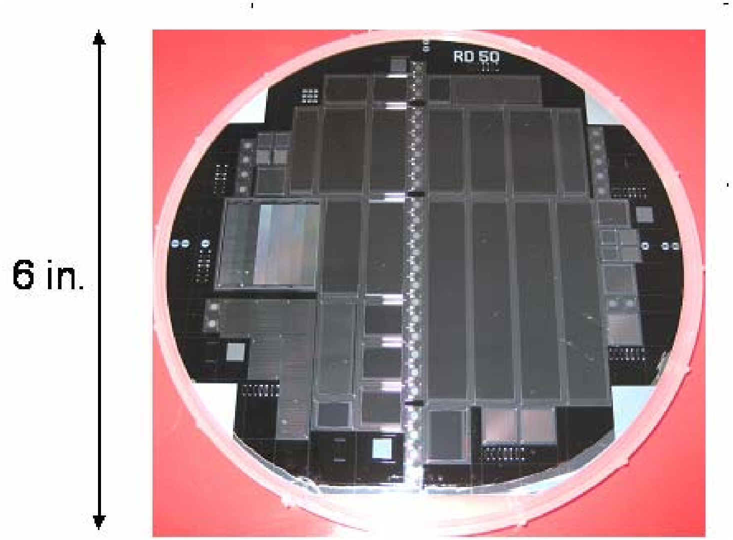
Annealing studies of mixed irradiated MICRON diodes

G.Kramberger, V. Cindro, I. Dolenc, 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>

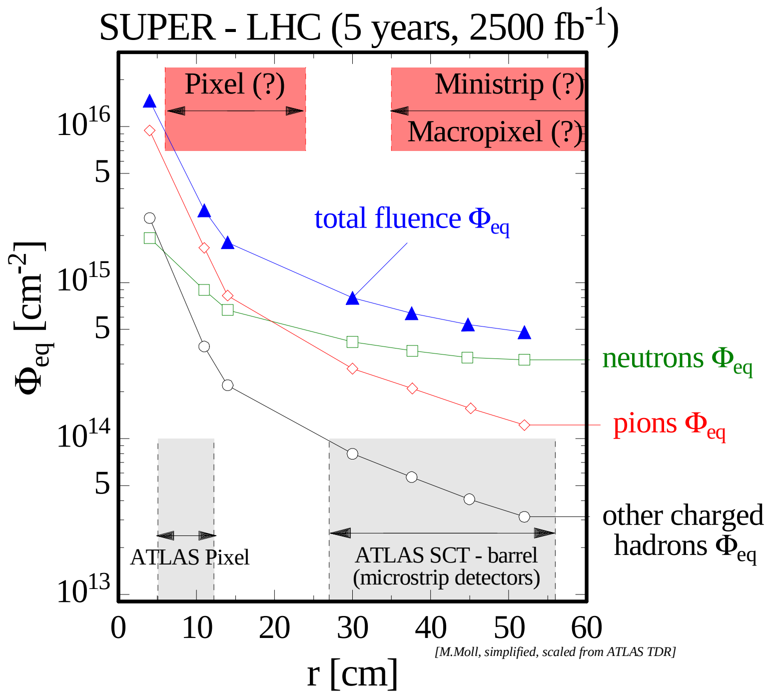
SSDs and diodes irradiated with neutrons and protons and pions;
a collaboration of Santa Cruz, Liverpool and Ljubljana!

Motivation

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

- ✓ Damage appears to be additive, both for I_{leak} and V_{fd}!
- ✓ The **dominant** space charge of MCz-n detectors after fast charge hadron irradiations (24 GeV p and 200 MeV π) is positive
- ✘ What about the MCz-p?
- ✘ What are annealing properties (V_{fd}, CCE)?

THIS TALK !



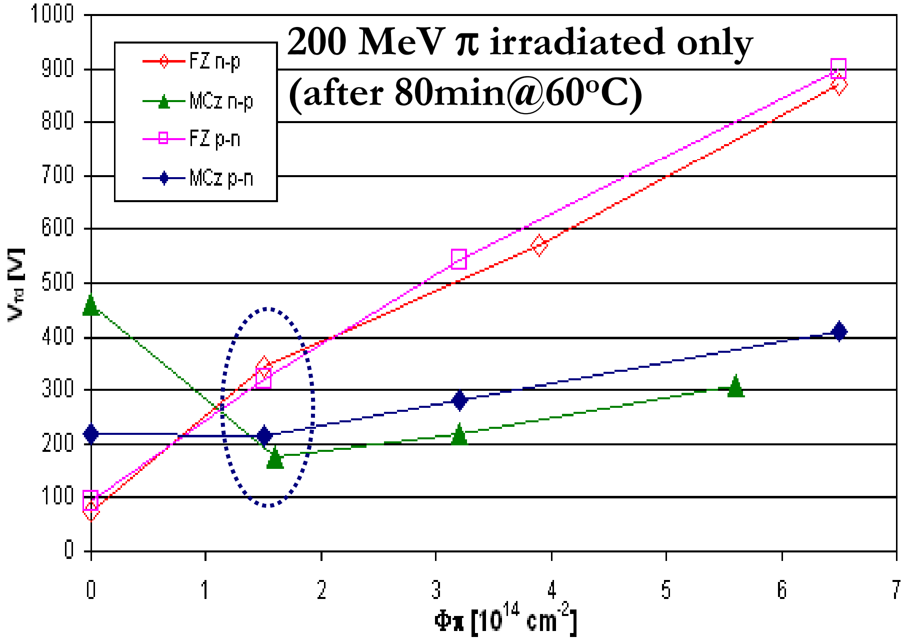
The following detectors were exposed to additional $2\cdot10^{14}$ cm^{-2} neutrons:

