Design of portable-transportable units:
Comparison of possible choices

Román Padilla Alvarez
Maria Liz Crespo

International Atomic Energy Agency
MLAB, ICTP

Outline:

- Analytical needs
  - Bulk analysis
  - Spatially resolved measurements
- Excitation
  - Radioisotopes
  - X-ray tubes
- Modifying excitation spectrum
  - Filters
  - Optical elements
- Detectors
- Geometry arrangements
- Concluding remarks

Analytical needs:

- Bulk analysis (average composition)
  - Large area needs to be illuminated
- Spatially resolved measurements (identifying changes in elemental distribution)
  - Suitable collimation / focusing device is needed

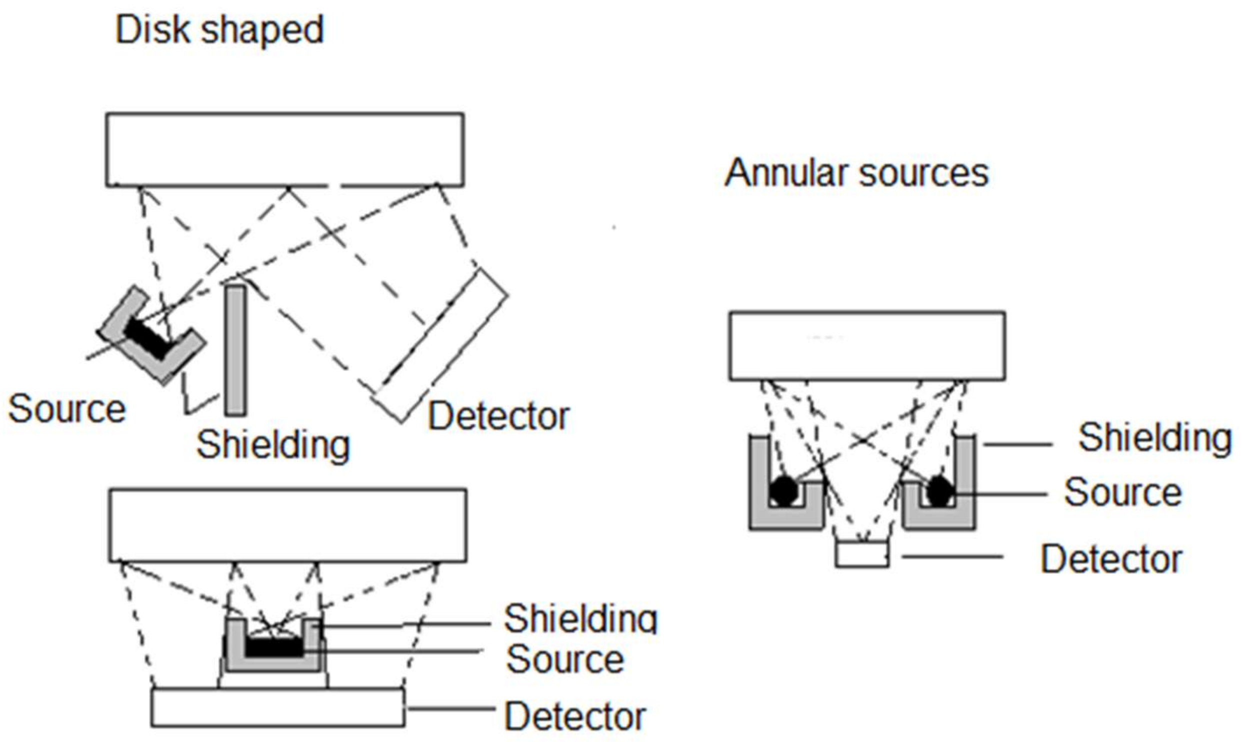
Hardware for excitation

- Sources
  - Radioisotopes (α, γ, x-rays)
  - X-Ray Tubes
  - Electrons (SEM)
  - Charged particles (accelerators)
  - Synchrotron radiation

Hardware for excitation

- Sources
  - **Radioisotopes (α, γ, x-rays)**
  - **X-Ray Tubes**
  - Electrons (SEM)
  - Charged particles (accelerators)
  - Synchrotron radiation

Radioisotopes



Main arrangements for source excitation

Radioisotopes

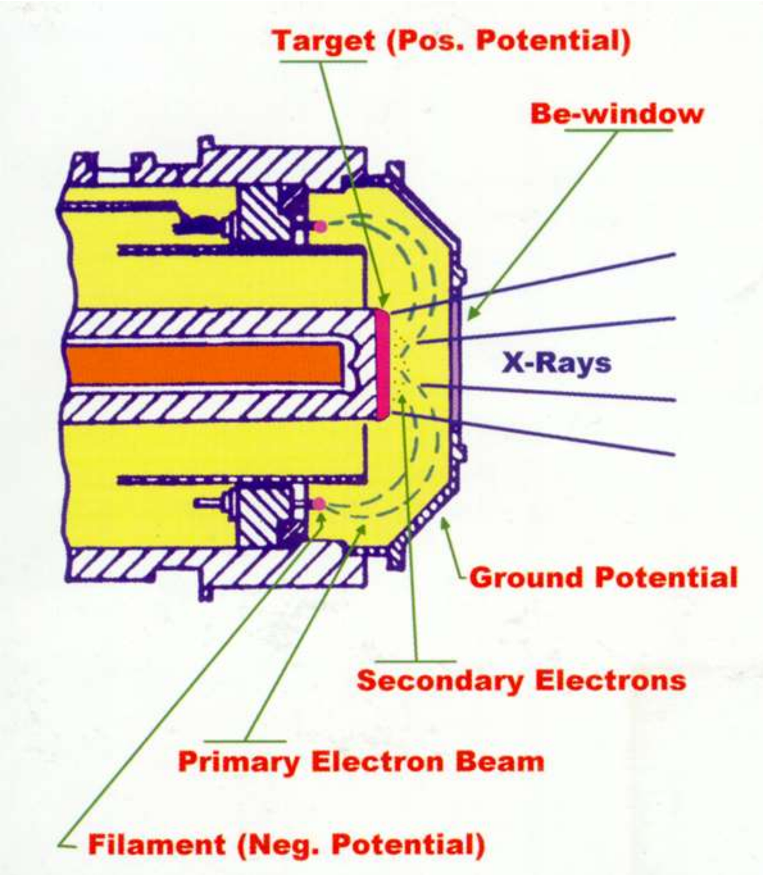
Isotope	^{55}Fe	^{244}Cm	^{109}Cd	^{241}Am	^{57}Co
Energy (keV)	5.9	14.3, 18.3	22.1, 88	59.5	122
Elements (K-lines)	Al – V	Ti-Br	Fe-Mo	Ru-Er	Ba - U
Elements (L-lines)	Br-I	I- Pb	Yb-Pu	None	none

- While isotopes have fallen out of favor they are still useful for many portable applications.

Radioisotopes: Advantages and limitations

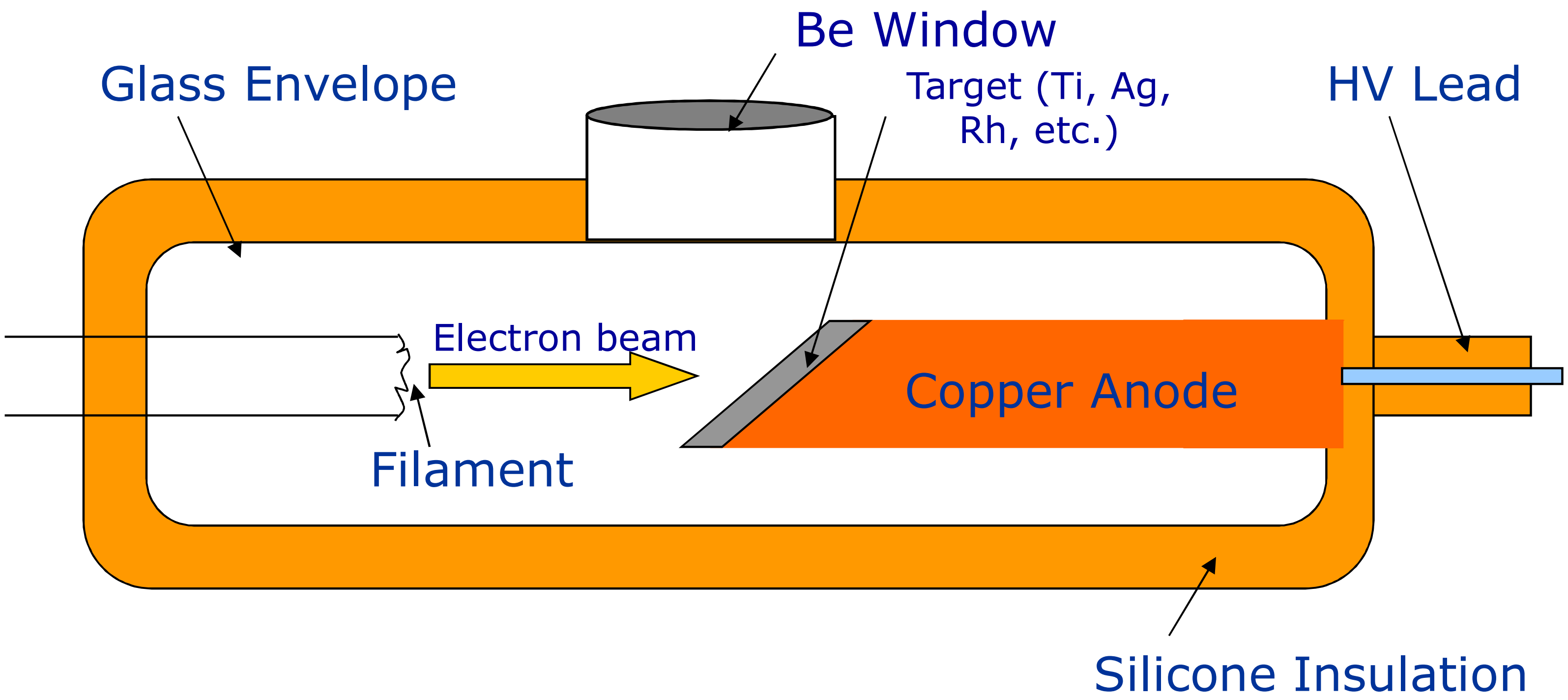
- Pro´s
  - Compact, simple construction
  - Portability
  - Monochromatic excitation
  - Low cost
- Con´s
  - Change in flux due to radioactive decay
  - Constant radiation exposure
  - Non-tunable energy

