Joint Institute for Nuclear Research

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Development of X-ray Monochromatization Devices for Per-Pixel Energy Calibration of Semiconductor Detectors

Speaker: Truong Hoai Bao Phi[a,b]

[a] Institute of Physics, Vietnam Academy of Science and Technology
[b] Joint Institute for Nuclear Research, Dubna

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  Operating principle, structure of developed system, supporting software.

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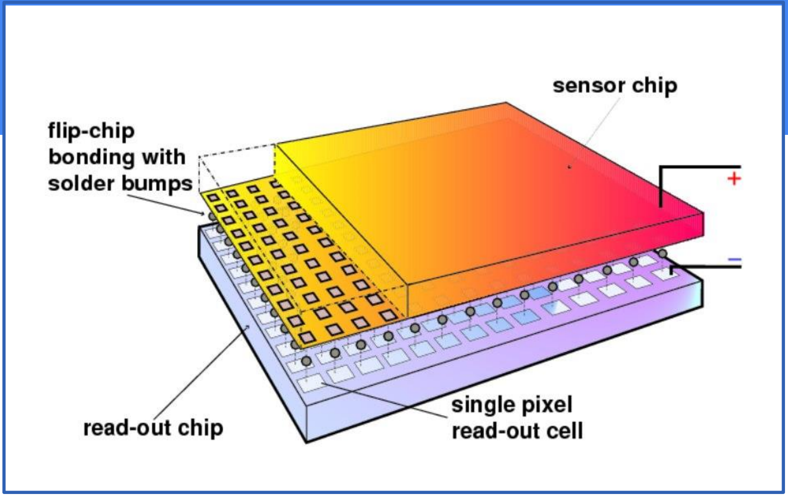
- Conclusions

Motivation



Semiconductor pixel detectors are used in:

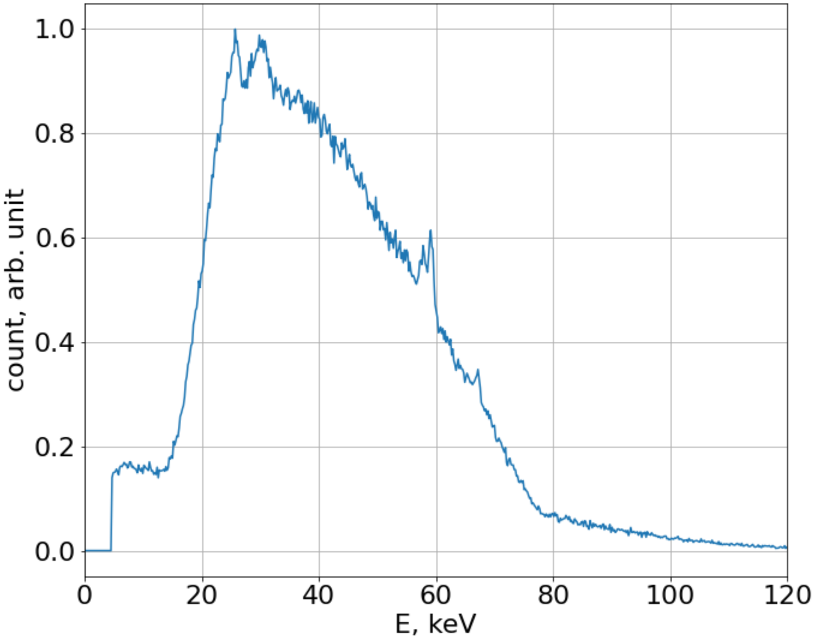
- High-energy physics
- Medical imaging
- Environmental radiation monitoring

Per-pixel procedure of energy calibration is required to achieve a good energy resolution.

To provide this procedure, monochromatic X-ray sources are needed.

Goal of this study: to develop devices for X-ray monochromatization and to investigate the capability of these devices to provide the energy calibration for semiconductor pixel detectors.

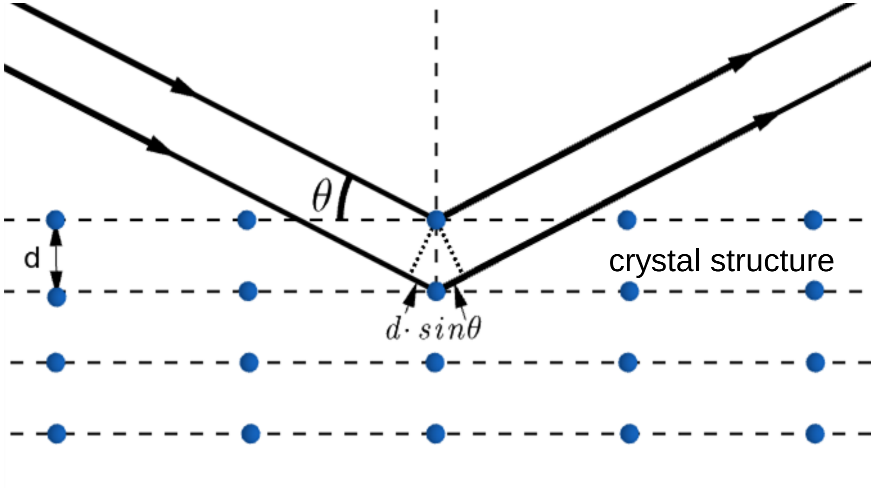
Introduction



Typical continuous spectrum of X-ray tube

(U = 80kV, I = 50uA, t = 20s, $E_{threshold}$ = 4.5keV)

Bragg's law



constructive interference when

$n \cdot \lambda = 2d \cdot \sin\theta$

$$E = \frac{n \cdot h \cdot c}{2 \cdot d \cdot sin\theta} \quad (1)$$

Introduction

1. X-ray tube

(anode: W, U=60-120kV, I=10-350uA)

