Charge Collection in p-type Si Tracking Detectors

1) LHC Upgrade environment
2) C-V and CCE after Proton/Pion Irradiation
3) Annealing after neutron irradiation
4) Bias Dependence of collected charge
5) Efficiency

M.K. Petterson, R.F. Hurley, K. Arya, C. Betancourt, B. Colby, M. Gerling, C. Meyer, J. Pixley, T. Rice, H. F.-W. Sadrozinski
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Fluence in Proposed sATLAS Tracker

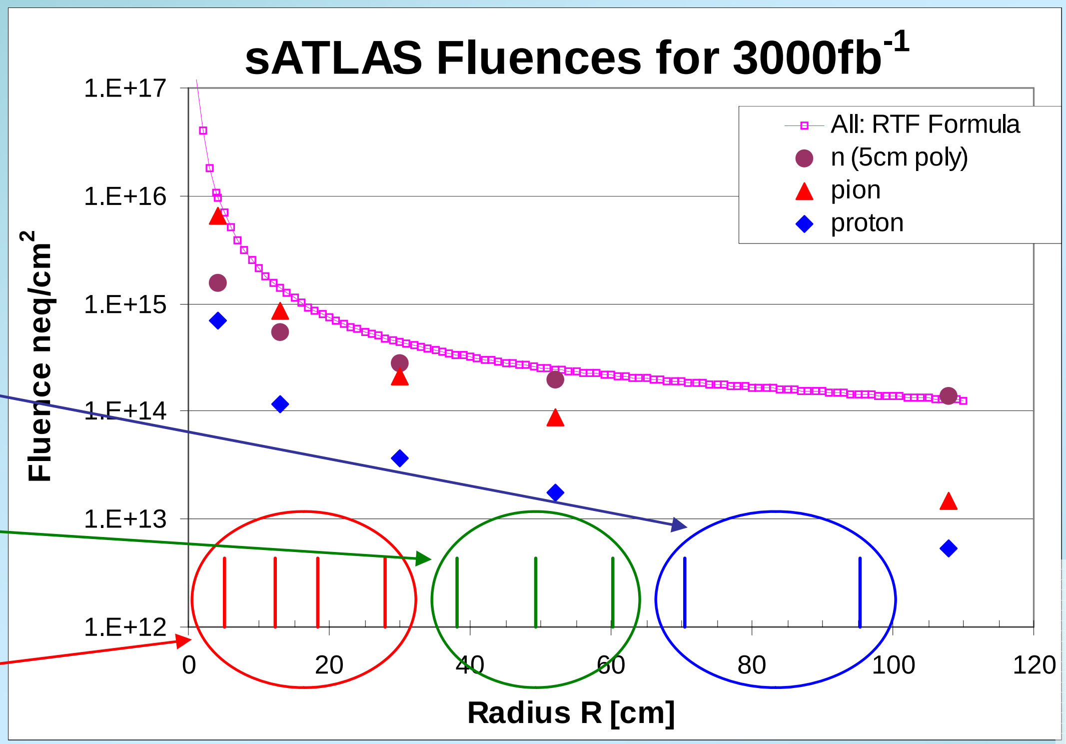
SCIPP

Radial Distribution of Sensors determined by Occupancy < 2%

Long Strips

Short Strips

Pixels



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

5 - 10 x LHC Fluence

Mix of n, p, π depending on radius R

Strips damage largely due to neutrons

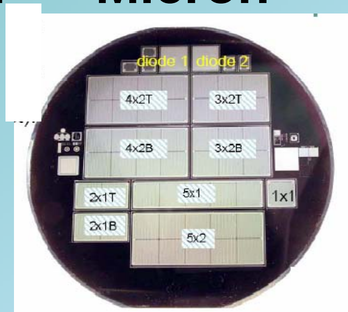
Pixels Damage due to neutrons+pions: need high fluence proton irradiations

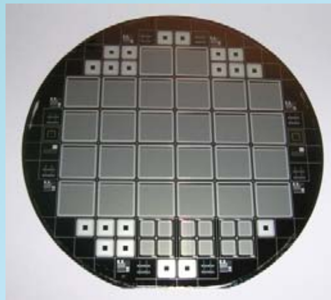
Design fluences for sensors (includes 2x safety factor) **:**

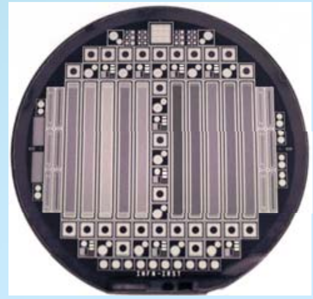
Innermost Pixel Layer:	$1*10^{16}$ neq/cm^2
Outert Pixel Layers:	$3*10^{15}$ neq/cm^2
Short strips:	$1*10^{15}$ neq/cm^2
Long strips:	$4*10^{14}$ neq/cm^2

RD50 Test Sensors

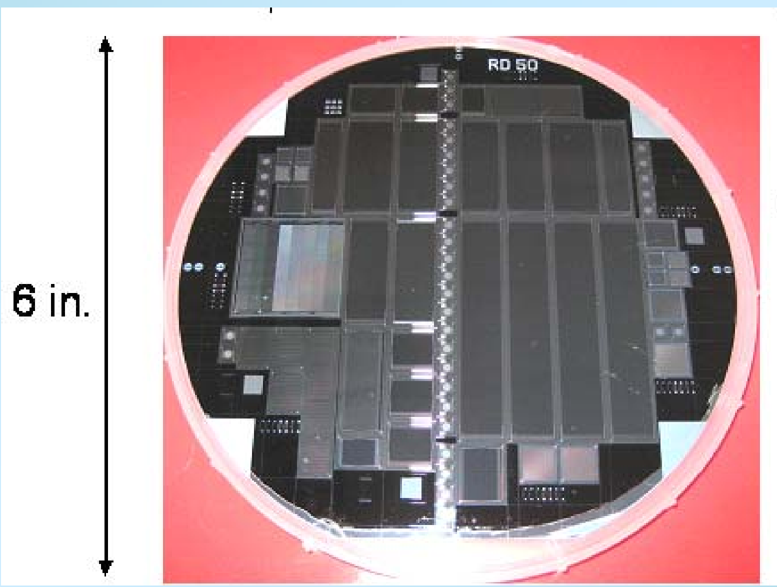
4" : Micron CNM IRST



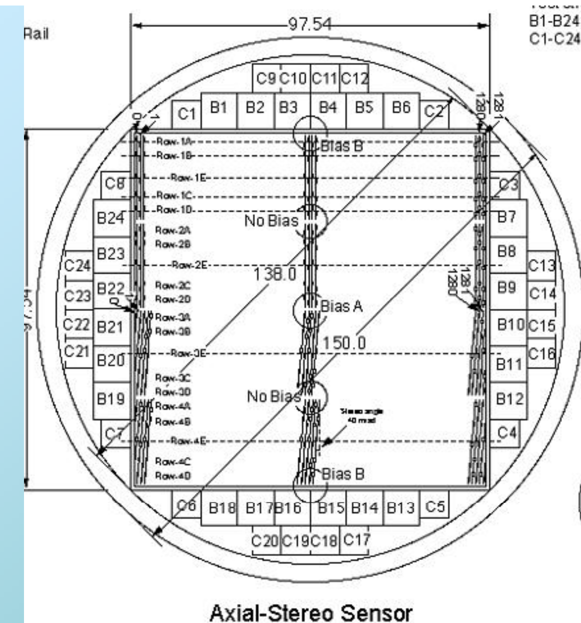




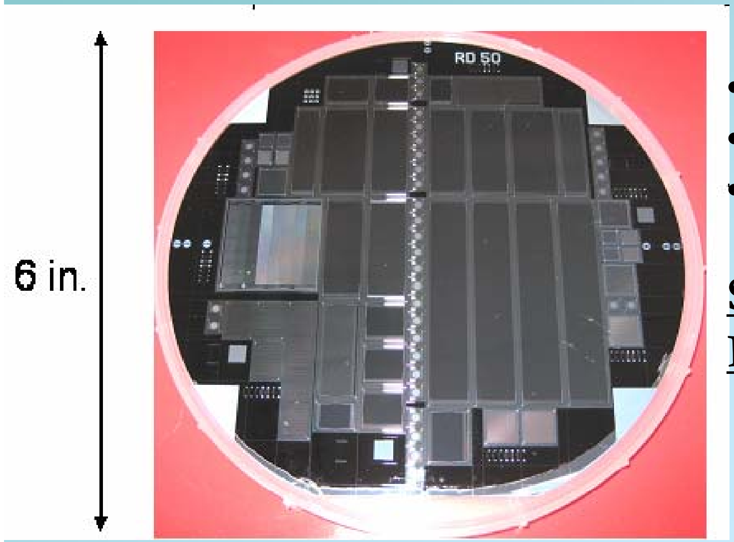
RD50 Common Micron (6")



