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Title:	Introduction to Gamma-Ray Detection
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Intended for:	Customized instructional slides for an informal training about gamma ray detectors.
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Los Alamos
NATIONAL LABORATORY

Introduction to Gamma-Ray Detection

Goals and Objectives

Goal:

Demonstrate the operation of gamma spectroscopy instrumentation

Objectives:

1. Discuss basic principles of detectors and electronics for gamma spectroscopy
2. Compare types of gamma detectors
3. Operate a germanium detector system

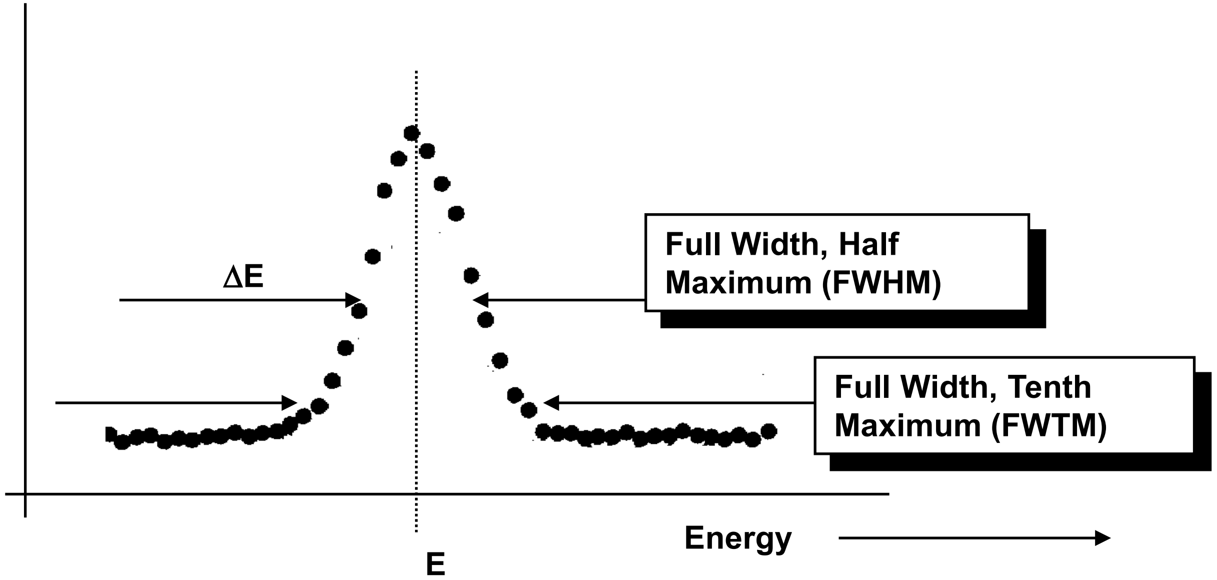
Detector Parameters

- Resolution: how precisely can the detector determine the gamma ray energies?
- Efficiency: how many of the available gamma rays are actually detected?
- Efficiency curve: how efficient is the detector at various energies?
- Dead time: in a given measurement period, how much of the time can the detector actually respond to gamma rays?

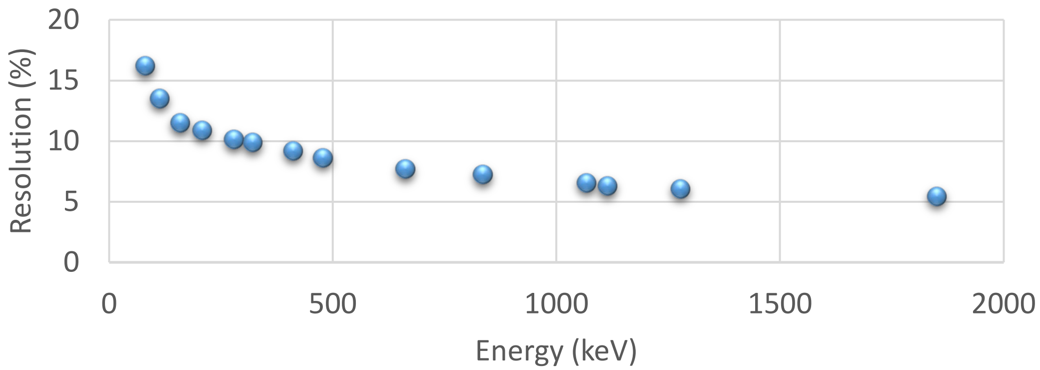
Energy Resolution

- Resolution is defined by the *full width at half max (FWHM)*
- For a Gaussian peak, FWHM=2.35σ

Detector	FWHM (keV)	Energy (keV)	Typical Resolution (FWHM/E)
NaI (2x2)	9.2	122	13.0%
NaI (2x2)	50	662	7.5%
HPGE (Planar)	0.5	122	0.4%
HPGE (Planar)	1.3	662	0.2%
HPGE (Coaxial)	0.9	122	0.8%
HPGE (Coaxial)	4	662	0.6%

