DE LA RECHERCHE À L'INDUSTRIE

CALISTE and its applications

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www.cea.fr

SUMMARY

CALISTE: a compact X-ray spectro-imager module

- history
- IDeF-X family
- CALISTE family

ORIGAMIX: a portable X- and gamma-ray spectro-imaging camera

- history of the project
- fields of application
- physical concepts
- actual status
- next steps

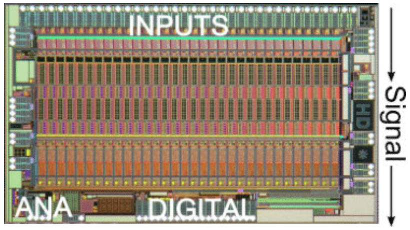
SATBOT: realtime dosimetry for radiotherapy

- NP + radiotherapy
- XRF dosimetry
- physical concepts
- actual status
- next steps

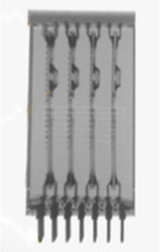
PROJECT HISTORY

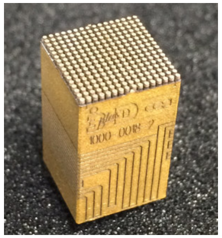
CALISTE is based on a long line of experience
but also aims for challenging new developments

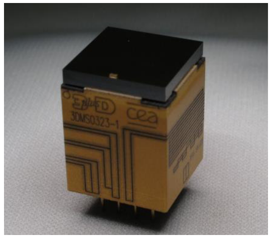
- based on IDeF-X readout ASICs
  - started in 2003; now in 7th generation
  - properties: ultra-low noise, low power consumption, channel individual triggered readout



- integrated into a CALISTE module
  - combining several ASICs
  - 3D electronics by 3D+







- different combinations of ASICs + housing

CALISTE-64	CALISTE-256	CALISTE-HD	CALISTE-SO	D2R1	CALISTE-HD-BD
2007	2009	2011	2013	2016	

more pixel	less power	better spec. & spat. resolution	larger energy range
64 → 256	200mW→200mW	900µm → 300µm 900 eV → 580 eV FWHM @ 60keV	250 keV → 1 MeV

ORIGAMIX uses a CALISTE module (HD or O) and builds a portable device

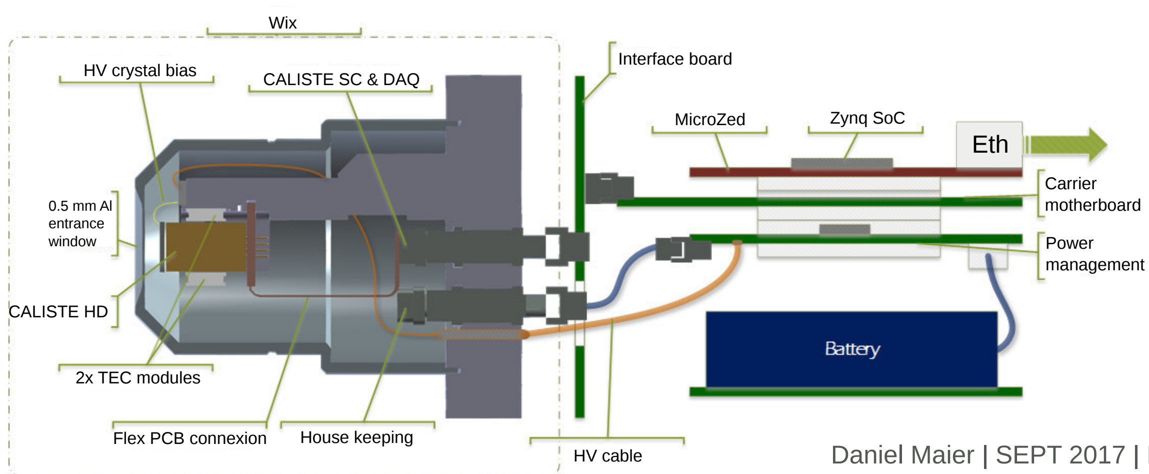
- a *portable* *device*

  - stable & safe housing
  - ensure vacuum tightness
  - cooling?
  - compact, low-power electronics
  - power supply: batteries, HV?

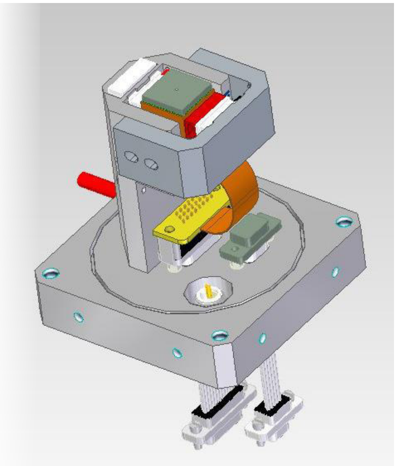
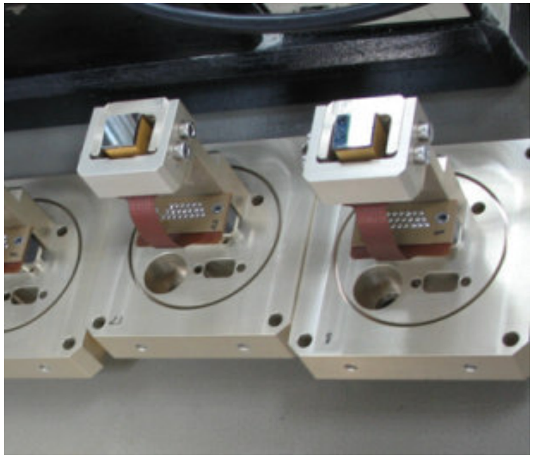
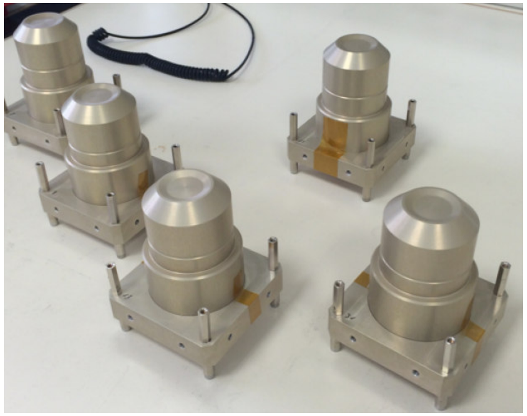
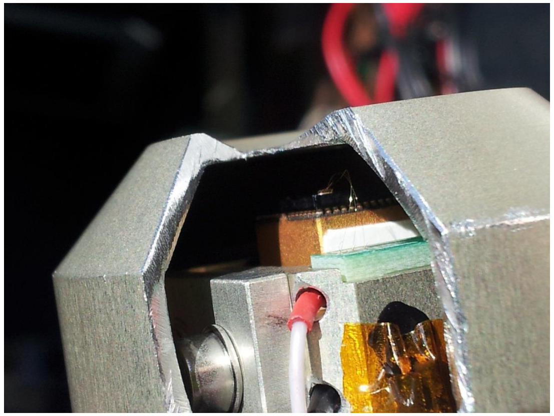
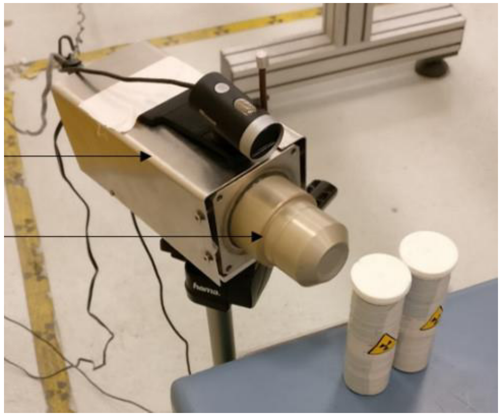
  control of operation → user-friendly
  control of operation → mostly autonomous → parameters / calibration / analysis

  software → reliability
  software → easy to use and to understand → alert

- design:

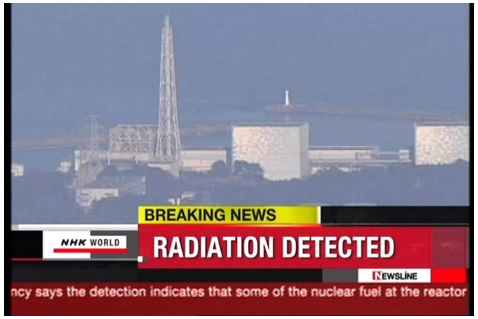


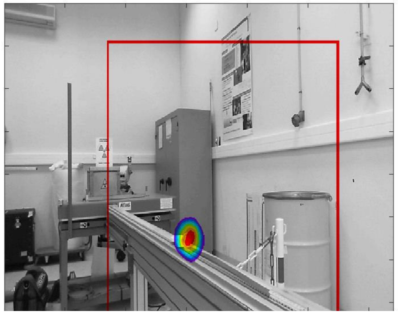
- detector:
  - Caliste-HD
  - 10 x 10 x 1 mm³ CdTe
- camera:
  - system-on-chip aq. system
  - thermo-electrical coolers
  - dimension: 7.5 x 7.5 x 23 cm³
  - mass: m < 1 kg
  - power: p < 10 W

we have a few ideas on that...

- inspection after nuclear accidents

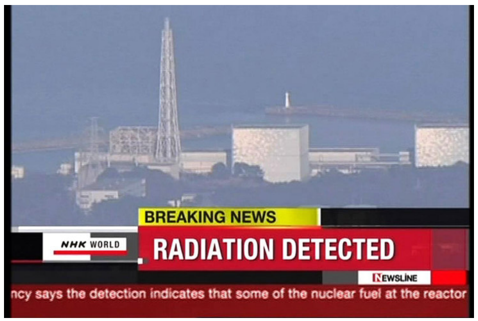




TYPICAL FIELDS OF APPLICATION

we have a few ideas on that...

- inspection after nuclear accidents



- monitoring areas

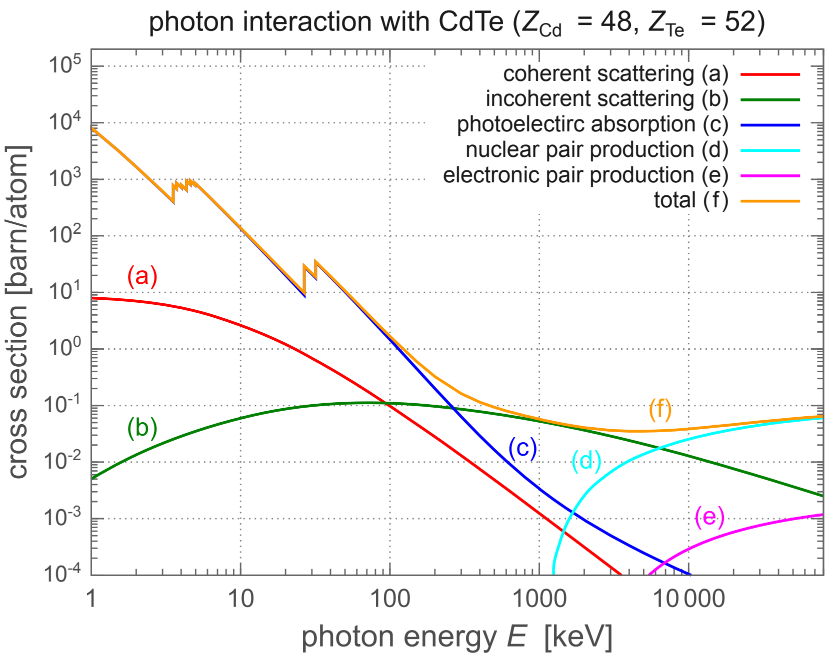
- medical imaging / radiotherapy

- safety inspections

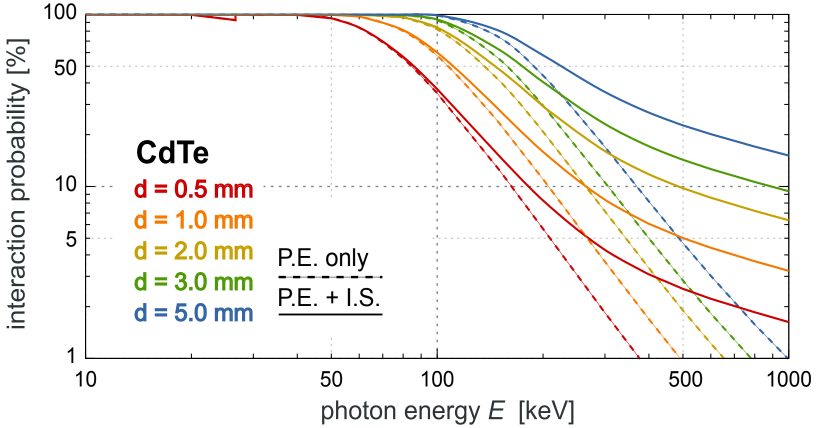
... but there might be others...

