$2nd\ Allpix^2\ Workshop$
DIGITIZER PLUG-IN FOR KRUMMENACHER CSA

Lukas Tlustos, Pinelopi Christodoulou

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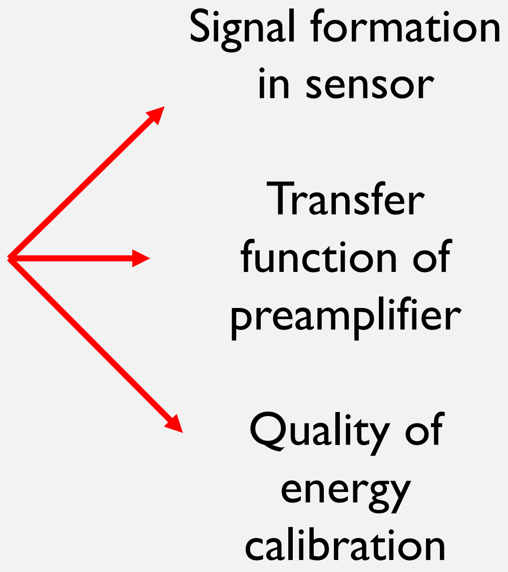
CONTENTS

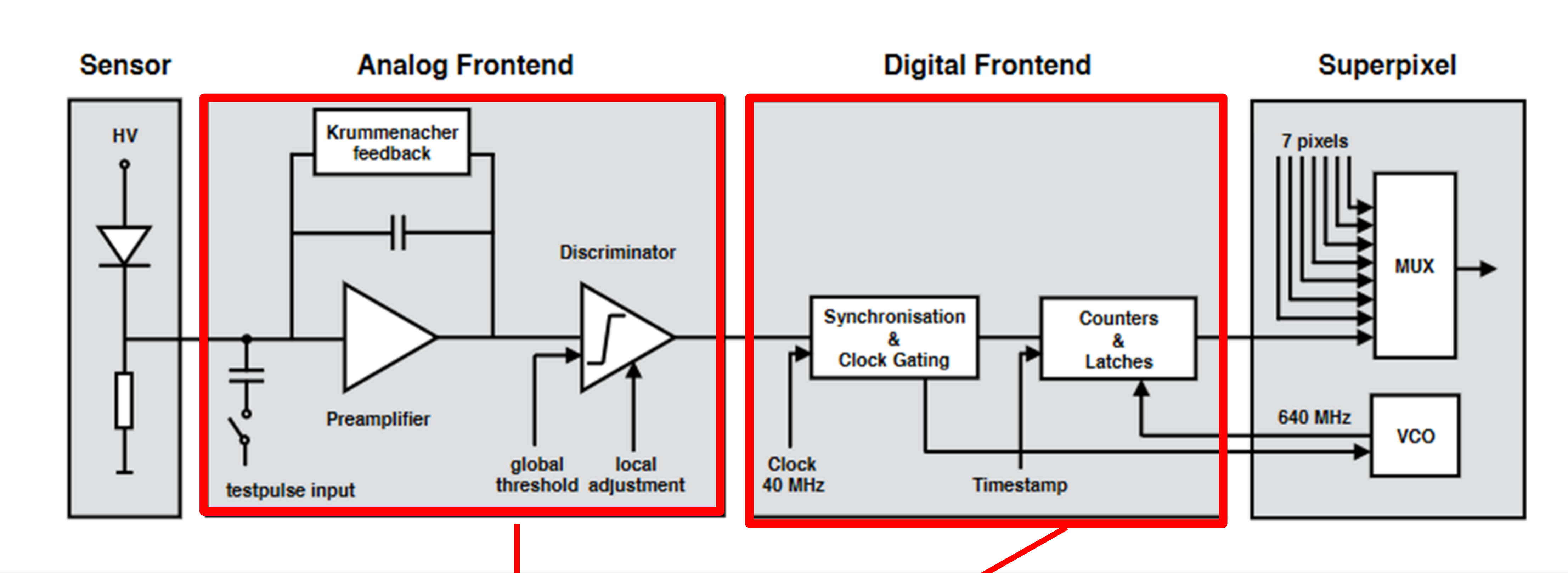
- Introduction – Aim of research
- Configuration file - New Digitizer module implementation
- Results
- Conclusions- Future steps

MOTIVATION

- Optimization of energy calibration for Timepix detectors in order to improve spectral fidelity.
- Spectrum fidelity is a critical property for material reconstruction in spectroscopic X-ray Imaging.
- Simulation has to match the actual detector response as close as possible.



TIMEPIX3 DETECTOR

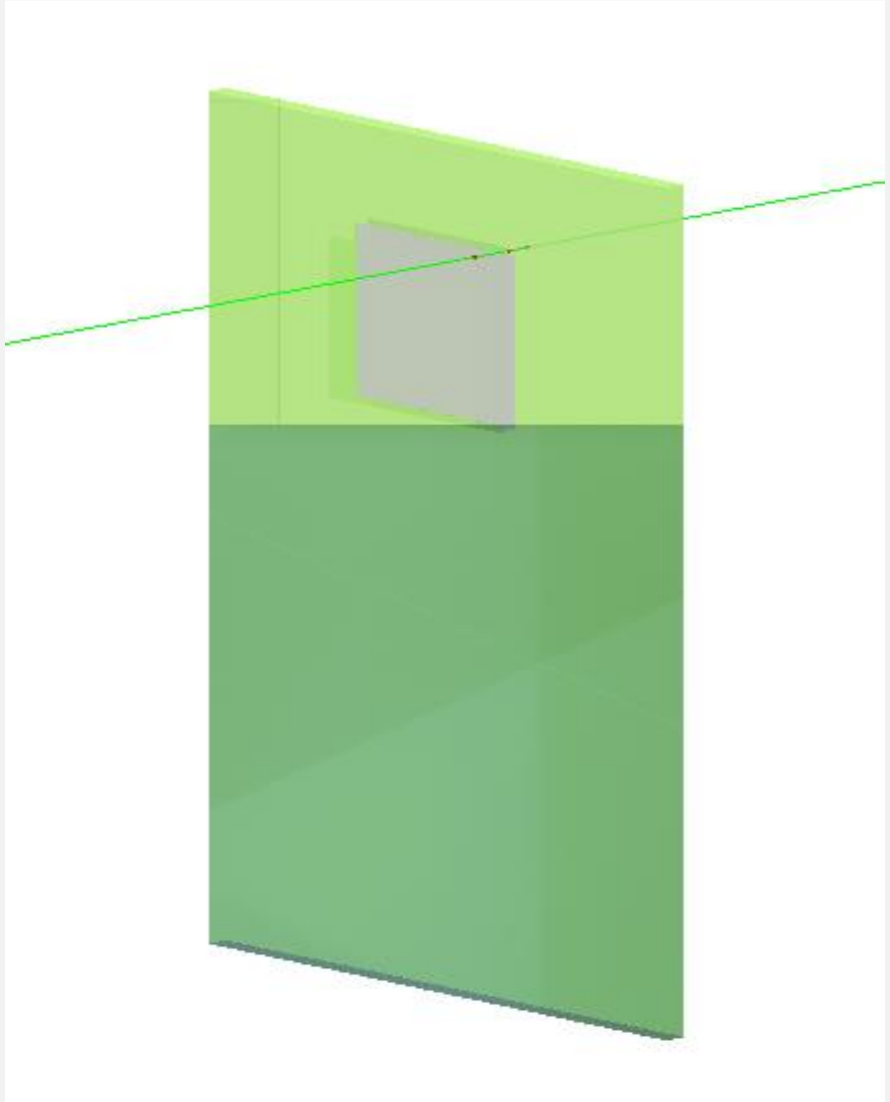


Adapted from: Time and Energy Calibration of Timepix3 Assemblies with Thin Silicon Sensors, F. Pitters, A. Nurnberg, M. Munker, D. Dannheim, A. Fiergolski, D. Hynds, X. L. Cudie, N. Tehrani, M. Williams, W. Klempt, S. Spannagel, 2018

Important to have a realistic simulation of the Front - End response of the Timepix detector.

ALLPIX SQUARED CONFIGURATION FOR TIMEPIX SENSOR

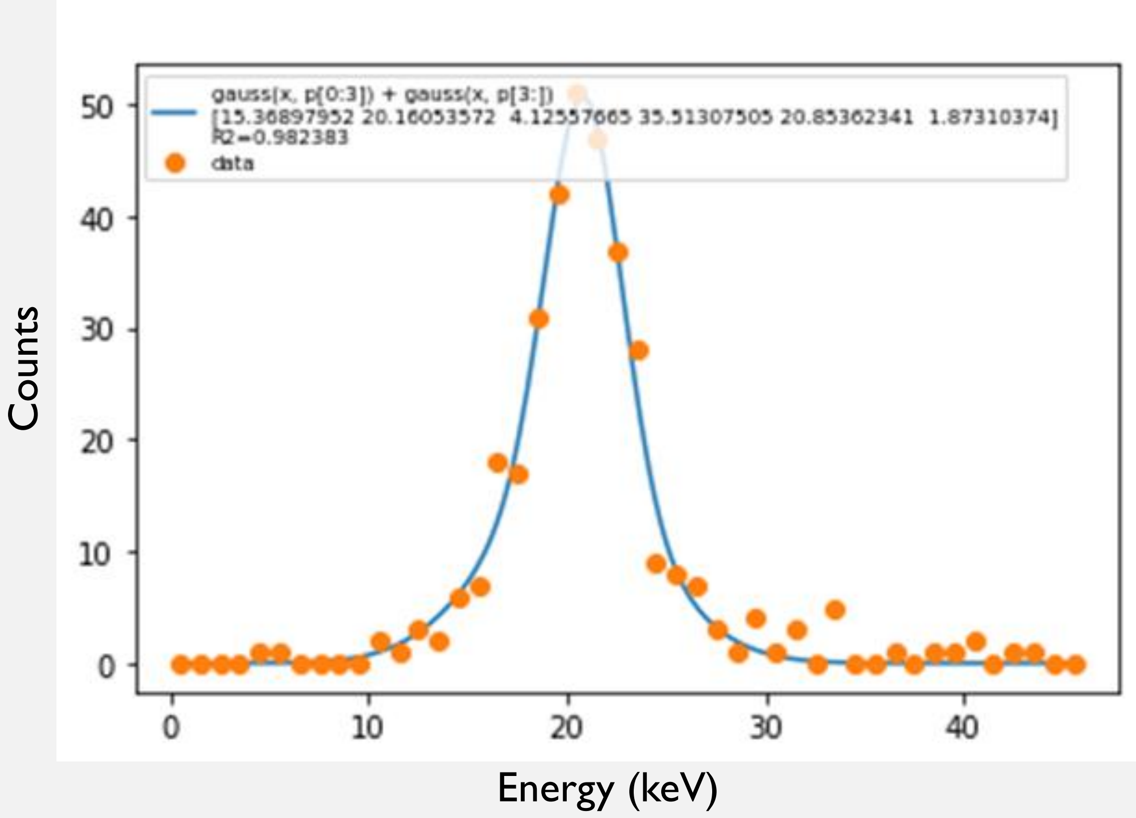
- About Allpix squared: generic simulation framework for silicon tracker and vertex detectors written in modern C**++.**
- Timepix configuration file



