PERFORMANCE COMPARISON

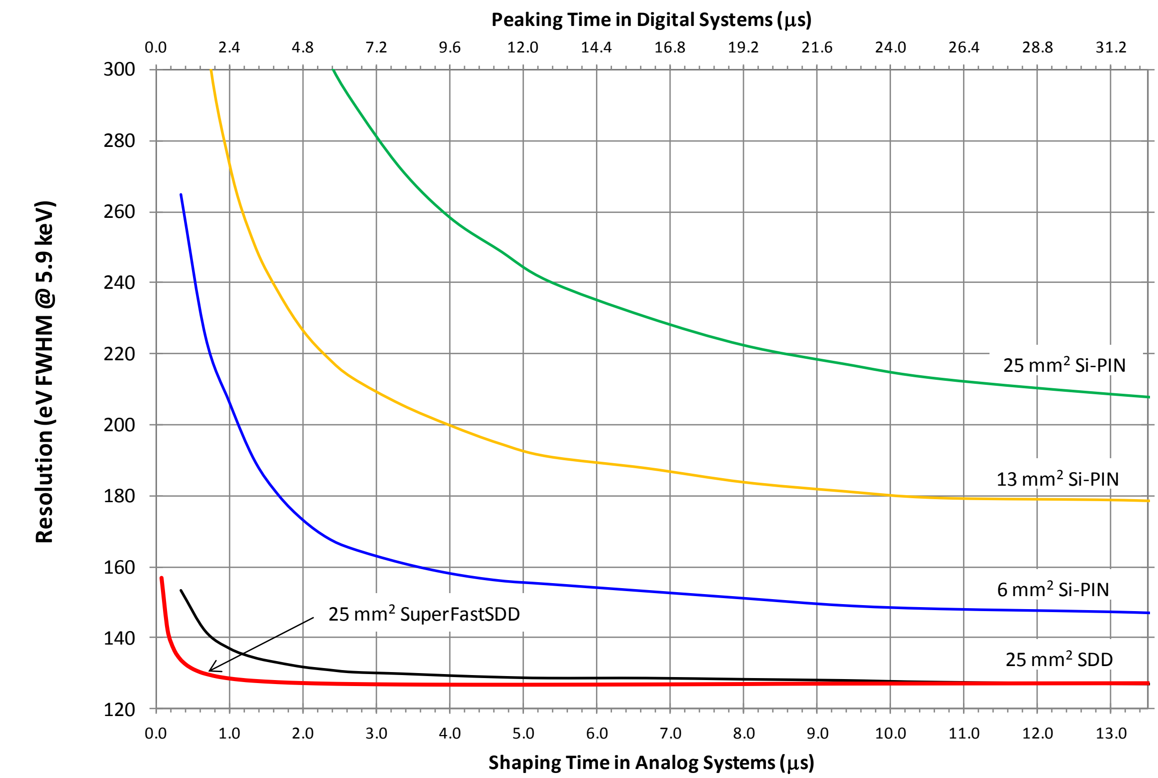
This document has charts which compare typical performance for Amptek's detectors.

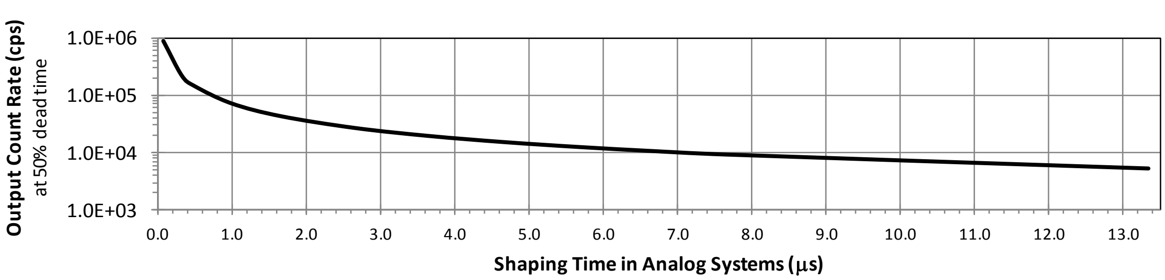
Energy Resolution and Count Rate

Two very important parameters are the energy resolution and the count rate. The ideal detector would have Fano limited energy resolution at extremely high count rates. In real detectors, to operate at a high count rate, the signal processor must have a very short peaking time, and this degrades energy resolution.