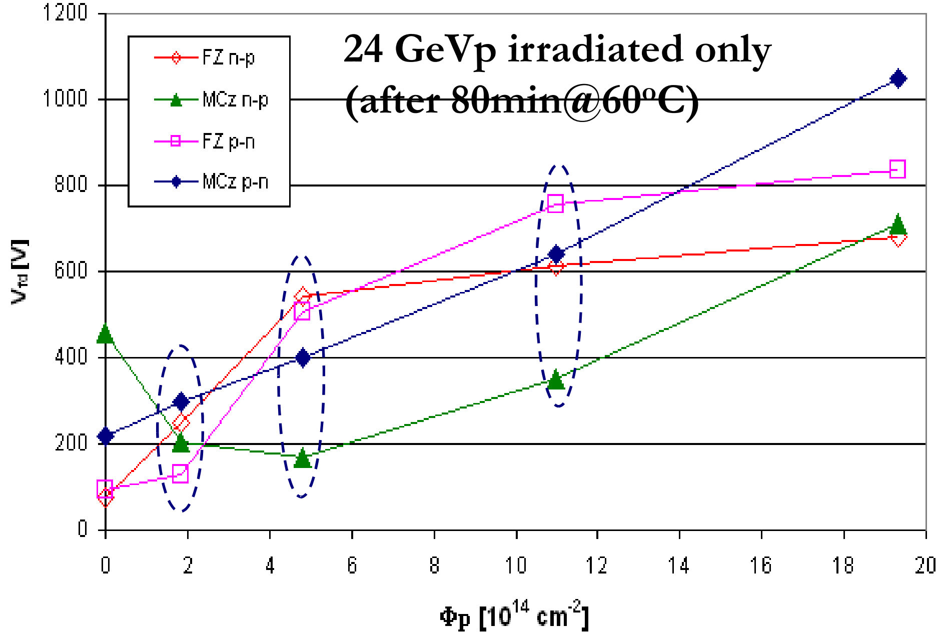
- Fz n-p: 1.85, 4.81 p; 1.5 π [10^{14} cm^{-2}]
- Fz p-n: 1.85,4.81 p; 1.5 π [10^{14} cm^{-2}]
- MCz n-p: 1.85, 4.81,11 p; 1.5 π [10^{14} cm^{-2}]
- MCz p-n: 1.85, 4.81,11 p; 1.5 π [10^{14} cm^{-2}]

Each of these detectors has a counterpart without neutrons!

Proton irradiated detectors were annealed prior to neutron irradiations for 10 min@60^{o}C.

Charge hadrons irradiations – control samples





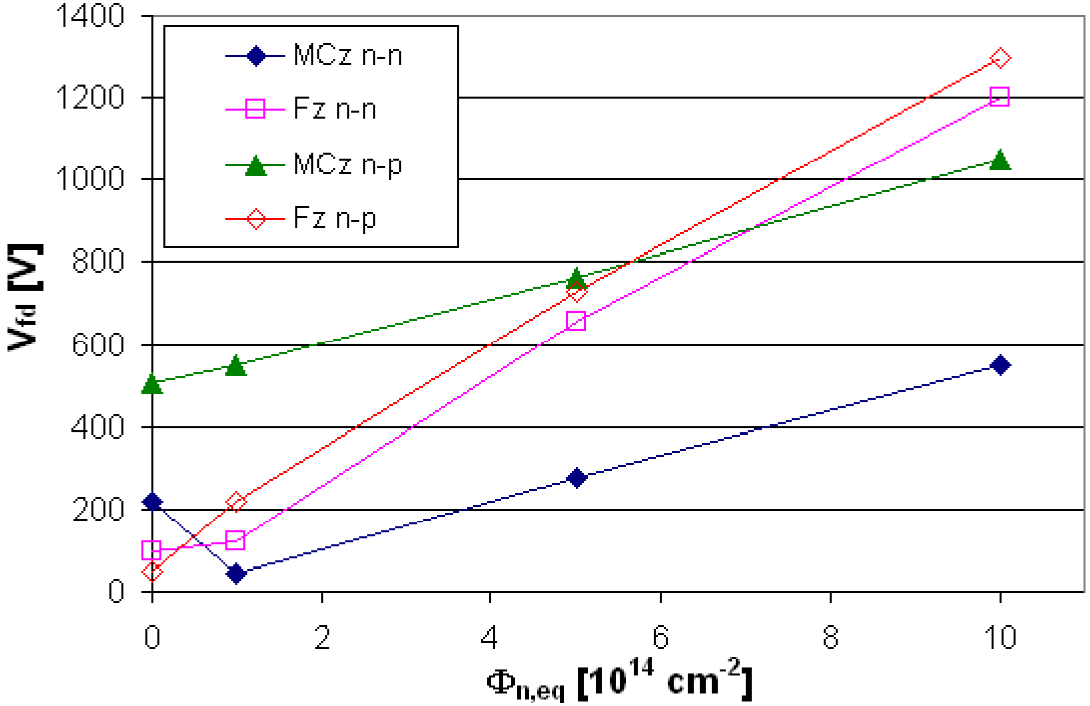
- Slope of V_{fd} increase with fluence
  - ✓ : MCz (p and n type): ~38 V/10^{14} cm^{-2} , **|g$_c$| ~ 0.005 cm^{-2}** ,using κ=1.14
  - ✓Fz (p and n type): ~110 V/10^{14} cm^{-2} **g$_c$~0.014 cm^{-2}** ,using κ=1.14

Slope of V_{fd} increase with fluence

✓MCz (p and n type): 54 V/10^{14} cm^{-2} **|g$_c$|~0.008 cm^{-2}** ,using κ=0.62

✓ 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?