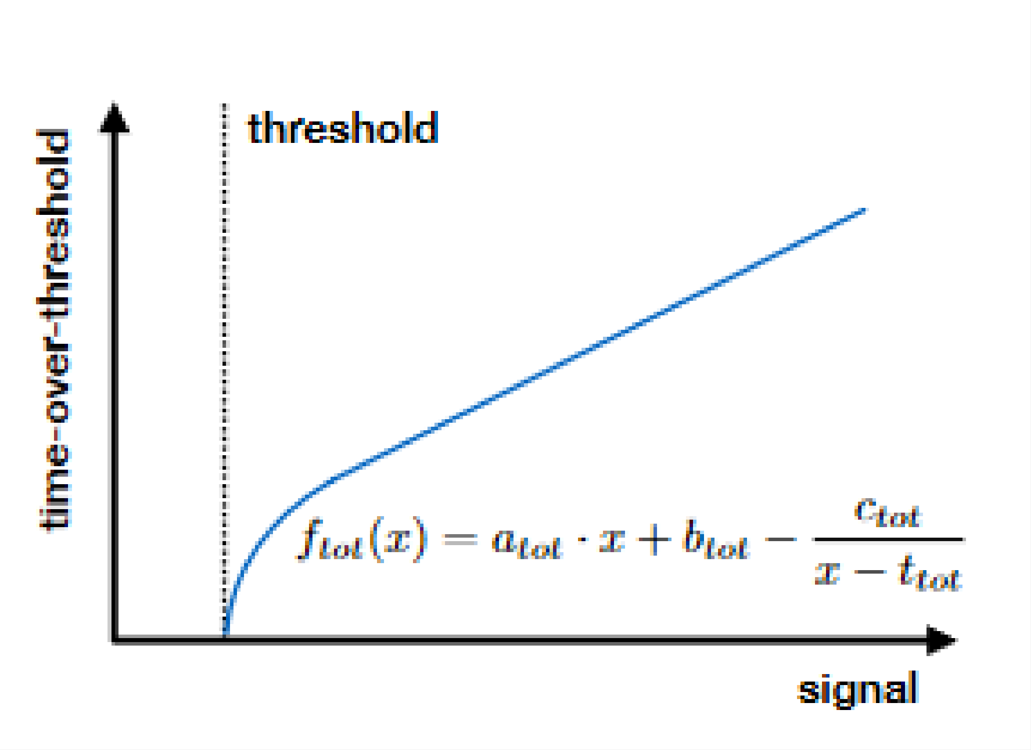
type = "hybrid"
number_of_pixels = 256 256
pixel_size = 55um 55um
sensor_thickness = 300um
sensor_excess = 1mm
bump_sphere_radius = 9.0um
bump_cylinder_radius = 7.0um
bump_height = 20.0um
chip_thickness = 700um
chip_excess_left = 15um
chip_excess_right = 15um
chip_excess_bottom = 2040um

[support]
thickness = 1.76mm
size = 47mm 79mm
offset = 0 -22.25mm

ENERGY CALIBRATION OF TIMEPIX3



Gaussian fit of Fe fluorescence line



Energy calibration surrogate function for Timepix3. Adapted from: Time and Energy Calibration of Timepix3 Assemblies with Thin Silicon Sensors, F. Pitters,A. Nurnberg, M. Munker, D. Dannheim, A. Fiergolski, D. Hynds, X. L. Cudie, N. Tehrani, M. Williams, W. Klempt, S. Spannagel, 2018

CSA DIGITIZER

[CSADigitizer]

model = "csa“ or "simple"

