



# Photon-counting CT

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# Současná CT

- Standardní mód – prostorové rozlišení 15 lp/cm
- UHR mód – až 20 lp/cm
- Tloušťka řezu 0,5-0,6 mm (+ plovoucí ohnisko)
- Stále nedostatečné pro zobrazení koronárních tepen
- Blooming artefakty

# Co přináší Photon-counting CT

**keV místo kV**

**Polovodičový detektor  
(spektrální informace)**

**(U)HR  
detektory,  
matice a pokrytí**

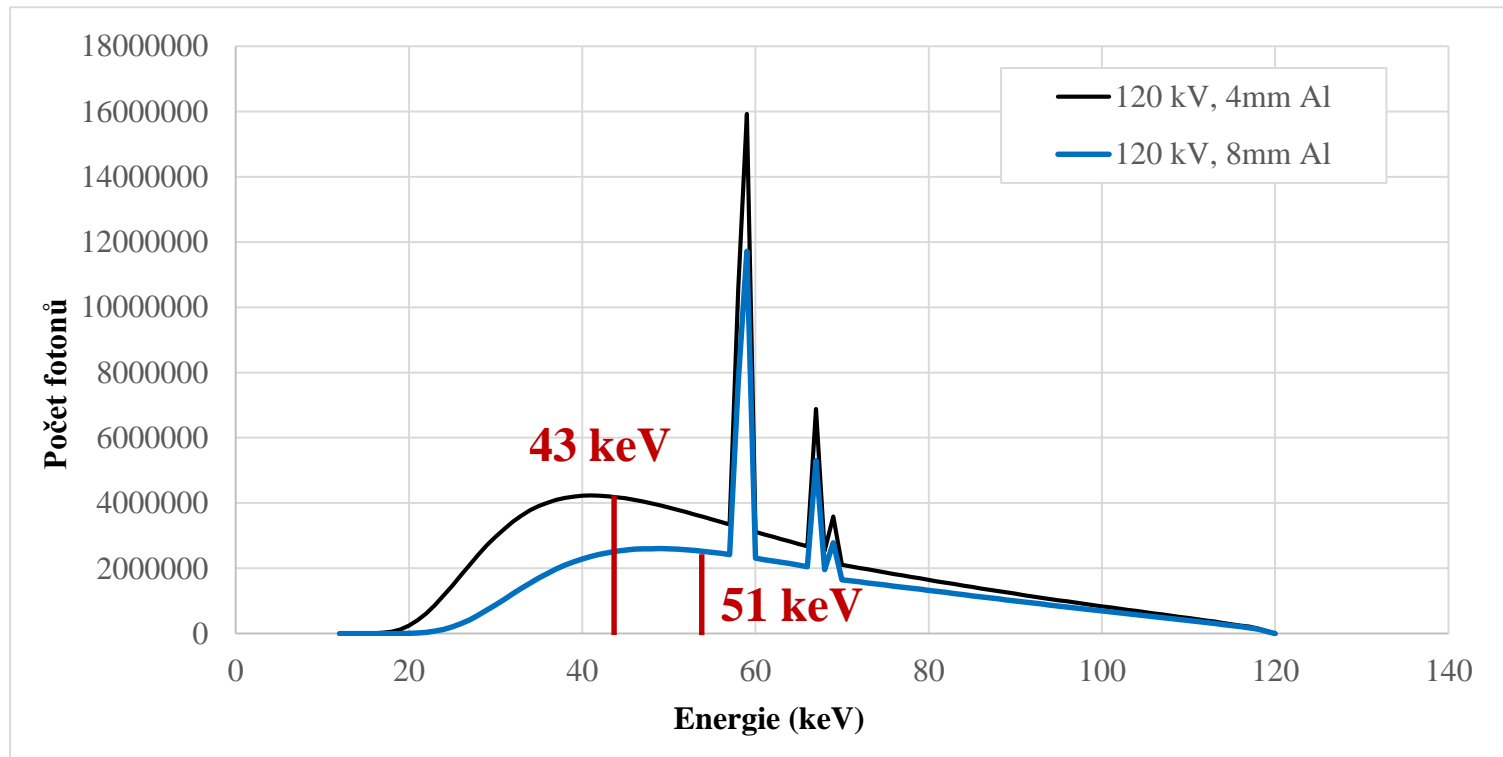


**kV vs. keV**



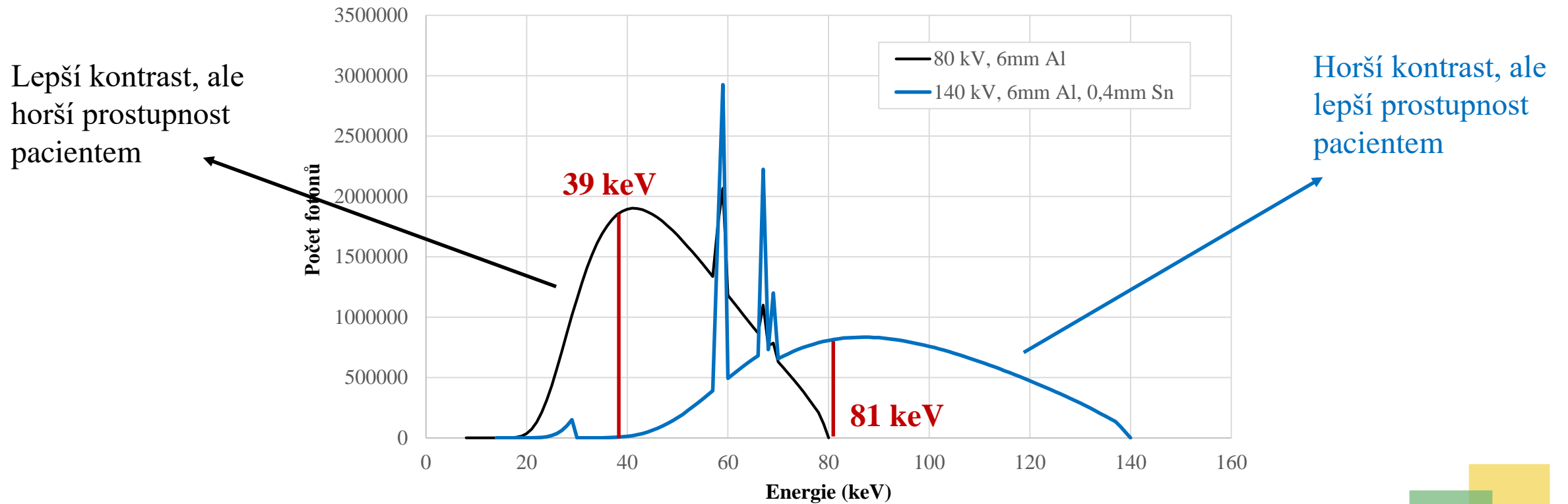
# Rtg spektrum

- Napětí „udává“ maximální energii ve spektru, ale **jak lze popsat celé spektrum**, např. s ohledem na filtraci? Pomocí **efektivní energie**