ATLAS Upgrade HPK (6")



RD50 MICRON 6” project



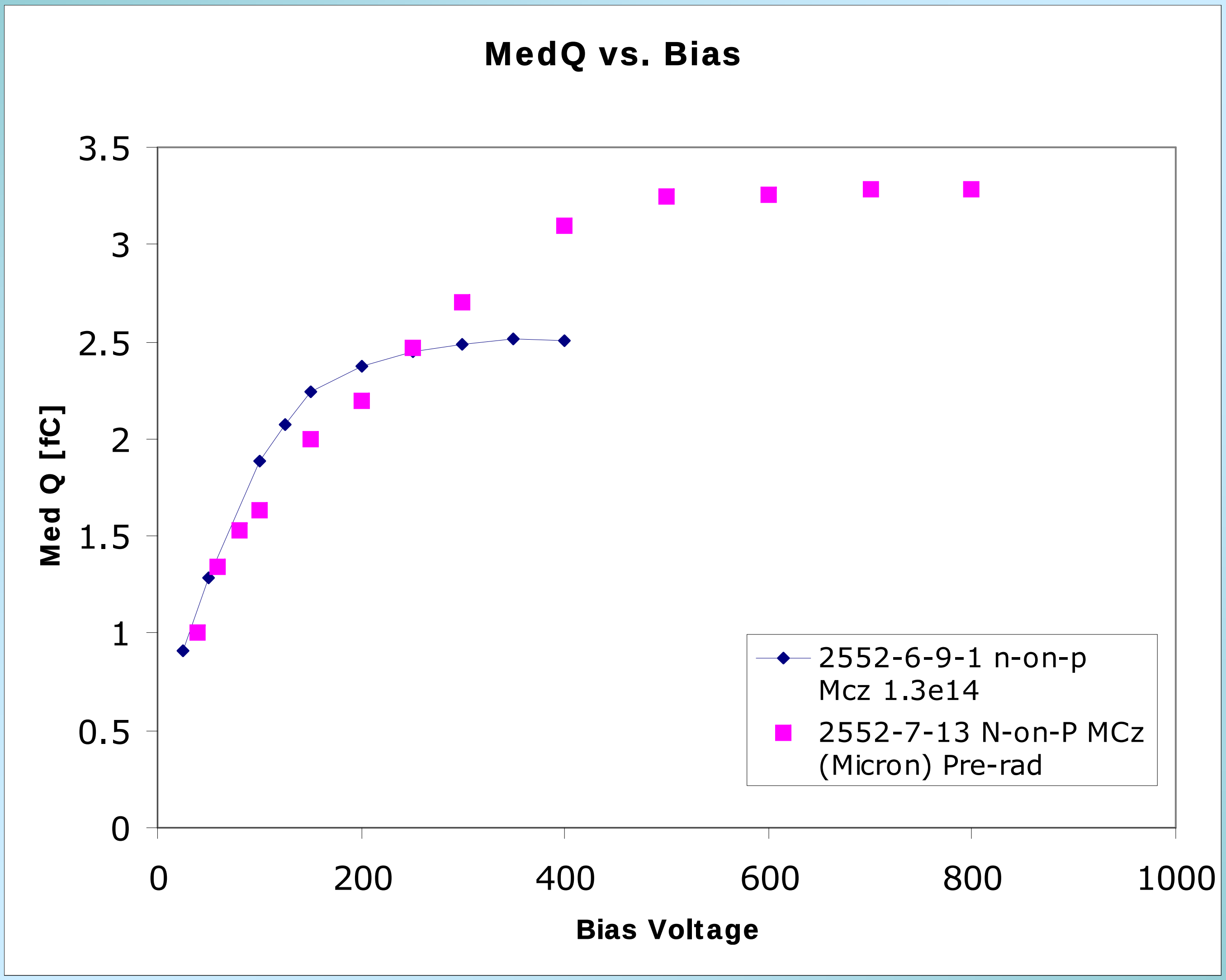
- 36 processed , 20 received
- Fz (Topsil) and MCz (Okmetic) wafers of p&n type material
- n-on-n, n-on-p, p-on-n structures (pixels, strips, diodes)

Strips: ATLAS strips geometry 80 μm pitch (w/p~1/3)
Pads: 5 x 5 mm^2 , multiple guard rings

	MCz (n-p)	MCz(n-n), (p-n)	Fz (n-p)	Fz (n-n), (p-n)
V(FD) [V]	520	220	75	95
Resitivity	1.9 kΩcm	1.4 kΩcm	13 kΩcm	3.3 kΩcm
Orientation	<100>	<100>	<100>	<100>

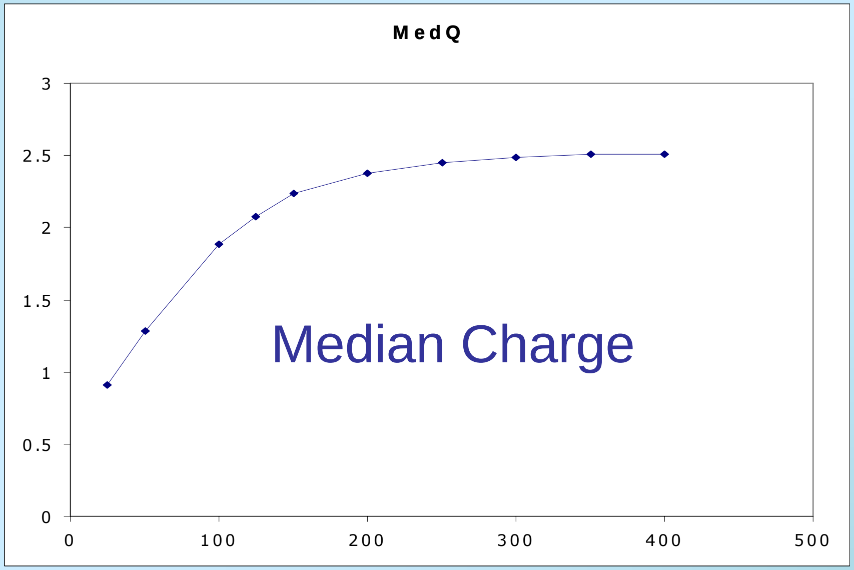
Neutron and Proton and Pion (Aug. ’07) irradiation of SSD and Diodes

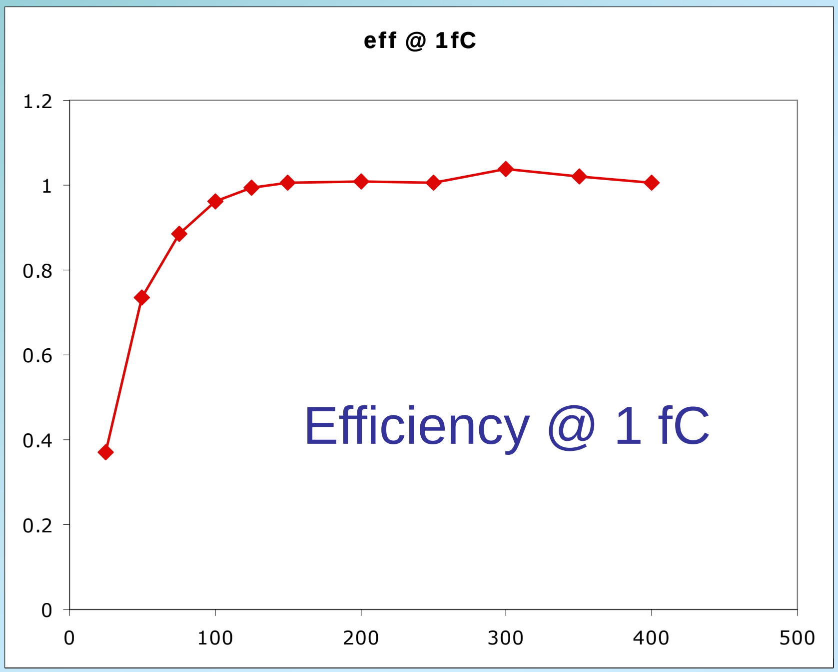
Charge collection CCE in p-type MCz after Proton Irradiation

