

# Refresher Course

# Geant 4

A Simulation Tool for Multi-disciplinary Applications

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

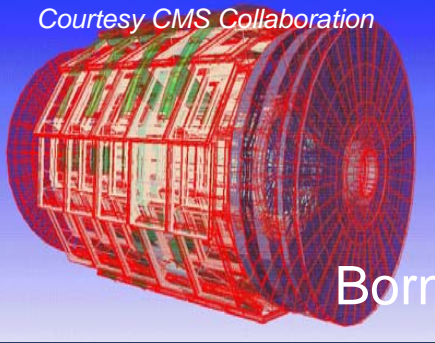
Maria Grazia Pia

INFN Genova

MariaGrazia.Pia@ge.infn.it

Based on the Refresher Course at IEEE NSS 2007

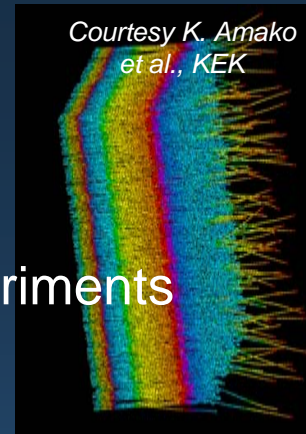
Courtesy CMS Collaboration



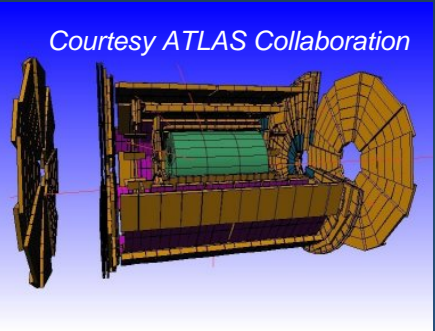
# Geant 4

Born from the requirements of large scale HEP experiments

Courtesy K. Amako et al., KEK



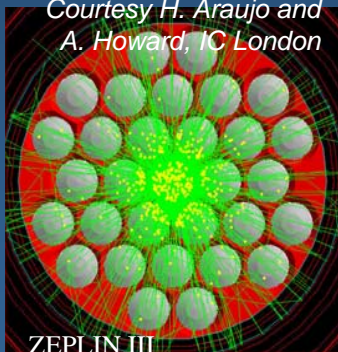
Courtesy ATLAS Collaboration



Widely used also in

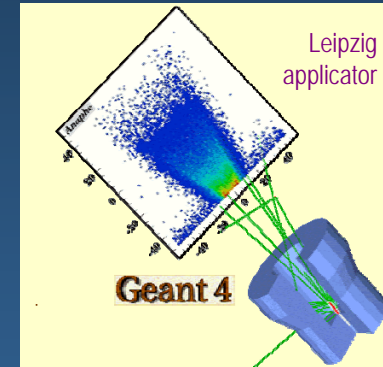
- Space science and astrophysics
- Medical physics, nuclear medicine
- Radiation protection
- Accelerator physics
- Pest control, food irradiation
- Humanitarian projects, security
- etc.
- Technology transfer to industry, hospitals...

Courtesy H. Araujo and A. Howard, IC London



ZEPLIN III

Leipzig applicator



Geant 4

Courtesy R. Nartallo et al., ESA

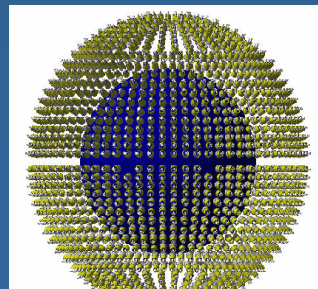
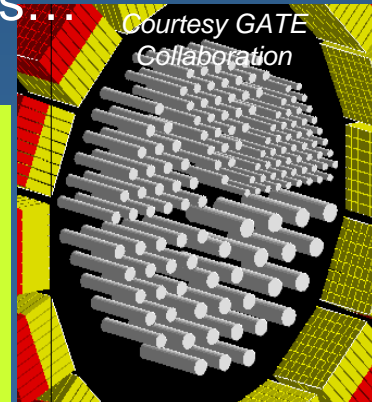


INFN Genova

**Most cited  
“Nuclear Technology”  
publication!**

32 journals, >132000 papers  
ISI Web of Science, 1990-2007

Courtesy GATE Collaboration



Courtesy Borexino

# Technology transfer

## Particle physics software aids space and medicine

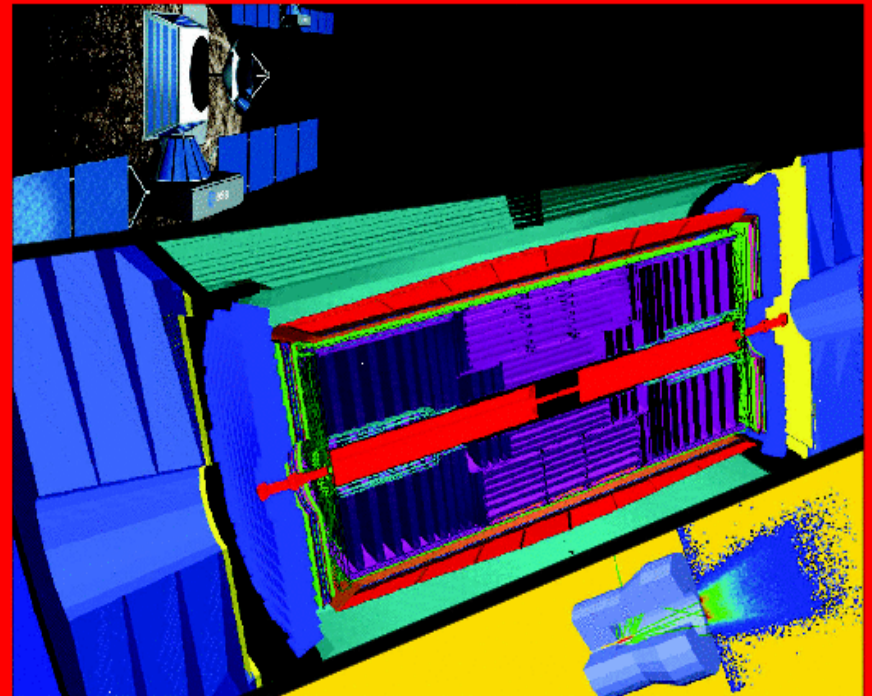
Geant4 is a showcase example of technology transfer from particle physics to other fields such as space and medical science [...].

CERN Courier, June 2002

Maria Grazia Pia, *INFN Genova*



VOLUME 42 NUMBER 5 JUNE 2002



Simulation for physics, space and medicine

### NEUTRINOS

Sudbury Neutrino Observatory confirms neutrino oscillation p5

### TESLA

Electropolishing steers superconducting cavity to new record p10

### COSMOPHYSICS

Joint symposium brings CERN, ESA and ESO together p15

# What is Geant 4 ?

OO Toolkit for the simulation of next generation HEP detectors

*...of the current generation*

*...not only of HEP detectors*

also...

An experiment of distributed software production and management

An experiment of application of rigorous software engineering methodologies and of the Object Oriented technology to the HEP environment

R&D phase: **RD44**, 1994 - 1998

1<sup>st</sup> release: December 1998

2 new releases/year since then

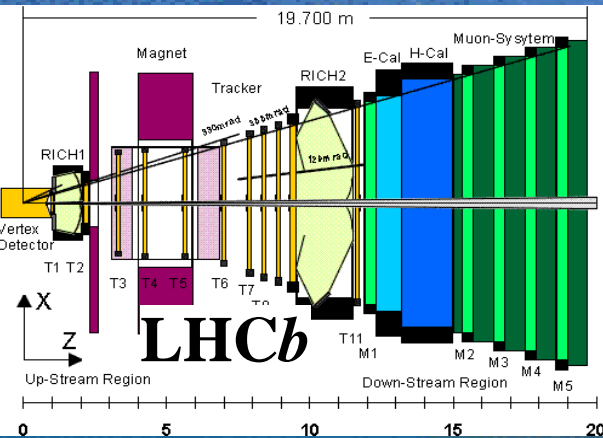


scientific...

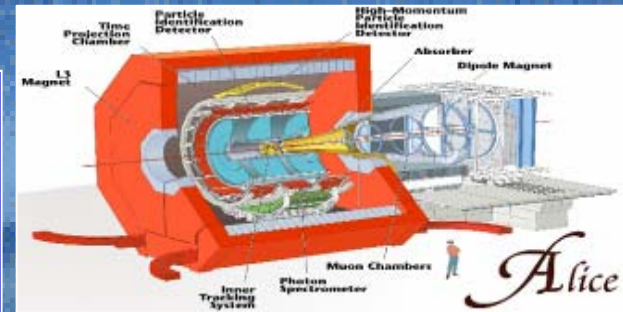
# Globalisation

Sharing requirements and functionality  
across diverse fields

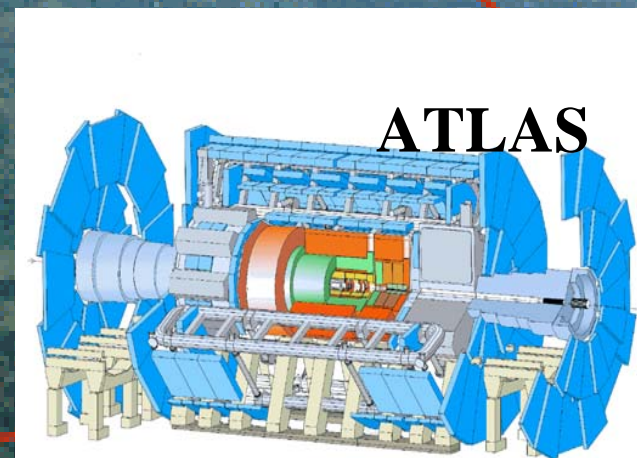
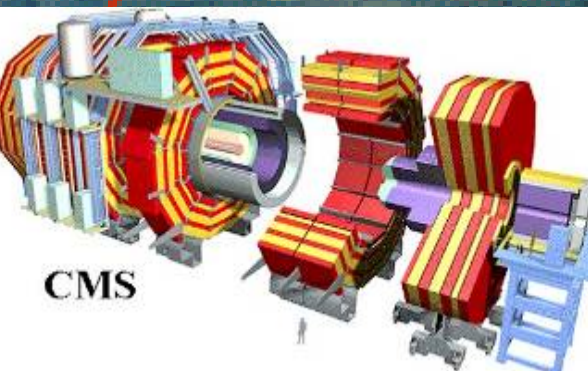
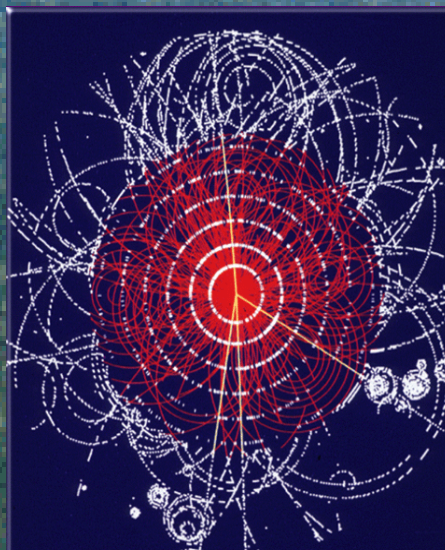




Complex physics  
Complex detectors  
20 years  
software life-span



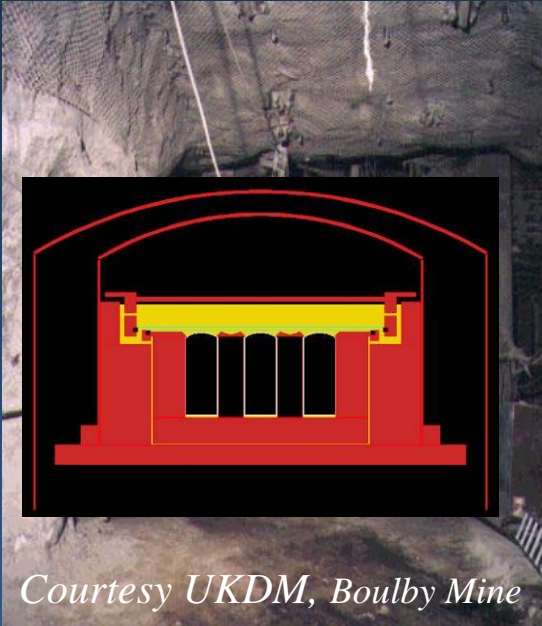
LHC



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 applications

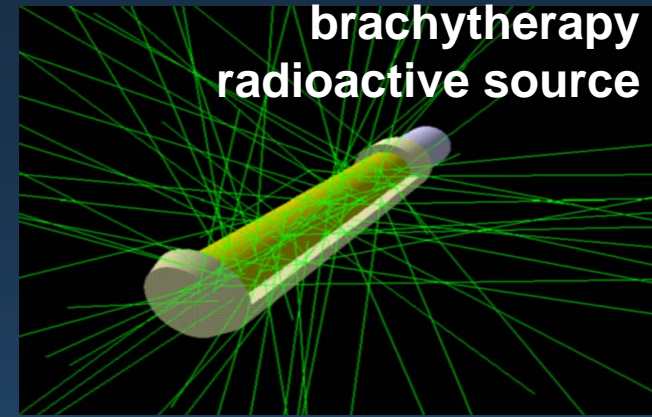
Physics  
from the  $eV$  to the  $PeV$  scale

Detectors,  
spacecrafts and environment

For such experiments software is often **mission critical**  
Require **reliability**, rigorous **software engineering standards**



# Medical Physics



from  
hospitals...

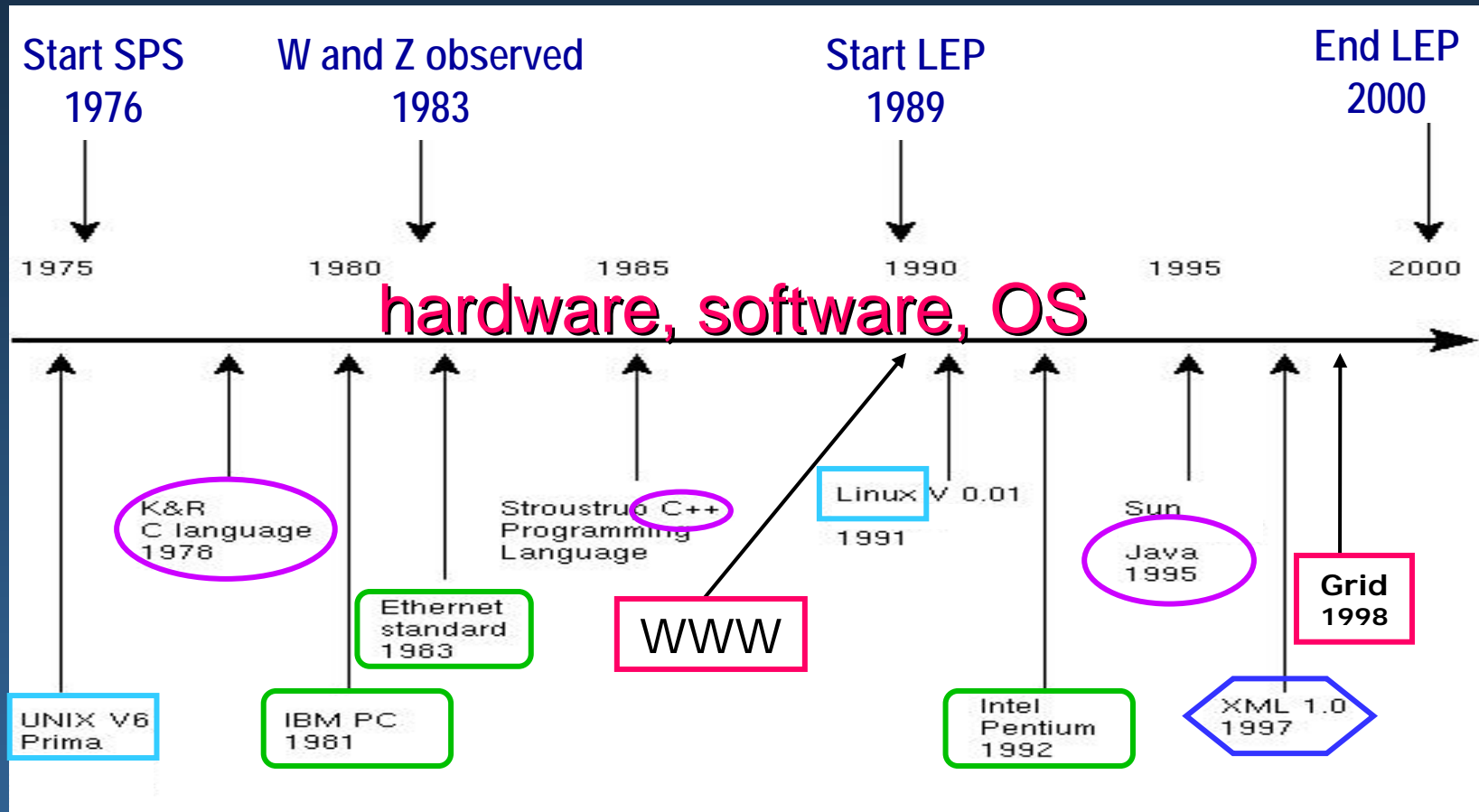
...to Mars



- Accurate modelling of 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

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

# The foundation

What characterizes Geant4  
*Or:* the fundamental concepts, which all the  
rest is built upon

# Physics

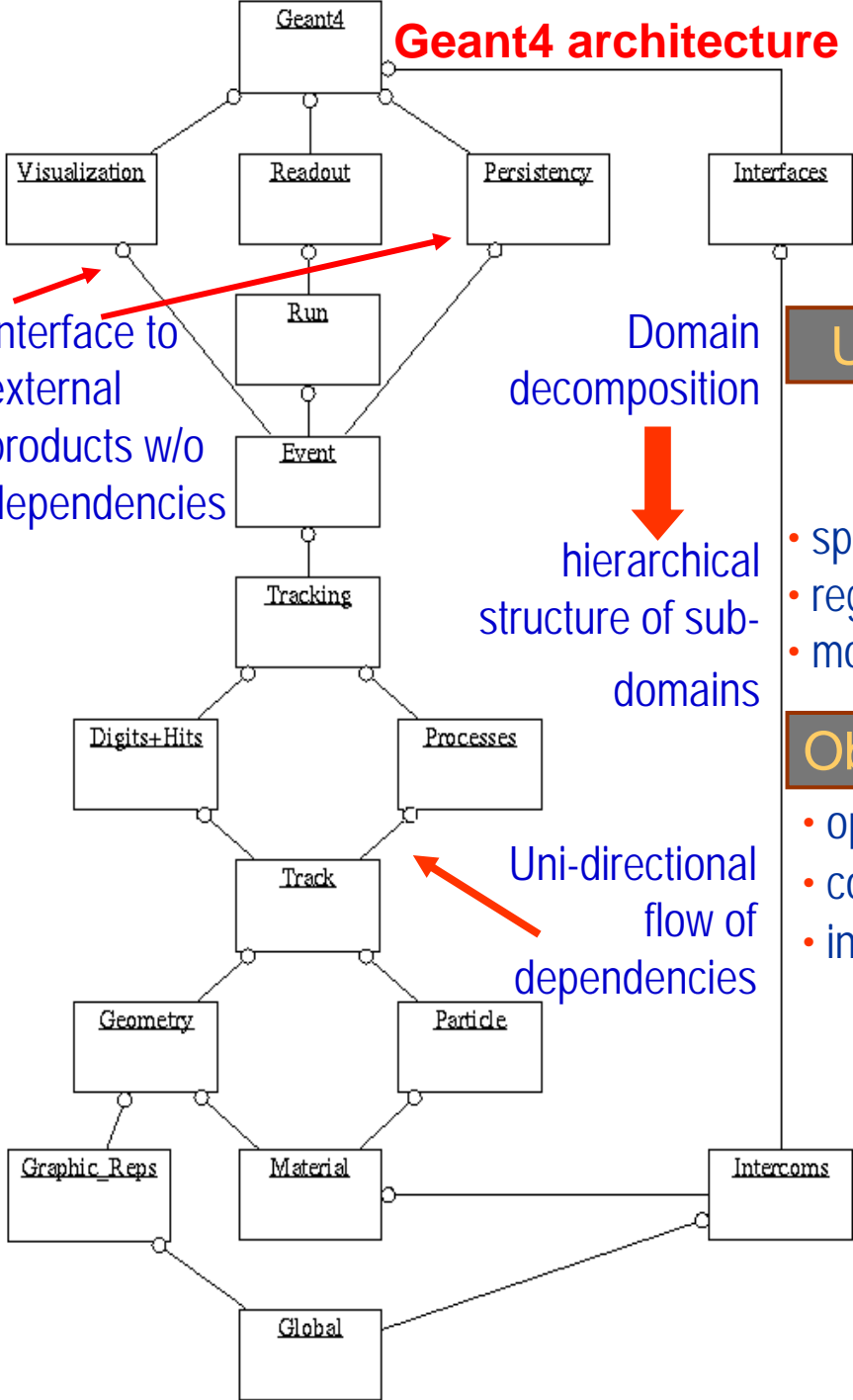
From the Minutes of LCB (LHCC Computing Board) meeting on 21 October, 1997:

“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.”



# Software Engineering

plays a fundamental role in Geant4



## Geant4 architecture

### 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

# The functionality

What Geant4 can do  
How well it does it

# The kernel

## Run and event

- Multiple events
  - possibility to handle the 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.

