Detector Response

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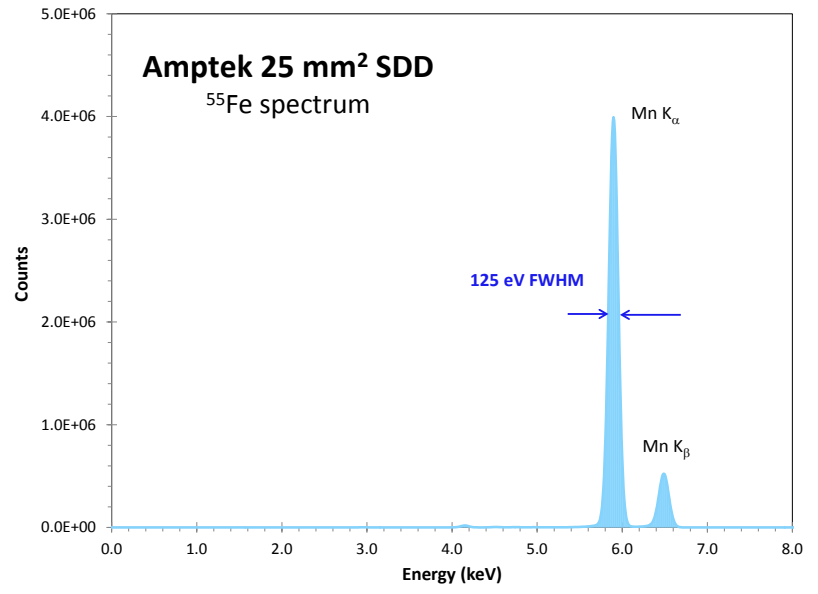
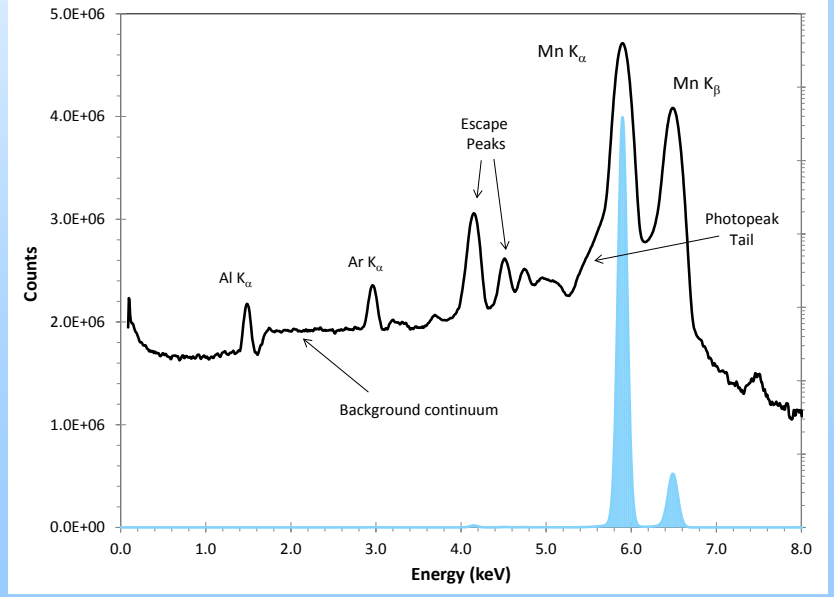
Detector response function

- Linear plot (left) shows main photopeaks
- Log plot (right) shows many additional features
  - Some (e.g. escape peaks, some continuum) due to physics
  - Some (e.g. Al and Ar K_α lines, tail) from detector or setup
  - Details very important for trace analysis





Photopeak

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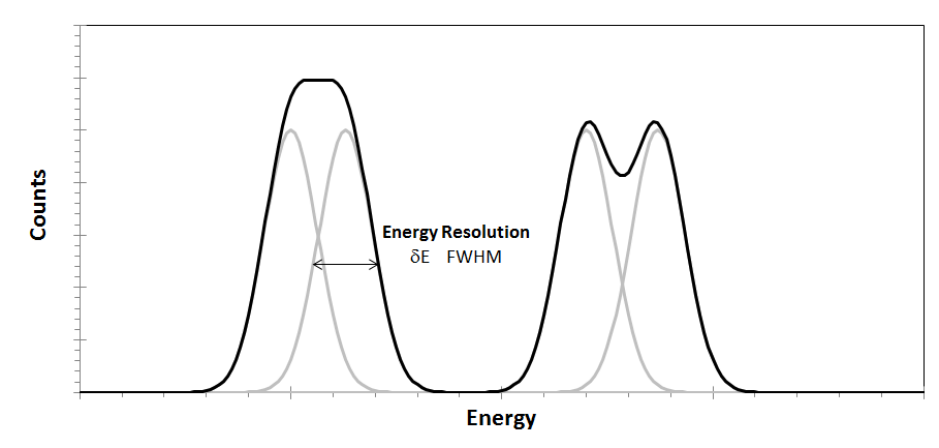
What is the "resolution"?

