Speckle-based imaging (SBI) applications with spectral photon counting detectors at the newly established OPTIMATO (OPTimal IMAging and TOmography) lab

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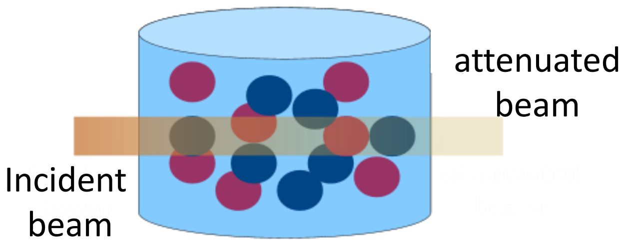
Scattering BAsed X-ray Imaging and Tomography project (S-BAXIT)

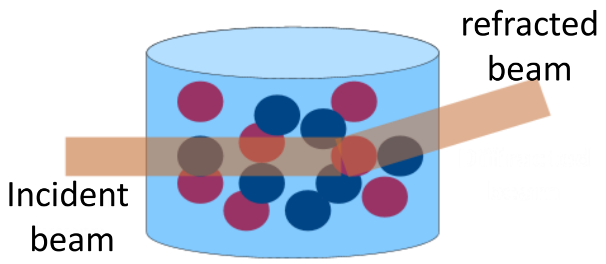
*H2020 ERC Consolidator Grant project lead by prof. P. Thibault (University of Trieste, Italy), website https://s-baxit.optimato.eu/

Scattering BAsed X-ray Imaging and Tomography project*

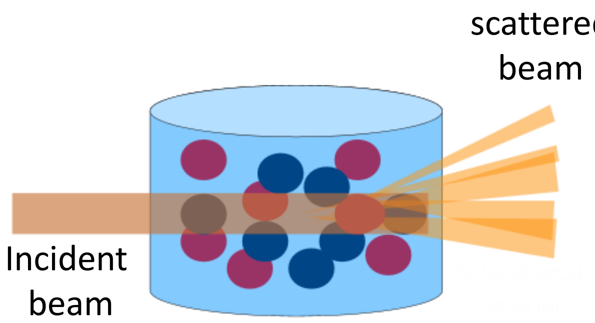
- Development of algoritmic solutions for phase sensitive tehcniques exploiting all the contrast mechanisms for x-rays



Attenuation: reduction of the intensity



Refraction: deviation of the X-ray beam caused by the sample's features and geometry

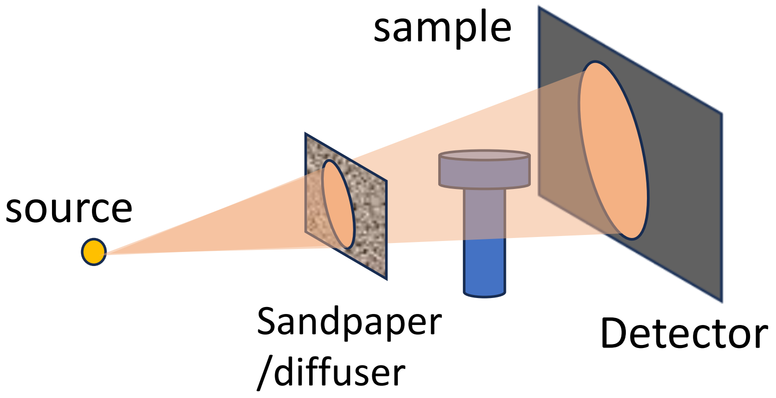


Small angle scattering (dark-field): scattering arising from features not resolved by the detection system

