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Simulation of Gamma Ray response of Detectors

Anton Khaplanov

www.europeanspallationsource.se
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Introduction

What is gamma sensitivity?
Gamma interactions
Low-energy effects
High-energy effects
Definition of gamma-sensitivity

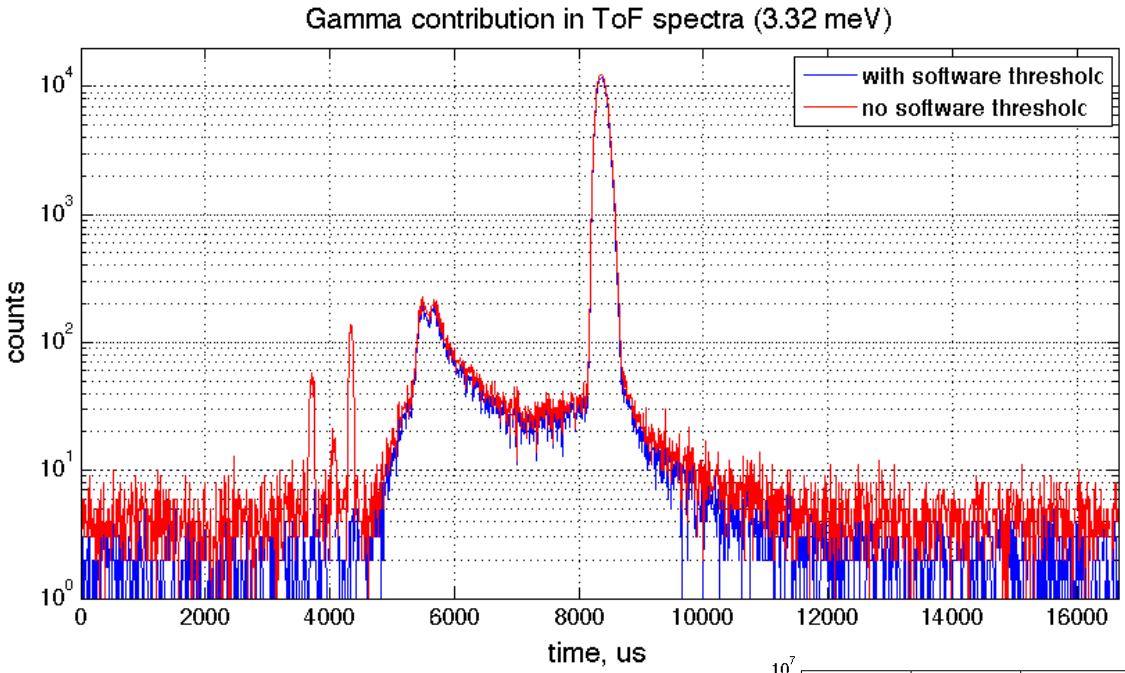
A. Khaplanov et al. "Investigation of gamma-ray sensitivity of neutron detectors based on thin converter films", Journal of Instrumentation 8, P10025 (2013); doi:10.1088/1748-0221/8/10/P10025; arXiv:1306.6247v1.

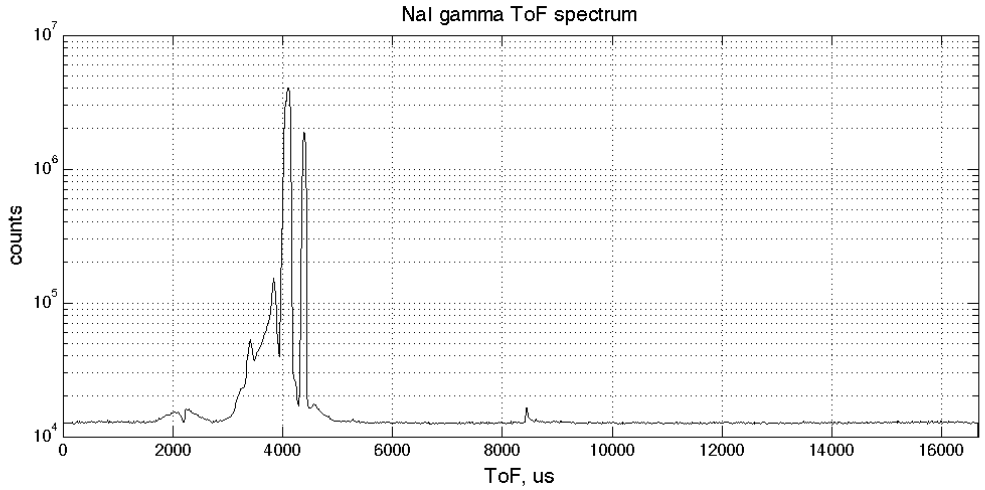
A.Khaplanov, PhD thesis, “Position-sensitive germanium detectors for gamma-ray tracking, imaging and polarimetry”
Trita-FYS, ISSN 0280-316X ; 2010:04

Gamma “efficiency” vs “sensitivity”

The same thing.
Except we aim to minimize gamma efficiency and maximize neutron efficiency (in neutron detectors…)