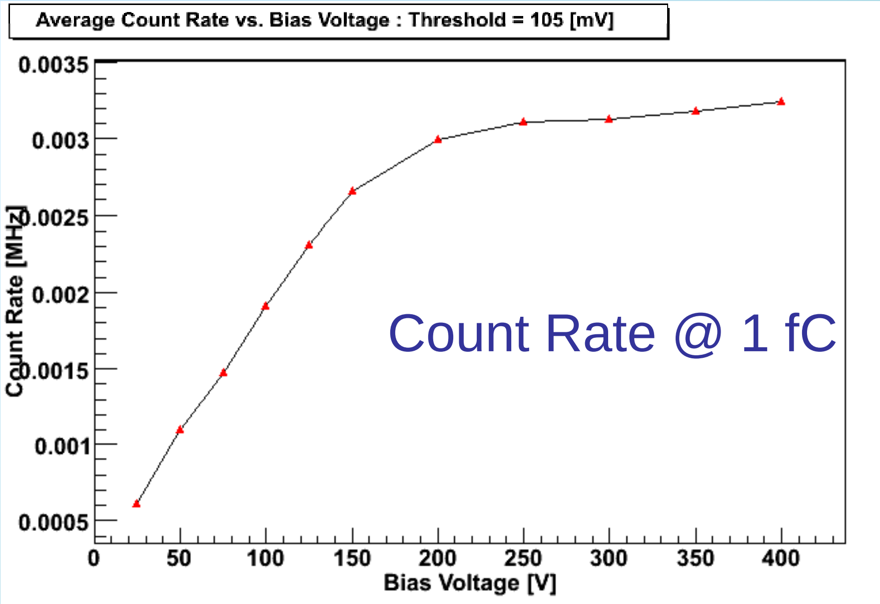


Curious: large loss of charge at small fluence

Bias Dependence of Efficiency, CCE, Singles
Proton Irradiation 1.3e14





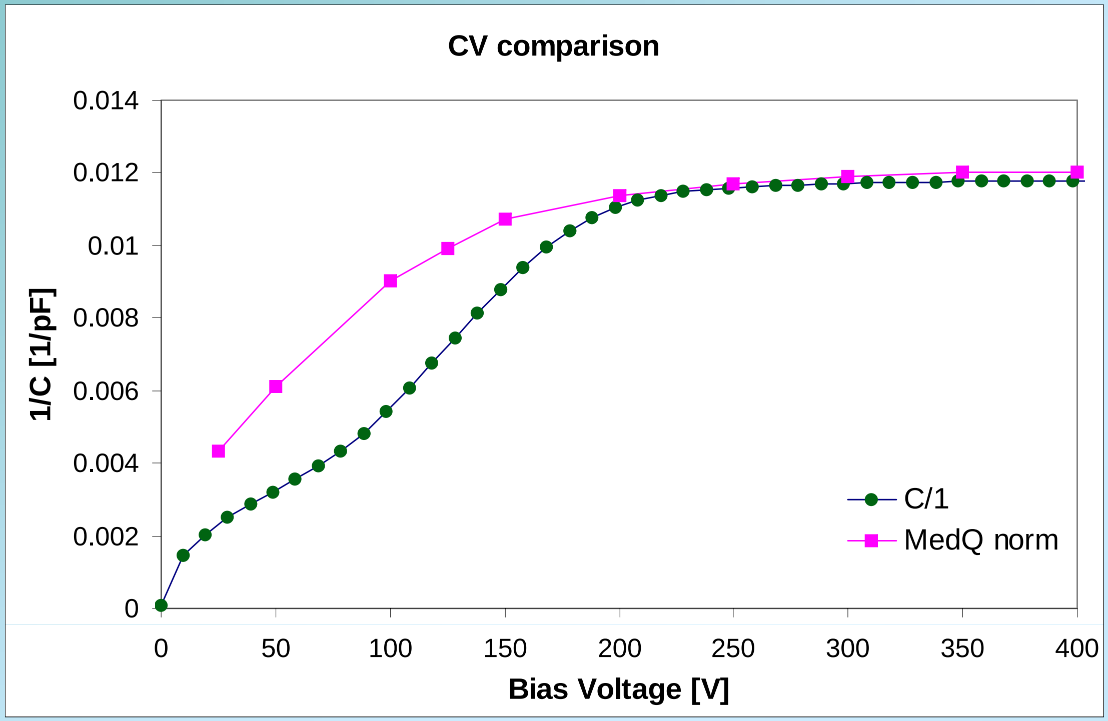


Saturation:

Efficiency before Median pulse height

Median pulse height = Single rate

C-V and CCE in MCz (Protons 1.3e14)

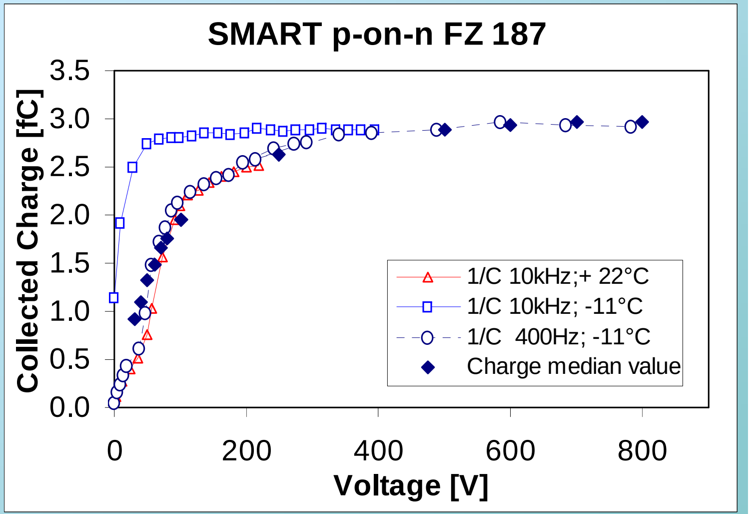


C-V taken at -20ºC and 450Hz

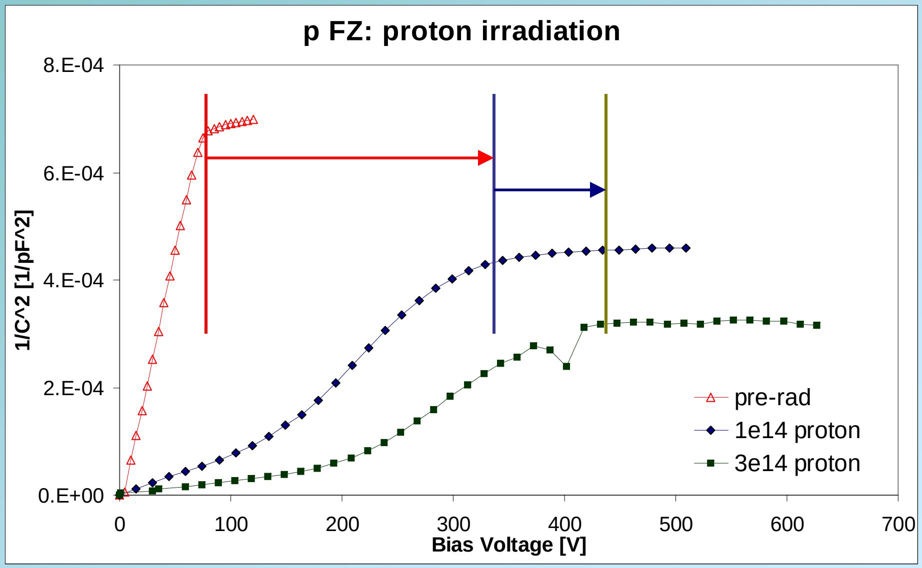
1/C overestimates the depletion voltage

Agreement between
low T– Low f 1/C-V and CCE
less perfect than seen before
in n-type FZ

M.K. Petterson et al., NIMA 583, 189 (2007)

