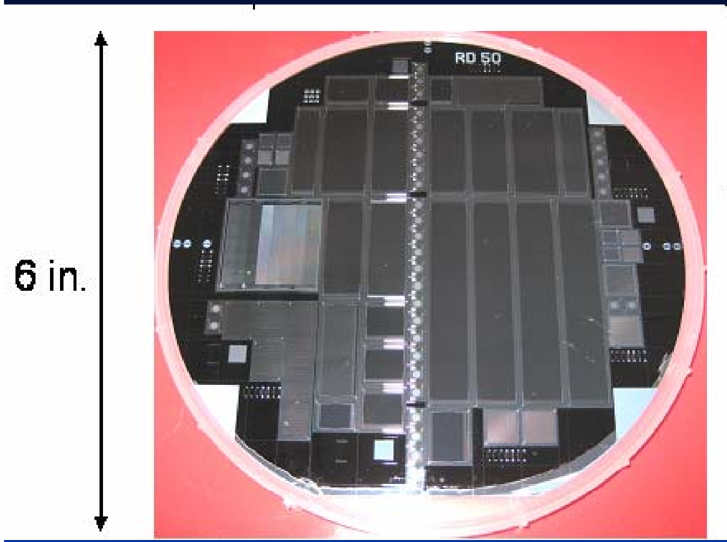
Charge collection measurements on MICRON RD50 detectors

G. Kramberger
Jožef Stefan Institute, Ljubljana
the work done in collaboration with
Santa Cruz and Liverpool

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: 2.5 x 2.5 mm^2 , multiple guard rings
Material selected for the study!

	MCz-p	MCz-n	Fz-p	Fz-n
Wafers	2552-6,7	2553-11; 2552-10,14	2551-1,3,4,6,7	2535-11; 2535-8,9
Resitivity	1.5 Ωcm	2 kΩcm	14 kΩcm	~20 kΩcm, ~3 kΩcm
Orientation	<100>	<100>	<100>	<100>

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

- **Liverpool and Santa Cruz:** CCE with SSD
- **Ljubljana:** CCE with Diodes, C-V, I-V

Samples

Single particle irradiations:

•**Reactor neutron irradiations:** for each material 3 fluences
$1, 5, 10 \cdot 10^{14}$ cm^{-2} – **12 diodes**
- **6 strip detectors**

•**200 MeV pion irradiations:** for each material 3 fluences
1.5, 3.2 (3.9), ~6.5(5.6)$\cdot 10^{14}$ cm^{-2} – **12 diodes**

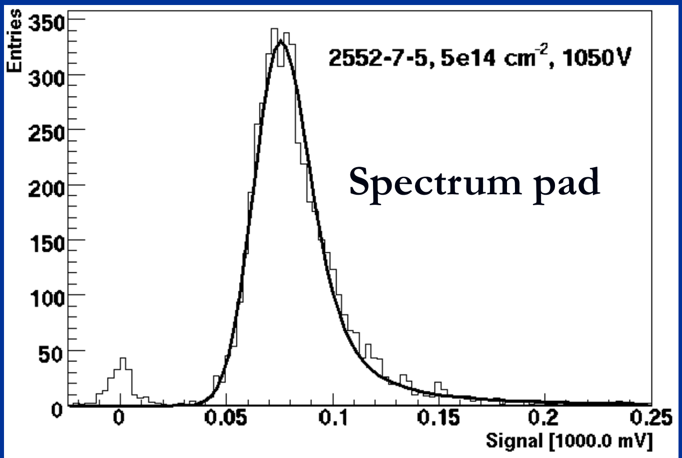
•**24 GeV proton irradiations:** for each material 5 fluences
1.85, 4.81,11,19.3,48.7$\cdot 10^{14}$ cm^{-2} – **20 diodes**

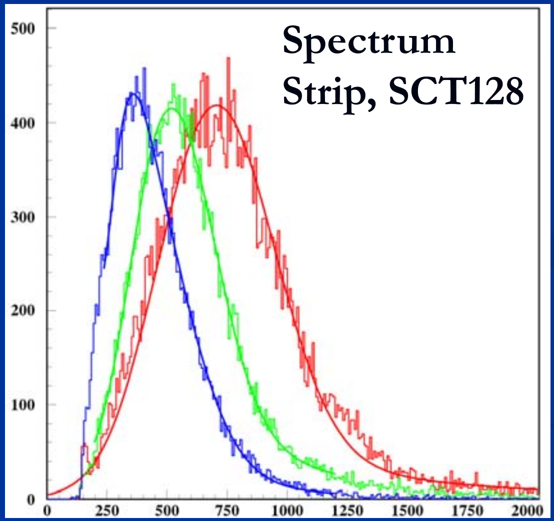
The fluences are in range of upgraded ATLAS - SCT

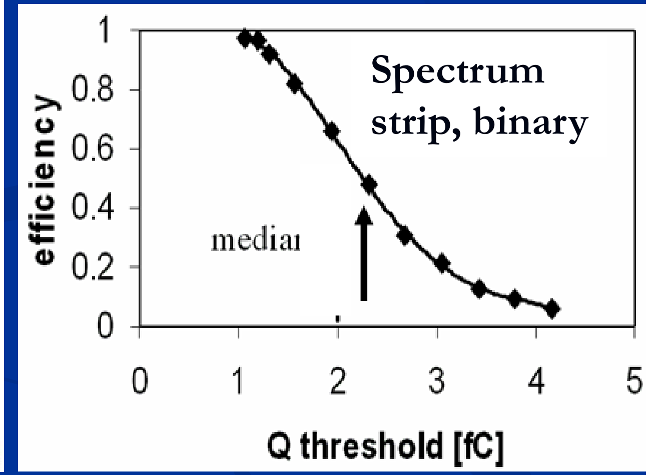
Samples annealed in steps to 80 min@60°C (this is still ongoing study …):

Measurement techniques

- Charge collection
  - pads, 25 ns shaping, T=-10^{o}C (JSI), most probable – "peak" charge shown
  - Strips, SCT128A, T=-25^{o}C (Liverpool), most probable cluster charge – "peak" charge shown
  - Strips, binary 100 ns, T=-30^{o}C shaping (SCIPP), mean charge shown







- CV (10 kHz, T=20C)

What do we want to know?

The work has been motivated by ATLAS strips!

Fluences

- target fluence 10^{15} cm^{-2} for short strips (composition 50% neutrons, 50% charged hadrons)
- target fluence $5\cdot10^{14}$ cm^{-2} for long strips (neutrons dominate >80%)

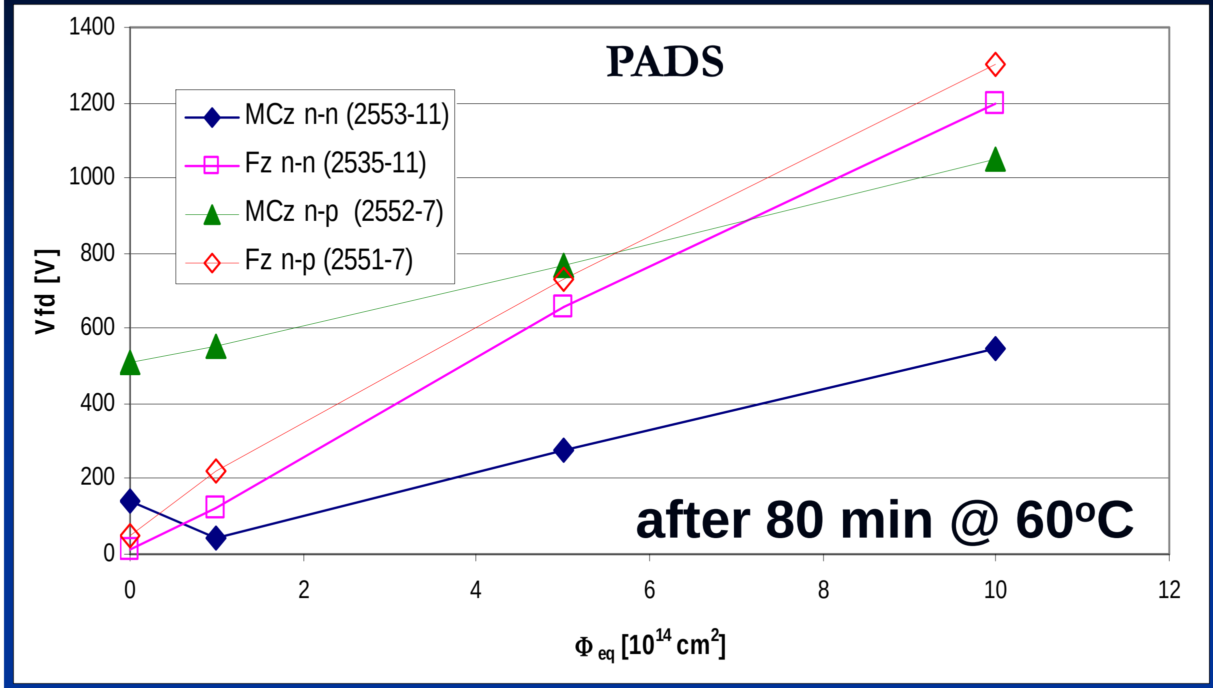
- All strip detectors studied are with n^+ readout (n-on-p and n-on-n) – “electron collection”
- Pion and proton irradiated diodes used for material study

