P13 – Monte Carlo-based experiment simulation: Silicon microstrip detector

CPAN NETWORK ON INSTRUMENTATION AND DETECTORS

TIDPAN Valencia 2026

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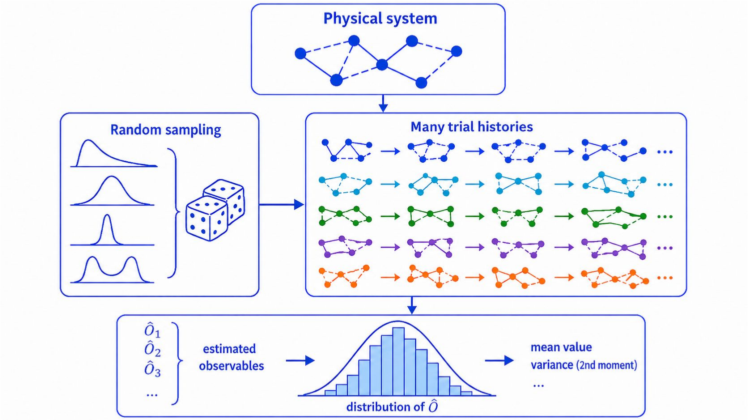
CSIC Consejo Superior de Investigaciones Científicas

IFCA

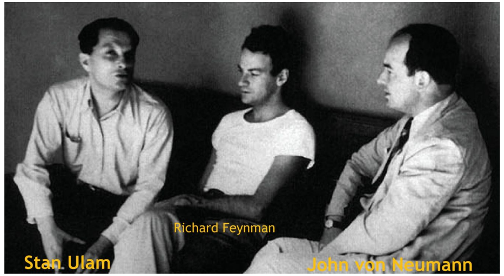
Monte Carlo methods

Numerical techniques based on random sampling.

- Generate a representative ensemble of possible configurations (histories) in order to estimate quantities of interest without solving the full problema analytically or enumerating all possible outcomes.

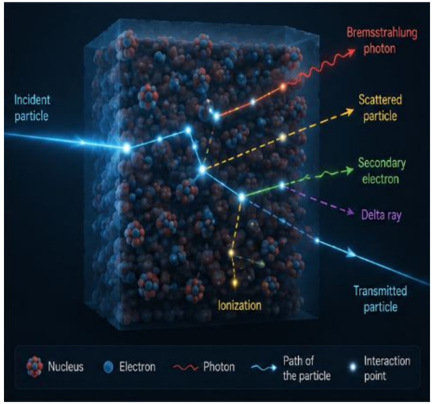


- The MC methods use random sampling to explore complex problems by generating many possible histories → estimate the quantities of interest from statistical averages.



Monte Carlo for particle transport in matter

- Particle-matter interaction: intrinsically **probabilistic** and **stochastic** problem.
  - Particle physics theory provides interaction probabilities and final states
  - The transport process is a stochastic sequence of interactions, energy losses, secondary production, and detector responses as radiation propagates through matter.



The radiation transport problem

Radiation source → **Propagation in matter** → **Detection**

Radiation source

- Photons
- Leptons (e^{+}, μ^{+}, τ^{+}, ν)
- Hadrons (n, p, π, Σ,…)
- Ions (Z,A)
- Radioactive sources
- Cosmic rays

- Colliding particle beams
- Synchrotron radiation
- …

- “Monoenergetic” / Spectral

- Energies:
  - keV–PeV
  - down to thermal energies for neutrons

Propagation in matter

- Arbitrary geometry

- Various shapes materials, compounds

- Radiation–matter interaction

- Secondary particles Particle shower

- Material activation

- Magnetic and electric fields…

Detection

Measure / estimate / score:

- Energy–angle particle spectra
- Deposited energy
- Material damage
- Biological effects
- Radioactive inventories…

