Silicon Sensor Developments for the CMS Tracker Upgrade

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On behalf of the CMS Tracker Collaboration

Overview

- Motivation
- Measurement campaign overview
  - Why new sensors?
  - What is done?
- What materials are studied?
- Test structures
  - Which structures are studied?
  - Some basic structures
- Some new strip layouts
- First results

Motivation for new materials

Phase II Upgrade:

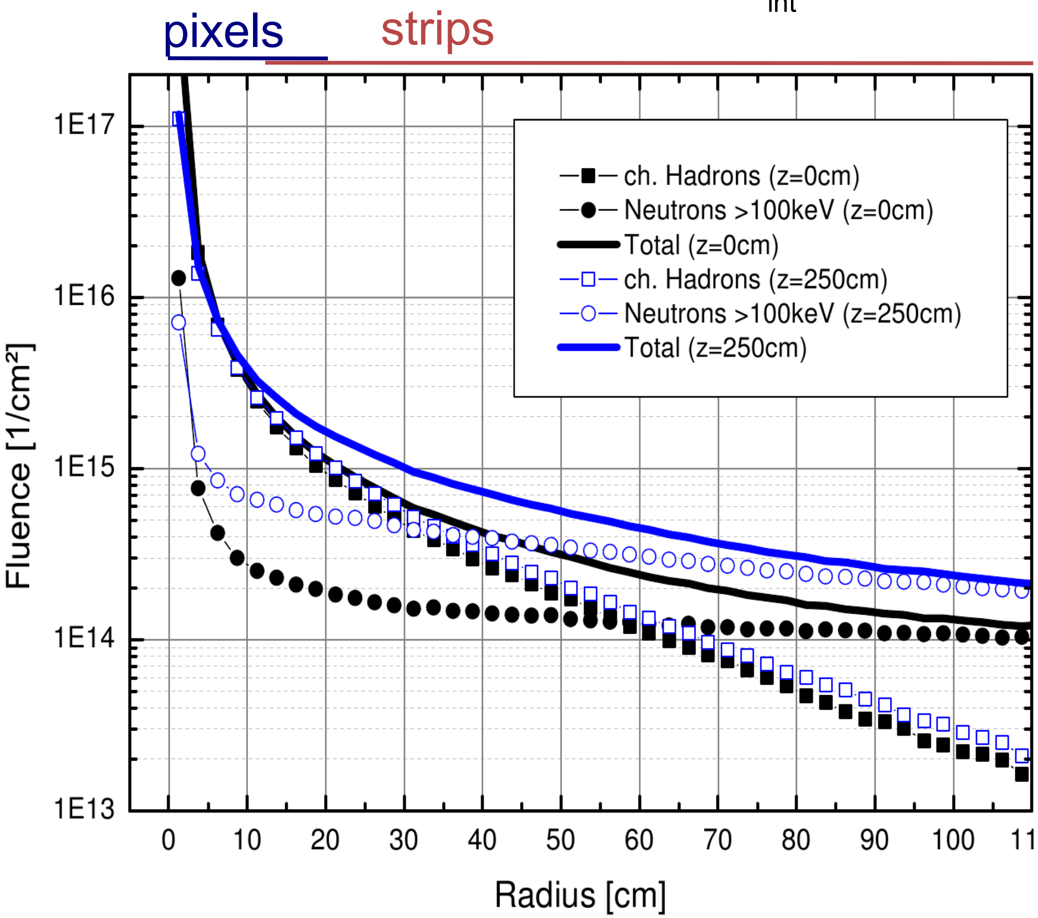
- Higher radiation
  - Higher leakage current
  - Higher operation voltage
  - Less signal

→ Radiation harder sensors
  - More radiation hard material
  - More radiation hard layouts

- Higher occupancy
  - Multiple signals on one channel more likely

→ Higher granularity
  - e.g. shorter strips

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



New sensors of new material needed

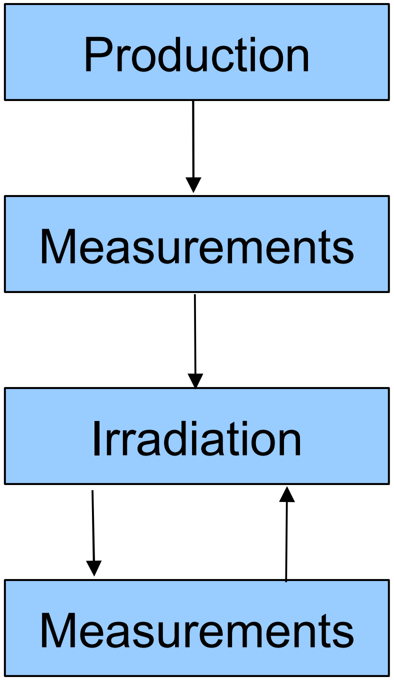
- There is already knowledge about possible materials (e.g. MCz, p-type bulk)
- In order to define the baseline for the phase II upgrade a large campaign has been started with the participation of a significant number of institutes
- For best comparability different materials and structures are ordered from one high quality producer

The campaign has different goals:

- Find best material (wafer doping, thickness doping-type)
- Find best sensor layout
- Test some new layouts

Measurement Campaign Introduction

- All materials will be irradiated to the same fluences and undergo the same measurements
- There are different structures for different purposes
  - Standard structures (for material studies)
  - Some new layouts
  - Structures for tuning of geometries
- Main measurements:
  - IV/CV - understanding the material basics
  - TCT – understanding the shape of signals in the material
  - R and C – understanding the structure-parameters
  - CCE (with LHC-readout) – understanding the signal height