End Window X-Ray Tube

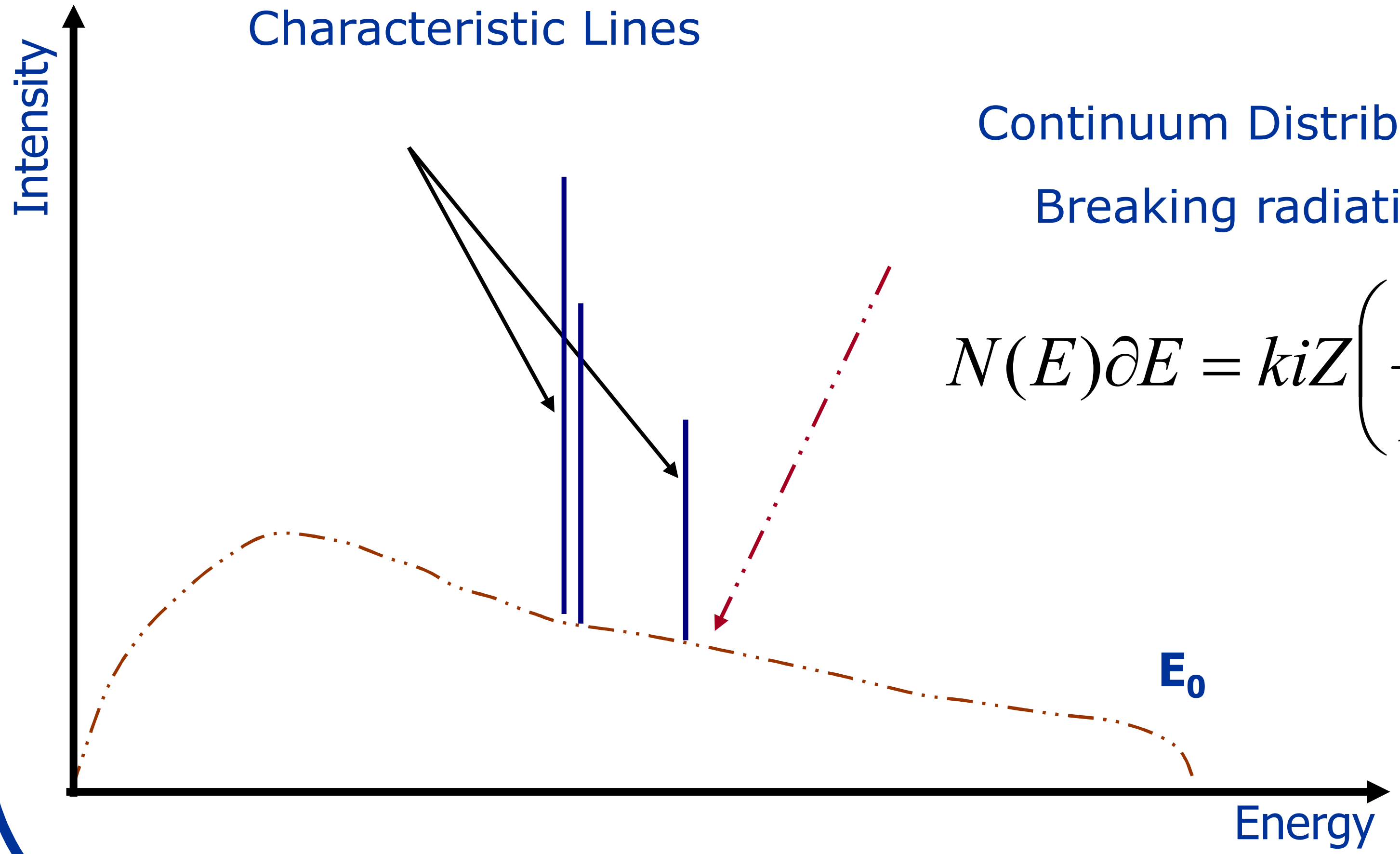


- X-ray Tubes
  - Voltage determines which elements can be excited.
  - More power = larger sensitivity
  - Anode selection determines optimal source excitation (application specific).

Side Window X-Ray Tube



X-ray production in an x-ray tube

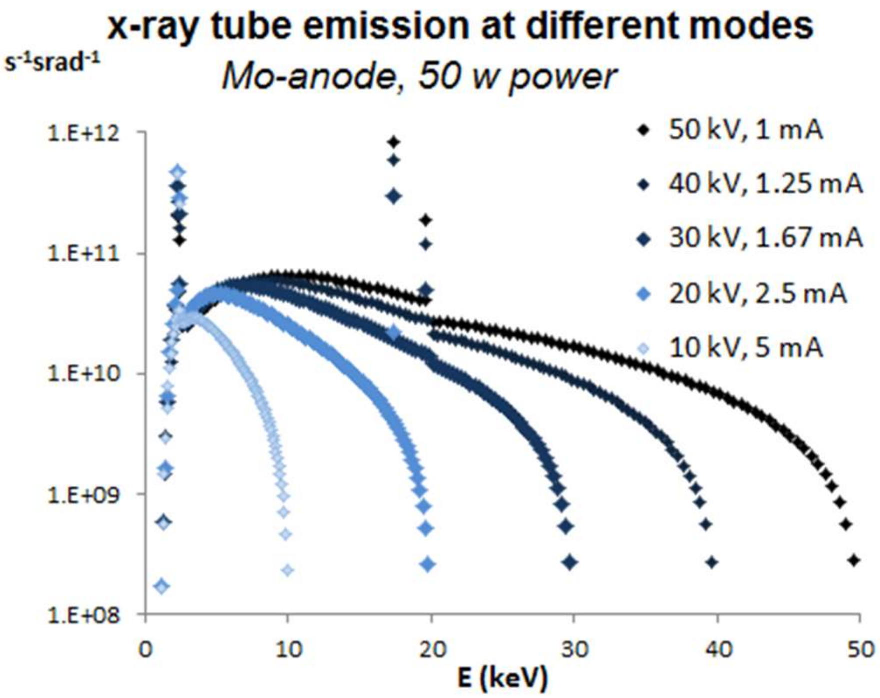


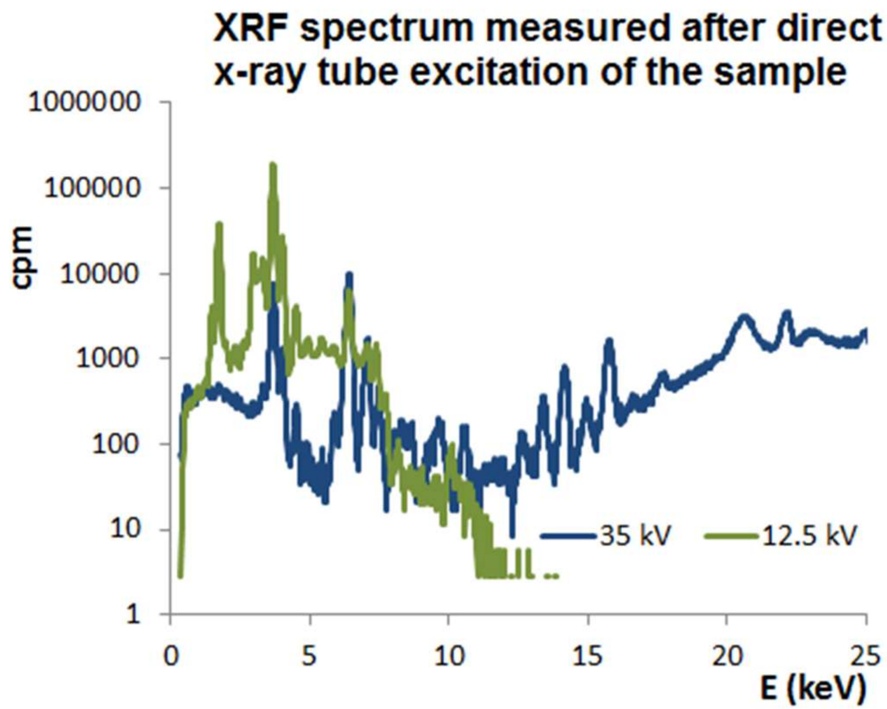
Continuum Distribution

Breaking radiation

$$N(E)\partial E = kiZ\left(\frac{E_0}{E-1}\right)\partial E$$

Tunable energy distribution





X-ray tubes: Advantages and limitations

- Pro´s
  - Different anode materials available
  - Tunable energy by selecting HV
  - Low power tubes can be even portable
  - Not constant radiation exposure (on/off)
  - Possibility to use modifyiing devices

- Con´s
  - Require of power generator
  - For power 600 w cooling system is required
  - Limited life time (~ 3000 hrs)

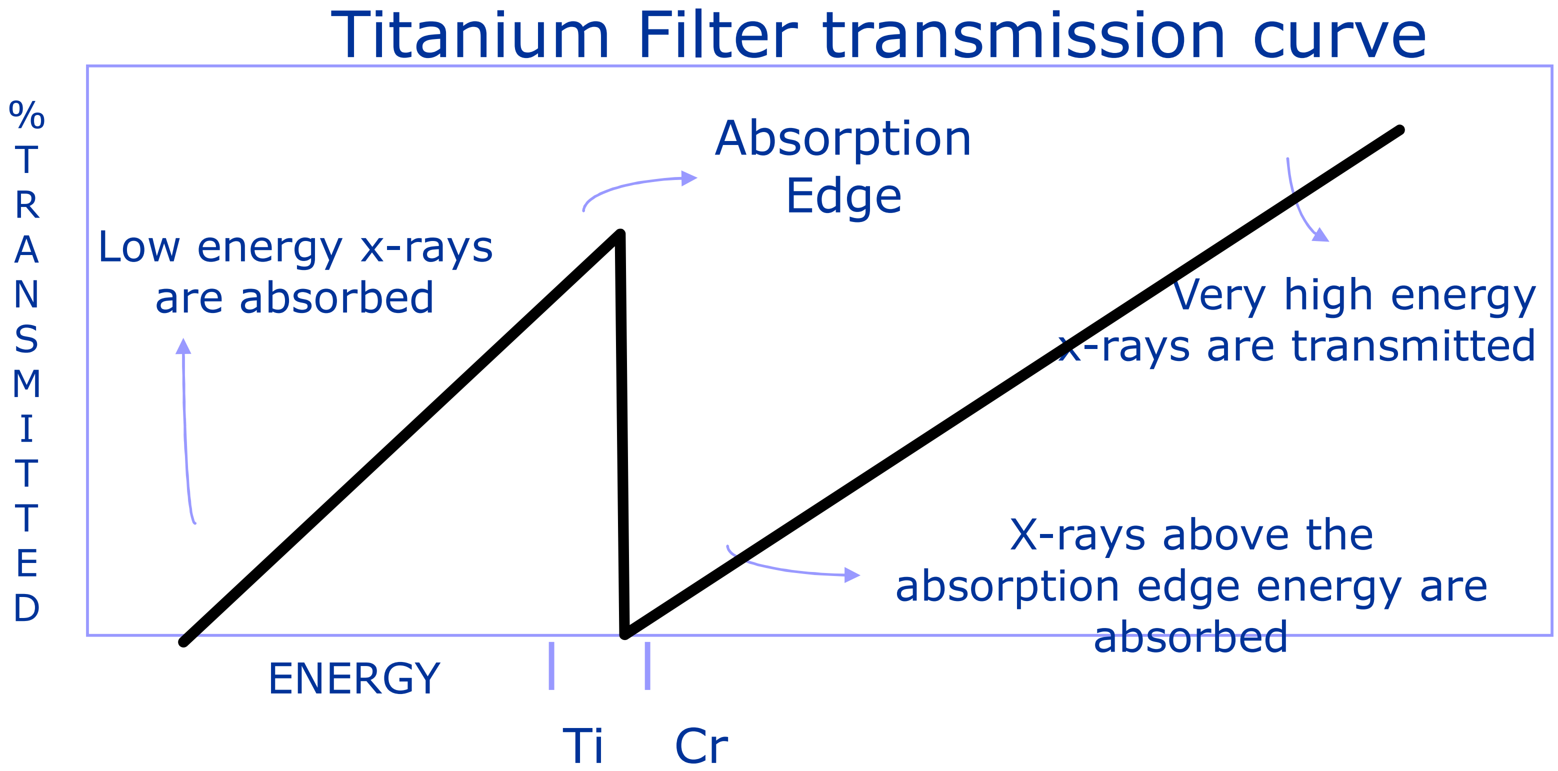
Hardware for excitation

- Modifiers
  - Energy selection:
    - Filters
    - Monochromators
    - Secondary targets
  - Spatial:
    - Collimators
    - x-ray optics devices