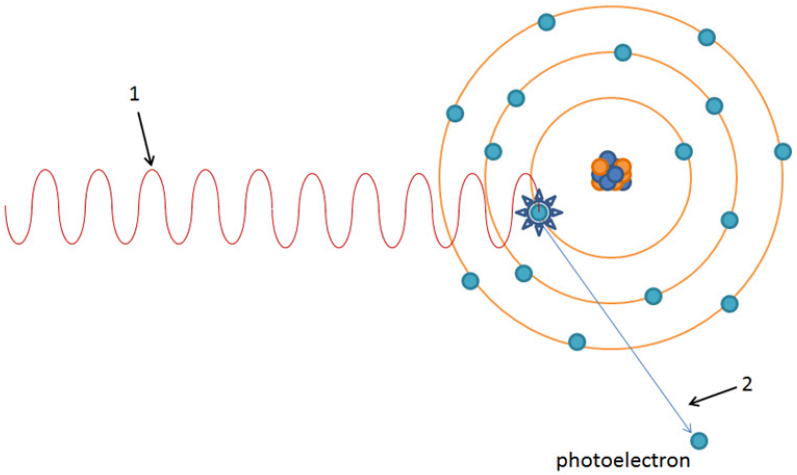
Gamma detection in neutron detectors



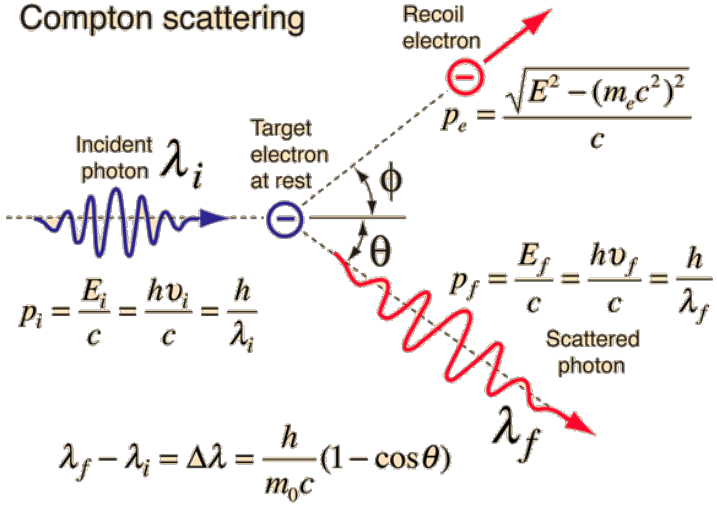


Gamma interactions

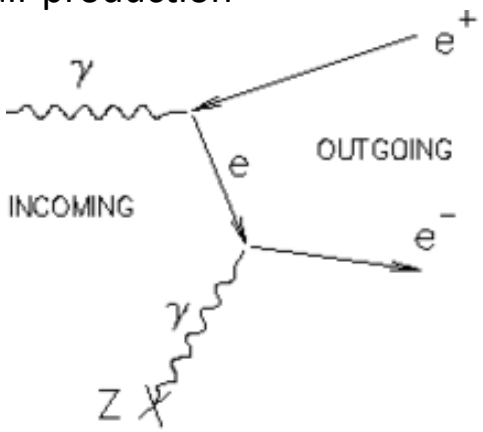
Photoelectric effect



Compton scattering



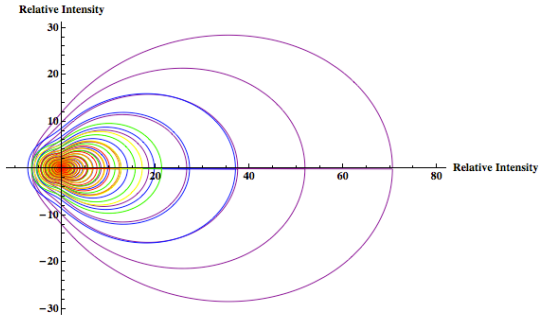
Pair production



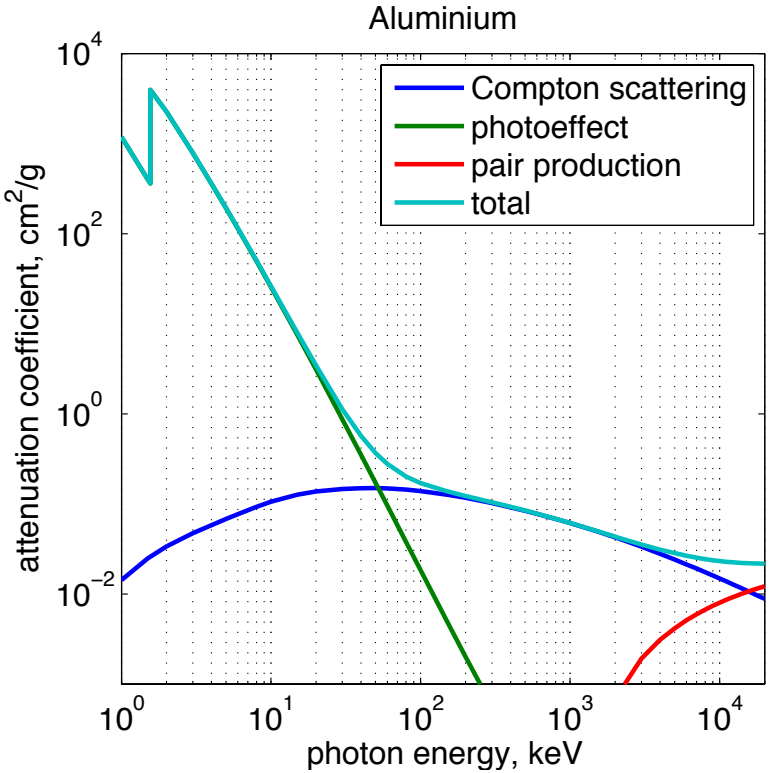
Rayleigh scattering for γ energies:

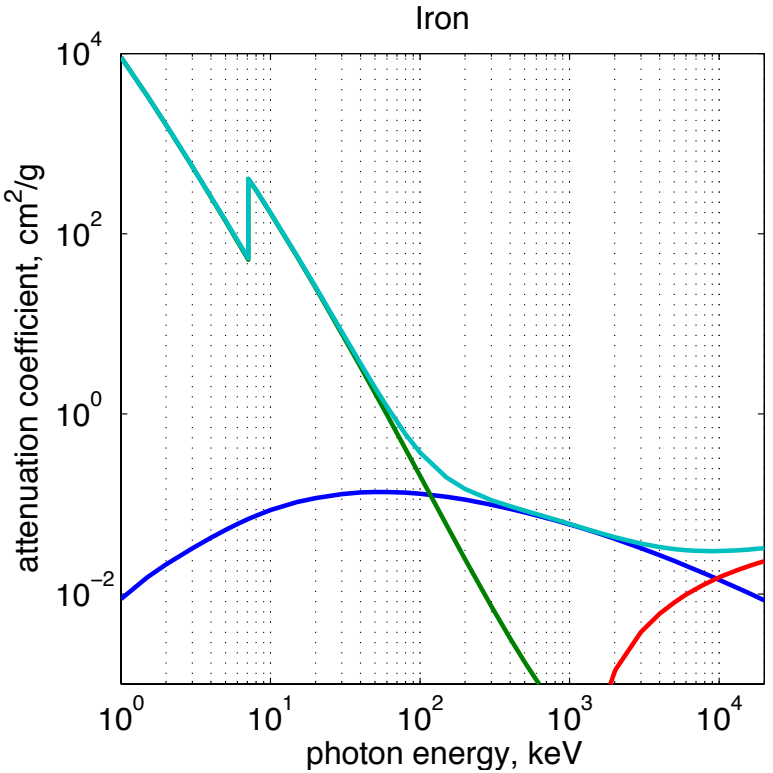
- Forward-focused
- Inelastic
- Low cross section