⬇

Answer to the following questions:

- Is V_{fd} from C-V relevant for Q(CCE)-V ?
- What charge can we expect at 500 V for different materials?
- How much does charge collection depend on different readout (pads, strips, binary, analog)
- What is the most promising material ?
  - Is there acceptor removal with neutrons?
  - What is introduction rate of stable damage?
- Is there any difference in CCE for equivalent fluence of different particles and materials

C-V Measurements (neutrons)



- all detectors have negative space charge (decrease of V_{fd} during short term annealing)
- Leakage current agrees with expectations ($\alpha \sim 3.5\text{-}5.5 \cdot 10^{-17}$ A/cm)

Slope of V_{fd} increase with fluence
- MCz (p and n type): 55 V/10^{14} cm^{-2} ($g_c \sim 0.8$ cm^{-2}) – **lower stable damage than seen before ?**
- Fz (p and n type): 125 V/10^{14} cm-2 ($g_c \sim 1.8$ cm^{-2}) – in agreement with previous results

There is no evidence of acceptor removal (neutron irradiated samples)

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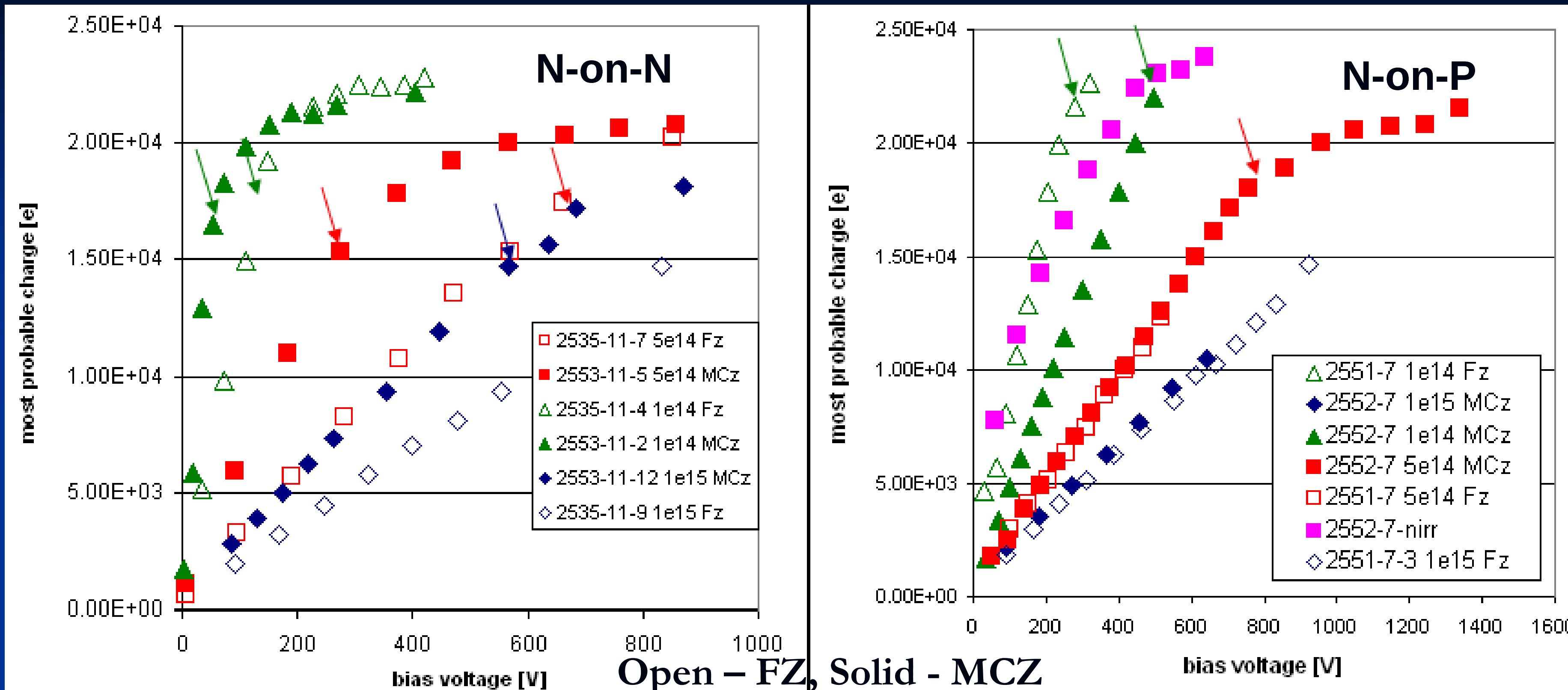
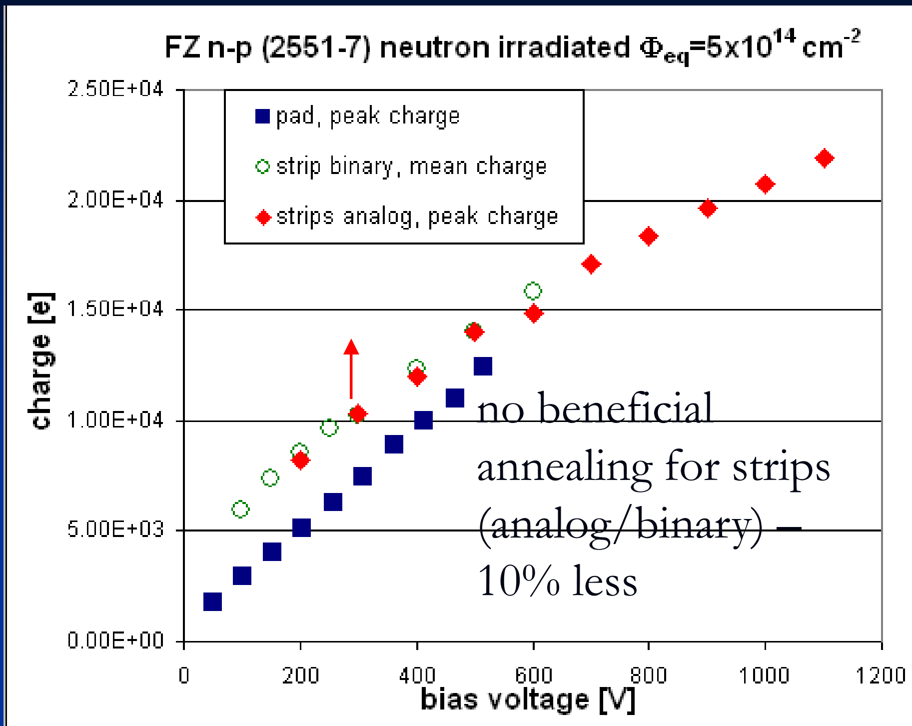
It seems that MCz should perform better – do we see this performance in CCE!

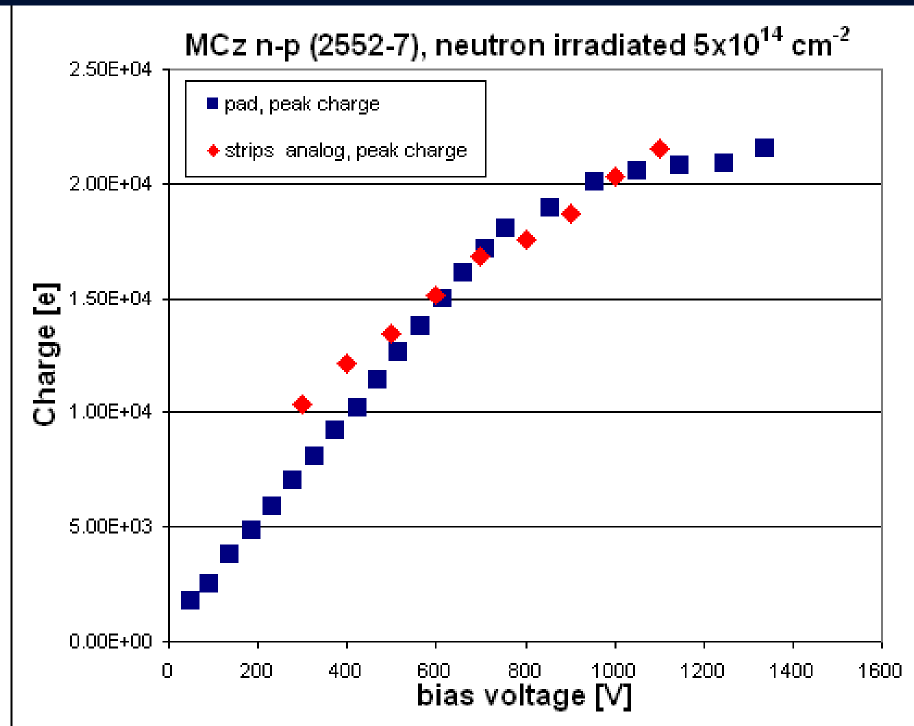
Charge collection pads (neutrons)



- V_{fd} from CV (denoted by arrows) agrees well with the kink in CCE
- The slope of charge increase with voltage is directly related to V_{fd}:
  - increase of V_{fd} can be measured by the change of slope and vice versa
  - Similar V_{fd} = similar slope -> same E field or not very important, true for pads
- High resistive non-depleted bulk is well reflected in linear increase of charge – different from non-irr.