2. Primary slit

(3-6mm)

3. Primary collimator

(copper tube: d = 30mm, D = 36mm, L = 56cm)

4. Secondary slit

(0-2mm horizontal, 0-3mm vertical)

5. Crystal

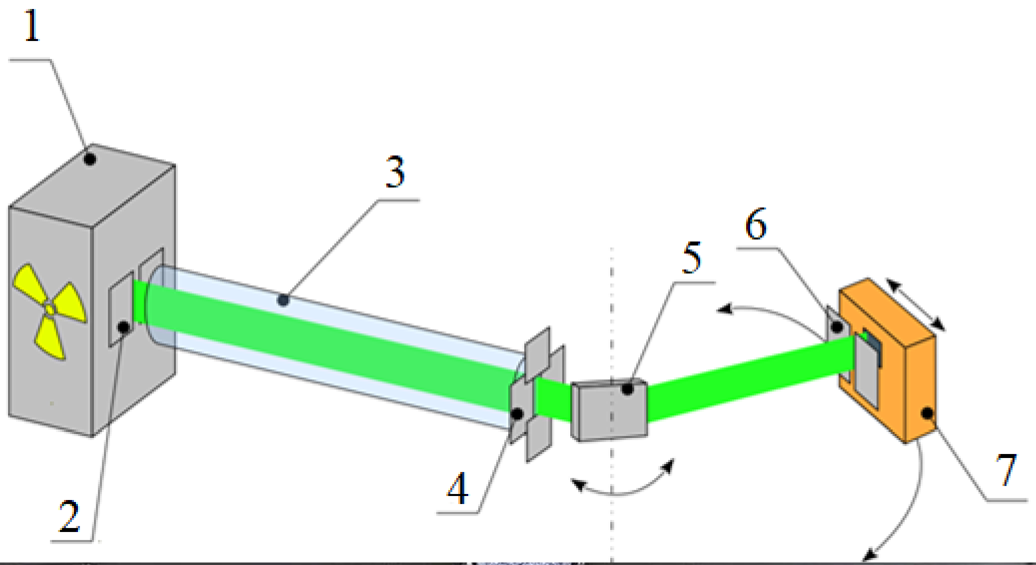
(graphite lattice)

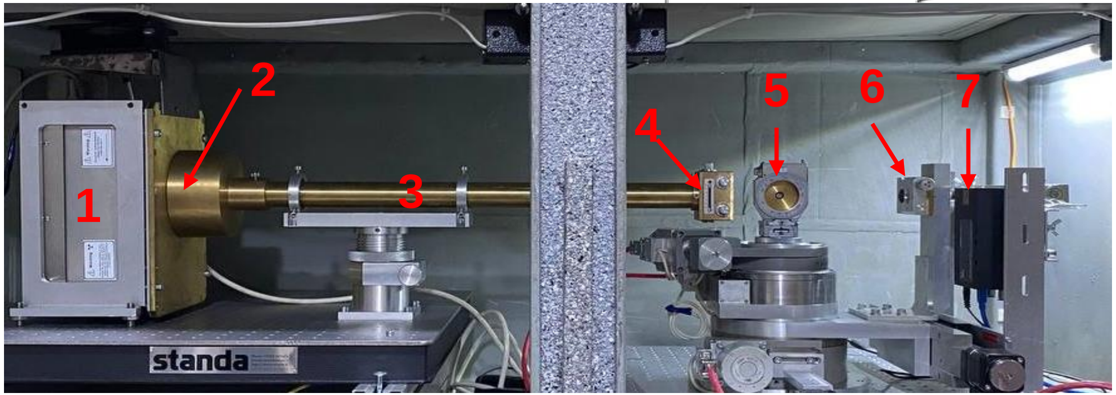
6. Secondary collimator

(0-5mm horizontal)

7. Detector

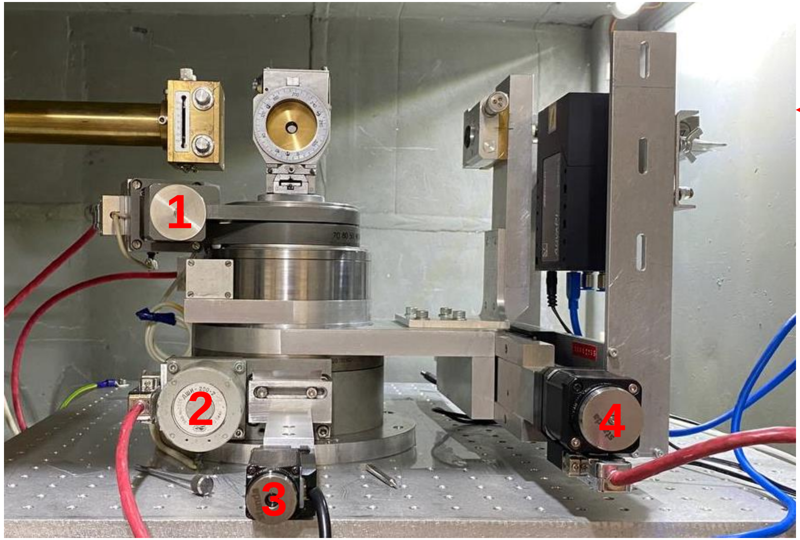
(any portable detectors)





Introduction

Control devices + software



4 motors for:

1. Rotational motion of the crystal
(1^0 = 4710 steps)

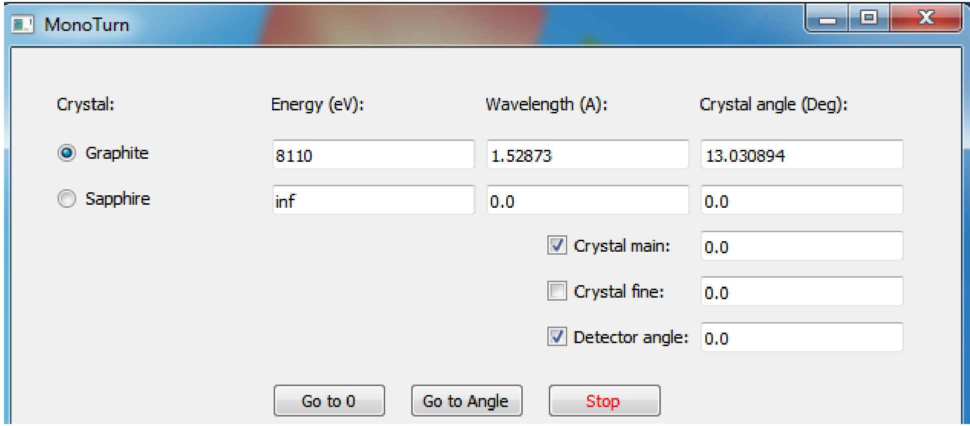
2. Precise rotational motion of the crystal
(1^0 = 55940 steps)

3. Rotational motion of the detector
(1^0 = 431 steps)

4. Translational motion of the detector
(1mm = 400 steps)

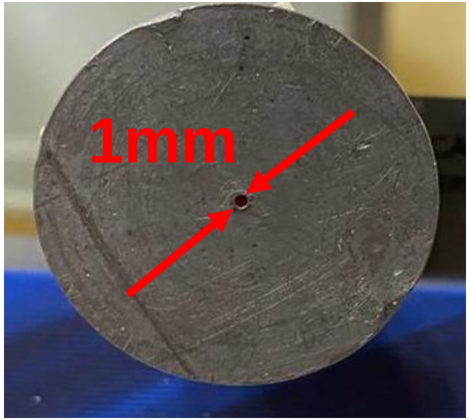
Control software:

- Input: the expected energy (eV)
- Run motors to needed angle



Measurements

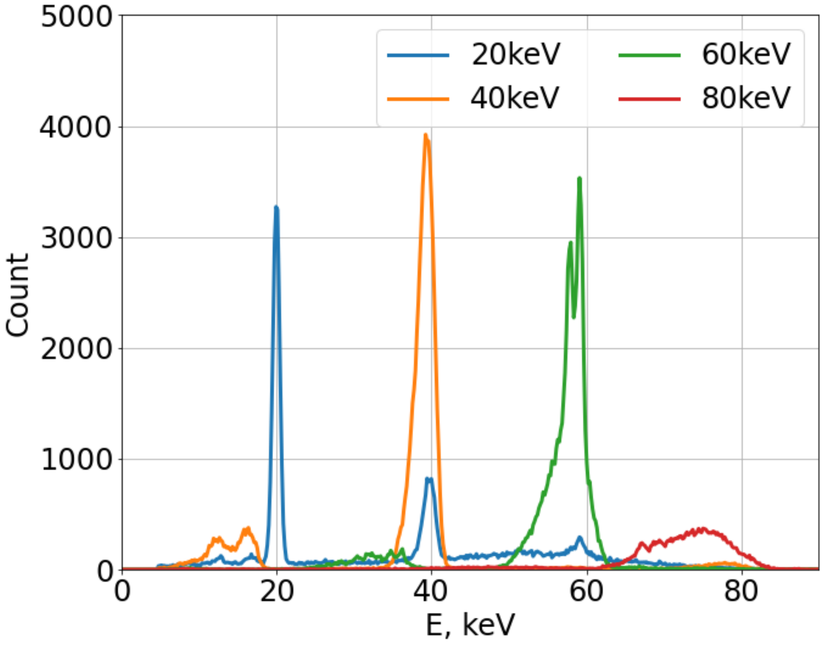
X-123CdTe Complete X-Ray & Gamma Ray Spectrometer



lead collimator

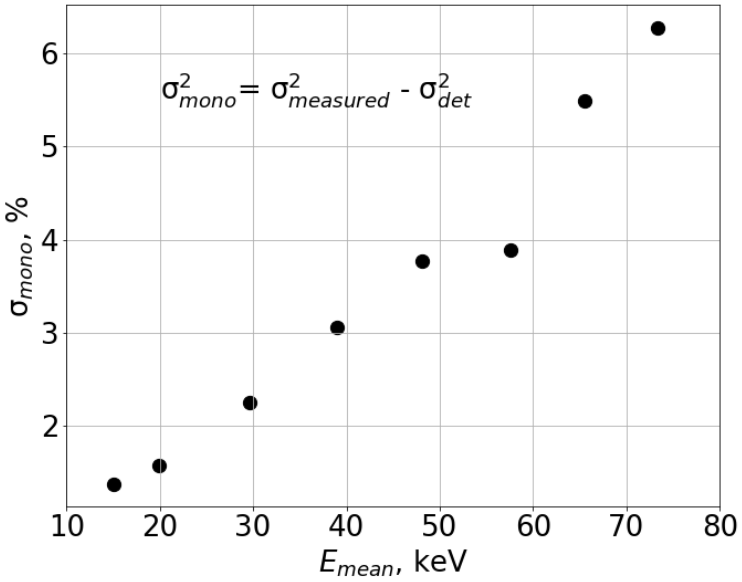
(thickness 3mm, diameter 1mm)

