Thin n-in-p planar pixel modules for the ATLAS pixel detector at HL-LHC

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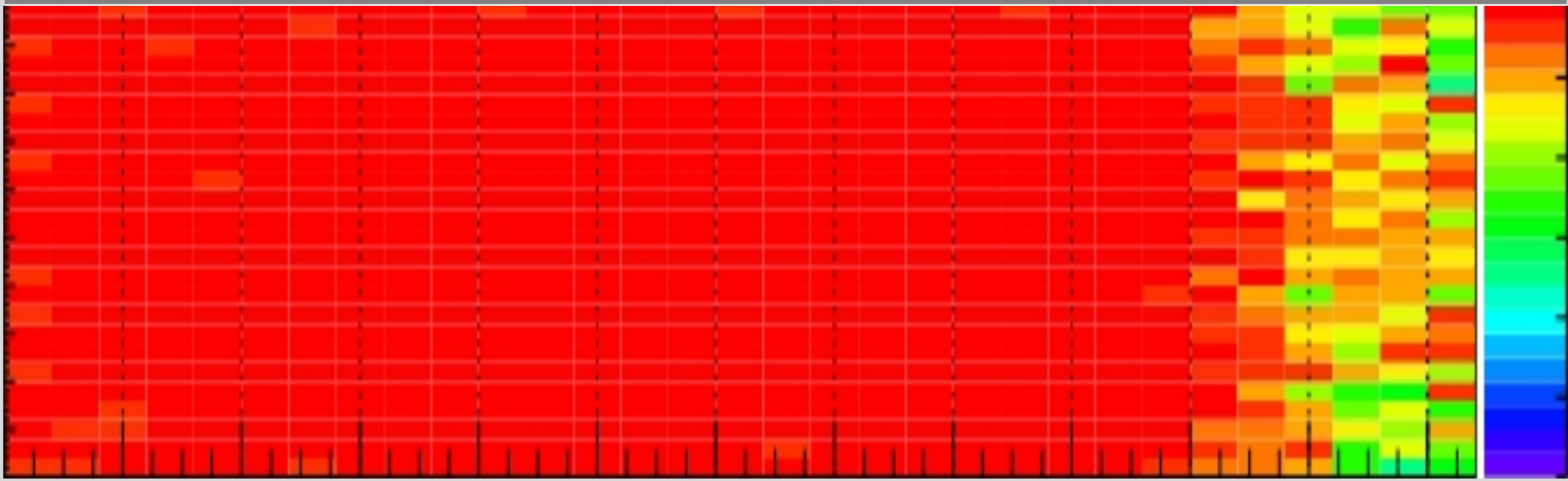

Motivation

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The ATLAS experiment will undergo a major upgrade of its tracker system in view of the high luminosity phase of the HL-LHC in 2024–2026

- **Goal**: radiation hardness of the innermost detector

➔ optimization of hit efficiency, leakage current and operation voltage

i. reduction of the sensor thickness

➔ higher electric field leads to less charge trapping

ii. improvement of pixel biasing structure and size

➔ increasing efficiencies of pixel cells for irradiated modules

- **Experimental investigations**

i. charge collection measurements in the laboratory

ii. efficiency measurements during test beam campaigns

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Sensors with different thicknesses at MPP

Sensors with different thicknesses designed at MPP

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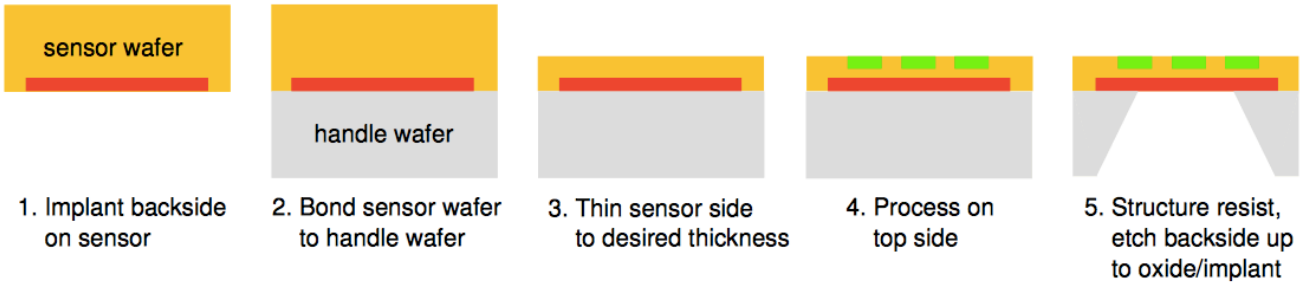
MPG HLL	VTT
• sensor active thickness: 75 to 150 µm	• sensor active thickness: 100 and 200 µm
• produced on 6” wafers on p-type Float Zone (FZ) material	• produced on 6” wafers on p-type FZ material
• bump bonded at IZM to ATLAS FE-I4 chips	• bump bonded at VTT to ATLAS FE-I4 chips



