# Summary of measurements after first irradiation of HPK samples

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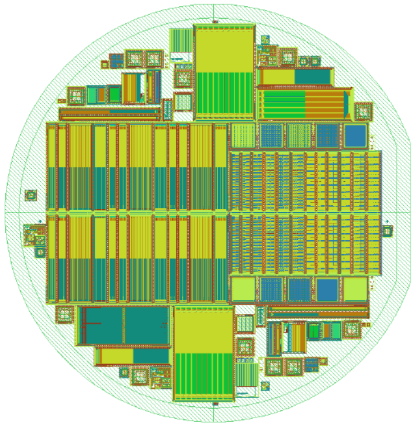
Joachim Erfle
University of Hamburg

On behalf of the CMS Tracker Collaboration

# Overview

- introduction to the HPK-campaign
- results of first irradiations
    - dark current
    - effective doping concentration
    - signal collection
- conclusions



Size of logos has **no** meaning!!!

courtesy of A. Dierlamm, KIT

# Goals of the HKP-campaign

The main challenges of the HL-LHC will be:

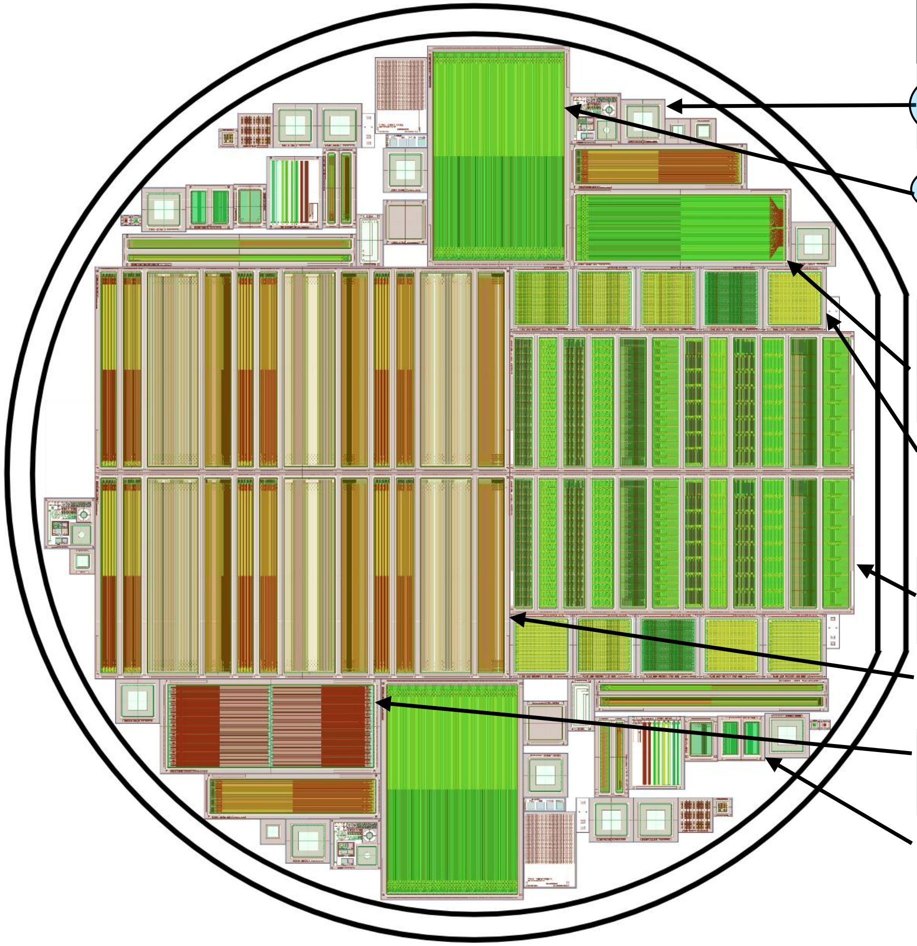
- higher radiation damage
- higher occupancy

therefore we want to find the best suiting material and layout for the coming tracking sensors.

To achieve that we investigate a large variety of materials and structures that are irradiated and measured.

The first step is to check, if at low fluences everything is compatible with available data. After that we will go to higher fluences.

# Wafer overview



| structure | to study |
|---|---|
| diodes | material |
| baby strip sensor | reference design / material |
| baby with integrated pitch adapter | design |
| pixel sensor | reference Design / material |
| multigeometry pixel | layout parameters |
| multigeometry strips | layout parameters |
| baby strixel | design |
| teststructures | process parameters |

# Material

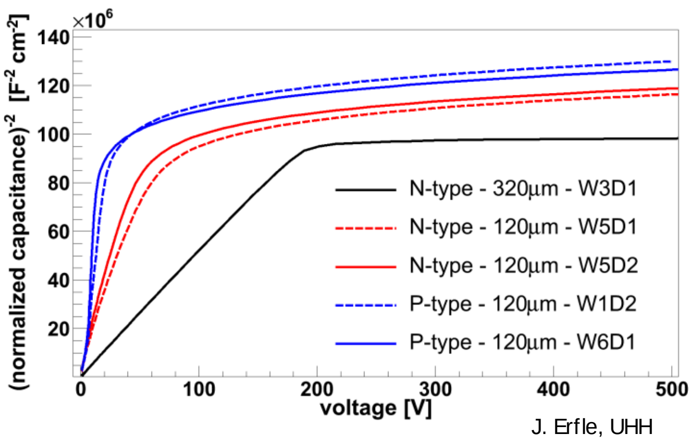
| material | thinning method | active thickness | physical thickness |
|---|---|---|---|
| FZ | deep diffusion | 120,200,300 µm | 320 µm |
| FZ | --- | 200 µm | 200 µm |
| FZ | handling wafer | 120 µm | 320 µm |
| MCz | --- | 200 µm | 200 µm |
| Epi | handling wafer | 50,100 µm | 320 µm |

of each material there are 3 different types:

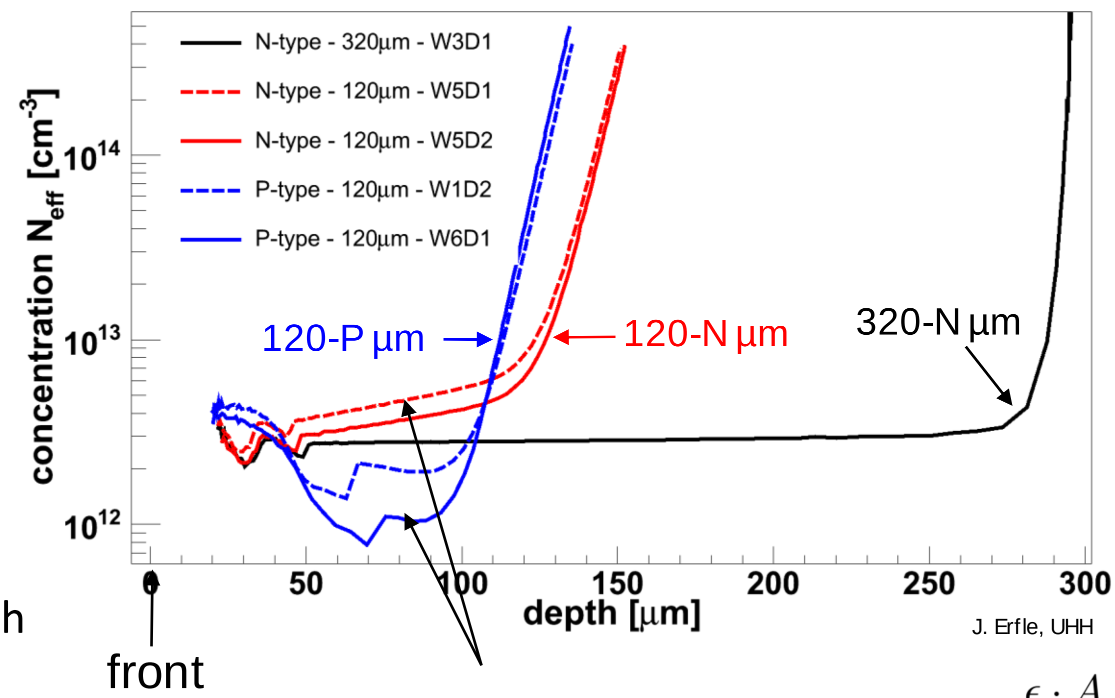
- n-type (N)
- p-type with p-stop (P)
- p-type with p-spray (Y)

# Material characteristics of thin FZ: deep diffusion

Concentration profile from CV-curve: $N_{eff} = \frac{\frac{2 \cdot \Delta V}{\Delta(C^{-2})}}{q \cdot \epsilon \cdot A^2}$




Diodes behave like parallel-plate capacitors
→ measure capacitance vs voltage to determine depletion depth and charge carrier concentration




Deep diffusion influences effective doping $\text{depth} = \frac{\epsilon \cdot A}{C}$

