# SIMSPEC-G: A NEW CODE FOR SIMULATING THE WORKING OF HPGE DETECTORS

Satya Samiran Nayak and Gopal Mukherjee

*Variable Energy Cyclotron Centre, 1/AF Bidhannagar, Kolkata-700064, INDIA*

## INTRODUCTION

Simulations help us better understand the working of a HPGe detector

- Can point to unaccounted processes playing important role in experiments
- Better insight about events leading to peak formation
- Reasonable estimate for various parameters like addback factor, efficiency, etc
- Illuminate the role of geometry in determining the above mentioned parameters

Basic code (SIMSPEC-G) to simulate the spectrum generated by HPGe detector

Confined to $E_\gamma \leq 1$ MeV (at present)

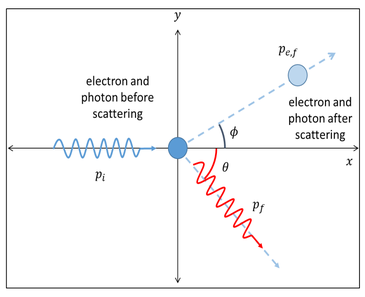
- Compton Scattering (CS)
- Photoelectric effect (PE)
- No pair production
- PE and CS cross section data taken from photon cross section database at NIST[1]

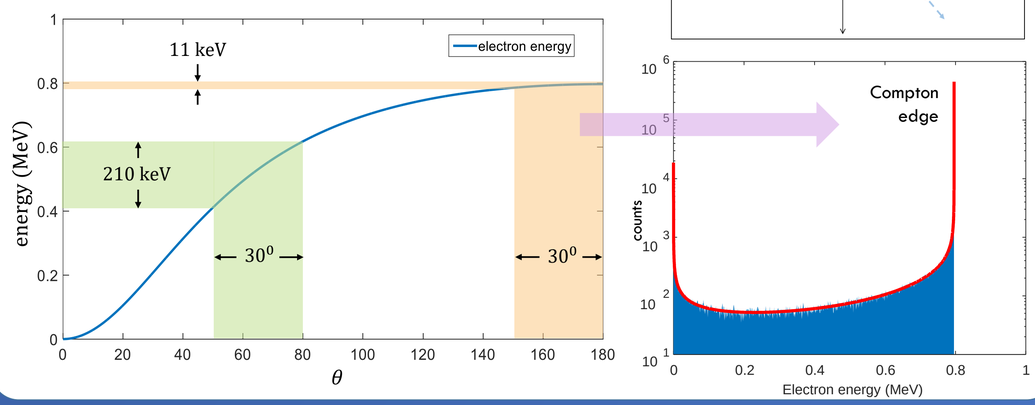
## COMPTON SCATTERING

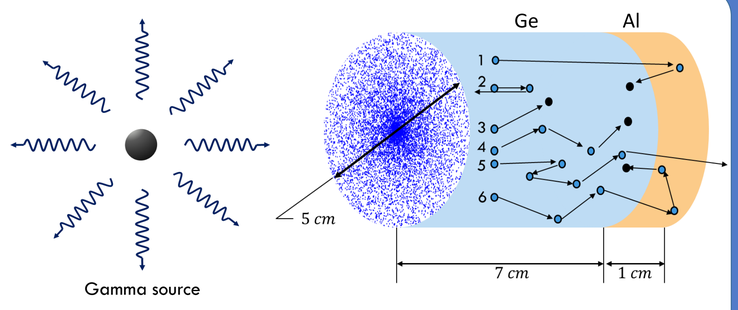
- Scattering of a photon by free electron

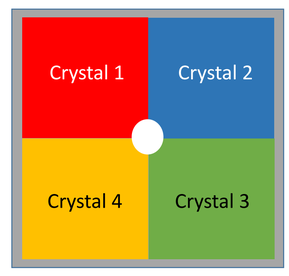
$$\lambda_f = \lambda_i + \lambda_c(1 - \cos\theta)$$

