technische universität dortmund

Physik EIV

Investigation of highly irradiated ATLAS n^{+}-in-n planar pixel sensors

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Andreas Gisen

Mona Abt, Silke Altenheiner, Karola Dette, Claus Gößling, Bettina Hillringhaus, Jara Helmig, Jennifer Jentzsch, Reiner Klingenberg, Kevin Kröninger, Arno Kompatscher, Felix Wizemann

GEFÖRDERT VOM Bundesministerium für Bildung und Forschung

FSP 101 ATLAS

CERN

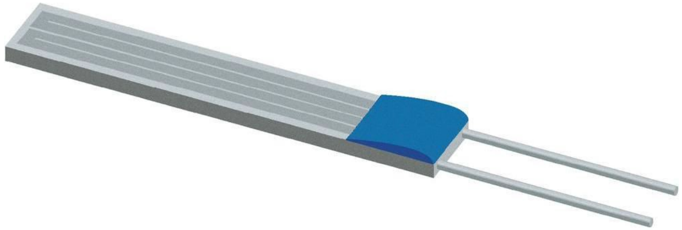
Motivation

- Leakage current has great influence on the operation of sensors
- Leakage current depends heavily on temperature and fluence
- Scaling is important for comparision and estimation

- Annealing is a further parameter that has to be investigated
- Charge collection could be improved with different pixel designs

Leakage current investigations

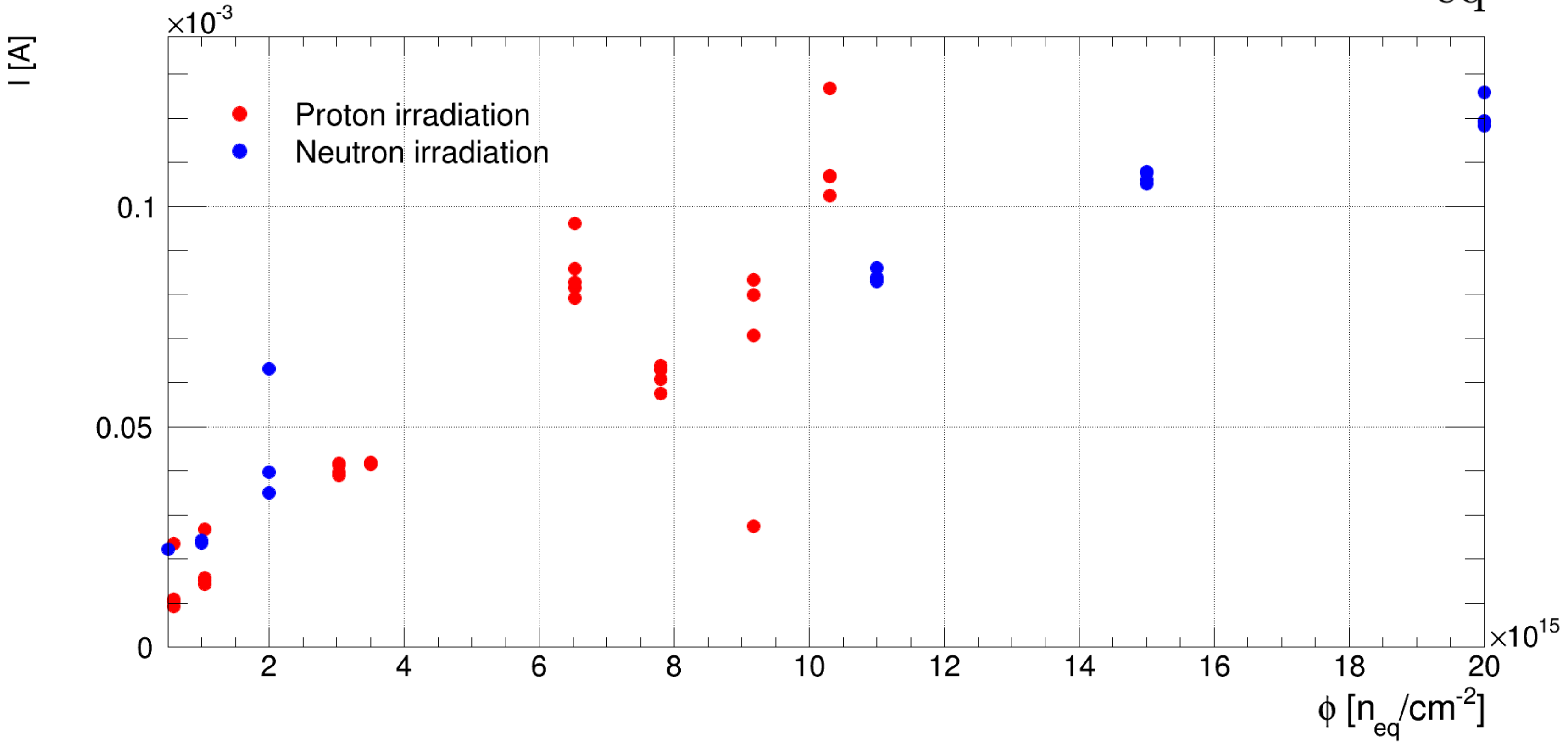
- 250 µm n^{+}-in-n DOFZ-Si planar pixel sensors
- 17 irradiated with neutrons from 0.5 up to $20 \cdot 10^{15}$ n_{eq}/cm^2
- 21 irradiated with protons from 0.58 up to $10.3 \cdot 10^{15}$ n_{eq}/cm^2
- Temperature measured directly on sensor with flat Pt1000
- IV characteristics for fluence effects
- IT characteristics for temperature scaling behaviour



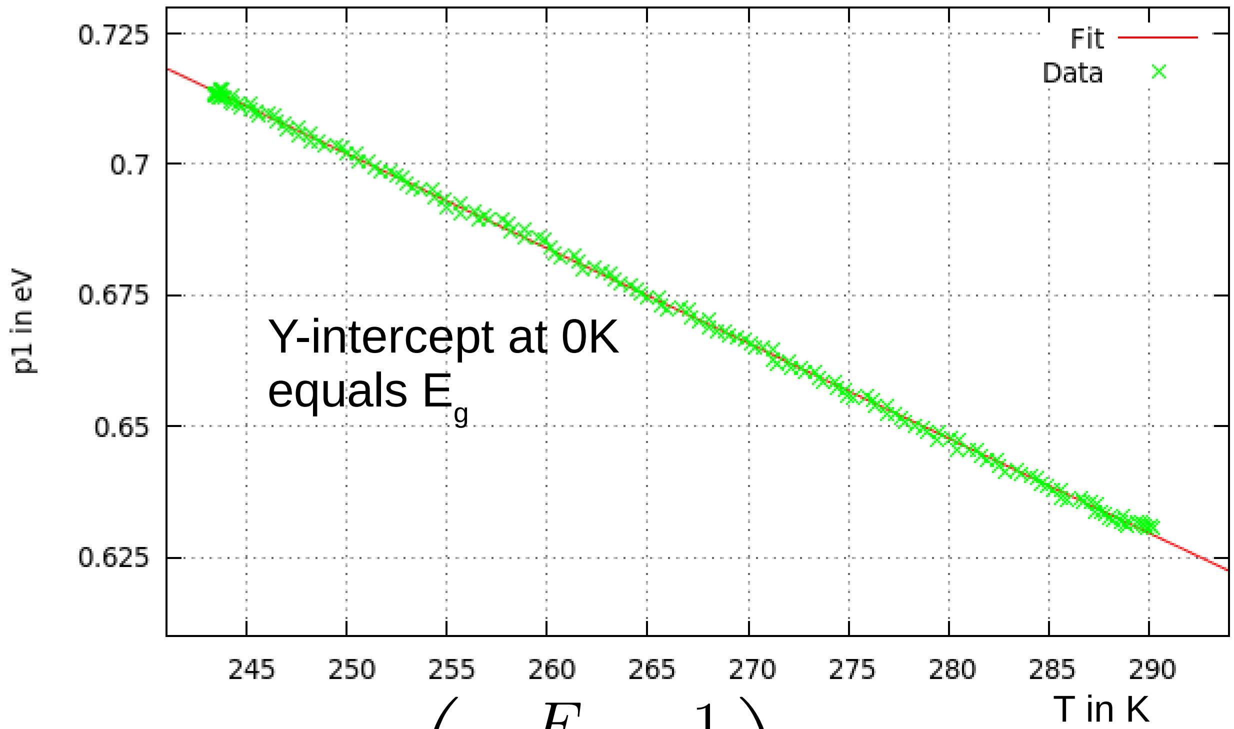
Leakage current vs fluence (at -500V)

I @ -20°C

$$\Delta I = \alpha V \Phi_{\mathrm{eq}}$$



Linearisation of IT characteristics



$$I(T) = A \cdot T^2 \cdot \exp\left(-\frac{E_g}{2k_B} \cdot \frac{1}{T}\right)$$

