A New Biasing Method for Variance Reduction of Compton Events in GEANT4

For MCnet Meeting 2019 - CERN

Presented By

Sunil Kumar

Junior Research Fellow,

Panjab University, Chandigarh, India

in mentorship of

Prof. Frank Krauss

IPPP, Durham University, Durham

United Kingdom

Dr Paul Scott

IBEX Innovations, Stockton-on-Tees

United Kingdom

Overview

- Introduction
- The imaging technology used by IBEX
- Problems caused by scatter in medical images.
- Standard approach to minimising scatter.
- The IBEX Scatter Reassignment Method.
- The role of Geant4.
- Preliminary results.
- Summary.

Introduction

I am pursuing Ph.D. at Panjab University, Chandigarh, INDIA under the guidance of Prof. Vipin Bhatnagar & Dr Sushil Singh Chauhan. We are working on the topic related ***Quantum Entanglement based Positron Emission Tomography***. I am also member of ***CMS***.

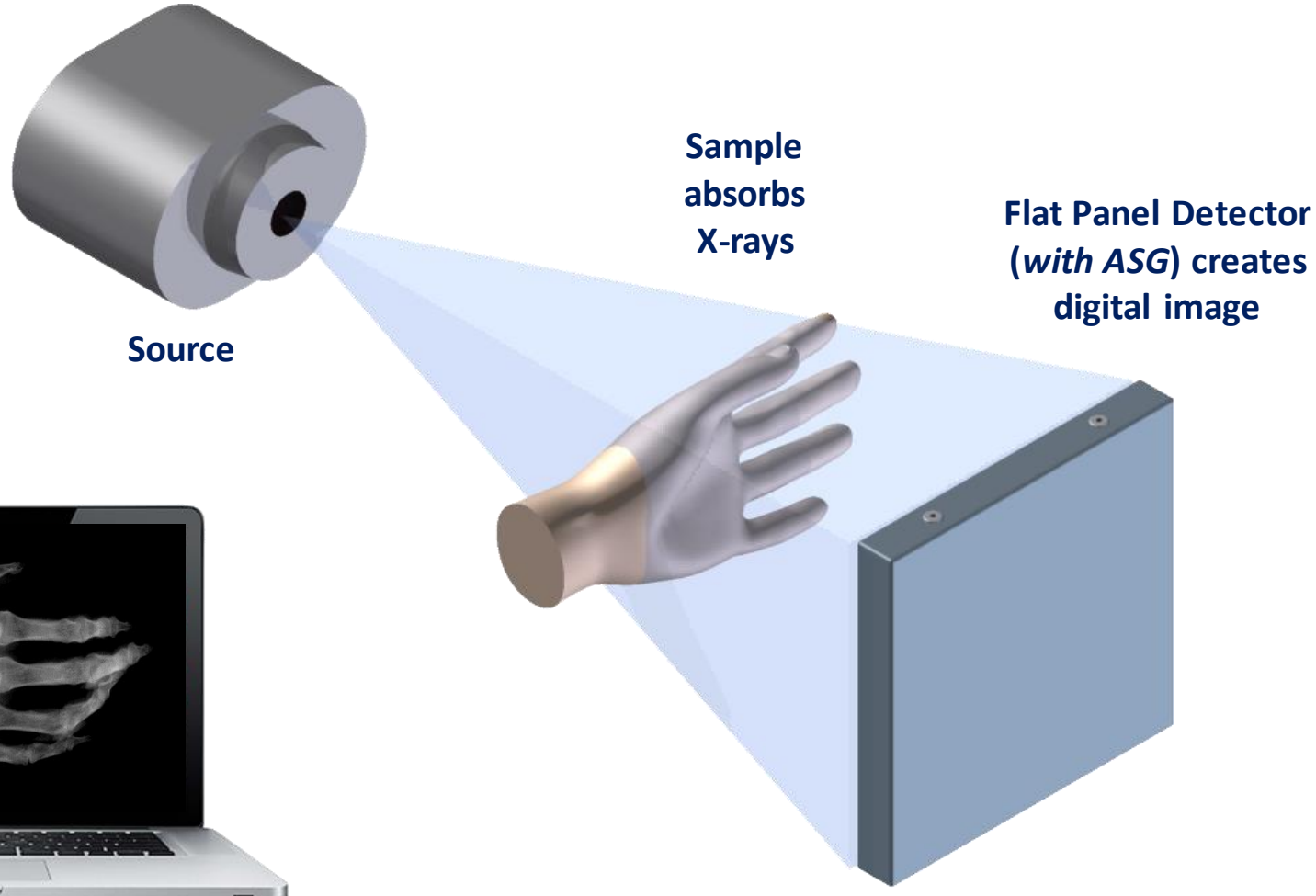
I have experience in ***GEANT4*** which is must for this MCnet project.