# Rtg spektrum

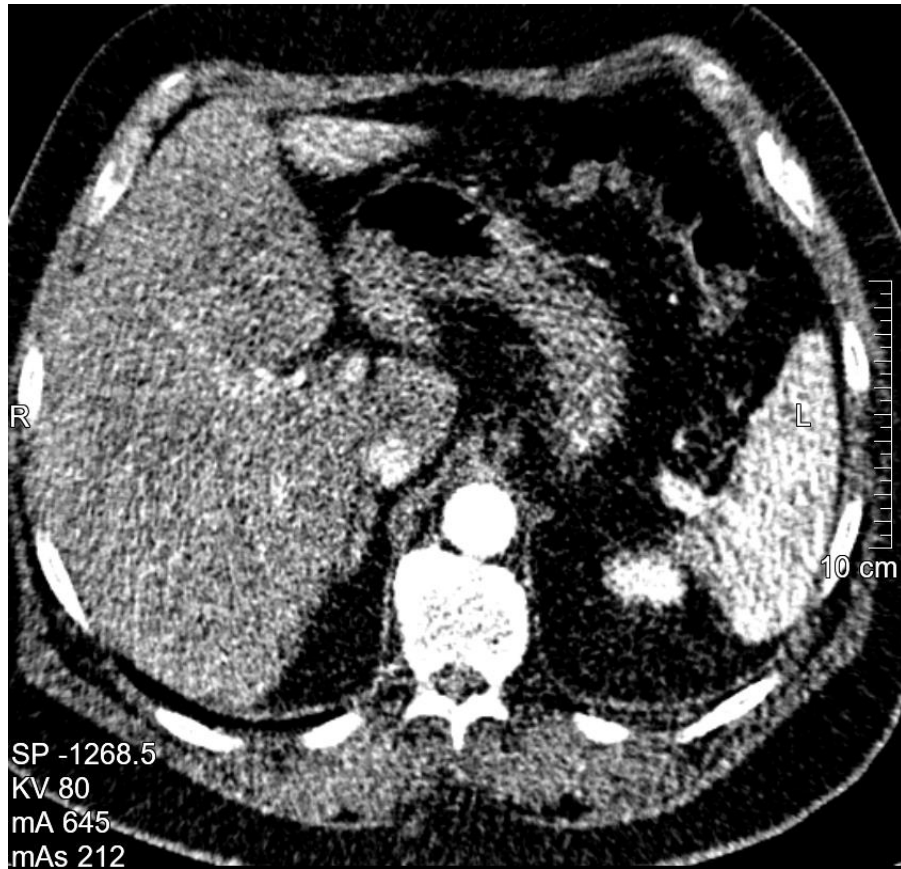
- Efektivní energie dvou spekter



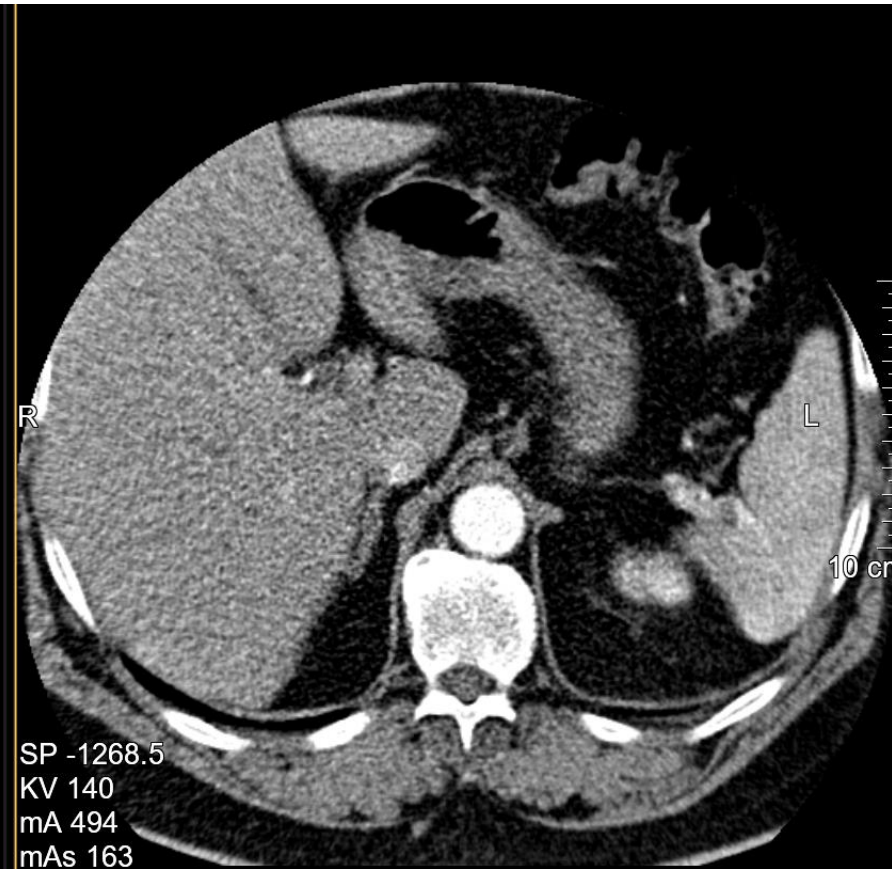
# Vliv na kontrast

- Rozdíl v prostupnosti způsobí rozdílnou kvalitu CT obrazu

**80 kV (39 keV)**



**140 kV (81 keV)**



# Vliv na kontrast

- Rozdíl v prostupnosti zp

80 kV (39 k

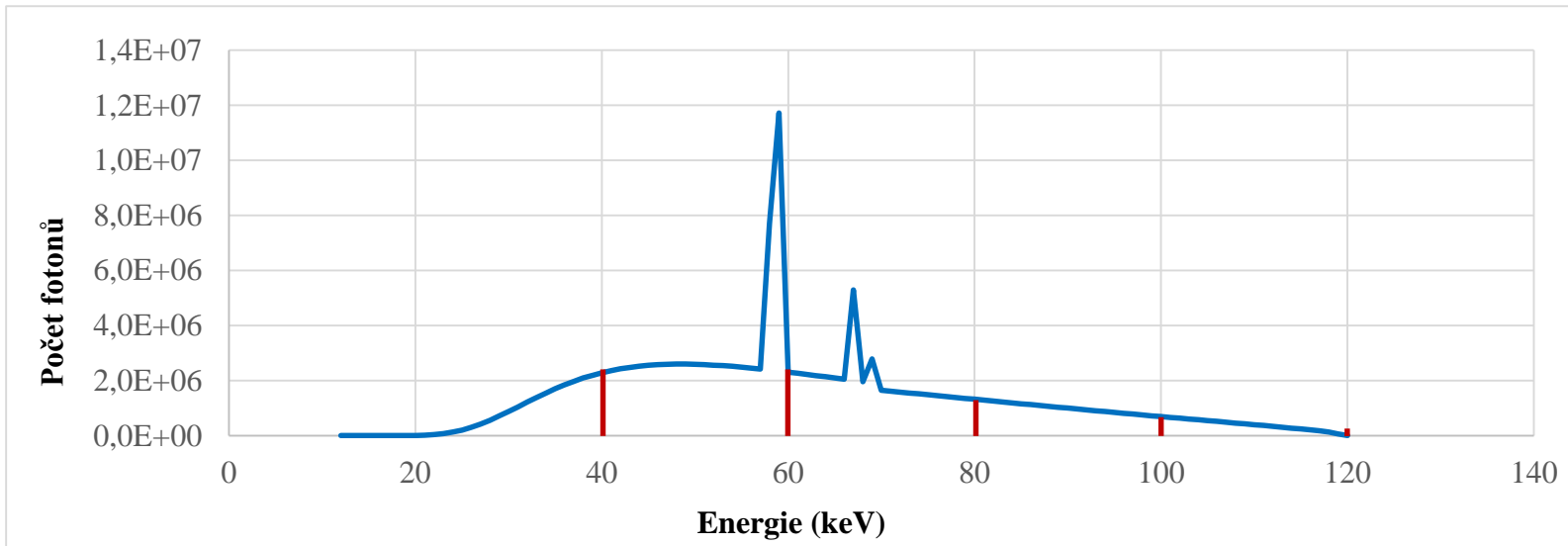
$\Gamma$  obrazu

(81 keV)

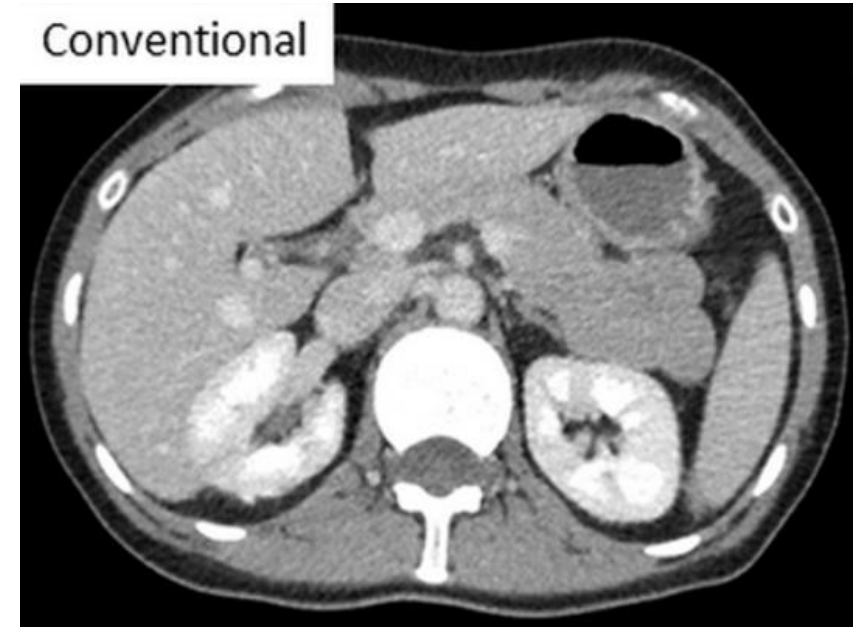




# Monoenergetické CT obrazy



Conventional



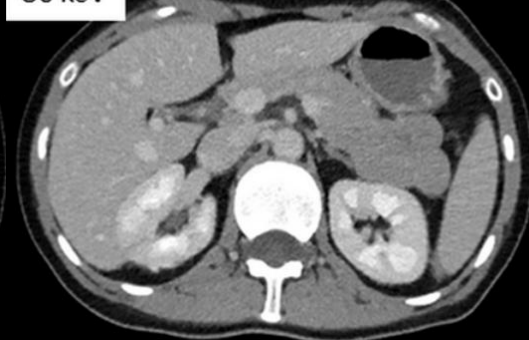
40 keV



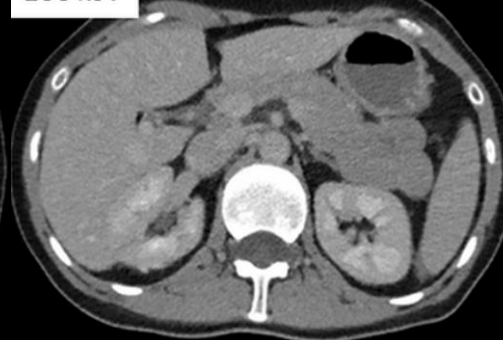
60 keV



80 keV




100 keV



120 keV



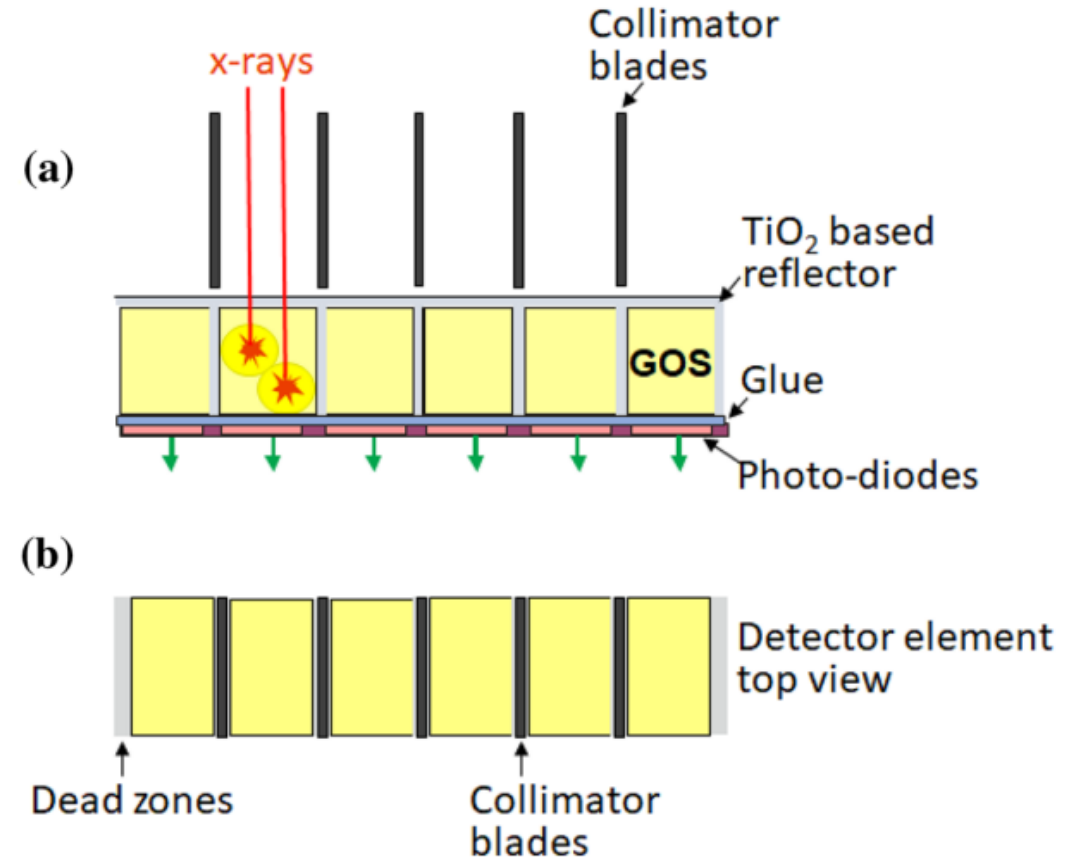


**Scintilační detektor  
vs.  
polovodičový detektor**



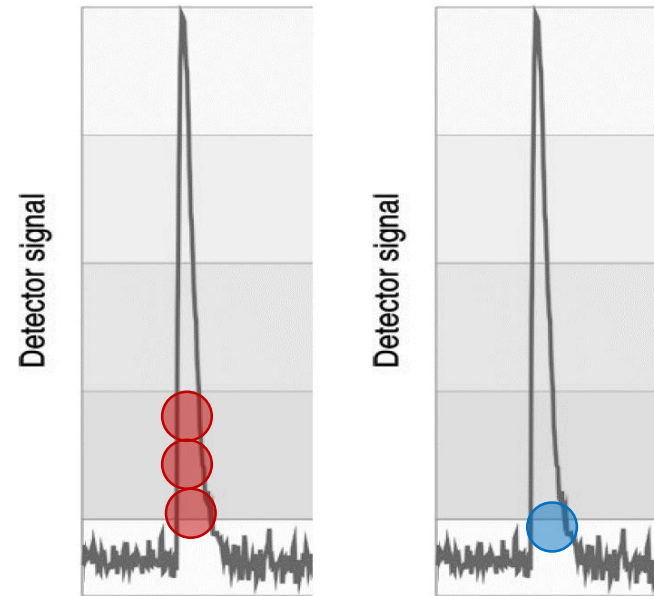
# Scintilační detektor (EID)

- **Energy-integrating detector (EID)**
- Dvoukroková detekce
  - Rtg fotony převedeny ve scintilátoru na fotony viditelného světla
  - Viditelné fotony generují pulsy ve fotodiodě
- Limitní prostorové rozlišení – nutnost netransparentních sept mezi detekčními elementy
- Sub-optimální kontrast obrazu – nízkoenergetické fotony přispívají méně
- Žádná spektrální informace



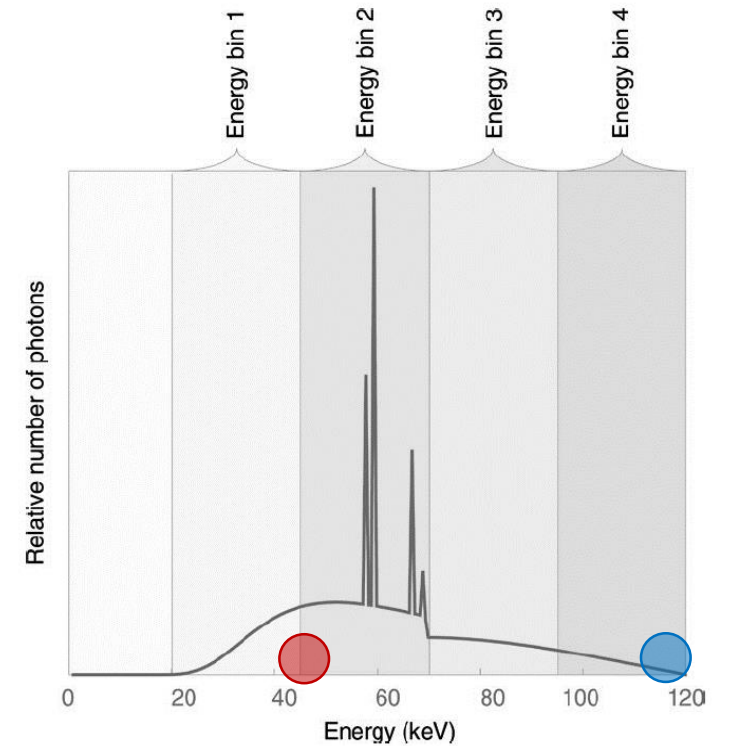
# EID vs. PCD

- Podhodnocení nízkoenergetických fotonů
- Tři fotony, každý o energii 40 keV mají stejný příspěvek energie jako jeden 120 keV foton.
- Ale právě fotony o energii 40 keV nesou informaci o kontrastu v CT obraze.

