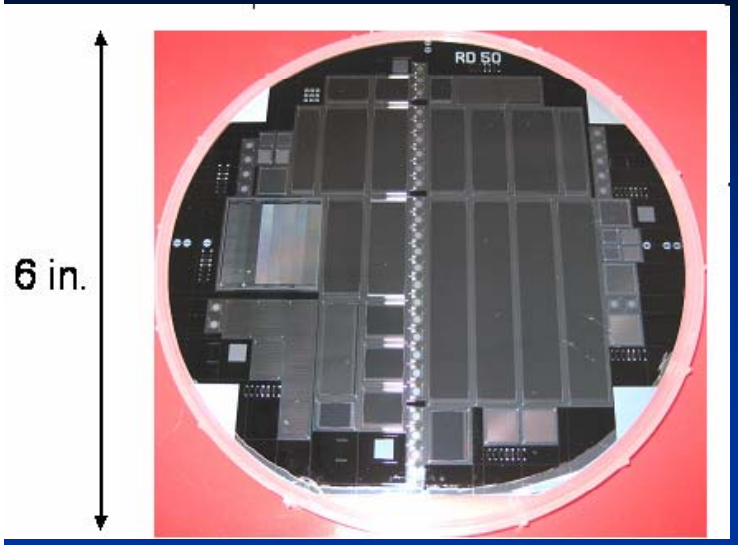
C-V/IV and CCE measurements of MCz and FZ p and n type diodes after mixed irradiations

G.Kramberger, V. Cindro, I. Mandić, M. Mikuž, M. Zavrtanik

Jožef Stefan Institute

Ljubljana, Slovenia

RD50 MICRON 6” project



- 36 processed wafers
- 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 – diodes only !

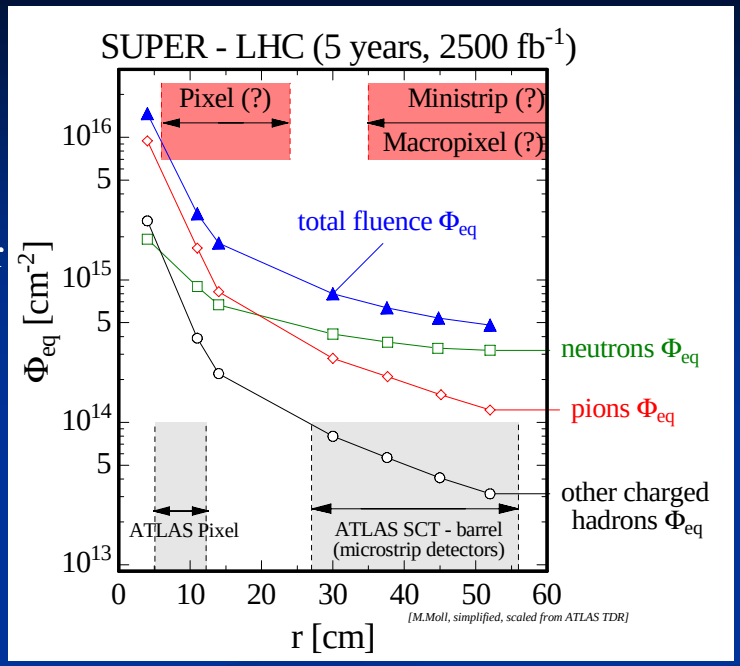
	MCz-p	MCz-n	Fz-p	Fz-n
Wafers	2552-6,7	2553-11; 2552-10,14	2551-1,3,4,6,7	2535-11; 2535-8,9
Resitivity	1.5 Ωcm	2 kΩcm	14 kΩcm	~20 kΩcm, ~3 kΩcm
Orientation	<100>	<100>	<100>	<100>

SSDs and diodes irradiated with neutrons and protons and pions; a collaboration of Santa Cruz, Liverpool and Ljubljana!

Motivation

The detectors at experiments will be exposed to both charged hadrons and neutrons!

- Are damages additive, both for I_{leak} and V_{fd}?
- What is the space charge of MCz-n detectors after fast charge hadron irradiations (for neutrons we know that they introduce negative space charge)?
  - Is there any difference between our standard "24 GeV protons" and "real" LHC pions
  - How much is CCE affected?



