BERKELEY LAB

Sensor Response Studies for SVT

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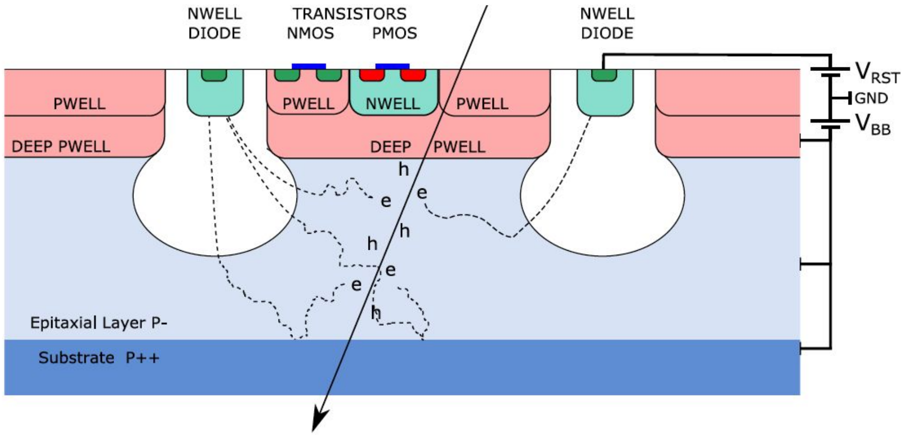
MAPS Sensor Response



- P/N-well: high doping, electrical circuit
- Epitaxial: low doping, sensor active volume
- Substrate: high doping, mechanical handling

1. Particles interact with sensor and generate signal charges [1]
2. Signal charges collected through drifting and diffusion [2-7]
3. Collected charges are processed by integrated readout electronics

- **References**

[1] Passage of Particles Through Matter, S. Navas et al. (Particle Data Group), Phys. Rev. D110, 030001 (2024)

[2] Simulation and measurements of charge collection in monolithic active pixel sensors, Grzegorz Deptuch et al., NIMA 465 (2001) 92–100

[3] New Generation of Monolithic Active Pixel Sensors for Charged Particle Detection, Grzegorz Deptuch (2002).

[4] Study of Monolithic Active Pixel Sensors for the Upgrade of the ALICE Inner Tracking System, Miljenko Šuljić, CERN-THESIS-2017-304

[5] MC simulation of charge collection processes in Monolithic Active Pixel Sensors for the ALICE ITS upgrade, Miljenko Šuljić, NIMA 950 (2020) 162882

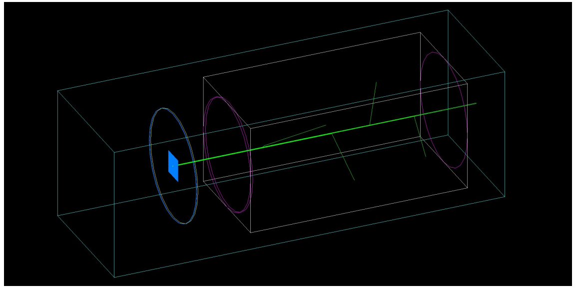
[6] Development and performance study for the ALICE ITS3: the first truly cylindrical inner tracker, Isabella Sanna, CERN-THESIS-2024-359

[7] TCAD and charge transport simulations of MAPS in 65nm for the ALICE ITS3, Isabella Sanna et al., JINST 20 (2025) C06032