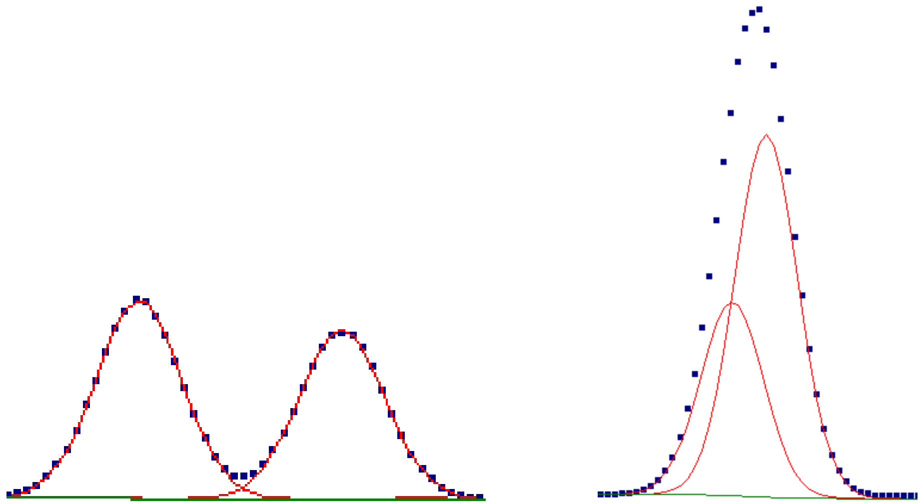


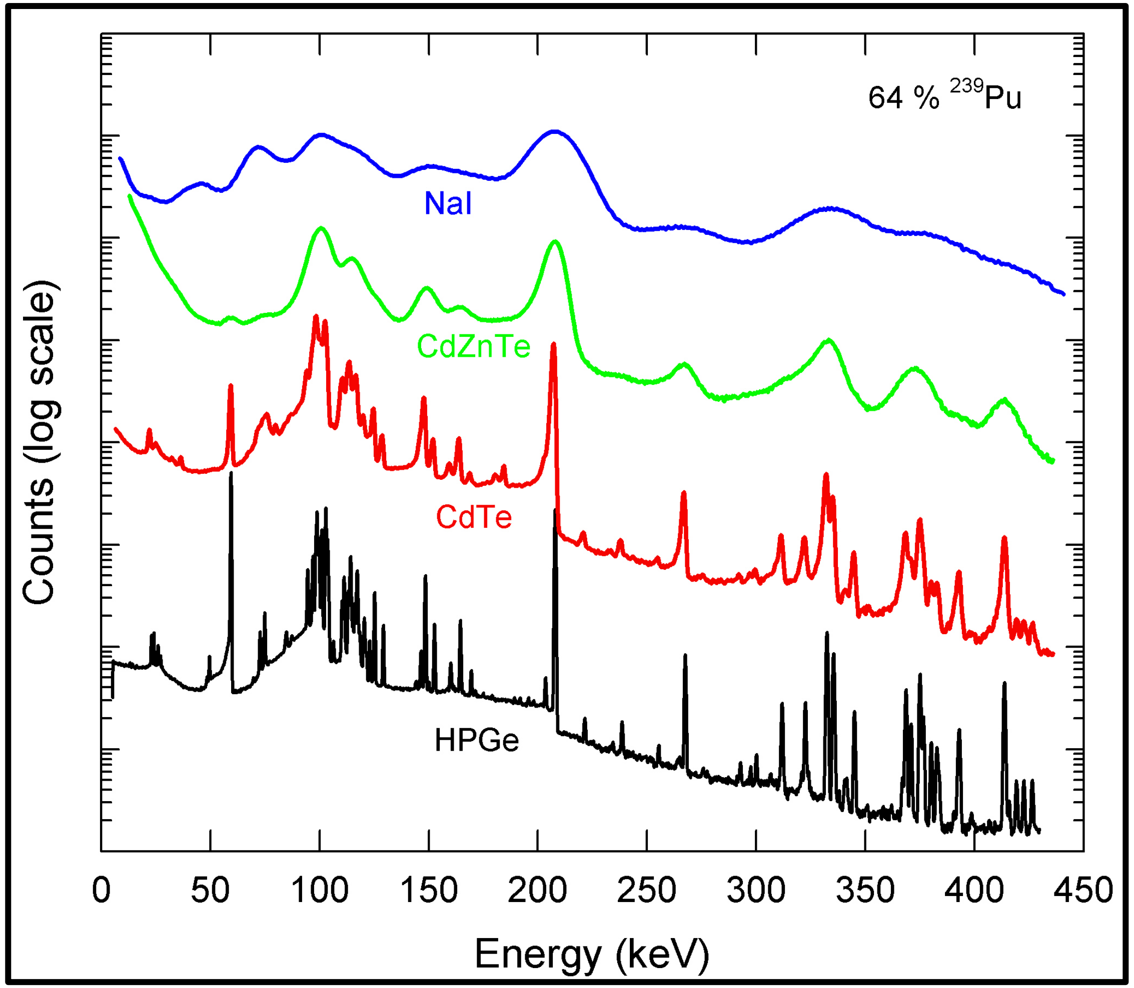
Typical Resolution of a NaI(Tl) Detector



Energy Resolution

A spectrographic system's energy resolution determines how far apart peaks have to be to be resolved



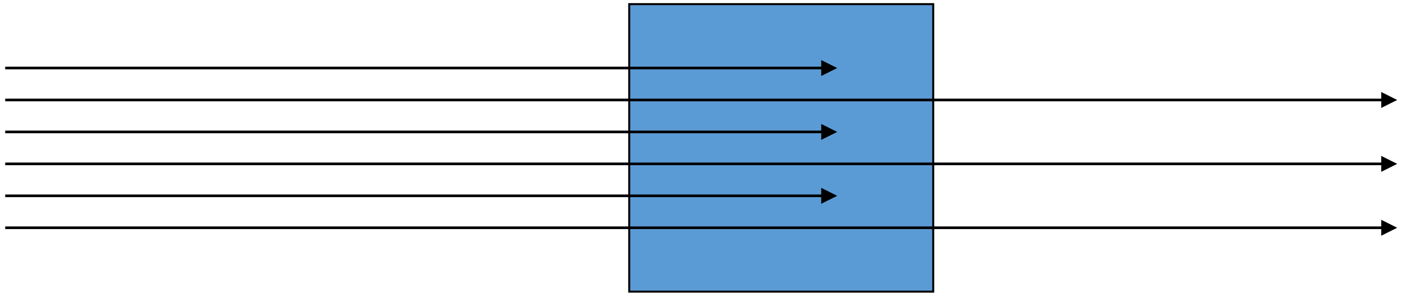


Factors that Affect Resolution

- The detector type (NaI, Ge, CZT,...)
- Radiation damage to the detector
- The measurement environment
  - Radiation
  - Electronic
  - Physical (vibrations, temperature, humidity,...)
- Measurement electronics
- Quality
  - Settings (pole-zero, baseline restoration, time constants, pileup rejection, count rates,...)
  - Placement (near electronic sources, near other radiation fields, ...)

Detector Parameters - Efficiency

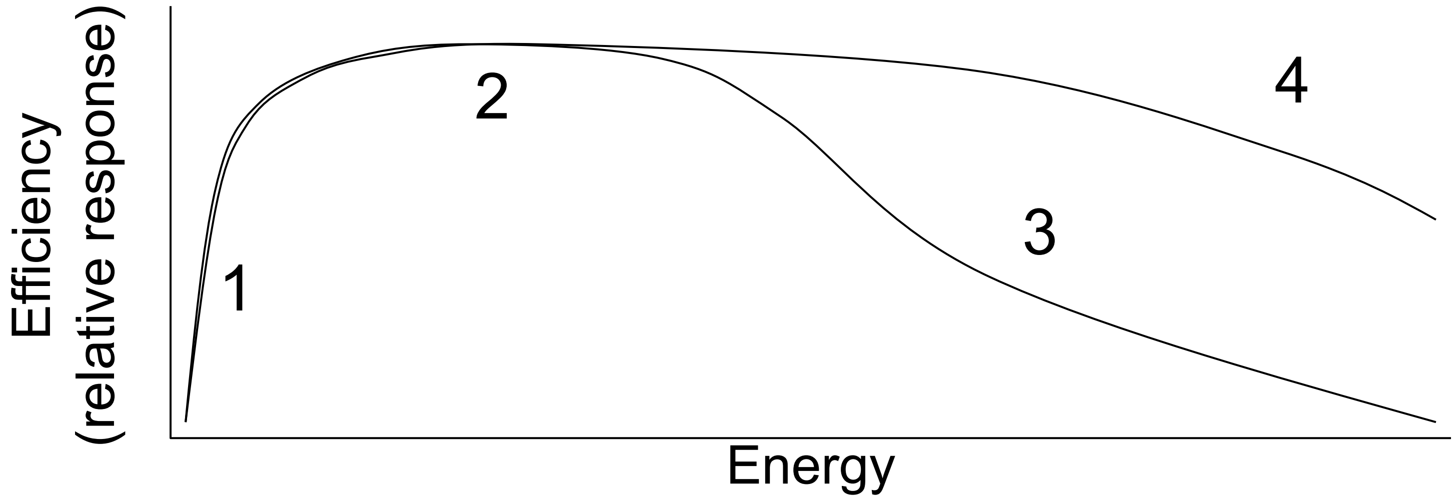
- 50% efficiency is illustrated here



- Note: relative efficiency is often used; this compares a detector's efficiency to that of a 3" by 3" sodium iodide detector

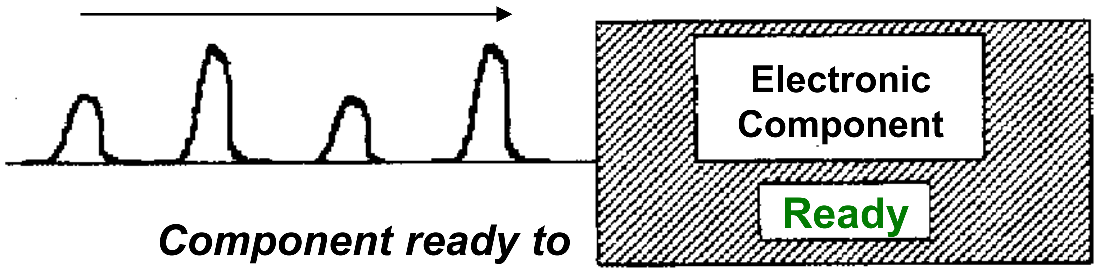
Detector Parameters - Efficiency

1. *Very* low energy rays can have difficulty penetrating to the crystal
2. Moderate energy rays are generally fully absorbed
3. High energy rays can go through the entire crystal
4. Larger detectors have better high-energy efficiency

