Effect of the time characteristics of the Compton camera on its performance

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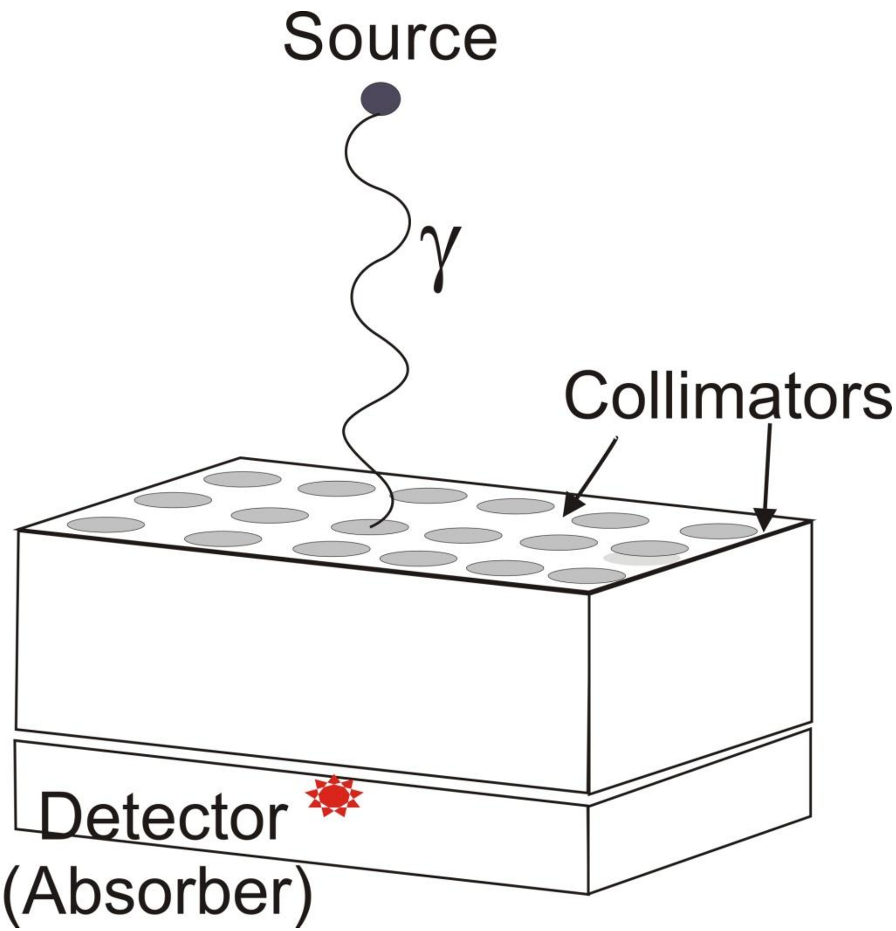
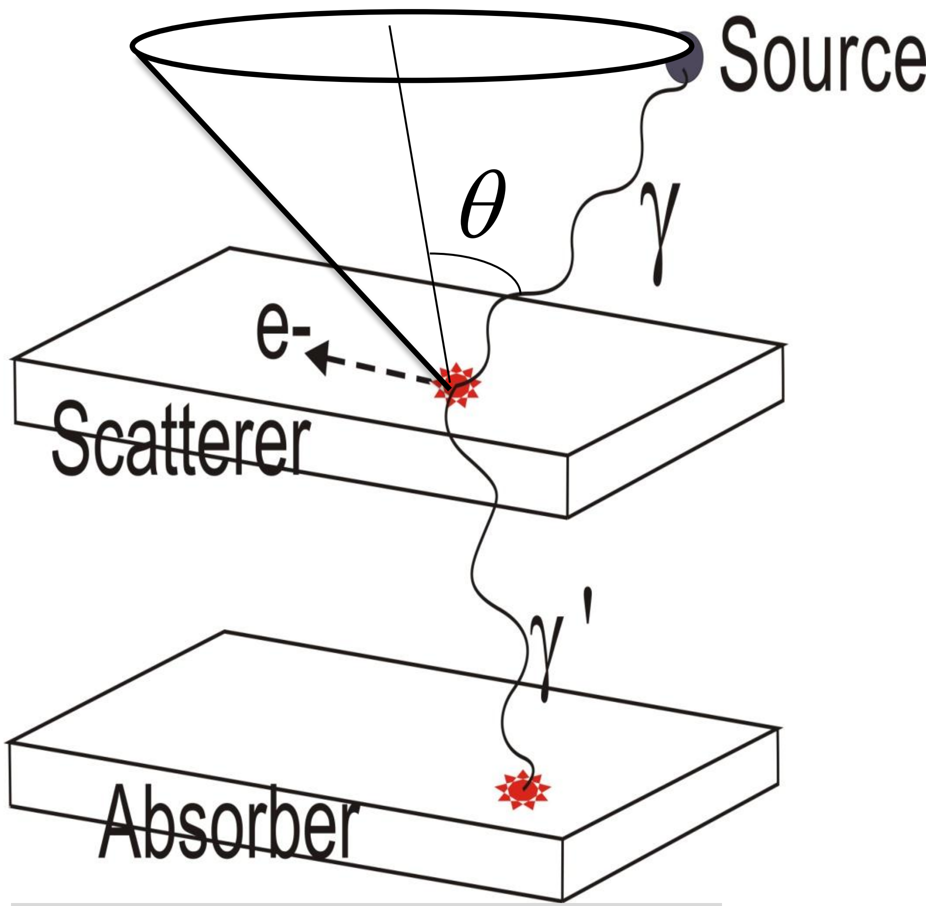
Introduction



