Update on charge collection measurements with SCT128 chip in Ljubljana

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Introduction:

- charge collection measurements with ^{90}Sr source on SCT128 chip setup in Ljubljana
  → accelerate annealing: repeat charge collection measurements (at -20°C) after several annealnig steps at 60° C

- ATLAS07 mini strip detectors produced by Hamamatsu irradiated with pions at PSI in 2010 and with neutrons in Ljubljana
  → p-type, 6 inch FZ wafer, 320 µm thick, 75 µm strip pitch, 1x1 cm^2, V_{fd} ~ 190 V

- many results of measurements with these detectors already published:

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

➔ annealing studies with pion irradiated detectors published in:
I. Mandić et al., 2011 - JINST - 6 - P11008

Outline of this presentation:

- short summary of annealing measurements with pion and neutron irradiated detectors

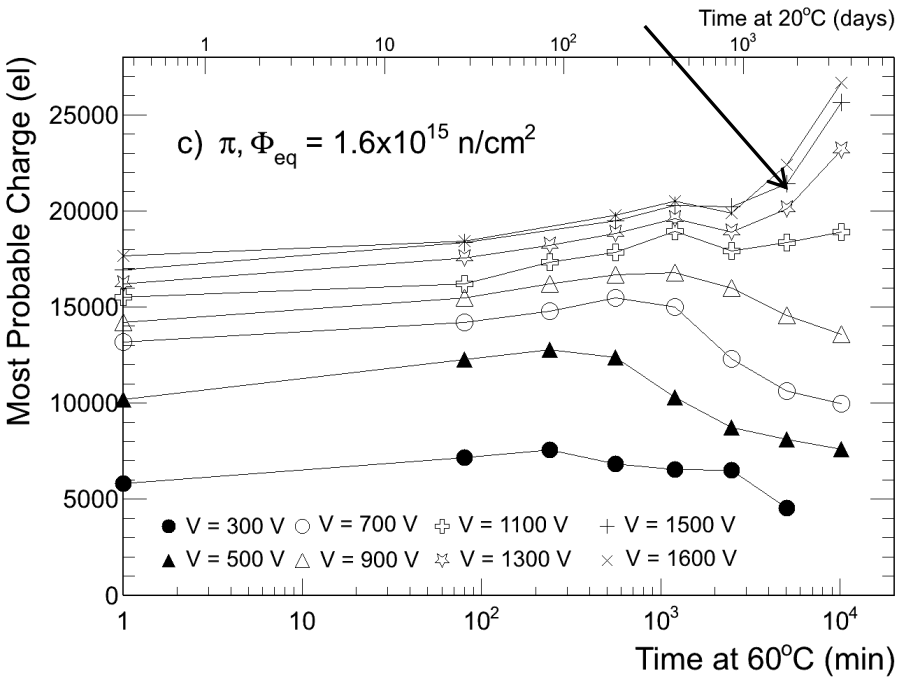
- measurements with mixed irradiated detector: pions at PSI + neutrons in Ljubljana

- time dependence of collected charge

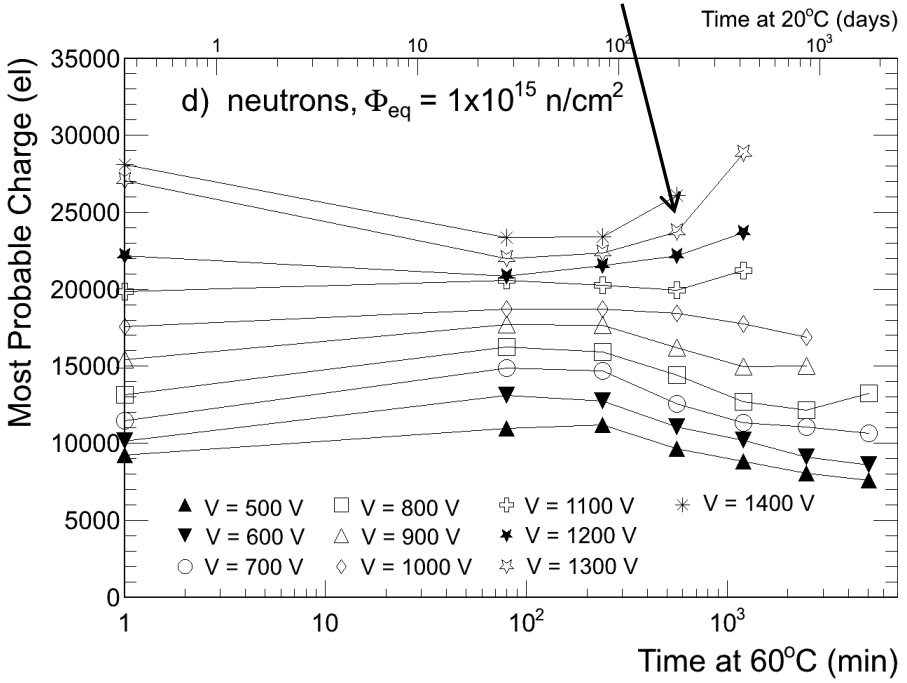
Shown in the last RD50 workshop *(19th RD50 Workshop, CERN, 21 – 23 November 2011)* :

http://indico.cern.ch/getFile.py/access?contribId=4&sessionId=2&resId=1&materialId=slides&confId=148833

Pions: t ~ 5000 minutes, V ~ 1300 V



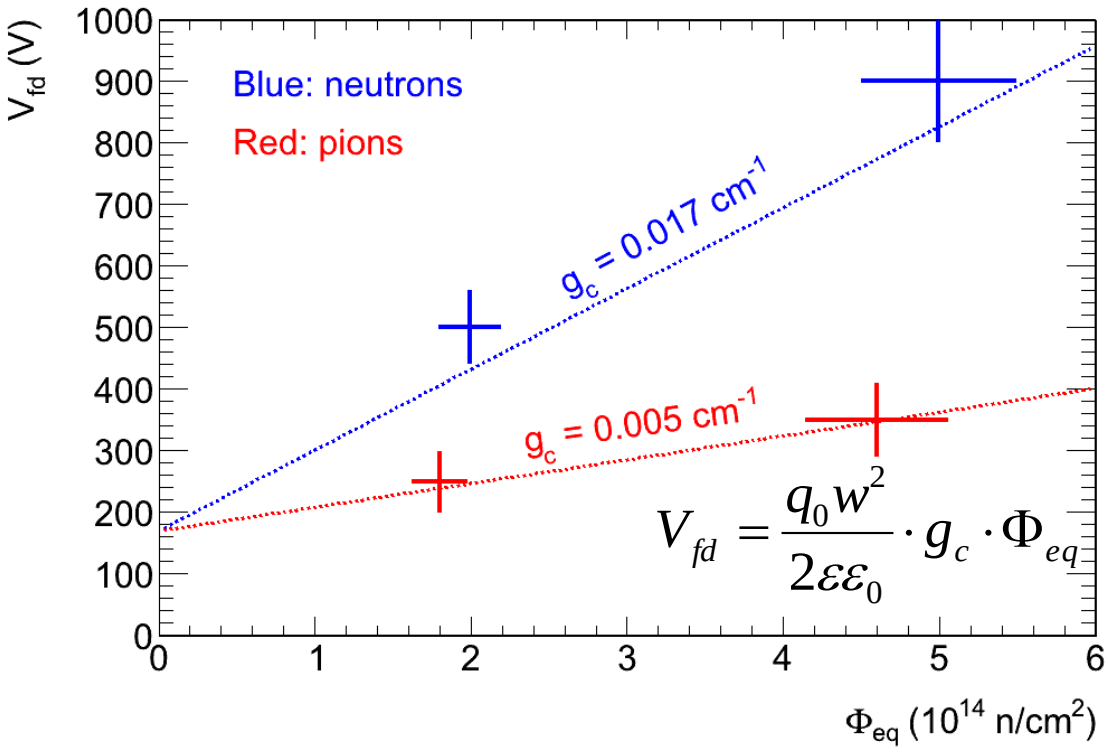
Neutrons: t ~ 500 minutes, V ~ 1300 V



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

➔ smaller stable damage and reverse annealing introduction rates for pions ➔ takes longer to reach sufficient N_{eff} for high enough peak electric field for multiplication