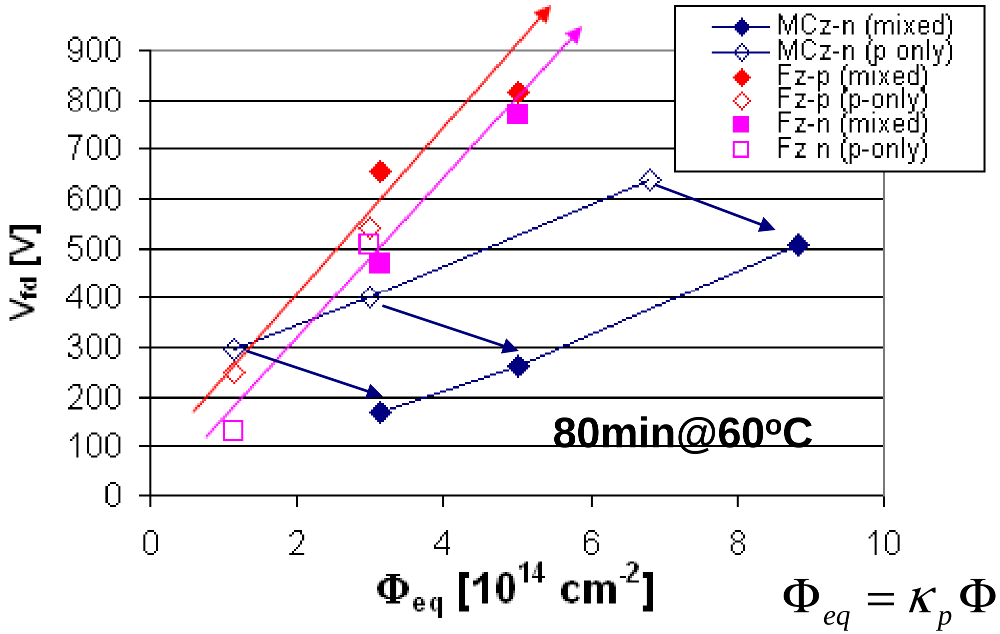
Neutron irradiations – control samples

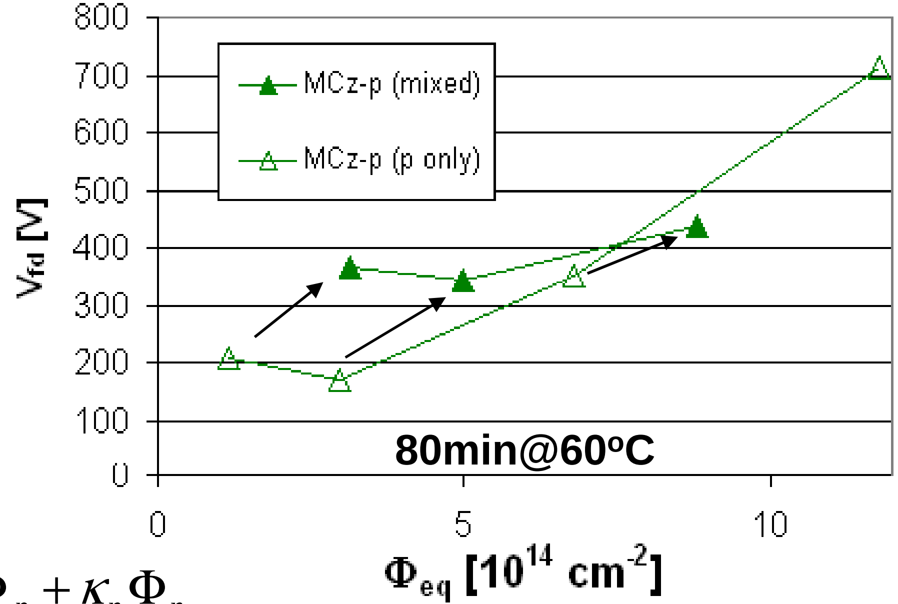


- Slope of V_{fd} increase with fluence
  - MCz (p and n type): ~56 V/10^{14} cm^{-2} ,
    g_c~ 0.008 cm^{-2}
  - Fz (p and n type): ~120 V/10^{14} cm^{-2}
    g_c~0.018 cm^{-2}

Mixed irradiations – 24 GeV protons+neutrons

Micron diodes irradiated with protons first and then with 2e14 n cm^{-2} (control samples p-only, open marker)





$$\Phi_{eq} = \kappa_p \Phi_p + \kappa_n \Phi_n$$

$$N_C = g_{c,p} \Phi_{eq,p} + g_{c,n} \Phi_{eq,n}$$

g_c can be + or -

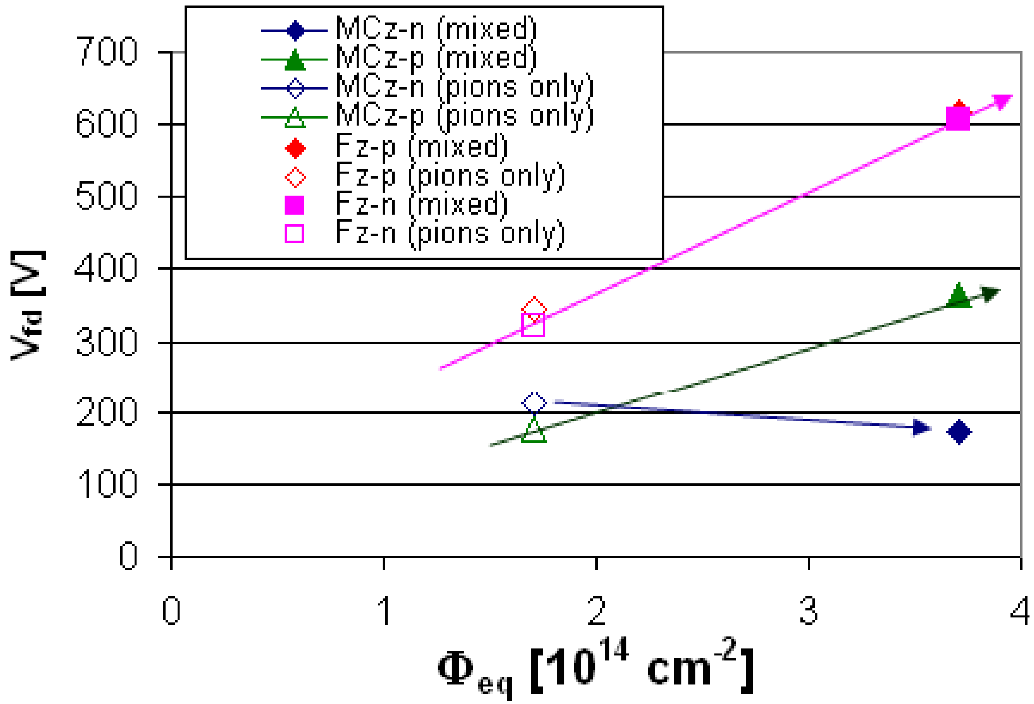
always +

- FZ-p,n: increase of V_{fd} proportional to Φ_{eq}
- MCz-n: decrease of V_{fd} , due to different signs of $g_{c,n}$ and $g_{c,p}$
- **MCz-p at larger fluences the increase of V_{fd} is not proportional to the added fluence**

–as if material becomes more “n-like” with fluence – same as observed in annealing plots