Detectors irradiated to $\Phi_{eq}=5\cdot10^{14}cm^{-2}$ (neutrons)



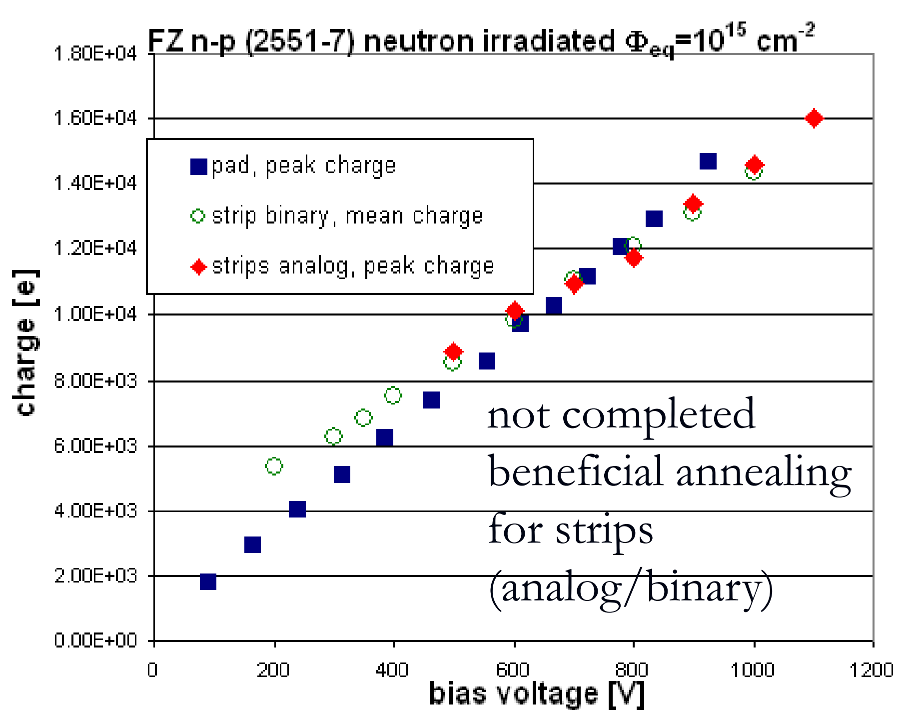


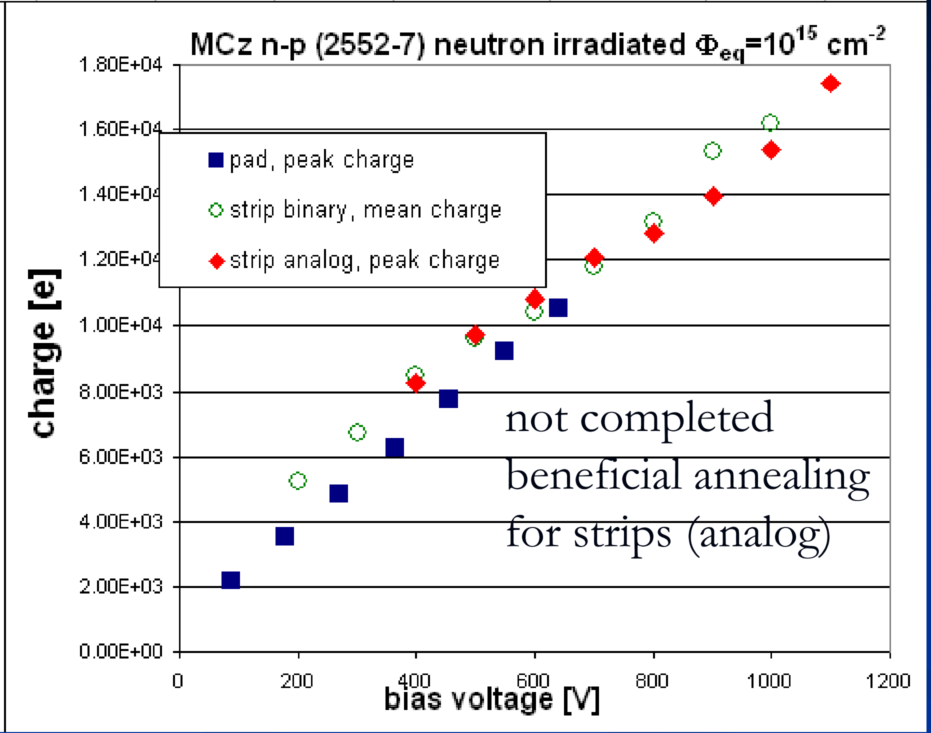
•The values for strips are underestimated, due to non-completed beneficial annealing

•The beneficial effect of electron collection at low bias voltages, due to strip segmentation depletion growth in that region (at high voltages the effect becomes smaller)

•the charge on neighbors in binary is often below the threshold (high) – reduction of "visible" mean charge (binary) = most probable charge (analog) → around ~20% charge in analog comes from neighbors

Detectors irradiated to $\Phi_{eq}=1\cdot10^{15}cm^{-2}$ (neutrons)





- The values for strips are underestimated, due to non-completed beneficial annealing
- Similar charge collection properties of MCz and Fz (similar V_{fd})!
- For material characterization pads are very useful -> a reasonable agreement with strips!

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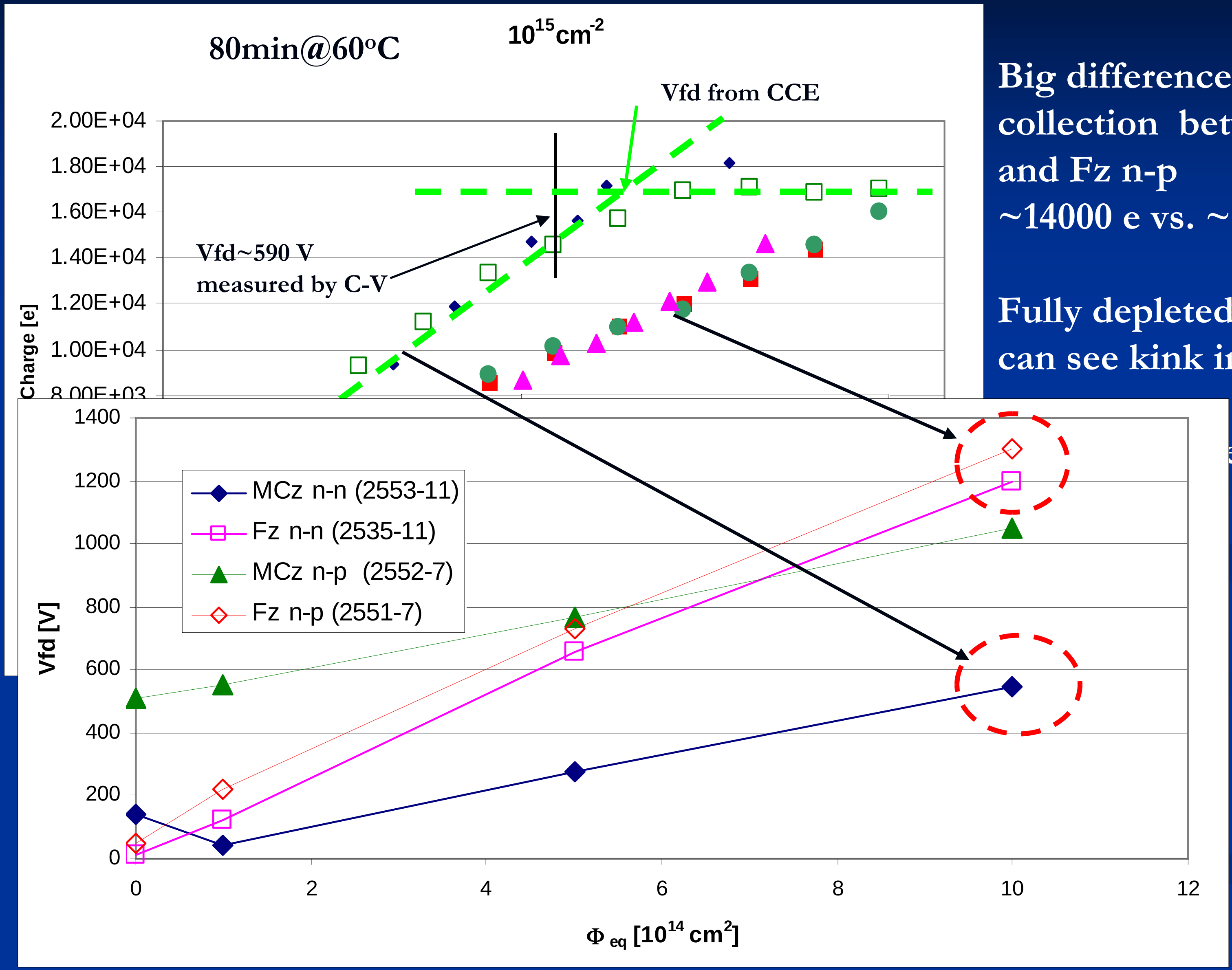
- The higher the fluence (larger V_{fd}, larger trapping) the more the strips will outperform the pads – also seen in simulations!