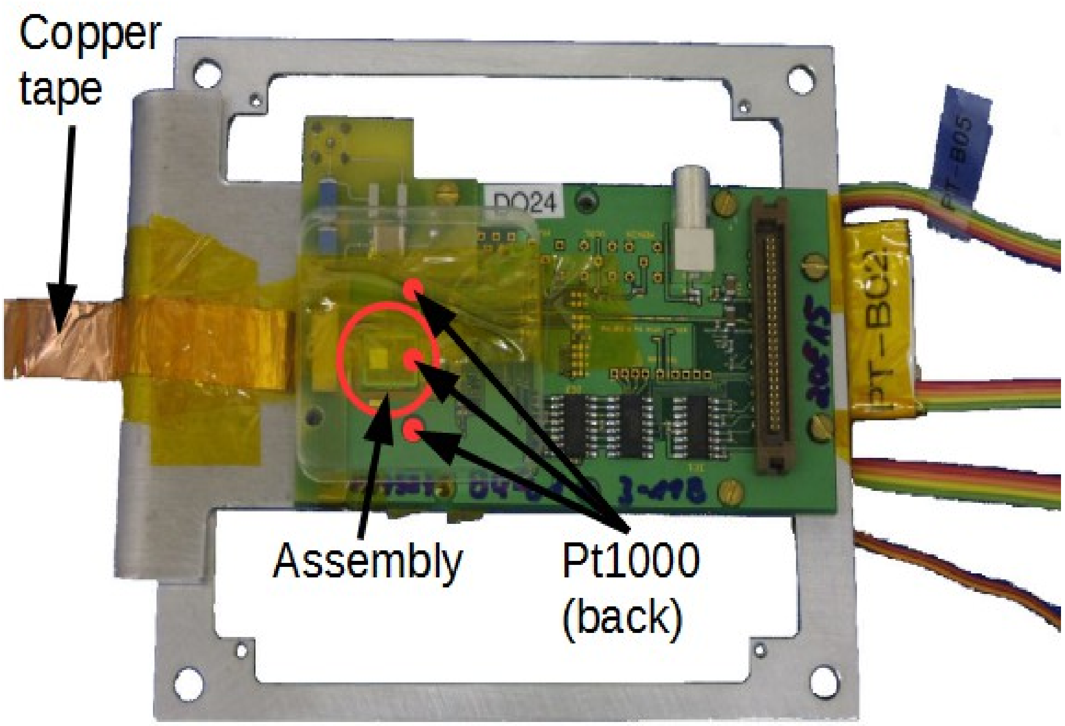
R. Klingenberg et al.
NIM A765 (2014) 135

$$p_1(T) = -2k_B T \cdot \ln\left(\frac{I(T)}{AT^2}\right) = E_g + C \cdot 2k_B T$$

Results for scaling factor

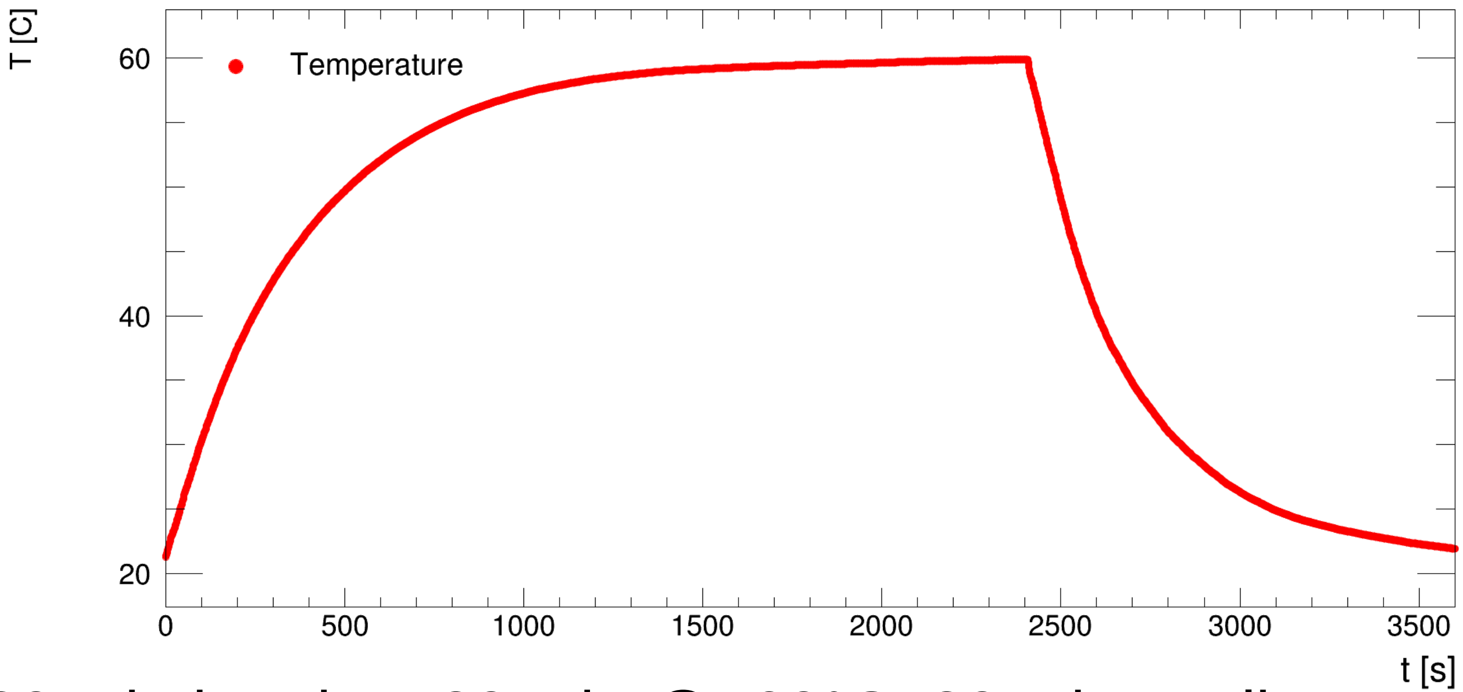
- Scaling factor E_g obtained from current-temperature characteristics
- E_g varies from 1.12 eV to 1.30 eV for neutron irradiation
- E_g varies from 1.13 eV to 1.26 eV for proton irradiation
- No obvious relationship to fluence is seen

DO-24 Single Chip Assembly



- FE-I3 readout
- n^+-in-n DOFZ-Si
- 285 µm
- $2{\cdot}10^{16}$ n_{eq}/cm^2 (HL-LHC-like)
- Reactor neutrons (IJS Ljubljana)
- ~700 min @+60°C in 16 steps

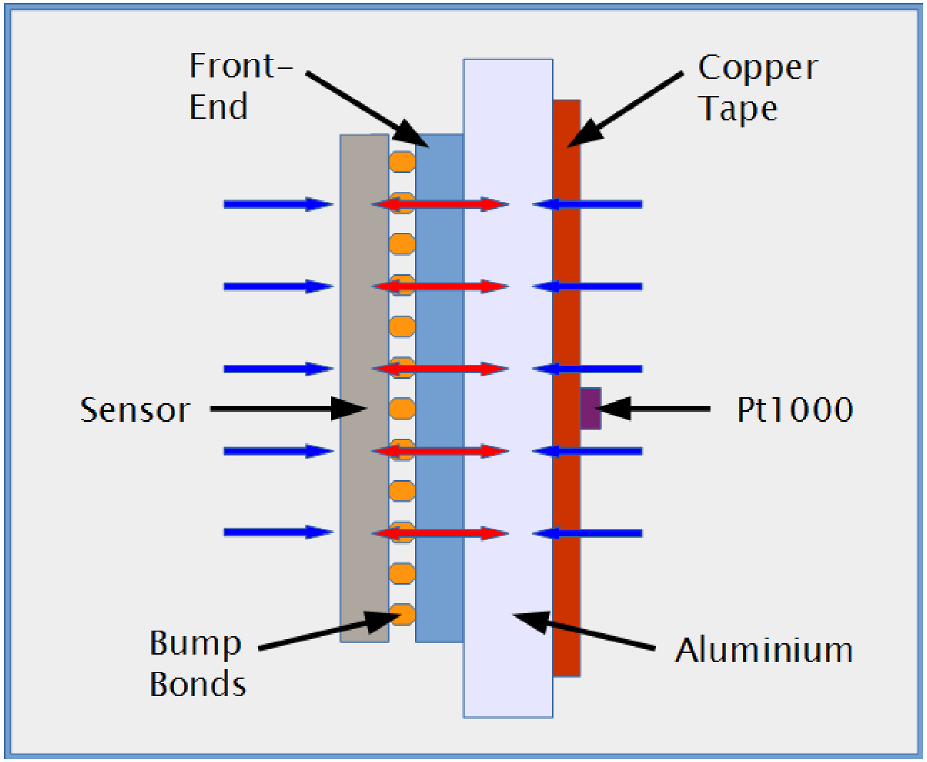
Annealing (Heraeus T6060 heating oven)



