HelXAS: Design and function

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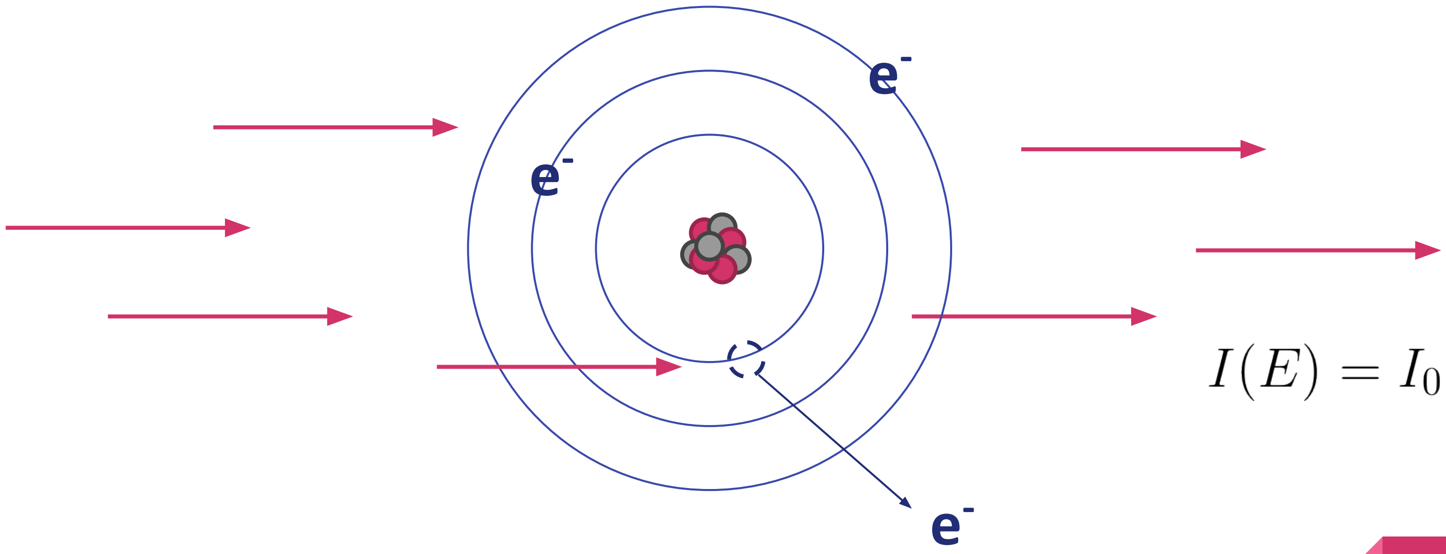
GOAL: THE ABSORPTION COEFFICIENT



$$I(E) = I_0(E)e^{-\mu(E)x}$$

Attenuation of photons connected to the properties of matter

How to measure in home lab?

Parts needed:

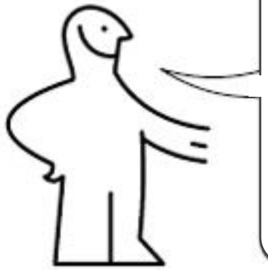
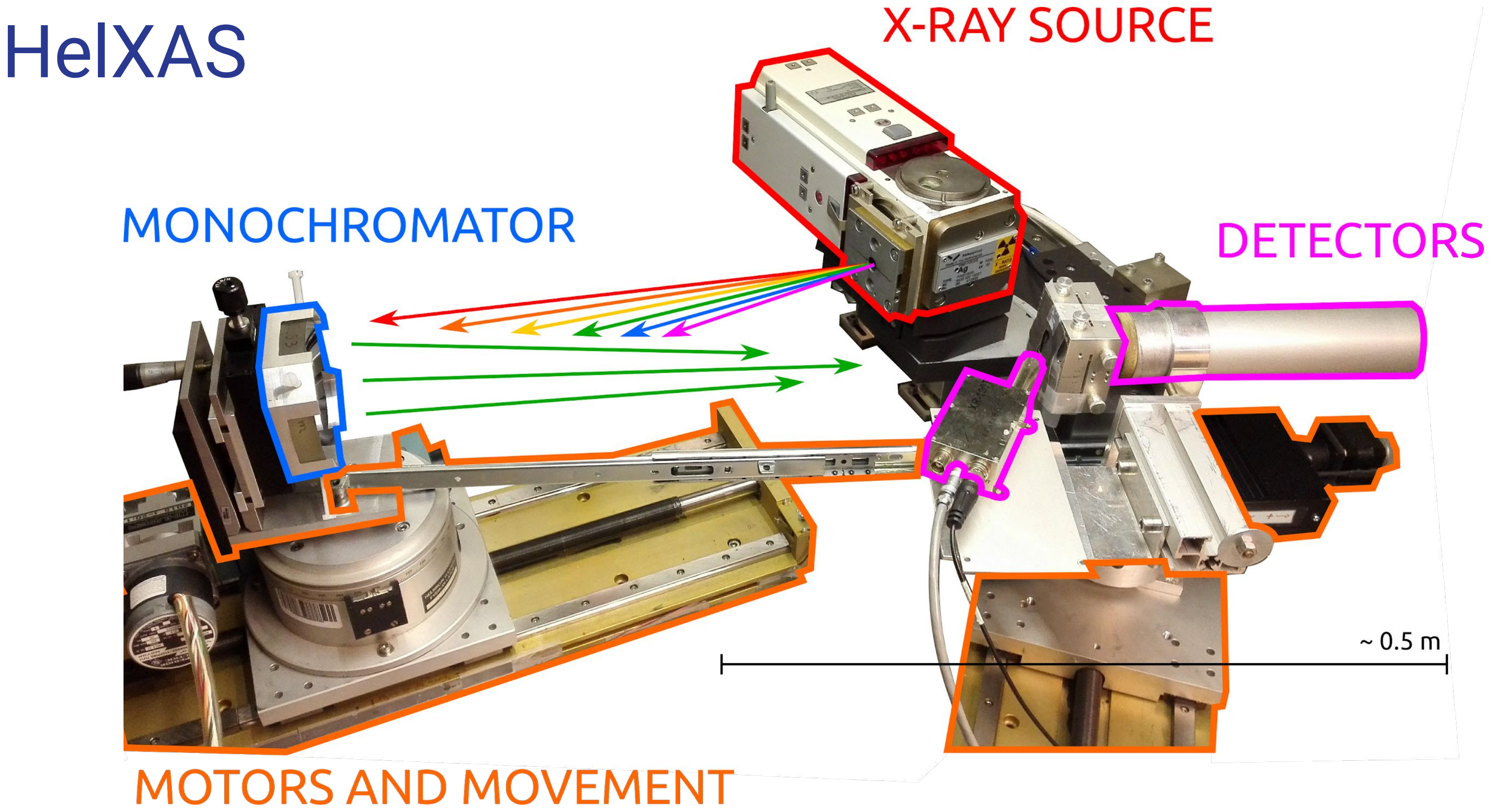


