Annealing studies on MCz and FZ Si-diodes after 24 GeV/c proton irradiation and CCE of 150um Epitaxial Si-diodes

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CERN-PH

RD50

Experimental procedure

- **Measurements on MCz**
  - Fluence dependence
  - Isothermal annealing on subset
  - Isochronal annealing

- **Measurements on EPI:**
  - Fluence dependence

- **CV/IV**
  - Measured at room temperature in parallel mode at 10kHz

- **CCE**
  - NIKHEF setup by Fred Hartjes

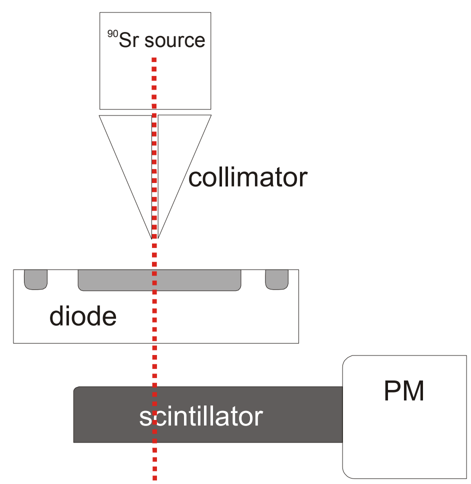
  signal shaping time: 2.5 μs

  guard ring connected to ground

  measured at -20±1°C

  humidity 12-20% (flushed with dry nitrogen)

  gain of 247 e^-/mV for these conditions



Material and irradiation

Material

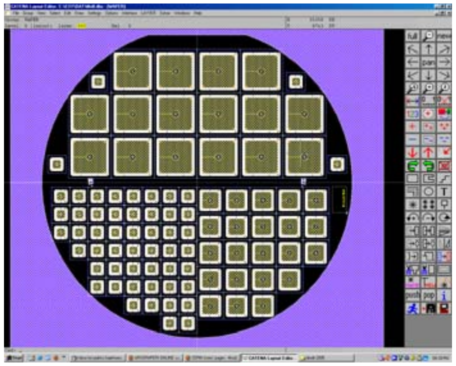
- **MCz n-type (ρ ~ 1 kΩcm) 300um**
  - **HIP-003-C** 0.25 x 0.25 cm^2 V_{fd} ~290V
  - **HIP-MCz-01-n** 0.5 x 0.5 cm^2 V_{fd} ~320V
  - **SMG** 0.5 x 0.5 cm^2 V_{fd} ~310V

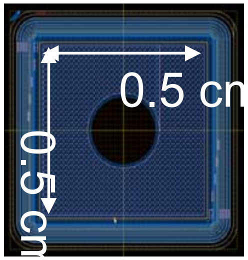
- **MCz p-type (ρ ~ 7.4 kΩcm) 300um**
  - **P069** 0.5 x 0.5 cm^2 V_{fd} ~115V

- **Fz n-type (ρ ~ 15.3 kΩcm) 300um**
  - **CNM-03** 0.5 x 0.5 cm^2 V_{fd} ~20V

- **Epi n-type (ρ ~ 500 Ωcm) 150um**
  - **HIP-004-C** 0.25 x 0.25 cm^2 V_{fd} ~150V

- **Epi p-type (ρ ~ 1 kΩcm) 150um**
  - **CNM-22-E** 0.5 x 0.5 cm^2 V_{fd} ~210V

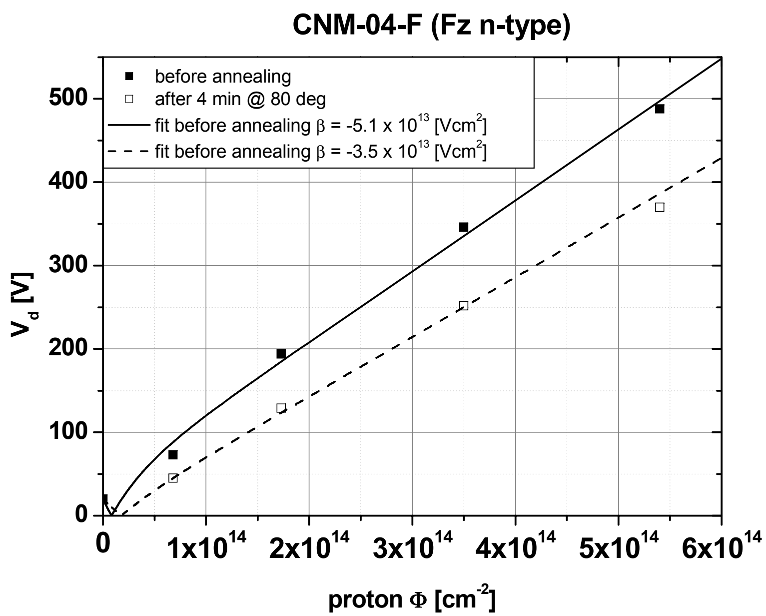


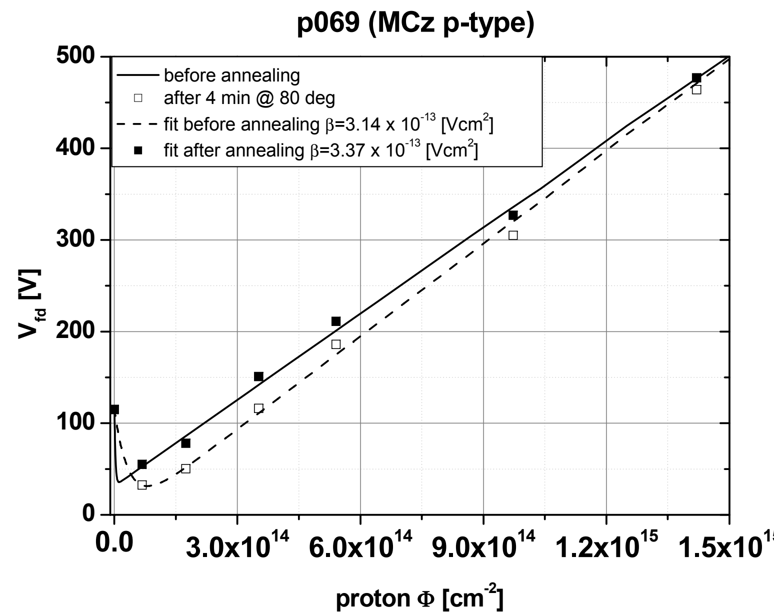


Irradiation

- proton irradiation at CERN (24 GeV/c, 27 °C)
- between 1.43 x 10^{13} cm^{-2} and 1.73 x 10^{15} cm^{-2} proton fluence

MCz Depletion voltage (CV)





before annealing: $\beta = 12 \times 10^{-3}\ cm^{-1}$

after 4 min @ 80 °C : $\beta = 10.5 \times 10^{-3}\ cm^{-1}$

before annealing: $\beta = 4.6 \times 10^{-3}\ cm^{-1}$

after 4 min @ 80 °C : $\beta = 4.9 \times 10^{-3}\ cm^{-1}$

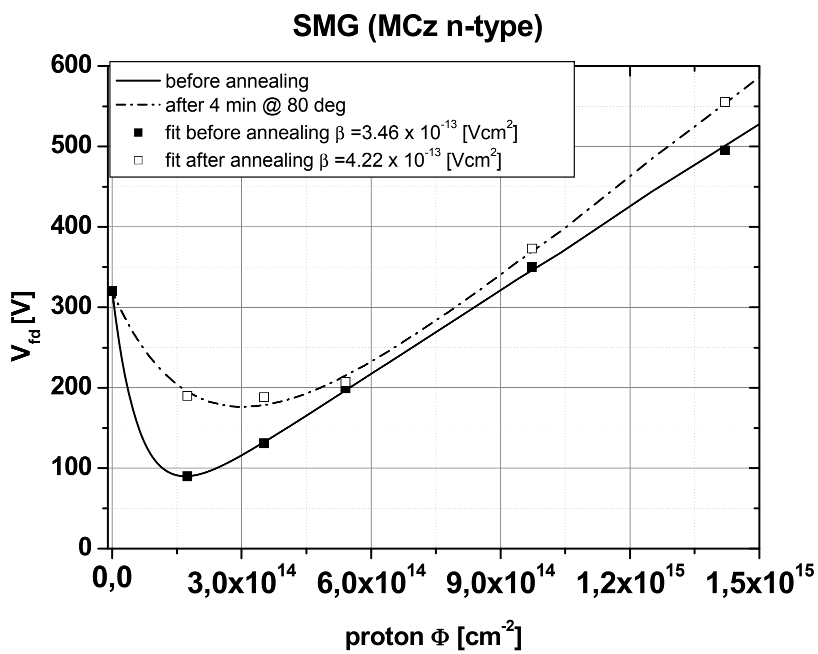
Fz n-type :

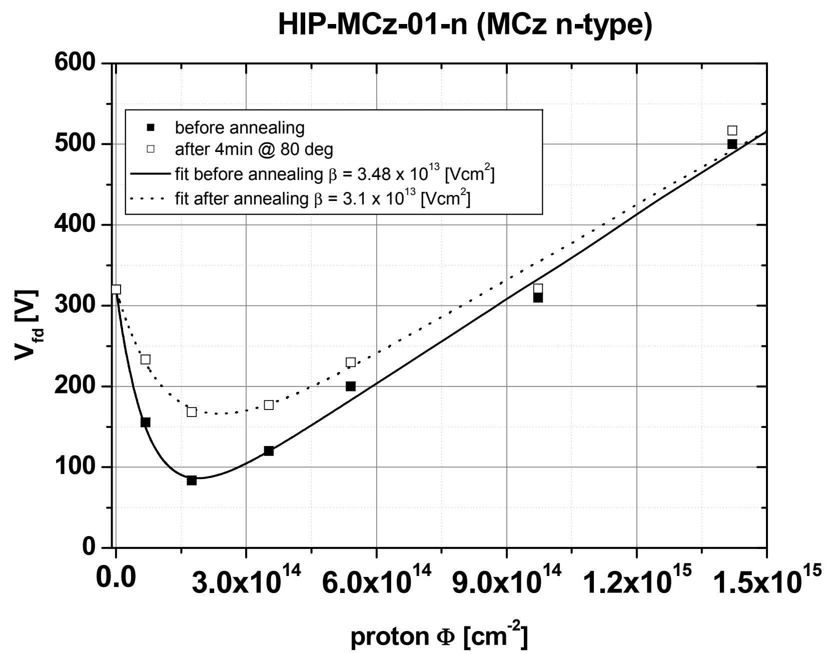
depletion voltage goes down after annealing for 4 min @ 80 °C => indicates p-type (i.e. type inversion)

MCz p-type:

depletion voltage goes down after annealing for 4 min @ 80 °C => indicates p-type (i.e. no type inversion)

MCz Depletion voltage (CV)





before annealing: $\beta = 5.1 \times 10^{-3}\ \mathrm{cm}^{-1}$

after 4 min @ 80 °C : $\beta = 6.1 \times 10^{-3}\ \mathrm{cm}^{-1}$

before annealing: $\beta = 5.1 \times 10^{-3}\ \mathrm{cm}^{-1}$

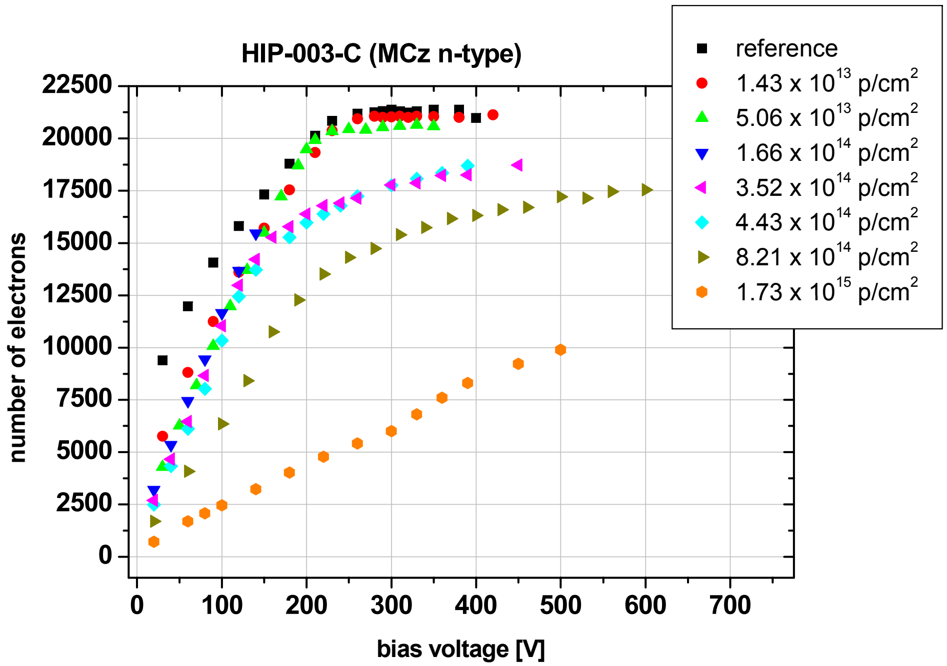
after 4 min @ 80 °C : $\beta = 4.5 \times 10^{-3}\ \mathrm{cm}^{-1}$

