Status Report on New EPI-Devices

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- **Material parameter and process technology**
- **Preliminary results for 26 MeV proton and neutron irradiated devices**
- **Outlook**

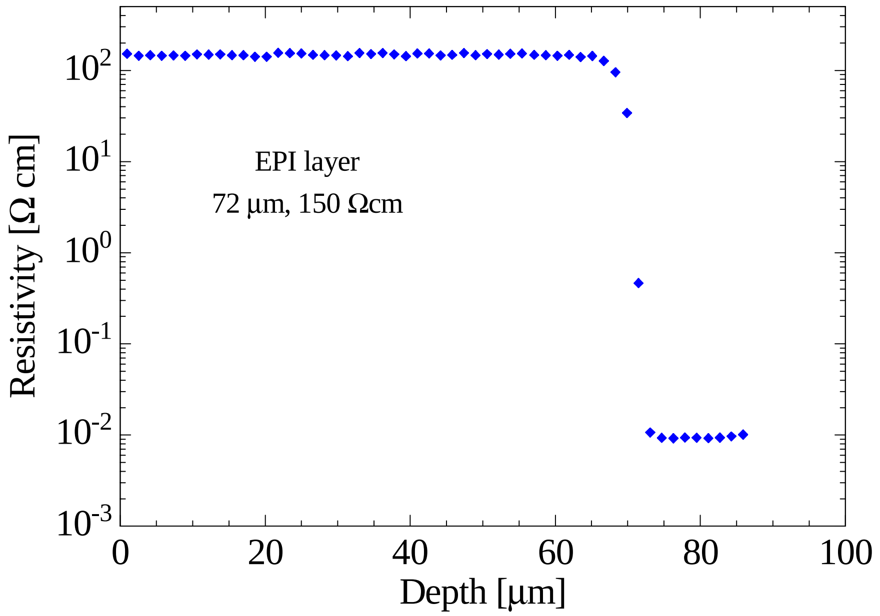
Material Parameter

- **EPI Material:**

  Type: n-type, P doped
  Resistivity: 150 Ωcm
  Layer thickness: 72 µm
  Cz-Substrate:
  Type: n-type, Sb doped, <111>
  Resistivity: 0.01 Ωcm

- **MCz Material:**

  Type: n-type, P doped, <100>
  Resistivity: > 600 Ωcm nominal
  Thickness: 280 µm



