

Refresher Course

Geant 4

A Simulation Tool for Multi-disciplinary Applications

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

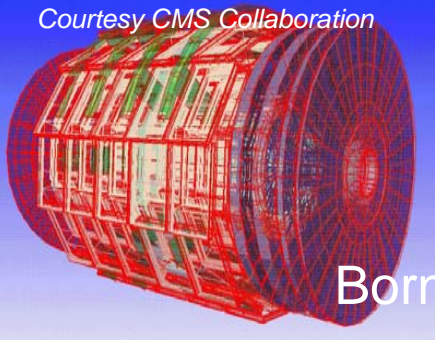
Maria Grazia Pia

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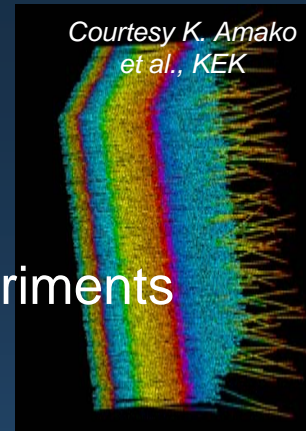
Based on the Refresher Course at IEEE NSS 2007

Courtesy CMS Collaboration



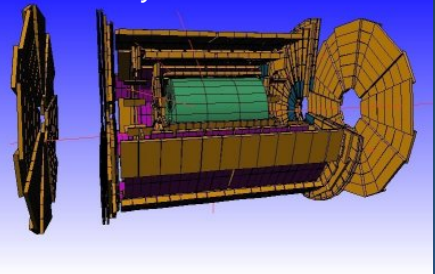
Geant 4

Born from the requirements of large scale HEP experiments



Courtesy K. Amako et al., KEK

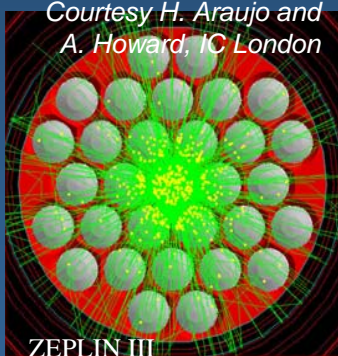
Courtesy ATLAS Collaboration



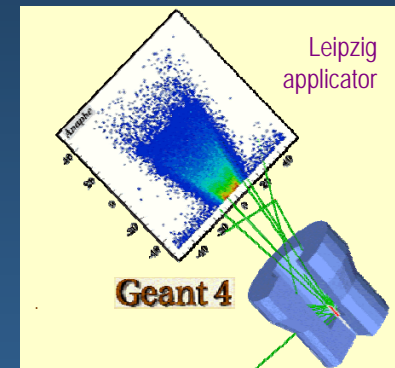
Widely used also in

- 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

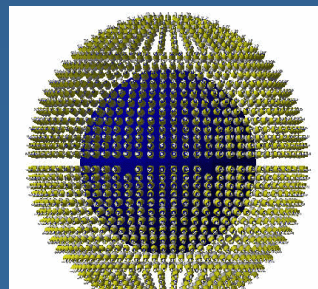


Courtesy R. Nartallo et al., ESA

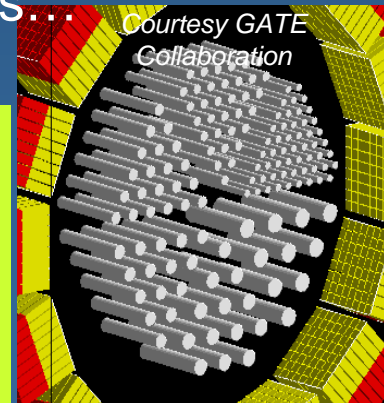
INFN Genova

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

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



Courtesy Borexino



Courtesy GATE Collaboration

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 [...].

