Fermilab Geant Research Project
(Introduction)

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Why to Simulate Detectors

Simulation saves time and money and improves the quality and accuracy of physics measurements

- Detector design and optimization
- Software development, including reconstruction algorithms
- Design of methods for calibration and data analysis
- Detector studies of new particles as predicted by theories

Simulation helps us design the optimal detector, for best physics at a given cost, even before we fasten the first screw !

Opportunity of Particle Physics - Scientific Computing partnership

- Geant is an essential tool for HEP experiments
- Geant transformation to run in HPC systems may be an interesting use-case for computer scientists

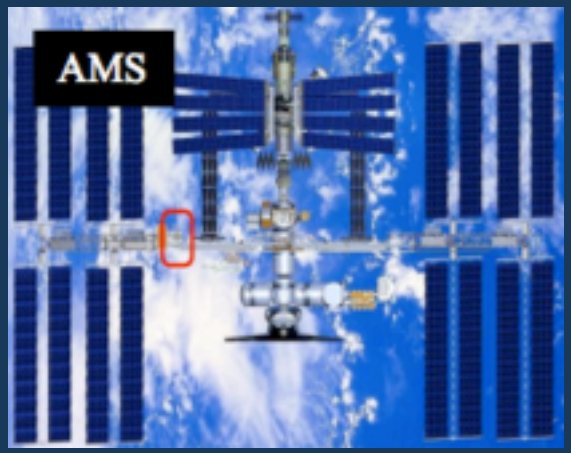
The Geant4 Simulation Toolkit

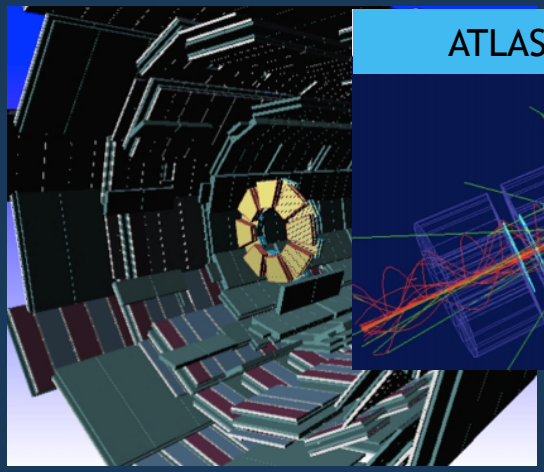
Geant 4 is a software toolkit to simulate the passage of particles through matter and EM fields

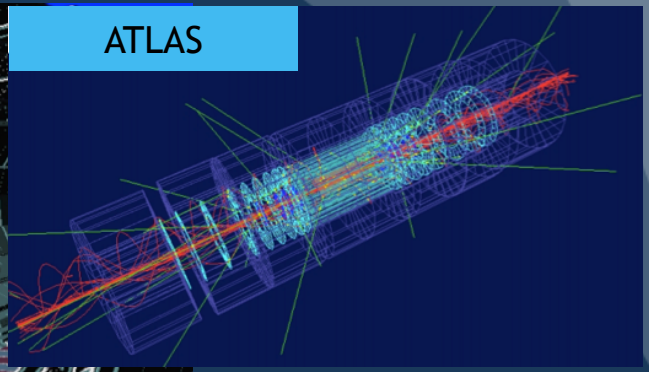
- International Collaboration of tens of institutions and ~100 physicists and Computer Professionals (~25 FTE), including Fermilab
- Written in OO C++, > 1 million lines of code, > 2000 classes
- Used by almost all HEP experiments (10,000 users), space, and medical applications

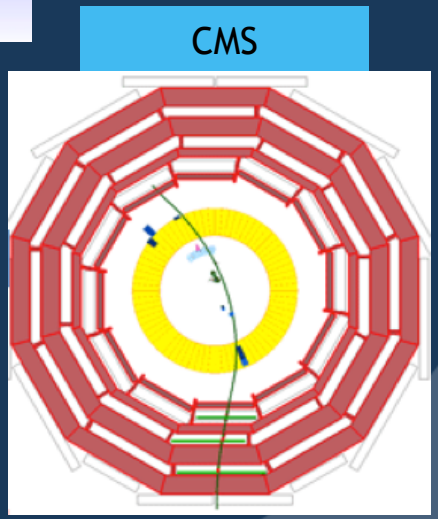
20th G4 Collaboration meeting at FNAL (2015)

