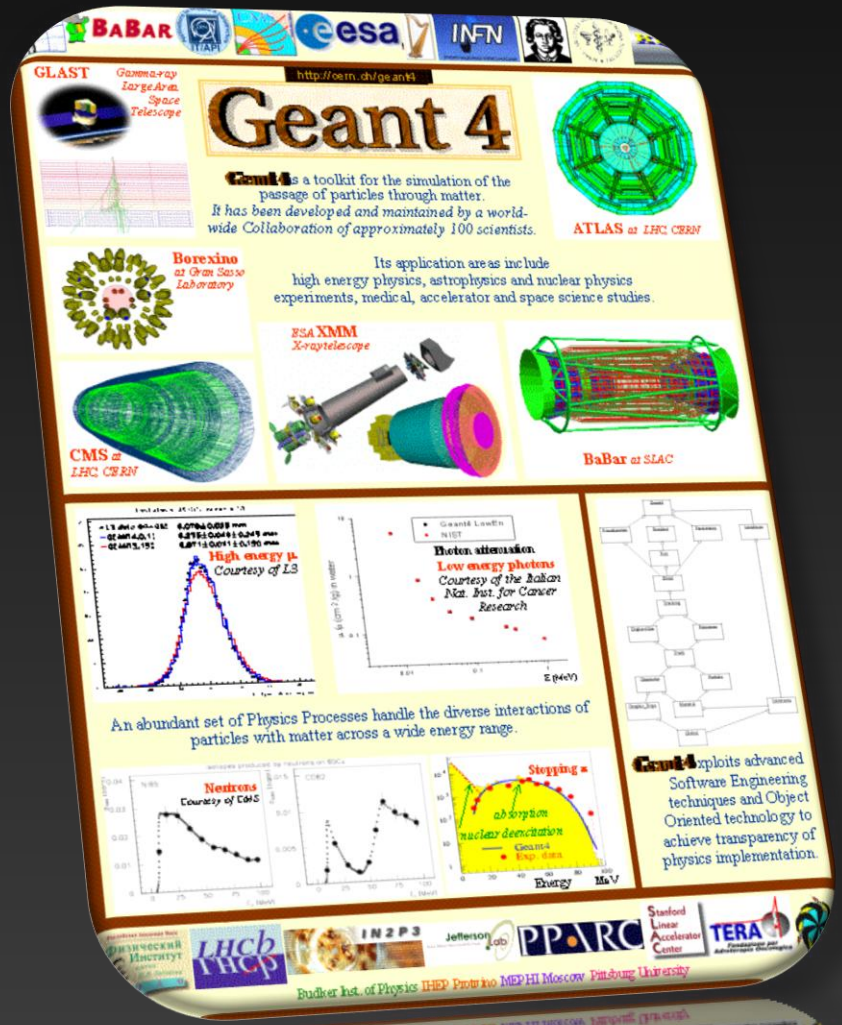
# Geant4 Overview and Kernel

Geant4 Tutorial @ Japan 2007
Geant4 Collaboration

KEK/CRC

# Contents




Introduction

Kernel structure

User support

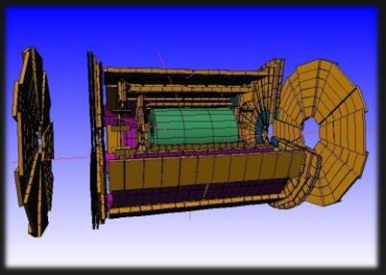
What is Geant4?

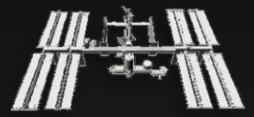
User applications

Basic Concept in Monte Carlo Simulation

# INTRODUCTION

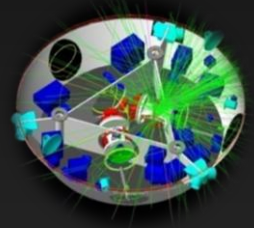
# What is Geant4?

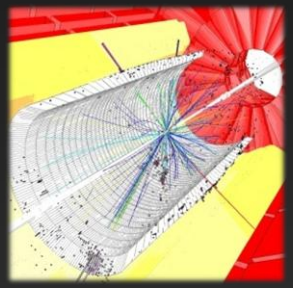




## A world-standard toolkit for HEP detector simulation

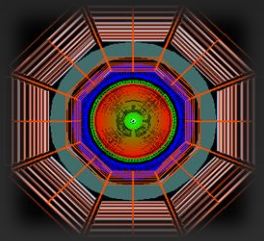
- Successor of GEANT3
- A successful project to re-design a HEP software using an Object-Oriented approach (C++)
  - ✓ for LHC experiments

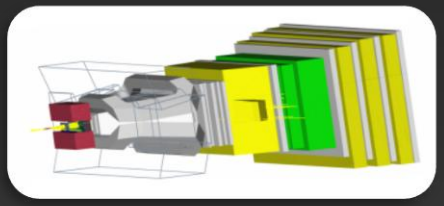


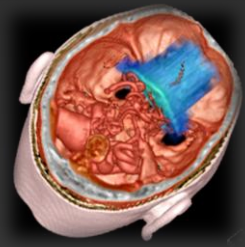


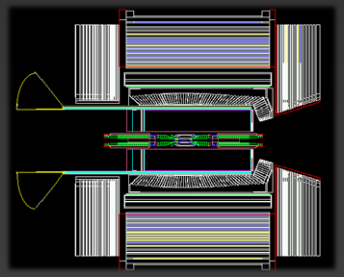
## A large degree of functionality and flexibility

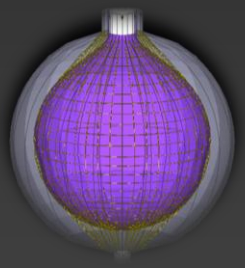
- Many application fields beyond HEP
- A variety of requirements from
  - ✓ HEP experiments, under ground experiments, cosmic ray physics, astrophysics, accelerator engineering, shielding studies, space science and medical applications

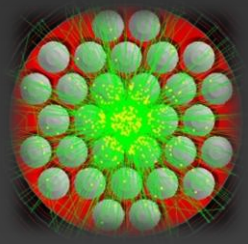




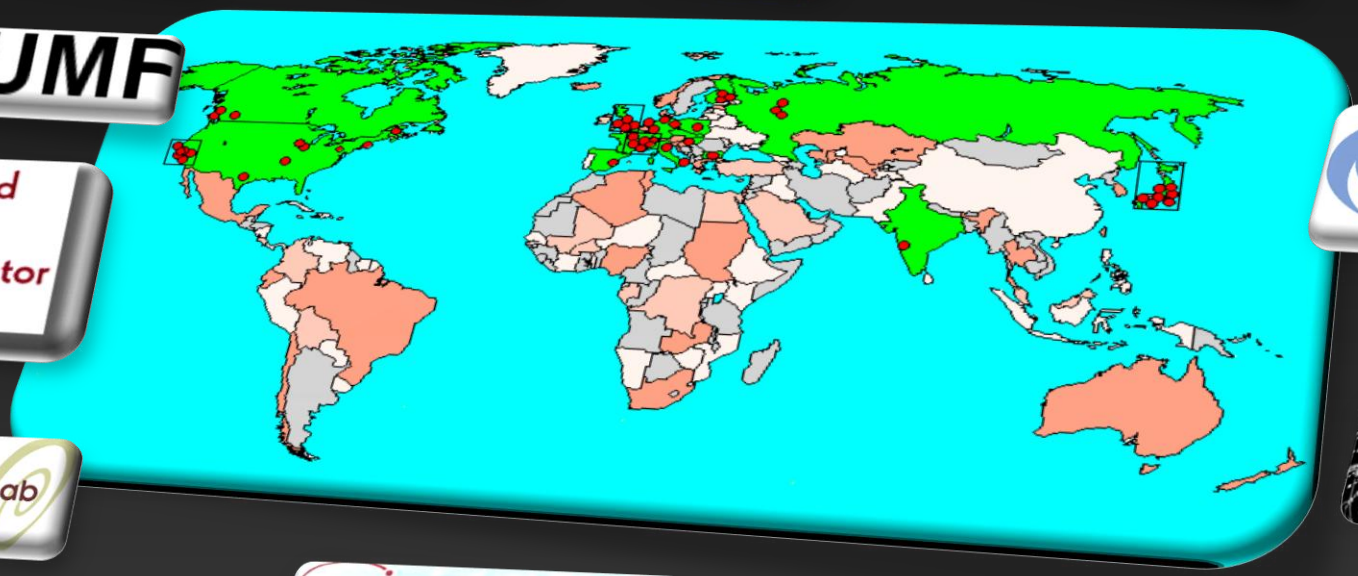








# Geant4 Collaboration



Collaborators also from non-member institutions, including
Budker Inst. of Physics
IHEP Protvino
MEPHI Moscow
Pittsburg University

# Geant4 at the LHC Today

Now Geant4 has become the standard simulation for ATLAS, LHCB, and CMS

| | ATLAS | CMS | LHCb |
|---|---|---|---|
| Transition to Geant4 (G3 stopped) | DC02 '04 | Nov '03 | May '04 |
| Produced # of events in DC | 12 M | 40 M | 80 M |
| CPU time (sec)/ event (2.8 Ghz) | 600 (pp→Z→ee)<br>700 (SUSY) | 200 (QCD jets)<br>60 (min bias) | 22-65 |
| Memory used | 400 Mb | 220 Mb | 220 Mb |
| # of placed volumes | 5 M | 1.2 M | 18 M |

No memory leaks!!

⇒ Observations:

- Geant4 in production is running now very stable/very few problems (~ $10^{-5}$)
- Transition to Geant4 has been a very smooth process for all experiments

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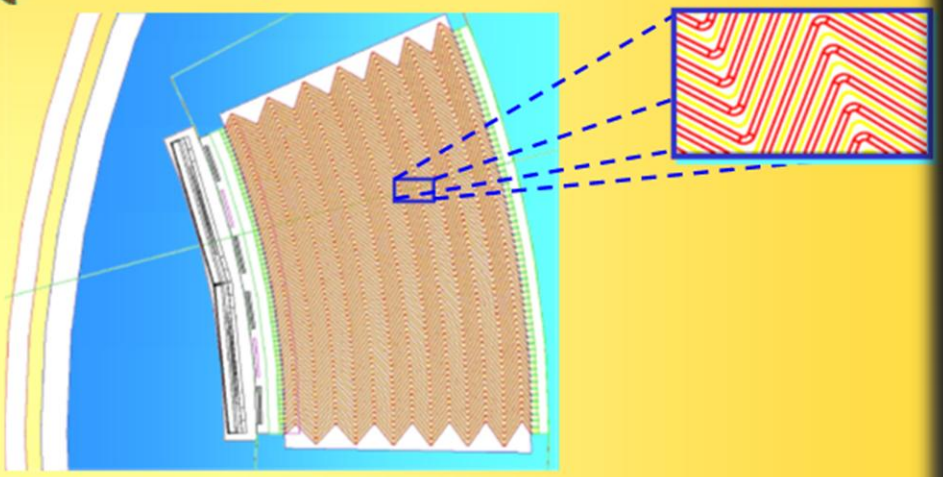
Peter Loch
University of Arizona
Tucson, Arizona 85721

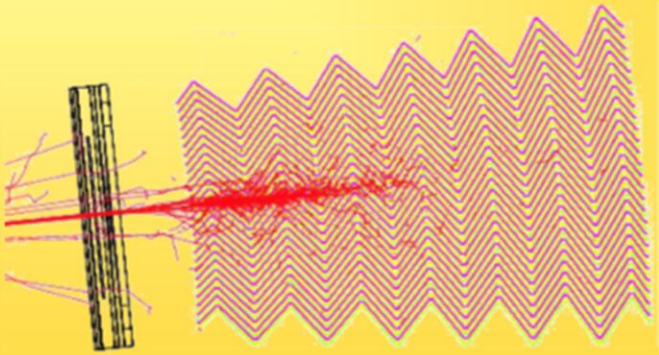
# Geant4 Setups (2)