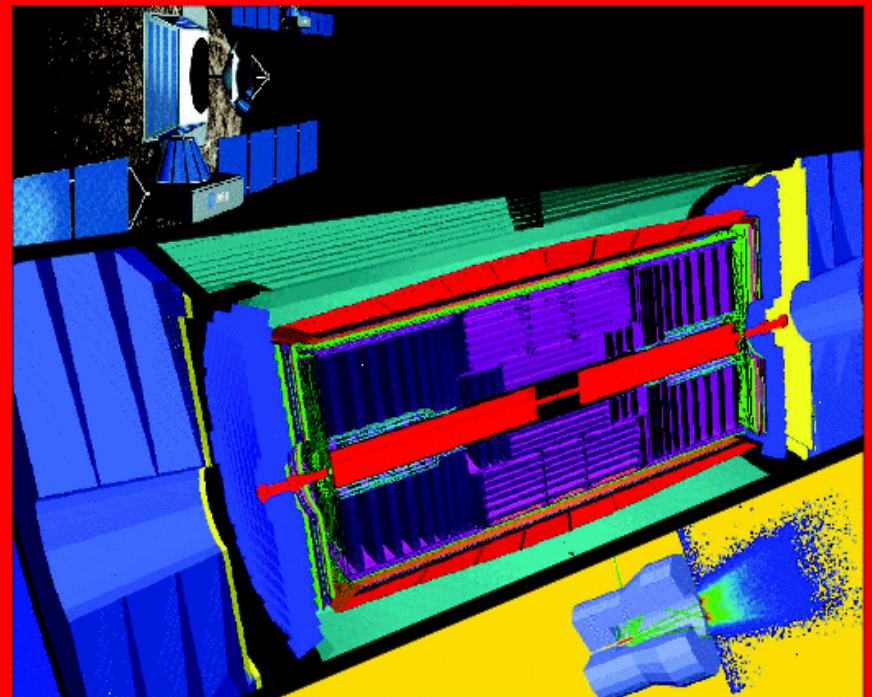
CERN Courier, June 2002

Maria Grazia Pia, *INFN Genova*

INTERNATIONAL JOURNAL OF HIGH-ENERGY PHYSICS

CERN COURIER

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

1st release: December 1998

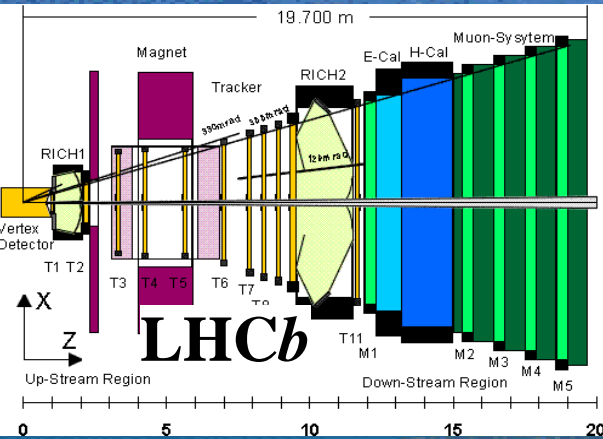
2 new releases/year since then



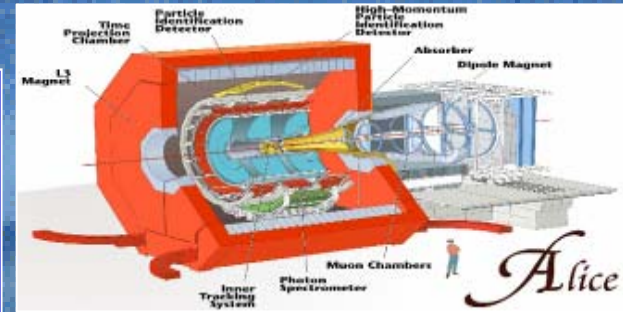
scientific...