- Resolution defined as the full-width at half maximum (FWHM) of a peak
- If two peaks are separated by more than FWHM, there is a valley between them and we say they are resolved.



What is the peak shape?

- Theoretical limits give a Gaussian (FWHM=2.35 σ)
  - Real detectors always deviate at least a little

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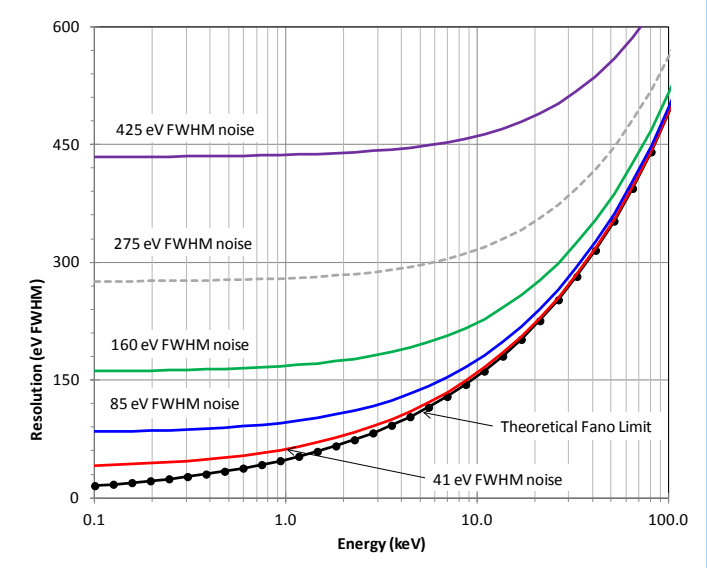
What contributes to photopeak shape & FWHM?

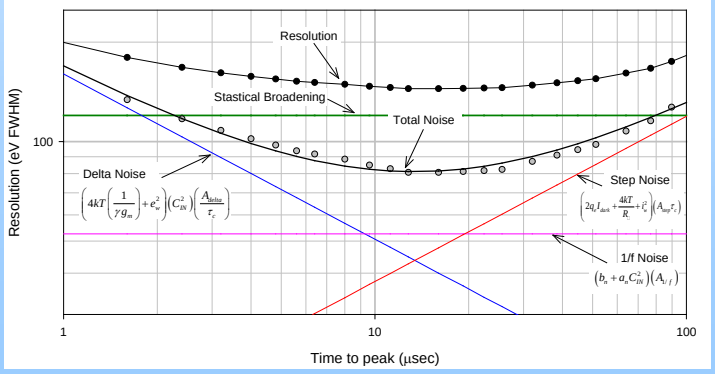
- Statistical fluctuation in charge
  - Depends only on the energy
  - A theoretical limit and cannot be avoided
  - Truly Gaussian

- Intrinsic electronic noise
  - Independent of energy
  - Depends on detector, temperature, T_{peak}
  - Can be minimized but not eliminated
  - Truly Gaussian

$$\delta E = \sqrt{F \square E + ENC^2}$$

$$ENC^2 = C_{IN}\left(\frac{A_1}{T_{peak}}\right) + N_{1/f} + \sqrt{I_{leak}}\left(A_2 T_{peak}\right)$$





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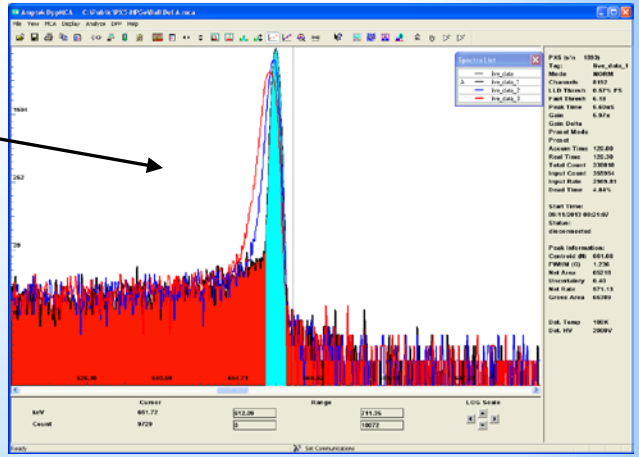
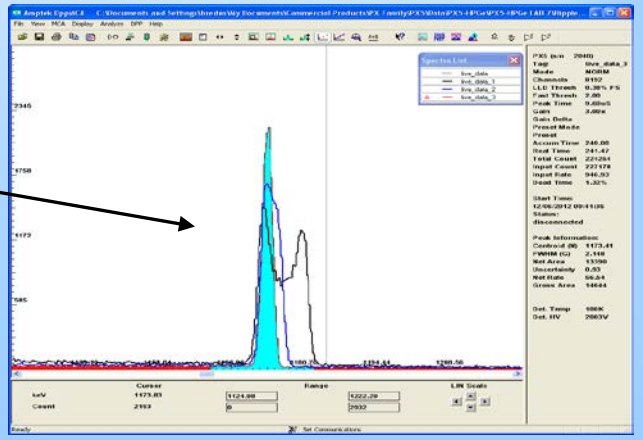
What else contributes to photopeak shape & FWHM?