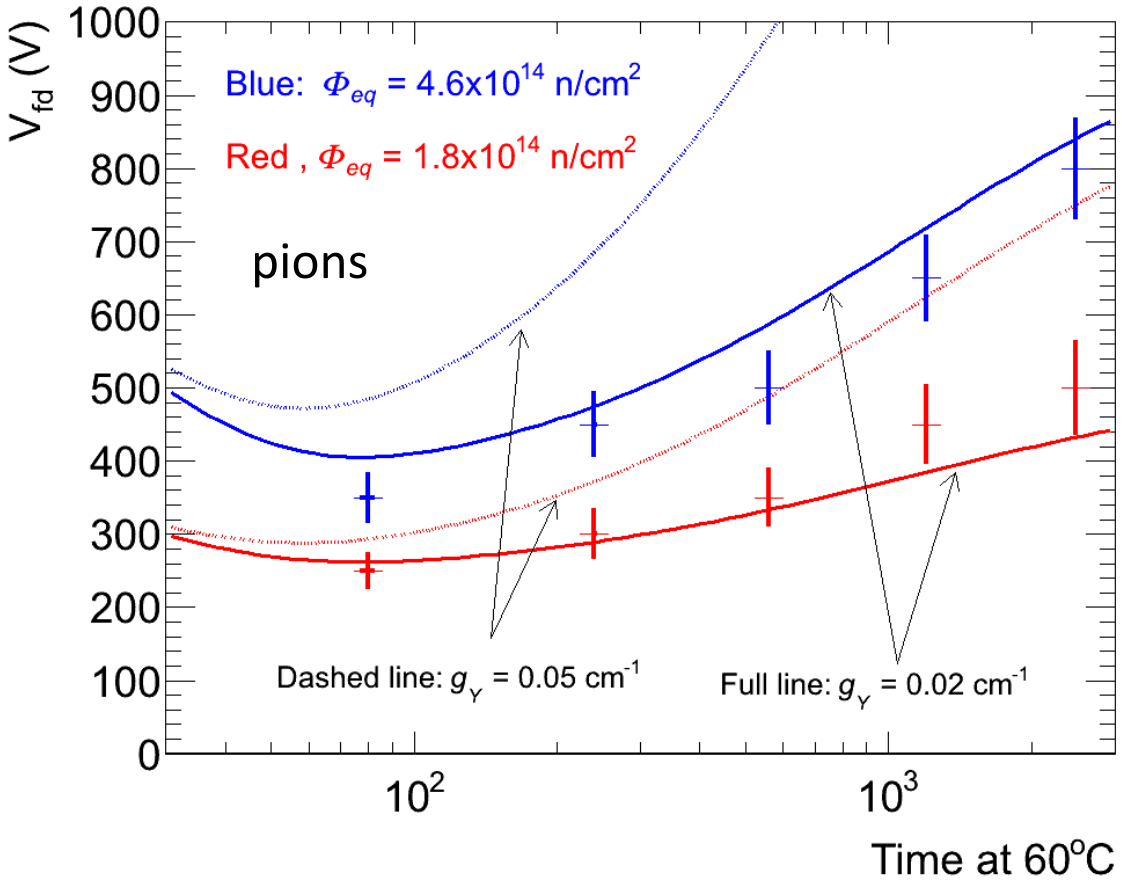
• V_{fd} (estimated from the kink in the Q-V plot) after 80 minutes at 60°C



• 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
→ 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.

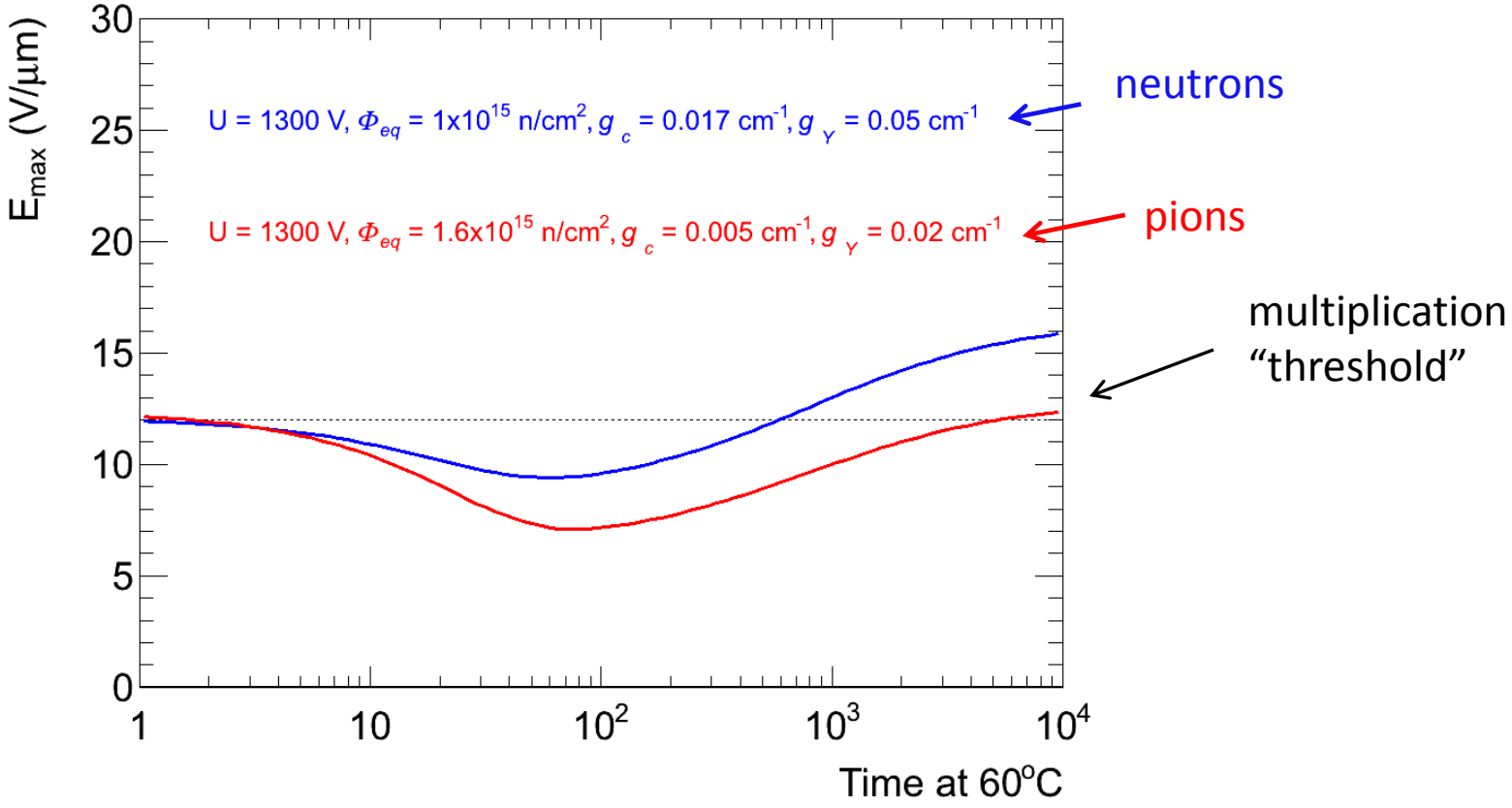
• compare with Hamburg model, long term annealing described by: $N_Y = \Phi_{eq} \cdot g_Y \cdot (1 - 1/(1 + \frac{t}{\tau_Y}))$



• 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.)

