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PHYSICS AT THE TERA SCALE
Helmholtz Alliance

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

Irradiation study on diodes of different silicon materials for the CMS tracker upgrade

20th RD50 Workshop
30 May – 1 June 2012, Bari

Joachim Erfle
University of Hamburg

On behalf of the CMS Tracker Collaboration

Overview

- Introduction to the CMS irradiation study campaign
- Results of first irradiations
  - Dark current
  - Effective doping concentration
  - Signal collection
- Conclusions

Goals of the HKP-campaign

The main challenges for the tracker at the HL-LHC will be:

- Higher radiation dose (up to a fluence of $\Phi_{eq} = 10^{16}$ cm^{-2})
- Higher occupancy
- Level 1 trigger capability

The current tracker would not withstand the radiation and also develop occupancy problems

→ Find best suitable silicon material a future tracking detector

To achieve that we investigate a large variety of materials:

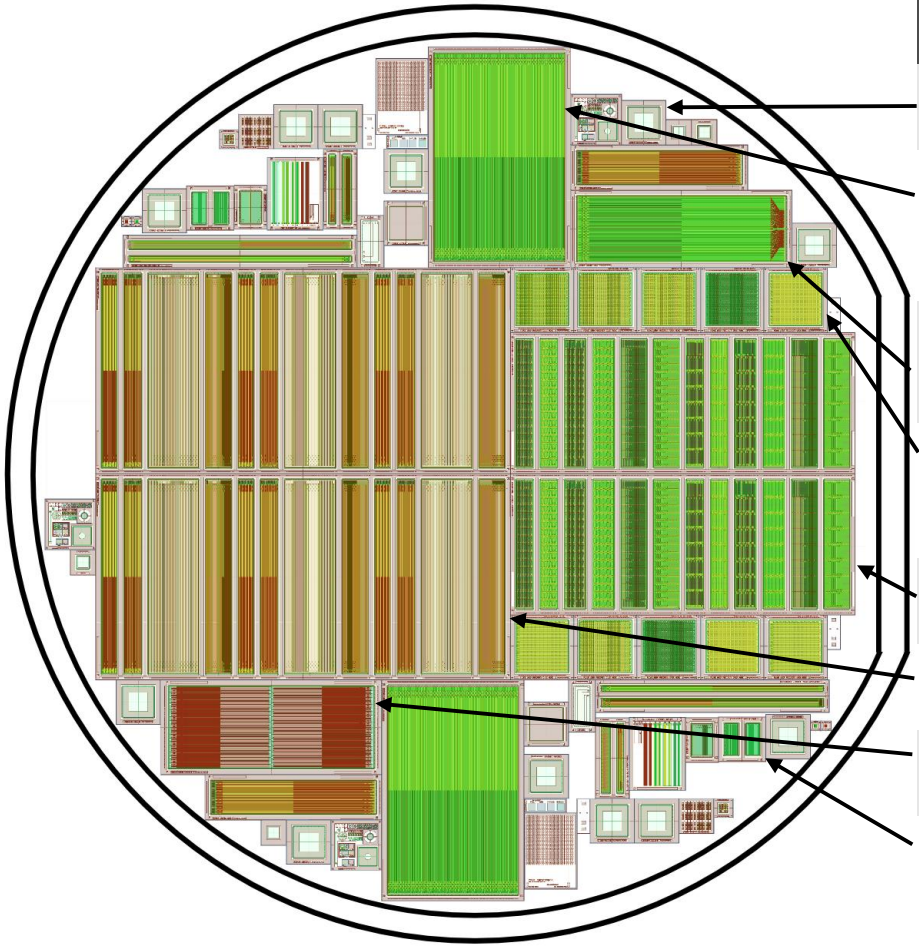
- Different bulk doping (n and p)
- Different fabrication procedures
- Different oxygen content
- Different Thicknesses

Test sensor geometries and layouts

Irradiations with neutrons or/and protons to simulate HL-LHC radiation dose

Wafer overview

6“ Wafer



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

Silicon material

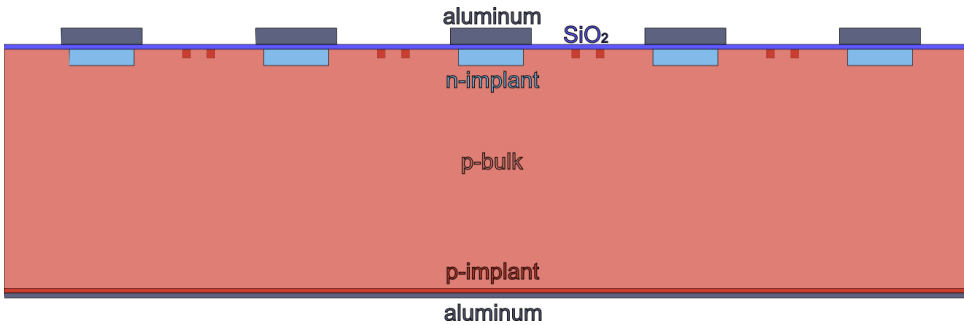
material	thinning method	active thickness [µm]	wafer thickness [µm]	oxygen concentration [10^{17} cm^{-3}]
FZ	deep diffusion	120,200,300	320	5, 3, 1
FZ	---	200	200	
FZ	handling wafer	120	320	
MCz	---	200	200	4
Epi	---	50,100	320	1,1

Of each material there are 3 different types:

- n-type (N)

Two different strip isolation technologies for p-bulk:

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



Irradations

radius	protons Φ_{eq} [cm^{-2}]	neutrons Φ_{eq} [cm^{-2}]	total Φ_{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

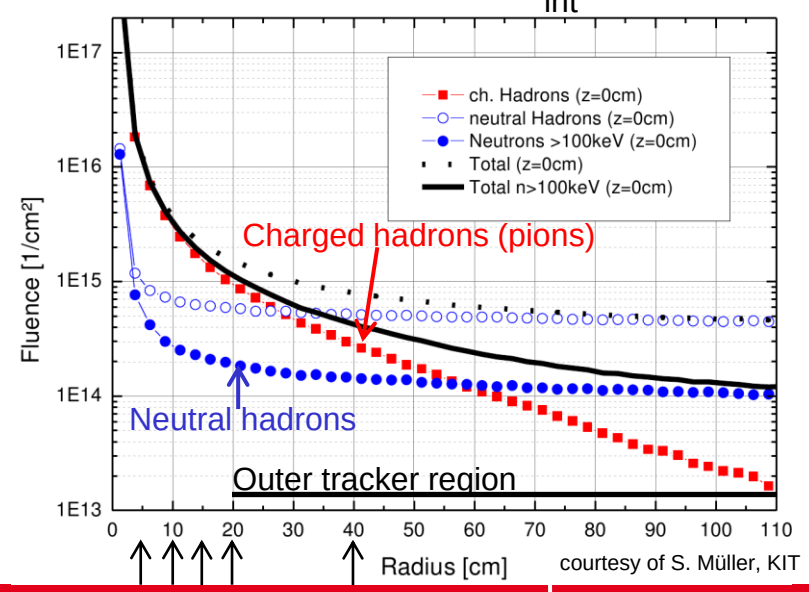
Neutrons: 1 MeV (TRIGA Reactor Ljubljana)

