

**GEANT4**  
A SIMULATION TOOLKIT

Version 10.5

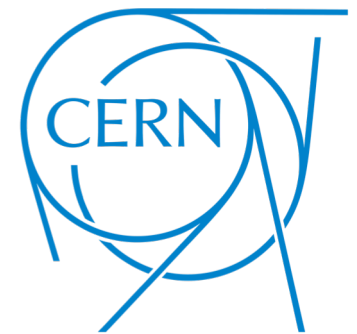
# Concluding Remarks

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Geant4 tutorial course @ São Paulo



# Contents

- The tutorial lecture team sincerely hope you could enjoy our tutorial and you found it informative and useful.
- We also appreciate the organizers, Mauro, Mauricio and Marcelo, for providing us this wonderful opportunity.
- Let me add a few more slides for
  - Following up
  - Geant4 – the Future





## Geant4 Physics & Applications

### A Monte Carlo toolkit for passage of particles through matter

#### Geant4 Hadronic Physics

Hadronic interactions involve three main regimes: high energy, with string models (Quark Gluon String (QGS), Fritiof (FTF)), intermediate energy, with intranuclear cascade models (Bertini (BERT), Binary (BIC)), and low energy, with precompound, Fermi breakup, 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**

**Low Energy Nucleus dominating behavior**

Neutron simulation down to thermal energies:

Geant4 can use the same neutron data library than MCNP. Verification consists of MCNP and Geant4 output of outgoing neutrons produced in neutron collisions.

#### Geant4 Electromagnetic Physics

The electromagnetic physics covers interactions of photons and electrons, and ionization 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. CEUS calorimeter: E. Bernini et al., NIM A, 262, 228-242, (1987); G. D'Agostini et al., NIM A, 274, 134, (1989)).

(b) Comparison of Geant4 energy loss models with ALICE test beam data (D. Antoniouk et al., NIM A, 565, 555-560 (2006)) & 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. Rosa 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.

DNA geometry model simulated: 46 chromosomes, 332k chromatin 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. Most irradiation chemical attacks amount for ~60% of total damages on DNA.

#### 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

The recent Higgs boson discovery

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 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.

ISAR-MarsNet 3rd mission, launched in 1999

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

Planetosimics: 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.

#### Very Low Energy Atomic and molecular structures dominating

Gamma

Water Molecule Size

Electron

Proton, neutron

Carbon Ion

#### Medical Applications


Medical Applications interest in Monte Carlo is the accuracy capability in complex structures. Geant4 is used for radio-therapy & radio-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 HIMAC (Japan). The proton energy is 150 MeV. (Laso IEEE NSS '2007 4602-1)

DICOM geometry and dose visualization with a dMocres+ tool. [www.geant4.lisn.fr/Mocres/](http://www.geant4.lisn.fr/Mocres/)

Projectile Kinetic Energy (GeV)

Projectile de Broglie  $\lambda$  (fm)



- Please keep maintaining your Geant4 installation updated.
  - **Geant4 10.5 is the current version**
    - Soon or later “the current version” would be 10.5-patch01
  - Irregular patch releases may be more important than regular releases.
  - Check our web page regularly to find release news, or register to Geant4 announcement mailing list.
- If you have a question
  1. Look for our documents.
    - Users guides, Twiki pages, tips pages, examples and their READMEs
  2. Post your question on Geant4 HyperNews
    - <http://hypernews.slac.stanford.edu/HyperNews/geant4/cindex>
      - Please make sure to do a bit of survey that no one has already asked the same question before you.
  3. As the final method, write us a mail.
    - Avoid anonymous mail account such as hotmail, gmail, etc.
  4. Or, catch us at meetings/conferences.

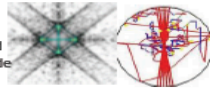
# Geant4 Software

## Introduction

Geant4 is being used in many different fields where simulation of radiation passing through and interacting with matter is critical. User domains include: high energy and nuclear physics, medical physics and space engineering, shielding protection and more. Its abstract layers based on robust OO design enables flexibility and extensibility of the code, and its open-source code and open collaboration have allowed substantial extensions of the code. New features are constantly added to the code, while increasing attention is paid to improving software performance and robustness by employing cutting-edge software engineering technologies.

## New physics

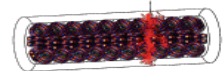
The flexibility and extensibility of Geant4 design allows it to be applied to new physics domains. These include the physics of condensed matter (phonon transportation in crystals, drift of electrons and holes in semiconductors) and processes for bio-chemical substances and DNA.



SuperCDMS Cryogenic Dark Matter Search seeks to directly detect dark matter. Geant4 models the caustic pattern in a Ge crystal (left) by tracking individual phonons (right)

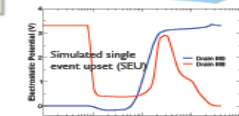
Reaction	Reaction rate (10 <sup>17</sup> M <sup>-1</sup> s <sup>-1</sup> )
H <sup>+</sup> + e <sup>-</sup> → H <sub>2</sub> → OH + H <sub>2</sub>	2.65
H <sup>+</sup> + OH → H <sub>2</sub> O	1.44
H <sup>+</sup> + H <sub>2</sub> O → H <sub>3</sub> O <sup>+</sup>	1.20
H <sub>2</sub> + OH → H <sub>2</sub> O	4.17 × 10 <sup>7</sup>
H <sub>2</sub> O <sup>+</sup> + e <sup>-</sup> → OH + H <sub>2</sub>	1.41
H <sub>2</sub> O <sup>+</sup> + H <sub>2</sub> O → H <sub>3</sub> O <sup>+</sup>	2.11
H <sub>2</sub> O <sup>+</sup> + OH → H <sub>2</sub> O	1.43
OH + e <sup>-</sup> → OH <sup>-</sup>	2.93
OH + OH → H <sub>2</sub> O	0.44
e <sup>-</sup> + H <sub>2</sub> O → e <sup>-</sup> + H <sub>2</sub> O	0.50

Reactions of radicals available in Geant4.



