Irradiated n-in-p planar pixel sensors with different thicknesses and active edge designs

Stefano Terzo
L. Andricek, A. Macchiolo, H.-G. Moser, R. Nisius,
B. Paschen, R.-H. Richter, and P. Weigell

Max-Planck-Institut für Physik & Max-Planck-Gesellschaft Halbleiterlabor München

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N-in-p planar pixel samples

VTT active/slim edges:

- FE-I4 modules 100 μm thick (125 μm edge, p-type MCz)
- FE-I3 modules 100 μm thick (125 μm edge, p-type FZ)
- FE-I4 modules 200 μm thick (450 μm edge, p-type FZ)

MPP/HLL samples:

- FE-I4 modules 150 μm thick (450 μm edge, p-type FZ)

Irradiations:

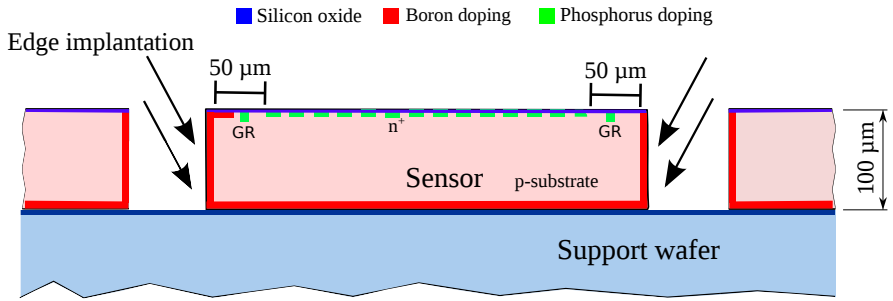
$\rightarrow$ $5\times10^{15}\,\mathrm{n_{eq}/cm^2}$ at KIT (25 MeV protons)

$\rightarrow$ $5\times10^{15}\,\mathrm{n_{eq}/cm^2}$ at KIT + Ljubljana (reactor neutrons)

$\rightarrow$ $6\times10^{15}\,\mathrm{n_{eq}/cm^2}$ at KIT + Ljubljana

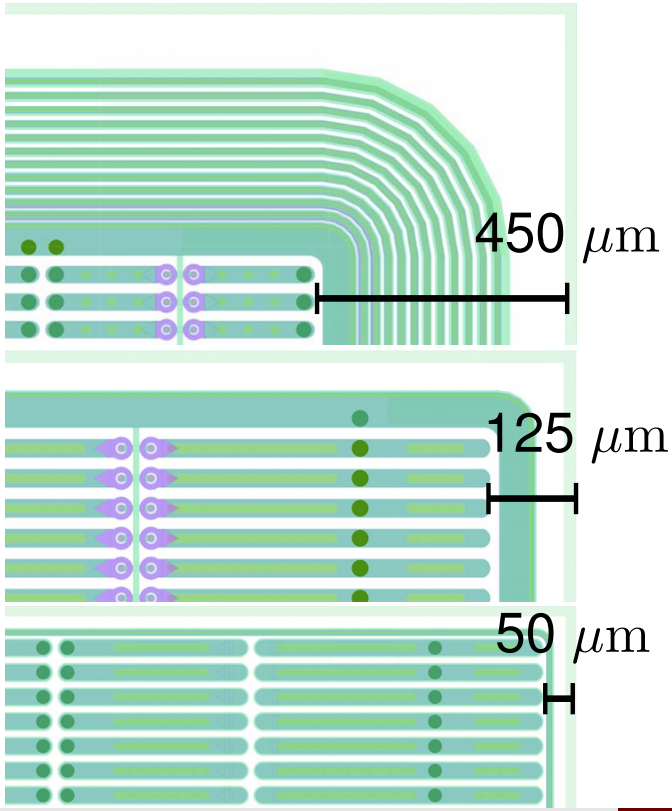
$\rightarrow$ $1\times10^{16}\,\mathrm{n_{eq}/cm^2}$ in Los Alamos (800 MeV protons)

The VTT active/slim edge production



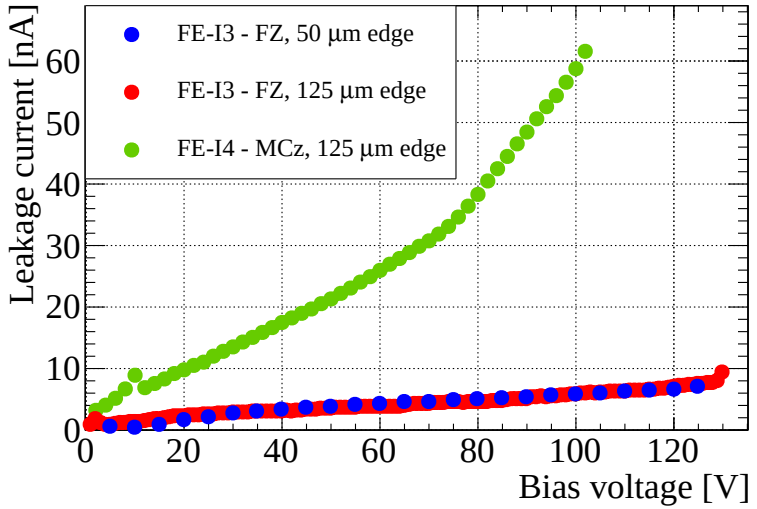
trenches doped by four-quadrant implantation

- **different edge designs:**
  - 450 μm distance between the last pixel implant and the slim edge (Bias Ring (BR) and 11 Guard Rings (GR))
  - 125 μm distance between the last pixel implant and the slim edge (only 1 BR and 1 floating GR)
  - 50 μm distance between the last pixel implant and the active edge (only 1 floating GR)

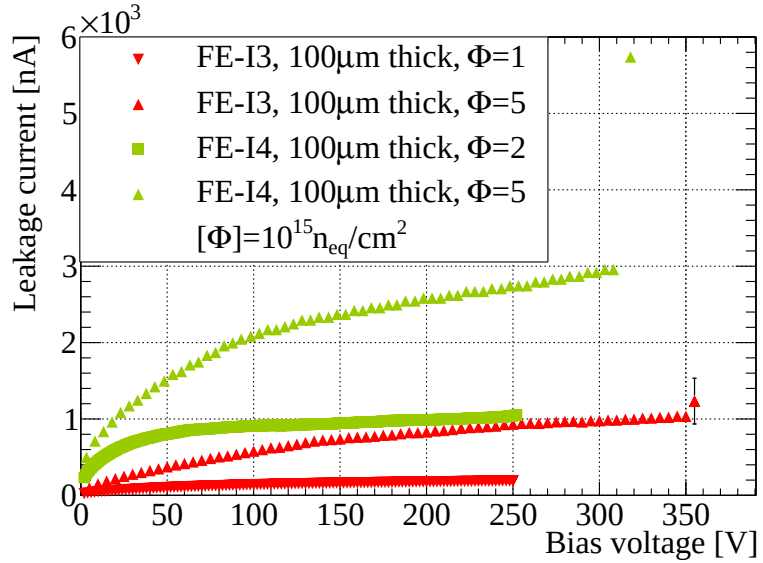


IV measurements

- VTT sensors before irradiation:
  - depletion voltage 10-15 V
  - breakdown 100-120 V