→ Usually neglected



Gamma Interactions

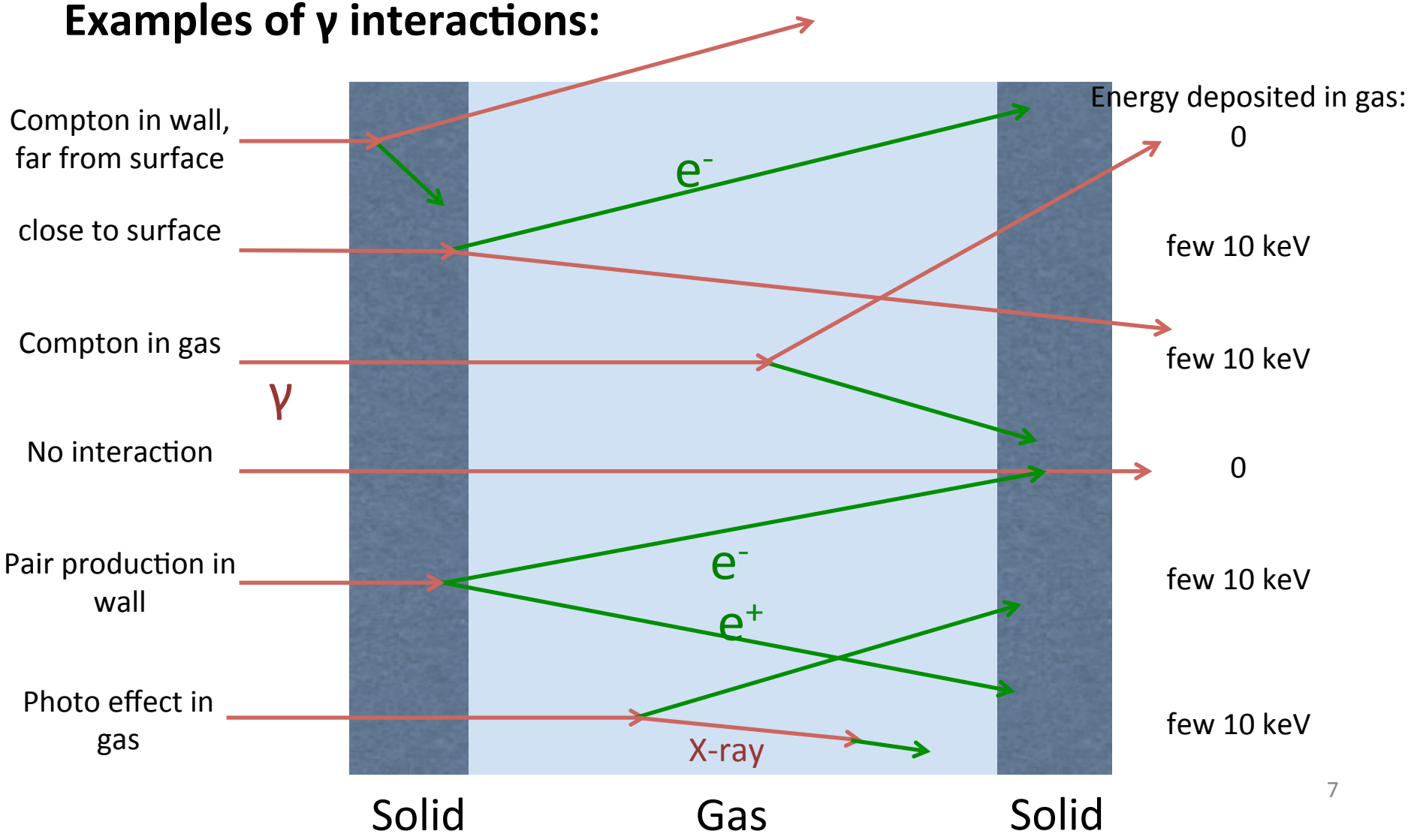




M.J. Berger et al.,
XCOM: Photon Cross Sections Database
http://www.nist.gov/pml/data/xcom/index.cfm

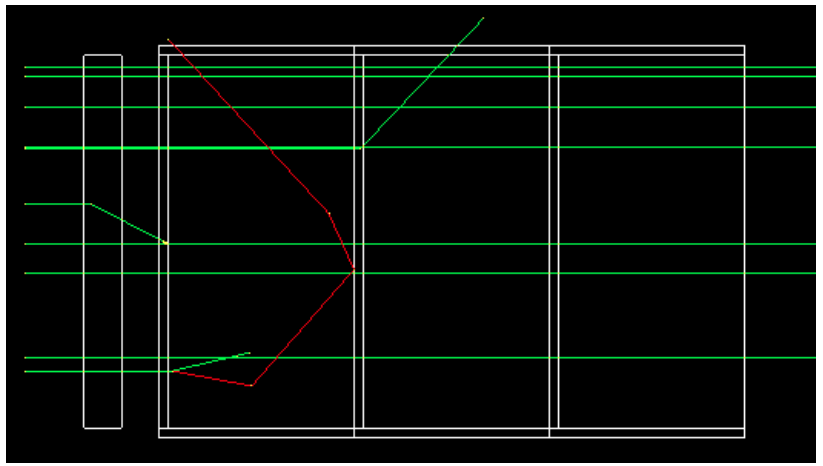
Gamma detection in neutron detectors

Examples of γ interactions:

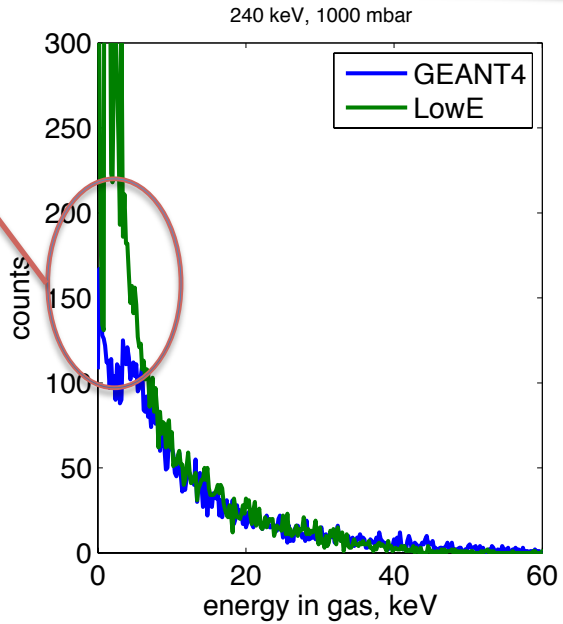


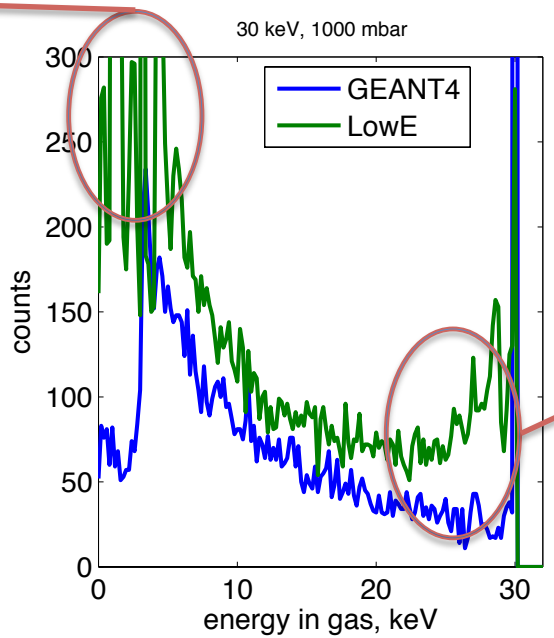
Low energy effects

- Momentum of e- before Compton or photo-interaction
- Production / tracking of x-rays
- Production / tracking of Auger electrons



