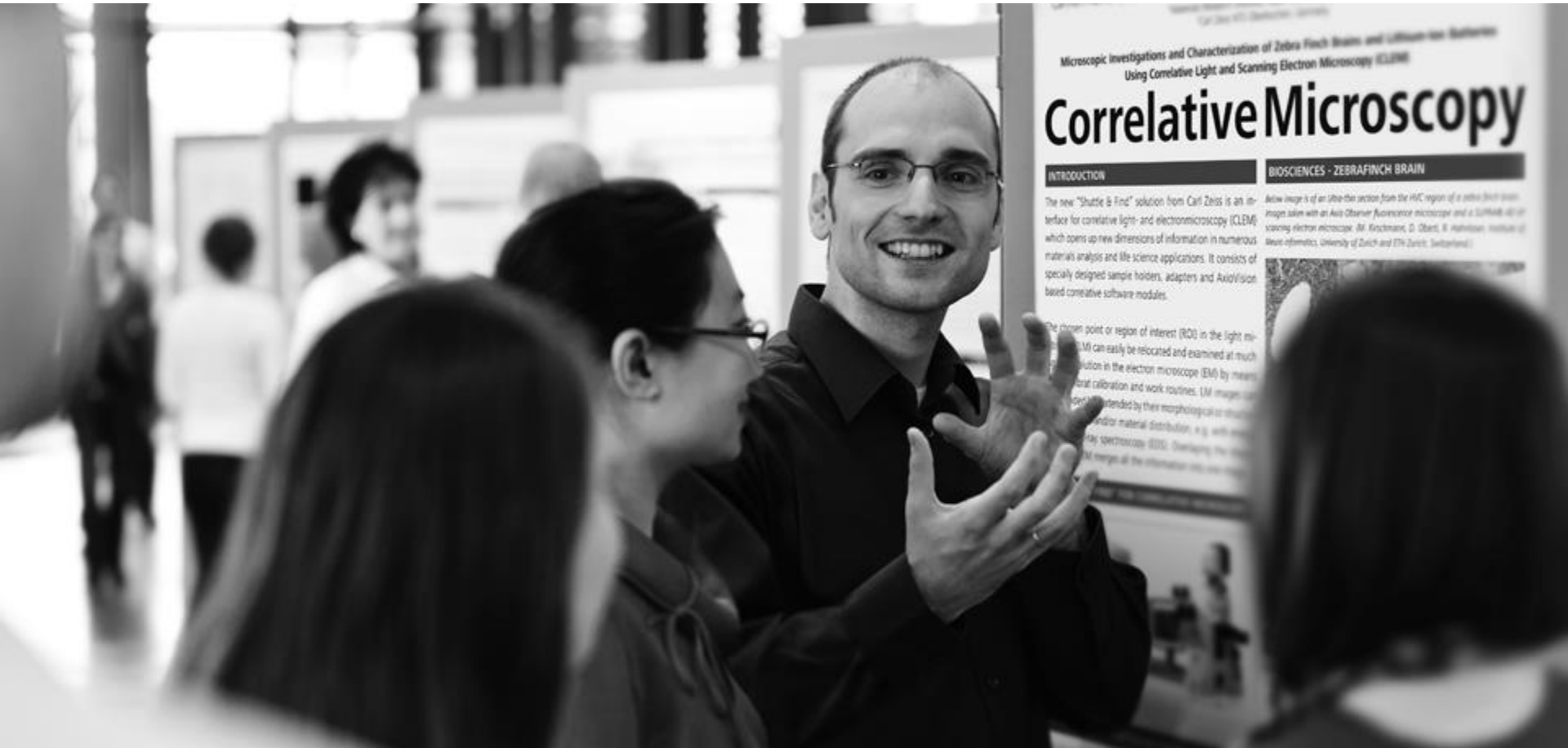


Understanding Dual Energy and DSCoVer



Carl Zeiss X-ray Microscopy, Inc.