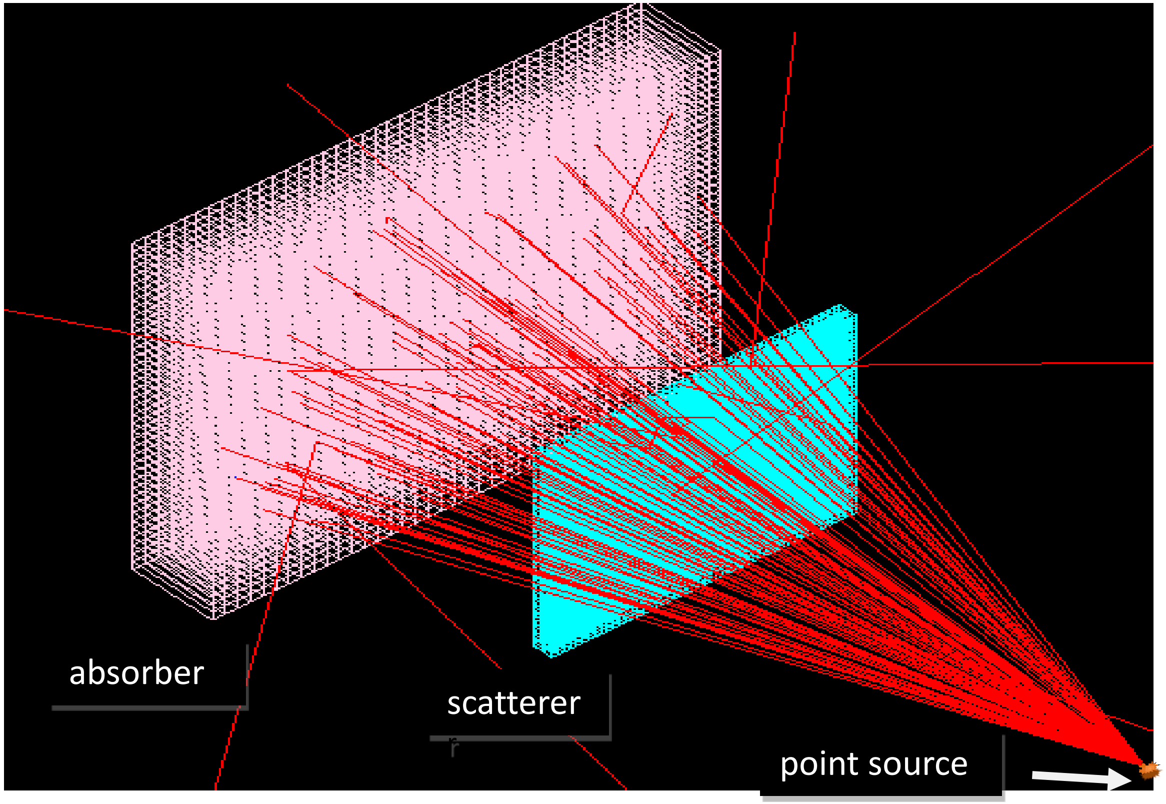
Anger camera



Compton camera

Simulation

GEANT4 simulation software



Compton camera model

Scatterer

- Silicon
- 9 cm x 9 cm x 4 mm
- 1.2 mm x 1.2 mm pixels

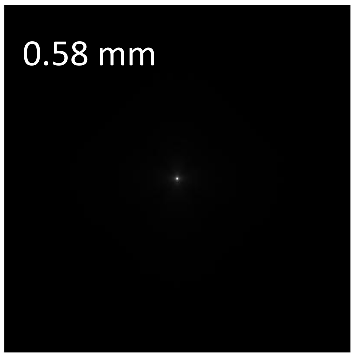
Absorber

- Cadmium-zinc-telluride (CZT)
- 10 cm x 10 cm x 18 mm
- 2.5 mm x 2.5 mm pixels

- Source/scatterer separation 5 or 10 cm
- Scatterer/ absorber separation 10 cm

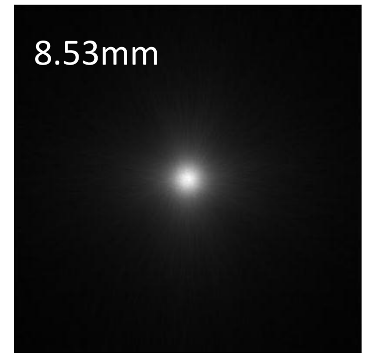
Preliminary results with ^{99m}Tc point source

ideal camera image

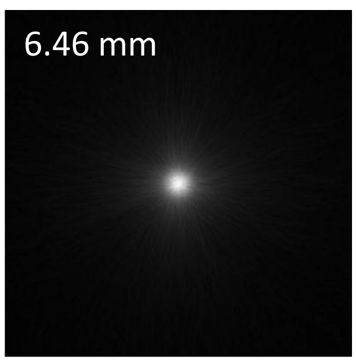


with Doppler broadening

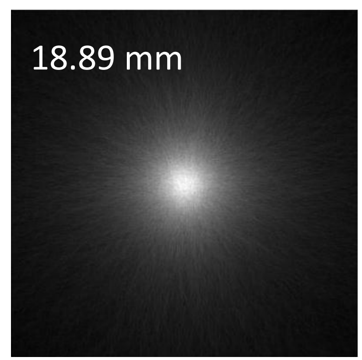
with energy uncertainty



with pixelation



with combined parameters



Camera resolution (mm)

Incident energy (keV)	Ideal camera	With Doppler broadening	With detected energy uncertainty	With pixelation	With combined parameters
140.5	0.58	7.30	8.53	6.46	18.36
511	0.58	2.40	1.85	6.28	7.53

- Doppler broadening & energy detection uncertainty is more significant at lower energies
- At higher energies, detector pixelation is the most significant factor

Comparison with An et al

(140.5 keV source 10 cm from scatterer)

Resolution (mm)

Research group		Ideal camera	With Doppler broadening	With energy uncertainty	With pixelation	With combined parameters
Waikato	Si scatterer 1.2 mm pixels CZT absorber 2.5 mm pixels	0.58	7.30	8.53	6.46	18.36
An et al. (2007)	Si scatterer 3.125 mm pixels Ge absorber 10 mm pixels	0.38	7.99	8.74	16.50	20.30

- even if the most significant contributor to resolution degradation is reduced, the resolution of the image may not improve significantly