Al x-rays detection





Ar x-ray escape

Gamma interaction simulation

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```
if (particleName == "gamma") {
pmanager->AddDiscreteProcess(new G4PhotoElectric);
pmanager->AddDiscreteProcess(new G4ComptonScattering);
pmanager->AddDiscreteProcess(new G4GammaConversion);
```

```
if (particleName == "gamma") {
pmanager->AddDiscreteProcess(new G4LowEnergyPhotoElectric);
pmanager->AddDiscreteProcess(new G4LowEnergyCompton);
pmanager->AddDiscreteProcess(new G4GammaConversion);
```

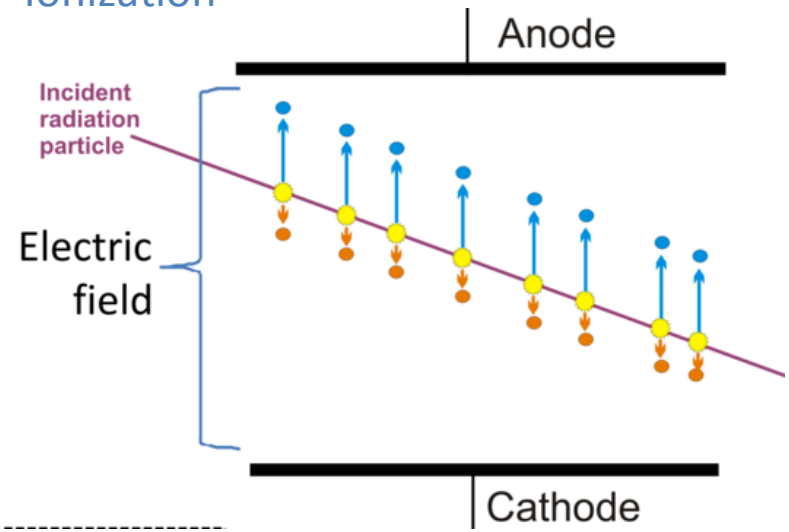
```
if (particleName == "gamma") {
pmanager->AddDiscreteProcess(new G4PenelopePhotoElectric);
pmanager->AddDiscreteProcess(new G4PenelopeCompton);
pmanager->AddDiscreteProcess(new G4GammaConversion);
```

S. Chauvie et al.,
Geant4 low energy electromagnetic physics,
IEEE NSS Conf. vol .3 (2004) 1881 - 1885.