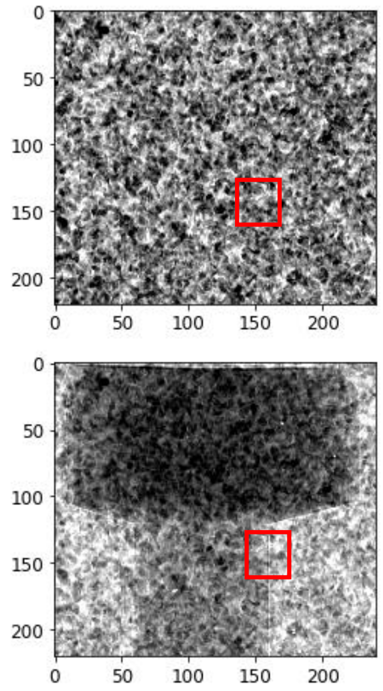
Speckle-based imaging

Speckles imaging

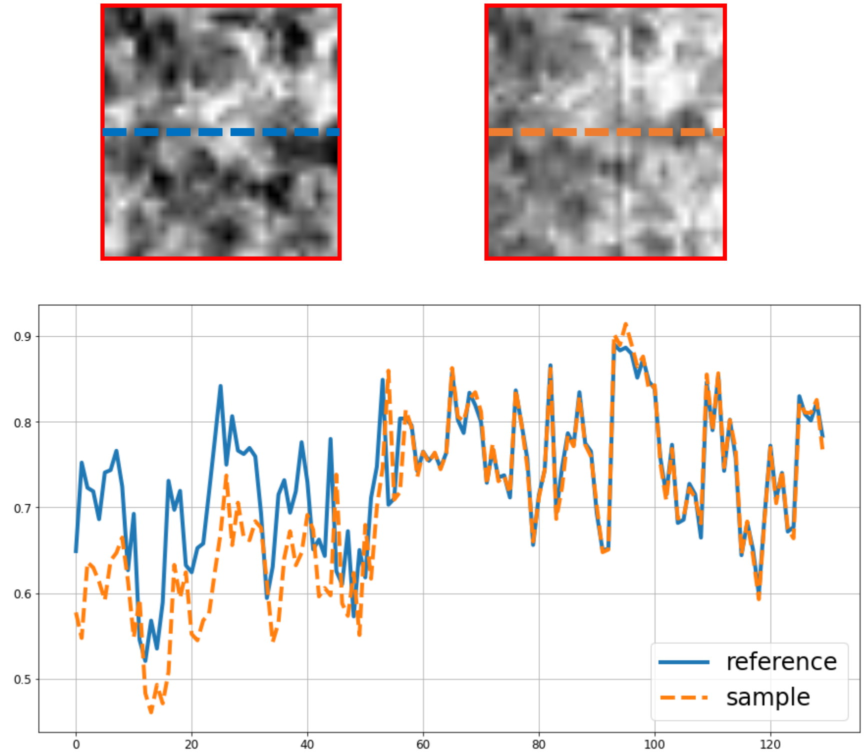
Setup



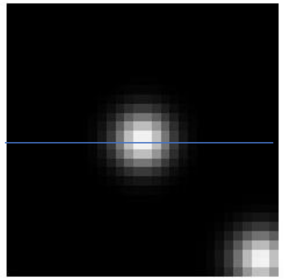
Reference and sample images

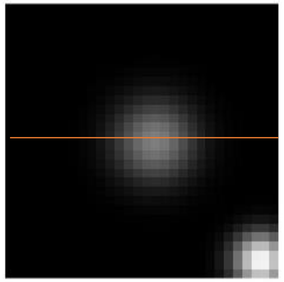


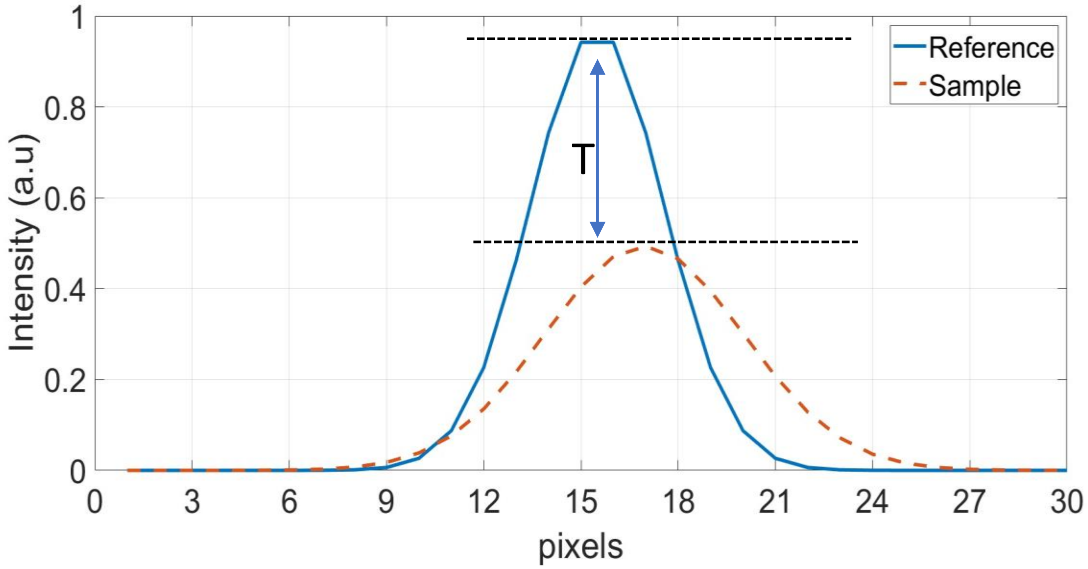
Signals



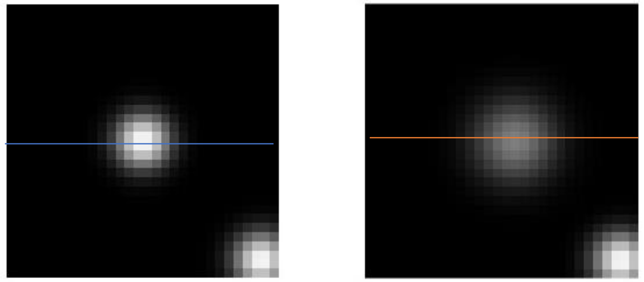
Transmission

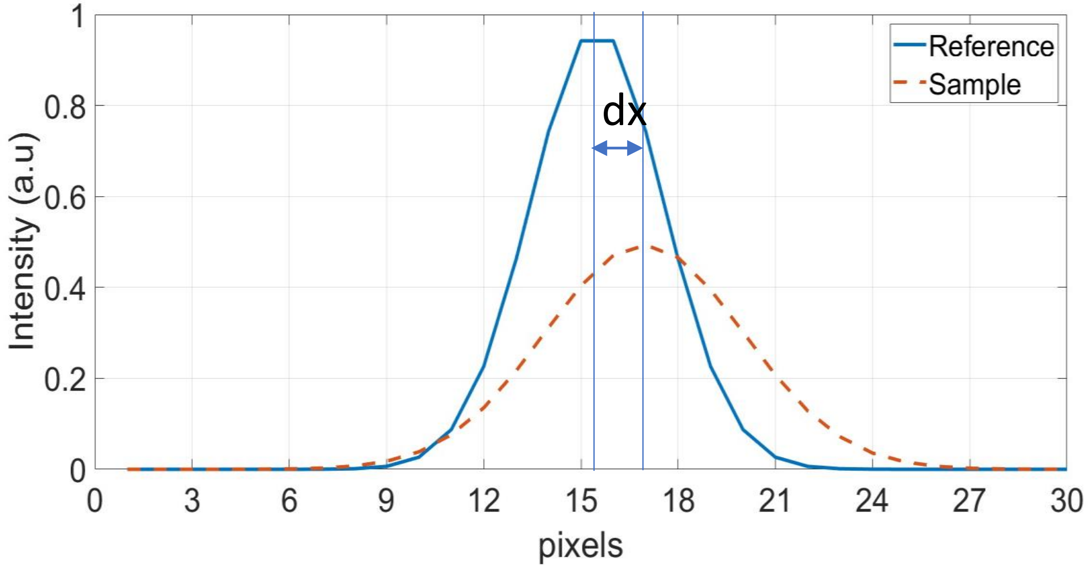




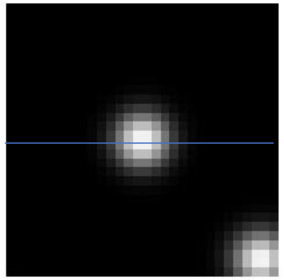


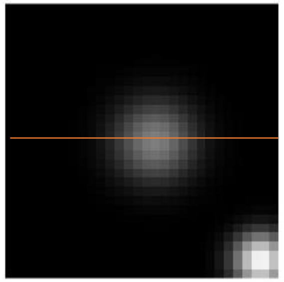
Diffraction

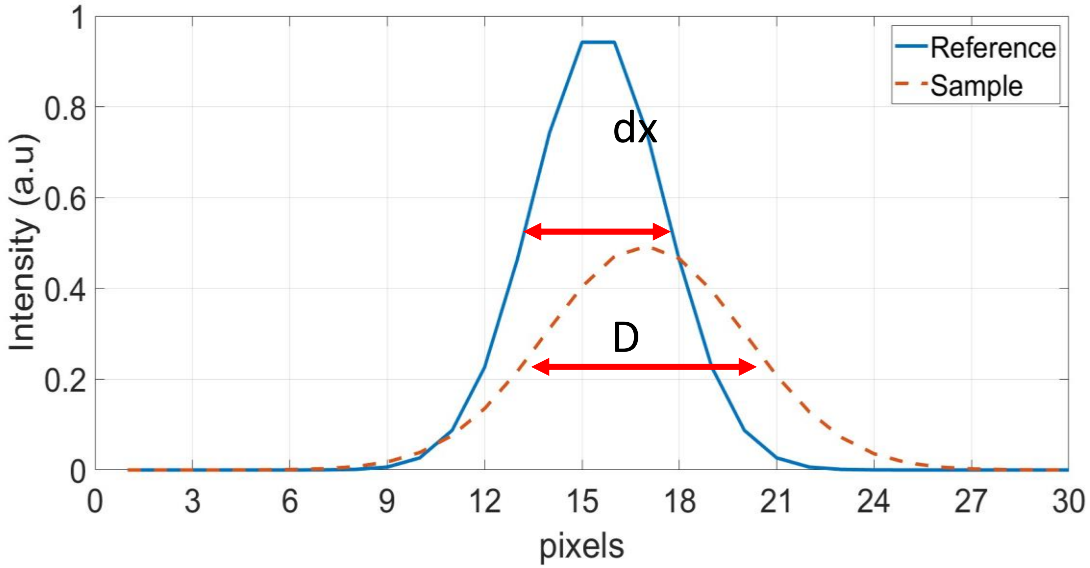




Dark field





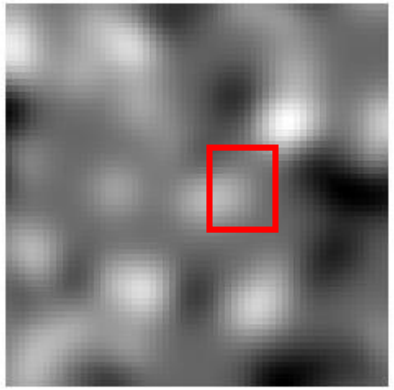

Reference
Sample
dx
D
Intensity (a.u)
pixels
1
0.8
0.6
0.4
0.2
0
0
3
6
9
12
15
18
21
24
27
30

Unified Modulated Pattern Analysis (UMPA)

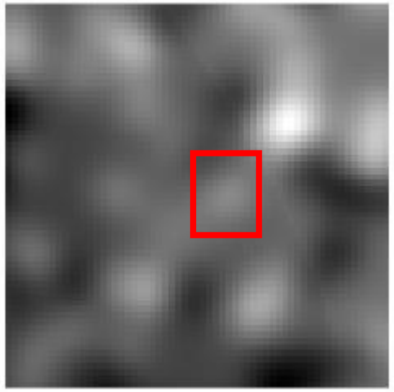
Sample refraction and attenuation can be analyzed directly from the speckle pattern: the signal is extracted using a cost function and a sliding-window.

$$I^{\text{model}}(x, y) = T(x, y) \cdot \{\langle I_0(x+u, y)\rangle + D(x, y) \cdot [I_0(x+u, y) - \langle I_0(x+u, y)\rangle]\}$$

$$\mathscr{L}(x, y; u, T, D) = \sum_{m=1}^{M} \sum_{w_x=-N}^{N} \sum_{w_y=-N}^{N} \Gamma(w_x, w_y) \cdot |I_m^{\text{model}}(x+w_x, y+w_y; u, T, D) - I_m(x, y)|^2$$



Reference



Sample image

[1] F. De Marco, et al., Opt. Exp. 31(1) 635-650 (2023)

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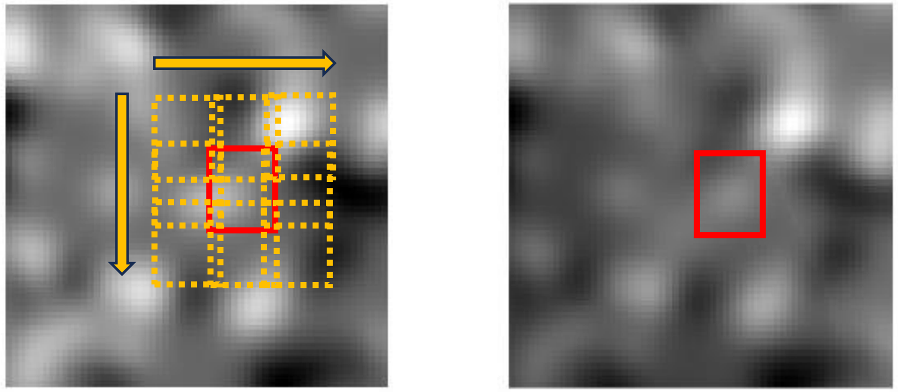

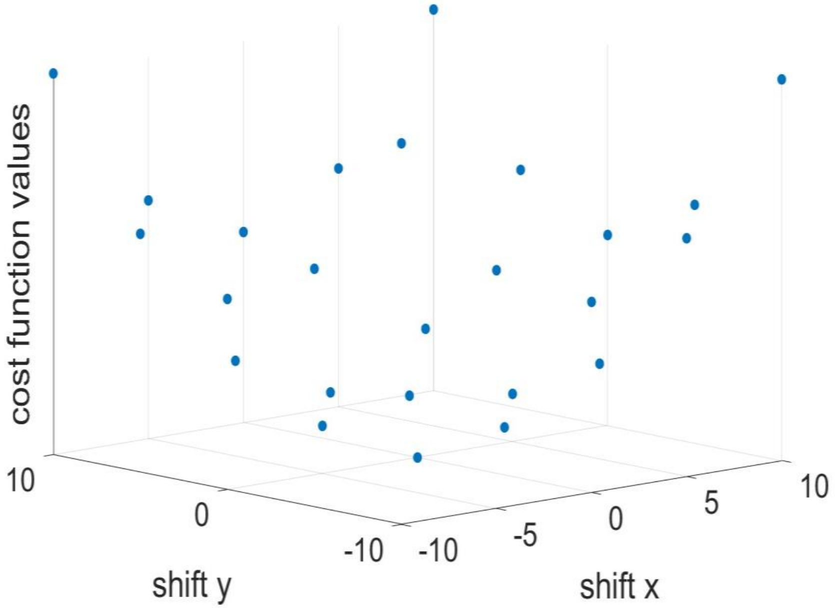

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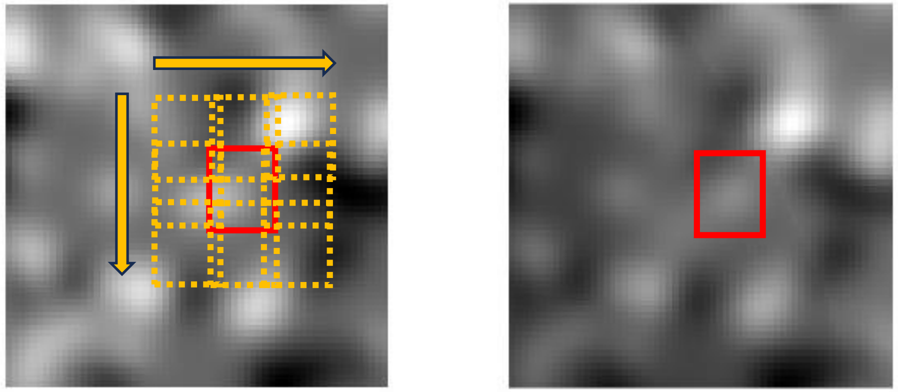

