Study on transport of photons (Background) in DD4hep and FLUKA

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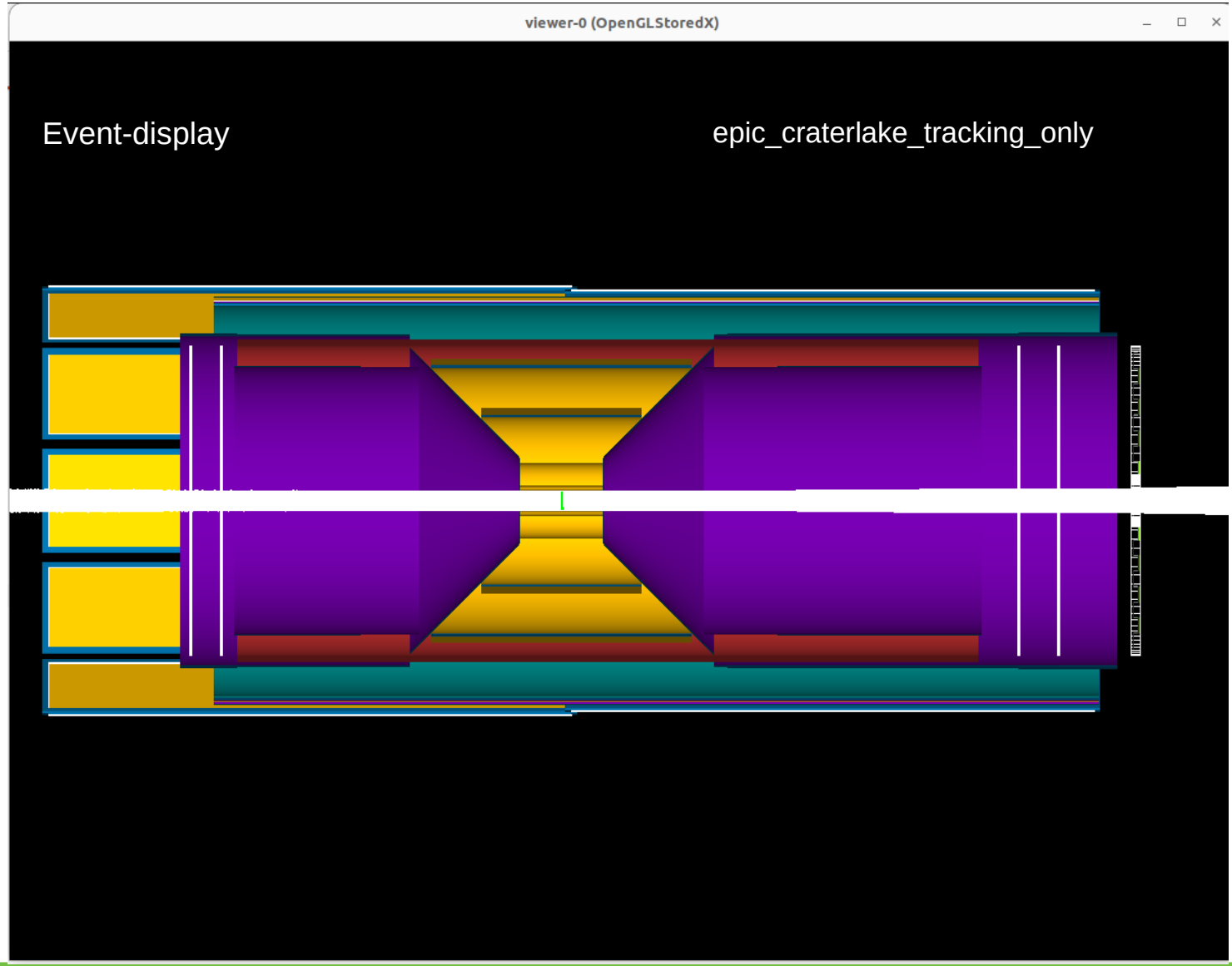
Geometry Name: epic_craterlake_tracking_only

epic tag: 23.07.2

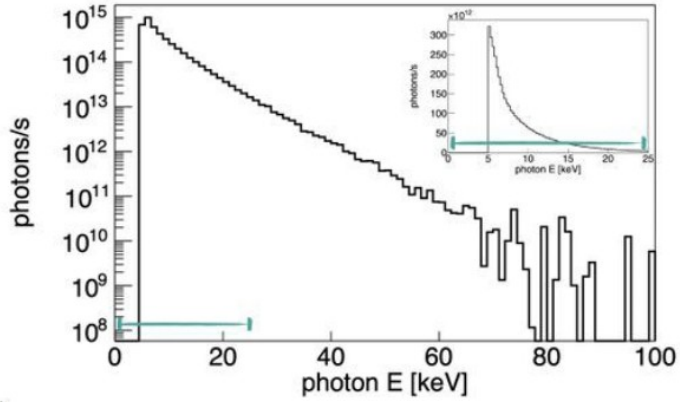
Geometry


viewer-0 (OpenGLStoredX)
Event-display
epic_craterlake_tracking_only

Background Modeling

Sources:

- **e+gas, h+gas:** "Fixed target" events
- **Synchrotron Radiation:** 1.8M photons from SynRad:
- NB: No "MB events" background for now



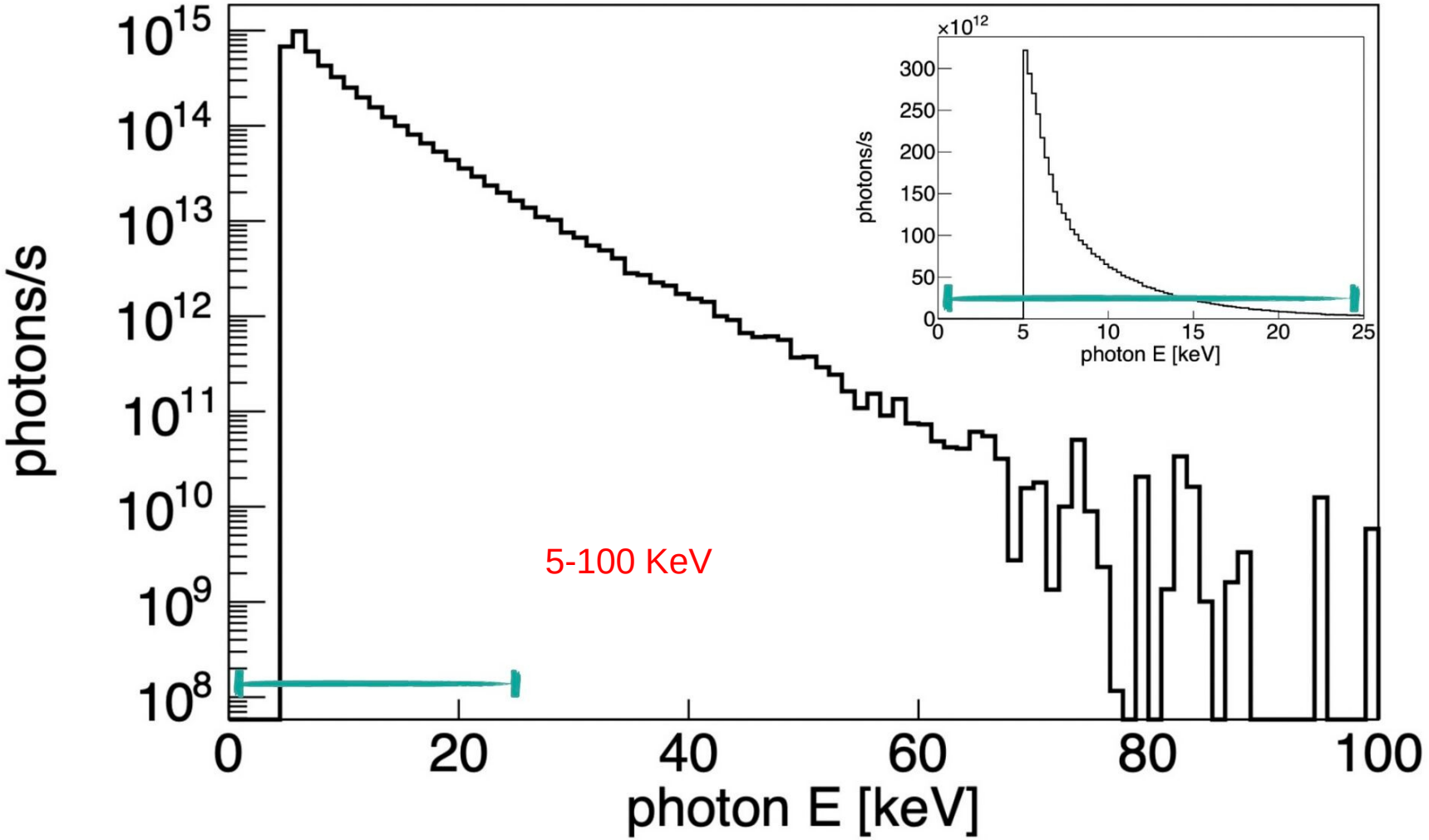
- **Input files, rates, etc.:** Zhengqiao Zhang, Jarda Adam, Benjamen Sterwerf, Rey Cruz Torres - Background Wiki

- **Merge** with a given signal (DIS, particle gun):
  1. Select a time slice width, e.g. 2μs for MAPS integration time
  2. Place signal event(s) at random point(s) in the slice
  3. Select **how many** background events to add from Poisson distribution
  4. Draw random events, or SR photons from weighted distribution
  5. Place at **uniformly random times**

The hepmc file is here:S3/eictest/EPIC/EVGEN/BACKGROUNDS/bgmerged_ep_noradcor.10x100_q2_10_100_run001_n_10000.hepmc

Photon Transport

https://wiki.bnl.gov/EPIC/index.php?title=Synchrotron_Radiation#/media/File:SR_synrad_energy_spectrum.jpg



s

Transport

Transport Codes: GEANT4 and FLUKA

Each particle in hepmc file is transported using G4ParticleGun in GEANT4, there may be some default class for physics process and cuts

https://geant4-userdoc.web.cern.ch/UsersGuides/PhysicsListGuide/html/

FTFP_BERT
QBBC
QGSP_BERT

What is in DD4HEP?

