Comparison of proton damage in thin FZ, MCz and epitaxial silicon detectors

L. Andricek (b), D. Eckstein (a), E. Fretwurst (a), J. Lange (a), G. Lindström (a), H.G. Moser (b), I. Pintilie (c), R. Richter (b), R. Röder (d)

(a) University of Hamburg
(b) MPI-Semiconductor Laboratory Munich
(c) NIMP Bucharest
(d) CiS Institute for Microsensoric Erfurt

Introduction

- **Motivation for thin detectors**
  Advantage:
  lower depletion voltage ($V_{fd} \propto d^2$)
  lower leakage current ($I_{rev} \propto d$) → lower noise, lower power dissipation
  smaller collection time ($t_c \propto d$) → less charge carrier trapping
  Draw-back:
  smaller signal for mips (signal $\propto d$)
  larger capacitance ($C_{det} \propto 1/d$) → larger electronic noise

  → find an optimal thickness

- **Different Materials and thicknesses studied**
- **Irradiated with 23GeV protons at CERN**
- **Studied annealing behaviour, fluence dependence**
- **Continuation of work presented in Talk of E.Fretwurst in Nov.07 RD50 Workshop**

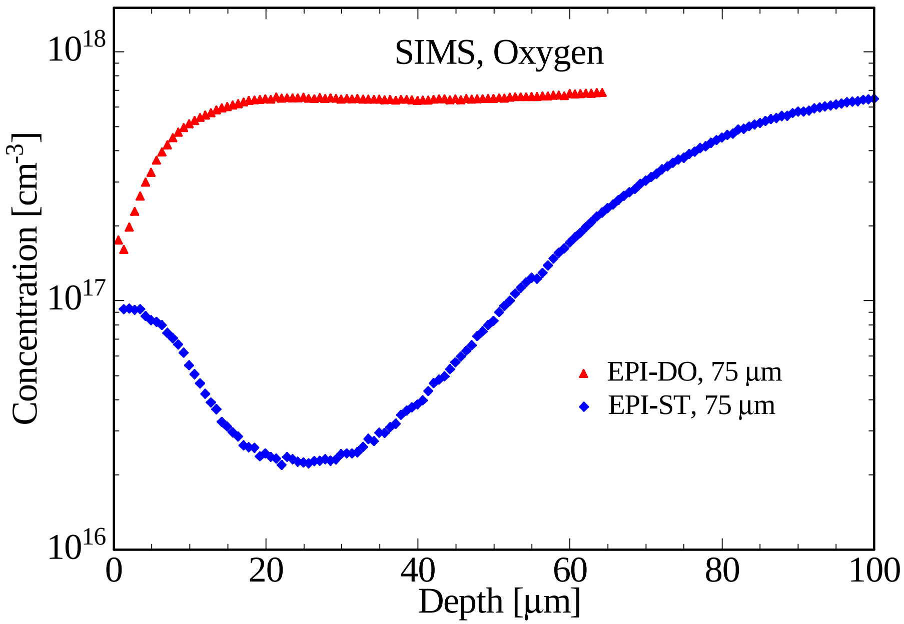
Material under investigation

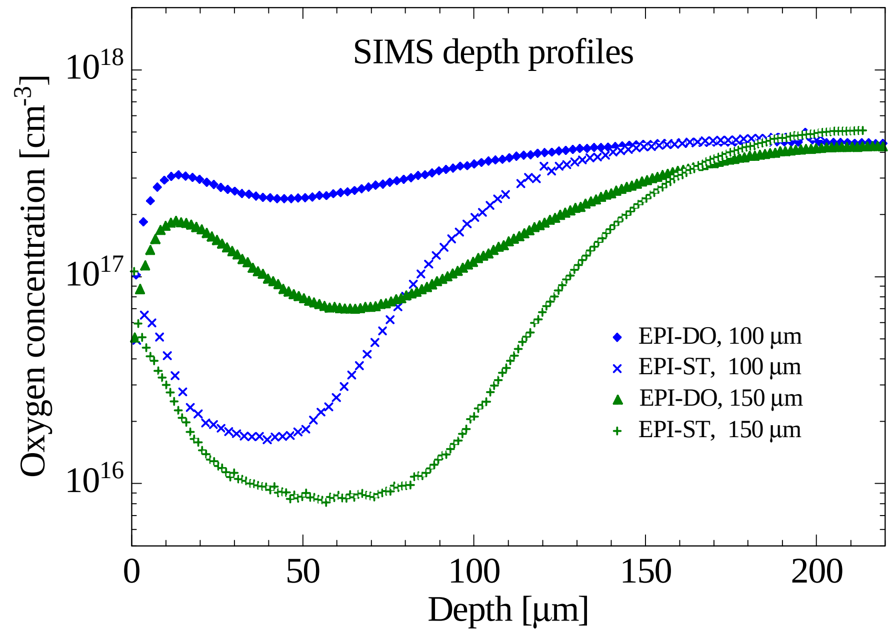
irradiated with 23GeV protons

Material	Cond. type	Orientation	$N_{eff,0}$ [10^{13} cm^{-3}]	d [µm]
EPI-ST (1)	N	<111>	2.6	75
EPI-DO (2)	N	<111>	2.6	75
EPI-ST (1)	N	<100>	1.5/0.88	100/150
EPI-DO (2)	N	<100>	1.3/0.80	100/150
FZ-50 (3)	N	<100>	3.3	50
FZ-100 (4)	N	<100>	1.4	100
MCz (5)	N	<100>	0.42	100

(1) *Standard detector process (CiS)*
(2) *Oxygen enriched, diffusion for 24 h at 1100°C (CiS)*
(3) *Produced in wafer bonding technology (MPI)*
(4) *Rear side: P diffusion after thinning (CiS)*
(5) *Rear side: P implantation after thinning (CiS)*

