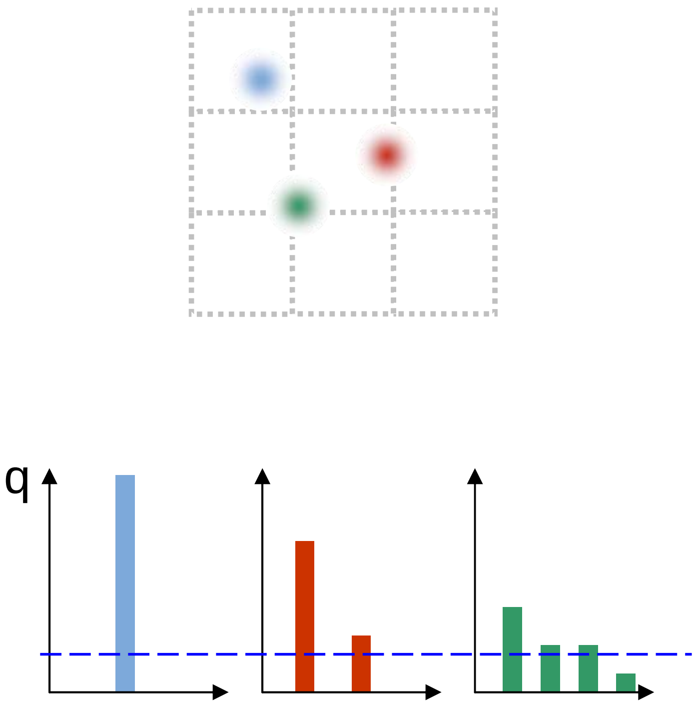
Correction of the charge sharing in photon-counting pixel detector data

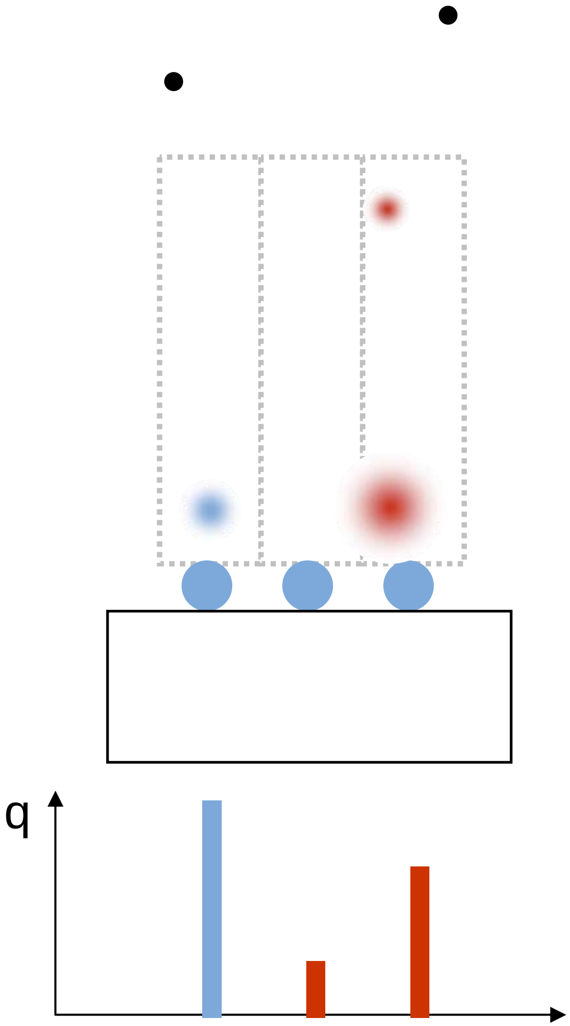
Cyril Ponchut
ESRF

Outline

- Charge sharing
- Detector response model
- Spectrum reconstruction algorithm
- Results
- Conclusion