Started the project on 9th July, 2019 in collaboration of ***Durham University*** and ***IBEX Innovations Ltd***.

Currently, at the verge of this project.

.....let's start.

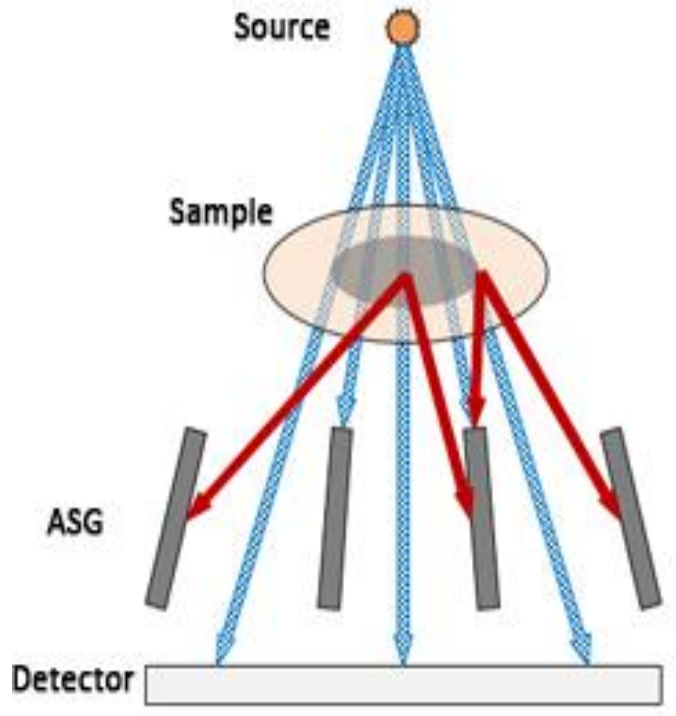
Conventional X-Ray Imaging



Grey scale image results from the combination of changes in both thickness and density

Scatter in Medical Images

- Bone, muscle and fat contain significant amounts of low Z (Atomic Number) elements leading to good amounts of scatter.
- Scatter blurs the image and makes contrast windowing difficult.
- Measurements show that an ASG gives a contrast to noise ratio improvement of around a factor 2.
- This can result in absorption of up to 80% of the X-rays by the ASG.
- Scatter from ASG material also degrade the image quality.



Classical physical ASG blocks scattered X-Rays (solid) but also removes useful direct beam (patterned)

