Experimental Simulation of a Spectroscopic Pixel X-Ray Detector

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Overview

- Measurement
- Simulation
- Energy Weighting and Weighting Function
- Results of Simulation and Measurement
- Conclusions

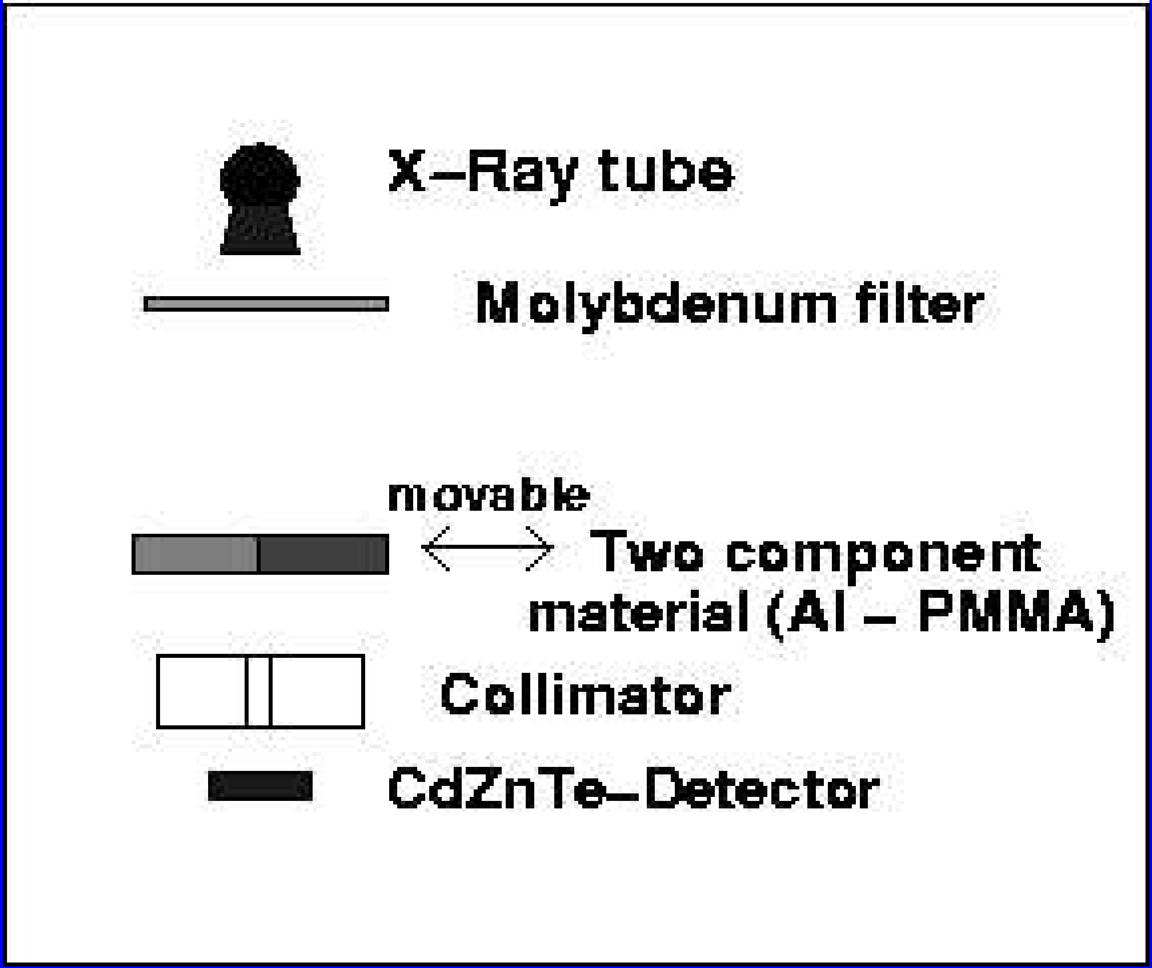
Equipment

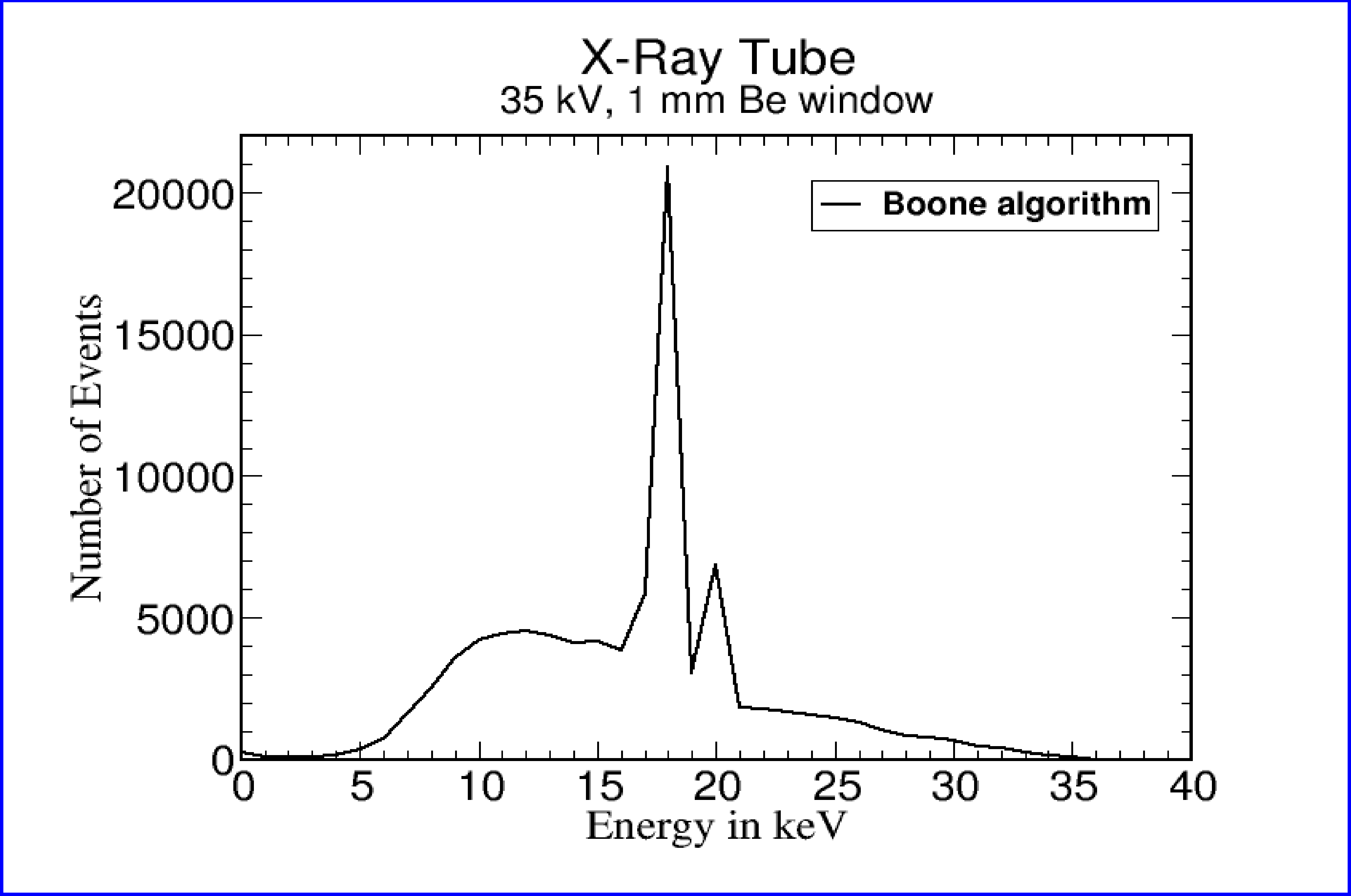
- Detector
  material: CdZnTe
  size: 3 mm x 3 mm x 2 mm
- Preamplifier
- Amplifier in NIM-Crate
- 12-Channel-ADC in CAMAC-Crate
- VME – Data acquisition system