Globalisation

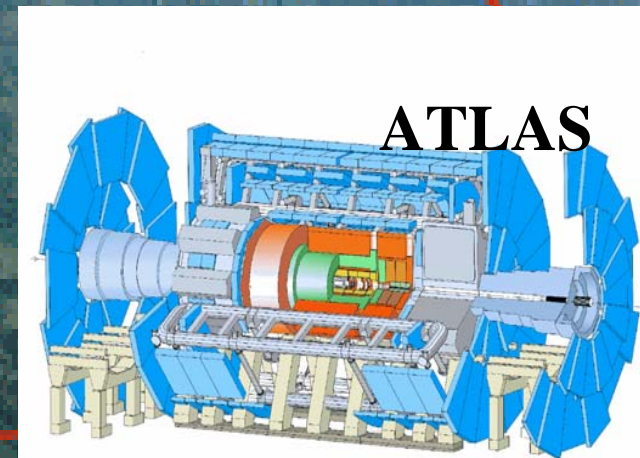
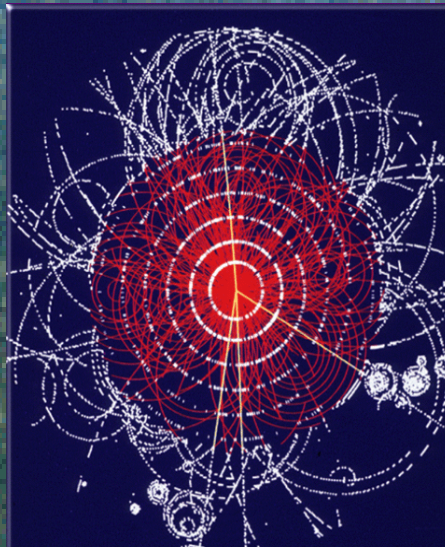
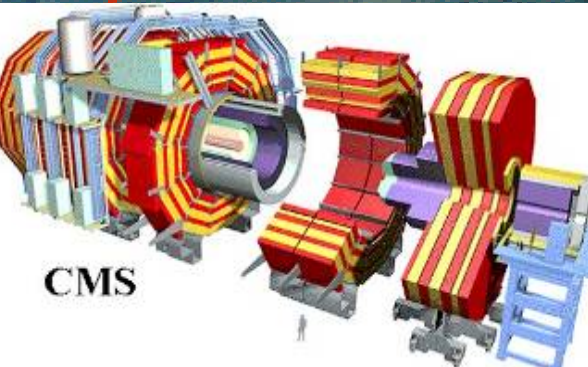
Sharing requirements and functionality
across diverse fields



Complex physics
 Complex detectors
 20 years
 software life-span



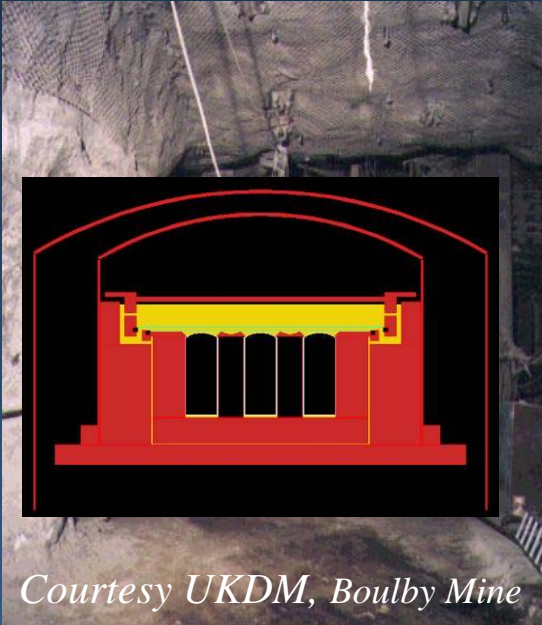
LHC



From deep underground...

...to space

Dark matter and ν experiments



X and γ astronomy,
gravitational waves,
radiation damage to
components etc.

