Geant4 Physics & Applications

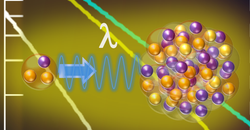
A Monte Carlo toolkit for passage of particles through matter

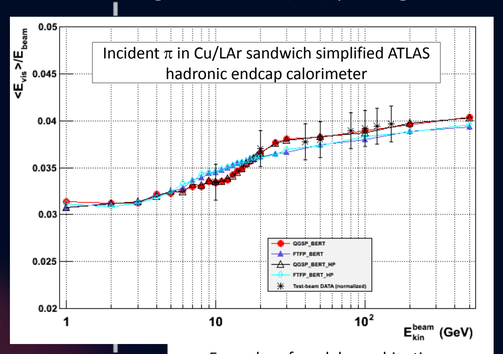
Projectile Kinetic Energy (GeV)

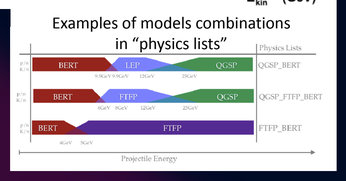
Geant4 Hadronic Physics

Hadronic interactions involve three main regimes : high energy, with string models (Quark Gluon String [QGS], Fritiof [FTF]), intermediate energy, with intra-nuclear cascade models (Bertini [BERT], Binary [BIC]), and low energy, with precompound, Fermi break-up, fission/evaporation, capture at rest models and radioactive decays. From 20 MeV down to thermal energy neutrons are handled by means of cross-section databases, with the High Precision [HP] package.

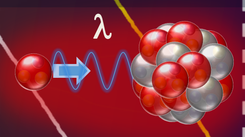
High Energy
Quark/gluon dominating behavior





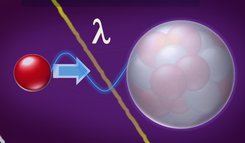


Intermediate Energy
Nucleon dominating behavior



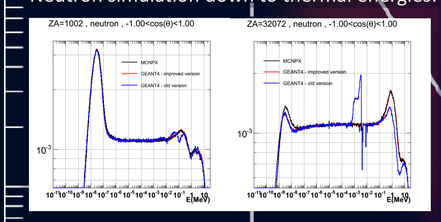
Nucleon Size

Low Energy
Nucleus dominating behavior



Uranium Nucleus Size

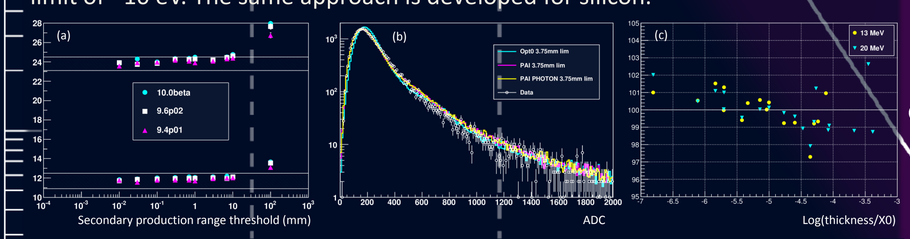
Neutron simulation down to thermal energies:



Geant4 can use the same neutron data library than MCNPX. Verification spectra of MCNP and Geant4 output of outgoing neutrons produced in neutron collision.

Geant4 Electromagnetic Physics

The electromagnetic physics covers interactions of gammas, muons and electrons, and ionisation of all charged particles. A "standard" package offers an implementation suited for applications disregarding effects below a few ~10 keV, and a "low energy" one provides approaches (Livermore, Penelope) for more accurate modeling of atomic shell effects allowing simulation down to ~250 eV. A very low extension, Geant4-DNA, includes particle-molecule effects for an energy limit of ~10 eV. The same approach is developed for silicon.



(a) The simulation energy resolution (in %) in two sampling calorimeters compared with one standard deviation measurement (ZEUS calorimeter : E. Bernardi E *et al.*, NIM A, 262, 229-242, (1987); G. D'Agostini *et al.*, NIM A, 274, 134, (1989))).

