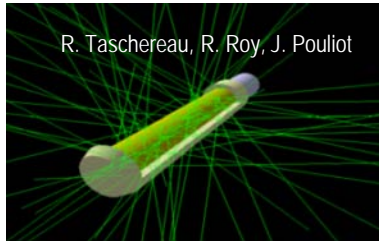


*Courtesy T. Ersmark, KTH Stockholm*

# Geant 4

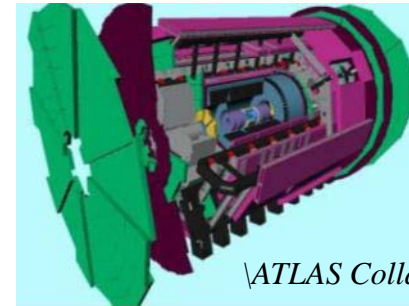


*GATE  
Collaboration*

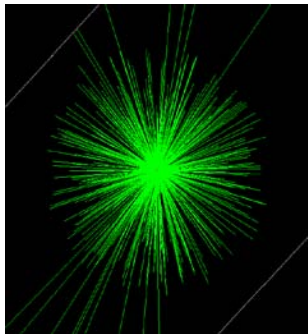


*R. Taschereau, R. Roy, J. Pouliot*

## Overview

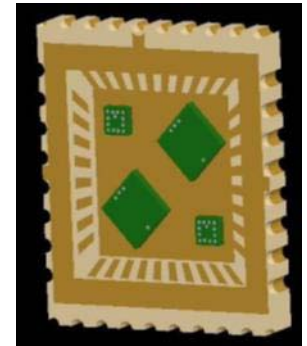


*ATLAS Collaboration*



Maria Grazia Pia

*INFN Genova, Italy*

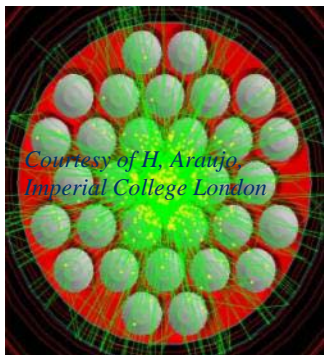


*RADMON and INFN Genova*

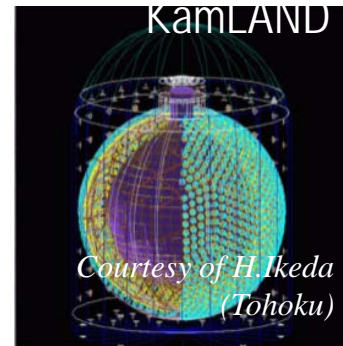
**ANS Winter Meeting 2010**

Thursday, 11 November 2010

Las Vegas, NV



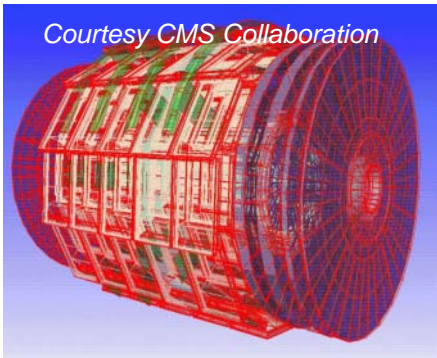
*Courtesy of H. Arango  
Imperial College London*



**KamLAND**  
*Courtesy of H. Ikeda  
(Tohoku)*

<http://cern.ch/geant4>

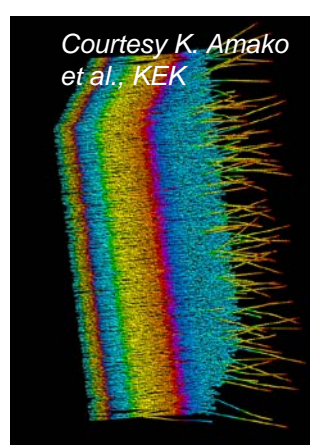
Courtesy CMS Collaboration



# Geant 4

Object oriented toolkit for the simulation of particle interactions with matter

Courtesy K. Amako et al., KEK

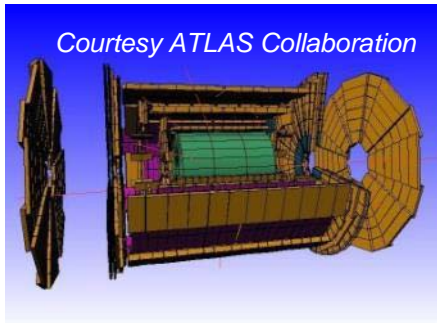


**Born from the requirements of large scale HEP experiments**

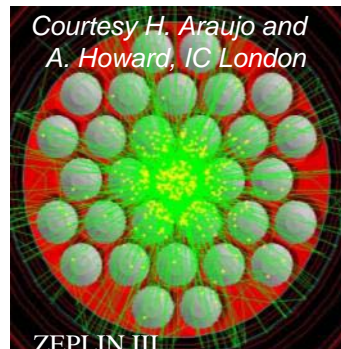
Widely used in:

- Space science and astrophysics
- Medical physics, nuclear medicine
- Radiation protection
- Accelerator physics
- Pest control, food irradiation
- Humanitarian projects, security
- etc.
- Technology transfer to industry, hospitals

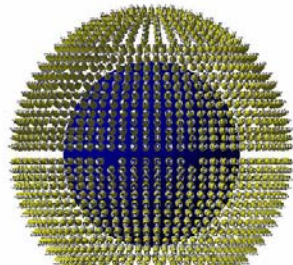
Courtesy ATLAS Collaboration



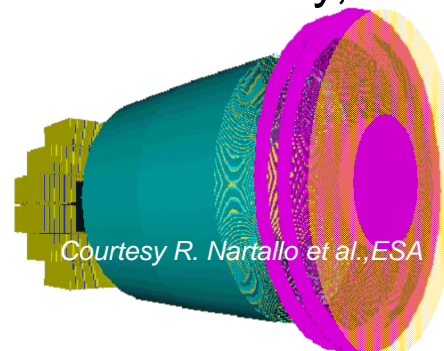
Courtesy H. Araujo and A. Howard, IC London



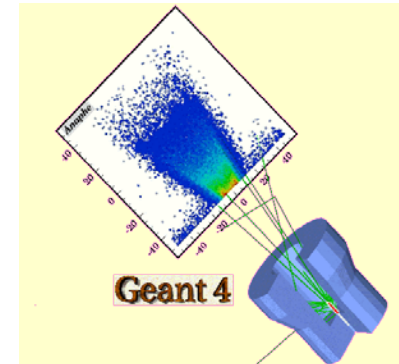
ZEPLIN III



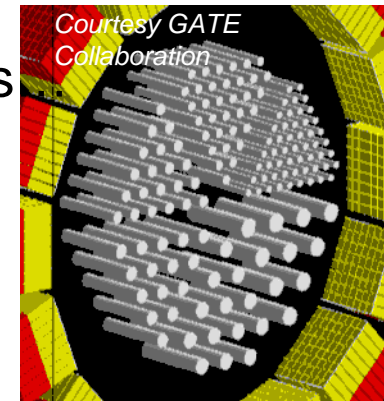
Courtesy Borexino



Courtesy R. Nartallo et al., ESA



IST and INFN Genova




Courtesy GATE Collaboration

S. Agostinelli et al.,  
**Geant4—a simulation toolkit**  
 NIM A 506 (2003) 250–303

**Most cited**  
**“Nuclear Science**  
**and Technology”**  
**publication**

Thomson-Reuters,  
 ISI Web of Science,  
 1970–November 2010

  
 ELSEVIER

Available online at [www.sciencedirect.com](http://www.sciencedirect.com)  
**SCIENCE @ DIRECT®**

**NUCLEAR  
INSTRUMENTS  
& METHODS  
IN PHYSICS  
RESEARCH**  
 Section A

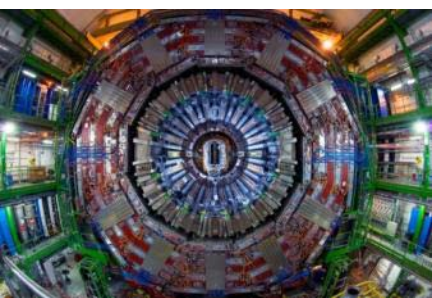
Nuclear Instruments and Methods in Physics Research A 506 (2003) 250–303  
[www.elsevier.com/locate/nima](http://www.elsevier.com/locate/nima)