- 20 min heating, 20 min @+60°C, 20 min cooling
- Numerical: ~30 min@+60°C

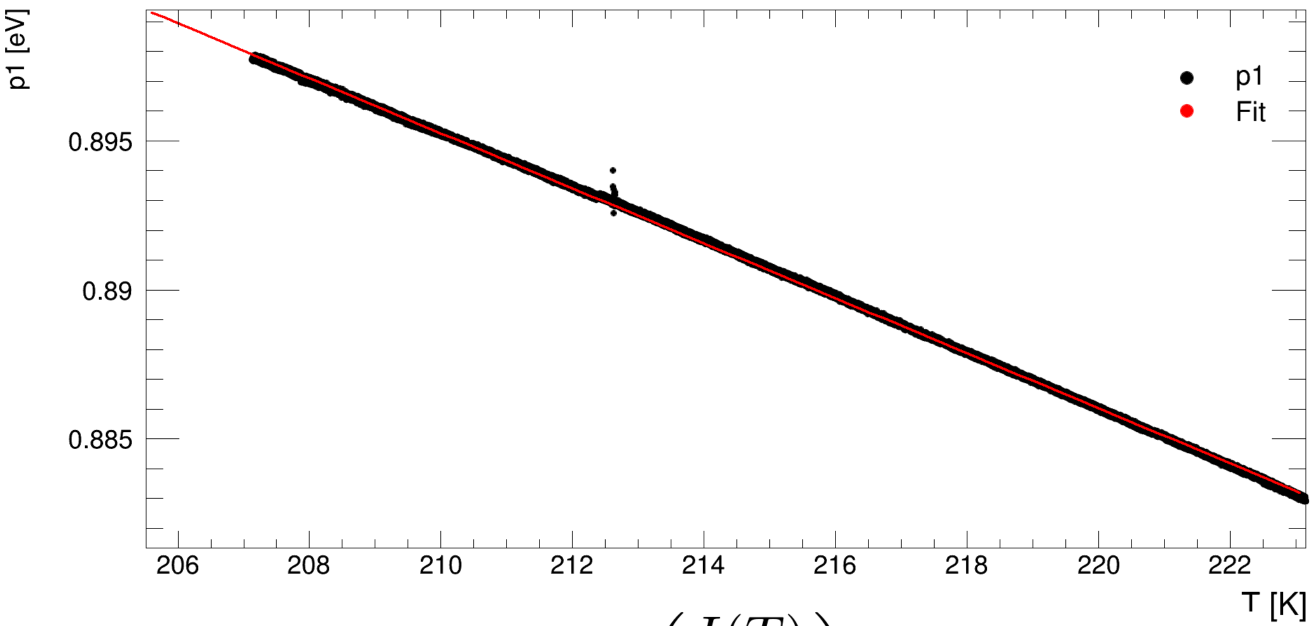
$$\alpha(T_a, t) = \alpha_I \cdot \exp\left[-t/\tau_I(T_a)\right] + \left[\alpha_0(T_a) - \beta \cdot \ln(t/t_0)\right]$$

Sensor temperature



- Not possible to measure temperature directly on sensor
- Reveal relation through current-temperature characteristics

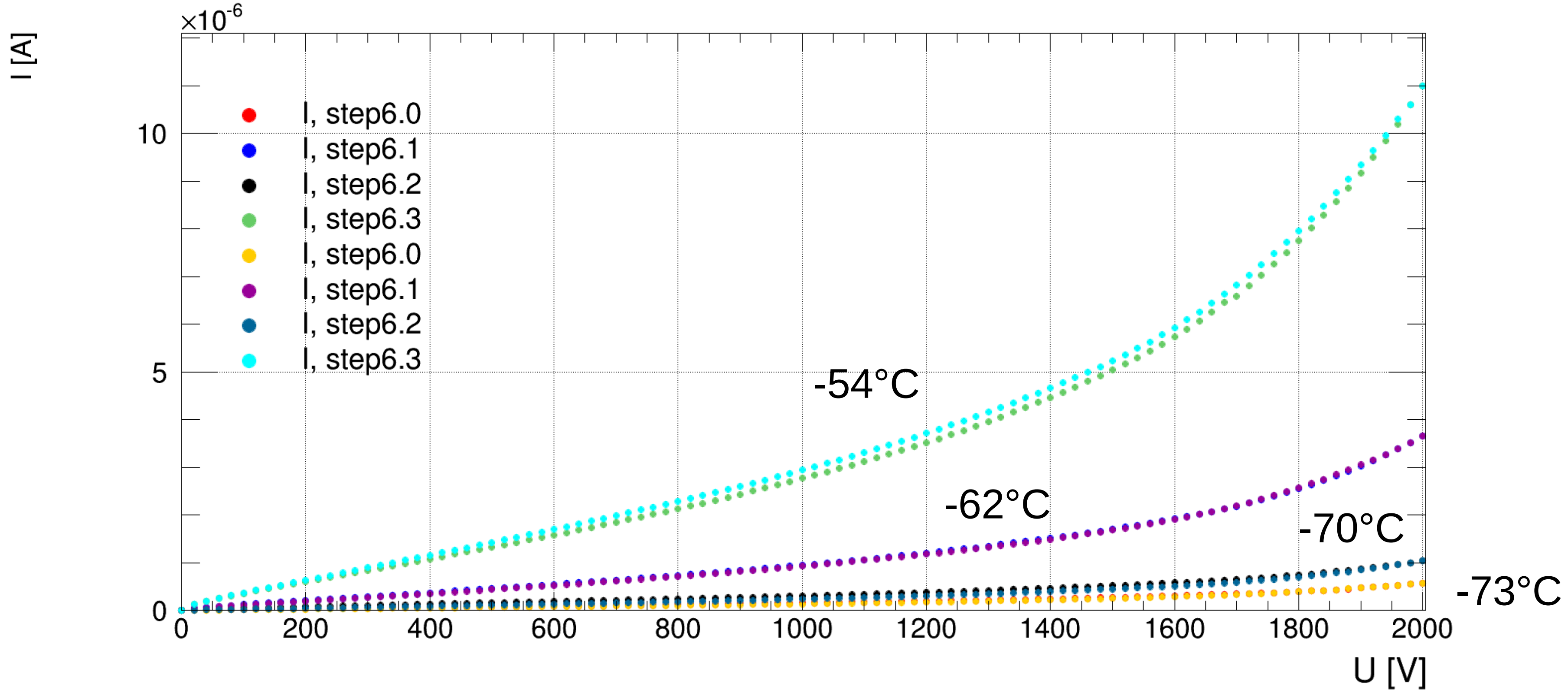
Effective leakage current scaling factor E



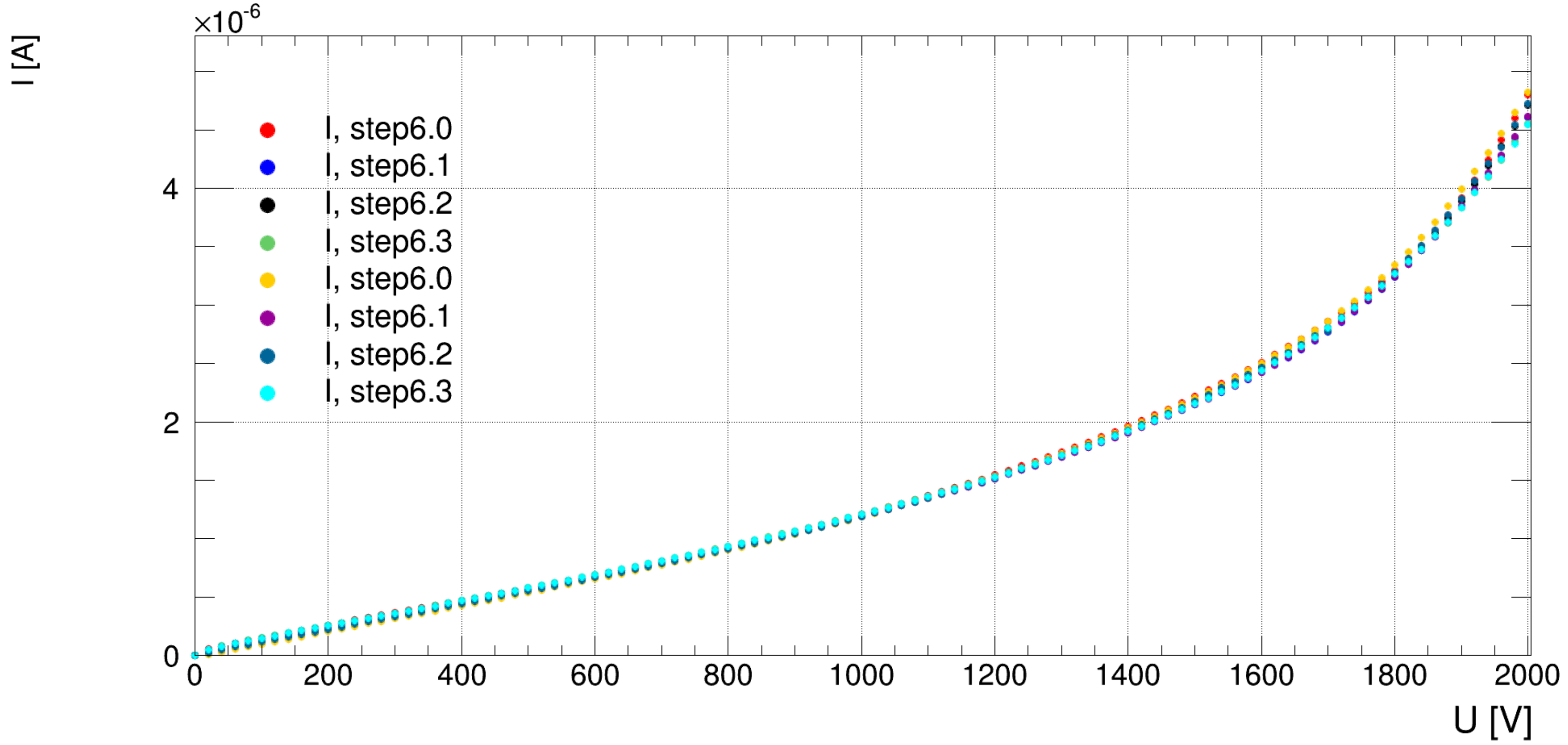
$$p_1(T) = -2k_B T \cdot \ln\left(\frac{I(T)}{T^2}\right) = E + C \cdot 2k_B T$$

