Development of planar pixel sensors for ATLAS tracker upgrade

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JRJC Instrumentation session

ATLAS EXPERIMENT

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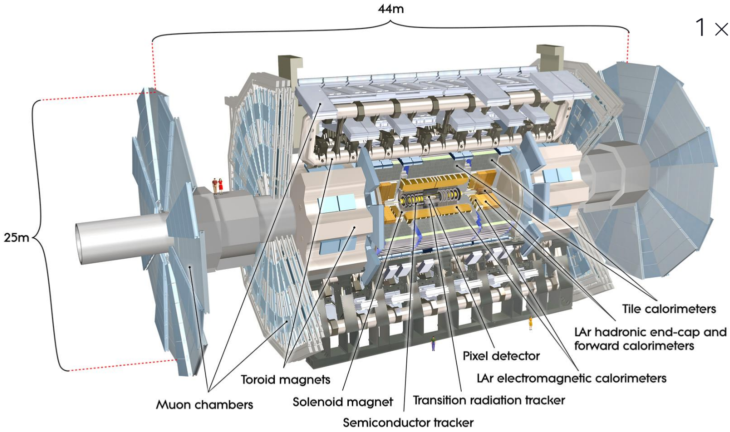
ATLAS Tracker Upgrade

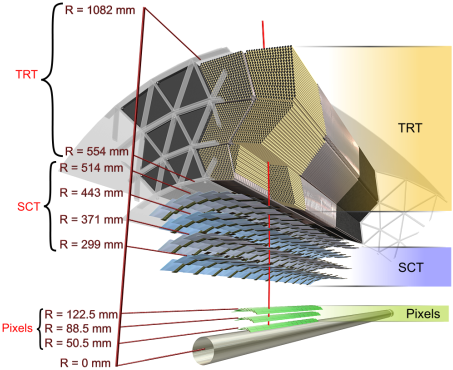
ATLAS detector

Luminosity of
$1 \times 10^{34} cm^{-2} s^{-1}$



- Inner Tracker
- Electromagnetic and hadronic calorimeter
- Muon spectrometer
- Solenoid and Toroidal magnets

ATLAS Tracker



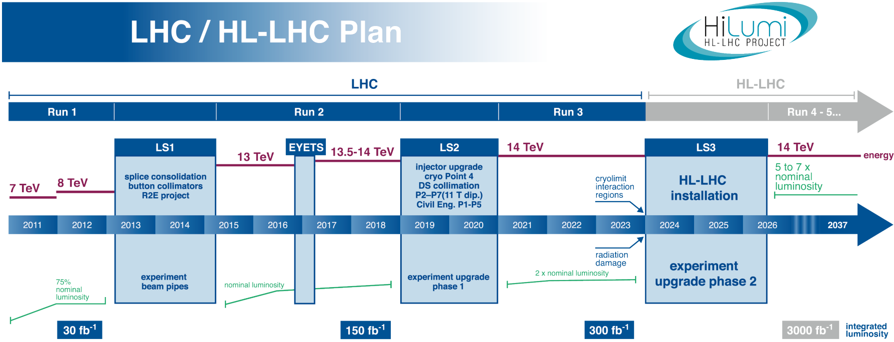
$\eta \equiv -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$

- 3 subdetectors: Pixels, SCT, TRT
- Pixel detectors composed of now 4 layers (IBL)
- Pixel longitudinal resolution 100 μm
- Pixel transverse spatial resolution 10 μm
- Pixel radiation hardness between 1 and 5 $\times 10^{15} n_{eq}/cm^2$
- η acceptance: -2.5 $< \eta <$ 2.5

ATLAS Upgrade

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

- challenging 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}
- Fluence inner tracker $2 \times 10^{16} n_{eq}/cm^2$ (4 times IBL fluence)

