Time-resolved X-ray spectrometry

IWORID 2012

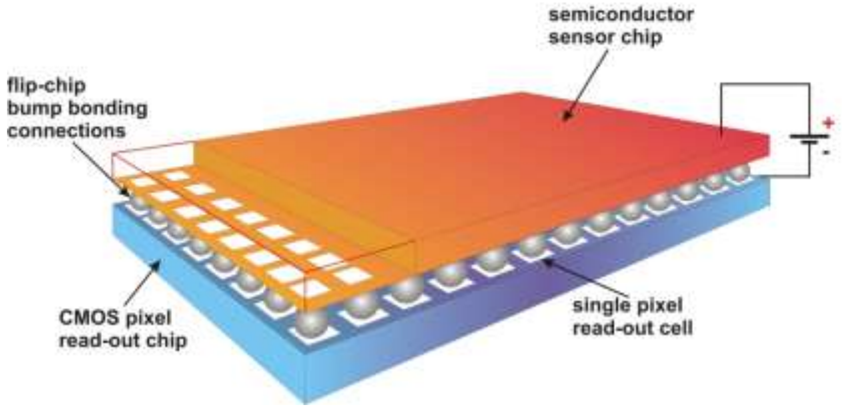
Peter Sievers, Jana Klammer, Oliver Hupe, Thilo Michel and Gisela Anton

Physikalisch-Technische Bundesanstalt
Department 6.3 „Radiation Protection Dosimetry“
Bundesallee 100, 38116 Braunschweig

Outline

- **Timepix detector**
- Deconvolution
- Spectrometry

Timepix detector



ASIC:

- Bump-bonds: Pb/Sn or Sn/Ag
- 256 x 256 = 65536 Pixel
- Pixel pitch: 55 µm
- Size: 14x14 mm^2 (2 cm^2)

Sensor:

- Materials: Si, GaAs, CdTe
- Bias voltage: 150 V (300 µm Si)

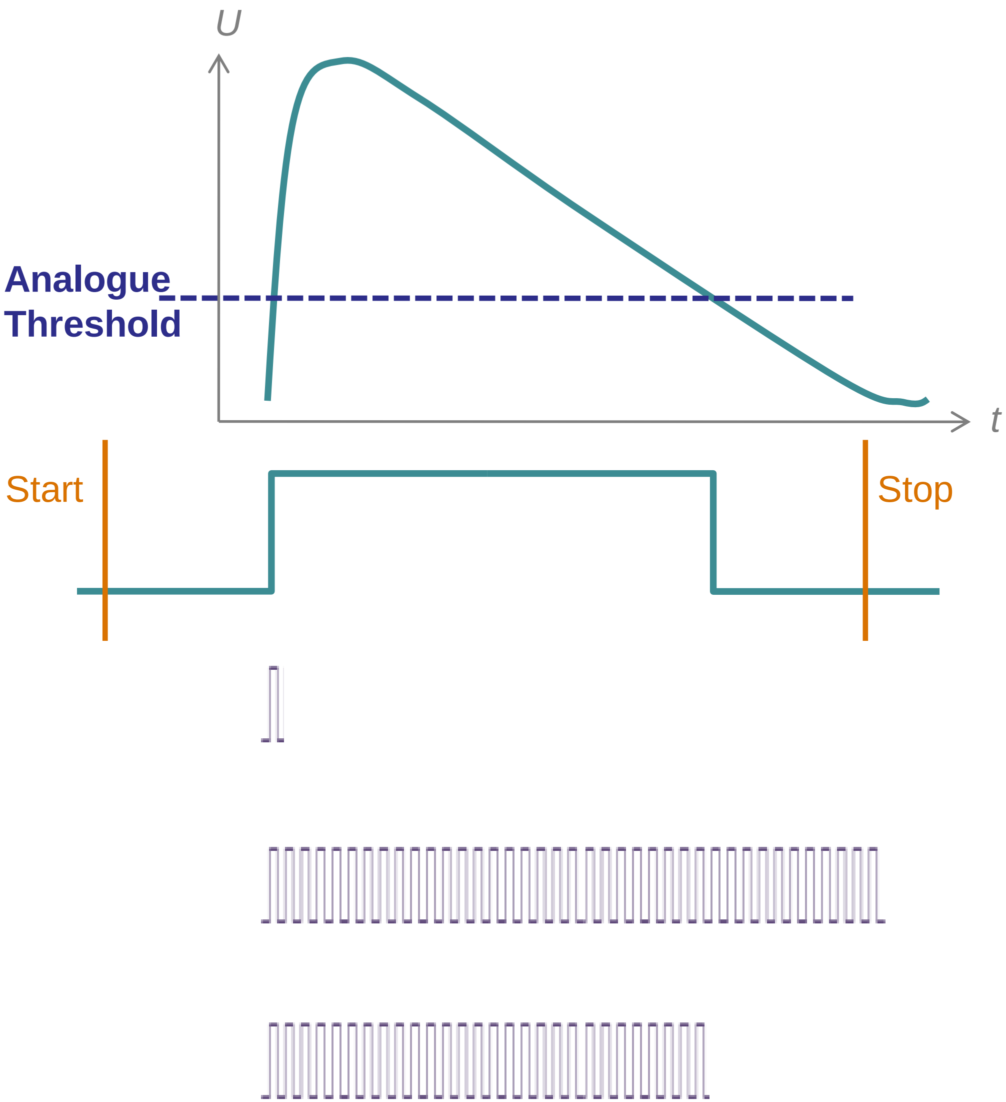
Advantage:

- High spatial resolution
- Timing information
- Different sensor materials
- Operated at room temperature

Disadvantage:

- Low energy resolution
- Energy distortion

Functional principle

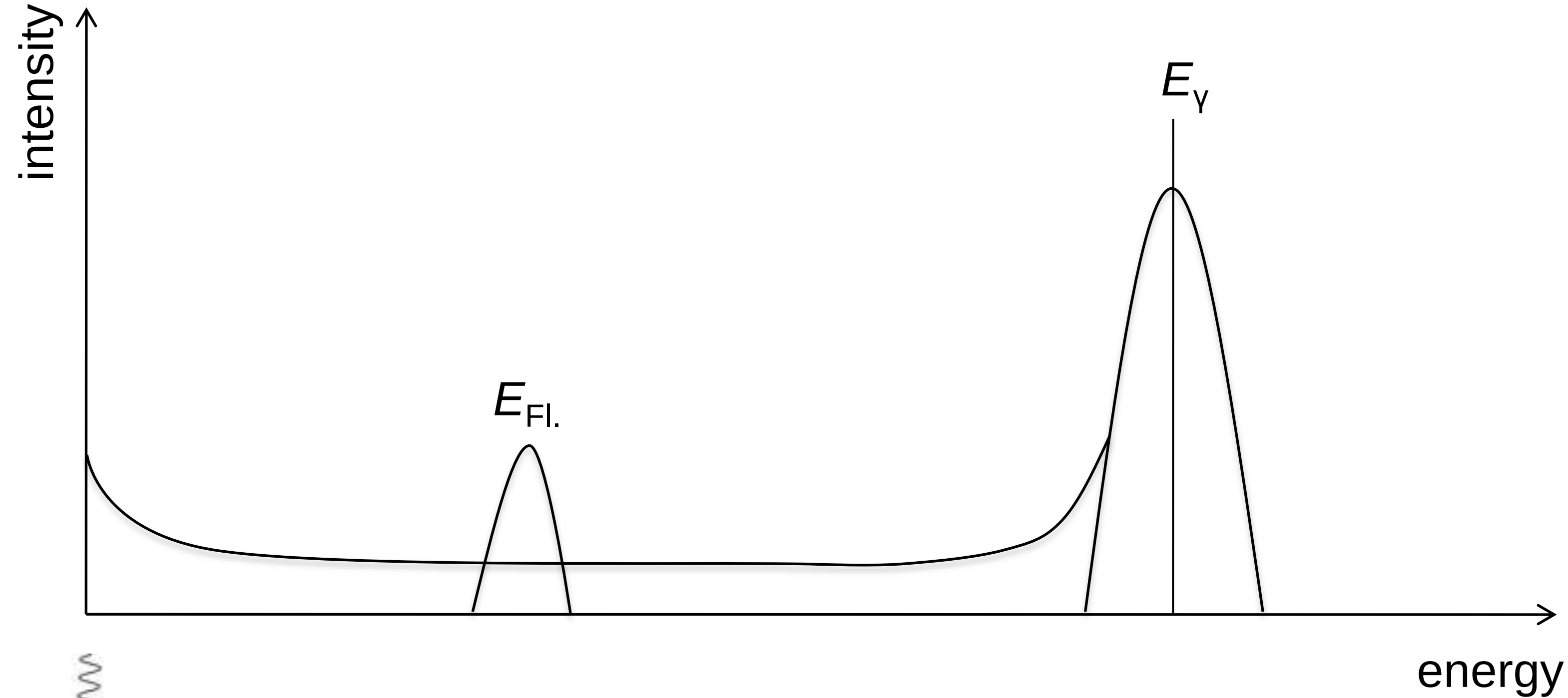


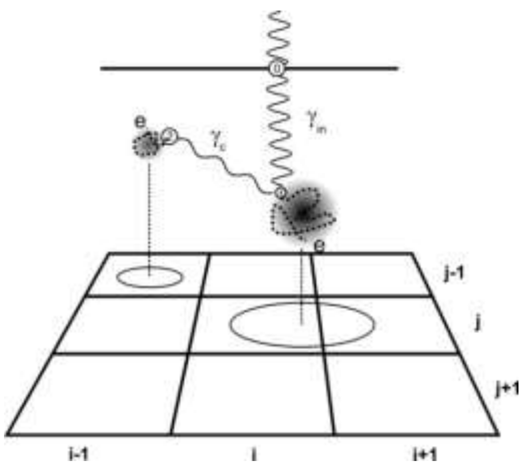
Counting (Medipix2 & Timepix)

Time of Arrival (ToA) (Timepix)

Time over Threshold (ToT) (Timepix)

Energy distortion





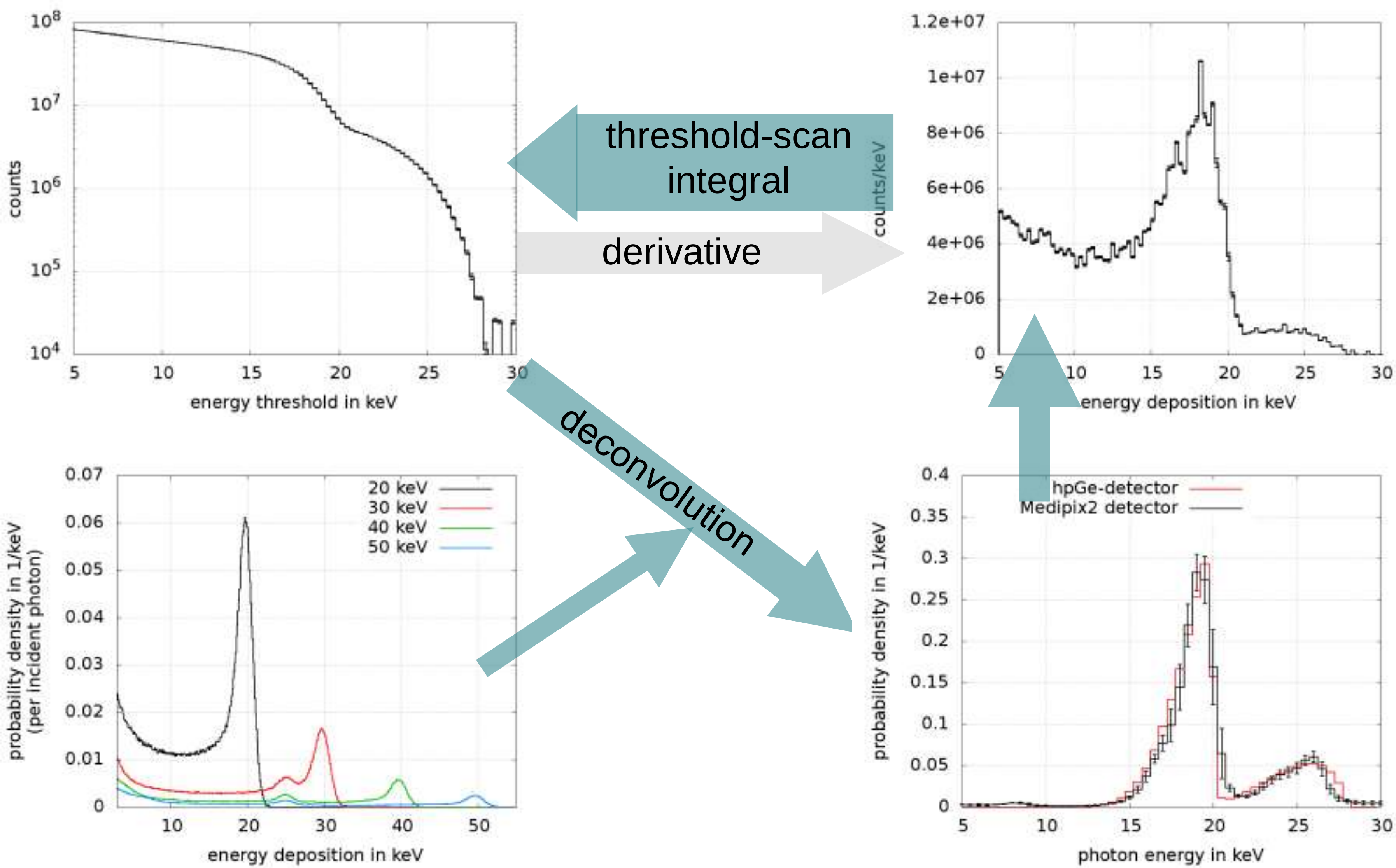
Contribution to detector response by:

- Electronic noise
- Events caused by fluorescence photons
- Charge Sharing
- Scattering (Compton)