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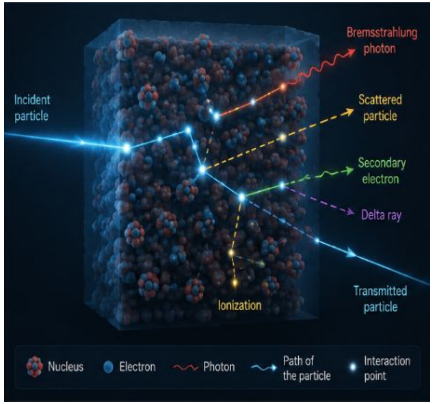
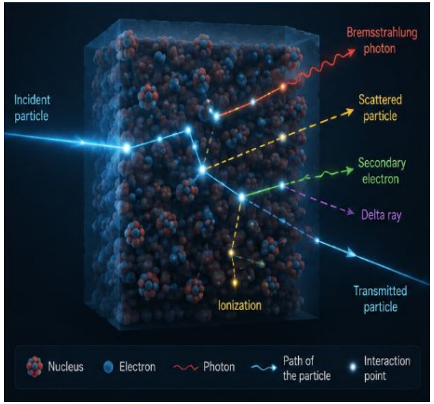


The radiation transport problem

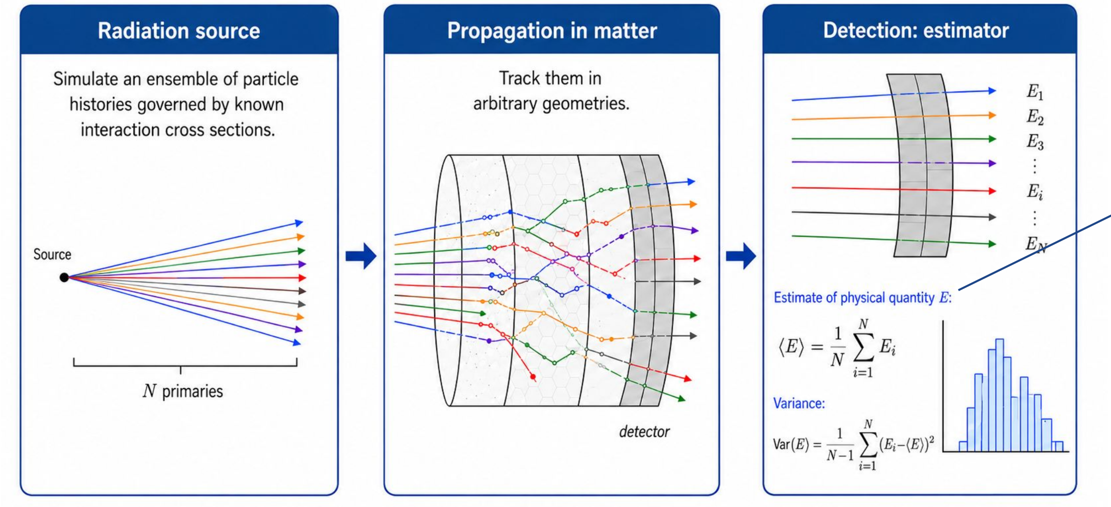
$$
\begin{aligned}
\int_V \mathrm{d}\boldsymbol{r}\,\frac{\partial n_i(\boldsymbol{r},E,\Omega,t)}{\partial t} = & -\oint_S \mathrm{d}A\,\mathbf{j}(\boldsymbol{r},E,\Omega,t)\cdot\hat{\boldsymbol{a}} && \text{(unscattered particles)}\\
& - N\int_V \mathrm{d}\boldsymbol{r}\; n_i(\boldsymbol{r},E,\Omega,t)v(E)\sigma(E) && \text{(particles scattered out)}\\
& + N\int_V \mathrm{d}\boldsymbol{r}\int \mathrm{d}E'\int \mathrm{d}\Omega'\; n_i(\boldsymbol{r},E',\Omega',t)v(E')\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega''\mathrm{d}W''} && \text{(particles scattered in)}\\
& + N\int_V \mathrm{d}\boldsymbol{r}\int \mathrm{d}E'\int \mathrm{d}\Omega'\;\sum_j n_j(\boldsymbol{r},E',\Omega',t)v(E')\frac{\mathrm{d}\sigma_{\mathrm{sec},i}}{\mathrm{d}\Omega''\mathrm{d}W''} && \text{(production of secondaries)}\\
& + \int_V \mathrm{d}\boldsymbol{r}\; Q_{\mathrm{source}}(\boldsymbol{r},E,\Omega,t) && \text{(source)}
\end{aligned}
$$