# Irradations

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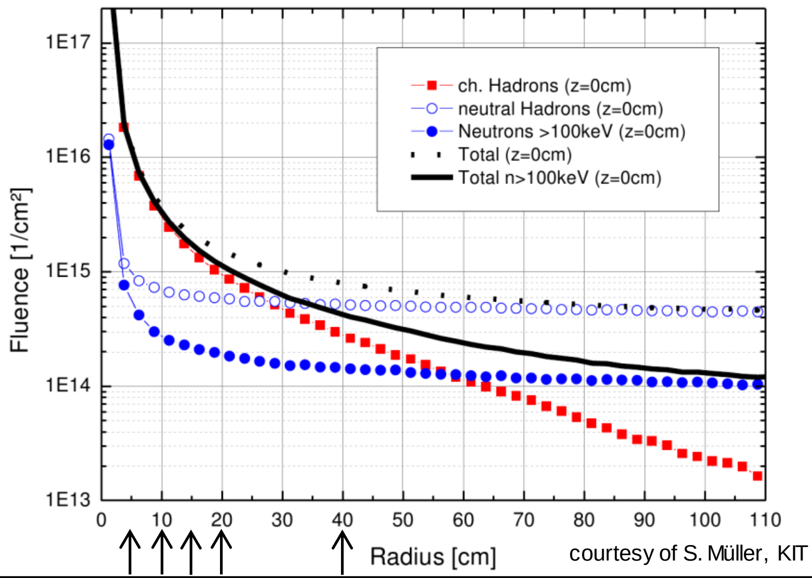
HL-LHC: $L_{int}$=3000 $fb^{-1}$

neutrons: 1 MeV (TRIGA Reactor Ljubljana)

protons: 25 MeV (Karlsruhe Synchrotron)




courtesy of S. Müller, KIT

| radius | protons $\Phi_{eq}$ [$cm^{-2}$] | neutrons $\Phi_{eq}$ [$cm^{-2}$] | total $\Phi_{eq}$ [$cm^{-2}$] | active thickness |
|---|---|---|---|---|
| 40 cm | $3 \cdot 10^{14}$ | $4 \cdot 10^{14}$ | $7 \cdot 10^{14}$ | ≥ 200 µm |
| 20 cm | $1 \cdot 10^{15}$ | $5 \cdot 10^{14}$ | $1.5 \cdot 10^{15}$ | ≥ 200 µm |
| 15 cm | $1.5 \cdot 10^{15}$ | $6 \cdot 10^{14}$ | $2.1 \cdot 10^{15}$ | ≥ 200 µm |
| 10 cm | $3 \cdot 10^{15}$ | $7 \cdot 10^{14}$ | $3.7 \cdot 10^{15}$ | ≤ 200 µm |
| 5 cm | $1.3 \cdot 10^{16}$ | $1 \cdot 10^{15}$ | $1.4 \cdot 10^{16}$ | < 200 µm |


Joachim Erfle
joachim.erfle@desy.de

# Volume current versus fluence:

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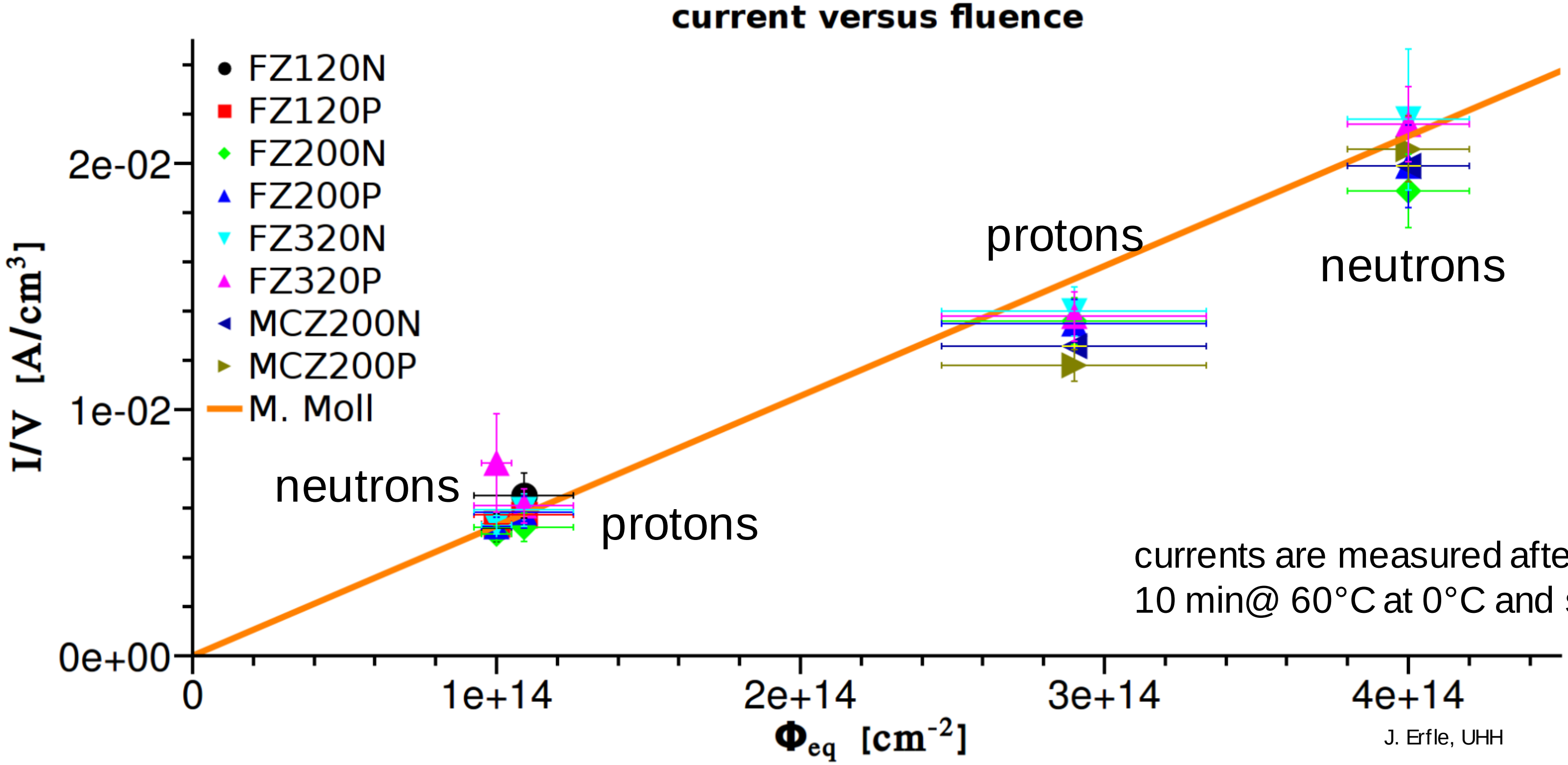


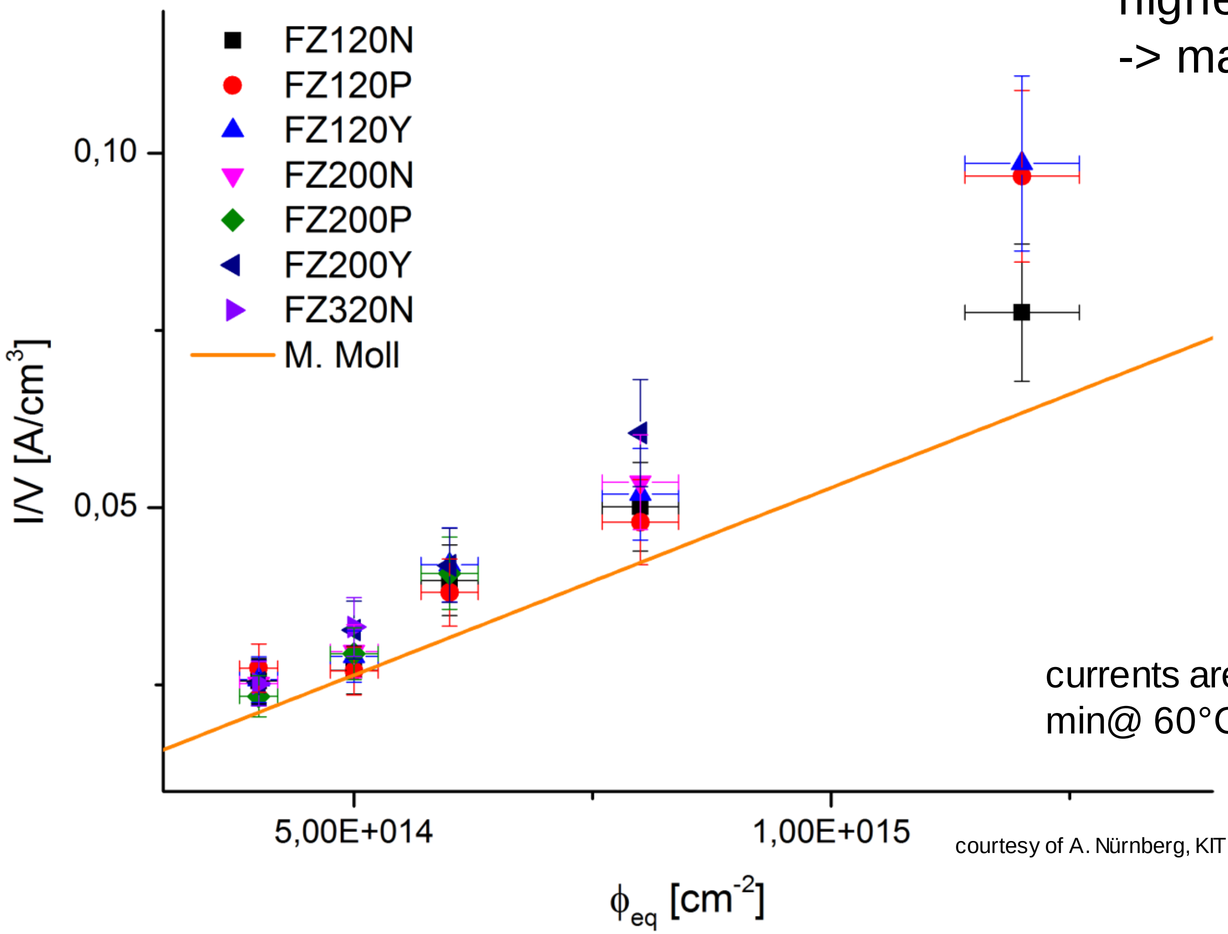

$$\frac{\Delta I}{V} = \alpha \Phi_{eq}$$

currents are measured after annealing of 10 min@ 60°C at 0°C and scaled to 20°C

currents match expected value from M.Moll's thesis within the uncertainties.
-> dose measurements are ok.

