Annealing of CCE in HPK strip detectors irradiated with pions and neutrons

Igor Mandić[1], **Vladimir Cindro**[1], **Andrej Gorišek**[1], **Gregor Kramberger**[1],
Marko Milovanović[1], **Marko Mikuž**[1,2], **Marko Zavrtanik**[1]

[1]Jožef Stefan Institute, Ljubljana, Slovenia
[2] Faculty of Mathematics and Physics, University of Ljubljana, Slovenia

Introduction:

- ATLAS07 mini strip detectors produced by Hamamatsu irradiated with pions at PSI in 2010 and with neutrons in Ljubljana
- charge collection measurements with ^{90}Sr source on SCT128 setup in Ljubljana
- measurements repeated after several annealing steps at 60°C
- update of results with pion irradiated detectors and comparison with neutrons

➔ annealing studies for neutron irradiation published in:
I. Mandić et al., NIM A 629 (2011) 101–105

➔ annealing studies with pion irradiated detectors accepted for publication in JINST

- first results with mixed (pion + neutron) irradiated detector

Detectors:

- p-type, FZ, 320 µm thick, 75 µm strip pitch, 1x1 cm^2, V_{fd} ~ 170 V produced by Hamamatsu

- ATLAS07-PSSSD_Series I, batch number: VXX73414

➔ 6 inch FZ wafer, but*: "wafer producer has a control of oxygen content to an order of 10^{17} ions/cm^3. ..“….* Y. Unno, private communication

- detectors irradiated with pions:

1) A07, W19, Z3, P21: $\Phi = 1.65\cdot10^{14}\,\pi/\text{cm}^2 = 1.8\cdot10^{14}\,n_{eq}/\text{cm}^2$, irrad. time: 2 days

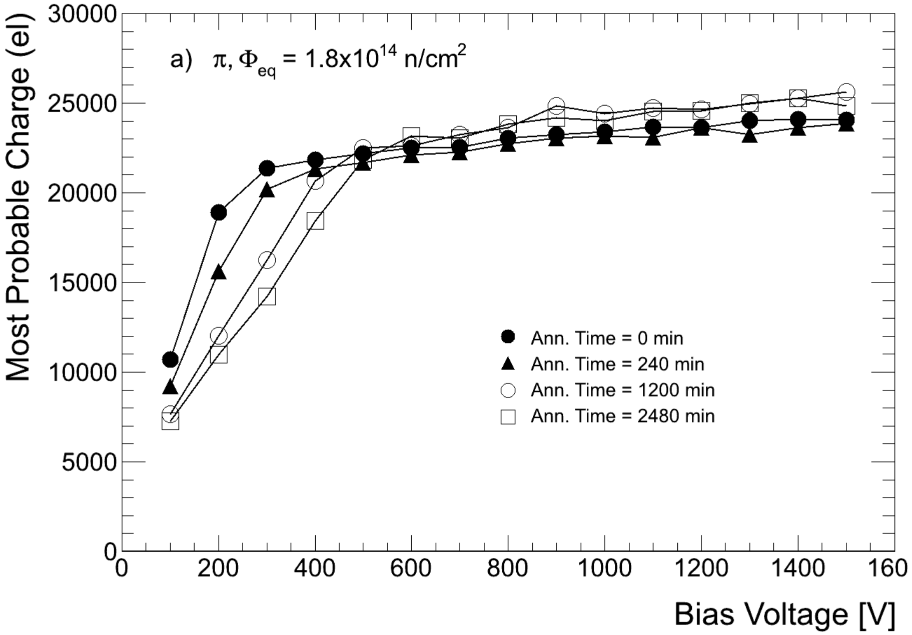
2) A07, W49, Z1, P19: $\Phi = 4.14\cdot10^{14}\,\pi/\text{cm}^2 = 4.6\cdot10^{14}\,n_{eq}/\text{cm}^2$, irrad. time: 4.5 days

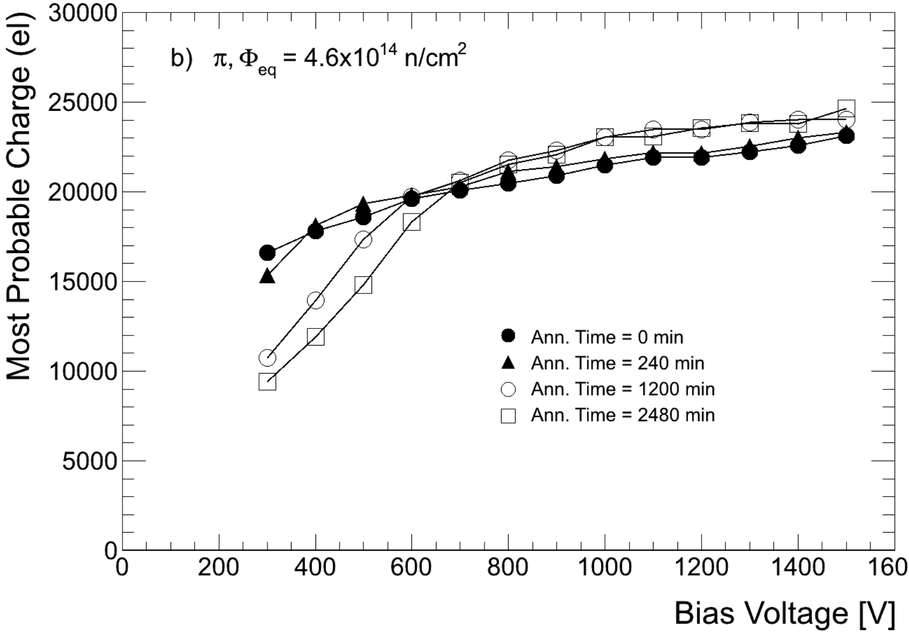
3) A07, W22, Z3,P1: $\Phi = 1.43\cdot10^{15}\,\pi/\text{cm}^2 = 1.6\cdot10^{15}\,n_{eq}/\text{cm}^2$, irrad. time: 16 days