Outline

- Timepix detector
- **Deconvolution**
- Spectrometry

Deconvolution



Deconvolution

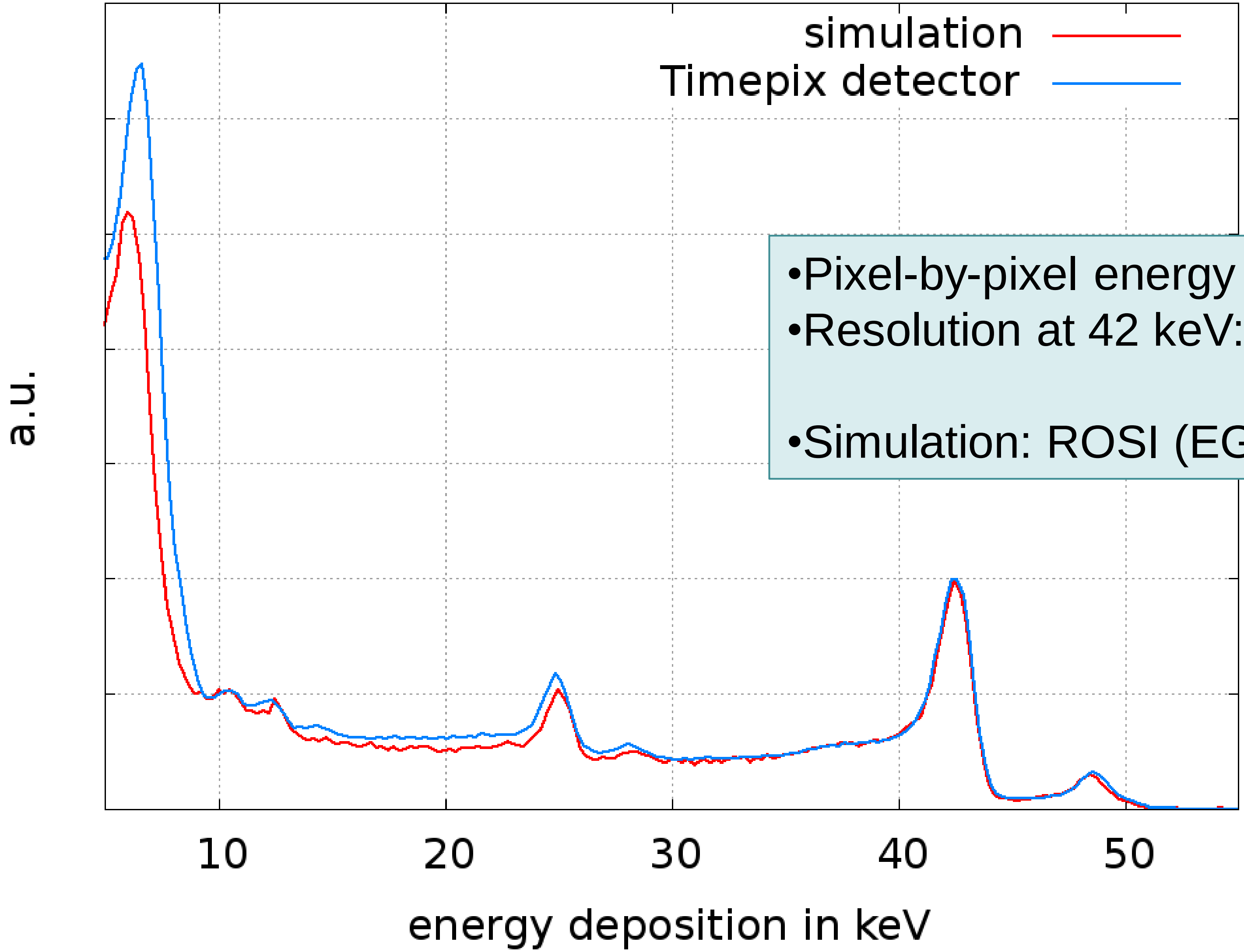
$$M(E'_k) = \sum_i R(E'_k, E_i) \cdot T(E_i)$$

measurement (threshold-scan) — response-matrix — impinging spectrum

Possible Solutions:

- Pseudo Matrix-Inversion
- Spectrum-Stripping
- Bayesian deconvolution (new)

Comparison measurement/simulation



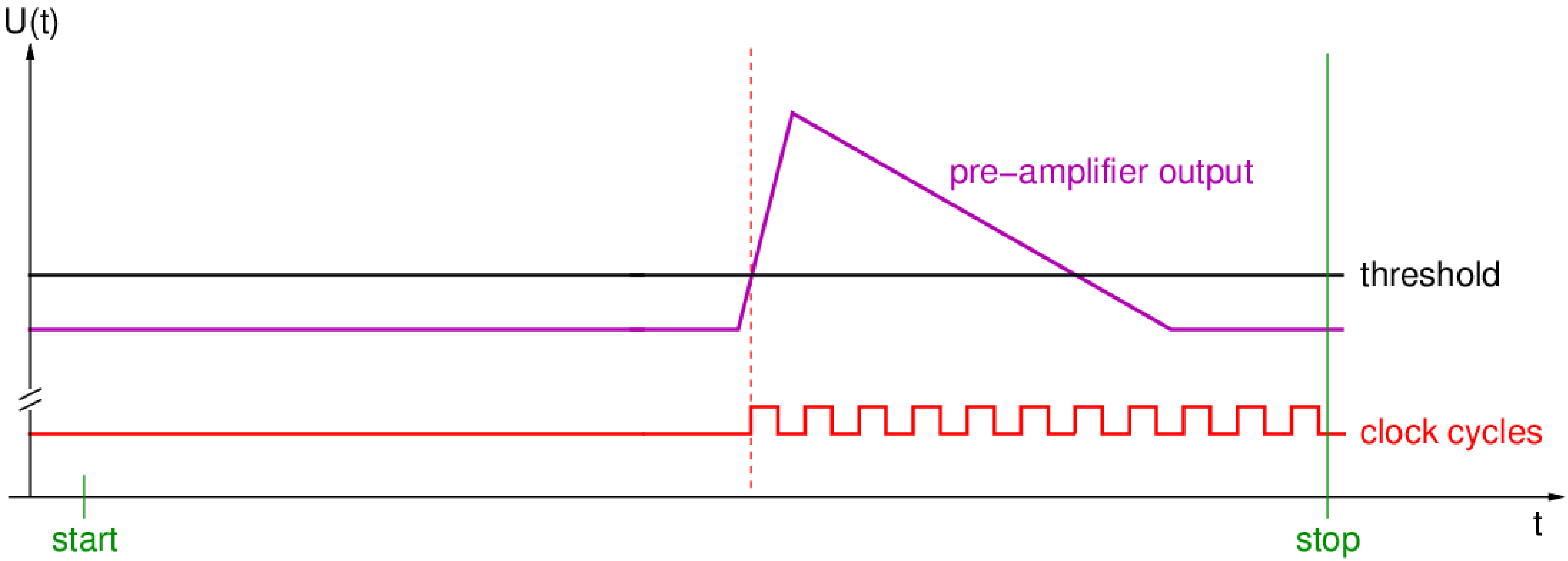
- Pixel-by-pixel energy calibrated
- Resolution at 42 keV: 4,2%

- Simulation: ROSI (EGS4, LSCAT)

