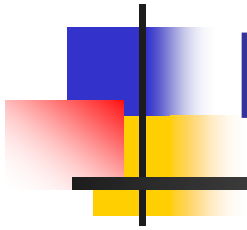


Part II

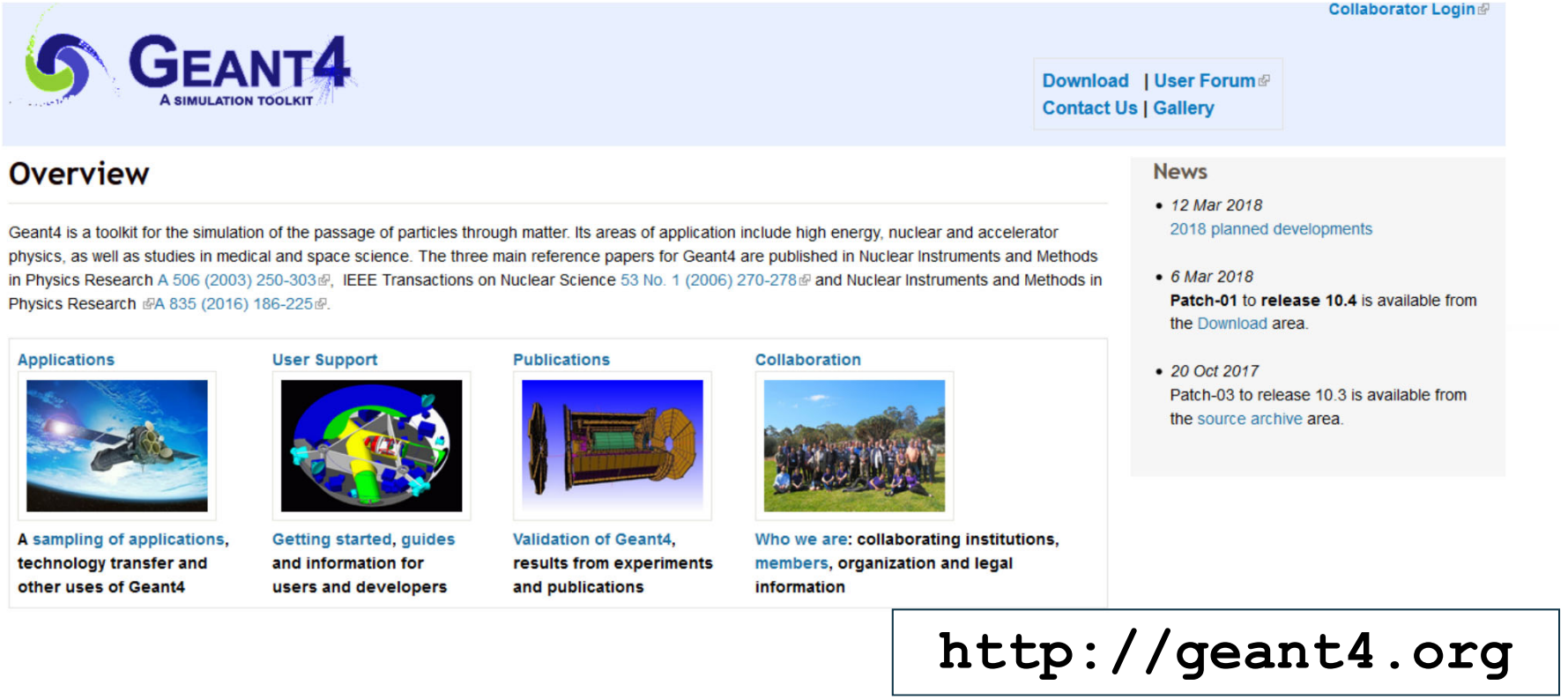
S. Agostinelli et al., Nucl. Instr. Meth. A **506** (2003) 250
J. Allison et al., IEEE Trans. Nucl. Scie. **53** (2006) 270
J. Allison et al., Nucl. Instr. Meth. A **835** (2016) 186

What is GEANT4

A SIMULATION TOOLKIT

- Toolkit for the **Monte Carlo simulation** of the interaction of **particles** with **matter**
  - physics processes (EM, hadronic, optical) cover a comprehensive set of particles, materials and over a wide energy range
  - offers a complete set of support functionalities (tracking, geometry)
  - **Distributed** software production and management: developed by an **international Collaboration**
    - Established in 1998
    - Approximately 100 members, from Europe, America and Asia
- Written in **C++** language
  - Takes advantage from the Object Oriented software technology
- **Open source**

http://geant4.org

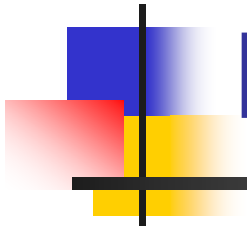


http://geant4.org

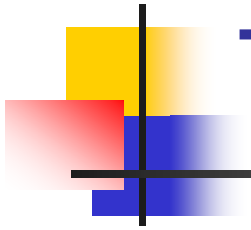
- **Code** and **documentation** available in the main **web page**
- Regular **tutorial courses** held worldwide

versions and releases

- First release (Geant4 1.0) in December 1998
  - ~Two releases per year since then
  - Major releases (**x**.y) or minor releases (x.**y**) or beta releases
  - Patches regularly issued
- Last version: Geant4 10.5
  - Released December 7th, 2018
  - The VM used for this course has Geant4 10.5
- Requires C++11 since 10.2 (gcc > 4.8.x)
  - Native C+11 features in-place (= compilation with old compilers **fails**)

