

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

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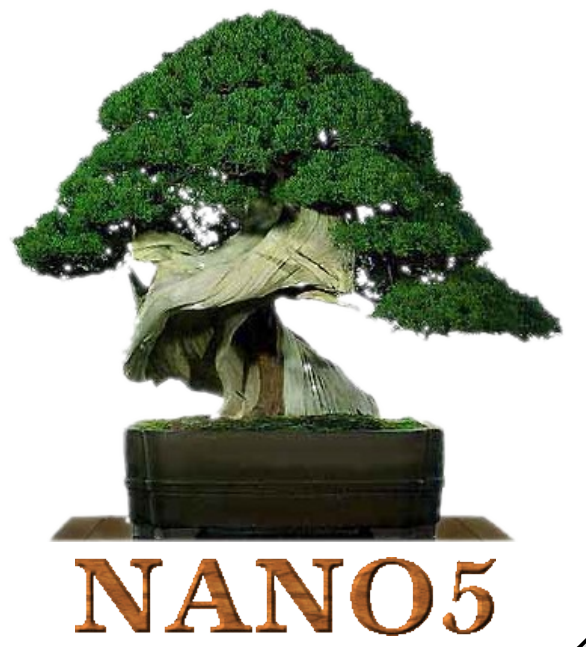


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Abstract

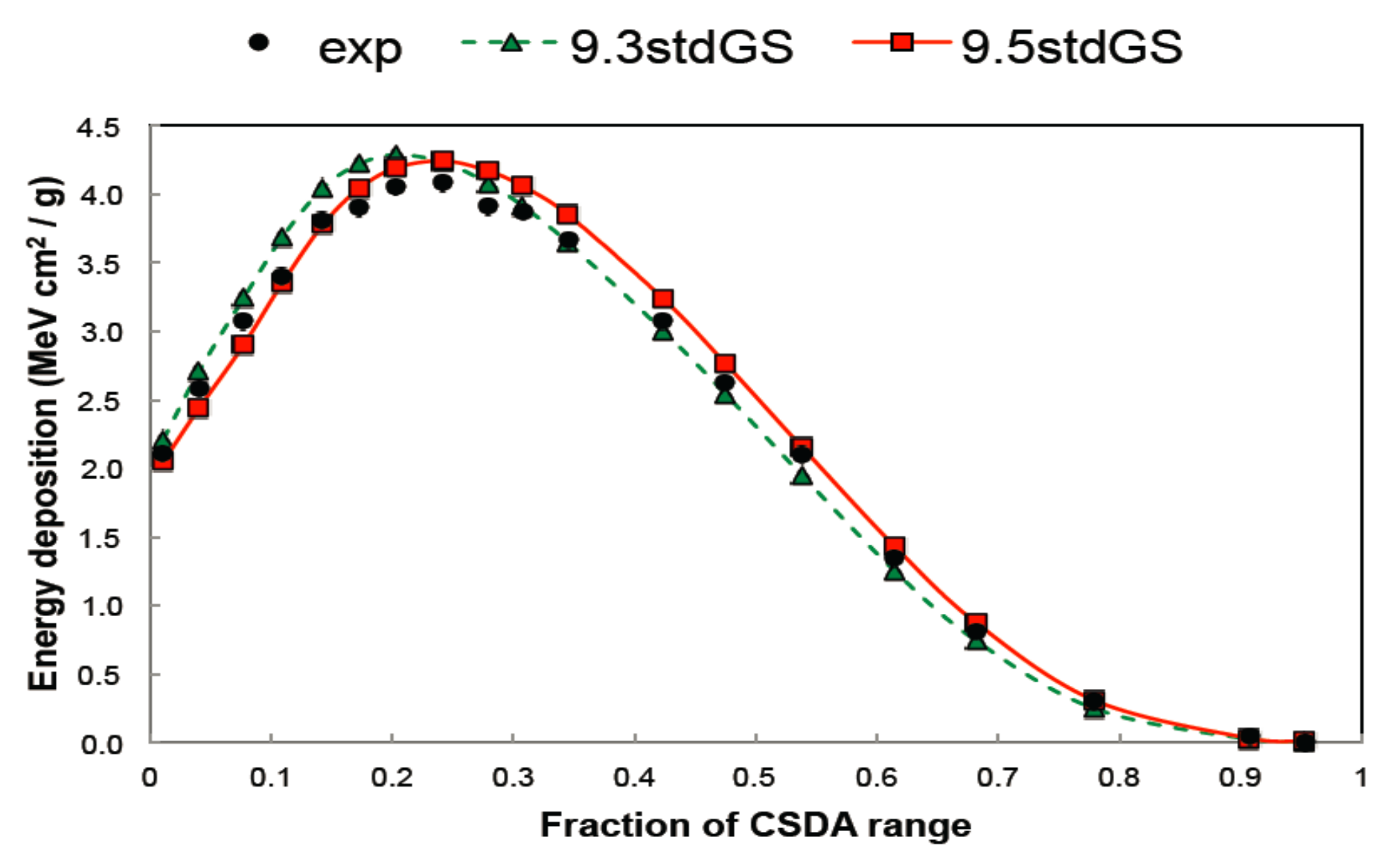
Physics models and algorithms operating in the condensed transport scheme - multiple scattering and energy loss of charged particles - play a critical role in the simulation of energy deposition in detectors.