feedback_capacitance = 10e-15C/V

detector_capacitance = 100e-15C/V

krummenacher_current = 25e-9C/s

amp_output_capacitance = 15e-15C/V

transconductance = 50e-6C/s/V

temperature = 298

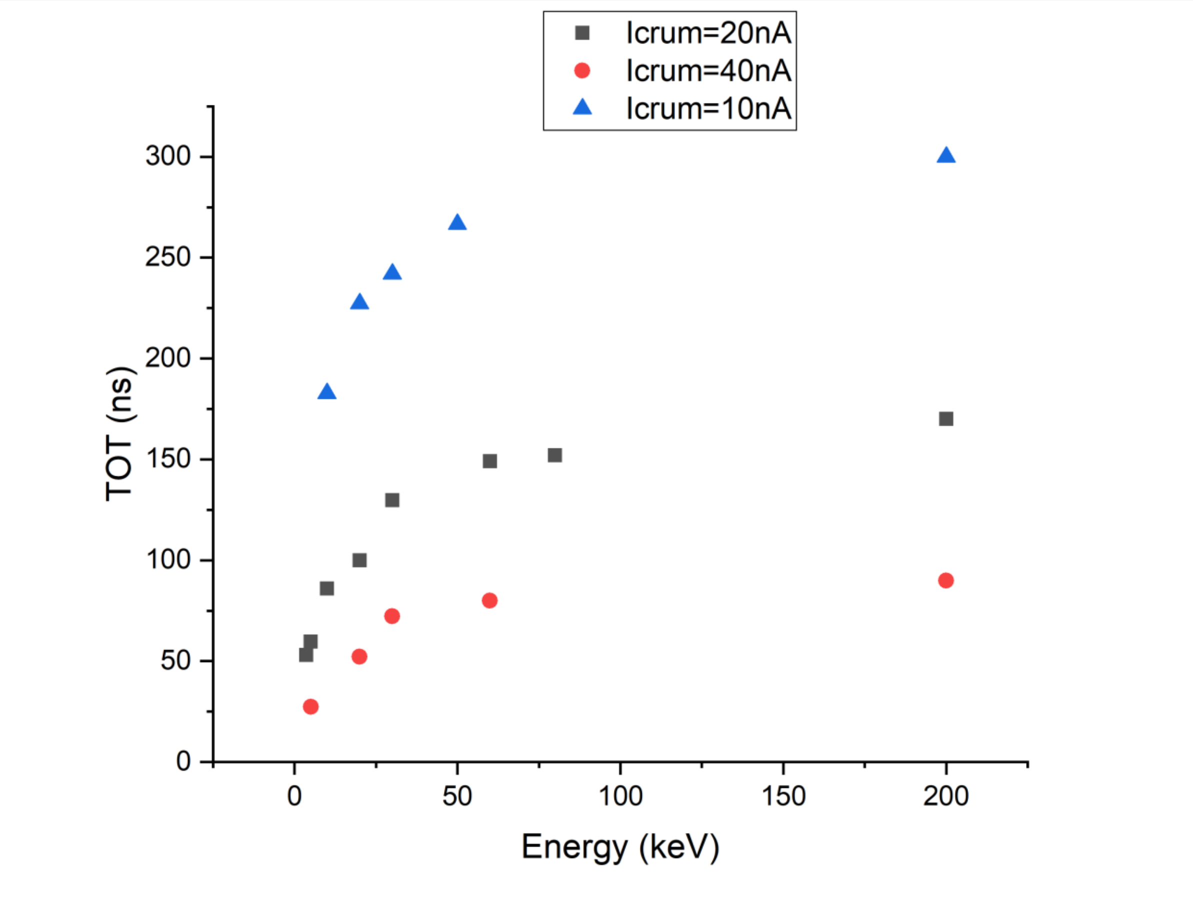
integration_time = 0.5e-6s

threshold = 10e-3V

sigma_noise = 0.1e-3V

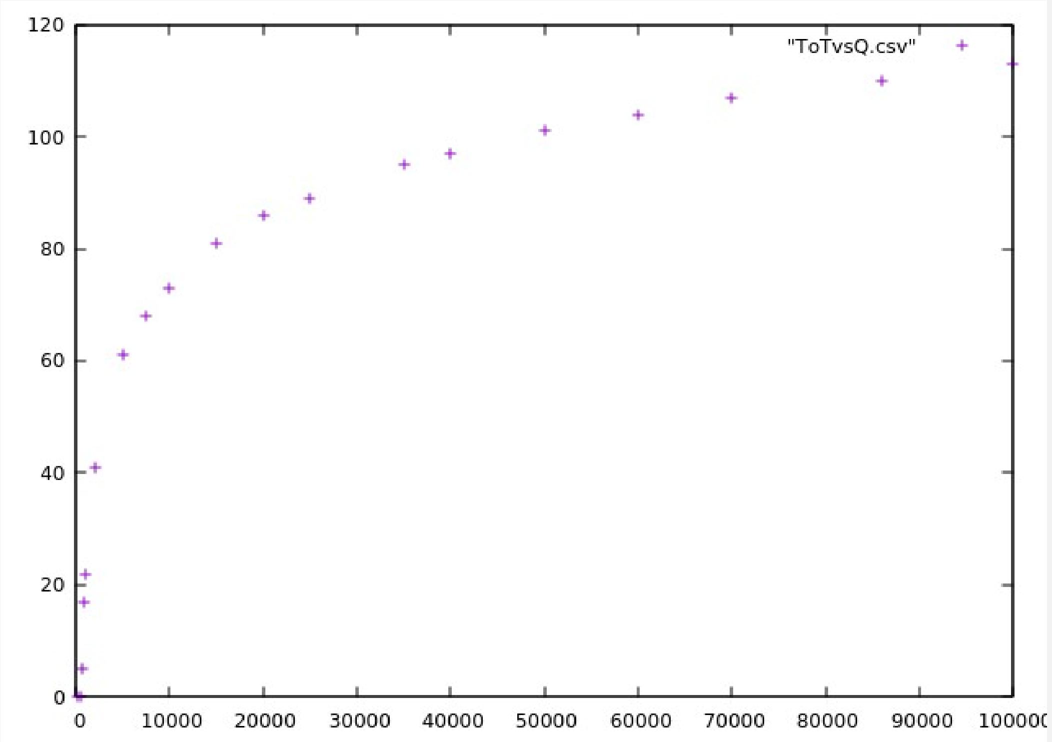
clock_bin_toa = 1.5625ns

clock_bin_tot = 25.0ns

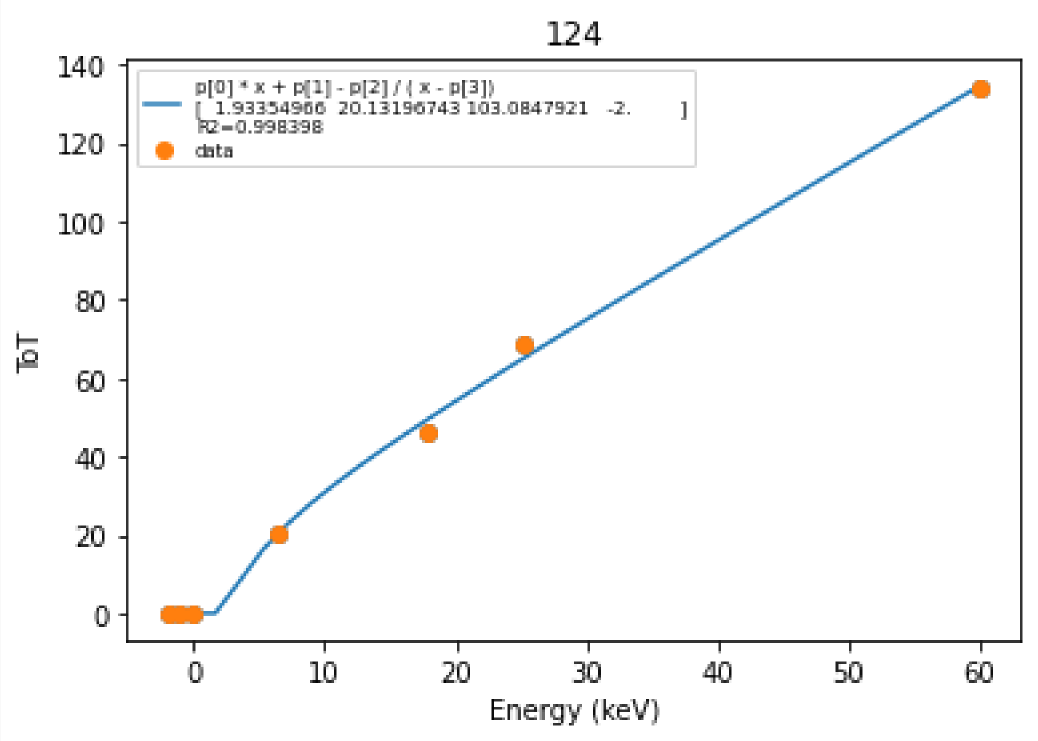


Implementation using design values for capacitances and resistors → preamp output in [V]
Good approximation for Tpx-like detectors for small signal amplitudes
Saturation at higher input charges

CSA DIGITIZER EXAMPLE



vs

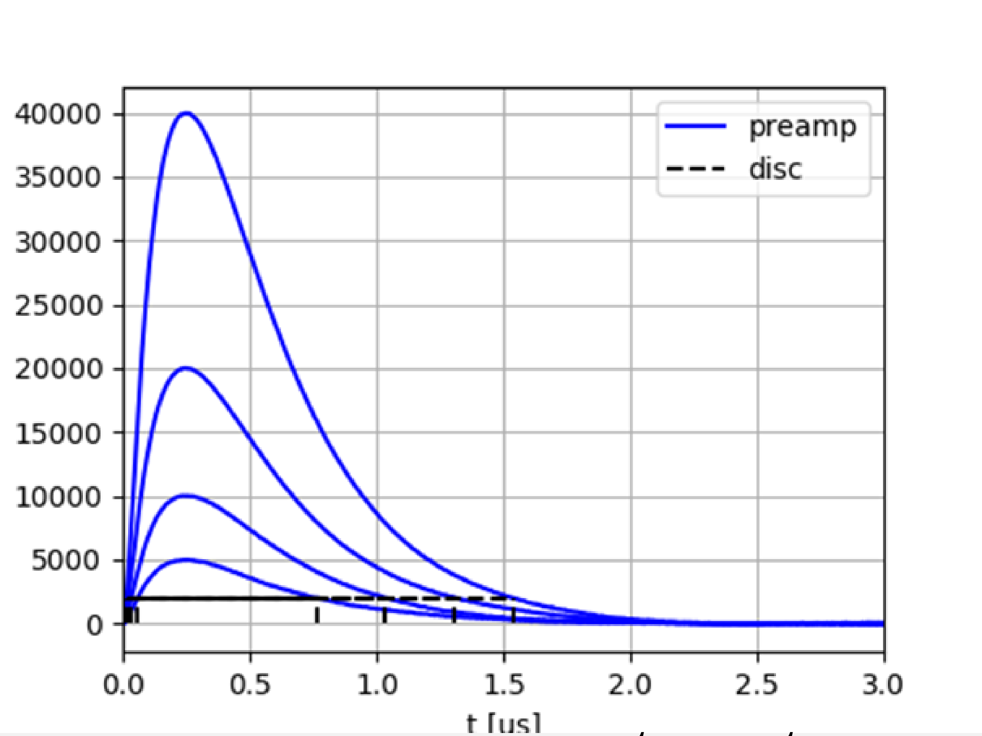


[CSADigitizer]
clock_bin_tot = 25ns
integration_time = 20us
threshold = 5e-3V
model = "simple"
feedback_capacitance = 10e-15C/V
feedback_time_constant = 400ns
rise_time_constant = 300ns
sigma_noise = 0

Example of energy calibration for an individual pixel using fluorescence lines from radioactive sources and fit with surrogate function.

EXPLANATION OF THE SATURATION OF THE TOT

Krummenacher + Shaper

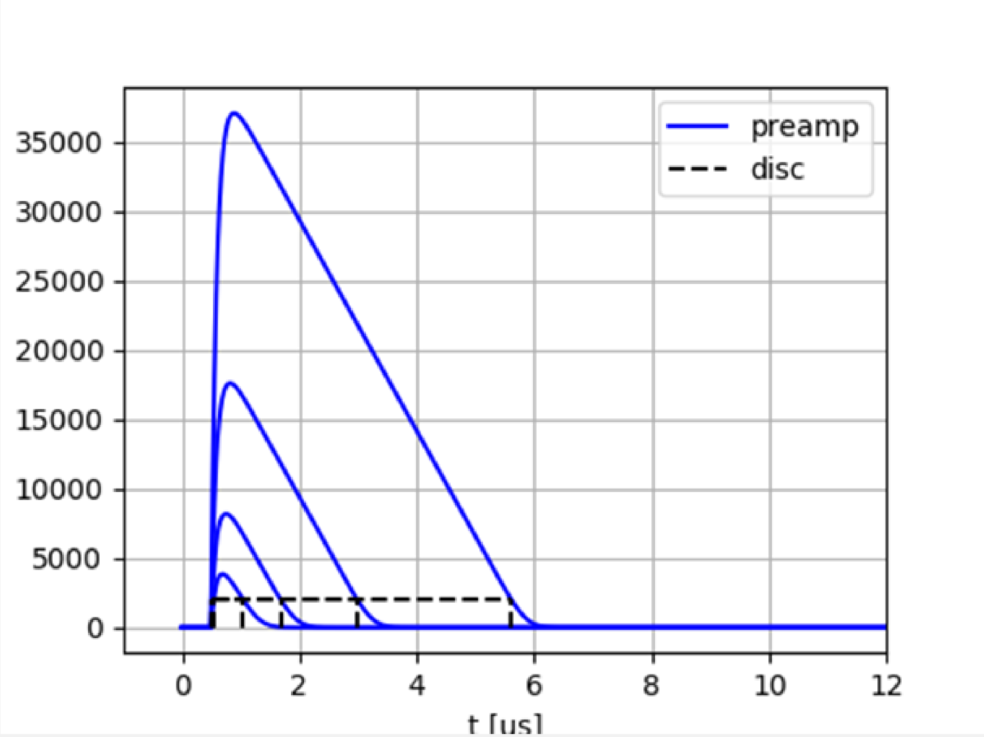


$$output \propto input * \left(e^{-\frac{t}{\tau 1}} - e^{-\frac{t}{\tau 2}}\right)$$

CSA Plugin
Maximum ToT ~ 2.0μs

Krummenacher only

- return to zero proportional to input



Output shape depends on input

This Plugin
Maximum ToT: correctly modelled

IMPLEMENTATION OF NEW DIGITIZER

GOAL: realistic simulation of the Front - End response of the Timepix detector. Valid for signal within the linear range of the preamplifier.

Parametrization of the dependence of :

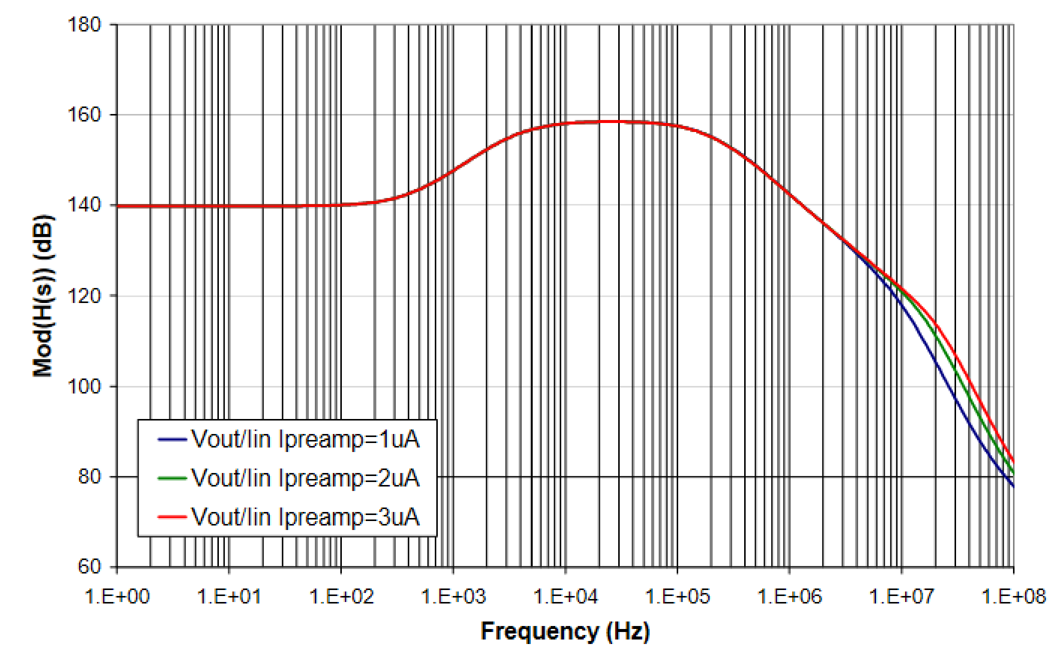
- the effective feedback current on the output amplitude,
- the bandwidth limited output noise,
- threshold and feedback current variations,
- ToA and ToT clock frequency and clock phase shifts.