Hardware for excitation

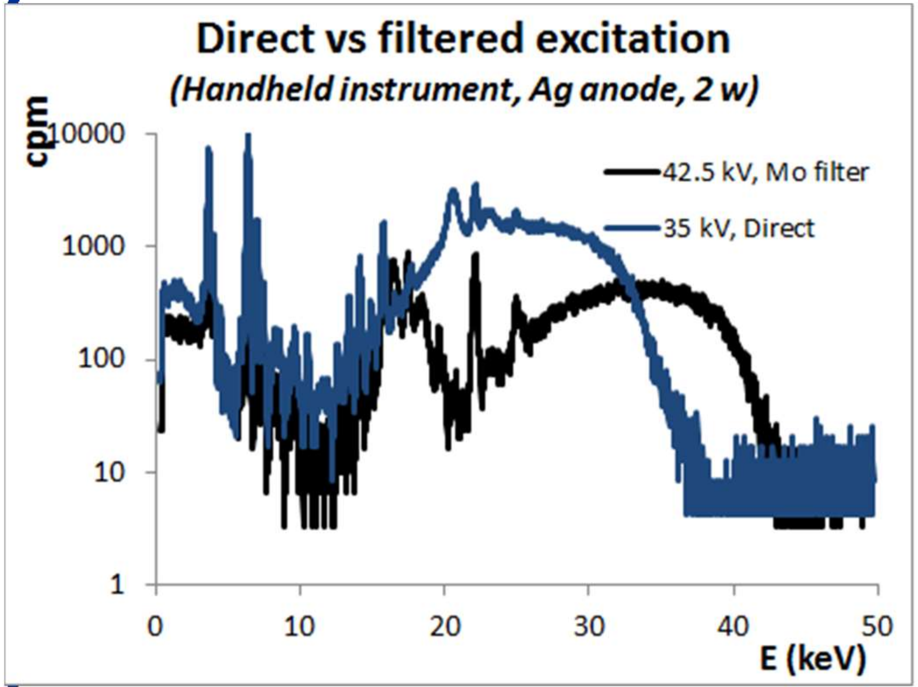
- Modifiers
  - Energy selection:
    - Filters
    - Monochromators
    - Secondary targets
  - Spatial:
    - Collimators
    - x-ray optics devices

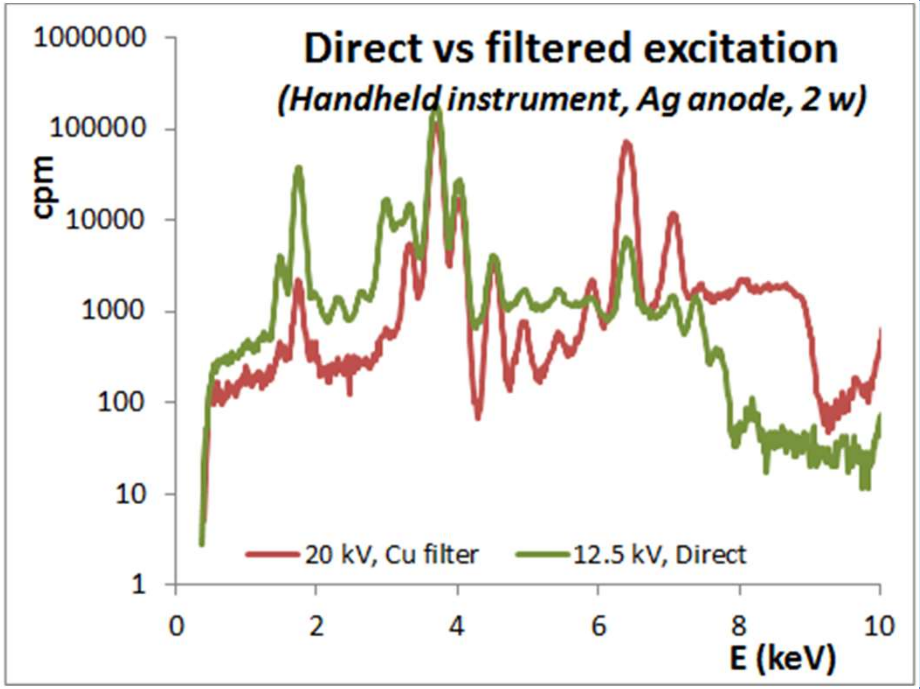
Absorption filters



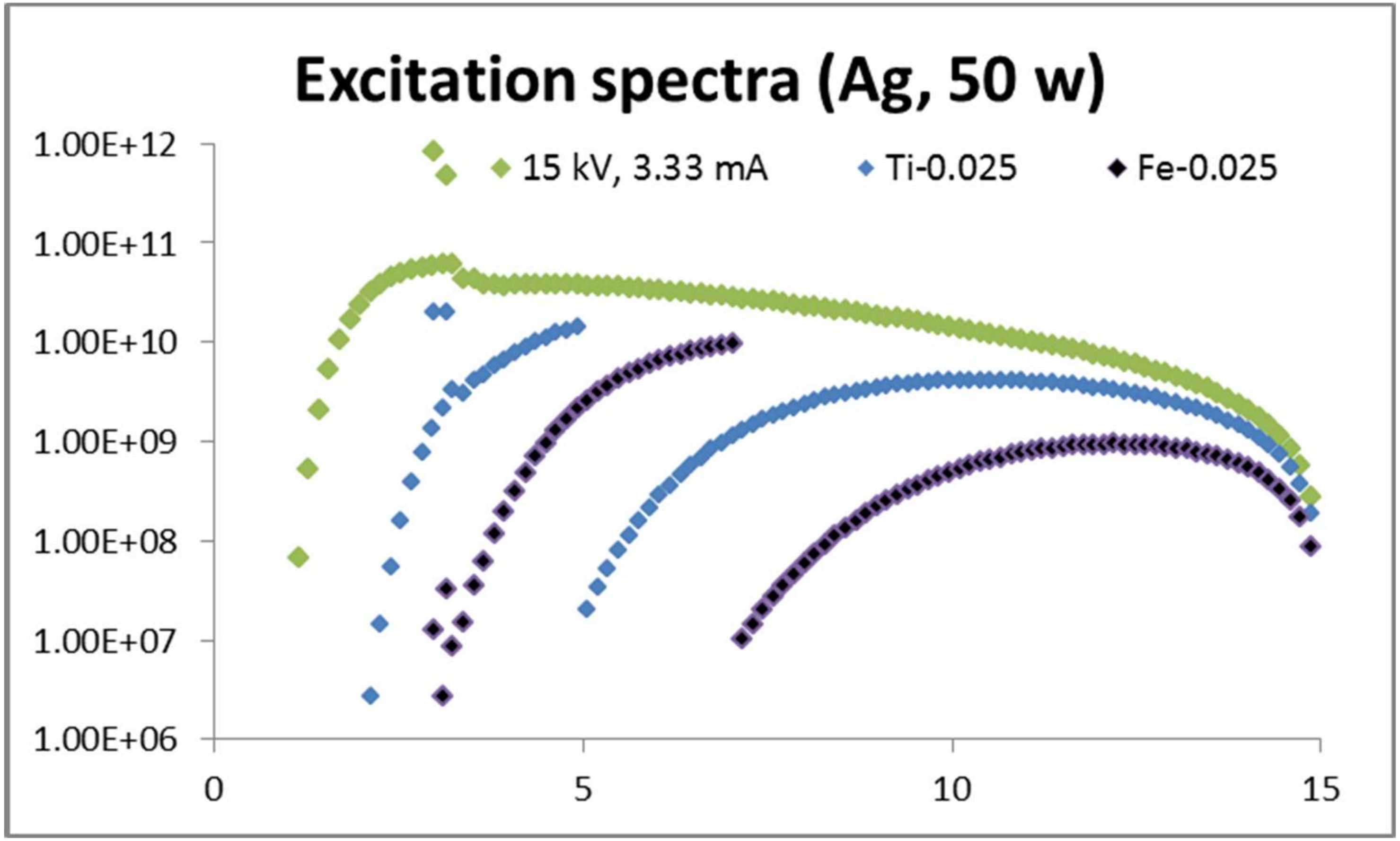
The transmission curve shows the parts of the source spectrum are transmitted and those that are absorbed

