Refining the Simulation of LHCb SciFi Detectors in Geant4

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Technical Note for Summer Internship 2025

Abstract

This document is a summary of my Summer Internship project. The repository of this simulation can be found at

https://gitlab.cern.ch/lphe-lab-tools/SciFiMatG4

The results mentioned in this document can be found at

/home/gui/SciFiMatG4/SimulationData/outcome_3

I hope people reading this document will find it helpful.

1 Operation of the code

This part introduces how to operate the code. The detailed modifiable parameters in each file will be included in later subsections.

- Inside **/SimulationData** file, change settings of incident particles in **submit.sh** and detector parameters in **/parameterFiles/parameters.json**, then submit jobs by typing

  sbatch submit.sh

  This will submit 24 jobs with incident particles injected at z positions from 50 mm to 2350 mm with 100 mm intervals. (Mirrors at z = 0, SiPM at z = 2424). The files in **/logs** folder records the running information of each slurm job.

- To run visualisation, inside **/SimulationData/visualisation**, can change settings of **vis.mac**, then run

  ../../SciFiSim-build/scifiSim

  in the same folder. Then inside the **Session** box, type

  /control/execute vis.mac

- To analyse the simulation output, copy **analyse_scatter.py** from **/SimulationData/analysis_scripts** to the folder where the .root files are.

  To plot multiple tasks (i.e. outputs in different folders) together, move both **extract_cluster_data.py** and **plot_cluster_comparison.py** inside a folder containing the multiple folders. Run **extract_cluster_data.py** first to extract plotting information (make sure the name of the folders are correctly matched in the **main()** part), then plot with **plot_cluster_comparison.py**.

2 Changes made to the existing code

2.1 In /SimulationData

Added the **submit.sh** file to submit simulation jobs with different z position onto slurm. Now outcomes will be saved in a subdirectory of **/SimulationData** with the name in the format of:

/output_<particle>_<energy>_<nEvents at each zPos>_<comment>

In the **submit.sh** file, the modifiable parameters include:

- **PARTICLE**: This takes a string of the incident particle type, i.e. ”e-”, ”mu-”, etc.
- **ENERGY**: Energy of the incident particle in GeV.
- **TEMPLATE_MAC**: This chooses the template .mac file, based on which the simulations will be performed
- **Z_START, Z_END, Z_STEP**: This defines the z position of different jobs sent in this batch. Please make sure from **Z_START** and **Z_END** there are integer number of **Z_STEP**. Please make sure the line 10:

  #SBATCH --array=0-23%24

  is matched with number of tasks.
- **NEVENTS**: Number of events for each z position.
- **COMMENT**: This is the suffix of the output folder name for remark purposes. Nothing in the simulation will be affected.

2.2 In /SimulationData/parameterFiles

1) Added Photon Detection Efficiency (PDE) file:

H2024_50um_039_TP4b_ch38_OV_6V_PDE.txt

(this can be replaced by other PDE files by changing the **”sipmDetectionEfficiency-FileName”** variable inside **parameters.json** file.)

2) Added the **mie_results.csv** file, in which the first column is the photon energy and the second column is mean free path of the Mie scattering. The other three columns are **forward_ratio**, **backward_ratio** and **g_values** respectively, but they are not used in the simulation. This document is calculated using

/SciFiSim/python/CalculateTiO2EpoxyMIE.py

in which I refined calculation method and input parameters.

3) Modified **parameters.json** file. Now it can define:

- **airGapZ1**: defines the starting position of the first air gap (mm from SiPMs).
- **airGapL1**: length of the first air gap (mm).
- **airGapZ2**: the starting position of the second air gap (mm from SiPMs).
- **airGapL2**: length of the second air gap (mm).

Notice: only the section inbetween the two air gaps will be covered in black polyimide film.

- **nLayers**: number of scintillating fibre layers in the SciFi mat.
- **ifMIEHG**: if MIEHG scattering will be simulated inside the epoxy.
- **MieHG parameters**: **MIEHG_FORWARD_RATIO**, **MIEHG_FORWARD**, and **MIEHG_BACKWARD**. Their actual physical implication needs to be better understood.