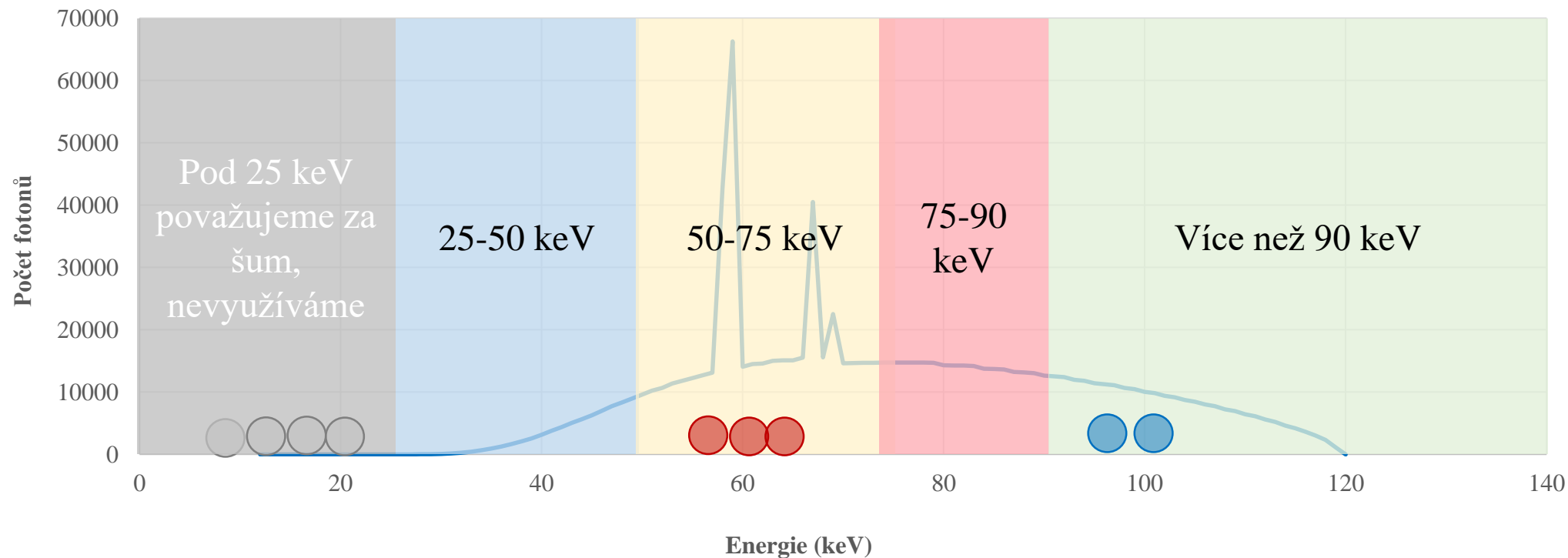


● 40 keV

● 120 keV



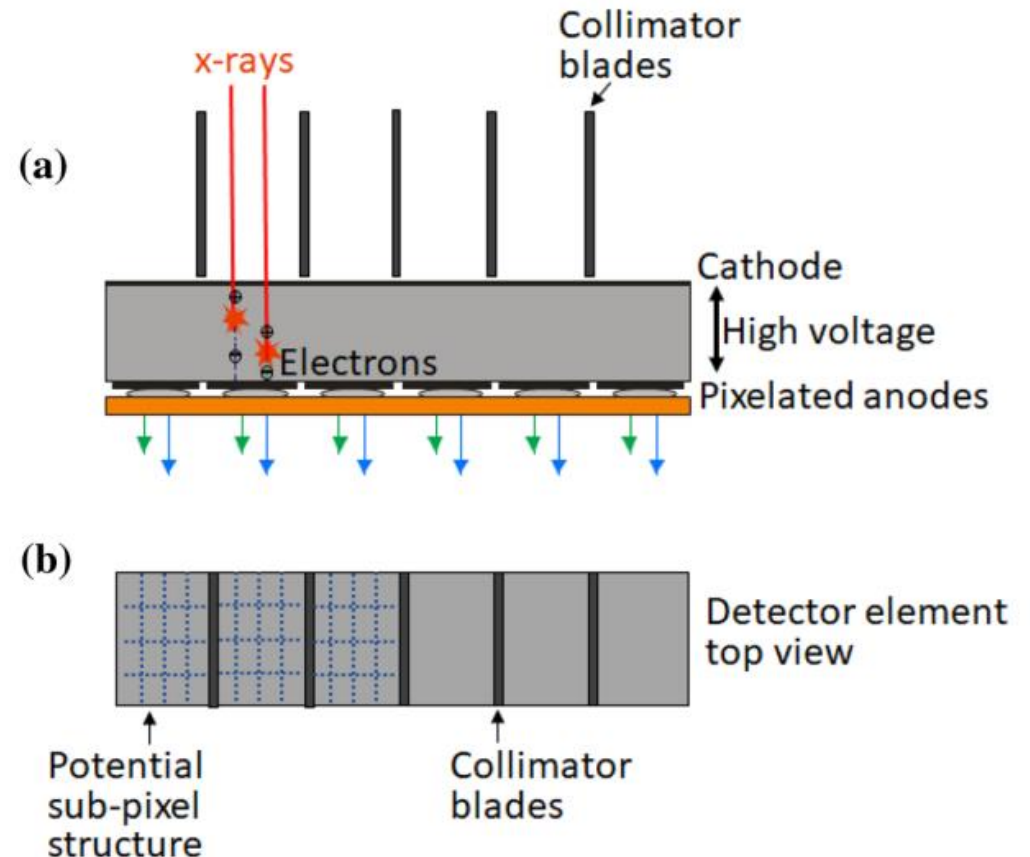
# Rtg spektrum – energetické biny



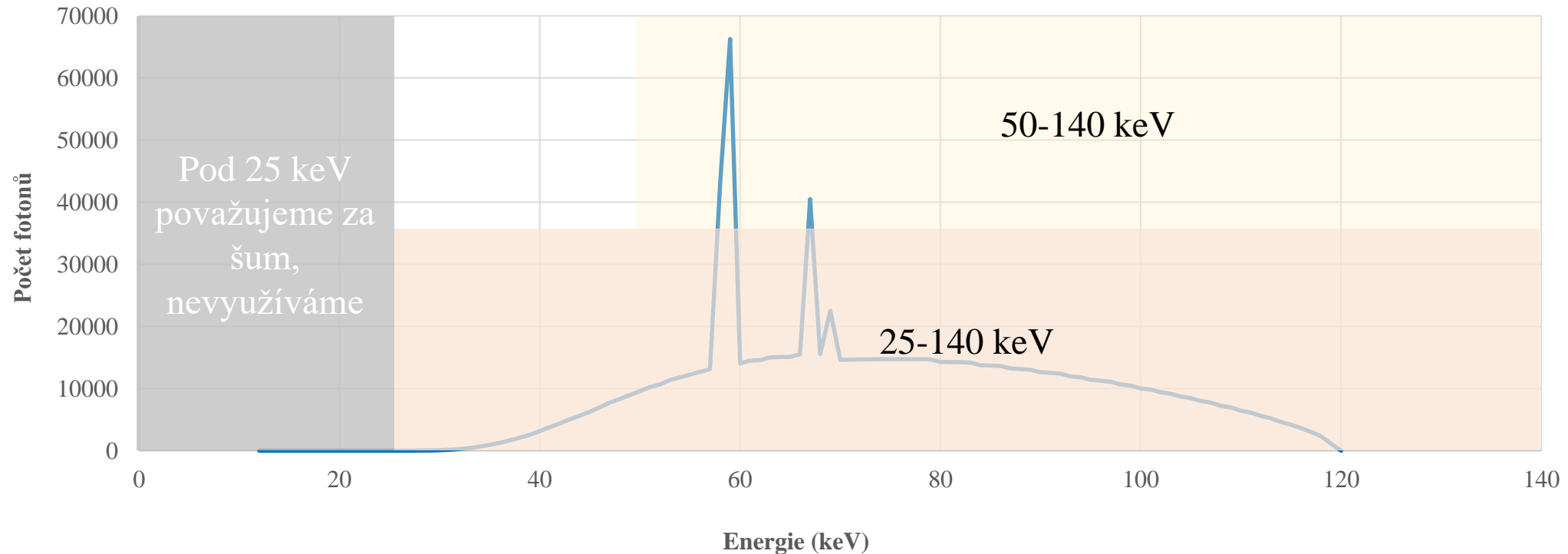
- Práh šumu 25 keV
- Energetické prahy nejčastěji 50, 75 a 90 keV

# Polovodičový detektor (PCD)

- **Photon-counting detector (PCD)**
- Rtg fotony generují pulzy v polovodičovém detektoru (CdTe, CZT)
- Lepší prostorové rozlišení – nejsou potřeba separační septa mezi pixely
- Není elektronický šum – je pod prahovou hodnotou
- Lepší kontrast obrazu – všechny rtg fotony přispívají stejně
- Spektrální informace – energie každého fotonu je měřena (4 energetické biny)

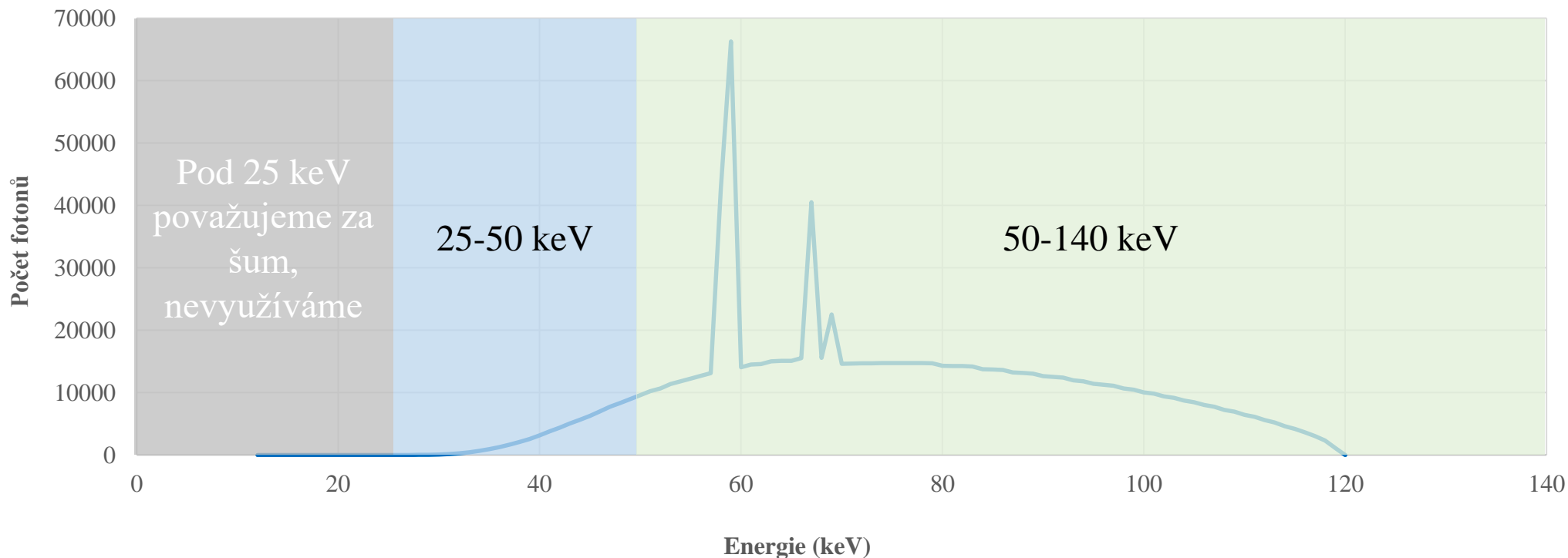


# Rtg spektrum – energetické biny



- Skutečnost – každý sub-pixel má 2 energetické biny
- Nechť je práh 25 keV a 50 keV – pak mám dvě skupiny fotonů – 25-140 keV a 50-140 keV
- Odečtením těch dvou od sebe mám 25-50 keV a 50-140 keV

