



# Simulation capabilities and application results

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

<http://www.ge.infn.it/geant4/>

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# Technology transfer

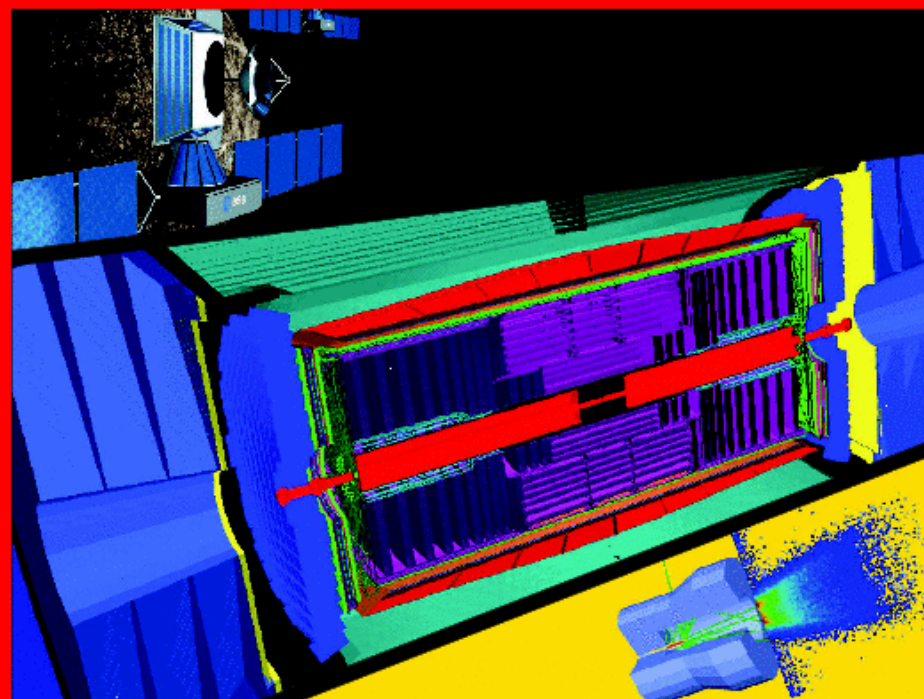
## Particle physics software aids space and medicine

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

CERN Courier, June 2002



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

# United Nations World Summit on Information Society Geneva, December 2003

## Geant4 – INFN presentation



Precise physics models for  
radiation interactions with matter

Open source code providing  
advanced technologies to  
developing countries at no cost


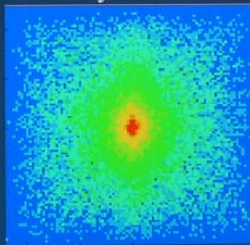
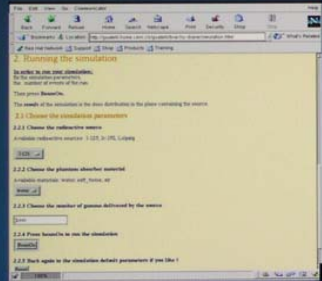
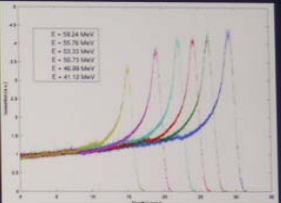
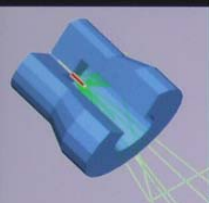
Accurate geometry and  
material modeling

**Particle Physics Software aids Medicine**  
in the fight against cancer

Powerful data  
analysis tools

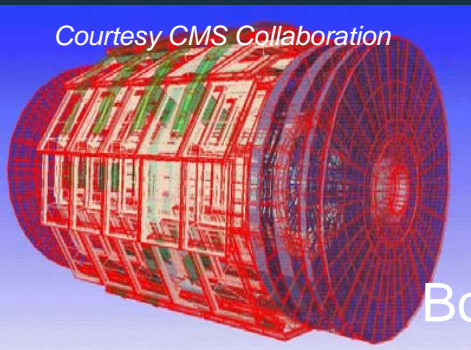
Friendly interface through  
the World Wide Web

The GRID for fast and cheap  
processing on distributed  
computing resources





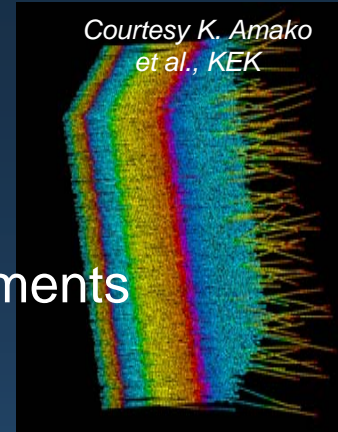
Courtesy CMS Collaboration



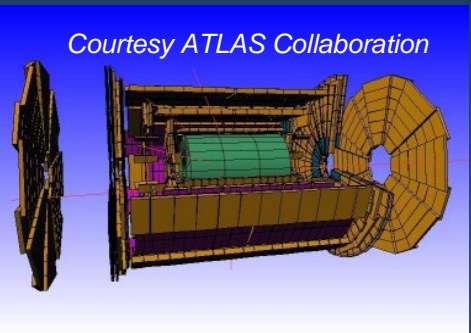
# Geant 4

Born from the requirements of large scale HEP experiments

Courtesy K. Amako  
et al., KEK



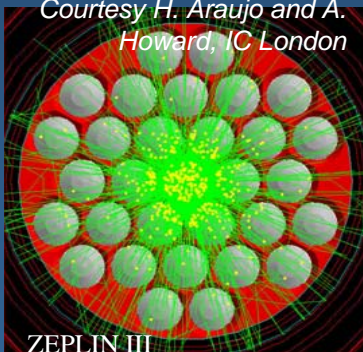
Courtesy ATLAS Collaboration



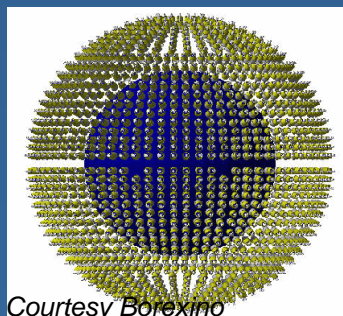
Widely used also in

- 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



Courtesy Borexino

NFN Genova

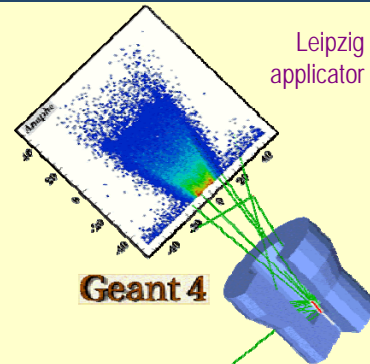


Courtesy R. Nartallo et al., ESA

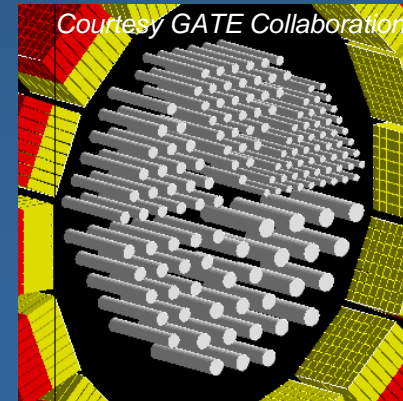
**Most cited  
“engineering”  
publication in the  
past 2 years!**

Leipzig  
applicator

Geant 4



Courtesy GATE Collaboration





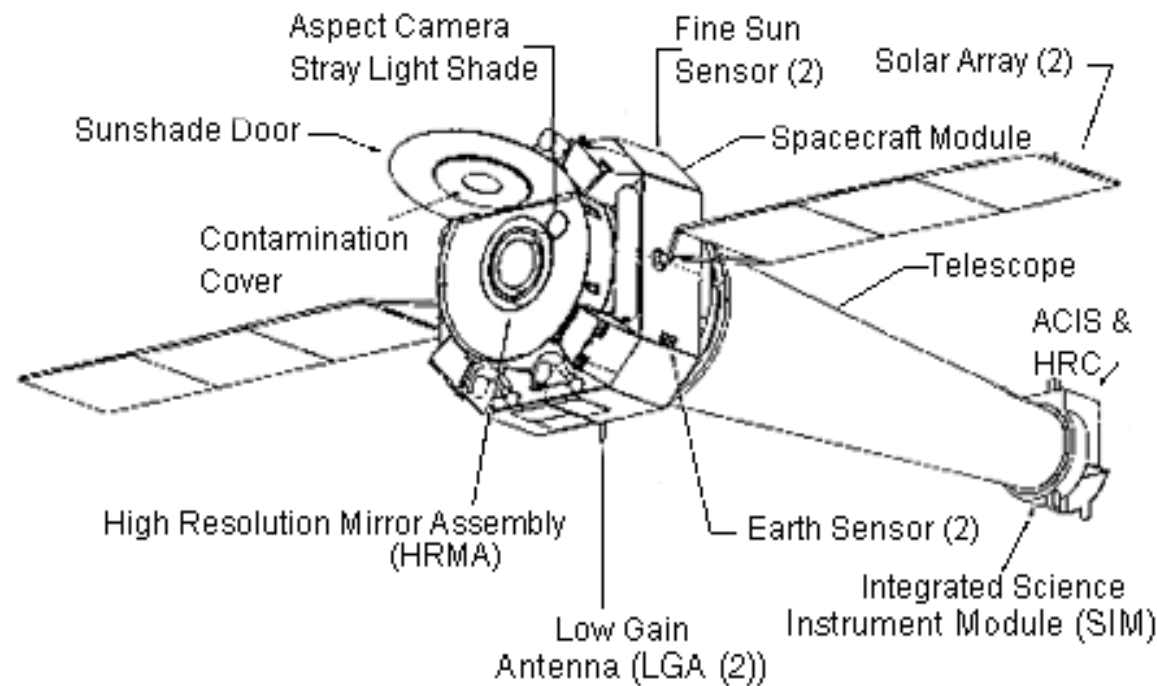


scientific...

# Globalisation

Sharing requirements and functionality  
across diverse fields

Once upon a time  
there was a X-ray telescope...

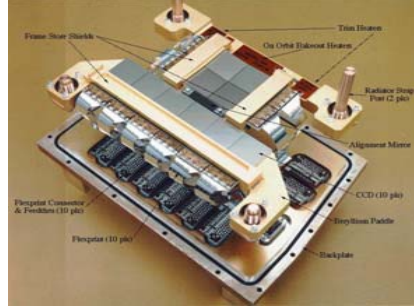


*Courtesy of NASA/CXC/SAO*

# Chandra X-ray Observatory

## Status Update

September 14, 1999  
MSFC/CXC



CHANDRA CONTINUES TO TAKE SHARPEST IMAGES EVER; TEAM STUDIES INSTRUMENT DETECTOR CONCERN

Normally every complex space facility encounters a few problems during its checkout period; even though Chandra's has gone very smoothly, the science and engineering team is working a concern with a portion of one science instrument.

The team is investigating a **reduction in the energy resolution** of one of two sets of X-ray detectors in the Advanced Charge-coupled Device Imaging Spectrometer (ACIS) science instrument.

A series of diagnostic activities to characterize the degradation, identify possible causes, and test potential remedial procedures is underway.

The degradation appeared in the **front-side** illuminated Charge-Coupled Device (CCD) chips of the ACIS. The instrument's **back-side** illuminated chips have shown no reduction in capability and continue to perform flawlessly.

## What could be the source of detector damage?

- Radiation belt electrons?
- Scattered in the mirror shells?
- Effectiveness of magnetic “brooms”?
- Electron damage mechanism? - NIEL?
- Other particles? Protons, cosmics?





# Requirements for low energy p in **Geant 4**

## GEANT4 LOW ENERGY ELECTROMAGNETIC PHYSICS

### User Requirements Document

Status: in CVS repository

Version: 2.4

**Project:** Geant4-LowE

**Reference:** LowE-URD-V2.4

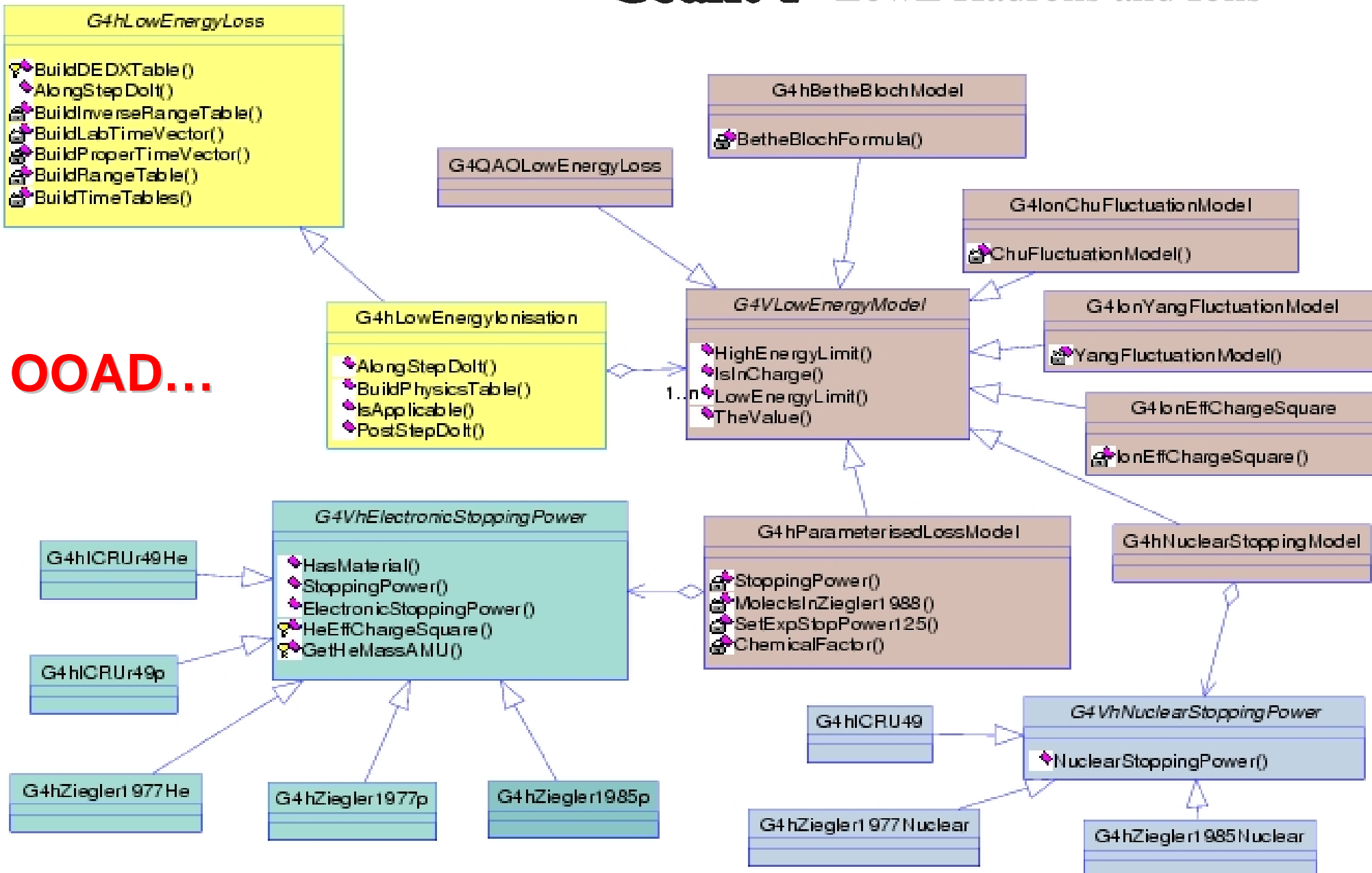
**Created:** 22 June 1999

**Last modified:** 26 March 2001

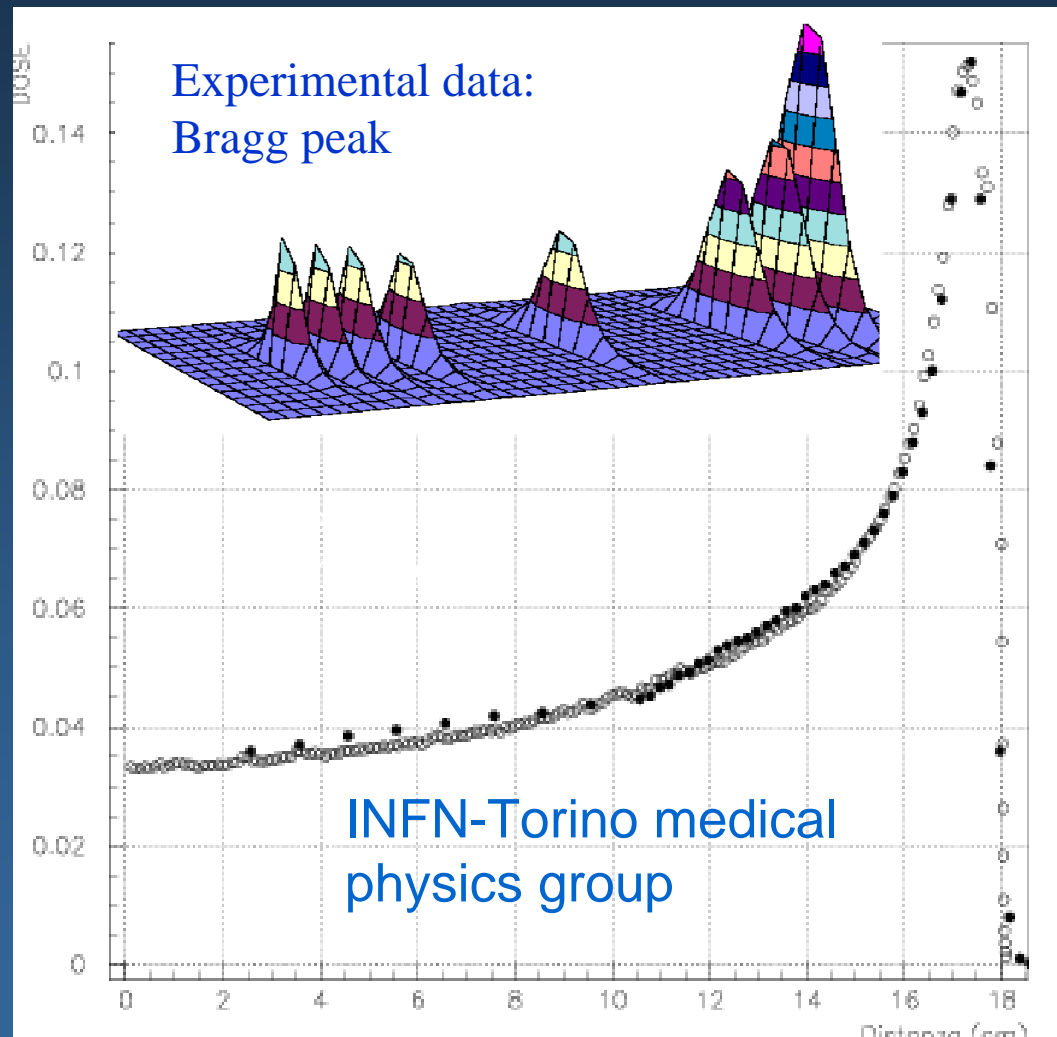
**Prepared by:** Petteri Nieminen (ESA) and Maria Grazia Pia (INFN)

- **UR 2.1** The user shall be able to simulate electromagnetic interactions of positive charged hadrons down to  $< 1$  KeV.
- **Need:** *Essential*
- **Priority:** *Required by end 1999*
- **Stability:** *Stable*
- **Source:** *Medical physics groups, PIXE*
- **Clarity:** *Clear*
- **Verifiability:** *Verified*

# Geant 4 LowE Hadrons and Ions

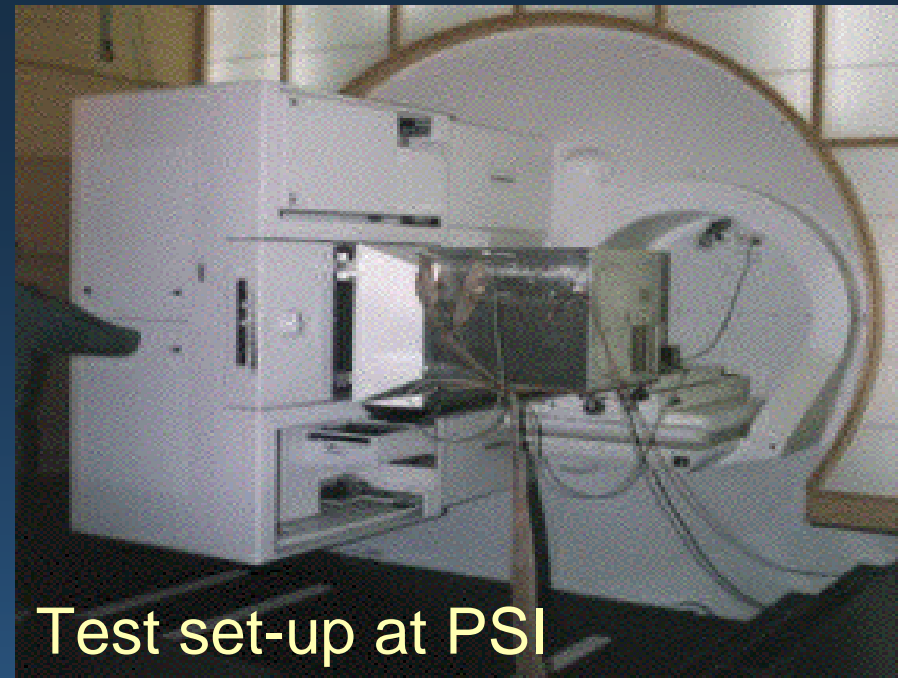


# ...and validation

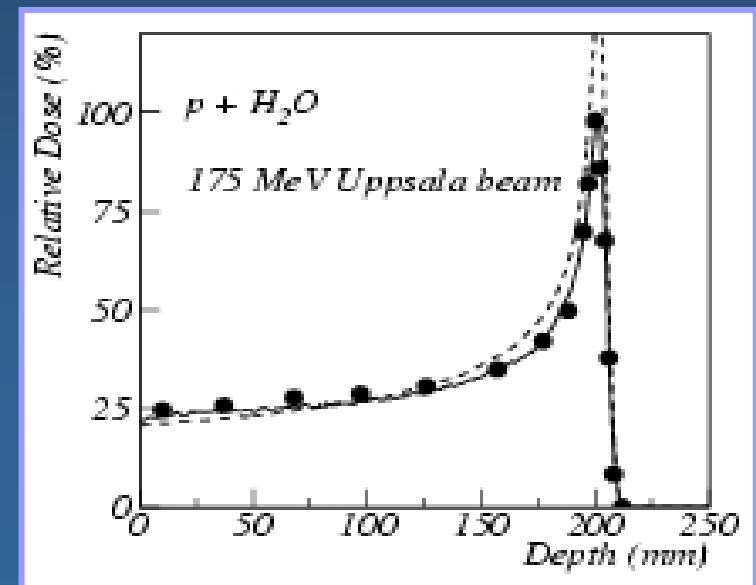


Courtesy of R. Gotta, Thesis

Maria Grazia Pia, INFN Genova

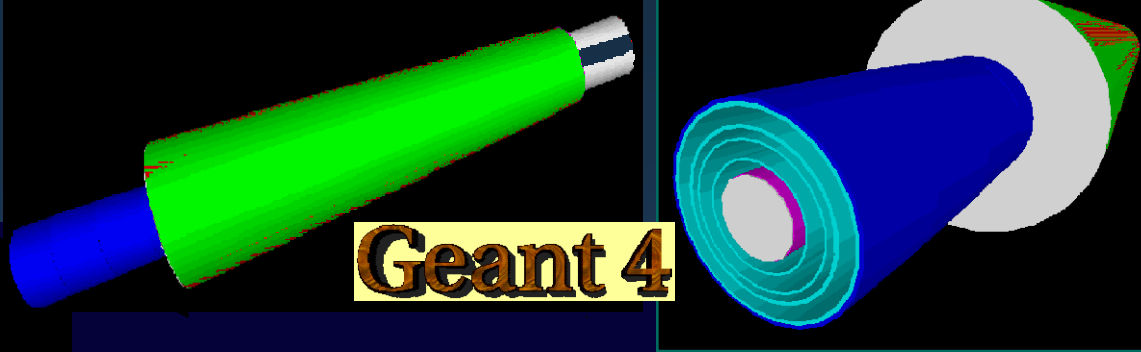


Test set-up at PSI

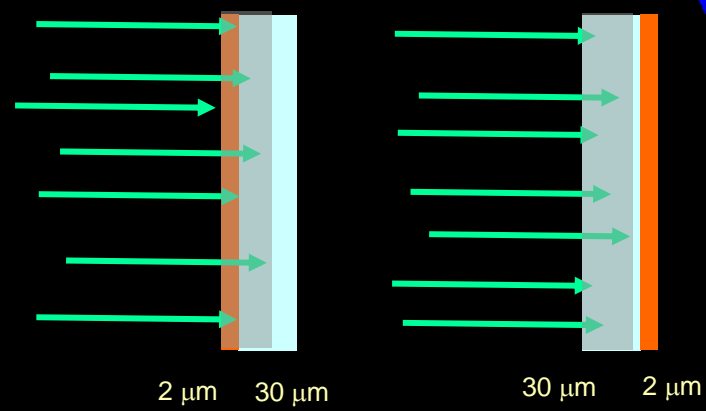


Geant4 LowE Working Group




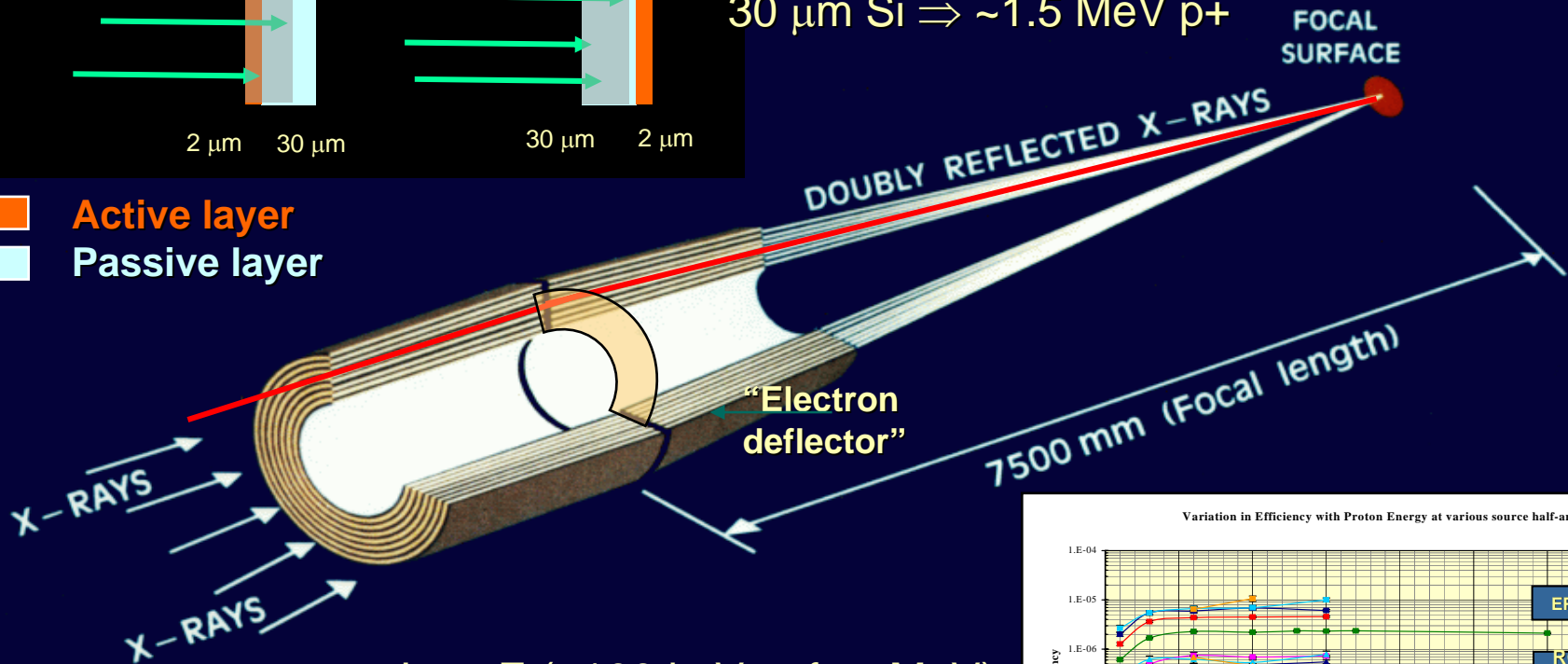


**Geant 4**

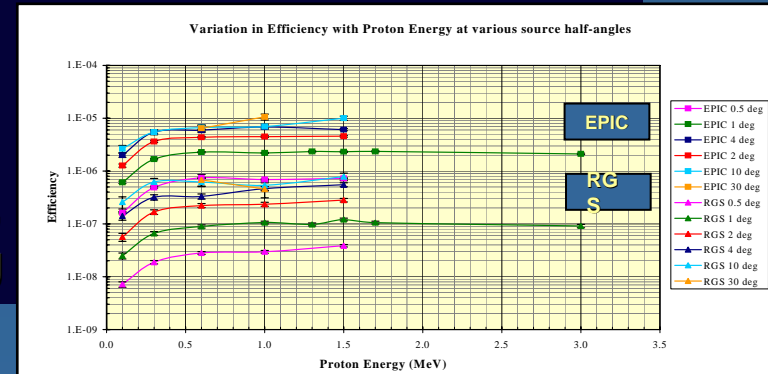


CCD displacement damage:  
 front vs. back-illuminated  
 $30\ \mu\text{m Si} \Rightarrow \sim 1.5\ \text{MeV p}^+$

 **Active layer**  
 **Passive layer**



Low-E ( $\sim 100\ \text{keV}$  to few MeV),  
 low-angle ( $\sim 0^\circ$ - $5^\circ$ ) proton scattering

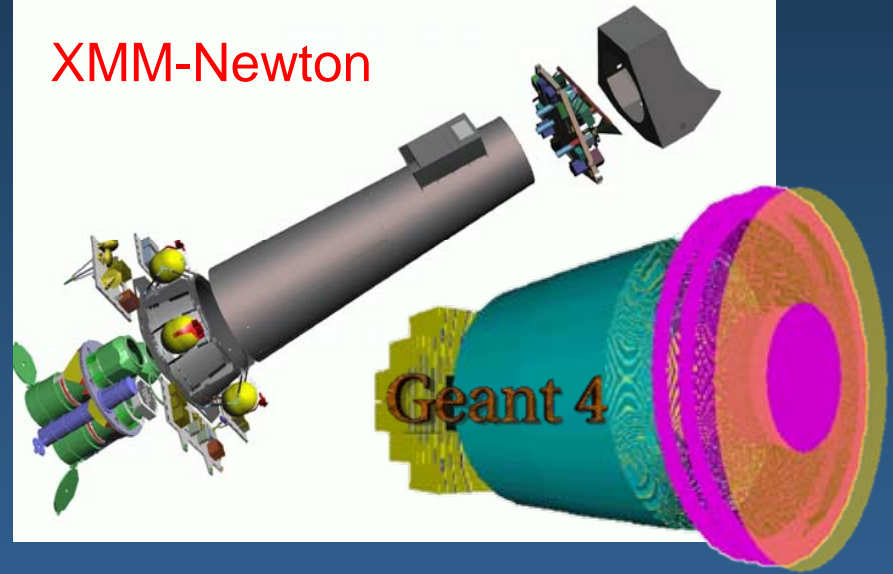




XMM-Newton was launched on 10 December 1999

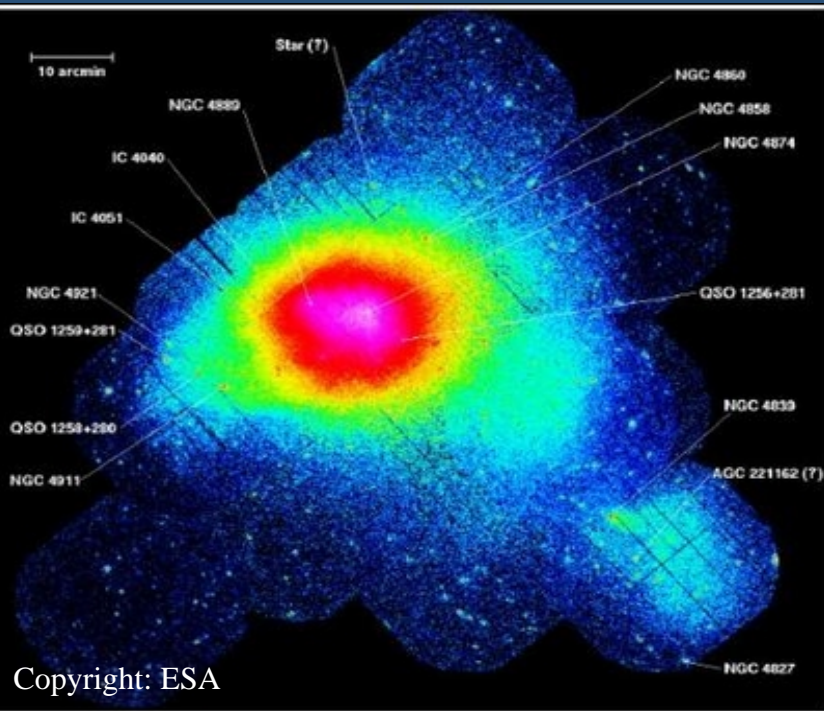
*Courtesy of R. Nartallo, ESA*

**XMM-Newton**



**Simulation can be mission-critical!**

(not only in a space mission...)