Aim

To investigate the effects on Compton camera images by

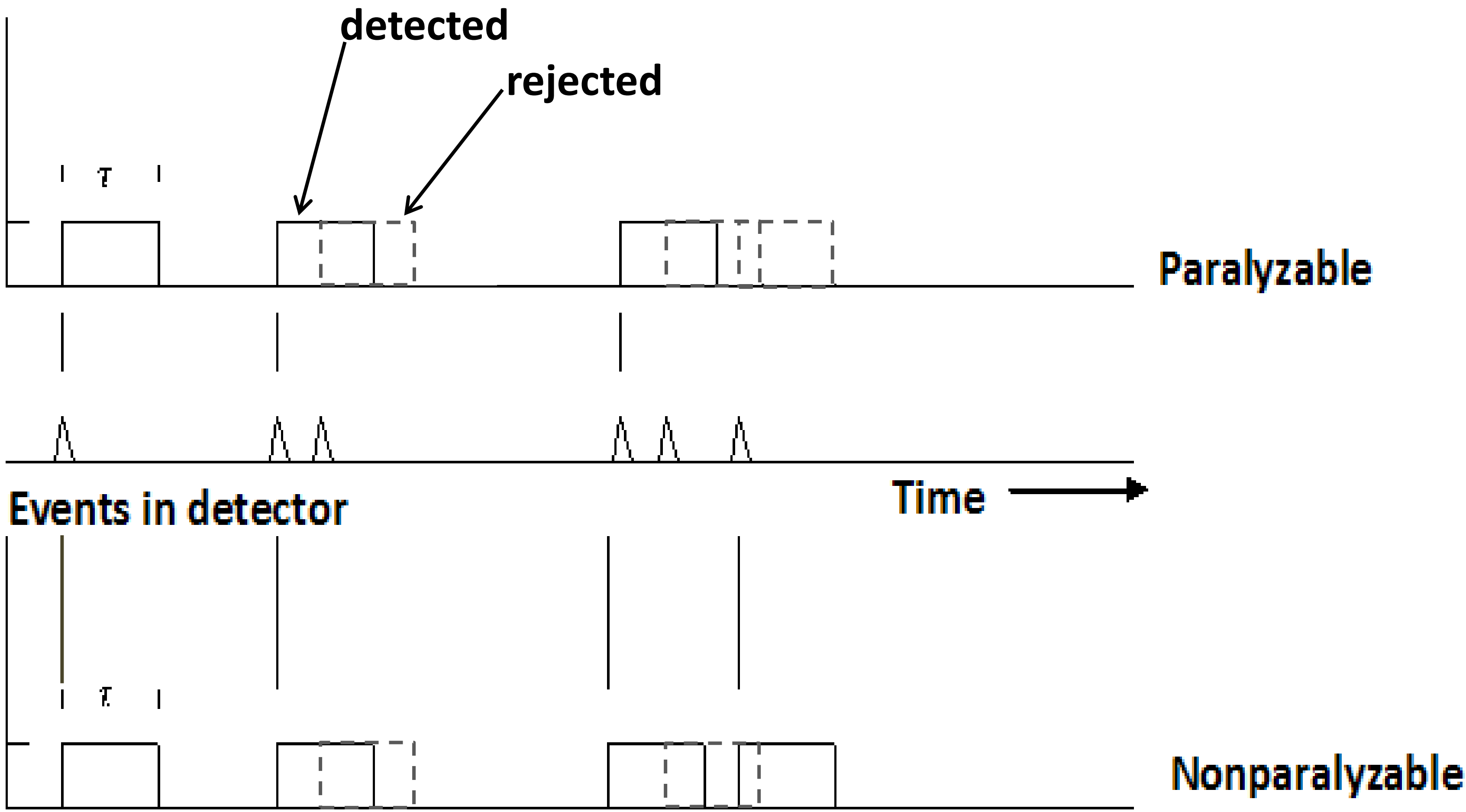
- dead time
- energy discrimination

Modelling of the Compton camera time characteristics

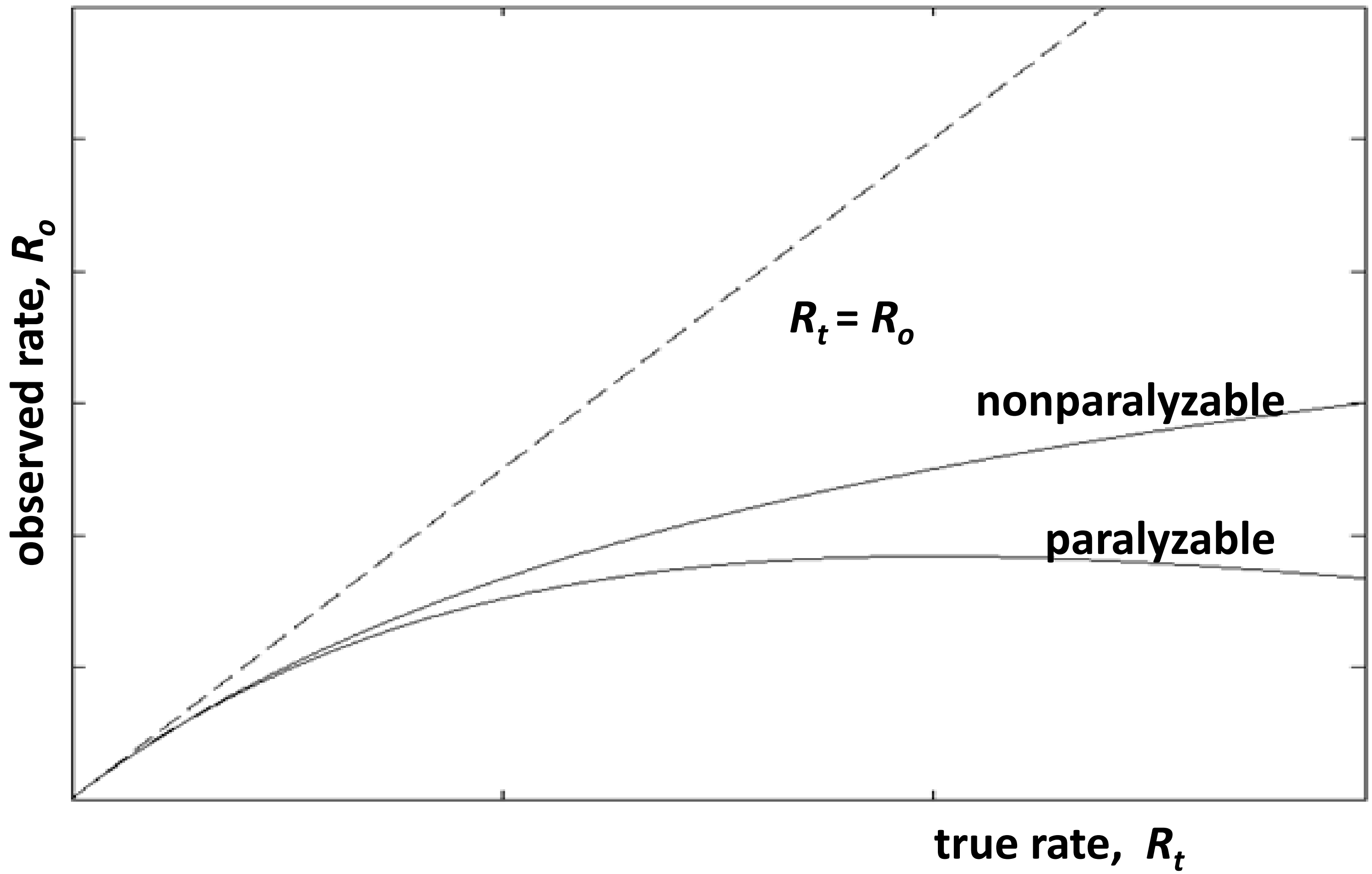
Parameters of interest –

- Decay times – **G4Poisson class (decay constants, activity)**
- Detection times - **Decay times + interaction times**
- Detection time jitter – **G4Gauss class**
- Energy discrimination levels