CdTe is becomming inefficient for E > 100-300 keV. Then, Compton scattering gets the dominant effect.

photon interactions



detection efficiency



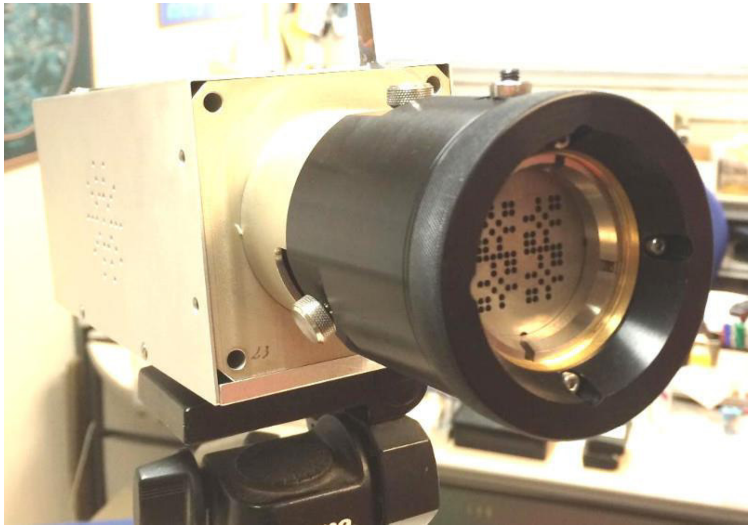
P.E. = photo electric absorption
I.S. = incoherent scattering ("Compton")

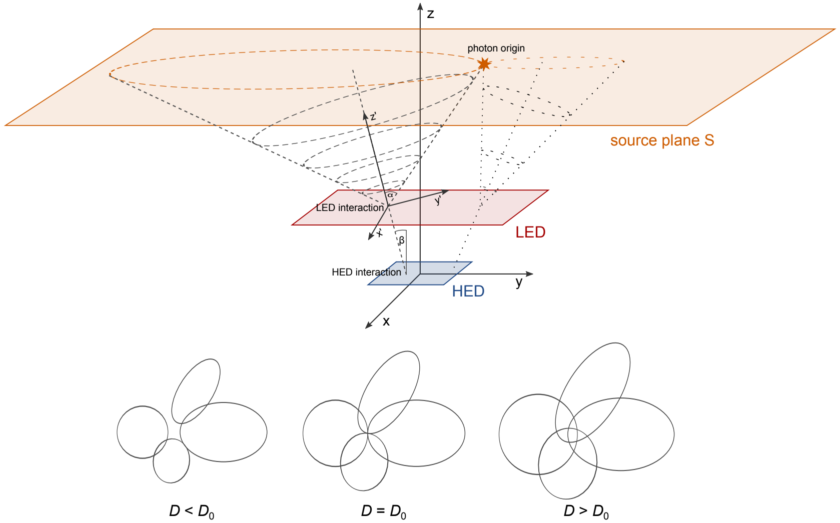
IMAGING = source location

most promising is a two fold approach: mask + Compton

- coded mask
  + high spatial resolution
  + big field-of-view
  ~ about 50% active area
  → easy solution for low energies

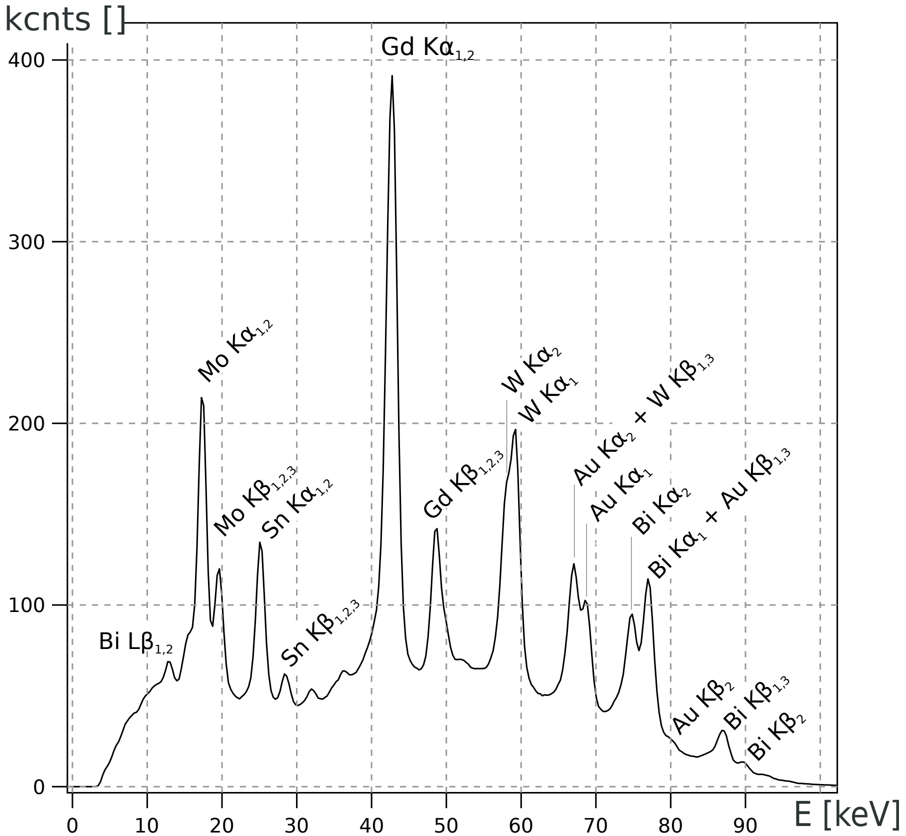
- Compton imaging
  - low spatial resolution
  + nearly 4π field-of-view
  + 100% "active" area
  → extension to higher energies





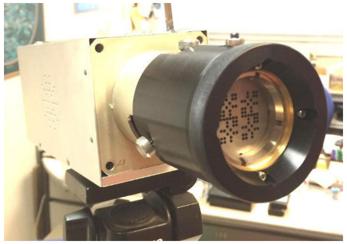
SPECTROSCOPY = source identification
source separation
flux estimation

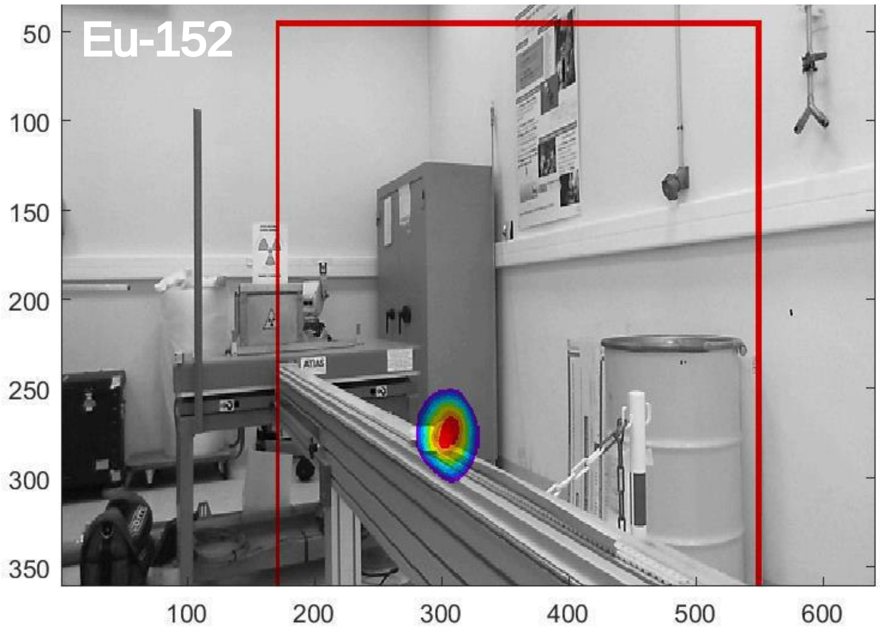
- what kind of sources are in the field-of-view?
- what is the flux of the different sources?
- which source is where? → imaging
- are there multiple sources? → subtracting the strongest source

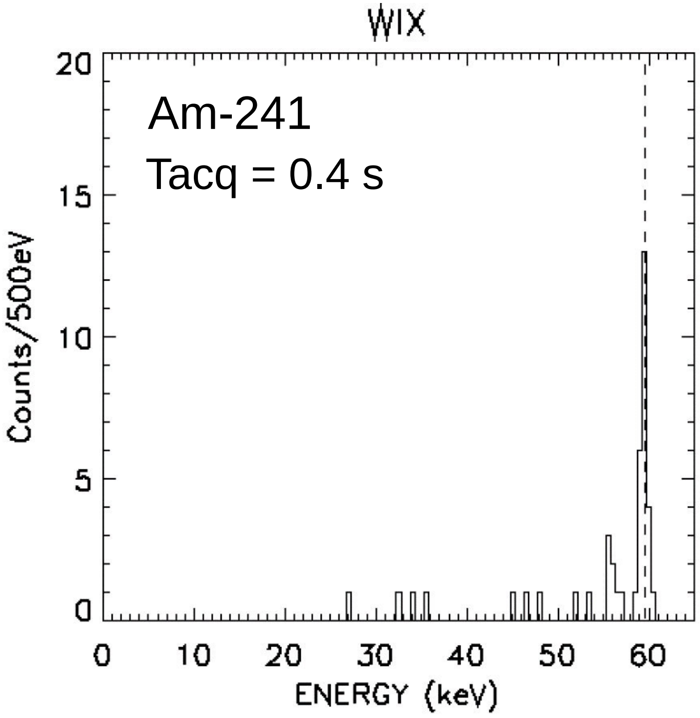


several test campaings gave us useful feedback and new ideas

- test with coded mask (MURA)
  - 74 MBq Am-241 in 1 m (290 nS/h): source identification within 400 ms
  - 10 MBq Eu-152 in 1 m (1.2 µS/h): source localization: 7° ang. res.







