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

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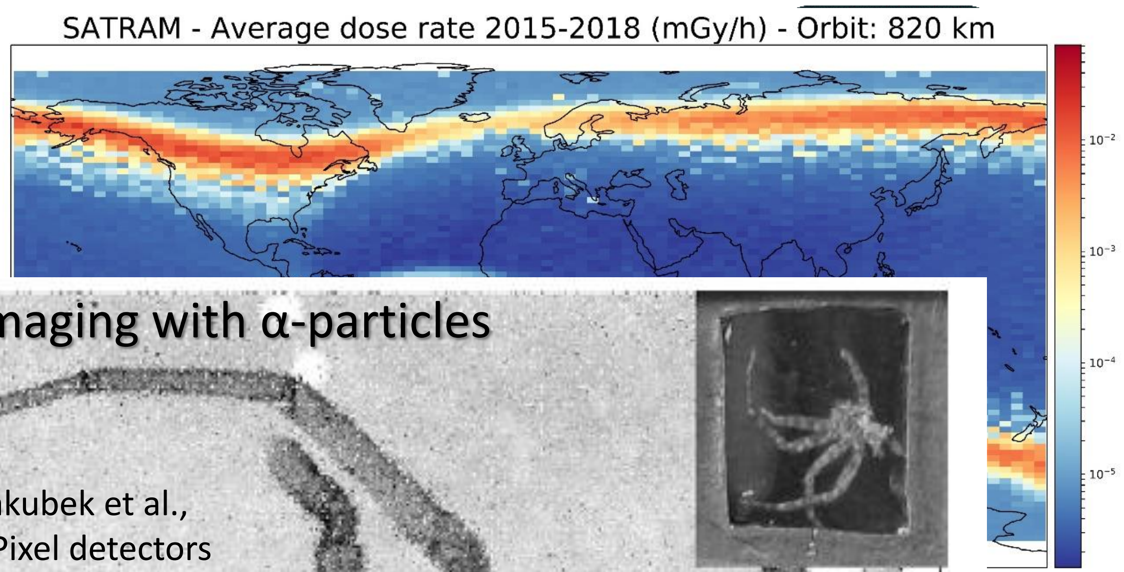
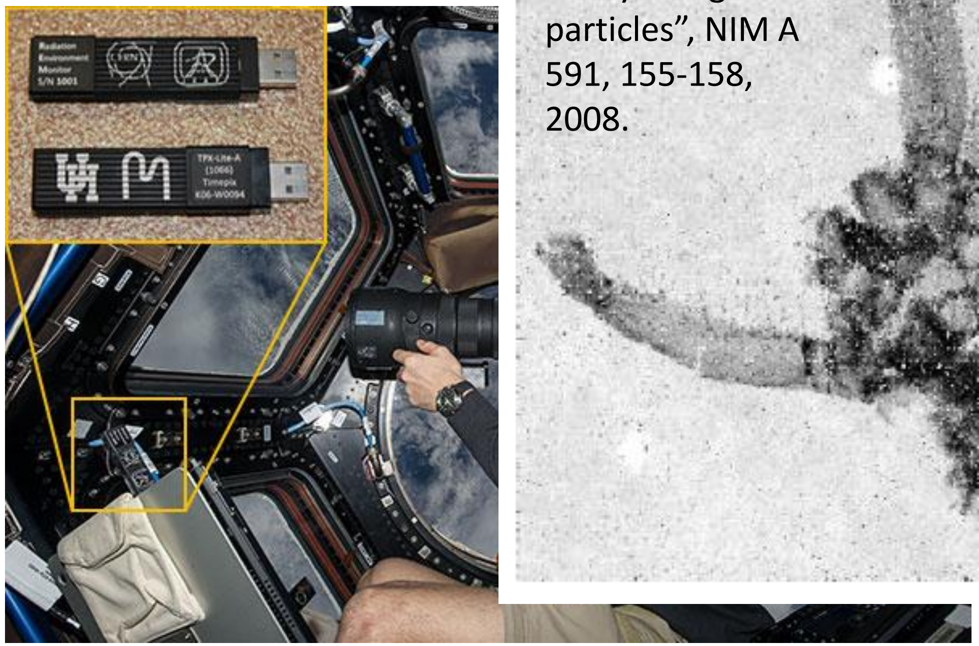
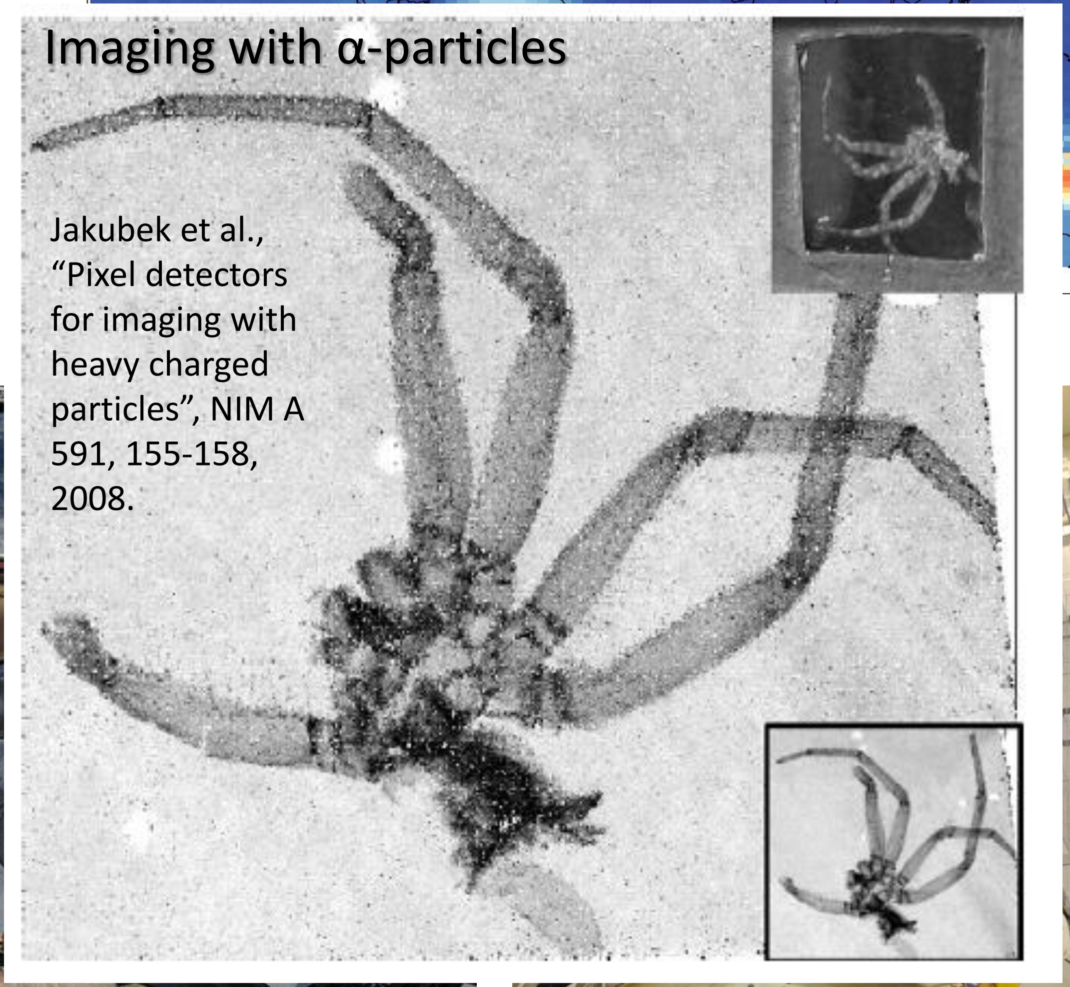
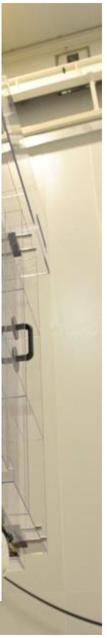
Motivation – Timepix applications

- Radiation field characterization and dosimetry in
  - Space application
  - Nuclear and particle physics experiment
  - Hadron therapy
- Imaging
  - X-rays
  - Neutrons
  - Alphas









Timepix2 – improved capabilities

256 x 256 pixels

Pixel pitch 55 µm

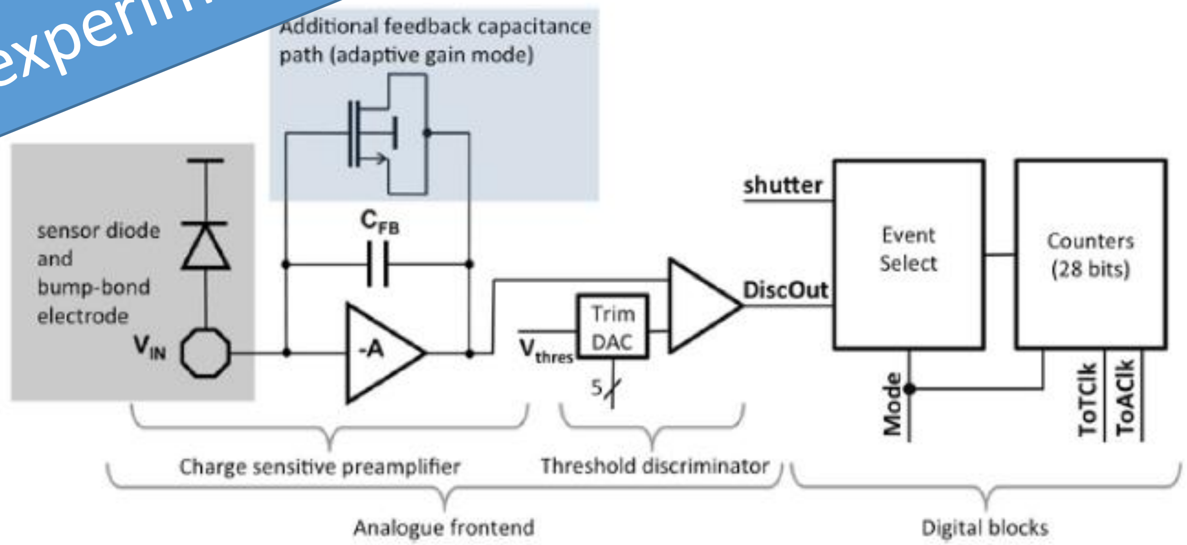
Frame-based readout scheme

Silicon sensor of 300 µm

Improvements (among others):