What is Dual Energy



- Signal (contrast) from an element depends on
 - Energy - E
 - Effective atomic number - Z_{eff}
 - Density - ρ
- It is a method to understand if the contrast difference between two objects is due to
 - Same density – different material
 - Same material – different densities

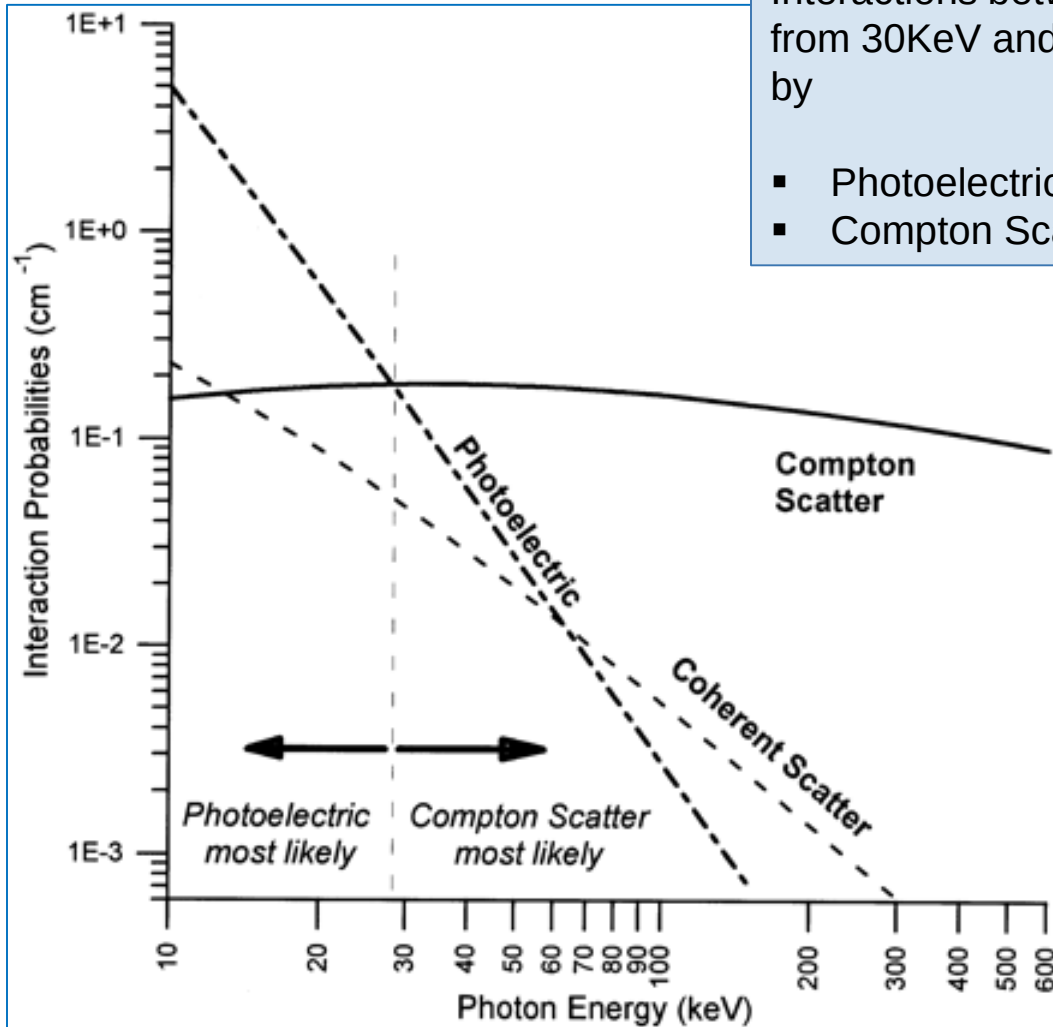
....and successfully separate them
- Samples very close in atomic number or densities (at least 8% combined difference) may be separated
- What it will help to ultimately achieve is
 - Z_{eff} – due to composition of materials mixed
 - ρ - Density of the material

X-rays Interactions

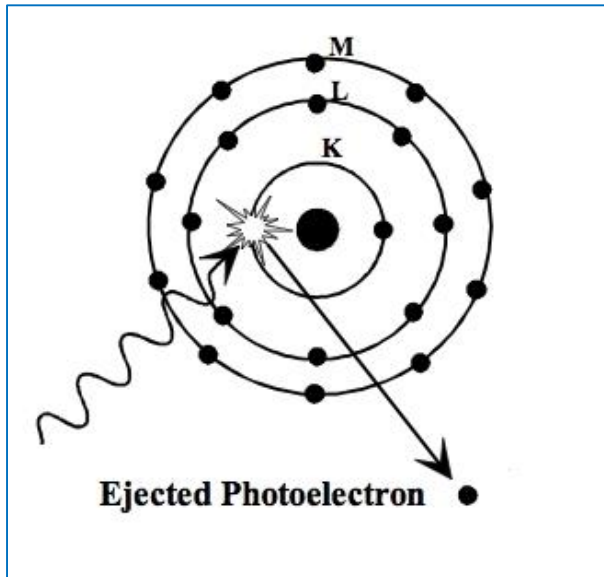


Interactions between x-rays with photon energy ranging from 30KeV and 200KeV and materials are dominated by

- Photoelectric Effect
- Compton Scattering



Photoelectric Effect



Photoelectric (PE)

Absorption of x-rays occurs when the x-ray photon is absorbed resulting in the ejection of electrons from the inner shell of the atom, resulting in the ionization of the atom.

