Performance Studies of the ATLASpix HV-MAPS Prototype for Different Substrate Resistivities

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*on behalf of the CLICdp collaboration

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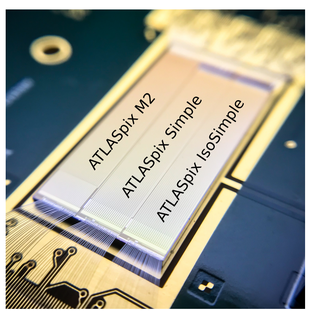
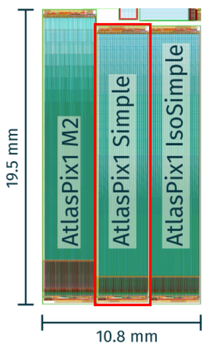
The ATLASpix Test Chip

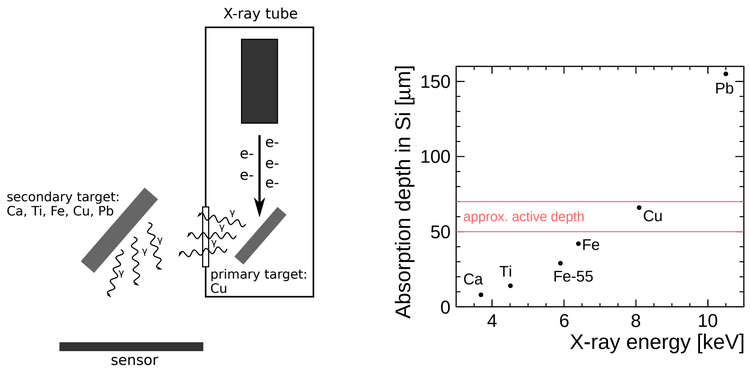
- Designed for ATLAS ITk Upgrade and CLIC Tracker Detector
- High-Voltage Monolithic Active Pixel Sensor (HV-MAPS):
  - fully integrated readout
  - fast charge collection
  - low material budget
- Commercial 180 nm HV-CMOS process: reduced cost/manufacturing complexity
- Here only submatrix *ATLASpix_simple*:

pixel matrix	25 columns × 400 rows
pitch pitch	130 µm × 25 µm
readout scheme	triggerless column drain
readout mode	time + energy (in each pixel)
substrate resistivity	**20, 80, 200 Ωcm**





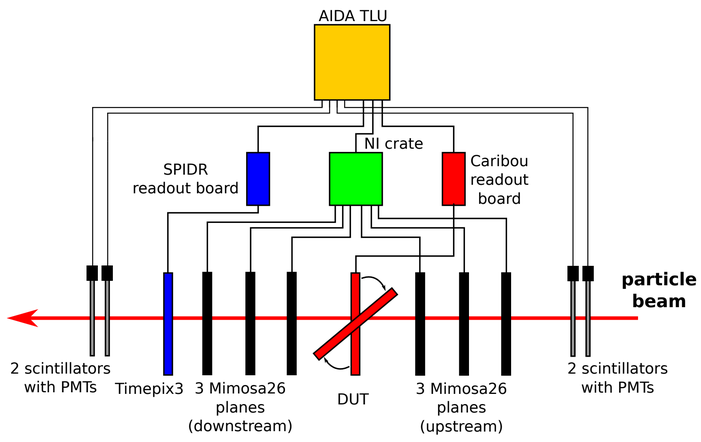
The X-Ray Setup



- Mono-energetic X-rays:
  - different fluorescence targets
  - β-source: Fe-55
- For each energy: perform threshold scan → record s-curve (see "X-Ray Calibration: How to?")

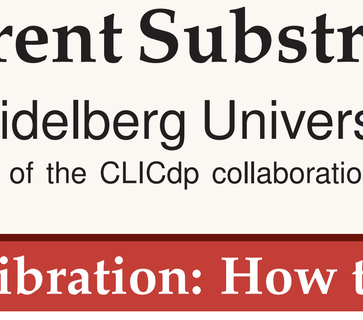
The Beam Telescope at DESY

- EUDET-type telescope at DESY (Hamburg, Germany)
- AIDA TLU + Mimosa26 telescope planes + Timepix3 timing reference
- Telescope performance:
  - track pointing resolution on DUT: 2 µm to 5 µm (depending on plane spacing and beam momentum)
  - track time resolution: 1.1 ns



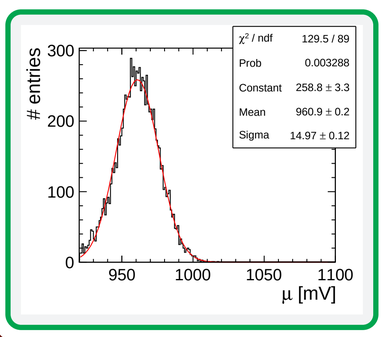
X-Ray Calibration: How to?