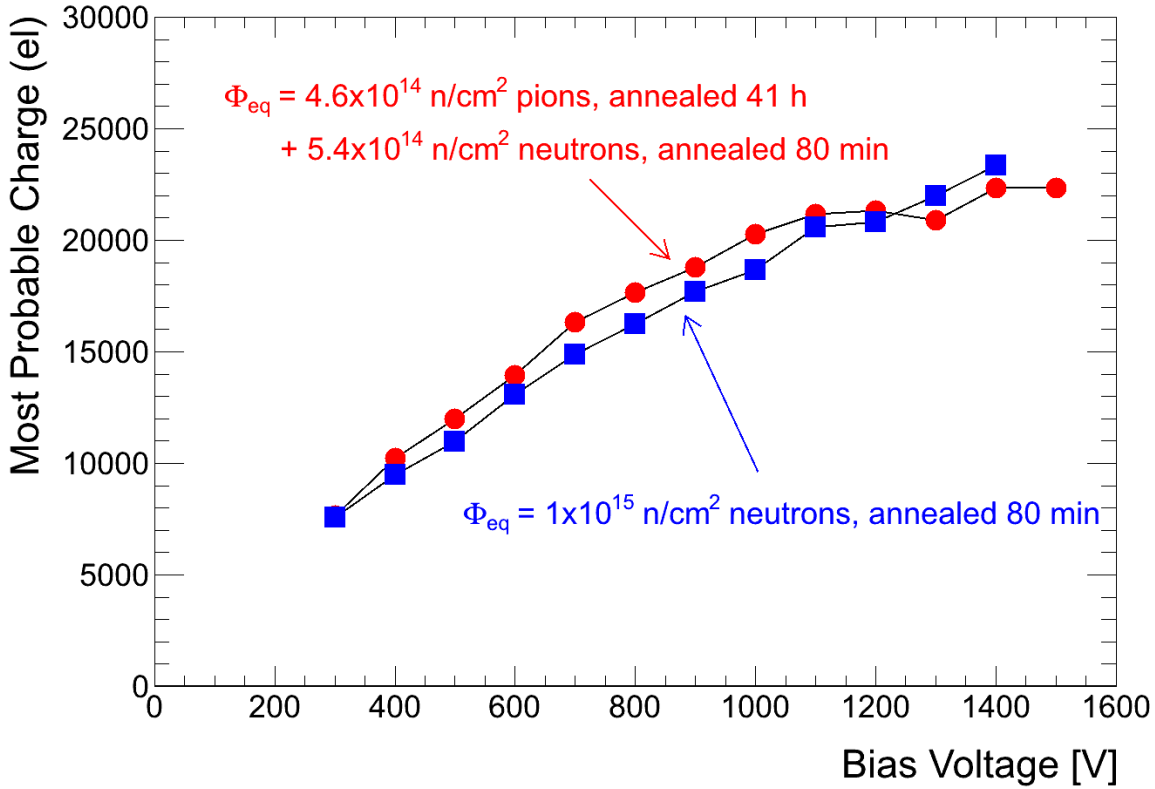
• other parameters used in the Hamburg model: g_c ~ 0.005 cm^{-1}, $V_{fd,0}$ = 170 V, g_a = 0.018 cm^{-1}, τ_a = 19 min

- pad detector geometry, uniform N_{eff}, $V < V_{fd}$: $E_{\max} = \sqrt{\frac{2q_0 N_{eff} V}{\varepsilon\varepsilon_0}}$ $\left(E_{\max} = \sqrt{\frac{2q_0 N_{eff} V_{fd}}{\varepsilon\varepsilon_0}} + \frac{V - V_{fd}}{w} \quad \text{if } V > V_{fd} \right)$
- annealing of N_{eff} according to Hamburg model



- 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

Mixed irradiation



- mixed: 1. Φ_{eq} = 4.6e14 n/cm^2, pions, annealed for 41 h at 60°C ➔ N_{eff} ~ 1.1e13 cm^{-3}
  2. Φ_{eq} = 5.4e14 n/cm^2, neutrons, annealed 80 min. at 60°C ➔ N_{eff} ~ 2.3e13 cm^{-3}
  Sum: N_{eff} ~ 3.4e13 cm^{-3}

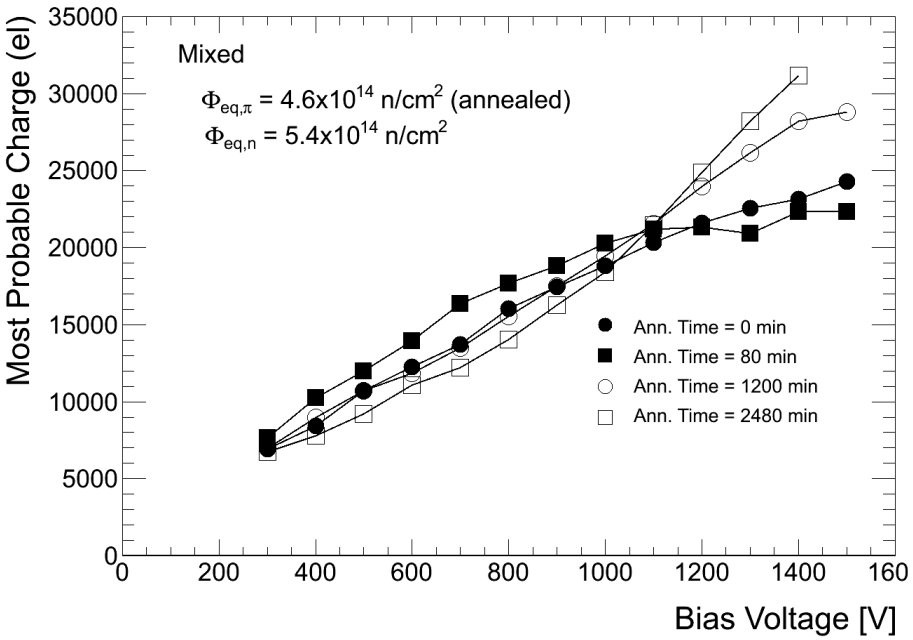
- neutrons: Φ_{eq} = 1e15 n/cm^2, annealed for 80 min. at 60°C ⟶ N_{eff} ~ 3.3e13 cm^{-3}

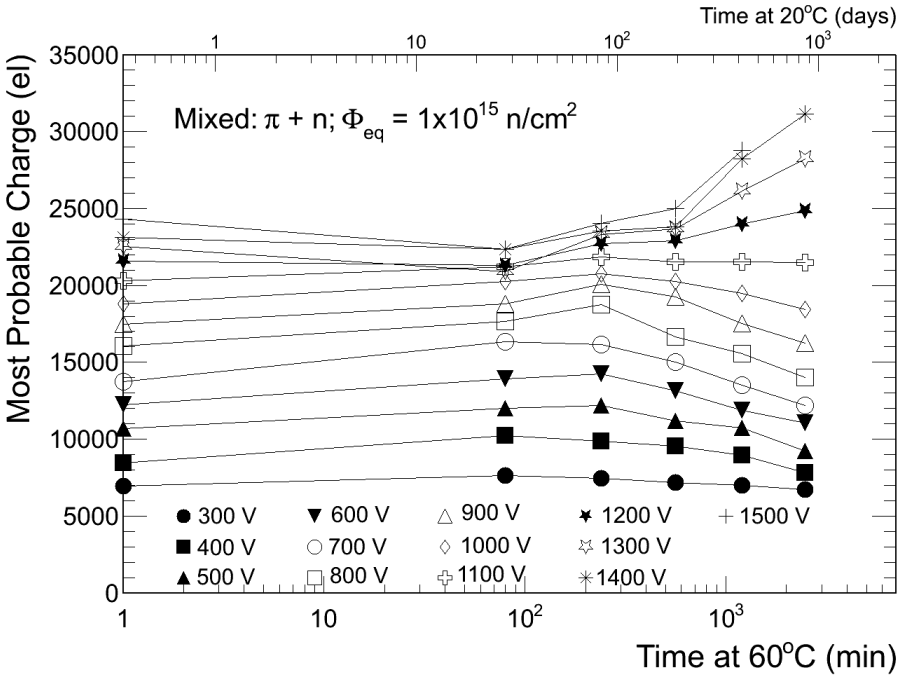
- trapping: mixed: τ_e = 2.3 ns, τ_h = 1.6 ns
  neutrons: τ_e = 2.3 ns, τ_h = 2.2 ns

