New CCE results with microstrip detectors made on various substrates

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OUTLINE:

The charge collection efficiency of µ-strip sensors made with the RD50 mask set with various silicon substrates have been compared to different high doses of neutron and protons, well in the range of the anticipated fluences in SLHC. Detectors: 1x1 cm^{-2}, ~300µm thick, 80µm pitch, produced by Micron Semiconductor on Liverpool design. Readout: SCT128A, Source: ^{90}Sr, Temperature: ~-20/25^{o}C.

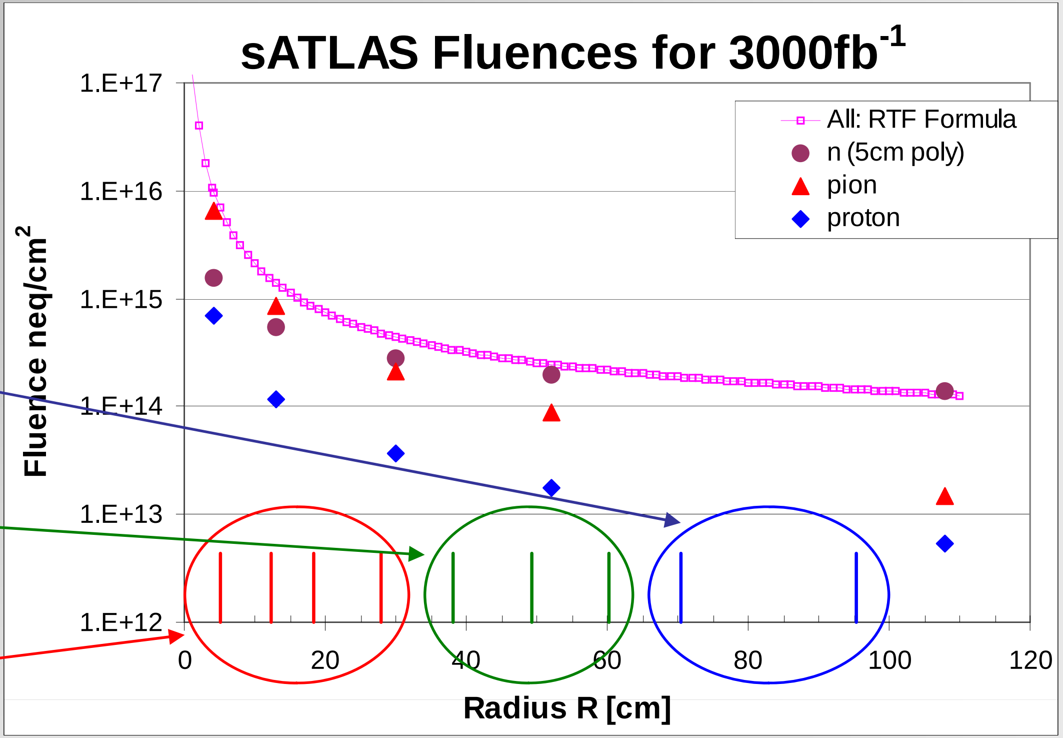
Substrate types and detector geometries:

- FZ n-in-p (10 and 30 kΩ cm^{-1}) (V_{FD} ~ 40/100V)
- FZ p-in-n (V_{FD} ~ 70V)
- FZ n-in-n (V_{FD} ~ 70V)
- MCz p-in-n (V_{FD} ~ 170V)
- MCz n-in-n (V_{FD} ~ 170V)
- MCz n-in-p (V_{FD} ~ 500V)

Most of this work has been performed using material and detectors produced within the framework of RD50.

Fluence in Proposed sATLAS Tracker

Strip length and segmentation determined by occupancy< 2%



Long Strips

Short Strips

Pixels

ATLAS Radiation Taskforce http://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/RADIATION/RadiationTF_document.html

Mix of neutrons, protons, pions depending on radius R

Long and short strips damage largely due to neutrons

Pixels damage due to neutrons and pions

Design fluences for sensors (includes 2x safety factor) **:**

Innermost Pixel Layer:	1-1.6*10^{16} n_{eq}/cm^2 = 500 Mrad
Outer Pixel Layers:	3*10^{15} n_{eq}/cm^2 = 150 Mrad
Short strips:	1*10^{15} n_{eq}/cm^2 = 50 Mrad
Long strips:	4*10^{14} n_{eq}/cm^2 =20 Mrad

Need to study response to both neutral (neutrons) and charged (proton) particle irradiations

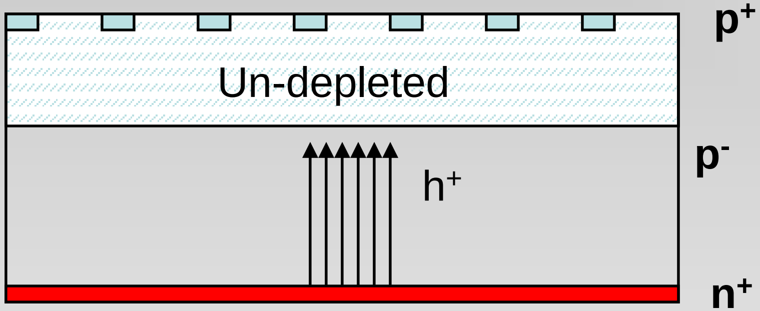
P-strip vs N-strip Readout

Effect of trapping on the Charge Collection Efficiency (CCE)

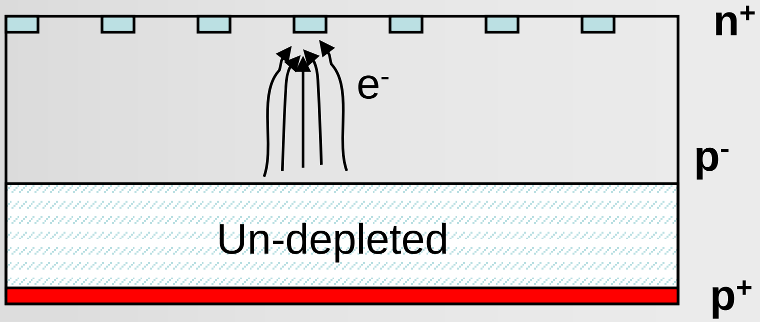
$$Q_{tc} \cong Q_0 \exp(-t_c/\tau_{tr}),\ 1/\tau_{tr} = \beta\Phi.$$

t_C is collection “time”, τ_{tr} is effective trapping time

- **“Standard” p-on-n after type inversion**



- **“New” n-on-p before/after type inversion**

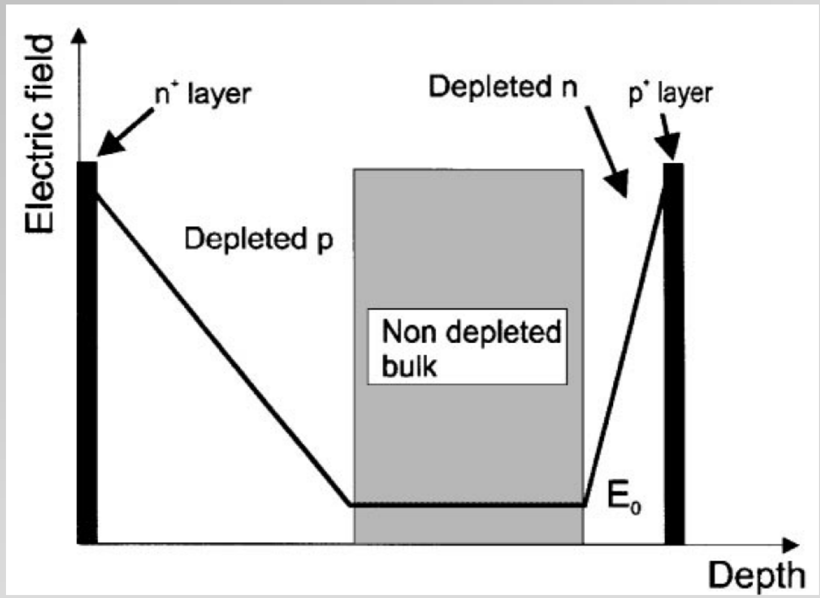


Type inversion turns lightly doped material to “p” type

- Holes collected
- Deposited charge cannot reach electrode
  - Charge spread over many strips
  - Lower signal