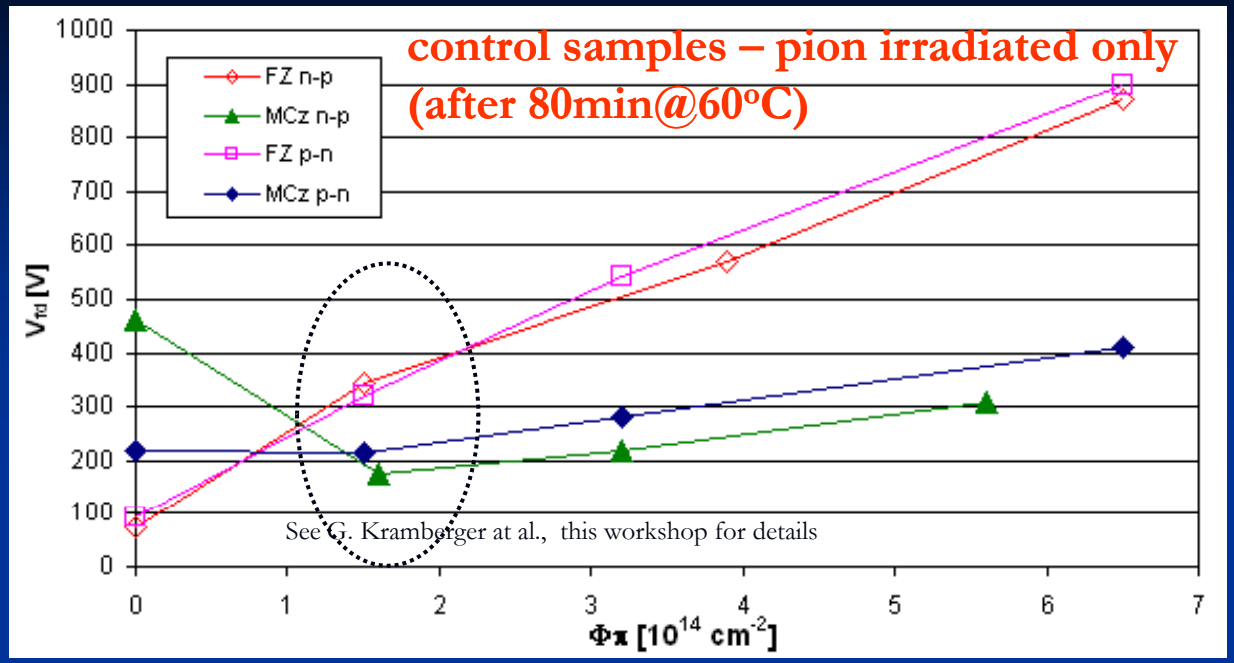
The following detectors were exposed to additional $2 \cdot 10^{14}$ cm^{-2} neutrons:

- Fz n-p: 1.85, 4.81 p; 1.5 π [10^{14} cm^{-2}]
- Fz p-n: 1.85,4.81 p; 1.5 π [10^{14} cm^{-2}]
- MCz n-p: 1.85, 4.81,11 p; 1.5 p [10^{14} cm^{-2}]
- MCz p-n: 1.85, 4.81,11 p; 1.5 p [10^{14} cm^{-2}]

Each of these detectors has a counterpart without neutrons!

Proton irradiated detectors were annealed prior to neutron irradiations for 10 min@60°C.

Pion irradiations



- It seems that fluence is large enough that the initial dopant removal is completed
- FZ detectors seem to perform similarly

What do we expect from additional neutron irradiations:

Fz-p,n , MCz-p

after pions: N_{eff} <0

additional neutrons 2e14 cm^{-2}

N_{eff}<0 and **increases in time**

MCz-n

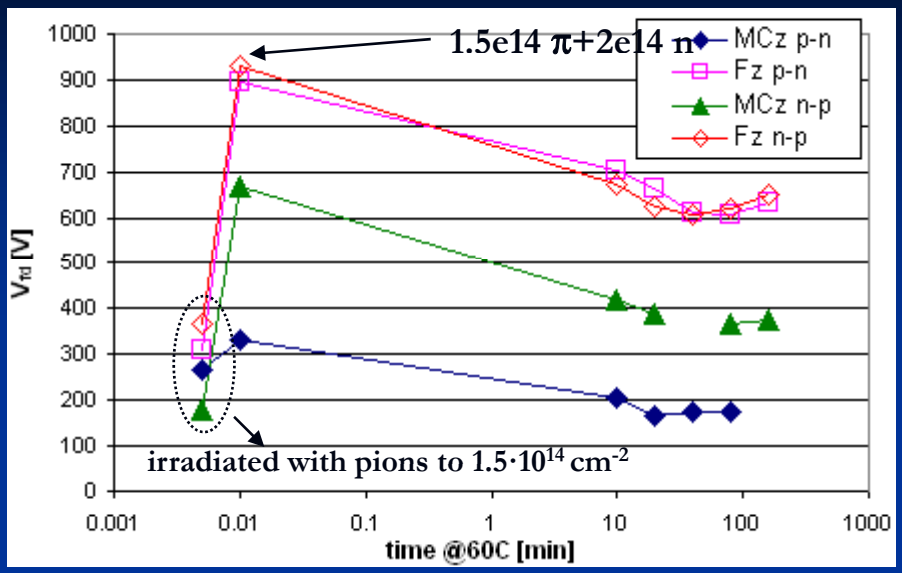
after pions: N_{eff} >0

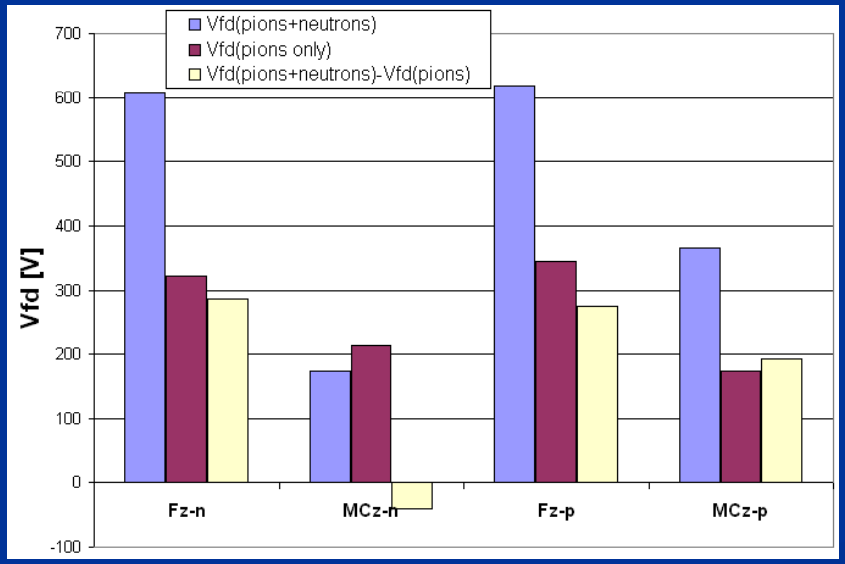
additional neutrons 2e14 cm^{-2}

N_{eff} < 0 and **decreases in time**

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

Mixed irradiations – pions V_{fd}





Expectations are confirmed!