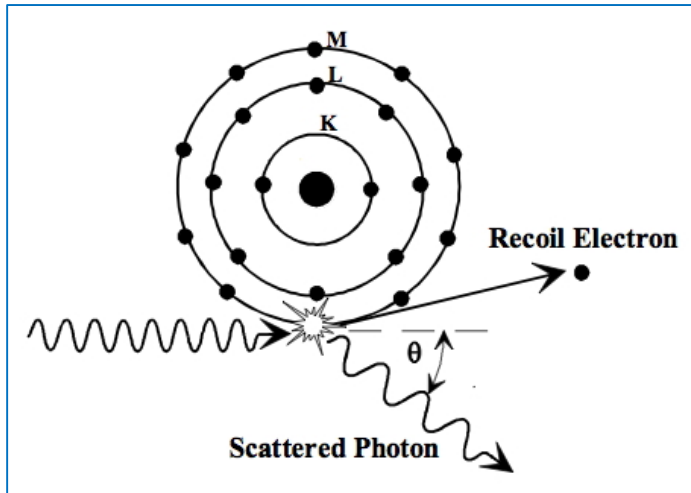
Subsequently, the ionized atom returns to the neutral state with the emission of an x-ray characteristic of the atom.

$$PE \propto \frac{\text{Atomic Number}^{3.8}}{\text{Energy}^3}$$

Bottom Line

- P.E decreases with Energy
- P.E increases with Z

Compton Scattering



Compton Scattering (CS)

occurs when the incident x-ray photon is deflected from its original path by an interaction with an electron. Here, not all of the photon energy is absorbed during the liberation of the electron. This excess energy takes on the form of a new photon having longer wavelength (less energy) than that of the original photon. In addition, the new photon moves through the material in a new path.

Bottom Line

- With increase in energy of the spectrum, Compton scattering becomes the dominant X-ray interaction
- Compton Scatter is high in low Z materials and biological materials

Bringing it all together



Attenuation has a photoelectric component and a Compton component

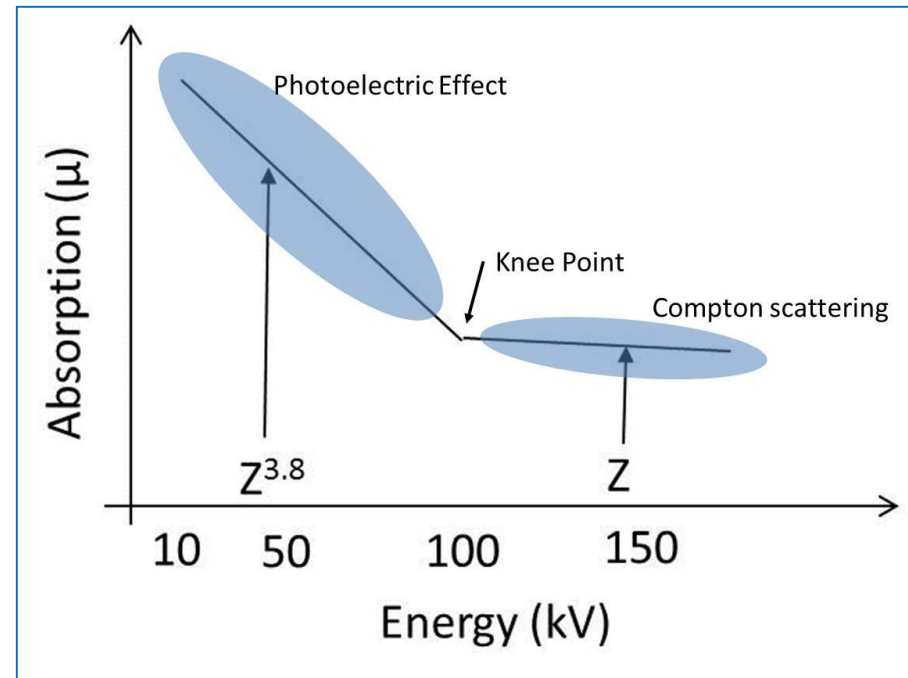
$$\mu(E) = a * \text{Photoelectric}(E) + b * \text{Compton}(E)$$