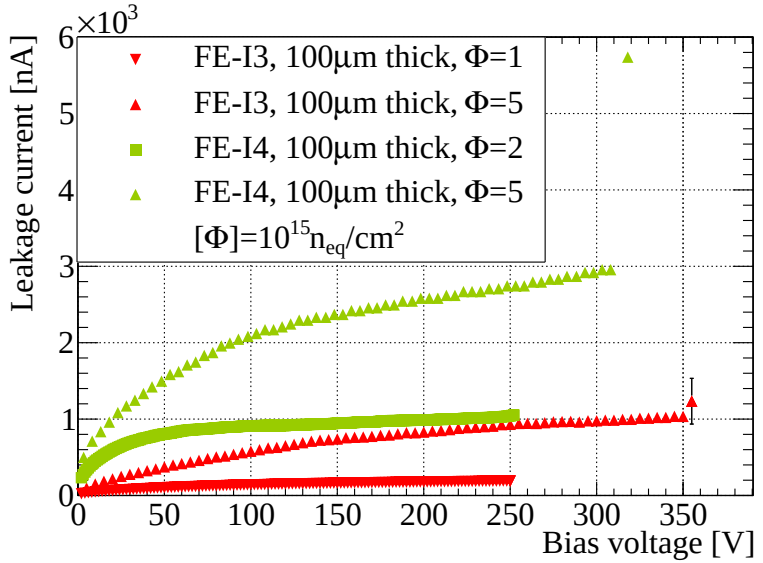


- VTT sensors after irradiation:
  - breakdown voltage of VTT sensors is above the saturation of the collected charge

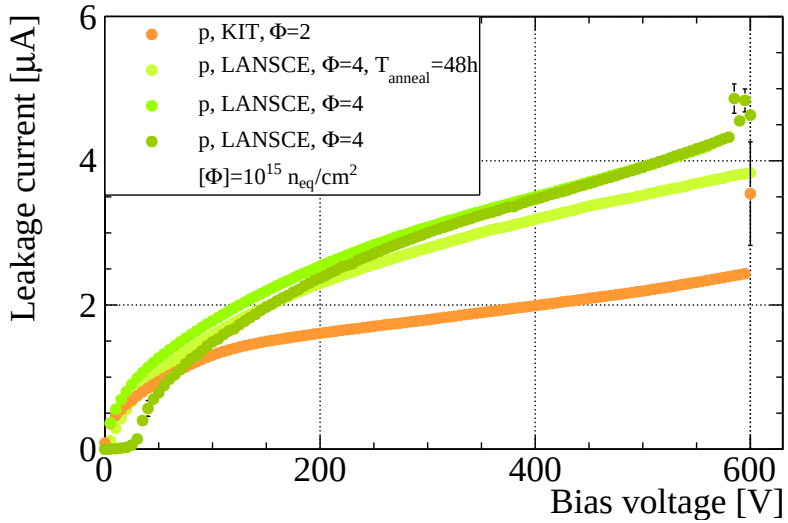


IV measurements

- VTT sensors 100 μm thick:
  - 125 μm edge design without full GR structure
  - $\leq$350 V in the lab (400 V at beam test) up to a fluence of $5\times10^{15}\,\mathrm{n_{eq}/cm^2}$

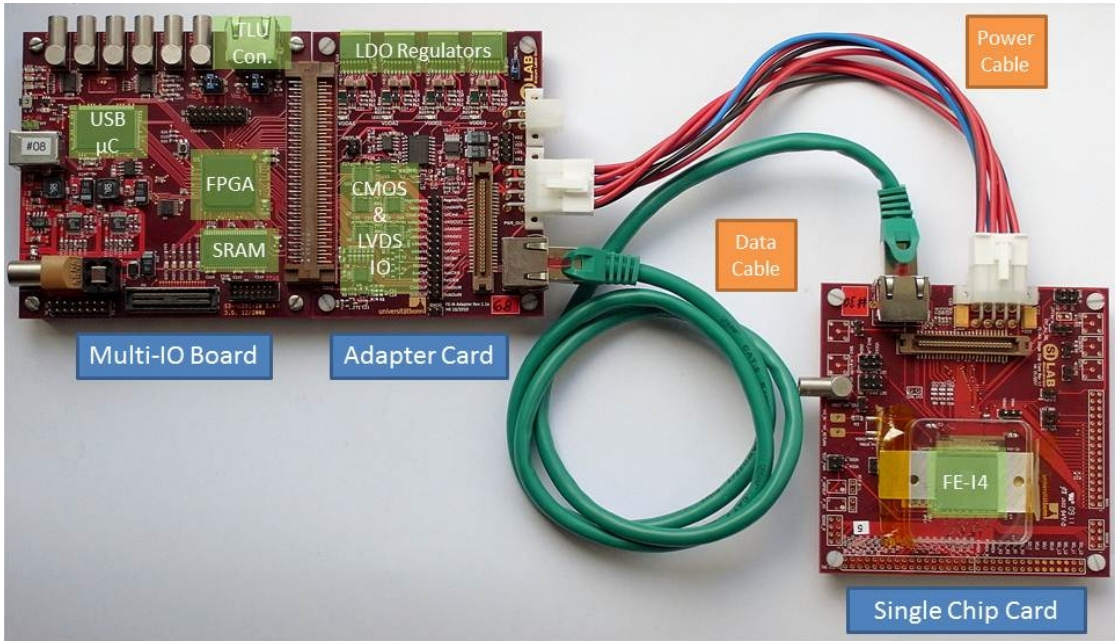


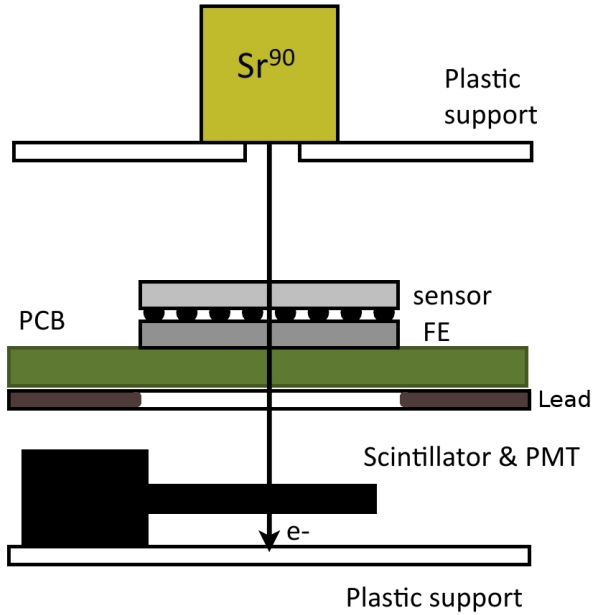
- MPP/HLL sensors 150 μm thick:
  - 450 μm with full GR structure
  - breakdown at 600 V after irradiation up to $4\times10^{15}\,\mathrm{n_{eq}/cm^2}$



Characterization setup in laboratory

- ^{90}Sr beta source
- external trigger via scintillator
- from 20°C to -50°C cooling
- ATLAS USBPix read-out system