G. Kramberger et. al, C-V/IV and CCE measurements of MCz and FZ p and n type diodes after mixed irradiations, 12th RD 50 Workshop, Ljubljana, June 2008

Fz-p vs. MCz-n and "V_{fd}" of strip detectors



Big difference in the charge collection between MCz n-n and Fz n-p
~14000 e vs. ~8000 e at 500V!

Fully depleted detector – one can see kink in Q-V plot

e in CCE is
difference in

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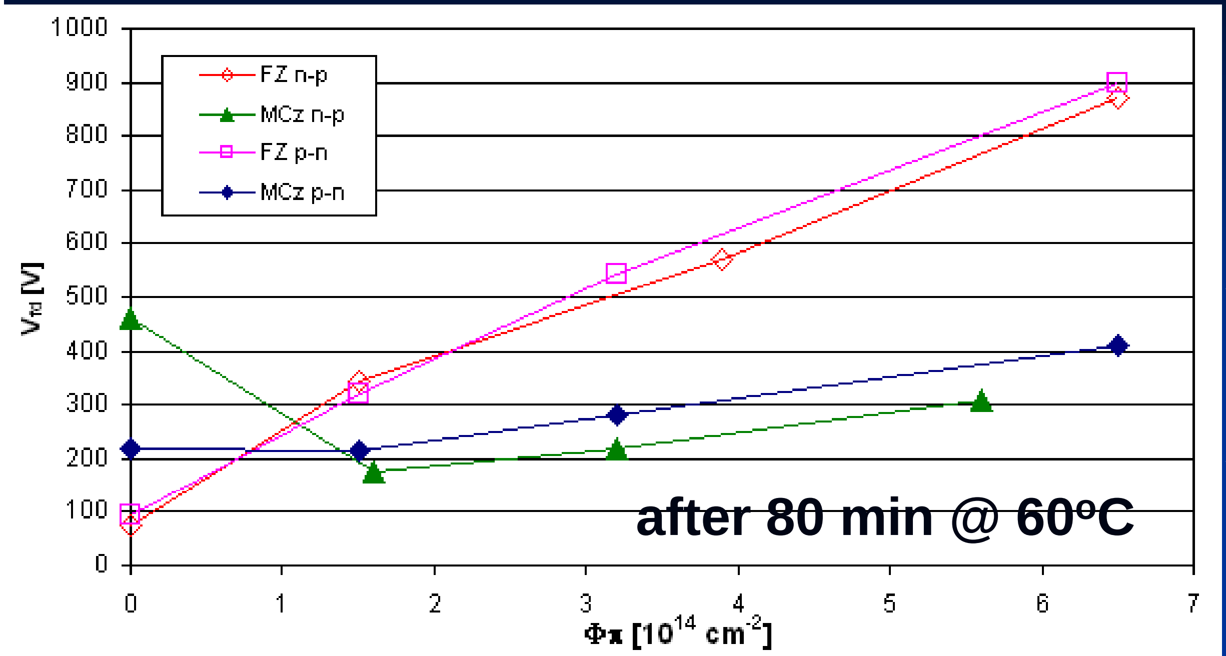
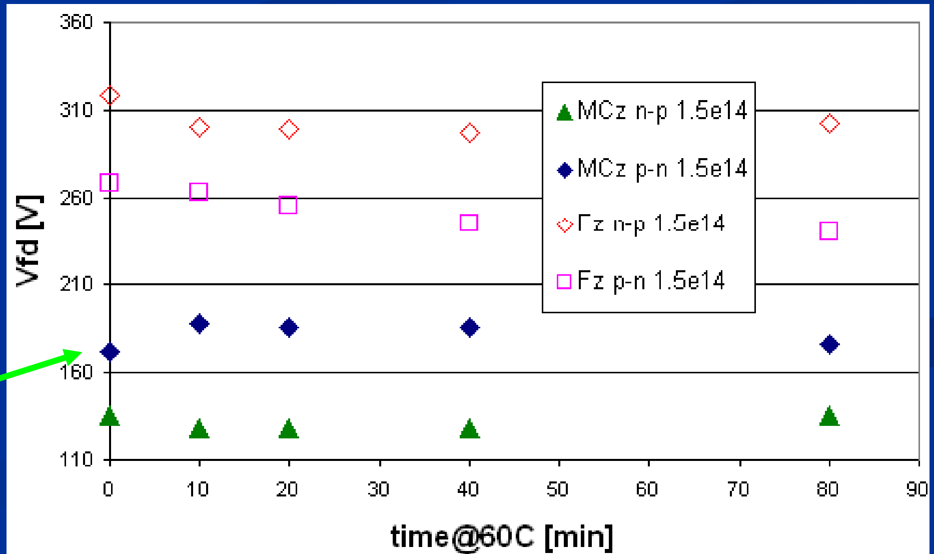
Pion irradiated diodes



- leakage current agrees with expectations
- all detectors but MCz-n seem to be have negative space charge after irradiations.
- a large part of initial annealing has already taken place during irradiations
- What is sign of space charge for MCz?

➢ Slope of V_{fd} increase with fluence
  - ✓ : MCz (p and n type): ~38 V/10^{14} cm^{-2} , **$|g_c|$~0.0055 cm^{-2}** ,using κ=1.14 (as expected)
  - ✓ Fz (p and n type): ~110 V/10^{14} cm^{-2} **g_c~0.014 cm^{-2}** ,using κ=1.14 (as expected)

➢ There is a strong "effective acceptor removal" for MCz p type material!
  - It seems that that "effectively positive space charge is introduced for MCz-n
  - V_{fd} of MCz-p is lower than MCz-n!