- The rise ΔV_{fd}~550 V of MCz-p, Fz-p,n is almost identical after additional neutrons confirming the N_{eff}<0. MCz-n rises much less after additional pions, what can be explained by SCSI
- Short term annealing indicates Neff<0 for all; reduction of acceptors during annealing
- large introduction rates of short term annealing can be of short irradiation and immediate storage at low T

- the difference V_{fd}(pions+neutrons)-V_{fd}(pions) after 80min@60°C corresponds roughly to expectations for **(additive damage)**
  - ~180 V for MCz-p (expected: 120 V = 2 x 60 V)
  - ~280 V for Fz (expected: 250 V=2 x 125 V)

- The difference is too large for MCz-n -> more complicated picture! Also less beneficial annealing!

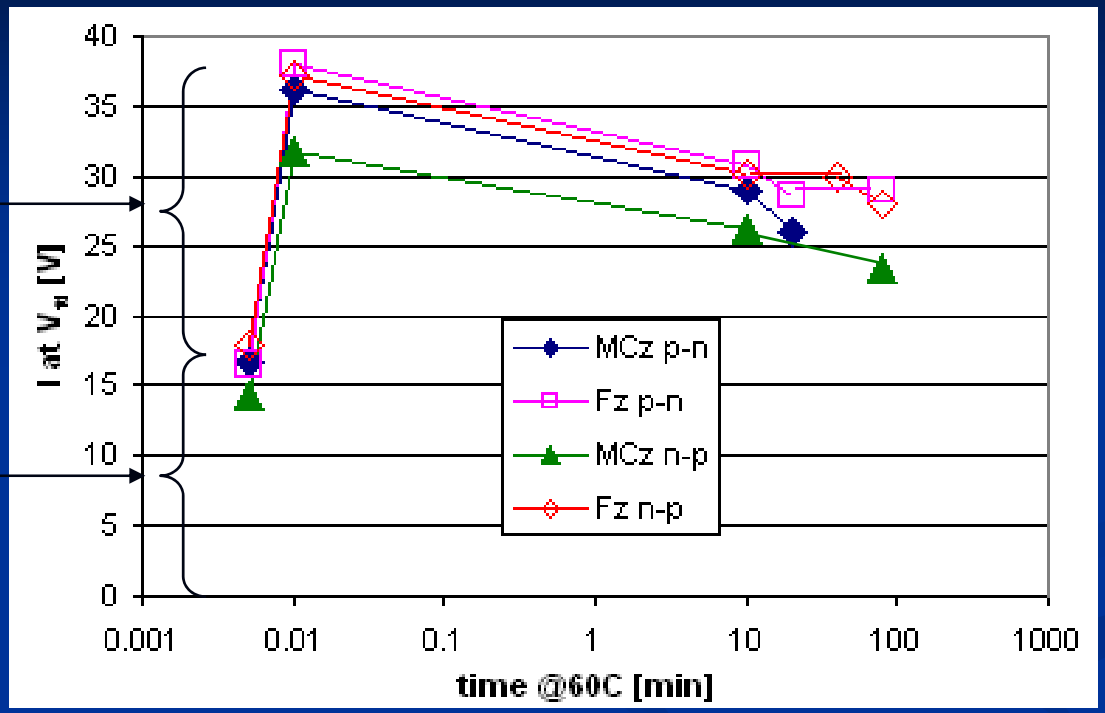
V_{fd} at equivalent fluence of ~4e14 cm^{-2} < 200 V!

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

Mixed irradiations – pions I_{leak}

after additional neutrons $\Delta I_{neutrons}$

after pions ΔI_{pions}



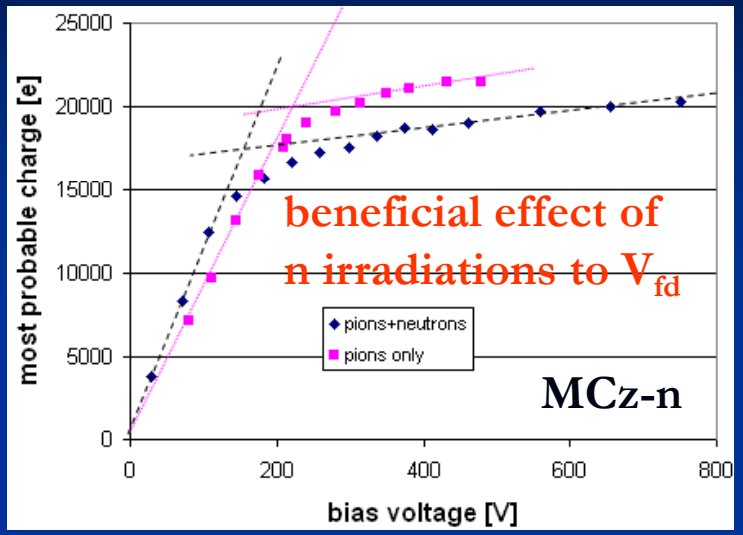
•The current increase after neutron irradiation is the same for all!
The contribution from the pion and neutron irradiation are additive.