## Forward Calorimeter (FCal) Testbeam Setup


## Electromagnetic Barrel Accordion Calorimeter



## 10 GeV Electron Shower



# Heavy-Ion Collisions

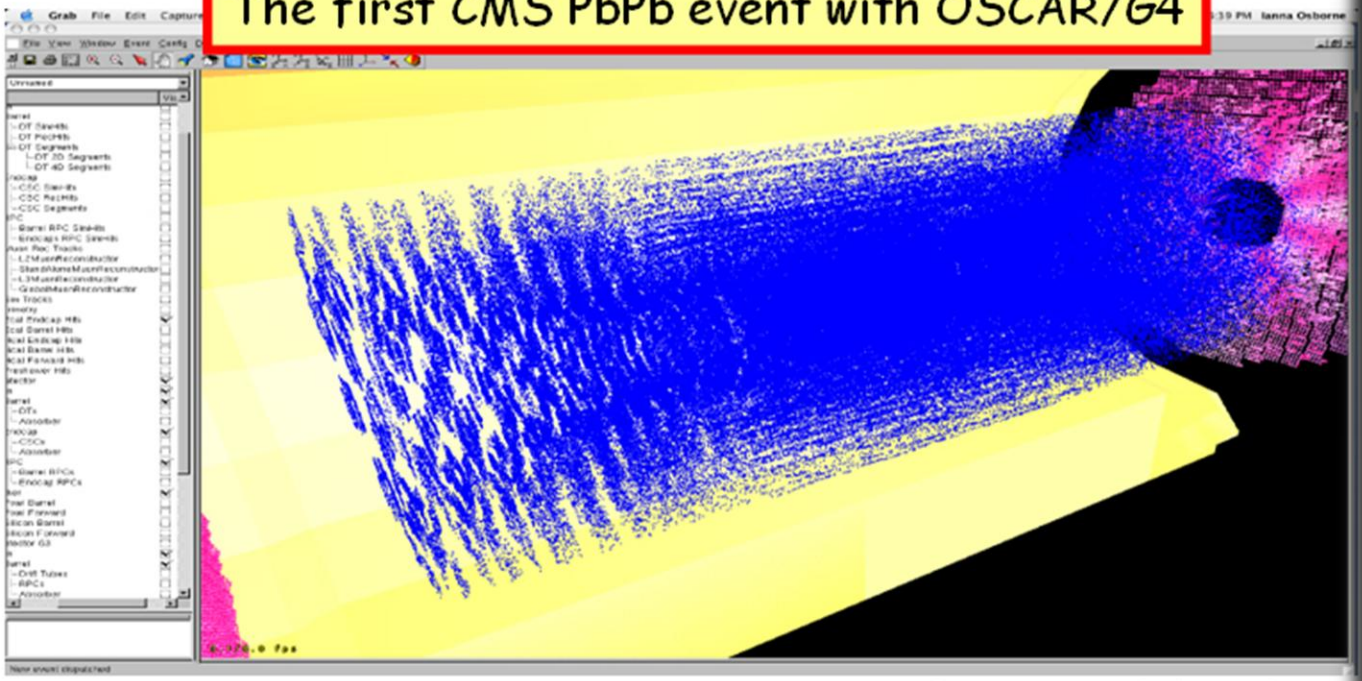
OSCAR/Geant4 can run full heavy ion events.

- Timing is good/Memory > 500 Mbyte (2GB memory machines used)
- Have now run > 100 events without problems

~ Timing for the first event with 55K generator tracks

| Program | CPU (2.8GHz) (min) |
|---|---|
| CMSIM | 230 |
| OSCAR 2_4_5 | 320 |
| OSCAR 3_4_0 | 180 |

The first CMS PbPb event with OSCAR/G4



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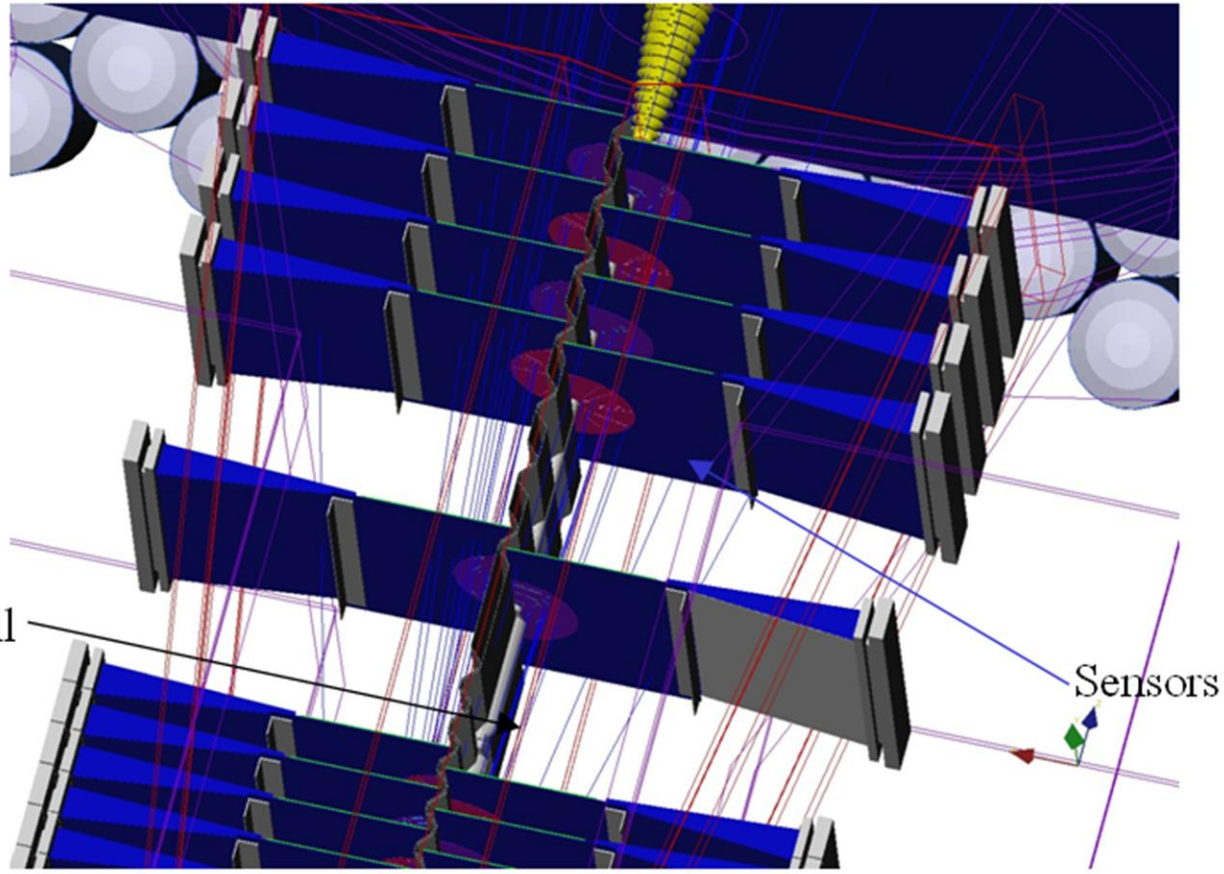
# Geant4 at the LHC Today




LHCb Vertex Locator description

Complicated geometry
Details are very important

Geant4 can handle it!!

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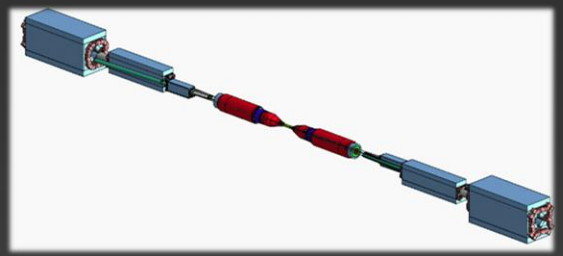
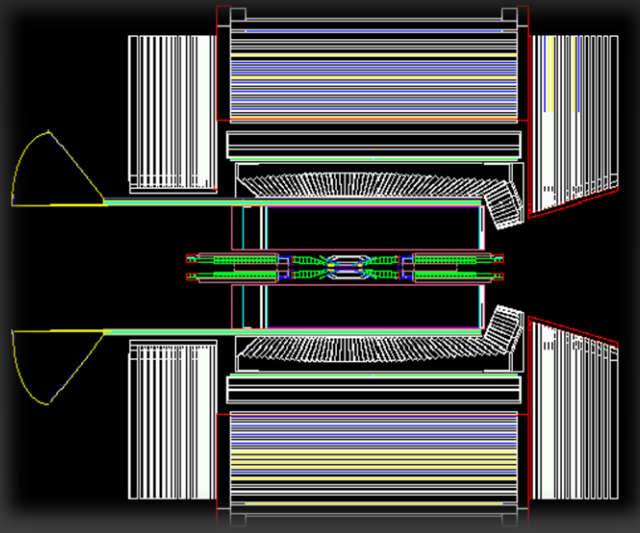
# BaBar

BaBar at SLAC is pioneer in the use of Geant4

- Started in 2000
- Simulated $10^{10}$ events so far
- Produced at 20 sites in North America and Europe
- Current average production rate  6.1 x $10^{7}$ events/week





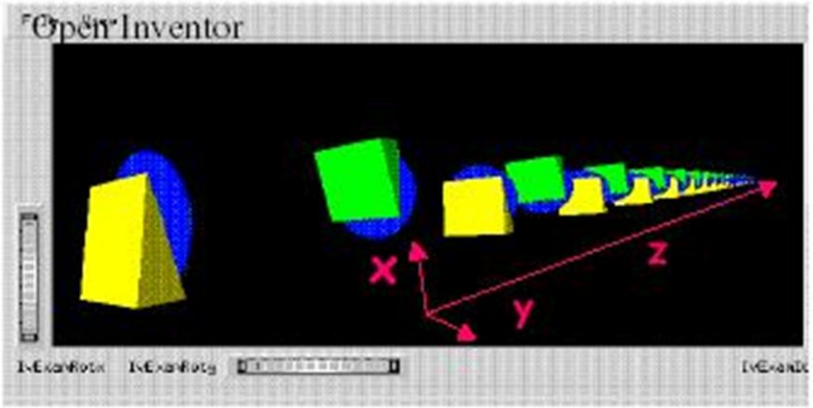
# Geant4 for beam transportation

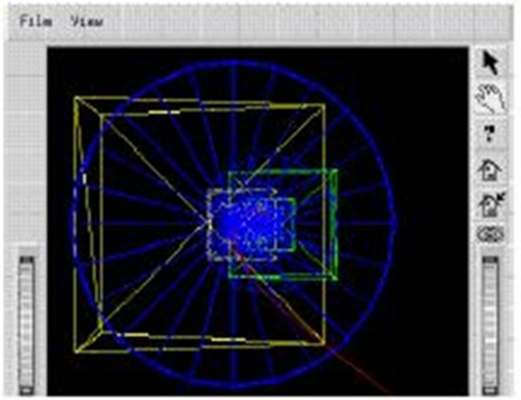
## Example: Helical Channel

Published in proc. of PAC 2001
(Fermilab-Conf-01-182-T)

