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An annealing study on 23 GeV proton irradiated n-type MCz pad detectors

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Outline:

- Material, Irradiation and Measurements
- Leakage Current, depletion voltage and trapping times
- Annealing experiments at different temperatures
- Preliminary conclusion (analysis ongoing)

Experimental procedure

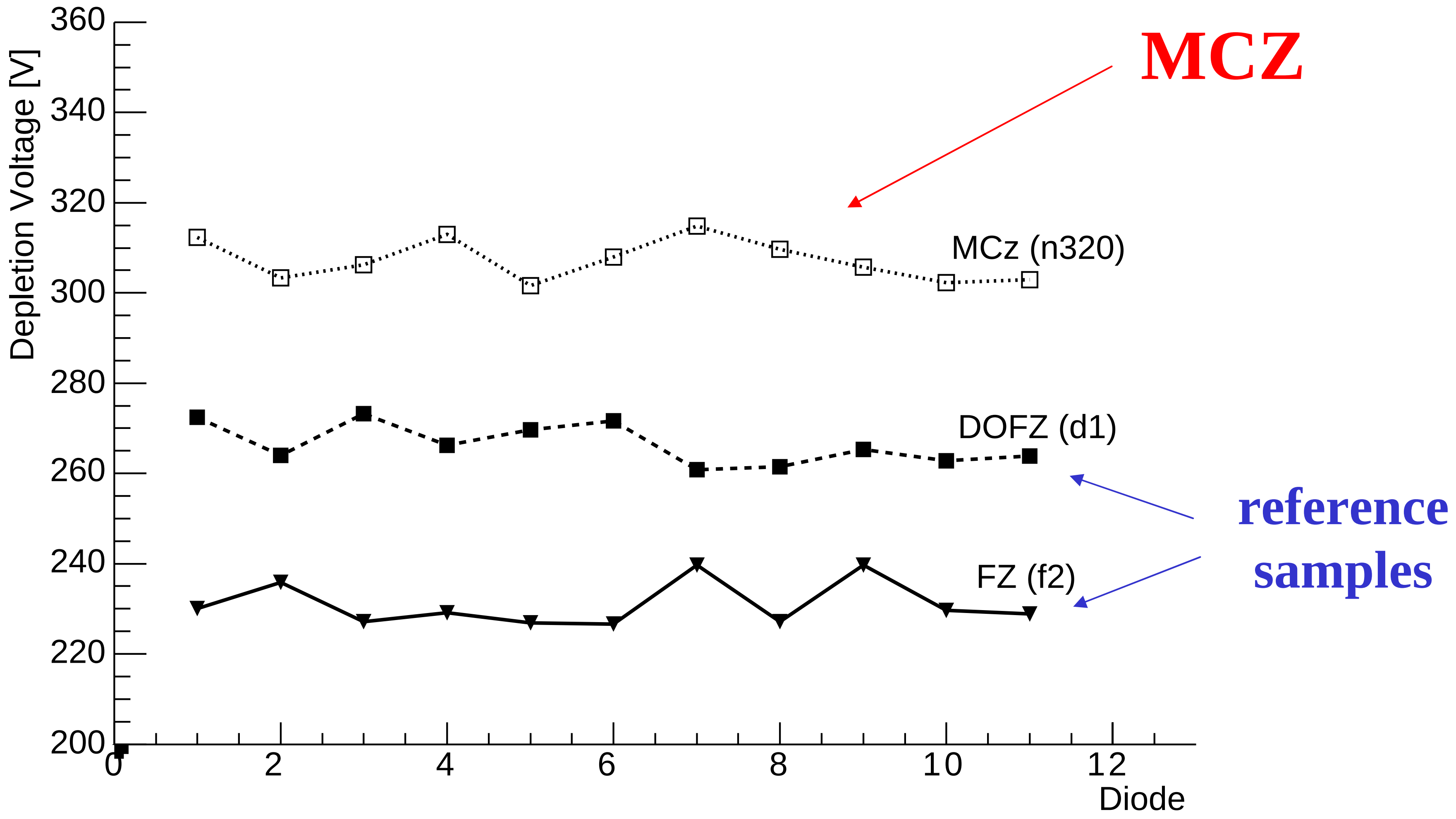
Samples and Irradiation

- **MCZ silicon produced by Okmetric Oyj**
  - 1 KΩcm, n-type, <100>, [O] = 4.9×10^{17} cm^{-3} (IR, B.Surma, ITME)
- **Pad detectors produced by Helsinki Institute of Physics**
  - d ~ 304 μm, A=0.25 cm^2, V_{fd} ~ 310 V
  - Many thanks to Jaakko Haerkoenen and the HIP group
- **Irradiation performed at CERN with 24 GeV/c protons**
  - Many thanks to Maurice Glaser and Federico Ravotti