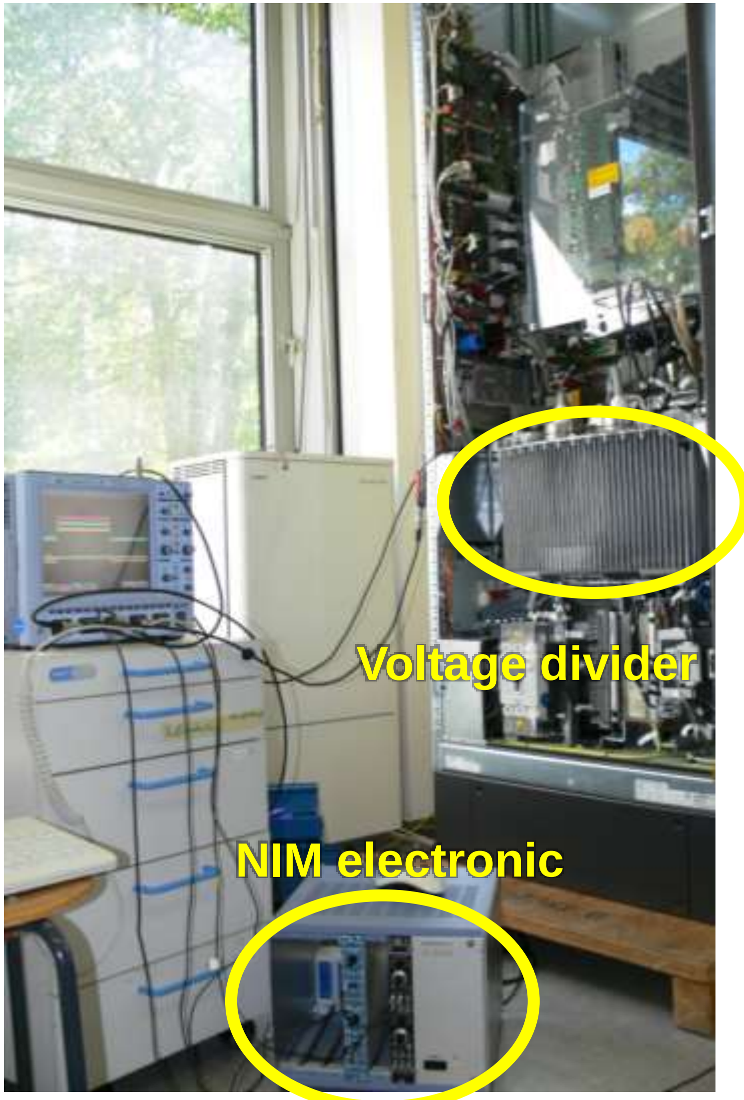
Outline

- Timepix detector
- Deconvolution
- **Time resolved Spectrometry**

Time-of-Arrival mode



Time resolved spectrometry

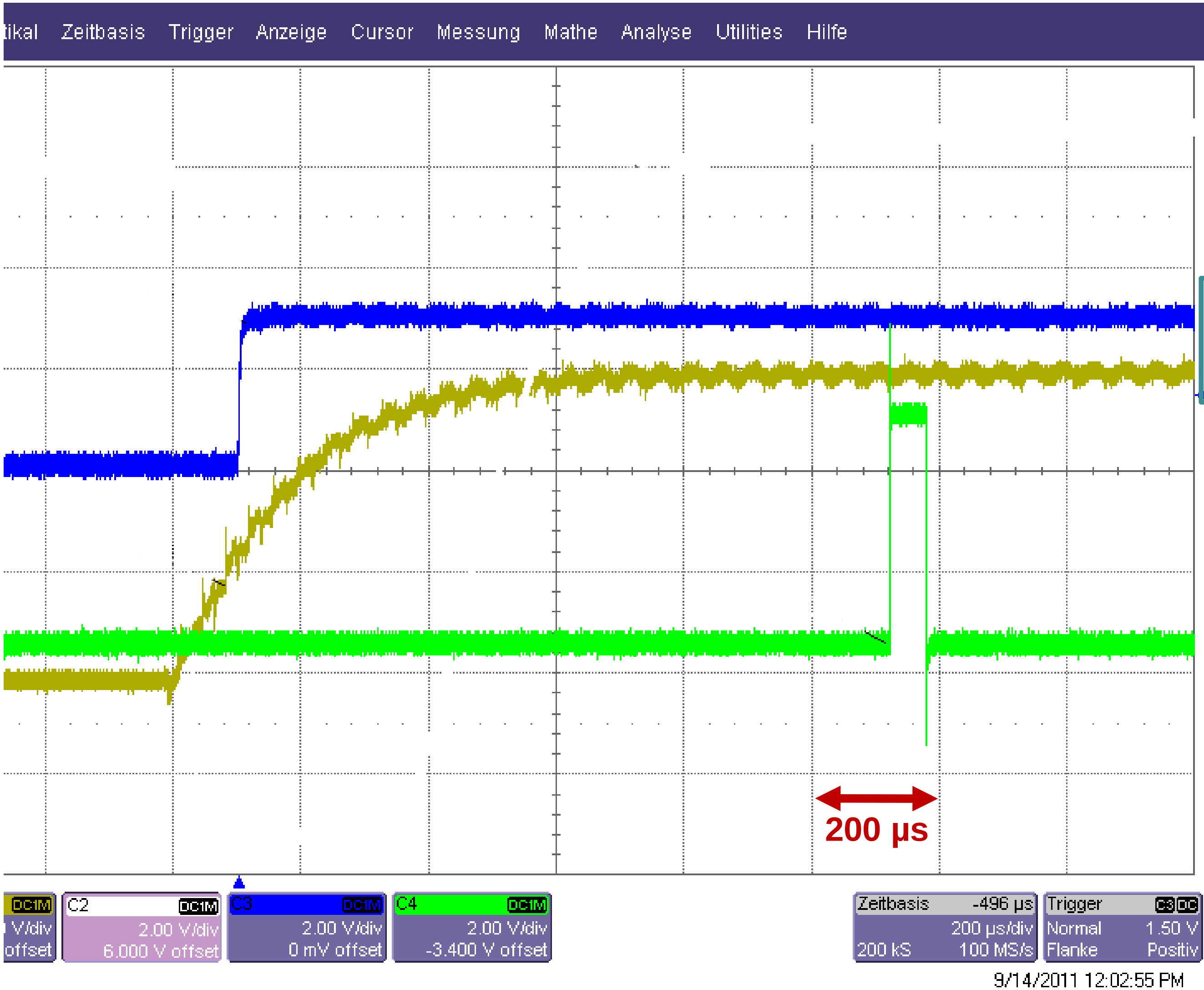


Parameter:

Generator-Pulsing

- Voltage: 60 kV
- Current: 2 mA
- Frequency: 1,5 Hz
- Pulse width: 100 ms
- **Number of Pulses: 45000 per threshold: 150**
- Distance: 384 cm