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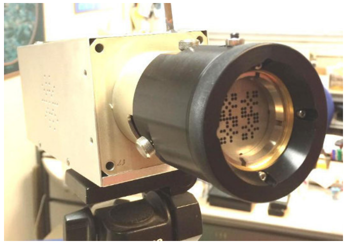
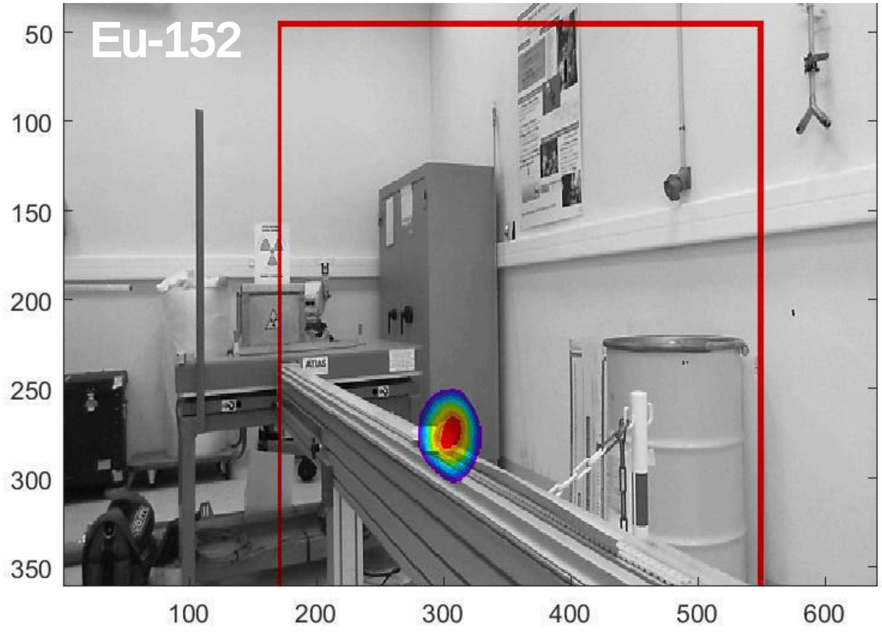
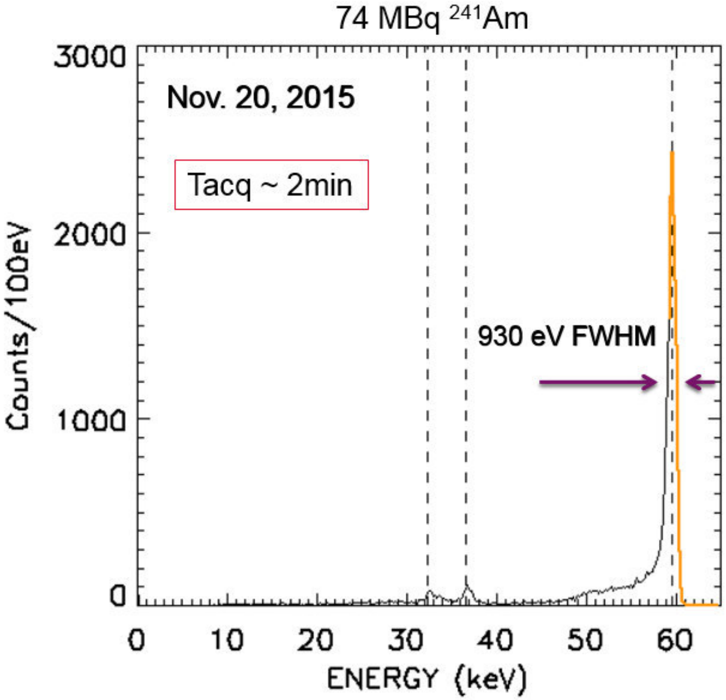
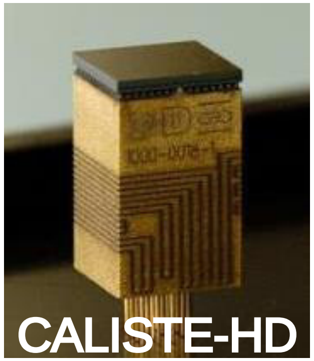






WIX-HD → WIX-O

- lots of improvements in electronics and mechanics:
  - improved temperature sensing
  - enhanced vacuum capacity
  - pressure sensor added
  - embedded HV generation
  - embedded TEC power & control
  - batteries with charger and power ctrl.



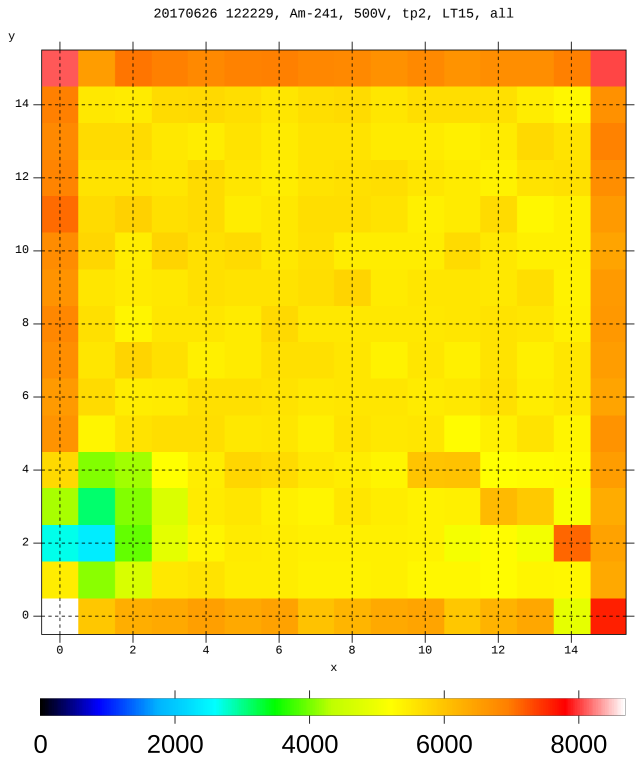
CALISTE-HD → CALISTE-O

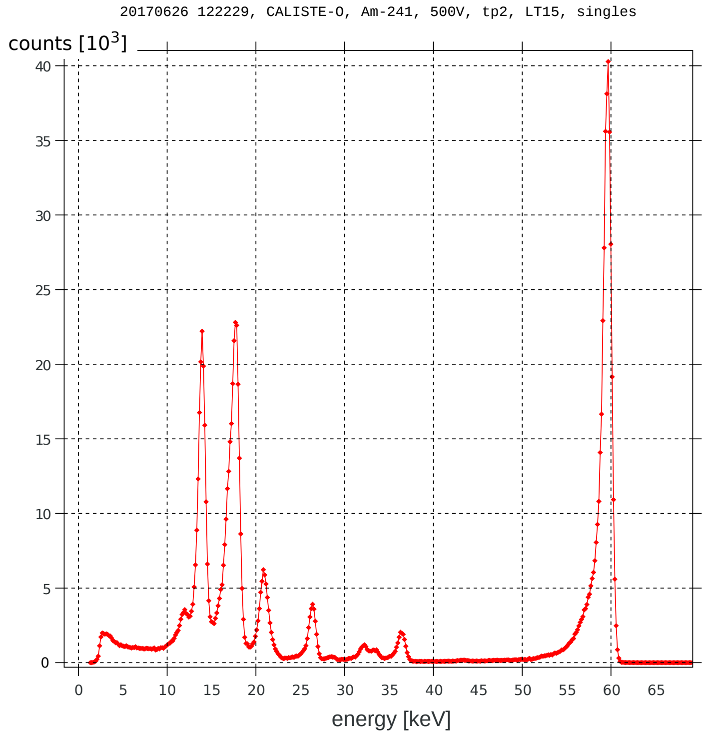
- from space to industry standard:
  - 16x16 pixels, Schottky CdTe
  - same power: 200 mW (0.8 mW/ch)
  - same energy range: 2 keV to 1 MeV
  - 1cm² x 1 mm → 2 cm² x 2 mm
  - 625 µm → 800 µm pixel pitch

CALISTE-O

- first tests show that all pixel are working

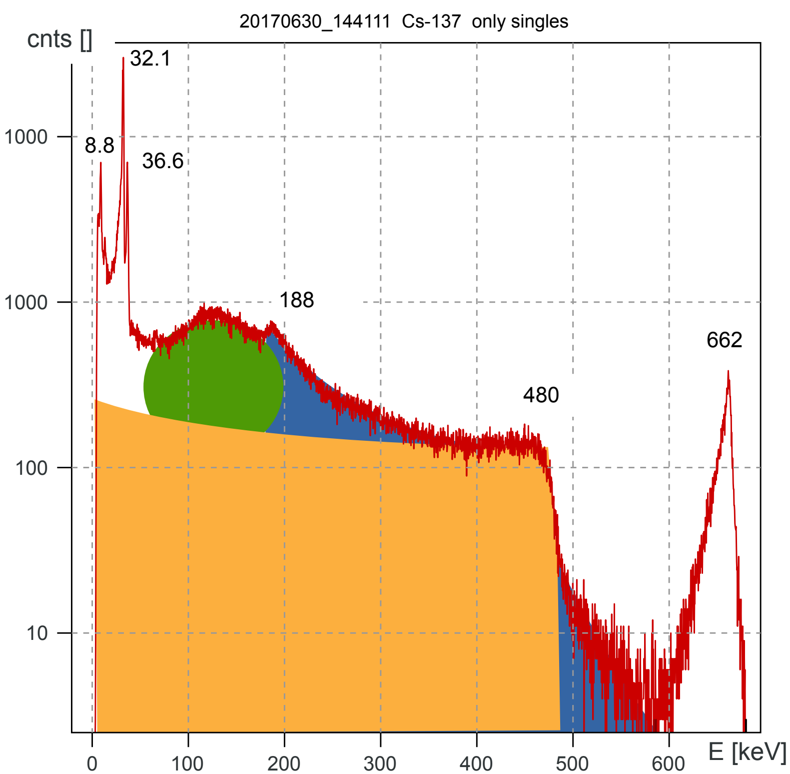
- spectral resolution:
  - best pixel: 927 eV FWHM @ 60 keV
  - all pixel: 1.3 keV FWHM @ 60 keV





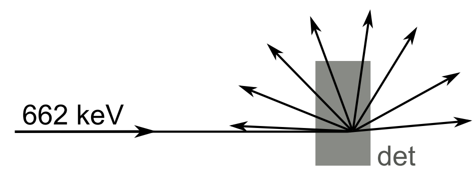
CALISTE-O aims to detect gamma rays

- Cs-137 source

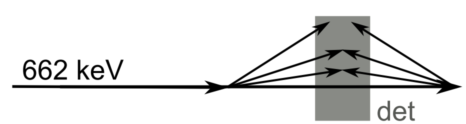


- spectral resolution:
  - all pixel: 6.7 keV FWHM @ 662 keV

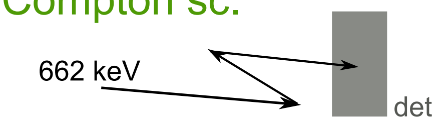
- spectral features:
  - Cu fluorescence (8.8 keV)
  - Ba Ka and Kb lines (32.1 & 36.6 keV)
  - Ba* after Cs decay (662 keV)
  - Compton scattering in the detector (E < 480 keV)



  - Compton scattering outside (E > 188 keV)



  - multiple (>2x) Compton sc.



NEXT STEPS

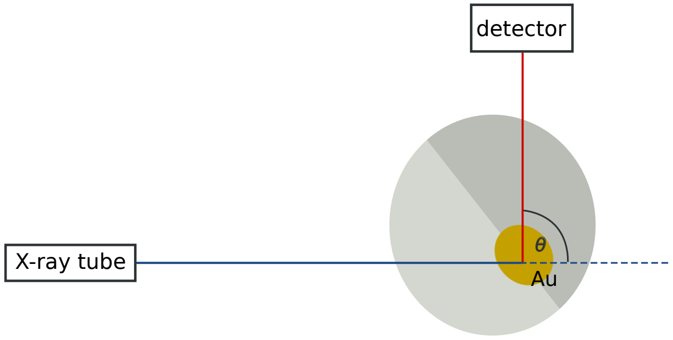
we are not at the end...