Measurements

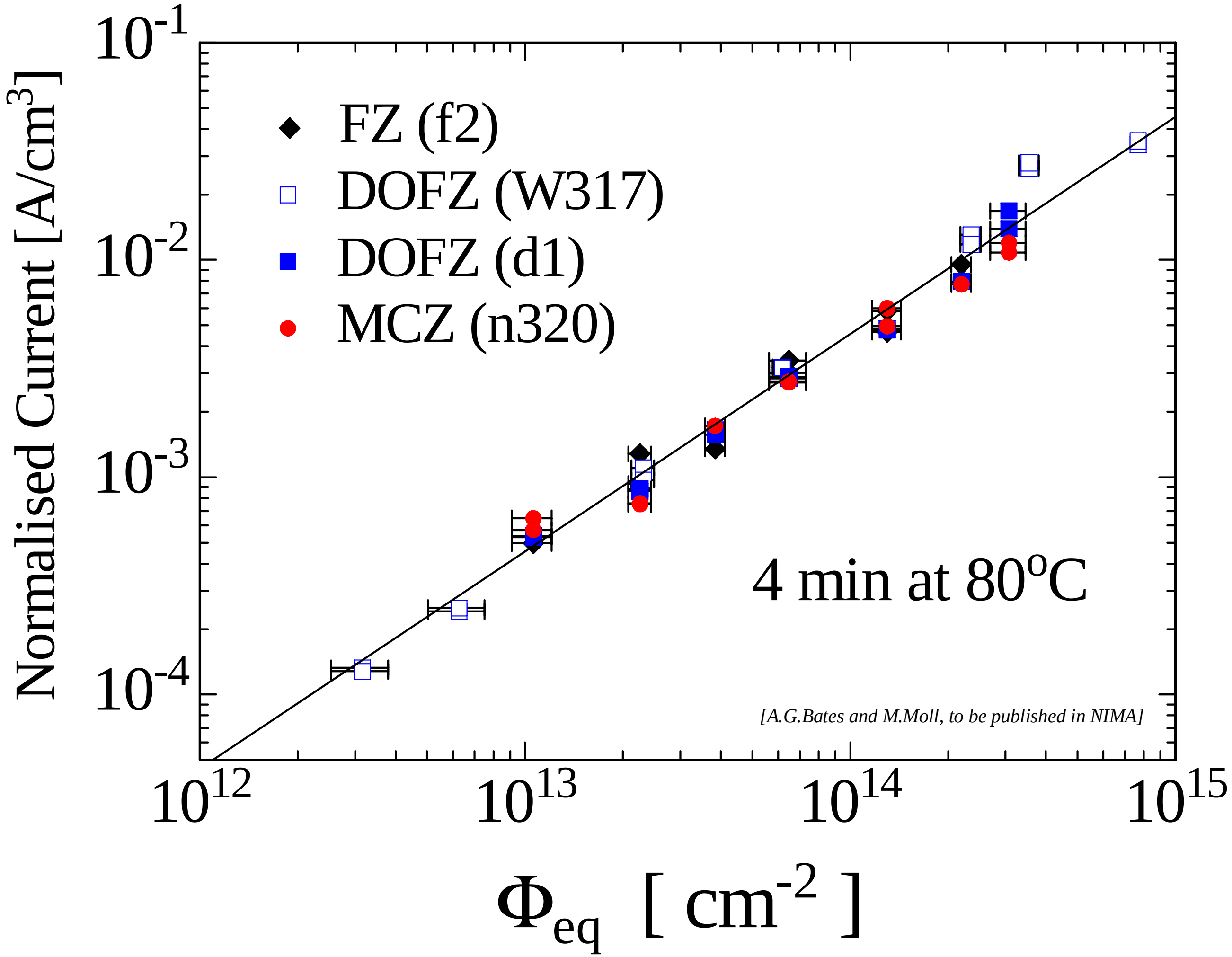
- **TCT, CV and IV after 4 min 80°C annealing**
- **CV and IV during annealing studies at different temperatures**

Before irradiation



- Same depletion voltage for all samples before irradiation (309±5 V)

MCZ – Leakage current



- **Leakage Current : As for DOFZ, FZ (and EPI)**

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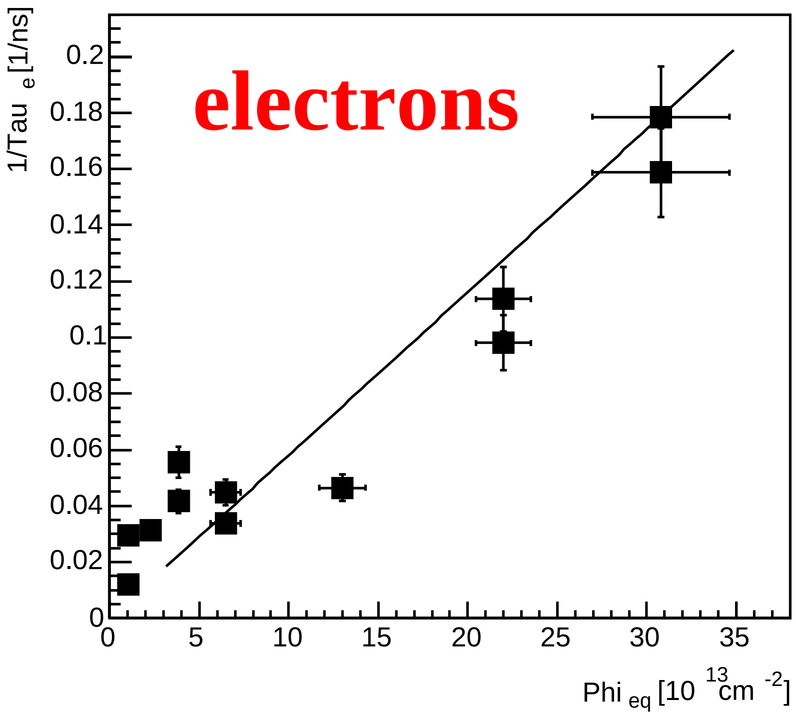
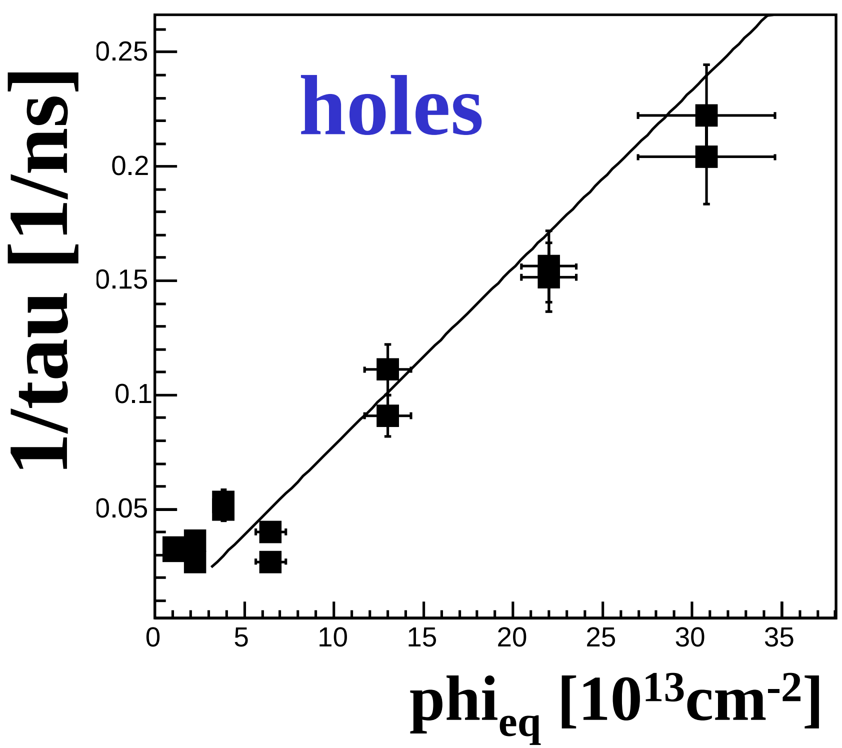
MCZ - Inverse trapping time