Cosmic ray experiments

Variety of requirements from diverse applications

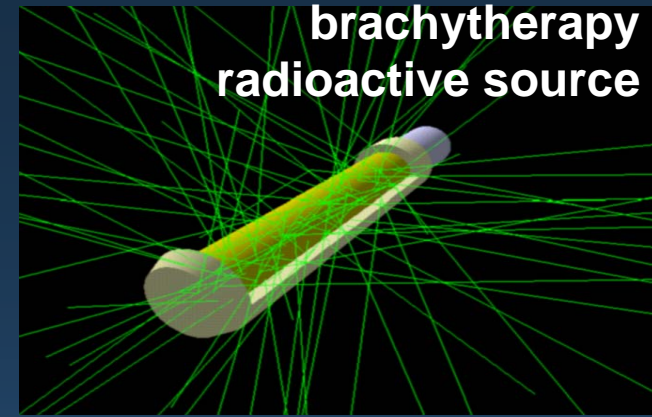
Physics
from the eV to the PeV scale

Detectors,
spacecrafts and environment

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



Medical Physics



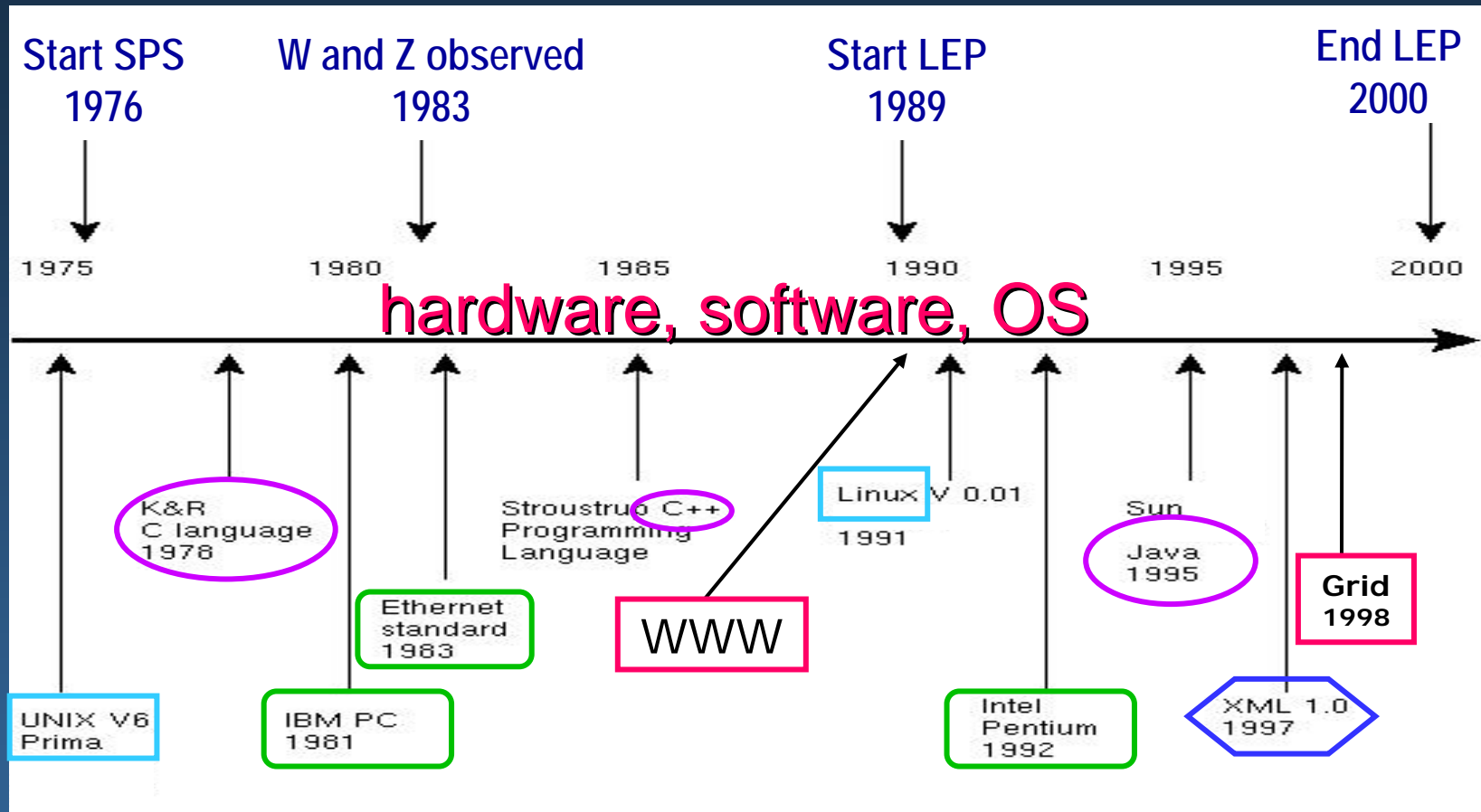
from
hospitals...

