LPNHE-FBK-INFN thin edgeless n-on-p pixel sensors: testbeam results and future plans

A. Ducourthial[1], A. Bagolini[2], M. Bomben[1], M. Boscardin[2], L. Bosisio[3], G. Calderini[1], Louis D'Eramo[1], G. Giacomini[2,4], G. Marchiori[1], N. Zorzi[2]

1 Laboratoire de Physique Nucléaire et de Hautes Énergies (LPNHE), 75005 Paris, France
2 Fondazione Bruno Kessler, Centro per i Materiali e i Microsistemi (FBK-CMM), I-38123 Povo di Trento (TN), Italy
3 Università di Trieste, Dipartimento di Fisica and INFN, I-34127 Trieste, Italy
4 Brookhaven National Laboratory, Instrumentation Division 535B, Upton, NY - USA

LPNHE PARIS

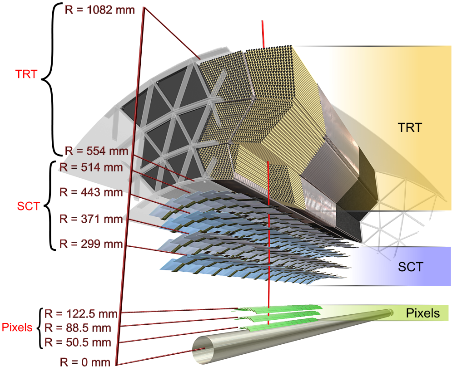
12th Trento Workshop - February 20, 2017

ATLAS EXPERIMENT

Table of contents

Introduction: ATLAS Tracker Upgrade

ATLAS Tracker

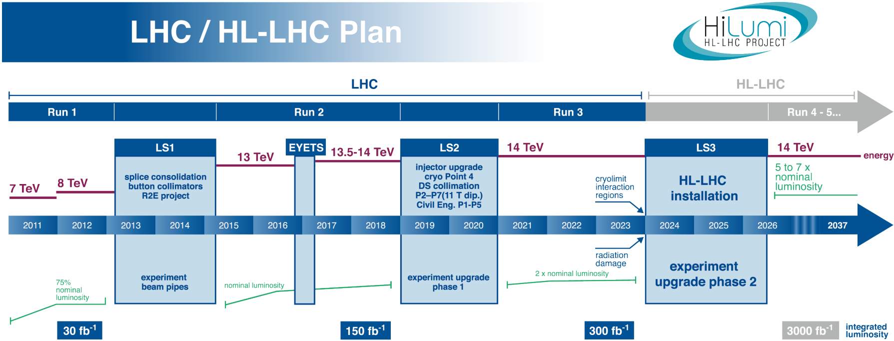


- 3 subdetectors: Pixels, SCT, TRT
- Pixel detectors composed of now 4 barrel layers (IBL)
- η acceptance: -2.5 $<\eta<$ 2.5
- Excellent performances in terms of spatial resolution and hit efficiency, but
- Pixel radiation hardness between 1 and 5 $\times 10^{15} n_{eq}/cm^2$

ATLAS Upgrade

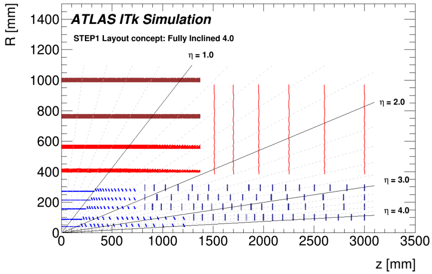
ATLAS data taking phase in HL LHC conditions (start in early 2026):

- Peak luminosity of $L_{inst} \simeq 7.5 \times 10^{34} cm^{-2} s^{-1}$
- 200 inelastic pp collisons per bunch crossing
- By the end of 2035, ATLAS will collect 3000 fb^{-1} (4000 fb^{-1}?)
- Fluence inner tracker $2 \times 10^{16} n_{eq}/cm^2$ (4 times IBL fluence)