## 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 production thresholds, **no tracking cuts**

- all particles are tracked down to zero range
- energy, TOF ... cuts can be defined by the user

# Geometry

## ■ Role

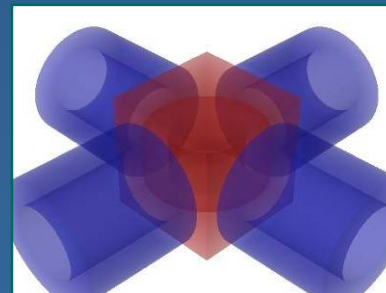
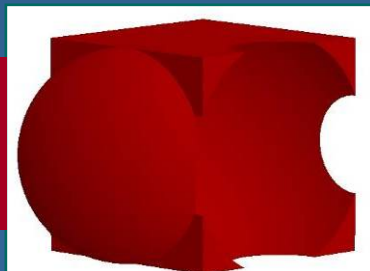
- detailed detector description
- efficient navigation

## ■ Three conceptual layers

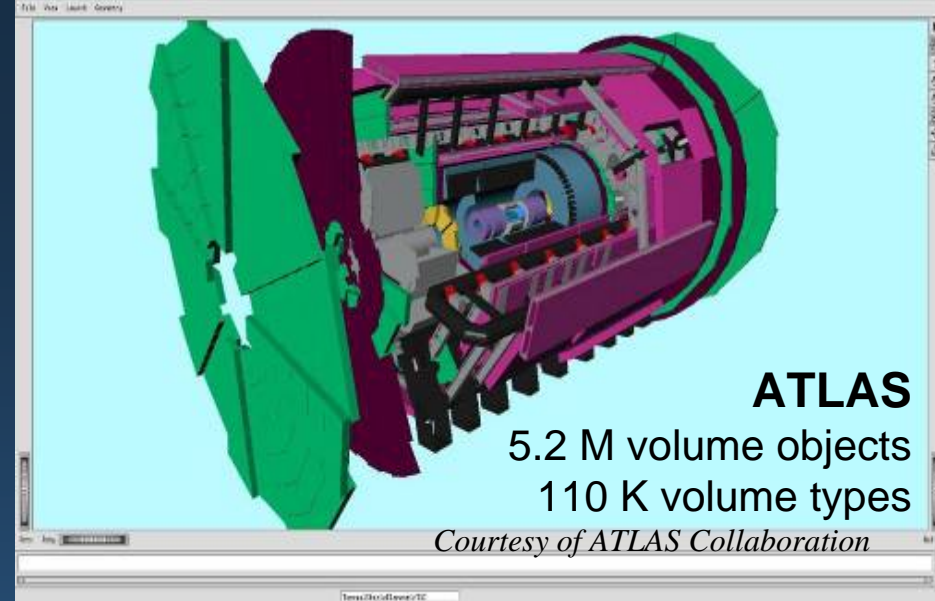
- **Solid**: shape, size
- **LogicalVolume**: material, sensitivity, daughter volumes, etc.
- **PhysicalVolume**: position, rotation

## ■ One can do fancy things with geometry...

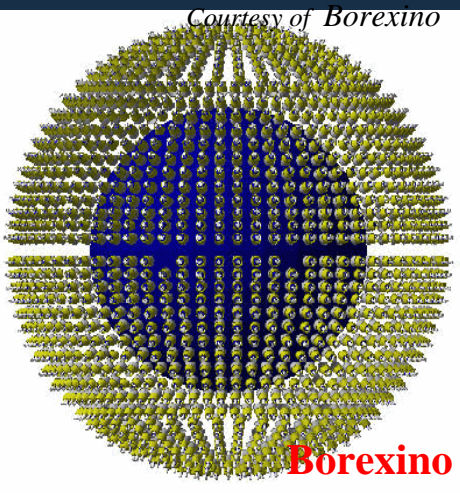
Boolean  
operations



Transparent  
solids







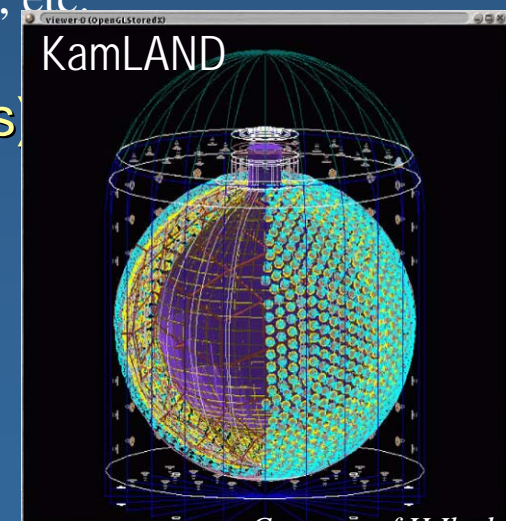
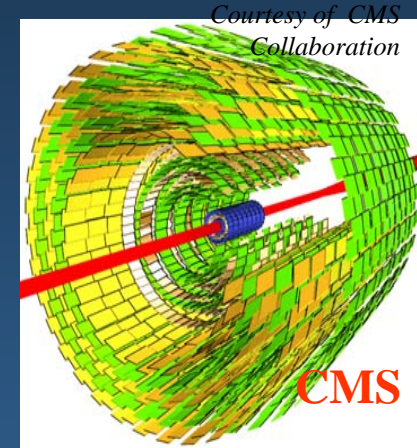
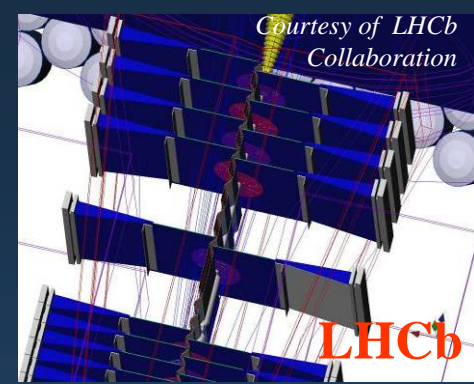
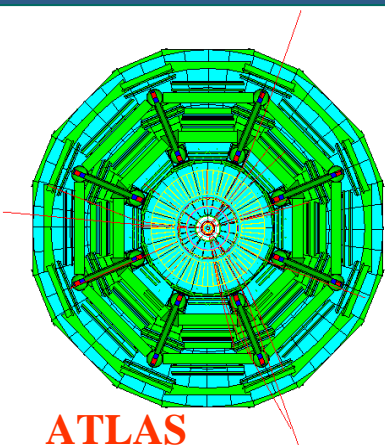
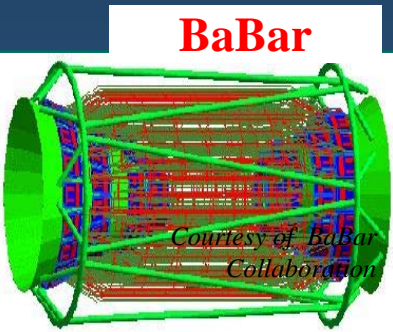
# Solids

## Multiple representations

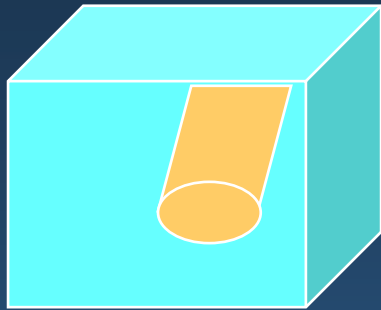
## Same abstract interface

- **CSG (Constructed Solid Geometries)**
  - simple solids
- **STEP extensions**
  - polyhedra, spheres, cylinders, cones, toroids, etc.
- **BREPS (Boundary REPresented Solids)**
  - volumes defined by boundary surfaces

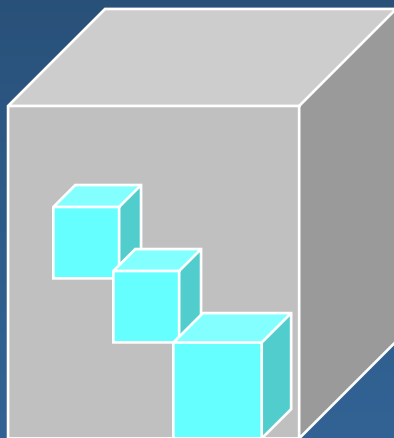
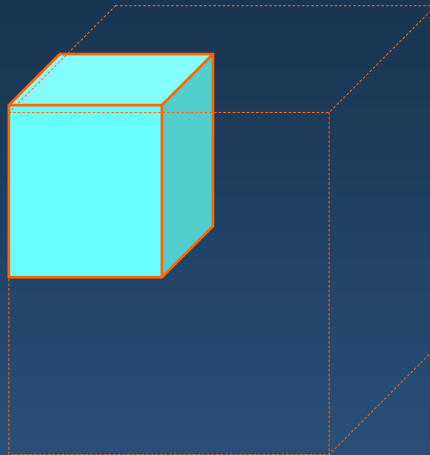
*CAD exchange*



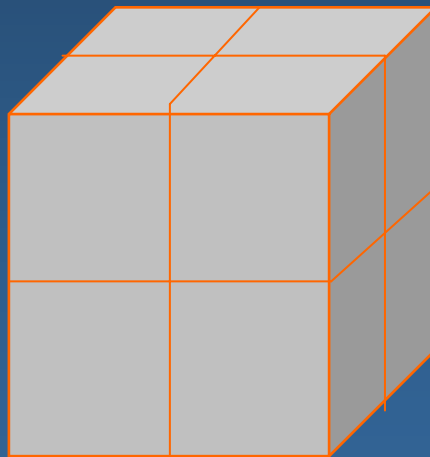
# Physical Volumes



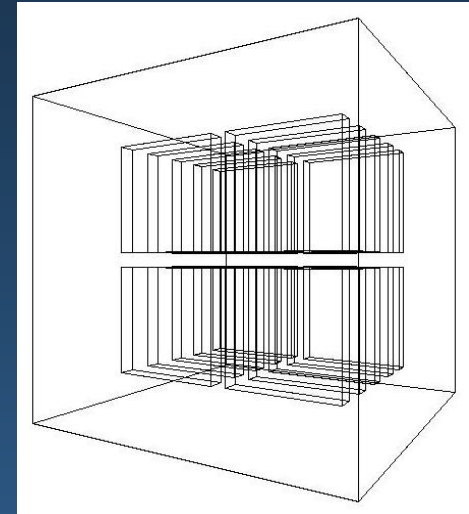
placement



parameterised



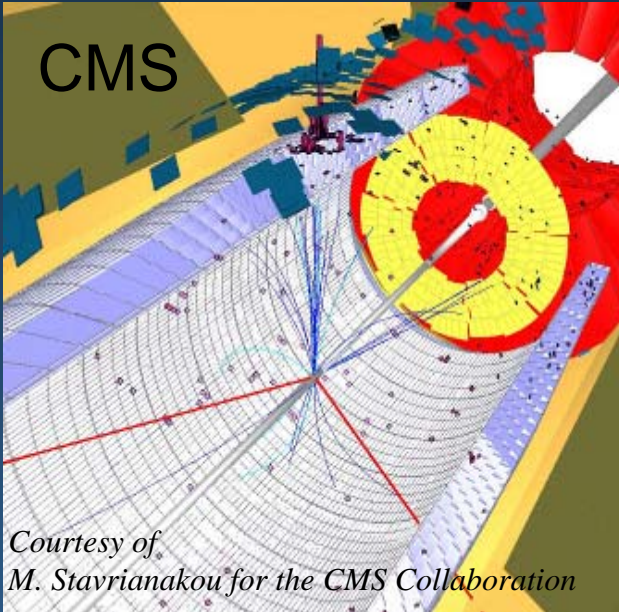
replica



assembled

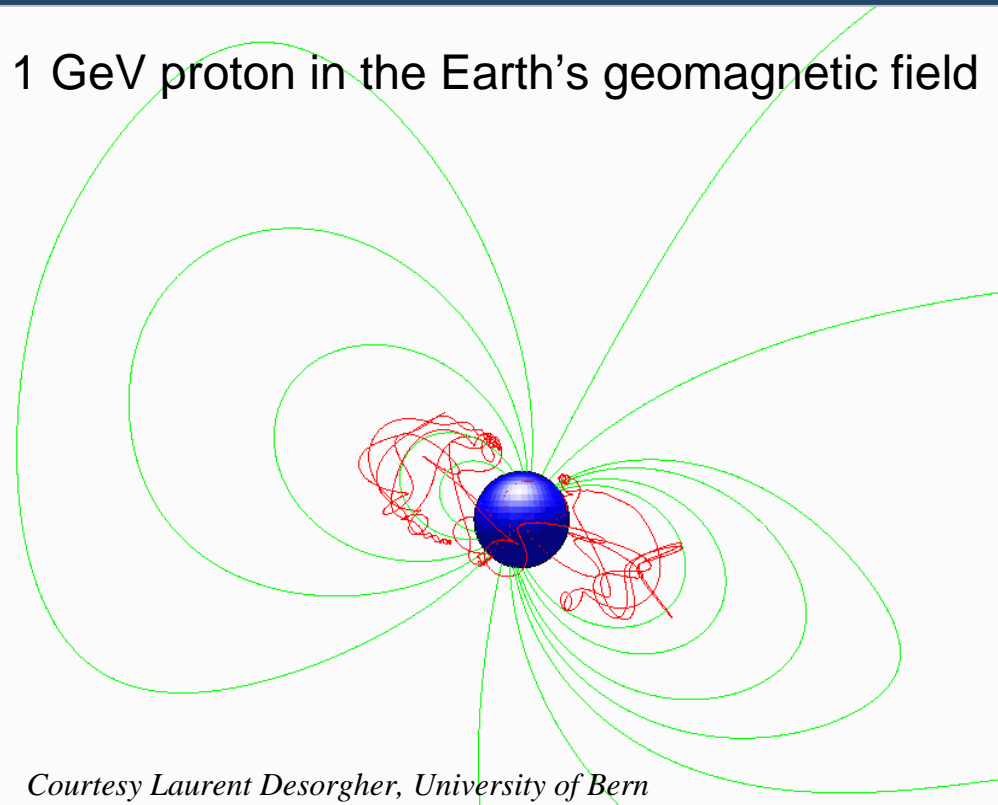
Versatility to describe  
complex geometries

# Electric and magnetic fields of variable non-uniformity and differentiability



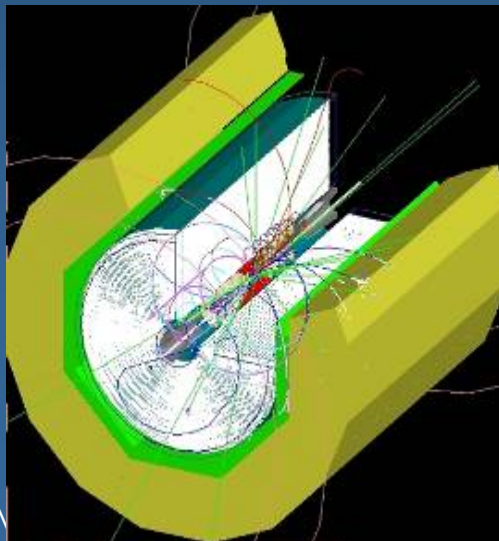
Geant4 field ~ 2 times faster than FORTRAN/GEANT3

1 GeV proton in the Earth's geomagnetic field

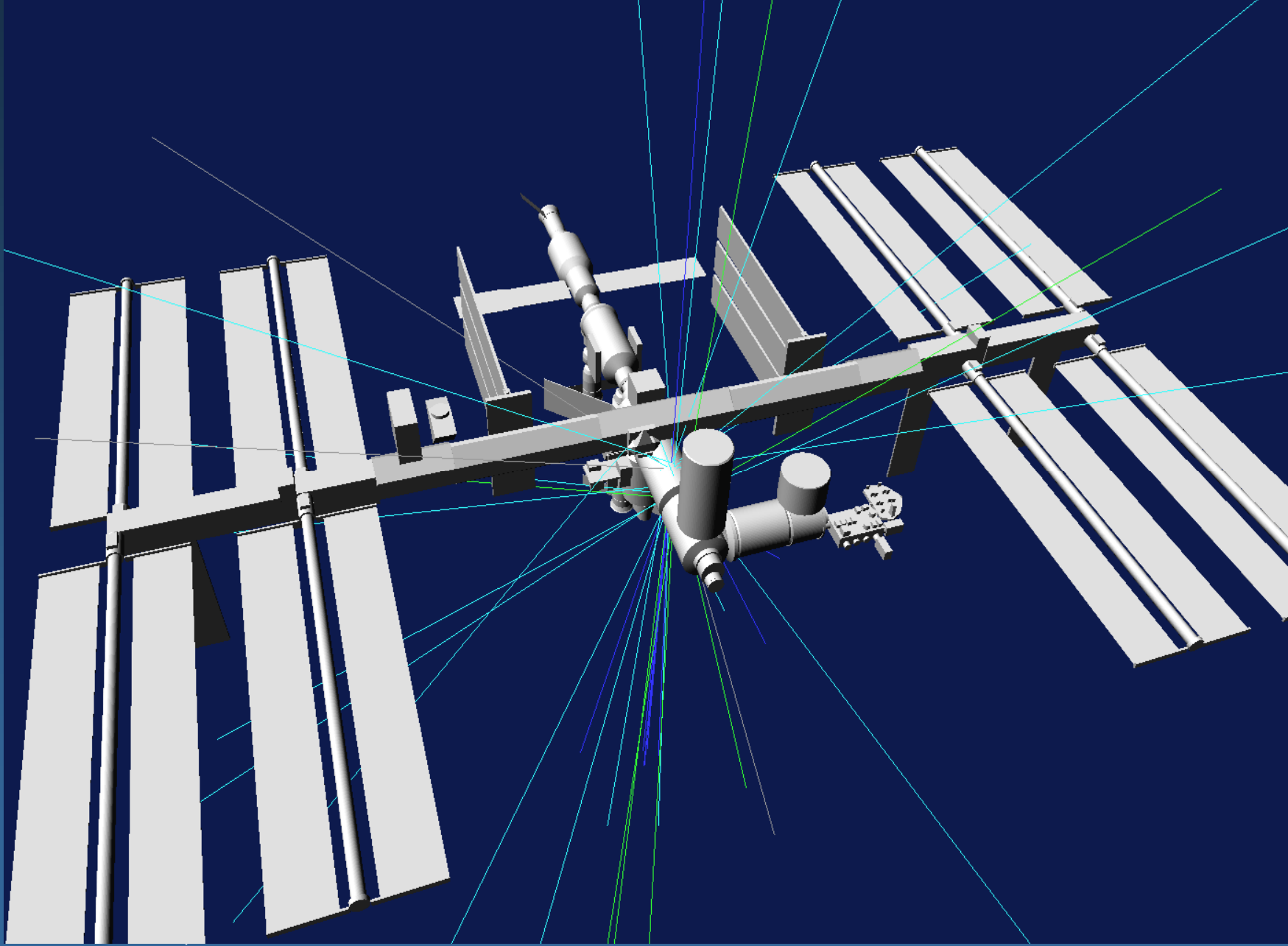


MOKKA

Linear  
Collider  
Detector



Maria Grazia Pia, IN



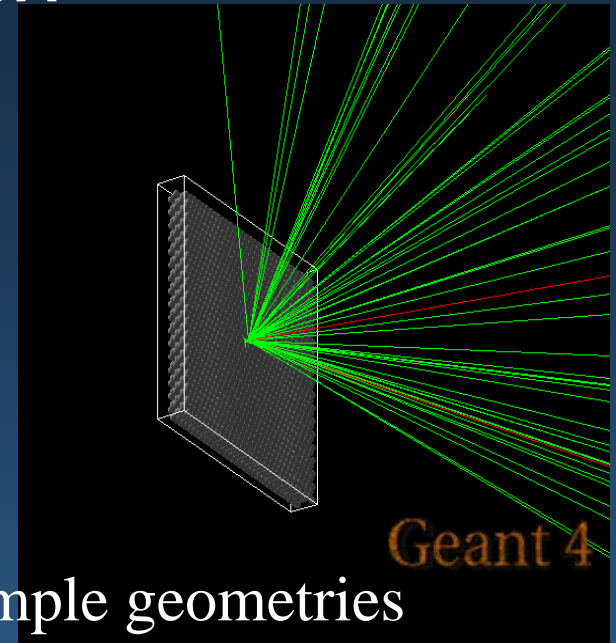
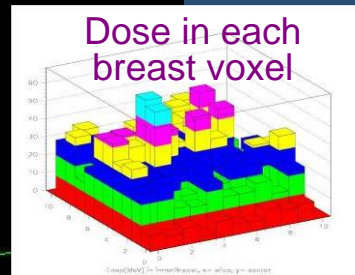


