LAB on Simulation

RD51 School

27/11/2023 – 01/12/2023

Riccardo Farinelli

Piet Verwilligen

Slide courtesy: W. Riegler

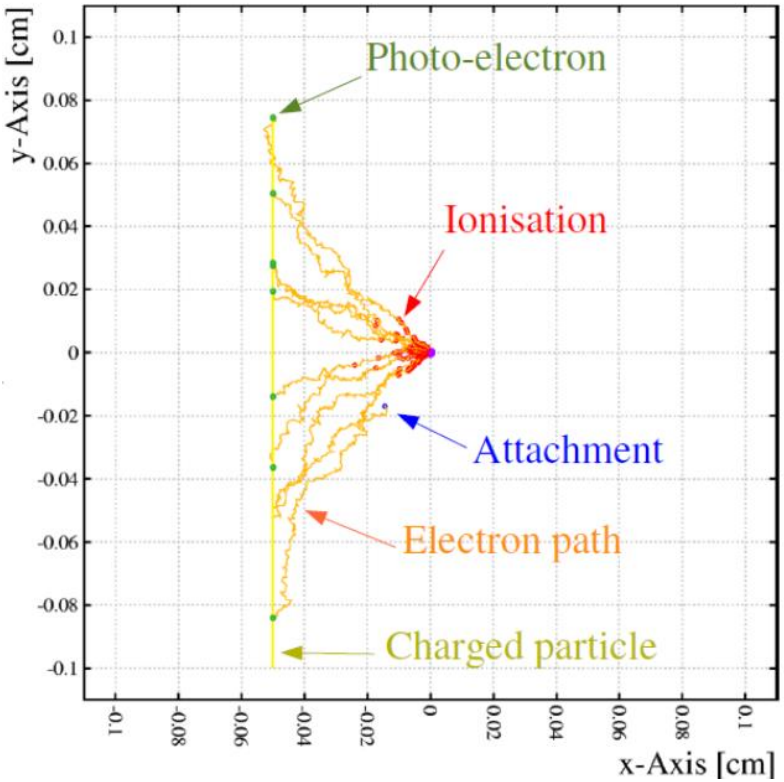
Simulation Frameworks

- **Garfield**
  - Originally in Fortran
  - Developed in '90ies by Rob Veenhof to simulate drift chambers
  - Provides analytic solutions for Electric Field in 2D geometries
  - Tracks electrons and ions in gas using v_{drift}, α, $\sigma_{\perp}$, $\sigma_{\parallel}$ (gas properties from Gas table calculated with Magboltz)
  - For MPGDs: Added Microscopic Tracking
  - Rewritten in C++
  - Interface with HEED (Primary Ionization) and Magboltz

- **GEANT**
  - Originally in Fortran (GEANT 3) then C++ (4)
  - Tracks particles through geometry with materials
  - Calculates energy loss in materials
  - Simulated Hit = Energy deposit in sensitive medium
  - Maintained / developed by GEANT4 collaboration
    - Extensive validation
  - Does not simulate what happens with electrons created in energy deposit

