Threshold characterisation of the Medipix1 chip

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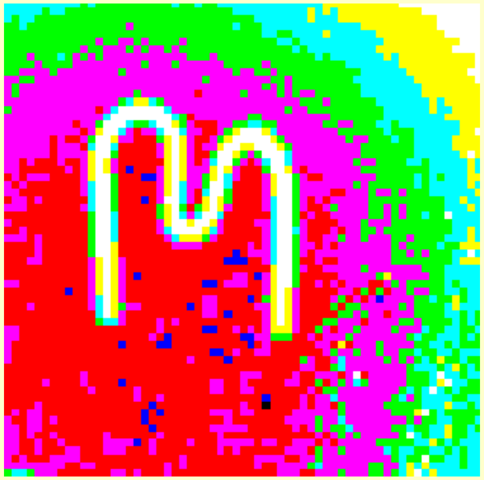
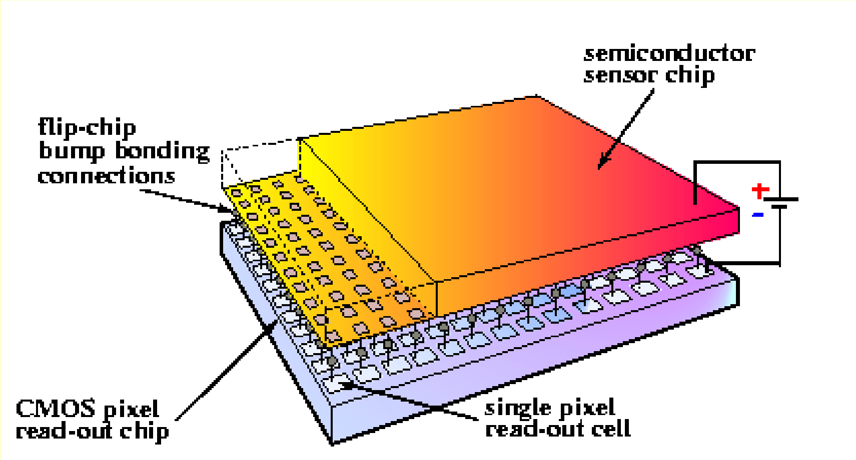


Overview

- Short description of the Medipix1 chip
- Standard mask generation with Medisoft
- New way to generate a mask by including the sensor material
- Properties of new mask and comparison with standard mask
- Simulation of noise characteristics of Medipix1 and comparison with measured values
- Conclusions

The Medipix1 chip

- Bump-bonded hybrid pixel detector; e. g. with a 300 μm Si layer as sensor material
- Single photon counting device



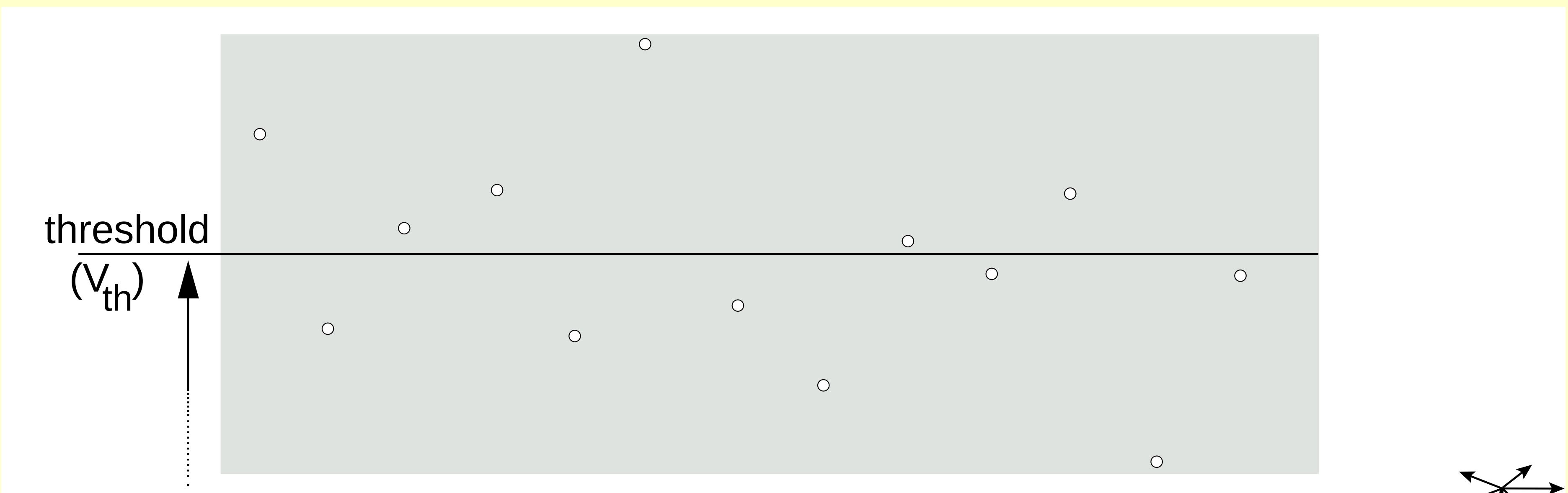
- 64×64 pixels with a size of 170×170 μm^2 each with 15 bit counter
- Energy sensitivity due to a global threshold (V_{th}) discriminating the charge generated by photons
- Threshold can be fine tuned for every pixel
  $\rightarrow$ equalisation over the whole chip is possible

