Summary of Liverpool CC(V) Measurements

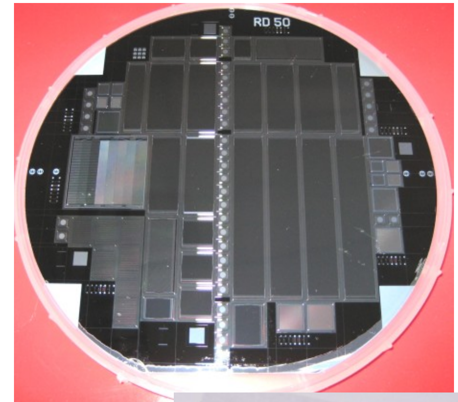
A. Affolder, P. Allport, H. Brown,
G. Casse, V. Chmill, D. Forshaw,
T. Huse, I. Tsurin, M. Wormold
University of Liverpool

Purpose of this Talk

- Summarize all the charge collection measurements made at Liverpool with RD50 4" and 6" wafers
  - Some shown at previous RD50 meetings
  - Some at other conferences
  - Some are new measurements
  - Also have more extensive ATLAS07 HPK and VELO test structure results to compare with
- Wanted to provide one location to find our latest data and updated papers

Apologizes if you seen these previously

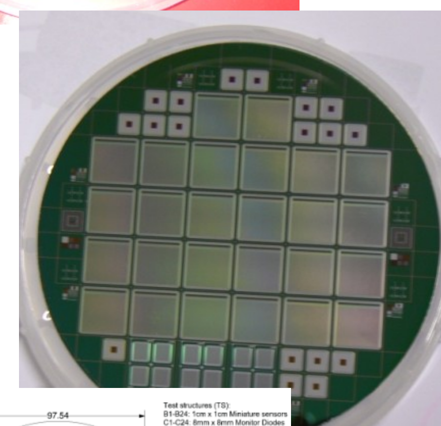
Miniature Silicon Micro-strip Sensors



Microstrip, ~1x1 cm^2, 100-128 strips, 75-80 µm pitch

Micron/RD50 4” & 6” wafers (300 µm)

- n-in-p FZ (V_{FD} ~15V/~70 V)
- n-in-n FZ (V_{FD}~10 V)
- p-in-n FZ (V_{FD} ~10V)
- n-in-p MCz (V_{FD}~550 V)
- n-in-n MCz (V_{FD}~170 V)
- p-in-n MCz (V_{FD} ~170 V)



Micron/RD50 4” (500 µm)

- n-in-p FZ (V_{FD}~350 V

Micron/RD50 4” (140 um)

- n-in-p FZ (VFD~2-10 V)

CNM RD50 EPI miniatures (~150 µm active)

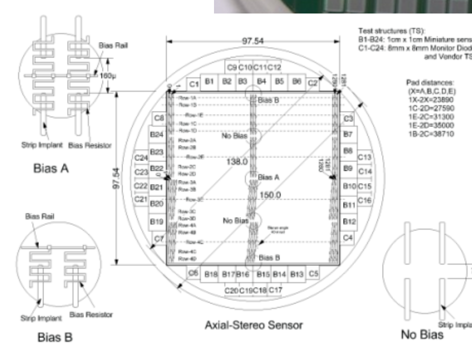
- p-in-n EPI
- n-in-p EPI

Micron/VELO test structures (~300 µm)

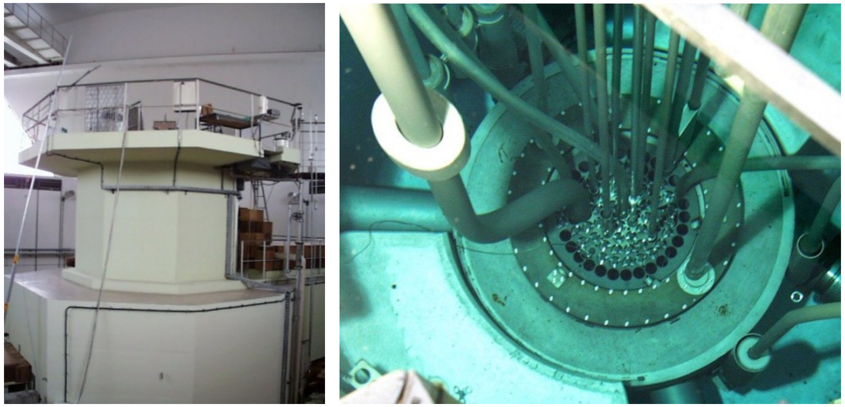
- n-in-n FZ (V_{FD} ~70V)

ATLAS07 HPK test structures (~310 mm)

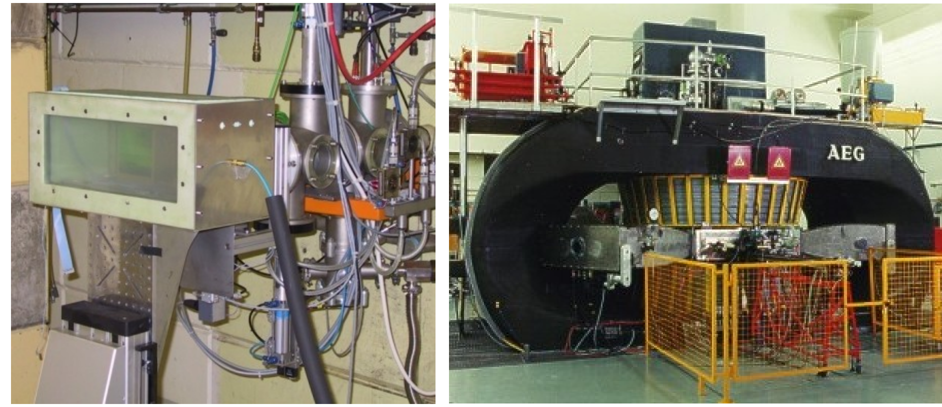
- n-in-p FZ (V_{FD}~150-200 V)



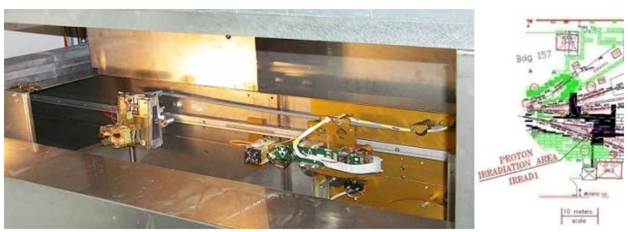
Irradiation Sources



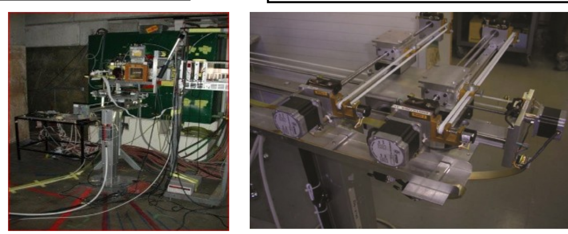
Irradiation and dosimetry (Neutrons):
Triga Reactor, Jozef Stefan Institute,
Ljubljana, Slovenia: **V. Cindro, et. al.**



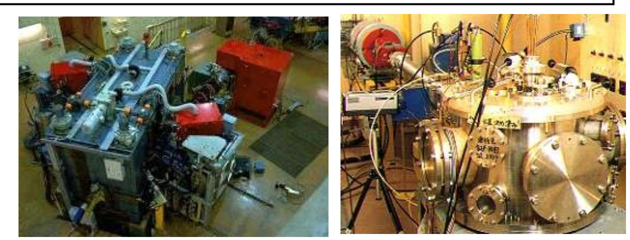
Irradiation and dosimetry (26 MeV Protons):
Compact Cyclotron, Karlsruhe, Germany:
W. de Boer, A. Dierlamm, et. al.