Charge sharing

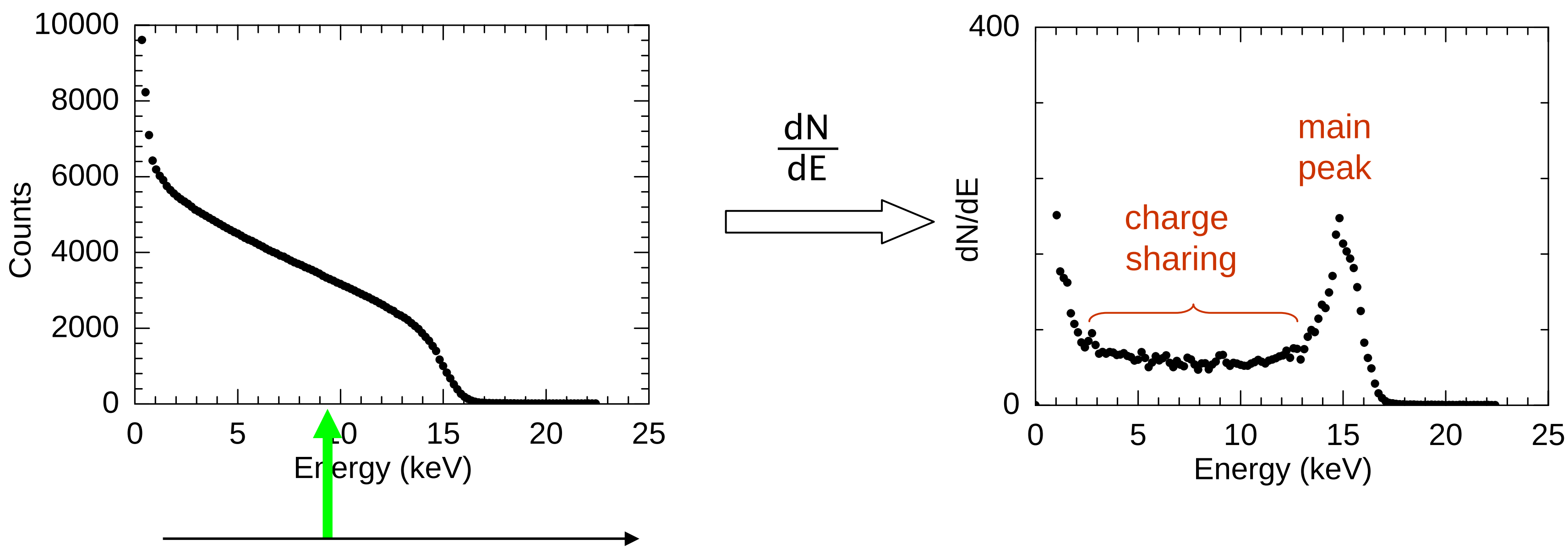




For details : papers from B. Norlin, C. Frödjh, L. Tlustos, H. E. Nilsson, G.Pellegrini, A. Korn,...

Energy spectra measurements

15 keV monoenergetic beam

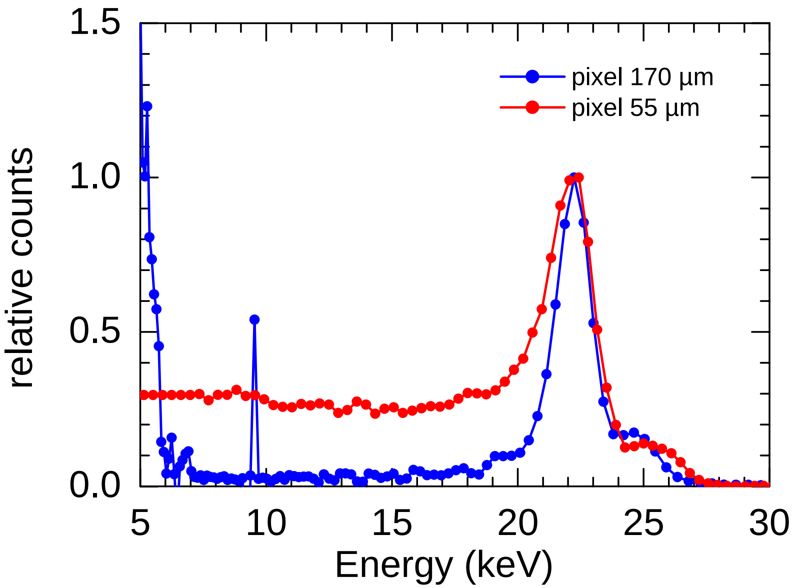


threshold scan acquisition

basic processing : S-curve differentiation

Effect of pixel size

^{109}Cd source spectrum (22.1 keV, 25 keV)



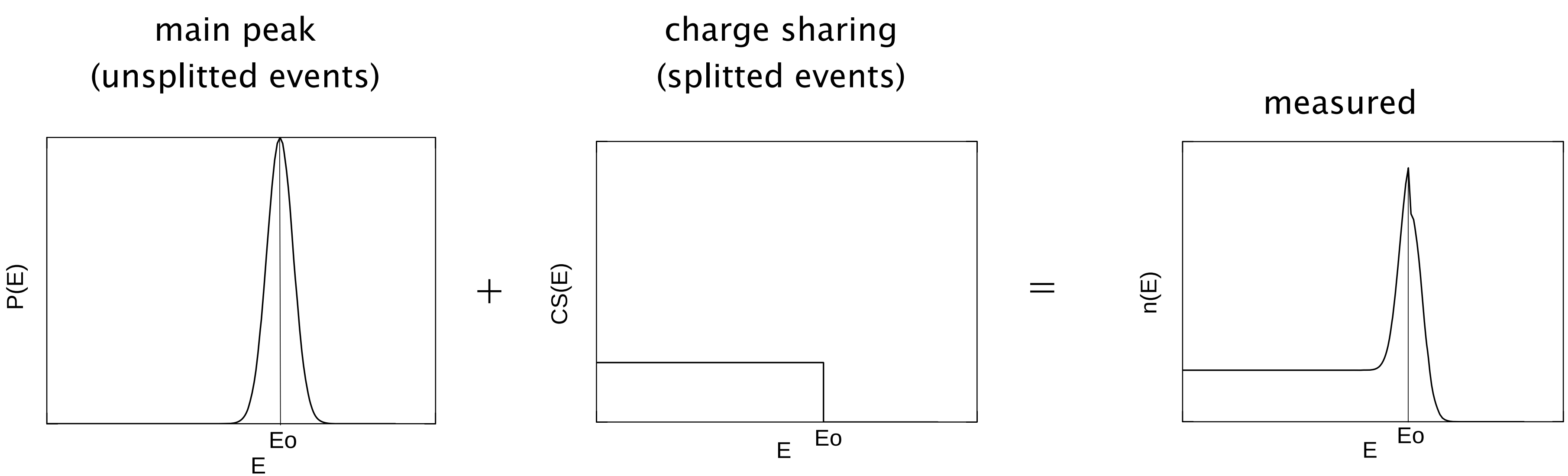
- Same sensor thickness (300 µm)
- Pixel sizes 55 µm and 170 µm

How to correct charge sharing ?