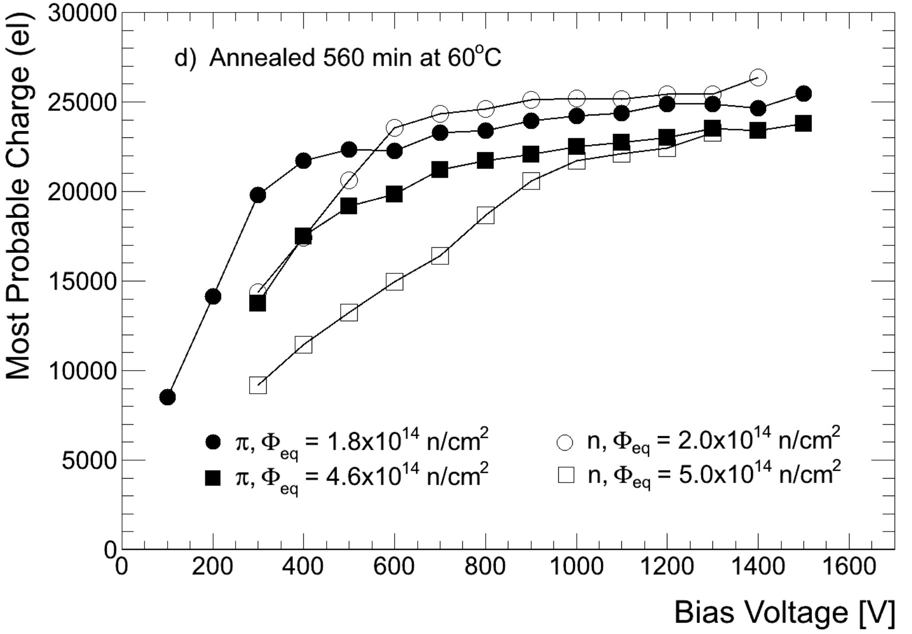
→ detectors at T ~ 26 ° C during irradiation

- detectors irradiated with neutrons: W45-Z3-P15, W19-Z3-P18, W22-Z3-P3, W16-Z3-P21

Fluences: 2, 5, 10 and $50\cdot10^{14}\,n_{eq}/\text{cm}^2$ irradiation times less than 1 hour, T < 45 ° C.



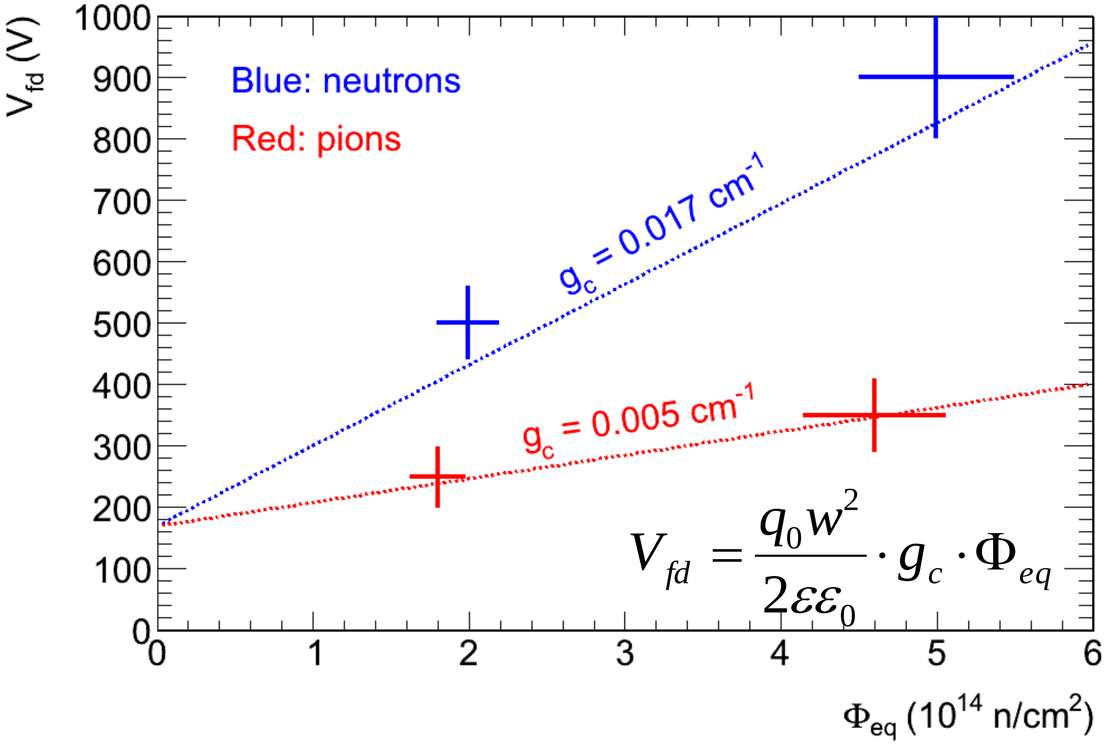




➔ significantly lower V_{fd} for pions compared to neutrons

➔ lower acceptor introduction rates for pion irradiation expected in oxygenated detector material