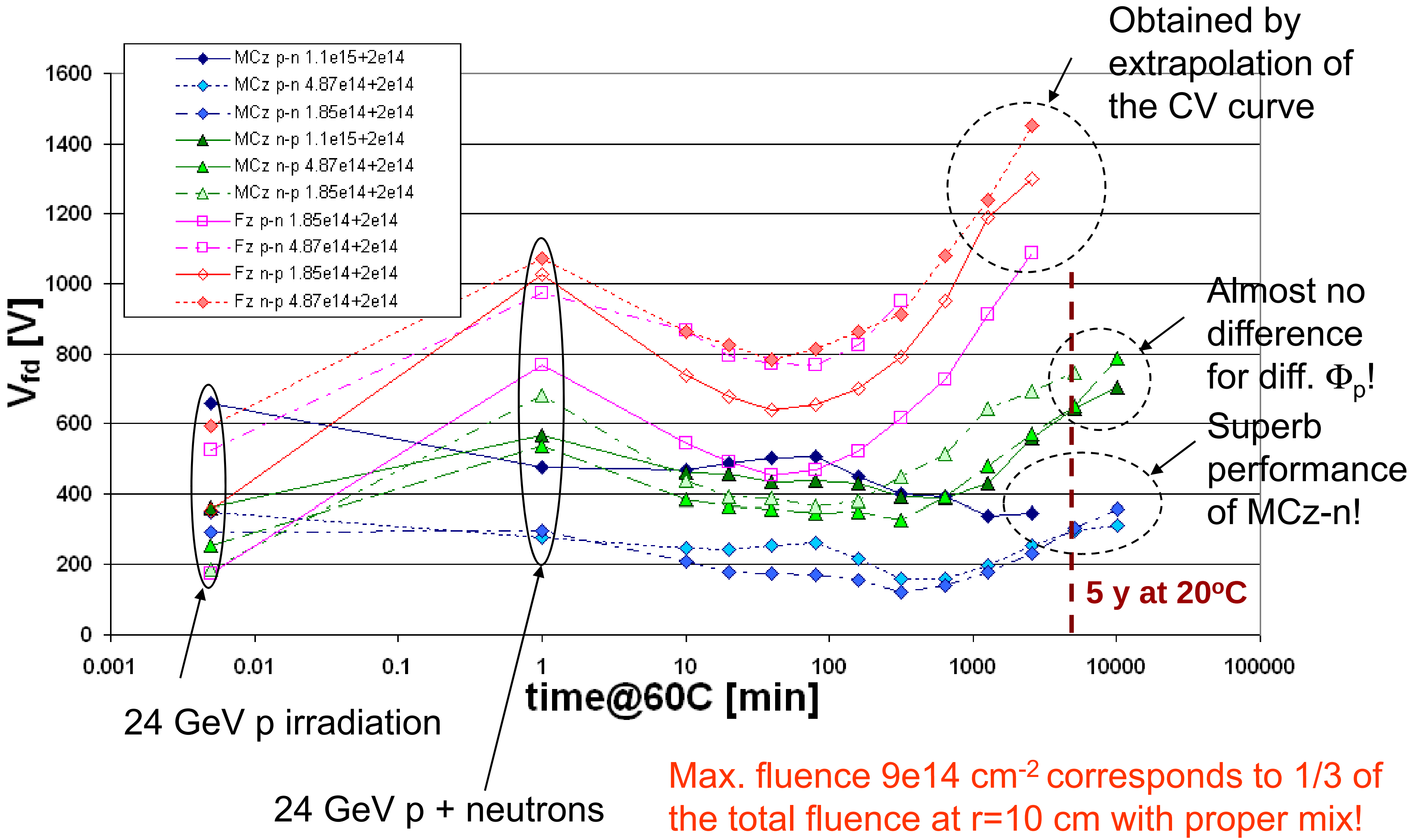
Mixed irradiations – 200 MeV pions + neutrons

Micron diodes irradiated with pions first and then with 2e14 n cm^{-2} (control samples pions-only, open marker)



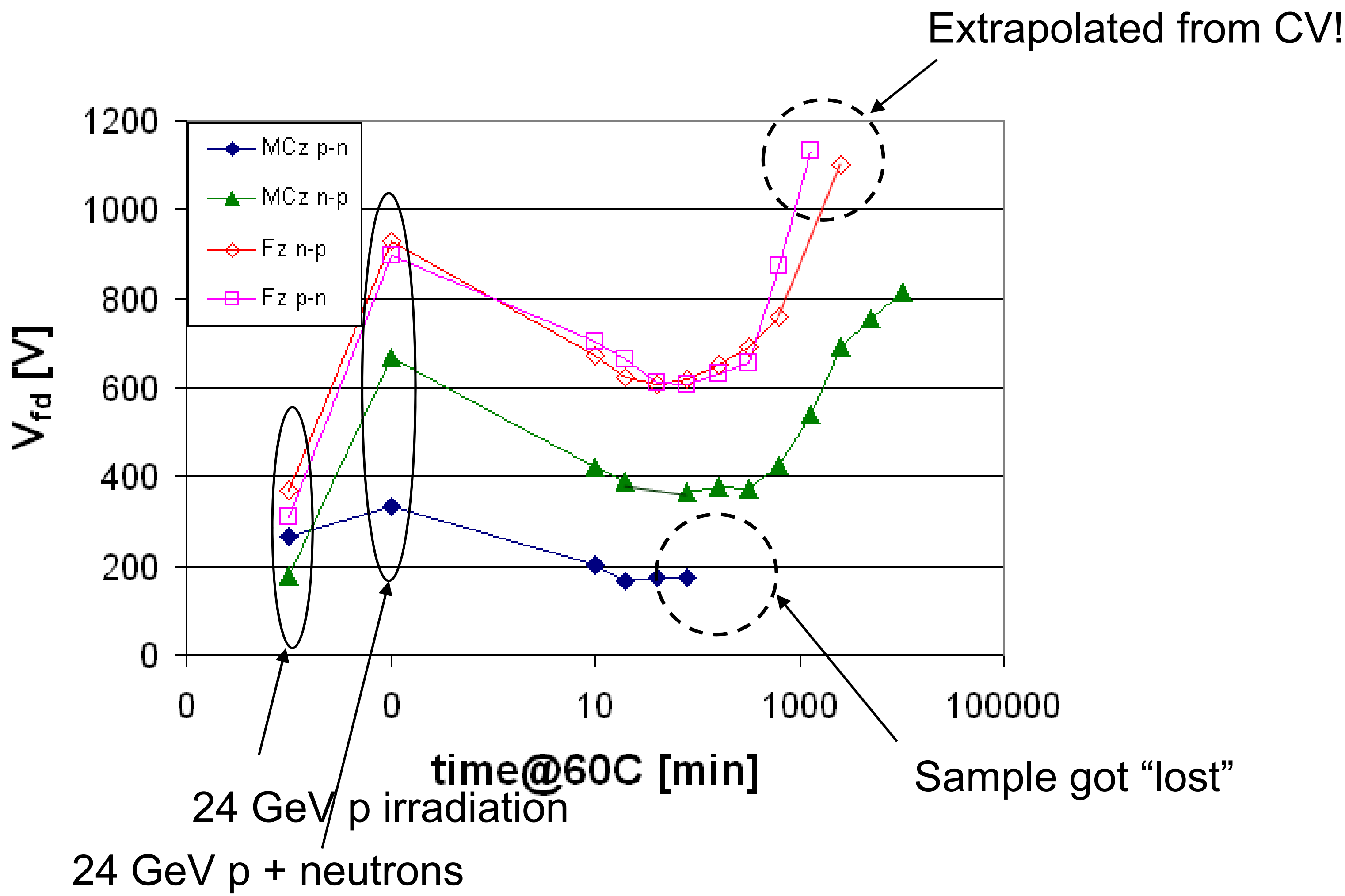
- FZ-p,n: increase of V_{fd} proportional to Φ_{eq}
- MCz-n: decrease of V_{fd}, detector underwent SCSI -only small change of V_{fd}
- MCz-p as expected for negative space charge