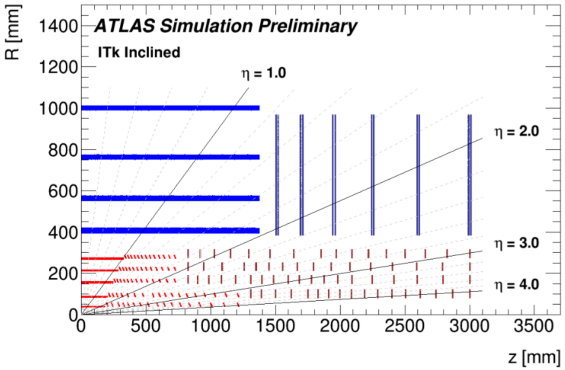


ATLAS Upgrade: Physics goals

- Collect a large data sample to do precision measurements of Higgs boson, especially coupling to b quarks
- Precision measurements on other SM phenomena
- BSM searches

To achieve these physics goals we need:
∗ Efficient reconstruction of pile up vertices
∗ Better rejection of QCD background
∗ Upgrade of b tagging algorithm to be efficient at high pile up and high eta

ATLAS Inner Tracker Upgrade Layout



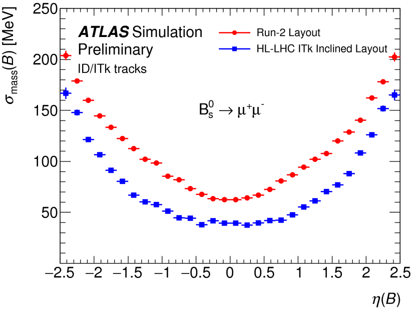
Pixel options:

- 3D silicon pixels (L1)
- Planar silicon pixels (L2 -L4)
- CMOS pixels (L5)
- (Diamond pixels)

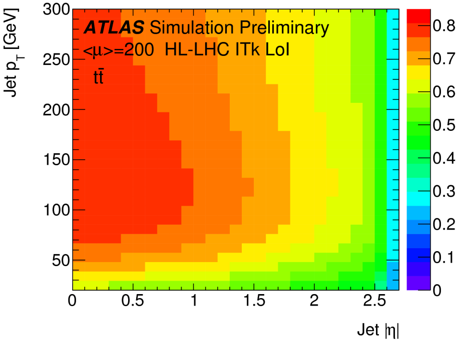
TDR due for end of 2017

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

ATLAS Inner Tracker Upgrade Physics impact



B_s^0 mass resolution as a function of η in the decay channel $B_s^0 \to \mu^+\mu^-$



b-jet tagging efficiency for 200 events per bunch crossing (HL-LHC conditions)

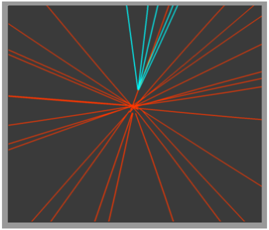
ATLAS Inner Tracker Upgrade Challenges

ATLAS ITK collaboration:

- Radiation hardness: 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 $3 \times 10^{15} n_{eq}/cm^2$ and $1 \times 10^{16} n_{eq}/cm^2$
- Pile up compliance:
  - ∗ granularity ($50\mu m \times 50\mu m$ pitch instead of $250\mu m \times 50\mu m$)
  - ∗ new chip RD53 ASICs $50 \times 50\mu m$ to deal with higher data rate than run1
- Increase the geometrical acceptance
  - ∗ Instrument at high eta (Alpine sensors)
  - ∗ Reduction of dead area ⇒LPNHE Active edge sensors

Reduction of dead area

b quarks $\Rightarrow$ fragmentation



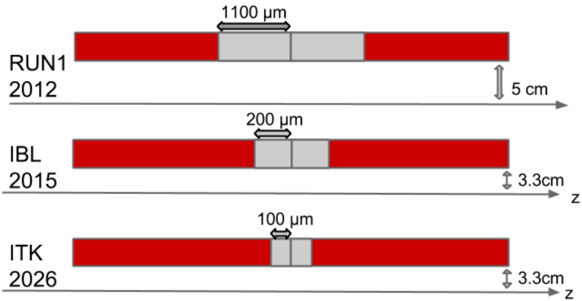
Better reconstruction of secondary vertices