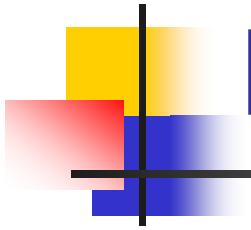


Basic concept of Geant4



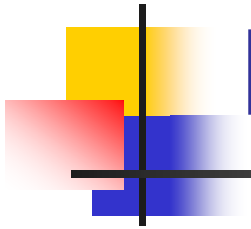
Toolkit and User Application

- Geant4 is a **toolkit** (= a collection of tools)
  - i.e. you cannot "run" it out of the box
  - You must **write an application**, which uses Geant4 tools
- Consequences:
  - There are no such concepts as "Geant4 defaults"
  - You must provide the necessary information to configure your simulation
  - You must deliberately choose which Geant4 tools to use
- Guidance: many **examples** are provided



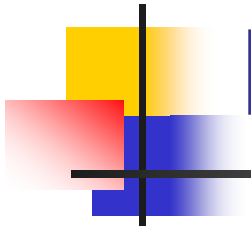
Basic concepts

- What you **MUST** do:
  - Describe your **experimental set-up**
  - Provide the **primary particles** input to your simulation
  - Decide which **particles** and **physics models** you want to use out of those available in Geant4 and the precision of your simulation (cuts to produce and track secondary particles)
- You **may also want**
  - To interact with Geant4 kernel to **control** your simulation
  - To **visualise** your simulation configuration or results
  - To produce **histograms, tuples** etc. to be further analysed



Main Geant4 capabilities

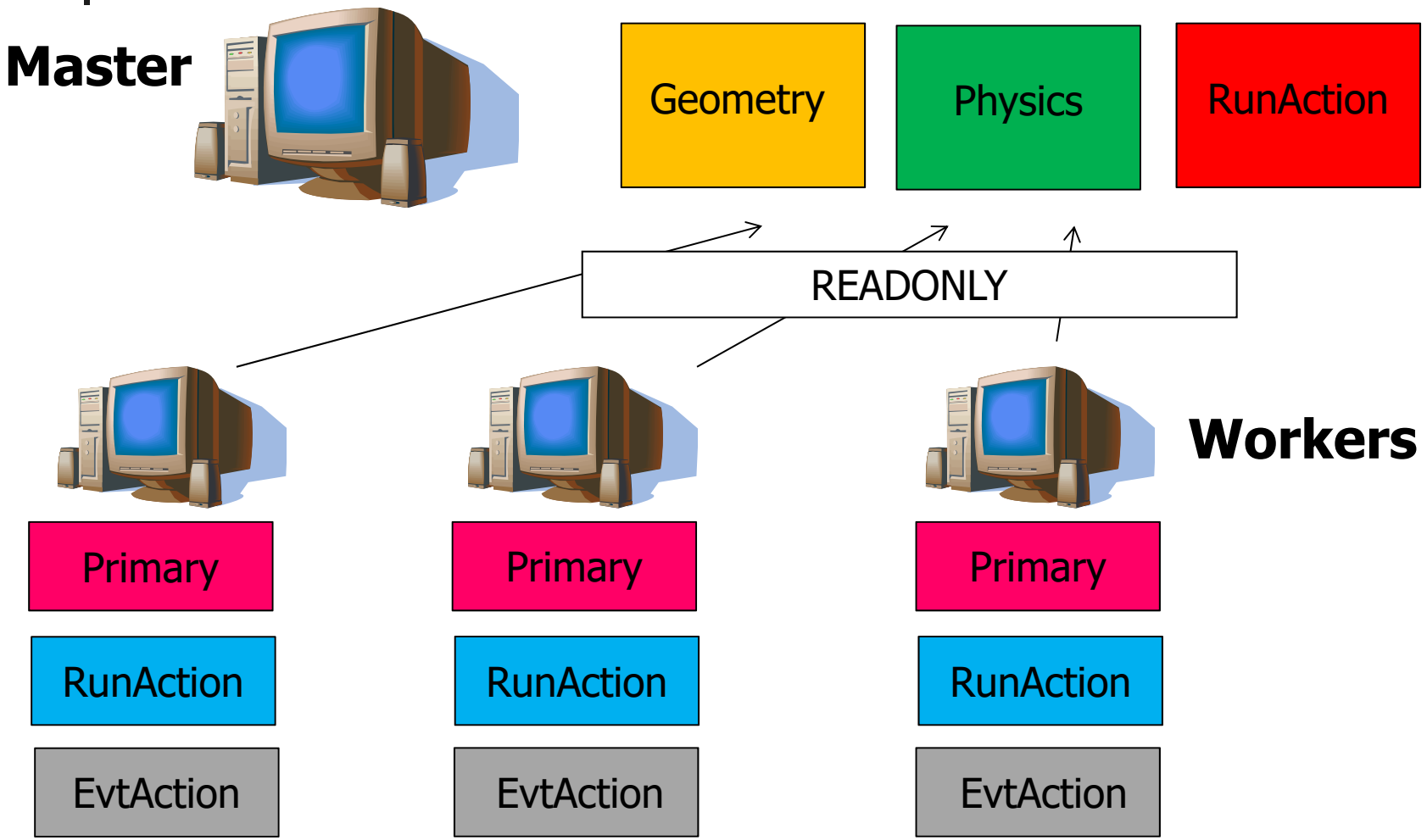
- **Transportation of a particle 'step-by-step'** taking into account all possible interactions with materials and fields
- **The transport ends** if the particle
  - is slowed down to zero kinetic energy (and it doesn't have any interaction at rest)
  - disappears in some interaction
  - reaches the end of the simulation volume
- Geant4 allows the User to access the transportation process and retrieve the results (USER ACTIONS)
  - at the beginning and end of the transport
  - at the end of each step in transportation
  - if a particle reaches a sensitive detector
  - Others…