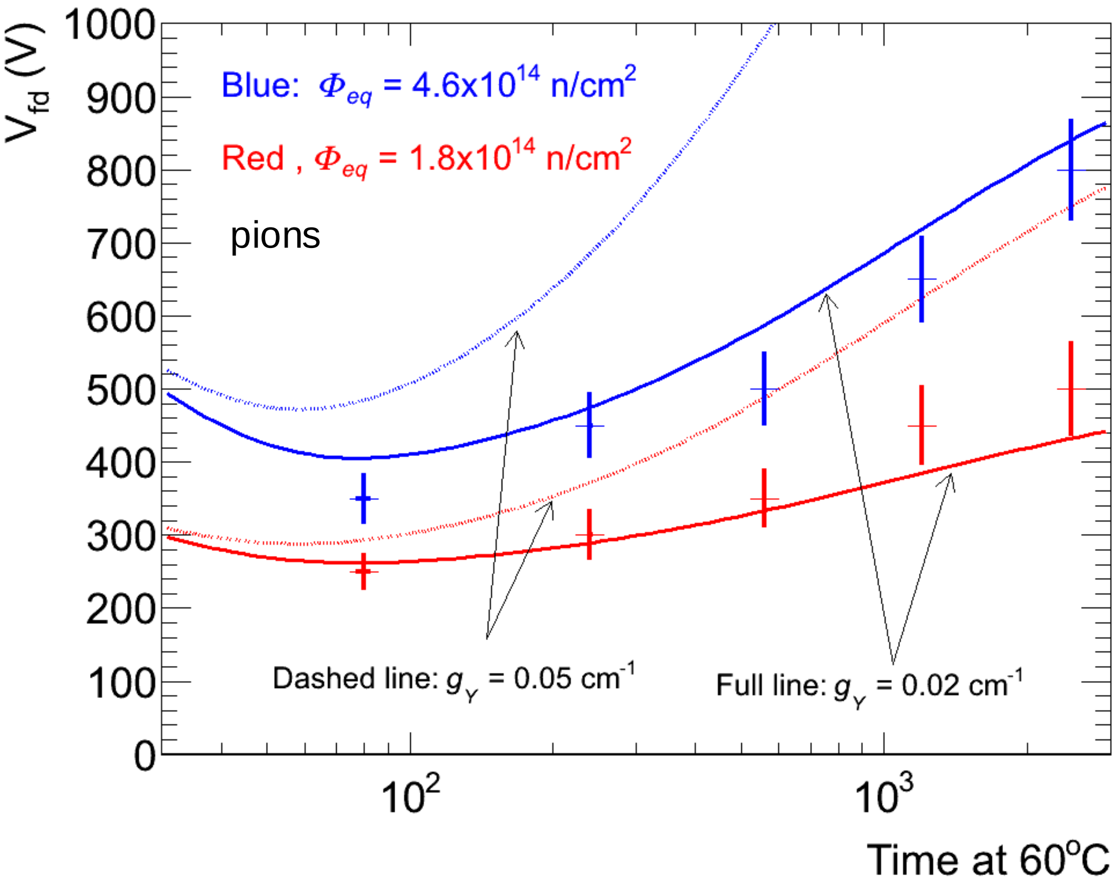
- V_{fd} (estimated from the kink in the Q-V plot) after 80 minutes at 60°C



- g_c = 0.017 cm^{-1} measured for FZ-p type material irradiated with neutrons (G. Kramberger et al,. NIMA 612 (2010) 288-295, V. Cindro et al., NIMA 599 (2009) 60-65)

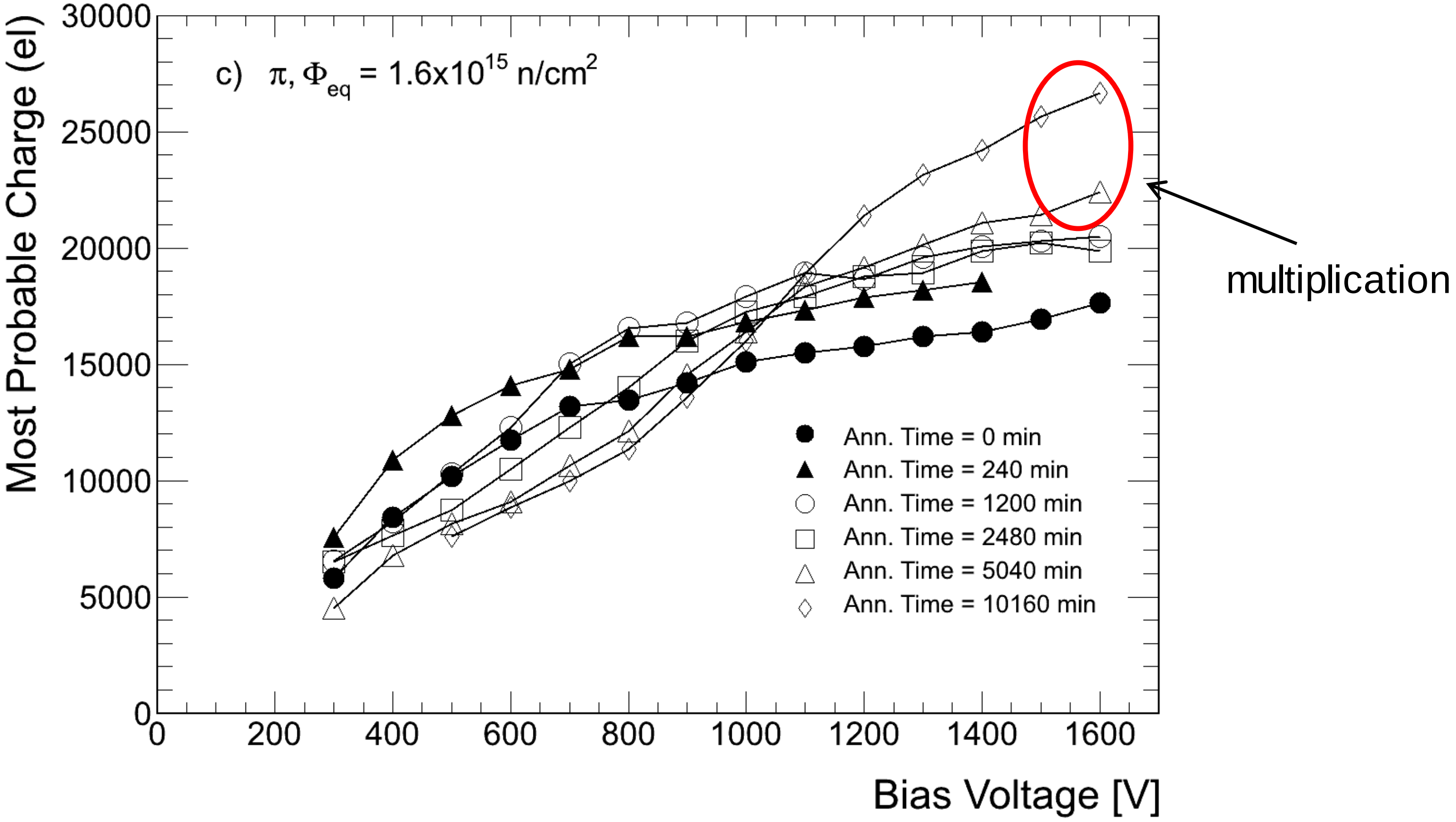
- pions compatible with g_c ~ 0.005 cm^{-1}
  → significantly smaller than for neutrons
  → smaller than g_c = 0.013 cm^{-1} measured for FZ-p type material irradiated with pions (G. Kramberger et al,. NIMA 612 (2010) 288-295)
  → lower V_{fd} increase after proton irradiation of HPK sensors measured also by K. Hara et al., Nucl. Instr. Meth. A 636 (2011) S83-S89.