Protons: 23 MeV (Karlsruhe cyclotron)

23 GeV (CERN PS)

→see talk of Coralie Neubüser

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



courtesy of S. Müller, KIT

Volume current versus fluence

■ N-Type
◇ P-Type

n
Neutron irradiated

p-M/G eV
Proton irradiated

■ FZ 200 µm
■ FZ 320 µm
■ MCz 200 µm
Expectation from M. Moll

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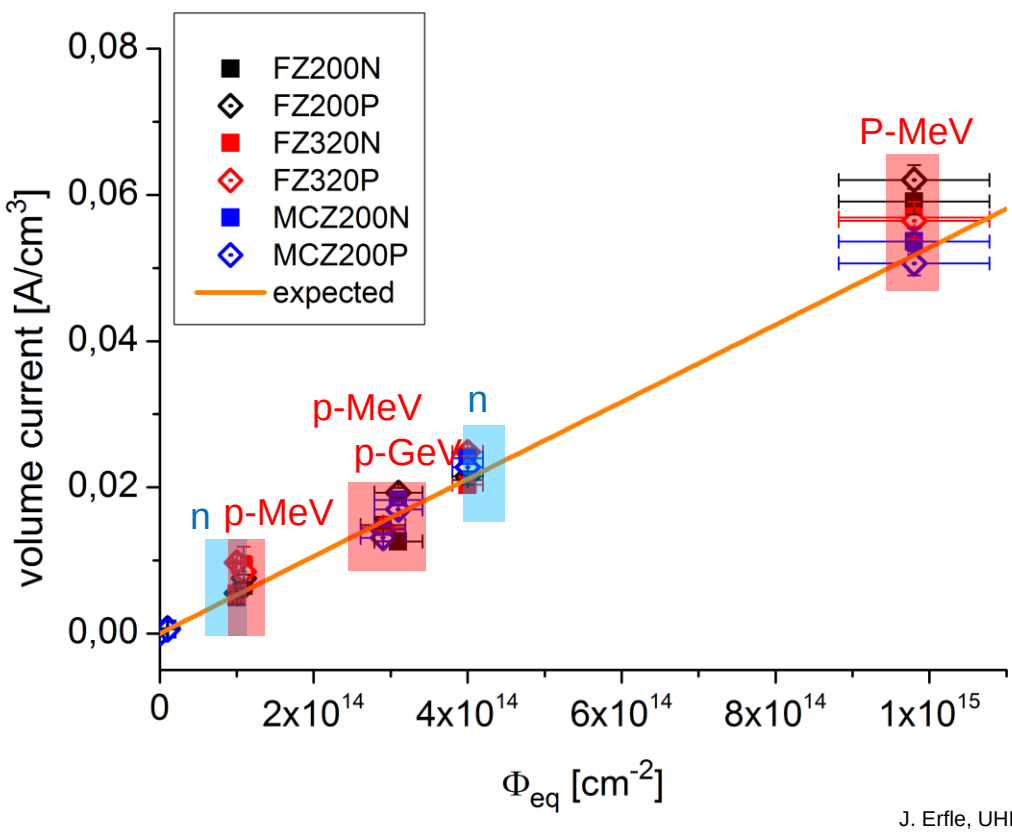

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$$\frac{\Delta I}{V} = \alpha \Phi_{eq}$$

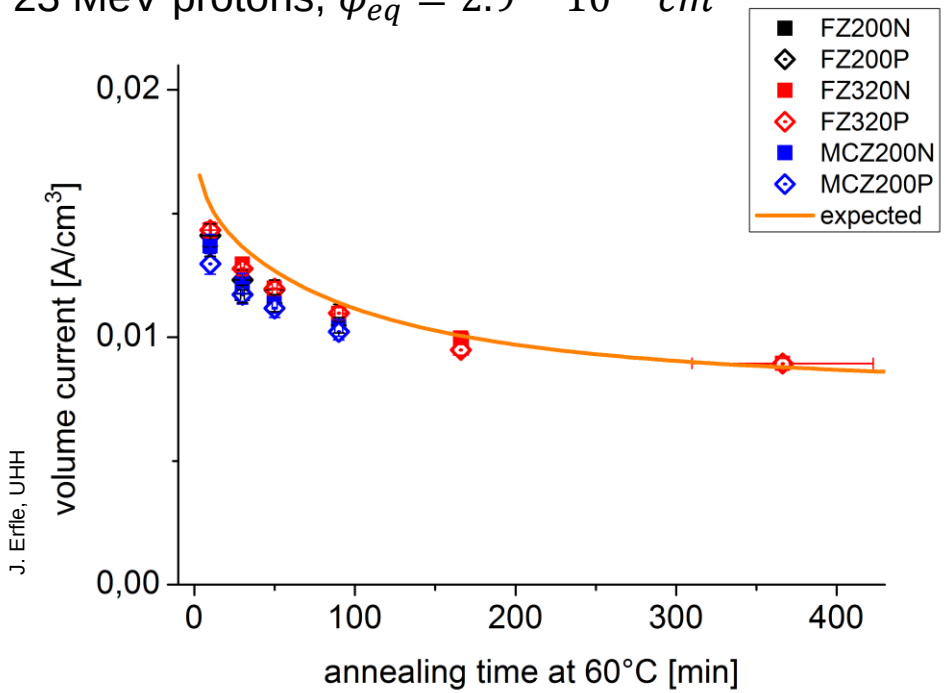
$$\alpha = 5{,}0 \pm 0{,}6 \cdot 10^{-17} A/cm$$
$$\alpha_{Moll} = 5{,}3 \cdot 10^{-17} A/cm$$

volume current scales with fluence as expected, independent of silicon material (oxygen content).
→ NIEL scaling works.