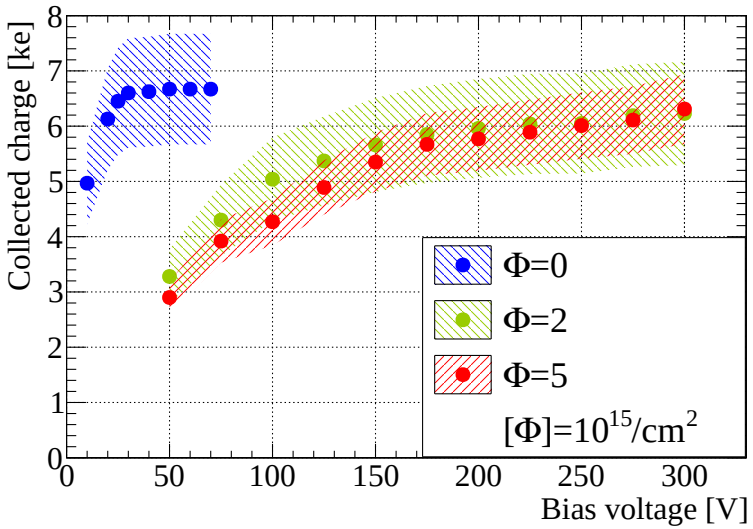




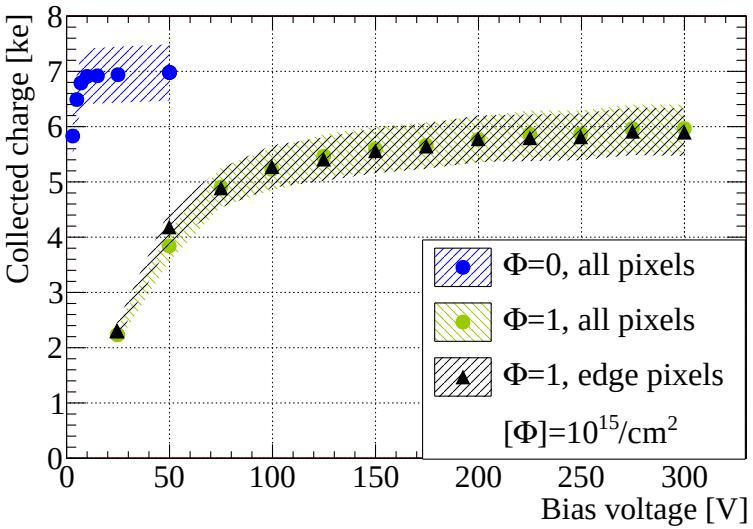
Pixel modules are wire-bonded to detector boards designed by the University of Bonn for FE-I4 and FE-I3

Charge Collection

- FE-I4 MCz silicon 100 μm thick
- 125 μm slim edge
- threshold: 1100 e^-
- **95% CCE** at 300 V up to $5\times10^{15} n_{eq}/cm^2$

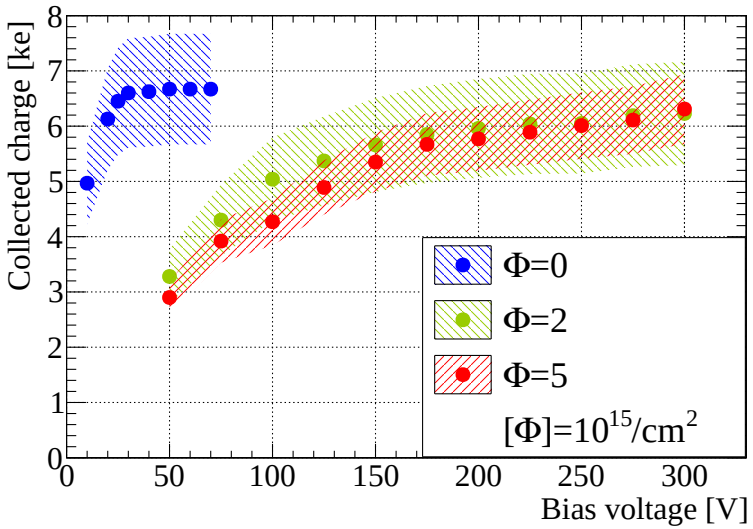


- FE-I3 FZ silicon 100 μm thick
- 125 μm slim edge
- threshold: 1500 e^-
- **87% CCE** at 300 V up to $5\times10^{15} n_{eq}/cm^2$

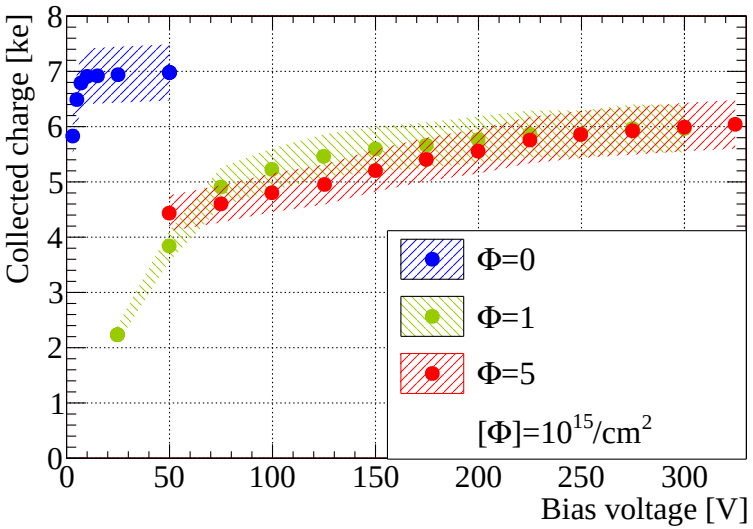


Charge Collection

- FE-I4 MCz silicon 100 μm thick
- 125 μm slim edge
- threshold: 1100 e$^-$
- **95% CCE** at 300 V up to $5\times10^{15}\mathrm{n_{eq}/cm^2}$

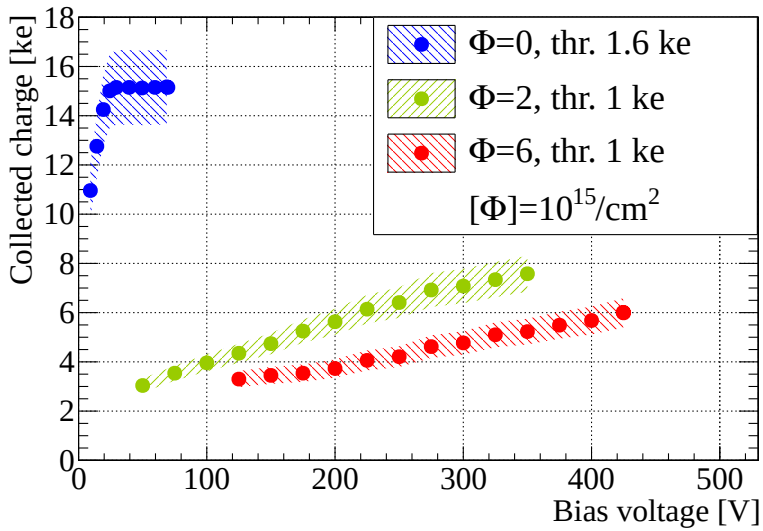


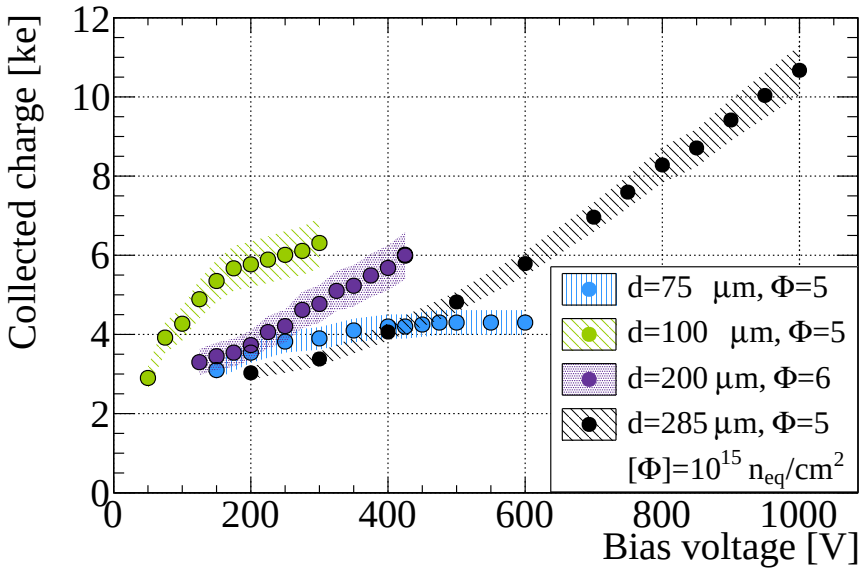
- FE-I3 FZ silicon 100 μm thick
- 125 μm slim edge
- threshold: 1500 e$^-$
- **87% CCE** at 300 V up to $5\times10^{15}\mathrm{n_{eq}/cm^2}$



