Test-beam analysis for ATLAS modules at different beam incident angles

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The Detector Under Test (DUT)

- N-in-p planar pixel sensor 150 $\mu$m thick
- designed and produced by MPP/HLL
  - 6 inches wafers with ATLAS FE-I4 chips ($250 \times 50 \mu m^2$ cells)
  - interconnected with bump-bonding at IZM
- irradiated in Los Alamos to $4 \times 10^{15} n_{eq}/cm^2$
- Data reconstruction performed with the EUTelescope software
- TBmon analysis
- Threshold 1.6 ke

![Graph showing collected charge vs bias voltage with high and low charge markers.](image)
Hit efficiency

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

The graph shows the hit efficiency as a function of bias voltage. The efficiency is measured for different tilt angles and bias conditions. The systematic error associated with hit efficiency is estimated to be 0.3%.
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Pixel cell efficiency

- **FE-I4 150 µm thick, irradiated at** $4 \times 10^{15} \text{n_{eq}/cm}^2$ **in Los Alamos**
  - test-beam at SpS, CERN with 120 GeV pions
  - threshold 1.6 ke (MPV $\sim$ 9.5 ke)

- 97.7% hit efficiency at $\perp$ incidence (690 V)

- 98.2% hit efficiency at $\varphi = 15^\circ$ (650 V)
Hit efficiency at different $\eta$ incidence

- **FE-I4 150 $\mu m$ thick, irradiated to $4 \times 10^{15}$ n$_{eq}$/cm$^2$ in Los Alamos**
- threshold: 1.6 keV

- 96.6% hit efficiency at $\perp$ incidence (500 V)
Hit efficiency at different $\eta$ incidence

- **FE-I4 150 $\mu$m thick, irradiated to $4 \times 10^{15} \text{n}_{\text{eq}}/\text{cm}^2$ in Los Alamos**
- threshold: 1.6 keV

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

- FE-I4 150 $\mu$m thick, irradiated to $4 \times 10^{15} \text{n}_{\text{eq}}/\text{cm}^2$ in Los Alamos
- threshold: 1.6 keV

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

- **FE-I4 150 $\mu$m thick, irradiated to $4 \times 10^{15} n_{eq}/cm^2$ in Los Alamos**
- threshold: 1.6 keV

$99.8\%$ hit efficiency at $\vartheta = 85^\circ$ ($\eta \sim 3.1$) (500 V)
EUTelescope settings for high-eta analysis

- **EUTelescope alignment:**
  - run by run: 50’000 triggers (2/4 minutes per run)
  - long cluster selection on the high-eta DUT (software change not yet in svn)
  - only tracks with hits on all planes (6 telescope planes and 2 DUTs)

more than 1000 tracks selected for the alignment for each run

Cluster distribution along the tilted direction before tracking
EUTelescope results

Final tracking:
- no additional cluster pre-selection
- \( \sim 36\% \) of the reconstructed tracks have a matched cluster on the DUT after the alignment
Cluster analysis after tracking

- **FE-I4 150 μm** thick, irradiated to $4 \times 10^{15} \text{n}_{\text{eq}}/\text{cm}^2$ in Los Alamos
- $\varphi=0^\circ$, $\vartheta=85^\circ$ track incidence ($\eta \sim 3.1$)
- bias voltage: 500 V
- threshold: 1.6 keV

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

Cluster distribution along the tilted direction.
Arithmetic mean = 6.2
Cluster analysis after tracking

- **FE-I4 150 \(\mu\)m thick, irradiated to \(4 \times 10^{15} n_{eq}/cm^2\) in Los Alamos**
- \(\varphi \sim 1°/2°\) (alignment output), \(\vartheta = 85°\) track incidence
- Bias voltage: 500 V
- Threshold: 1.6 ke

Mean cluster width expected along the not tilted direction for different incident angles

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

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

Residual along the tilted direction (pitch: 250 µm)

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

- cluster reconstructed with the charge weighting algorithm (TBmon)
Collected charge

- FE-I4 $150 \, \mu m$ thick, irradiated to $4 \times 10^{15} n_{eq}/cm^2$ in Los Alamos
- $\vartheta=85^\circ$ track incidence ($\eta \sim 3.1$)

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

Single pixel ToT distribution (for all matched clusters)

- overflow peak in the single pixel ToT distribution due to the calibration (10ToT @10 ke) at the edge of the ToT range (1-14) for a particle crossing 250 $\mu m$ (15 ke expected)
Conclusions and outlook

Conclusions:
▶ good results and smooth reconstruction up to 45° track incidence
▶ alignment at high incident angels requires:
  ▶ a good starting parameters for millepede
  ▶ selection of the good clusters on the DUT
▶ good preliminary results at high incidence considering that the sensor is irradiated and not fully depleted

Outlook:
▶ cluster reconstruction of more than 2 hit clusters can be improved considering only hits at the edge of the cluster
▶ further analysis and comparison with not irradiated devices for a better understanding of results