The plots below illustrate this trade-off for Amptek's SDD and Si-PIN detectors. The top plot shows the energy resolution, measured at the 5.9 keV Mn K_α line, as a function of the signal processor's shaping time (note that the equivalent peaking time for a digital processor is also shown). The lower plot shows the output rate one can achieve at 50% dead time as a function of the shaping time. There are two key points:

- For any given detector, one can optimize for the highest resolution or for the highest count rate by selecting an appropriate peaking time (set in software with Amptek's processors).
- It is the high count rate performance which distinguishes the SDD from the Si-PIN.





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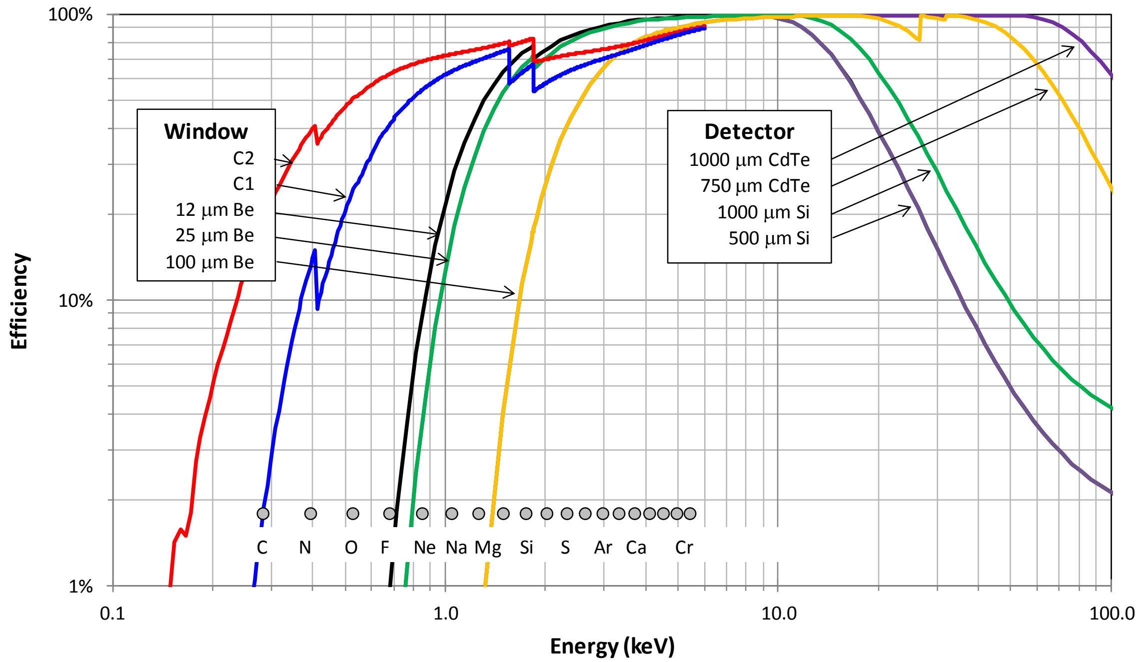
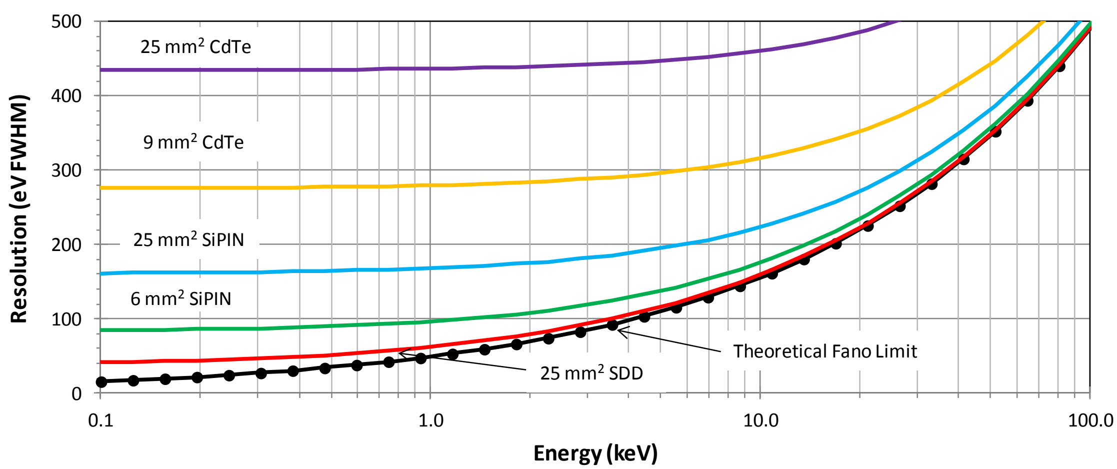
Energy resolution, efficiency, and X-ray energy

