Friedrich-Alexander-Universität
Erlangen-Nürnberg

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

Deconvolution of Spectra of High-Flux Mixed Radiation Fields with Dosepix

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Hamburg, 22.05.2023

Outline

– FLASH Therapy

– Laser induced plasma shocks

– The Dosepix Detector

– Existing Few-Channel-Spectrometer with TLDs

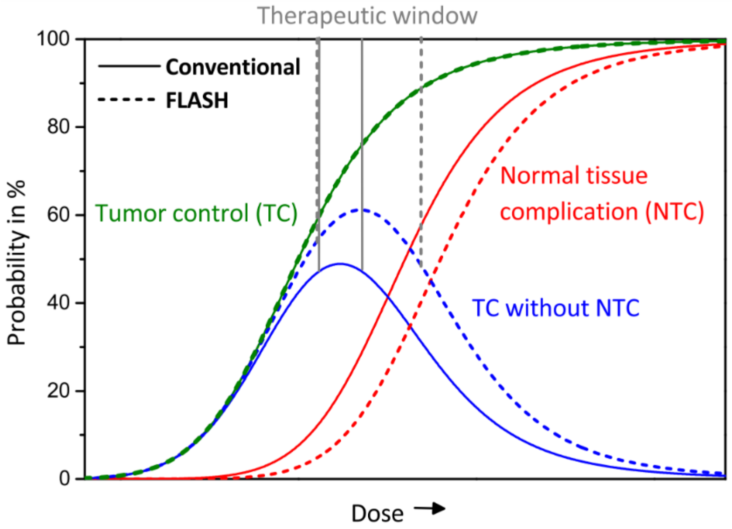
– Dosepix Spectrometer

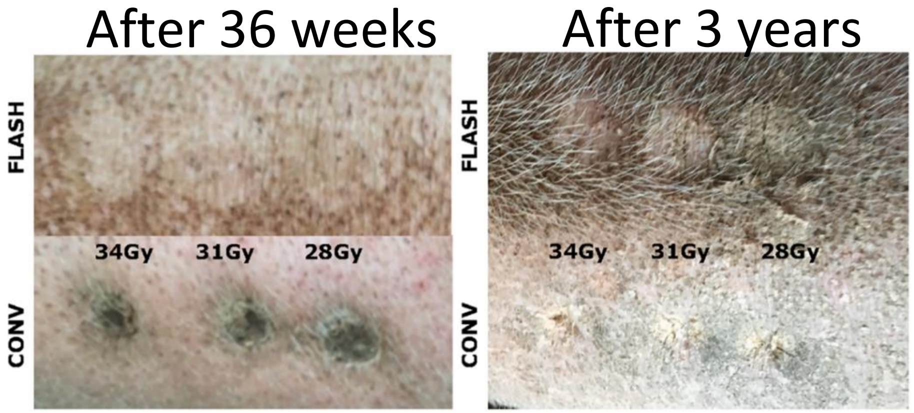
– First Results

– Conclusion and Outlook

FLASH Radiotherapy

- High dose rates (several Gy/s)
- Conventional radiotherapy: maximal 0.4 Gy/s
- Reduction of normal tissue complication (FLASH effect)
- Tumor control similar to conventional radiotherapy
- Larger therapeutic window