Production process flow at HLL

Laboratory measurements

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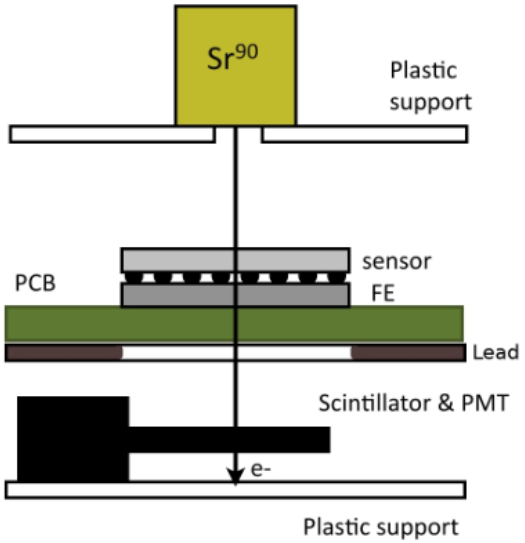
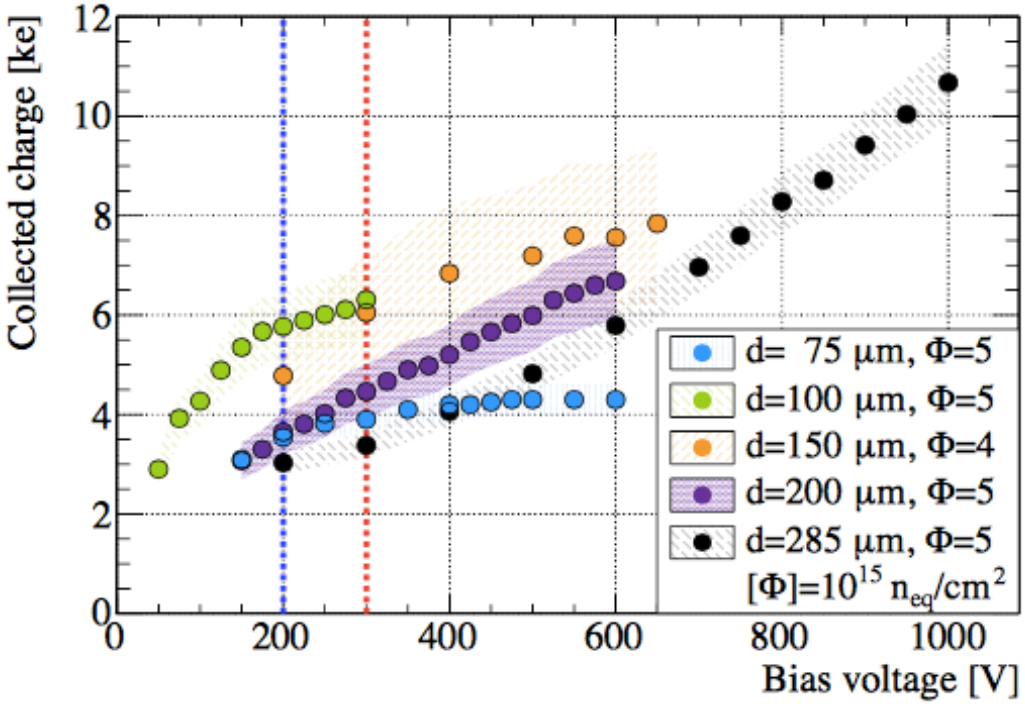
Charge collection





- Method : ^{90}Sr radioactive β-source with external trigger via scintillator
- Cooling : in climate chamber down to -40 °C sensor temperature
- Samples : irradiated modules with sensor thicknesses between 75 and 285 µm