Production

Measurements

Irradiation

Measurements

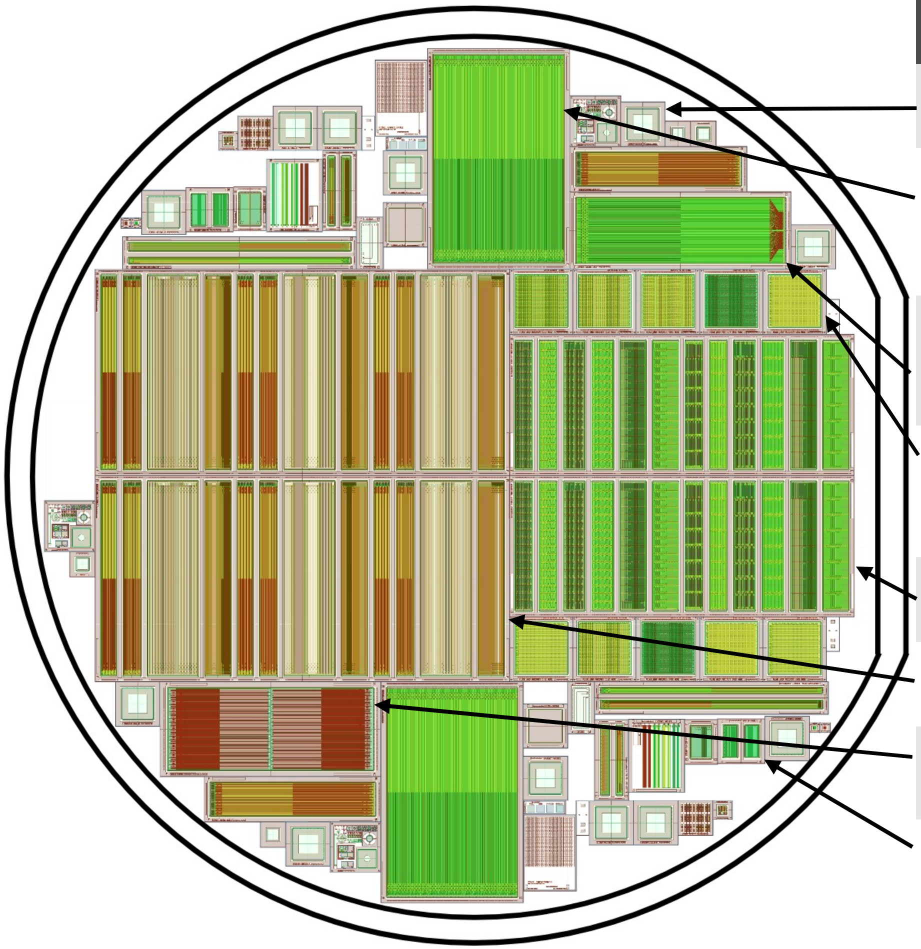
Material and irradiations

- 6 wafers of each bulk doping (N, P (with P-stop), P(with P-spray))
- 18 wafers of
  - FZ 320µm, FZ 200µm and FZ 120µm active thickness (all physical 320µm thick, thinned by deep diffusion)
  - FZ 200µm (physical thickness), FZ 120µm (active thickness, on handling wafer)
  - Mcz 200µm (physical thickness)
  - Epi 100µm and Epi 50µm (on substrate)
- In total 140 wafers

Planned irradiation fluences (in E14 [cm^{-2}]):

Radius	Protons	Neutrons	Ratio p/n	Total	Material
40 cm	3	4	0,75	7	≥ 200 µm
20 cm	10	5	2,00	15	all
15 cm	15	6	2,50	21	all
10 cm	30	7	4,29	37	all
5 cm	130	10	13,00	140	< 200 µm

Wafer overview

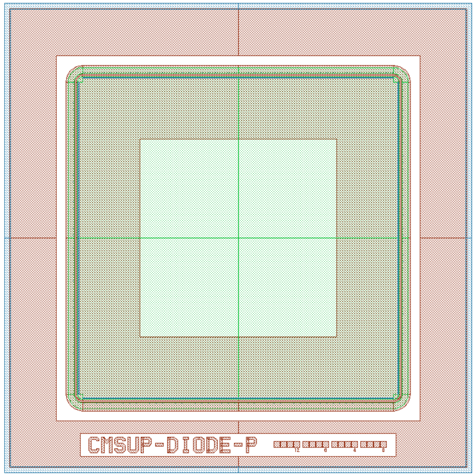


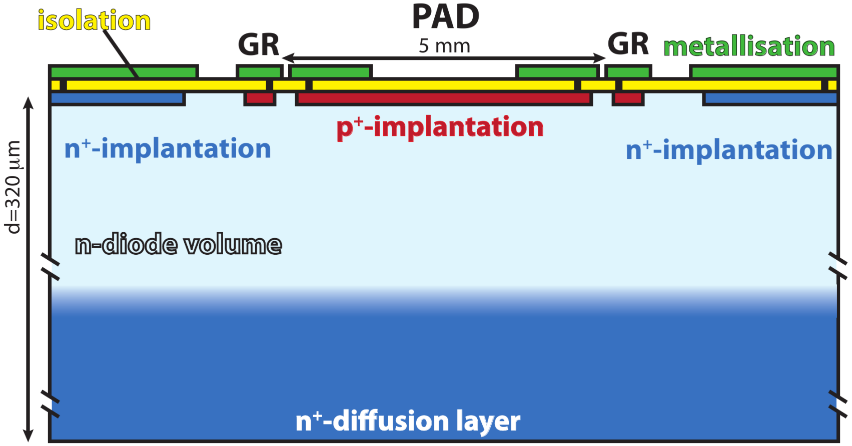
Structure	To study
Diodes	Material
Baby standard	Reference Design / Material
Baby with integrated pitch adapter	Design
Pixel	Reference Design / Material
Multigeometry Pixel	Layout parameters
Multigeometry Strips	Layout parameters
Baby strixel	Design
Teststructures	Process parameters

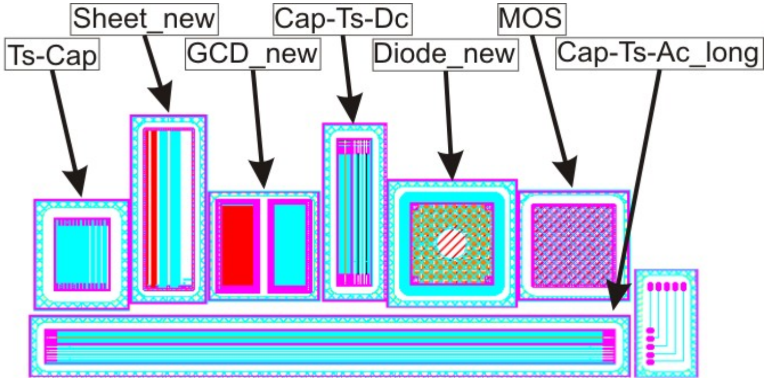
Some basic structures in detail

Diode:

- Structure to determine bulk properties (N_{eff} V_{dep})