The optimum detector and configuration depends on the energy range of the X-rays to be measured. The plots below show two key parameters which vary with X-ray energy: the efficiency (top) and the energy resolution (bottom). .





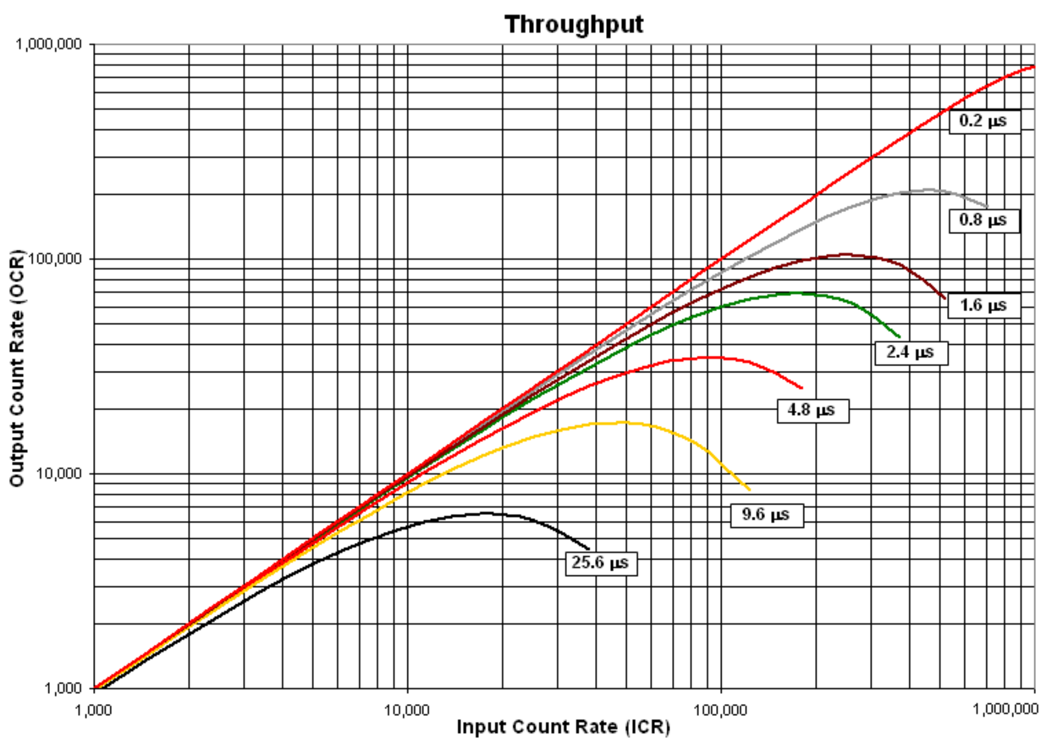
- Between about 2 and 20 keV, an SDD or a SiPIN with an 8 or 12 µm Be window is a very good choice. The efficiency is high over this full range. For both the 25 mm^2 SDD and the 6 mm^2 SiPIN, the energy resolution is very close to the theoretical Fano limit.
- Below 2 keV, the SDD with a C1 or C2 window is recommended. As the top plot shows, the Be window affects the efficiency significantly below 2 keV; the new C series windows provide much better efficiency. The C2 window, with a good response down to the 283 eV C K_α line, is not light tight – it is intended for vacuum systems. As the bottom plot shows, the resolution difference between SiPIN and SDD becomes significant below 2 keV – and this is the region with the most overlapping characteristic X-ray lines, so resolution is very important.