# Not only large scale, complex detectors....

Analytical breast

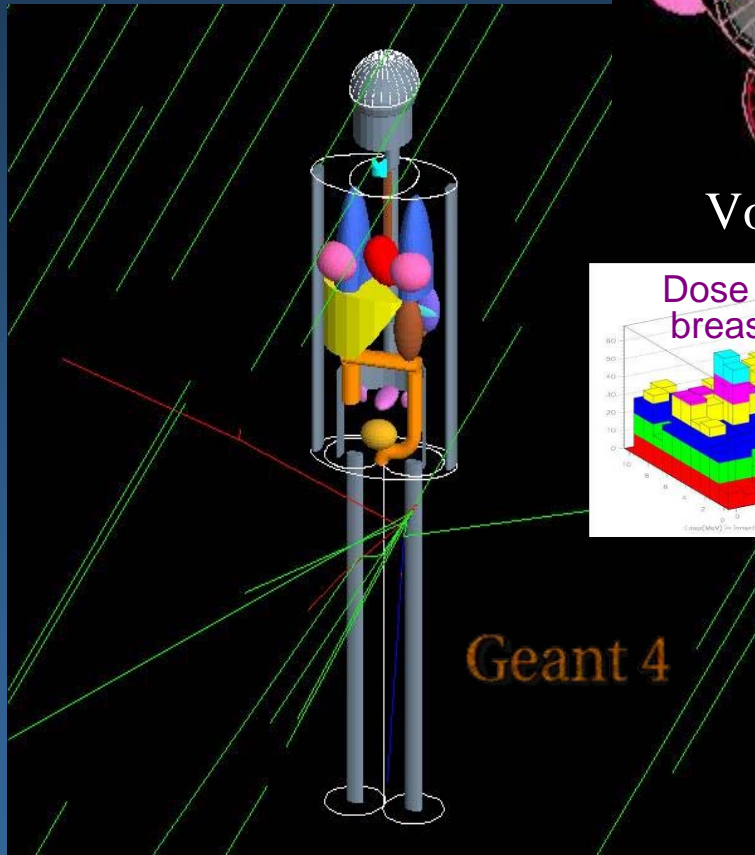


Voxel breast

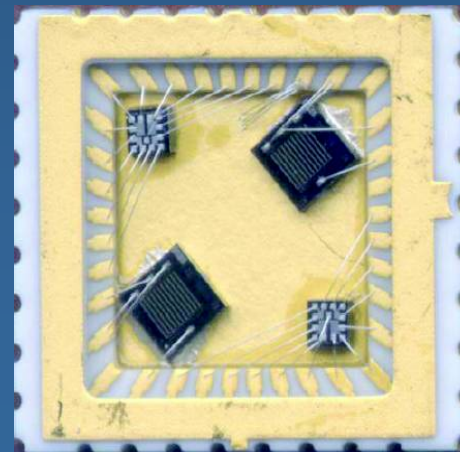


simple geometries

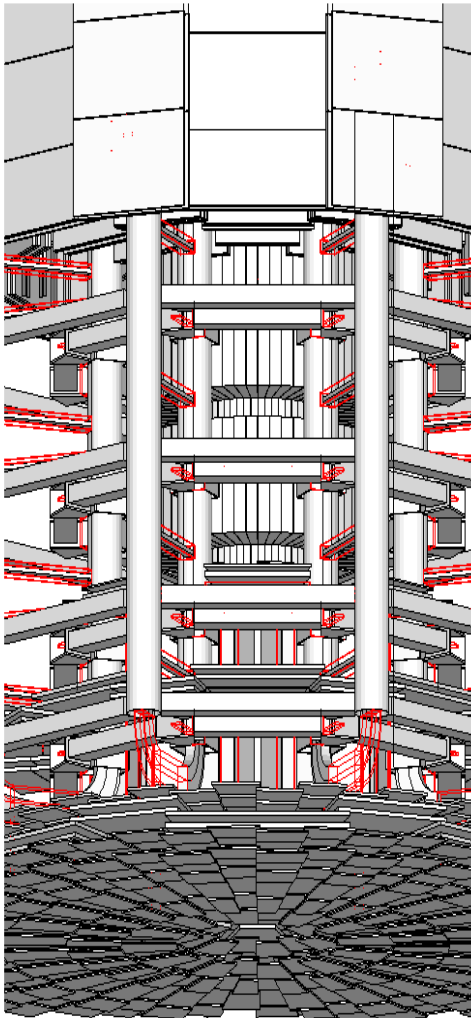
small scale components



Geant4 anthropomorphic phantoms



# You may also do it wrong...



**DAVID**

Tools to detect badly defined geometries

graphical indication of detected overlaps

```
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] ...

red: mother  
blue: daughters

daughters are protruding their mother

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

# Physics

- Abstract interface to physics processes
  - **Tracking independent from physics**
  - Uniform treatment of electromagnetic and hadronic processes
- Distinction between **processes** and **models**
  - multiple models for the same physics process  
(*complementary/alternative*)
- **Transparency** (supported by *encapsulation* and *polymorphism*)
  - Calculation of cross-sections independent from the way they are accessed  
(data files, analytical formulae etc.)
  - Calculation of the final state independent from tracking
- Explicit use of units throughout the code
- Open system
  - Users can easily create and use their own models

# Electromagnetic physics

- electrons and positrons
- $\gamma$ , X-ray and optical photons
- muons
- charged hadrons
- ions

Comparable to Geant3 already in the  $\alpha$  release (1997)

Further extensions (*facilitated by the OO technology*)

energy  
loss

- 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

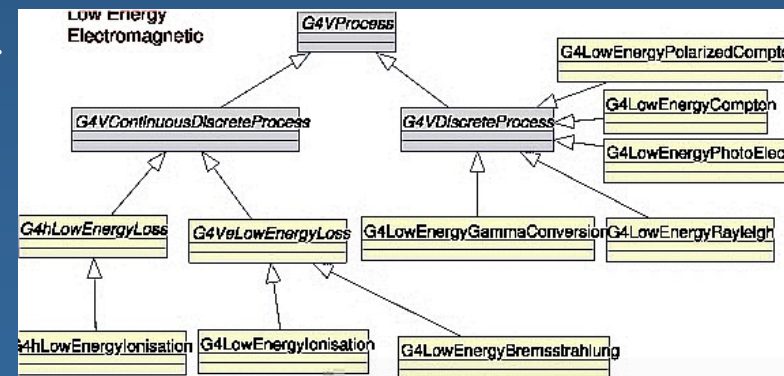
## ■ High energy extensions

- needed for LHC experiments, cosmic ray experiments...

## ■ Low energy extensions

- fundamental for space and medical applications, dark matter and  $\nu$  experiments, antimatter spectroscopy etc.

## ■ Alternative models for the same process

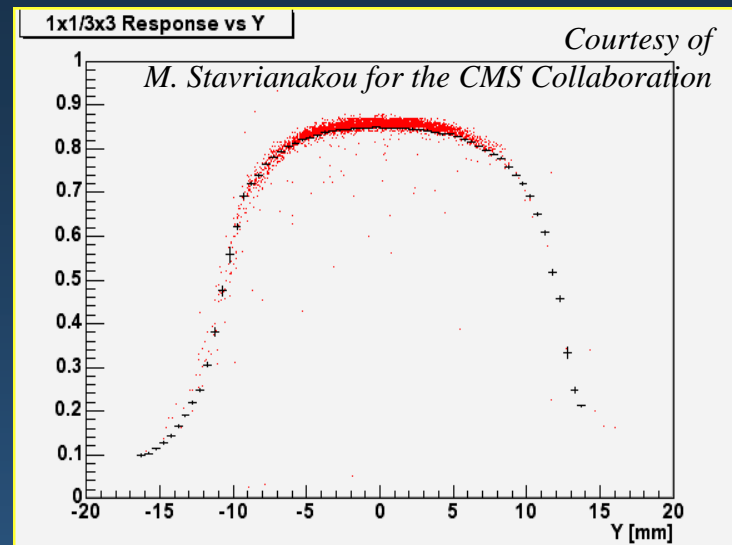
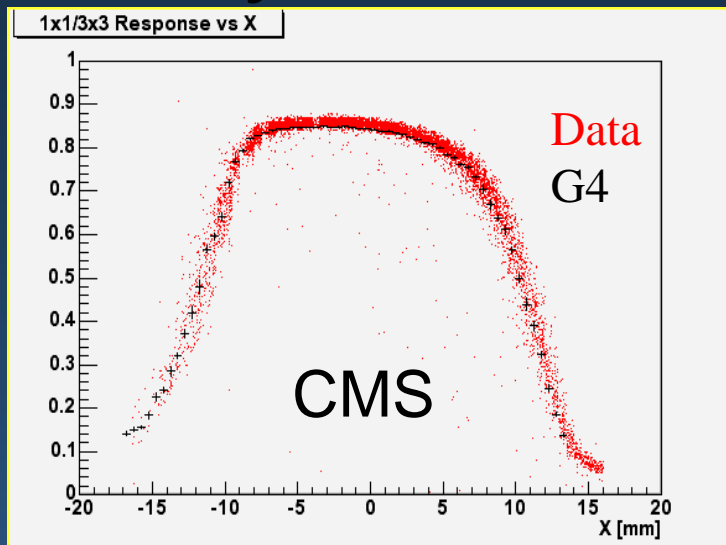


All obeying to the same abstract Process interface transparent to tracking 24



# Calorimetry

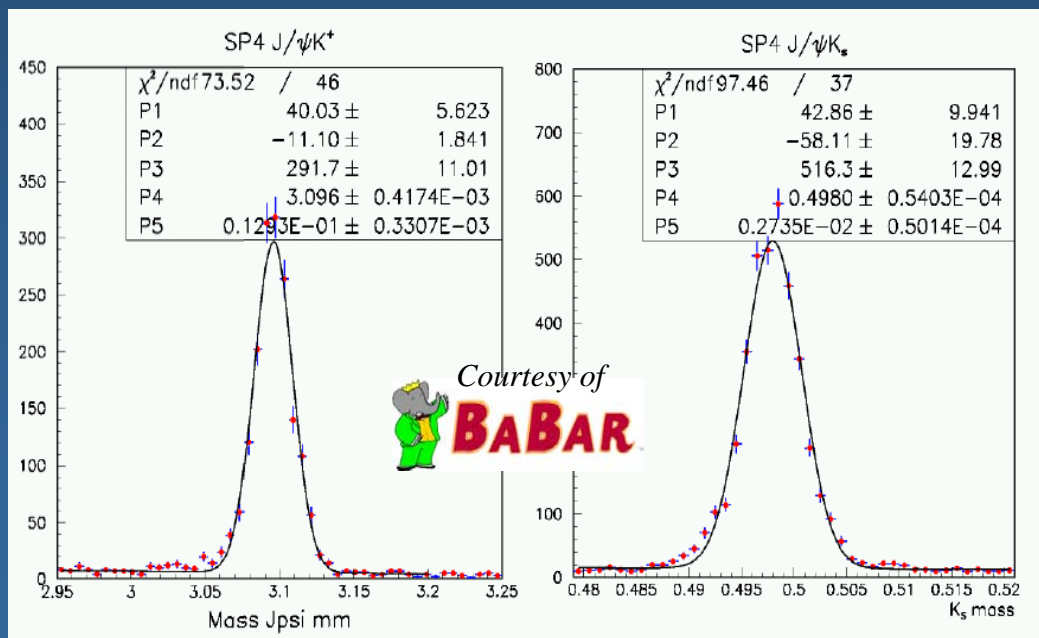
Single crystal containment:  $E_{1x1}/E_{3x3}$  versus position

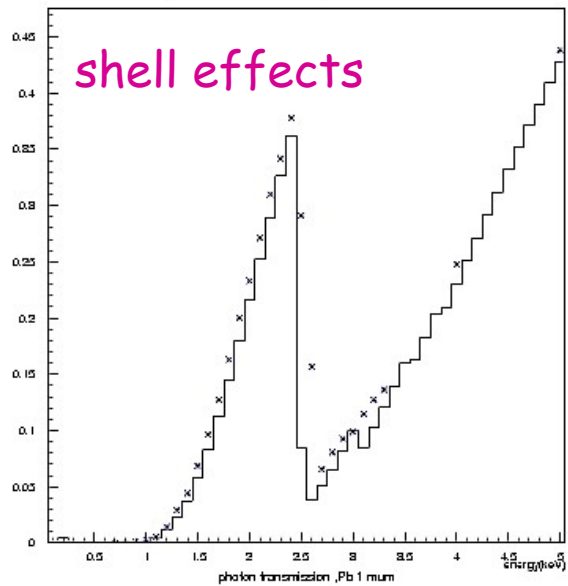


# Tracking

Geant4  
Standard  
Electromagnetic  
Physics

Maria Grazia Pia, INFN Genova

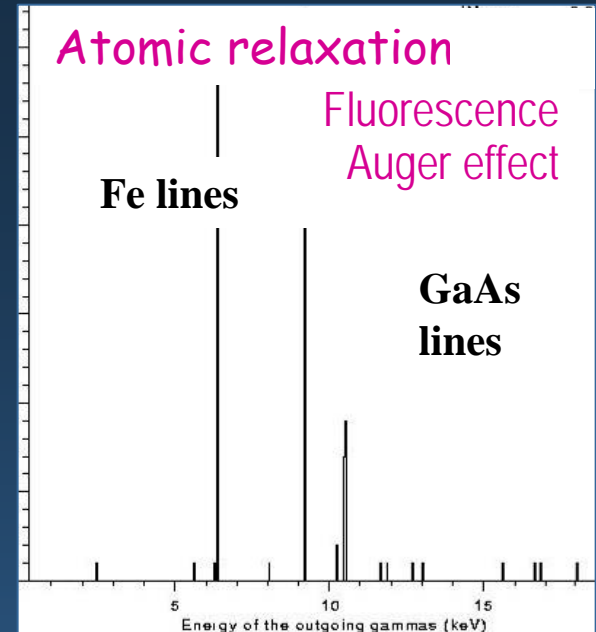




# Geant 4

$e, \gamma$  down to 250/100 eV  
 EGS4, ITS to 1 keV  
 Geant3 to 10 keV

- ① Based on EPDL97, EEDL and EADL evaluated data libraries
- ② Based on Penelope analytical models



**Hadron and ion** models based on Ziegler and ICRU data and parameterisations

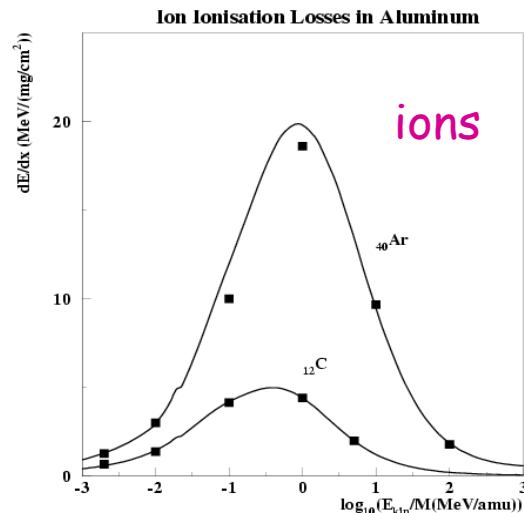
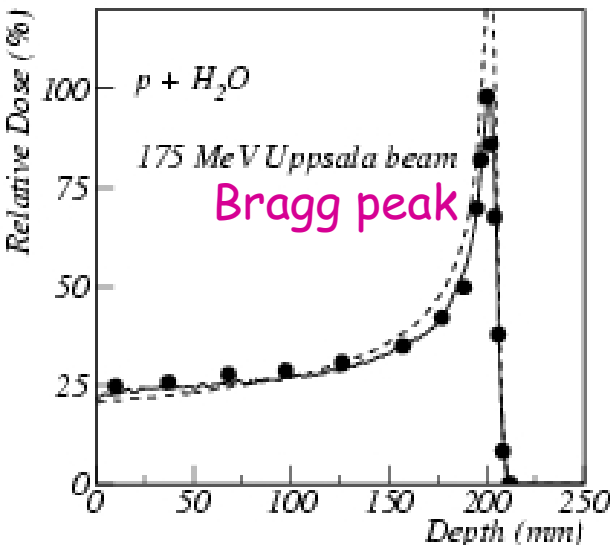
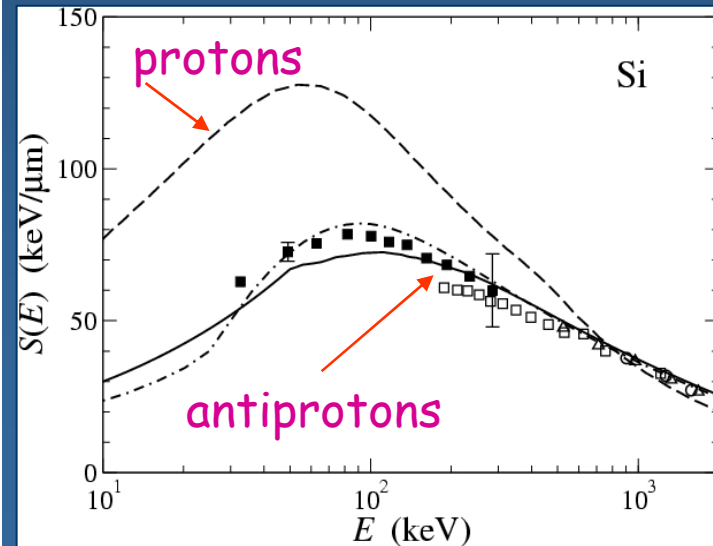


Figure 9: Ion electronic stopping power in aluminum. Points - the best fit on the data from Ref.[12], solid line - GEANT4 parameterisation. The accuracy of the data is about 5 %.

Barkas effect (charge dependence) models for **negative hadrons**



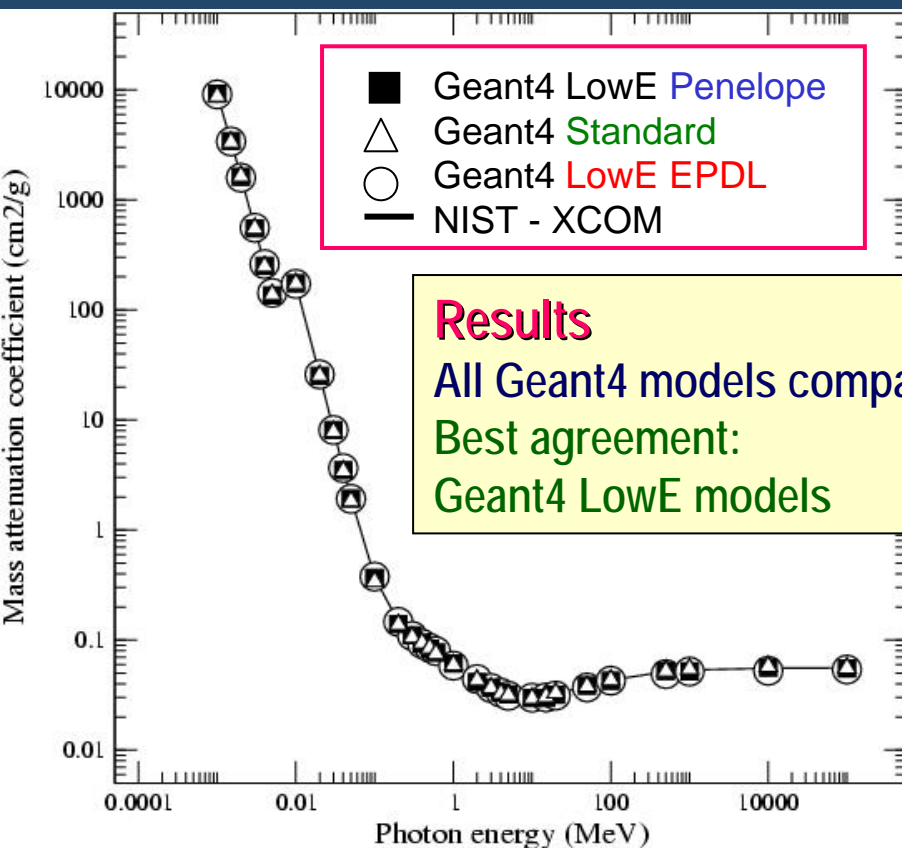
# “Comparison of Geant4 electromagnetic physics models against the NIST reference data”

*IEEE Transactions on Nuclear Science, vol. 52 (4), pp. 910-918, 2005*

## Geant4 electromagnetic physics models are accurate

Compatible with NIST data within NIST accuracy (LowE p-value > 0.9)

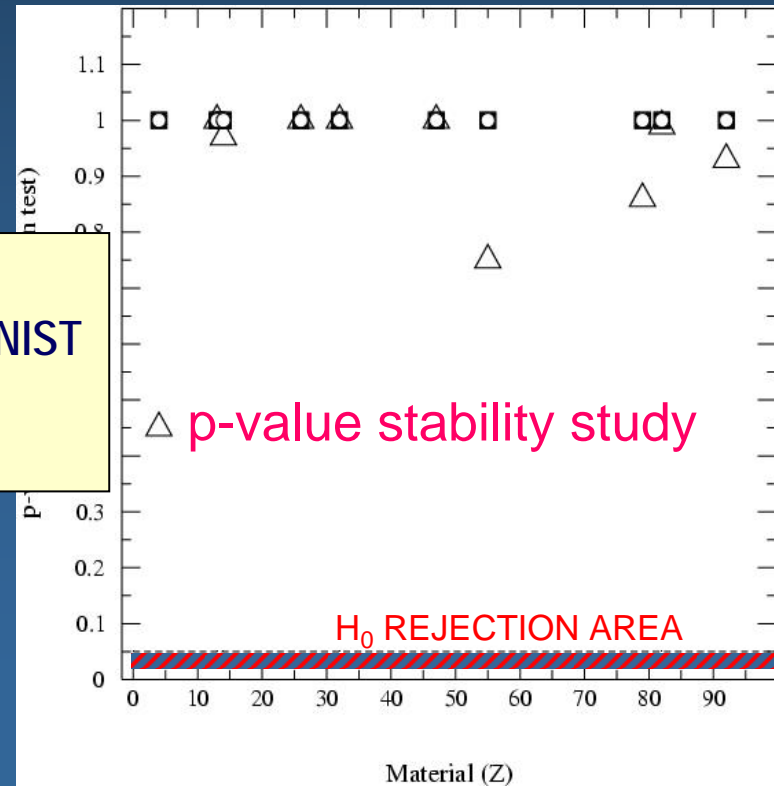
### Mass attenuation coefficient in Fe



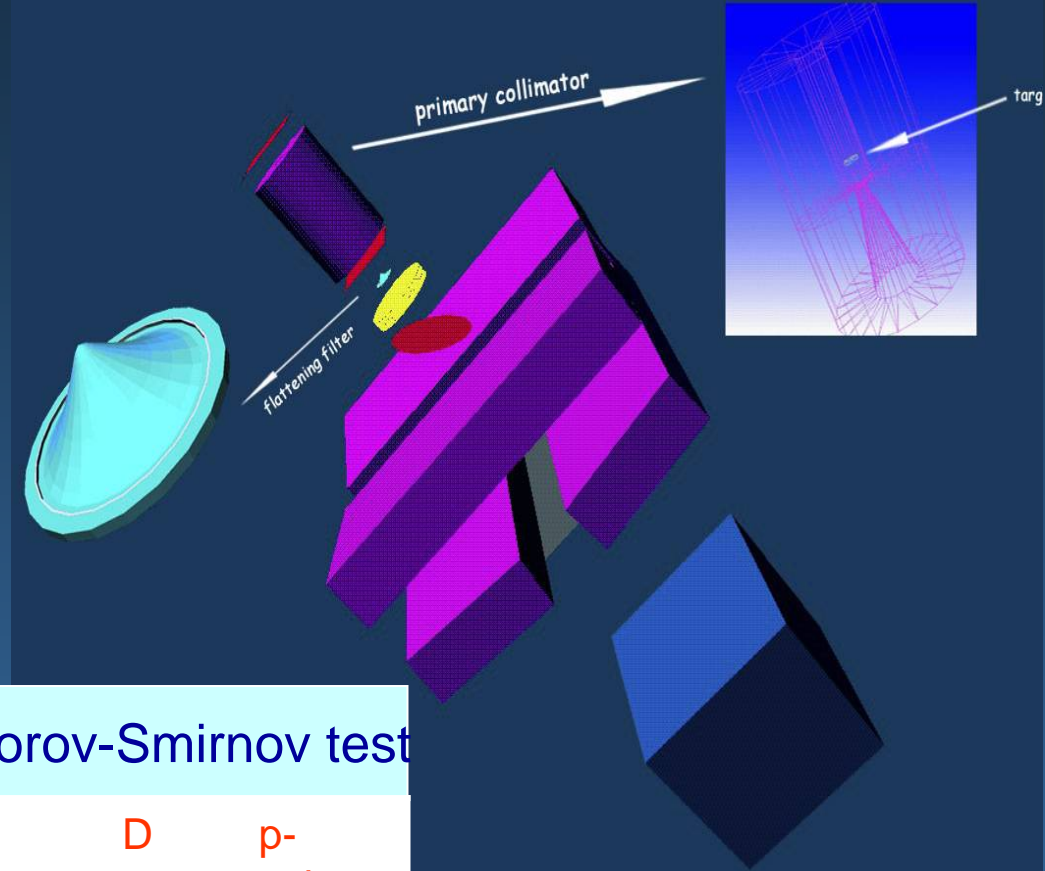
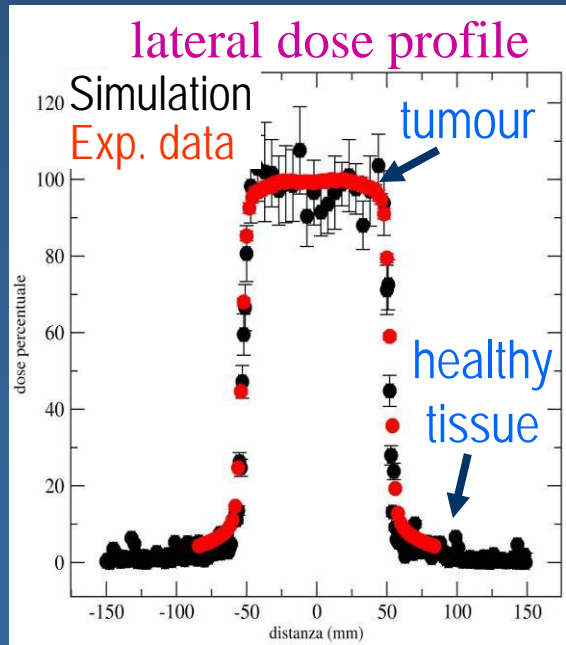
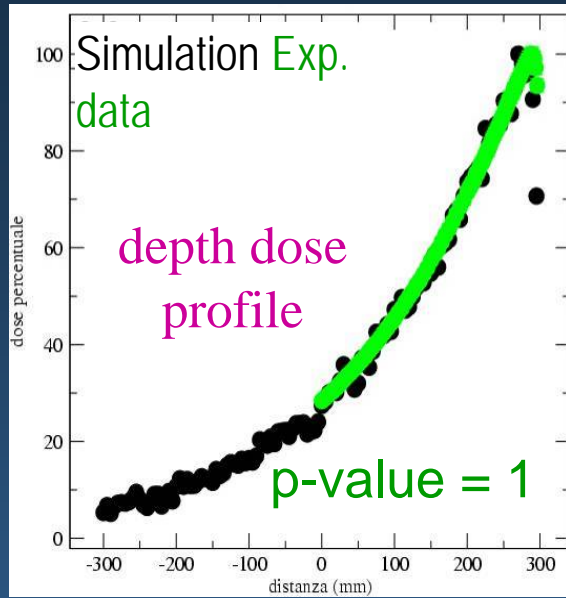
### Results

All Geant4 models compatible with NIST

Best agreement:  
Geant4 LowE models



# A medical accelerator for IMRT



## Kolmogorov-Smirnov test

range	D	p-value
-84 ÷ -60 mm	0.385	0.23