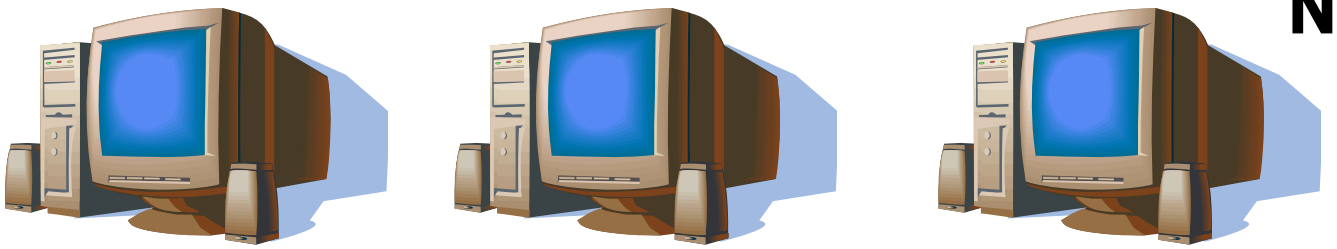
Multi-thread mode

- Geant4 10.0 (released Dec, 2013) supports multi-thread approach for multi-core machines
  - Simulation is automatically split on an event-by-event basis
    - different events are processed by different cores
  - Can fully profit of **all cores** available on modern machines → substantial **speed-up** of simulations
  - **Unique** copy (master) of geometry and physics
    - All cores have them as read-only (saves memory)
- Backwards compatible with the **sequential** mode
  - The MT programming requires some care: need to avoid conflicts between threads
  - Some modification and porting required

Concept for multi-thread …



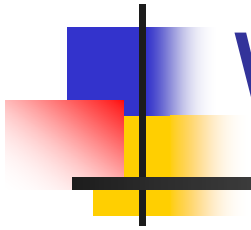
… vs. parallelisation



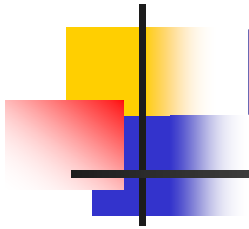
Nodes

Geometry	Geometry	Geometry
Physics	Physics	Physics
Primary	Primary	Primary
RunAction	RunAction	RunAction
EvtAction	EvtAction	EvtAction

- Each node hosts a complete simulation
- Many copies of geometry and physics tables
- More memory-thristy



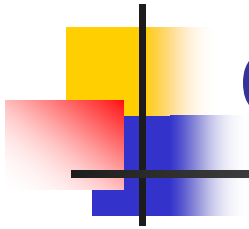
Who/why is using Geant4?



Experiments and MC

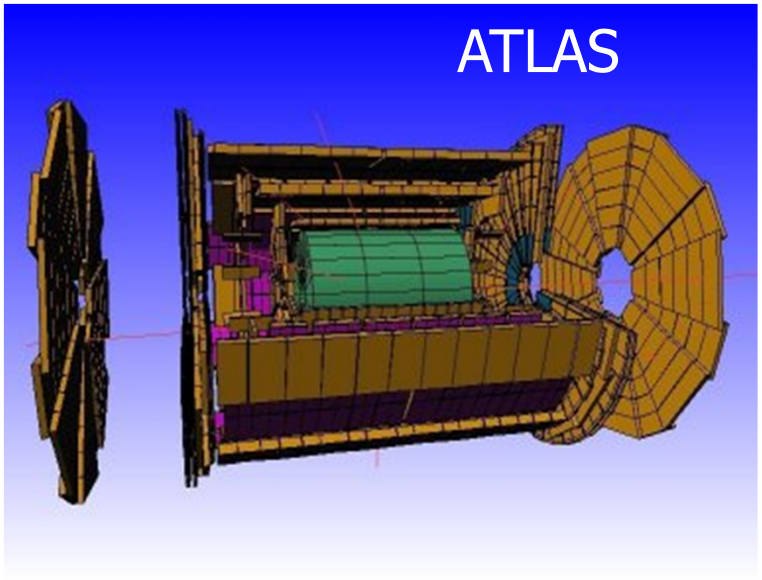
- In my knowledge, **all experiments** have a (more or less detailed) full-scale Monte Carlo simulation
- Design phase
  - Evaluation of background
  - Optimization of setup to maximize scientific yield
    - Minimize background, maximize signal efficiency
- Running/analysis phase
  - Support of data analysis (e.g. provide efficiency for signal, background, coincidences, tagging, …).
    - Often, Monte Carlo is the only way to convert *relative rates* (events/day) in *absolute yields*

Why Geant4 is a common choice in the market



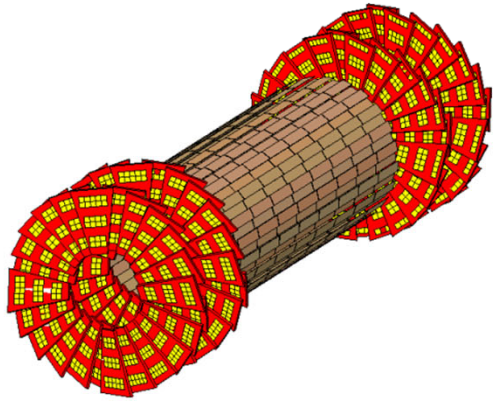
- Open source and object oriented/C++
  - No black box
  - Freely available on all platforms
  - Can be easily extended and customized by using the existing interfaces
    - New processes, new primary generators, interface to ROOT analysis, …
- Can handle complex geometries
- Regular development, updates, bug fixes and validation
- Good physics, customizable per use-cases
- End-to-end simulation (all particles, including optical photons)