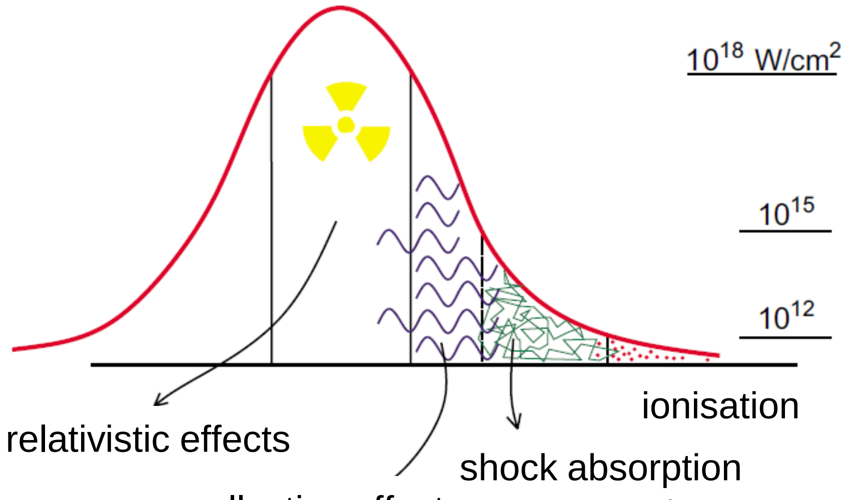




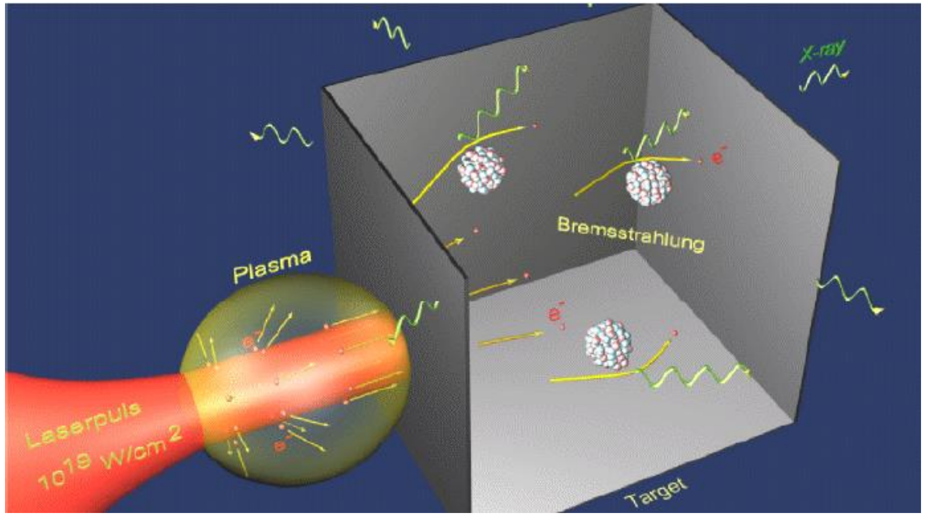
Schüller et al.: "The European Joint Research Project UHDpulse – Metrology for advanced radiotherapy using particle beams with ultra-high pulse dose rates" In: Physica Medica 80 (2020), S. 134–150

Laser Induced Plasma Shocks

- Shots of very-high intensity laser into material
- Production of plasma
- Emission of mixed particle signals (mostly electrons & photons)
- Similar to solar processes
- Exact combination unclear
- No active device existing



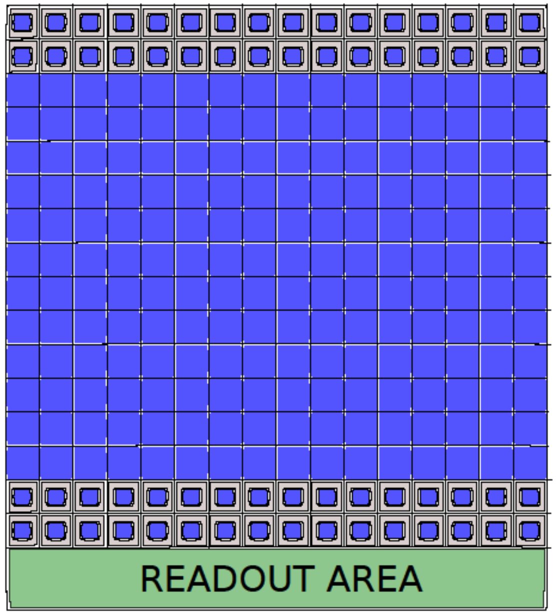
Dr. H. Schwoerer, IOQ Jena



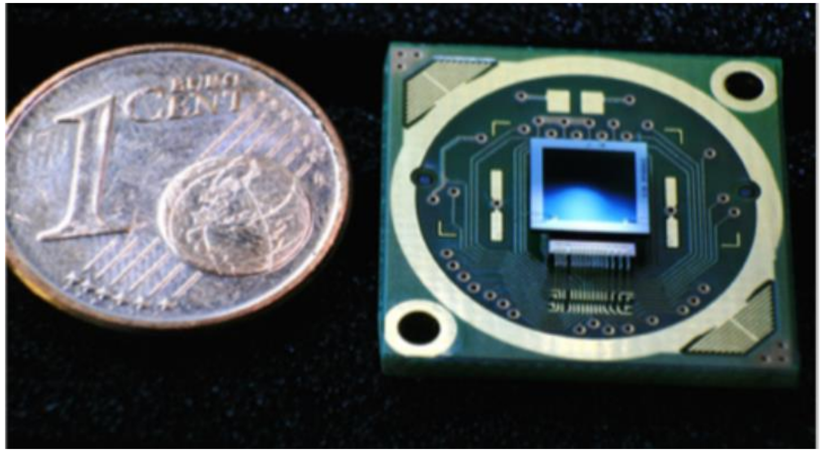
F. Ronneberger, IOQ Jena

The Dosepix Detektor