EPIC-PN image of the Coma Cluster

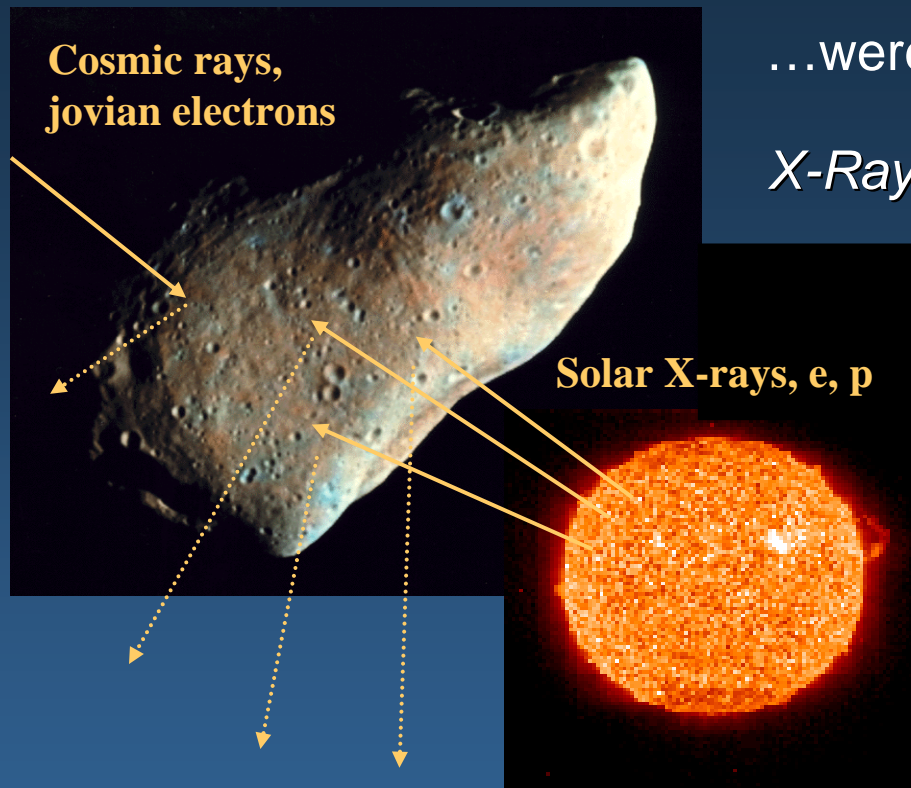
**...and the other way round**



# Geant4 low energy e, $\gamma$ extensions

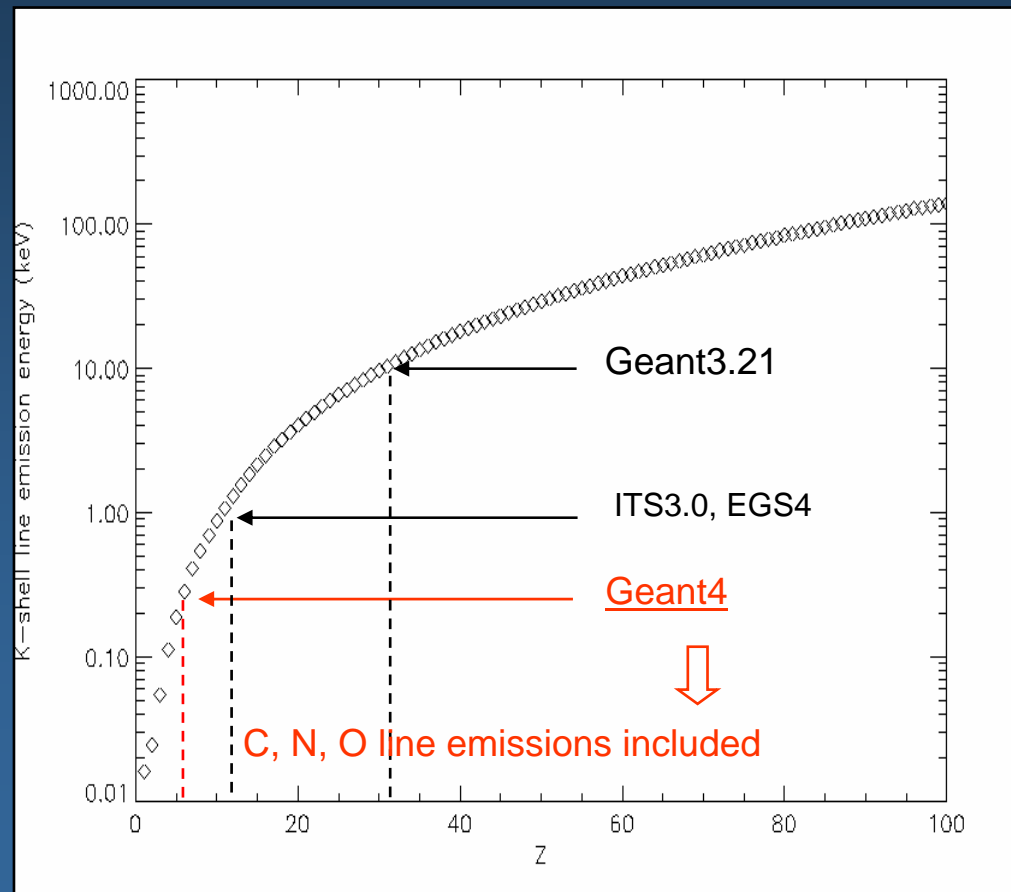
...were triggered by astrophysics requirements

*X-Ray Surveys of Planets, Asteroids and Moons*



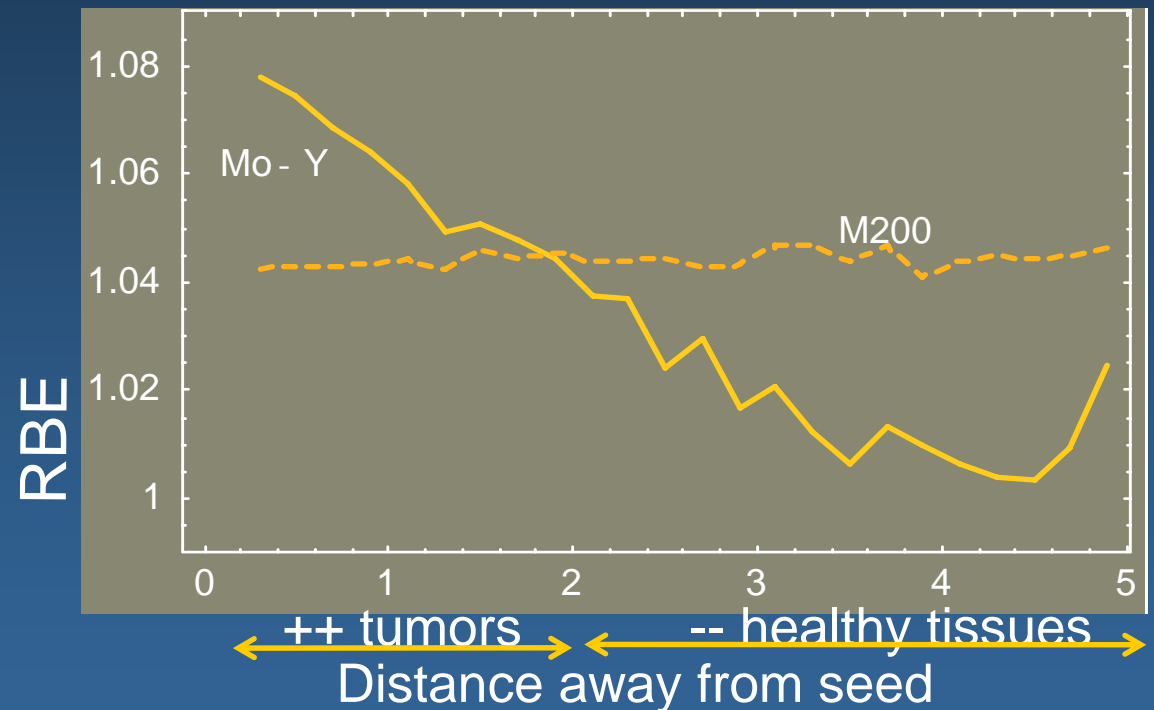
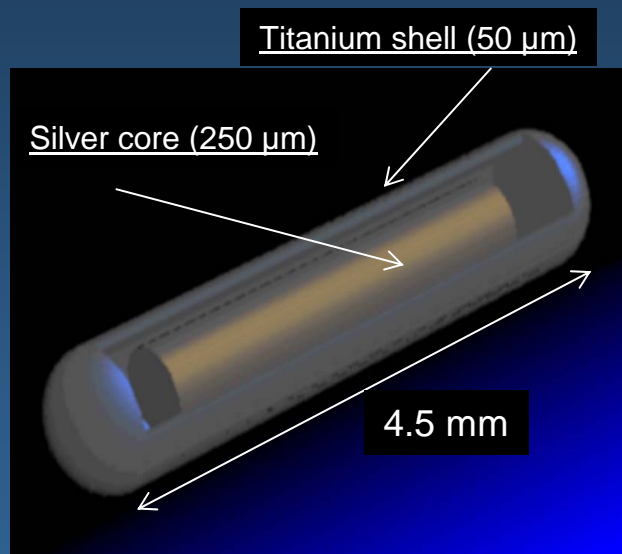
Courtesy SOHO EIT

Induced X-ray line emission:  
indicator of target composition  
(~100  $\mu\text{m}$  surface layer)



# ...the first user application

Goal: improve the biological effectiveness of titanium encapsulated  $^{125}\text{I}$  sources in permanent prostate implants by exploiting X-ray fluorescence



R. Taschereau, R. Roy, J. Pouliot

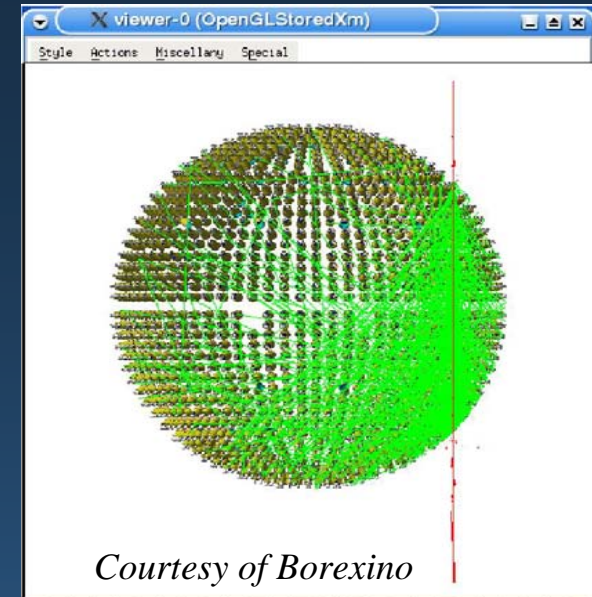
*Centre Hospitalier Universitaire de Quebec, Dept. de radio-oncologie, Canada*

*Univ. Laval, Dept. de Physique, Canada*

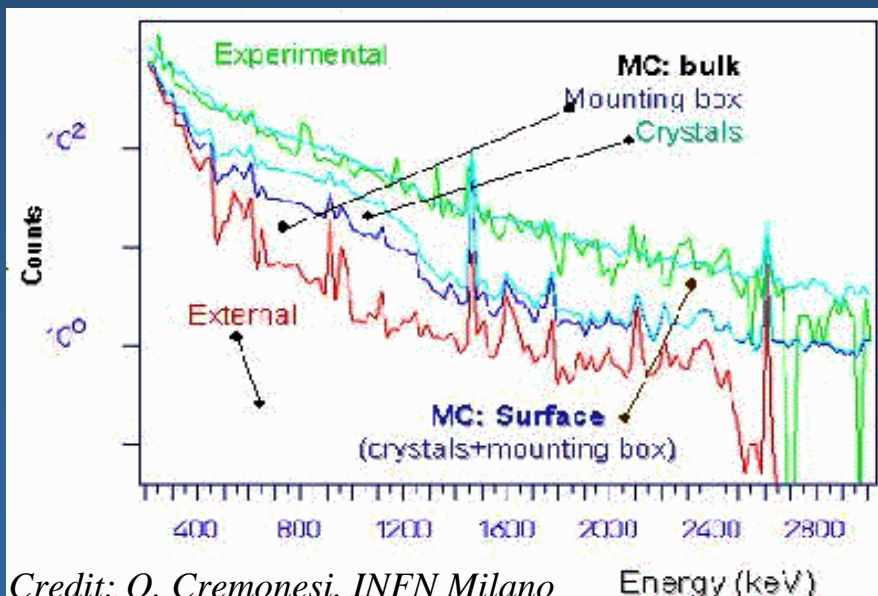
*Univ. of California, San Francisco, Dept. of Radiation Oncology, USA*

Maria Grazia Pia, *INFN Genova*

## Gran Sasso Laboratory



*Courtesy of Borexino*



*Credit: O. Cremonesi, INFN Milano*

## ...back to HEP

- Similar requirements on low energy physics from underground neutrino and dark matter experiments
- Recent interest on these physics models from LHC for precision detector simulation



# Publications on Medical Physics in 2004-2005 (1)

**1) Monte Carlo derivation of TG-43 dosimetric parameters for radiation therapy resources and 3M Cs-137 sources ,**  
J. Pérez-Calatayud, D. Granero, F. Ballester, E. Casal, R. Cases, and S. Agramunt, Med. Phys. **32**, 2464 (2005)

**2) Octree based compression method of DICOM images for voxel number reduction and faster Monte Carlo**  
V Hubert-Tremblay, L Archambault, L Beaulieu, and R Roy, Med. Phys. **32**, 2413 (2005)

**3) Simulation of Dosimetric Properties of Very-High Energy Laser-Accelerated Electron Beams**  
T Fuchs, H Szymanowski, Y Glinec, J Faure, V Malka, and U Oelfke, Med. Phys. **32**, 2163 (2005)

**4) Quantum Efficiency of An MCP Detector: Monte Carlo Calculation,**  
PM Shikhaliev, JL Ducote, T Xu, and S Molloy, Med. Phys. **32**, 2158 (2005)

**6) The Use of a Miniature Multileaf Collimator in Stereotactic Proton Therapy**  
R Slopsema, H Paganetti, H Kooy, M Bussiere, J Sisterson, J Flanz, and T Bortfeld, Med. Phys. **32**, 2088 (2005)

**7) Simulation of Organ Specific Secondary Neutron Dose in Proton Beam Treatments**  
H Jiang, B Wang, X Xu, H Suit, and H Paganetti, Med. Phys. **32**, 2071 (2005)

**8) Study of Truncated Cone Filters Using GEANT4**  
T Himukai, Y Takada, and R Kohno, Med. Phys. **32**, 2030 (2005)

**9) Proton Dose Calculation Using Monte-Carlo-Validated Pencil Beam Database for KonRad Treatment Planning System**  
A Trofimov, A Knopf, H Jiang, T Bortfeld, and H Paganetti, Med. Phys. **32**, 2030 (2005)

**10) Monte-Carlo Investigation of Proton-Generated Radioactivity in a Multileaf Collimator for a Proton Therapy Facility**  
J McDonough, D Goulart, M Baldytchev, P Bloch, and R Maughan, Med. Phys. **32**, 2030 (2005)

**11) Energy Distributions of Proton Interactions in MCNPX and GEANT4 Codes Using a Slab Target**  
B Wang, X George Xu, H Jiang, and H Paganetti, Med. Phys. **32**, 2029 (2005)

**12) Monte Carlo Calculation of the TG-43 Dosimetric Parameters of a New BEBIG Ir-192 HDR Source**  
F Ballester, E Casal, D Granero, J Perez-Calatayud, S Agramunt, and R Cases, Med. Phys. **32**, 1952 (2005)

## Publications on Medical Physics in 2004-2005 (2)

### **13) Comparison of Pencil Beam Algorithm and Monte Carlo Dose Calculation for Proton Therapy of Paranasal Sinus Cancer**

H Jiang, J Adams, S Rosenthal, S Kollipara, and H Paganetti, Med. Phys. **32**, 2028 (2005)

### **14) Clinical Implementation of Proton Monte Carlo Dose Calculation**

H Paganetti, H Jiang, and S Kollipara, Med. Phys. **32**, 2028 (2005)

### **15) Validation of a Monte Carlo Algorithm for Simulation of Dispersion Due to Scattering of a Monoenergetic Proton Beam**

D Goulart, S Avery, R Maughan, and J McDonough, Med. Phys. **32**, 2019 (2005)

### **16) Monte Carlo Simulations of the Dosimetric Characteristics of a New Multileaf Collimator**

M Tacke, H Szymanowski, C Schulze, S Nuss, E Wehrwein, S Leidenberger, and U Oelfke, Med. Phys. **32**, 2018 (2005)

### **17) Verification of Monte Carlo Simulations of Proton Dose Distributions in Biological Media**

H Szymanowski, S Nill, and U Oelfke, Med. Phys. **32**, 2014 (2005)

### **18) Octree Based Compression Method of DICOM Images for Voxel Number Reduction and Faster Monte Carlo Simulations**

V Hubert-Tremblay, L Archambault, L Beaulieu, and R Roy, Med. Phys. **32**, 2013 (2005)

### **19) Design Characteristics of a MLC for Proton Therapy**

S Avery, D Goulart, R Maughan, and J McDonough, Med. Phys. **32**, 2012 (2005)

### **20) Clinical Impact of Seed Density and Prostate Elemental Composition On Permanent Seed Implant Dosimetry**

J Carrier, F Therriault-Proulx, R Roy, and L Beaulieu, Med. Phys. **32**, 2011 (2005)

### **21) Monte Carlo Dosimetric Study of the New BEBIG Co-60 HDR Source**

J Perez-Calatayud, D Granero, F Ballester, E Casal, S Agramunt, and R Cases, Med. Phys. **32**, 1958 (2005)

### **22) Monte Carlo Derivation of TG-43 Dosimetric Parameters for Radiation Therapy Resources and 3M Cs-137 Sources**

E Casal, D Granero, F Ballester, J Perez-Calatayud, S Agramunt, and R Cases, Med. Phys. **32**, 1952 (2005)

## Publications on Medical Physics in 2004-2005 (3)

### **23) PSF and S/P in Mammography: A Validation of Simulations Using the GEANT4 Code**

V Grabski, M-E Brandan, C. Ruiz-Trejo, and Y. Villaseñor, Med. Phys. **32**, 1911 (2005)

### **24) Validation of GATE Monte Carlo Simulations of the Noise Equivalent Count Rate and Image Quality for the GE Discovery LS PET Scanner**

CR Schmidtlein, AS Kirov, SA Nehmeh, LM Bidaut, YE Erdi, KA Hamacher, JL Humm, and HI Amols, Med. Phys. **32**, 1900 (2005)

### **25) SU-EE-A2-05: Accuracy in the Determination of Microcalcification Thickness in Digital Mammography**

M-E Brandan and V Grabski, Med. Phys. **32**, 1898 (2005)

### **26) Accuracy of the photon and electron physics in GEANT4 for radiotherapy applications**

Emily Poon and Frank Verhaegen, Med. Phys. **32**, 1696 (2005)

### **27) Density resolution of proton computed tomography,**

Reinhard W. Schulte, Vladimir Bashkirov, Márgio C. Loss Klock, Tianfang Li, Andrew J. Wroe, Ivan Evseev, David C. Williams, and Todd Satogata, Med. Phys. **32**, 1035 (2005)

### **28) The role of nonelastic reactions in absorbed dose distributions from therapeutic proton beams in different medium**

Andrew J. Wroe, Iwan M. Cornelius, and Anatoly B. Rosenfeld, Med. Phys. **32**, 37 (2005)

### **29) Monte Carlo and experimental derivation of TG43 dosimetric parameters for CSM-type Cs-137 sources**

J. Pérez-Calatayud, D. Granero, E. Casal, F. Ballester, and V. Puchades, Med. Phys. **32**, 28 (2005)

### **30) Dosimetric study of the 15 mm ROPES eye plaque**

D. Granero, J. Pérez-Calatayud, F. Ballester, E. Casal, and J. M. de Frutos, Med. Phys. **31**, 3330 (2004)

### **31) Monte Carlo dosimetric study of Best Industries and Alpha Omega Ir-192 brachytherapy seeds**

F. Ballester, D. Granero, J. Pérez-Calatayud, E. Casal, and V. Puchades, Med. Phys. **31**, 3298 (2004)

## **Publications on Medical Physics in 2004-2005 (4)**

### **32) Adaptation of GEANT4 to Monte Carlo dose calculations based on CT data**

H. Jiang and H. Paganetti, Med. Phys. **31**, 2811 (2004)

### **33) Accurate Monte Carlo simulations for nozzle design, commissioning and quality assurance for a proton radiation therapy facility**

H. Paganetti, H. Jiang, S.-Y. Lee, and H. M. Kooy, Med. Phys. **31**, 2107 (2004)

### **34) Phantom size in brachytherapy source dosimetric studies**

J. Pérez-Calatayud, D. Granero, and F. Ballester, Med. Phys. **31**, 2075 (2004)

### **35) Monte Carlo dosimetric characterization of the Cs-137 selectron/LDR source: Evaluation of applicator attenuation and superposition approximation effects**

J. Pérez-Calatayud, D. Granero, F. Ballester, V. Puchades, and E. Casal, Med. Phys. **31**, 493 (2004)

### **36) Validation of GEANT4, an object-oriented Monte Carlo toolkit, for simulations in medical physics**

J.-F. Carrier, L. Archambault, L. Beaulieu, and R. Roy, Med. Phys. **31**, 484 (2004)

### **37) Dosimetry characterization of 32P intravascular brachytherapy source wires using Monte Carlo codes PENELOPE and GEANT4,**

Javier Torres, Manuel J. Buades, Julio F. Almansa, Rafael Guerrero, and Antonio M. Lallena, Med. Phys. **31**, 296 (2004)



# Publications on Physics in Medicine and Biology in 2004-2005 (1)

## **1) Neutrons from fragmentation of light nuclei in tissue-like media: a study with the GEANT4 toolkit**

Pshenichnov I, Mishustin I, Greiner W, Phys Med Biol. **50** No 23, 5493-5507.

## **2) Monte Carlo dosimetric study of the BEBIG Co-60 HDR source.**

Ballester F, Granero D, Perez-Calatayud J, Casal E, Agramunt S, Cases R., Phys Med Biol. **50** No 21, 309-316

## **3) Monte Carlo simulation and scatter correction of the GE advance PET scanner with SimSET and Geant4**

Barret O, Carpenter TA, Clark JC, Ansorge RE, Fryer TD, Phys Med Biol. **50** No 20, 4823-4840.

## **4) GATE: a simulation toolkit for PET and SPECT**

S Jan, G Santin, D Strul, S Staelens, K Assié, D Autret, S Avner, R Barbier, M Bardiès, P M Bloomfield, D Brasse, V Breton, P Bruyndonckx, I Buvat, A F Chatziioannou, Y Choi, Y H Chung, C Comtat, D Donnarieix, L Ferrer, S J Glick, C J Groiselle, Guez, P-F Honore, S Kerhoas-Cavata, A S Kirov, V Kohli, M Koole, M Krieguer, D J van der Laan, F Lamare, G Largeron, Lartzien, D Lazaro, M C Maas, L Maigne, F Mayet, F Melot, C Merheb, E Pennacchio, J Perez, U Pietrzyk, F R Rannou, Rey, D R Schaart, C R Schmidlein, L Simon, T Y Song, J-M Vieira, D Visvikis, R Van de Walle, E Wieërs and C Morel  
Phys. Med. Biol. **49** No 19, 4543-4561

## **5) Monte Carlo simulations of a scintillation camera using GATE: validation and application modelling**

S Staelens, D Strul, G Santin, S Vandenberghe, M Koole, Y D'Asseler, I Lemahieu and R V de Walle  
Phys. Med. Biol. **48** No 18, 3021-3042

## **6) Simulation of organ-specific patient effective dose due to secondary neutrons in proton radiation treatment**

*Hongyu Jiang, Brian Wang, X George Xu, Herman D Suit and Harald Paganetti*  
Phys. Med. Biol. **50** No 18, 4337-4353

## **7) Validation of the Monte Carlo simulator GATE for indium-111 imaging**

*K Assié, I Gardin, P Véra and I Buvat, Phys. Med. Biol. 50* No 13, 3113-3125

## Publications on Physics in Medicine and Biology in 2004-2005 (2)

### **8) Integrating a MRI scanner with a 6 MV radiotherapy accelerator: dose increase at tissue–air interfaces in a lateral magnetic field due to returning electrons**

A J E Raaijmakers, B W Raaymakers and J J W Lagendijk, Phys. Med. Biol. **50** No 7, 1363-1376

### **9) Consistency test of the electron transport algorithm in the GEANT4 Monte Carlo code**

Emily Poon, Jan Seuntjens and Frank Verhaegen, Phys. Med. Biol. **50** No 4, 681-694

### **10) Monte Carlo evaluation of kerma in an HDR brachytherapy bunker**

J Pérez-Calatayud, D Granero, F Ballester, E Casal, V Crispin, V Puchades, A León and G Verdú, Phys. Med. Biol. **49** No 24, 389-396

### **11) Optimizing Compton camera geometries**

Sudhakar Chelikani, John Gore and George Zubal, Phys. Med. Biol. **49** No 8, 1387-1408

### **12) Four-dimensional Monte Carlo simulation of time-dependent geometries**

H Paganetti, Phys. Med. Biol. **49** No 6, 75-81

### **13) Validation of the GATE Monte Carlo simulation platform for modelling a CsI(Tl) scintillation camera dedicated to small-animal imaging**

D Lazaro, I Buvat, G Loudos, D Strul, G Santin, N Giokaris, D Donnarieix, L Maigne, V Spanoudaki, S Styliaris, S Staelens and V Breton, Phys. Med. Biol. **49** No 2, 271-285

### **14) Monte Carlo simulations of a scintillation camera using GATE: validation and application modelling**

S Staelens, D Strul, G Santin, S Vandenberghe, M Koole, Y D'Asseler, I Lemahieu and R V de Walle, Phys. Med. Biol. **48** No 18, 3021-3042

...and many more: publications in IEEE Trans. Nucl. Sci. and IEEE Trans. Med. Imag. etc.

# What is Geant 4?

OO Toolkit for the simulation of next generation HEP detectors

*...of the current generation*

*...not only of HEP detectors*

also...