Tools Used In This Study

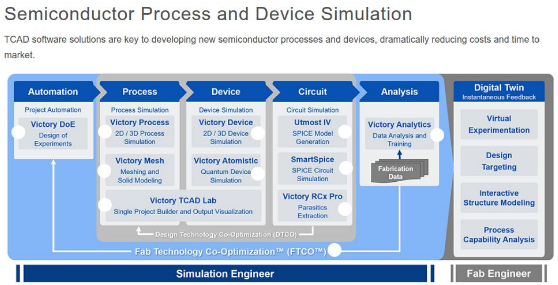
Particles interaction with silicon

40 um inactive + 10 um active Si with $20 \times 20\ um^2$ pixels



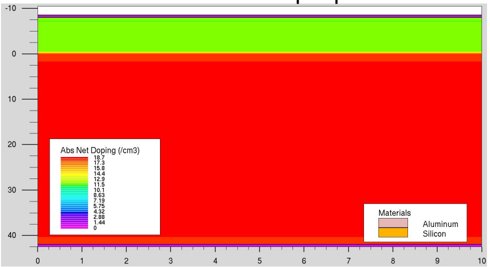
10 E_γ @ 80 keV

Sensor Doping profile and E-field

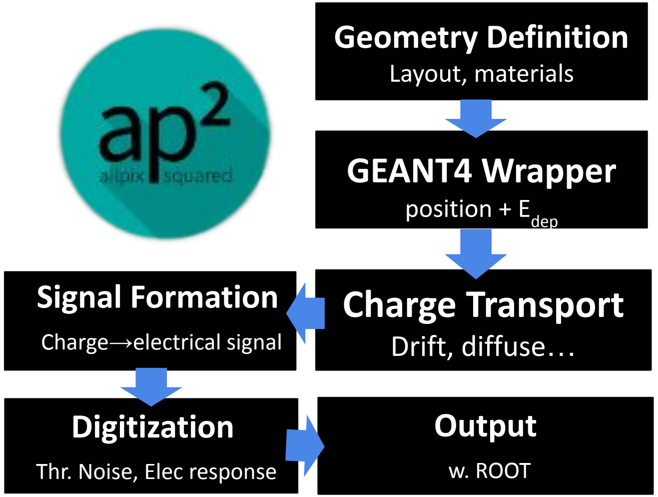


comprehensive suite of **Technology Computer-Aided Design (TCAD)** software tools to model semiconductor fabrication processes and device behaviors

Simple p-n structure



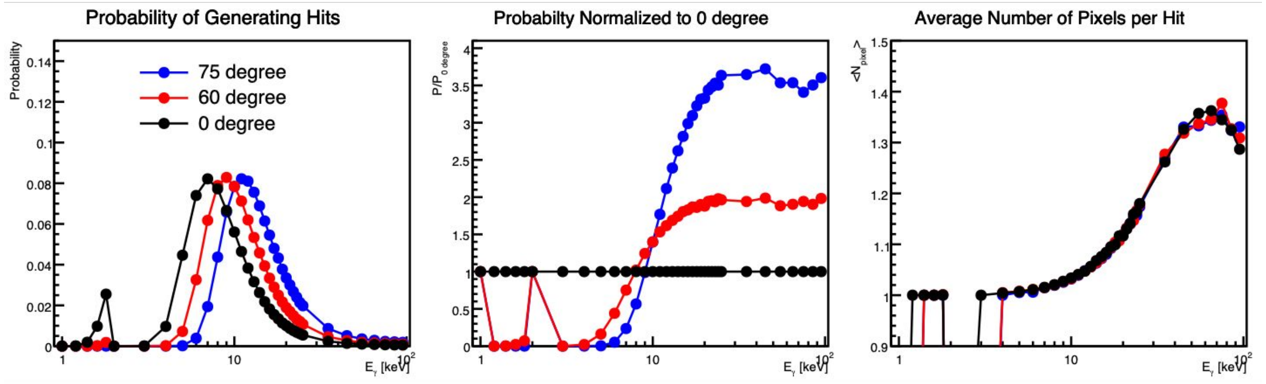
Transport model + Detector Response



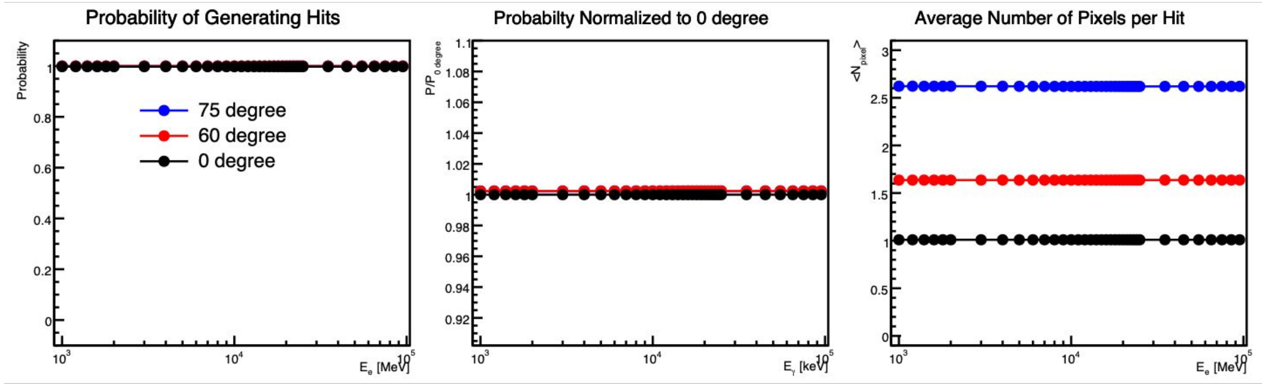
Generic simulation framework for semiconductor tracker and vertex detector which combines particle transport and detailed detector response simulation