- compare with Hamburg model, long term annealing described by: $\Phi_{eq}\cdot g_Y\cdot(1+1/(1+\frac{t}{\tau_Y}))$



- with τ_Y = 1100 min (G. Kramberger et al.) better agreement with g_Y = 0.02 cm^{-1} than with g_Y ~ 0.05 cm^{-1} measured for p-type FZ material irradiated with pions (by G. Kramberger et al.)

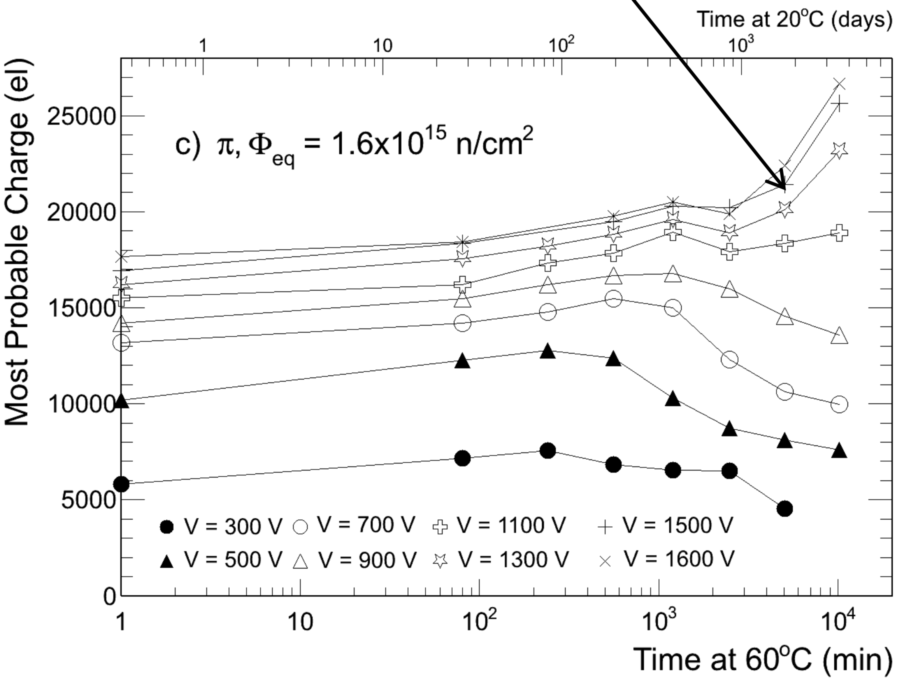
- (other parameters used in the Hamburg model: g_c ~ 0.005 cm^{-1}, $V_{fd,0}$ = 170 V, g_a = 0.018 cm^{-1}, τ_a = 19 min)

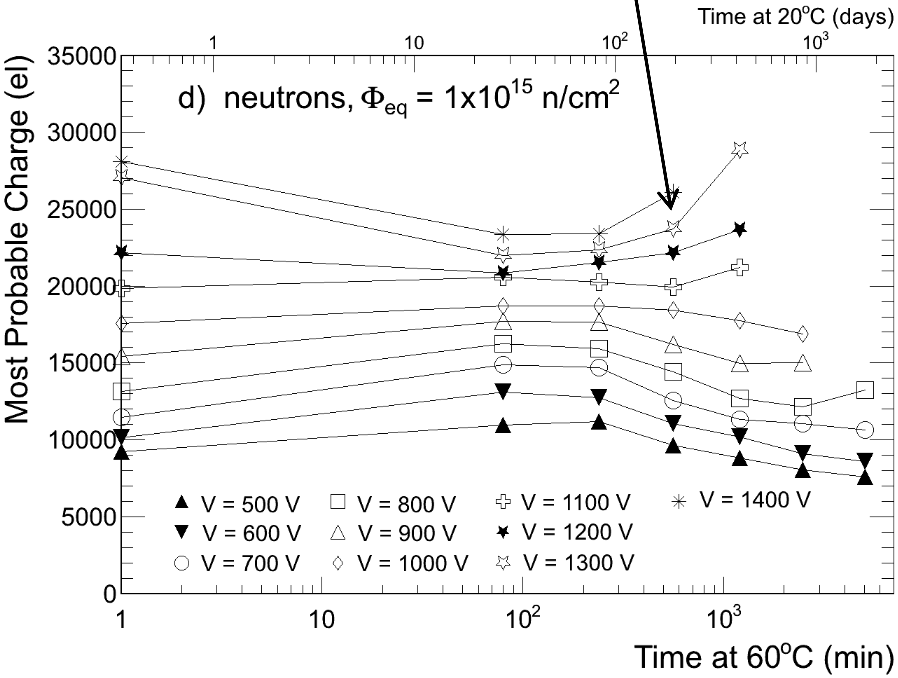


- rise of CCE characteristic for charge multiplication observed after long annealing times → longer than after neutron irradiation