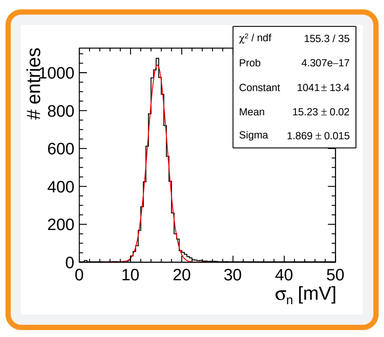
- record pixel hits vs. detection threshold
- for each pixel of the matrix:
  - fit s-curve: $f_s(x) = \frac{A}{2}\left(1 - \mathrm{erf}\left(-\frac{x-\mu}{\sqrt{2}\sigma_n}\right)\right)$ with $\mathrm{erf}(x) = \frac{1}{\sqrt{\pi}}\int_{-x}^{x} e^{-t}\mathrm{d}t$
  - histogram fit parameters μ and σ, then fit Gaussian
- Example s-curve fit (1 pixel, 200 Ωcm, iron target):



- Interpretation:
  - mean of μ → signal size
  - std dev of μ → threshold dispersion
  - mean of σ_n → pixel noise
  - std dev of σ_n → pixel noise dispersion

Fit results for all pixels (200 Ωcm):



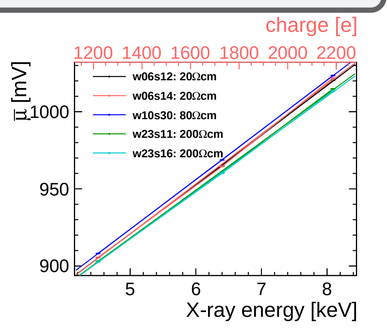


Gain and Baseline

- energy → charge: 3.7 eV per e^-/h^+ pair

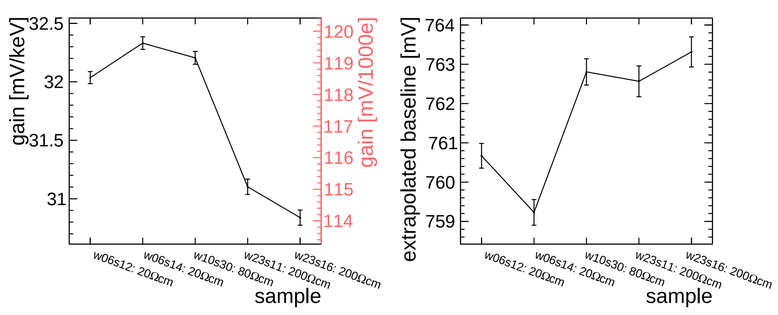
$$\text{mean signal size } \overline{\mu} = g[mV/keV] \cdot E + b = g[mV/1000e^-] \cdot Q + b$$

- g: gain
- b: baseline
- E: absorbed energy
- Q: deposited charge



Result:

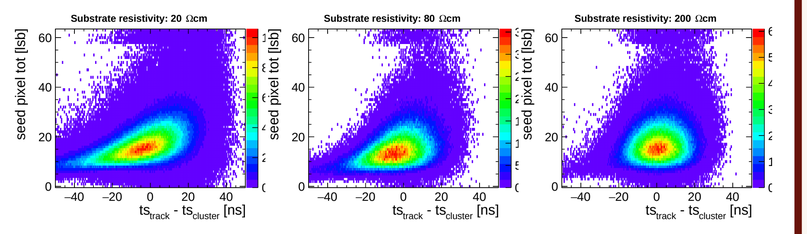
- gain independent of resistivity, but sample-to-sample variations



Summary & Outlook

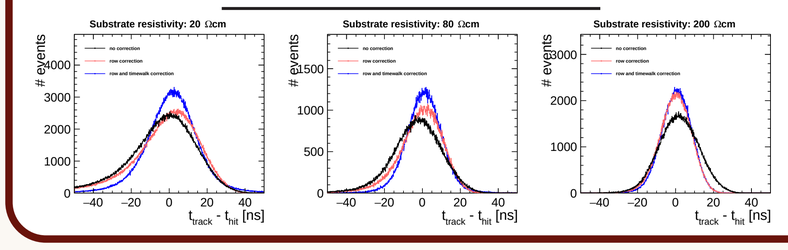
- higher substrate resistivity → higher efficiency + faster timing performance
- HV-CMOS: suitable technology for tracking detectors
  (now explored for LHCb Phase II Upgrade and others)
- further performance studies ongoing