72 m long solenoidal + dipole field with wedge absorbers and thin cavities

$$B_{xy} = B_T \cos,\sin\left(\frac{2p}{L} z\right) \qquad B_z = B_0$$

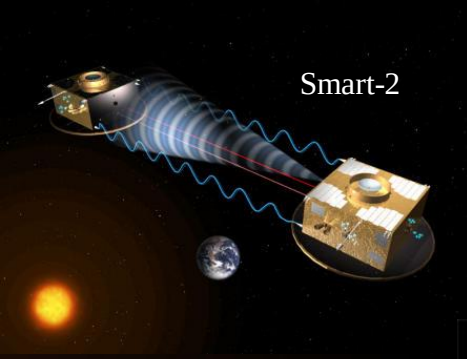


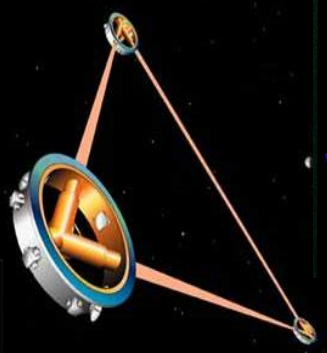

### Other simulations:

- Alternate Solenoid Channel (sFoFo), published in proceedings of PAC2001 and Feasibility Study II for a Neutrino Factory at BNL (2001)
- Bent Solenoid Channel, presented at Emittance Exchange Workshop, BNL 2000
- Low Frequency r.f. Cooling Channel, presented at International Cooling Experiment Workship, CERN 2001
- Cooling Experiment (MICE) Simulation (in progress)