...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

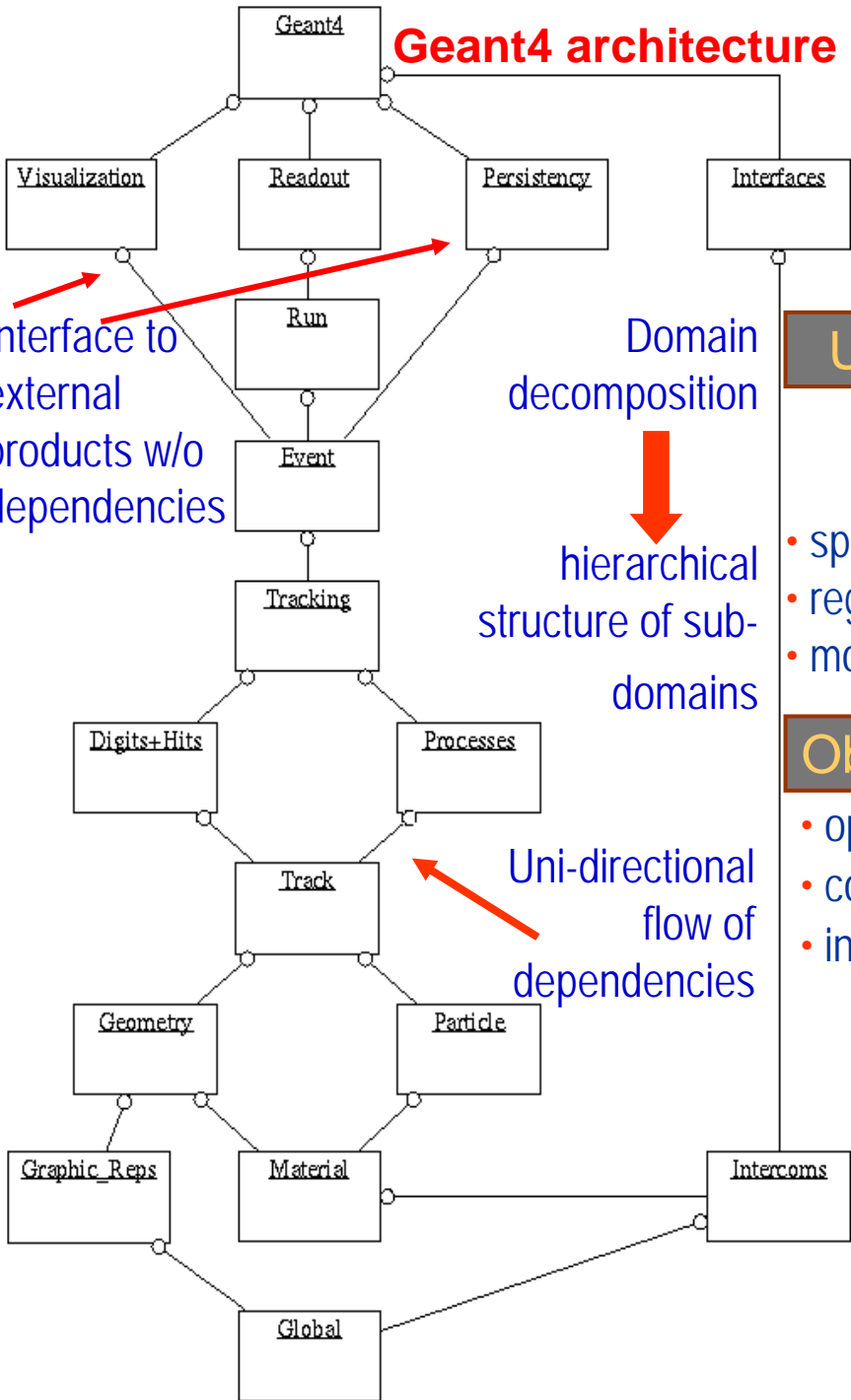
Physics

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

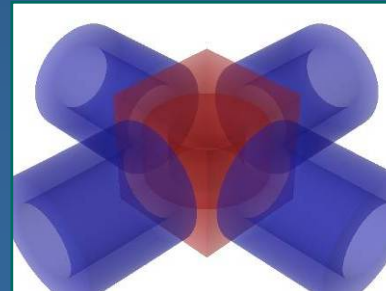
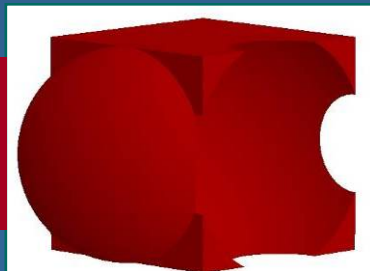
- detailed detector description
- efficient navigation