Irradiation and dosimetry
(24 GeV Protons):
CERN PS Irrad1 facility,
Geneva Switzerland:
M. Glaser, et. al.



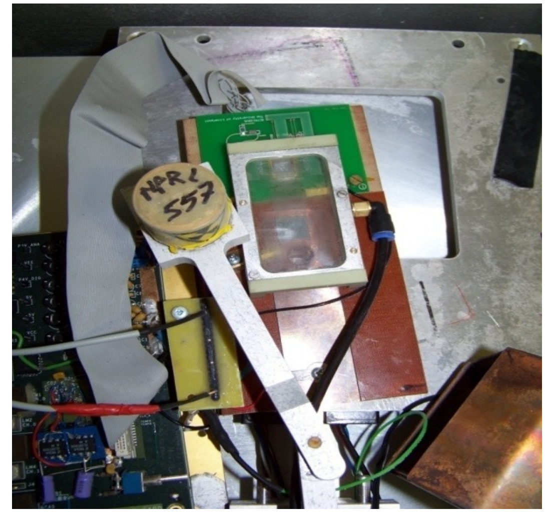
Irradiation and dosimetry
(280 MeV/c Pions):
Paul Scherrer Institut,
Switzerland:
M. Glaser, T. Rohe, et. al.



Irradiation and dosimetry
(70 MeV Protons):
AVF Cyclotron at CYRIC,
Sendai, Japan:
Y. Unno, T. Shinozuka, et. al.

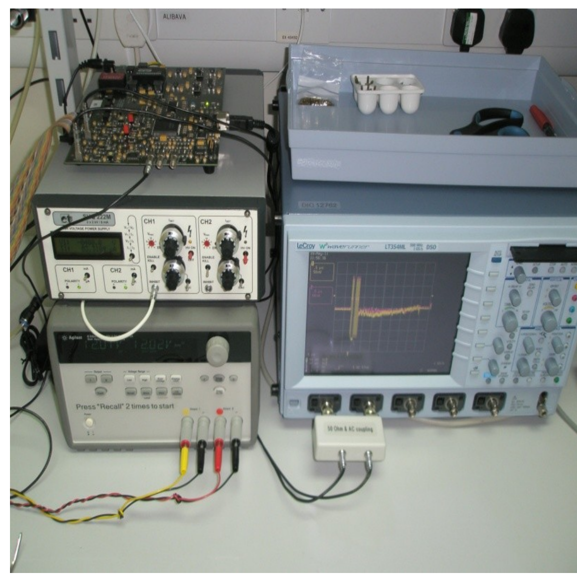
Experimental Setups

- Charge collection efficiency (CCE) measured using an analogue electronics chips (SCT128 or Beetle) clocked at LHC speed (40MHz clock, ~25ns shaping time).
  - Measurements performed n chest freezer at a temperature of ~-25 °C with N_2 flush



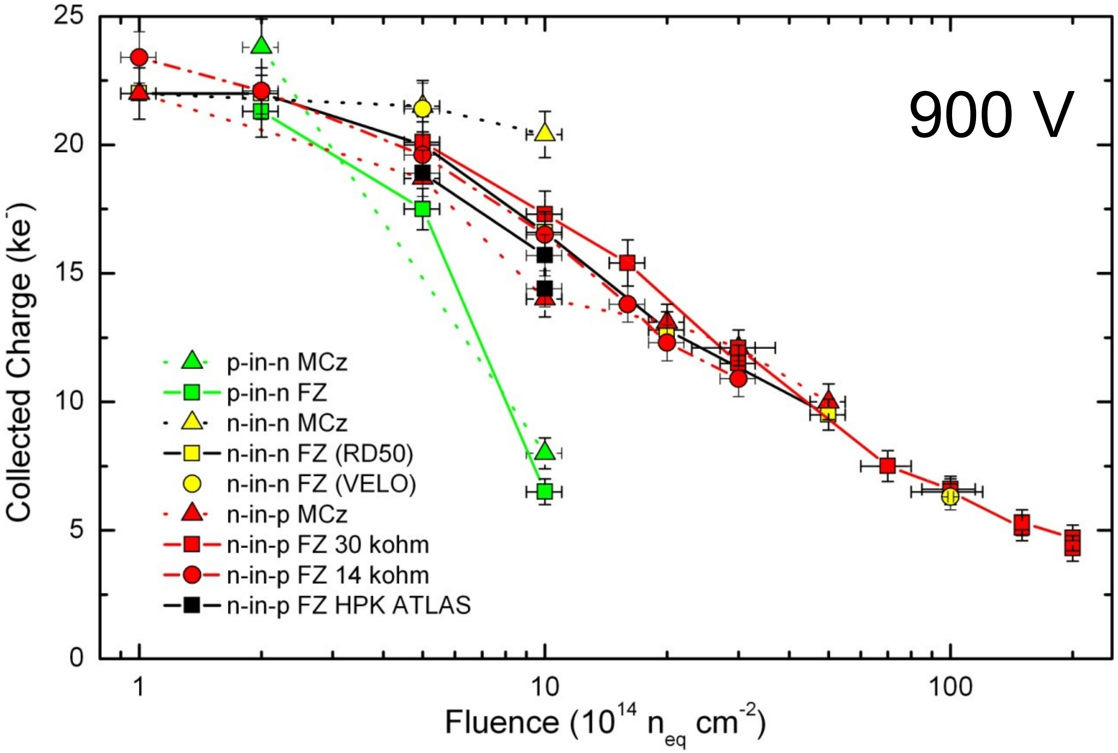
- ^{90}Sr fast electron source triggered with scintillators in coincidence used to generate signal.

- The system is calibrated to the most probable value of the MIP energy loss in a non-irradiated 300μm thick detector (~23000 e^-)



Neutron Summary

- After ~5×10^{14} n cm^{-2}, n-in-n FZ, n-in-p FZ, n-in-p MCz very similar
- At higher voltage, n-in-n MCz superior up to maximum fluence (10^{15} n cm^{-2})
  - Still need higher fluence. Detectors for irradiation in hand
- HPK and Micron consistent