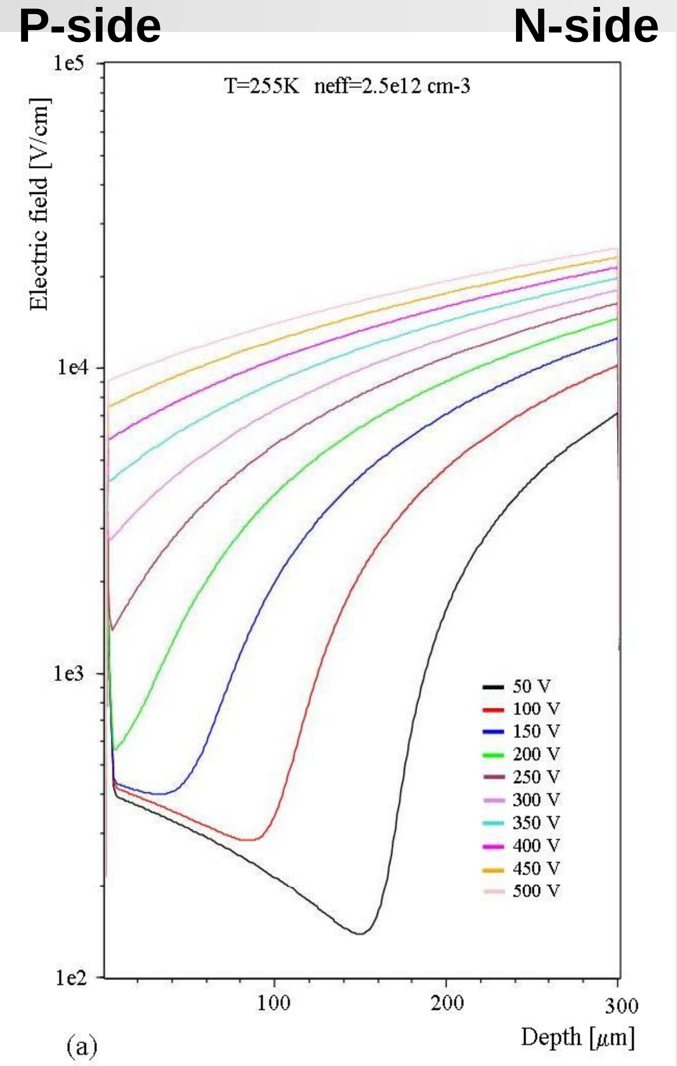
- Electron collected
  - Higher mobility and ~33% smaller trapping constant
- Deposited charge can reach electrode

P-strip vs N-strip Readout



In reality, after irradiation electric fields show a double junction structure with a non-depleted bulk in the middle of the sensor below the full depletion voltage

See G. Casse, et. al., NIMA **426** (1999) 140-146 and G. Kramberger, et. al., NIMA **579** (2007) 762-765 for details



ISE-TCAD simulation after 6. 10^{14} p cm^{-2}

Irradiation

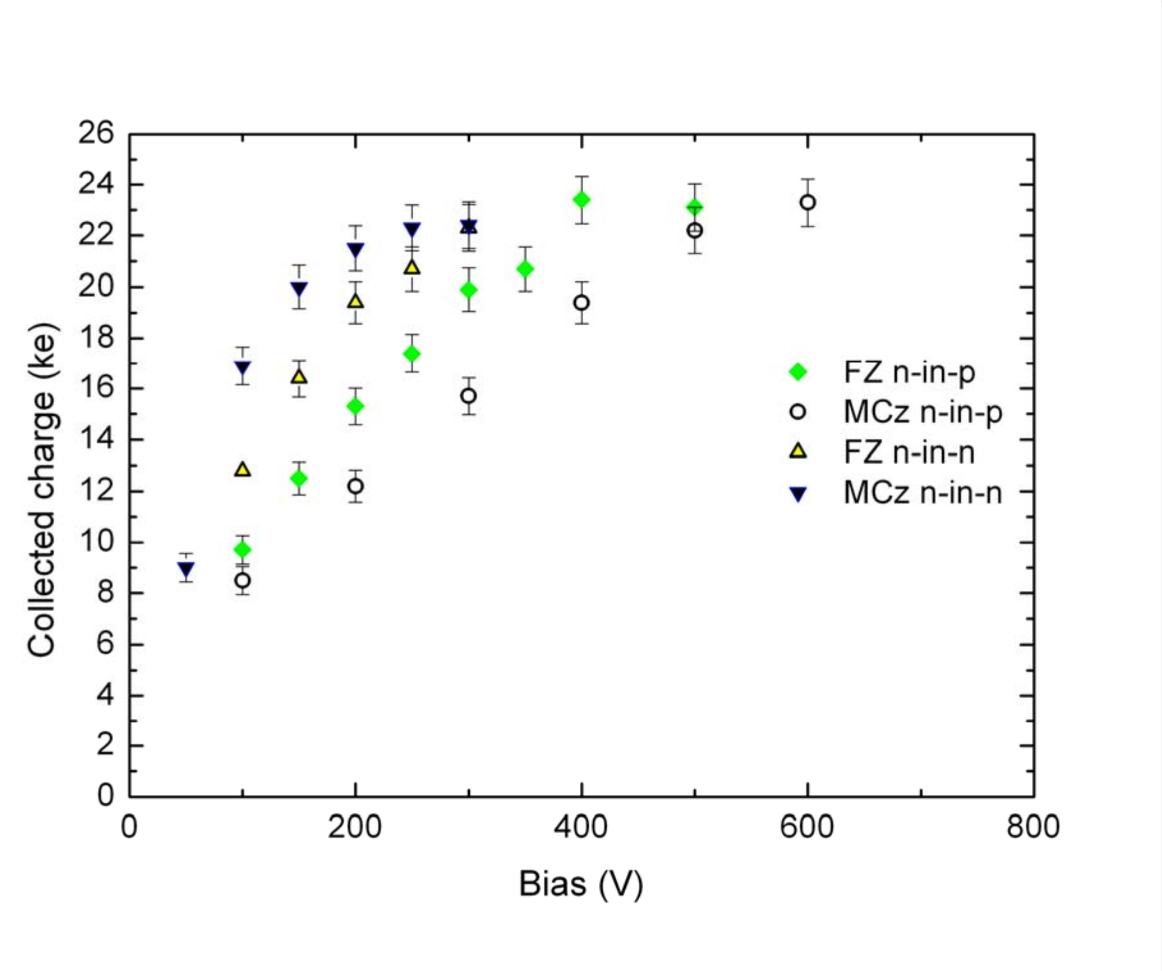
Many thanks to our RD50 collaborators:

Neutron irradiations: JSI of Ljubljana (V. Cindro et al.).

24GeV/c protons, CERN/PS: M. Glaser et al.

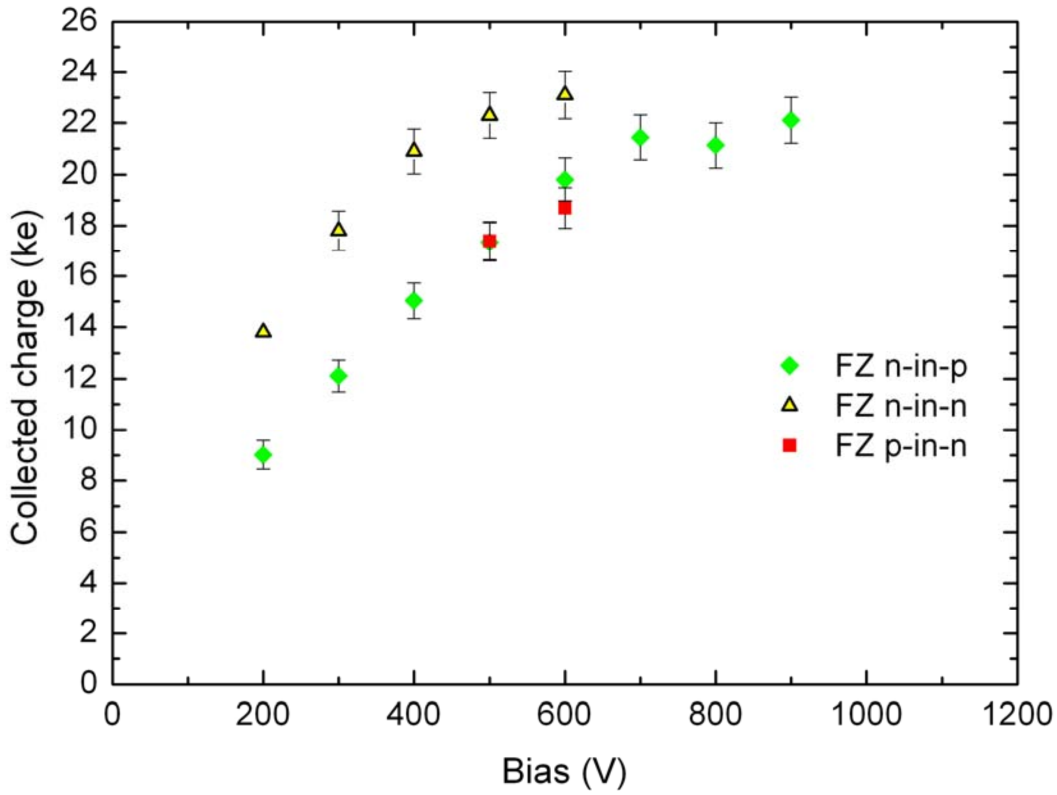
26 MeV protons Karlsruhe (W. de Boer et al).

