HOMELAND SECURITY & DEFENSE

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Enhanced NaI Detector

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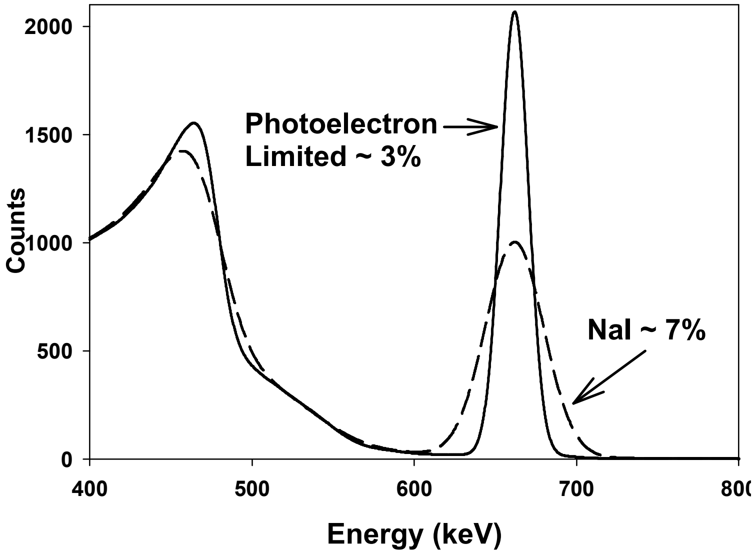
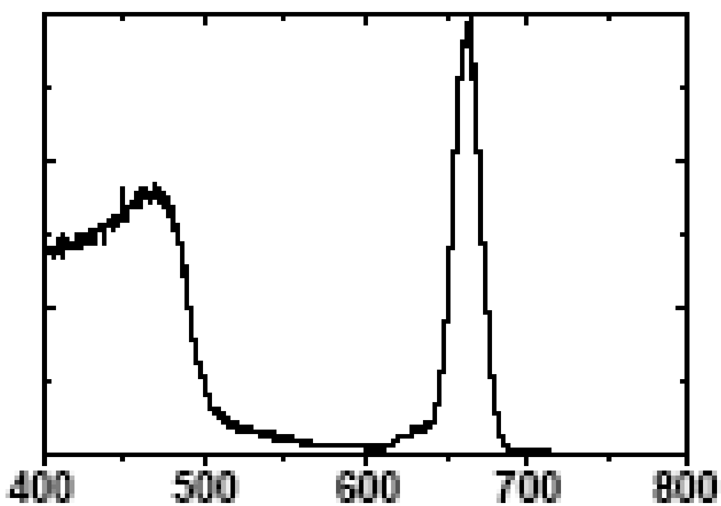
Motivation

- Our goal is to enhance the resolution of common existing detector technologies by correcting for nonlinear effects due to multiple interactions.
- Such enhanced detectors could have wide application, given the relative ease of producing these existing materials and their large installed base.