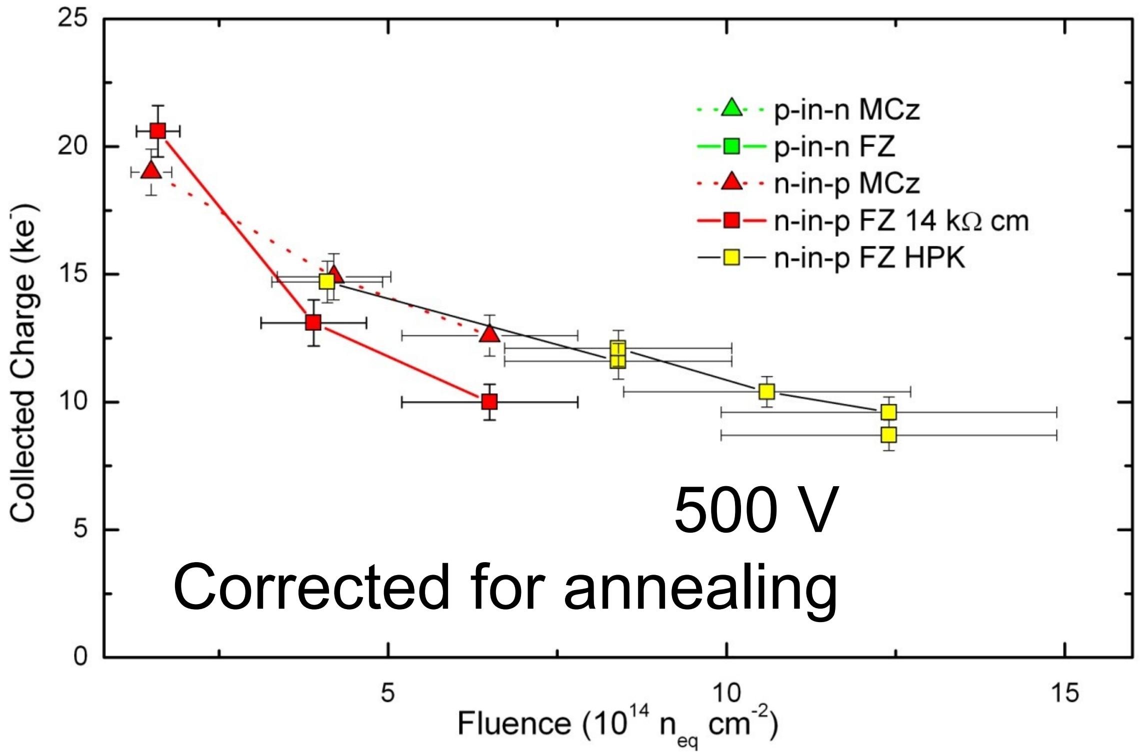


Micron: shown at RESMDD08, Florence, 15th-17th October 2008
published A. Affolder, et. al., Nucl. Instr. Meth. A, Vol. 612 (2010), 470-473.
HPK: shown HSTD7 Hiroshima, 28th Aug-1st Sept 2009
published K. Hara, et. at., Nucl. Inst. Meth. A, Vol. 636 (2011) S83-S89.

All n-strip readout choices studied are the same after neutron irradiation once effects of "active" base and multiplication dominant

Pion Summary

- Interpretation of pion data made more problematic by annealing during irradiations
  - For Micron data, up to 13 days at 24 C
  - For HPK data, up to 12.5 days at 26 C

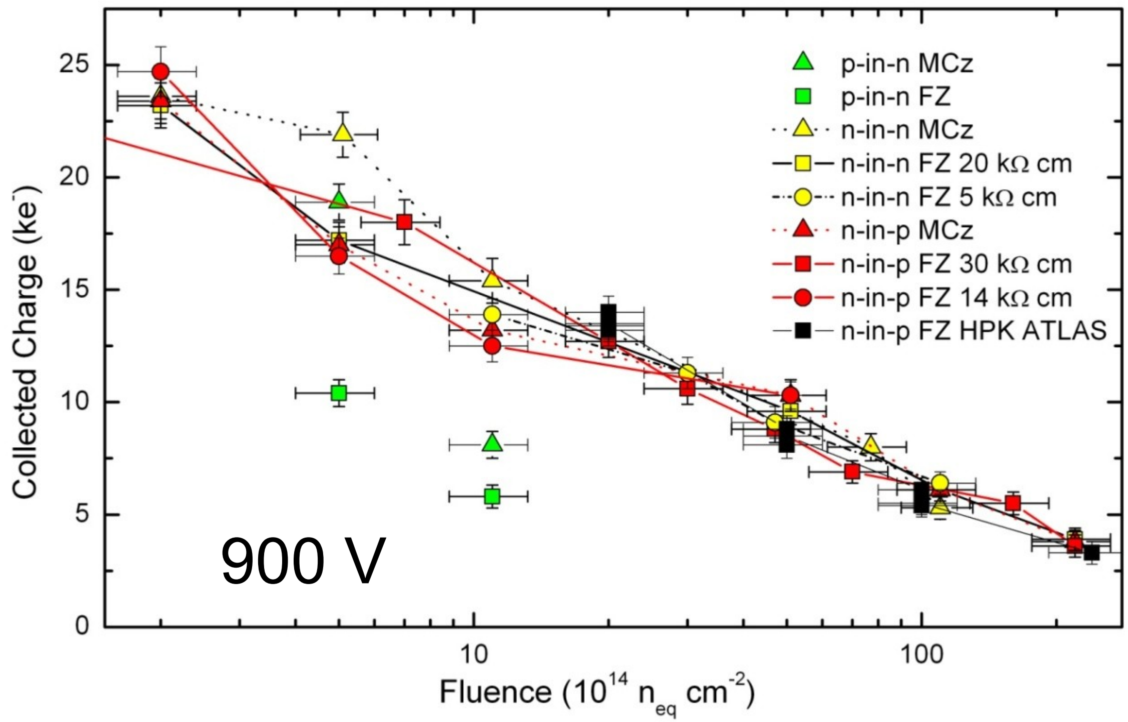


Micron: shown at TIPP09, Tsukuba, 12th-17th March 2009
published A. Affolder, et. al., Nucl. Instr. Meth. A, Vol.623 (2010), 177-179.
HPK: New and unpublished

Results similar to neutron measurements after removing effects of annealing during irradiation

26 MeV Proton Summary

- Above $1\times10^{15}\ n_{eq}\ cm^{-2}$, all n-strip readout devices give similar results
  - All $2\times10^{14}\ n_{eq}\ cm^{-2}$ and all n-in-n MCz except $1\times10^{15}\ n_{eq}\ cm^{-2}$ new and unpublished
- HPK and Micron also consistent within uncertainties

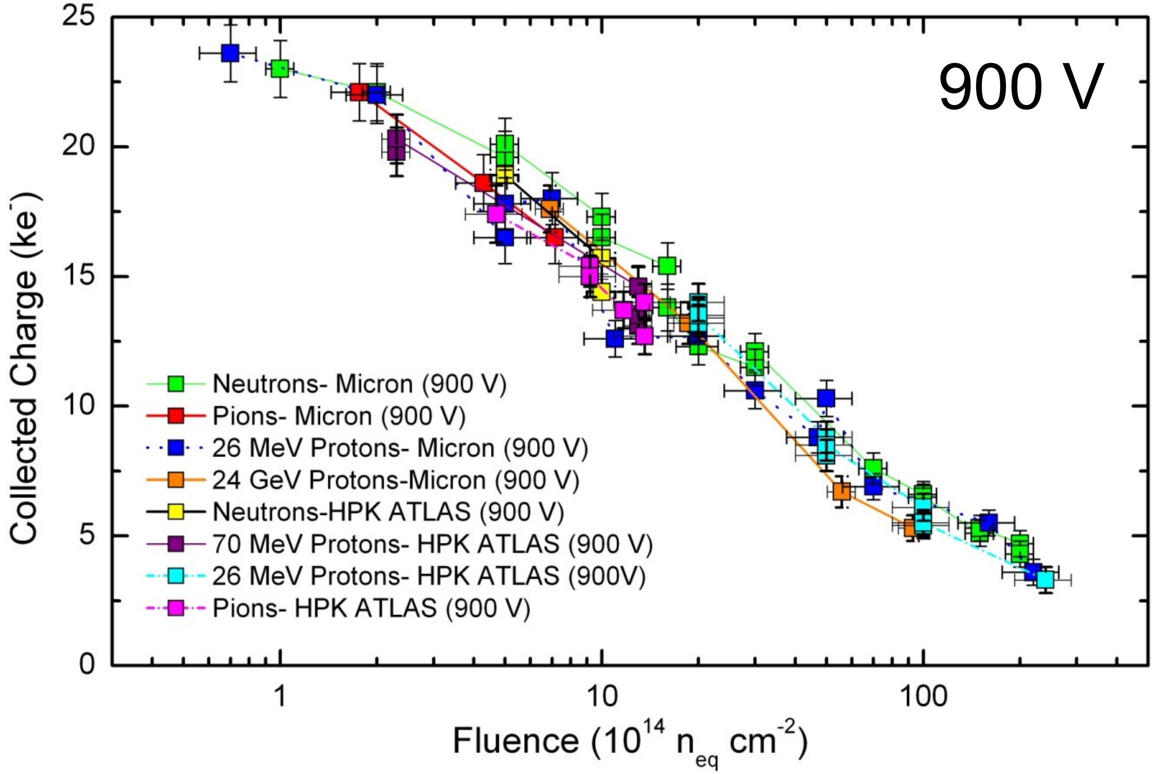


Micron: shown at TIPP09, Tsukuba, 12th-17th March 2009 published A. Affolder, et. al., Nucl. Instr. Meth. A, Vol.623 (2010), 177-179.
HPK: shown at 5th Trento Workshop (2010) and unpublished