Threshold equalisation

- Problem: due to fabrication tolerances the discriminators are not totally equal so the individual responses diverge

- Threshold of every pixel can be varied around the global threshold by 8 settings (3 bit)
  $\rightarrow$ distribution can theoretically be narrowed by a factor of 8

- Maximum range of the variations is controlled by a global parameter: adjustment range (V_{tha})



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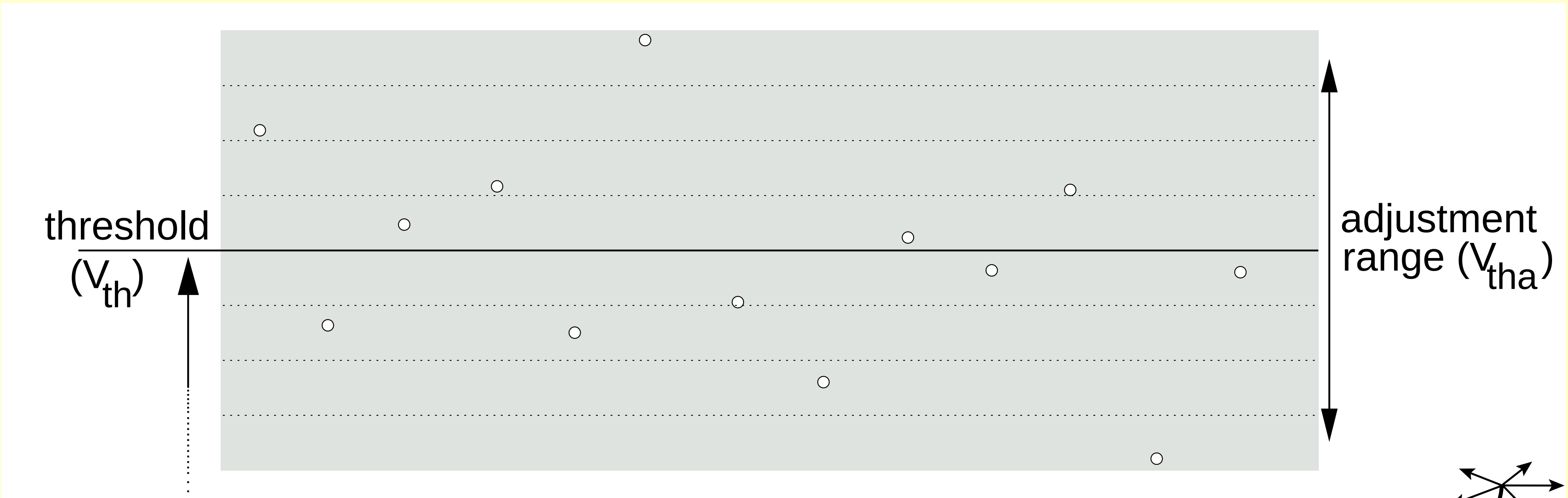

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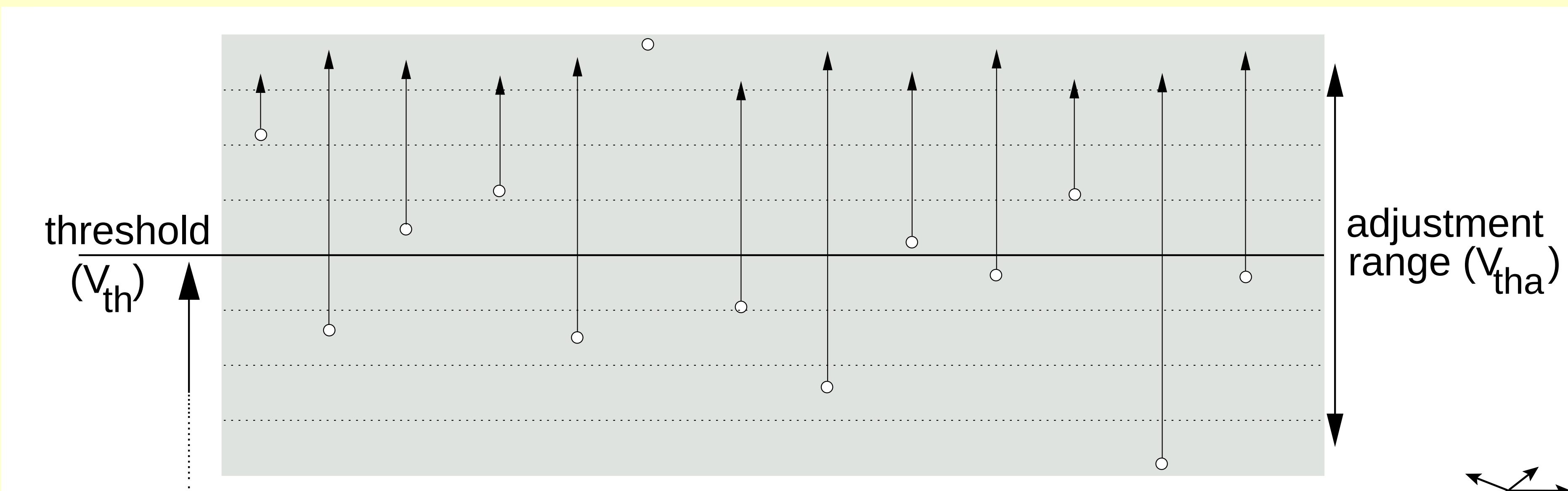

