

Studies of thin irradiated planar pixel sensors at different beam incidence and characterization of the new CiS n-in-p pixel production

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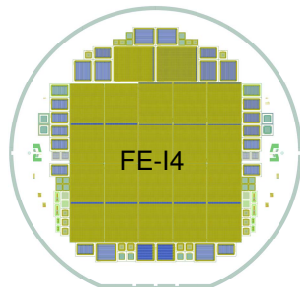
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München

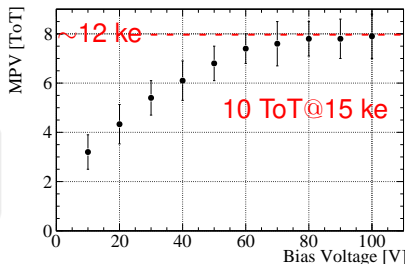
22nd RD50 Workshop, Albuquerque 3rd June 2013

n-in-p planar pixel modules 150 μm thick

- ▶ designed and produced by MPP/HLL
 - ▶ 6 inches wafers with ATLAS FE-I4 chips ($250\ \mu\text{m} \times 50\ \mu\text{m}$ pitch)
 - ▶ interconnected with bump-bonding at IZM
- ▶ irradiated up to $4 \times 10^{15}\ \text{n}_{\text{eq}}/\text{cm}^2$ in:
 - ▶ KIT \rightarrow 25 MeV protons
 - ▶ Los Alamos \rightarrow 800 MeV protons

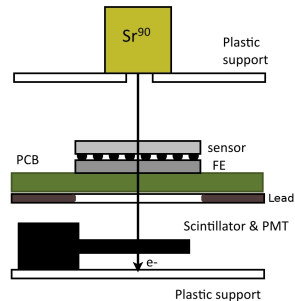
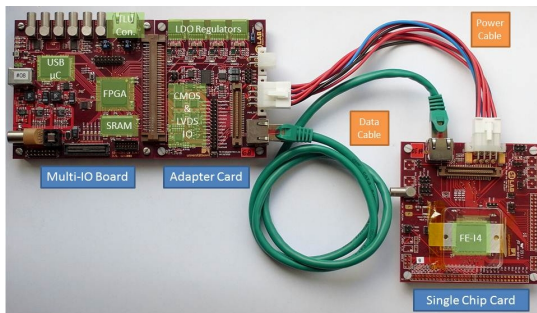


Results from test-beams and laboratory measurements with radioactive sources



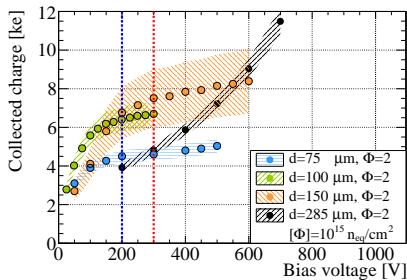
Characterization setup in laboratory

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

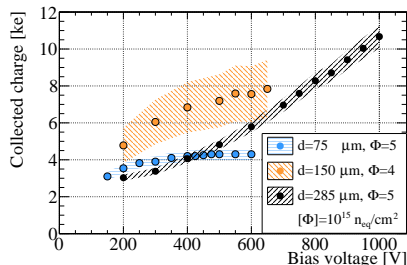
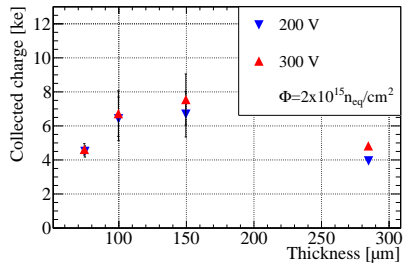


Pixel modules are wire-bonded to detector boards designed by the University of Bonn for FE-14a