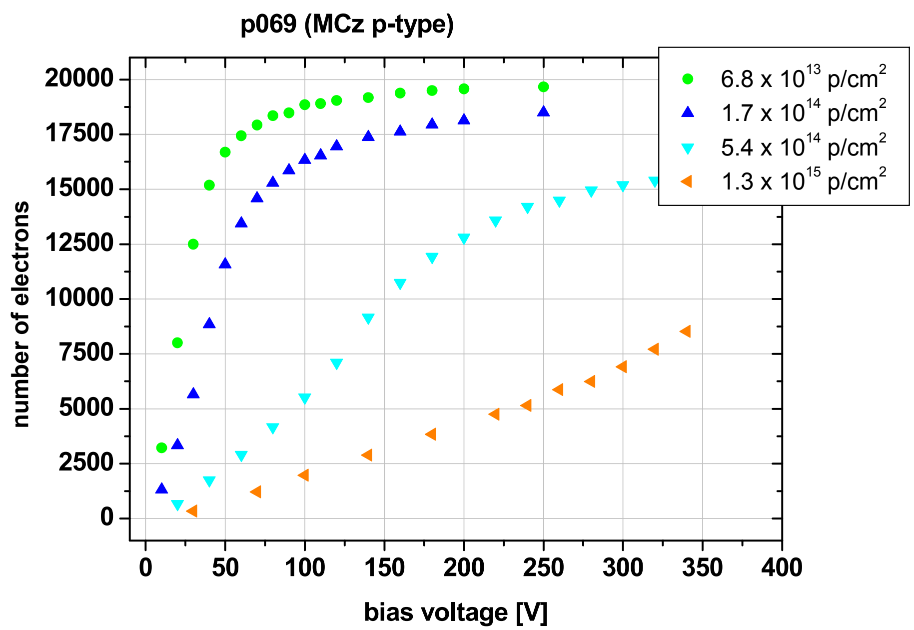
MCz n-type:

depletion voltage goes up after annealing for 4 min @ 80 °C => indicates n-type (i.e. no type inversion)

???

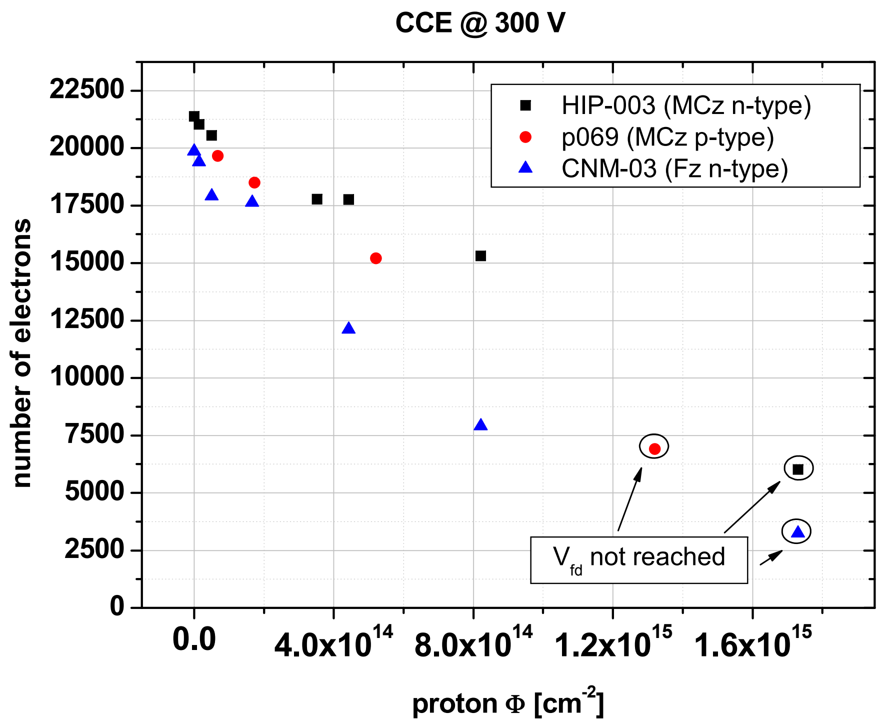
MCz CCE curves

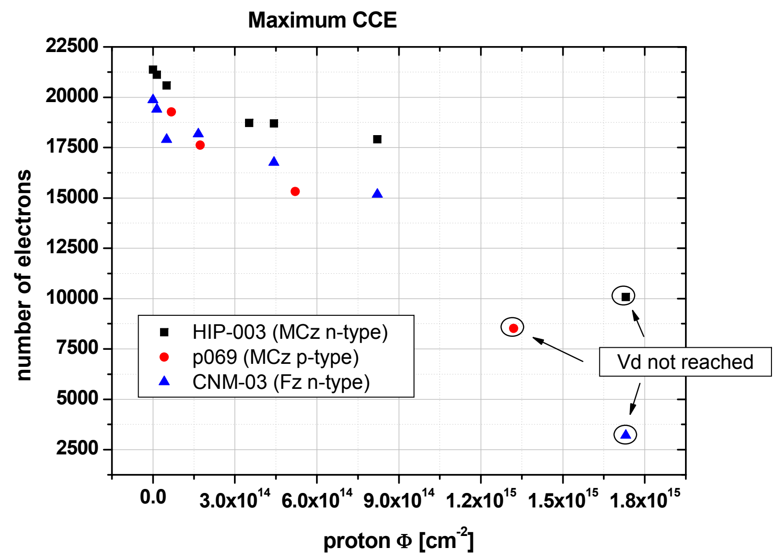


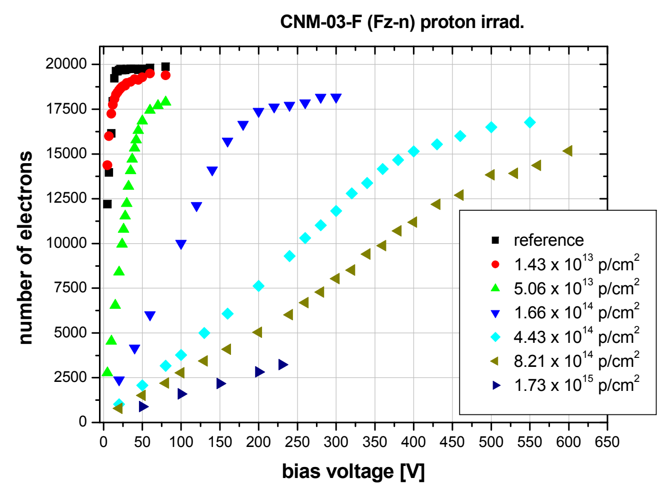


Number of electrons from landau most probable

MCz: CCE vs. fluence

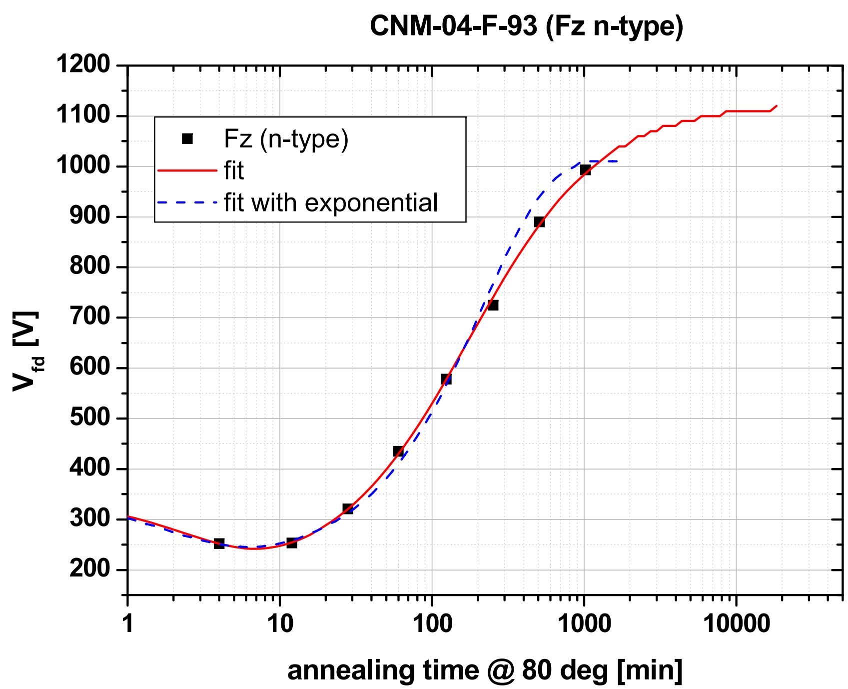




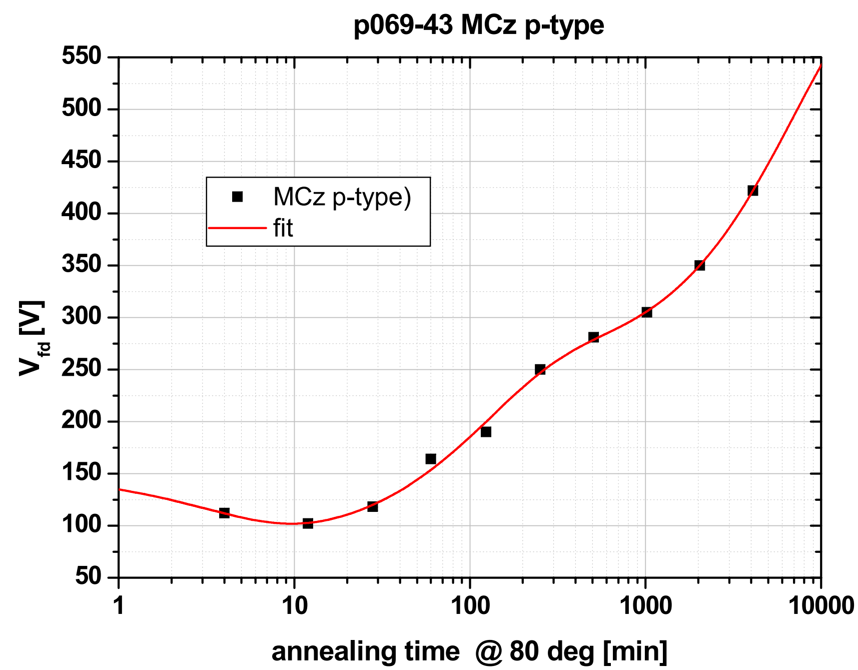


Charge collection comparison
MCz and Fz

MCz p-type isothermal annealing



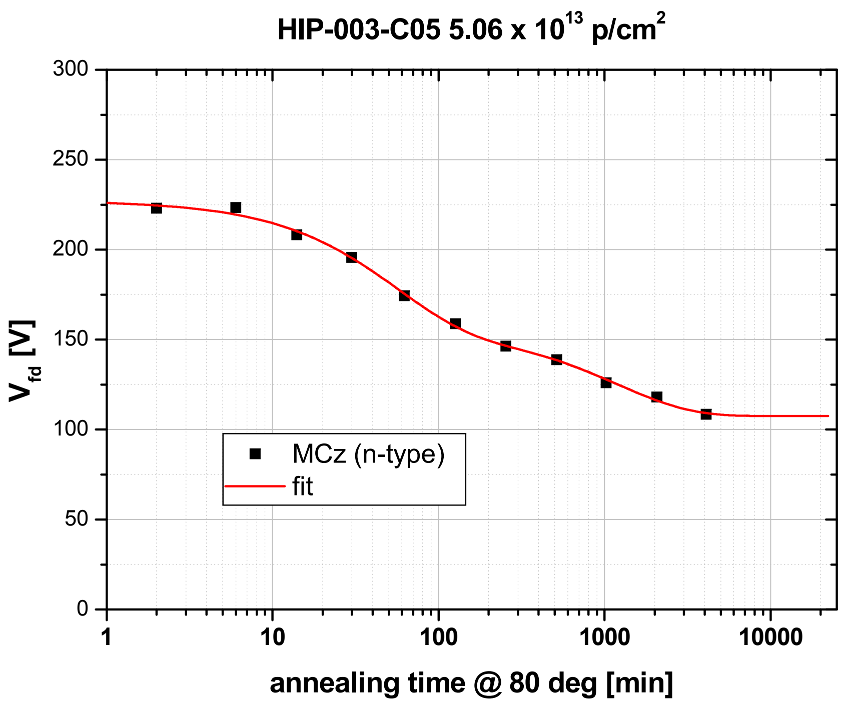
$$\Delta N_{eff} = g_a \Phi_{eff} e^{-\frac{t}{\tau_a}} + N_C + N_{\infty,y}(1 - \frac{1}{1+\frac{t}{\tau}})$$