Monte Carlo for particle transport in matter

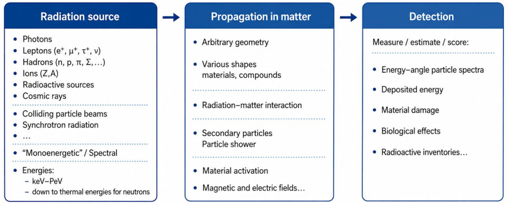


Solution strategies to the radiation transport problem

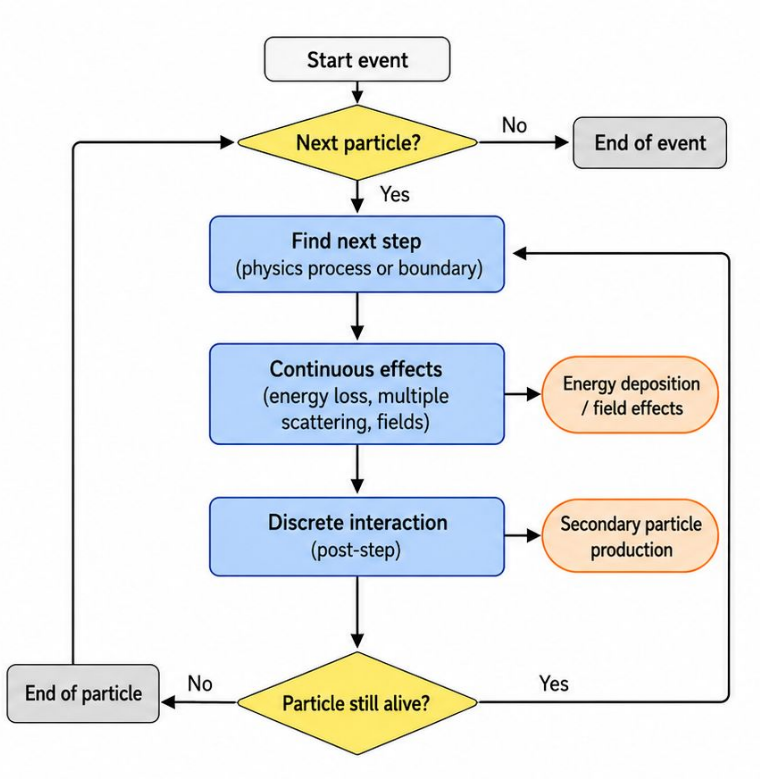
- Analytical / spectral methods: accurate, but limited to simplified cases.
- Numerical integration: general, but inefficient in high dimensions.
- **Monte Carlo method**: general, efficient, and flexible: can treat arbitrary radiation fields and geometries.