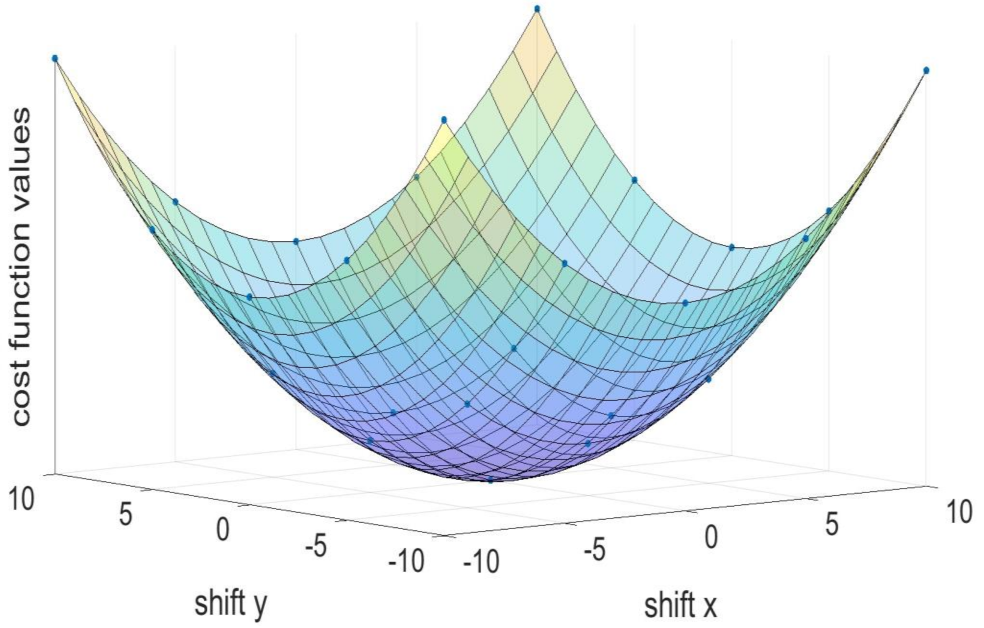

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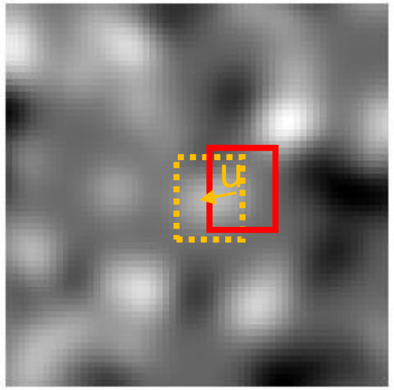
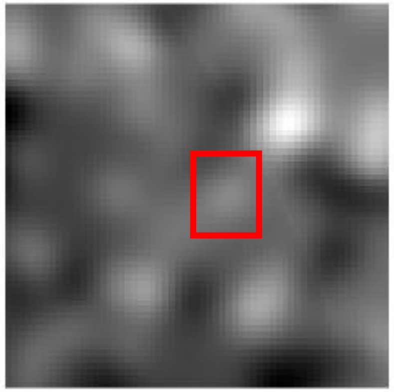
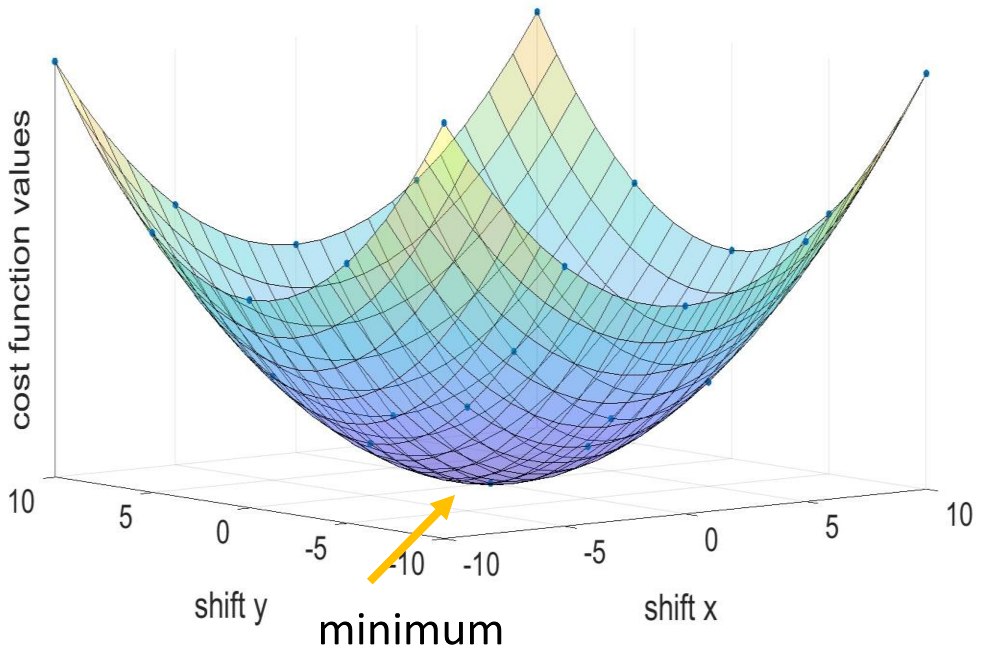


Reference image



Sample image



From synchrotrons to compact X-ray sources

Requirements

High spatial resolution:

- Source: small source-size, stable beam
- Detector: optimal spatial resolution

High statistics:

- Source: high intensity
- Detector: high efficiency

High visibility:

- Speckles have higher contrast at low energies, or for long propagation distances

Limitations:

- Cone beam geometry → the effective propagation distance scales with the magnification **M**
- Microfocus sources→ the source size (SS) limits the maximum resolution achievable (if the resolution of the detection system is > SS)
- Reduced speckles contrast (i.e., visibility) → hampers speckles tracking