- Compton scattering is isotropic (uniform in $\theta$)
- Compton edge : a unique feature of Compton scattering ($\theta = 180^0$)
  - ➢ Wide range of $\theta$ in small energy range

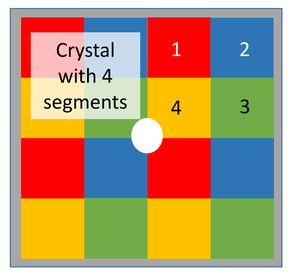


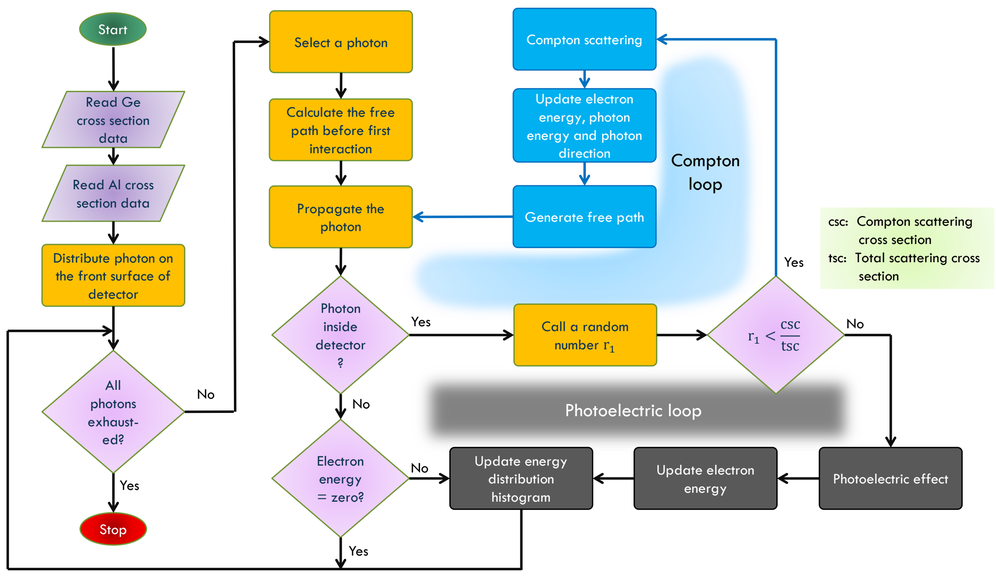




Clover Geometry




Segmented Clover Geometry

## ALGORITHM




## TRACKING THE PHOTON

The Beer-Lambert's
- intensity ($I$) after a material of length $l$

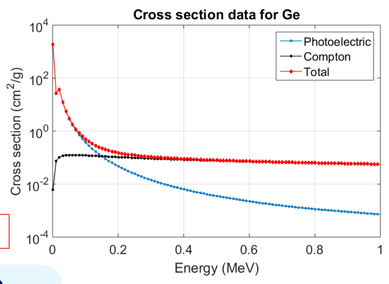
$$I = I_0 \exp(-n\,\Omega\,l) = I_0 \exp(-\mu\,l)$$

$I_0 \rightarrow$ incident intensity

$n \rightarrow$ number density

$\Omega \rightarrow$ scattering cross section

$\mu \rightarrow$ linear attenuation coefficient




**Mean Free Path Generation**

Probability ($p$) of photon interaction

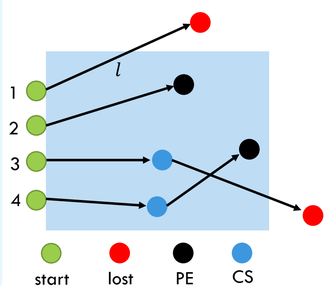
$$p = \frac{I_0 - I}{I_0} = 1 - \exp[-\mu\,l]$$

