

# Montecarlo Methods for Medical Physics

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# Summary of the Course

- Part1 (Today)
  - General (and brief) introduction to Monte Carlo methods
  - Montecarlo methods in Medical Physics
- Part2 (Today – 1<sup>st</sup> part)
  - Introduction to the Geant4 toolkit
- Part3
  - Fundamentals of a Geant4 application (Today – 2<sup>nd</sup> part)
  - Geometry, Physics, Particle Flux, Scoring needs (Thursday)
- Laboratory (Next weeks)
  - Realisation of an example relevant to Medical Physics

# Evaluation for the “Laboratory”

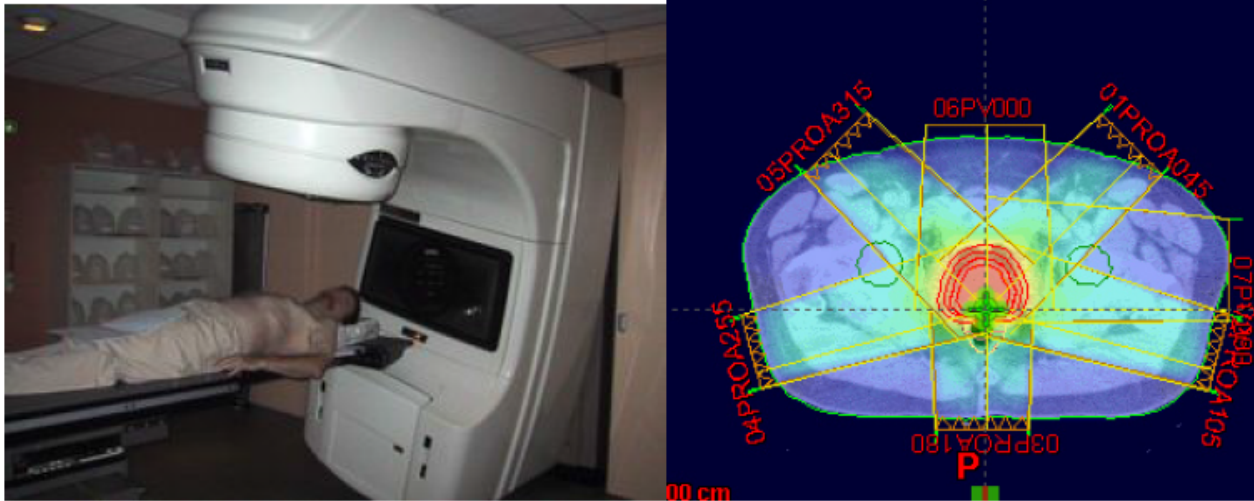
- Discussion of Geant4 example
  - G4 example relevant to Medical Physics
- Discussion of requirements and methods
  - Medical Physics “environment”
  - Geant4 modeling
  - “Basic” analysis of results
- Realization of “new” example – Laboratory
  - Might just be an improvement of the existing G4 examples

# Part 1

## Montecarlo in Medical Physics

# Montecarlo for Medical Physics

## Overview of Medical Physics Applications

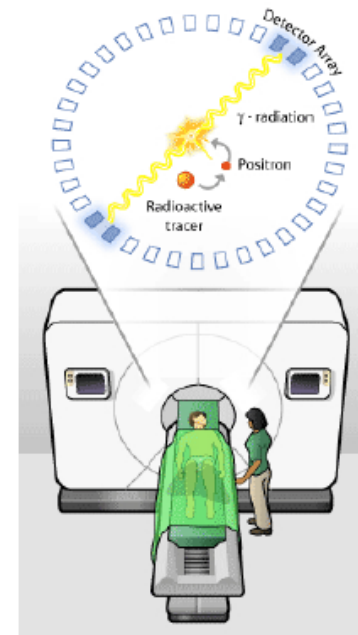
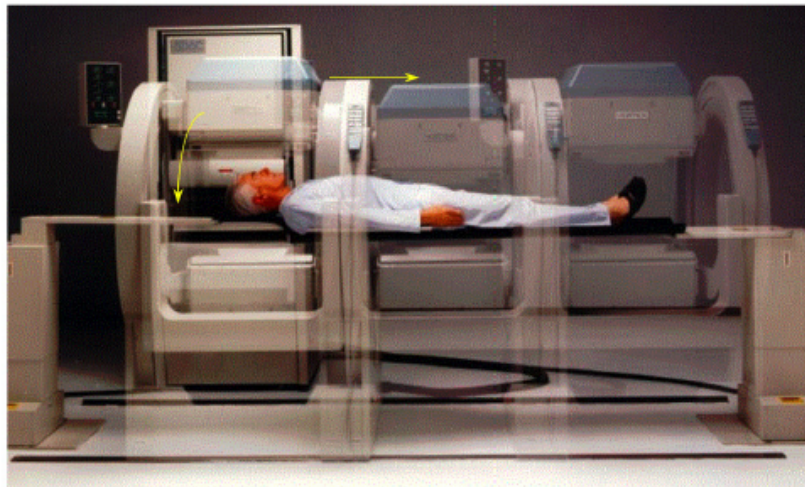


### Radiotherapy physics

- ▶ external/internal sources and dosimetry
- ▶ phantom simulations
- ▶ treatment planning

# Montecarlo for Medical Physics

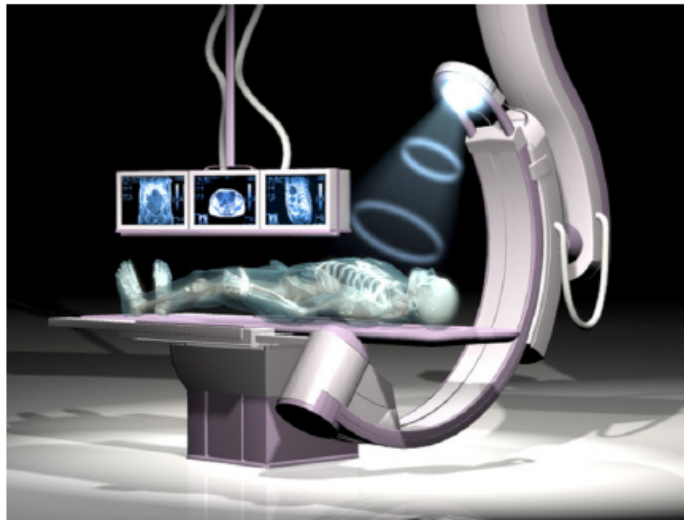
Single Photon Emission Computer Tomography (SPECT)



## Nuclear medicine

- ▶ detectors
- ▶ imaging correction
- ▶ absorbed dose

# Montecarlo for Medical Physics



## Diagnostic radiology

- ▶ detection systems
- ▶ physical quantities
- ▶ radiation protection

# Montecarlo in Treatment Planning Systems



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## MONACO®

### Precision planning for photon and electron based plans

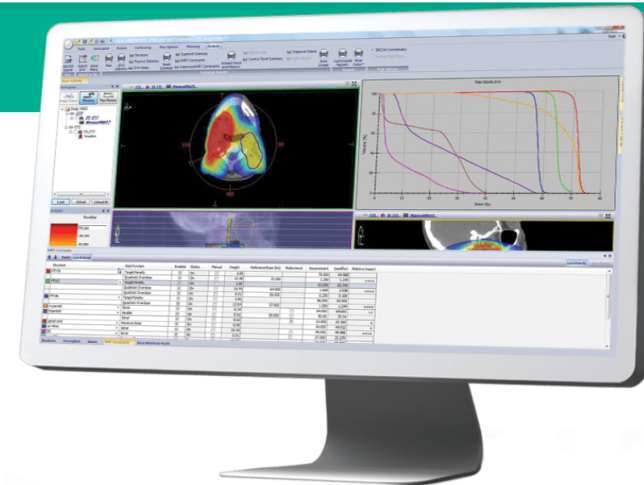
Monaco delivers high performance and high precision radiotherapy treatment planning for all major treatment techniques for photon and electron based plans.

Its rich, intuitive tools make the radiotherapy planning process faster, easier and clinically reliable.

By combining the superior accuracy of Monte Carlo and Collapsed Cone algorithms with the richness of advanced optimization tools in a modern, intuitive user workspace, Monaco delivers highly accurate 3D, IMRT, VMAT and SRS plans in a single, easy to use solution.

Monaco can handle very complex plans and exquisite dose distribution available in one rotation with its high dose modulation capabilities.

Monaco provides superior quality assurance with Monte Carlo used as the gold standard from which to compare other third party plans. Simply import a plan from any treatment planning system and re-calculate with Monte Carlo for a secondary check.



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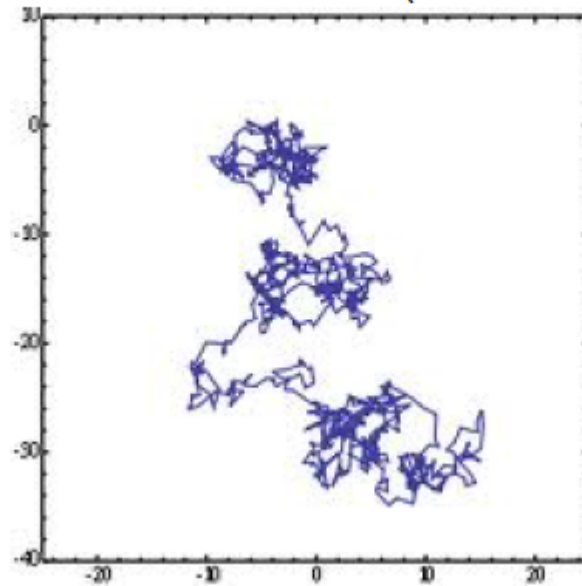
# What is a Montecarlo program?