- ToT is not cut by the shutter signal
- Simultaneous ToT and ToA m
- Frame occupation m ter frame termination
- Power
- gy range is increased due to

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

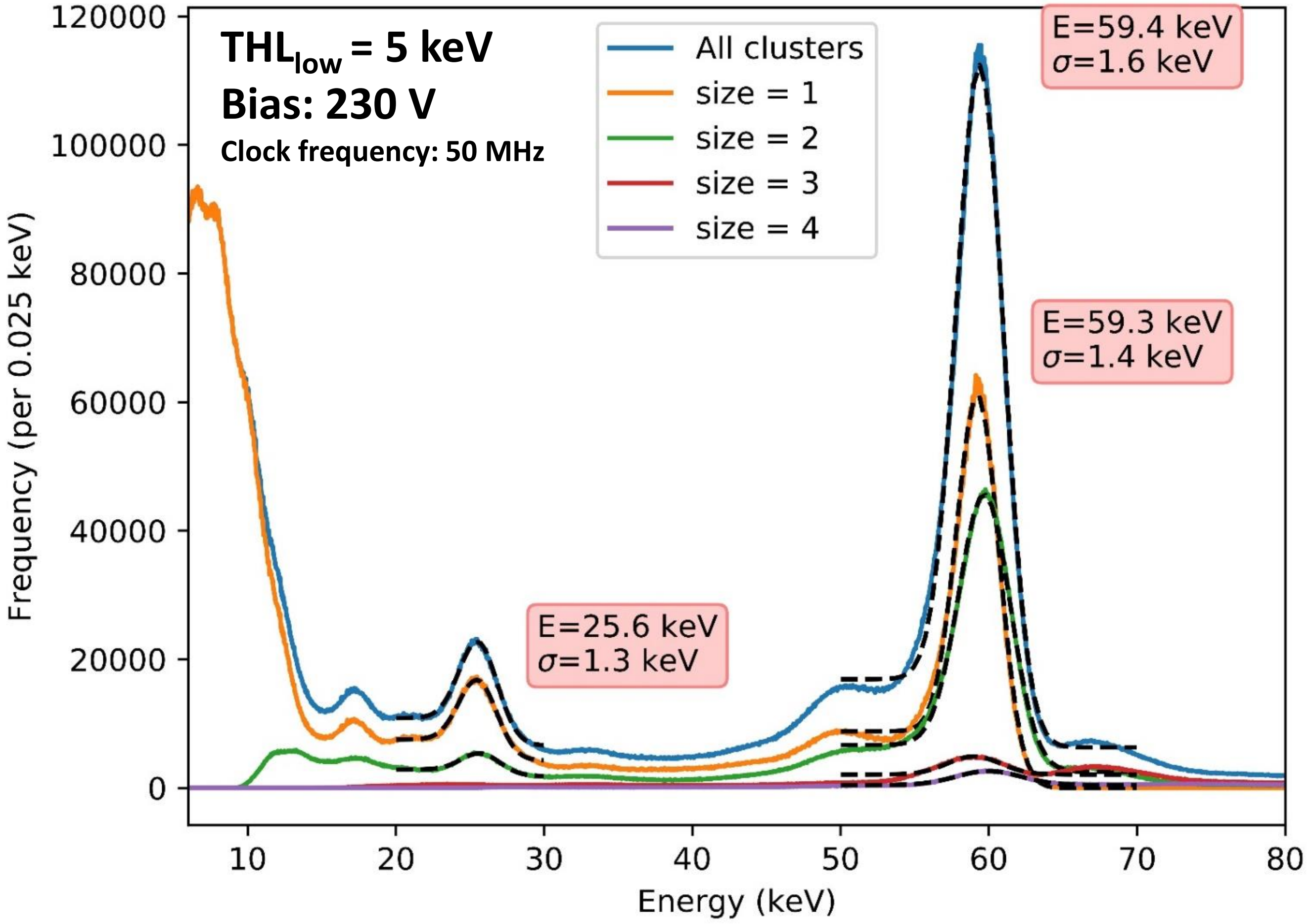


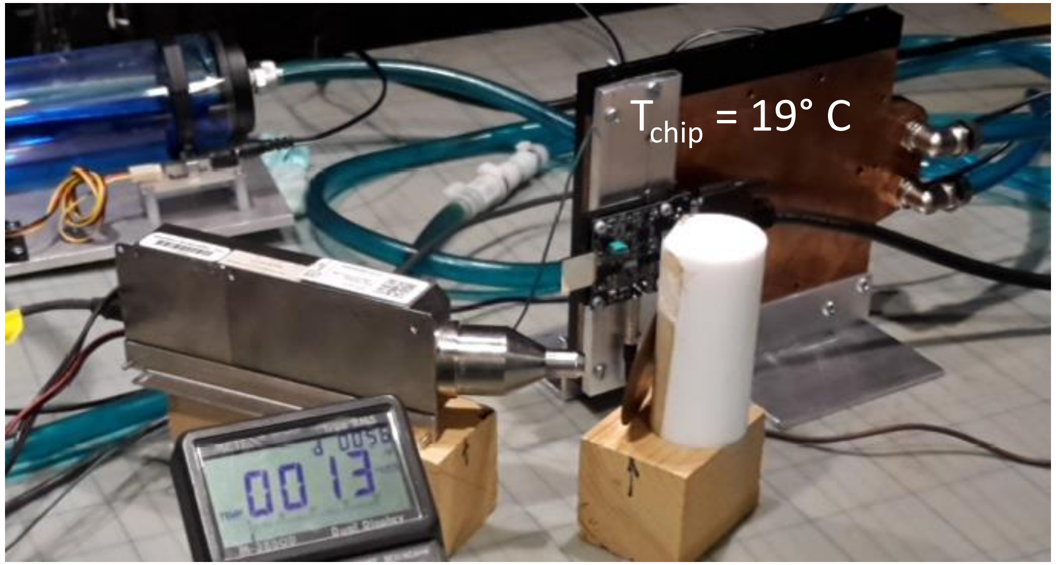
Wong et al., "Introducing Timepix2, a frame-based pixel detector readout ASIC measuring energy deposition and arrival time", Radiation Measurements 131, 2020.

Calibrations with photons

Energy calibration with photons:

Per-pixel ToT calibration results

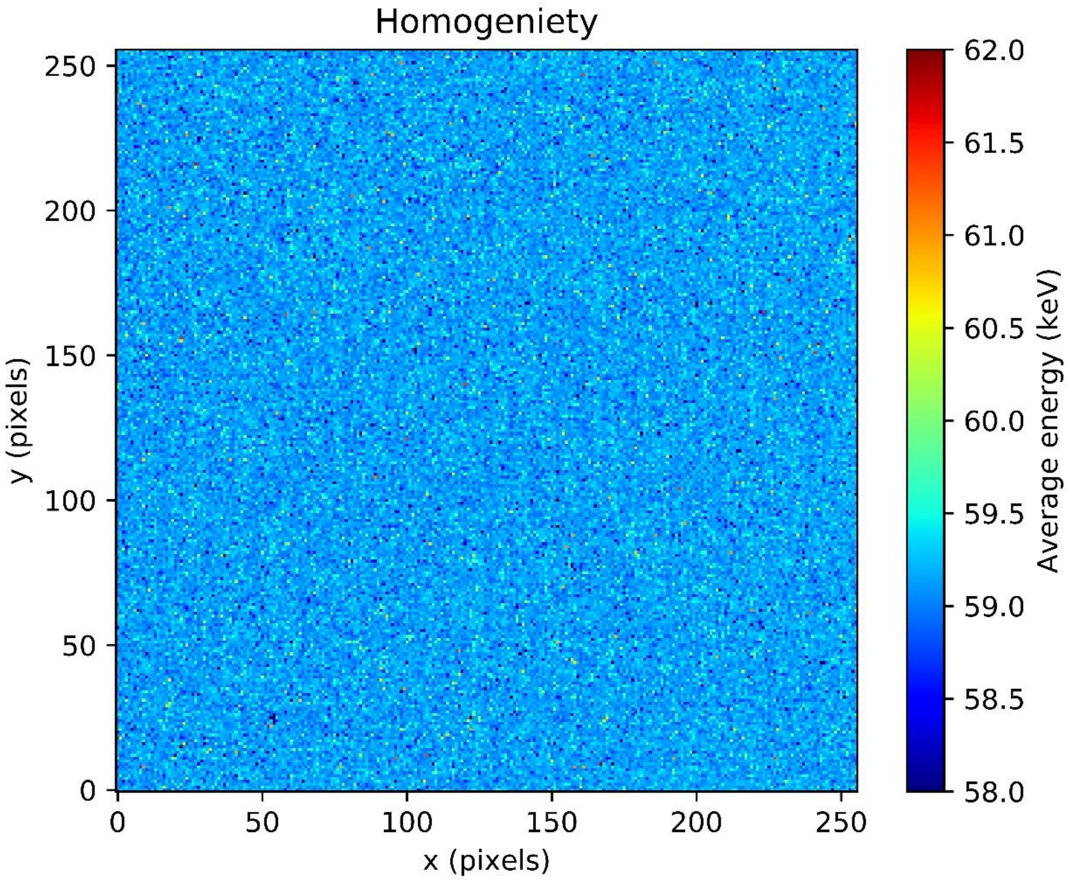


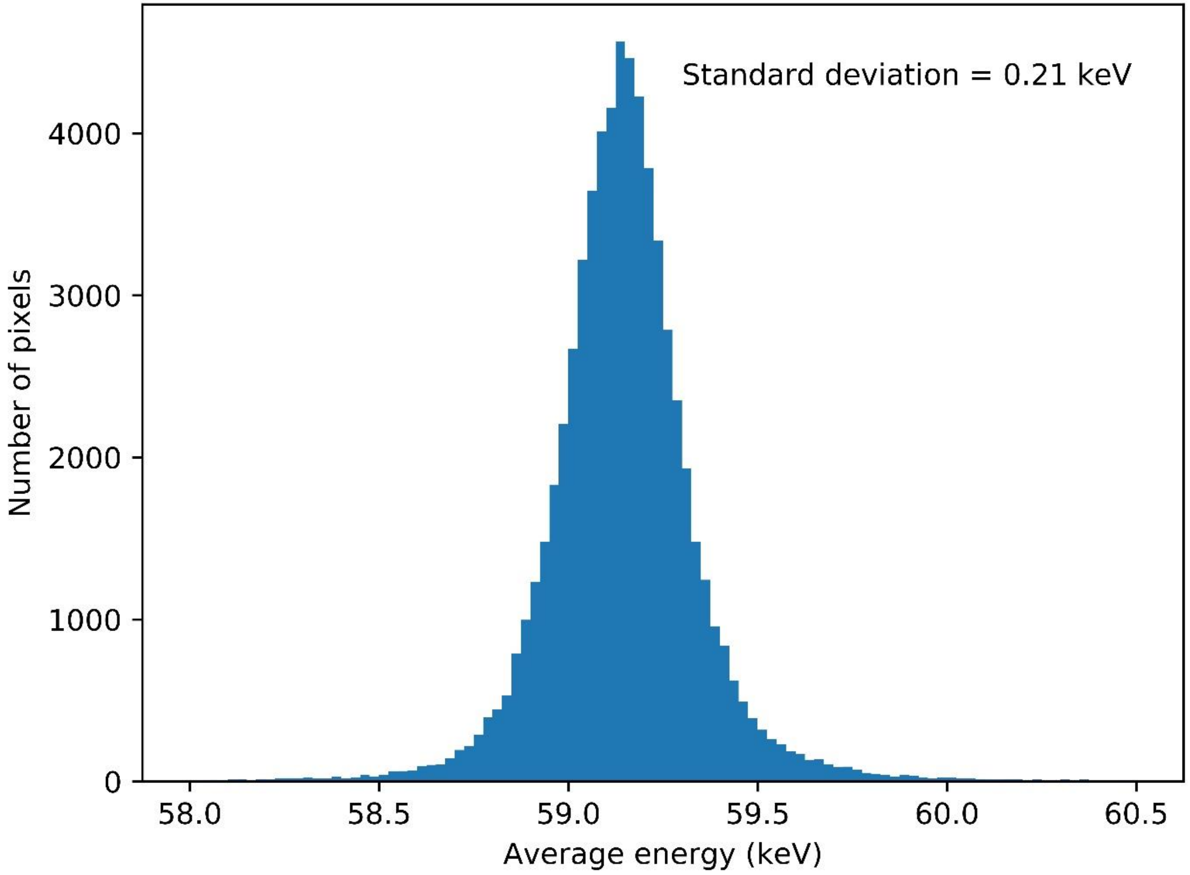


- Katherine readout system used for detector control
- Calibration XRF from Cu, Cd, and gammas from ^{241}Am with single pixel clusters

Energy calibration with photons:

Per-pixel ToT calibration results - homogeniety

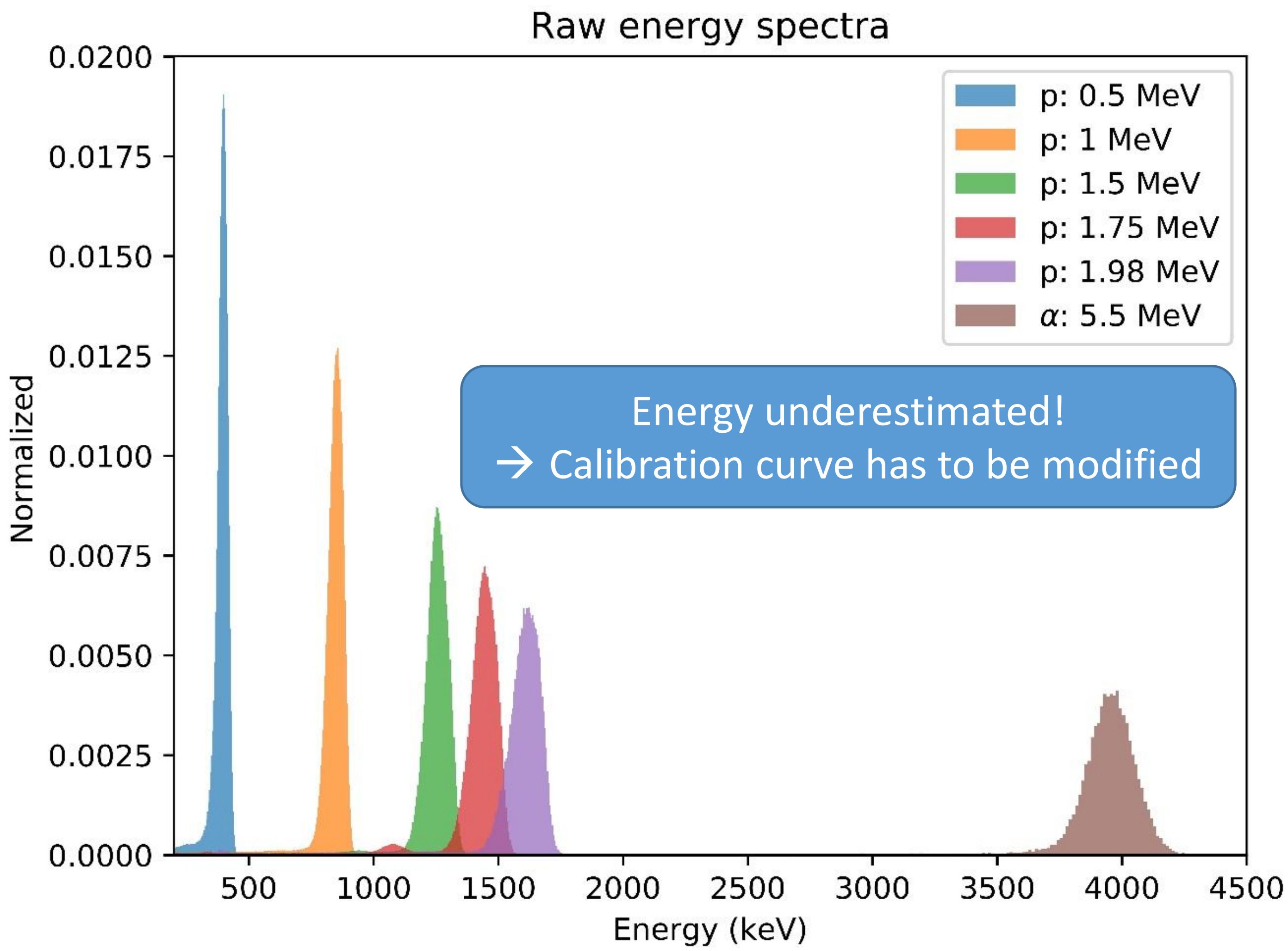




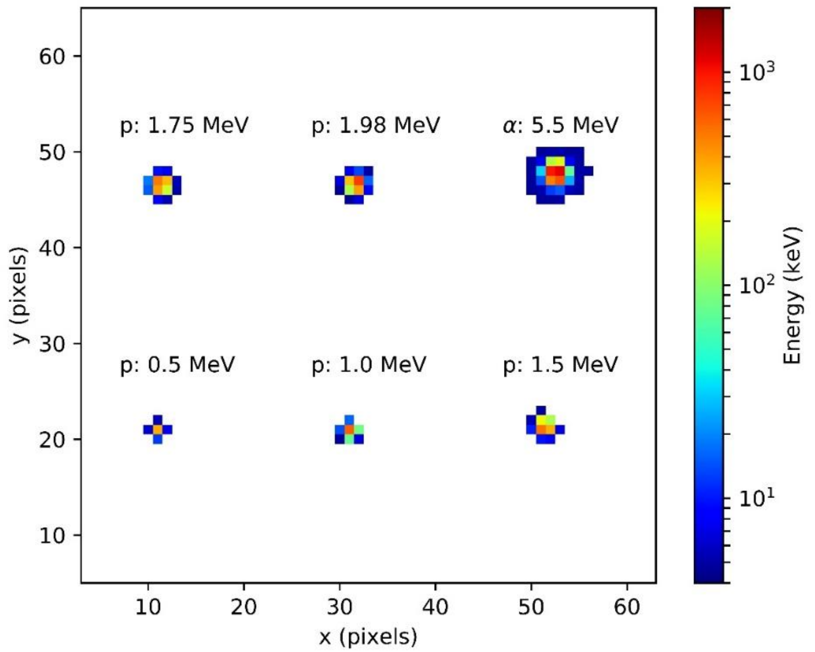
Determination of the pixels‘ high energy behavior

Measurement at Van-de-Graaff:

Measurement setup



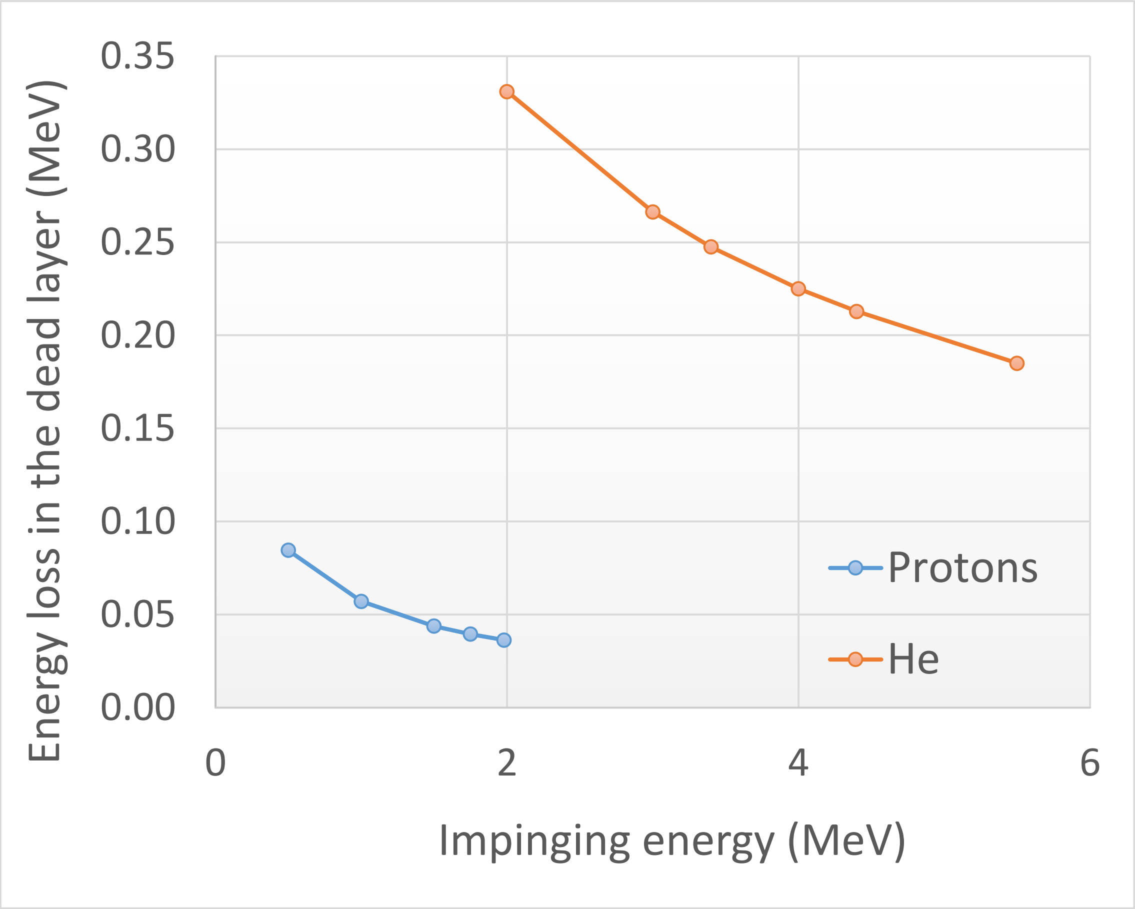
- Tunable source of monoenergetic protons in the range from 500 keV – 2 MeV.
- 5.5 MeV α-particles from a ^{241}Am source