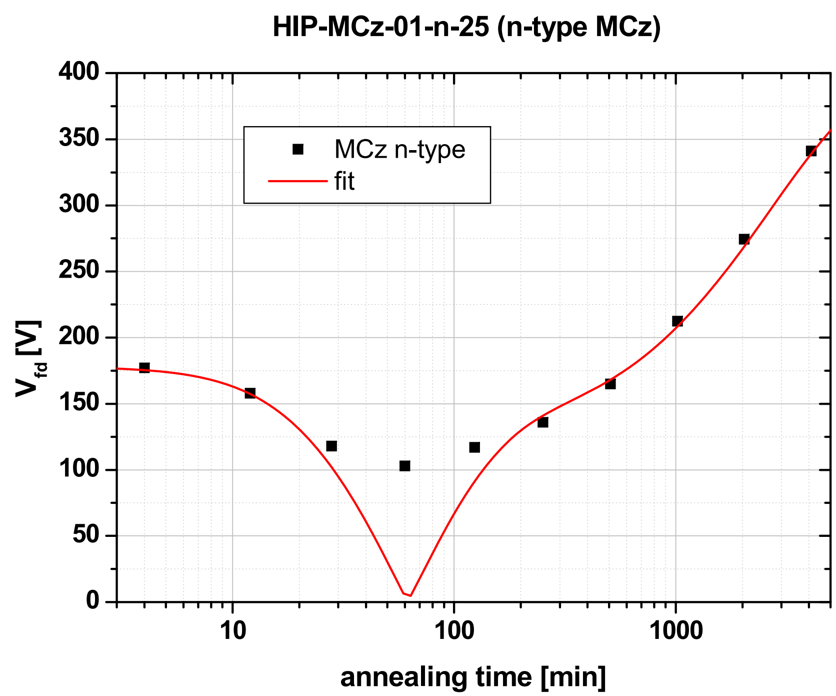


$$\Delta N_{eff} = g_a \Phi_{eff} e^{-\frac{t}{\tau_a}} + N_C + N_{\infty,Y,1}(1 - e^{-k_{1,Y}t}) + N_{\infty,Y,2}(1 - e^{-k_{2,Y}t})$$

Second annealing step visible in p-type MCz ($3.5\text{x}10^{14}$ p/cm^2)

MCz n-type isothermal annealing

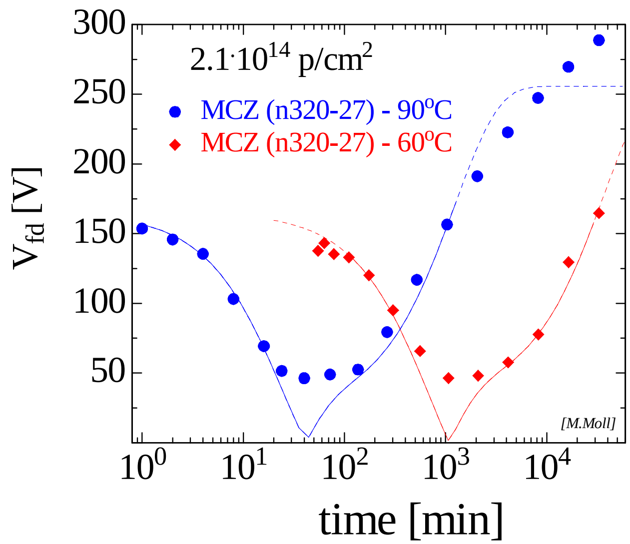


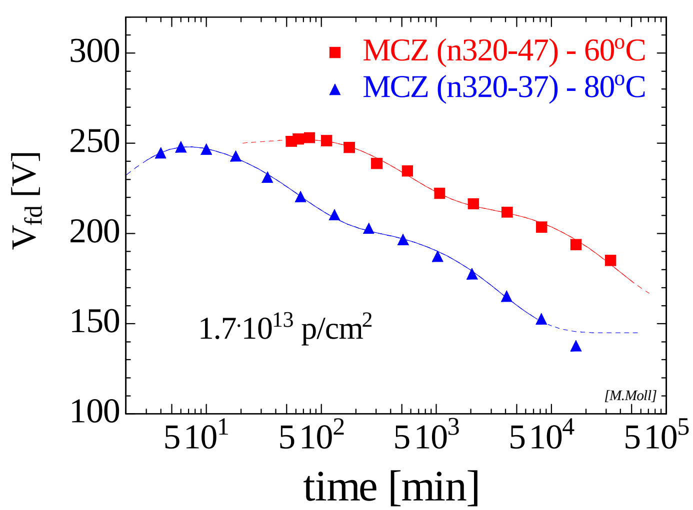


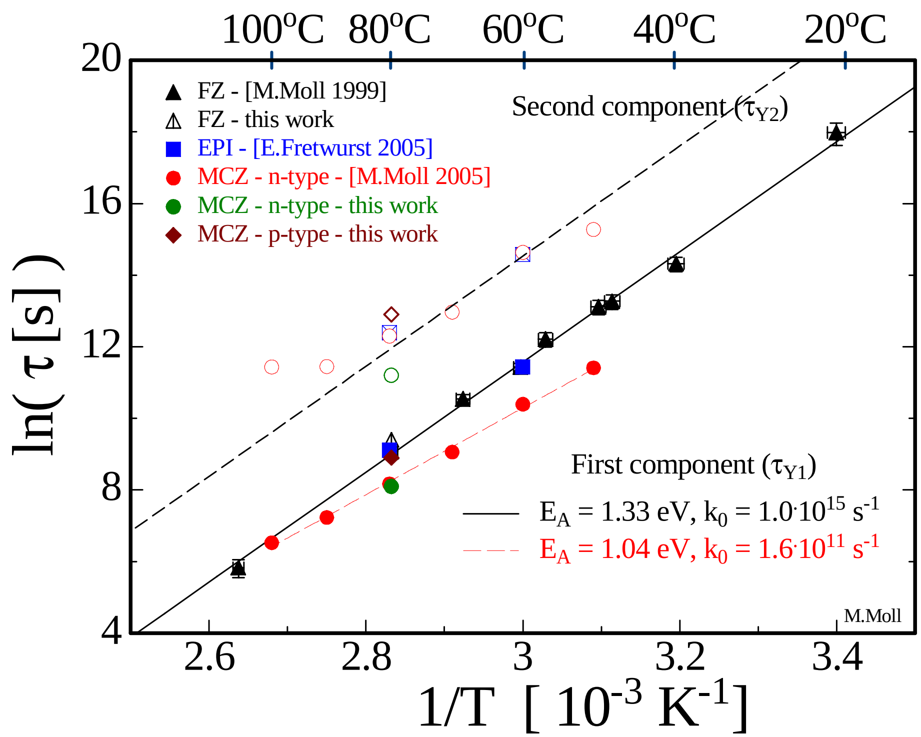
At $5x10^{13}$ proton fluence second annealing step also visible in n-type silicon

At $3.5x10^{14}$ proton fluence type inversion during annealing

Seen before in MCz...







Updated Arrhenius plot

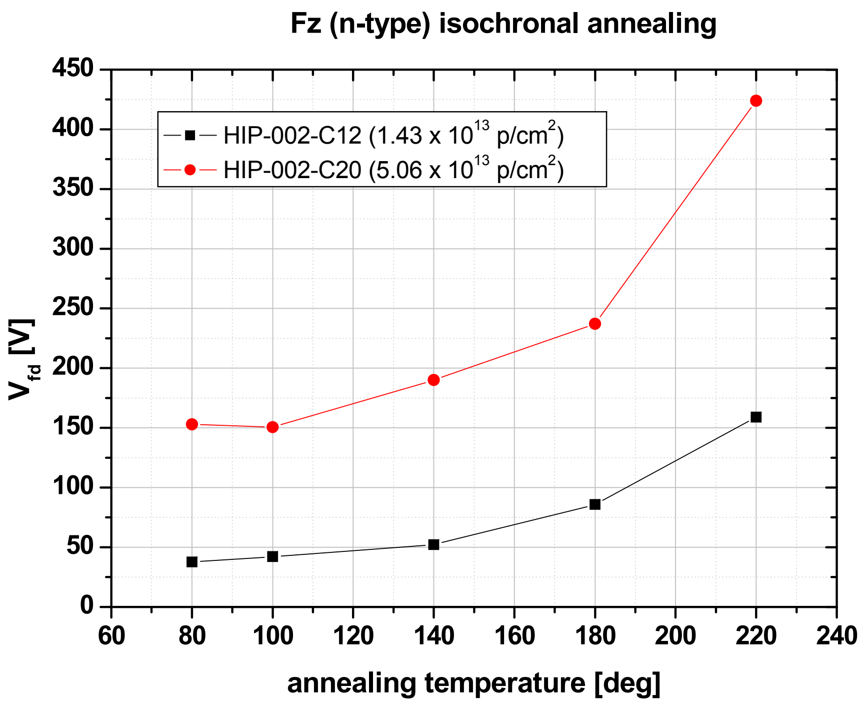
M. Moll 7th RD50 workshop

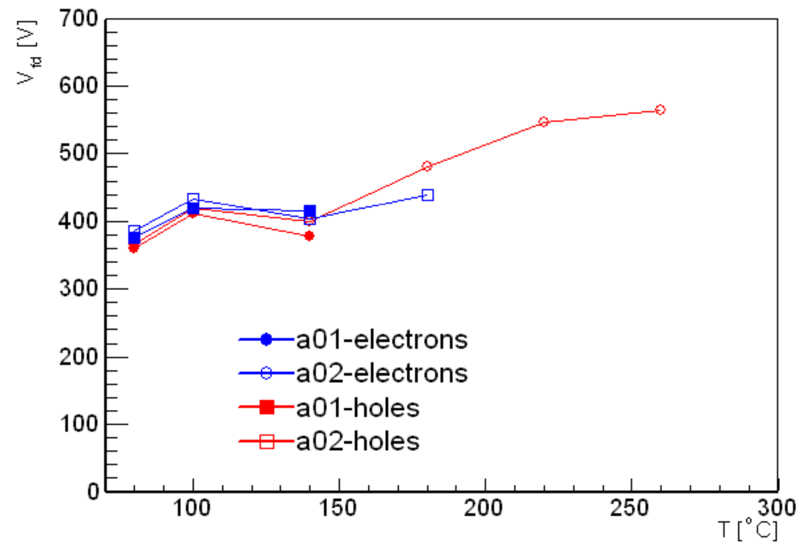
Isochronal annealing

- **Gregor's procedure (WODEAN):**
  - Annealing for 800 min @ 80 °C
  - 40 °C steps, starting at 100 °C
  - Detectors left at RT for one day before measurement

