

The basic model of crystalline medium simulation in GEANT4

V.V. Haurylavets¹, V.V. Tikhomirov,
L. Bandiera^a, A.I. Sytov^{a,b}, A.S. Lobko, M. Soldani^a,
M. Sachyuka

^aINFN Ferrara Division, Via Saragat 1, 44122 Ferrara, Italy,

^b Korea Institute of Science and Technology Information (KISTI), 245
Daehak-ro, Yuseong-gu, Daejeon 34141, Korea

The 9th International Conference
Channeling 2023

¹E-mail:bycel@tut.by

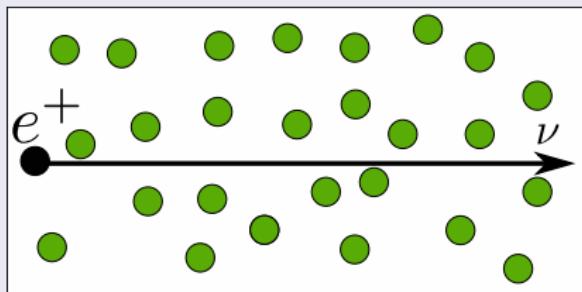
Motivation

- Simulate large experimental setups with crystals.
- Fast simulation of electromagnetic shower when we don't need details on atomistic level.

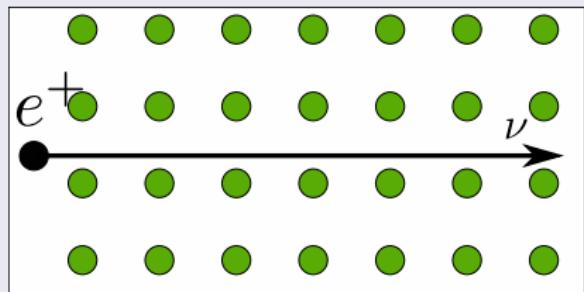
We propose the basic model of crystalline medium simulation in GEANT4. It is capable to simulate fast electromagnetic shower in large oriented crystalline volumes.

Amorphous and crystal medium

Amorphous medium, atoms have random position



Oriented crystal medium, atoms are arranged in a strict order



GEANT4 uses amorphous medium. Exceptions are a project written by Enrico Bagli - INFN and University Ferrara (Italy) and new model with use FastSimulationModel by Alexei Sytov. All of this models are microscopic.

Processes in GEANT4

We have a number of processes in GEANT4 with cross-sections which is calculated in dependence of material, energy.

$$\sigma(E) \quad (1)$$

The physical interaction length is calculated from the cross-section and using Monte Carlo method simulate these processes. When they happen and how the initial particle is changed.

Crystalline medium in GEANT4

We change the cross-sections of the processes :

- Gamma conversion to electron-positron pair ($e^- e^+$)
- Bremsstrahlung by electrons and positrons

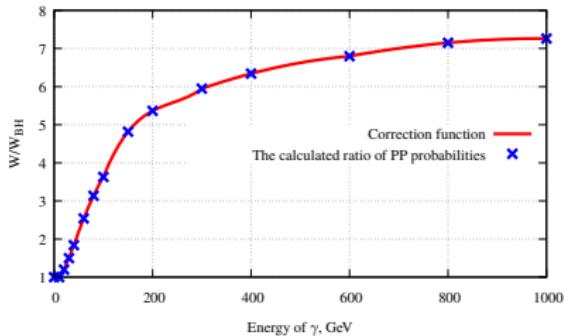
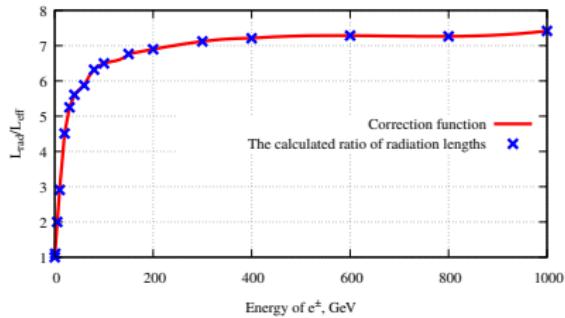
Steps for modification of processes in GEANT4:

- Calculation of correction functions with using microscopic model
- Changing the cross-sections

$$\sigma' (E) = \sigma(E) * \phi(E) \quad (2)$$

where σ is the standard cross-section if GEANT4, $\phi(E)$ is correction function, σ' is the corrected cross-section of process.

Correction functions $\phi(E)$



Bremsstrahlung

Gamma conversion to $e^- e^+$ pair

The corrections functions for $PbWO_4$. They are approximately equal 1 below 1 GeV for Bremsstrahlung and equal 1 below 10 GeV for gamma conversion.