Particle Interaction with Silicon (GEANT4)

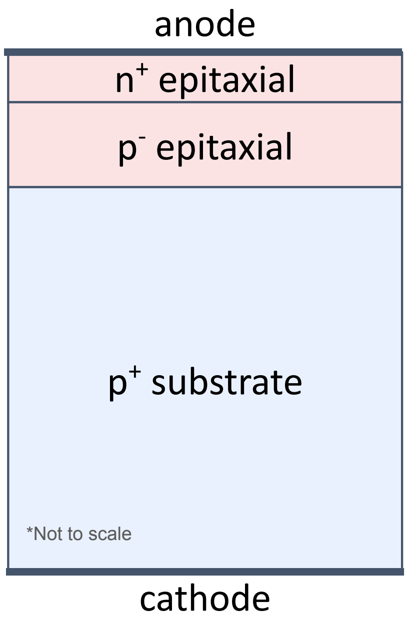
Low-Energy Photon

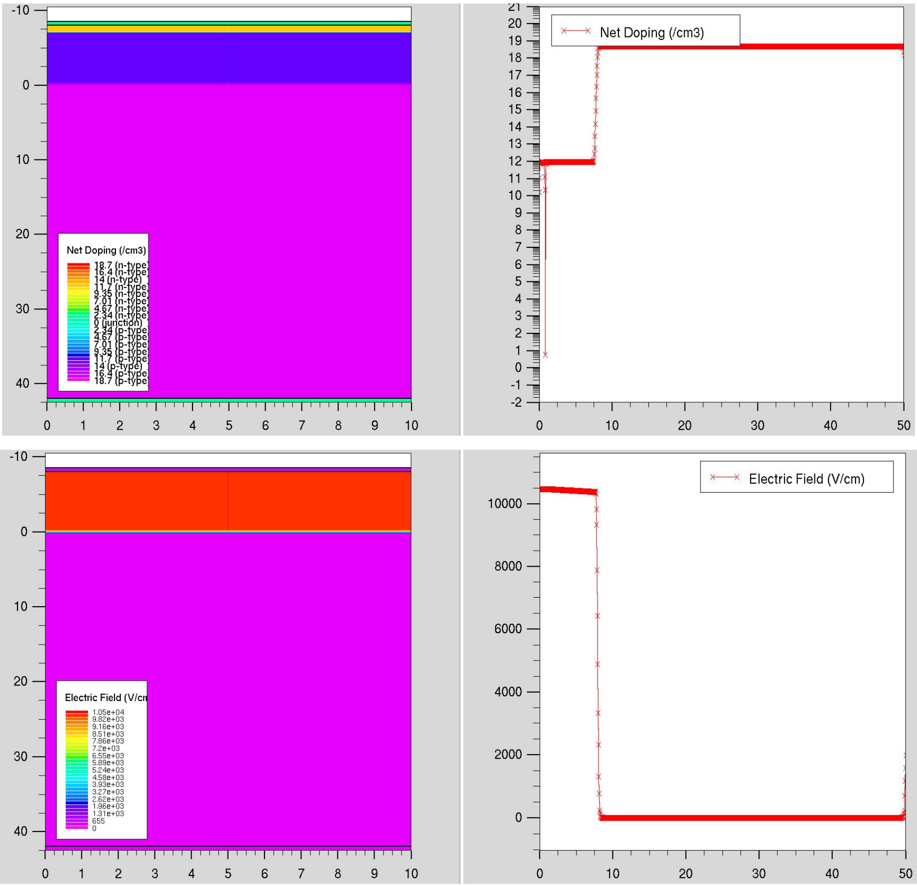


High-Energy Electron



Doping and E-field from Silcavo TCAD Simulation





We don’t know the manufacture process and doping profiles for ITS3 sensors made from TowerJazz 65 nm process