Oxygen depth profiles from SIMS measurements - EPI

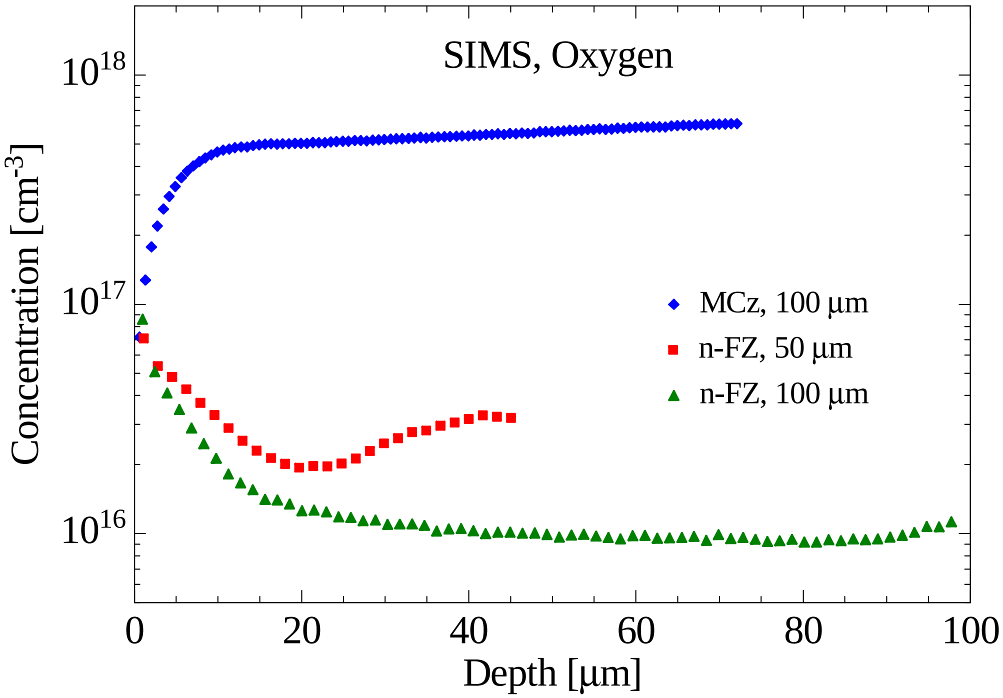




- **EPI-ST, 75 µm: [O] inhomogeneous, <[O]> = 9.3 10^{16} cm^{-3}**
- **EPI-DO, 75 µm: [O] homogeneous, except surface, <[O]> = 6.0 10^{17} cm^{-3}**
- **EPI-ST, 100/150 µm: [O] inhomogeneous, <[O]> = 5.4 10^{16} / 4.5 10^{16} cm^{-3}**
- **EPI-DO, 100/150 µm: [O] more homogeneous <[O]> = 2.8 10^{17} / 1.4 10^{17} cm^{-3}**

EPI-DO: 24h at 1100°C, oxygen diffuses from Cz substrate

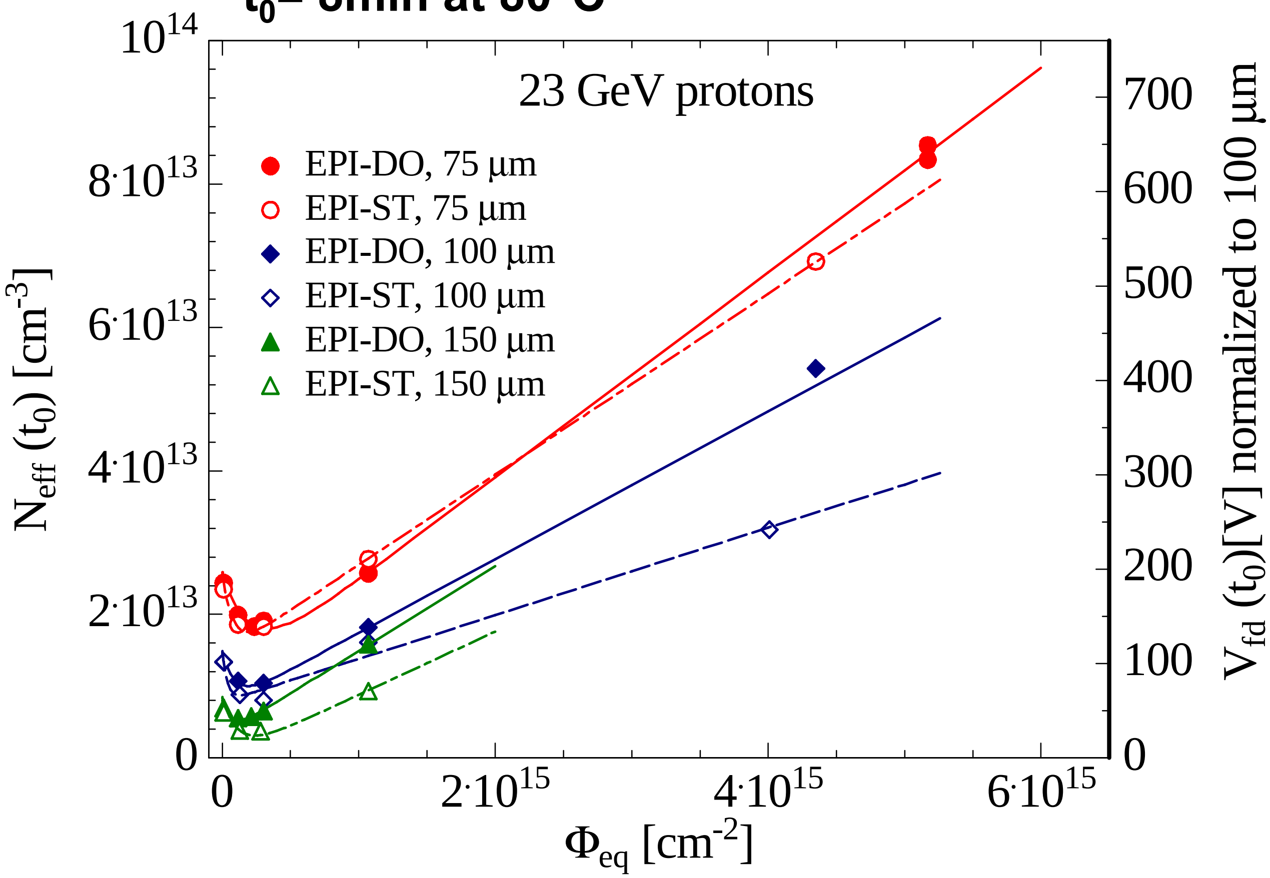
Oxygen depth profiles from SIMS measurements – FZ and MCz