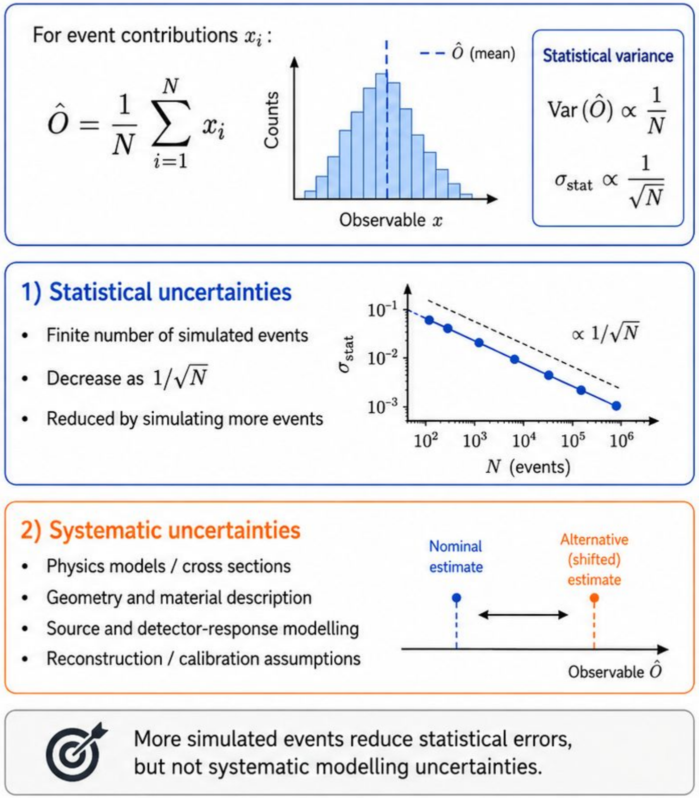


Estimator: the equivalent to a measurement in a real experiment



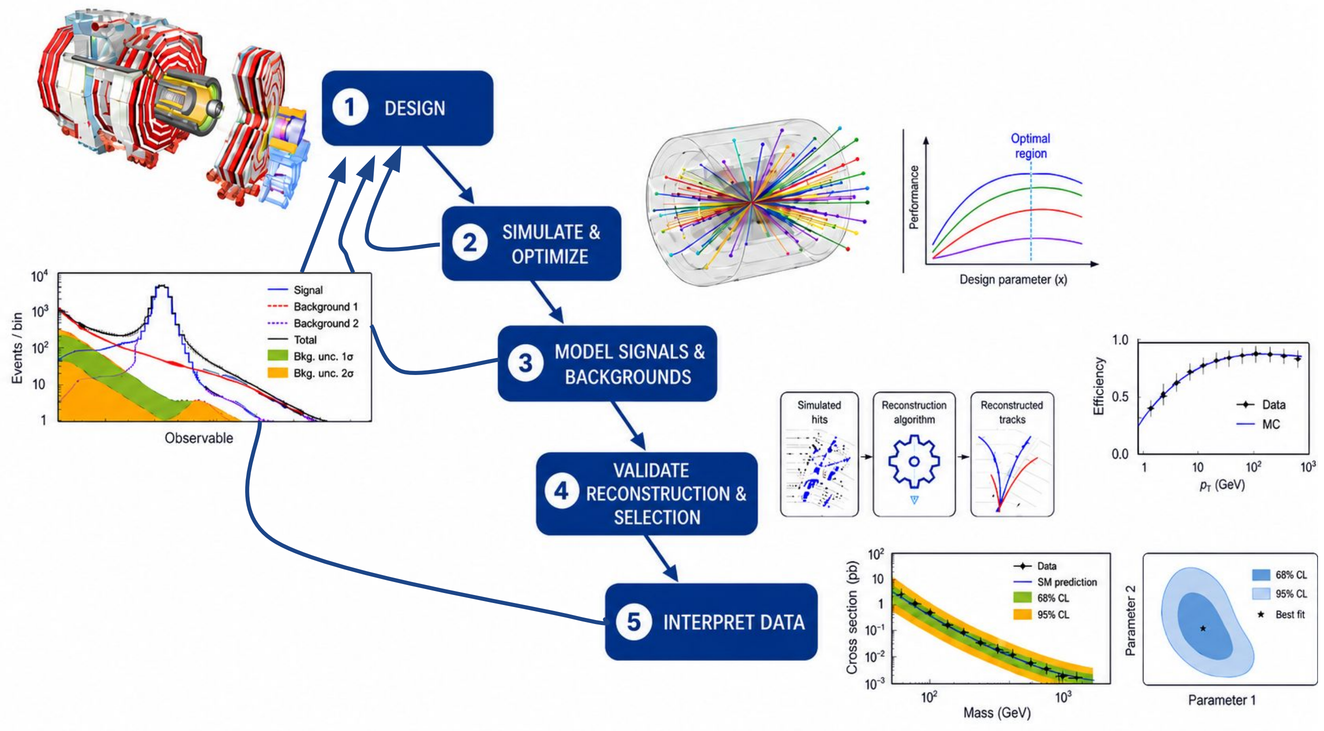
Monte Carlo for particle transport in matter





