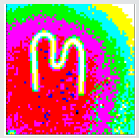
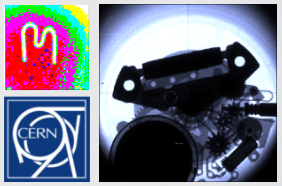


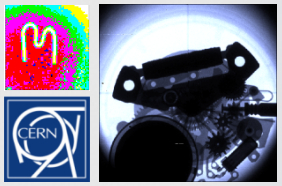
ENERGY RESOLUTION OF TIMEPIX AND MEDIPIX3

G. Blaj, R. Ballabriga



Overview

- Ideal vs. real detectors – THL scans
- Timepix results
- Medipix3 (SPM, CSM) results
- Conclusions



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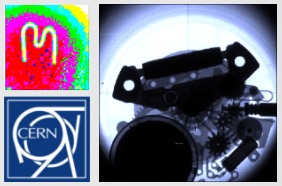
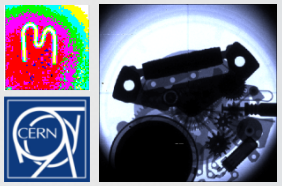


Spectral Measurements

- The ideal energy dispersive detector (for *e.g.*, EDXRF):
  - Stability (time, temperature, radiation damage, …)
  - High Q.E. over a wide energy range
  - Zero read-out time, zero pile-up *etc.*
  - Infinite dynamic range
  - Unlimited energy resolution (common: ~160 eV)
  - No charge sharing / incomplete charge collection
  - No sensor fluorescence / escape peaks



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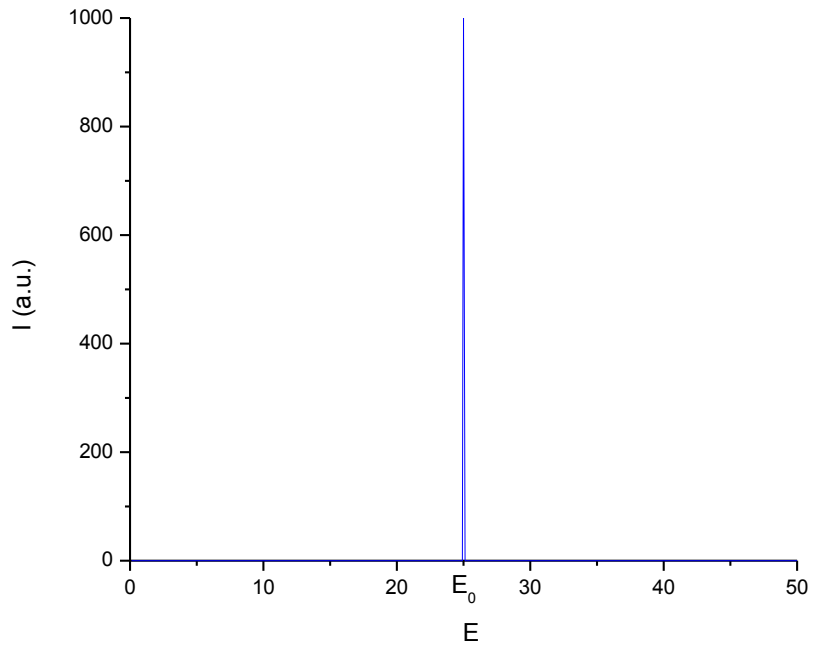
Ideal detector

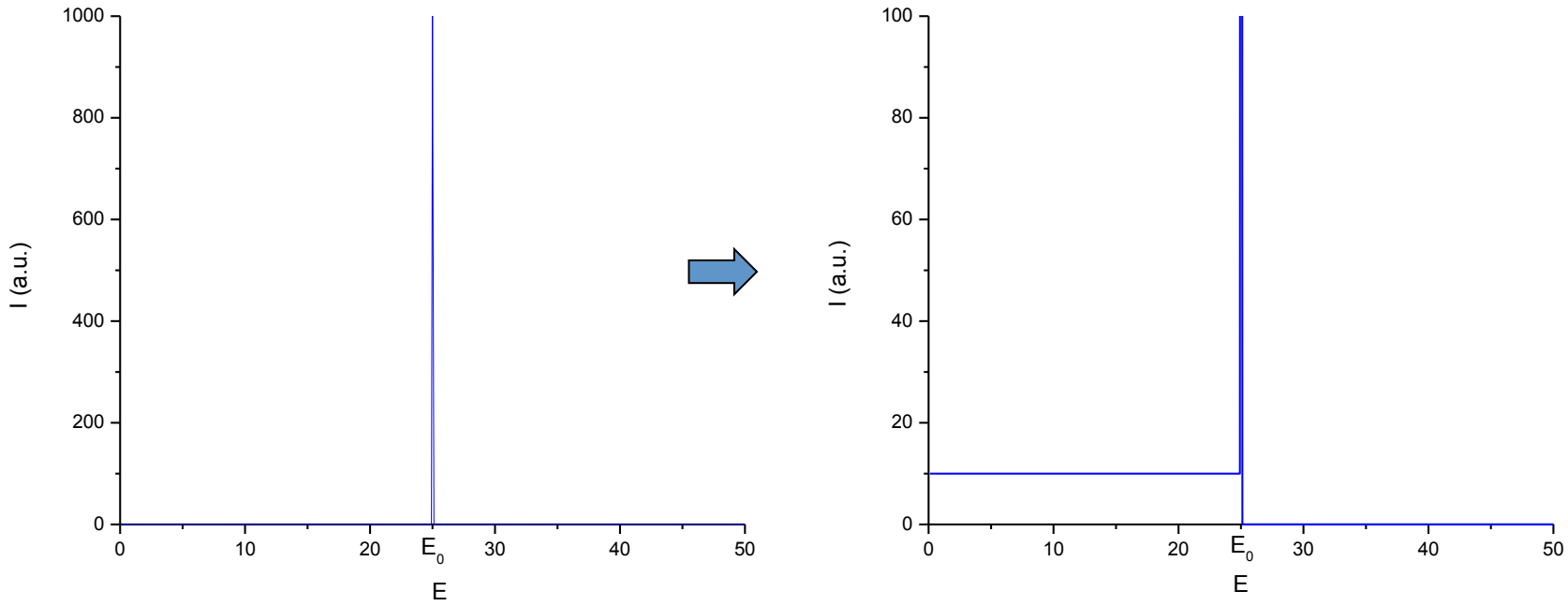
- Spectrum of monochromatic radiation (E_0) using an ideal detector (σ=0):
  - $\delta(E-E_0)$ function



Less ideal detectors: incomplete charge collection…

- Spectrum of monochromatic radiation (E_0) using an ideal detector (σ=0):
  - $I(E) = \delta(E-E_0)$

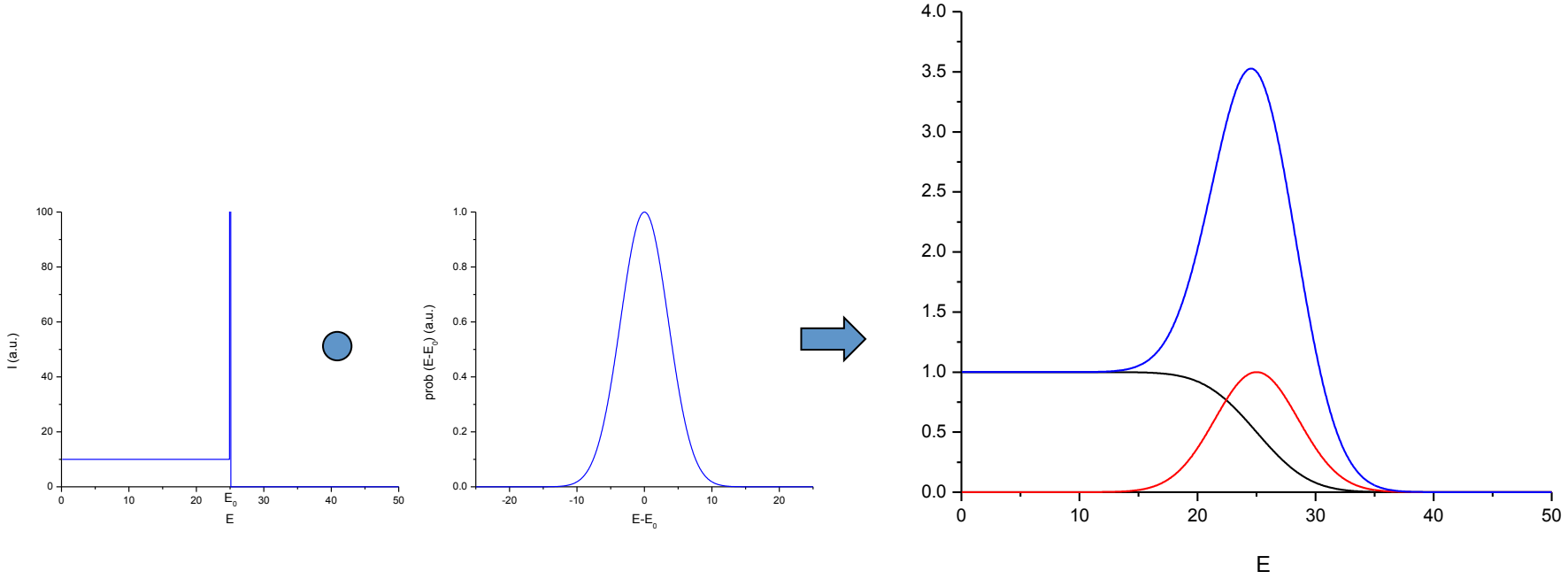
- Charge sharing (f):
  - $I(E) = f * H(E_0-E) + (1-f) * \delta(E-E_0)$