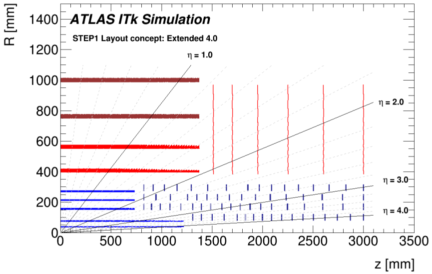


ATLAS Inner Tracker Upgrade Layout

Inclined Layout



Extended Layout



Pixel options:

- 3D silicon pixels
- Planar silicon pixels
- CMOS pixels

TDR due for end of 2017

∗ All silicon tracker

∗ 10 m^2 of pixels more than 600 Millions electronical channels

∗ 200 m^2 of strips

strips (red) - pixels (blue)

ATLAS Inner Tracker Upgrade Challenges

ITK major challenges:

- Radiation hardness: Retain a 97% efficient with a fluence up to $2 \times 10^{16} neq/cm^2$
  - $*$ Thinner sensors to fight charge trapping
  - $*$ Better understanding of radiations impact on silicon sensors
  - $*$ LPNHE 100 μm thick sensors irradiated at $3 \times 10^{15} n_{eq}/cm^2$
- Pile up compliance:
  - $*$ granularity ($50\mu m \times 50\mu m$ or $25\mu m \times 100\mu m$ pitch instead of $250\mu m \times 50\mu m$)
  - $*$ new chip RD53 $50 \times 50\mu m$ to deal with high data rate at HL-LHC
- Increase the geometrical acceptance
  - $*$ Instrument at high eta (for example"Alpine sensors")
  - $*$ Reduction of dead area $\Rightarrow$LPNHE Active edge sensors

ITK - Edgeless sensors

Reduction of dead area

b quarks $\Rightarrow$ fragmentation

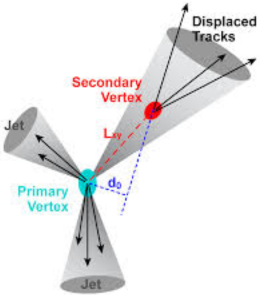
Better reconstruction of secondary vertices

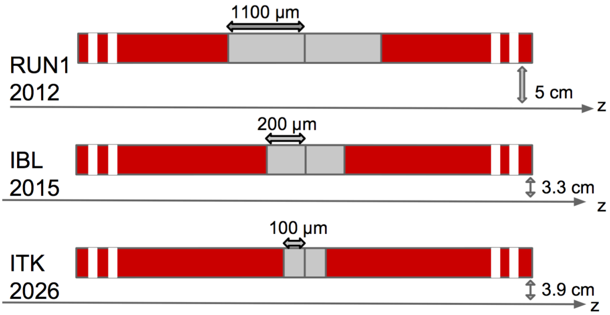
⇓ ⇓

Put sensors closer to the beam

⇓

Reduction of dead area



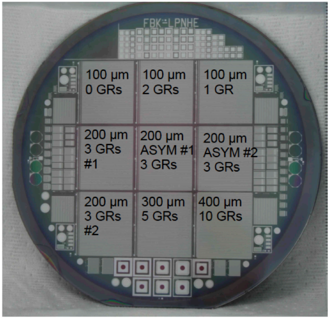


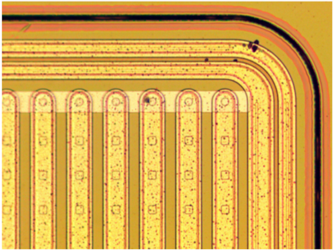
ACTIVE

EDGE $\rightarrow$ 100 μm

LPNHE-FBK-INFN sensors

Production 1: Active edge sensors





FBK-LPNHE production:

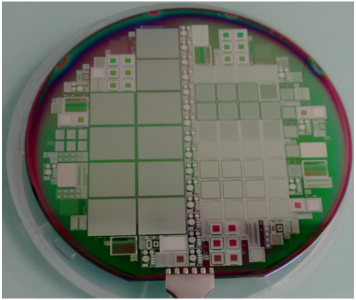
- 9 sensors compatible with actual ATLAS IBL read-out chip (FEI4b)
- n-on-p devices
- pixel pitch: 50 μm by 250 μm
- thickness: 200 μm
- support wafer: 500 μm thick
- Biased during test thanks to temporary metal

Active edge production:

- Deep Reactive Ion Etching
- LPNHE5: 100 μm from last pixel, 0 GR
- LPNHE7: 100 μm from last pixel, 2 GR innermost GR connected, outermost GR floating

Development of Edgeless n-on-p Planar Pixel Sensors for future ATLAS Upgrades, *M Bomben et al*, Nucl. Instr. and Meth. A 2013:712:41-47

Production 2: Thin sensors



FBK-INFN-LPNHE production:
Thin Sensors: W80 & W30

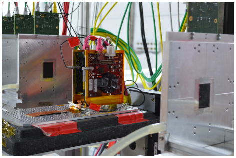
- 6 inches SiSi wafers
- n-on-p devices
- thickness: 100 μm
- unirradiated (W30) and irradiated (W80) at a fluence of $3 \times 10^{15} n_{eq}/cm^2$

Production 3 (Soon to be delivered):

- Thin Active edge sensors (thickness: 100 μm, 50/75 μm pixel to trench, 0/1 GRs)
- Alpine sensors, RD53 compatible sensors, HGTD pad

For more details, see presentation of Sabina Ronchin

TestBeams



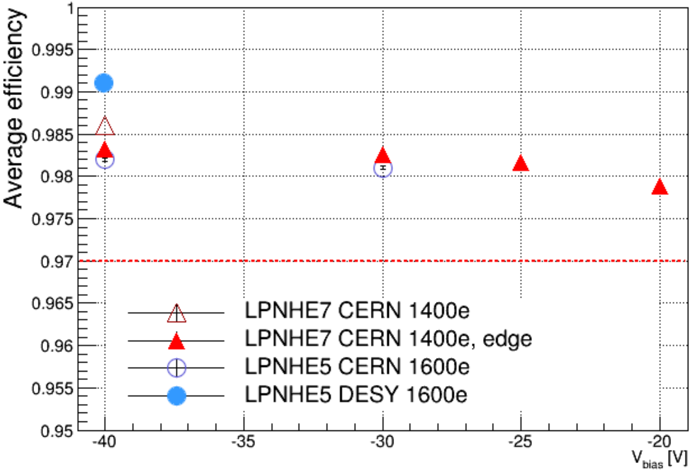
* March 2015: DESY with 4GeV electrons **LPNHE5**
* July 2015: CERN SPS 120 Gev pions **LPNHE5**
* May 2016: CERN SPS **LPNHE7, W80 unirradiated**
* August 2016: CERN SPS **LPNHE7, W30 unirradiated**
* October 2016: CERN SPS **LPNHE7, W80 irradiated**

Reconstruction and analysis :

- Global Hit Efficiency
- In Pixel Hit Efficiency: Efficiency homogeneity inside a pixel cell
- Edge area Hit Efficiency
- Spatial resolution: Residuals study
- Radiation hardness $\Rightarrow$ Tests on irradiated sensors

Production 1: Active edge sensors

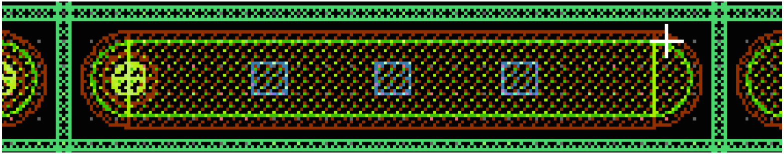
GLOBAL HIT EFFICIENCY



- Efficiency higher than **97.5%** for LPNHE 5 and LPNHE7 (0/2 GRs)