## GEANT4—a simulation toolkit

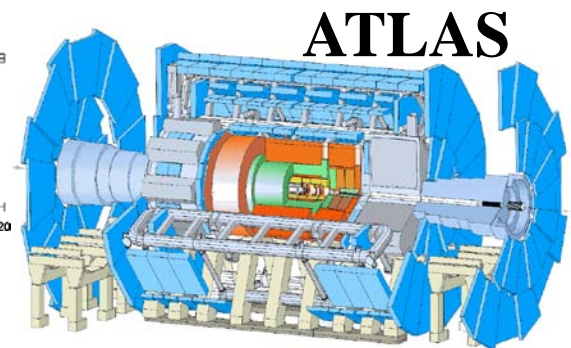
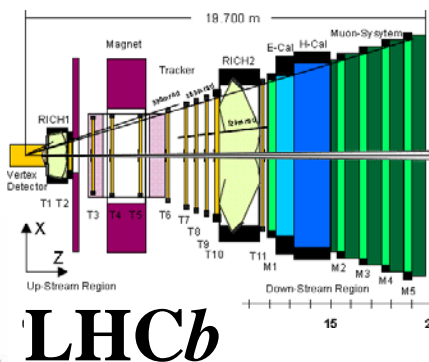
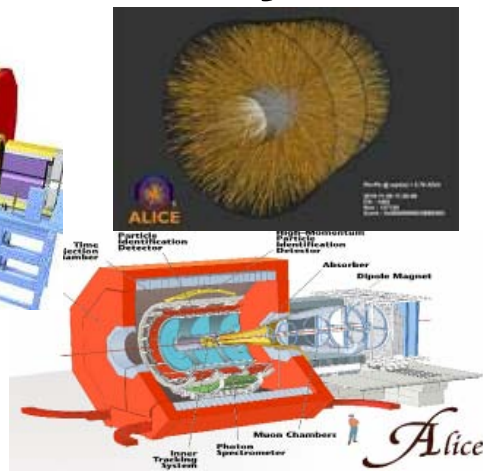
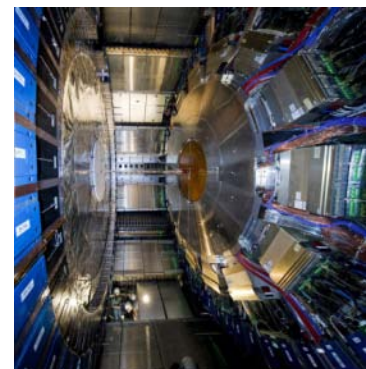
S. Agostinelli<sup>ae,\*</sup>, J. Allison<sup>as,\*</sup>, K. Amako<sup>e</sup>, J. Apostolakis<sup>a</sup>, H. Araujo<sup>aj</sup>,  
 P. Arce<sup>am,x,a</sup>, M. Asai<sup>ga</sup>, D. Axen<sup>it</sup>, S. Banerjee<sup>bi,j</sup>, G. Barrand<sup>an</sup>, F. Behner<sup>l</sup>,  
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 A. Forti<sup>as</sup>, S. Garelli<sup>ac</sup>, S. Giani<sup>a</sup>, R. Giannitrapani<sup>bo</sup>, D. Gibin<sup>m,bc</sup>, J.J. Gómez  
 Cadenas<sup>m,bp</sup>, I. González<sup>q</sup>, G. Gracia Abril<sup>n</sup>, G. Greeniaus<sup>p,h,ag</sup>, W. Greiner<sup>af</sup>,  
 V. Grichine<sup>f</sup>, A. Grossheim<sup>m,z</sup>, S. Guatelli<sup>ad</sup>, P. Gumplinger<sup>h</sup>, R. Hamatsu<sup>bk</sup>,  
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 E. Tcherniaev<sup>a</sup>, E. Safai Tehrani<sup>g</sup>, M. Tropeano<sup>ae</sup>, P. Truscott<sup>be</sup>, H. Uno<sup>aw</sup>,  
 L. Urban<sup>v</sup>, P. Urban<sup>ai</sup>, M. Verderi<sup>ap</sup>, A. Walkden<sup>as</sup>, W. Wander<sup>av</sup>, H. Weber<sup>af</sup>,  
 J.P. Wellisch<sup>al</sup>, T. Wenaus<sup>u</sup>, D.C. Williams<sup>j,bf</sup>, D. Wright<sup>g,h</sup>, T. Yamada<sup>aw</sup>,  
 H. Yoshida<sup>aw</sup>, D. Zschiesche<sup>af</sup>

<sup>a</sup> European Organization for Nuclear Research (CERN) Switzerland  
<sup>b</sup> European Space Agency (ESA), ESTEC, The Netherlands  
<sup>c</sup> Istituto Nazionale di Fisica Nucleare (INFN), Italy  
<sup>d</sup> Jefferson Lab, USA  
<sup>e</sup> KEK, Japan





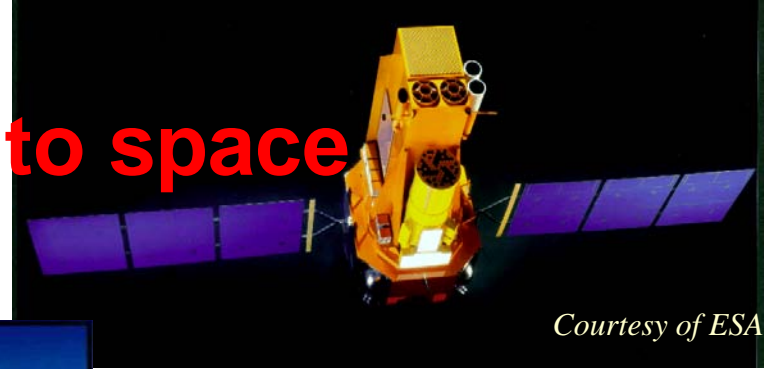
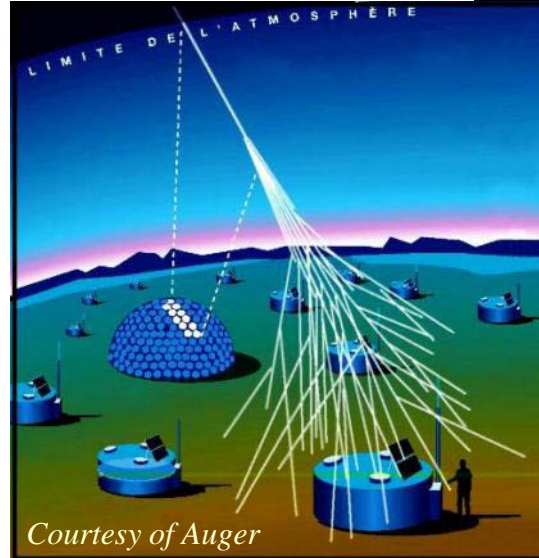
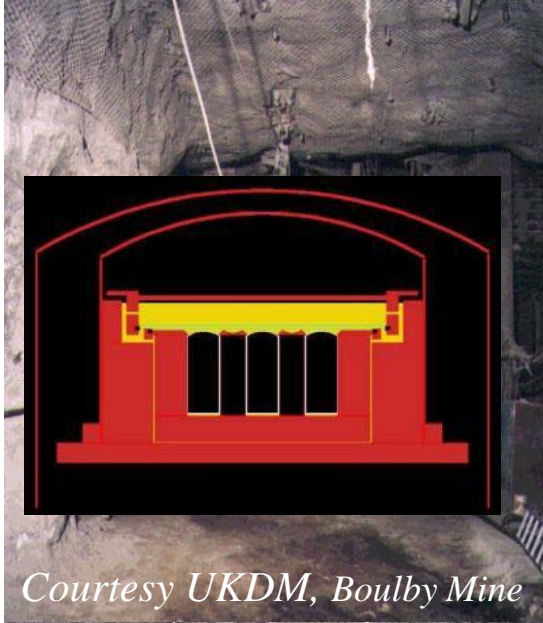
**Complex physics  
Complex detectors  
~20 years software life-span**





# From deep underground...to space

Dark matter and  $\nu$  experiments



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

Cosmic ray experiments

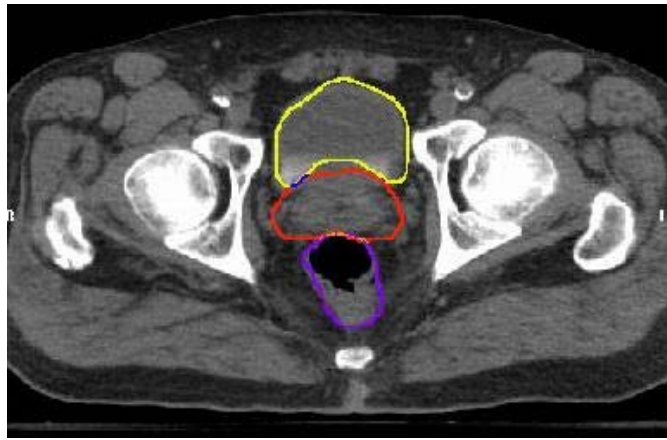
Variety of requirements from diverse experiments

**Physics**  
from the **eV** to the **PeV** scale

**Detectors,**  
spacecrafts and **environment**

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

Require **reliability**, rigorous **software engineering standards**



# Medical Physics

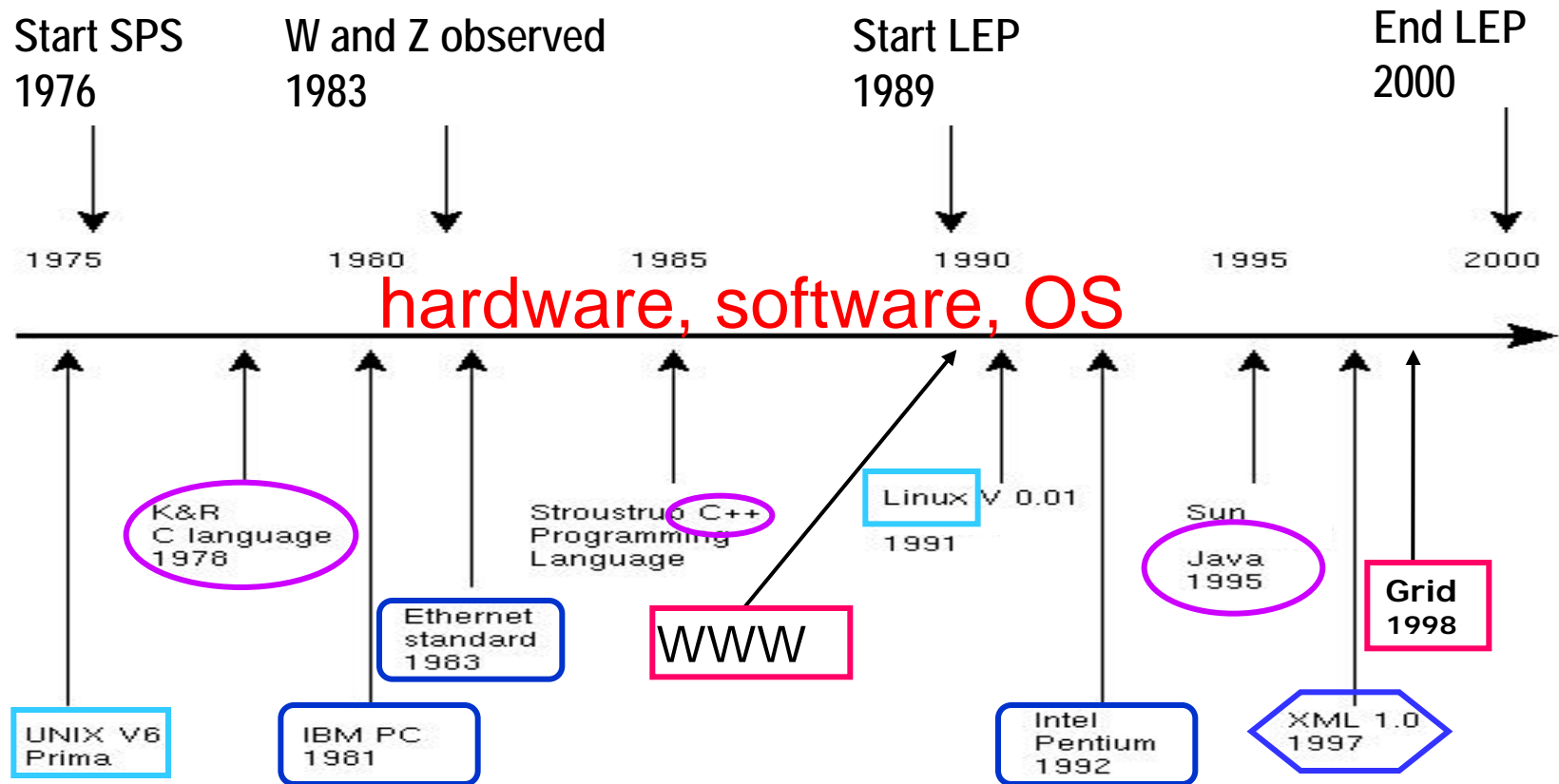


# Radiation protection



- Modeling 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

- Open to **extension** and **evolution**

new implementations can be added w/o changing 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
- components can **cooperate** at any degree of complexity
- it is easy to provide (and use) alternative components
- the user application can be **customised** as needed



# The foundation

# Physics

“It was noted that experiments have requirements for **independent, alternative physics models**. In Geant4 these models, *differently from the concept of packages*, allow the user to **understand** how the results are produced, and hence improve the **physics validation**. Geant4 is developed with a modular architecture and is the ideal framework where existing components are integrated and new models continue to be developed.”