- Large pixels
- Medipix 3
- Timepix in TOT mode (V.Tichy's poster, J. Jakubek's talk)
- e.g. spectrum stripping (M. Firshing's talk)
- this method
- ...

Basic energy response model

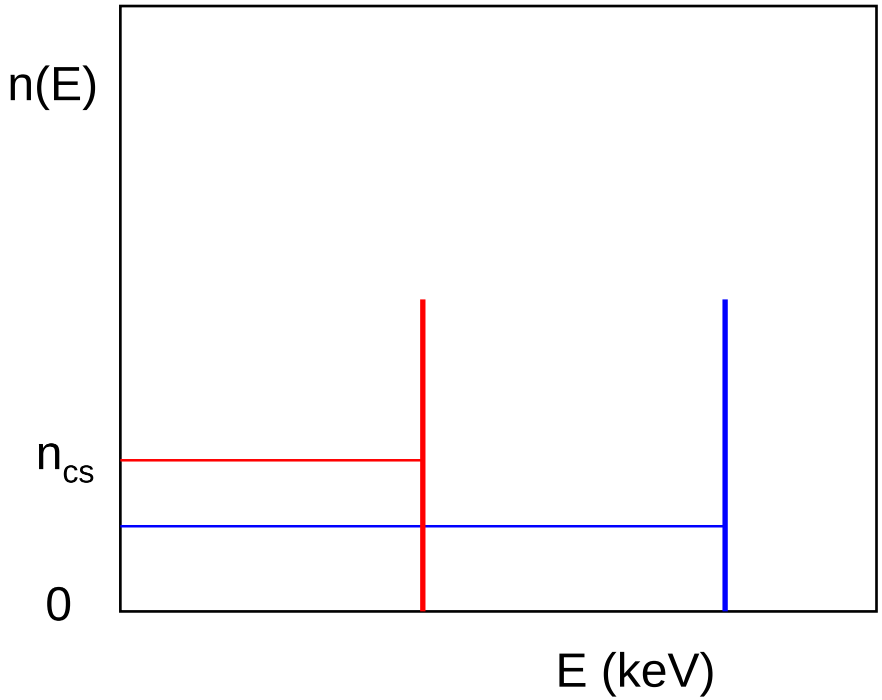
Monoenergetic incident beam



$$n_p(E) = \frac{I_p}{w\sqrt{\pi}} \exp-\left(\frac{E-Eo}{w}\right)^2$$

$$n(E) = (1-k).n_p(E) + k.n_{cs}(E)$$

Model approximations



k = charge sharing probability for one absorbed photon

Approximation 1 : k = n_{cs}.E

Approximation 2 : k independent of E

Hence for 1 absorbed photon of energy E :

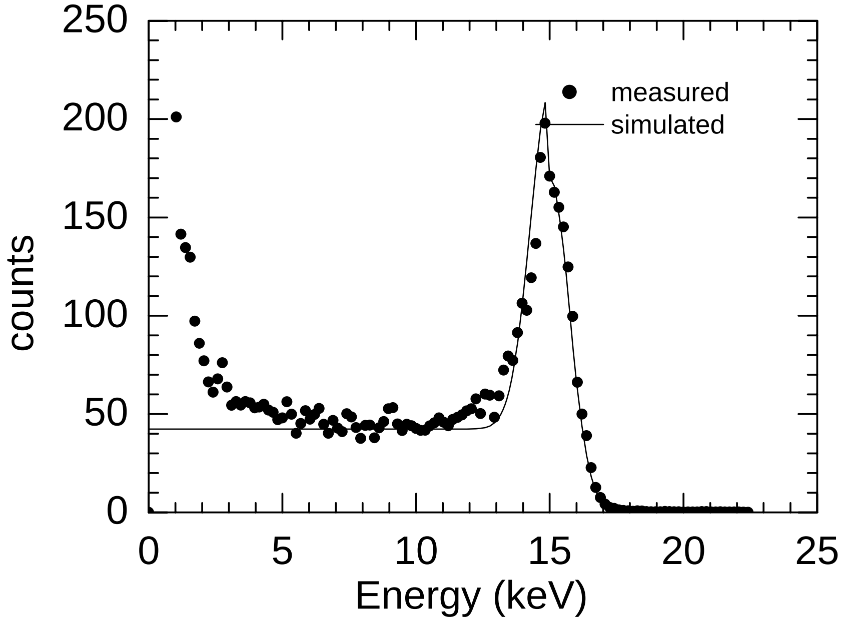
$$n_{cs}(E) = \frac{k}{E}$$

For Φ(E) absorbed monochromatic photons :