- Charge trapping
  - Gives a tail to lower energies
  - Always present, sometimes important
  - Can be low energy, high energy, etc
- Ballistic deficit
  - Gives a tail to lower energies
  - Occurs when $T_{flat} < T_{collection}$
- Interference noise
  - Photopeak shape can be surprising
  - From ground loops, EMI, microphonics
  - Can be eliminated
- Other physical effects
  - There other effects which may broaden a peak





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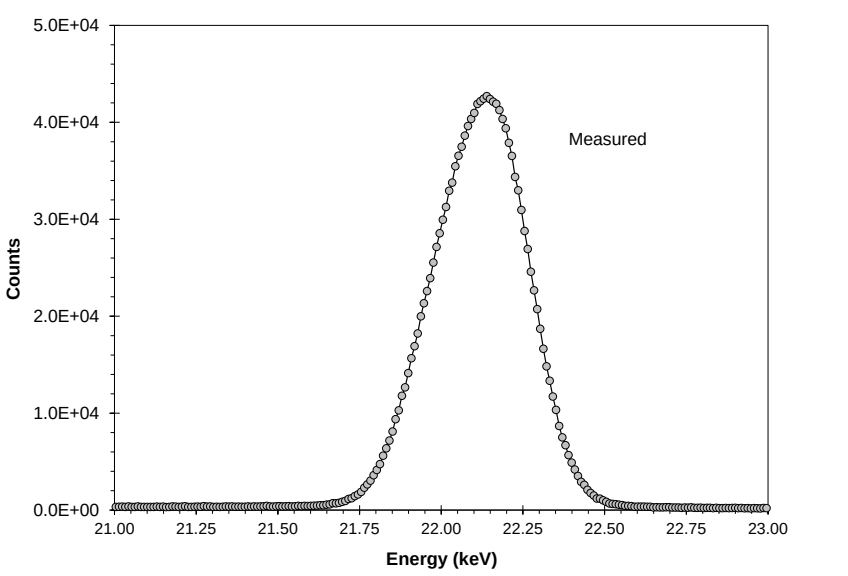
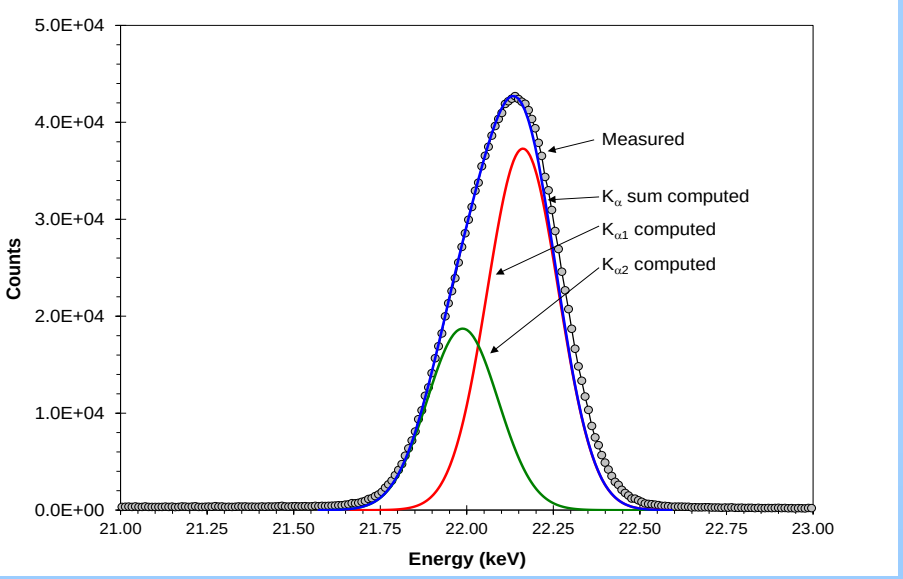
What else contributes to photopeak shape & FWHM?

- Peak splitting
  - Not really part of the detector response but affects what you see
  - What we call a "single peak", e.g. K_α line, really has multiple lines ($K_{\alpha 1}$ and $K_{\alpha 2}$)
  - When the detector resolution is good enough, this splitting affect peak shape
  - Example below shows Ag K_α line. Detector response is 250 eV FWHM but line splitting leads to a 310 eV wide, non-Gaussian peak