- System dead time – **processed with MATLAB code**
- Coincident timing

Dead time τ



How dead time affects count rate



Does a Compton camera follow a paralyzable or a non-paralyzable model?

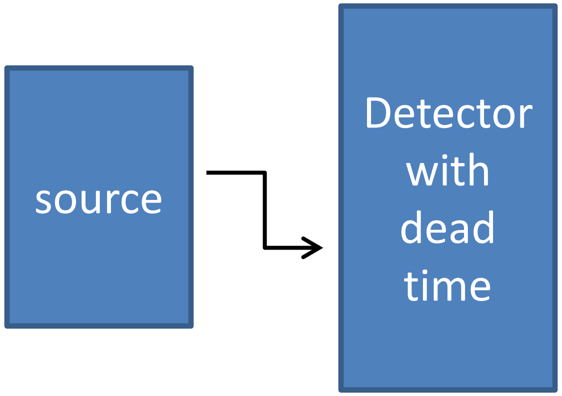
Scatterer, absorber and amplifiers → paralyzable

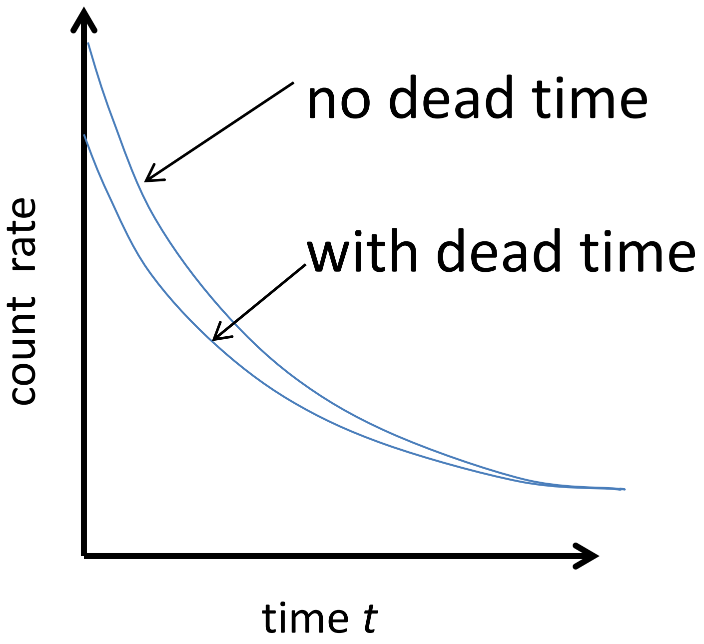
Coincidence detectors and m/c analyzers → non-paralyzable

One of these will dominate – but which one?

Estimate the dead time using the “decaying source method”