- test Compton imaging
  - point and interval estimations in x-, y-, and z-directions
  - combining mask and Compton
- autonomous control
  - HV cycling to prevent CdTe instability
  - pixel individual trigger thresholds
  - optimal peaking time
- autonomous analysis
  - energy calibration
  - source identification
  - flux / dose estimation

SATBOT:

- radiotherapy
  +
  nano particles

- multidisciplinary field



physics

enhanced absorption because of high Z

generation of → Auger e^-, photo e^-, Compton e^-

generation of fluorescence radiation

enhanced attenuation -> dose enhancement

chemistry

oxidative stress by reactive oxigen species (ROS):

$e^- + H_20$ → H_2O_2, OH^-, O^{2-}

surface effec:
catalysator
coating

chemical enhancement

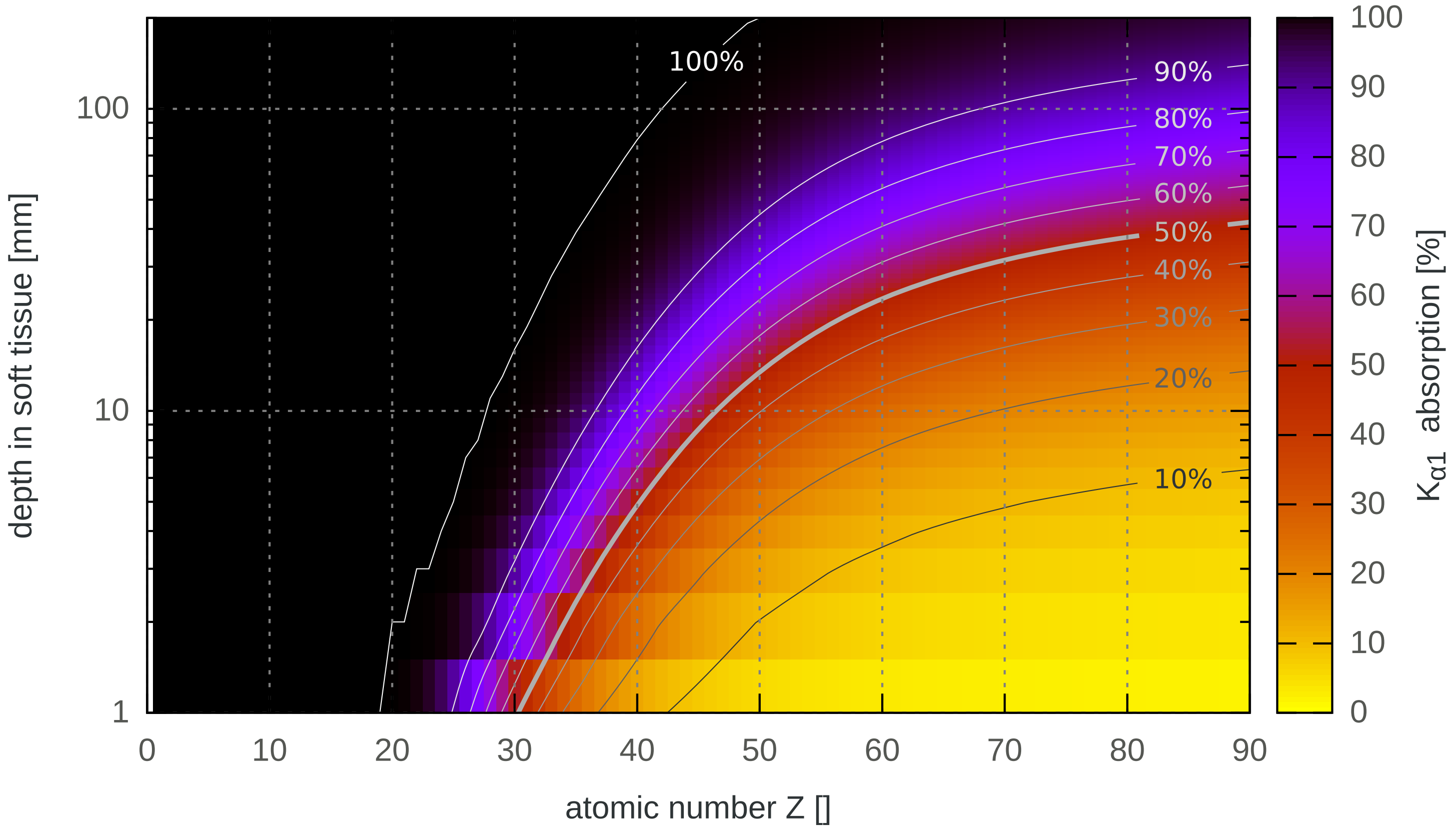
biology

accumulation of NP
degradation of NP

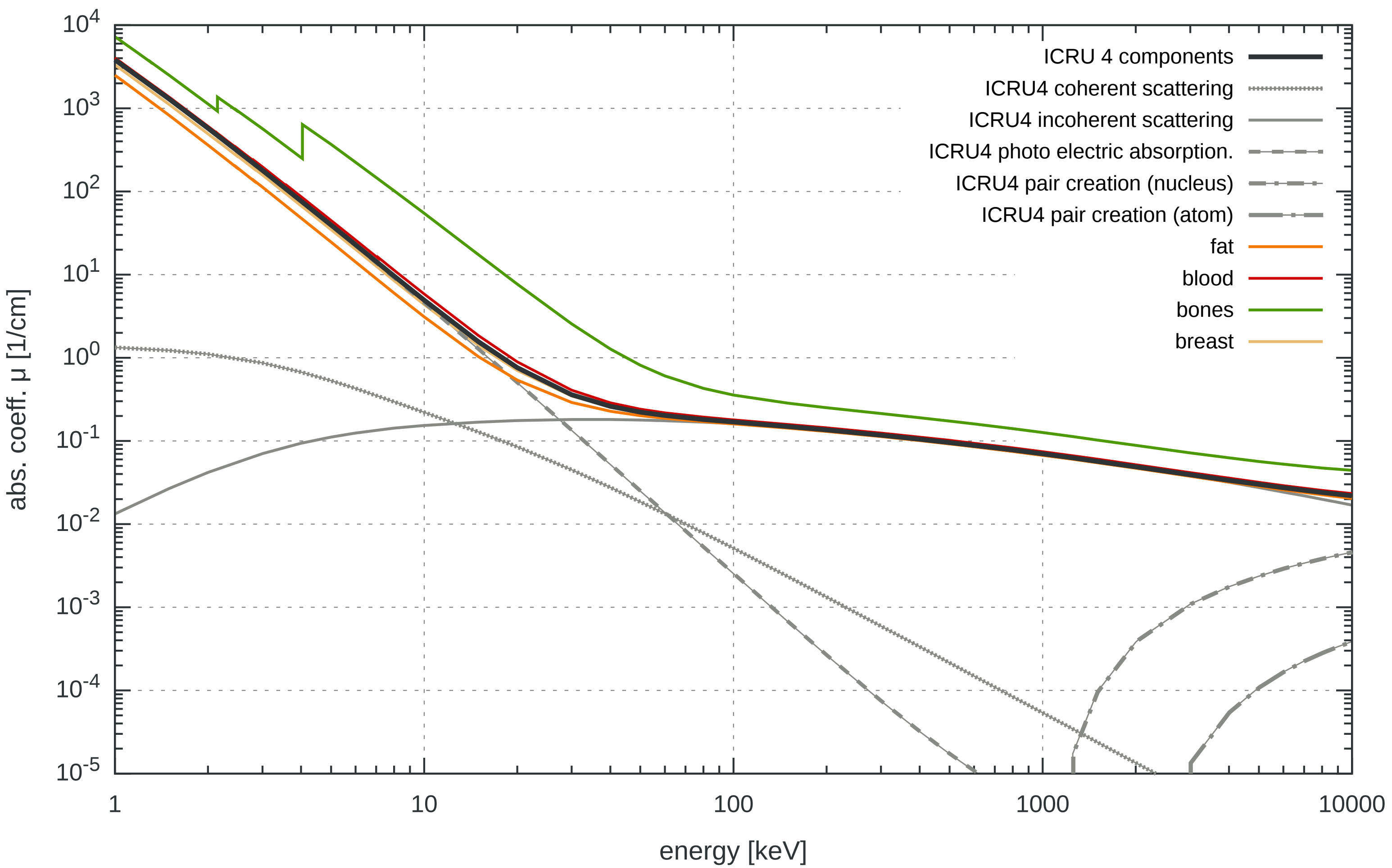
5 Rs: repair, redistribution, reoxygeneration, repopulation, radiosensitivity