Neutron irradiations: low doses (1×10^{14} n cm^{-2})

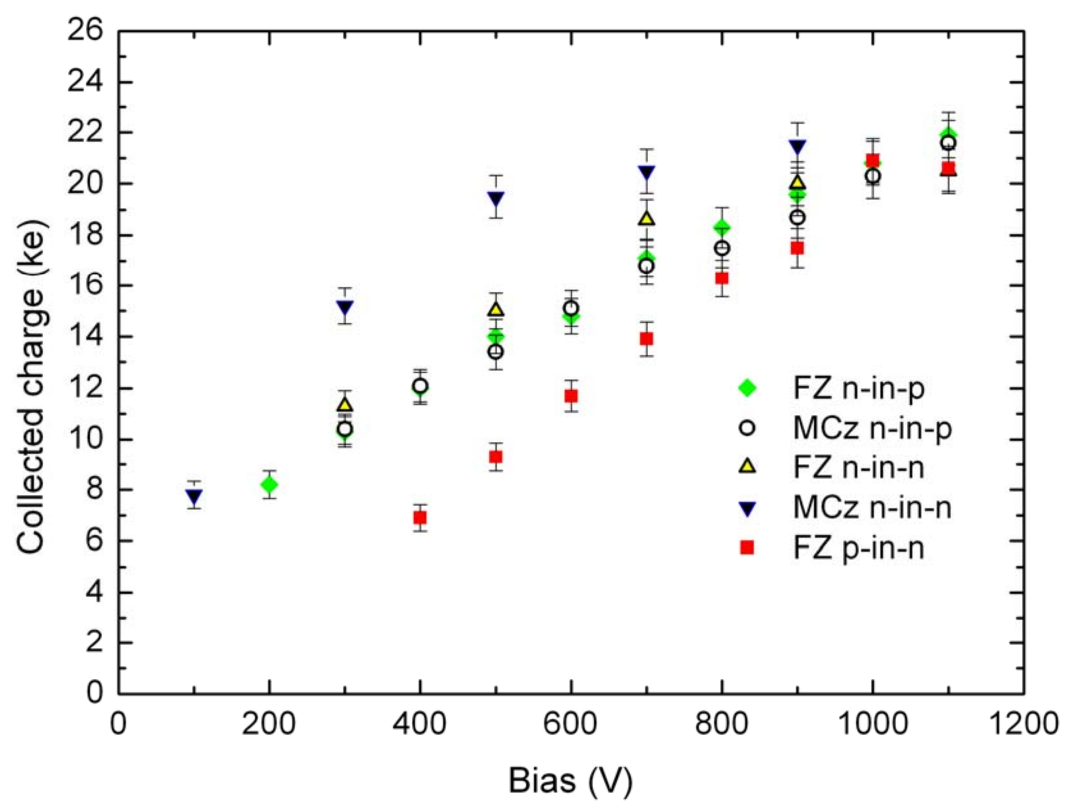


Neutron irradiations: still low doses

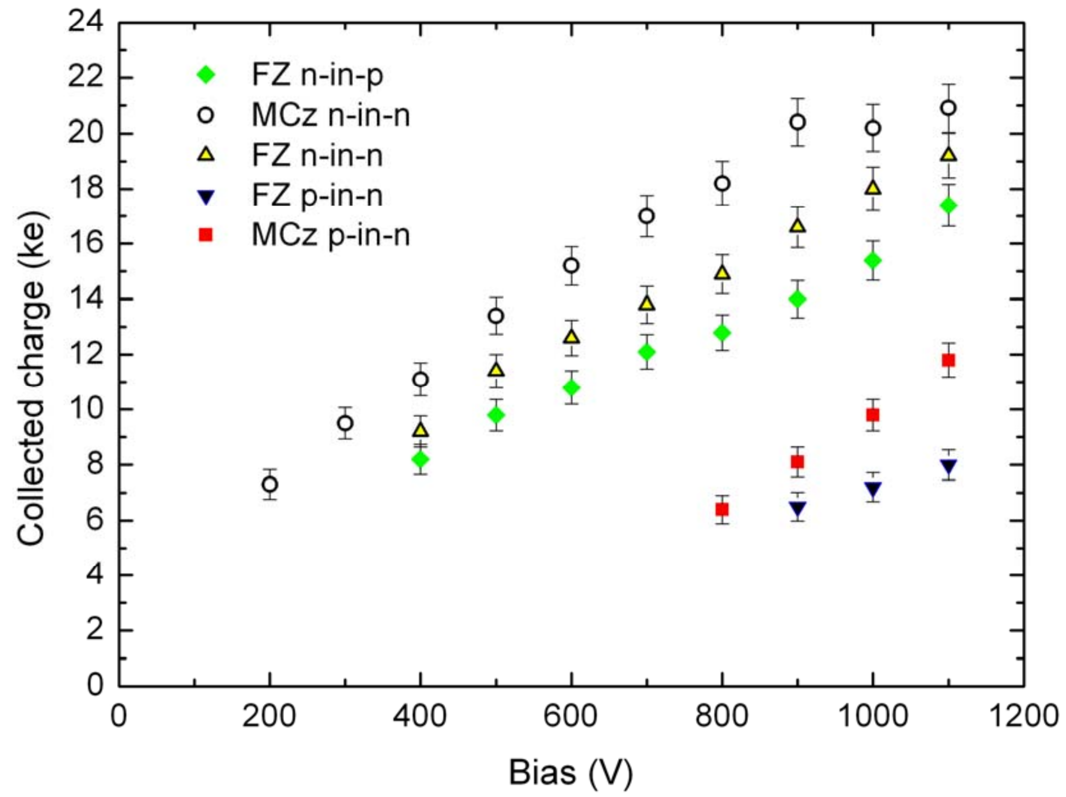
(2×10^{14} n cm^{-2})



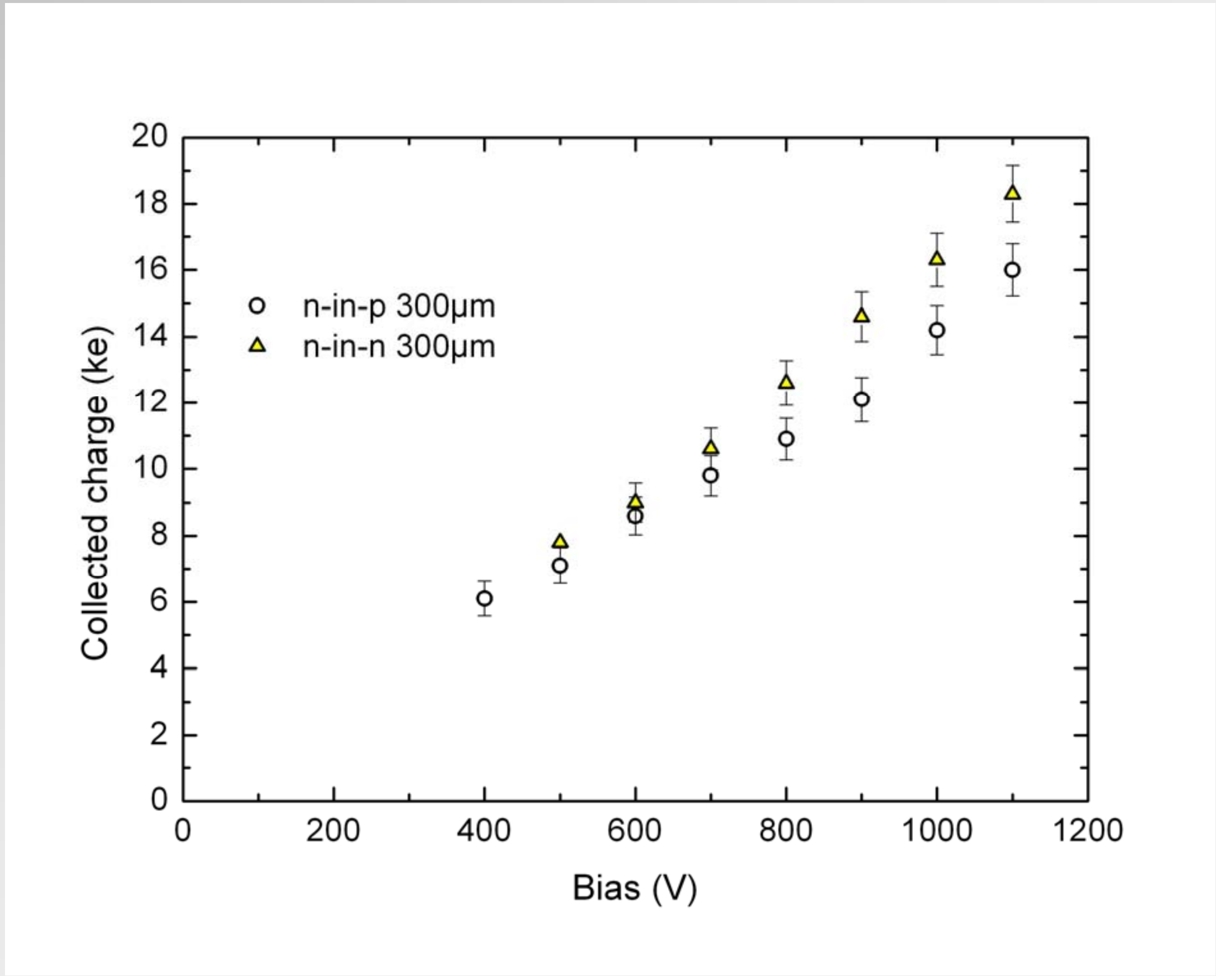
Neutron irradiations: low/medium doses (5×10^{14} n cm^{-2})