Reference Physics Lists

5

- LHEP
  - fastest of all physics lists
  - not the most precise
  - contains standard EM processes
  - good at describing showers in detectors
- QGSP_BERT
  - the physics list most recommended for HEP
  - used by ATLAS
  - contains standard EM processes
  - uses Bertini cascade for hadrons of energy below ~10 GeV
  - uses QGS model for high energies (> 20 GeV)
- QGSP_BIC
  - uses Binary cascade, precompound and various de-excitation model for hadrons
  - standard EM
  - recommended for use at energies below 200 MeV (medical)
- QGSP_BIC_HP
  - same as QGSP_BIC, but with high precision neutron model used for neutrons below 20 MeV
  - use for radiation protection, shielding and medical applications

http://geant4.in2p3.fr/IMG/pdf_PhysicsLists.pdf

Physics List Naming Convention

4

- "QGS" Quark gluon string model (>~20GeV)
- "FTF" Fritiof Model (>~10GeV)
- "LHEP" Low and High energy parameterization model
- "BIC" Binary Cascade Model (<~10 GeV)
- "BERT" Bertini Cascade Model (<~10 GeV)
- "HP" High Precision Neutron Model (<20MeV)
- "PRECO" Pre compound Model (<~150MeV)
- "EMV(X)" Variation of Standard EM package

```
// Fun4All G4 module
PHG4Reco* g4Reco = new PHG4Reco();
// no magnetic field
g4Reco->set_field(0);
// size of the world - every detector has to fit in here
g4Reco->SetWorldSizeX(500);
g4Reco->SetWorldSizeY(500);
g4Reco->SetWorldSizeZ(2000);
// shape of our world - it is a box
g4Reco->SetWorldShape("G4BOX");
// this is what our world is filled with
g4Reco->SetWorldMaterial("G4_AIR");
// Geant4 Physics list to use
g4Reco->SetPhysicsList("QGSP_BERT");
```

https://sphenix-collaboration.github.io/doxygen/de/d55/Fun4All__G4__block_8C_source.html

Transport of Photons

In our case, Transport of Photons of energy **5 KeV-100 KeV** (Synchrotron radiation)
Photon Interactions: Photeletric effect, Compton Scattering, Ralyleigh, Pair Production (Min energy 1.02 MeV)

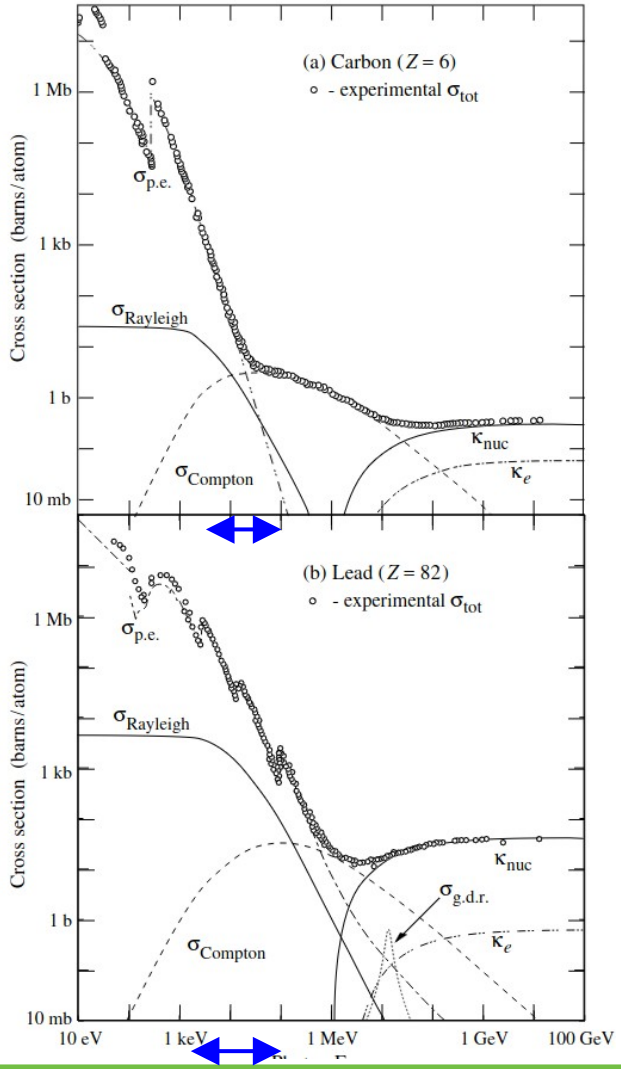


Figure 33.15: Photon total cross sections as a function of energy in carbon and lead, showing the contributions of different processes [50]:

$\sigma_{\text{p.e.}}$ = Atomic photoelectric effect (electron ejection, photon absorption)
σ_{Rayleigh} = Rayleigh (coherent) scattering–atom neither ionized nor excited
σ_{Compton} = Incoherent scattering (Compton scattering off an electron)
κ_{nuc} = Pair production, nuclear field
κ_e = Pair production, electron field
$\sigma_{\text{g.d.r.}}$ = Photonuclear interactions, most notably the Giant Dipole Resonance [51]. In these interactions, the target nucleus is usually broken up.

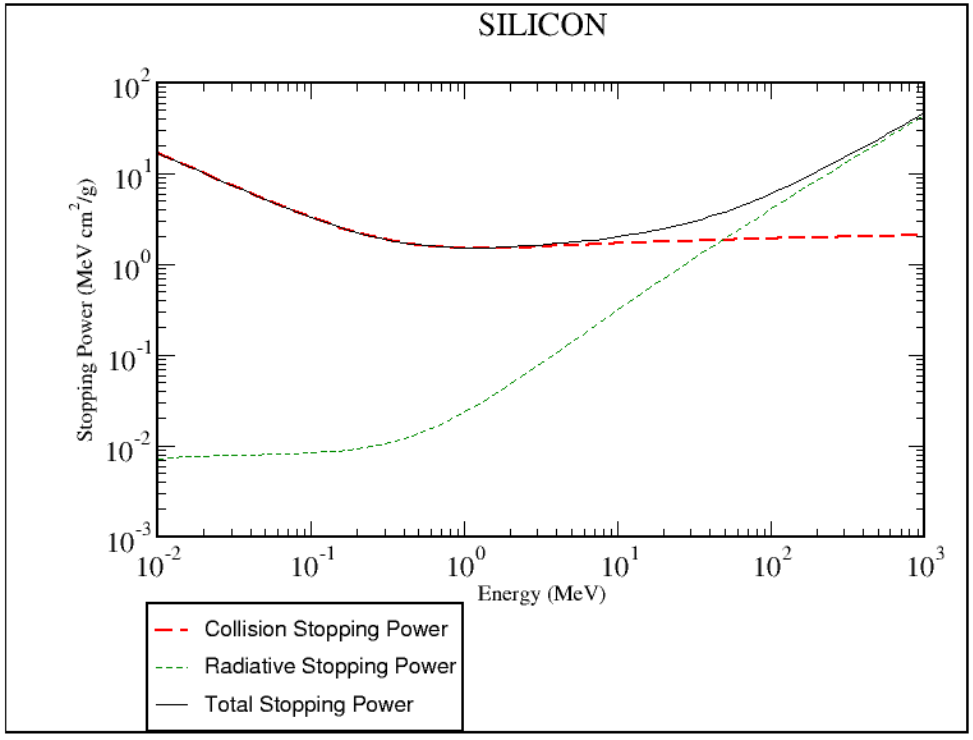
Original figures through the courtesy of John H. Hubbell (NIST).

https://pdg.lbl.gov/2019/reviews/rpp2018-rev-passage-particles-matter.pdf Page 21

In Carbon:
Photo-electric effect: 10 eV-100 eV
Compton Scattering: 100 eV-1 GeV
Rayleigh Scattering: below 500 KeV

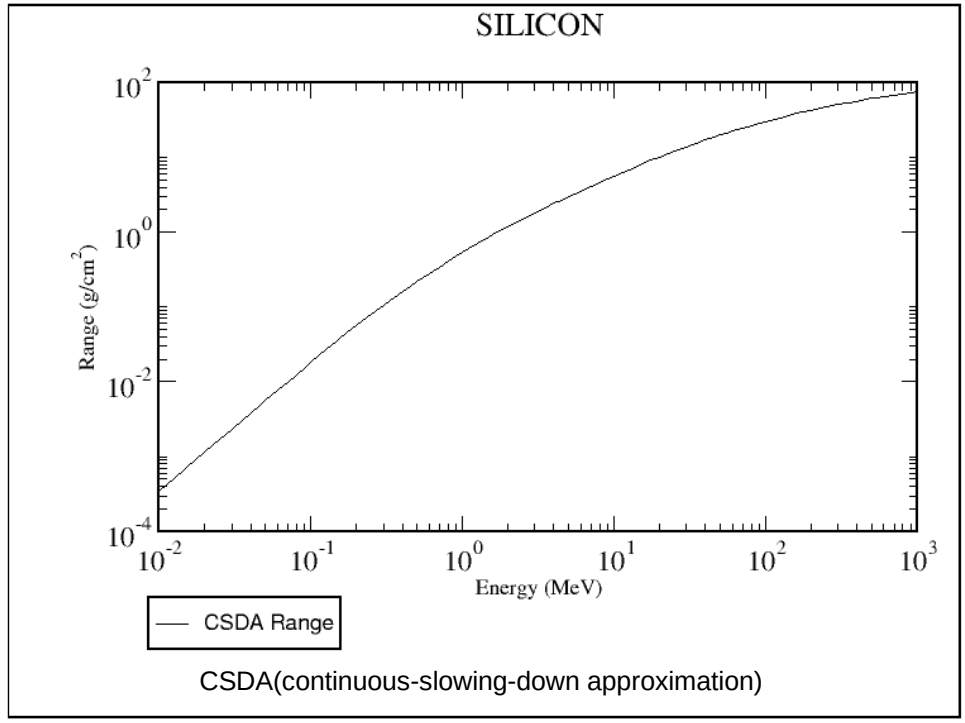
Estimation of Stopping Power and Range of Electrons

ESTAR : Stopping Power and Range Tables for Electrons



Show compositional data for SILICON

ESTAR : Stopping Power and Range Tables for Electrons



CSDA(continuous-slowing-down approximation)

Show compositional data for SILICON

Composition of SILICON:

