Characterization of thin high irradiated n-in-p planar pixel sensors

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N-in-p planar pixel samples

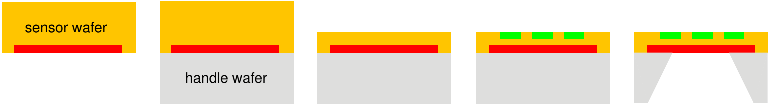
CiS samples:

Irradiations:

- FE-I3 modules 285$\mu\mathrm{m}$ thick → $1\times10^{16}\mathrm{n_{eq}/cm^2}$ in Lubljana (reactor neutrons)

MPI/HLL samples:

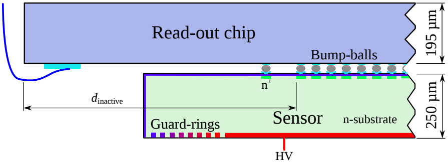
- FE-I3 modules 75$\mu\mathrm{m}$ thick (SLID interconnected) → $1\times10^{16}\mathrm{n_{eq}/cm^2}$ in Lubljana (reactor neutrons)
- FE-I4 modules 150$\mu\mathrm{m}$ thick → $4\times10^{15}\mathrm{n_{eq}/cm^2}$ in Los Alamos (800MeV protons)



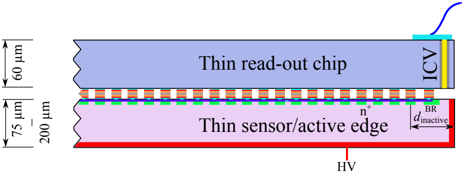
1. Implant backside on sensor
2. Bond sensor wafer to handle wafer
3. Thin sensor side to desired thickness
4. Process on top side
5. Structure resist, etch backside up to oxide/implant

Full module concept

- the present ATLAS module design



- through a 3D integration assembly:
  - thin sensors (75-150μm)
  - Solid Liquid InterDiffusion (SLID) interconnection
  - present chips thinned up to 200μm
  - Through Silicon Vias (TSV) to bring the signal directly to the backside passing through the chip (thinned to 60μm)
- to active edge sensors (see Anna Macchiolo's talk)



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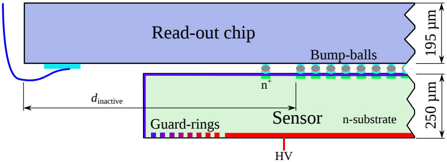

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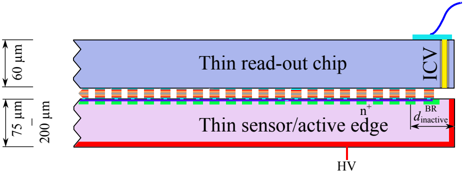
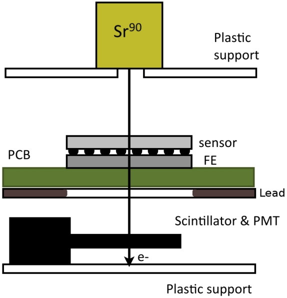
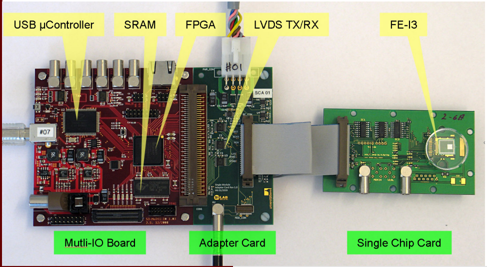


Characterization setup in laboratory

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

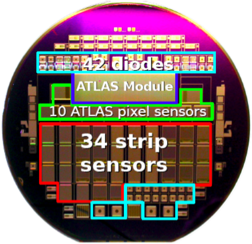


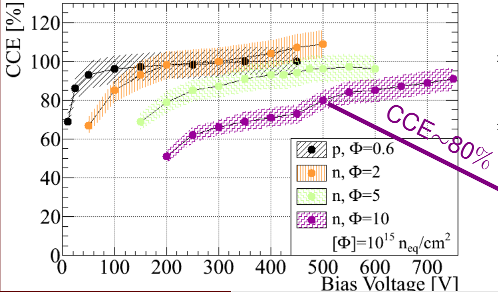


Pixel modules are wire-bonded to detector boards designed by the University of Bonn for FE-I3 and FE-I4

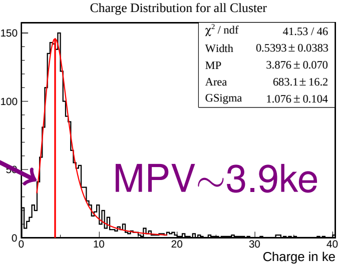
SLID modules 75μm thick

- Good Charge Collection Efficiency after $10^{16} n_{eq}/cm^2$
- SLID interconnection is radiation hard (the number of unconnected channels is stable)