Charge Collection: thickness comparison

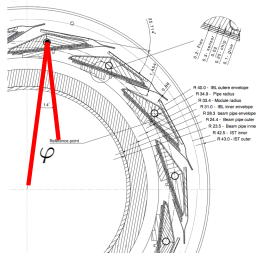
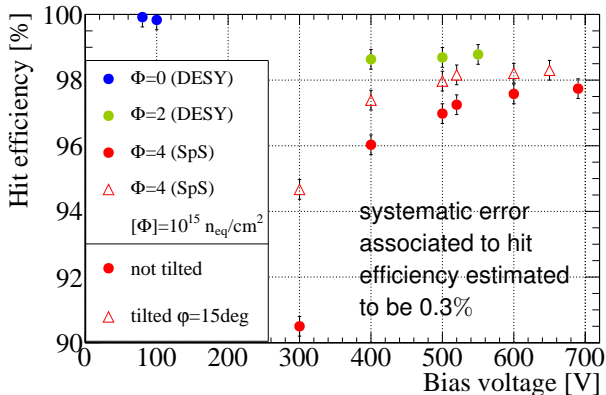
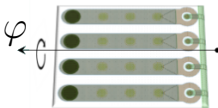


- ▶ the 150 μm thick sensors show higher charge collection up to a fluence of $\phi=4-5 \times 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$



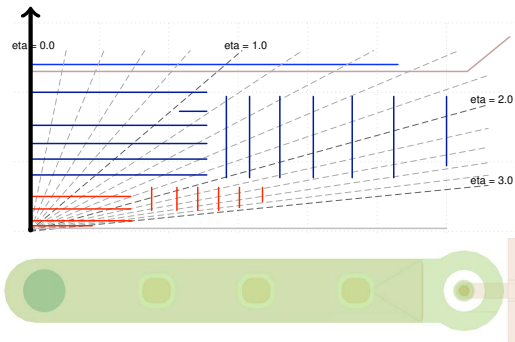
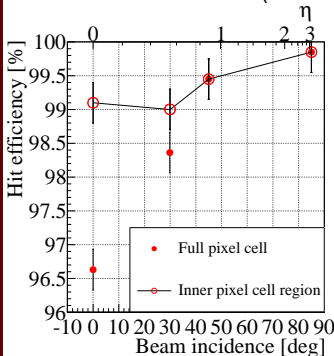
FE-I4 150 μm thick: hit efficiency

- ▶ Test-beam measurement with the EUDET telescope
 - ▶ at SpS, CERN with 120 GeV pions
 - ▶ at DESY, Hamburg with 4-6 GeV electrons

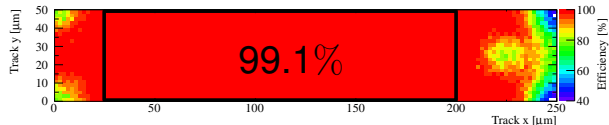


Hit efficiency at different η incidence

- ▶ **FE-I4 150 μm thick, irradiated to $4 \times 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$ in Los Alamos**
- ▶ **threshold: 1.6 ke (MPV ~ 7 ke at \perp incidence)**

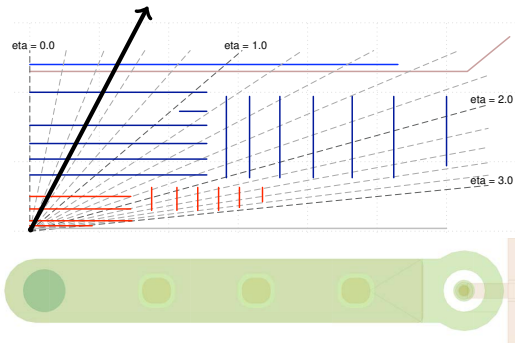
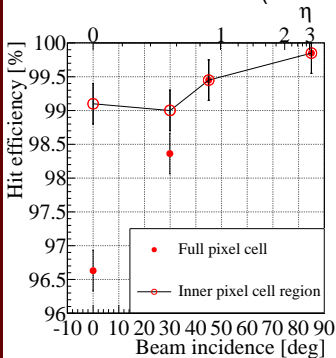