$\Downarrow$ $\Downarrow$

Put sensors closer to the beam

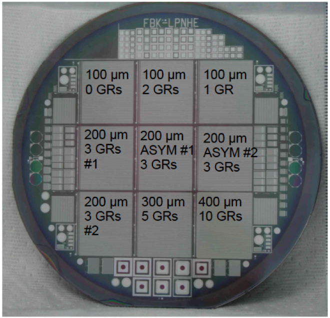
$+$

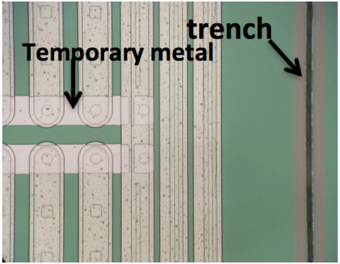
Reduction of dead area



ACTIVE EDGE $\rightarrow$ 100 μm

Upgrade LPNHE pixel sensors production: Testbeam results





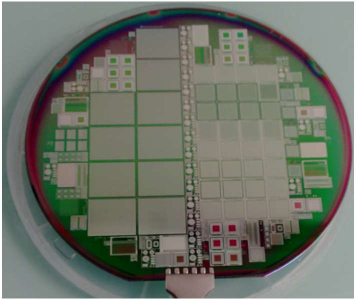
FBK production:

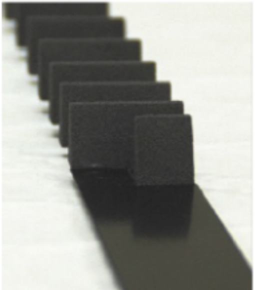
- n on p device
- thickness: 200 μm
- pixel pitch 250 μm x 50 μm
- Biased during test thanks to temporary metal

Active edge production:

- Minimize dead area at the sensor edge
- LPNHE5 100 μm from last pixel, 0 GR
- LPNHE7 100 μm from last pixel, 2 GR

Thin sensors & Alpine sensors





Thin Sensors: W80 & W30

- n on p device
- thickness: 100 μm
- unirradiated (W30) and irradiated (W80) at a fluence of $3 \times 10^{15} n_{eq}/cm^2$
- pixel pitch 250 μm x 50 μm

Alpine sensors:

- High eta forward layout
- Tilted sensors
- Double sensors (2 FEI4, 1 sensor)
- Analysis ongoing

High Luminosity requirement and tests of interest

Efficiency above 97 % ⇒ Global Efficiency

Homogeneous efficiency ⇒ Pixel efficiency

Good spatial resolution ⇒ Residuals

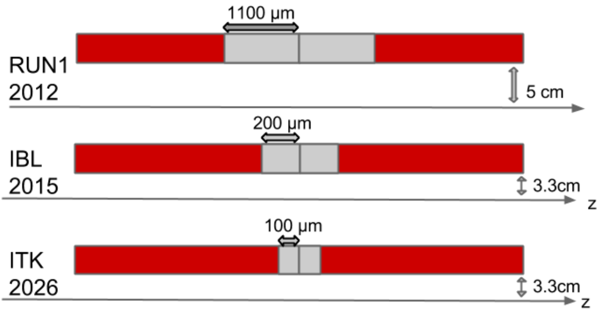
Radiation hardness ⇒ Tests on irradiated sensors