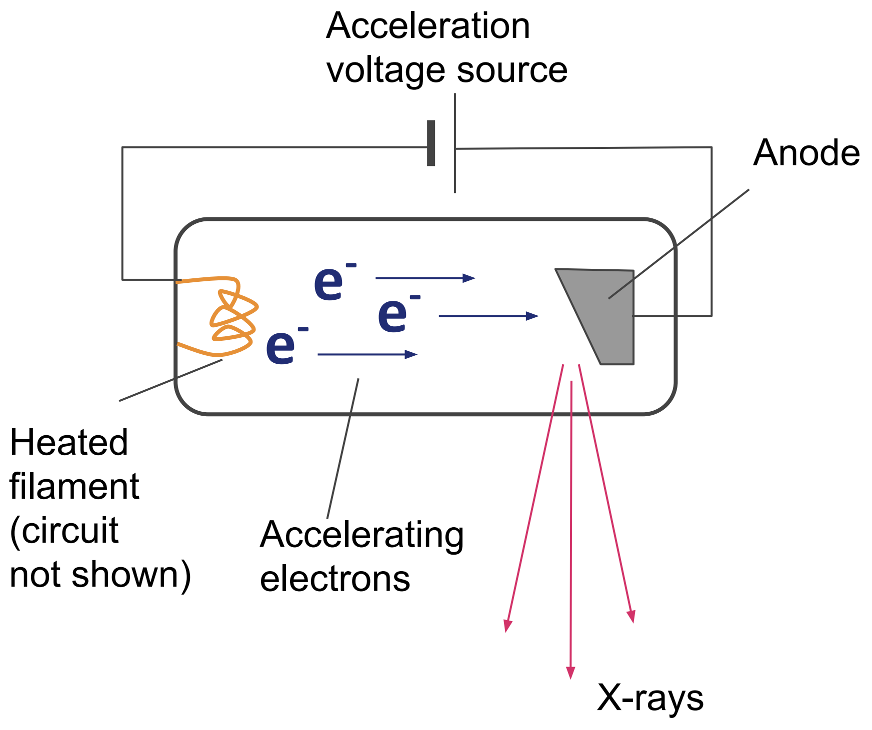
Image source: www.ikea.com

1. Source öf X-rays
2. Device för wavelength separation
3. Photön detectör

+ some control and acquisition electronics..


