Precision analysis of Geant4 condensed transport effects on energy deposition in detectors

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Abstract

Physics models and algorithms operating in the condensed transport scheme - multiple scattering and energy loss of charged particles - play a critical role in the simulation of energy deposition in detectors.

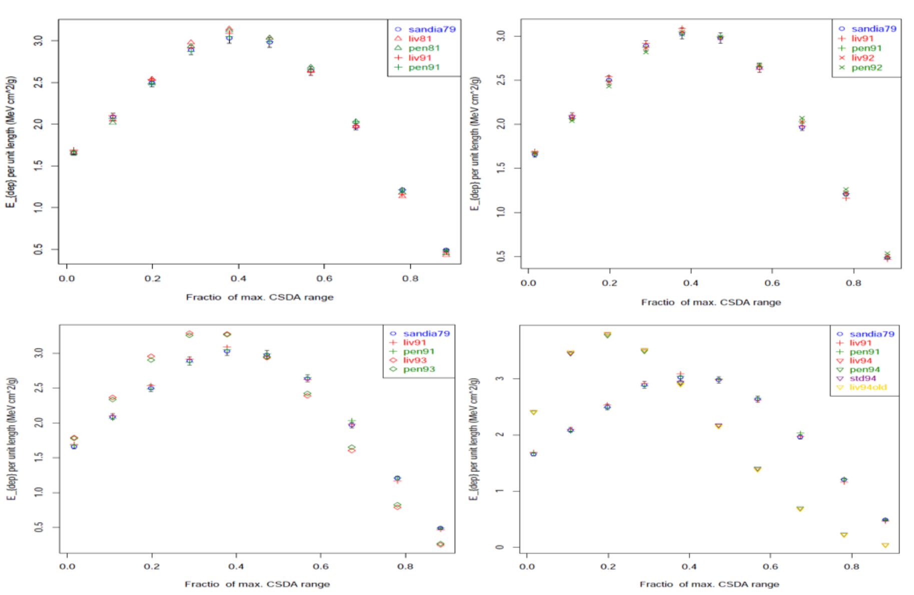
Geant4 algorithms pertinent to this domain involve a number of parameters and physics modeling approaches, which have evolved in the course of the years. Results in the literature document their effects on physics observables in detectors, but comparisons with experiment for model validation are relatively scarce, and a comprehensive overview of the problem domain is still missing, despite its relevance to experimental applications.

A simultaneous validation with respect to experimental data is performed to evaluate the accuracy of backscattering and energy deposition simulated by Geant4: accurate rendering of both observables through the same physics settings is a known issue in Monte Carlo simulation, and a sensitive test of the robustness of the algorithms. The analysis involves the contributions of Geant4 charged particle interaction models, energy loss and multiple scattering algorithms. A sample of preliminary results of an ongoing large-scale validation project is shown.

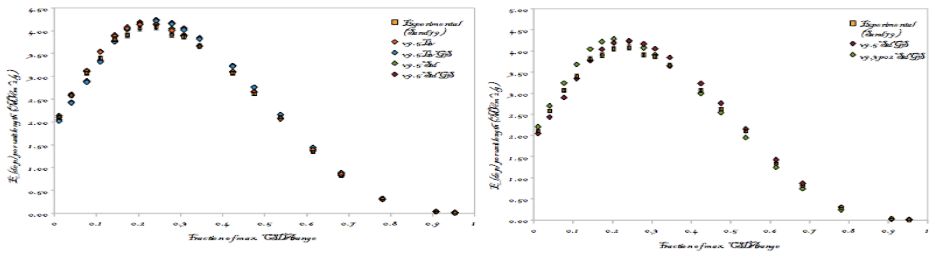
Test settings

The validation was performed based on experimental data in Sandia reports Sand79 [1] and Sand80 [2]. The validation of energy deposition (E_{dep}) was published in [3] for Geant4 8.1 and 9.1 versions. The application calculates the deposited energy and backscattering factor (BSF) in the same conditions as in the experiment. It deals with different target materials for E_{dep} evaluation (Beryllium, Carbon, Aluminum, Iron, Copper, Molybdenum, Tantalum, Uranium) and BSF calculation (Beryllium, Carbon, Titanium, Molybdenum, Tantalum, Uranium). The electron beam energy ranges from 0.058 MeV to 1.033 MeV. The electron angle of incidence varies from 0^o to 75^o. Geant4 8.1.p02, 9.1.p03, 9.2.p04, 9.3p02, 9.4.p03 and 9.5 versions were evaluated.

