

Geant4 Hands-on Session Tasks

Example Applications for Detector Simulation and Analysis

Prof. Sunanda Banerjee, IACS Kolkata (sunanda.banerjee@cern.ch)

Dr. Ashim Roy, BNMU, Madhepura (ashim.roy@cern.ch)

Dr. Pralay Das, SINP, Kolkata (pralay.das@sinp.ac.in)

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Hands-on Examples Overview

Two Geant4 detector simulation tasks (16–17 Feb 2026)

- Example 1 (16 Feb 2026): **Homogeneous electromagnetic calorimeter (PbWO₄)**
- Example 2 (17 Feb 2026): **Hybrid calorimeter (CeF₃ ECAL + Scintillator/Brass HCAL)**

Both examples require: **geometry + sensitive detector + hit handling + ROOT** output
Offline analysis: calibration using MIPs, linearity, energy and position resolution

Example 1: Step 1

(Detector Construction, Sensitive Detector, Hit, Event Action, Primary Generator Action)

Step 1: Create an application code writing 5 (Detector Construction, Sensitive Detector, Hit, Event Action, Primary Generator Action) classes and the main program:

Detector construction:

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Element Name	Z	A	Density
Ar	18	39.948*g/mole	1.662*mg/cm3
O	8	15.999*g/mole	1.3315*mg/cm3
N	7	14.007*g/mole	1.165*mg/cm3
Al	13	26.98*g/mole	2.70*g/cm3
Pb	82	207.2*g/mole	11.35*g/cm3
W	74	183.84*g/mole	19.3*g/cm3

Example 1: Step 1 (Detector Construction)

(Detector Construction, Sensitive Detector, Hit, Event Action, Primary Generator Action)

Material Name	Density	Composition (by weight)
Air	1.214*mg/cm ³	N: 0.75 O: 0.24 Ar: 0.01
PbWO ₄	8.300*g/cm ³	Pb: 0.455 W: 0.404 O: 0.2780420

- Make a world volume made of Air of size 1.0m x 1.05m x 2.0m
- Inside the volume make an aluminum box of outer dimension 50.4 cm x 30.4 cm x 121.9 cm with a wall of 2 mm on each size.
- Make lead tungstate crystals of box shape of length 23.6 cm and front surfaces of size 2.2 cm x 2.2 cm
- Place 7 such crystals side-by-side in a slice of length 23.7 cm.
- Then place 7 such slices inside the box such that it becomes a crystal matrix of 7 x 7 with all crystals with axis along z-direction

Example 1: Step 1 (Hit)

(Detector Construction, Sensitive Detector, Hit, Event Action, Primary Generator Action)

Hit Class with attributes:

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Crystal index (combined slice & crystal #)

Energy deposit

Time of the first hit

Example 1: Step 1 (Sensitive Detector)

(Detector Construction, Sensitive Detector, Hit, Event Action, Primary Generator Action)

Sensitive Detector class:

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- Attach to the logical volumes corresponding to: Each PbWO4 cell
- Find the overall cell id ($100 * \text{slice ID} + \text{cell ID}$).
- Apply correction due to saturation (Birks law).
- Apply loss of intensity of emitted scintillation light (not necessary to create light - only apply an efficiency factor depending on the longitudinal position of the hit point)
- Search within the hit collection class a hit with the same overall Id. If not found, store cell ID, time, and corrected energy deposit as a single hit else, if the time matches with the stored time within 1 ns, add the corrected energy deposit to the corresponding hit energies else create a new hit with the cell ID, new time and energy deposits

Example 1: Step 1 (Sensitive Detector-Bark's Law)

(Detector Construction, Sensitive Detector, Hit, Event Action, Primary Generator Action)

Light yield of scintillators depends not only of the particle energy but also on the particle stopping power dE/dx . The Birks law (semi-empirical account for scintillation quenching) reads [1]:

$$\frac{dL}{dx} = \frac{S \frac{dE}{dx}}{1 + kB \frac{dE}{dx}},$$

where dL/dx the scintillation yield density, S is the absolute scintillation factor, kB is the Birks factor ($B dE/dx$ is the density of excitation centers, k is the quenching factor).

Example 1: Step 1 (Event Action)

(Detector Construction, Sensitive Detector, Hit, Event Action, Primary Generator Action)

Event Action class:

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- At the beginning of the event define a ROOT tree where o/p is saved
- At the end of each event, fill the tree with the information from the hit collection

Example 1: Step 1 (Primary Generator Action)

(Detector Construction, Sensitive Detector, Hit, Event Action, Primary Generator Action)

Primary Generator Action:

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- Create a primary vertex at the left most edge of the world volume (must be just inside it)
- Create a particle of given type going along +z direction with a predefined energy

Example 1: Step 2

(Run simulations and produce ROOT outputs)

Step 2:

- Generate 1000 events with 20 GeV muon(-) varying the direction such that it hits the center of each cell and save the outputs as ROOT tree
- Generate 1000 events of electrons of energies 5, 10, 20, 50, 100 and 200 GeV with the vertex

Example 1: Step 3

(Analysis: calibration, linearity & resolution)

Step 3:

- Select all hits which satisfy a timing cut
- Analyze the muon sample to determine what a minimizing ionizing particle deposits energy in each layer
- Use the mean for all 49 cells to have relative calibration of each cell
- Now use the 10 GeV electron run and see number of MIP's in each cell.
- Scale total MIP's to 10 GeV to get overall energy scale factor
- Analyze all electron samples
- Get # of MIPS and convert to energies using the scale factor obtained from the previous step. From the energy distribution, compute most probable value and its mean dispersion to measure linearity as well as resolution.
- Try to extract position resolution (move the incident position to different locations on the front face)

End of Hands-on Tasks

- Participants should complete both Geant4 applications and produce ROOT outputs.
- Focus on correct geometry, hit logic, ROOT storage, and calibration procedure.
- Discussion: How detector design affects energy response and resolution.

Hope you are enjoying the hands on session!

Thank You!