*G4 Users Meeting, February 21st , 2002* *V. Daniel Elvira, Fermilab*

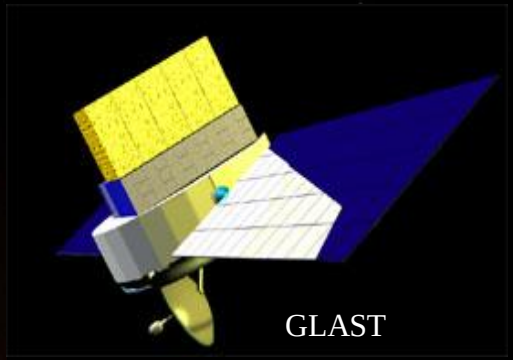

Smart-2

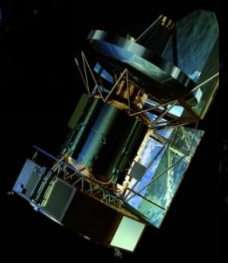

ACE

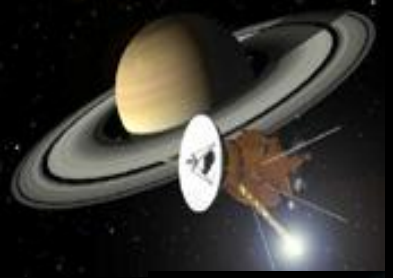

LISA


INTEGRAL
Cassini


Bepi Colombo


GLAST


Herschel

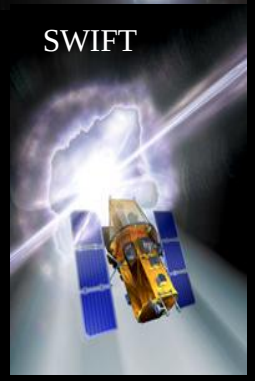



Astro-E2

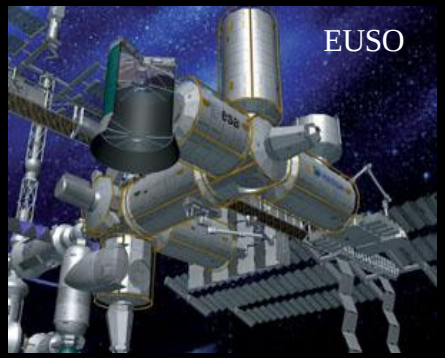

XMM-Newton

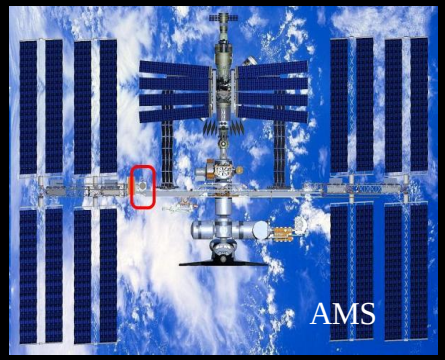

GAIA

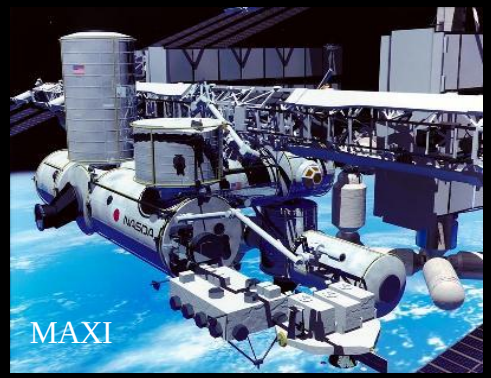

JWST

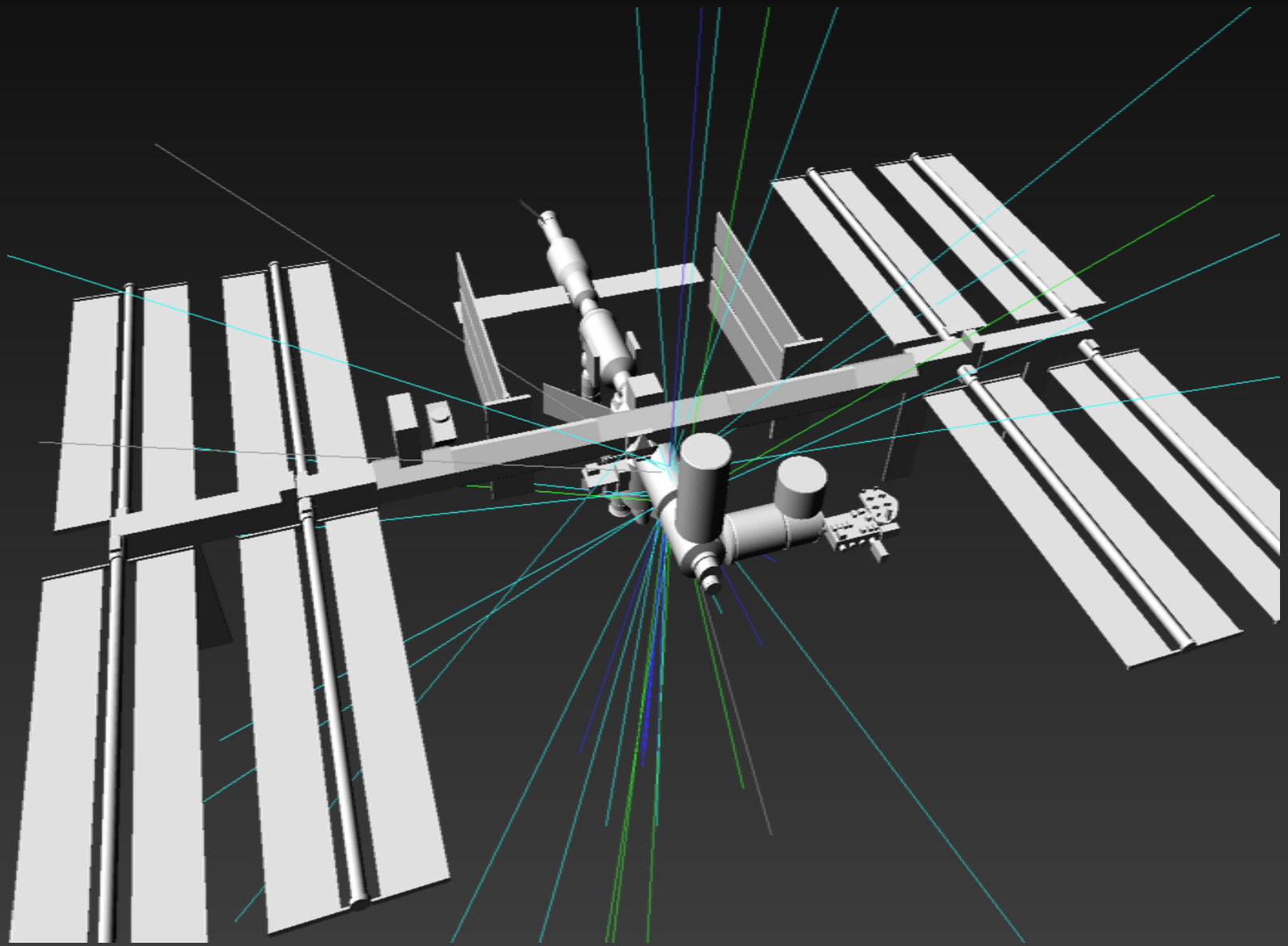

SWIFT


ISS Columbus

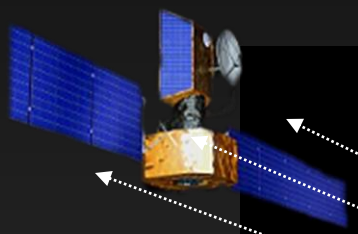

EUSO

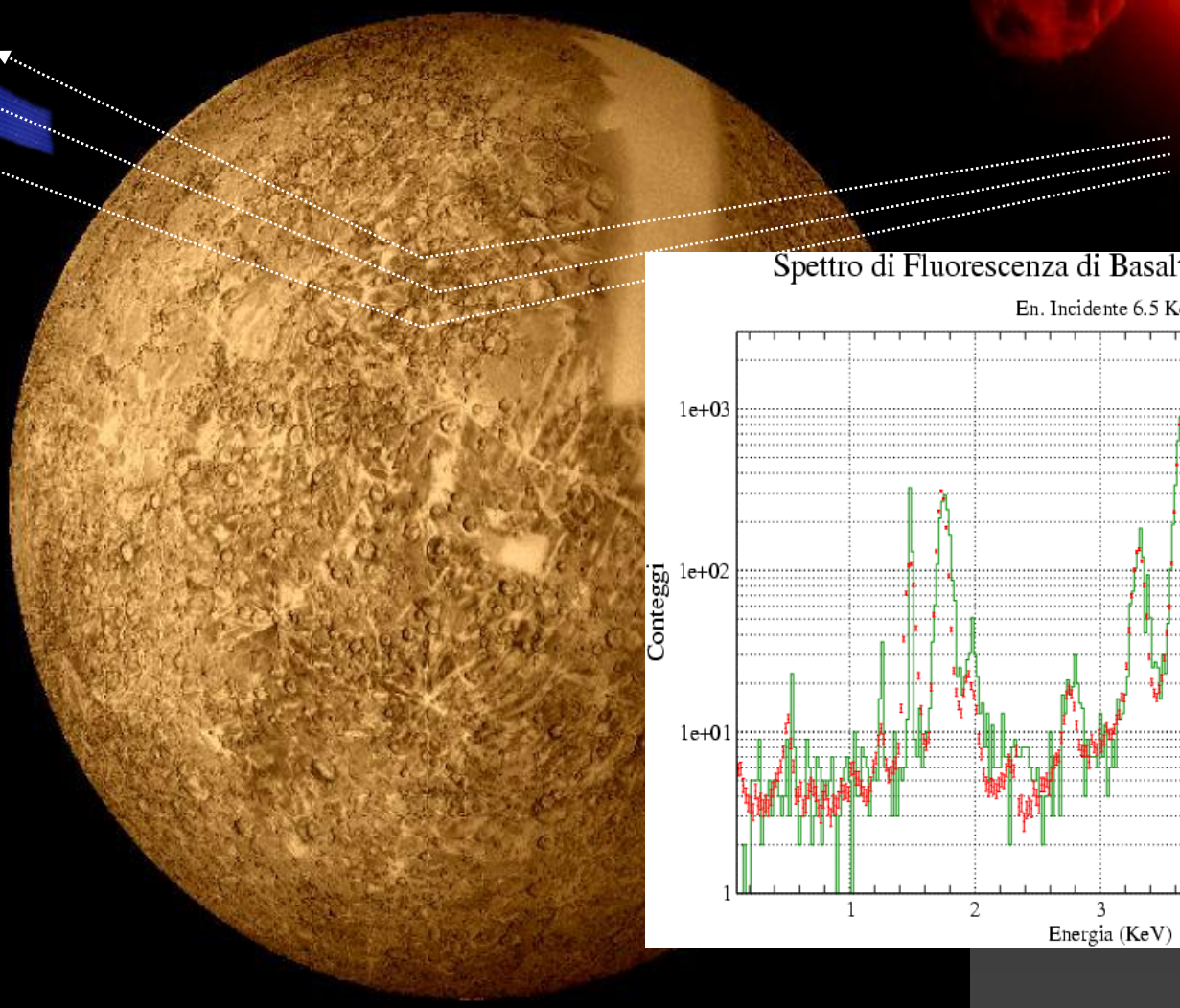

AMS


MAXI

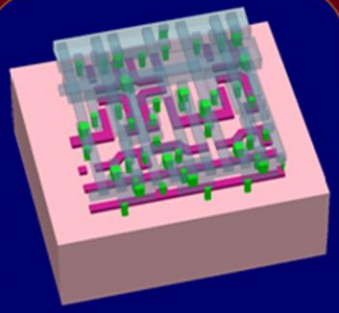


# Bepi Colombo: X-Ray Mineralogical Survey of Mercury

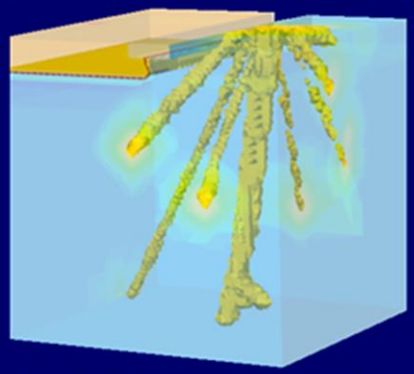




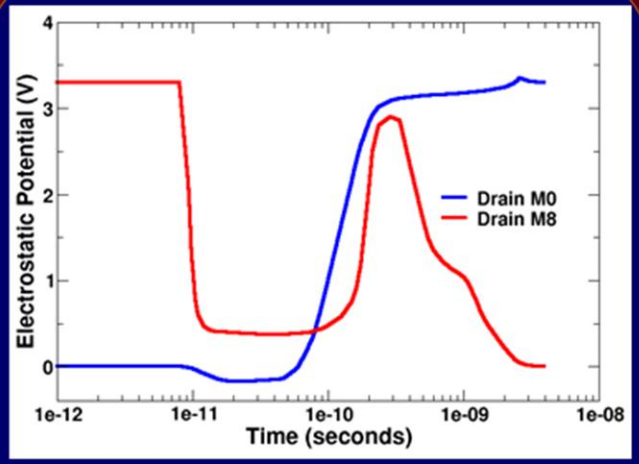
# RADSAFE on SEE in SRAMs



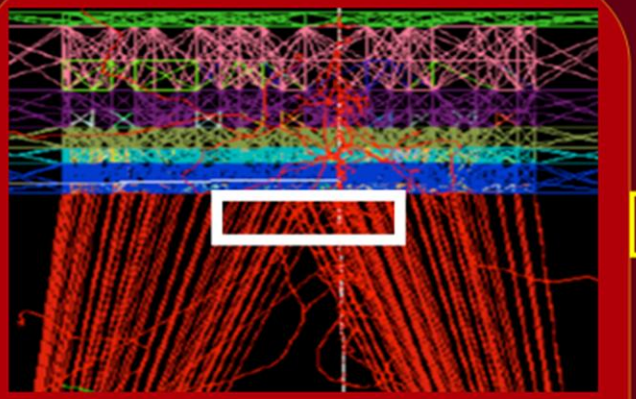
TCAD Cell Structure: SRAM Cell



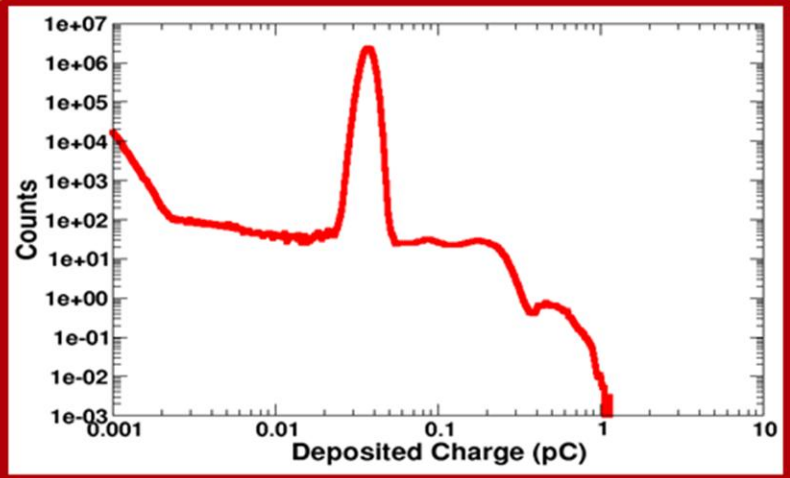
Single Charge Deposition in TCAD: Ne+W Event




SRAM Cell Upset

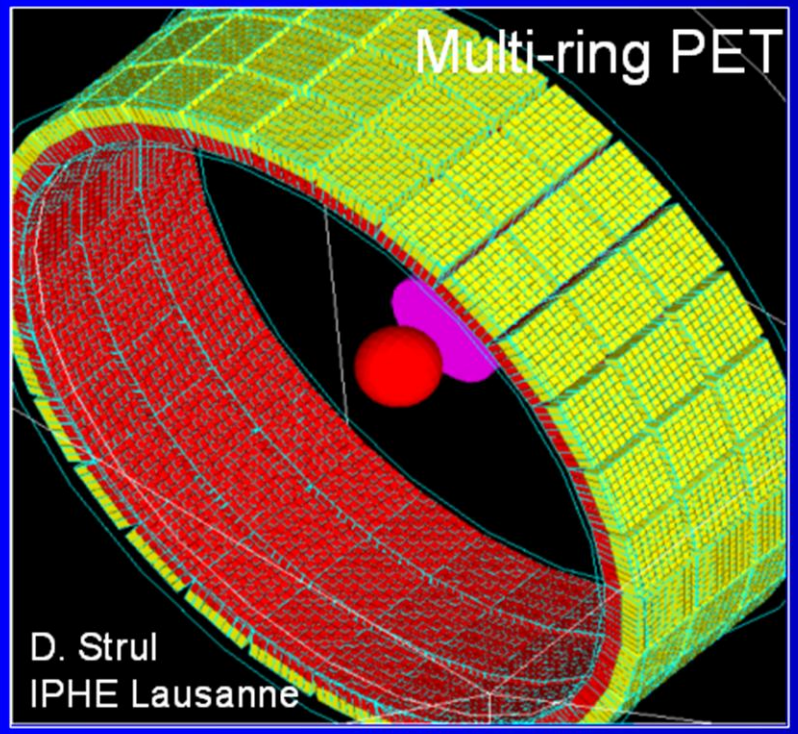


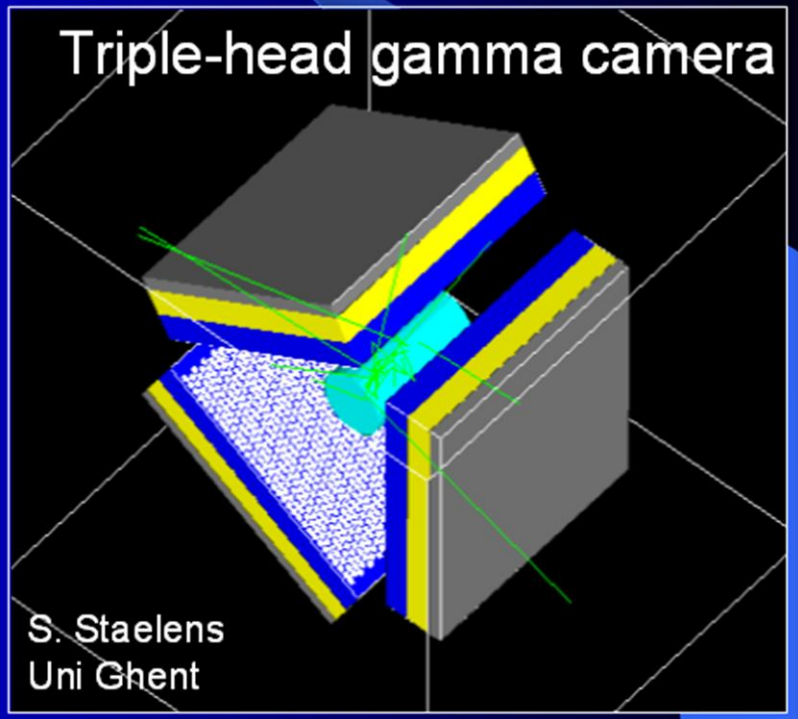
Geant4 Geometry and 523 MeV Neon Event




MRED Energy Deposition for $10^8$ Events

# Geometry examples of GATE applications

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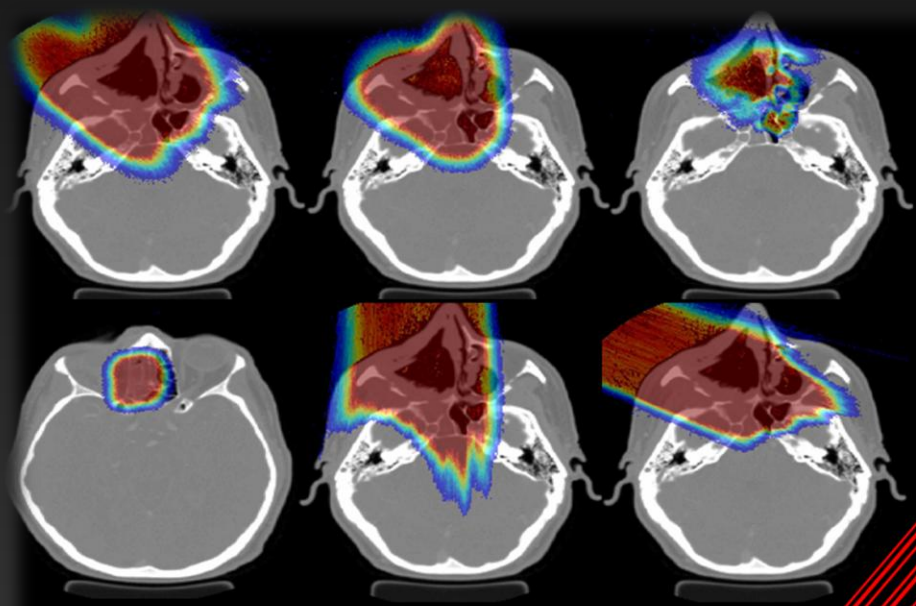
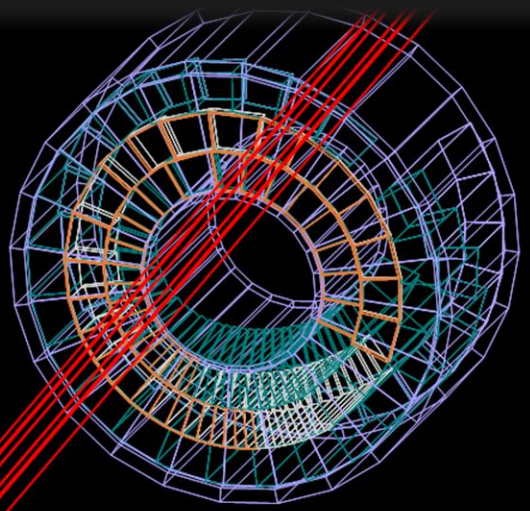
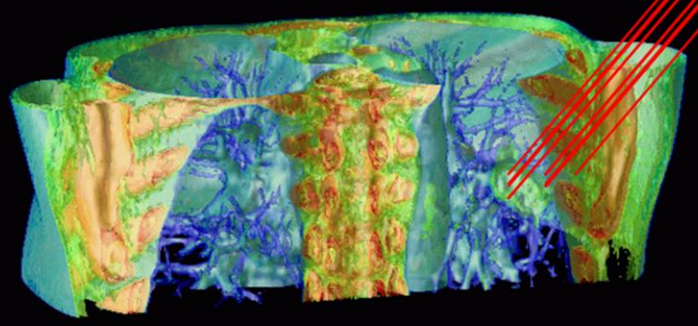
# GEANT4 based proton dose calculation in a clinical environment: technical aspects, strategies and challenges