Density (g/cm^3) = 2.33000E+00
Mean Excitation Energy (eV) = 173.000000

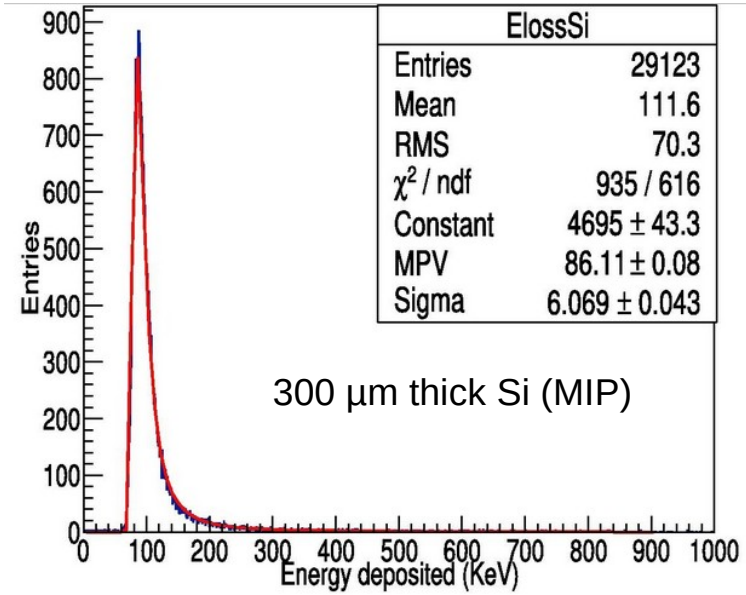
COMPOSITION:	
Atomic number	**Fraction by weight**
14	1.000000

Simulated using NIST database

10 KeV electron range = 1.485 μm

100 KeV electron range = 78 μm

Digitization



https://link.springer.com/chapter/10.1007/978-981-10-7665-7_9

300 µm thick Si MPV dE/dx = 86.0 KeV
50 µm thick Si MPV dE/dx = 14.0 KeV

Mean energy for e-h pair creation (Si):

If incident particle has mass ϵ = 3.6 eV (All Charged Particles)
If incident particle has zero mass ϵ = 1.1 eV (=bandgap e.g. photons)

50 µm thick Si MPV Charge = 14.0 KeV/3.6 eV = 3888 e-h pairs = 3888*1.1 eV = 4.3 KeV Photon

Digitization (DD4HEP): For each MonteCarlo (MC) point take the **energy loss** apply threshold to register the hit (DD4HEP)

```
52
53
54
55
56
```

```
double edep = sim_hit->getEDep();
if (edep < m_cfg.threshold) {
    m_log->debug("  edep is below threshold of {:.2f} [keV]", m_cfg.threshold / dd4hep::keV);
    continue;
}
```

https://github.com/eic/EICrecon/blob/main/src/algorithms/digi/SiliconTrackerDigi.cc#L33

Very important to calculate the energy loss properly at the level of MC points (Generation) set physics and cuts properly

Full digitization parameters (Based on my old work (2013))
https://subversion.gsi.de/fairroot/pandaroot/development/shyam/PANDAROOT-Source@pandaroot/macro/run/all.par

Energy loss in DD4HEP

Simulation of Photons from 5KeV to 100 KeV from theta 80 to 90 deg

2 Photons out of 200

```
root [2] events->Scan("MCParticles.PDG:sqrt(MCParticles.momentum.x*MCParticles.momentum.x+MCParticles.momentum.y*MCParticles.momentum.y+MCParticles.momentum.z*
MCParticles.momentum.z)")
```

Generated

Row	Instance	MCParticl	sqrt(MCPa
0	0	22	8.525e-05
1	0	22	8.446e-05
2	0	22	7.365e-05
3	0	22	6.872e-05
4	0	22	9.775e-05
5	0	22	6.180e-05
6	0	22	6.781e-05
7	0	22	2.623e-05
8	0	22	1.073e-05
9	0	22	3.242e-05
10	0	22	2.097e-05
11	0	22	9.176e-05
12	0	22	8.794e-05
13	0	22	8.342e-05
14	0	22	5.115e-05
15	0	22	3.268e-05
16	0	22	1.361e-05
17	0	22	1.251e-05
18	0	22	9.557e-05
19	0	22	8.306e-05
20	0	22	1.403e-05
21	0	22	3.514e-05
22	0	22	4.518e-05
23	0	22	1.715e-05
24	0	22	9.062e-06

Energy loss in vertex layers

```
root [2] events->Scan("VertexBarrelHits.EDep")
```

Row	Instance	VertexBa
0	0	
1	0	
2	0	
3	0	
4	0	
5	0	
6	0	
7	0	
8	0	
9	0	
10	0	
11	0	
12	0	
13	0	
14	0	
15	0	
16	0	
17	0	
18	0	
19	0	
20	0	
21	0	
22	0	
23	0	
24	0	

Type <CR> to continue or q to

25	0	
26	0	
27	0	
28	0	
29	0	
30	0	
31	0	
32	0	
33	0	
34	0	
35	0	
36	0	
37	0	
38	0	
39	0	
40	0	
41	0	
42	0	
43	0	
44	0	
45	0	
46	0	
47	0	
48	0	
49	0	

Type <CR> to continue or

50	0	
51	0	
52	0	
53	0	
54	0	
55	0	
56	0	
57	0	
58	0	
59	0	
60	0	
61	0	
62	0	
63	0	
64	0	
65	0	
66	0	
67	0	
68	0	
69	0	
70	0	1.844e-06
70	1	8.566e-06
71	0	
72	0	
73	0	

Type <CR> to continue or q to quit

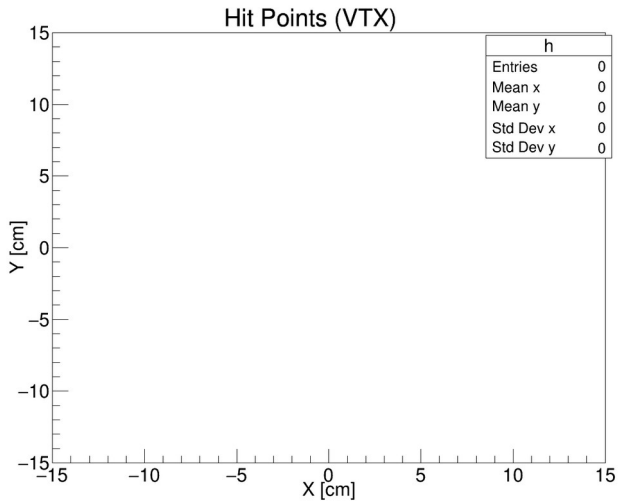
74	0	
75	0	
76	0	
77	0	
78	0	
79	0	
80	0	
81	0	
82	0	
83	0	
84	0	
85	0	
86	0	
87	0	
88	0	
89	0	
90	0	
91	0	
92	0	
93	0	
94	0	
95	0	
96	0	
97	0	
98	0	

Type <CR> to continue or q to quit

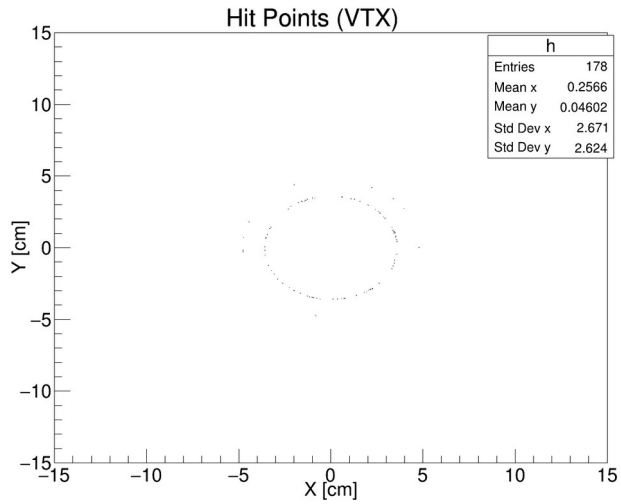
99	0	
100	0	
101	0	
102	0	
103	0	
104	0	
105	0	
106	0	
107	0	
108	0	
109	0	
110	0	
111	0	
112	0	
113	0	
114	0	
115	0	
116	0	
117	0	

Energy loss in DD4HEP with 100k Photons (with beam pipe)