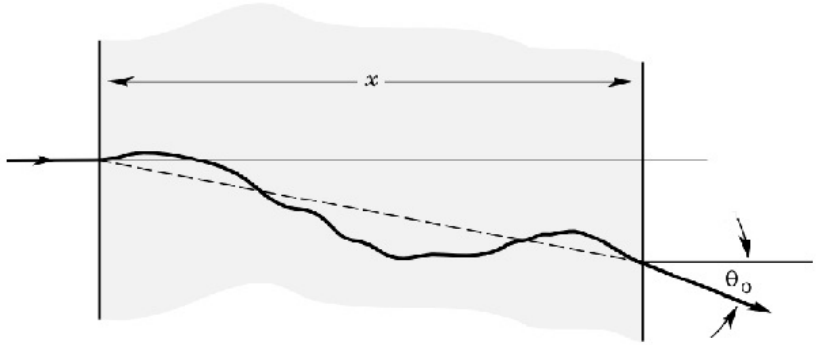
J. Sempau et al.,
Experimental benchmarks of the Monte Carlo code PENELOPE,
Nucl. Instr. Meth. B 207 (2003) 107-123.

e- / e+ interactions

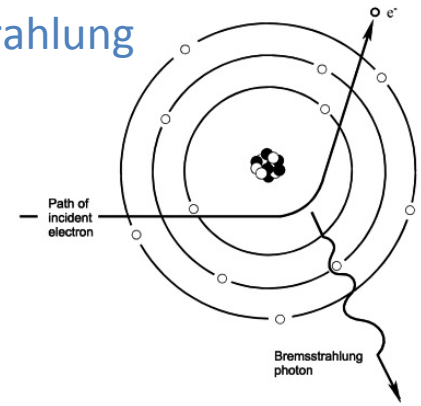
Ionization



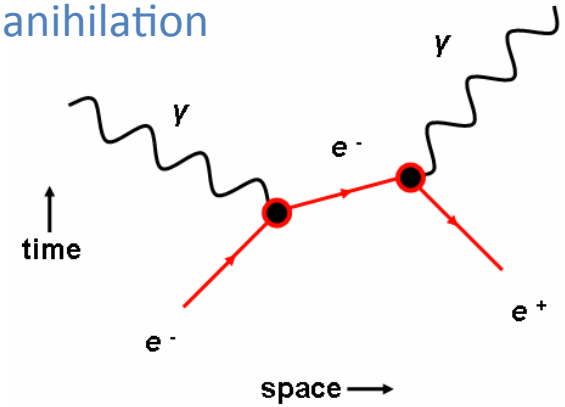
Multiple scattering



Bremsstrahlung



e+ / e- anihilation



e- / e+ interaction simulation

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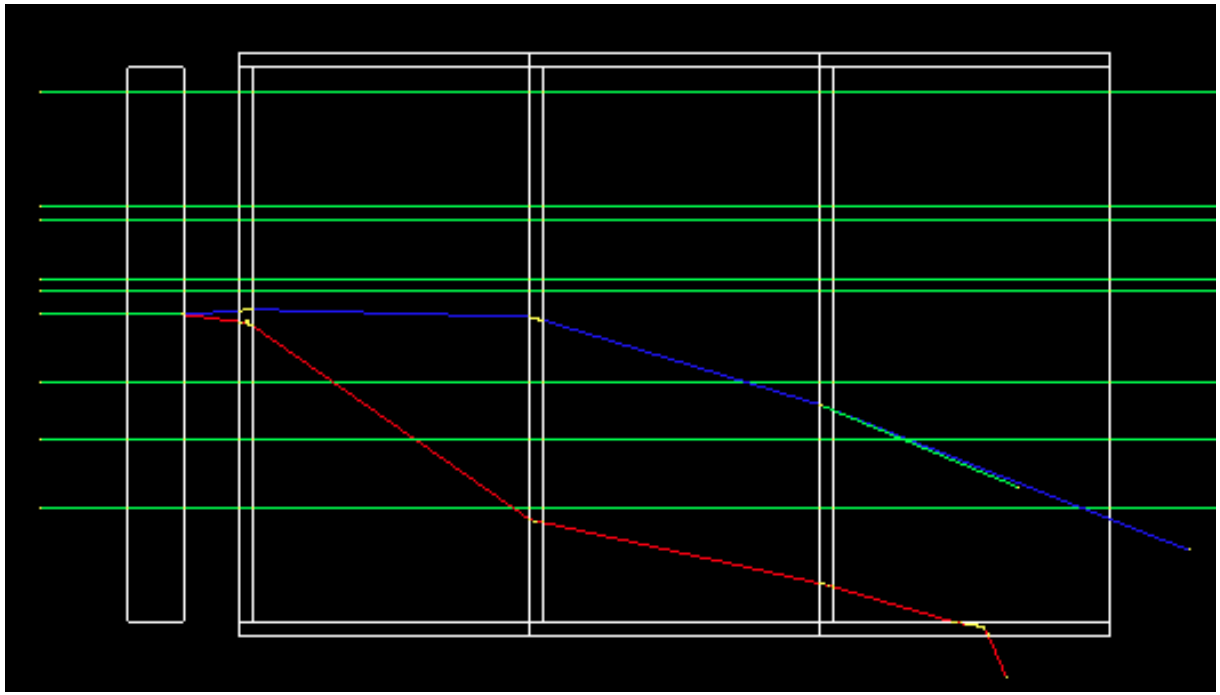
```
if (particleName == "e-") {
        pmanager->AddProcess(new G4eMultipleScattering,-1, 1, 1);
        pmanager->AddProcess(new G4eIonisation,        -1, 2, 2);
        //pmanager->AddProcess(new G4LowEnergyIonisation,        -1, 2, 2);
        //pmanager->AddProcess(new G4PenelopeIonisation,        -1, 2, 2);
        pmanager->AddProcess(new G4eBremsstrahlung,    -1, 3, 3);
}
else if (particleName == "e+") {