Reduction of dead area

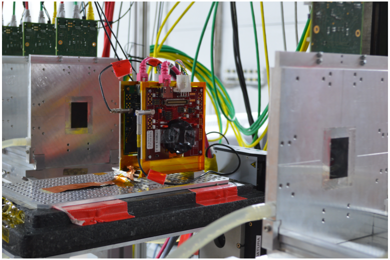
⇓

Edge Efficiency analysis

ACTIVE EDGE 100 μm

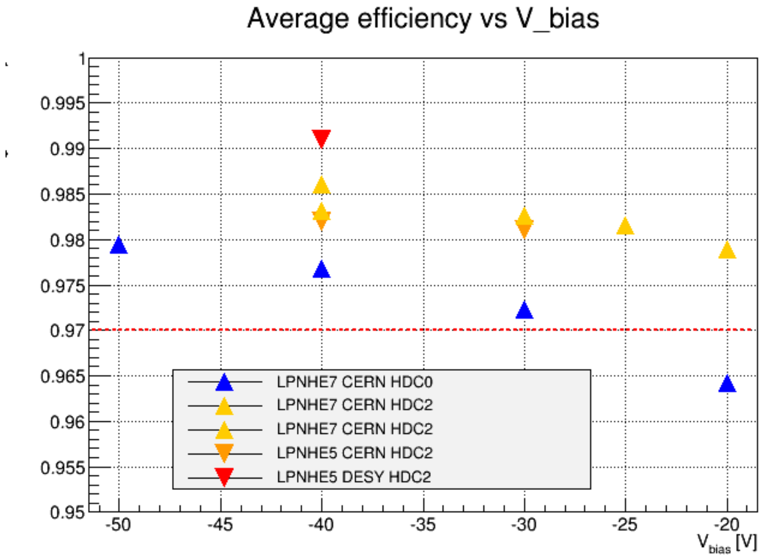


TestBeams



* 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**

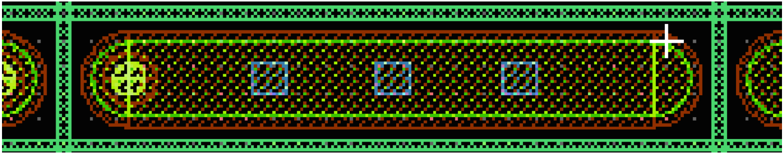
GLOBAL EFFICIENCY



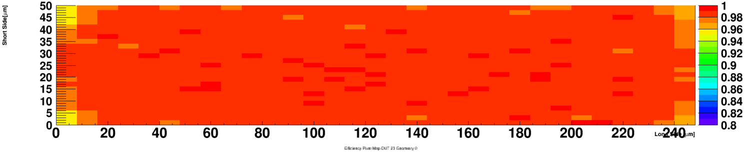
- Depleted at -20V
- Efficiency is higher than 97 % for the 2 sensors with HDC set to 2