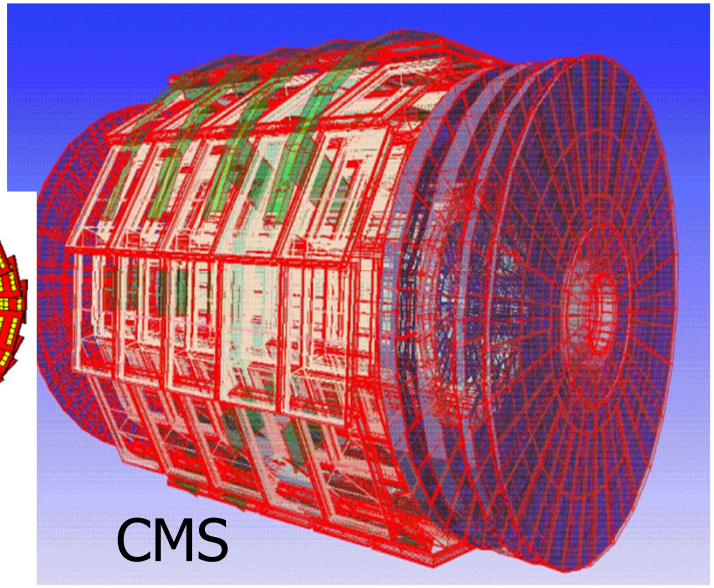
LHC @ CERN



- All four big **LHC experiments** have a Geant4 simulation
  - M of volumes
  - Physics at the TeV scale

- Benchmark with test-beam data
- Key role for the Higgs searches

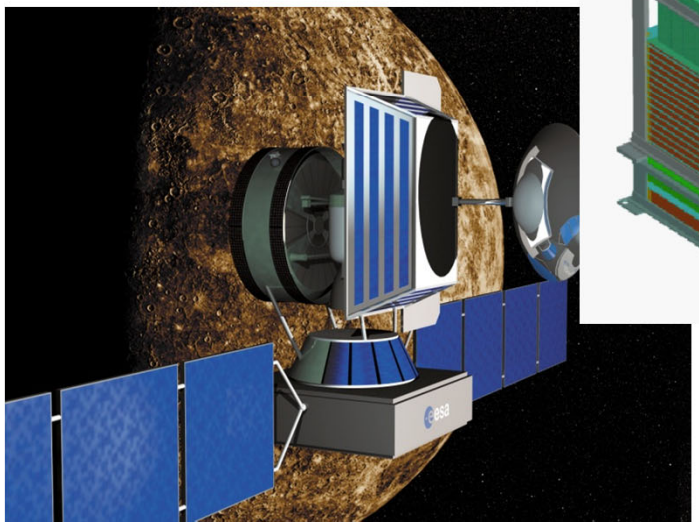


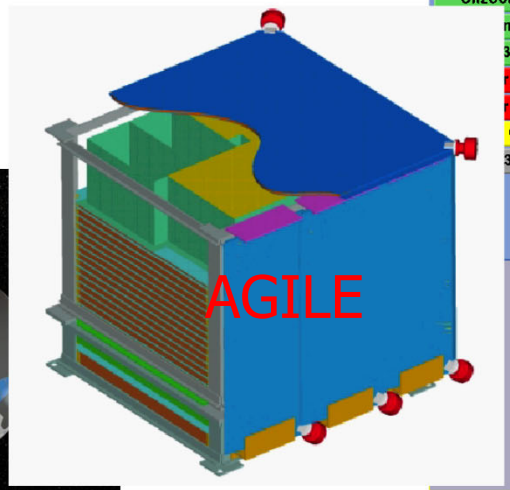


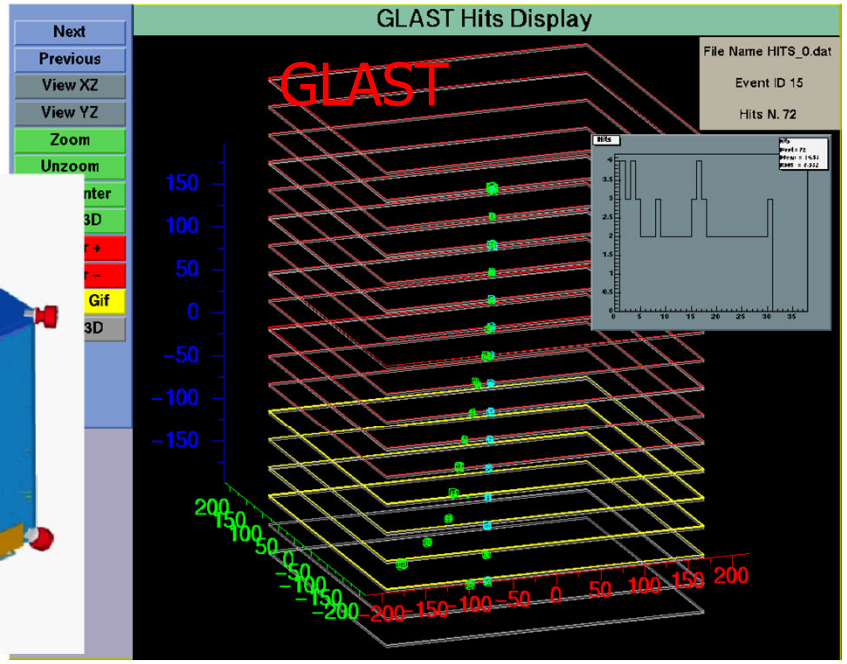
Space applications

- Satellites (γ astrophysics, planetary sciences)
- Funding from ESA

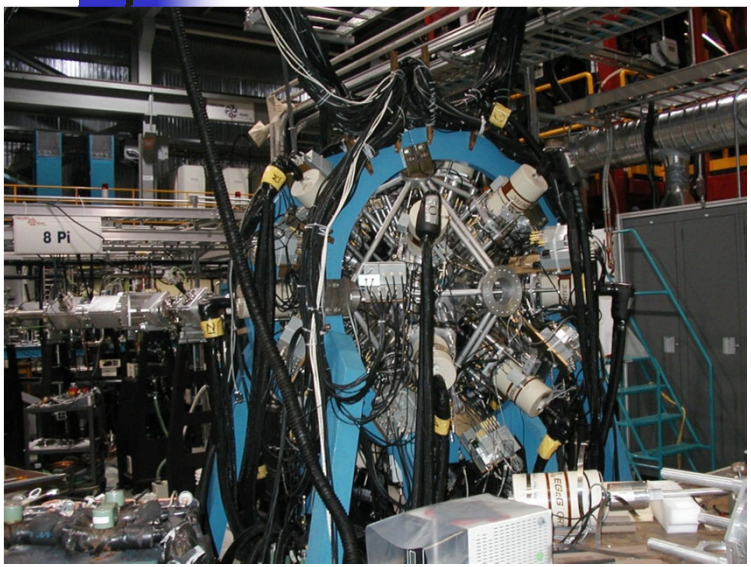
Typical telescope:
Tracker
Calorimeter
Anticoincidence