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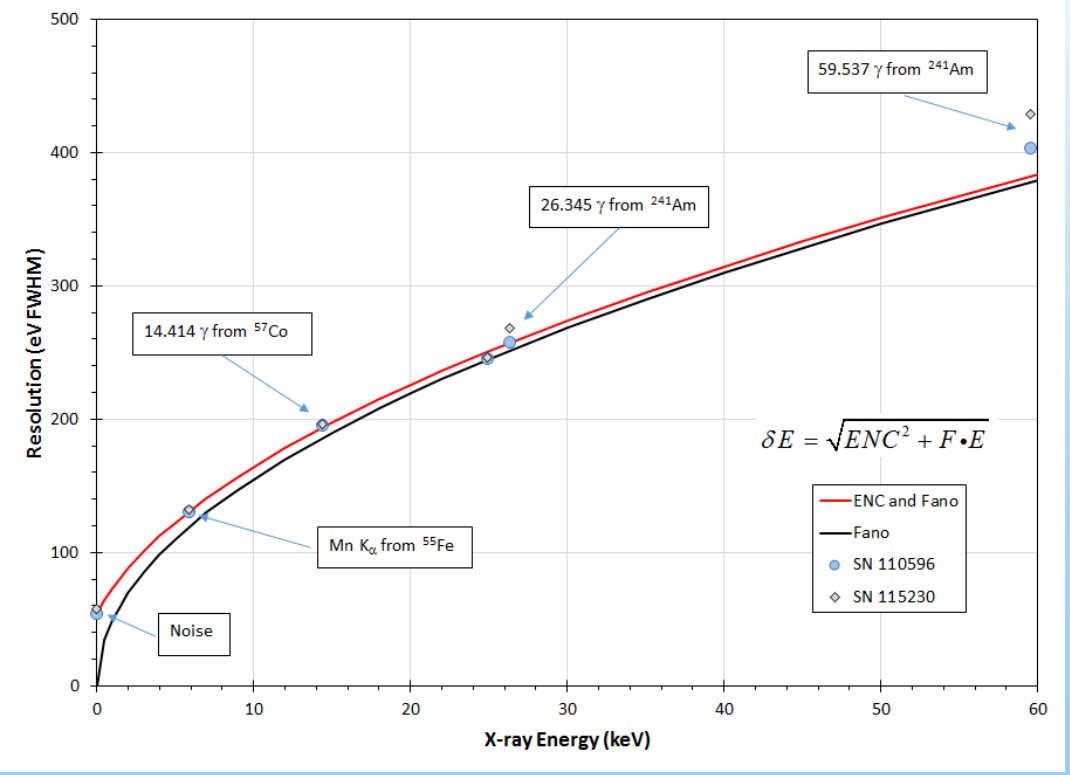
How close is the FWHM to the theory?

- Plot below shows theoretical Fano limit (black) and combination expected from noise and Fano (red). Data points are very close
- Used monoenergetic gamma sources to avoid peak splitting



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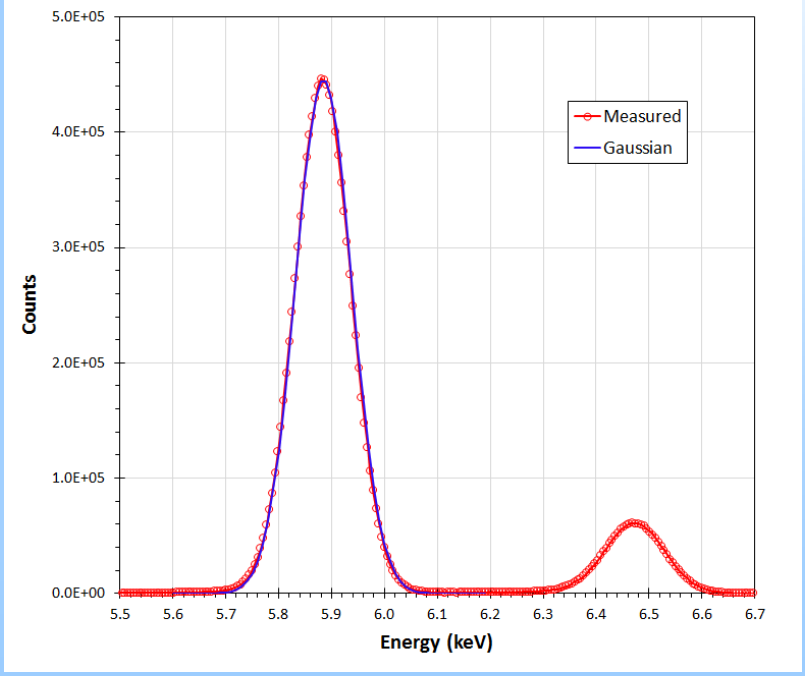
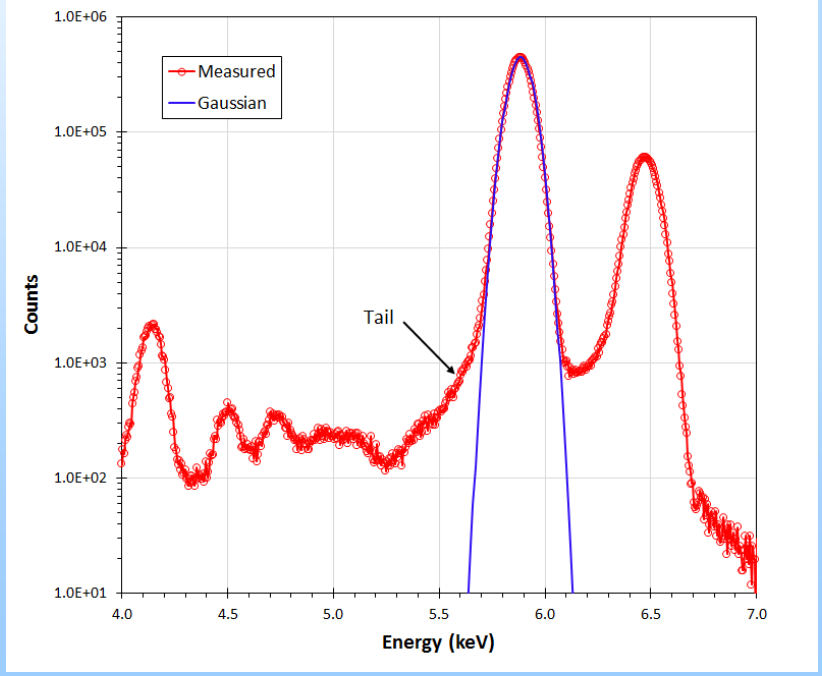
How close is the peak shape to Gaussian?