Measurements



Measured spectra at $E_{expected}$ = 20keV, 40keV, 60keV and 80 keV

detector X-123CdTe, lead collimator 1 mm, t = 20s

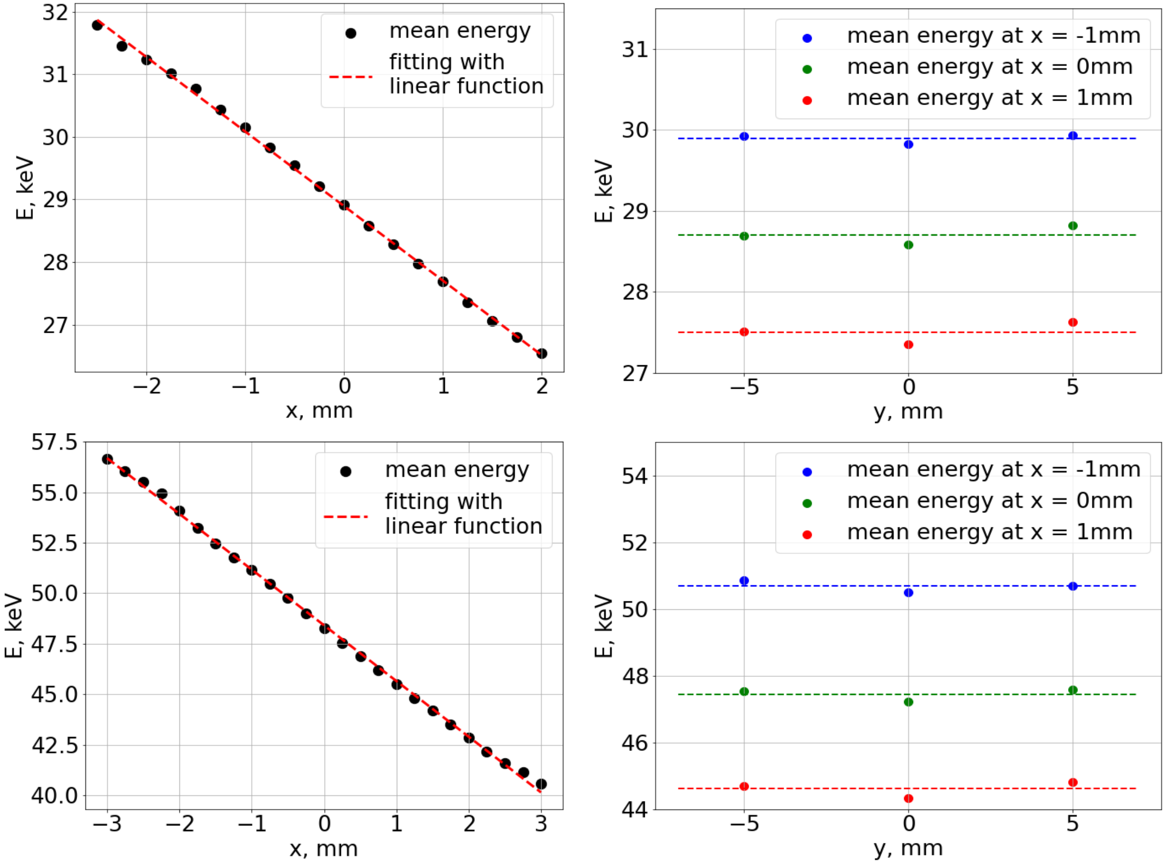


$\sigma_{measured}$	measured spectral standard deviation
σ_{det}	= FWHM detector/2.355 (1keV FWHM at 122 keV for X-123CdTe)
σ_{mono}	monochromaticity of the source

Measurements

@30keV

@50keV

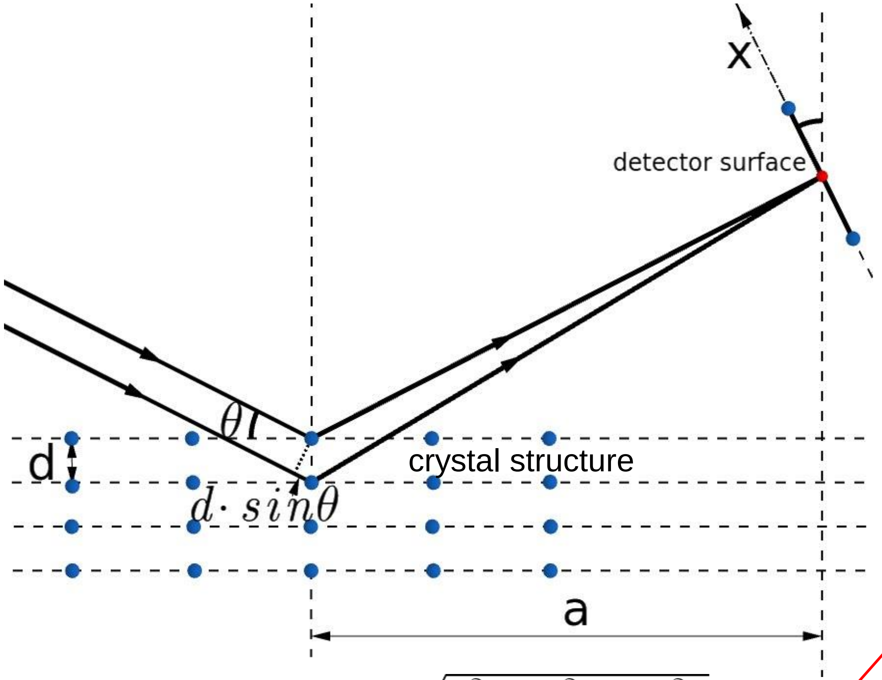


Measurements of energy distribution in x (horizontal) and y (vertical) directions at the output of monochromatic X-rays source show that, at any energy:

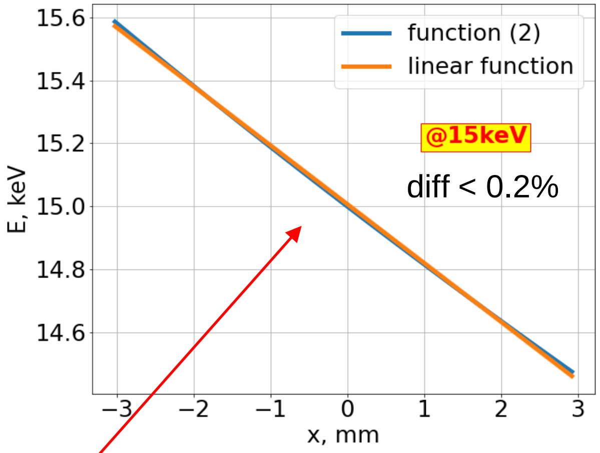
- In x direction: linear dependence is observed.
- In y direction: energy doesn’t change.