Absorption filters

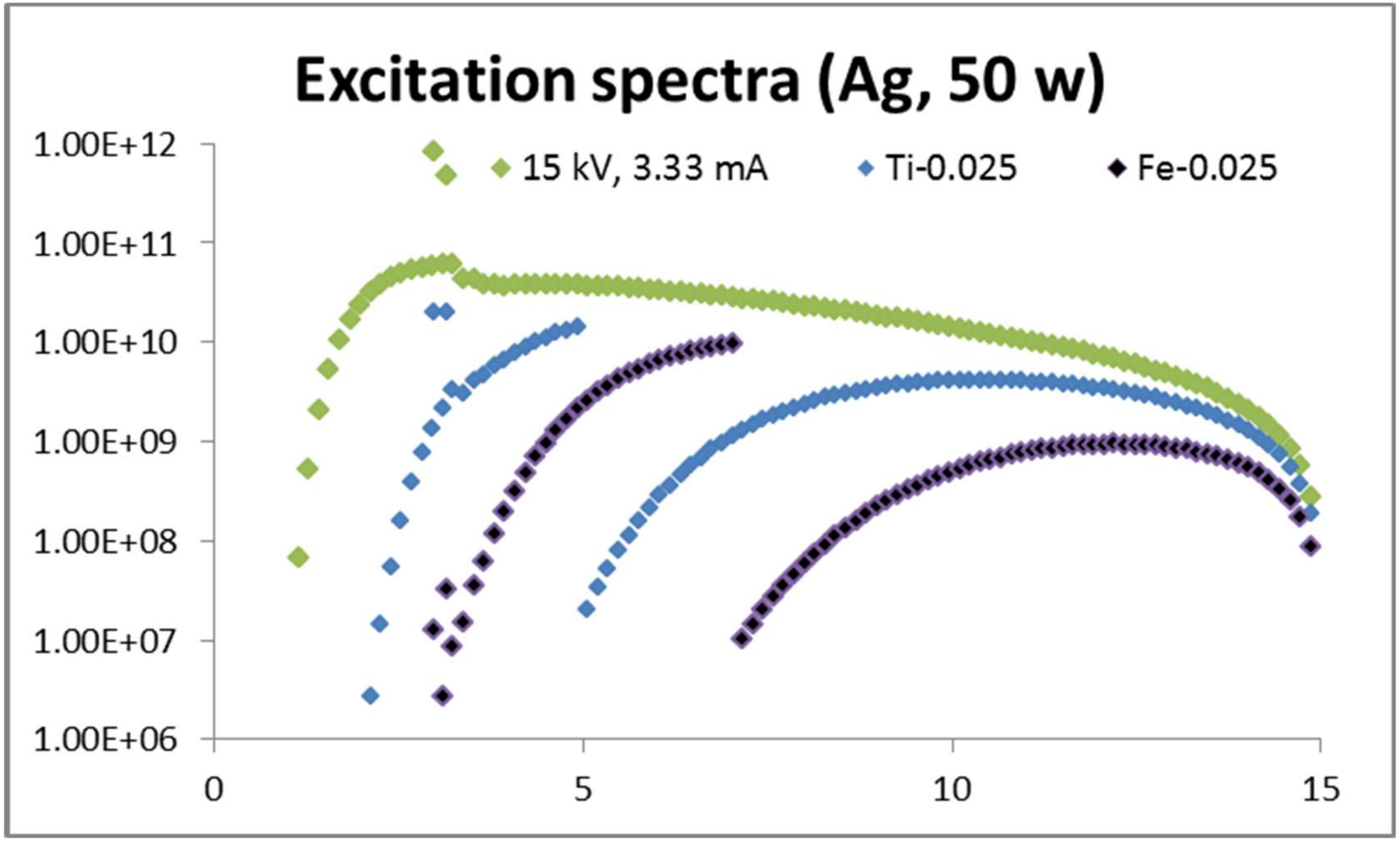




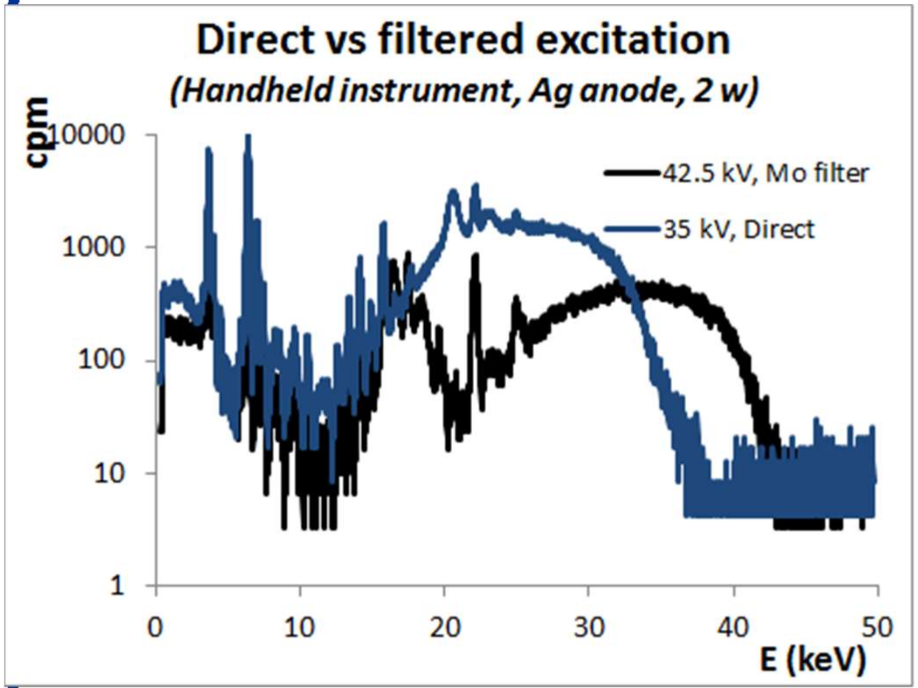
Absorption filters (Ag tube)

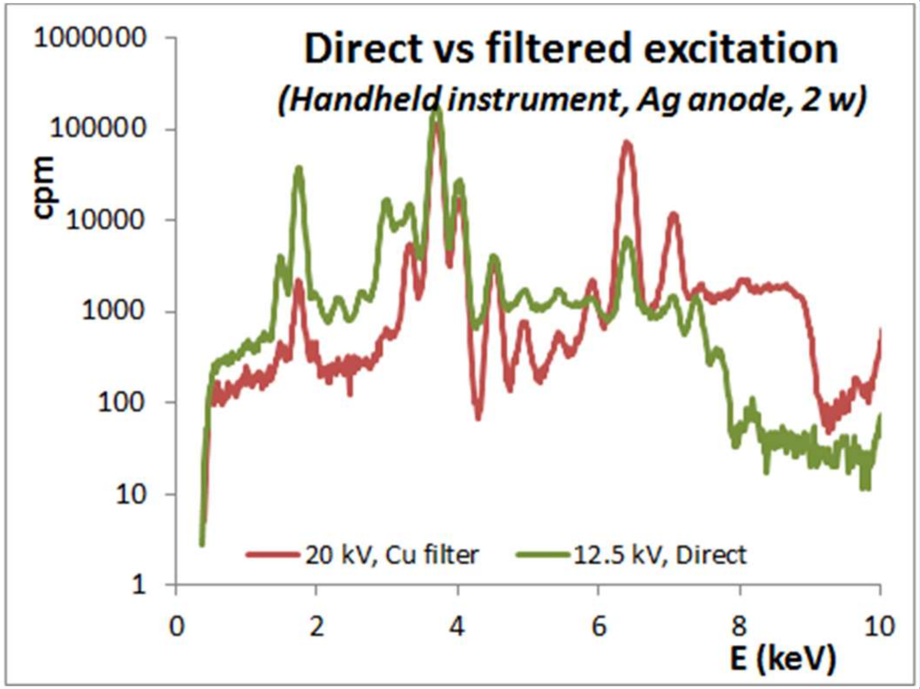


Absorption filters (Ag tube)



Absorption filters





Hardware for excitation

- Modifiers
  - Energy selection:
    - Filters
    - Monochromators
    - Secondary targets
  - Spatial:
    - Collimators
    - x-ray optics devices

Secondary targets

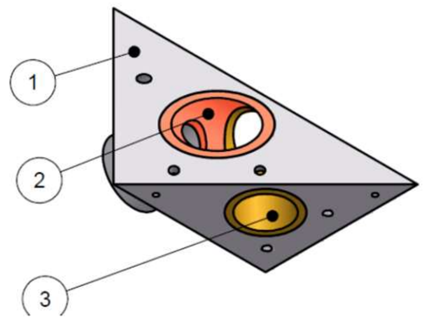
Improved Fluorescence and lower background

The characteristic fluorescence of the anode source is used to excite the sample, with the lowest possible background intensity.

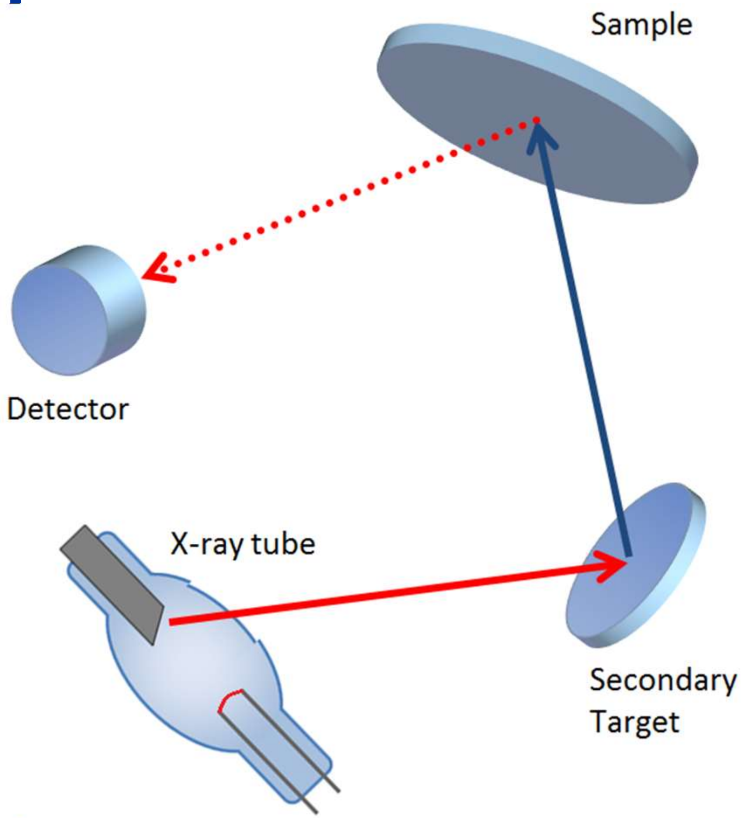
It requires almost 100x the flux of filter methods but gives superior results.

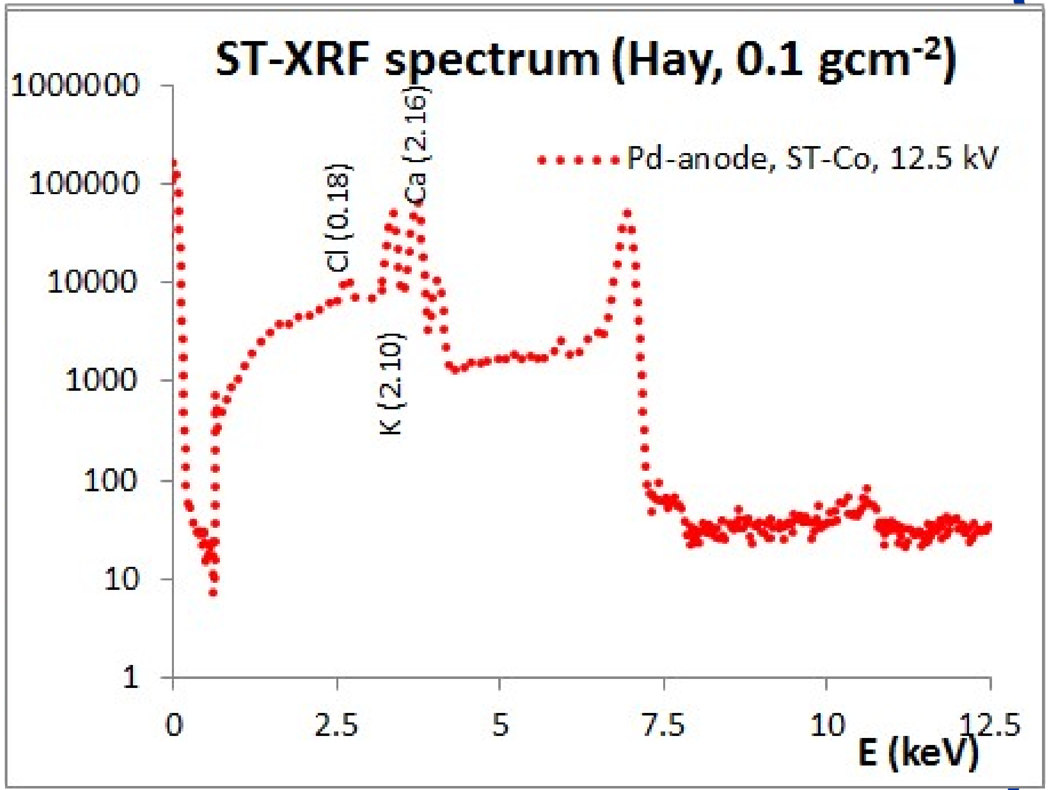
For lower power tube (50 w) still possible with optimized geometry designs