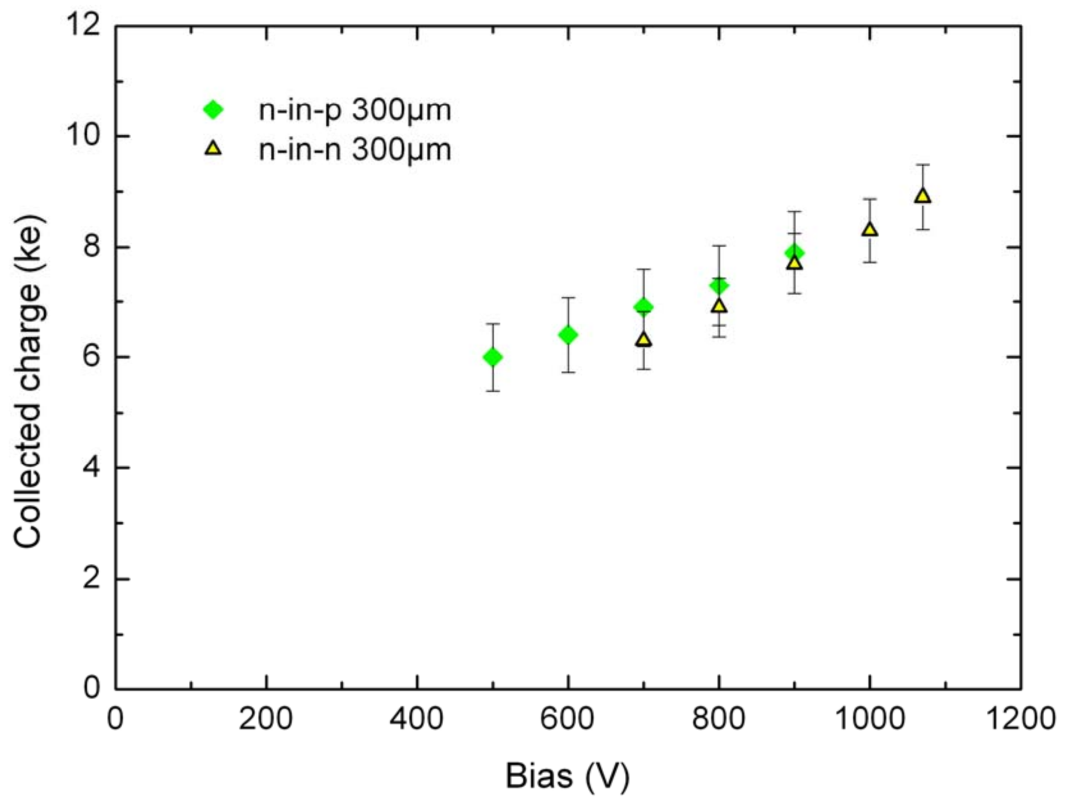
Neutron irradiations: medium doses ($1x10^{15}$ n cm^{-2})



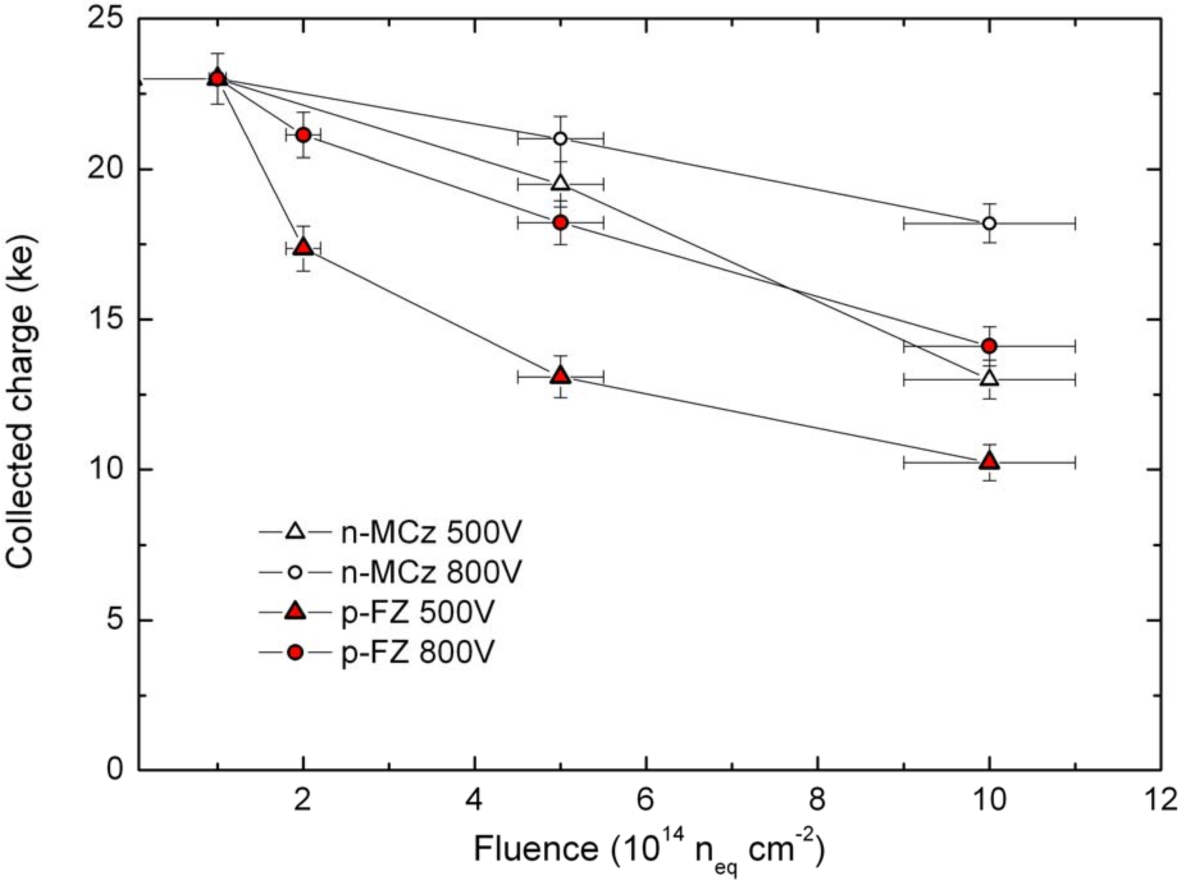
Neutron irradiations: high doses (3×10^{15} n cm^{-2})



Neutron irradiations: very high doses (1×10^{16} n cm^{-2})