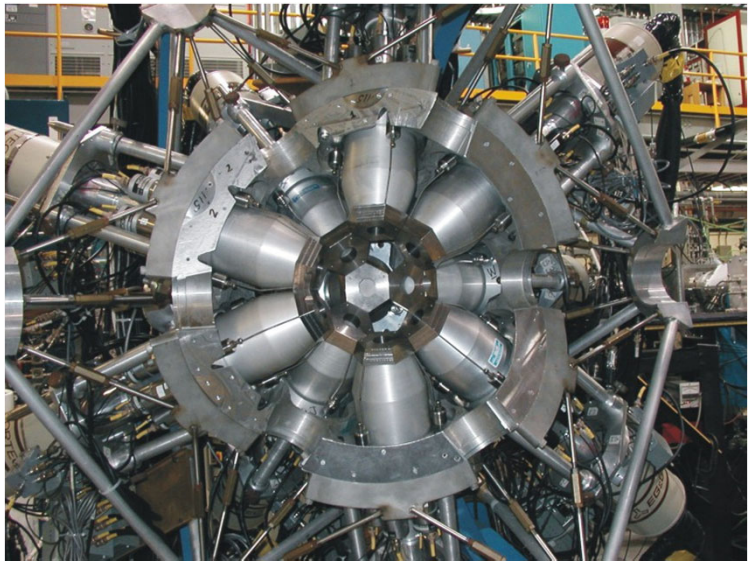


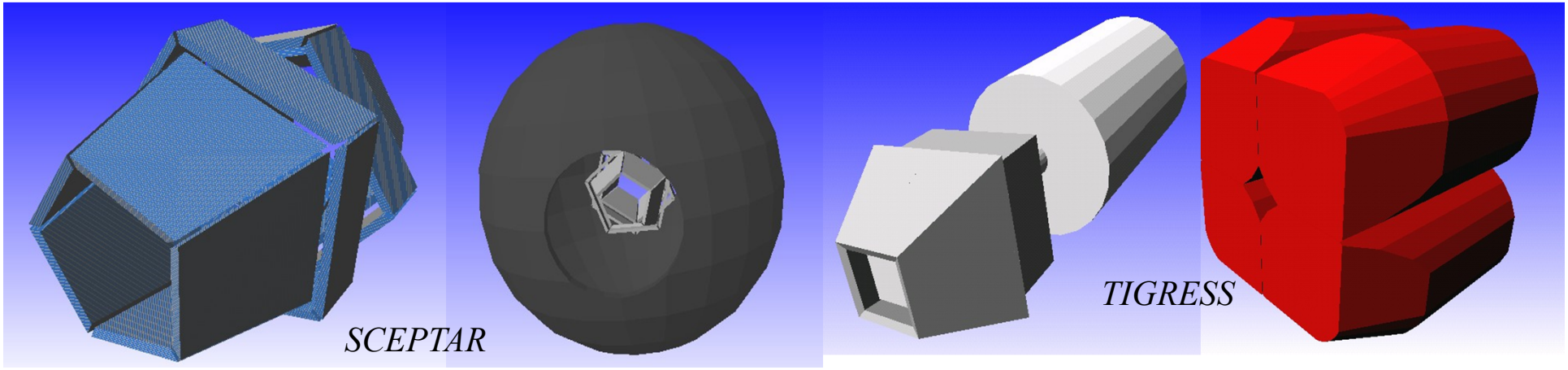




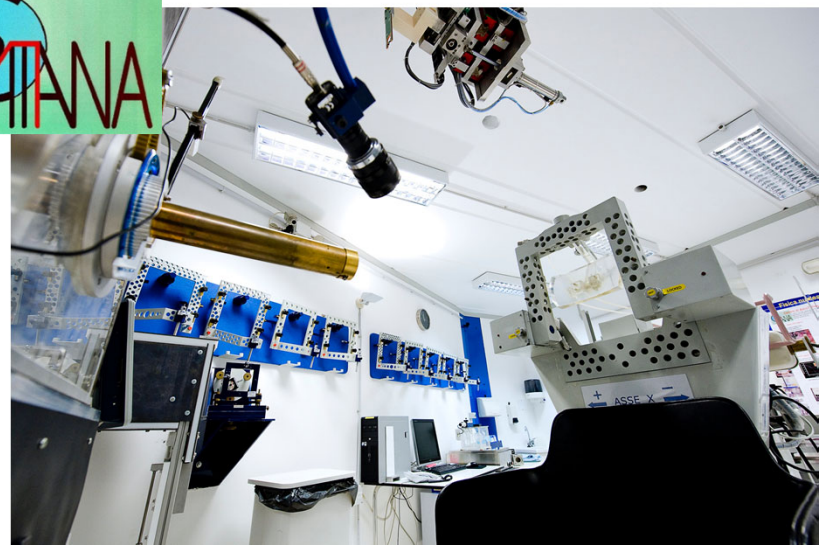
Nuclear spectroscopy

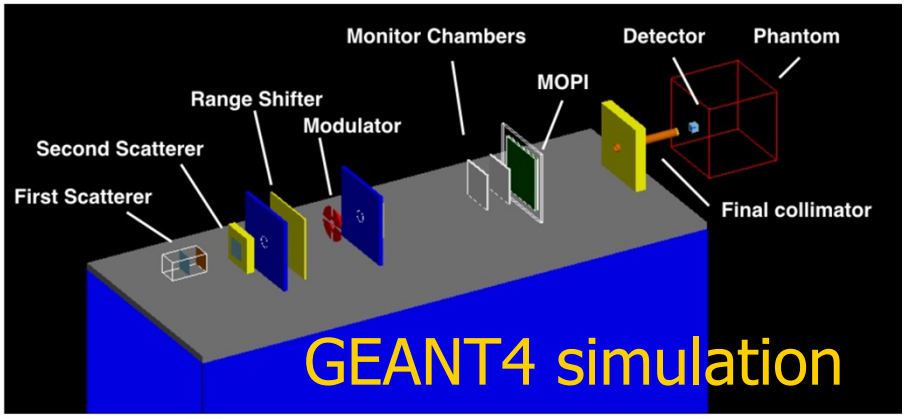






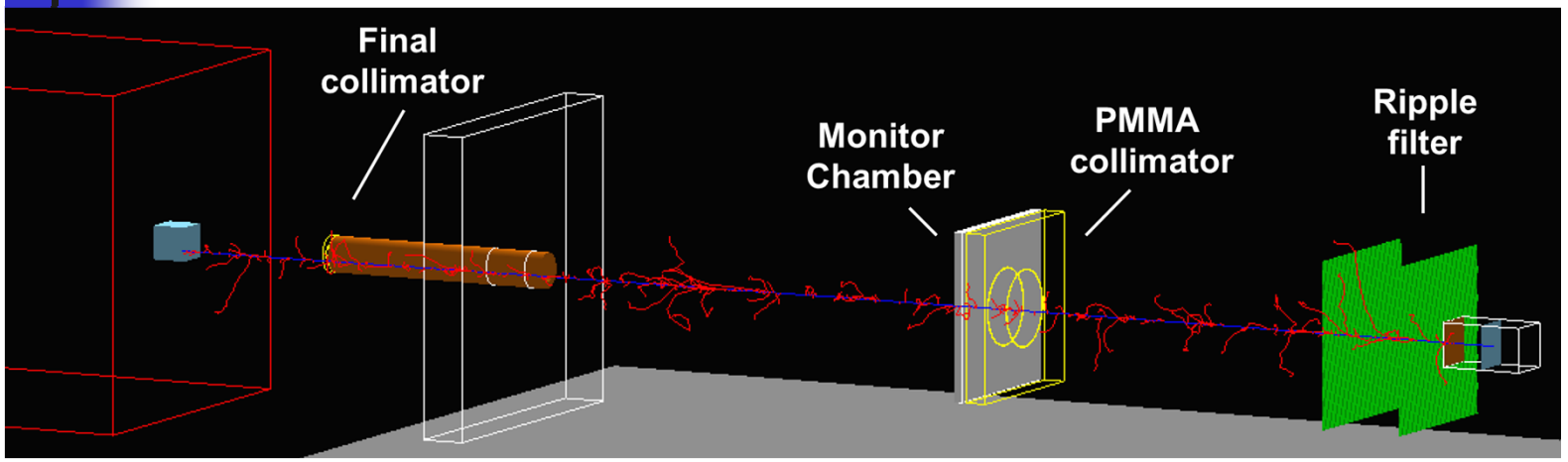
Medical applications

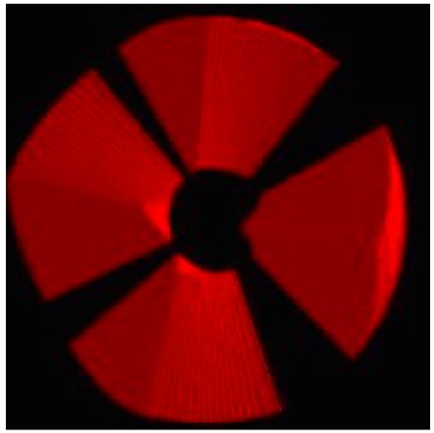




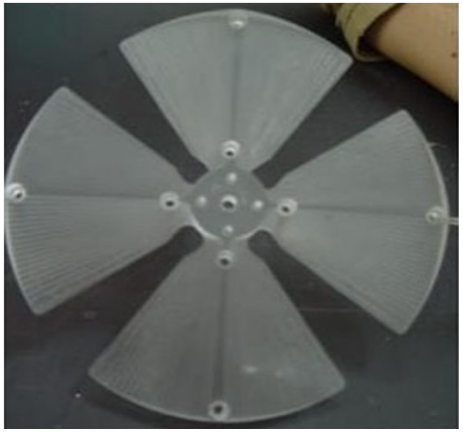
- **Treatment planning** for hadrontherapy and proton-therapy systems
  - Goal: deliver dose to the tumor while sparing the healthy tissues
  - Alternative to less-precise (and commercial) TP software
- Medical imaging
- Radiation fields from medical accelerators and devices
  - `medical_linac`
  - `gamma-knife`
  - `brachytherapy`