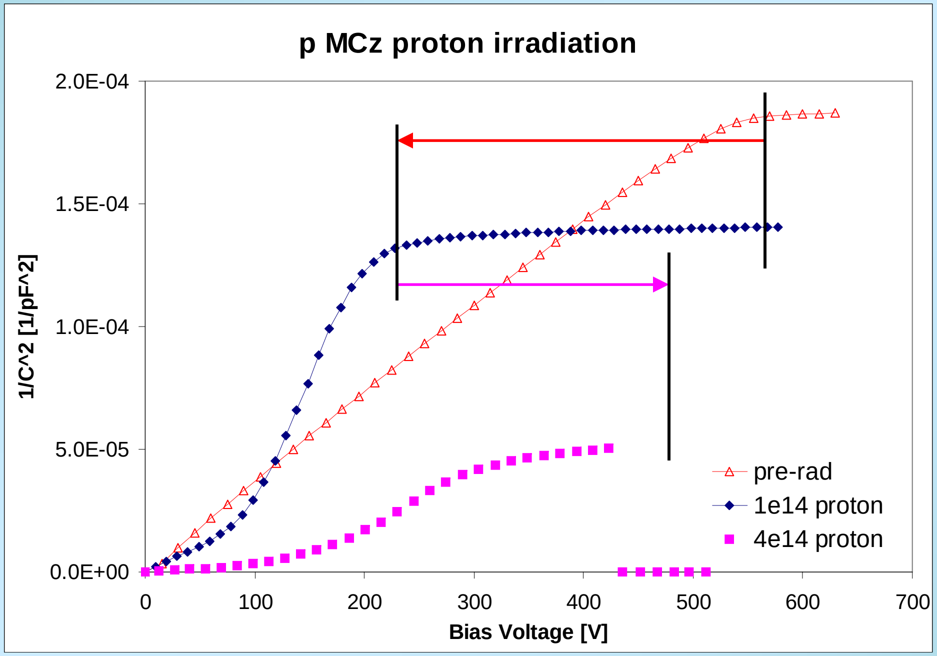


Protons & P-type: Compare FZ and MCz



p-type FZ:

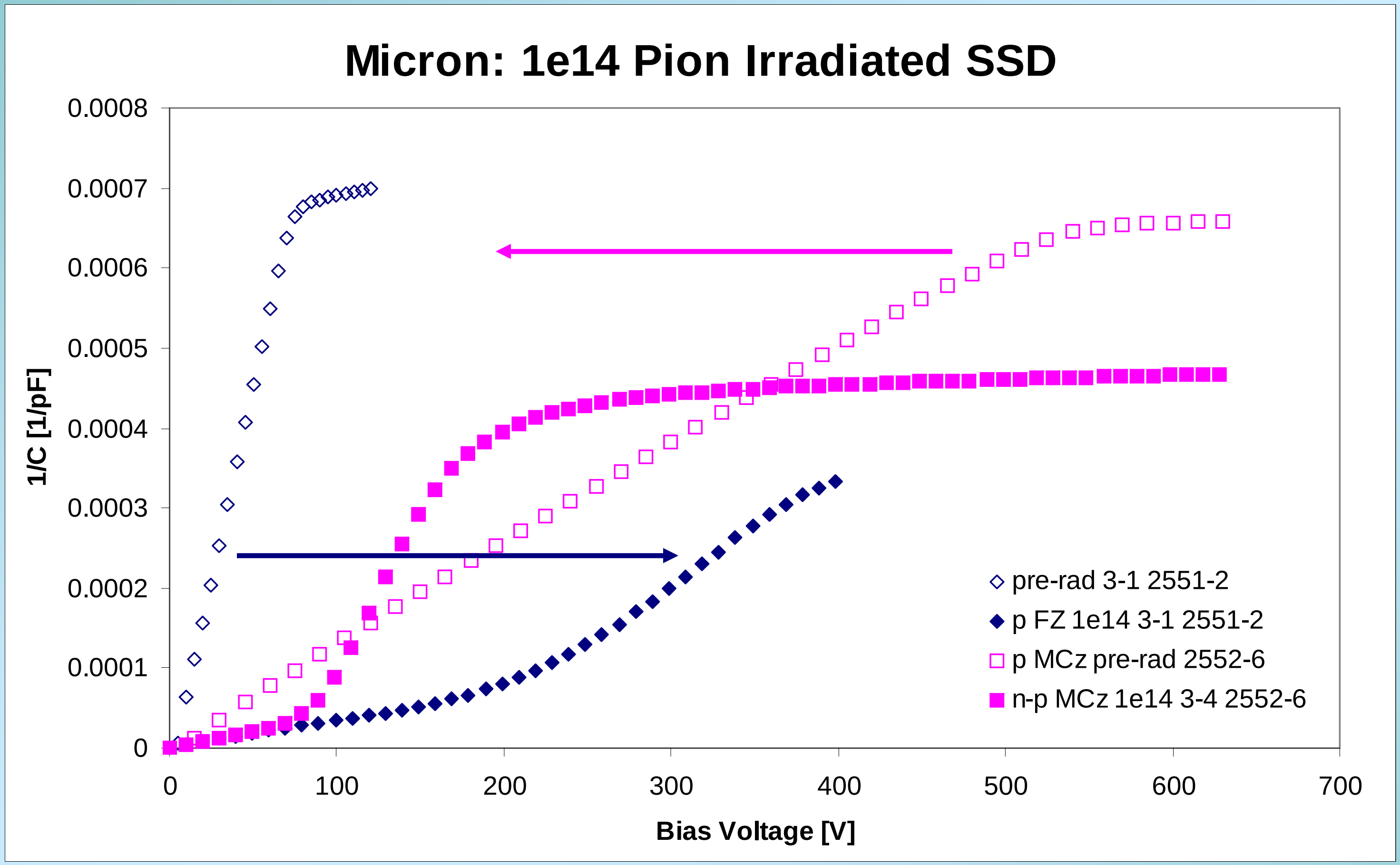
Monotonic Increase in Full Depletion Voltage:
Monotonic Introduction of Acceptors
Material becomes more p-type
Introduction rate not constant? Donor removal?



p-type MCz

Non-Monotonic Increase in depletion voltage:
Introduction of Donors
Material becomes initially more n-type:
Type inversion?
Large initial donor introduction rate

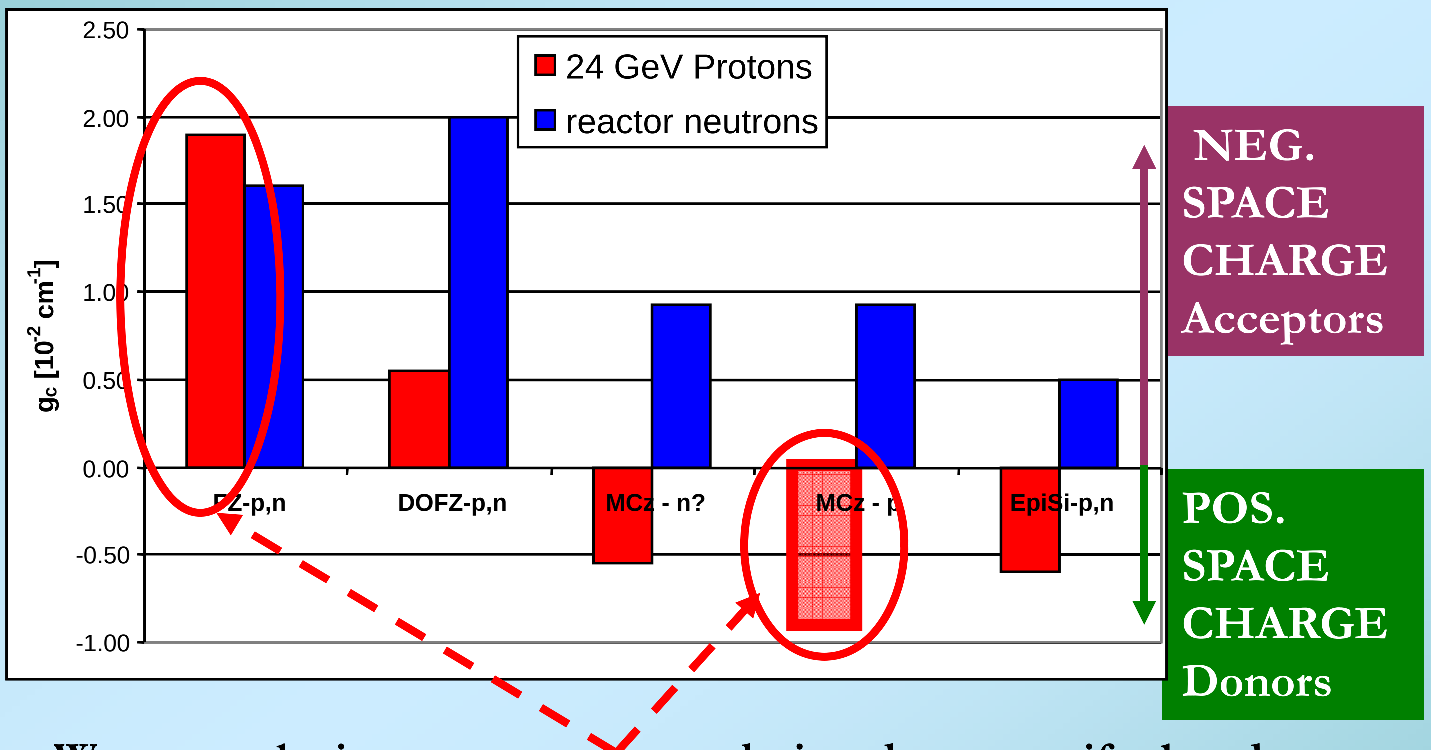
Pions & P-type: Compare FZ and MCz



Same as for Protons: MCz and FZ different!
CCE should be interesting!