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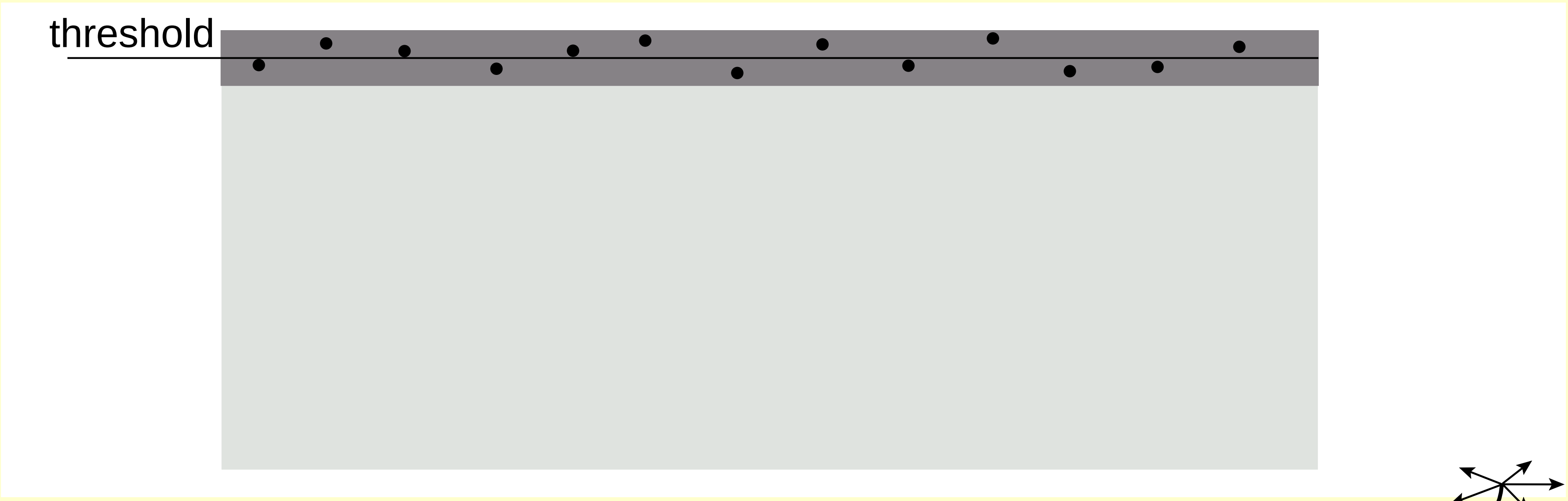
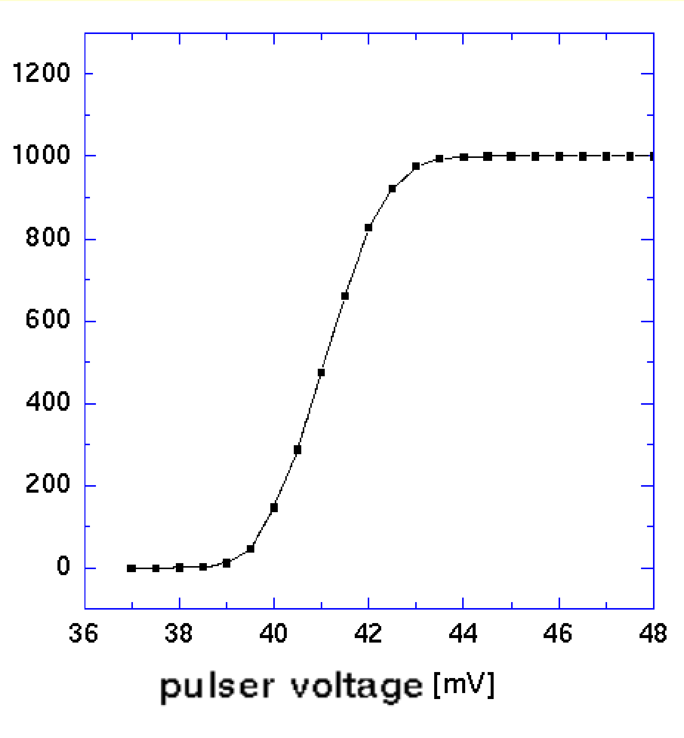


Electronic mask generation (I)