- Plot below shows theoretical Gaussian (blue) and a measured ^{55}Fe spectrum (red dots)
- Deviation occurs at 0.2% of the peak





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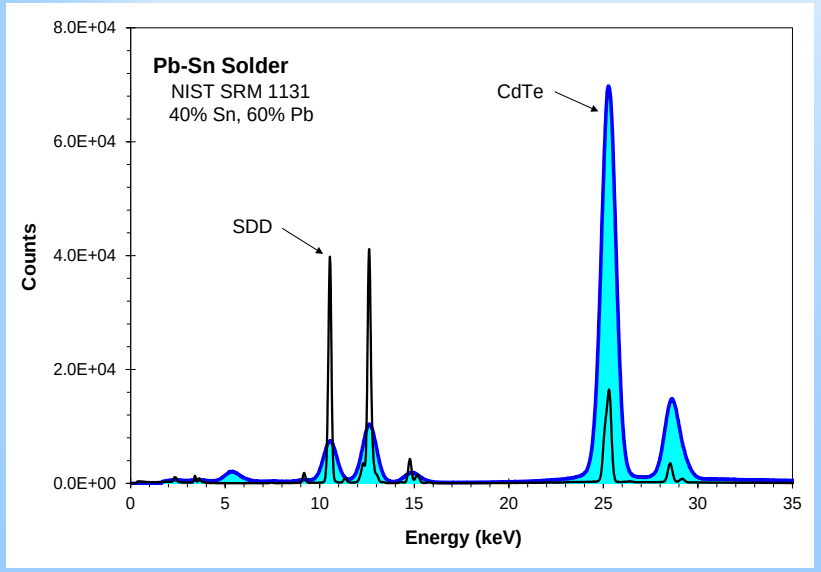
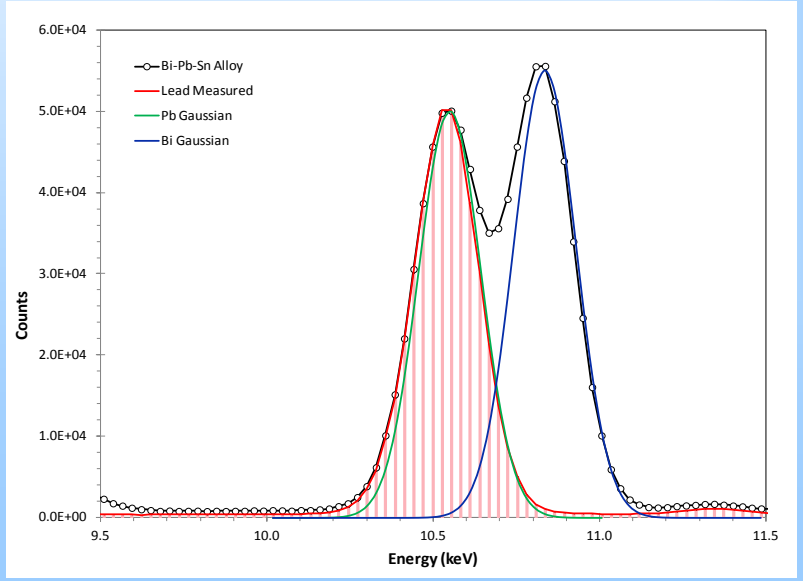
How important is the photopeak width and shape?

- In some applications, e.g. left below, with no overlapping peaks and little background, not important at all. One can set an ROI and simply count the X-rays.
- In some applications, e.g. right below, it is VITAL. When peaks overlap, the tail of a large peak affects ability to measure adjacent weak peak.
- Deviations from the ideal shape drive the detection limit.