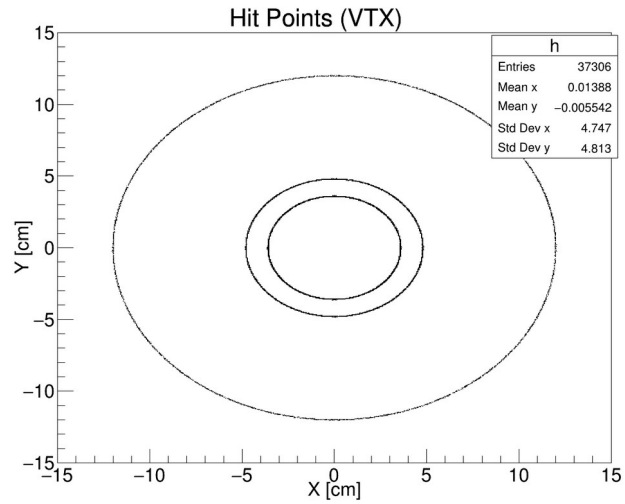
Photons E = 1 KeV



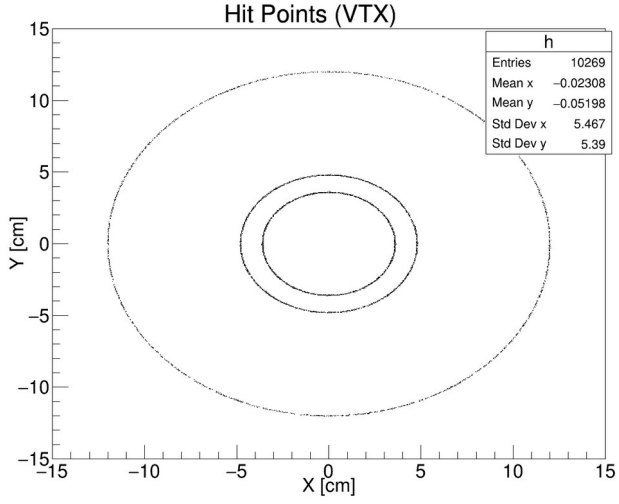
Photons E = 5 KeV



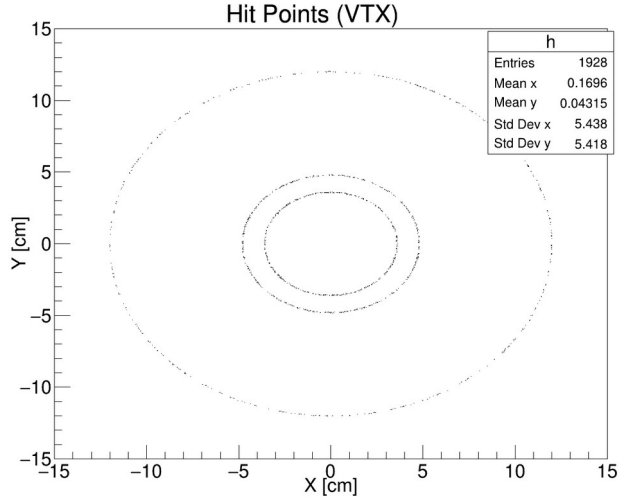
Photons E = 10 KeV



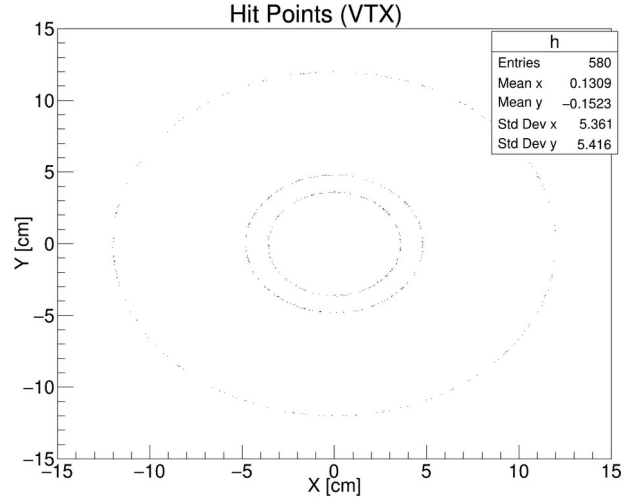
Photons E = 20 KeV



Photons E = 50 KeV



Photons E = 100 KeV



Energy loss in DD4HEP

Initial assumption that Gold coated beam-pipe is stopping Photons (Beam Pipe removed)

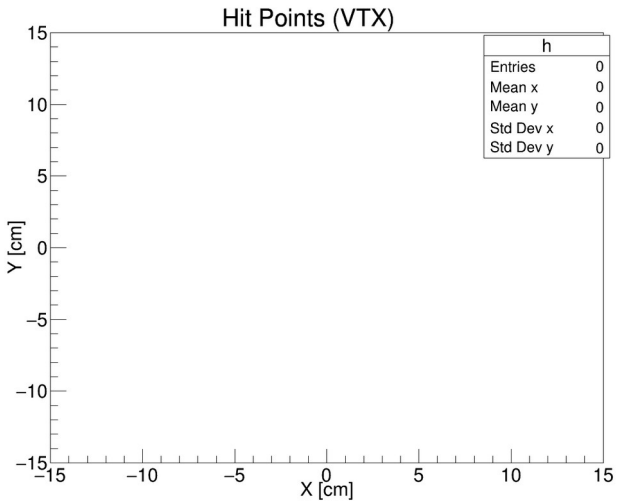
```
root [1] events->Scan("VertexBarrelHits.EDep")
***********************************
*    Row   * Instance * VertexBar *
***********************************
*        0 *        0 *         *
*        1 *        0 * 1.844e-06 *
*        1 *        1 * 7.171e-06 *
*        2 *        0 *         *
*        3 *        0 *         *
*        4 *        0 *         *
*        5 *        0 *         *
*        6 *        0 *         *
*        7 *        0 *         *
*        8 *        0 * 1.540e-07 *
*        8 *        1 * 7.450e-06 *
*        9 *        0 *         *
*       10 *        0 *         *
*       11 *        0 *         *
*       12 *        0 *         *
*       13 *        0 *         *
*       14 *        0 *         *
*       15 *        0 *         *
*       16 *        0 *         *
*       17 *        0 *         *
*       18 *        0 *         *
*       19 *        0 *         *
*       20 *        0 *         *
*       21 *        0 *         *
*       22 *        0 *         *
Type <CR> to continue or q to quit ==>
*       23 *        0 *         *
*       24 *        0 *         *
*       25 *        0 *         *
*       26 *        0 *         *
*       27 *        0 *         *
*       28 *        0 * 1.844e-06 *
*       28 *        1 * 1.385e-05 *
*       29 *        0 *         *
*       30 *        0 *         *
*       31 *        0 *         *
*       32 *        0 *         *
*       33 *        0 *         *
*       34 *        0 *         *
*       35 *        0 *         *
*       36 *        0 *         *
*       37 *        0 *         *
*       38 *        0 *         *
*       39 *        0 *         *
*       40 *        0 * 1.540e-07 *
*       40 *        1 * 6.807e-06 *
*       41 *        0 *         *
*       42 *        0 *         *
*       43 *        0 *         *
*       44 *        0 *         *
*       45 *        0 *         *
Type <CR> to continue or q to quit ==>
*       46 *        0 * 1.346e-08 *
*       46 *        1 * 2.463e-05 *
*       47 *        0 * 1.844e-06 *
*       47 *        1 * 1.339e-05 *
*       48 *        0 *         *
*       49 *        0 *         *
*       50 *        0 *         *
*       51 *        0 *         *
*       52 *        0 *         *
*       53 *        0 *         *
*       54 *        0 *         *
*       55 *        0 *         *
*       56 *        0 *         *
*       57 *        0 *         *
*       58 *        0 *         *
*       59 *        0 * 1.844e-06 *
*       59 *        1 * 8.405e-06 *
*       60 *        0 *         *
*       61 *        0 *         *
*       62 *        0 *         *
*       63 *        0 *         *
*       64 *        0 *         *
*       65 *        0 *         *
*       66 *        0 *         *
*       67 *        0 *         *
Type <CR> to continue or q to quit
*       68 *        0 *         *
*       69 *        0 *         *
*       70 *        0 *         *
*       71 *        0 *         *
*       72 *        0 *         *
*       73 *        0 *         *
*       74 *        0 *         *
*       75 *        0 *         *
*       76 *        0 *         *
*       77 *        0 *         *
*       78 *        0 *         *
*       79 *        0 *         *
*       80 *        0 *         *
*       81 *        0 *         *
*       82 *        0 *         *
*       83 *        0 *         *
*       84 *        0 * 1.844e-06 *
*       84 *        1 * 2.349e-05 *
*       85 *        0 *         *
*       86 *        0 *         *
*       87 *        0 *         *
*       88 *        0 *         *
*       89 *        0 *         *
*       90 *        0 *         *
*       91 *        0 *         *
Type <CR> to continue or q to quit ==>
*       92 *        0 *         *
*       93 *        0 *         *
*       94 *        0 *         *
*       95 *        0 *         *
*       96 *        0 *         *
*       97 *        0 *         *
*       98 *        0 *         *
*       99 *        0 *         *
*      100 *        0 *         *
*      101 *        0 *         *
*      102 *        0 *         *
*      103 *        0 *         *
*      104 *        0 *         *
*      105 *        0 *         *
*      106 *        0 *         *
*      107 *        0 *         *
*      108 *        0 *         *
```

16 Photons out of 200

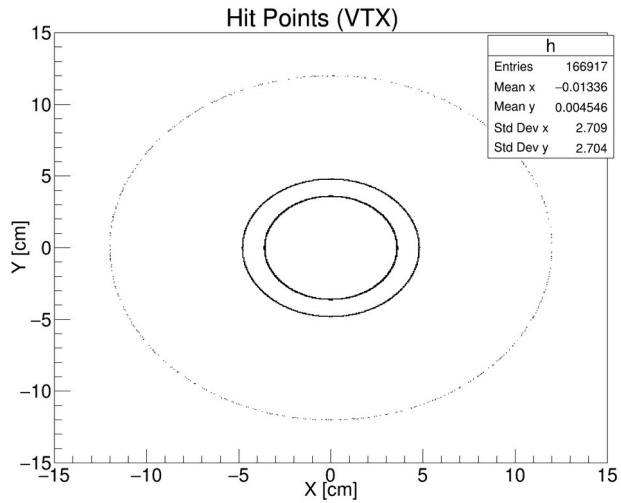
Photons depositing energy in Silicon are increased

Energy loss in DD4HEP with 100k Photons (without beam pipe)