2.3 In /SciFiSim/src

1) In **Analysis.cc**: changed the output file naming. They will be named with slurm job ID if submitted through **sbatch**, or **unknown** if run with

../../SciFiSim-build/scifiSim <MAC file name>.mac

Also added function to load SiPM PDE table to read detection probability, as well as an RNG to determine if the photon will be detected. These information are stored in branches **"detProb"** and **"ifDet"**.

2) In **DetectorConstruction.cc**:

- Added material of **PolyimideBlack**, absorption length and reflection properties of it;
- Changed the **absorption length** of **epoxy** and **glue**;
- Added **Mie scattering** parameters for **epoxy**;

- Defined SciFi mat geometry to be five separate parts: **epoxy, air, epoxy+polyimide, air, epoxy** as children of **detector_log** logical volume, and define fibres as sub-volumes for each of them

3) In **PrimaryGeneratorAction.cc**: added **xPos**, **yPos** and **zPos** as branches of the tree **InitialParticle**.

3 Results

3.1 Geometry

Different designs of the SciFi mat are simulated. They include different number of fibre layers, or different flexible part designs.

3.1.1 nLayers

In **parameters.json**, if set **"nLayers": 4**:

Figure 1: "nLayers": 4

If set **"nLayers": 6**:

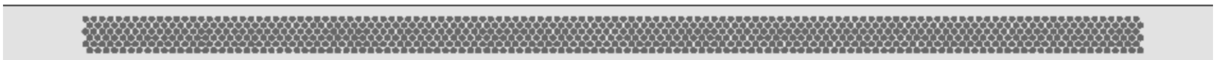


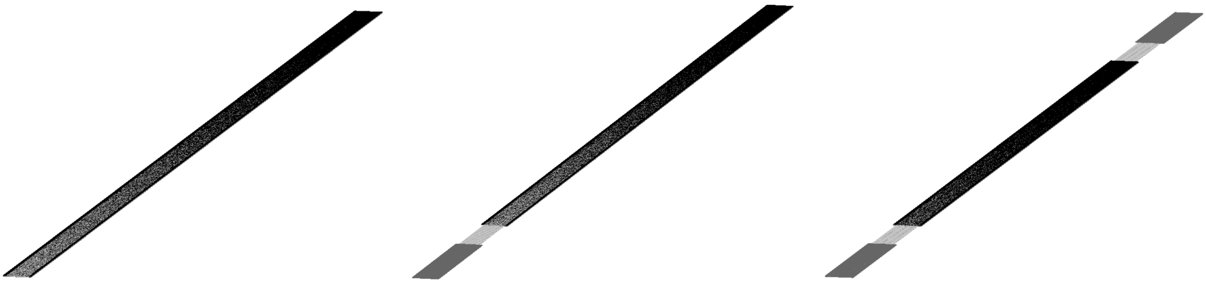
Figure 2: "nLayers": 6

3.1.2 Flexible part designs

RIGID: In **parameters.json**, set

"airGapZ1": 0,
"airGapL1": 0,
"airGapZ2": 2.424,
"airGapL2": 0,

FLEX: In **parameters.json**, set



(a) RIGID (b) FLEX (c) Double_FLEX

Figure 3: SciFi mat designs of RIGID, FLEX, and Double_FLEX.

"airGapZ1": 0.3,
"airGapL1": 0.17,
"airGapZ2": 2.424,
"airGapL2": 0,

Double_FLEX: In **parameters.json**, set

"airGapZ1": 0.3,
"airGapL1": 0.17,
"airGapZ2": 1.98,
"airGapL2": 0.17,

3.2 Simulation Outcome

In the **parameters.json** file, set MieHG scattering parameters to:

"MIEHG_FORWARD_RATIO":0.8,
"MIEHG_FORWARD":0.6,
"MIEHG_BACKWARD":0.6,

and in the **submit.sh** file, set:

PARTICLE="e-"
ENERGY=0.0009
NEVENTS=600

the simulation results of SciFi mats with different designs are:

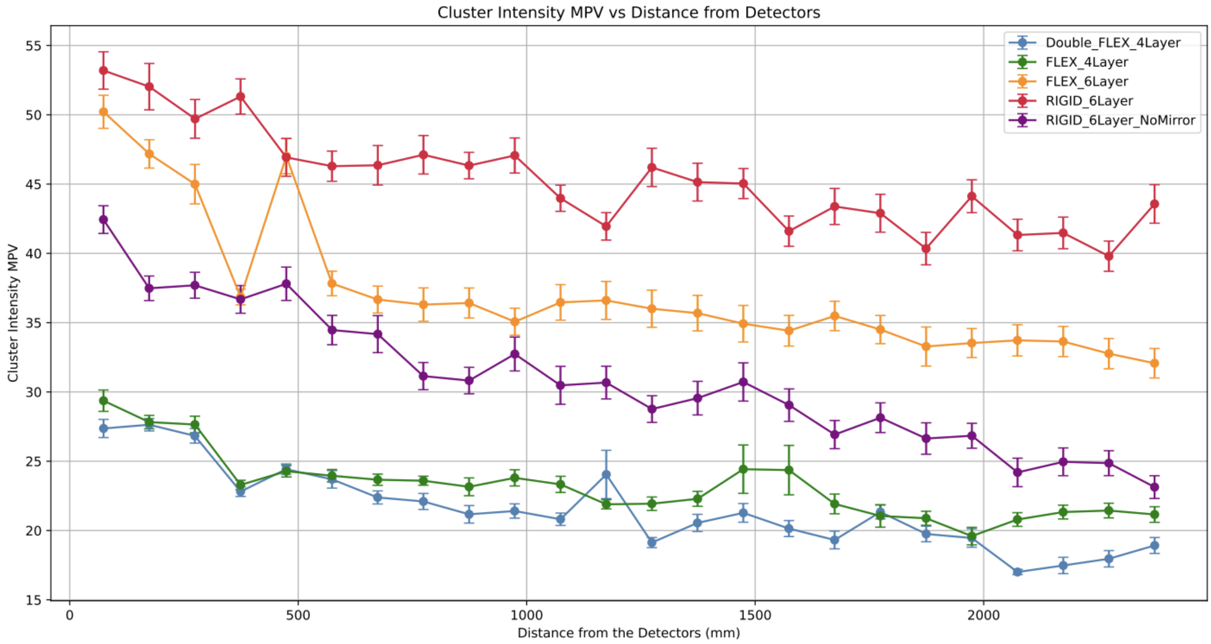


Figure 4: Cluster Indensity

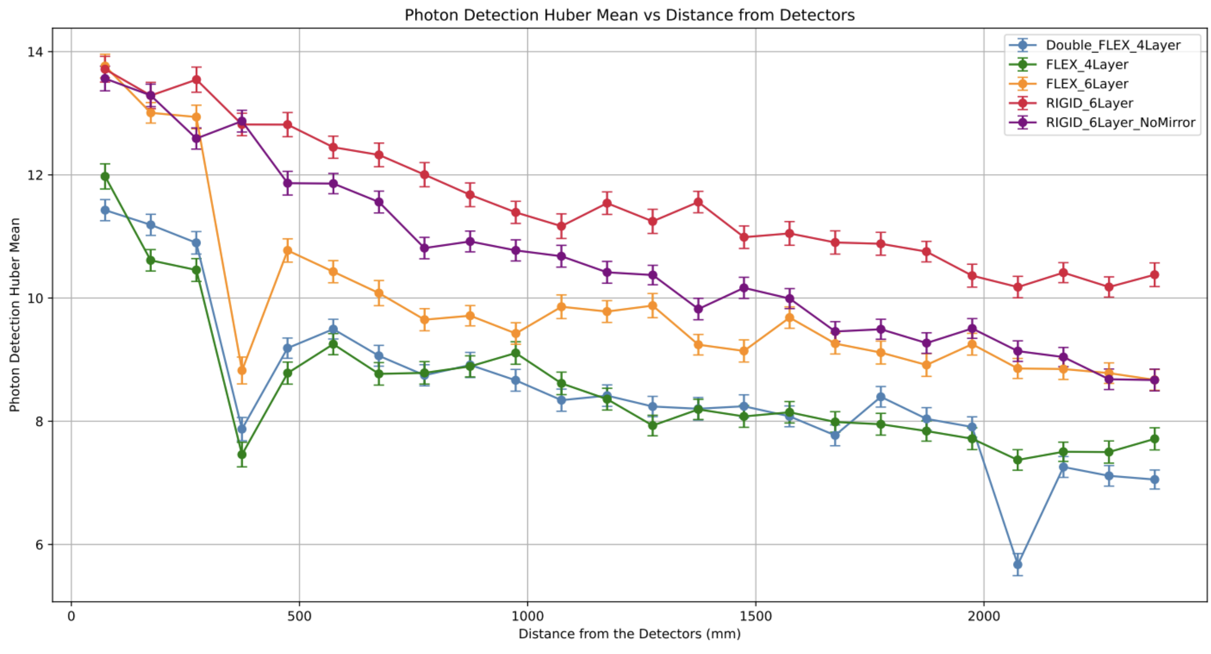


Figure 5: Photon Detection

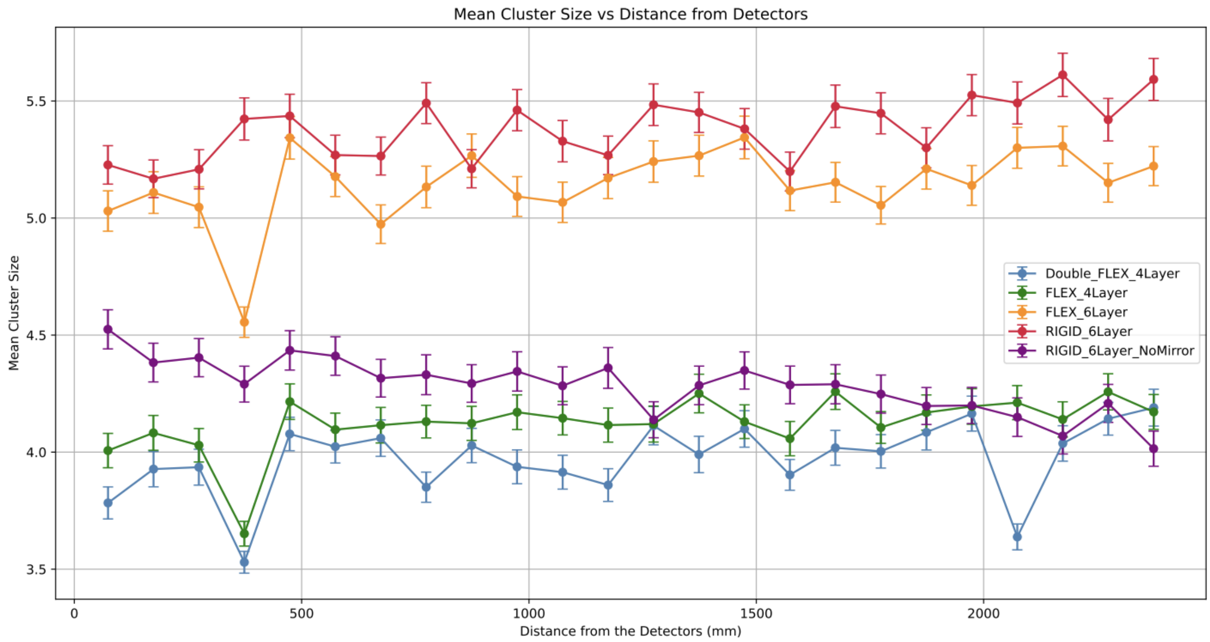


Figure 6: Cluster Size

Overall matching with the experimental data quite well, including the dips at the air gaps. However, the simulated Cluster sizes are larger than data, also the mean numbers of photon detected are smaller. These behaviours require further investigation.

4 Future Objectives

Numerous parameters awaits to be refined:

- Material refractive indices
- Material absorption lengths
- MieHG scattering parameters
- Mirror reflectivity
- SiPM photon detection efficiency

Once these are fine tuned and a close match between the simulation results and experimental data are obtained, alternative SciFi mat designs can be simulated for validity check.