Charge Collection

- VTT FE-I4 FZ silicon 200 μm thick
- 450 μm slim edge with GRs
- Φ=6$\times$10^{15}n$_{eq}$/cm^2
- **40% CCE** at 425 V at 6$\times$10^{15}n$_{eq}$/cm^2



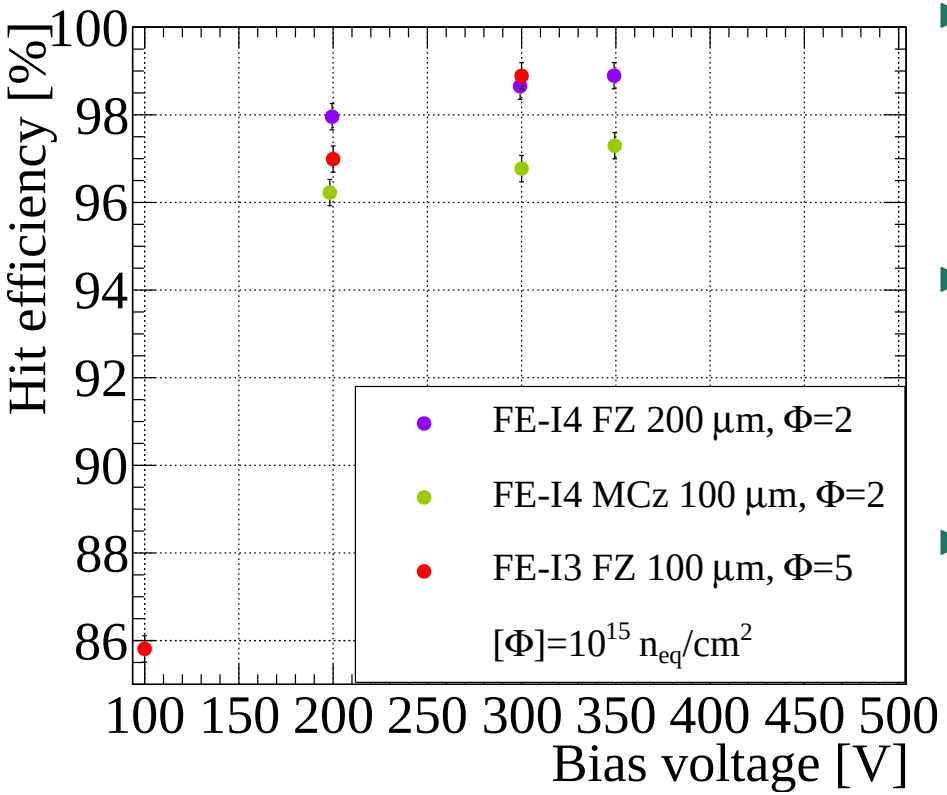


at Φ=5$\times$10^{15}n$_{eq}$/cm^2 200 μm thick devices are still under depleted up to 425 V

while the collected charge of 100 μm thick sensors saturates already at 200 V

Hit efficiency

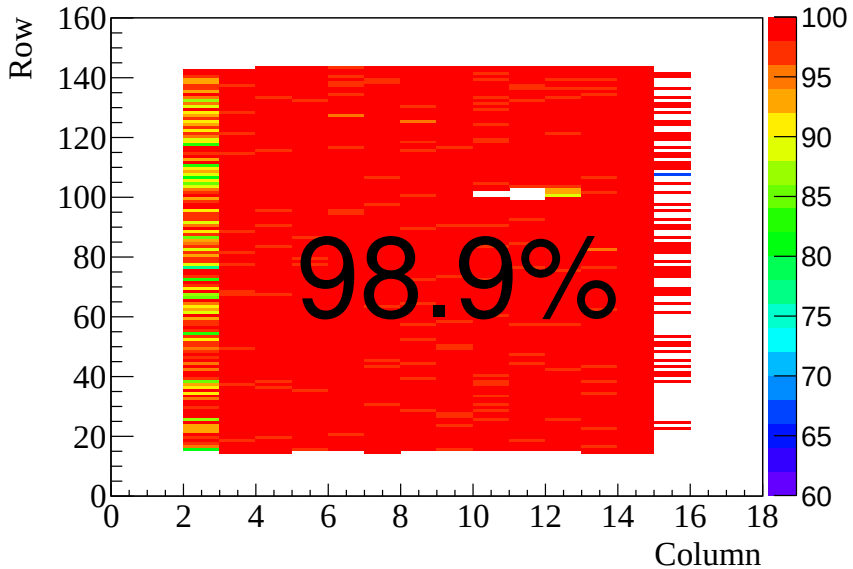
- PPS test beam at DESY
  - 4 GeV electrons
  - EUDET telescope
  - perpendicular incidence tracks



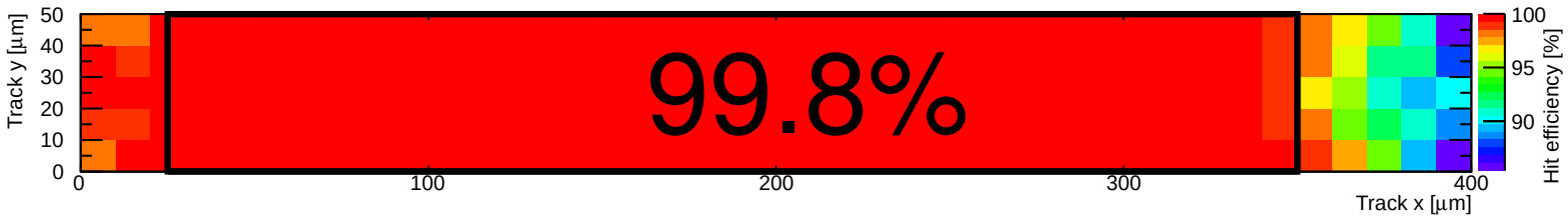
- **VTT FE-I4: 200 μm FZ**
  - threshold: 1100 e^-
  - Φ=2$\times 10^{15} n_{eq}/cm^2$
  - (98.9$\pm$0.3)% efficiency at 350 V
- **VTT FE-I4: 100 μm MCz**
  - threshold: 1600 e^-
  - Φ=2$\times 10^{15} n_{eq}/cm^2$
  - (97.3$\pm$0.3)% efficiency at 350 V
- **VTT FE-I3: 100 μm FZ**
  - threshold: 1600 e^-
  - Φ=5$\times 10^{15} n_{eq}/cm^2$
  - (98.9$\pm$0.3)% efficiency at 300 V

Hit efficiency: VTT 100 μm FE-I3

- PPS test beam at DESY
  - 4 GeV electrons
  - EUDET telescope
  - perpendicular incidence tracks