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.

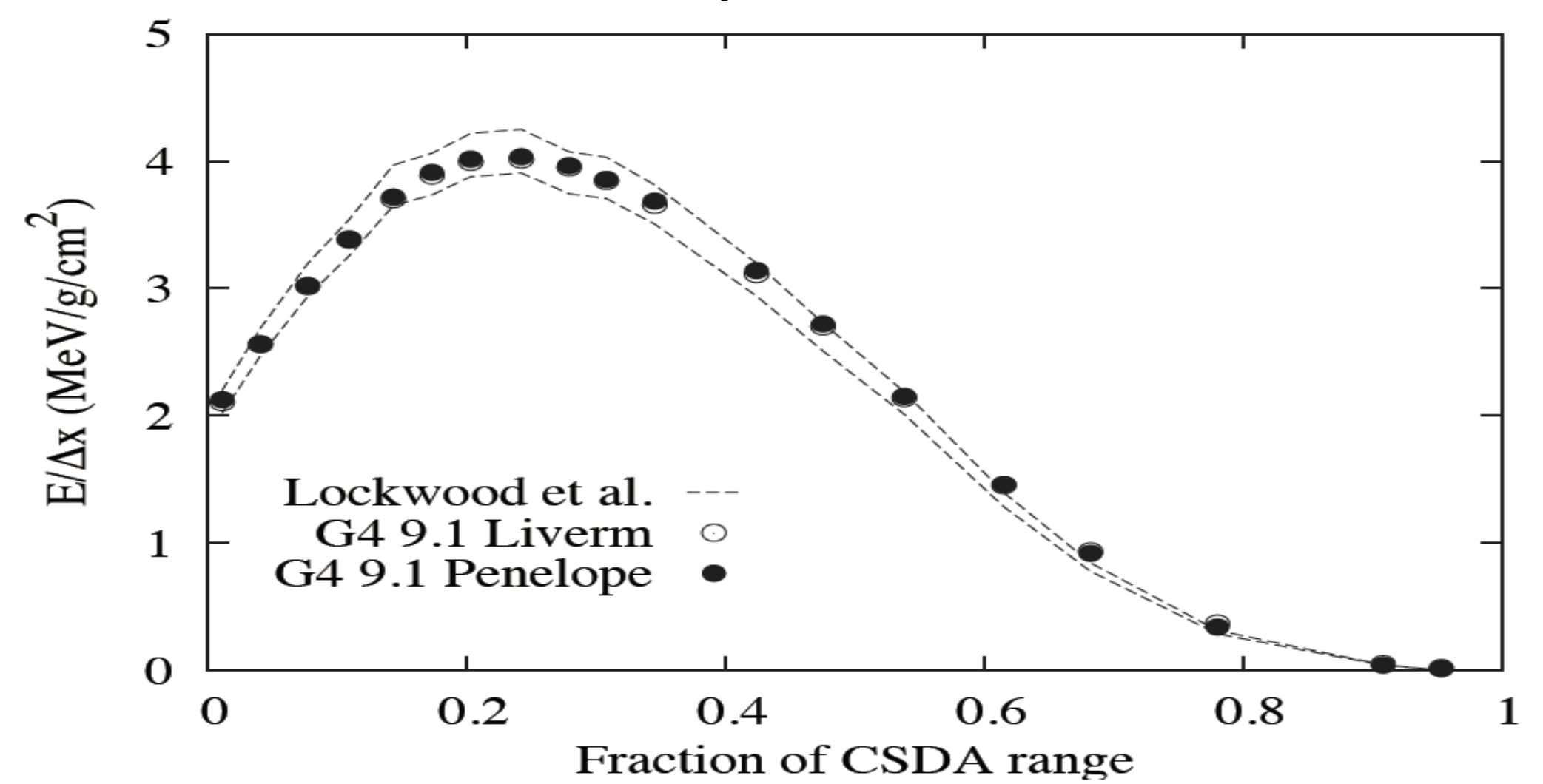
In-depth analysis of Geant4 models operating in the condensed transport scheme is reported. A simultaneous validation is performed to evaluate the accuracy of backscattering and energy deposition: accurate rendering of both observables through the same physics settings is a known issue in Monte Carlo 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: quantitative results highlighting the role of the various components are presented.