- Above 20 keV or 30 keV, the CdTe detectors are recommended. The efficiency of a 500 μm Si detectors falls rather quickly above 20 keV but the efficiency of CdTe detectors is high to the highest K lines. The resolution of a CdTe detector is worse than that of a Si detector, but above 30 keV or so the Fano limit dominates both and the X-ray lines are widely spaced.

The limits on these ranges, 2 and 20 keV, are approximate. The exact boundary depends on the details of your application: if you are trying to measure the Ag K_α X-rays, at 25.2 keV, the efficiency may be more important if you have a simple sample (few overlapping lines) or the resolution more important if you have a complicated sample (many overlapping lines). The user must understand the application but keep these ranges in mind. Note that the resolution data in the bottom plot are for a typical detector operated at low count rates, where the resolution is best.

Throughput and Count Rate

The chart below illustrates the throughput of Amptek's X-ray spectrometers. Note that this chart applies to all the detectors; the throughput depends on the peaking time in the signal processor, independent of the detector and preamplifier (up to some limit). There is a maximum count rate limit, which may depend on detector. The energy resolution at any given peaking time does depend on the detector, as noted above, so the resolution vs throughput curve depends on the detector also.



Maximum count rates

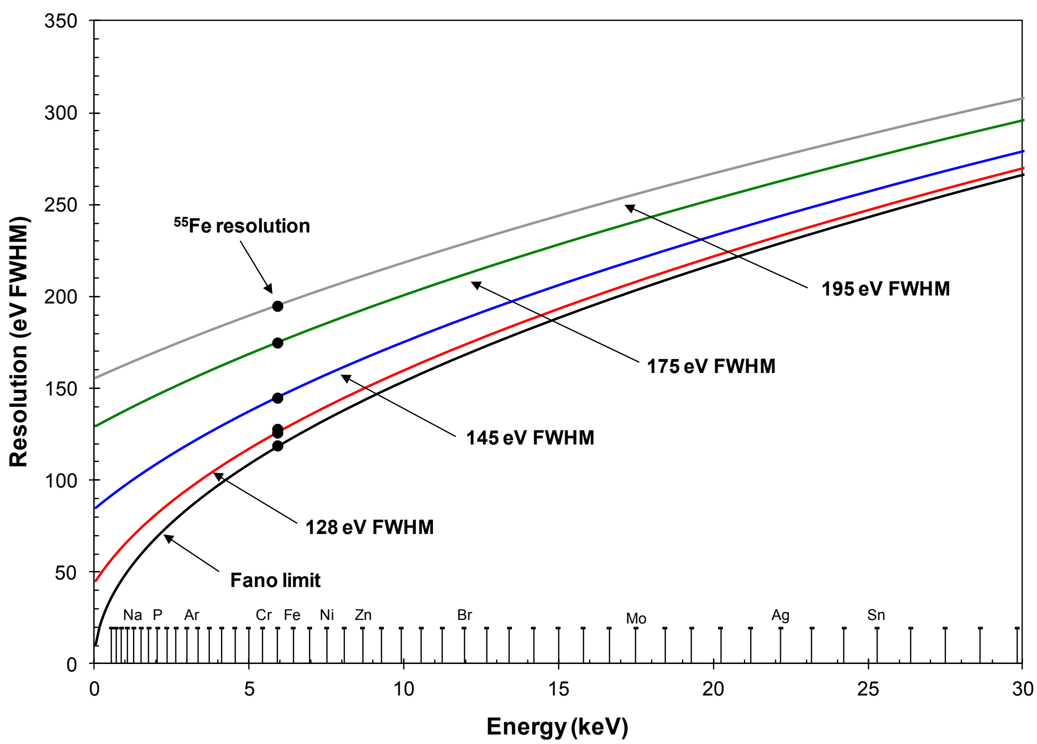
- Amptek's SiPIN and SDD detectors use reset-style preamplifiers, and with standard DP5 or PX5 settings, can be used up to approximately 1 Mcps. A rate of several hundred kcps requires a short peaking time, so SiPIN detectors are rarely used at these high rates.
- For rates at or above 1 Mcps, the signal processors require some minor modifications (hardware or software, depending on the unit). This is discussed in <LINK>
- Amptek's CdTe detectors with a reset preamplifier have a maximum count rate of 200 kcps. Amptek's CdTe detectors with a transistor preamplifier (-T option) have a maximum count rate of 10 kcps.