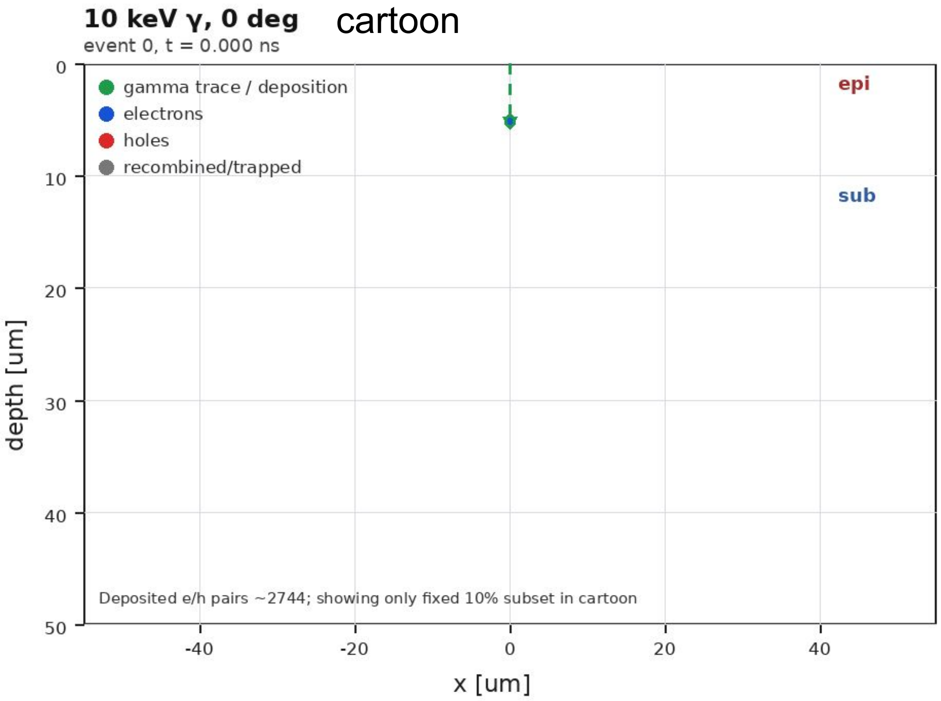
The following study uses a simple p-n structure to get carrier drifting, diffusion, and recombination parameters.

The doping densities are based on MAPS sensors made from TZ180nm process:

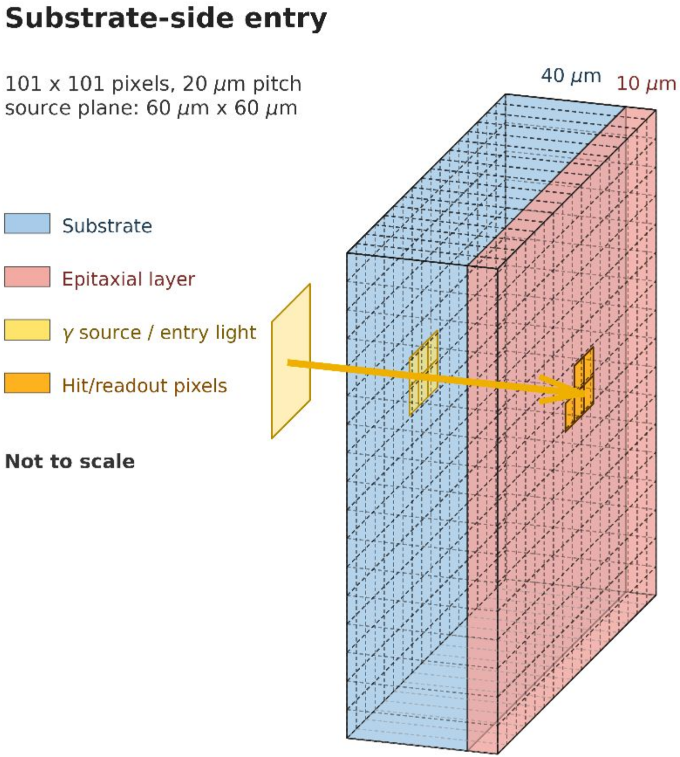
NIMA 950 (2020) 162882

NIMA 988 (2021) 164859

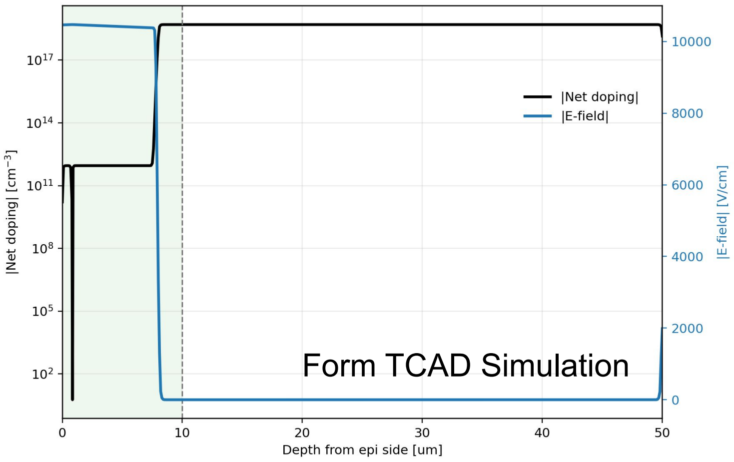
Interaction with Particle and Charge Transport via AllPix2