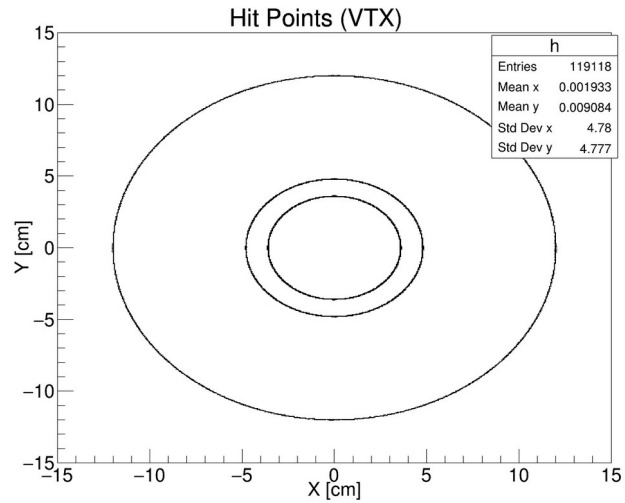
Photons E = 1 KeV



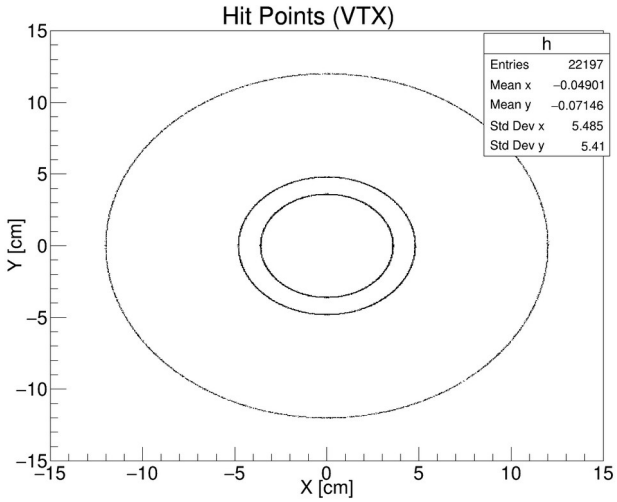
Photons E = 5 KeV



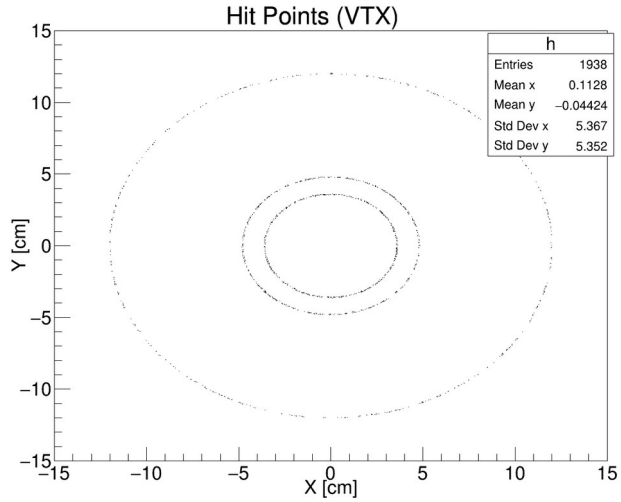
Photons E = 10 KeV



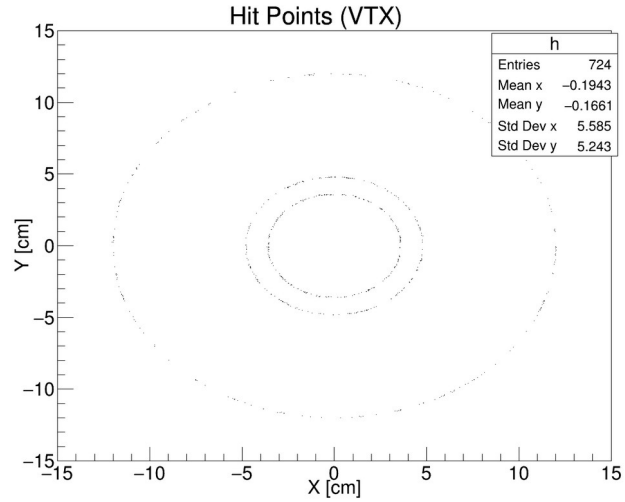
Photons E = 20 KeV



Photons E = 50 KeV



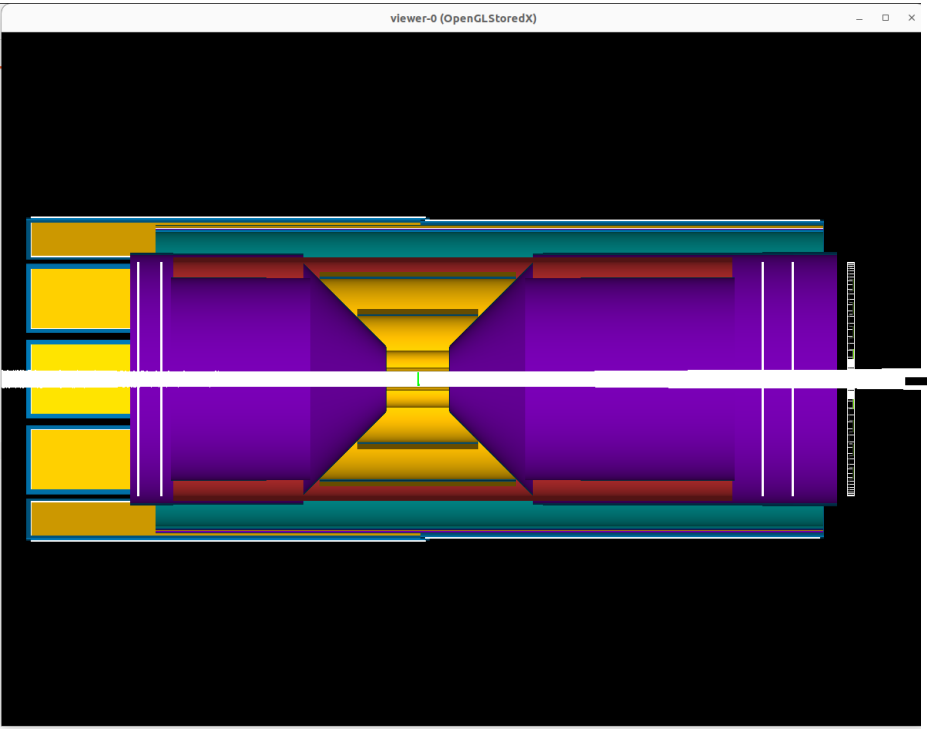
Photons E = 100 KeV



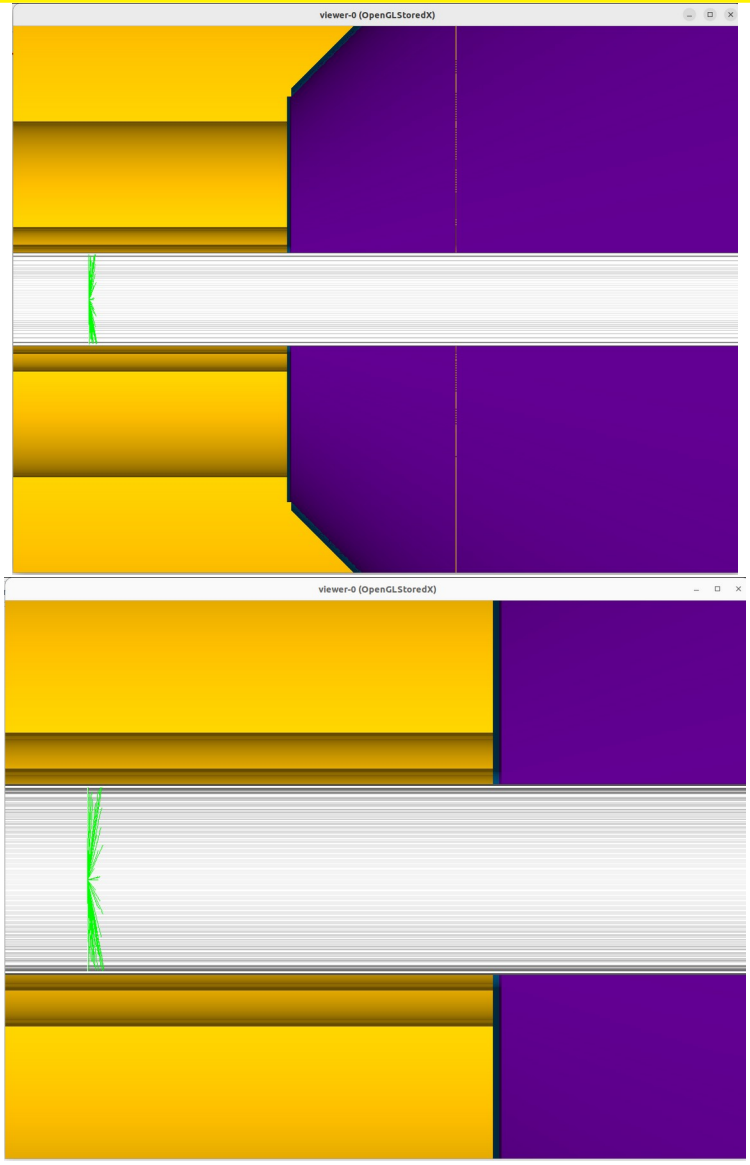
Event Visualization

1000 Photons

1-2 KeV Photon (80-90 deg)



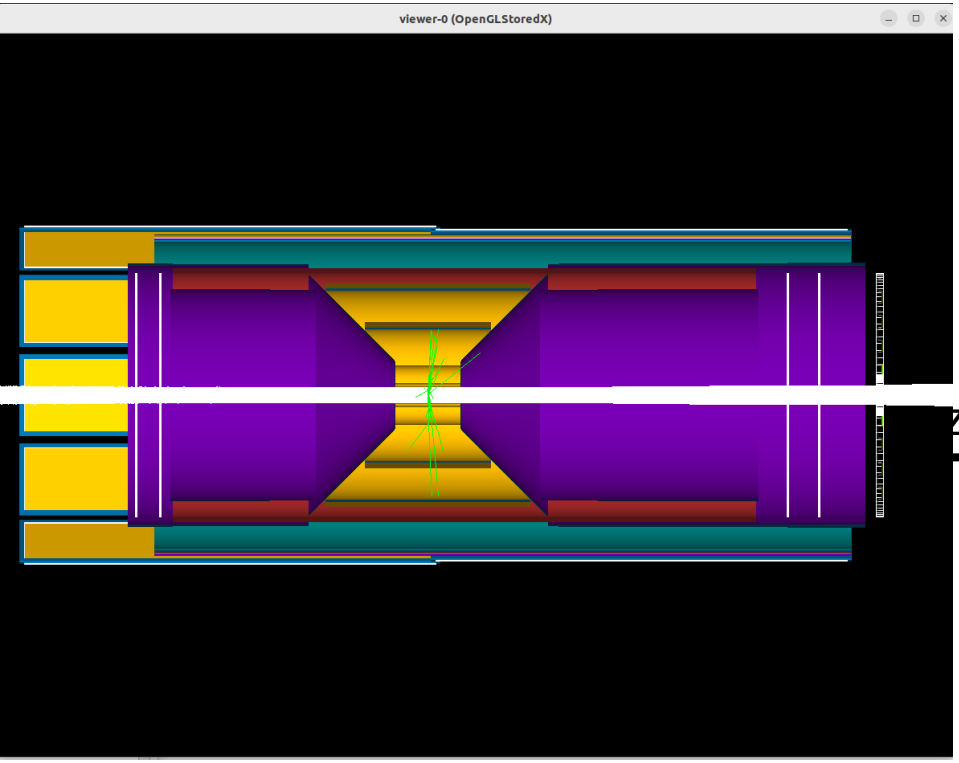
zoom



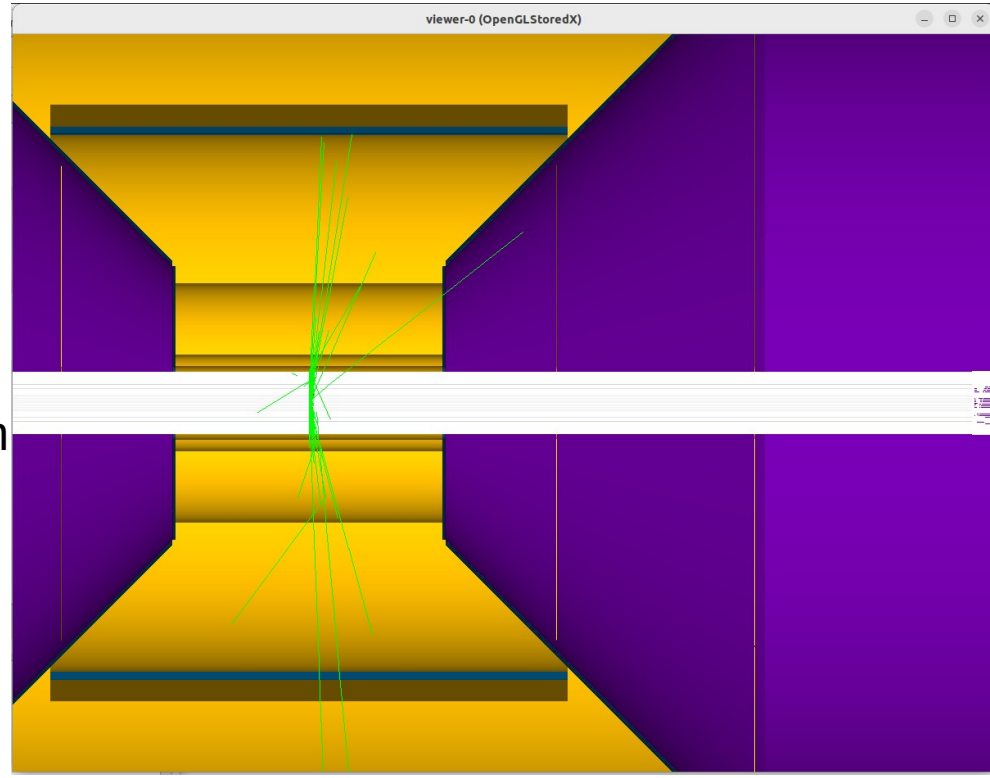
Green color for Photon and Magenta for Electrons