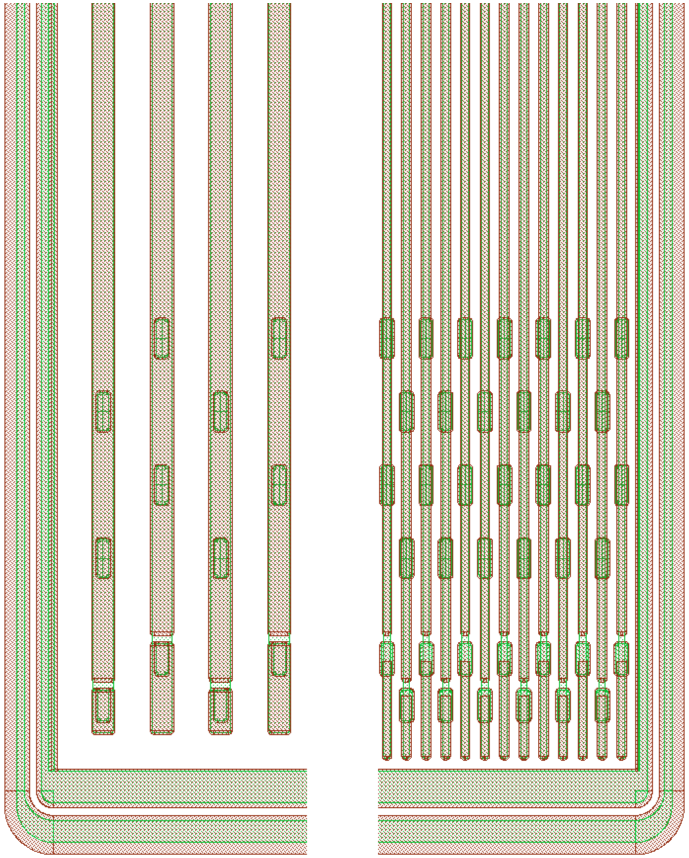




- Different structures to determine electrical characteristics of the process (capacities and resistances of different implant/poly layers)

Multi geometry Structures

Multi geometry strips

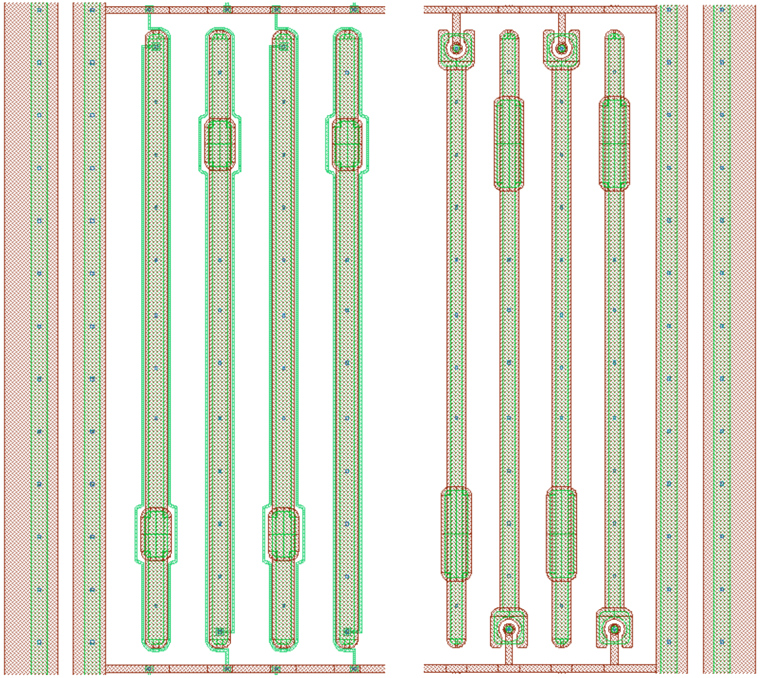


12 regions:

- 4 pitches
- 12 widths and overhangs

Aim:

Find best geometrical parameters for strips/pixels



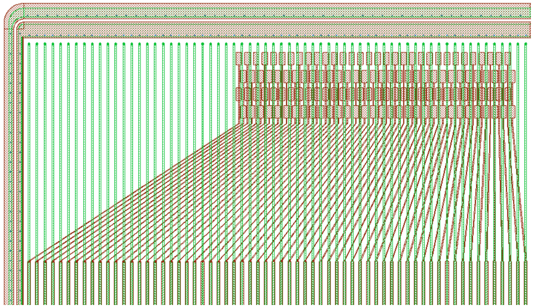
Multi geometry pixels

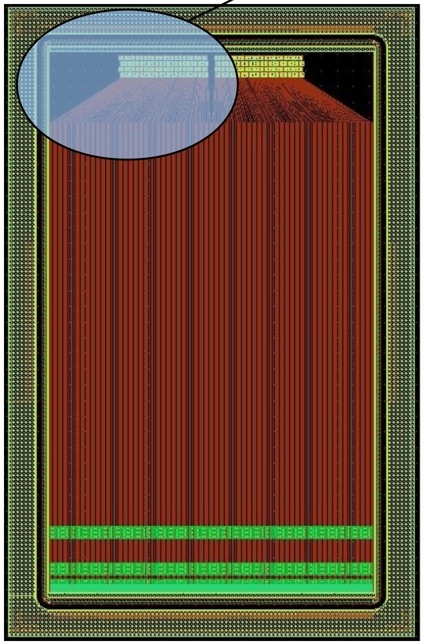
12 regions:

- 2 different bias technologies (punch-through and poly-silicon)
- 3 different width/pitch ratios
- 2 different pixel lengths

Some new layouts

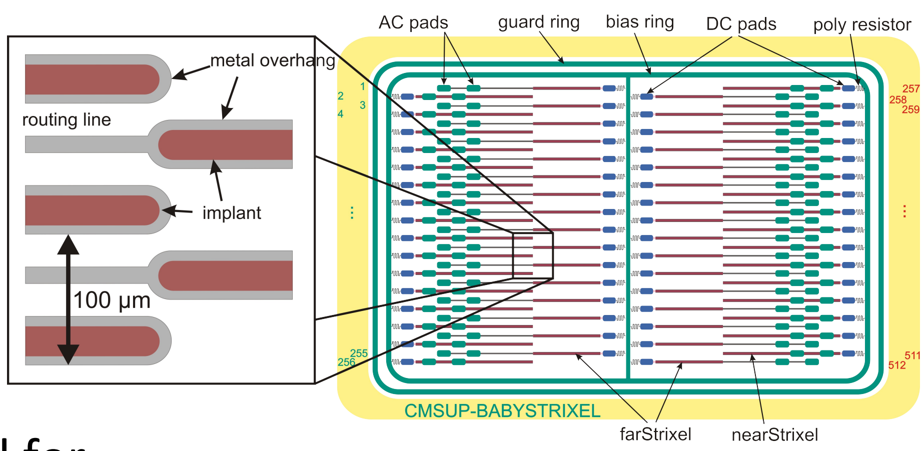
Strip sensor with integrated pitch adapter