Less ideal detectors: energy resolution…

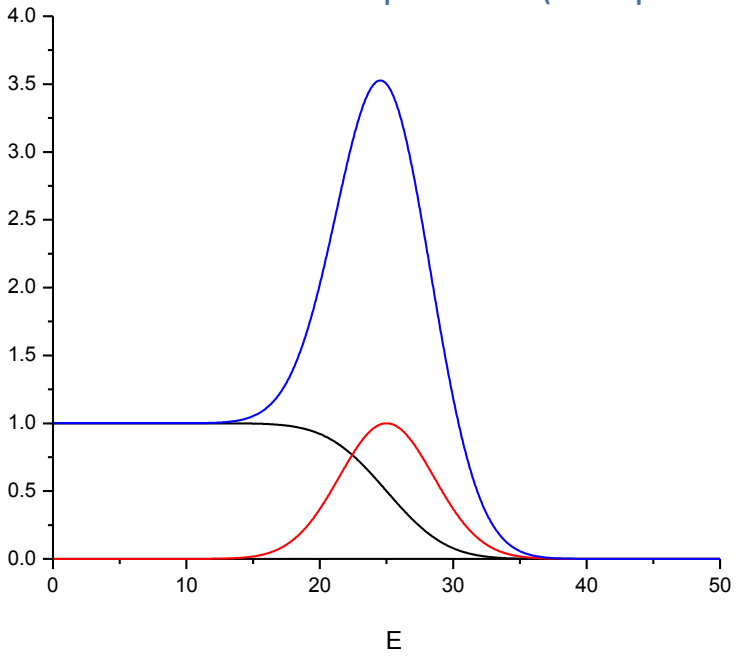
- Charge sharing (f):
  - $I(E) = f * \mathbf{H}(E_0-E) + (1-f) * \delta(E-E_0)$
- Charge sharing **o** Detector resolution (σ):
  - $I(E) = [f * \mathbf{H}(E_0-E) + (1-f) * \delta(E-E_0)]$ o **Gauss**$((E-E0)/\sigma)$

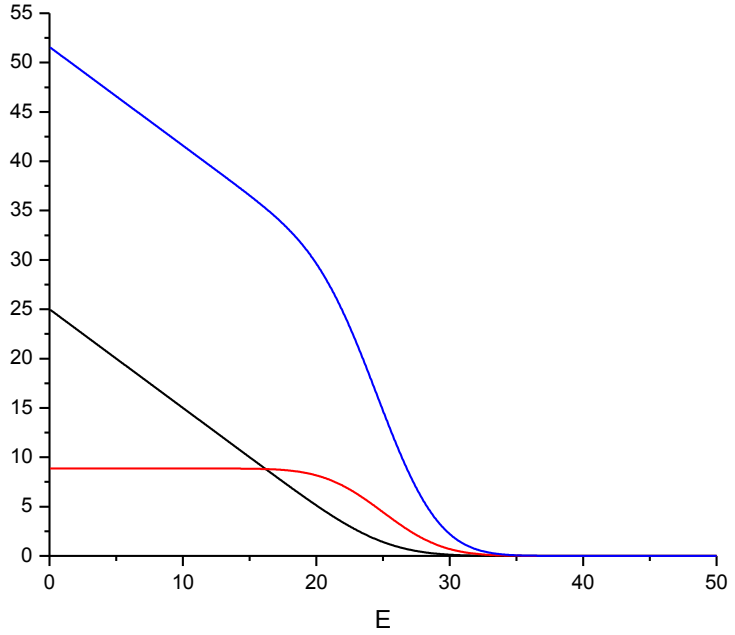
    $= f * [1-\mathbf{erf}((E-E0)/\sigma)]/2. + (1-f) * \mathbf{Gauss}((E-E0)/\sigma)$



Less ideal detectors: cumulative spectra (THL scans) …

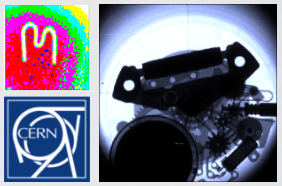
- Spectrum:
  - I(E) = f * [1-**erf**((E-E0)/σ)]/2. + (1-f) * **Gauss**((E-E0)/σ)
- Cumulative spectrum:
  - $$I(E) = \int_{E}^{+\infty} \left[\frac{f}{2} * \left(1 - erf\left(\frac{x - E_0}{\sigma}\right) \right) + (1 - f) * Gauss\left(\frac{x - E_0}{\sigma}\right) \right] * dx$$
  - Medipix detectors: cumulative spectra (THL scans)
    - Derivative: spectrum (but quite noisy)





Real spectra

- Monochromatic radiation:
  - $$I(E) = \int_{E}^{+\infty} \left[\frac{f}{2} * \left(1 - erf\left(\frac{x - E_0}{\sigma} \right) \right) + (1 - f) * Gauss\left(\frac{x - E_0}{\sigma} \right) \right] * dx$$
- Multiple energies present:
  - $$I(E) = \sum_{j=0}^{E_0} I_j(E_j)$$
- Slow but quite robust and accurate



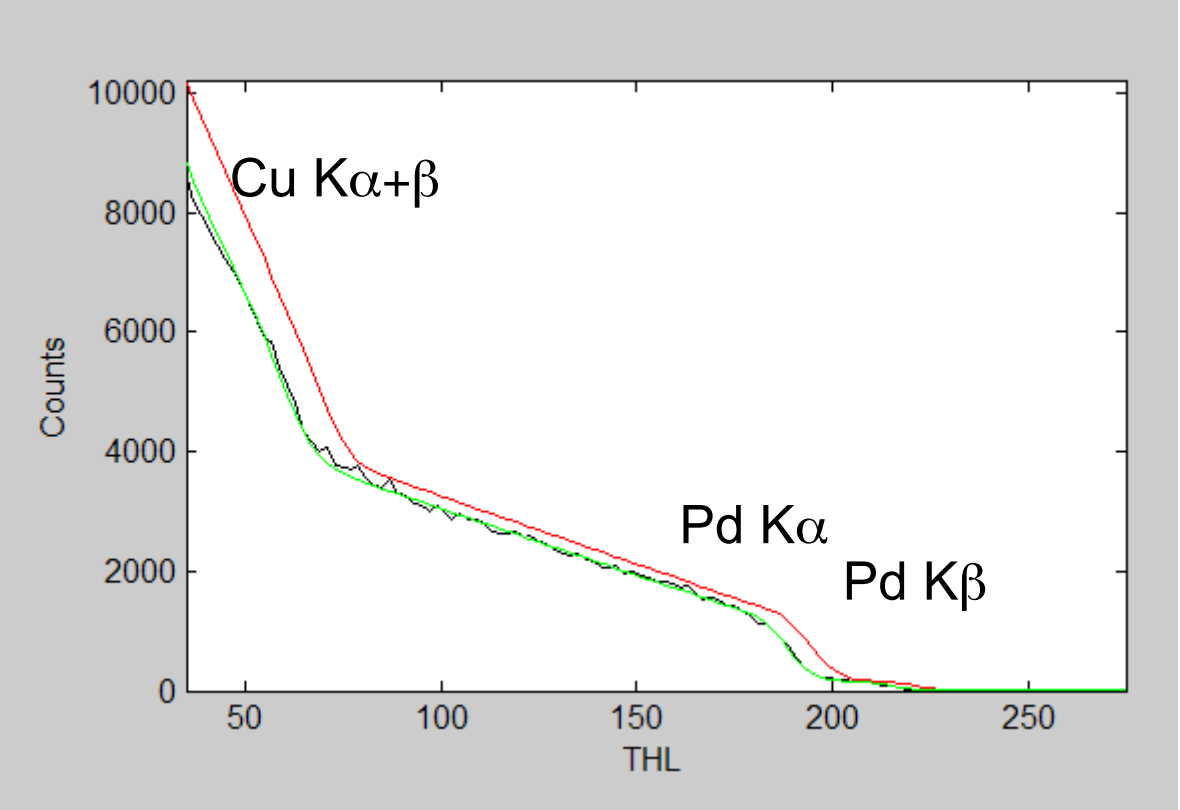
Real Spectra: Cu x-ray tube, fluorescence targets