Timing Performance

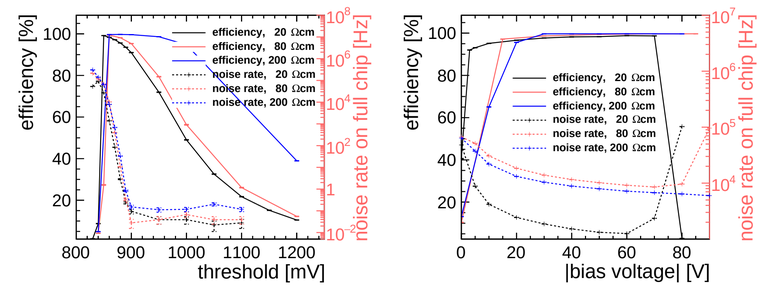


- higher substrate resistivity: less timewalk + faster timing
- after applying row-dependent delay and timewalk correction: Gaussian fit yields

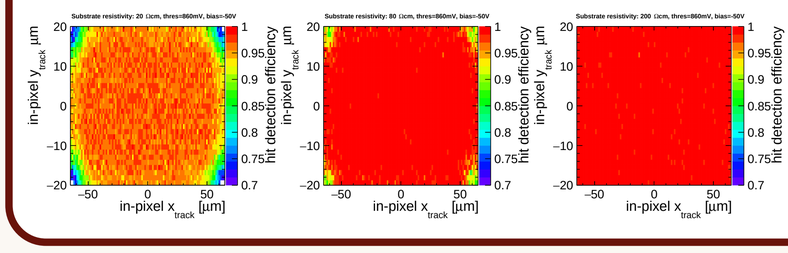
20 Ωcm	$\sigma \approx 13.7$ ns
80 Ωcm	$\sigma \approx 9.1$ ns
200 Ωcm	$\sigma \approx 7.7$ ns



Hit Detection Efficiency



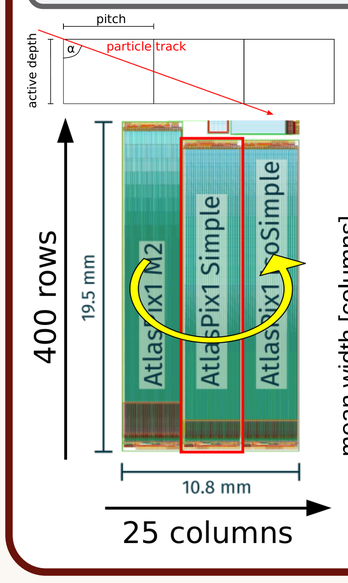
- efficiency plateaus well above 99.7 %
- larger substrate resistivity: higher efficiency + longer plateau
- at lower resistitivities: efficiency is lost in the pixel corners



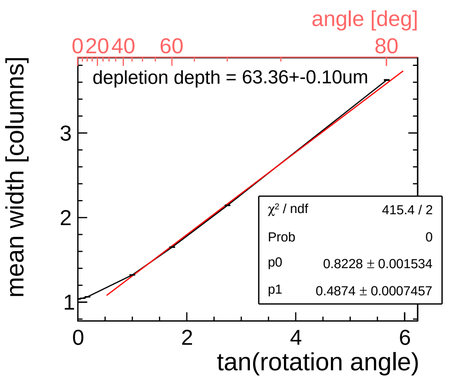
Active Depth Determination

- analyse width of track-associated clusters for highly inclined tracks
- simplified geometrical model:
  - mean cluster width depends on rotation
  - model ignores sub threshold effect and diffusion (but very little in ATLASpix)

$$\text{cluster width}_{\text{col/row}} = \frac{d_{\text{active}}}{\text{pitch}_{\text{col/row}}} \cdot \tan\alpha$$



- Result for 200 Ωcm: active depth ≈ 63 µm



Acknowledgements

The measurements leading to these results have been performed at the Test Beam Facility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF). This work has been sponsored by the Wolfgang Gentner Programme of the German Federal Ministry of Education and Research (grant no. 05E15CHA and 05E18CHA.