-59 ÷ -48 mm	0.27	0.90
-47 ÷ 47 mm	0.43	0.19
48 ÷ 59 mm	0.30	0.82
60 ÷ 84 mm	0.40	0.10

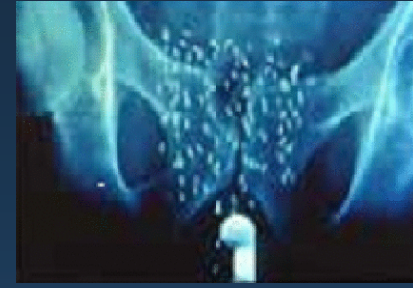




# Dosimetry

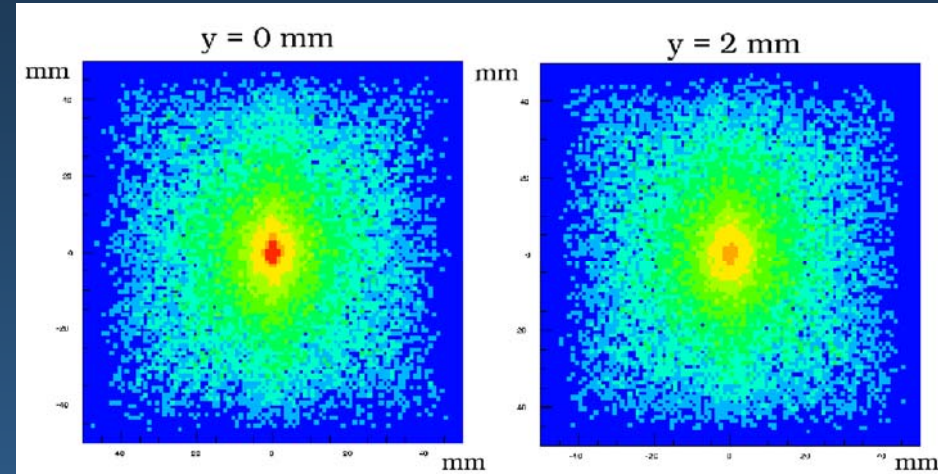
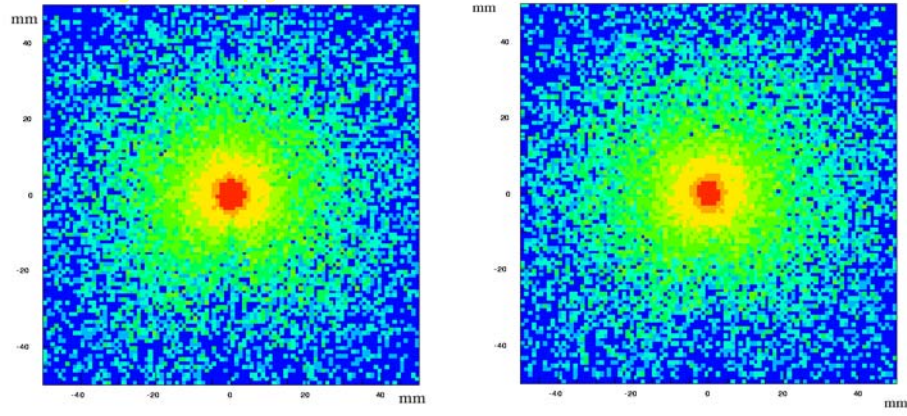
Endocavitary

brachytherapy MicroSelectron-HDR source



# Dosimetry

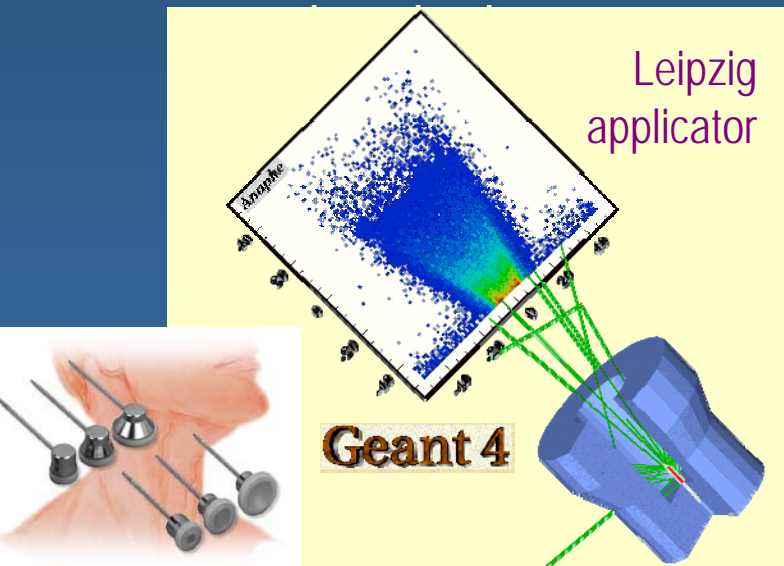
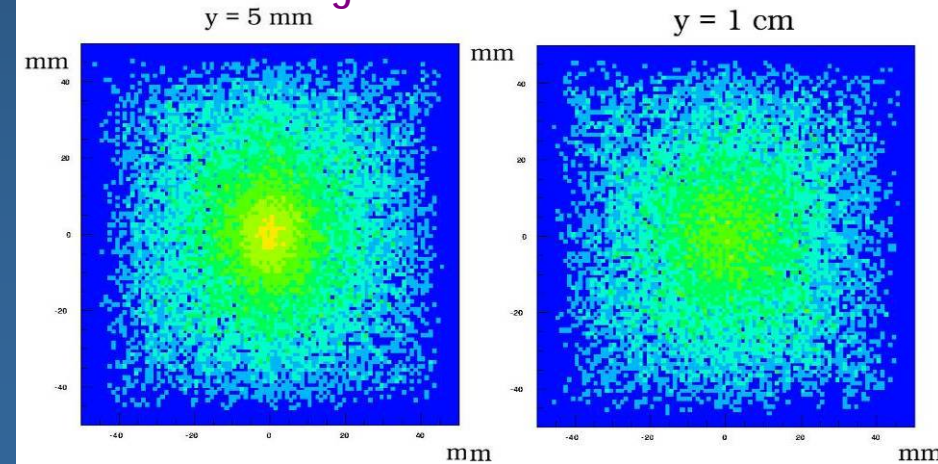
Interstitial



# Dosimetry

Superficial

Bebig Ioseed I-125 source





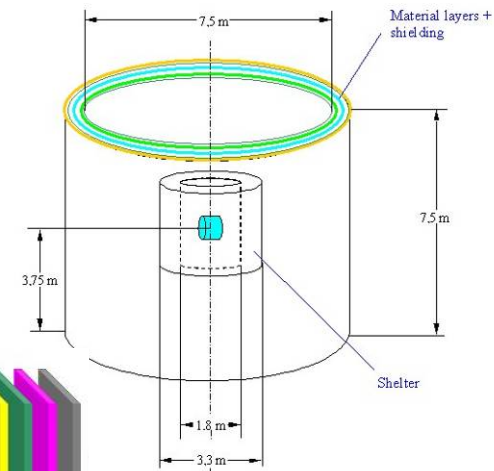
# Dosimetry in interplanetary missions



Aurora Programme



Courtesy of ESA

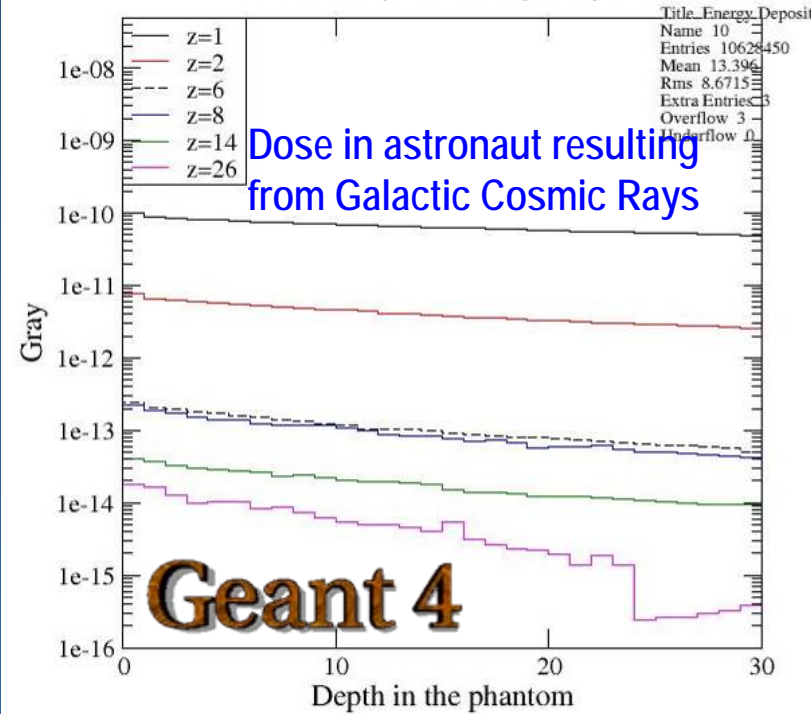


Courtesy of Alenia Spazio vehicle concept



## Dose in the phantom

GCR - EM Physics - 10 cm polyethylene



Dose in astronaut resulting from Galactic Cosmic Rays

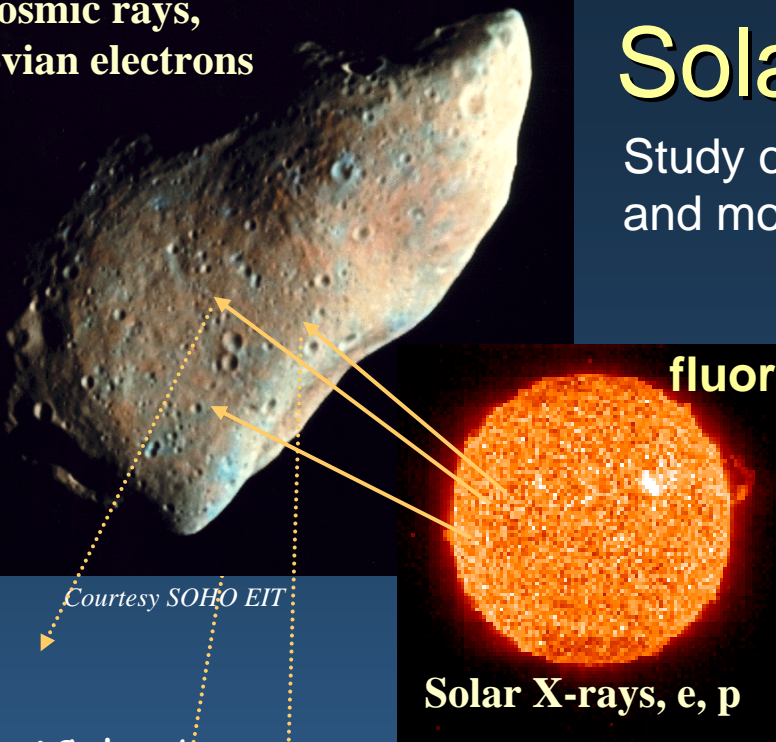


Maria Grazia Pia, INFN Genova

Cosmic rays,  
jovian electrons

# Solar system explorations

Study of the elemental composition of planets, asteroids and moons → clues to solar system formation



**X-ray fluorescence**

Arising from the solar X-ray flux, sufficient, for the inner planets, to significant fluorescence fluxes to an orbiter

**PIXE**

Significant only during particle events, during which it can exceed XRF

Courtesy SOHO EIT

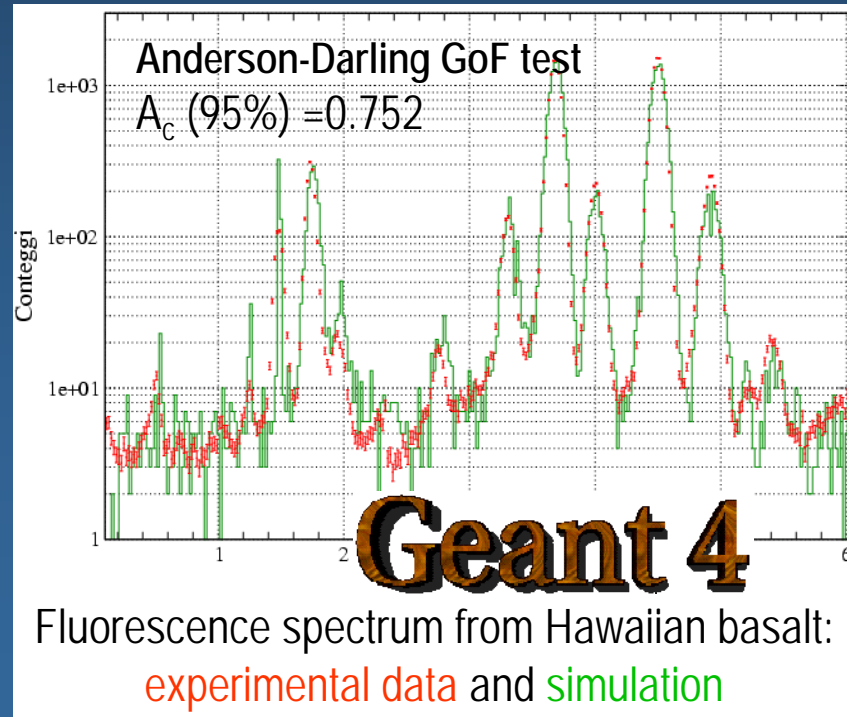
Solar X-rays, e, p

BepiColombo  
ESA cornerstone mission to Mercury



Maria

Courtesy of ESA Astrophysics





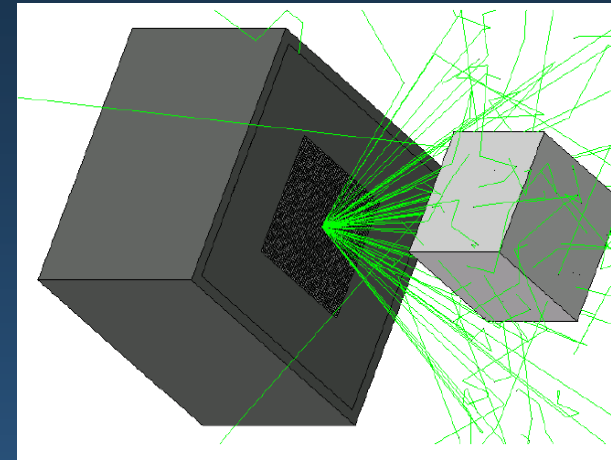
# Detection of Landmines using Radiation Based Techniques

## Geant4 User's Workshop, SLAC 2002 02 21

Dr Anthony A. Faust

Threat Detection Group

Defence Research Establishment Suffield

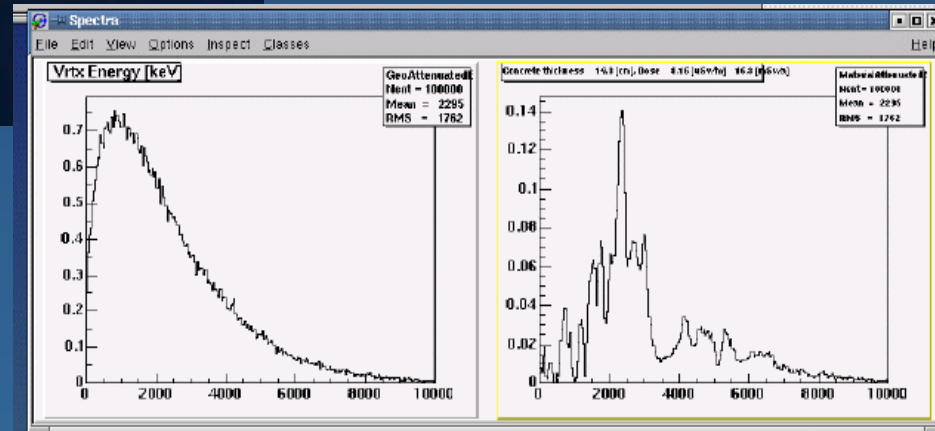


Defence R&D  
Canada

R et D pour la défense  
Canada

## X-ray Backscatter Imaging

- Exploit Z dependent differences in Compton/Photoelectric cross-sections
- $Z_{eff}^{mine} \sim 8$  and  $Z_{eff}^{soil} \sim 14$



Used Low Energy packages



# Polarisation

Cross section:

$$\frac{d\sigma}{d\Omega} = \frac{1}{2} r_0^2 \frac{h\nu^2}{h\nu_0^2} \left[ \frac{h\nu_0}{h\nu} + \frac{h\nu}{h\nu_0} - 2 \sin^2 \theta \cos^2 \phi \right]$$

## Low Energy Polarised Compton

250 eV - 100 GeV

Sample Methods:

Integrating over  $\phi$

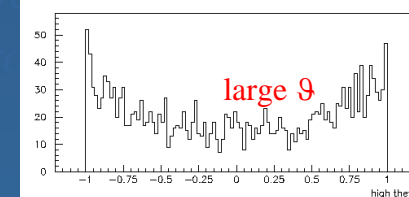
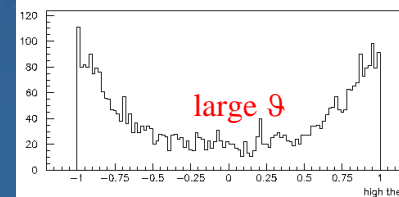
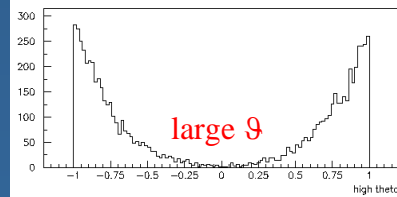
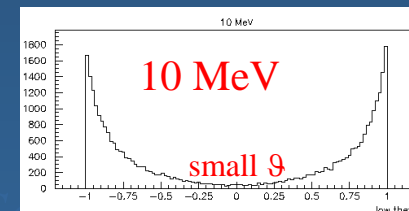
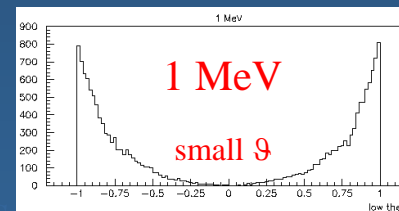
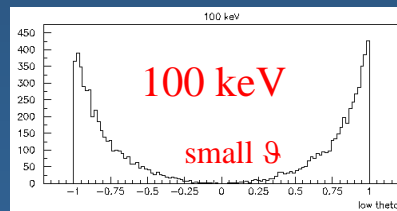
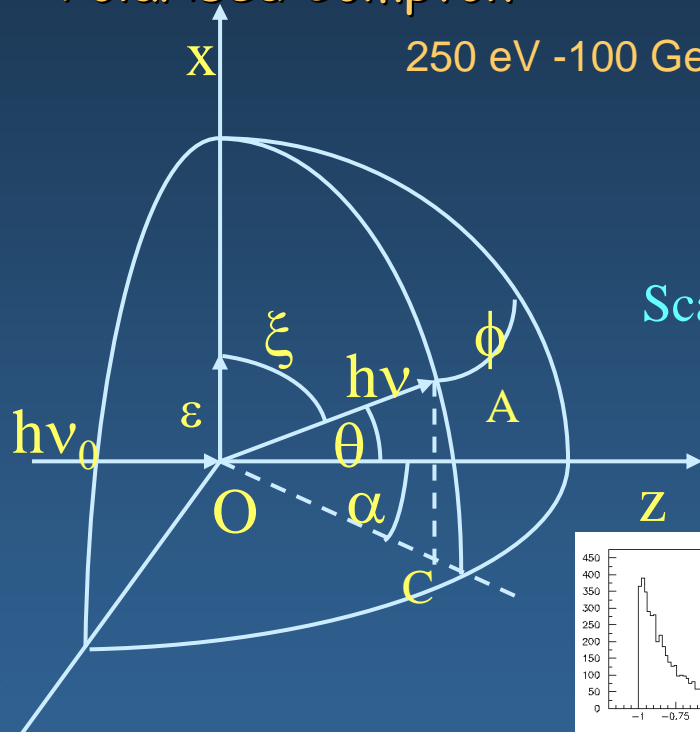
- Sample  $\theta$
- $\theta$  - Energy Relation  $\Rightarrow$  Energy
- Sample of  $\phi$  from  $P(\phi) = a (b - c \cos^2 \phi)$  distribution

$$\cos \xi = \sin \theta \cos \phi \Rightarrow \sin \xi = \sqrt{1 - \sin^2 \theta \cos^2 \phi} = N$$

Scattered Photon Polarization

$$\overline{\varepsilon_{\perp}} = \frac{1}{N} (\cos \theta \hat{j} - \sin \theta \sin \phi \hat{k}) \sin \beta$$

$$\overline{\varepsilon_{\parallel}} = \left( N \hat{i} - \frac{1}{N} \sin^2 \theta \sin \phi \cos \phi \hat{j} - \frac{1}{N} \sin \theta \cos \theta \cos \phi \hat{k} \right) \cos \beta$$

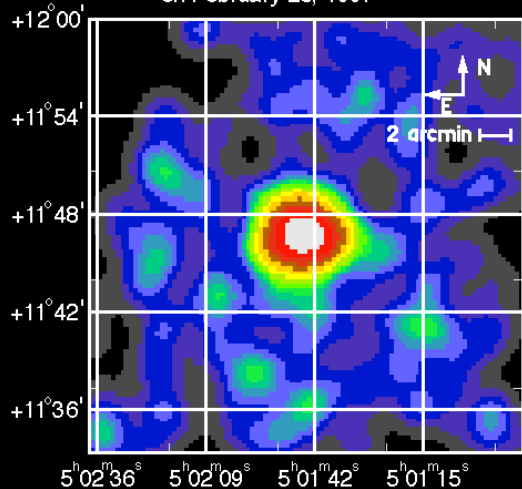


- $\theta$  Polar angle
- $\phi$  Azimuthal angle
- $\varepsilon$  Polarization vector

# $\gamma$ astrophysics

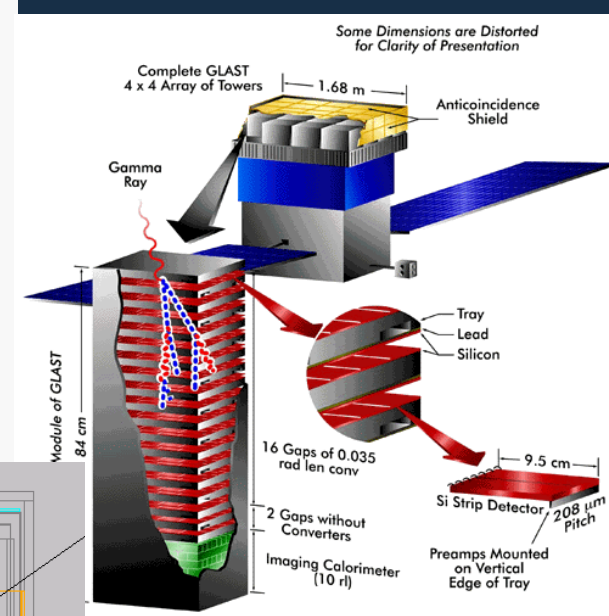
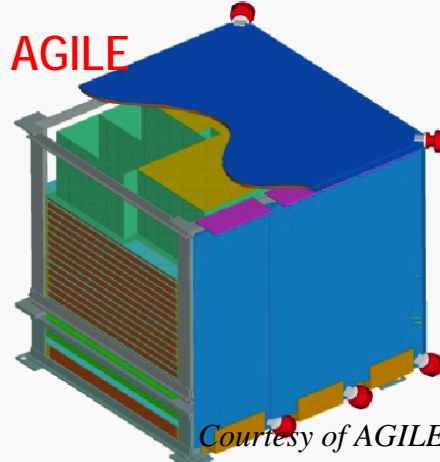
## $\gamma$ -ray bursts

BeppoSAX Observation of Gamma-Ray Burst  
on February 28, 1997



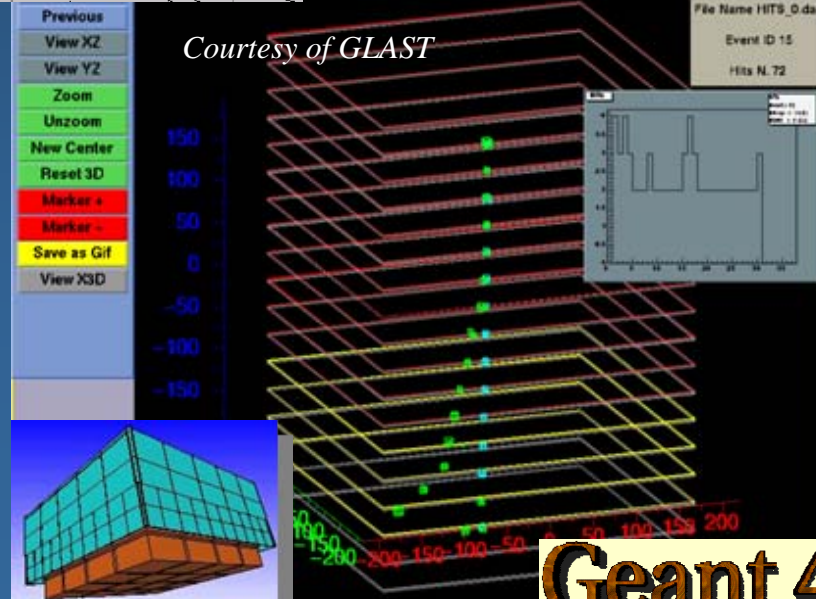
Courtesy of Fabrizio Fiore and the BeppoSAX Team

AGILE



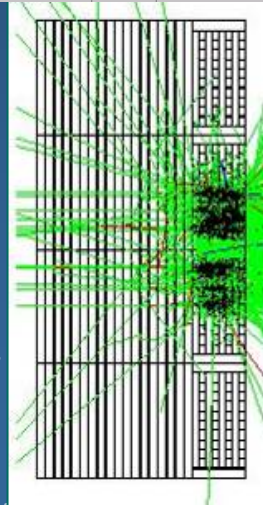
GLAST

GLAST Hits Display



Typical telescope:  
Tracker  
Calorimeter  
Anticoincidence

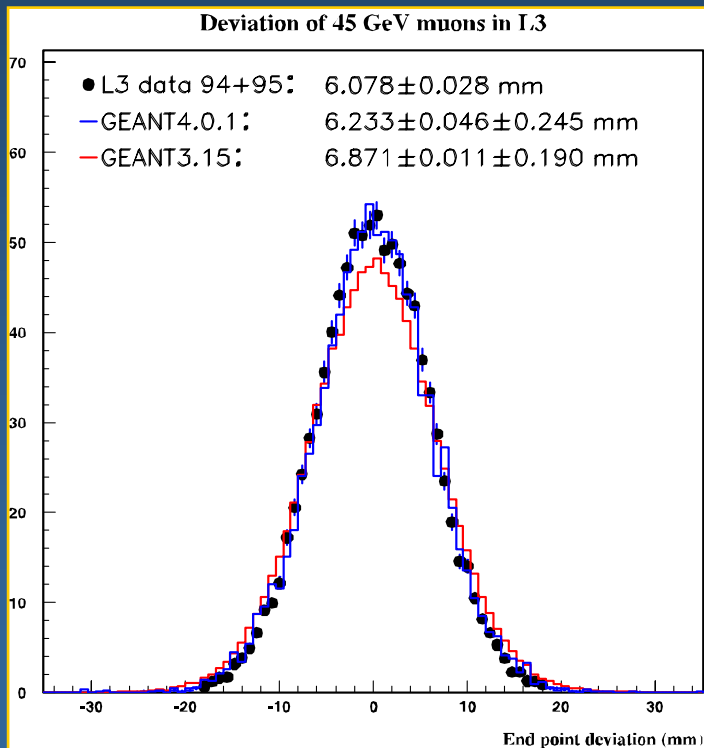
- $\gamma$  conversion
- electron interactions