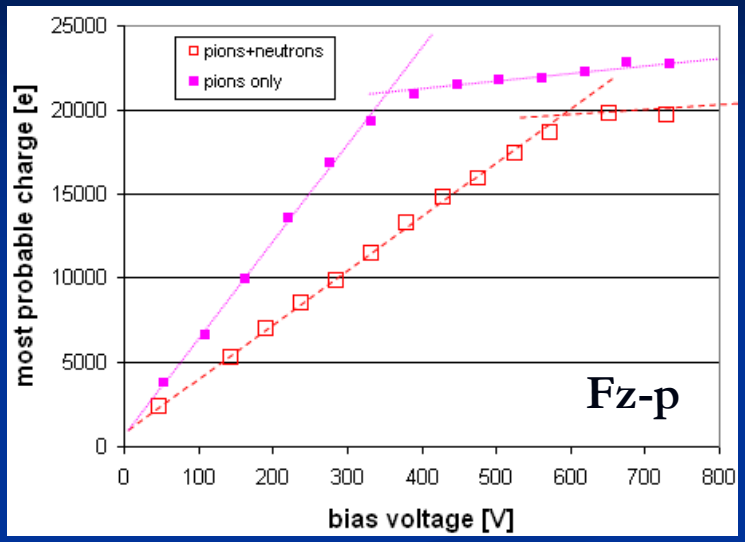
$$\frac{\Delta I_{pions}}{\Delta I_{neutrons}} \approx \frac{17\mu A}{19\mu A} = 0.9 \approx \frac{\Phi_{eq,pions}}{\Phi_{eq,neutrons}}$$

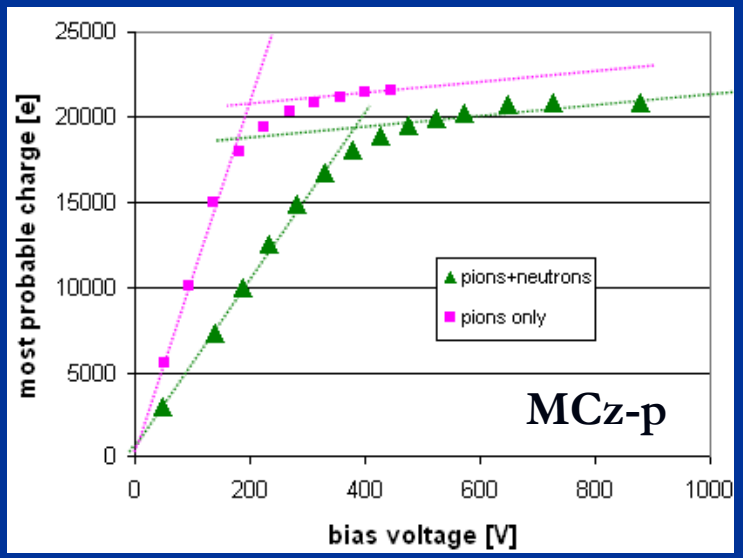
•Annealing is the same as for single particle irradiation.

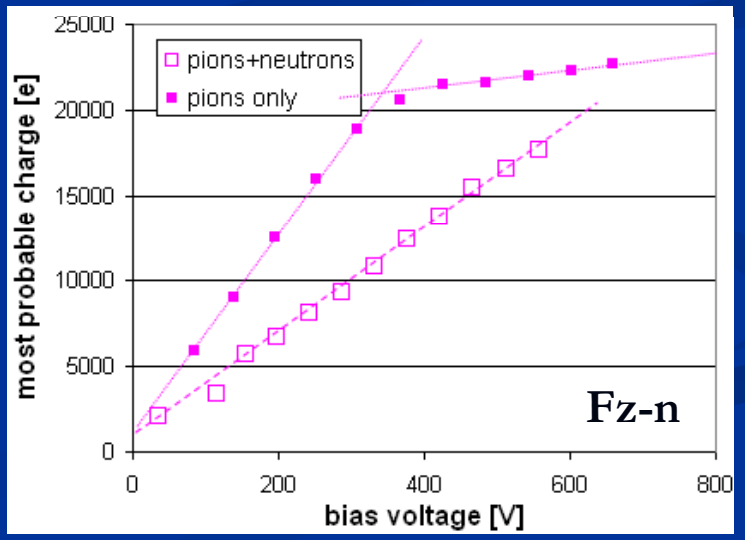
Mixed irradiations – pions CCE

Charge collection after 80 min @ 60°C for different detectors!