New Wafer Scorecard?

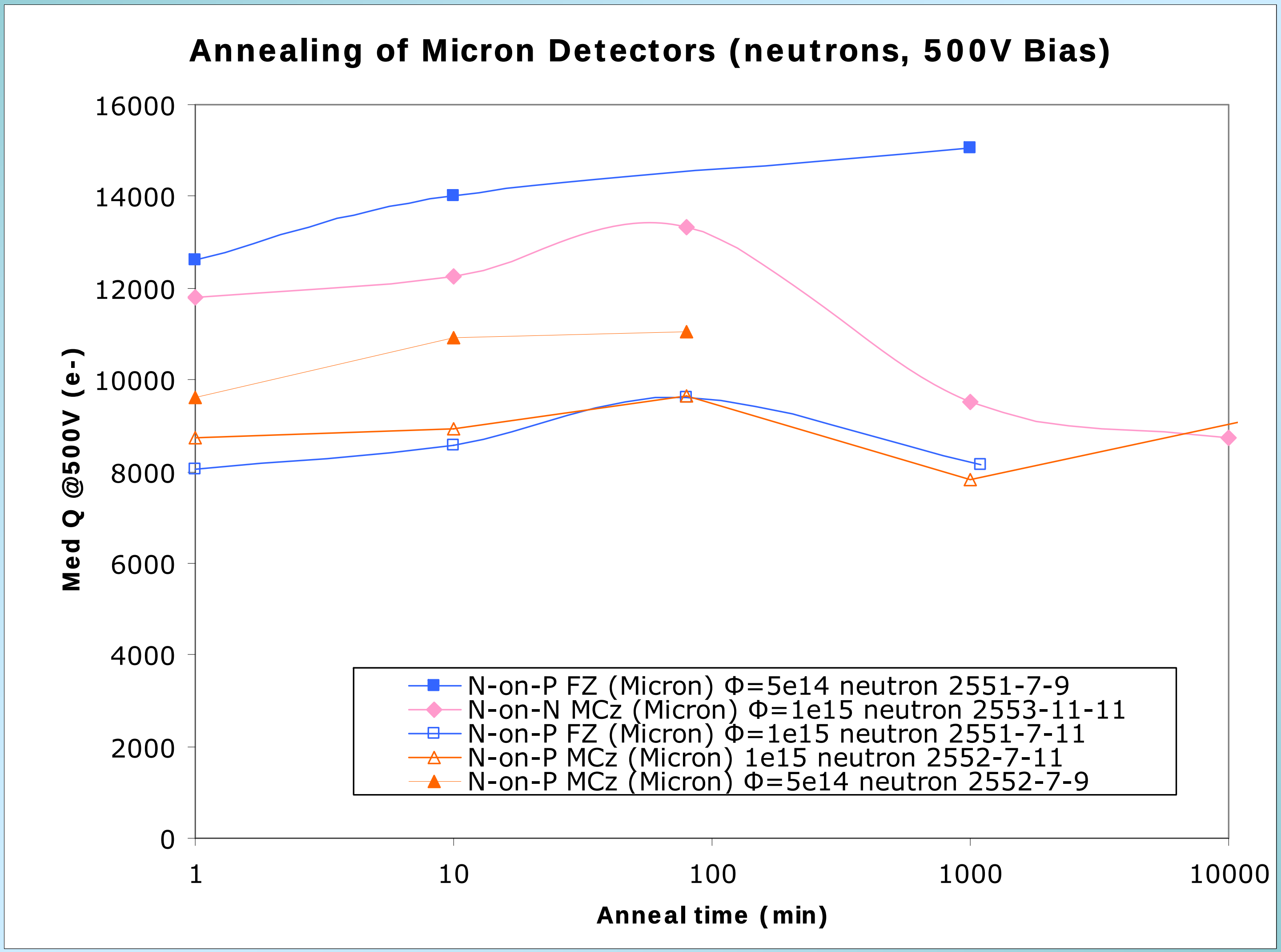
- Materials: $Neff = Neff_0 + g^*\Phi_{eq}$
- For p-type: need $Neff_0$ low: high resistivity
- For n-type, need $Neff_0$ high: low resistivity



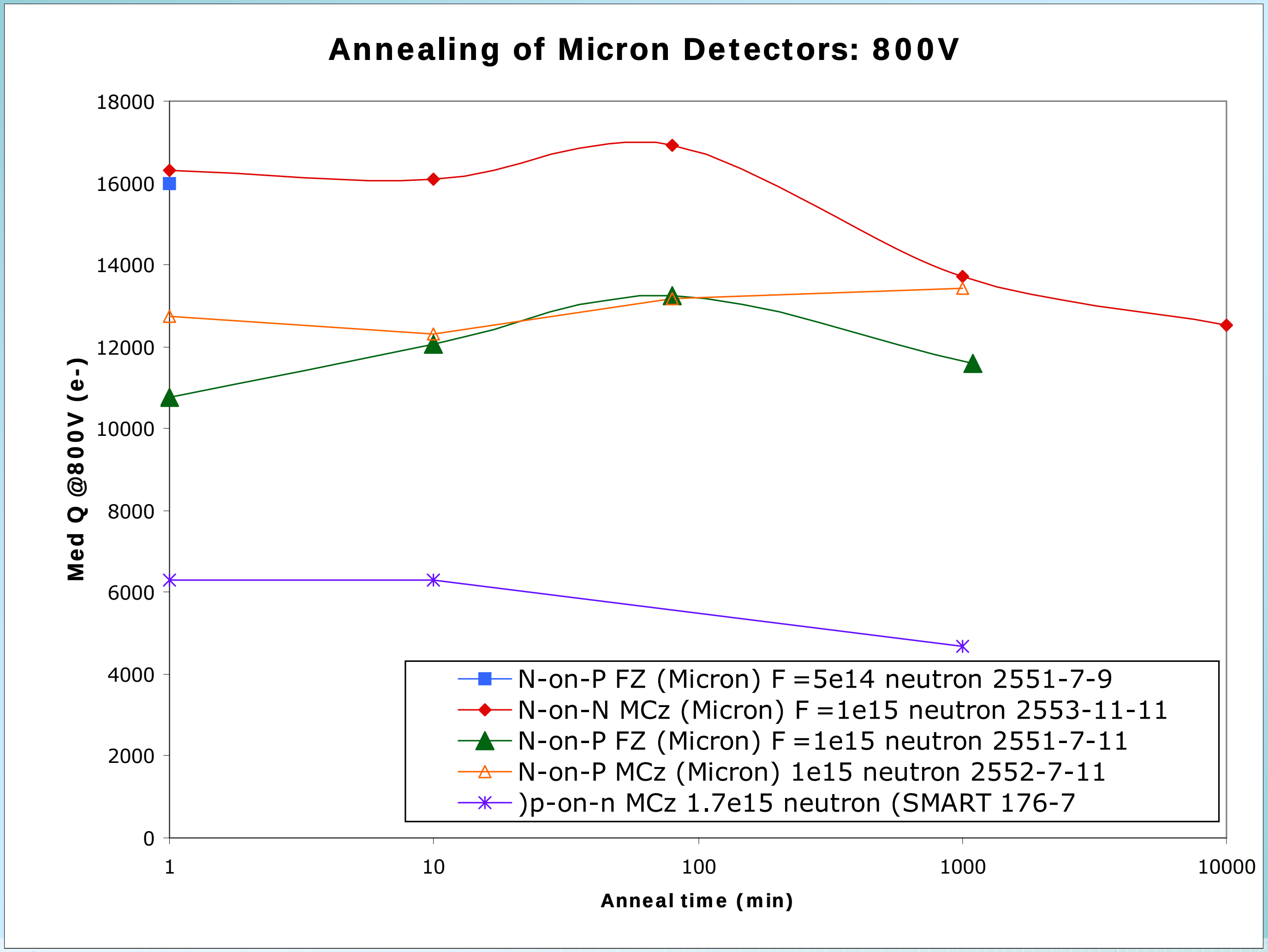
We are analyzing more proton and pion data to verify that donors are produced in p MCz
FZ and Mcz data verified for neutron irradiation:
Radiation damage in MCz different for protons and neutron irradiation?