- Average value **E = 1.075 eV** for -70°C to -50°C
- Value of E indicates sensor temperature higher than measured

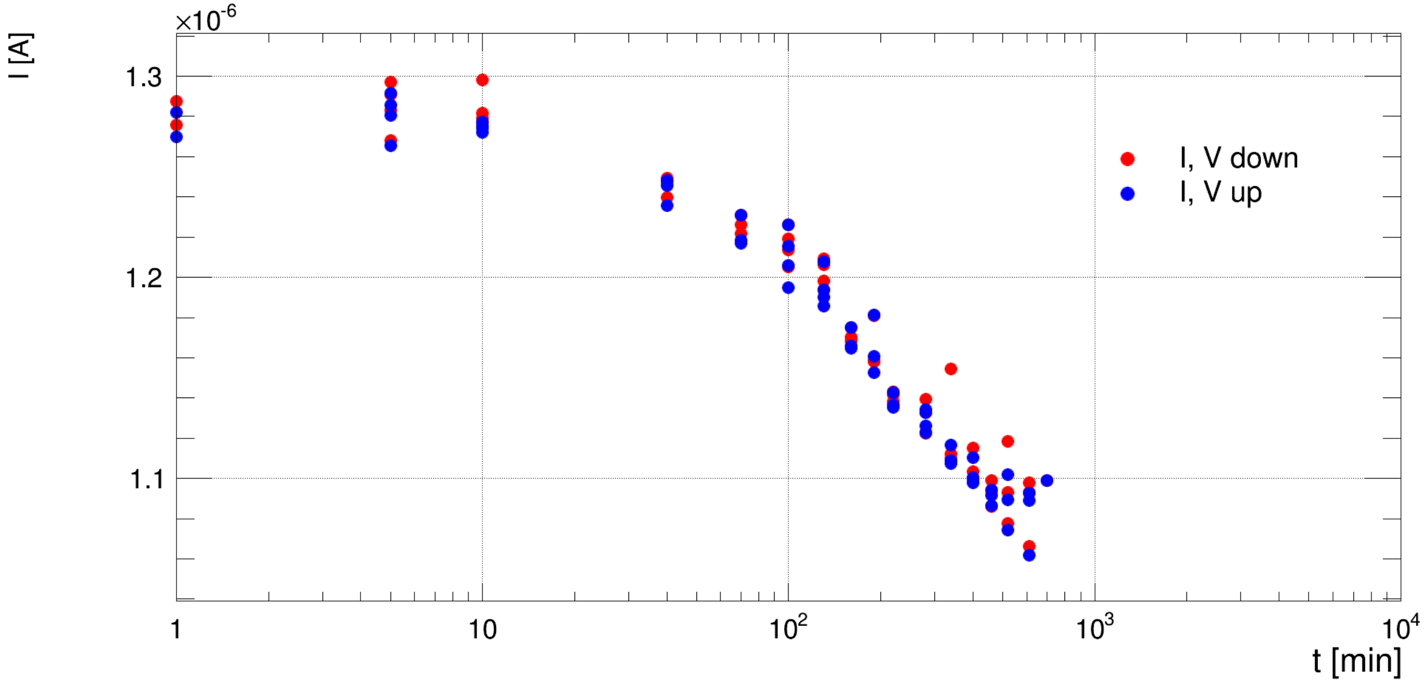
IV characteristics (130 min)



IV characteristics (130 min, adapted to -60°C)



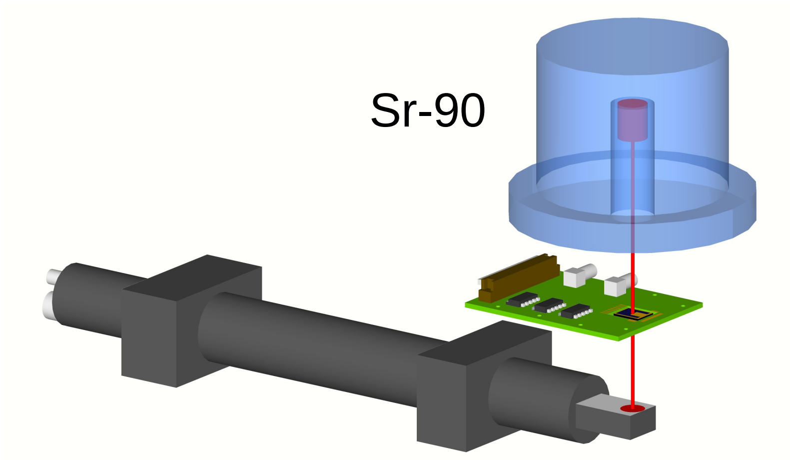
Leakage current (-1000V, -60°C)

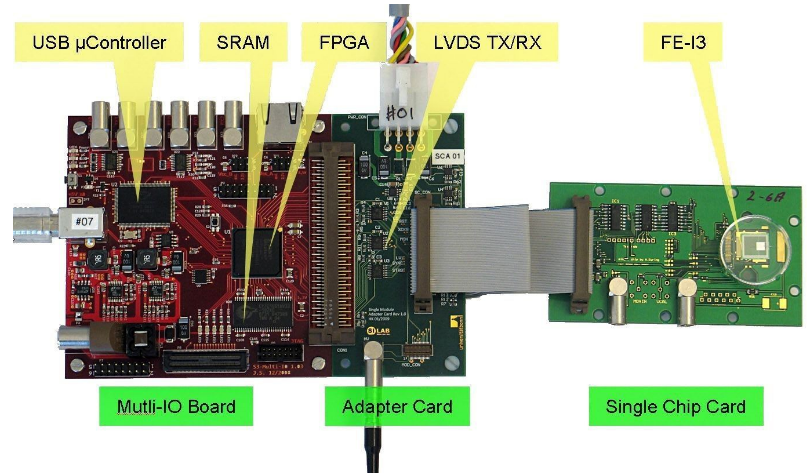


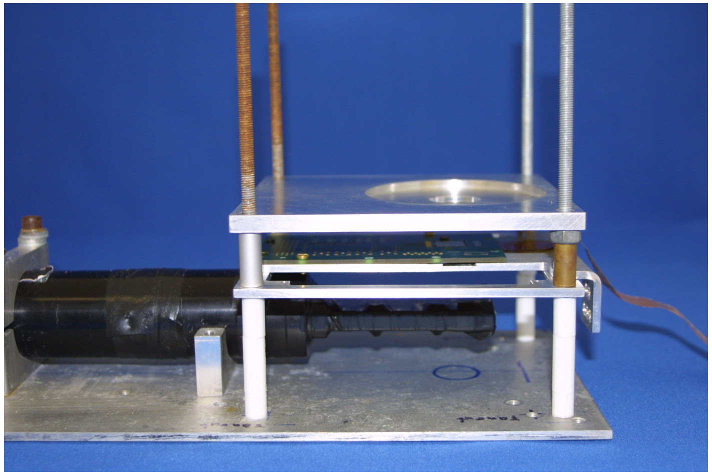
- Corresponding values for current related damage rate are around $2 \cdot 10^{-17}$ A/cm, 1/3 of expected value

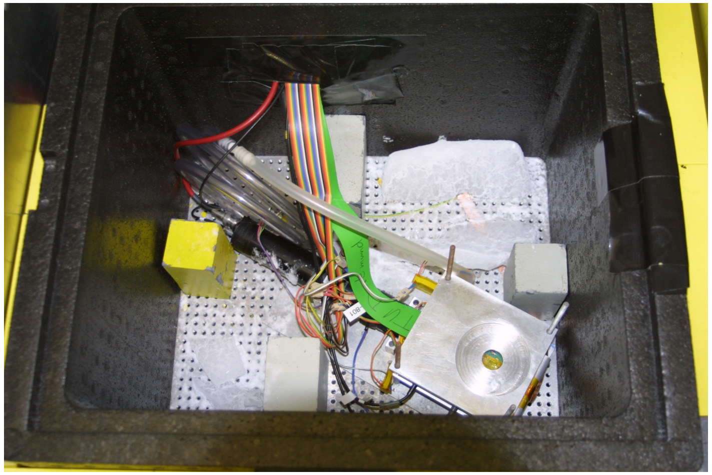
$$\alpha = \frac{\Delta I}{\Phi_{\mathrm{eq}} V}$$