# Volume current versus fluence: Baby sensors

neutron irradiated Baby sensors



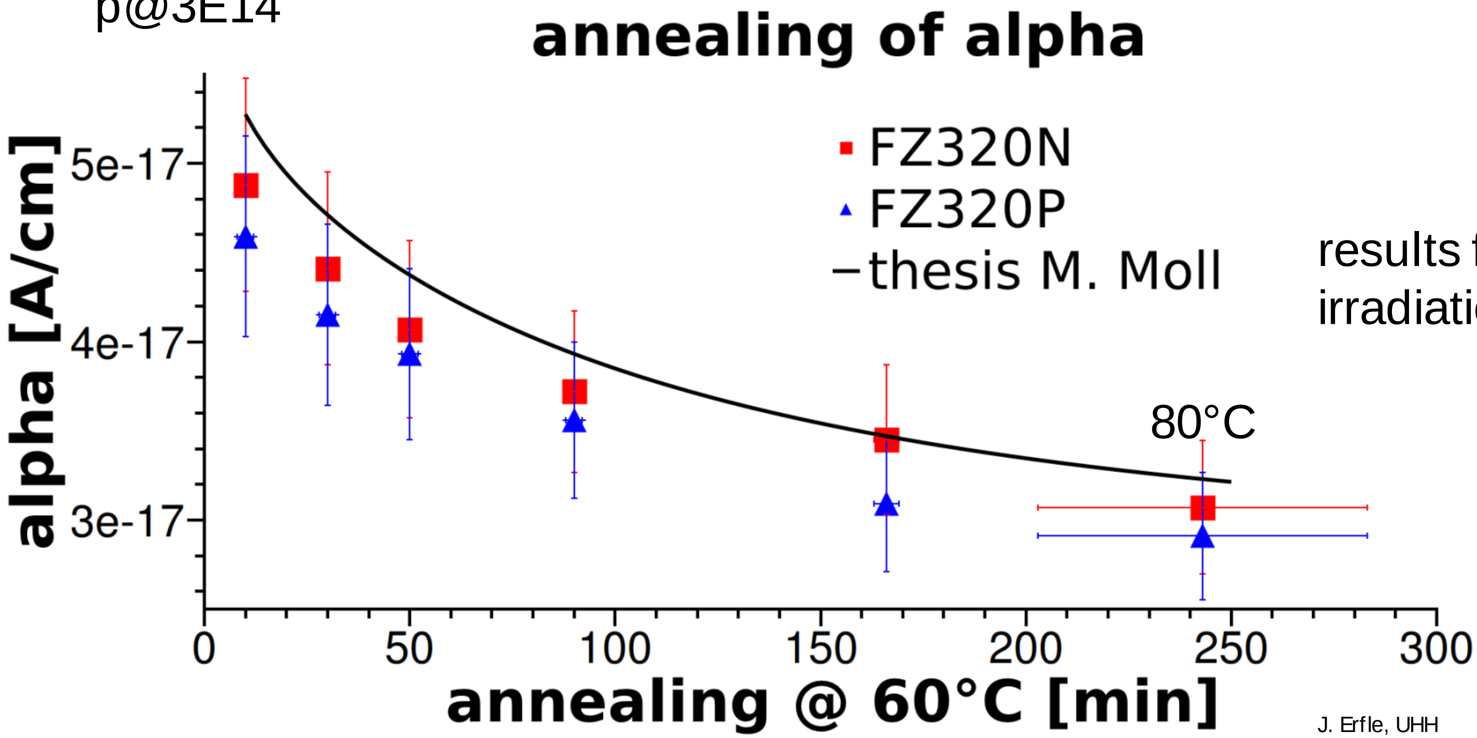

courtesy of A. Nürnberg, KIT

First Baby sensors show higher currents than diodes -> maybe a surface effect?

currents are measured after annealing of 10 min@ 60°C at -20°C and scaled to 20°C

# Annealing behaviour of dark current

p@3E14




J. Erfle, UHH

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

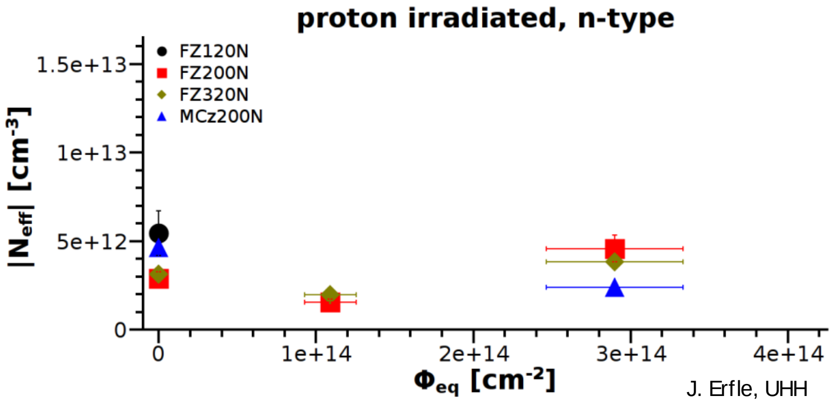
results for neutron irradiation coming soon

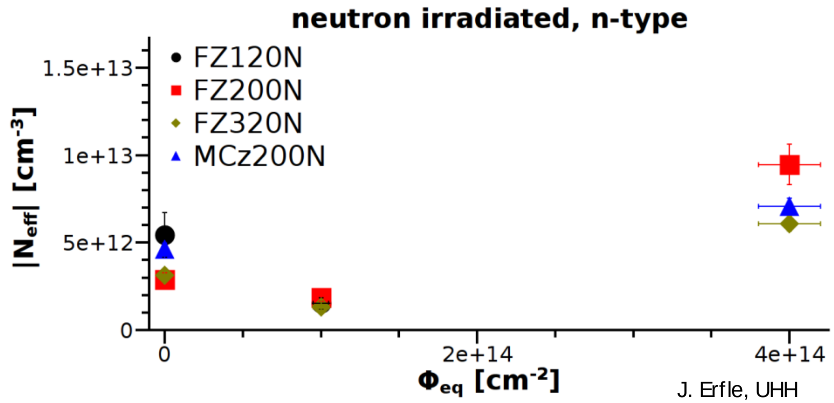
measurements are performed at 0°C and scaled to 20°C

the annealing of alpha matches the expected curve from M.Moll's thesis.

# $N_{eff}$ for different materials / irradiations

n-type




$$|N_{eff}| = \frac{2\epsilon\epsilon_0}{q_0}\frac{V_{dep}}{d^2}$$

protons

the FZ and the MCz n-type materials are type-inverted after neutron or proton irradiation.

neutrons

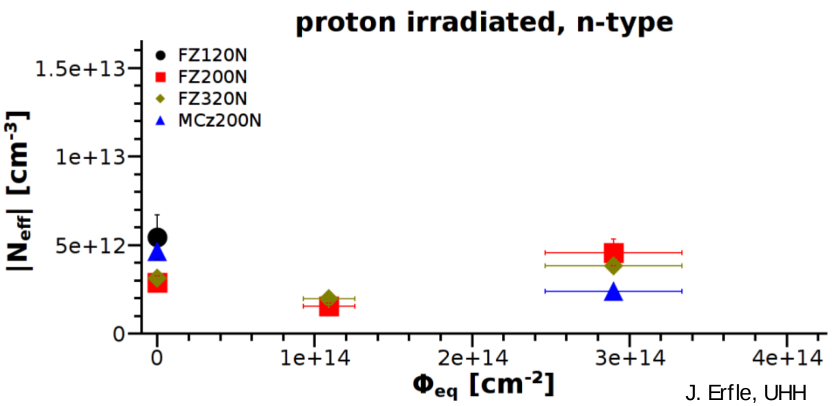
capacitances are measured at 0°C, 1KHz after annealing of 10min@60°C