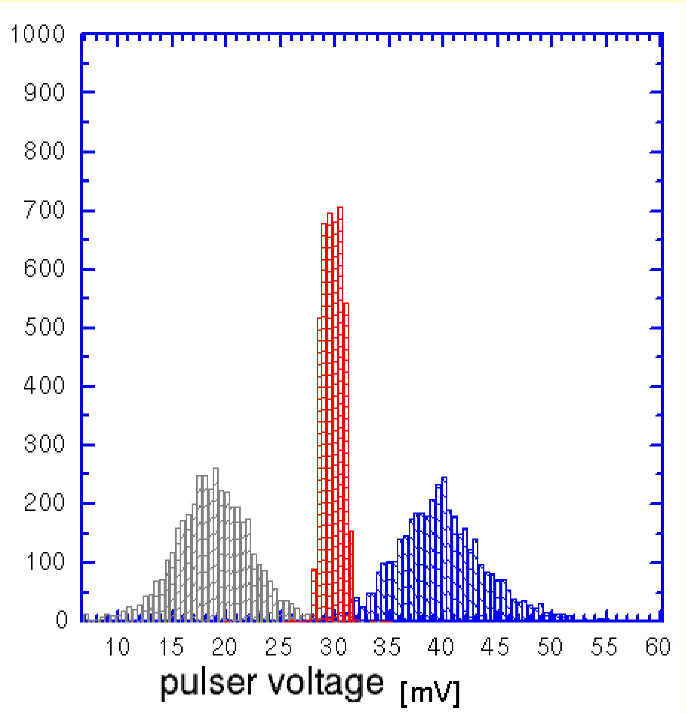
- Medisoft and MUROS can generate a "mask", which stores the necessary information per pixel to optimise for a desired threshold



- Different photon energies can be simulated by applying pulses with varying height to the test input of each pixel electronics

- A scan with the test pulse height yields response curve of every pixel

Electronic mask generation (II)



- Adjustment range has to be adapted to the width of the unadjusted threshold distribution

$\rightarrow$ 2 scans necessary:
without and with maximum correction

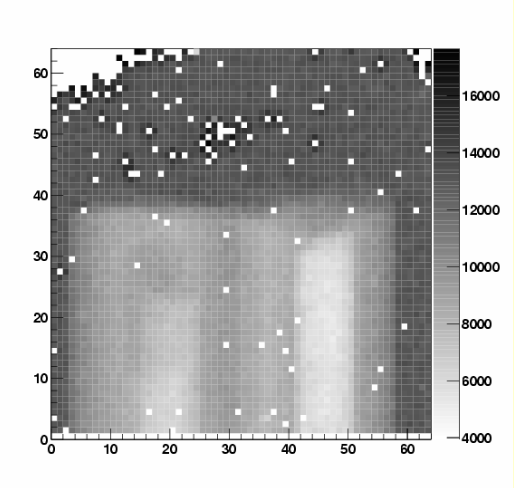
- Choose that bit setting for every pixel, which produces least threshold spread

- Distribution of the thresholds over whole chip is narrowed by a factor of $4-5$

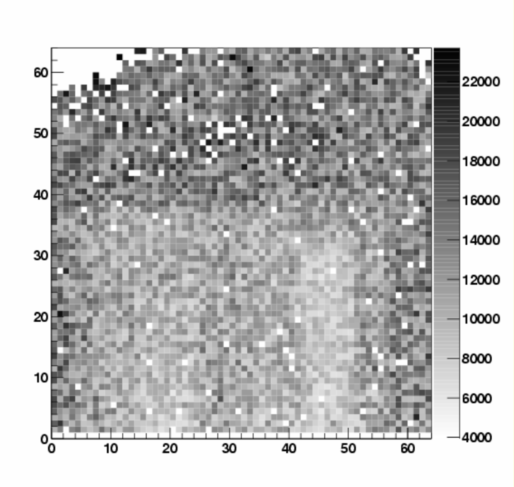
Limitations of the electronically generated mask

- Because of nonlinearities the mask is specific for the selected threshold
- Equalisation regards only the electronics, not the "physical frontend" (conversion layer and bump-bonds)
- Images are very noisy as soon as threshold is in the photon spectrum $\rightarrow$ What is the cause: bad frontend or mask?

$\rightarrow$ Generate a mask including the electronics and frontend by using X-ray photons: "absolute mask"