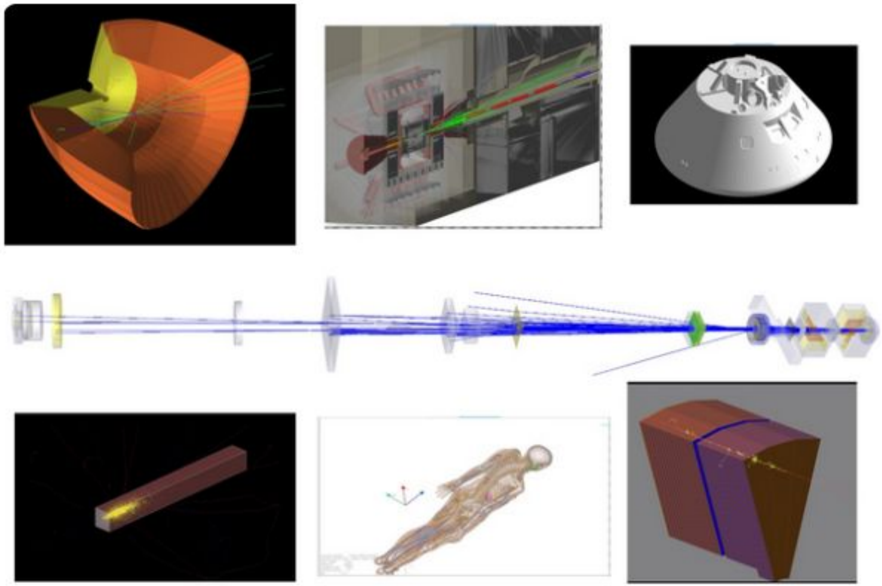
Monte Carlo methods in particle physics experiments