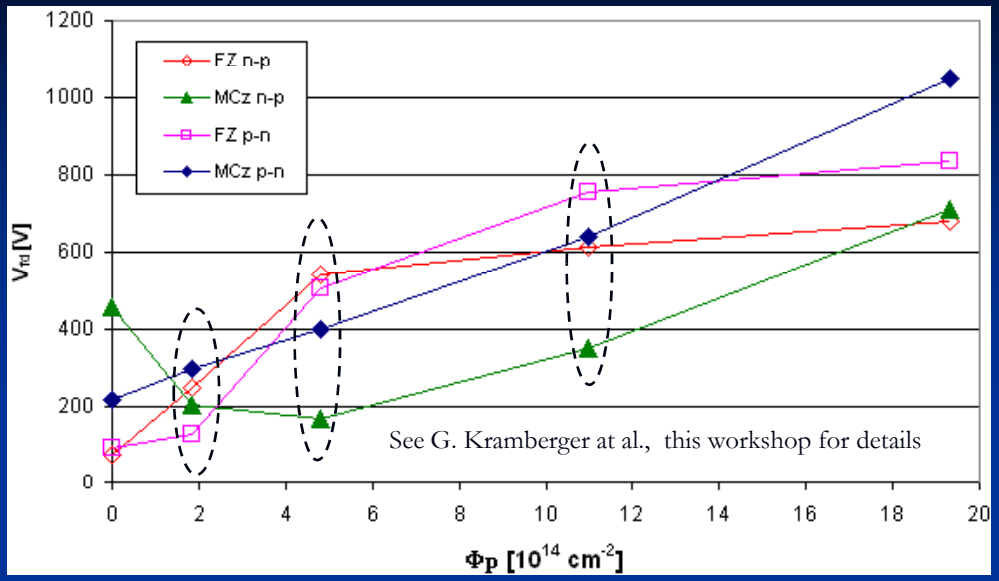






G. Kramberger et. al, C-V/IV and CCE measurements of MCz and FZ p and n type diodes after mixed irradiations, 12th RD 50 Workshop, Ljubljana, June 2008

Proton irradiations



We should expect the same as for pions!
Remember 24 GeV protons are our "replacement" for pions!

Fz-p,n , MCz-p

after protons: N_{eff} <0

additional neutrons 2e14 cm^{-2}

N_{eff}<0

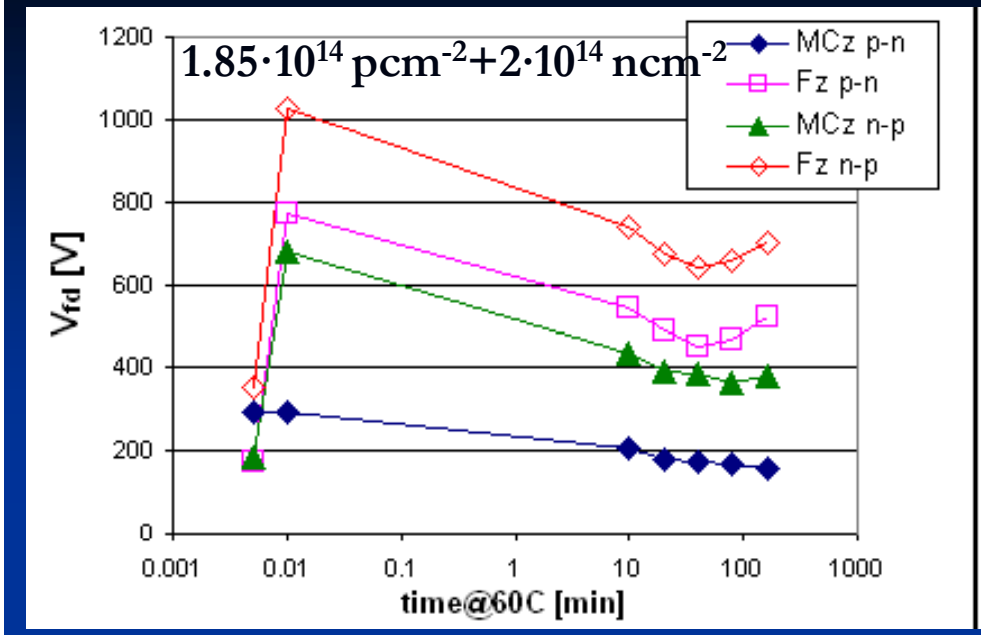
MCz-n

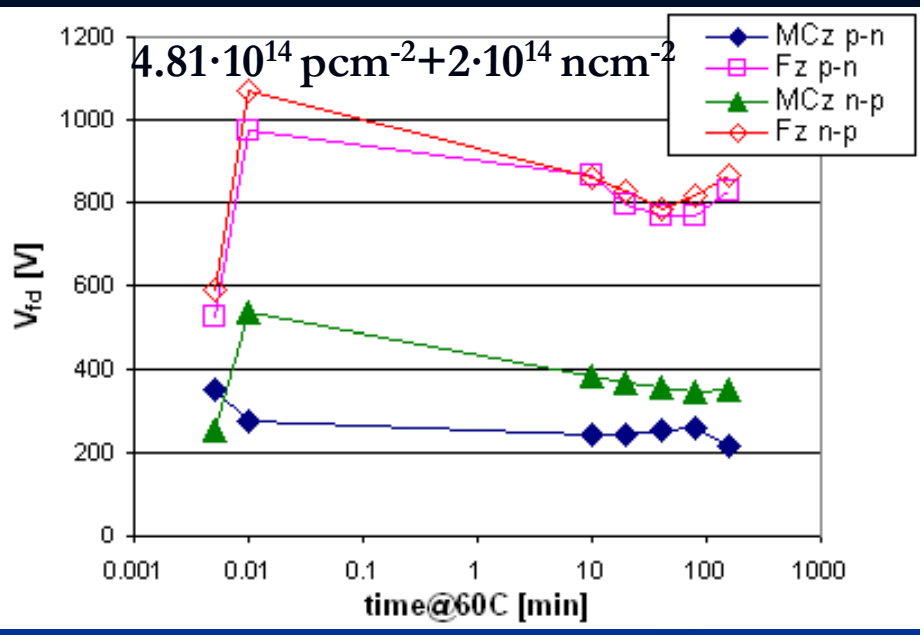
after protons: N_{eff} >0

additional neutrons 2e14 cm^{-2}

N_{eff} > 0 ???