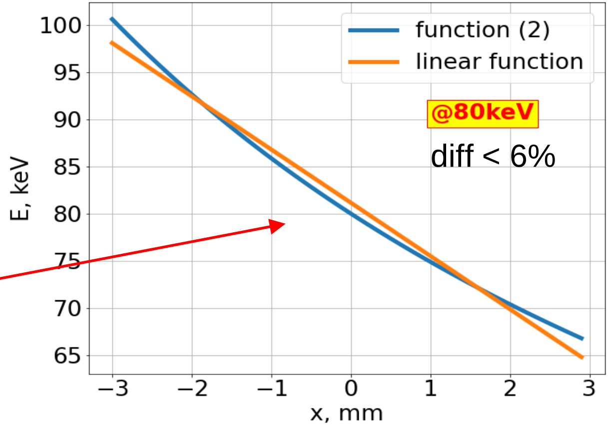
Measurements

Dependence of E on x: calculation

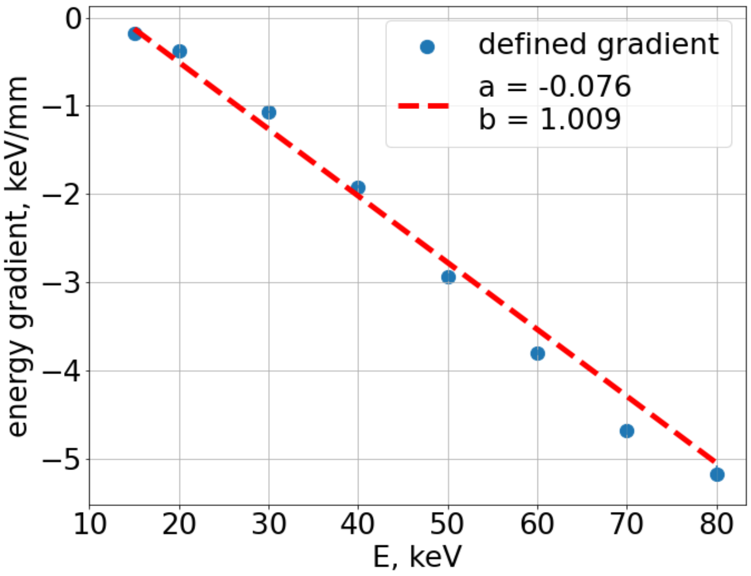


$$E = \frac{2 \cdot n \cdot h \cdot c \cdot \sqrt{a^2 + x^2 \cdot cos^2\theta}}{d \cdot (2 \cdot x \cdot cos\theta + 2 \cdot sin\theta \cdot \sqrt{a^2 + x^2 \cdot cos^2\theta})} \quad (2)$$





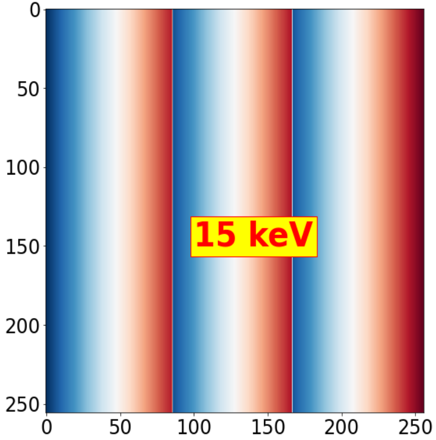
Measurements

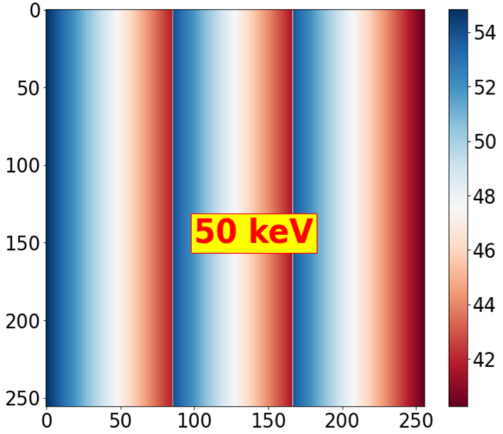


Energy gradient at different output energies

Energy map = energy at center pixel + gradient
By this way, energy of photon falling into every pixel is defined