The Geant4 Simulation Toolkit





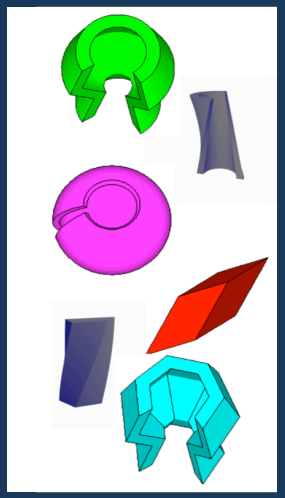




The Geant4 Simulation Toolkit

The users develop a simulation application for their detector using Geant4 by assembling each of the following elements:

Detector geometry (shapes and material)



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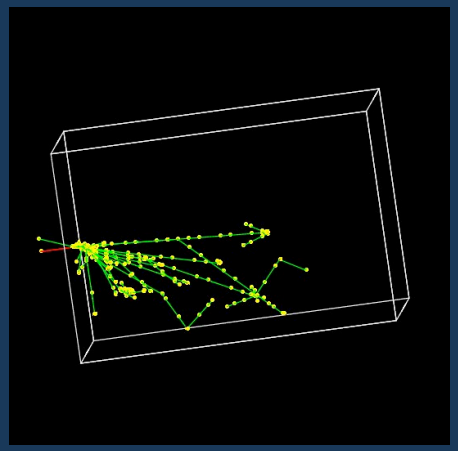
Particle Propagation through geometry and EM fields



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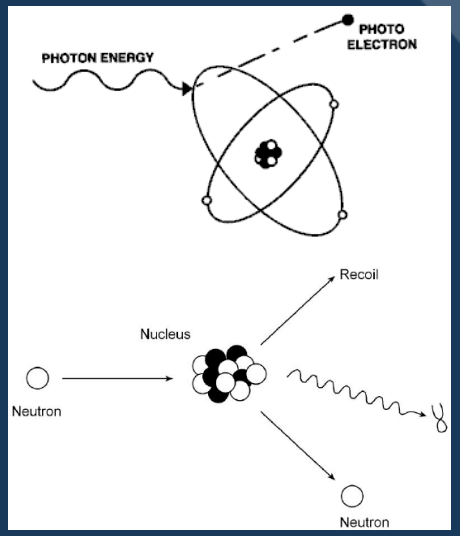
Physics Processess



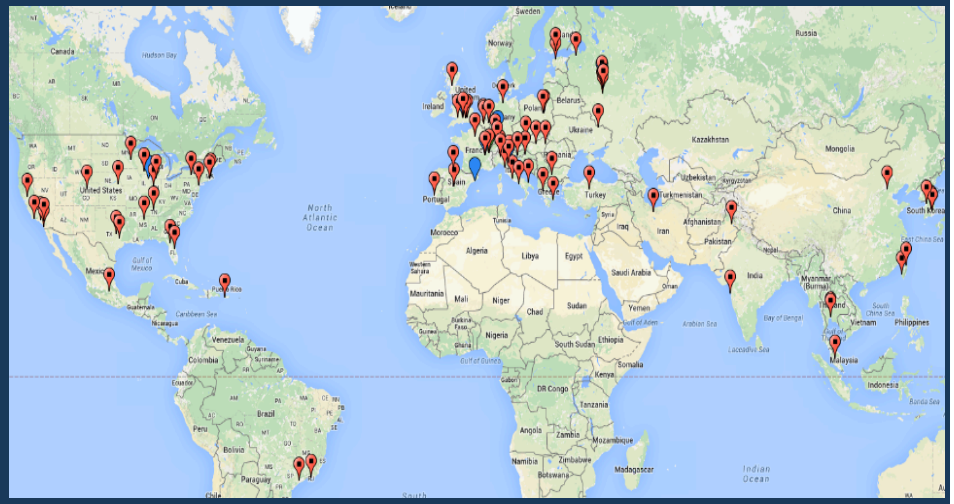
Simulation: accurate modeling of the detector ➔ accurate simulation of physics measurements

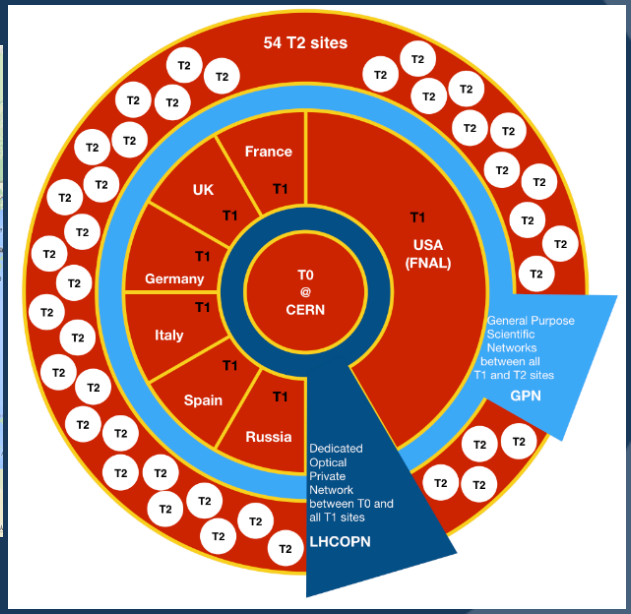
Goal: real detector output indistinguishable from simulation output