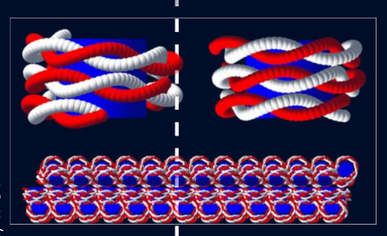
(b) Comparison of Geant4 energy loss models with ALICE test-beam data (D. Antonchyk *et al.*, NIM A, 565, 551-560 (2006); P. Christiansen *et al.*, Int. J. Mod. Phys. E, 16, 2457-2462 (2007)).

(c) Comparison of angular distribution width (Data/MC in %) for various materials after traversing various material thicknesses, data from electron scattering benchmark (C. Ross et al., Med. Phys., 35, 4121, 2008).

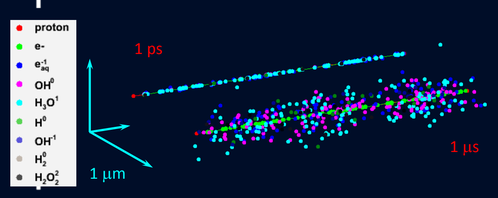
DNA Scale Level Simulation

Project initiated by the ESA, in view of manned mission to Mars: it is a bottom-up approach of dosimetry. Physics processes are extended down to a few eV, based on particle – molecule cross-sections. The approach is applied also to silicon, for accurate simulation of Single Upset Events.

M. Dos Santos, C. Villagrasa, I. Clairand, S. Incerti, NIM B 298 (2013) 47-54



DNA geometry model simulated : 46 chromosomes, 332k chromatine pieces, 30 millions nucleosomes, 6 billions base pairs…

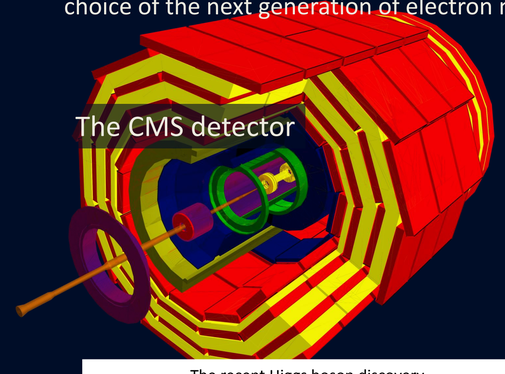


Simulation of water chemical species migration accounting for electrical mutual interaction after a 50 MeV proton irradiation. Post irradiation chemical attacks amount for ~60% of total damages on DNA.

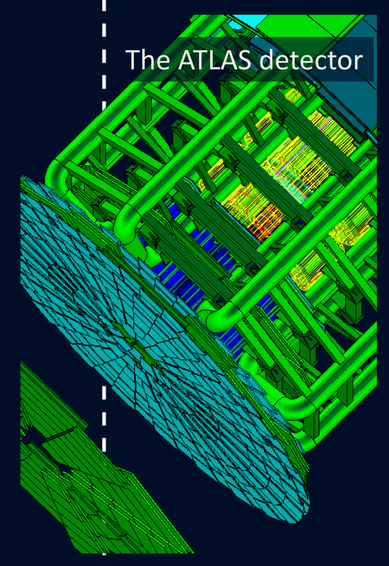
Proton, neutron
Carbon Ion
Electron
Gamma
Water Molecule Size

HEP Applications

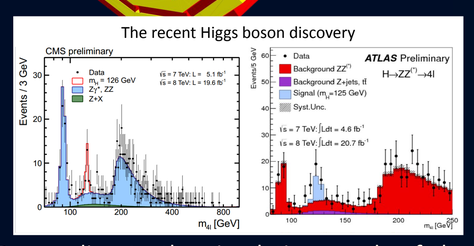
High Energy Physics has been the first domain to use Geant4 in production, with the BaBar experiment. LHC experiments have been using Geant4 in detector design and are using it in physics analysis. Geant4 is also the simulation engine choice of the next generation of electron machines.