- **MCz: [O] homogeneous, except surface**
  <[O]> = 5.2 10^{17} cm^{-3}
- **FZ 50 µm: inhomogeneous**
  <[O]> = 3.0 10^{16} cm^{-3}
- **FZ 100 µm: homogeneous, except surface**
  <[O]> = 1.4 10^{16} cm^{-3}

N_{eff} (V_{fd} normalized to 100µm) vs. fluence for EPI

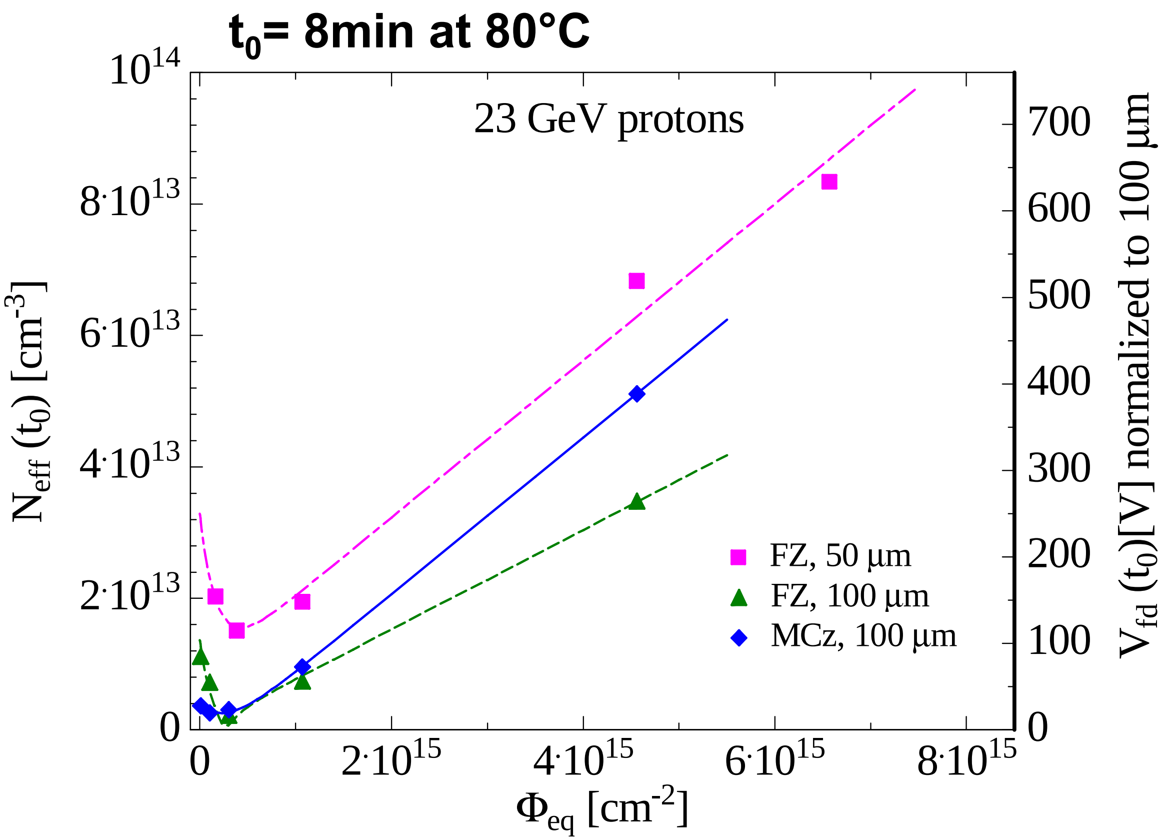
t_0= 8min at 80°C



- **donor removal in low fluence range**
- **Different $N_{eff,0}$**

- **no SCSI for all thicknesses**
- **High fluence range:**
 Dominant donor generation over-compensates acceptor generation

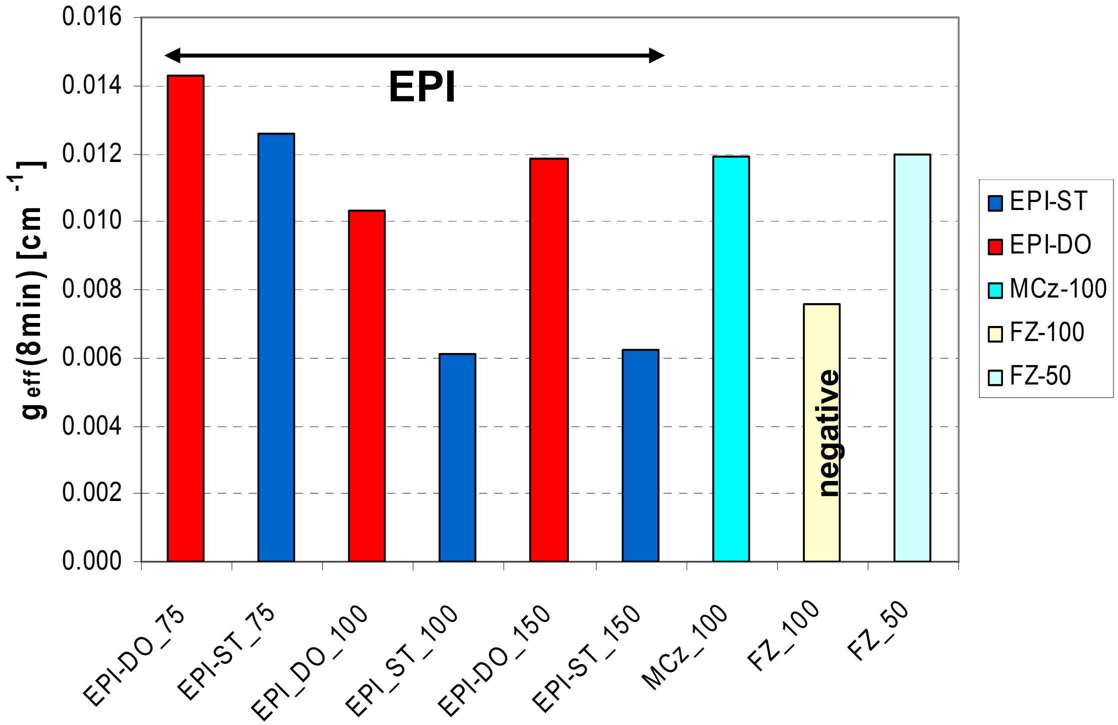
N_{eff} (V_{fd} normalized to 100µm) vs. fluence for FZ, MCz