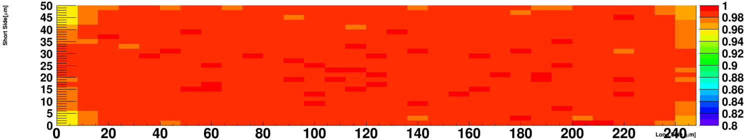
In Pixel Efficiency

PIXEL



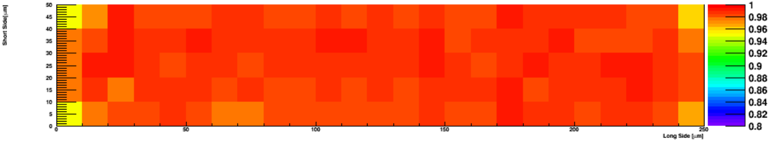
LPNHE5

-40V



LPNHE7

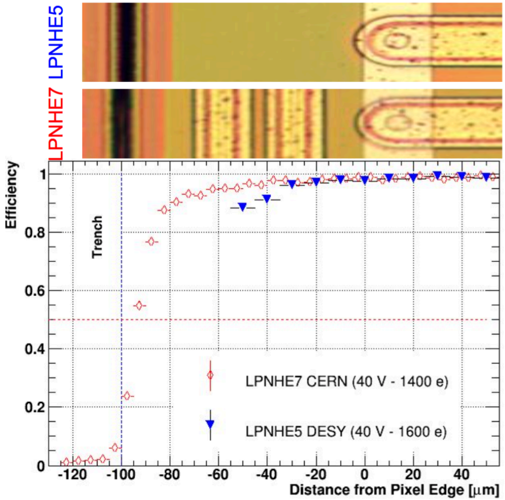
-40V



Temporary metal line to bias sensors before bump bonding:

No permanent bias structures results in **uniform hit efficiency**

Edge Efficiency



LPNHE 5 (0 GR):

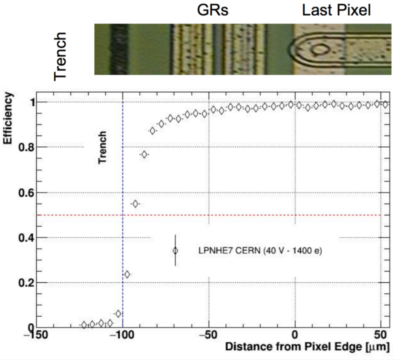
- Higher threshold 1600e
- Multiple scattering DESY

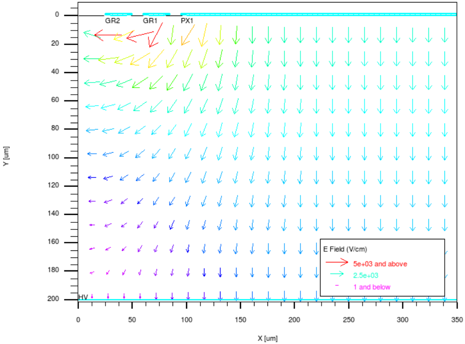
LPNHE 7 (2GR)

Efficiency higher than 50% up to 92 μm from the last pixel

Presence of GRs doesn't seem to impact too severely on the hit-efficiency

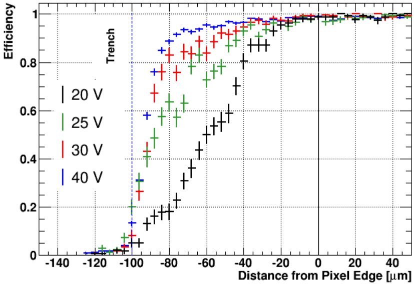
Edge Efficiency - Comparison with TCAD simulation



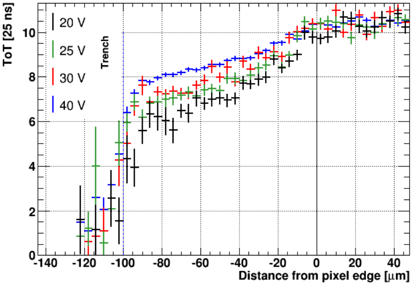


- **Charge is not collected and reemitted by GRs** apart from few μm below the GR
- **Simulation TCAD** supports the hypothesis
- **Uninstrumented area is no longer dead !**