- ▶ **96.6% hit efficiency at \perp incidence (500 V)**

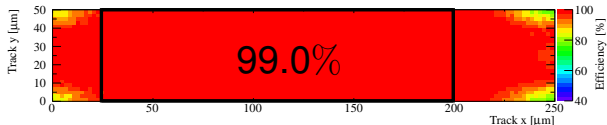


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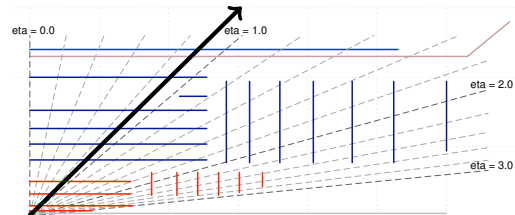
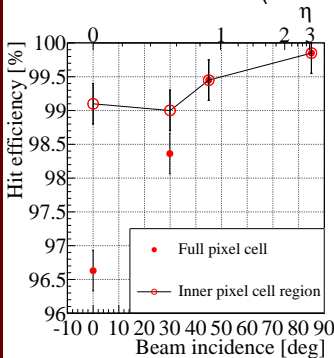


- ▶ **98.4% hit efficiency at $\vartheta=30^\circ$ ($\eta \sim 0.55$) (500 V)**

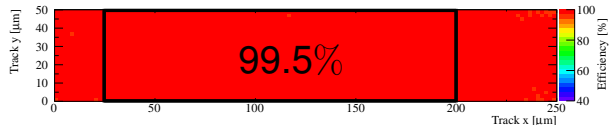


Hit efficiency at different η incidence

- ▶ **FE-I4 150 μm thick, irradiated to $4 \times 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$ in Los Alamos**
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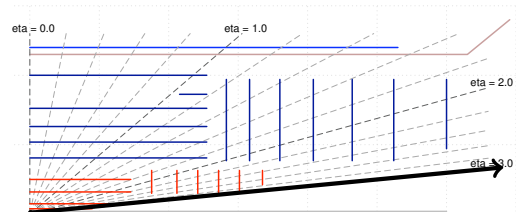
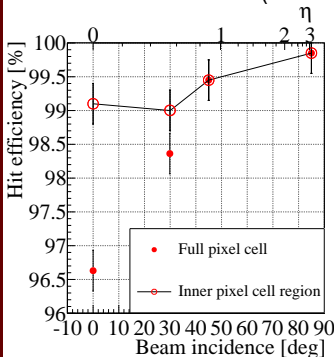


- ▶ **99.5% hit efficiency at $\vartheta=45^\circ$ ($\eta \sim 0.88$) (500 V)**

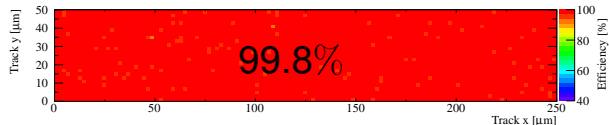


Hit efficiency at different η incidence

- ▶ **FE-I4 150 μm thick, irradiated to $4 \times 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$ in Los Alamos**
- ▶ **threshold: 1.6 ke (MPV ~ 7 ke at \perp incidence)**