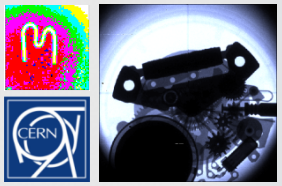
- X-ray tube: Cu anode, ~1.8 kW
  - 45 kV, 40 mA or 50 kV, 35 mA
  - (PANalytical X'pert Pro MRD)
- Fluorescence targets: Pd, Cd, In
- Medipix3 and Timepix detectors, USB interface
- Spectra:
  - Bremstrahlung (up to 50 keV)
  - (Compton scattering, diffraction, …)
  - Characteristic anode and target fluorescence lines

Material	Z	Ka (keV)	Kb (keV)
Cu	29	8.040	8.904
Pd	46	21.121	23.815
Cd	48	23.106	26.091
In	49	24.136	27.271

Typical THL scan

- **Typical THL scan**
  - **Single pixel scan (black) (Medipix3, Pd target)**
  - **Single pixel scan Fit (green)**
  - **Average scan Fit**





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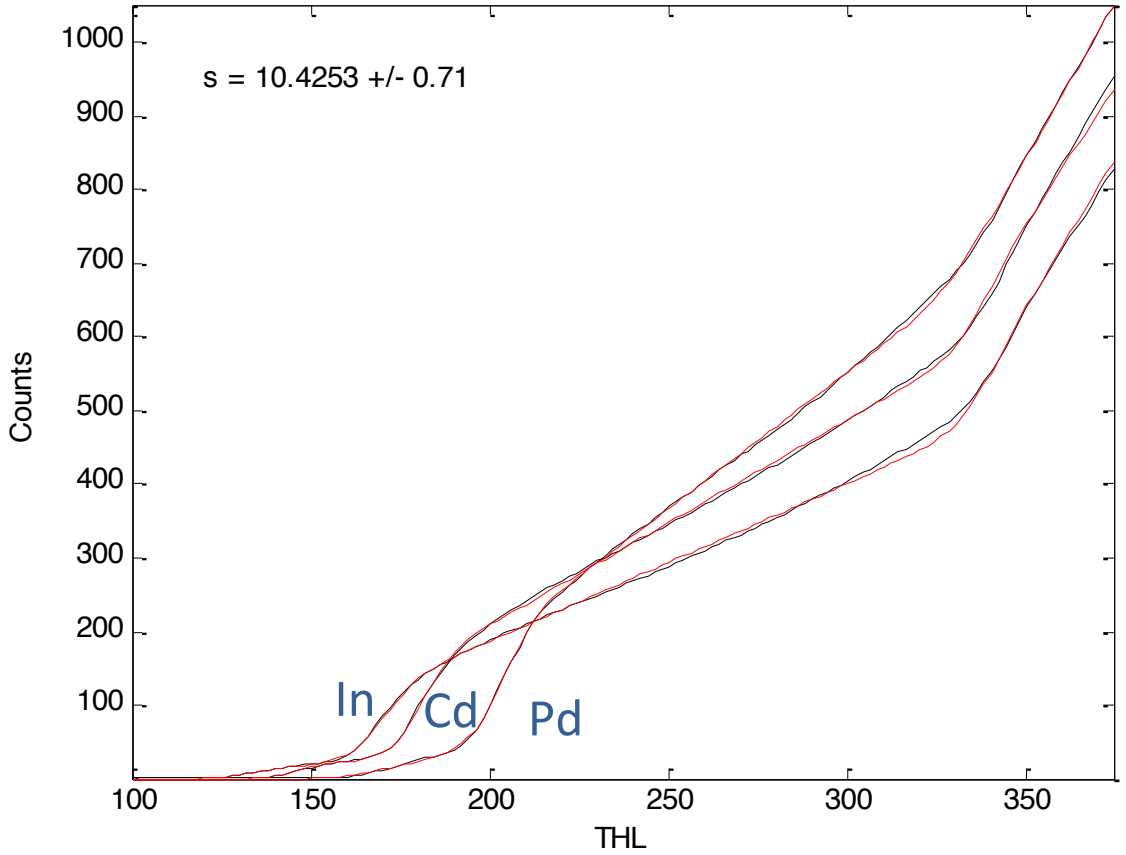
Timepix (Counting): Average scans

- Settings
  - Timepix (counting)
  - 45kV, 40mA
  - THL step 2
  - 4s / step

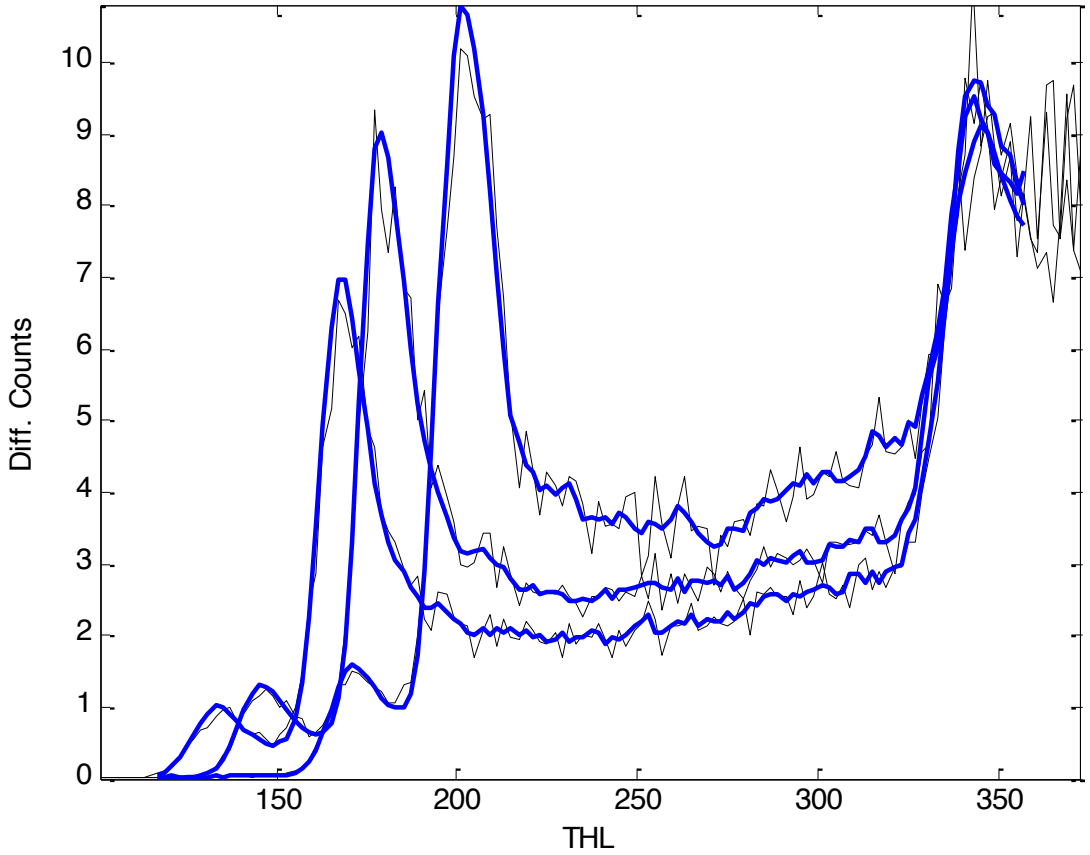
- Black: Average THL scans
- Red: Fit
- σ=10.43 +/- 0.71 THL steps

- However, individual pixel scans: offset!