- **Detectors used**
  - MCz n- and p-type, Fz n-type reference from isothermal study (3.52 x 10^{14} p/cm^2)
  - Additional Fz and MCz-n (1.43 x 10^{13} p/cm^2 and 5.06 x 10^{13} p/cm^2)
  - Starting point after 4100 min @ 80 °C

RD50 Isochronal annealing Fz-n (CV)



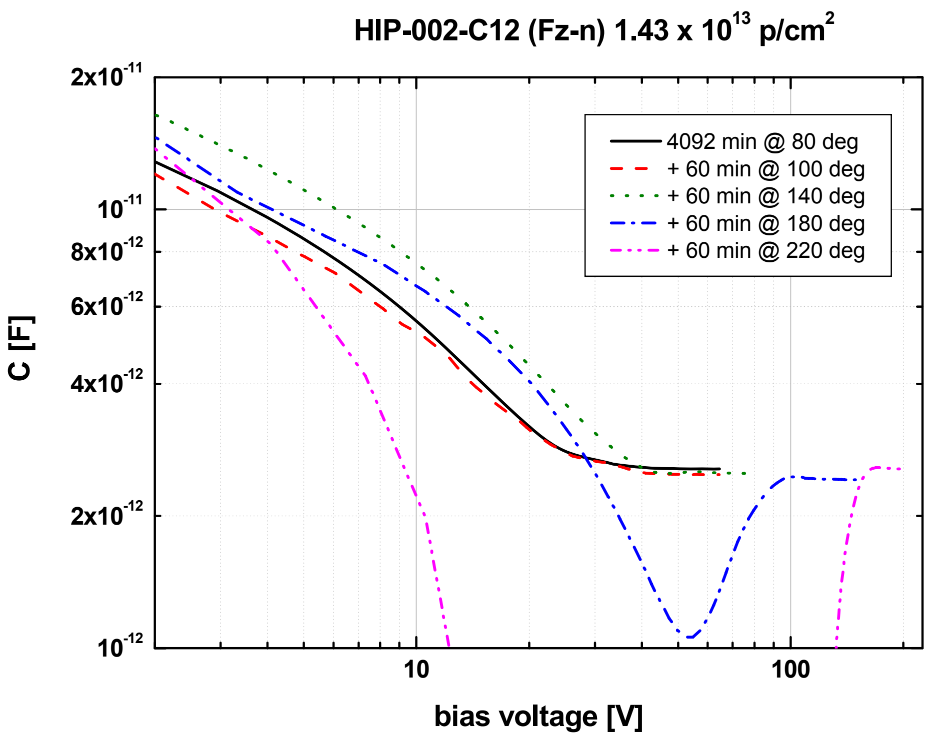


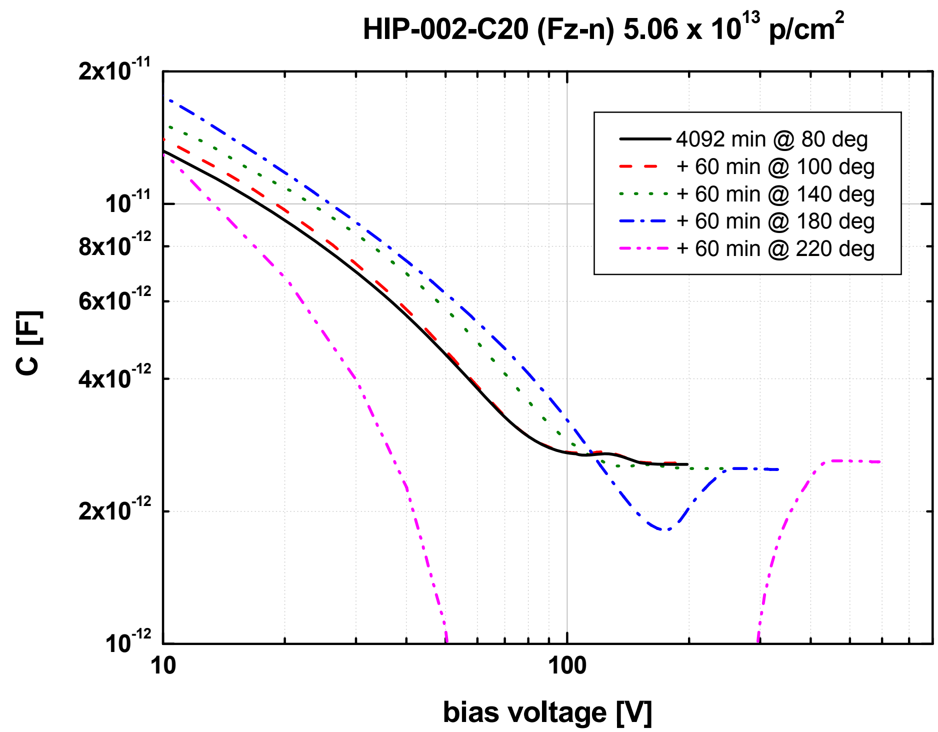
G. Kramberger, 2nd Wodean workshop, Vilnius

Proton irradiated Fz:
Increase in depletion voltage

Fz, 300 µm
7.5 x 10^{13} cm^{-2} **neutron fluence**

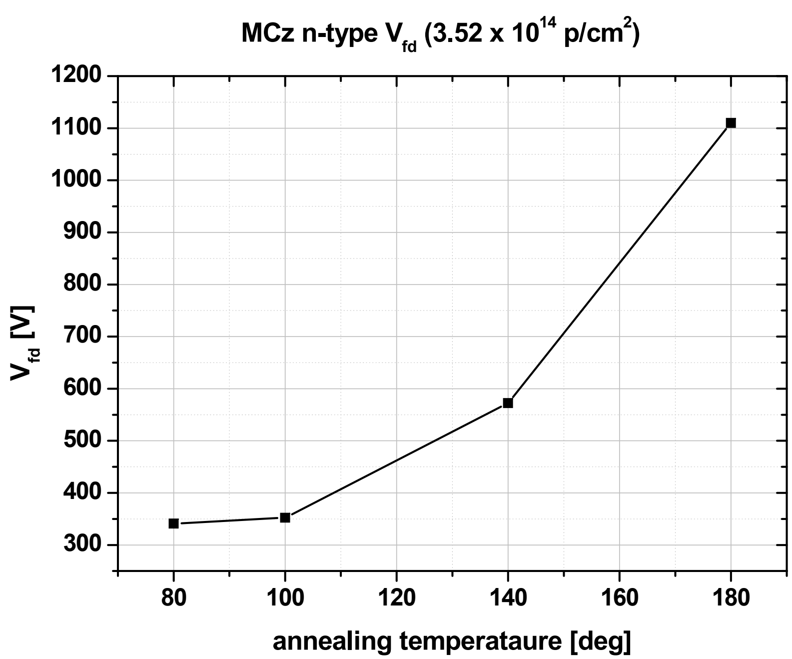
Fz CV curves

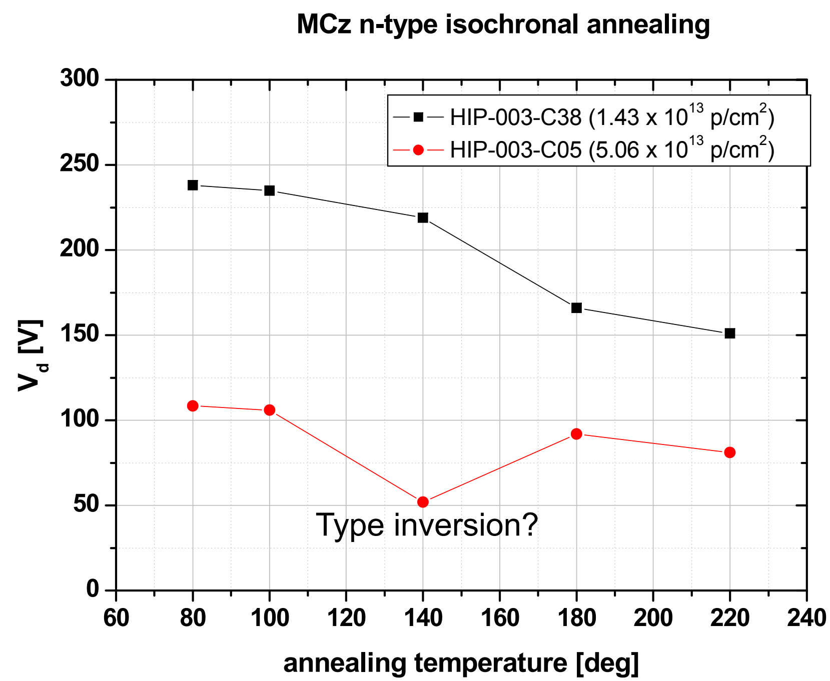




- negative C measured ????
- but expected end capacitance reached

Isochronal annealing MCz-n (CV)

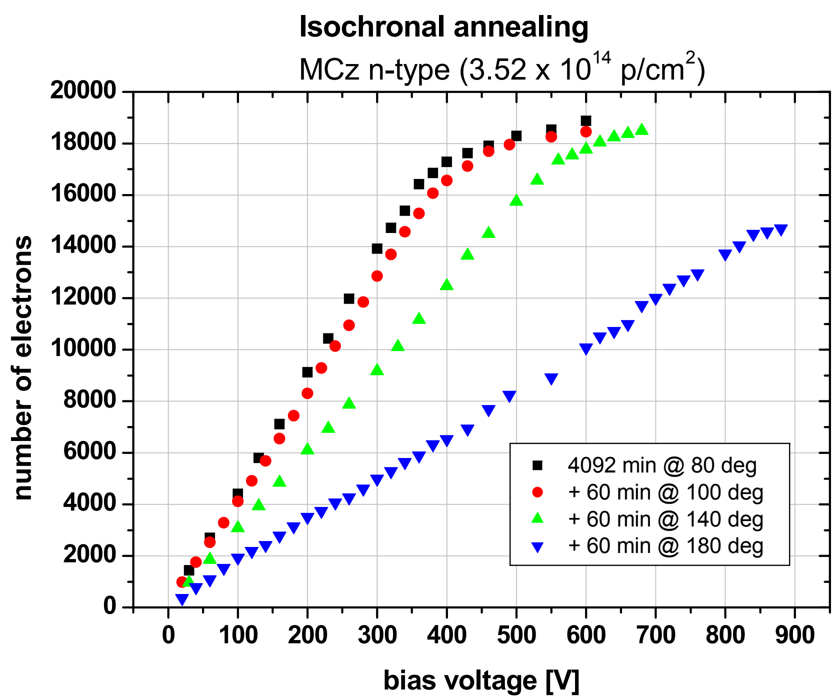


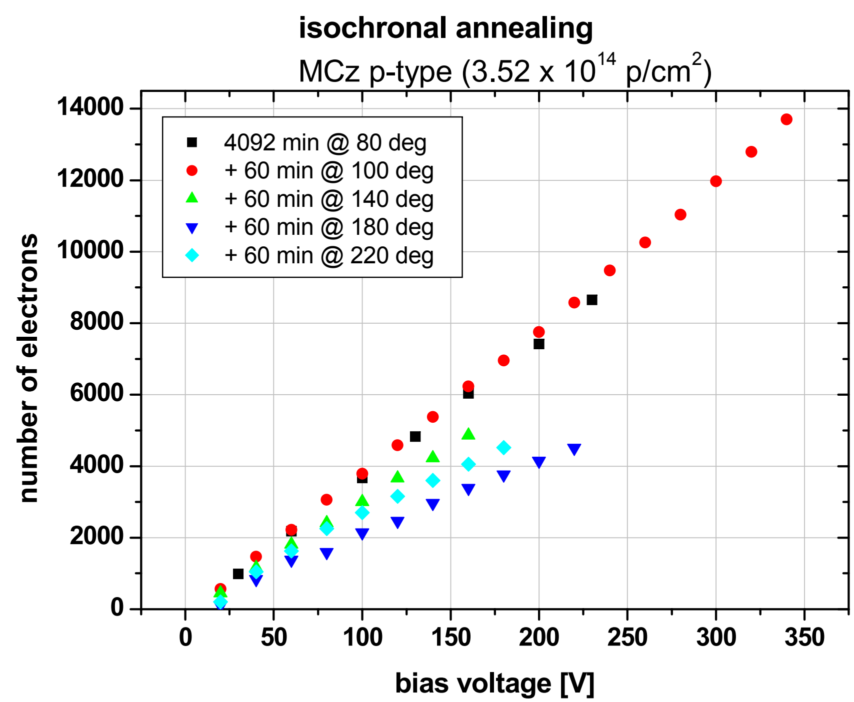


Type inverted during isothermal annealing => strong increase in depletion voltage

