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

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Introduction: ATLAS Tracker Upgrade
ATLAS Tracker

- 3 subdetectors: Pixels, SCT, TRT
- Pixel detectors composed of now 4 barrel layers (IBL)
- $\eta$ 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 $L_{\text{inst}} \simeq 7.5 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$
- 200 inelastic pp collisions per bunch crossing
- By the end of 2035, ATLAS will collect $3000 \text{ fb}^{-1}$ ($4000 \text{ fb}^{-1}$?)
- Fluence inner tracker $2 \times 10^{16} n_{eq}/\text{cm}^2$ (4 times IBL fluence)
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
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 $\mu m$ 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
Reduction of dead area

b quarks $\Rightarrow$ fragmentation

Better reconstruction of secondary vertices
$\Downarrow$ $\Downarrow$
Put sensors closer to the beam
$\Downarrow$
Reduction of dead area

ACTIVE EDGE $\rightarrow$ 100 $\mu m$
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 $\mu m$ by 250 $\mu m$
► thickness: 200 $\mu m$
► support wafer: 500 $\mu m$ thick
► Biased during test thanks to temporary metal

Active edge production:

► Deep Reactive Ion Etching
► LPNHE5: 100 $\mu m$ from last pixel, 0 GR
► LPNHE7: 100 $\mu m$ from last pixel, 2 GR innermost GR connected, outermost GR floating
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 ⇒ Tests on irradiated sensors
Production 1: Active edge sensors
Efficiency higher than 97.5% for LPNHE 5 and LPNHE7 (0/2 GRs)
In Pixel Efficiency

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 \( \mu m \) from the last pixel

Presence of GRs doesn’t seem to impact too severely on the hit-efficiency
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!
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**

\[ \text{RMS}_{\text{ResY}}(\text{all}) = 11.5 \mu m \]

**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

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**Spatial resolution in the short direction** \( \text{RMS}_Y(\text{all}) = 11.5 \mu m \)

\( \text{RMS}_{\text{ResY}}(\text{Cl1}) = 14 \mu m \) compatible with the expected digital resolution

Pointing resolution of the telescope, \( \text{RMS}_{\text{gauss}}(\text{Cl1}) = 5.5 \mu m \)

Charge sharing region, obtained as \( \text{RMS}_{\text{coregauss}}(\text{Cl2}) = 7.8 \mu m \)
Production 2: Thin sensors
Irradiated 100 $\mu$m 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 $\sim 92\%$
- 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%
THIN SENSORS IN PIXEL EFFICIENCY

W80 irradiated:

Lack of efficiency at the border due to punch through structure
Conclusions and Future plans
Thanks to the Active edge technology, the edge region is efficient above 97% up to 70\(\mu\)m 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 \(\times\) \(10^{15}\) \(n_{eq}/cm^2\)
For Productions 2 and 3:
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BACK UP: IV CURVES