XRF detection

- self absorptoin in humain tissue



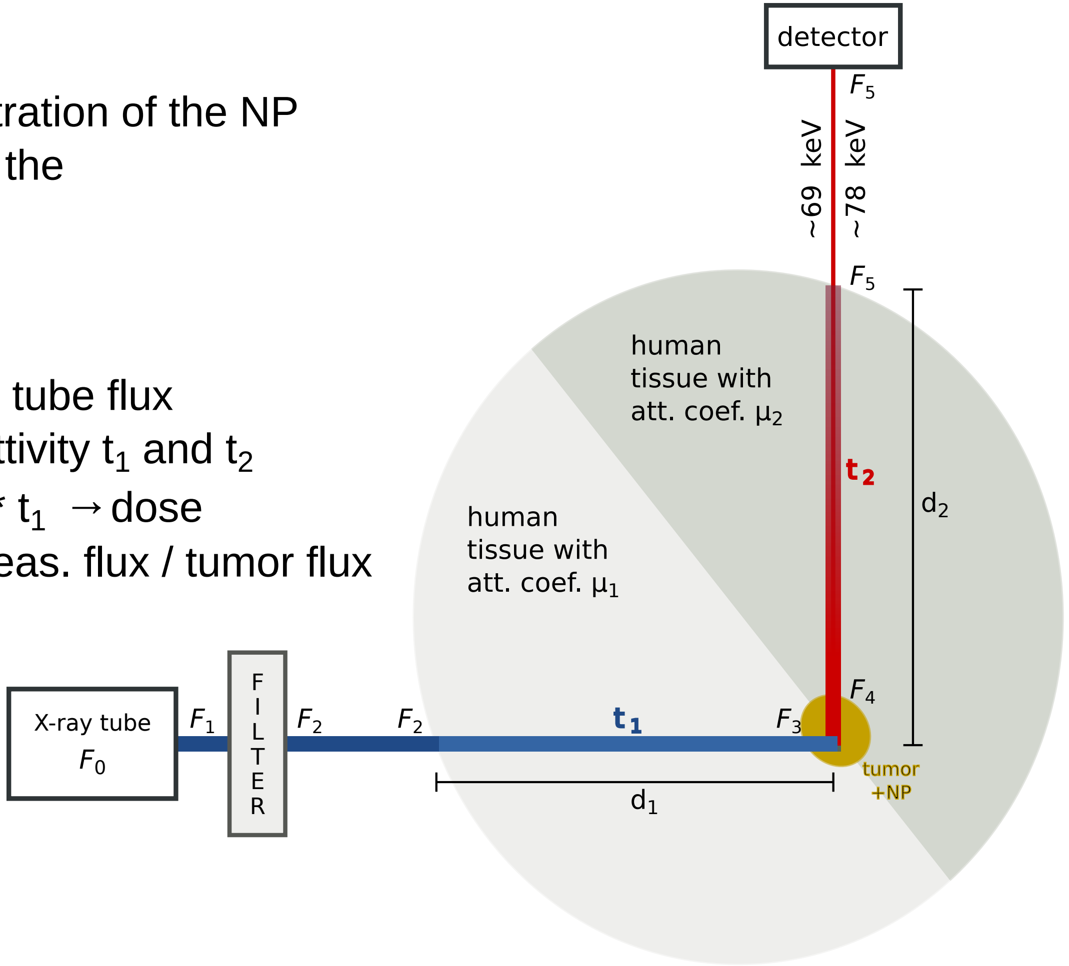
interaction photons ↔ humain



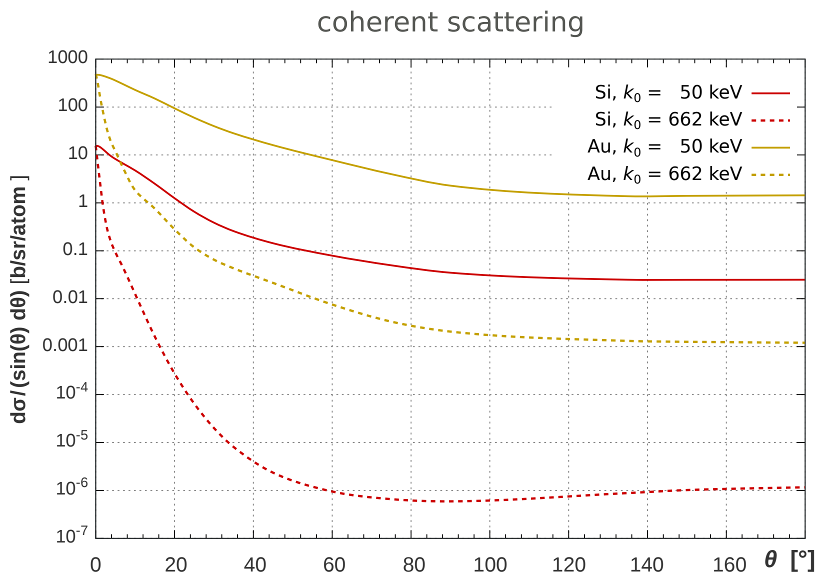
XRF dosimetry

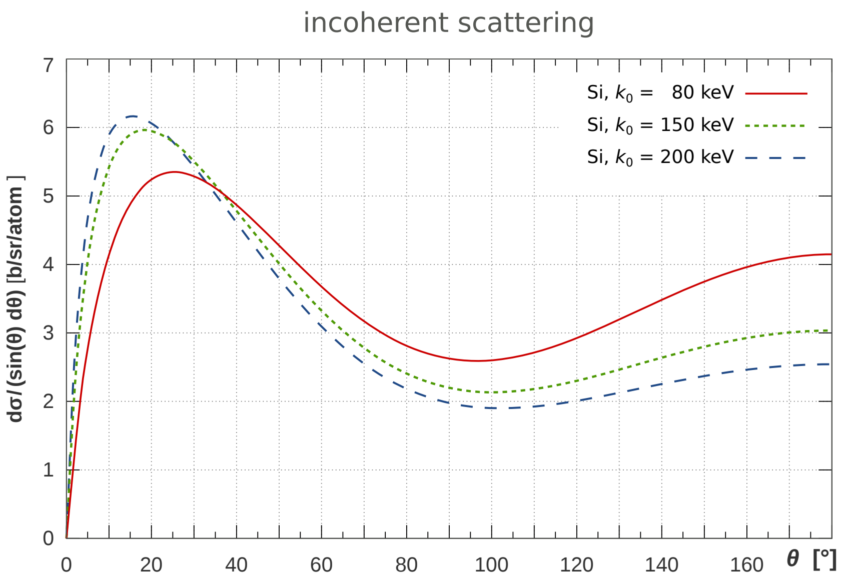
- goal:
  - determine the concentration of the NP
  - determine the dose at the tumor level

- approach:
  - prior knowledge of the tube flux
  - determine the transmittivity t_1 and t_2
  - tumor flux = tube flux * t_1 → dose
  - NP concentration ~ meas. flux / tumor flux



scattering makes it difficult...



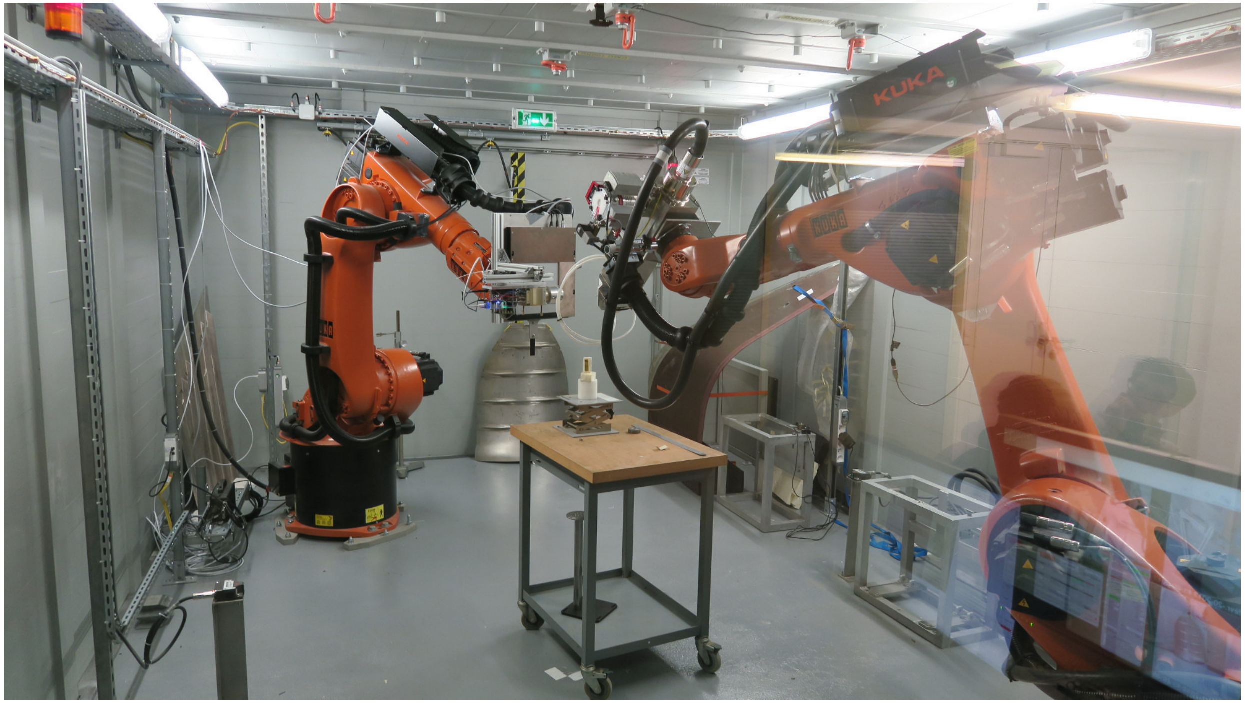


- coherent scattering:
  - for low energies
  - scattering angle > 90°
  - small effect
- incoherent scattering:
  - for all energies of interest
  - scattering angle ≈ 90°
  - big effect

SATBOT results

first SATBOT campaign FEB 2017:

- industrial robots for
  - alignment of X-ray tube
  - alignment of detector



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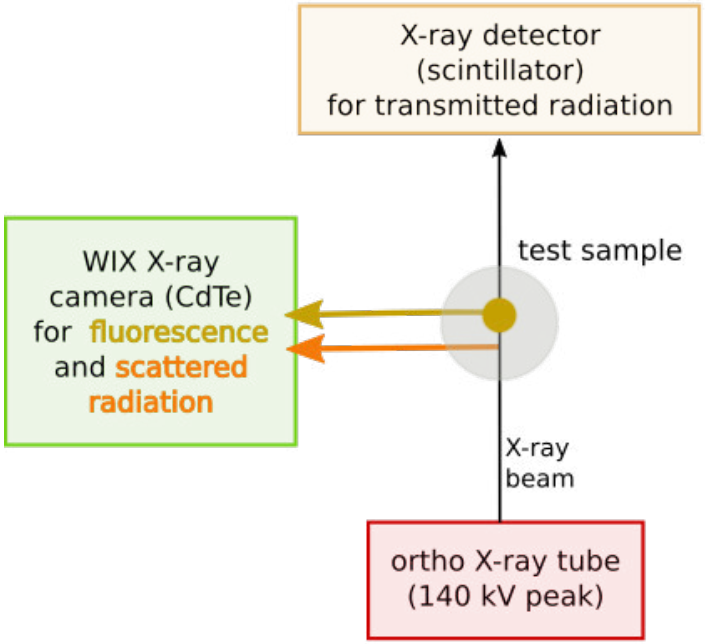
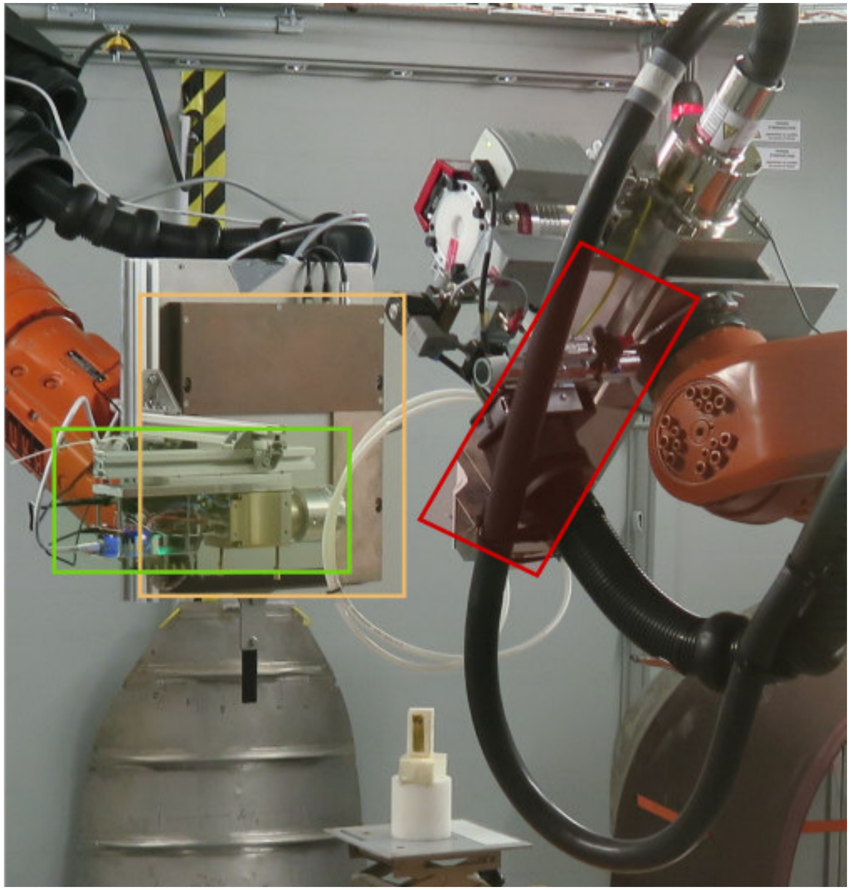
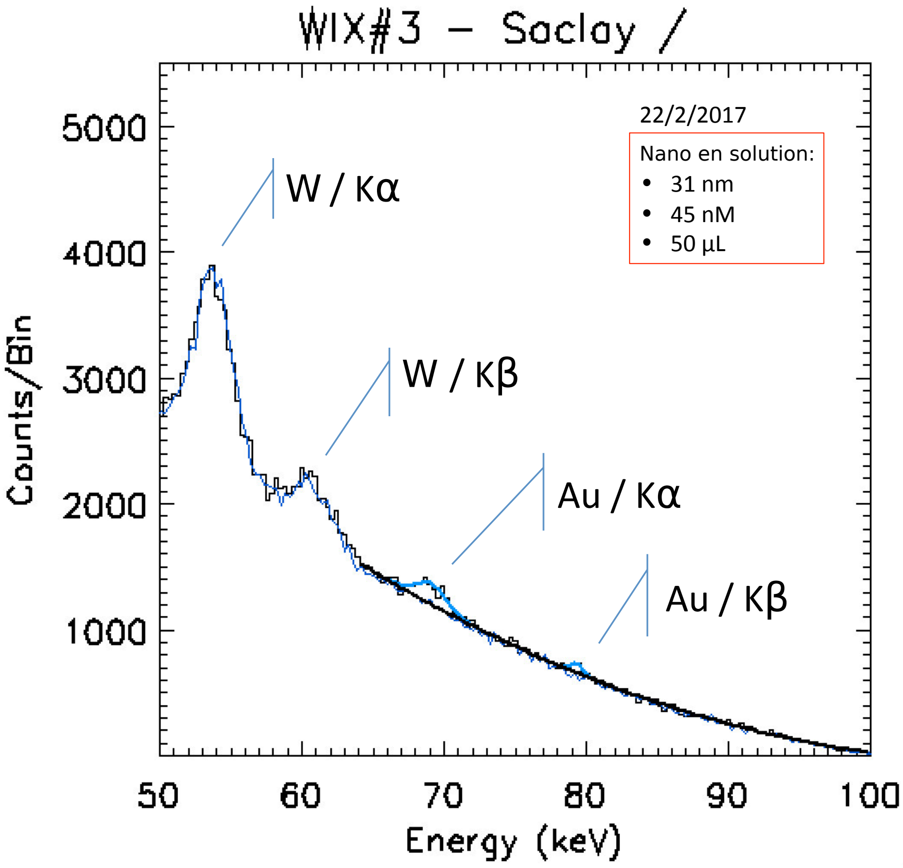