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

Current annealing of irradiated samples

23 MeV protons, $\phi_{eq} = 2.9 \cdot 10^{14}\ cm^{-2}$



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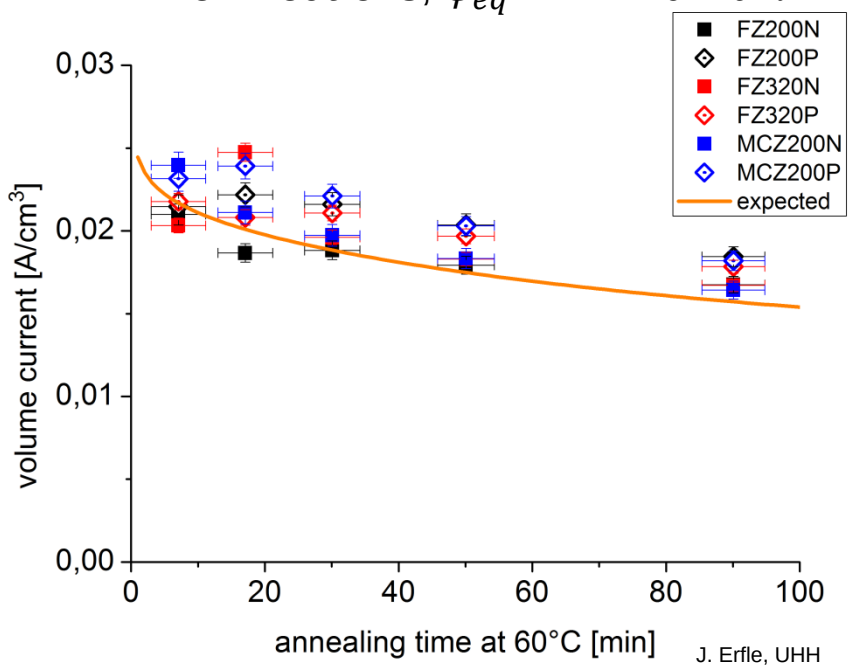
1 MeV neutrons, $\phi_{eq} = 4 \cdot 10^{14}\ cm^{-2}$



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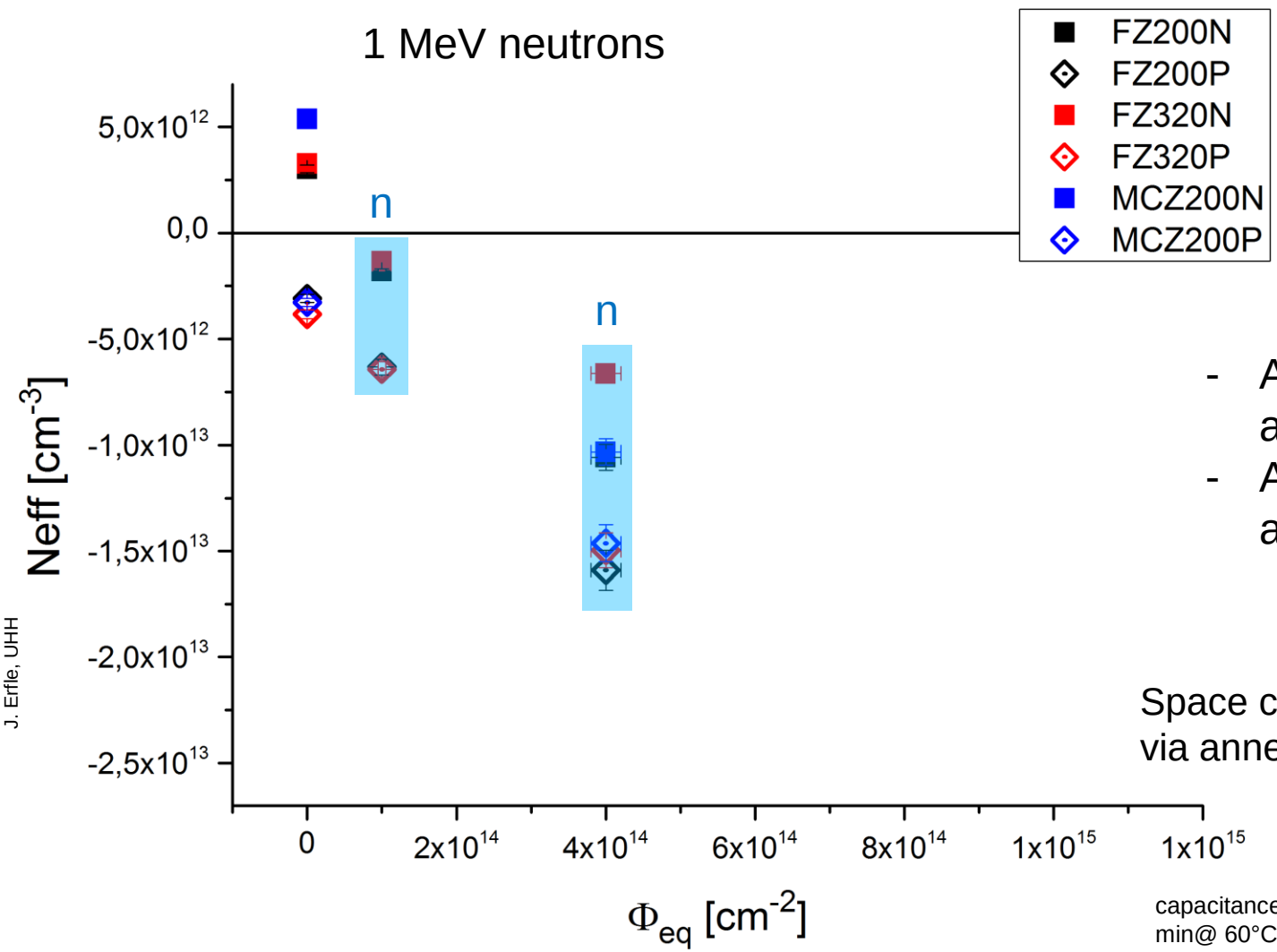
Current annealing matches expectation.

currents are measured at 0°C and scaled to 20°C, guard ring grounded

N_{eff} versus fluence

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



- All n-type materials are type inverted
- All p-type materials are not type inverted

Space charge sign determined via annealing and TCT.

capacitances are measured after annealing of 10 min@ 60°C at 0°C, 1kHz, guard ring grounded

