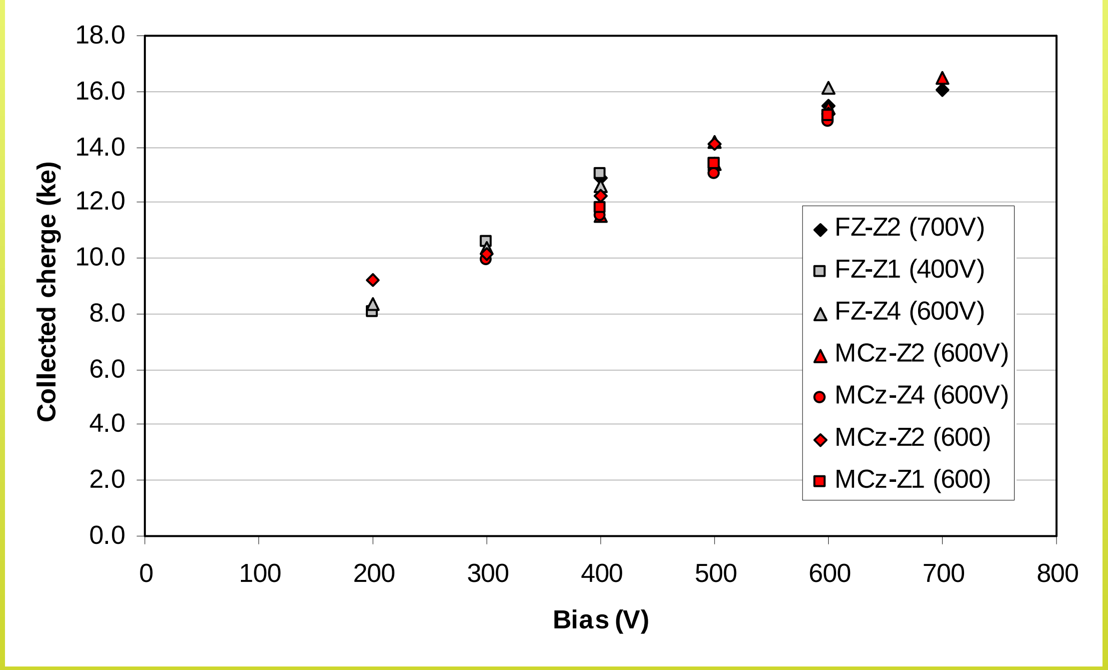
Micron (Higher resistivity, V_{FD} 100V)



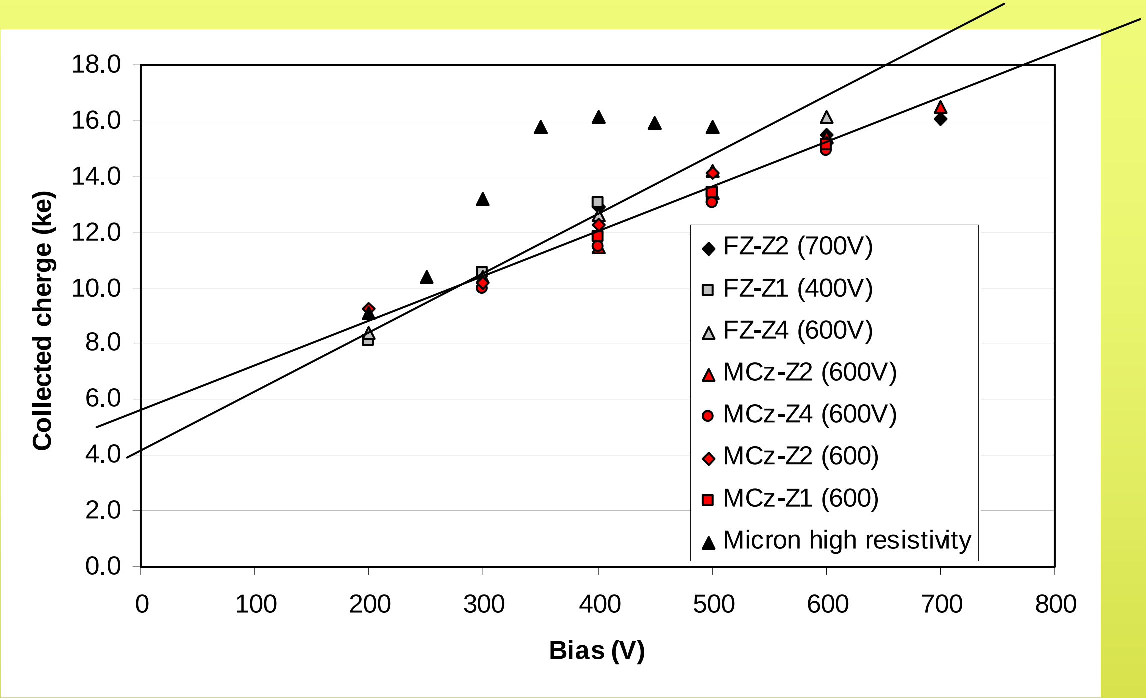
HPK: FZ V_{FD}~200V, MCz~500V



CCE after $5\times10^{14}\ n_{eq}\ cm^{-2}$



CCE after $5\text{x}10^{14}$ n_{eq} cm^{-2}



Further studies to clarify effect of resistivity, but it appears that with neutron irradiations low V_{FD} (higher initial resistivity) is much preferable.

Conclusions

The CCE properties of finely segmented MCz p-type detectors have been compared to FZ substrates after the anticipated dose for the inner μ-strip layer of the upgraded ATLAS tracker. All the detectors (MCz, FZ 10kΩ and FZ ~5kΩ) show the same maximum collected charge. High resistivity detectors reach the CCE *plateau* at lower voltage, before and after neutron irradiation. Although more systematic studies are required, these results suggest no inherent differences in the CCE performances between FZ and MCz substrates. The influence of the initial resistivity appears to be more important in order to keep significant advantages for CCE at low voltages after neutron irradiation.