- Hybrid pixelated x-ray detektor
- Developed by collaboration of Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU) and CERN
- 300 µm thick p-in-n doped silicon sensor layer
- 16×16 quadratic pixels
  - Pixel pitch: 220 µm
  - 192 large pixels (edge length 220 µm)
  - 64 small pixels (edge length 55 µm)
  - Area: $3.52\ \mathrm{mm} \times 3.52\ \mathrm{mm}$
- Energy threshold: ≈ 10 keV



Quelle: Dennis Haag: Active personal dosimetry with the hybrid pixelated DOSEPIX detector, 2018



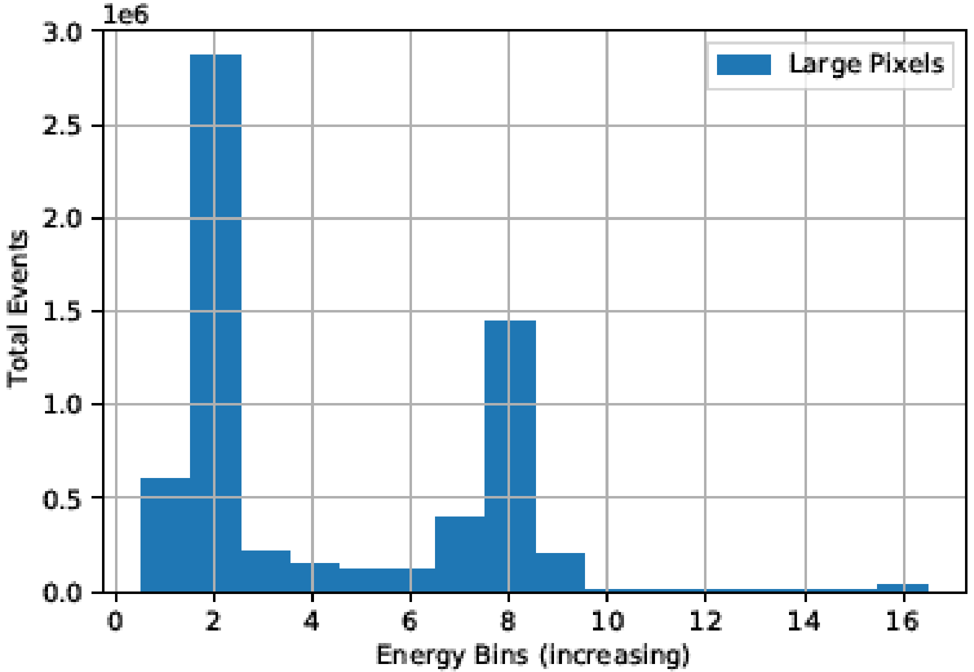
Quelle: Thomas Gabor: Simulationen und Experimente zur Anwendung eines neuartigen spektroskopischen Pixeldetektors in der Personendosimetrie, 2012