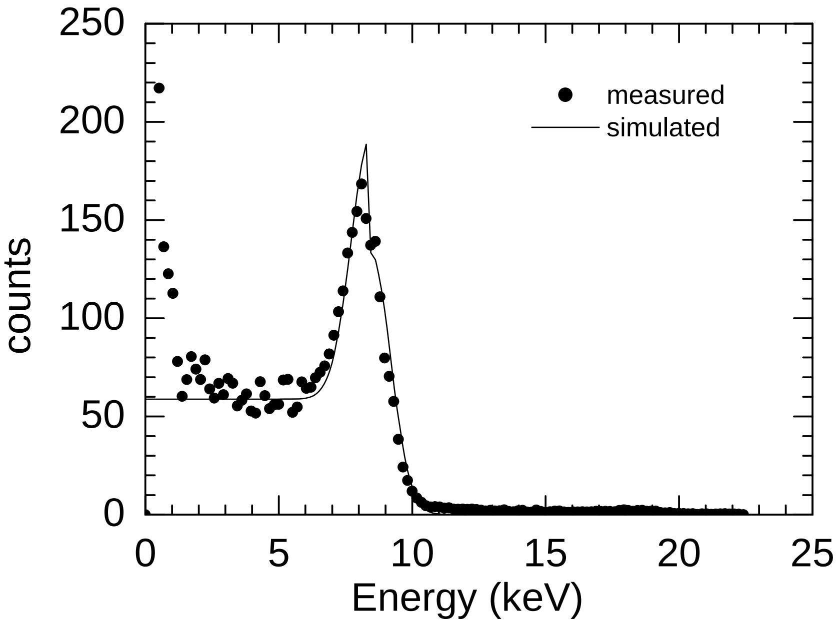
$$n_{cs}(E) = k\frac{\phi(E)}{E}$$

Model fitting

15 keV



8.62 keV



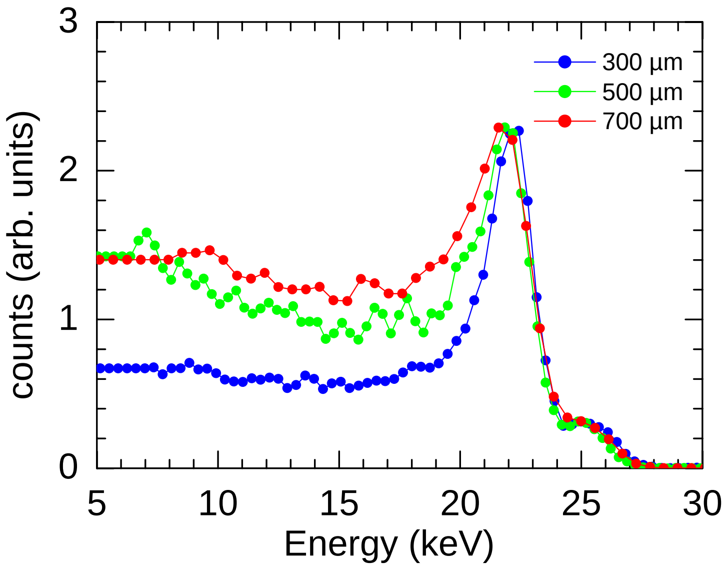
Same fitting parameters at different energies :

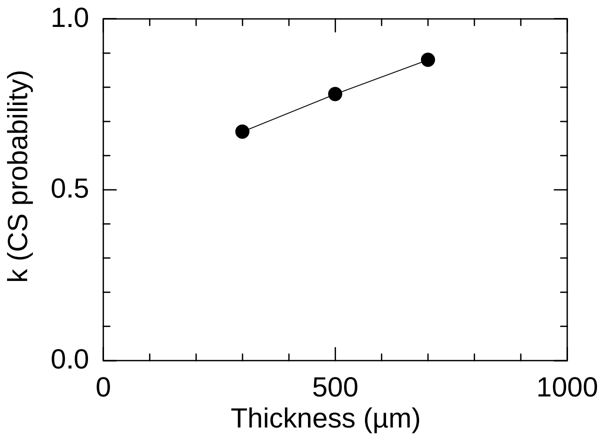
- k charge sharing = 0.67
- w peak = 1.03 keV (1/e)

=> validation of model

Effect of sensor thickness

Source : ^{109}Cd





charge sharing probability vs. thickness

Response for any input spectrum

Absorbed X-rays spectrum *Φ(E)*

Measured spectrum *N(E)*

$$N(E) = (1-k)\int_{-\infty}^{+\infty} P(E-Eo).\Phi(Eo)dEo + k\int_{E}^{+\infty} \frac{\Phi(Eo)}{Eo}dEo$$

main peak
(unsplitted events)