Annealing of p-type FZ and DOFZ sensors

(n irradiated)



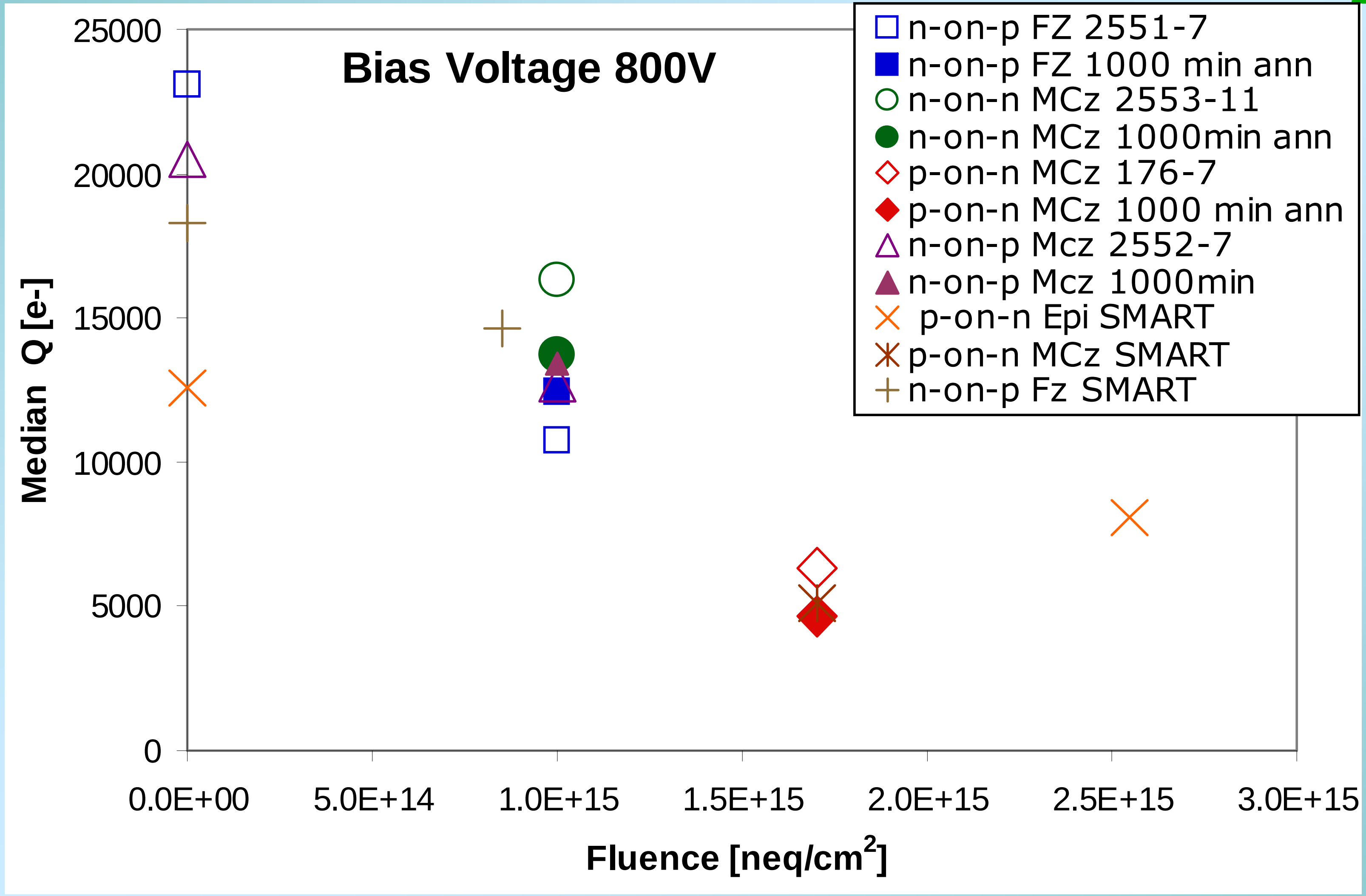
CCE vs. Annealing (n irradiated)



At sLHC fluences for p-type sensors, the entire annealing process is much less pronounced. than for n type FZ.

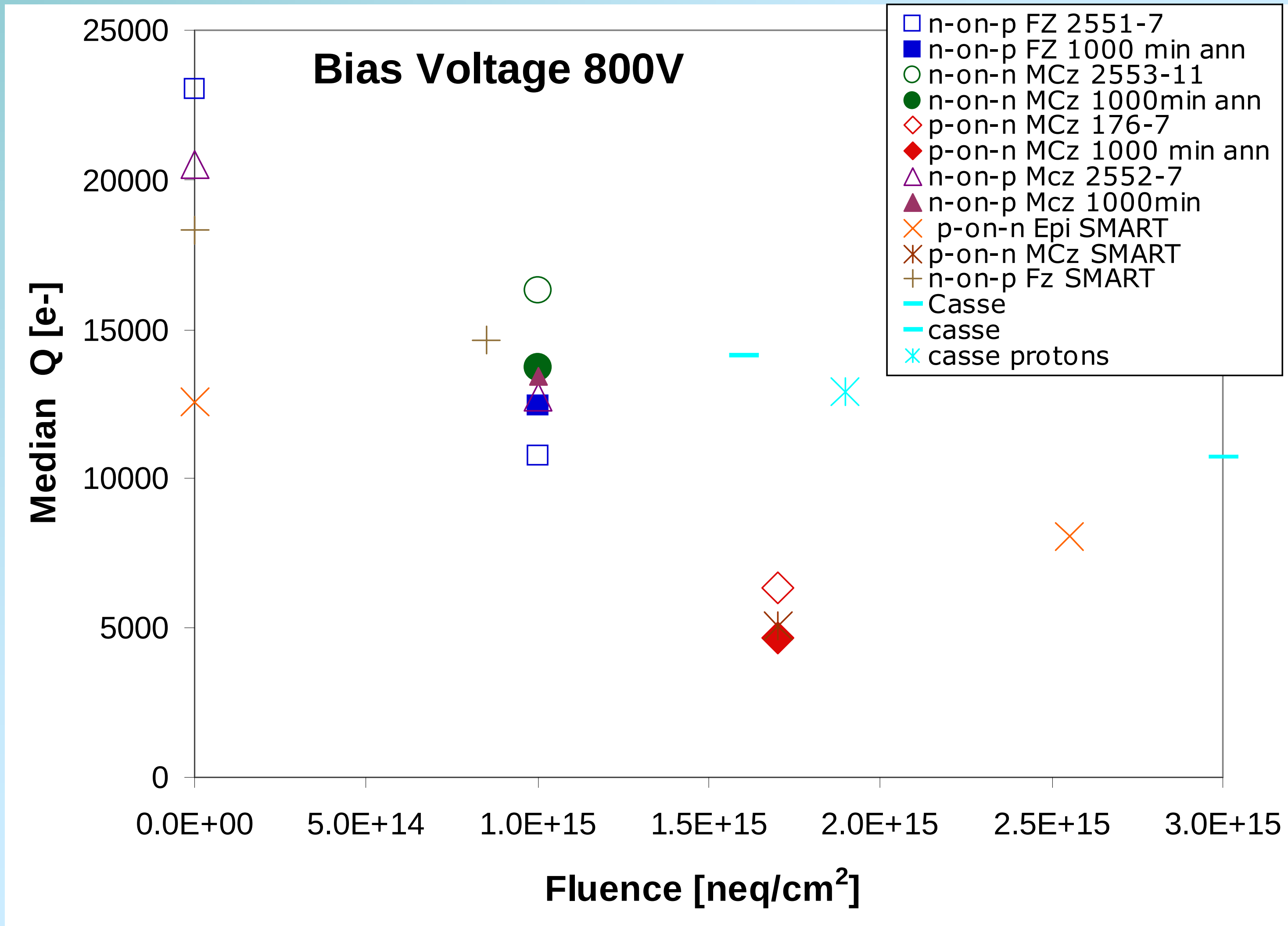
It opens the possibility that sensors need to be cooled only during operations to control the leakage current, but not during beam-off time to prevent anti-annealing