All low Z elements have an Atomic absorption cross-section that grows like
due to PE: approx. $Z^{3.8}$ (per atom)
due to CS: flat section that grows like Z

Therefore

$$\mu(E) = \rho_e Z_{\text{eff}}^{2.8} \alpha(E) + \rho_e \beta(E)$$

Unknowns : E, ρ_e (electron density) and Z



Procedure



Run scans at two energies E_1 and E_2 to solve for the 2 unknowns : ρ_e , Z_{eff}

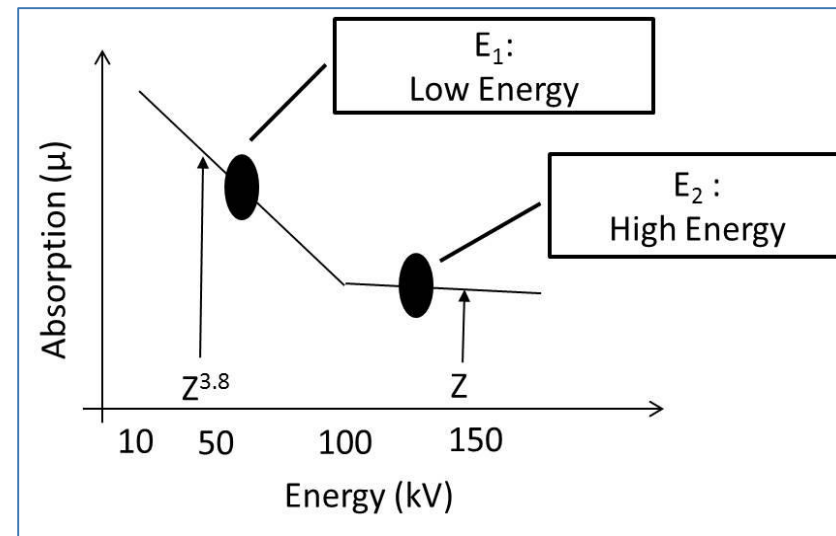
$$\mu(E_1) = \rho_e Z_{\text{eff}}^{2.8} \alpha(E_1) + \rho_e \beta(E_1)$$

$$\mu(E_2) = \rho_e Z_{\text{eff}}^{2.8} \alpha(E_2) + \rho_e \beta(E_2)$$

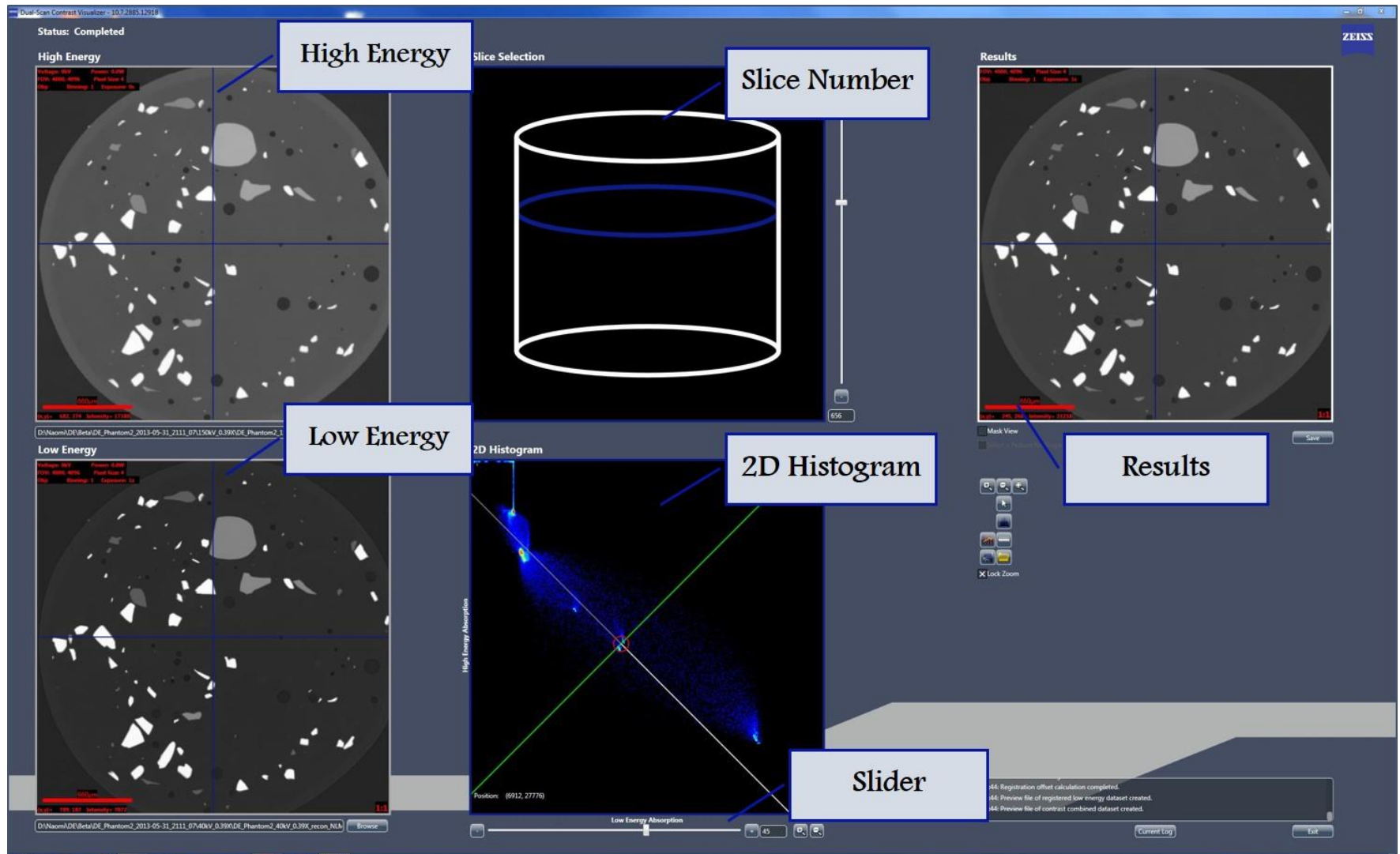
Scan I will be to maximize the Photoelectric Effect (low kV) while scan II will be used to obtain the contrast achieved due to Compton Scattering (high kV)