The CMS detector



The ATLAS detector



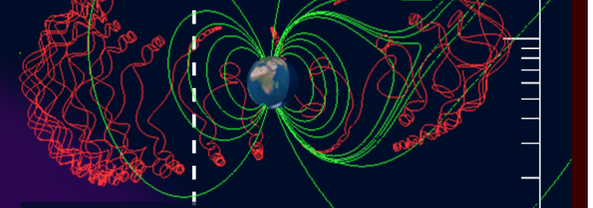
Responding to the simulation needs of the LHC era, with the Higgs boson hunting, had been the initial motivation of the creation of the proto-Geant4 project, RD44, in 1994.

Space Applications

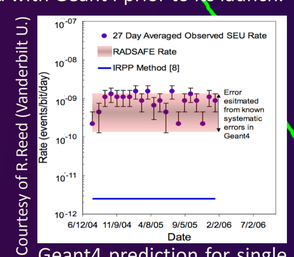
Applications of Geant4 in space cover planetary scale simulation for soil level media activation studies, soil composition through X-ray re-emission, space ship simulation for radioprotection and electronic single event upset predictions, electronic chip scale simulation for accurate understanding of single event upset generation. It includes also underground, ground level or satellite cosmic ray experiments simulation.

XMM-Newton X-ray telescope, launched in 1999

Radiation effects on its instruments were modeled with Geant4 prior to its launch.

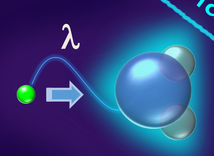


Planetocosmics : a simulation tool for planetary scale particle transport. The red curve is a proton trajectory in the Earth magnetic field. Irradiation level around a planet, at ground level, and with related activated isotopes can then be predicted.



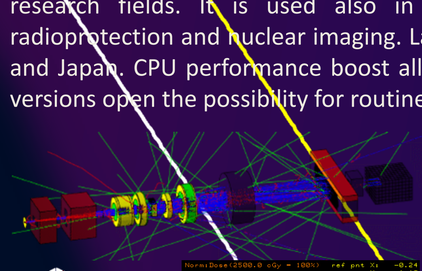
Geant4 prediction for single upset rate is more accurate than standard software.

Very Low Energy
Atomic and molecular structures dominating

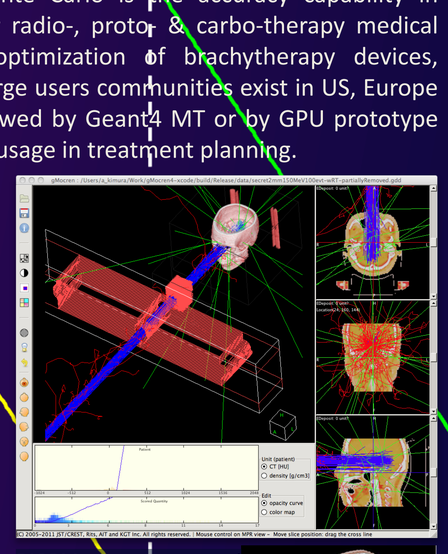


Medical Applications

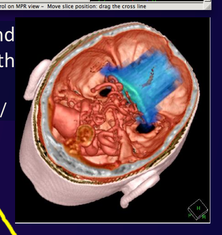
Medical Applications interest in Monte Carlo is the accuracy capability in complex structures. Geant4 is used for radio-, proton & carbo-therapy medical research fields. It is used also in optimization of brachytherapy devices, radioprotection and nuclear imaging. Large users communities exist in US, Europe and Japan. CPU performance boost allowed by Geant4 MT or by GPU prototype versions open the possibility for routine usage in treatment planning.



Proton beam line, range shifter and dose deposit simulations at HIBMC (Japan). The proton energy is 150 MeV. (T.Aso IEEE NSS 2007 N60-1)



DICOM geometry and dose visualisation with « gMocrem » tool:
http://geant4.kek.jp/gMocren/



Projectile de Broglie λ(fm)