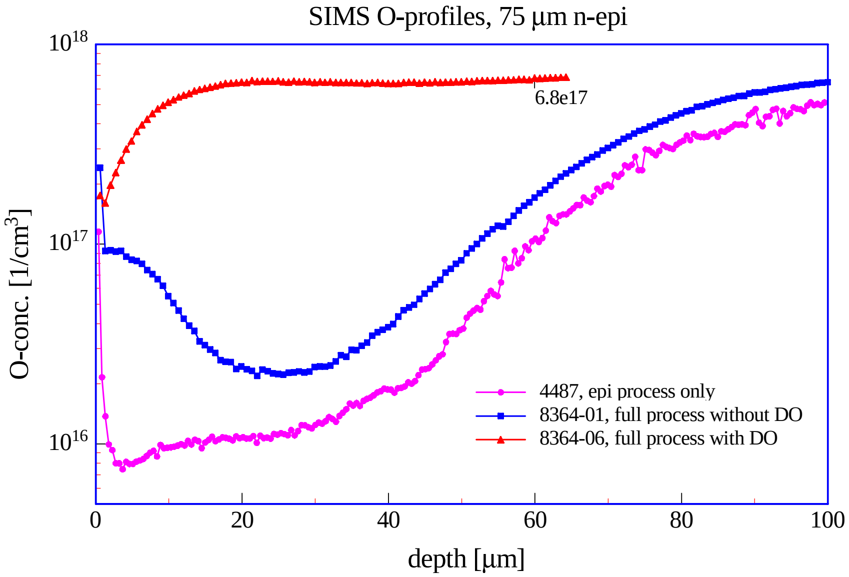
- **EPI-layer resistivity profile:**

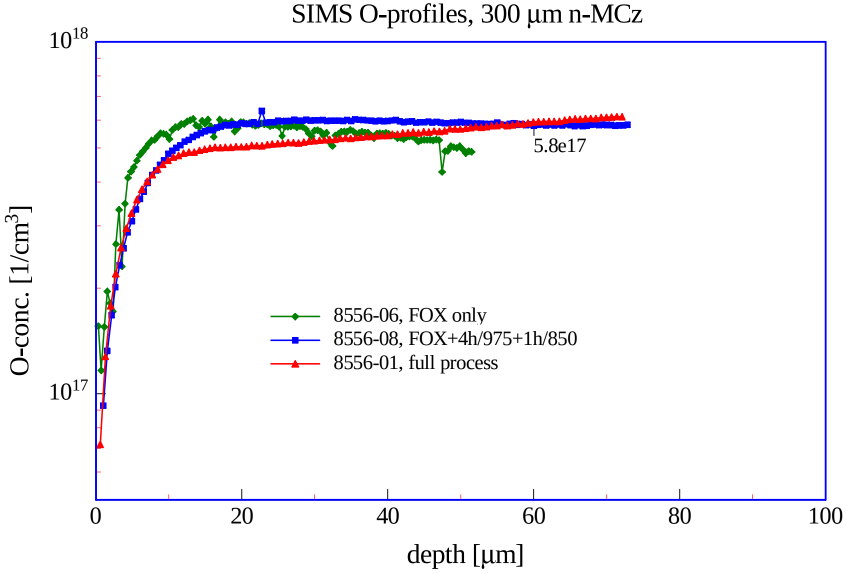
  SR ρ before diode process
  Excellent homogeneity in epi-layer

$$\rho = (148 \pm 4)\ \Omega\text{cm}$$

Oxygen Depth Profiles

after different process steps





- **EPI Material:**

  Magenta: after as grown epi-layer

  Blue: after full standard process

  Red: after „Diffusion Oxygenation“ (DO) and full device process

  O out diffusion on the epi front side after DO and full process

- **MCz Material:**

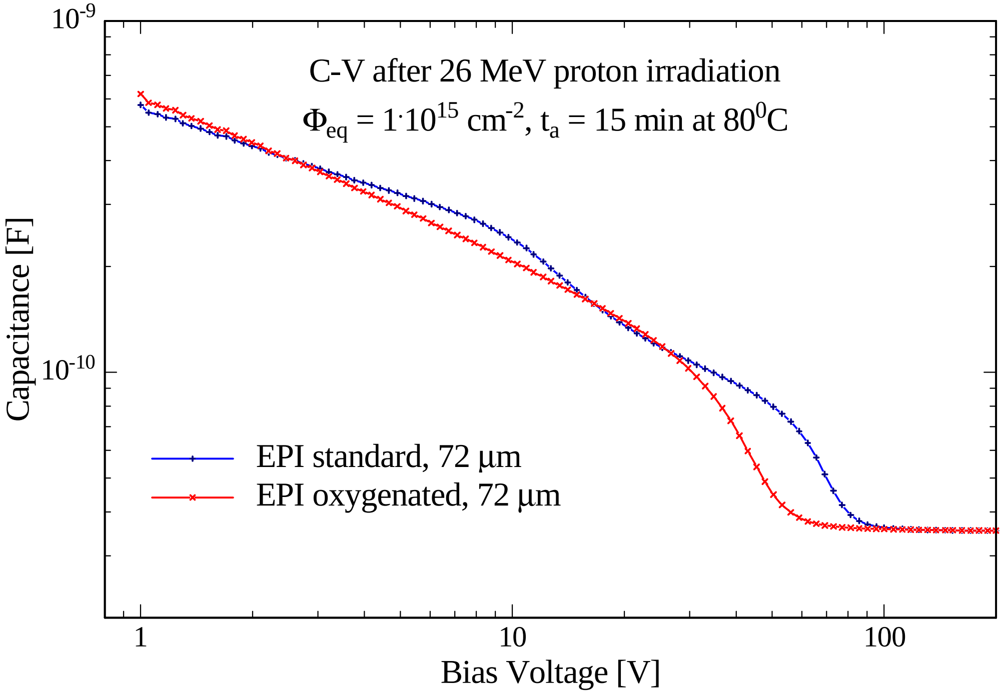
  Green: after oxidation (FOX)

  Blue: after FOX+4h 973°C+1h 850°C

  Red: after full standard process

  O out-diffusion on the front side after any step

Typical EPI C-V after 26 MeV Proton Irradiaton



- **Differences in C-V shape**

DO:

2 regions in log-log presentation before full depletion

Low bias → low slope (high N_{eff})

High bias → large slope (low N_{eff})