- donor removal in low fluence range
- Different $N_{eff,0}$
- Minimum in $N_{eff}(\Phi)$ shifts to larger Φ for higher doping

- SCSI for FZ 100µm
- no SCSI for MCz
- no SCSI for Fz 50µm !

Introduction rates g_{eff} for large fluence values



$N_{eff,0}$:

Fz-50 > EPI-75 > EPI-100, FZ-100 > EPI-150 > MCz

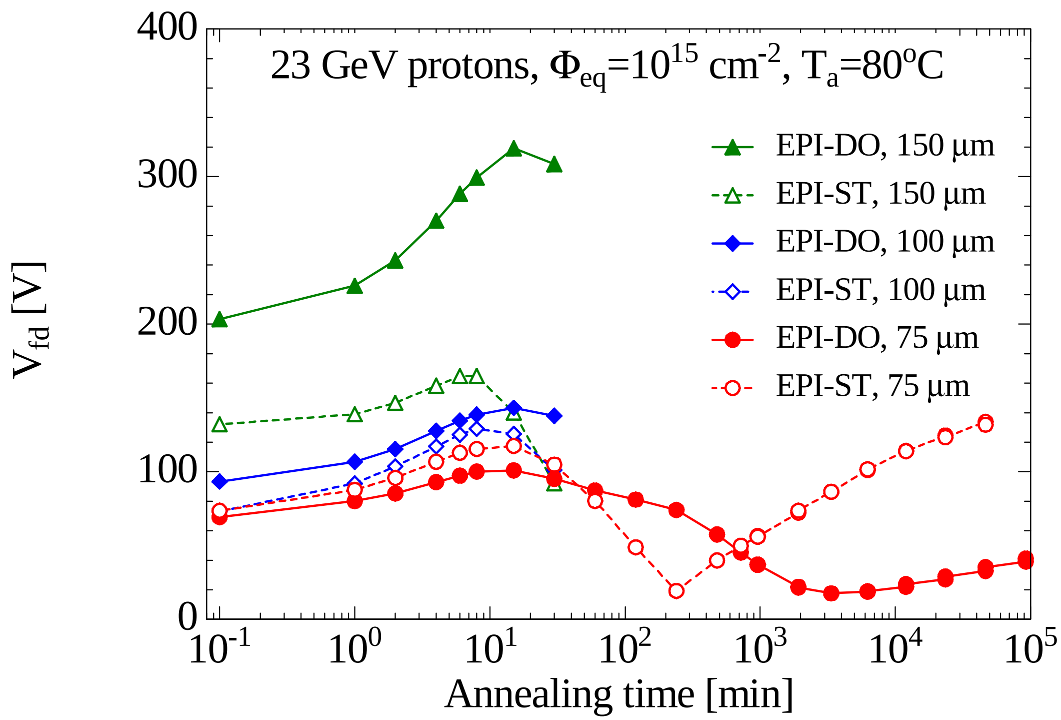
<[O]> :

EPI-DO-75 > MCz > EPI-DO-100 > EPI-DO-150
EPI-ST-75 > EPI-ST-100 > EPI-ST-150
> FZ-50 > FZ-100

No crrelation, maybe because [O] non-homogeneous?

- **g_{eff} <0 for dominant acceptor creation, inversion**
- **g_{eff} >0 for dominant donor creation, no inversion**