Event Visualization

5-10 KeV Photon (80-90 deg)



zoom



Green color for Photon and Magenta for Electrons

1 KeV Photon doesn't deposition energy in Silicon layers looks cut off is 1 KeV

If we shoot photons of 5 KeV energy it give small hits in Si layers in the presence of beam-pipe

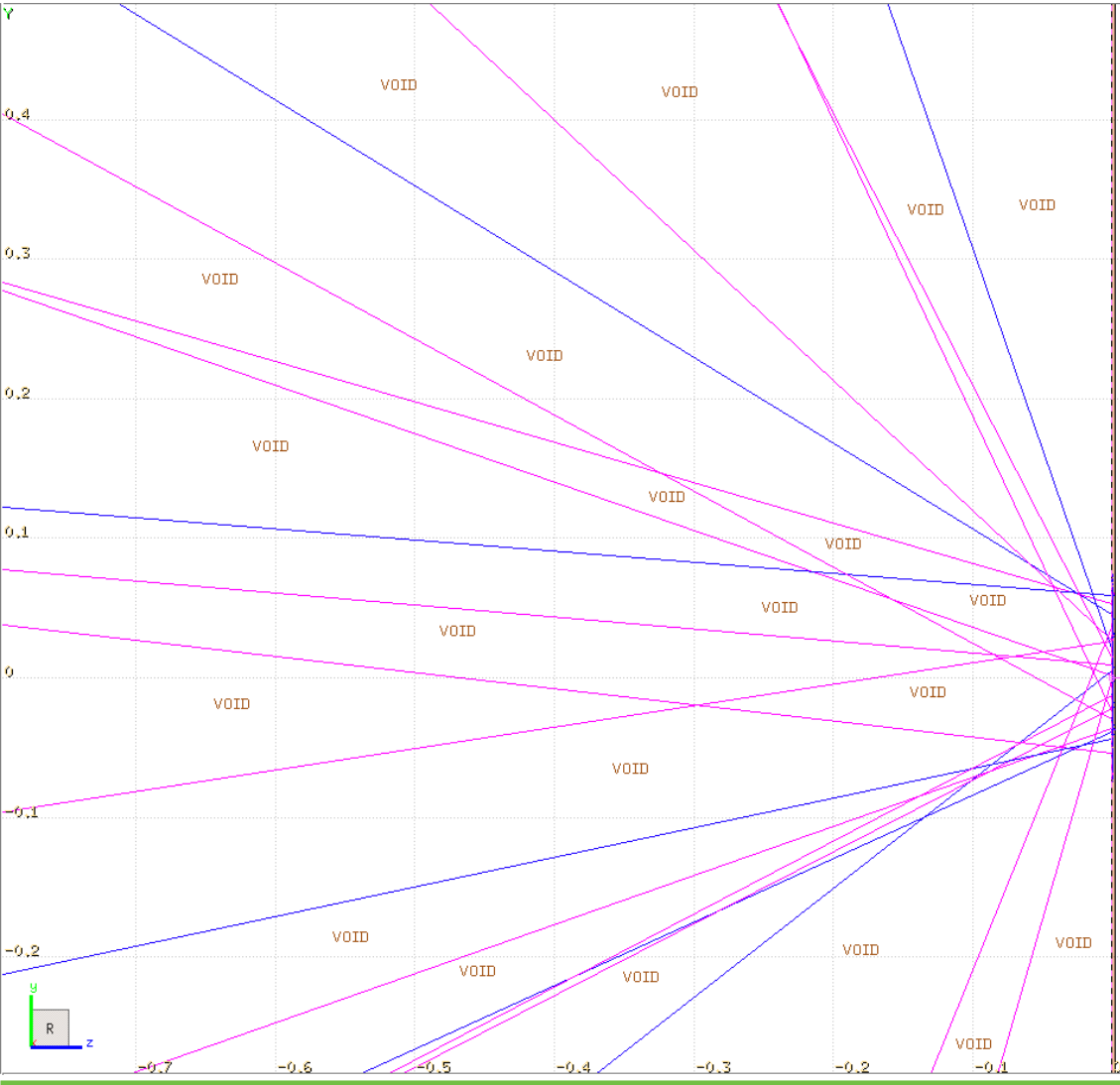
Event Visualization Window (Prints)

```
Region <DefaultRegionForParallelWorld> --  -- is not associated to any world.
 Root logical volume(s) :
 Pointers : G4VUserRegionInformation[0], G4UserLimits[0], G4FastSimulationManager
 Materials :
 Production cuts :   gamma 700 um      e- 700 um      e+ 700 um  proton 700 um

========= Table of registered couples ==========================

Index : 0     used in the geometry : Yes
 Material : Air
 Range cuts        :  gamma  700 um     e-  700 um     e+  700 um  proton 700 um
 Energy thresholds :  gamma  990 eV     e-  990 eV     e+  990 eV  proton 70 keV
 Region(s) which use this couple :
    DefaultRegionForTheWorld

Index : 1     used in the geometry : Yes
 Material : Silicon
 Range cuts        :  gamma  700 um     e-  700 um     e+  700 um  proton 700 um
 Energy thresholds :  gamma  5.85415 keV    e-  423.338 keV    e+  409.012 keV pr
 Region(s) which use this couple :
    DefaultRegionForTheWorld

Index : 2     used in the geometry : Yes
 Material : Vacuum
 Range cuts        :  gamma  700 um     e-  700 um     e+  700 um  proton 700 um
 Energy thresholds :  gamma  990 eV     e-  990 eV     e+  990 eV  proton 70 keV
 Region(s) which use this couple :
    DefaultRegionForTheWorld

Index : 3     used in the geometry : Yes
 Material : CarbonFiber
 Range cuts        :  gamma  700 um     e-  700 um     e+  700 um  proton 700 um
 Energy thresholds :  gamma  2.53375 keV    e-  348.445 keV    e+  338.848 keV pr
 Region(s) which use this couple :
    DefaultRegionForTheWorld

Index : 4     used in the geometry : Yes
 Material : Aluminum
 Range cuts        :  gamma  700 um     e-  700 um     e+  700 um  proton 700 um
 Energy thresholds :  gamma  5.84707 keV    e-  461.19 keV    e+  445.1 keV proton 70 keV
 Region(s) which use this couple :
    DefaultRegionForTheWorld

Index : 5     used in the geometry : Yes
 Material : Fr4
 Range cuts        :  gamma  700 um     e-  700 um     e+  700 um  proton 700 um
 Energy thresholds :  gamma  3.61038 keV    e-  392.487 keV    e+  380.676 keV proton 70 keV
 Region(s) which use this couple :
    DefaultRegionForTheWorld

Index : 6     used in the geometry : Yes
 Material : Ar
 Range cuts        :  gamma  700 um     e-  700 um     e+  700 um  proton 700 um
 Energy thresholds :  gamma  990 eV     e-  990 eV     e+  990 eV  proton 70 keV
 Region(s) which use this couple :
    DefaultRegionForTheWorld

Index : 7     used in the geometry : Yes
 Material : Kapton
 Range cuts        :  gamma  700 um     e-  700 um     e+  700 um  proton 700 um
 Energy thresholds :  gamma  2.59227 keV    e-  330.806 keV    e+  321.809 keV proton 70 keV
 Region(s) which use this couple :
    DefaultRegionForTheWorld

Index : 8     used in the geometry : Yes
 Material : Copper
 Range cuts        :  gamma  700 um     e-  700 um     e+  700 um  proton 700 um
 Energy thresholds :  gamma  20.5458 keV    e-  1.03403 MeV    e+  979.824 keV proton 70 keV
 Region(s) which use this couple :
    DefaultRegionForTheWorld

Index : 9     used in the geometry : Yes
```

Thresholds shown by visualization window

FLUKA Simulations (Silicon)

FLUKA event display (with Photons of 2 KeV energy with 10 mm thick silicon). Magenta (Photons) and blue electrons



http://www.fluka.org/content/manuals/online/EMFCUT.html

The minimum threshold energy for transport and production of photons is 100 eV. For electrons and positrons, it is 1 keV. from above link.