This includes selecting a kV and a filter combination to manipulate the spectrum

- Low energy scan (E_1): 40kV. No filter: to achieve the average kV of ~12kV
- High energy scan (E_2): 150kV, HE6: to achieve the average kV of ~ 73kV



DSCoVer – Dual Scan Contrast Visualizer



Reading the 2D Histogram



On the Images:

Pixel at location (x,y) on the images, has 2 absorption intensities

- I_1 in the LE scan
- I_2 in the HE scan

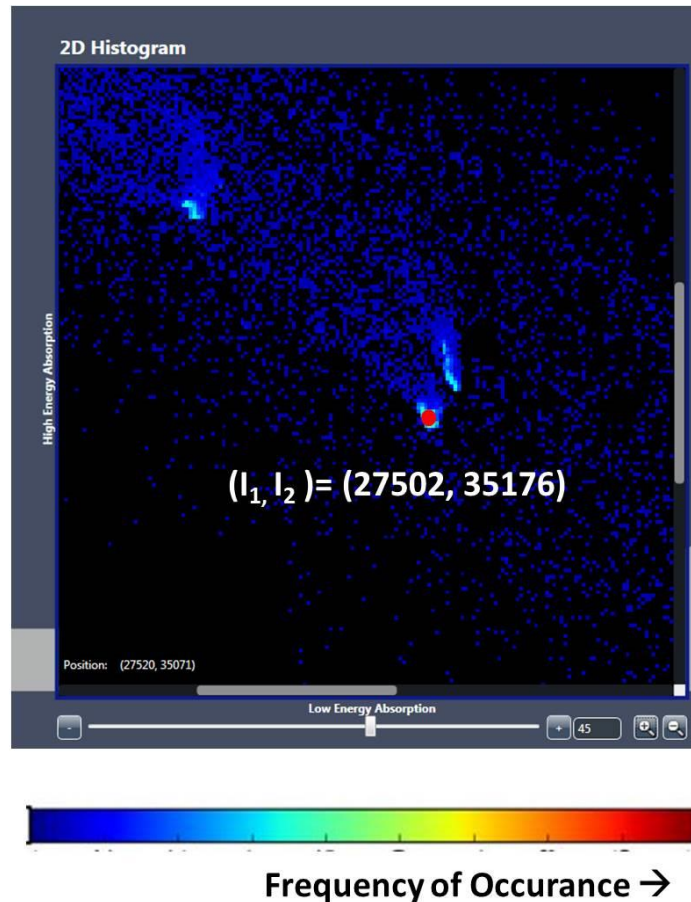
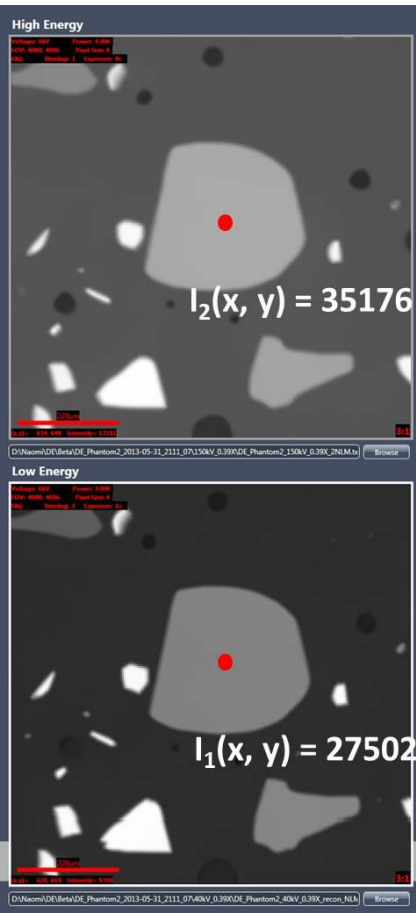
On the 2D Histogram Plot