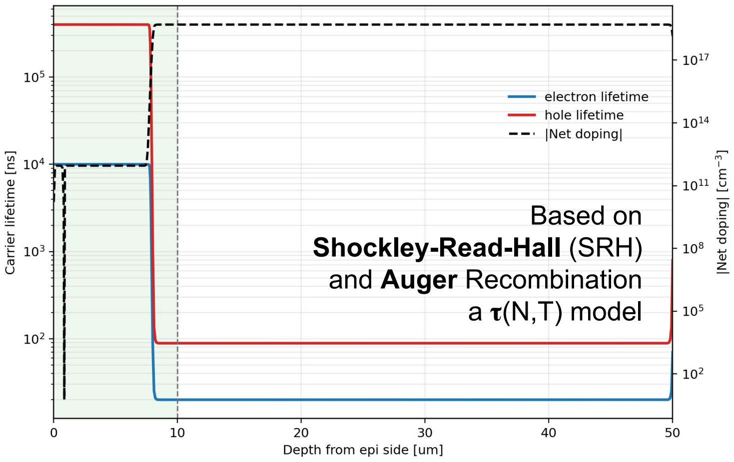


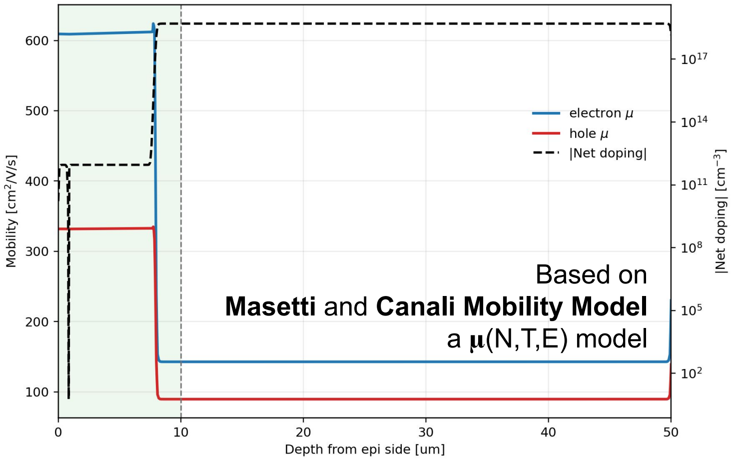
cartoon

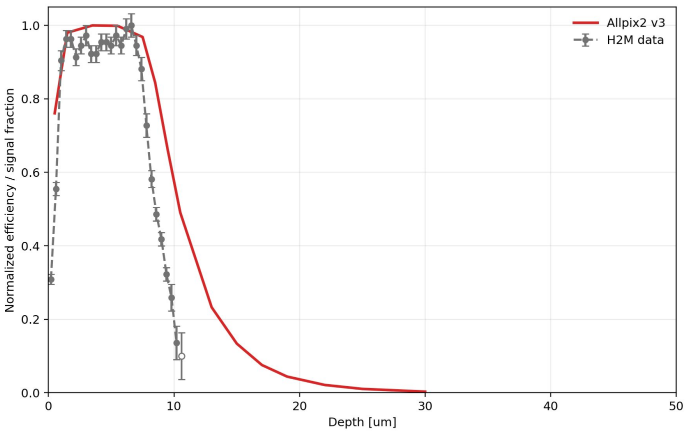


Doping profile, E-fields, and Carrier Mobility in AllPix2

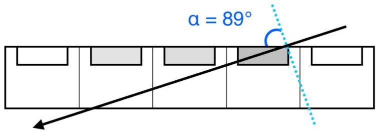




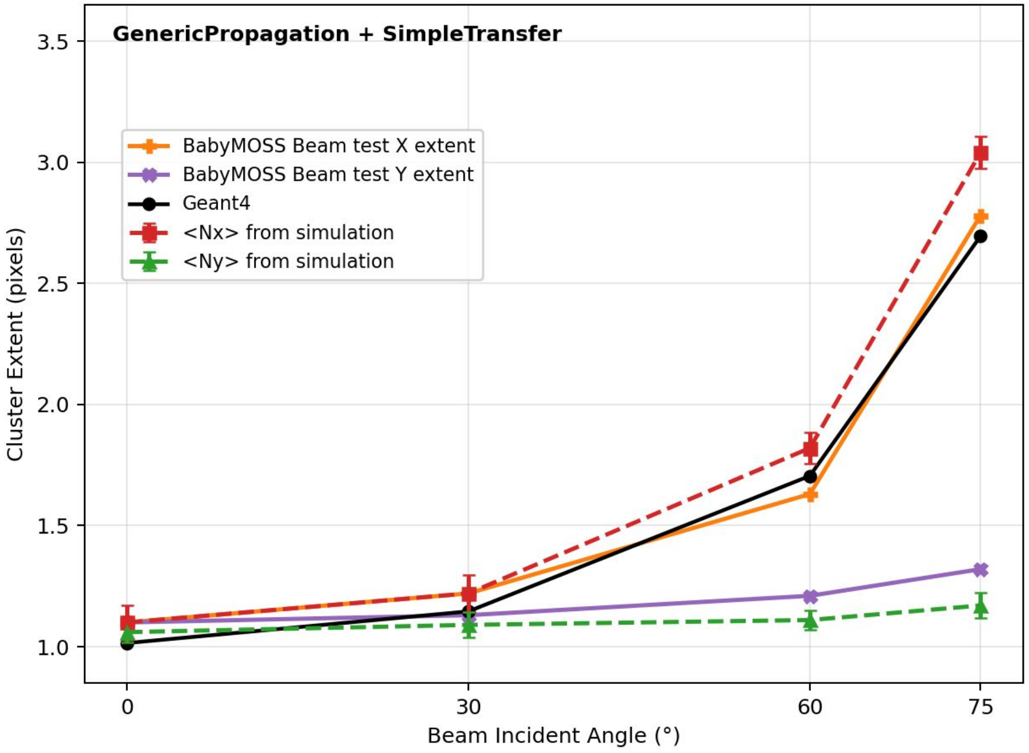


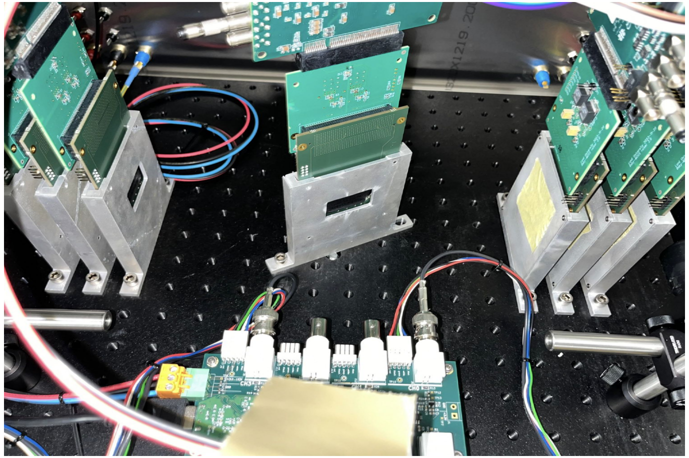


H2M (TZ65nm) beam test data:
doi:10.3204/PUBDB-2025-03980



Allpix2 Simulation vs 120 GeV proton Test Beam Data



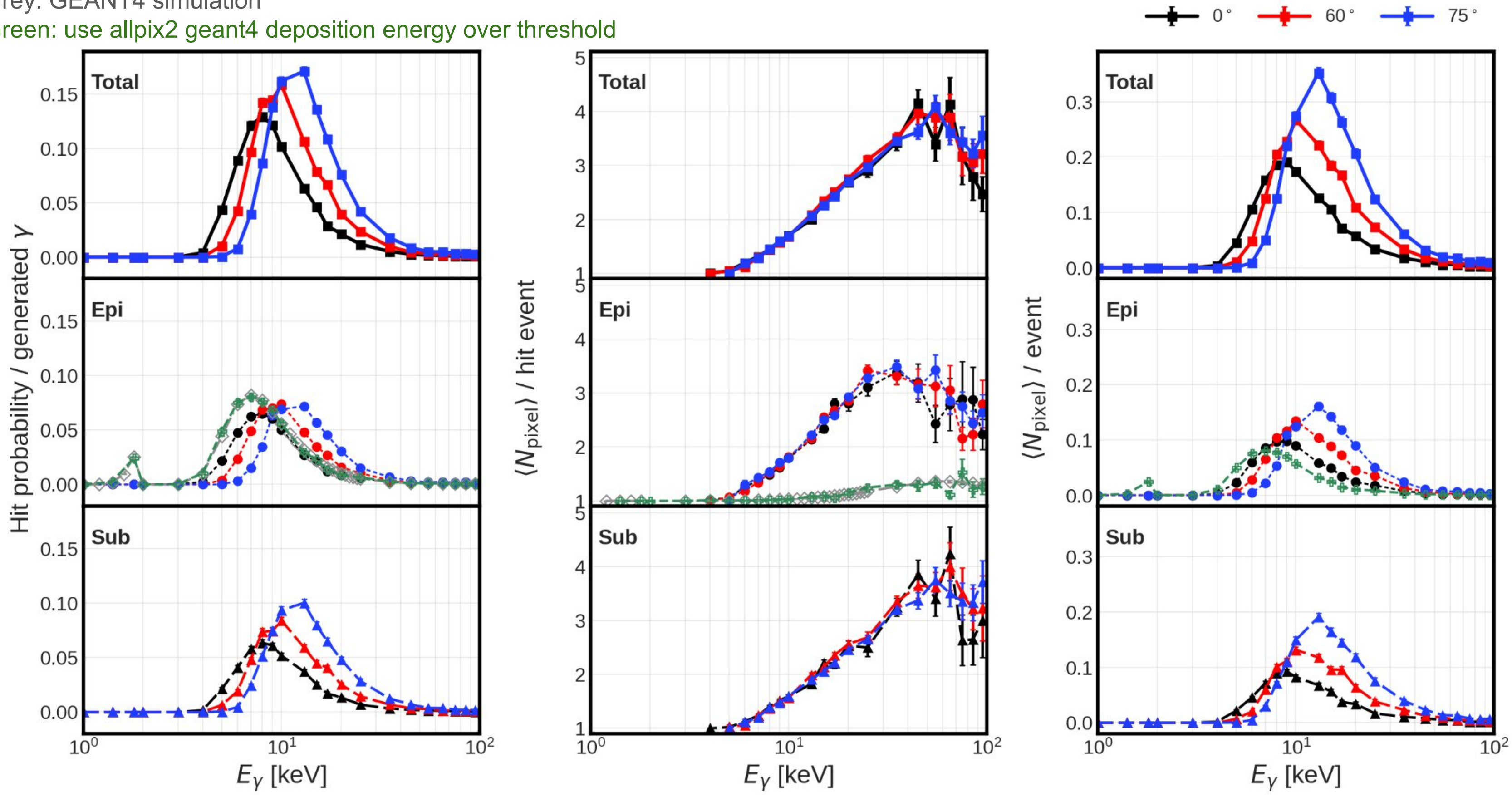


- AllPix2 consistent with beam test result and pure GEANT4 simulation
- Slightly higher <Nx> and lower <Ny> in simulation than data could partially be due to misalignment of the sensor w.r.t. beam