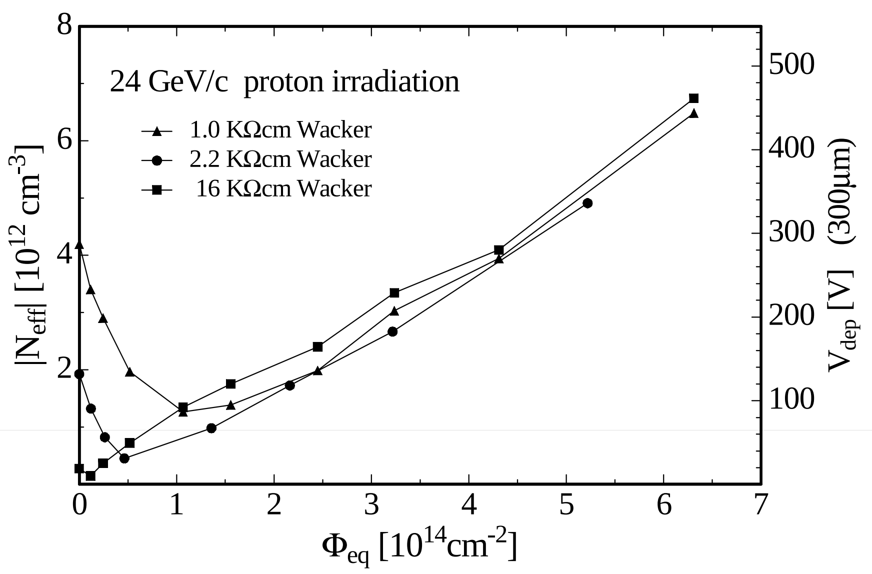


Neutron irradiations: CCE vs Φ



Differences between neutron and proton irradiations

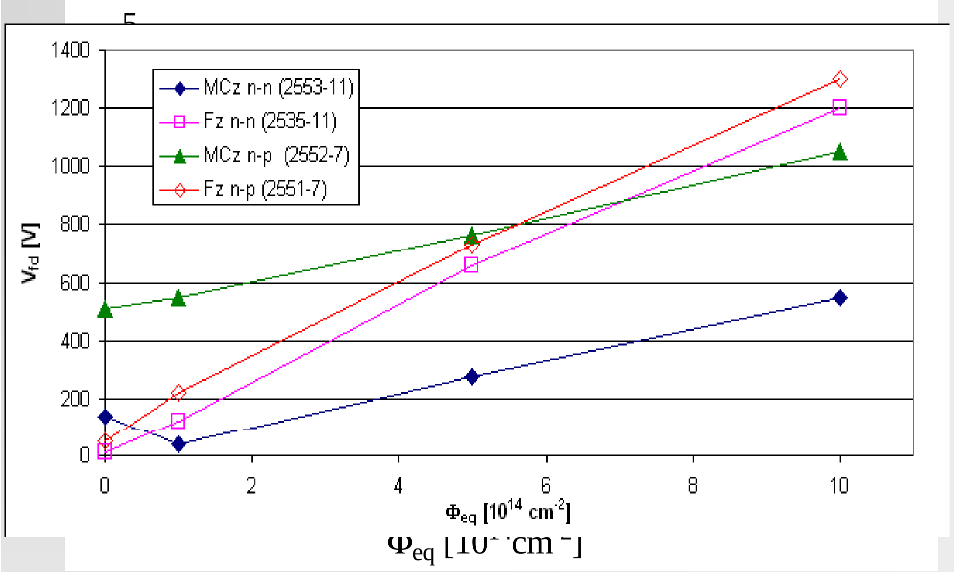
Proton irradiations



3^RD RD48 STATUS REPORT

CERN/LHCC 2000-009
LEB Status Report/RD48
31 December 1999

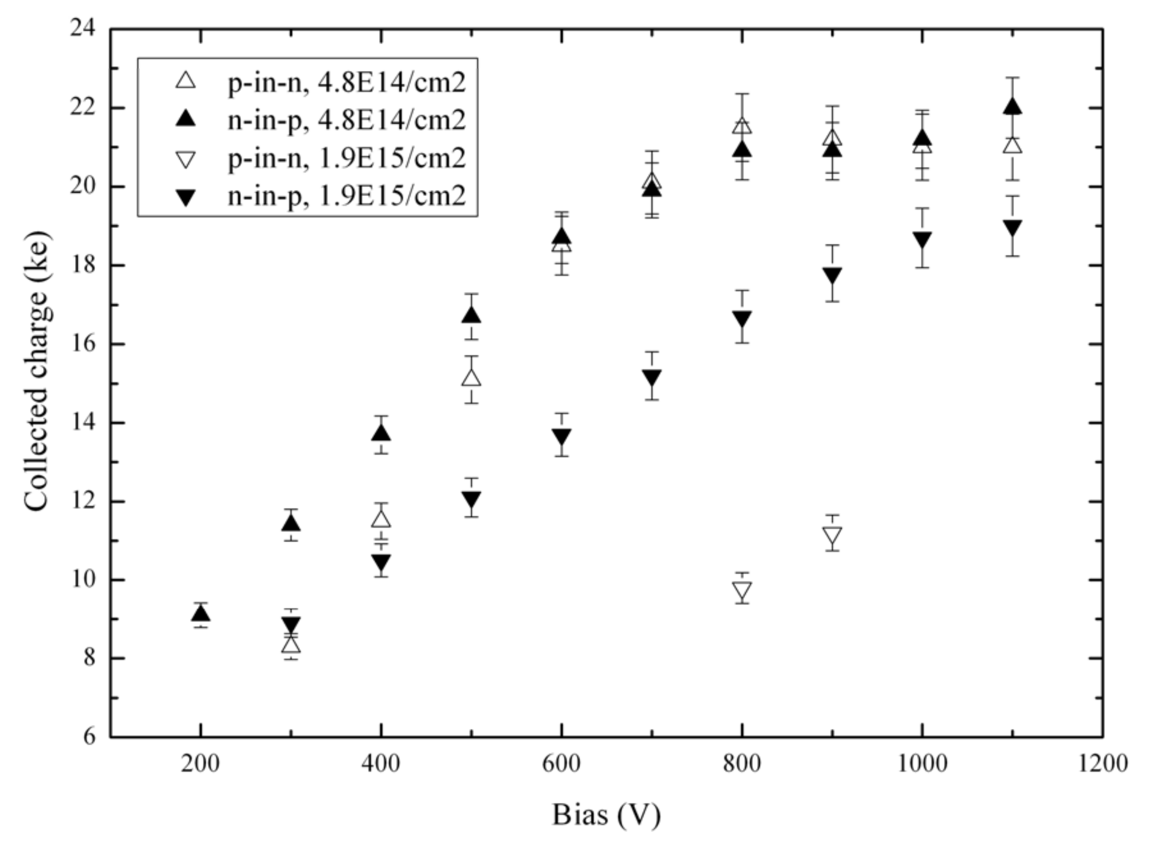
Neutron irradiations



G. Kramberger, "Charge collection measurements on MICRON RD50 detectors", ATLAS Tracker Upgrade Workshop, Valencia 11-14 December 2007, http://ific.uv.es/slhc/ATLASUpgrade/