C-V shape independent on annealing

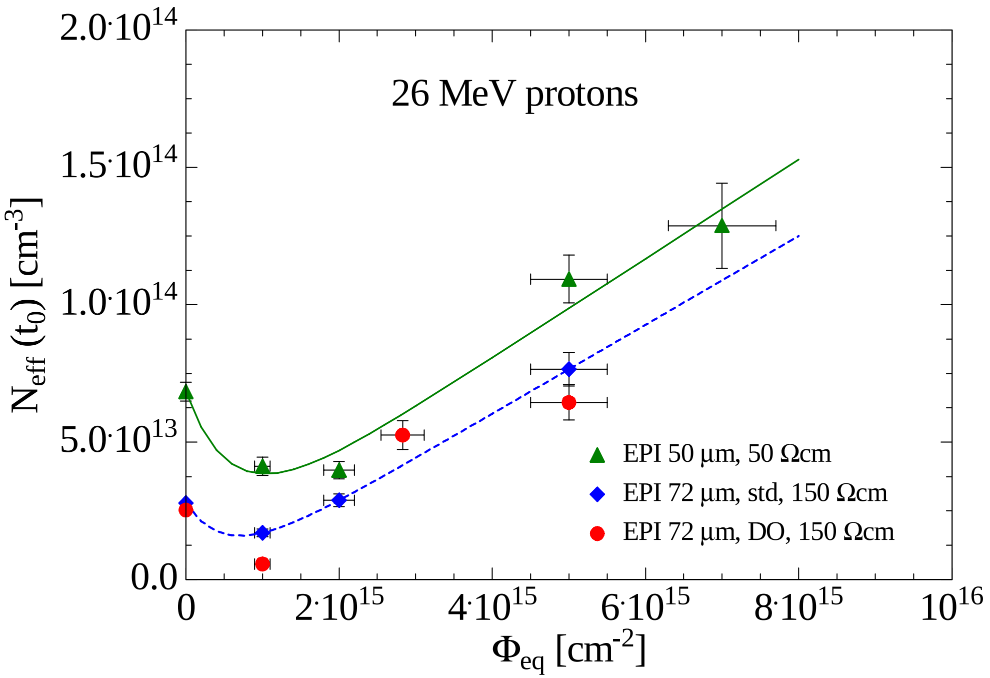
Standard:

4 regions in log-log presentation

2 shoulders appear
→ inhomogeneous space charge, possibly correlated with [O] profile

Specific C-V shape depends on fluence and annealing status

EPI - 26 MeV Protons - N_{eff}



N_{eff} development versus fluence

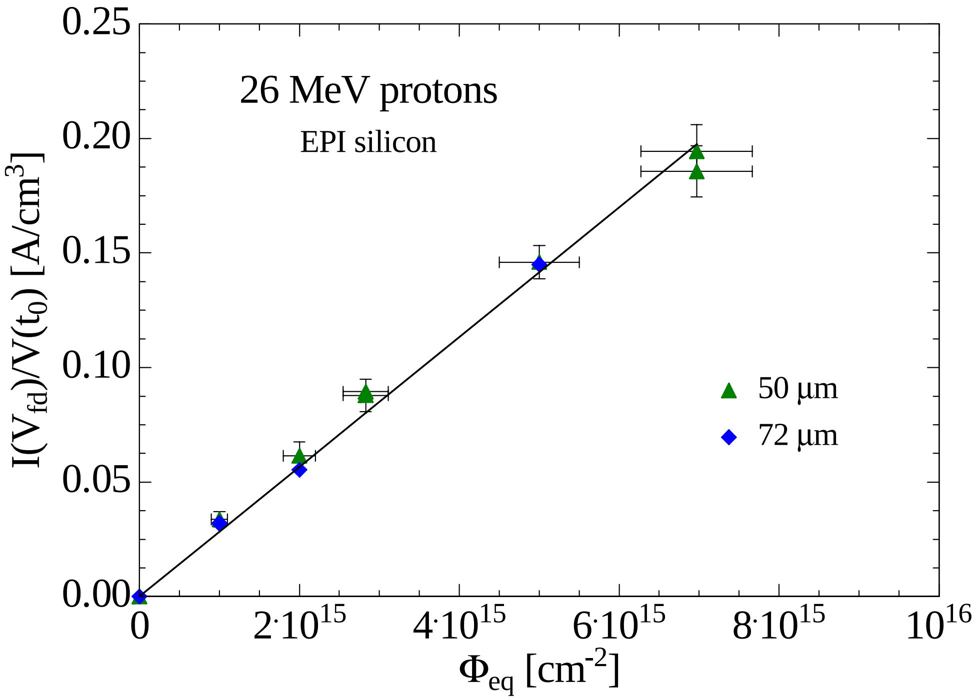
No obvious difference between 72 µm EPI-standard and –DO

Tendency quite similar to 50 µm EPI, only shifted due to different doping concentration resp. resistivity
72 µm, 150 Ωcm
50 µm, 50 Ωcm