- multiple scattering
- $\delta$ -ray production
- charged particle tracking



Geant 4

# Muons

- 1 keV up to 10 PeV scale
- simulation of ultra-high energy and cosmic ray physics
- High energy extensions based on theoretical models



- Muon Muon energy loss
- Muon radiation processes
- Gamma conversion to muon pair
- Positron annihilation to muon pair
- Positron annihilation into hadrons



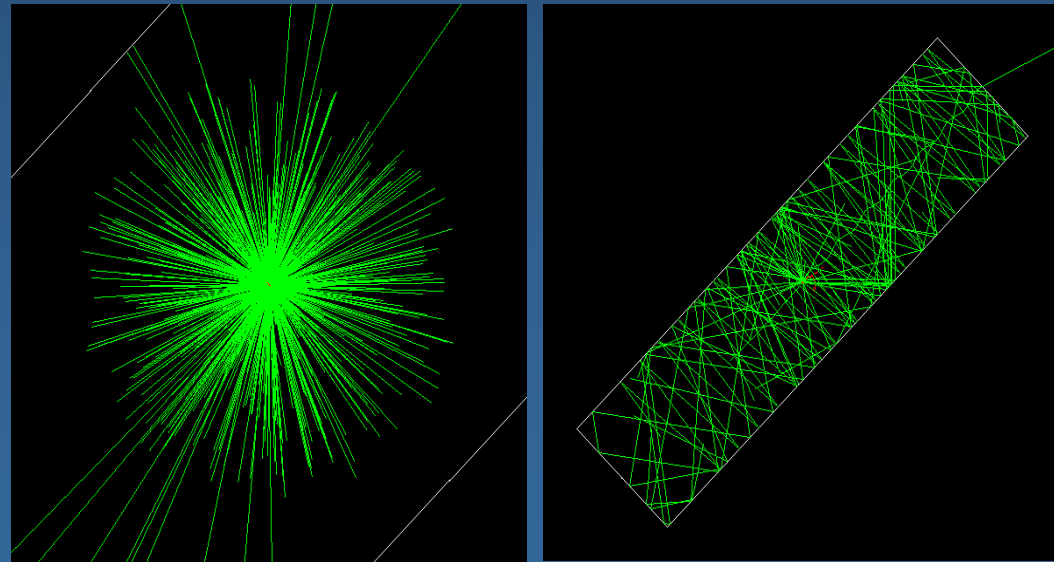
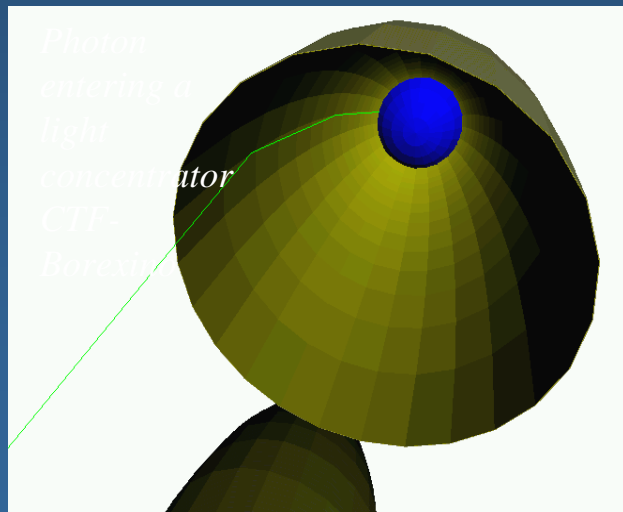
# Optical photons

*Production of optical photons in HEP detectors is mainly due to Cherenkov effect and scintillation*

## Processes in Geant4:

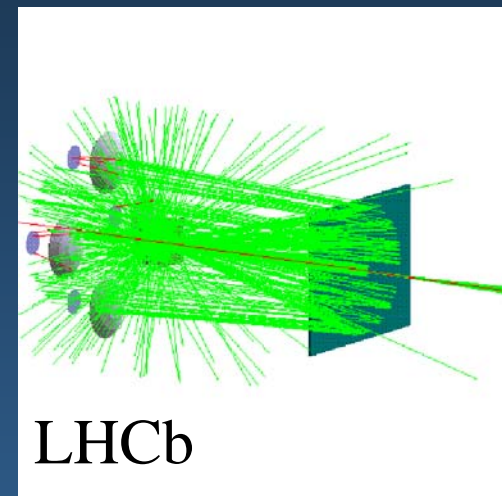
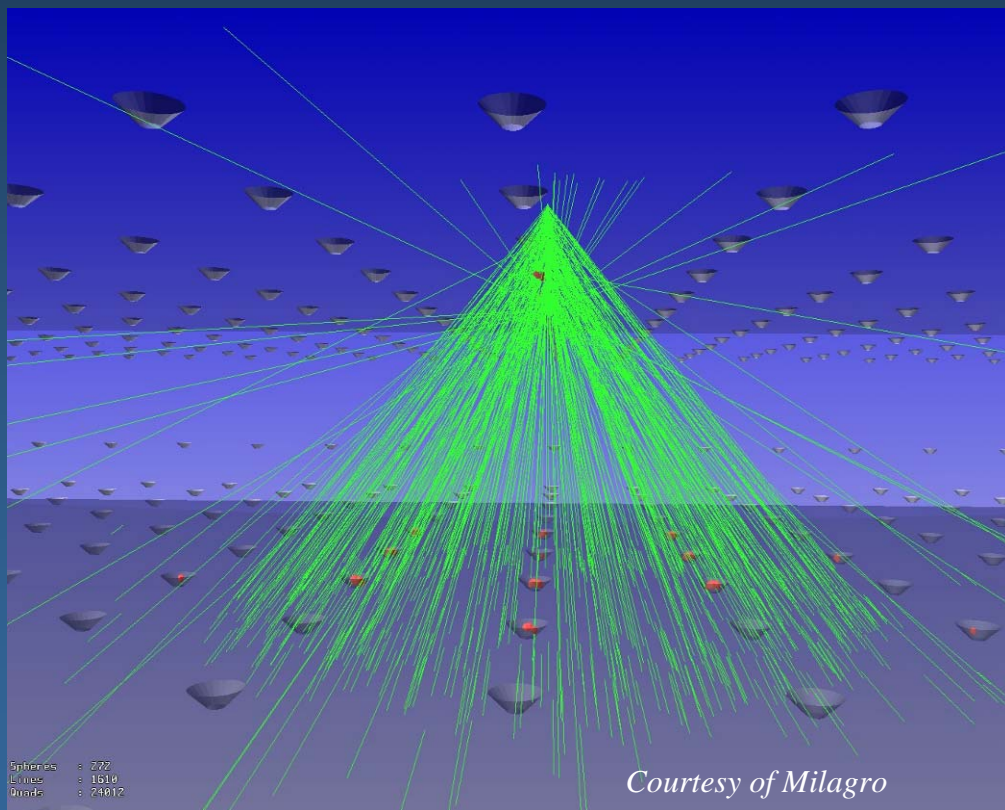
- in-flight absorption
- Rayleigh scattering
- medium-boundary interactions (reflection, refraction)

## Geant4 Optical Processes : Scintillating Cells and WLS Fibers



# Cherenkov

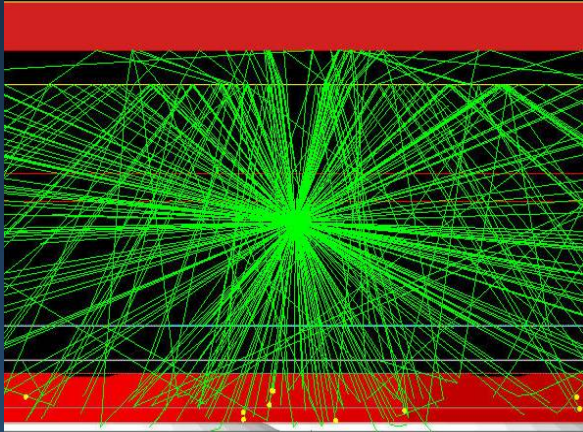
Milagro is a Water-Cherenkov detector located in a 60m x 80m x 8m covered pond near Los Alamos, NM



Aerogel Thickness	Yield Per Event	Cherenkov Angle mrad
4 cm DATA	$6.3 \pm 0.7$	$247.1 \pm 5.0$
MC	$7.4 \pm 0.8$	$246.8 \pm 3.1$
8 cm DATA	$9.4 \pm 1.0$	$245.4 \pm 4.8$
MC	$10.1 \pm 1.1$	$243.7 \pm 3.0$

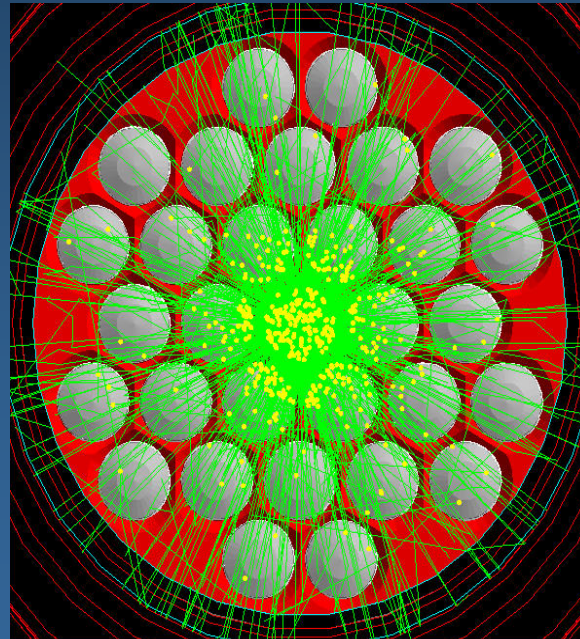


prompt scintillation

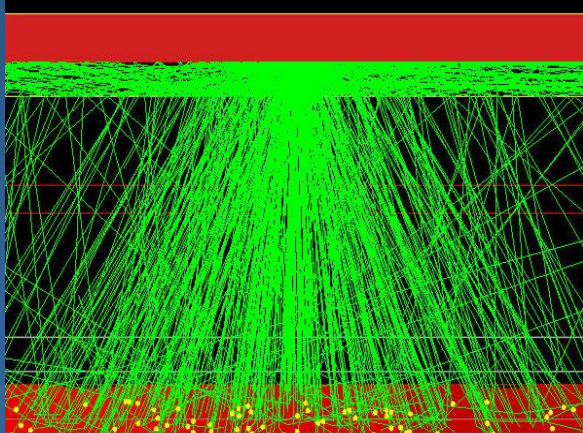


ZEPLIN III  
Dark Matter Detector

signal in PMT

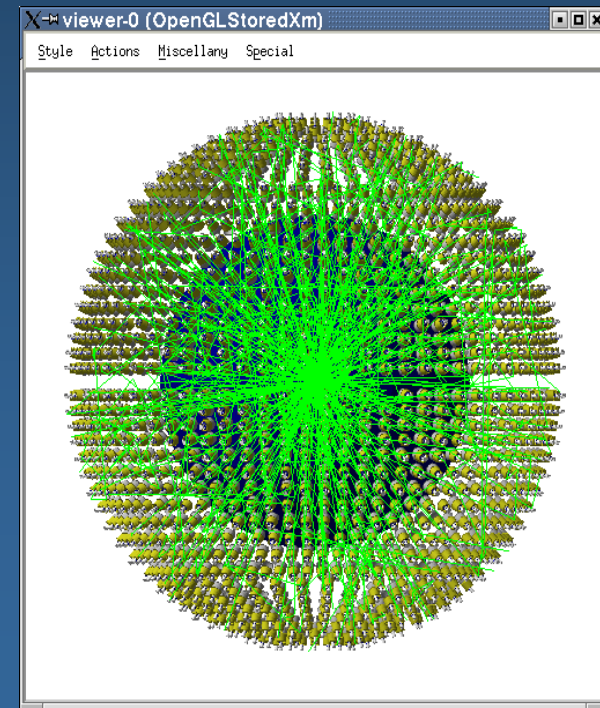


termoluminescence



# Scintillation

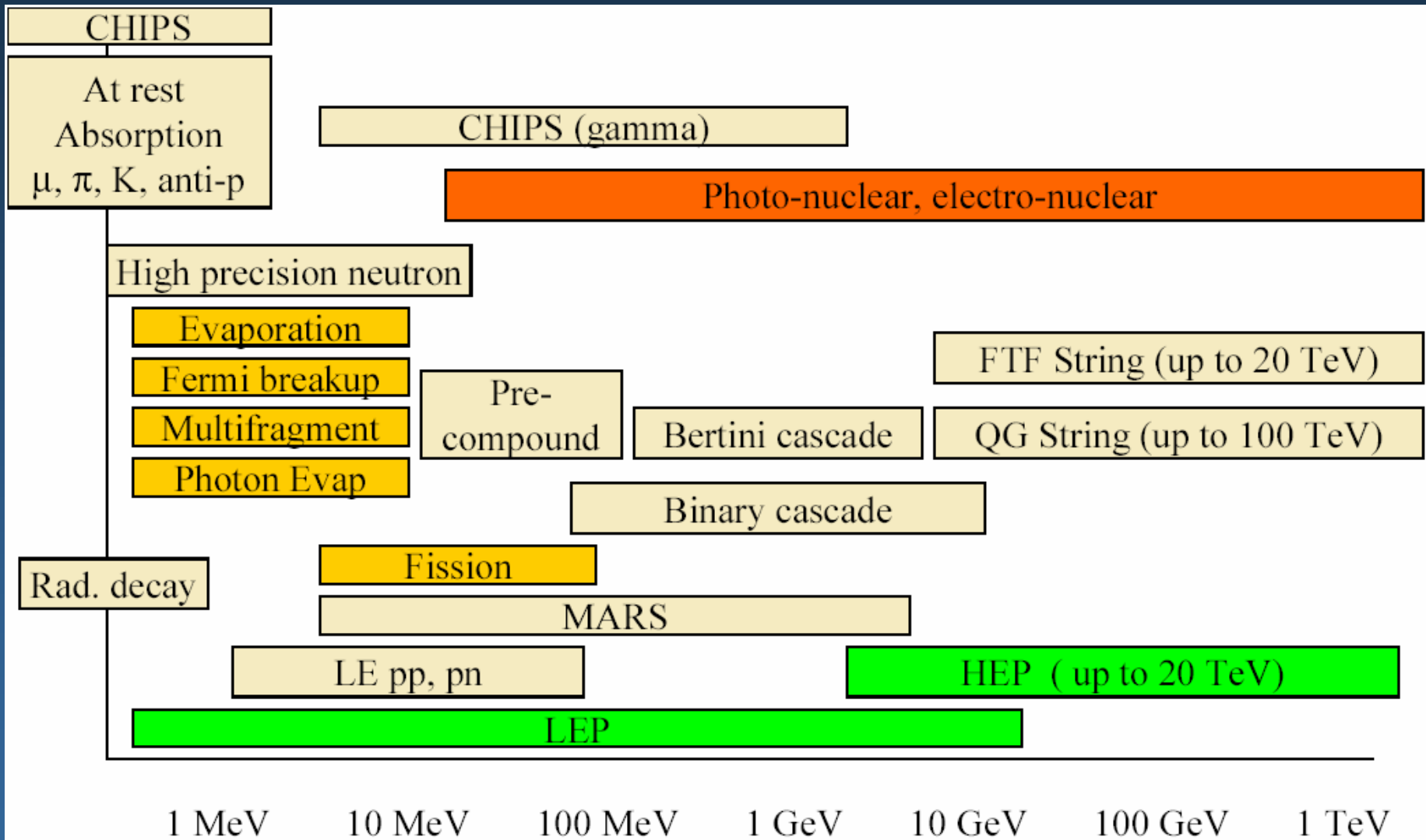
GEANT4 Scintillation  
Event in BOREXINO



# Hadronic physics

- Completely different approach w.r.t. the past (Geant3)
  - native
  - transparent
  - 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
  - the most complete hadronic simulation kit on the market
  - alternative and complementary models
  - data-driven, parameterised and theoretical models

# Hadronic model inventory





# Parameterised and data-driven hadronic models (1)

Based on experimental data

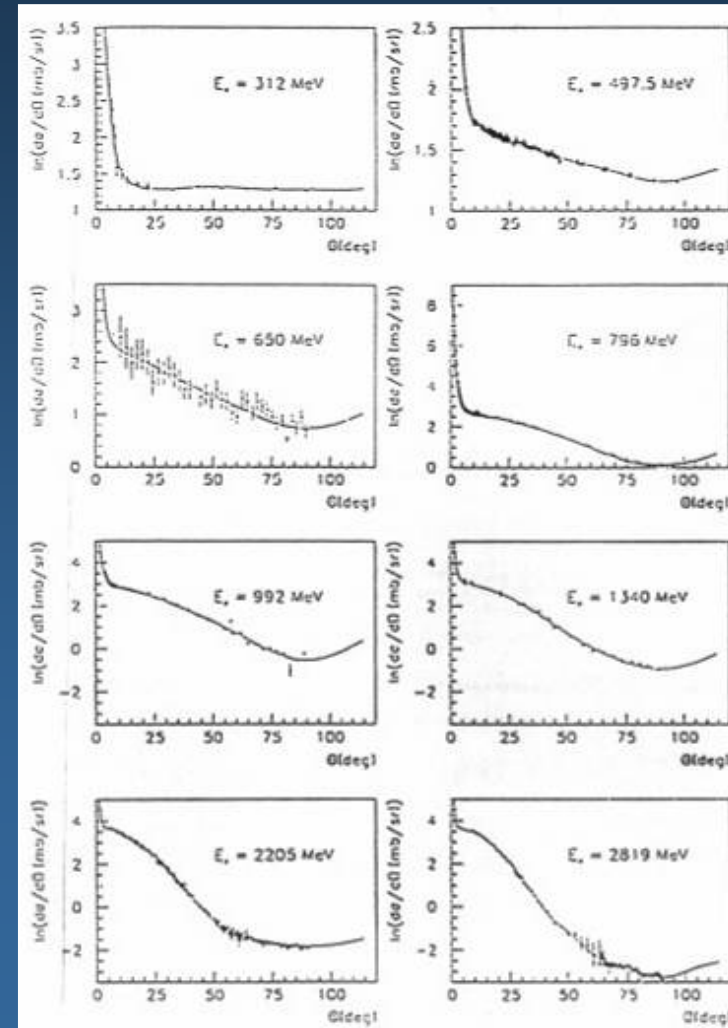
- Some models originally from GHEISHA

- completely reengineered into OO design
- refined physics parameterisations

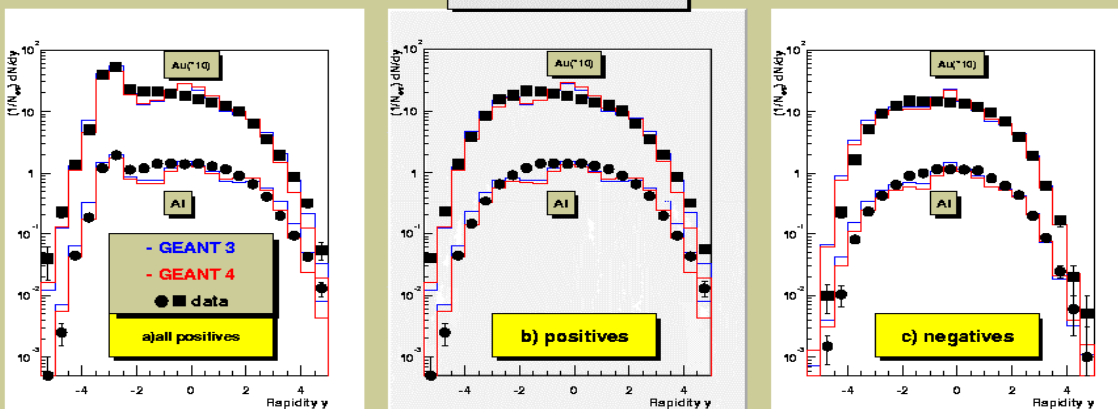
- New parameterisations

- pp, elastic differential cross section
- nN, total cross section
- pN, total cross section
- np, elastic differential cross section
- $\pi$ N, total cross section
- $\pi$ N, coherent elastic scattering

p elastic scattering on Hydrogen



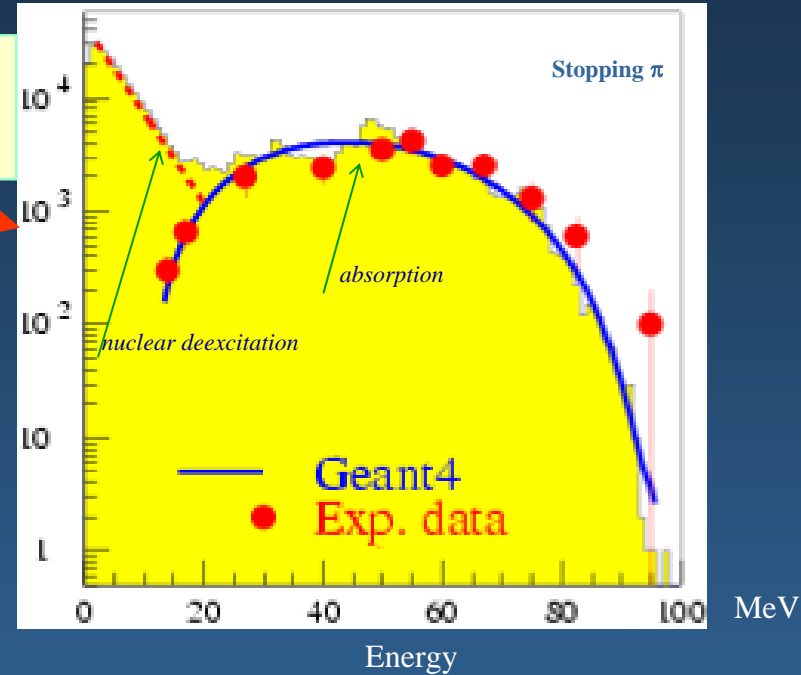
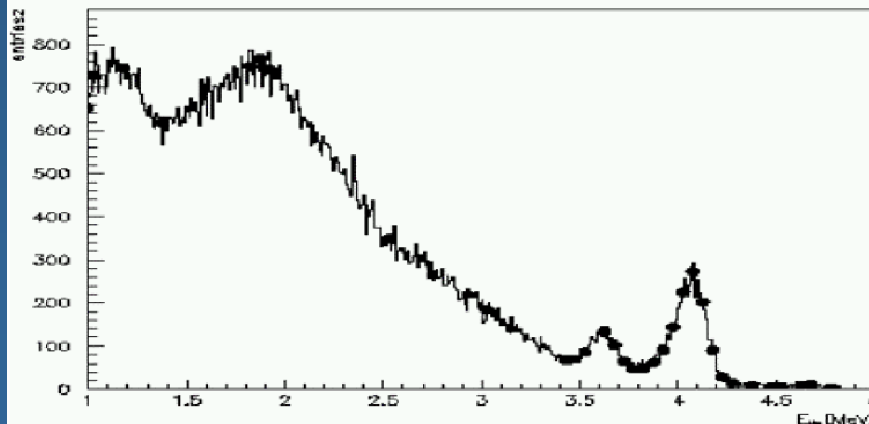
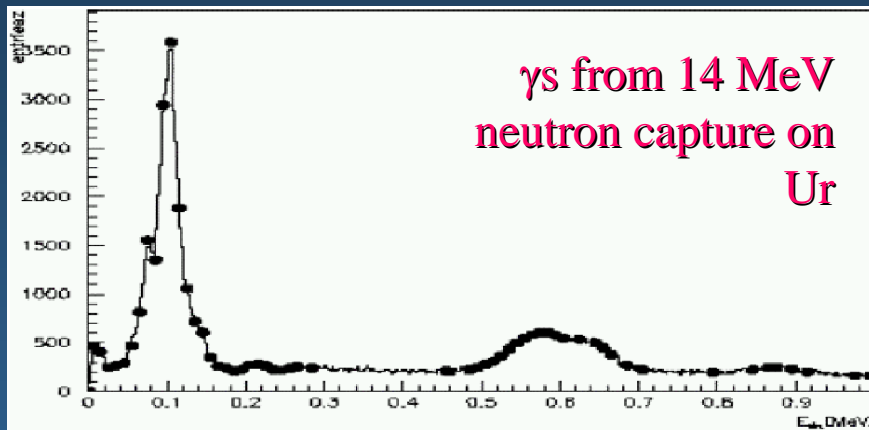
$(\pi^+, K^+)A$  at 250 GeV/c



# Parameterised and data-driven hadronic models (2)

Other models are completely new, such as:

stopping particles:  $\pi^-$ ,  $K^-$   
(relevant for  $\mu/\pi$  PID detectors)

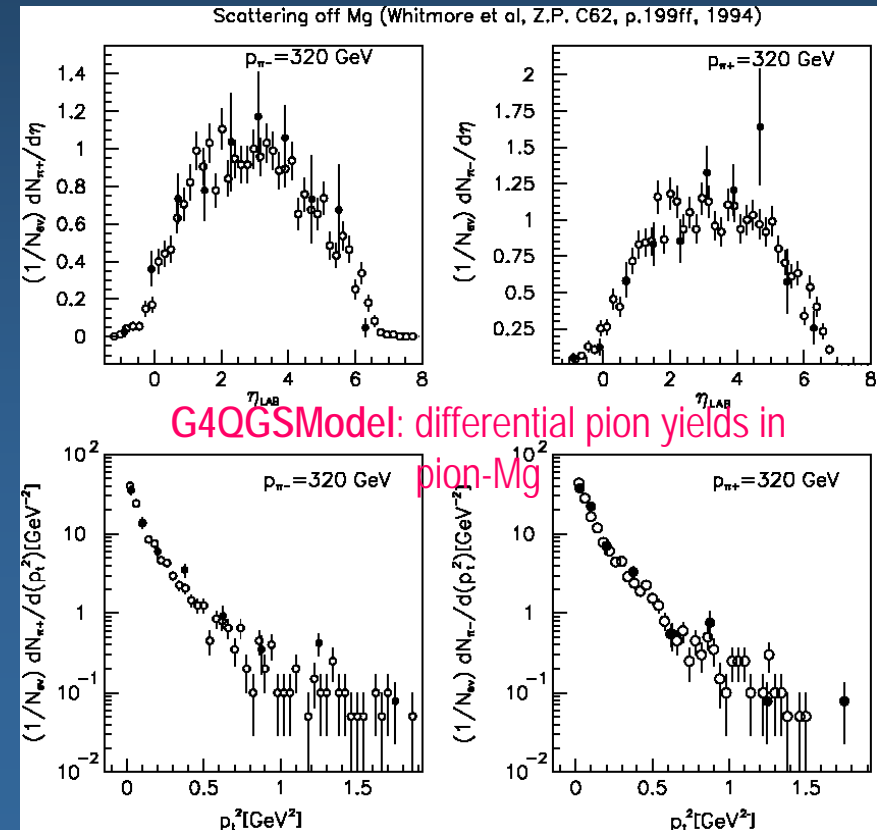
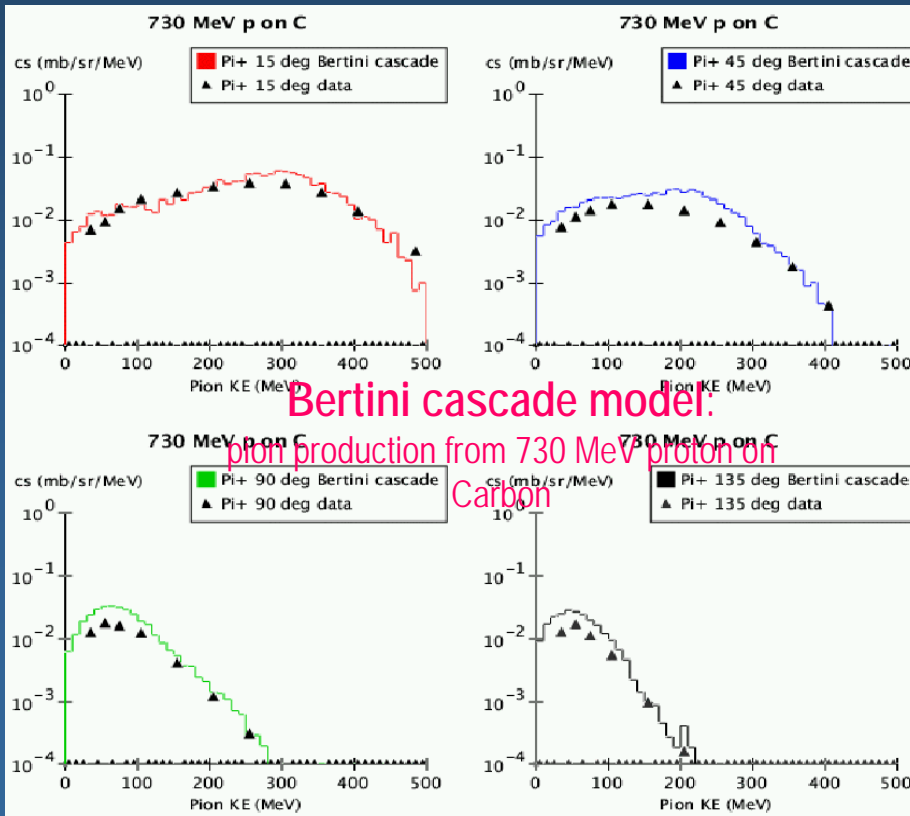


neutrons

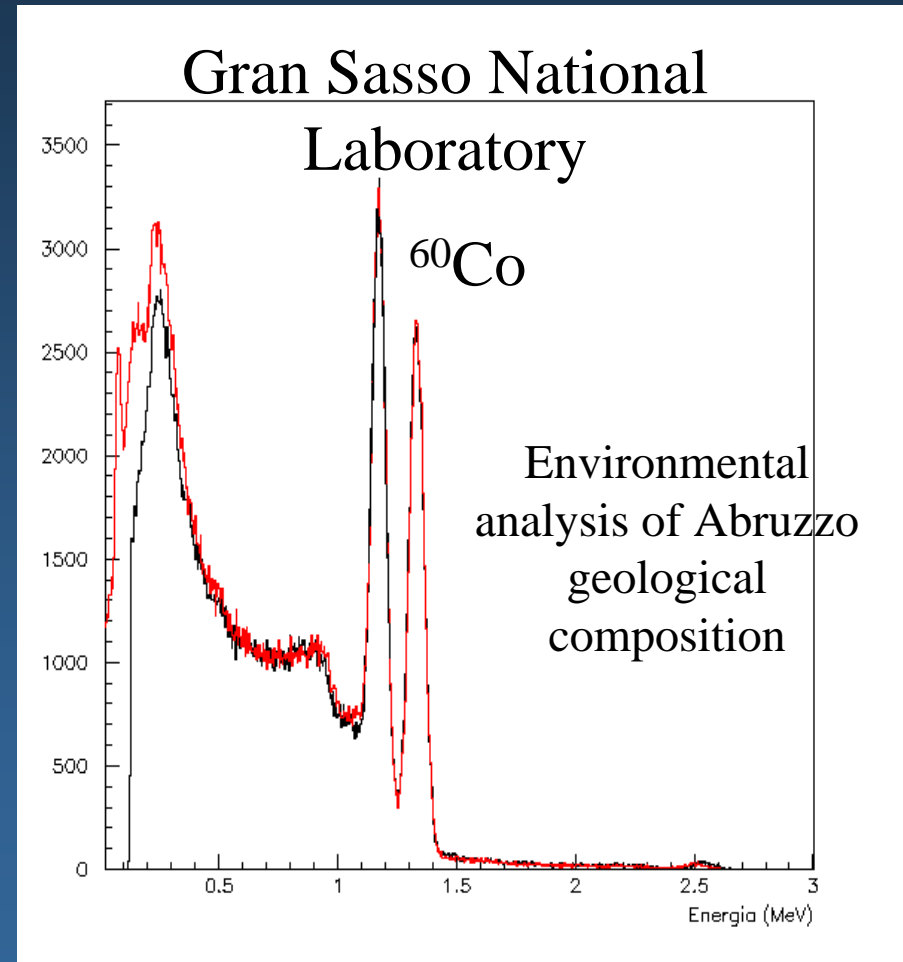
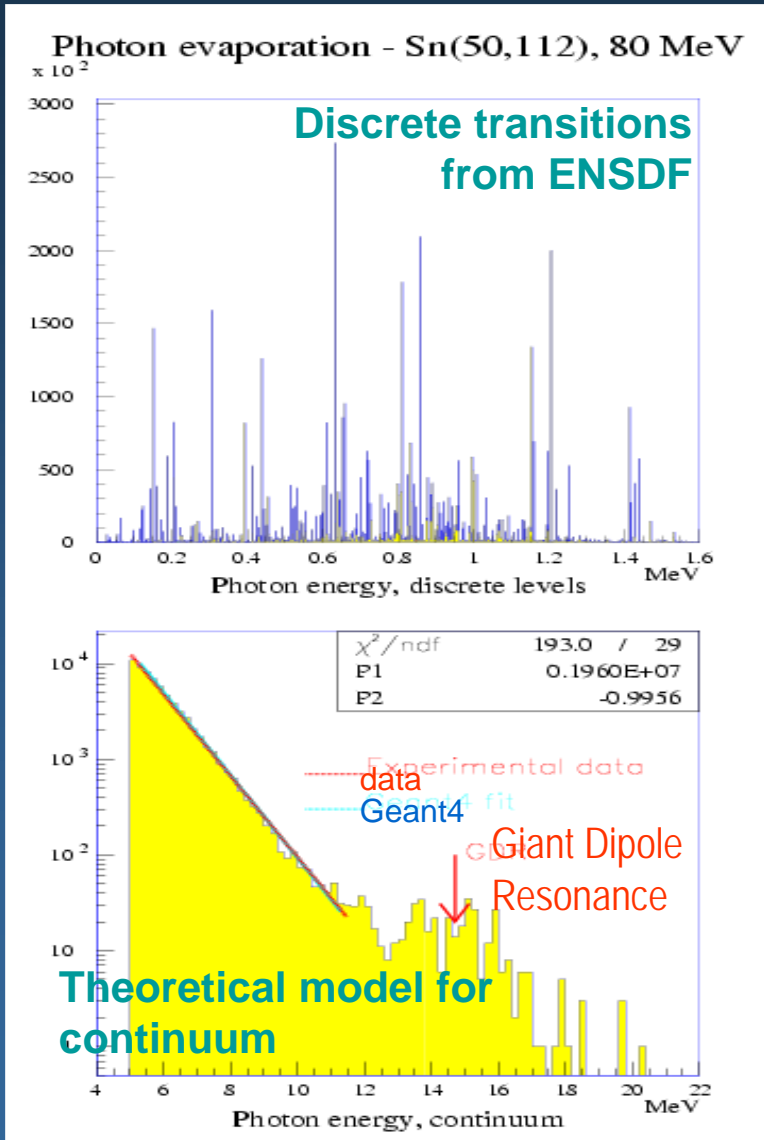
All worldwide existing databases  
used in **neutron** transport  
Brond, CENDL, EFF, ENDFB, JEF,  
JENDL, MENDL etc.

# Theory-driven models

- Complementary and alternative models
- Evaporation phase*
- Low energy range O(100 MeV): *pre-equilibrium*
- Intermediate energy range, O(100 MeV) to O(5 GeV): *intra-nuclear transport*
- High energy range: *hadronic generator* régime



# The two worlds can be mixed...



# Other components

## ■ Materials

- elements, isotopes, compounds, chemical formulae

## ■ Particles

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

## ■ Hits & Digi

- to describe detector response

## ■ Primary event generation

- some general purpose tools provided within the To  
▪ eg. GeneralParticleSource