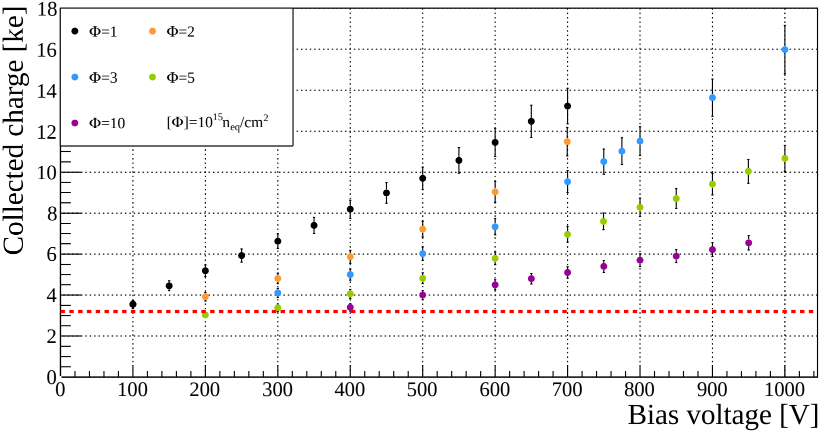
CCE~80%



MPV~3.9ke

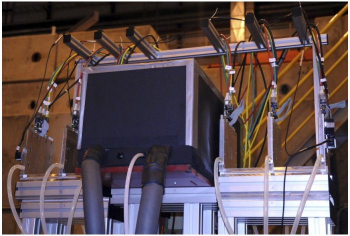
CC for FE-I3 modules 285μm thick

- MPP/HLL design produced by CiS irradiated up to $10^{16} n_{eq}/cm^2$
  - tested up to 1000V
  - threshold: 3200e



Test-beam results

- Test-beams with the EUDET telescope:
  - at SpS CERN with 120GeV pions
  - at DESY with electrons up to 6GeV
- cooling with dry ice up to ∼ -45°C

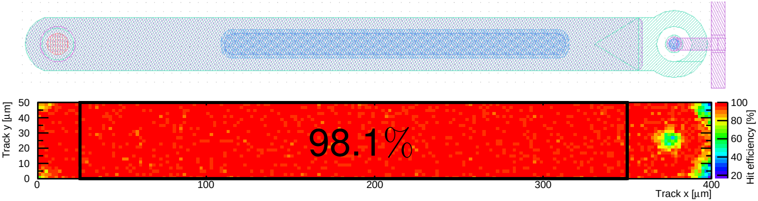


Many thanks to the PPS test-beam crew:

S. Altenheiner, M. Backhaus, M. Bomben, K. Dette, M. Ellenburg, D. Forshaw, C. Gallrapp, M. George, I. Gregor, J. Janssen, J. Jentzsch, R. Klingenberg, A. Kravchenko, T. Kubota, A. Macchiolo, R. Plümer, R. Nagai, B. Rastic, I. Rubinsky, A. Rummler, Y. Takubo, S. Terzo, K. Toms, R. Wang, Y. Unno, P. Weigell, J. Weingarten.

Efficiency for FE-I3 modules 285μm thick

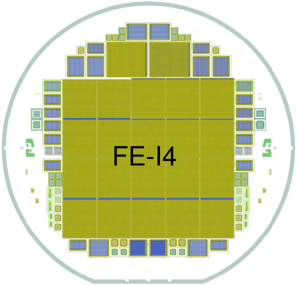
- Test-beam at SpS, CERN with the EUDET telescope:
  - Pions 120GeV
  - perpendicular beam incidence
  - bias voltage: 600V
  - threshold: 2ke (MPV∼5.5ke)



- **97.2% hit efficiency** at $10^{16} \mathrm{n_{eq}/cm^2}$ (98.1% in the inner region)
  - Main loss due to punch through and bias rail
  - efficiency loss also for charge sharing in the corners

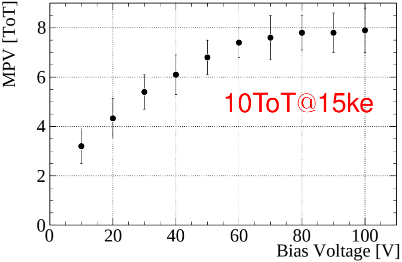
FE-I4 modules 150$\mu\mathrm{m}$ thick

- designed and produced by MPP/HLL
  - 6 inches wafers with ATLAS FE-I4 chips (50$\mu\mathrm{m}\times$250$\mu\mathrm{m}$)
  - interconnected with bump-bonding at IZM
- irradiated up to 4$\times$10$^{15}\mathrm{n_{eq}/cm^2}$