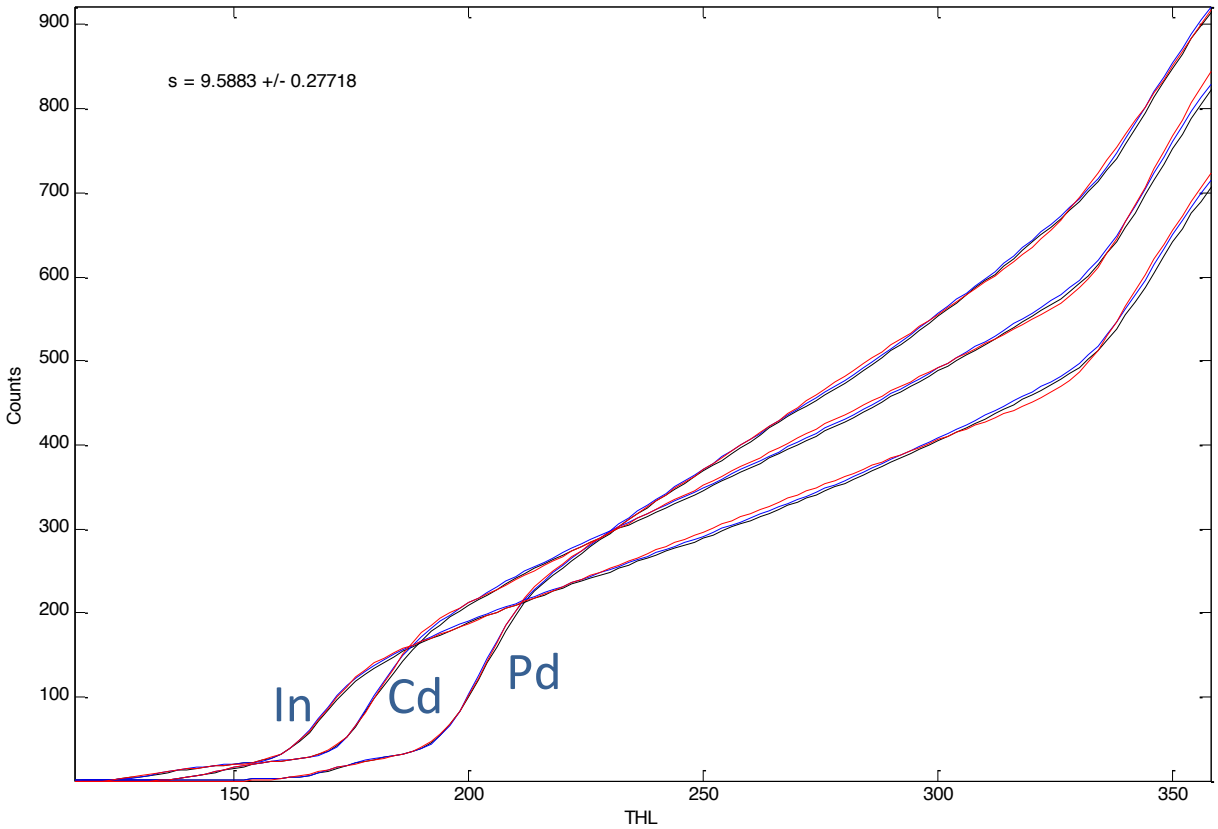
Timepix (Counting): Average spectra

- Differential threshold scans (black) appear noisy
  - Shutter timing?
  - Instability?
- This noise is reduced by aligning individual pixel scans
  - By shifting pixels, the systematic deviations at each threshold are spread out
  - Peak widths are slightly smaller*



Timepix (Counting): Average aligned scans

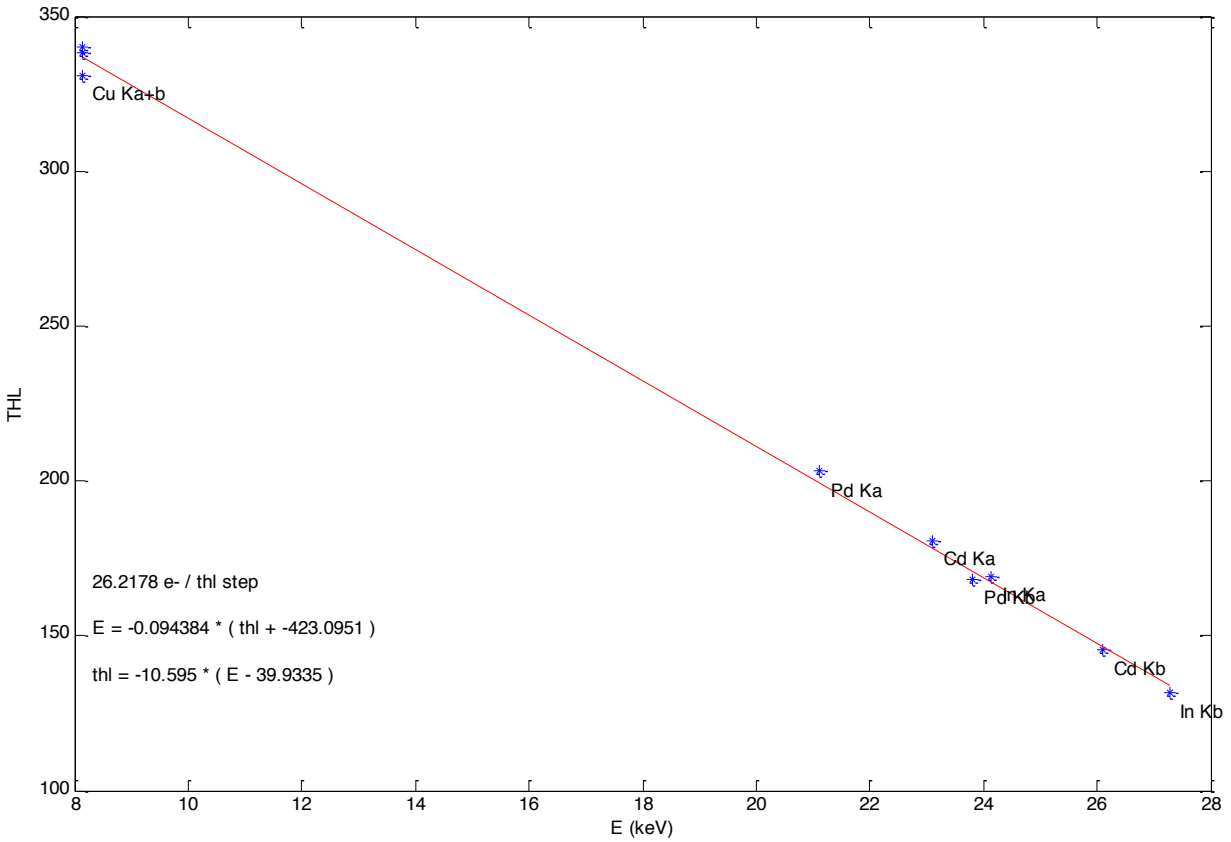
- Fit average of aligned scans:
- Slightly better energy resolution: σ=9.59+/-0.28 THL steps
  - Compared to σ=10.43 +/- 0.71
  - Most likely, measurements with better statistics will improve this difference



Timepix (Counting): THL – energy correspondence

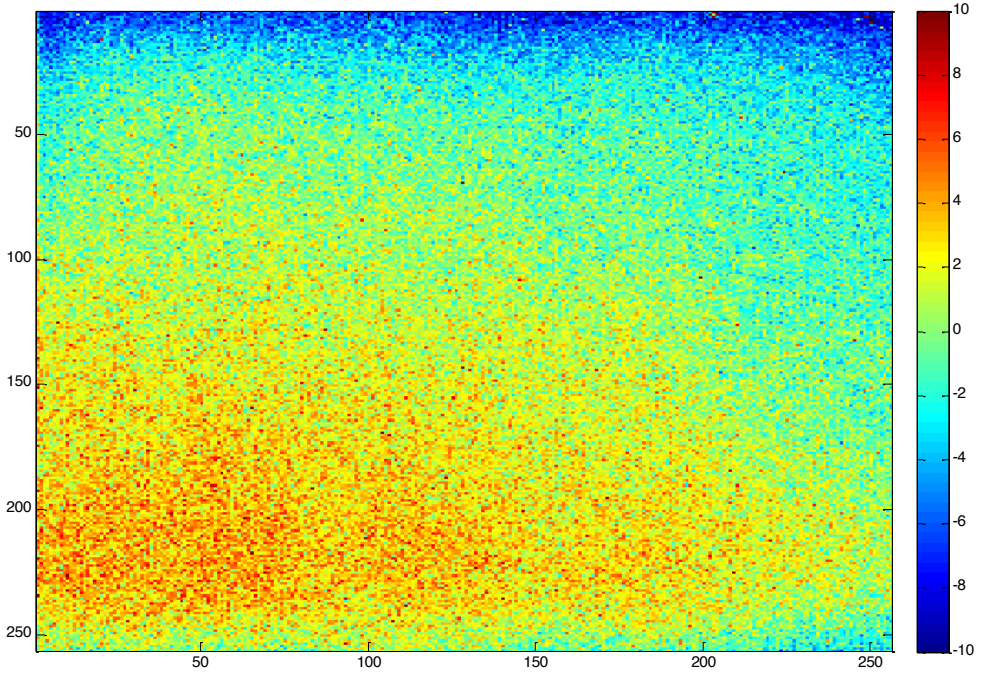
- Linear fit: peak thresholds = f (peak energies)