NaI(Tl) is often used because it is cost effective

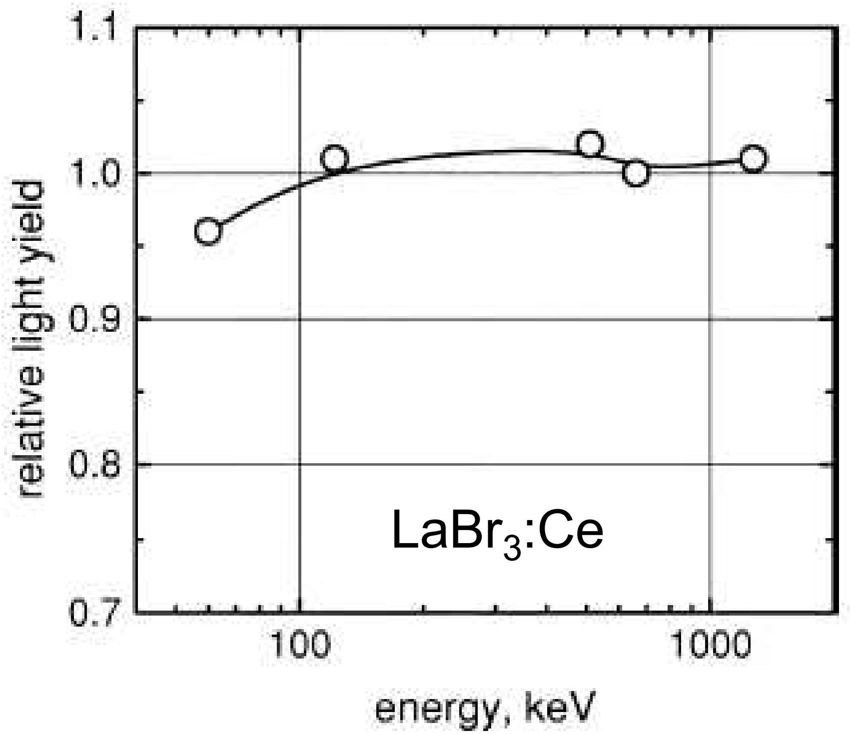


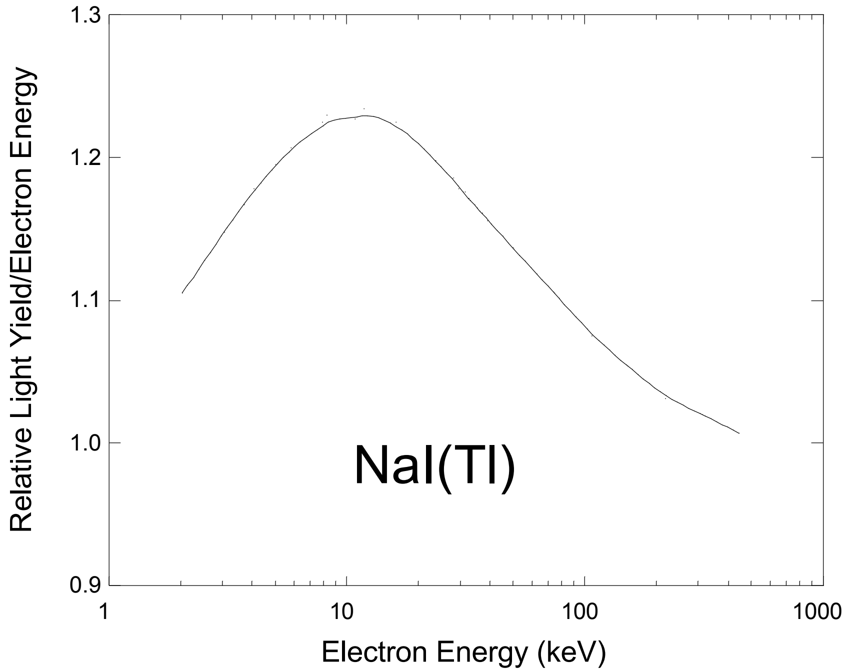
- **NaI(Tl)**
  - Resolution ~7%
  - Not just photoelectron statistics!
  - Cost ~ $ 4/cc



- **LaBr:Ce**
  - Lanthanum Halides have similar light yield, yet much better resolution ~ 3%
  - Cost ~ $ 150 – 700/cc.

Why is there such a difference?





The relative light yield is significantly more uniform for Lanthanum Halides than NaI(Tl), CsI(Tl), etc