V_{fd} Annealing at 80°C - EPI



- **Typical annealing behaviour of non-inverted diodes:**

→ V_{fd} increase, short term annealing

→ $V_{fd,max}$ (at $t_a \approx 8$ min), stable damage

→ V_{fd} decrease, long term annealing

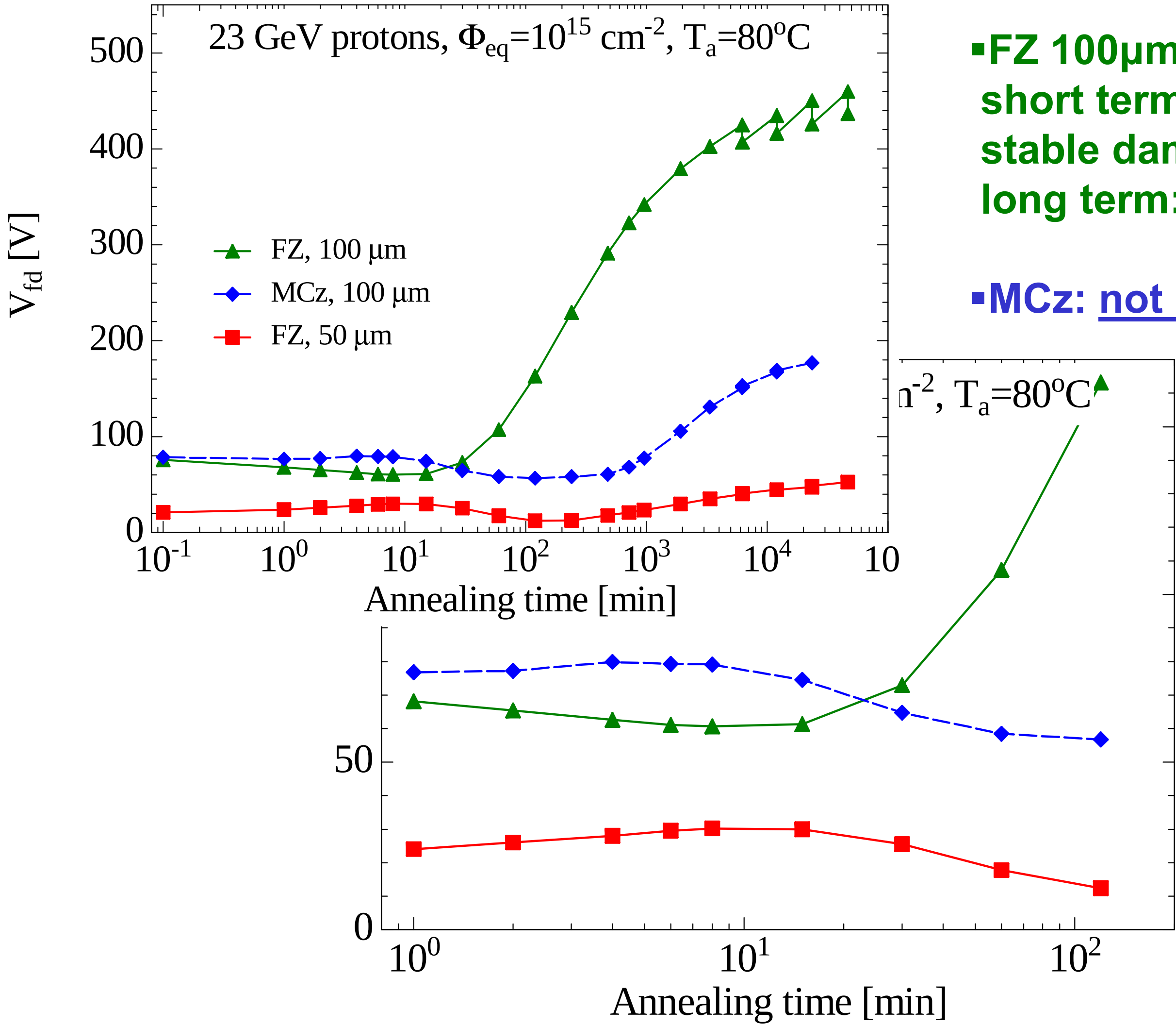
$$V_{fd}(\Phi,t) = V_C(\Phi) \pm V_a(\Phi,t) \pm V_Y(\Phi,t)$$

→ stable damage ± short term ± long term annealing

→ + sign if inverted

→ – sign if not inverted

V_{fd} Annealing at 80°C - for FZ and MCz



- **FZ 100µm: inverted**
  short term: V_{fd} decreases
  stable damage: minimum at ~8min
  long term: V_{fd} increases

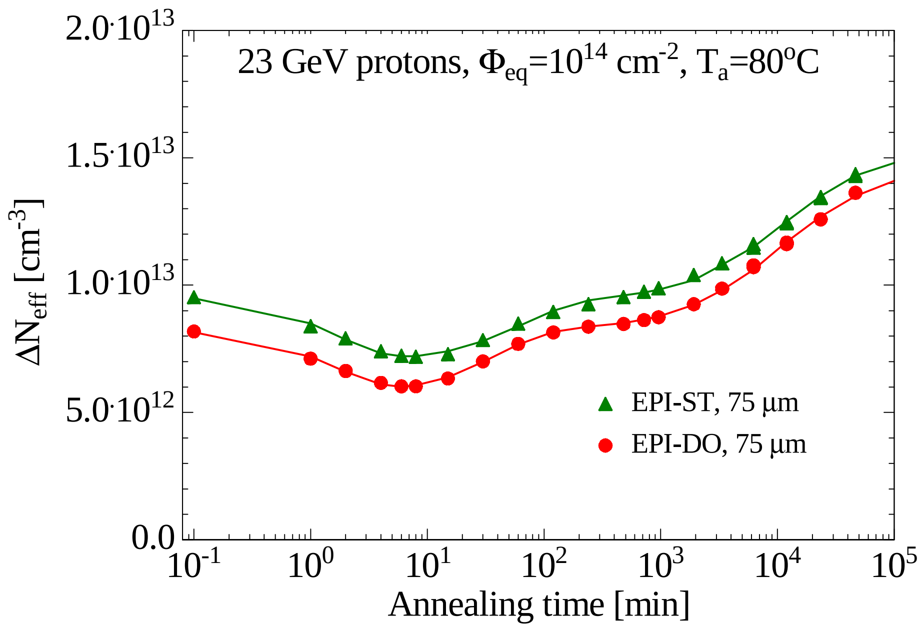
- **MCz: not inverted**

- **FZ 50µm: no inversion!**

(after neutron damage inversion observed)

why?
<[O]> = 3.0 10^{16} cm^{-3}
only factor 2 higher than for FZ 100µm

Annealing of ΔNeff at 80°C



- Typical annealing behavior:
  short term annealing N_a
  + stable component N_C
  + reverse annealing N_Y