- Pitch adapter needed for readout-chip connection
- Is it possible to integrate it on the sensor without loosing active area?

short-strip-sensor



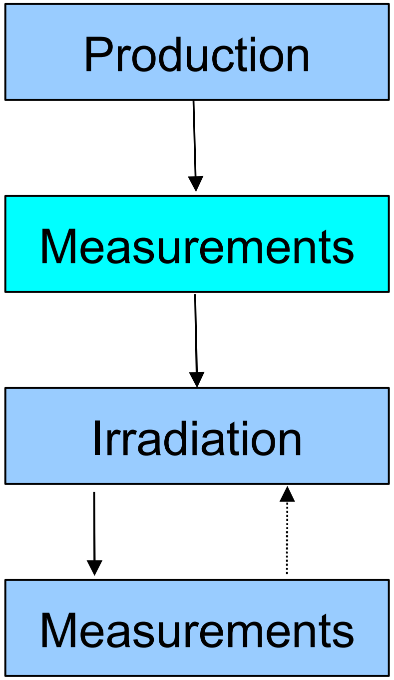
- Idea to reduce occupancy and increase resolution

Measurements of unirradiated sensors

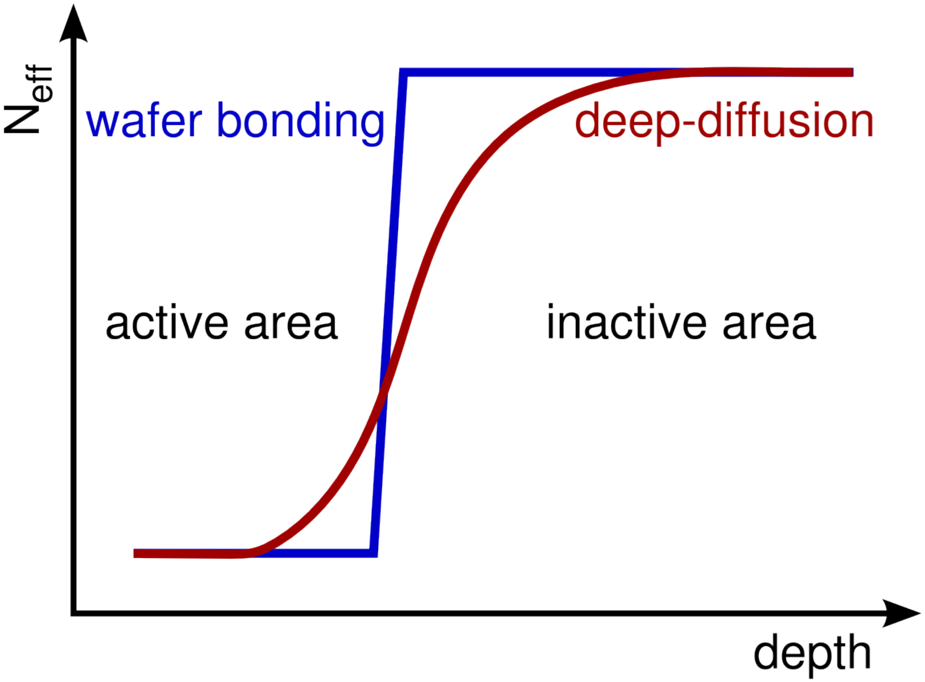
First: understand raw material

- Characterize wafers
- Check process reproducability
- Check for inhomogeneities inside wafers
- Check for material impurities and defects

→ to understand results after irradiation



Wafer-Processing (of the thin FZ-part)



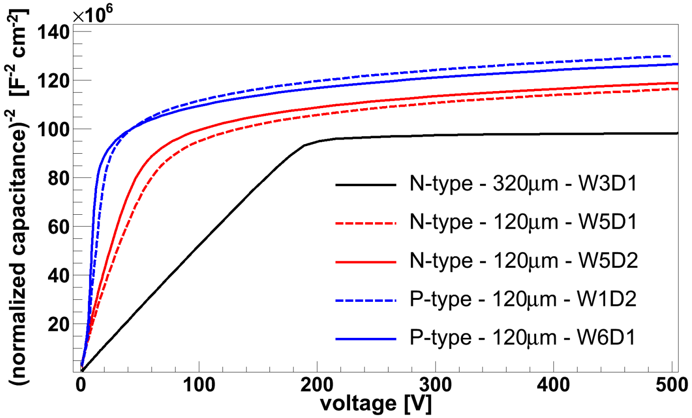
- Standard method:

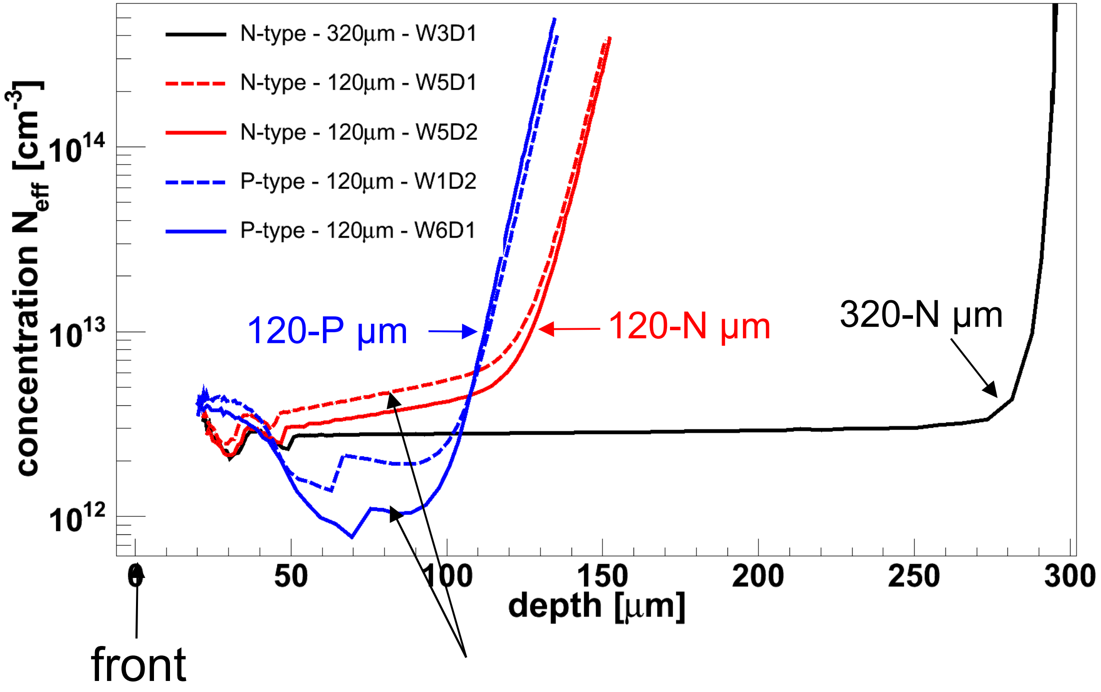
  wafer bonding
  - Well known process
  - Relatively expensive
- For deep diffusion a 320µm wafer is used but the active volume volume is reduced by diffusing high doping from the back
  - New process
  - Cheaper