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





Space charge determination based on short term annealing

- Low fluence: Neff<0 for all
- High fluence:
  - Neff<0 for MCz-p, Fz
  - Neff>0 for MCz-n

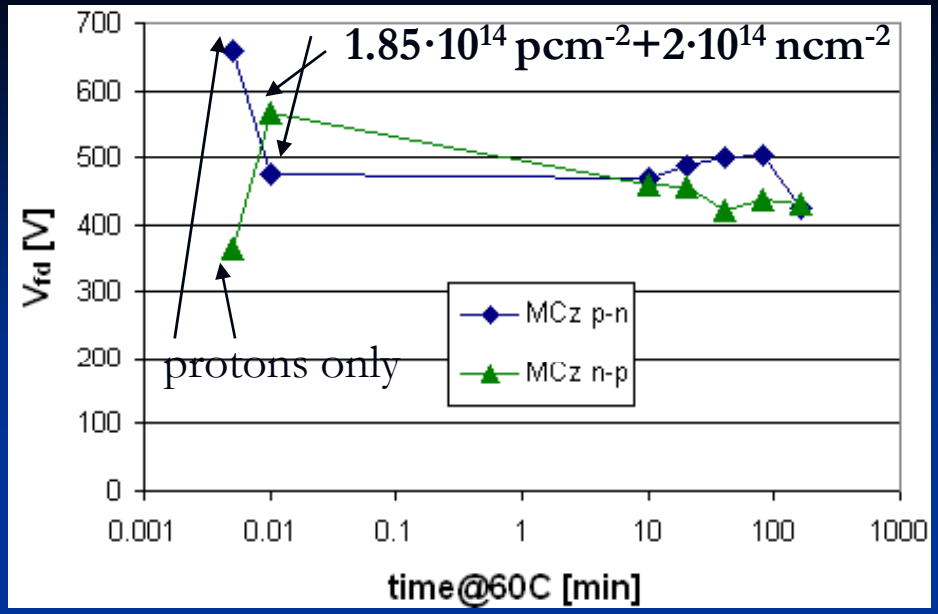
The V_{fd} decreases after n irradiation for MCz-n!

The initial jump of V_{fd} tends to be smaller at higher fluence for MCz-p and Fz

Long term annealing:

- seem to be faster for Fz than MCz
- follows expectations (decrease of V_{fd} in time for MCz-n, increase for Fz and MCz-p)

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



It is clear that:

•MCz-n -> "positive space charge"

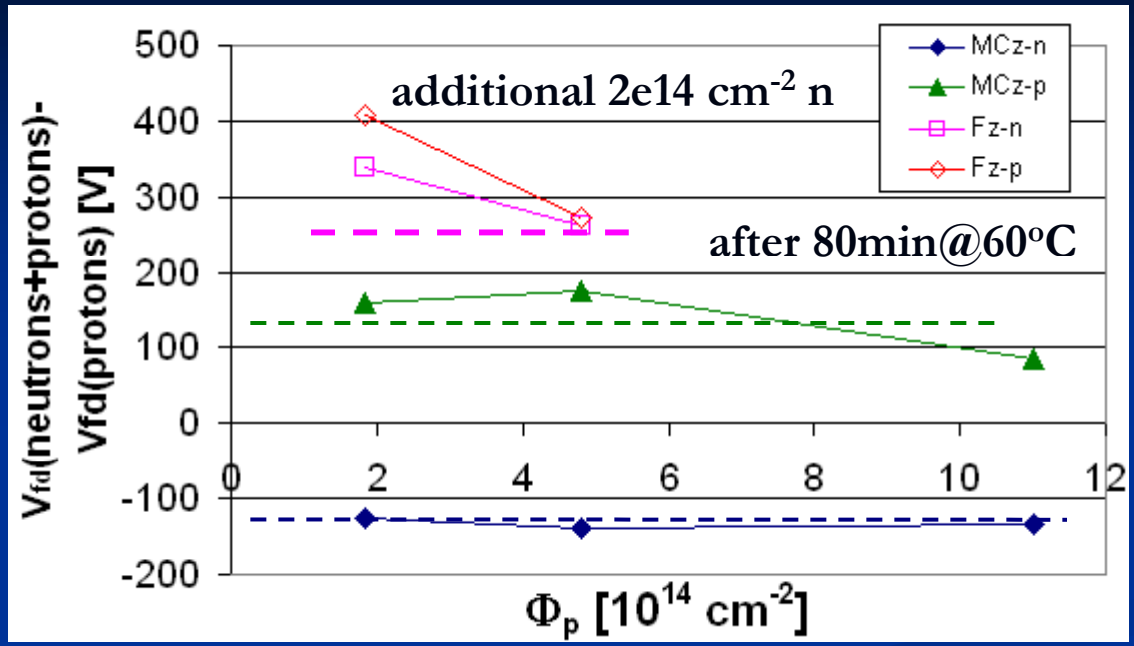
(N_{eff} before neutron irradiation is large enough not to be overcompensated). The V_{fd} is reduced by ~200 V after additional neutron irradiation.

•MCz-p -> "negative space charge", but increase of V_{fd} after additional neutrons is just 80V !

After almost Φ_{eq}=1e15 cm^{-2} the V_{fd} of MCz detectors is around 500V. Even if initial resistivity of MCz-p is low the "acceptor removal" will help to get the V_{fd} down.