Efficiencies for different thicknesses

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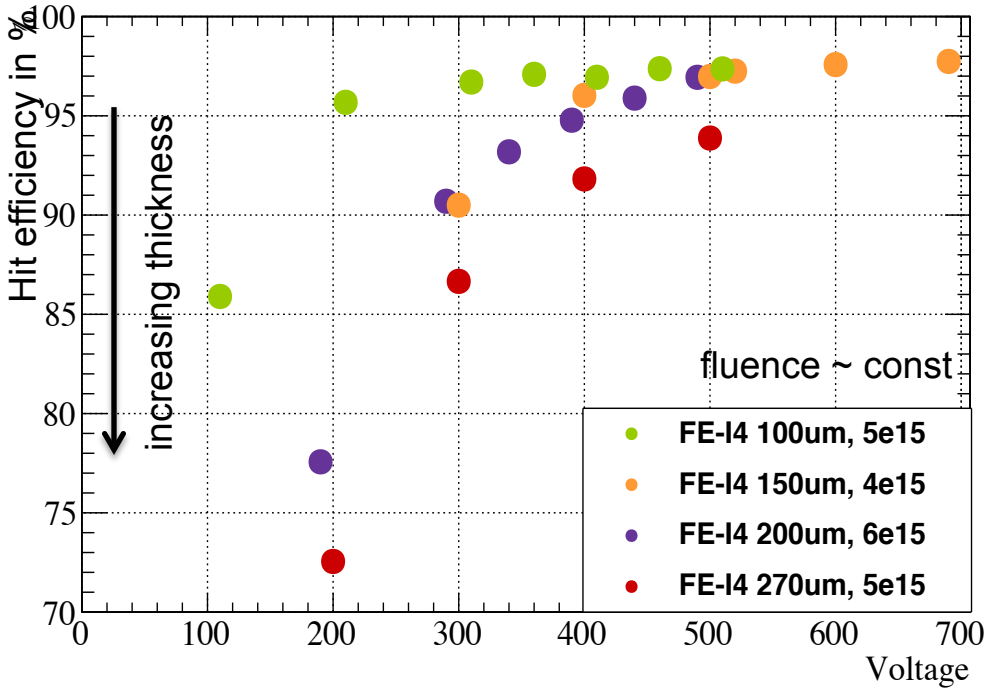
Efficiency measurements with the EUDET telescope at :



1) DESY in Hamburg with 4 GeV electrons

2) SpS at CERN with 120 GeV pions

using irradiated modules with sensor thickness from 100 to 270 µm

Among tested thicknesses thinner sensors show higher charge collection and hit efficiency up to 5×10^{15} $n_{eq}cm^{-2}$ at moderate voltage.

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Optimization of biasing structures and pixel pitches

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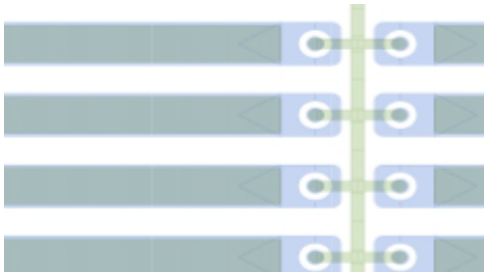
MPP designed sensors of 270 µm thickness produced at CiS and bonded to FE-I4 chips

50x250 µm² pixel

Standard punch-through



Biasline over center

Biasline over punch-through dot

individual punch-through (p-t)