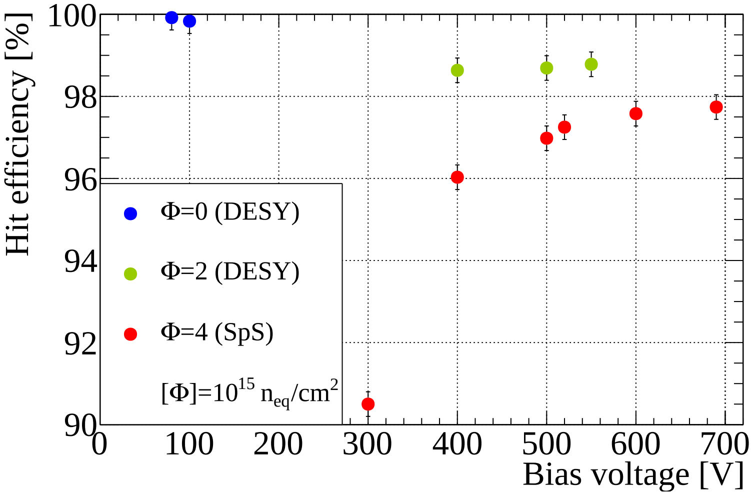
- Results from lab and test-beam measurements

not irradiated show excellent performances: $\epsilon \geq$99.7%



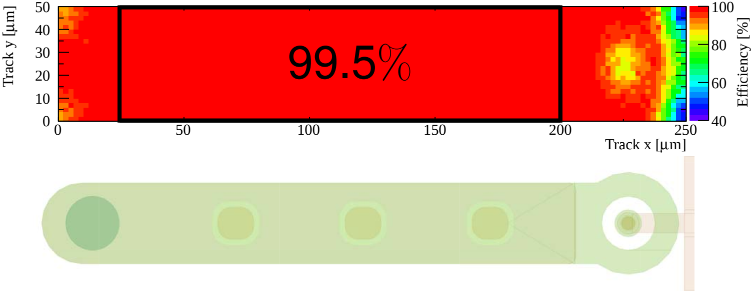
Efficiency: FE-I4 modules 150μm thick

- Test-beam measurement at perpendicular incidence:



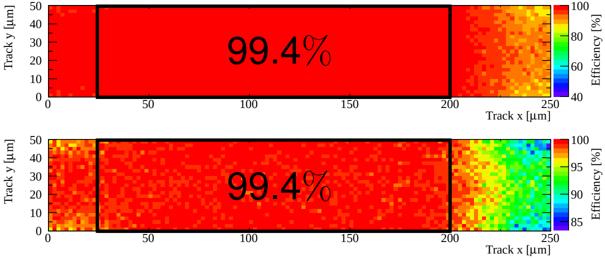
Pixel cell efficiency: FE-I4 modules 150μm thick

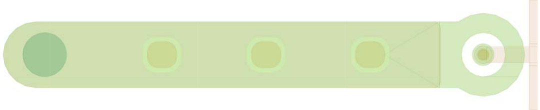
- irradiated to 4×$10^{15}\mathrm{n_{eq}/cm^2}$ in Los Alamos
- perpendicular beam incidence
- threshold: 1.6ke (MPV∼9.5ke)
- **97.7% hit efficiency** at 690V (∼99.5% in the central region)



Pixel cell efficiency: FE-I4 modules 150μm thick (tilted)

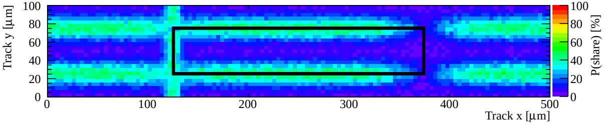
- irradiated to 4×$10^{15} n_{eq}/cm^2$ in Los Alamos
- 15° tilted in ϕ
- threshold: 1.6ke (MPV∼9.5ke)
- **98.2% hit efficiency** at 650V (∼99.4% in the central region)