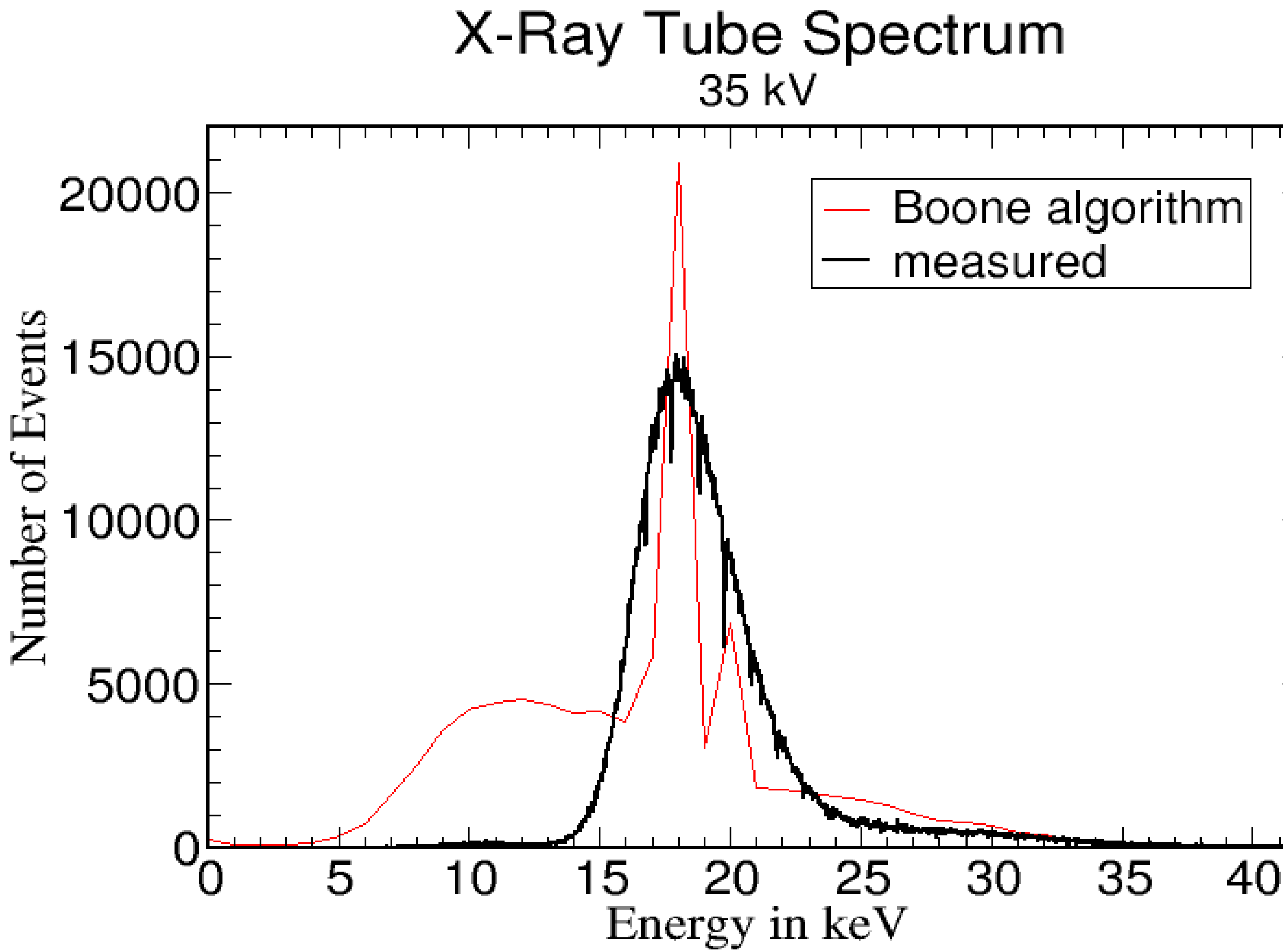
⇨ not the fastest equipment !

Experimental Setup

Several pixels are emulated by moving the object.