Lower fluence, no type inversion during isothermal annealing=> depletion voltage decreases

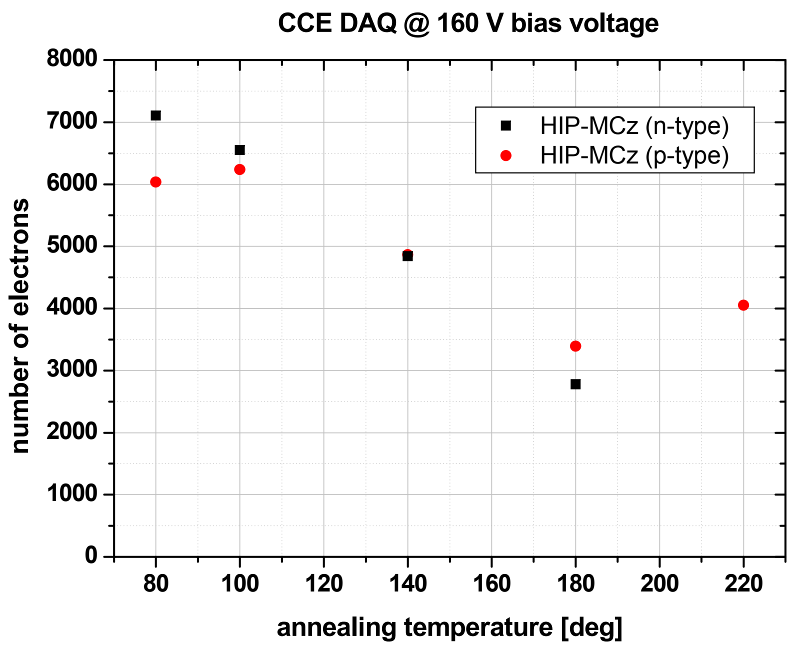
MCz CCE

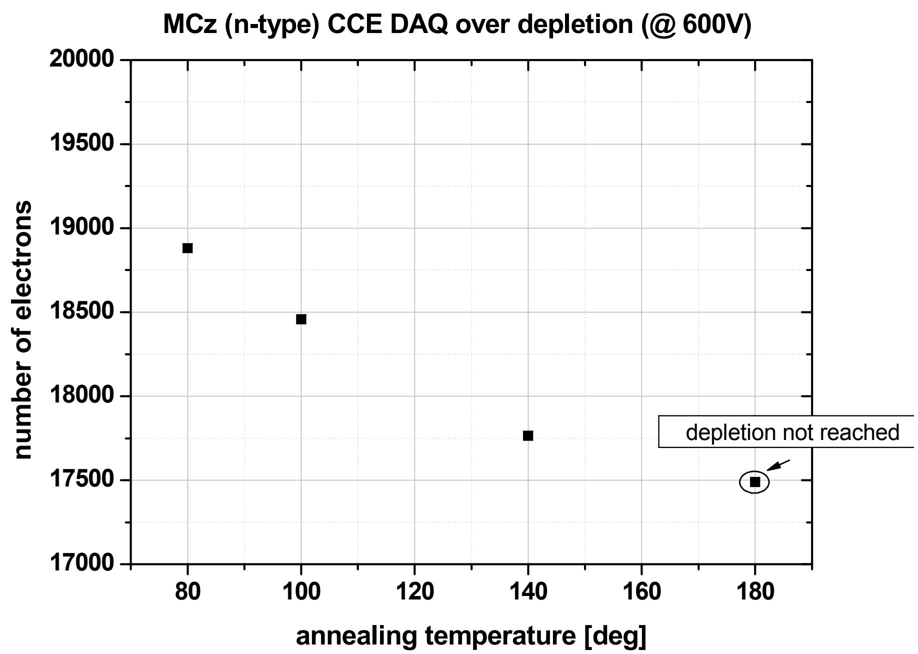




Noise went up quickly at around 150 V => impossible to measure up to depletion

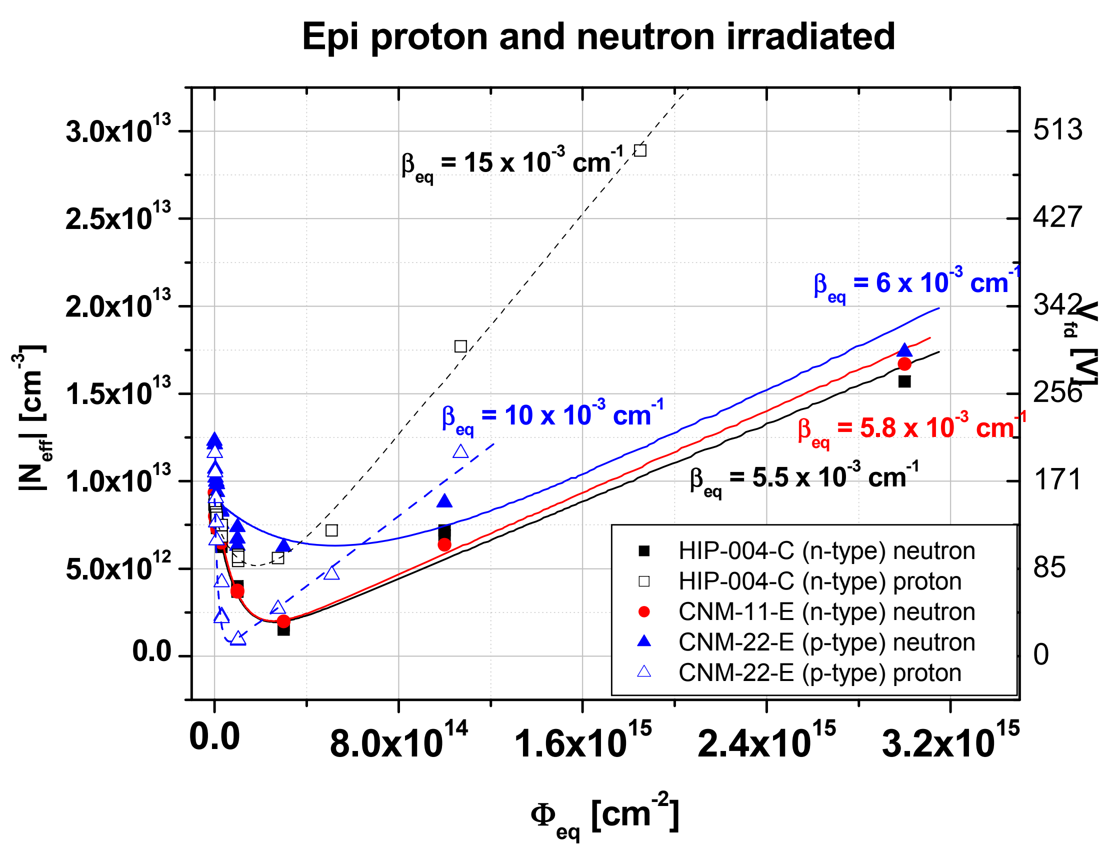
CCE vs. T





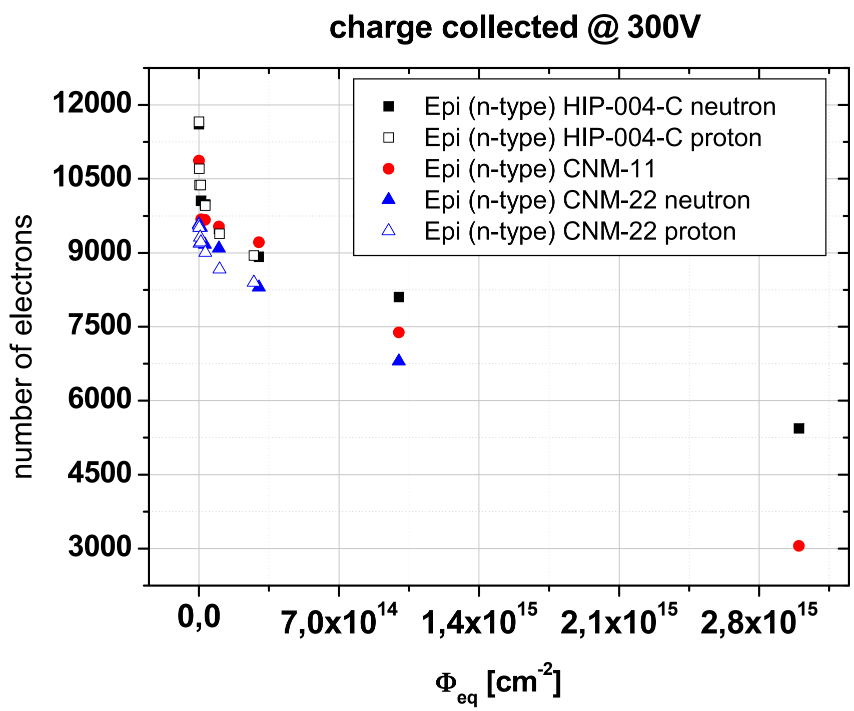
CCE seems to go up again in
p-type material

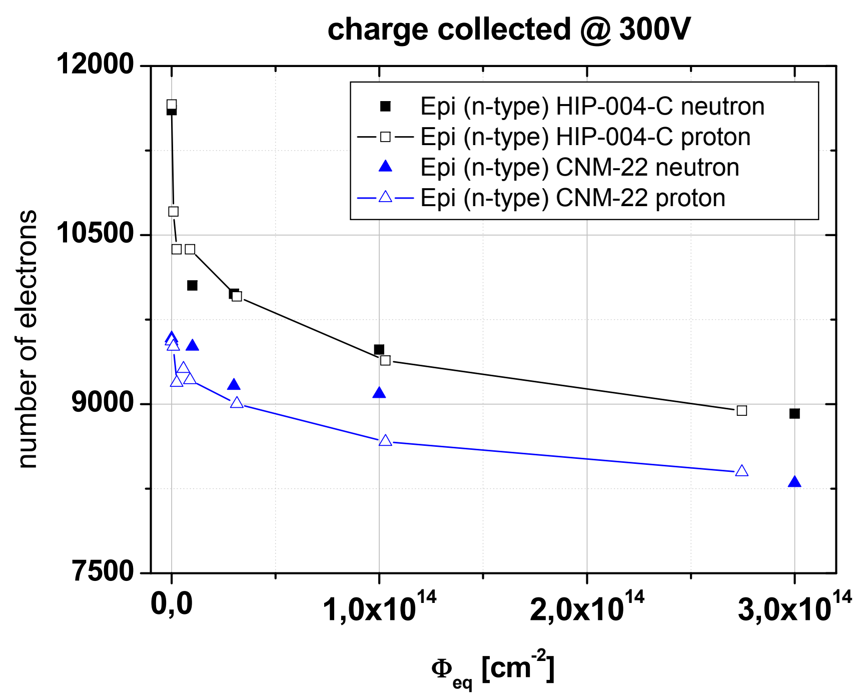
Epi depletion voltage



- 150 μm
- Irradiated with
  - 1 MeV reactor neutrons
  - 24 GeV/c protons

Epi: CCE comparison





- drop in CCE at low fluences in n-type material
- p type has lower charge collection efficiency
- proton and neutron irradiation similar