- Numerical method
- Random sampling of probability distributions
- Simulate stochastic processes in nature
  - Market fluctuations
  - Population studies
  - Weather forecasting
  - Radiation transport
  - Traffic flows
  - Astrophysics and Cosmology ...
  - ...

# Stochastic processes

- Random, probabilistic processes
- Physical parameters vary according to probability distribution
- Not “single” outcome but more/less probable outcome are possible ...

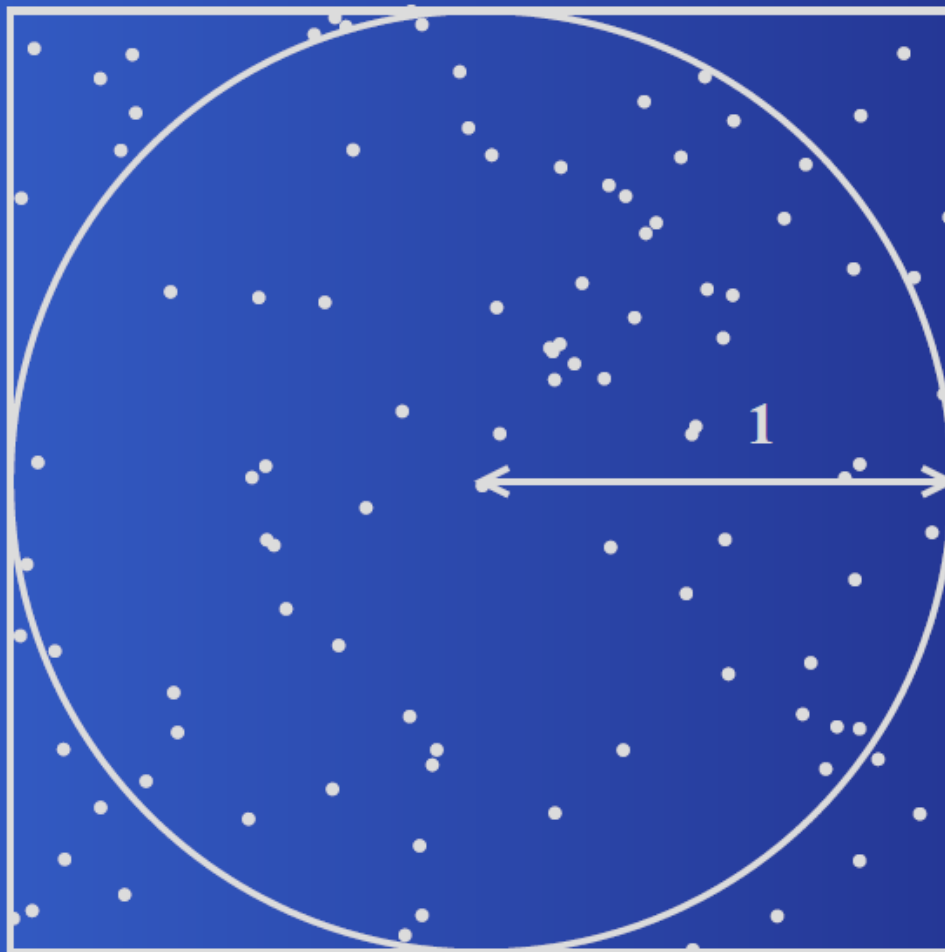
**Example:** Brownian motion (a.k.a. random walk)



# A brief history

- Comte du Buffon (1777): needle tossing experiment to calculate  $\pi$
- Laplace (1886): random points in a rectangle to calculate  $\pi$
- Fermi (1930): random method to calculate the properties of the newly discovered neutron
- Manhattan project (40's): simulations during the initial development of thermonuclear weapons. von Neumann and Ulam coined the term "Monte Carlo"
- Exponential growth with the availability of digital computers
- Berger (1963): first complete coupled electron-photon transport code that became known as ETRAN
- Exponential growth in Medical Physics since the 80's

# A brief history



Area of square:  $A_s = 4$

Area of circle:  $A_c = \pi$

Fraction  $p$  of random points inside circle:

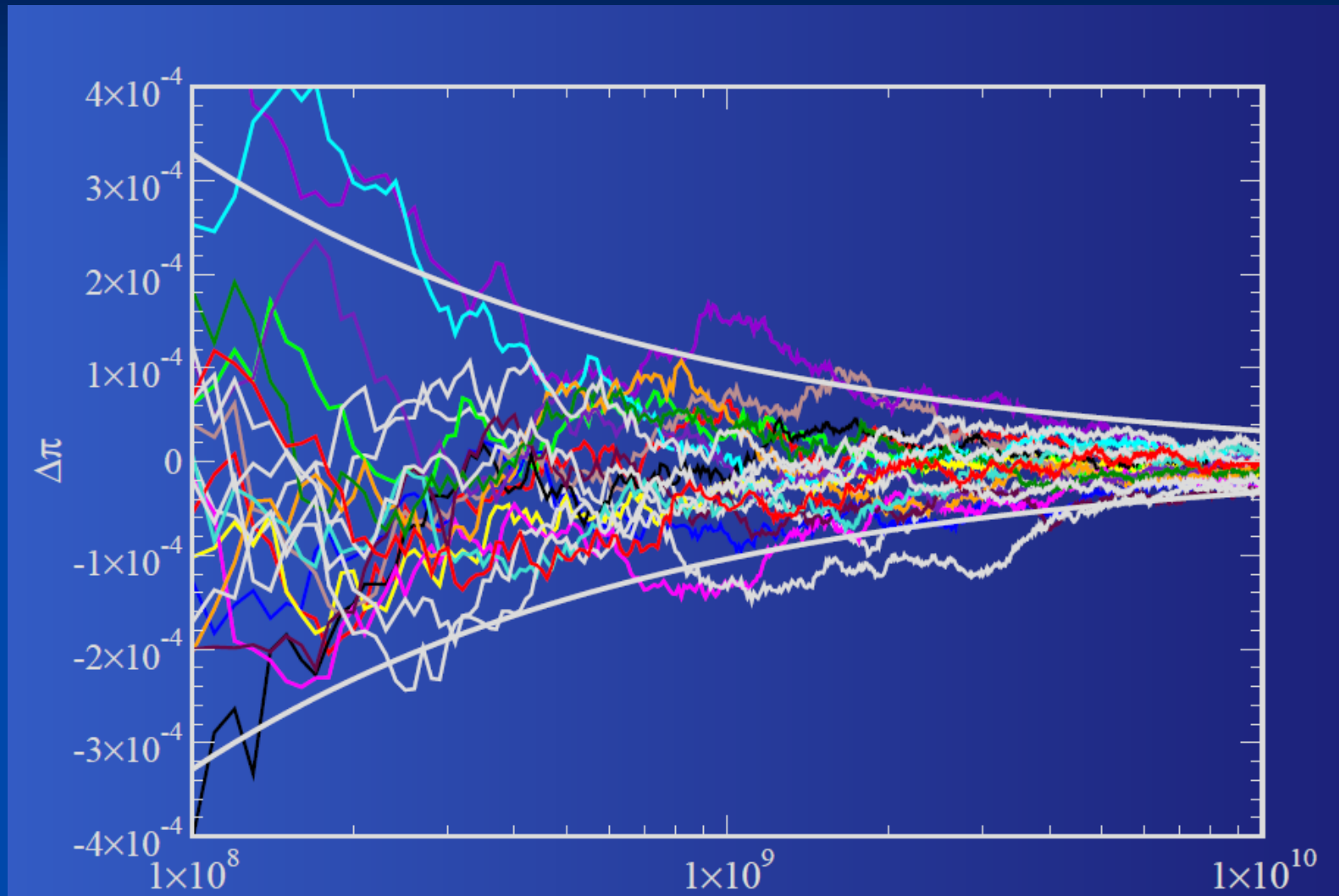
$$p = \frac{A_c}{A_s} = \frac{\pi}{4}$$

Random points:  $N$

Random points inside circle:  $N_c$

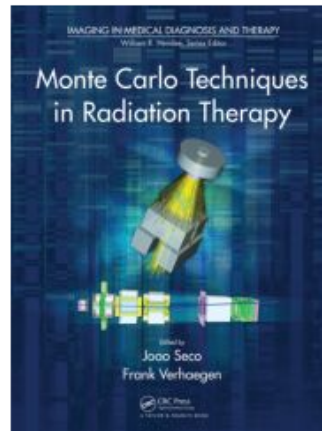
$$\Rightarrow \pi = \frac{4N_c}{N}$$

# A brief history



# Montecarlo for Medical Physics

[Home](#) » [Physics](#) » [Medical Physics](#) » [Monte Carlo Techniques in Radiation Therapy](#)



## Monte Carlo Techniques in Radiation Therapy

**Series:** Imaging in Medical Diagnosis and Therapy  
**Published:** March 25, 2013 by CRC Press  
**Content:** 342 Pages | 20 Color & 177 B/W Illustrations  
**Editor(s):** Joao Seco, Frank Verhaegen

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### Features

- Provides a broad practical guide to the rapidly growing field of Monte Carlo simulations used in medical physics in radiotherapy
- Includes the mathematical and technical background required for understanding Monte Carlo simulations and variance reduction techniques
- Covers real medical applications of Monte Carlo methods in proton/light ion therapeutics, beam models, quality assurance, radiation dosimetry, and patient dose calculation
- Incorporates examples to help illustrate key points



### Summary

Modern cancer treatment relies on Monte Carlo simulations to help radiotherapists and clinical physicists better understand and compute radiation dose from imaging devices as well as exploit four-dimensional imaging data. With Monte Carlo-based treatment planning tools now available from commercial vendors, a complete transition to Monte Carlo-based dose calculation methods in radiotherapy could likely take place in the next decade. **Monte Carlo Techniques in Radiation Therapy** explores the use of Monte Carlo methods for modeling various features of internal and external radiation sources, including light ion beams.