Event Visualization

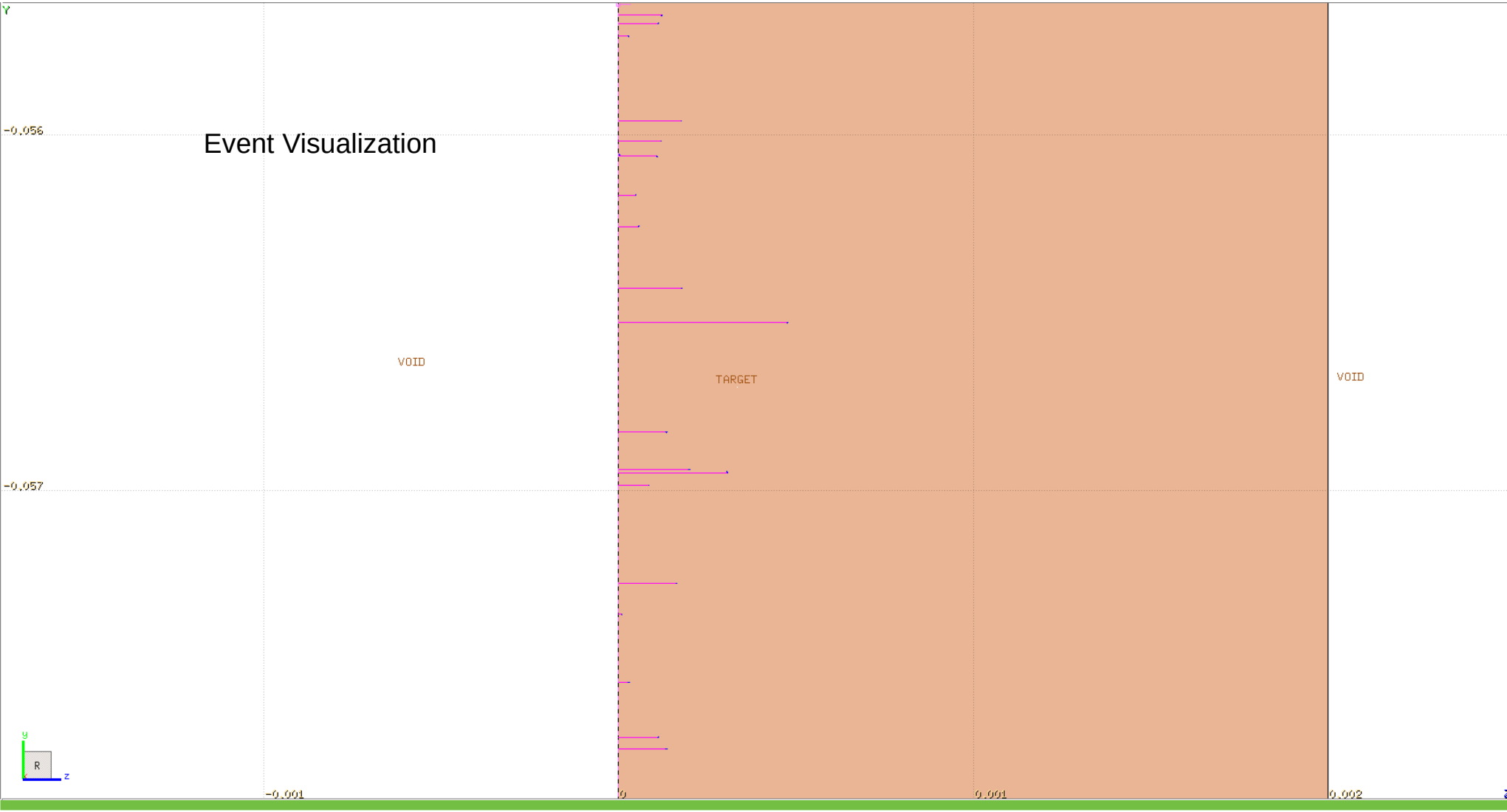
1. If you see the images there are few electrons emitted at the surface which are backward blue lines due to Photoelectric effect.

2. Each Photon absorbed in silicon is terminated by a blue line that means each photon is stopped through Photoelectric effect and electrons have a very short range in silicon at this energy (2KeV of Photon energy).

3. I can see some of the photons go inside silicon and are reflected back (Rayleigh Scattering).

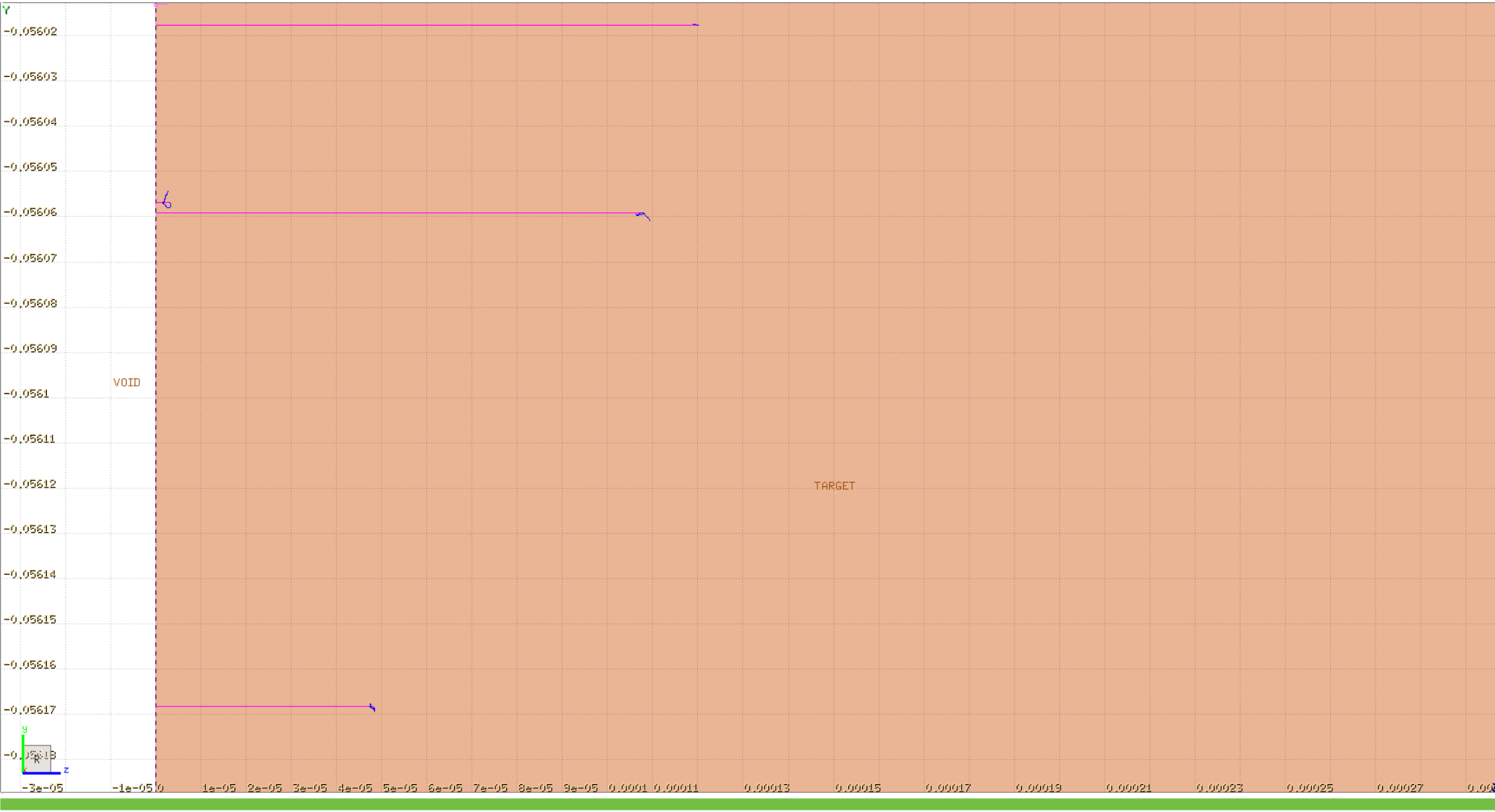
FLUKA Simulations (Silicon)

FLUKA event display (with Photons of 2 KeV energy with 10 mm thick silicon). Magenta (Photons) and blue electrons

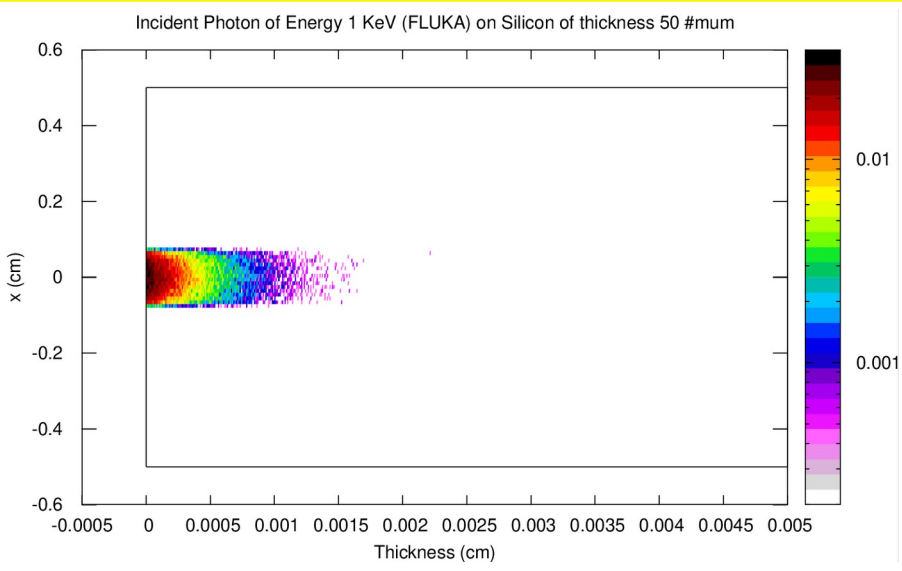


FLUKA Simulations (Silicon)

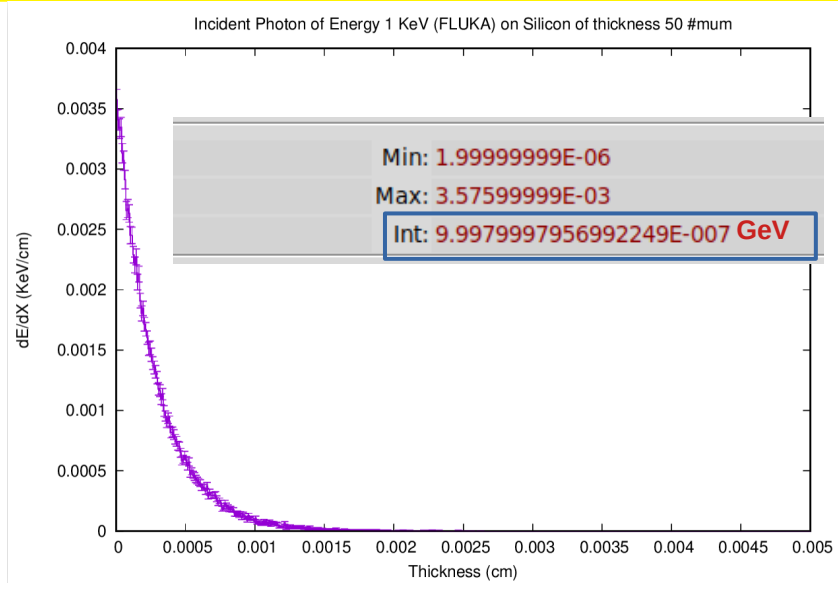
FLUKA event display (with Photons of 2 KeV energy with 10 mm thick silicon). Magenta (Photons) and blue electrons