Slope for high fluence regime

g_{eff} = 0.015 cm^{-1} for 72 µm
g_{eff} = 0.018 cm^{-1} for 50 µm

EPI - 26 MeV Protons - I/V



- **Generation current**

No difference between 50 µm and

72 µm EPI-diodes

but

damage parameter α at t_0

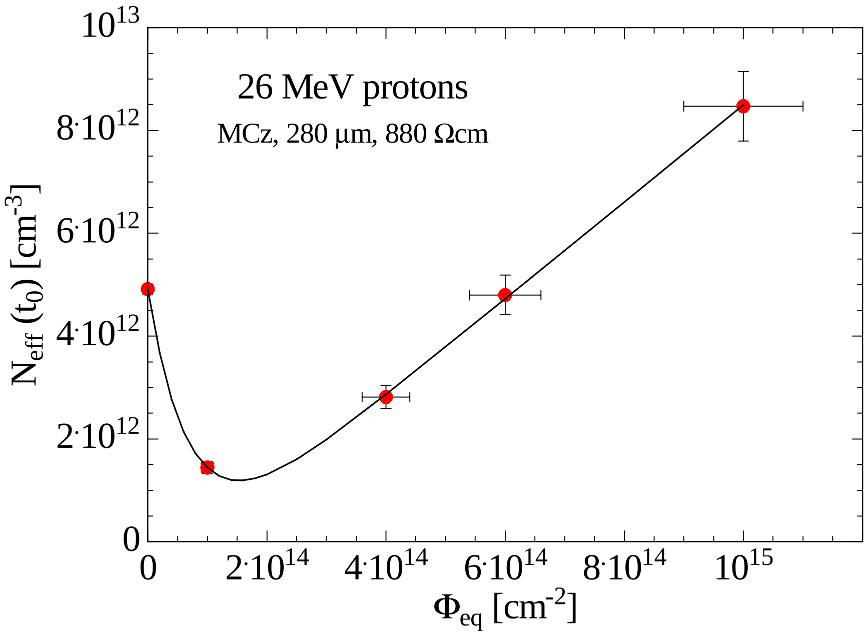
(after irradiation, no annealing)

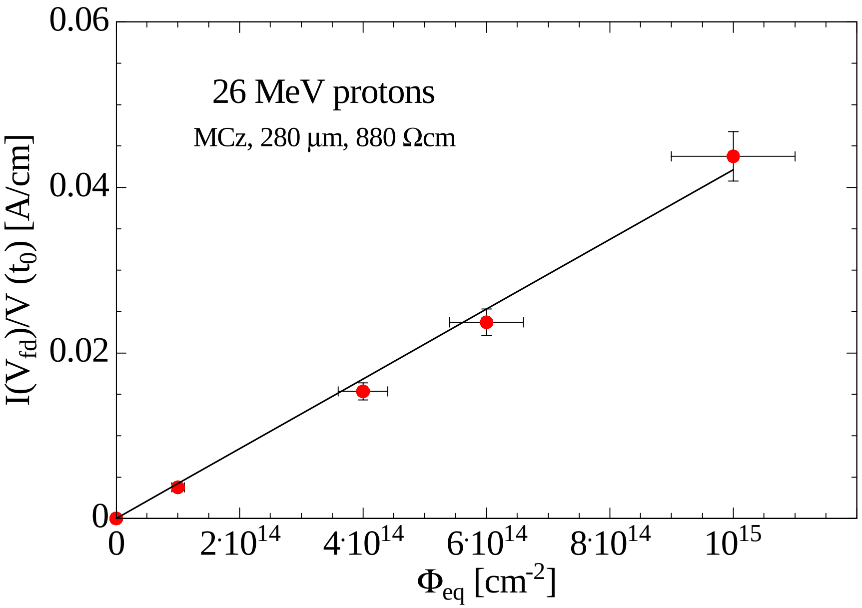
$$\alpha(t_0) = (3.0 \pm 0.2) \cdot 10^{-17}\ \text{A/cm}$$