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

Mixed irradiation

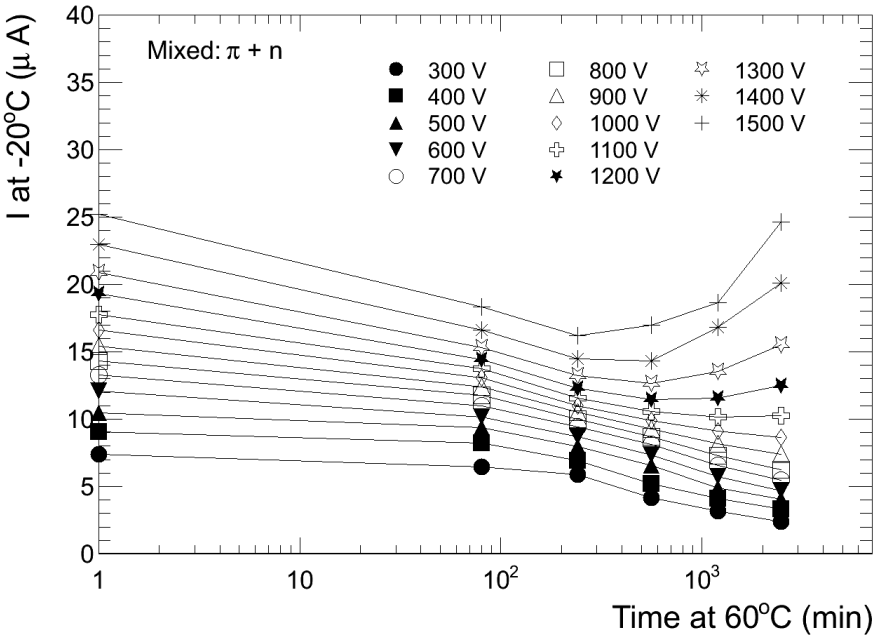
- accelerated annealing at 60 C with mixed irradiated detector