■ Three conceptual layers

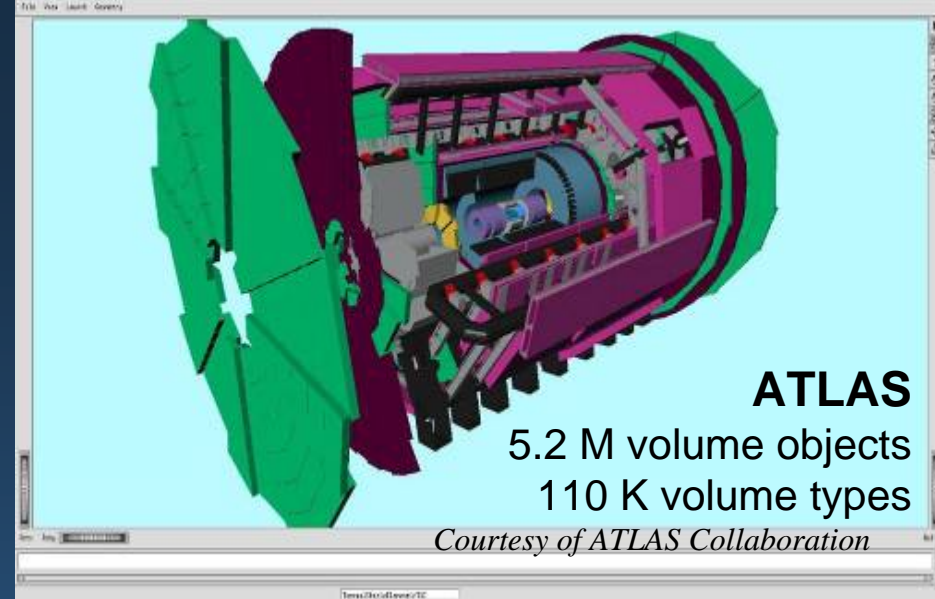
- **Solid**: shape, size
- **LogicalVolume**: material, sensitivity, daughter volumes, etc.
- **PhysicalVolume**: position, rotation

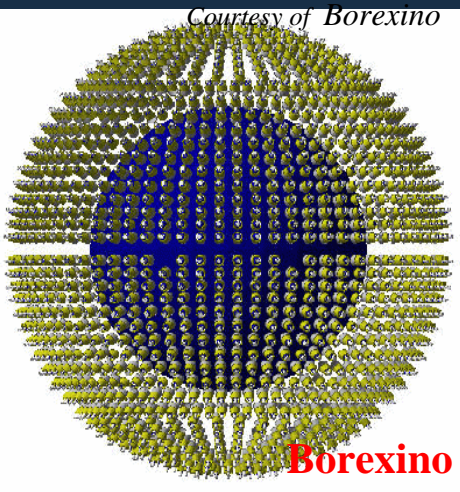
■ One can do fancy things with geometry...

Boolean
operations



Transparent
solids





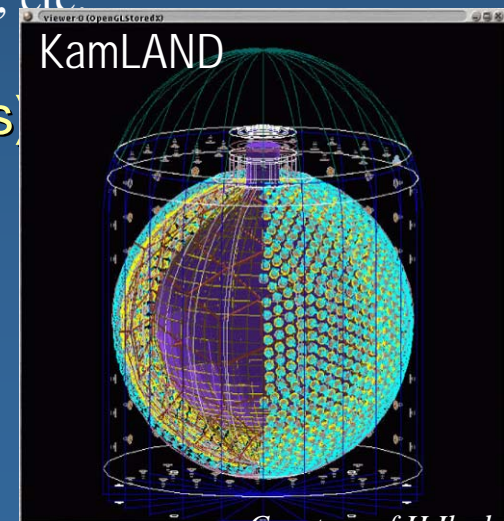
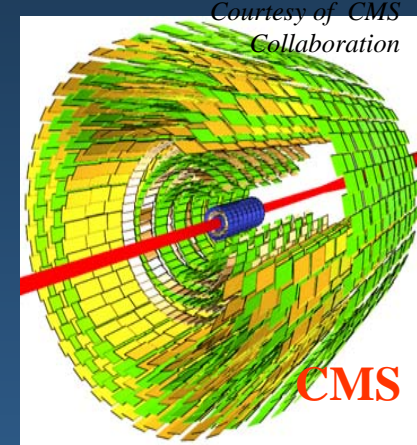
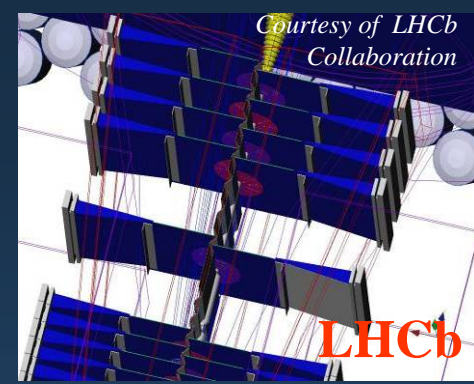
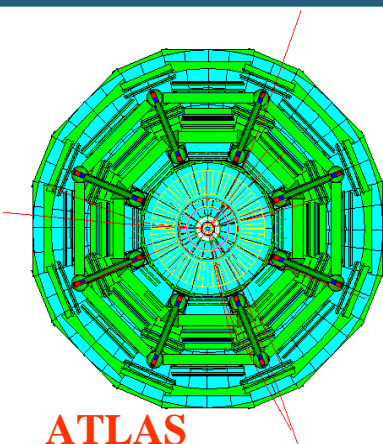
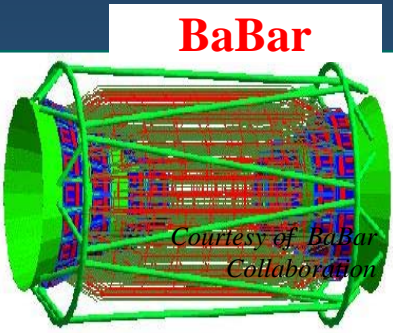
Solids