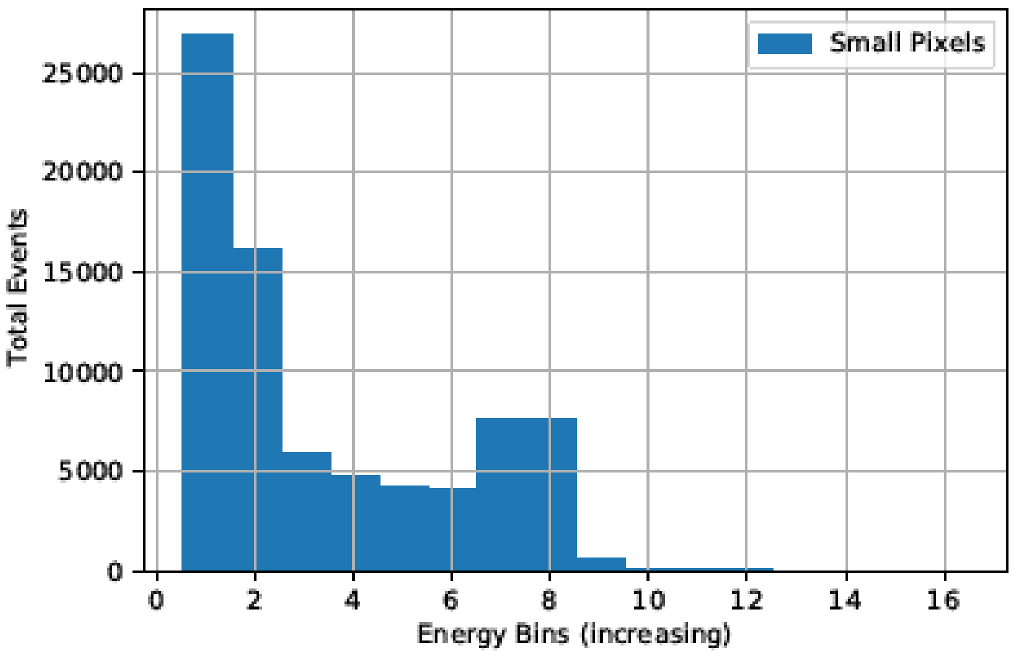
The Dosepix Detector
Energy-Binning Mode

– Hardware histogramming: Sorting *ToT*-events pixelwisely into 16 energy bins

– Energy thresholds: (12, 15, 20, 25, 30, 35, 40, 50, 60, 70, 80, 90, 100, 110, 130, 150) keV

– Exemplary spectrum of $^{241}_{95}\mathrm{Am}$ + Mo-XRF target





Existing Few-Channel Spectrometer

– Device for spectral reconstruction

– Usability in mixed photon and electron fields

– Optimised for short high-dose pulses (Laser-induced plasmas)