Radiation travel path	Average distance (mm)
x-ray tube exit window – secondary target	23
Secondary target – sample	17
Sample – detector window	23

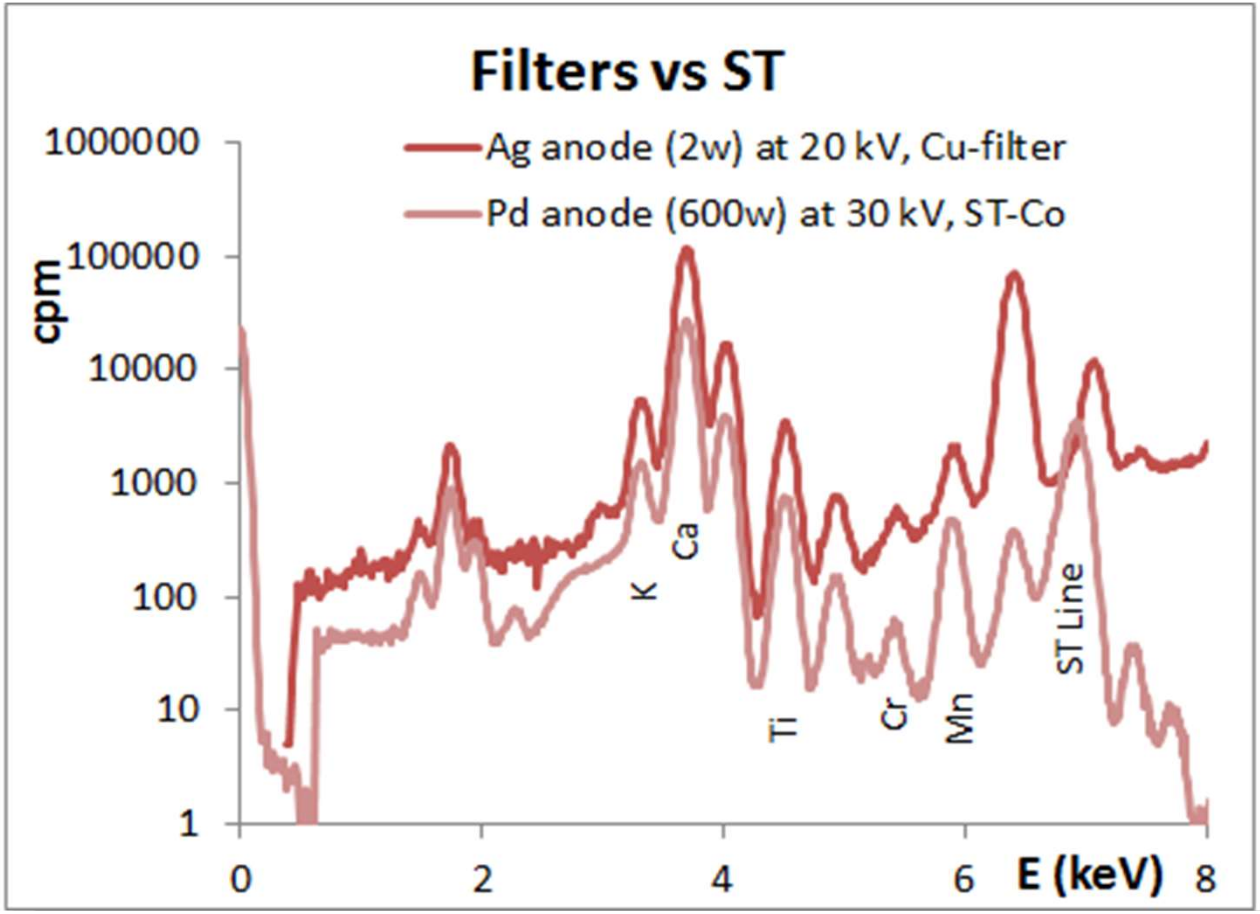


Secondary targets





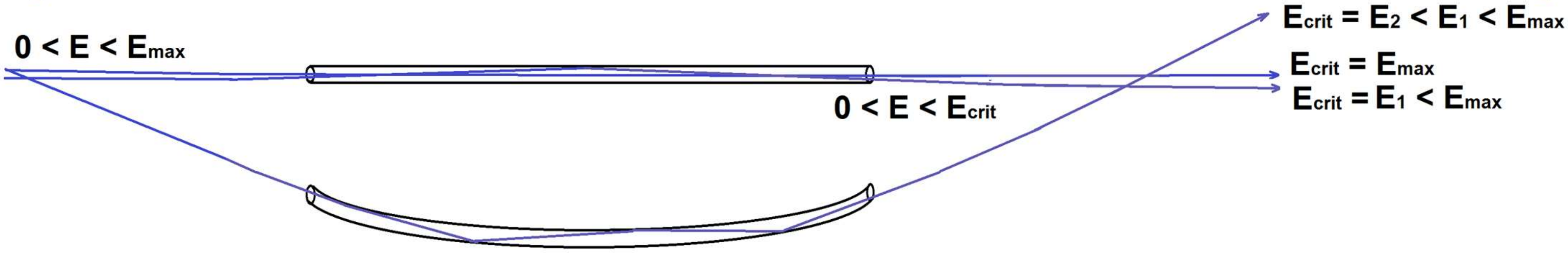
Comparison ST vs Direct or filtered



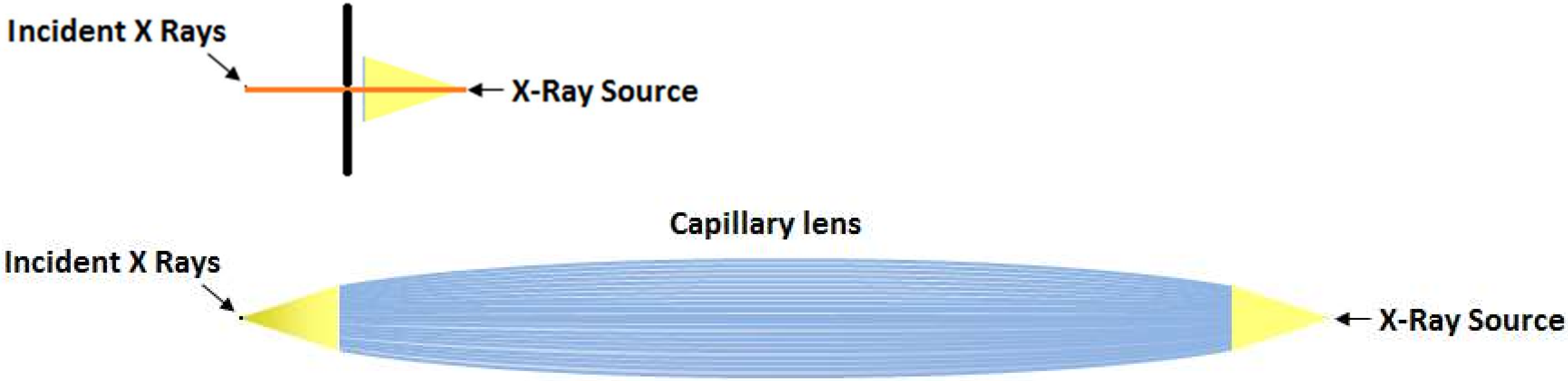
Hardware for excitation

- Modifiers
  - Energy selection:
    - Filters
    - Monochromators
    - Secondary targets
  - Spatial:
    - Collimators
    - x-ray optics devices

Policapillary lens



Policapillary lens vs Pinhole



Spot size ~ 15 - 20 μm

Gain in intensity x 300

Detectors

- Proportional Counters
- Scintillation Detectors
- Si(Li)
- LEGe
- PIN Diode
- SDD
- CCD cameras
- CZT, other

Proportional Counters, Scintillation Detectors: Poor energy resolution — WDXRF

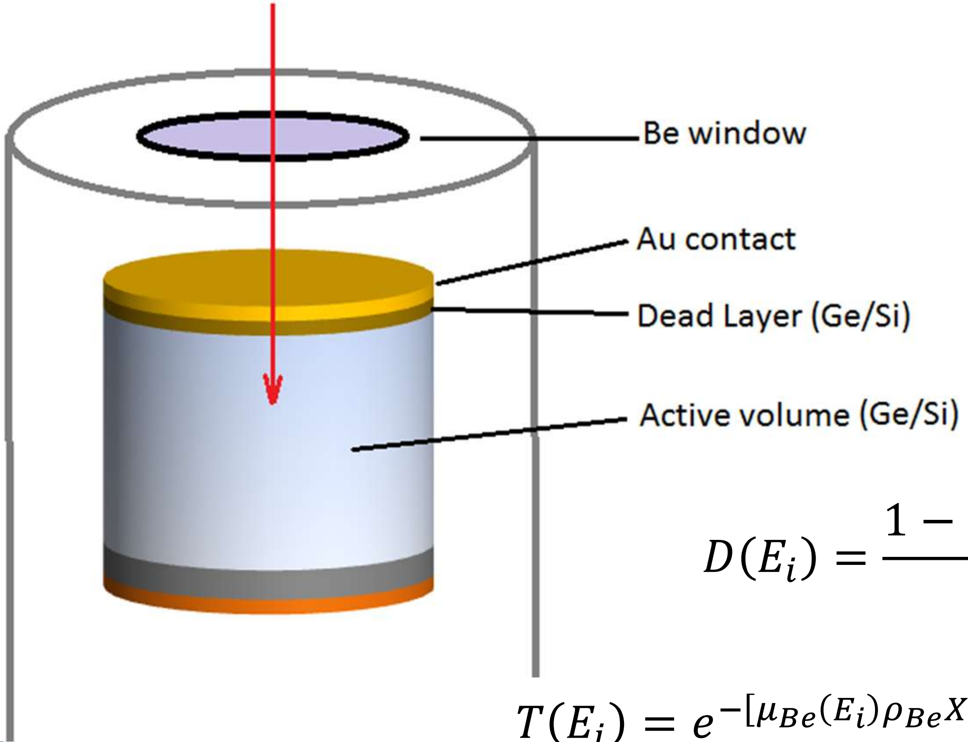
Si(Li), LEGe, PIN Diode, SDD, CCD cameras, CZT, other: Improved energy resolution — EDXRF

Main features of detectors

- Efficiency
  - How many photons produce a signal
- Energy resolution
  - Capability to differentiate close by amplitude (energy) signals
- Charge collection time
  - Time required to collect charge

