Experimental study of the adaptive gain feature for improved position-sensitive ion spectroscopy with Timepix2

Benedikt Bergmann\textsuperscript{1}, Petr Smolyanskiy\textsuperscript{1}, Petr Burian\textsuperscript{1,2}, Stanislav Pospisil\textsuperscript{1}, Jan Jakubek\textsuperscript{3}

\textsuperscript{1) Institute of Experimental and Applied Physics, Czech Technical University in Prague  
\textsuperscript{2) Faculty of Electrical Engineering, University of West Bohemia  
\textsuperscript{3) Advacam s.r.o, Advacam Oy.

benedikt.bergmann@utef.cvut.cz
Motivation – Timepix applications

• Radiation field characterization and dosimetry in
  • Space application
  • Nuclear and particle physics experiment
  • Hadron therapy

• Imaging
  • X-rays
  • Neutrons
  • Alphas

Imaging with α-particles

Timepix2 – improved capabilities

- 256 x 256 pixels
- Pixel pitch 55 µm
- Frame-based readout scheme
- Silicon sensor of 300 µm

Improvements (among others):
- ToT is not cut by the shutter signal
- Simultaneous ToT and ToA measurement
- Frame occupation monitor allowing to trigger frame termination
- Power saving by deactivating pixels
- Measurable energy range is increased due to adaptive gain

Energetic behavior of the adaptive gain feature has not been studied experimentally.

Calibrations with photons
Energy calibration with photons:
Per-pixel ToT calibration results

\( THL_{\text{low}} = 5 \text{ keV} \)

Bias: 230 V
 CLOCK frequency: 50 MHz

- Katherine readout system used for detector control
- Calibration XRF from Cu, Cd, and gammas from \(^{241}\text{Am} \) with single pixel clusters
Energy calibration with photons:

**Per-pixel ToT calibration results - homogeniety**

Homogeniety

![Homogeniety](image)

Standard deviation = 0.21 keV
Determination of the pixels’ high energy behavior
Measurement at Van-de-Graaff: Measurement setup

- Tunable source of monoenergetic protons in the range from 500 keV – 2 MeV.
- 5.5 MeV $\alpha$-particles from a $^{241}$Am source

Energy underestimated! $\rightarrow$ Calibration curve has to be modified
Determination of nominal energies:

Energy losses in the dead material at the backside contact

Energy losses simulated with SRIM
500 nm thick aluminum, 800 nm thick silicon
Methodology:

Strategy for the high energy calibration

Problem: Deposited energy of protons and alphas does not stay in a single pixel

Strategy:

1. Start with low energy protons and search for clusters few pixels are in the “uncalibrated“ \((E > 150 \text{ keV})\) energy region

2. Assign the missing energy to the latter pixels to create a global calibration curve

Examples:

- \(E_{\text{meas}} = 397 \text{ keV}, E_{\text{expected}} = 420 \text{ keV}\)
  - 1 pixel with \(E_{\text{pix}} > 150 \text{ keV}\)
  - \(\rightarrow\) Plot \((E_{\text{expected}} - E_{\text{meas}})/2\) vs \(<E_{\text{pix}}>\)

- \(E_{\text{meas}} = 888 \text{ keV}, E_{\text{expected}} = 940 \text{ keV}\)
  - 2 pixel with \(E_{\text{pix}} > 150 \text{ keV}\)
  - \(\rightarrow\) Plot \((E_{\text{expected}} - E_{\text{meas}})/2\) vs \(<E_{\text{pix}}>\)
Calibration correction curves determination:

Global energy correction function

- Different per-pixel energy depositions achieved by tuning the energy of the protons.
- Energy assumed to be correctly measured with current calibration up to 150 keV

Second order polynomial fit:
\[ f(x) = a + bx + cx^2 \]
- \( a = -42.7 \)
- \( b = 1.12 \)
- \( c = 0.000311 \)

Energy assumed correct up to 1000 keV

Exponential fit:
\[ f(x) = \exp(a + bx) \]
- \( a = 5.96 \)
- \( b = 0.000924 \)
Calibrated pixel energy response:

Comparison with design simulation

- Energy measurement up to ~2.2 MeV in each pixel.
- The per-pixel saturation level is 3.3 MeV (916 keV)

Design simulation predicts saturation at 950 keV

Reasonable agreement considering assumptions made in the simulation.
Results
Calibrated pixel energy response:
(Corrected) energy spectra

Protons at Van-de-Graaff

- 0.42 MeV
- 0.94 MeV
- 1.46 MeV
- 1.70 MeV
- 1.94 MeV

Relative resolution $\leq 5\%$

$< 3\%$
Application:
Spatially resolved α-particle energy loss in thin layers
Application: Subpixel spatial resolution

Spatial resolution determined from a 2D Gaussian fit to individual tracks.

Resolution defined as the error on the mean value.

5.5 MeV α-particle

500 keV p⁺

Δₖ = 355.9 nm
Δₖ = 346.4 nm

Δₖ = 1796.5 nm
Δₖ = 1738.1 nm

δ(E) = A E^B
A = 958 nm
B = -0.692
Conclusion

• The Timepix2 per pixel energy response has been studied in the range from 5 keV up to approximately 3.6 MeV to extend the calibration done with photons using a global correction function

• The following resolutions $\sigma$ were achieved:
  • 1.6 keV for X-rays at 60 keV (1.4 keV for single pixel clusters)
  • ~55 keV for 2 MeV protons
  • ~220 keV for 5.5 MeV alpha particles

Thank you very much!
Back up
Energy calibration with photons:

THL scan results

THL scans with photons of different energies used to determine the energy dependence of the THL on energy.

THL at which the sensor was “noise”-free:

\[ \text{THL}_{\text{low}} = 5 \text{ keV} \]

Remark: The behavior of the THL vs energy depends on the DAC settings of the chip. However, different DAC settings have not shown to impact the behavior of the adaptive gain and the ToT resolution.

\[ T_{\text{chip}} = 19^\circ \text{C} \]
\[ U_{\text{bias}} = 230 \text{ V} \]
THL scan results – setting 2

Linear behavior of energy on THL up to ~30 keV