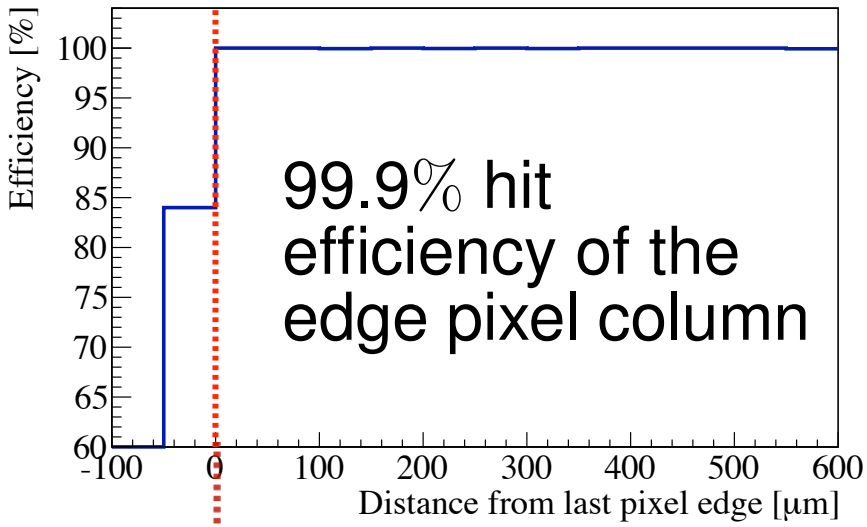


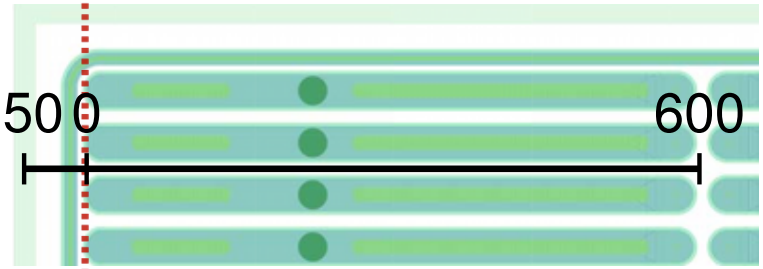
- **VTT 100 μm FE-I3 Float Zone**
  - 125 μm slim edge
  - threshold: 1600 e^-
  - 20 ToT at 60 ke
  - Φ=5$\times$10^{15} n_{eq}/cm^2
  - (98.9$\pm$0.3)% global hit efficiency at 300 V



Edge efficiency before irradiation (CERN SpS)

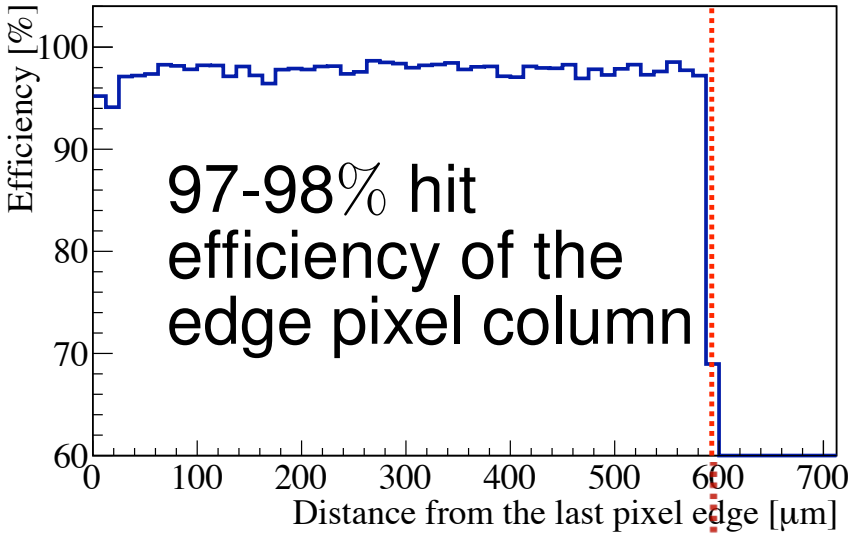
VTT FE-I3, 50 μm active edge

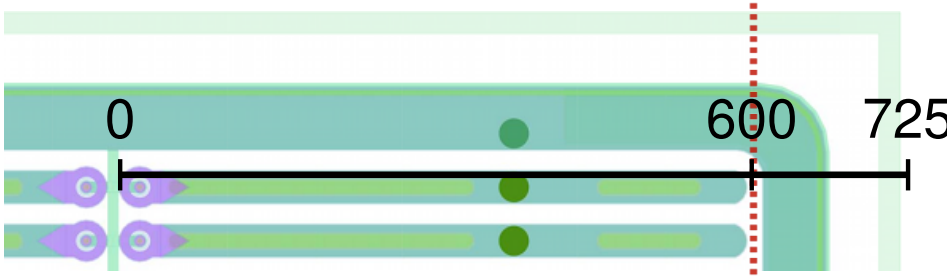




83$^{+9}_{-14}$% hit efficiency between the last pixel implant and the active edge

VTT FE-I3, 125 μm slim edge





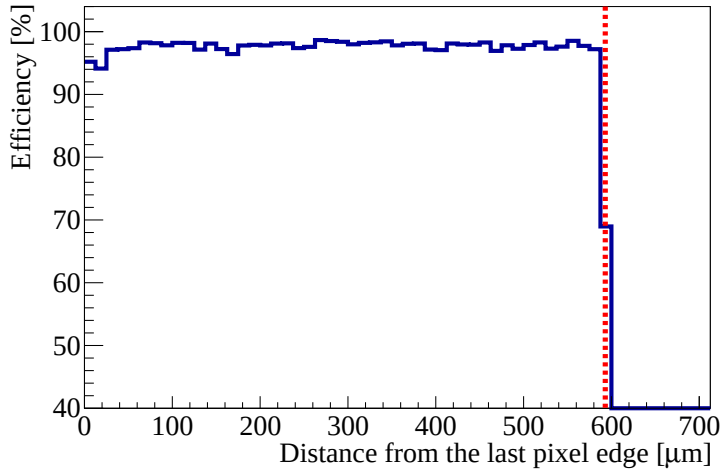
68$\pm$1% hit efficiency between the last pixel implant and the Bias Ring

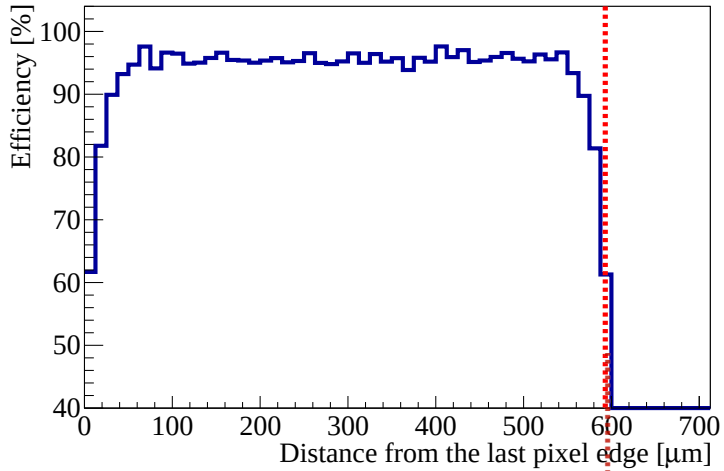
Edge efficiency: VTT 100 μm FE-I3

FE-I3, 125 μm slim edge

- not irradiated
- threshold: 1500 e^-
- **(68$\pm$1)%** hit efficiency between the last pixel implant and the BR (CERN SpS, 120 GeV pions)

- Φ=5$\times10^{15}\,n_{eq}/cm^2$
- V_{bias}=300 V
- threshold: 1500 e^-
- **(59$\pm$2)%** hit efficiency between the last pixel implant and the BR (DESY, 4 GeV electrons)