Computing in High Energy Physics

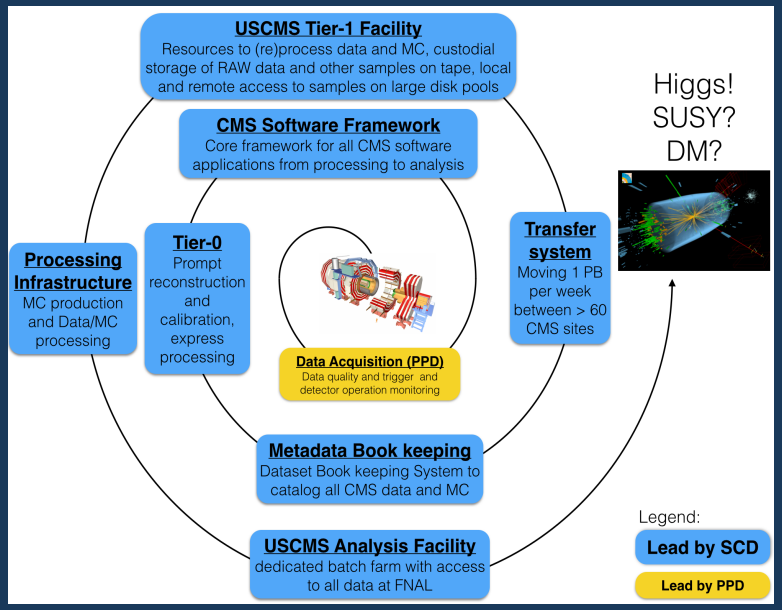
HEP experiments involve:

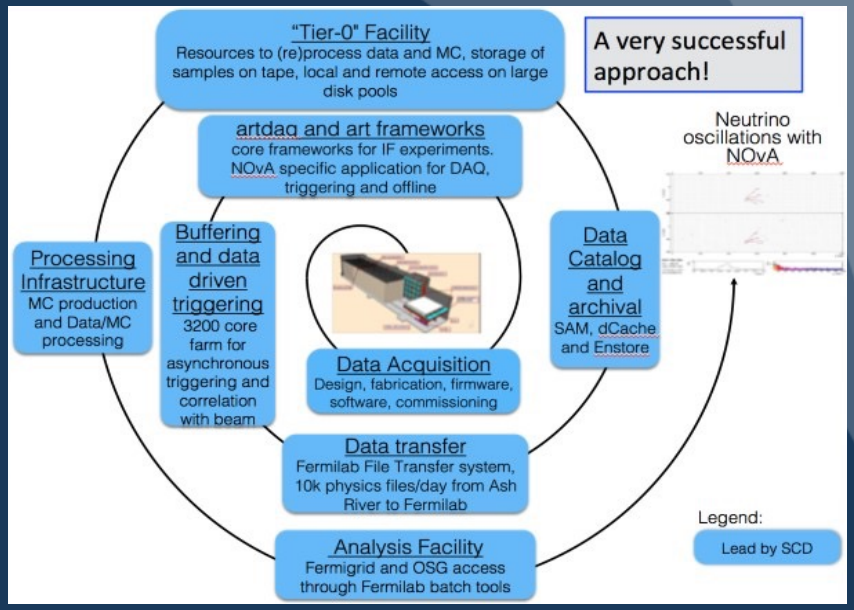
Large distributed computing systems running *millions of lines of code*, processing *many petabytes of data* every year which are transferred for physics analysis to every corner of the world





G4 Data Processing and Workflows





- Geant4 Application typical workflow:
  - Physics generator (Pythia/GENIE) ➔ Geant4 "hits" ➔ electronics modeling (digis) ➔ calibration ➔ particle reconstruction (e, γ, μ, jets from q and g) ➔ physics analysis (BSM searches, SM measurements)
- Significant expertise at FNAL (CMS and IF experiments)

A HEP Experiment in Numbers

HEP experiment data is BIG DATA. For example, in CMS:

- ~10 billion real collider events and ~10 billion simulated events were reconstructed and stored during 2010-2012
- Event size: ~ 1 MB for real data, ~ 1.5 MB for simulated data
- CPU time for simulated event ~ 15 sec – 3 min (~1 min for typical event), plus ~30 sec for reconstruction
- Memory usage/event ~ 2 GB
- Data transfers ~ 2 PB/week