- **Measured after 4 min at 80°C**
- **Details were given on the 5th RD50 Workshop in Florence by A. G. Bates**

$$\frac{1}{\tau_{eff_{e,h}}} = \beta_{e,h}\Phi_{eq}$$

MCZ – Trapping

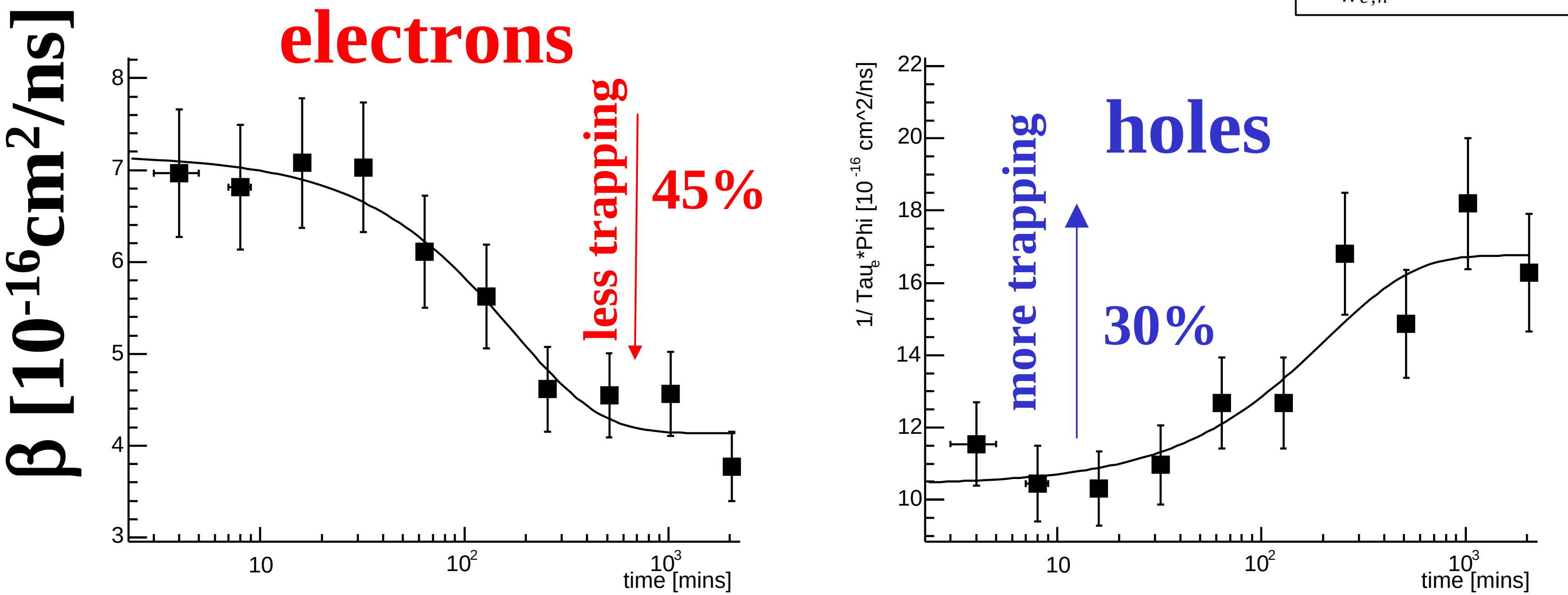
Trapping parameter β at 5°C	β_e [10^{-16} cm^2/ns]	β_h [10^{-16} cm^2/ns]
FZ (f2)	5.59 ± 0.29	7.16 ± 0.32
DOFZ (d1)	5.73 ± 0.29	6.88 ± 0.34
MCz (n320)	5.81 ± 0.32	7.78 ± 0.39
DOFZ (W317)	5.48 ± 0.22	6.02 ± 0.29
Dortmund [2] DOFZ	5.08 ± 0.16	4.90 ± 0.16
Ljubljana [3] DOFZ and FZ	5.34 ± 0.19	7.08 ± 0.18
Lancaster/Hamburg [4] FZ	5.32 ± 0.30	6.81 ± 0.29
Hamburg [5] FZ, DOFZ and MCz	5.07 ± 0.16	6.20 ± 0.54