Simulation Frameworks

GEANT4
A SIMULATION TOOLKIT



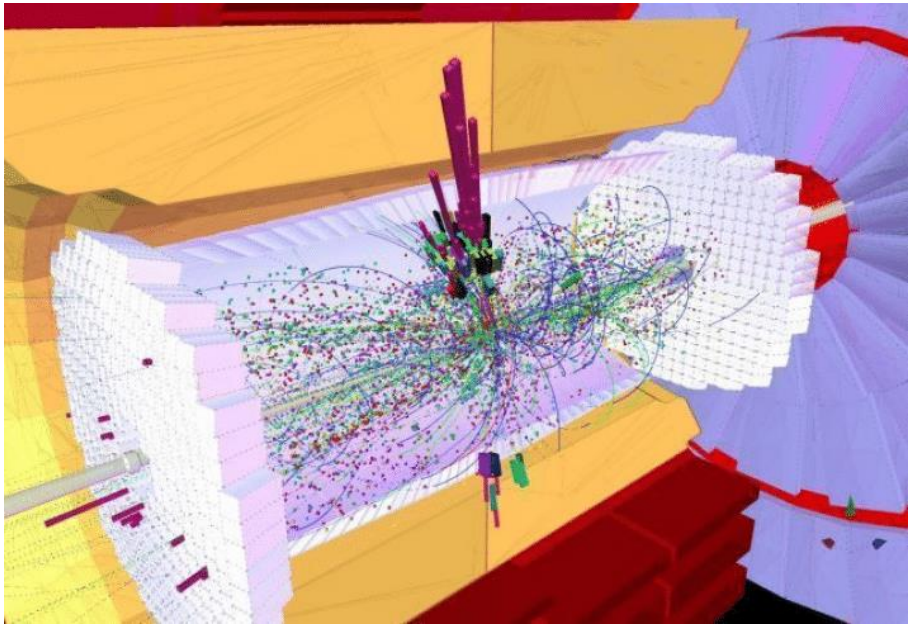


Figure courtesy: R. Veenhof

Simulation Toolbox

- **Toolbox of Simulator / Physicist:**

=

ROOT
Data Analysis Framework

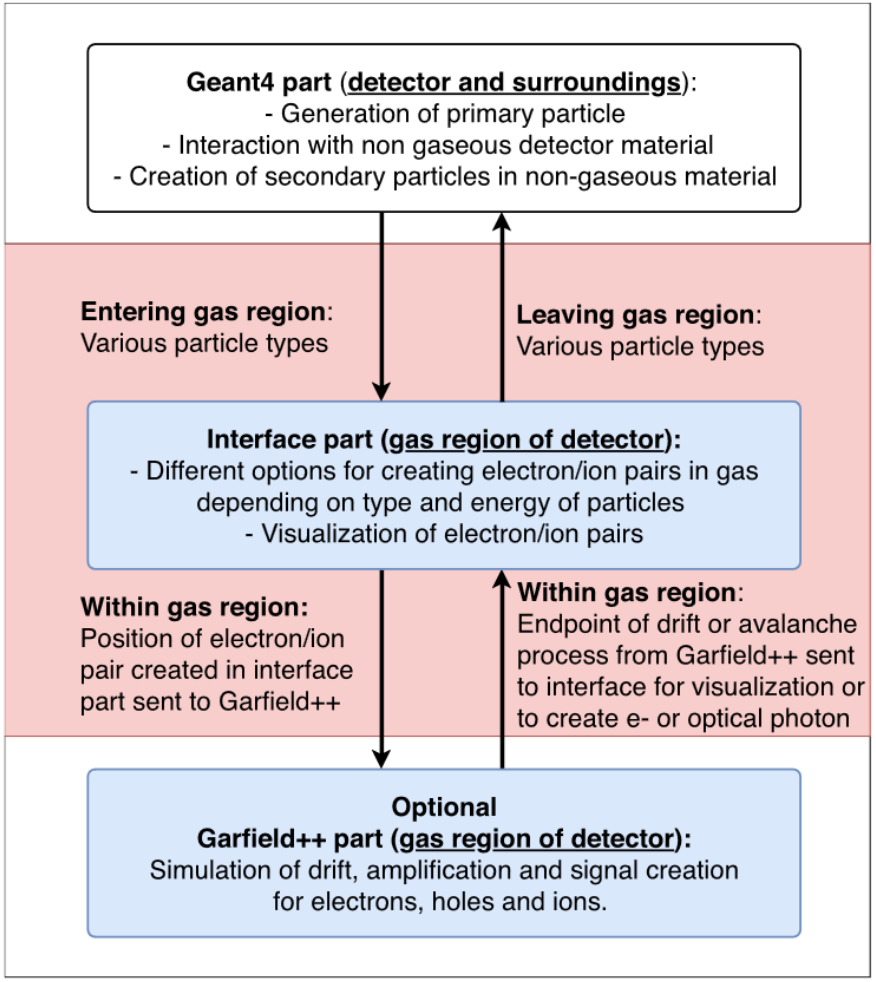
ANSYS

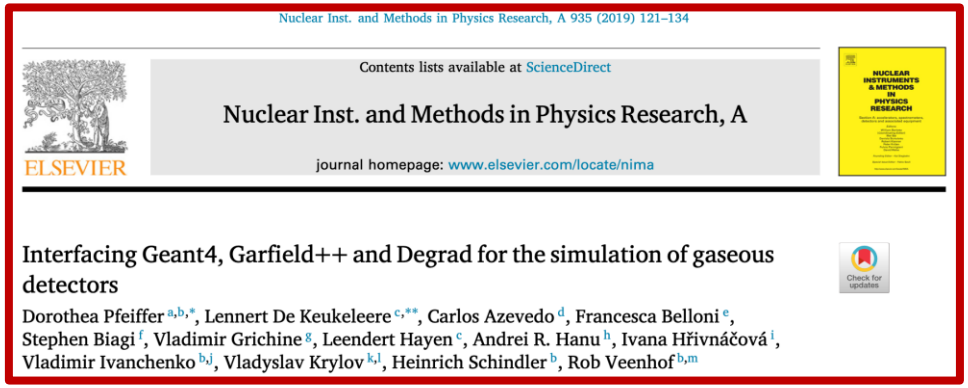
python™

COMSOL MULTIPHYSICS®

GEANT4
A SIMULATION TOOLKIT

Garfield – GEANT4 Interface




Nuclear Inst. and Methods in Physics Research, A 935 (2019) 121–134
Contents lists available at ScienceDirect
Nuclear Inst. and Methods in Physics Research, A
journal homepage: www.elsevier.com/locate/nima

Interfacing Geant4, Garfield++ and Degrad for the simulation of gaseous detectors

Dorothea Pfeiffer [a,b,*], Lennert De Keukeleere [c,**], Carlos Azevedo [d], Francesca Belloni [e], Stephen Biagi [f], Vladimir Grichine [g], Leendert Hayen [c], Andrei R. Hanu [h], Ivana Hřivnáčová [i], Vladimir Ivanchenko [b,j], Vladyslav Krylov [k,l], Heinrich Schindler [b], Rob Veenhof [b,m]

User need to define when and how to hand over information from GEANT to Garfield

Useful for detailed simulation of:

- Testbeam environment (beam is not clean)
- Neutron / Photon detectors
- Not-understood effects in the detector assuming only muons / MIPs

Garfield++

- Open-source toolkit for detailed simulation of charge transport and signals in particle detectors
- Can now simulate also semiconductor devices
- Typical steps:
  - Calculate static electric fields
  - Simulate Primary ionization (electron-ion pairs)
  - Simulate the trajectories of Primary and Secondary e-
    - Including multiplication if field > critical value
  - Calculate current induced on a readout electrode