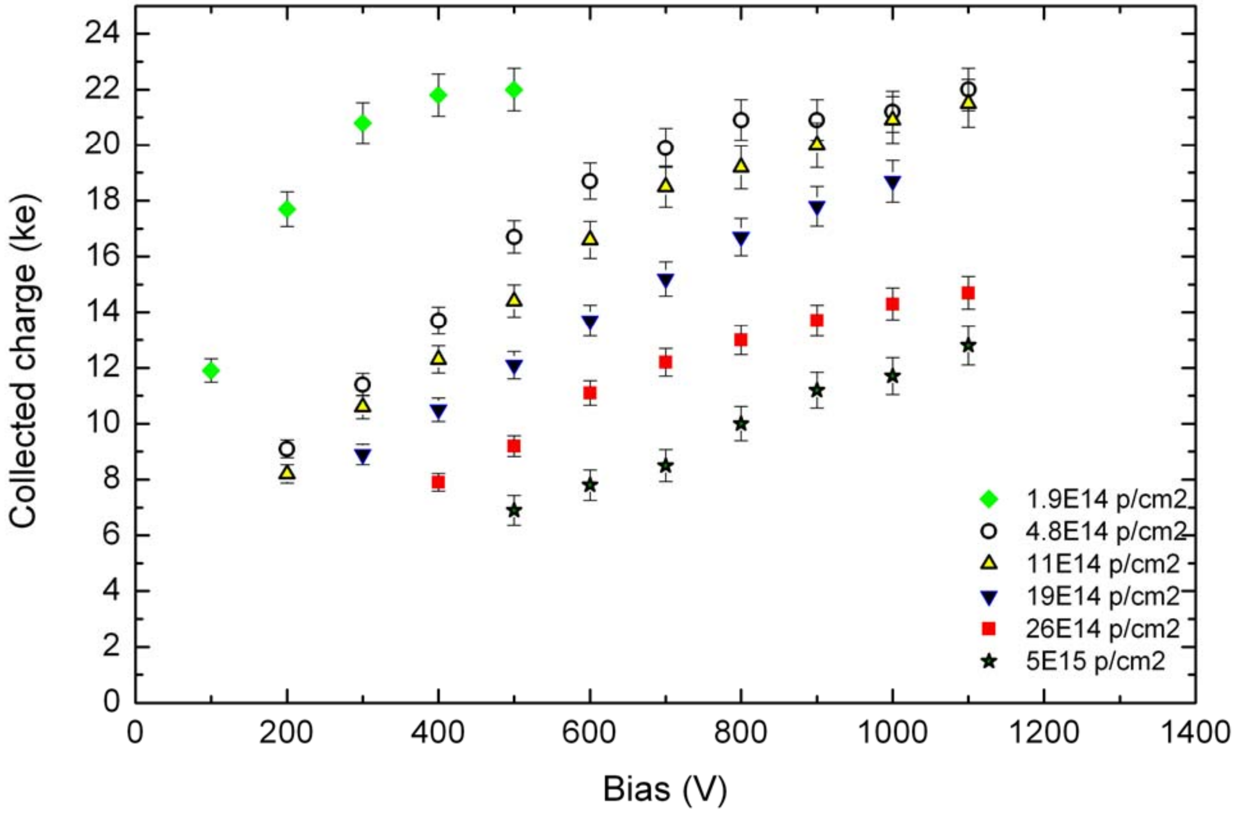
24GeV/c proton irradiations

N-side readout vs p-in-n @ $\Phi = 1.9$ and $4.8\ 10^{14}\ n_{eq}\ cm^{-2}$

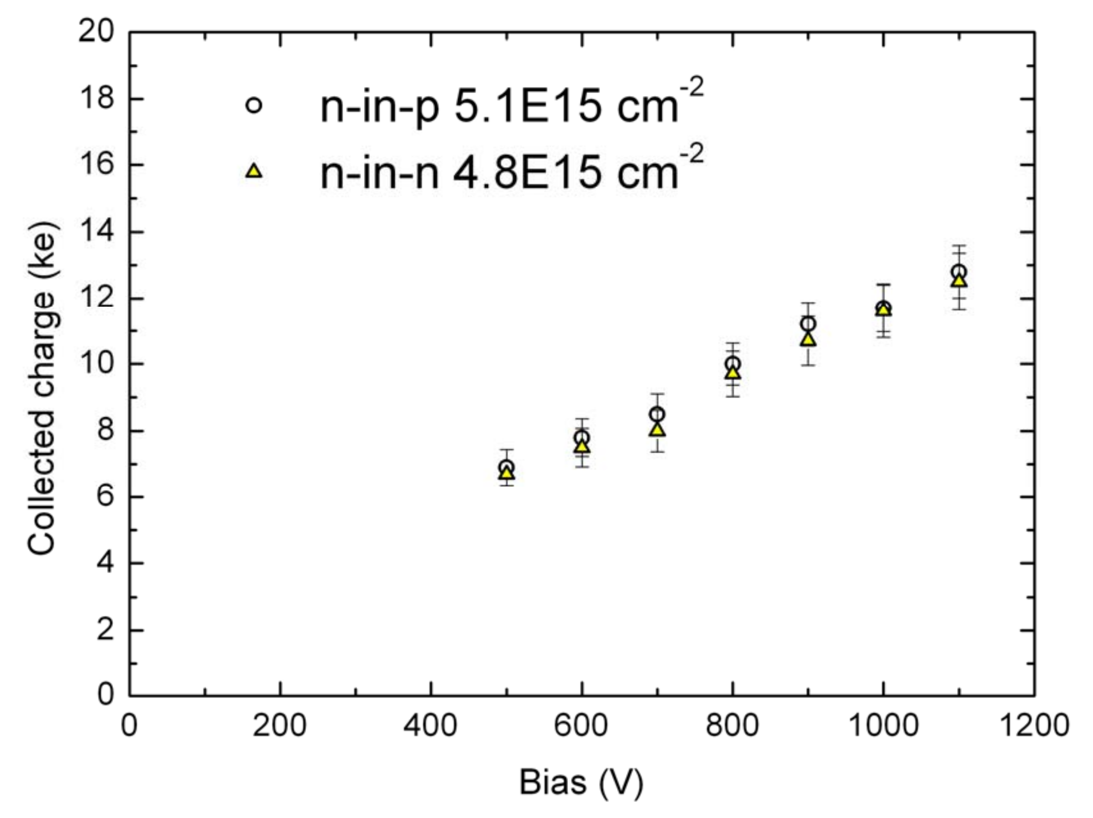


G. Casse – Vertex 2008, July 28–August 1, 2008, Utö Island, Sweden

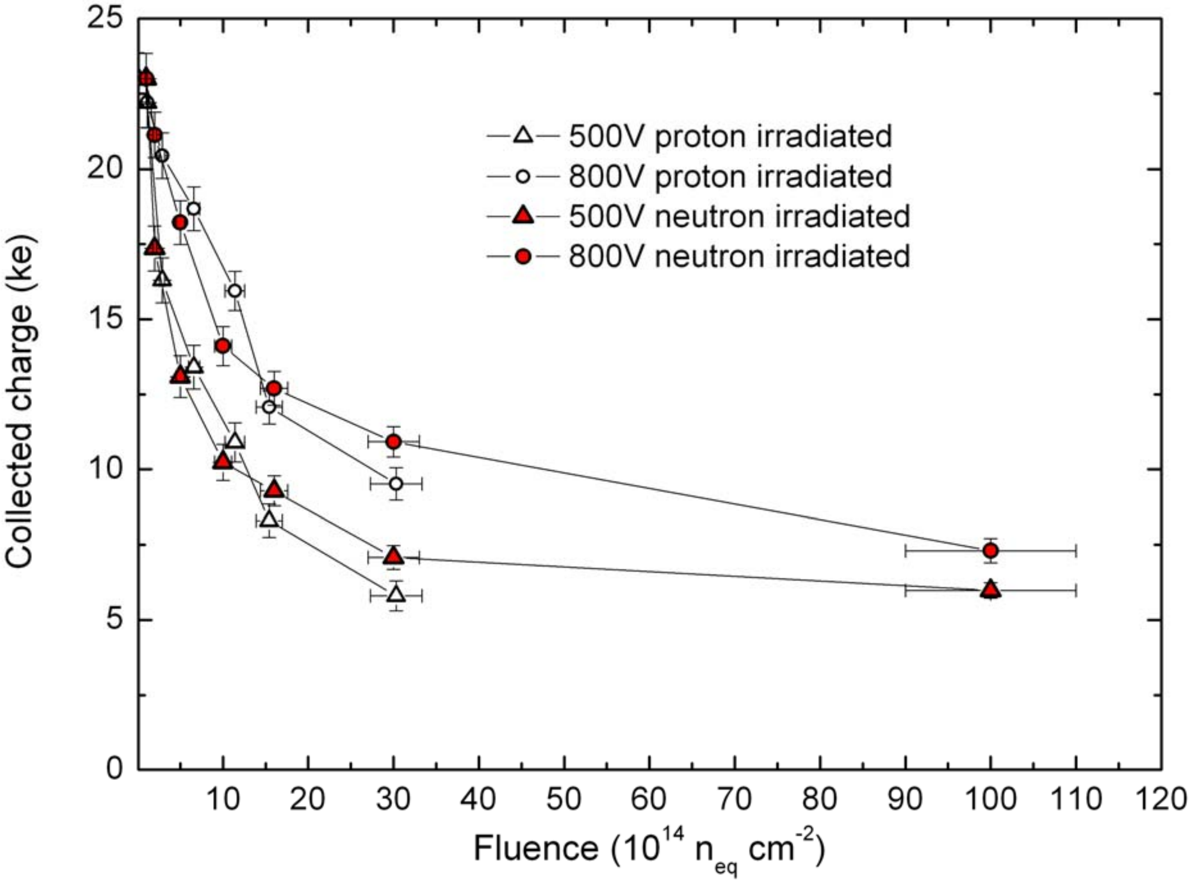
24GeV/c proton irradiations n-in-p detectors