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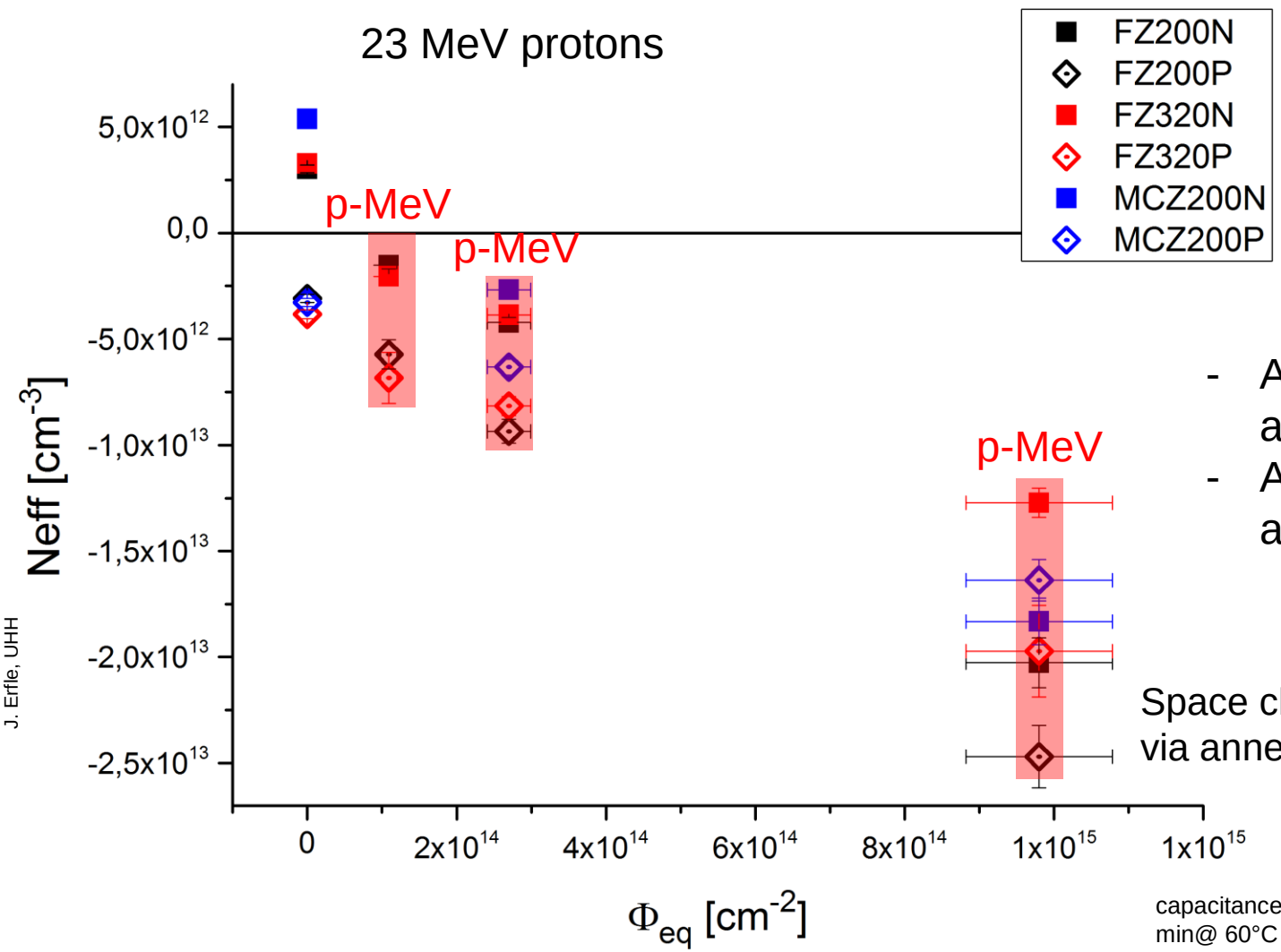

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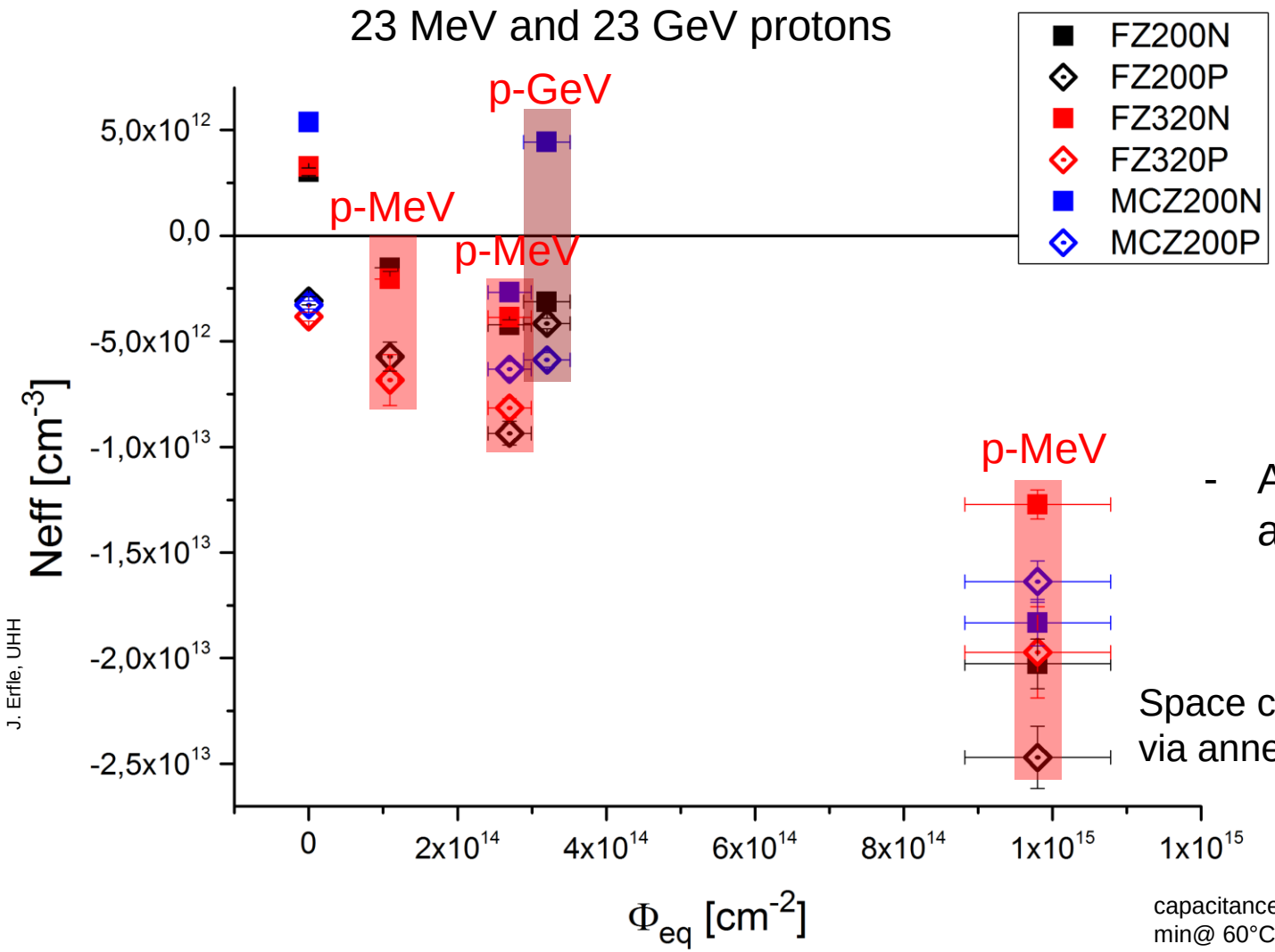