Diode characteristics of thin FZ

Concentration profile from CV-curve

$$\text{depth} = \frac{\epsilon \cdot A}{C} \qquad N_{eff} = \frac{\frac{2 \cdot \Delta V}{\Delta(C^{-2})}}{q \cdot \epsilon \cdot A^2}$$



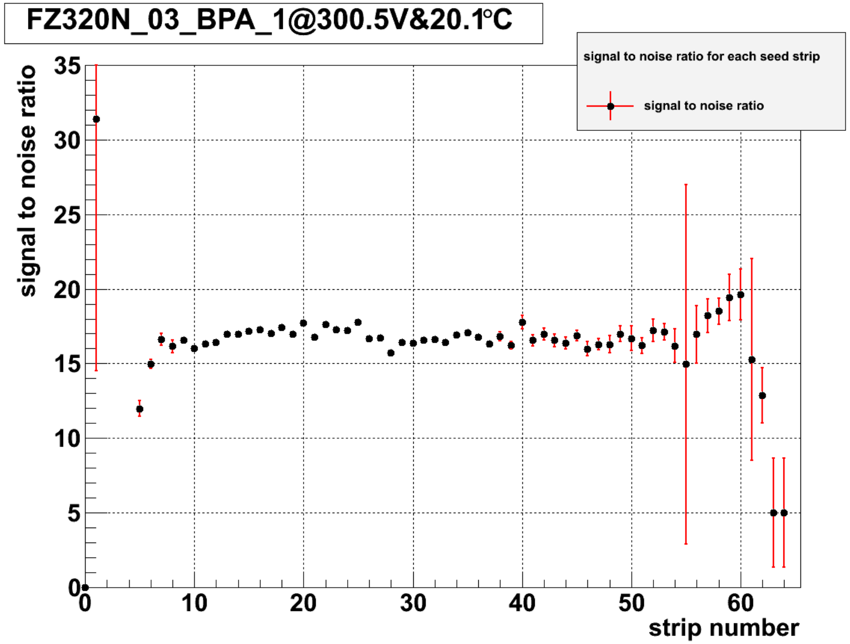


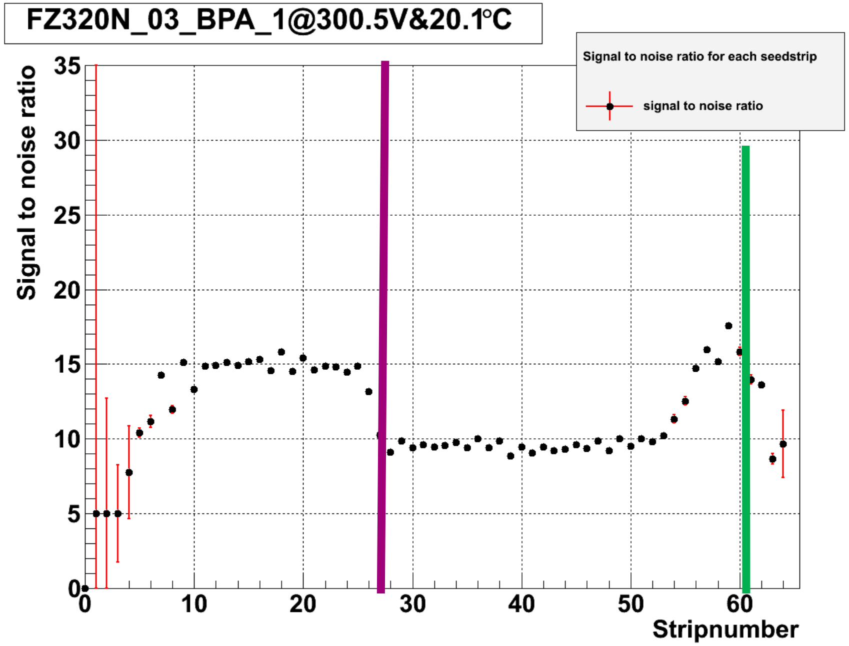
Diodes behave like parallel-plate capacitors

→ measure capacitance vs voltage to determine depletion depth and charge carrier concentration

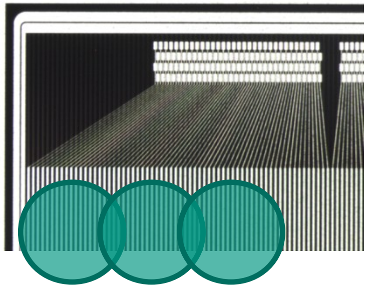
Deep diffusion influences effective doping