Decaying source method





decay constant is smaller if have dead time

If system is non-paralyzable

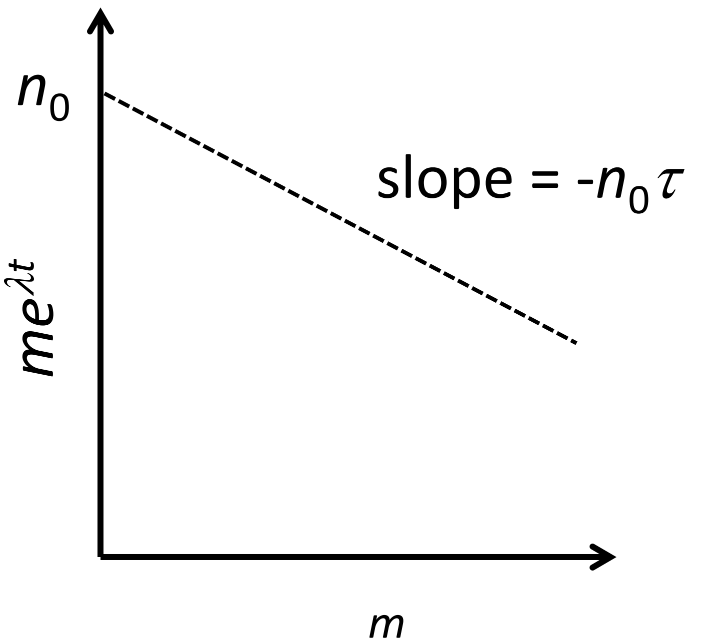
n = true rate

m = recorded rate

τ = dead time

$$n = \frac{m}{1 - m\tau}$$

$$me^{\lambda t} = -n_0 \tau m + n_0$$



If system is paralyzable

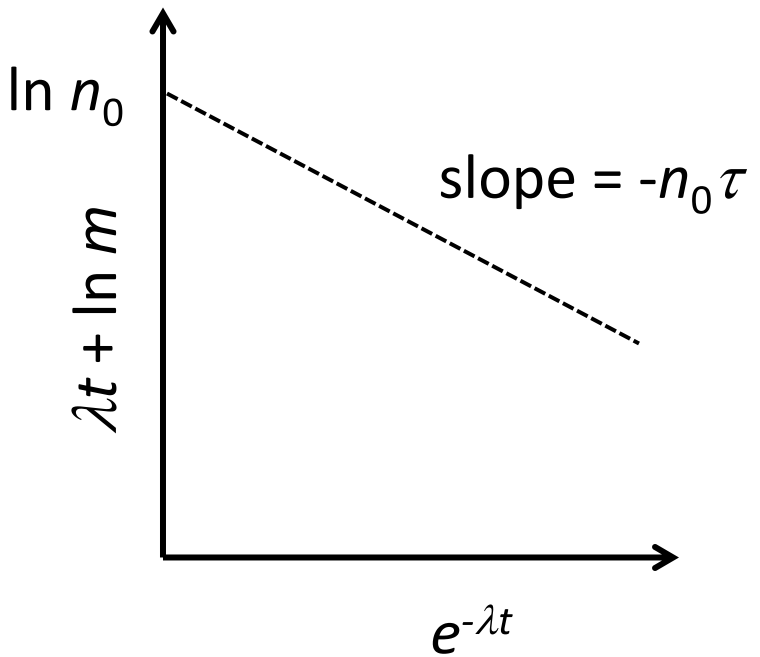
n = true rate

m = recorded rate

τ = dead time

$$m = ne^{-n\tau}$$

$$\lambda t + \ln m = -n_0 \tau e^{-\lambda t} + \ln n_0$$

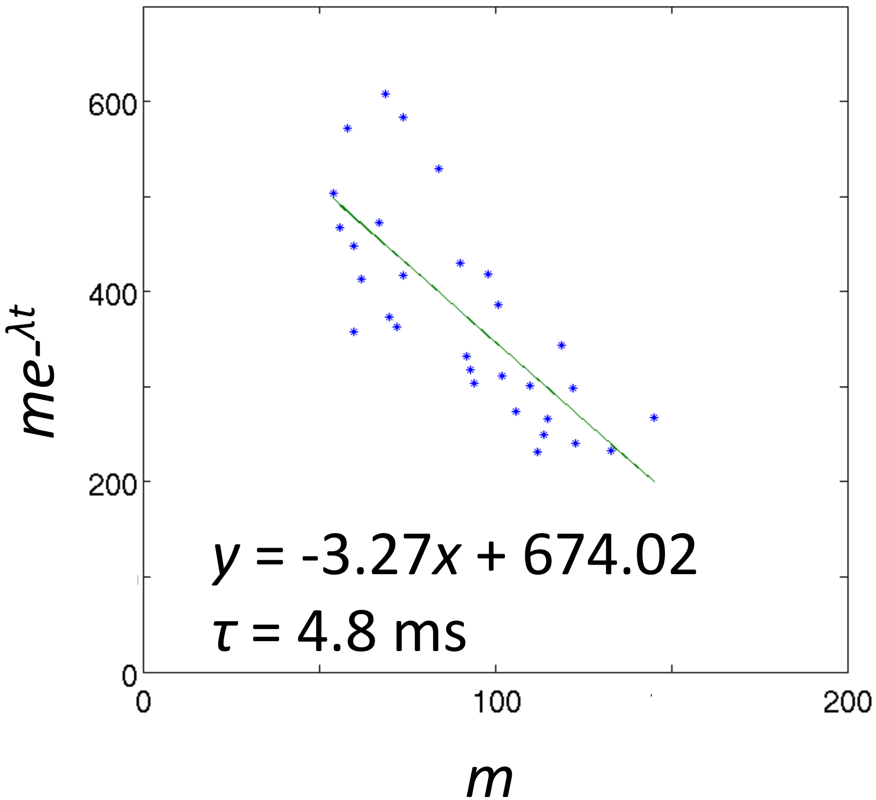


Does a Compton camera follow a paralyzable or a non-paralyzable model?

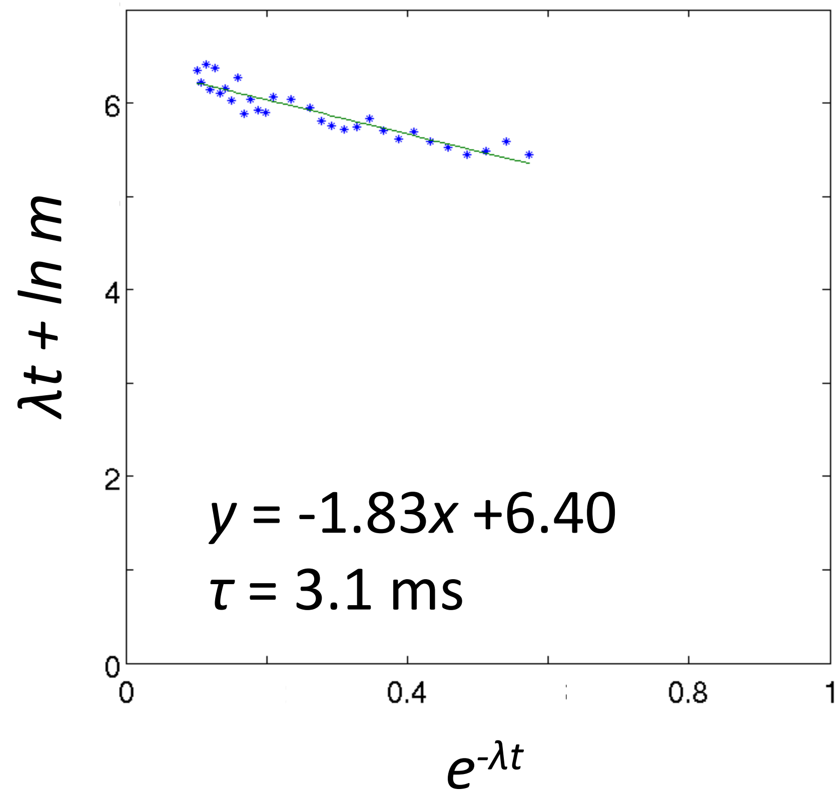
- Model a camera with fast-decaying isotope (^{15}O)
- Plot graphs for both non-paralyzable and paralyzable from count rates
- See which gives a straight line, and get dead time