Medical applications

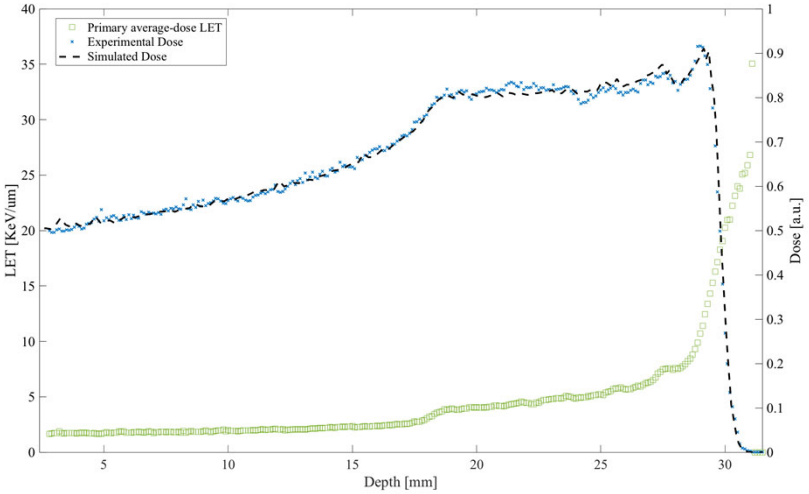




Monte Carlo Simulation

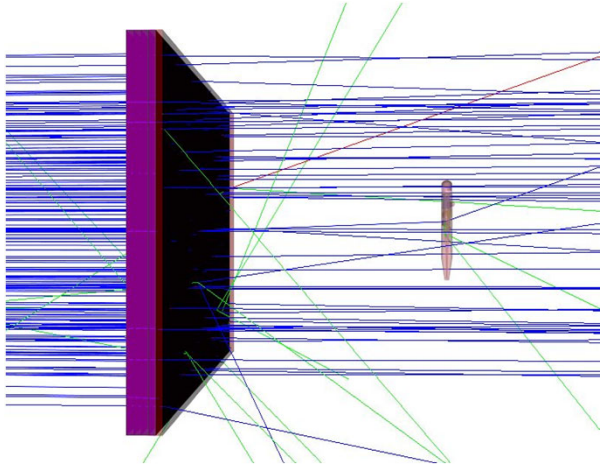


Real Modulator

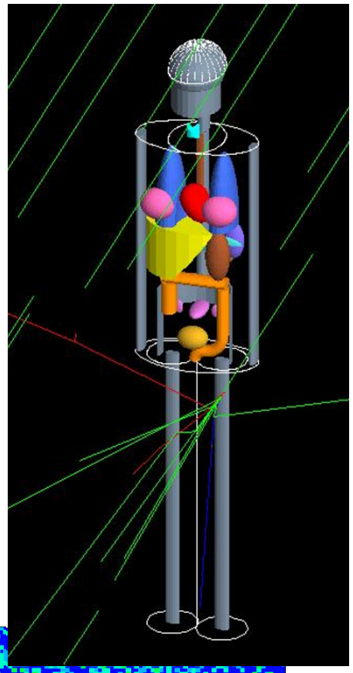


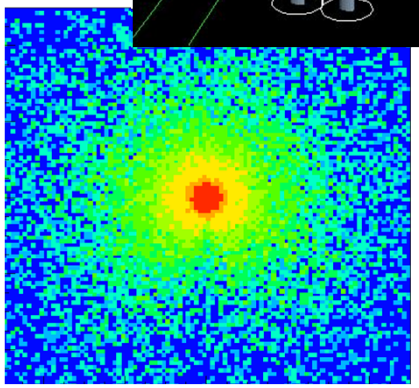
Dosimetry with Geant4

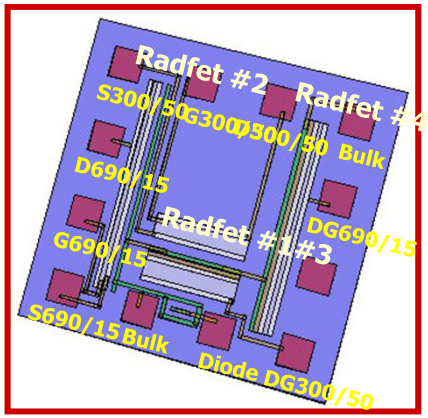
Space science



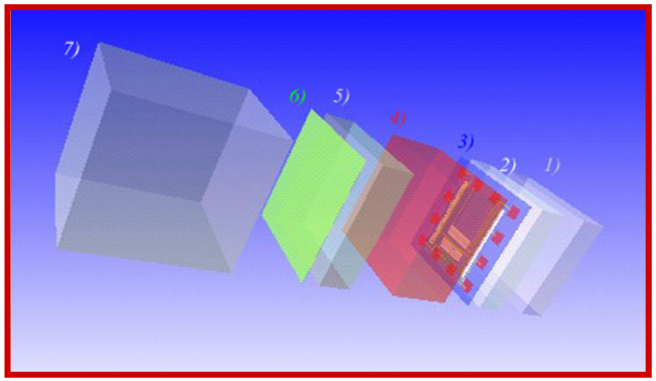
Radiotherapy



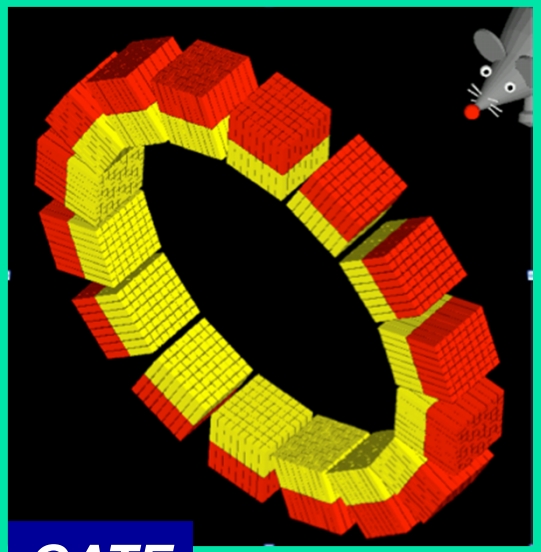




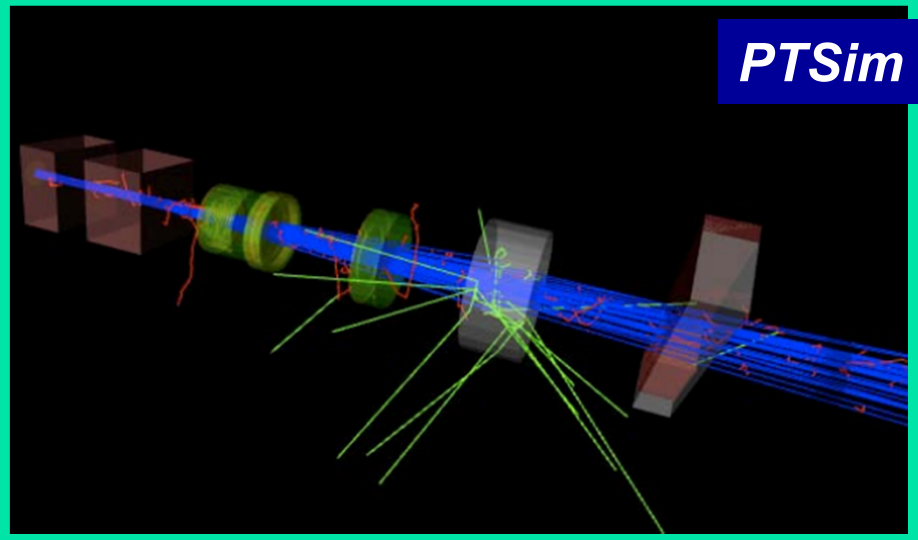
Effects on electronics components



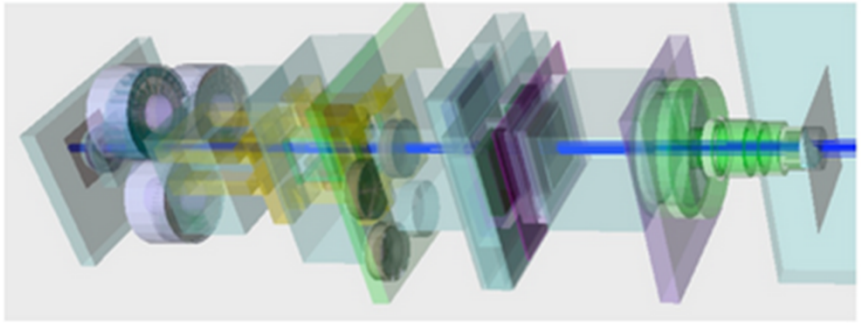
