Interfacing Geant4 and Garfield Physics evaluation

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Steps in gas detector simulation

To simulate a gaseous detector, the following five processes are relevant:

1. Primary high energy particle ionization (Geant4)
2. Forming of ionization clusters in gas and ionization electrons
3. Drift of ionization electrons to amplification stage and detector read out
4. Amplification/creation of additional ionization via avalanche
5. Forming of electronic signal at read out
The PAI model in Geant4 does not produce enough ionization electrons.

The ionization electrons in Geant4 still have a substantial kinetic energy (several tens of eV).

The asymptotic $W$ value and Fano factor can hence not be reproduced with Geant4.
How to interface Geant4/Garfield?

- Geant4 and Garfield++ are interfaced using the Geant4 physics parameterization capabilities.
- General idea of parameterization in Geant4 is to create a region, where the user can provide her own implementation of the physics and the detector response. For the Geant4/Garfield++ interface, the user implementation of the detector response is based on Garfield++.
- Details regarding the software implementation can be found in [https://indico.cern.ch/event/667256/contributions/2731974/](https://indico.cern.ch/event/667256/contributions/2731974/) and [https://garfieldpp.web.cern.ch/garfieldpp/examples/geant4-interface/](https://garfieldpp.web.cern.ch/garfieldpp/examples/geant4-interface/)
Task division Geant4/Garfield++

1a
Primary particle entering gas
Geant4
Physics model in Geant4
PAI/PAIPhot Model In gas region
Point of transfer of Control between Geant4/Garfield++
“Kill” secondary e- produced in gas region in Geant4
Methods in Heed/Garfield++
TrackHeed TransportDeltaElectron()

1b
Protons, muons, ions
Garfield++ simulation according to needs
TrackHeed or TrackSrim SetParticle()
NewTrack()

2
Gamma
Garfield++ simulation according to needs
TrackHeed TransportPhoton()
Evaluation of physics in case 1a

- In cases 1b (charged particles) and 2 (gamma), Geant4 is only used for physics processes that happen before the particles enter the gas volume. For gas detector simulation, the complete physics of Heed, SRIM or Degrad is used.
- Case 1a used the PAI model of Geant4 for primary ionization, then transfers these electrons to Heed to create the conduction electrons.
- Since two different physics codes are used, an evaluation of the correctness of the obtained results is needed.
- Production threshold in PAI model and transfer threshold (at which electrons are sent to Heed) have to be set correctly.
Ionization e- and transfer threshold for 1 GeV e- in Ar/CO2 70/30

In PAI model, a small percentage of first generation ionization e- (created directly by primary) have a kinetic energy that is high enough to further ionize the gas.

Best transfer threshold around 2keV, thresholds below 1.1 keV transfer not enough energy to Heed.
Transfer threshold and deposited energy (n*W)

- Transfer threshold optimized so that deposited energy (n*W) in Geant4 is equivalent to number of conduction e- multiplied by the W value.
- Independent of particle type, energy or gas mixture, a value of 2000 eV is appropriate.
Transfer threshold and W and Fano factor in He/isoButane 70/30

- Transfer threshold optimized so that W factor and Fano factor can be reproduced with fully contained 10 keV electron
- Whereas the correct W value can be reproduced, the Fano is slightly too high
- Independent of PAI model production cut (explained later), the results are very similar to the results obtained with the energy optimization of the transfer threshold
Geant4 PAI model, scan of lower production cut
1 MeV electron in Ar/CO2 70/30

I_{min} = 13.79 eV

W = 28.05 eV
PAI model production cut and deposited energy ($n^*W$) in ArCO2 70/30

- Best production cut lies around 21 eV
- Value independent of particle type and energy
Production cut, transfer threshold and W and Fano factor for 10 keV e- in He/isoButane 70/30

- Optimizing for W value and Fano factor in parallel, the production cut lies around 20 eV with a transfer threshold between 1.5 keV and 2.5 keV
- Results very similar to energy optimization
Production cut and transfer threshold calculation for gas mixtures

• Optimal production cut for a gas mixture, e.g. a mixture of Helium and Isobutane, can obtained from the optimal production of the two pure gases, and the ratio of the molar masses. The expression looks similar to the one for the W-value and is given by:

\[ P(f) = \frac{P_2 + \left(\frac{m_1}{m_2}P_1 - P_2\right)f}{1 + \left(\frac{m_1}{m_2} - 1\right)f} \]

• P1 and P2 are optimal production cuts for the pure gases, m1 and m2 the molar masses and f the fraction of gas 1

Fit agrees with values obtained with formula
The spatial distribution of the ionization electrons created by relativistic charged particles agrees between the Geant4/Garfield++ interface and Heed.

Geant4 PAI model creates the correct distribution, but underproduces ionization electrons.
Spatial distribution of ionization e- in ArCO2 70/30 for 100 keV e-

Geant4/Garfield++ interface also creates correct spatial distribution of charges for non-relativistic charged particles
Comparison Geant4 PAI, Interface, Heed deposited energy and n*W
1 GeV alpha and 1 Me- in ArCO2 70/30

- Mean deposited energy and shape of energy deposition agree between Geant4 PAI model and Geant4/Garfield++ interface
- Production cut was optimized for energy deposition (n*W)
Comparison Geant4 PAI, Interface, Heed deposited energy and n*W
1 MeV and 100 keV e- in He/isoButane 70/30

- Mean deposited energy and shape of energy deposition basically agree between Geant4 PAI model and Geant4/Garfield++ interface, but the interface slightly overproduces electrons
- Production cut was optimized for W value and Fano factor
Slow e- (100keV in ArCO2 70/30 and 10keV in He/isoButane 70/30)

- Geant4/Garfield++ interface also works for slow e- like 100 keV e- in ArCO2, where Heed cannot be used
- For fully contained e- like 10 keV e- in 2 cm of He/isoButane 70/30, energy spectrum of the interface is identical to the one obtained with TransportDeltaElectron() in Heed
Conclusions

• Geant4/Garfield++ interface works
• Optimizing either for deposited energy (n*W) or for W value and Fano factor together, the best combination of PAI model production cut and transfer threshold can be obtained
• Knowing the best parameters for pure gases, the correct parameters for gas mixtures can be calculated
• The spatial distribution of charges between the interface and Heed agrees for relativistic charged particles
• For non-relativistic charged particles, the interface gives correct results whereas Heed cannot be used
• The deposited energy spectra show for all particle types and energies good agreement between Geant4 and the interface