Calculation of mean free path ($l$) from $p$

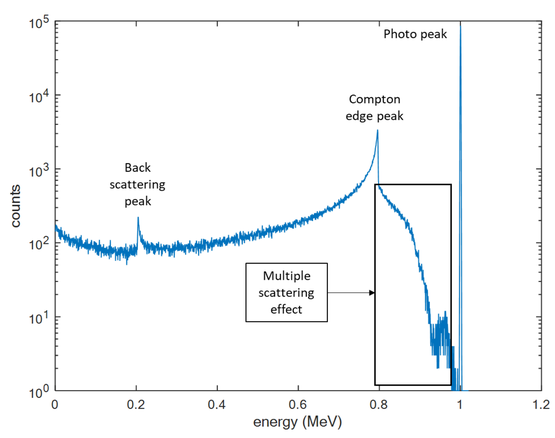
$$l = -\frac{\log[1-p]}{\mu}$$

**Propagation of photon**

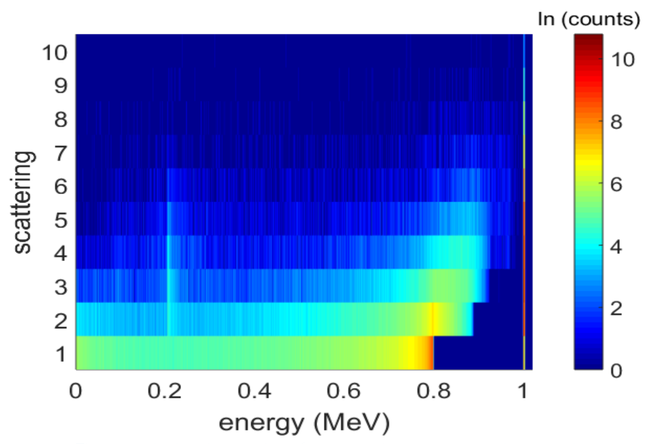
- ➢ Check if photon is within detector
- ➢ If within, determine
  - ➢ Photoelectric (PE) or
  - ➢ Compton scattering (CS)
- ➢ An event can end when
  - ➢ Photon lost (out of detector)
  - ➢ Photoelectric effect
  - ➢ Remnant photon energy goes below threshold




## DETECTOR RESPONSE FOR $E_\gamma$ =1 MEV

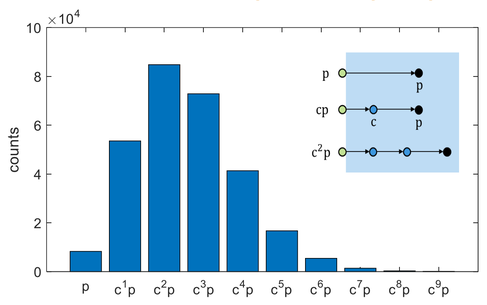


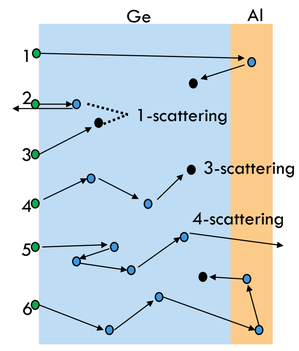

Detector FWHM has been chosen to be 0.15 % of incident energy or 1.3 keV, whichever is larger




- The step behaviour arises from maximum energy that can be deposited by a given scattering process
- Back scattering involves at least 2 scattering events

**Contribution of different processes to photo peak**

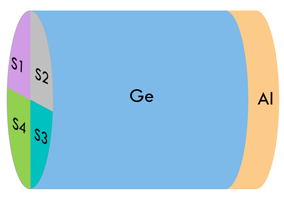


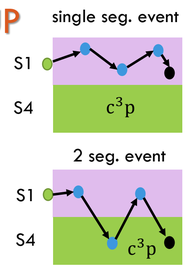




| Scattering | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Max $e^-$ energy (MeV) | 0.796 | 0.887 | 0.921 | 0.940 | 0.951 | 0.959 |

- Maximum contribution to photo peak comes from $c^2p$ type of events.
- Photoelectric effect alone accounts for only 2.9 % of all the photo peak counts

## HPGe CLOVER SETUP




The detector is of same dimensions

The single crystal is divided into 4 segments

Break up of counts for different $c^np$ according to # of segments they are spread across