threshold below the photon spectrum

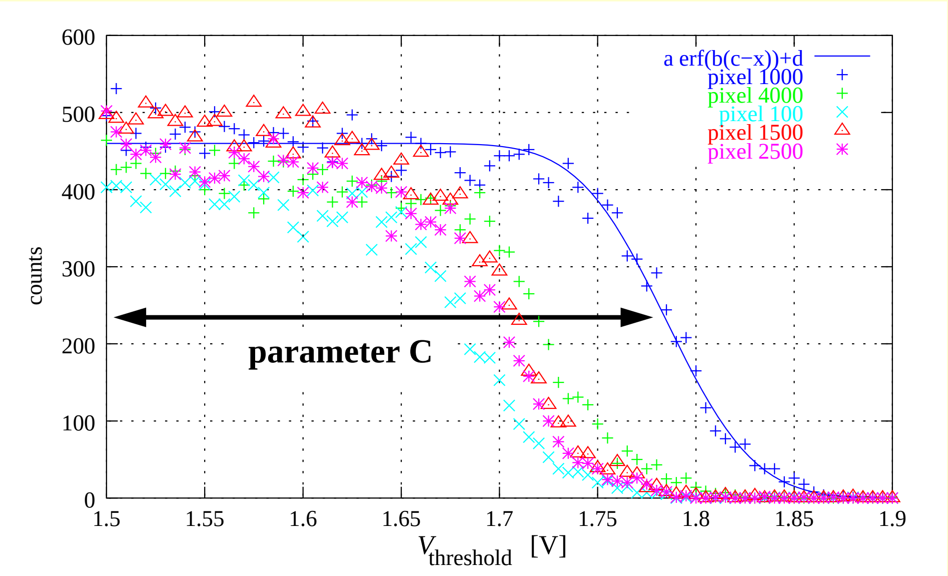


threshold inside of the photon spectrum

How to create an absolute mask (I)

- Thresholdscan with X-ray source: ^{109}Cd
  83 % of intensity at 22.1 keV, 17 % at 25 keV

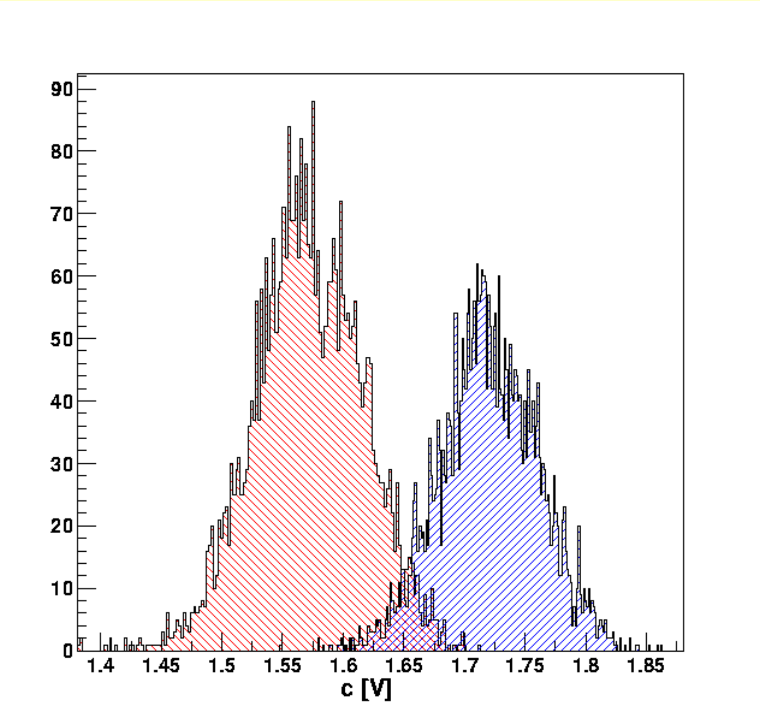
  Take images with different thresholds and plot the response of every pixel



- One would expect a superposition of two steps, but due to noise the response is smeared out
- Assume one error function and fit with $f(x) = a \cdot \text{erf}(b(c - x)) + d$
- Parameter c mirrors the individual response of each pixel to the incoming photon energy: reduce width of distribution

How to create an absolute mask (II)

- Measure influence of adjustment range (V_{tha}) on threshold by varying it with maximum correction
- Adapt adjustment range to width of unadjusted threshold distribution
- Thresholdscans for every adjust bit setting necessary
- Look up the best bit setting for every pixel to narrow the distribution

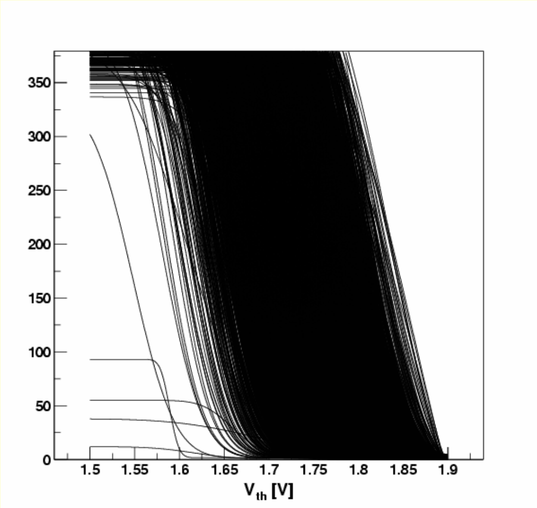


$\rightarrow$ Mask generation regarding the frontend is finished

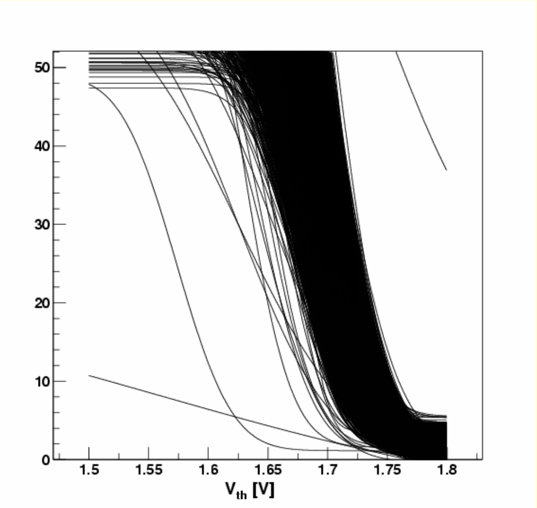
Threshold distributions before and after equalisation