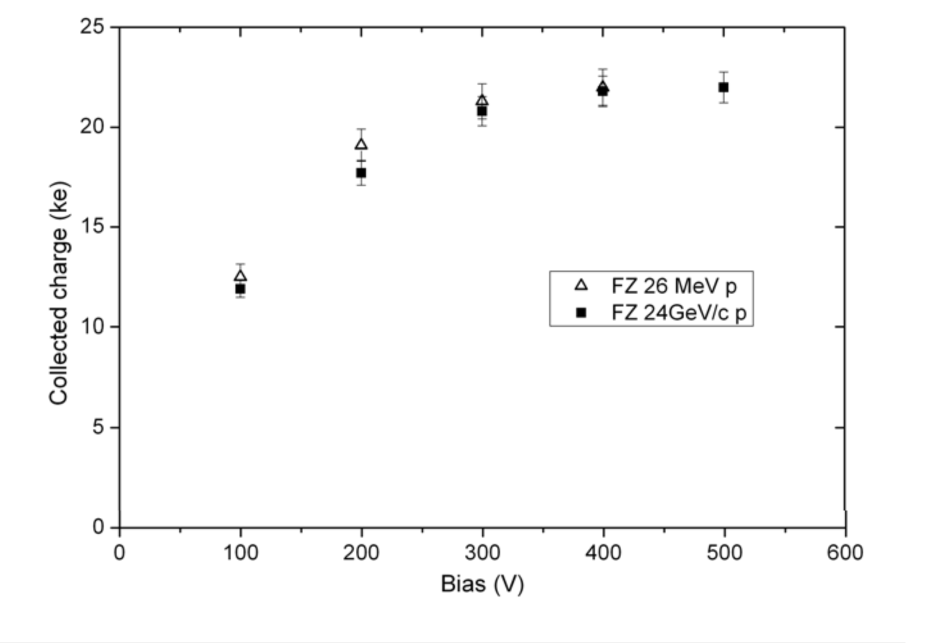
24GeV/c proton irradiations
n-in-p vs n-in-n detectors



24GeV/c proton irradiations vs neutron

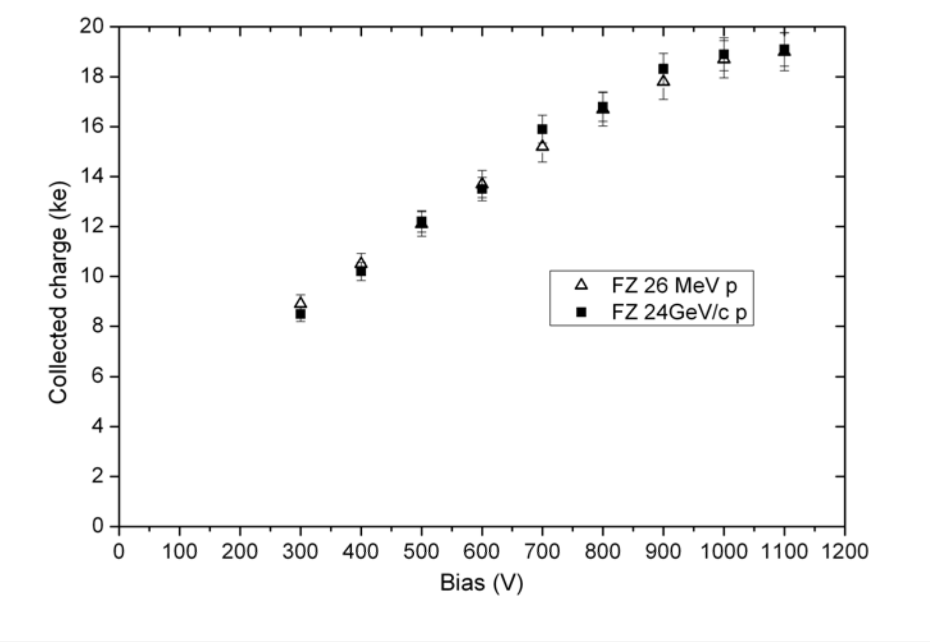


Low energy (26MeV) proton irradiations: comparison (with 24GeV/c p) of CCE for NIEL equivalent doses



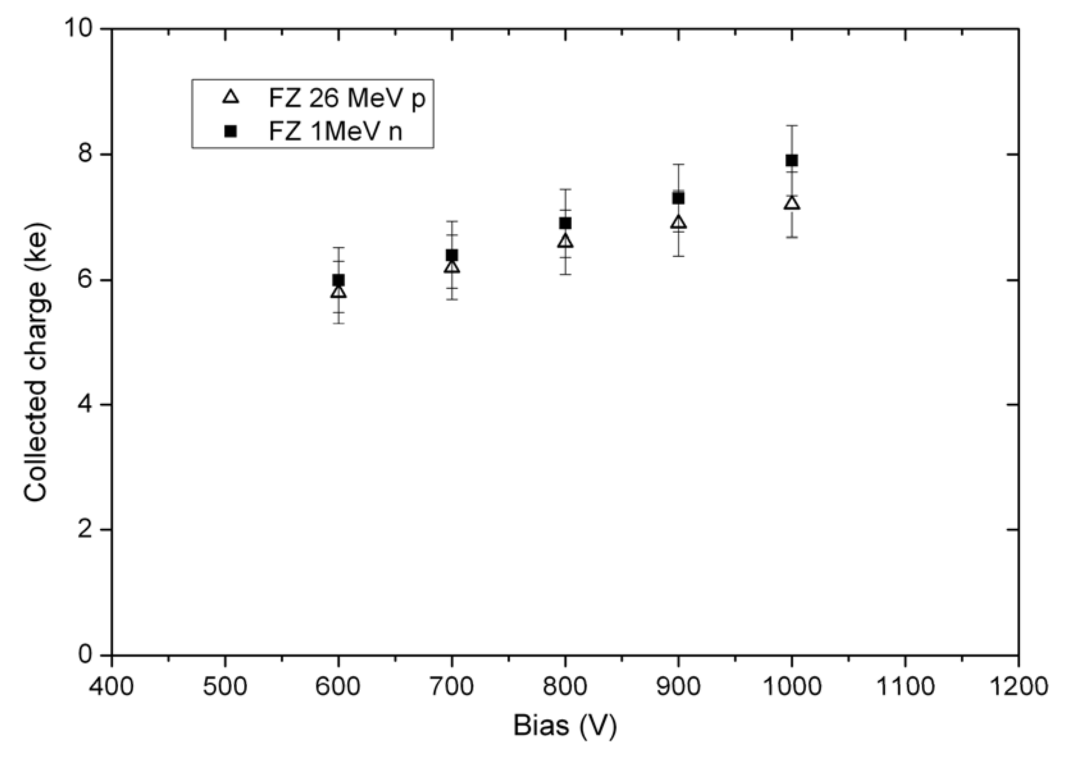
1×10^{14} n_{eq} cm^{-2}

1×10^{15} n_{eq} cm^{-2}



Low energy (26MeV) proton irradiations: comparison (with rector neutron) of CCE for NIEL equivalent doses

$1x10^{16}$ cm^{-2}!