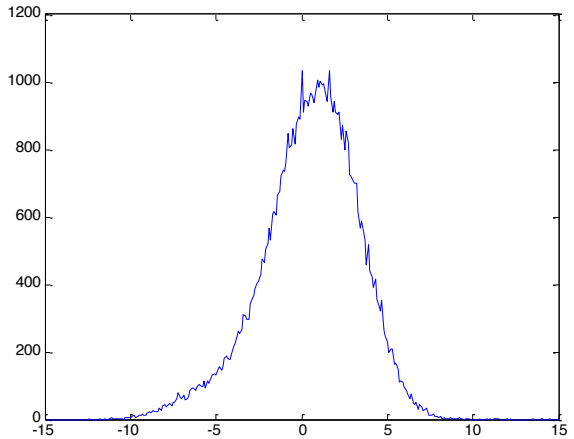
- ~26 e^- / THL step
- ~94 eV / THL step
- σ=9.59+/-0.28 THL steps



Timepix (Counting): THL Offset distribution

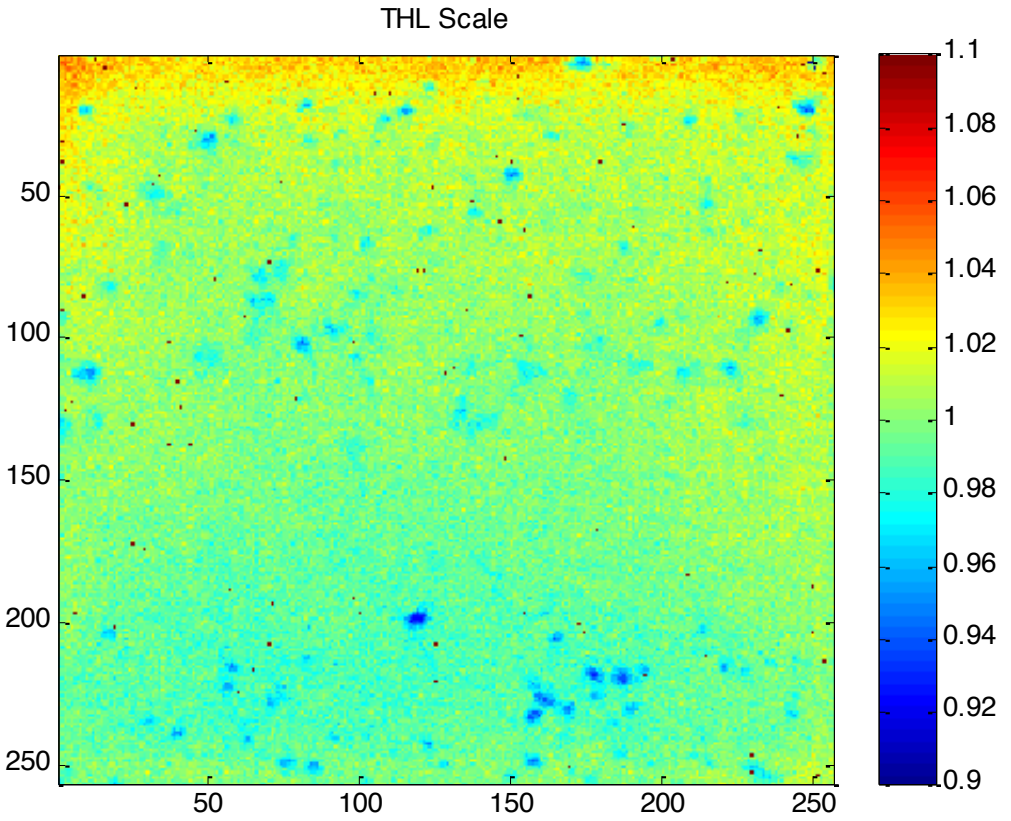
- Gradient across the matrix
- Top: read-out periphery
- σ = 2.85 THL steps





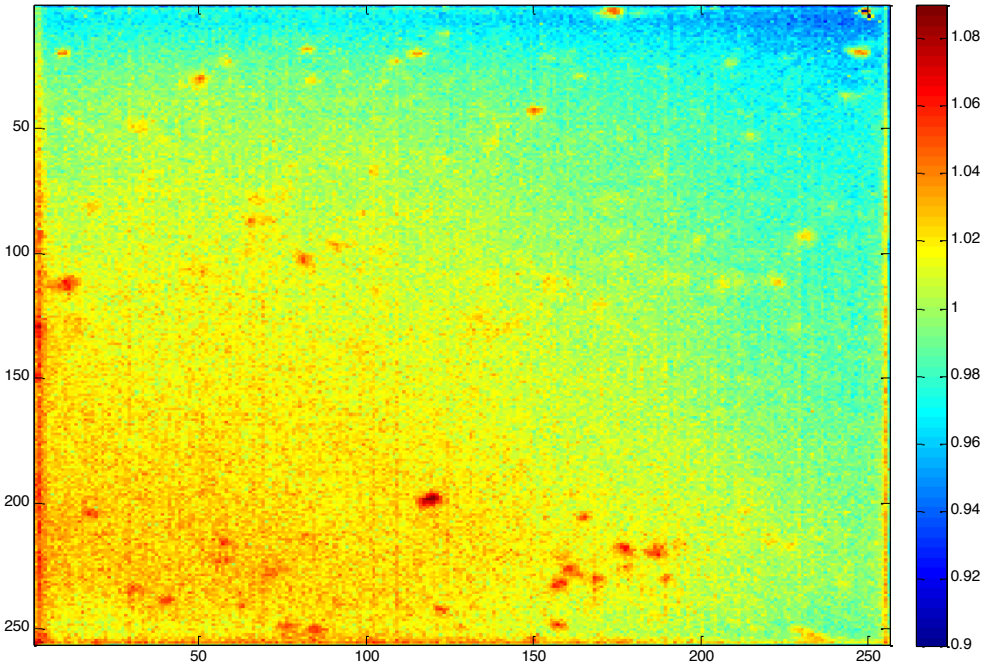
Timepix (Counting): THL Scale (Gain) distribution

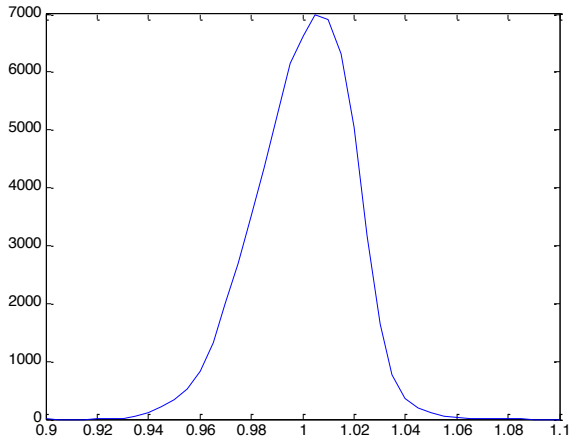
- Gradient across the matrix
- Top: read-out perifery
- Diffraction spots!