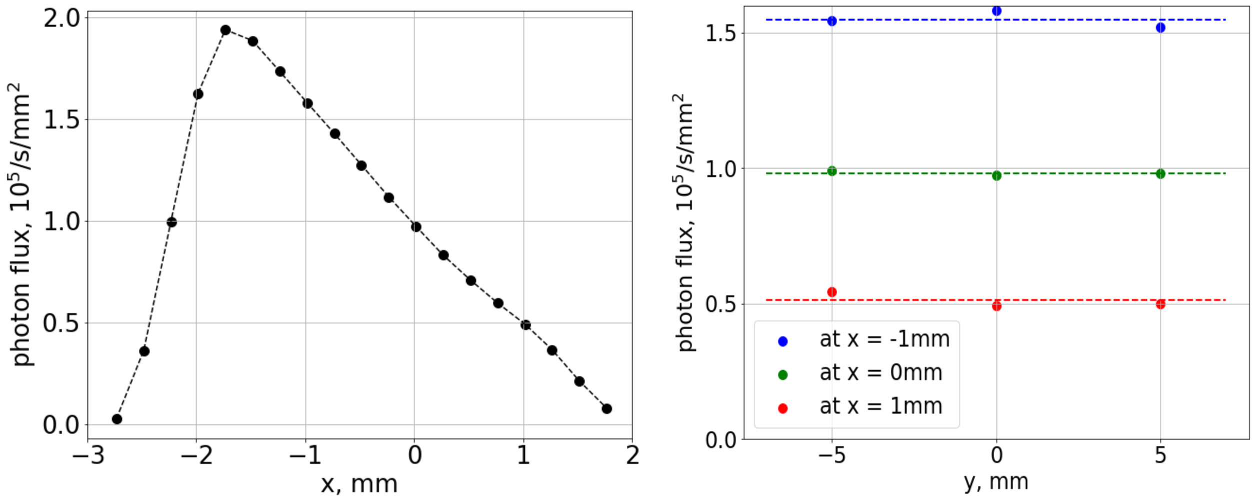
Energy point (keV)	Energy at center pixel (keV)	Gradient (keV/mm)
15	15.035 ± 0.828	-0.131
50	47.631 ± 2.150	-2.791





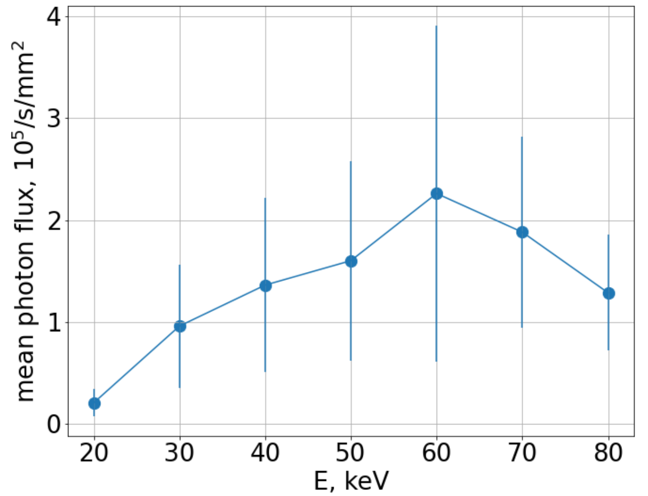
Measurements

Photon flux distribution



Photon flux distribution on x and y direction at 30keV

X-ray tube: 60kV, 200uA; t = 20s



Mean of photon flux depending on energy

High photon flux provides an ability to carry out the energy calibration procedure of pixel detectors, which need a high statistic at every pixel. In general, the output photon flux depends on the initial spectrum of X-rays tube and scattering ratio of radiation at specific wavelength.

Conclusions

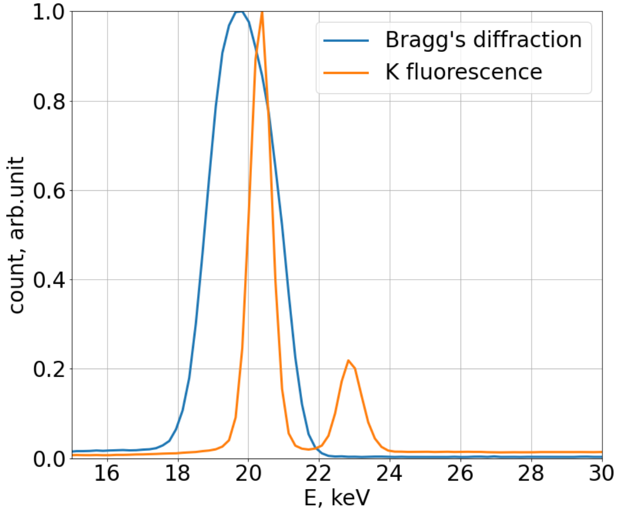
- Tunable X-rays monochromatic source was developed with an energy range of 15-80 keV and monochromaticity of 2-6%.
- Measurements on the energy and photon flux distributions was carried out.
- Providing an energy map, developed X-rays monochromatic source can be used to carry out the energy calibration procedure of semiconductor pixel detectors.

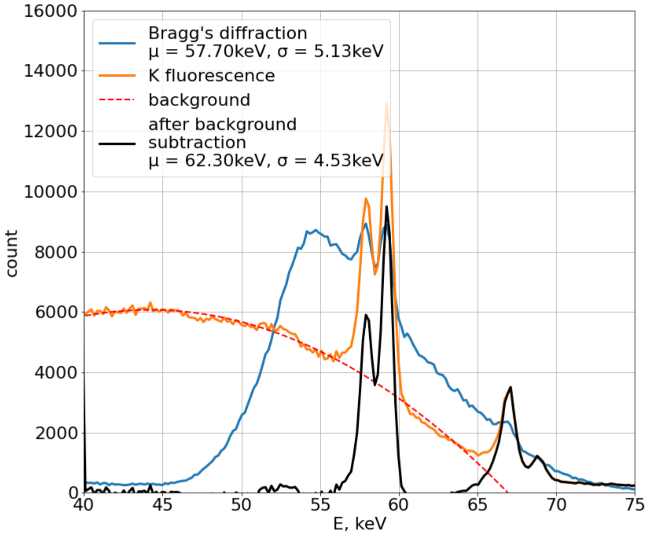
Thanks for your attention!