For MCz-p the V_{fd} is lower than the initial V_{fd} of 460 V!

Is the damage additive at different fluences?



dashed line – predicted difference

$\Delta V_{fd}=V_{fd}$(protons+2e14n cm^{-2})-V_{fd}(protons) = 250 V (Fz) , 120 V (MCz)

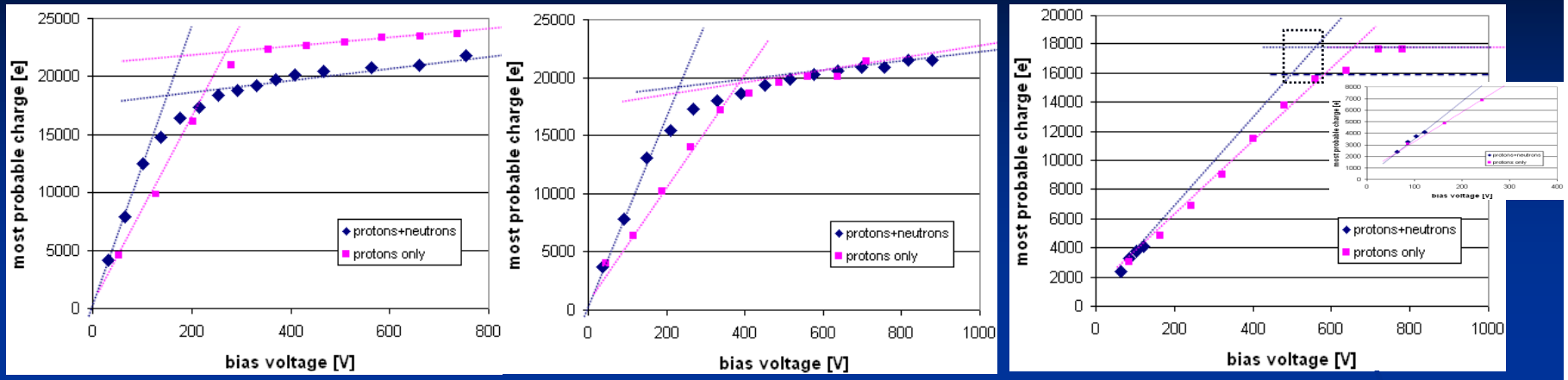
(for neutrons V_{fd} increases: ~60V/1e14 cm^{-2} (MCz) and ~125V/1e14 cm^{-2} (FZ))

The agreement is fair, except for disagreement at lowest fluence for FZ!

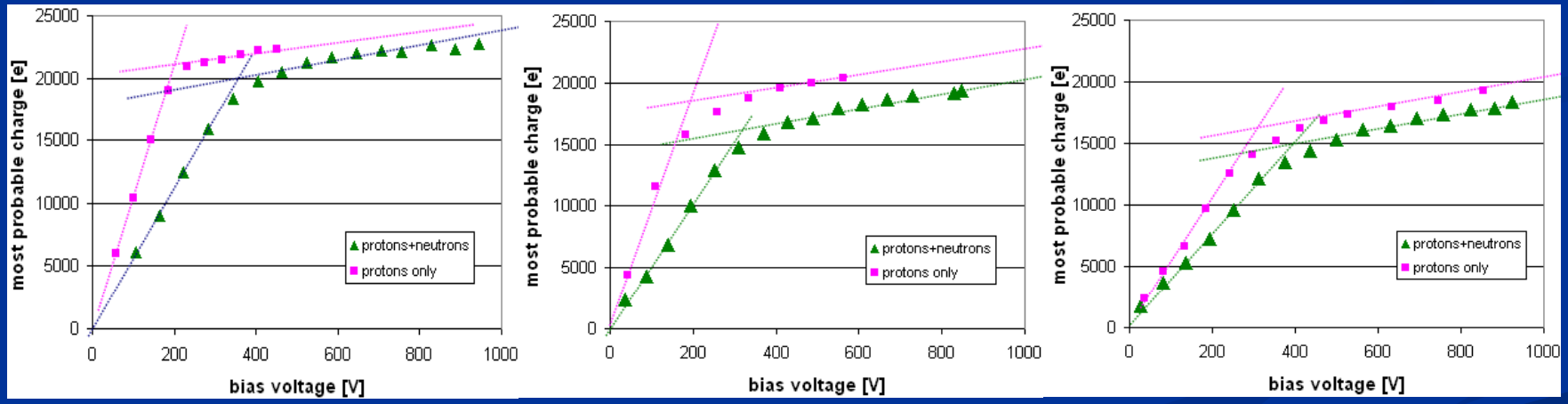
The damage is additive in the first approximation, but further studies are needed!

Do CCE measurements confirm the C-V ? Is trapping additive?

MCz-n



MCz-p



The V_{fd} from CCE agrees very well with (and so confirms) the V_{fd} from CV!