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N_{eff} annealing of irradiated samples

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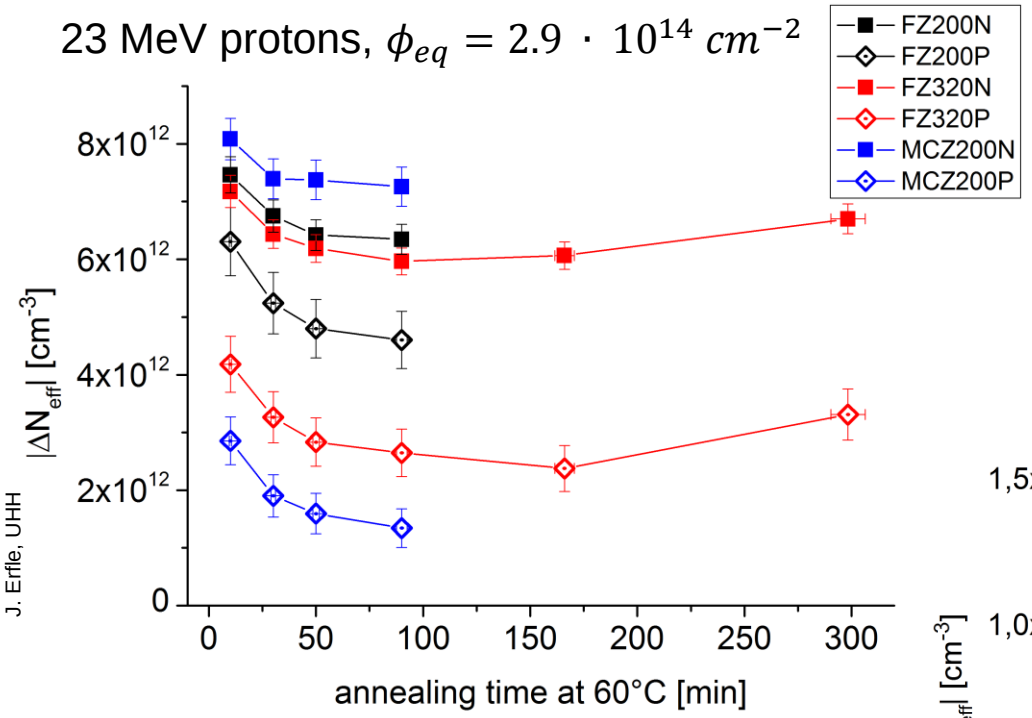
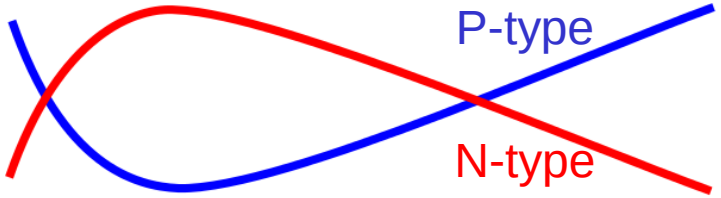
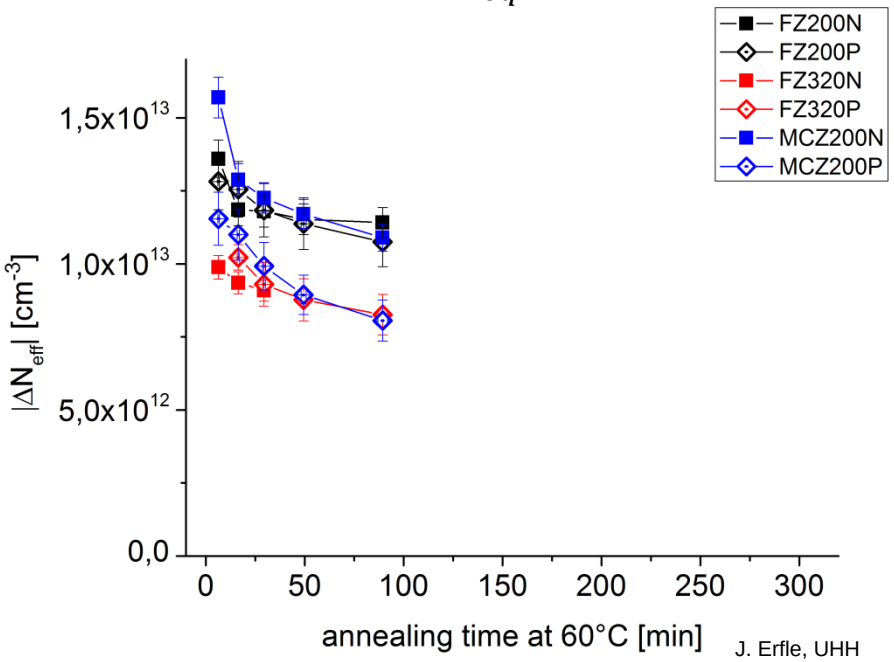




acceptor removal (short term annealing)