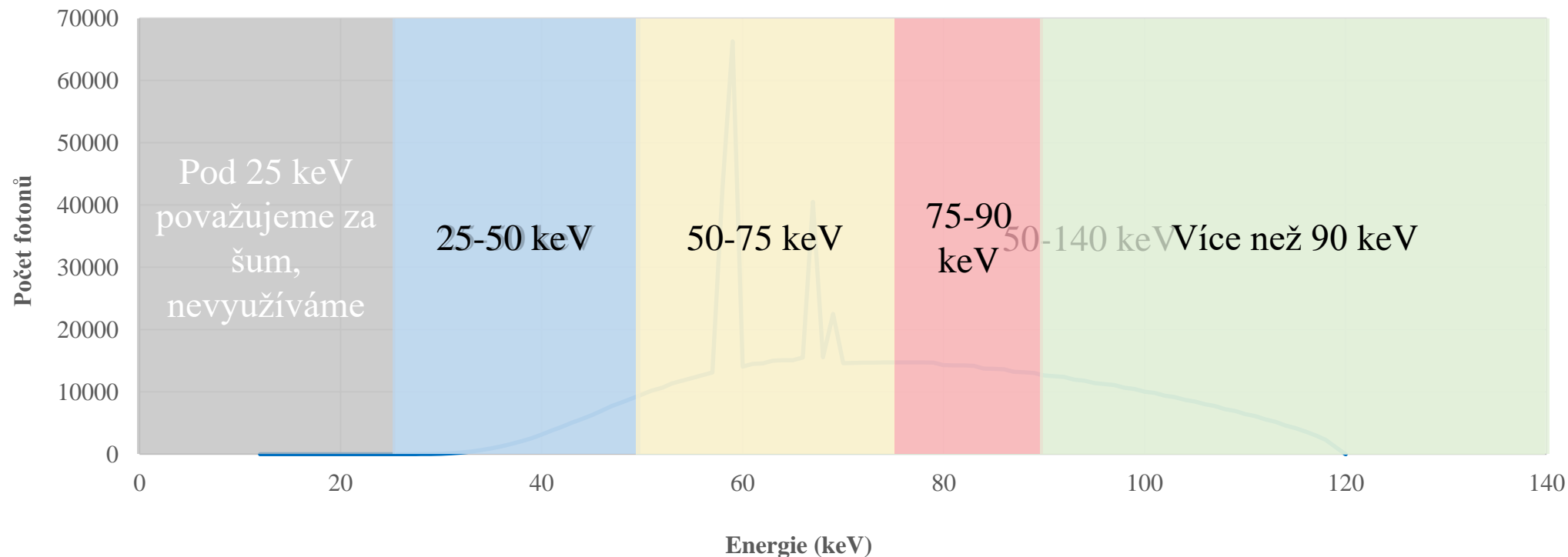
# Rtg spektrum – energetické biny



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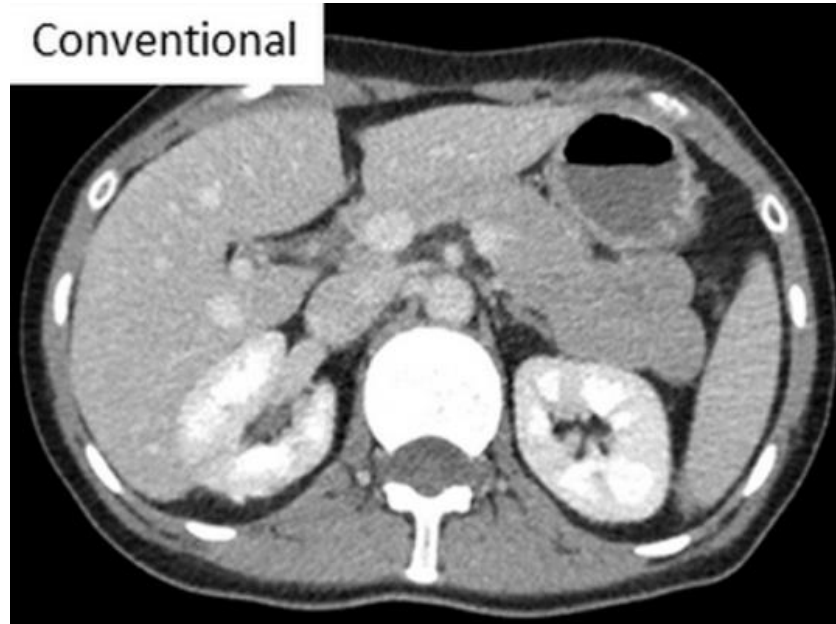
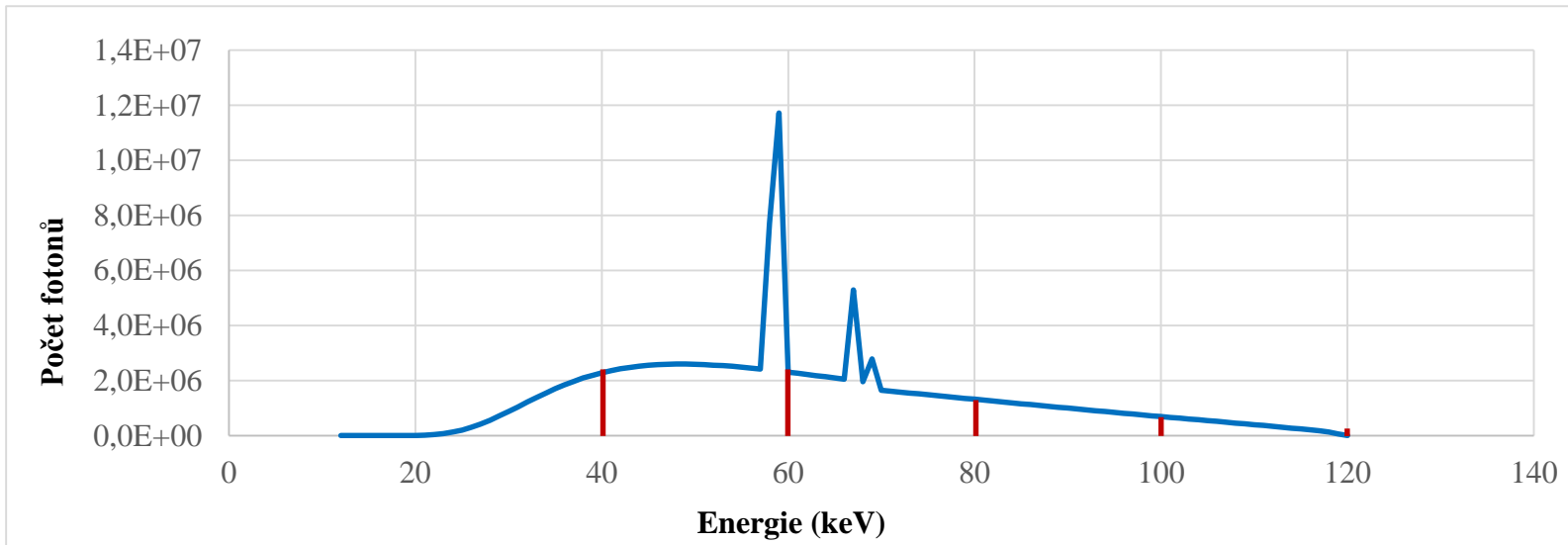
# Rtg spektrum – energetické biny



- Spojme 2 sub-pixely – každý má 2 energetické biny, pak společně mají 4 energetické biny
- 1. sub-pixel – práh 25 keV a 50 keV, pak mám 25-50 keV a 50-140 keV
- 2. sub-pixel – práh 75 keV a 90 keV, pak mám 75-140 keV a 90-140 keV
- Ve výsledku mám biny 25-50 keV, 50-75 keV, 75-90 keV, 90-140 keV



# Monoenergetické CT obrazy



# Monoenergetic CT obrazy



## Clinical Implementation of a First-generation Dual Source Photon Counting Detector CT: First Experience and Perspective for Clinical Use

M.L. Dijkshoorn, R.P.J. Budde, MD, PhD; N.R. van de Werf MSc;  
M. van Straten PhD; A. van der Lugt, MD, PhD; R. Booi PhD  
Erasmus MC, Rotterdam, The Netherlands

DEPARTMENT OF RAD

Scan type dependant automatic adaptation

70keV+

Non-contrast exam

65keV+

Bone/Calcium Exam

60keV+

Soft tissue with iodine contrast

55keV+

CT-Angiography

Or a manual keV output can be selected



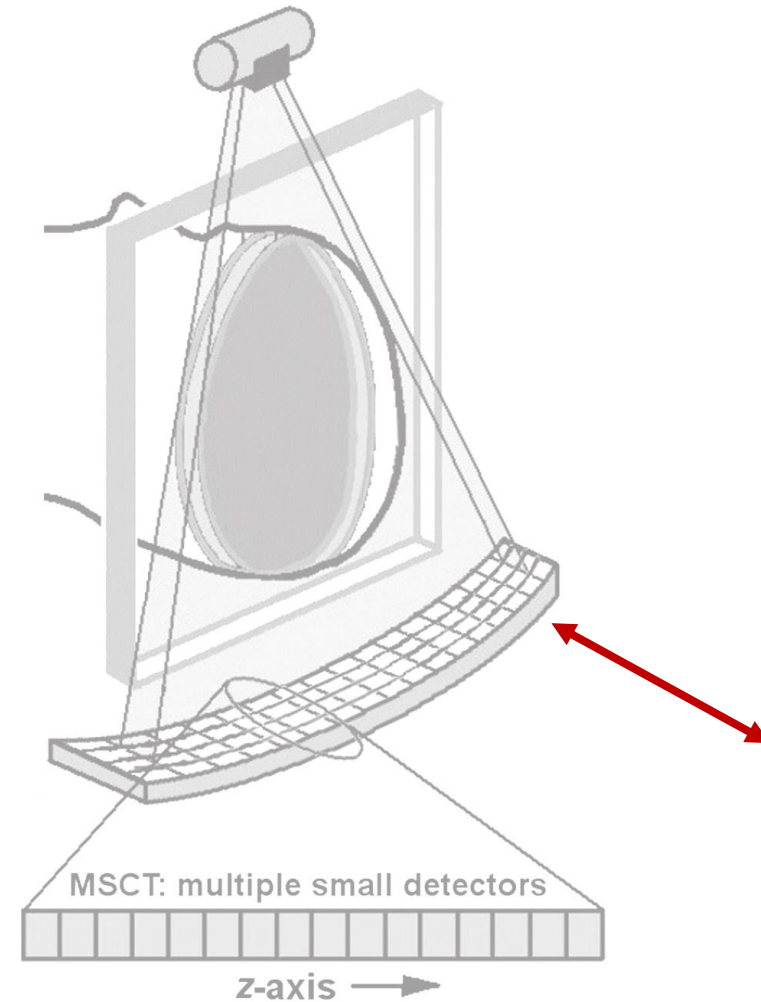
# **(U)HR detektory a pokrytí**

**Matice 1024 x 1024 (2048 x 2048)**



# Běžné vs. Photon-counting CT

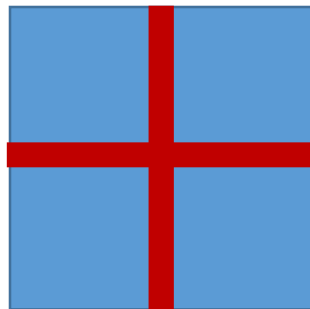
- Počet řad detektorů a velikost detekčních elementů:
  - **Flash** 2 x 64 řad, 0,6 mm
  - **Force** 2 x 96 řad, 0,6 mm
  - **Naeotom** 2 x 288, 0,2 mm (0,4 mm)
- Doba rotace:
  - **Flash** 0,28 s
  - **Force** 0,25 s
  - **Naeotom** 0,25 s
- Rekonstruovaná matice:
  - **Flash** 512 x 512 px
  - **Force** 1024 x 1024 px
  - **Naeotom** 1024 x 1024 px



# Standardní vs. UHR akvizice

- Scintilační detektor (EID) vs. polovodičový detektor (PCD)

EID

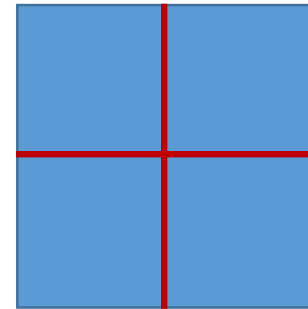


EID-UHR  
(comb filter)