smaller compared to expected value

$$\alpha(t_0) > 4\text{-}5 \cdot 10^{-17}\ \text{A/cm}$$

MCz - N_{eff} and I/V for 26 MeV Protons





- **N_{eff} development:**

  Typical fluence dependcence,

  Minimum between 1-2•10^{14} cm^{-2}

  Linear increase above 4•10^{14} cm^{-2}

  → $g_{eff} = 9.4 \cdot 10^{-3}$ cm^{-1}

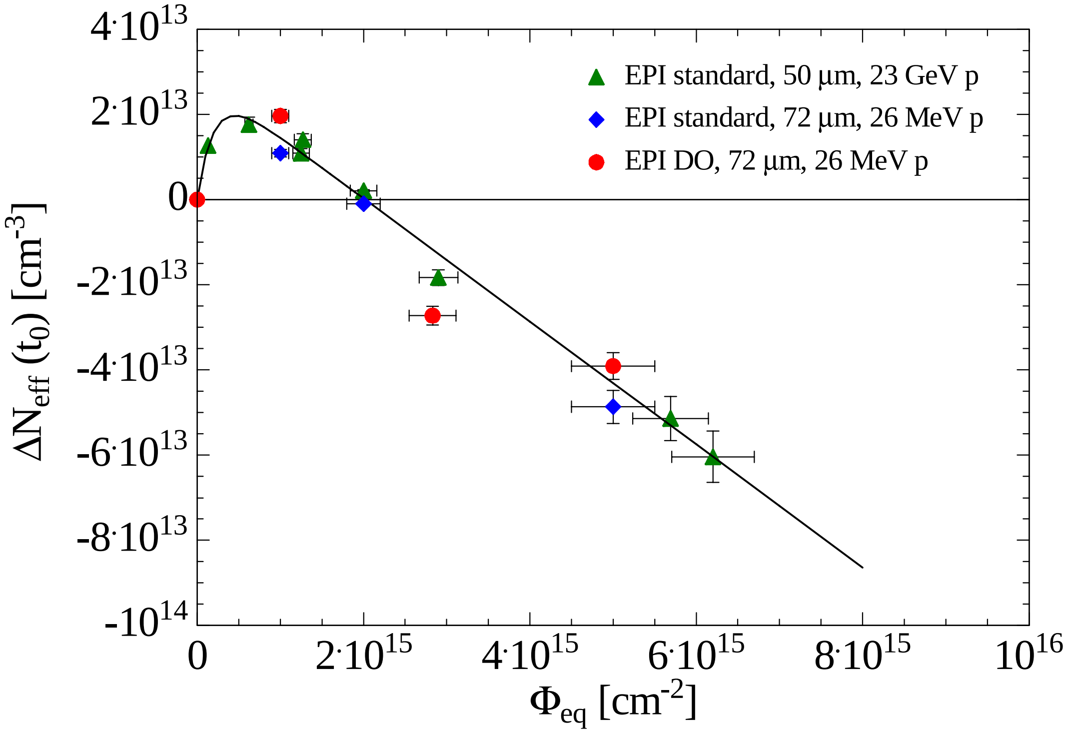
- **Generation current increase:**

  Damage coefficient for t = 0 min

  → $\alpha = (4.2 \pm 0.3) \cdot 10^{-17}$ A/cm

  Larger compared to EPI devices

EPI – Comparison 26 MeV with 23 GeV Protons



- **Change of N_{eff} :**

  $\Delta N_{eff} = N_{eff,0} - N_{eff}(\Phi)$

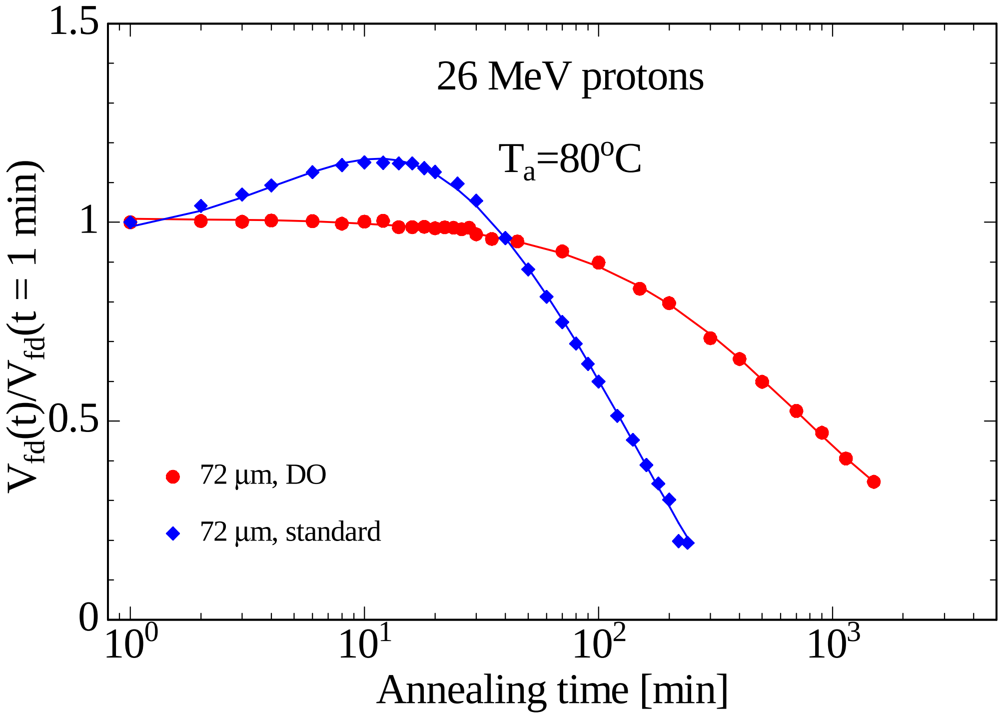
  Preliminary result:

  Similar fluence dependence of ΔN_{eff} for

  50 µm, 50 Ωcm, 23 GeV
  and
  72 µm, 150 Ωcm, 26 MeV

  presuming space charge stays positive

EPI – Annealing at 80 °C



- **Difference between standard and DO EPI**

- **DO EPI:**
  No short term annealing

  Long term annealing strongly delayed

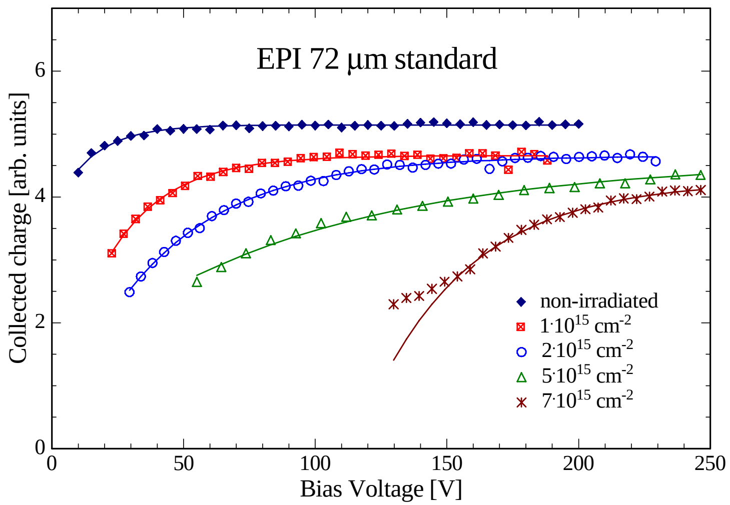
  τ_y = 700 min

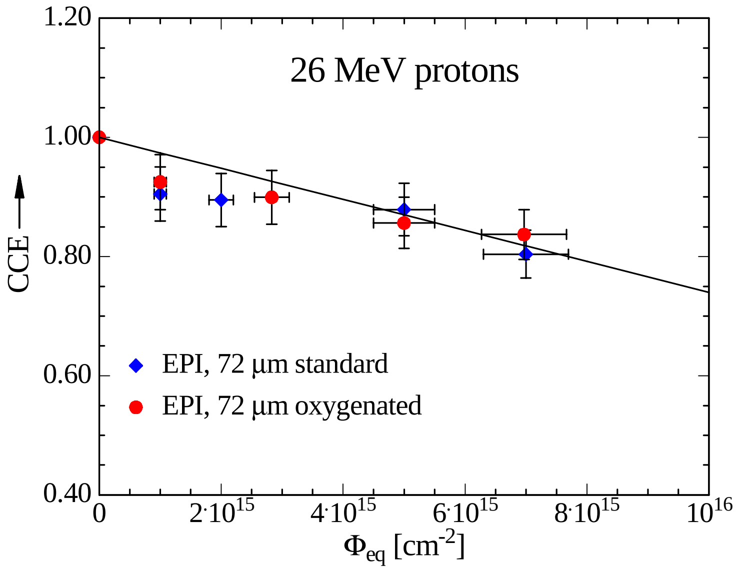
- **Standard EPI:**
  Short term annealing:
  → increase of V_{fd}
  → no type inversion at this dose ($\Phi_{eq} = 2 \cdot 10^{15}\ cm^{-2}$)

  Long term annealing:

  τ_y = 140 min

EPI - Charge Collection Efficieny





Charge collection efficiency

^{244}Cm α-source, $E_\alpha = 5.8$ MeV

Collected charge measured by TCT voltage scan
Integration time window 10 ns

Collected charge taken at about 2 x full depletion voltage from C-V or 250 V

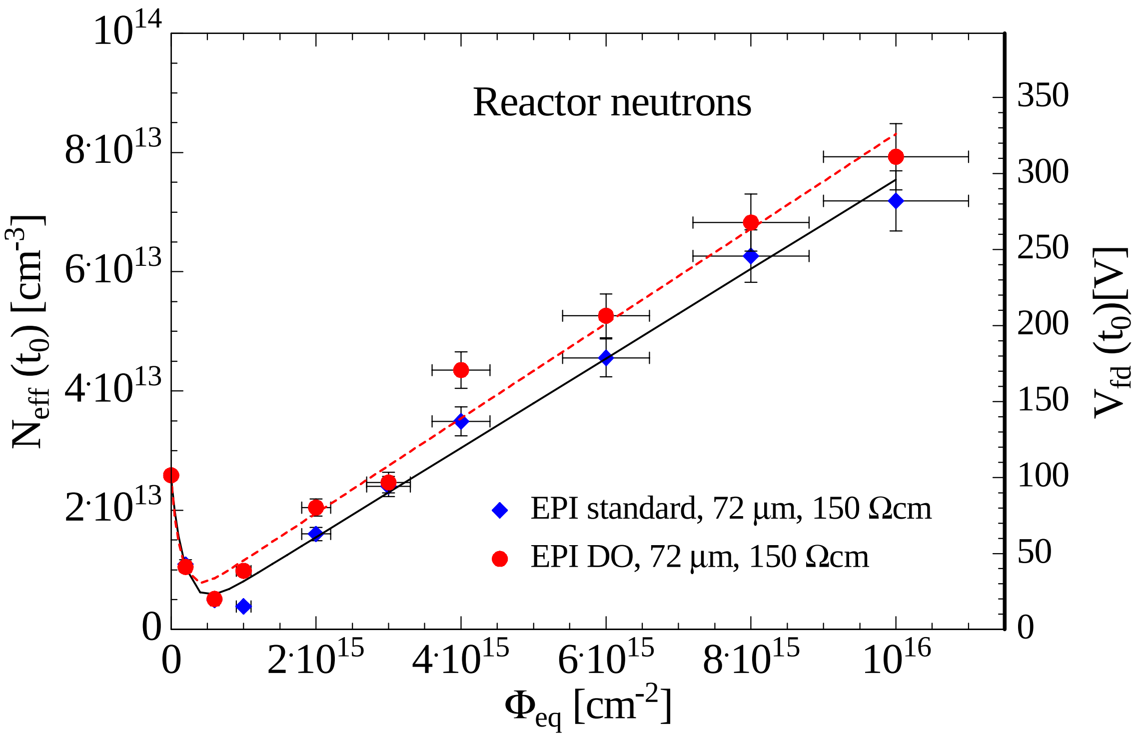
Rough estimate of damage parameter β_α from linear fit