Minutes of LCB (LHCC Computing Board) meeting, 21/10/1997

# Software Engineering

plays a fundamental role in *Geant4*

## User Requirements

- formally collected
- systematically updated
- PSS-05 standard

## Software Process

- spiral iterative approach
- regular assessments and improvements (SPI process)
- monitored following the ISO 15504 model

## Object Oriented methods

- OOAD
- use of CASE tools
- openness to extension and evolution
- contribute to the transparency of physics
- interface to external software without dependencies

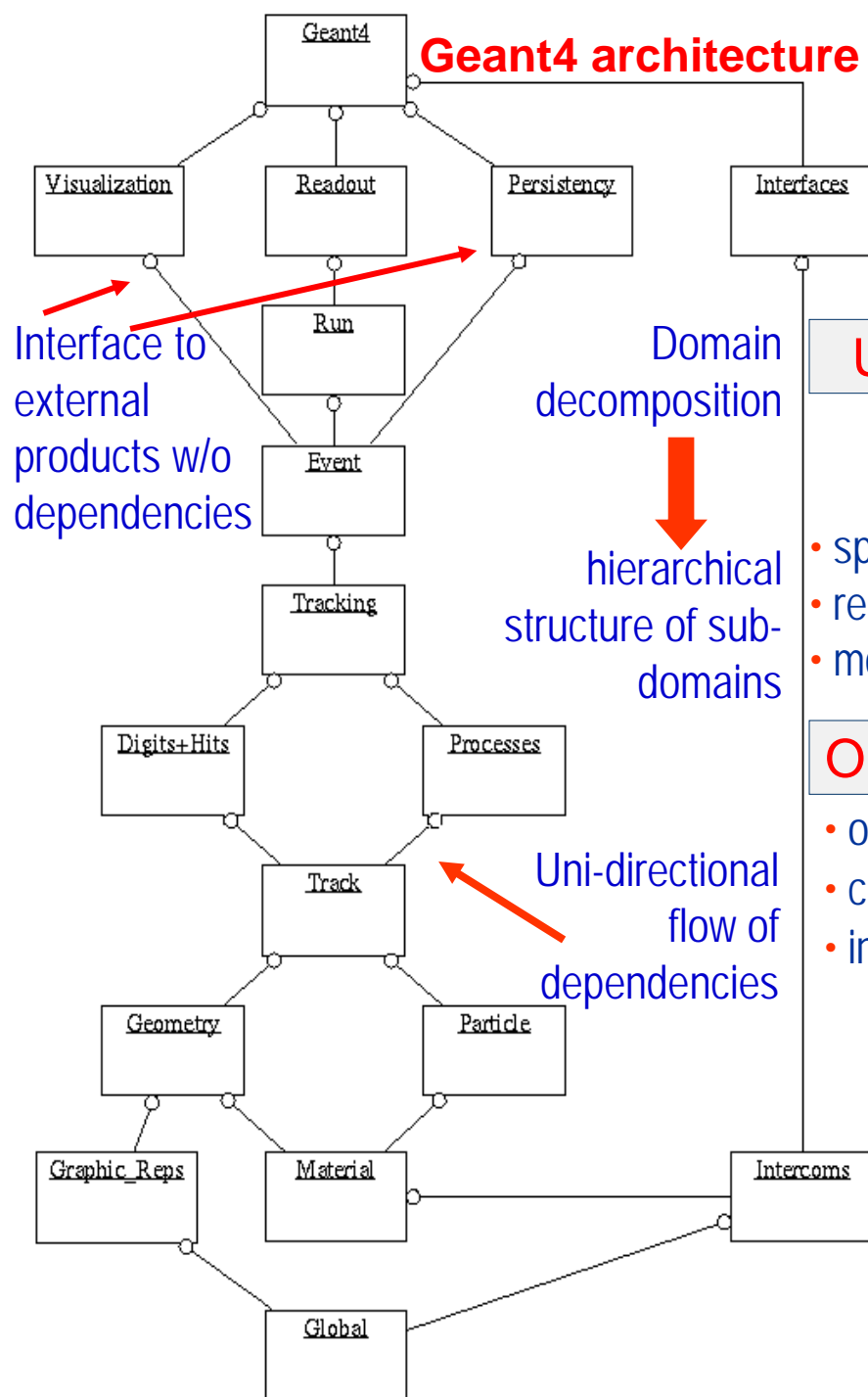
## Quality Assurance

- commercial tools
- code inspections
- automatic checks of coding guidelines
- testing procedures at unit and integration level
- dedicated testing team

## Use of Standards

- de jure and de facto

## Geant4 architecture





# Computing background to use Geant4

## • C++

- Geant4 is implemented in C++, therefore basic knowledge of C++ is required
- C++ is a complex language, but users are not required to be C++ experts

## • Object Oriented Technology

- basic concepts
- in-depth knowledge needed only for the development of complex applications

## • Unix/Linux

- it is a standard working environment for Geant4, therefore a minimum knowledge/experience is useful
  - How to use basic Unix command
  - How to compile a C++ code

## • Windows

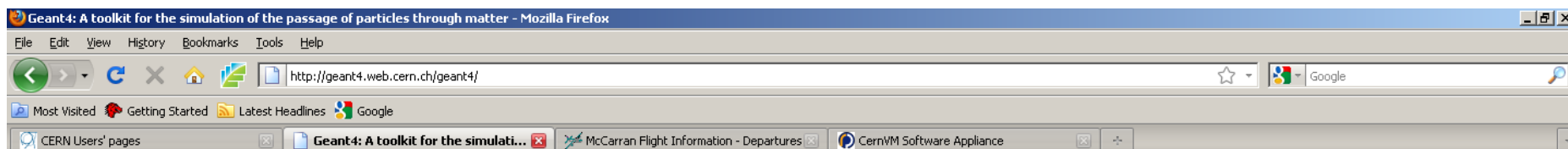
- One can use Visual C++
- Though still one needs some knowledge of Unix (cygwin) for installation

## • Mac

- Supported platform, growing popularity

# Distribution

- Geant4 is **open-source**
- **Freely available**
  - Source code, libraries, associated data files and documentation can be downloaded from <http://cern.ch/geant4>
- User support provided by the Geant4 collaboration
  - On a best effort basis
  - User Forum: mutual support within the user community



## Geant 4

[Download](#) | [User Forum](#) | [Gallery](#)  
[Contact Us](#)

Search Geant4

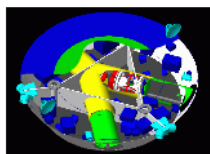
Geant4 is a toolkit for the simulation of the passage of particles through matter. Its areas of application include high energy, nuclear and accelerator physics, as well as studies in medical and space science. The two main reference papers for Geant4 are published in *Nuclear Instruments and Methods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

### Applications



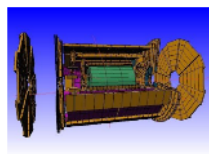
*A sampling of applications, technology transfer and other uses of Geant4*

### User Support



*Getting started, guides and information for users and developers*

### Results & Publications



*Validation of Geant4, results from experiments and publications*

### Collaboration



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

### News

- 24 September 2010 - Patch-02 to release 9.3 is available from the [download](#) area.
- 24 September 2010 - Patch-04 to release 9.2 is available from the [archive download](#) area.
- 25 June 2010 - Release 9.4 BETA is available from the [Beta download](#) area.
- 16 March 2010 - [2010 planned developments](#).

# Functionality

What Geant4 can do  
How well it does it







# Geant4 kernel: **Run and Event**

- Conceptually, a **run** is a collection of **events** that share the *same detector conditions*
  - Detector and physics settings are frozen in a run
- An event initially contains the primary particles; they are pushed into a stack and further processed
  - When the stack becomes empty, processing of an event is over
- **Multiple events**
  - possibility to handle pile-up
- **Multiple runs** in the same job
  - with different geometries, materials etc.
- **Powerful stacking mechanism**
  - three levels by default: handle trigger studies, loopers etc.