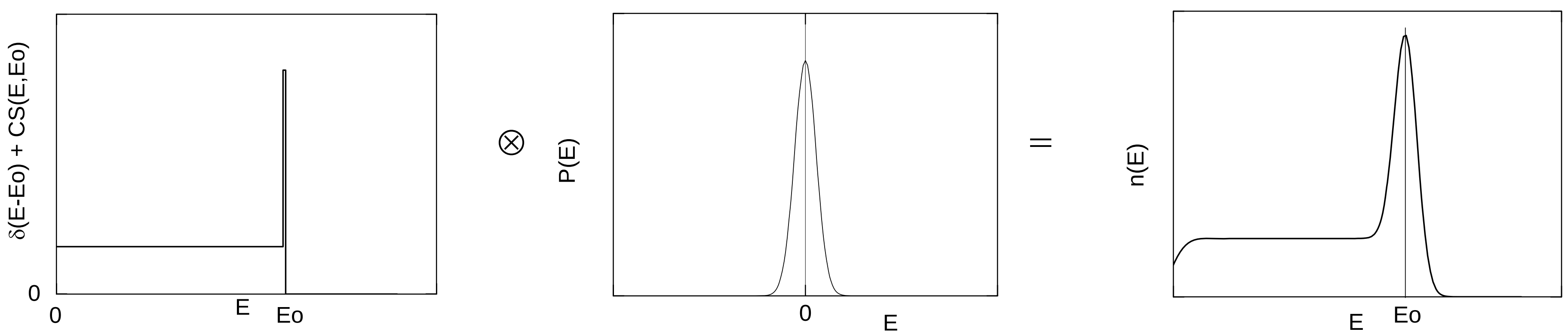
charge sharing

linearity with respect to Φ => $$N = H\Phi$$

finite approximation => $$N_i = \sum_{j=0}^{N-1} H_{ij} \cdot \Phi_j$$

Another model

Distribution broadening applied to main peak and to charge sharing (more rigourous)



charge detection   distribution broadening   energy response

$$N(E) = \int_{-\infty}^{+\infty} P(E - Eo).\left[(1-k)\Phi(Eo) + k\int_{E_0}^{+\infty} \frac{\Phi(E_1)}{E_1} dE_1 \right] dE_0$$

Estimation of the input spectrum

Problem : inversion of equation $N = H\Phi$

Method : iterative algorithm

$$\begin{cases} \Phi_{i+1} = \overline{\Phi_i} + k \cdot (N - H\ \overline{\Phi_i}) & \text{(Van Cittert)} \\ \overline{\Phi_i} = R\ \Phi_i & \text{(Regularization)} \end{cases}$$

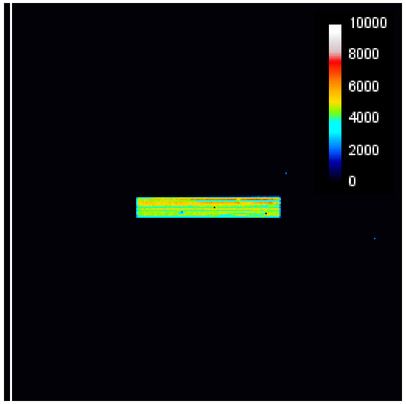
R : Regularization operator

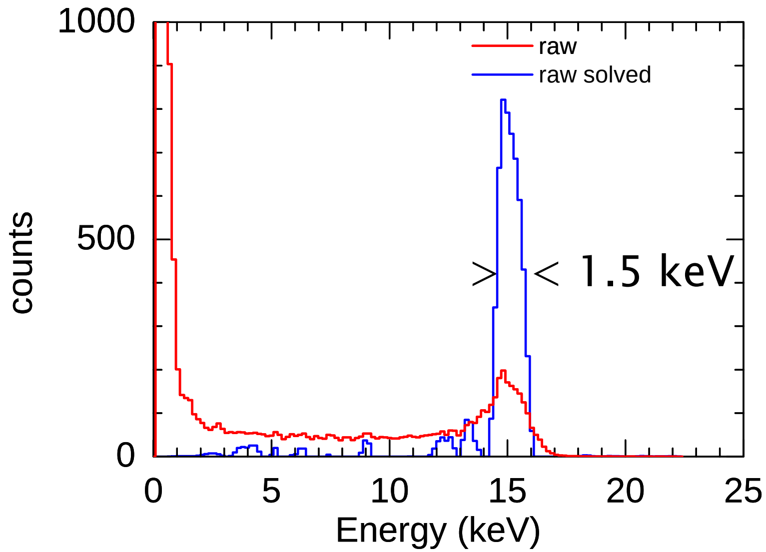
- positivity (*a priori* information on Φ)
- “smoothness” (noise reduction)