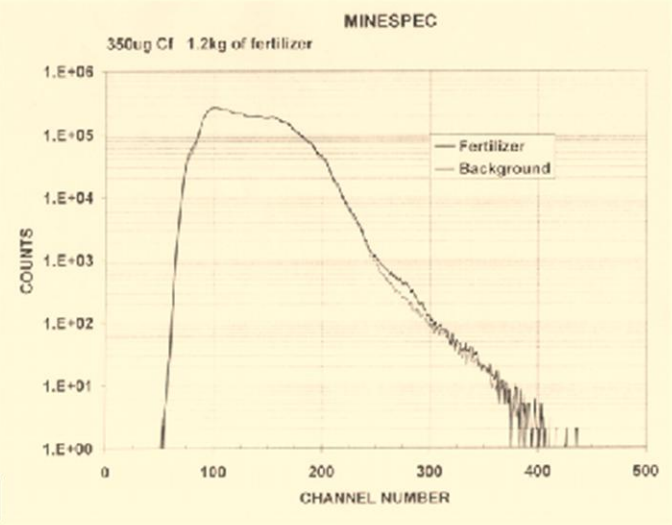




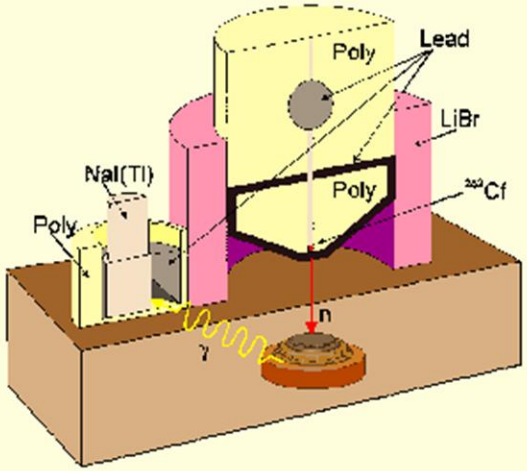
MASSACHUSETTS GENERAL HOSPITAL

HARVARD MEDICAL SCHOOL

# Thermal Neutron Activation




- TNA detects explosive by properties of constituents
  - High concentration of N
  - Does not ID explosive
- Can confirm presence of all surface laid or shallow AT mines in few seconds to 1 minute
- AT up to 20 cm deep and large AP mines in < 5 minutes

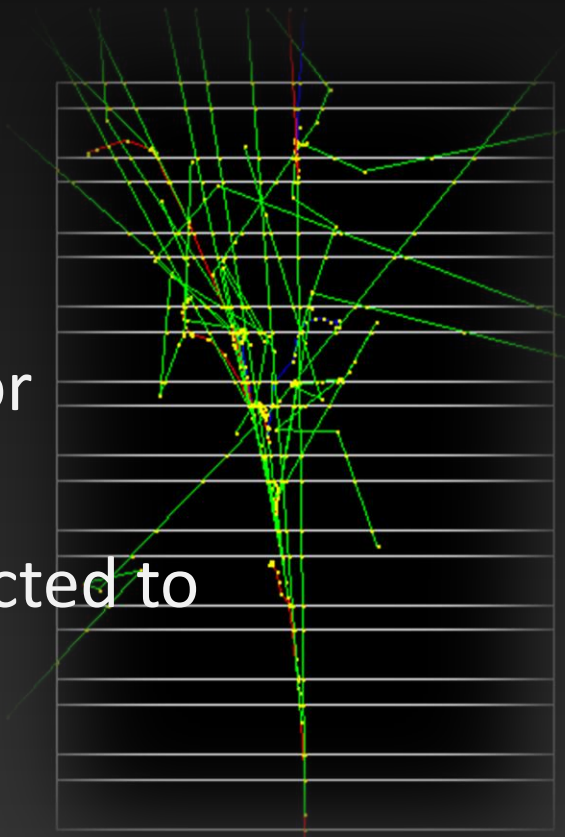



**Defence Research Establishment Suffield • Centre de recherches pour la défense, Suffield**

A. A. Faust, Geant4 User's Workshop, SLAC 2002 02 21

# GEometry ANd Tracking

General characteristics of detector simulation programs:



- specifying the *geometry* of a detector
- *transporting (tracking)* particles injected to the detector
- simulating the particle interactions in matter based on the *Monte Carlo technique*

# MC Simulation – *Exponential law*

$f(x)$ : probability of not having interaction after a distance $x$

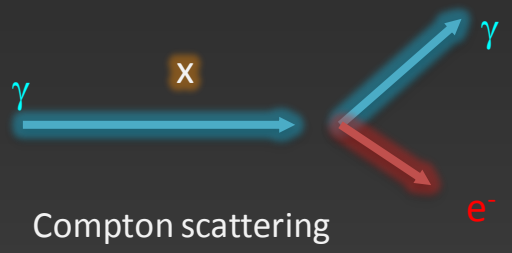
Microscopically,

$wdx$ : prob. of having interaction in $[x, x+dx]$

- $w = N_{at}\sigma$ : # atoms/unit x cross section
- $\lambda = 1/w$ : *interaction length / lifetime*

$$f(x+dx) = f(x)\,(1-wdx)$$

$$f(x) = exp(-x/\lambda)$$



Compton scattering

# MC Simulation – *How to randomize*

Interaction Probability in $[x, x+dx]$:

$$P(x)dx = f(x)\,w\,dx$$

- ✓ $P(x)$ : *Probability density function*

$$1 = \int_0^\infty P(x)dx = \int_0^\infty f(x)wdx = \int_0^\infty \frac{1}{\lambda}\exp\left(-\frac{x}{\lambda}\right)dx = \int_0^1 dr$$

$$r = \exp\left(-\frac{x}{\lambda}\right), \quad dr = -\frac{1}{\lambda}\exp\left(-\frac{x}{\lambda}\right)dx$$

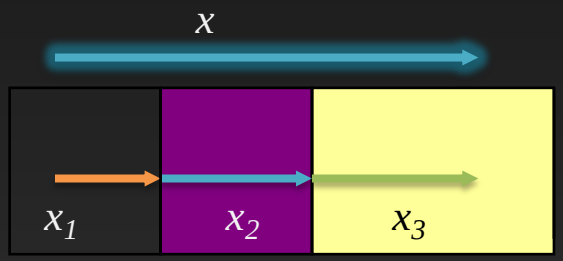
Interaction Point ($x$) can be generated by

$n_\lambda = x/\lambda = -\ln(r)$, with $r$ uniform in $[0, 1]$

# Practically, …

- $\lambda$ and $x$ are dependent of materials
- One can define the *number of interaction length* :

$$n_\lambda = \frac{x_1}{\lambda_1} + \frac{x_2}{\lambda_2} + \frac{x_3}{\lambda_3}$$




- $n_\lambda$ is independent of materials !

In a MC program,

- sample $n_\lambda$ at origin of the track (*fate*) : $n_\lambda = -\ln(r)$
- update elapsed $n_\lambda$ along the track : $n_\lambda = n_\lambda - d\lambda_i / \lambda_i$
- generate an interaction when $n_\lambda = 0$
- $n_\lambda$ is managed by each process

Basic concepts

# KERNEL STRUCTURE

# Terminology a.k.a. Jargons


*Analogy to the real HEP experiment / the real world (OO)*

Run, Event, Track, Step, Step Point

- XXXManager, XXXUserAction,…

DetectorConstruction

- LogicalVolume, PhysicalVolume, Parameterized, …

Primary, Vertex

- PrimaryGeneratorAction, ParticleGun, …

Process

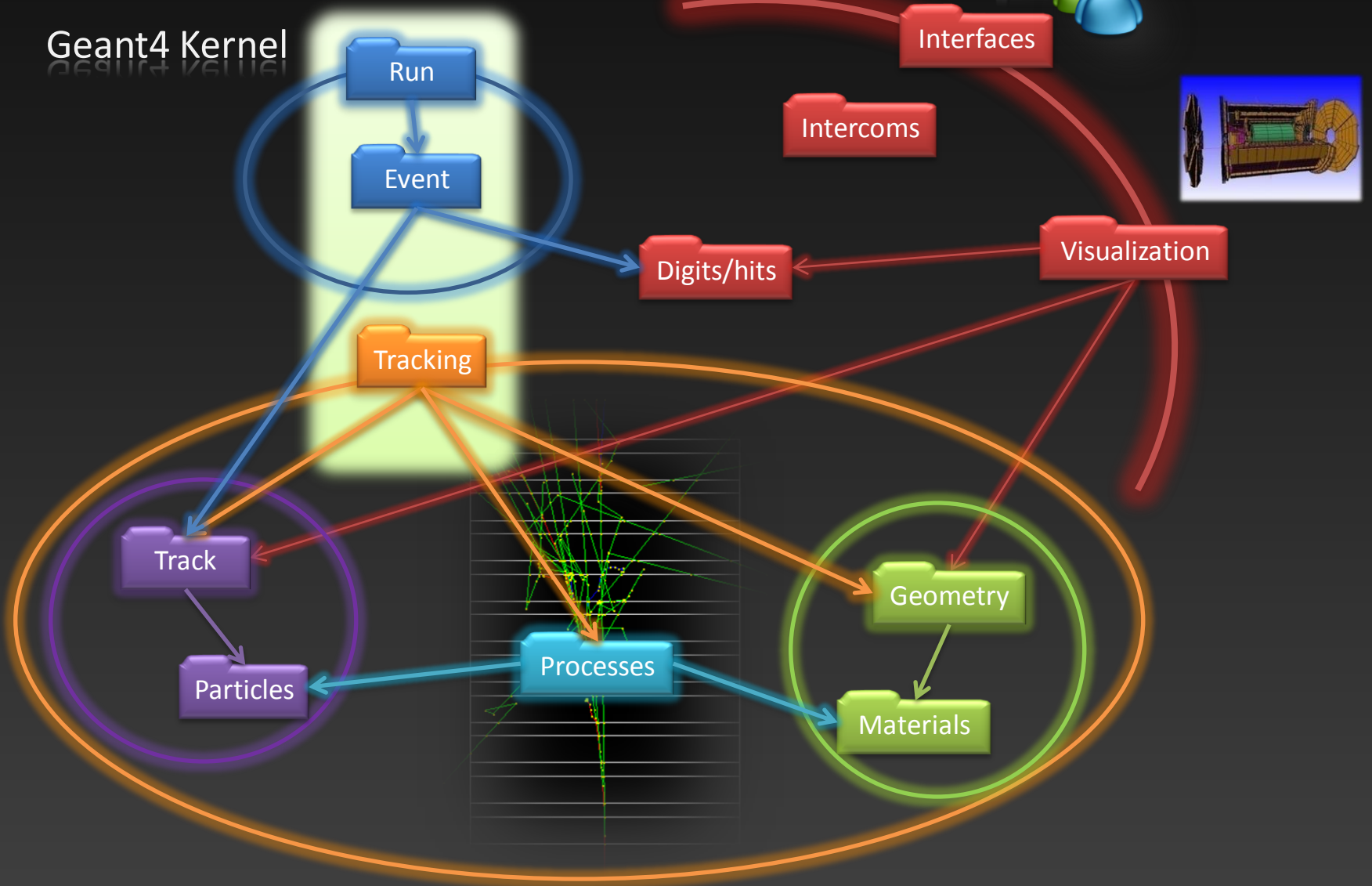
- At rest, Along Step, Post Step
- PhysicsList, …
- ParticleDefinition, Dynamic Particle, …
- Cut = Production Threshold

Sensitive Detector, Hit, Hits Collection

Trajectory / Trajectory Point

…

# Geant4 Overall Structure



# Run in Geant4

G4RunManager class manages processing a run.