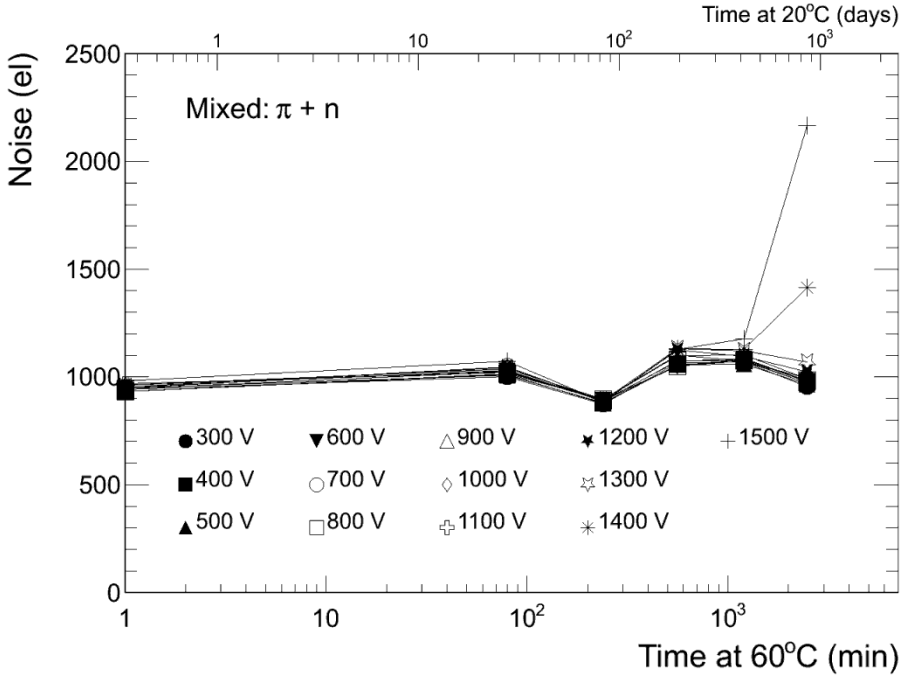




➔multiplication effects visible after 1200 minutes of annealing

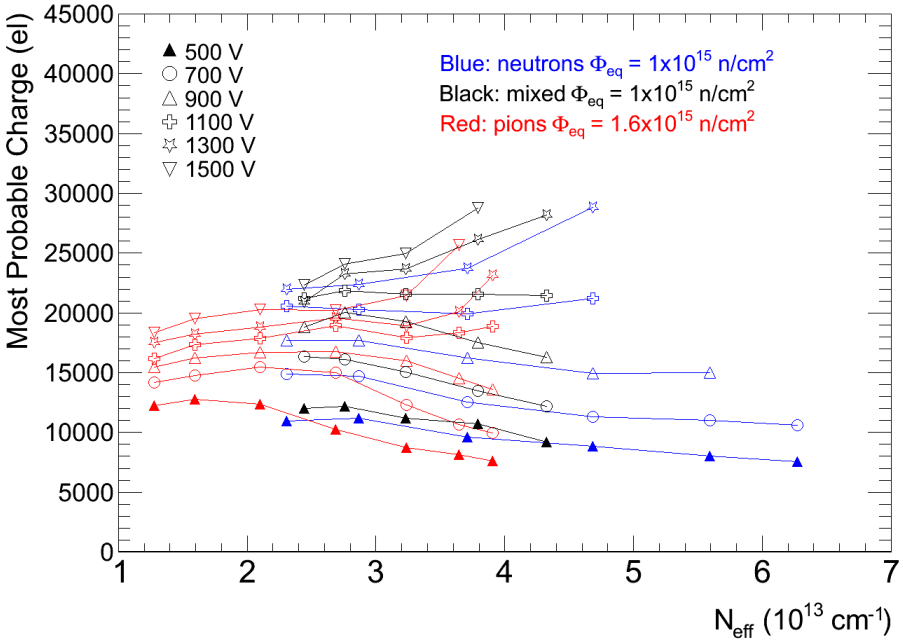
Mixed irradiation

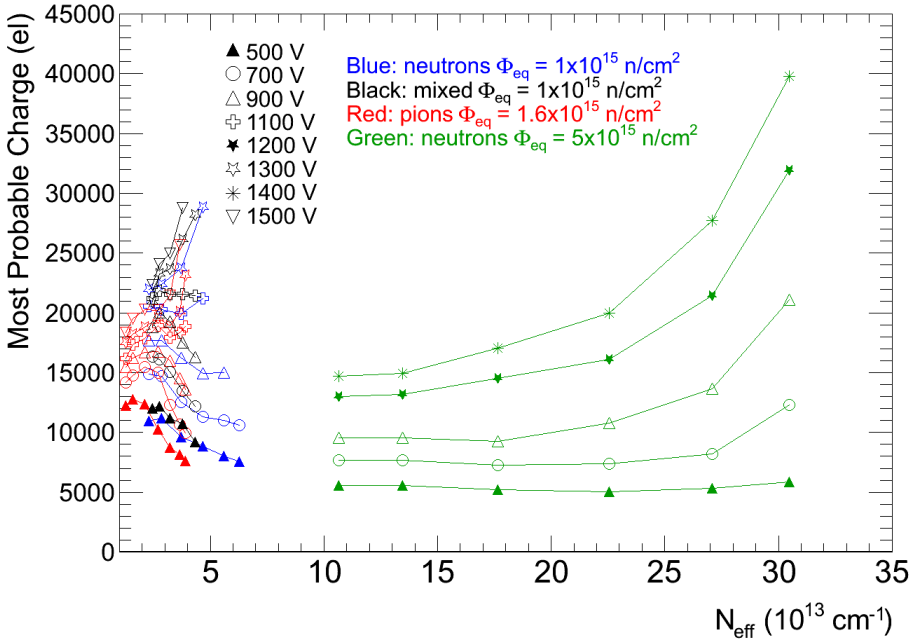




- multiplication affects also detector current and noise

Exercise: plot collected charge vs. N_{eff}





- lines connect measurements after different annealing steps

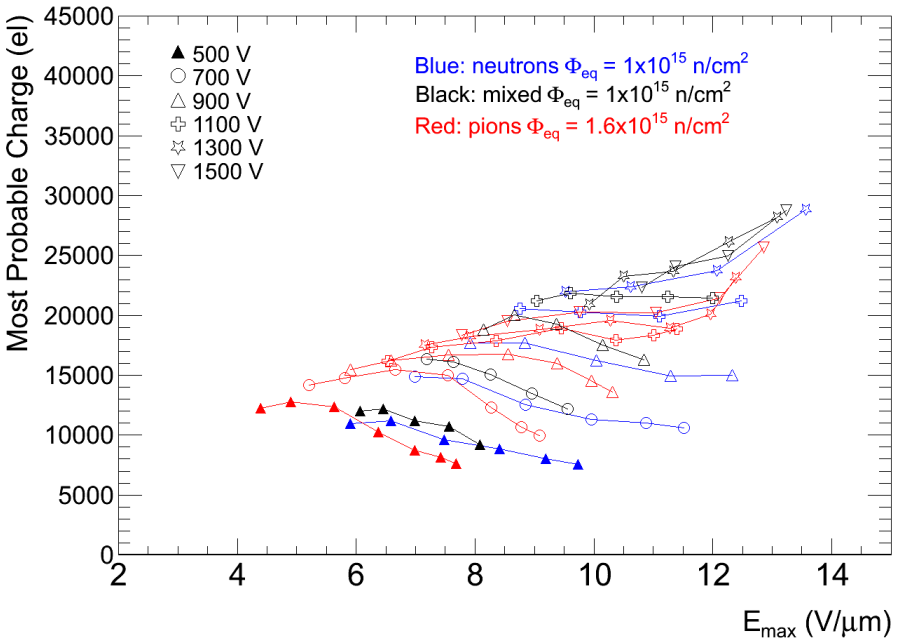
- N_{eff} calculated using Hamburg model with following parameters:
  pions: $V_{fd,0}$ = 170 V, g_a = 0.018 cm^{-1}, τ_a = 19 min, g_c ~ 0.005 cm^{-1}, g_Y ~ 0.02 cm^{-1}, τ_Y = 1100 min
  neutrons: $V_{fd,0}$ = 170 V, g_a = 0.018 cm^{-1}, τ_a = 19 min, g_c ~ 0.017 cm^{-1}, g_Y ~ 0.05 cm^{-1}, τ_Y = 1100 min

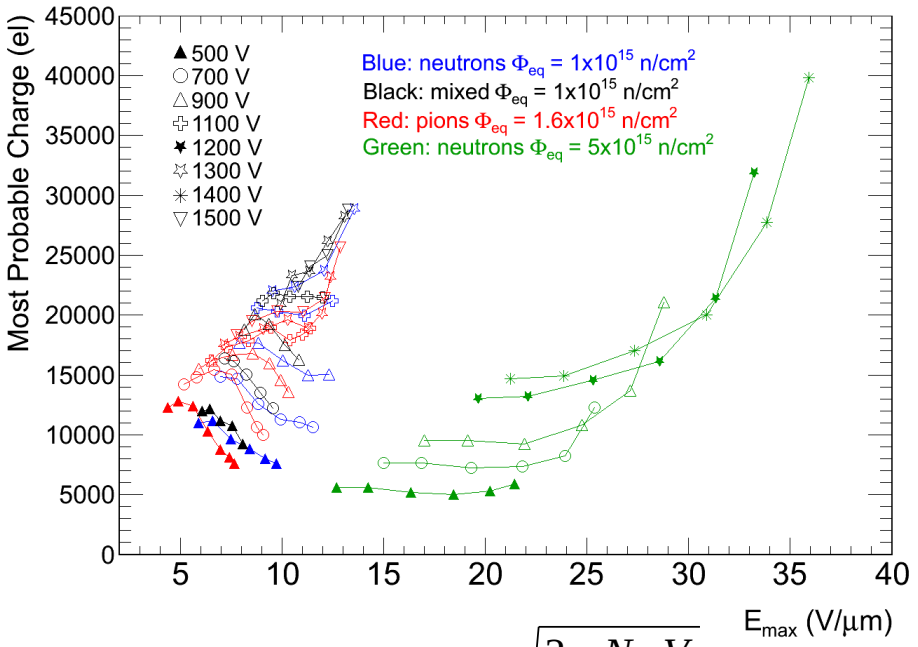
➔ increase of N_{eff} by reverse annealing may lead to increase or decrease of MPV, depending on bias voltage and fluence

➔ "sharp" increase of MPV with annealing (due to multiplication) seen if N_{eff} > 3e13 cm^{-3} and V > 1300 V

➔ increase of N_{eff} with irradiation decreases MPV → trapping

Exercise: plot collected charge vs. E_{max}





- MPV vs. maximum electric field (in pad detector geometry, uniform N_{eff}): $E_{\max} = \sqrt{\frac{2q_0 N_{eff} V}{\varepsilon\varepsilon_0}}$
- If E_{max} > 12 V/μm MPV does **not decrease** with annealing

  ➔ E_{max} ~ 12 V/μm threshold for multiplication

➔ N_{eff} or E_{max} are not sufficient parameters to describe the behavior

➔ electric field in heavily irradiated detector more complicated (polarization effects …)
→ see the 3D TCT results
→ see V. Eremin et al., NIMA 658 (2011) 145-151, M. Mikuž et al., NIMA 636 (2011) S50-S55

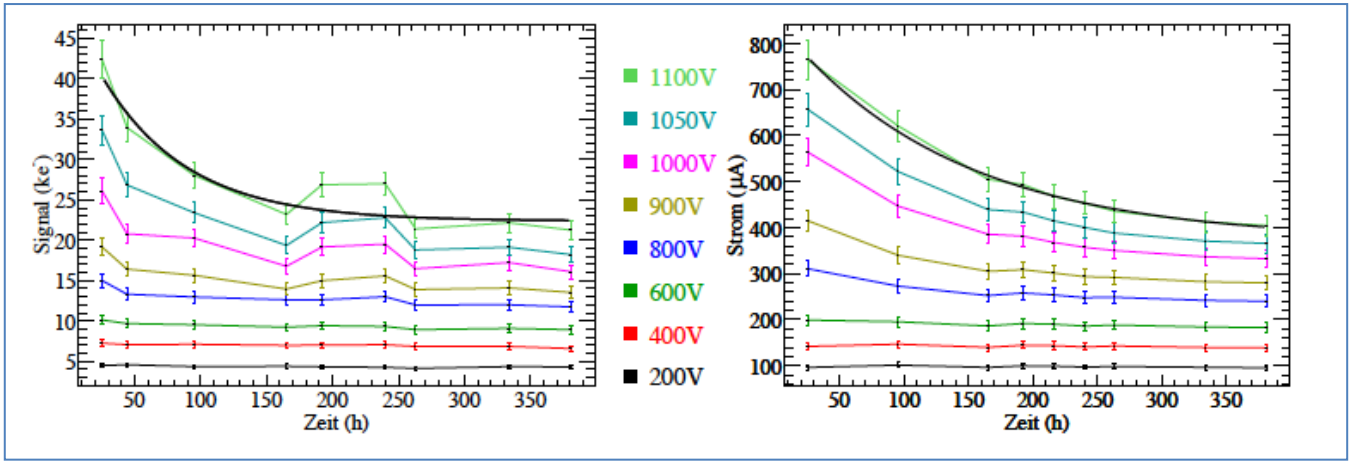
Time dependence

- changes of Charge Collection with bias history and time reported at the last RD50 workshop

Adrian Driewer:

Alibava

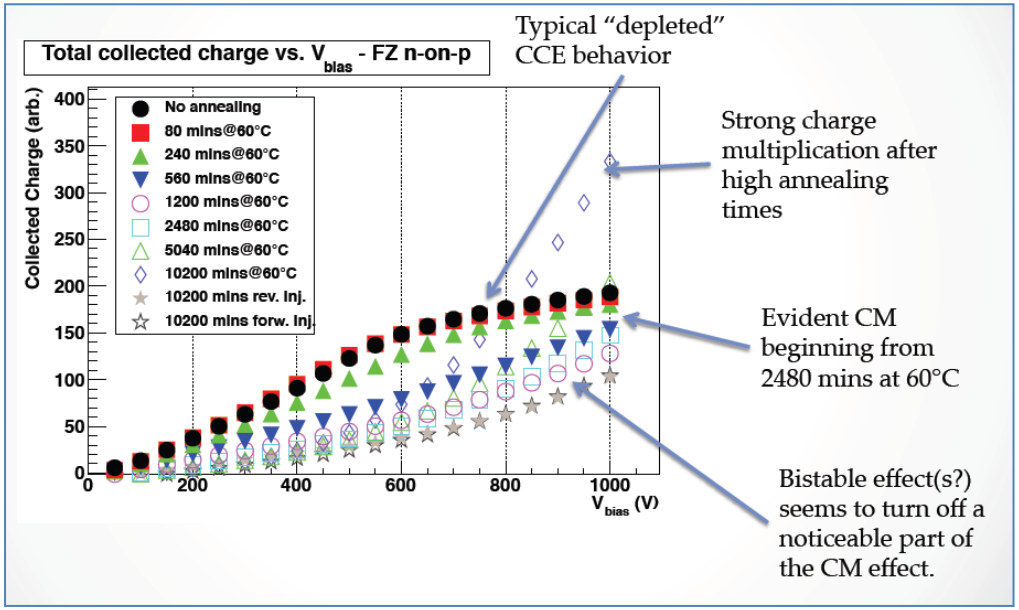
Multiplication fades with time



Nicola Pacifico:

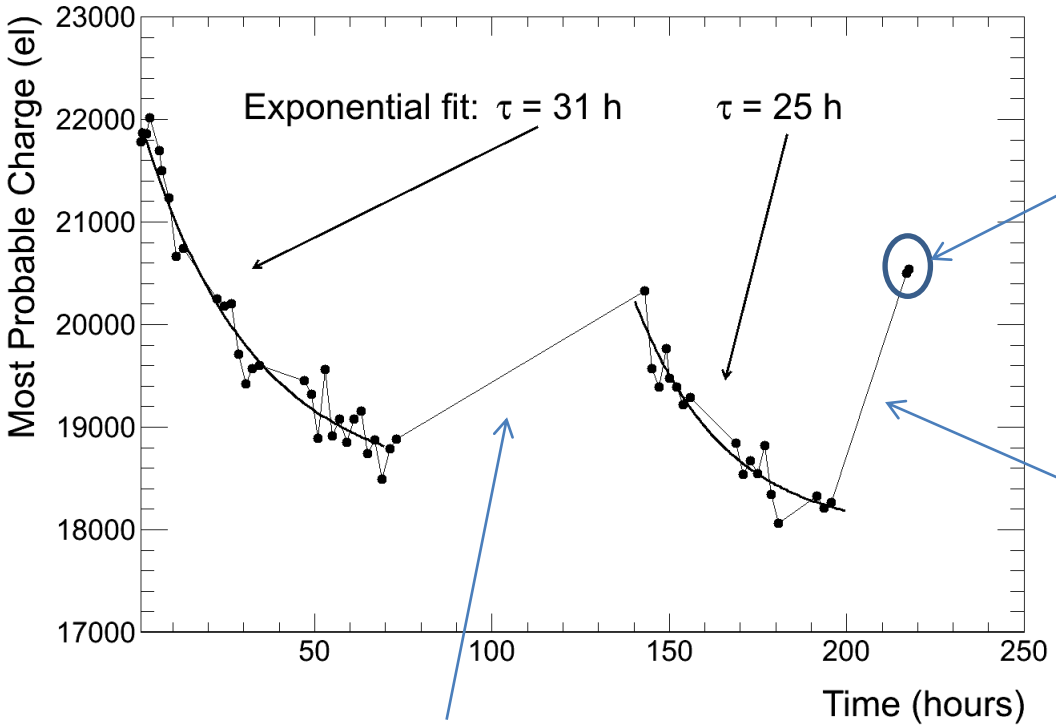
Edge TCT

Multiplication not seen after biasing the detector with high current (700 uA). Comes back after heating the detector to RT



Time dependence

- detector irradiated to Φ_{eq} = 1.6 ·10^{15} n_{eq}/cm^2 with pions, annealed for 84 hours at 60°C
- bias 1300 V (multiplication observed at this bias)
- measure collected charge with SCT128 at T ~ -20°C
- charge collection measurements repeated every few hours, bias 1300 V continuously on

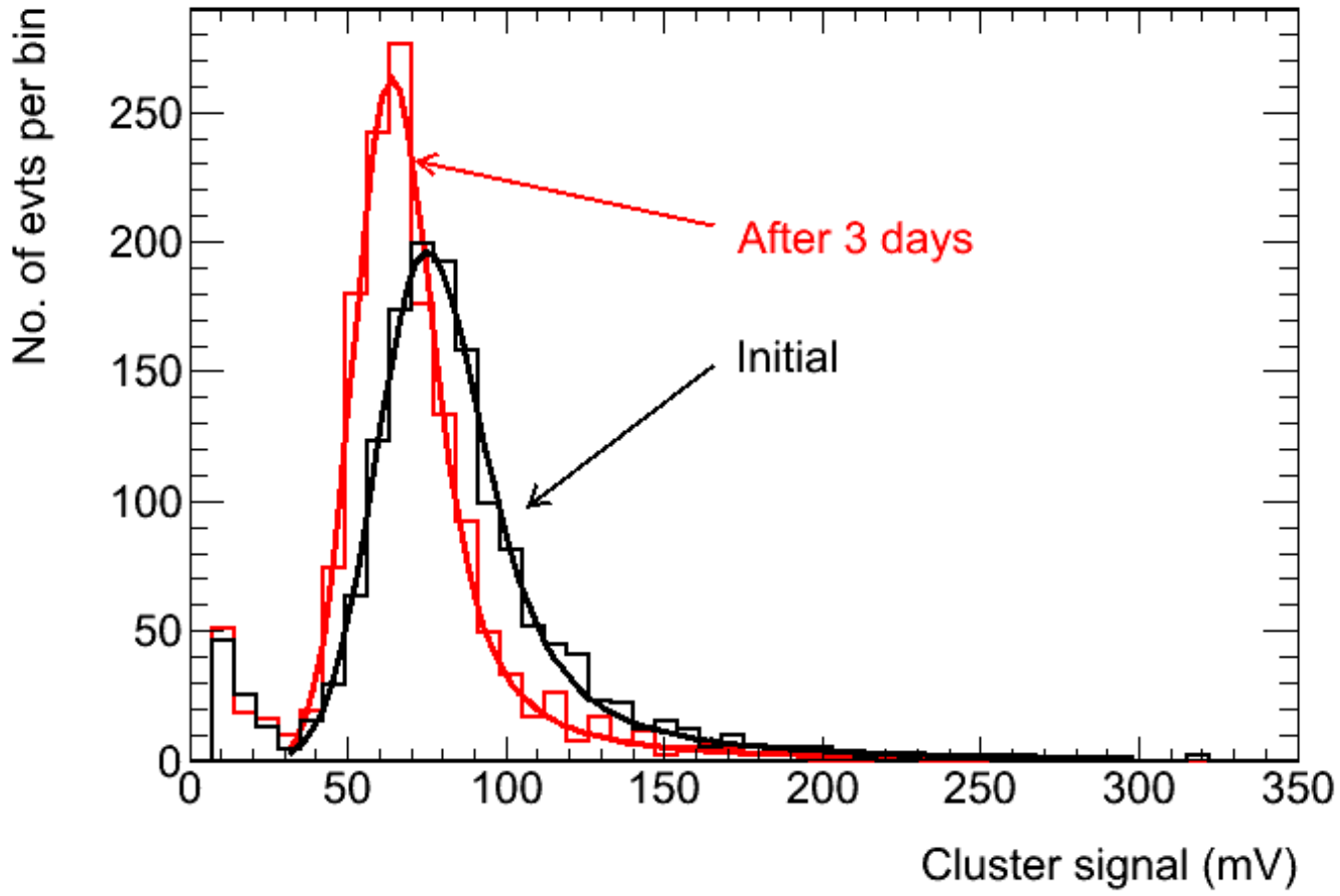


Two measurements: before and after applying forward bias (I = 750 μA)