- LE Absorption is plotted on the x-axis
- HE absorption is plotted on the y-axis

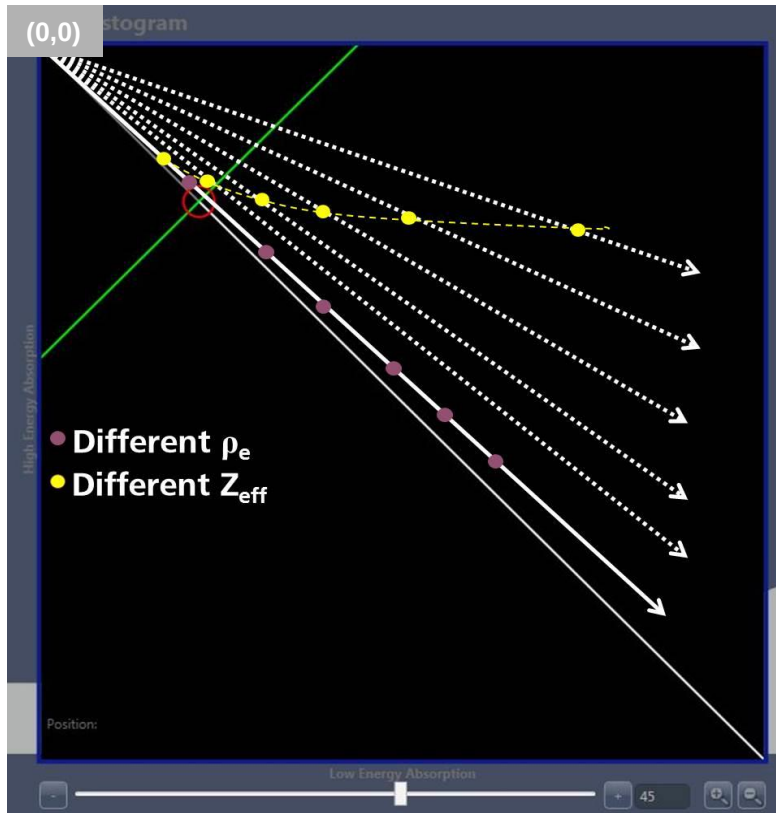
A point is plotted at location (I_1, I_2) on the 2D plot representing that pixel.



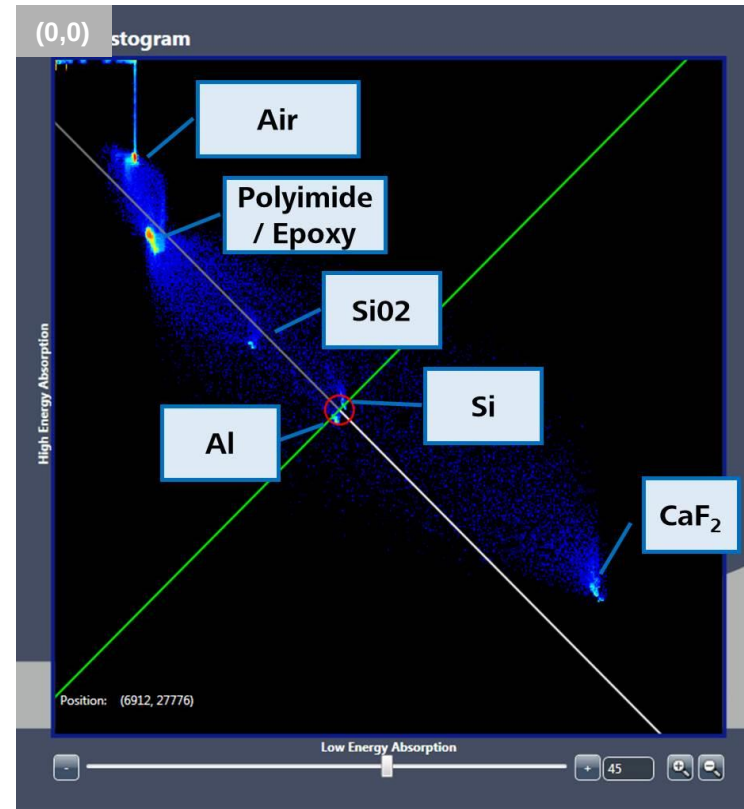
The pseudo color represents the density of these points; with the increase in the frequency shown as color change from blue to red.