# Montecarlo for Medical Physics







< Previous Article January 2017 Volume 33, Pages 179–181 Next Article >

## Monte Carlo simulations for medical physics: From fundamental physics to cancer treatment

[S. Guatelli](#) \*    
Centre For Medical Radiation Physics (CMRP), University of Wollongong (UOW), Wollongong, NSW, Australia

[S. Incerti](#)  
CENBG, CNRS/IN2P3, France

 PlumX Metrics

DOI: <https://doi.org/10.1016/j.ejmp.2017.01.002> |  Check for updates     

Article Info

Abstract **Full Text** References

### Highlights

- Focus Issue (FI) dedicated to the Monte Carlo (MC) Workshop for Medical Physics.
- The Monte Carlo workshop took place in April 2016.
- The event was organised by the Centre For Medical Radiation Physics, Wollongong.
- The FI contains 12 original, peer reviewed scientific contributions.
- The papers concern the projects presented in some oral presentations of the event.
- The contributions include research performed in Europe, US, Asia and Australia.

The 2016 Monte Carlo Workshop for Radiotherapy, Imaging and Radiation Protection, 28–30 April, was organised by the Centre For Medical Radiation Physics (CMRP), University of Wollongong (UOW), Wollongong, NSW, Australia. The Chair was S. Guatelli (CMRP, UOW), with two supporting Co-chairs, S. Incerti (CENBG, CNRS/IN2P3, France) and J. Brown (Queen's University Belfast, Northern Ireland, UK). The event, already at its third edition (<http://eis.uow.edu.au/cmcp/workshops-seminars/UOW204211.html>), is unique in Australia and South Pacific region as it is devoted to the development, validation and use of Monte Carlo radiation transport codes in medical physics.

# Montecarlo for Medical Physics

In: Medical Physics  
Editor: Marcin Balcerzyk

ISBN: 978-1-62257-590-9  
2013 Nova Science Publishers, Inc.

*Chapter V*

## Applications of the Monte Carlo Method in Medical Physics

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ENEA, Italy

### **ABSTRACT**

The Monte Carlo simulation of particle transport and interaction in matter finds growing applications in medical radiation physics. Dosimetric applications in radiation therapy span from internal dosimetry in radionuclide therapy of nuclear medicine, to the treatment planning in external beam radiation therapy with photons, electrons or fast heavy ions, to the assessment of radiation dose distribution in heterogeneous media such as lungs, bones or renal parenchyma.



# Part 2

## Introduction to Geant4

# Geant 4

## A Simulation Tool for Multi-disciplinary Applications

<http://cern.ch/geant4/>

An simple introduction to Geant4 with emphasis on medical physics.

The seminar will touch some aspects of Geant4 from basic description to advanced topics.

The seminar should be of interest to complete novices with no familiarity with Geant4.

Participants are expected to have a basic knowledge of C++.


Based on Training Lectures by the G4 collaboration

# Outline of Part2

- General Introduction to G4
  - What is G4 ?
  - Review of user documentation
  - Geant4 as a toolkit
- Basics of OO programming
- Geant4 Kernel and basics of the toolkit
  - Run, Event, Step
  - Particle and Physics processes
  - User classes

# Geant4 toolkit

- Highlights of user applications
- General introduction and brief history
- User Documentation
- The main program



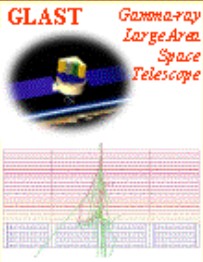
<http://cern.ch/geant4>

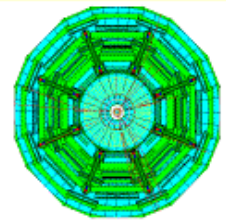
## Geant 4

**Geant4** is a toolkit for the simulation of the passage of particles through matter.  
It has been developed and maintained by a world-wide Collaboration of approximately 100 scientists.

Its application areas include high energy physics, astrophysics and nuclear physics experiments, medical, accelerator and space science studies.


**GLAST**  
*Gamma-ray Large Area Space Telescope*






**ATLAS at LHC, CERN**

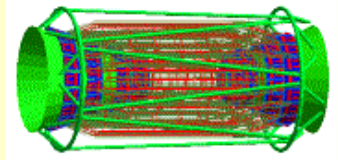
**Borexino**  
*at Gran Sasso Laboratory*



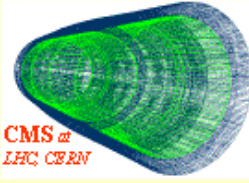
**ESA XMM**  
*X-ray telescope*

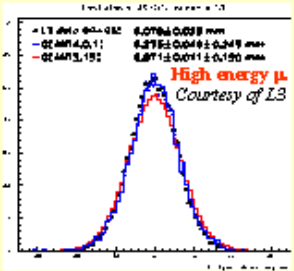


**BaBar at SLAC**

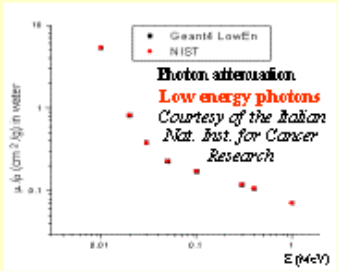


**CMS at LHC, CERN**



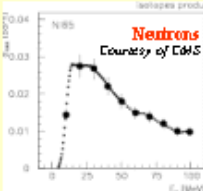


**High energy  $\mu$**   
*Courtesy of I3*

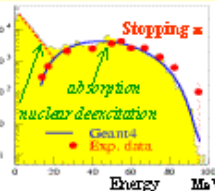


**Photon attenuation**  
*Low energy photons*  
*Courtesy of the Italian Nat. Inst. for Cancer Research*

An abundant set of Physics Processes handle the diverse interactions of particles with matter across a wide energy range.




**Neutrons**  
*Courtesy of CMS*



**Stopping =**  
*absorption*  
*nuclear deexcitation*

**Geant4** exploits advanced Software Engineering techniques and Object Oriented technology to achieve transparency of physics implementation.



Budker Inst. of Physics IHEP Protvino MEPHI Moscow Pittsburg University

# Geant4



# Geant4

A toolkit to simulate the interaction of particles with matter



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 Fax: +41 22 767 33 40  
 E-mail: helpdesk-tt@cern.ch  
 http://cern.ch/TTdb

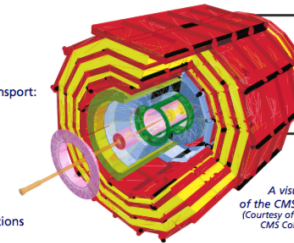
## Concept

Geant4 simulates the passage of particles through matter. It provides a complete set of tools for all domains of radiation transport:

- Geometry and Tracking
- Physics processes and models
- Biasing and Scoring
- Graphics and User Interfaces
- Propagation in fields.

Geant4 physics processes describe electromagnetic and nuclear interactions of particles with matter, at energies from eV to TeV. A choice of physics models exists for many processes providing options for applications with different accuracy and time requirements.

The toolkit is developed, maintained and supported by Geant4, a world-wide collaboration of about 100 scientists from many institutions, contributing in their area of expertise. Developers interact constantly with users, and combine efforts to validate physics results for application in high energy physics experiments, space and medical studies.



A visualization of the CMS detector (Courtesy of I. Osborne, CMS Collaboration)

## Applications

**High energy and nuclear physics detectors**

- ATLAS, CMS, HARP and LHCb at CERN and BaBar at SLAC

**Accelerator and shielding**

- Linacs for medical use

**Medicine**

- **Radiotherapy**
  - photon, proton and light ion beams
  - brachytherapy
  - boron and gadolinium neutron capture therapy

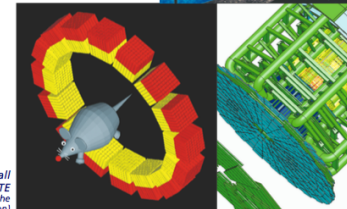
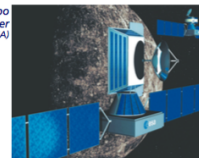
• **Simulation of scanners**

- PET & SPECT with GATE (Geant4 Application for Tomographic Emission)

**Space**

- **Satellites**
  - effect of space environment on components (especially electronics)
  - shielding of instruments
  - charging effects
- **Space environment**
  - cosmic ray cut-offs
- **Astronauts**
  - dose estimates

The BepiColombo Mercury orbiter (Courtesy of ESA)



Simulation of small PET scanner using GATE (Courtesy of the OpenGATE collaboration)

A view of the ATLAS detector (Courtesy of S. Tanaka, ATLAS-collaboration)

## Advantages

- Simulates the geometries of complex setups efficiently
- Provides configurations of physics processes for application areas
- Enables user to tailor simulation components and address accuracy needs
- Performant and adaptable
- Easy to embed into specific applications



XMM-Newton X-ray telescope: the effects of the radiation environment on its instruments was modeled with Geant4 prior to launch in 1999 (Courtesy of ESA)



The European Organization for Nuclear Research (CERN), one of the world's foremost particle physics laboratories, has introduced an active Technology Transfer policy to establish its competence in European industrial and scientific environments, and to demonstrate clear benefits of the results obtained from the considerable resources made available to particle physics research.

Technology Transfer is an integral part of CERN's principal mission of fundamental research.