# Geant4 kernel: **Tracking**

- Decoupled from physics
  - all processes handled through the same abstract interface
- Independent from particle type
- New physics processes can be added to the toolkit without affecting tracking
- Geant4 has only **secondary production thresholds, no tracking cuts**
  - all particles are tracked down to zero range
  - energy, TOF ... cuts can be defined by the user

# Materials

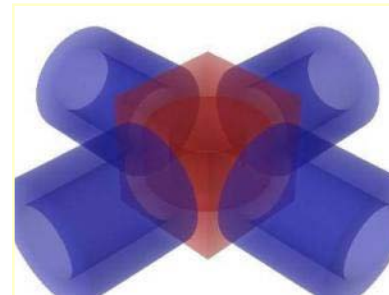
- Different kinds of materials can be defined
  - **isotopes**  G4Isotope
  - **elements**  G4Element
  - **molecules**  G4Material
  - **compounds and mixtures**  G4Material
- Associated attributes:
  - temperature
  - pressure
  - state
  - density



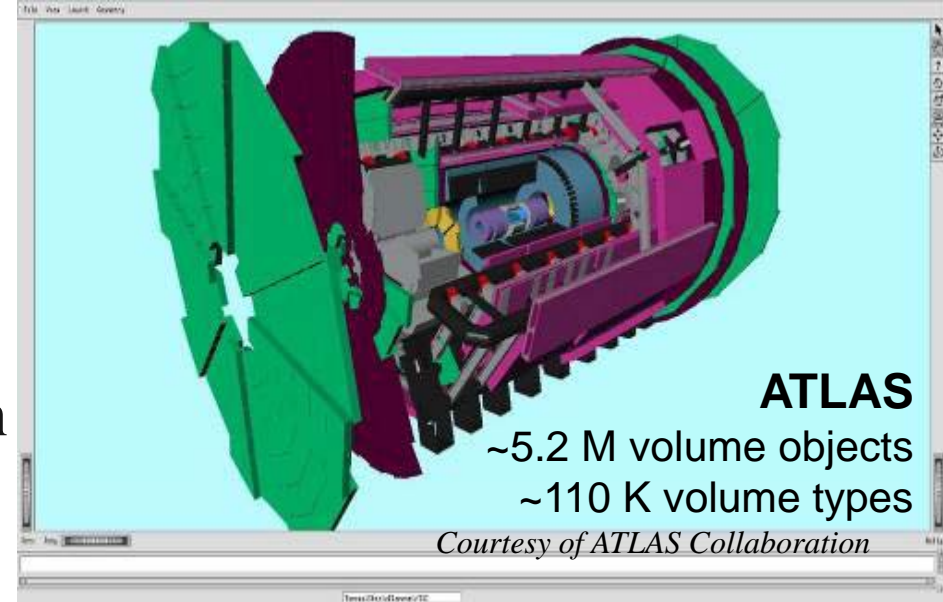
# Geometry

- Role
  - detailed detector description
  - efficient navigation
- Three conceptual layers
  - **Solid**: shape, size
  - **LogicalVolume**: material, sensitivity, daughter volumes, etc.
  - **PhysicalVolume**: position, rotation
- One can do fancy things with geometry...

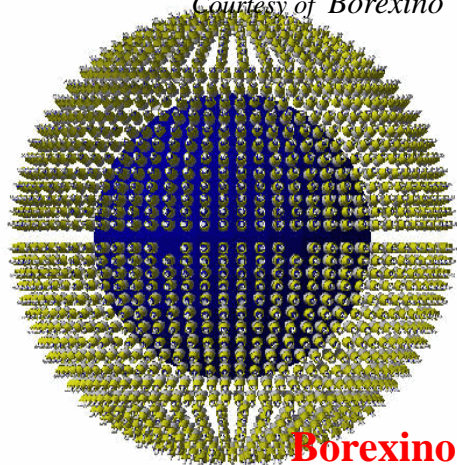
Boolean  
operations



Transparent  
solids



Courtesy of Borexino

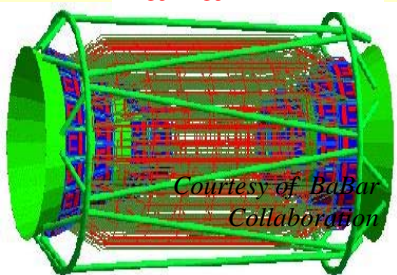


Borexino

# Solids

Multiple representations  
Same abstract interface

BaBar



Courtesy of BaBar  
Collaboration

## CSG (Constructed Solid Geometries)

- simple solids

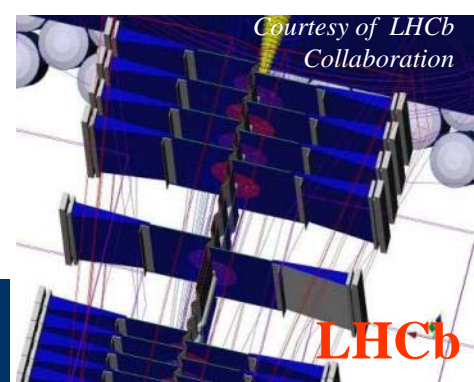
## STEP extensions

- polyhedra, spheres, cylinders, cones, toroids etc.

## BREPS (Boundary REPresented Solids)

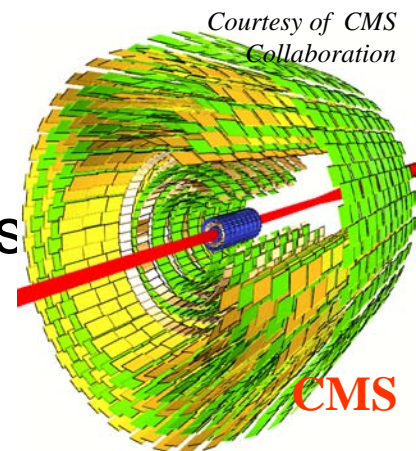
- volumes defined by boundary surfaces

CAD exchange



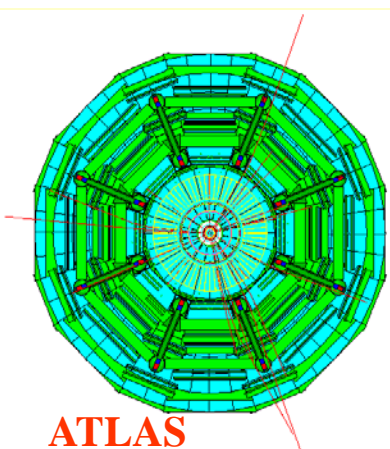
Courtesy of LHCb  
Collaboration

LHCb

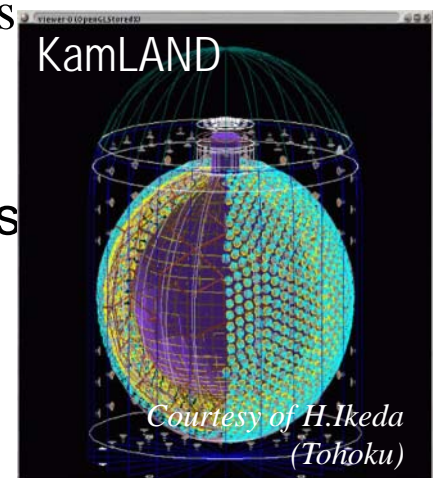


Courtesy of CMS  
Collaboration

CMS



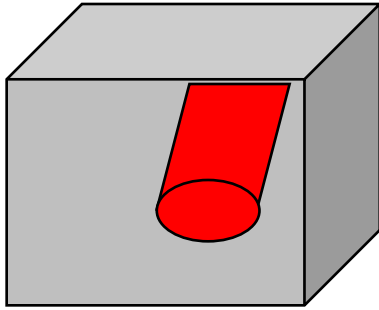
ATLAS



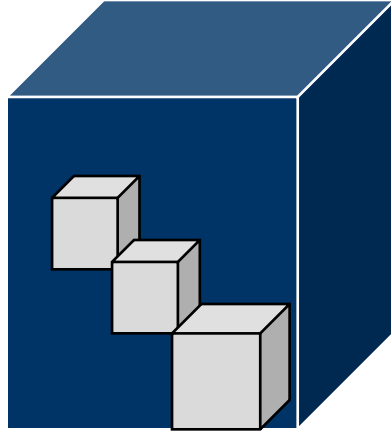
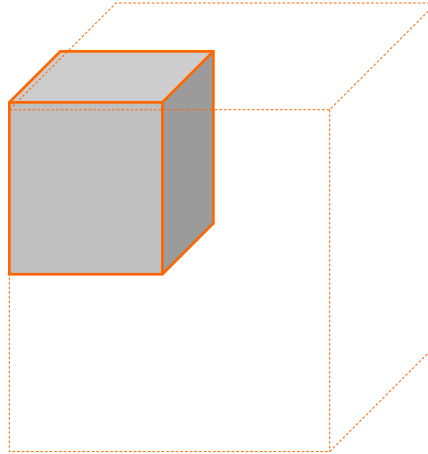
KamLAND

Courtesy of H. Ikeda  
(Tohoku)