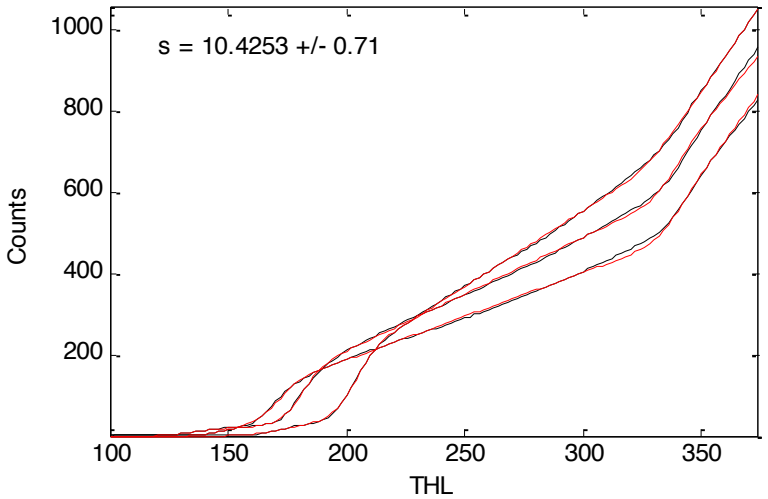
Timepix (Counting): I scale distribution

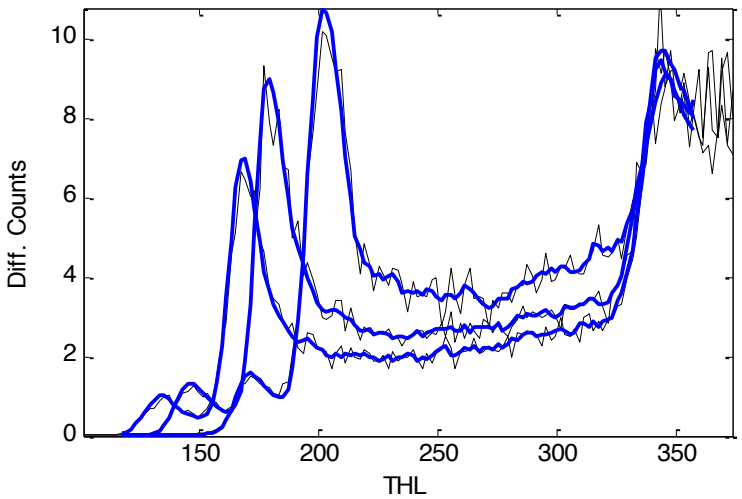
- Gradient across the matrix
- Vertical lines
- Top: read-out perifery
- σ = 1.9%
- Diffraction spots!

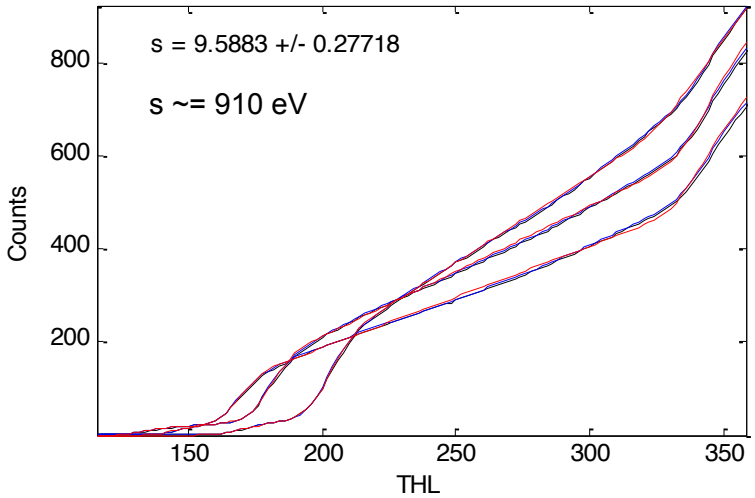


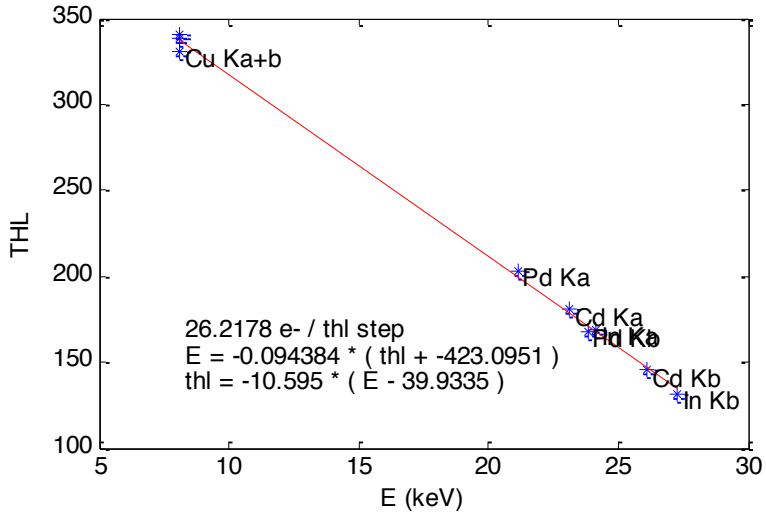


Timepix (counting)
THL Scans

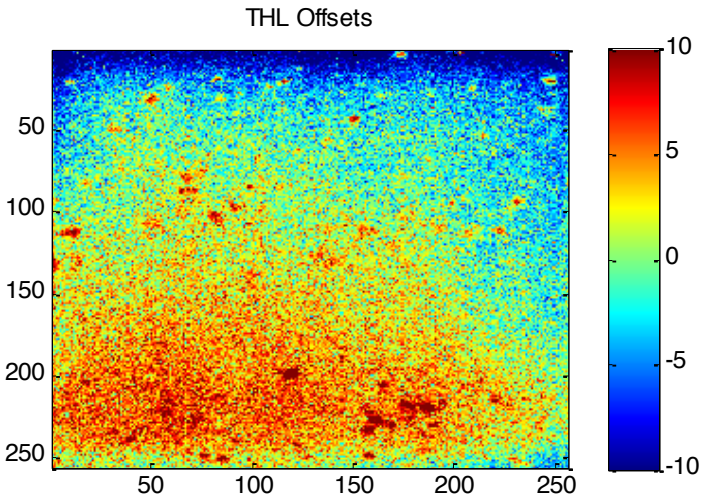


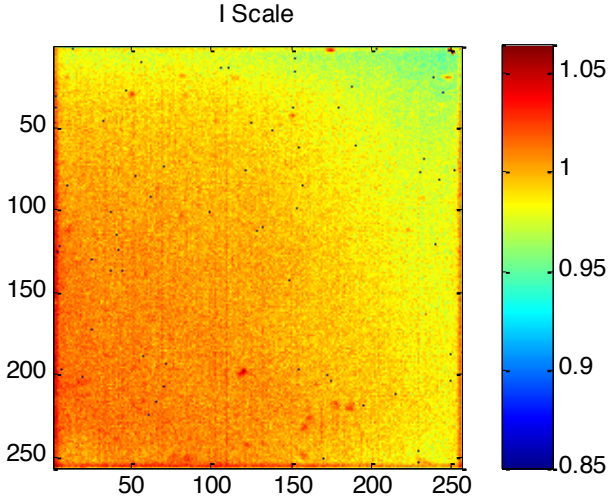


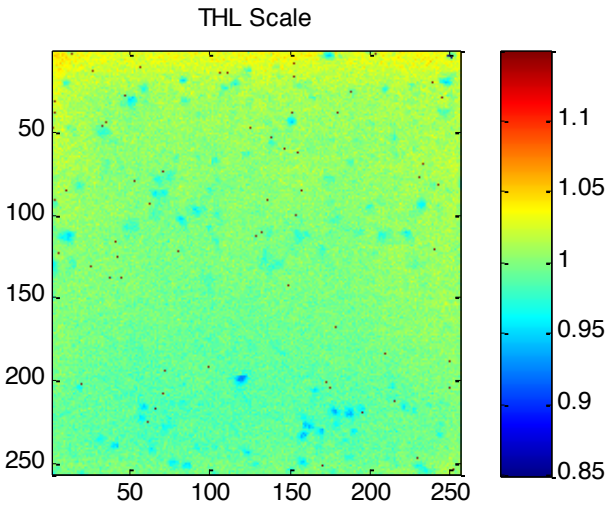


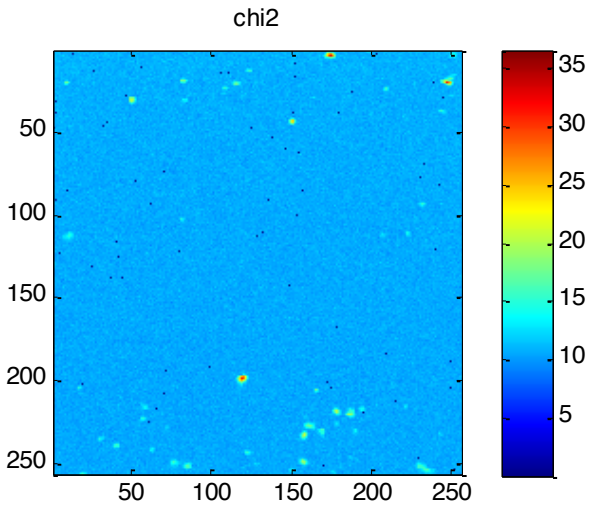


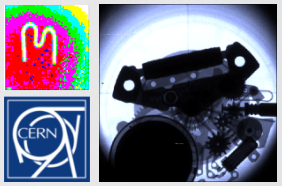
Timepix (counting)
Offsets, Scaling Factors