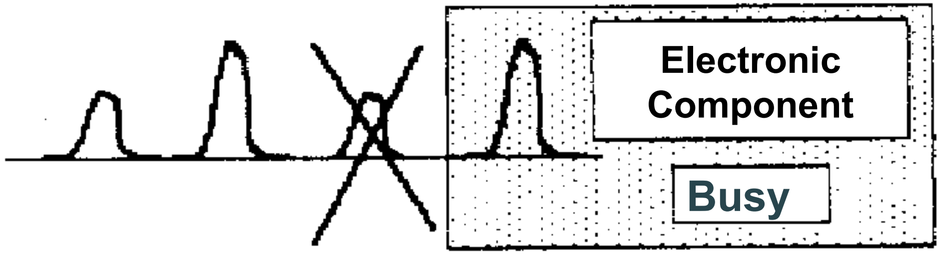


Electronic Dead Time

Incoming Pulse Train



Component ready to process next pulse

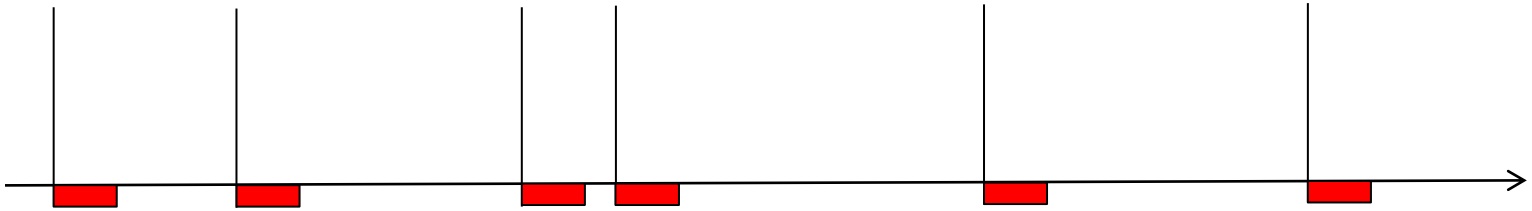


Component now busy processing first pulse and the following pulse is therefore ***LOST.***

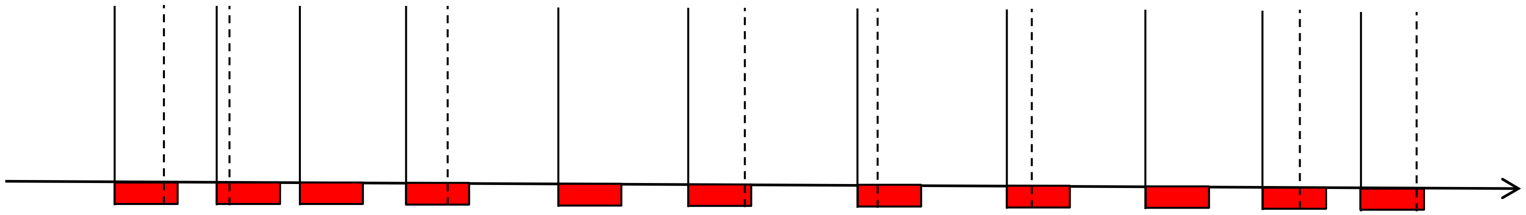
Electronic Dead Time

- The system requires a small time period to recover after producing a gamma pulse
  - Detector dead time – >0.5 µs
  - Electronics dead time – ~20 to 30 µs
- At high input rates, this can lead to significant total dead time - >50% is undesirable
- 100% dead time is possible; “saturated detector”
- Counting in “Live Time” corrects for the time lost to dead time
- Live Time mode extends the count time for every time unit in which the system is experiencing dead time

Electronic Dead Time



Low input rate; little or no loss of pulses

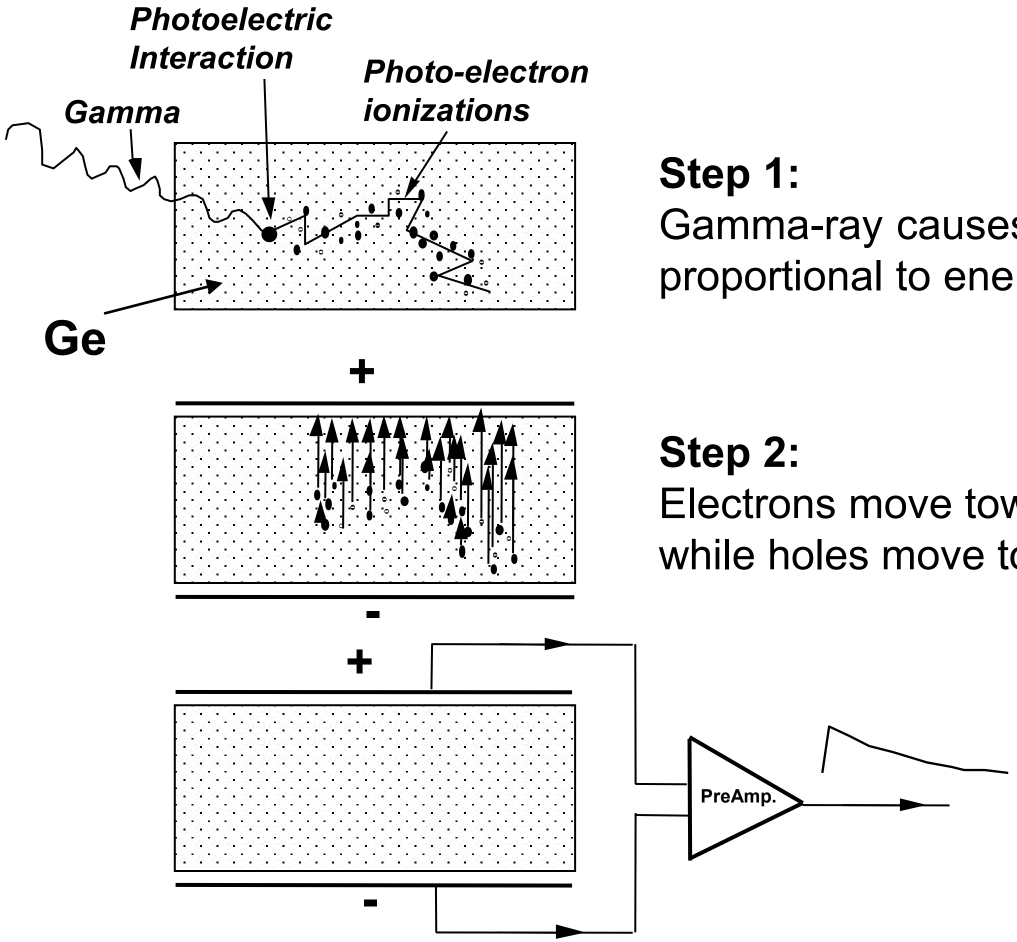


High input rate; frequent loss of pulses

Detector Technologies

- Scintillators
  - Sodium Iodide (NaI)
  - Lanthanum Bromide (LaBr3)
- Semiconductors
  - Cadmium Zinc Telluride (CdZnTe)
  - High Purity Germanium (HPGe)

(High Purity) Germanium Detector



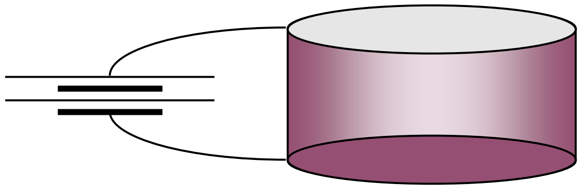
Step 1:
Gamma-ray causes ionization (electron-hole pairs) proportional to energy **deposited**

Step 2:
Electrons move toward the positive side of the detector while holes move toward the negative side.

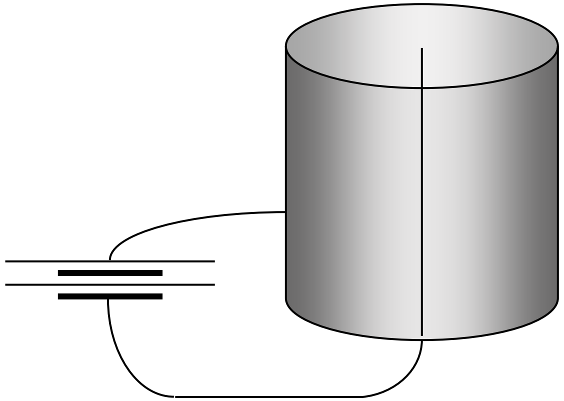
Step 3:
The charge burst is converted into a voltage pulse by a preamplifier. The pulse is proportional to the energy of the gamma ray.