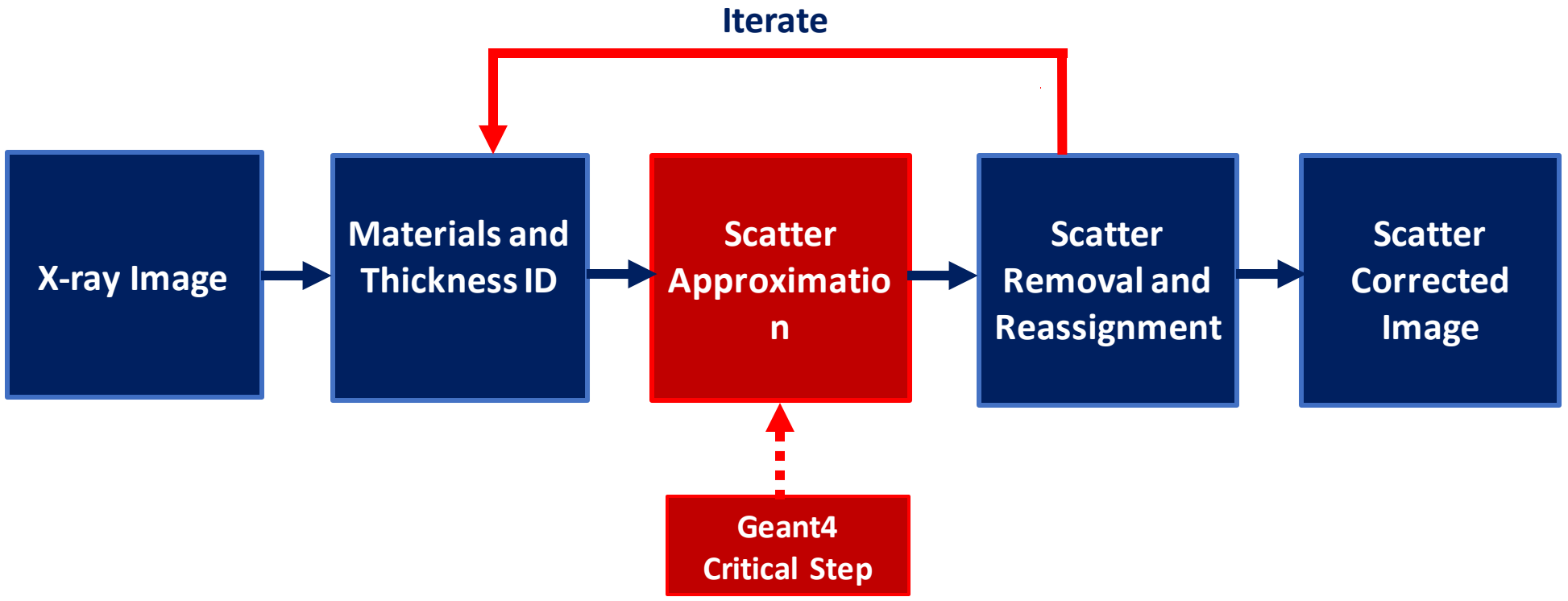
Trueview – IBEX Image Processing Software

The ***Trueview*** Processing Software (being developed by ***IBEX Innovations Ltd.***) works on these ideas:

- The materials information given by the MAP combined with a priori information from GEANT4 can be used to remove scatter without the need for an ASG.
- Better estimate of Scatter kernel because of the presence of only sample as scattering material before detector.
- Unlike an ASG which blocks scattered X-rays the SRM uses a mathematical technique to reassign them.
- This improves image quality without the dose penalty to the patient.
- We expect this to result in a dose reduction to the patient of around a factor 2-4.

Trueview – Algorithm

Using the MAP we get information about the material and thickness at each point in the image.



Comparison

Unprocessed Image
(with No ASG)

Focussed Grid
8:1, 80 lines per cm

Trueview Processed image
(without ASG)

Scatter estimate

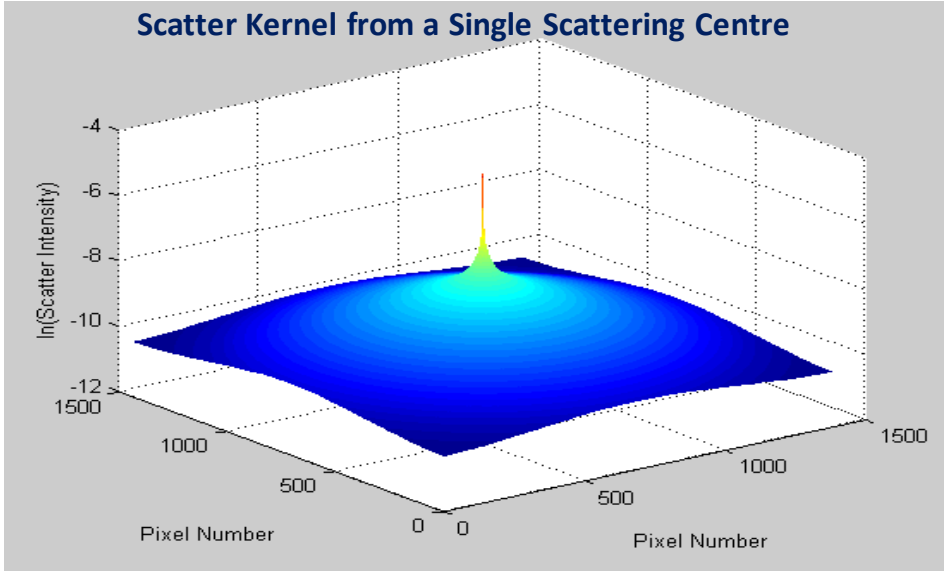
Why use GEANT4 ?