## ■ ...and much more (no time to mention all!)

read-out geometry  
event biasing  
fast simulation  
parallelisation  
persistency  
much more physics  
etc.



# Fast simulation

Environment suitable to introduce deterministic transport methods in Geant4

- Geant4 allows to perform full simulation and fast simulation in the same environment
- Geant4 parameterisation produces a direct detector response, from the knowledge of particle and volume properties
  - hits, digis, reconstructed-like objects (*tracks, clusters etc.*)
- Great flexibility
  - activate fast /full simulation by detector  
*example: full simulation for inner detectors, fast simulation for calorimeters*
  - activate fast /full simulation by geometry region  
*example: fast simulation in central areas and full simulation near cracks*
  - activate fast /full simulation by particle type  
*example: in e.m. calorimeter, e/ $\gamma$  parameterisation + full simulation of hadrons*
  - parallel geometries in fast/full simulation  
*example: inner and outer tracking detectors distinct in full simulation, but handled together in fast simulation*

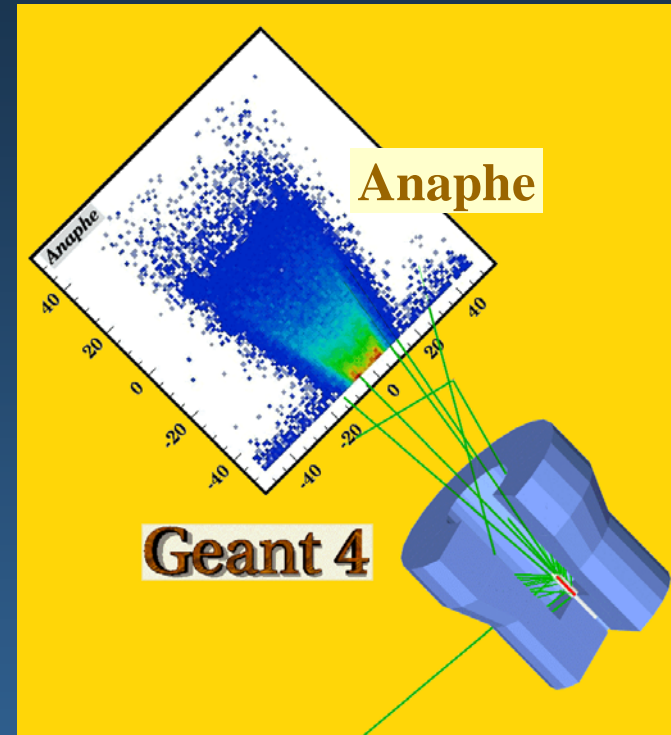
# Interface to external tools in Geant4

Through abstract interfaces

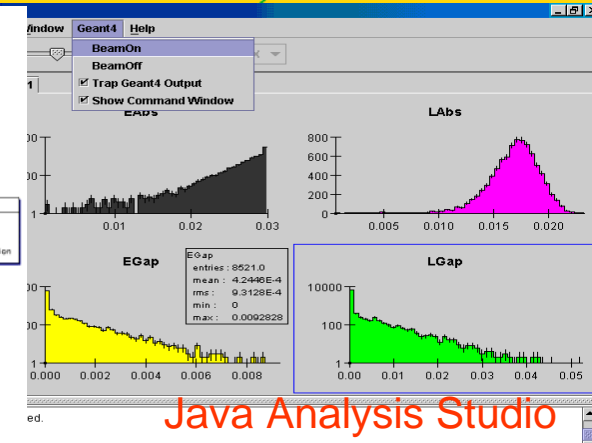
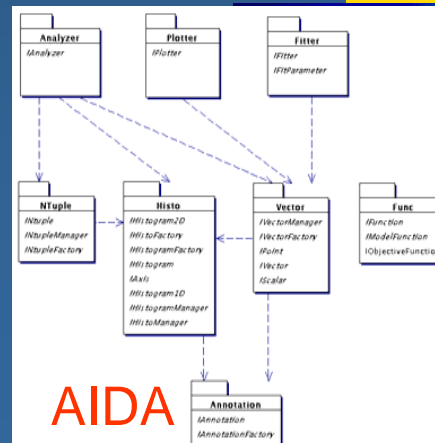
no dependence  
minimize coupling of components

Similar approach

- Visualisation
- (G)UI
- Persistency
- Analysis

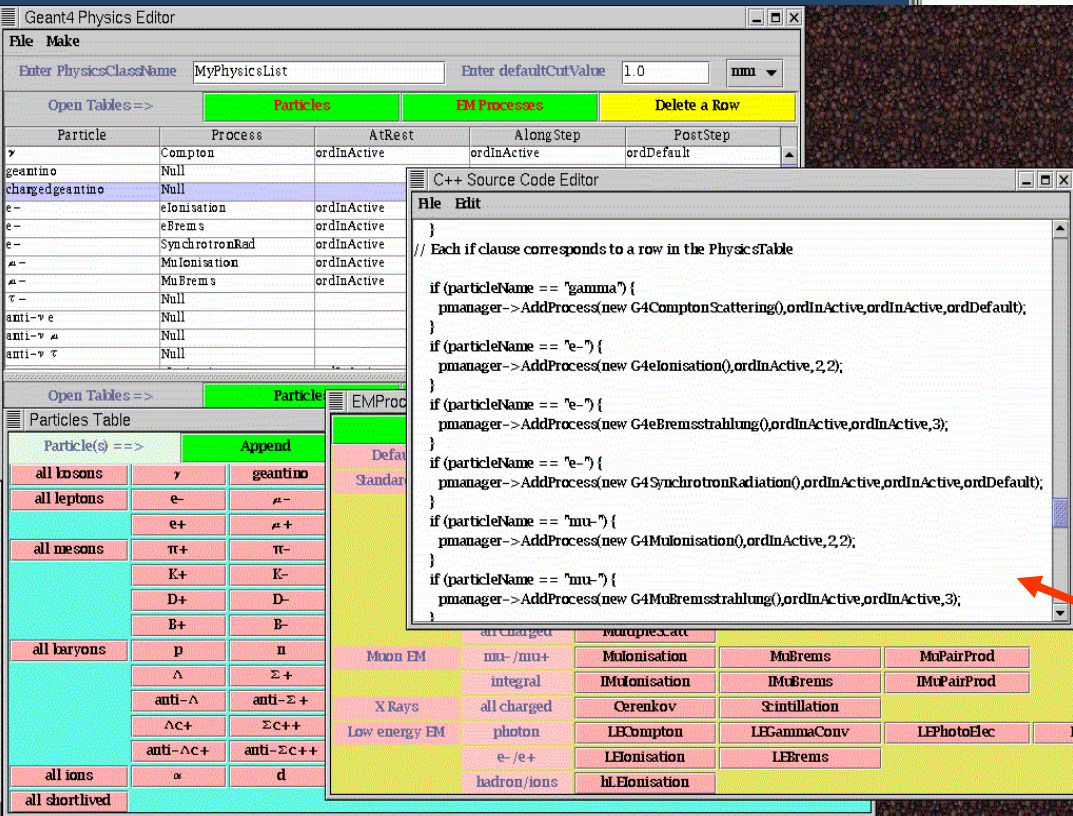
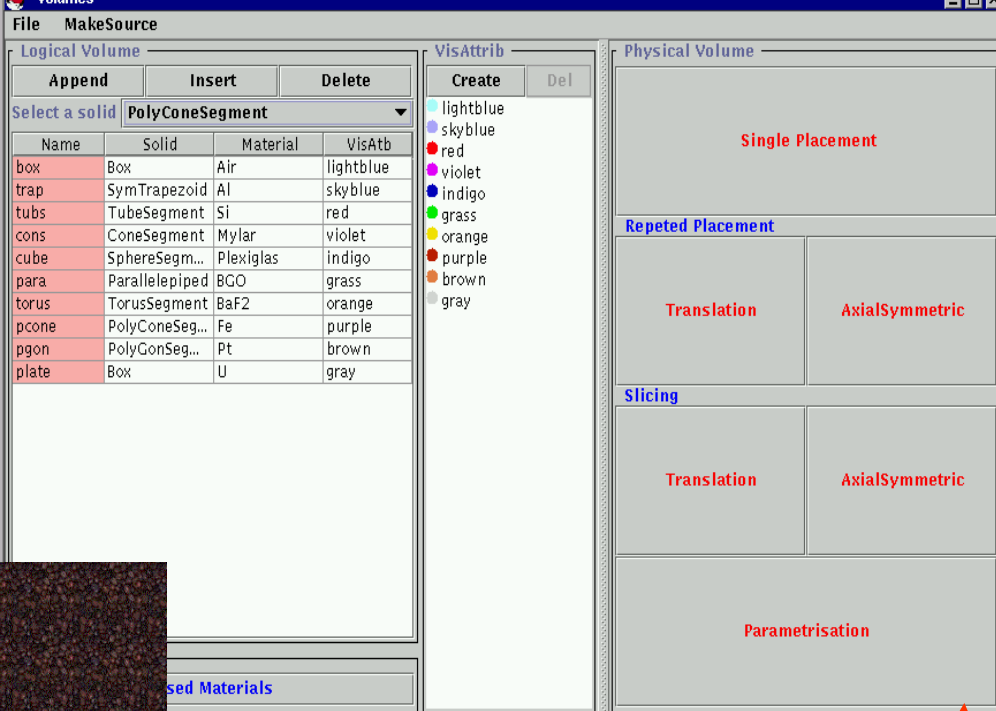


The user is free to choose the concrete system he/she prefers for each component



# 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

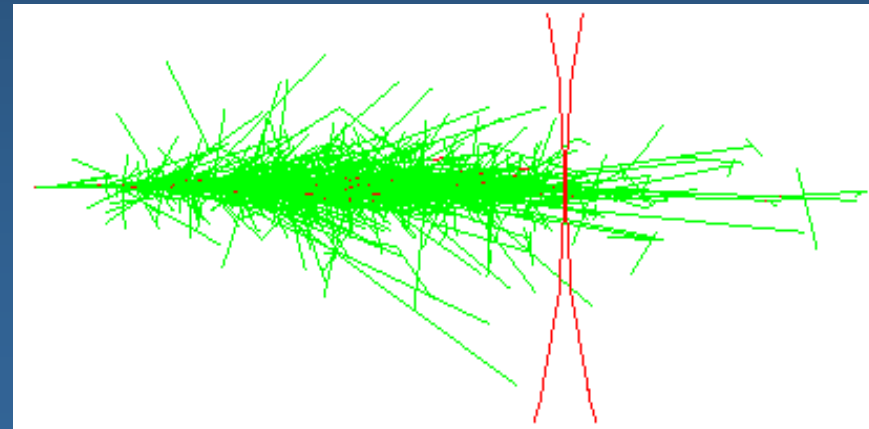
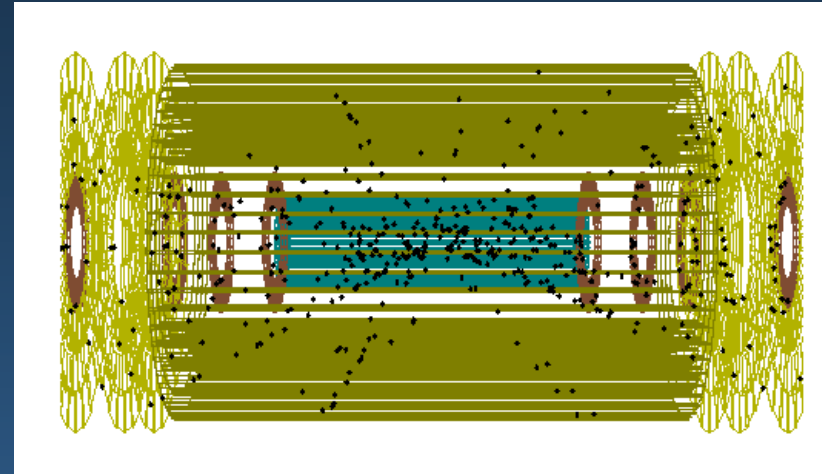
## ■ Control of several kinds of visualisation

- detector geometry
- particle trajectories
- hits in the detectors

## ■ Various drivers

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

## ■ all handled through abstract interfaces

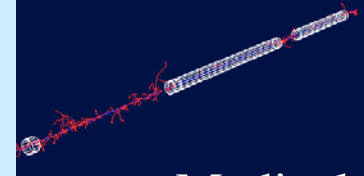


# Pushing Geant4 to the limit



# Heavy ion beams

*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

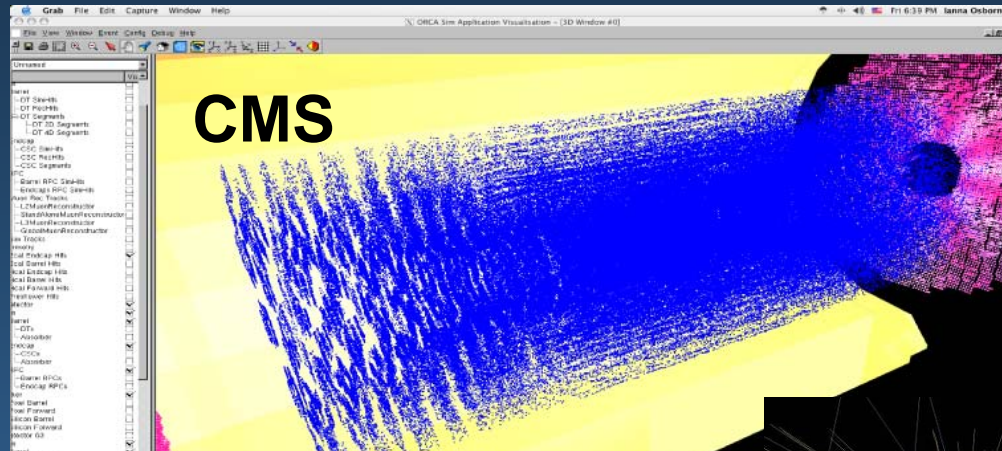


Medical ion beam

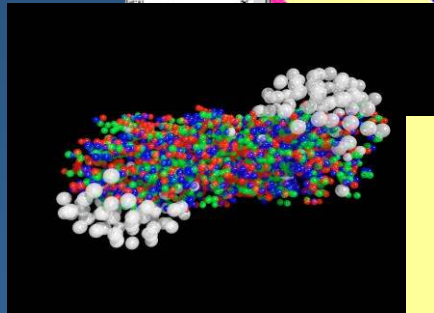
Geant4 simulation

Beam Track Reconstruction  
135 MeV/u  $^{12}\text{C}$  beam

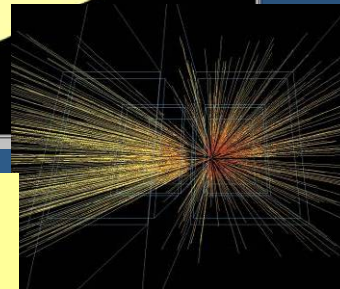
Cylinders : 14  
Cubes : 6226  
Lines : 51678



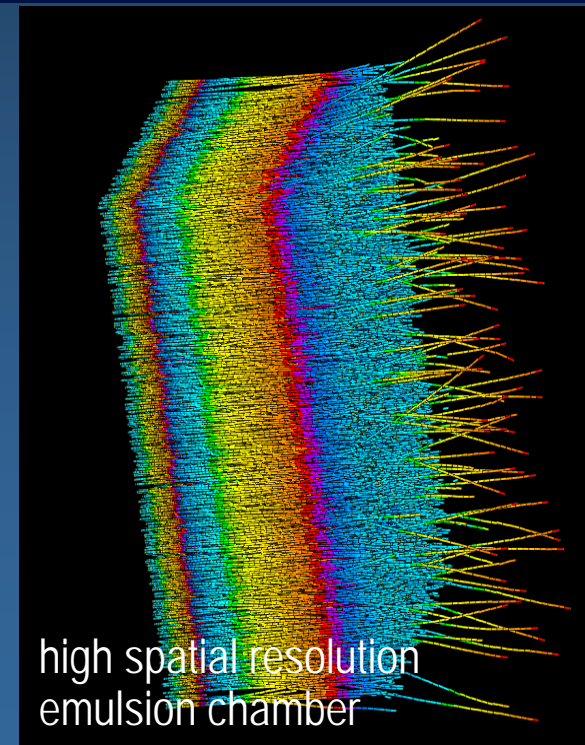
CMS



Events with > 50000 particles/event in detector acceptance



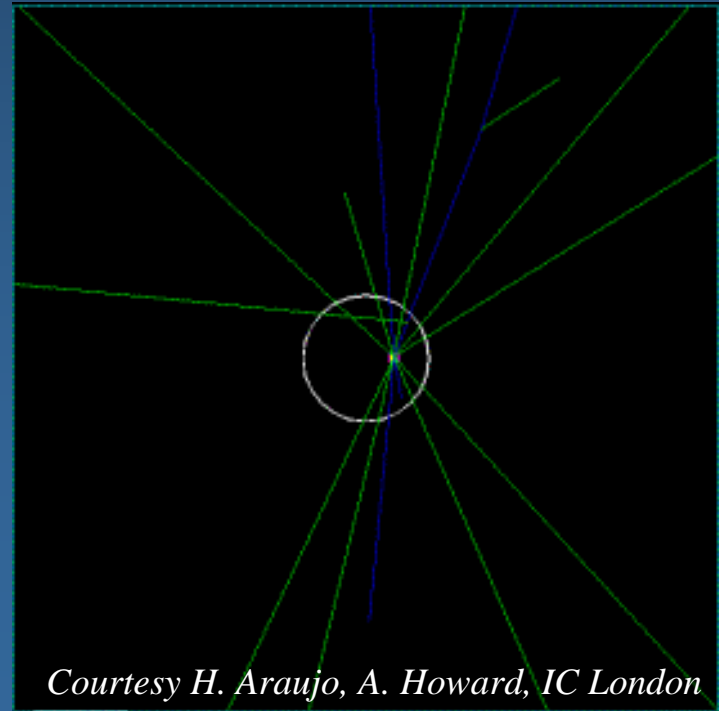
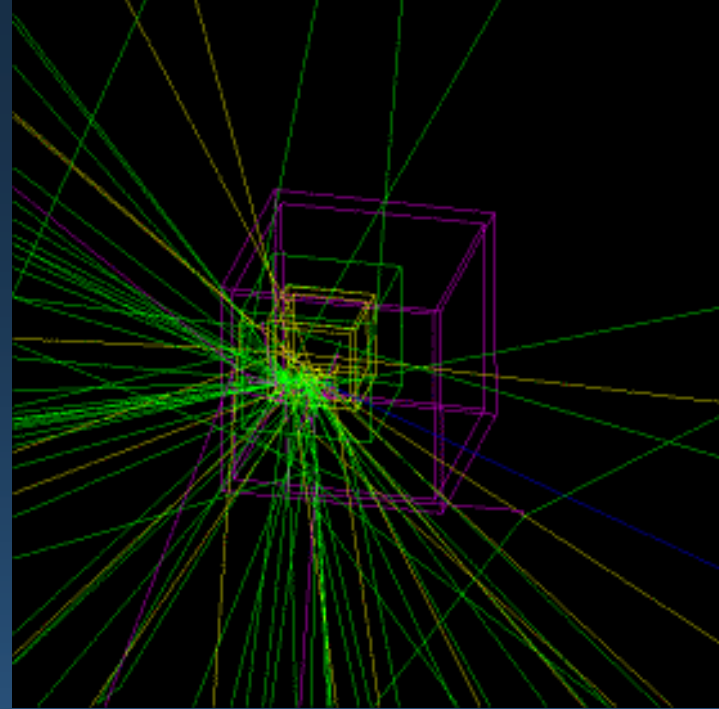
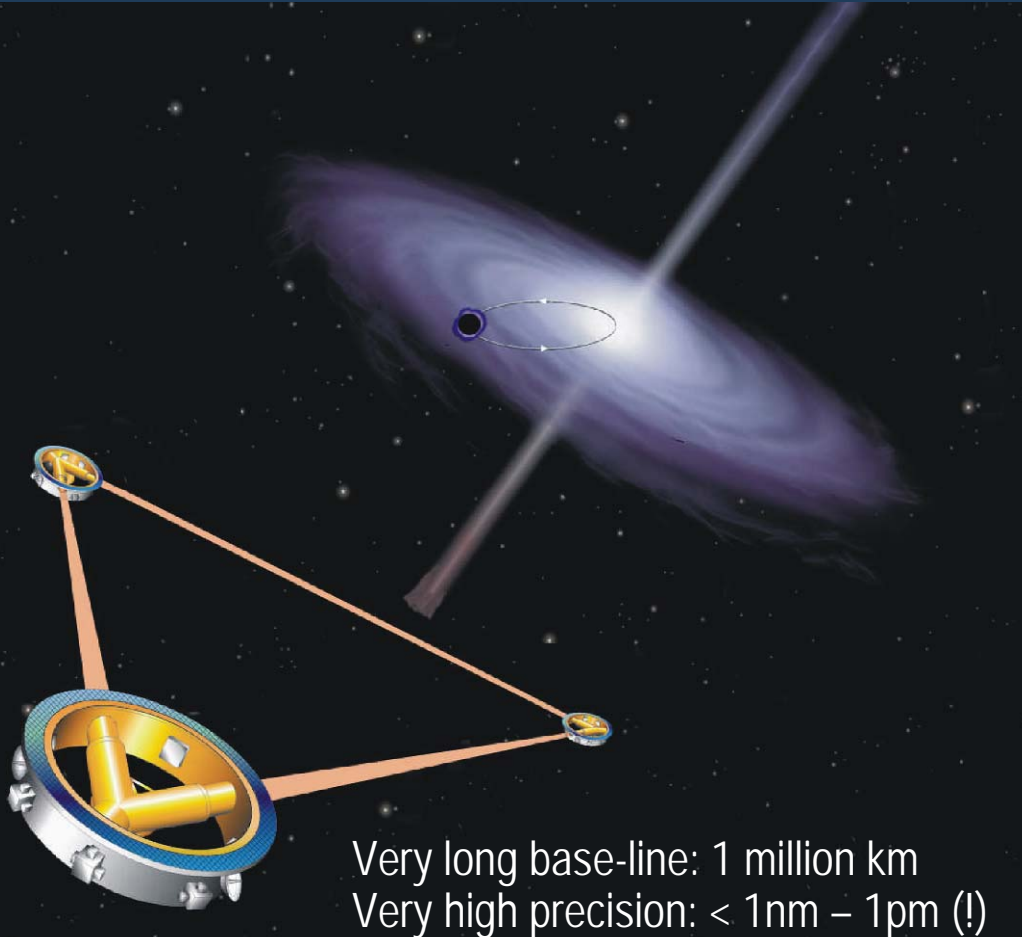
~ 180 minutes to simulate 1 event with 55K generator tracks



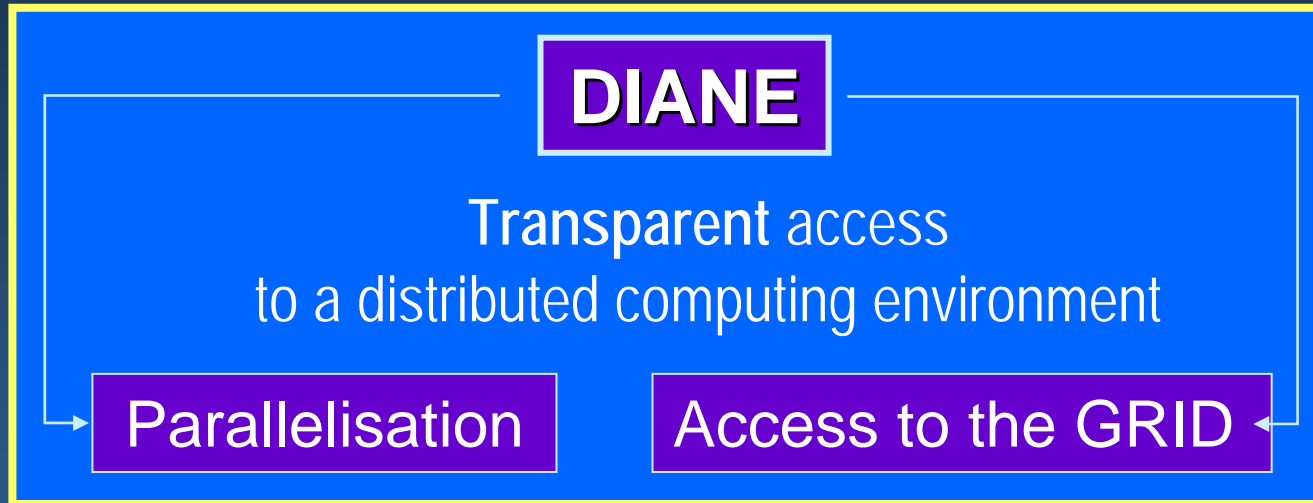
high spatial resolution emulsion chamber

# LISA (gravitational waves)

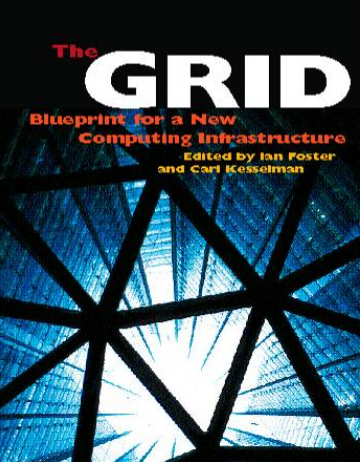
Geant4 relevant for evaluation of  
space charging effects



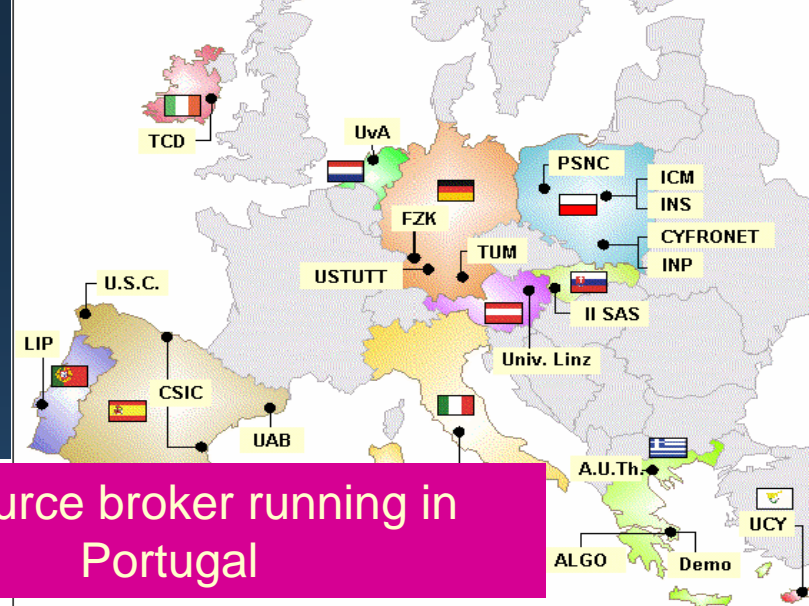
# Access to distributed computing



- Local computing farm
- Geographically distributed grid



# Traceback from a run on CrossGrid testbed



Current #Grid setup (computing elements)  
5000 events, 2 workers, 10 tasks (500 ev

Resource broker running in Portugal

matchmaking CrossGrid computing elements

- aocegrid.uab.es:2119/jobmanager-pbs-workq
- bee001.ific.uv.es:2119/jobmanager-pbs-qgrid
- cgnode00.di.uoa.gr:2119/jobmanager-pbs-workq
- cms.fuw.edu.pl:2119/jobmanager-pbs-workq
- grid01.physics.auth.gr:2119/jobmanager-pbs-workq
- xg001.inp.demokritos.gr:2119/jobmanager-pbs-workq
- xgrid.icm.edu.pl:2119/jobmanager-pbs-workq
- zeus24.cyf-kr.edu.pl:2119/jobmanager-pbs-infinite
- zeus24.cyf-kr.edu.pl:2119/jobmanager-pbs-long
- zeus24.cyf-kr.edu.pl:2119/jobmanager-pbs-medium