Methodology

The validation was performed based on Sandia reports Sand79 [1] and Sand80 [2]. The validation of Geant4 for this application was published by Lechner [3] for the version 8.1 and 9.1 for the energy deposition (Edep) evaluation. The application was changed in the way to make possible to define the backscattering factor (BSF), that represents the electron reflection coefficient desired. The application planned to run the calculate the deposited energy and backscattering in the same conditions than Sandia reports, covering different materials for Edep evaluation (Beryllium, Carbon, Aluminum, Iron, Copper, Molybdenum, Tantalum, Uranium) and BSF calculation (Beryllium, Carbon, Titanium, Molybdenum, Tantalum, Uranium), the energy range from 0.058 MeV up to 1.033 MeV and different angles for the incident electron beam (from 0° to 75°). The Geant4 versions evaluated were 8.1.p02, 9.1.p03, 9.2.p04, 9.3p02, 9.4.p03 and 9.5.



Energy deposition of 0.521 MeV electrons in aluminum with Geant4 Goudsmit-Saunderson multiple scattering algorithm in Geant4 9.5 (red) and Geant4 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 0.1610-34 for Geant4 9.3p02 and 1.810-22 for Geant4 9.5.

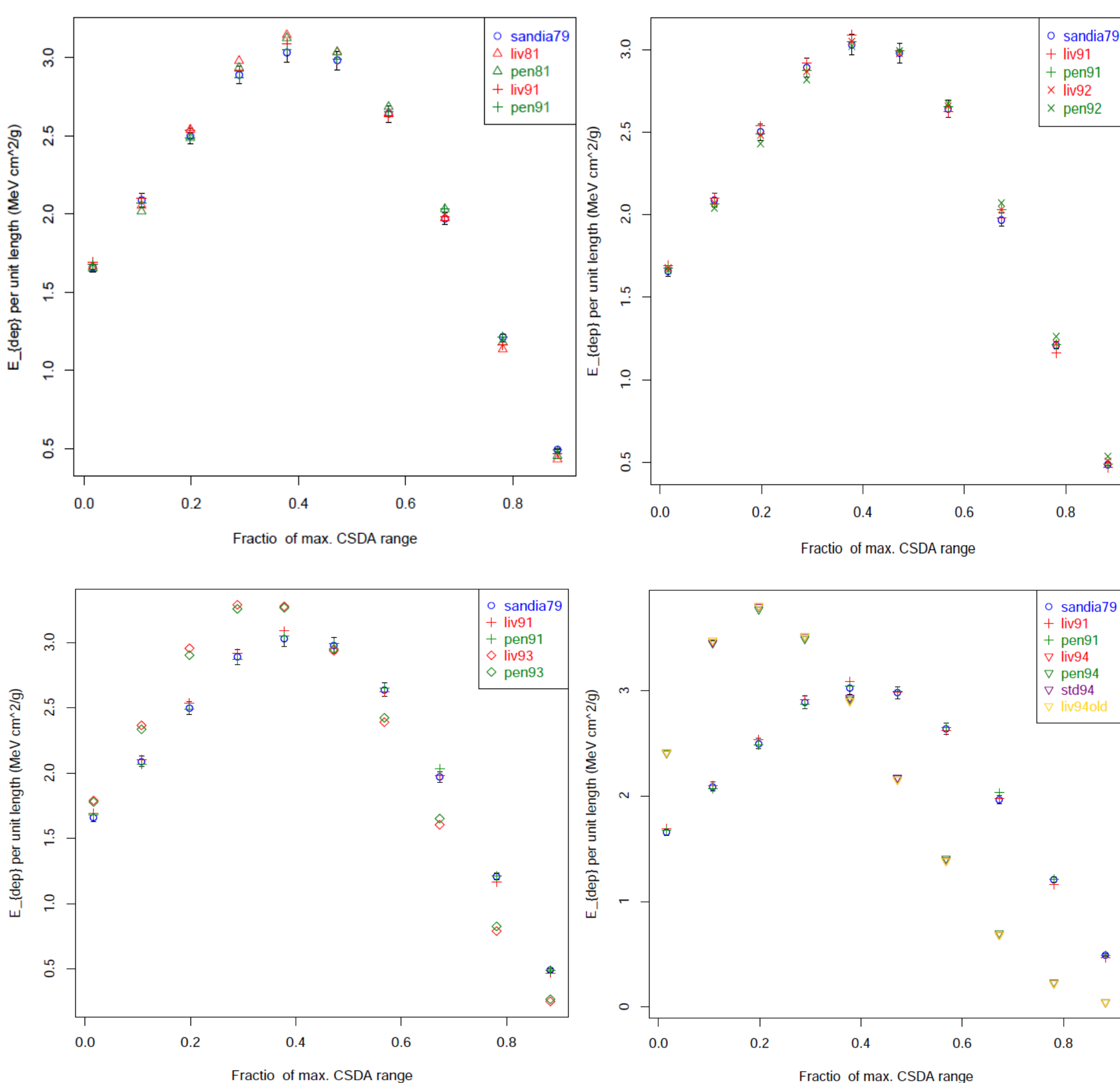


The same test case as above, resulting from simulation with Geant4 9.1, obtained with the only multiple scattering algorithm available in that version. The dashed lines represent an interval of three standard deviations around the experimental values. The p-value from the χ^2 test is 0.133.