Gamma rays that are fully absorbed typically undergo several interactions

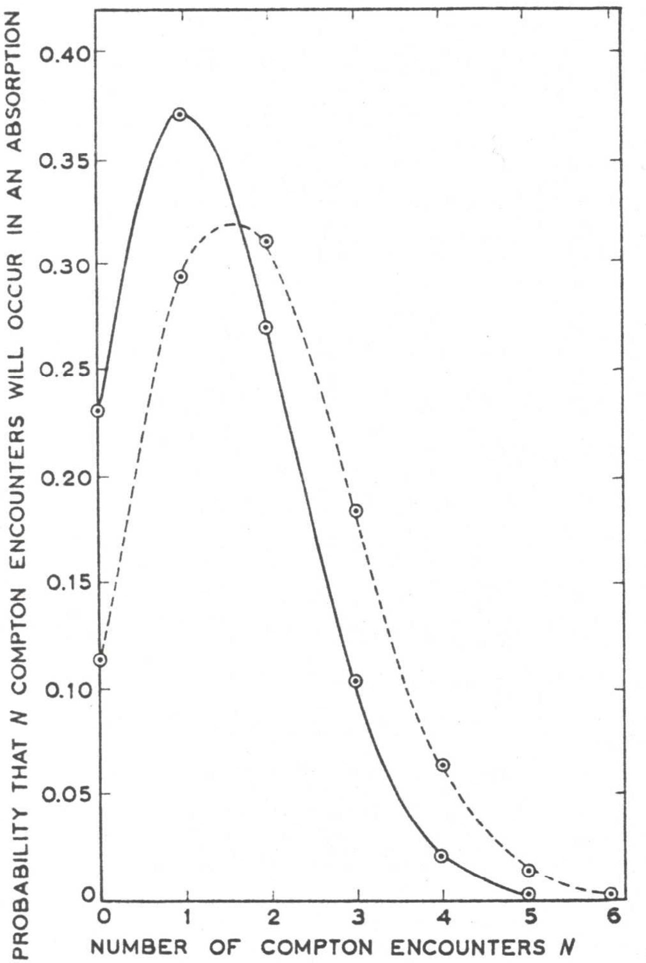
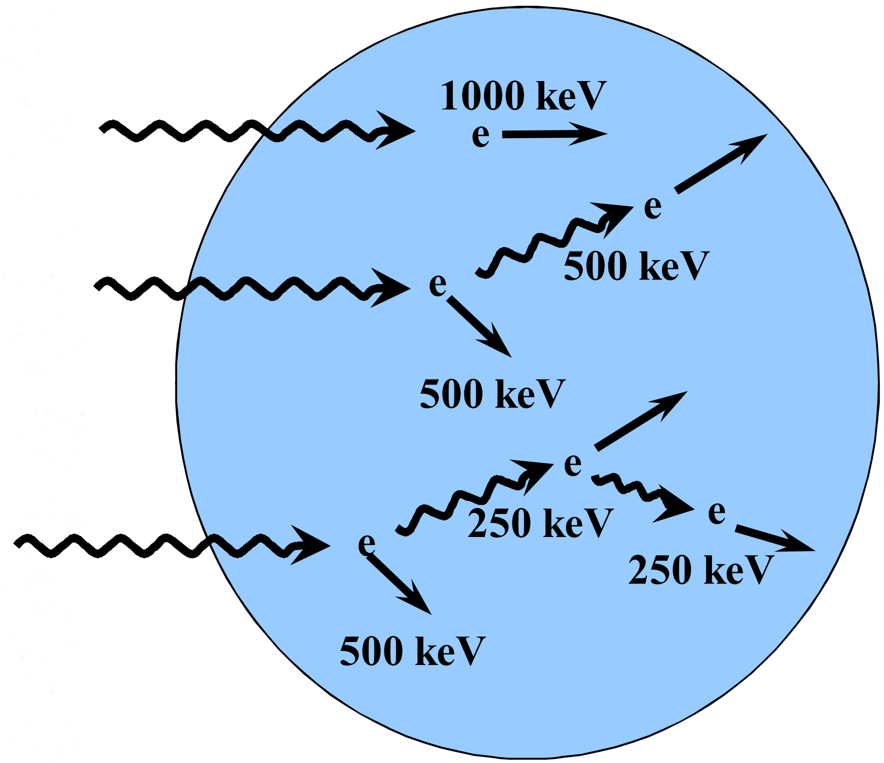


Fig. 1. The probability that N Compton collisions will occur in the full absorption of a γ-ray of 0.66 MeV. The full curve is for a $1\frac{1}{2} \times 2$ inch crystal and the dotted curve for an infinite crystal.