1MeV neutrons, $\phi_{eq} = 4 \cdot 10^{14}\ cm^{-2}$



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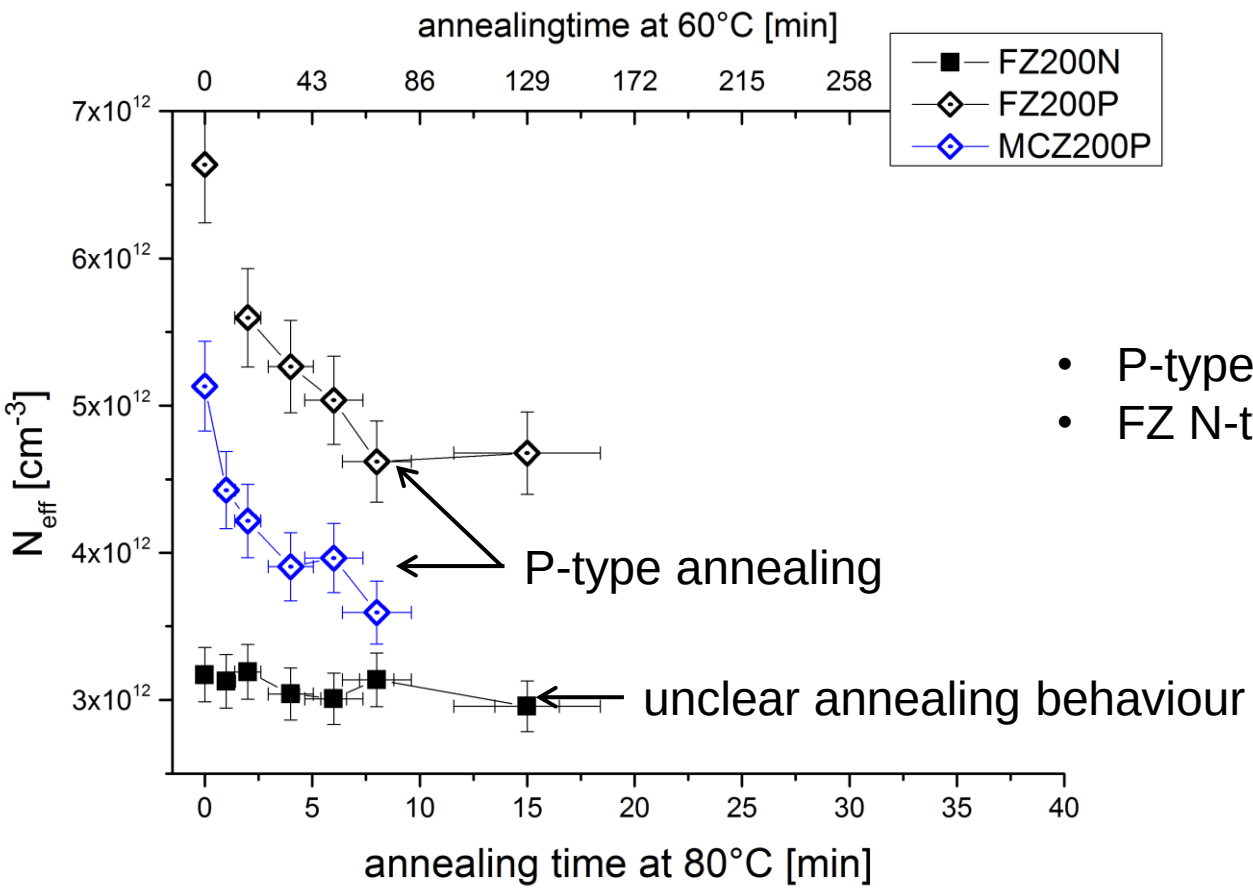
Annealing curves of N_{eff} of all samples irradiated with neutrons or 23 MeV protons show p-type behaviour

capacitances are measured after annealing of 10 min@ 60°C at 0°C, 1kHz, guard ring grounded

Annealing after 23GeV proton irradiation

23 GeV Protons, $\phi_{eq} = 3.1 \cdot 10^{14}\ cm^{-2}$



- P-type materials not type inverted
- FZ N-type not clear.