Time dependence

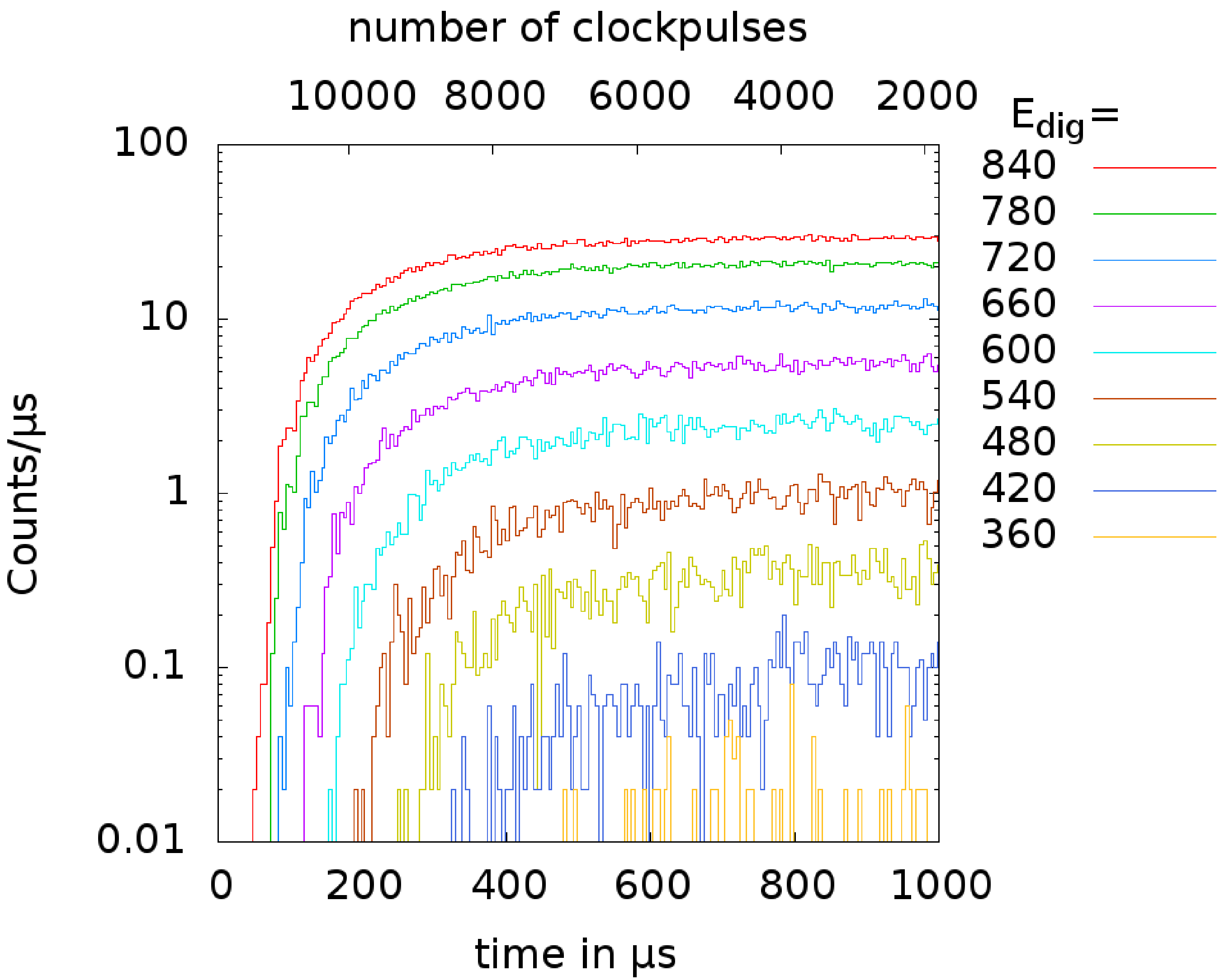


TTL-signal
HV / voltage-divider

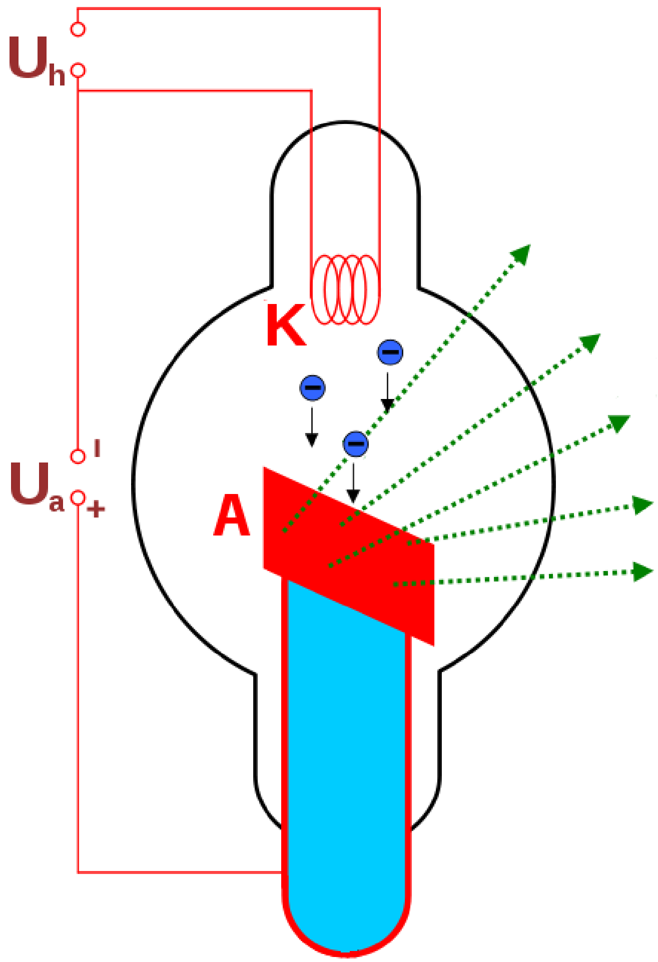
Generator signals

NIM-electronic

Radiation pulse shape

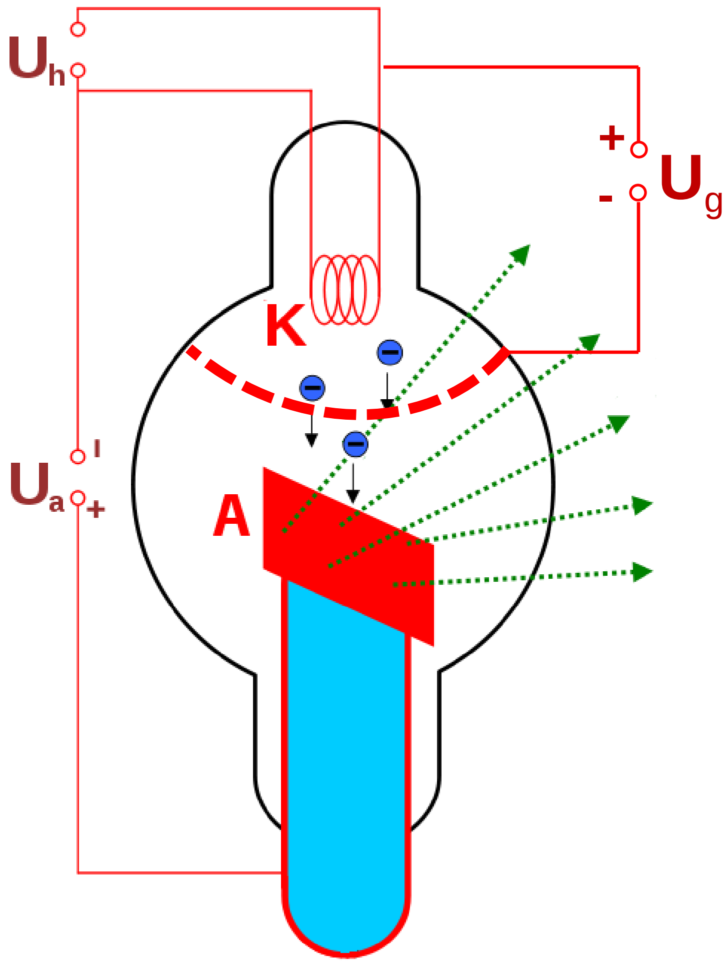


Generator-Pulsing



Source: Wikipedia

Grid-Pulsing

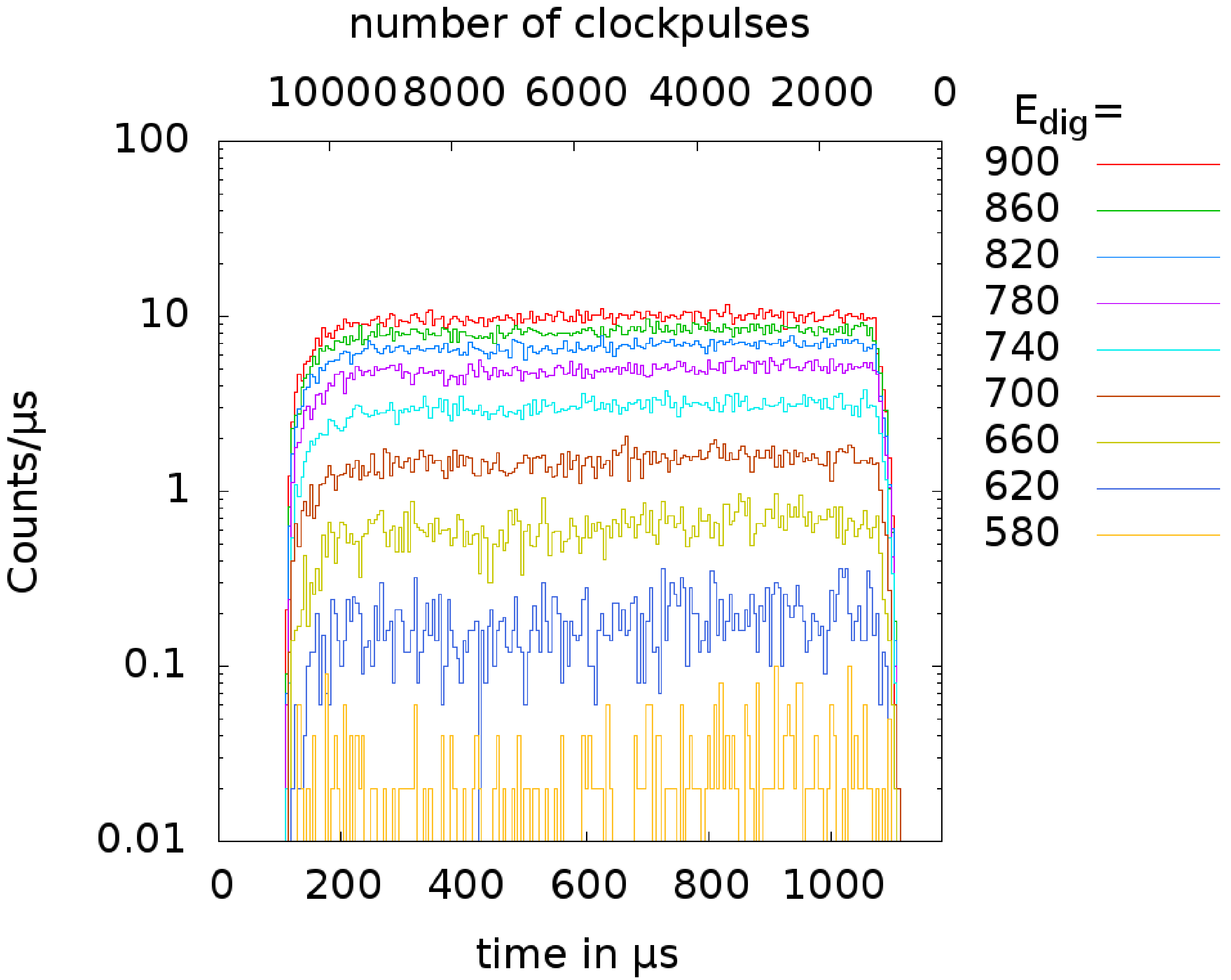


Source: Wikipedia

Parameter:

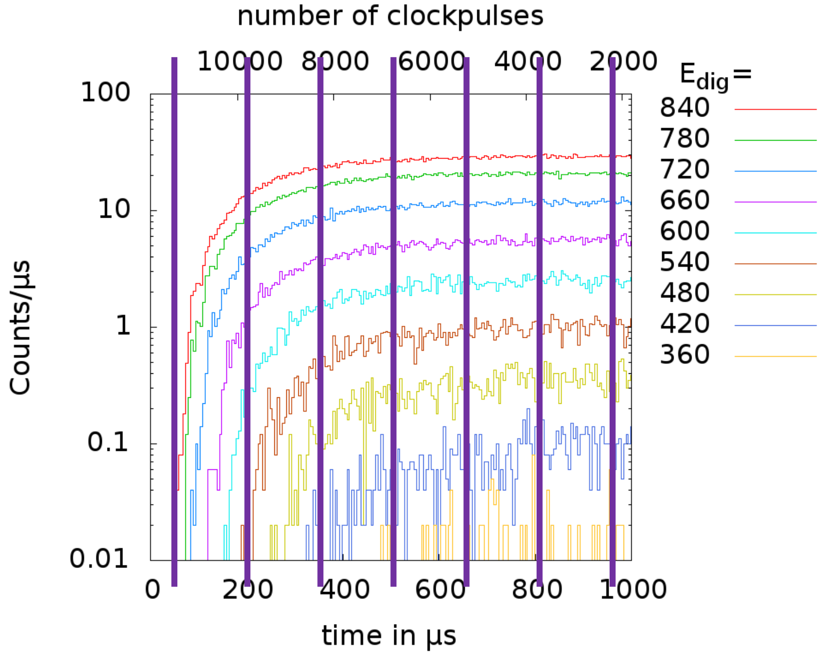
- Voltage: 40 kV
- Current: 10 mA
- Frequency: 2 Hz
- Pulse width: 1 ms
- **Number Pulses: 1000**
  per threshold: 25
- Distance: 325 cm

Radiation pulse shape



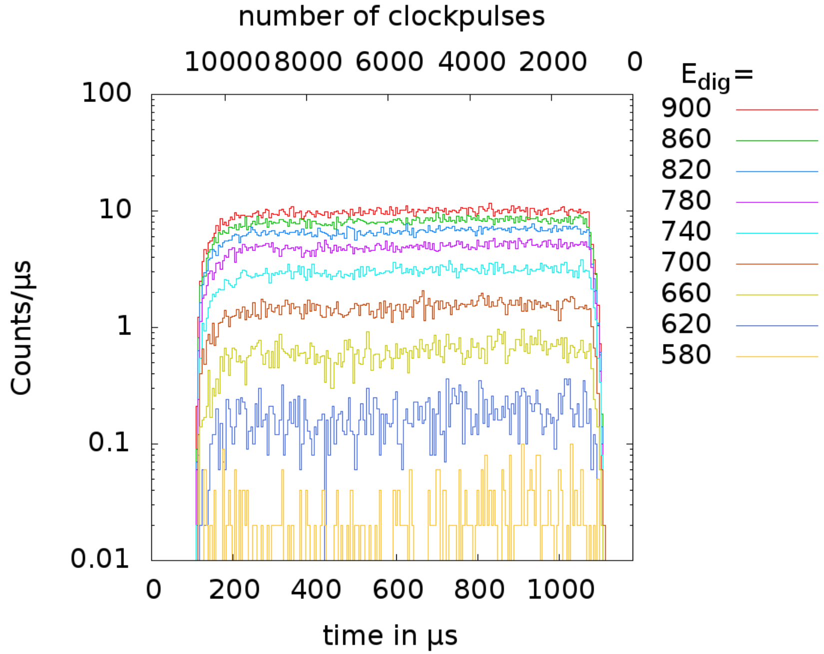
Comparison: Grid/Generator-Pulsing

Generator-Pulsing



- Tube voltage: 0 kV to 60 kV
- Tube current: 2 mA
- Number of pulses: 45000
  per threshold: 150

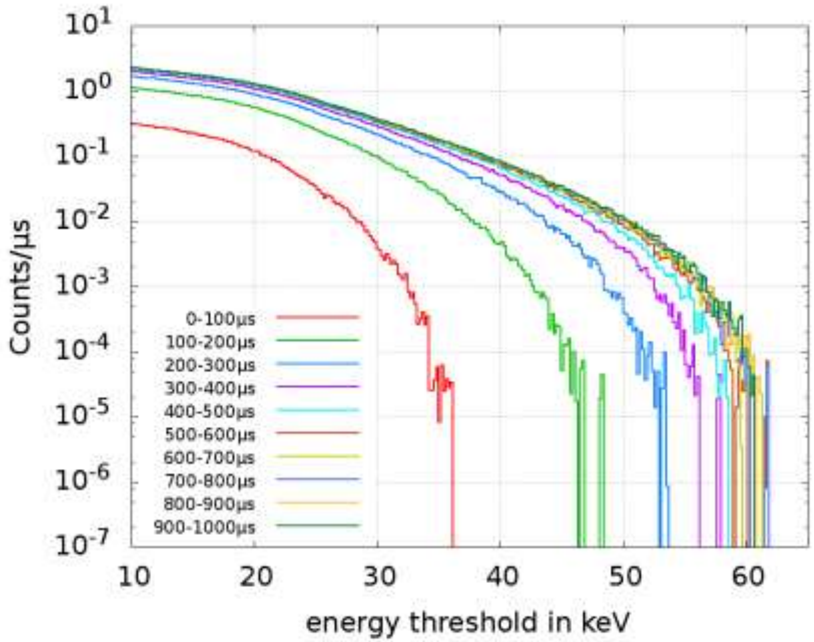
Grid-Pulsing



- Tube voltage: 40 kV
- Tube current: 10 mA
- Number of pulses: 1000
  per threshold: 25