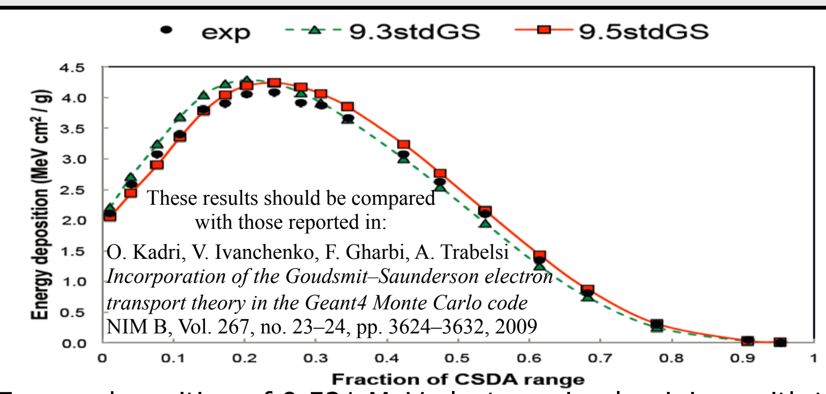
Some preliminary results



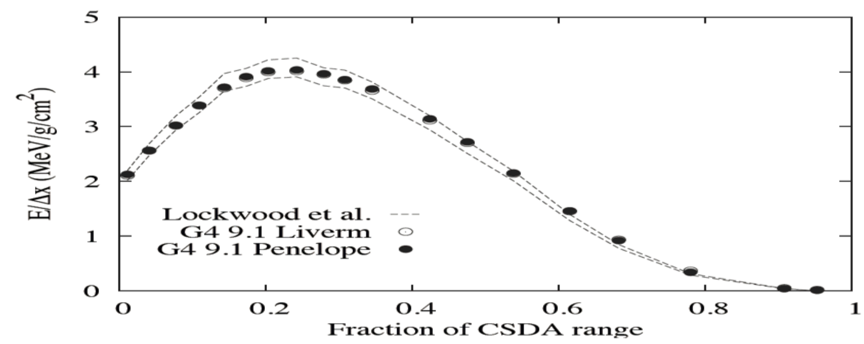
Comparison of simulated and measured deposited energy profiles for various Geant4 versions. The simulations activated the Urban* multiple scattering models with default settings. Results produced with Geant4 Standard and low energy "Livermore" electromagnetic models are presented. The results produced by Geant4 9.1 version, validated in a previous work, are shown in all plots.



Results for Geant4 9.5, also with the Goudsmit–Saunderson multiple scattering model (a) along with Geant4 Livermore and Standard electromagnetic models, and (b) evolution with the Standard electromagnetic model between versions 9.3p02 and 9.5.



Energy deposition of 0.521 MeV electrons in aluminium with the Goudsmit-Saunderson multiple scattering model in Geant4 9.5 (red) and 9.3p02 (green), and experimental data by Lockwood et al., SAND79-0414. The p-value from the χ^2 test of compatibility with experiment is 1.6 10^{-34} for Geant4 9.3p02 and 1.8 10^{-22} for Geant4 9.5.



The same test case as above, simulated with Geant4 9.1, activating the only multiple scattering algorithm available for electrons in that version. The dashed lines represent an interval of 3σ around the experimental values. The p-value from the χ^2 test is 0.133.

Probability of E_g to escape from the detector and backscattering calculation

Material	Incident Energy	Sand80 (ProbScape)	G4v93p02 (ProbScape)	Sand80 (BS)	G4v93p02 (BS)
Tantalum	1 MeV	$1.63 * 10^{-2}$	$2.90 * 10^{-2}$	0.191	0.310
Carbon	25 keV	$4.31 * 10^{-5}$	$1.86 * 10^{-5}$	0.103	0.296

Conclusions

Preliminary results show that different accuracy in electron energy deposition and backscattering is achieved by different versions of Geant4, when the same experimental settings (geometry, energies, material) are simulated. The differences appear larger for light target materials and higher energies. Previous published tests attributed the source of differences to the evolution of Geant4 multiple scattering modeling. The identification of the source of discrepancies is not possible, when more than one physics modeling component is subject to uncontrolled evolution across different Geant4 versions. The Goudsmit-Saunderson multiple scattering model does not appear to substantially improve the accuracy of electron energy deposition. The full set of results will be documented in a forthcoming report.

References

[1] G. J. Lockwood, et al. Sandia report 79. Sandia National Laboratories, Albuquerque, NM, 1987.
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[3]A. Lechner, M. G. Pia, M. Sudhakar. IEEE Trans. Nucl.Sci., vol. 56, no. 2, p. 398-416, 2009.