$$\beta_\alpha \approx 2.6\cdot10^{-17}\ \text{cm}^2$$

Comparable with data from 50 µm EPI at 23 GeV

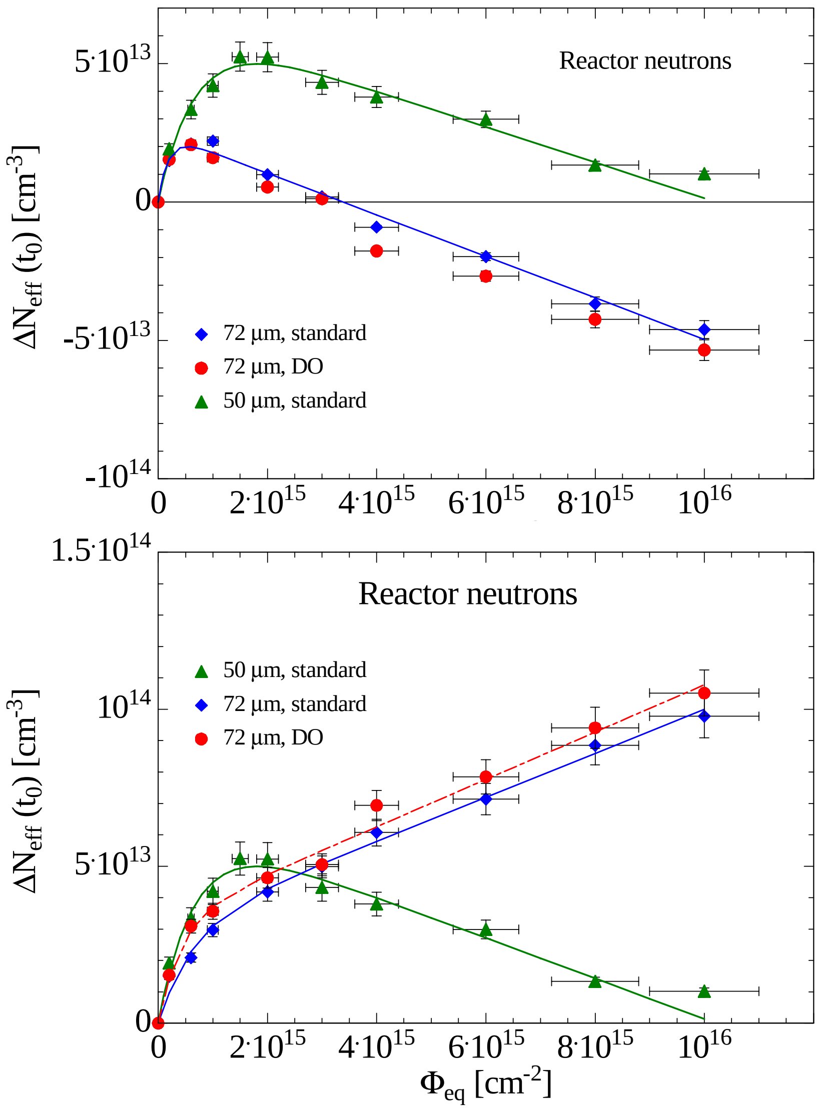
$$\beta_\alpha \approx 2.7\cdot10^{-17}\ \text{cm}^2$$