<http://knowledge-transfer.web.cern.ch/technology-transfer/external-partners/geant4>

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# Geant4



Projectile Kinetic Energy (GeV)

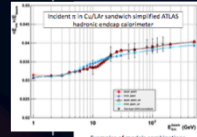
## Geant4 Physics & Applications

A Monte Carlo toolkit for passage of particles through matter

### Geant4 Hadronic Physics

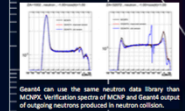
Hadronic interactions involve three main regimes: high energy, with string models (Quark Gluon String (QGS), Fritiof (FTF)), intermediate energy, with intra-nuclear cascade models (Bertini (BERT), Binary (BIC)), and low energy, with precompound, Fermi break-up, fission/evaporation, capture at rest models 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



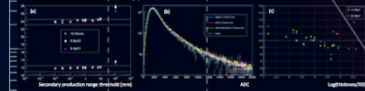
Intermediate Energy Nucleon dominating behavior

Neutron simulation down to thermal energies:



### Geant4 Electromagnetic Physics

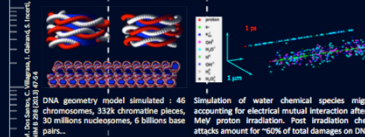
The electromagnetic physics covers interactions of gammas, muons and electrons, and ionization of all charged particles. A "standard" package offers an implementation suited for applications disregarding effects below a few  $\sim 10$  keV, and a "low energy" one provides approaches (Livermore, Penelope) for more accurate modeling of atomic shell effects allowing simulation down to  $\sim 250$  eV. A very low extension, Geant4-DNA, includes particle-molecule effects for an energy limit of  $\sim 10$  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 et al., NIM A, 262, 229-242, (1987); G. D'Agostini et al., NIM A, 274, 324 (1990)).  
 (b) Comparison of Geant4 energy loss models with ALICE test-beam data (D. Antonchik et al., NIM A, 565, 551-560 (2006); P. Christensen et al., Int. J. Mod. Phys. E, 16, 2457-2462 (2007)).  
 (c) Comparison of angular distribution with (Data/FMC 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

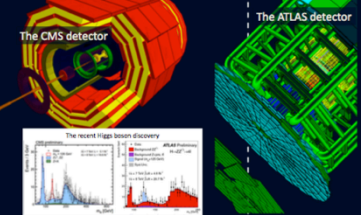
Project initiated by the ESA. In view of manned mission to Mars: It is a bottom-up approach of dosimetry. Physics processes are extended down to a few eV, based on particle-molecule cross-sections. The approach is applied also to silicon, for accurate simulation of Single Upset Events.



DNA geometry model simulated: 46 chromosomes, 3128 chromosome 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  $\sim 60\%$  of total damages on DNA.

### HEP Applications

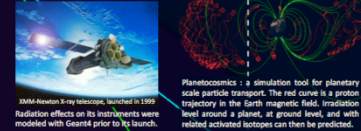
High Energy Physics has been the first domain to use Geant4 in production, with the Belle experiment. LHC experiments have been using Geant4 in detector design and are using it to physics analysis. Geant4 is also the simulation engine choice of the next generation of electron machines.



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.

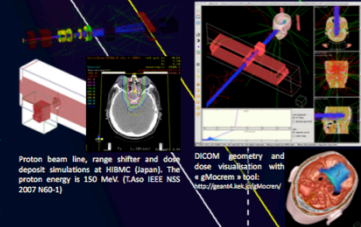


Planetocosmos: a simulation tool for planetary scale particle transport. The red curve is a proton trajectory in the Earth magnetic field. Irradiation level around a plane, at ground level, and with related activated isotopes can then be predicted.

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

### Medical Applications

Medical Applications interest in Monte Carlo is the accuracy capability in complex structures. Geant4 is used for radio-, proton & carbon-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. GPU performance boost allowed by Geant4-MI or by GPU prototype versions open the possibility for routine usage in treatment planning.



Proton beam line, range shifter and dose escape simulations at HIMAC (Japan). The proton energy is 150 MeV. (TASO IEEE NSS 2007 NSS-1)  
 DICOM security and dose visualization with gMocrem a tool (http://www.himac.ncc.go.jp/)



# Geant4



## 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).

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

Reaction	Reaction rate (10 <sup>21</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 <sub>2</sub> + OH → H <sub>2</sub> O	1.44
H <sub>2</sub> + H <sub>2</sub> → H <sub>4</sub>	1.30
H <sub>2</sub> + H <sub>2</sub> → H <sub>2</sub> + H <sub>2</sub>	4.17 × 10 <sup>17</sup>
H <sub>2</sub> O + OH → H <sub>2</sub> O + OH	1.41
H <sub>2</sub> O + H <sub>2</sub> → H <sub>2</sub> O + H <sub>2</sub>	2.11
H <sub>2</sub> O + OH → H <sub>2</sub> O + OH	1.62
OH + OH → OH + OH	2.93
OH + OH → H <sub>2</sub> O	3.64
e <sup>-</sup> + e <sup>-</sup> → 2 OH → 2 OH + H <sub>2</sub>	0.80

Reactions of radicals available in Geant4.

Energy depositions in DNA structure.

### 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".

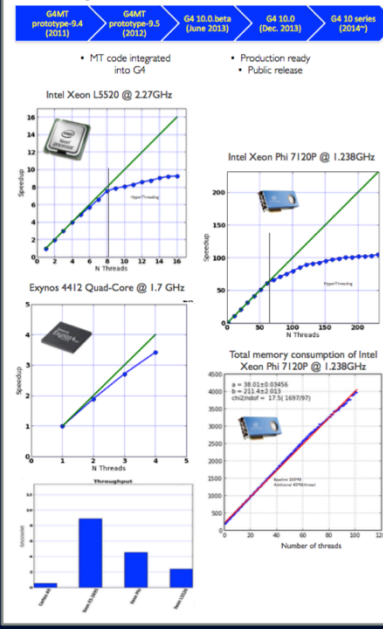
### Software quality assurance

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
- API re-design
- Example migration
- Further testing
- First optimizations
- Further refinements



### 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.

Gamma-therapy simulation running on NVIDIA GPGPU (Stanford/SLAC/KEK project with support of NVIDIA)

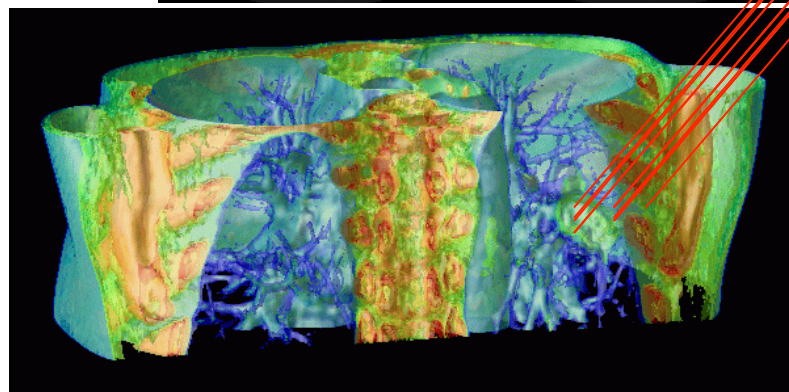
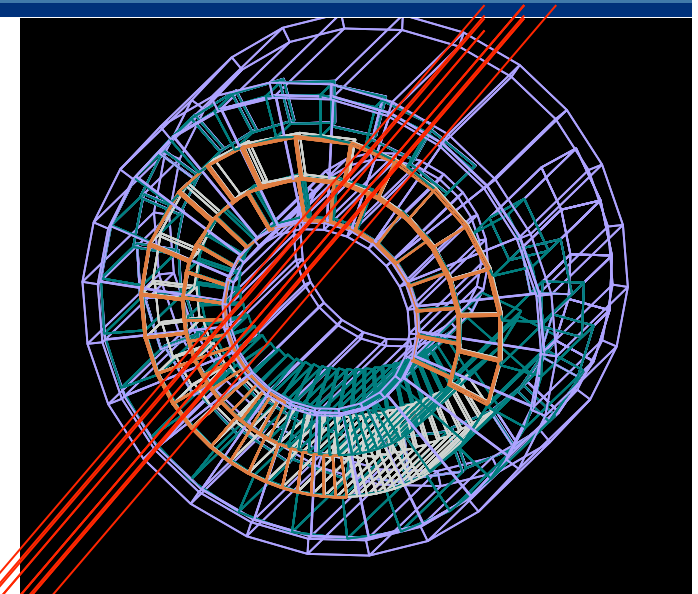
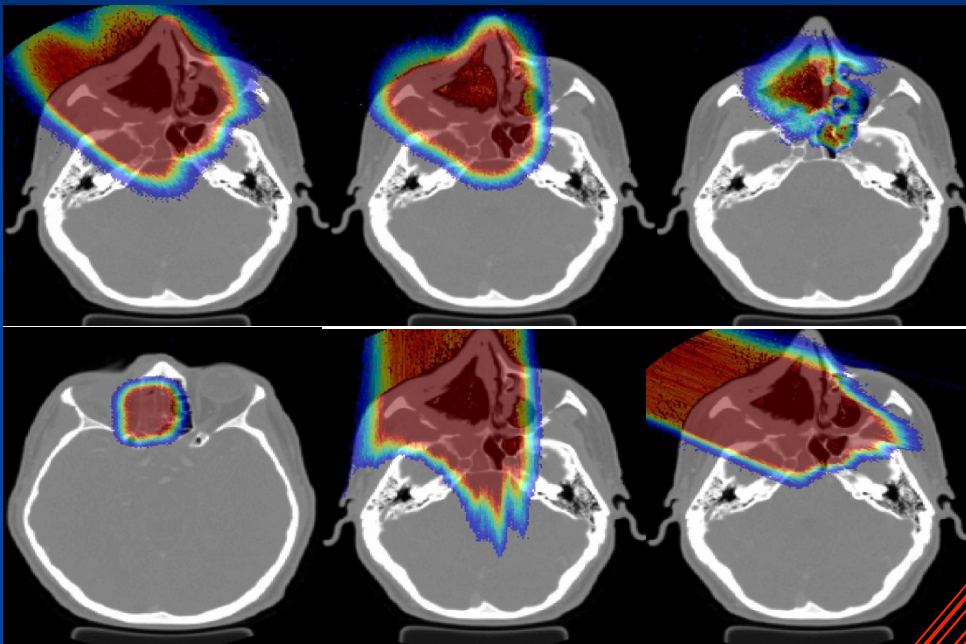


# Highlights of Users Applications

To provide you some ideas how Geant4 would be utilized...