Energy resolution and X-ray energy

The plot and table below show how the energy resolution of the SiPIN and SDD detectors depends on X-ray energy. The energy resolution of an X-ray detector is specified at the 5.9 keV Mn K_α line but is actually a function of energy, as shown below.

- The black curve shows the "Fano limit", a theoretical limit (which arises from quantum fluctuations in the charge generation process). The Fano limit is 119 eV FWHM at 5.9 keV. The actual resolution is due to the combination of the Fano limit and electronic noise.
- A detector listed as "128 eV FWHM" falls on the red curve below; this would be typical for an SDD <10 kcps. It is very close to the theoretical Fano limit.
- A detector listed as "145 eV FWHM" falls on the blue curve; this would be typical for a 6 mm^2 SiPIN at a few thousand cps or a 25 mm^2 SDD up to 100 kcps.

At high energies, all of the curves are fairly close to the Fano limit. This means that, at high energies, there is little difference when using different detectors, optimizing peaking times, etc. At low energies, the curves are far apart, so minimizing noise is quite important.



The curves in this figure are given by

$$(\delta E)^2 = K_F E + ENC^2 \qquad [1]$$

where $K_F E$ is the theoretical Fano limit and *ENC* is the input equivalent noise charge, i.e. intrinsic electronic noise. The magnitude of Fano broadening is a theoretical limit; there is nothing a user can do to change it. Electronic noise, on the other hand, depends strongly on the detector which was selected and the system configuration, specifically detector temperature, peaking time, and pulse shaping. Electronic noise cannot be eliminated but its magnitude can be made much larger or smaller by what detector you select and how you operate the spectrometer.