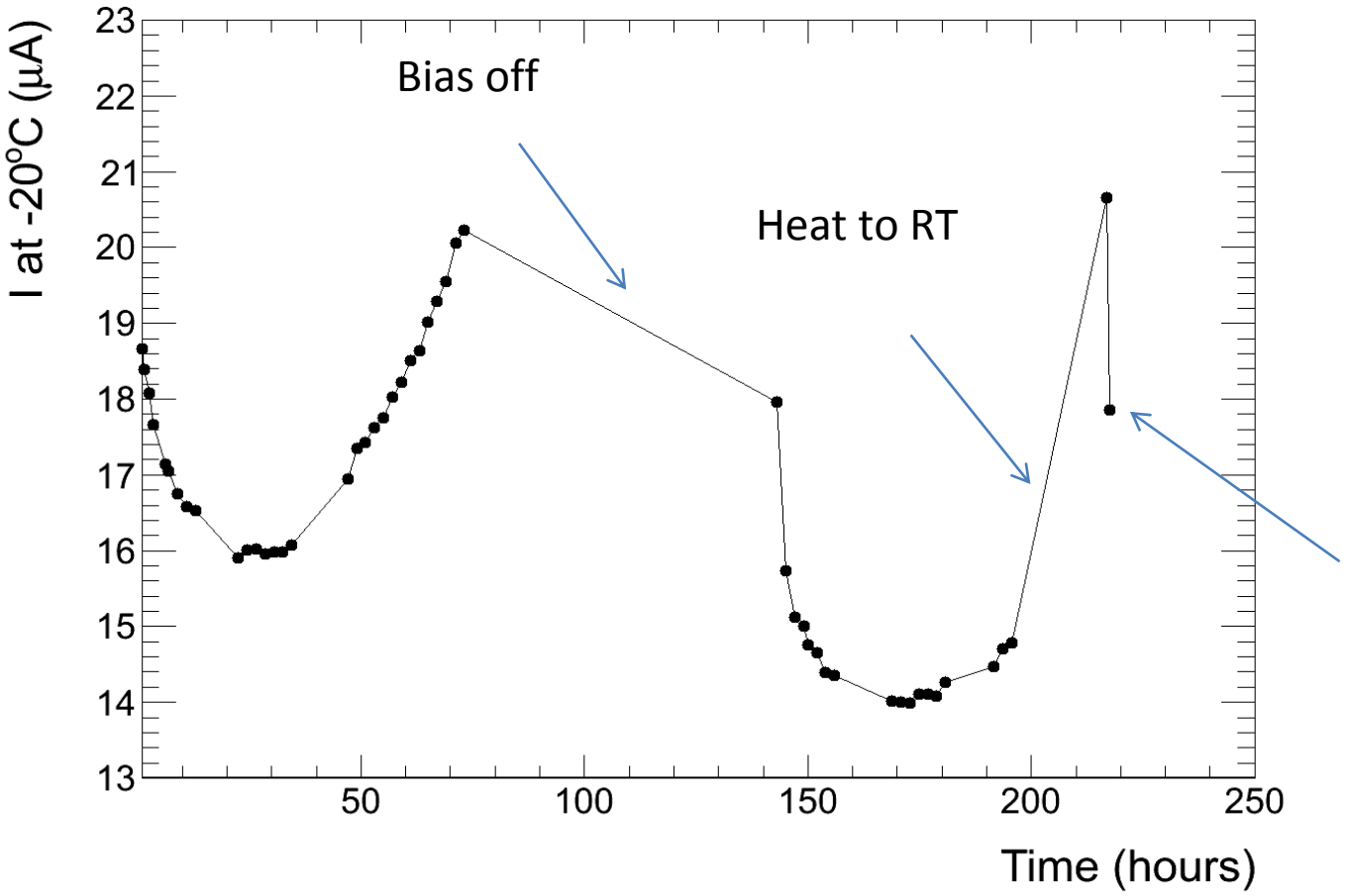
Heat to RT

Bias off, T ~ -20 C

• spectrum of cluster signals changes with time on bias:



- detector current changes with time on bias
  - → detector current measured from voltage drop on a resistor in high voltage power supply line
  - → guard ring not bonded



• bias dependence of N_{eff} measured before: M. Mikuž et al., NIMA 466 (2001) 345

→ FZ n-type diodes irradiated to 2e11 n/cm^2

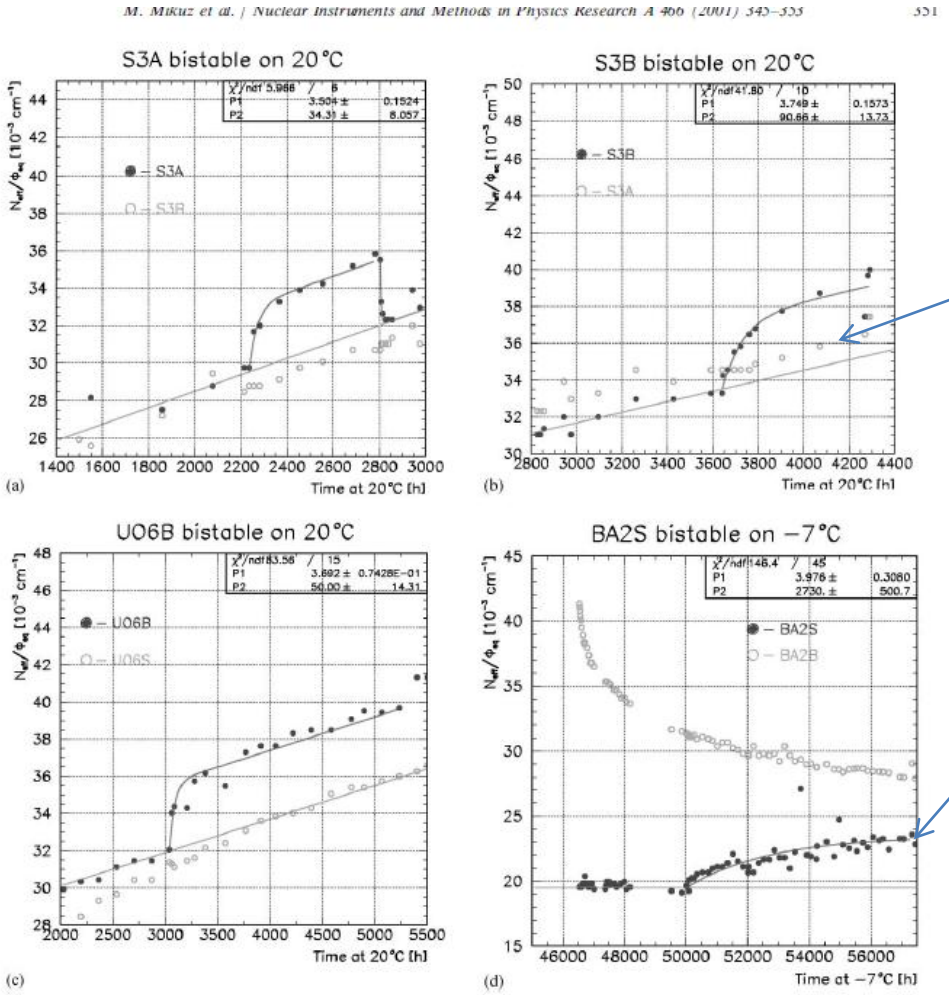


Fig. 6. Activation of bistable damage in S3A, S3B and UO6B at 20°C and in BA2S at −7°C. Lines represent results of fits according to Eq. (3) and the weakly printed straight lines the subtracted linear fits to reverse annealing. The other diode in the sample pair is depicted in open circles.