Once “active” base and multiplication dominates, all n-strip readout choices studied are the same after 26 MeV protons irradiation as well

n-in-p FZ Irradiation Summary

- After reducing the measured collected charge after pion and 70 MeV proton irradiations to remove estimated annealing during irradiation/shipment , all sources give consistent CCE vs. fluence within uncertainties
  - NIEL looks really good!!
  - Micron and HPK produced sensors also give really consistent results!!!

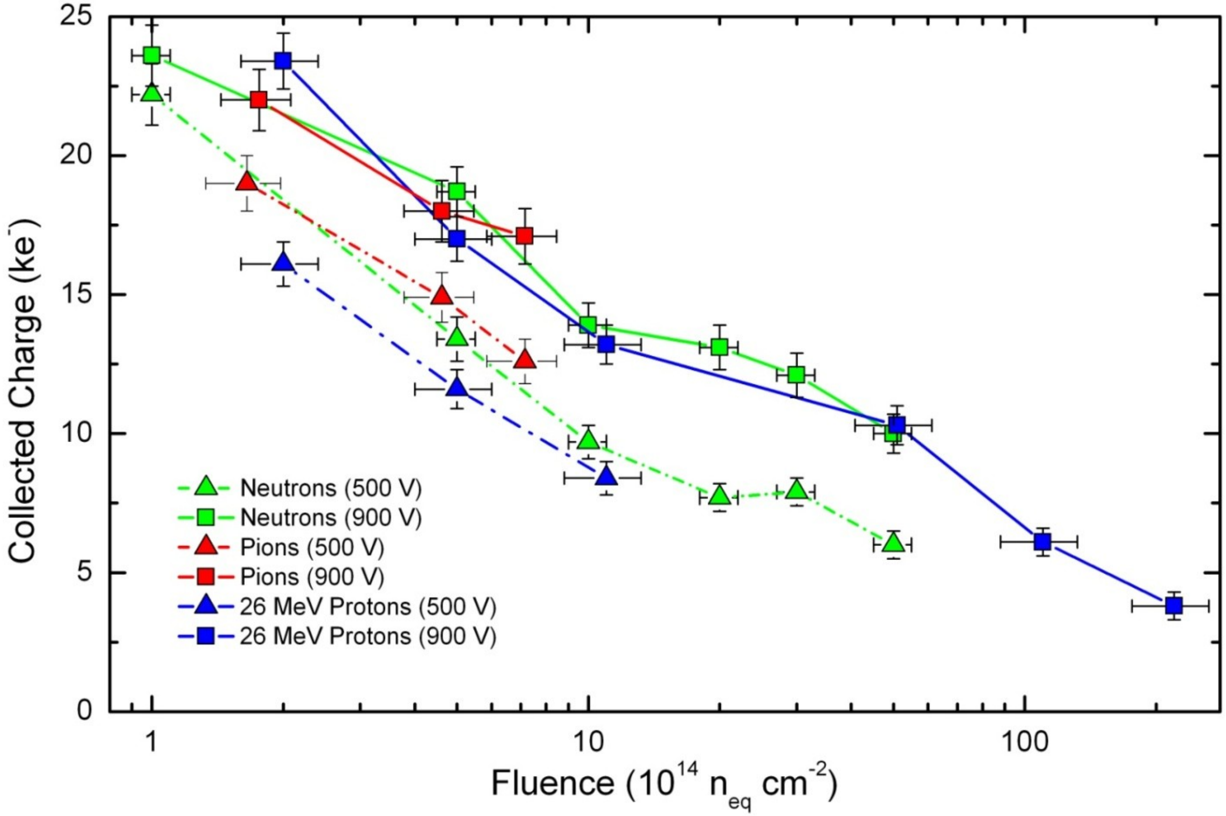


Micron: shown at TIPP09, Tsukuba, 12th-17th March 2009
published A. Affolder, et. al., Nucl. Instr. Meth. A, Vol. 623 (2010), 177-179.

HPK: Neutrons and 70 MeV protons shown HSTD7 Hiroshima, 28th Aug-1st Sept 2009
26 MeV protons shown at 5th Trento Workshop; pions new results
Neutrons and 70 MeV protons published K. Hara, et. at., Nucl. Inst. Meth. A, Vol. 636 (2011) S83-S89.

n-in-p MCz Irradiation Summary

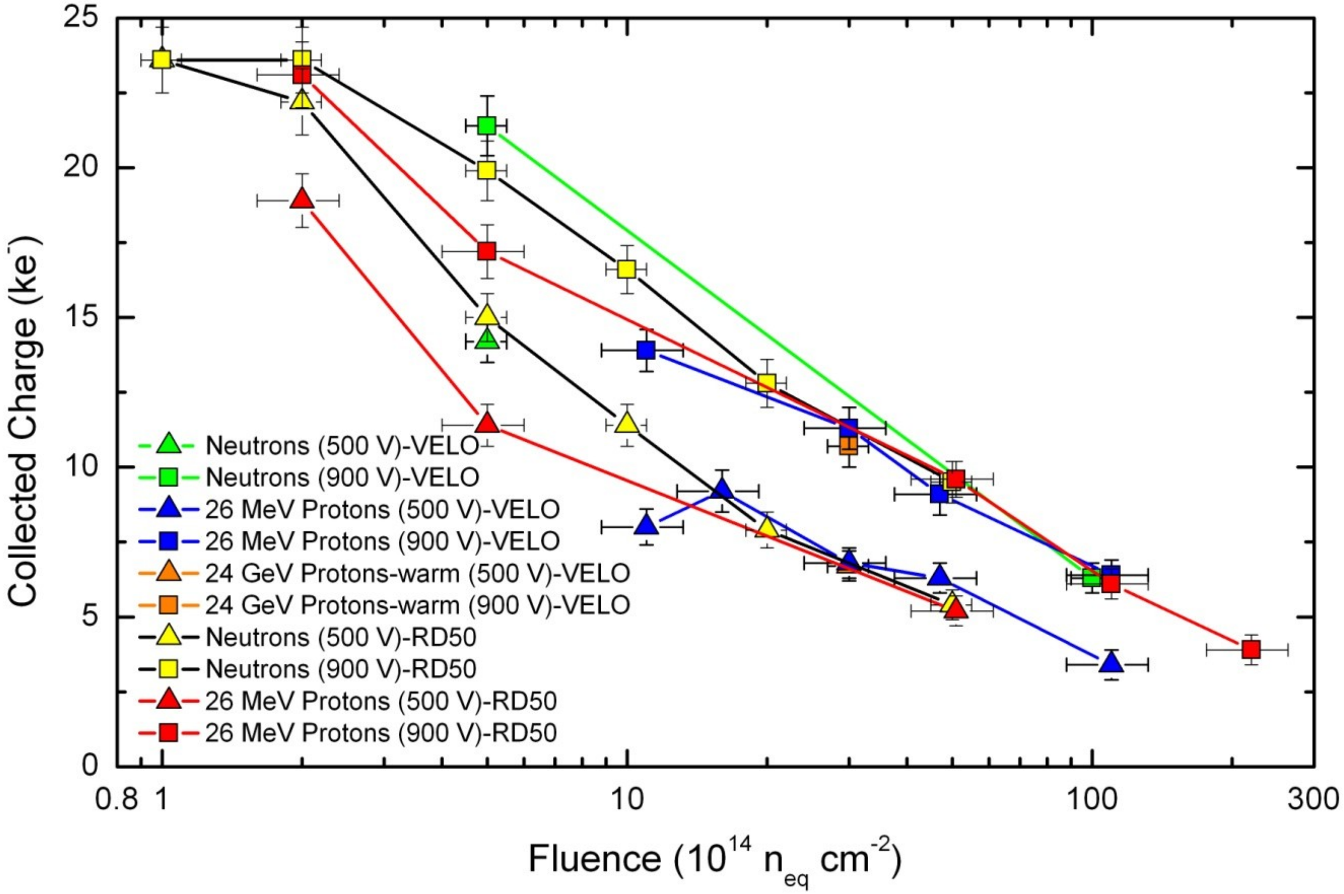
- After reducing the pion CCE to remove estimated annealing during irradiation, all sources give consistent CCE vs. fluence within uncertainties
  - NIEL looks good again!!