25x500 µm² pixel

Common punch-through

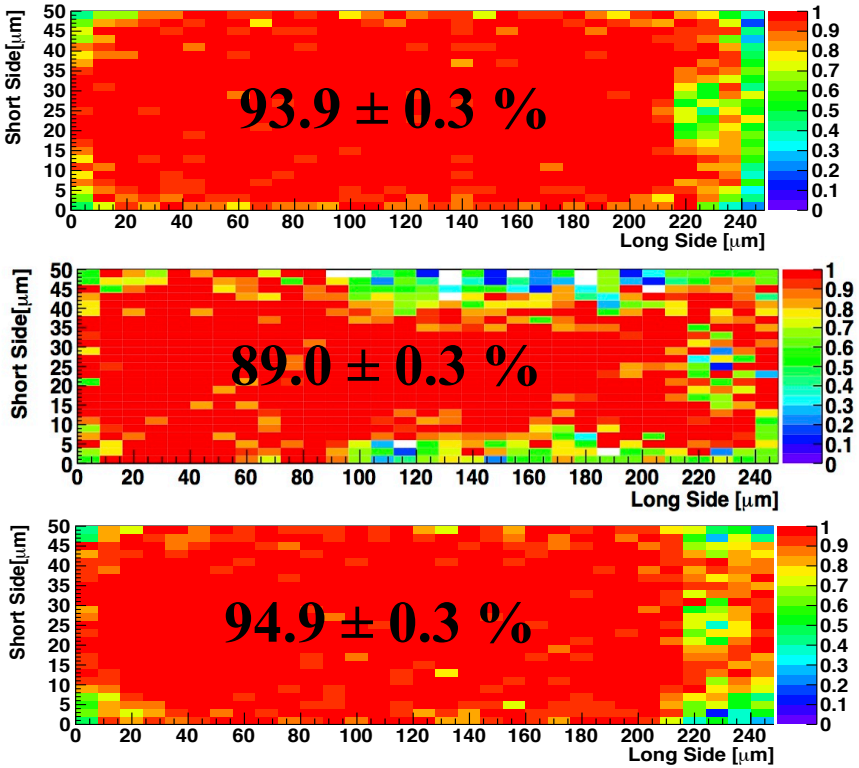
combined p-t

Comparison of performance of different p-t designs

In-pixel hit efficiency

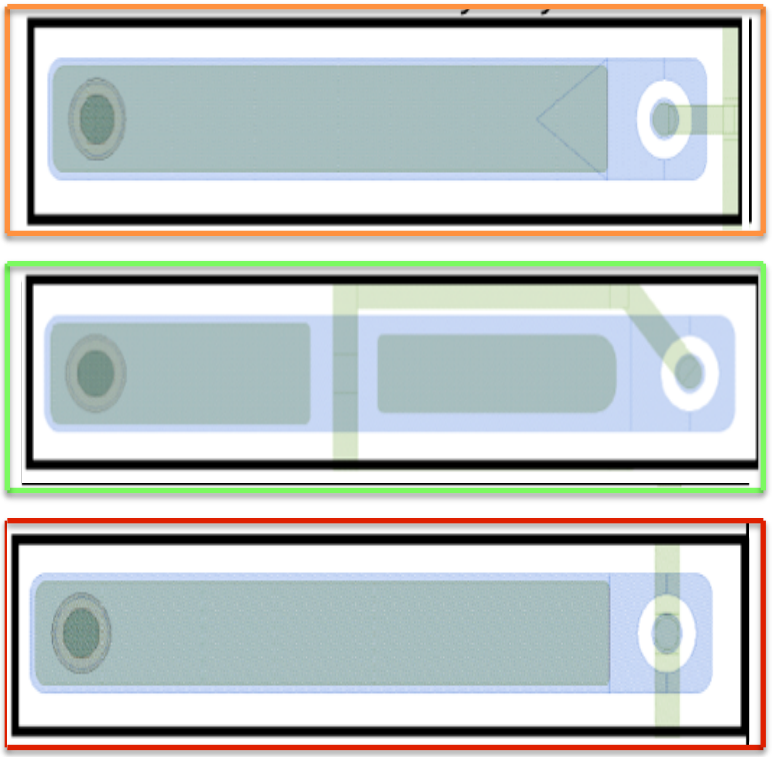
- Irradiated at 5 ·10^{15} n_{eq}/cm^2, U= 500 V

50x250 μm² pitch



100 % hit efficiency
before irradiation

all three p-t designs implemented in one module

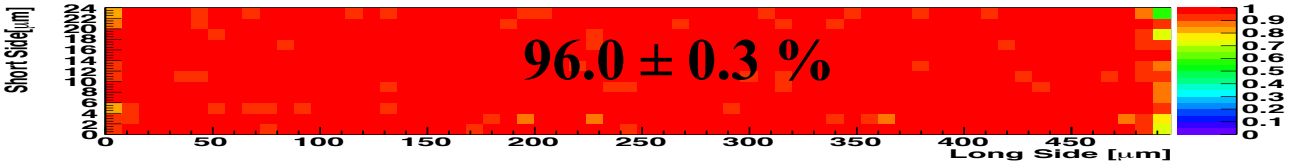


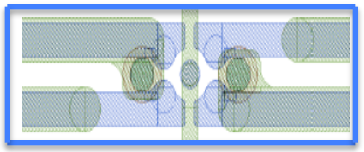
Test beam analysis shows better hit efficiency when the p-t and bias rail is over-imposed to the pixel implant

