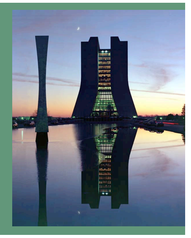
Simulation in High Energy Physics – Detector and Radiation Modeling

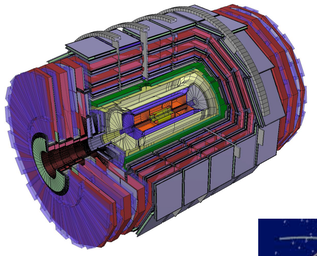
Fermi National Accelerator Laboratory

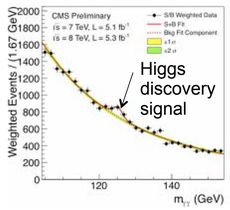


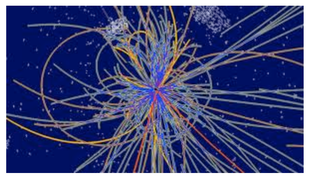
Simulation to Explore the Energy and Intensity Frontiers

Simulation plays a fundamental role in:

- **Detector** design and optimization
- **Elementary Particle** reconstruction, calibration
- Demonstration of **physics analysis** methods
- Understanding signatures of **new physics models**

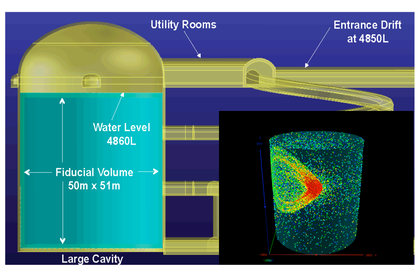






The CMS detector at the Large Hadron Collider (CERN)

The **Higgs Boson** discovery effort at the LHC used billions of simulated proton-proton events generated at Fermilab's computing facilities with software developed by Fermilab's scientists



Simulated Neutrino Event as would be seen by the Long Baseline Neutrino experiment (LBNE-FNAL)

Simulation helps to separate **Neutrino signatures** (showers) in the detectors, from spurious marks caused by noise and background events

Software Tool Kits for Simulation of Detectors and Interaction of Radiation with Matter

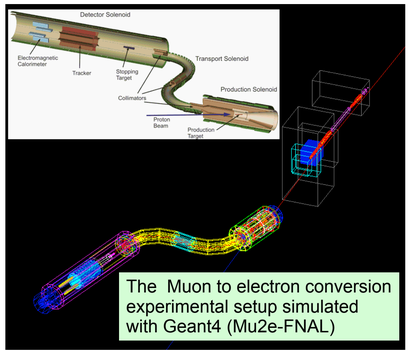
Geant4 is a toolkit to simulate the passage of particles through matter

Areas of application: high energy, nuclear and accelerator physics, studies in medical and space science

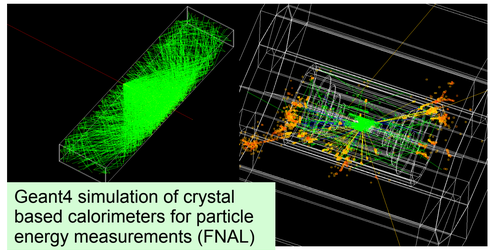
Geant4 (G4) describes your experimental setup (geometry and radiation source) and provides:

- Tracking and propagation through geometry
- Modeling of physics interactions
- Visualization and persistency

The DOE Office of Science (High Energy Physics) supports the development of software tools for detector simulation such as Geant4



The Muon to electron conversion experimental setup simulated with Geant4 (Mu2e-FNAL)



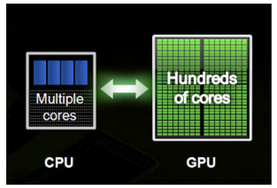
Geant4 simulation of crystal based calorimeters for particle energy measurements (FNAL)

Complex Codes and Infrastructure being adapted for High Performance Computing, GPUs

Scientists at Fermilab are factorizing Geant4 into pieces and studying their performance (particle propagation, geometry, physics) in a GPGPU (CUDA code) as compared to a CPU

Ratio of Processing Time: CPU/GPU	Kernel (Computation) Only	Kernel + Data Transfer
Stepper	67	29
Geometric limit of step length	74	32
Particle Transportation (no physics)	33	27
EM Physics	88	9
Particle Transportation with EM Physics	34	30

EM Physics refers to Bremsstrahlung process only



Per unit of work (gflop):

- 2/3 of CPU price
- 55% of CPU operating cost (20% if code tuned)

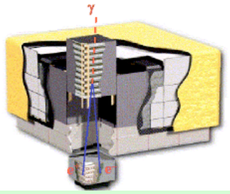
Particle Physics Detectors enable discovery in basic research and applied sciences. Detector R&D leads to technological breakthroughs in the areas of materials, radiation detection technology, and fast electronics. They also improve quality of life through their uses in medical applications, security. Simulation is an essential tool in the design and optimization of detectors

Collaboration Across the World, including the DOE Complex, with Value to the Energy, Space, Industry

The Geant4 Collaboration is an international team of more than a hundred physicists and computer scientists who develop the software and the physics of the tool kit and provide support to the users

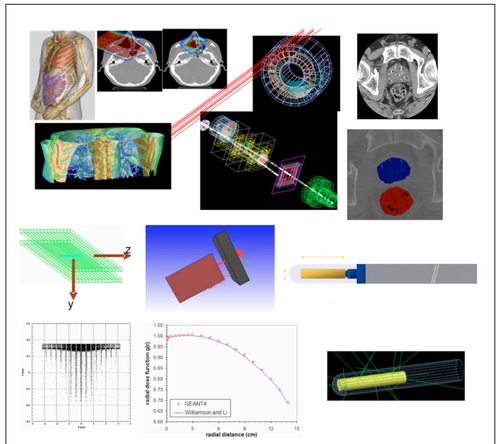
Fermilab and SLAC collaborate with many other institutions from the US and around the world as members of the G4 Collaboration

Fermilab collaborates with the European Center of Nuclear Research (CERN) in software R&D for the re-engineering of HEP code to run in HPC platforms



In Addition to High Energy Physics, Geant4 is extensively used in Medical and Space Applications

Gamma Ray Large Area Space Telescope (DOE, NASA)



Geant4 North American Medical User Organization