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Refactoring, reengineering and evolution: paths to Geant4 uncertainty quantification and performance improvement

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Quantitative results on Geant4 physics validation and computational performance are reported: they cover a wide spectrum of electromagnetic and hadronic processes, and are the product of a systematic, multi-disciplinary effort of collaborating physicists, nuclear engineers and statisticians. They involve comparisons with established experimental references in the literature and ad hoc measurements by collaborating experimental groups.

The results highlight concurrent effects of Geant4 software design and implementation on physics accuracy, computational speed and memory consumption. Prototype alternatives, which improve these three aspects, are presented: they span a variety of strategies - from refactoring and reengineering existing Geant4 code to new and significantly different approaches in physics modeling, software design and software development methods. Solutions that simultaneously contribute to both physics and computational performance improvements are highlighted.

In parallel, knowledge gaps embedded in Geant4 physics models are identified and discussed: they are due to lack of experimental data or conflicting measurements preventing the validation of the models themselves, and represent a potential source of systematic effects in detector observables.

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