CCE in neutron Irradiated SSD



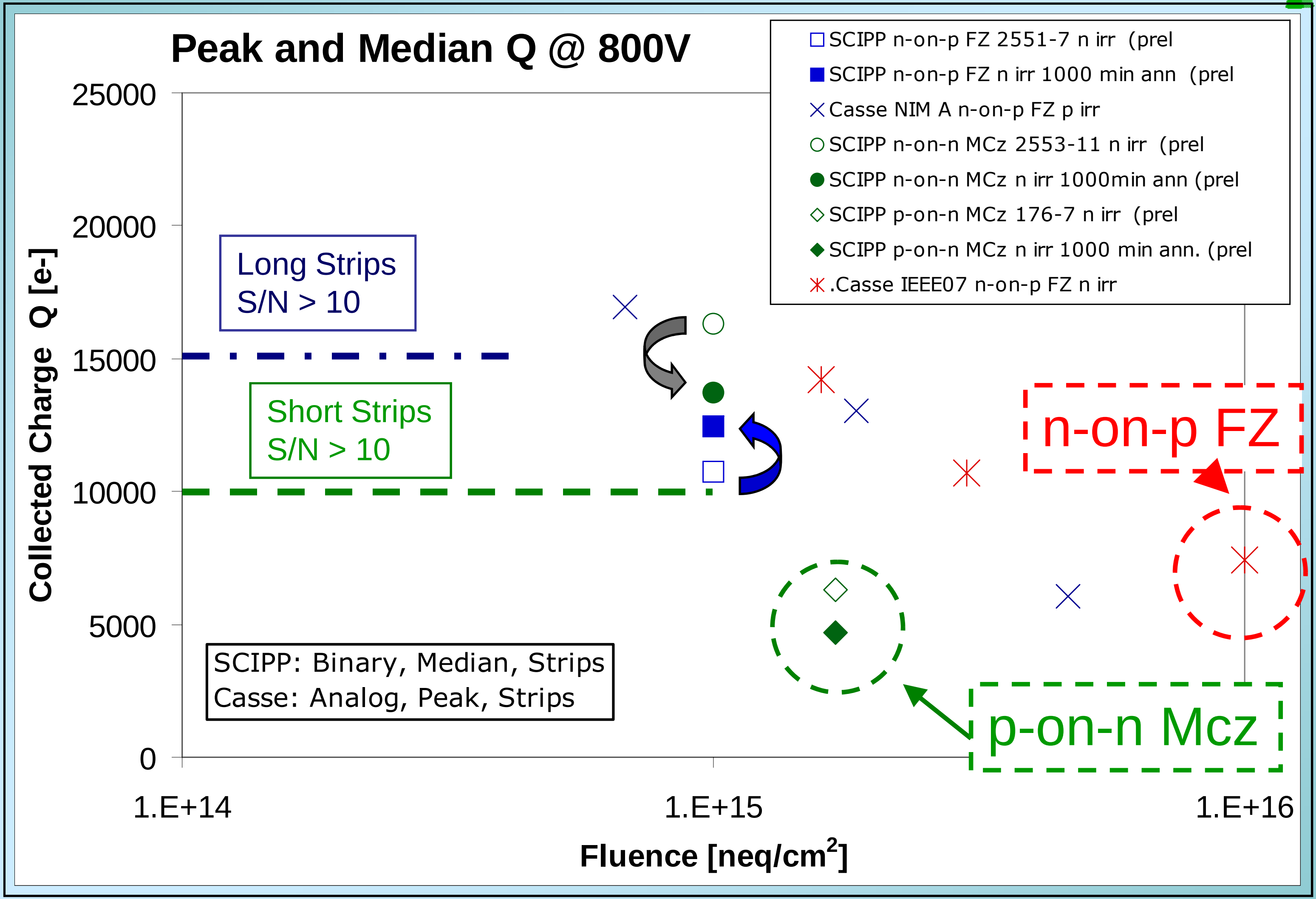
SMART data from A. Messineo (Pisa), Epi(150um) at ~ 300V

Charge Collection in Irradiated SSD



P-on-n MCz and FZ strip sensors not sufficiently radiation-hard for the sLHC
P-on-n Epi (150 µm) is better alternative