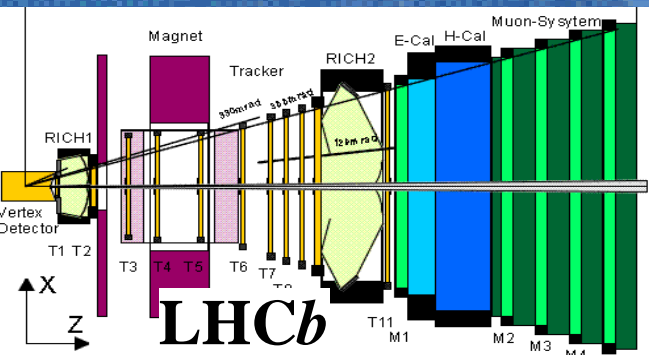
An experiment of distributed software production and management

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

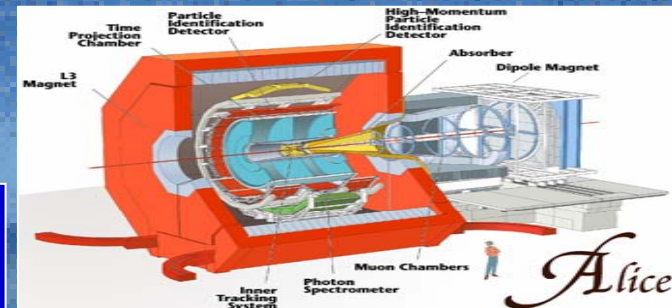
R&D phase: **RD44**, 1994 - 1998

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

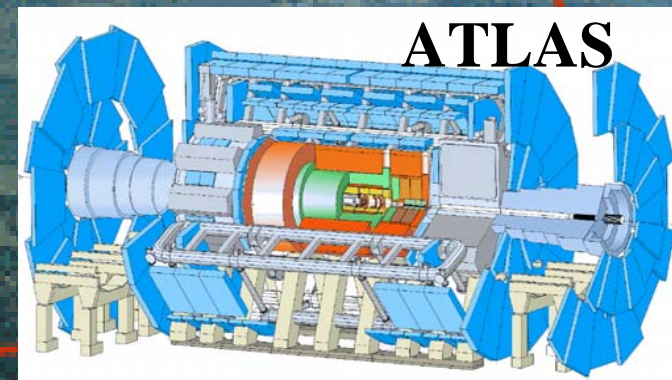
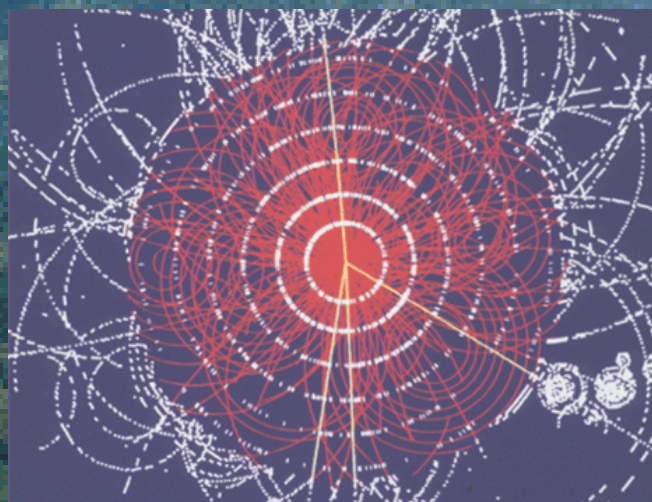
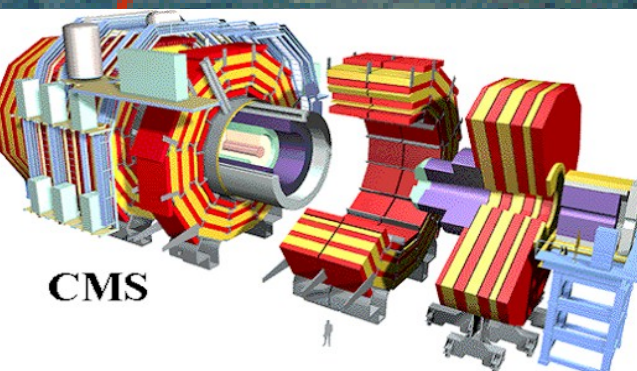
2 new releases/year since then



Complex physics  
Complex detectors  
20 years software life-span



LHC

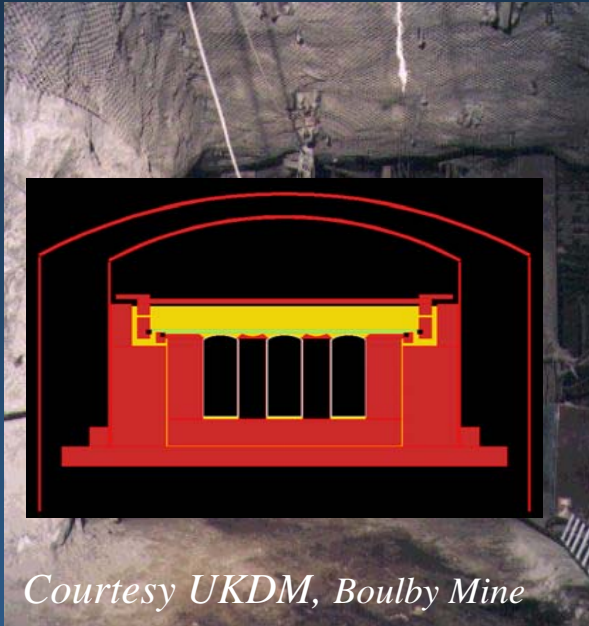




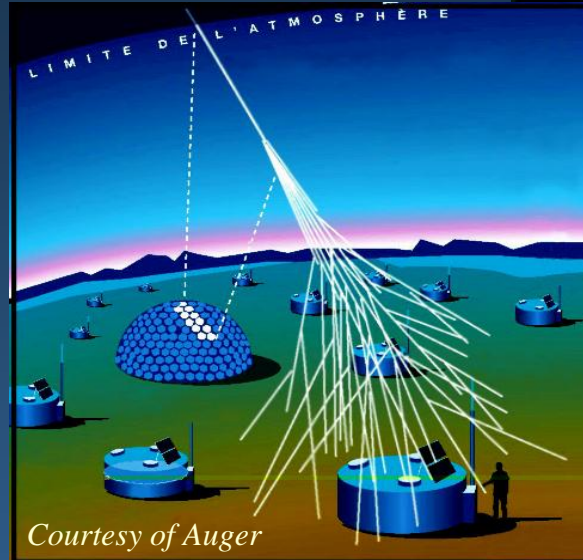
# From deep underground...

# ...to space

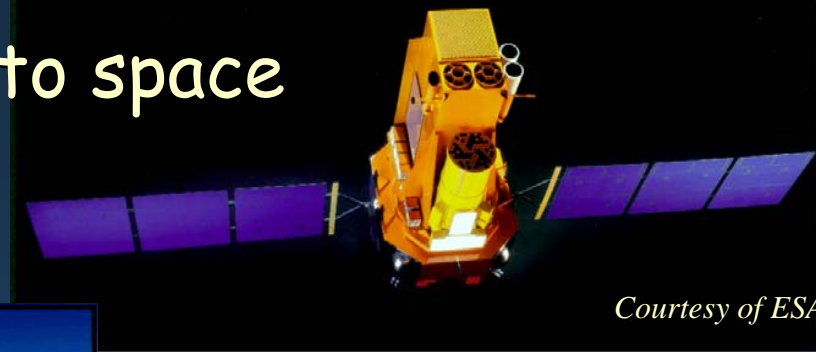
## Dark matter and $\nu$ experiments



*Courtesy UKDM, Boulby Mine*



*Courtesy of Auger*



*Courtesy of ESA*

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

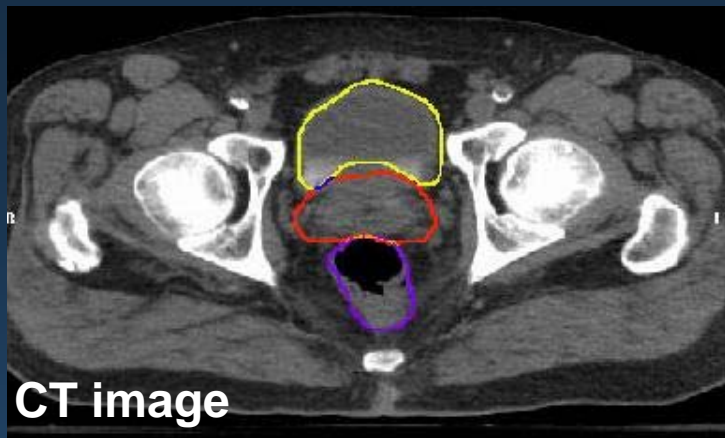
## Cosmic ray experiments

## Variety of requirements from diverse applications

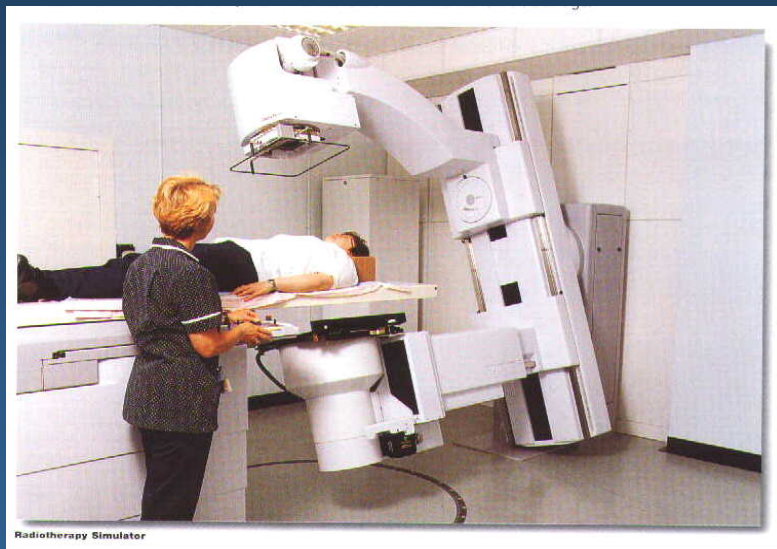
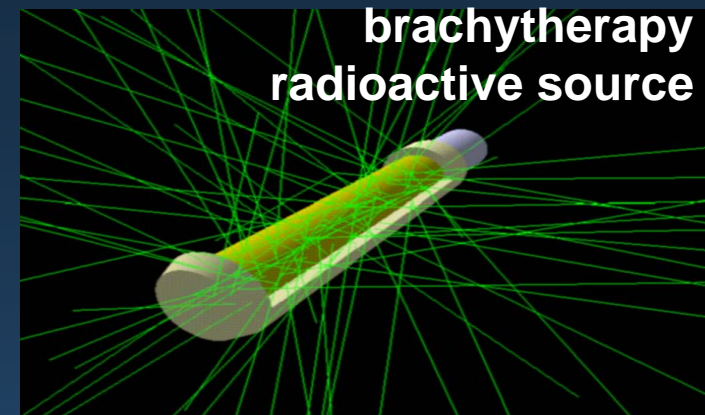
Physics  
from the  $eV$  to the  $PeV$  scale

Detectors,  
spacecrafts and environment

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



# Medical Physics



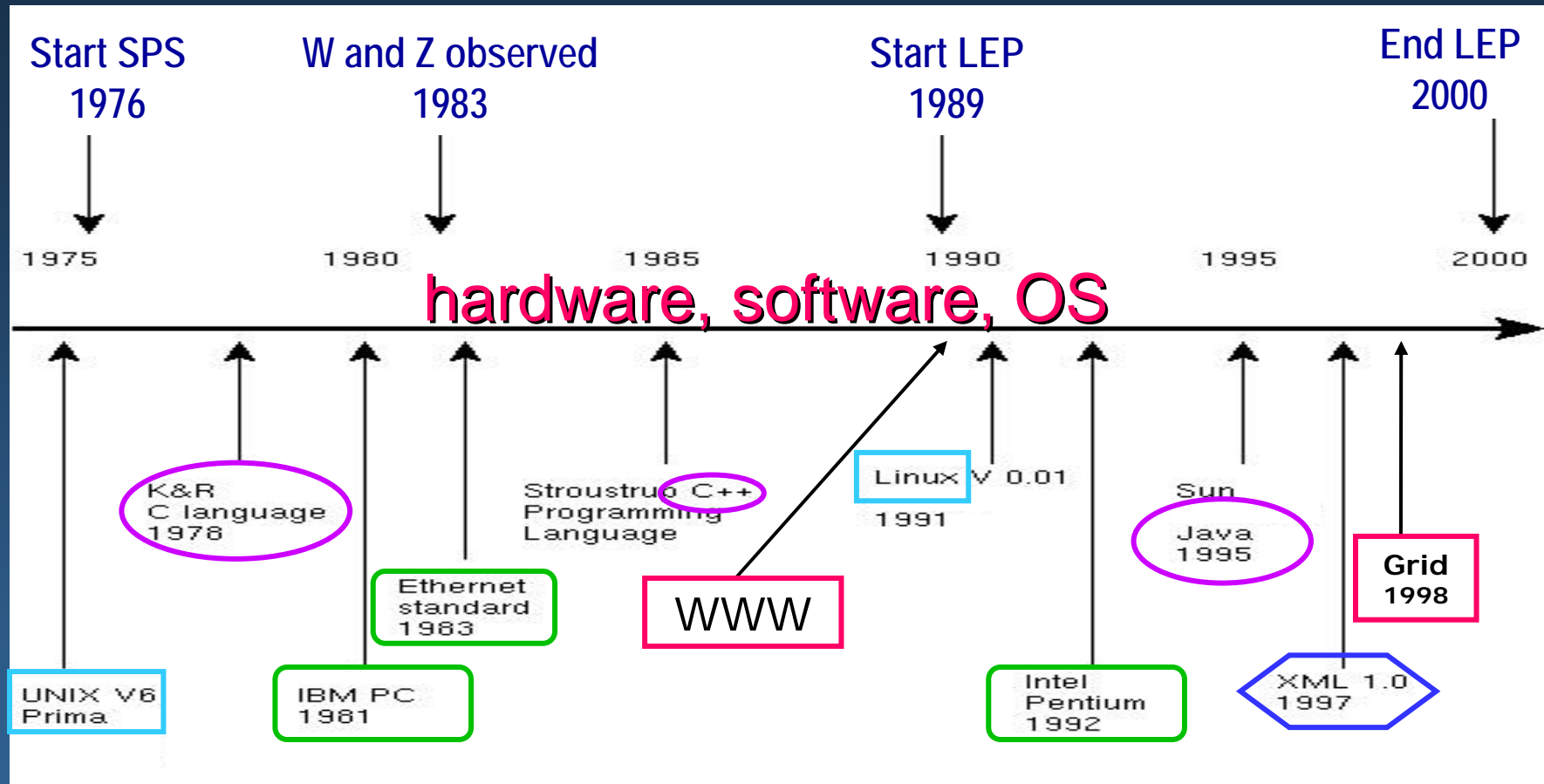
from  
hospitals...

...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

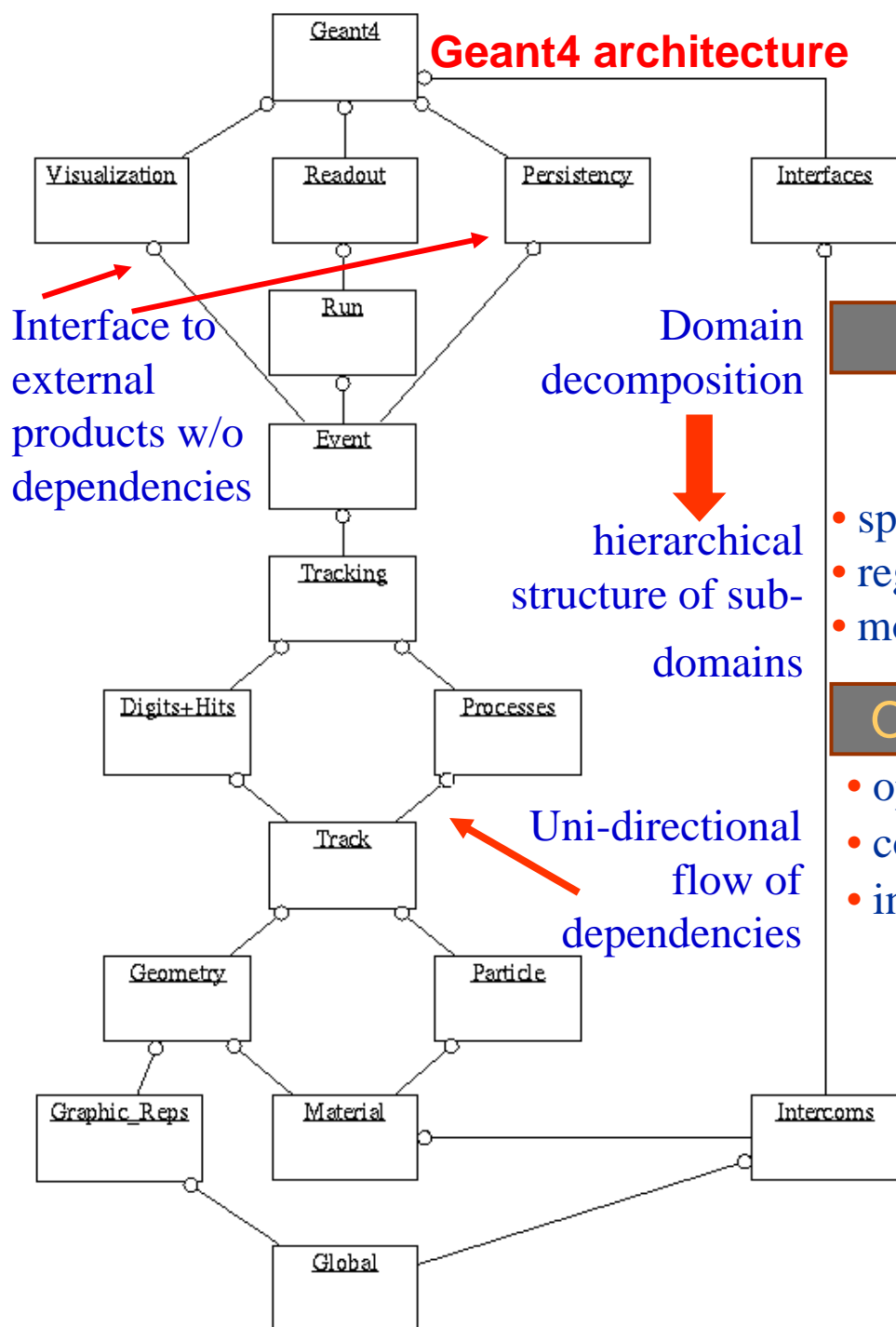
# Physics

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



## 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

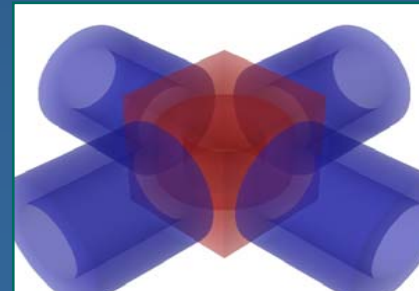
- detailed detector description
- efficient navigation

## ■ Three conceptual layers

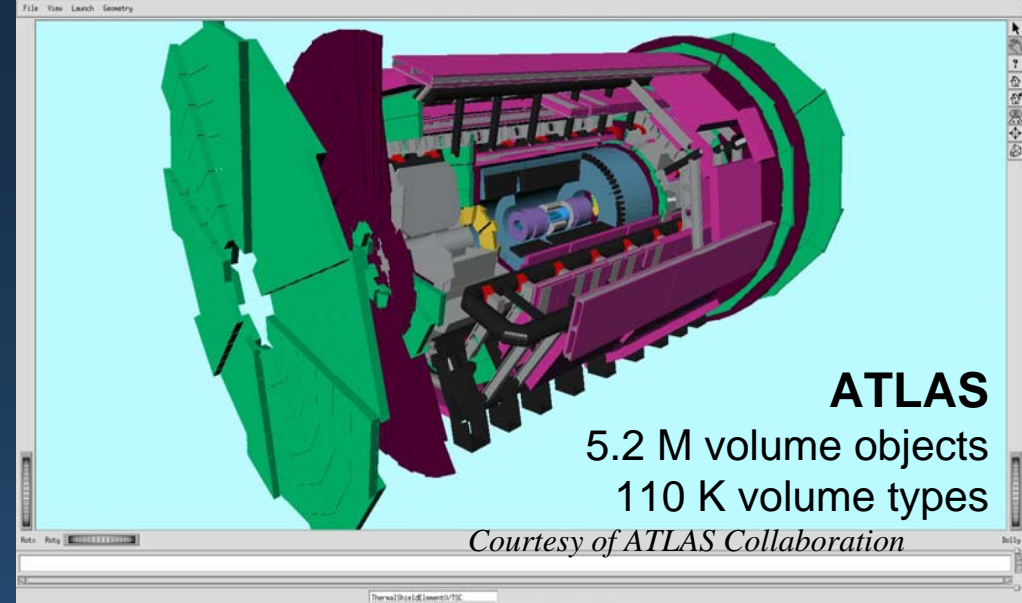
- **Solid**: shape, size
- **LogicalVolume**: material, sensitivity, daughter volumes, etc.
- **PhysicalVolume**: position, rotation

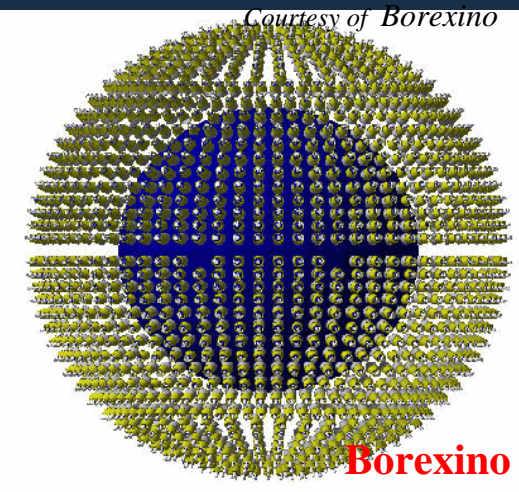
## ■ One can do fancy things with geometry...

Boolean  
operations



Transparent  
solids

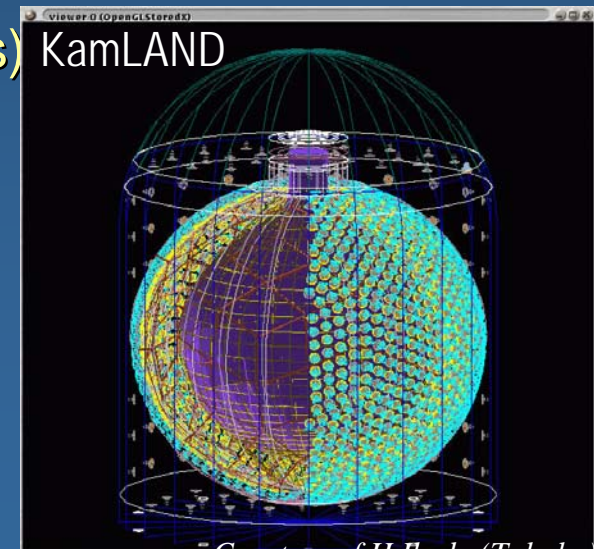
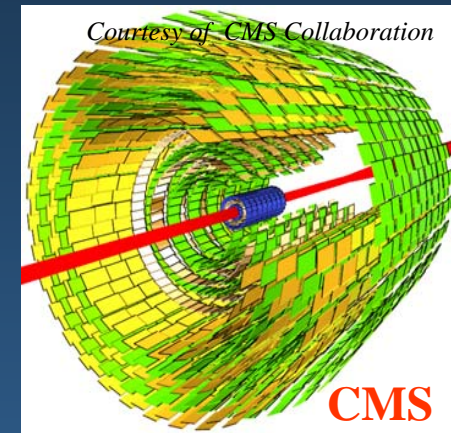
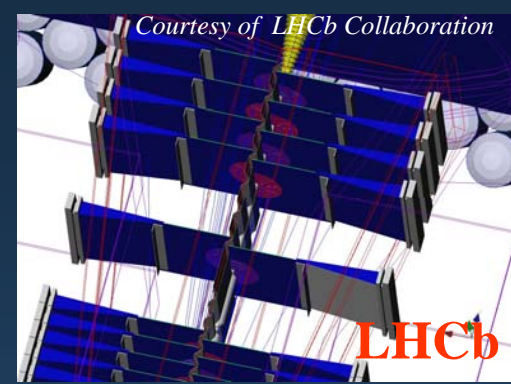
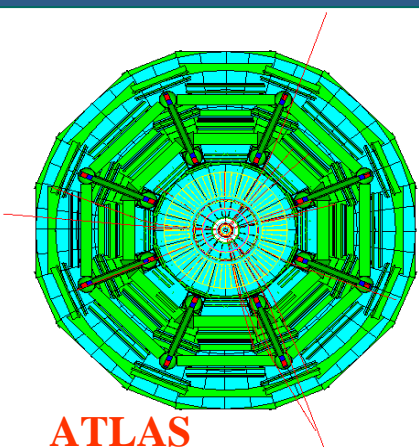
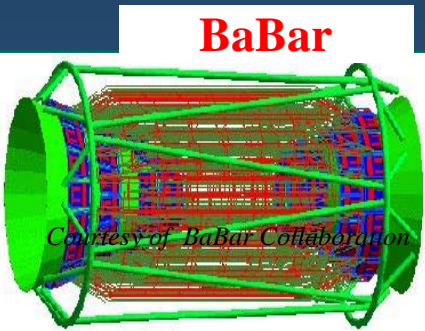




# Solids

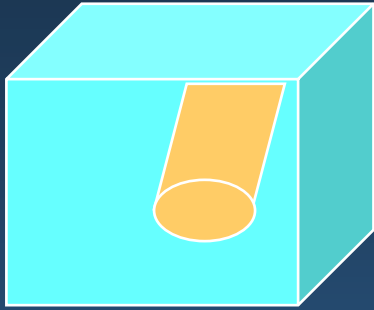
## Multiple representations Same abstract interface

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

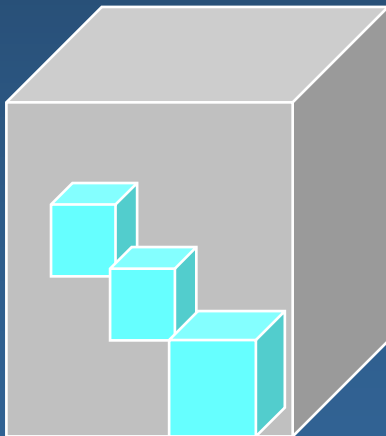
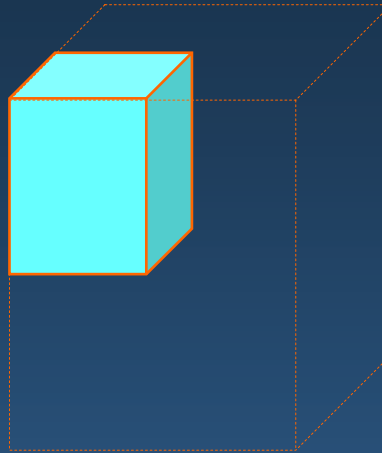