Germanium Detectors

There are two contacts on the detector, and a high voltage is applied.



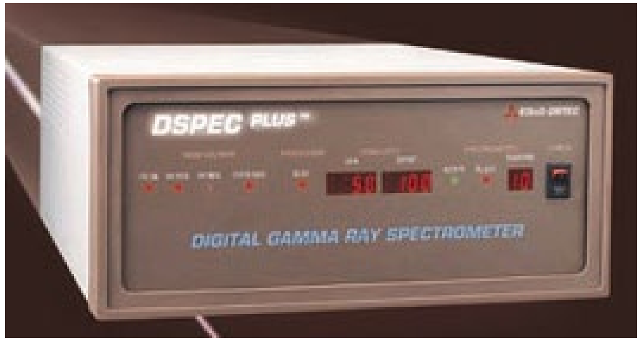
Planar detector; better resolution, lower efficiency

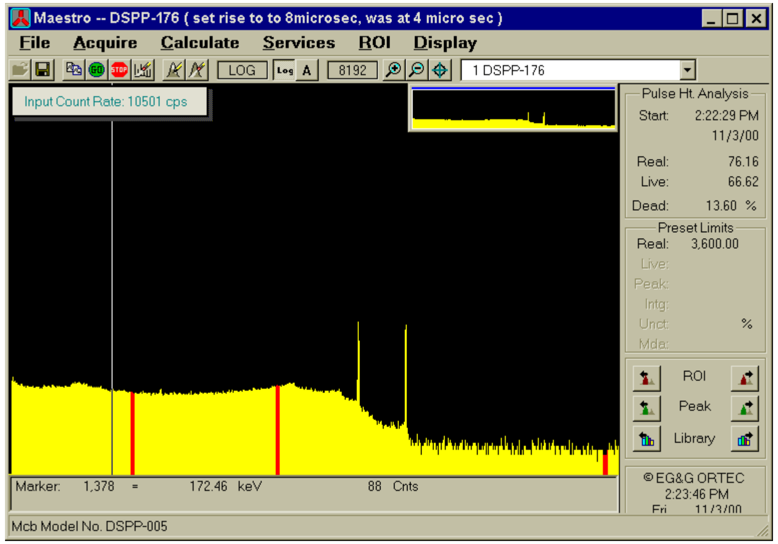


Coaxial detector; lower resolution, better efficiency

Germanium Detectors

- The output pulse from the crystal has to be amplified and shaped
- It is then sent to the spectrographic software to be binned into a spectrum





1 DSPP-176

Input Count Rate: 10501 cps

Pulse Ht. Analysis
Start: 2:22:29 PM 11/3/00
Real: 76.16
Live: 66.62
Dead: 13.60 %

Preset Limits
Real: 3,600.00
Live:
Peak:
Intg:
Unct: %
Mda:

Marker: 1,378 = 172.46 keV 88 Cnts

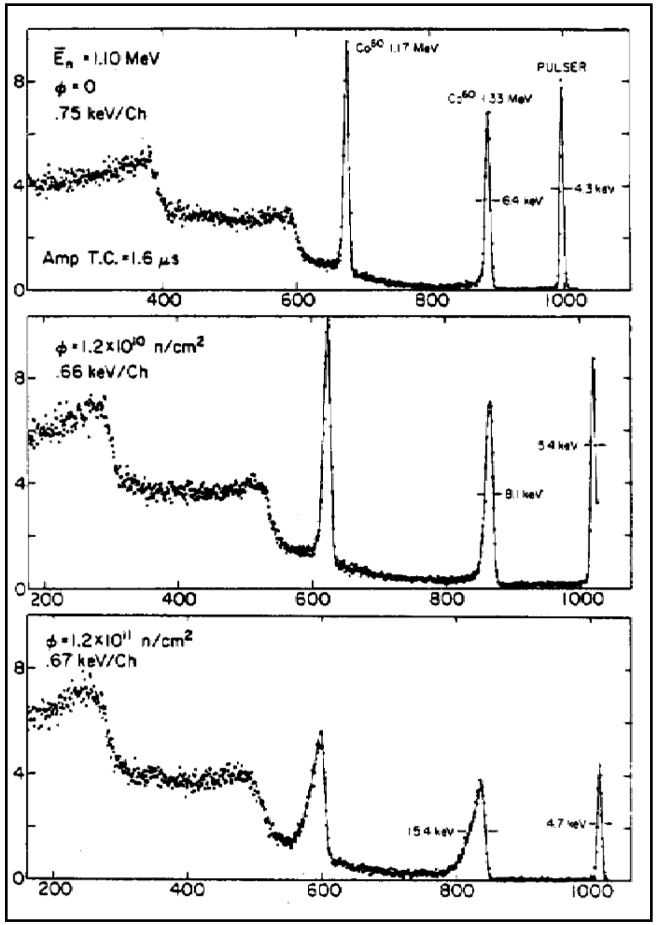
© EG&G ORTEC
2:23:46 PM
Fri 11/3/00

Mcb Model No. DSPP-005

Germanium Detectors

- Best detector for identifying an unknown isotope or mix of isotopes because of high resolution
- Not convenient for field use; even mechanically cooled systems require time to stabilize at operating temperature
- Can be sensitive to power spikes, noise, and neutron damage