Pions: t ~ 5000 minutes, V ~ 1300 V

Neutrons: t ~ 500 minutes, V ~ 1300 V





- multiplication obvious in detectors irradiated with pions after longer annealing times then after irradiation with neutrons:

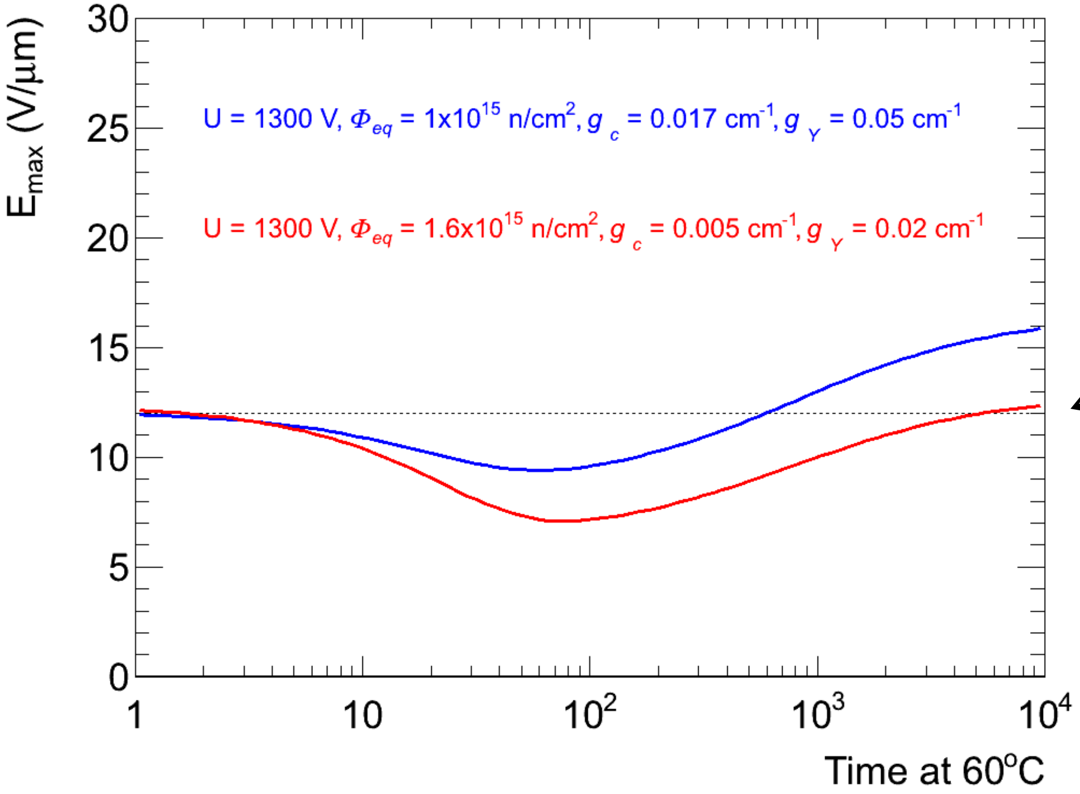
➔ smaller introduction rates for pions ➔ takes longer to reach sufficient N_{eff} for high enough peak electric field

➔ N_{eff} ~ 4e13 cm^{-3} at annealing points where multiplication starts to be obvious

- pad detector geometry, uniform N_{eff}:

$$E_{\max} = \sqrt{\frac{2q_0 N_{eff} V}{\varepsilon\varepsilon_0}}$$

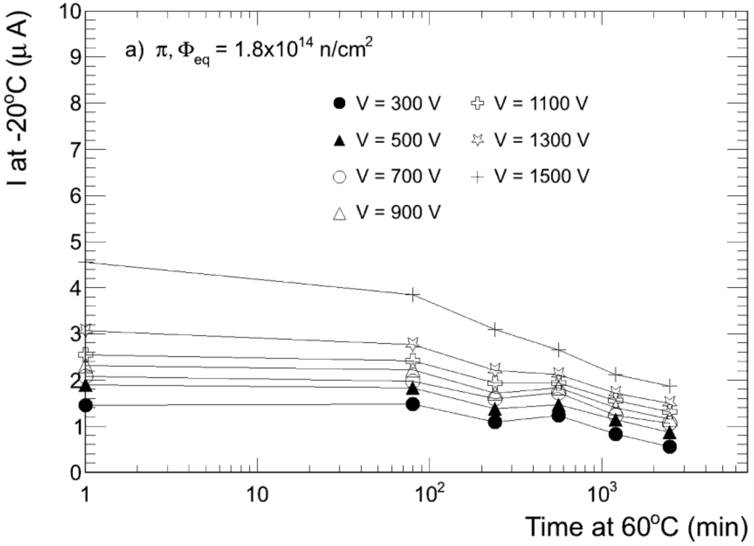
- annealing of N_{eff} according to Hamburg model