Comparison of monochromatic X-rays sources

Our devices (Bragg's diffraction) vs K fluorescence

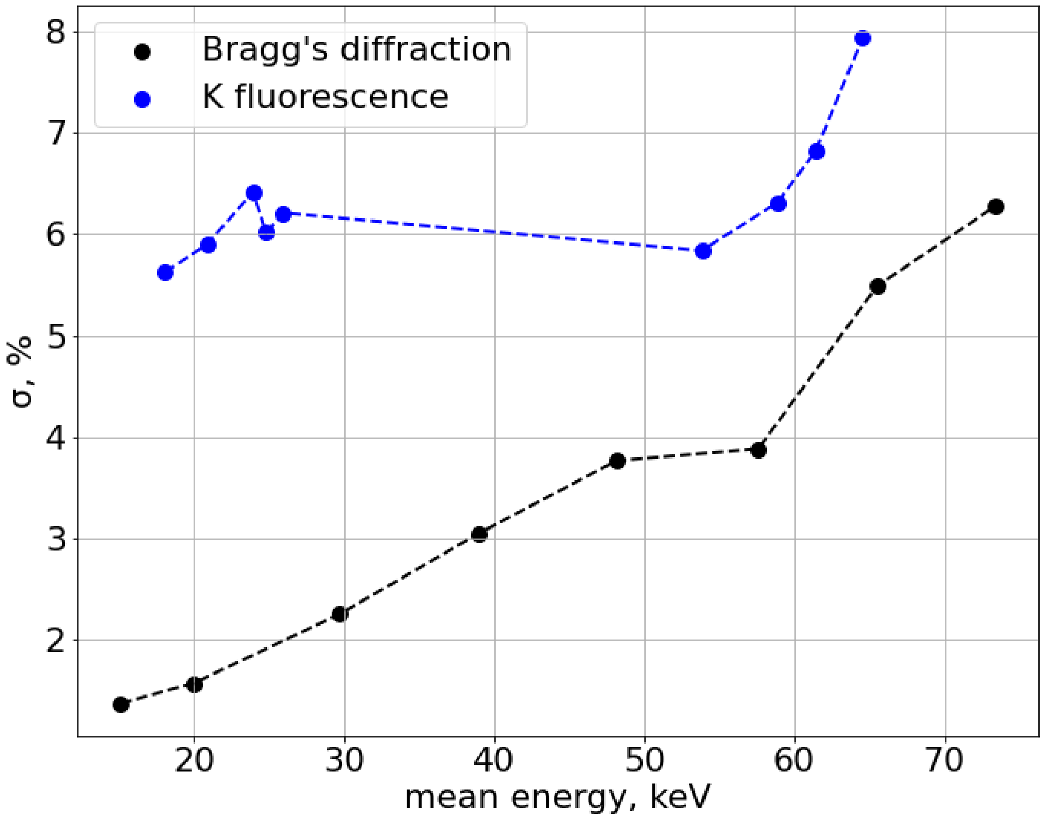
Used metal leaves	Output energies from our devices (keV)
Zr	15.78
Mo	17.48
Rh	20.22
Cd	23.17
In	24.21
Sn	25.27
	30
	40
	50
Yb	52.36
Ta	57.54
W	59.32
Re	61.13





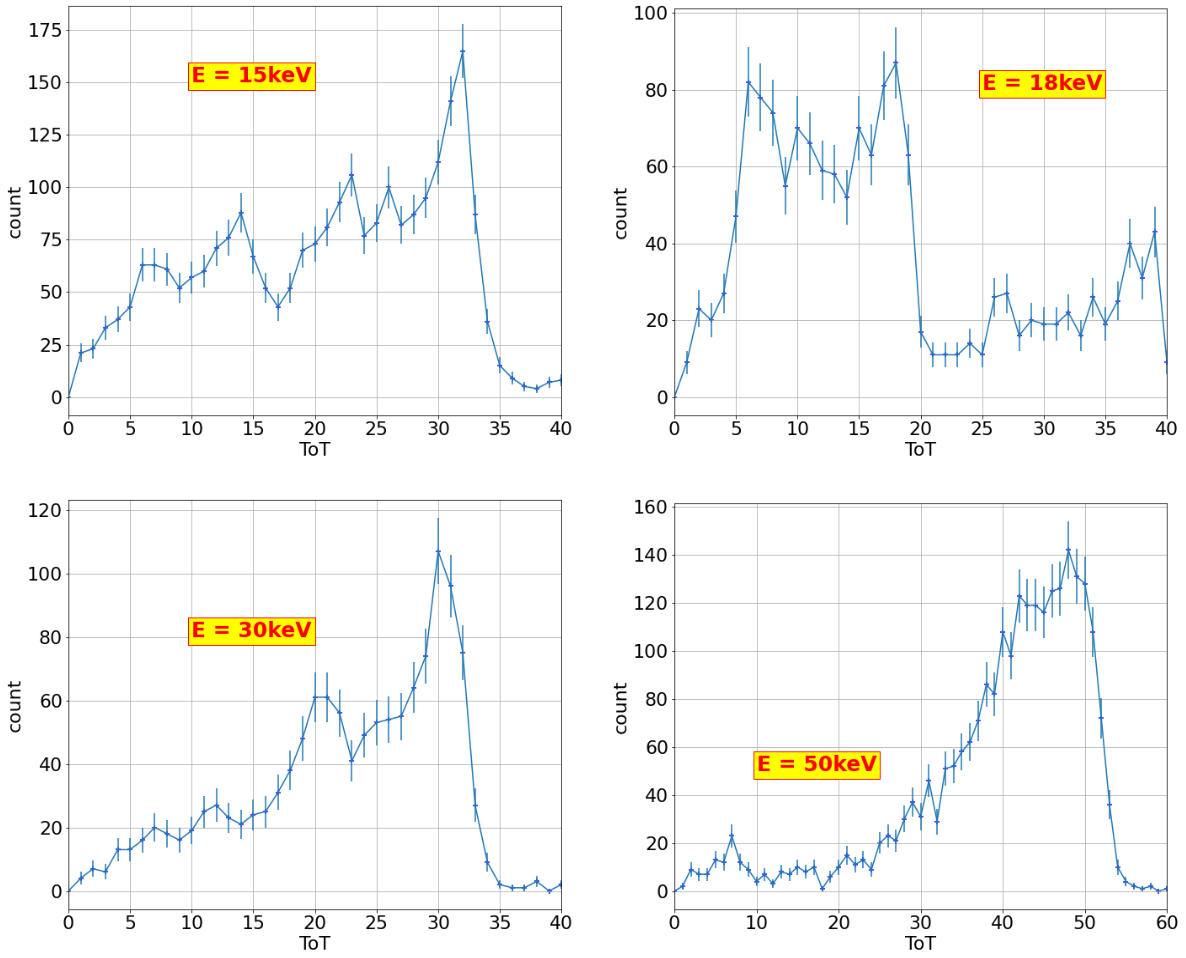
Measurement was carry out with an anod voltage of 60kV (if expected output energy is below 30keV) and 80kV (otherwise), tube's current 20uA, exposure time 100s, without collimator.