- Trapping parameter β after 23 GeV proton irradiation normalized to 5 °C

RD50 Annealing of Trapping parameters

- **Annealing of β at 80°C**

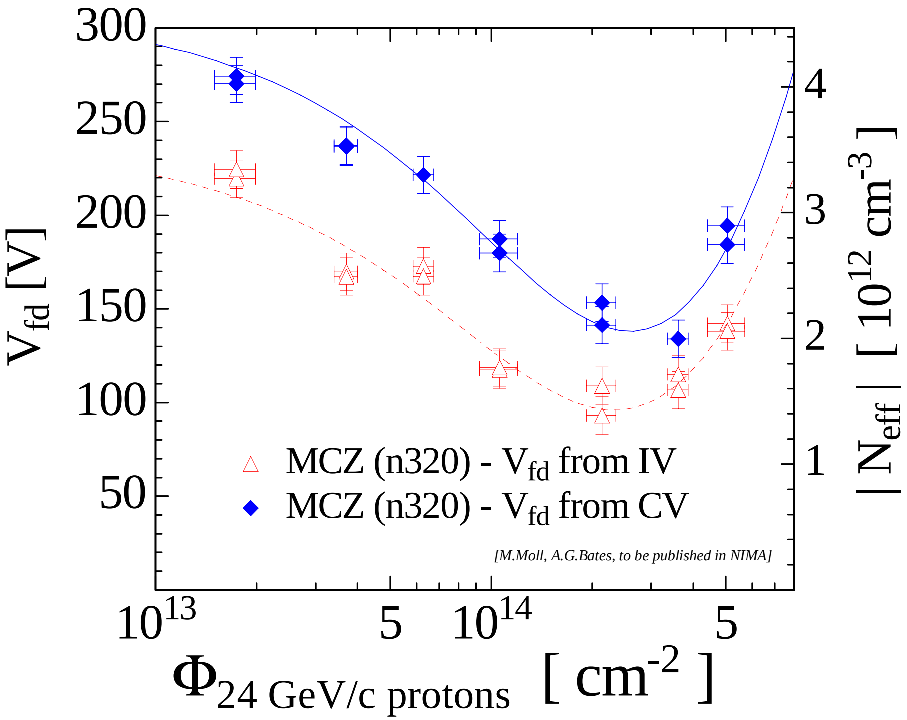
$$\frac{1}{\tau_{eff_{e,h}}} = \beta_{e,h}\Phi_{eq}$$