Intrinsic Efficiency

- *T*: Fraction that is transmitted through the entrance layers
- *D*: Fraction that is detected in the sensitive volume

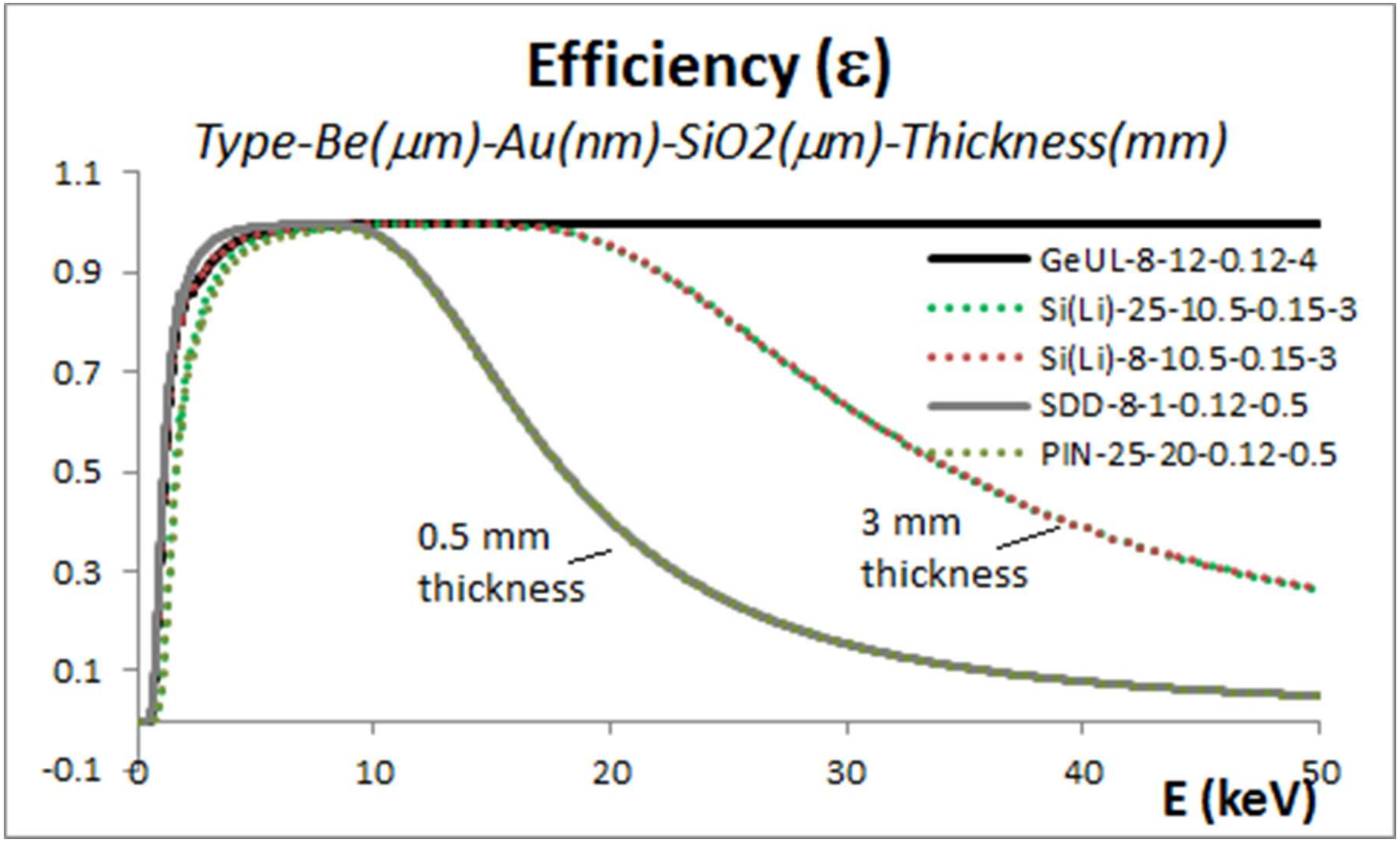


$$\varepsilon(E_i) = T(E_i)\ D(E_i)$$

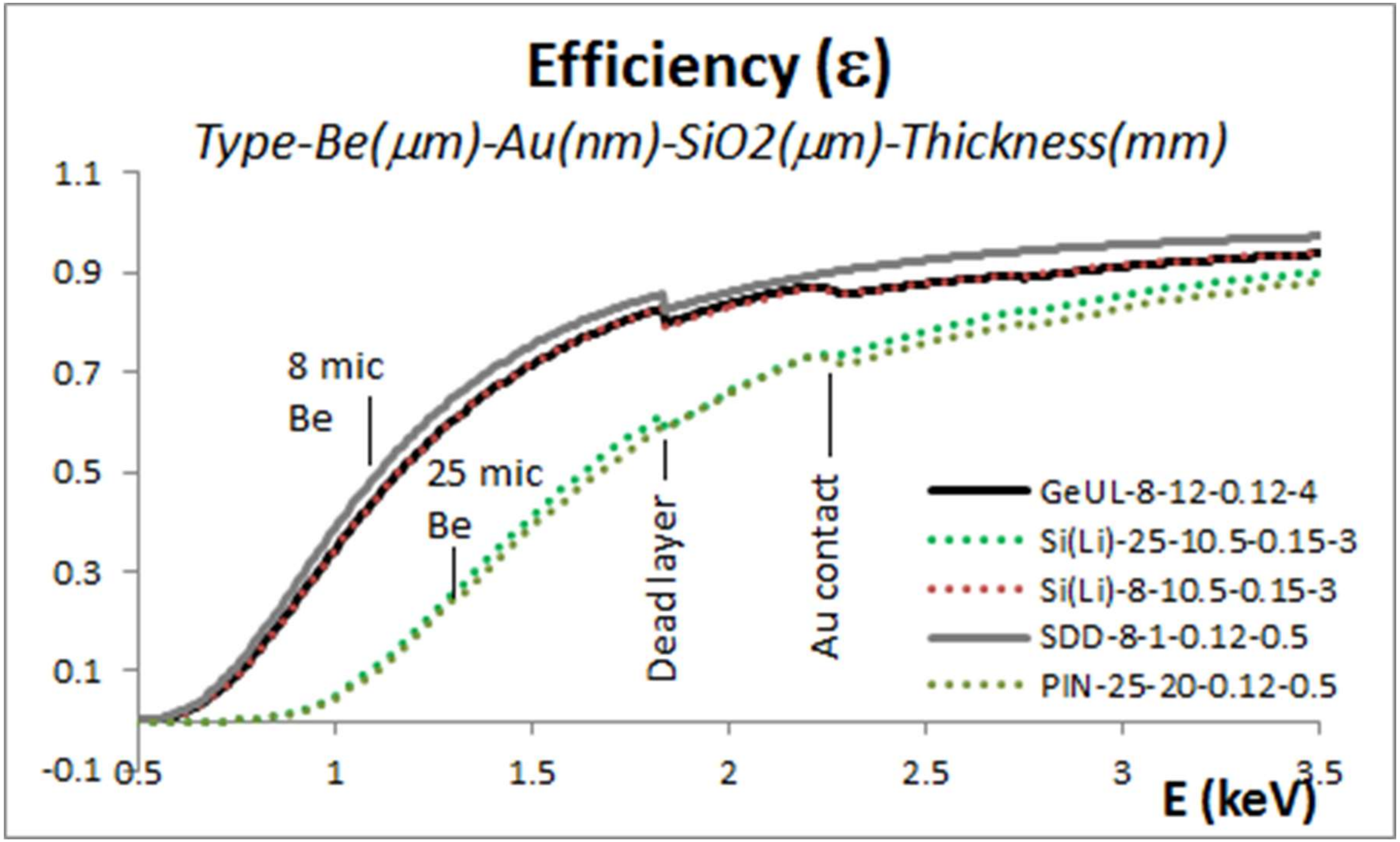
$$D(E_i) = \frac{1 - e^{-[\mu_{Si}(E_i)\rho_{Si}X_{Si}]}}{\mu_{Si}(E_i)\rho_{Si}}$$

$$T(E_i) = e^{-[\mu_{Be}(E_i)\rho_{Be}X_{Be}+\mu_{Au}(E_i)\rho_{Au}X_{Au}+\mu_{Si}(E_i)\rho_{Si}X_{Si}]}$$

Efficiency for various semiconductor detectors



Efficiency for various semiconductor detectors



Energy resolution

Full Width at Half Maximum (FWHM) of a peak

$$FWHM^2_{Peak} = FWHM^2_{Elec} + FWHM^2_{Det}$$

Electronic noise: ~100 eV

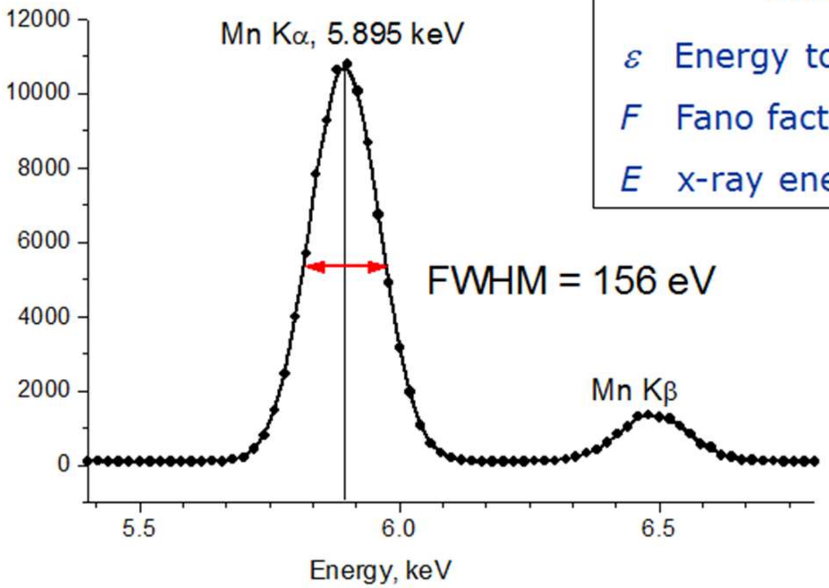
Intrinsic contribution:

$$2.3548\sqrt{\varepsilon \times F \times E}$$

ε Energy to create e-h pair (3.85 eV)

F Fano factor (~0.114)