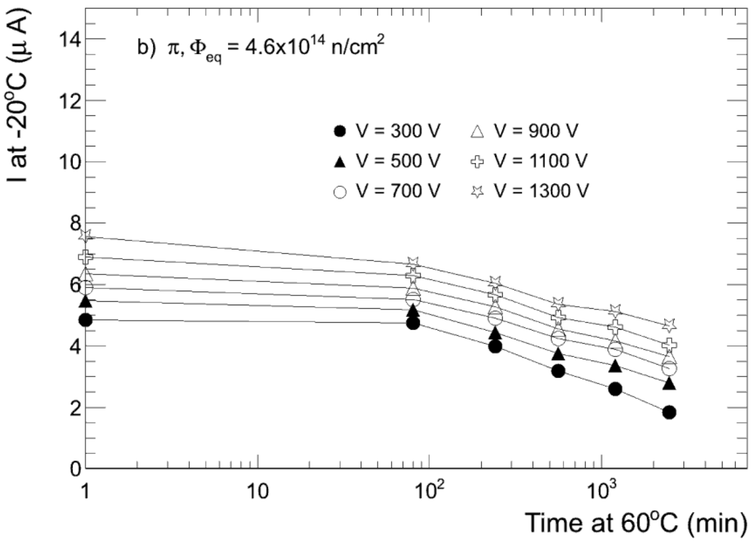


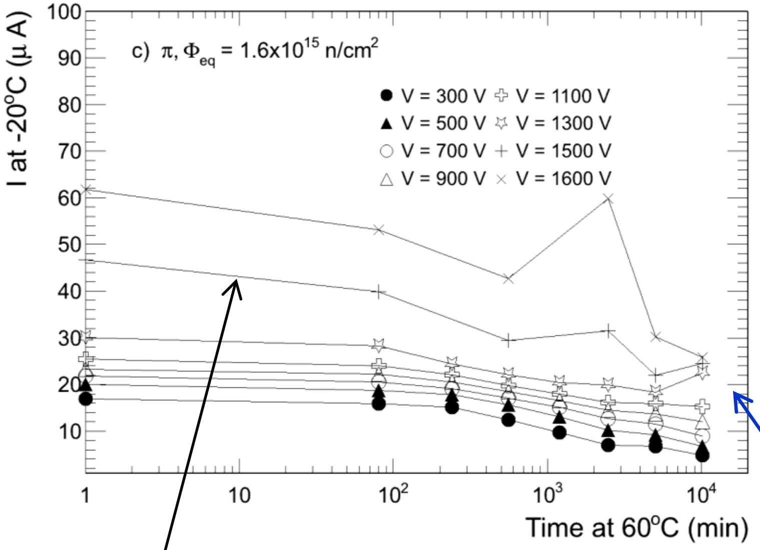
multiplication
“threshold”

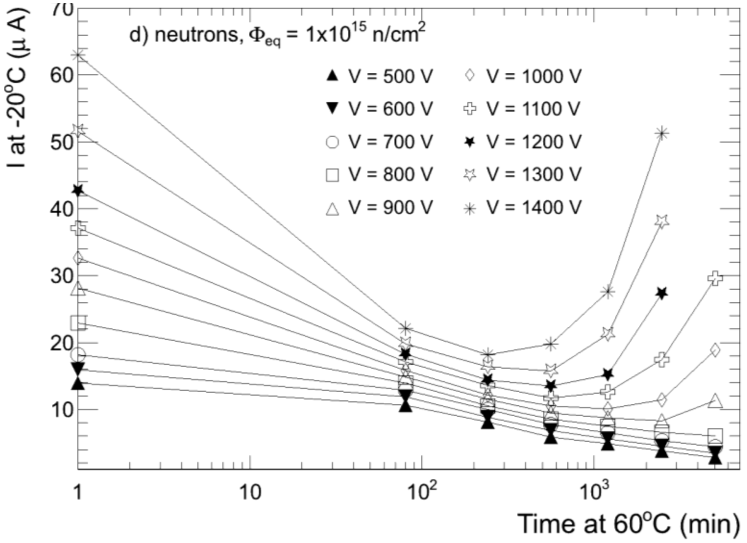
- multiplication after: - few hundred minutes on 60°C for neutrons (Φ_{eq} = 1e15 n/cm^2)
  - few thousand minutes on 60°C for pions (Φ_{eq} = 1.6e15 n/cm^2)
  → agrees with measurements