# GEANT4 based proton dose calculation in a clinical environment: technical aspects, strategies and challenges



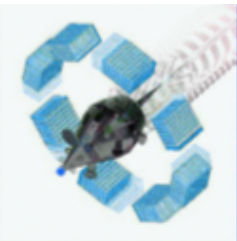
Harald Paganetti



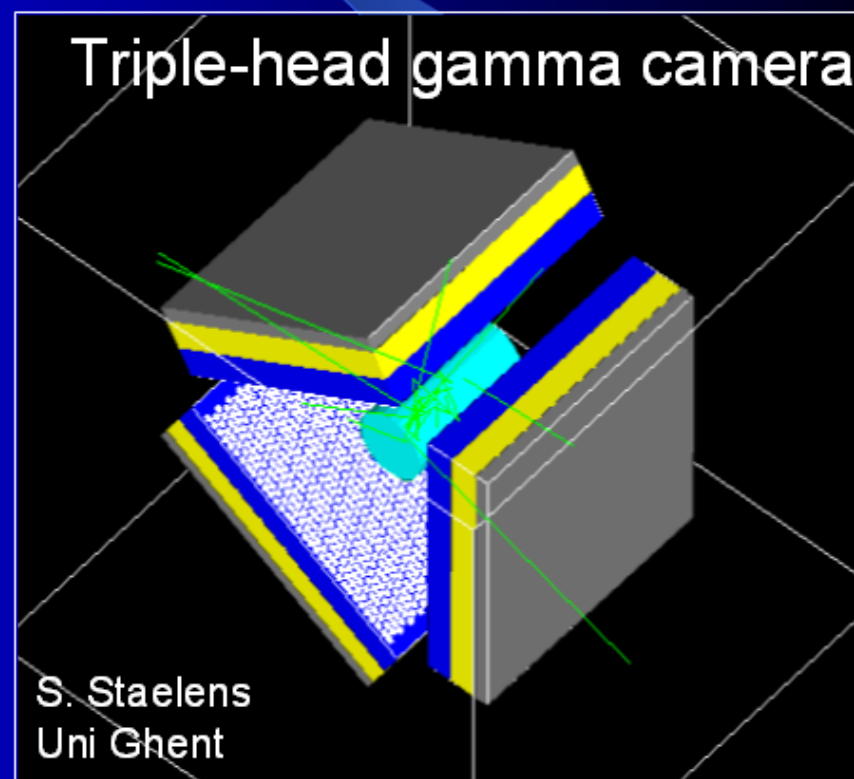
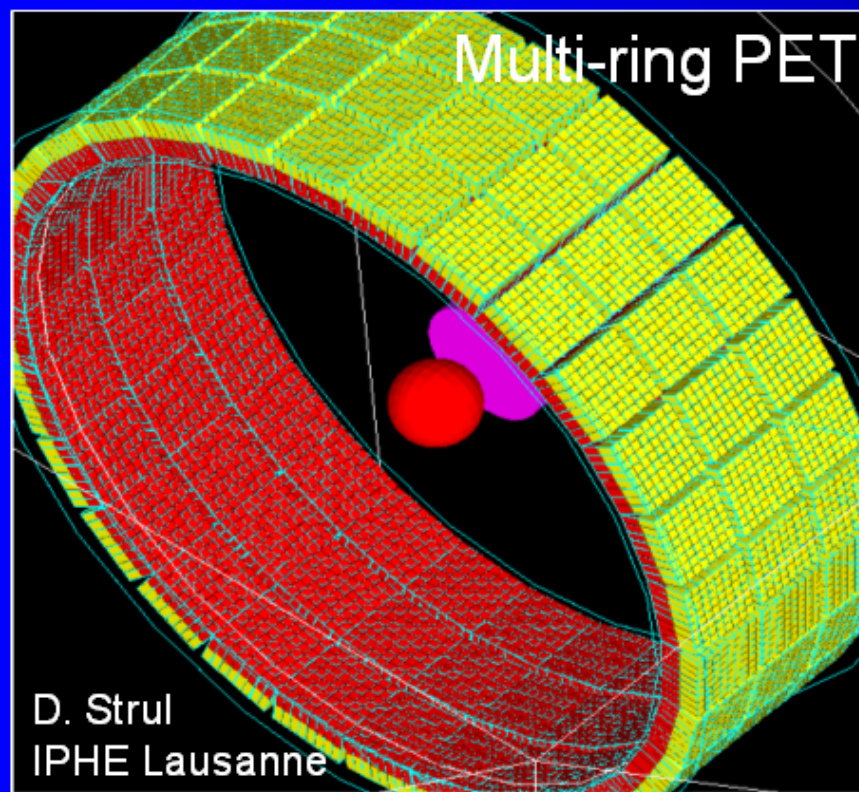
MASSACHUSETTS  
GENERAL HOSPITAL

**HARVARD**  
MEDICAL SCHOOL





# Geometry examples of GATE applications



# Advanced Topics



## GATE

Simulations of Preclinical and Clinical Scans in Emission Tomography, Transmission Tomography and Radiation Therapy

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### User login

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### PMB Citations Prize

Members of the OpenGATE collaboration have won the Physics in Medicine & Biology Citations Prize twice, in 2009 for their paper 'GATE: a simulation toolkit for PET and SPECT' and in 2015 for their paper 'GATE V6: a major enhancement of the GATE simulation platform enabling modelling of CT and radiotherapy'.

## Forewords

GATE is an advanced opensource software developed by the international OpenGATE collaboration and dedicated to numerical simulations in medical imaging and radiotherapy. It currently supports simulations of Emission Tomography (Positron Emission Tomography - PET and Single Photon Emission Computed Tomography - SPECT), Computed Tomography (CT), Optical Imaging (Bioluminescence and Fluorescence) and Radiotherapy experiments. Using an easy-to-learn macro mechanism to configurate simple or highly sophisticated experimental settings, GATE now plays a key role in the design of new medical imaging devices, in the optimization of acquisition protocols and in the development and assessment of image reconstruction algorithms and correction techniques. It can also be used for dose calculation in radiotherapy experiments.

If you are interested in contributing to GATE, here are a few tips regarding what you can do to be part of this collaborative effort:

- Reply to the mailing list
  - Contribute to the documentation: ask for a login/password and then modify the documentation on the wiki
  - Report bugs
- GATE project is now publicly available on GitHub. So, any people identified as a GATE contributor on GitHub can create, assign and close an issue
- Add/modify the source code or fix bugs
    - Start by copying the GATE public repository from GitHub  
`git clone https://github.com/OpenGATE/Gate.git`
    - Create a specific branch on your repository copy and commit your modifications in that branch
    - Create your own copy (fork) of GATE public repository inside your GitHub account so as to be able to push your branch onto this copy
    - Once your code is ok,
      1. Create a pull-request from your Gate repository to the official Gate repository

### Shortcuts



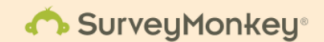
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## GitHub

[Access to GATE project on GitHub](#)



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<http://www.opengatecollaboration.org/>

# G4 documentation basics

# G4 home page

- <https://geant4.web.cern.ch/>



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Geant4

## Overview

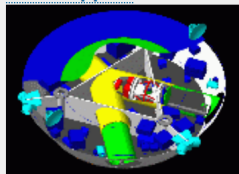
Geant4 is a toolkit for the simulation of the passage of particles through matter. Its areas of application include high energy, nuclear and accelerator physics, as well as studies in medical and space science. The three main reference papers for Geant4 are published in Nuclear Instruments and Methods in Physics Research [A 506 \(2003\) 250-303](#), IEEE Transactions on Nuclear Science [53 No. 1 \(2006\) 270-278](#) and Nuclear Instruments and Methods in Physics Research [A 835 \(2016\) 186-225](#).

### Applications



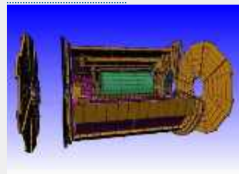
[A sampling of applications](#), technology transfer and other uses of Geant4

### User Support



[Getting started, guides](#) and information for users and developers

### Publications



[Validation of Geant4](#), results from experiments and publications

### Collaboration



[Who we are:](#) collaborating institutions, [members](#), organization and legal information

### News

2021-03-10

[2021 planned developments.](#)

2021-02-05

**Patch-01** to release **10.7** is available from the [Download area](#).

2020-11-06

**Patch-03** to release **10.6** is available from the [Download archive area](#).

# G4 Application Developer

🏠 Book For Application Developers



10.5

Search docs

Introduction

Getting Started with Geant4 - Running a Simple Example

Toolkit Fundamentals

Detector Definition and Response

Tracking and Physics

User Actions

Control

[Docs](#) » Geant4 Book For Application Developers

## Geant4 Book For Application Developers

### Scope of this manual

The User's Guide for Application Developers is the first manual the reader should consult when learning about GEANT4 or developing a GEANT4 -based detector simulation program. This manual is designed to:

- introduce the first-time user to the GEANT4 object-oriented detector simulation toolkit,
- provide a description of the available tools and how to use them, and
- supply the practical information required to develop and run simulation applications which may be used in real experiments.