X-Ray Tube
35 kV, 1 mm Be window
Boone algorithm
Number of Events
0
5000
10000
15000
20000
0
5
10
15
20
25
30
35
40
Energy in keV


X-Ray Tube Spectrum
35 kV
Boone algorithm
measured
Number of Events
20000
15000
10000
5000
0
0
5
10
15
20
25
30
35
40
Energy in keV

Why are these Spectra so different?

- Energy blurring caused by electronic noise and detector noise
- Blur of the threshold – a discriminator triggers the signal only above a minimum threshold
- Molybdenum filter – in the used X-Ray tube is a 30 µm molybdenum filter integrated

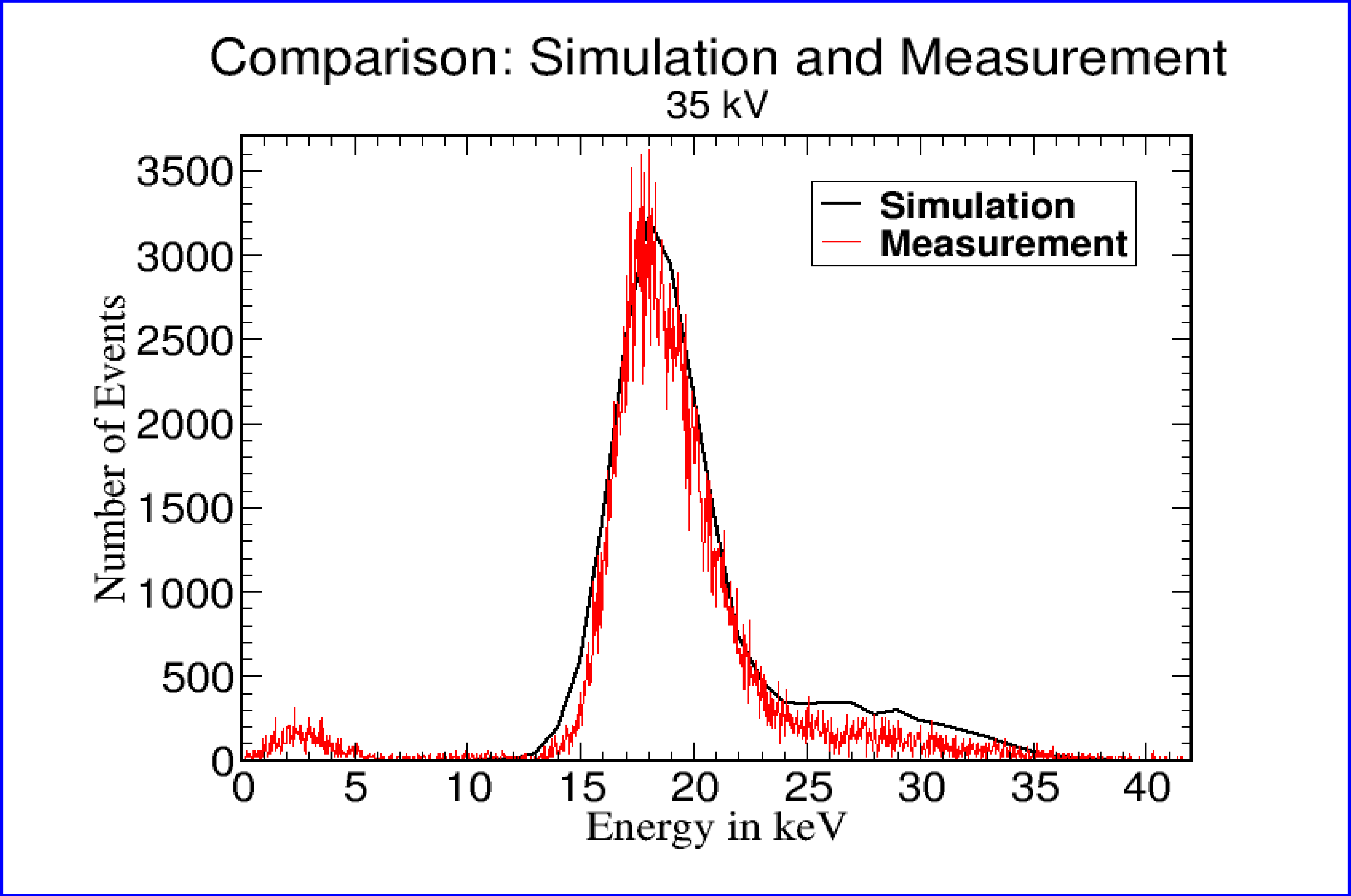
Adaptation of the Simulation

Energy- and threshold blur are estimated as a standard gauss function and multiplied with the geometrically added noise.