In Pixel Efficiency

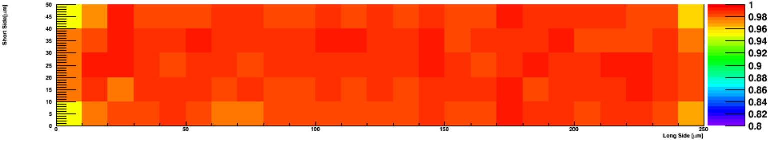
PIXEL



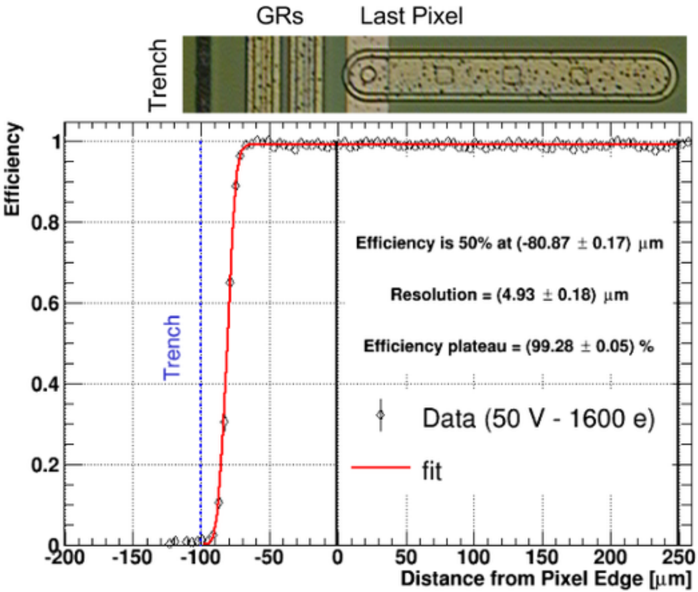
LPNHE5
-40V

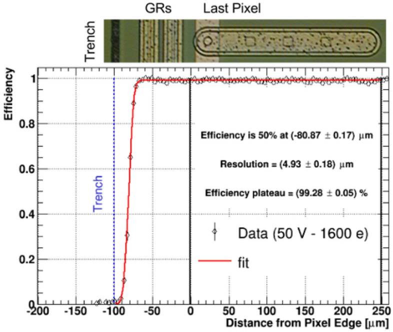


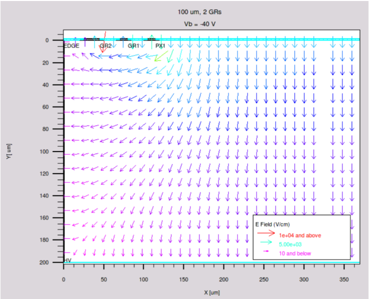
LPNHE7
-40V



No permanent bias structures ⇒ uniform charge efficiency

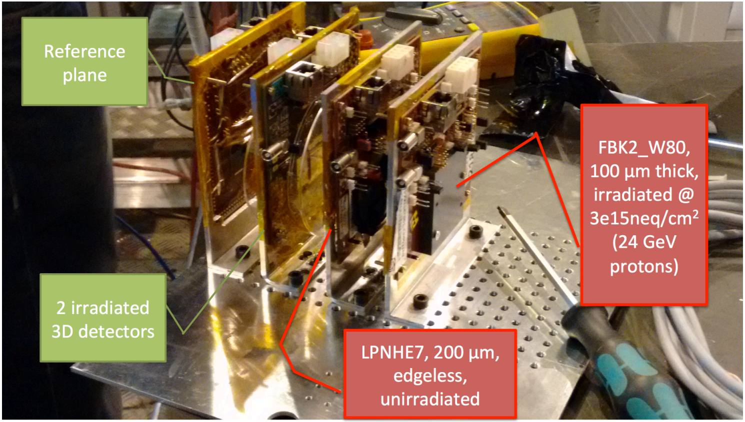

GRs
Last Pixel
Trench
Efficiency
Trench
Efficiency is 50% at (-80.87 ± 0.17) μm
Resolution = (4.93 ± 0.18) μm
Efficiency plateau = (99.28 ± 0.05) %
Data (50 V - 1600 e)
fit
Distance from Pixel Edge [μm]
0
0.2
0.4
0.6
0.8
1
-200
-150
-100
-50
0
50
100
150
200
250



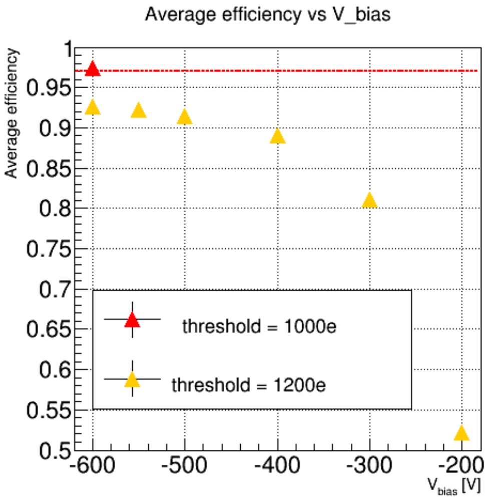


- Charge is not collected and not reemitted by Guard Rings
- Simulation and data are in good agreement
- Uninstrumented area is no longer dead :) !