- zeus24.cyf-kr.edu.pl:2119/jobmanager-pbs-short
- ce01.lip.pt:2119/jobmanager-pbs-qgrid

Spain

Greece

Poland

Portugal

# Is it worthwhile?



# Comparison with commercial radiotherapy treatment planning systems

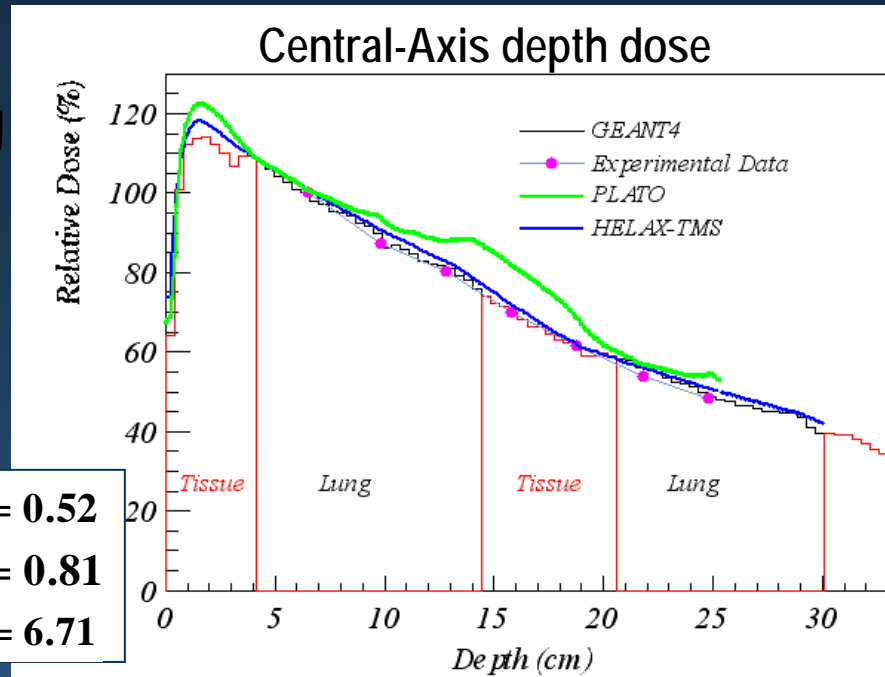
M. C. Lopes, L. Peralta, P. Rodrigues, A. Trindade

IPOFG-CROC Coimbra Oncological Regional Center  
LIP - Lisbon

$$\chi^2 / \text{ndf (GEANT 4)} = 0.52$$

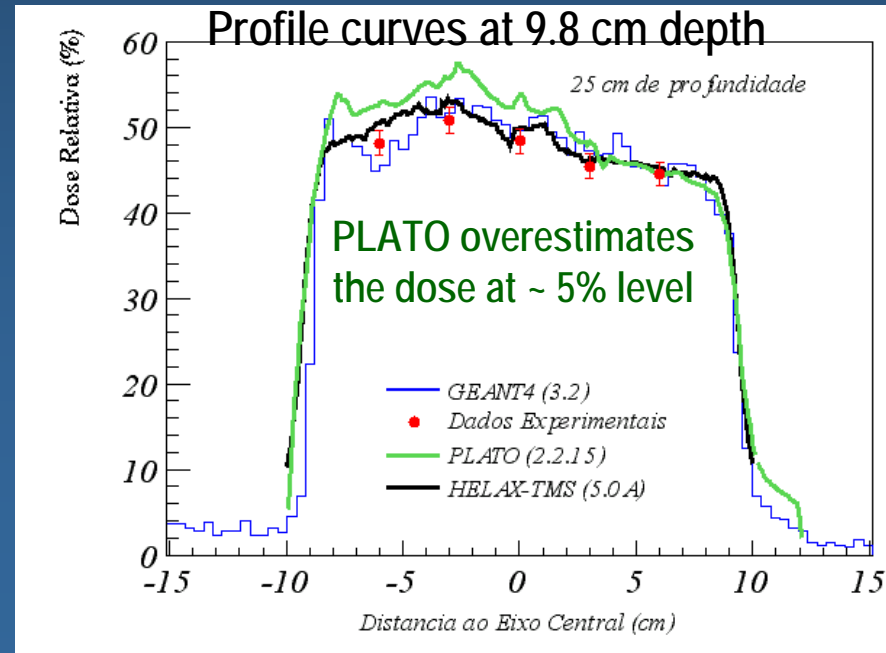
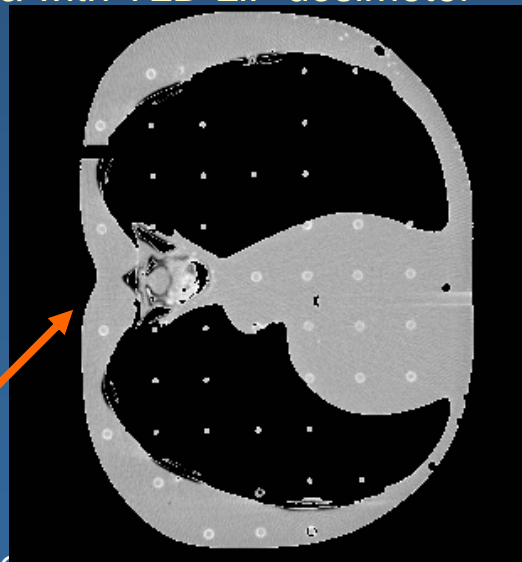
$$\chi^2 / \text{ndf (TMS)} = 0.81$$

$$\chi^2 / \text{ndf (PLATO)} = 6.71$$



CT-simulation with a Rando phantom  
Experimental data with TLD LiF dosimeter

CT images used to define the geometry:  
a thorax slice from a Rando anthropomorphic phantom



# Robustness

TM & © Neivana



## *BaBar Simulation Production*

BaBar simulation production – a millennium of work in under a year.

D. A. Smith, D. Andreotti, F. Blanc, C. Bozzi, A. Khan  
for the BaBar computing group.

IEEE 2004 - Oct. 21, 2004

Data Challenges in LHC experiments

# The **Geant 4** kit

## ■ Code

- ~1M lines of code
- continuously growing
- publicly downloadable from the web

## ■ Documentation

- 5 manuals
- publicly available from the web

## ■ Examples

- distributed with the code
- various complete applications of (simplified) real-life experimental set-ups

## ■ Platforms

- Linux, SUN, Windows, (MacOS)

## ■ Commercial software

- None required
- Can be interfaced

## ■ Free software

- CVS
- gmake, g++
- CLHEP

## ■ Graphics & (G)UI

- OpenGL, X11, OpenInventor, DAWN, VRML...
- OPACS, GAG, MOMO...

## ■ Persistency

- it is possible to run in transient mode
- in persistent mode use a HepDB interface, ODMG standard



# Geant4 Collaboration

MoU based

Development, Distribution and User Support of Geant4





# The next frontier

The power of abstract interfaces



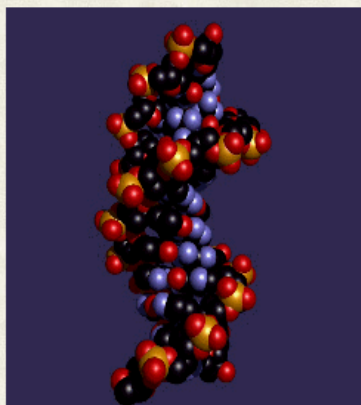
# Geant 4 DNA



S. Chauvie et al., Geant4 physics processes for microdosimetry simulation, IEEE TNS vol. 54, no. 6, Dec. 2007

- [Home](#)
- [Requirements](#)
- [Documents](#)
- [Talks](#)
- [Papers](#)
- [Meetings](#)
- [Team](#)
- [Geant4](#)
- [Geant4-INFN](#)
- [Geant4 LowE Physics](#)
- [Useful links](#)

## Simulation of Interactions of Radiation with Biological Systems at the Cellular and DNA Level

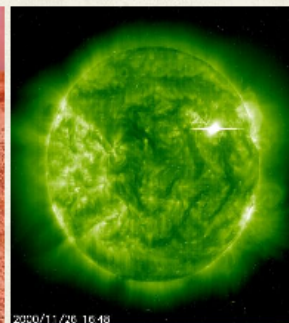


Estimating cancer risk for human exposures to space radiation is a challenge which involves a wide range of knowledge in physics, chemistry, biology and medicine.

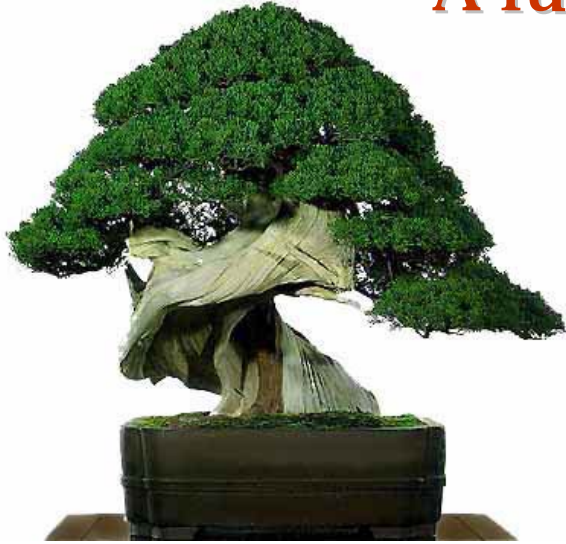
Traditionally, the biological effects of radiation are analysed in top-bottom order, i.e. evaluation of the absorbed macroscopic radiation dose at a given location in the biological tissue is translated to the degree of danger it presents, and dose limits are consequently set that are considered to be acceptable.

A novel approach, based on the new-generation object-oriented **Geant4** Monte Carlo Toolkit, proceeds in a reverse order, from bottom to top, by analysing the nano-scale effects of energetic particles at the cellular and DNA molecule level.

This project is sponsored by the European Space Agency ([ESA](#)) and is pursued by a multidisciplinary European team of biologists, physicians, physicists, space scientists and software engineers.



A further step forward



# Nano5

## New architectural design for novel experimental domains

R&D on  
simulation methods, technology and architectural design  
for new experimental domains

M. Augelli, M. Begalli, E. Gargioni, B. Grosswendt, S. Hauf, C. Hyeong Kim, M. Kuster, P. de Queiroz Filho, L. Quintieri, P. Saracco, R. Schulte, D. de Souza Santos, M. Sudhakar, G. Weidenspointner, A. Wroe, A. Zoglauer