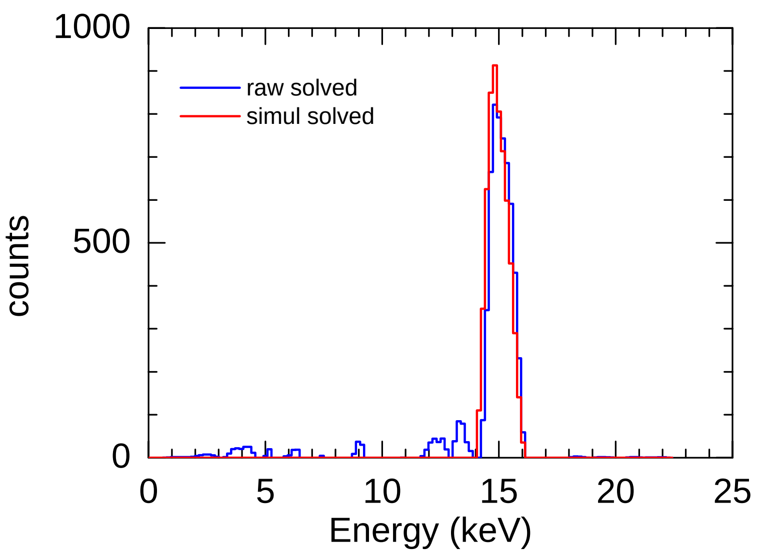
15 keV monoenergetic beam

Multilayer mirror monochromator, 200 eV bandwidth
exposure 1 s/frame

300 µm Si sensor



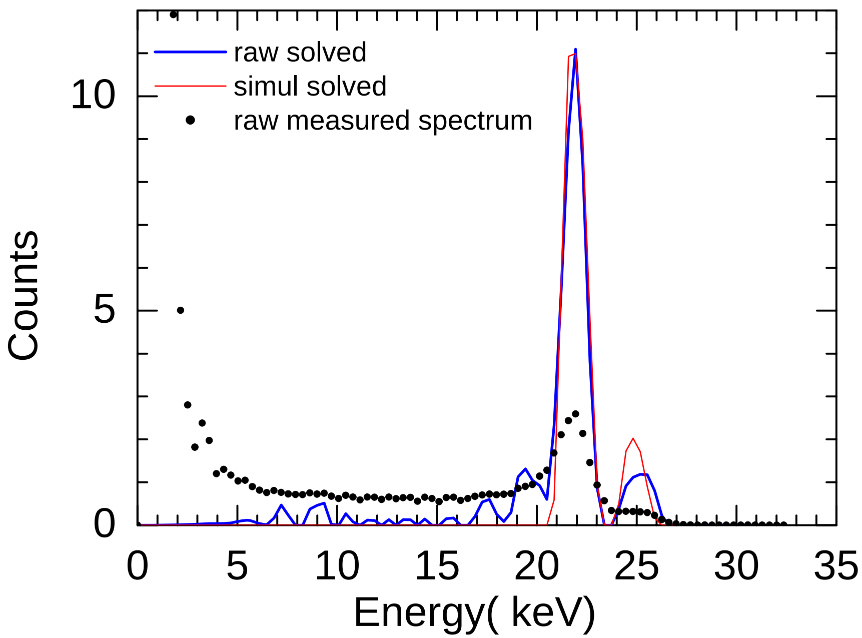




^{109}Cd source

300 µm Si sensor

Spectrum average over 130x130 pixels ROI

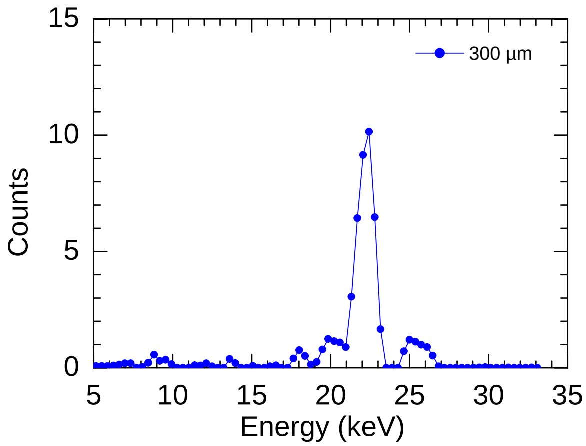


- Peaks 22.16 keV and 24.94 keV resolved
- E. resolution = 1.4 keV (peak FWHM)
- Residual low energy ripple
- Slight peak ratio mismatch (no Si absorption correction)