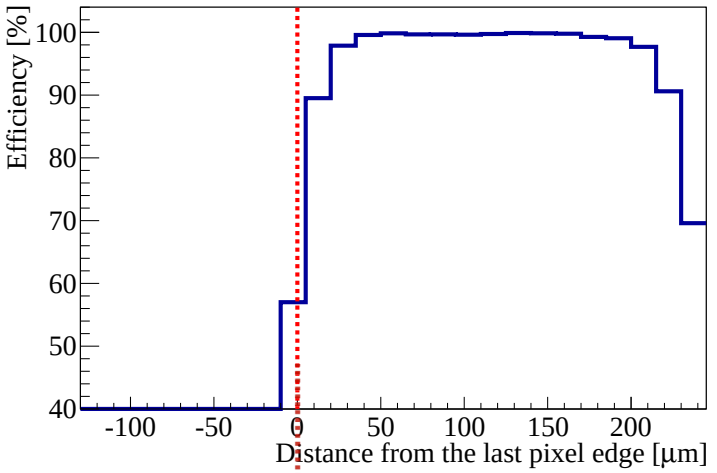


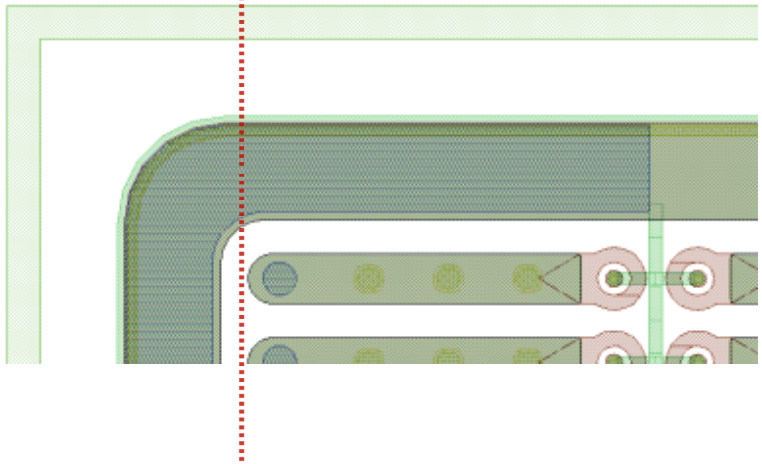


Edge efficiency: VTT 100 μm FE-I4

FE-4, 125 μm slim edge

- un-irradiated
- V_{bias}=300 V
- threshold: 1600 e^-
- over $99.9^{+0.1}_{-0.3}$% global hit efficiency
- **(57$\pm$1)%** hit efficiency between the last pixel implant and the BR (DESY)



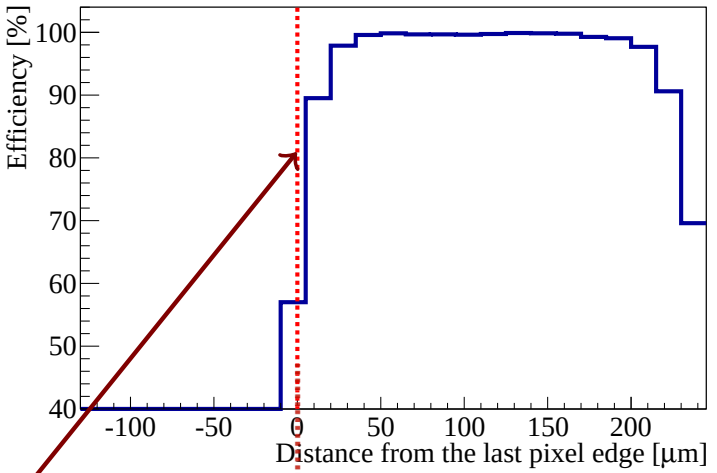


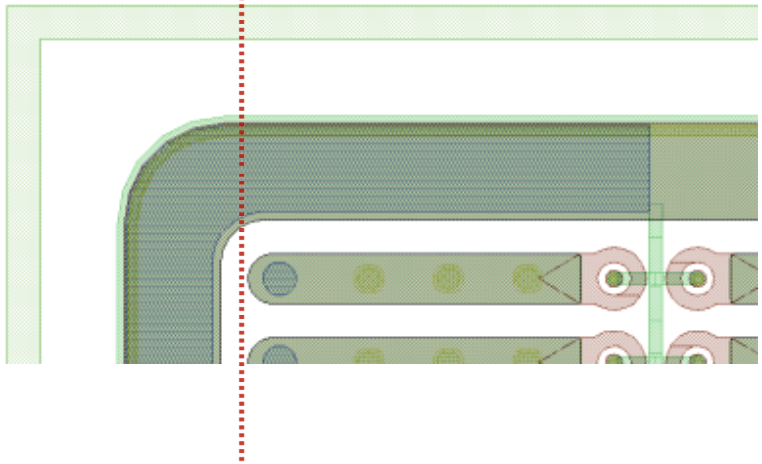
smearing effects due to the multiple scattering that deteriorates the pointing resolution at DESY ($\sim$15 μm)

Edge efficiency: VTT 100 μm FE-I4

FE-4, 125 μm slim edge

- un-irradiated
- V_{bias}=300 V
- threshold: 1600 e^-
- over $99.9^{+0.1}_{-0.3}$% global hit efficiency
- **(57$\pm$1)%** hit efficiency between the last pixel implant and the BR (DESY)



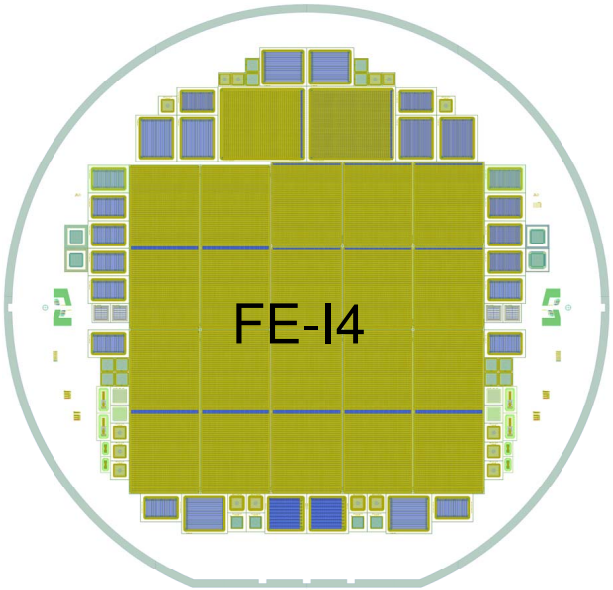


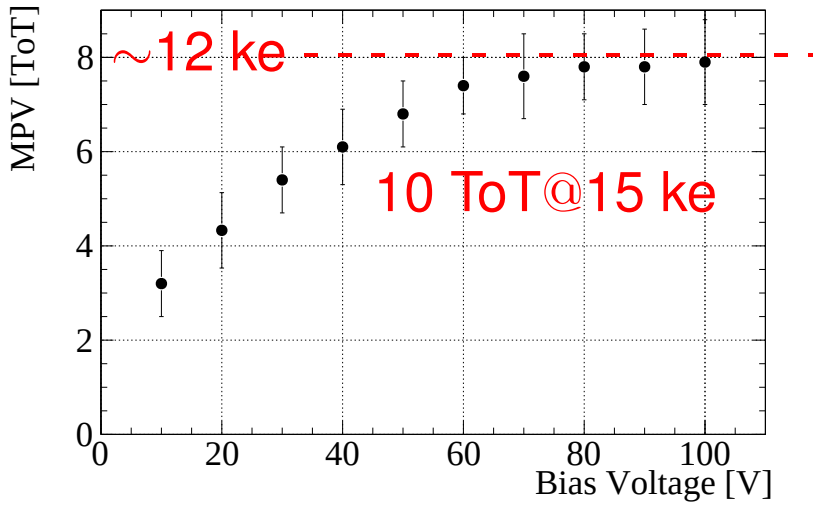
smearing effects due to the multiple scattering that deteriorates the pointing resolution at DESY ($\sim$15 μm)