– Deconvolution not perfect

– Laborious read-out

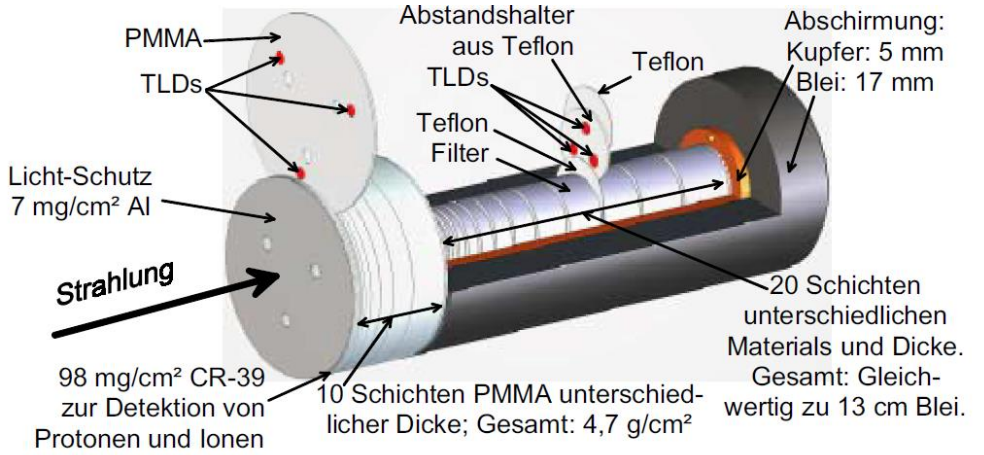
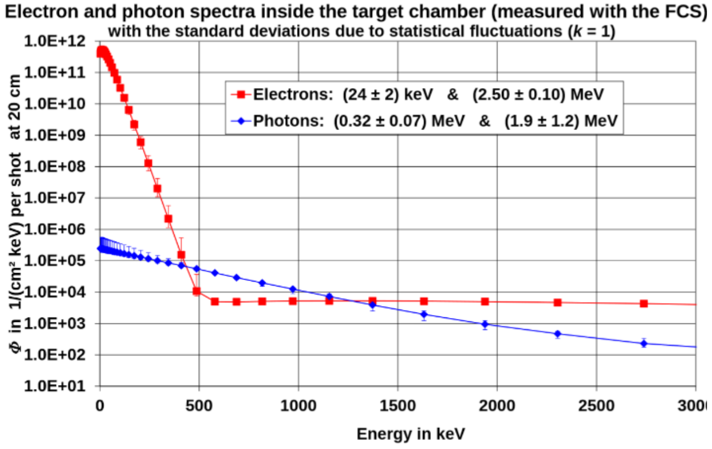
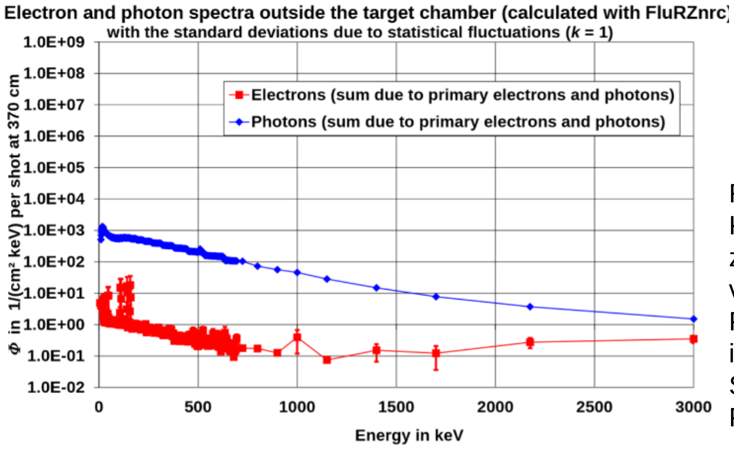


Abbildung 4-3: Aufbau des Wenig-Kanal-Spektrometers. Abmessungen: Länge: 21 cm; Durchmesser: 7 cm; Gewicht: 7 kg. Grafik: B. Pullner, PTB Braunschweig, FL 6.31.





R. Behrens: Wenig-Kanal-Spektrometer zur Messung von Elektronen- und Photonenspektren in ultrakurz gepulsten Strahlungsfeldern, PTB, 2003

R. Behrens et al: Radiation measurements and simulations at the PHELIX laser facility, GSI, 2022

Existing Few-Channel-Spectrometer

Spectral Reconstruction via Deconvolution

– Solving equation: $D_i^{\text{mess}} \stackrel{!}{=} D_i^{\text{rech}} = \sum_{j=1}^{M} R_{i,j}^{\text{El}} \cdot \Phi_j^{\text{El}} + \sum_{j=1}^{M} R_{i,j}^{\text{Ph}} \cdot \Phi_j^{\text{Ph}}$

– D_i^{mess} Dose in layer *i*, $R_{i,j}^{[\cdot]}$ Response in layer *i* for particle from energy bin *j*, $\Phi_j^{[\cdot]}$ fluence of energy bin *j*

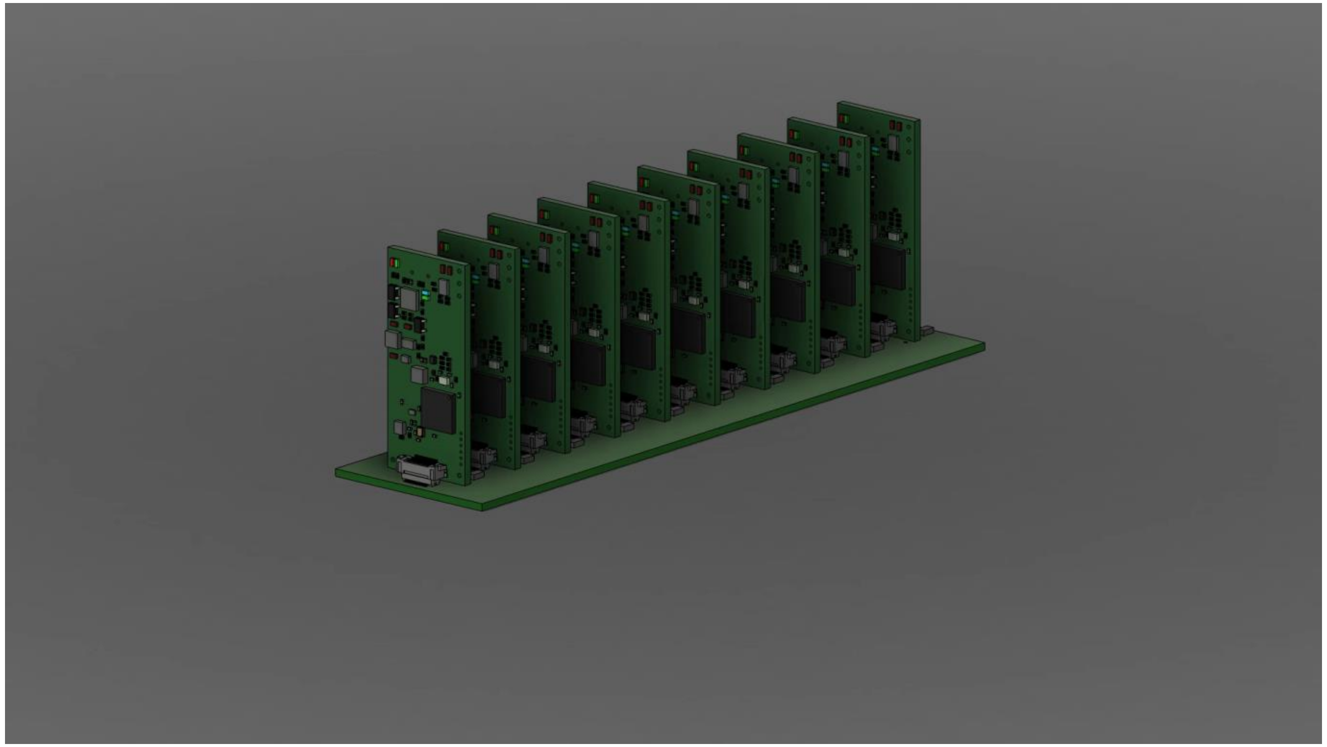
– Energy bins: $E_{j+1} = E_j + \Delta E_j$ mit $E_{j+1} = 1{,}1885 \times E_j$, *j*=1….60, $E_1 = 3{,}0$ keV