OPTimal IMAging and TOmography (Optimato) lab

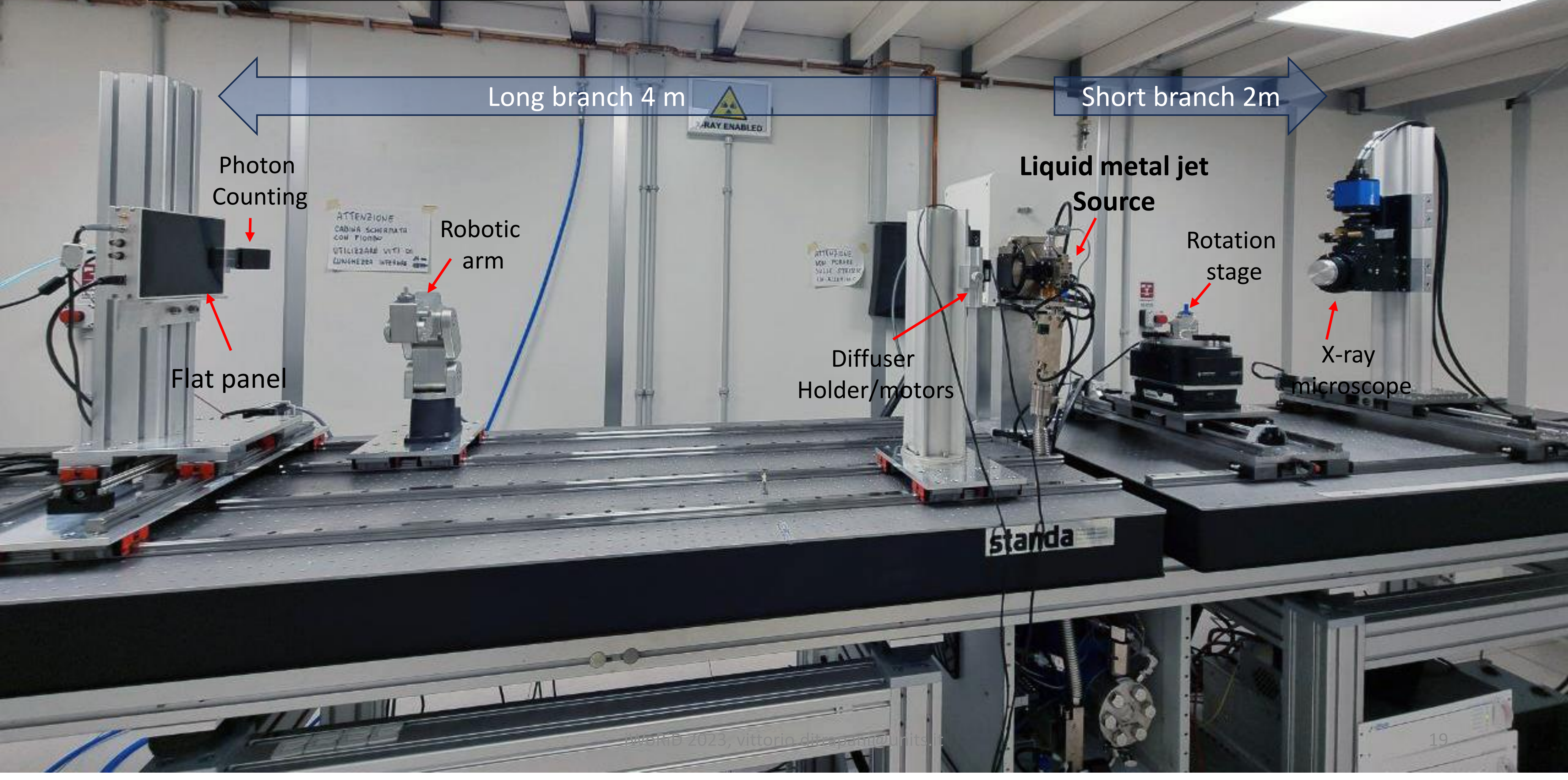
The lab


2.5 m
7 m

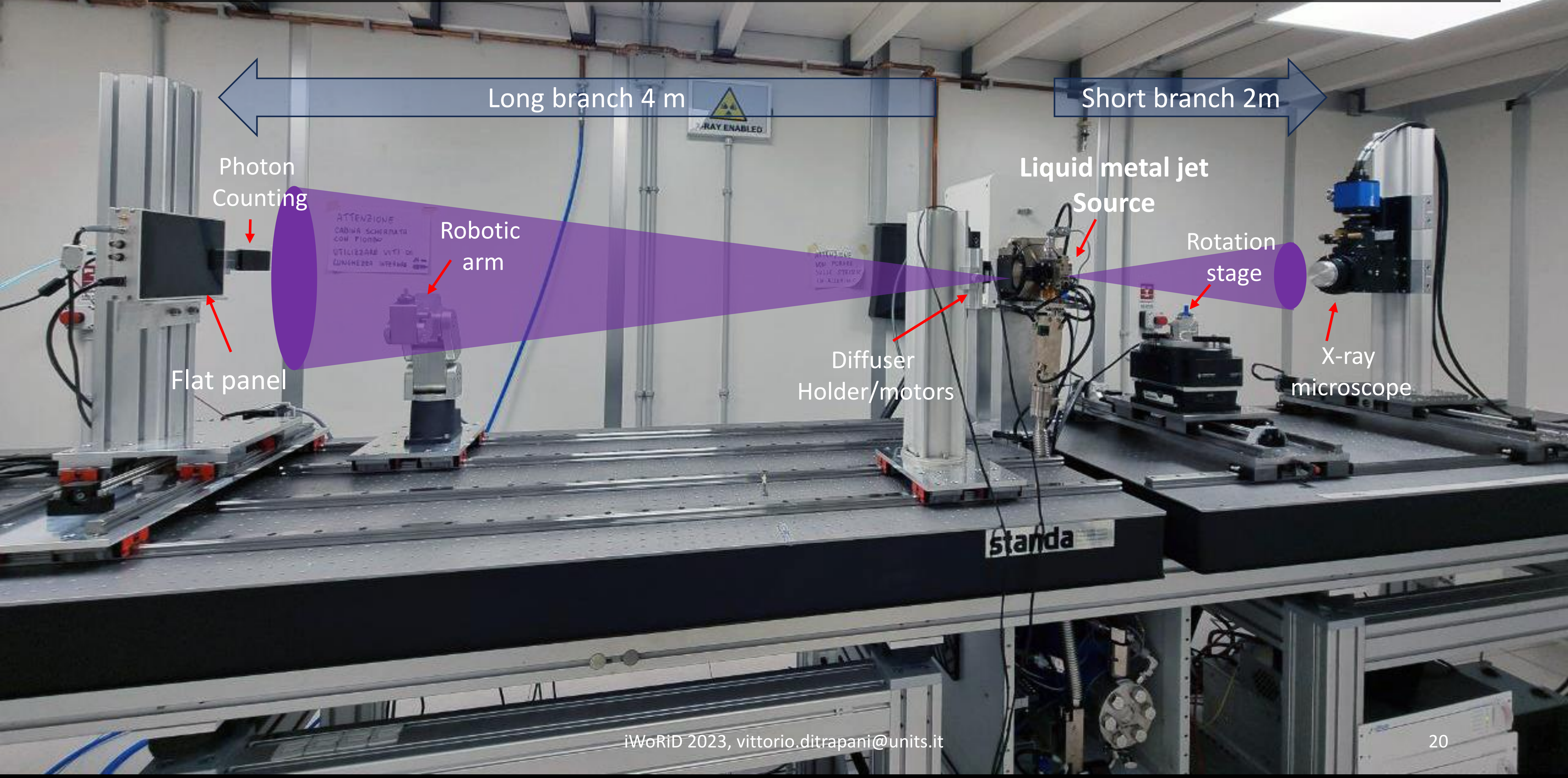

ATTENZIONE
NON FORARE
SULLE STRISCIE
IN ALLUMINIO

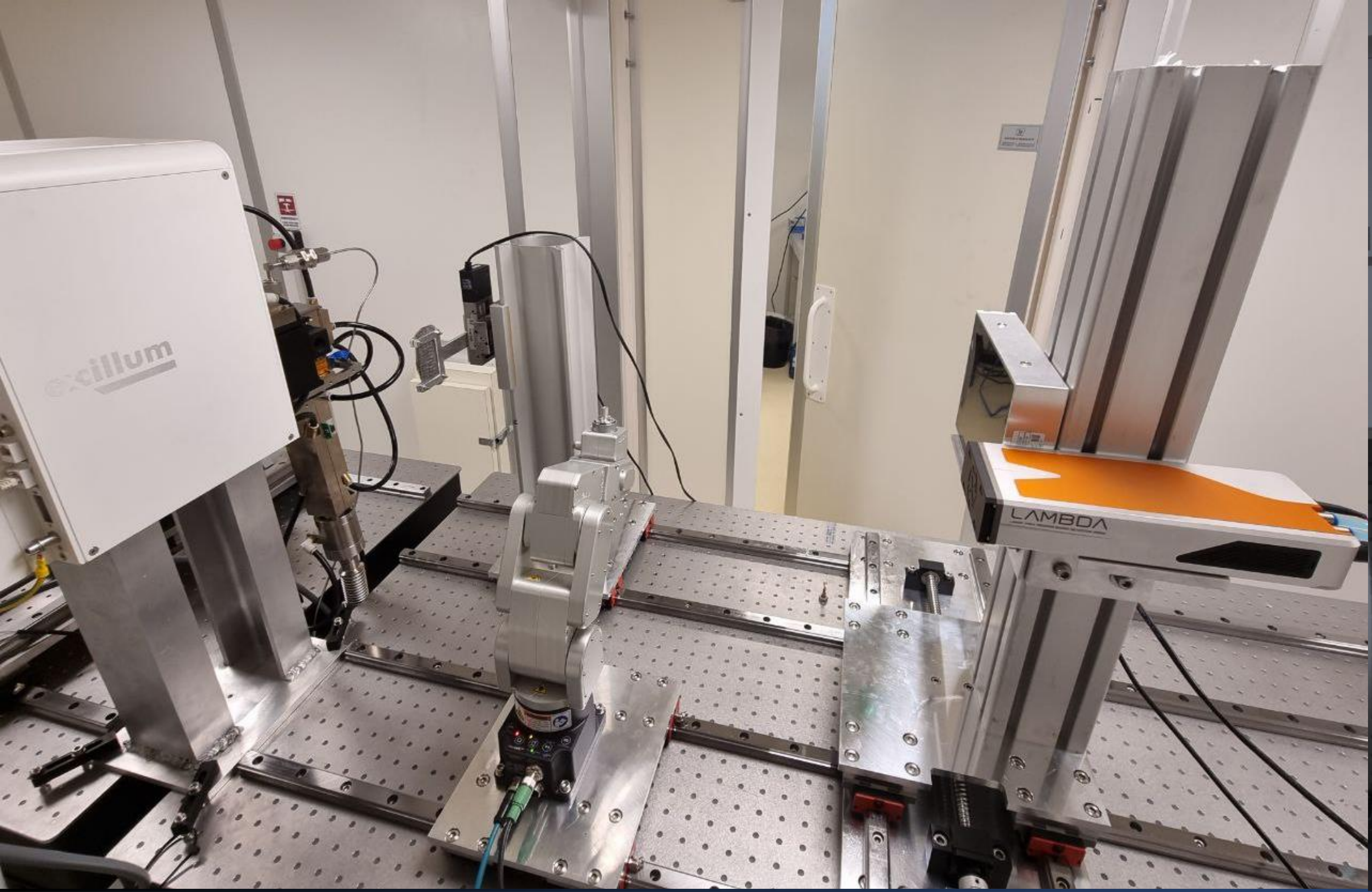

ATTENZIONE
CABINA SCHERMATA
CON PIOMBO
UTILIZZARE VITI DI
ATTENZIONE
NON FORARE
SULLE STRISCIE
IN ALLUMINIO

Inside the hutch

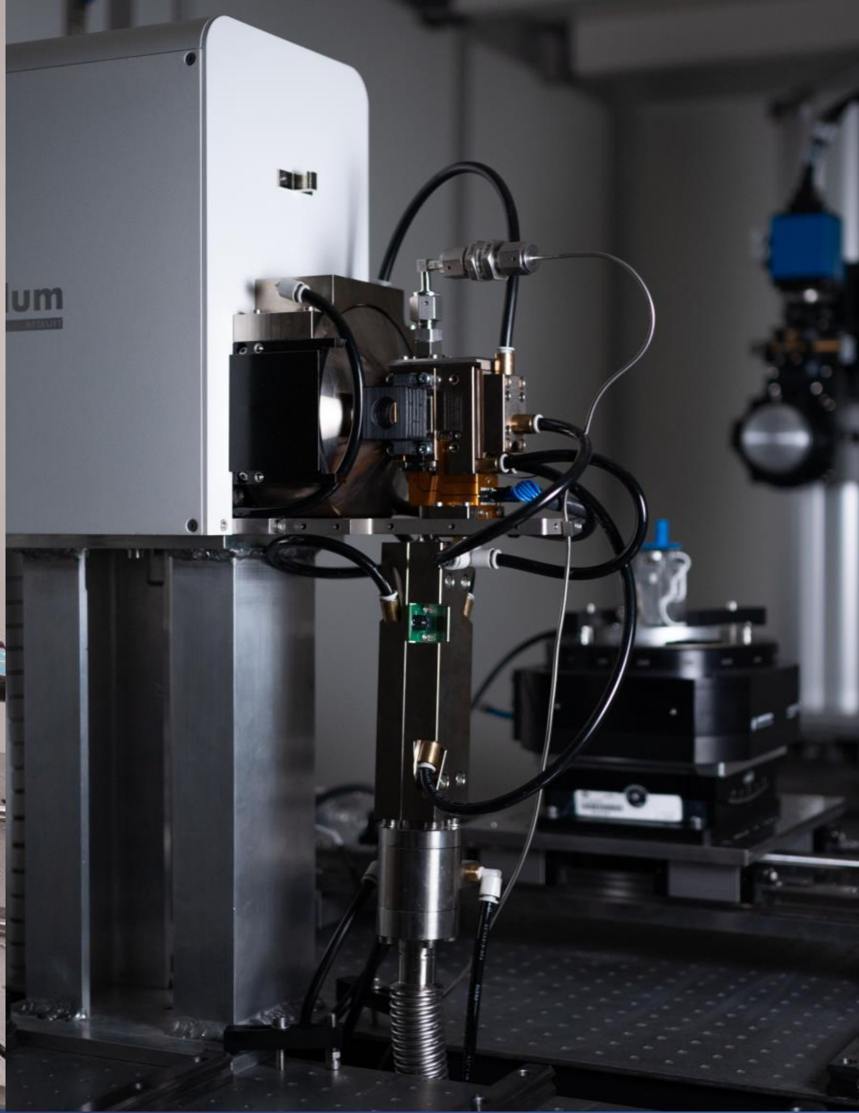


Inside the hutch





medium/low resolution branch >15 µm



High resolution branch >0.6 µm

The long branch

Excillum liquid metaljet D2 + 160 kV

Main features:

- Microfocus (15/20 µm)
- 160 kV max voltage
- Galinstan anode, main peaks 9.2 keV (Ga) and 24 keV (In)
- 13° beam angle

Lambda 350 K (x-spectrum)

Main features:

- 3x2 Medipix-3 chip bonded to a **single** sensor (area 42×28 mm^2)
- Charge summing mode for 'optimized' spatial and spectral resolution
- Noise threshold (csm) 10/11 keV
- 1mm CdTe sensor
- 55 µm pixel size

Varex 1512N CMOS flat panel

Main features:

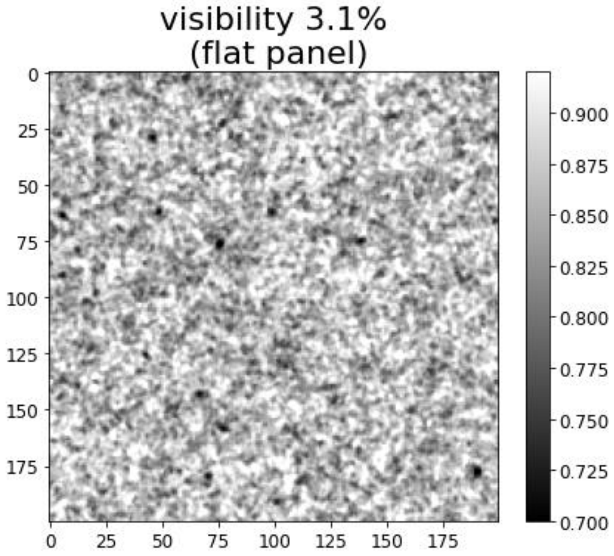
- 200 µm CsI micro-columnar scintillator
- 74.8 µm pixel size
- Large area 14.5 ×11.4 cm^2

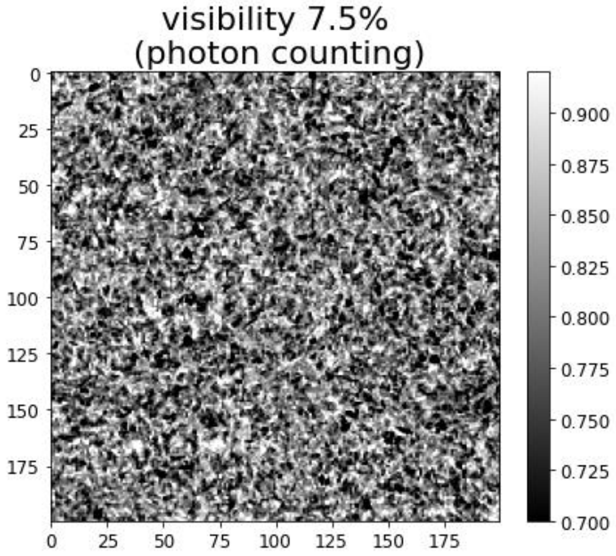
Speckle-imaging at the Optimato lab

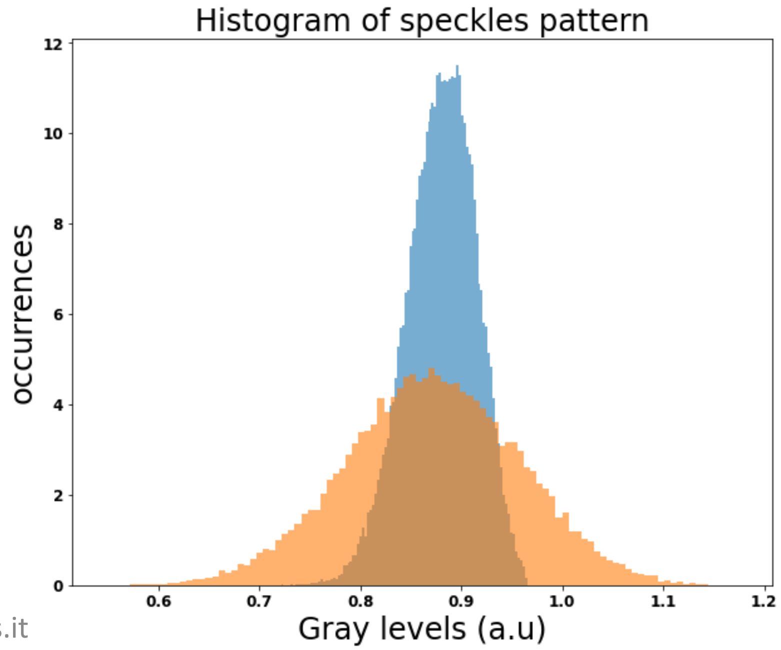
Main limitation

Speckles must be detectable:

- Speckles must be well resolved
- Visibility may be defined as the standard deviation of gray levels in the reference image (the larger, the higher the contrast of speckles)
- The visibility may be enhanced by increasing the propagation distance sandpaper-detector (fringes + absorption contrast)





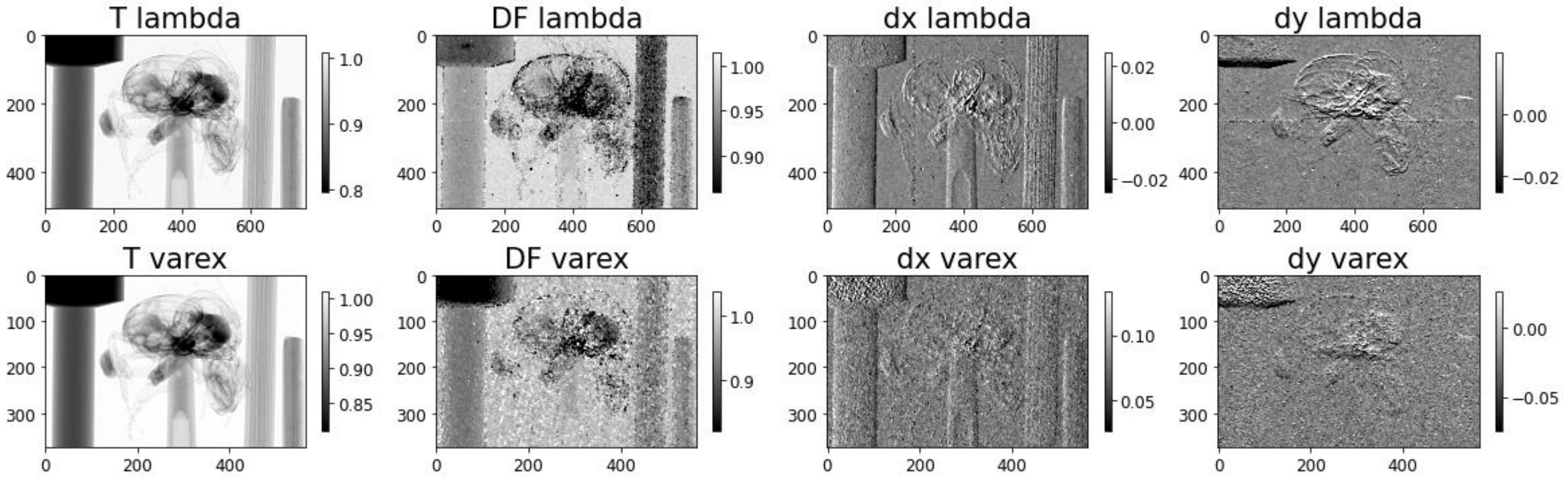


First images

Same conditions (varex/lambda acquisition)

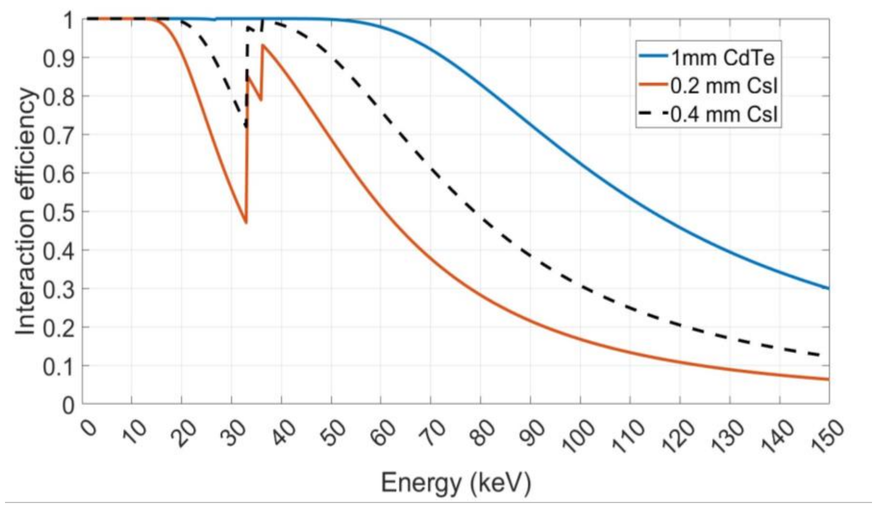
- 5 layers of P120 sandpaper (grit size 125 µm)
- Distance source sandpaper 75 cm
- Distance source-detector 150 cm
- Distance source sample 80 cm
- Magnification ~1.9
- 20 sandpaper positions × 30 s exposure time
- Source: 50 kV, 250 W, focal spot 20 μm