Shown at TIPP09, Tsukuba, 12th-17th March 2009
Published: A. Affolder, et. al., Nucl. Instr. Meth. A, Vol.623 (2010), 177-179.
2×10^{14} n_{eq} cm^{-2} 26 MeV RD50 new and unpublished

n-in-n FZ Irradiation Summary

Results after neutron and proton irradiations are again very similar



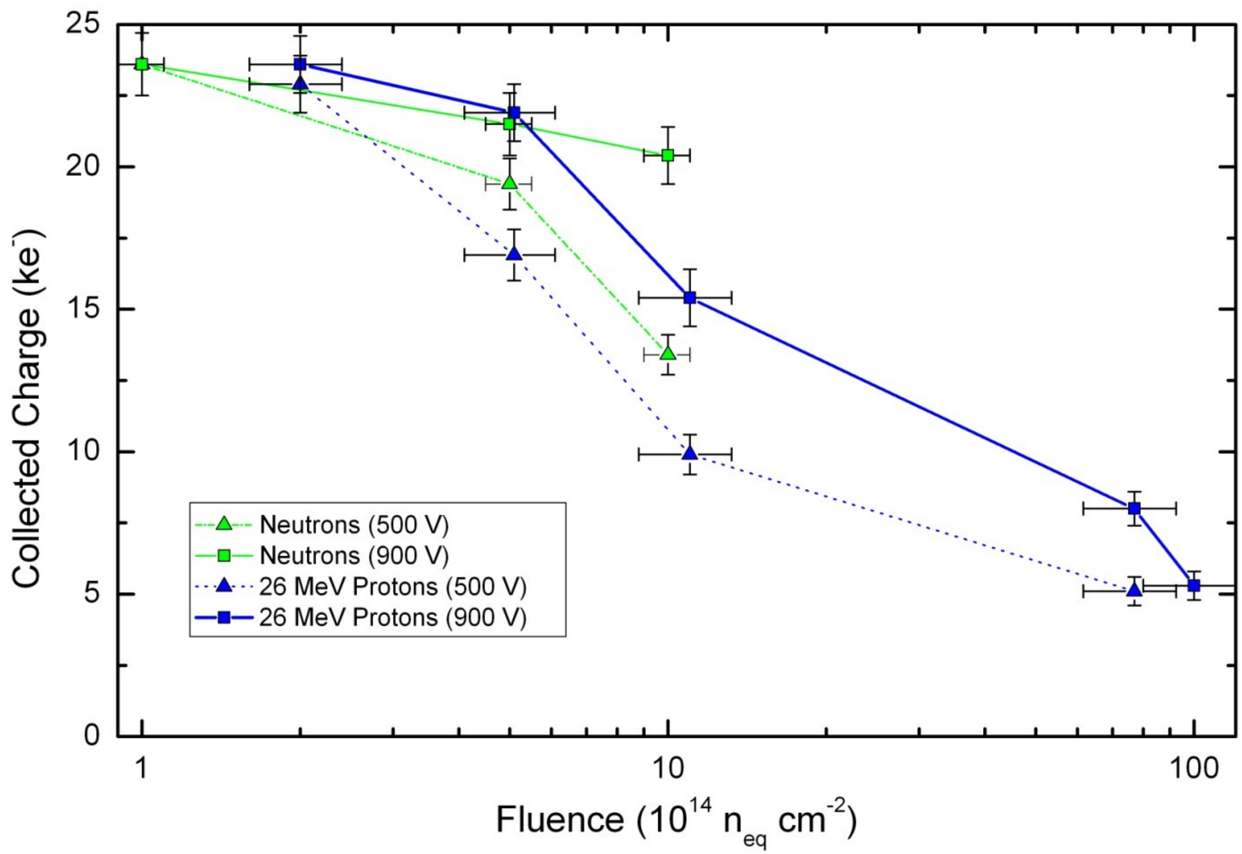
Shown at TIPP09, Tsukuba, 12th-17th March 2009

Published: A. Affolder, et. al., Nucl. Instr. Meth. A, Vol.623 (2010), 177-179.

2×10^{14} n_{eq} cm^{-2} 26 MeV RD50 & 11 and 110×10^{14} n_{eq} cm^{-2} 26 MeV VELO data new and unpublished