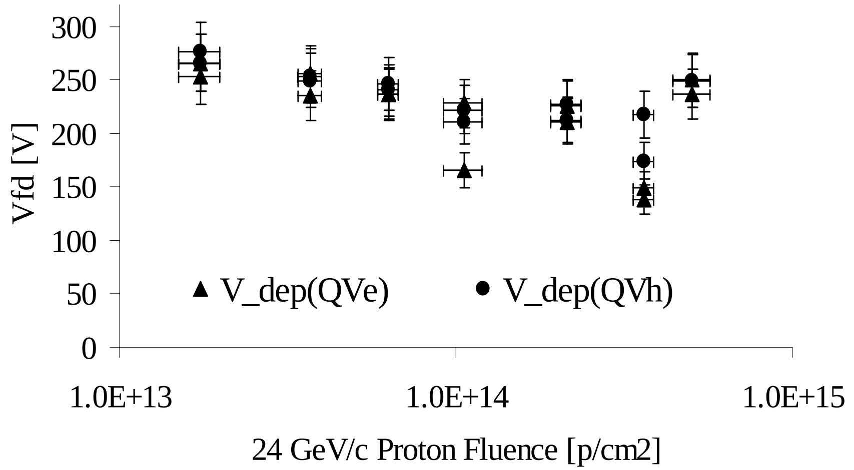


- **Same behavior as previously observed for FZ silicon**

RD50 **Depletion Voltage (4 min 80°C)**

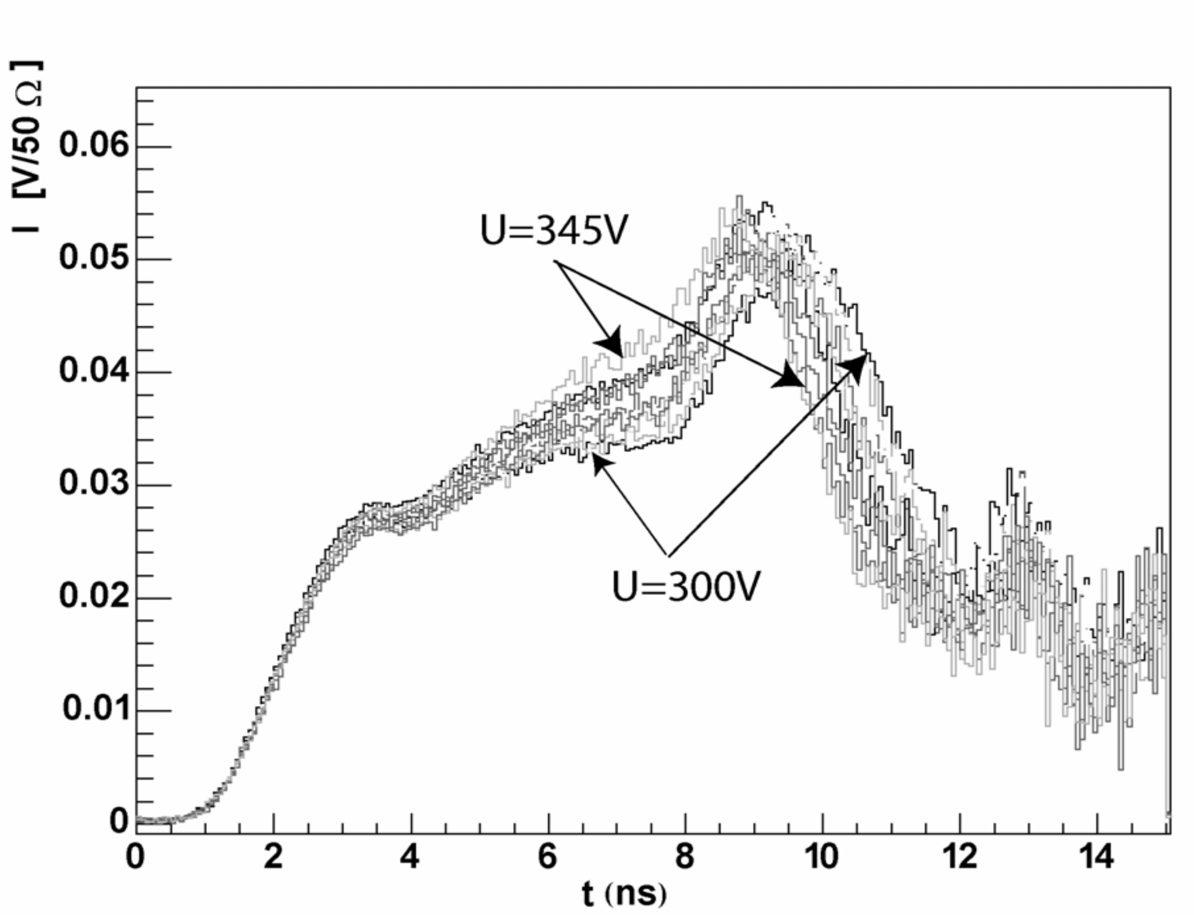
- **Deletion voltage extracted from CV, IV and TCT measurements**





- **Question: Is the material type inverted ?**

RD50 TCT measurement – Hole injection



The induced current signal resulting from hole injection into a MCz silicon detector. The detector had been irradiated to 5.1x10^{14} p/cm^2 and the Vfd found through electron injection-QV method was 237V.

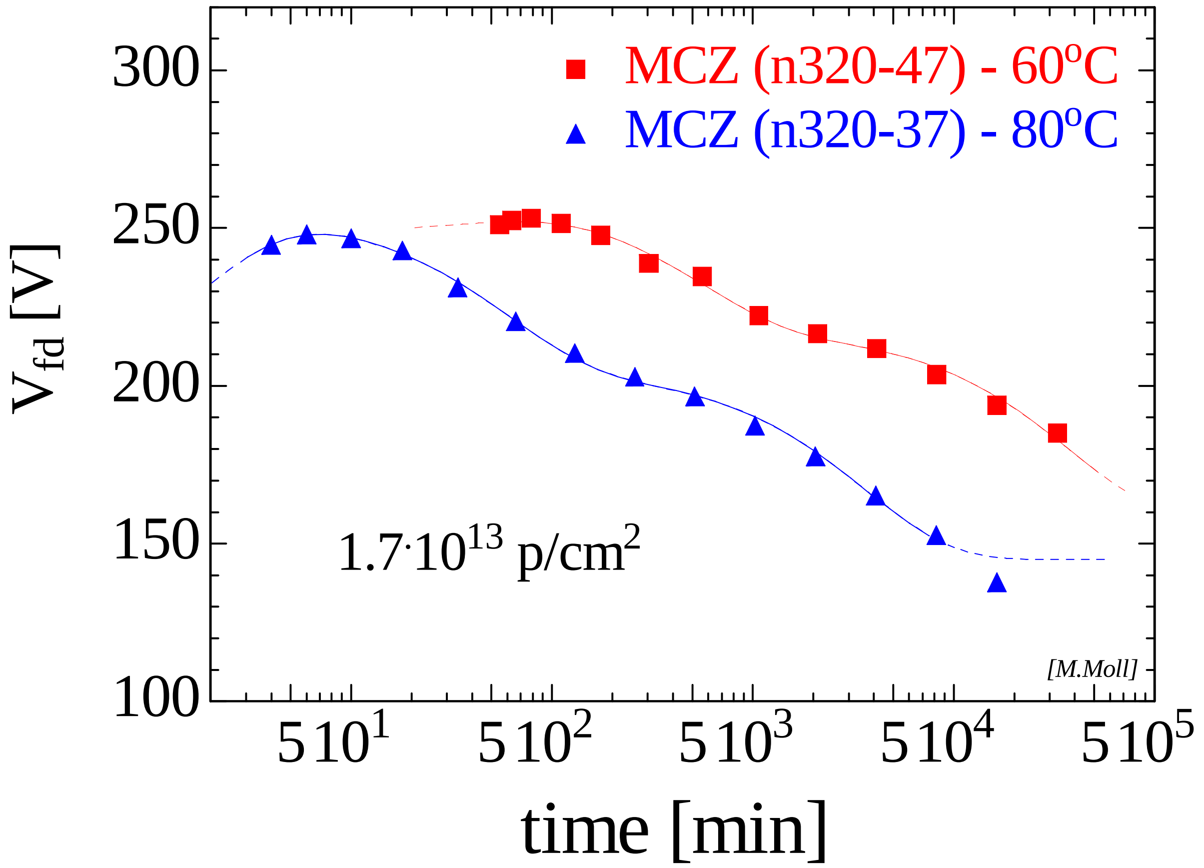
(660nm laser, backside illuminated)

- **Detector is not "type inverted" after 5.1x10^{14} p/cm^2**

A summer student project

- **Annealing at various temperatures (50 – 100°C)**
- **Measurement of full depletion voltage via CV measurements**
- **Aim:**
  - **See if material has undergone “type inversion”**
  - **Determine activation energy for the reverse annealing**