Annealing after 23GeV proton irradiation

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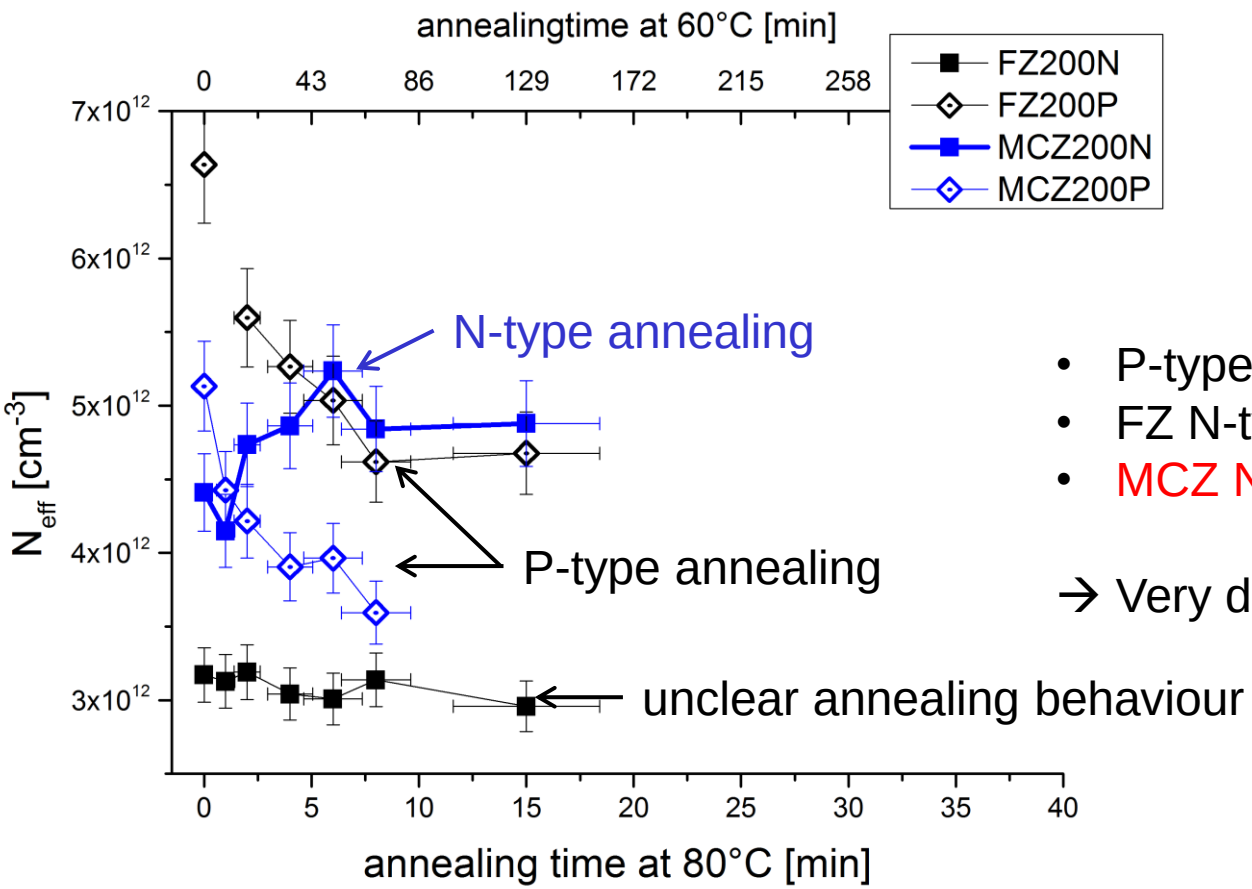
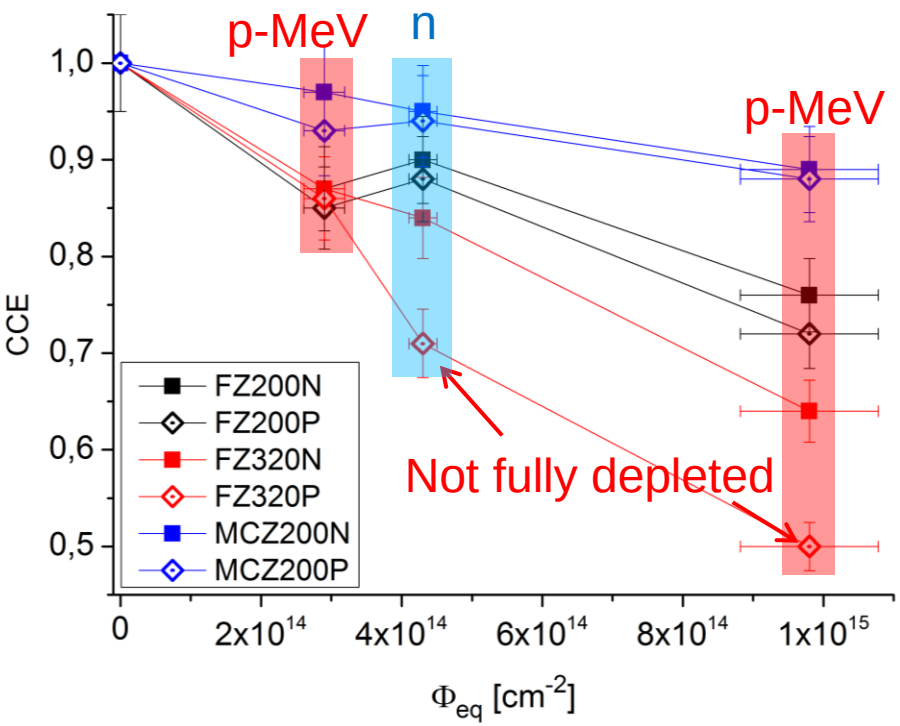


- P-type materials not type inverted
- FZ N-type not clear.
- MCZ N-type type inverted

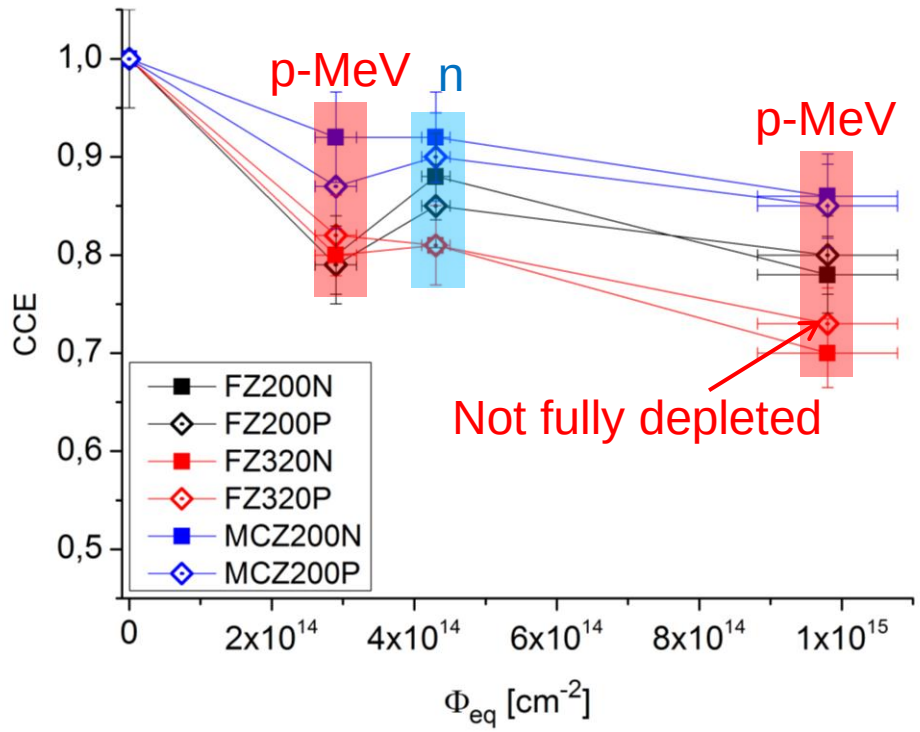
→ Very different from 23MeV protons

Charge Collection Efficiency

Charge Collection Efficiency at 600V



Charge Collection Efficiency at 100V over depletion



→ Thick material is not beneficial anymore: High depletion voltage and more effected by trapping
→ MCz seems promising

Conclusions and outlook

- Diodes have been studied to find radiation hard material. So far, performed irradiation studies corresponding to HL-LHC fluences expected at the CMS tracker at radii of 40 and 20 cm.
- Diode currents increase as a function of fluence as expected
- Depletion voltage and TCT show:
  - type inversion for all n-type materials
  - no type inversion for p-type, with steep increase

    → Not expected → Also irradiations at the PS with 23GeV protons
- CCE reduced to ~70-90% after 1E15 23MeV proton irradiation

- More irradiations to come: Higher fluences, different energies!
- Trying to understand material properties in detail
- Full annealing studies to be done