Estimation of the camera dead time

nonparalyzable



paralyzable



- Paralyzable seems to be the most appropriate model

System dead time comparison

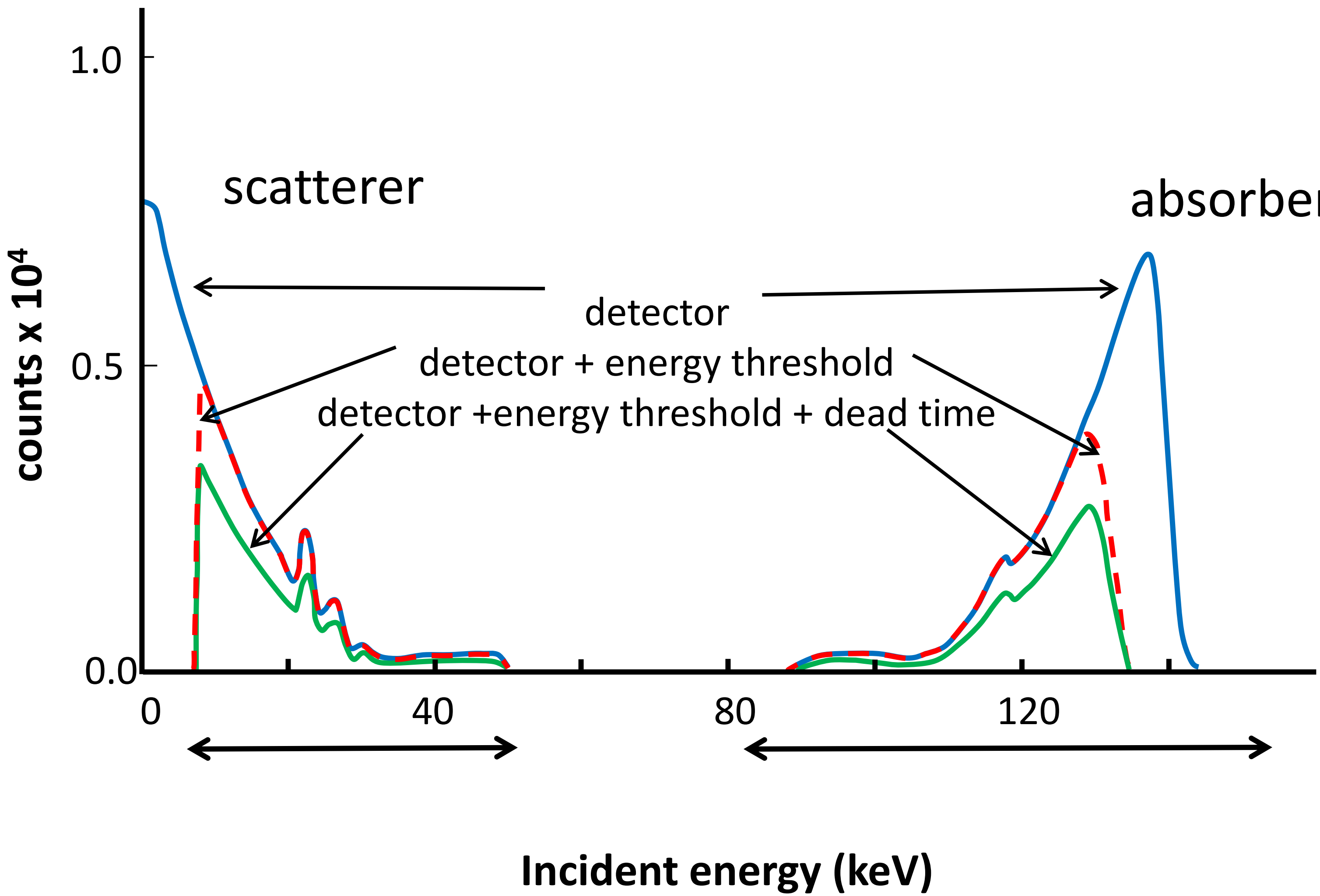
	Dead time	
Experiment	**Nonparalyzable (ms)**	**Paralyzable (ms)**
Simulation (present study)	**4.8**	**3.1**
Laboratory (LeBlanc et al. (1998))	**8.5**	**3.8**