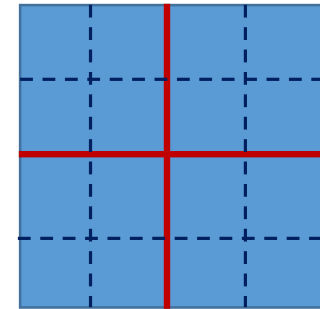


Změna aktivní  
velikosti detekčního  
elementu

PCD



PCD-UHR



# Ukázka CT obrazů



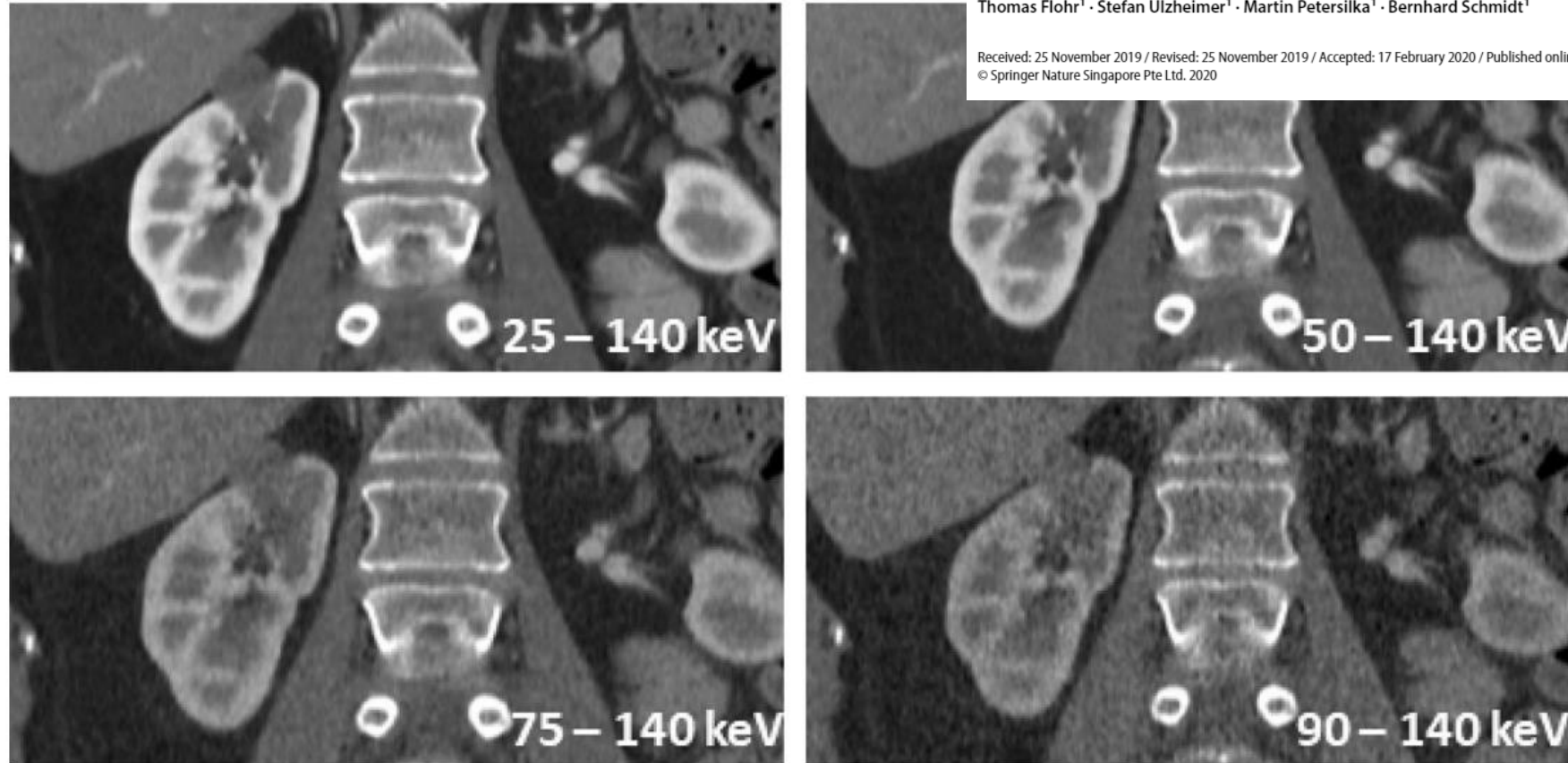


# Ukázka CT obrazů

## Basic principles and clinical potential of photon-counting detector CT

Thomas Flohr<sup>1</sup> · Stefan Ulzheimer<sup>1</sup> · Martin Petersilka<sup>1</sup> · Bernhard Schmidt<sup>1</sup>

Received: 25 November 2019 / Revised: 25 November 2019 / Accepted: 17 February 2020 / Published online: 2 March 2020  
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**Fig. 5** Contrast-enhanced kidney scan of a 71-year-old female patient acquired with a pre-clinical hybrid photon-counting CT prototype. The X-ray tube voltage was 140 kVp. The photon-counting detector simultaneously provided four CT raw data sets with low-energy thresholds of 25 keV, 50 keV, 75 keV, and 90 keV (see Fig. 4).

Images reconstructed from the four CT raw data sets demonstrate decreasing iodine contrast and increasing image noise with increasing low-energy threshold (top left to bottom right), because fewer low-energy X-ray photons contribute to the image. Courtesy of National Institute of Health NIH, Bethesda, MD, USA





# Ukázka CT obrazů

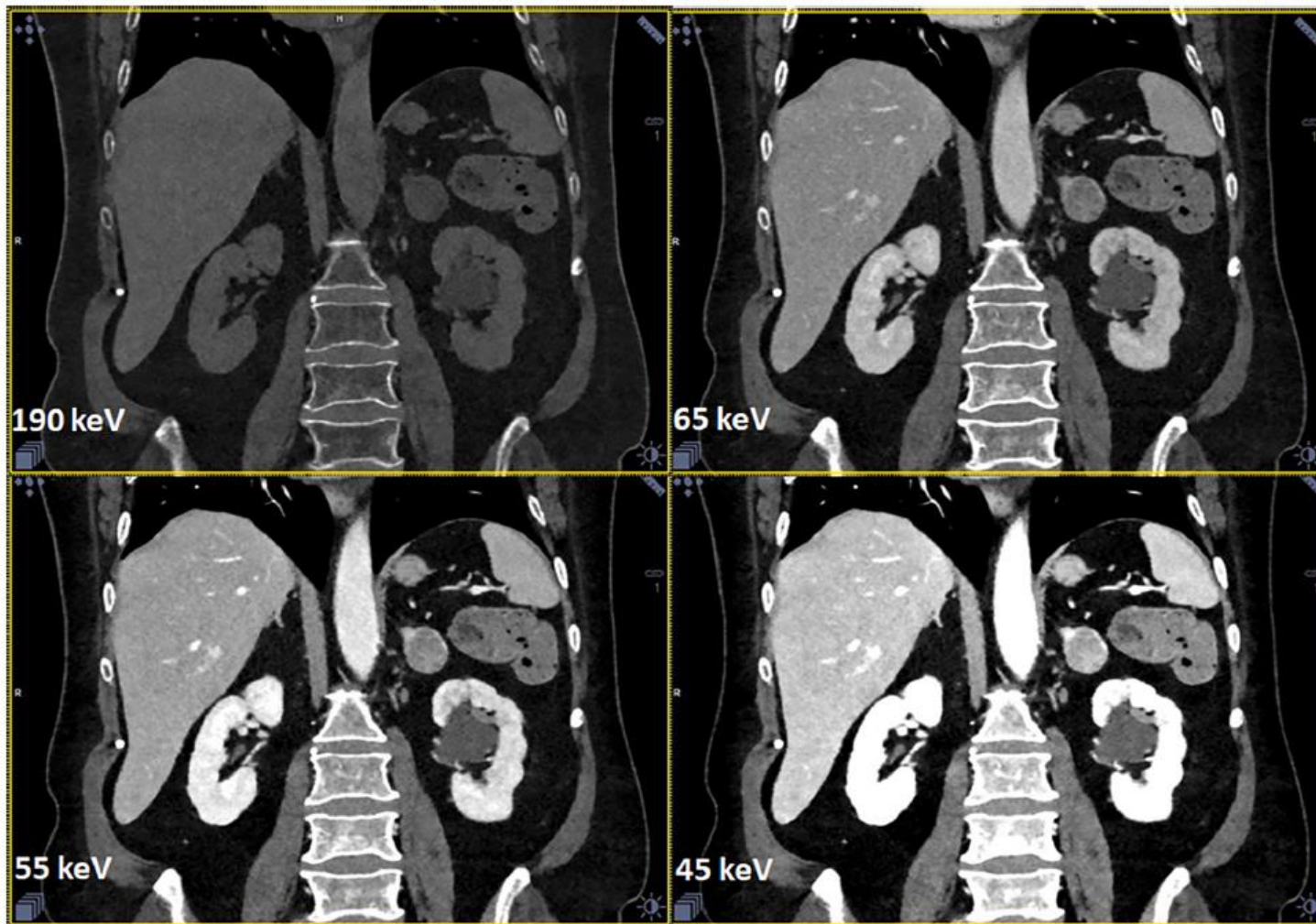
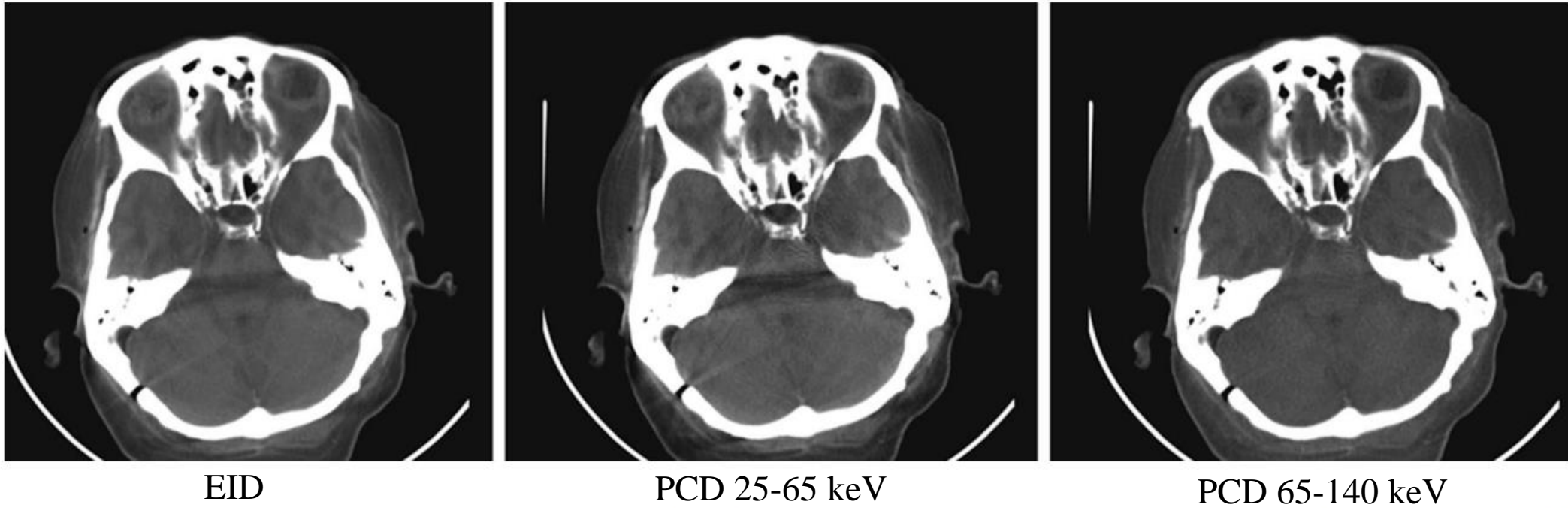


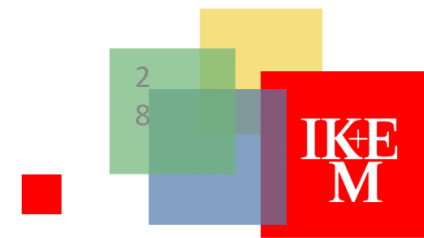
Fig. 14. Abdominal images of a 67-year old woman with adrenal adenoma and parapelvic renal cyst, acquired with a pre-clinical single source CT prototype with photon-counting detector. Data acquisition: “standard” mode, 144x0.4 mm collimation, 0.3 s rotation time,  $CTDI_{vol} = 10.2$  mGy,  $DLP = 450$  mGycm. Image reconstruction: VMIs at 190 keV, 65 keV, 55 keV and 45 keV, 0.4 mm slice width. Note the decreasing contrast of iodine and calcium with increasing keV – the 190 keV image can serve as a substitute for a virtual non-contrast image. Courtesy of Dr. J. Ferda, Pilsen, Czech Republic.