n-in-p planar pixel modules 150 μm thick

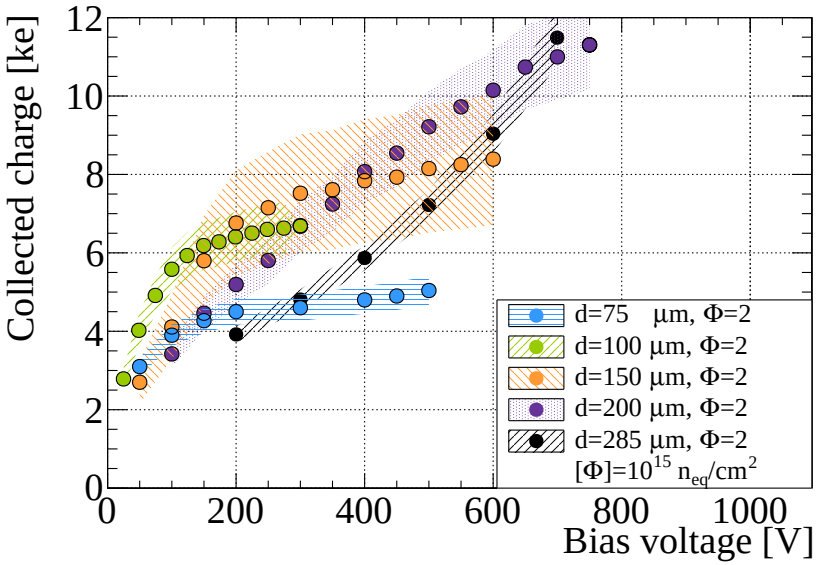
- designed and produced by MPP/HLL
  - 6 inches wafers with ATLAS FE-I4 chips (250 μm$\times$ 50 μm pitch)
  - 450 μm edge design with full GR
  - interconnected with bump-bonding at IZM
- irradiated up to $10^{16} \mathrm{n_{eq}/cm^2}$ in:
  - KIT $\rightarrow$ 25 MeV protons
  - Los Alamos $\rightarrow$ 800 MeV protons

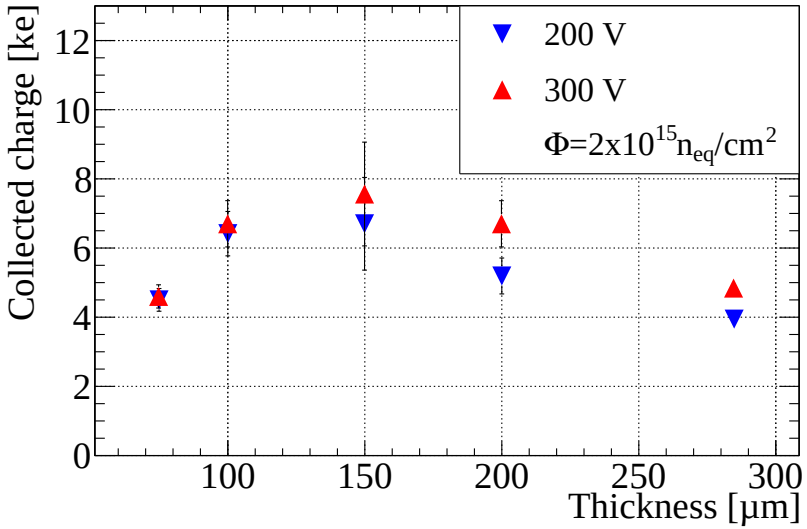
not irradiated show the expected collected charge after full depletion