Estimated processing time of silicon pad detectors per event = 1 – 3 ms

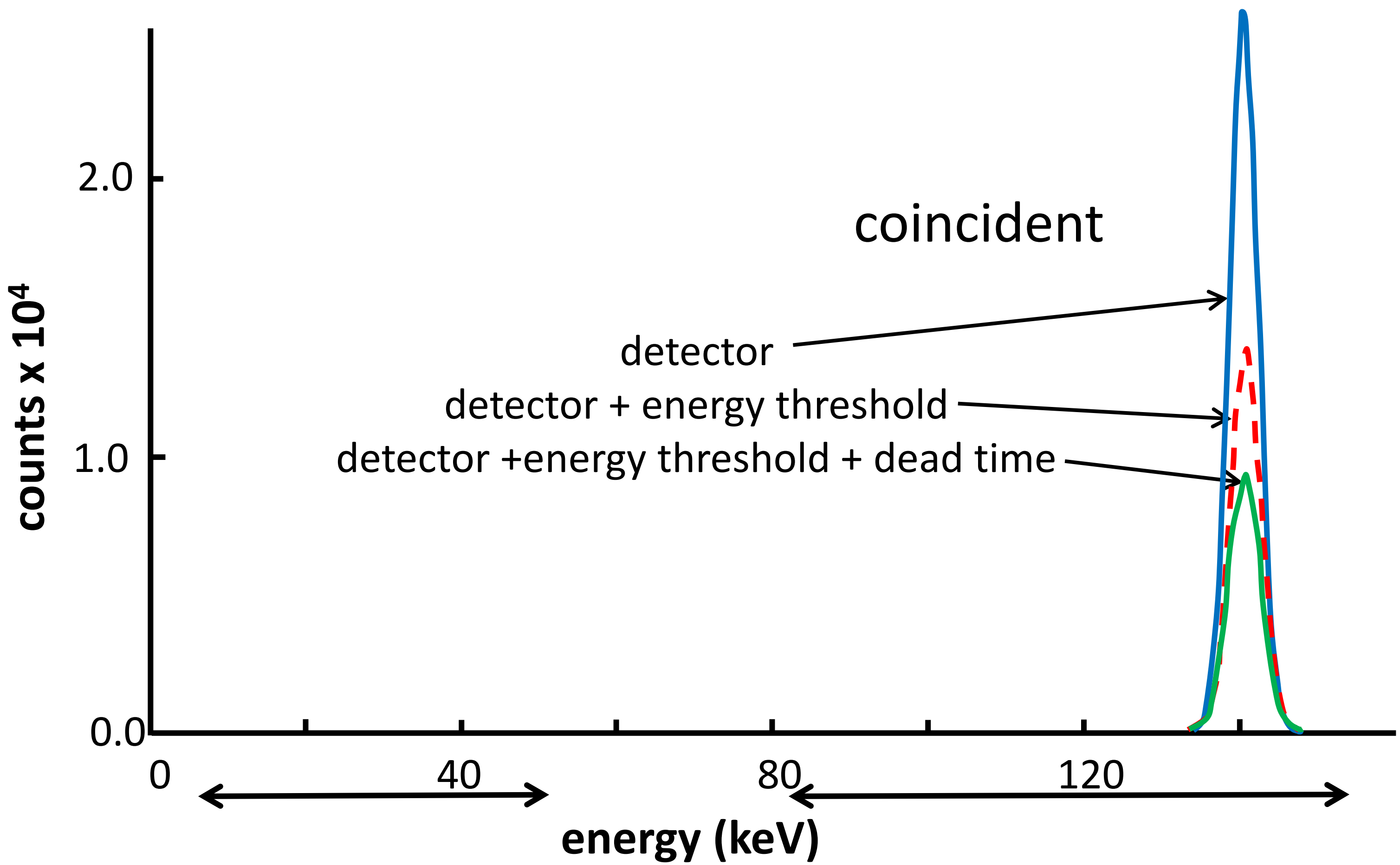
Detection considerations

- Detected scatterer and absorber interactions must be ‘coincident’
- Scattering must occur before absorption
- Sum of scattered electron+ absorber-detected energies must be that of initial gamma energy
- Should put energy threshold limits on detectable energies for scatter and absorber
  - Scatterer lower level to reject noise
  - Scatterer upper level to allow for large fraction of single Compton scattering events
  - Absorber limits to allow all possible energy depositions whose sum falls in coincidence window

Energy spectra for 10 MBq Tc99m radiotracer



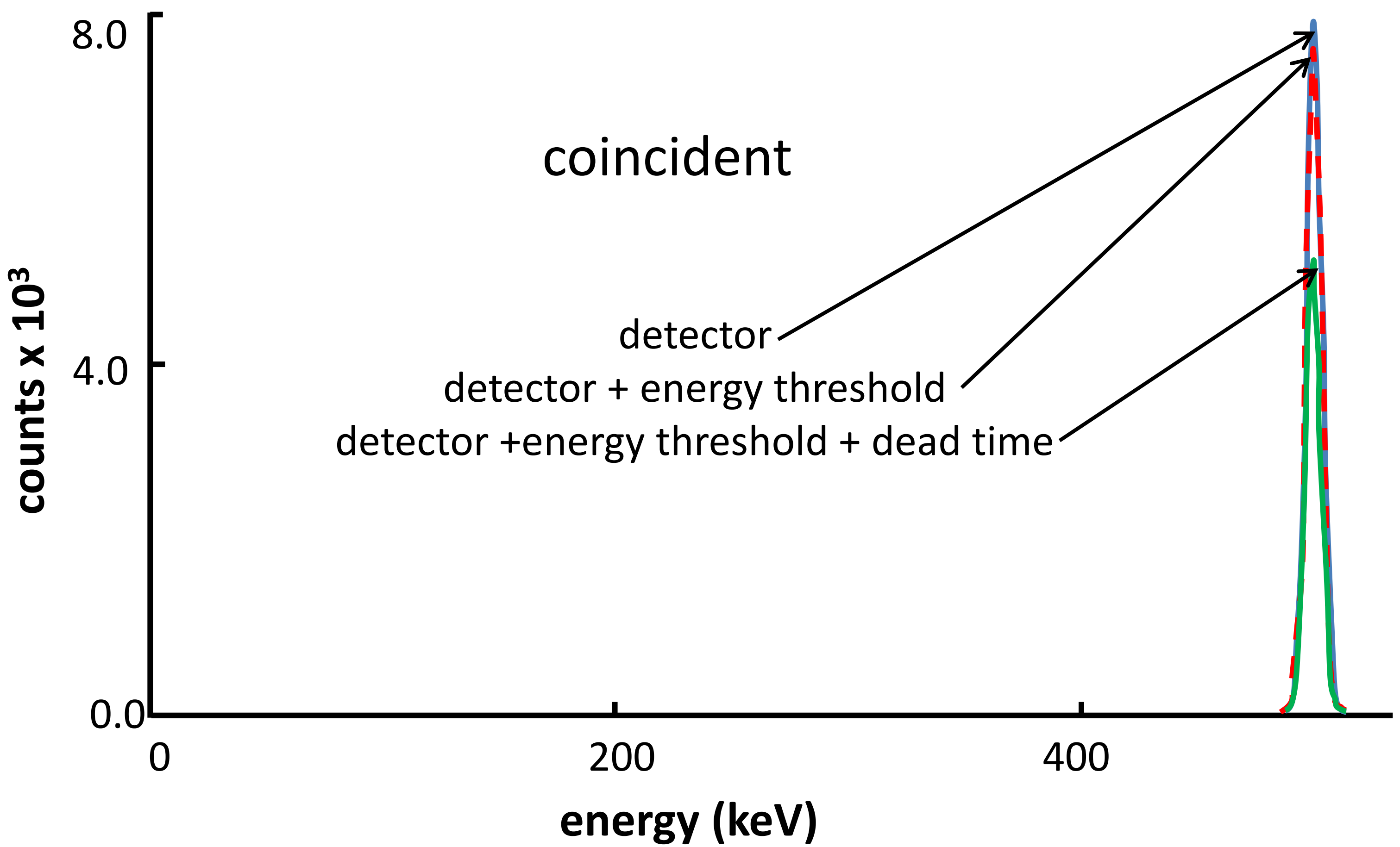
Energy spectra for 10 MBq 99mTc radiotracer