*CAD exchange: ISO STEP interface*

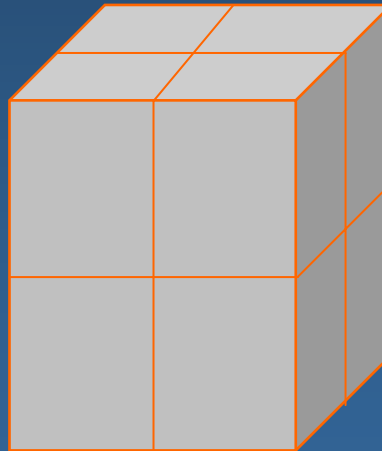
# Physical Volumes



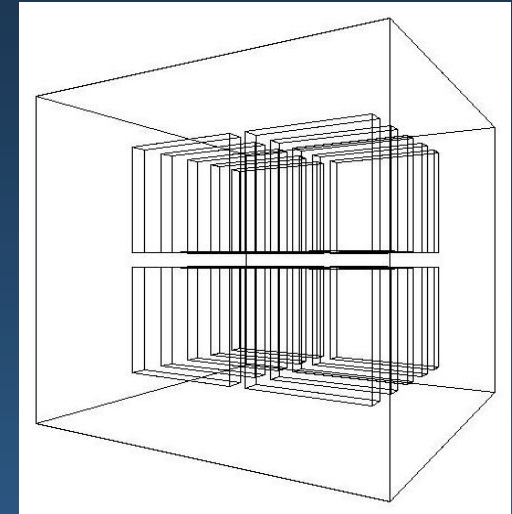
placement



parameterised



replica



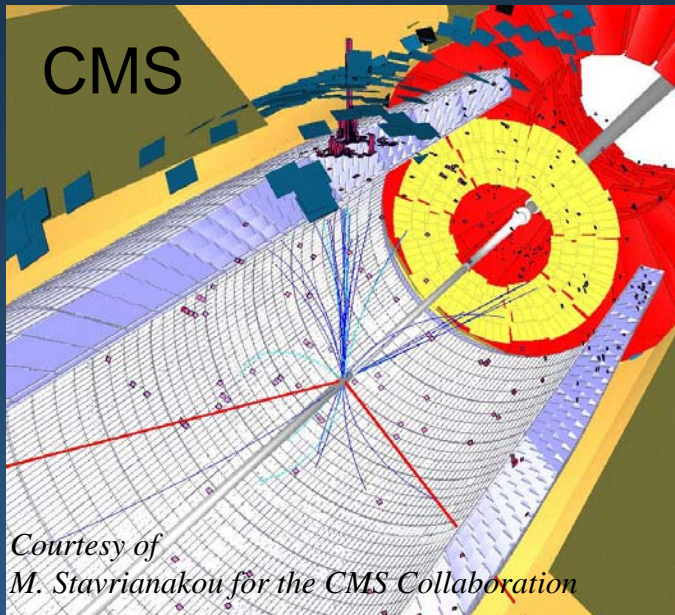
assembled

Versatility to describe  
complex geometries



# Electric and magnetic fields

of variable non-uniformity  
and differentiability

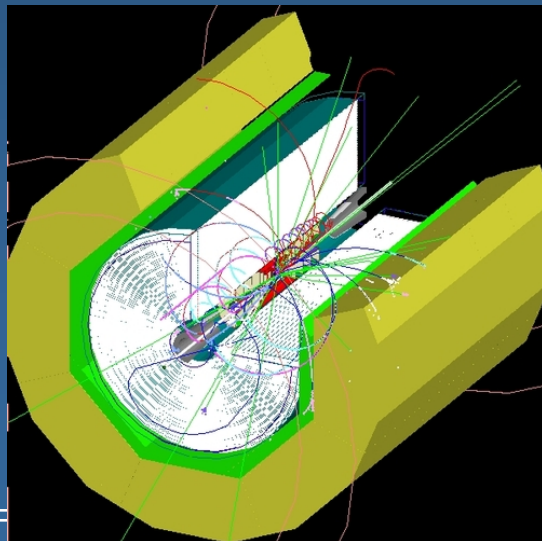


Geant4 field ~ 2 times faster  
than FORTRAN/GEANT3

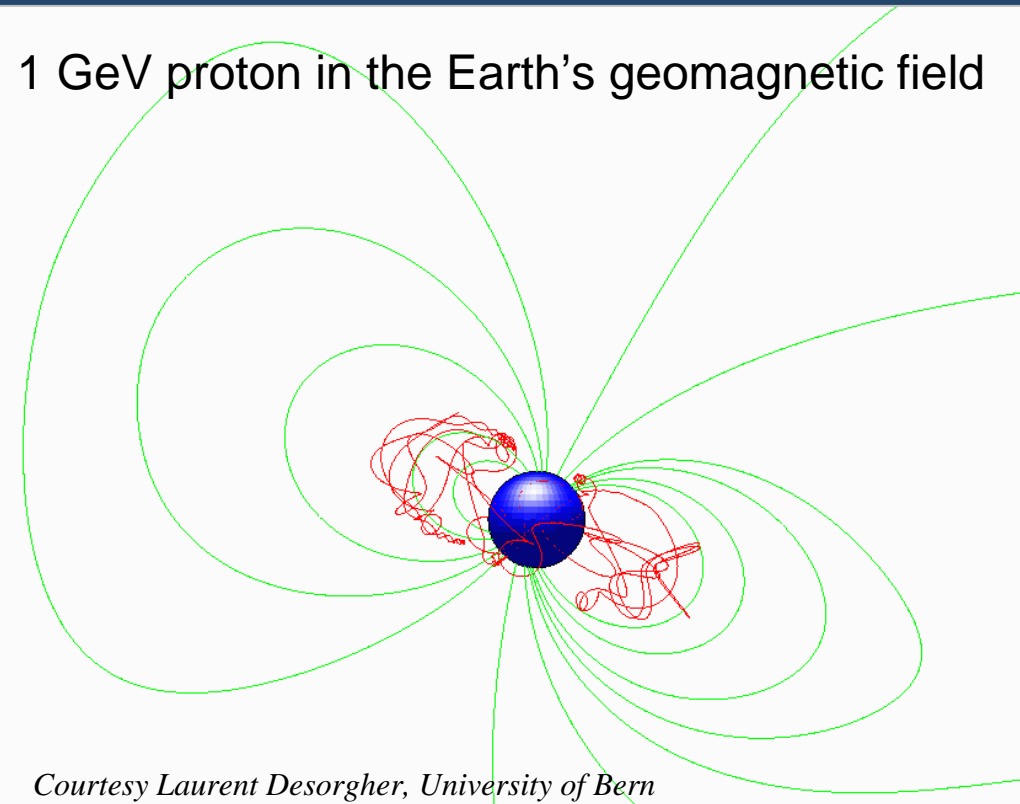
MOKKA

Linear  
Collider  
Detector

Maria Grazia Pia, INFN

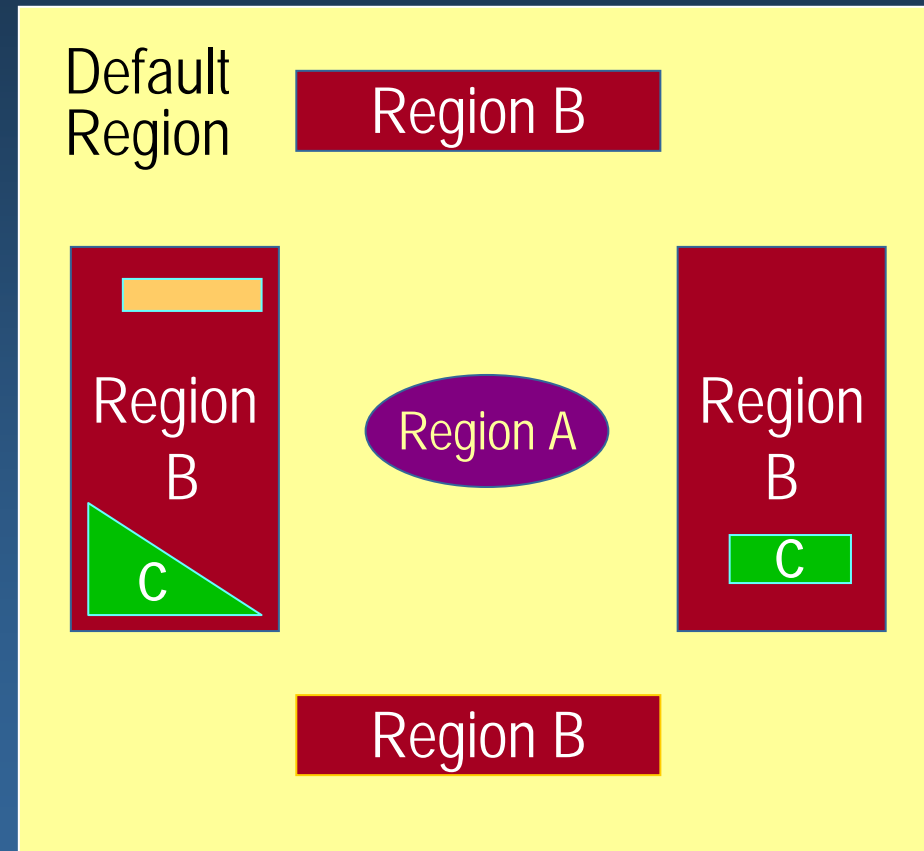


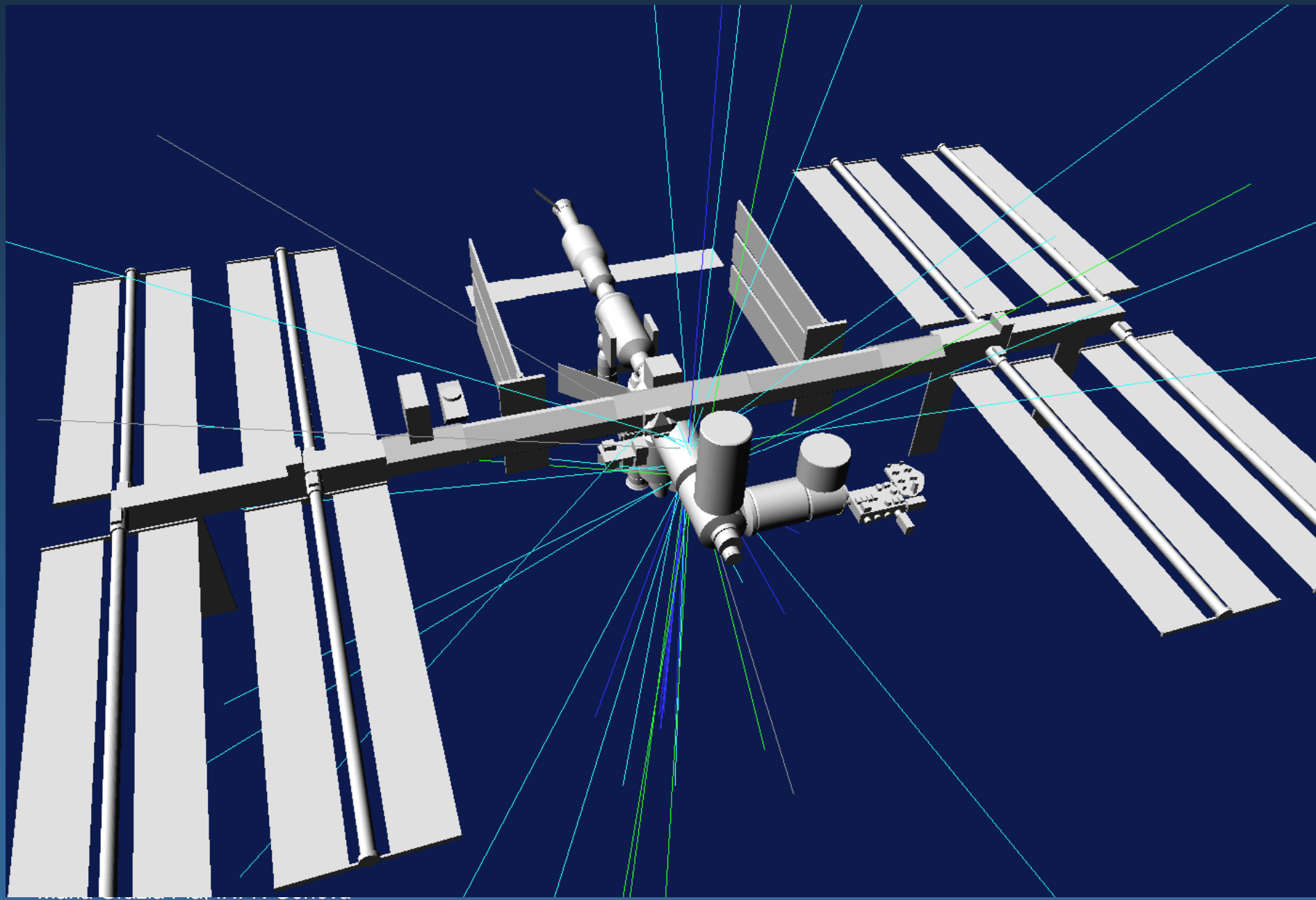
1 GeV proton in the Earth's geomagnetic field



# Detector Region

- Concept of region:
  - Set of geometry volumes
    - barrel + end-caps of the calorimeter
    - support structures
    - etc.
  - Or any group of volumes
- A set of cuts in range is associated to a region
  - a different cut for each particle is allowed in a region





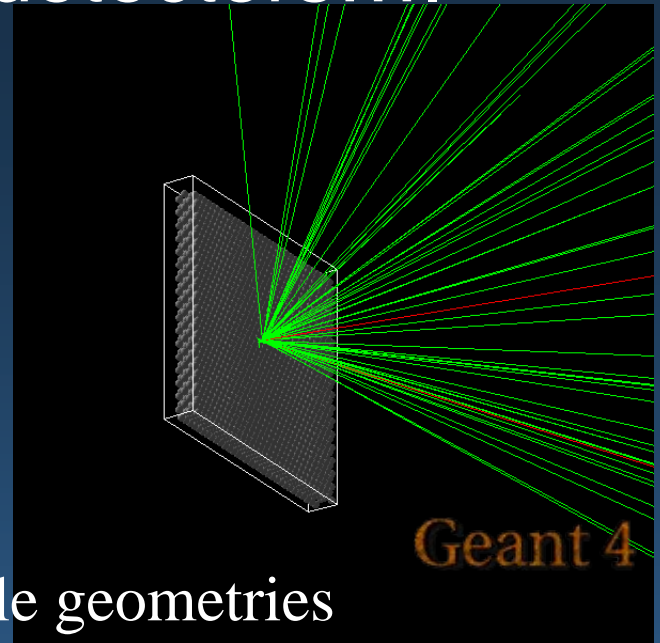
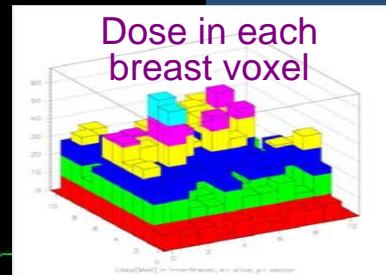
Courtesy T. Ersmark, KTH Stockholm

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

Analytical  
breast breast

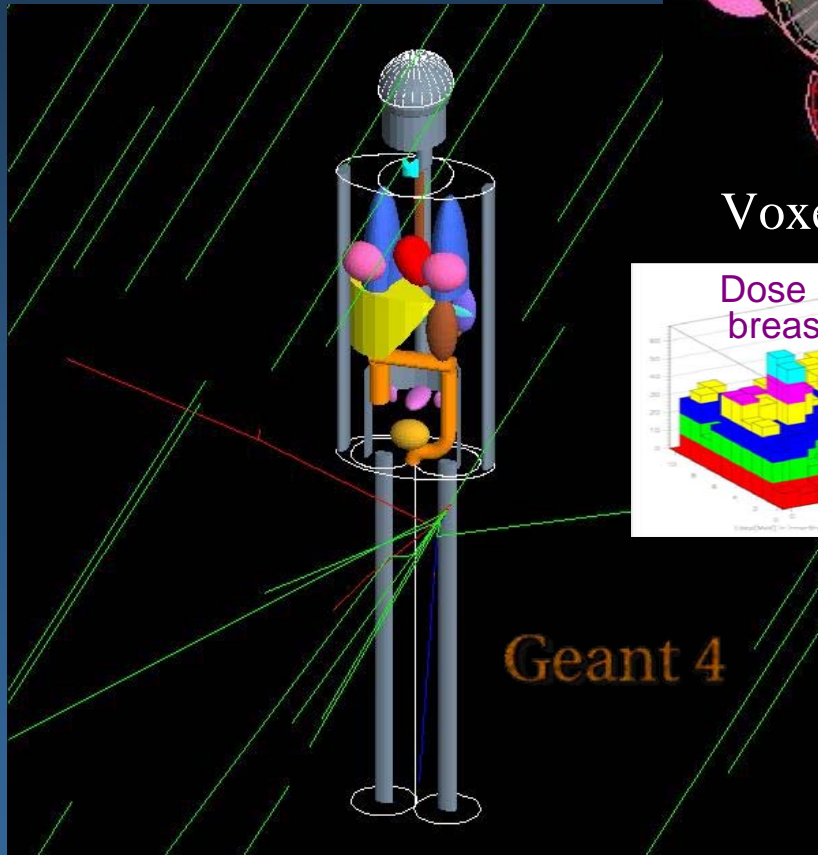


Voxel breast

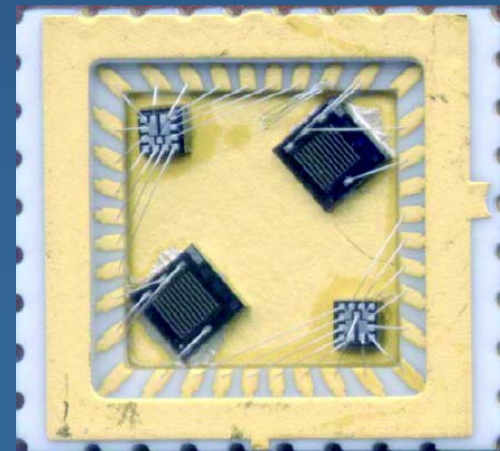


simple geometries

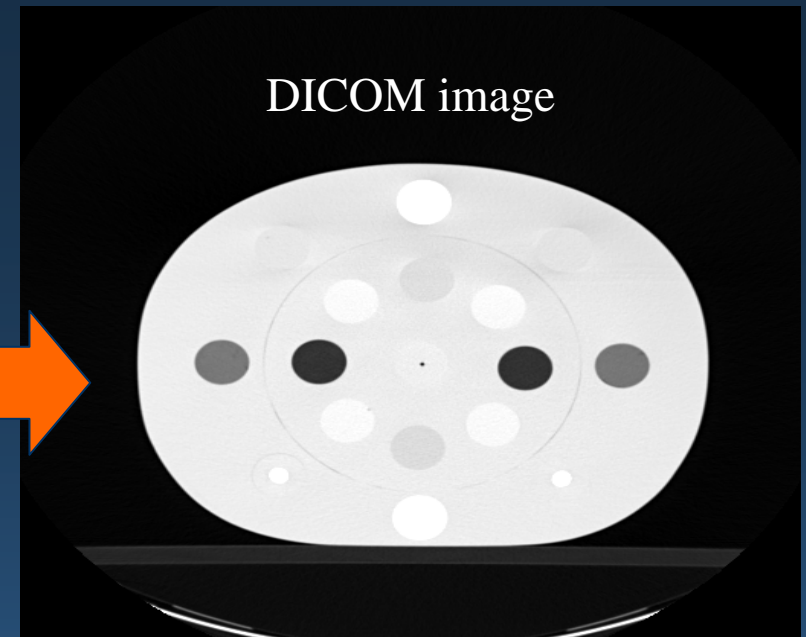
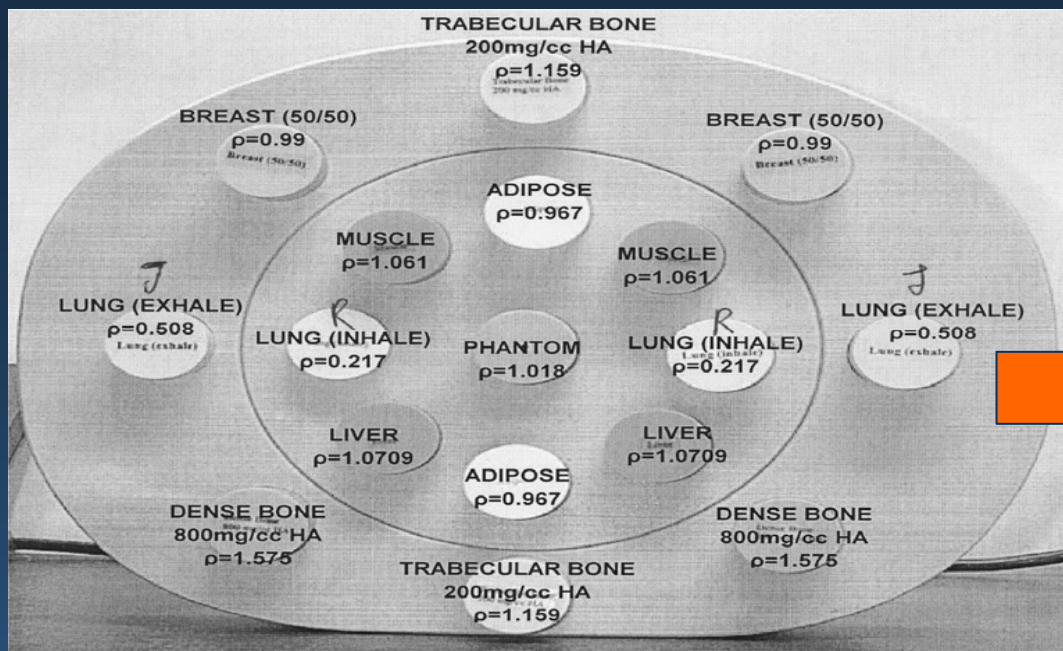
small scale components



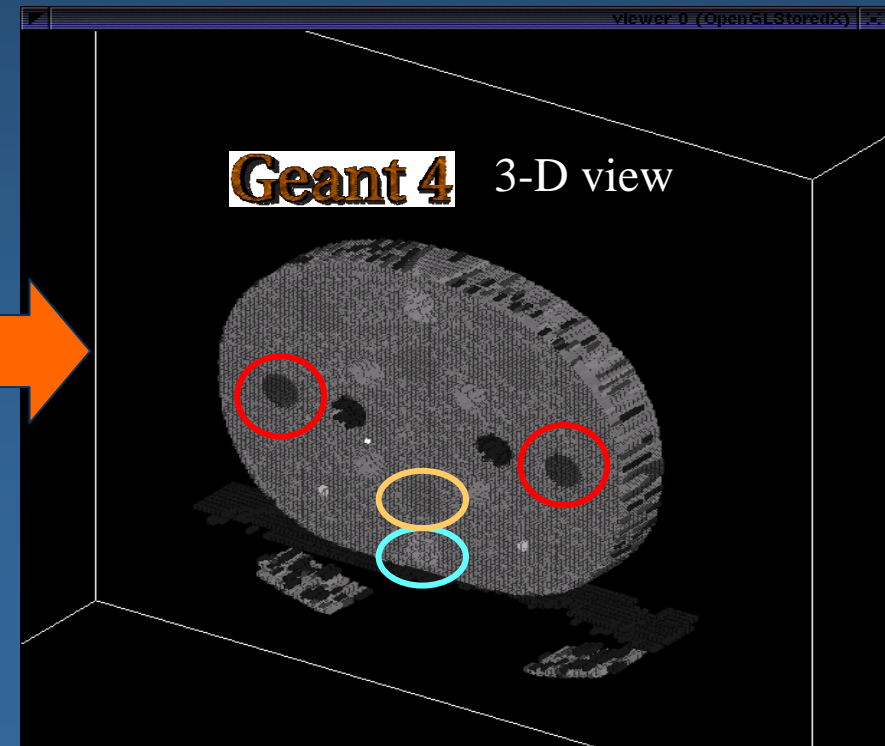
Geant4 anthropomorphic phantoms



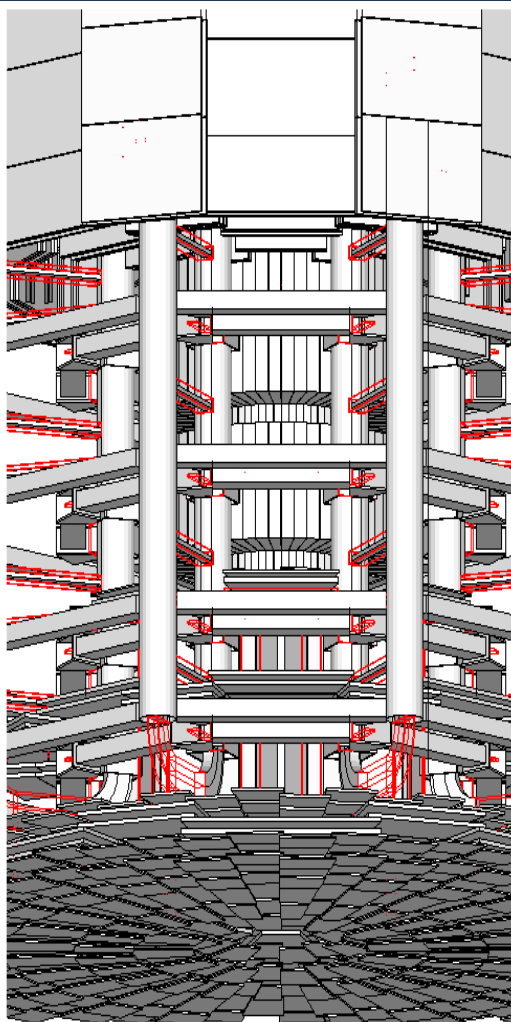




- Reading image information
- Transformation of pixel data into densities
- Association of densities to a list of materials
- Defining the voxels
  - Geant4 parameterised volumes
  - parameterisation function: material