SATBOT results

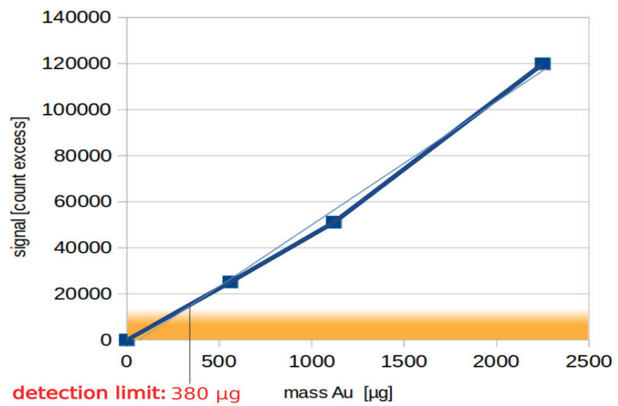
first SATBOT campaign FEB 2017:

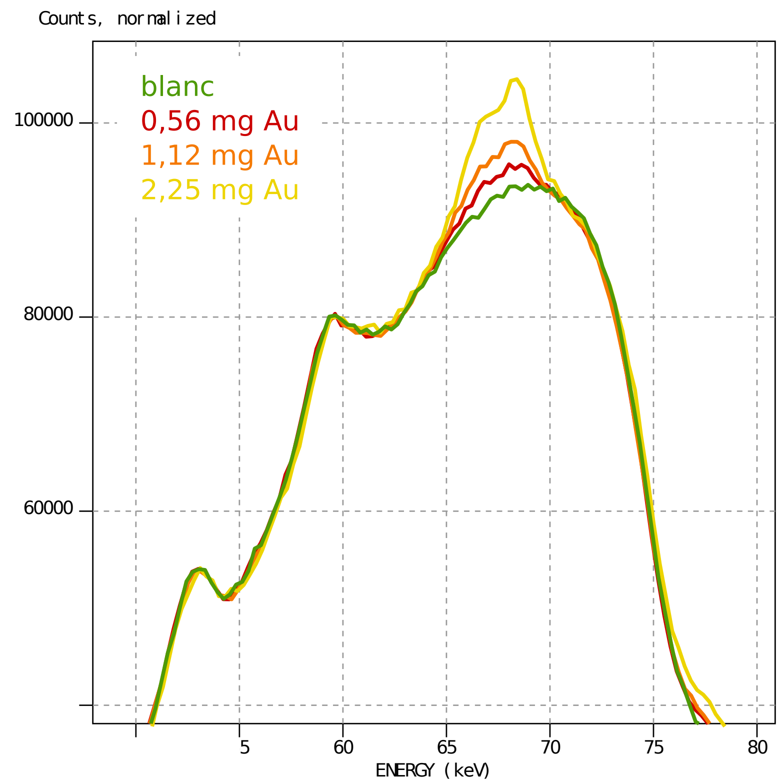
- industrial robots for
  - alignment of X-ray tube
  - alignment of detector
- result
  - Au identification
  - independent of NP size
  - sensitivity: 408 ug Au



second SATBOT campaign APRIL 2017:

- filter for X-ray tube
  - shape the tube spectrum
  - enhance the high energetic part
- result
  - Au identification for different m_{Au}
  - lin. relation between signal & m_{Au}
  - sensitivity: 380 ug Au



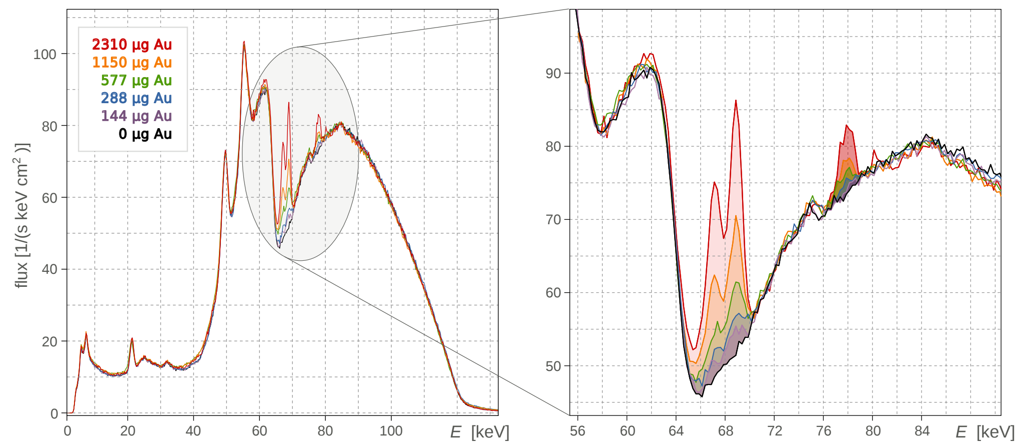


- problem:
  detect a peak on top of a peak!

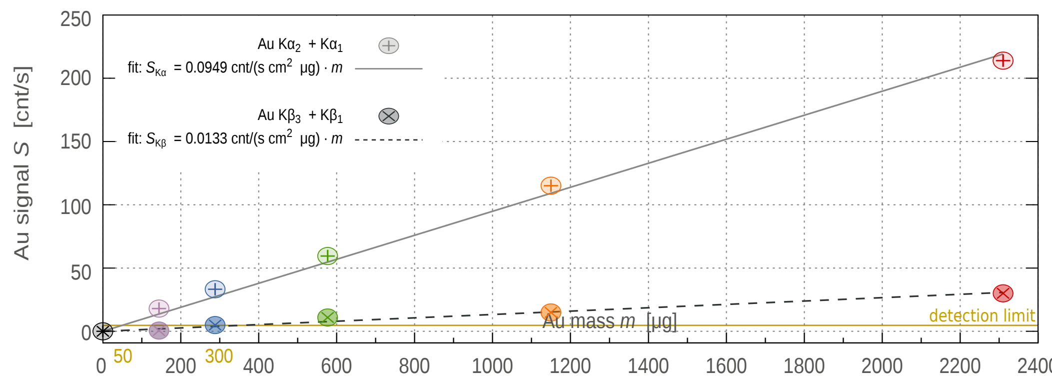
SATBOT results

third SATBOT campaign AUG 2017:

- filter for X-ray tube
  - advaced filter

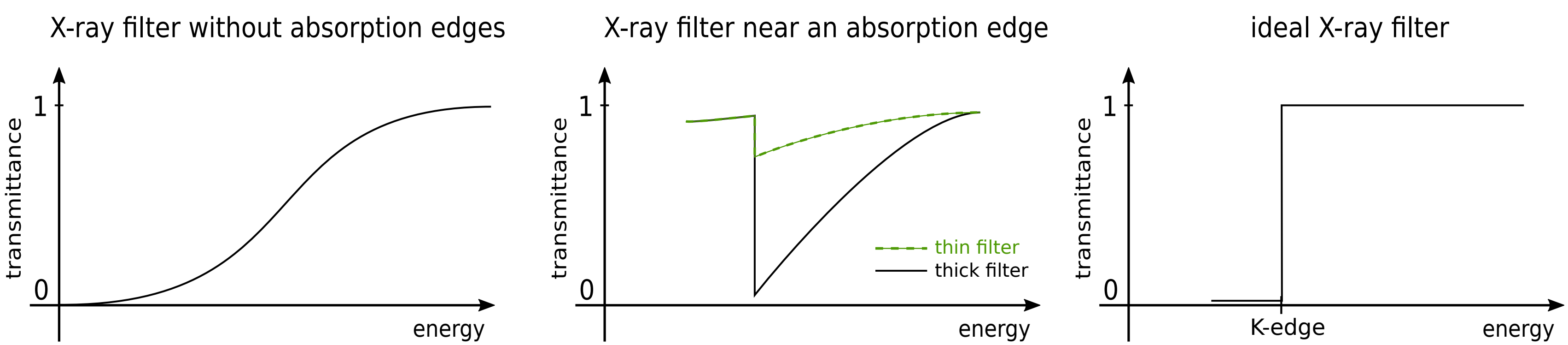


- result
  - XRF peak in valley
  - clear Ka and Kb detection
  - sensitivity:
    Ka: 50 ug Au
    Kb: 300 ug Au

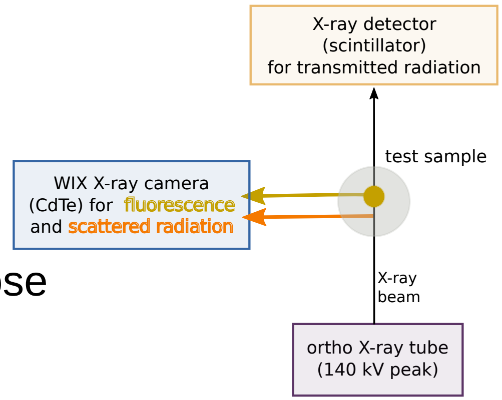


SATBOT new ideas: advanced X-ray filter

- E_{XRF} < K-edge
  - only E > K-edge causes XRF
  - background photons $E_{XRF} < E <$ K-edge → noise
  - unnecessary photons $E < E_{XRF}$ → unnecessary dose

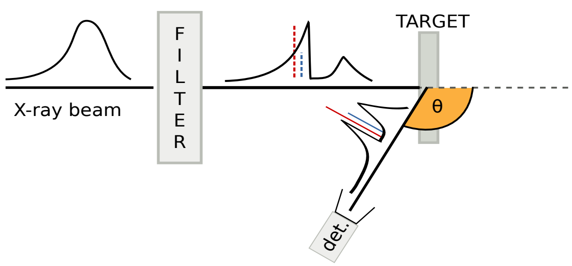


SATBOT new ideas: advanced X-ray filter

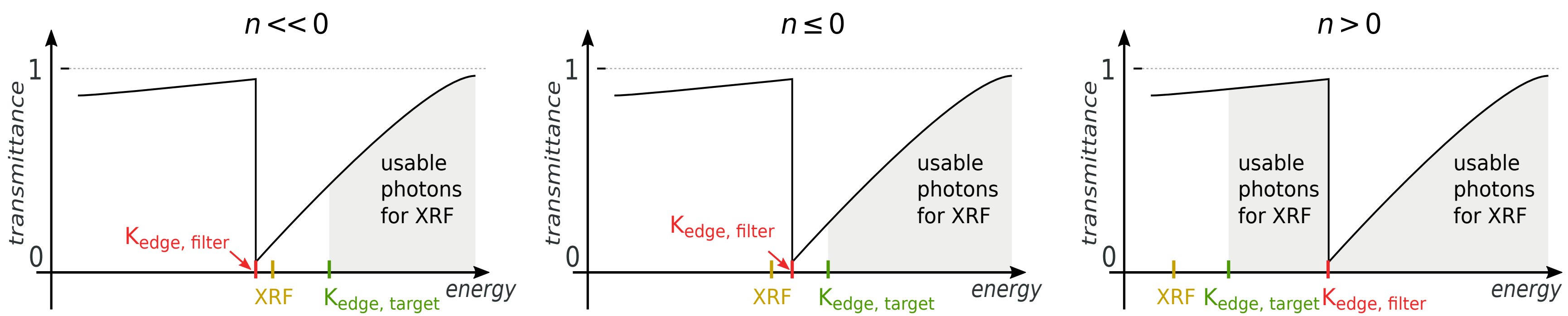


- E_{XRF} < K-edge
  - only E > K-edge causes XRF
  - background photons E_{XRF} < E < K-edge → noise
  - unnecessary photons E < E_{XRF} → unnecessary dose
- Combine filter with incoherent scattering
  - scattered radiation loses energy