- Used throughout the full experimental lifecycle



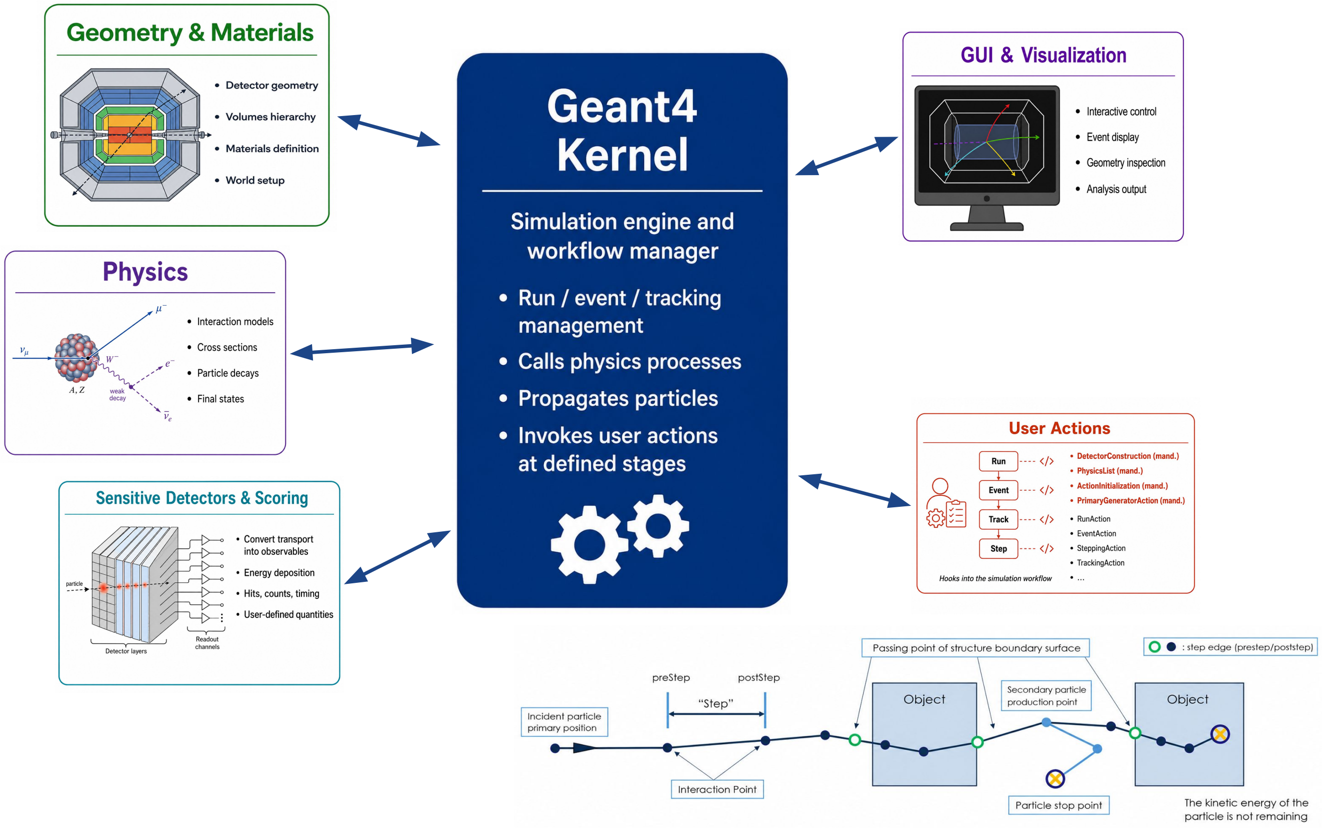
Geant4

- Toolkit for the simulation of passage of particles through matter

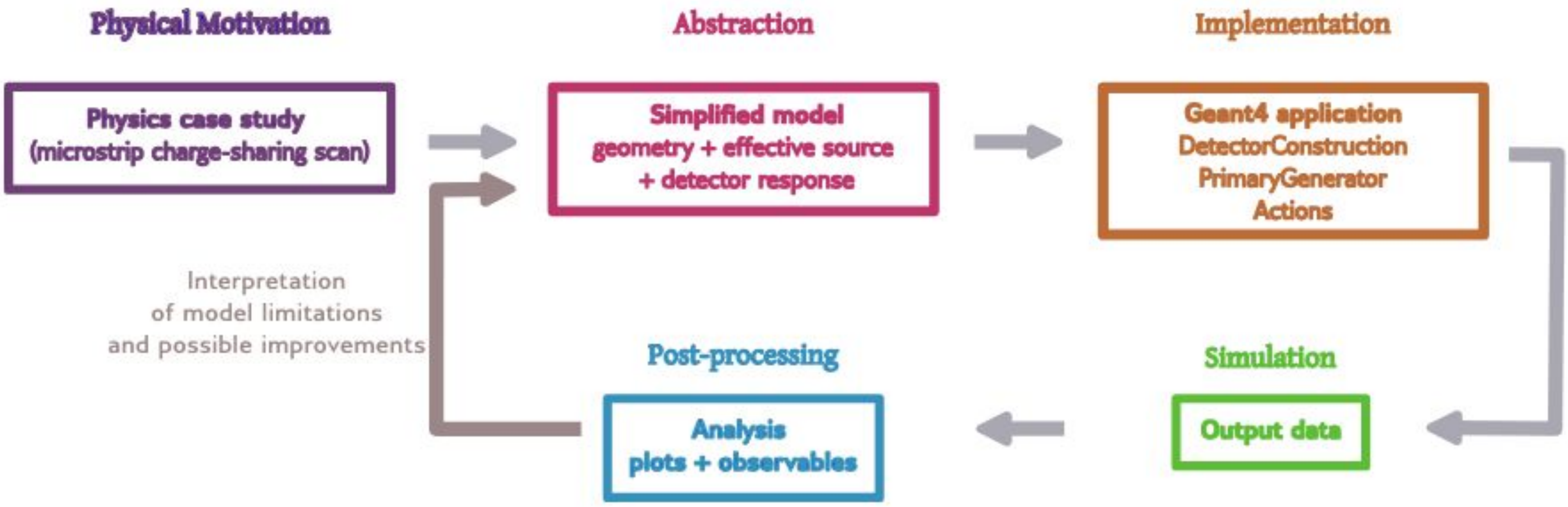


- **High Energy Physics**
  - LHC experiments (ALICE, ATLAS, CMS, LHCb)
  - future experiments (CLIC, ILC, FCC)
  - and many others (Fermilab experiments, HARP, SLAC, BaBar, ...)
- **Space and Radiation Science**
  - European Space Agency (Geant4 Space Users, SPENVIS, GRAS, MULASSIS)
  - Medium Energy Gamma-ray Astronomy library (MEGAlib)
- **Medical Physics**
  - Geant4-DNA - Geant4-DNA project
  - G4MED (in Japanese) - Geant4 Medical Physics in Japan