# You may also do it wrong...

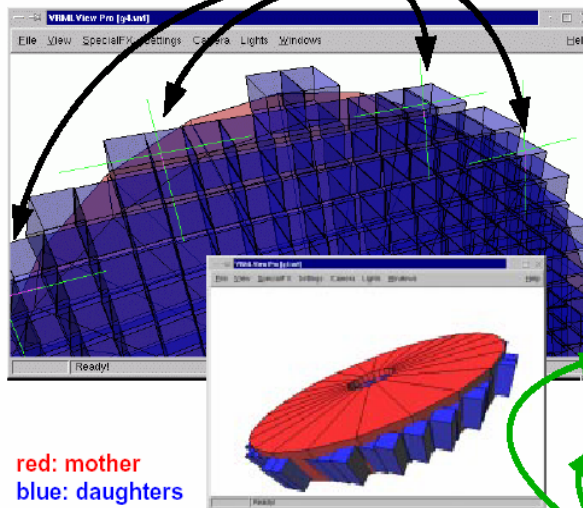


**DAVID**

Tools to detect badly defined geometries

**OLAP**

graphical indication of  
detected overlaps



red: mother  
blue: daughters

daughters are protruding their mother

Geant4 Macro:

```
/vis/scene/create  
/vis/scenHandler/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)

# 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

# Data libraries

- Systematic collection and evaluation of experimental data from many sources worldwide
- Databases
  - ENDF/B, JENDL, FENDL, CENDL, ENSDF, JEF, BROND, EFF, MENDL, IRDF, SAID, EPDL, EEDL, EADL, SANDIA, ICRU etc.
- Collaborating distribution centres
  - NEA, LLNL, BNL, KEK, IAEA, IHEP, TRIUMF, FNAL, Helsinki, Durham etc.
- The use of evaluated data is important for the validation of physics results of the experiments

# 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*)

## ■ 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.

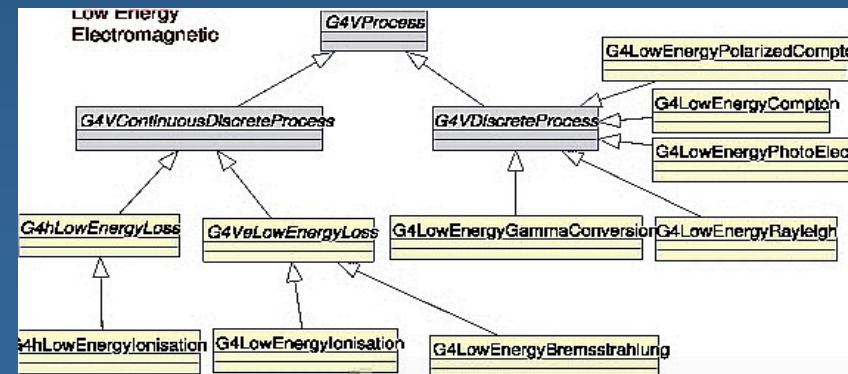
## ■ Alternative models for the same process

All obeying to the same abstract Process interface  transparent to tracking

Maria Grazia Pia, INFN Genova

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





# Standard electromagnetic processes

1 keV up to  $O(100 \text{ TeV})$

## ■ Multiple scattering

- model based on Lewis theory
- computes mean free path length and lateral displacement

## ■ New energy loss algorithm

- optimises the generation of  $\delta$  rays near boundaries

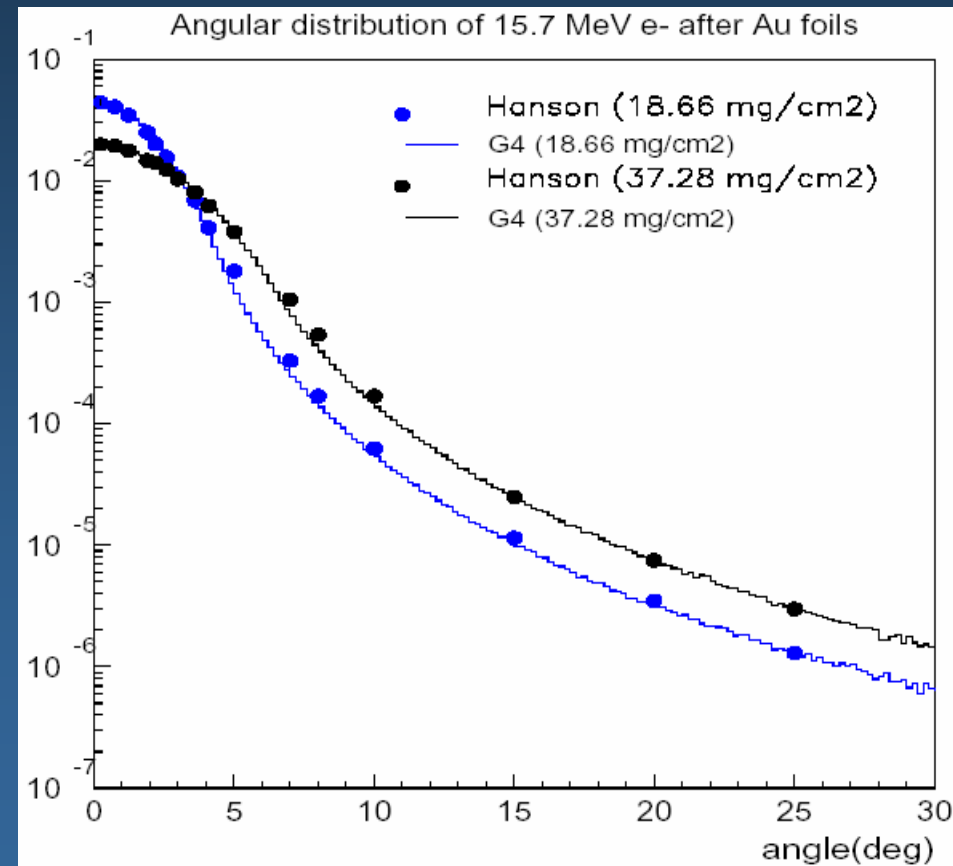
## ■ Variety of models for ionisation and energy loss

- including PhotoAbsorption Interaction model (for thin layers)

## ■ Many optimised features

- Secondaries produced only when needed
- Sub-threshold production

## Multiple scattering



# MuScat (TRIUMF E875)

- Multiple scattering of muons of momenta up to 200 MeV/c
- Important for the optimal design of a cooling channel for a  $\nu$  factory or  $\mu$  collider

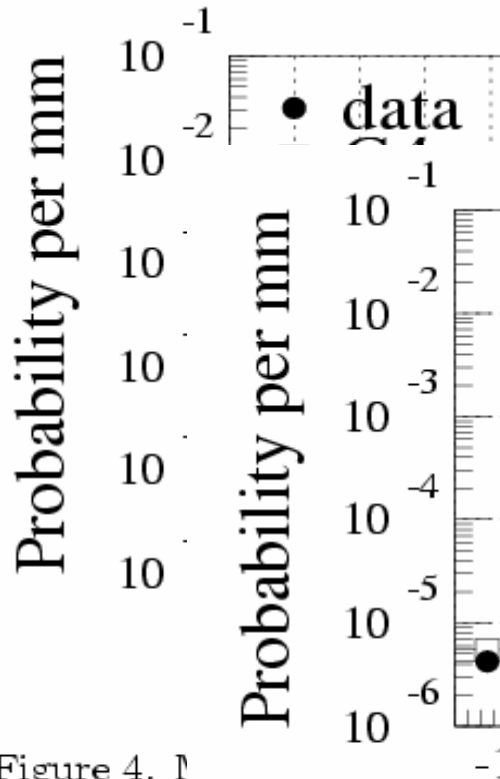


Figure 4. Probability per mm distribution for tracker plane central  $\pm 1\sigma$ .

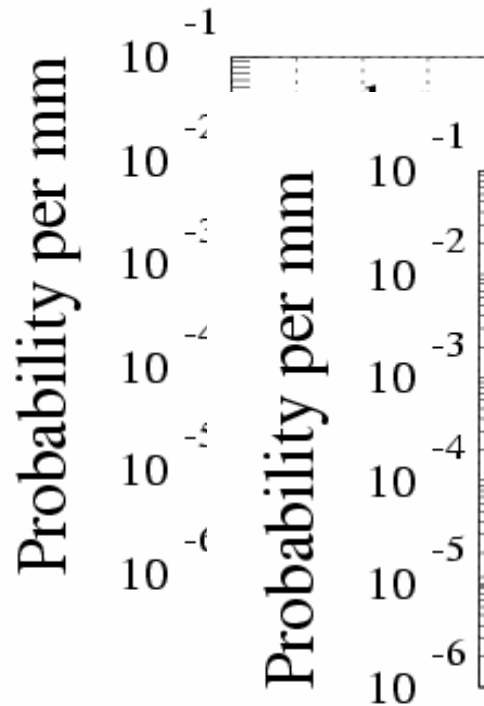


Figure 5. The Sci-Fi plane when no target.

Figure 6. Probability per mm distribution with a 3.0 mm liquid hydrogen target.

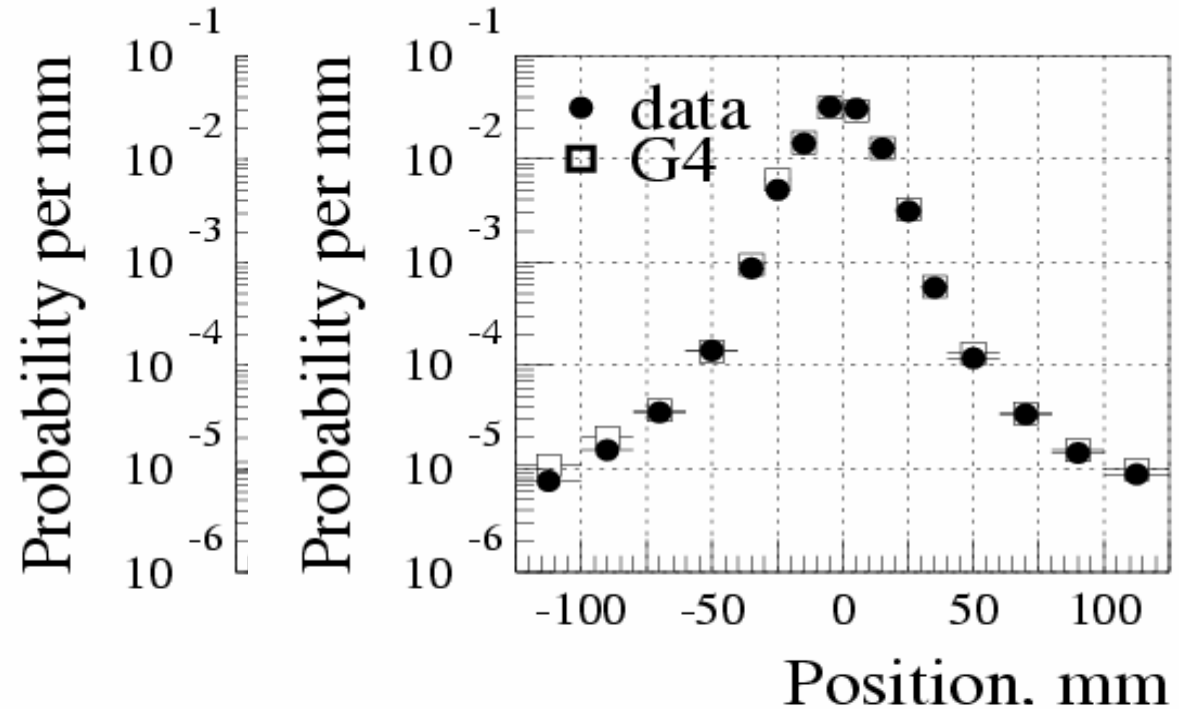
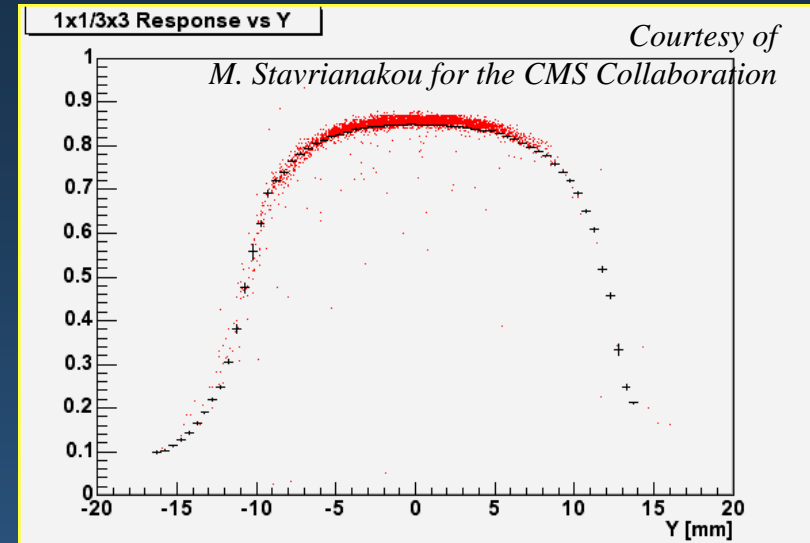
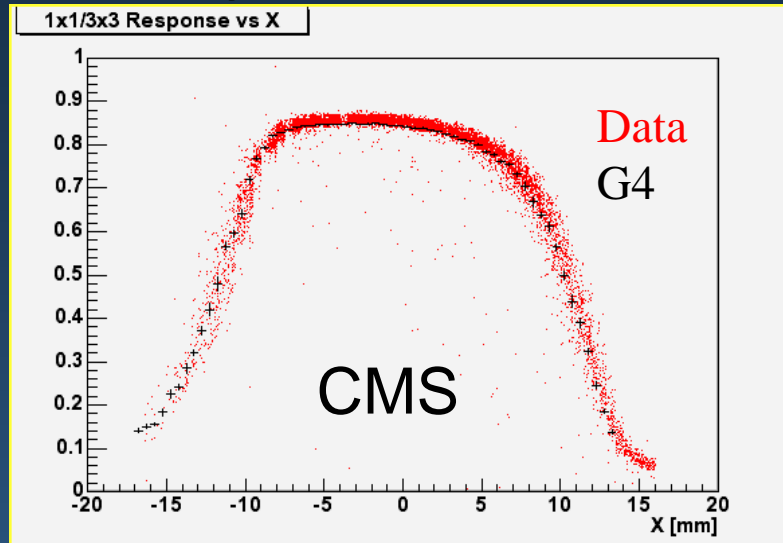


Figure 7. The measured and simulated arrival position distributions with a 150 mm liquid hydrogen target.

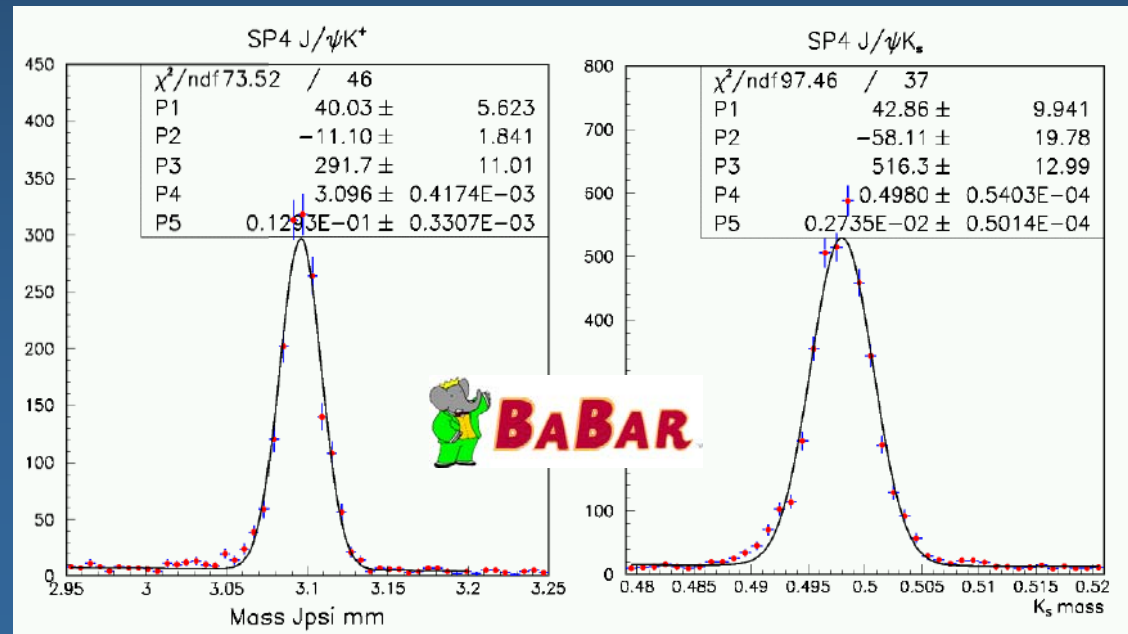
# Calorimetry

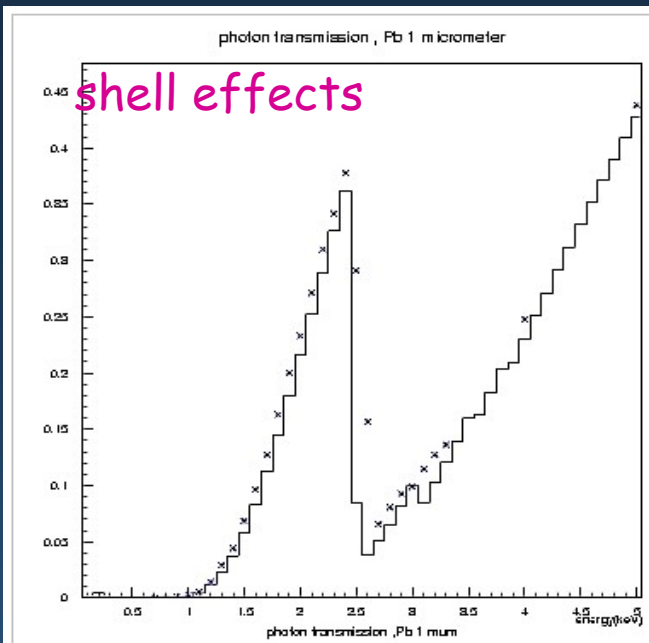
Single crystal containment:  $E_{1x1}/E_{3x3}$  versus position



# Tracking

Geant4 Standard  
Electromagnetic  
Physics

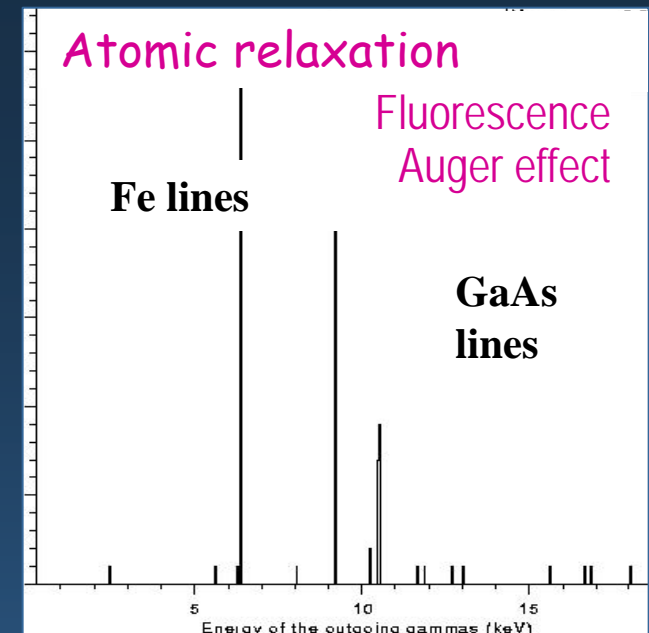




# Geant 4

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

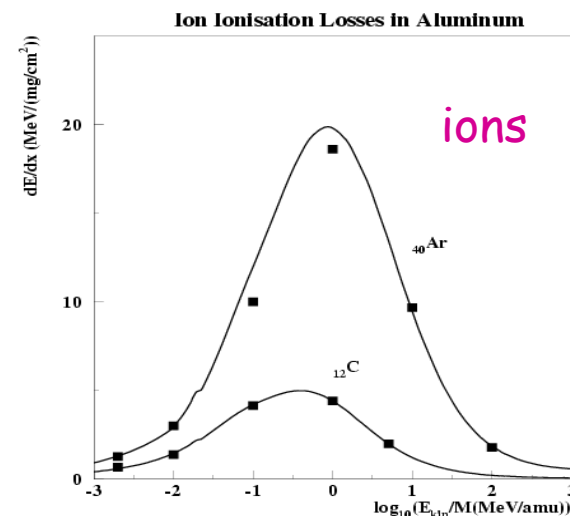
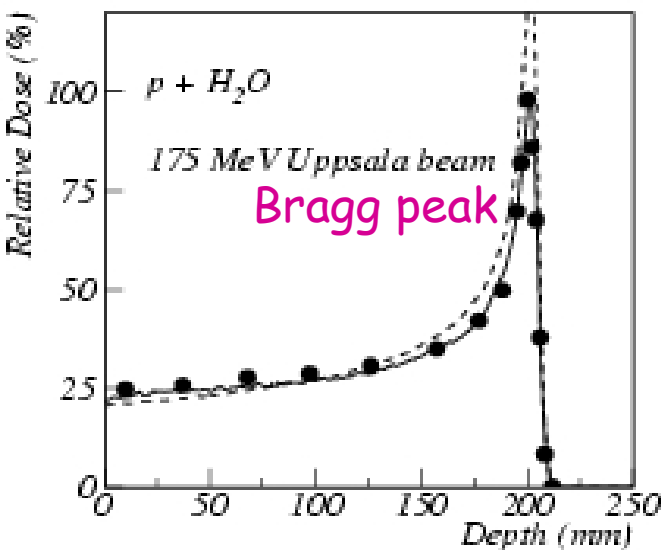
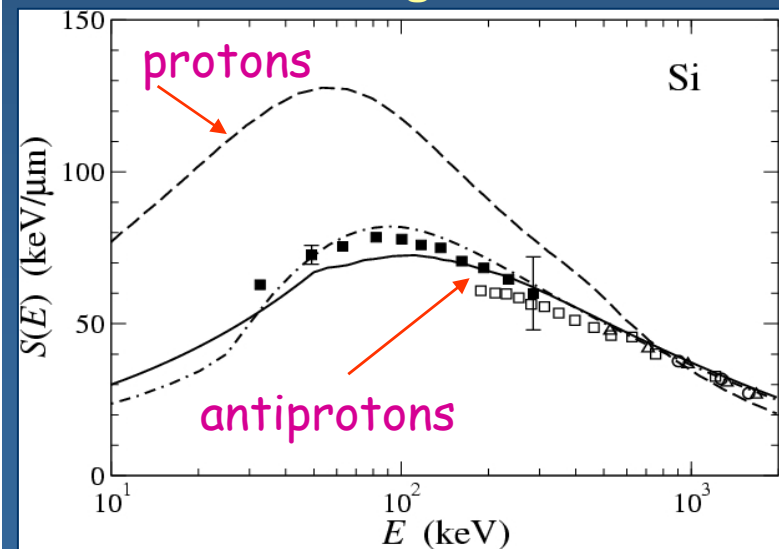


Figure 9: Ion electronic stopping power in aluminum. Points - the best fit on the data from Ref.[12], solid line - GEANT4 parameterisation. The accuracy of the data is about 5 %.

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



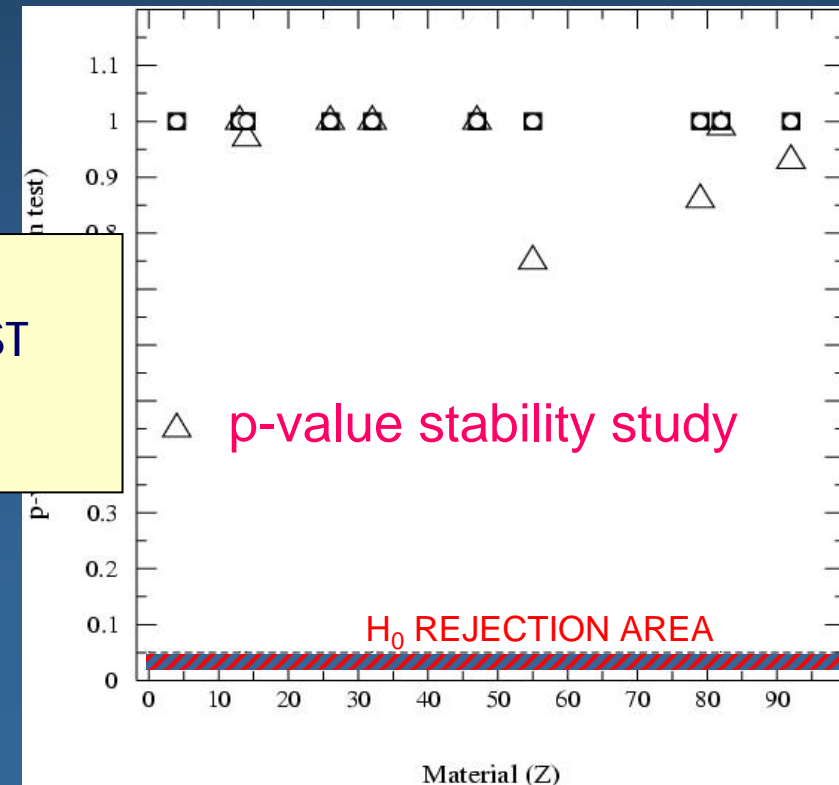
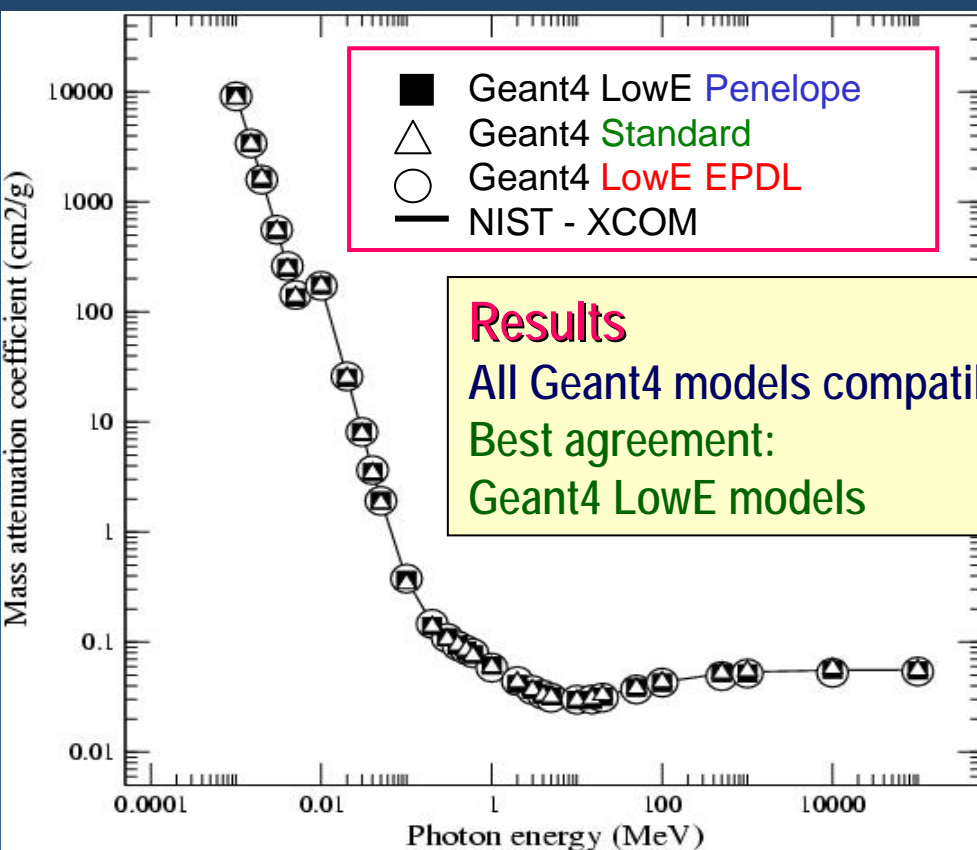
# “Comparison of Geant4 electromagnetic physics models against the NIST reference data”

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

## Geant4 electromagnetic physics models are accurate

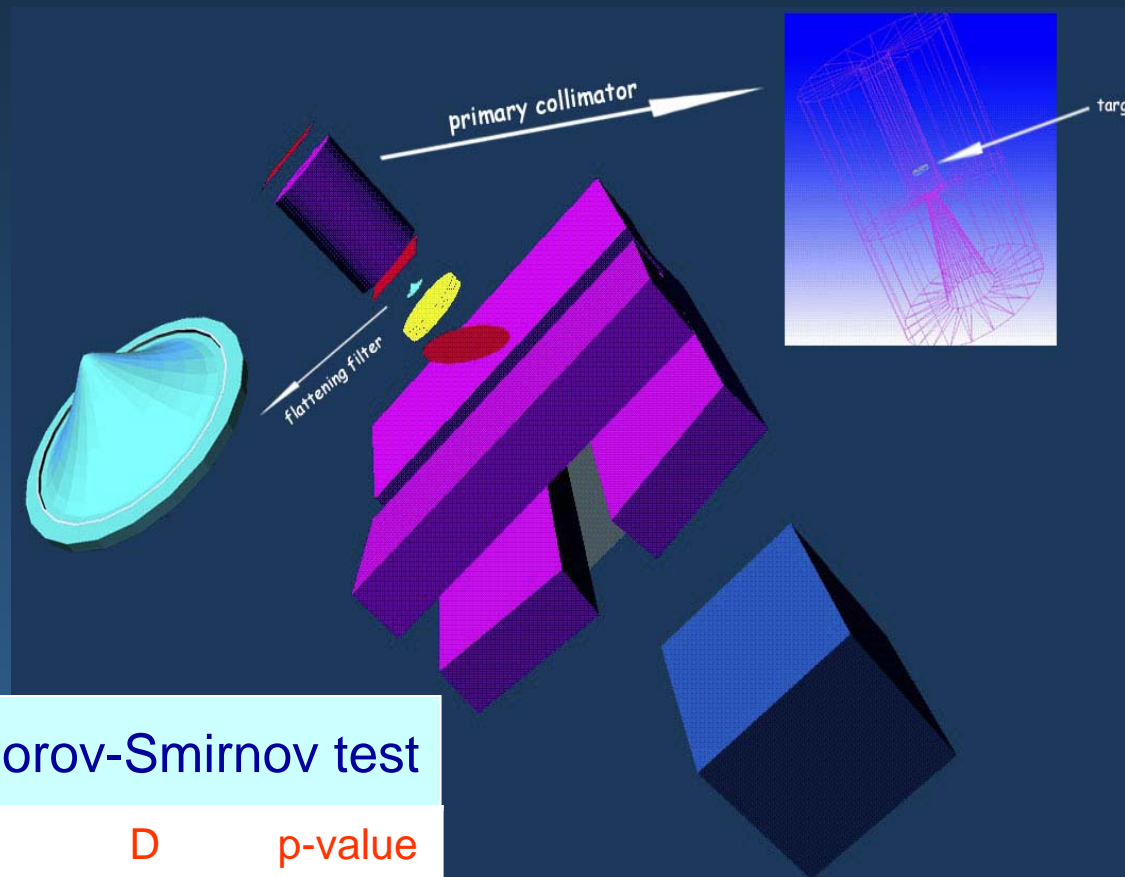
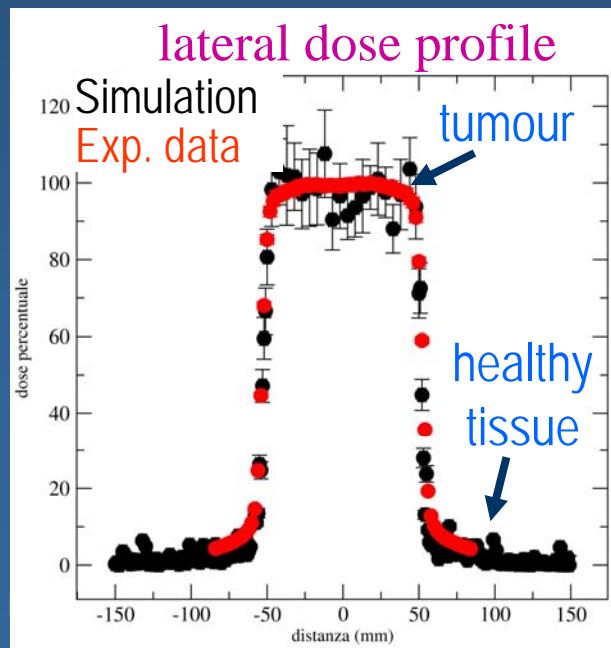
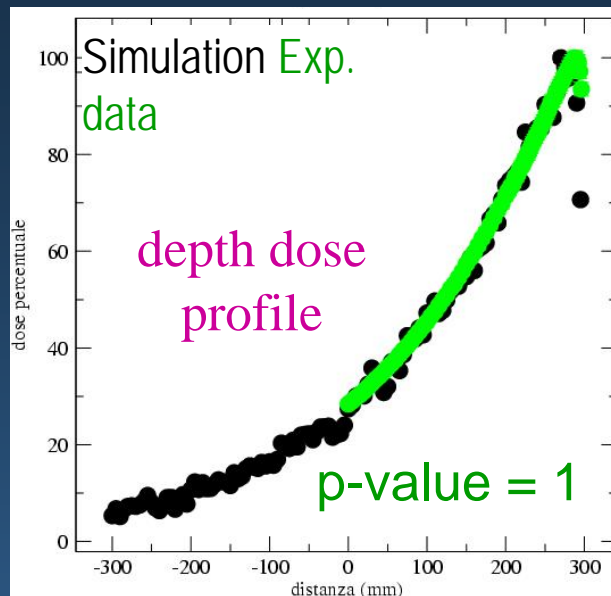
Compatible with NIST data within NIST accuracy (LowE p-value > 0.9)

### Mass attenuation coefficient in Fe





# 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

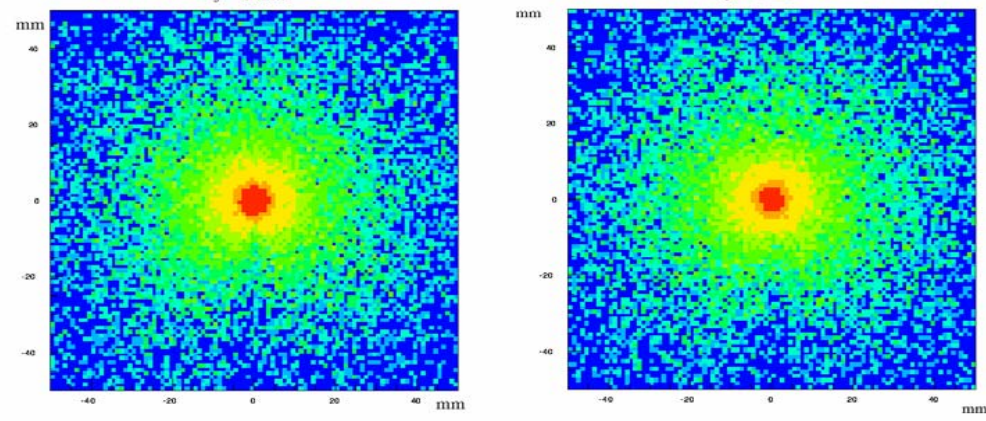


# Dosimetry

Endocavitary brachytherapy