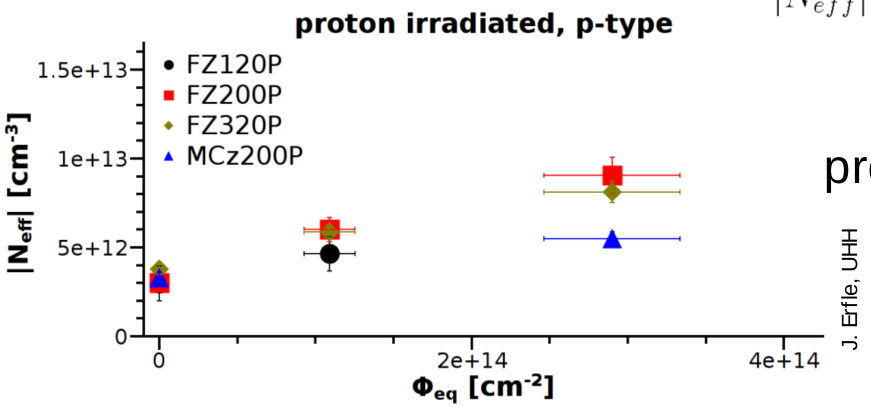
# $N_{eff}$ for different materials / irradiations

n-type

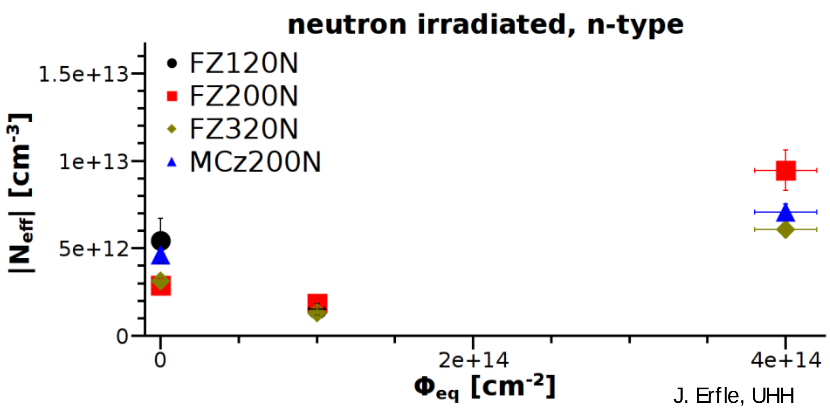
p-type

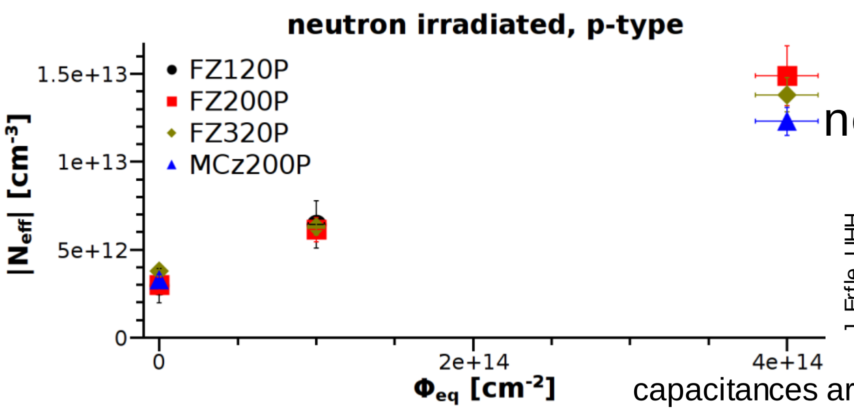
$$|N_{eff}| = \frac{2\epsilon\epsilon_0}{q_0}\frac{V_{dep}}{d^2}$$




protons



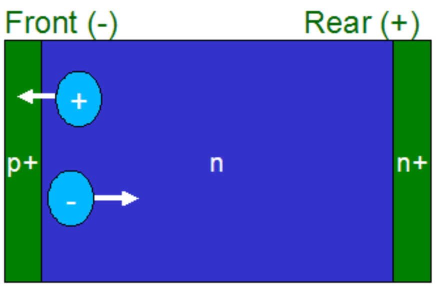

neutrons

MCz: lowest increase in $N_{eff}$.

capacitances are measured at 0°C, 1KHz after annealing of 10min@60°C

# Time resolved charge collection measurement with Transient Current Technique (TCT)

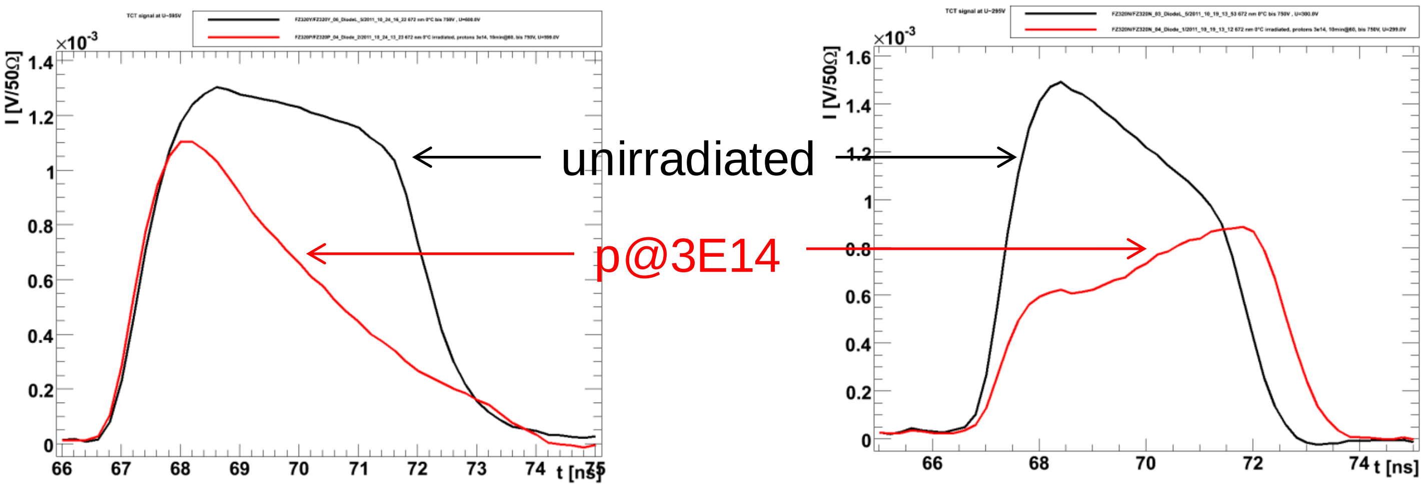
# TCT curves show type inversion




courtesy of J. Lange

FZ320P - holes

FZ320N - electrons




courtesy of T. Pöhlsen, UHH

courtesy of T. Pöhlsen, UHH

Laser: 672 nm, red

not type inverted U=600V

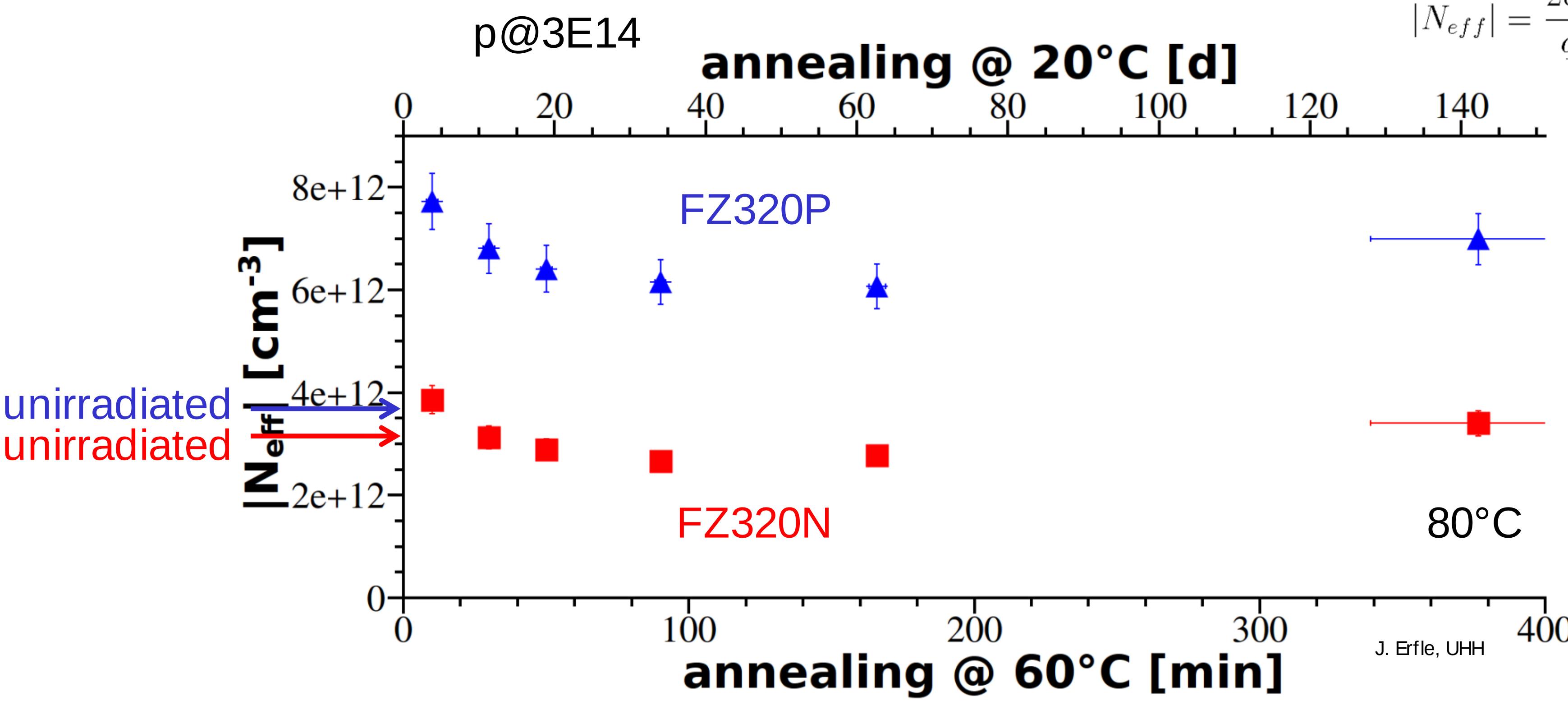
type inverted U=300V

type inversion of FZ and MCz n-type materials is confirmed by TCT.