Modification of processes in GEANT4

These standard processes are modified:

The process: G4eBremsstrahlung.

G4SeltzerBergerModel under 1 GeV and

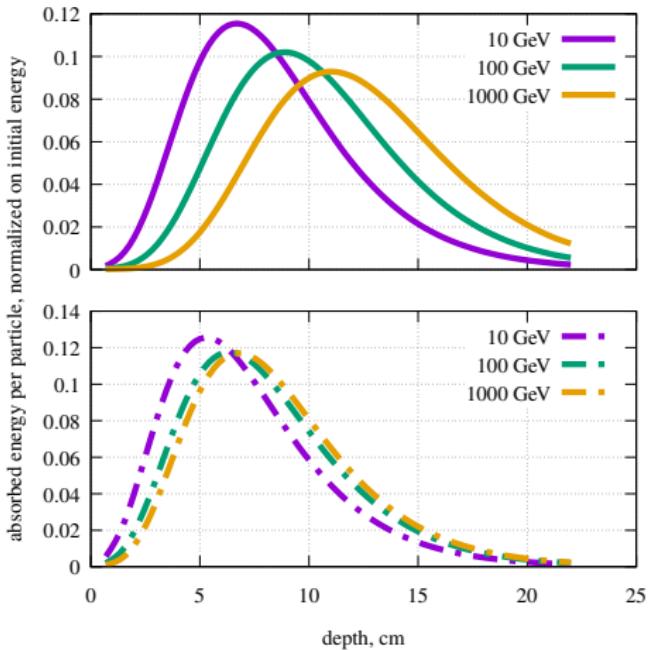
G4eBremsstrahlungRelModel for gamma energy more than 1 GeV.

The correction function for electrons may be differ from the one for positrons.

The process: G4GammaConversion.

G4BetheHeitlerModel for primary particle energy under 80 GeV and G4PairProductionRelModel for primary particle energy above 80 GeV.

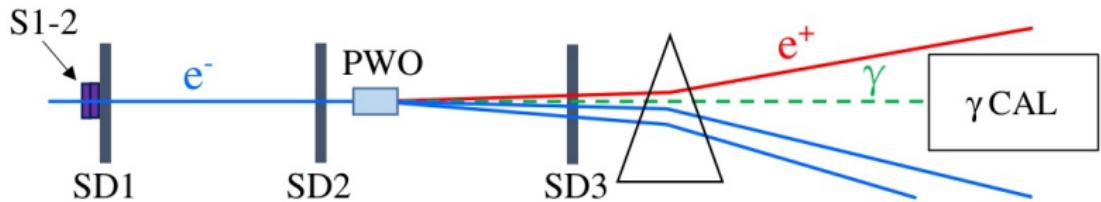
Deposited energy



Solid lines are for standard GEANT4, dotted lines are for the basic model with include crystalline medium.

Experiment with 4 mm crystal of $PbWO_4$

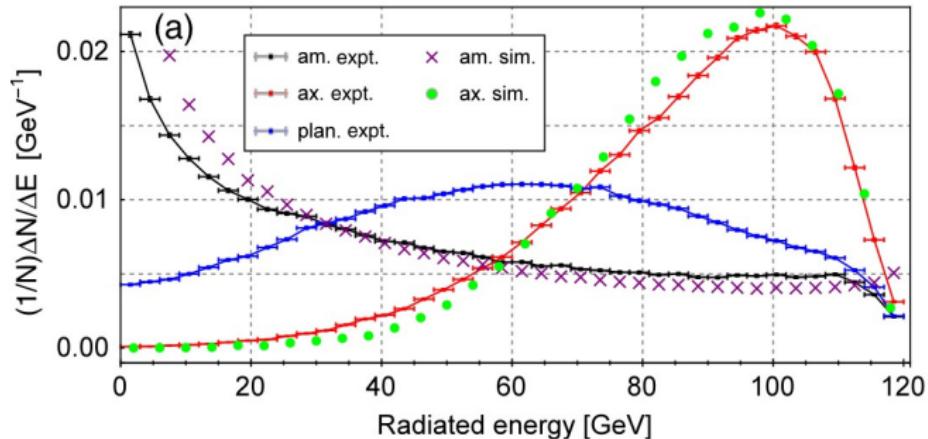
Experiment at Super Proton Synchrotron of LHC [1]. Initial particles are 120 GeV.



The target is the oriented $PbWO_4$ crystal of 4 mm thickness.