n-in-n MCz Irradiation Summary

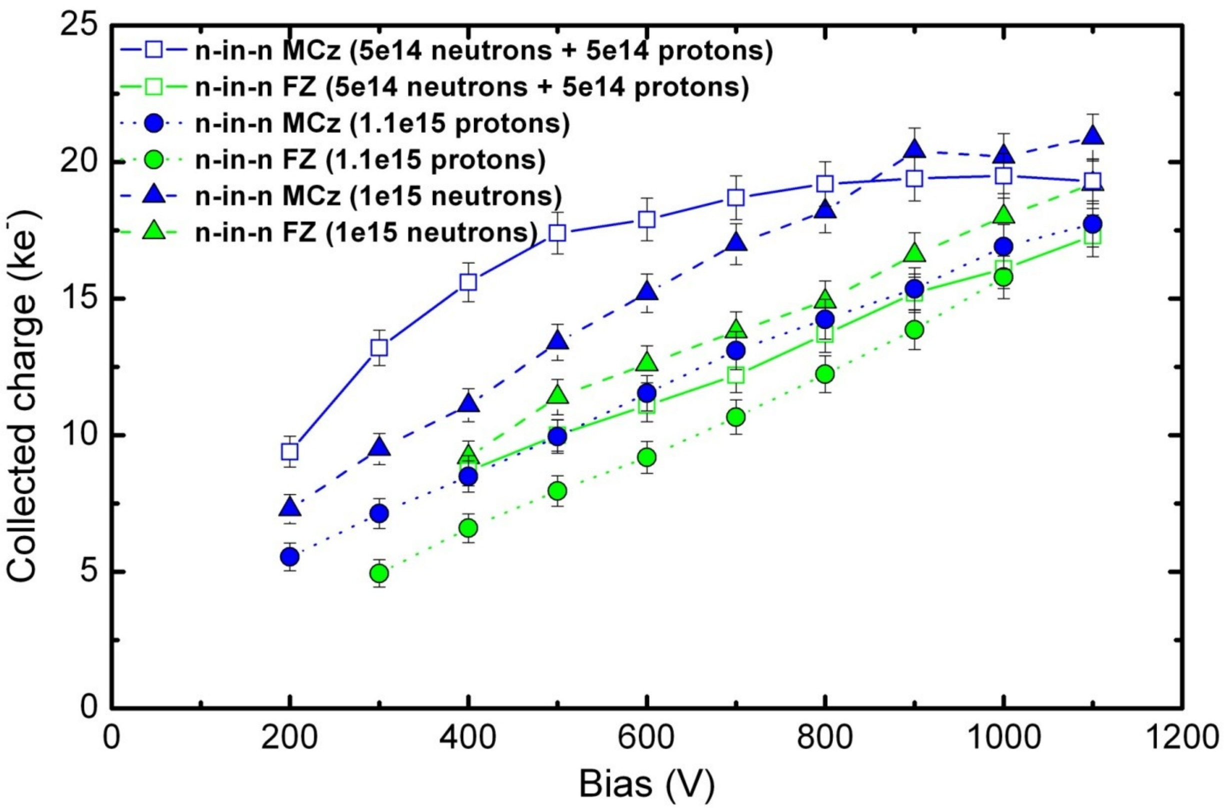
There are signs that n-in-n MCz might be the most radiation hard material up to $1 \times 10^{15}\ n_{eq}\ cm^{-2}$. More study is still needed especially after mixed irradiations.



Shown at TIPP09, Tsukuba, 12th-17th March 2009
Published: A. Affolder, et. al., Nucl. Instr. Meth. A, Vol.623 (2010), 177-179.
All 26 MeV protons except $1 \times 10^{15}\ n_{eq}\ cm^{-2}$ new and unpublished

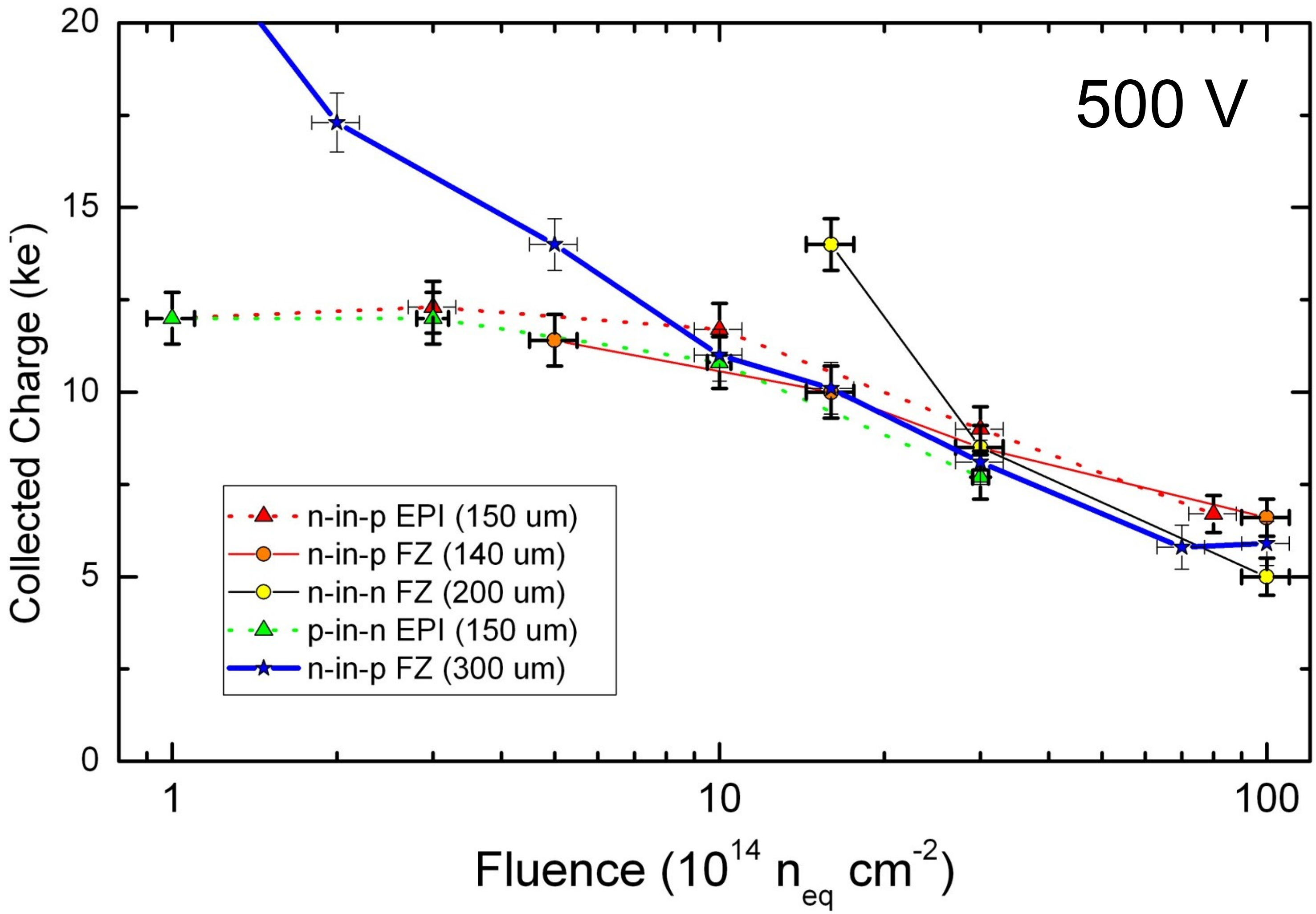
Mixed Irradiations

- Radiation damage from neutrons and protons appear to compensate for MCz material
  - Adds for FZ
- New mixed irradiations planned for n and p-bulk material to much higher fluences



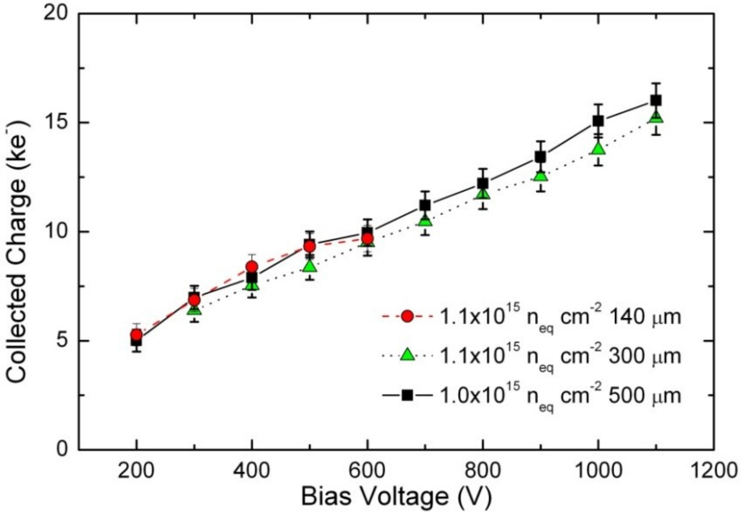
Shown at 2009 IEEE Nuclear Science Symposium, Orlando, 25th-31st Oct 2009
Published: G. Casse, et. al., PoS(Vertex 2008) 036.