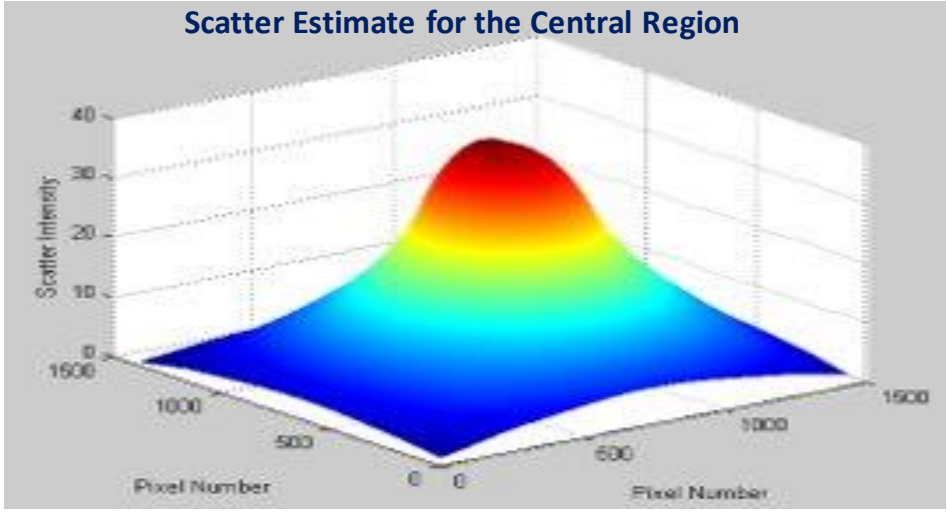
GEANT4 is integral to the SRM technique for the following reasons:

- Production of scatter kernels using a simulated pencil beam.
- Simulation of an entire 9 megapixel image removes issues with experimental artefacts during early phase development.
- We can create a scatter free version of simple test cases in GEANT4, allowing the algorithm to be validated.
- The SRM relies on an iterative process. GEANT4 allows us to check for convergence.

Scatter Estimate for an Image

- A scatter kernel for each material is simulated by setting the beam divergence to zero.
- Direct X-rays are detected in the central pixel and scattered X-rays appear in the rest of the image.
- Radial symmetry allows the number of starting events to be reduced.
- Adding together the scatter kernels for each point in the image gives the scatter estimate.





Need of biasing ?

Problem

- To get the better scatter estimate with least variance, one has to simulate for very large number of Primary events.
- ⬆ the computational time.
- ⬆ the cost for the computation (if you run on a paid service).

Solution !

- Generic biasing to produce more secondary events to get more population of events reaching to the detector for same number of Primaries.
- 〓 computational time.
- 〓 cost for the computation.