Direct detection photon counting vs scintillator-based charge-integrating flat panels

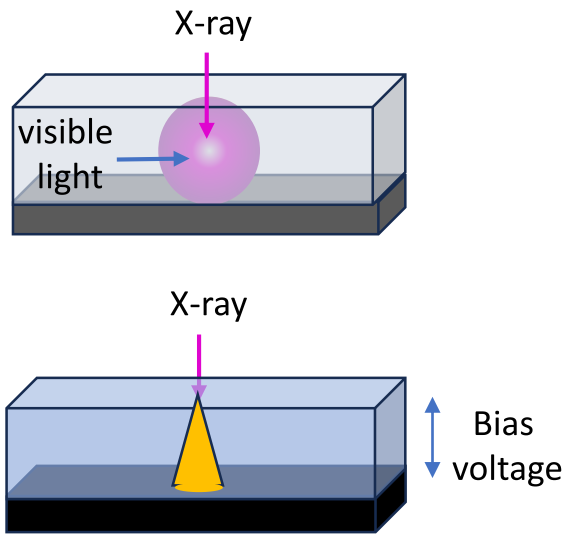


‘Passive’ advantages of CdTe XPCDs over flat panels

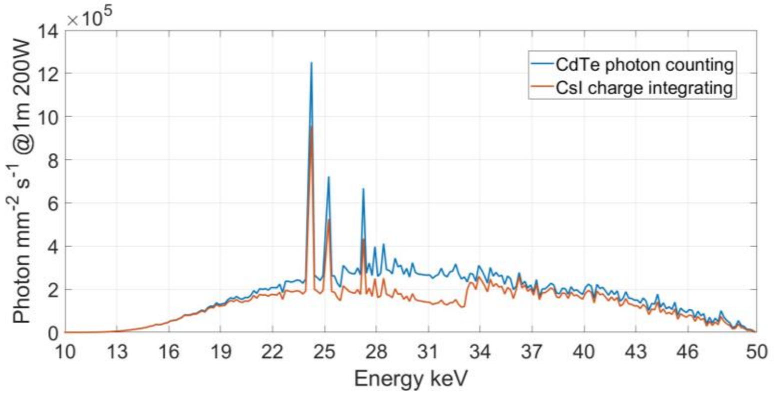
Efficiency



Spatial resolution



Effective energy



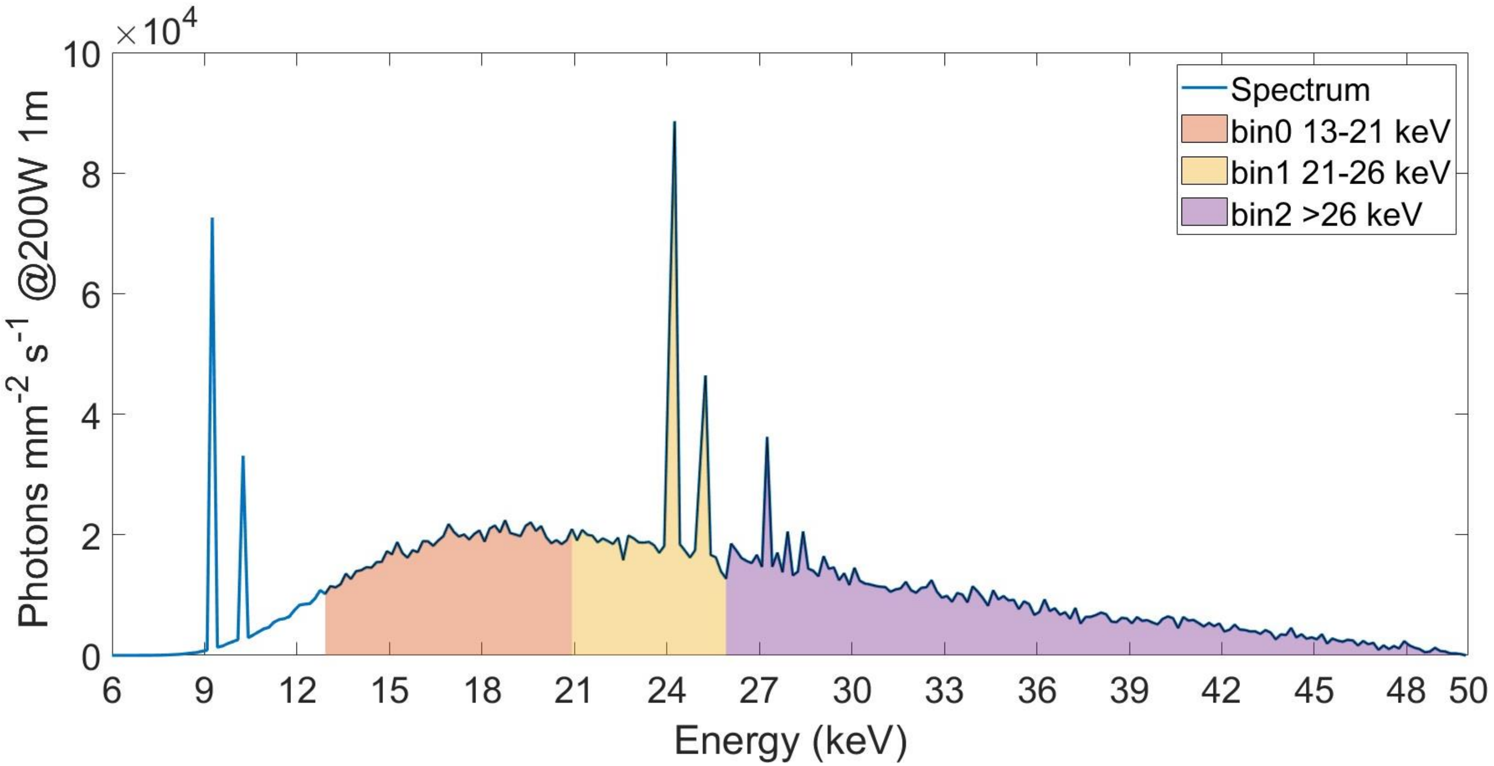
Source 50 kV, 200 W + 1mmAl

Mean Energy:

CdTe photon counting = 28.7 keV

CsI charge integrating = 31.1 keV

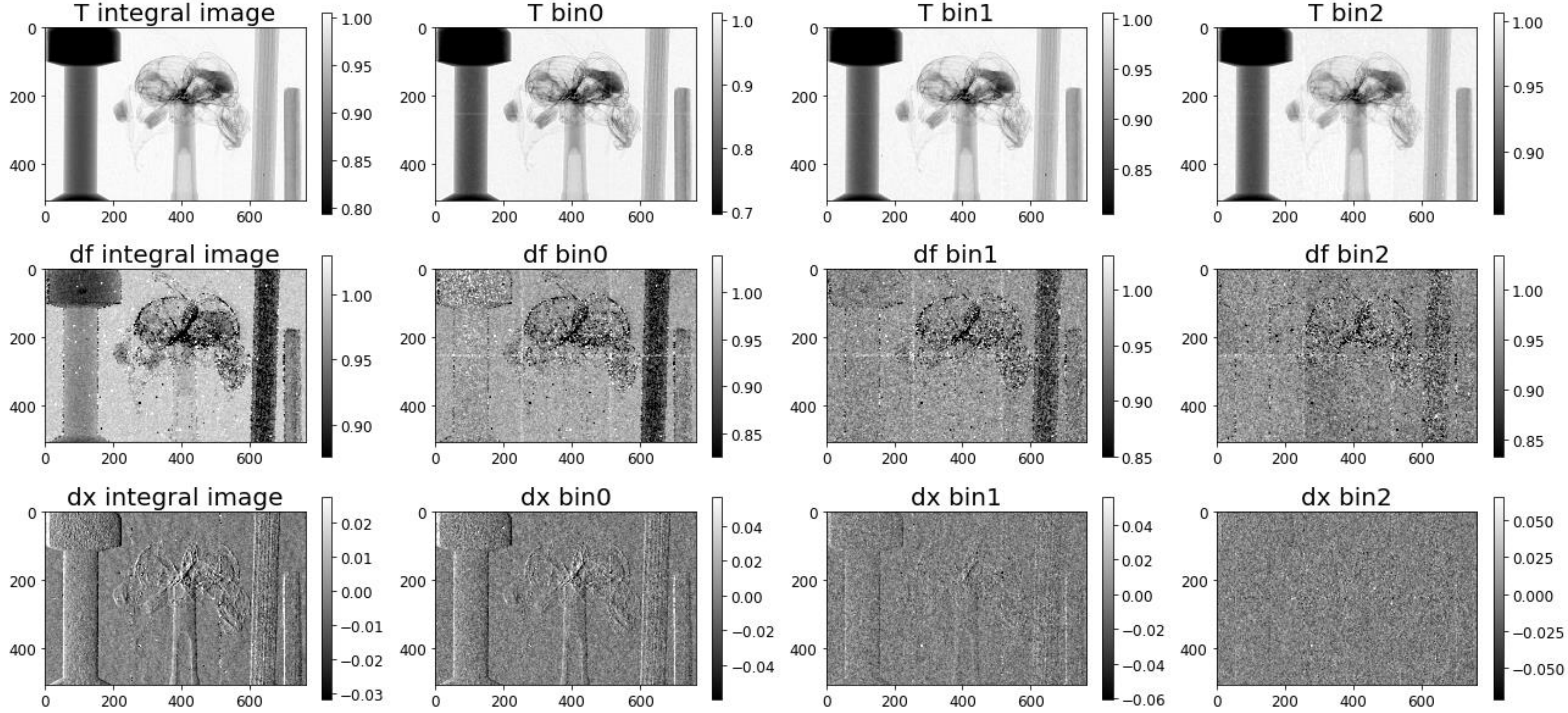
Exploiting spectral capabilities of photon counting detectors