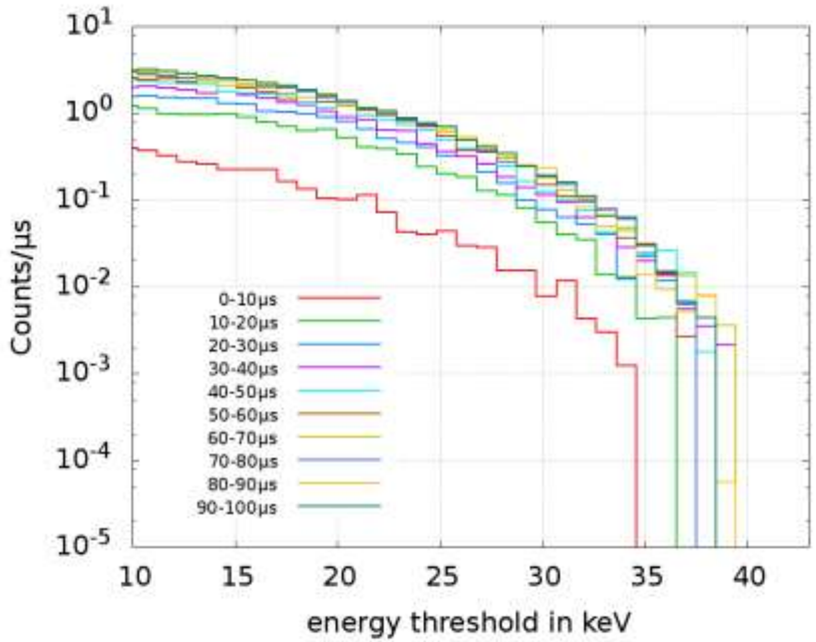
Comparison: Grid/Generator-Pulsing

Generator-Pulsing



- Timeframe Δt **100 µs**
- Full energy after approx.: 600 µs

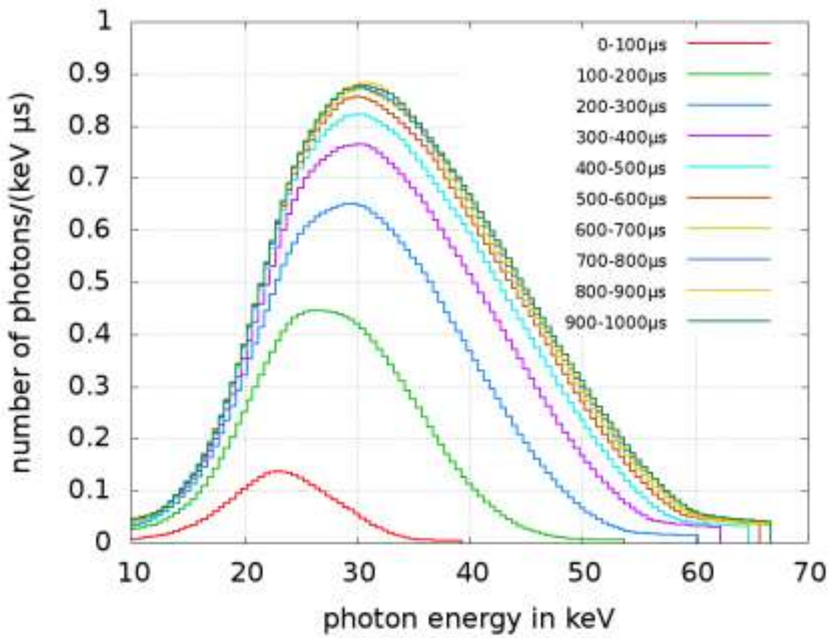
Grid-Pulsing



- Timeframe Δt **10 µs**
- Full energy after approx.: 25 µs

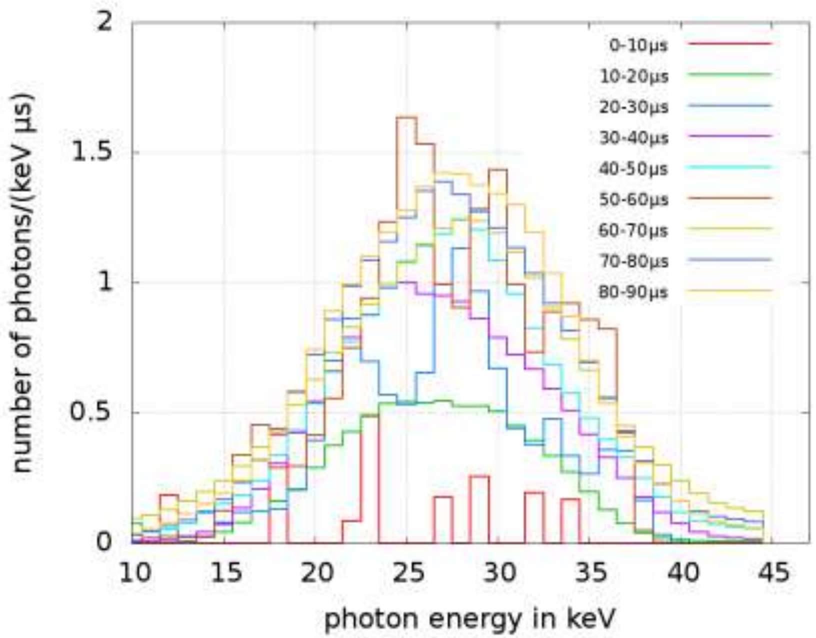
Comparison: Grid/Generator-Pulsing

Generator-Pulsing



- Timeframe Δt **100 µs**
- Full energy after approx.: 600 µs
- Full intensity after approx.: 600 µs
- Number of pulses: 45000
  per threshold: 150

Grid-Pulsing



- Timeframe Δt **10 µs**
- Full energy after approx.: 25 µs
- Full intensity after approx.: 55 µs
- Number of pulses: 1000
  per threshold: 25

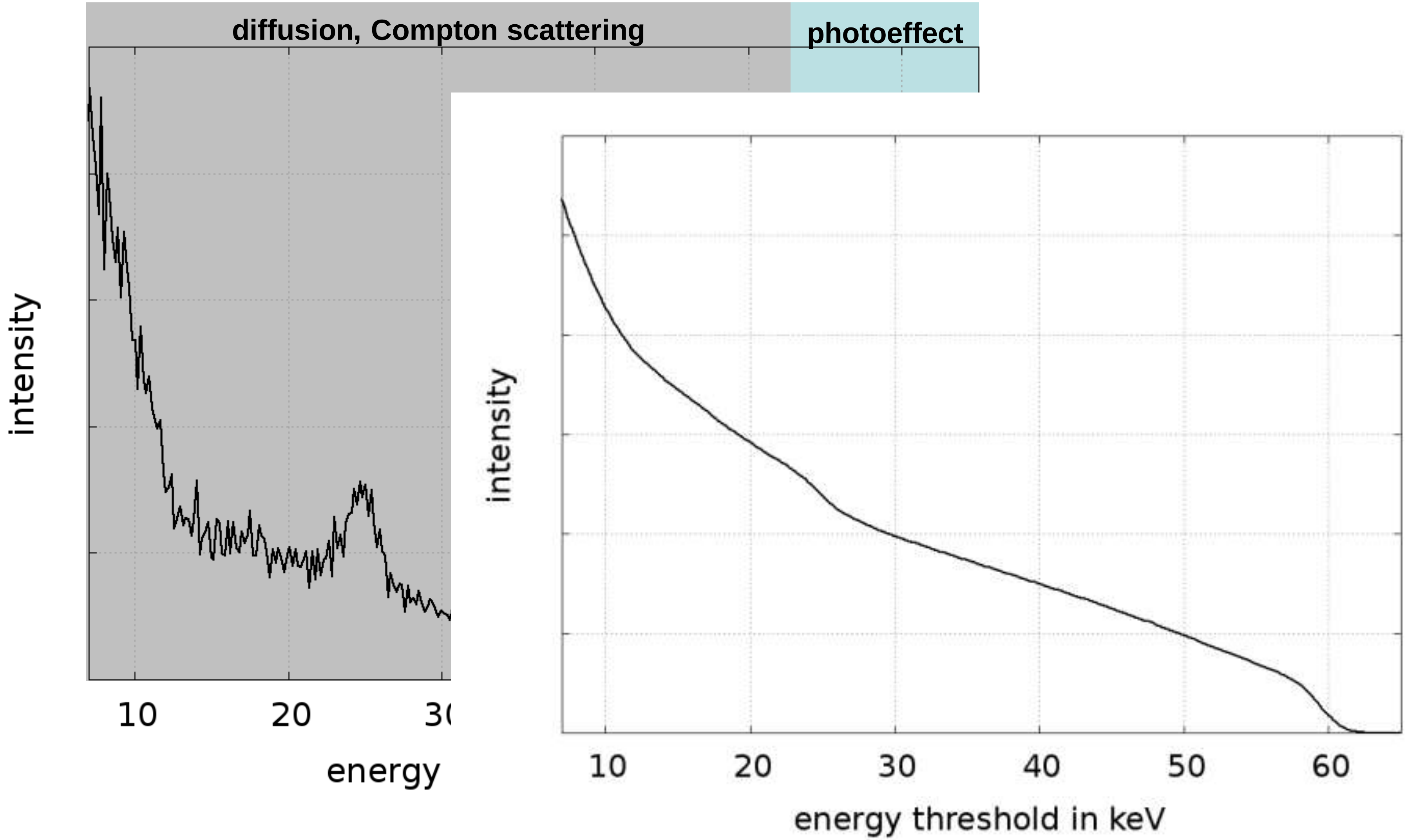
Summary

- Functional principle of Timepix detector
- Novel deconvolution method based on Bayesian statistics
- Spectrometry with time resolution of 10 µs
- No significant time-dependence of energy measureable for tubes operated in Grid-Pulsing mode