Detector current





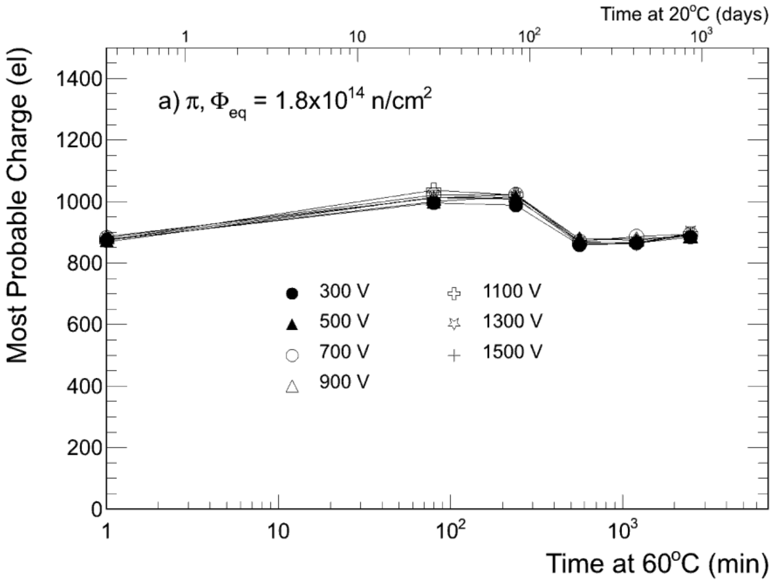


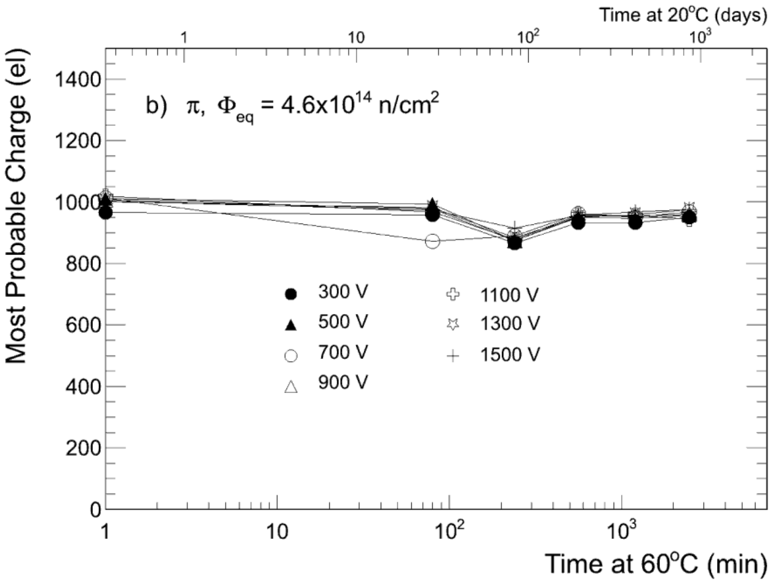


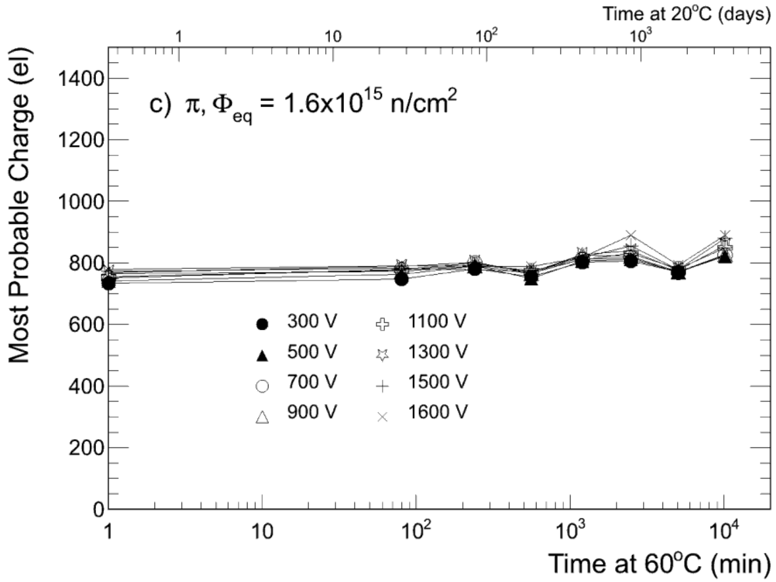
Near breakdown, unstable

Multiplication not as obvious for pions as for neutrons
→ higher N_{eff} (i.e. E_{max}) reached with neutrons

