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U.S. DEPARTMENT OF ENERGY
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SVT Sensor Structure in DD4hep

Shujie Li

07.23.2026

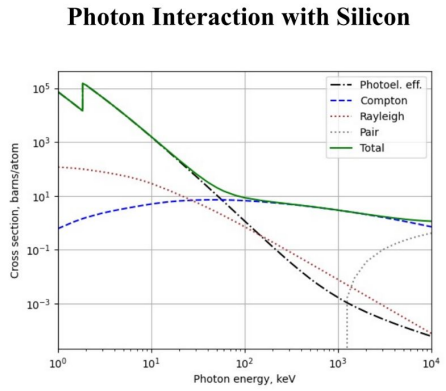
ePIC tracking++ meeting

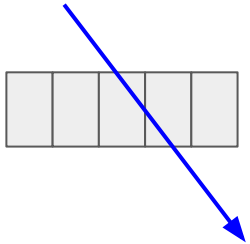
Check PR for this discussion

Motivation

Improve sensor response handling in simulation

	Low energy photons	Charged Particles
Interaction probability	Sensitive to material thickness	-
Cluster size	-	Mainly geometry dependent e.g. pitch size, thickness, incident angle

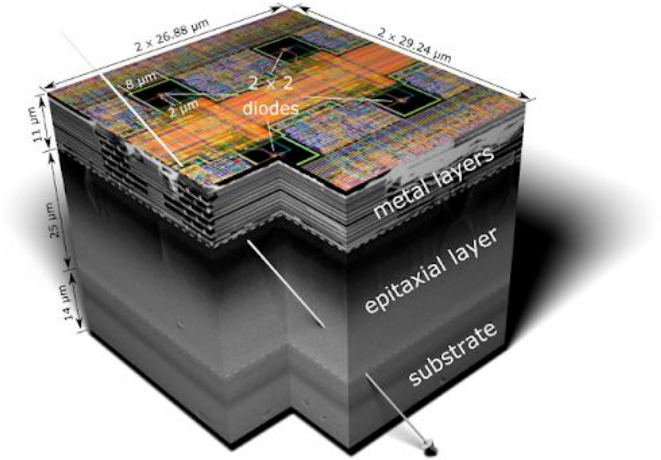




Sensor Structure

Currently in DD4hep: 1 layer of 40um of sensitive Si

Sensor Design:



Particles interact with sensor and generate signal charges ⇒

Signal charges collected through drifting and diffusion ⇒

Collected charges are processed by integrated readout electronics

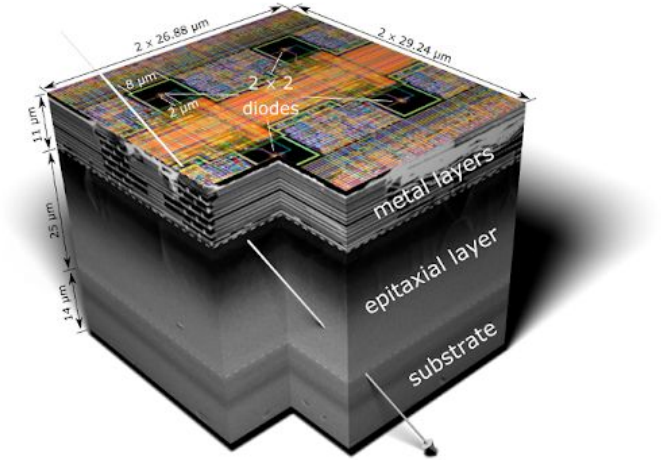
Sensor Structure

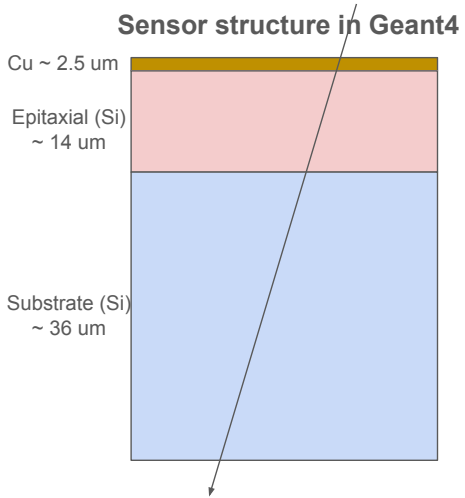
Currently in DD4hep: 1 layer of 40um of sensitive Si

Match sensor response between stand-alone **Geant4** and **TCAD+Allpix2** simulation, and validate against beam test data