Garfield++

material properties

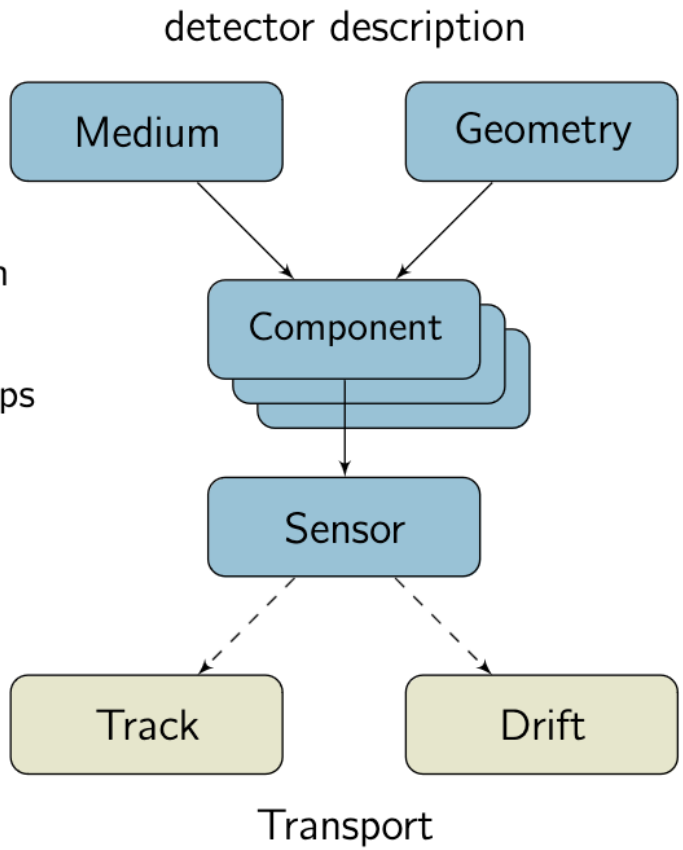
- gases → Magboltz
- semiconductors

field calculation

- analytic
- field maps
- neBEM

primary ionisation

- Heed
- SRIM, TRIM
- Degrade



charge transport

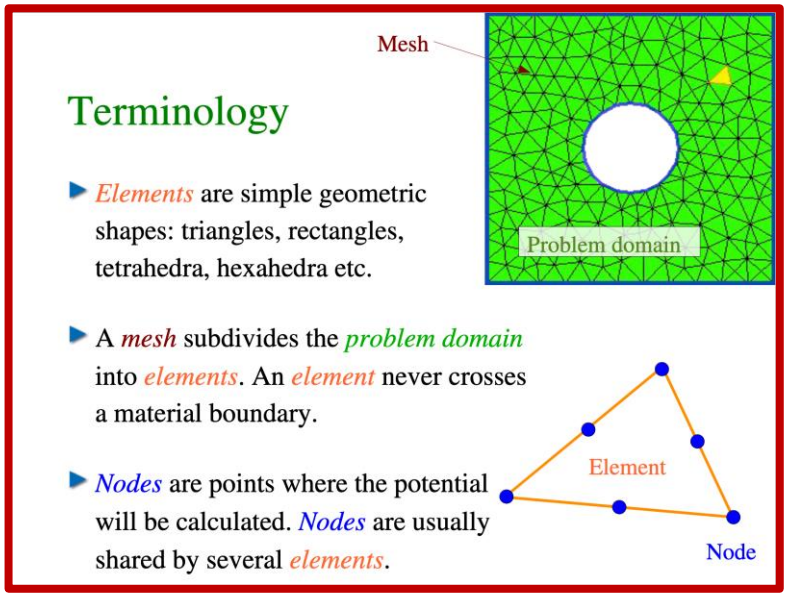
- microscopic
- MC
- RKF

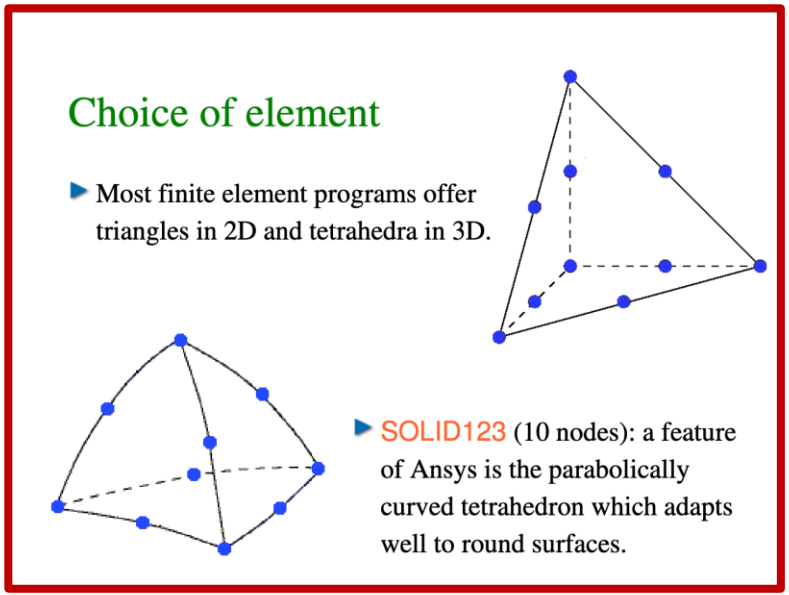
ANSYS Electric Fields

- https://garfieldpp.web.cern.ch/garfieldpp/examples/gem/
- A field solution consists of 4 files:
  - *ELIST.lis*: the list of elements with pointers to the material property table and to the node list;
  - *NLIST.lis*: the list of nodes, with their position in space;
  - *MPLIST.lis*: material property table
  - *PRNSOL.lis*: estimated potentials at each of the nodes.

geom

V





Slides courtesy: R. Veenhof

Charge Transport Methods