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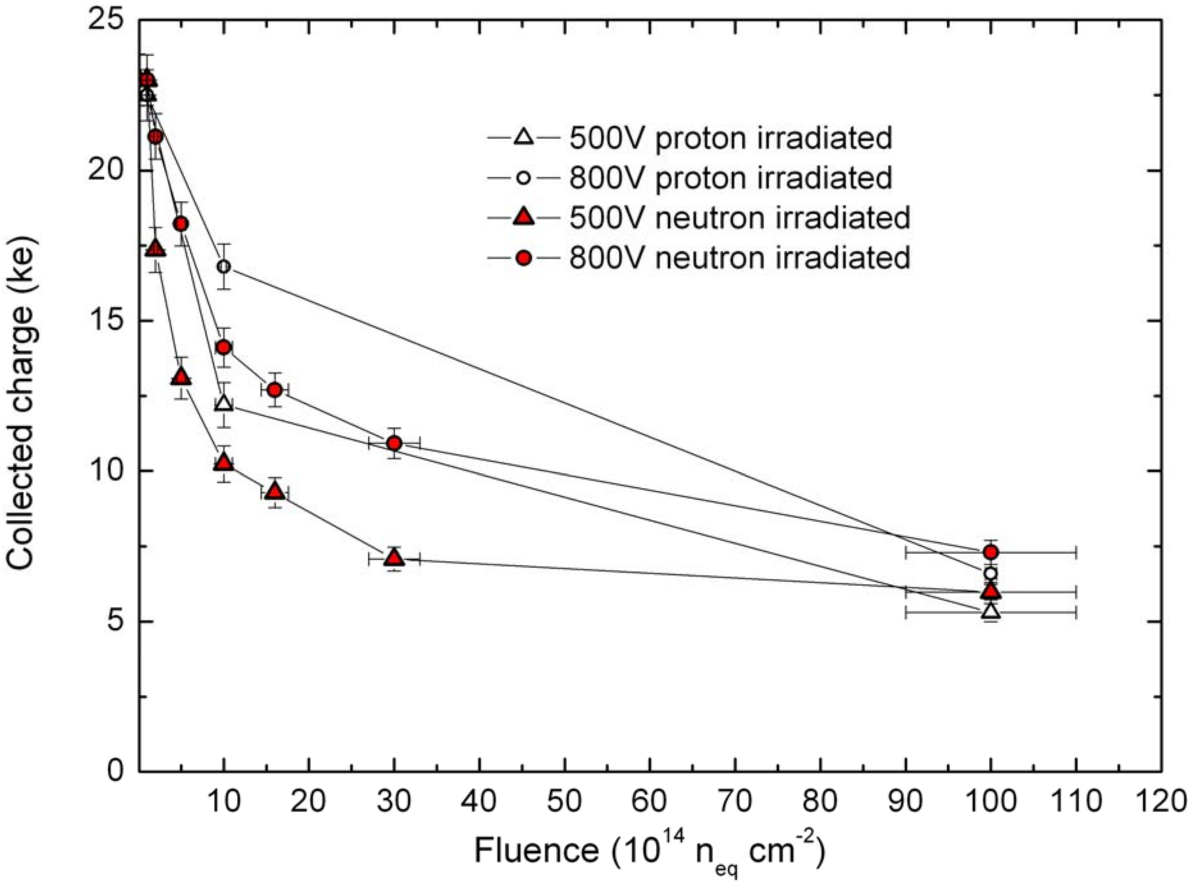
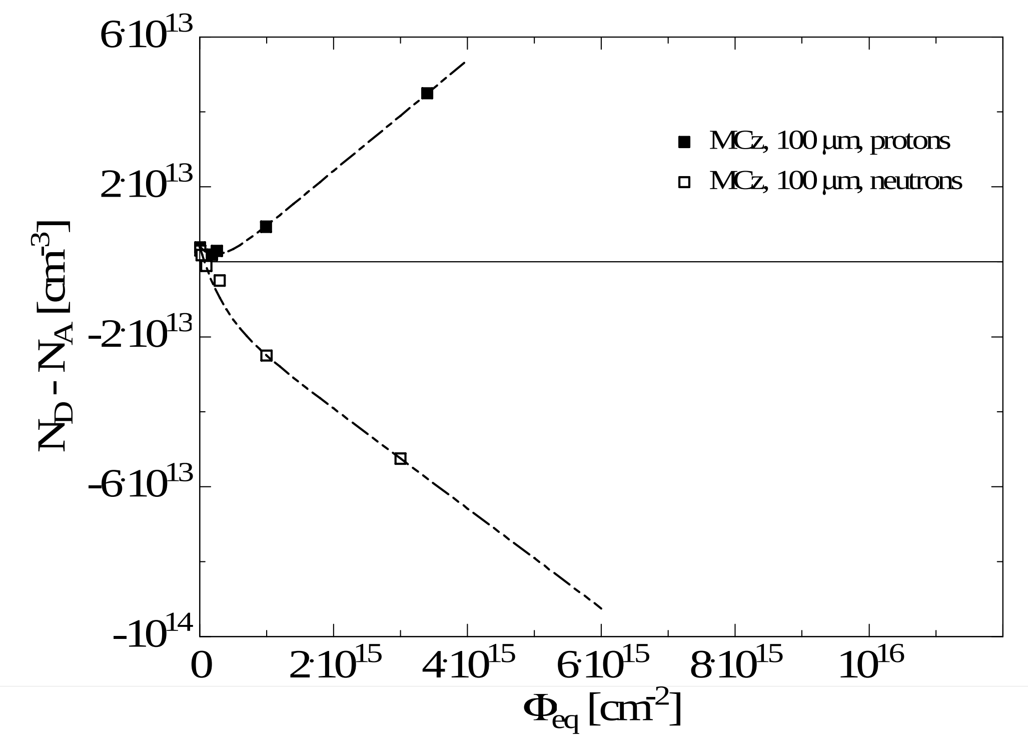
Low energy proton irradiations vs neutron



Special effects: mixed irradiations (neutrons + protons)

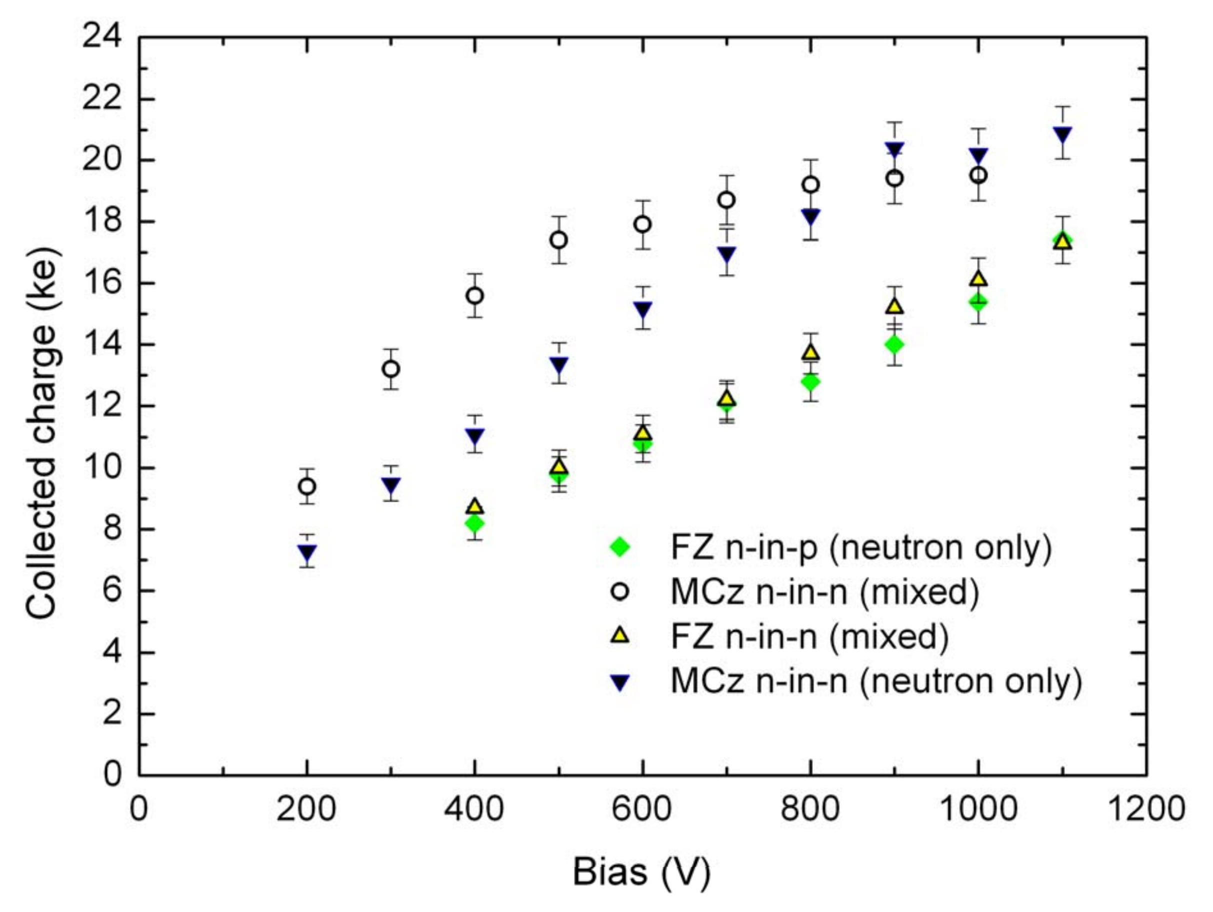


E. Fretwurst et al., 11th RD50 workshop

Practical outcome: possible partial compensation of N_{eff}, therefore **better CCE at low voltages**?

- **Same behavior holds for thin MCz-diodes reveal no SCSI after proton damage, contrary to neutron damage**
- **β > 0 (dominant donor creation) for protons (more point defects than clusters)**
- **β < 0 (dominant acceptor creation) for neutrons (more clusters than point defects)**

Special effects: mixed irradiations (neutrons + protons): $1x10^{15}$ n_{eq} cm^{-2}



Conclusions

With neutron irradiation, a beneficial effect of the high resistivity and lower degradation of the V_{fd} with Φ in n-MCz detectors leads to a significant advantage in CCE at low voltages.

With 24GeV/c proton irradiation, only FZ materials have been investigated. The comparison with similar, neutron irradiated material, indicates that (for NIEL corrected equivalent Φ), the p-irradiations induce a higher charge trapping.

Low energy protons have shown comparable results to n and 24GeV/c p irradiations, and can be used for achieving high doses, otherwise difficult to attain in the CERN/PS.

An overall extremely good charge collection (about 8000e^-) can be achieved at 800V with p-FZ devices.

The mixed irradiation experiment has shown that the n-MCz in fact really builds up positive and negative N_{eff} with protons and neutron respectively, resulting in a partial compensation effect that makes this material very rad-hard in mixed field radiation areas.

One comment on thin devices