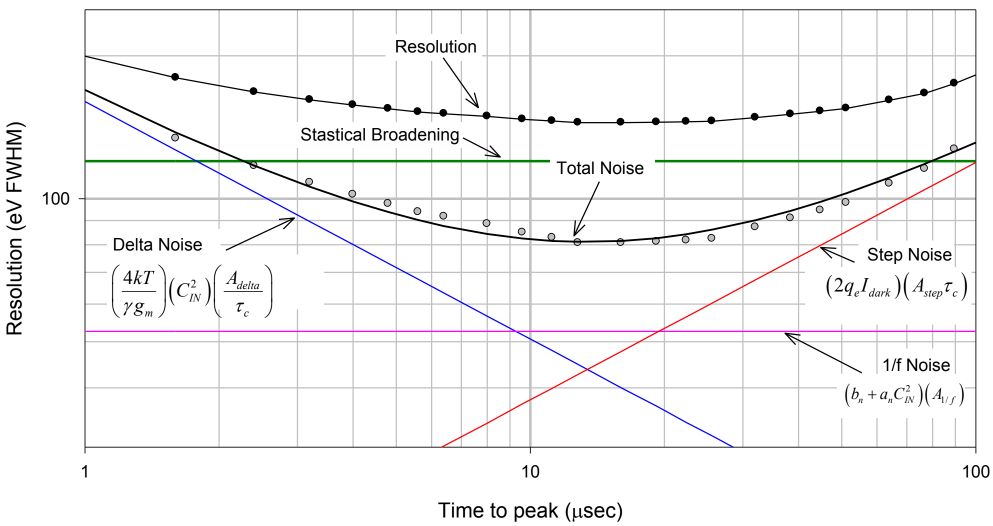
These curves and table include only the Fano broadening and intrinsic electronic noise. The observed resolution is usually quite close to these, but not always. There are other factors which can be important, particularly when a system is not properly configured. These other sources of resolution loss include electromagnetic interference (e.g. ground loops), imperfect charge collection in the detector (dead layers in silicon detectors and hole tailing in CdTe), ballistic deficit, etc.

Energy resolution and electronic noise

The magnitude of Fano broadening is a theoretical limit; there is nothing a user can do to change it. Electronic noise, on the other hand, depends strongly on the detector which was selected and the system configuration, specifically detector temperature, peaking time, and pulse shaping. You can make the intrinsic noise much better or much worse by how you operate the spectrometer.

Intrinsic electronic noise arises from random fluctuations in the current through the detector, preamplifier, and other signal processing electronics. The noise cannot be eliminated but its magnitude, the rms value of the voltage fluctuations, depends on parameters which are under the user's control.

The input equivalent noise arises from three terms: delta noise (a.k.a. series white noise or white voltage noise), 1/f noise, and step noise (a.k.a. parallel white noise or white current noise). Each term has a different dependence on the pulse shaping time constant (or peaking time) in a digital processor. The plot below shows the energy resolution versus peaking time for a typical silicon detector and the contributions of the three terms.



Plot showing the energy resolution of a Si detector versus peaking time, showing the components to the resolution: statistical broadening (a.k.a. Fano limit) and the three dominant intrinsic noise terms.

Quantitatively, the square of the input equivalent noise charge is the sum of the three terms:

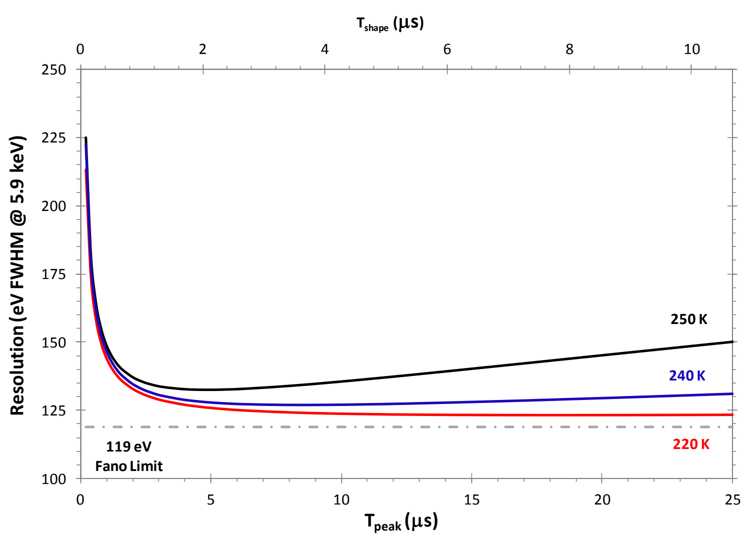
$$ENC^2 = \left(2q_e I_{dark}\right)\left(A_{step}\tau_c\right) + \left(b_n + a_n C_{IN}^2\right)\left(A_{1/f}\right) + \left(\frac{4kT}{\gamma g_m}\right) C_{IN}^2 \left(\frac{A_{delta}}{\tau_c}\right) \qquad [3]$$