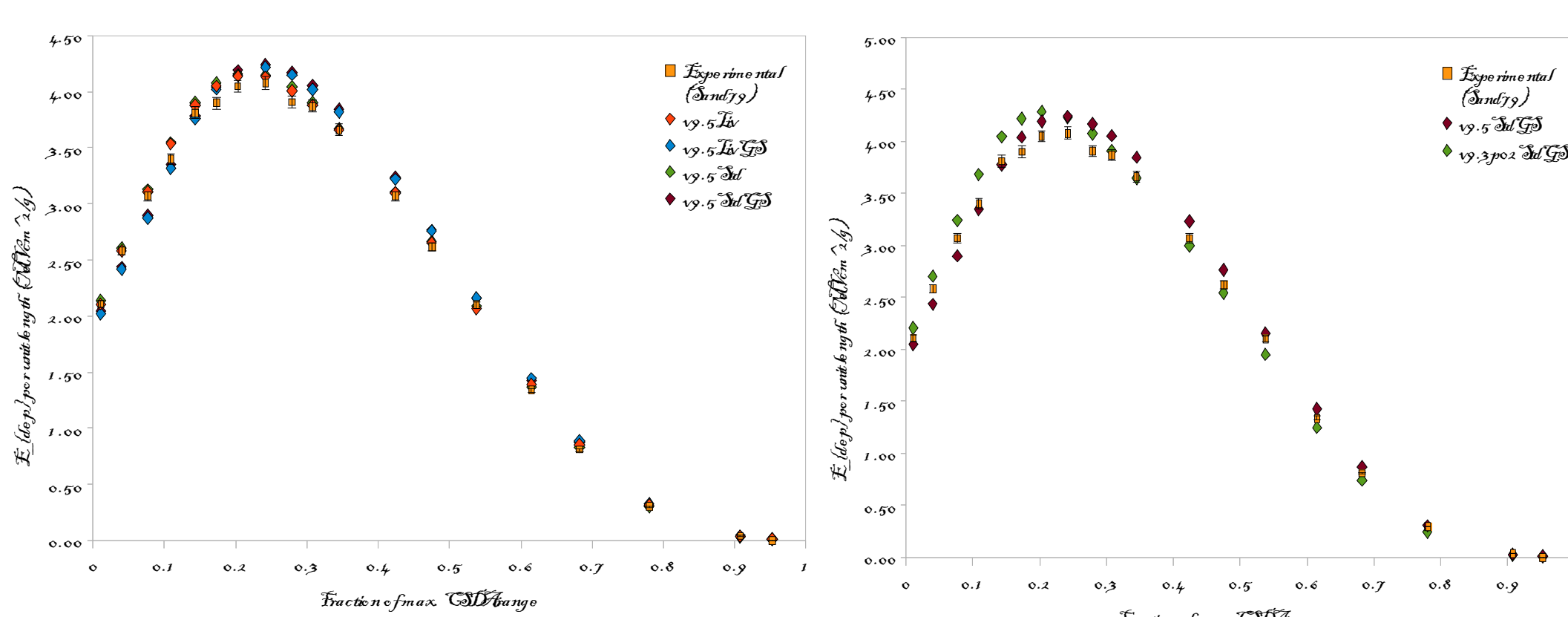
Probability of energy from gamma that escape from the detector and backscattering calculation between Sand80 and G4v93p02.

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

Resultados



Comparison of the simulated absorbed energy profile for Carbon and different Geant4 versions to the experimental data. The version 9.1, already validated in a previous work, is presented in all plots to show the changes in Geant4 results.



Results for the Goudsmit-Saunderson implementation (a) using it with Livermore and Standard physics list and (b) changes of the results for the Standard physics list between the versions 9.3p02 and 9.5.

Conclusions

The preliminary results have shown that the different versions of Geant4 presented significant differences when the same conditions (geometry, energies, material, processes and models) are compared. The plots presented previously show some of the results and some of the significant differences observed.

Differences in the results presented by Geant4 when the same processes and models were activated for different Geant4 versions. Some versions are showing a significant disagreement to the experimental data, specially to the version 9.3 and 9.4. This disagreement increases to low atomic number material and increases when the incident energy increases.

References

- [1] G. J. Lockwood, et al. Sandia report 79. Sandia National Laboratories, New Mexico, 158p, 1987.
- [2] G. J. Lockwood, et al. Sandia report 80. Sandia National Laboratories, New Mexico, 158p, 1987.
- [3] A. Lechner, M. Grazia Pia, M. Sudhakar. IEEE Transaction on Nuclear Science, vol. 56, no. 2, p. 398-416, April 2009.