EPI - N_{eff} for Reactor Neutrons



- **Development for both materials quite similar**
- **N_{eff} values for DO always a bit larger**
- **Minimum between 0.5 - $1\cdot10^{15}$ cm^{-2}**
- **SCSI above $1\cdot10^{15}$ cm^{-2} ? (indication found by G. Kramberger)**
- **Introduction rate for large fluence values: $g_{eff} \approx 7.7\cdot10^{-3}$ cm^{-1}**

EPI - ΔNeff Comparison 50 µm and 72 µm



- ΔNeff versus fluence substantially different for 72 µm and 50 µm material
- Donor removal more effective for 72 µm compared to 50 µm due to lower [P]-concentration in 72 µm material (shift of the maximum to lower fluence)

no

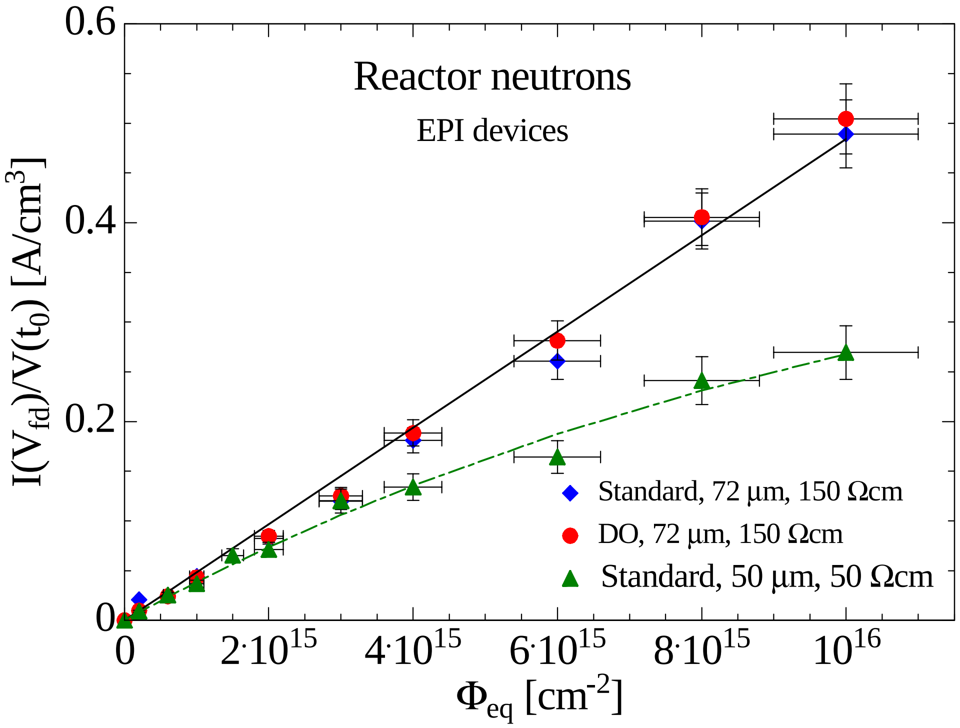
?

yes

- Space Charge Sign Inversion for 72 µm ??

  Has to be studied by different methods

EPI – I/V for Reactor Neutrons



Generation current:

- No difference between 72 µm standard and DO
- Linear increase for 72 µm
- Saturating tendency for 50 µm
- Damage parameter 72 µm:

$\alpha(72\mu m, t_0) = (4.8 \pm 0.4)\cdot10^{-17}$ A/cm

- Damage parameter 50 µm: (low fluence limit)

$\alpha(50\ \mu m, t_0) = (4.0 \pm 0.4)\cdot10^{-17}$ A/cm

Outlook

- **Next steps:**

  (a) Irrad. of EPI, MCz (normal and thinned), thinned FZ with 23 GeV protons

  (b) Special irrad. with electrons and Co-60 for defect kinetic studies

  (c) Continuation of annealing and TCT studies

  (d) Continuation of defect studies

- **New material:**

  EPI, p-type, 50 Ωcm, 50 µm (Process at CiS in progress)
  Different EPI material ready for processing at CiS (RD50 project)
  n-type: 100 µm and 150 µm
  p-type: 100 µm and 150 µm

- **Processing:**

  Standard and DO
  DO has to be adapted to the different thicknesses

Microscopic defects working group meeting in the framework of RD50

University of Hamburg

August, 23.-24., 2006

- **Meeting devoted to defect analysis in radiation damaged silicon detectors**
- **Proposed topics:**
  - **Survey of defect analysis tools (DLTS, TSC, PL, IR, PITS,..), sensitivity, parameters of investigation, limitations**
  - **Results of defect analysis (in FZ, DOFZ, EPI, Cz, MCz), correlation with material parameters, generation, annealing**
  - **Discussion on specific defects (like V_2O, X, higher order V and I related complexes)**
  - **The role of Oxygen, Carbon, Hydrogen,… for defect engineering**
  - **Possibilities for a coordinated investigation of most important issues**