- A run is represented by G4Run class, which has summary results of each run.
- Within a run, users cannot change
  - ✓ detector setup
  - ✓ settings of physics processes
- Conceptually, a run is a collection of "*events*" (G4Event).
- G4UserRunAction class is an optional user hook.

A run of Geant4 is started by saying "*Beam On*".

- Practically, we call "*run beam on*" as executing a UI command "*/run/beamOn*".
- At the beginning of a run, geometry is optimized for navigation and cross section tables are calculated according to materials in the geometry.

# Event in Geant4

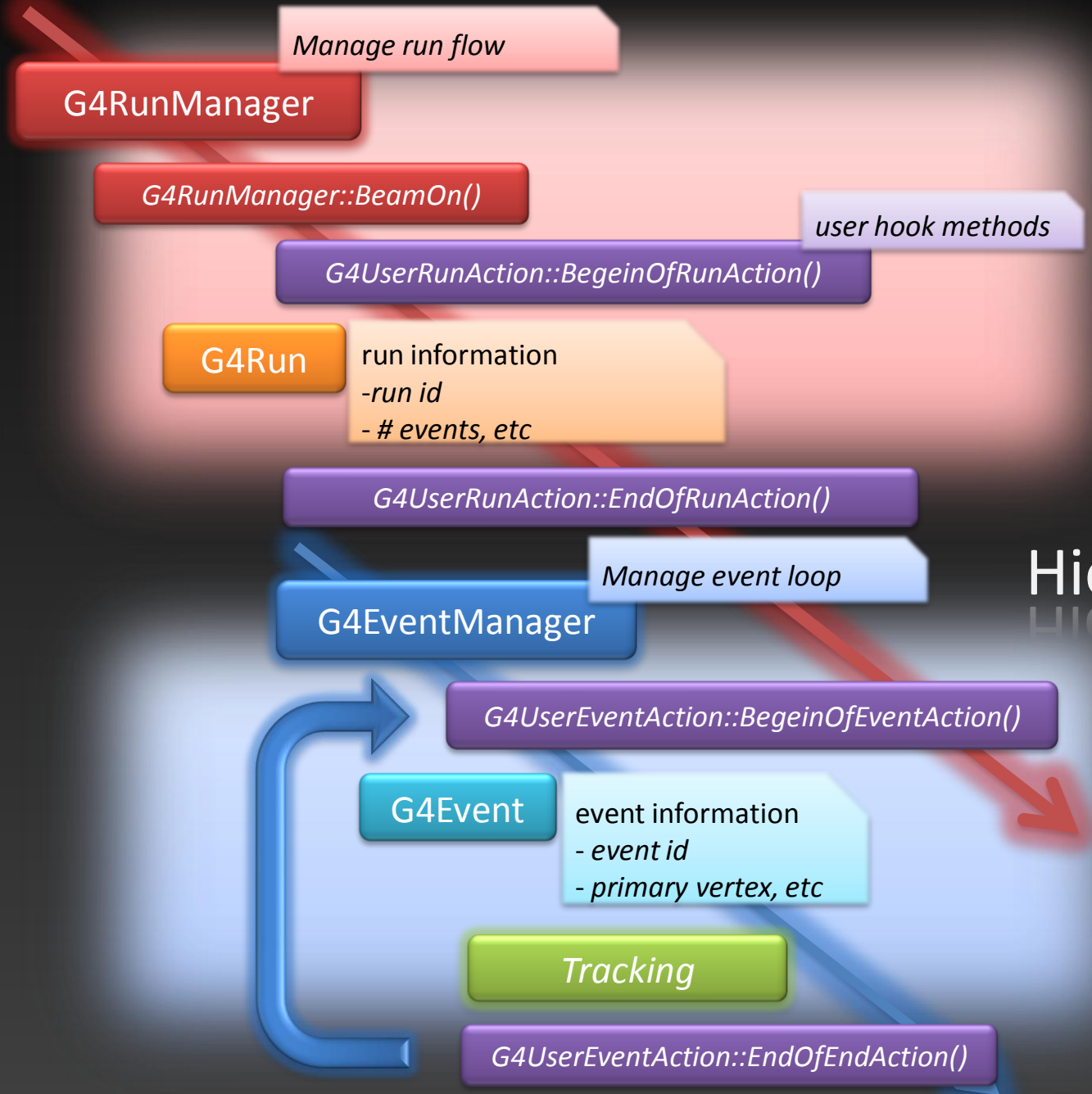
An event is the basic unit of simulation.

G4EventManager class manages processing an event.

- At the beginning of processing, primary tracks are generated and pushed into a *stack*.
- A track is popped up from the stack one by one and "*tracked*".
  - ✓ Resulting secondary tracks are also pushed into the stack.
- When the stack is empty, event processing is over.
- G4UserEventAction is an optional user hook.

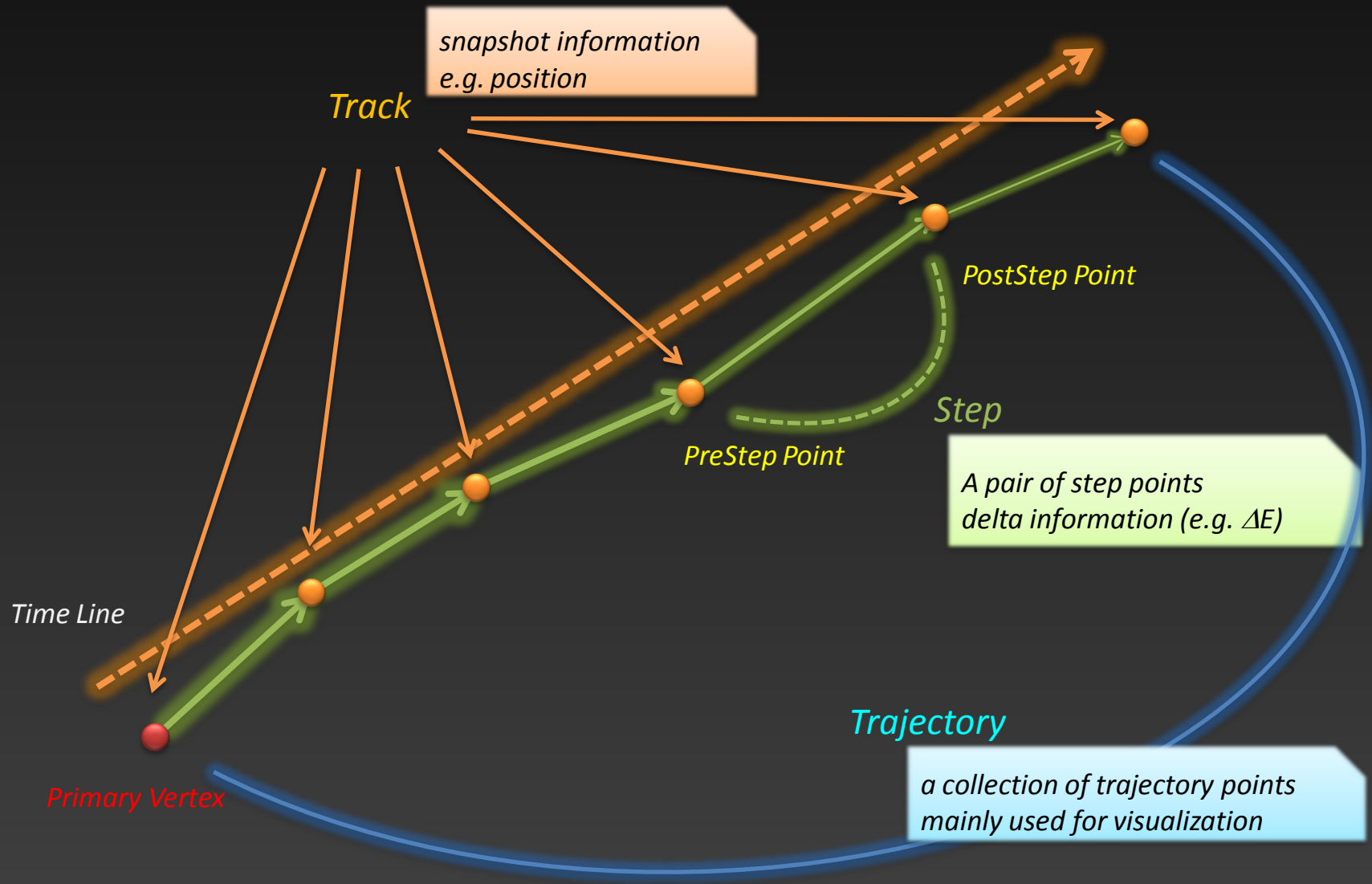
G4Event class represents an event.

- List of primary vertices and particles (as input)
- Hits and Trajectory collections (as output)




# Run/Event Hierarchy/Flow

# Tracking a particle, *Track, Step, Step Point, and Trajectory*



# Track in Geant4

Track is a *snapshot* of a particle.

- It has physical quantities of current instance only, being updated by steps.
- No track object persists at the end of event.
  - ✓ For recording tracks, use *trajectory* objects.

G4TrackingManager manages processing a track

- A track is represented by G4Track class.
- G4UserTrackingAction is an optional user hook.

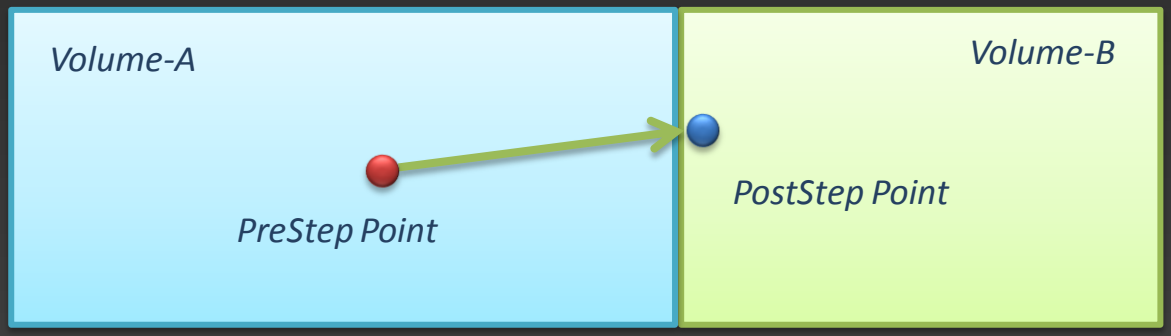
# Step/Step Point in Geant4

Step has *two points* (G4StepPoint, *pre-/post- step point*) and also "*delta*" information of a particle

- energy loss, TOF spent by the step, etc.
- In case a step is limited by a volume boundary, the *post-step point* physically stands on the boundary, but *logically belongs to the next volume*.
  - ✓ Boundary processes such as transition radiation or refraction require material information in both volumes

G4SteppingManager class manages processing a step

- a step is represented by G4Step class.
- G4UserSteppingAction is an optional user hook.



# Trajectory and Trajectory Point

G4Trajectory class copies some of G4Track information.

G4TrajectoryPoint class copies some of G4Step information.

- Track does not keep its trace.
- G4Trajectory has a collection of G4TrajectoryPoint.
- Given G4Trajectory/G4TrajectoryPoint objects persist until the end of an event.
- G4Event has a collection of G4Trajectory objects.
  - ✓ `/tracking/storeTrajectory` must be set to 1.
- They are mainly used for visualization.

# Track status

At the end of each step, the state of a track may be changed.