Pulse mode	Generator	Grid
Full energy after approx	600 µs	25 µs
Full intensity after approx	600 µs	55 µs

Thank you for your attention

Detector response



Deconvolution

$$M\left(E'_k\right) = \sum_i R\left(E'_k, E_i\right) \cdot T\left(E_i\right)$$

measurement (threshold-scan)

response-matrix

impinging spectrum

$$T_i^{(n+1)} = \frac{1}{\tau_i} T_i^{(n)} \sum_k \frac{R_{ki} \cdot M_k}{\sum_j R_{kj} \cdot T_j^{(n)}}$$

$$\tau_i = \sum_k R_{ki}$$

Bayesian deconvolution

$$P(A|B) = \frac{P(B|A) \cdot P(A)}{P(B)}$$

$$P(T_i | M_k) = \frac{P(M_k | T_i) \cdot P(T_i)}{P(M_k)} \qquad (1)$$

$$P(M_k)P(T_i | M_k) = P(T_i)P(M_k | T_i)$$

Bayesian deconvolution

$$\sum_i P(M_k)P(T_i \mid M_k) = \sum_i P(T_i)P(M_k \mid T_i)$$

$$P(M_k)\underbrace{\sum_i P(T_i \mid M_k)}_{=1} = \sum_i P(T_i)P(M_k \mid T_i)$$

$$P(M_k) = \sum_i P(T_i)P(M_k \mid T_i) \qquad (2)$$

$$\sum_k P(T_i)P(M_k \mid T_i) = \sum_k P(M_k)P(T_i \mid M_k)$$

$$P(T_i)\sum_k \underbrace{P(M_k \mid T_i)}_{=\varepsilon_i \neq 1} = \sum_k P(M_k)P(T_i \mid M_k)$$

$$P(T_i) = \frac{1}{\varepsilon_i}\sum_k P(M_k)P(T_i \mid M_k) \qquad (3)$$

Bayesian deconvolution

$$P(T_i \mid M_k) = \frac{P(M_k \mid T_i) \cdot P(T_i)}{P(M_k)}$$

(1)

$$P(M_k) = \sum_i P(T_i) P(M_k \mid T_i)$$

(2)

$$P(T_i) = \frac{1}{\varepsilon_i} \sum_k P(M_k) P(T_i \mid M_k)$$

(3)

$$P(T_i) = \frac{1}{\varepsilon_i} \sum_k \frac{P(M_k \mid T_i) \cdot P(T_i) \cdot P(M_k)}{\sum_j P(M_k \mid T_j) \cdot P(T_j)}$$

Bayesian deconvolution

$$P(T_i) = \frac{1}{\varepsilon_i} \sum_k \frac{P(M_k \mid T_i) \cdot P(T_i) \cdot P(M_k)}{\sum_j P(M_k \mid T_j) \cdot P(T_j)}$$

$$P^{(n+1)}(T_i) = \frac{1}{\varepsilon_i} P^{(n)}(T_i) \sum_k \frac{P(M_k \mid T_i) \cdot P(M_k)}{\sum_j P(M_k \mid T_j) \cdot P^n(T_j)}$$

Bayesian deconvolution

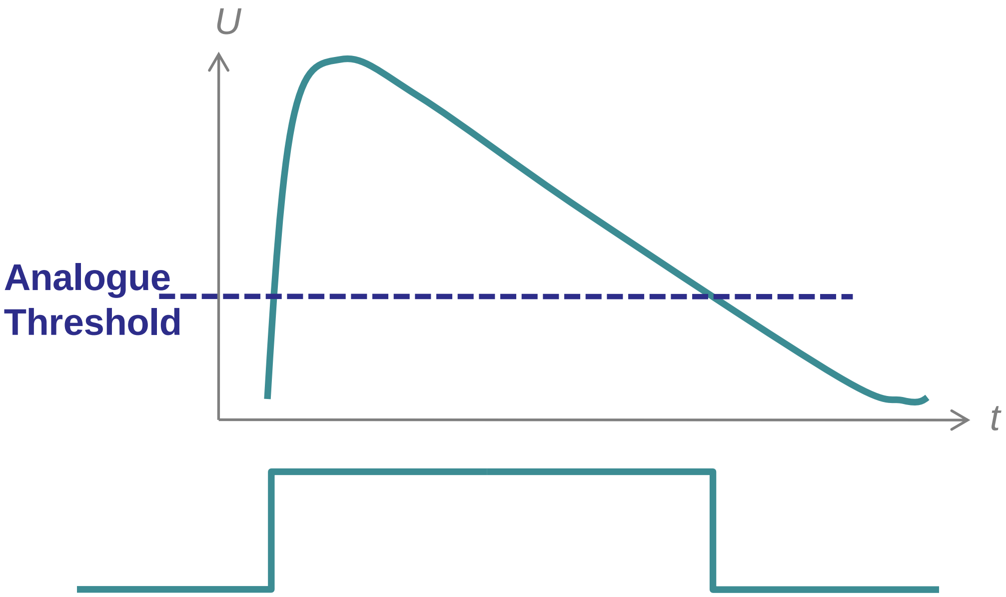
$$T_i^{(n+1)} = \frac{1}{\varepsilon_i} T_i^{(n)} \sum_k \frac{R_{ki} \cdot M_k}{\sum_j R_{kj} \cdot T_j^{(n)}}$$

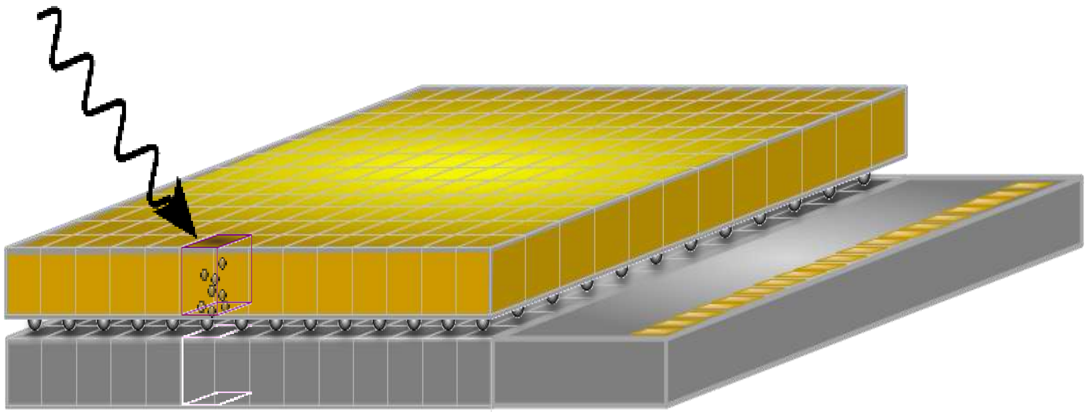
$$\varepsilon_i = \sum_k R_{ki}$$

$$\chi^2 = \frac{\sum_{k=1}^{U} \left(\frac{M_k^{(n+1)} - M_k}{\sigma(M_k)} \right)^2}{U} \overset{!}{=} 1$$

$$M_k^{(n+1)} = \sum_i R_{ki} T_i^{(n+1)}$$

Functional principle





Source: Winnie Wong