Summary

After 24 GeV/c proton irradiation

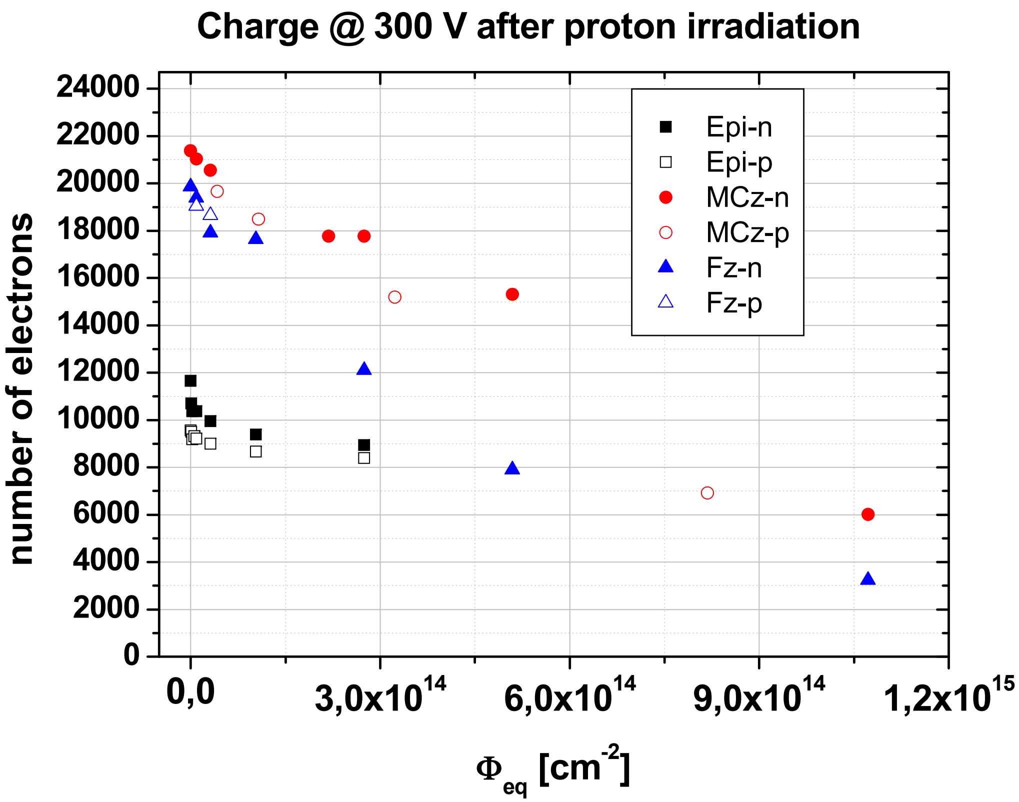
- **MCz inversion problem**: no inversion in both types deduced from CV
  explanation ????
- **Isothermal annealing**: second step in reverse annealing for MCz
  n- and p-type observed
- **Isochronal annealing (a lot of technical problems)**
  - **CV**: depletion voltage increase for Fz-n and inverted MCz-n, decreases for not inverted MCz-n
  - **CCE**: MCz n- and p-type similar
- **Epi:** drop in CCE at low fluences

Outlook

- **Repeat isochronal study**, maybe with smaller temperature steps and include TCT measurements
- **TCT measurements** on all samples for depletion voltage comparison
- **Isothermal annealing** studies at different temperatures

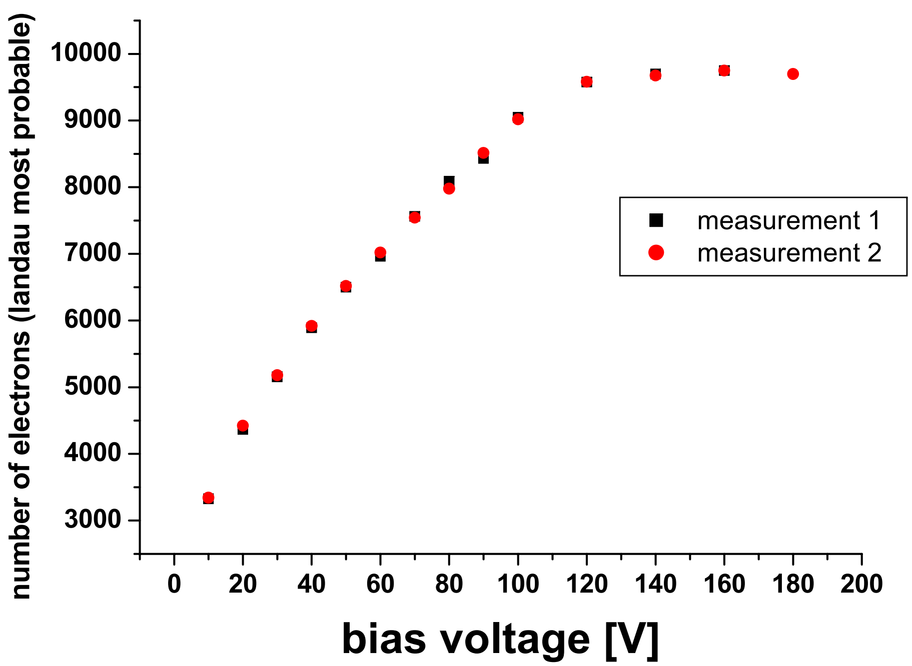
QUESTIONS?????

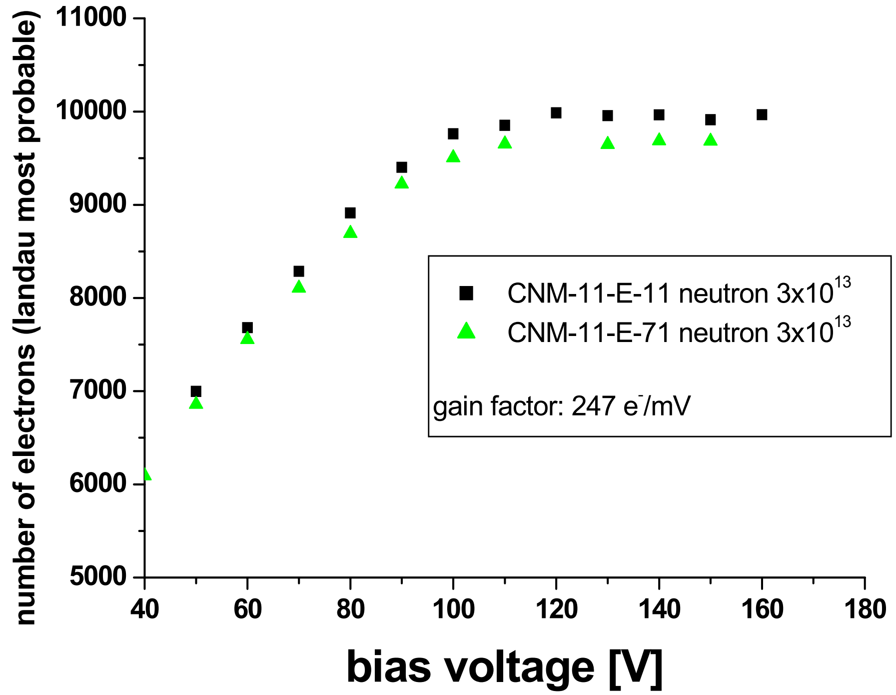
CCE comparison all materials



Reproducibility

CNM-11-E-79 (n-type) 1x10^{13} neutrons





- Detector was **taken out** of the setup and remounted between measurements
- Temperature and humidity were approximately the same

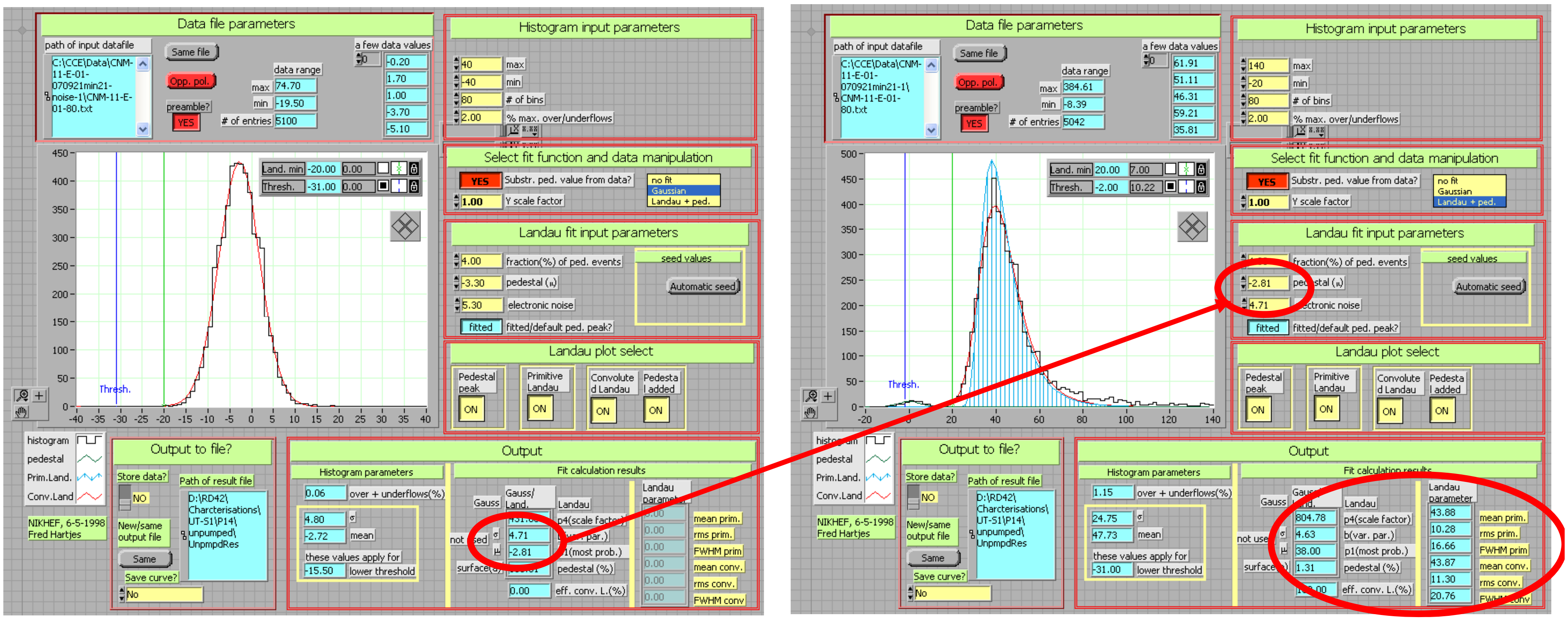
- Different detectors, same fluence
- Temperature and humidity were approximately the same
- 3-4 % difference over depletion

Data fitting

Example: CNM-11-01 (n-type)

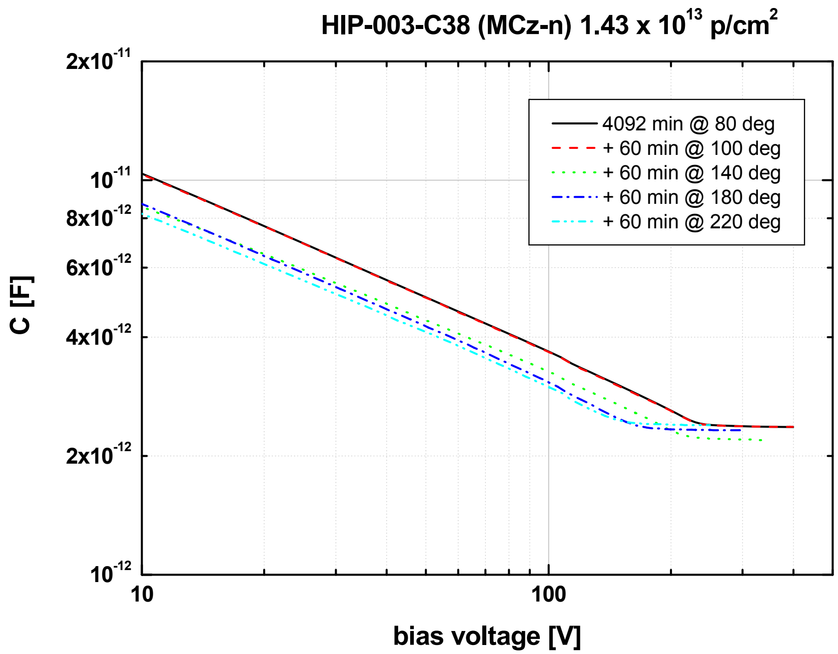
irradiation: $\Phi = 1\times10^{14}$ p/cm^2 temperature: -21 ^{o}C