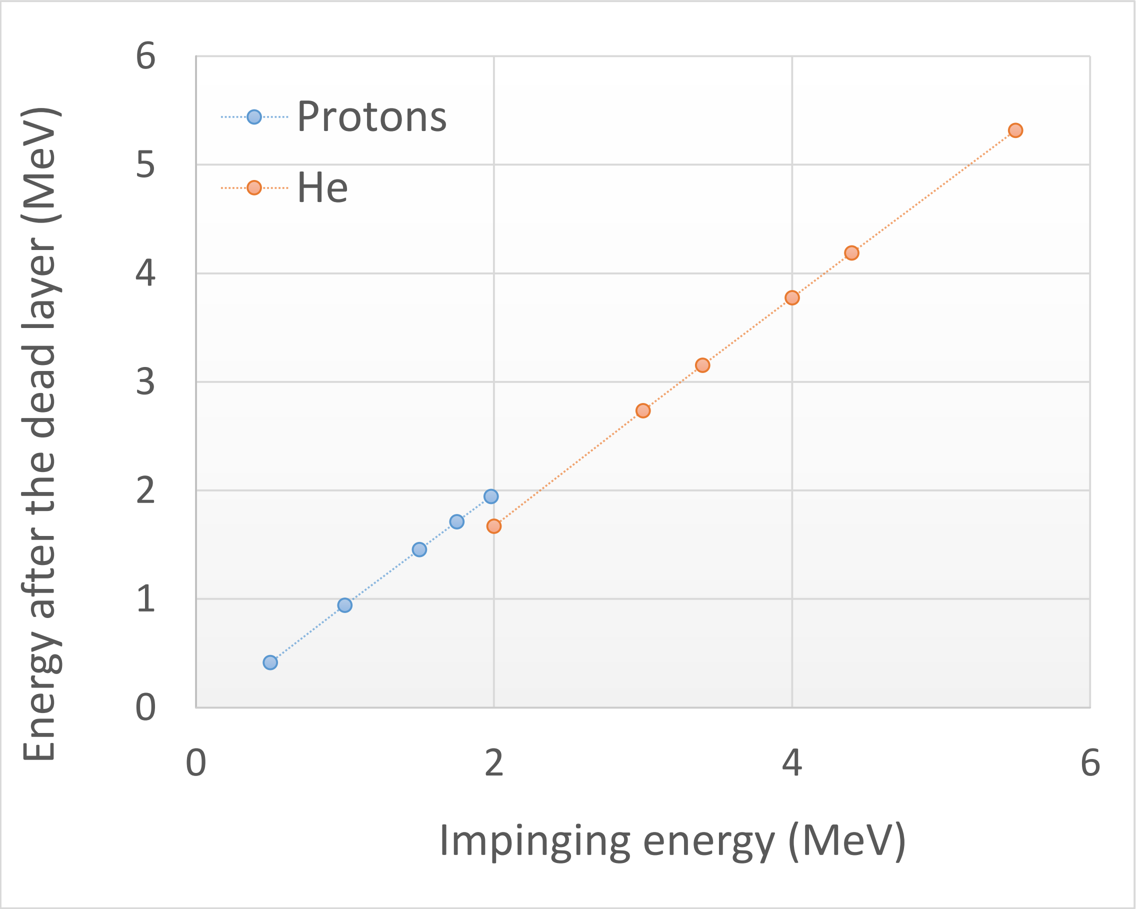


Determination of nominal energies:

Energy losses in the dead material at the backside contact

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





Methodology:

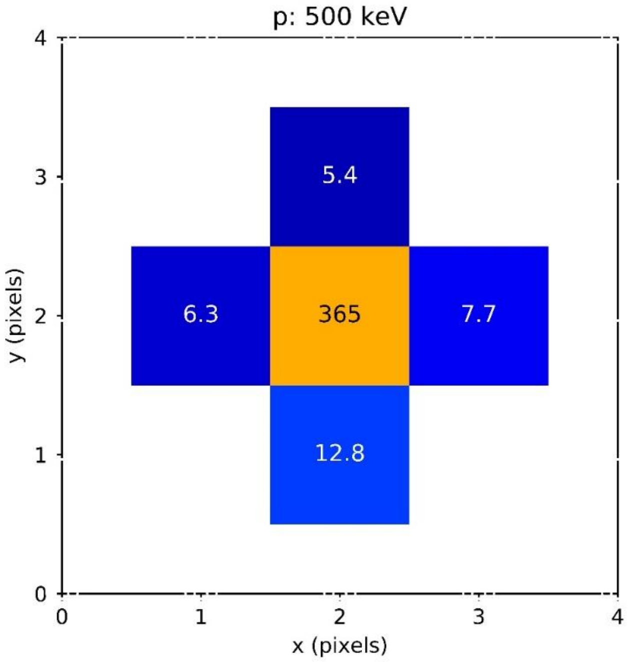
Strategy for the high energy calibration

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

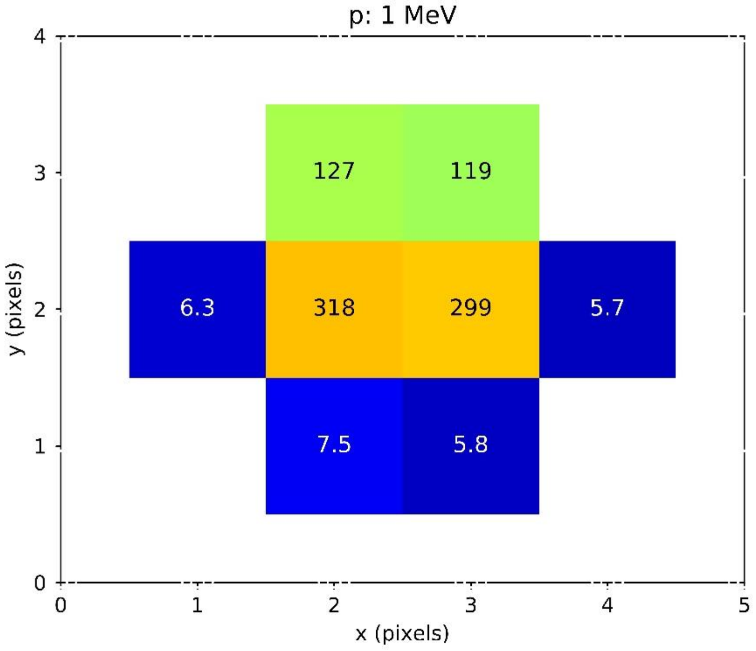
Strategy:

1. Start with low energy protons and search for clusters few pixels are in the “uncalibrated“ (E > 150 keV) energy region
2. Assign the missing energy to the latter pixels to create a global calibration curve

Examples:



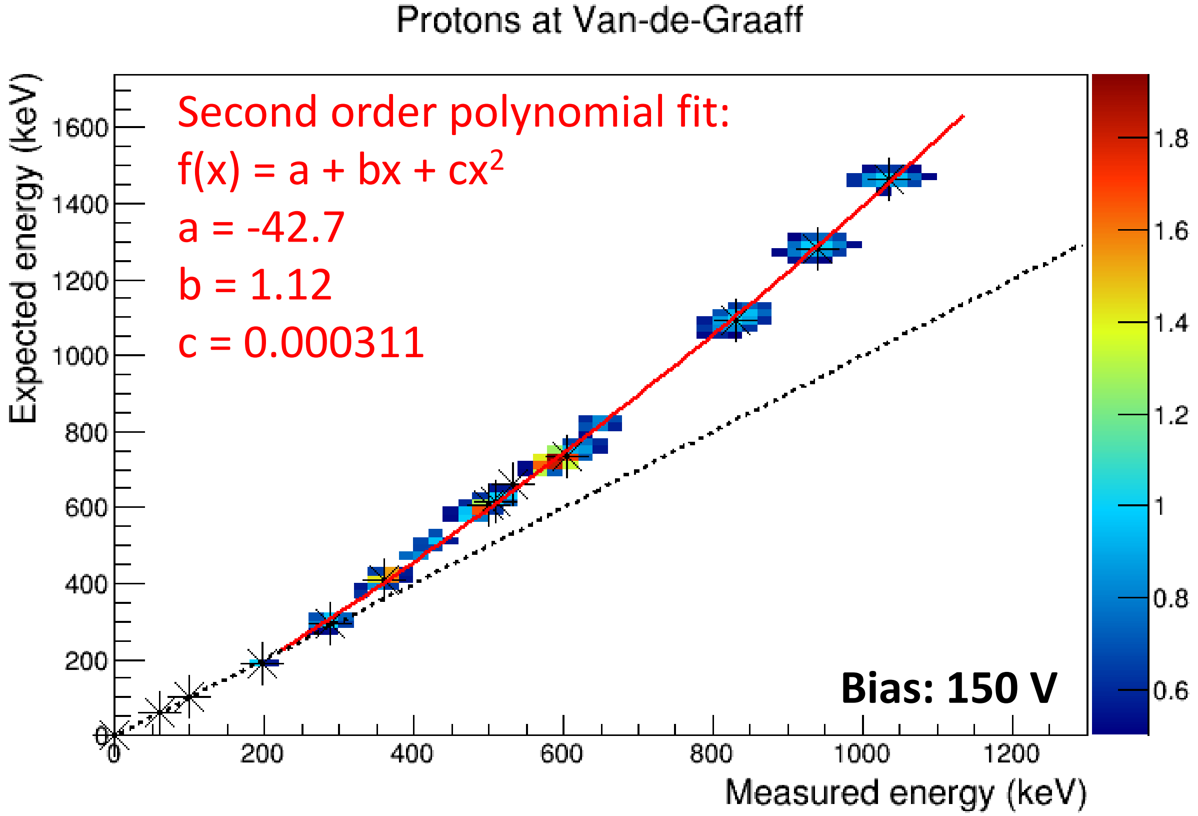
E_{meas}= 397 keV, $E_{expected}$ = 420 keV
1 pixel with E_{pix} > 150 keV
→ Plot ($E_{expected}$ – E_{meas}) vs E_{pix}