capacitances are measured at 0°C, 1KHz after annealing of 10min@60°C

# Annealing beaviour of $N_{eff}$

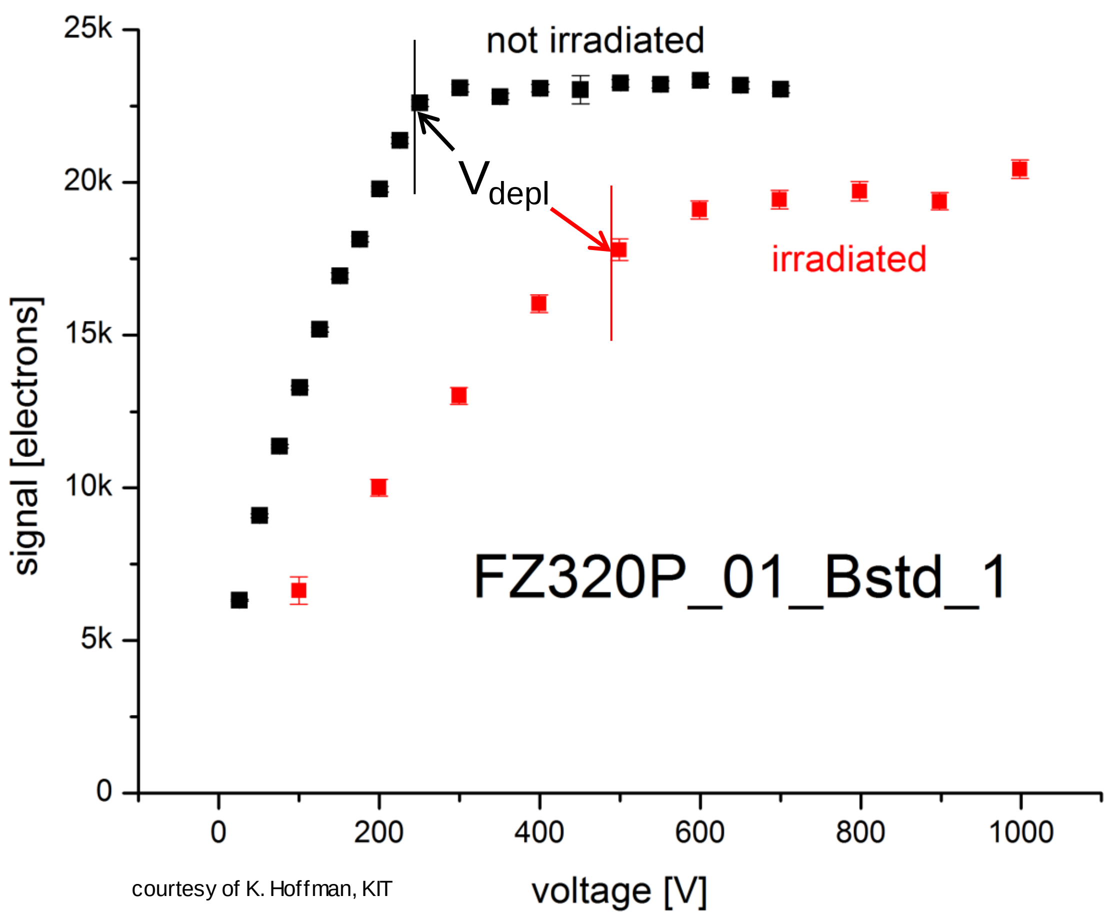
$$|N_{eff}| = \frac{2\epsilon\epsilon_0}{q_0}\frac{V_{dep}}{d^2}$$




$N_{eff}$ changes of FZ320N typical for type inverted material.
FZ320P behaviour looks similar but is not type inverted: not completely understood yet.

measurements are performed at 0°C (1KHz)

# Signal of FZ320P baby sensor, after p@3E14




courtesy of K. Hoffman, KIT

signal induced by a $^{90}Sr$ source, readout by ALiBaVa

CCE of FZ320 p-type is about 87% at p@3E14, compared to non-irradiated

measurements are performed at -20°C

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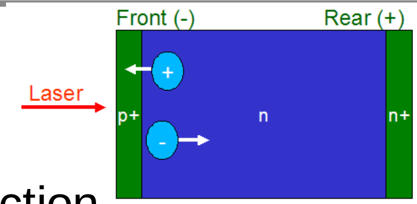
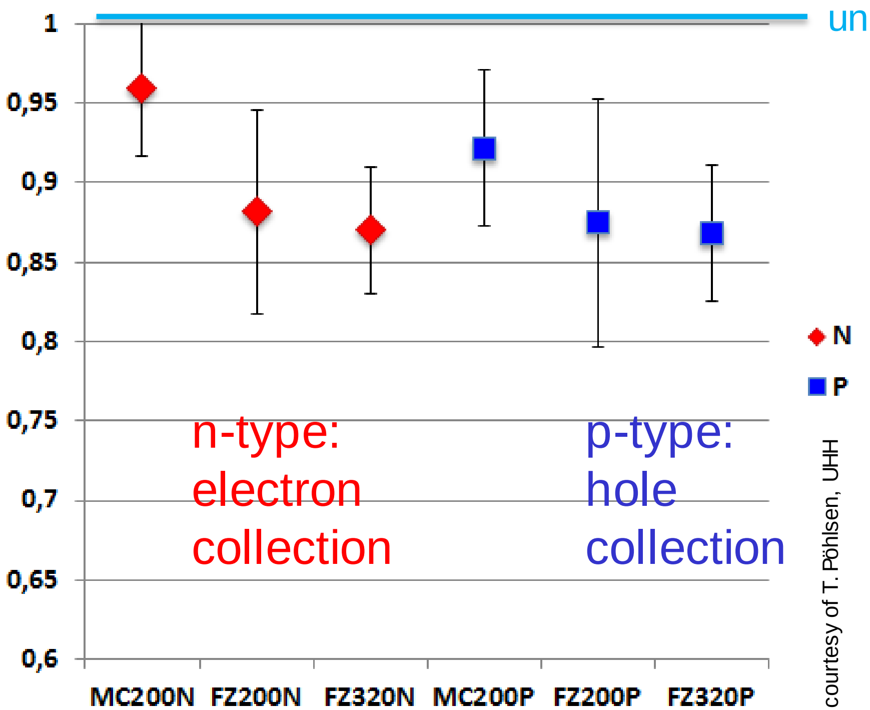
# CCE of diodes, after p@3E14

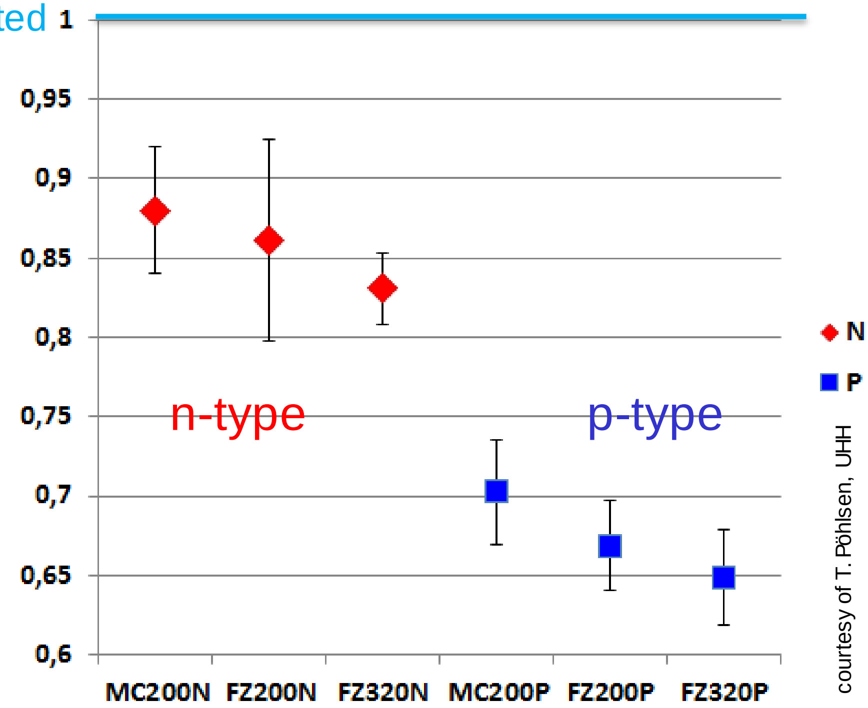



courtesy of J. Lange

infrared laser




red laser, front injection




measurements are performed at 0°C and 600V, with 20ns integration time

infrared laser: CCE is about 90%

electrons only: CCE ~ 85%, holes collection only: CCE ~ 67%

# Conclusions and outlook

- CMS silicon measurement campaign is gaining speed, analysis tools are up and running
- Trying to understand material properties in detail
- Comparison shows currents as expected -> dose measurement ok
- $N_{eff}$ compared before and after irradiation
- CCE with baby sensors and diodes investigated