  reverse annealing best described by 2 components: 1. order + 2. order process

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

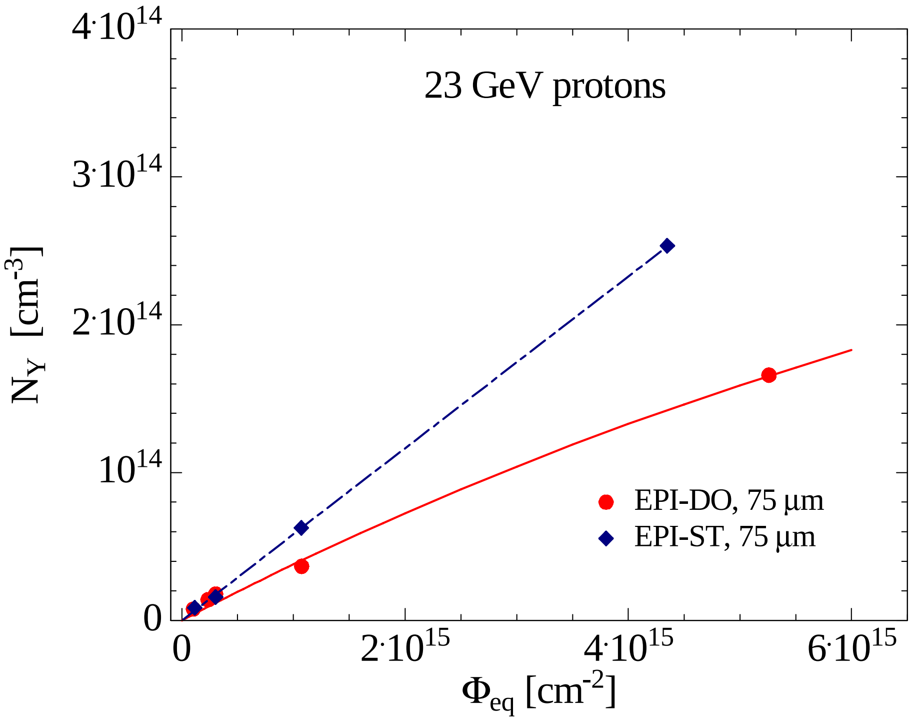
$\Delta N_{eff}(\Phi,t) = N_a(\Phi,t) + N_C(\Phi) + N_Y(\Phi,t)$