HelXAS
X-RAY SOURCE
MONOCHROMATOR
DETECTORS
~ 0.5 m
MOTORS AND MOVEMENT

X-RAY TUBE - POLYCHROMATIC SOURCE



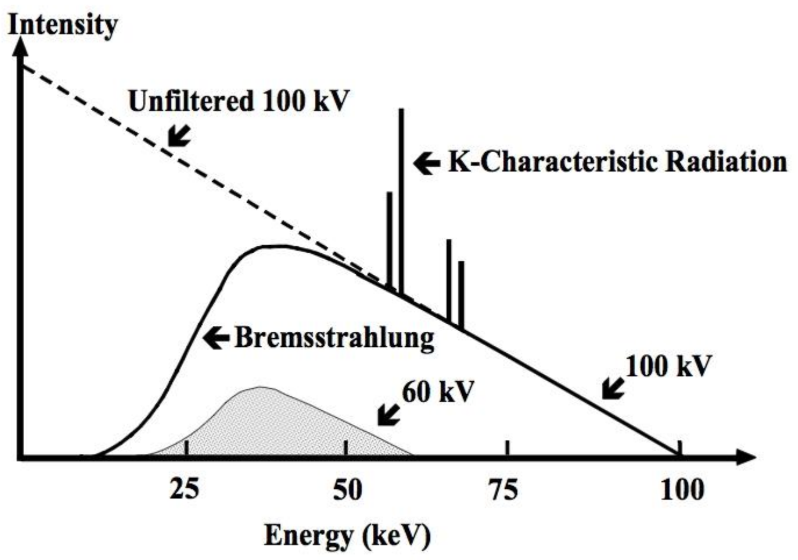
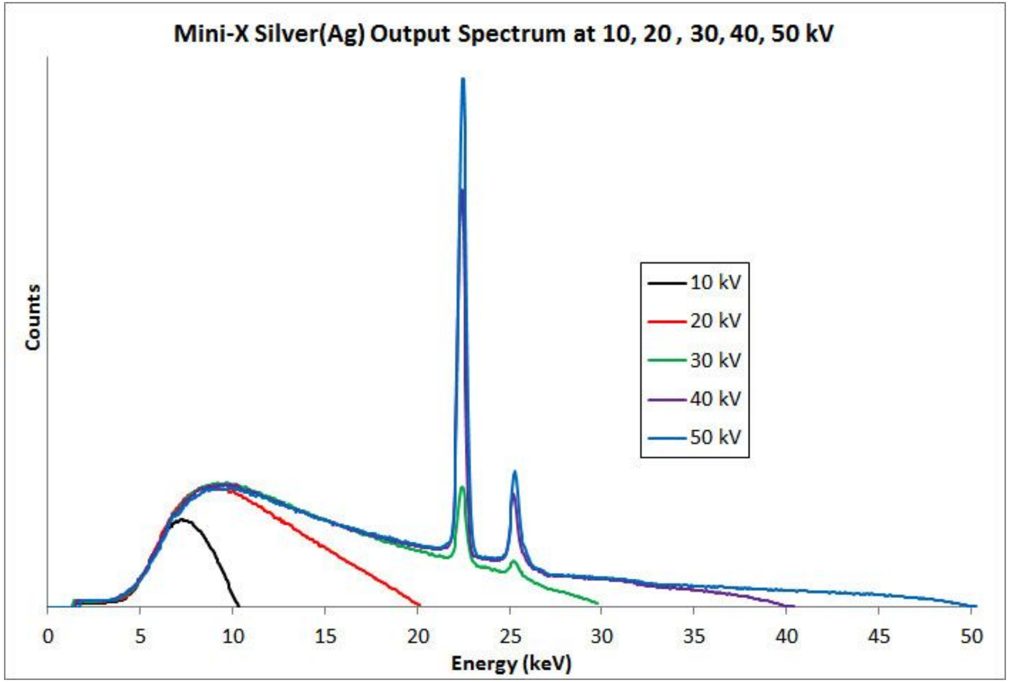


Image source: https://commons.wikimedia.org/wiki/File:XrtSpectrum.jpg

Ag TUBE SPECTRUM

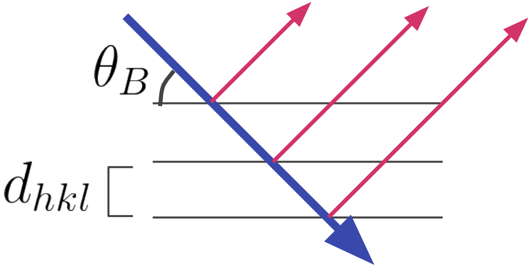


- HelXAS designed for 3*d* transition metal K edges -> energy range ~5-15 keV
- X-ray tube with silver anode, since Ag characteristic lines above 20 keV

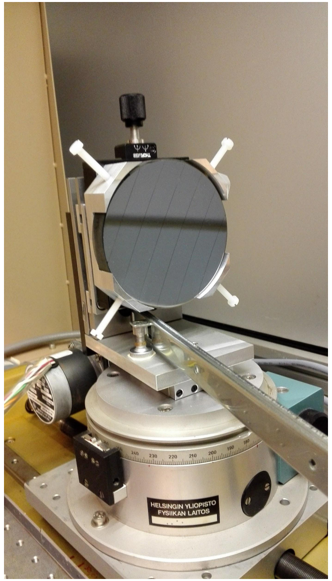
Image source: http://www.inspection-kits.com/Mini-X-X-ray-tube-s-521-674.html