Excillum D2 spectrum 50 kV, 200W, 1 mm, no additional filtration

Spectral capabilities

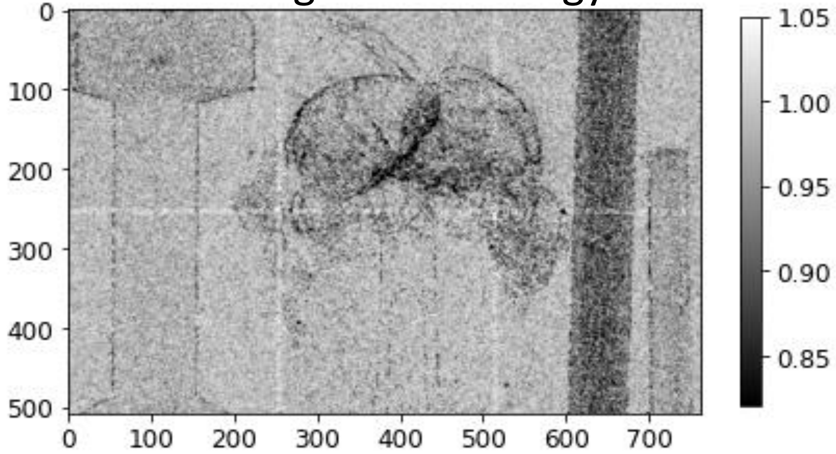
13-21 keV | 21-26 keV | >26 keV



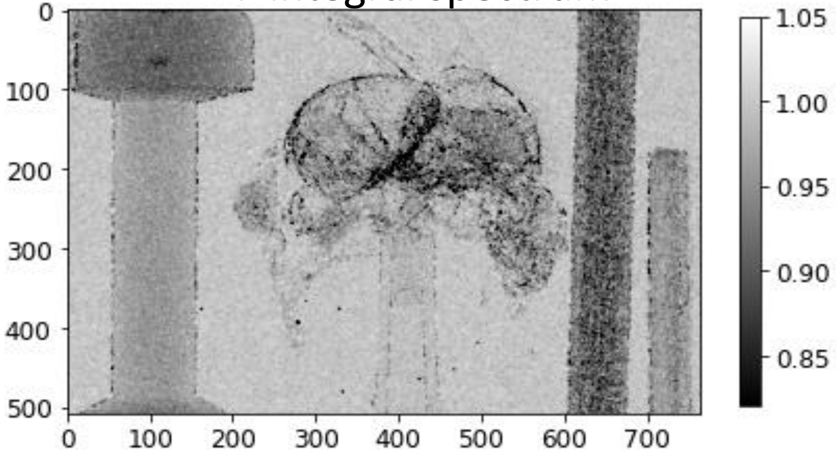
Visibility = 7.0% | Visibility = 14.5% | Visibility = 6.5% | Visibility = 3.8%

beam hardening artifact in dark field images

DF averaged over Energy bins



DF integral spectrum



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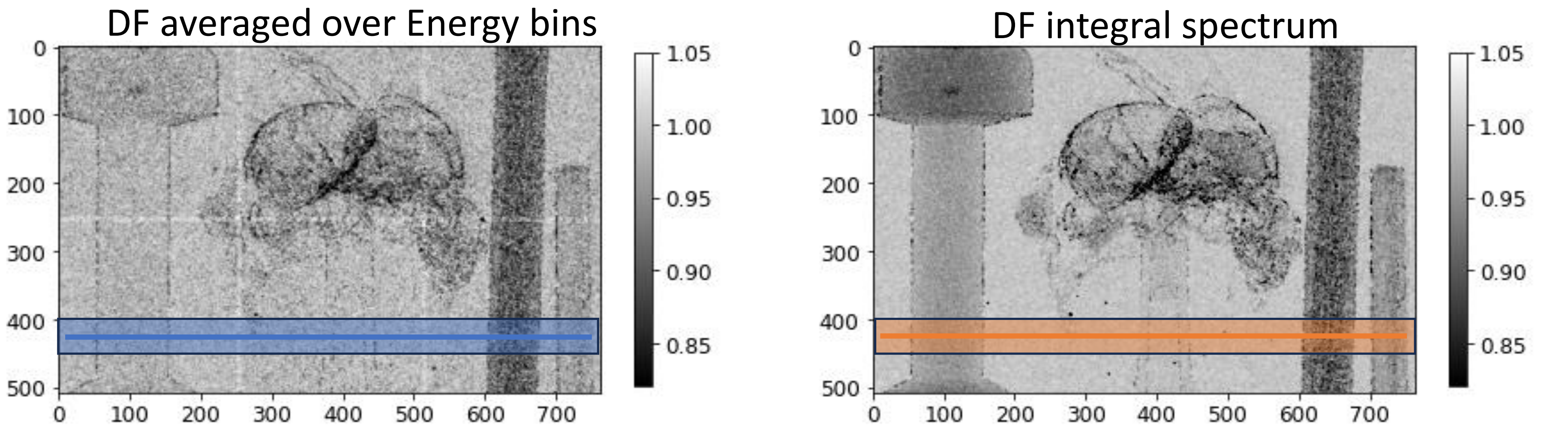
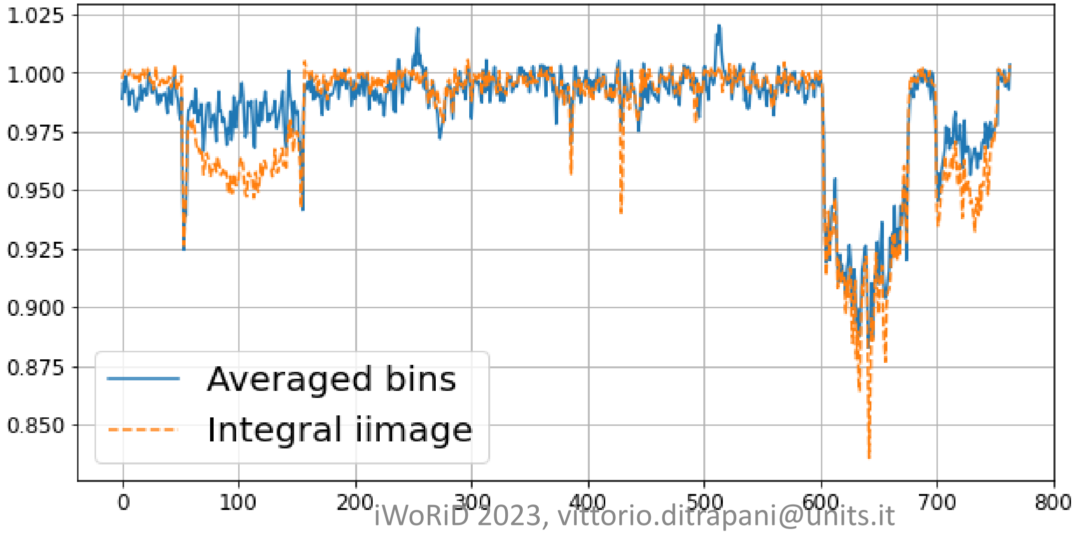
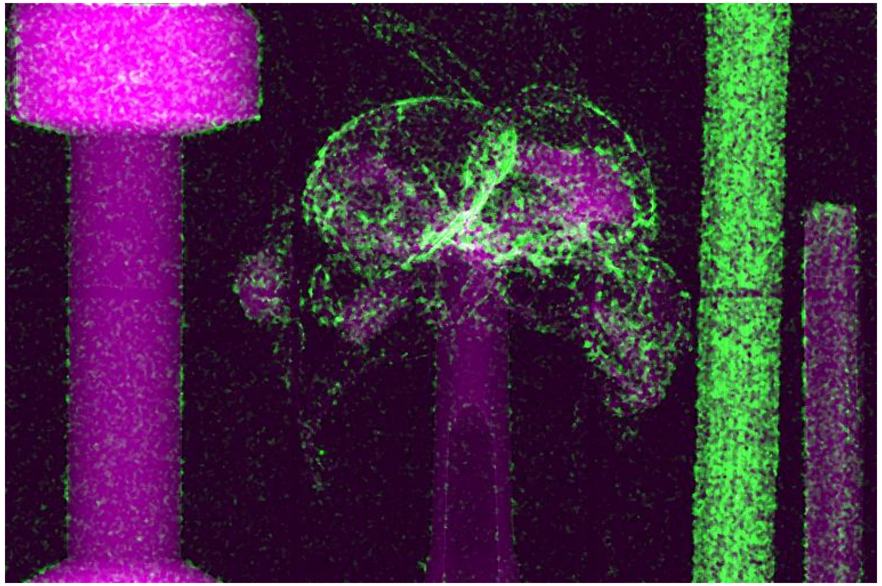
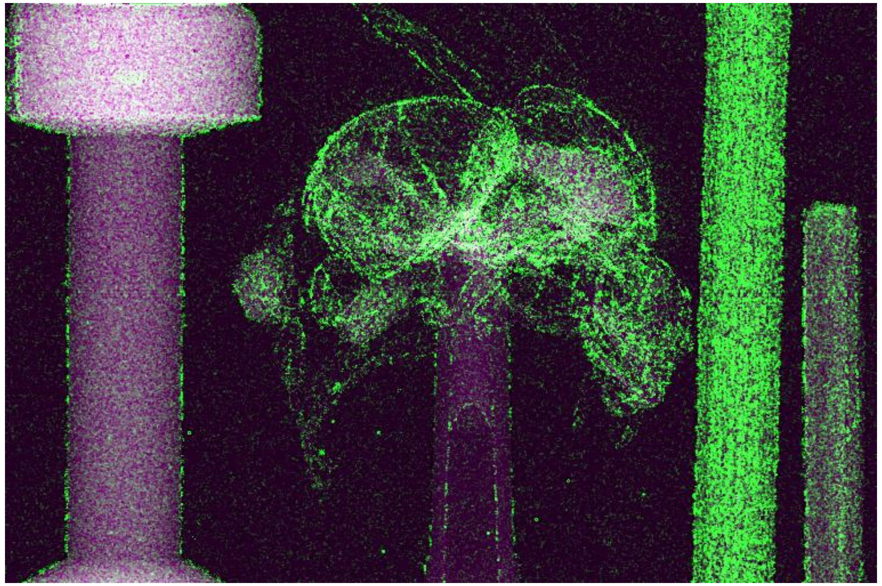