Setup for charge collection

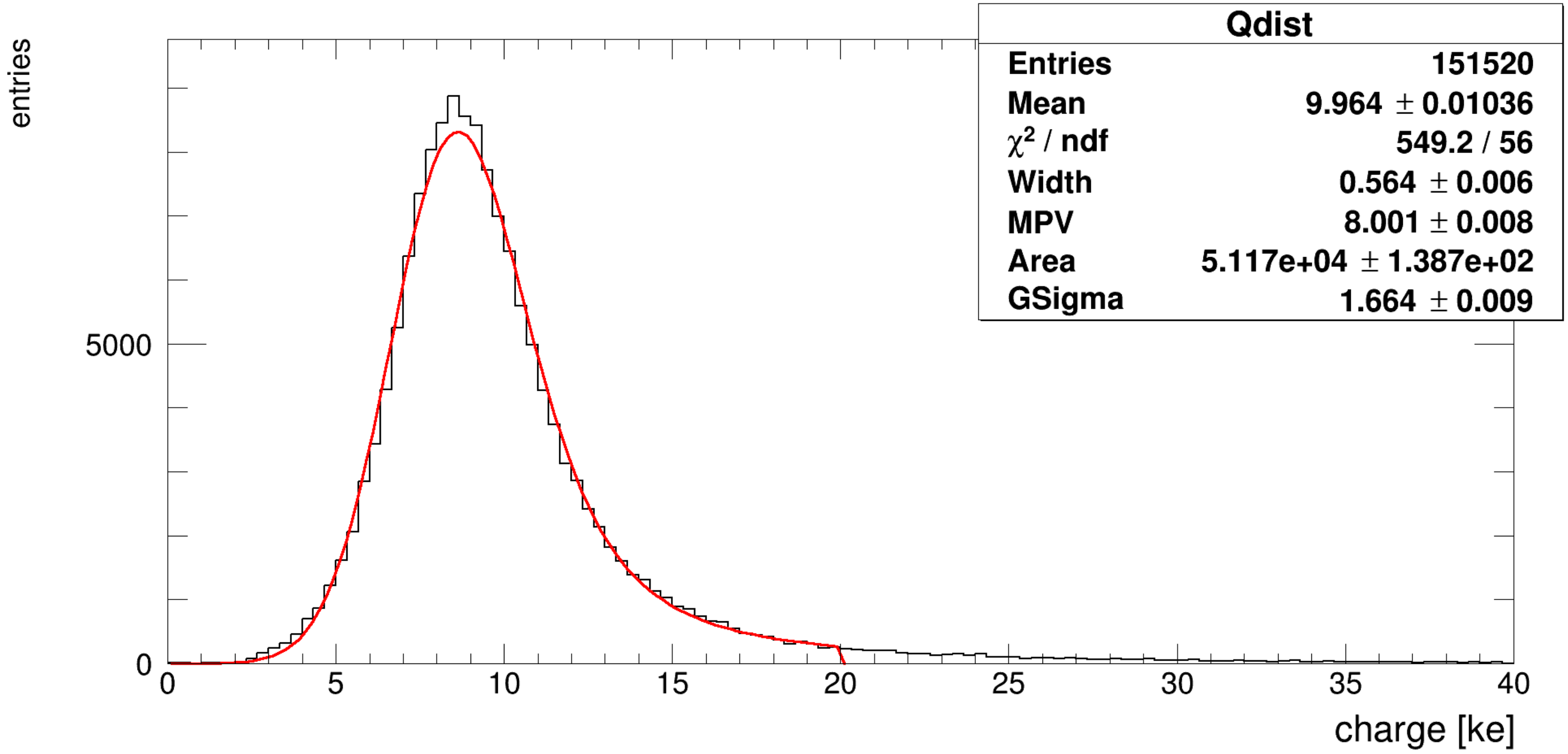






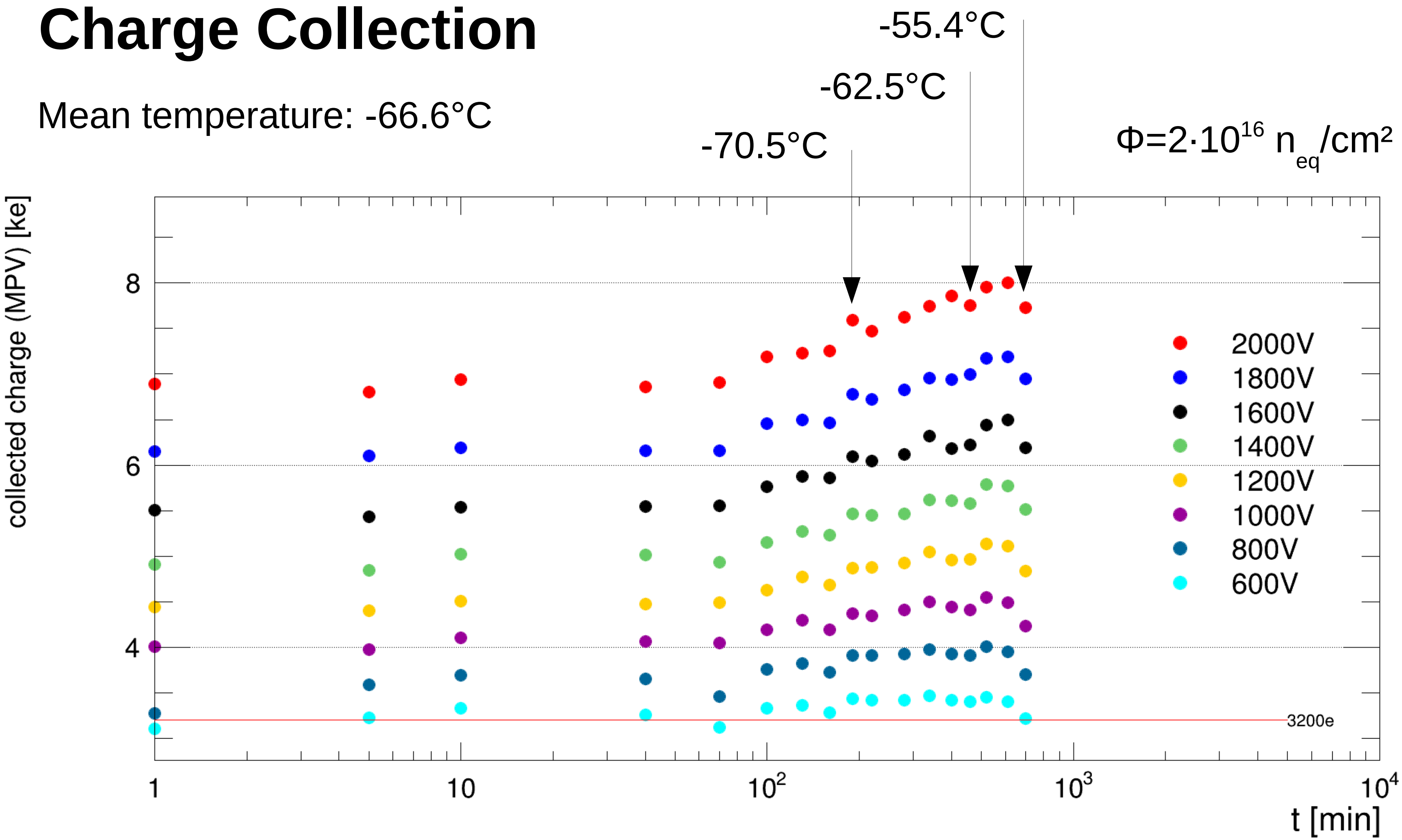


Charge distribution (610min, 2000V)