This manual is intended to be an overview of the toolkit, rather than an exhaustive treatment of it. Related physics discussions are not included unless required for the description of a particular tool. Detailed discussions of the physics included in GEANT4 can be found in the [Physics Reference Manual](#). Details of the design and functionality of the GEANT4 classes can be found in the [User's Guide for Toolkit Developers](#).

# G4 Application Developer



## Book For Application Developers

*Release 10.5*

**Geant4 Collaboration**

# G4 Physics manual

🏠 Physics Reference Manual



10.5

Search docs

General Information

Particle Decay

Electromagnetic Interactions

Solid State Physics

Hadronic Physics in GEANT4

Gamma- and Lepto-Nuclear Interactions

Solid State Physics

[Docs](#) » Physics Reference Manual

## Physics Reference Manual

### Scope of this Manual

The Physics Reference Manual provides detailed explanations of the physics implemented in the GEANT4 toolkit.

The manual's purpose is threefold:

- to present the theoretical formulation, model, or parameterization of the physics interactions included in GEANT4,
- to describe the probability of the occurrence of an interaction and the sampling mechanisms required to simulate it, and
- to serve as a reference for toolkit users and developers who wish to consult the underlying physics of an interaction.

This manual does not discuss code implementation or how to use the implemented physics interactions in a simulation. These topics are discussed in the *User's Guide for Application Developers*. Details of the object-oriented design and functionality of the GEANT4 toolkit are given in the *User's Guide for Toolkit Developers*. The *Installation Guide for Setting up [Geant4] in Your Computing Environment* describes how to get the GEANT4 code, install it, and run it.



# G4 Physics manual



**GEANT4**  
A SIMULATION TOOLKIT

## Physics Reference Manual

*Release 10.5*

**Geant4 Collaboration**

# Geant4 Cross Reference














## Geant4 Cross Reference

[Cross-Referencing](#) [Geant4](#)  
[Geant4/](#)

Version: [ [ReleaseNotes](#) ] [ [1.0](#) ] [ [1.1](#) ] [ [2.0](#) ] [ [3.0](#) ] [ [3.1](#) ] [ [3.2](#) ] [ [4.0](#) ] [ [4.0.p1](#) ] [ [4.0.p2](#) ] [ [4.1](#) ] [ [4.1.p1](#) ] [ [5.0](#) ] [ [5.0.p1](#) ] [ [5.1](#) ] [ [5.1.p1](#) ] [ [5.2](#) ] [ [5.2.p1](#) ] [ [5.2.p2](#) ] [ [6.0](#) ] [ [6.0.p1](#) ] [ [6.1](#) ] [ [6.2](#) ] [ [6.2.p1](#) ] [ [6.2.p2](#) ] [ [7.0](#) ] [ [7.0.p1](#) ] [ [7.1](#) ] [ [7.1.p1](#) ] [ [8.0](#) ] [ [8.0.p1](#) ] [ [8.1](#) ] [ [8.1.p1](#) ] [ [8.1.p2](#) ] [ [8.2](#) ] [ [8.2.p1](#) ] [ [8.3](#) ] [ [8.3.p1](#) ] [ [8.3.p2](#) ] [ [9.0](#) ] [ [9.0.p1](#) ] [ [9.0.p2](#) ] [ [9.1](#) ] [ [9.1.p1](#) ] [ [9.1.p2](#) ] [ [9.1.p3](#) ] [ [9.2](#) ] [ [9.2.p1](#) ] [ [9.2.p2](#) ] [ [9.2.p3](#) ] [ [9.2.p4](#) ] [ [9.3](#) ] [ [9.3.p1](#) ] [ [9.3.p2](#) ] [ [9.4](#) ] [ [9.4.p1](#) ] [ [9.4.p2](#) ] [ [9.4.p3](#) ] [ [9.4.p4](#) ] [ [9.5](#) ] [ [9.5.p1](#) ] [ [9.5.p2](#) ] [ [9.6](#) ] [ [9.6.p1](#) ] [ [9.6.p2](#) ] [ [9.6.p3](#) ] [ [9.6.p4](#) ] [ [10.0](#) ] [ [10.0.p1](#) ] [ [10.0.p2](#) ] [ [10.0.p3](#) ] [ [10.0.p4](#) ] [ [10.1](#) ] [ [10.1.p1](#) ] [ [10.1.p2](#) ] [ [10.1.p3](#) ] [ [10.2](#) ] [ [10.2.p1](#) ] [ [10.2.p2](#) ] [ [10.2.p3](#) ] [ [10.3](#) ] [ [10.3.p1](#) ] [ [10.3.p2](#) ] [ [10.3.p3](#) ] [ [10.4](#) ] [ [10.4.p1](#) ] [ [10.4.p2](#) ] [ [10.4.p3](#) ] [ [10.5](#) ] [ [10.5.p1](#) ]

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 <a href="#">digits_hits/</a>		2019-04-17 07:34:31	
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 <a href="#">error_propagation/</a>		2019-04-17 07:34:32	
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 <a href="#">global/</a>		2019-04-17 07:34:33	
 <a href="#">graphics_reps/</a>		2019-04-17 07:34:32	

# User Forum

GEANT4 at [hypernews.slac.stanford.edu](http://hypernews.slac.stanford.edu) Forum List by Category



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# Basics of OO programming in C++

# Class and Object

## Class and Object

**Object:** is characterized by **attributes** (which define its state) and **operations**  
A **class** is the **blueprint** of objects of the same **type**

```
class Rectangle {  
    public:  
    Rectangle (double,double); // constructor  
    ~Rectangle() { // empty; } // destructor  
    double area () { return (width * height); } // member function  
    private:  
    double width, height; // data members  
};
```

```
Rectangle rectangleA (3.,4.); // instantiate an object of type "Rectangle"  
Rectangle* rectangleB = new Rectangle(5.,6.);  
cout << "A area: " << rectangleA.area() << endl;  
cout << "B area: " << rectangleB->area() << endl;  
delete rectangleB; // invokes the destructor
```

# Inheritance

## Inheritance

- A key feature of C++
- Inheritance allows to create classes derived from other classes
- Public inheritance defines an “**is-a**” relationship
  - *In other words: what applies to a base class applies to its derived classes*

```
class Base {  
    public:  
        virtual ~Base() {}  
        virtual void f() {...}  
    protected:  
        int a;  
    private:  
        int b; ...  
};
```

Mania Grazia F.

```
class Derived : public Base {  
    public:  
        virtual ~Derived() {}  
        virtual void f() {...}  
        ...  
};
```

# Header File

## How a Header File looks like

header file

begin header guard

forward declaration

class declaration

constructor

destructor

member functions

member variables

need semi-colon

end header guard

Segment.h

```
#ifndef SEGMENT_HEADER
#define SEGMENT_HEADER

class Point;
class Segment
{
public:
    Segment();
    virtual ~Segment();
    double length();
private:
    Point* p0,
    Point* p1;
}
#endif // SEGMENT_HEADER
```

# Implementation

## Header file and implementation

### File Segment.hh

```
#ifndef SEGMENT_HEADER
#define SEGMENT_HEADER

class Point;
class Segment
{
public:
    Segment();
    virtual ~Segment();
    double length();
private:
    Point* p0,
    Point* p1;
};
#endif // SEGMENT_HEADER
```

### File Segment.cc

```
#include "Segment.hh"
#include "Point.hh"

Segment::Segment() // constructor
{
    p0 = new Point(0.,0.);
    p1 = new Point(1.,1.);
}

Segment::~~Segment() // destructor
{
    delete p0;
    delete p1;
}

double Segment::length()
{
    function implementation ...
}
```



# OOP programming

## OOP basic concepts

### ● Object, Class

- A class defines the abstract characteristics of a thing (object), including the thing's attributes and the thing's behaviour

### ● Inheritance

- “Subclasses” are more specialized versions of a class, which *inherit* attributes and behaviours from their parent classes (and can introduce their own)

### ● Encapsulation

- Each object exposes to any class a certain *interface* (i.e. those members accessible to that class)
- Members can be **public**, **protected** or **private**

### ● Abstraction

- Simplifying complex reality by modelling classes appropriate to the problem
- One works at the most appropriate level of inheritance for a given aspect of the problem

### ● Polymorphism

- It allows one to treat derived class members just like their parent class' members

Maria Grazia Pia

# General Introduction to Geant4

# Technology transfer

## Particle physics software aids space and medicine

Geant4 is a showcase example of technology transfer from particle physics to other fields such as space and medical science [...].