Configuration example using TPX Digitizer

```
[TPXDigitizer]
gain = 1.25
gain_asymmetry = 2.5perc

gain_dispersion = 2.5perc
tau_integrator_ = 80ns
alpha_ikrum = 8.5e/ns

Ikrum_sigma = 1e/ns

# logistic, linear, erf, tanh or exp
fb_taper_type = exp
fb_taper_width = 4500e

dt = 0.05ns
noise_ENC = 80e
noise_bw_low = 1e4Hz
noise_bw_high = 1e7Hz

threshold = 950e

threshold_sigma = 30e

# ToT/ToA clock period for Tpx3

clock_bin_toa = 1.5624ns
clock_bin_tot = 25ns

# histogram settings

ToT_hist_maximum = 5us
ToT_hist_bin_size = 1ns
ToA_hist_bin_size = 0.1ns
```

Defines the function to be used for the feedback tapering

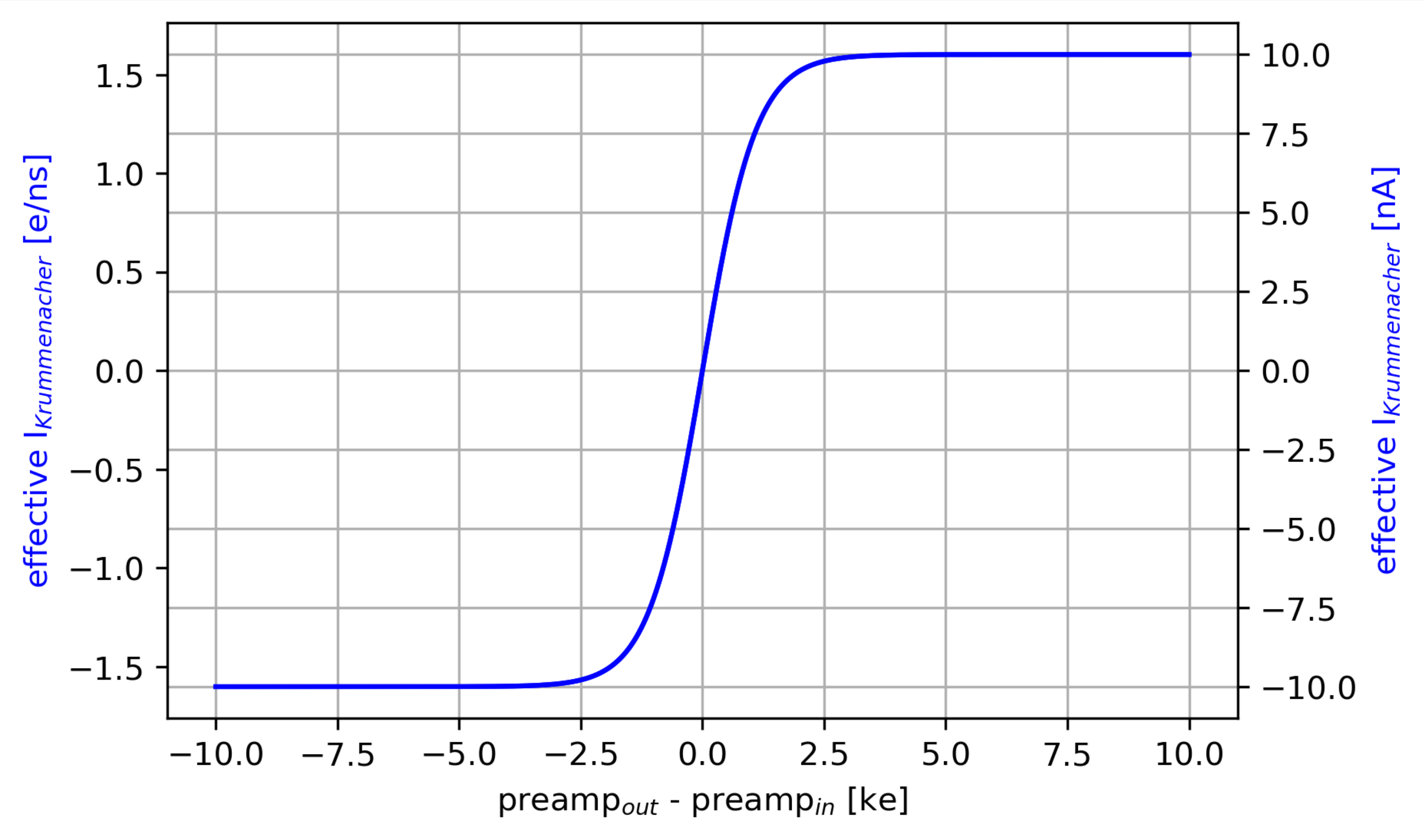
Dependence from the bandwidth output noise



Simulated transfer function of the preamplifier. *Adapted from R. Ballabriga's Doctoral Thesis*

SIMULATED EFFECTIVE KRUMMENACHER FEEDBACK CURRENT

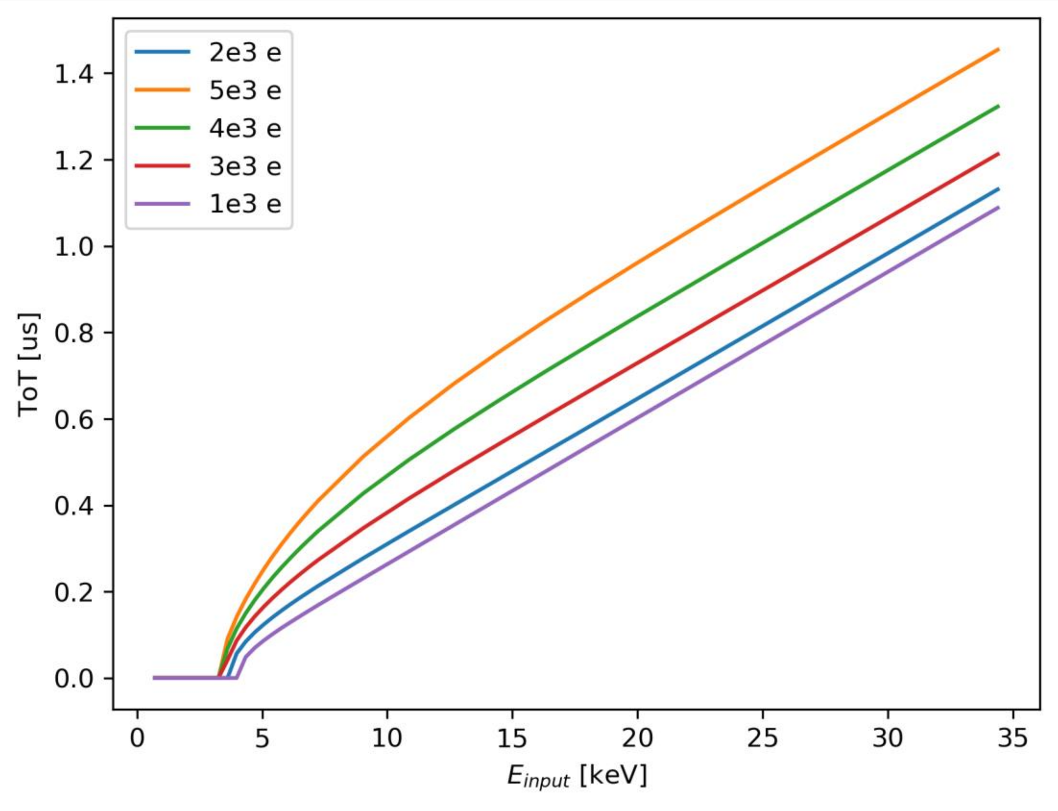
- Effective Krummenacher current varies with the difference in voltage in the nodes of the CSA.



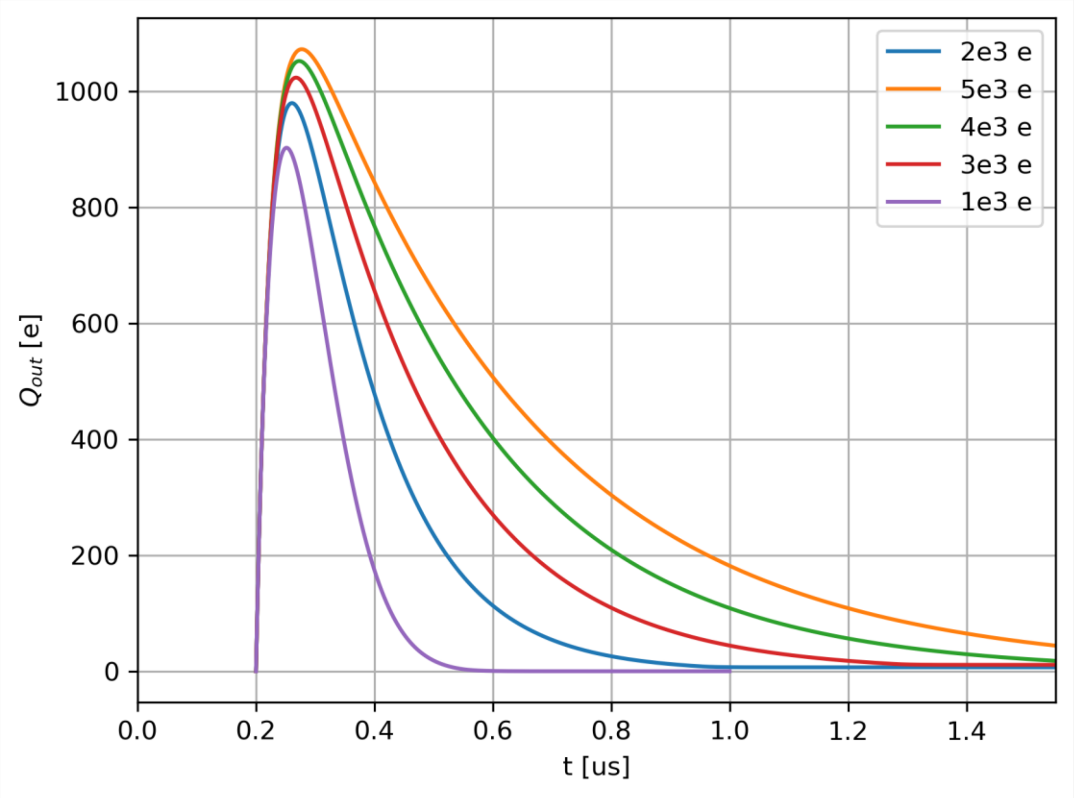
Simulation for nominal krummenacher current of 10 nA and taper width of 3ke.