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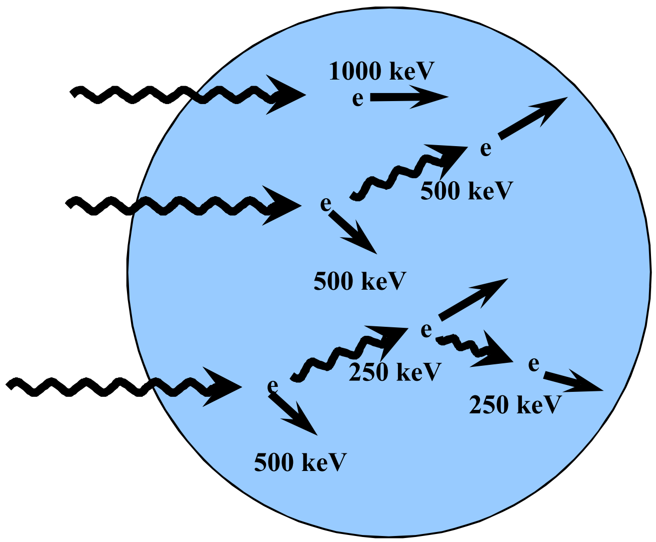
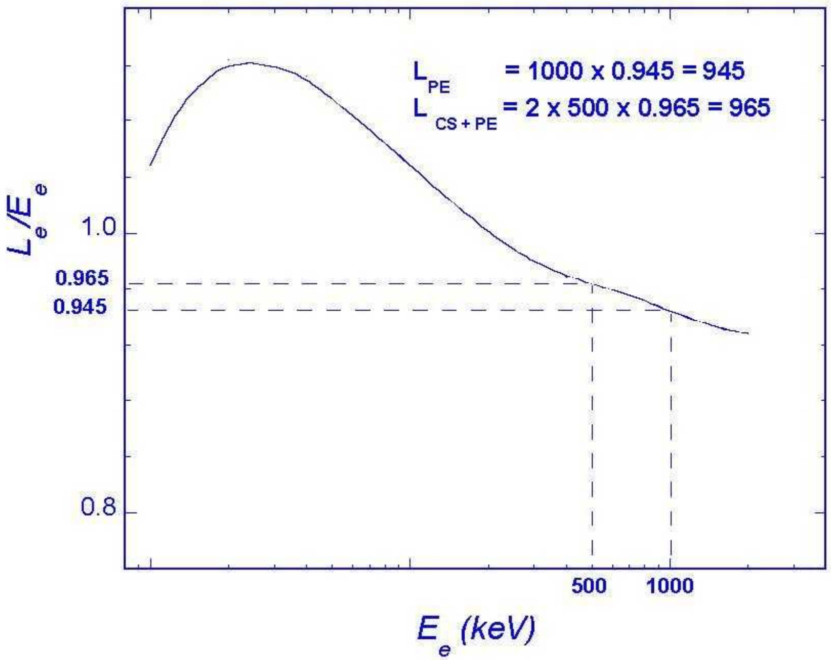
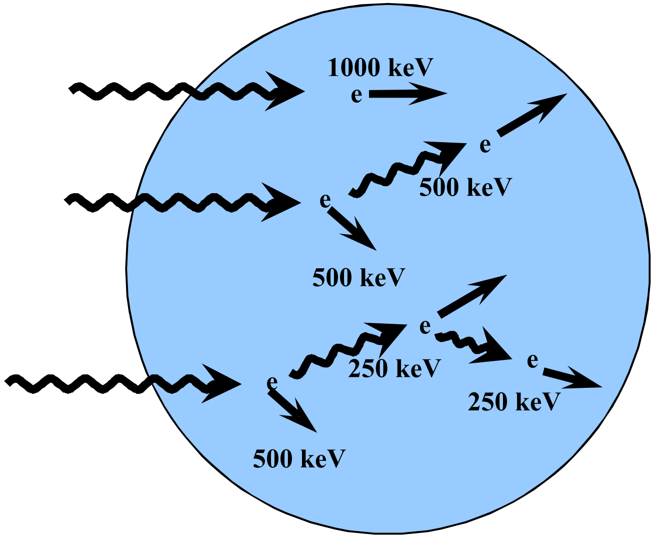
Non-proportionality results in different, multiple interactions pathways producing different amounts of light.