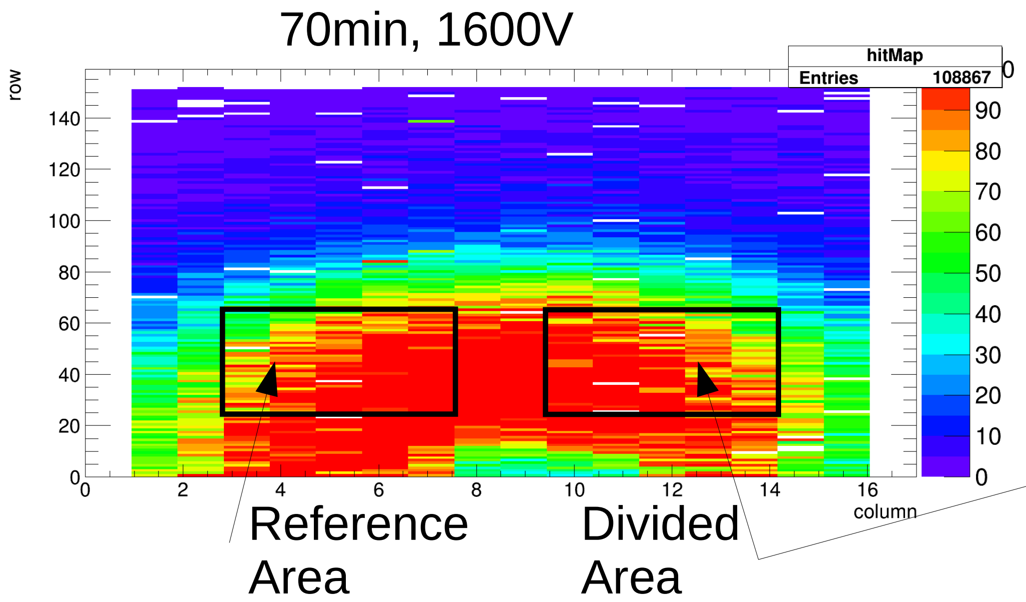


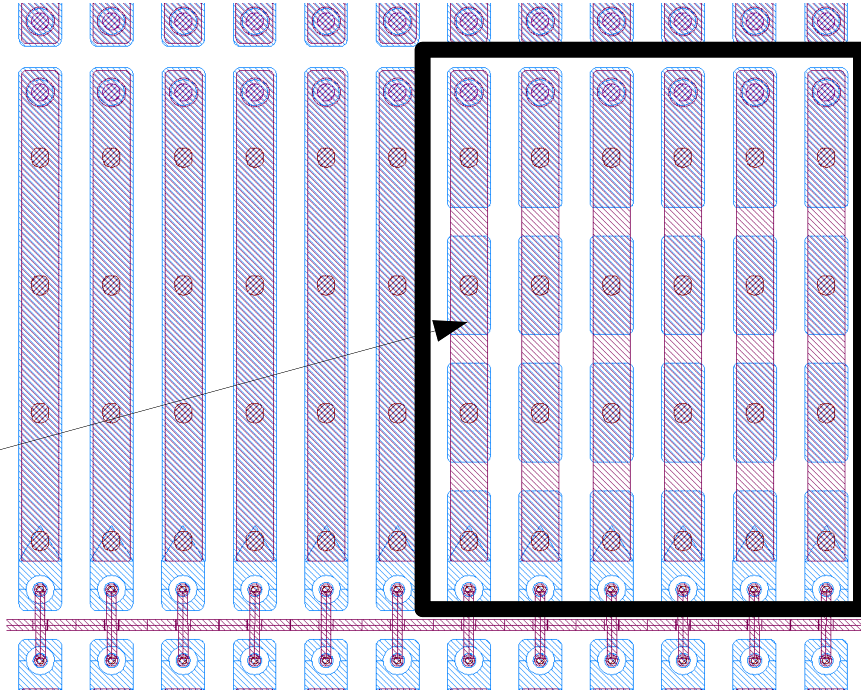
Charge Collection

Mean temperature: -66.6°C



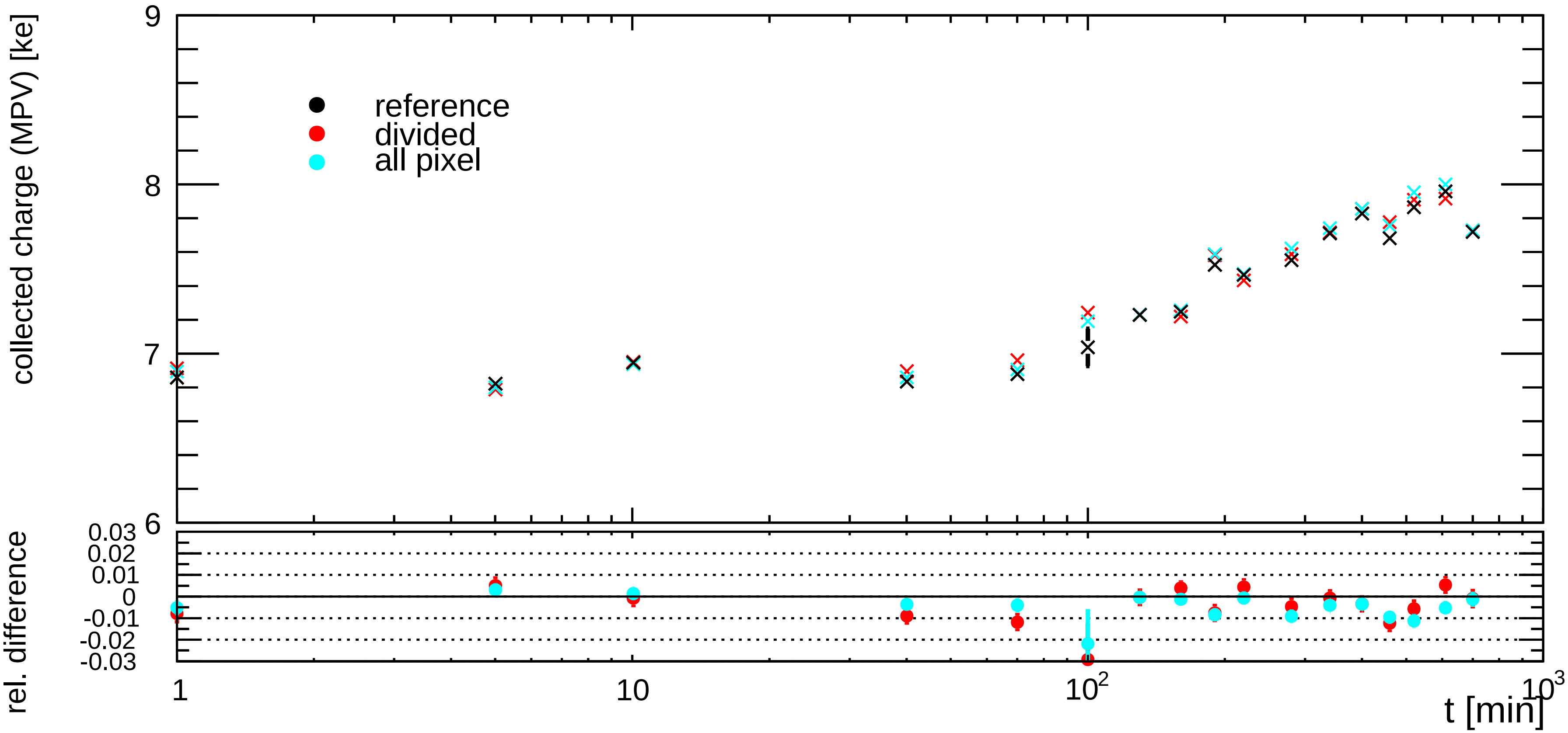
Divided pixel design





- 5x40 pixels with divided design
- Higher electric field strength
- Increased collected charge expected

Charge collection (Divided pixel design)



- No increase observed
- Rel. dev. smaller than 1%

Conclusion

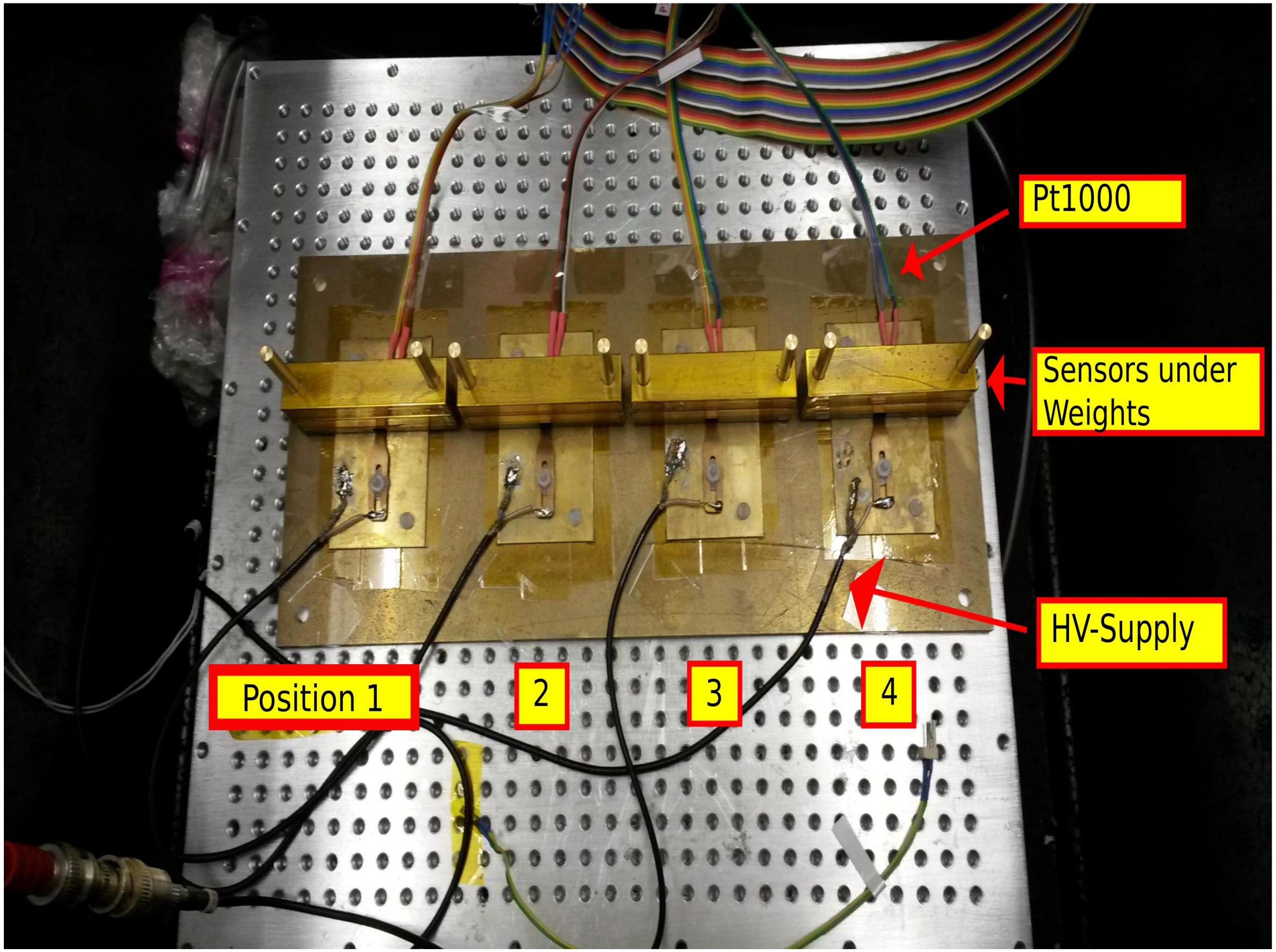
- Scaling factor seems to have a strong dependence on sensor
- Leakage current shows expected relative annealing time evolution
- Collected charge increases after 100 min of annealing
- No observable impact of the divided design