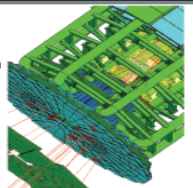
Energy depositions in DNA structure.

Geant4 performs mission critical studies of radiation and charging effects on spacecraft electronics. Impact of Neon ion on MOS FET.



## Geometry

The flexibility and extensibility of Geant4 design also enables handling rich collection of shapes including CSG (Constructed Solid Geometry), Boolean operation, Tessellated solid, etc. and the user can easily add new shapes. Geant4 geometry navigation can deal with setups up to billions of volumes with automatic optimization. In addition, geometry models can be 'dynamic', i.e. changing the setup at run-time, e.g. "moving objects".



## Software quality assurance

Geant4 uses modern tools to manage the code and improve code quality: from handling issues with JIRA to continuous testing integration with CTest/CDash, profiler based optimizations, Quality/Assurance (Coverity, Valgrind, etc.), and IDE integration (Xcode, Eclipse, VisualStudio).



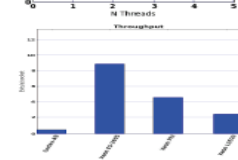
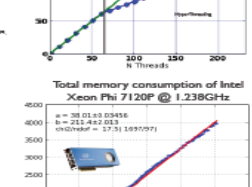
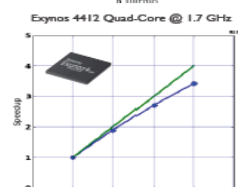
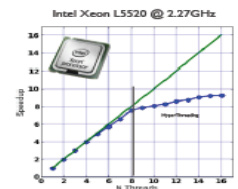
## New era - Geant4 version 10 series

The new release of Geant4 - Version 10.0 (December 2013) include event-level parallelism via multi-threading. To efficiently use new computing architectures the workload of a single job is sub-divided to many worker threads each responsible for the simulation of one or more events. Version 10.0 has already shown good scalability on a number of different architectures: Intel Xeon servers, Intel Xeon Phi co-processors and low-power ARM processors

- Proof of principle
- Identify objects to be shared
- First testing
- ARI re-design
- Example migration
- Further testing
- First optimizations
- Further refinements

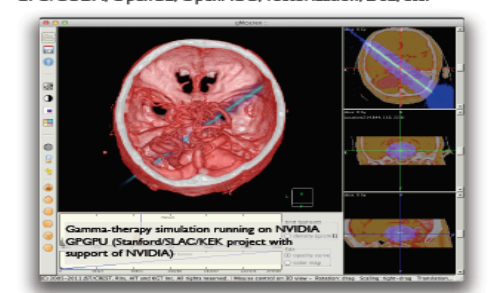


- MT code integrated into G4
- Production ready
- Public release



## Investments for the future

Geant4 collaboration members are participating in various explorations of emerging technologies. These technologies include GPU/CUDA, OpenCL, OpenACC, vectorization, DSL, etc.



# Geant4 - the Future

- Physics of O(100TeV)
  - Neutrino interactions
    - Should come with enriched event biasing options
  - Electron/hole drift in semiconductor
  - More phonon physics
  - Channeling effects and physics with crystal structure in general
    - X-ray diffraction
  - Single atom irradiation
  - Target material polarization
  - Chemical reactions of radicals in DNA-scale
  - New domains ?
- Note : Geant4 kernel is robust enough over 20 years of evolution. This stability enables risk-free extensions to new physics.

- HPC and cloud friendliness
  - Seamlessly combining MPI and MT
  - Smart data collection from millions of threads
- Code re-engineering
  - Solid library, EM physics
  - Splitting transportation process
  - Sub-event level parallelization
- GPU as a co-processor
  - Off-loading some calculations to GPU, e.g. EM physics, thermal neutron physics, DNA physics and chemical processes, etc.
- Will be integrated into Geant4 with (hopefully) minimum API changes



- Geant4 is a general purpose Monte Carlo simulation tool for elementary particles passing through and interacting with matter. It finds quite a wide variety of user domains including high energy and nuclear physics, space engineering, medical applications, material science, radiation protection and security.
- 2019 is the 20<sup>th</sup> year anniversary of Geant4 public releases. After 20 years with several architectural evolutions, Geant4 is still steadily evolving.
  - Latest major evolution was Geant4 version 10.0 released in December 2013 that is the first fully multithreaded general-purpose large-scale physics software in the world.
  - New physics models for coming experiments, e.g. hadronic model for multi-TeV regime (for energy frontier), specialized EM model for noble liquid (e.g. liq.Xe) and neutrino physics model (for intensity frontier)
- Given Geant4 is nowadays mission-critical for many users including all HEP experiments, space missions, medical applications, etc., Geant4 is to be kept maintained and still evolving for at least next decade.