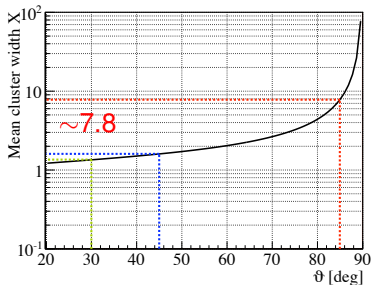


- ▶ **99.8% hit efficiency at $\vartheta=85^\circ$ ($\eta \sim 3.1$) (500 V)**

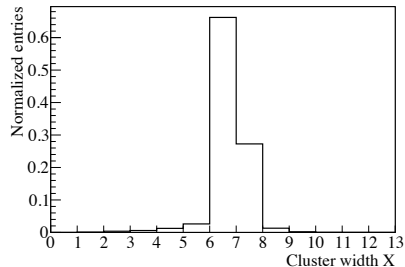


High-eta cluster analysis

- ▶ **FE-I4 150 μm thick, irradiated to $4 \times 10^{15} n_{\text{eq}}/\text{cm}^2$ in Los Alamos**
- ▶ $\vartheta=85^\circ$ track incidence ($\eta \sim 3.1$)
- ▶ bias voltage: 500 V
- ▶ threshold: 1.6 ke



Mean cluster width expected along the tilted direction for different incidence angles

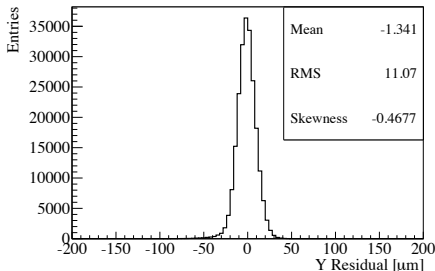


Cluster distribution along the tilted direction.

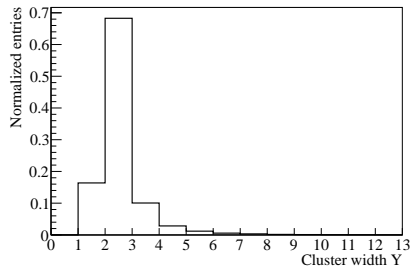
Arithmetic mean = 6.2

High-eta cluster analysis

- ▶ **FE-I4 150 μm thick, irradiated to $4 \times 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$ in Los Alamos**
- ▶ $\gamma \sim 1^\circ/2^\circ$ (alignment output), $\vartheta = 85^\circ$ track incidence ($\eta \sim 3.1$)
- ▶ bias voltage: 500 V
- ▶ threshold: 1.6 ke



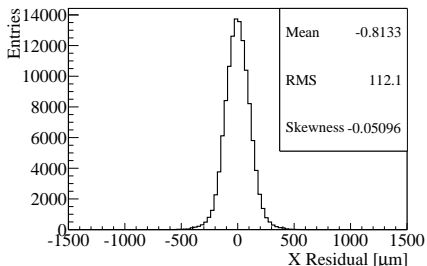
Residual along the not tilted direction (pitch: 50 μm)



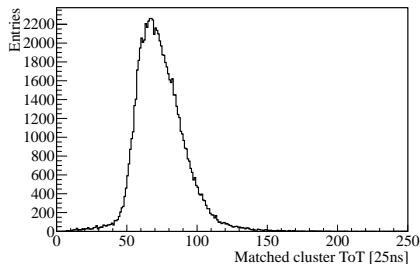
Cluster distribution along the not tilted direction.
Arithmetic mean = 2.1

High-eta collected charge

- ▶ **FE-I4 150 μm thick, irradiated to $4 \times 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$ in Los Alamos**
- ▶ $\vartheta=85^\circ$ track incidence ($\eta \sim 3.1$)
- ▶ bias voltage: 500 V
- ▶ threshold: 1.6 ke



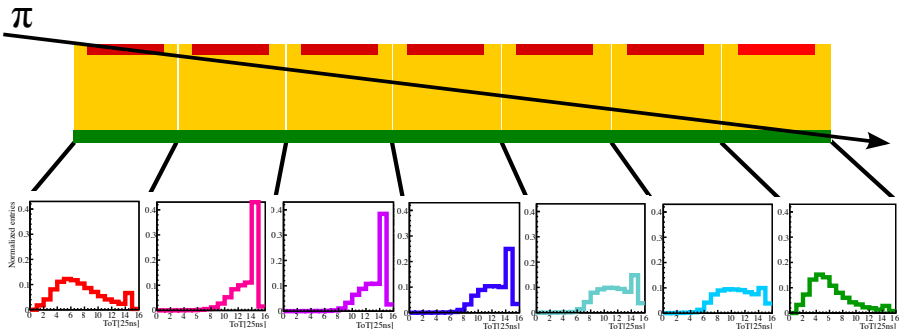
Residual along the tilted direction (pitch: 250 μm)