Multiple representations

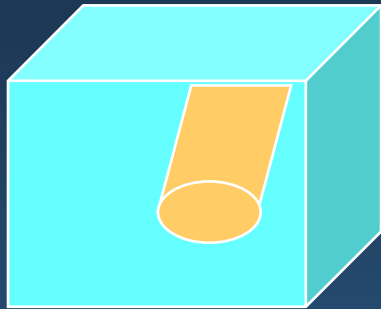
Same abstract interface

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

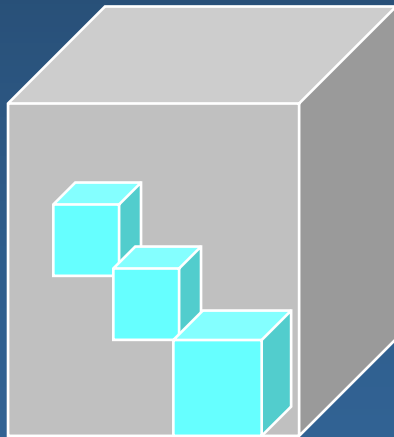
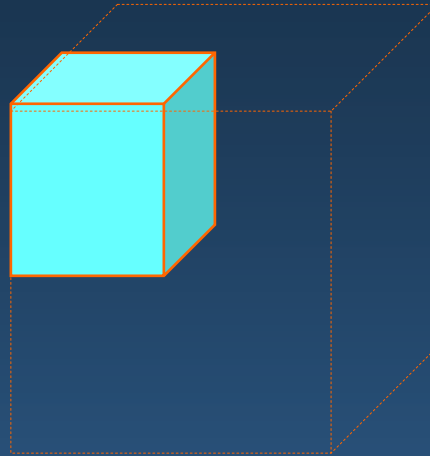
CAD exchange