- The user can also change the status in *UserSteppingAction/UserStackingAction*.
- Statuses shown in *blue* are artificial, i.e. Geant4 kernel does not set them.

`fAlive`
- Continue the tracking.

`fStopButAlive`
- The track has *come to zero kinetic energy*, but still "AtRest" process to occur.

`fStopAndKill`
- The track has lost its identity because it has decayed, interacted or *gone beyond the world boundary*.
- used for forcedly killing an unnecessary track

`fKillTrackAndSecondaries`
- Kill the current track and also associated secondaries.

`fSuspend`
- Suspend processing of the current track and push it and its secondaries to the stack.

`fPostponeToNextEvent`
- Postpone processing of the current track to the next event.
- Secondaries are still being processed within the current event.

# Step status

Step status is attached to G4StepPoint to indicate why that particular step was determined.

- Use "*PostStepPoint*" to get the status of *this step*.
- "*PreStepPoint*" has the status of *the previous step*.

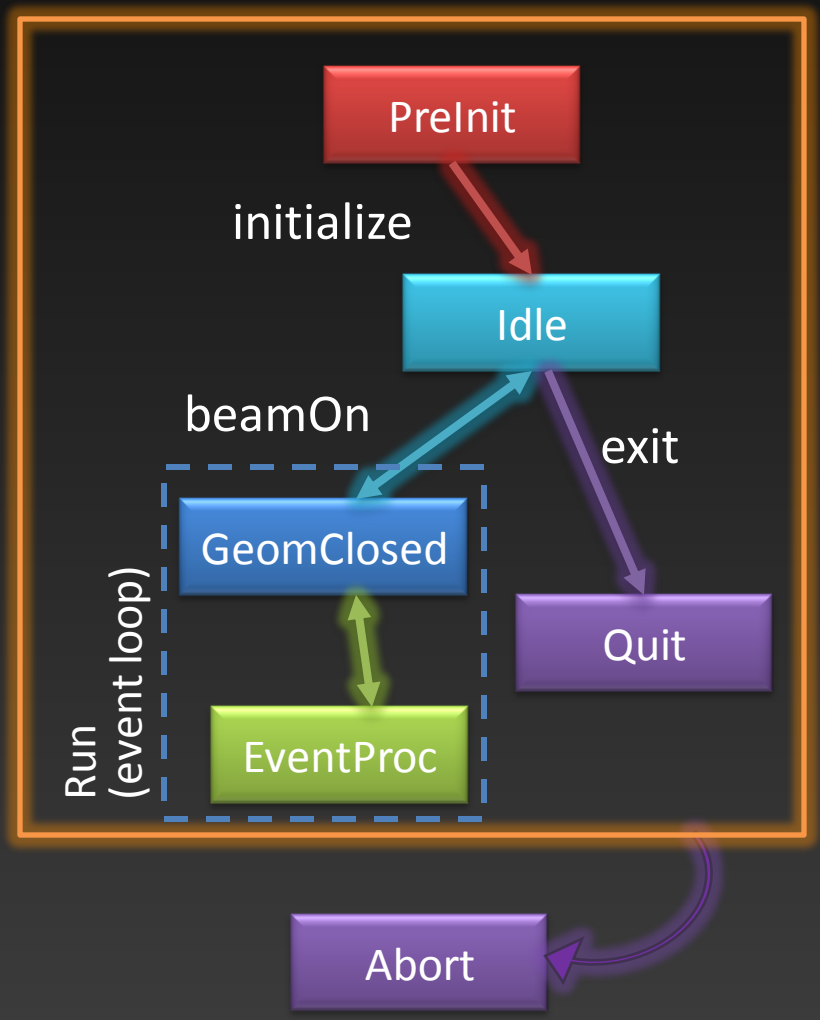
- `fWorldBoundary`
  - ✓ Step reached the world boundary
- `fGeomBoundary`
  - ✓ Step is limited by a volume boundary except the world
- `fAtRestDoItProc, fAlongStepDoItProc, fPostStepDoItProc`
  - ✓ Step is limited by a AtRest, AlongStep or PostStep process
- `fUserDefinedLimit`
  - ✓ Step is limited by the user Step limit
- `fExclusivelyForcedProc`
  - ✓ Step is limited by an exclusively forced (e.g. shower parameterization) process
- `fUndefined`
  - ✓ Step not defined yet

- If you want to identify *the first step in a volume*, pick fGeomBoudary status *in PreStepPoint*.
- If you want to identify the step getting out of a volume, pick fGeomBoundary status *in PostStepPoint.*

# Geant4 as a state machine

Geant4 has *6 application states*.

- G4State_PreInit
  - ✓ Material, Geometry, Particle and/or Physics Process need to be initialized/defined
- G4State_Idle
  - ✓ Ready to start a run
- G4State_GeomClosed
  - ✓ Geometry is optimized and ready to process an event
- G4State_EventProc
  - ✓ An event is processing
- G4State_Quit
  - ✓ (Normal) termination
- G4State_Abort
  - ✓ A fatal exception occurred and program is aborting



Documentations

User support process

License

# USER SUPPORT

# Geant4 Web Pages

*Download from here*

Geant 4

Download | User Forum | Gallery | Site Index
Contact Us
Search Geant4

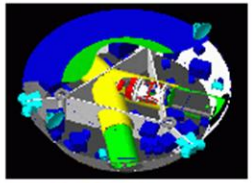
**Geant4** is a toolkit for the simulation of the passage of particles through matter. Its areas of application include high energy, nuclear and accelerator physics, as well as studies in medical and space science. The two main reference papers for Geant4 are published in *Nuclear Instruments and Methods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

*Reference*

**Applications**

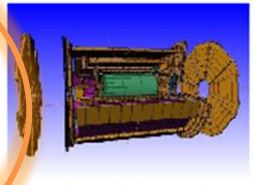
A sampling of applications: technology transfer and other uses of Geant4

**User Support**



Getting started, user guides and information for developers

**Results & Publications**



Validation of Geant4, results from experiments and publications

**Collaboration**

Who we are: collaborating institutions, members, organization and legal information

**News**

- *18 September 2007* - GDML 2.10.0 released.
- *28 August 2007* - **Patch-01** to **release 9.0** is available from the download area.
- *17 August 2007* - **Patch-01** to **release 8.3** is available from the archive download area.
- *23 March 2007* - 2007 planned developments.

**Events**

- 5th Geant4 Space Users' Workshop, University of Tokyo, Tokyo (JP), **13-15 February 2008**.
- **Past events**

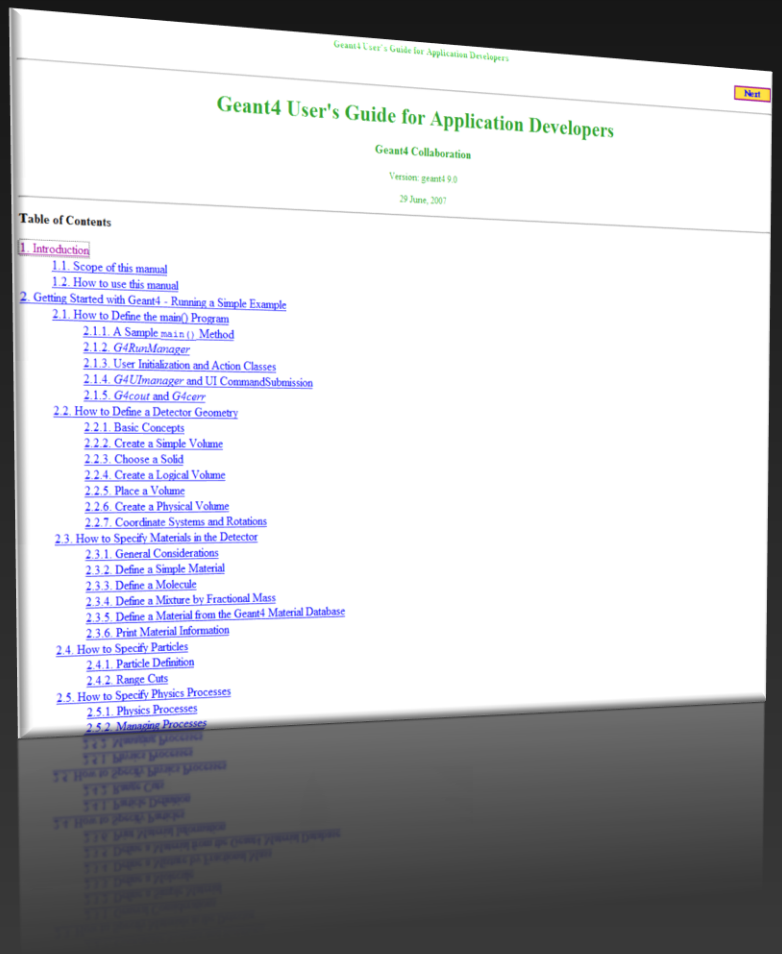
http://geant4.web.cern.ch/geant4

Applications | User Support | Results & Publications | Collaboration | Site Map

Contact Webmaster

Last updated: 04 Oct 2007

# Geant4 Documents




Introduction of Geant4

Installation Guide

User's Guide: For Application Developers

- *You must read it!!*

User's Guide: For Toolkit Developers

Physics Reference Manual

Software Reference Manual

# Installation Guide

*http://geant4.web.cern.ch/geant4/G4UsersDocuments/UsersGuides/InstallationGuide/html/index.html*

List of *required* software

- C++ compiler, CLHEP, GNU make, Geant4 toolkit
- choices for visualization software

How to install on Linux

Tips for installing on Windows

SLAC team provides a good practical installation guide:
*http://geant4.slac.stanford.edu/installation/*

*In the practical viewpoint, we recommend Geant4 on*

# Application Developper Guide

*http:// geant4.web.cern.ch/geant4/G4UsersDocuments/UsersGuides/ForApplicationDeveloper/html/index.html*

Most important document both for novice & advanced users.

- Step-by-step tutorial for novice users
- Describes how to set up and run a simulation application with a lot of example codes
- *You should read this first if you are new to G4.*

Intended as an overview of the toolkit, not an exhaustive treatment. For more details:

- *Physics Reference Manual*
- *Toolkit Developers Guide*

# Physics Reference Manual

*http://geant4.web.cern.ch/geant4/UserDocumentation/UsersGuides/PhysicsReferenceManual/html/PhysicsReferenceManual.html*

Dedicated to the detail description of the physics model used in each Geant4 interaction process.

- separate physics topics from how to use the toolkit
- Dedicated to physics models, theories, etc
  - ✓ There are no C++ codes.
  - ✓ *You should read this when you start to wonder what is going on behind the scene.*

# LXR Code Browser

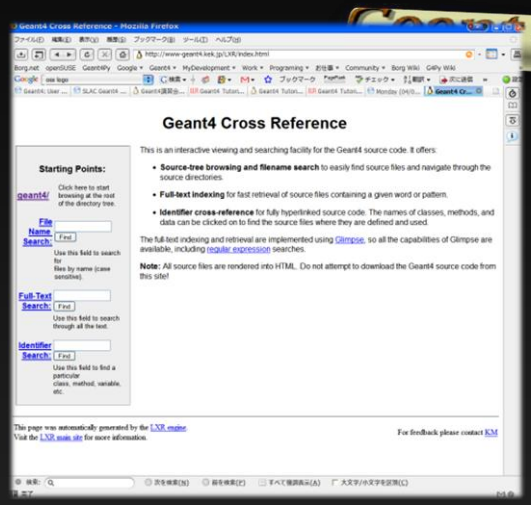
*http://www-geant4.kek.jp/LXR/*

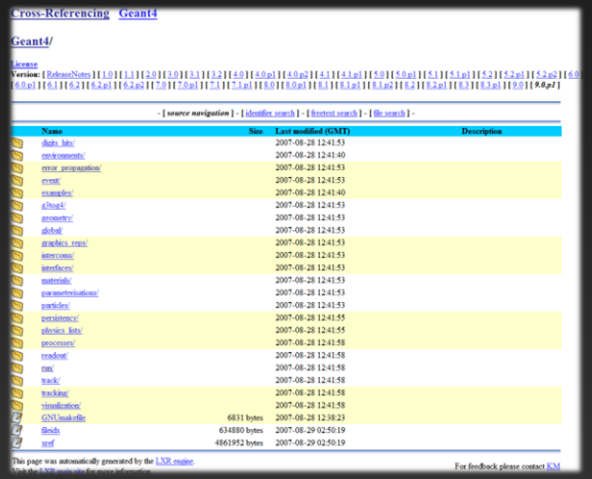
Search the entire Geant4 source trees by

- *filename (e.g. G4Track.hh)*
- *text*
- *identifier*

*Source files fully hyper-linked to classes and methods;*

- tells where classes and methods are defined
- also where they are referenced




# User Supports

Geant4 Collaboration offers extensive user supports.