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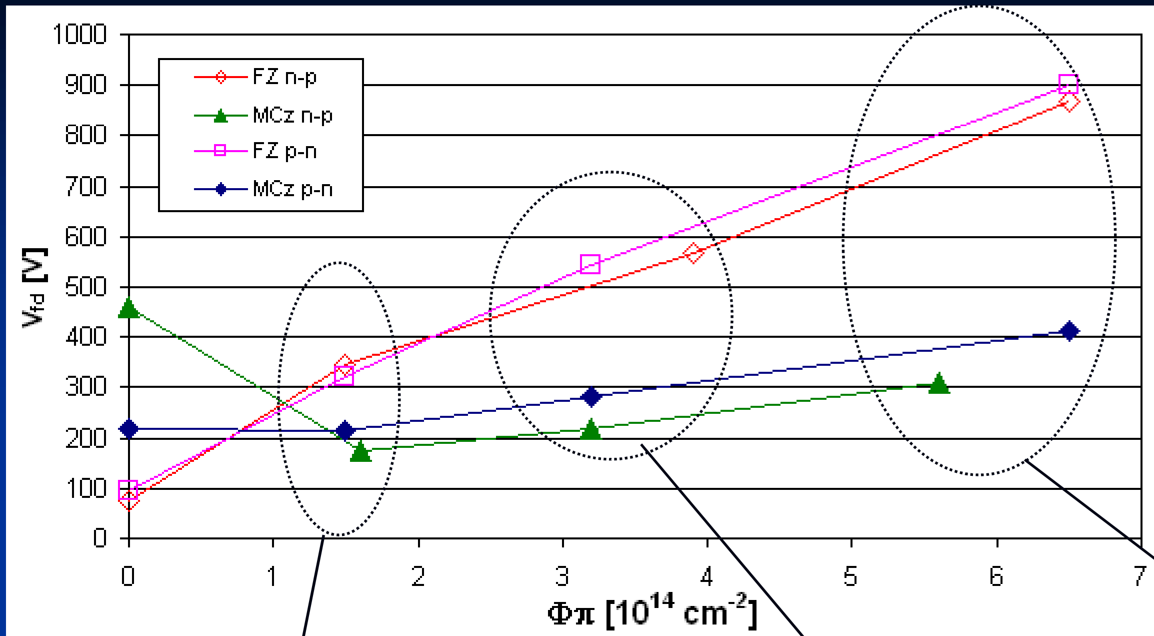
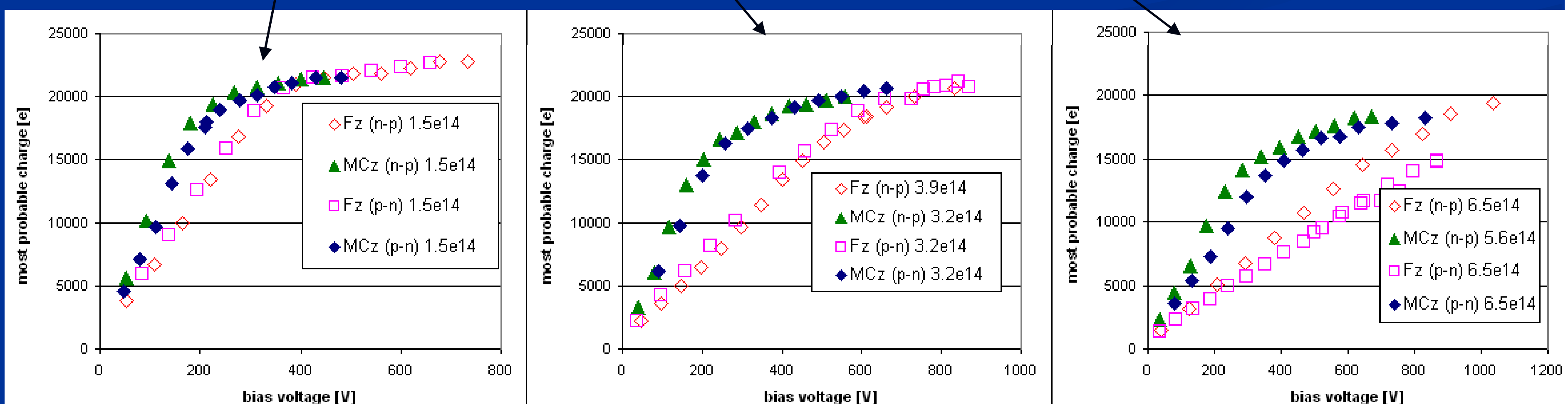
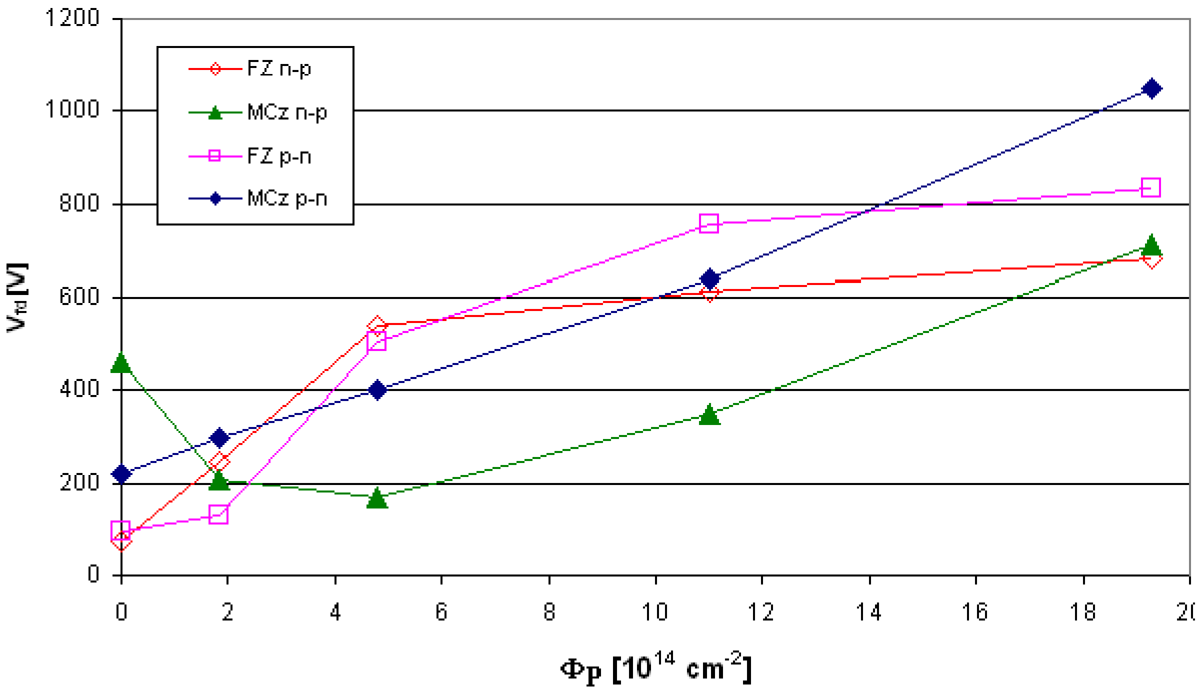


As in the case of neutron irradiated samples:

- the difference in V_{fd} can be clearly seen in CCE
- CCE for over-depleted samples is the same for all samples



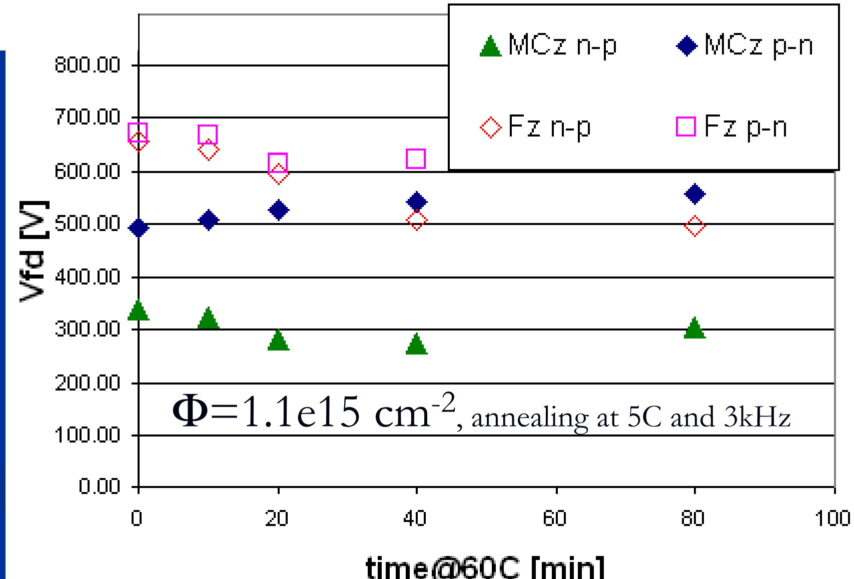
Proton irradiated diodes

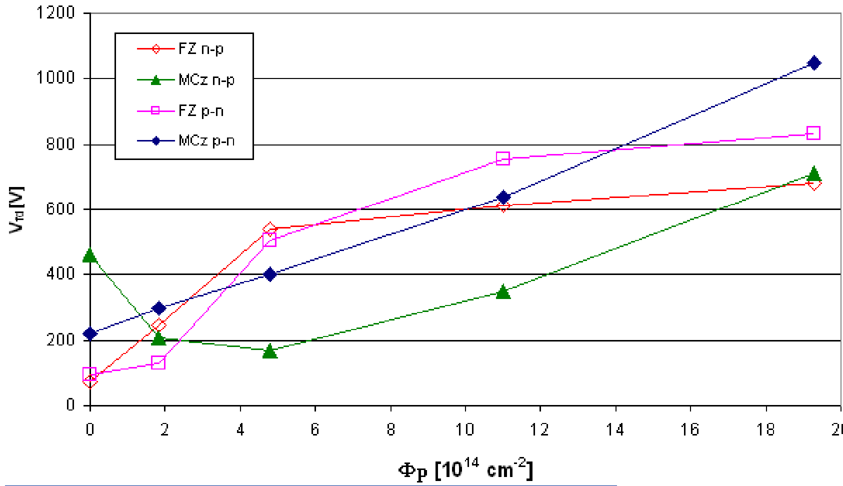


Annealing confirms the observation from pion irradiations; all have negative space charge except MCz-n shows annealing typical for positive space charge!