Comparison of monochromatic X-rays sources

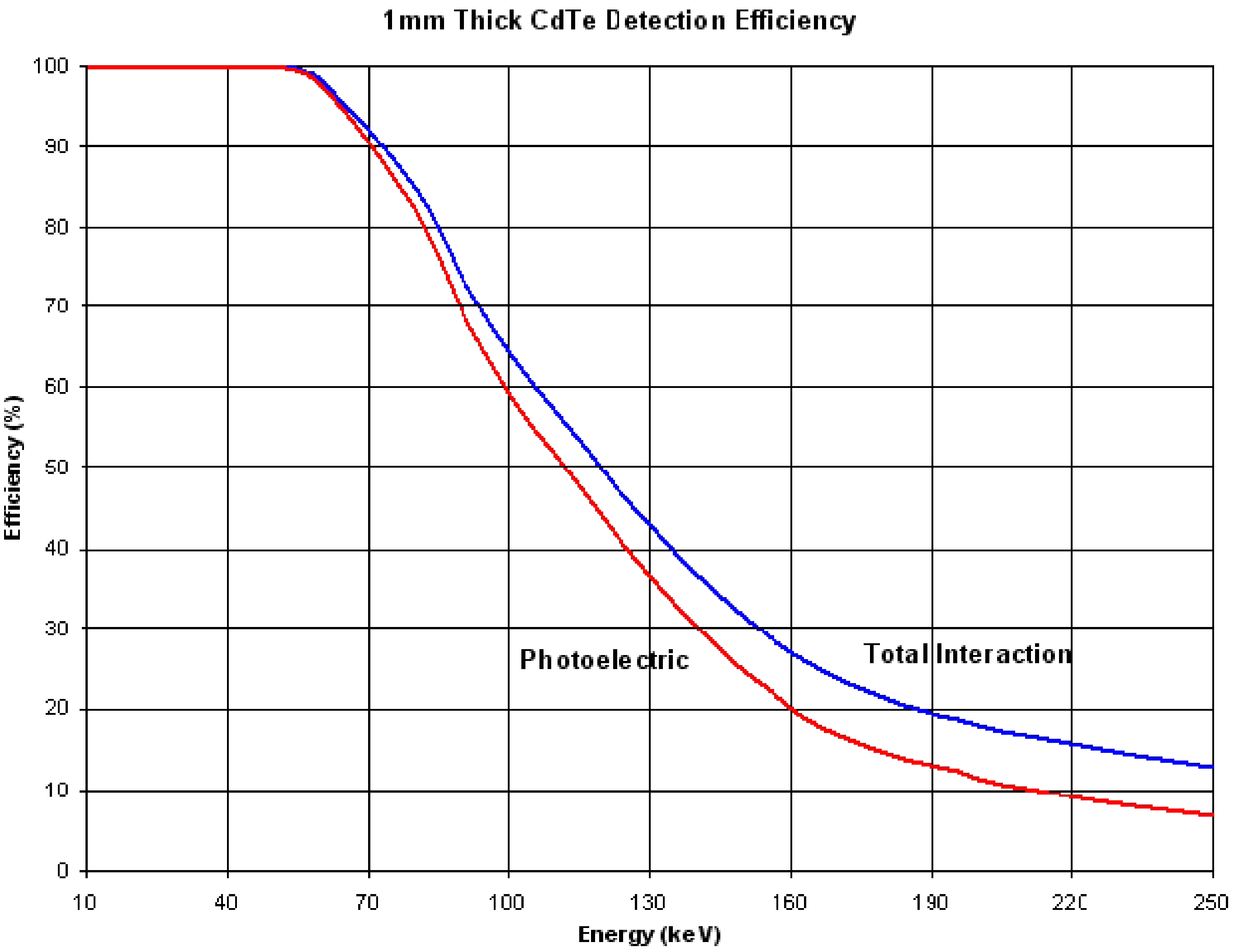


Extra slides

Spectra obtained at a single pixel:



1. Пики сливаются – найти хорошо разрешаемые пики, найти типичный сигма.
2. Моделировать allpix2
3. Surrogate function fitting


1mm Thick CdTe Detection Efficiency
Efficiency (%)
100
90
80
70
60
50
40
30
20
10
0
10
40
70
100
130
160
190
220
250
Energy (keV)
Photoelectric
Total Interaction