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Background

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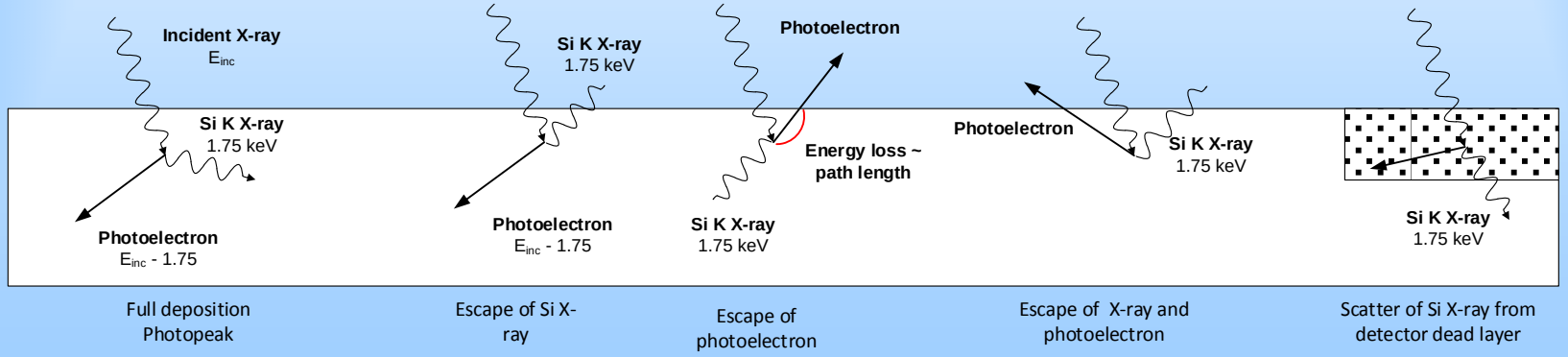
What causes the background (1)?

- Background includes both continuum and peaks
- X-rays scatter out of the detector active volume
  - This cannot be eliminated: due to physics of X-ray interactions
  - Continuum from escape of secondary electrons
  - Escape peaks from escape of silicon X-rays



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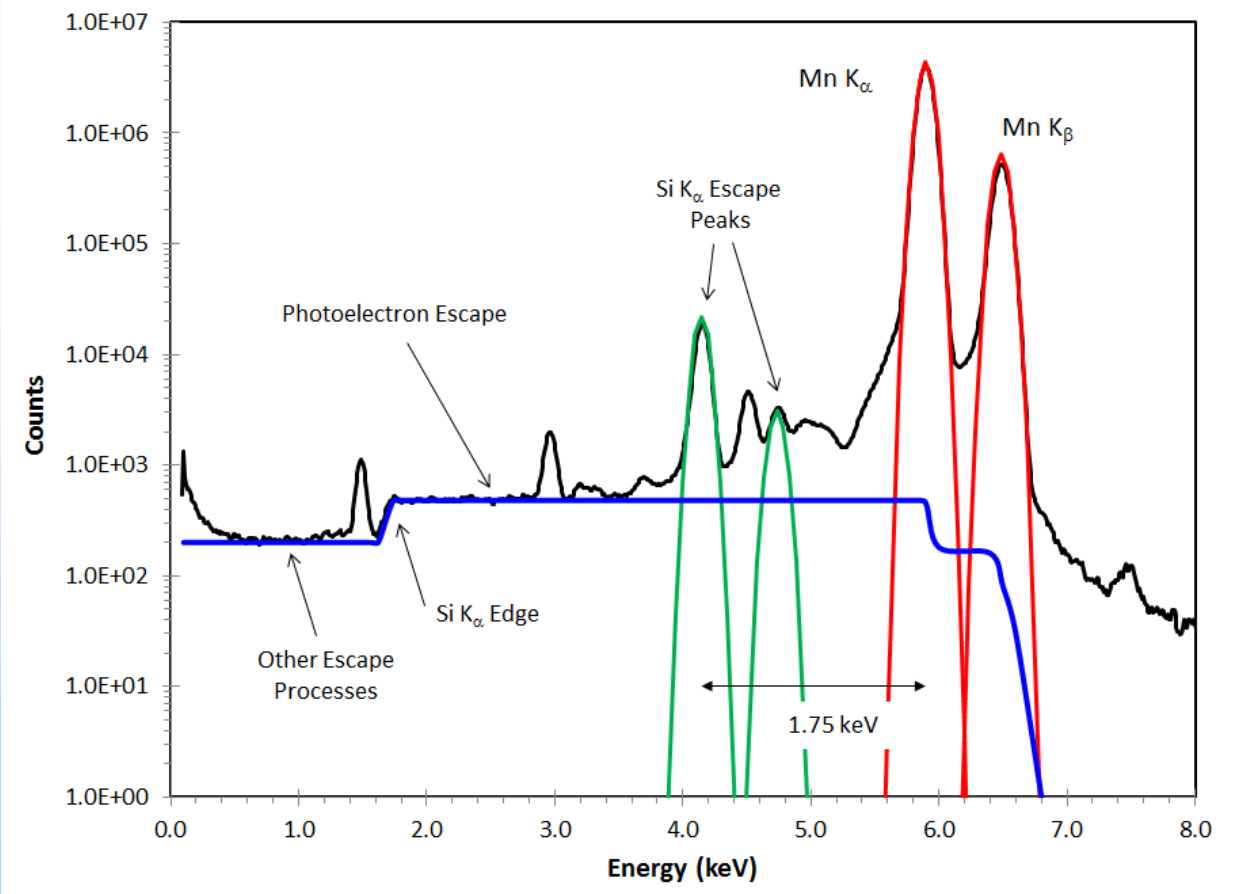