Outlook

- Extend the annealing studies
- Investigate further pixel designs

Backup

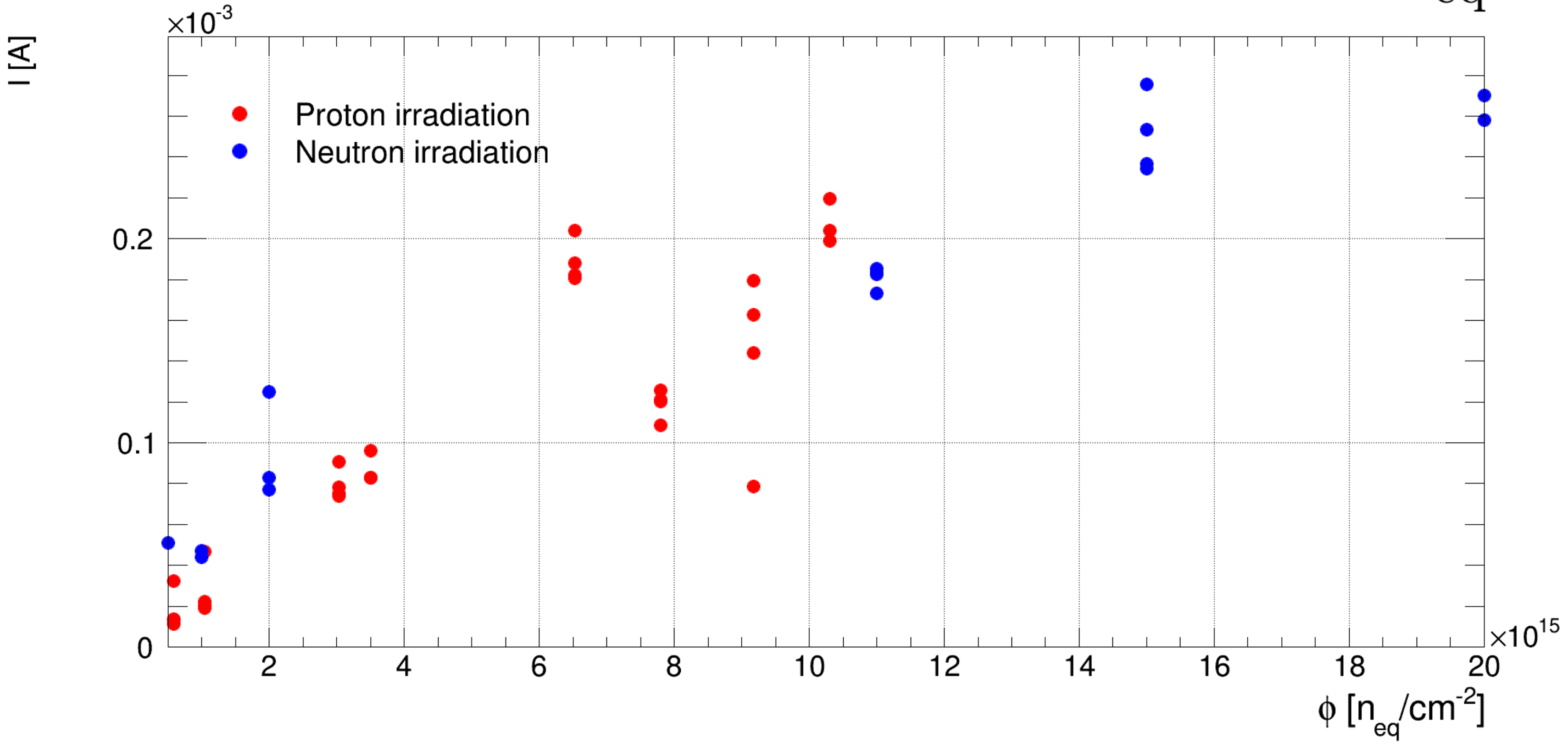
Setup



Leakage current vs fluence (at -900V)

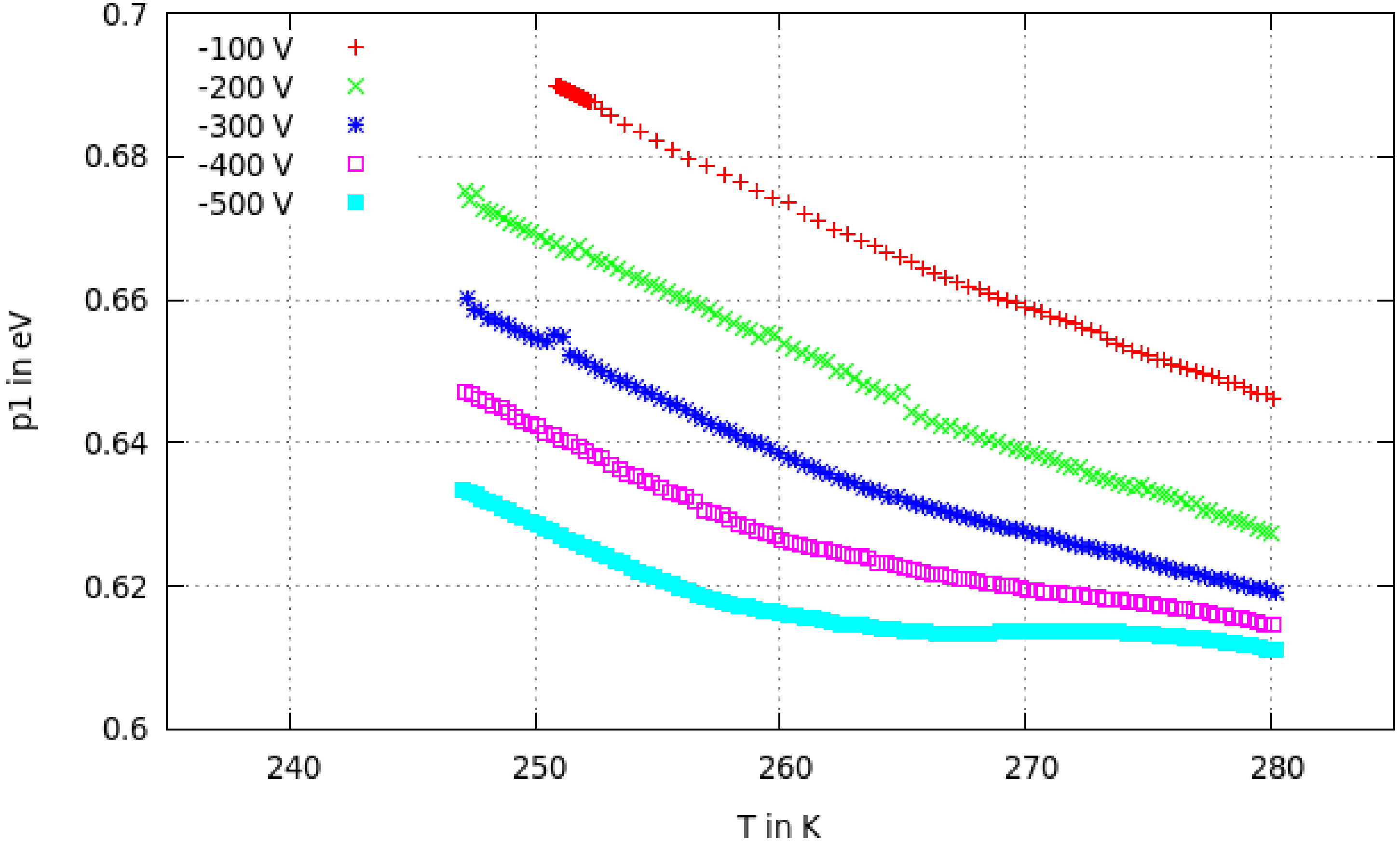
I @ -20°C

$$\Delta I = \alpha V \Phi_{\mathrm{eq}}$$



Failed linearisation for one sensor

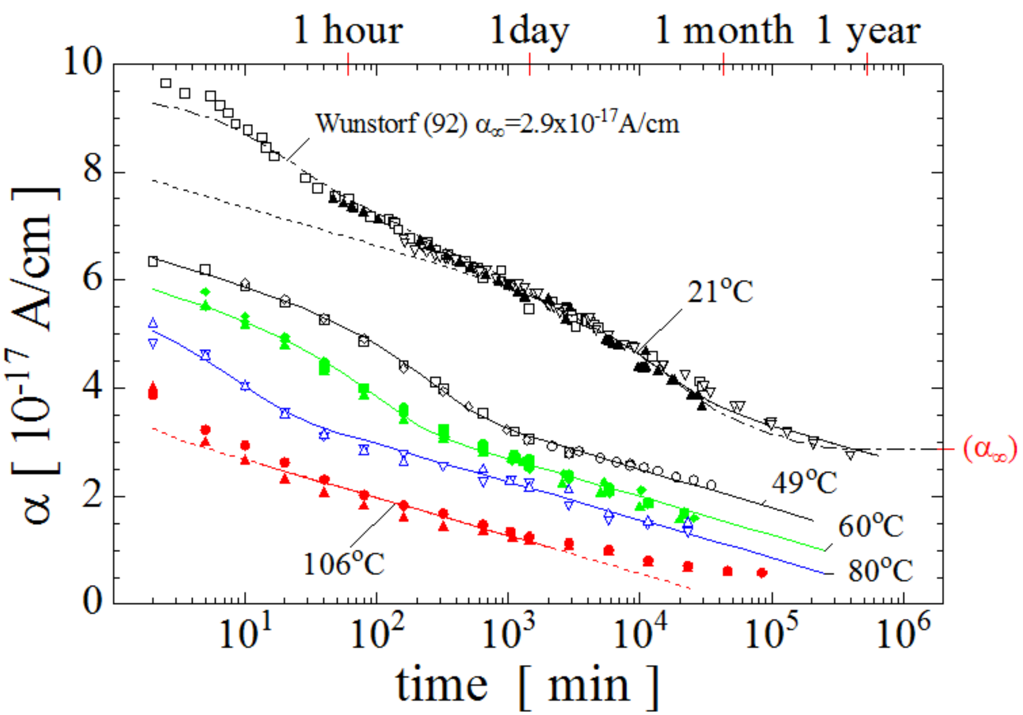
- 6137-06-04, Φ=5.81·10^{14} n_{eq}/cm²
- Surface current?