  - G4NAMU - Geant4 North American Medical User Organization
  - GAMOS - Geant4-based Architecture for Medicine-Oriented Simulations
  - GATE - Geant4 Application for Tomographic Emission
  - GHOST - Human Oncology Simulation Tool
  - TOPAS - Geant4 Monte Carlo Platform for Medical Applications
- **Accelerator Physics**
  - BDSIM
  - G4Beamline

Geant4 components



A Geant4 simulation: workflow of the exercise

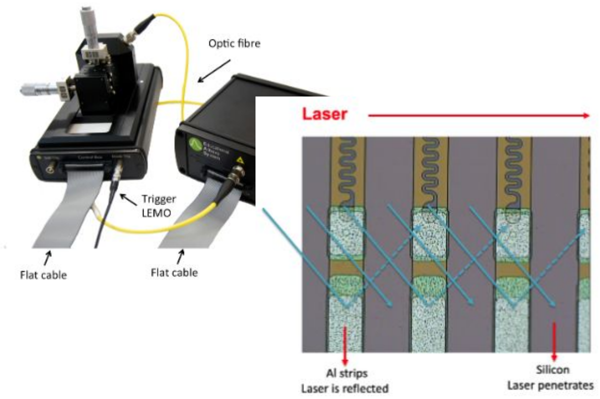


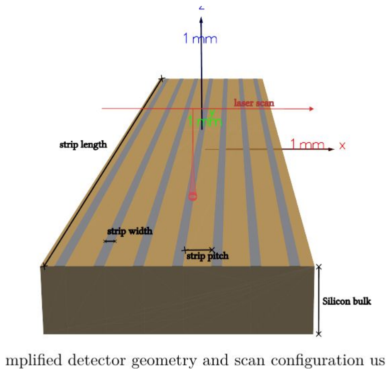
A Geant4 simulation: workflow of the exercise

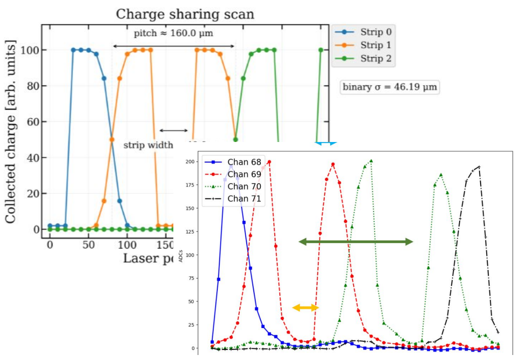
Physical case
- Scanned laser measurement of a silicon microstrip detector (P7)