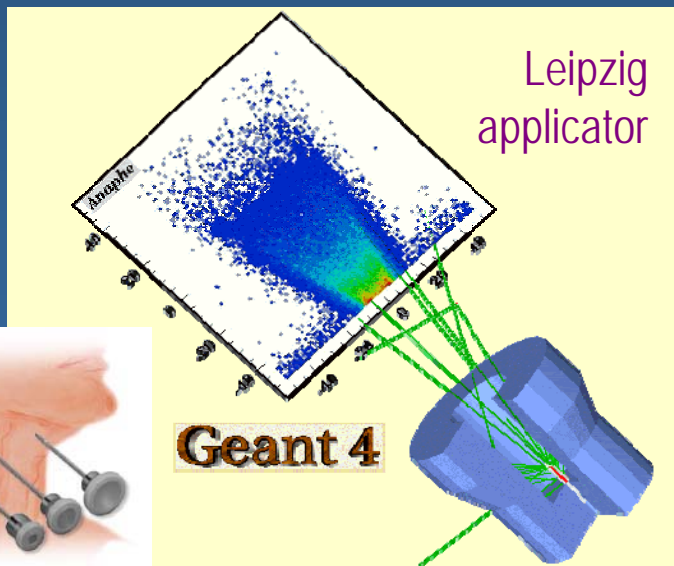


MicroSelectron-HDR source



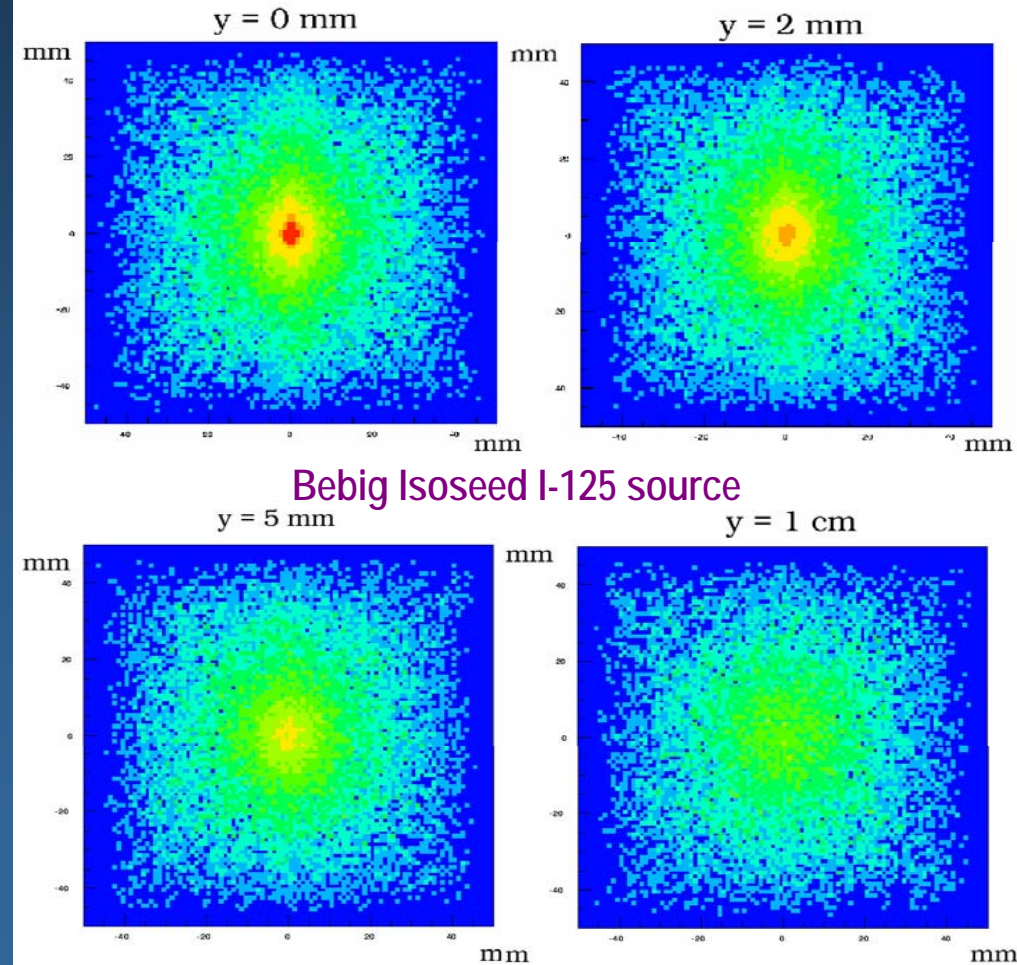
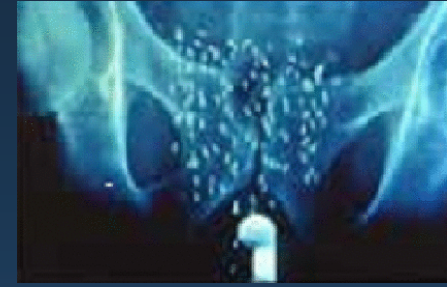
# Dosimetry

Superficial brachytherapy



# Dosimetry

Interstitial brachytherapy



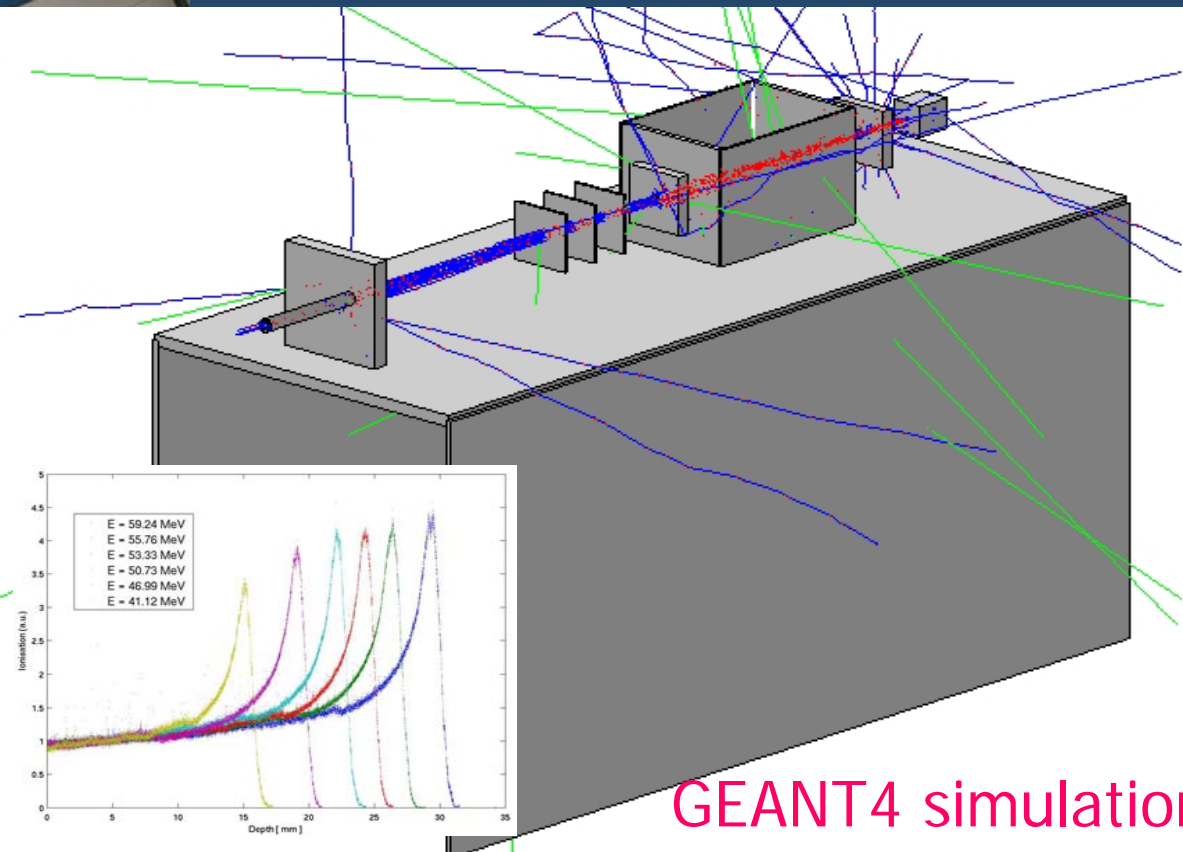
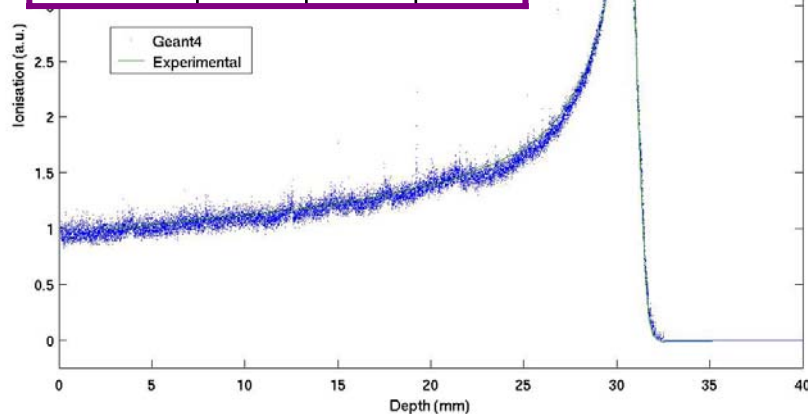




# CATANA hadrontherapy

Paper to be submitted to  
IEEE Trans. Nucl. Sci., Dec. 2006

	p-value		
	CvM	KS	AD
Left branch	0.977		
Right branch		0.985	
Whole curve			0.994

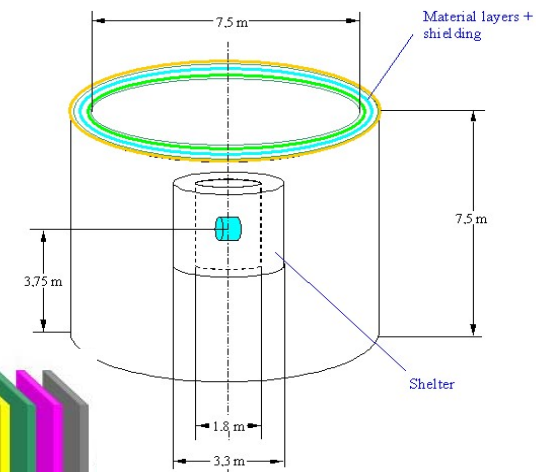


GEANT4 simulation

# Dosimetry in interplanetary missions



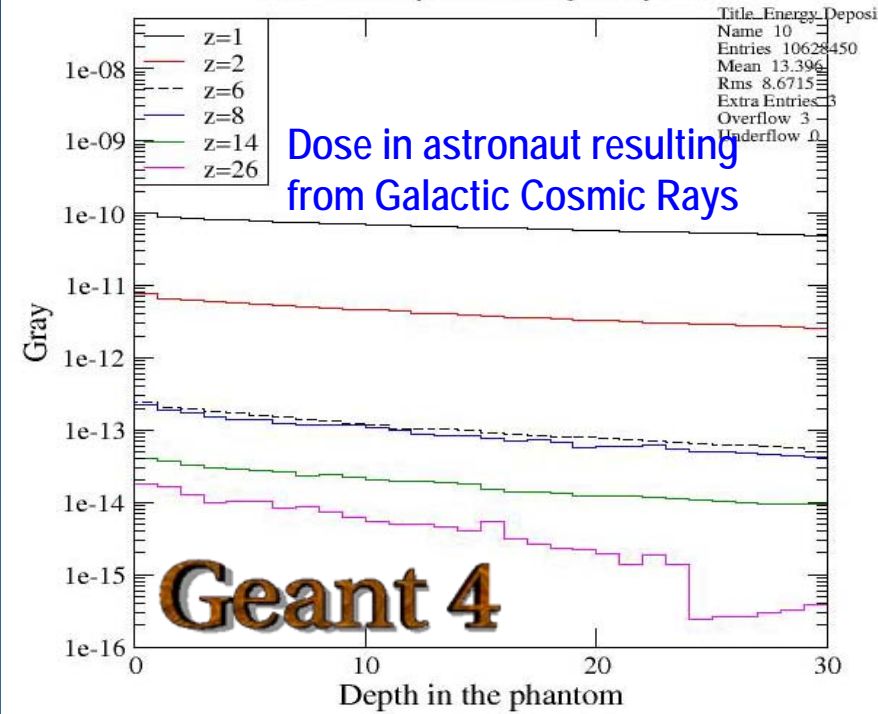
Aurora Programme



vehicle concept

Dose in the phantom

GCR - EM Physics - 10 cm polyethylene



Maria Grazia Pia, INFN Genova

Cosmic rays,  
jovian electrons

# Solar system explorations

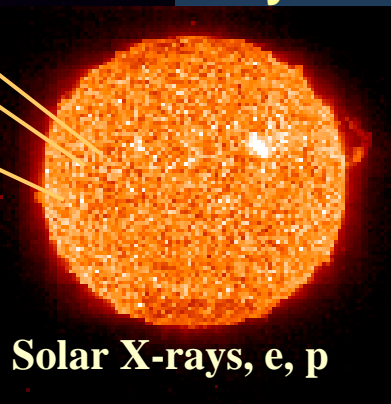
Study of the elemental composition of planets, asteroids and moons → clues to solar system formation

## X-ray fluorescence

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

## PIXE

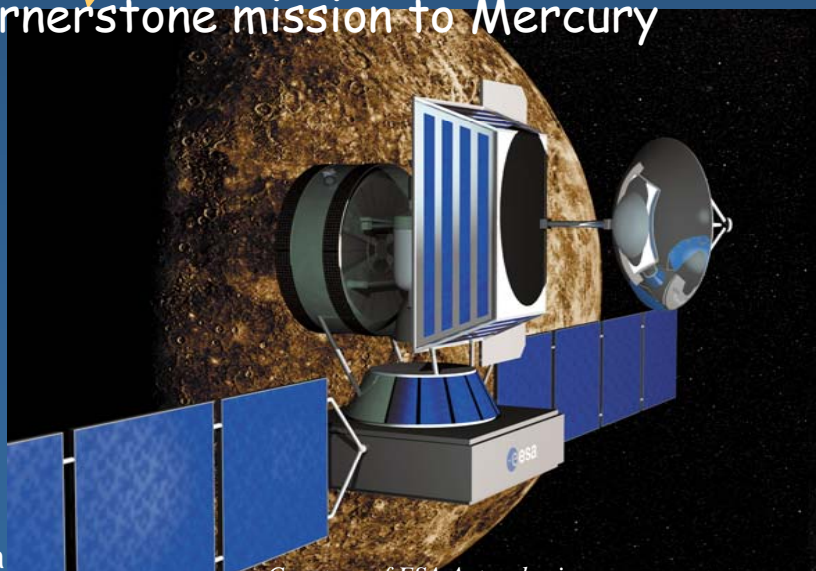
Significant only during particle events, during which it can exceed XRF



Solar X-rays, e, p

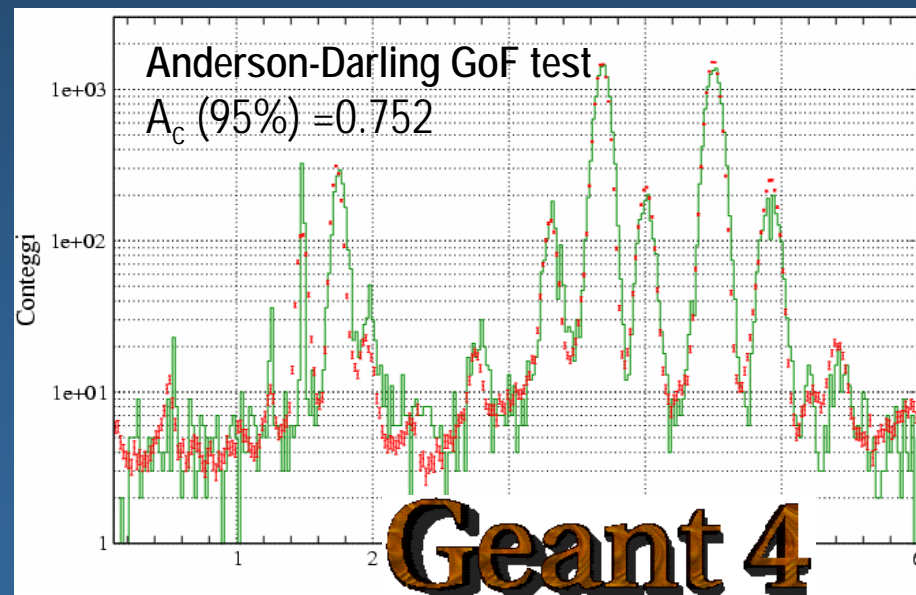
Courtesy SOHO EIT

BepiColombo  
ESA cornerstone mission to Mercury



Maria

Courtesy of ESA Astrophysics



Fluorescence spectrum from Hawaiian basalt:  
experimental data and simulation



DEFENCE



DÉFENSE

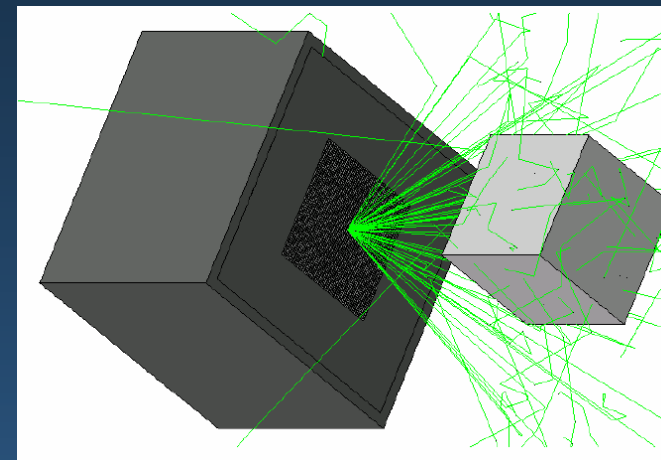
## Detection of Landmines using Radiation Based Techniques

Geant4 User's Workshop, SLAC 2002 02 21

Dr Anthony A. Faust

Threat Detection Group

Defence Research Establishment Suffield

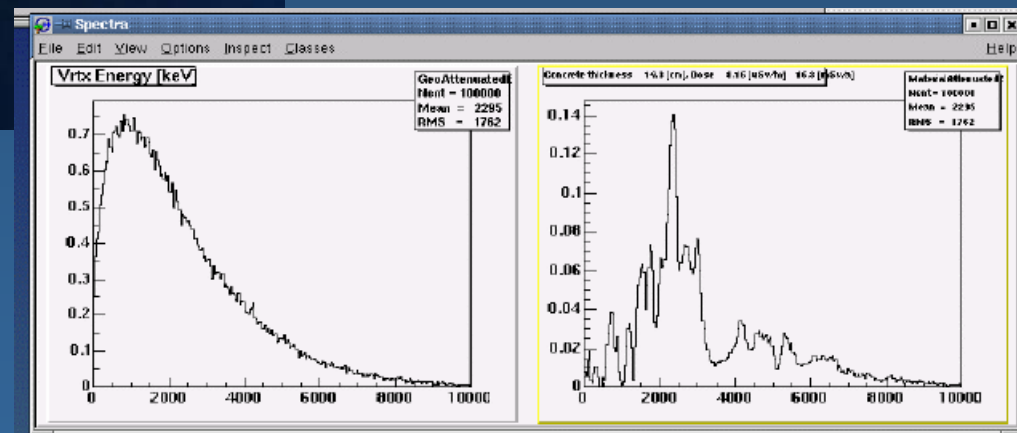


Defence R&D  
Canada

R et D pour la défense  
Canada

## X-ray Backscatter Imaging

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



Used Low Energy packages

# Polarisation

Cross section:

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

Sample Methods:

Integrating over  $\phi$

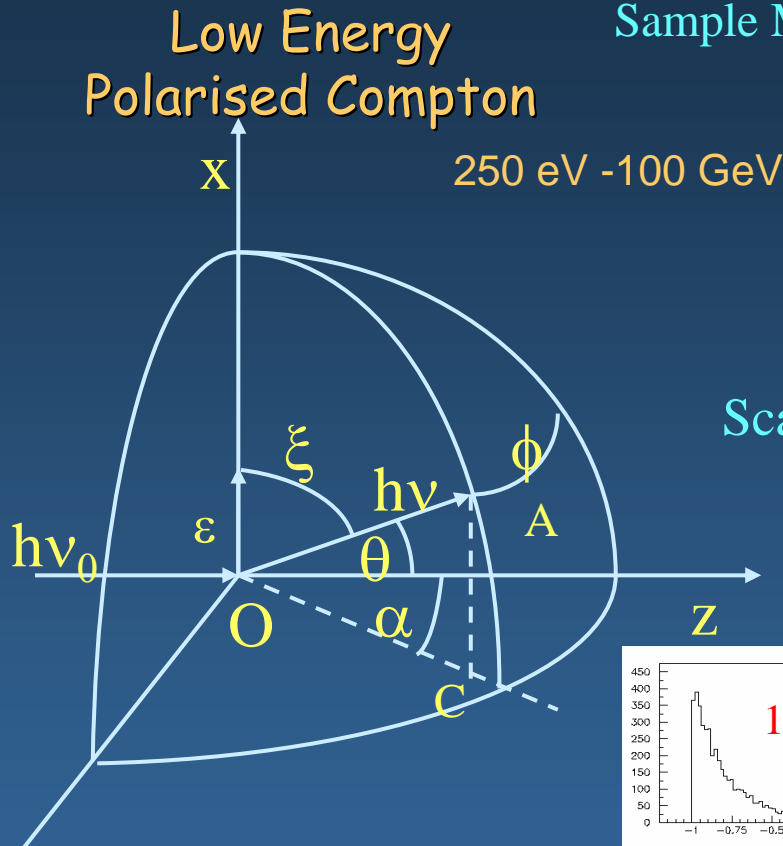
- Sample  $\theta$
- $\theta$  - Energy Relation  $\Rightarrow$  Energy
- Sample of  $\phi$  from  $P(\phi) = a(b - c \cos^2 \phi)$  distribution

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

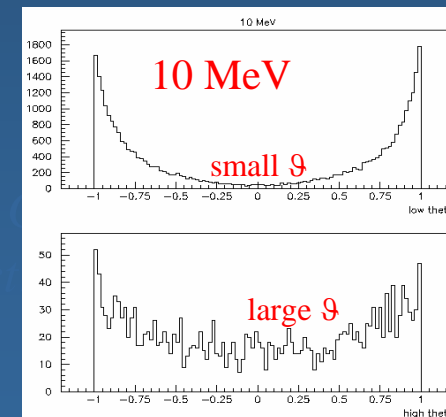
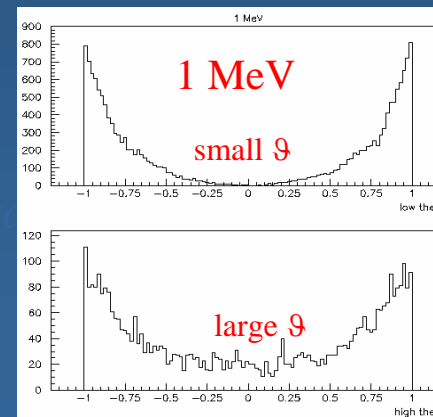
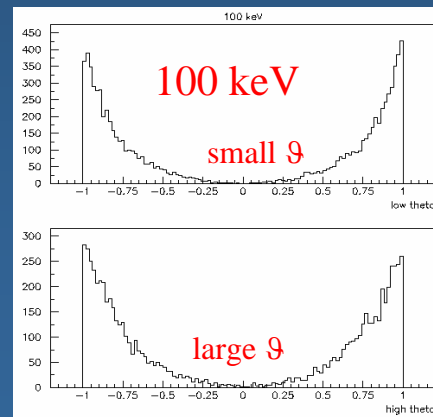
$$\overline{\varepsilon}_{\perp} = \frac{1}{N} (\cos \theta \hat{j} - \sin \theta \sin \phi \hat{k}) \sin \beta$$

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

Scattered Photon Polarization



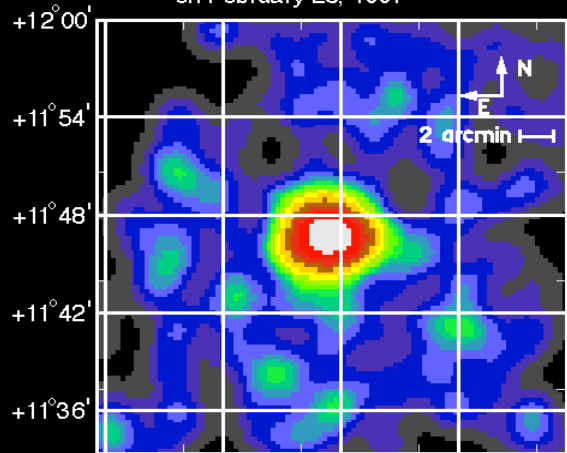
- $\theta$  Polar angle
- $\phi$  Azimuthal angle
- $\varepsilon$  Polarization vector



# $\gamma$ astrophysics

## $\gamma$ -ray bursts

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

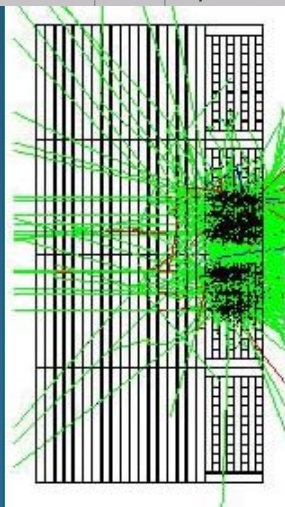
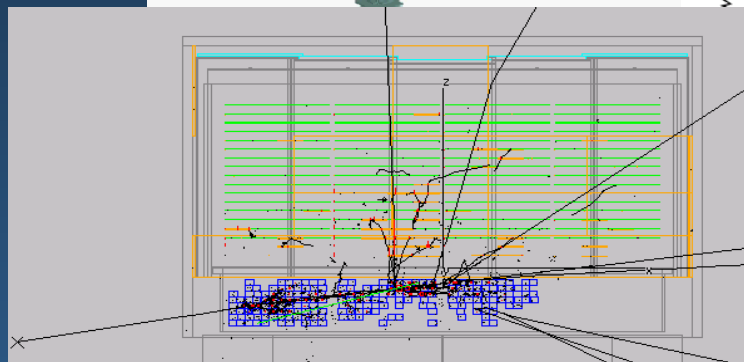
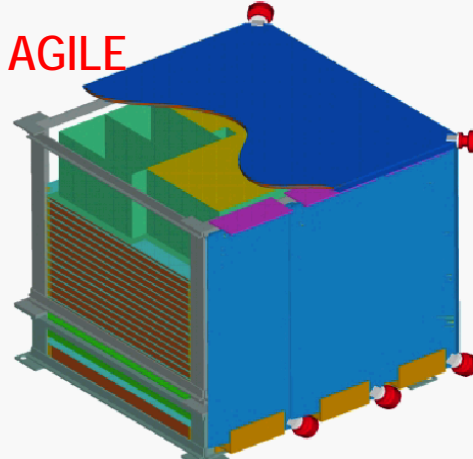


Courtesy of Fabrizio Fiore and the BeppoSAX Team

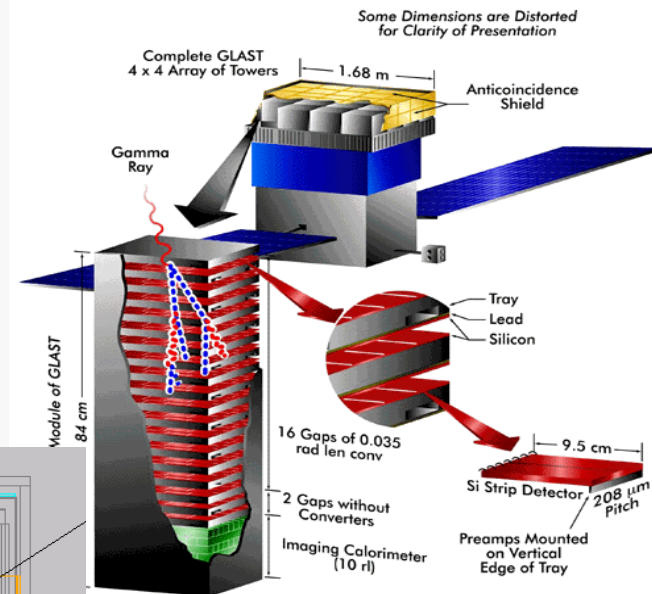
Typical telescope:  
*Tracker*  
*Calorimeter*  
*Anticoincidence*

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

AGILE



Previous  
View XZ  
View YZ  
Zoom  
Unzoom  
New Center  
Reset 3D  
Marker +  
Marker -  
Save as Gif  
View X3D



GLAST

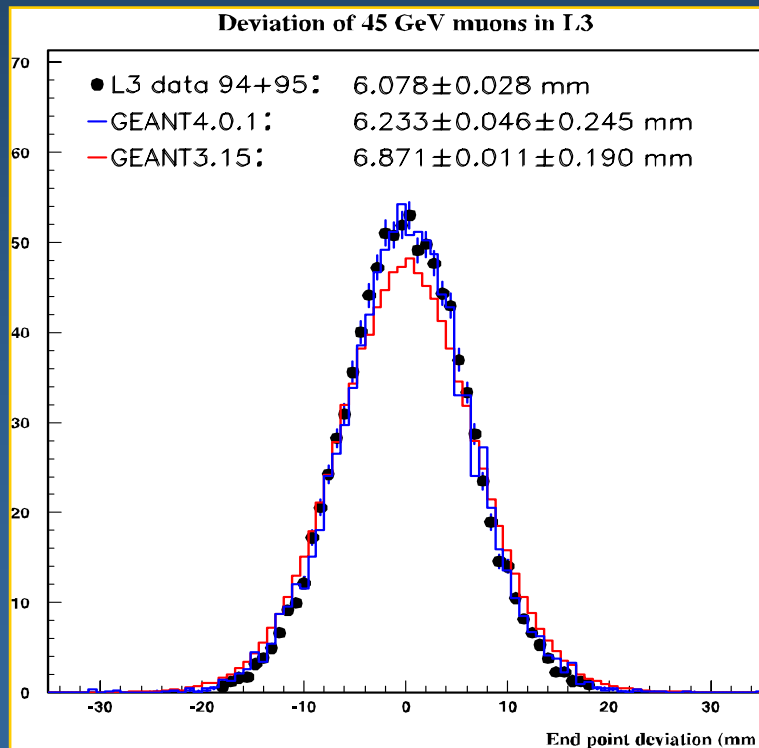
GLAST Hits Display



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

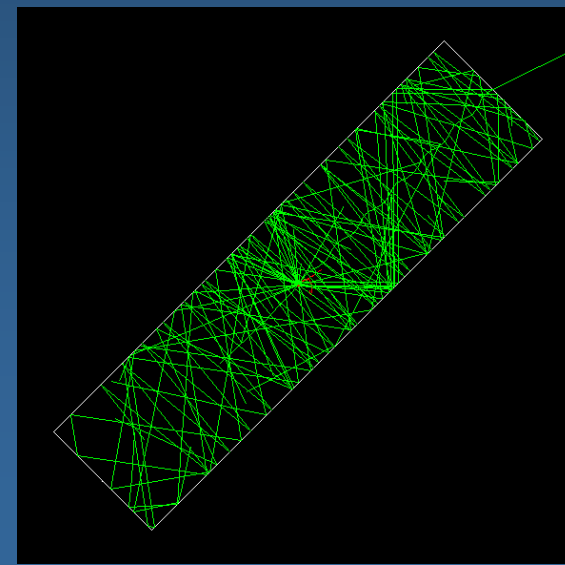
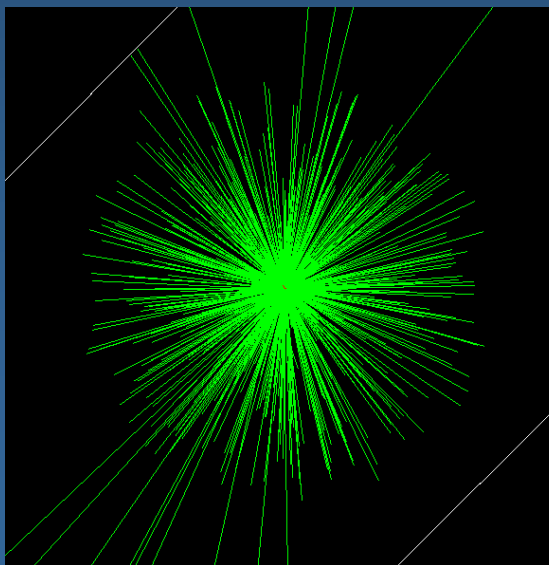
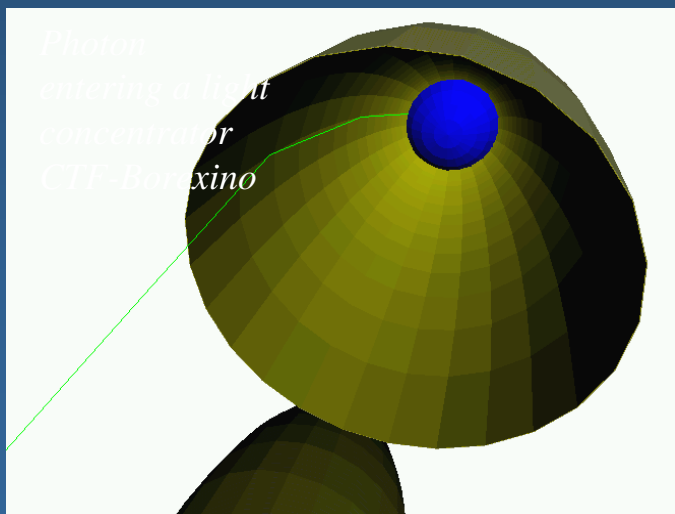
# Optical photons

*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)

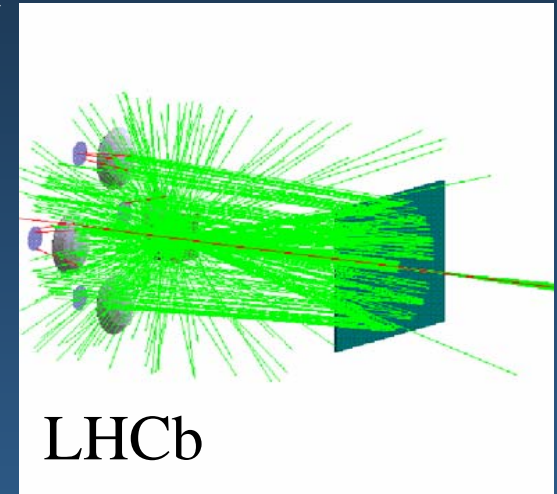
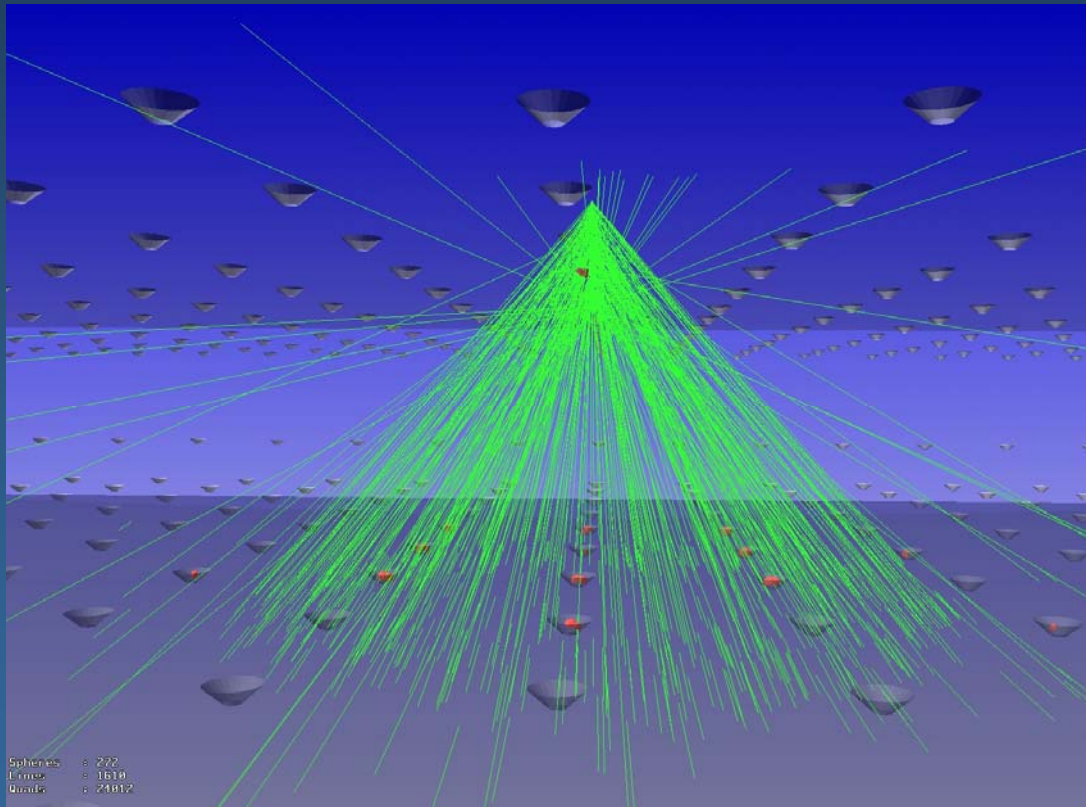
## Geant4 Optical Processes : Scintillating Cells and WLS Fibers





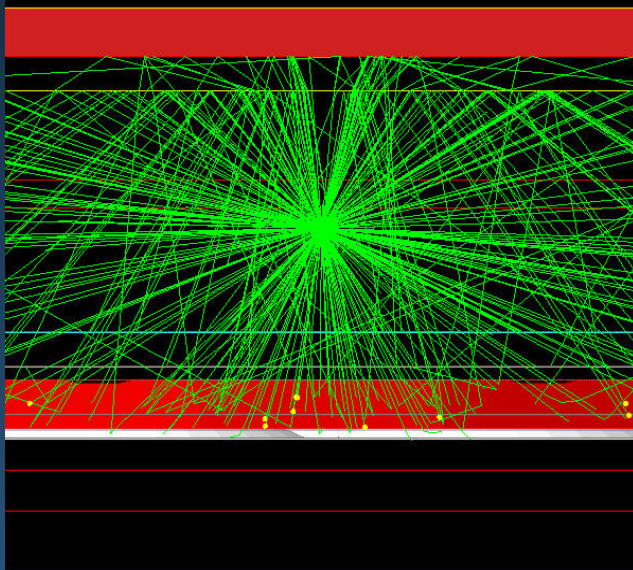
# Cherenkov

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



