Detector Simulation

Fast Sim and Full Sim etc.

PED-Higgs kick-off meeting
18 June, 2021

Daniel Jeans / KEK
Motivation

Full-sim

Fast-sim
inter-linked tasks for detector simulations

@ future experiments

- investigation of facility's physics potential including new reco techniques
- comparison of different
  - detector designs
  - sub-detector technologies
- understanding of detector prototypes e.g. in test beam
- seamless transition to simulation of real detector

different levels of simulation accuracy required
different levels of detail required for these tasks

**Fast simulation**

parameterisation [more or less sophisticated] of
detector acceptance and response to particles
[particle type, $E$, $\theta$, $\phi$, …]

**Full simulation**

track each particle through detailed detector model interactions, decays, energy deposits
→ digitisation → detector signals
→ event reconstruction

**Hybrid approaches**

increase speed by simplifying where possible,
while preserving accuracy where needed
a wealth of detector concepts being studied in the context of future [e+e-] colliders
use of **common software** tools for simulation is highly desirable:

- economise on person-power
- avoid reinventing the wheel
- more robust comparisons

different detector concepts are increasingly using common SW tools

→ more in Gerardo’s talk
Full Simulation

description of geometry, materials, sensitive volumes

interfaced to

simulation of particle transport & interactions
Geometry / material description

DD4hep is used in many studies

some use “standalone” G4 descriptions,
but trend is to migrate to DD4hep

central definition of geometry, materials, sensitive volumes, EM fields
→ referred to by simulation, reconstruction, analysis, visualisation
→ designed for use from experiment’s conception to its death
  (eg alignment, conditions, ...)
describe system in **Detector constructor** code (c++, .py)
many basic “idealised” examples exist
also several highly detailed examples
→ reuse existing code, or write your own if necessary

include subdetectors, set their parameters, materials, segmentation...
in a **compact description** ( .xml , JSON )
highly detailed simulations

describe material due to support structures cooling, power, DAQ

scalable models

change detector size by changing just a few parameters in an .xml file

→ in principle enables “plug and play” of different subsystems, even from different concepts [if suitable]
different programs used to simulate processes in models

- ddsim (part of DD4hep)

- integrated into other framework e.g. k4SimGeant4 (Gaudi-based FCCSW)

work ongoing to integrate full functionality into all approaches
some examples:
DD4hep for test-beam prototypes

validation of simulation with test-beam

realistic detector simulation requires close contact with hardware groups
using the same simulation framework makes it much easier!

extension of test-beam model → full detector

realistic services, dead materials, cracks, ... in simulation model
“hybrid” calorimeter simulation [ILD]

simultaneously simulate two technologies:
- sensor thickness ~ readout layer → scintillator & RPC [HCAL]
- silicon & scintillator [ECAL]

→ save CPU
→ particle-by-particle comparisons

The IDEA DR calorimeter

Design of the fully projective fiber calorimeter

Barrel: Inner length: 5m
Outer diameter: 9 m @ 90°
2 m long copper based towers
36 rotation around z axis

About 130 x 10^6 fibers considered.

Each fiber is coupled to a dedicated SiPM, to achieve:
- Excellent spatial resolution
- Excellent angular resolution
- Excellent shower shape sensitivity for PID.

If not stated otherwise, all results in the following are obtained with the Geant4 toolkit.
New studies about the Cluster Counting

**Goal:** Investigation of the potential of the C.C. (for He based drift chamber) with parametrization of the generation of ionization clusters

Studies done with 2m long tracks through a 1cm$^3$ box of gas (80% He and 10% iC$_4$H$_{10}$)

**Garfield++:**
- simulates the ionization process in a detailed way
- computes the gas properties (drift and diffusion coefficients as function of the fields value)
- solves the electrostatic planar configuration and simulates the free charges movements and collections on the electrodes.
- cannot simulate a full detector and collider events.

**Geant4:**
- simulates the particle interaction with material of a full detector.
- But... the fundamental properties and performance of the sensible elements (drift cells) are either parameterized or ad-hoc physics models have to be defined.

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**TPC dE/dx:**
Geant4 prediction scaled to testbeam measurements
digitisation from Geant4 signal → recorded signal

often crucial for good description of reality
diffusion, amplification in TPC
photon production / transport in crystals, scintillators
SiPM response
avalanche in gas detectors
time structure
readout electronics

...
fast simulation tools
tracking detector layout

calculate track covariance matrices from
sensor positions, resolutions, materials

→ single particle performance

**LiC Detector Toy**  PoS (Vertex 2011) 026

specific tool for studying tracking layout [MatLab]

**tkLayout**

widely used for
CMS tracker studies

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The sensor spatial resolution in z
on measurement layer i is noted \( \sigma_i \).

Multiple scattering is treated as a measurement error \( M_{z1} \).
“full event”-level fast-sim tools
DELPHES

4-vector smearing with parameterised detector resolutions, efficiencies

charged particle momentum resolution and
single-particle calorimeter energy resolution typically tuned to full-sim, prototype performance, ...

b/c/tau-tagging:
averaged approach, based on efficiency & fake rates at one or more operating points

recently introduced lookup table of full track covariances [IDEA concept]
→ will allow much more correct vertexing & HF-tagging

several relevant DEPHES cards:
CircularEE IDEA generic ILC CLICdet ...

https://cp3.irmp.ucl.ac.be/projects/delphes
SGV  Simulation a Grande Vitesse

fast simulation;
similar speed to eg DELPHES

Tracking:
detailed description of tracking and material layers
→ calculation of full track covariance matrix
→ meaningful b/c-tagging possible

Calorimeters:
smeering by single-particle resolution

Particle Flow reconstruction:
parameterise confusion effects between near-by particles,
tune by comparison with fullsim results (PandoraPFA)

e.g. study of how ILD performance scales with
detector radius, length, field, cost, ...
~300 models simulated
**mixed simulation:** as accurate as necessary where needed

- hybrid
  - full sim &
  - fast parameterised simulation e.g. GFlash
    selected by particle-type, subdetector

- semi-fast simulation,
  - especially of computing-hungry calorimeters
    → e.g. machine-learned detailed parameterisation
      description of shower shapes & correlations
    → potentially very significant reduction in computing resources

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**Fast and Accurate Electromagnetic and Hadronic Showers from Generative Models**

Erik Buhmann, Sascha Diefenbacher, Engin Eren, Frank Gaede, Daniel Hundhausen, Gregor Kasiezka, William Korcari, Anatolii Korol, Katja Krüger, Peter McKeown, Lennart Rustige

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vCHEP 2021

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**Geant4**

60°

**GAN**

60°
summary

detector simulations are essential to investigate
- physics capabilities
- detector optimisation
- technology development, prototypes
- technology comparisons

required simulation detail differs

tools are available for
detailed geometry description
full event simulation
fast parametrised simulation at different levels of sophistication
→ hybrid approaches

strong trend to use common tools to simulate
detectors at future Higgs Factories

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