- Graphs show fitted error functions for all pixels before and after the equalisation: spreading is obviously smaller
- Corresponding fit parameter c is still gaussian distributed with variation σ as a measure for the quality of the equalisation:

$$\frac{\sigma_{\text{before}}}{\sigma_{\text{after}}} = 4.53$$



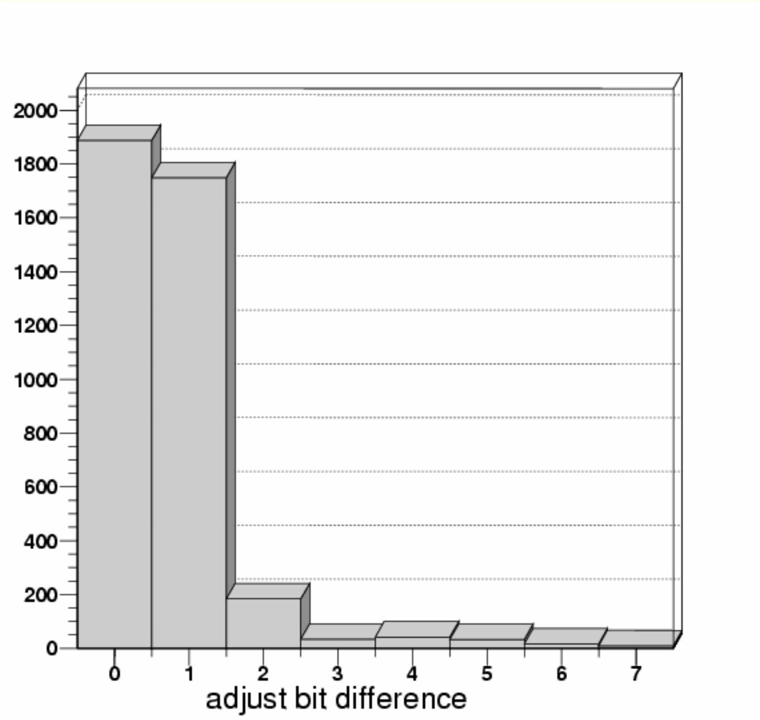
before equalisation: $\sigma = 0.0403$



after equalisation: $\sigma = 0.0089$

Comparison of masks – bit settings

- Histogram the pixelwise difference of electronically generated mask and absolute mask
- Almost 50 % of the pixels have identical setting
- Less than 10 % differ by more than one



→ Main reason for different response of pixels is not the frontend: it is the spread of the response of pixel electronics that cannot be completely corrected

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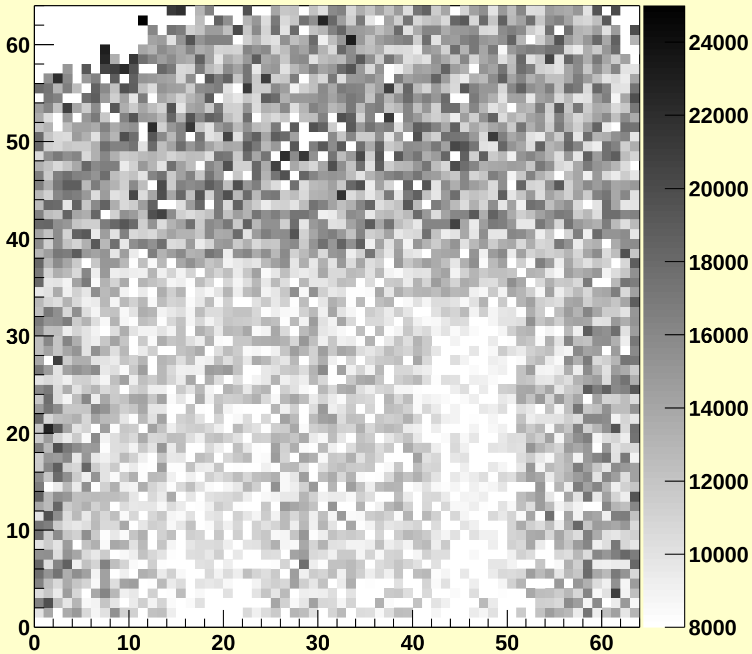
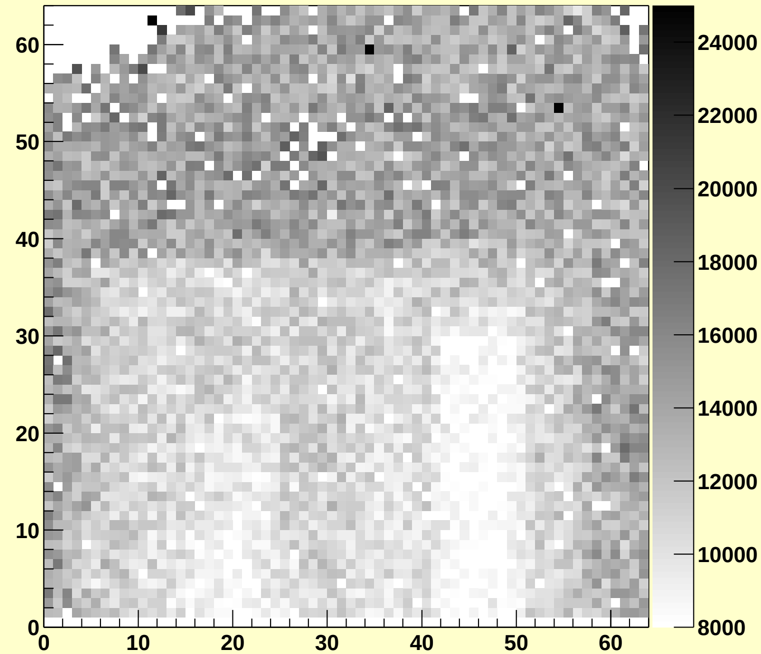
Comparison of masks – image quality