Macroscopic Simulation

- Medium = continuum
- Class. Electrodynamics

Two Classes

- Monte-Carlo (Stochastic)
  `CLASS AvalancheMC`
  - `DriftElectron, DriftHole, DriftIon`
  - `AvalancheElectron, AvalancheHole`
- Runge-Kutta-Fehlberg
  CLASS `DriftLineRKF`
  - `DriftElectron, DriftHole, DriftIon, DriftPositron, DriftNegativeIon`

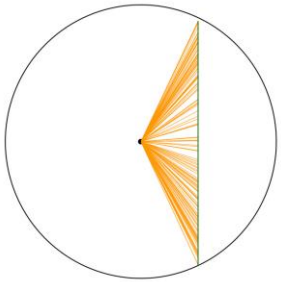
Microscopic Simulation

- Collision electron-atom
- Only implemented for electrons
- Cross-sections provided by class MediumMagboltz

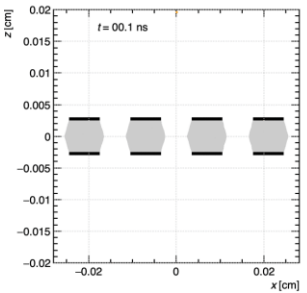
One Class:

- `CLASS AvalancheMicroscopic`
  - `AvalancheElectron,`
  - `DriftElectron`
    (does not track secondaries)

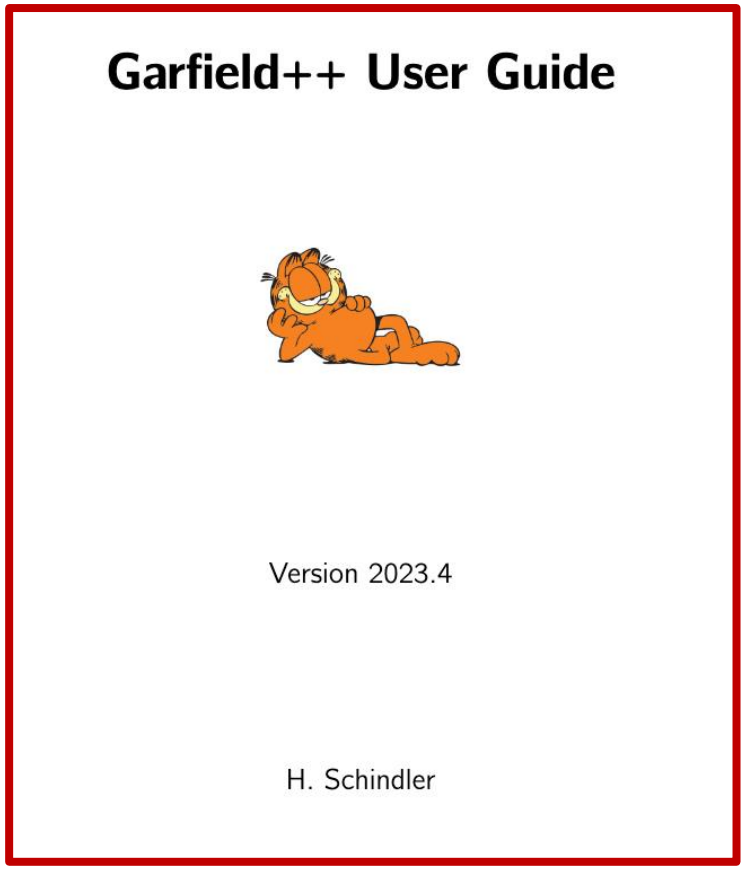
Electron drift lines simulated with DriftLineRKF
Ion drift lines not simulated