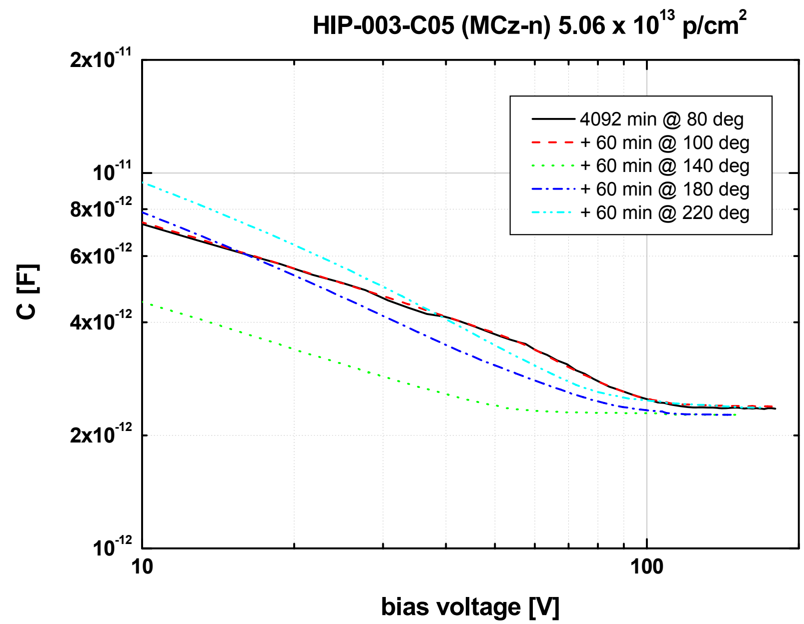
bias: 80 V



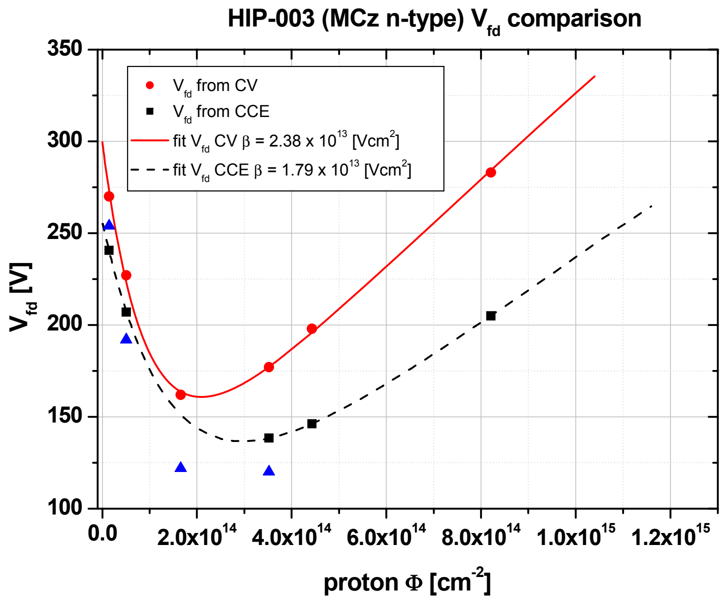
Noise/pedestal measurement for each bias point => values used for deconvoluted landau distribution

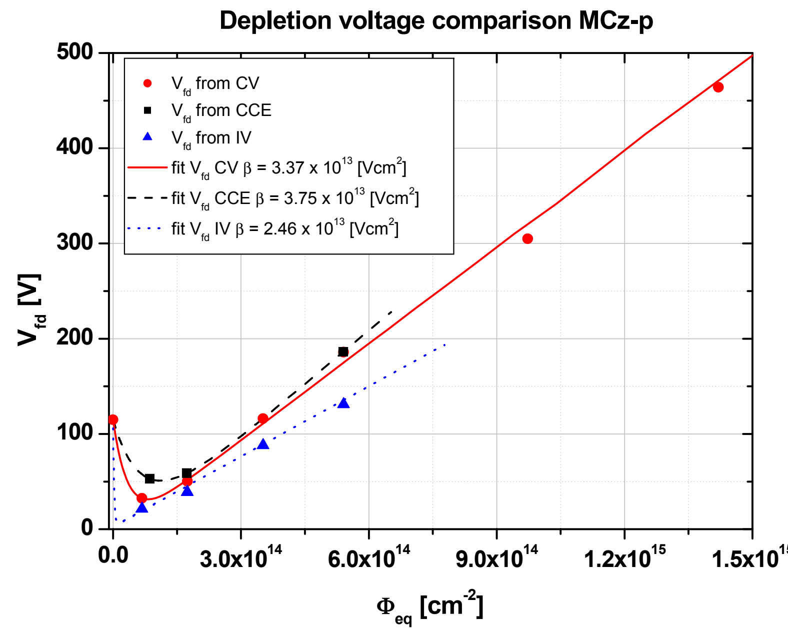
MCz CV curves





Depletion voltage comparison





CV: $\beta = 3.48 \times 10^{-3}\ \mathrm{cm}^{-1}$

CCE: $\beta = 2.6 \times 10^{-3}\ \mathrm{cm}^{-1}$

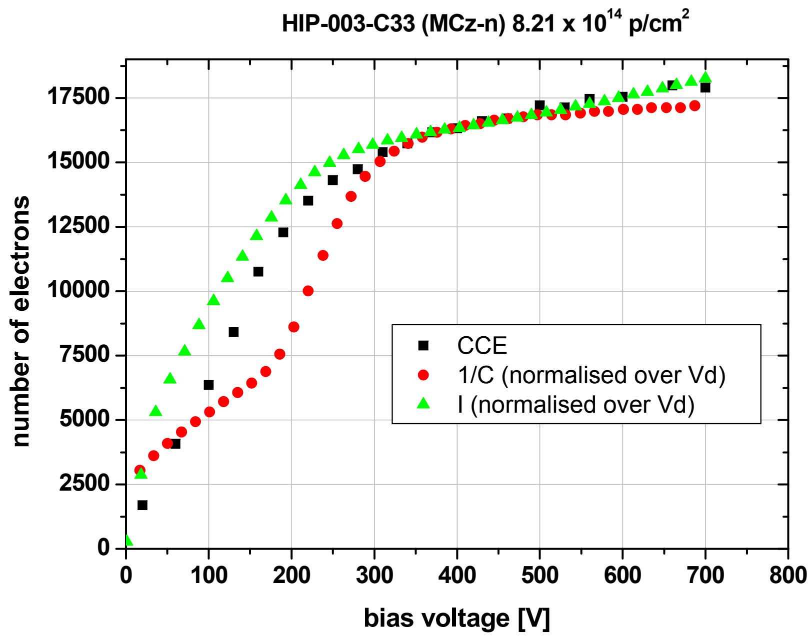
CV: $\beta = 4.9 \times 10^{-3}\ \mathrm{cm}^{-1}$

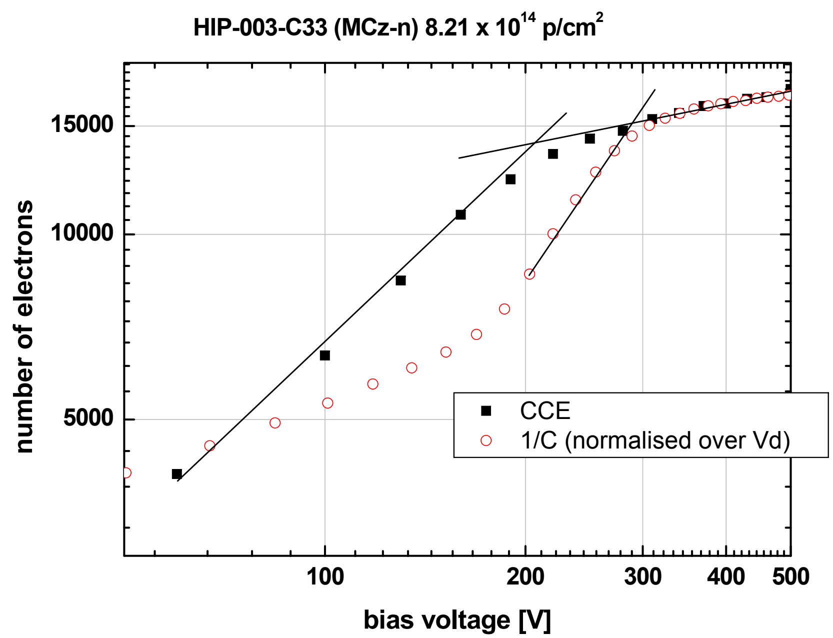
IV: $\beta = 3.6 \times 10^{-3}\ \mathrm{cm}^{-1}$

CCE: $\beta = 4.6 \times 10^{-3}\ \mathrm{cm}^{-1}$

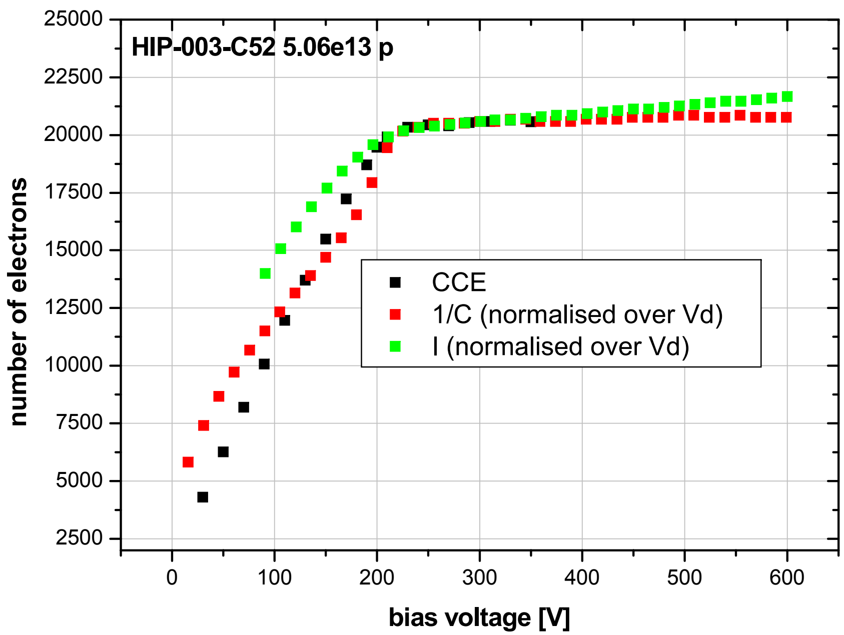
Difference in depletion voltage between CCE and CV => worse for higher fluences