$$\sigma_{\text{Energy}} = \sqrt{\sigma^2_{\text{Electronic}} + \sigma^2_{\text{Detector}}}$$

$$\sigma_{\text{Threshold}} \approx \sigma_{\text{Energy}}$$

The molybdenum filter is added between tube and object.



Comparison: Simulation and Measurement
35 kV
Simulation
Measurement
Number of Events
Energy in keV
0
500
1000
1500
2000
2500
3000
3500
0
5
10
15
20
25
30
35
40

Energy Weighting

- is an approach to receive the benefit that photons which have additional information (e. g. energy information) are stronger weighted.

- requires the information of the energy and the location. Therefore it is the best to use a energy resolving pixel detector.

Advantages of Energy Weighting

- Improvement of the image quality at constant dose

- Reduction of the applied patient dose at constant image quality

Weighting Function

The weighting function (***w**$_i$*) can be generated using tabulated absorption data.

$$
\begin{aligned}
T_{1i} &= \text{Transmittance of the material 1 in energy bin i} \\
T_{2i} &= \text{Transmittance of the material 2 in energy bin i} \\
T_{1i} &= T_0 \cdot e^{-\mu_{1i} d_1} \quad \Rightarrow \quad w_i = \frac{T_{1i} - T_{2i}}{T_{1i} + T_{2i}} \\
T_{2i} &= T_0 \cdot e^{-\mu_{2i} d_2} \quad\quad w_i = \text{weighting function}
\end{aligned}
$$

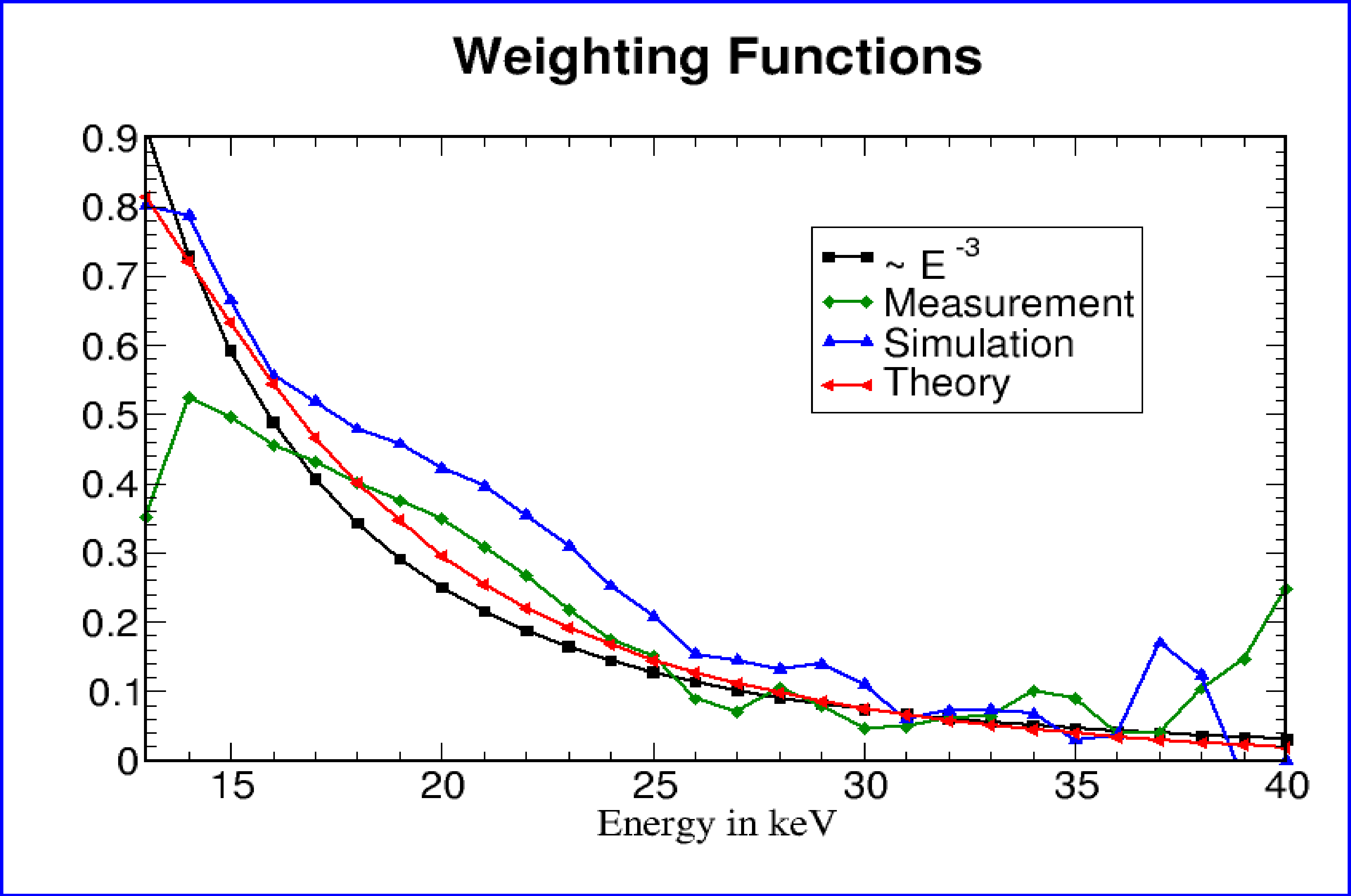
Or it can be calculated by the simulated/measured data.