Features in spectrum arising from physics of X-ray interaction causing X-rays or secondary electrons to scatter from the detector

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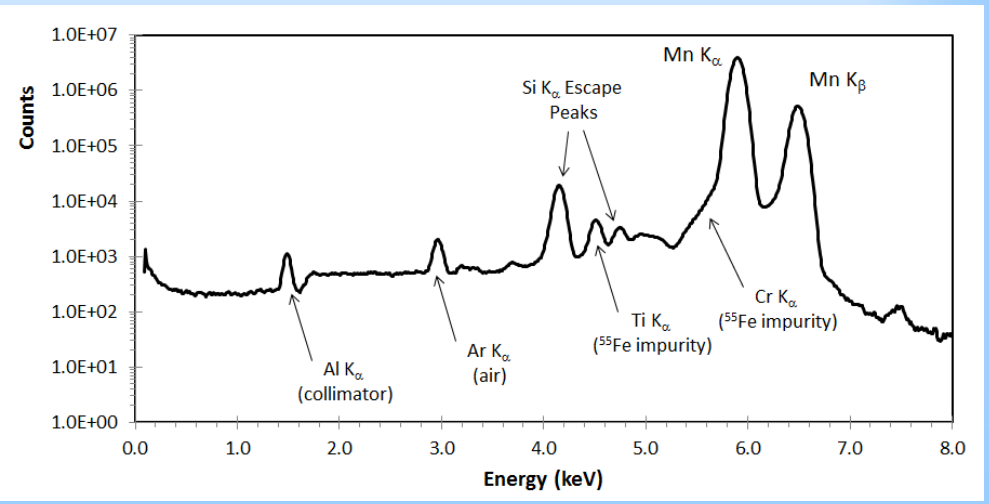
What causes the background (2)?

- X-ray scattering from detector dead layers
  - Can be minimized with good design but never eliminated
  - Also leads to continuum and peaks
- X-ray scattering from material around the detector
  - Detector is always surrounded by stuff: housing, mount, wire bonds, capacitors, collimators, shutters, etc. These materials produce characteristic X-rays
  - Minimized with good design but cannot be eliminated

Features in spectrum due to characteristic X-ray from material near spectrometer (includes impurities in the radioactive ^{55}Fe)



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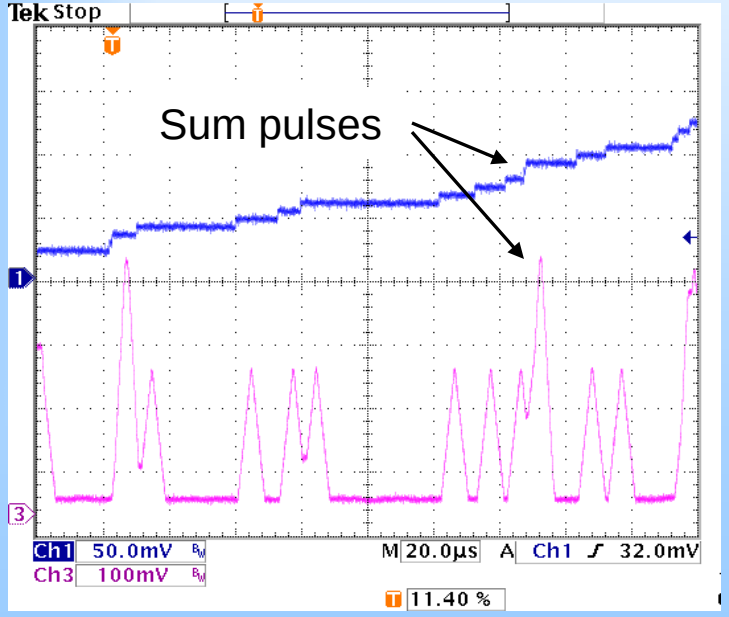
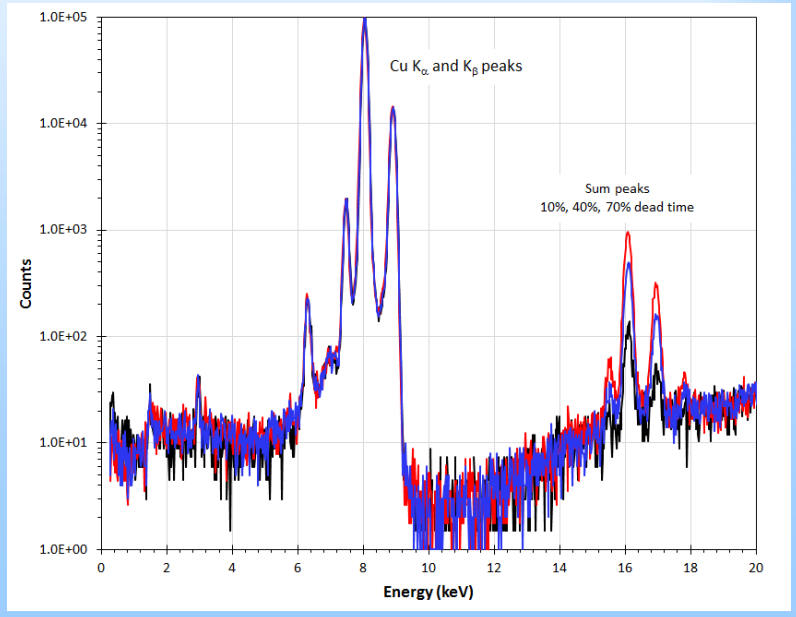
What causes the background (3)?