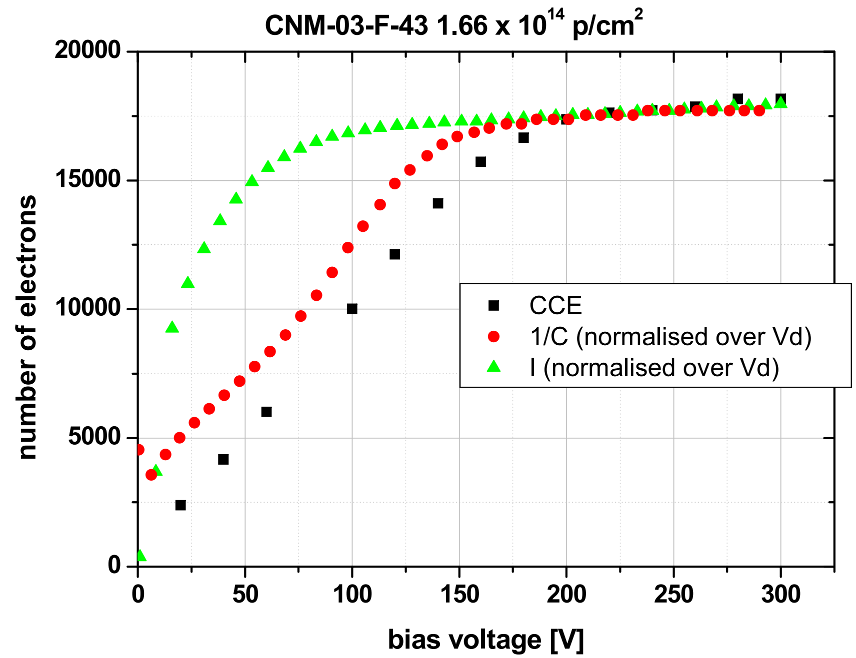
CCE CV IV curves





CV vs CCE other materials





better fit at lower fluence

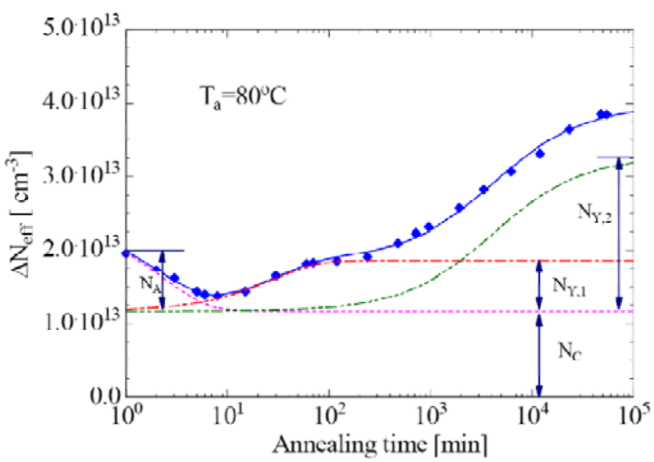
similar behaviour in Fz-n

…. and Epi material

Parameterization of Annealing Results

Change of effective "doping" concentration: $\Delta N_{eff} = N_{eff,0} - N_{eff}(\Phi,t(T))$

Standard parameterization: $\Delta N_{eff} = N_A(\Phi,t(T)) + N_C(\Phi) + N_Y(\Phi,t(T))$



- **Annealing components:**

  Short term annealing → $N_A(\Phi,t(T))$

  Stable damage → $N_C(\Phi)$

  Long term (reverse) annealing:
  Two components:

  → $N_{Y,1}(\Phi,t(T))$, first order process
  → $N_{Y,2}(\Phi,t(T))$,second order process

E. Fretwurst, Univ. Hamburg, RD50 workshop, Helsinki, June 2005

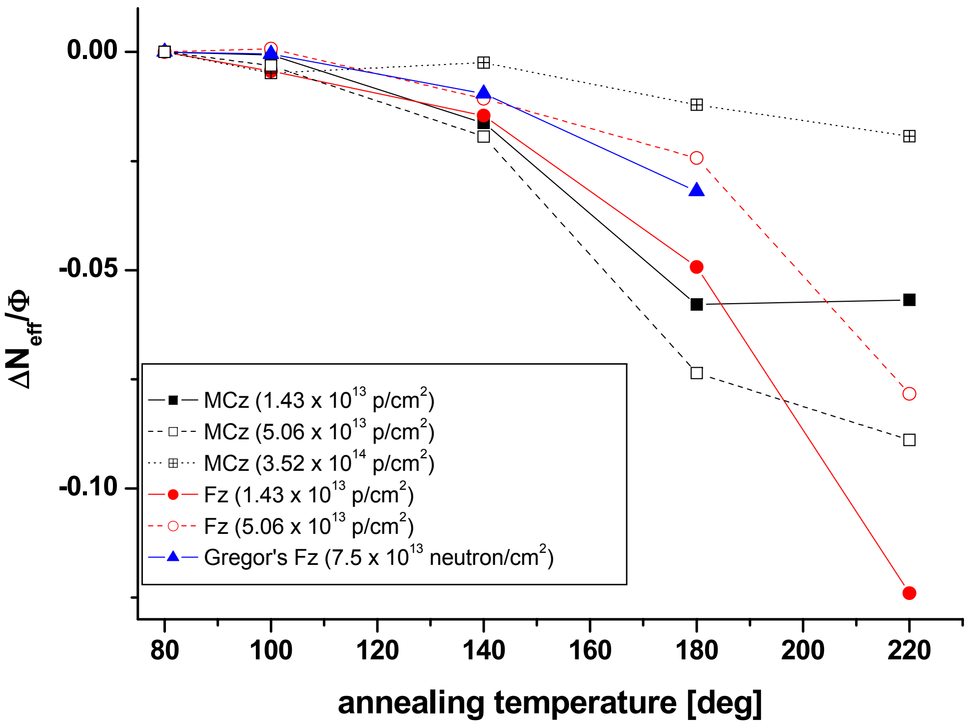
G. Lindstroem et. Al. NIMA 568 (2006) 66

G. Kramberger et. al. NIMA 515 (2003) 665

Common RD50 project

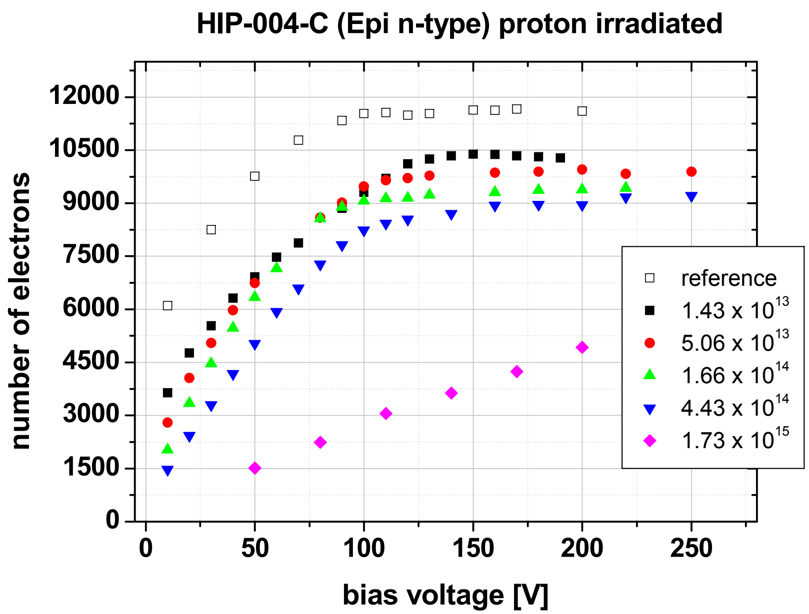
- **What?**
  - Investigation of type inversion problem in MCz
- **Who?**
  - Ljubljana
  - CERN
  - HIP
  - Bari
  - BNL
- **How?**
  - Irradiations with protons at CERN and reactor neutrons in Ljubljana
  - sets of MCz-n, MCz-p and Fz-n reference distributed
  - only CERN data is presented in this talk (project ongoing)

Comparison

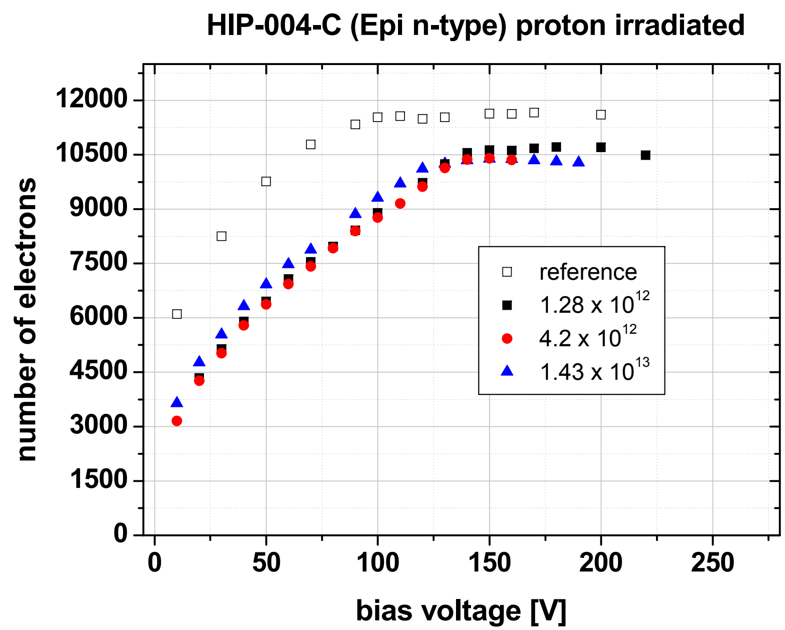


Comparison of change in N_{eff} with annealing temperature

Epi: n-type CCE after proton irrad.



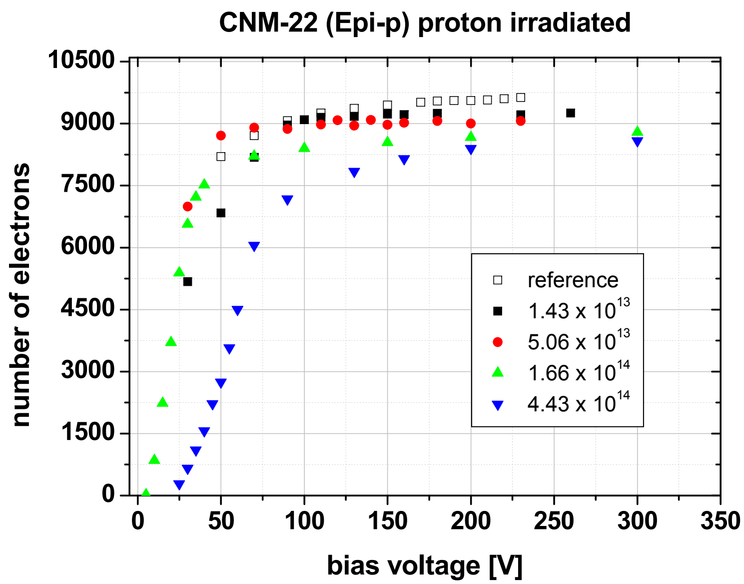
Up to highes fluence

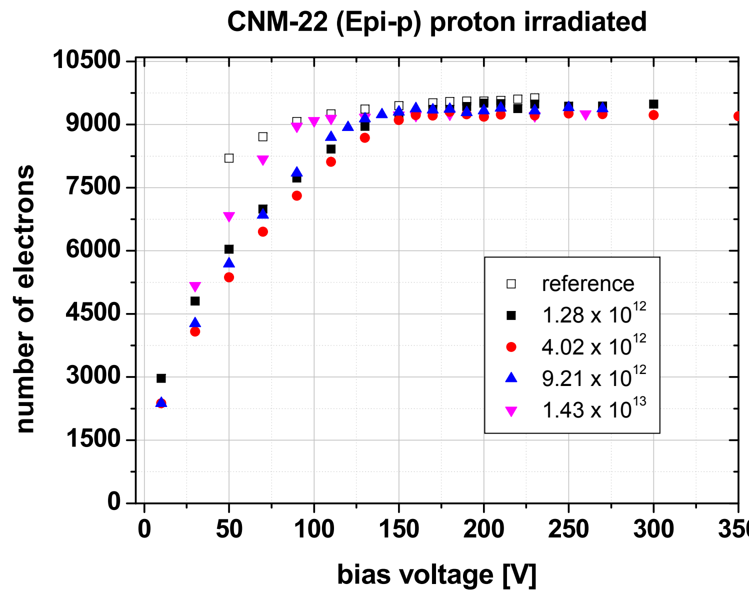


Low fluences only

=> significant drop in charge after low fluence in EPI n-type

Epi: p-type CCE after proton irrad.





Up to highes fluence

Low fluences only

=> no drop in charge after low fluence in EPI p-type