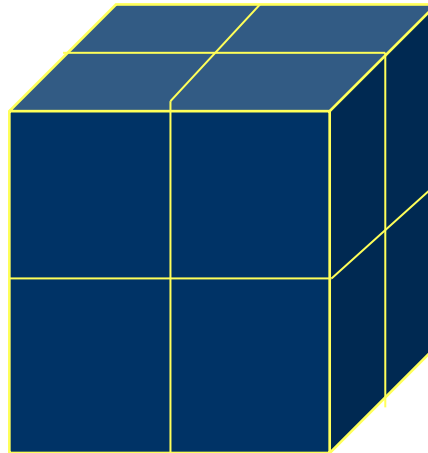
# Physical Volumes



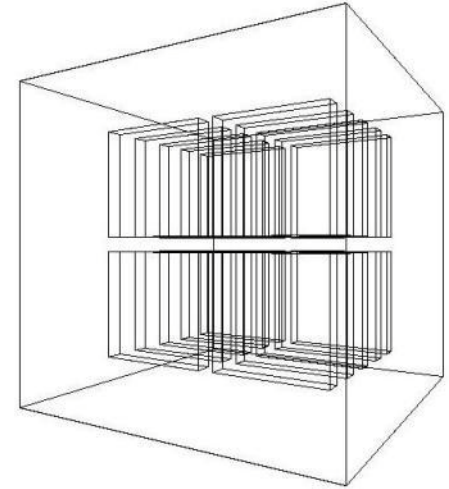
**placement**



**parameterised**



**replica**

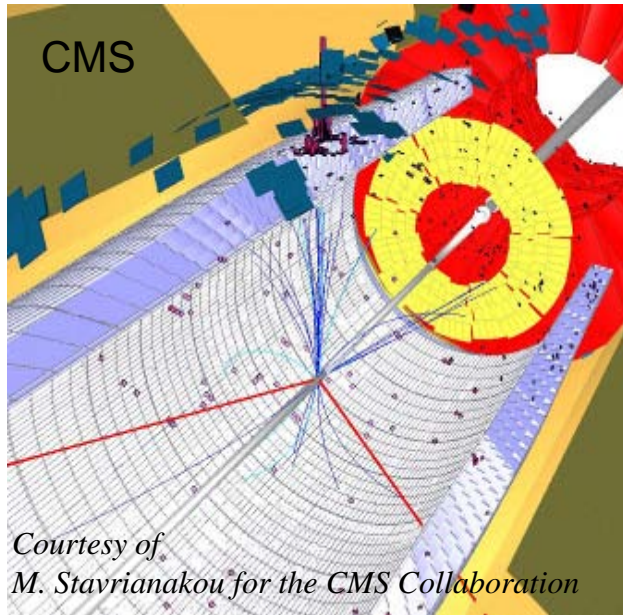


**assembled**

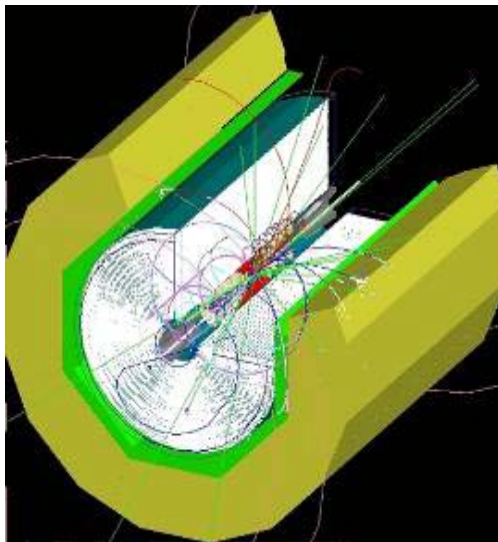


# Electric and magnetic fields

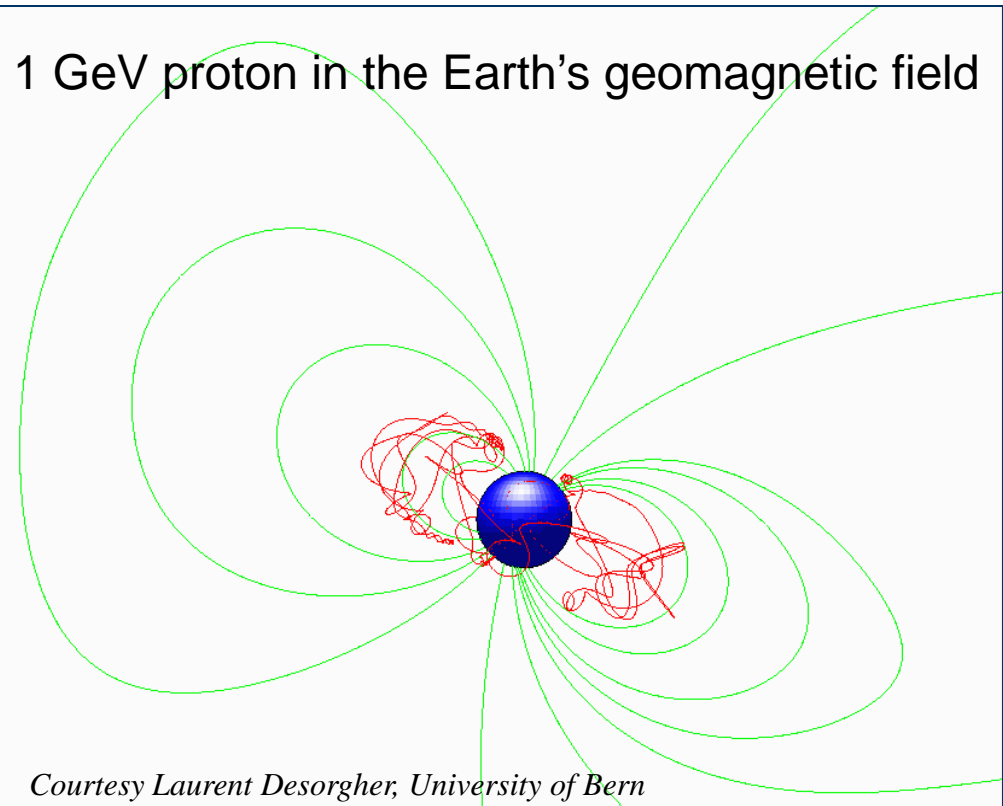
of variable non-uniformity  
and differentiability

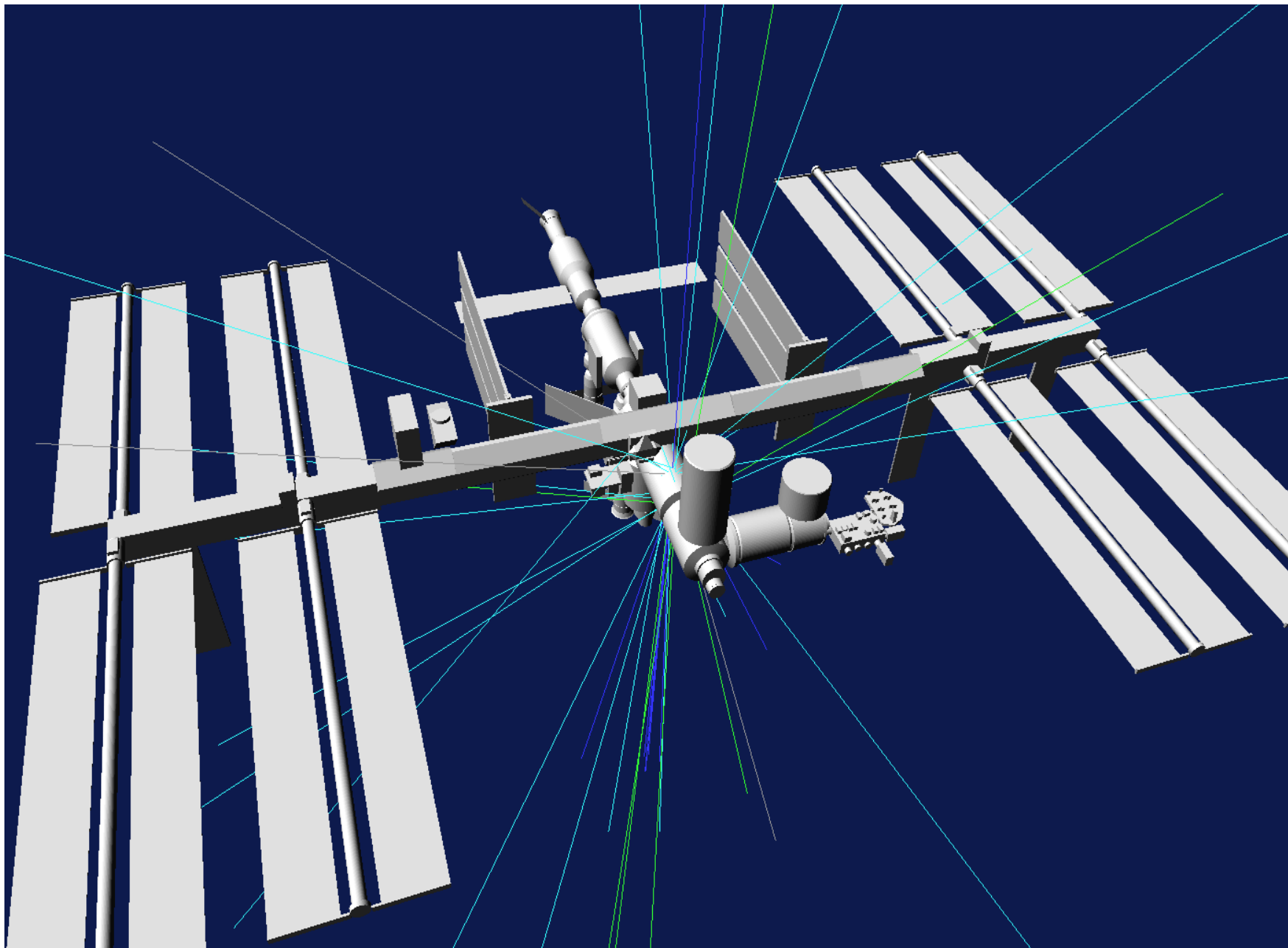


MOKKA  
Linear Collider  
Detector



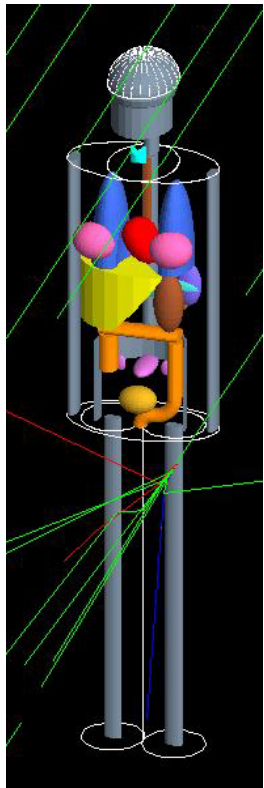
1 GeV proton in the Earth's geomagnetic field



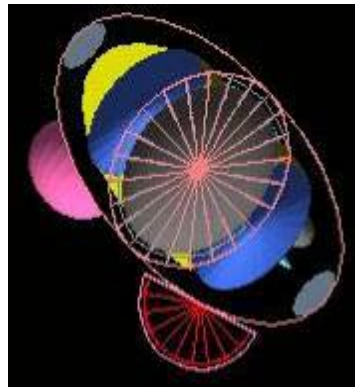


# Not only large scale, complex detectors...

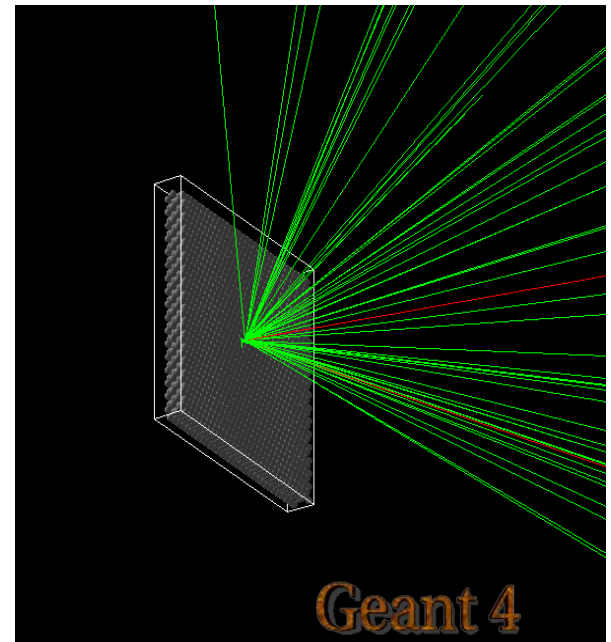
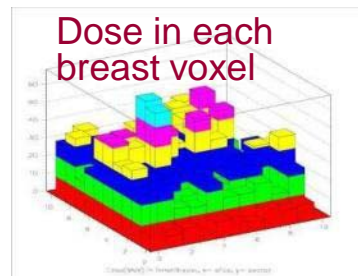
Geant 4