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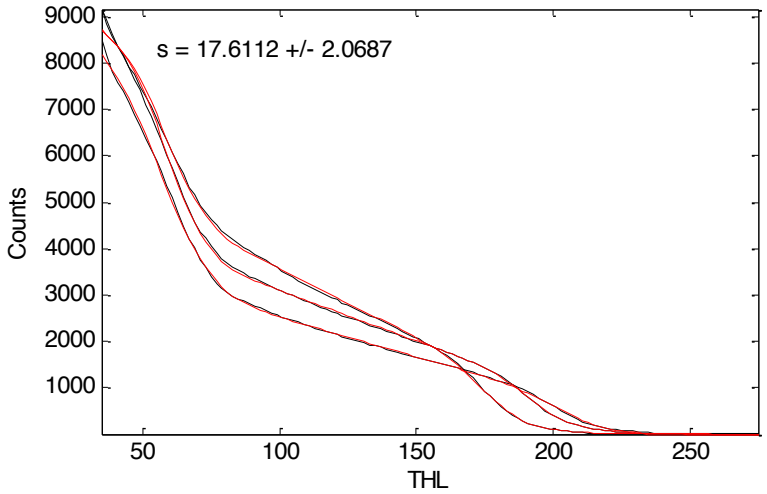
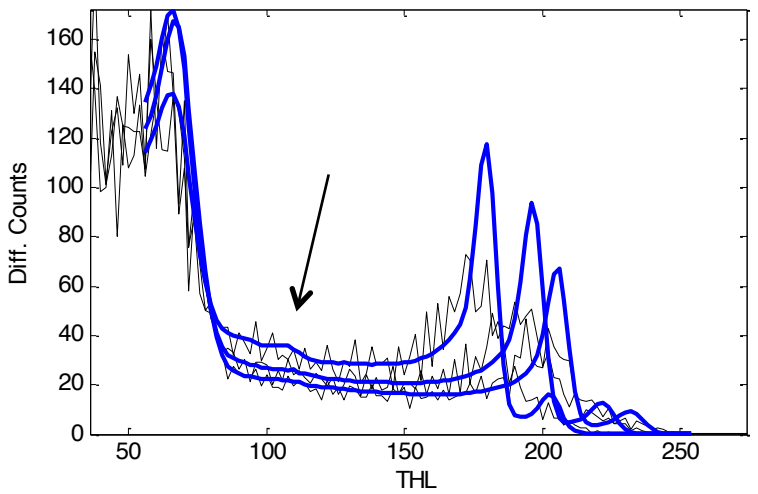
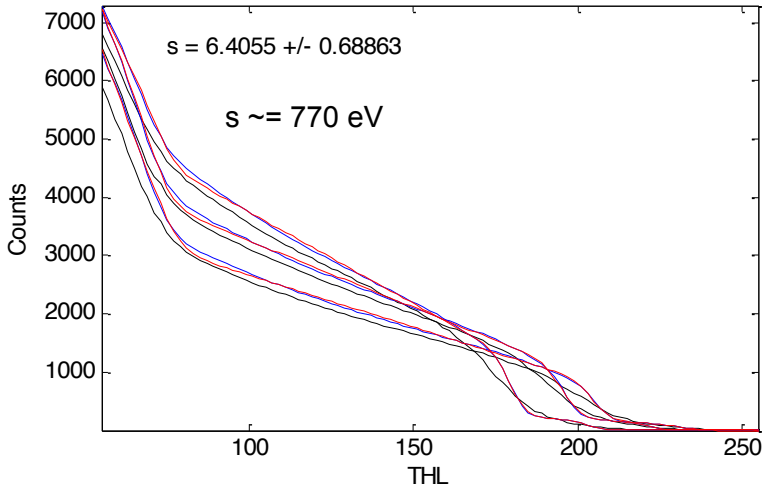
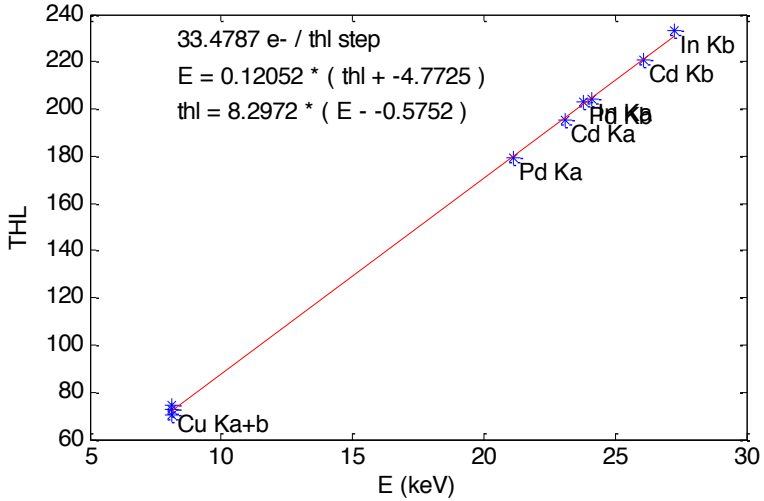
Medipix3 SPM
THL Scans