Annealing of the V_{fd} – 24 GeV p + n



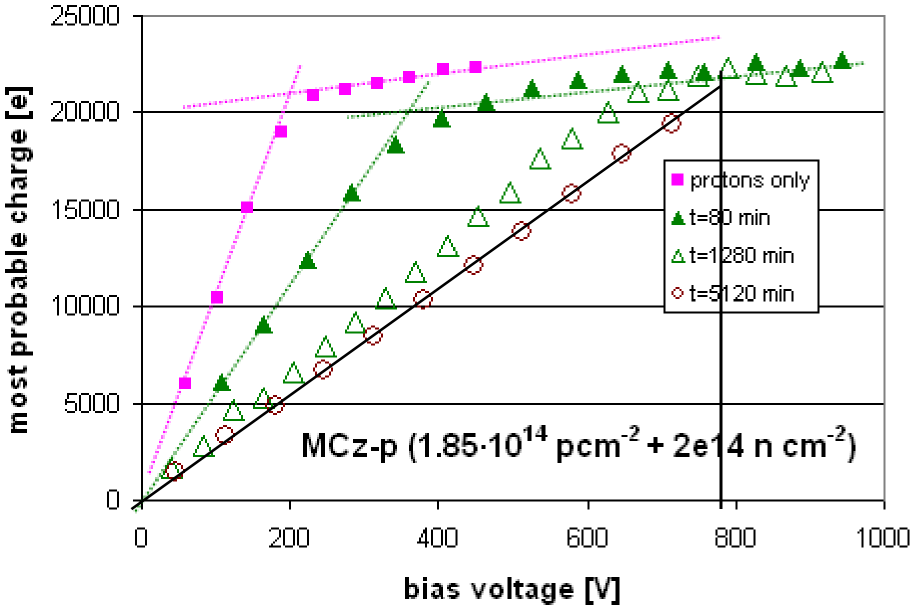
Max. fluence 9e14 cm^{-2} corresponds to 1/3 of the total fluence at r=10 cm with proper mix!

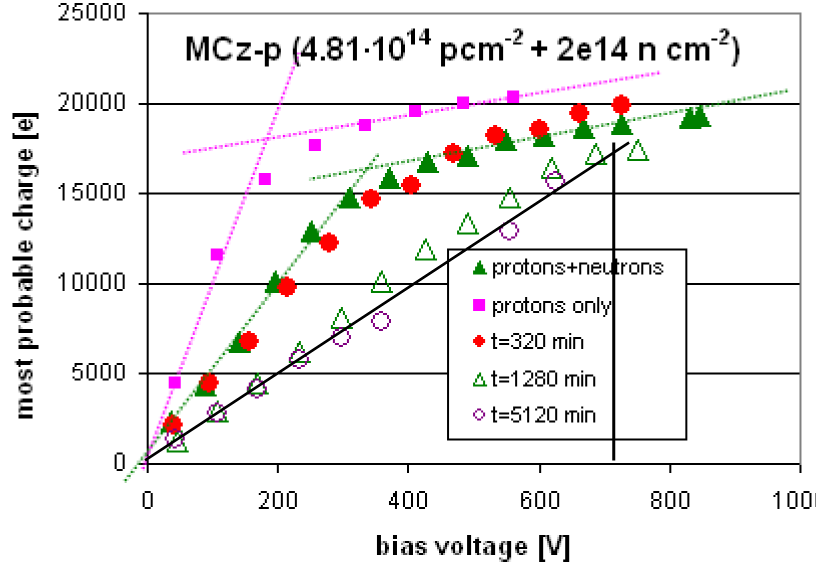
Annealing of the V_{fd} – 200 MeV π + n



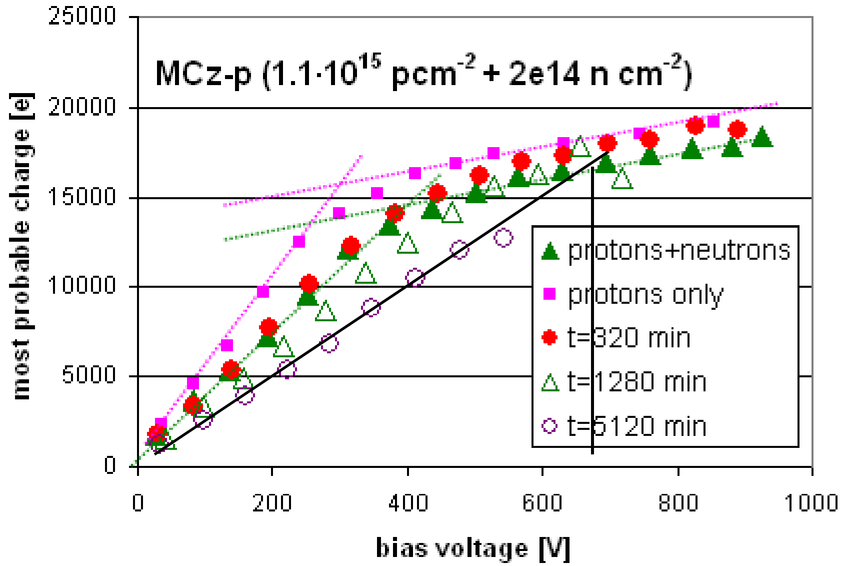
Same behavior as for p irradiated samples!

MCz-p diodes (24 GeV p + neutrons)