(A total of ~120k cores in > 60 centers around the world, ~75 PB disk, ~100 PB tape, C++ code, i.e. Intel Sandy Bridge X86 machines)

150 times more data expected through 2030 – unsustainable situation given predicted computing resources

Increasing Demand and a Flat Budget

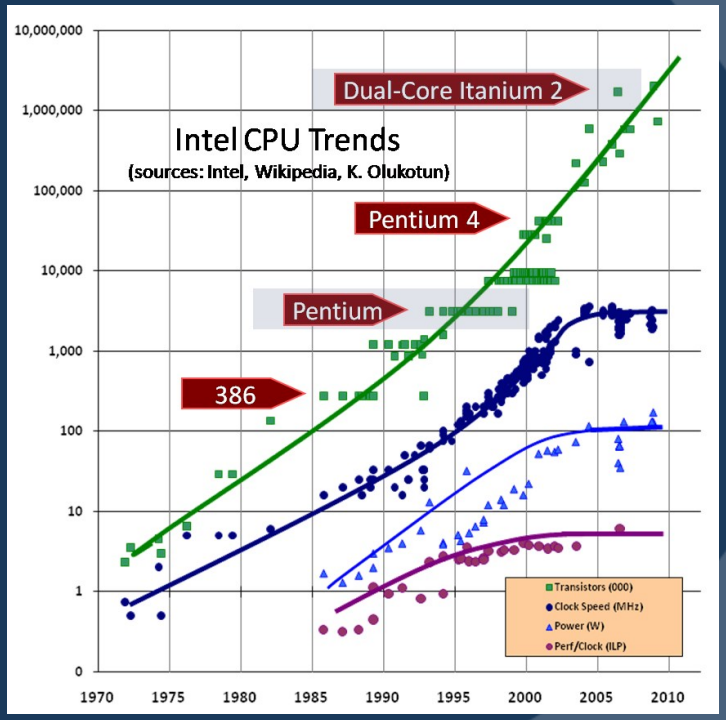
By ~2023, LHC experiments will need a factor of ~100 more computing resources in a flat budget scenario.

The DUNE Fermilab neutrino experiment has a similar timeline

Leverage from growth in:

- Core count (multi-core machines)
- Coprocessors
- Concurrency and parallel computing

Geant research evolved from an interesting idea to an urgent need



Geant Research started in 2011 at FNAL

Test G4 functionalities in modern architectures as a first step to redesign the toolkit for improvements in event production rate (throughput) and memory use

Objective: more physics with the same money

Performance in HPC systems may benefit from:

- Improved *instruction pipelining*
- *Vectorization* and *Single instruction Multiple Data (SIMD)*
- *Multi-thread Track level parallelization*
- *Data locality*

DOE supports FNAL's Geant research since 2012

Geant Research Funded Proposals

"Fermilab R&D Effort Towards Geant4 re-engineering" (2012, FNAL)

- Evaluation of a small set of G4 functionalities in CPU and GPUs

"HEP-ASCR R&D Effort Towards Geant4 re-engineering" (2013-2014, ANL/Oregon, FNAL, RENCI/N. Carolina, S. California, SLAC)

- Geant4 performance evaluation with HPCtoolkit/Tau - ASCAR
- Co-processor prototype to test propagation of photons through CMS EM calorimeters in GPUs - FNAL
- Designed/started a Geant Vector Prototype: GeantV – FNAL/CERN

"Research towards Geant re-engineering" (2015-2017, FNAL)

Approved proposal includes a plan with timeline/milestones for a full vector prototype including transportation, geometry, physics, coprocessor broker (CPU, GPUs, XeonPhi) – FNAL/CERN

Ph. Canal's presentation

Geant Research International Context

FNAL and CERN initial sharing of ideas through 2011 led to the creation of the (International) Concurrency Forum:

"an attempt to share knowledge among interested parties that should work together to develop 'demonstrators' and agree minimally on technology so that they can share code and compare results"

- Annual meetings at FNAL (2011, 2012) and CERN (2014), attended by ~50 HEP developers from around the world including our ASCR partners
- Worked on "demonstrators", then prototypes
- Partnerships were born

The GeantV effort consolidated in ~2013
Current partners are FNAL, CERN, UNESP (Brazil), BARC (India)
Geant4-GeantV teams at CERN and FNAL are fully integrated
(The total effort at the moment is ~8-10 FTEs, 2 FTE at FNAL)

Some Useful Links

Fermilab's Geant Research:

https://web.fnal.gov/project/geant4rd/sitepages/home.aspx

(Includes instructions on how to download and install the code: GeantV prototype, NavidationBenchmark and XRayBenchmark mini-apps on Cori)

Geant4 Collaboration:

https://geant4.web.cern.ch/geant4/

GeantV Webpage:

http://geant.cern.ch/