Low Energy Photons in AllPix2 - entering from Substrate

Grey: GEANT4 simulation

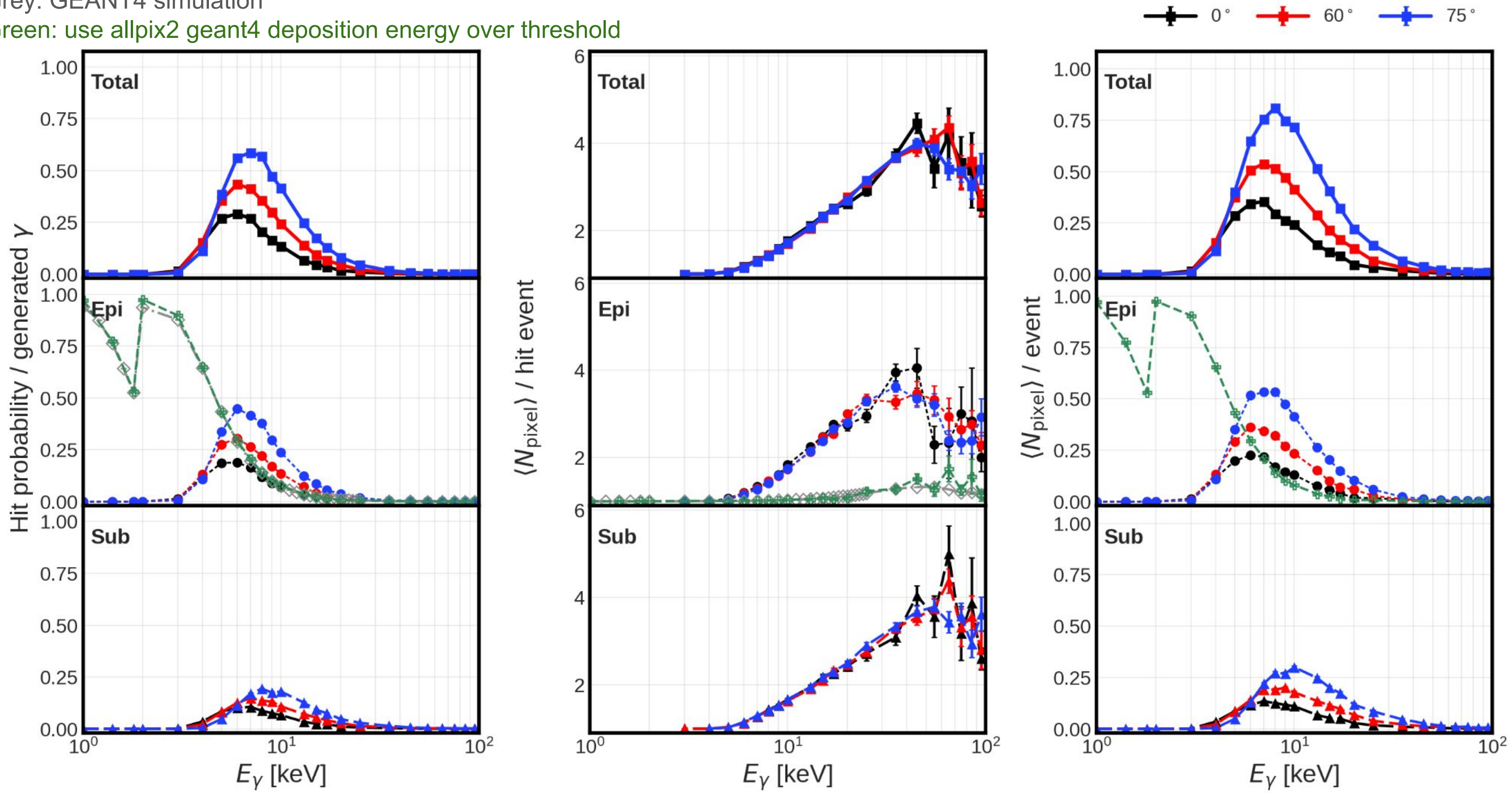
Green: use allpix2 geant4 deposition energy over threshold



Low Energy Photons in AllPix2 - entering from Epitaxial

Grey: GEANT4 simulation

Green: use allpix2 geant4 deposition energy over threshold



Summary and Outlook

We studied 10um epitaxial+40um substrate sensor response to incident particles, taking into drifting, diffusion and recombination of charge carriers (e/h) in Silicon.

- Sensor doping profiles are tuned to have similar charge collection efficiency as a function of depth to a TZ65 nm CMOS sensor (H2M).
- Cluster size for high energy charged particle: Allpix^2 simulation is compatible with ER1 results with 120 GeV proton at FTBF, and with pure GEANT4 for 10um active +40um inactive Si, suggesting small contribution from substrate.
- Cluster size for low energy photons: Allpix^2 simulation is largely different from pure GEANT4 simulation, suggesting large contribution from substrate.

To-do

- The low energy photon simulation needs to be cross-checked by experimental data with x-ray radiative source or Synchroton light source.
- Simulation can be improved by taking into account the sensor structure and doping profile, once we have access to the TZ65nm PDK and ITS3 design DB
- Study should be repeated for ER2/final sensors and incorporated into ePIC simulation.