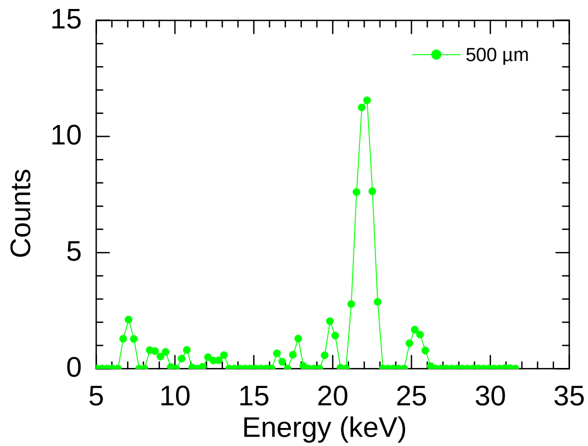
^{109}Cd source with different sensors

Reconstructed spectra

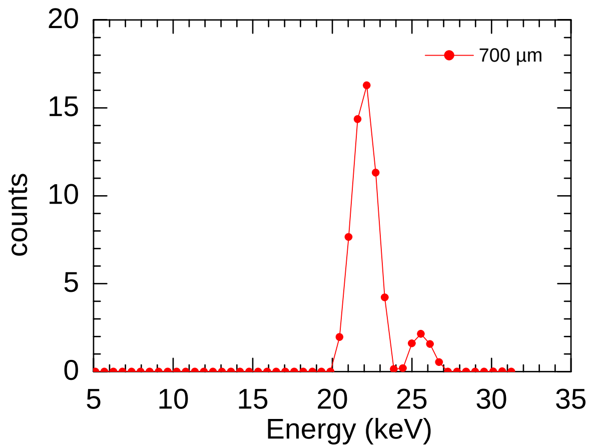
300 µm Si



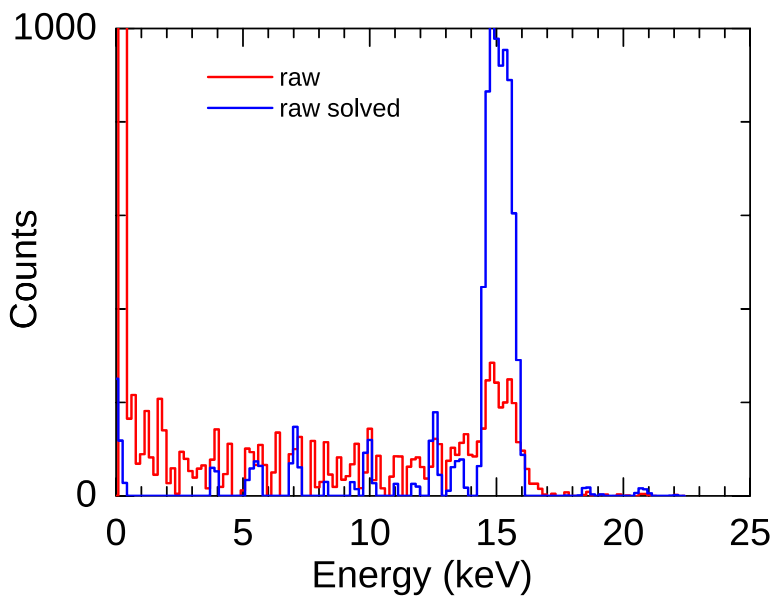
500 µm Si



700 µm Si



Single pixel 15 keV



~32 ms/pixel (1.7 GHz i386, 40-50 iterations)

→ ~35’ for the whole image

→ ~9’ for a 2x2 rebinned image

→ pixel-by-pixel spectrum resconstruction slow but possible (color imaging)

raw pixel value : ~ 6800 counts (min. threshold)