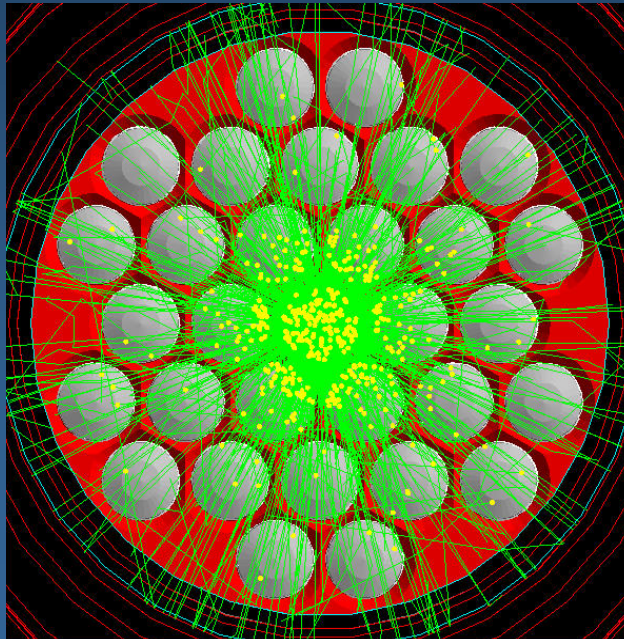
Aerogel Thickness	Yield Per Event	Cherenkov Angle mrad
4 cm DATA	$6.3 \pm 0.7$	$247.1 \pm 5.0$
MC	$7.4 \pm 0.8$	$246.8 \pm 3.1$
8 cm DATA	$9.4 \pm 1.0$	$245.4 \pm 4.8$
MC	$10.1 \pm 1.1$	$243.7 \pm 3.0$

prompt scintillation

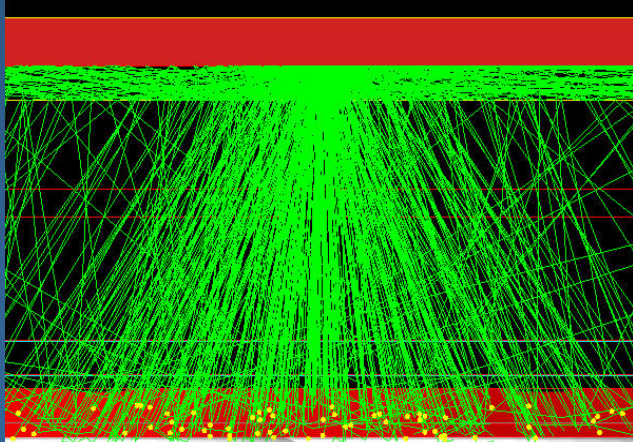


ZEPLIN III  
Dark Matter Detector

signal in PMT

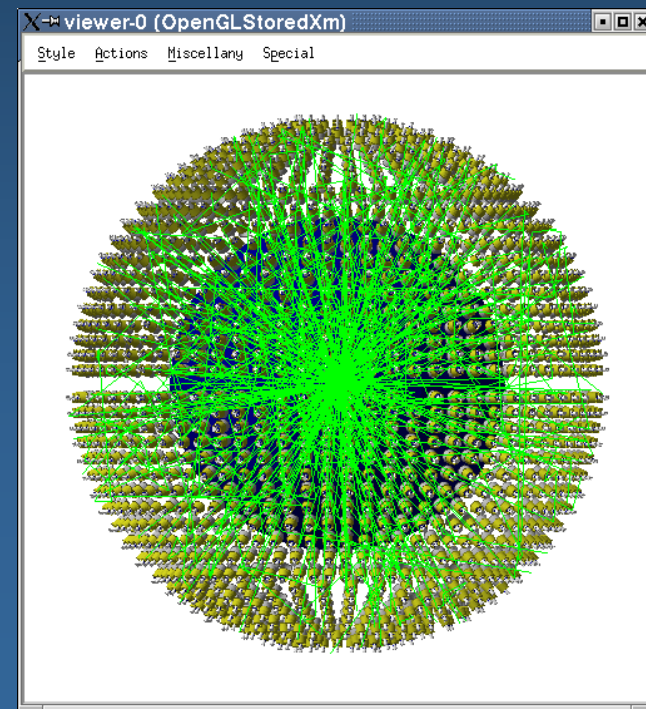


termoluminescence



# 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

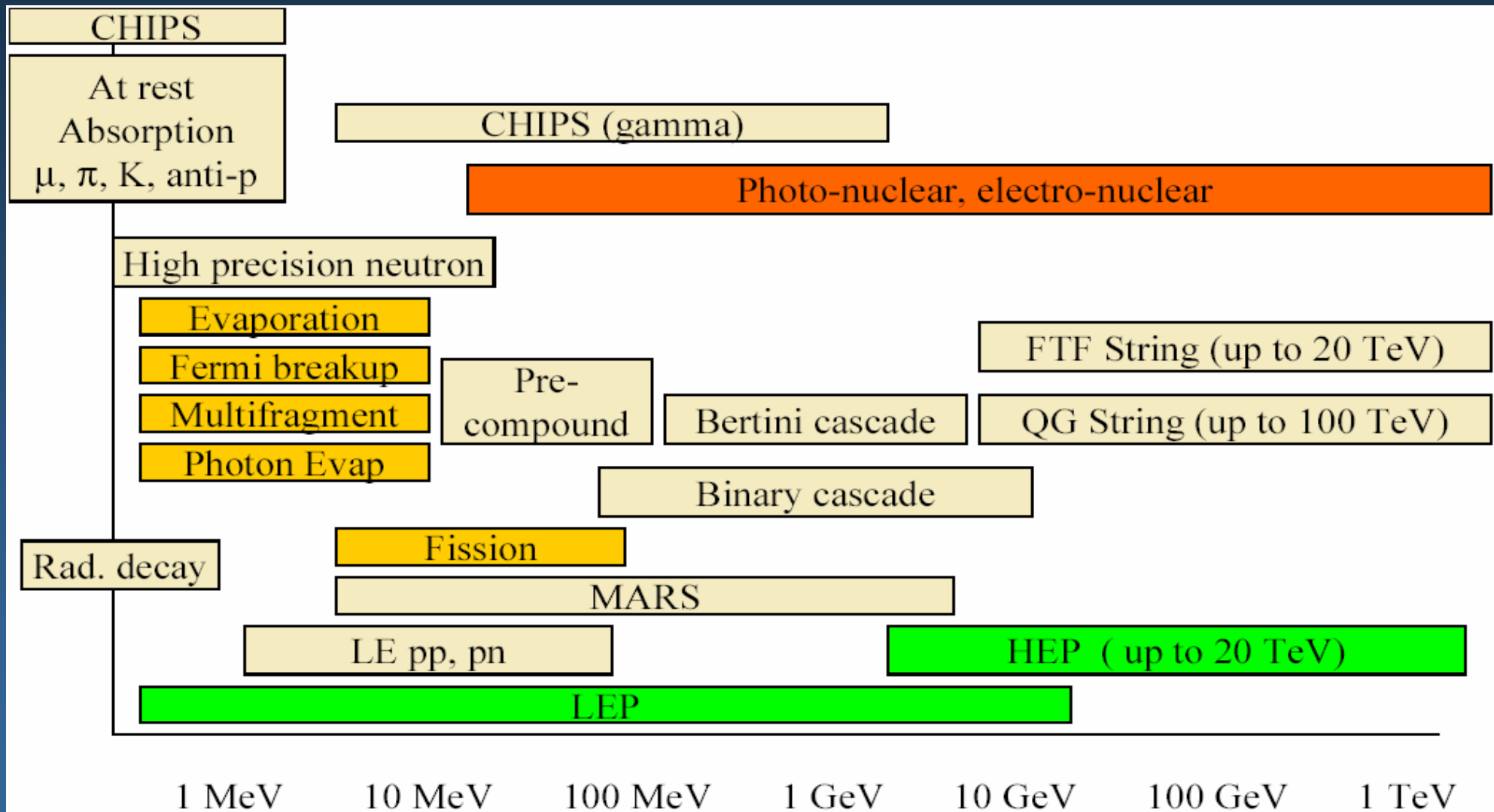
## ■ Final state calculation

- 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

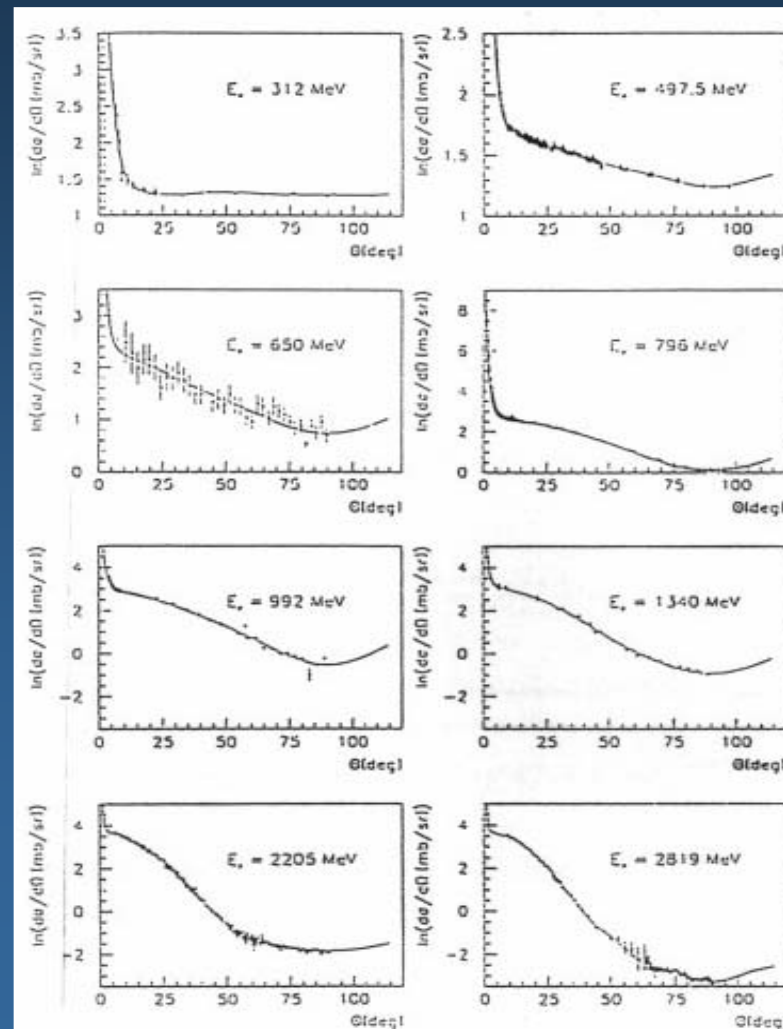
### ■ Some models originally from GHEISHA

- completely reengineered into OO design
- refined physics parameterisations

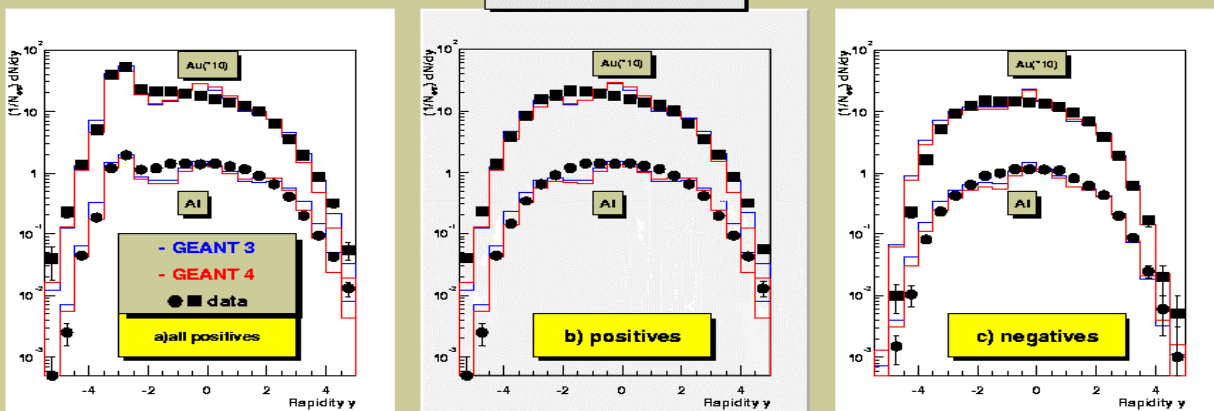
### ■ New parameterisations

- 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

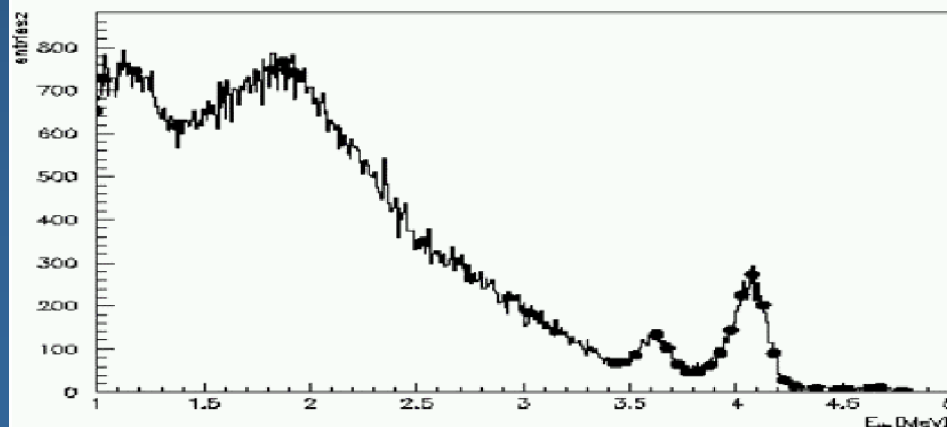
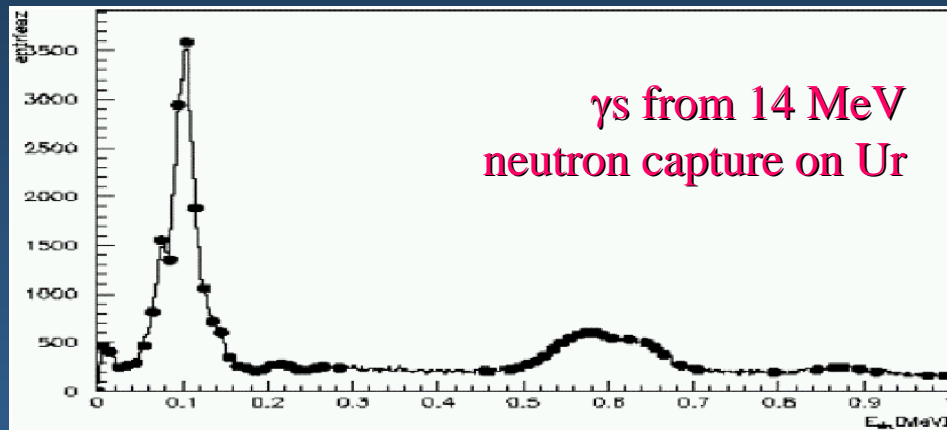




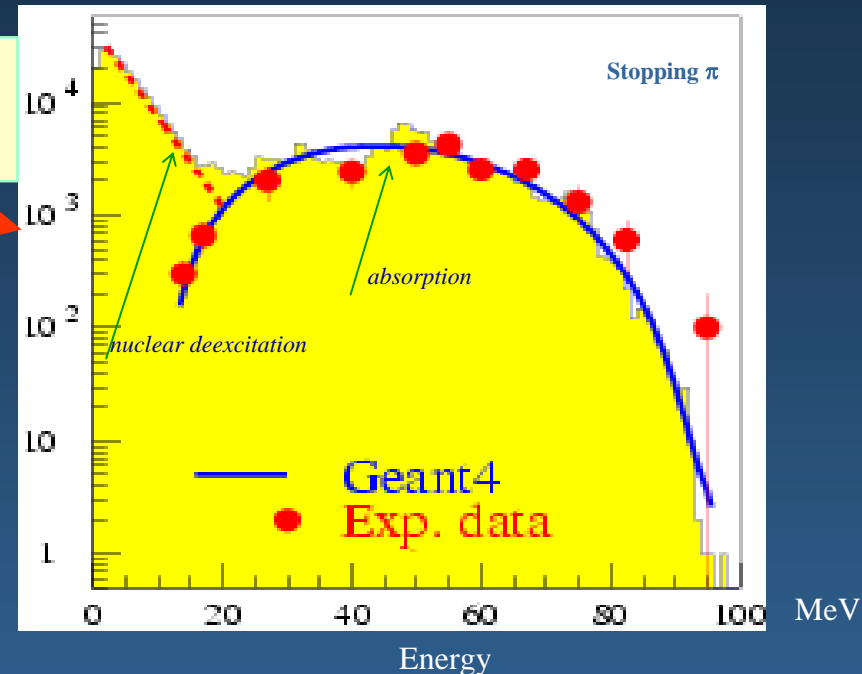
# Parameterised and data-driven hadronic models (2)

Other models are completely new, such as:

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



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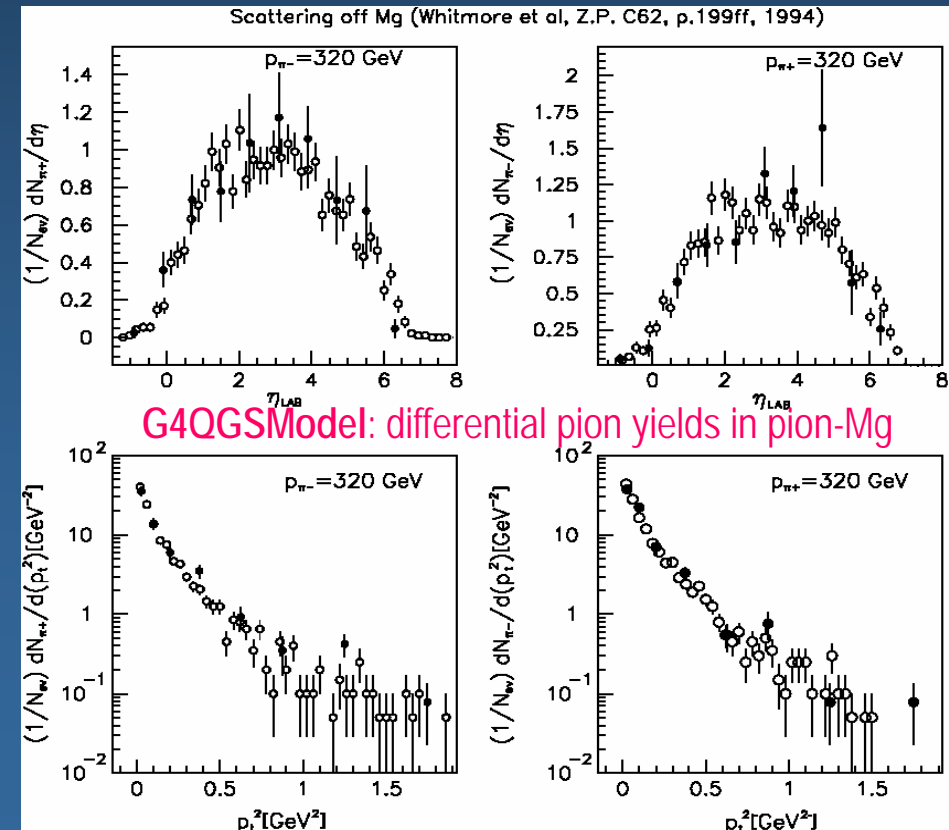
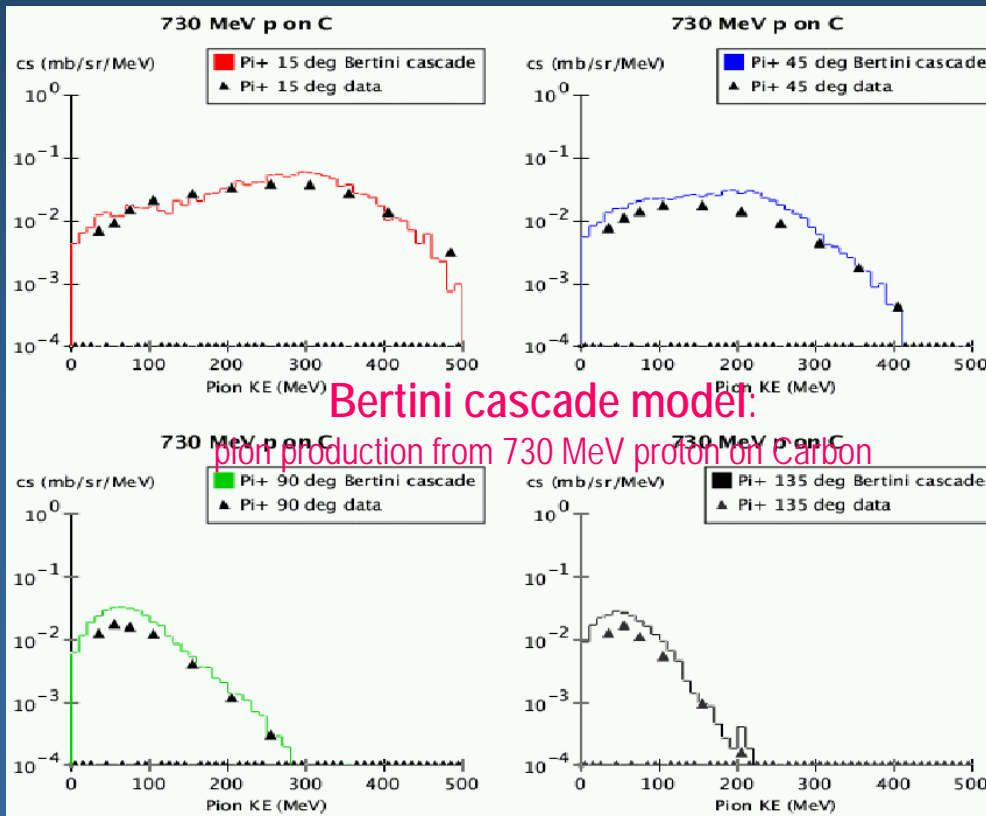


neutrons

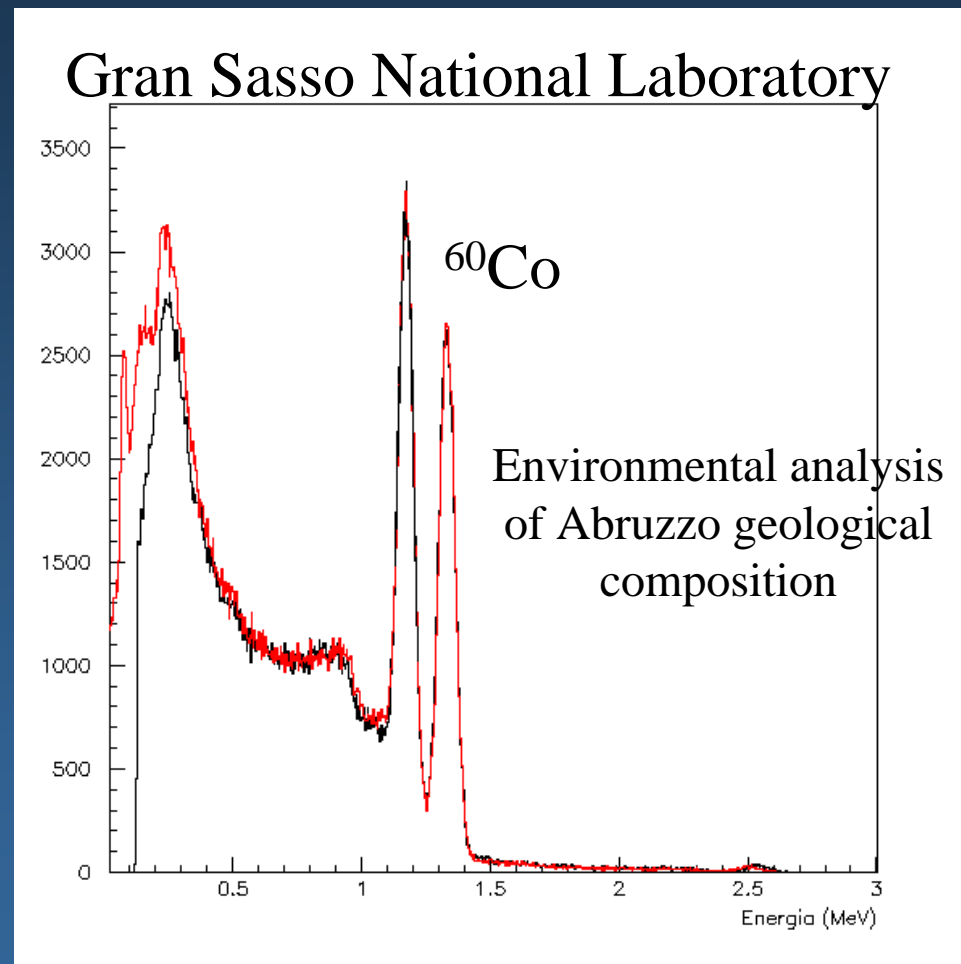
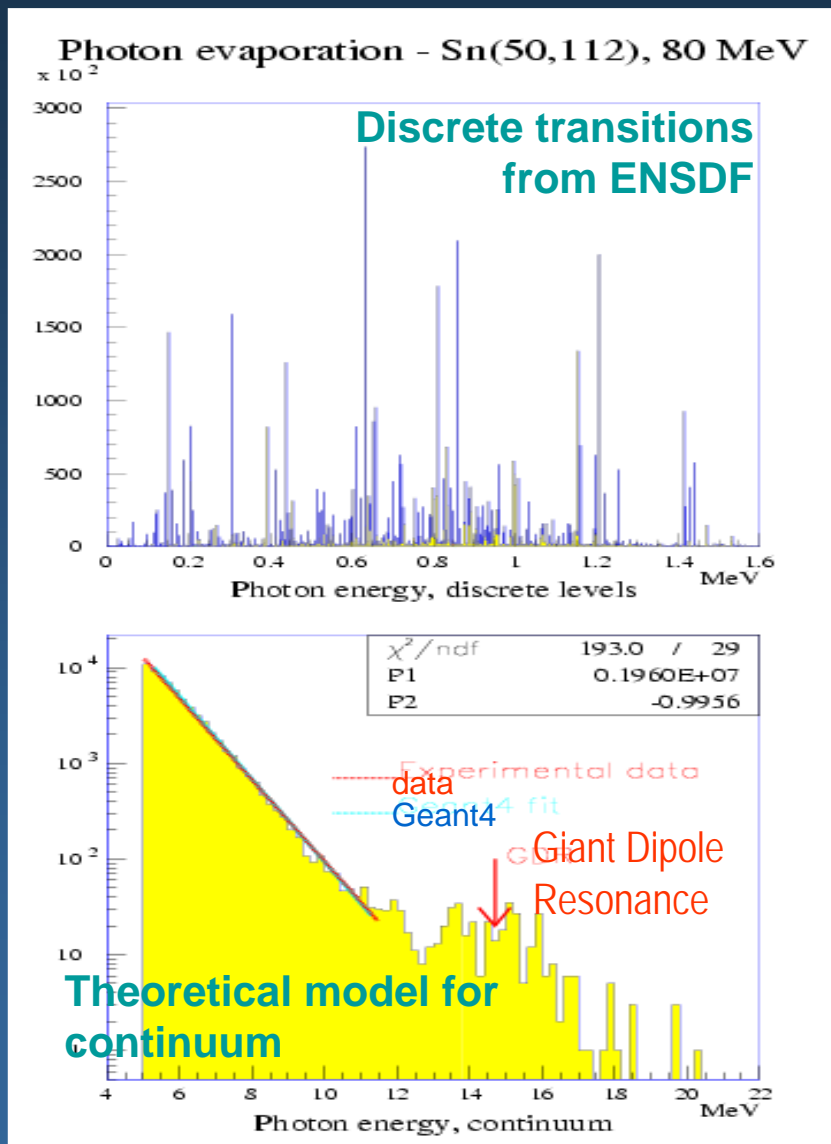
All worldwide existing databases  
used in **neutron** transport  
Brond, CENDL, EFF, ENDFB, JEF,  
JENDL, MENDL etc.

# Theory-driven models

- Complementary and alternative models
- *Evaporation phase*
- Low energy range  $O(100 \text{ MeV})$ : *pre-equilibrium*
- Intermediate energy range,  $O(100 \text{ MeV})$  to  $O(5 \text{ GeV})$ : *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 Toolkit
  - eg. GeneralParticleSource

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

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

# Interface to external tools in Geant4

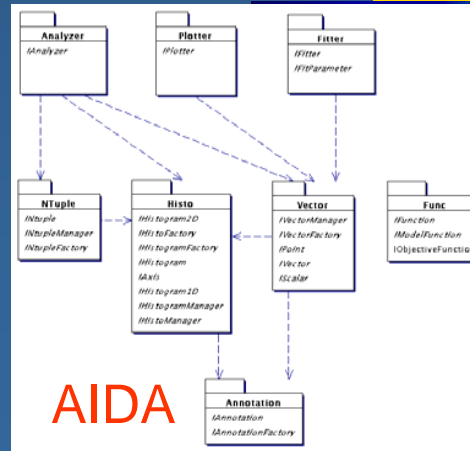
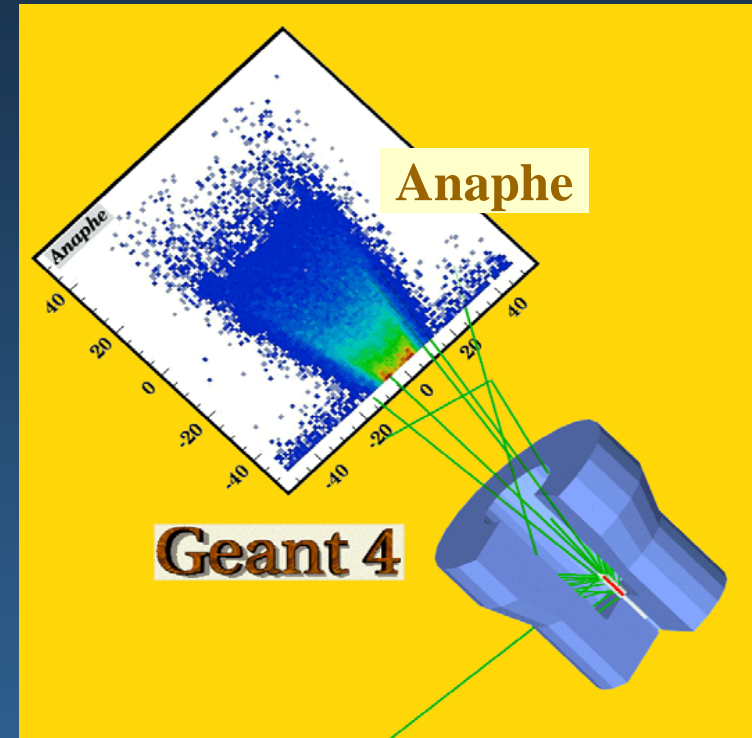
Through **abstract interfaces**

no dependence  
minimize coupling of components

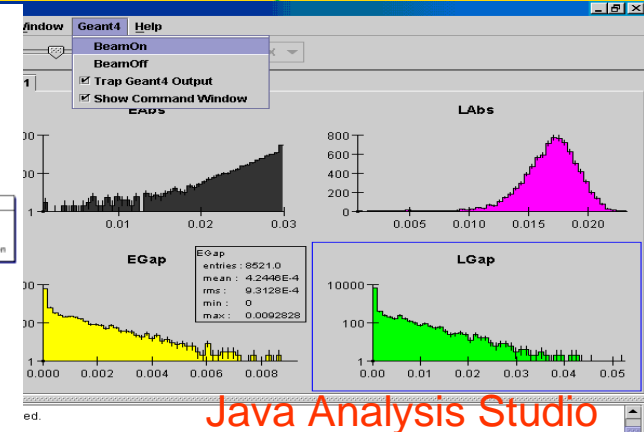
Similar approach

- Visualisation
- (G)UI
- Persistency
- Analysis

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



AIDA

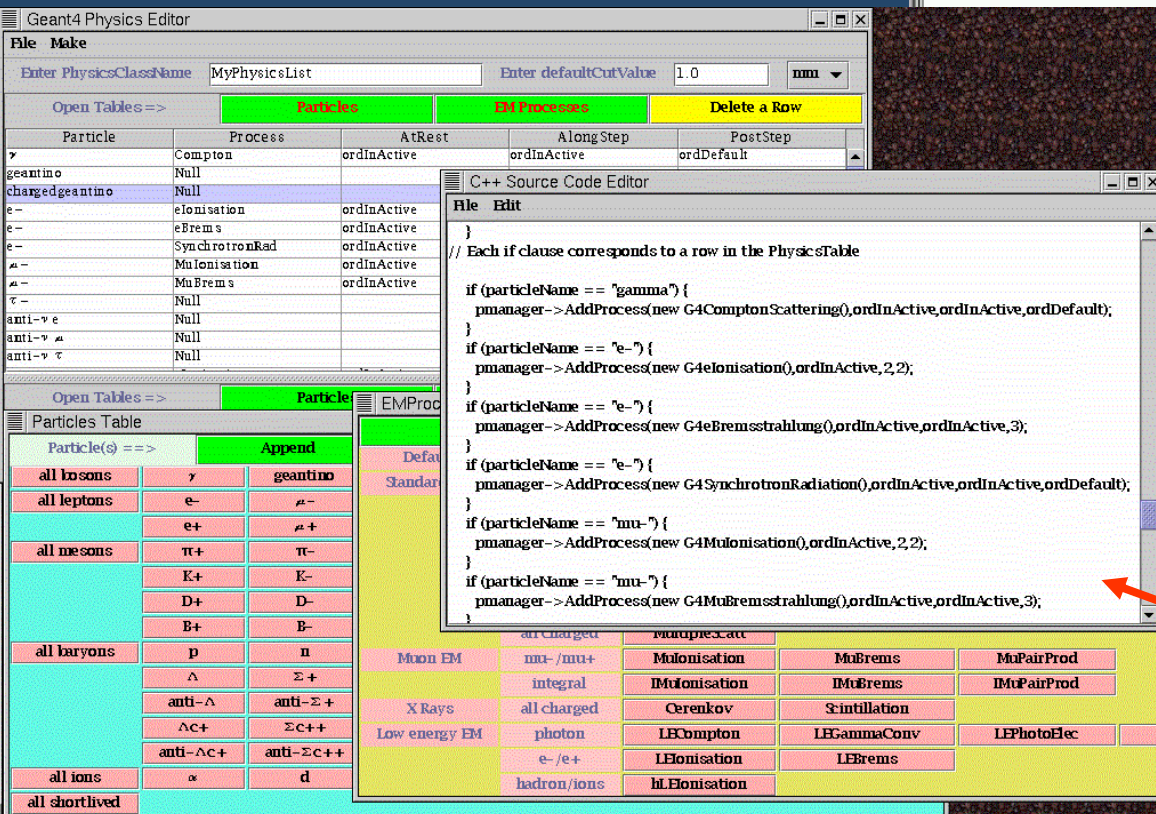
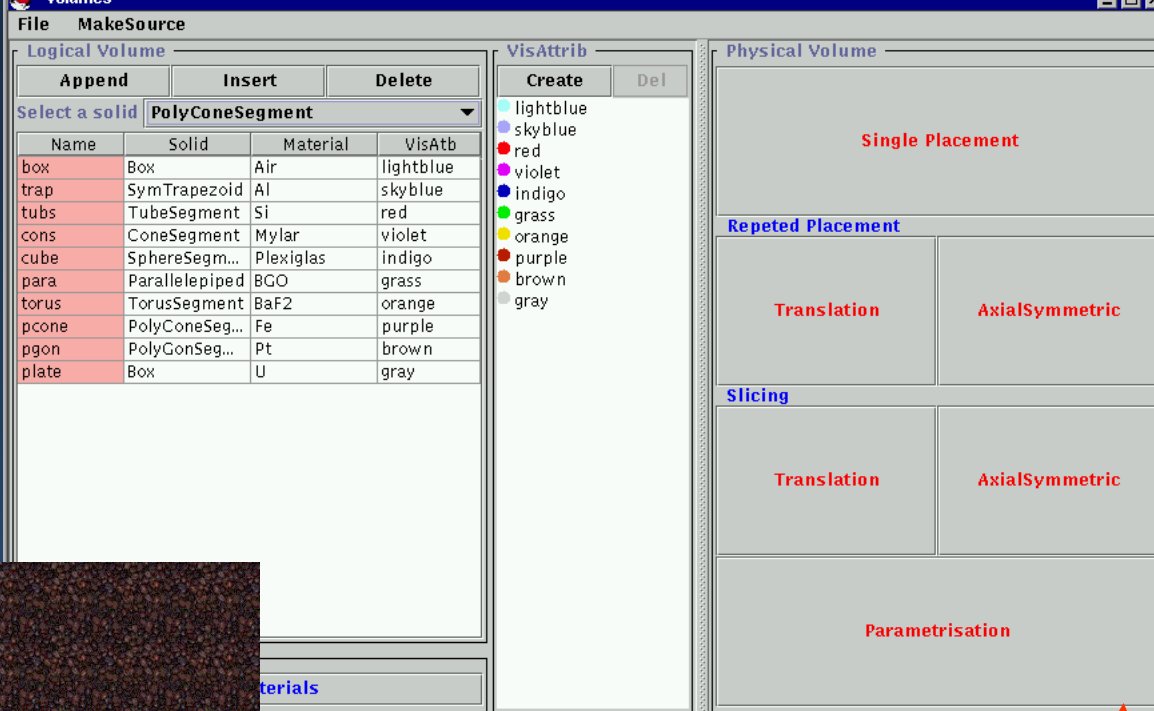


Java Analysis Studio



# 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

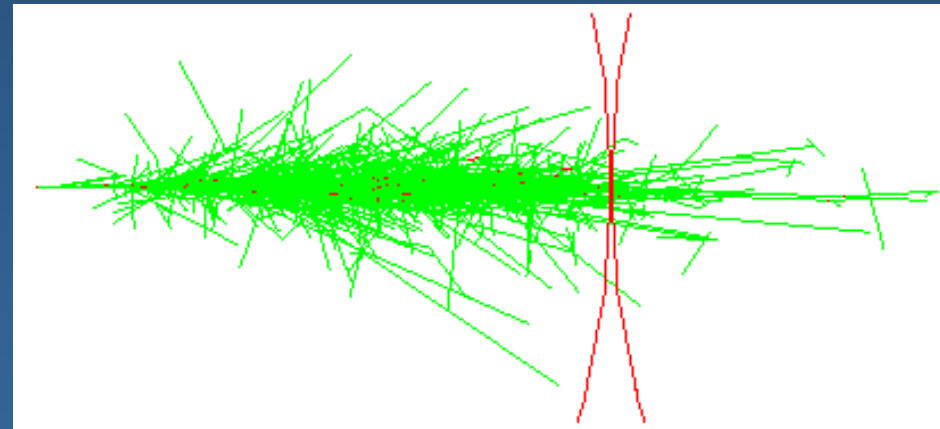
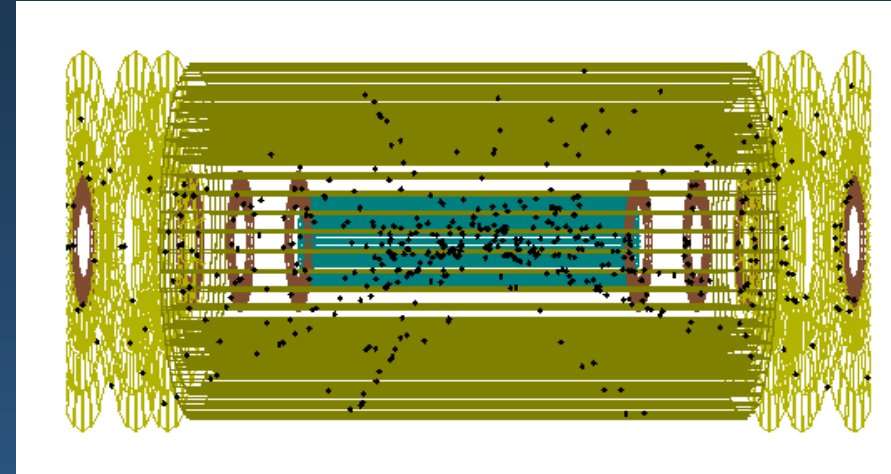
## ■ Control of several kinds of visualisation

- detector geometry
- particle trajectories
- hits in 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

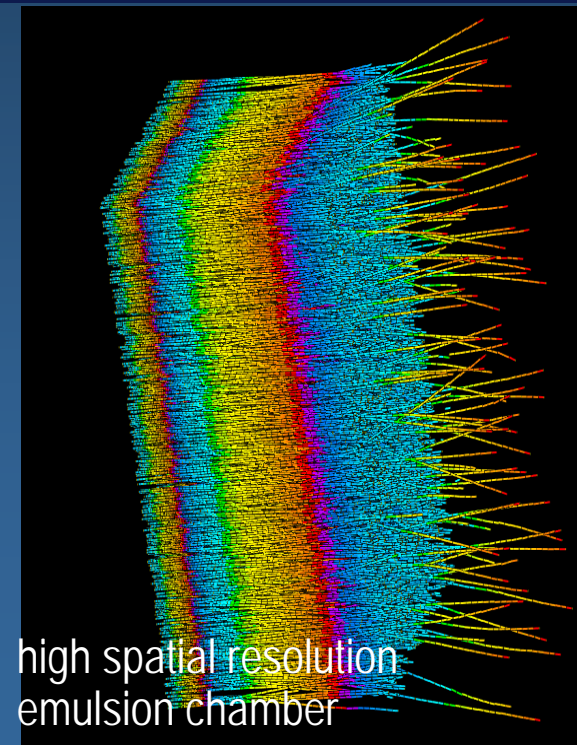
*NIRS* N. Kanematsu, M. Komori - *Nagoya* K. Niwa, T. Toshito, T. Nakamura, T. Ban, N. Naganawa, S. Takahashi - *Uchu-ken* M. Ozaki - *Kobe* S. Aoki - *Aichi* Y. Kodama - *Naruto* H. Yoshida - *Ritsumei* S. Tanaka - *SLAC* M. Asai, T. Koi - *Tokyo* N. Kokubu - *Gunma* K. Yusa - *Toho* H. Shibuya, R.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

Geant4 simulation

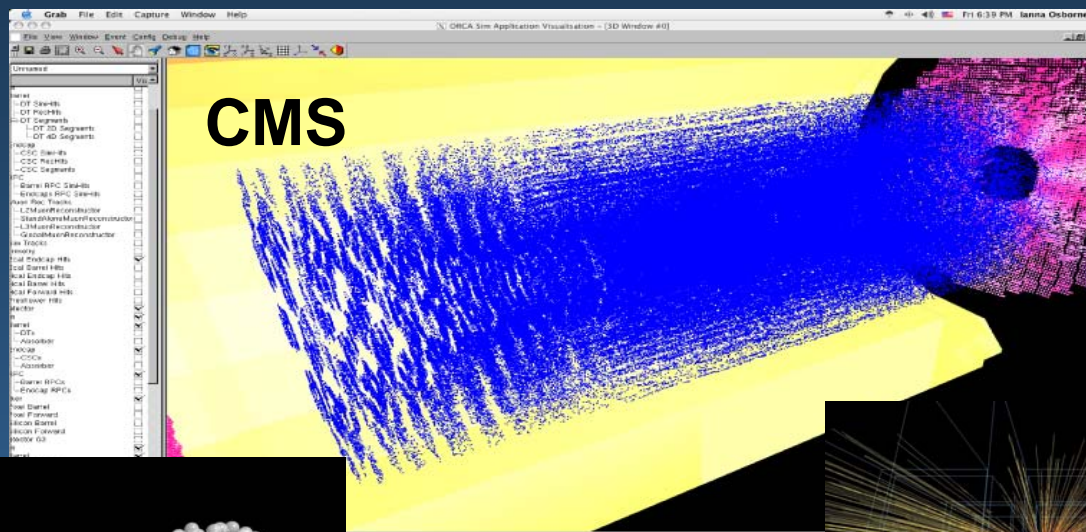
Medical  
ion beam

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

Cylinders : 14  
Cubes : 6226  
Lines : 51678



high spatial resolution  
emulsion chamber



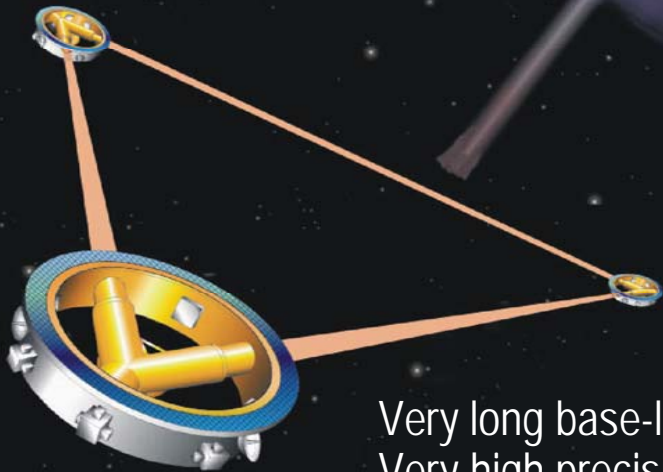
Events with > 50000  
particles/event in  
detector acceptance

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

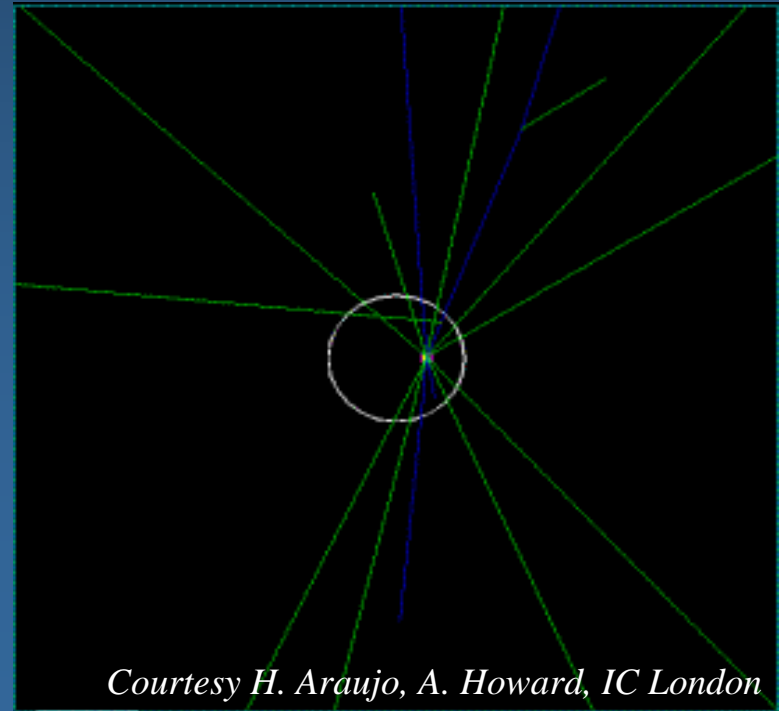
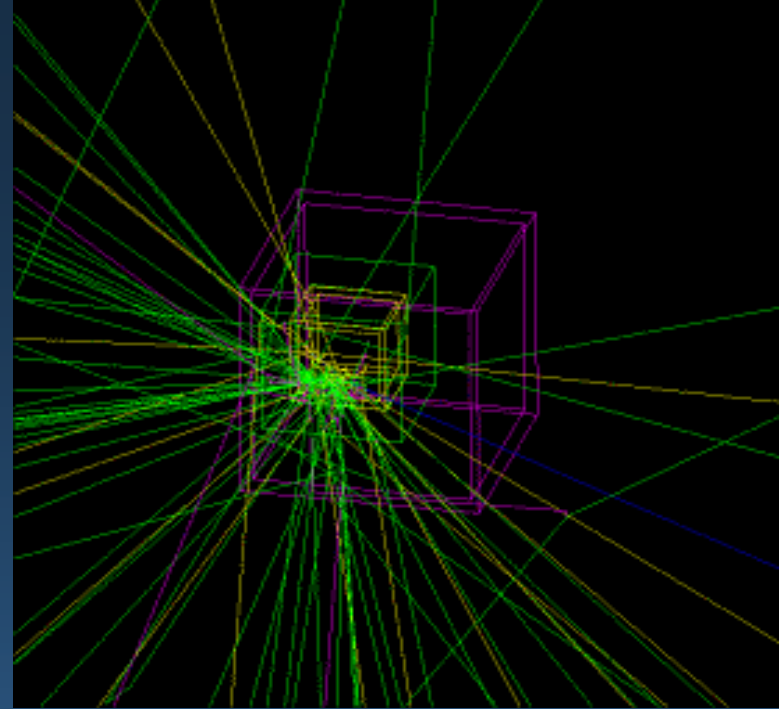


# LISA (gravitational waves)

Geant4 relevant for evaluation of space  
charging effects



Very long base-line: 1 million km  
Very high precision:  $< 1\text{ nm} - 1\text{ pm}$  (!)



# Is it worthwhile?

# Comparison with commercial radiotherapy treatment planning systems

M. C. Lopes