Electron events	Energy(light-output)	Measured Energy
1 electron: 1000keV	E(1000*0.945)	1000 keV
2 electrons: 2*500 keV	E(2*500*0.965)	1021 keV
3 electrons: 500keV +2*250 keV	E(500*0.965+2*250*0.990)	1034 keV

Enhancement Concept: Bulk Crystal



- **Different interaction pathways can not be distinguished from bulk crystals.**

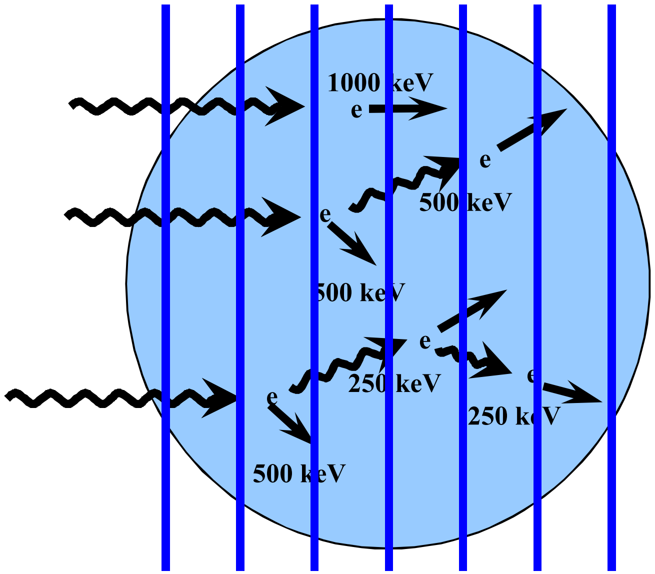
$$\text{Light Output} = \sum_{\text{i}} (\text{Electron Energy} \times \text{Light Yield})_i$$

$$\text{Energy}_{measured} = F(\text{Light Output})$$

$$\text{Energy}_{measured} = F\left(\sum_{i} (\text{Electron Energy} \times \text{Light Yield})_i \right)$$

Electron events	EnergyFunction(light-output)	Measured Energy
1 electron: 1000keV	*F*(1000*0.945)	1000 keV
2 electrons: 2*500 keV	*F*(2*500*0.965)	1021 keV
3 electrons: 500keV +2*250 keV	*F*(500*0.965+2*250*0.990)	1034 keV

Enhancement Concept: Segmented Crystal



- **Measure the individual interactions, and use the known light yield curve to correct.**

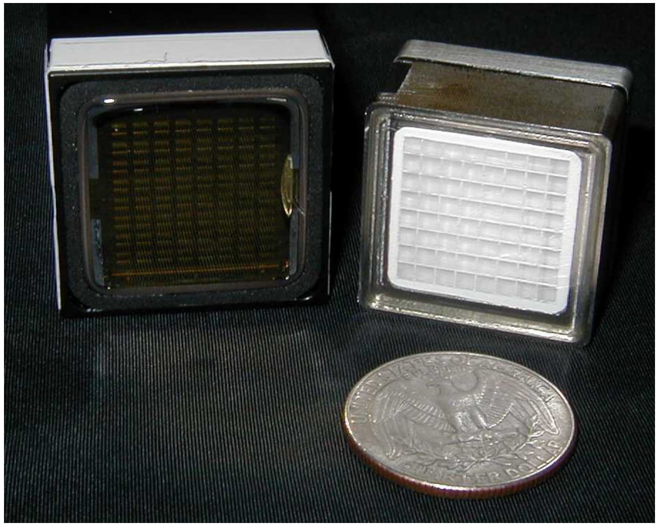
$$\text{Energy}_{measured} = F\left(\sum_i (\text{Electron Energy} \times \text{Light Yield})_i\right)$$

$$\text{Energy}_{measured} = \sum_i F(\text{Light Output})_i$$

Electron events	EnergyFunction(light-output)	Measured Energy
1 electron: 1000keV	*F*(1000*0.945)	1000 keV
2 electrons: 2*500 keV	2**F*(500*0.965)	1000 keV
3 electrons: 500keV +2*250 keV	*F*(500*0.965)+2**F*(250*0.990)	1000 keV