VISUALIZATION OF THE IMPACT OF THE FEEDBACK TAPERING FUNCTION

- Tapering width needs to match the chip implementation (according to the expected design values of the chip).
- Test pulse measurements are needed to verify this.



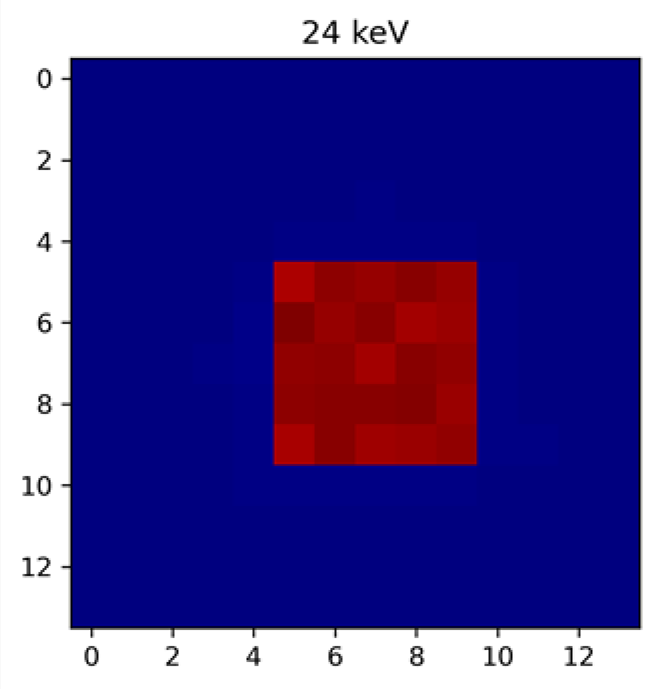
Effect on the ToT

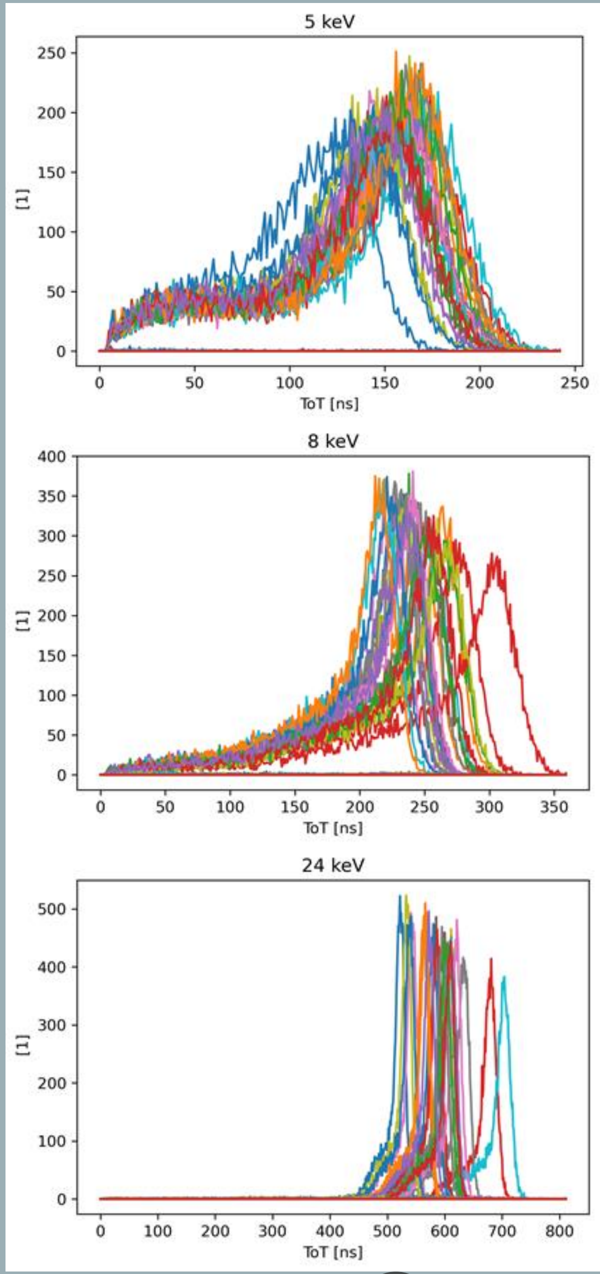


Effect on the Preamplifier output for 1ke input

EXAMPLE: SIMULATION OF ENERGY CALIBRATION

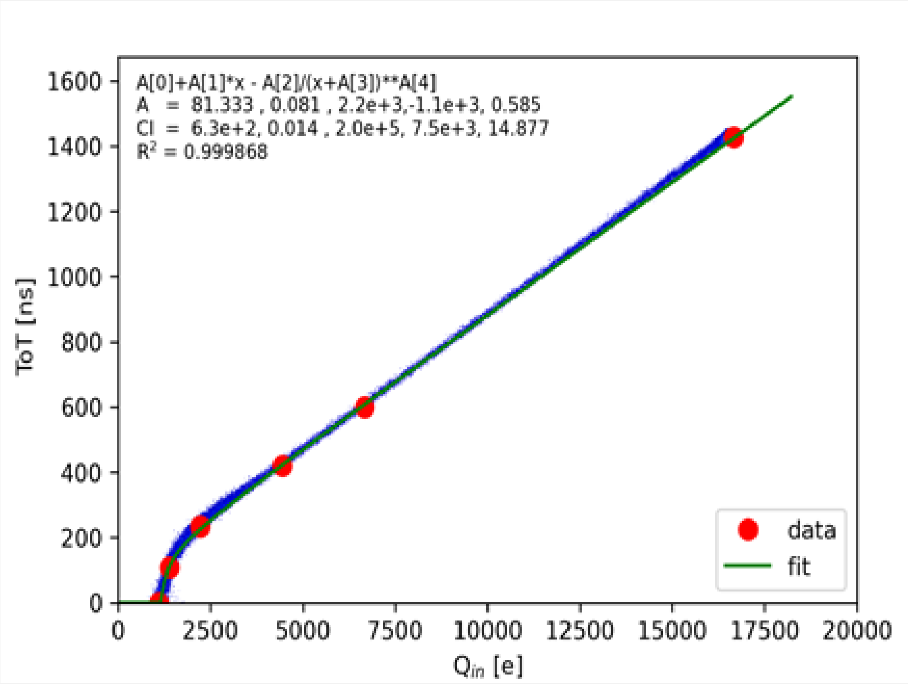
- Uniform irradiation 5x5 pixel area within of 15x15 pixel matrix.
- Incoming beam 5, 6, 8, … 24 keV.
- Calculation of the 25 single pixel hit spectra.
- Simulation includes gain, threshold and krummenacher current variations.