IPOFG-CROC Coimbra Oncological Regional Center

L. Peralta, P. Rodrigues, A. Trindade

LIP - Lisbon

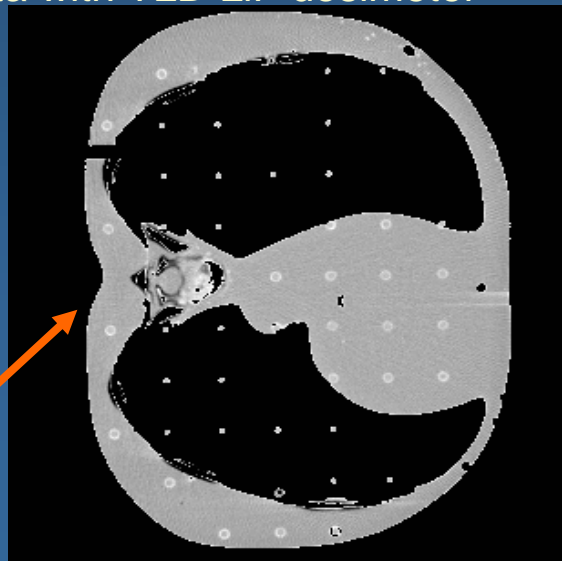
$$\chi^2/ndf \text{ (GEANT 4)} = 0.52$$

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

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

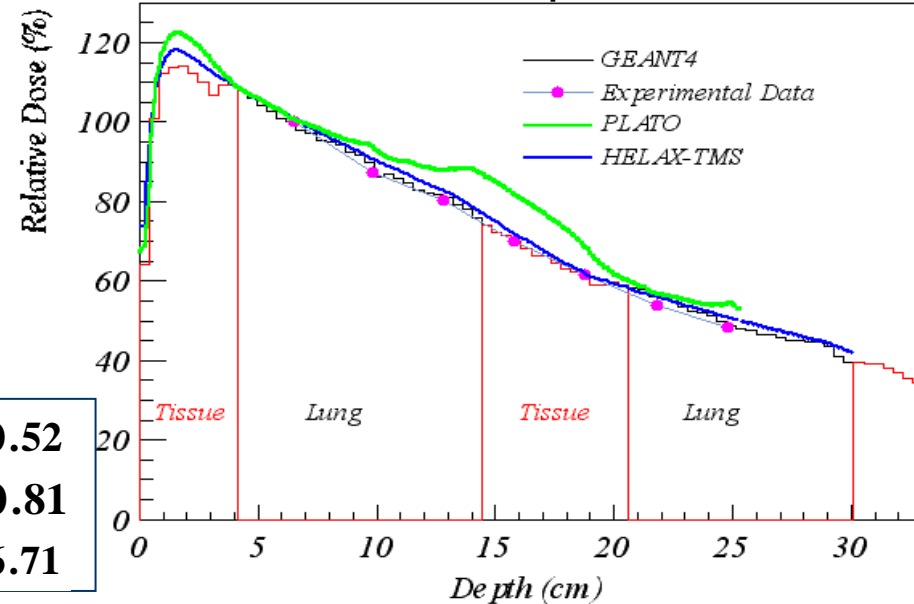
CT-simulation with a Rando phantom  
Experimental data with TLD LiF dosimeter

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

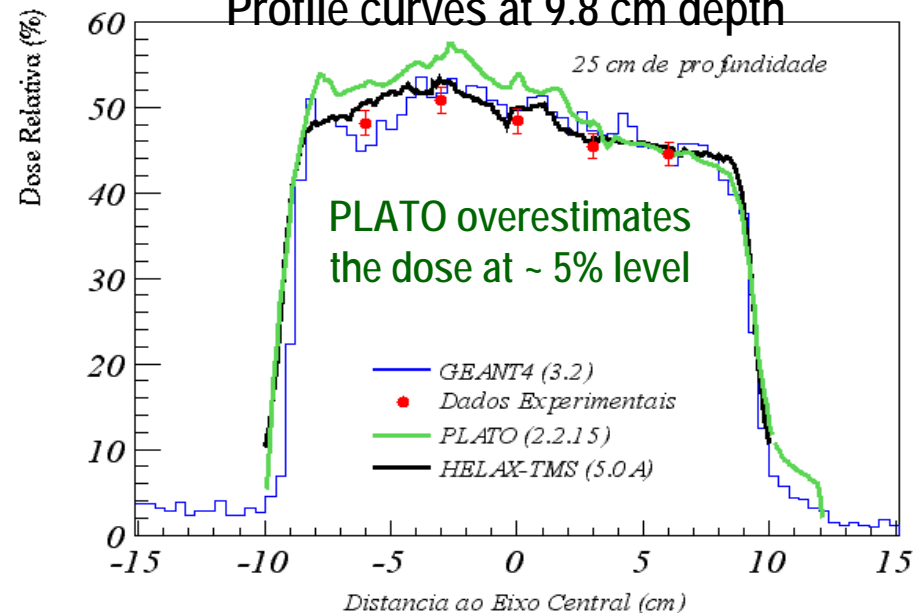


Maria Grazia Pia, INFN Genova

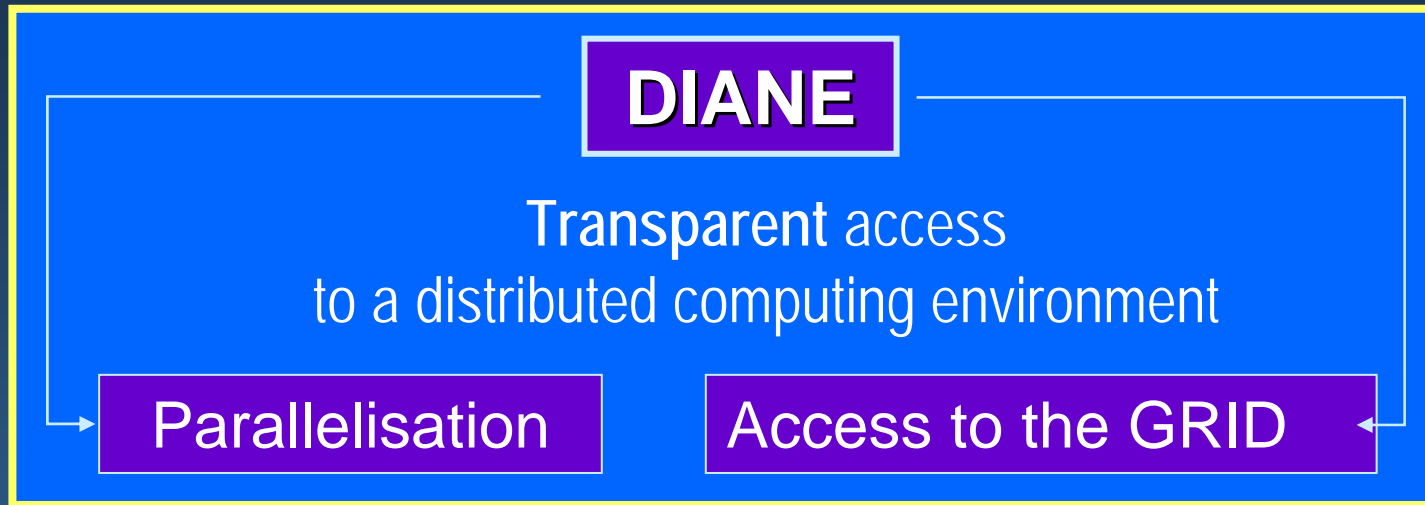
## Central-Axis depth dose



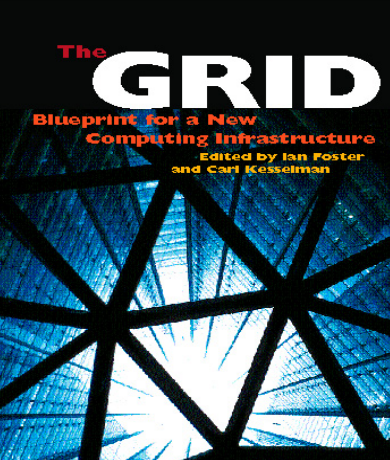
## Profile curves at 9.8 cm depth



# Access to distributed computing



- Required production of *Brachytherapy*: 20 M events
- 20 M events in sequential mode: 16646 s (~ 4h 38')  
on an Intel ® Pentium IV, 3.00 GHz
- The same simulation runs in 5' in parallel on 56 CPUs  
– appropriate for clinical usage



# Traceback from a run on CrossGrid testbed



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

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

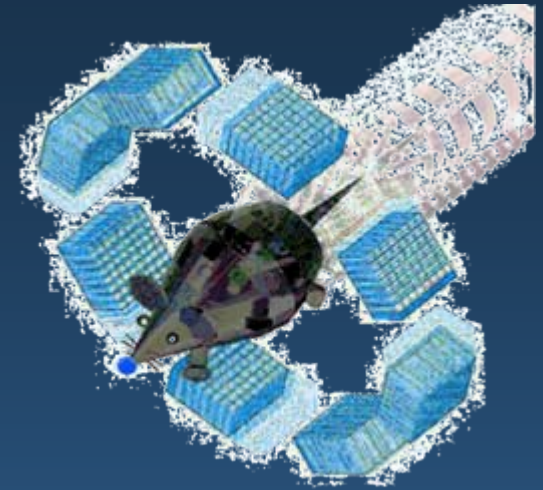
Poland

Portugal



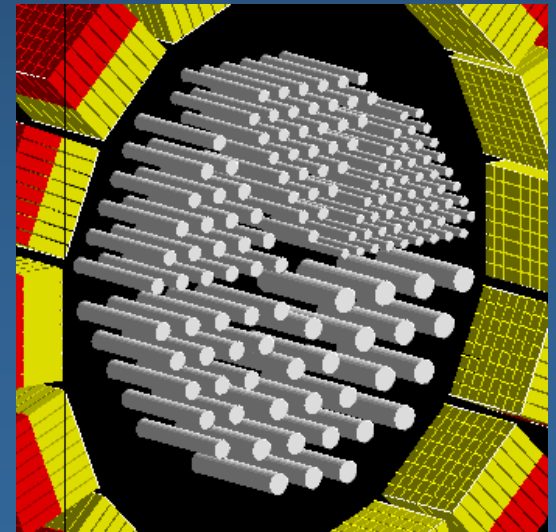
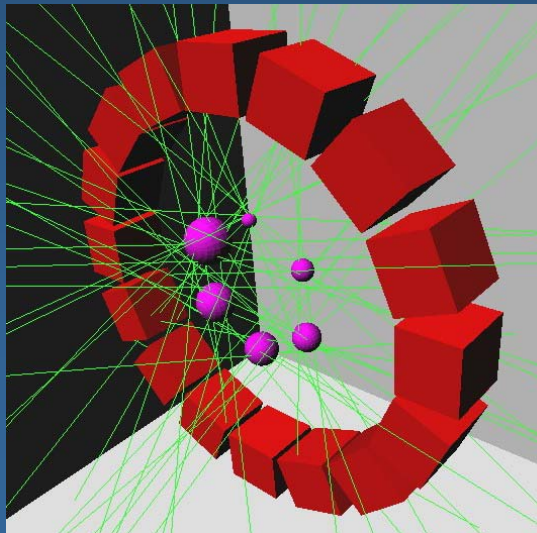
# GATE

a Geant4 based simulation  
platform,  
designed for PET and SPECT



GATE Collaboration

Recently released as  
an open source  
software system  
under GPL





## *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

# 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



Major physics laboratories:  
**CERN, KEK, SLAC, TRIUMF, TJNL**

European Space Agency:  
**ESA**

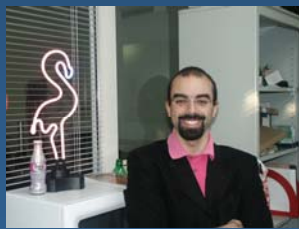
National Institutes:  
**INFN, IN2P3, PPARC**

Universities:  
**Budker Inst., Frankfurt Univ., Karolinska Inst., Helsinki Univ.,  
Lebedev Inst., LIP, Northeastern Univ. etc.**

*21-121 members in the RD44 phase, ~ 60 currently*







INF





# The next frontier

The power of abstract interfaces

# Geant 4 geometry: a cell

# Geant 4 process: mutagenesis

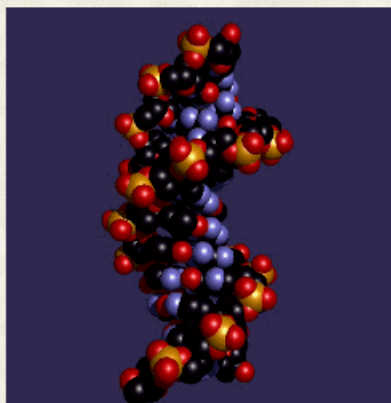


# Geant 4 DNA



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

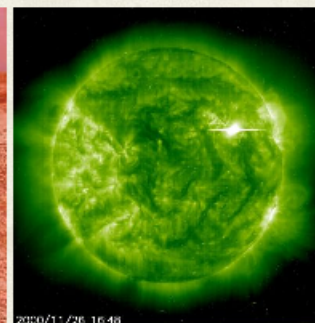


Estimating cancer risk for human exposures to space radiation is a challenge which involves a wide range of knowledge in physics, chemistry, biology and medicine.

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.



# Geant 4 for medicine

## ■ Macroscopic

- calculation of dose
- medical imaging
- already feasible with Geant4
- develop useful associated tools

## ■ Cellular level

- cell modelling
- processes for cell survival, damage etc.

## ■ DNA level

- DNA modelling
- physics processes at the eV scale
- processes for DNA strand breaking, repair etc.

Complexity of  
software, physics and biology  
addressed with an iterative and  
incremental software process



Parallel development at  
all the three levels  
(domain decomposition)

# 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

# Meditations...

- Software for medical physics
  - R&D vs usage in a clinical environment
  - requirements engineering

- Technological background
  - what is the technological education in Medical Physics Schools in Italy?
  - how do medical physicists keep up-to-date in a fast evolving computing environment?
  - software technology course in Medical Physics School in Genova suppressed after 1<sup>st</sup> year!

- Geant4 usage for medical applications in Italy
  - Bari, Cagliari, Catania, Cosenza, Cuneo, Genova, ISS, Pisa, Torino, Trieste...
  - small community w.r.t. much larger usage in Europe, America, Australia, Japan
  - limiting factor: medical physics students not involved in Monte Carlo developments

- Geant4 Course
  - Proposal: Geant4 course at ISS in 2007?
  - Course in advanced software technology?