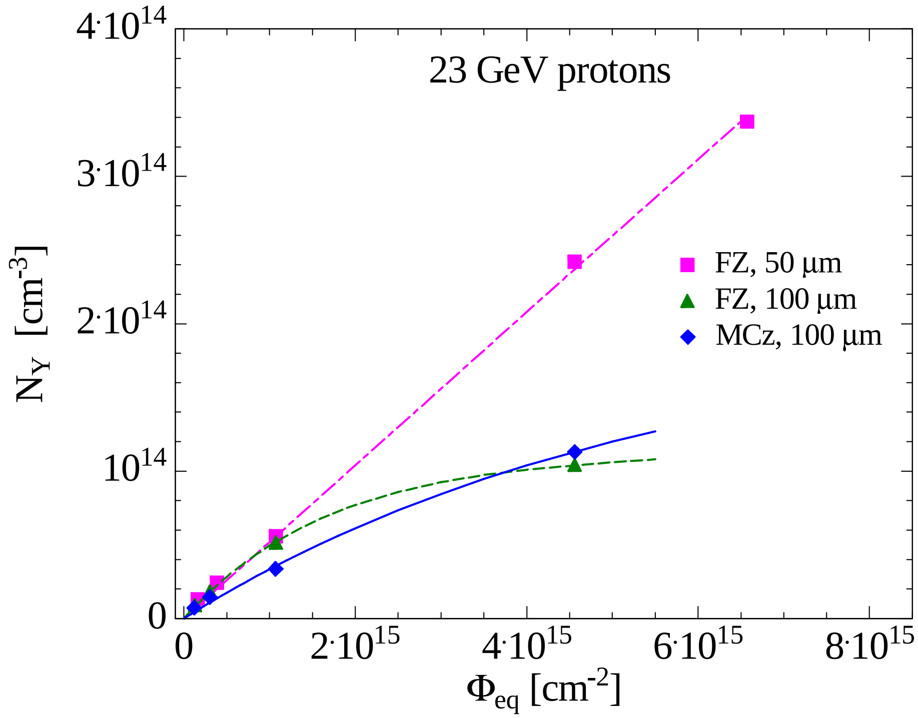
with

$N_Y(\Phi,t) = N_{Y,1}(\Phi,t) + N_{Y,2}(\Phi,t)$

In the following, N_Y is shown

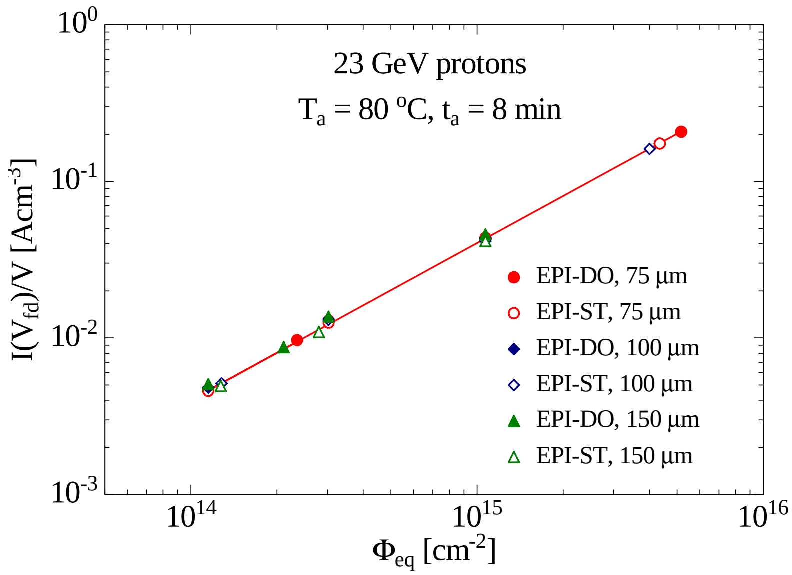
Reverse annealing Amplitude N_Y

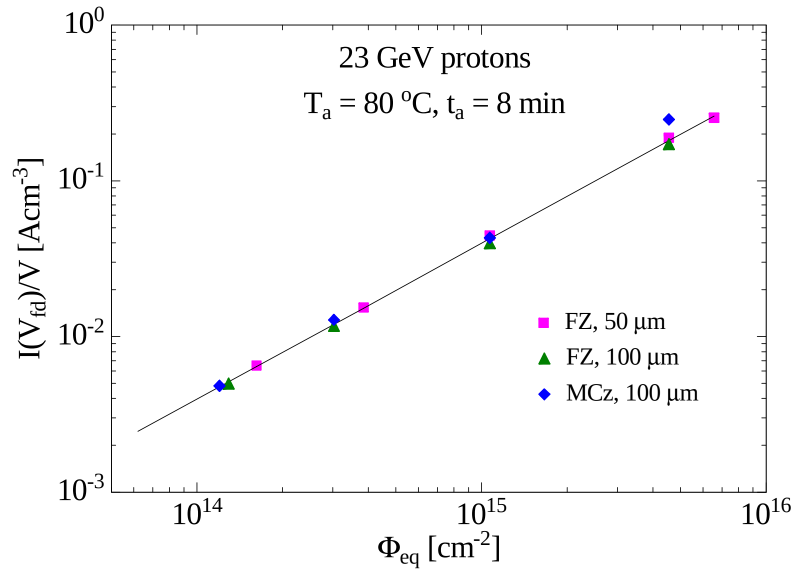




- EPI-DO, FZ 100µm and MCz saturate, FZ 50 µm does not
- EPI-ST?
- No correlation with oxygen concentration seen

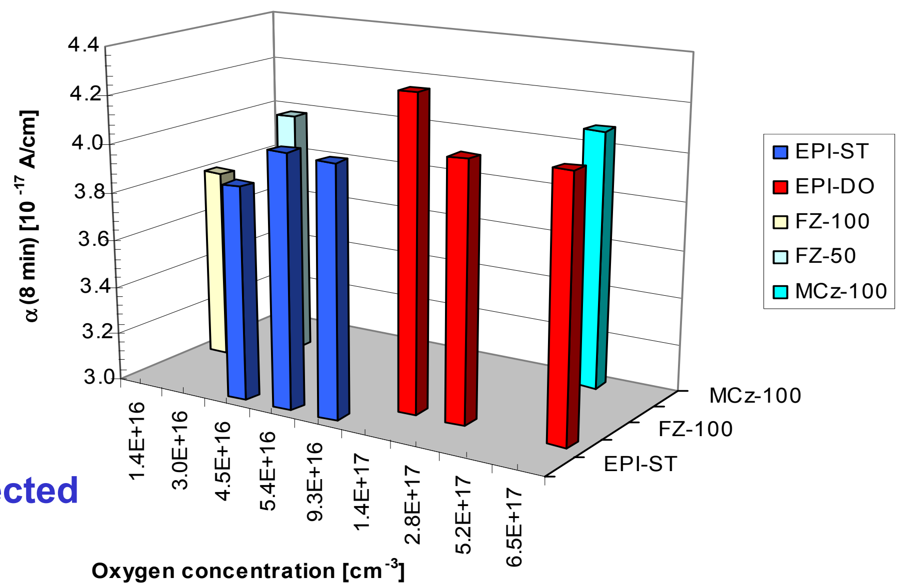
Generation Current





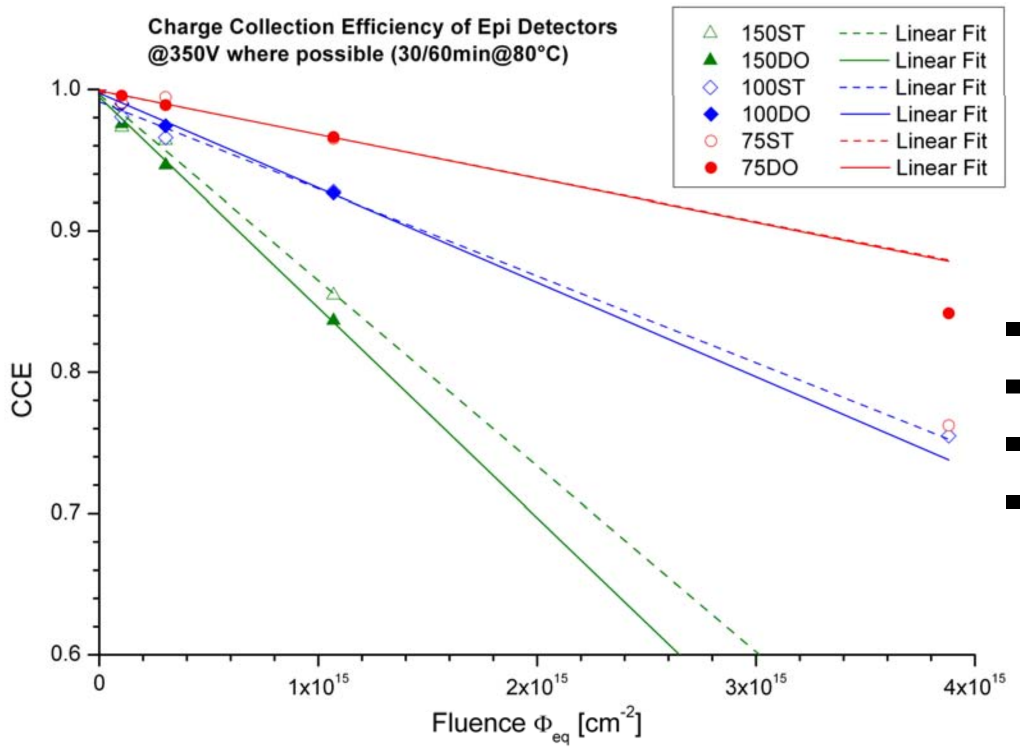
after annealing for 8min at 80°C:

- linear increase
- damage parameter α varies from 3.8 to 4.3 10^{-17}A/cm
- nearly independent on material type



but note, that for FZ 50µm the fluence was corrected

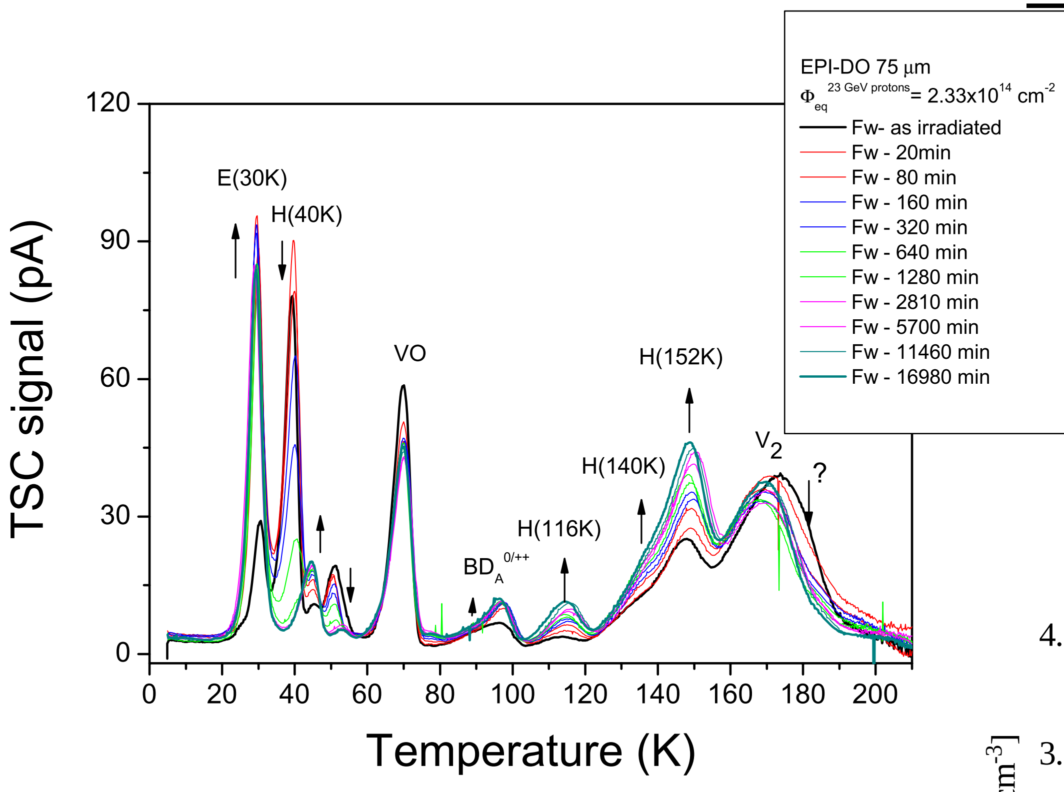
Charge Collection Efficiency



- ^{244}Cm α-source, E_α=5.8MeV
- Charge collection measured with TCT
- Measured at 350V where possible
- EPI: only front injection
  → electron signal

- CCE decreases with increasing thickness
- CCE for ST and DO quite similar

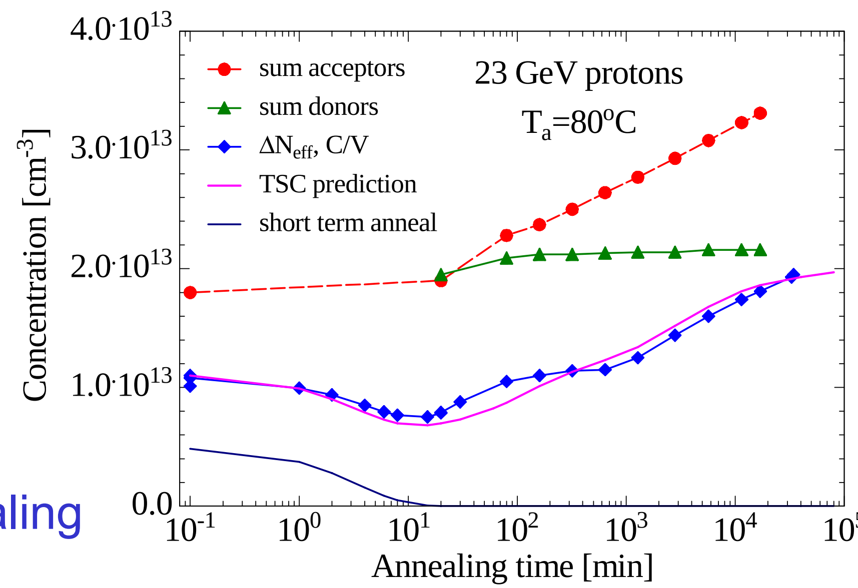
Comparison of TSC studies with Δ_{Neff} from C/V



EPI-DO 75µm
$2.33x10^{14}cm^{-2}$

Annealing at 80°C

•Donators to over-compensate Acceptors BD and mainly E(30K)



Comparison:

Δ_{Neff} extracted from C/V
Acceptors, donors from TSC
[E]-center added

→ Good understanding of long-term annealing

Summary

- Compared thin Si-detectors processed on different materials
  (n-type EPI, FZ and MCz) after 23 GeV/c proton irradiation

- N_{eff}: at low fluence dominated by doping removal (P)
  at high fluence introduction of positive space charge (donors) except FZ-100 µm
  oxygen effect not or only partially seen
- Inversion/no inversion demonstrated by annealing of V_{fd}

- Surprise: no SCSI for FZ-50 µm after proton damage contrary to neutron damage
  although [O] much smaller compared to EPI or MCz material

- Introduction of donors that over-compensate acceptor generation was seen in TSC
  a good agreement with macroscopic long-term annealing was demonstrated