Annealing of leakage current

M.Moll/RD48:

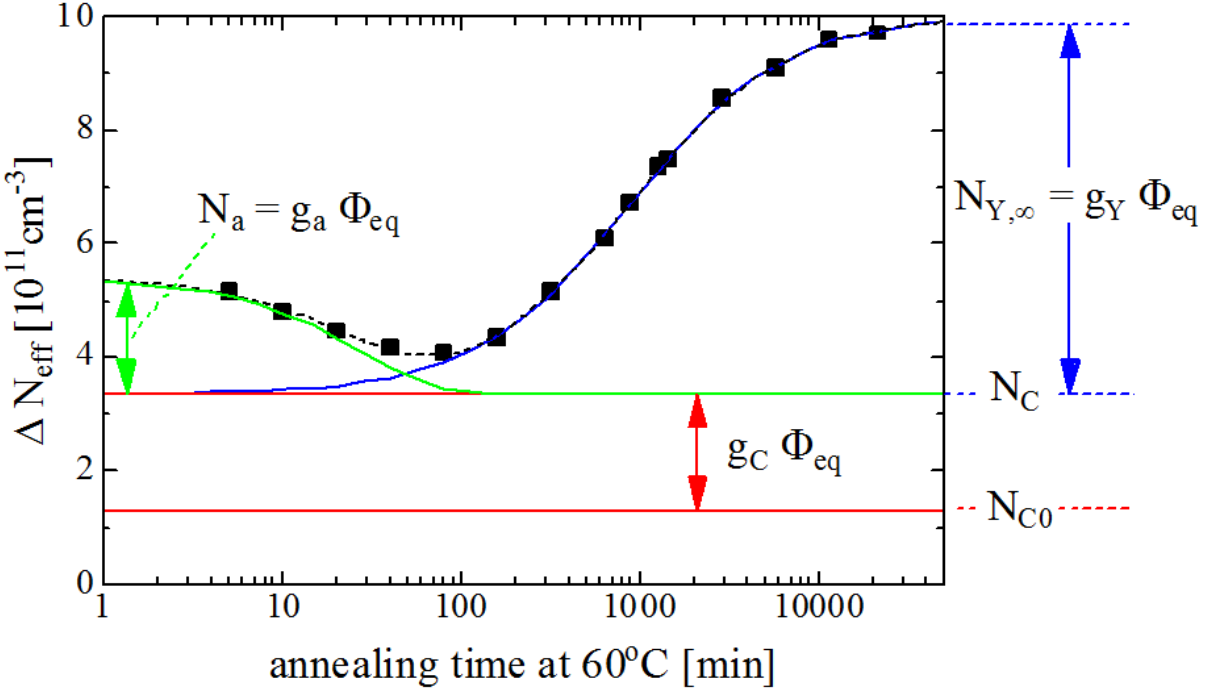
$$\alpha = \frac{\Delta I}{\Phi_{\mathrm{eq}} V}$$



$$\alpha(T_a, t) = \alpha_I \cdot \exp\left[-t/\tau_I(T_a)\right] + \left[\alpha_0(T_a) - \beta \cdot \ln(t/t_0)\right]$$

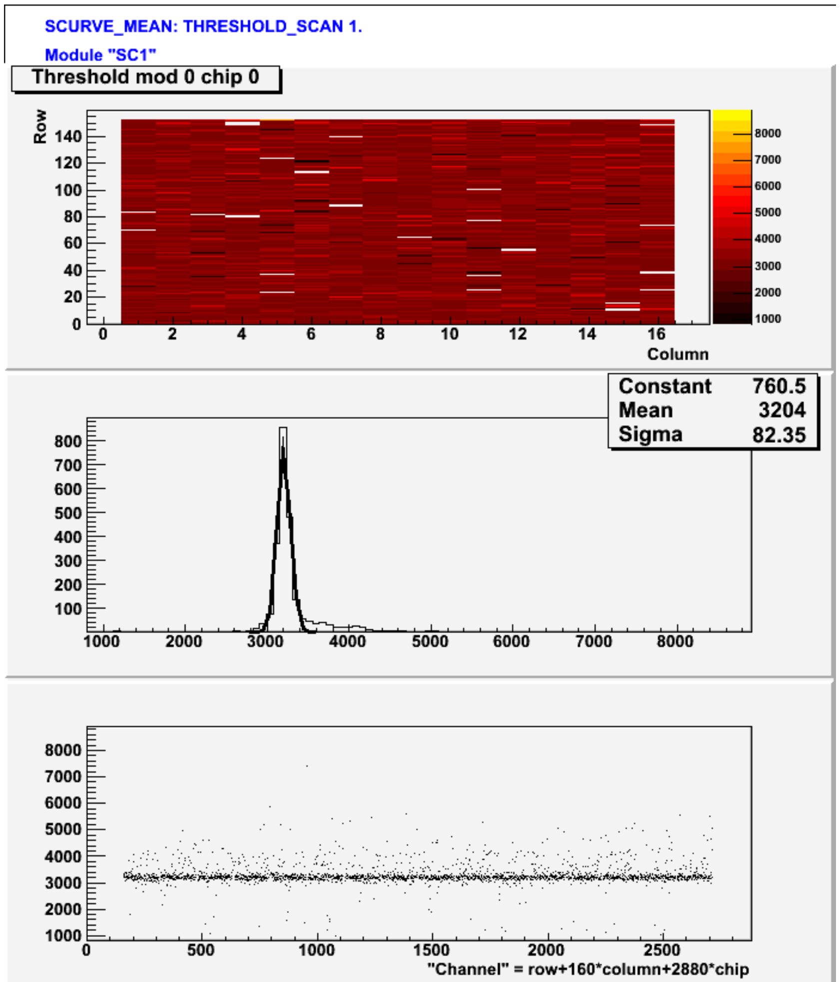
Annealing of effective doping concentration

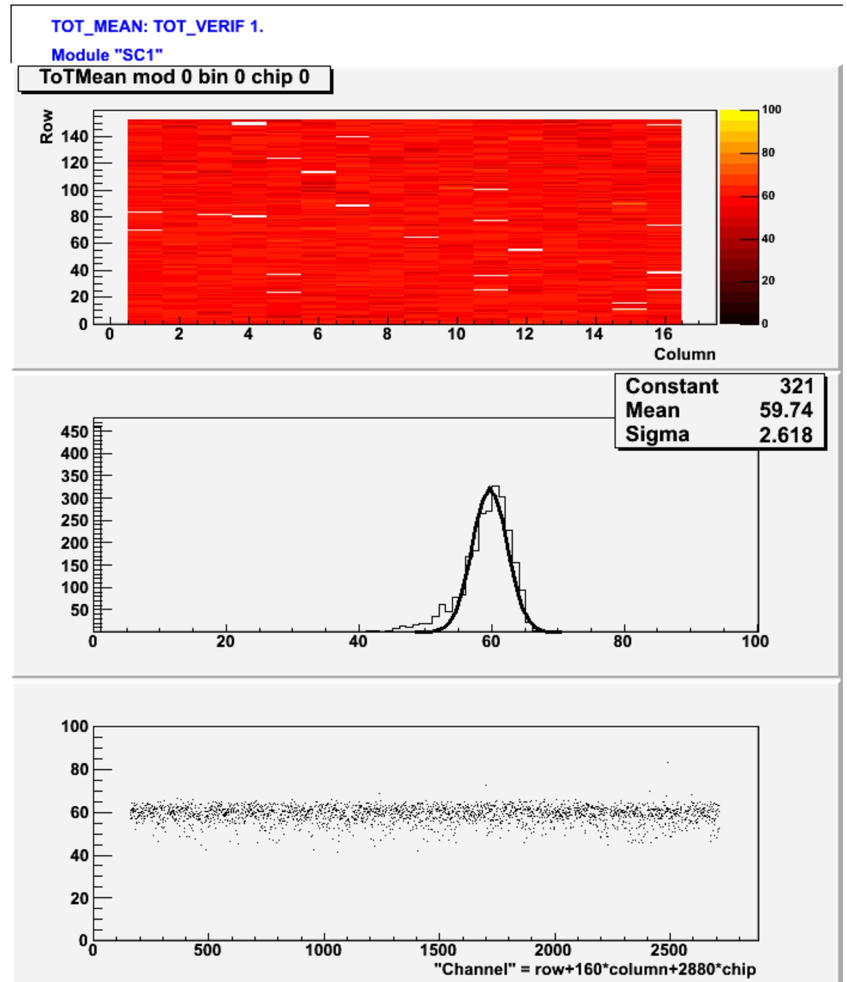
M.Moll/RD48:



$$\Delta N_{\mathrm{eff}}(\Phi_{\mathrm{eq}}, t) = N_C(\Phi_{\mathrm{eq}}) + N_a(\Phi_{\mathrm{eq}}, t) + N_Y(\Phi_{\mathrm{eq}}, t)$$

Tuning (610min, 2000V)





Modificated pixel implantations