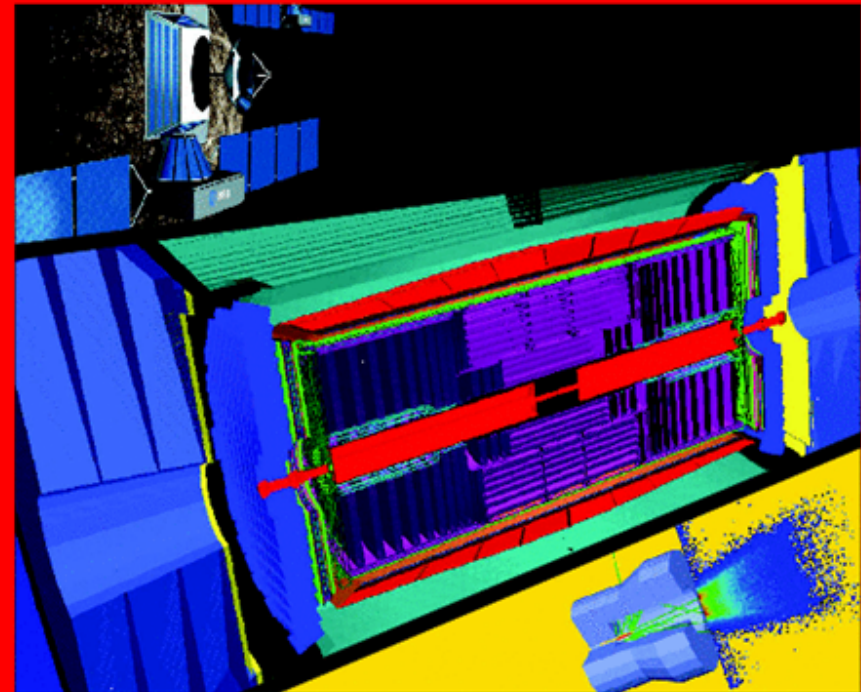
CERN Courier, June 2002

**Geant 4**

INTERNATIONAL JOURNAL OF HIGH-ENERGY PHYSICS

# CERN COURIER

VOLUME 42 NUMBER 5 JUNE 2002



Simulation for physics, space and medicine

#### NEUTRINOS

Sudbury Neutrino Observatory confirms neutrino oscillation p5

#### TESLA

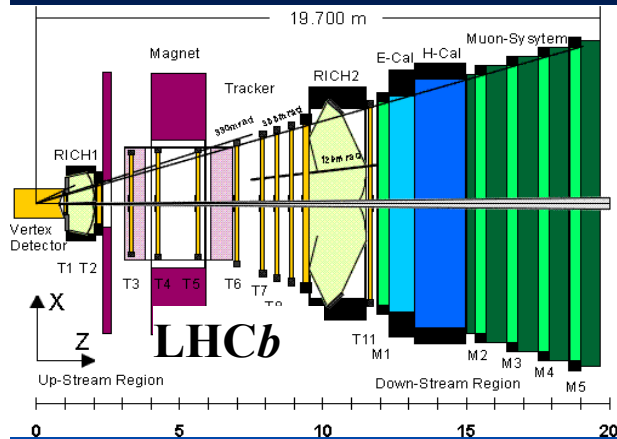
Electropolishing steers superconducting cavity to new record p10

#### COSMOPHYSICS

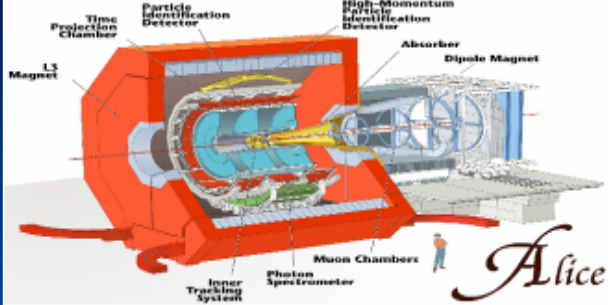
Joint symposium brings CERN, ESA and ESO together p15

# Globalisation

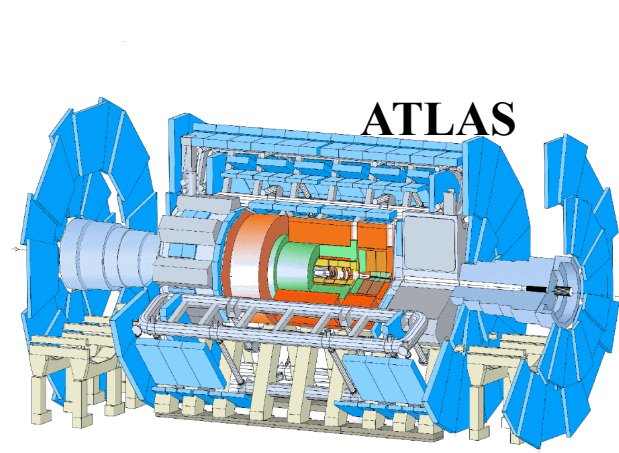
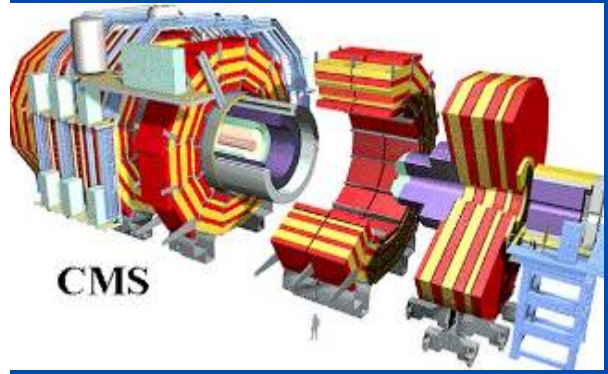
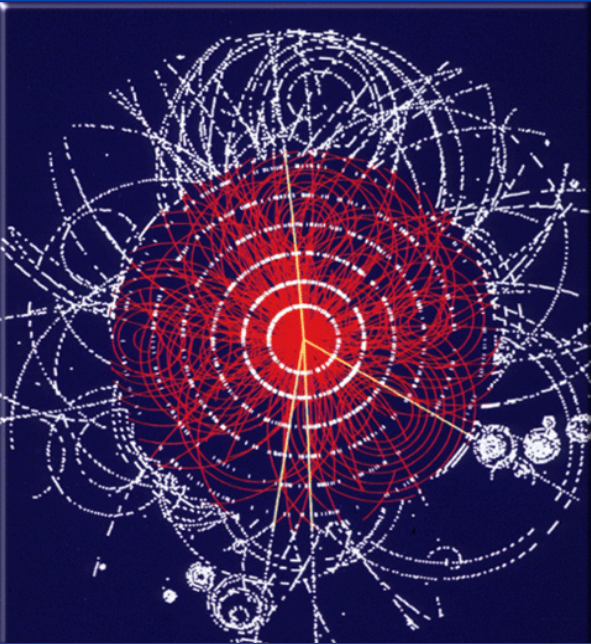
Sharing requirements and functionality  
across diverse fields



Complex physics  
 Complex detectors  
 20 years  
 software life-span



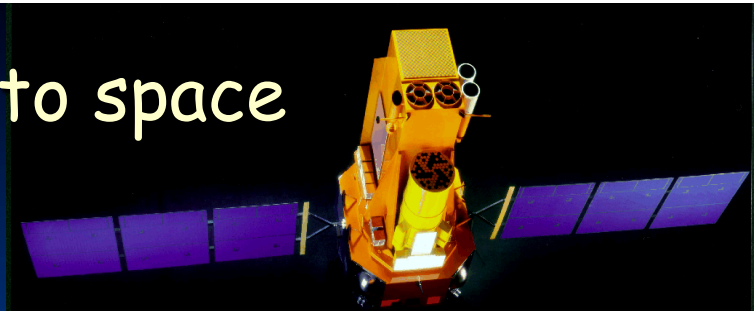
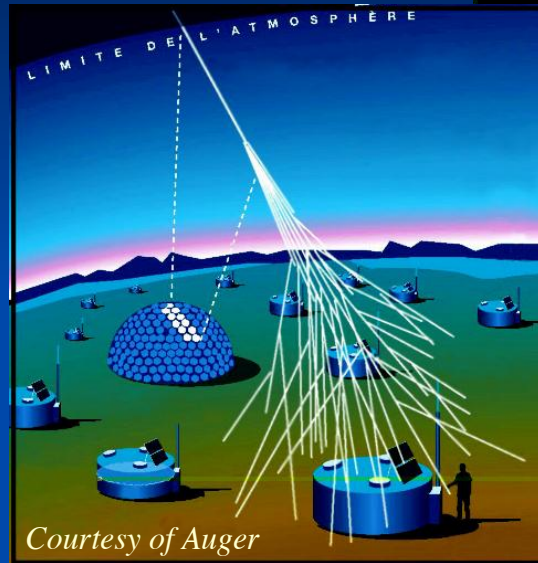
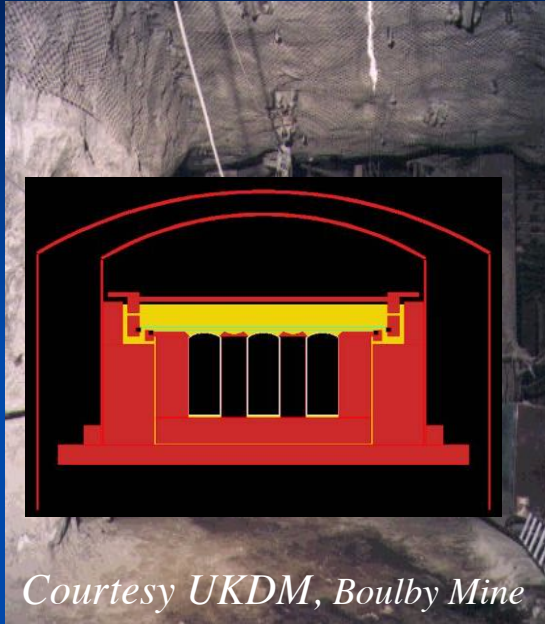
# LHC



From deep underground...

...to space

Dark matter and  $\nu$  experiments



Courtesy of ESA

X and  $\gamma$  astronomy,  
gravitational waves,  
radiation damage to  
components etc.