with electronically generated mask



with absolute mask

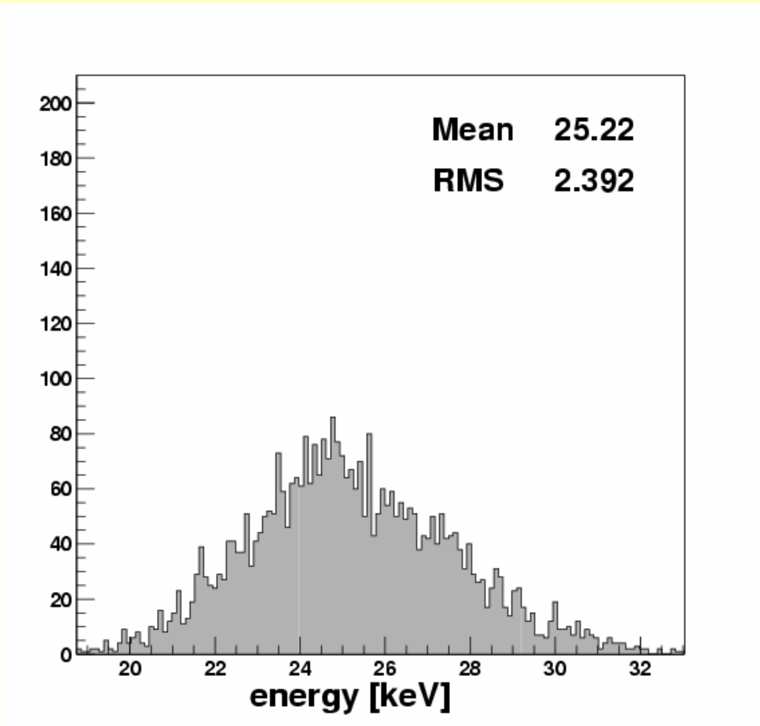
Different way of generating the absolute mask has an obvious impact on the image quality

$\rightarrow$ Difference in settings are small but important

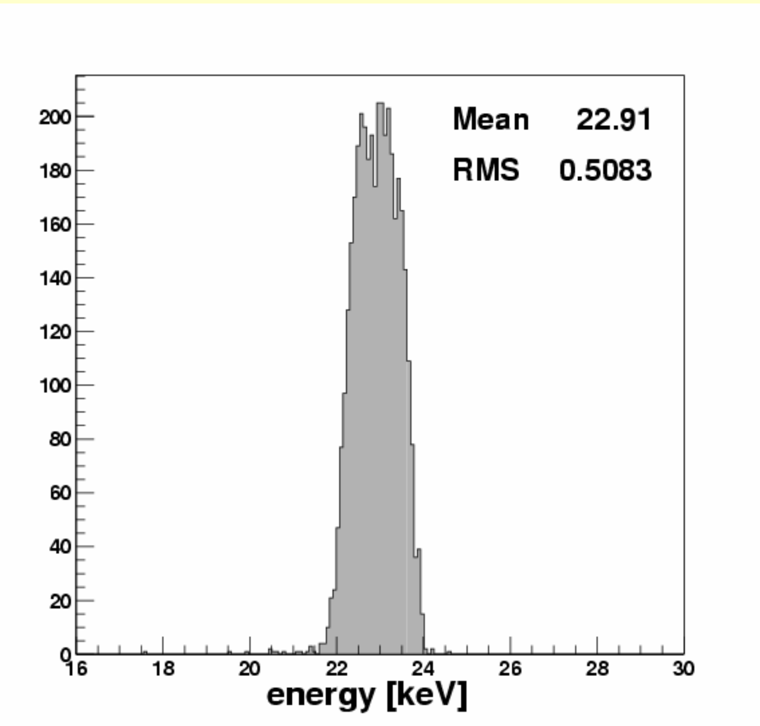
Properties of absolute mask

- New way of generating a mask with almost same results:
  - Distribution of thresholds narrowed by 4 − 5, but still $\pm$ 1 keV