- More irradiations to come
- Full annealing studies to be done


Joachim Erfle
joachim.erfle@desy.de

# Backup

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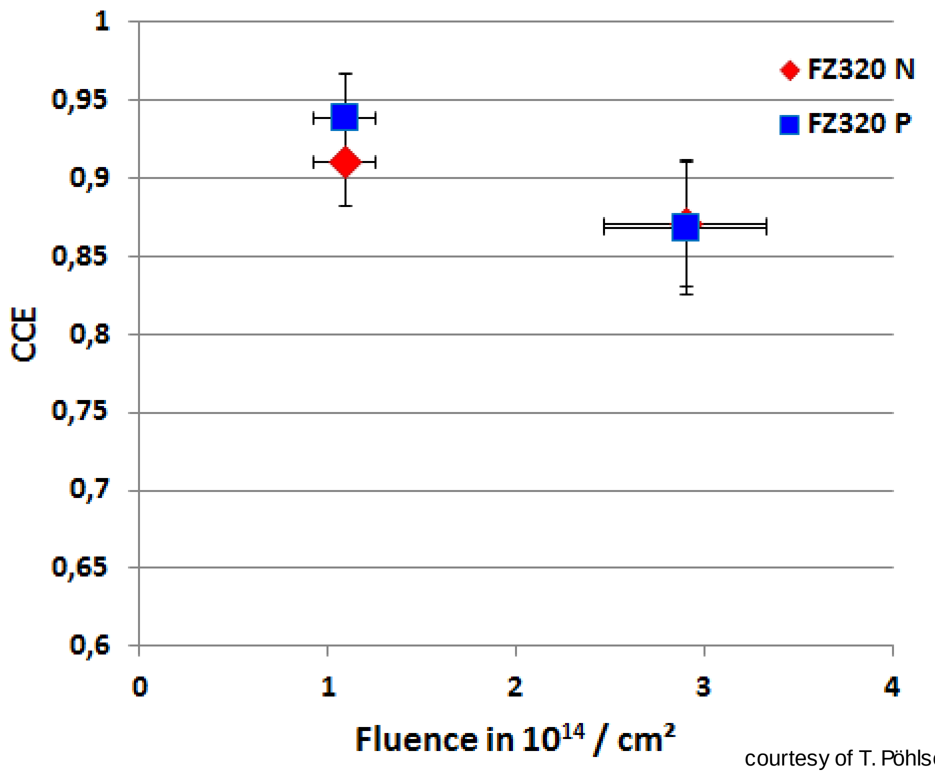
# CCE of FZ320 after proton irradiation



courtesy of T. Pöhlsen

measurements are performed at 0°C



Joachim Erfle
joachim.erfle@desy.de

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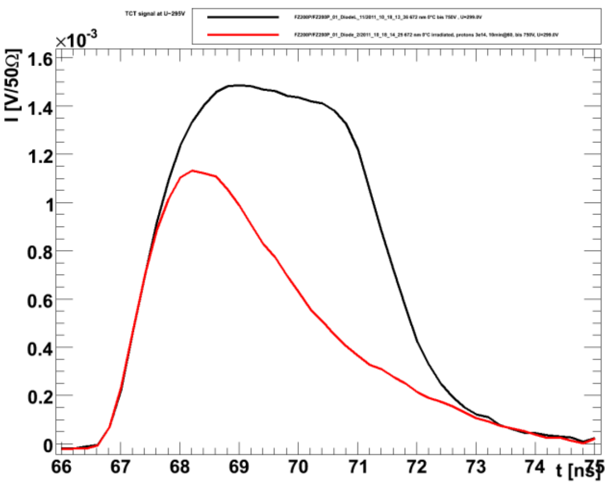
# TCT pulses – p-type