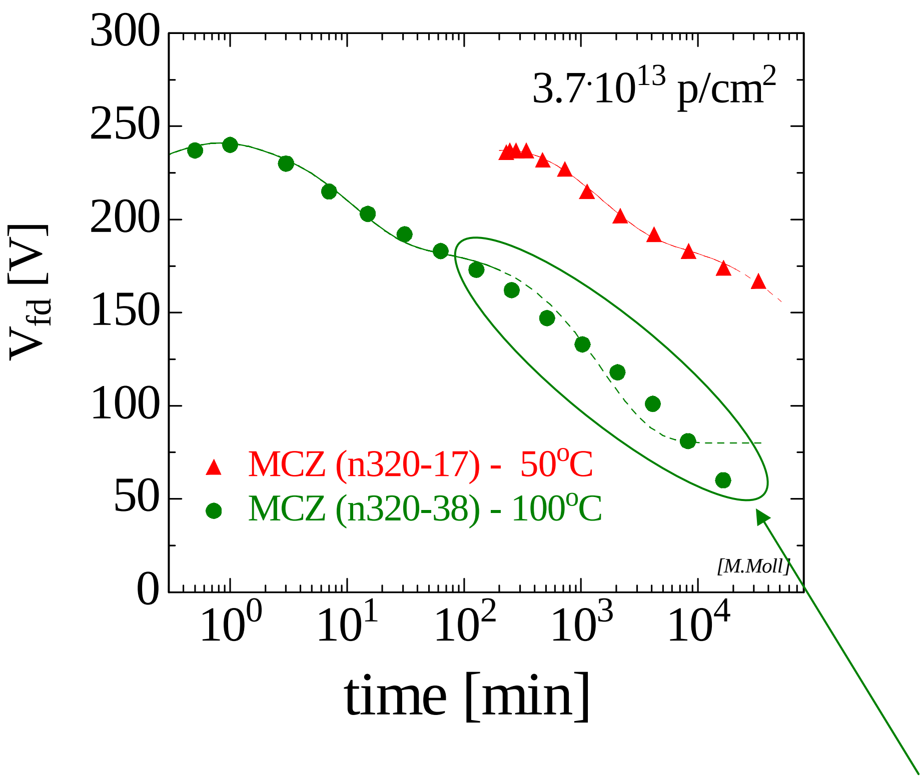
Long Term Annealing - V_{fd}

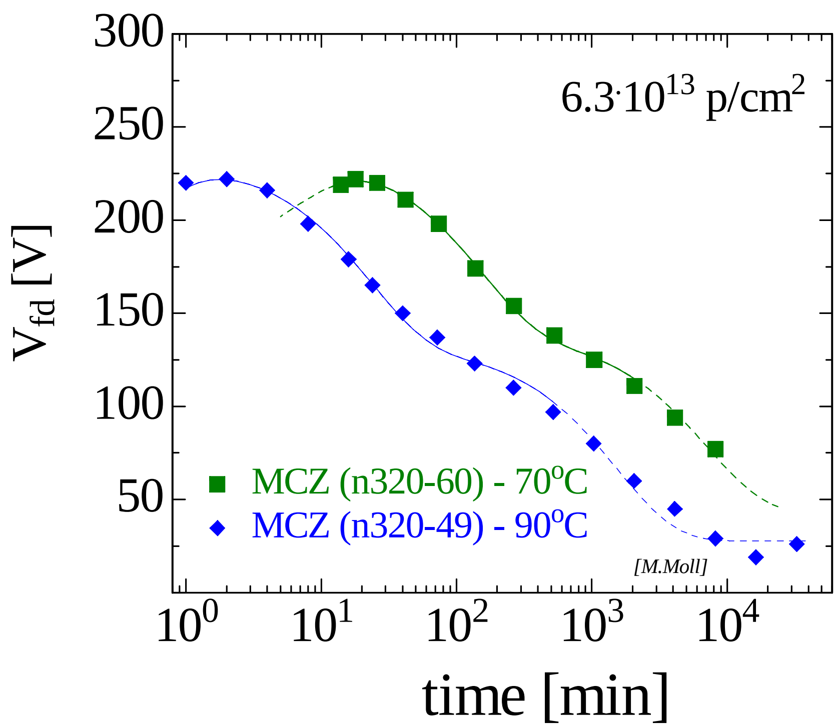


- **Two long term annealing steps observed in MCZ silicon**
- **Second step: Adds negative space charge as “reverse annealing”**