where τ_c is the time constant of the shaping amplifier, I_{dark} is the dark current through the detector, C_{IN} is the preamplifier's input capacitance, T is the FET temperature, k is the Boltzmann constant, g_m is the FET's transconductance, γ characterizes the FET's thermal noise, b_n and a_n characterize low frequency (or 1/f noise), and A_{step}, $A_{1/f}$, and A_{delta} characterize the noise filtering properties of the shaping amplifier. There are a few key points which result from this equation and plot:

1. **The noise depends strongly on the peaking time.** There is an optimum peaking time (the noise corner) at which the noise is minimal, where the step and delta noise contributions are equal. If one uses a shorter peaking time, there will be more electronic noise. Resolution will be degraded, but if Fano statistical fluctuations dominate, the total resolution loss may not be significant. Shorter peaking times permit one to operate at a higher count rate and still maintain a low dead time fraction. In most practical applications, the best system performance (defined as the precision and accuracy of the analytical results) are found at peaking time shorter than the noise corner, at higher count rates. But the optimum depends strongly on the spectrum and on the analysis algorithms.
2. **The noise increases with detector area.** The delta noise, dominant at short τ_c, increases with C_{IN}. In a planar Si-PIN detector, C_{IN} scales with area, so larger area detectors are more sensitive but have more delta noise. In a SDD, C_{IN} is much smaller than in the Si-PIN and is independent of detector area. The reduced delta noise is the primary advantage of an SDD: it yields lower noise at the corner and much lower noise at short peaking times, allowing higher count rates while maintaining good energy resolution. The step noise, dominant at long τ_c, increases with I_{dark}. This increases with detector volume so also increases for large area detectors, for both SiPIN and SDD. Clearly, small detectors will yield lower noise.
3. **The noise increases with detector temperature.** The delta noise, dominant at short τ_c, is proportional to $\sqrt{T}$ so changes slowly at typical operating conditions. However, I_{dark} is an exponential function of temperature, so step noise, dominant at long τ_c, changes rapidly with detector temperature. At elevated temperatures, the noise corner shifts to shorter peaking times. If one uses the optimal τ_c at full cooling, the resolution change with temperature will be clearly seen. If one uses a short τ_c (usually optimal from a system perspective, including count rate effects), the noise increases slightly with temperature. This can be seen in the plot in <LINK>

Energy resolution and temperature

The energy resolution of Amptek's detectors is specified at full cooling, typically around 220K. The resolution is degraded at higher temperatures, so operating at the lowest temperatures is recommended. The plot below shows resolution, at the 5.9 keV Mn K_α line, as a function of peaking time for a typical SDD at three different temperatures. Note that the resolution at long peaking times increases significantly with temperature while at short peaking times the different is much smaller. The "noise corner", the peaking time for optimum resolution, shifts to lower peaking times with increasing energy.



The electronic noise at short peaking times is dominated by thermal noise in the preamplifier; this increases as the square root of the temperature. The electronic noise at long peaking times is dominated by shot noise due to the detector's leakage current and this increases exponentially with temperature.

The curve for each detector will have a shape qualitatively similar to the one shown above but the details will vary. In the FastSDD, the noise corner is shifted to shorter peaking times. In the SiPIN detectors, the noise corner is shifted to longer peaking time, and since there is more noise than with an SDD, the performance change with temperature is more pronounced. This curve shows electronic noise only. The total resolution of a peak, including Fano broadening, is a much weaker function of temperature.