Effect of Neutron Damage



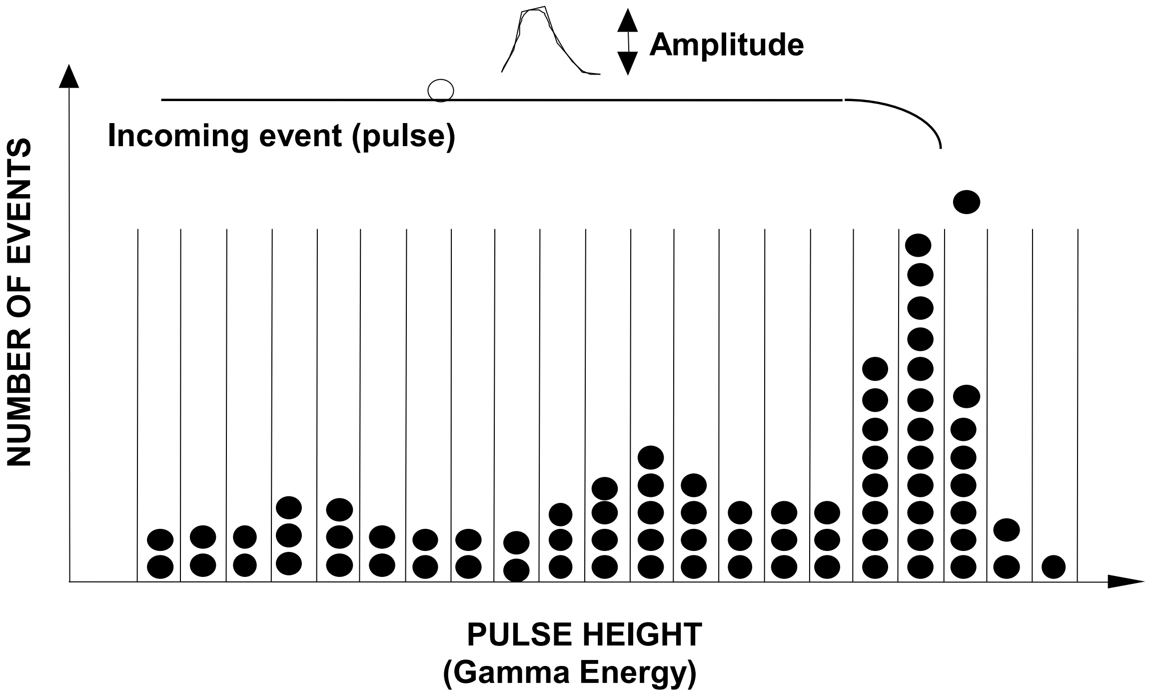
ϕ = 0 neutron / cm^2

ϕ = 1.2 x 10^{10} neutron / cm^2

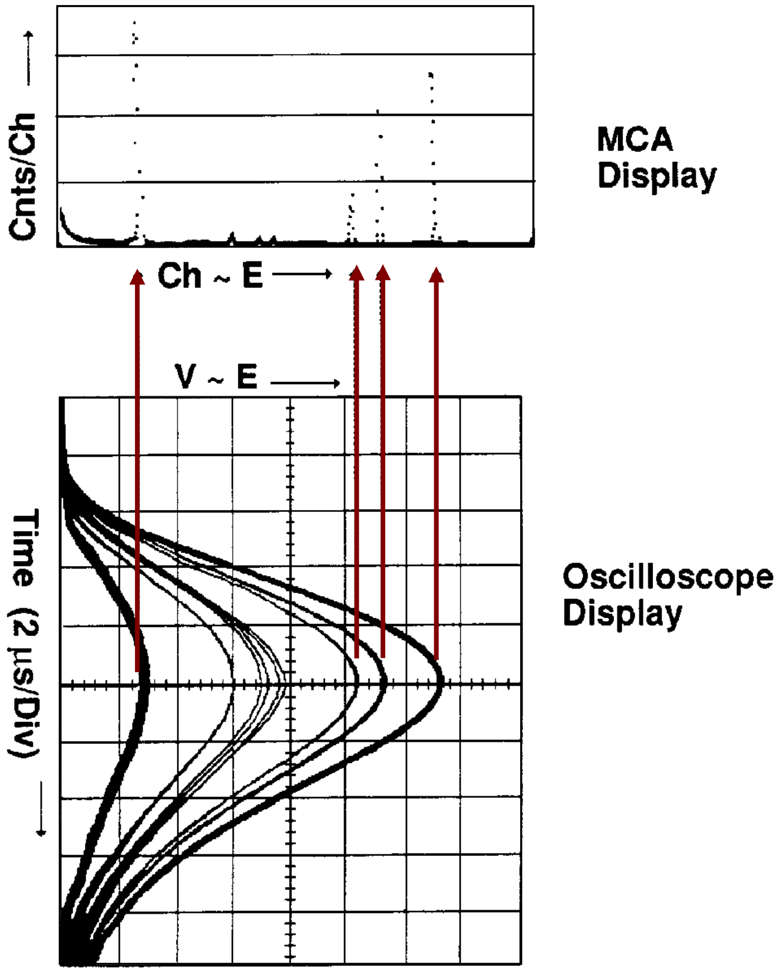
ϕ = 1.2 x 10^{11} neutron / cm^2

From Voltage Pulses to a Spectrum

The Multi-Channel Analyzer (MCA) electronically sorts voltage pulses of different amplitudes into “bins” which correspond to the energy deposited by each detected gamma ray. This forms a pulse-height or gamma ray energy spectrum.



Comparison of Oscilloscope and MCA

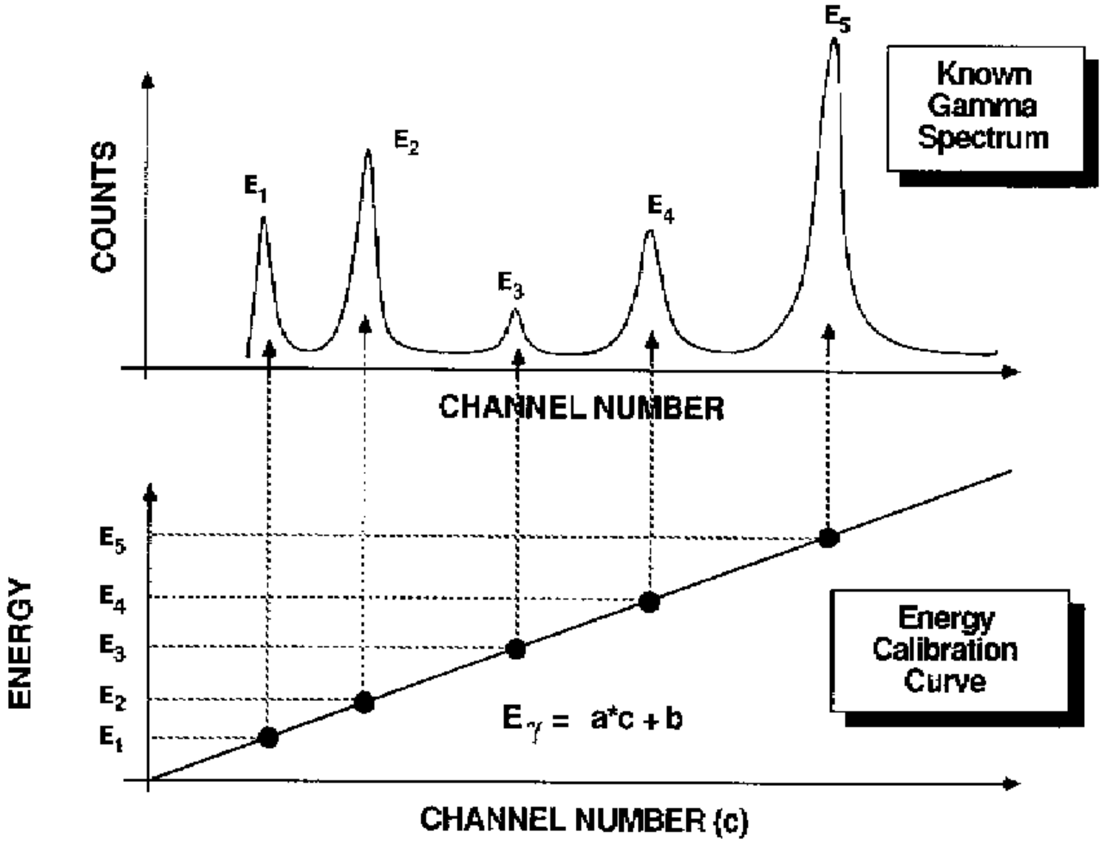


J. L. Parker

The detector pulse rises to a maximum amplitude, which is measured by the multichannel analyzer (MCA).

In the MCA display, a count is stored at an address that is proportional to that maximum amplitude.

Energy Calibration



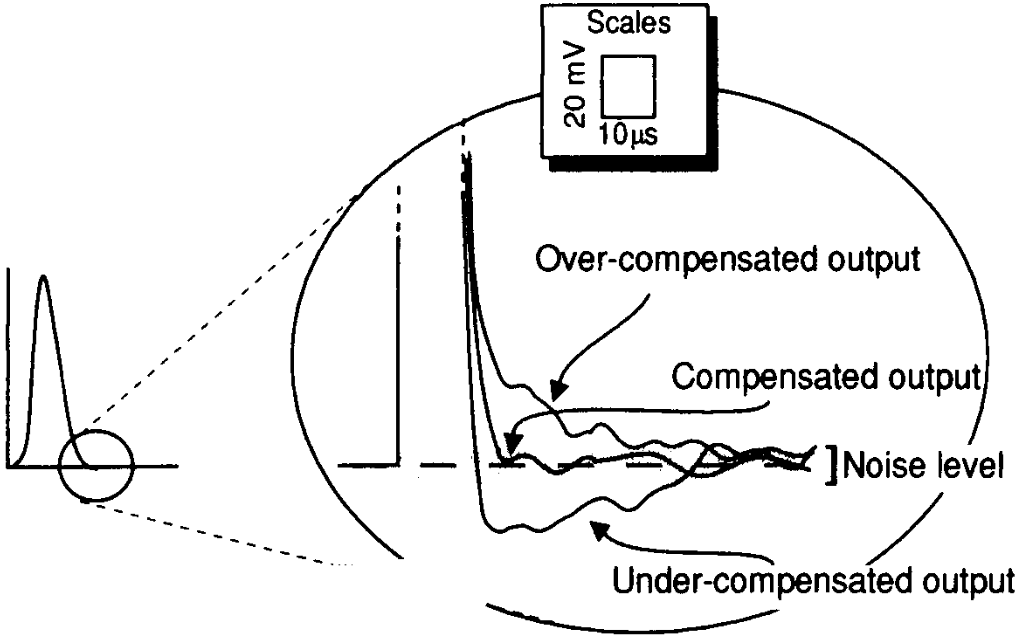
E_γ (keV) = A*Channel# + B

Energy accuracy to about 0.5 keV usually possible

- HPGe and LaBr3 have very linear calibrations with small offsets (B)
- NaI has an approximately linear calibration with a larger offset