- Months of effort led by Zhenyu Ye and Yu Hu [link]
- Tune effective thickness in Geant4 to match the **interaction probability**:
  2.5um Cu (metal layer) + 14um active Si (epitaxial) + 36um inactive Si (substrate)
- Benchmark b/w DD4hep and Geant4 has been performed previously

Sensor Design:



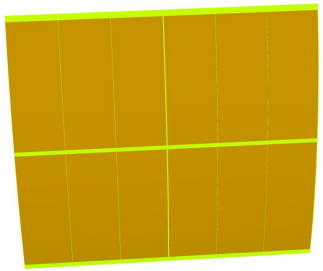


Implementation in DD4hep

Summary of PR:

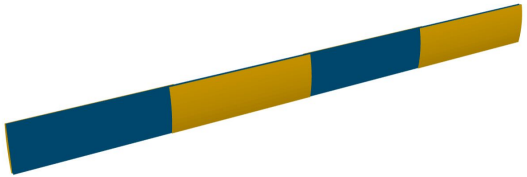
Inner Barrel: Each RSU contains

- One Cu layer always facing outward (larger R)
- One Si layer with into 12 active tiles + dead areas (shown on the right)
- One Inactive Si layer



Outer Barrel:

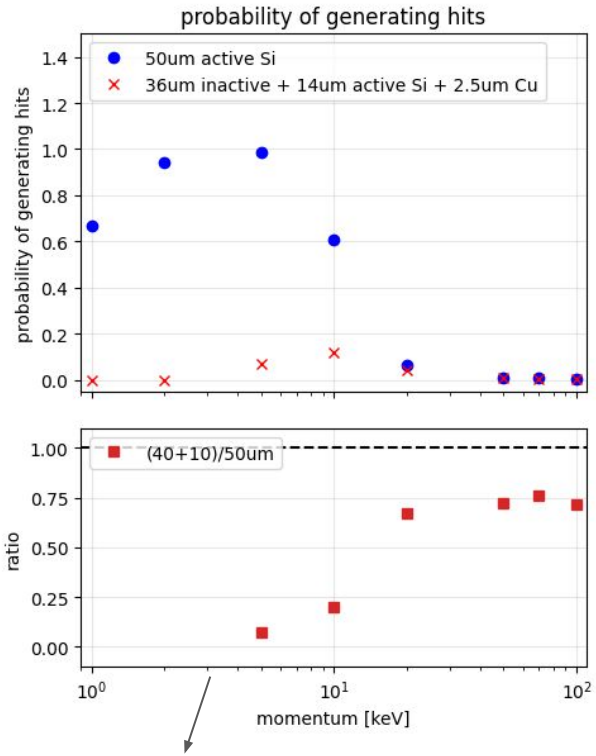
- Cu always facing the external side i.e. away from the support stave and alternating in Z
  - Same geometry as before, just added layer components
  - Sam Henry is leading a separate effort to produce a detailed description with support structures and fully curved RSU/tile.

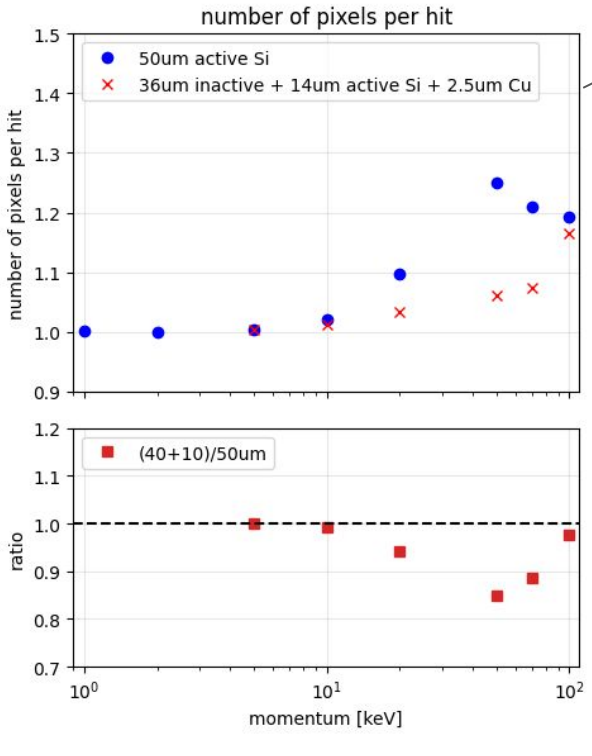


Disks:

- Keep the 40um Si for now until the disk layout with EIC-LAS modules in place [PR]

Test Impact with L0





Interaction prob.: Consistent with stand-alone simulations

Cluster size:
Still too low

- **diffusion/charge-sharing** is not considered in dd4hep but very small
- **Geometry** effect is missing in dd4hep b/w it only records one hit (weighted sum) per sensitive surface per particle

Summary

- The IB and OB sensor structure are updated to match the interaction probability in detailed simulations. PR is ready to merge. The corresponding material map will be provided once the PR is approved. Disks will be updated later.