Long Term Annealing - V_{fd}

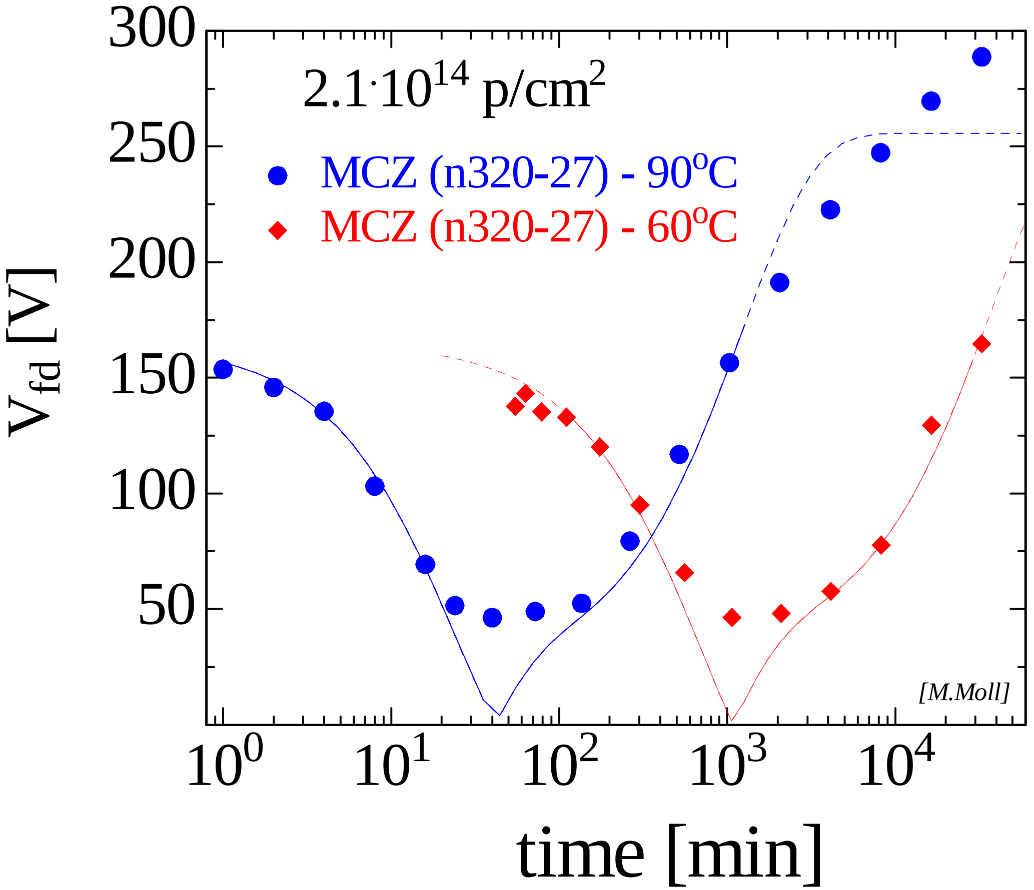
- **Measurement for different fluences and temperatures**





- **Second component: Can not be fitted with exponential function.**
- **No saturation observed (heated up to 10 days at 100°C)**

Long Term Annealing - V_{fd}



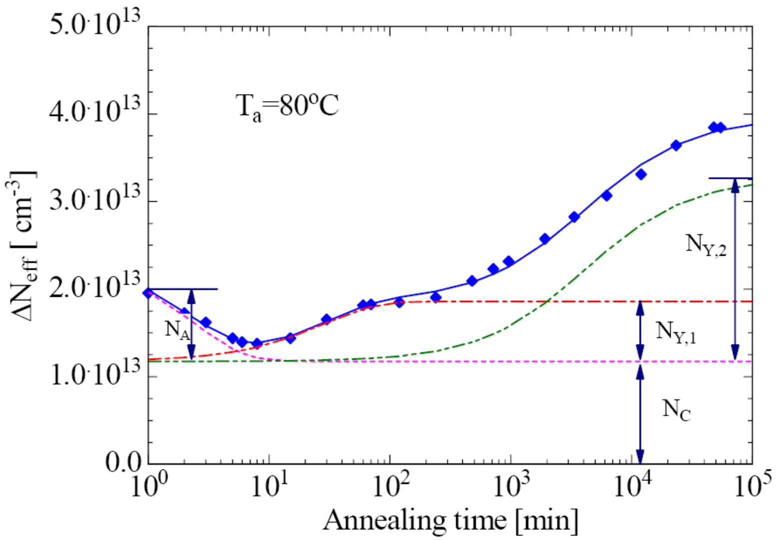
- **Type inversion during annealing**
- **Fit to the data impossible**

…. seen before in EPI Silicon

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 → $N_C(\Phi)$

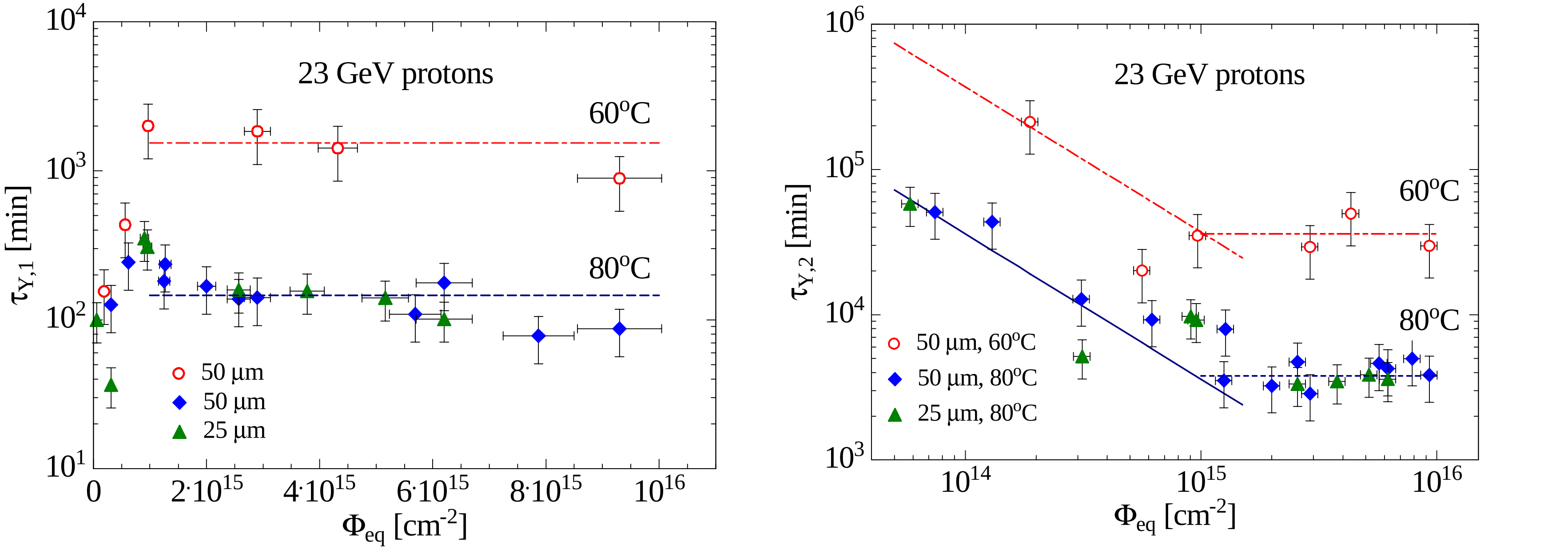
  Long term (reverse) annealing:
  Two components:

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

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

Epitaxial silicon

- E.Fretwurst (RD50 Workshop in Helsinki, June 2005)



- Time constants for the two components
  - First component: time constant independent of fluence
  - Second component: time constant depending on fluence

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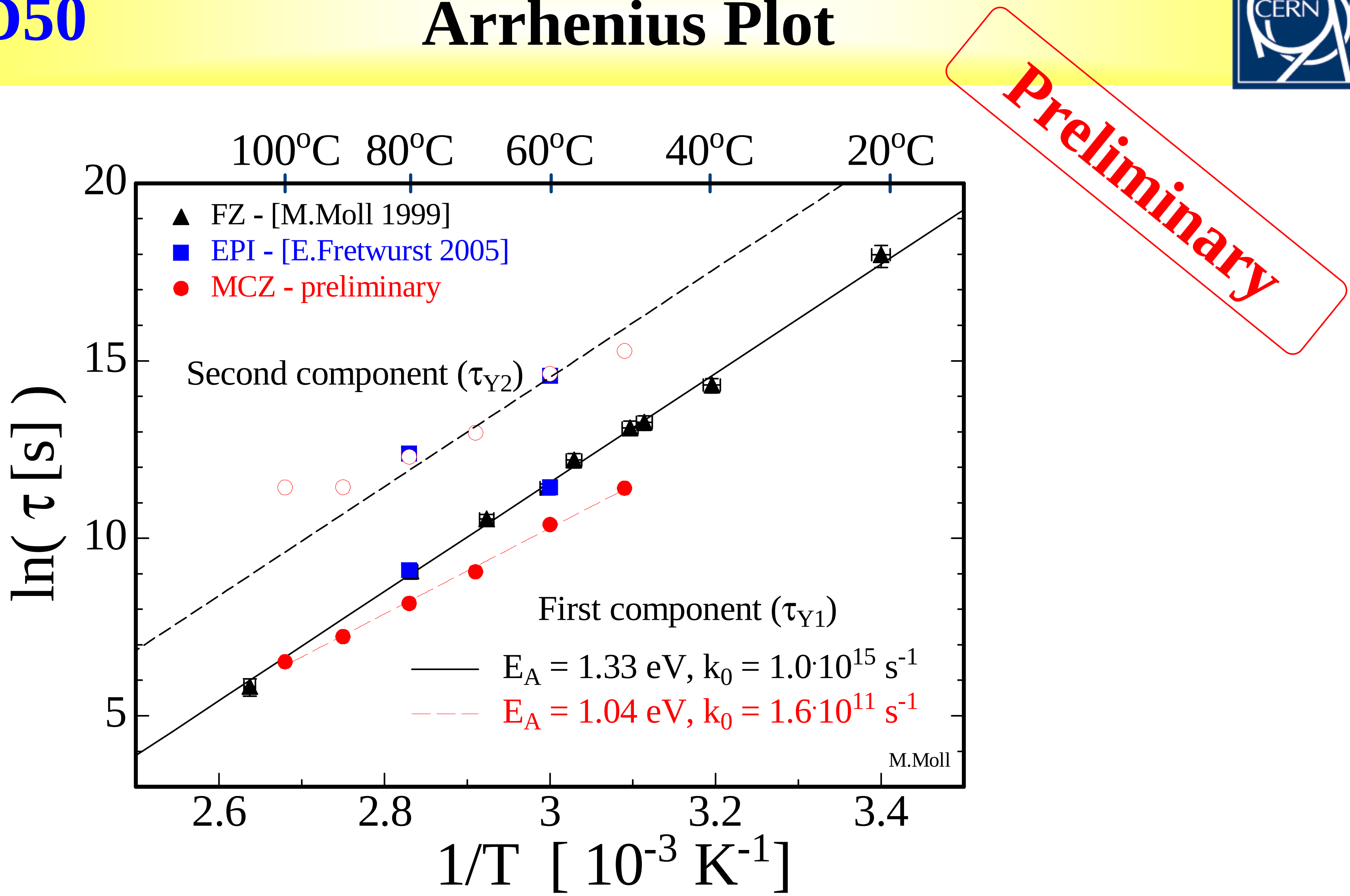
Arrhenius Plot



- **Reverse annealing (1st component) faster for MCZ than for FZ/EPI ?**

Conclusion

24 GeV/c proton irradiated n-type MCZ detectors have been investigated:

- Same leakage current increase as other silicon materials
- Same electron/hole trapping as for other silicon materials (including an annealing study at 80°C)
- Detector has not undergone "type inversion" up to 5×10^{14} p/cm^2
  ➔ Reverse annealing is a beneficial effect (V_{fd} becoming less with time)
- Reverse annealing shows two annealing stages (like previously observed in EPI silicon)
- Unlike in EPI silicon no saturation of the 2nd stage observed (heated up to 10 days at 100°C)
- Preliminary results indicate that the first stage of the reverse annealing ("standard reverse annealing") occurs faster than in standard FZ silicon