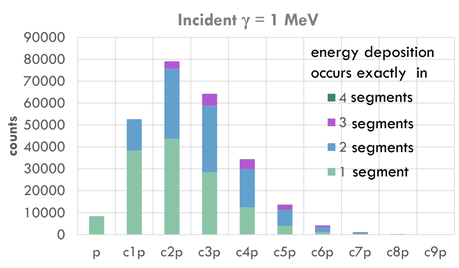
| # of segment in event | % of events in photo peak | |
|---|---|---|
| | 1 MeV | 0.3 MeV |
| 1 | 52.888 | 71.733 |
| 2 | 40.510 | 25.974 |
| 3 | 6.309 | 2.225 |
| 4 | 0.293 | 0.067 |

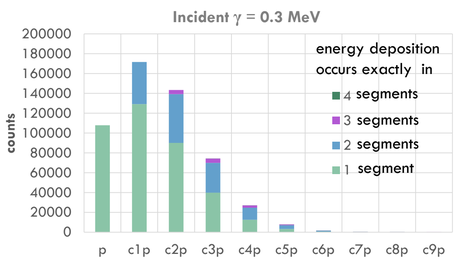
incident photon energy ↓

addback efficiency ↓

polarization sensitivity ↓

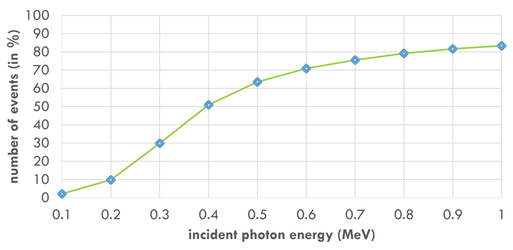
**Contribution of different processes to photo peak**




## DETERMINATION OF FIRST INTERACTION SEGMENT

Highest energy deposition in first interaction segment

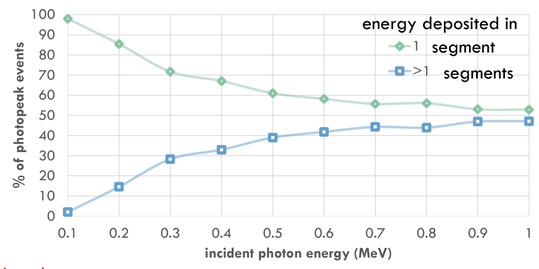



Helpful in improving angular resolution of detector

For 1 MeV γ photon
- ➢ Highest energy deposition in first interaction segment = 83.4 % of photopeak events

Remains relatively flat till 700 keV

Energy deposition in 1and in multiple segments




For 1 MeV γ photon
- 52% → inside 1 segment, 48% → in > 1 segments.

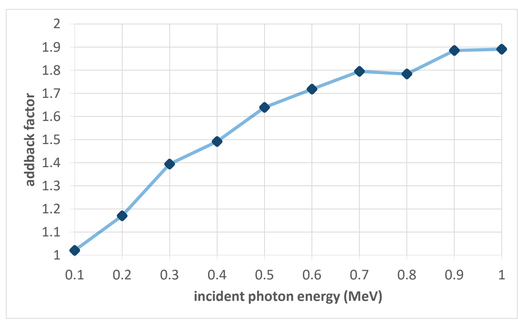
Below 700 keV, single segment events increase to nearly 100% at ≈100 keV

Polarisation sensitivity is poor below 300 keV due to fewer multiple segment events

For $E_\gamma \leq 200$ keV, we can take crystal angle information without much loss