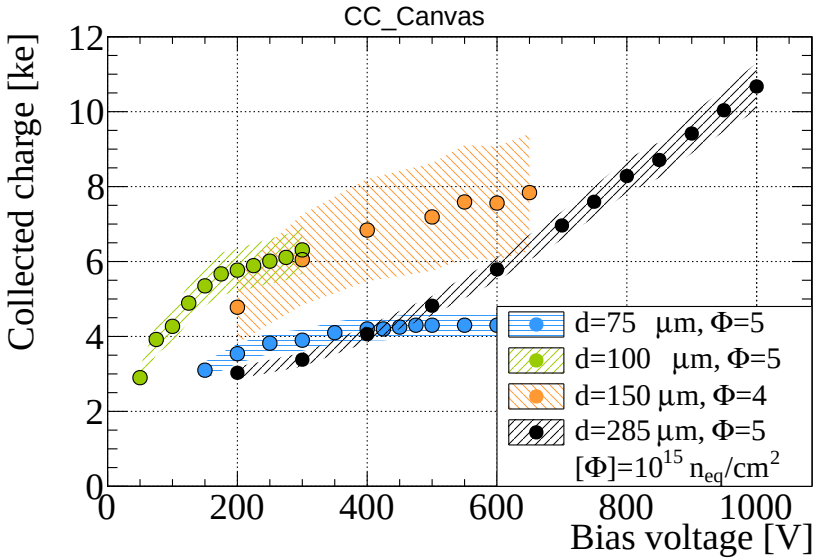


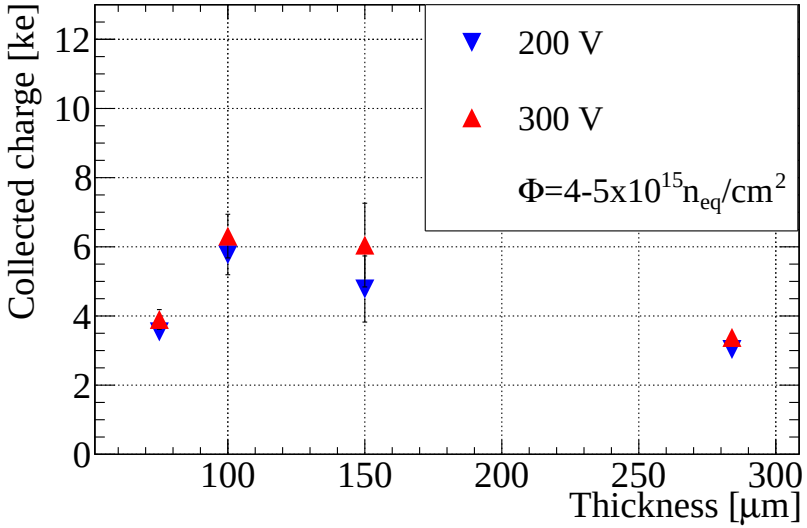


Charge Collection: thickness comparison



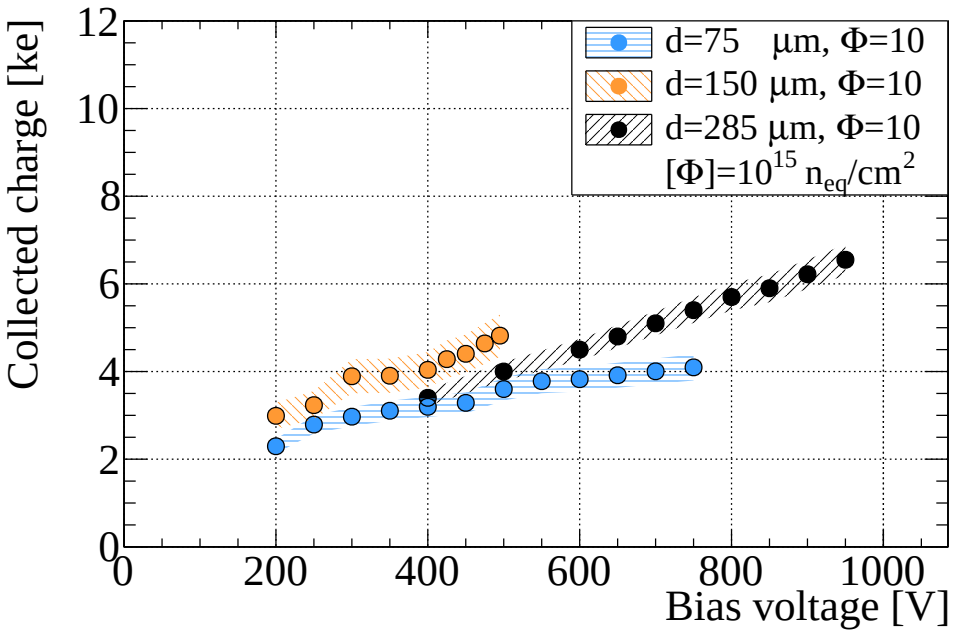




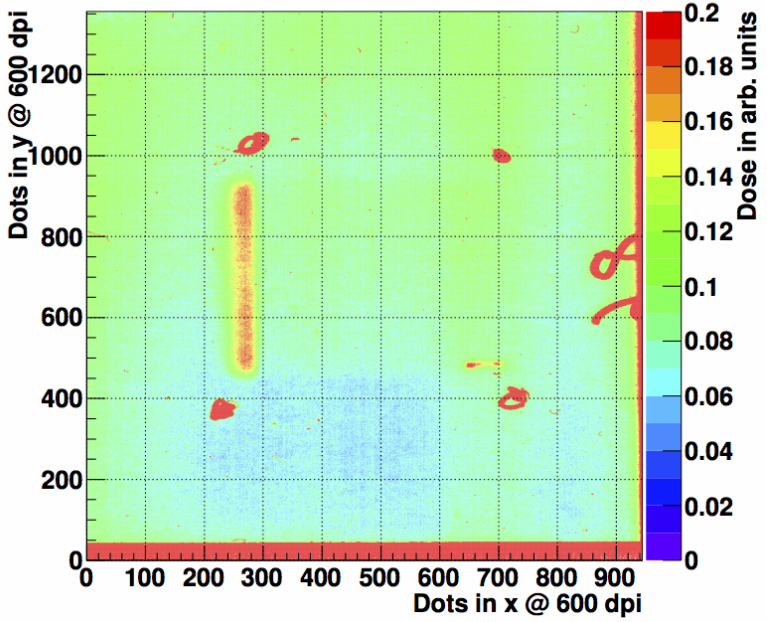


Charge Collection: thickness comparison

- **FE-I4 150 μm thick, irradiated to $10^{16} \mathrm{n_{eq}/cm^2}$ at Los Alamos**



The collected charge becomes similar to the one of other tested thicknesses



FE-I4 chip is radioactive:

- 3.10 mGy/h in pad region*
- 1.15 mGy/h under chip*

*These levels correspond to 205 kBq for the ^{182}Ta

Summary and outlook

- 100-150 μm thick sensors show the highest collected charge at moderate voltages (200-300 V) up to a fluence of $10^{16}\mathrm{n_{eq}/cm^2}$ among the tested thicknesses.
- VTT active edges 100 μm thick sensors show (98.9$\pm$0.3)% hit efficiency at 300 V after irradiation up to $5\times10^{15}\mathrm{n_{eq}/cm^2}$.
- The active area of the VTT sensors extends out of the pixel surface up to the Bias Ring also after irradiation.

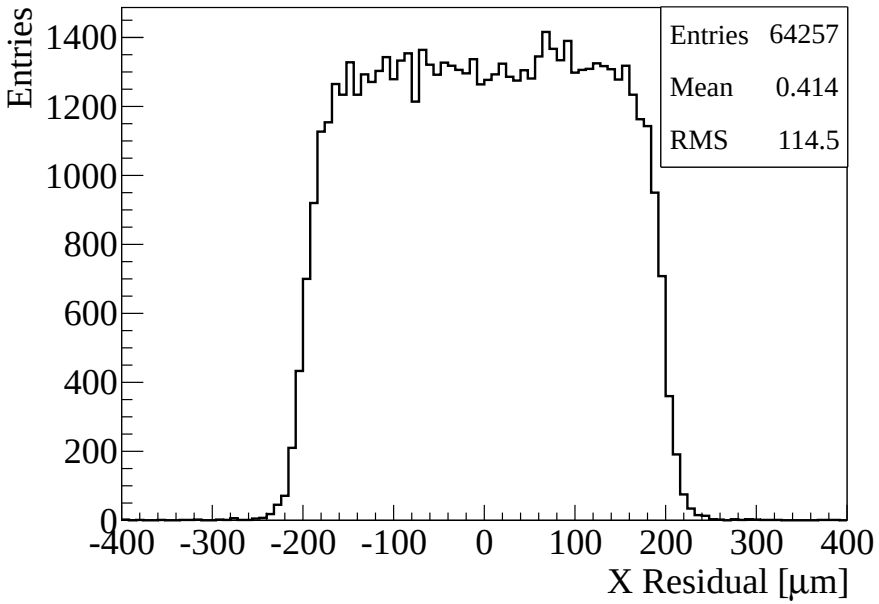
What's next:

- FE-I4 150 μm:
  - two modules have been irradiated to $1.8\times10^{16}\mathrm{n_{eq}/cm^2}$ in Los Alamos and they are about to be bonded.
- VTT active edges:
  - test of FE-I4 modules irradiated at $5\times10^{15}\mathrm{n_{eq}/cm^2}$ at KIT;
  - irradiation up to $10^{16}\mathrm{n_{eq}/cm^2}$ in Los Alamos.
- More characterizations after irradiation with beam test at DESY

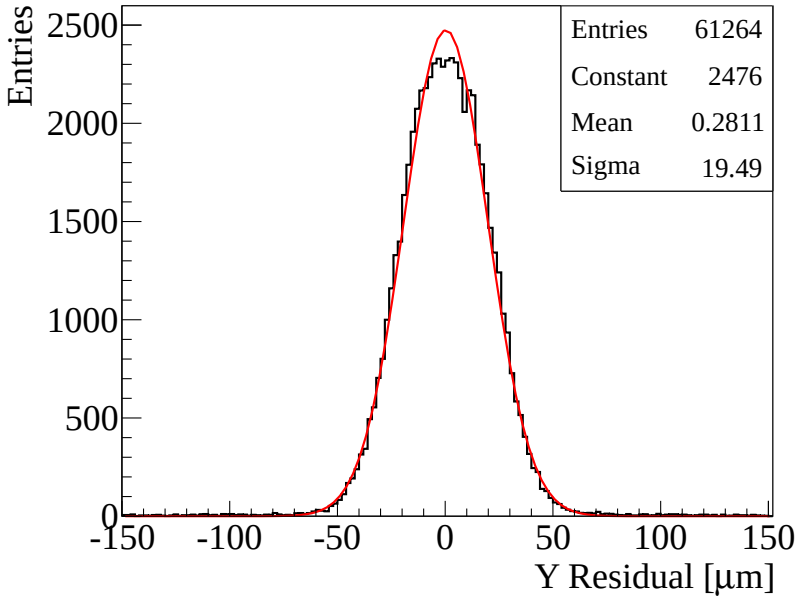
Backup slides

Residuals (DESY)

- **FE-I3 100 μm thick, irradiated to 5$\times$10^{15} n$_{eq}$/cm^2**
- PPS test beam August 2013 in DESY
- perpendicular track incidence
- bias voltage: 300 V
- threshold: 1.5 ke



Residual in X direction
(400 μm pitch)



Residual in Y direction
(50 μm pitch)