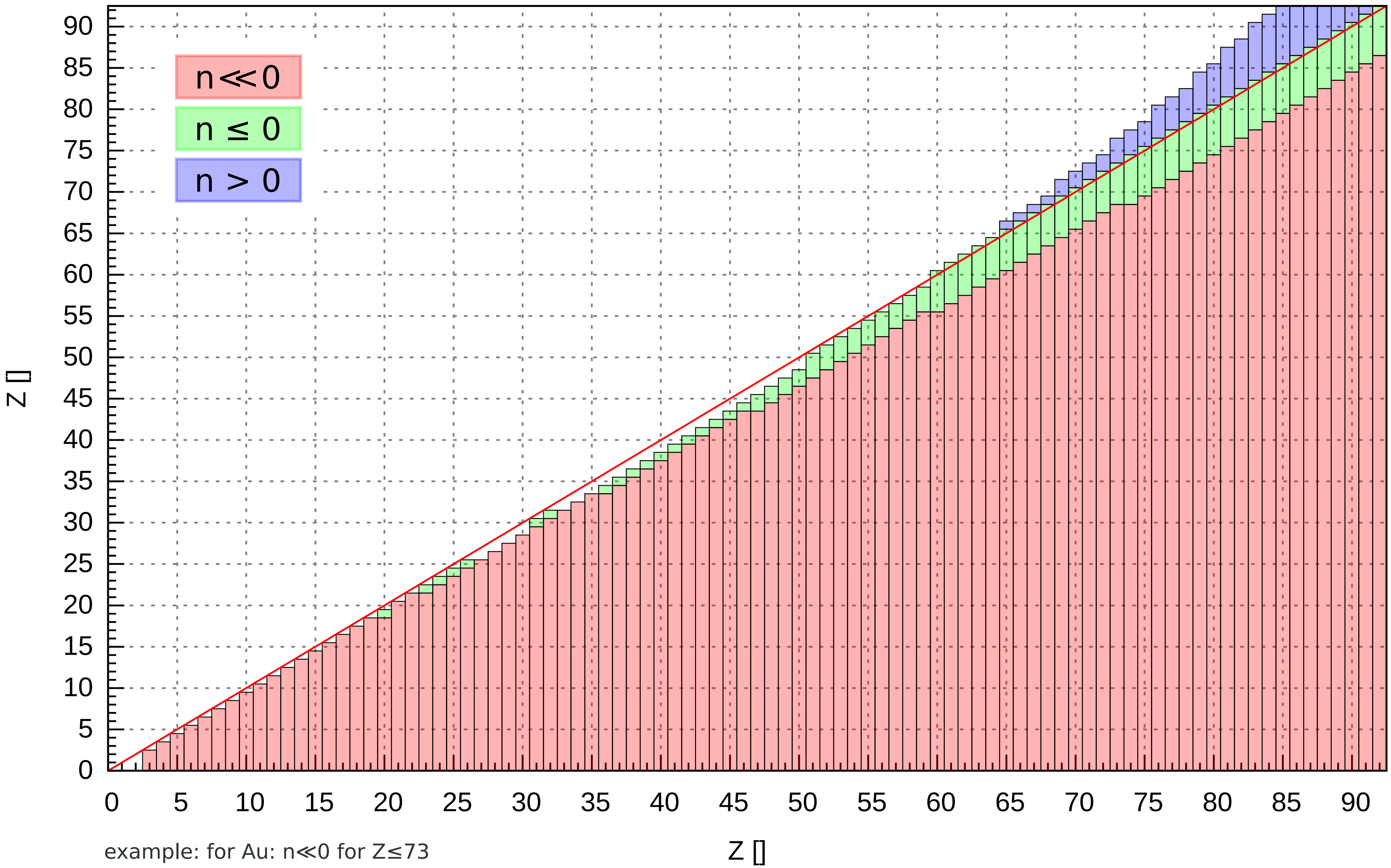
$$E^{sc} = \frac{E}{1 + \frac{E}{511\,\mathrm{keV}}\left(1 - \cos(\theta)\right)}$$



$Z_{filter} = Z_{target} + n$

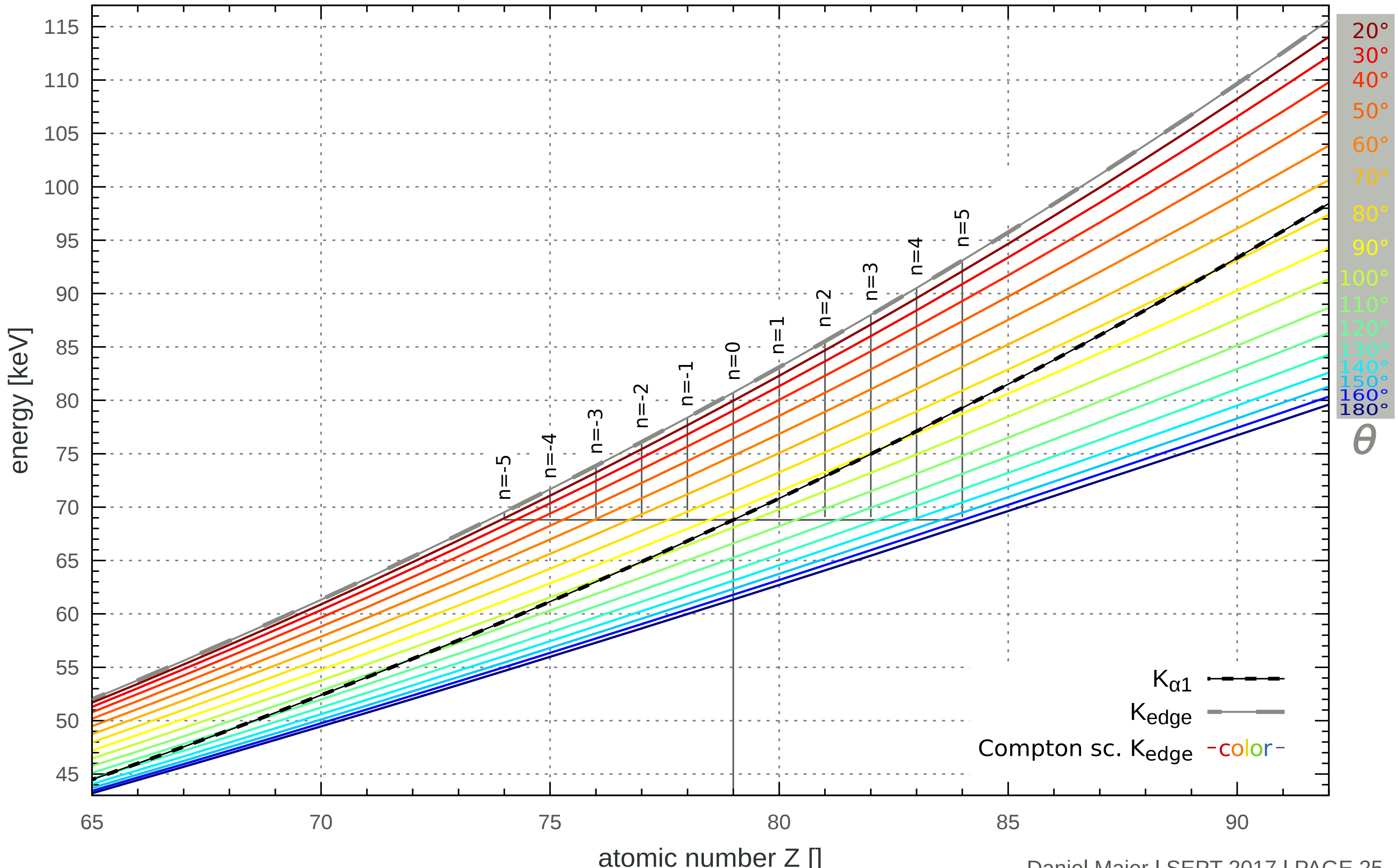


SATBOT new ideas: advanced X-ray filter



example: for Au: n≪0 for Z≤73
n<0 for 74 ≤ Z ≤79
n>0 for 80 ≤ Z ≤ 84

Which filter and which observation angle should we choose?

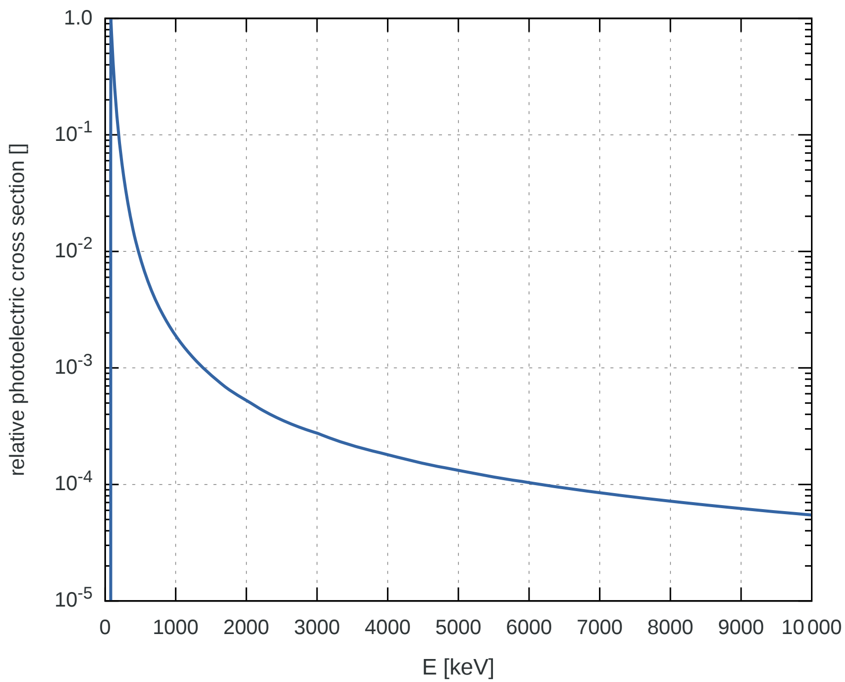


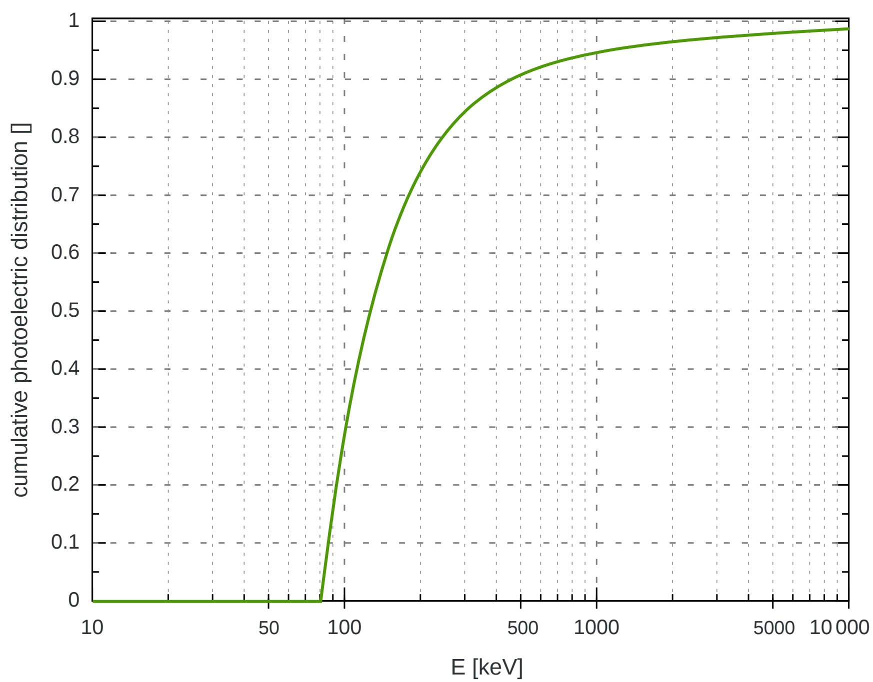
- How thick should the filter be?
  - signal analysis:

$$F_2(E) = F_1(E) \cdot \mathrm{e}^{-\mu\, d}$$

flux after filter ($F_2(E)$); flux before filter ($F_1(E)$)

$$S \propto \int_{E_\mathrm{K}}^{E_\mathrm{max}} F_2(E) \cdot \sigma_\mathrm{PE}(E)\, \mathrm{d}E$$