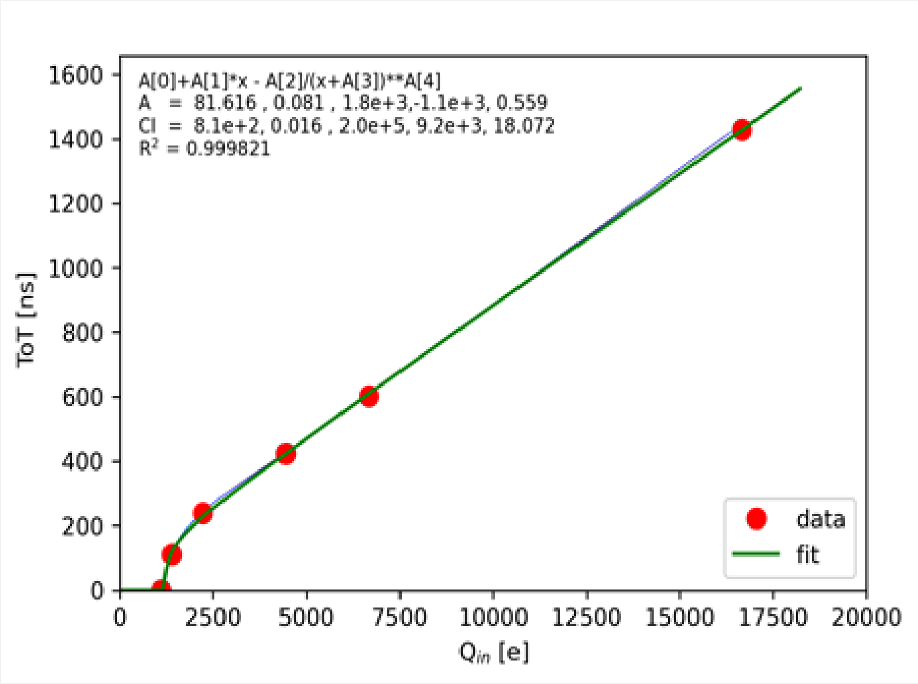


EXAMPLE: SIMULATION OF ENERGY CALIBRATION “USING” SOURCES

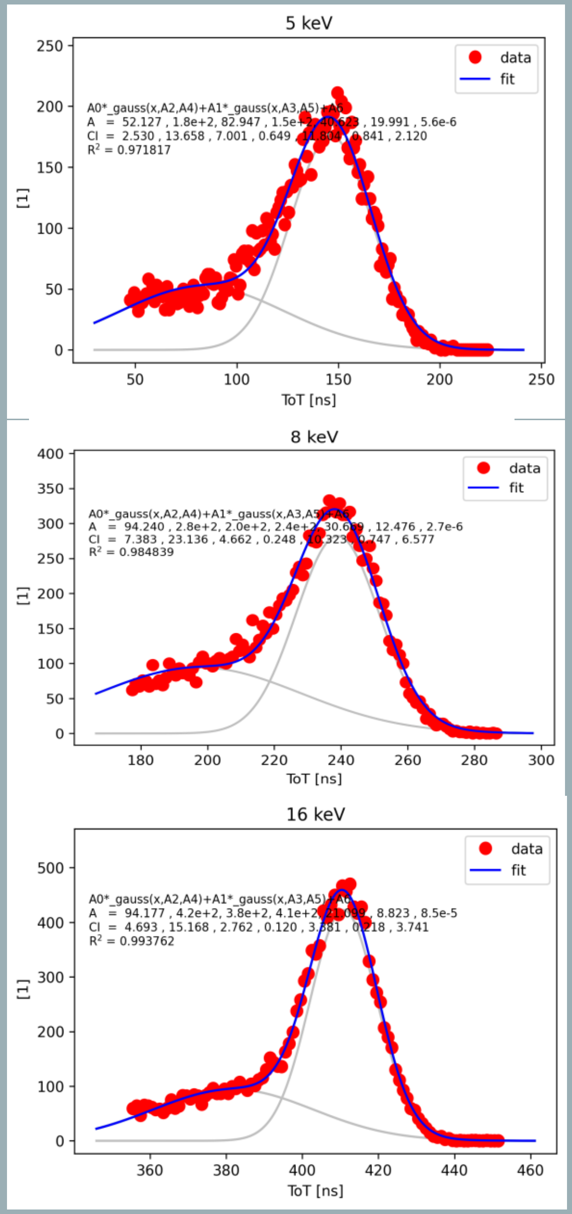
- Standard energy calibration procedure tends to distort low energy reconstruction.
- Surrogate function used for fitting too “elastic”, very sensitive to small deviations in the low energy region.
- Simulations do not (yet) include effect of temperature variations on feedback current.
- Blue dots are due to charge shared events from the 60keV “source”.



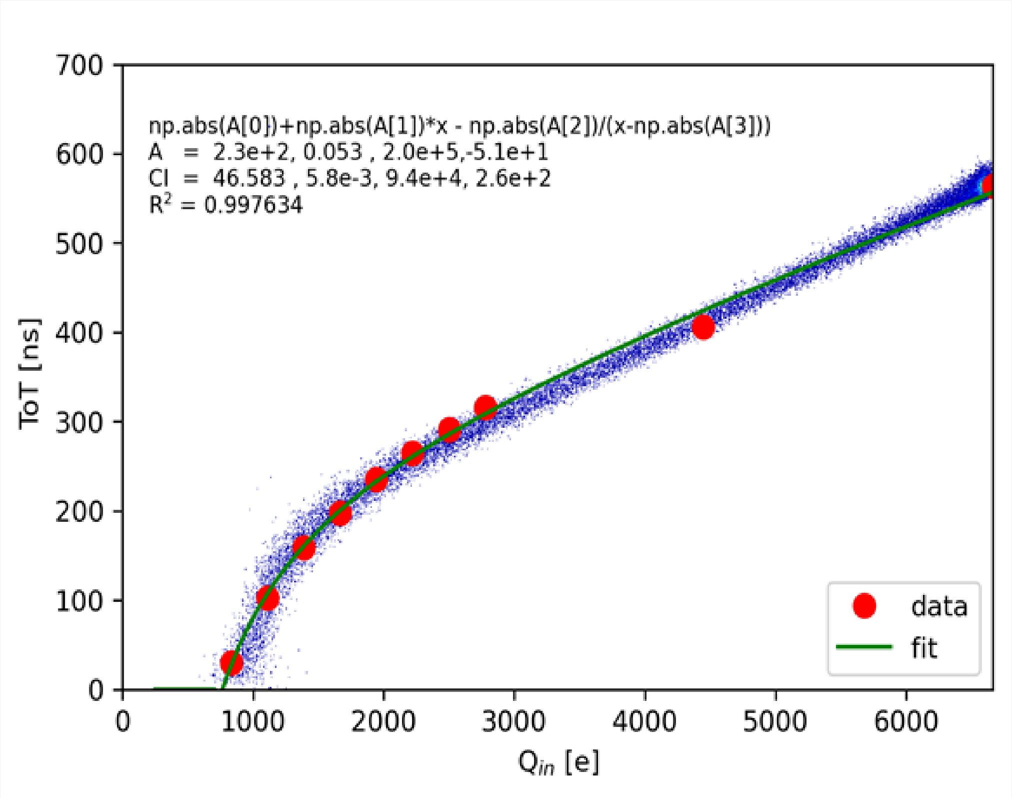
ENC 80e



ENC 0e



EXAMPLE: SIMULATION OF ENERGY CALIBRATION



Additional slight offsets emulated by threshold variations

↓

Deformed energy calibration

↓

Loss of spectral fidelity

CONCLUSIONS

Aim: Validate and improve the energy calibration procedure for Timepix3 detectors.

The implementation of the new Digitizer:

- Fixed the problem of saturation of the signal for the energy calibration.
- Showed that feedback Tapering affects the energy response / calibration
- Tapering needs to match the chip implementation

Future Steps:

- Find a function with better and more robust fit.
- Compare the results of this calibration with actual measurements.

THANK YOU VERY MUCH FOR YOUR ATTENTION!

EXTRA SLIDES

- **CSA implementation:**
Transfer function from *[Kleczek 2016 JINST11 C12001*] which is applied in allpix squared digitizer:
$H(s) = R_f / (1 + \tau_f s) * (1 + \tau_r s)$

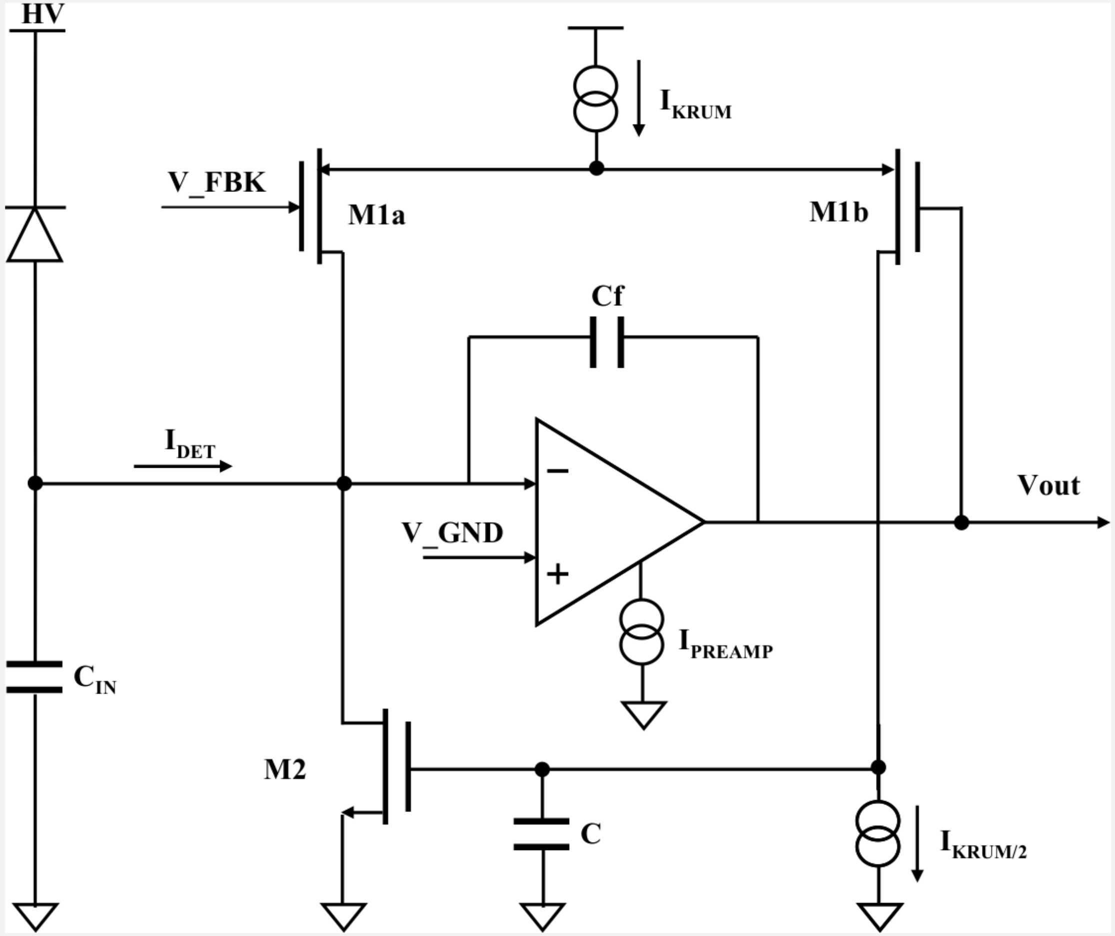
with $\tau_f = R_f C_f$, rise time constant $\tau_r = \frac{C_{det} * C_{out}}{g_m * C_f}$

Impulse response: $L^{-1}(K)$

SIMULATION LIST MODE OUTPUT

idx	row	col	raise[ns]	t_fall[ns]	ToT[ns]	clk_raise[1]	clk_fall[1]	peak[e]	input[e]
1	6	6	9.154	527.365	518.211	6	21	5451.497	6173.000
3	6	8	10.886	527.365	516.479	7	21	5167.234	5873.000
6	9	6	17.436	350.562	333.126	12	14	3284.135	3945.000
6	9	7	23.541	321.817	298.276	16	12	2172.722	2624.000
7	6	7	9.063	624.399	615.336	6	24	6170.912	6559.000

ANALOG FRONTEND



Krummenacher circuit. Adapted from:

Transfer Function of CSA [Ballabriga, 2009]

$$H(s) = -K\frac{1-s\tau_{z1}}{(1+s\tau_{p1})(1+s\tau_{p2})}$$

$$\tau_{z1} = \frac{C_{Leak}}{G_{oikhalf}}$$

$$\tau_{p2} = \frac{2C_f}{G_{mFB}}$$

.

.