First results for integrated pitch adapter



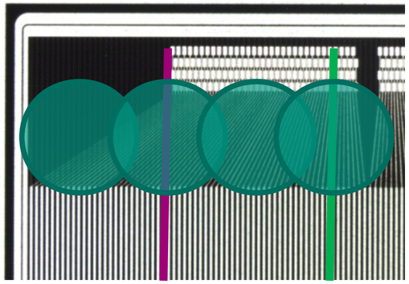


Electron from a Sr^{90}-source at different positions



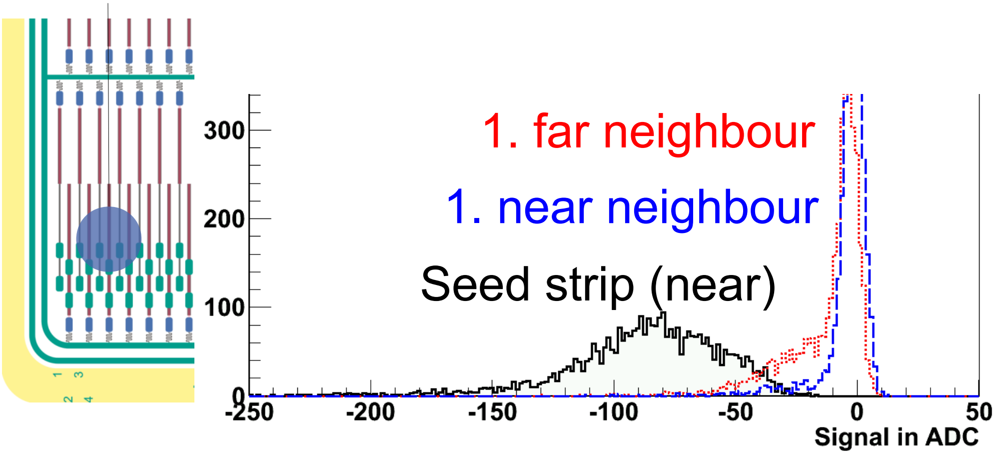
Flat S/N in standard region of about 17

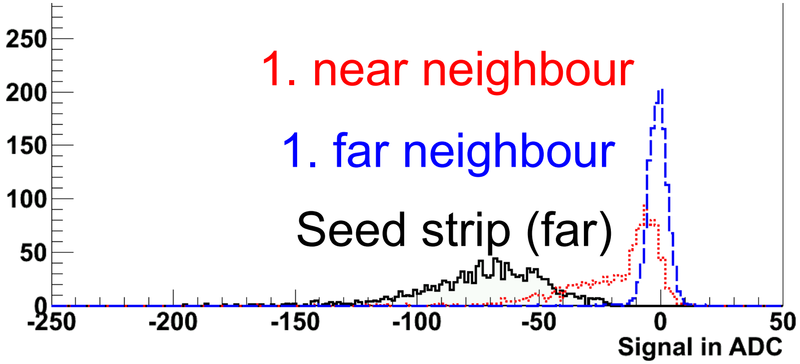
Reduced S/N in PA-region, noise stays constant