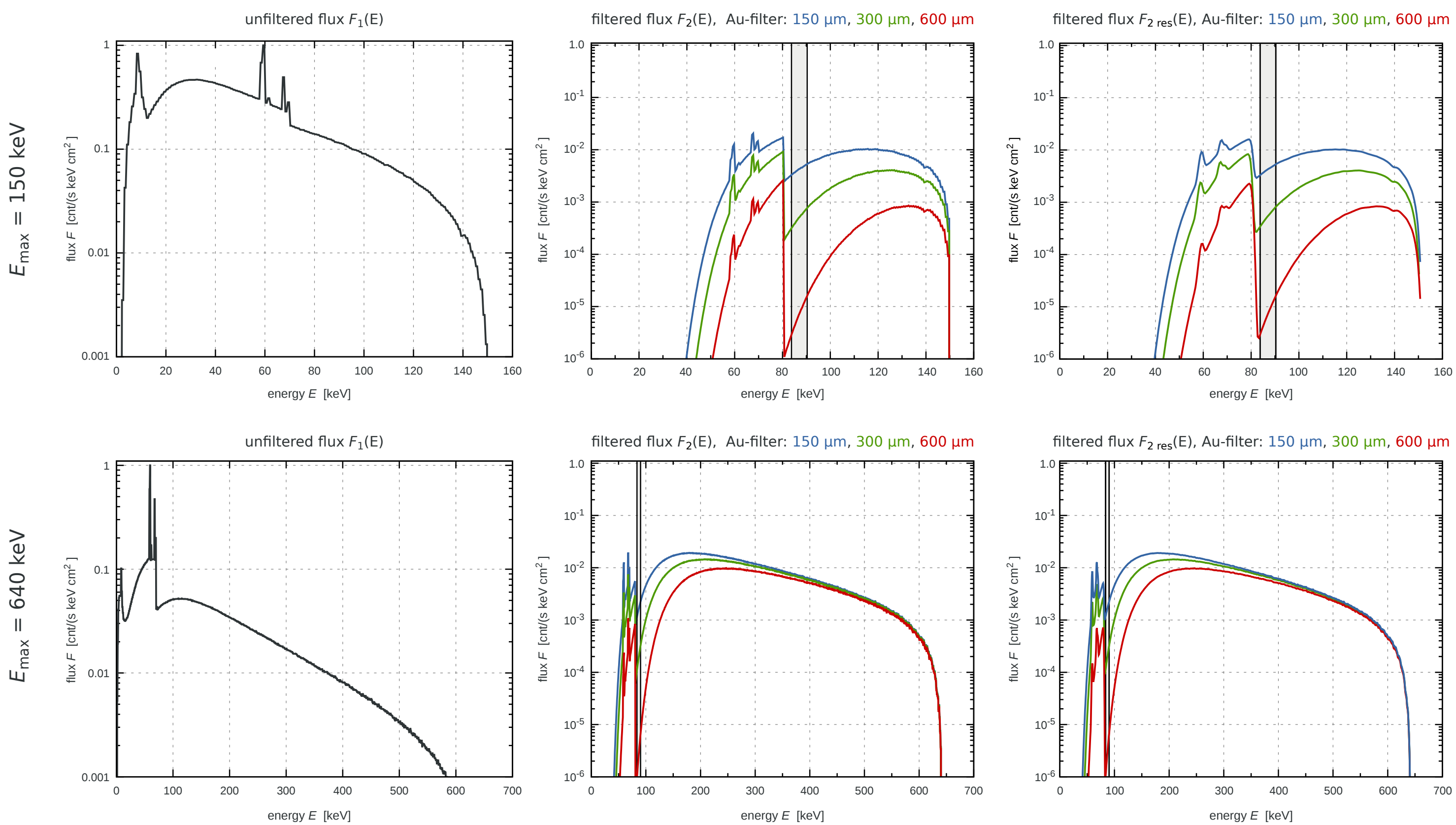




SATBOT new ideas: advanced X-ray filter

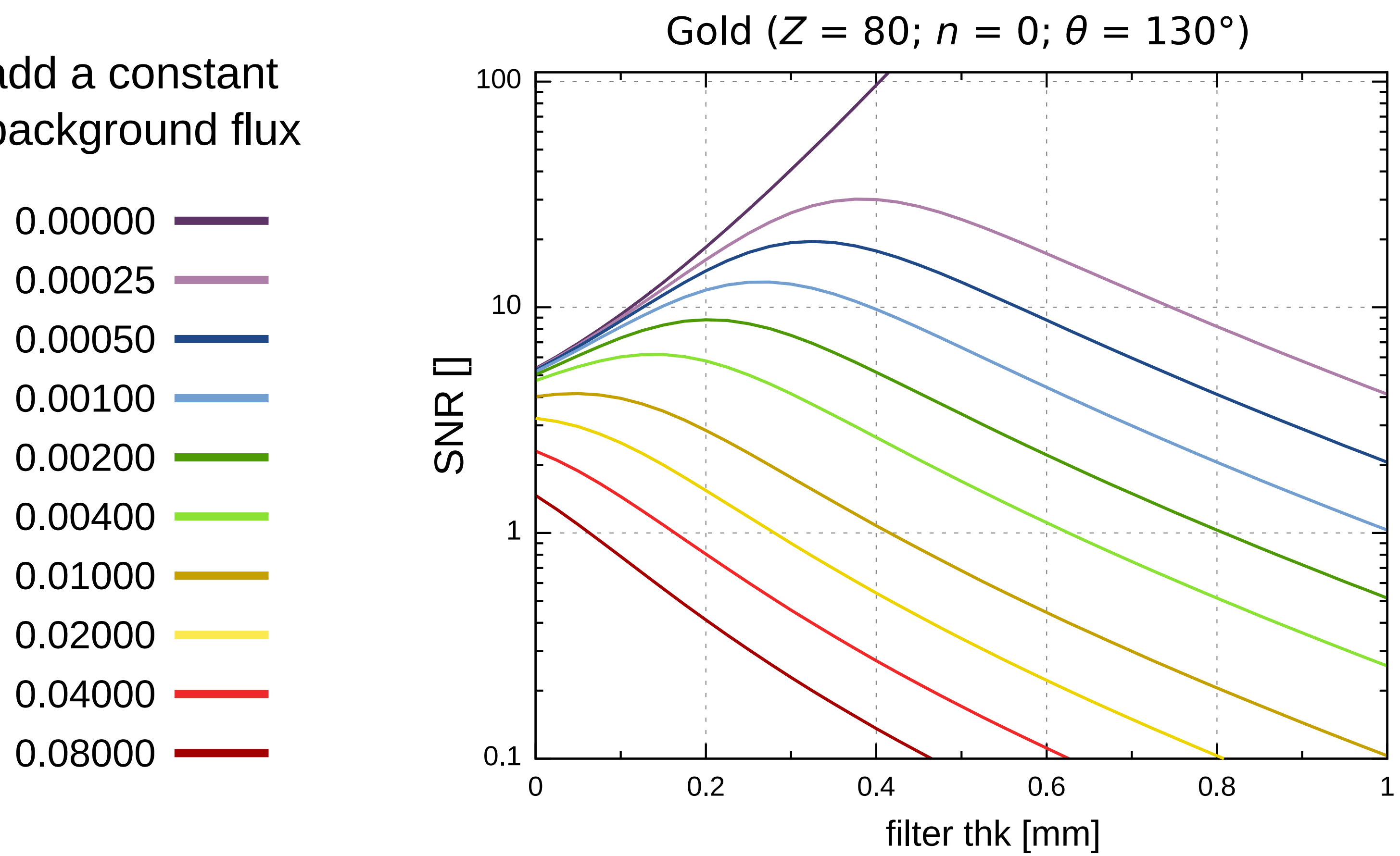
- How thick should the filter be?
  - noise analysis:

$$N \propto \int_{\mathrm{K}_{\alpha 1}-\Delta E/2}^{\mathrm{K}_{\alpha 1}+\Delta E/2} F_2^{\mathrm{sc}}(E)\,\mathrm{d}E$$



SATBOT new ideas: advanced X-ray filter

- How thick should the filter be?
  - maximize signal-to-noise ratio
  - add a constant background flux

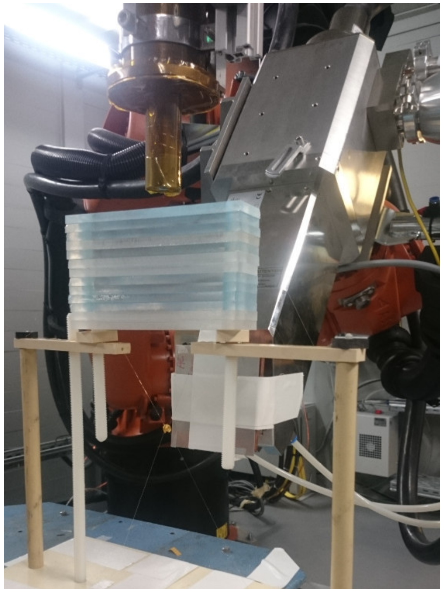


SATBOT new ideas: advanced X-ray filter

- How thick should the filter be?
  - a filter can make it worse
  - a higher voltage of the X-ray tube makes the SNR always better ;-)
  - the optimal filter thickness is independent of the chosen voltage

	Os	Ir	Au	Hg
atomic number Z	76	77	79	80
filter-sample shift n	-3	-2	0	+1
observation angle θ	93°	105°	130°	140°
SNR ($U = 200\,\mathrm{kV}$)	1.65	1.49	1.00	0.94
SNR ($U = 640\,\mathrm{kV}$)	2.72	2.48	1.77	1.67

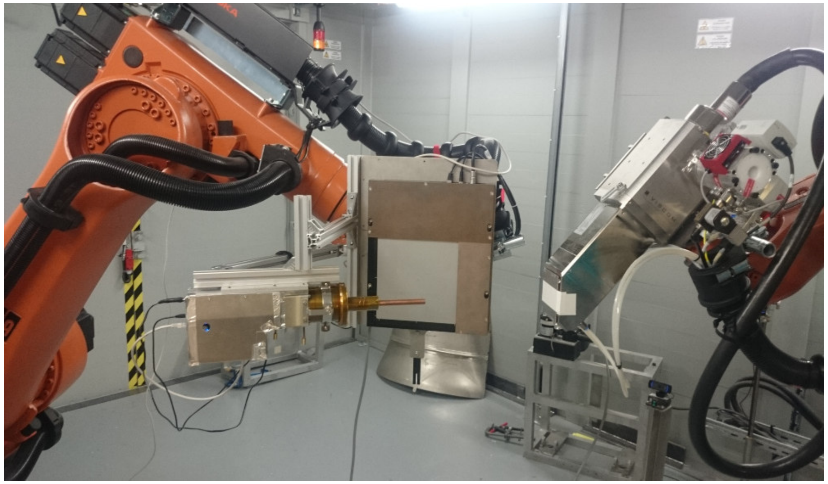
SATBOT conclusions

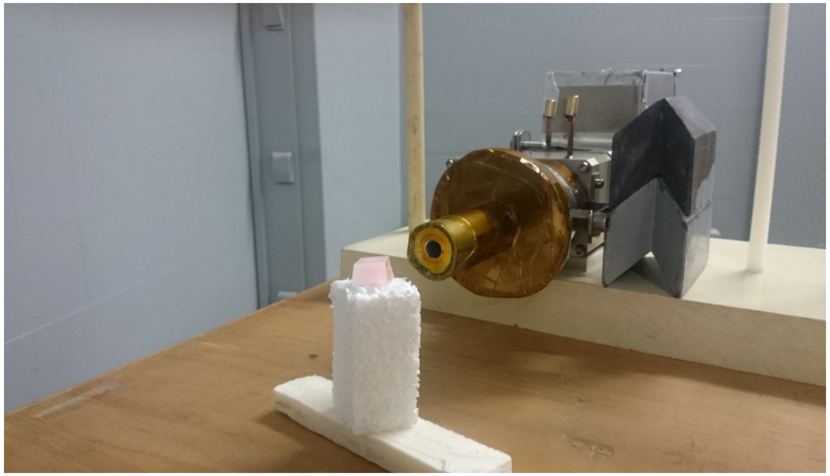


- SATBOT is a very dynamic project
- the work is very interdisciplinary

next steps:

- new filter: sensitivity < 20 ug
- XRF tomography





SATBOT conclusions

- the SATBOT team is very nice