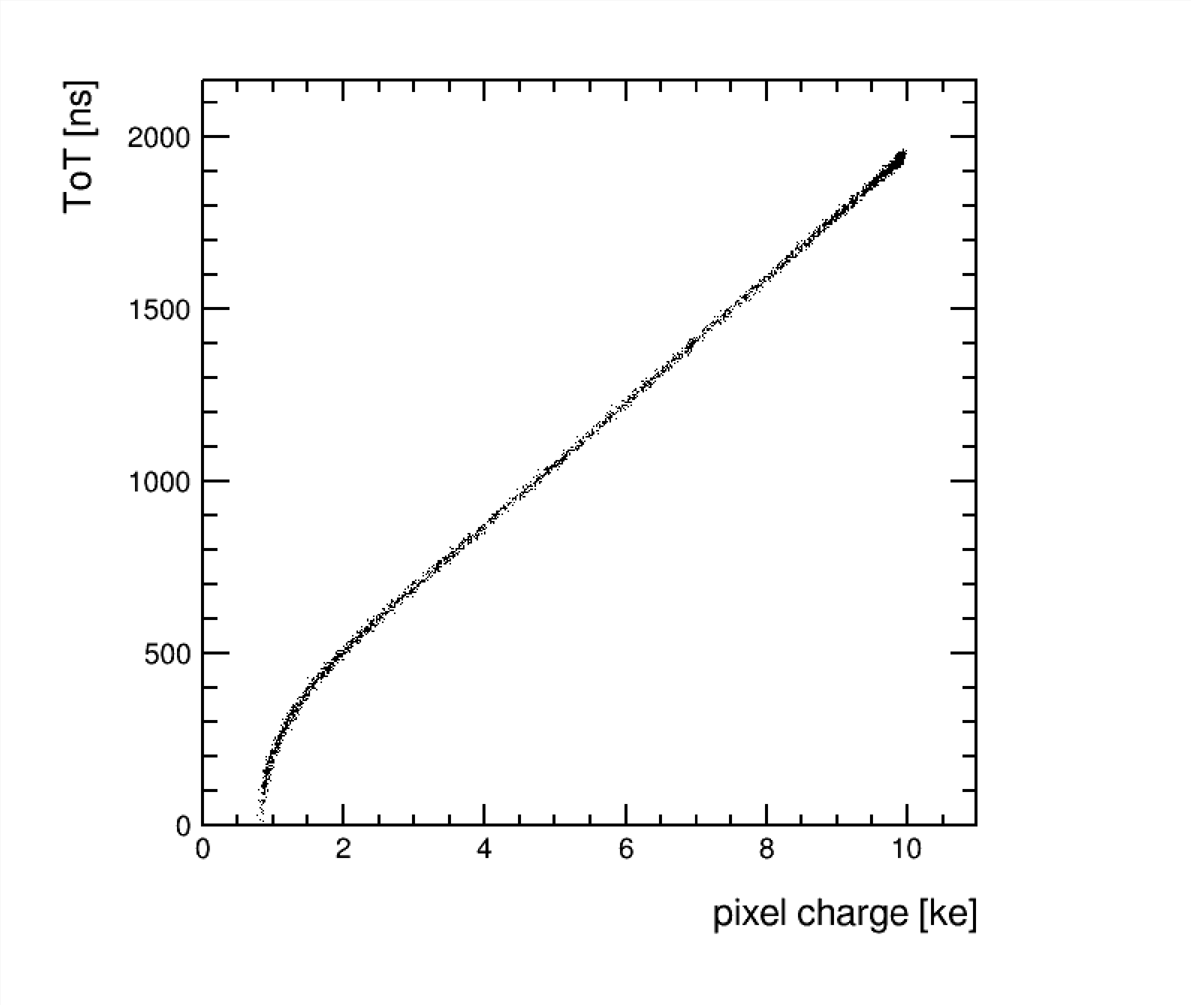
$$V_{out}(t) \propto e^{-\frac{t}{\tau_{p1}}} - e^{-\frac{t}{\tau_{p2}}}$$

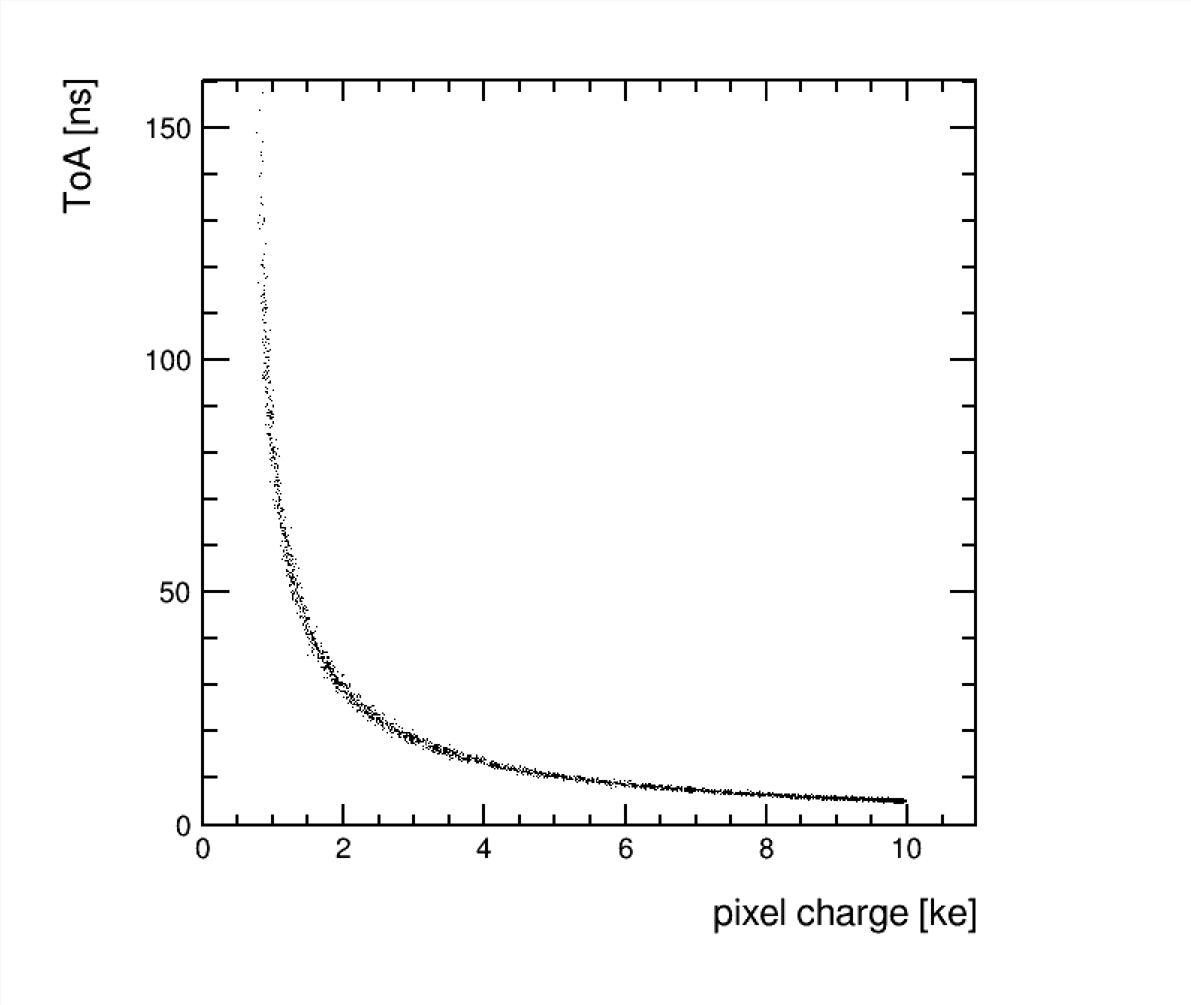
$$H(s) = \frac{R_f}{((1+\tau_f s)*(1+\tau_r s))}$$

$$\tau_f = R_f C_f$$

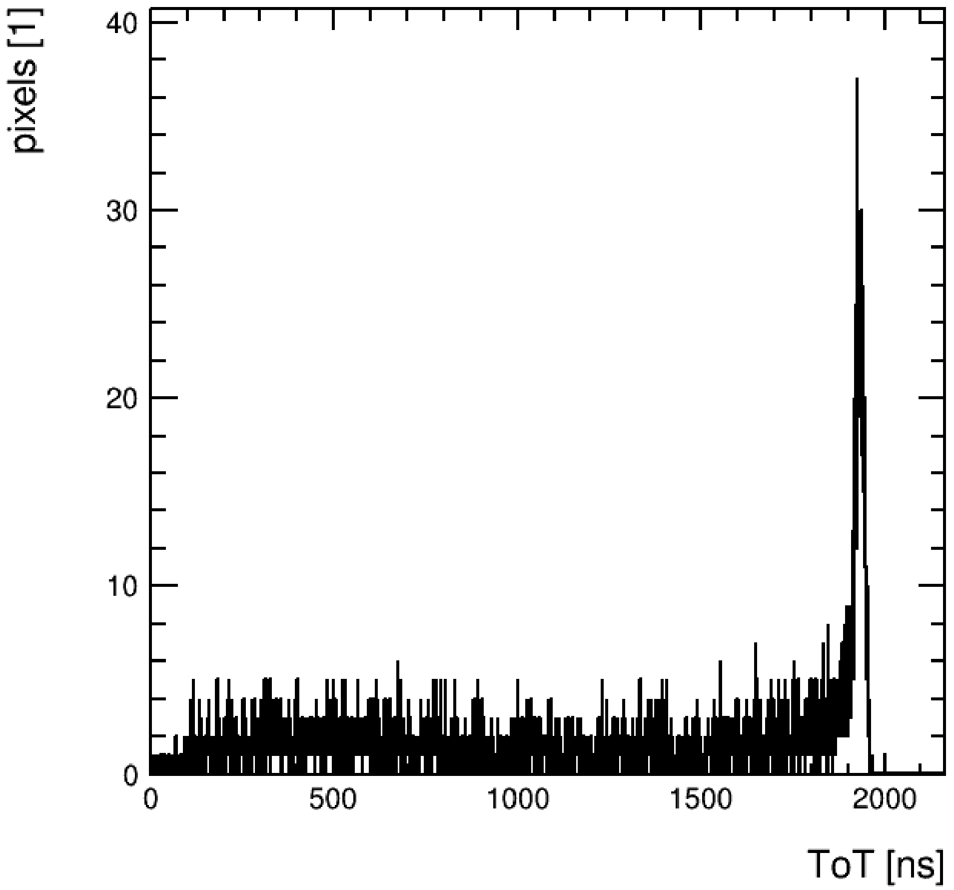
$$\tau_r = \frac{C_{det}*C_{out}}{g_m*C_f}$$