Amplifier Pole-Zero (PZ) Compensation

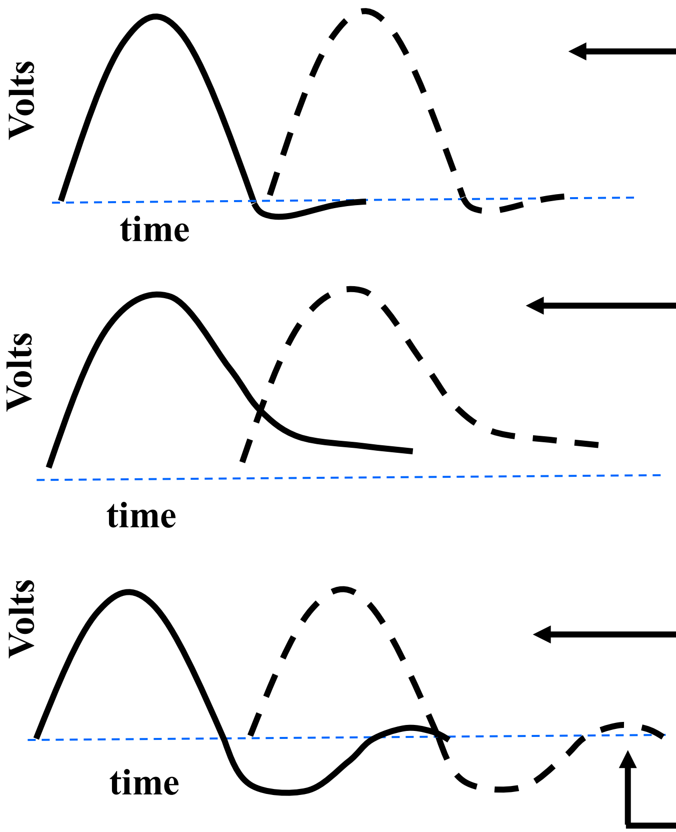
- Located at input of amplifier
- Matches impedance of the amplifier to the impedance of the detector



- PZ adjustment is the first step in attempting to correct bad resolution and asymmetrical peaks
- Poor PZ settings can worsen resolution, increase deadtime, and shift the spectrum nonlinearly

Pole-Zero and Peak Shapes

Amplifier Pulses



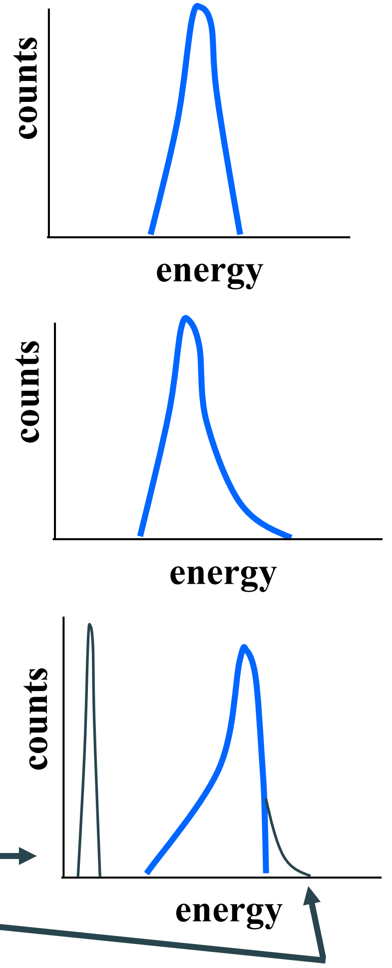
Proper pole-zero: negligible tailing unless very high count rates

Undershooting the baseline: high energy tailing

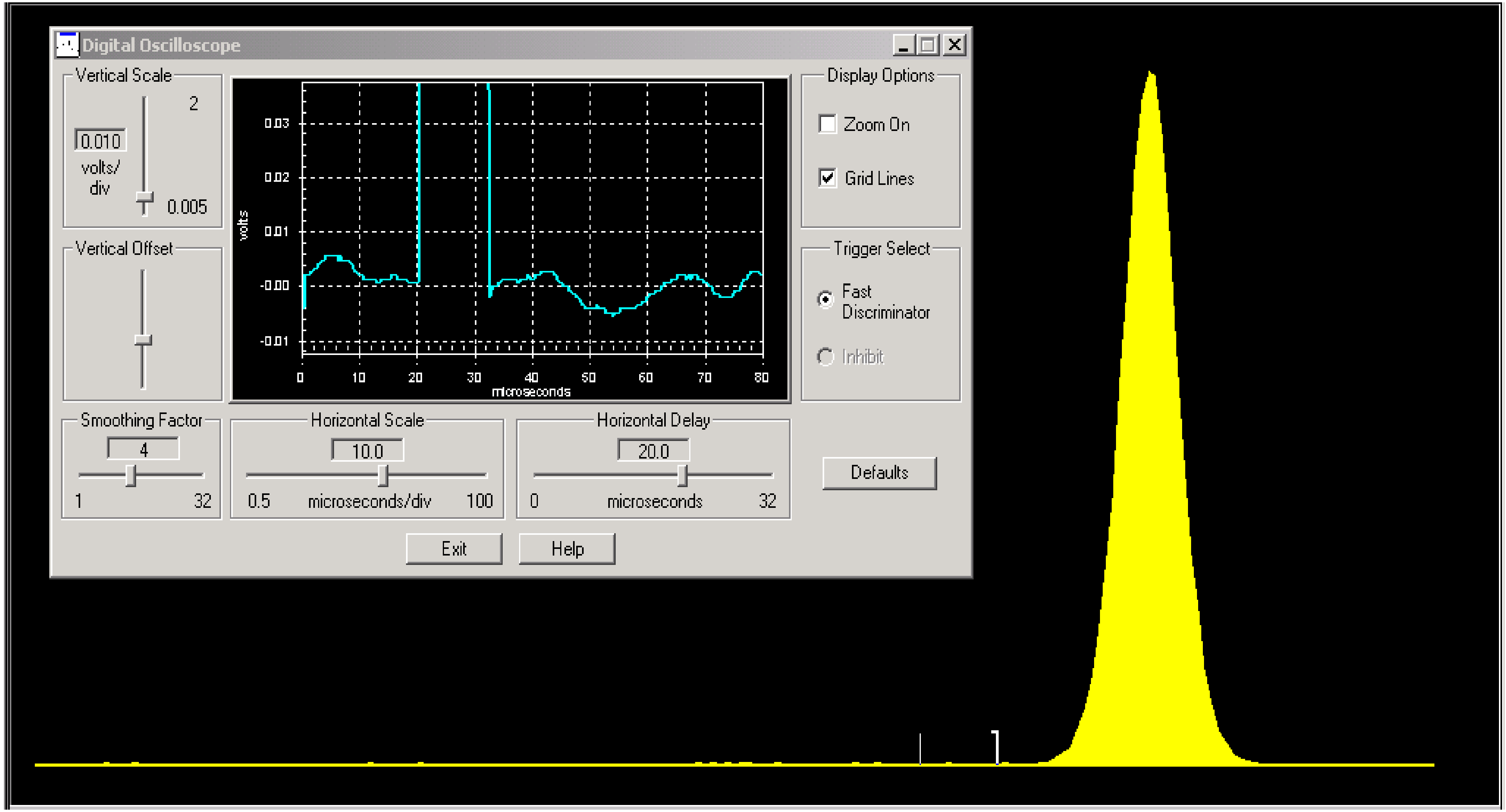
Overshooting the baseline: low energy tailing