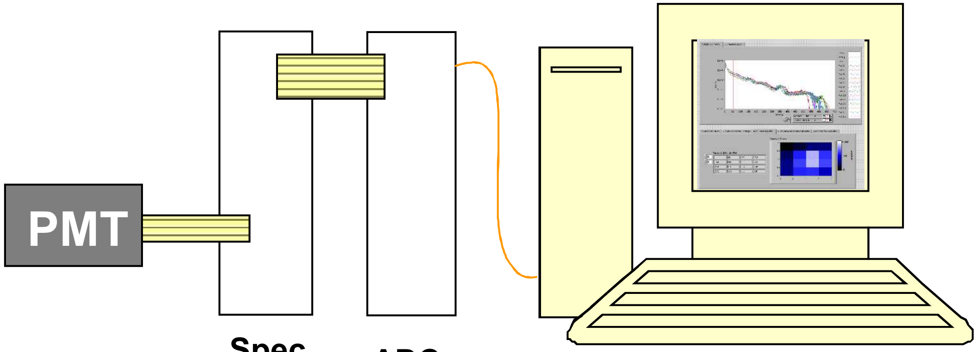
Experimental Work

PMT and NaI Crystal



Segmented NaI Crystal:
(Bicron) 64 2x2 mm NaI crystals wrapped in Teflon

multi-anode PMT:
(Hamamatsu) 8x8 H7546B



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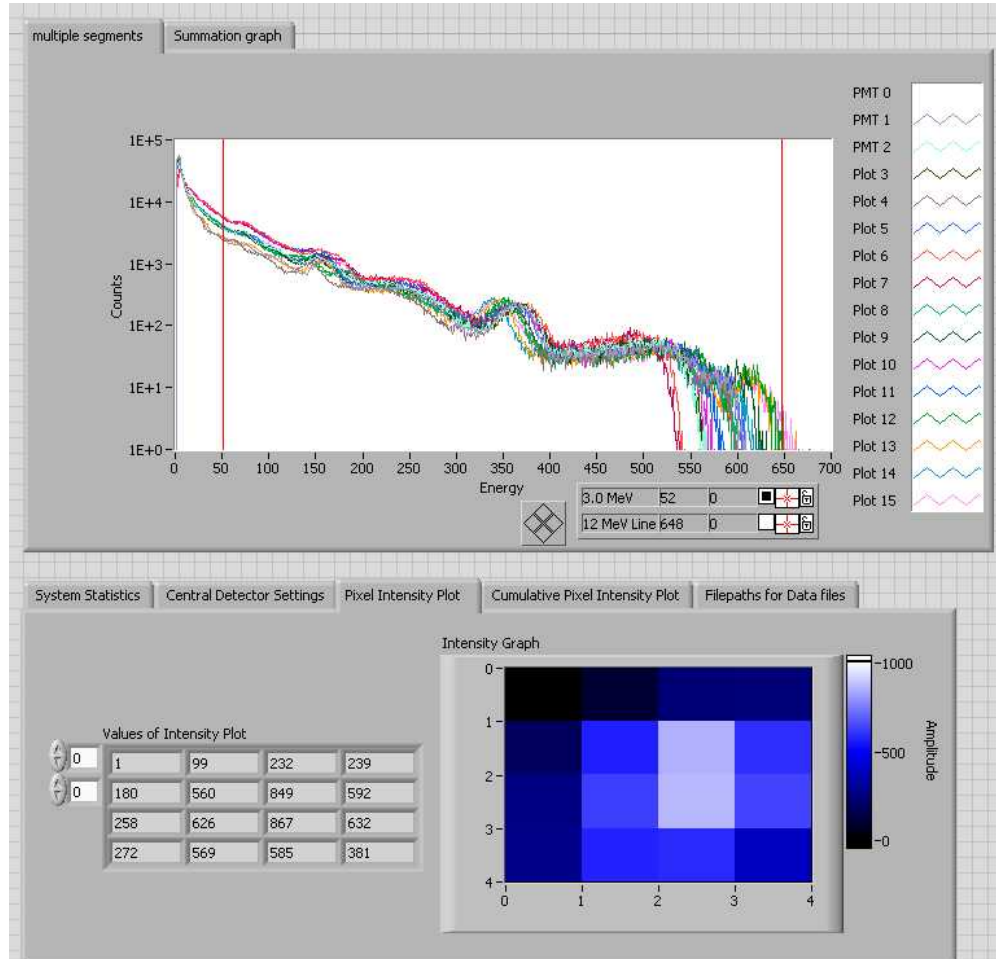
Recent Experimental Results

- Recently acquired 16 channel spectrum of Cs-137.