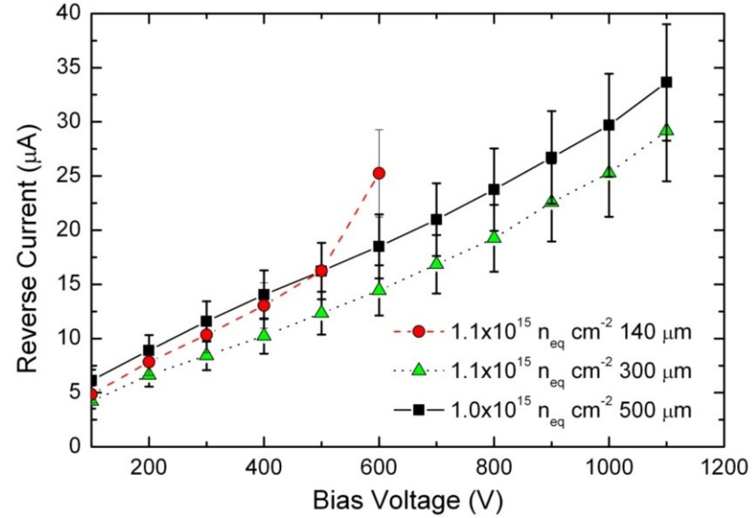
EPI/Thin Comparison

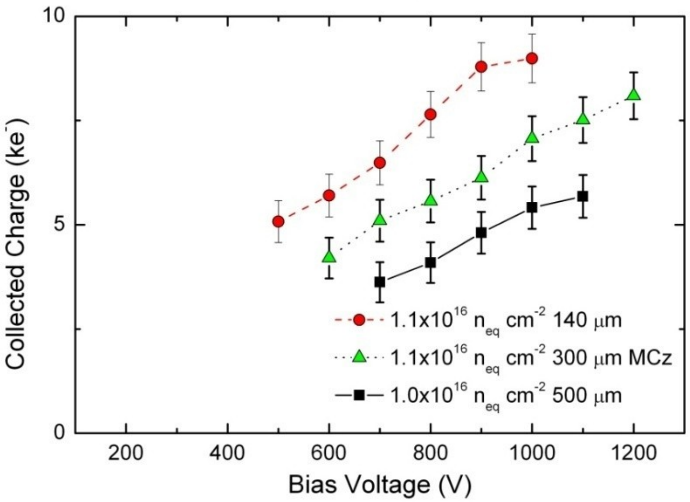


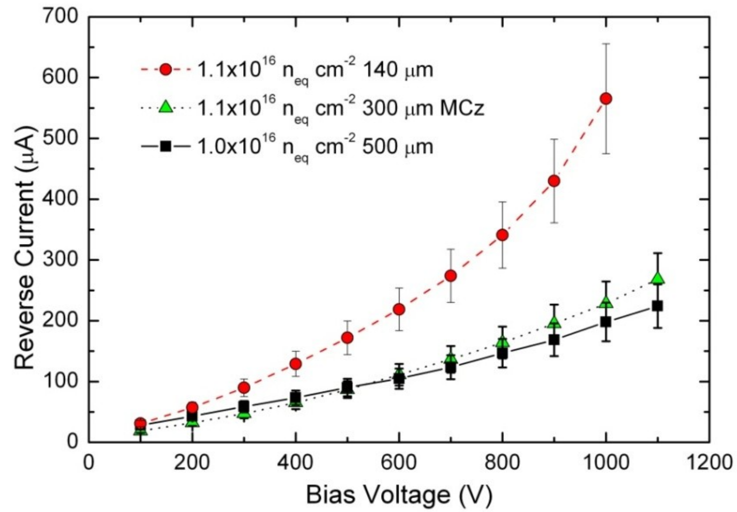
Shown at 2008 IEEE Nuclear Science Symposium, Dresden, 19th-25th Oct 2008
Published: G. Casse, et. al., IEEE Trans. Nucl. Sci., Vol.56 (2009), 3752-3758.

500 Micron Thick Sensors





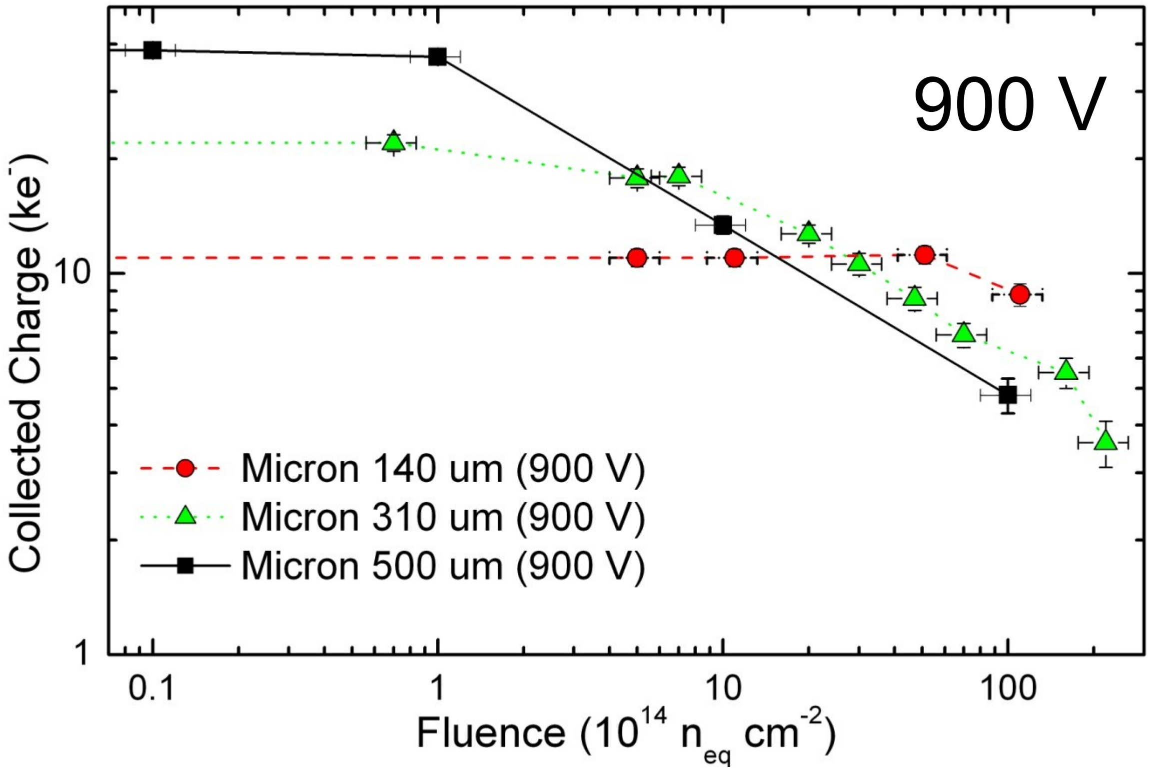




Shown at 5th Trento Workshop, Manchester, 24th-26th Feb 2010
Paper under review IEEE Trans. Nucl. Sci.