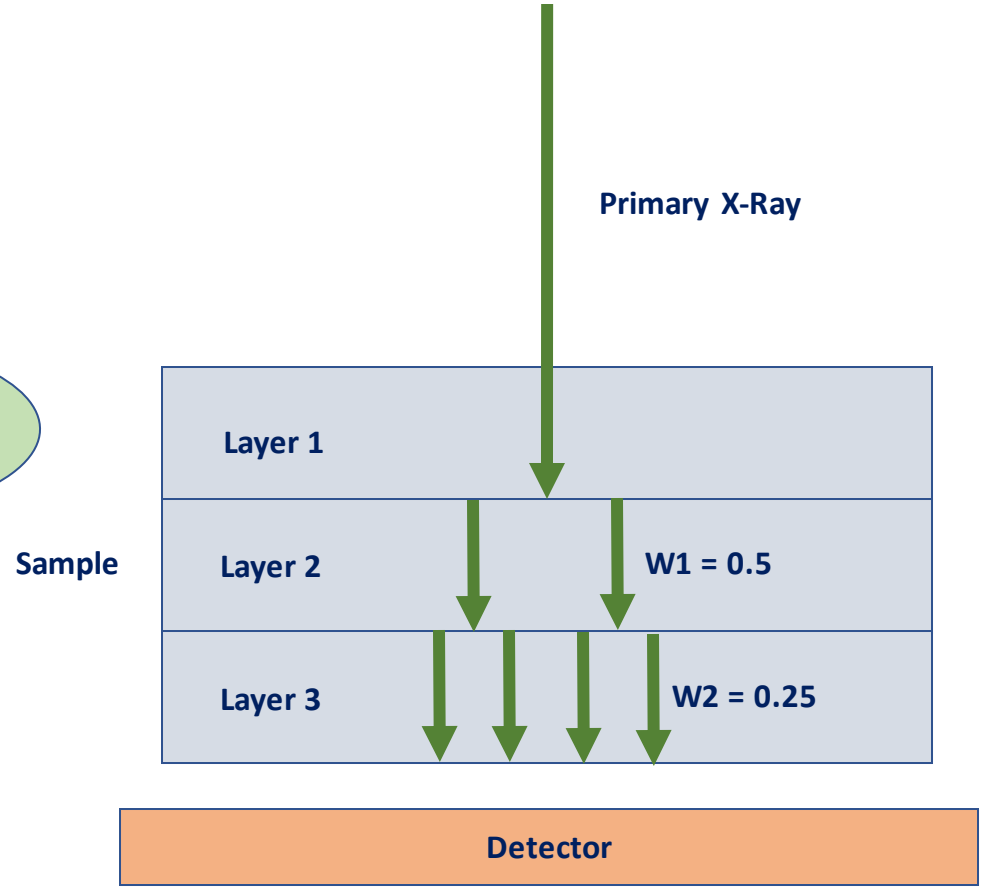
Existing Methods in GEANT4

Methods of variance reduction

If talk about the GEANT4, there are few methods to reduce the variance using different bias technique

- Importance Sampling ✓
- Cross-section biasing
- Geometrical biasing
- Hadronic Cross-Section biasing
- User defined process wrapping

save time but do not reduce Variance too much



Importance sampling method

New Technique

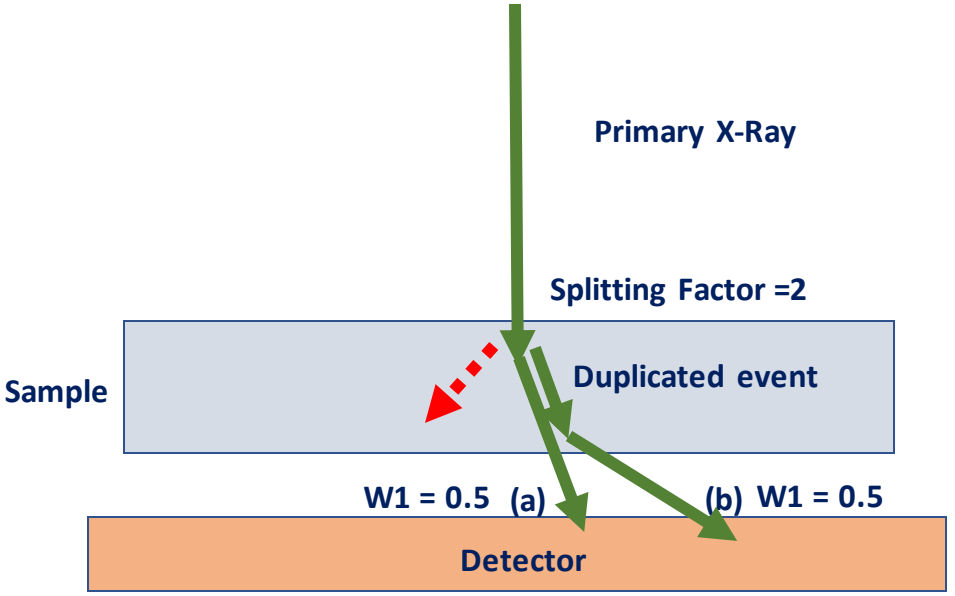
- As the energy is low (70 KVp X-ray spectrum), so scattered photon has less probability to reach the detector.
- We are splitting the Compton scattered photon to some integer value.
- By Splitting, we are trying to populate the pixels far away from central one.
- Weight of the photon will decrease which will affect the energy submitted in the detector.
- But definitely **decrease** the **variance**.