# Ukázka CT obrazů



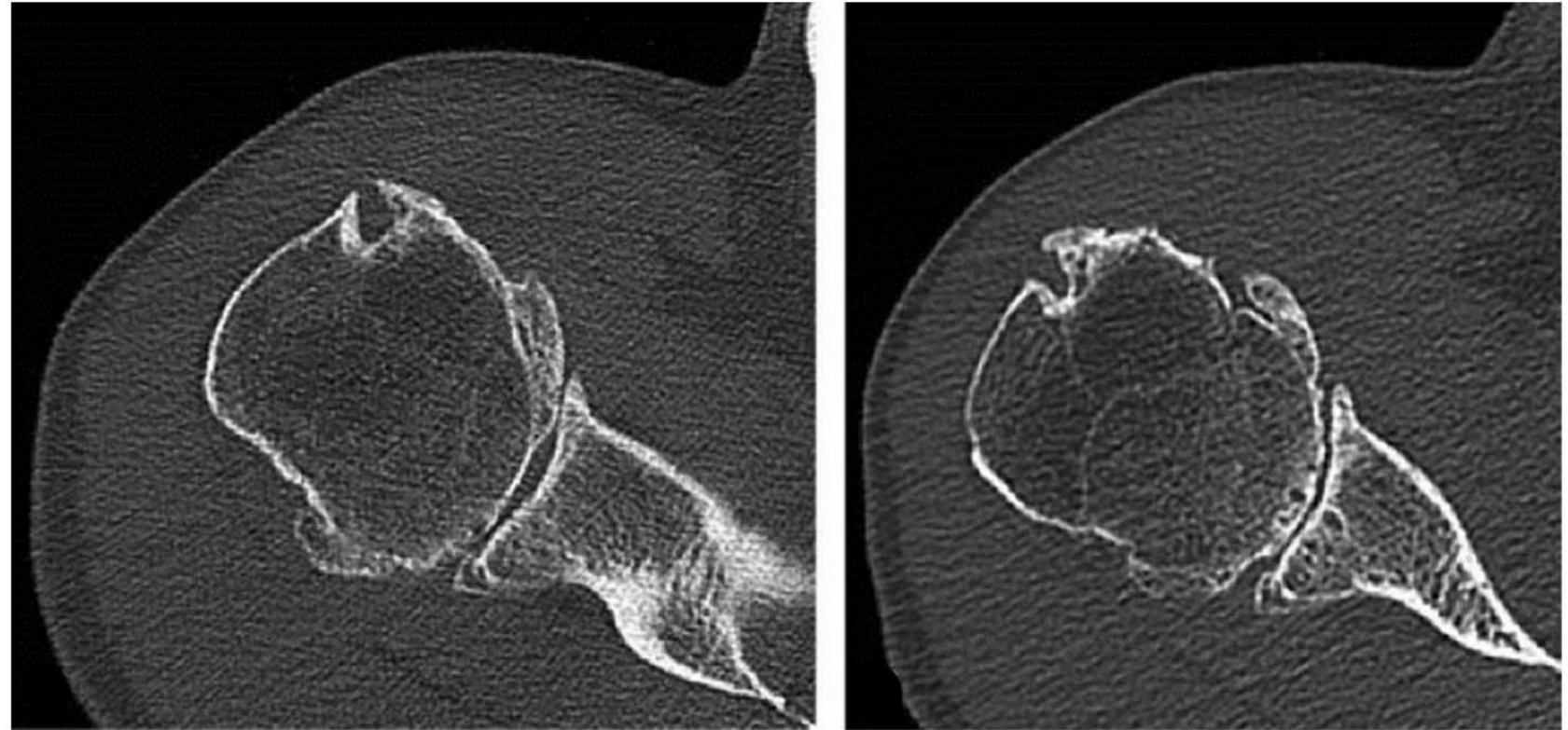
**Fig. 11** Images of a cadaver head scanned on a pre-clinical hybrid dual-source CT prototype with energy-integrating detector and photon-counting detector. Left: energy-integrating detector. Center: photon-counting detector, low-energy bin 25–65 keV. Right: photon-

counting detector; high-energy bin 65–140 keV. The high-energy images of the posterior fossa acquired with the photon-counting detector (right) show significantly less beam-hardening artifacts (dark streaks between areas of dense bone). With permission from [14]



# Ukázka CT obrazů

**Fig. 15** Example of a shoulder scan acquired with the pre-clinical hybrid dual-source CT prototype. Left: energy-integrating detector image. Right: photon-counting detector image, “sharp mode”, demonstrating higher spatial resolution and significantly improved visualization of bony structures. With permission from [26]



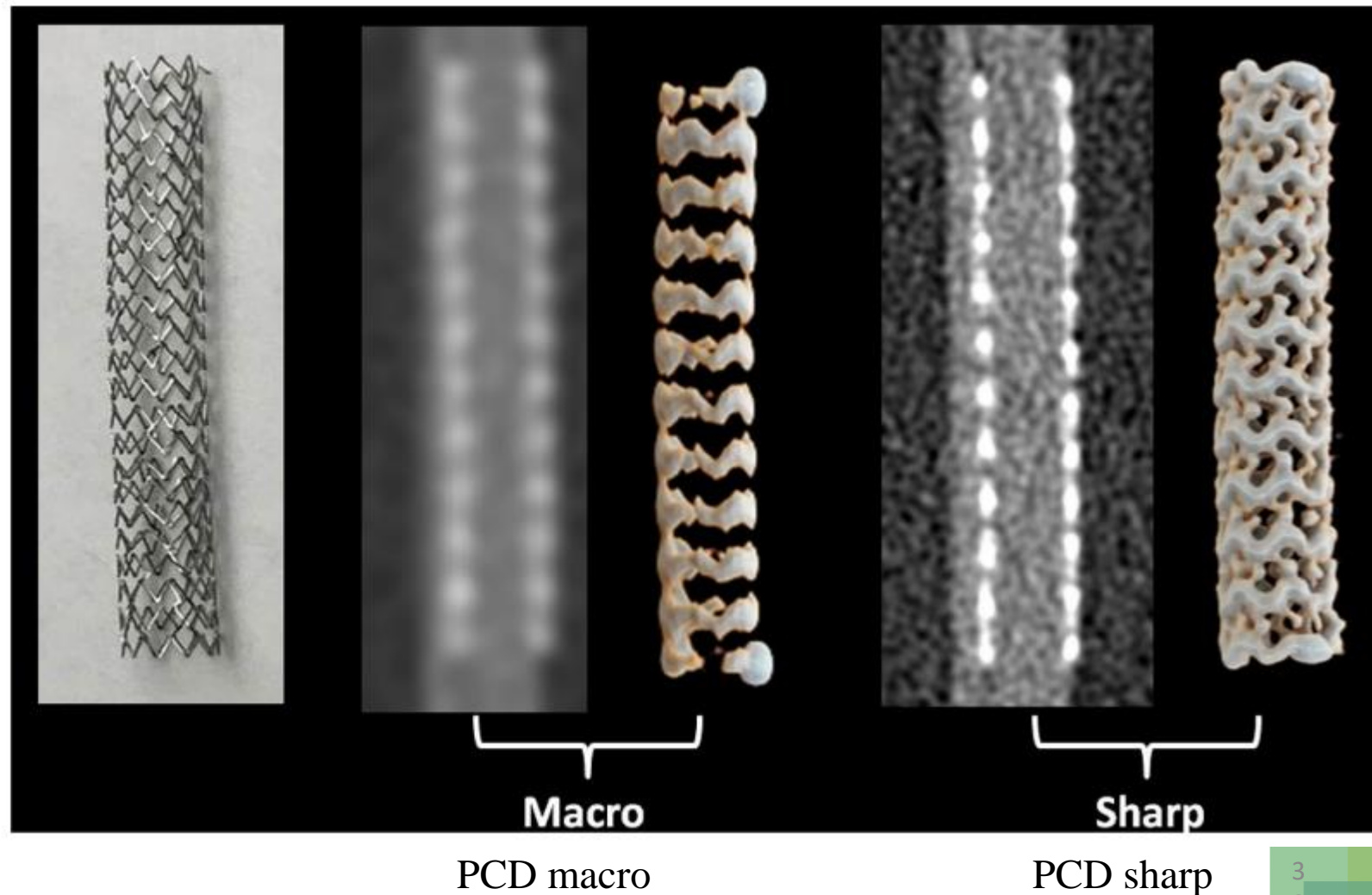
EID

PCD sharp

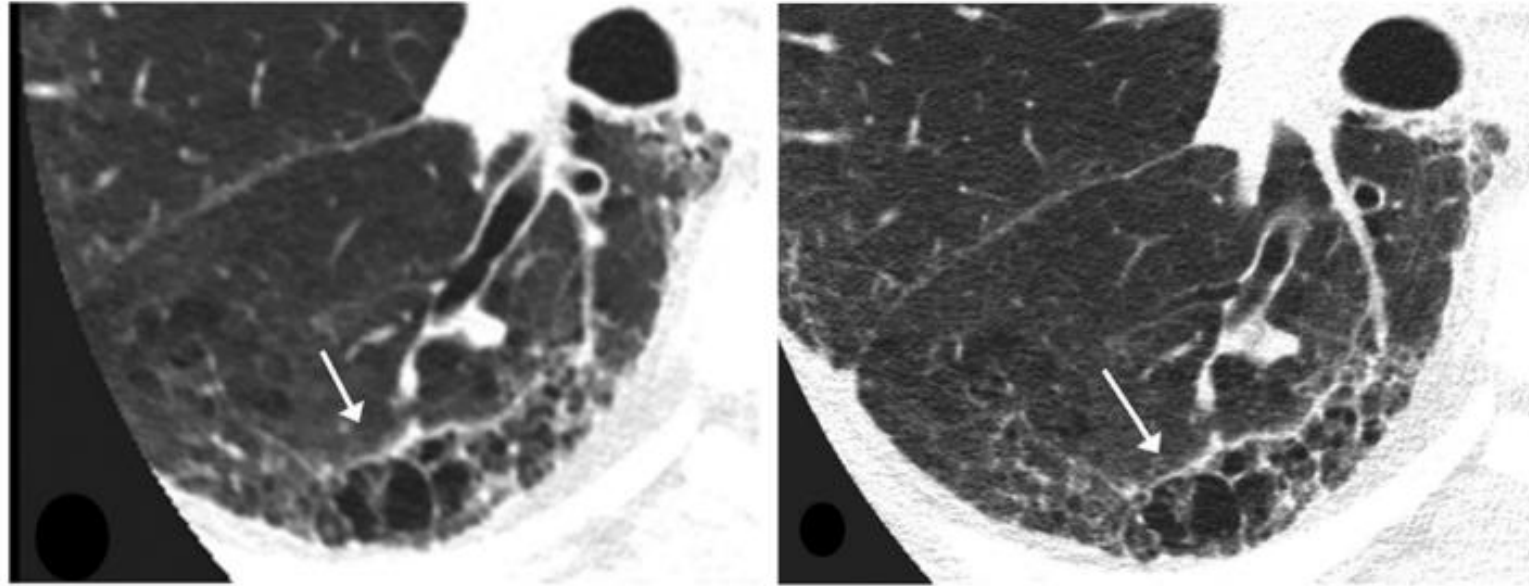


# Ukázka CT obrazů

**Fig. 16** Image of a coronary stent (left) scanned with the pre-clinical hybrid dual-source CT prototype with photon-counting detector. The “macro mode” (center, see also Fig. 10) corresponds to the resolution level of today’s medical CT systems. The “sharp mode” (right, see also Fig. 10) provides a cut-off spatial resolution of 32 lp/cm [26]. Images courtesy of Clinical Innovation Center, Mayo Clinic Rochester, MN, USA



# Ukázka CT obrazů



**Fig. 17** Lung images of a 68-year-old man acquired with the pre-clinical hybrid dual-source CT prototype. Left: clinical reference image, medium sharp convolution kernel,  $512 \times 512$  image matrix. Right: photon-counting detector image, "sharp mode", sharp convolu-