$\rightarrow$ Images are still noisy when threshold is inside spectrum



parameter c without adjustment



parameter c with adjustment

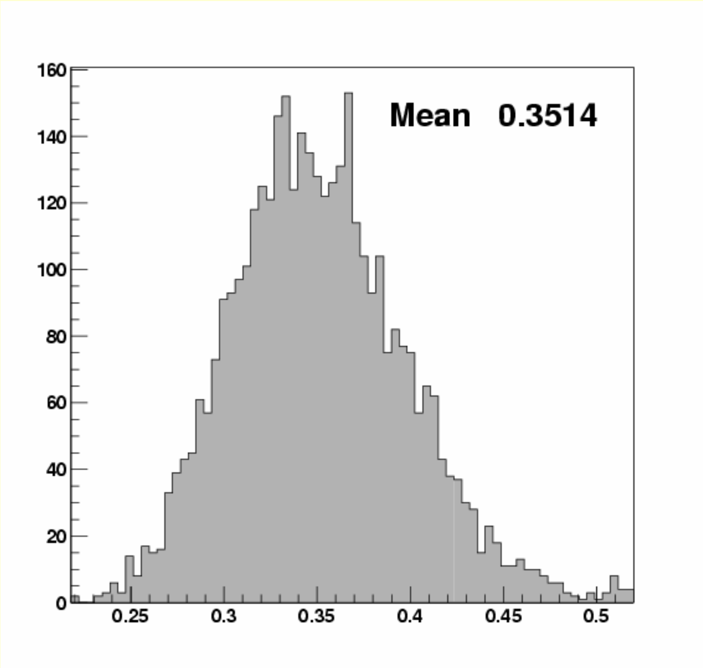
Simulations on the electronics noise

- Two causes for decrease of image quality:
  - Time invariant gaussian distributed pixel thresholds: adjusted to $\pm$ 1 keV
  - Gaussian gain noise from preamplifier in each pixel electronics

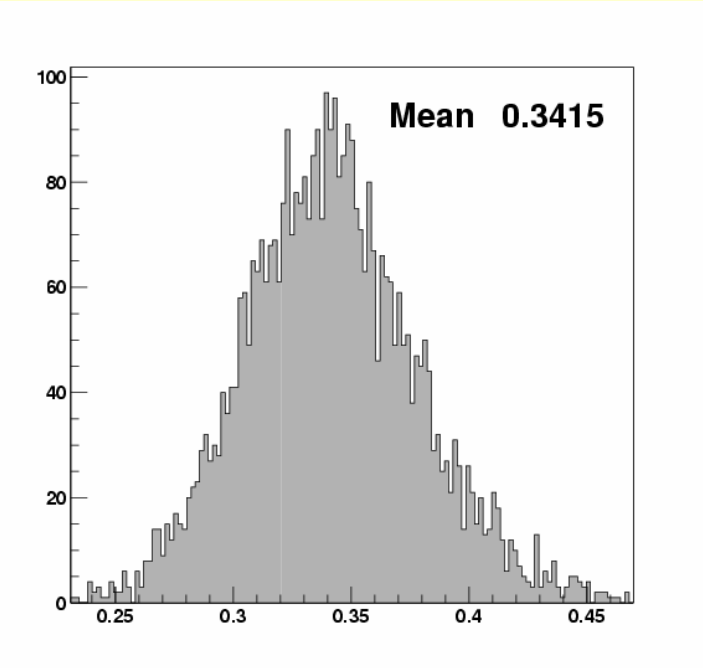
- Simulations including the frontend to find magnitude of noise in keV (ROSI):
  - Thresholdscans with ^{109}Cd source analogue to measurement
  - Threshold spread: gaussian distributed $\pm$ 1 keV
  - Gaussian distributed gain noise with different widths
  - Fit data with $f(x) = a \cdot \mathrm{erf}(b(c-x)) + d$ and compare with results from measurement
  - Slope of error function is characterised by parameter b

Results of simulations

- Best match of parameter c to measured data when electronics noise varies $\pm$ 3.2 keV
- Model of gaussian distributed noise is confirmed
- Magnitude of noise corresponds to previously measured values



parameter b – measured



parameter b – simulated

Conclusions

- Mask generation with X-ray source regards the whole chip: electronics and physical frontend (conversion layer and bump-bonds)
- Frontend is not the reason for poor image quality when threshold is inside of X-ray spectrum
- Electronic noise ($\approx \pm 3\,\mathrm{keV}$) decreases the possibility of taking energy resolved images
- Hopefully less noise and nonlinearities in Medipix2
  $\rightarrow$ Improved image quality

Thanks to . . .

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Medipix Collaboration

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[2]CERN