E x-ray energy in eV



Mn Kα @ 5.895 keV

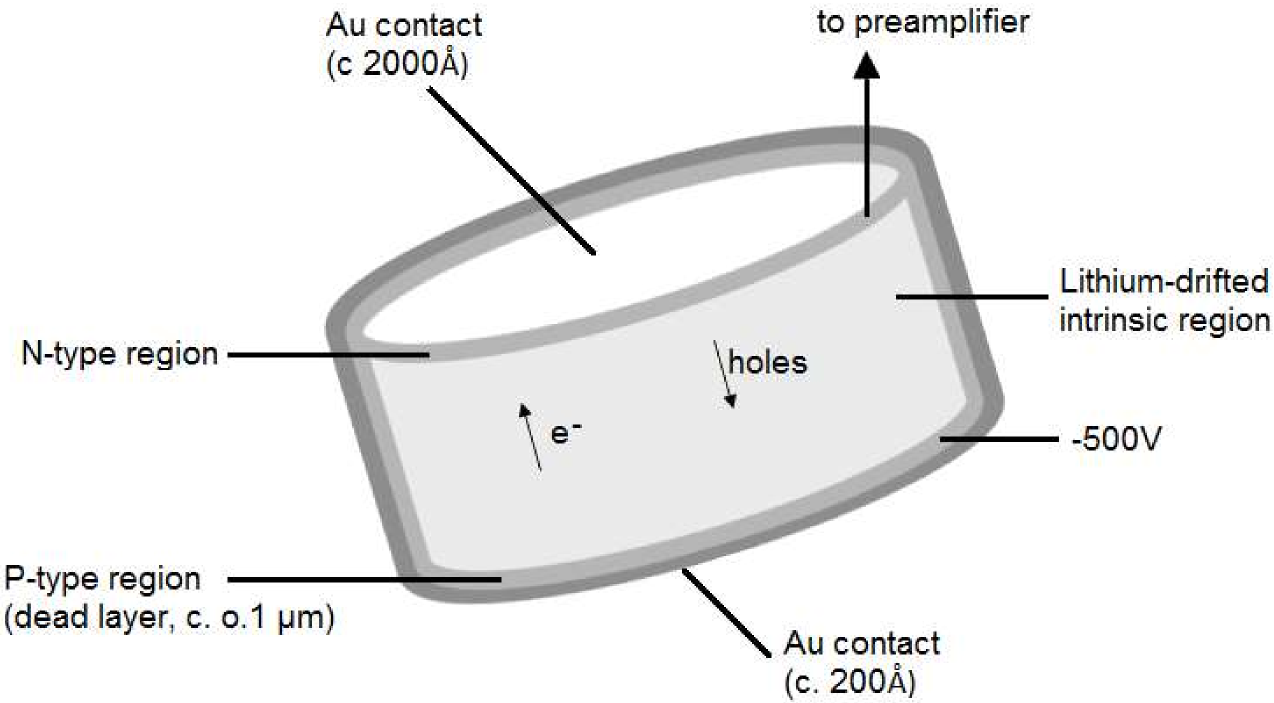
$FWHM_{Det}$ = 120 eV

$FWHM_{Elec}$ = 100 eV

=> $FWHM_{Peak}$ = 156 eV

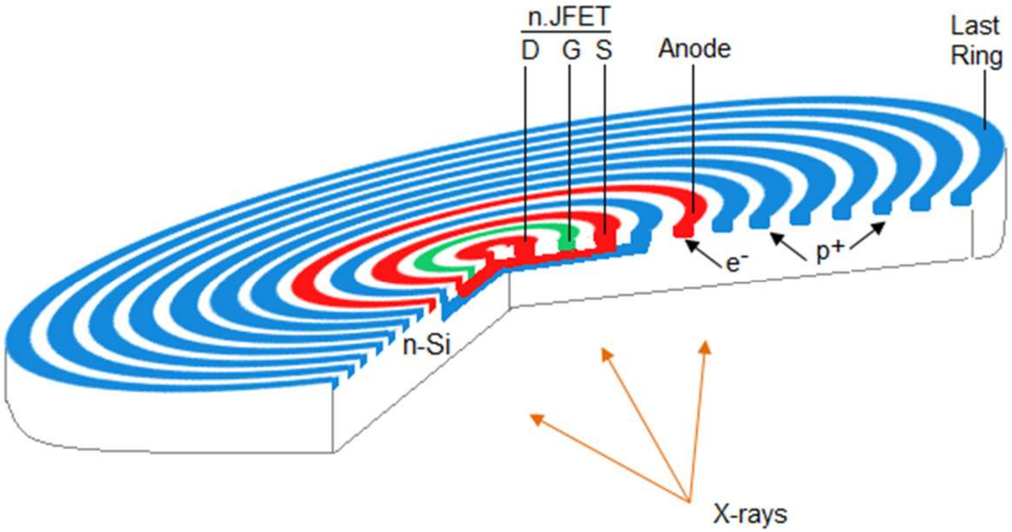
(Modified from an original lecture by Prof. P. Van Espen, AXES, University of Antwerp)

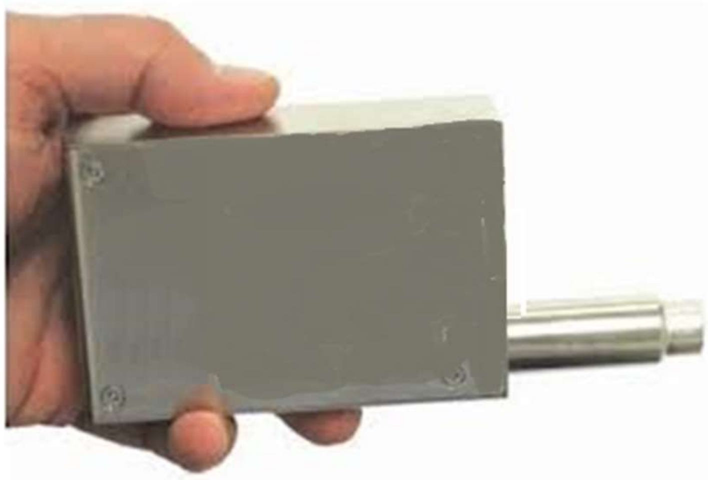
PIN



- *Energy resolution ~ 180 – 190 eV (Mn-Kα)*
- *Charge collection ~ 10 μs*
- *Input capability ~ 10^5 photons/sec*

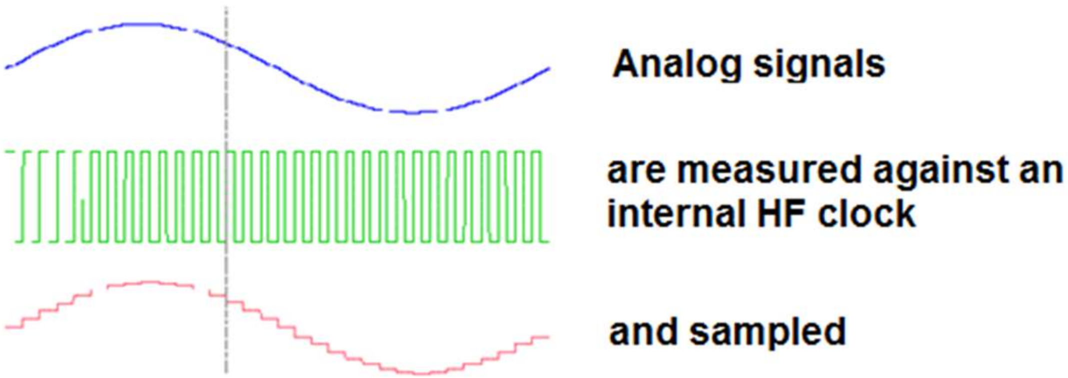
Silicon Drift (SDD)





- *Energy resolution ~ 140 – 160 eV (Mn-Kα)*
- *Charge collection ~ 1 μs*
- *Input capability ~ 10^6 photons/sec*

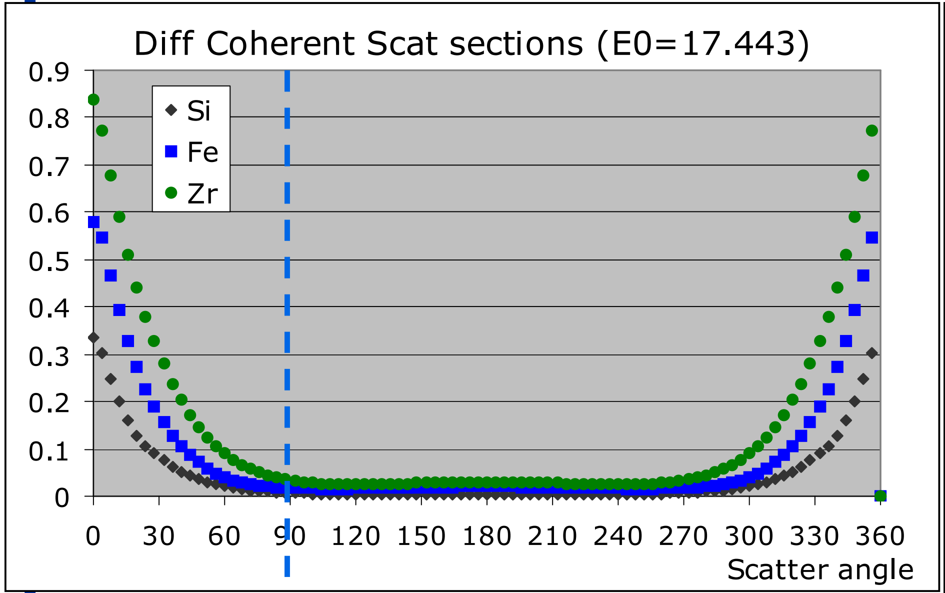
Digital signal processing (DSP)