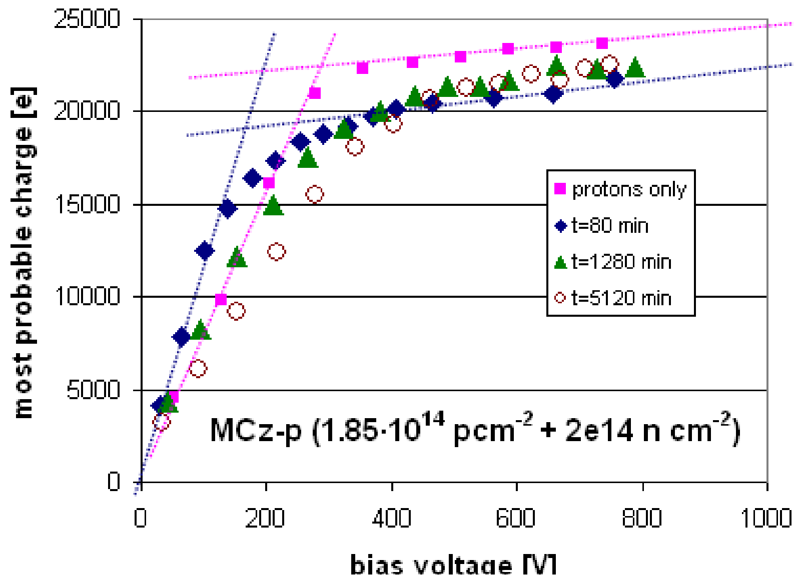


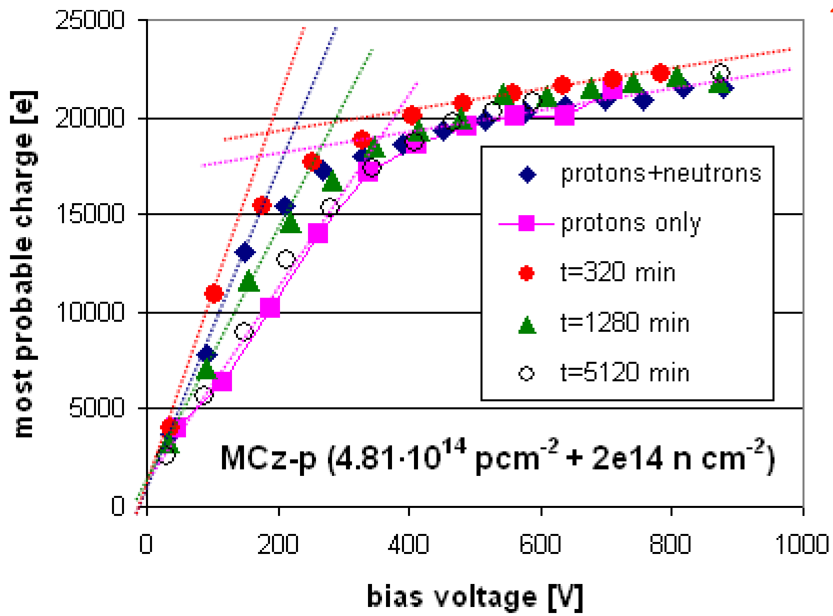


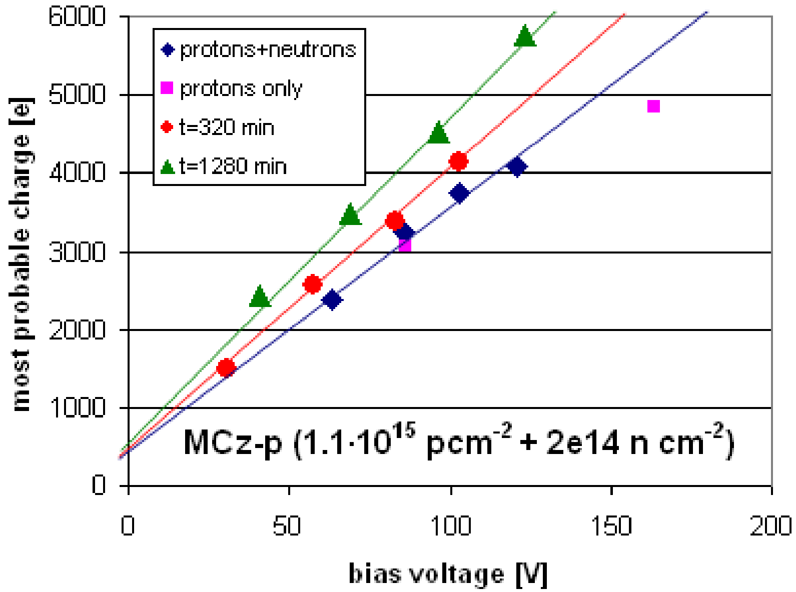
- As observed in V_{fd} annealing the impact on neutrons is smaller at larger fluence !
  - Prolonged annealing
  - Smaller amplitude?
- No/very small impact of annealing on charge collection efficiency for over-depleted detectors.



MCz-n diodes (24 GeV p + neutrons)