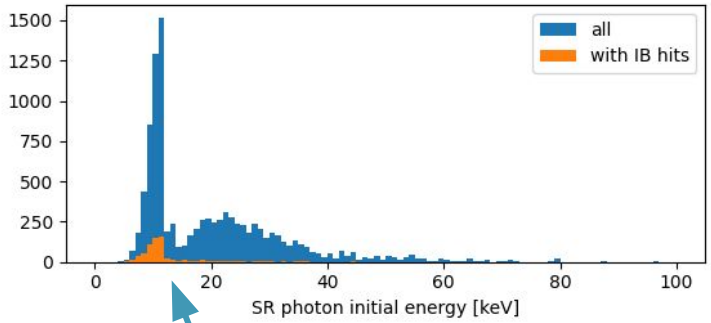
- The cluster size (number of pixels per hit) needs additional care.
  Proposed plan (w/ Zhenyu):
  - **Photon**: no angle dependence from TCAD+ALLpix2, only energy dependence
    - Map out the energy dependence in the stand-alone simulation
    - then introduce a parameterization function at digitization stage
  - **Charged particle:**
    - Map out both energy and incident angle dependence in the stand-alone simulation
    - 2d parameterization at digitization stage

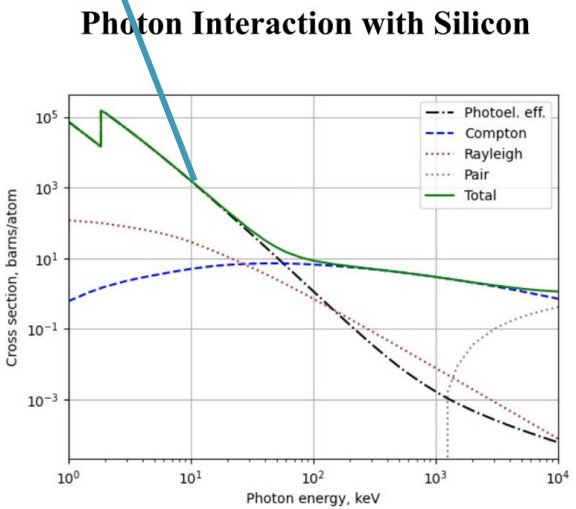
  - Additional check: primary vs secondary particles?

  - The cluster size parameterizations and corresponding **clustering algorithms** need to come online at the same time

backup

Photon Interaction Probability





SR Photon energy peaks at ~10 and 20 keV.

The **interaction probability** (dominated by **photo-electric** process in the case of SR)

$$P(E) = 1 - e^{\rho(\frac{\mu}{\rho})_{pe}(E)t}$$

At E=10 keV, the silicon mass attenuation coefficient [link]

$$(\frac{\mu}{\rho})_{pe}(E = 10\text{keV}) \approx 30\text{cm}^2/\text{g}$$

For t=O(10um) silicon (rho=2.33g/cm^3), the exponent < 0.1

⇒ probability P $\propto$ thickness t

Check steps and edep configs in dd4hep

Inspect default steering file:

```
npsim --compactFile ${DETECTOR_PATH}/epic_craterlake_tracking_only.xml
--dumpSteeringFile > steering.py

## set the default tracker action
SIM.action.tracker = ('Geant4TrackerWeightedAction', {'HitPositionCombination': 2,
'CollectSingleDeposits': False})
```

integer HitPositionCombination

1. Use energy weights to define the position of the energy deposit
2. Set the hit position between the step pre and post point
3. Set the hit position to the position of the step pre point
4. Set the hit position to the position of the step post point

Check steps and edep configs in dd4hep

Step size (Geant4):

- Geant4 determines step boundaries dynamically from: geometry boundaries, active physics processes' proposed limits, field/transport integration limits, and optional user step limits.
- The sensitive detector receives one callback per step occurring inside the sensitive volume.

Segmentation is NOT involved here. The entire sensitive component is one element

In Geant4TrackerWeightedSD:

- Accumulates deposits from the same G4Track within the same sensitive element (cellID/volume context) and writes a hit when a flush condition occurs (e.g., leaving/transitioning, track ends).
    - CollectSingleDeposits = False: merge multiple steps into one hit per sensitive element for that track; edep is summed over steps; position follows HitPositionCombination.