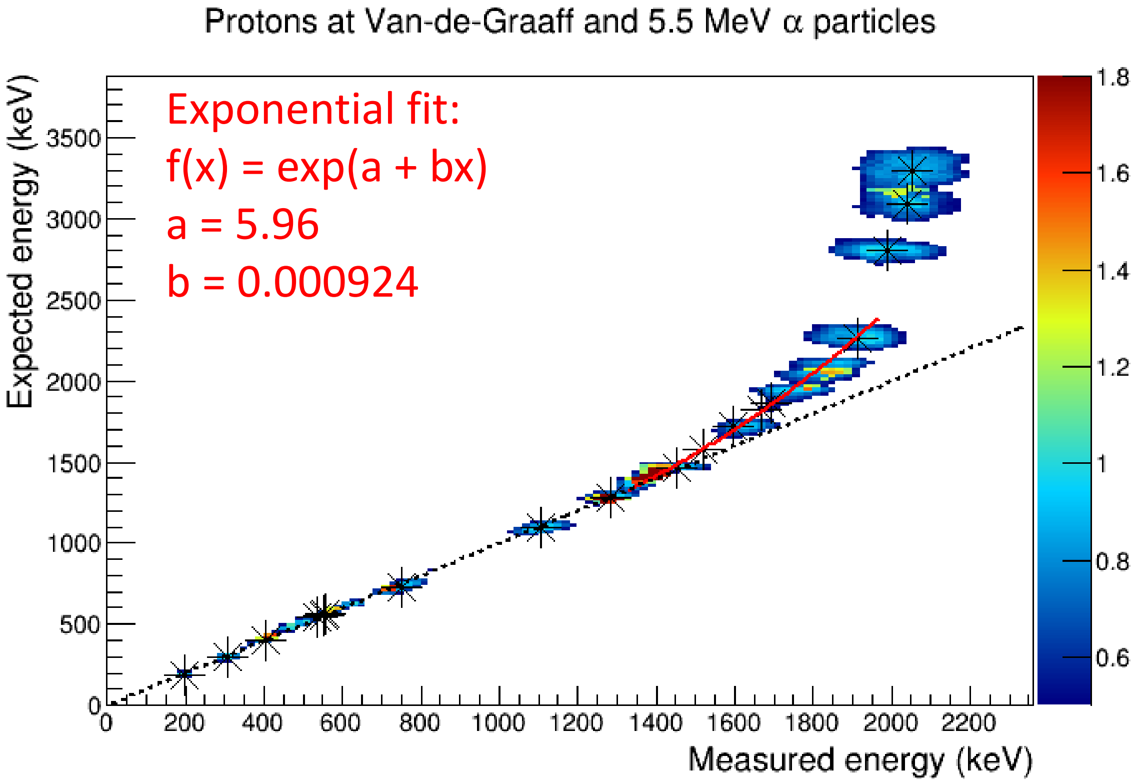
E_{meas}= 888 keV, $E_{expected}$ = 940 keV
2 pixel with E_{pix} > 150 keV
→ Plot ($E_{expected}$ – E_{meas})/2 vs <E_{pix}>

Calibration correction curves determination:

Global energy correction function

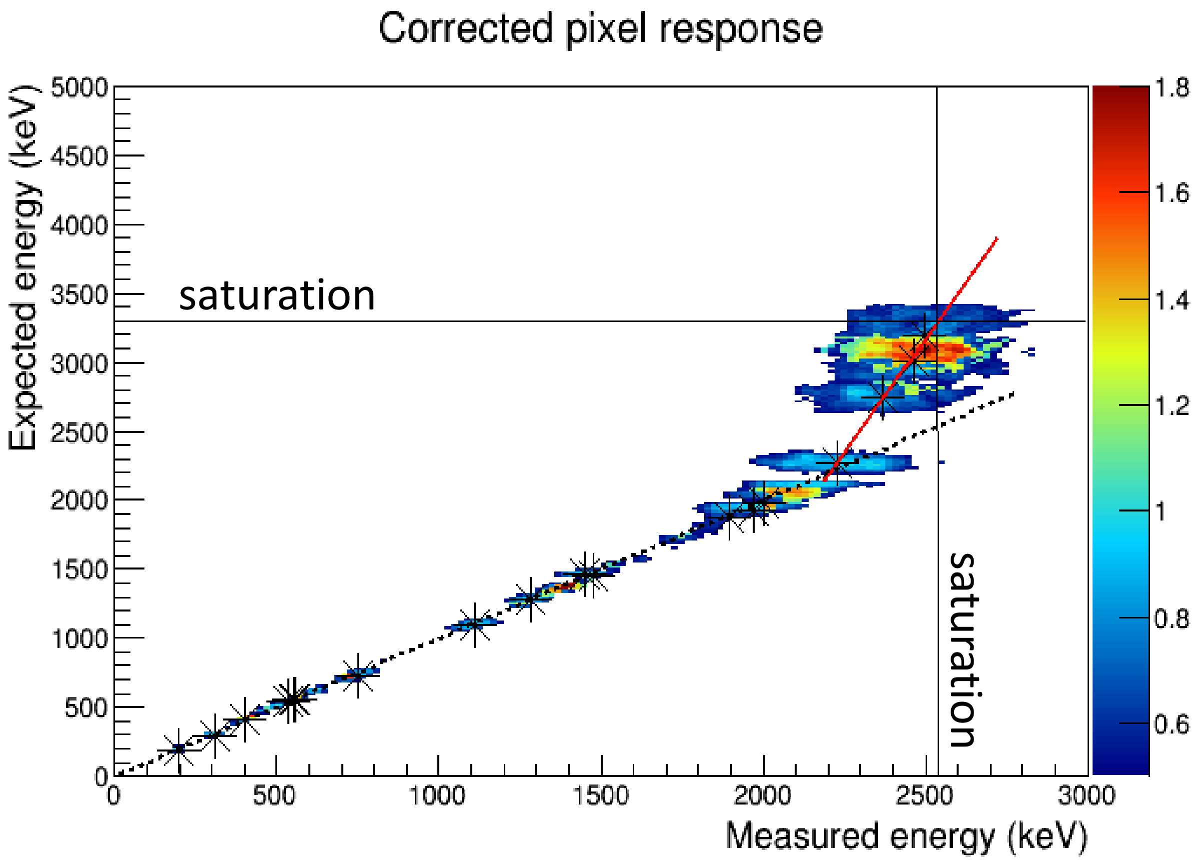


- Different per-pixel energy depositions achieved by varying the bias voltage.
- Energy assumed correct up to 1000 keV

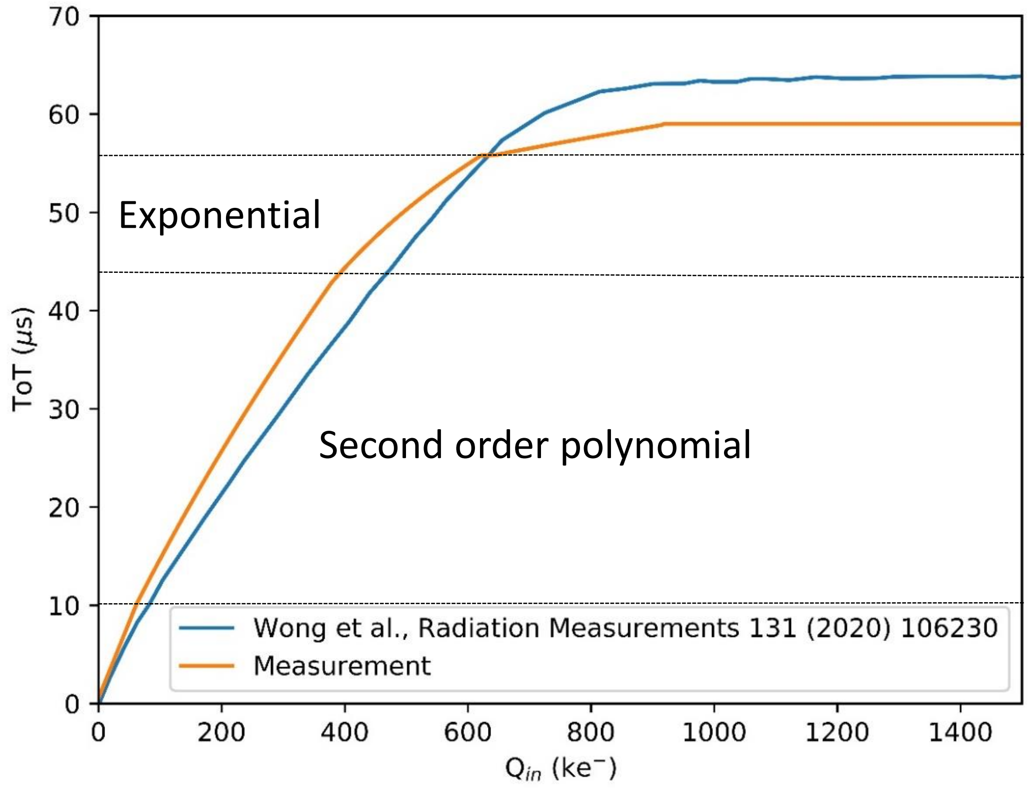


- Different per-pixel energy depositions achieved by tuning the energy of the protons.
- Energy assumed to be correctly measured with current calibration up to 150 keV