SBCA - MONOCHROMATING MIRROR

Wavelength selection with crystals according to Bragg's law



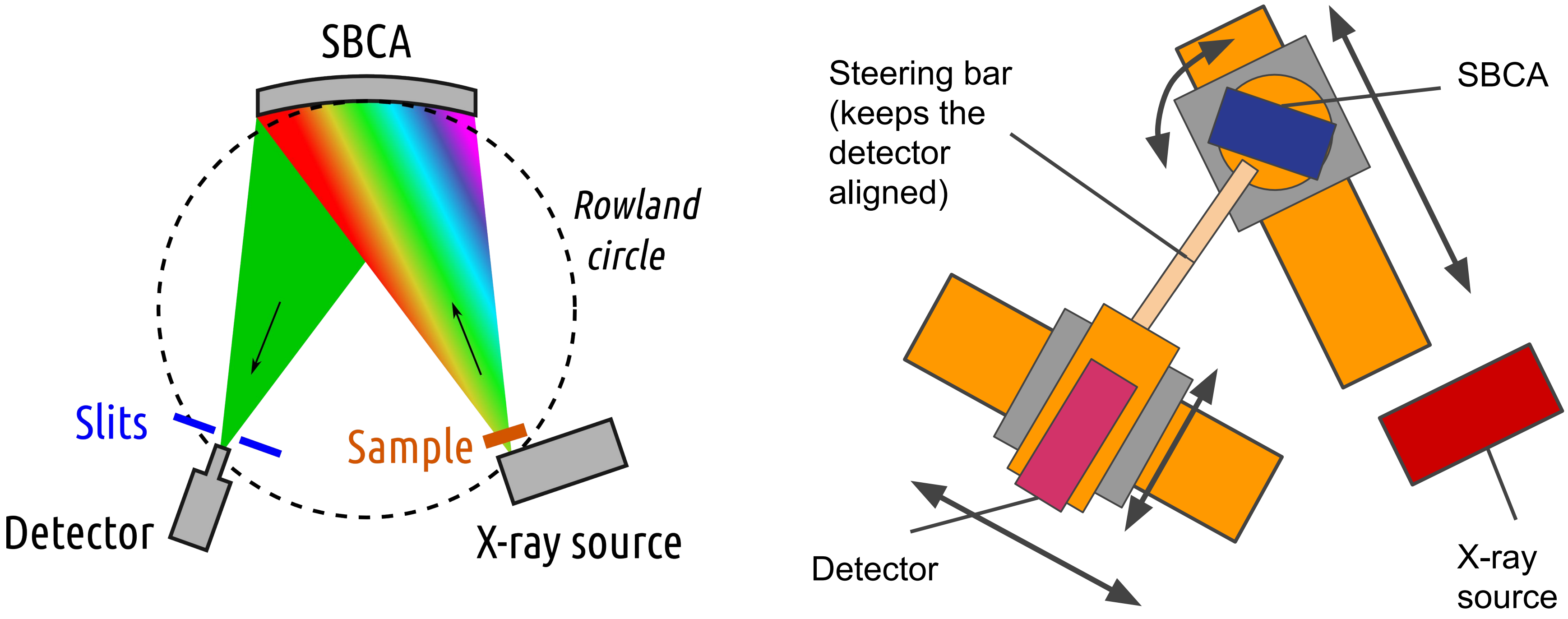
$$\lambda = 2d_{hkl}\sin\theta_B$$



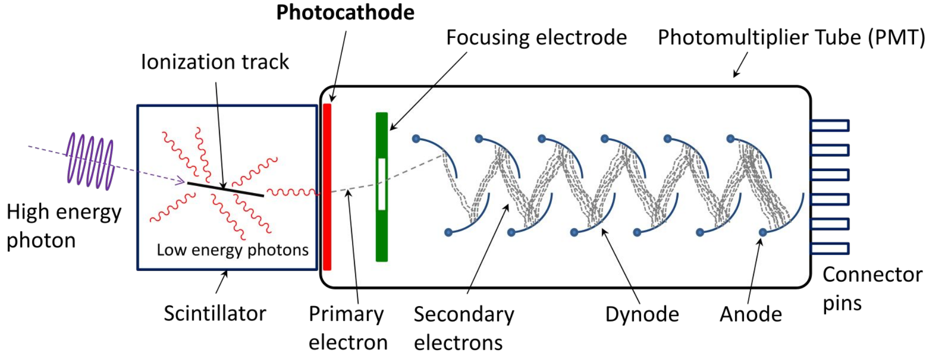
Spherically Bent Crystal Analyser

Monochromatizes *and* focuses the beam

MOTORIZED JOHANN GEOMETRY



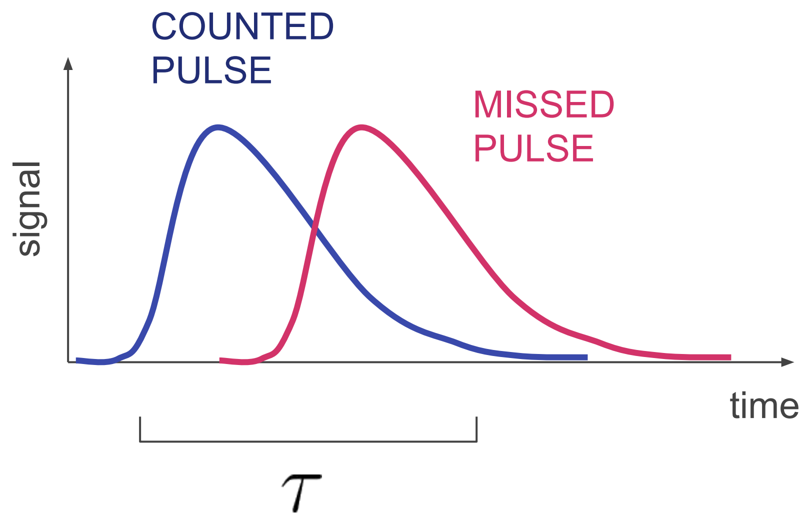
SCINTILLATOR DETECTOR



- Doped NaI crystal converts X-ray photons to low energy photons, which again are converted to a cascade of electrons
- Electron pulse is collected and transformed into voltage pulse
- Pulses proportional to photon energy but poor resolution (~30%)

Image source: https://upload.wikimedia.org/wikipedia/commons/e/e8/PhotoMultiplierTubeAndScintillator.svg