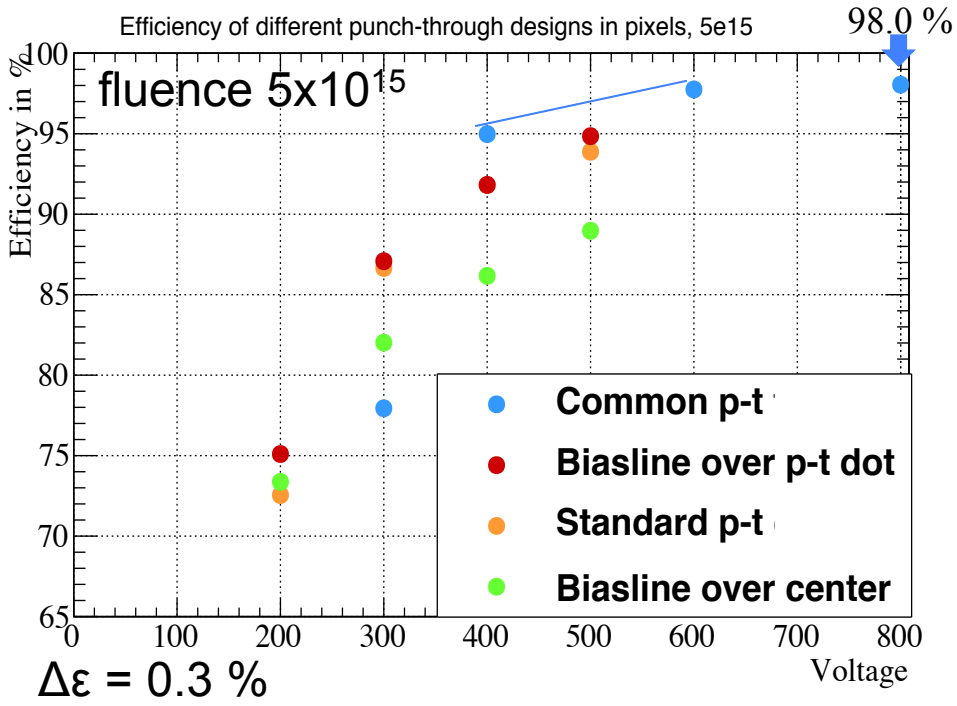
Novel p-t design for 25x500 µm² pixel

- In-pixel hit efficieny of CiS module irradiated at $5 \cdot 10^{15}$ n_{eq}/cm^2 with common punch through structure for 4 pixels, U= 500 V

25x500 µm² pitch







Improved hit efficiency with respect to the standard design for the common p-t and the biasline over the p-t dot

Estimation of hit efficiency for a 25x100 μm^2 pitch

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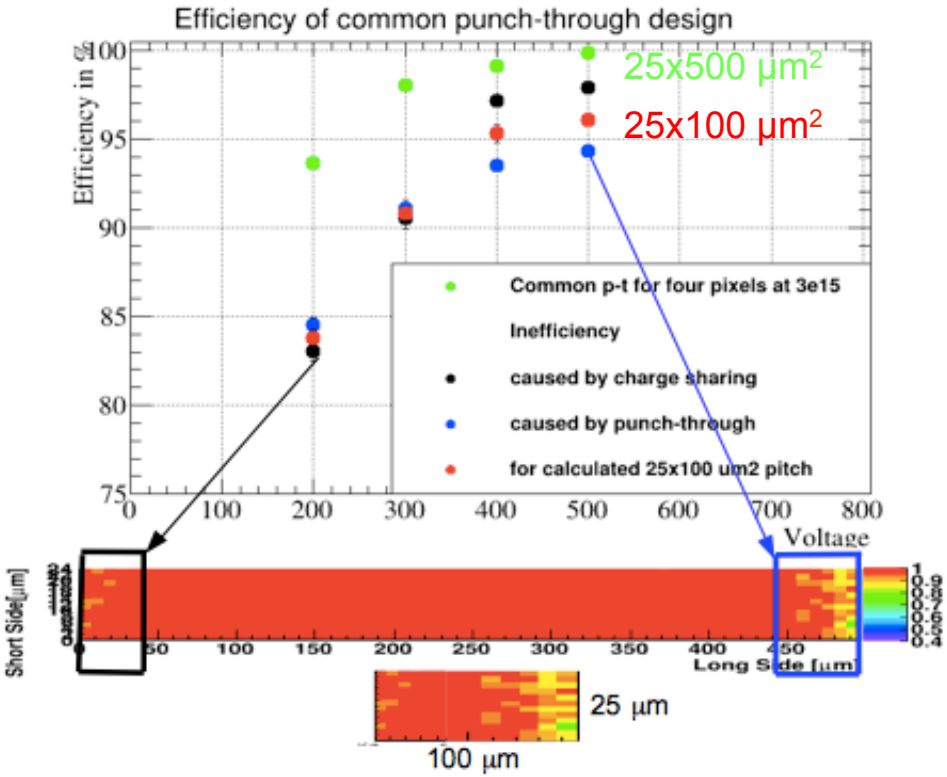
Hit efficiency at 3x10^{15} n_{eq}cm^{-2}