        pmanager->AddProcess(new G4eMultipleScattering,-1, 1, 1);
        pmanager->AddProcess(new G4eIonisation,        -1, 2, 2);
        pmanager->AddProcess(new G4eBremsstrahlung,    -1, 3, 3);
        pmanager->AddProcess(new G4eplusAnnihilation,   0,-1, 4);
}
```

Include or not include Low-energy models?
Depends on statistics needed, energy ranges

High energy effects

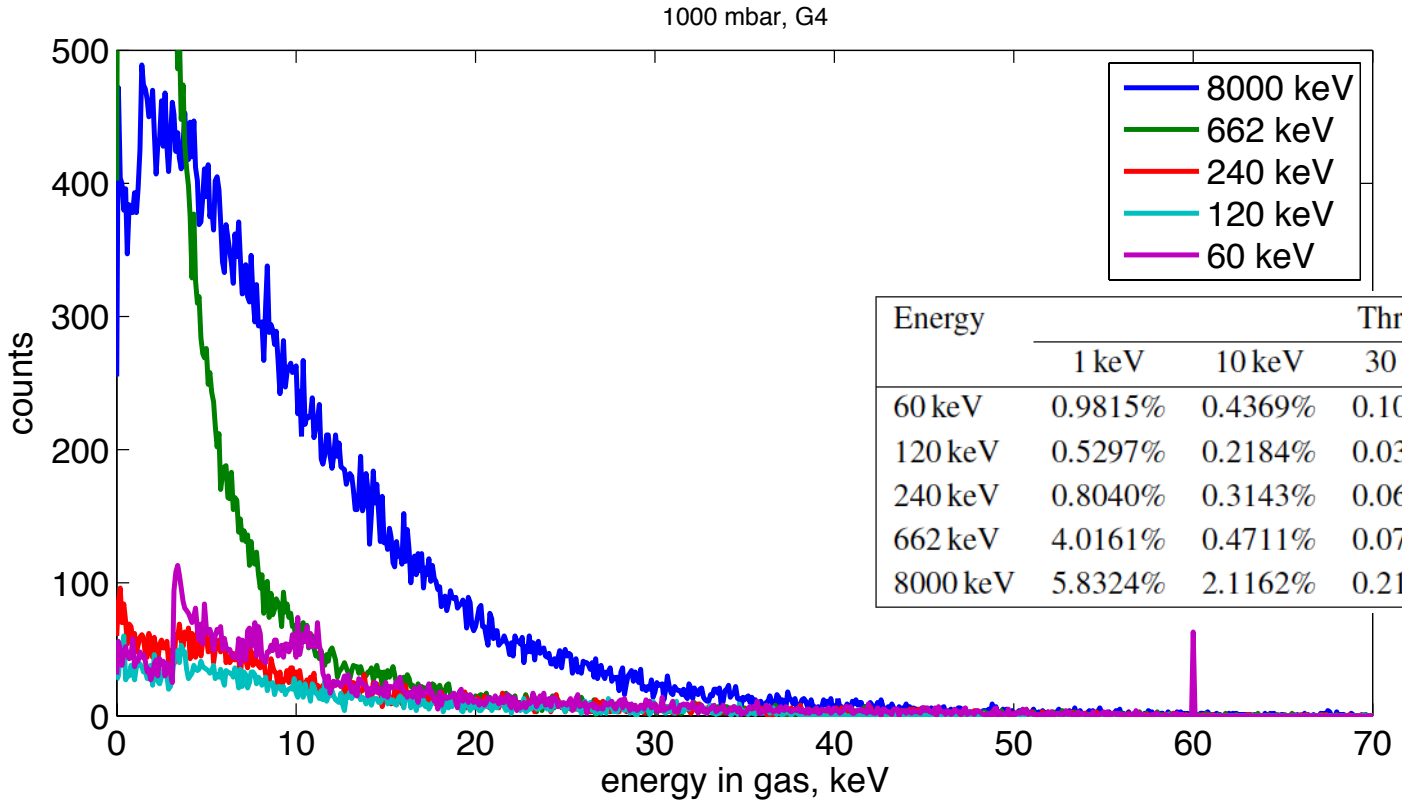
- From ~10MeV, e+/e- production is main effect
- e- (or e+) range enough to traverse several volumes



Example: 8 MeV pair-production event

Gamma energy dependence

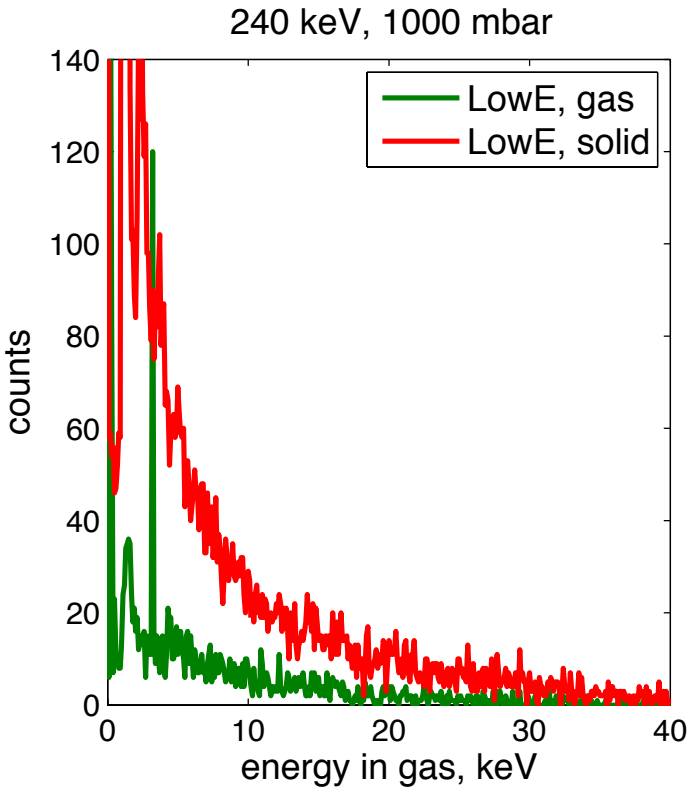
Spectra vs. γ-ray energy
For high enough energy (here, 8 MeV), electrons cross more than one cell. This can be rejected in data acquisition

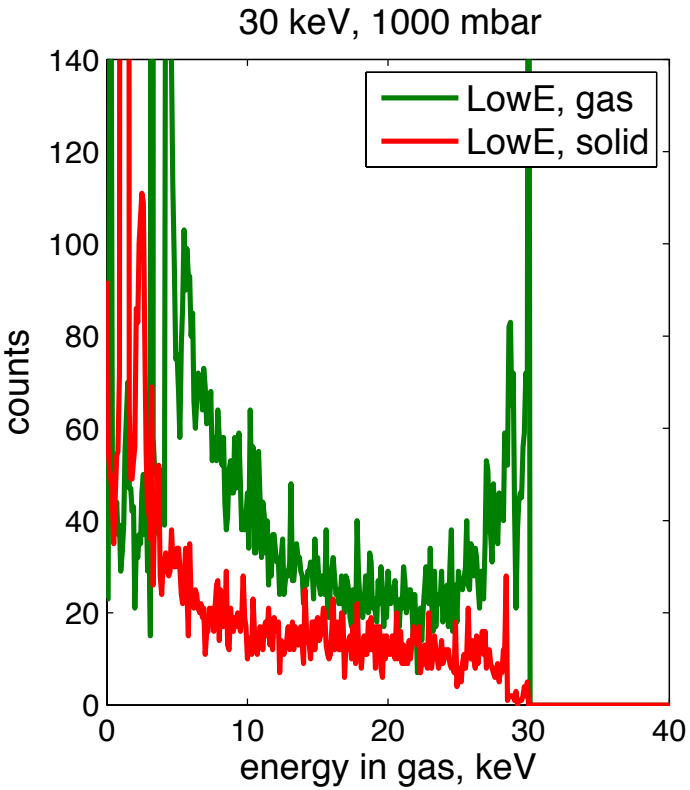


Energy	Threshold				
	1 keV	10 keV	30 keV	60 keV	100 keV