DEAD-TIME CORRECTION

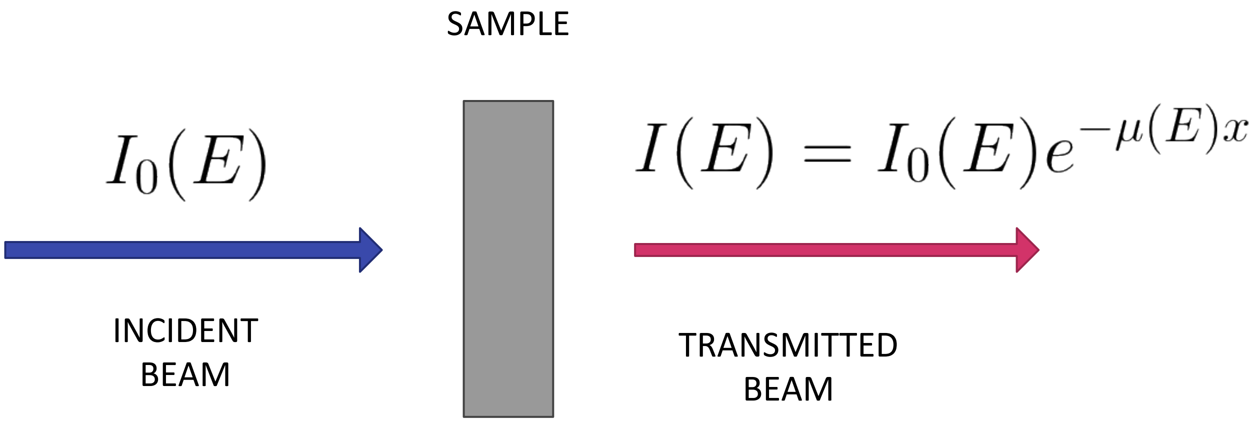


- The detector has a finite response time to incident photons, known as the dead time τ
- During that time, the detector can not count other photons
- If the effect is fairly small, can be corrected using

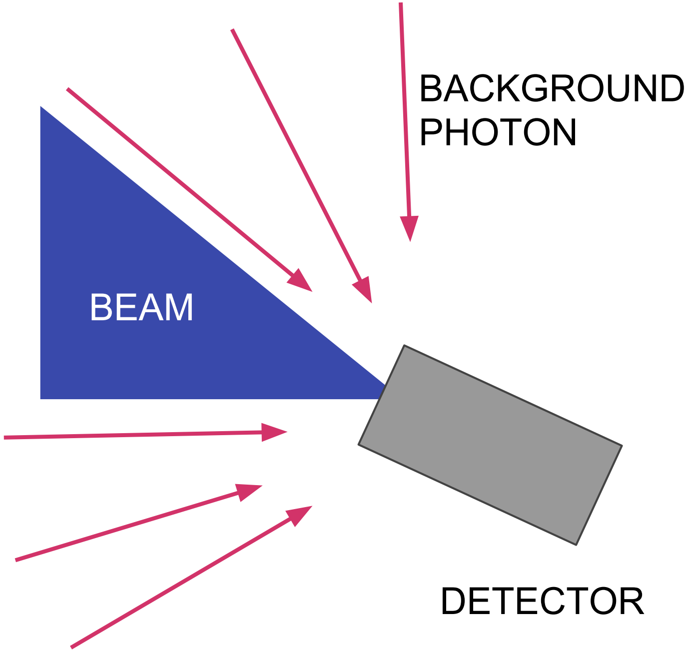
$$N_{\text{correct}} \approx \frac{N}{1 - \frac{\tau}{T} N}$$

where N is the number of counts and T is the time in which they were acquired

ABSORPTION IN TRANSMISSION GEOMETRY

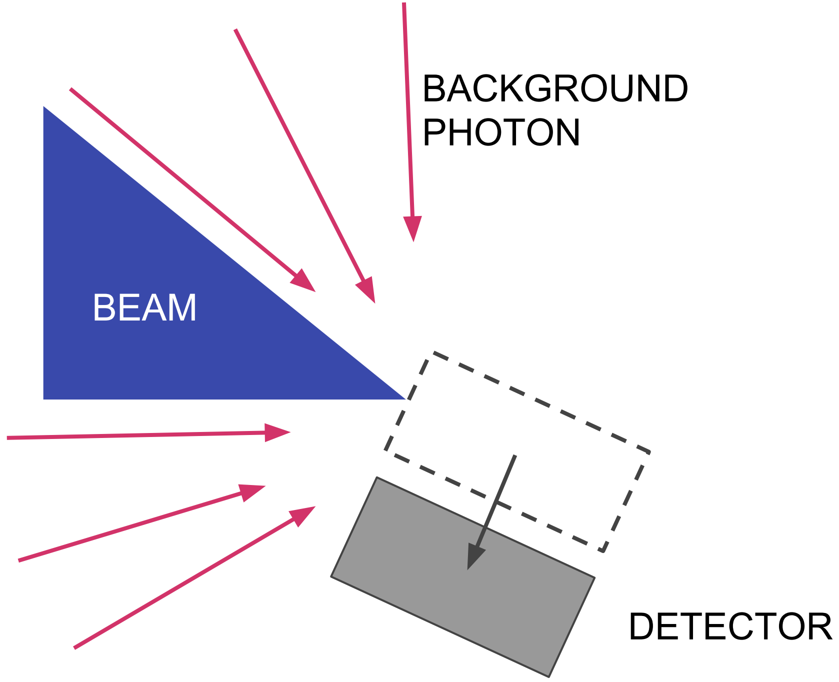


BACKGROUND NOISE



- In addition to signal, there is always background of elastic scattering, fluorescence, etc. present
- μx from logarithm = highly non-linear = sensitive to background