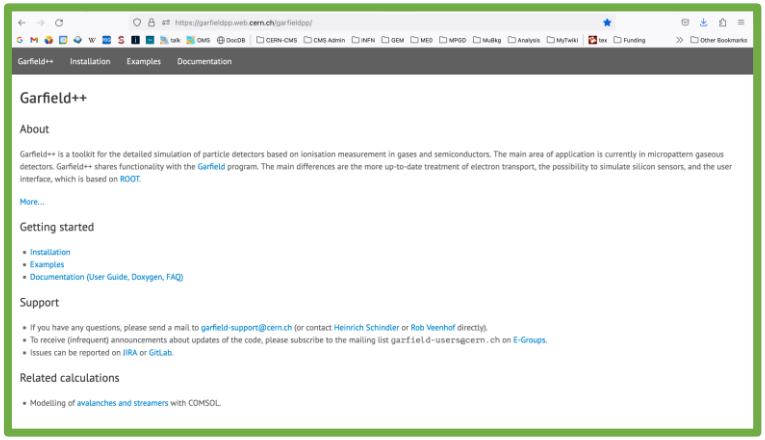


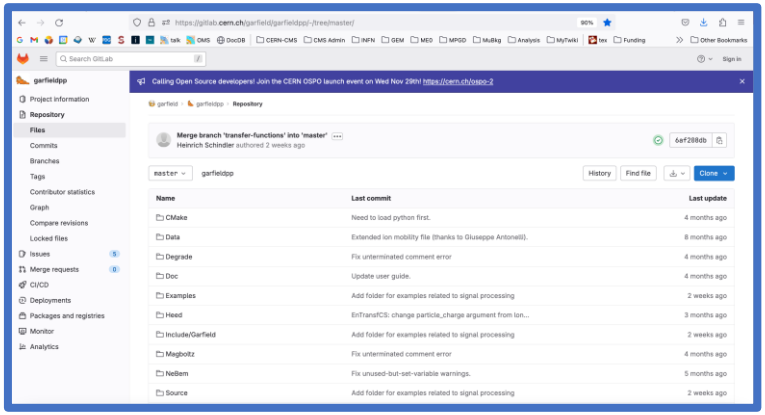
Electrons simulated with AvalanceMicroscopic
Ions created in AvalancheMicroscopic but simulated with AvalanceMC



Your Friends:







Your best friends: the Holy Trinity: The Manual, The Source Code, The Examples

- *Maybe also your tutors - we will do our best ☺*
- https://garfieldpp.web.cern.ch/garfieldpp/documentation/UserGuide.pdf
- https://gitlab.cern.ch/garfield/garfieldpp/-/tree/master/
- https://garfieldpp.web.cern.ch/garfieldpp/documentation/

Prepared Exercises

- Exercise 1 :: install Garfield, Electric Fields (plot *V, E*)
- Exercise 2 :: Simulate Primary Ionization (calculate N_{prim})
  - *Homework: find the Bethe-Bloch function for energy loss*
- Exercise 3 :: Electron transport (plot v_{drift}, track e^- in detector)
  - *Homework: Evaluate the diffusion as function of the distance*
- Exercise 4 :: Gas Gain (simulate avalanche in Single-GEM)
  - *Homework: find the gain curve for a single-GEM detector*
- Exercise 5 :: Signal Induction in Parallel-Plate Avalanche Counter
  - *Homework: find the signal in a single-GEM detector*
- Exercise 6 :: Gain in a Triple-GEM detector
- Exercise 7 :: Parametrized simulation of a Triple-GEM detector

Contact - Questions

- Riccardo.farinelli@cern.ch
- piet.Verwilligen@cern.ch