- Strong reduction of the effective radiation length in an axially oriented scintillator crystal / L. Bandiera, V.V. Tikhomirov, M. Romagnoni, N. Argiolas, E. Bagli, G. Ballerini, A. Berra, C. Brizzolari, R. Camattari, D. De Salvador, V. Haurylavets, V. Mascagna, A. Mazzolari, M. Prest, M. Soldani, A. Sytov, and E. Vallazza // Phys. Rev. Lett. . – 2018. – Vol. 121, №. 2. – P. 021603 . – DOI 10.1103/PhysRevLett.121.021603.

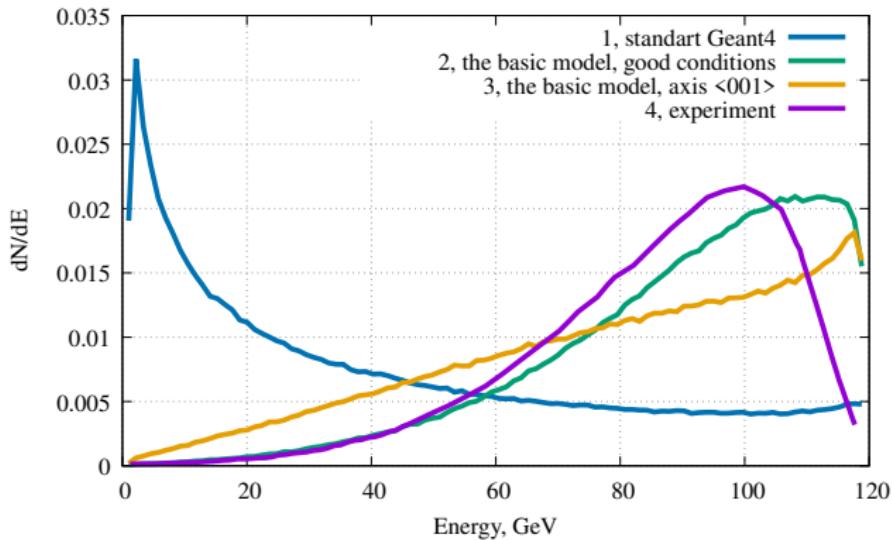
Experiment with 4 mm crystal of $PbWO_4$



The results from [1]. Big difference between amorphous and crystal. Here the simulation with trajectory calculation of microscopic model.

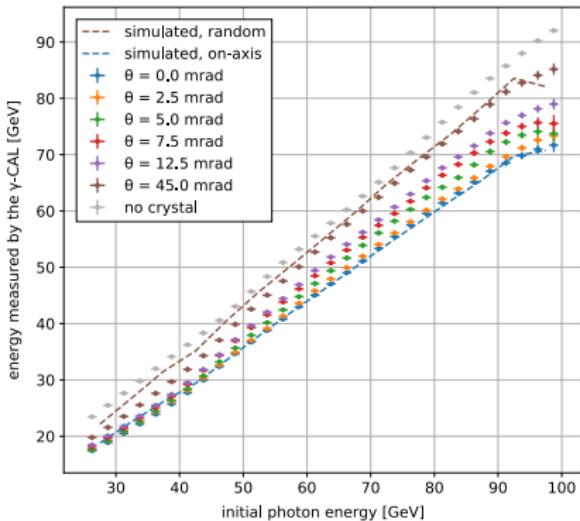
- Strong reduction of the effective radiation length in an axially oriented scintillator crystal / L. Bandiera, V.V. Tikhomirov, M. Romagnoni, N. Argiolas, E. Bagli, G. Ballerini, A. Berra, C. Brizzolari, R. Camattari, D. De Salvador, V. Haurylavets, V. Mascagna, A. Mazzolari, M. Prest, M. Soldani, A. Sytov, and E. Vallazza // Phys. Rev. Lett. . – 2018. – Vol. 121, №. 2. – P. 021603 . – DOI 10.1103/PhysRevLett.121.021603.

Experiment with 4 mm crystal of $PbWO_4$



The agreement is much better between GEANT4 with the basic model.

1 cm of W crystal



The target is the oriented 1 cm crystal of W . The axes is
 $<111>$.



Strong enhancement of electromagnetic shower development induced by high-energy photons in a thick oriented tungsten crystal / M. Soldani, L. Bandiera,..., V. G. Baryshevsky,..., V.V. Tikhomirov, ..., V. Haurylavets,..., A. Sytov et al. // Eur. Phys. J. C . – 2023. – Vol. 83, №. 101. – P. 1-8 . – DOI 10.1140/epjc/s10052-023-11247-x.

Limitation of the model

- Correction functions are calculated for each material, axis or plane and angle distribution.
- All particles are moving along axis or plane.
- The model are good for large volumes.

Thank for your attention!

Thank for your attention!