Edge efficiency



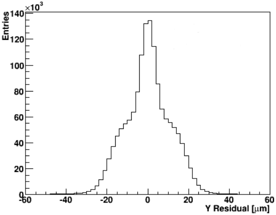
Edge ToT



- Lateral depletion completed around 40V
- Few events yield non zero efficiency and ToT up to 20μm beyond the edge; this is compatible with the spatial resolution of one pixel cell clusters

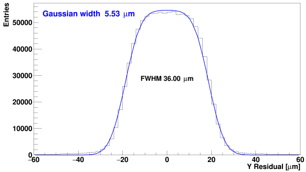
RESIDUALS

All Clusters



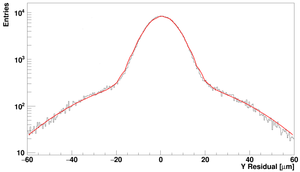
$RMS_{ResY}(all) = 11.5\mu m$

Clusters of 1 pixel (Cl1)



Fit: Box function convoluted with a gaussian

Clusters of 2 pixels (Cl2)



Fit: core gaussian convoluted with an outlier gaussian

Spatial resolution in the short direction $RMS_Y(all) = 11.5\mu m$

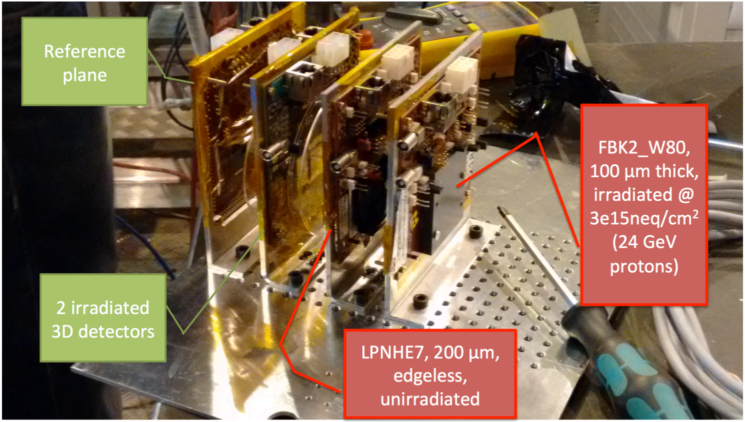
$RMS_{ResY}(Cl1) = 14\mu m$ compatible with the expected digital resolution

Pointing resolution of the telescope, $RMS_{gauss}(Cl1) = 5.5\mu m$

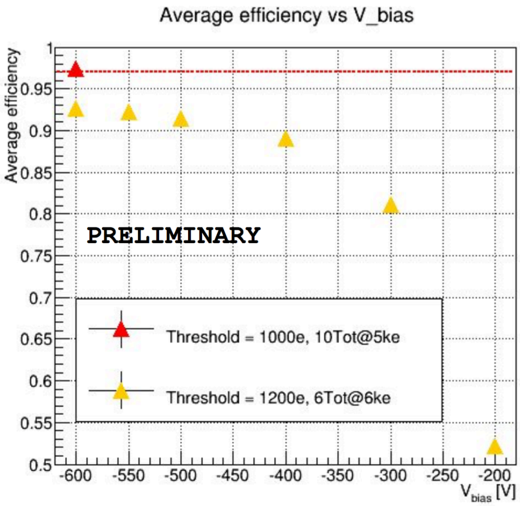
Charge sharing region, obtained as $RMS_{coregauss}(Cl2) = 7.8\mu m$