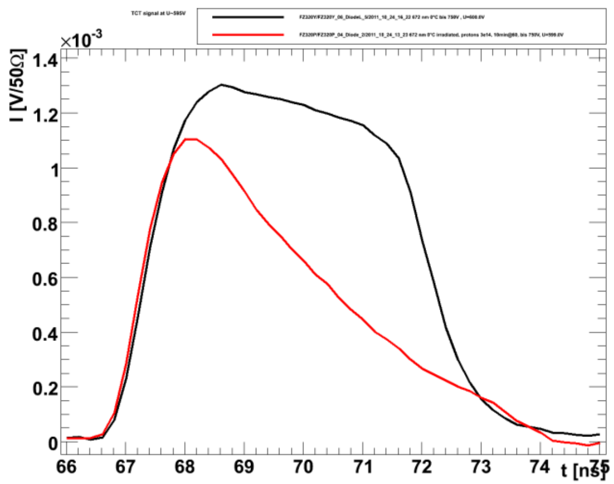
FZ200P




courtesy of T. Pöhlsen

300V

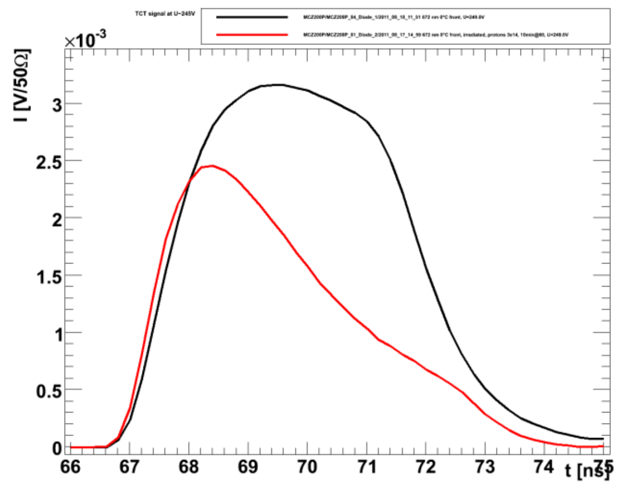
FZ320P




courtesy of T. Pöhlsen

600V

MCZ200P




courtesy of T. Pöhlsen

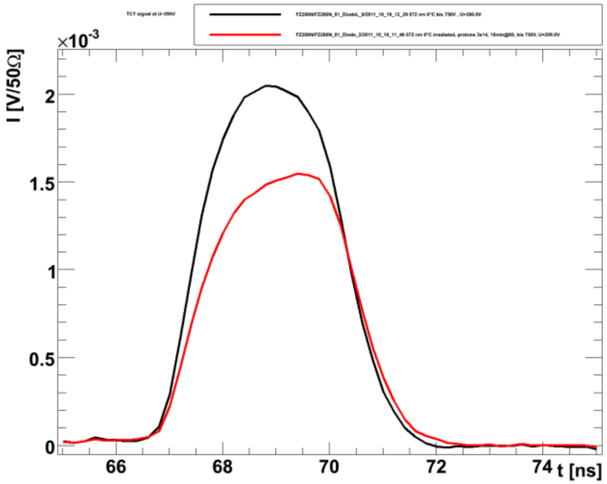
250V

measurements are performed at 0°C, using a red laser

not type inverted

# TCT pulses – n-type

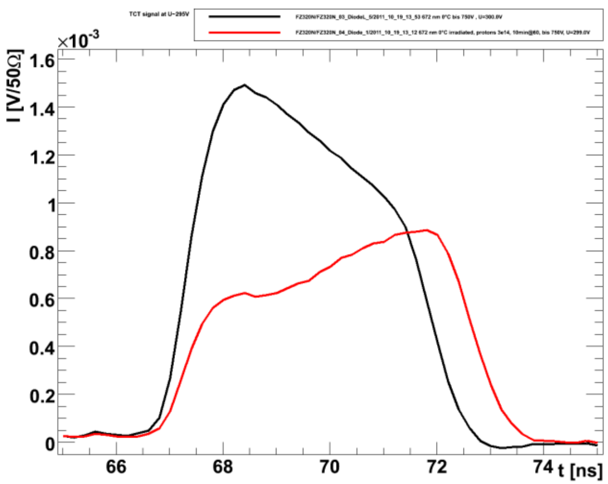
FZ200N




courtesy of T. Pöhlsen

300V

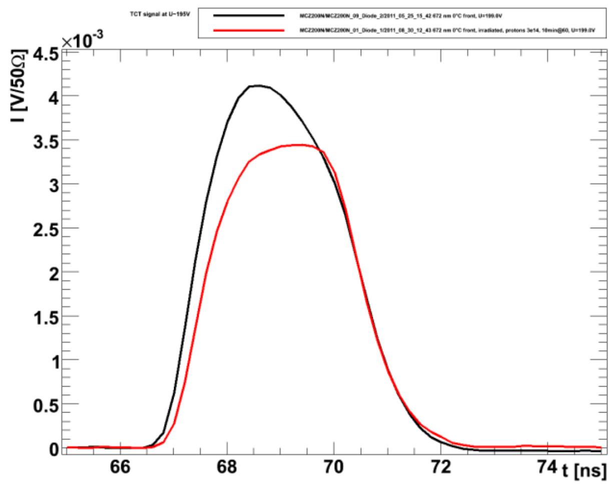
FZ320N




courtesy of T. Pöhlsen

300V

MCZ200N



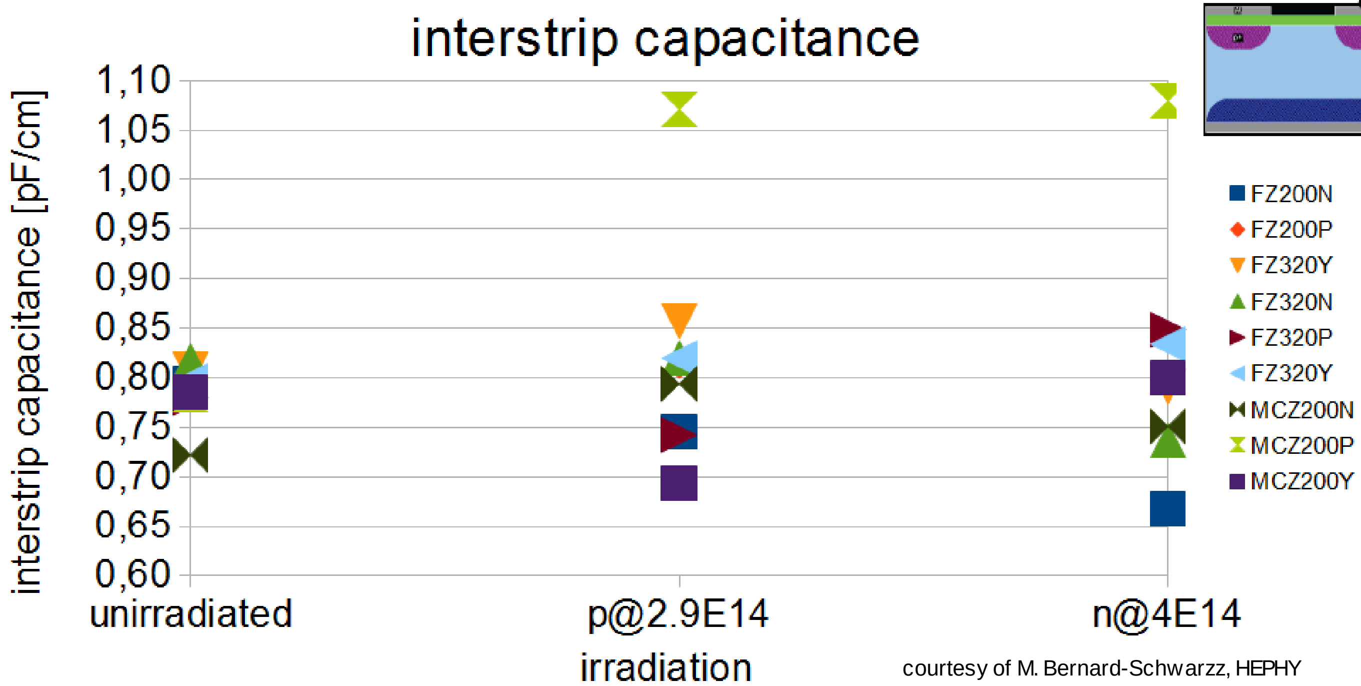

courtesy of T. Pöhlsen

200V

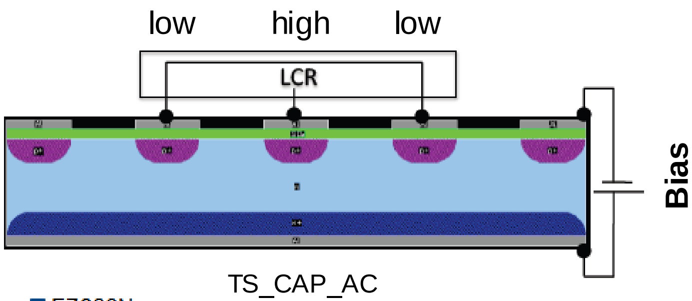
type inverted

measurements are performed at 0°C, using a red laser

# Interstrip capacitance on teststructure after neutron and proton irradiation




courtesy of M. Bernard-Schwarzz, HEPHY



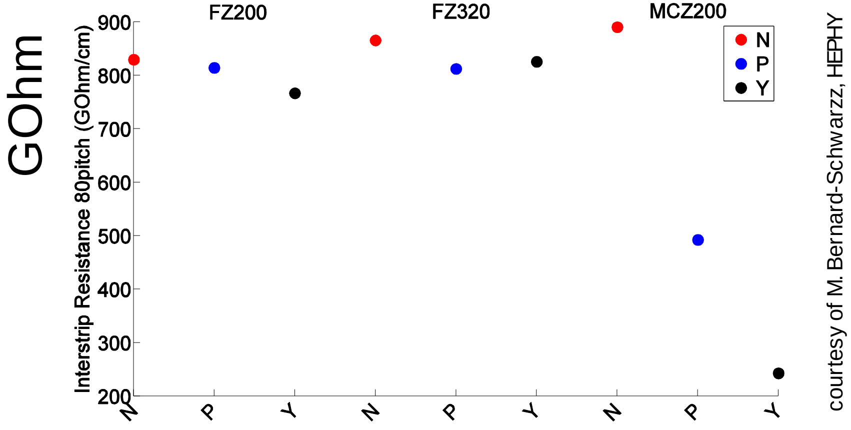

courtesy of M. Bernard-Schwarzz, HEPHY

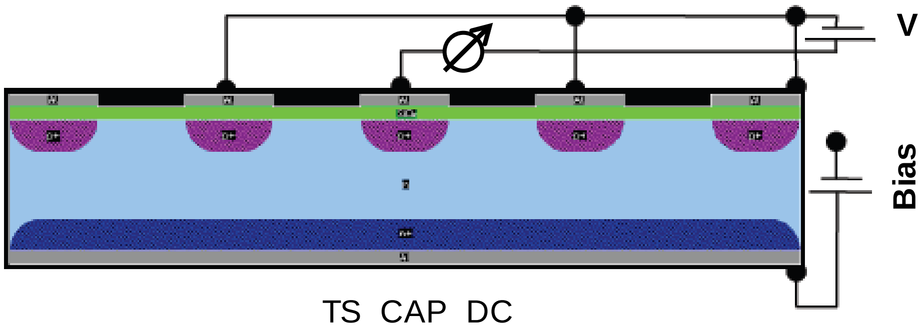
measurements are performed at -20°C, 1MHz

Interstrip capacitance also is stable

# Interstrip resistance on teststructure

unirradiated




TS_CAP_DC

courtesy of M. Bernard-Schwarzz, HEPHY

interstrip resistance in unirradiated material is pretty good.

measurements are performed at -20°C

# Strip structures: measurement of basic properties

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| characteristic | unirradiated | p@3E14 |
|---|---|---|
| coupling capacitance | 43.4 ± 1.8 [pF/cm] | 44.4 ± 0.7 [pF/cm] |
| dielectric breakdown | 249 ± 2 [V] | 244 ± 6 [V] |

| material | unirradiated | p@3E14 | n@4E14 |
|---|---|---|---|
| aluminum | 22 ± 2 mOhm/sq | 20 ± 1 mOhm/sq | 22 ± 1 mOhm/sq |
| poly | 3.7 ± 0.8 kOhm/sq | 3.9 ± 1 kOhm/sq | 4 ± 1.2 kOhm/sq |
| p+ | 120 ± 10 Ohm/sq | 160 ± 10 Ohm/sq | 120 ± 10 Ohm/sq |
| n+ | 29 ± 2 Ohm/sq | 26 ± 6 Ohm/sq | 28 ± 2 Ohm/sq |

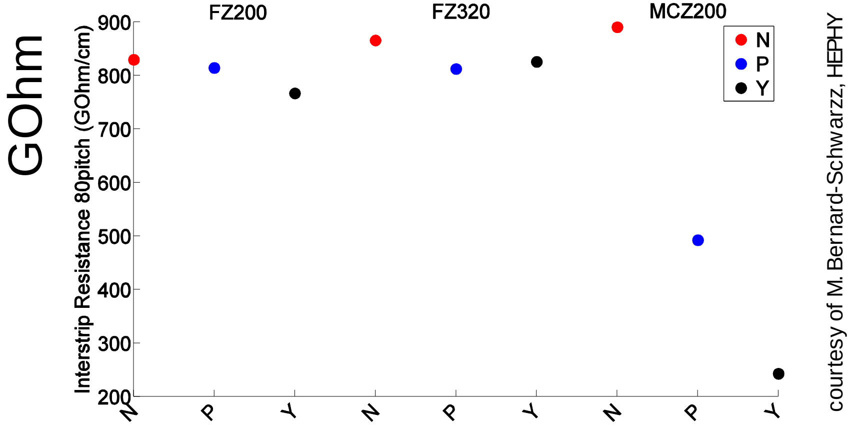
courtesy of M. Bernard-Schwarz, HEPHY

measurements are performed at -20°C, (1kHz)

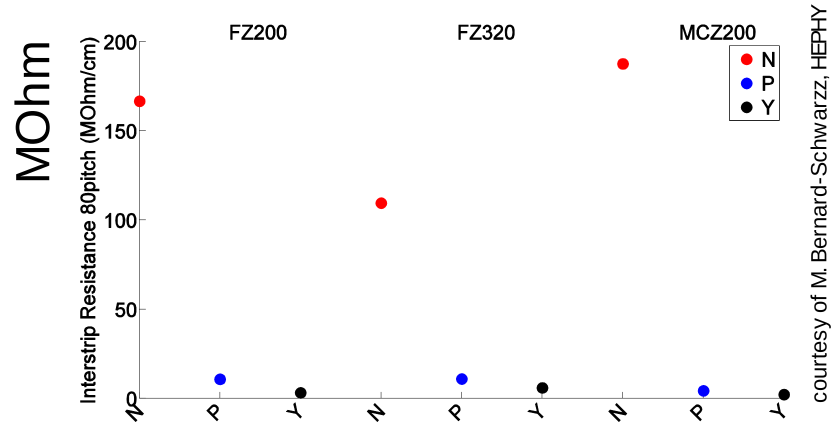
Basic properties don't change at these fluences