BACKGROUND REMOVAL



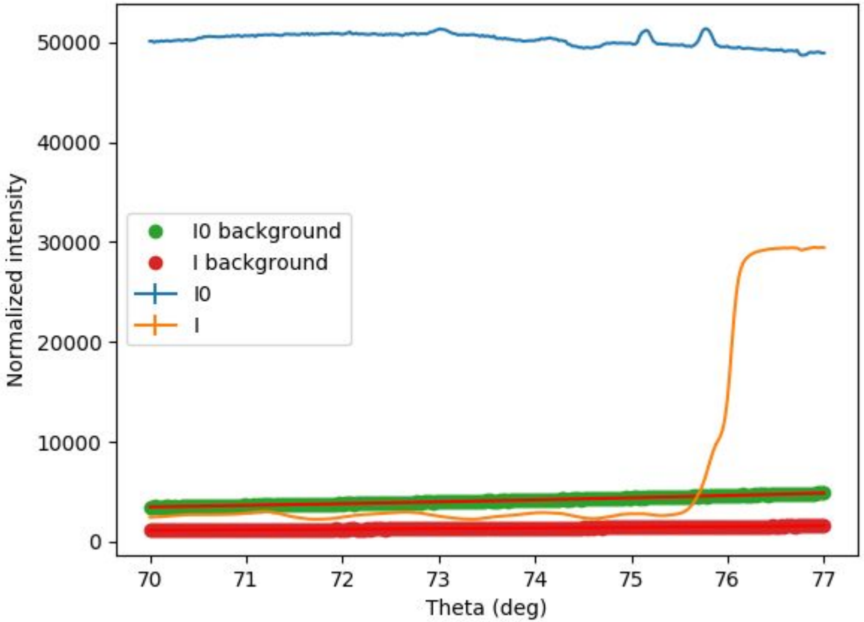
- Measure background by moving the detector away from the direct beam
- For accuracy, measure on both sides of the focus and take the mean
- Background slowly varying -> fit low-order polynomial and remove the fit from the signal to avoid increased statistical noise

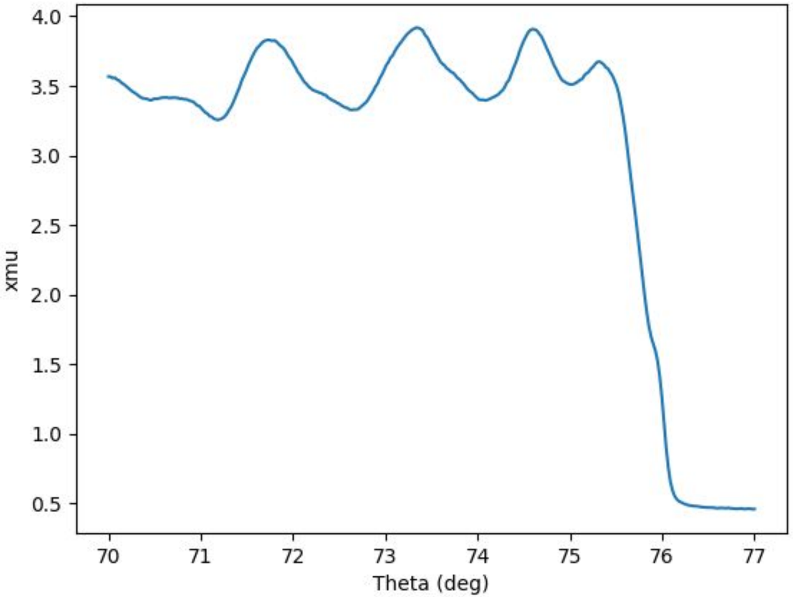
MEASUREMENT PROCEDURE (ABSORPTION)

1. Measure the direct beam I_0, the transmitted beam I, and their backgrounds $I_{0,\mathrm{bg}}$ and I_{bg}
2. Apply the dead-time correction
3. Fit the low order polynomials y and y_0 to the backgrounds $I_{0,\mathrm{bg}}$ and I_{bg}
4. Compute μx from the equation:

$$\mu x = \ln \frac{I_0 - y_0}{I - y}$$

EXAMPLE: Co foil in transmission



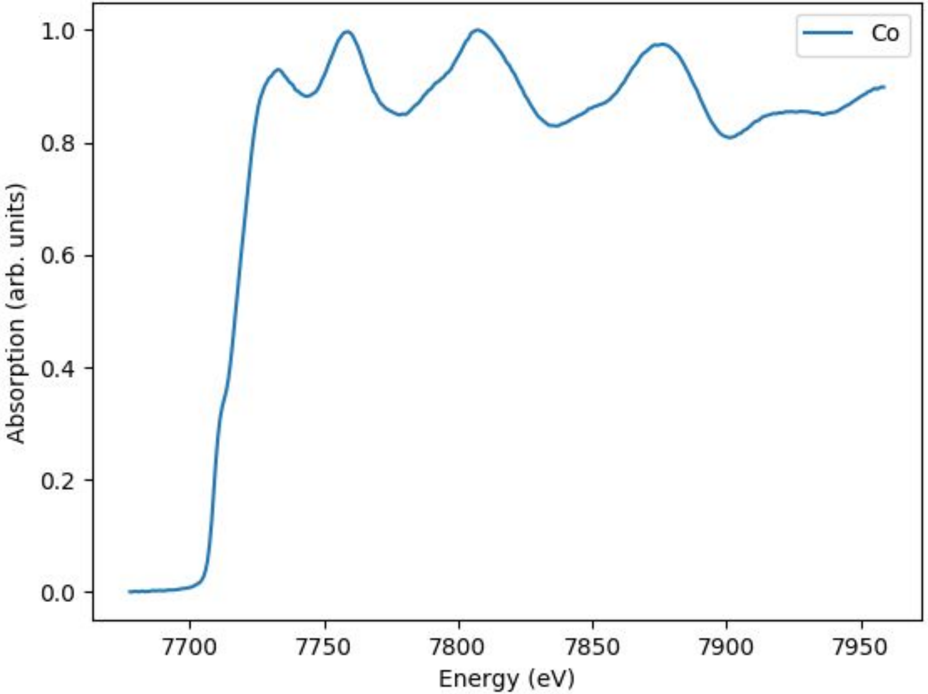


EXAMPLE: Co foil in transmission

Energy scale conversion:

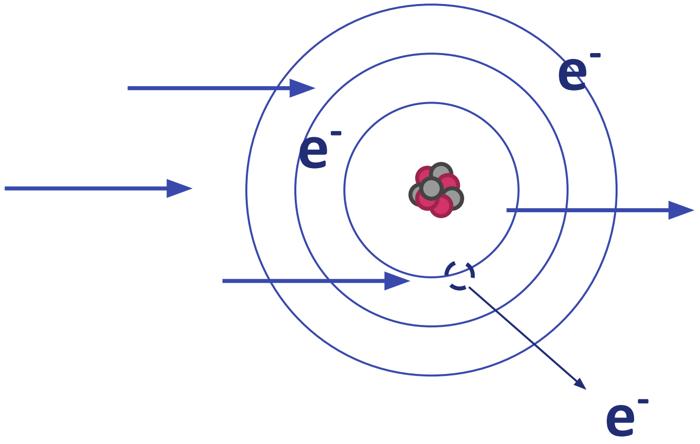
$$\lambda = 2d_{hkl} \sin\theta$$

$$E = \frac{hc}{\lambda}$$

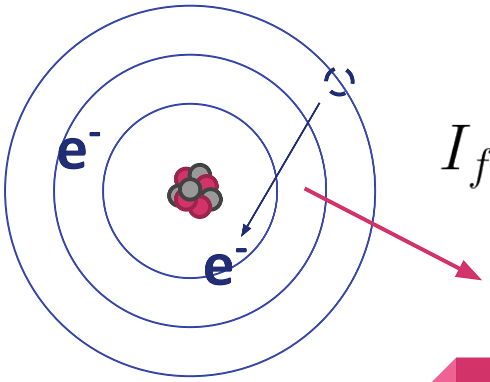


ABSORPTION THROUGH FLUORESCENCE

Ionization of a core electron leaves a hole behind



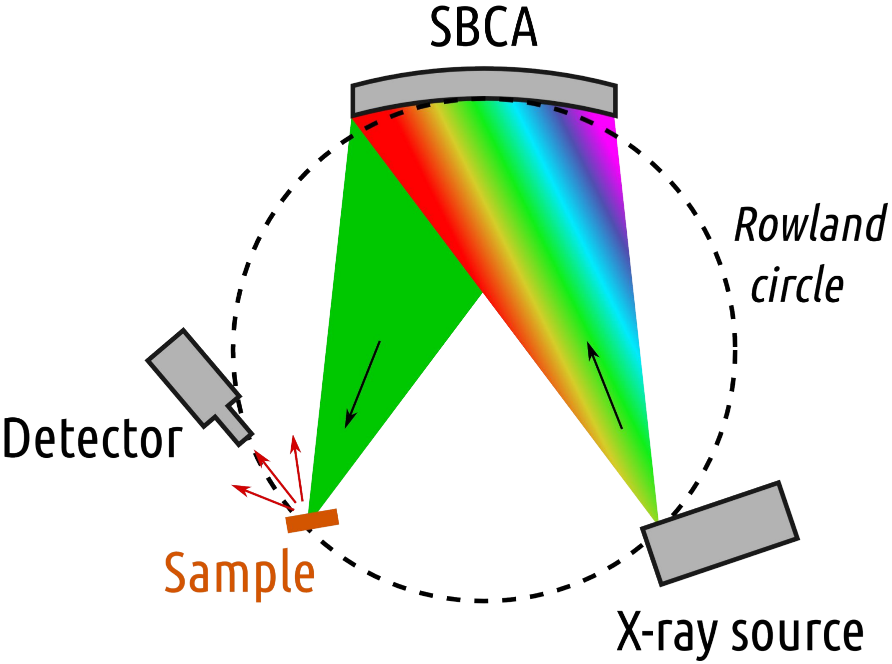
Hole is filled and a fluorescence photon is emitted