Irradiated 100 μm thick sensor tested in October testbeam



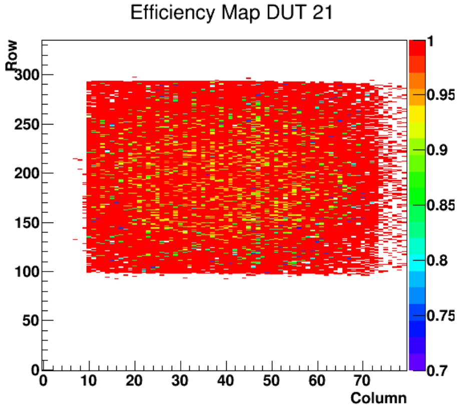
THIN SENSORS EFFICIENCY



- Fluence $3 \times 10^{15} n_{eq}/cm^2$
- Due to irradiation, Need of high voltage to be depleted
- For threshold=1200e an important fraction of signal is too low $\Rightarrow$ low efficiency
- For threshold=1000e Good efficiency > 97%

THIN SENSORS EFFICIENCY

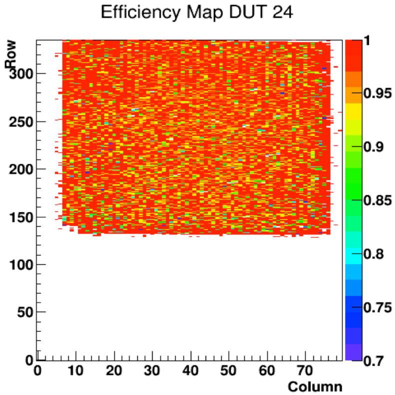
W30 (W80 twin) unirradiated



Tuning: Thresold 1000e ; -150V

Global efficiency: 98, 6%

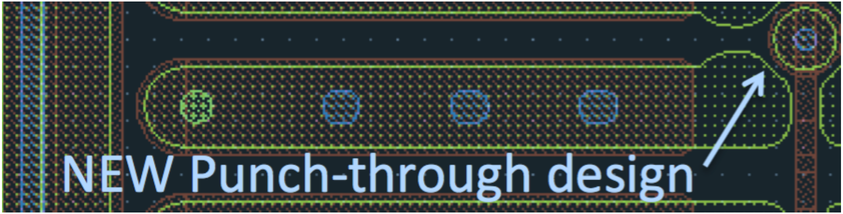
W80 irradiated $3 \times 10^{15} n^{eq}/cm^2$



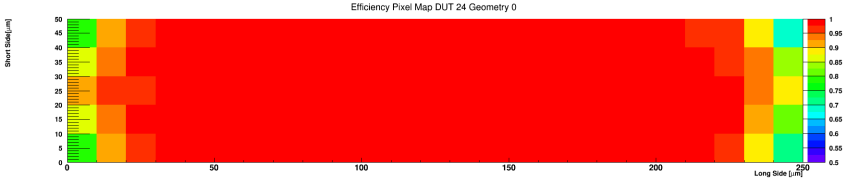
Tuning: Thresold 1000e ; -600V

Global efficiency: 97, 4%

THIN SENSORS PIXEL EFFICIENCY



W80 irradiated:



Lack of efficency at the border due to punch through structure

Summary

- **Edge region efficient above** 97% **up to** $70\mu m$ **from last pixel**
- **Thin sensors highly efficient after irradiation**
- Use of temporary metal during test results in homogeneous efficiency performances after removal
- Good 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 $1 \times 10^{16} n_{eq}/cm^2$

Future Plans

FUTURE PLANS

Testbeams: 3 to 5 weeks of Testbeams in 2017 to test the new production (active edge and thin sensors) and highly irradiated thin sensors. TDR expected next year.

Radiation study: Study of the Si-SiO_2 interface damage and its interplay with the bulk damage. Simulation and measurements on irradiated devices

B tagging for upgrade: Adapting the algorithms or tuning the parameters for the upgrade layout, especially extended forward one (Alpine)