beam hardening artifact in dark field images

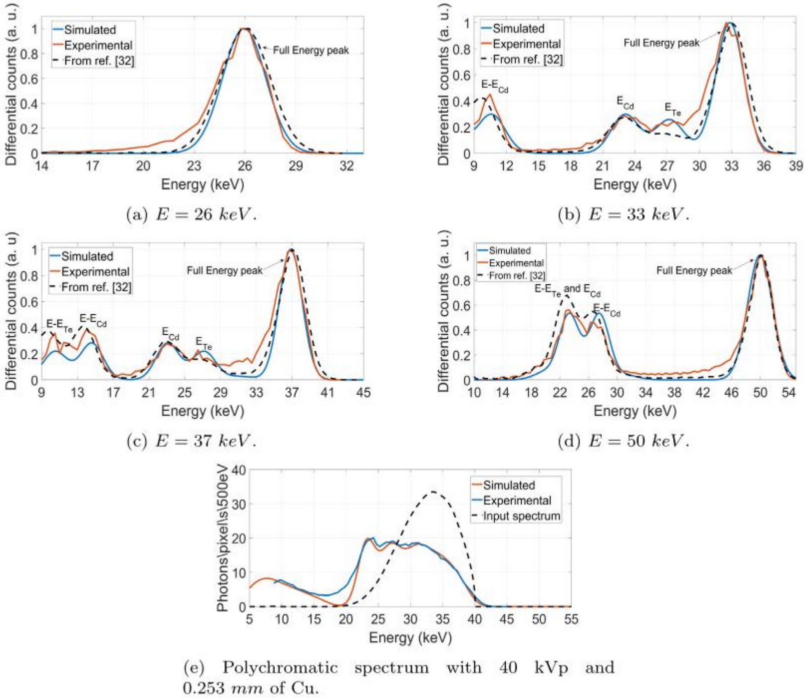


Overlay –log(T) (purple), -log(DF) (green) for the averaged DF from single bins



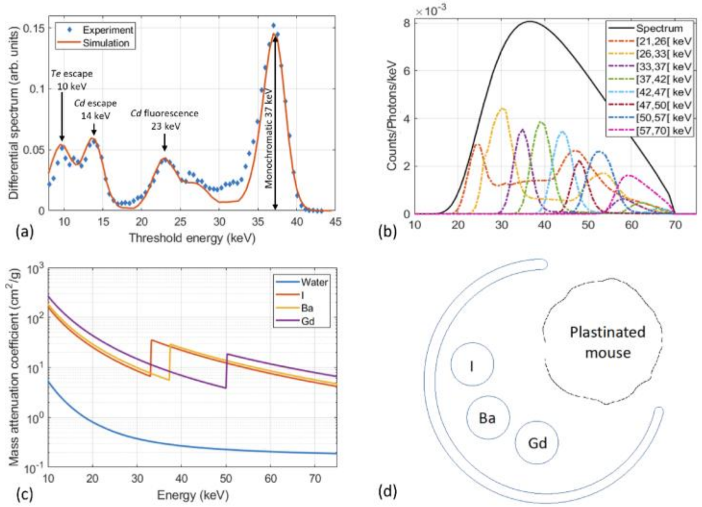
Overlay –log(T) (purple), -log(DF) (green) for the averaged DF from integral image

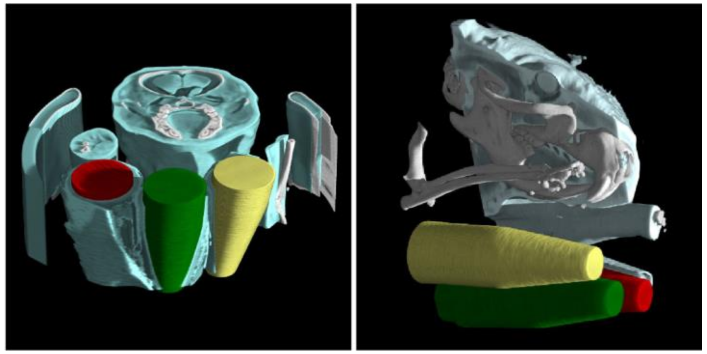
Spectral decomposition



(a) $E = 26\ keV$. (b) $E = 33\ keV$. (c) $E = 37\ keV$. (d) $E = 50\ keV$. (e) Polychromatic spectrum with 40 kVp and 0.253 mm of Cu.

V. Di Trapani et al. Development and validation of a simulation tool for K-edge Subtraction imaging with polychromatic spectra and X-ray photon counting detectors, NIM(A) 2023

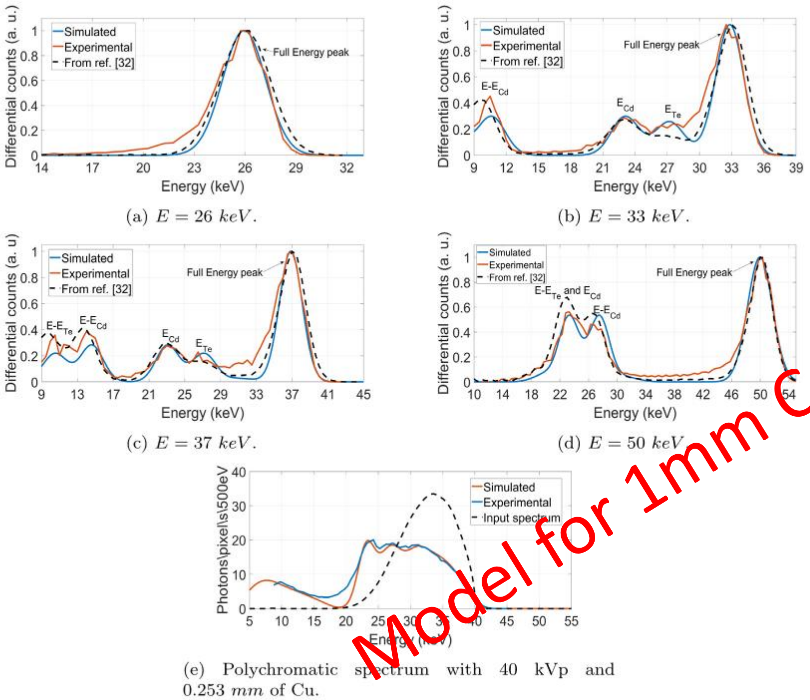




(a) (b)

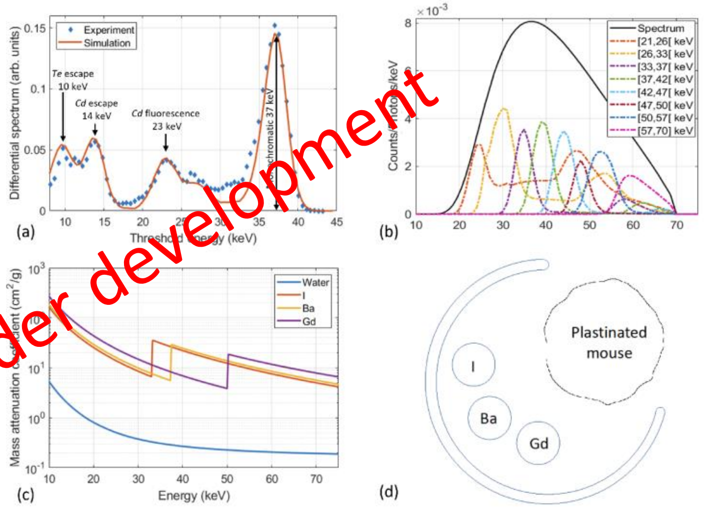
V. Di Trapani, L. Brombal, and F. Brun, "Multi-material spectral photon-counting micro-CT with minimum residual decomposition and self-supervised deep denoising," Opt. Express **30**, 42995-43011 (2022)

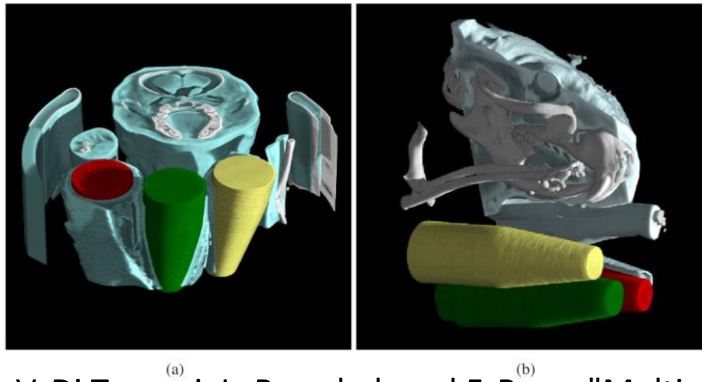
Spectral decomposition



Model for 1mm CdTe medipix-3 under development

V. Di Trapani et al. Development and validation of a simulation tool for K-edge Subtraction imaging with polychromatic spectra and X-ray photon counting detectors, NIM(A) 2023





V. Di Trapani, L. Brombal, and F. Brun, "Multi-material spectral photon-counting micro-CT with minimum residual decomposition and self-supervised deep denoising," Opt. Express **30**, 42995-43011 (2022)

Future developments

- Include the spectral information in the model of the Unified Modulated Pattern Analysis:
  - including a basis material decomposition
  - corrections for beam-hardening artifacts in dark field images
- Build/find custom-made random diffusers for increased visibility

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POSTER: S. Savatović et al., Helical sample-stepping for faster speckle-based multi-modal tomography with the Unified Modulated Pattern Analysis (UMPA) model

International Workshop on Radiation Imaging Detectors 24th iWoRiD

S-BaXIT
Scattering-Based X-ray Imaging and Tomography

Thank you