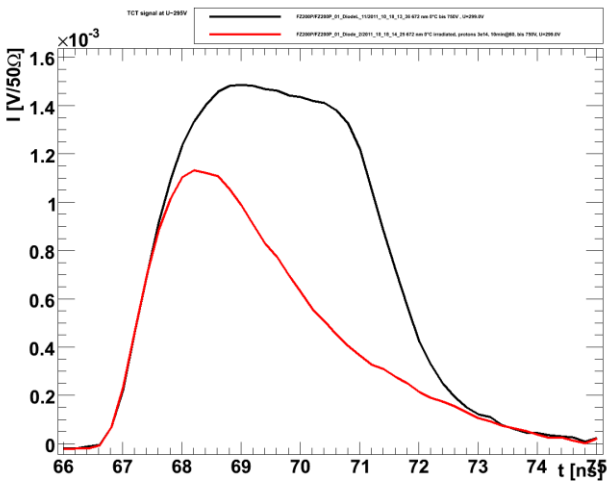
Backup

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

TCT pulses – p-type

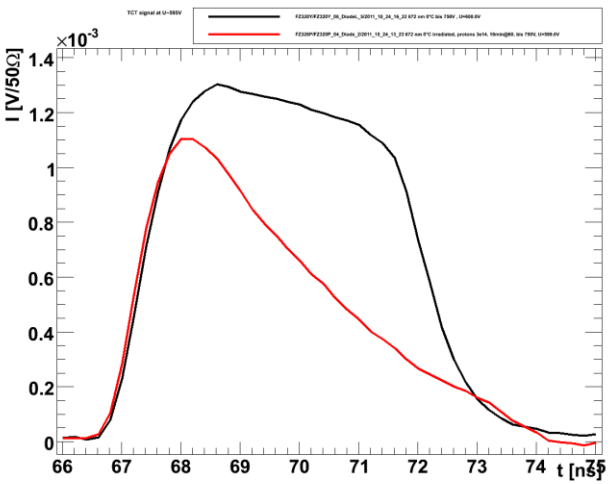
FZ200P



courtesy of T. Pöhlsen

300V

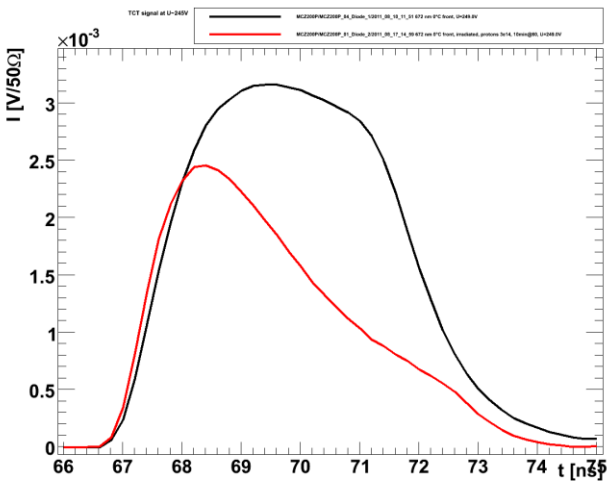
FZ320P



courtesy of T. Pöhlsen

600V

MCZ200P



courtesy of T. Pöhlsen

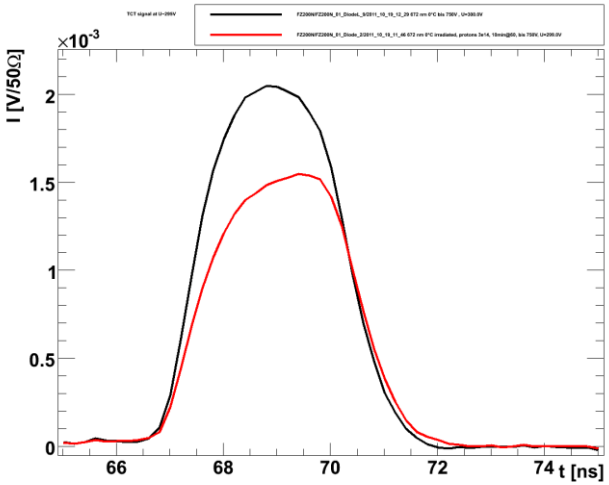
250V

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

not type inverted

TCT pulses – n-type

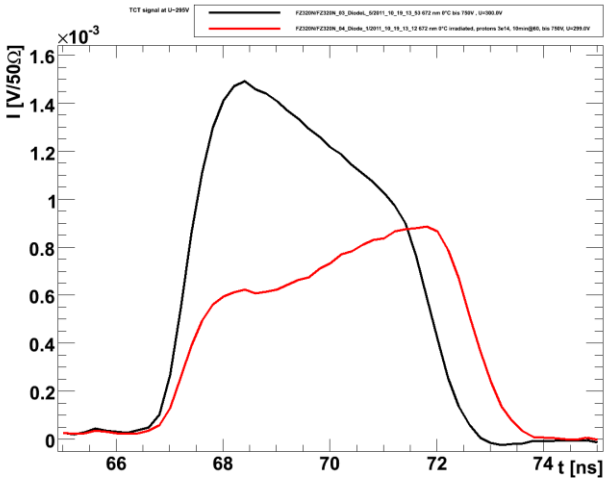
FZ200N



courtesy of T. Pöhlsen

300V

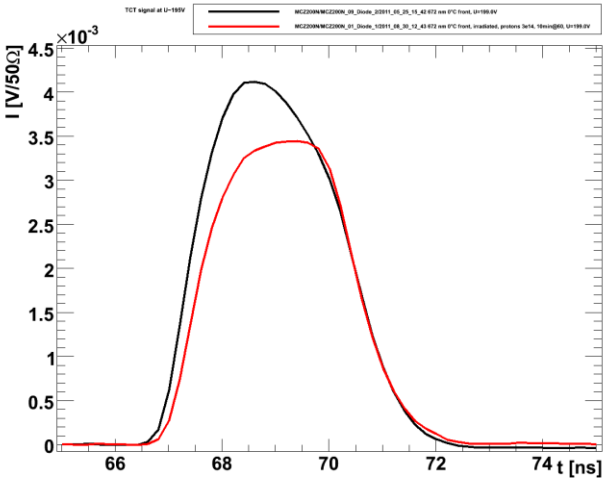
FZ320N



courtesy of T. Pöhlsen

300V

MCZ200N



courtesy of T. Pöhlsen

200V

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

type inverted