$$I_f(E) \propto \mu(E)$$

for thin sample

FLUORESCENCE MODE



SOLID STATE DETECTOR

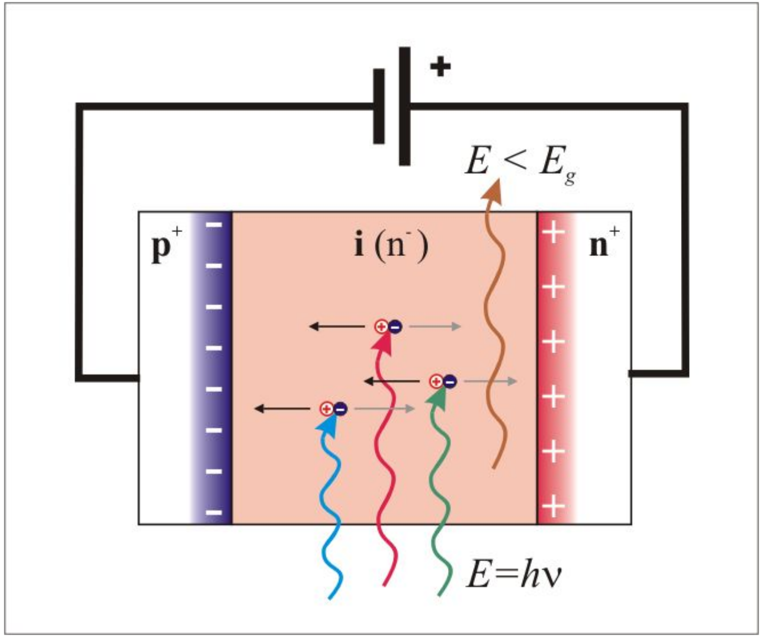
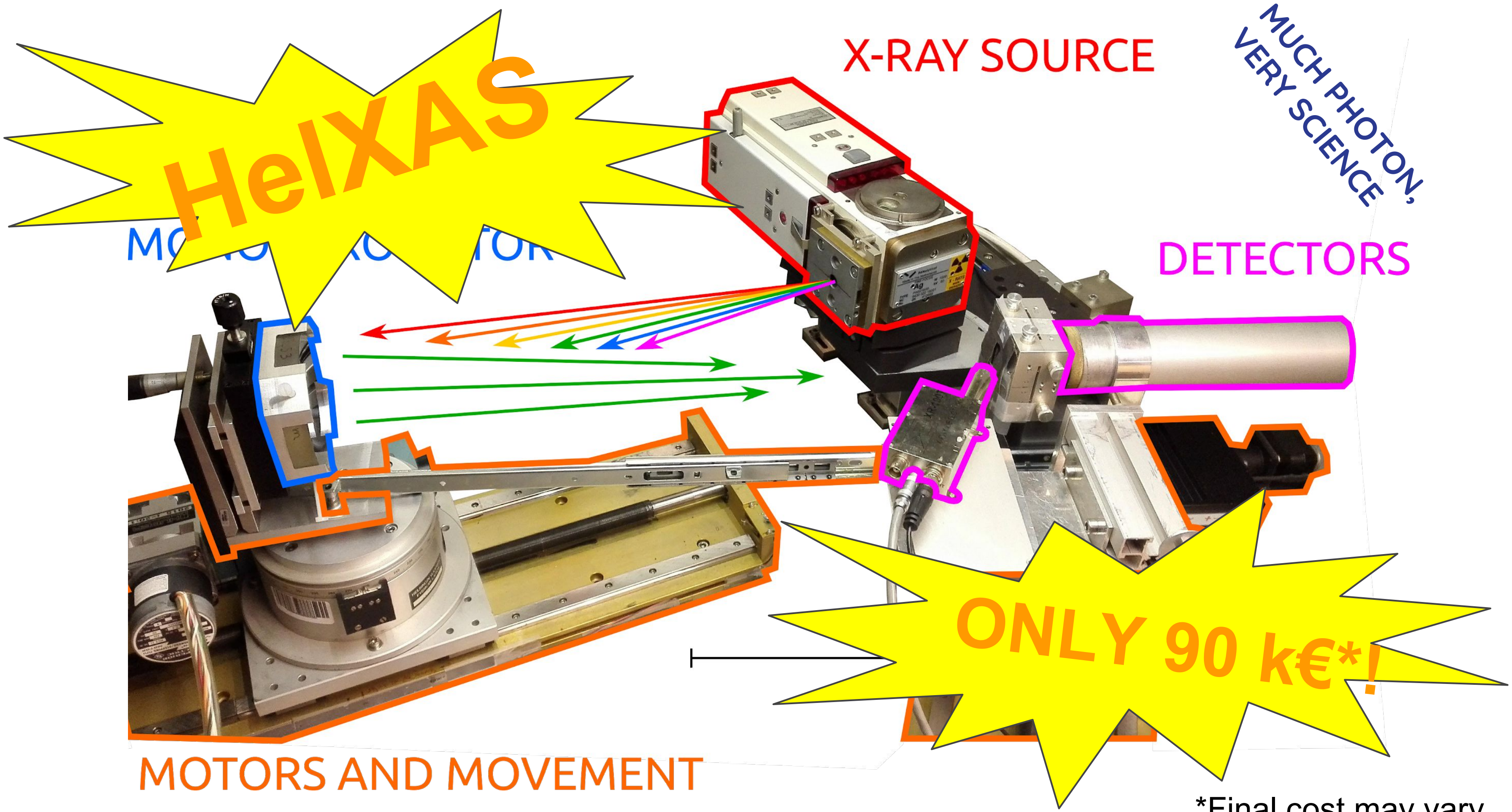


Image source https://upload.wikimedia.org/wikipedia/commons/f/f0/Pin-Photodiode.png

- For fluorescence signal, we need to able to separate the fluorescence lines -> better energy resolution needed
- CdTe-detector is used with multichannel analyser
- Saturates easily, not good for transmission

WHEN TO USE FLUORESCENCE?

- Never, if the transmission mode works
- In fluorescence: no absolute absorption coefficient, not good for (optically) thick samples, low photon yield, geometric difficulties due to spherical aberration
- However, useful for dilute samples, thin films on thick substrate, some complex environments



*Final cost may vary