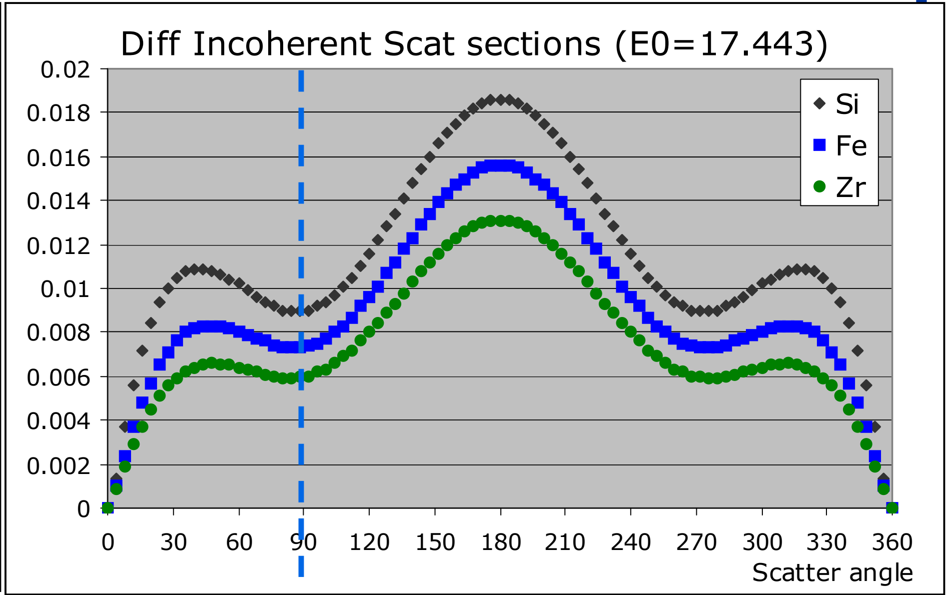


- *Total time for processing one pulse ~ 15-20 ns*

Geometry arrangement: Excitation and detection angles

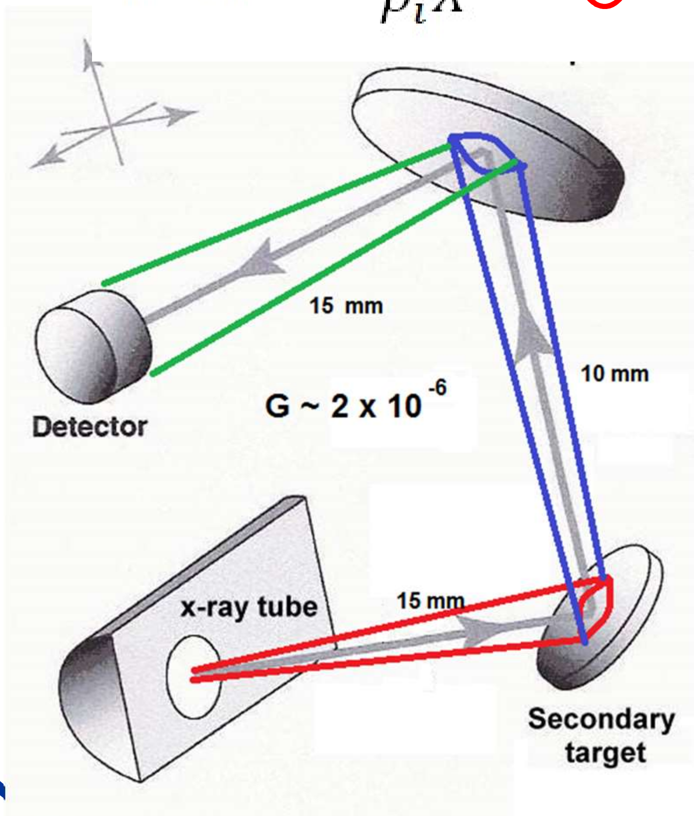
✓ Maximize the detection of x-ray emission while minimizing the detection of the primary radiation scattered at the sample

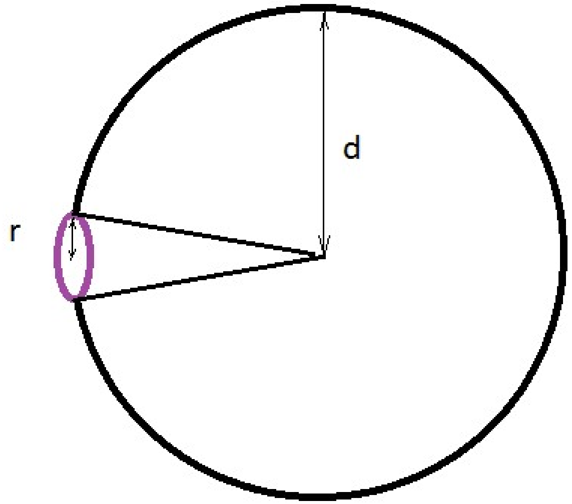




Geometry arrangement: Effective Solid angles

$$S_i(E_0) = \frac{I_D(E_i)}{\rho_i X} = G\varepsilon(E_i)K_iT_{env}(E_i)\int_{E=E_{edge}^{K}}^{E_{max}} \tau_i(E_0)I_1(E_0)dE_0$$

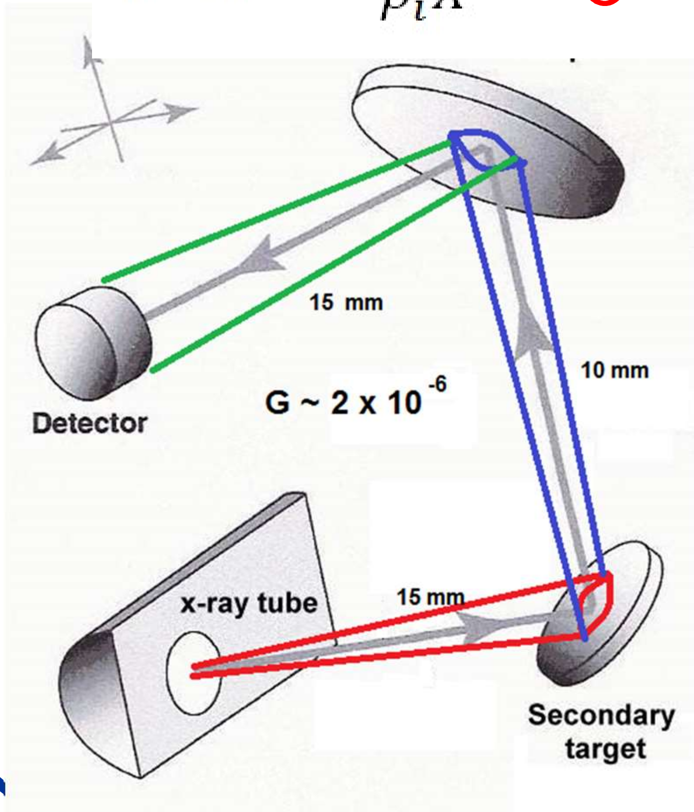


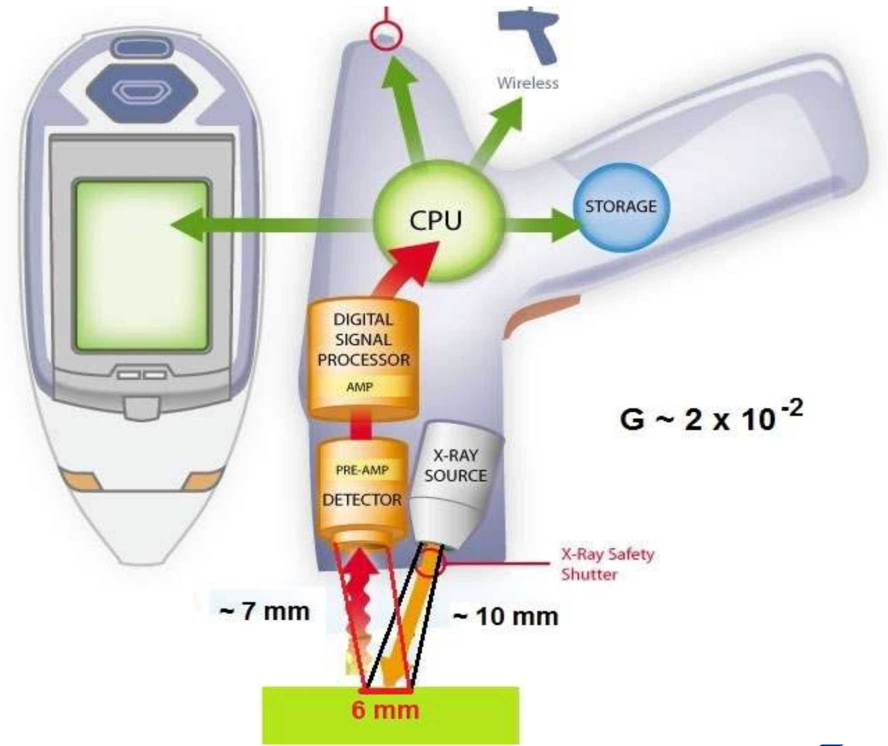


$$\Omega = 4\pi\frac{\pi r^2}{4\pi d^2}$$

Geometry arrangement: Effective Solid angles

$$S_i(E_0) = \frac{I_D(E_i)}{\rho_i X} = G\varepsilon(E_i)K_i T_{env}(E_i)\int_{E=E_{edge}^K}^{E_{max}} \tau_i(E_0)I_1(E_0)dE_0$$



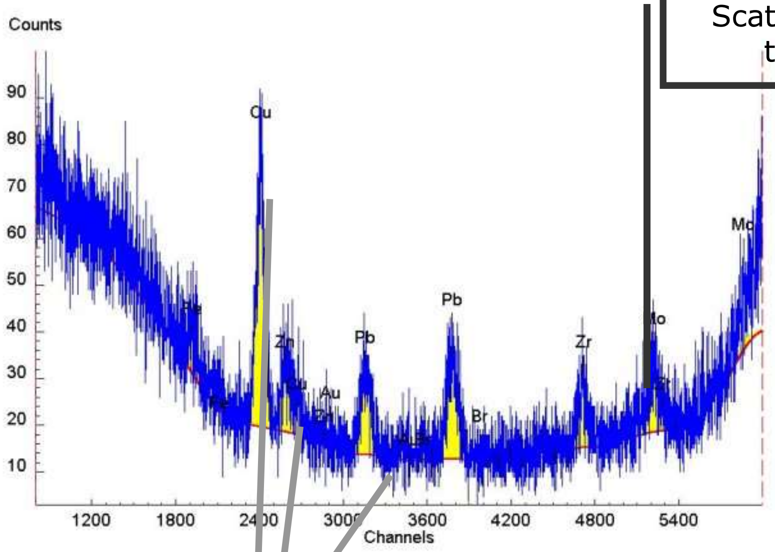


Removal of spurious peaks

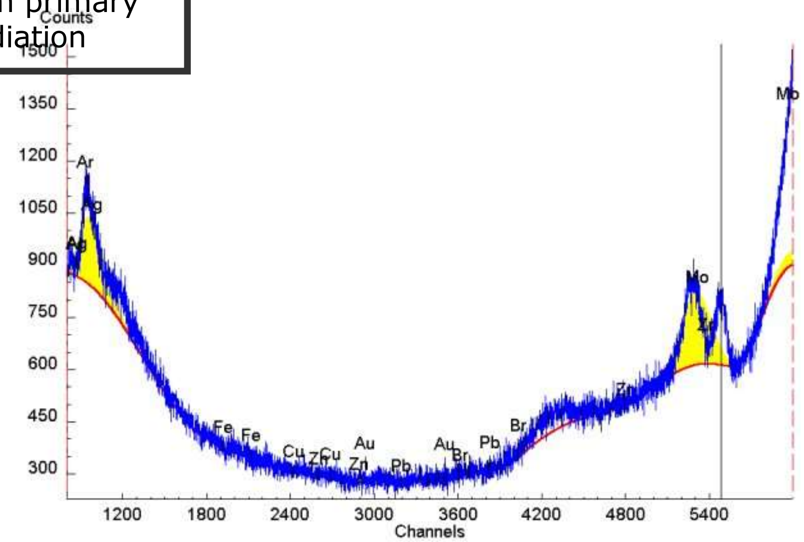
✓ **Reducing instrumental background**

ST: Ag, HV: 50 kV, DSP, Si(Li) (30 mm^2, 4 mm, 190 eV), t_{meas}= 2000 s

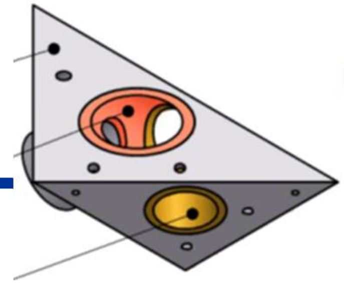
Scatter from primary tube radiation



Unshielded Duralumin ST sample holder,
No sample, I=5 mA



After Ag coating,
Sample SUPRAPUR H_3BO_3,
I= 20 mA



Concluding remarks

Design of XRF spectrometers requires of a thorough selection of options, based on

- Pursued features of analytical performance.
- Cost/benefit analysis

Thanks for your time and attention…