ToT distribution of matched clusters (10 ToT@10 ke)

High-eta collected charge

- ▶ overflow peak due to the calibration (10ToT @10 ke) at the edge of the ToT range (1-14) for a particle crossing 250 μm (~ 12 ke)
- ▶ observed higher charge collected near the n-implant



ToT distribution inside clusters of width $X=7$ along the wide pixel side

The new n-in-p pixel production at CiS

The new CiS production

► n-in-p sensors produced at CiS on 4 inches wafers:

► RD50 common project 2011/04

- Float-Zone silicon $200\ \mu\text{m}$ and $300\ \mu\text{m}$ thick

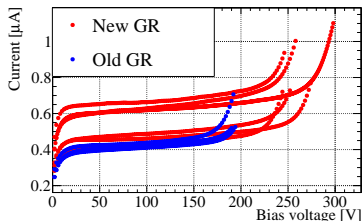
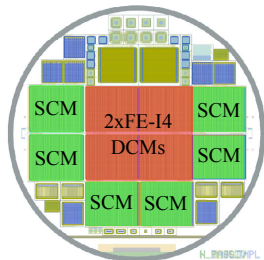
► on each wafer:

- n-in-p strips and diodes available for distribution
- FE-I4 Single Chip Module (SCM) and Double Chip Module (DCM)

- interconnected to ATLAS FE-I4 chips with bump bonding at IZM

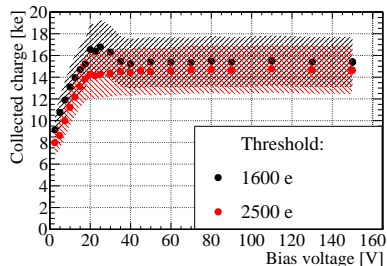
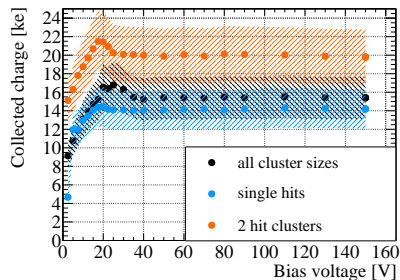
- $460\ \mu\text{m}$ distance of the last pixel implant to the edge

- two different Guard Ring designs (Old GR, New GR)



CiS modules 200 μm thick

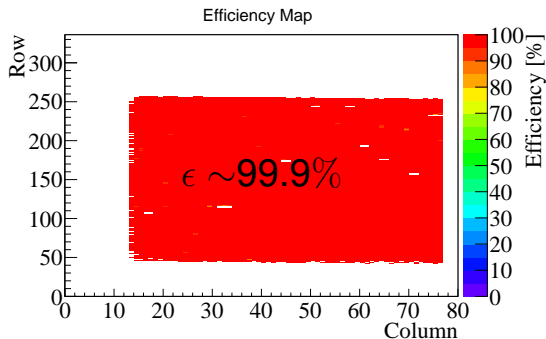
- ▶ Charge collection measurements with ^{90}Sr beta source:
 - ▶ preliminary ToT calibration with Am and Cd gamma sources as reference
 - ▶ collected charge compatible with the expected for a 200 μm thick sensor (~ 14 ke)
 - ▶ observed higher collected charge for cluster size 2
- ▶ all sensors show a peak of collected charge at the full depletion voltage
- ▶ increasing the threshold this effect is reduced



CiS modules 200 μm : test-beam measurement

► data from PPS test-beam at DESY in March 2013:

- Eudet telescope
- 4 GeV electrons
- $V_{\text{bias}}=40\text{ V}$
- threshold 1.6 ke (MPV $\sim 14\text{ ke}$)



over 99.9% hit
efficiency at \perp
track incidence

Conclusions and outlook

- ▶ 150 μm thick sensors show the highest charge collection up to a fluence of $4 \times 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$ among the tested thicknesses.
- ▶ With incident tracks at $\vartheta=45^\circ$ the efficiency loss in the punch through is recovered.
- ▶ Observed higher charge collection near the electrode.
- ▶ Most of the tested modules from the new CiS production work excellent, but some behavior still needs to be understood.

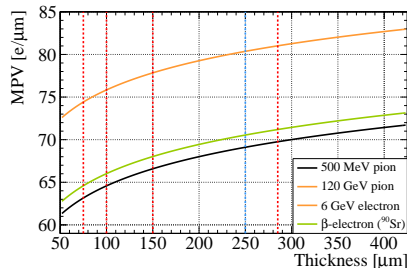
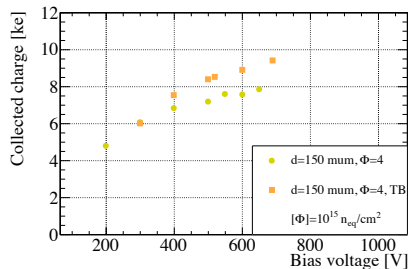
What's next:

- ▶ FE-I4 150 μm :
 - ▶ two modules have been irradiated to $2 \times 10^{16} \text{ n}_{\text{eq}}/\text{cm}^2$ in Ljubljana and they are about to be bonded;
 - ▶ one more module irradiated to $1 \times 10^{16} \text{ n}_{\text{eq}}/\text{cm}^2$ is about to be shipped back from Los Alamos.
- ▶ CiS2 production:
 - ▶ irradiation up to $5 \times 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$ at KIT;
 - ▶ irradiation up to $10^{16} \text{ n}_{\text{eq}}/\text{cm}^2$ in Los Alamos.
- ▶ Characterization after irradiation at DESY in August.

Backup slides

Comparison with laboratory measurements

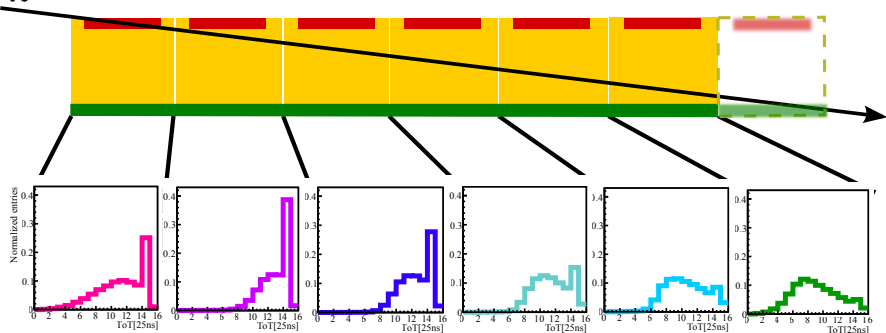
- ▶ Collected charge is in agreement between:
Test-Beam (TB, 120 GeV pions) and **lab measurements (^{90}Sr)**
- ▶ Small difference due to the dependence of e-h pairs generated from the particle energy ($\sim 10 \text{ e}/\mu\text{m}$)



High-eta charge in the cluster

- ▶ **FE-I4 150 μm thick, irradiated to $4 \times 10^{15} n_{\text{eq}}/\text{cm}^2$ in Los Alamos**
 - ▶ $\vartheta=85^\circ$ track incidence ($\eta \sim 3.1$)
 - ▶ bias voltage: 500 V
 - ▶ threshold: 1.6 ke

π



ToT distribution inside clusters of width $X=6$ along the wide pixel side