Inefficiencies appear at the edges of the pixel

left:
first 40 μm show inefficiency caused by charge sharing

right:
last 60 μm show inefficiency caused by punch-through

- effective pitch of 25x100 μm^2 obtained by combining first 40 μm and last 60 μm of pixel cell
- example created to estimate a hit efficiency for the 25x100 μm^2 pitch

Estimated hit efficiency for 25x100 μm^2 pitch at 500 V : 96.4 %

New design for sensors foreseen for the FE65 chip

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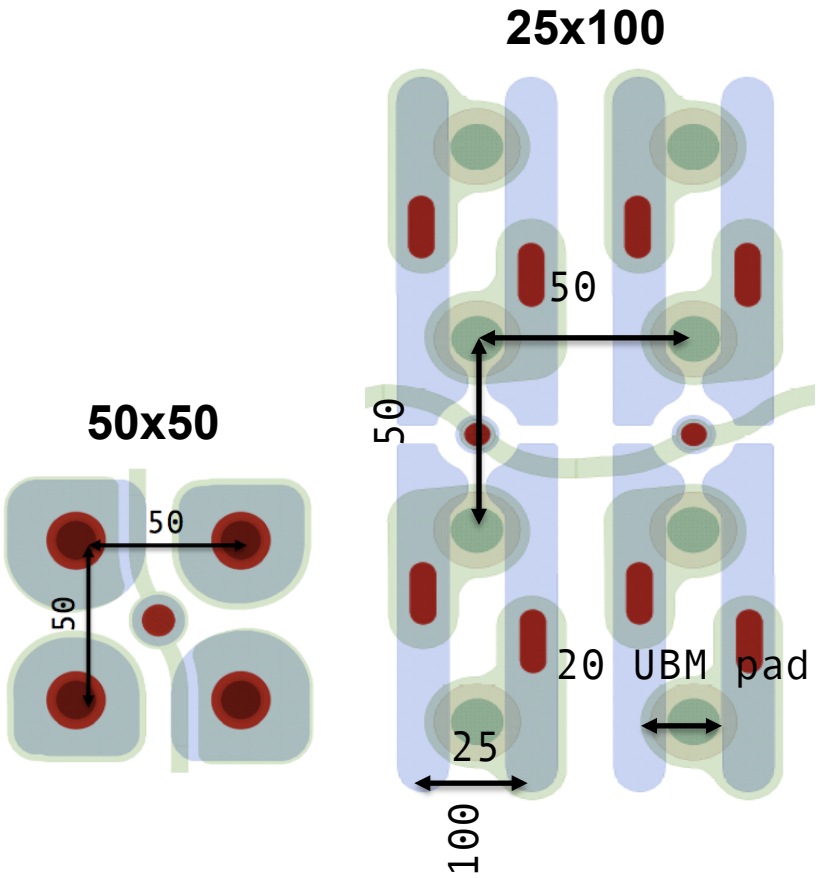
- Punch-through design adopted from the two best performing ones: combination of biasline over p-t dot and common p-t

25x100 μm² pixel pitch

- Pixel staggered to be compatible with a regular 50x50 μm² grid on the chip
- Design based on the existing prototype with 25x500 μm² pitch (results shown before)