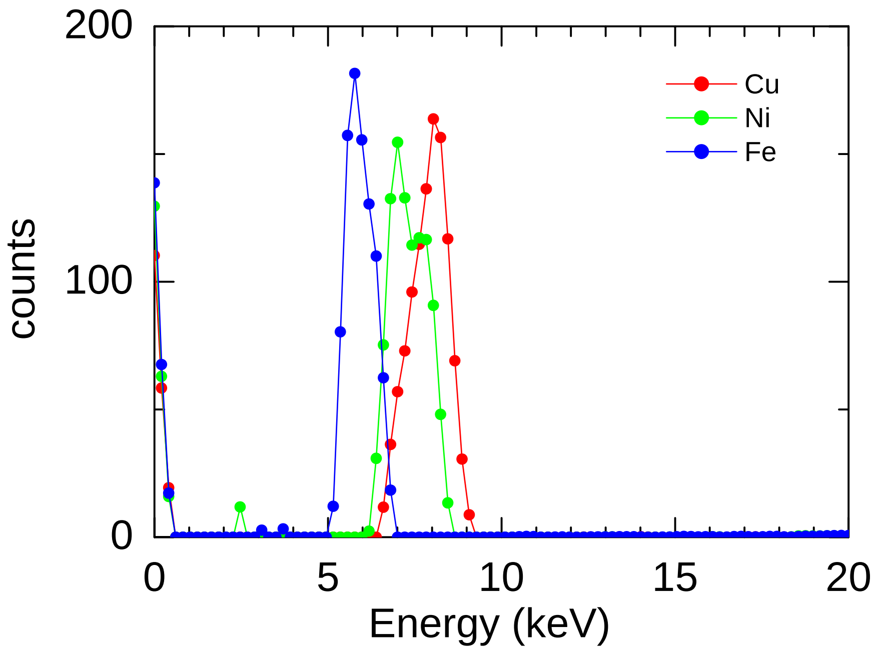
corrected peak integral : 7072 counts

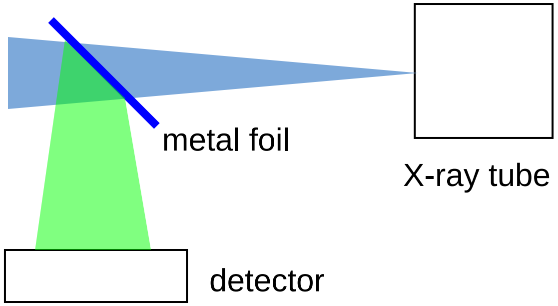
Fluorescence spectra

Metal foils Fe 25 µm, Cu 50 µm, Ni 50 µm

Excitation : Mo X-ray tube 30 kV

300 µm Si sensor

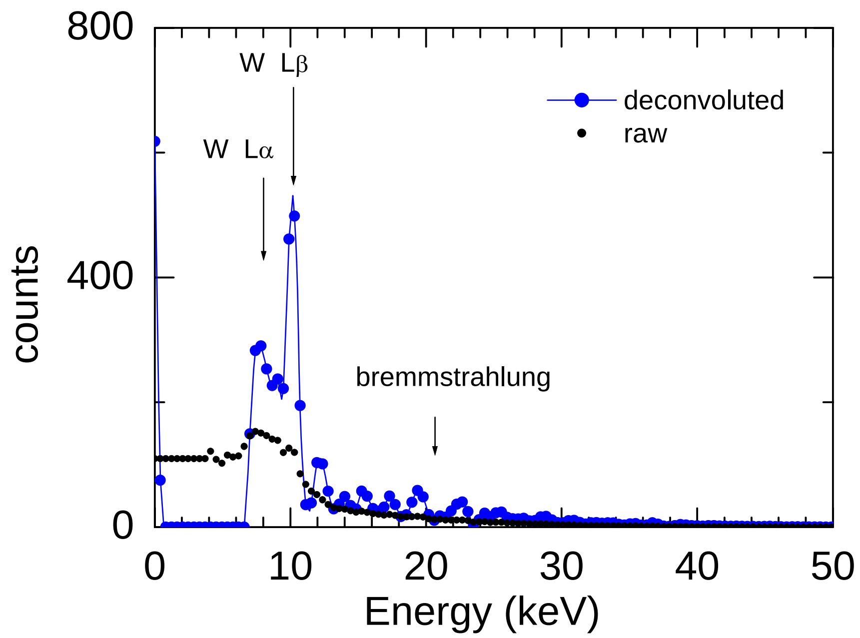




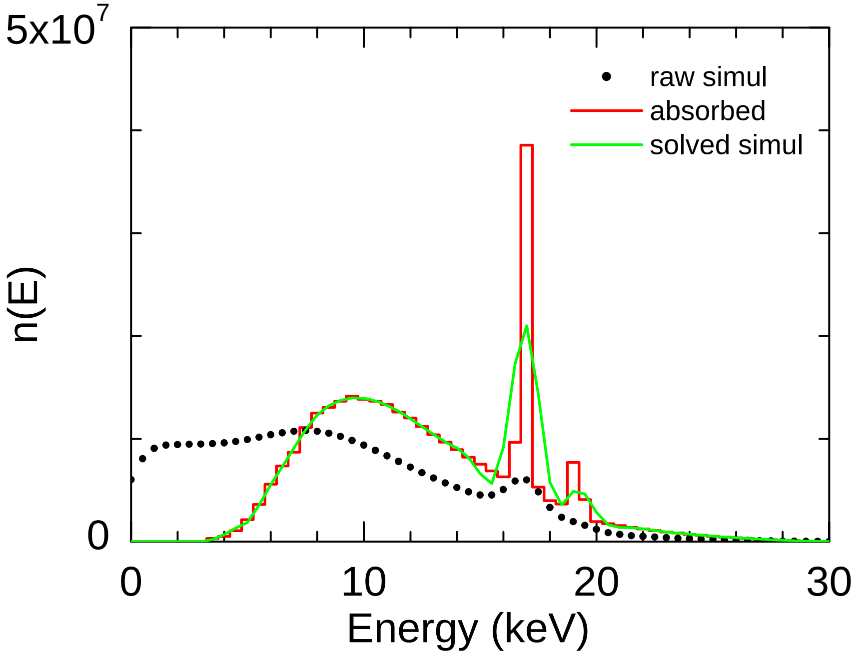
W anode

40 kV, 10 mA, Be window

300 µm Si sensor



Mo anode simulation



Mo anode spectrum Φ (30 kVp) simulated with XOP*

Raw measured spectrum = N=H Φ

Reconstructed spectrum calculated by inversion algorithm

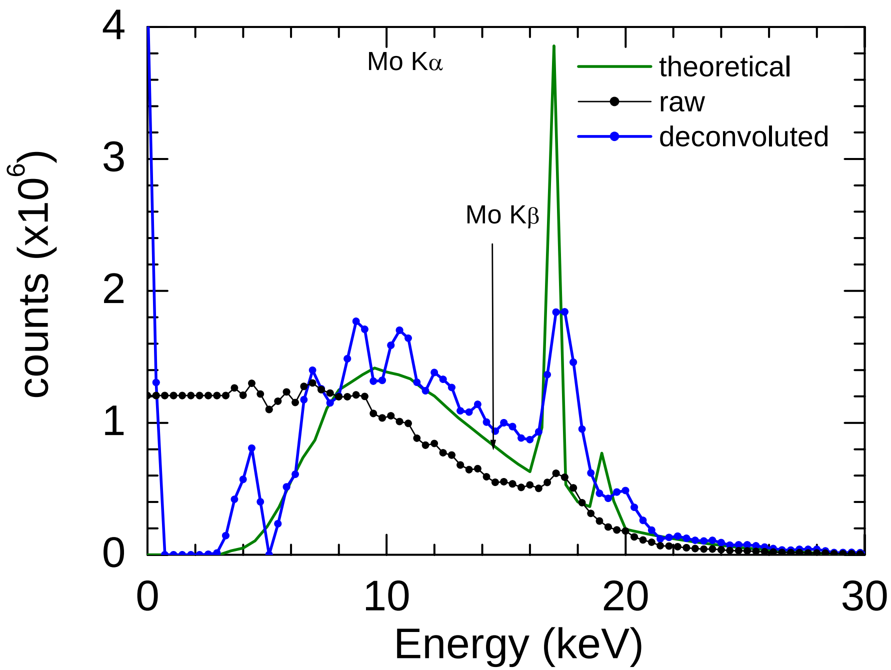
- Bremmstrahlung should be reconstructed
- 17.4 keV and 19.6 keV peaks should be resolved

*http://www.esrf.eu/computing/scientific/xop2.1/

Mo anode real spectra

30 kV, 10 mA, Be window

300 µm Si sensor



– Kα (17.4 keV) and Kβ (19.6 keV) lines separated

– low energy ripple pattern (also present in raw spectrum)

Conclusions

Energy spectra corrected from charge sharing can be obtained from thresholds scan data using a deconvolution method

The method also provides improved energy resolution (peaks separation, peak/valley ratio)

Drawbacks :

- not applicable on low signal data (noise)
- long acquisition time (threshold scans)

Next steps :

- refine model
- explain ripple features in raw and reconstructed spectra
- attempt pixel by pixel processing
- compare with other methods

Acknowledgement

Medipix2 collaboration	Medipix chips
Eric Ziegler (ESRF)	BM5 beamline
Joël Clément, Jean-Marie Rigal (ESRF)	Readout system
Didier Ferrère, Daniel La Marra (Univ. Geneva)	Chipboards