Cosmic ray experiments

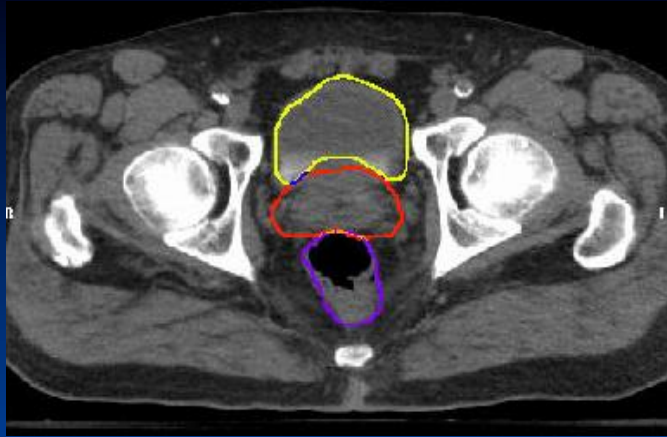
Variety of requirements from diverse applications

Physics  
from the  $eV$  to the  $PeV$  scale

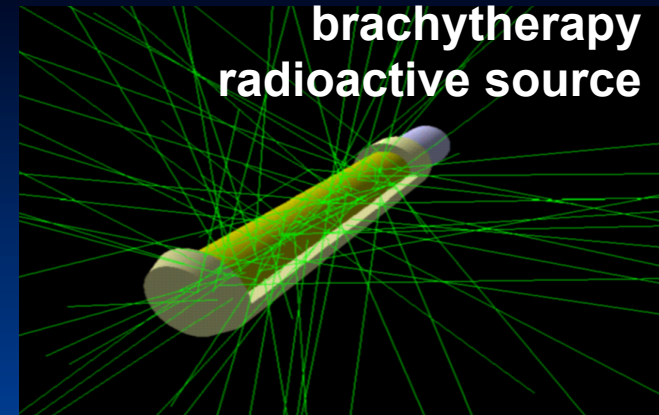
Detectors,  
spacecrafts and environment

For such experiments software is often **mission critical**

Require **reliability**, rigorous software engineering standards



# Medical Physics



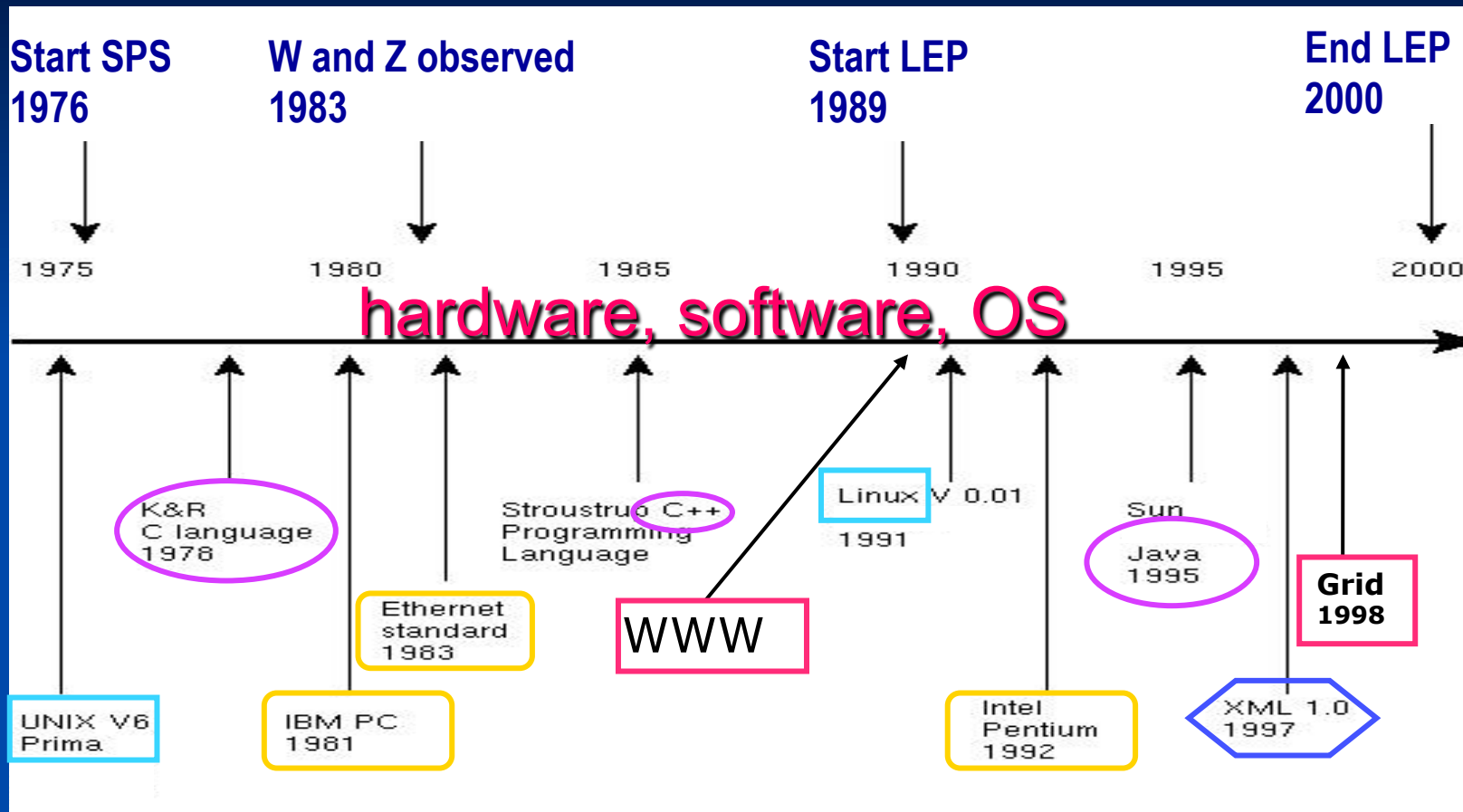
from hospitals...



...to Mars

- Accurate modelling of radiation sources, devices and human body
- Precision of physics
- Reliability
- Easy configuration and friendly interface
- Speed

# ...in a fast changing computing environment



...and don't forget changes of requirements!

Evolution towards greater diversity



we must anticipate changes



# OO technology

- Openness to **extension** and **evolution**  
new implementations can be added w/o changing the existing code
- Robustness and ease of **maintenance**  
**protocols** and well defined dependencies minimize coupling

## Strategic vision

## Toolkit

- A set of compatible components
- each component is **specialised** for a specific functionality
  - each component can be **refined** independently to a great detail
  - components can be **integrated** at any degree of complexity
  - it is easy to provide (and use) **alternative** components
  - the user application can be **customised** as needed

# Geant4 official publications





## Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment

Volume 506, Issue 3, 1 July 2003, Pages 250-303



## GEANT4—a simulation toolkit

S. Agostinelli <sup>ae</sup>, J. Allison <sup>as</sup>  , K. Amako <sup>e</sup>, J. Apostolakis <sup>a</sup>, H. Araujo <sup>aj</sup>, P. Arce <sup>l, m, x, a</sup>, M. Asai <sup>g, ai</sup>, D. Axen <sup>i, t</sup>, S. Banerjee <sup>bi, l</sup>, G. Barrand <sup>an</sup>, F. Behner <sup>l</sup>, L. Bellagamba <sup>c</sup>, J. Boudreau <sup>bd</sup>, L. Broglio <sup>ar</sup>, A. Brunengo <sup>c</sup>, H. Burkhardt <sup>a</sup>, S. Chauvie <sup>bj, bl</sup>, J. Chuma <sup>h</sup> ... D. Zschiesche <sup>af</sup>

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[https://doi.org/10.1016/S0168-9002\(03\)01368-8](https://doi.org/10.1016/S0168-9002(03)01368-8)

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# Geant4 official publications

## Geant4 developments and applications

Publisher: IEEE

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73 Author(s)

J. Allison ; K. Amako ; J. Apostolakis ; H. Araujo ; P. Arce Dubois ; M. Asai ; G. Barrand ; R. Capra ; S. Ch...

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Paper  
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7  
Patent  
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10901  
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### Abstract

#### Document Sections

- I. Introduction
- II. New Developments in the Geant4 Kernel
- III. Improvements in Detector Modeling
- IV. Physics Extensions and Validation
- V. Enhancement of Geant4 Interactive Capabilities

### Abstract:

Geant4 is a software toolkit for the simulation of the passage of particles through matter. It is used by a large number of experiments and projects in a variety of application domains, including high energy physics, astrophysics and space science, medical physics and radiation protection. Its functionality and modeling capabilities continue to be extended, while its performance is enhanced. An overview of recent developments in diverse areas of the toolkit is presented. These include performance optimization for complex setups; improvements for the propagation in fields; new options for event biasing; and additions and improvements in geometry, physics processes and interactive capabilities

**Published in:** [IEEE Transactions on Nuclear Science](#) ( Volume: 53 , Issue: 1 , Feb. 2006 )

**Page(s):** 270 - 278

**INSPEC Accession Number:** 8999460

**Date of Publication:** 27 March 2006

**DOI:** [10.1109/TNS.2006.869826](#)

**ISSN Information:**

**Publisher:** IEEE

# Geant4 official publications



## Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment

Volume 835, 1 November 2016, Pages 186-225



## Recent developments in GEANT4

J. Allison <sup>a, b</sup>, K. Amako <sup>c, a</sup>, J. Apostolakis <sup>d</sup>, P. Arce <sup>e</sup>, M. Asai <sup>f</sup>, T. Aso <sup>g</sup>, E. Bagli <sup>h</sup>, A. Bagulya <sup>i</sup>, S. Banerjee <sup>j</sup>, G. Barrand <sup>k</sup>, B.R. Beck <sup>l</sup>, A.G. Bogdanov <sup>m</sup>, D. Brandt <sup>n</sup>, J.M.C. Brown <sup>o</sup>, H. Burkhardt <sup>d</sup>, Ph. Canal <sup>j</sup>, D. Cano-Ott <sup>p</sup>, S. Chauvie <sup>q</sup> ... H. Yoshida <sup>bs, a</sup>

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<https://doi.org/10.1016/j.nima.2016.06.125>

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