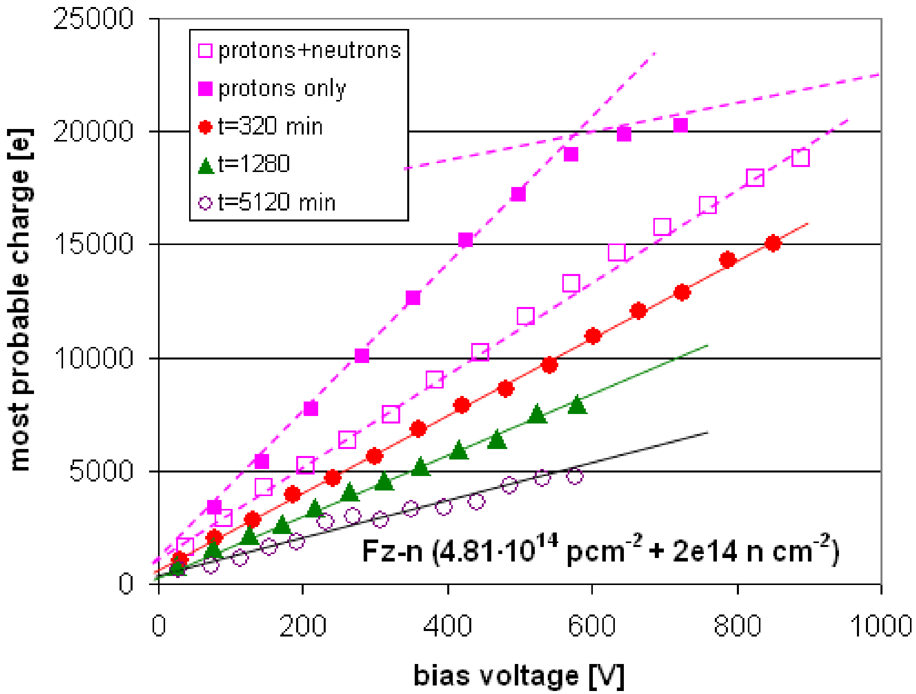


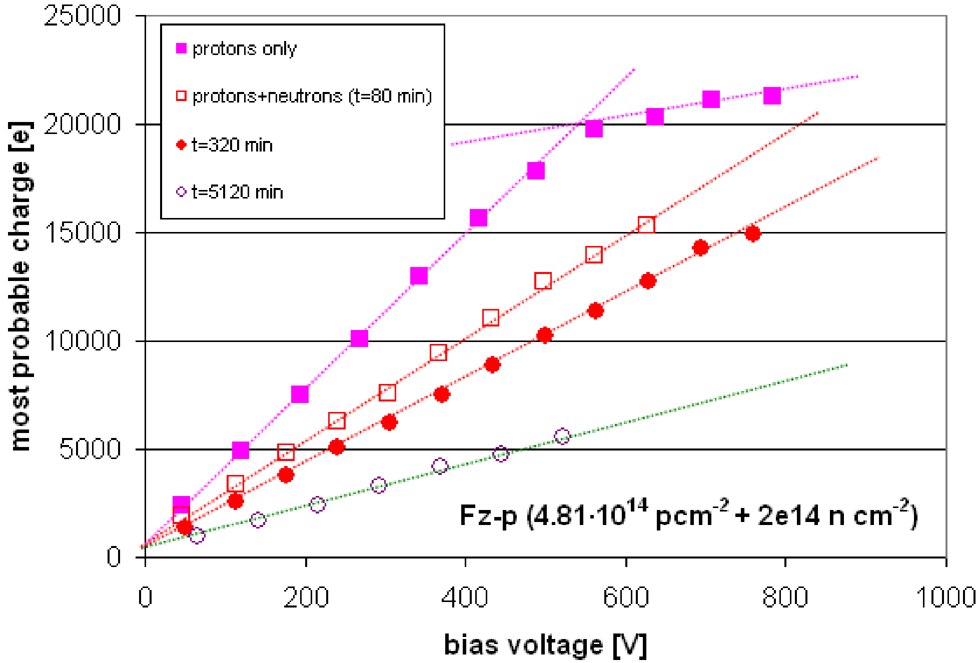


Again, the V_{fd} translates to CCE!

- Adding neutrons is beneficial also for CCE!
  - Middle fluence – mixed is always better that control!
- Unfortunately the high fluence sample broke close to the guard ring region and there were micro discharges in CCE measurements at high bias! CV works fine. Initial slope of Q(V) fits in the picture!

Fz-n,p type (24 GeV p + neutrons)



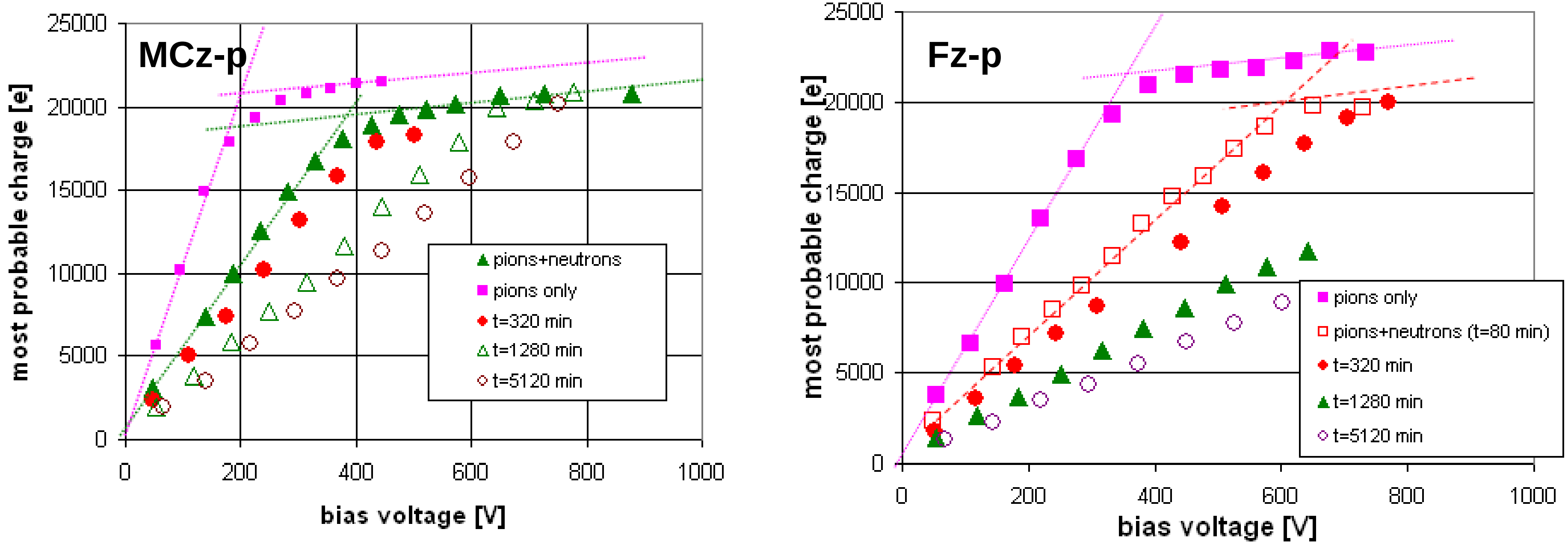


V_{fd} nicely reflects in CCE – much worse performance of Fz detectors!

Generally we see earlier breakdown at late stages of annealing of Fz/MCz-p samples!

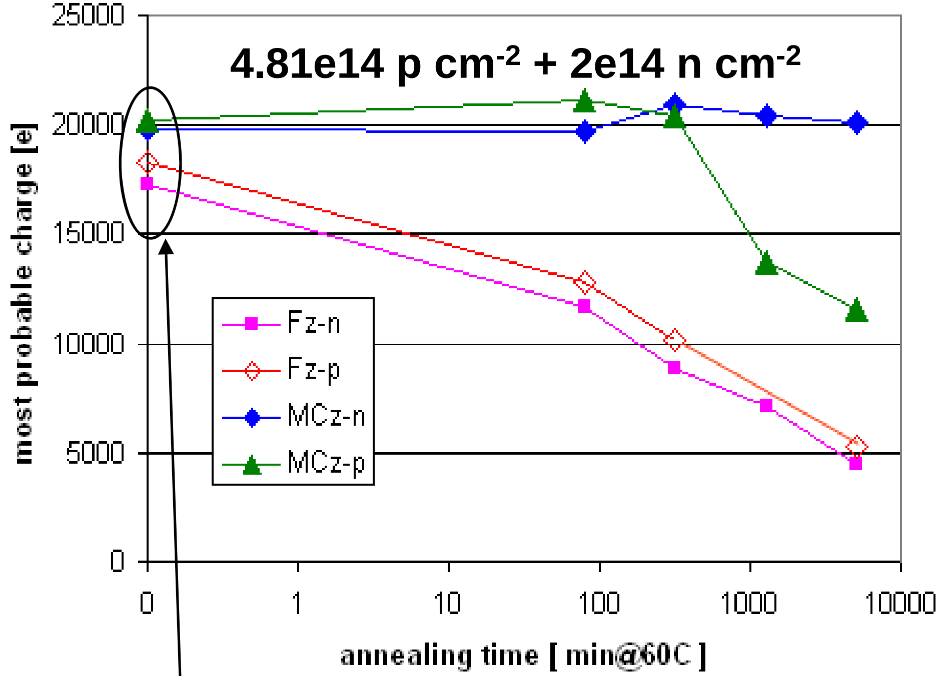
Larger N_{eff} -> higher field -> earlier break down ?