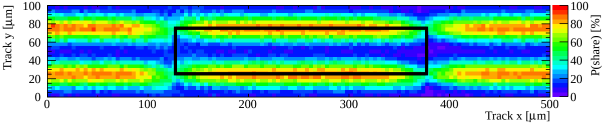


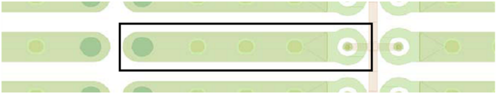
Modules charge sharing

- ϕ=0° 690V



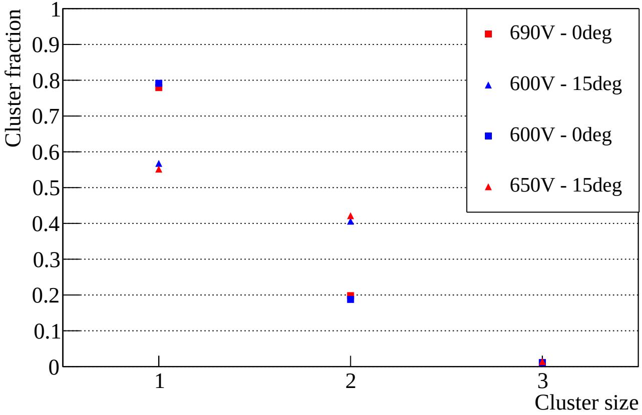
- ϕ=15° 650V





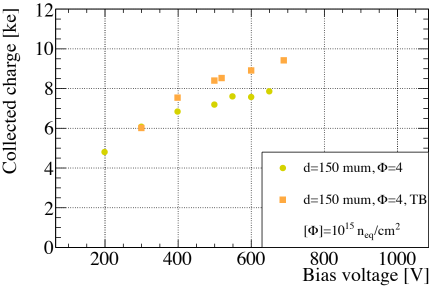
Modules charge sharing: cluster properties

- slightly increase of charge sharing with the voltage
- ϕ=15° → 2× more cluster of size 2

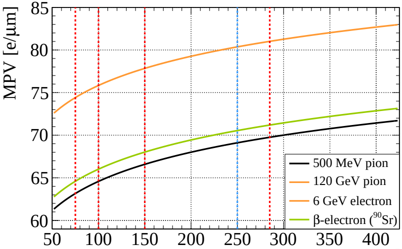


Comparison with laboratory measurements

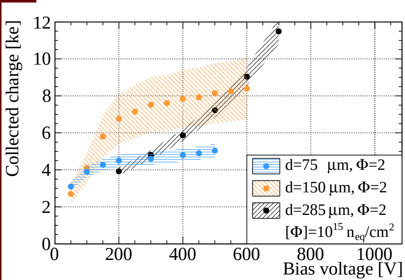
- Collected charge is in agreement between:
  TB (120GeV pions) and
  lab measurements (^{90}Sr)

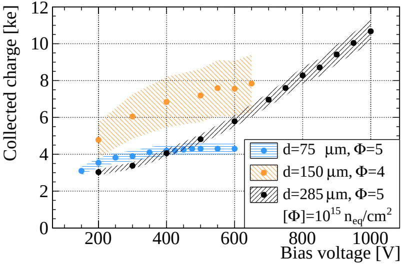


- Small difference due to the dependence of e-h pairs generated from the particle energy ($\sim$10 e/μm)

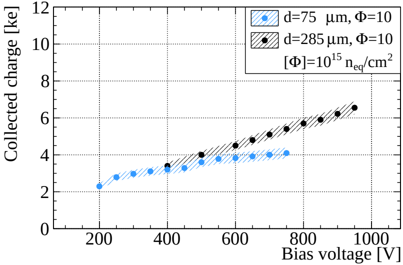


Thickness comparison





- 150$\mu\mathrm{m}$ thick sensors show higher charge up to a fluence of ϕ=4-5$\times 10^{15}\mathrm{n_{eq}/cm^2}$
- charge collected by thin and thick sensors tend to equalize at high fluences (due to trapping)



Conclusions and outlook

- demonstrated the feasibility of employing n-in-p pixel sensors of standard thickness up to $10^{16}\mathrm{n_{eq}/cm^2}$
  - in particular suited for the outer pixel layer of Phase II
- very good performances of thin 150$\mu\mathrm{m}$ sensors suited for the internal or intermediate layers up to $4\times10^{15}\mathrm{n_{eq}/cm^2}$

What's next:

- FE-I4 150$\mu\mathrm{m}$:
  - paraylene coating (allows for high voltages without discharges)
  - irradiation up to $2\times10^{16}\mathrm{n_{eq}/cm^2}$ in Lubljana and Los Alamos
- FE-I3 285$\mu\mathrm{m}$ and SLID 75$\mu\mathrm{m}$:
  - irradiation to $2\times10^{16}\mathrm{n_{eq}/cm^2}$ in Lubljana
- ...more test-beams in DESY (no beam at SpS next year)

Backup slides

SLID interconnection technique

An alternative chip connection to bump bonding

Pros:

- high T_{melt} allows for vertical integration
- smaller pitches and arbitrary geometries
- wafer to wafer and chip to wafer possible
- cost effective: less process steps.

Cons:

- planarity of 1 $\mu\mathrm{m}$ needed
- no rework possible
- homogeneous pressure needed