– Pre-given information: $\Phi_j^{\text{El}} = a_1^{\text{El}} (k_B T_1)^{-\frac{3}{2}} \sqrt{E_j^{\text{El}}} \mathrm{e}^{-\frac{E_j^{\text{El}}}{k_B T_1}} + a_2^{\text{El}} (k_B T_2)^{-\frac{3}{2}} \sqrt{E_j^{\text{El}}} \mathrm{e}^{-\frac{E_j^{\text{El}}}{k_B T_2}}$

– $\Phi_j^{\text{Ph}} = a_1^{\text{Ph}} \mathrm{e}^{-\frac{E_j^{\text{Ph}}}{k_B T_1}} + a_2^{\text{Ph}} \mathrm{e}^{-\frac{E_j^{\text{Ph}}}{k_B T_2}}$ → 8 parameters for deconvolution

Dosepix Spectrometer
General Idea

- 10 Dosepix detectors in line
- Filters with varying material and thicknesses
- Combined Read-out
- Currently: Allpix-Squared Simulation

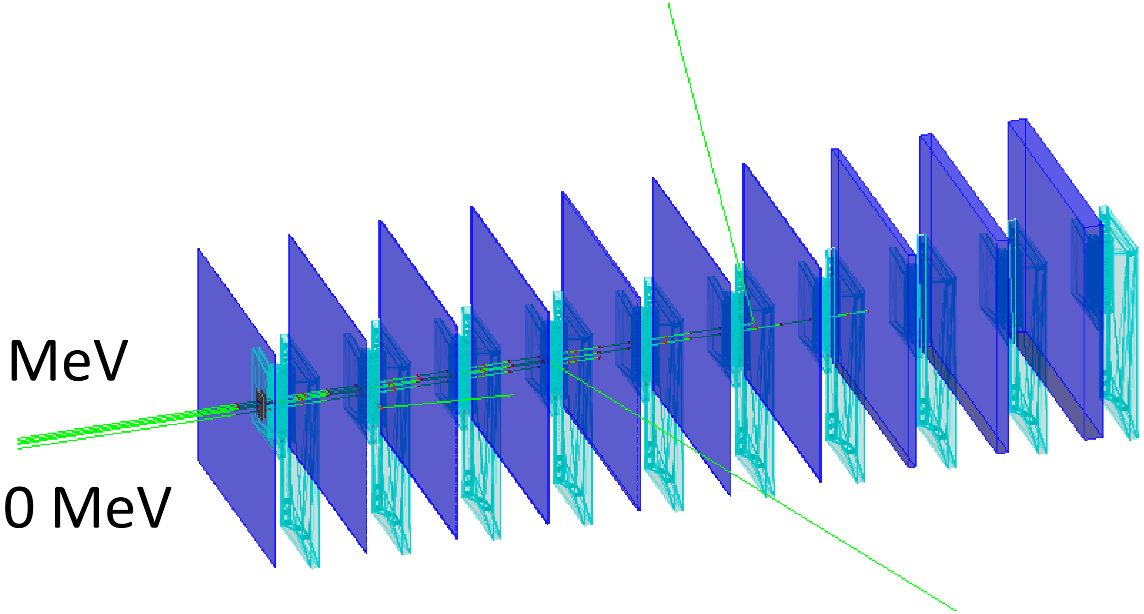


Video by Thomas Kurin

Dosepix Spectrometer

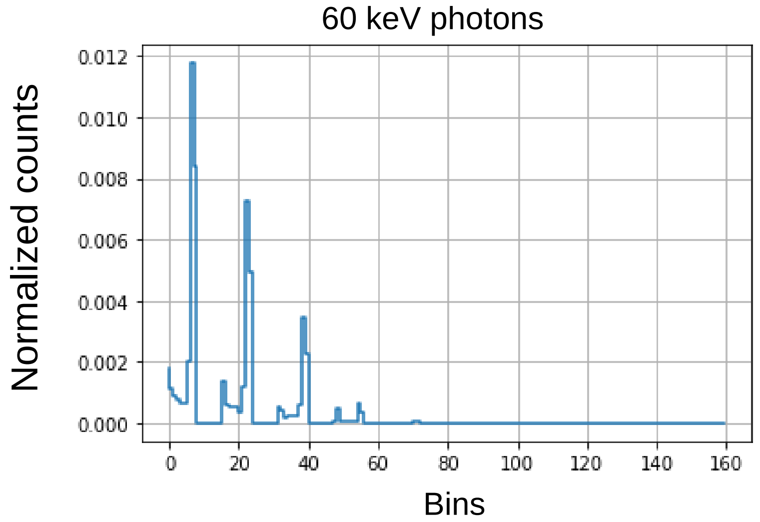
Simulated Setup

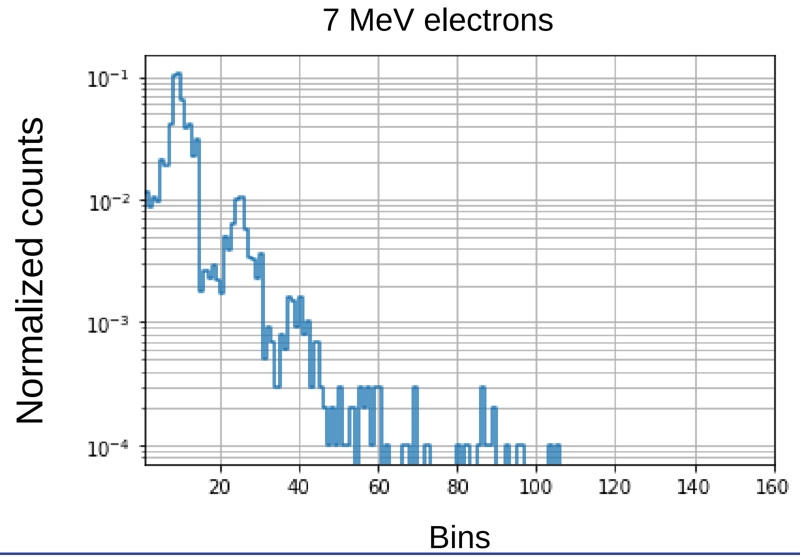
- Filter combinations inspired by TLD-spectrometer
- 1 cm lead surrounding on five sides
- Total length: 20 cm
- Monoenergetic photons from 15 keV to 1.5 MeV
- Monoenergetic electrons from 120 keV to 20 MeV
- N-series radiation qualities acc. to ISO 4037-1



Dosepix Spectrometer

- Detector output binned like Dosi-Mode data
- Energy deposition spectra from all detectors clinged together
- Currently: Photons and electrons separately
- Planned steps:
  - Combination of particles
  - Pile-up inclusion
  - Machine-learning based method