Calibrated pixel energy response:
Comparison with design simulation



<u>Design simulation</u> predicts saturation at 950 ke$^-$



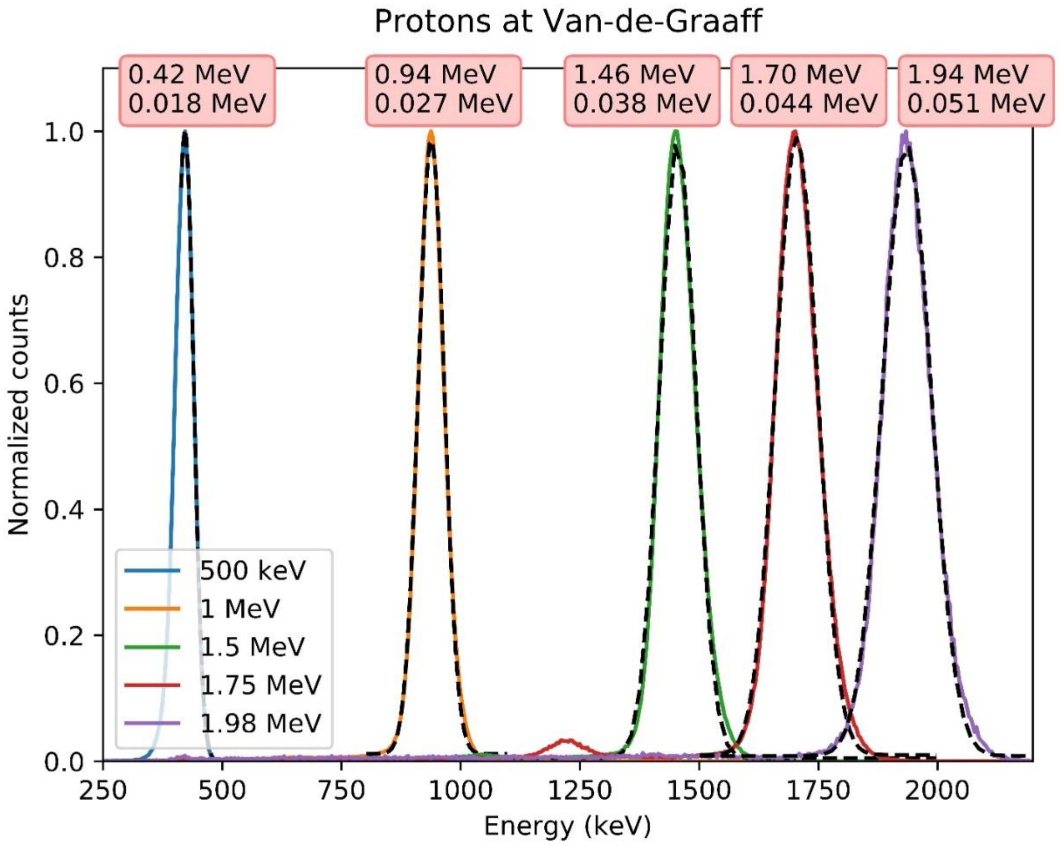
- Energy measurement up to ~2.2 MeV in each pixel.
- The per-pixel saturation level is 3.3 MeV (916 ke$^-$)

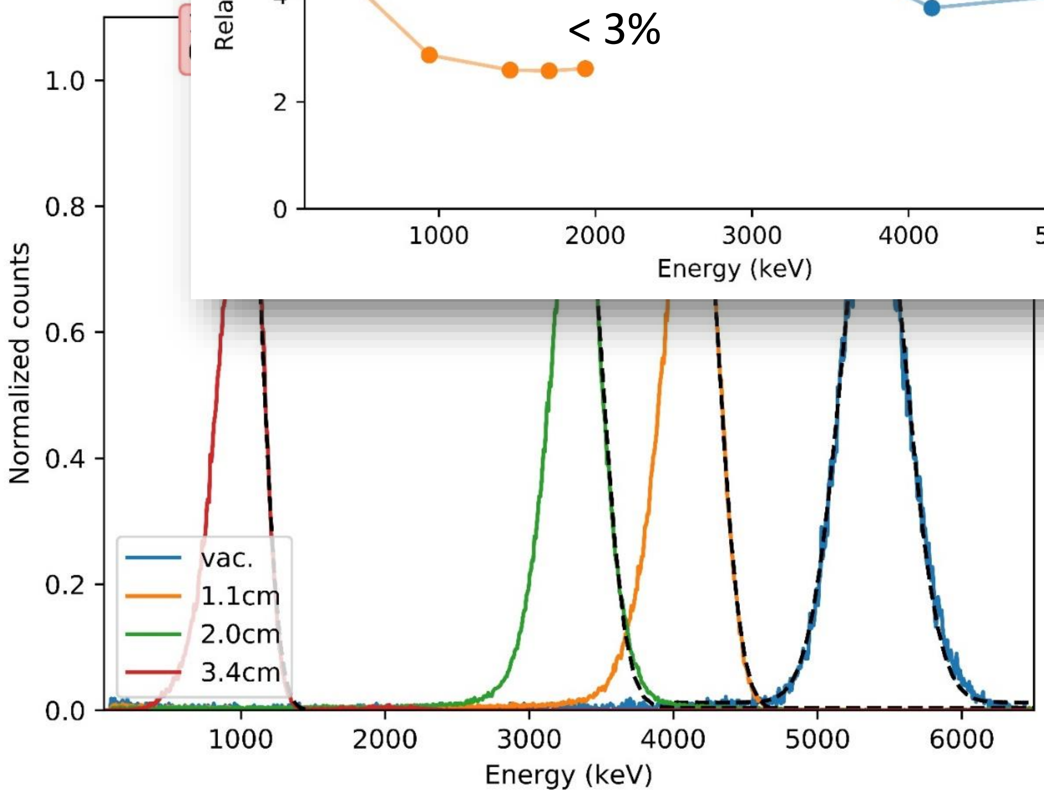
Reasonable agreement considering assumptions made in the simulation.

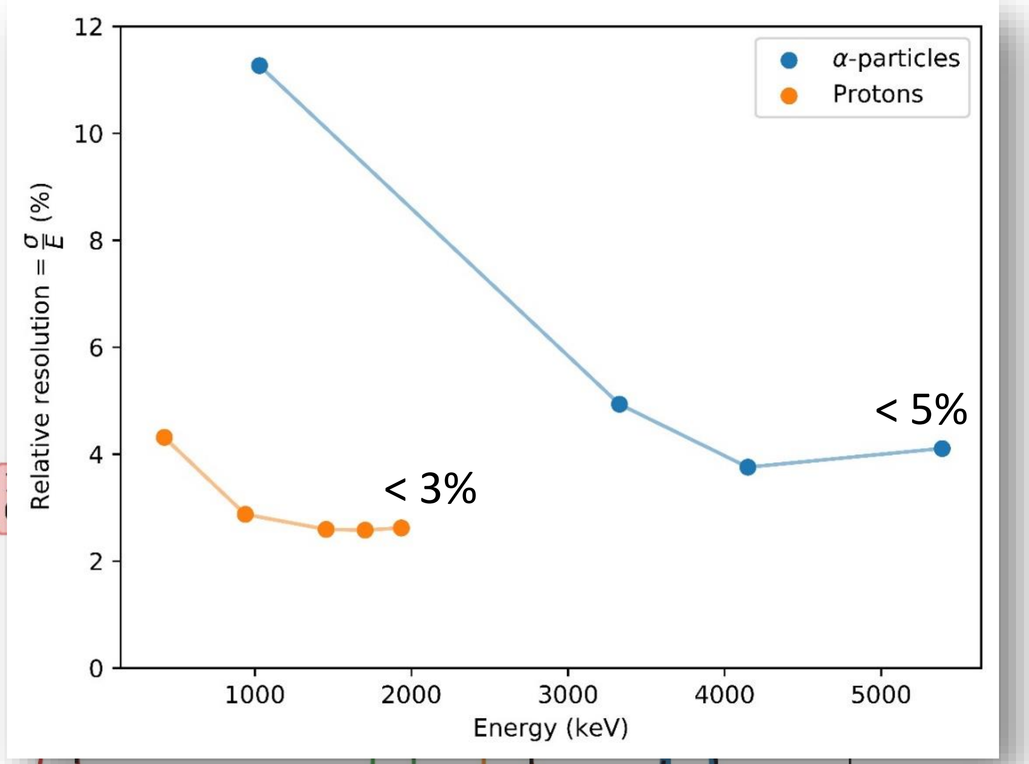
Results

Calibrated pixel energy response:

(Corrected) energy spectra

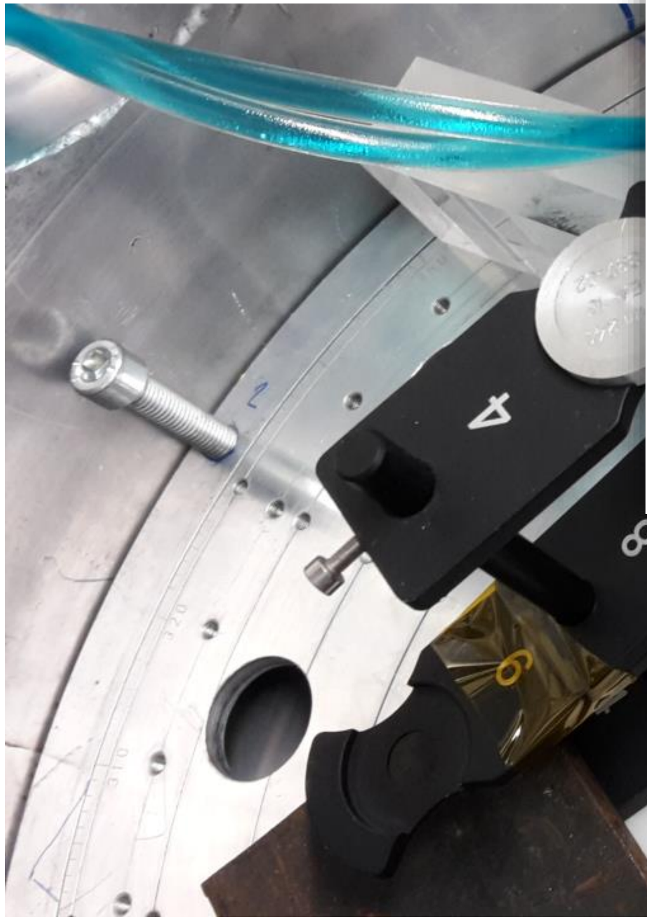


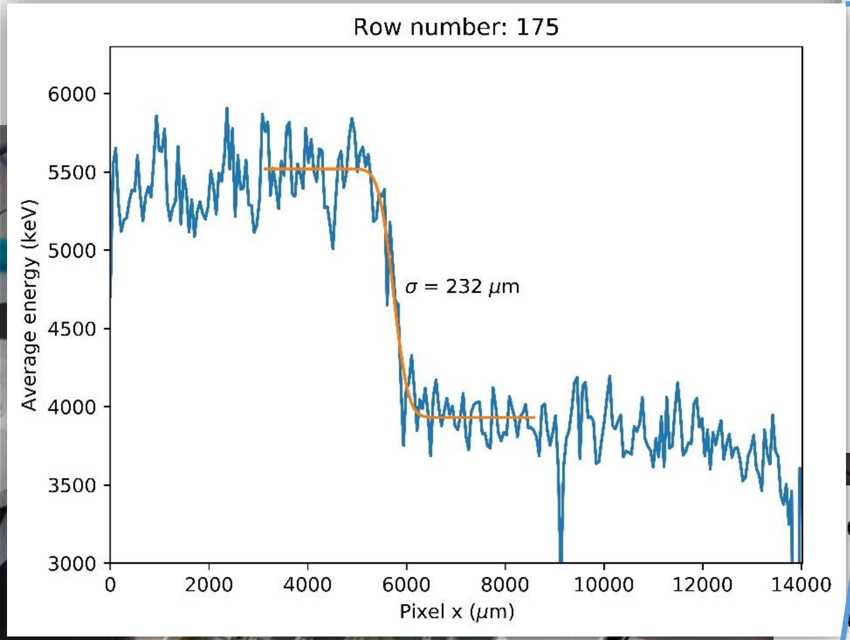


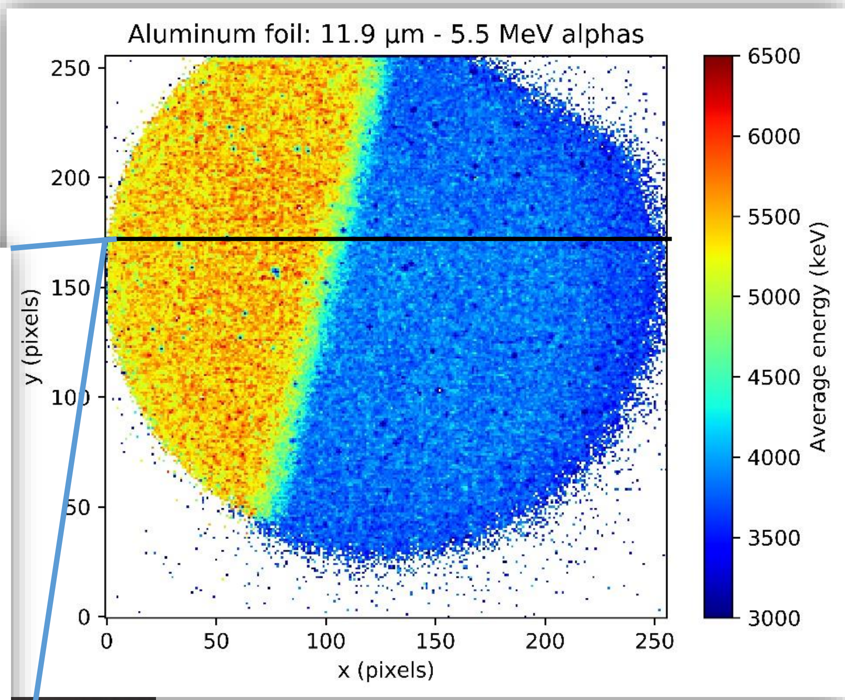


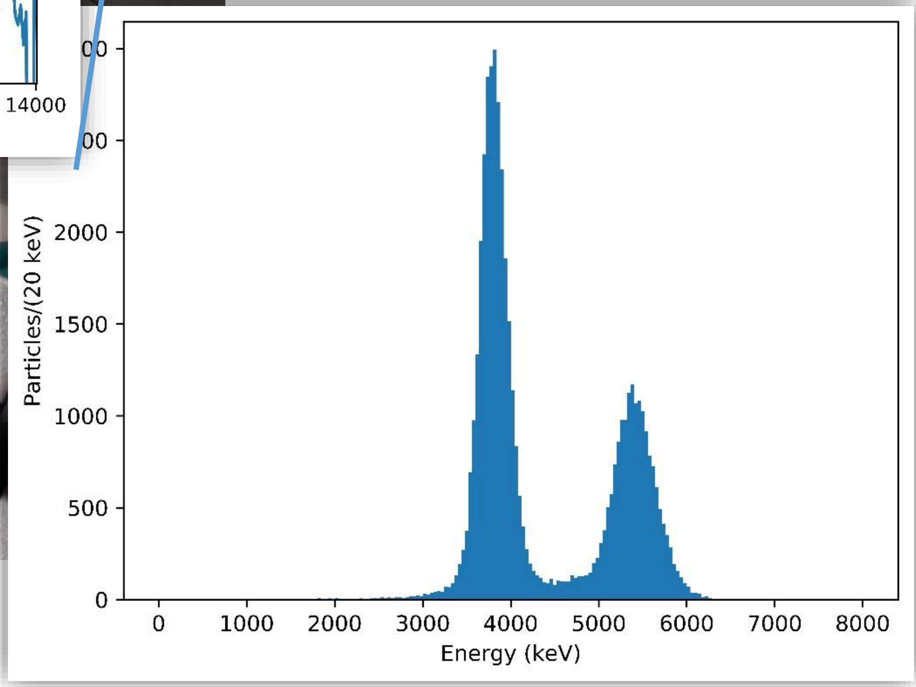
Application:

Spatially resolved **α-particle energy loss in thin layers**





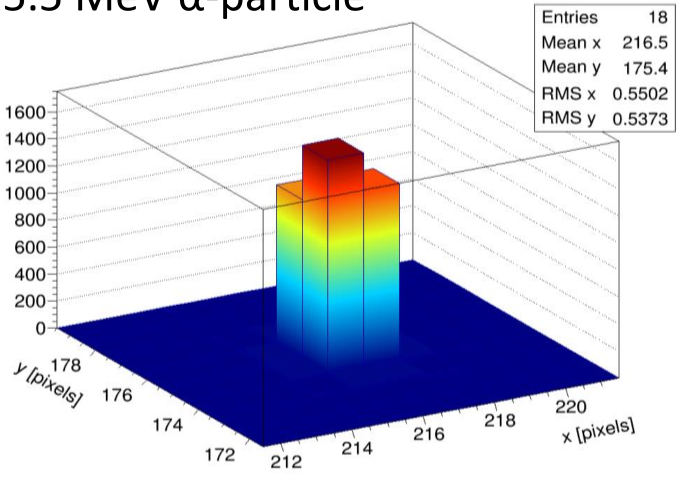


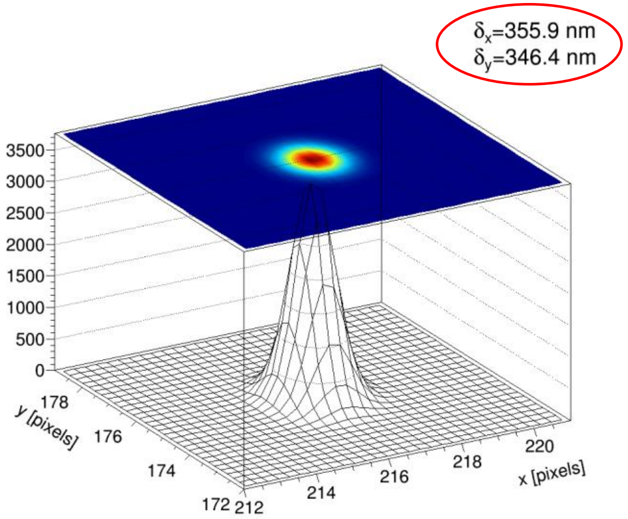


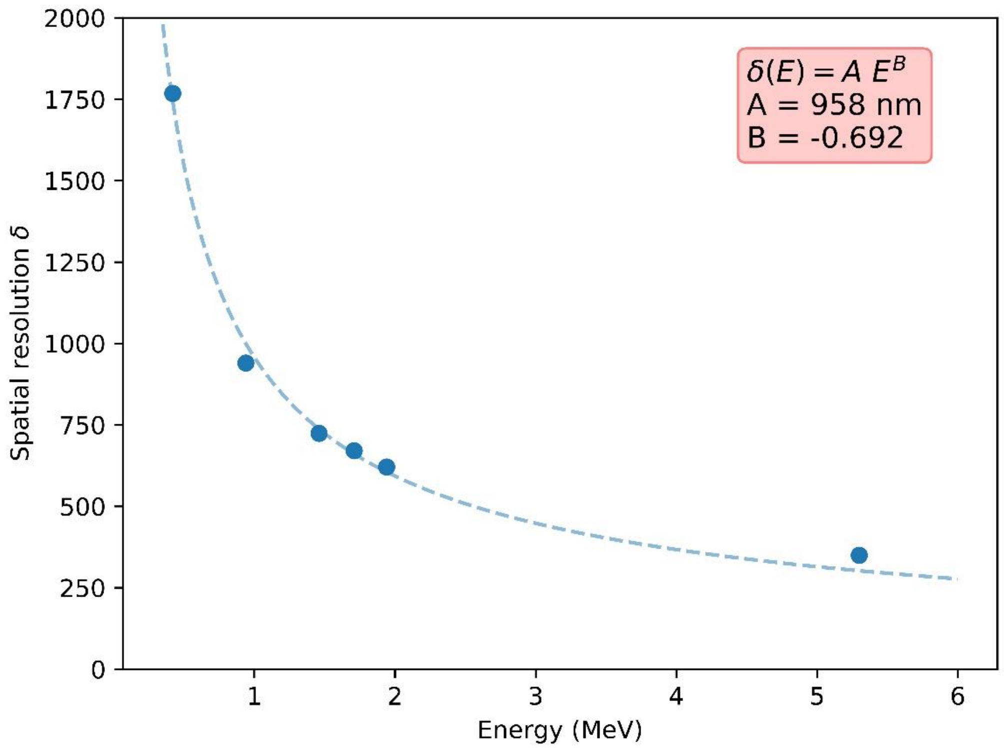
Application:

Subpixel spatial resolution

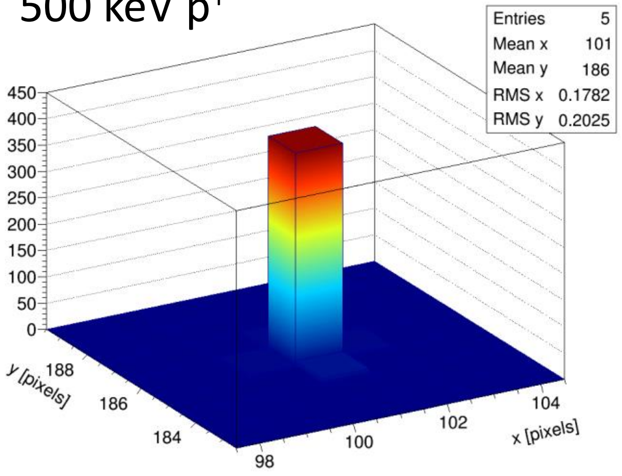
5.5 MeV α-particle

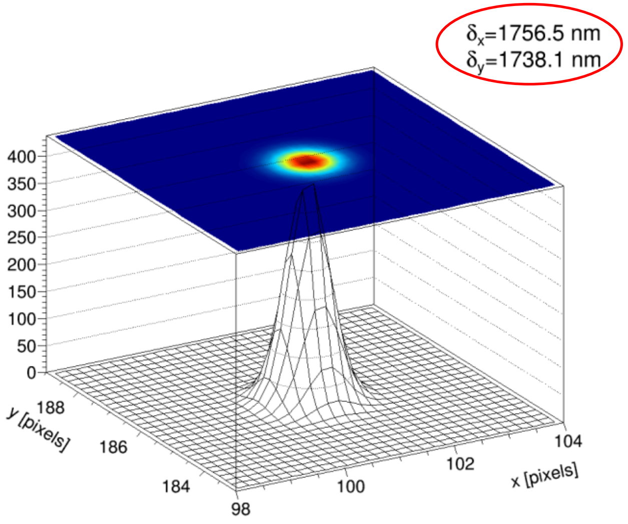






500 keV p^+





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

→ Resolution defined as the error on the mean value

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

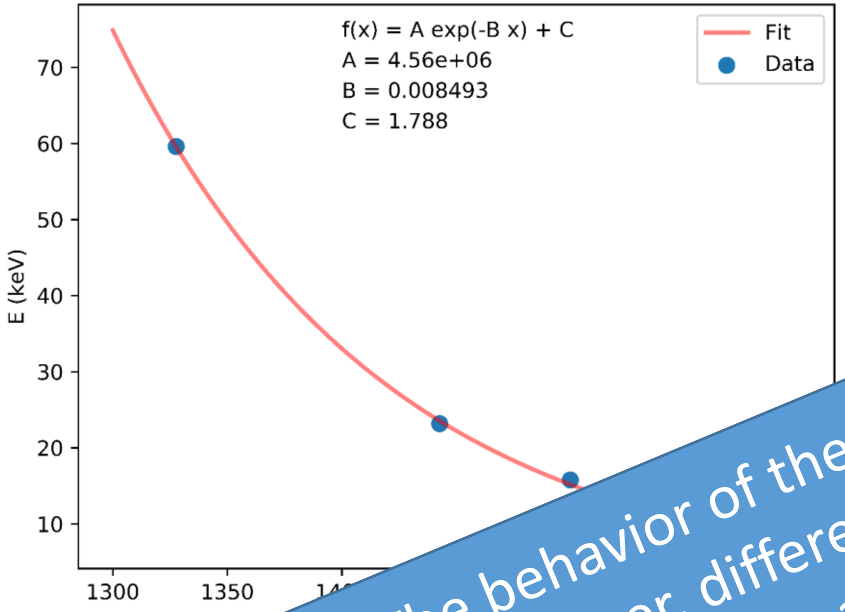
- The following resolutions σ were achieved:
  - 1.6 keV for X-rays at 60 keV (1.4 keV for single pixel clusters)
  - ~55 keV for 2 MeV protons
  - ~220 keV for 5.5 MeV alpha particles

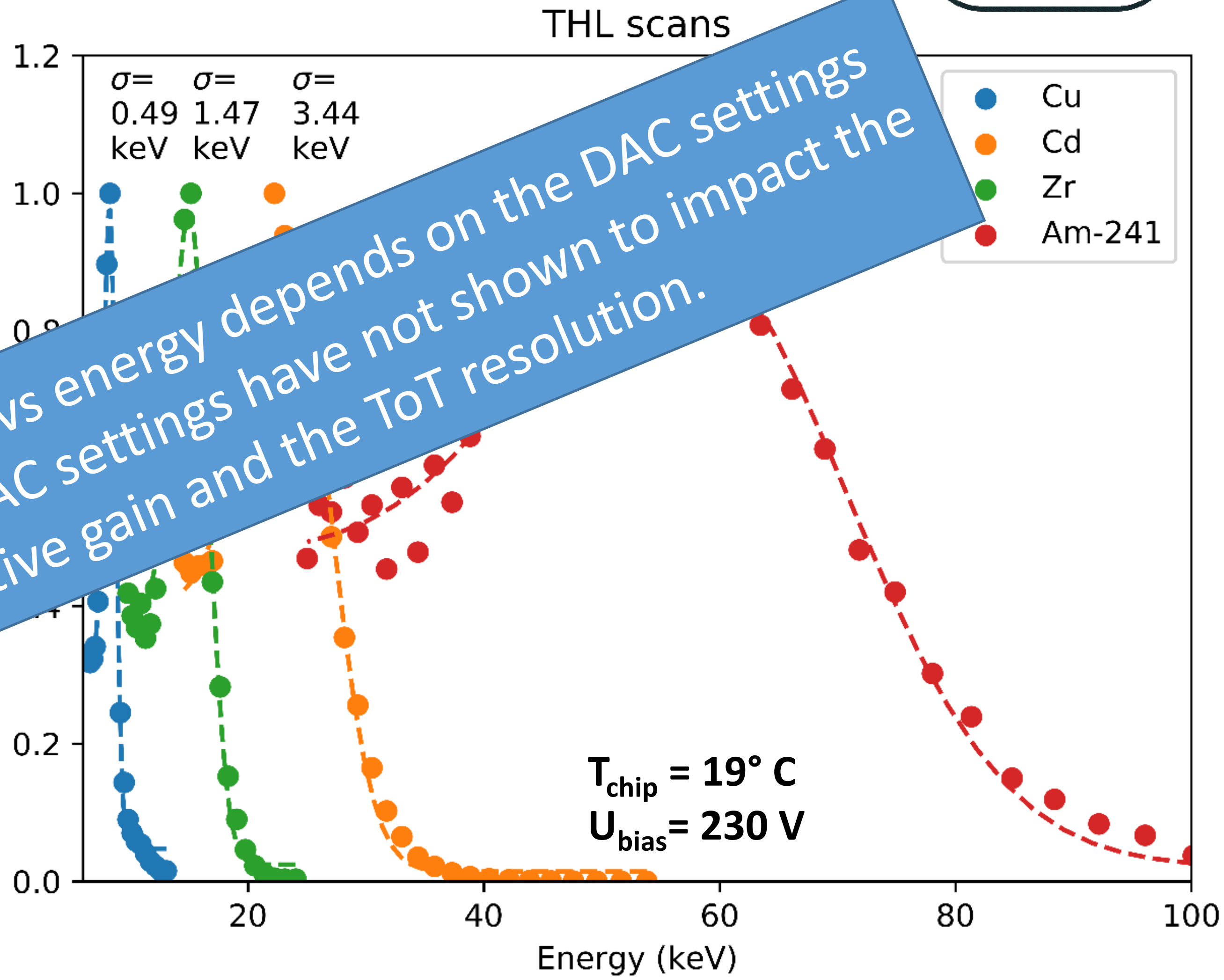
Thank you very much!

Back up

Energy calibration with photons:

THL scan results

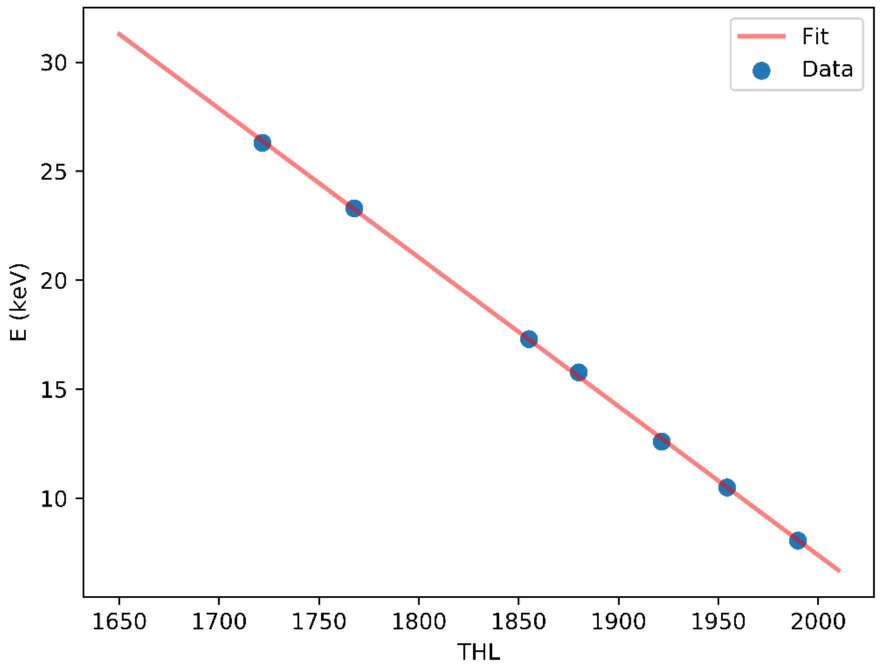




THL s… …gies
used … …pendence of
the TH…
THL at w… …nsor was „noise“-free:
THL_{low} = 5 …eV

<u>Remark:</u> 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.

THL scan results – setting 2



Linear beahvior of energy on THL up to ~30 keV