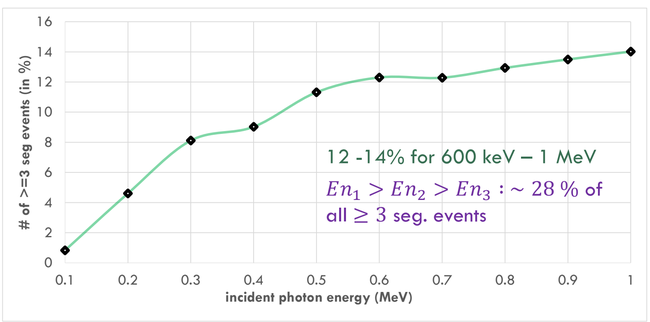
## ESTIMATION OF ADDBACK FACTOR

Variation of addback factor with $\gamma$ energy

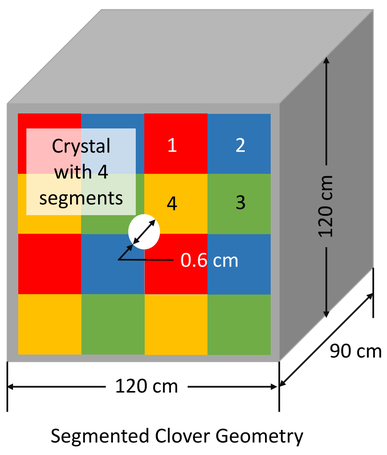



## ESTIMATION OF ≥ 3 SEGMENT EVENTS

# of ≥ 3 seg. events in multi seg. events




## HPGe SEGMENTED CLOVER SETUP

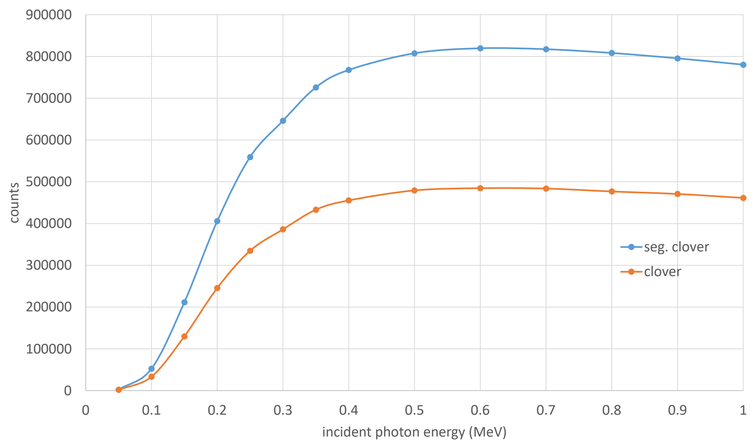



Segmented Clover Geometry

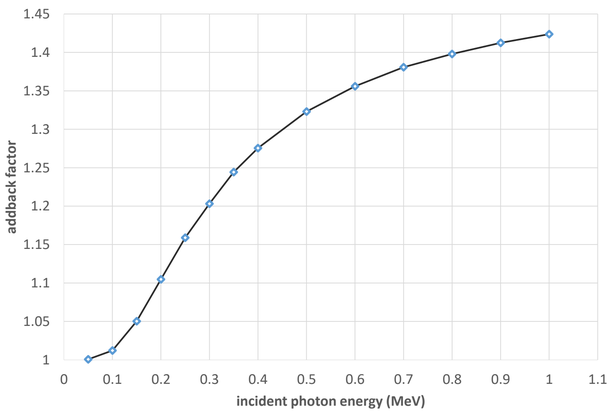
### SEGMENTED CLOVER GEOMETRY

- Each crystal 60 cm x 90 cm
- Each segment is 30 cm x 90 cm
- Surface is a square of dimensions 120 cm x120 cm
- Covered with 3 mm thick Al on each face except for the front where the thickness is 1.5 mm
- A hole of diameter 6 mm is taken at the centre of the detector front surface

**Parallel scattering counts for segmented clover and clover detector for different incident gamma energy**




**Variation of addback factor with $\gamma$ energy**




## FUTURE PLANS

- Addition of Compton suppression shield
- Simulating an actual $^{60}$Co source and $^{152}$Eu source
- Introduction of pair production and other interactions

## ACKNOWLEDGEMENT

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## REFERENCES

[1] M. J. Berger, J. Hubbell, S. Seltzer, J. Chang, J. Coursey, R. Sukumar, D. Zucker and K. Olsen, "XCOM: Photon Cross Sections Database," 1 November 2020. [Online]. Available: www.nist.gov/pml/xcom-photon-crosssections-database