Analytical  
breast



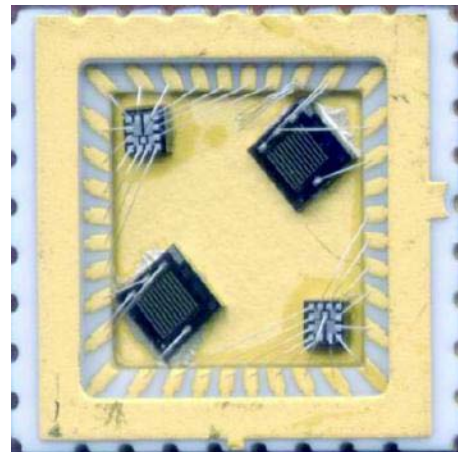
Voxel breast



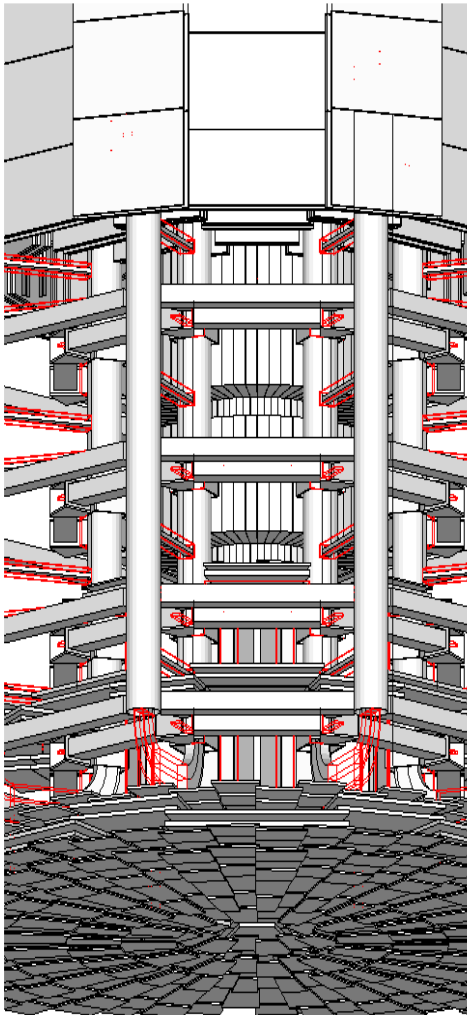
simple geometries

small scale components

Geant4 anthropomorphic phantoms

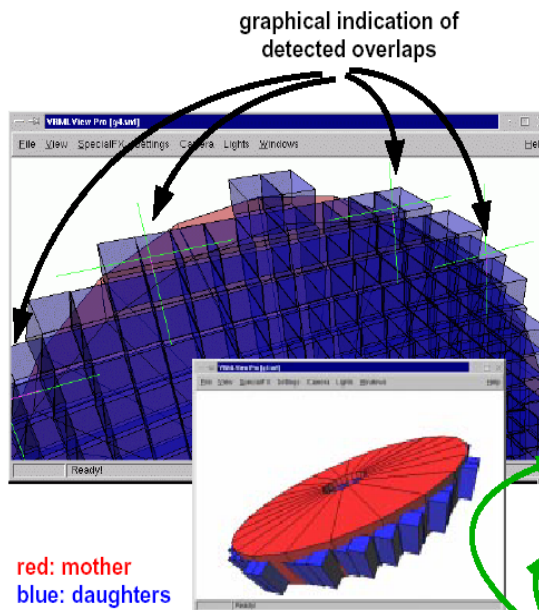


# One may also do it wrong...



DAVID

## Tools to detect badly defined geometries



red: mother  
blue: daughters

daughters are protruding their mother

### Geant4 Macro:

```
/vis/scene/create  
/vis/sceneHandler/create VRML2FILE  
/vis/viewer/create  
/olap/goto ECalEnd  
/olap/grid 7 7 7  
/olap/trigger  
/vis/viewer/update
```

### Output:

```
delta=59.3416  
vol 1: point=(560.513,1503.21,-141.4)  
vol 2: point=(560.513,1443.86,-141.4)  
A -> B:  
[0]: ins=[2] PVName=[NewWorld:0] Type=[N] ...  
[1]: ins=[0] PVName=[ECalEndcap:0] Type=[N] ..  
[2]: ins=[1] PVName=[ECalEndcap07:38] Type=[N]  
B -> A:  
[0]: ins=[2] PVName=[NewWorld:0] Type=[N] ...
```

NavigationHistories of points of overlap  
(including: info about translation, rotation, solid specs)

# Other features

- **Particles**

- all PDG data and more for specific Geant4 use, like ions

- **Hits & Digitization**

- to describe detector response

- **Primary event generation**

- some general purpose tools provided in the toolkit

- **Event biasing**

- **Fast simulation**

- **Persistency**

- **Parallelisation**

- **No time to review them in detail**

- Geant4 user documentation



# Interface to external tools

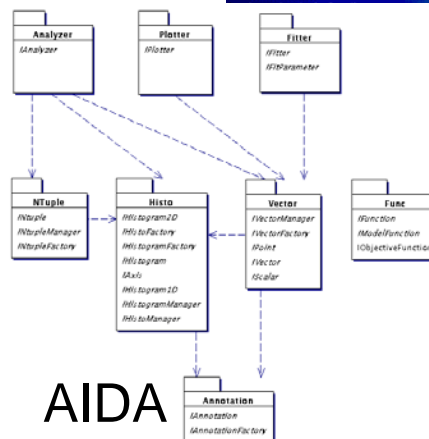
through abstract interfaces

no dependency  
minimize coupling of components

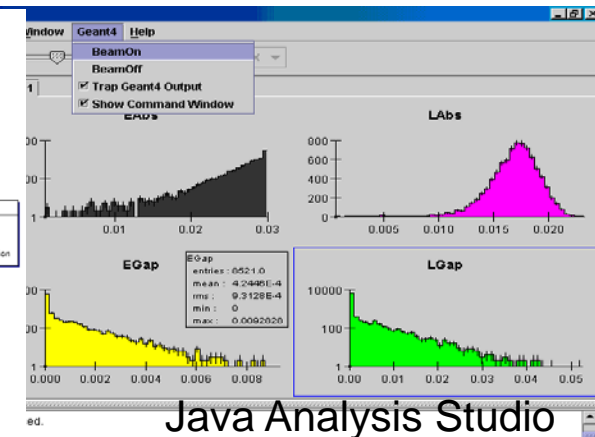
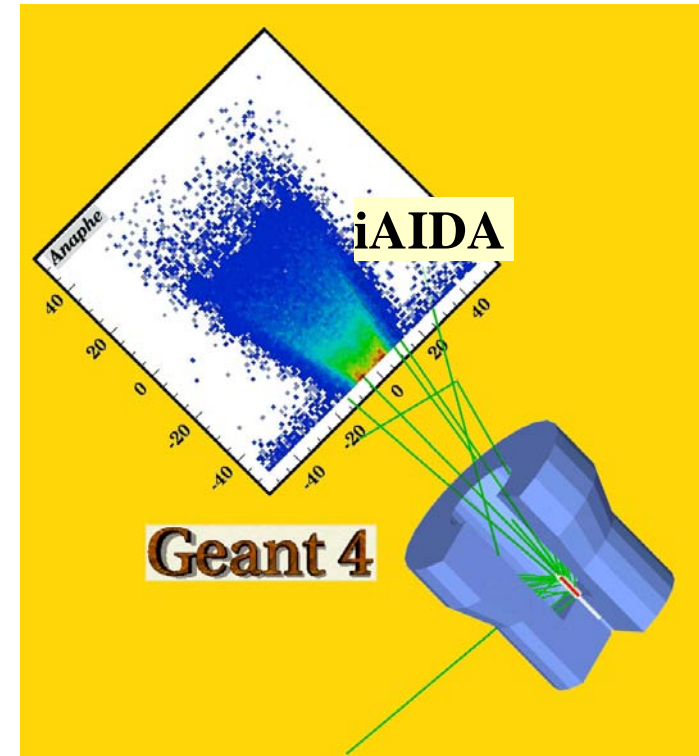
Similar approach

- Visualisation
- (G)UI
- Persistency
- Analysis

The user is free to choose  
the concrete system  
he/she prefers for each  
component