Thickness Comparisons

- With same masks and base material (n-in-p FZ) used to make three thicknesses, a clear pattern emerges
  - At low fluences ($<5\times10^{14}$ $n_{eq}cm^{-2}$), "classic" model of V_{FD}, n_{eff} and charge trapping holds
  - At higher fluences (3×10^{15} $n_{eq}cm^{-2}$), "active" base and multiplication are dominant effects



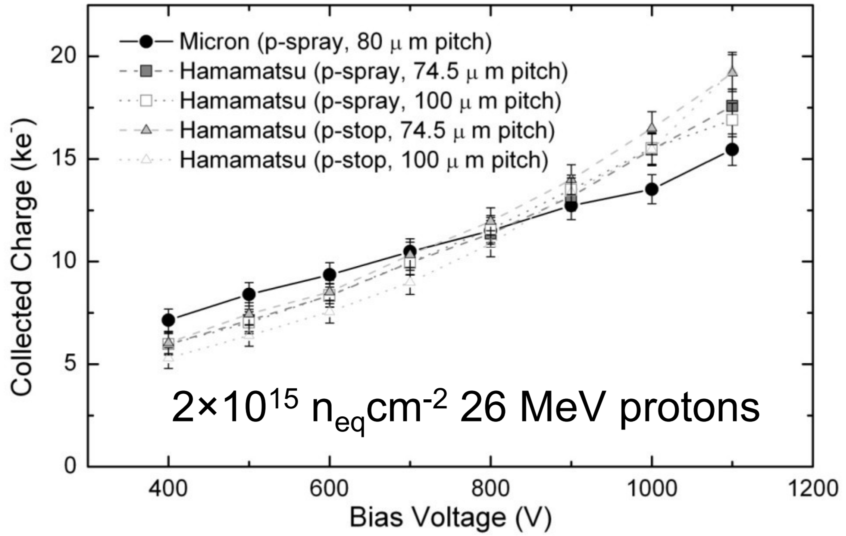
Shown at 5th Trento Workshop, Manchester, 24th-26th Feb 2010
Paper under review IEEE Trans. Nucl. Sci.

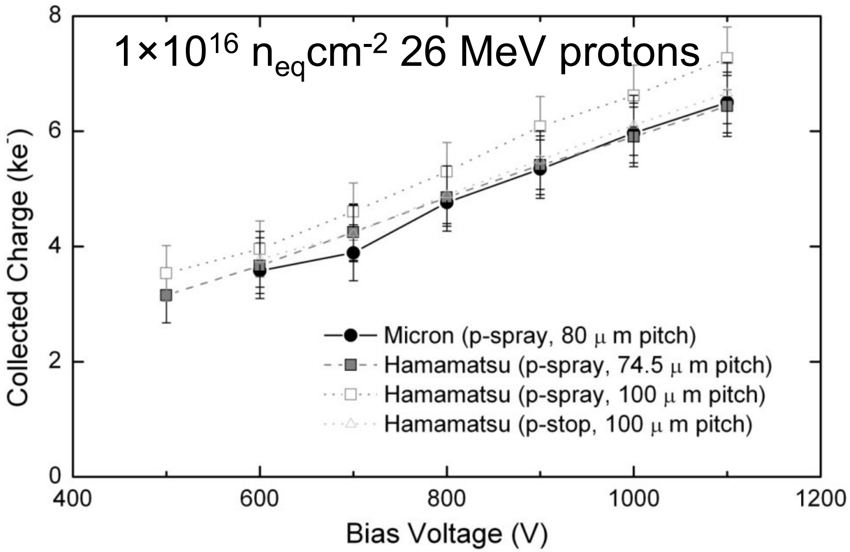
Below 5×10^{14} $n_{eq}cm^{-2}$, charge advantage to being thicker
Above 3×10^{15} $n_{eq}cm^{-2}$, charge advantage to being thinner

P-stop/P-spray

- Used available ATLAS07 HPK minis to start study of the effects of manufacturer, isolation technique (stop/spray) and pitch on collected charge with highly irradiated devices
  - No measureable difference between HPK/Micron, stop/spray or pitch. Weird!

Shown at 5th Trento Workshop, Manchester, 24th-26th Feb 2010
Paper in draft



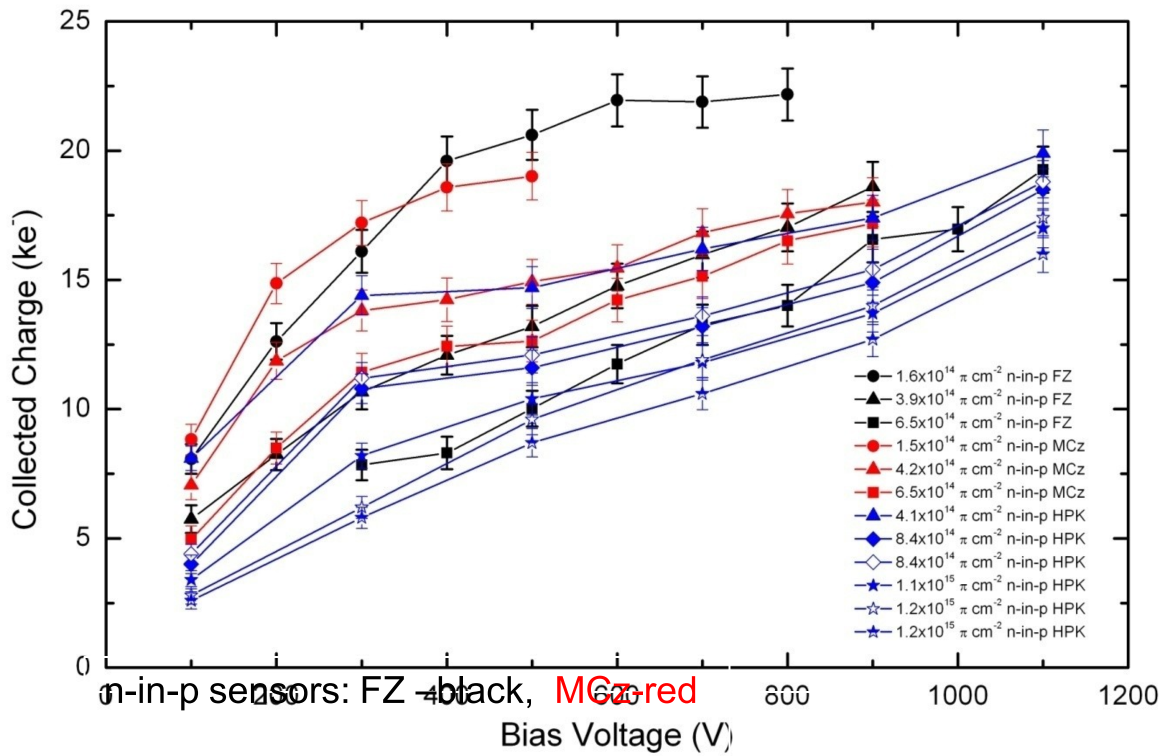


Conclusions

- Various detector configurations and bulk material types have been studied after neutron, pion, and proton irradiations
- With n-strip readout, bulk material type is important for collected charge at lower fluences ($<1\times10^{15}$ $n_{eq}cm^{-2}$)
- At higher fluences ($>3\times10^{15}$ $n_{eq}cm^{-2}$), the collected charge is fairly independent of bulk material type
  - Due to “active” base and charge multiplication
  - Bulk thickness is important with thinner devices yielding higher collected charge and reverse current
- With current RD50 devices, only mixed irradiations and n-in-n MCz after high neutron fluences ($>2\times10^{15}$ $n_{eq}cm^{-2}$) studies left
- New Micron charge multiplication wafer and CNM trenched devices will allow for further study and hopefully design optimization for charge multiplication and “active” base effects

Pion Irradiations

- n-in-p
  - MCz better than FZ as expected



n-in-p sensors: FZ -black, MCz-red

Micron: shown at TIPP09, Tsukuba, 12th-17th March 2009
published A. Affolder, et. al., Nucl. Instr. Meth. A, Vol.623 (2010), 177-179.
HPK: New and unpublished

Significant annealing during irradiation
For highest doses, 13 days at 24 C°