Leakage currents are as expected
κ_p/κ_π=0.543=0.62/1.14 agrees perfectly with α_p/α_π=0.553

Slope of V_{fd} increase with fence
✓MCz (p and n type): 38 V/10^{14} cm^{-2}
|g_c|~0.007 cm^{-2} ,using κ=0.62 (as expected)
✓ Fz (p and n type), **at low fluences**: ~150 V/10^{14} cm^{-2}
g_c~0.02 cm^{-2} ,using κ=0.62 (as expected). At higher fluences very low increase of V_{fd} for Fz materials?



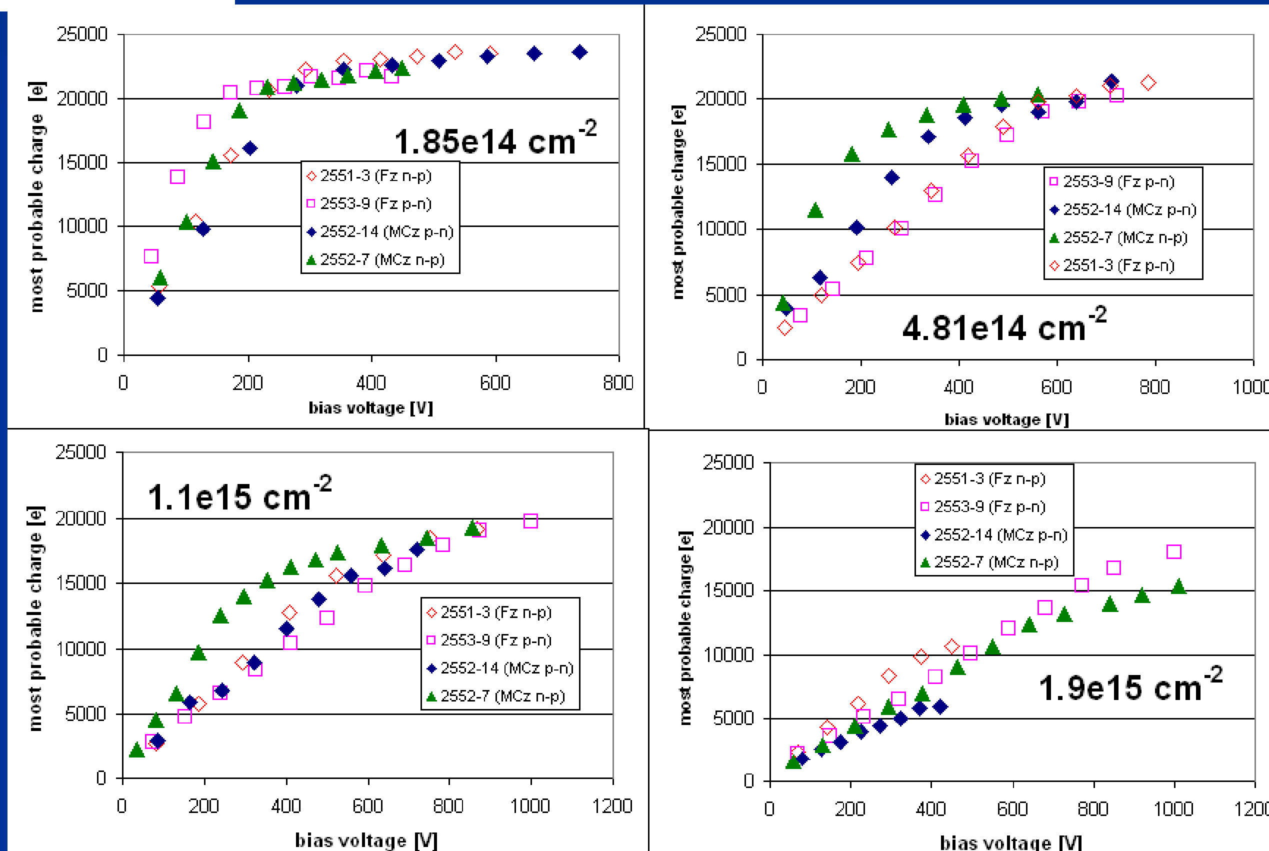


As in the case of neutron and pion irradiated samples:

- the difference in V_{fd} can be clearly seen in CCE
- CCE for over-depleted samples is the same for all samples

For Φ_p=1.93e15 cm^{-2} only two detectors could be over-depleted before the onset of micro discharges.

Remember: MCz-n is at the maximum of V_{fd} – for positive space charge the reverse annealing "should" be beneficial.



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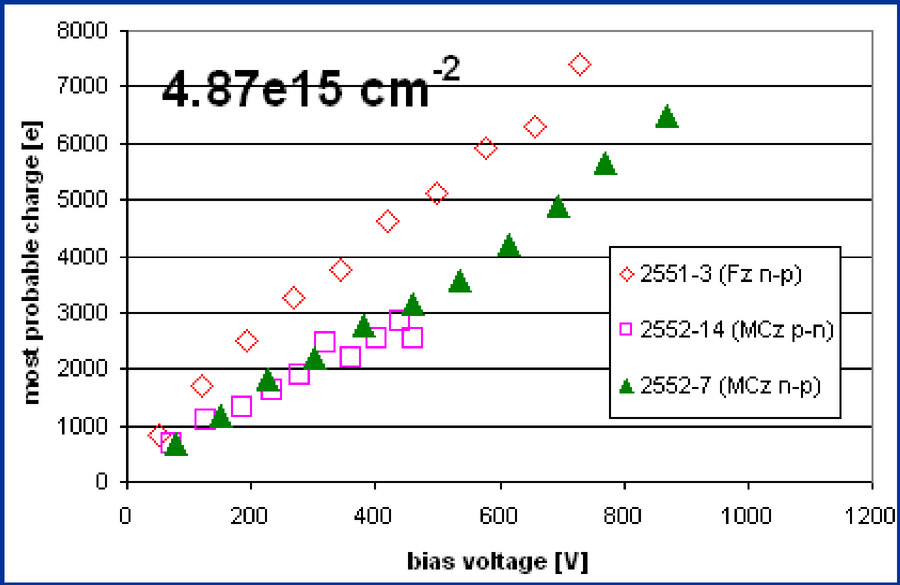
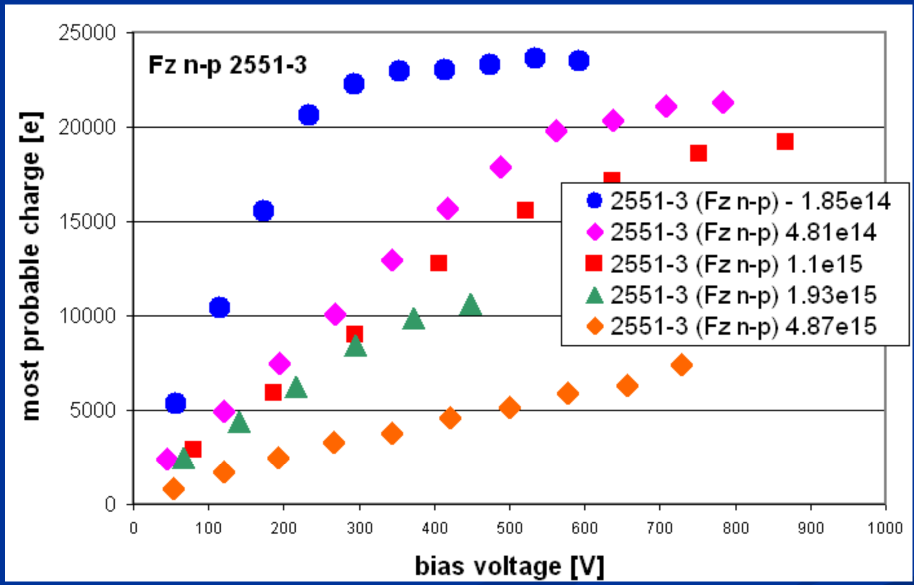
The estimated V_{fd} from the slope of the Q-V plot and assuming "saturated" charge of 16000e would give V_{fd} of around 1500V (far less than for "normal" Fz)

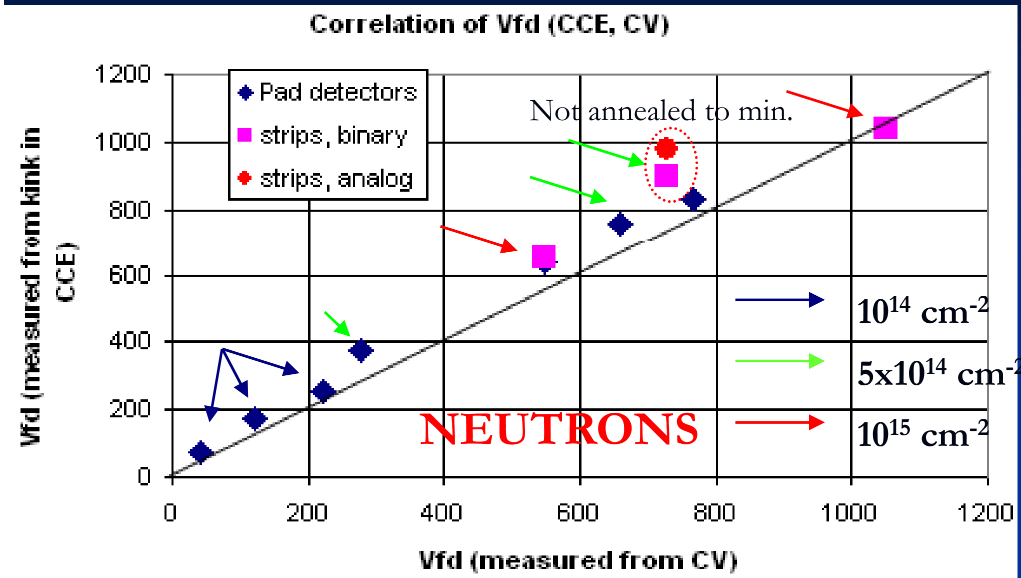
The Fz n-p performs best of all at the highest fluence. Around 5100 e at 500V, which should be considerably more for SSD!