***We used this method for N = 5 & 50**

Example:

For N=5, Weight w = 1/N = 0.2

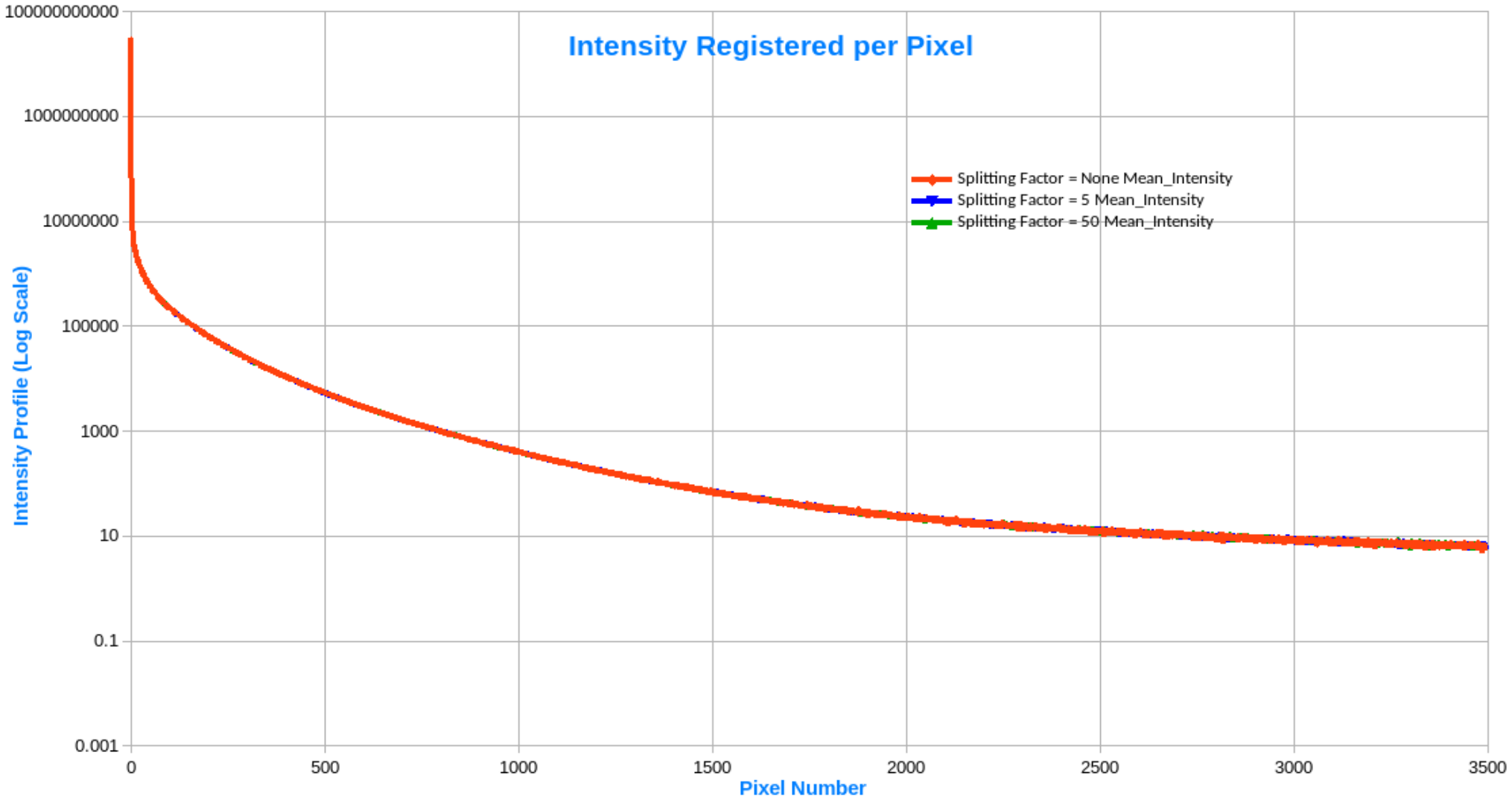
Compton Scattering



$$E = w_1E_a + w_1E_b$$

New method for splitting the scattered photon

Intensity Profile



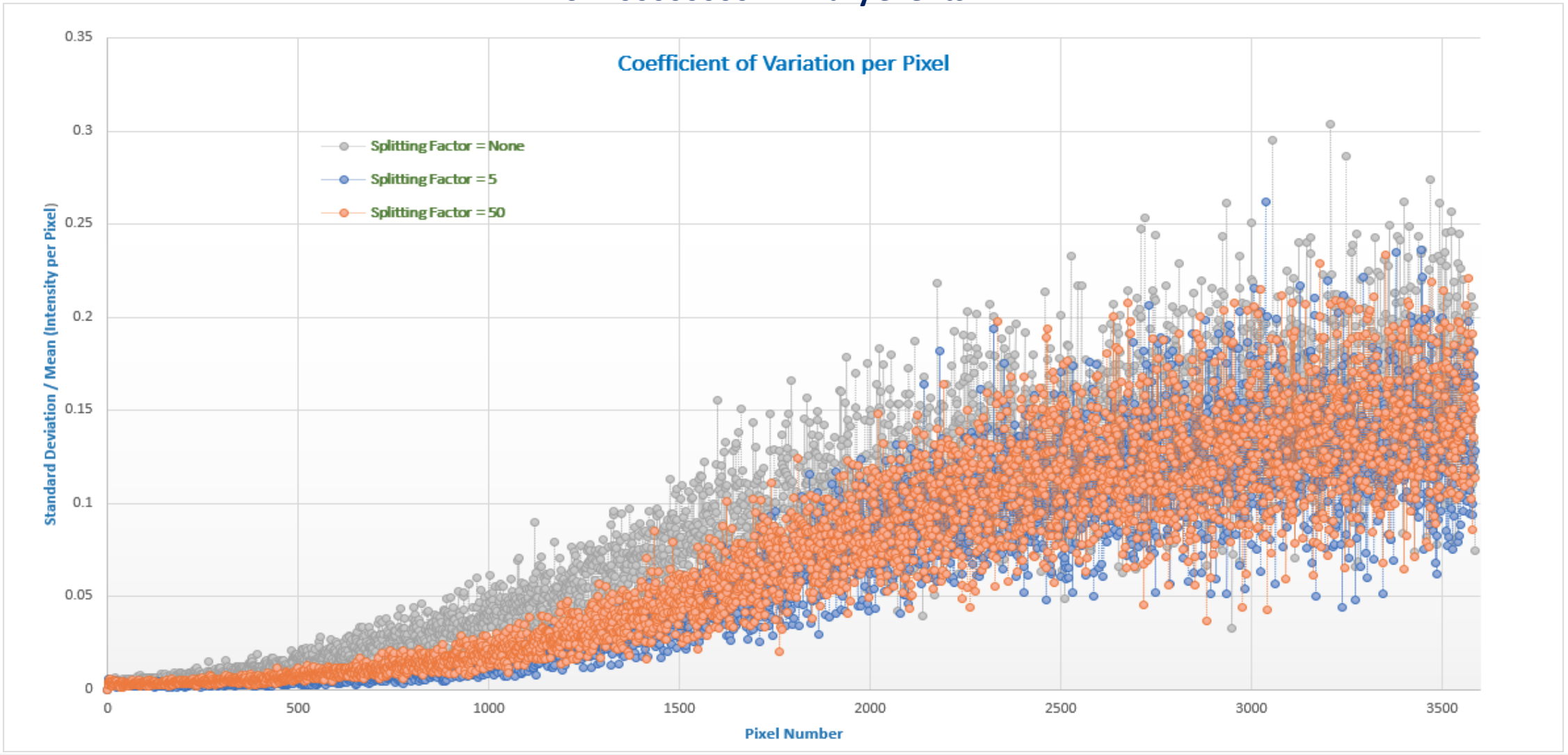
For 10000000 generated primary events of 70 keV X-Ray spectrum.

Material used as sample is PMMA of 3 cm Thickness

Detector Material is Cesium Iodide (CsI).

Coefficient of Variation

For 100000000 Primary events



Results & Summary

Splitting (For 10000000 Primary events)	Time Taken (seconds)
None	523.33
5	900.40
50	4671.00

For 50000000 Primary events (No Splitting)	2487

Reduction in time = 2487 – 900 = 1587 seconds

Preliminary results…..needs more verification

- This method of Compton event biasing is promising in medical imaging for the better scatter estimate with a low variance and less computational time.
- We are working towards the further improvement in both reduction in variance and time.

Acknowledgement

At the end, I want to thank MCnet for giving me the opportunity to work on this project as the technique learned and developed will definitely help in my research.

I want to thank Durham University & IBEX Innovation for the kind support.

I want to thank in person, Prof. Frank Krauss, Dr Paul Scott, Dr Marion Weinzierl and Dr Gurpreet Singh Chahal for the guidance and support.

Special thanks to John Allison, for the support related to GEANT4.

Thank You..

Any Questions..