• time constant for N_{eff} rise after bias switched on at T = 20°C
τ ~ 60 h

• time constant at T = -7 C
τ ~ 2700 h

- G. Kramberger et al., NIMA 600 (2009) 555
  - n-type MCz and epitaxial diodes
  - annealed 500 h (MCz) and 20000 h (Epi) at RT
  - T = -8°C , fit with two exponentials, with short and long time constants

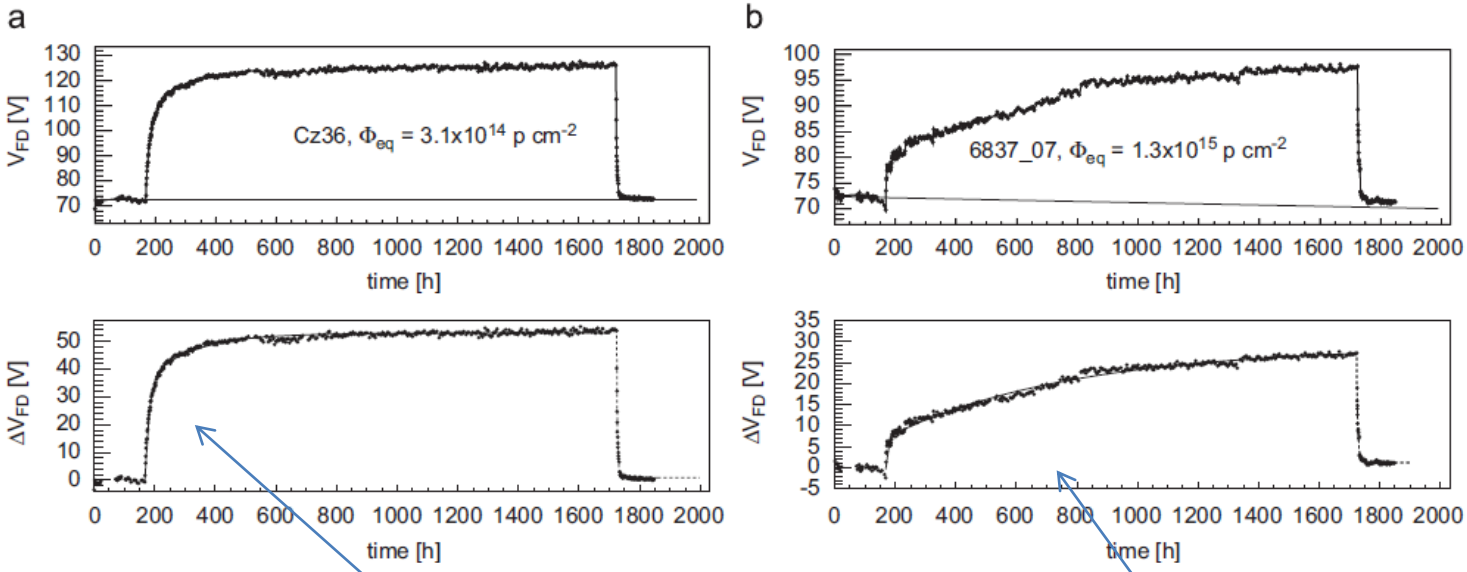


Fig. 5. Dependence of V_{fd} on time before, during, and after the applied bias voltage of 300 V for two different samples: (a) Cz36 and (b) 6837_07 at $T = -8$°C. The fit of Eq. (1) to the measured ΔV_{fd} is also shown; activation by a solid line and deactivation by a dashed line.

- τ_s ~ 10 h, τ_L ~ 260 h
- τ_s ~ 8 h, τ_L ~ 700 h

- at T = -8°C τ_s ~ 10 h and τ_s ~ 8 h
  → at T = 20° C τ_s ~ 0.8 h and τ_s ~ 3.6 h
  → we measure τ ~ 30 h at T ~ -20°C so maybe it is a related effect
  but: increase of N_{eff} should increase collected charge if multiplication is on

Summary

- 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

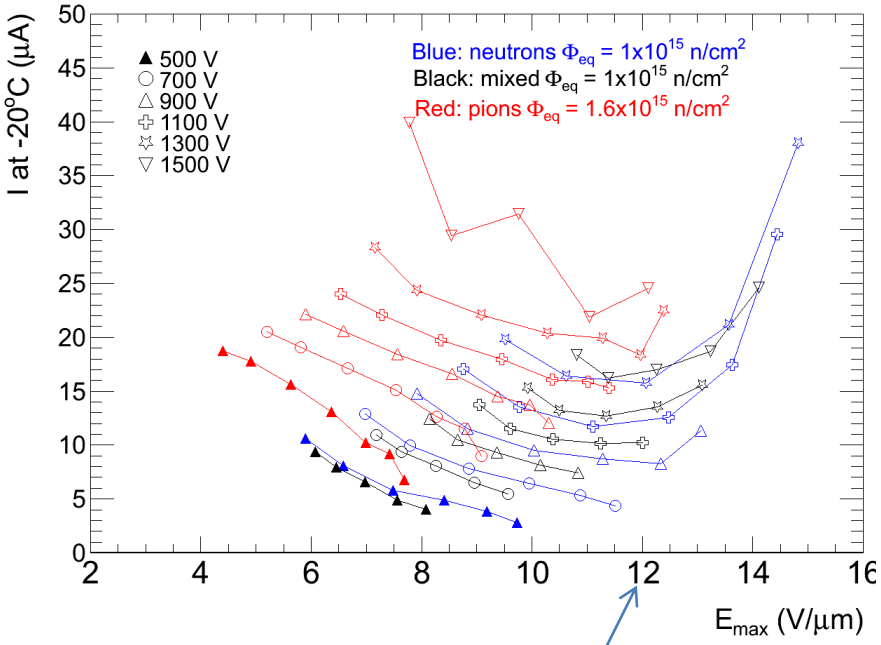
- CCE and annealing behavior of mixed irradiated detector as expected from measurements with neutron and pion irradiations

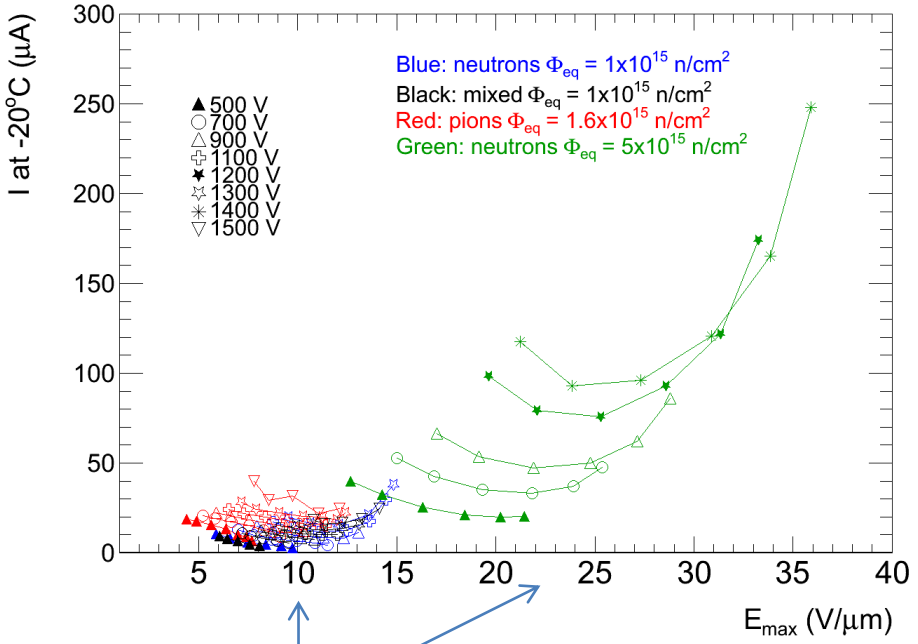
- CCE and detector current change with time on bias:

➔ collected charge falls with time on bias with time constant $\tau \sim 30$ h at $T = -20°$ C, could be the consequence of the "bistability" effect

➔ changes of detector current with time observed

• exercise: plot detector current vs. E_{max}





• threshold at about E_{max} ~ 12 V/μm

• threshold ??

Detectors:

- p-type, 6 inch FZ wafer, 320 µm thick, 75 µm strip pitch, 1x1 cm^2, V_{fd} ~ 170 V produced by Hamamatsu

- ATLAS07-PSSSD_Series I, batch number: VXX73414

1. mixed irradiation: A07, W49, Z1, P19

   - pions at PSI: $\Phi = 4.14 \cdot 10^{14}\ \pi/cm^2 = 4.6 \cdot 10^{14}\ n_{eq}/cm^2$
   - neutrons in Ljubljana: $\Phi = 5.4 \cdot 10^{14}\ n_{eq}/cm^2$

2. time dependence: A07, W22, Z3,P1

   - pions at PSI $\Phi = 1.43 \cdot 10^{15}\ \pi/cm^2 = 1.6 \cdot 10^{15}\ n_{eq}/cm^2$