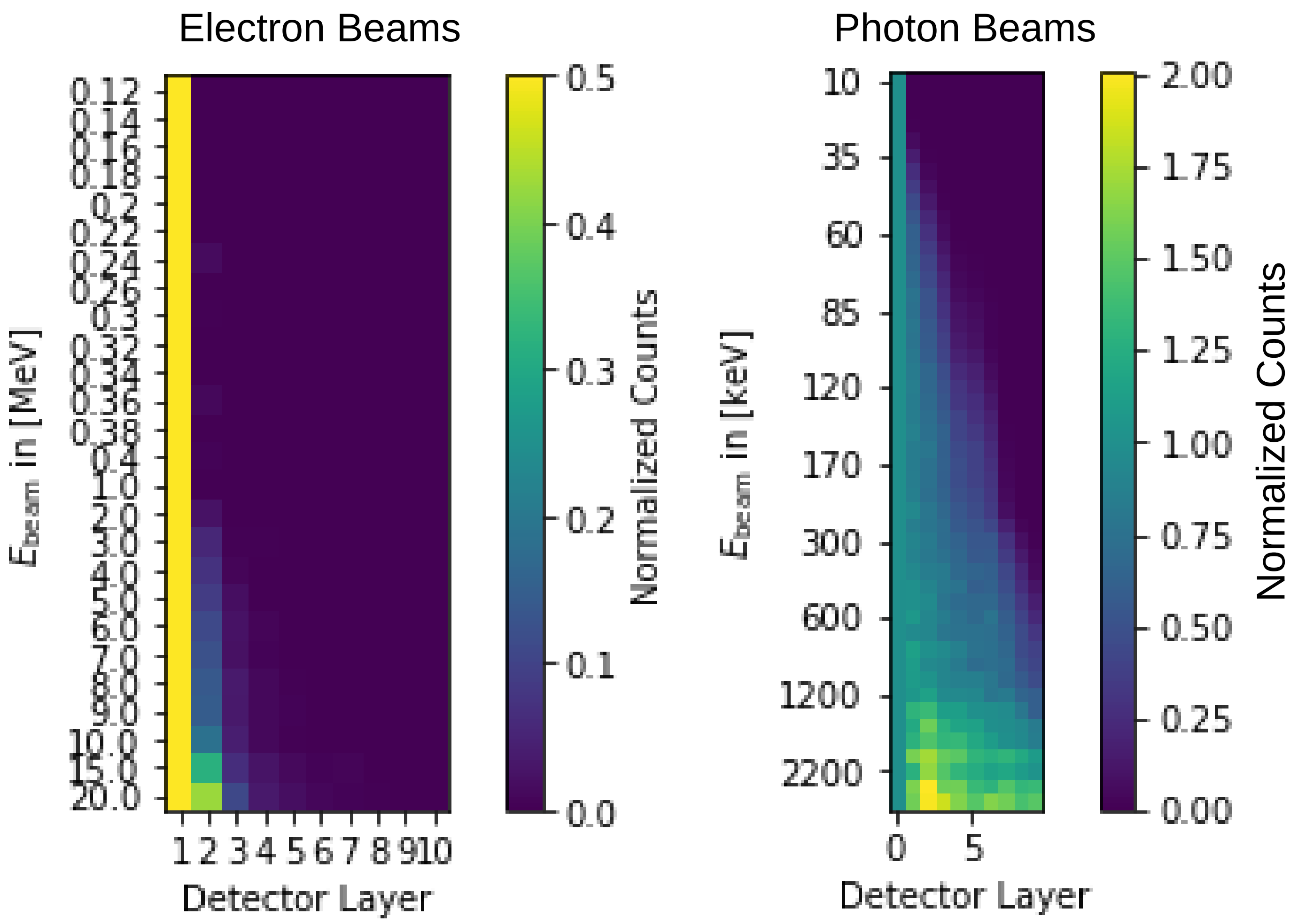




First Results

Transmission

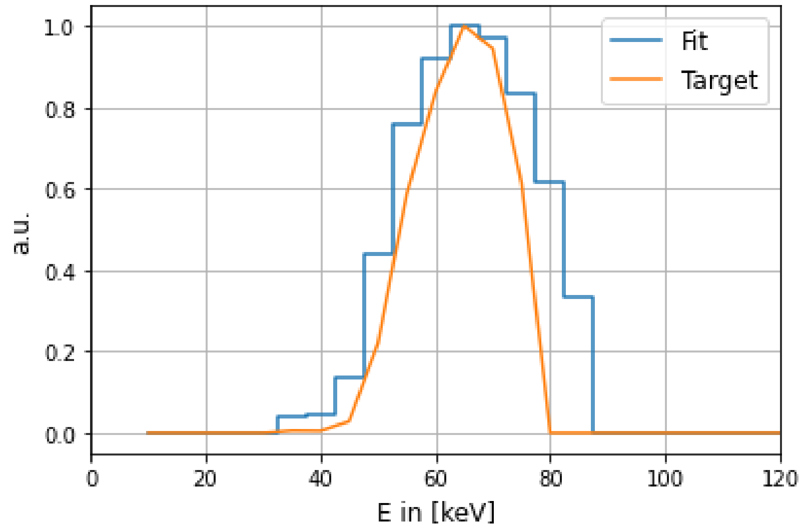
- Transmission behaviour for photons and electrons
- All detector layers required for aimed range of reconstructable energies
- Problem of high absorption of low energy electrons
- More layers might be beneficial

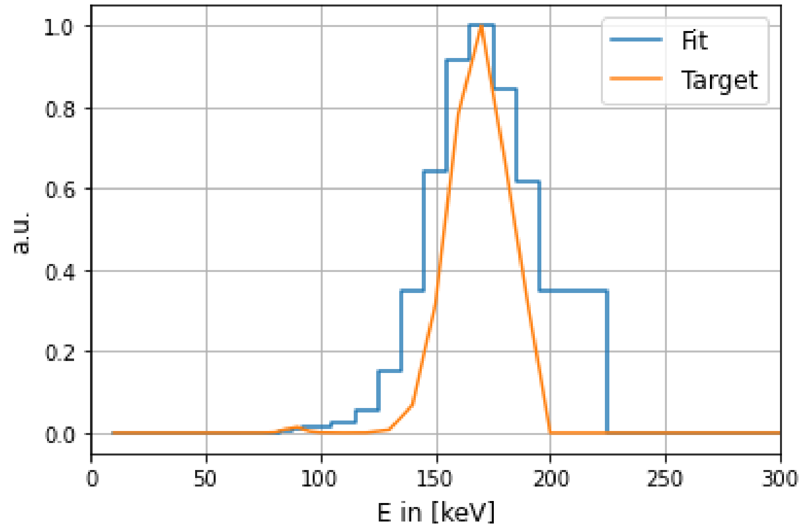


First Results

Photons

- Spectral reconstruction in continuous photon fields working adequately
- Increasing overestimation of energy maximum for higher energies
- Fluence determination flawed