AIDA

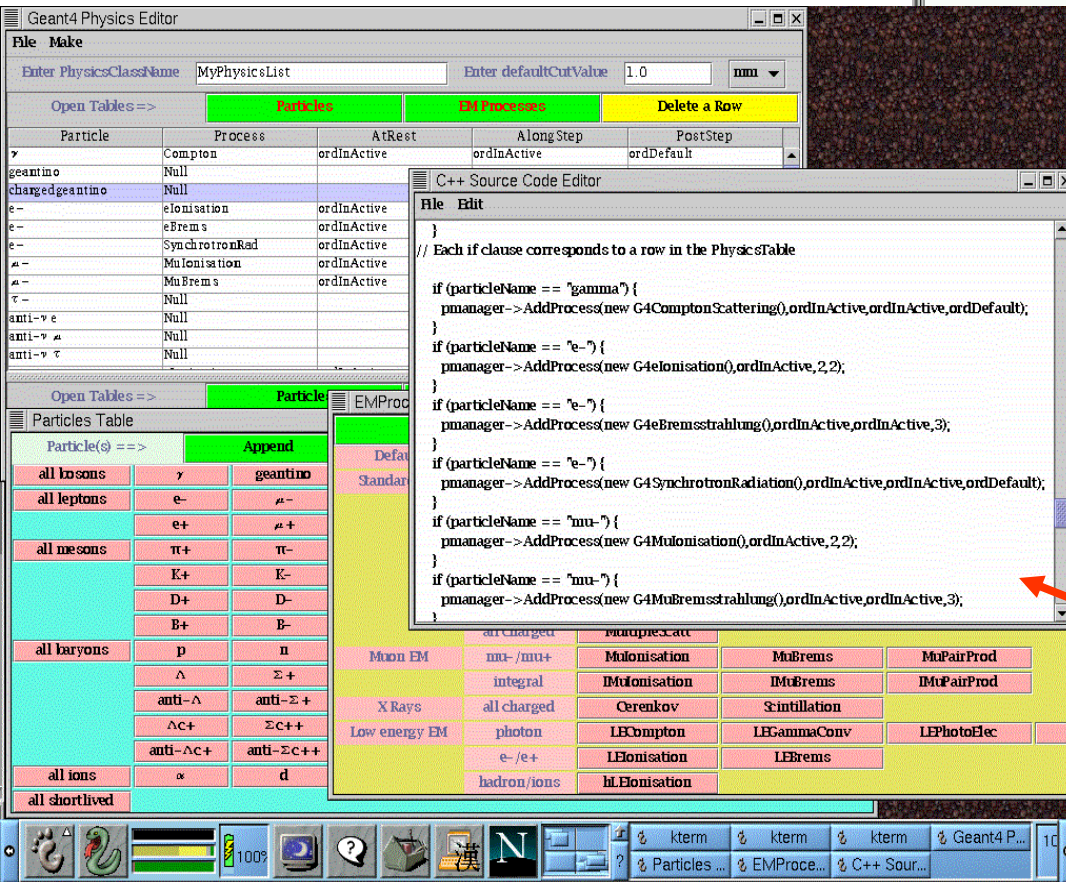
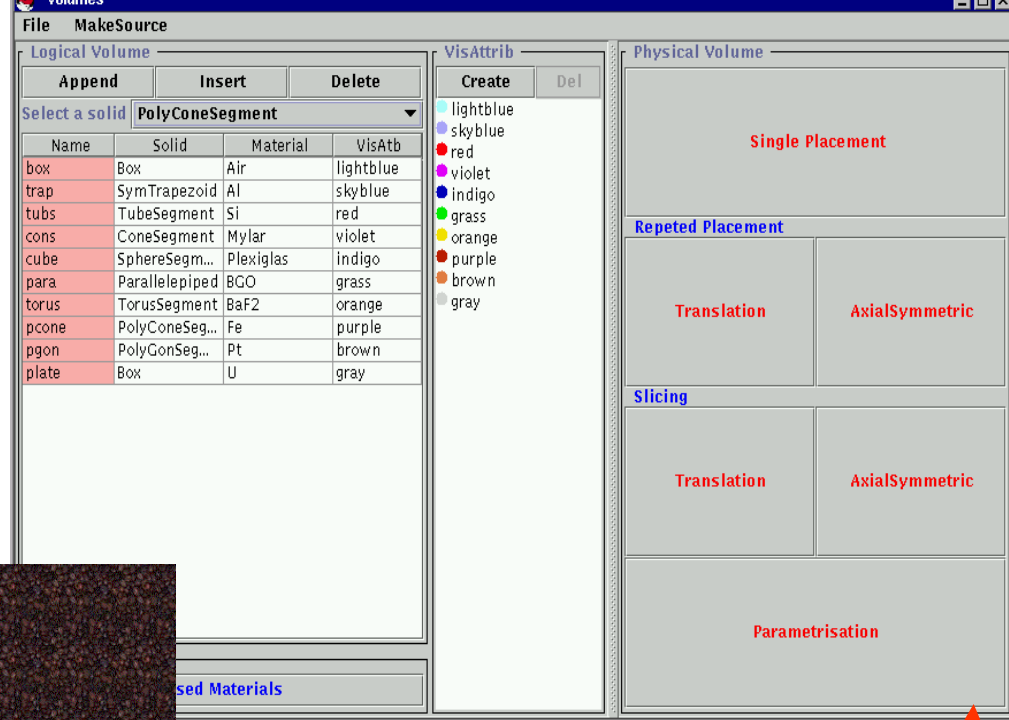


Java Analysis Studio

# User Interface

- Several implementations, all handled through abstract interfaces
- Command-line (batch and terminal)
- GUIs

X11/Motif, GAG, MOMO, OPACS, Java



Automatic code generation for geometry and physics through a GUI

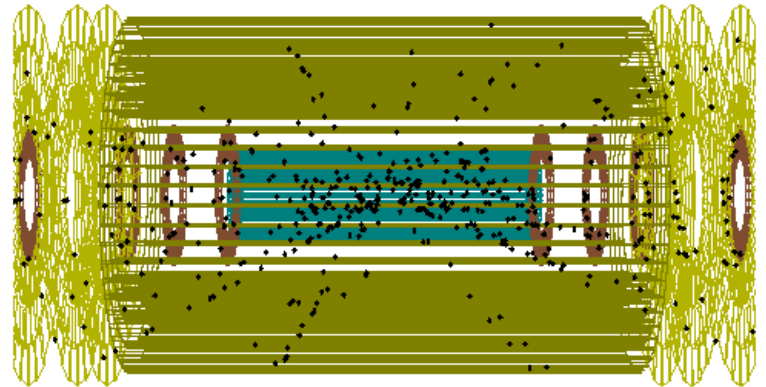
GGE (Geant4 Geometry Editor)

GPE (Geant4 Physics Editor)

# Visualisation

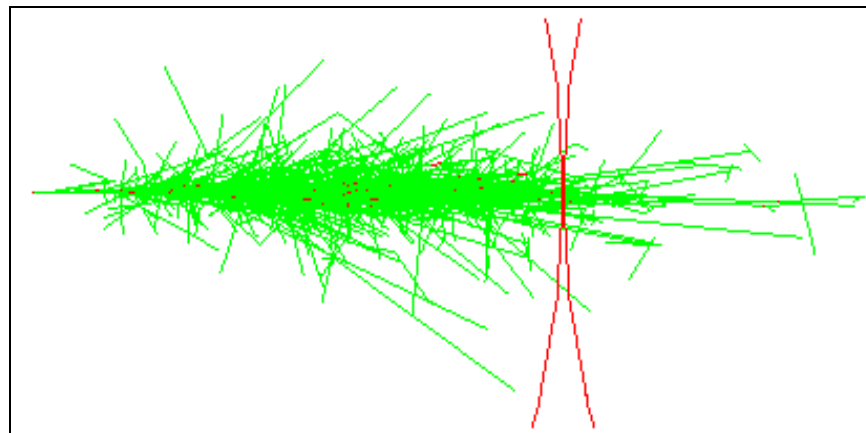
- Control of several kinds of visualisation

- detector geometry
- particle trajectories
- hits in detectors



- Various **drivers**

- OpenGL
- OpenInventor
- X11
- Postscript
- DAWN
- OPACS
- HepRep
- VRML...



- all handled through abstract interfaces

# Physics

Details in a dedicated lecture

# Electromagnetic physics

- electrons and positrons
- photons (including optical photons)
- muons
- charged hadrons
- ions

- Comparable to GEANT 3 already in  $\alpha$  release 1997
- Further extensions (*facilitated by OO technology*)

- **High energy extensions**

- Motivated by LHC experiments, cosmic ray experiments...

- **Low energy extensions**

- motivated by space and medical applications, dark matter and  $\nu$  experiments, antimatter spectroscopy, radiation effects on components etc.

- **Alternative models for the same process**

- Multiple scattering
- Bremsstrahlung
- Ionisation
- Annihilation
- Photoelectric effect
- Compton scattering
- Rayleigh effect
- $\gamma$  conversion
- $e^+e^-$  pair production
- Synchrotron radiation
- Transition radiation
- Cherenkov
- Refraction
- Reflection
- Absorption
- Scintillation
- Fluorescence
- Auger emission



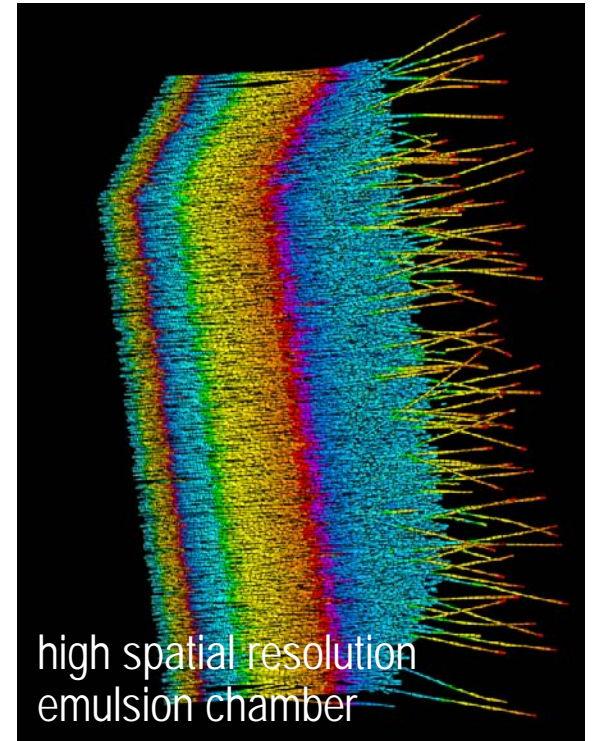
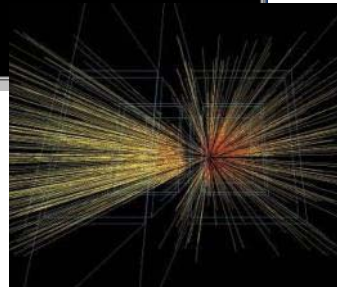
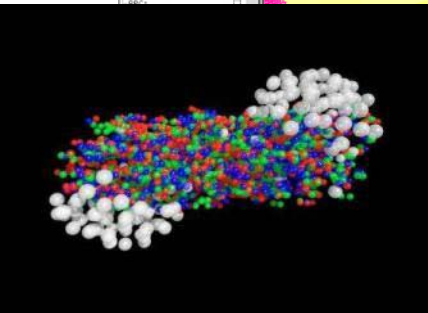
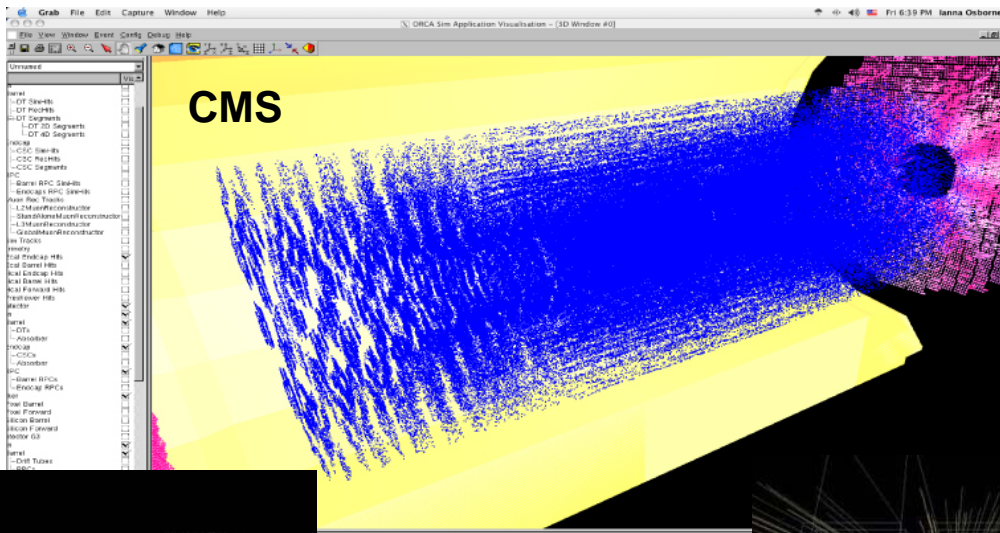
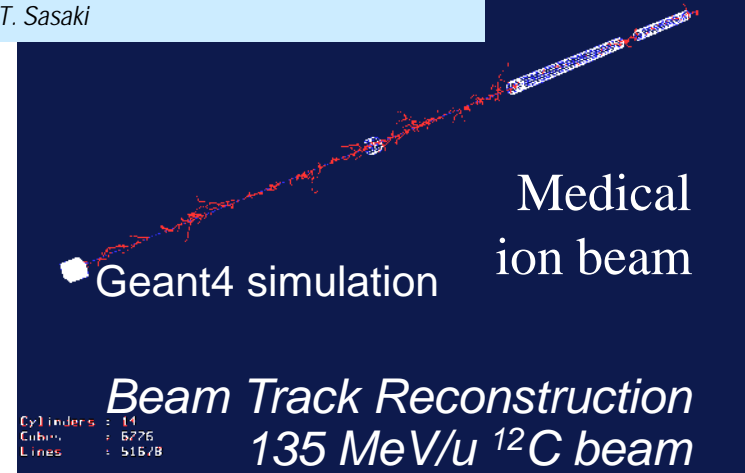
# Hadronic physics