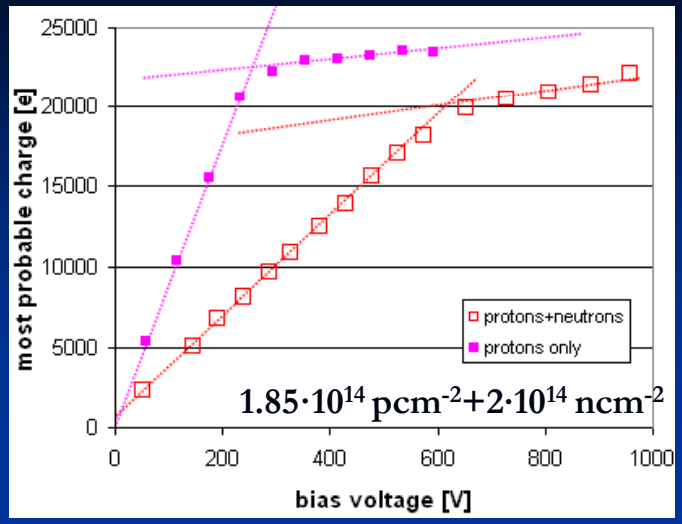
Collected charge for p+n irradiated samples is systematically lower than for p only:

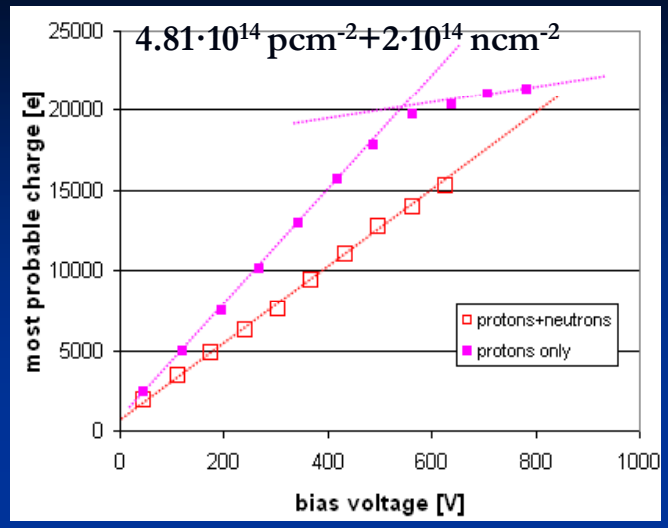
expected reduction after neutron irradiation for $V>V_{fd}+200V$: ~ 2 x 700 e ~1400 e agrees approximately with measured one!

It is an indication that also trapping is additive (except MCz-n ?? Should be re-measured)!

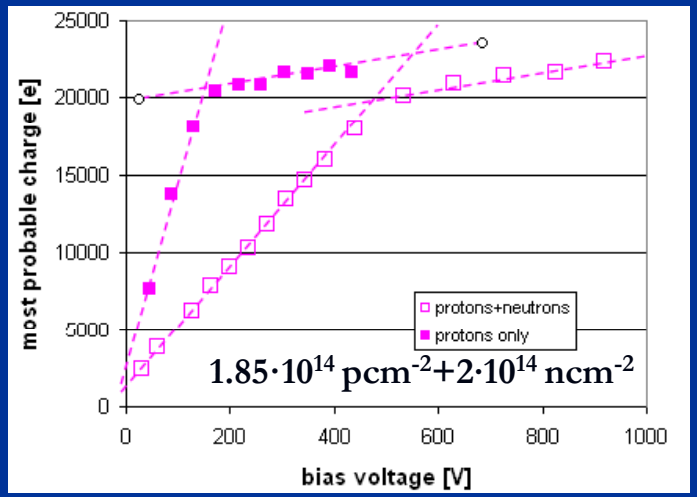
G. Kramberger et. al, C-V/IV and CCE measurements of MCz and FZ p and n type diodes after mixed irradiations, 12th RD 50 Workshop, Ljubljana, June 2008

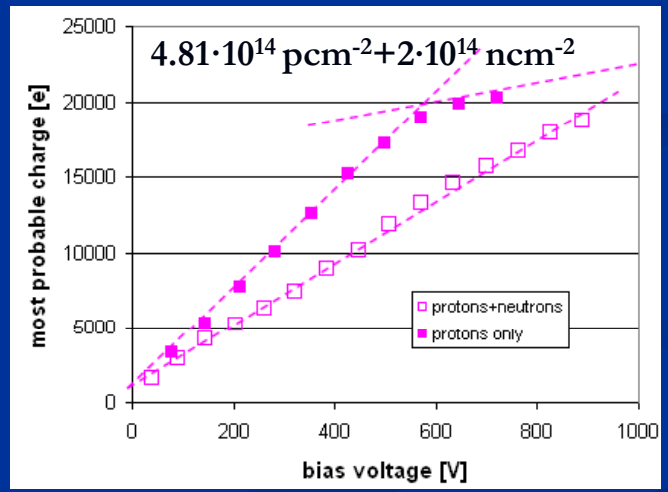
Fz-p


most probable charge [e]
bias voltage [V]
protons+neutrons
protons only
1.85·10^14 pcm^-2+2·10^14 ncm^-2


most probable charge [e]
bias voltage [V]
protons+neutrons
protons only
4.81·10^14 pcm^-2+2·10^14 ncm^-2

Fz-n


most probable charge [e]
bias voltage [V]
protons+neutrons
protons only
1.85·10^14 pcm^-2+2·10^14 ncm^-2


most probable charge [e]
bias voltage [V]
protons+neutrons
protons only
4.81·10^14 pcm^-2+2·10^14 ncm^-2

Conclusions

- The damage of different particles:
  - Is additive for leakage current
  - Seem to be additive also for N_{eff} (V_{fd})

  discrepancy at low proton fluence for FZ at low pion fluence for MCz-n
  - Seem to be additive also for trapping
- "Space charge "after pion/proton irradiation in MCz-n detector is positive-> additional neutron irradiation reduces the V_{fd}!
- V_{fd} from CV and QV agree well for mixed irradiated diodes