- Technical Forum
- Users workshops and Tutorial courses
- HyperNews and mailing list
- Problem tracking system
- Daily “private” communications

# Technical Forum

The Technical Forum is open to all interested parties

- To be held at least 4 times per year

The purpose of the forum is to:

- Achieve, as much as possible, a mutual understanding of the needs and plans of users and developers.
- Provide the Geant4 Collaboration with the clearest possible understanding of the needs of its users.
- Promote the exchange of information about physics validation performed by Geant4 Collaborators and Geant4 users.
- Promote the exchange of information about user support provided by Geant4 Collaborators and Geant4 user communities.

# Geant4 Users/Collaboration Workshop and Tutorials

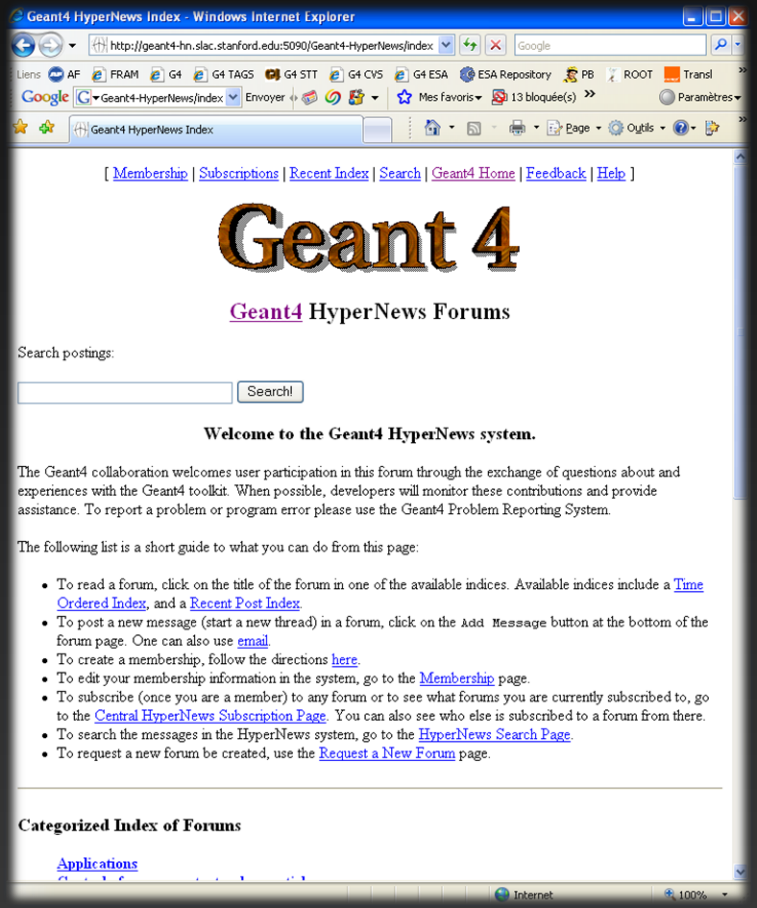
Users/Collaboration workshops were held.

- Catania - Oct. 2004
- Bordeaux - Nov.2005
- Lisbon - Oct. 2006
- Manchester - Sep. 2007
- Kobe - Sep. 2008

Local workshops/tutorials were organized various places *for different user communities.*

- SLAC/FNAL/ Jefferson : users workshops, tutorials
- NASA/ESA : space users workshops
- KEK : users workshops, tutorials
- IN2P3: tutorials
- INFN : tutorials
- IEEE/MIC : tutorials
- …

# HyperNews User Forum

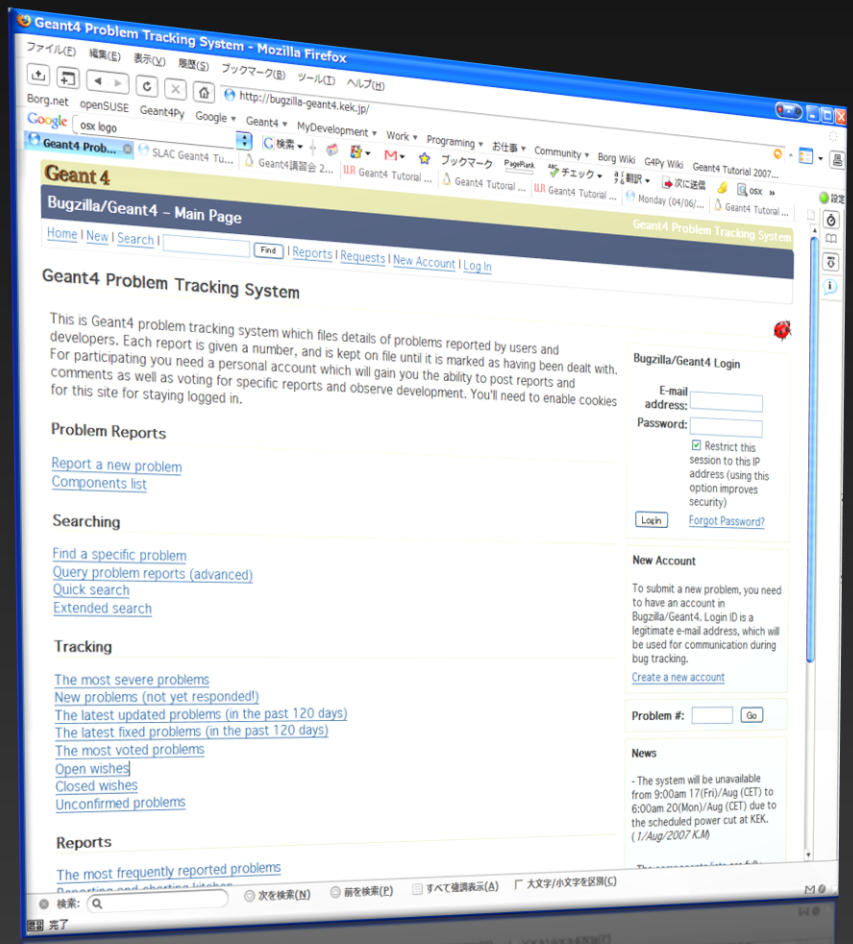



*http://geant4-hn.slac.stanford.edu:5090/Geant4-HyperNews/index*

Discuss problems with other users, post questions for experts, etc.

- 18 forums roughly based on Geant4 categories
- 4 forums for specific application areas (education, medicine, space, industry)
- New forums may be requested by users

# Geant4/Bugzilla




*http://bugzilla-geant4.kek.jp/*

Geant4 Problem Tracking System based on *Bugzilla*

- *Archives and tracks details of problems reported by users and developers*

# Geant4 Reference Papers

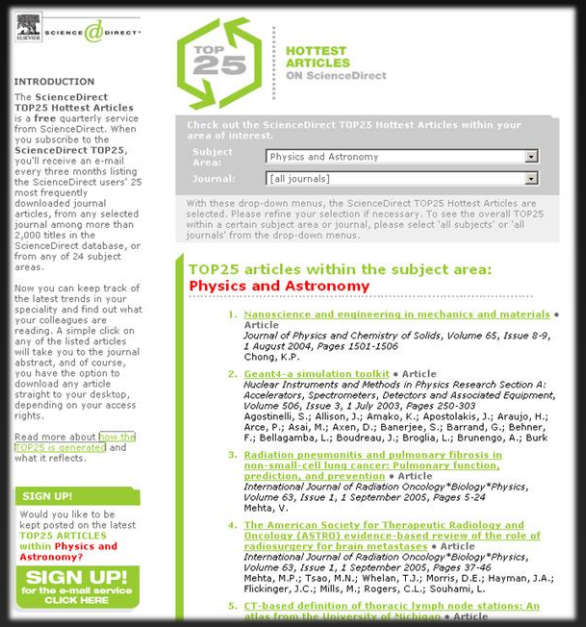
The two main reference papers for Geant4:

**Geant4—a simulation toolkit**

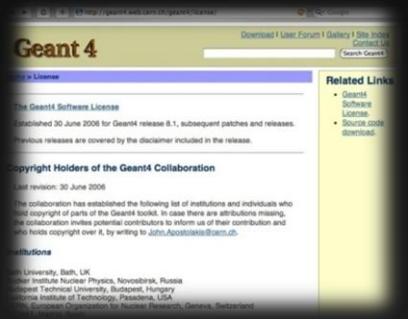
*Nuclear Instruments and Methods in Physics Research Section A: Volume 506, Issue 3, 1 July 2003, Pages 250-303*

**Geant4 developments and applications**

*Nuclear Science, IEEE Transactions Publication Date: Feb. 2006 Volume: 53, Issue: 1, Part 2 On page(s): 270- 278*




# The Geant4 License

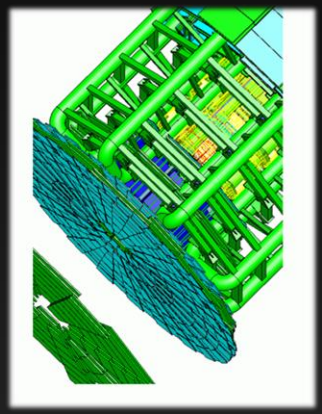



The collaboration presets *the Geant4 license*.

- *Makes clear the user's wide-ranging freedom to use, extend or redistribute Geant4, even as part of some for-profit venture.*
- The license was released along with the latest Geant4 release 8.1.
- Simple enough that you can read and understand it.

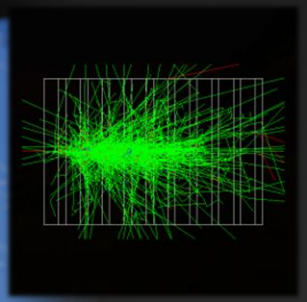
http://cern.ch/geant4/license/

# Flexibility of Geant4



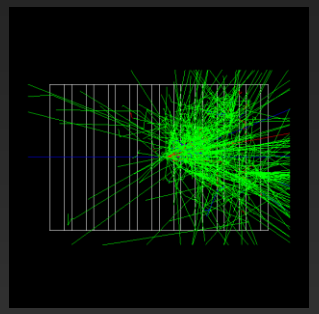
## Many types of geometry descriptions

- CSG solids, BREP and boolean solids
- Placement, replica, divided, parameterized, reflected and grouped
- XML description



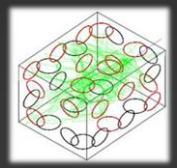
## Wide coverage of physics processes

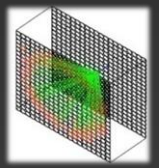
- EM, hadron, ion, optical photon, decay, shower parameterization event biasing, and your own processes
- Model mixture of theory-driven, data-driven and parameterized

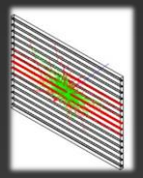


## Everything is open to the user

- Choice of physics processes/models
- Choice of analysis/user interface/visualization technologies







**Geant4 is a tool kit, NOT a simulation black box!!**