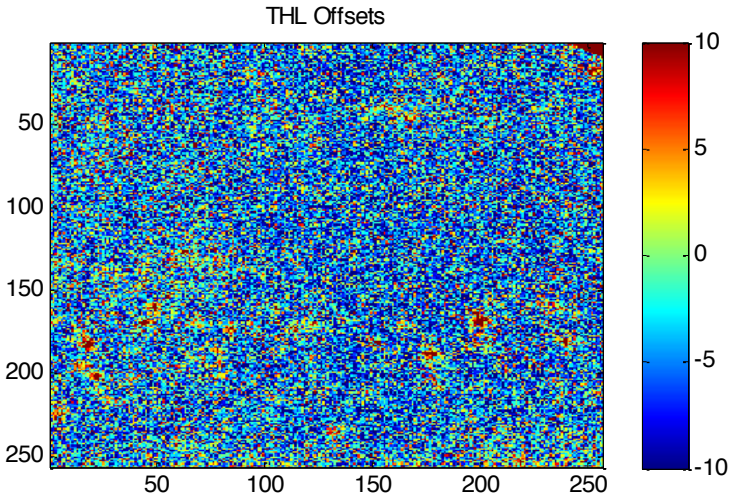


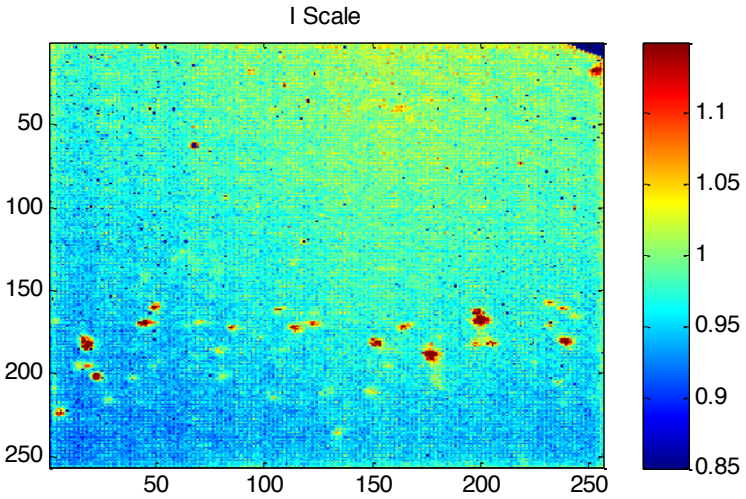


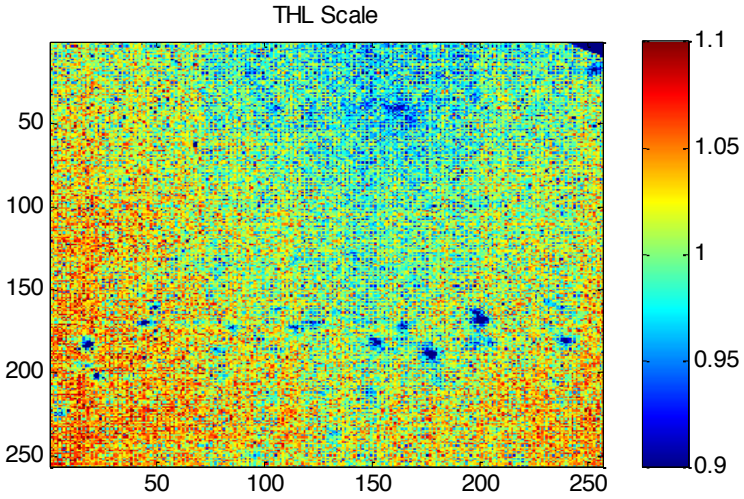


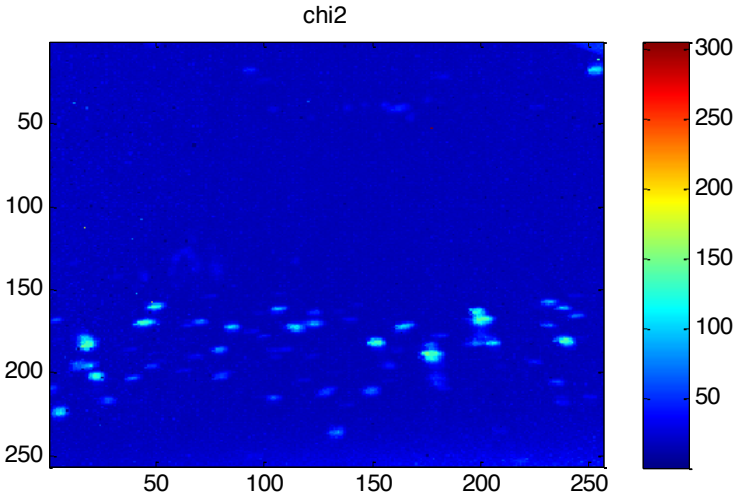


Medipix3 SPM
Offsets, Scaling Factors

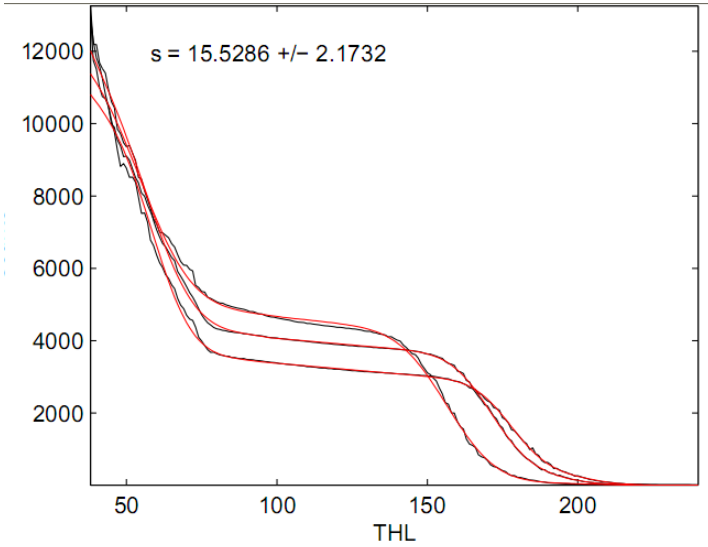


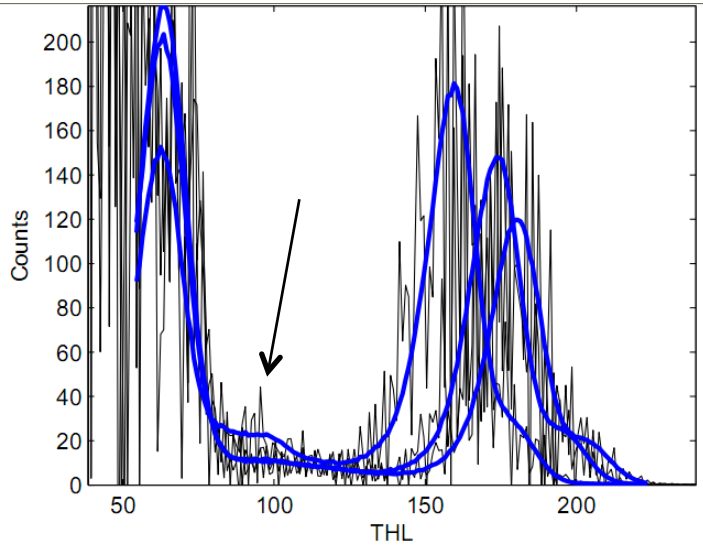


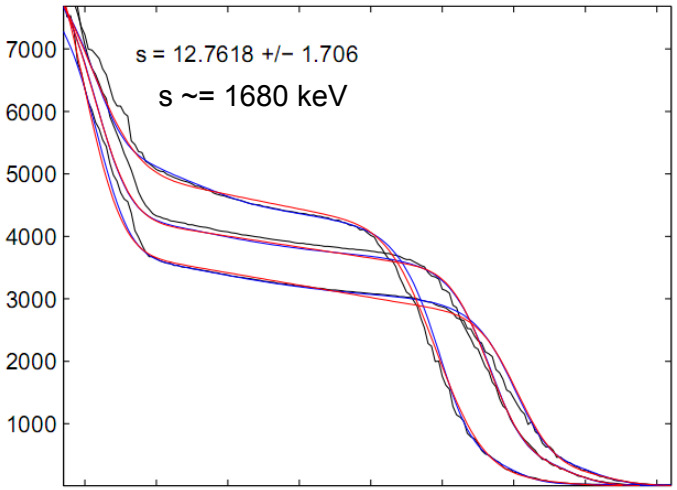


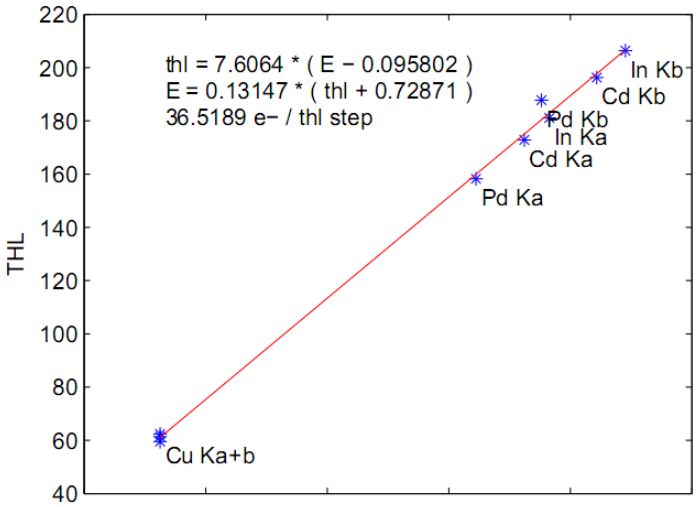


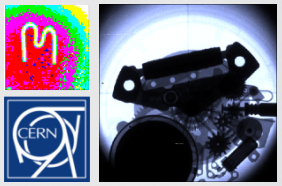
Medipix3 CSM
(Sum of 4 neighboring pixels!)





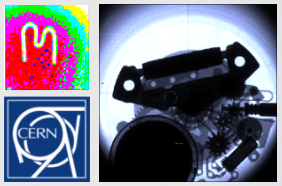






Medipix3 CSM
(Sum of 4 neighboring pixels!)

- **Offsets, scaling: N/A**



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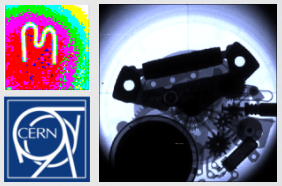
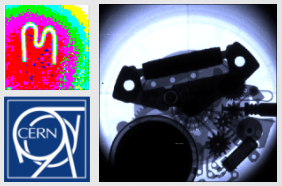


Conclusions

- Threshold scans appear noisy
  - Shutter timing?
  - Instability?
- By aligning individual pixel scans:
  - Noise is spread out
  - Energy resolution is improved
  - Threshold equalization with noise edge: suboptimal
- Energy resolution:
  - 910 eV * / Timepix (+ Charge sharing)
  - 770 eV / Medipix3 SPM (+ Charge sharing)
  - 1680 eV / Medipix 3 CSM (sum of 4 *) (low Charge sharing)
  - 160 eV / typical EDXRF detectors
- Distribution of Offsets, Gain:
  - Gradient across matrix
  - Interesting systematic differences / every 4 pixels in Medipix3 SPM



Thank you!

- Questions?

Medipix3 SPM – Shaper 150