Simulation model
- Geant4 application
  - with **simplified detector response**

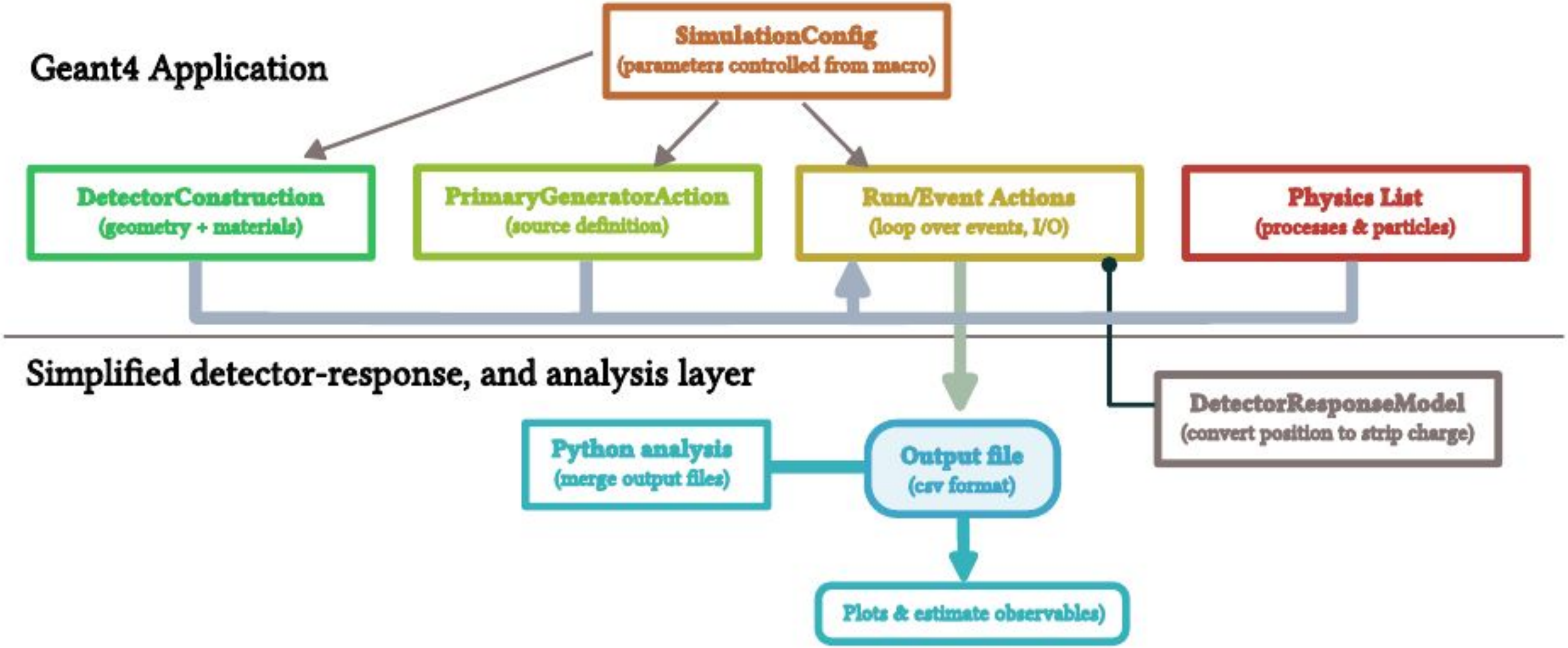
Observable
- Collected charge in electrode collectors a a function of scan position







Code Architecture



Practicum procedure

A. Understand the application

Inspect repository, classes, geometry and visualization macro

C. Modify the model

Change effective source size; optionally pitch or strip width

B. Run nominal simulation

Produce strip-charge output for the default scan

D. Interpret output

Extract pitch, effective strip width and binary resolution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Workshop on Instrumentation and Detectors for Nuclear, Particle and Astroparticle Physics