Production 2: Thin sensors

Irradiated 100 μm thick sensor tested in October testbeam



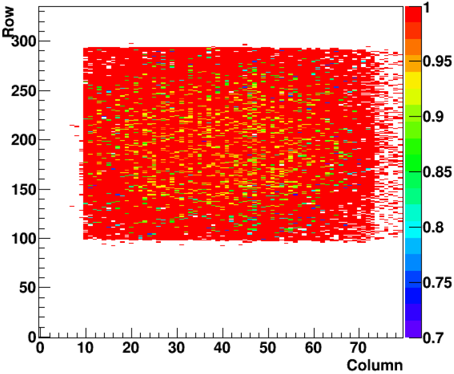
THIN SENSORS EFFICIENCY



- Fluence $3 \times 10^{15} n_{eq}/cm^2$
- Almost full efficiency recovered at 600V
- For threshold=1200e and 6ToT@6ke Hit efficiency $\simeq 92\%$
- For threshold=1000e and 10ToT@5ke Hit efficiency $> 97\%$
- To be remeasured at DESY in 3 weeks

THIN SENSORS EFFICIENCY

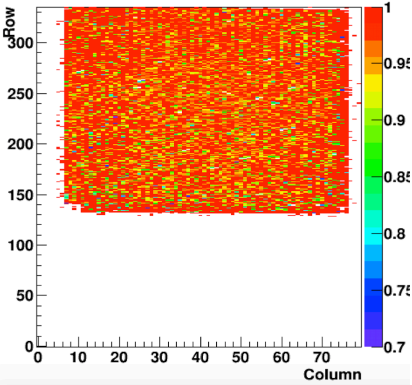
W30 (W80 twin) unirradiated



Thresold 1000e ; -150V

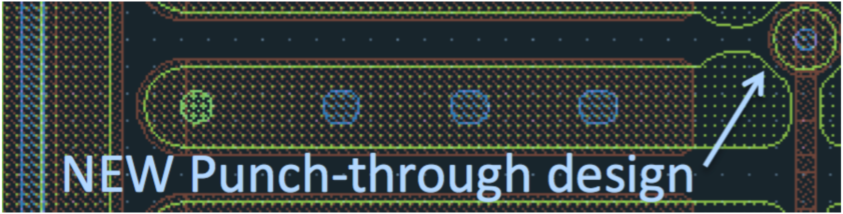
Global efficiency: $98,6\%$

W80 irradiated $3 \times 10^{15} n_{eq}/cm^2$

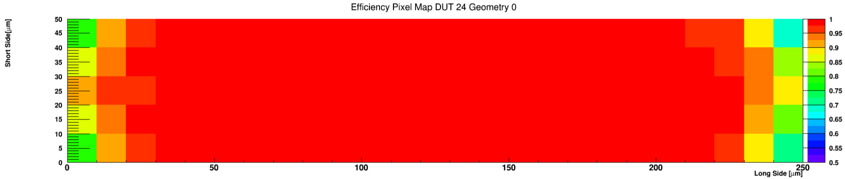


Thresold 1000e ; -600V

Global efficiency: $97,4\%$



W80 irradiated:



Lack of efficiency at the border due to punch through structure

Conclusions and Future plans

Conclusions

- **Thanks to the Active edge technology, the edge region is efficient above 97% up to 70μm from last pixel**
- **Thin sensors highly efficient after irradiation**
- Thanks to **temporary metal** no permanent biasing structures, so **very homogeneous efficiency** in the whole pixel cell
- Excellent performances in terms of efficiency and spatial resolution

To be tested in beam in spring 2017:

- Combination of thin and active edge sensors (production 3) soon to be delivered.
- W30 irradiated non uniformly with fluence peak at $4 \times 10^{15} n_{eq}/cm^2$

ACKNOWLEDGEMENTS

For Productions 2 and 3:
This work was supported by the Italian National Institute for Nuclear Physics (INFN), Projects ATLAS, CMS, RD-FASE2 (CSN1)

- Principal investigators: Marco Meschini, Gian Franco Dalla Betta, Maurizio Boscardin, Giovanni Darbo, Gabriele Giacomini, Sabina Ronchin, Alberto Messineo

and by AIDA-2020 Project EU-INFRA Proposal no. 654168.

The authors want to thank the CERN IRRAD team for helping with the irradiation of the detectors.

BACK UP: IV CURVES