60 keV	0.9815%	0.4369%	0.1000%	0%	0%
120 keV	0.5297%	0.2184%	0.0351%	0.0002%	0%
240 keV	0.8040%	0.3143%	0.0675%	0.0015%	0%
662 keV	4.0161%	0.4711%	0.0711%	0.0039%	0%
8000 keV	5.8324%	2.1162%	0.2199%	0.0138%	2×10^{-4}%

Where gammas interact

Detected interaction energy (deposited in gas):
low γ energy – most interactions in gas
medium/high γ energy – most interactions in wall





Gamma detection in neutron detectors

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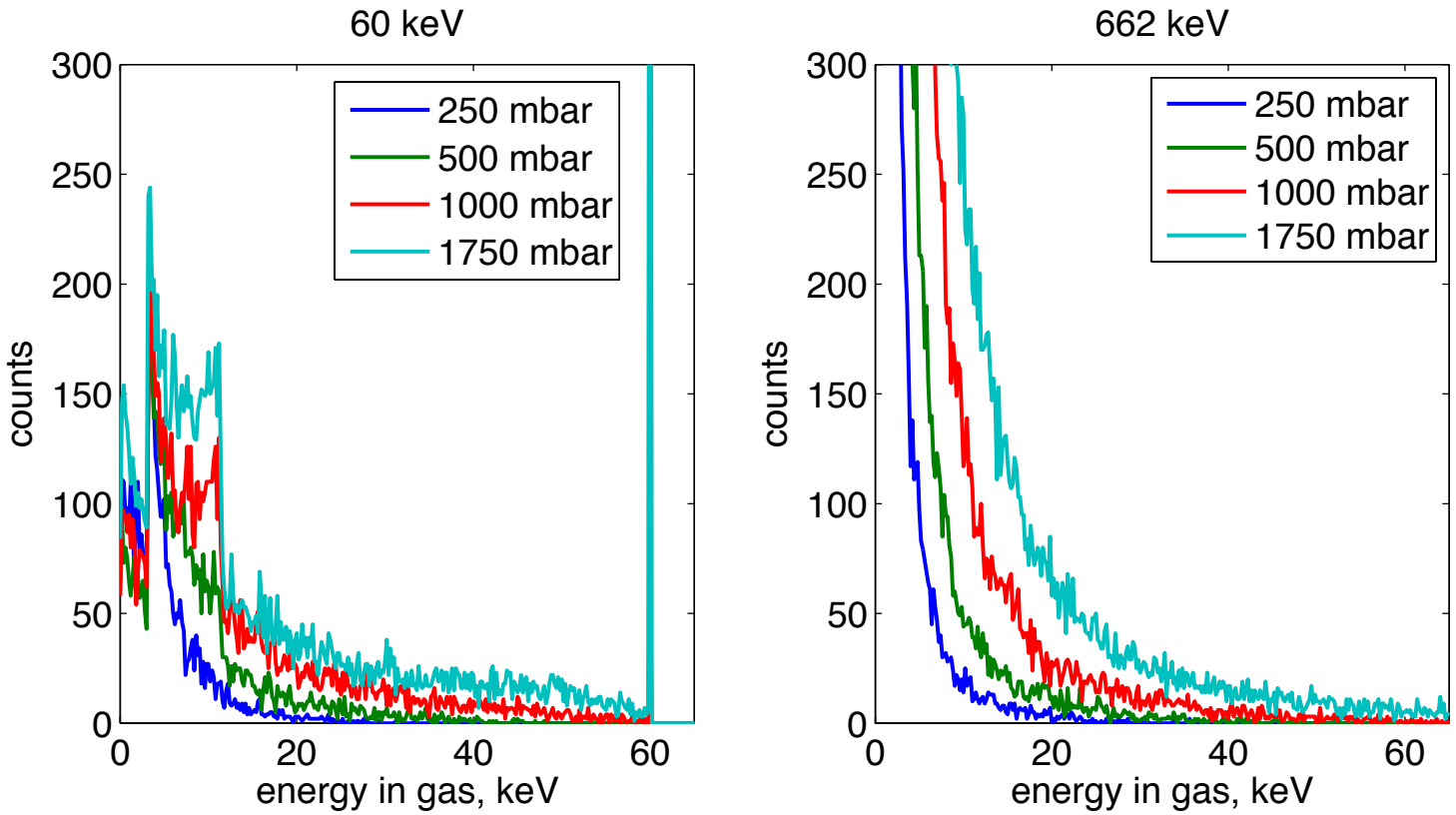
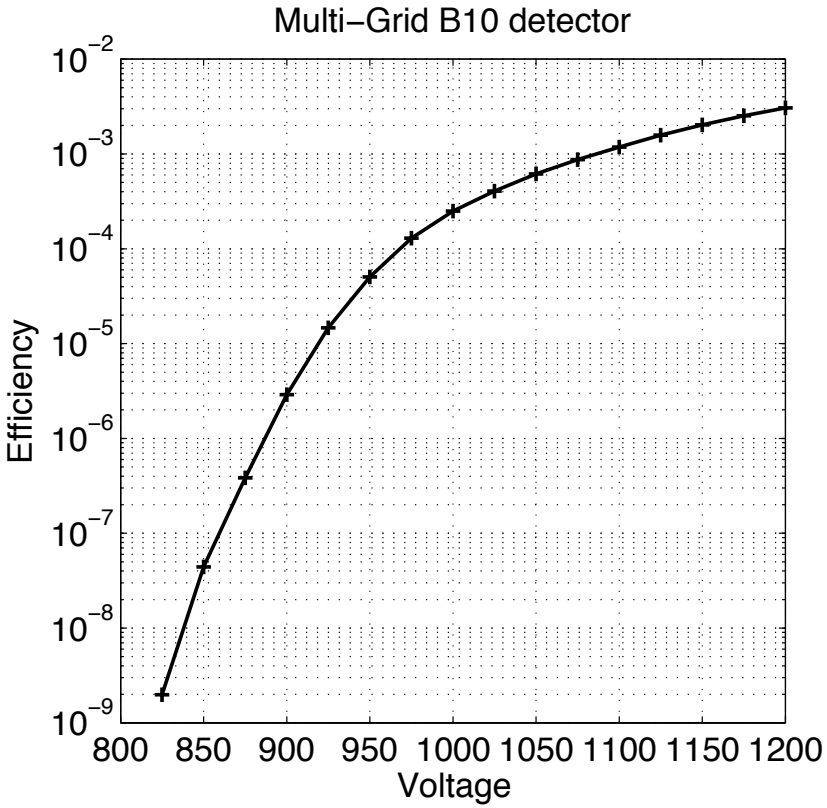
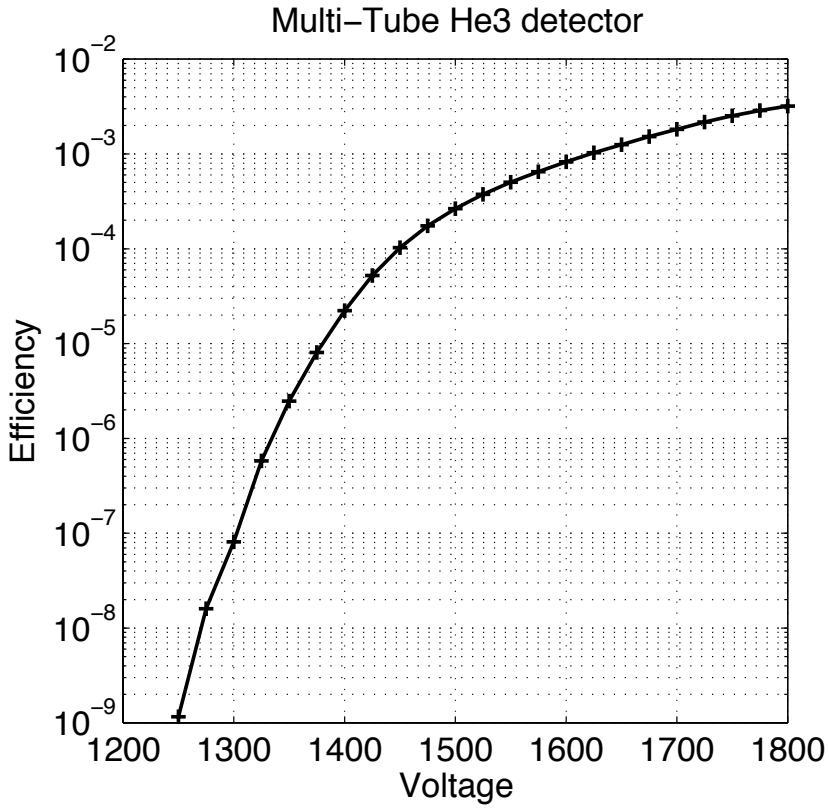
Spectra vs. gas pressure

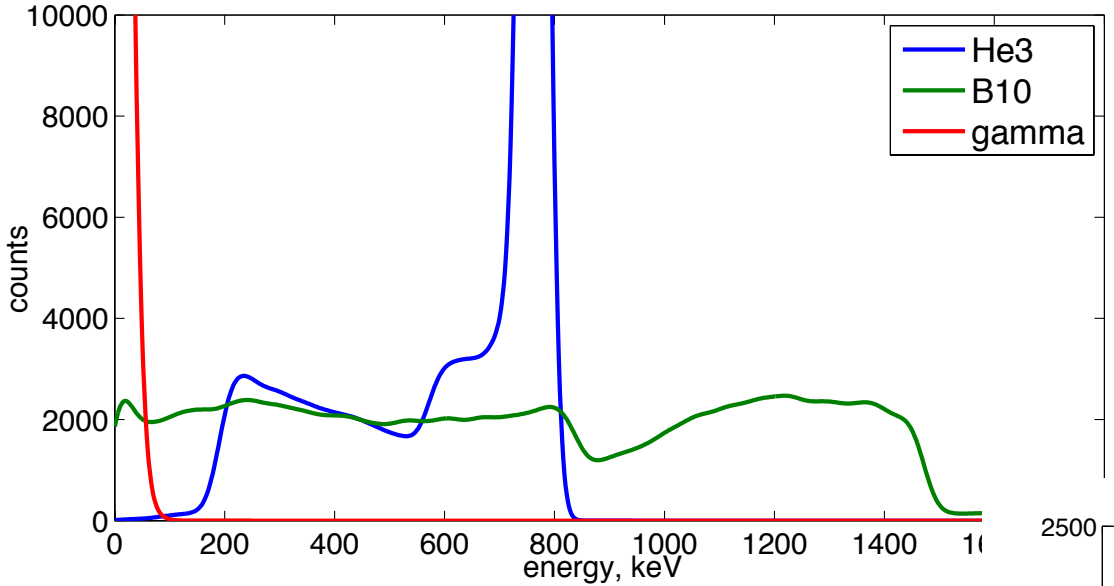


Gamma efficiency in neutron detectors Measurement



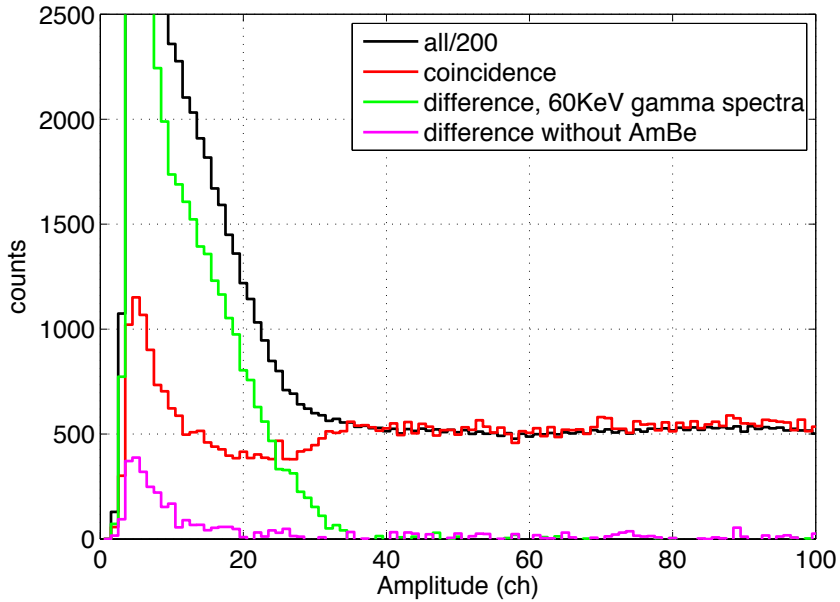


Gamma “sensitivity”



- Same detector filled with He3,
- or coated with B10
- B10 coating (~1um), He3 (Z=2) have negligible effect on γ