Reading the 2D Histogram

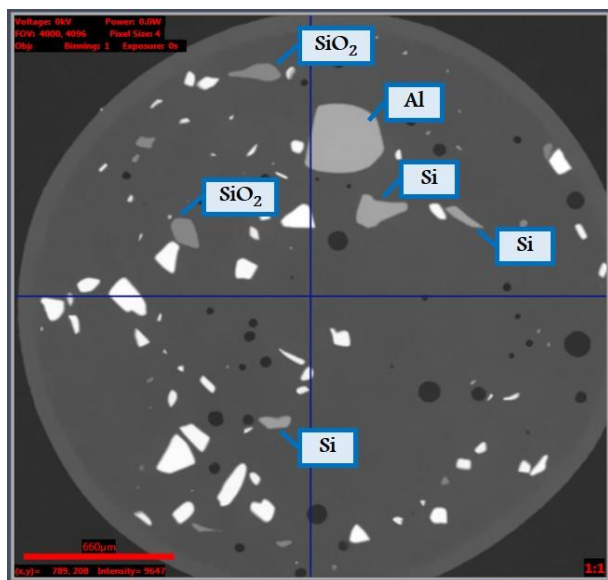


- ❑ Two “clusters” lying on the same line drawn from air, represent same materials but different densities.
- ❑ Two “clusters” separated horizontally represent materials with different Z_{eff}

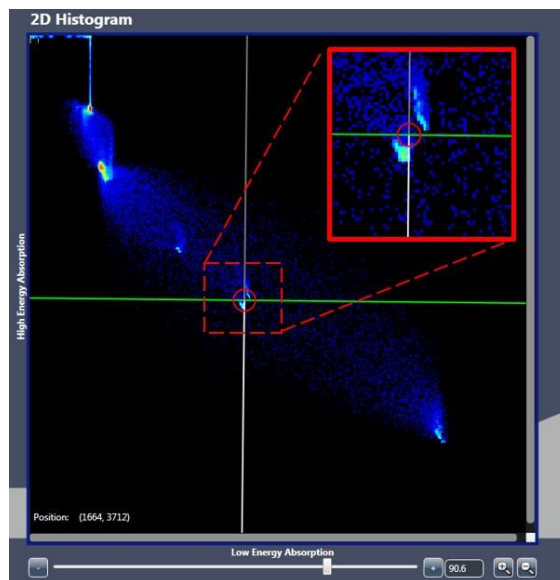


- ❑ The top-left corner is the origin (0,0). As you go towards the bottom right corner, the materials represented have higher atomic numbers and/or densities.

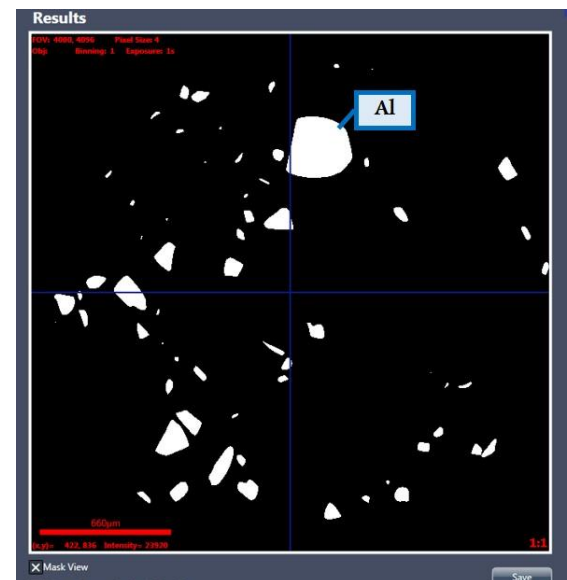
DE Example : Al – Si Separation



INPUT



2D HISTOGRAM



OUTPUT

- Work with elements up to **atomic number 20**
- Recommended **feature sizes** : ~ **50-100 μm**
- **Not** a tool for **elemental analysis** – or any quantifications yet.
 - We do not currently have the option of getting the Z_{eff} or ρ numbers.
 - The data that can be obtained by researchers is Z_{eff} and not Z
- A combined Z_{eff} and ρ change should be greater than at least 10% for us to be able to differentiate using DE.