# Interstrip resistance on TS

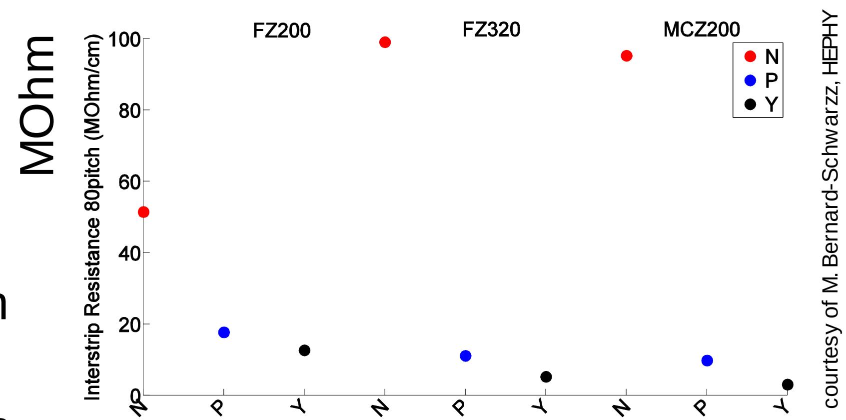
unirradiated




proton irradiated




neutron irradiated




interstrip resistance on teststructures drops from >200GOhm to <200MOhm after irradiation

measurements are performed at -20°C

resistances on baby sensors in similar range

# oxygen content

| material | bulk resistivity | oxide concentration |
|---|---|---|
| FZ320P | 3-8 | 3,50E+016 |
| FZ200P | 3-8 | 3,00E+017 |
| FZ120P | 3-8 | 5,00E+017 |
| FZ320N | 1.2-2.4 | 1,80E+016 |
| FZ200P | 1.2-2.4 | 3,00E+017 |
| FZ120P | 1.2-2.4 | 5,00E+017 |
| MCZ200P | >2 | 3,75E+017 |
| MCZ200N | >0.5 | 3,00E+017 |

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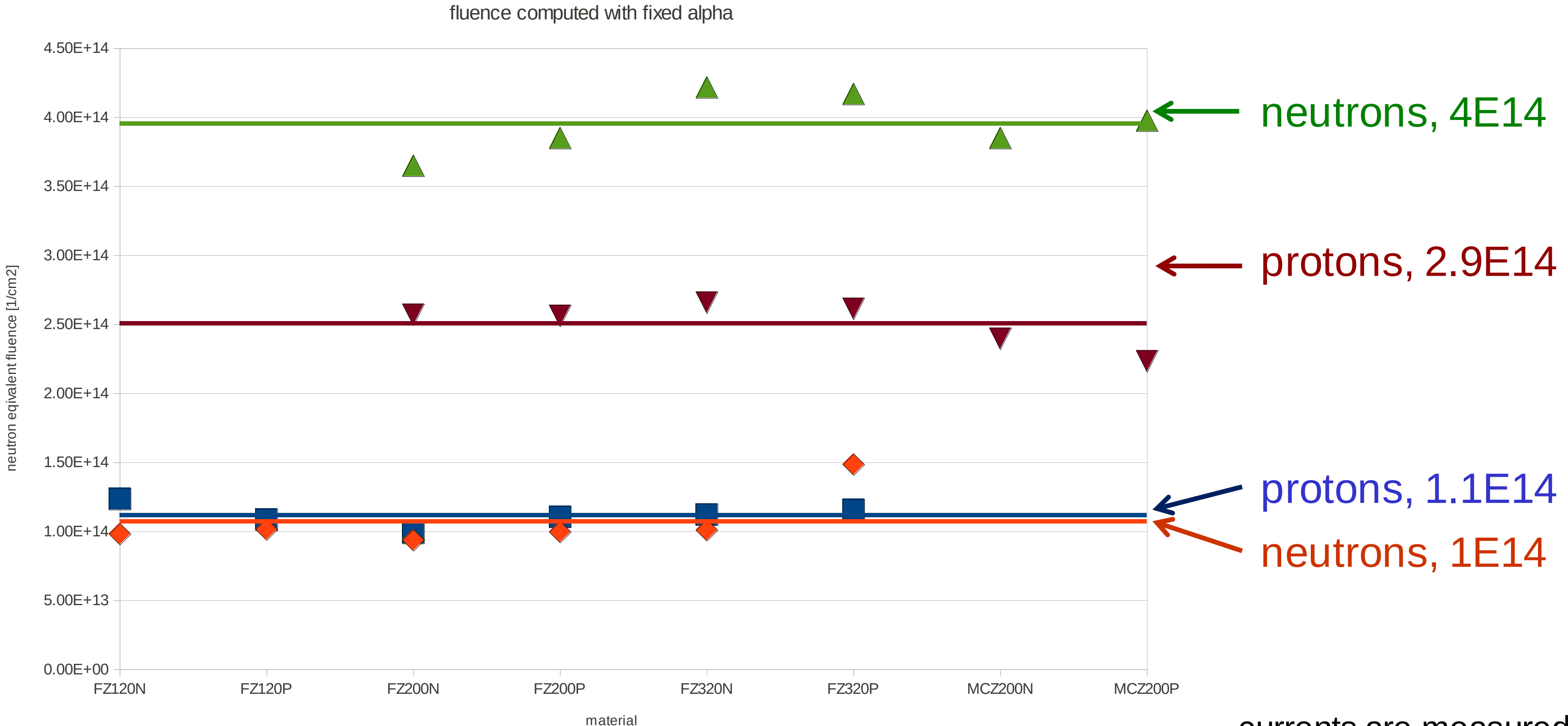
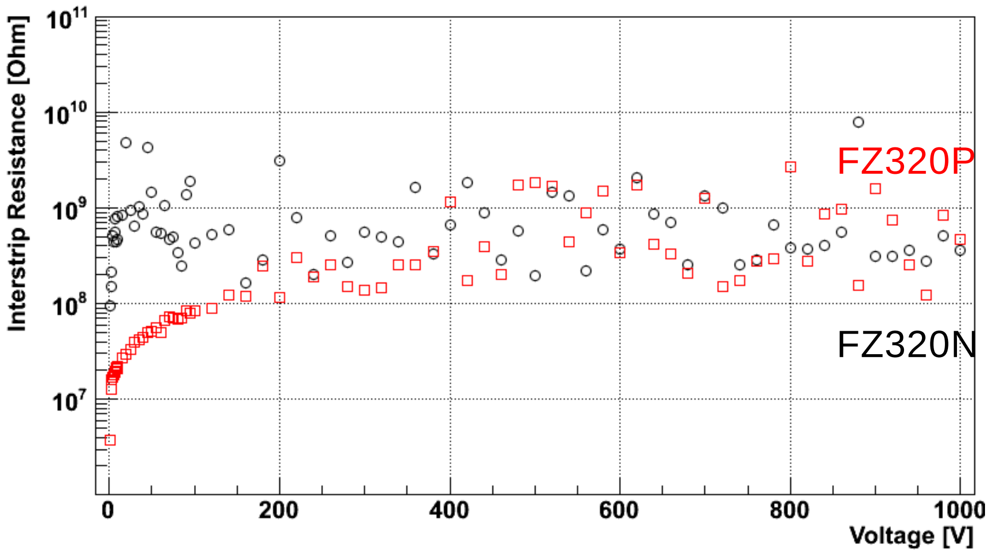
# fluence computed from data with a fixed alpha




currents are measured at 0°C and scaled to 20°C

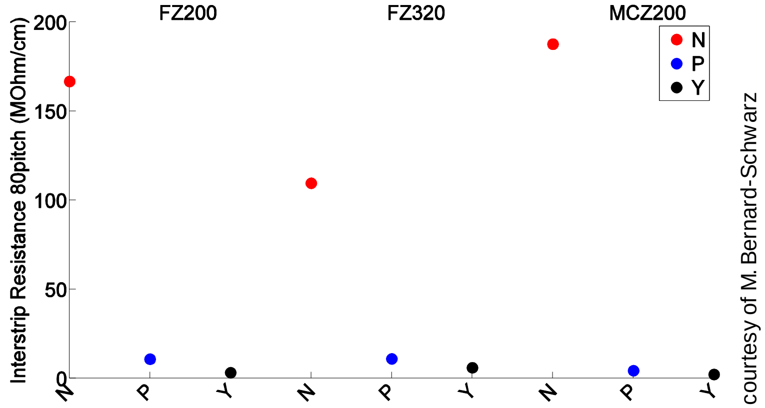
# interstrip resistance on baby sensor

## proton irradiated

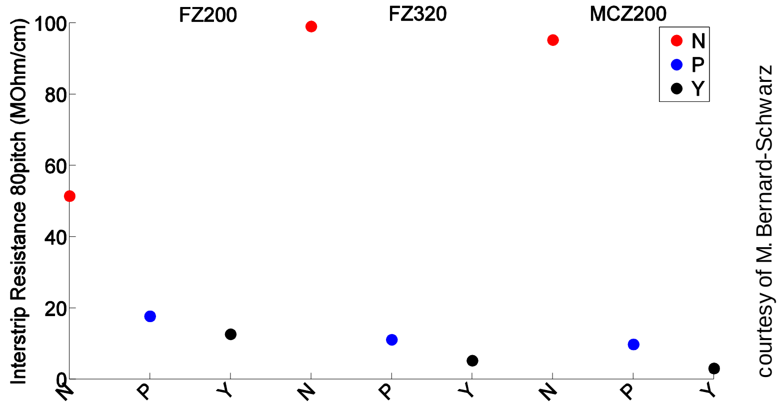



courtesy of K. Hoffmann

## proton irradiated




## neutron irradiated




interstrip resistance drops on baby sensors from >100GOhm to >100MOhm

measurements are performed at -20°C