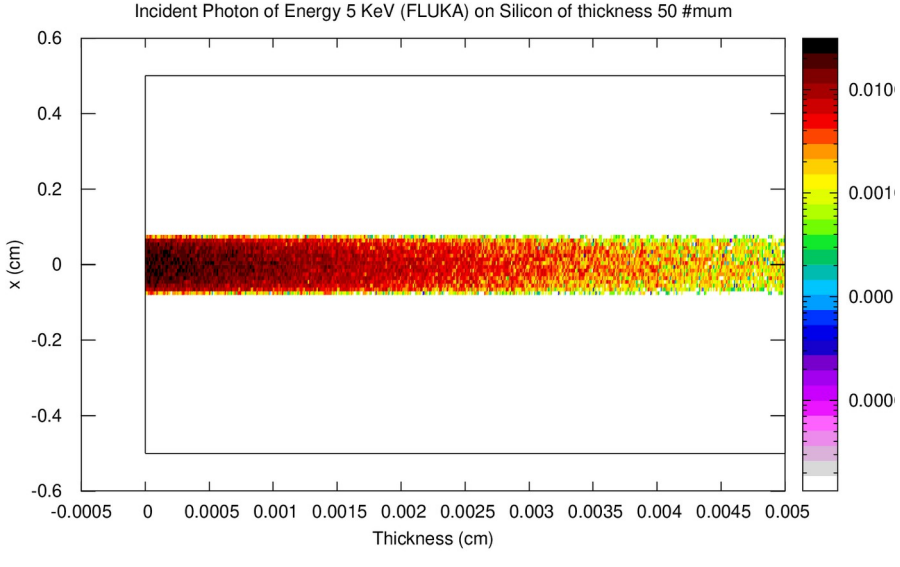


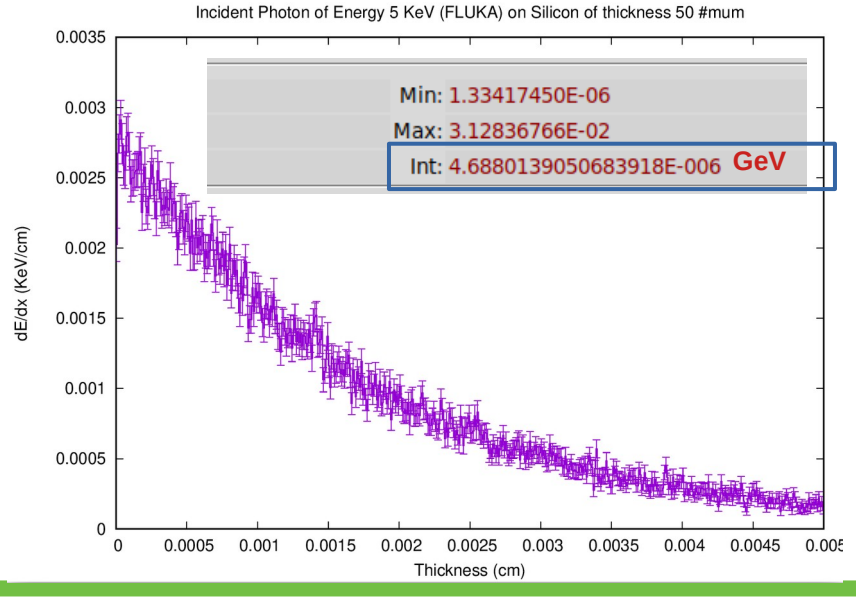
FLUKA Energy loss (Silicon)



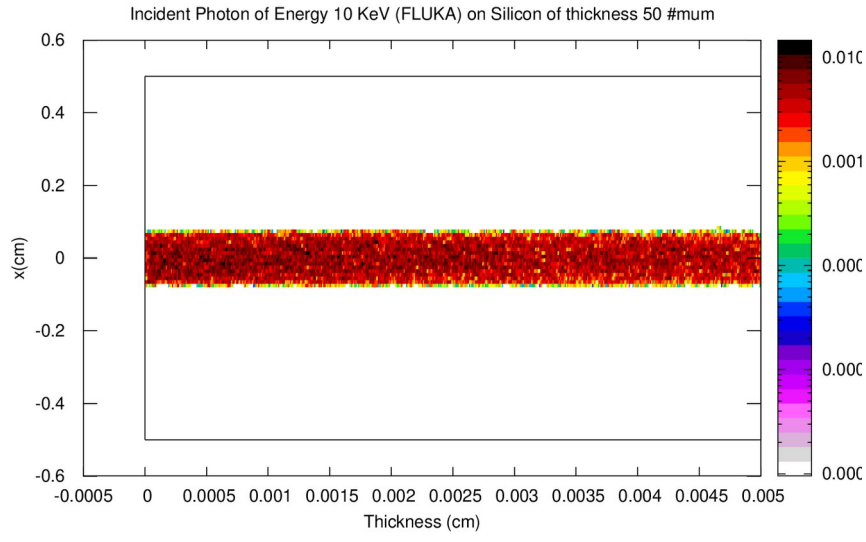
Ignore (KeV)



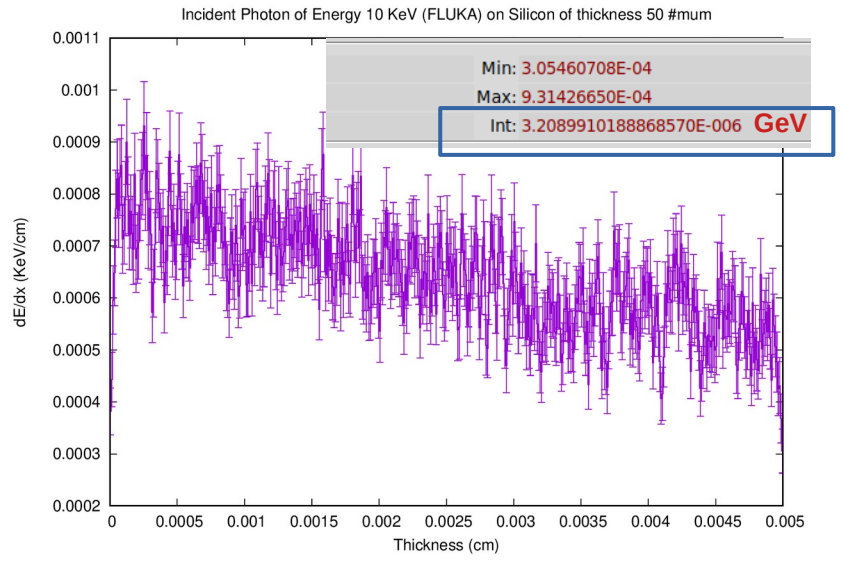


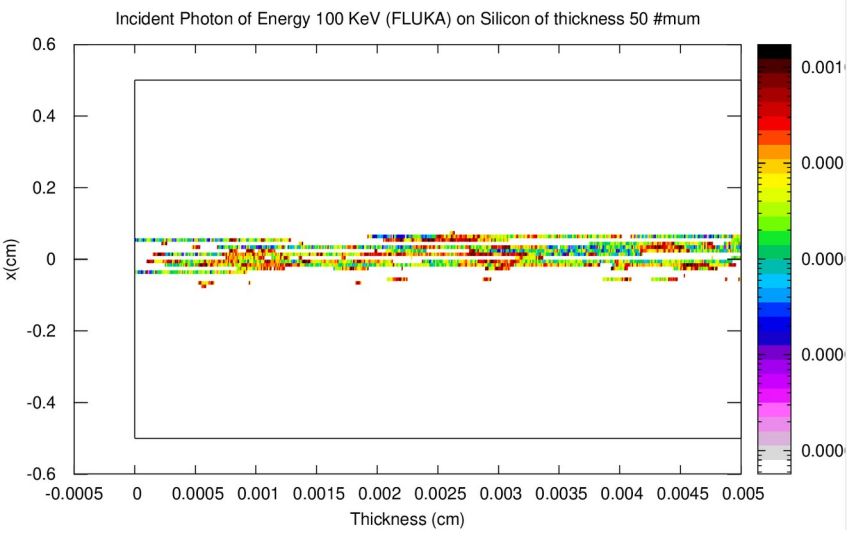


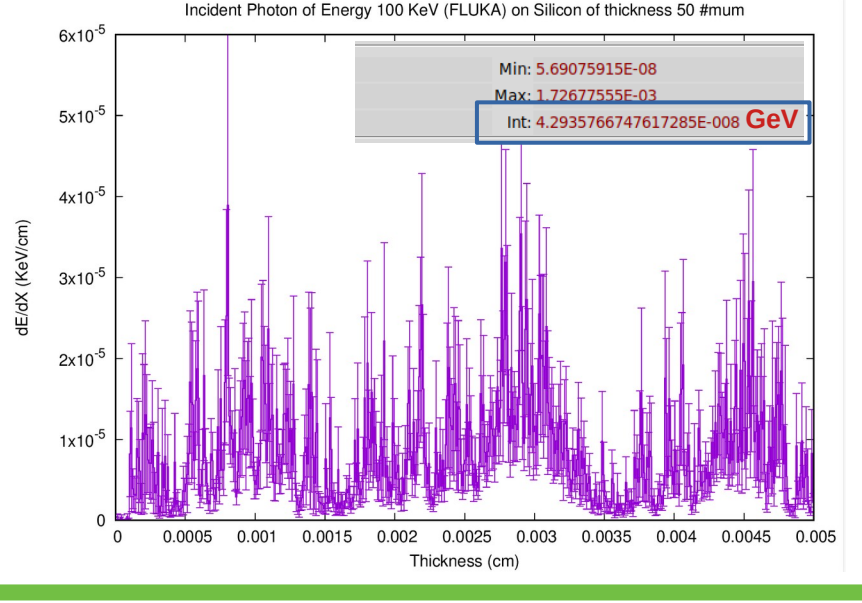
FLUKA Energy loss (Silicon)



Ignore (KeV)







Summary

- Presented the studies on background radiation
- Further need to repeat the studies using the lower threshold in GEANT4
- Will also look in FLUKA to understand in more detail

Thank You !!