Weighting Function

Both methods are afflicted with advantages and disadvantages.

Theoretical weighting function:
- For high statstics this function yields best results
- Always useable!

Simulated/Measured weighting function:
- For a special case a better contrast will be achievable
- It is a measure for Energy Weighting



Weighting Functions
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
15
20
25
30
35
40
Energy in keV
~ E -3
Measurement
Simulation
Theory

Signal-to-Noise Ratio

Ideal SNR improvement:

$$SNR = \sqrt{\left(\frac{\left(\sum_i \langle n_i \rangle (T_{1i} - T_{2i}) w_i\right)^2}{\sum_i \langle n_i \rangle (T_{1i} + T_{2i}) w_i^2}\right)}$$

$\langle n_i \rangle$ = Number of photons in energy bin i

T_{1i} = Transmittance of the material 1 in energy bin i

T_{2i} = Transmittance of the material 2 in energy bin i

Theoretical Maximum SNR Improvement

Weighting function: theory

Signal-to-noise ratio improvement: **9.4 %**

Results of Simulation and Measurement

Signal-to-noise ratio improvement
10 pixel

	weighting function	SNR improvement
Simulation 1	theory	32.3 %
Simulation 1	sim.	27.7 %
Measurement 1	theory	25.9 %
Measurement 1	meas.	21.6 %

...but also
with high variance

	weighting function	SNR improvement
Simulation 1	theory	32.3 %
Simulation 1	sim.	27.7 %
Simulation 2	theory	-0.2 %
Simulation 2	sim.	7.2 %
Measurement 1	theory	25.9 %
Measurement 1	meas.	21.6 %
Measurement 2	theory	-10.9 %
Measurement 2	meas.	-22.9 %

100 Pixels

	weighting function	SNR improvement
Simulation 1	theory	2.7 %
Simulation 1	sim.	3.7 %
Simulation 2	theory	7.7 %
Simulation 2	sim.	8.1 %
Simulation 3	theory	5.0 %
Simulation 3	sim.	5.8 %

1000 Pixels

	weighting function	SNR improvement
Simulation 1	theory	5.3 %
Simulation 1	sim.	6.9 %

Conclusions

a) Measurement of a tube spectrum with a CdZnTe detector is possible

b) Simulated spectra are near to the measurement

c) The Energy Weighting technique is only workable at high statistics