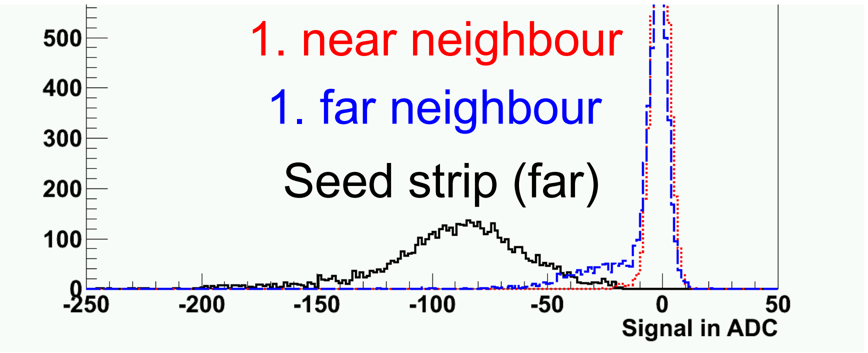
First results for strixel sensors

Electron from a Sr^{90}-source at near area

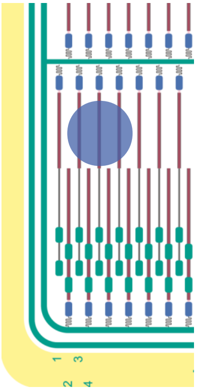




Electron from a Sr^{90}-source at far area

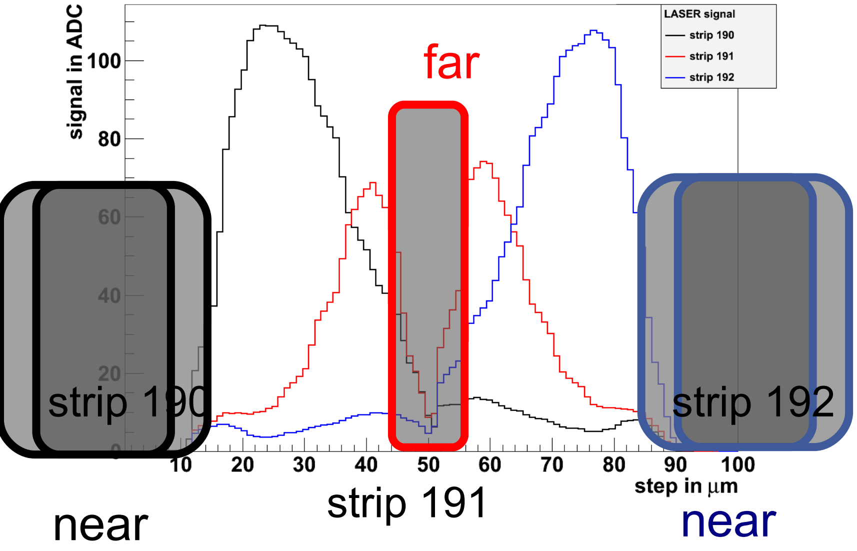


Far area looks ok, signals in near area appear also on far strips



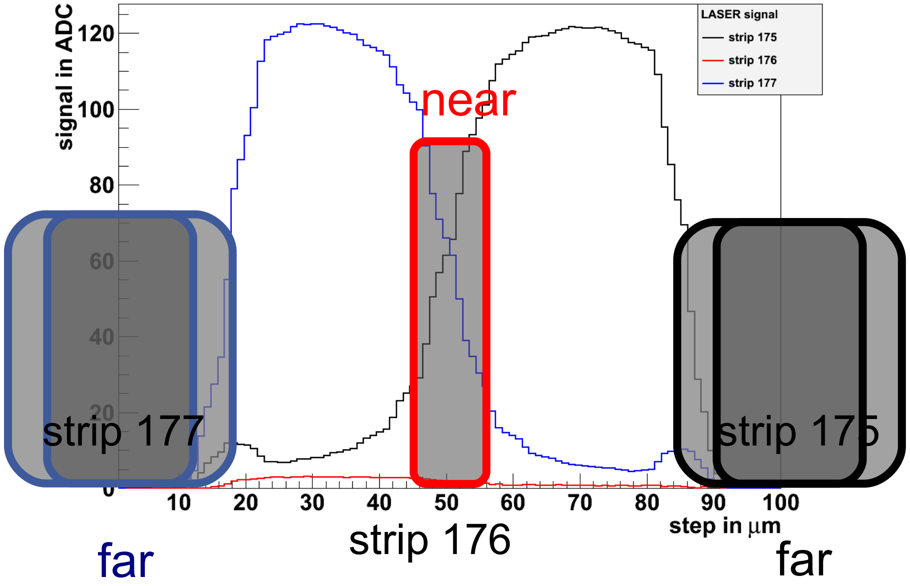
First results for strixel sensors II

Laser scan near area



In the near area the far strip also collects charge

Laser scan far area



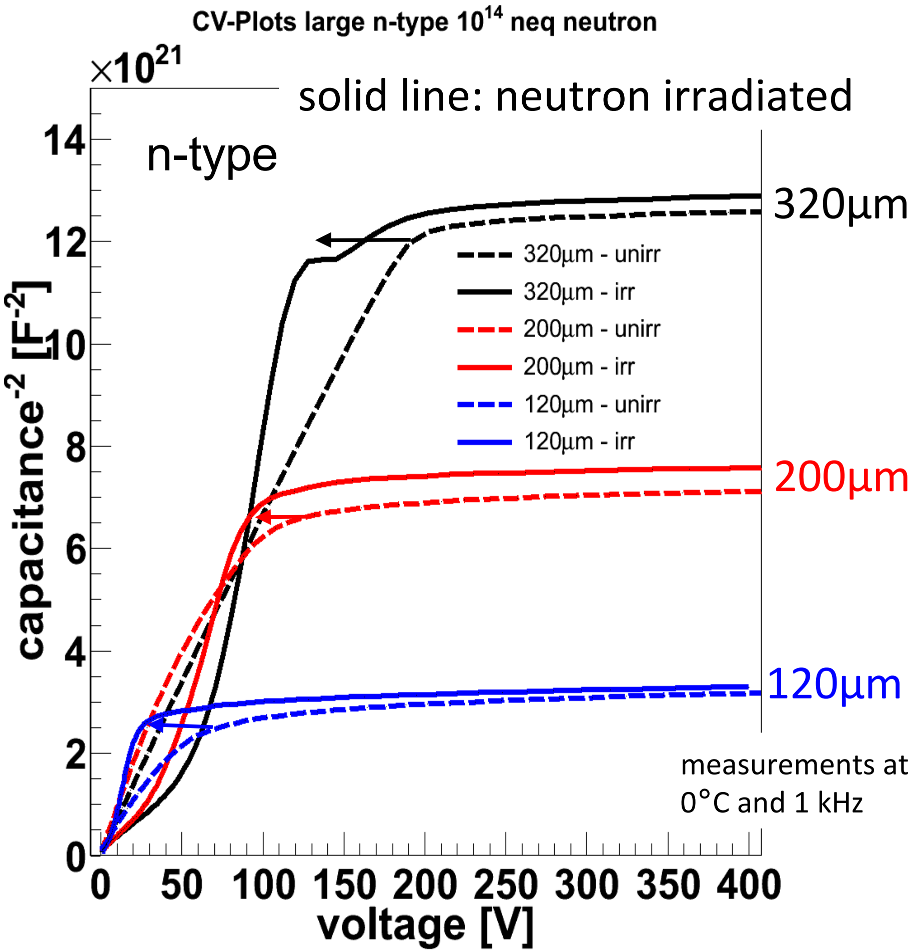
In the far area everything looks fine – nearly no coupling between near and far strips

Irradiation overview

- This first irradiation is a step to check the deep-diffusion material (on a small sample)
- p-type and n-type floatzone material of three thicknesses:

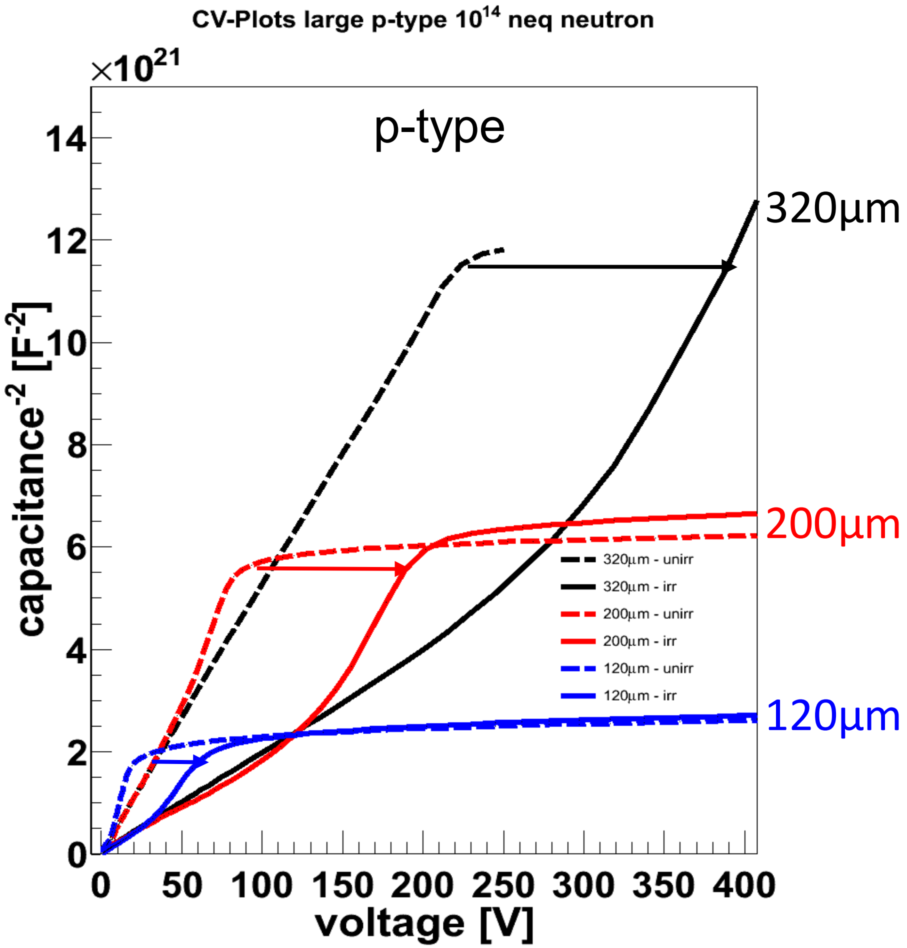
  120µm, 200µm and 320µm
- One large and one small diode per type and irradiation-set
- Three irradiation sets, with a fluence of 10^{14} neq/cm^2:
  - neutrons (reactor, 10^{14} neq/cm^2)
  - protons (25 MeV, 1.09*10^{14} neq/cm^2)
  - mixed (neutrons (reactor, 10^{14} neq/cm^2) + protons (25 MeV, 1.09*10^{14} neq/cm^2))