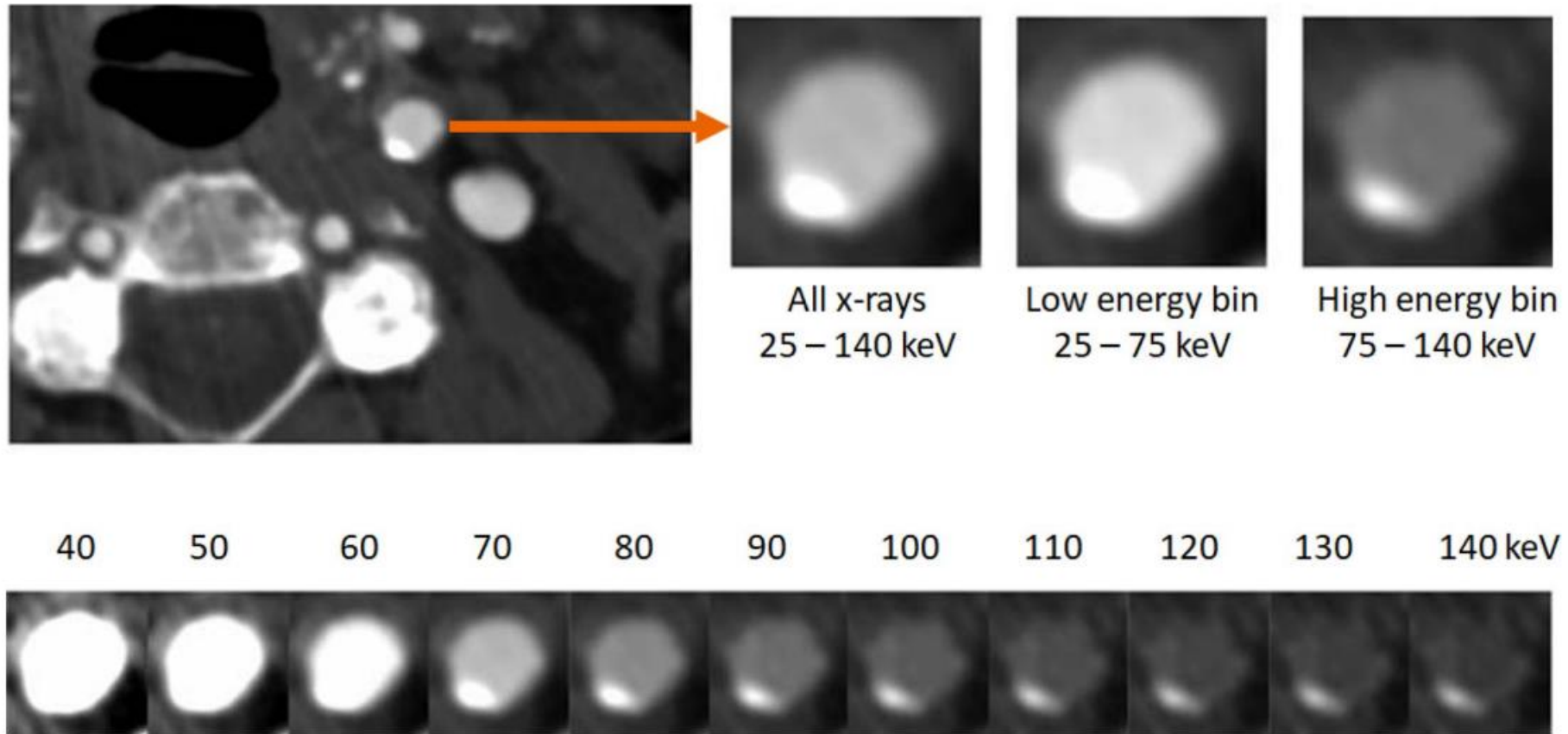
EID

tion kernel (10% value of the MTF 18.9 lp/cm) beyond the resolution limits of the energy-integrating detector,  $1024 \times 1024$  image matrix. Improved visualization of honeycombing and fibrosis. With permission from [2]

PCD sharp

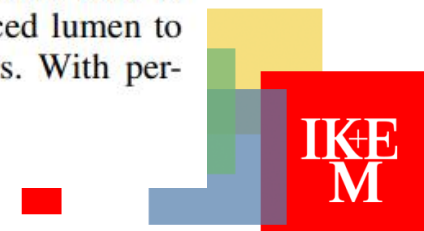


# Ukázka CT obrazů



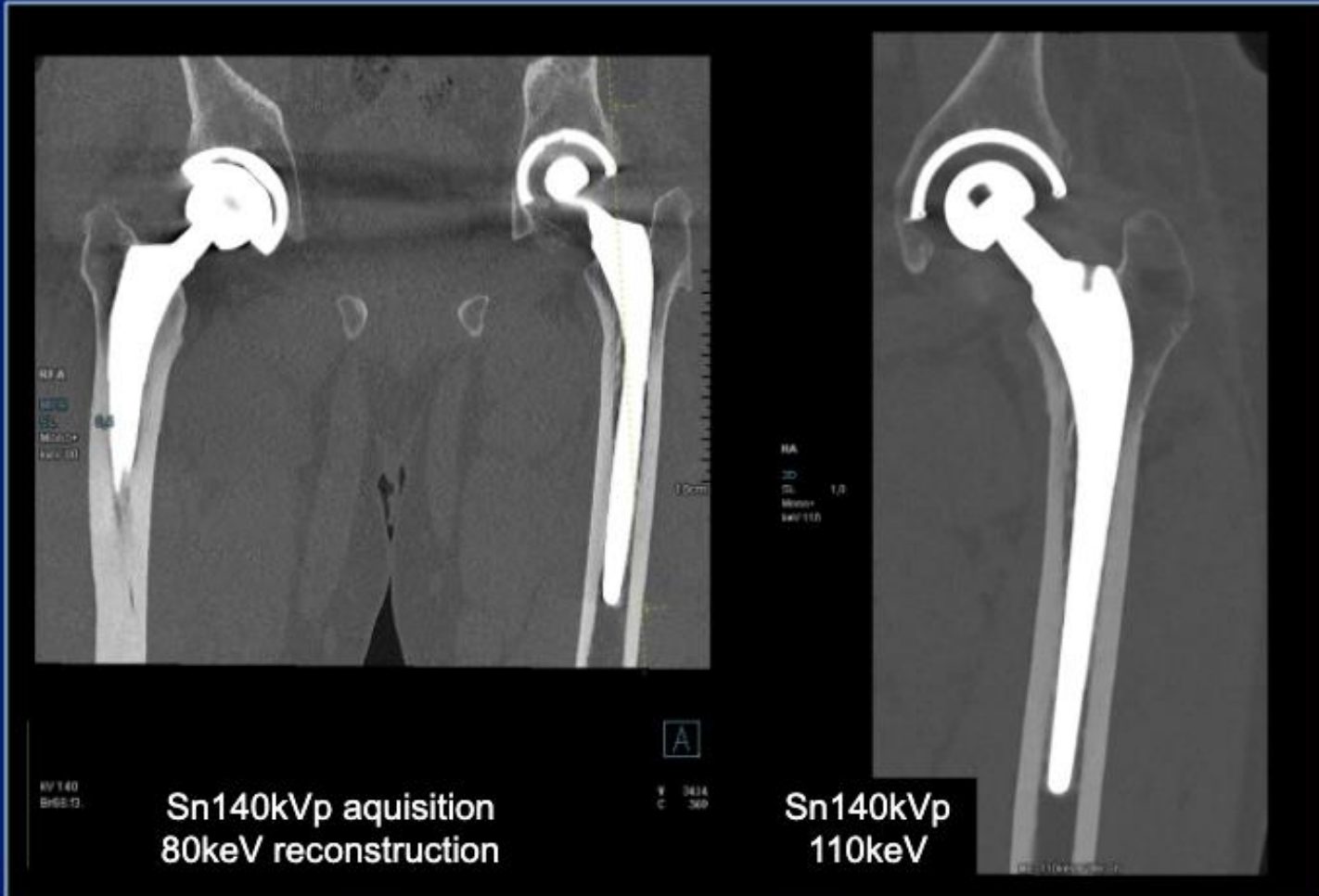
**Fig. 18** Contrast-enhanced images of the internal carotid artery of a 73-year-old woman acquired with the pre-clinical hybrid dual-source CT prototype. All images are displayed with center 145 HU, width 800 HU. The high-energy bin image demonstrates less blooming of the calcified plaque than the low-energy bin image. Virtual monoenergetic

images at different keV (shown at the bottom) can be used to optimize the contrast between plaque and iodine-enhanced lumen to improve plaque characterization and grading of stenosis. With permission from [56]



# RSNA 2021

## High energy spectral information with Sn filter



The dose and FOV characteristics of EID CT UHR mode limit the use to extremities and inner ear studies.

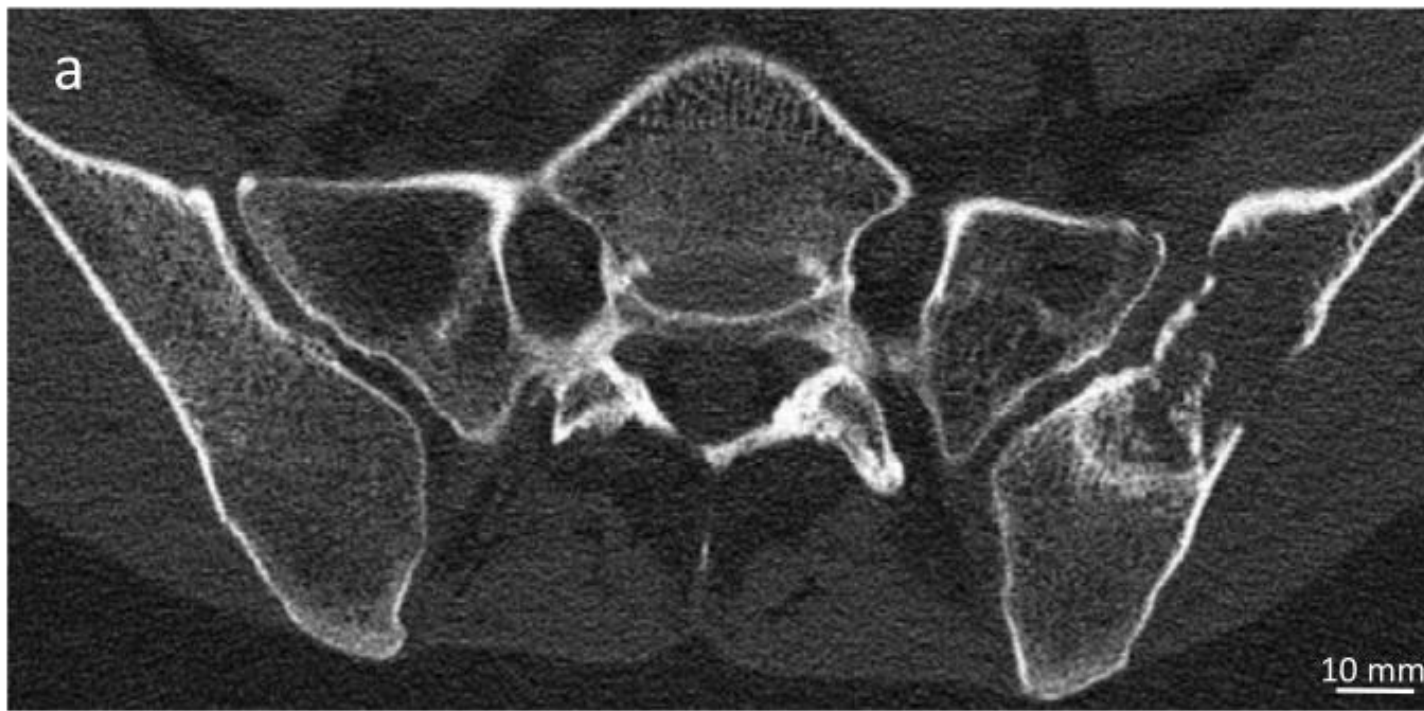
With PCCT the same or better resolution can now be achieved in other body parts such as pelvis and spine.

In bone studies with metal where the low energetic spectra is not of interest an added tin filter (Sn) in the x-ray beam can further reduce dose and beam hardening artifacts. An optimization of keV visualization level only in the higher range of the spectra is still possible.

A similar technique is also available on the EID CT, however not in highest resolution and no fine-tuning of keV level is possible.