initial coincident detection efficiency = 8.99×10^{-4}

final coincident detection efficiency = 3.16×10^{-4}

Energy spectra for 10 MBq 18F radiotracer



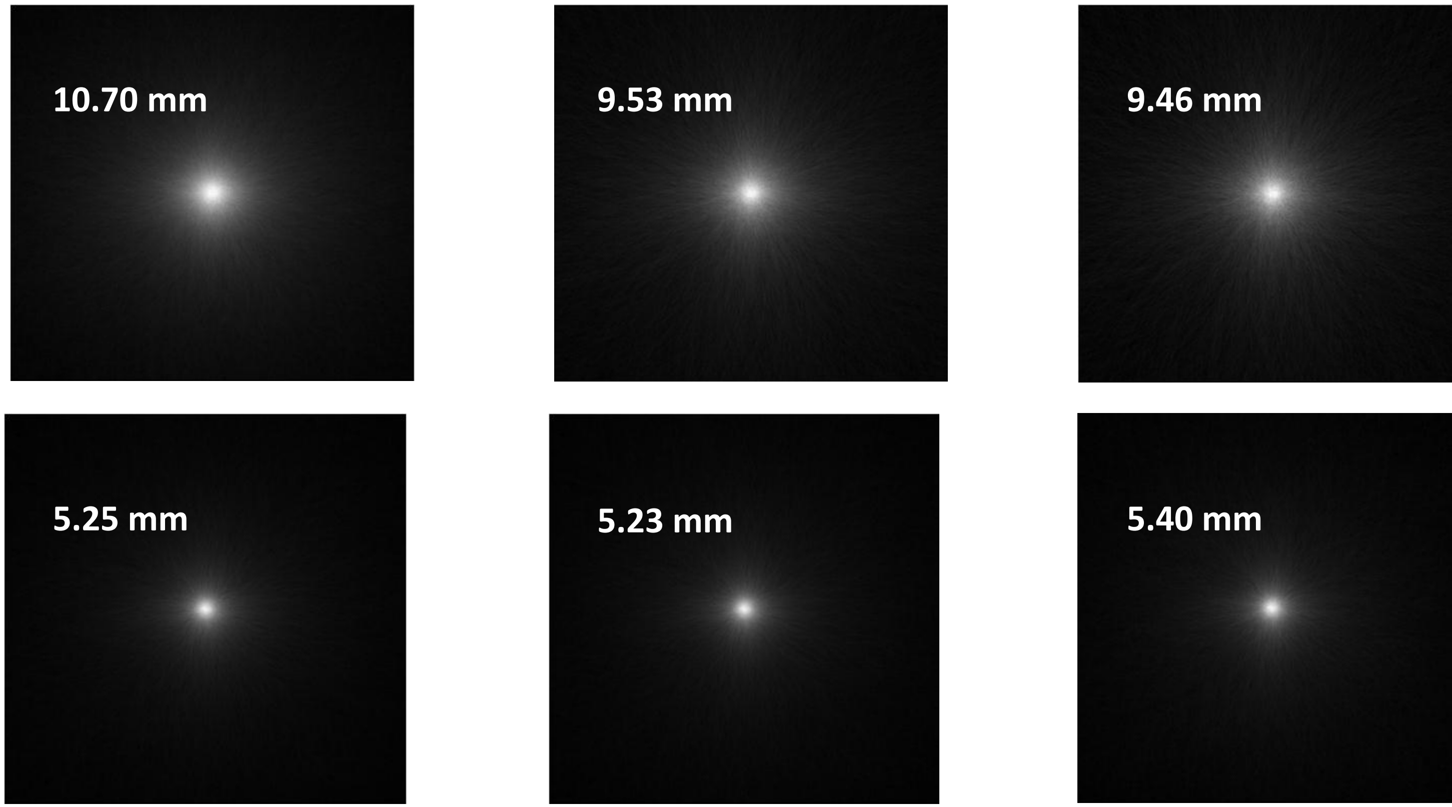
initial coincident detection efficiency = 3.84 × 10^{-4}
final coincident detection efficiency = 3.10 × 10^{-4}

Compton camera image resolution

source-to-scatterer distance = 5 cm

^{99m}Tc (140.5 keV)

^{18}F (511 keV)



no energy discrimination & dead time

with energy discrimination

with energy discrimination & dead time

- energy discrimination and dead time do not affect resolution very much

Conclusions

- Compton cameras are basically paralyzable
- Dead time and energy discrimination reduces efficiency, especially at lower energies
- Accounting for dead time and energy discrimination improves resolution marginally at lower energies, but seems to have little effect at higher energies.