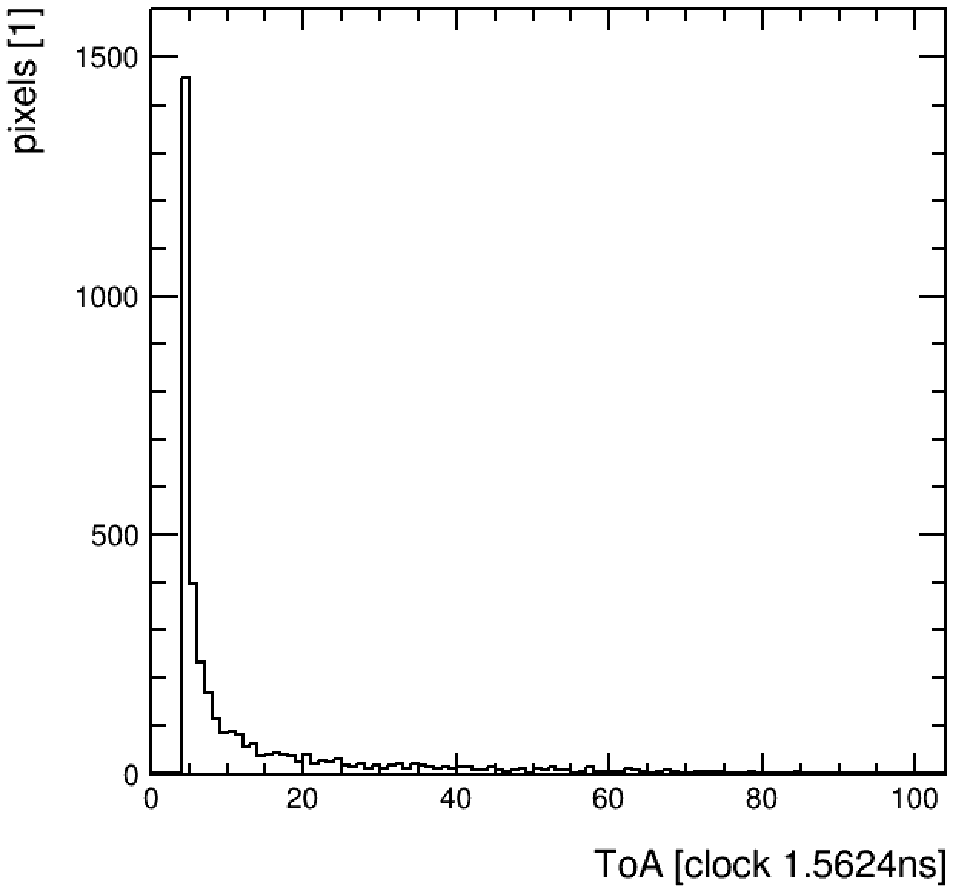
RESULTS: TOT AND TOA VS PIXEL CHARGE





RESULTS USING TPX DIGITIZER



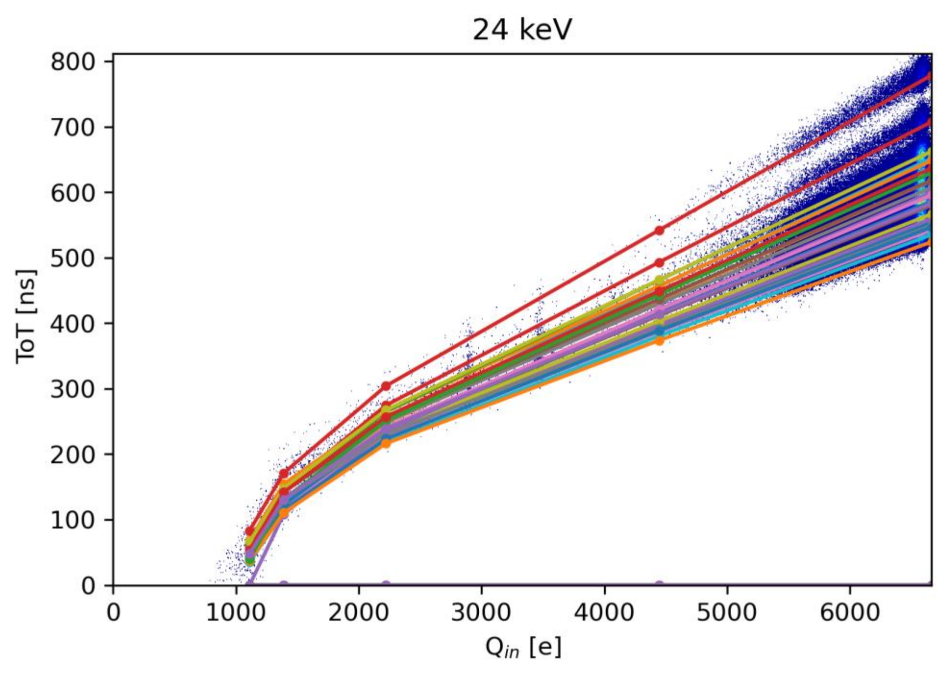


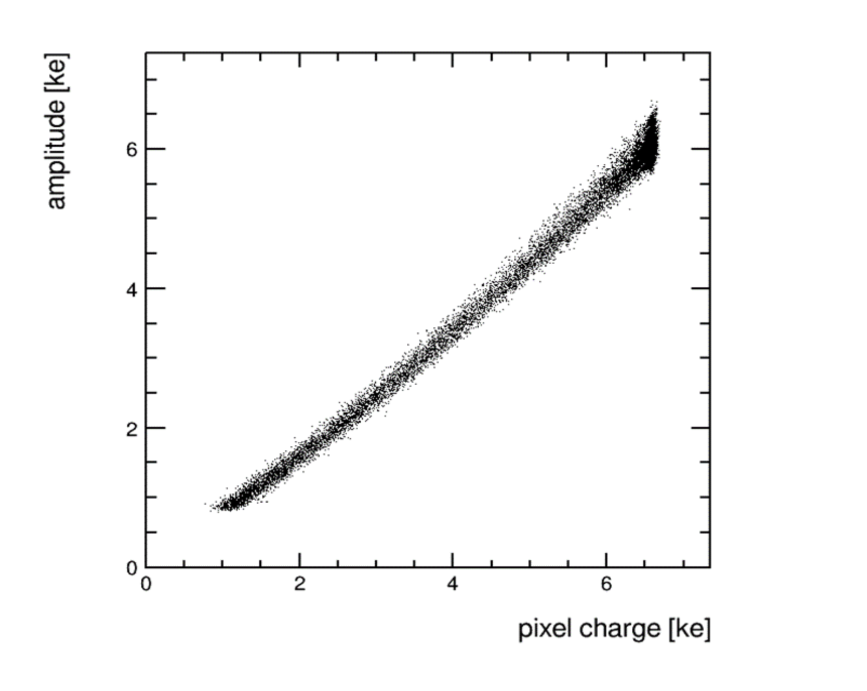
GAIN DISPERSION EXPLANATION

Need to adjust the gain in order to be sure that the charge output from the preamplifier is the same as the incoming charge.

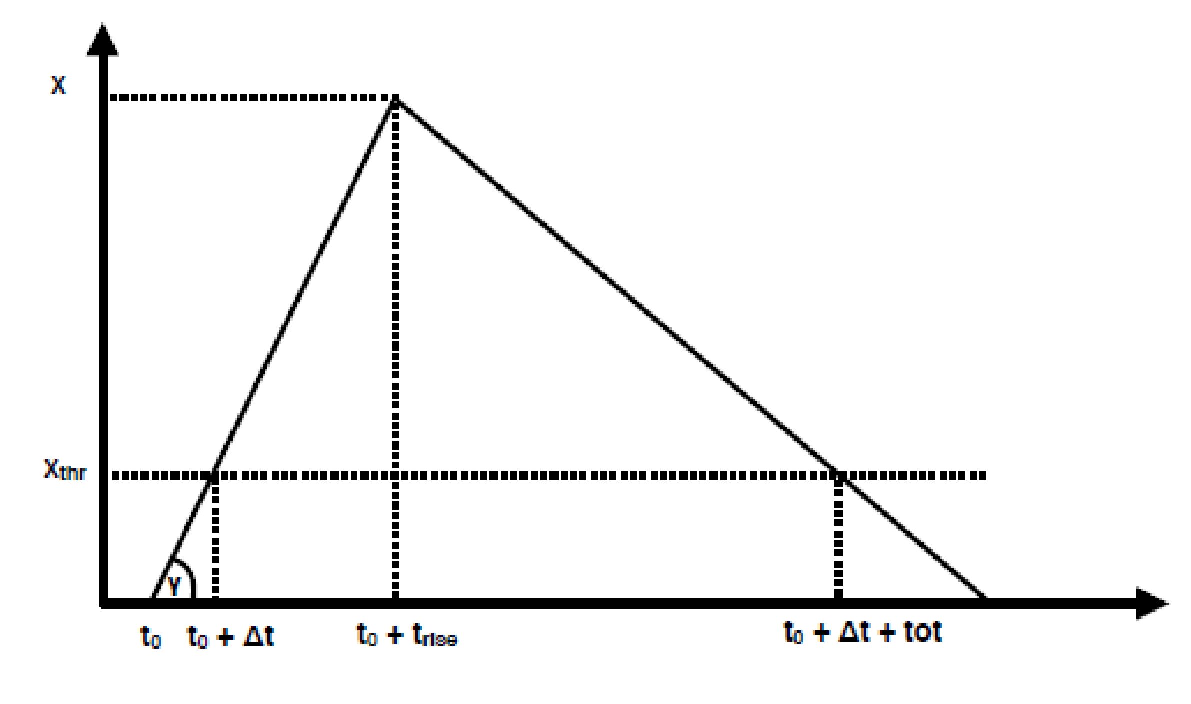
This is an example of not proper alignment (it is too low).

It is important to set the gain in a proper value to be sure that the threshold that we set (for example 750e) is implemented correctly!





EXPLANATION OF THE SURROGATE FUNCTION FOR THE ENERGY CALIBRATION



Sketch of the timewalk and time over threshold principle.

Adapted from: Time and Energy Calibration of Timepix3 Assemblies with Thin Silicon Sensors, F. Pitters,A. Nurnberg, M. Munker, D. Dannheim, A. Fiergolski, D. Hynds, X. L. Cudie, N.Tehrani, M.Williams,W. Klempt, S. Spannagel, 2018

- $tan\gamma = \frac{x_{thr}}{\Delta t} = \frac{x}{t_{rise}}$

$$\Delta t = \frac{c_0}{x' - c_1} + c_2$$

$$\text{tot} = \frac{c_0}{x' - c_1} + c_3 x' + c_4$$

However, the signal shape is not a perfect triangle!

- ❑The rising edge is not fully linear
- ❑The discharge already starts as soon as there is a potential difference across the CSA.