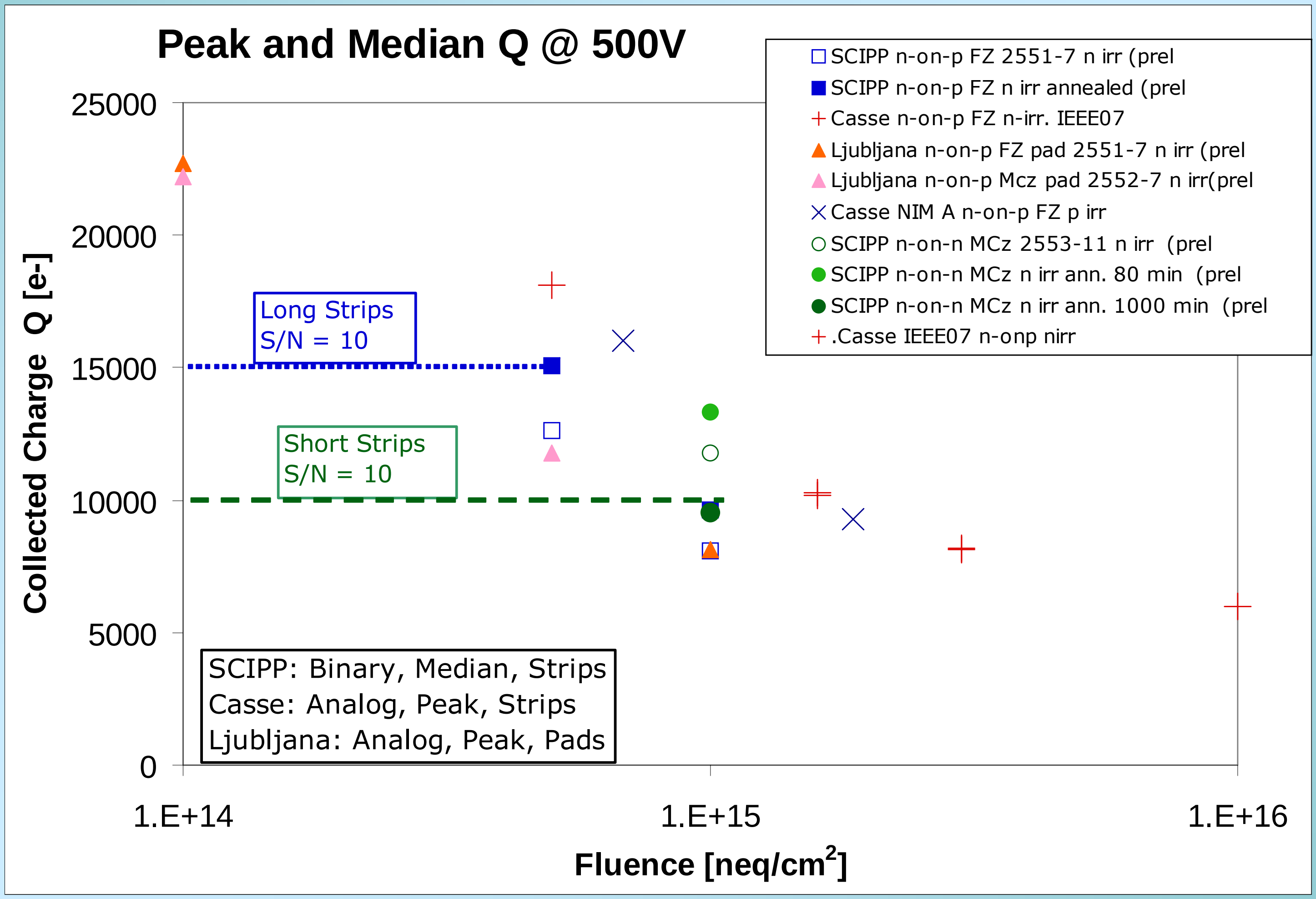
Charge Collection in Irradiated SSD



N-on-p strip sensors are sufficiently radiation-hard for the sLHC

Charge Collection in Upgrade Strips

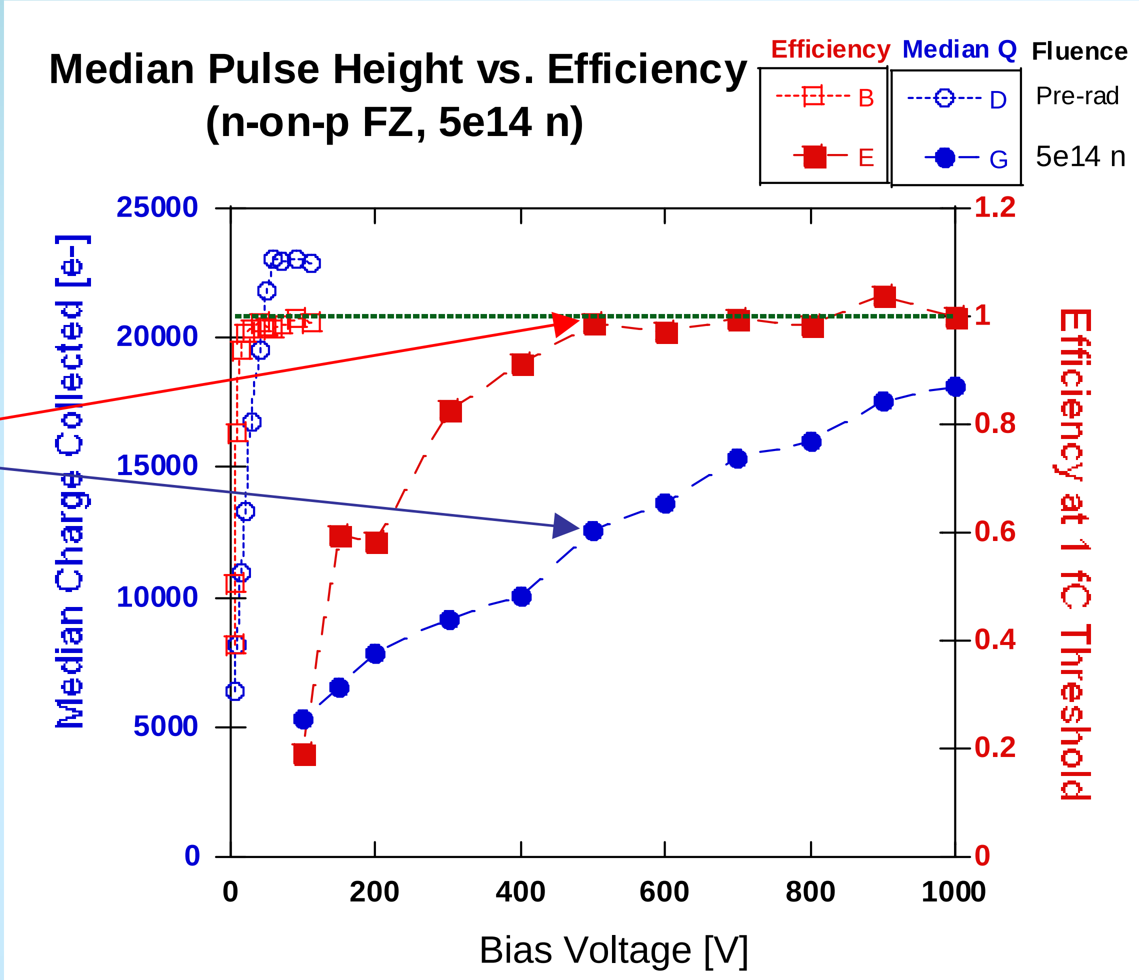
ATLAS bias voltage is constraint to < 500V (cables!).



N-on-p strip sensors are sufficiently radiation-hard for the sLHC ?

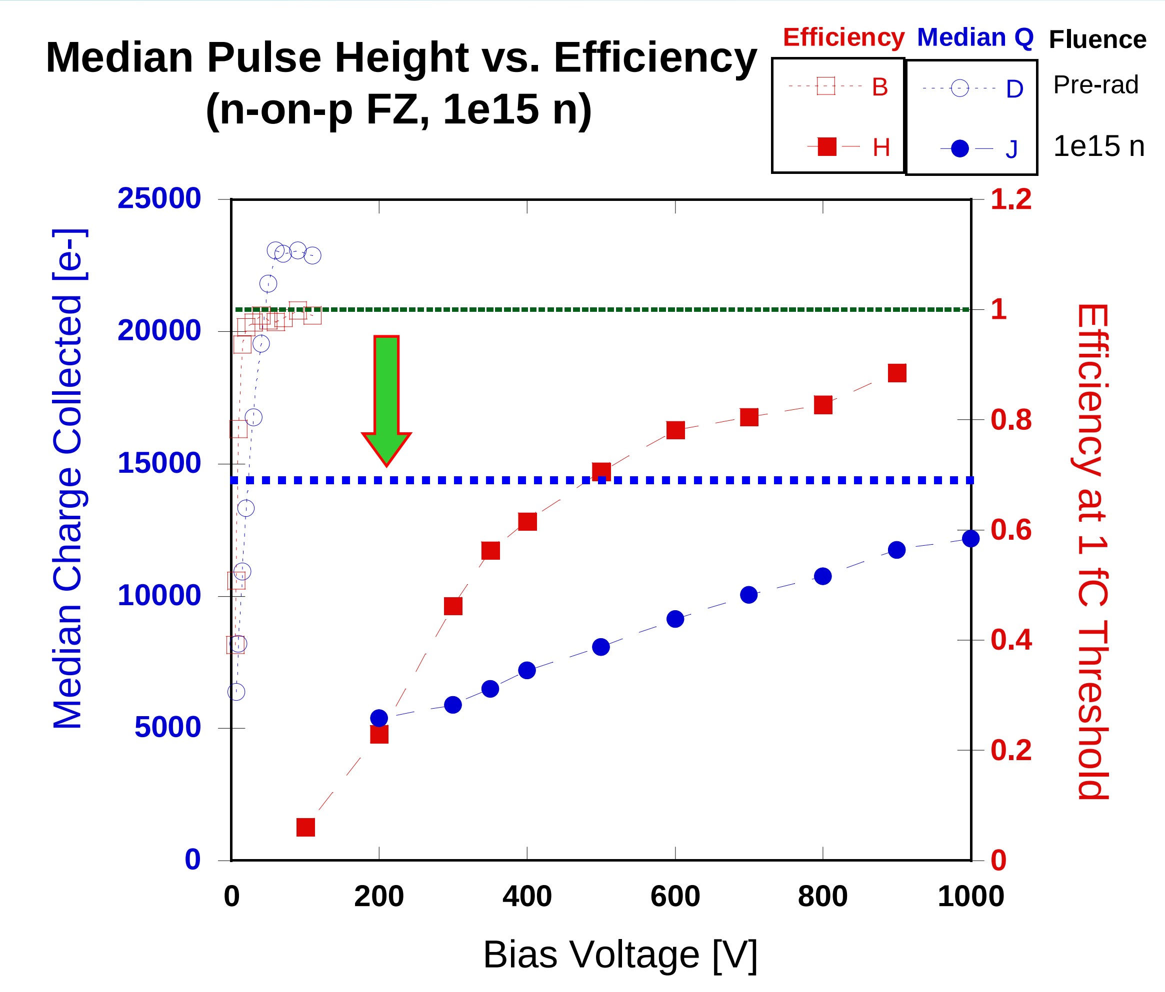
Efficiency vs. Collected Charge

- For tracking sensors with **binary readout**, the **figure of merit** is not the collected charge, but the **efficiency**.
- **100% efficiency** is reached at a signal-to-noise ratio of **S/N ≈ 10**, **S/Thr > 2**
- For **long strips** (5e14 cm^{-2}) with a signal of about 14ke, the usual threshold of 1fC = 6400 e can be used.



Long strips efficient at 1fC threshold

Efficiency vs. Collected Charge



- For **short strips** (1e15 cm^{-2}) with a signal of about 8ke, the efficiency at 500V is only 70%.
- The threshold needs to be reduced to about 4500 e, i.e. electronics must be designed for a noise of ~700e.

Short strips efficient if threshold can be lowered

Conclusions

SCIPP

Much progress with p-type sensors,
both in production and understanding

Difference between proton/pion and neutron radiation damage in MCz.

P-type: FZ seems to be more predictable than MCz.

Good annealing behavior for CCE in p-type

N-on-n has good CCE.

Long strips will work with 1 fC threshold at 500V (ATLAS).

Short strips need lowered threshold at 500V (ATLAS).

Acknowledgments

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