- Pulse pile-up
  - Occurs when two or more X-rays interact within pulse pair resolving time
  - "Sum peak" at sum of the X-ray energies. Intensity increases with count rate
  - Minimized at low count rate or short T_{peak}





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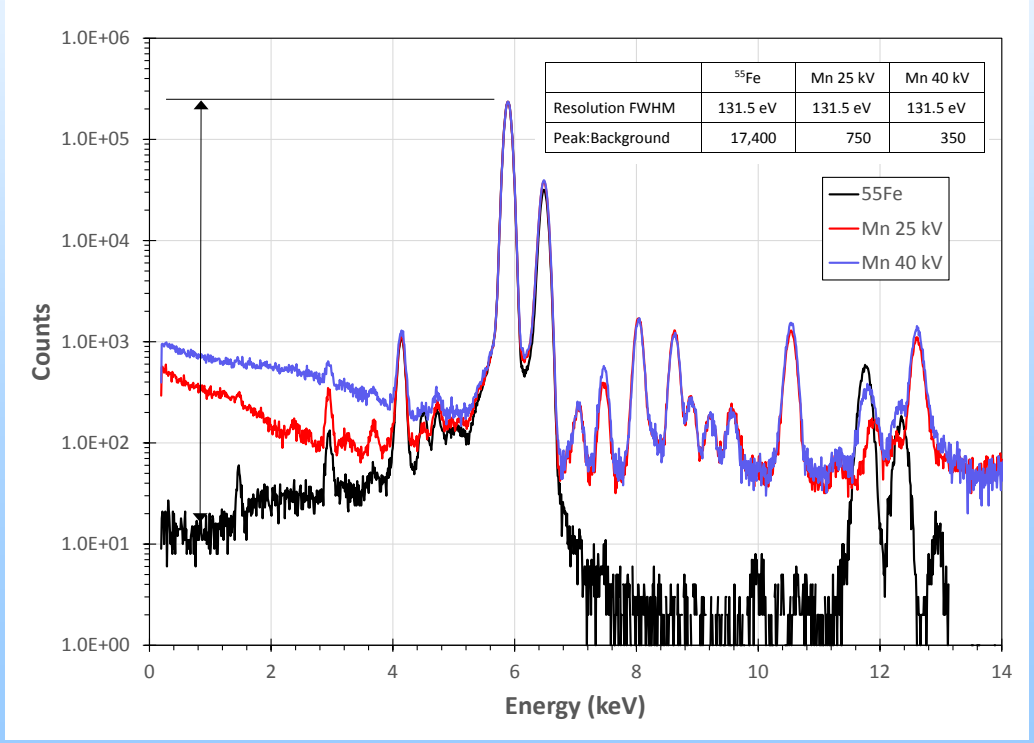
What causes the background (4)?

- Background in the spectrum
  - Not really part of detector response but affects what you see
  - Plot below shows Mn spectrum from ^{55}Fe decay and X-ray excitation of Mn target
  - Same FWHM but X-ray tube produces much more background



	^{55}Fe	Mn 25 kV	Mn 40 kV
Resolution FWHM	131.5 eV	131.5 eV	131.5 eV
Peak:Background	17,400	750	350

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How important is the background?

- In some applications, where the peak intensity is strong, not important at all. One can set an ROI and apply a simple background correction
- In some applications, it is VITAL. When trying to measure small amounts, near detection limit, background features are huge.
- Plot below shows 0.5ppm Cd in a sample. Background is key