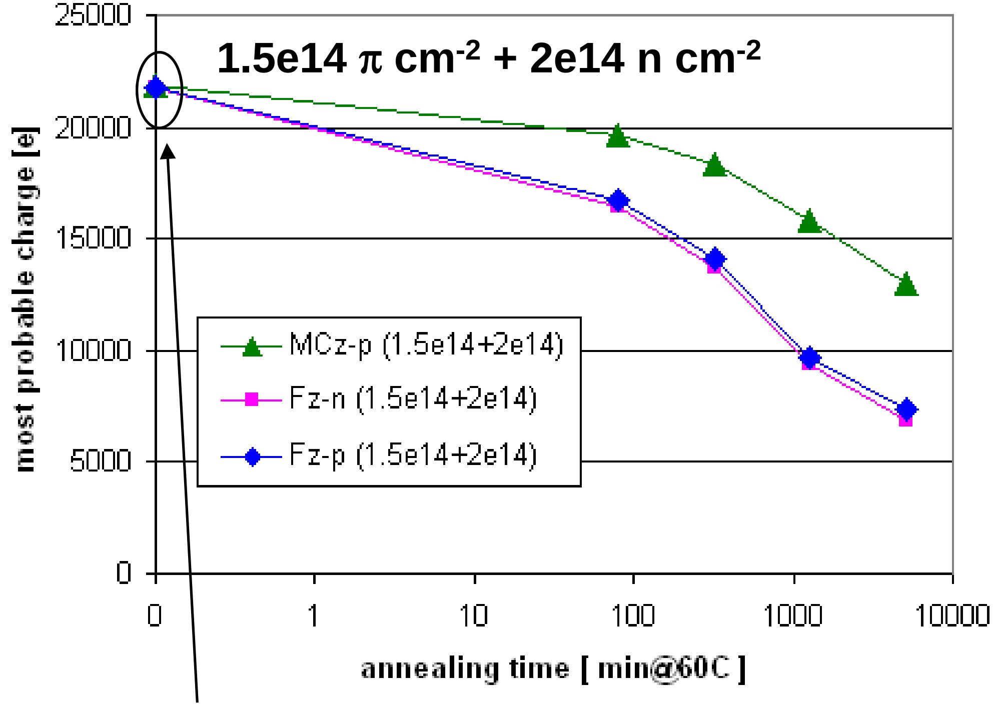
MCz-p/Fz-p type (π + neutrons)



Same picture as for proton irradiated samples!

Annealing of Q at 500 V



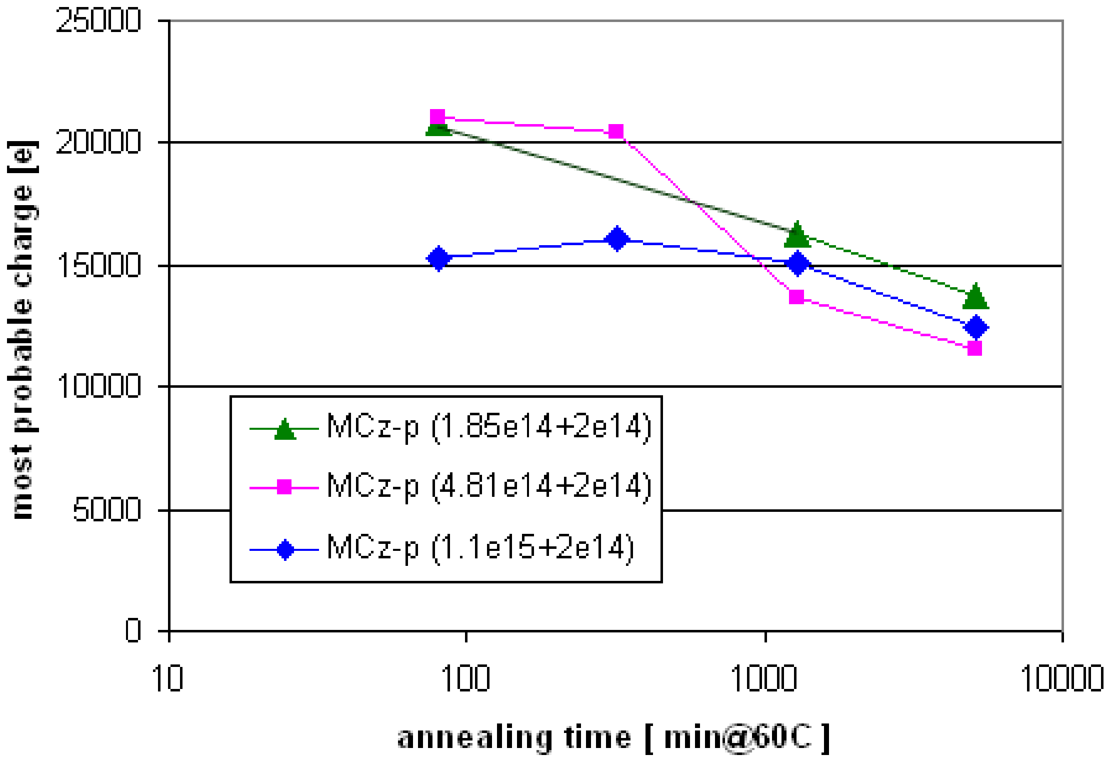


24 GeV p
irradiation only

200 MeV π
irradiation only

- constant degradation of Fz detectors due to reverse annealing – very similar performance of Fz-p and Fz-n
- MCz-p starts to suffer due to loss of depletion
- MCz-n no degradation

Annealing of CCE for MCz-p at 500 V



Almost no difference between different fluences after very long annealing times:

•prolonged annealing at high fluences

•smaller impact of neutron irradiation on V_{fd} for higher Φ_p

Around 13000 e after $\Phi_{eq}=9\cdot10^{14}$ cm^{-2} annealed to times equivalent to 5 years at 20^{o}C.

Conclusions

- The damage of different particles:
  - is additive for: leakage current and also for V_{fd} (N_{eff})
  - discrepancy for MCz-p for N_{eff} at high fluences-smaller increase of V_{fd} as expected if damage is additive
- V_{fd} from C-V and Q-V agree well for mixed irradiated diodes also during annealing after fluence up to ~10^{15} cm^{-2}
- MCz-n best of all in terms of V_{fd} (compensation of space charge), but MCz-p is also better than Fz (during long term annealing scale of SLHC)
- Would the “compensation” of space charge work also at higher fluences? We’ll see soon …