- 2-D Intensity plot shows cross over between pixels.



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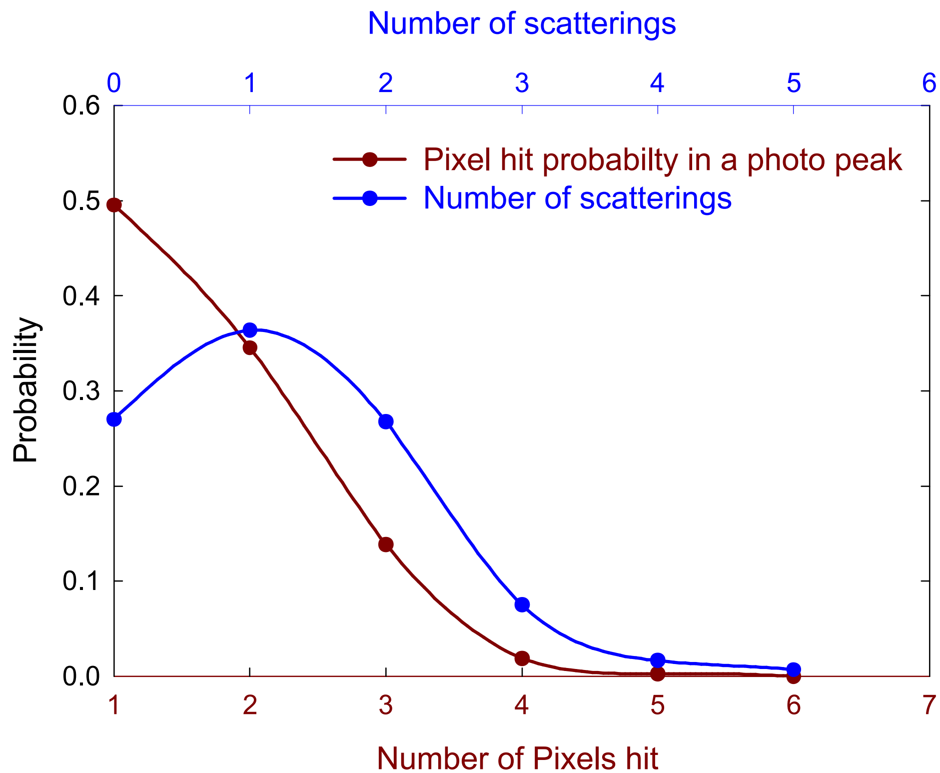
Compton Scattering and Pixel-hit Probability

> 70% of gamma rays have at least one scattering event.

50% of incident gamma rays interact in more than one pixel.



Technique applies to those gamma rays that interact in more than one pixel and deposit all of their energy in the detector.