It seems "double peak" becomes visible at high fluences!



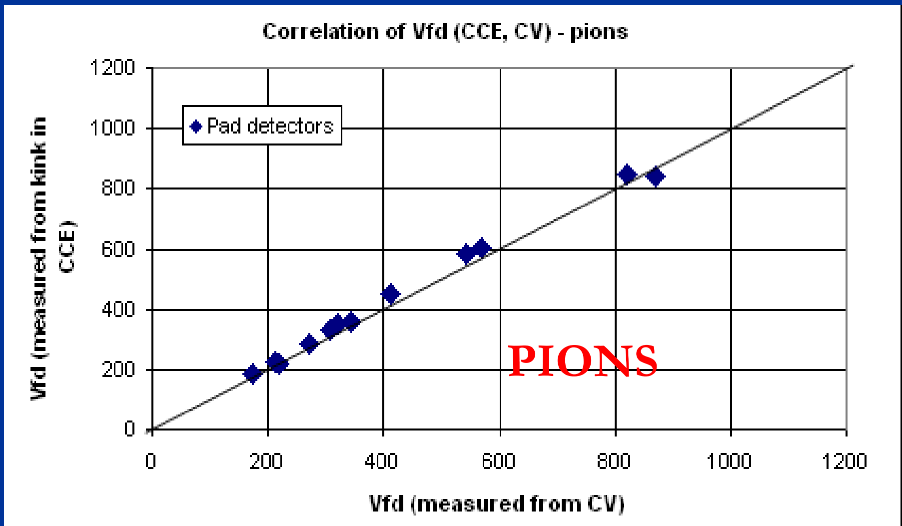


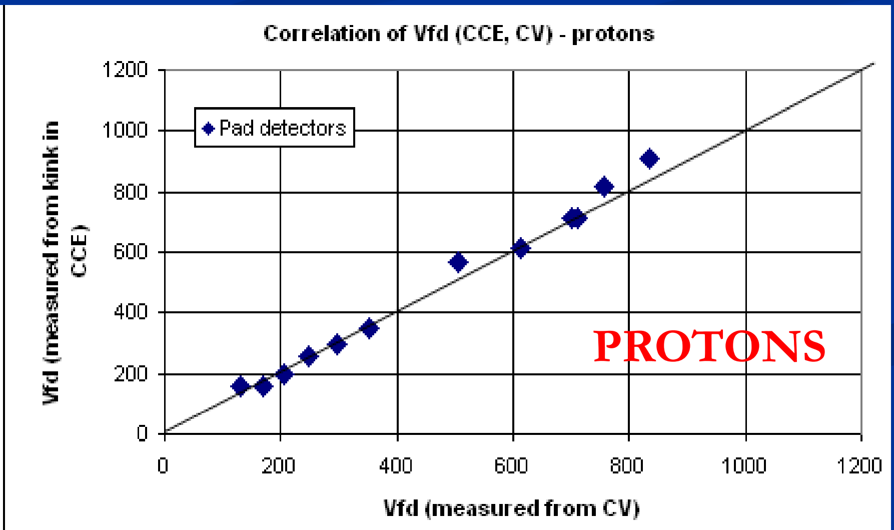
V_{fd} from C-V vs. V_{fd} from Q-V (pads, strips)



V_{fd} from C-V is determined for pad detectors (80min @ 60°C – end of beneficial annealing)

- V_{fd} from CV underestimates the onset of saturation in CCE by max. 100-150 V
- It seems that correlation is even better for protons and pions (electric field?)
- after V_{fd} the collected charge continues to increase due to shorter drift





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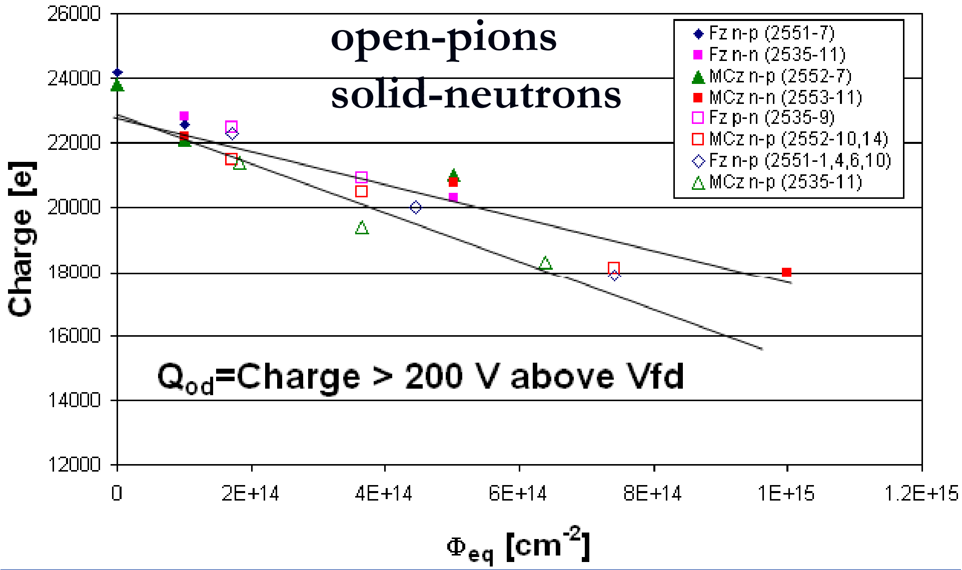
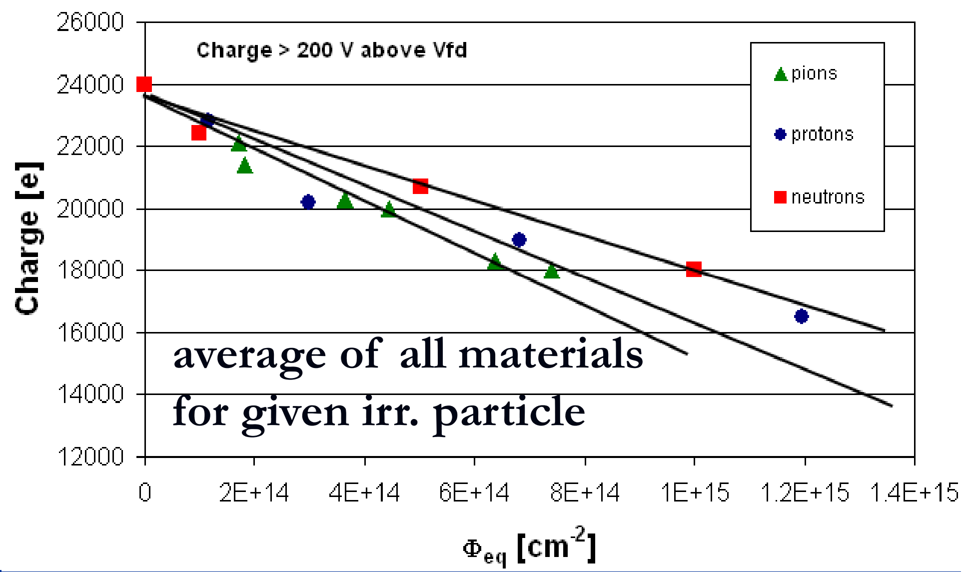
Charge collection efficiency (CCE)





At the same equivalent fluence, charge hadrons seem to be more damaging thus confirming the $\tau_{au,eff}$ measurements:

$dQ_{od}/d\Phi_{eq}$~600 e/1e14 cm^{-2} for neutrons

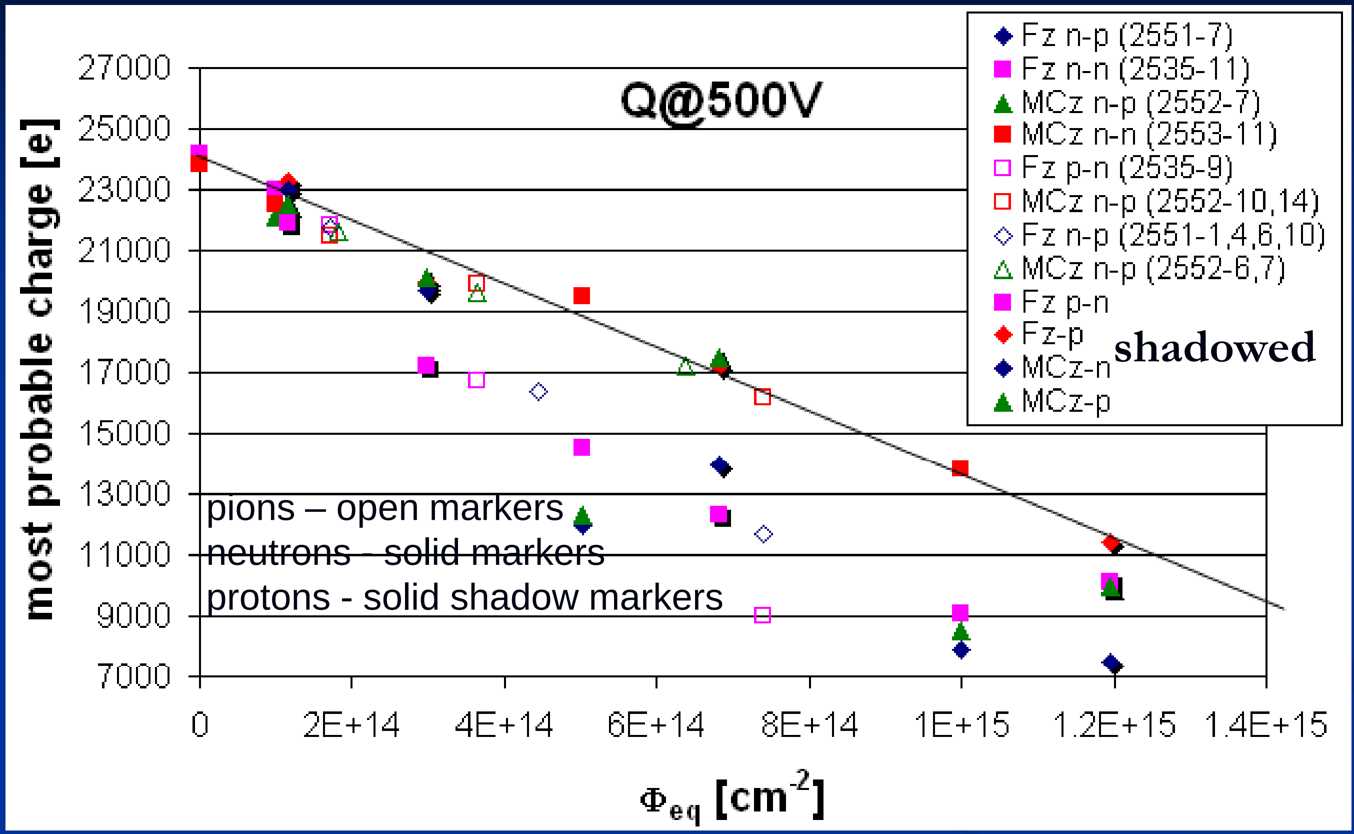
$dQ_{od}/d\Phi_{eq}$~850 e/1e14 cm^{-2} for pions

$dQ_{od}/d\Phi_{eq}$~800 e/1e14 cm^{-2} for protons

The measured trapping probabilities from TCT are around 40% too large to give the agreement with measured charge!

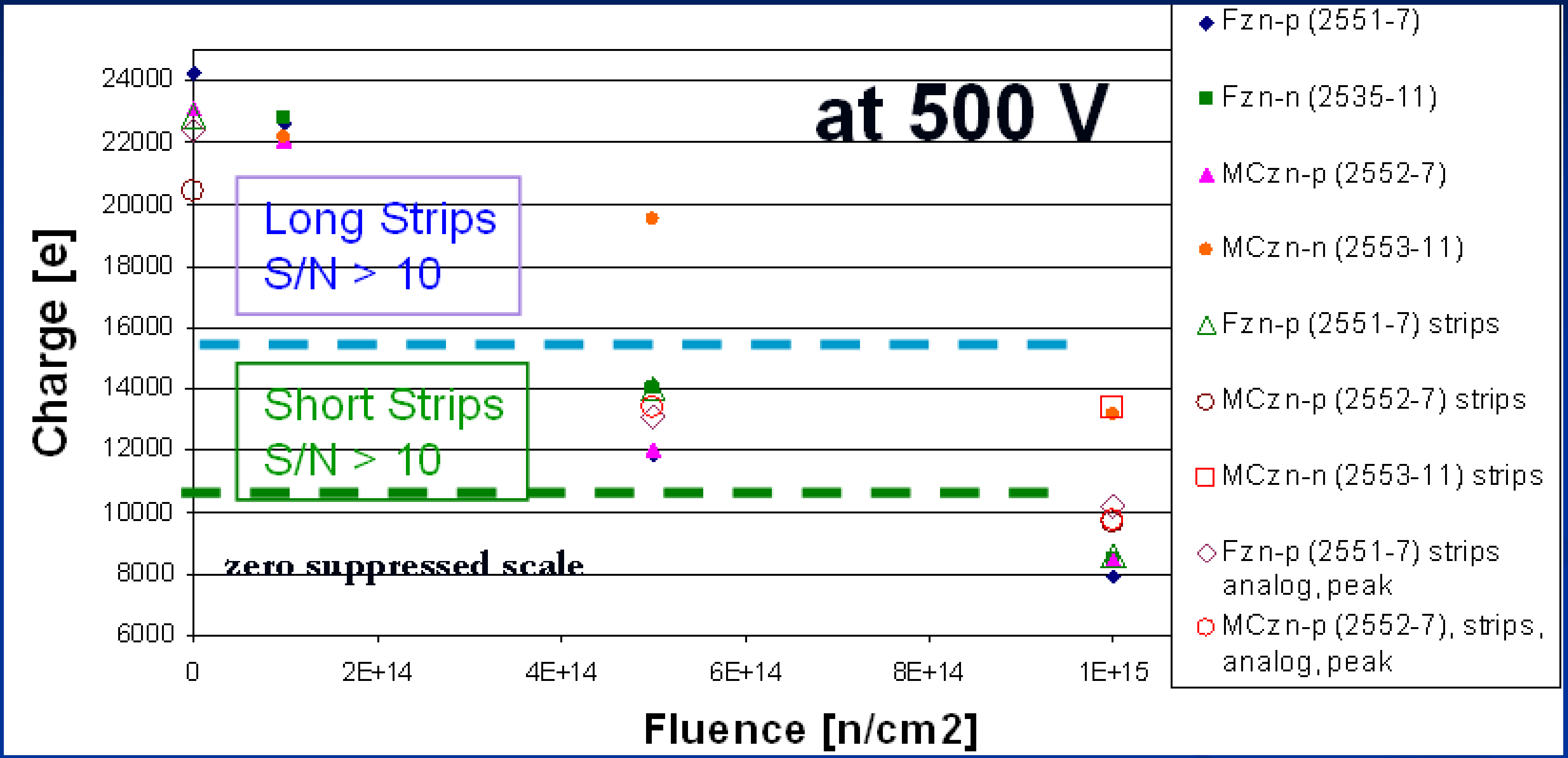
There is no dependence of Q_{od} on material!

The over depletion is more important at lower V_{fd} and less at high V_{fd} as the <E> is already very high and drift velocities close to saturated in large part of the detector



Except the Fz-p (irradiated with protons) all diodes lying on the "ideal line" are MCz. With SSD you should get more…

Neutron irradiated detectors



Conclusions

- V_{fd} is an important parameter → CCE at 500V is higher for smaller V_{fd}
- MCz n,p perform better than Fz
- Pions/protons seem to be more damaging at the same Φ_{eq}
  - Trapping times seem to be longer than measured by ~35% at $\Phi_{eq}=10^{15}$ cm^{-2}:
  - at 500 V (12-14 ke for $5\cdot10^{14}$ cm^{-2} and 8-10 ke for 10^{15} cm^{-2})
  - for an over-depleted detector 17-18 ke at 10^{15} cm^{-2}
- Different measurement techniques show good agreement – as expected the strips (n^+ readout) perform better than pads
- It is still an ongoing process