First irradiation step - neutrons


CV-Plots large n-type 10^{14} neq neutron

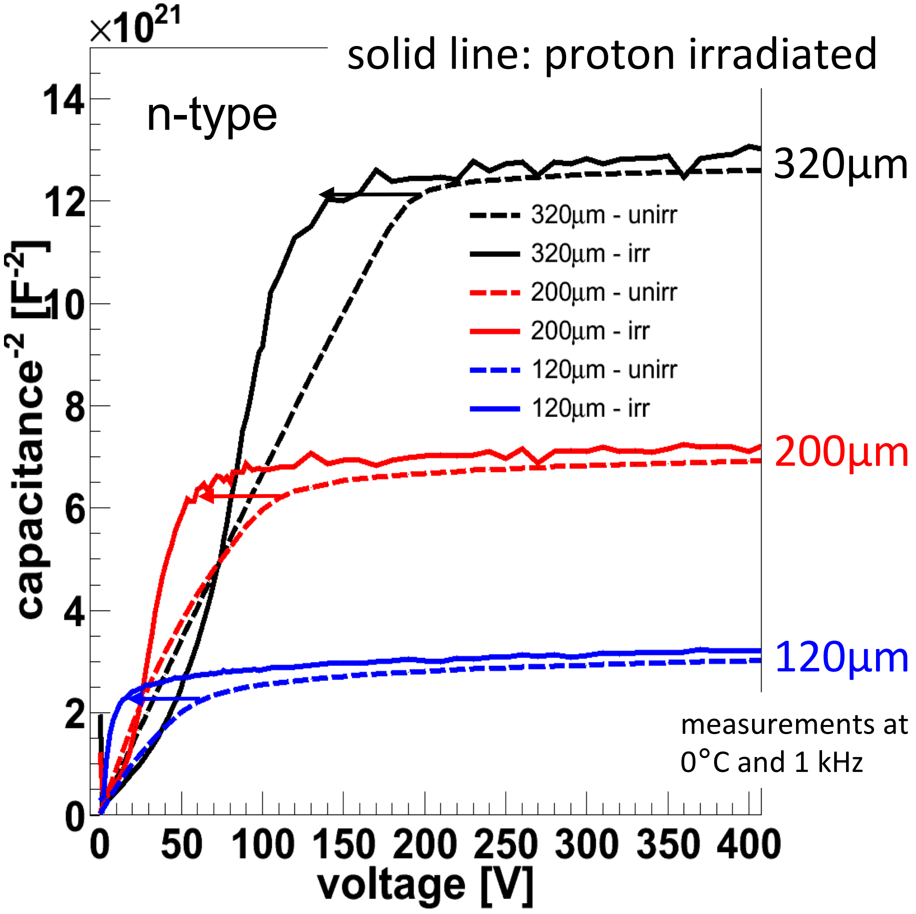
solid line: neutron irradiated

measurements at 0°C and 1 kHz


CV-Plots large p-type 10^{14} neq neutron

First irradiation step - protons

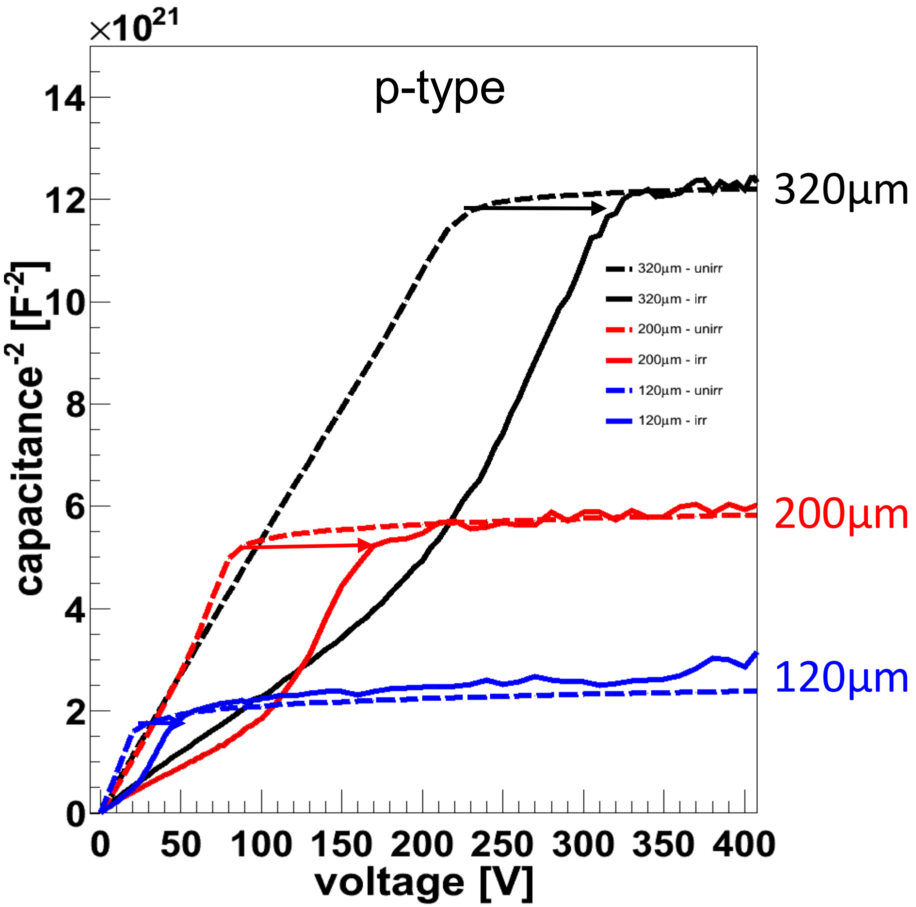
CV-Plots large n-type 1.09 * 10^{14} neq proton



solid line: proton irradiated

measurements at 0°C and 1 kHz

CV-Plots large p-type 1.09 * 10^{14} neq proton



Conclusions and Acknowledgement

- New materials / designs needed for HL-LHC radiation-levels
- This Campaign started to measure a big set of different structures / materials of one high quality producer
- Materials look promising so far
- Standard structures give good results
- More to come with the new layouts
- Looking forward to looking at samples that are irradiated at higher fluences

Thanks to everyone providing material / data for this talk:
- Alexander Dierlamm (KIT)
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