Geant4-based frameworks in the medical physics

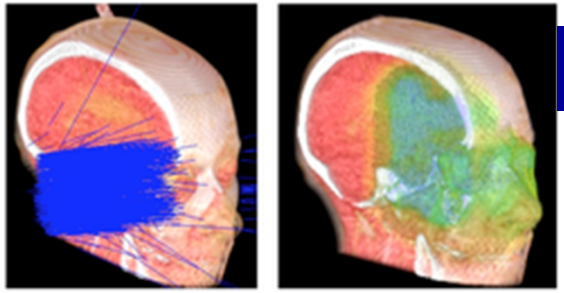


GATE



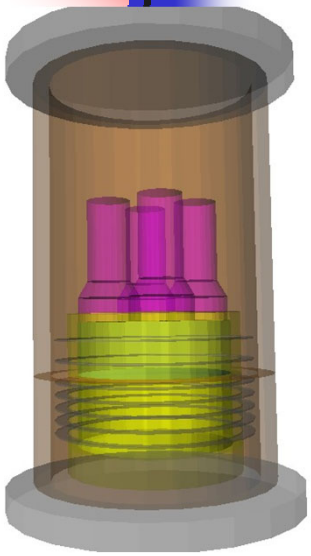
PTSim





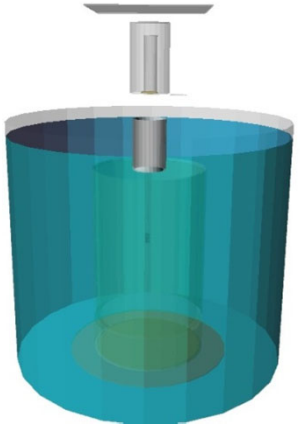
TOPAS

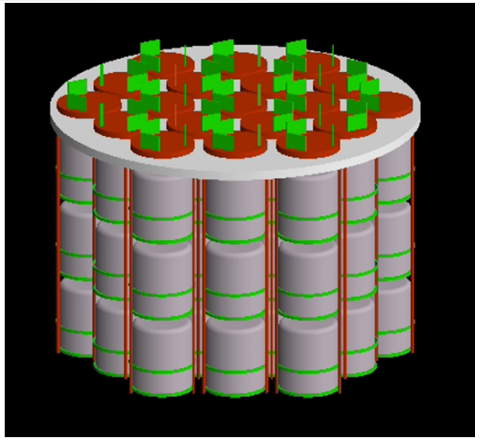
Low background experiments

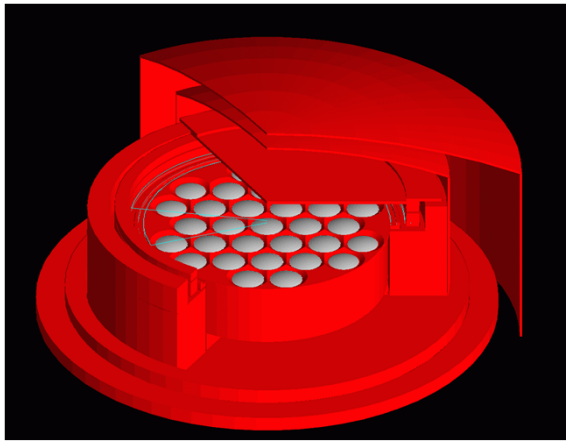


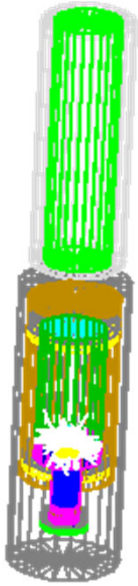
Neutrinoless ββ decay:

GERDA, MJD, COBRA, CUORE, EXO









Dark matter detection:

Zeplin-II/III, Super-CDMS, Edelweiss, ArDM, Xenon, CRESST, Lux, Elixir,

Solar neutrinos:

Borexino, ...