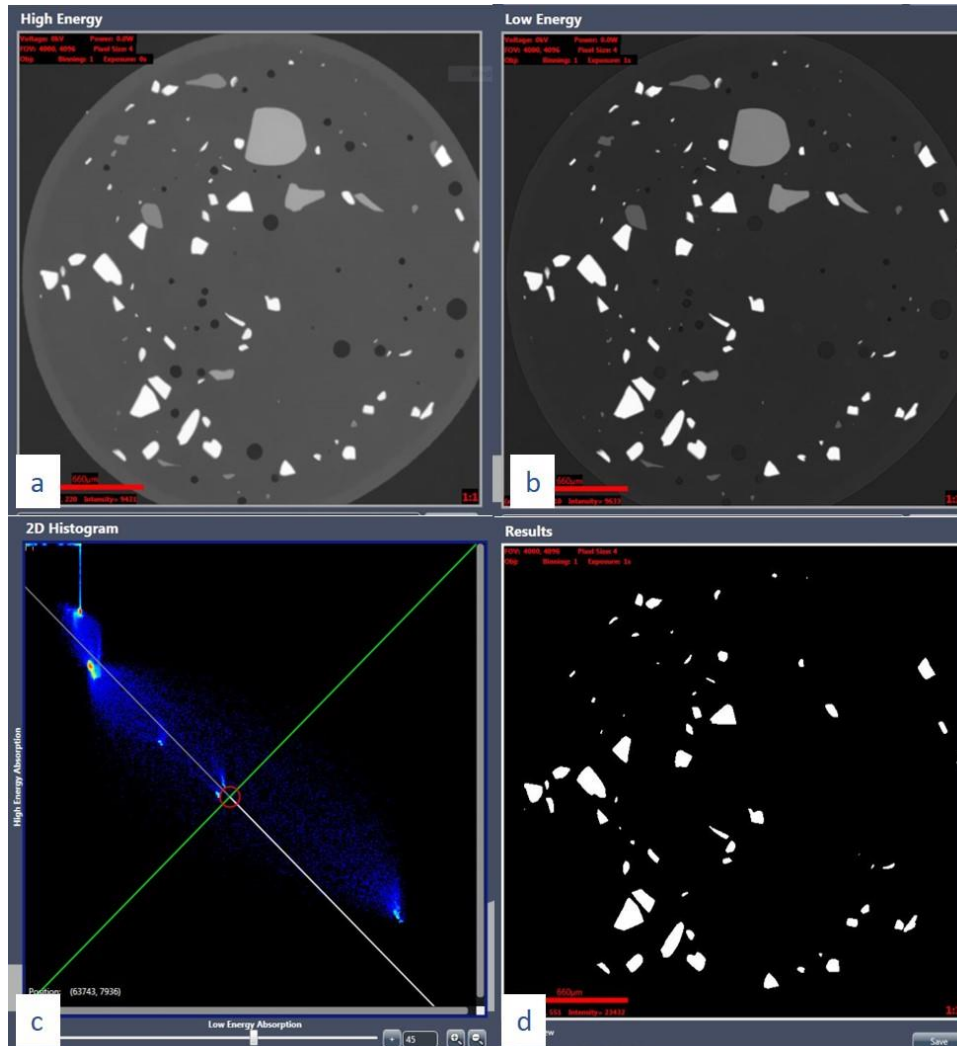
1. HE (a) and LE (b) datasets are uploaded

2. Data registration and alignment carried out by the software

Carefully selecting the “high density spots” on the 2D histogram, allow us to segment out various elements.

3. The green line divides the 2D histogram (c) in two parts.

- i. Elements in the area pointed by the “white” part of the grey-white line are kept in the segmented image
- ii. The elements in the region pointed by the “grey” part of the line are segmented out



The region pointed by the white line is binarized and shown in the results panel (d).

The brighter objects in high and low energy scans (a) and (b) are the ones shown in (d)

Objects that fall on same white line drawn from the (0,0) mark or air, vary by density

Objects that fall on different white lines drawn from the (0,0) mark or air, are chemically different

4. The segmented dataset can be then output as a .txm. for visualization.