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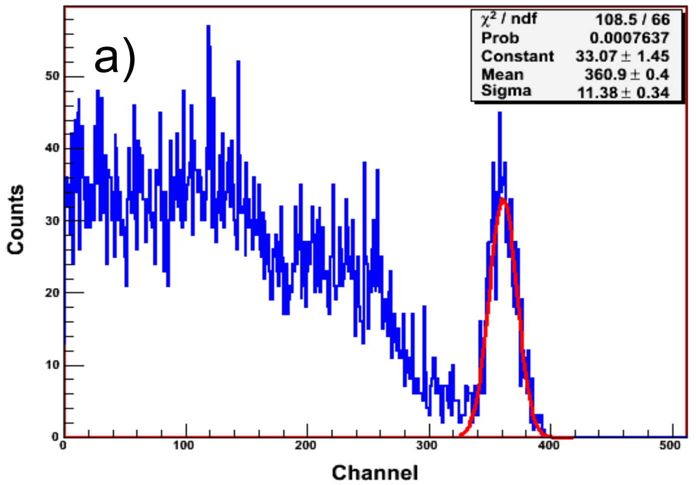
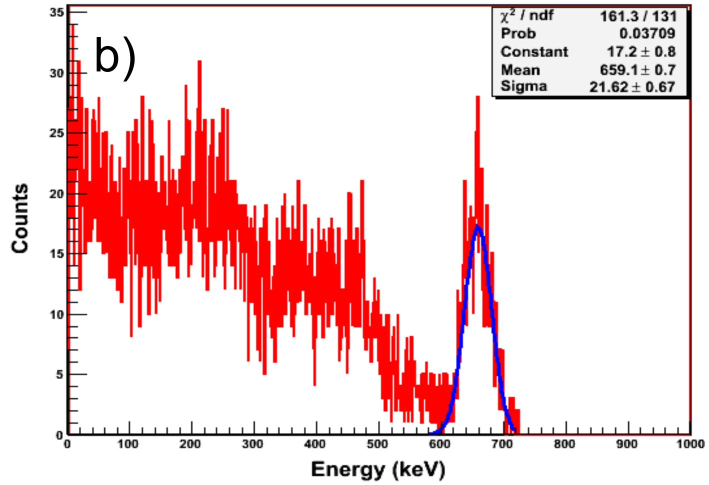
Simulations suggest that effect due to primary electrons is small.

- **Primary electrons are all that we can resolve in the experiment**



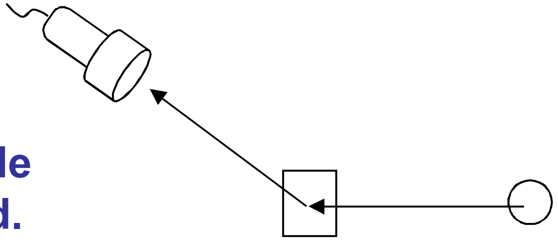
Deconvolved PMT photocathode detected light yield (pulse height) spectrum



Calculated gamma energy deposition spectrum

- **We will confirm the magnitude of the resolution due to primary electrons by a simple expt.**

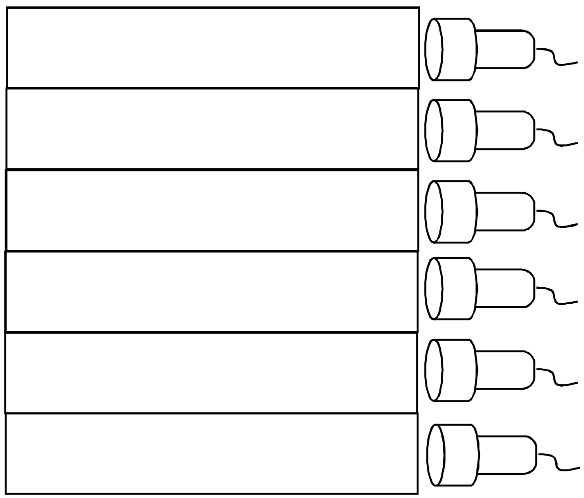
PMT at determined angle from source and NaI crystal. Only single Compton scatters will be detected.



Another material that may benefit from non-linearity correction: plastic for neutron spectroscopy:

- **Resolution for a 1 MeV neutron (e.g. fission) in plastic should be about 20%**
- **In practice is as much 50% in a capture gated spectrometer arrangement**
  - How much could this be improved by resolving individual proton recoils?

Segmented Plastic: neutron detection



Improve resolution of plastic neutron detectors

CONCLUSION

- **We are investigating the nonproportionality of NaI**
- **Computational technique to deconvolve spectra has been developed**
- **We have begun experiments with 64-segment NaI and 64-anode PMT**
- **Looking ahead**
  - improvement in NaI resolution may be modest at best—making LaBr a more practical choice.
  - we will examine the resolution from NaI single-Compton scatter spectrum.
  - can technique be used to improve resolution of plastic neutron detectors?

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