- Choice of threshold and γ
- sensitivity – the same
- N spectra can be very different

Overlap between n and γ spectra defines gamma sensitivity.



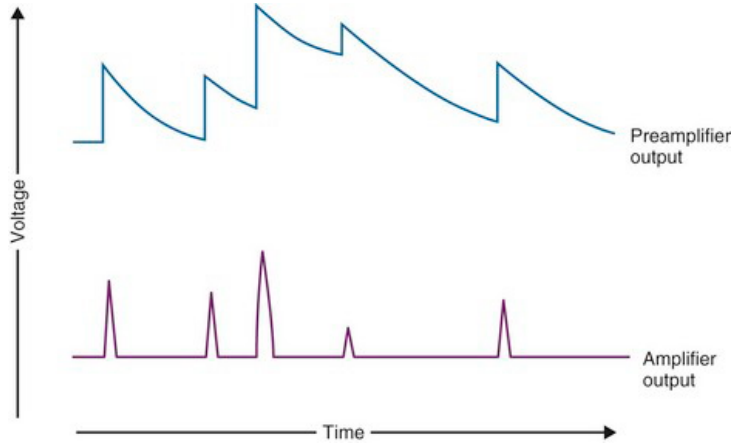
Pile-up effects

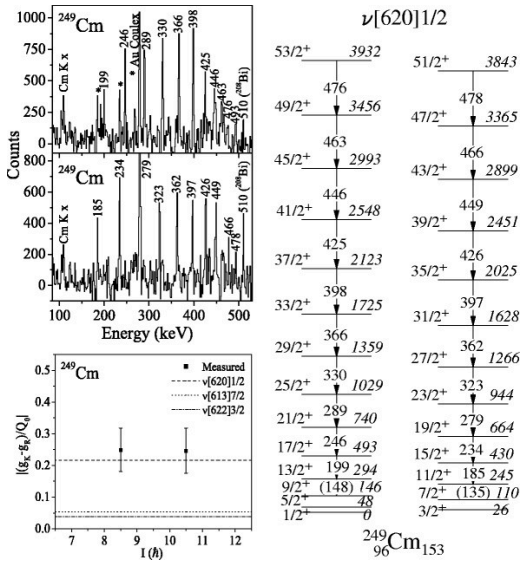
- Rate:

Individual γs under threshold, but if rate is extremely high – pile up of signals may be above threshold

- Coincident gammas

Nucleus emitting many gammas at once
Ex. Cd113, Gd155/157





Conclusion

Take your simulation of the detector and shoot gammas at it

At low energy – consider x-ray energies of materials involved
- if significant check which model is used

At high energy – consider how far e- can travel through detector
- compare to volume of common readout

Gamma response depends on detector geometry, not on neutron converter

Overlap between n and γ spectra define threshold and sensitivity