*INFN Sezione di Genova and INFN Laboratori Nazionali di Frascati, Italy*

*Space Sciences Laboratory, UC Berkeley, USA*

*CNES, Toulouse, France*

*University Medical Center Hamburg-Eppendorf, Germany*

*Hanyang University, Seoul, Korea*

*Institute for Radiation Protection and Dosimetry (IRD), Rio de Janeiro, Brazil*

*Loma Linda University Medical Center, USA*

*Max-Planck-Institut für extraterrestrische Physik and Halbleiterlabor, Germany*

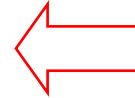
*Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany*

*State University of Rio de Janeiro (UERJ), Brazil*

# Background

## ■ Geant4 R&D phase: **RD44**

- 1994-1998 (*Geant4 0.0: 15 December 1998*)
- Designed and built Geant4
- New software technology: **object oriented**
- GEANT 3 experience + new ideas



**1994**  
mid of LEP era  
**GEANT 3**  
successfully used in  
many experiments

## ■ **Foundation of the current Geant4: dates back to the mid '90s**

- Requirements for core capabilities ← Collected from the experimental community
- Software technology ← Object Oriented methods introduced in HEP

## ■ **Evolution: 1998-2009**

- Consolidation, validation, extension and refinement of existing capabilities
- Support to the experimental community
- Proliferation of physics models
- Same **core capabilities** and **software technology** as in the **mid '90s**

# R&D



- Motivated by **scientific interests**
- Response to **current limitations** of Geant4
  - of all major Monte Carlo systems, not only Geant4
- Address **concrete experimental use cases**
  - by going to the very **core of Monte Carlo methods**
- Exploit **new software technology**
  - in response to experimental issues
- Build on **existing experience**
  - Domain knowledge: simulation in multi-disciplinary research
  - Software technology expertise



# Topics of research

R&D on  
**complementary, co-working  
transport methods**

**Condensed-random-walk scheme**  
**Discrete scheme**

Nanotechnology detectors  
Radiation effects on components  
Radiobiology  
Plasma physics  
Material analysis  
etc.

**Monte Carlo method**  
**Deterministic methods**

Nuclear power plants  
Radiotherapy  
Homeland security  
etc.

Side topics (instrumental to the main objectives)

Physics  
configurability

Concerns  
(scattered and tangled)

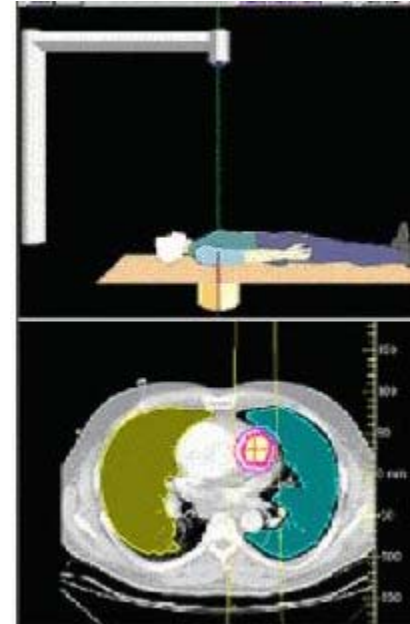
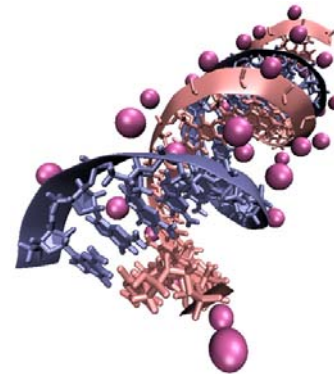
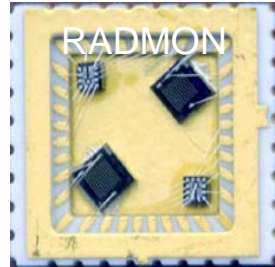
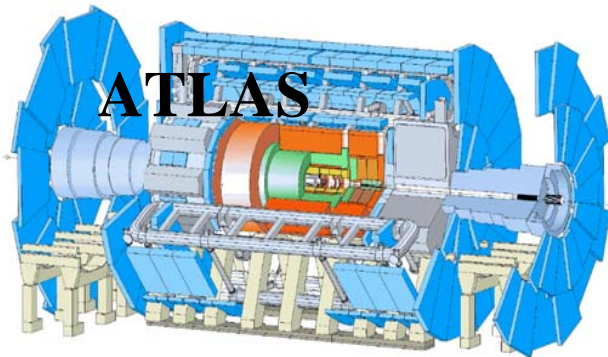
Built-in physics  
V&V-ability

# Two worlds...

## ■ Condensed-random-walk OR “discrete” régime

Characterizing choice in a Monte Carlo system

### What does it mean in practice?



How do you estimate radiation effects on components exposed to LHC + detector environment?

How do you link dosimetry to radiation biology?

*And what about the plasma facing materials in a fusion reactor?  
And nanotechnology-based detectors for HEP?  
And tracking in a gaseous detector?*

## ■ Subtle consequences

- e.g. X-ray fluorescence emission (PIXE) by impact ionisation has a dependence on secondary production cut introduced to handle infrared divergence!
- can affect macroscopic applications: material analysis, precise dosimetry etc.

# Conclusions

Complexity of physics, detectors, environments

A rapidly changing computing environment

Similar requirements across diverse fields (HEP, astrophysics, medicine...)

## The response:

- rigorous approach to software engineering
- OO technology
- powerful functionality, rich physics

## Achieve:

- openness to extension and evolution
- maintainability over an extended time scale
- transparency of physics

## Results:

- HEP, space science, medical physics...
- science + technology transfer