Oscillation: Low E spike and or high E tailing

Peaks in Spectrum



Good Pole-Zero


Digital Oscilloscope

Vertical Scale: 0.010 volts/div

Vertical Offset

Smoothing Factor: 4

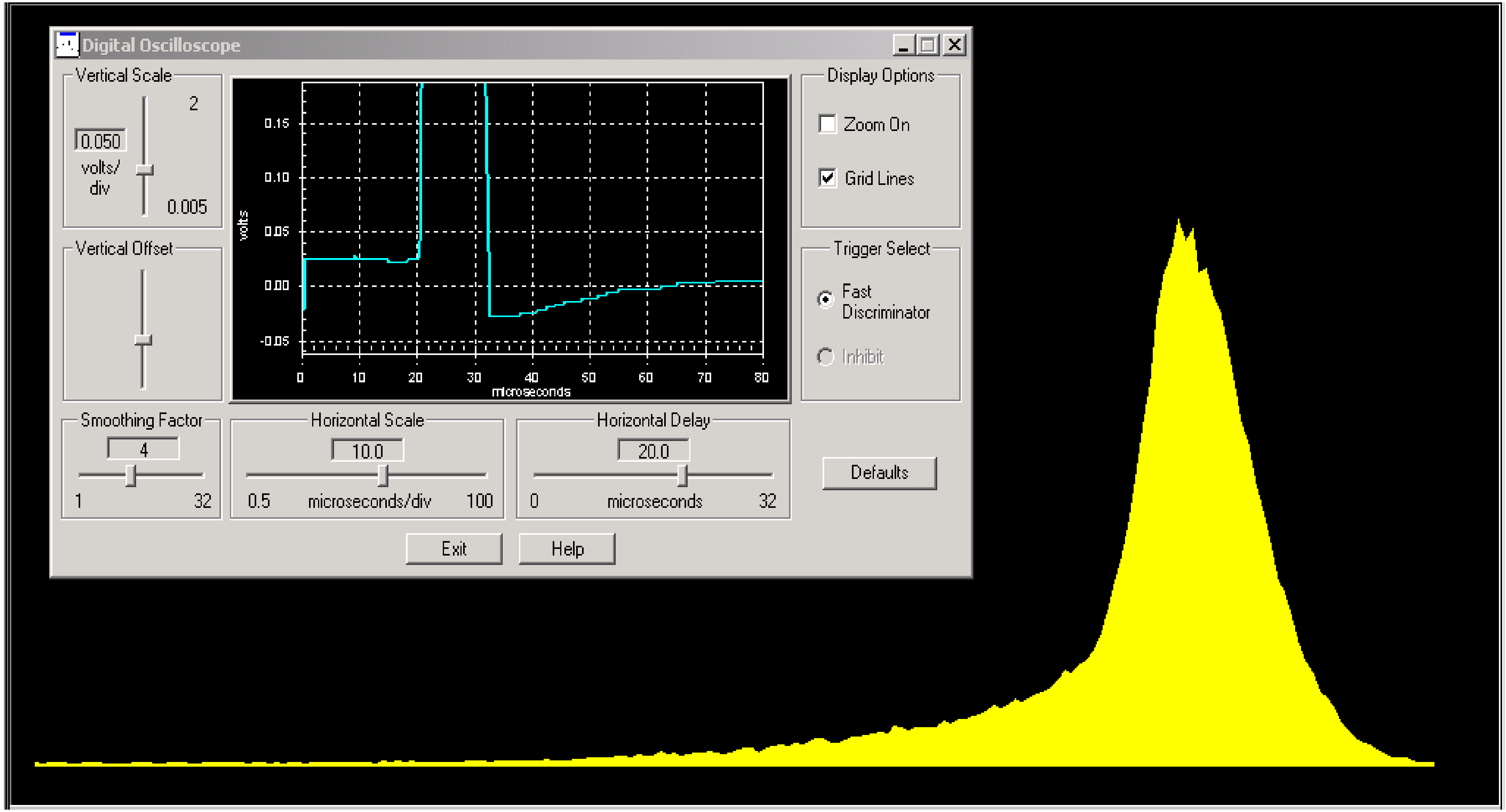
Horizontal Scale: 10.0 microseconds/div

Horizontal Delay: 20.0 microseconds

Display Options:
- ☐ Zoom On
- ☑ Grid Lines

Trigger Select:
- ● Fast Discriminator
- ○ Inhibit

Low Pole-Zero



Digital Oscilloscope

Vertical Scale: 0.050 volts/div

Smoothing Factor: 4

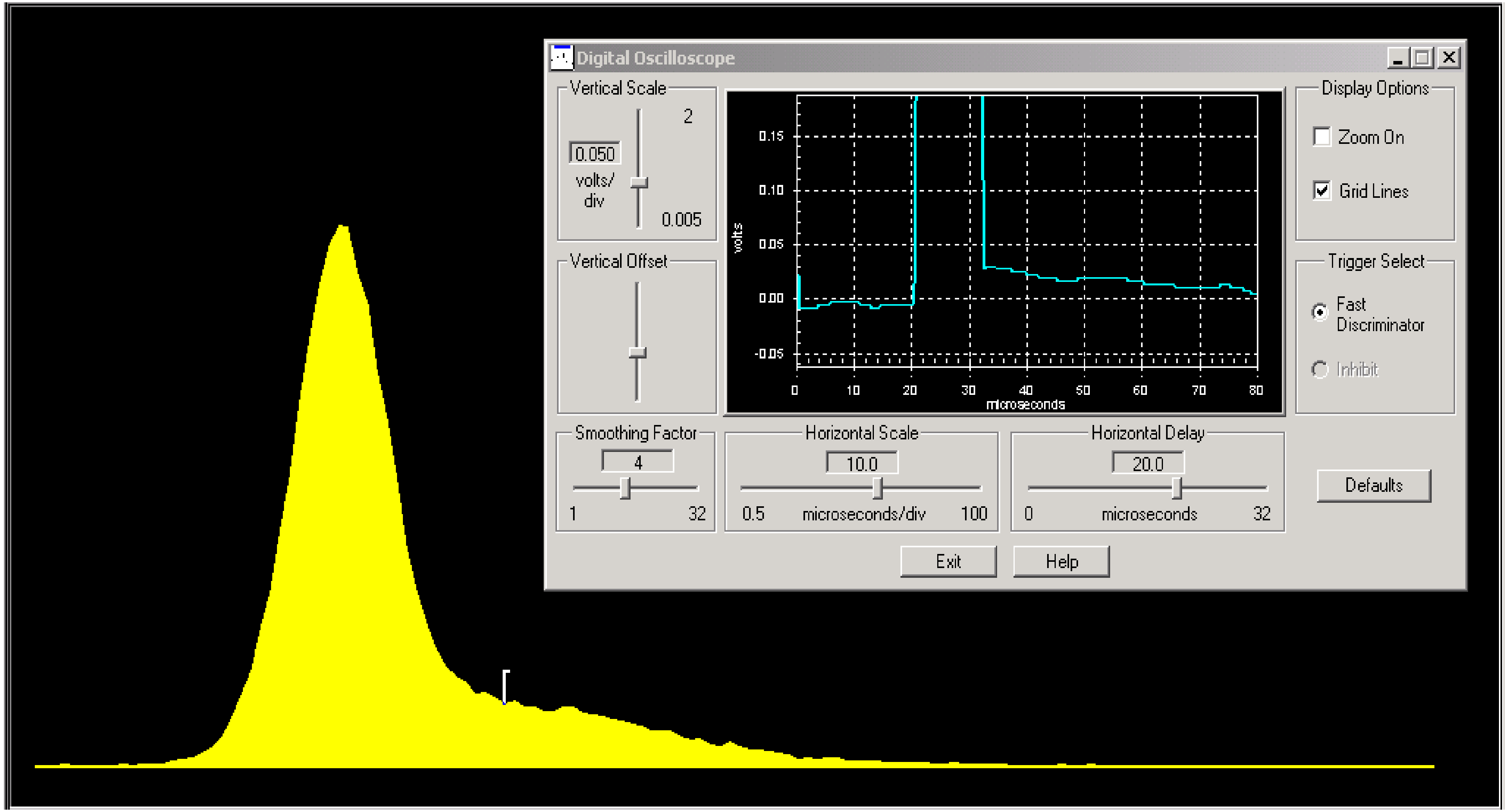
Horizontal Scale: 10.0 microseconds/div

Horizontal Delay: 20.0 microseconds

Display Options:
- ☐ Zoom On
- ☑ Grid Lines

Trigger Select:
- ● Fast Discriminator
- ○ Inhibit

High Pole Zero



Digital Oscilloscope

Vertical Scale: 0.050 volts/div

Vertical Offset

Smoothing Factor: 4

Horizontal Scale: 10.0 microseconds/div