PCD



EID



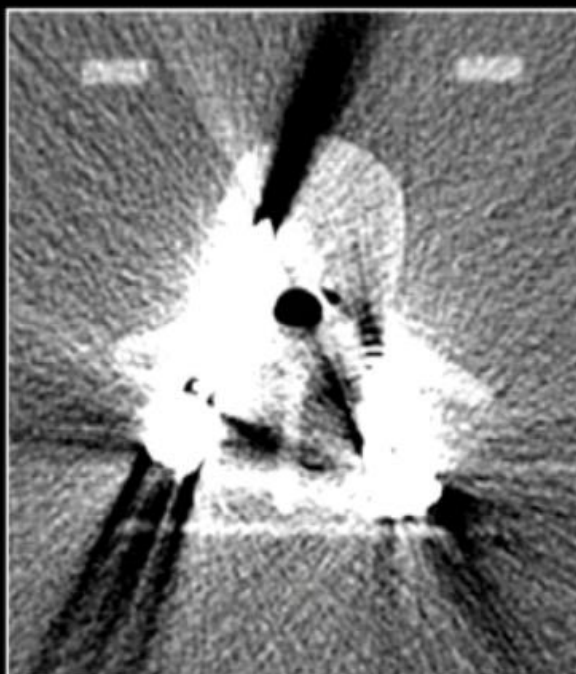


# Metal Artifact Reduction w/ Tin Filter

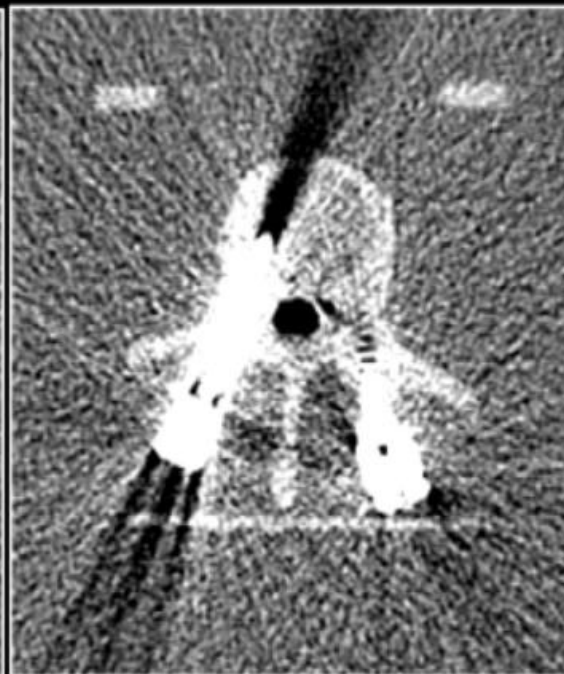
Spine Hardware



[25 140) keV  
w/o Tin



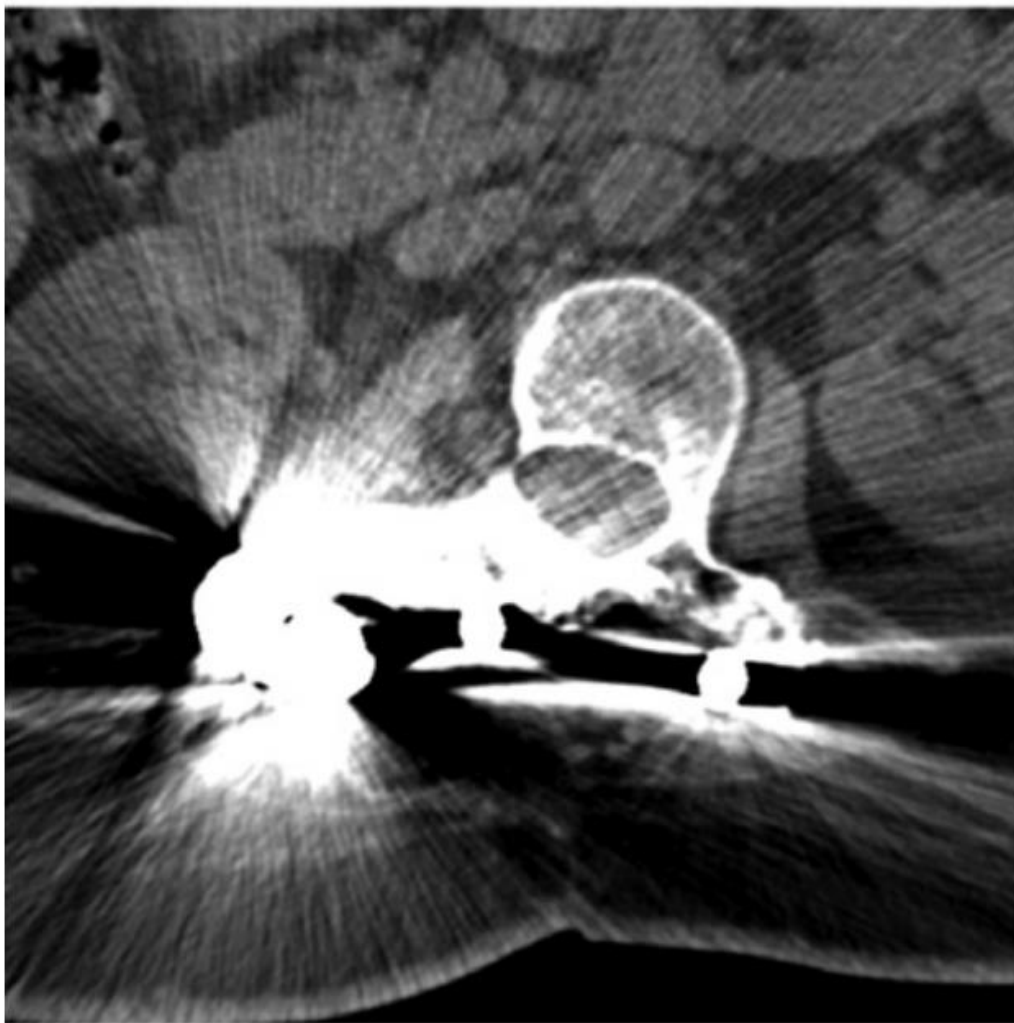
[75 140) keV  
w/o Tin



[75 140) keV  
with Tin



## EID-CT



a.

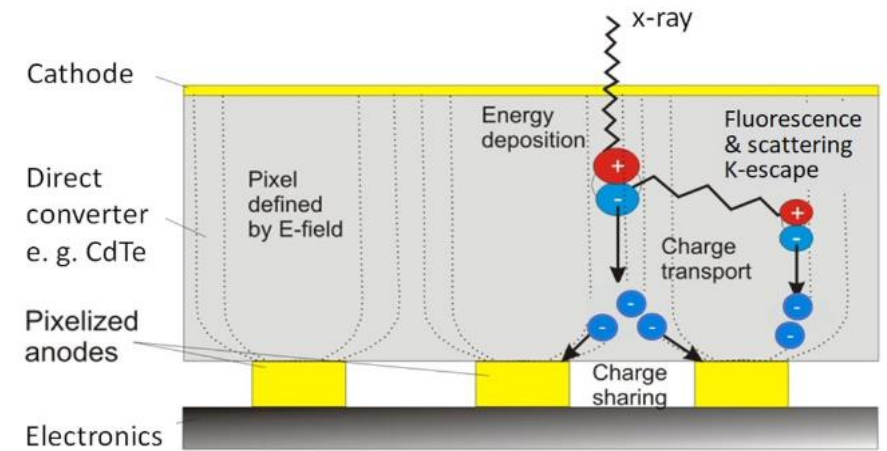
## PCD-CT



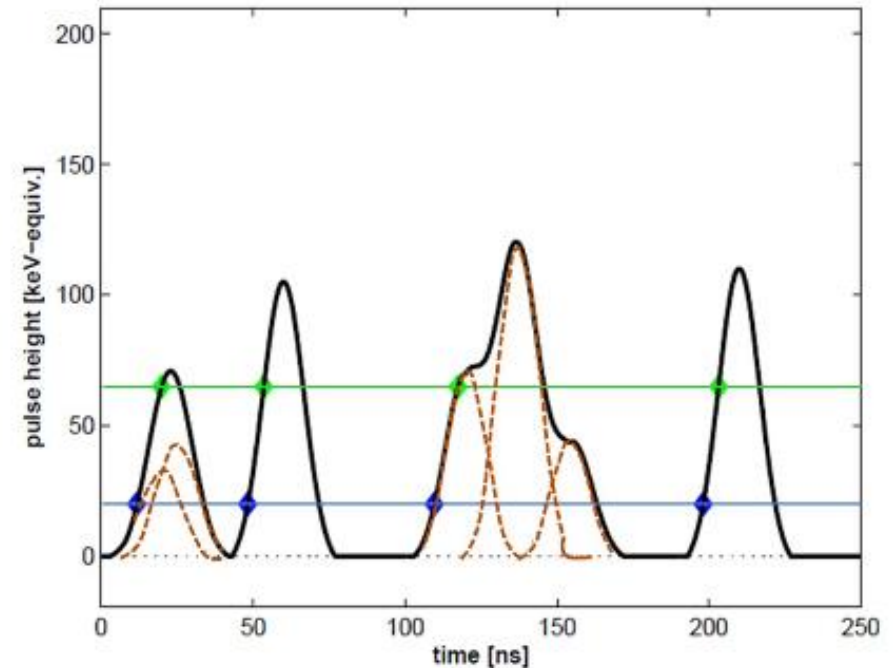
b.

# Limitace

- Signál splitting na okrajích detekčních elementů – jeden foton vysoké energie zaznamenaný jako dva fotony o nižší energii ve dvou detekčních elementech – čím větší element, tím lepší
- Přenos náboje
- Pulse pile-up efekt – fluence na CT až  $10^9$  cts/(s.mm<sup>2</sup>) – čím menší element, tím lepší



**Fig. 6** Schematic illustration of the effects that reduce spectral resolution in a photon-counting detector. Among them are charge sharing at pixel boundaries or energy loss due to fluorescence and K-escape, which lead to double counting of X-ray pulses at wrong energies



# Shrnutí

- **Hlavní přínos**
- Lepší kontrast obrazu
- Zlepšení poměru signálu a šumu
- Lepší prostorové rozlišení
- Redukce elektronického šumu
- Lepší odlišení tkání a materiálů
- Možnost kvantitativního hodnocení
- Redukce artefaktů

**Table 1: Potential Benefits and Clinical Applications of PCD CT**

Features and Benefits of PCD CT	Potential Clinical Applications
High spatial resolution	Temporal bone imaging Musculoskeletal imaging Lung imaging Cardiovascular imaging (stent imaging)
Simultaneous multienergy acquisition	Material decomposition Plaque removal Bone removal Virtual noncontrast imaging Virtual noncalcium imaging Virtual monoenergetic synthesis
Energy binning	
Low electronic noise	Imaging large patients Low-radiation-dose examinations
K-edge imaging	Dual-contrast imaging*
Metal artifact reduction	Metal implant imaging (musculoskeletal, neurologic)
Uniform photon weighting and improved contrast-to-noise ratio with iodinated contrast material	Contrast material-enhanced CT (abdominal, neurologic, cardiovascular)

**Děkuji za pozornost.**



# Použitá literatura

- [Photon-counting CT review - ScienceDirect](#)
- [Photon-counting Detector CT: System Design and Clinical Applications of an Emerging Technology | RadioGraphics \(rsna.org\)](#)
- [Photon-counting x-ray detectors for CT \(iop.org\)](#)
- [Mayo Clinic Begins Use of New Photon-counting CT Detector | DAIC \(dicardiology.com\)](#)
- [Opportunities for new CT contrast agents to maximize the diagnostic potential of emerging spectral CT technologies \(europepmc.org\)](#)
- [Spectral Performance of a Whole-Body Research Photon Counting Detector CT: Quantitative Accuracy in Derived Image Sets - PMC \(nih.gov\)](#)
- [Basic principles and clinical potential of photon-counting detector CT \(springer.com\)](#)
- [Feasibility of lung imaging with a large field-of-view spectral photon-counting CT system – ScienceDirect](#)
- [Noise characteristics of virtual monoenergetic images from a novel detector-based spectral CT scanner - European Journal of Radiology \(ejradiology.com\)](#)
- [Virtual monoenergetic images from photon-counting spectral computed tomography to assess knee osteoarthritis | European Radiology Experimental | Full Text \(springeropen.com\)](#)
- [Spectral Computed Tomography: Fundamental Principles and Recent Developments - PMC \(nih.gov\)](#)
- [\(16\) \(PDF\) Photon-counting CT: Technical Principles and Clinical Prospects \(researchgate.net\)](#)