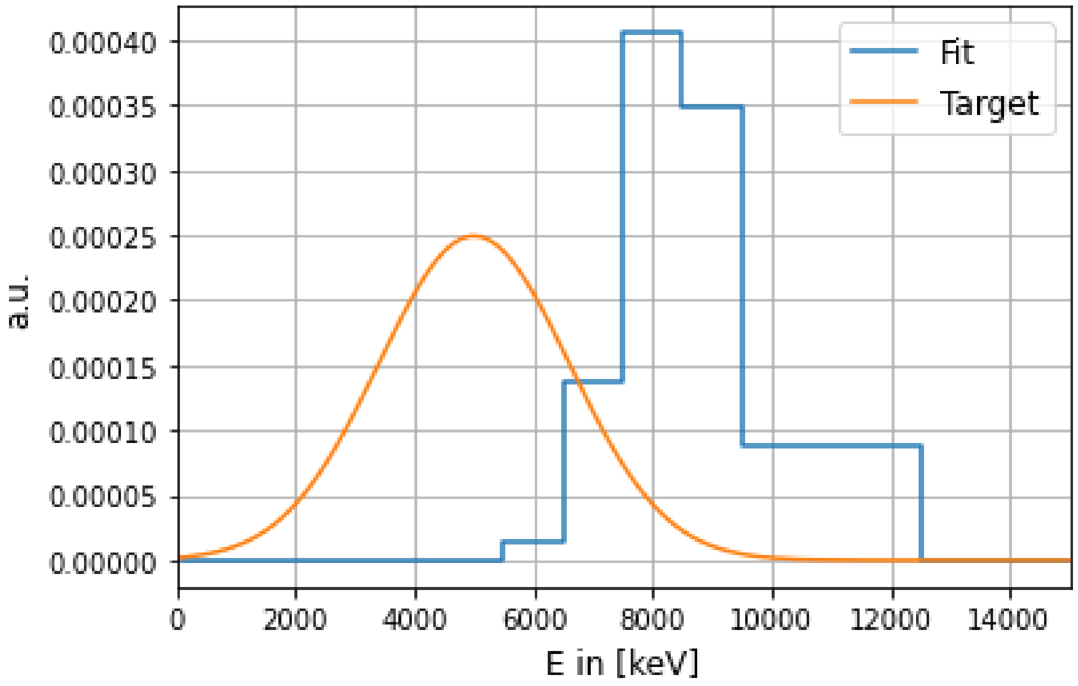




First Results

Electrons

- Several problems even in easiest scenario (continuous, non-mixed)
- Severe energy overestimation
- similar energy deposition spectra
- Large absorption in low-energy regime → little information



Conclusion and Outlook

- Simulation setup of Dosepix-based spectrometer
- Many challenges for spectral reconstruction, especially electrons
- Future steps:
  - Introduction of mixed radiation fields
  - Increasing dose rate → consideration of pile-up effects
  - Approach with Machine-Learning based reconstruction (proof of concept done for 3 DPX up to 120 keV photons)
- Building

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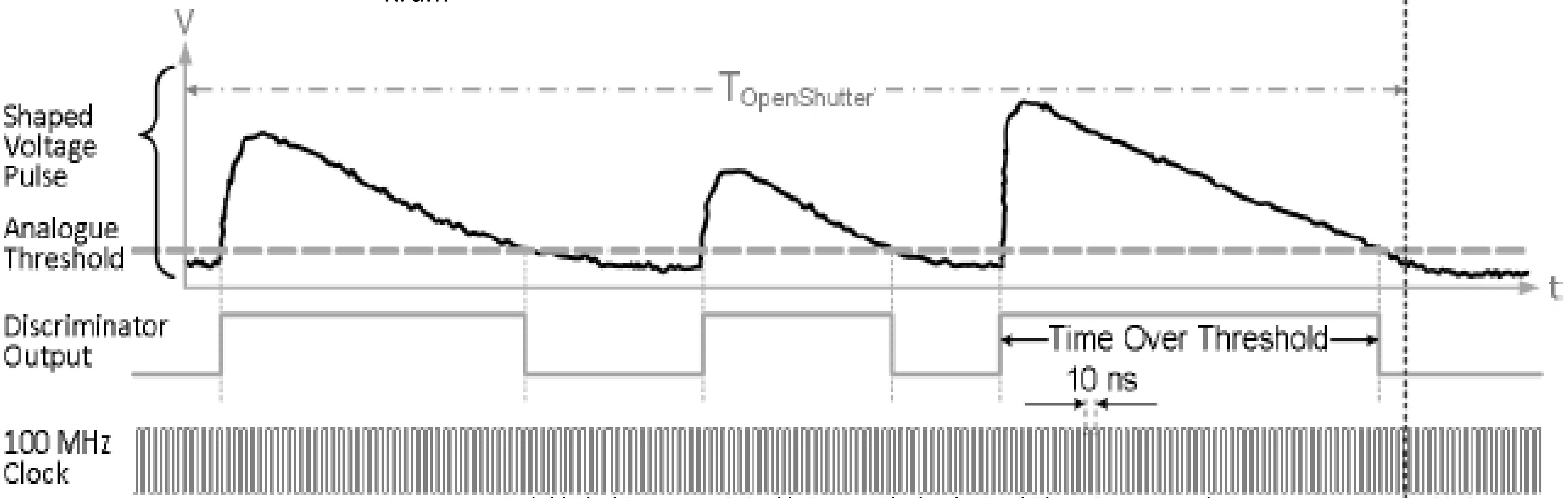
Thank You for Your Attention!

Bonus Slides

The Dosepix Detector
Time-over-Threshold (*ToT*)

- Measure of deposited energy
- Incoming voltage signal
- Discharge current I_{Krum}
- Reading clock cycles of 100 MHz Ref-Clk
- Number of cycles: *ToT*
- Procession in each individual pixel



W. Wong: A Hybrid Pixel Detector ASIC with Energy Binning for Real-Time, Spectroscopic Dose Measurements, 2012

Filter Combinations

0.025 mm Al

0.095 mm Al

0.24 mm Fe

0.24 mm Mo

0.51 mm Sn

0.1 mm Mo

0.2 mm Pb

1.45 mm Pb

2.5 mm Pb

4.0 mm Pb

Dosepix Spectrometer

Simulated Setup

- Focus on large pixels (12x16)
- Implementation of CSA-Digitizer module for total pile-up case
- Read-out hardware consisting of connector board and read-out hardware
- Approximation from existing Dosepix hardware and first drafts
- Might have large effect especially on electrons