Horizontal Delay: 20.0 microseconds

Display Options

☐ Zoom On

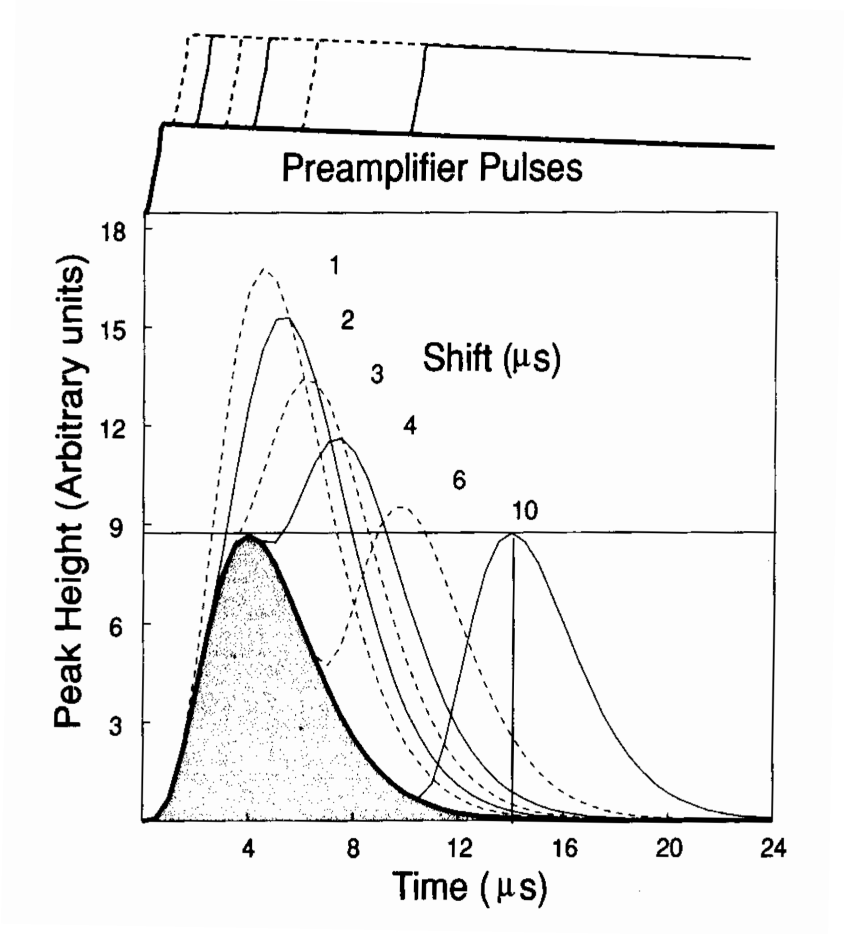
☑ Grid Lines

Trigger Select

● Fast Discriminator

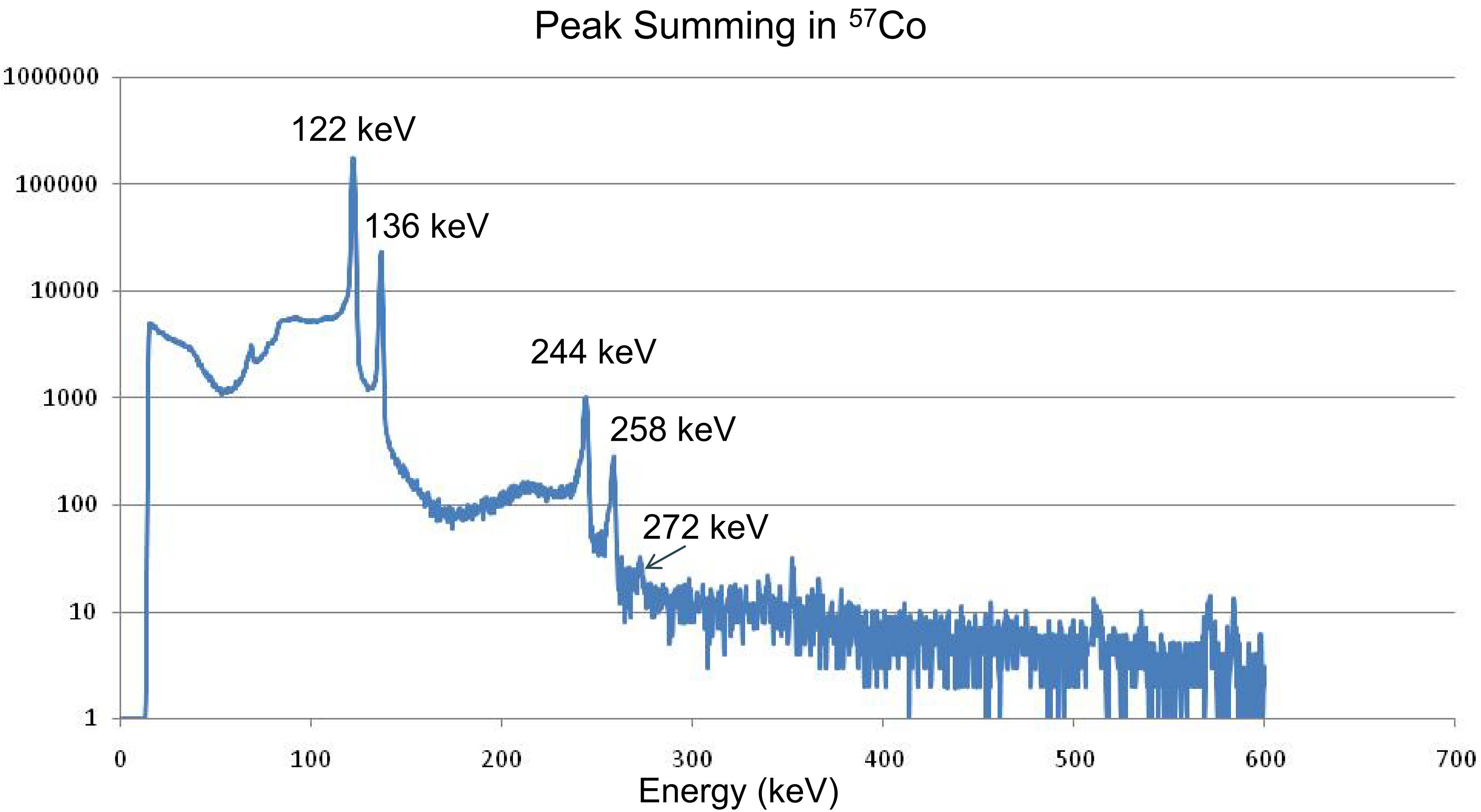
○ Inhibit

Amplifier Pulse-Pileup Rejection



- Rejects pulses that are separated by less than the amplifier rise time
- If the pulses were accepted, they would sum as a single shaped pulse at an energy greater than either of the two original pulses

Pulse Pileup Produces Sum Peaks



Lab Activities

- Setup NaI detector system (1 – 1.5 hours)
  - Electronic settings (gain, pole-zero, etc)
  - Reviewing MCA operations
  - Calibrating detector system
  - Acquiring U, Pu spectra
- Setup Ge detector system (1 – 1.5 hours)
  - Electronic settings
  - Reviewing MCA operations
  - Acquiring U, Pu spectra
  - Deadtime effects
  - Attenuation effects