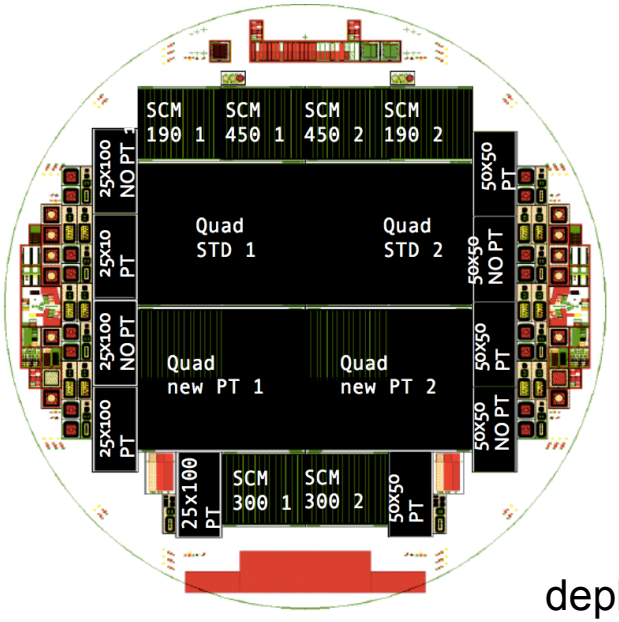


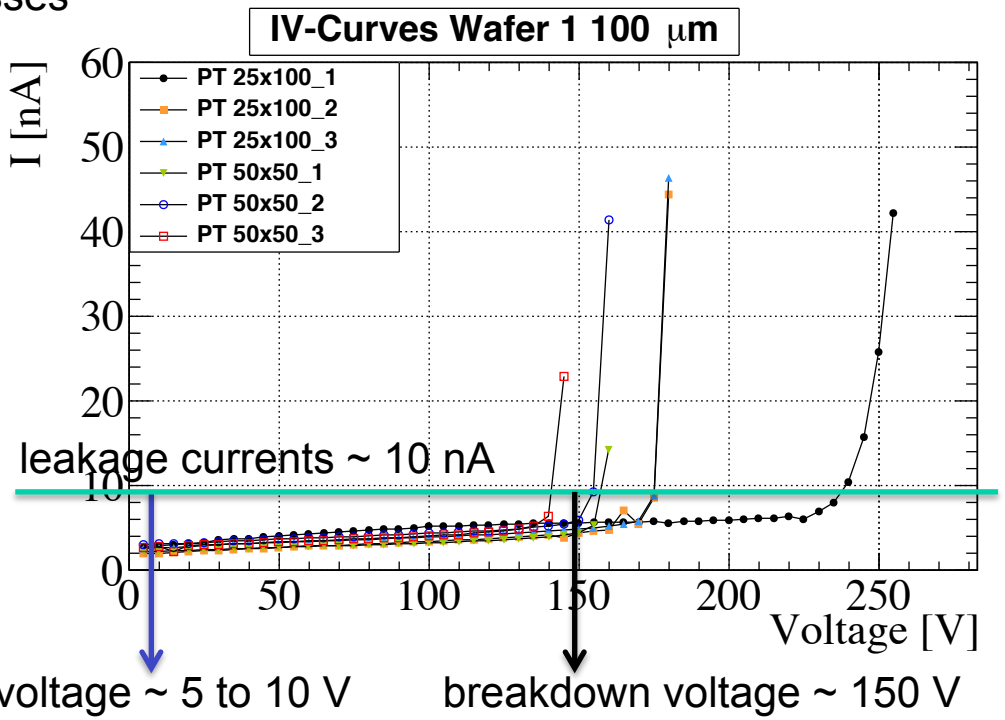
SOI wafers of new production at MPG-HLL with 100 and 150 μm active thickness successfully tested

Leakage currents and breakdown voltages of new MPG-HLL production

New thin sensor production combines and implements new pixel cell design and best performing biasing structures

- with **50x50, 25x100** and standard 50x250 μm^2 pixels
- on 10 6" wafers on p-type FZ material
- with **100 and 150 μm** sensor thicknesses





Summary and Outlook

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- **Thin sensors**
  - 100 and 150 µm thick sensors show higher charge collection and hit efficiency
  - 100 µm thick sensor reaches hit efficiency of up to **97.1 %** after irradiation at $5 \cdot 10^{15}$ n_{eq}/cm^2 at 300 V
- **Investigations of new pixel cell design**
  - Improved hit efficiency for the common p-t and the biasline over the p-t with respect to the standard design after irradiation at $5 \cdot 10^{15}$ n_{eq}/cm^2
- **New MPG-HLL production**
  - Combines and implements new pixel cell design on thinner sensors

➔ Promising innovations of sensor design successfully tested and will be connected to the new FE65 chips and tested by the end of 2016

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Thank you for your attention!