- Completely different approach w.r.t. the past (GEANT 3)
  - native
  - transparent (in the original design)
  - **no longer interface to external packages**
  - clear separation between data and their use in algorithms
- **Cross section data sets**
  - Transparent and interchangeable
- **Final state calculation**
  - Models by particle, energy, material
- **Ample variety of models**
  - Alternative/complementary
  - It is possible to mix-and-match, with fine granularity
  - **Data-driven, parameterised and theory-driven** models

# Pushing Geant4 to the limit

NIRS N. Kanematsu, M. Komori - *Nagoya* K. Niwa, T. Toshito, T. Nakamura, T. Ban, N. Naganawa, S. Takahashi - *Uchu-ken* M. Ozaki - *Kobe* S. Aoki - *Aichi* Y. Kodama - *Naruto* H. Yoshida - *Ritsumei* S. Tanaka - *SLAC* M. Asai, T. Koi - *Tokyo* N. Kokubu - *Gunma* K. Yusa - *Toho* H. Shibuya, R. Ogawa, A. Shibazaki, T. Fukushima - *KEK* K. Amako, K. Murakami, T. Sasaki

# Heavy ion beams

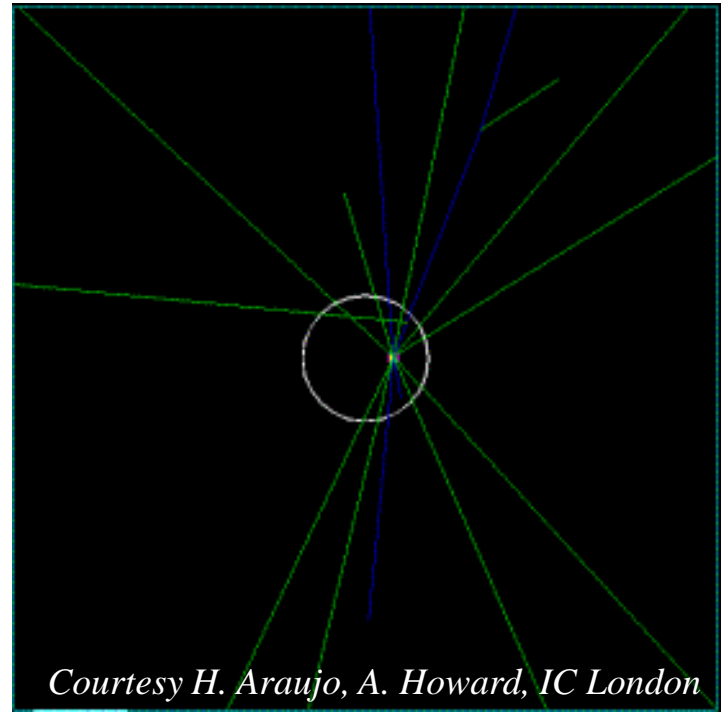
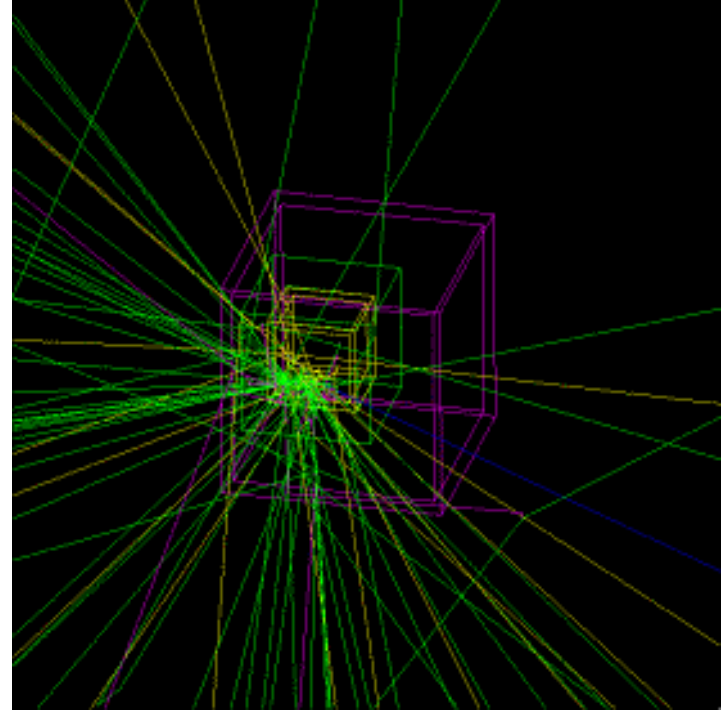
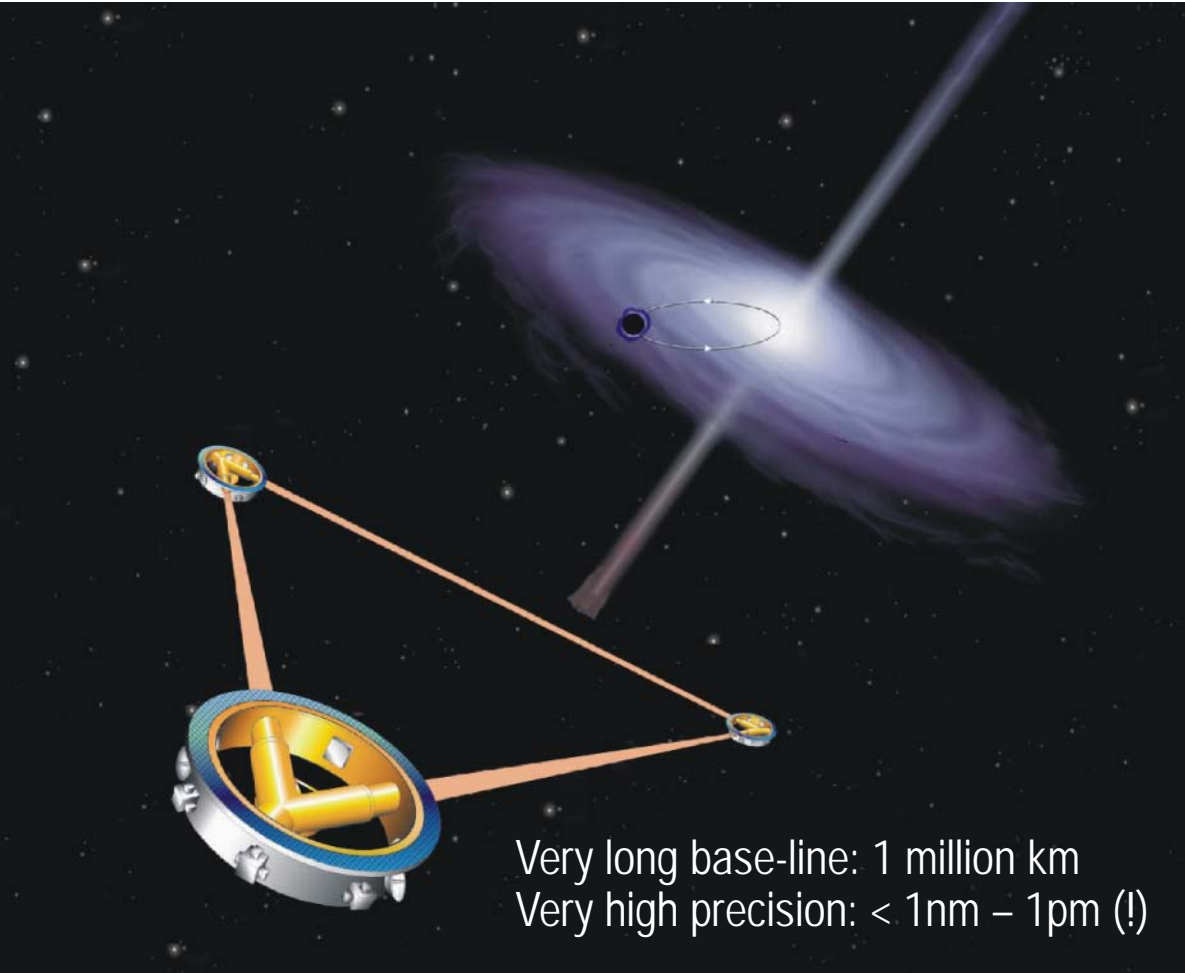


Events with > 50000 particles/event  
in detector acceptance

# LISA

## Gravitational waves

Geant4 relevant to evaluation of space charging effects



*Courtesy H. Araujo, A. Howard, IC London*

Slides available at  
<http://www.ge.infn.it/geant4/training>

Collection of physics references  
<http://www.ge.infn.it/geant4/papers>

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

Acknowledgment: **Geant4 developers** and **users**