Noise

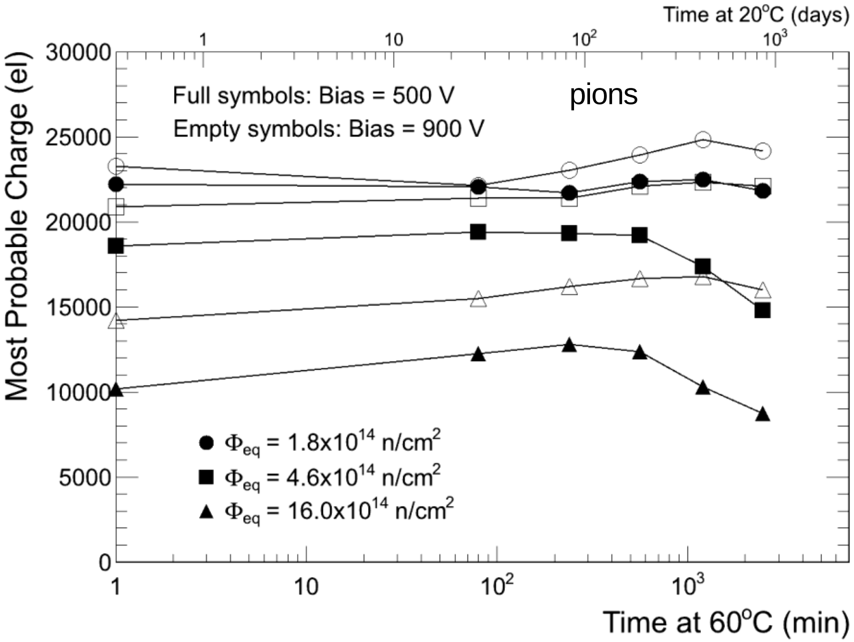


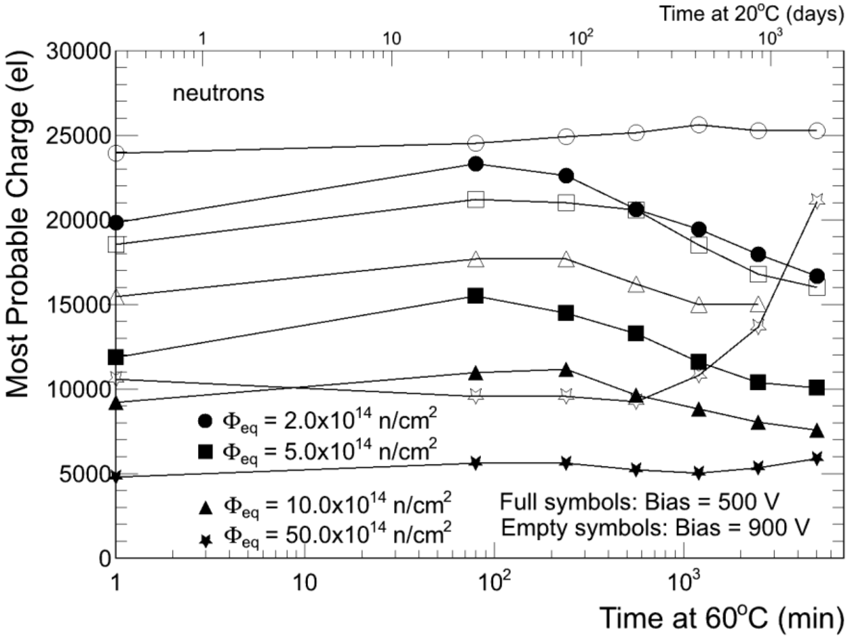




- no large multiplication
  - ➔ no significant increase of noise

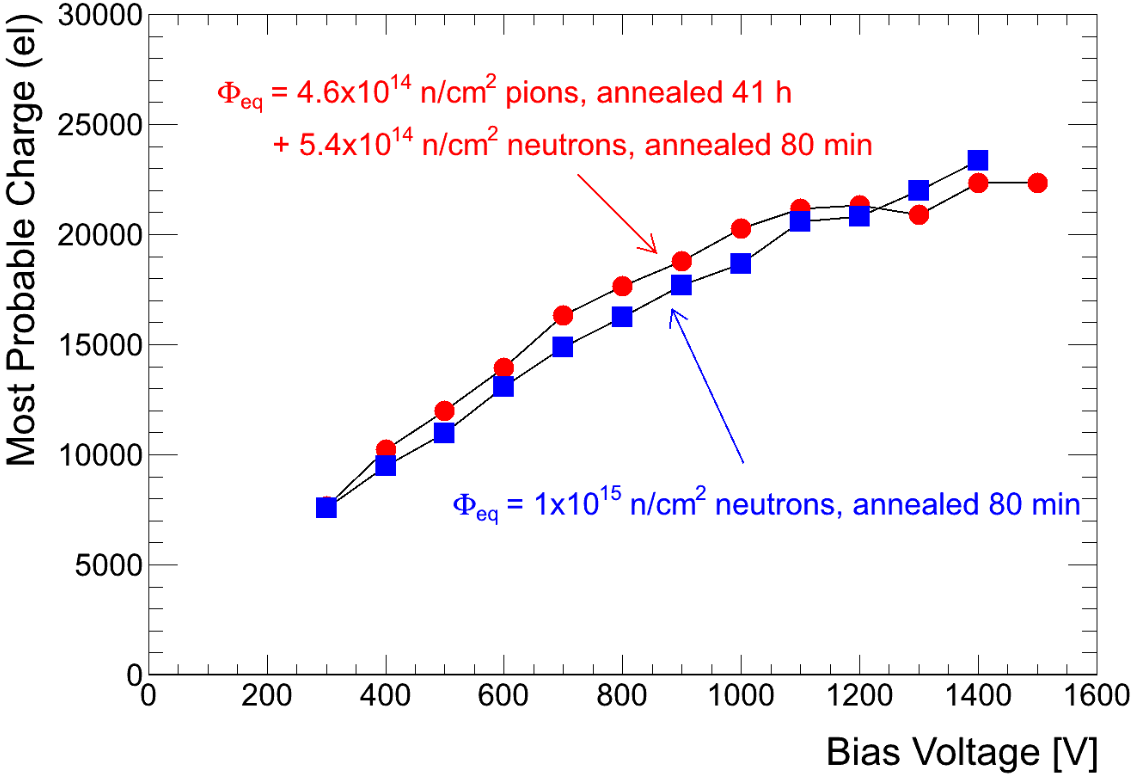
Summary annealing plots





- at 500 V CCE loss after long annealing at 60°C not very bad → max. 20%
- at higher voltages smaller losses

Mixed irradiation



- mixed: 1. $\Phi_{eq} = 4.6e14$ n/cm^2 , pions, annealed for 41 h at 60°C ➔ $N_{eff} \sim 1.1e13$ cm^3
  2. $\Phi_{eq} = 5.4e14$ n/cm^2 , neutrons, annealed 80 min. at 60°C ➔ $N_{eff} \sim 2.3e13$ cm^3
  Sum: $N_{eff} \sim 3.4e13$ cm^3
- neutrons: $\Phi_{eq} = 1e15$ n/cm^2 , annealed for 80 min. at 60°C ⟶ $N_{eff} \sim 3.3e13$ cm^3
- trapping: mixed: $\tau_e = 2.3$ ns, $\tau_h = 1.6$ ns
  neutrons: $\tau_e = 2.3$ ns, $\tau_h = 2.2$ ns
  } not very different

→ result consistent: similar N_{eff} and similar $\tau_{e,h}$ ==> similar collected charge

Conclusions

- in ATLAS07 Hamamatsu p-type mini strip detectors irradiation with pions causes smaller increase of V_{fd} than irradiation with neutrons
- increase of V_{fd} with long term annealing slower than after irradiation with neutrons

➔ both can be expected for oxygenated FZ material

- after pion irradiation increase of collected charge due to multiplication is observed after longer annealing time and at higher Φ_{eq} than in neutron irradiated detectors

➔ because of oxygen higher fluences and longer annealing times are needed to reach sufficiently high space charge concentration and consequently high electric field for significant charge multiplication

- expected losses of collected charge due to long term annealing in these detectors are not very severe, especially if bias voltage higher than 500 V is available

- mixed irradiations: collected charge as expected