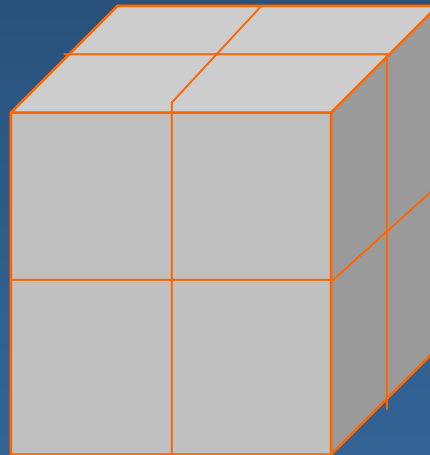
Physical Volumes



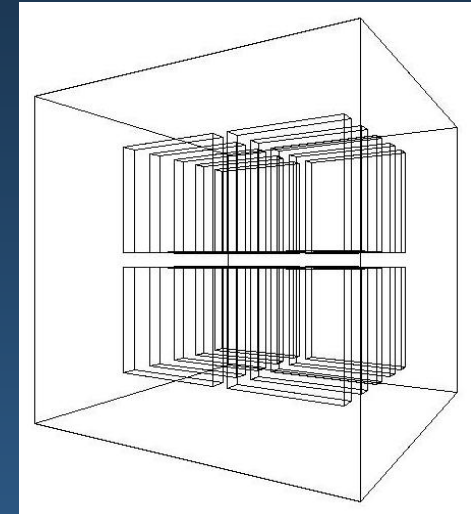
placement



parameterised



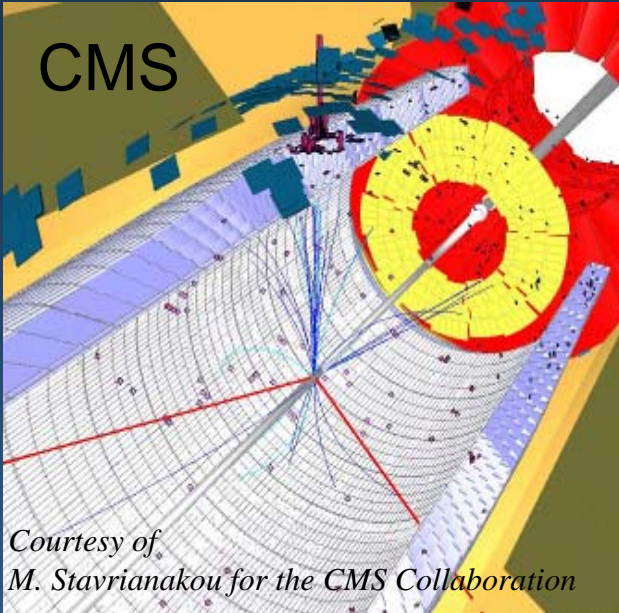
replica



assembled

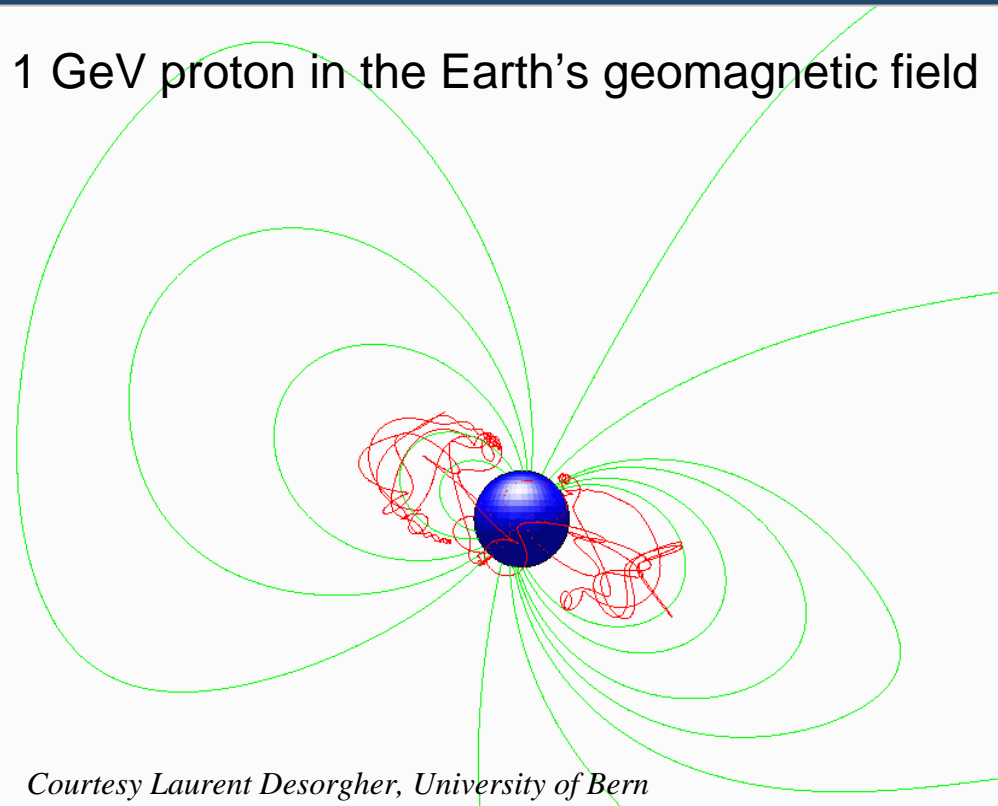
Versatility to describe
complex geometries

Electric and magnetic fields of variable non-uniformity and differentiability



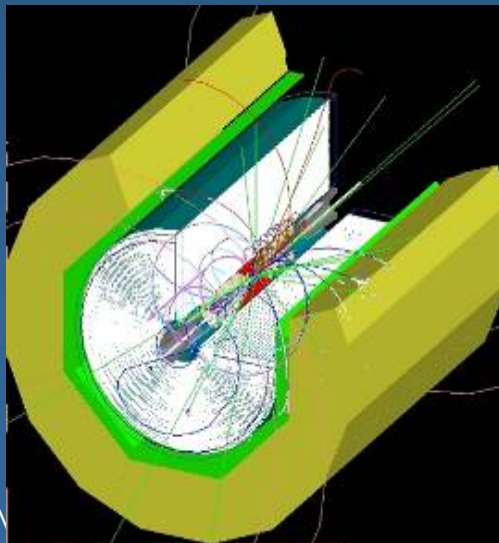
Geant4 field ~ 2 times faster than FORTRAN/GEANT3

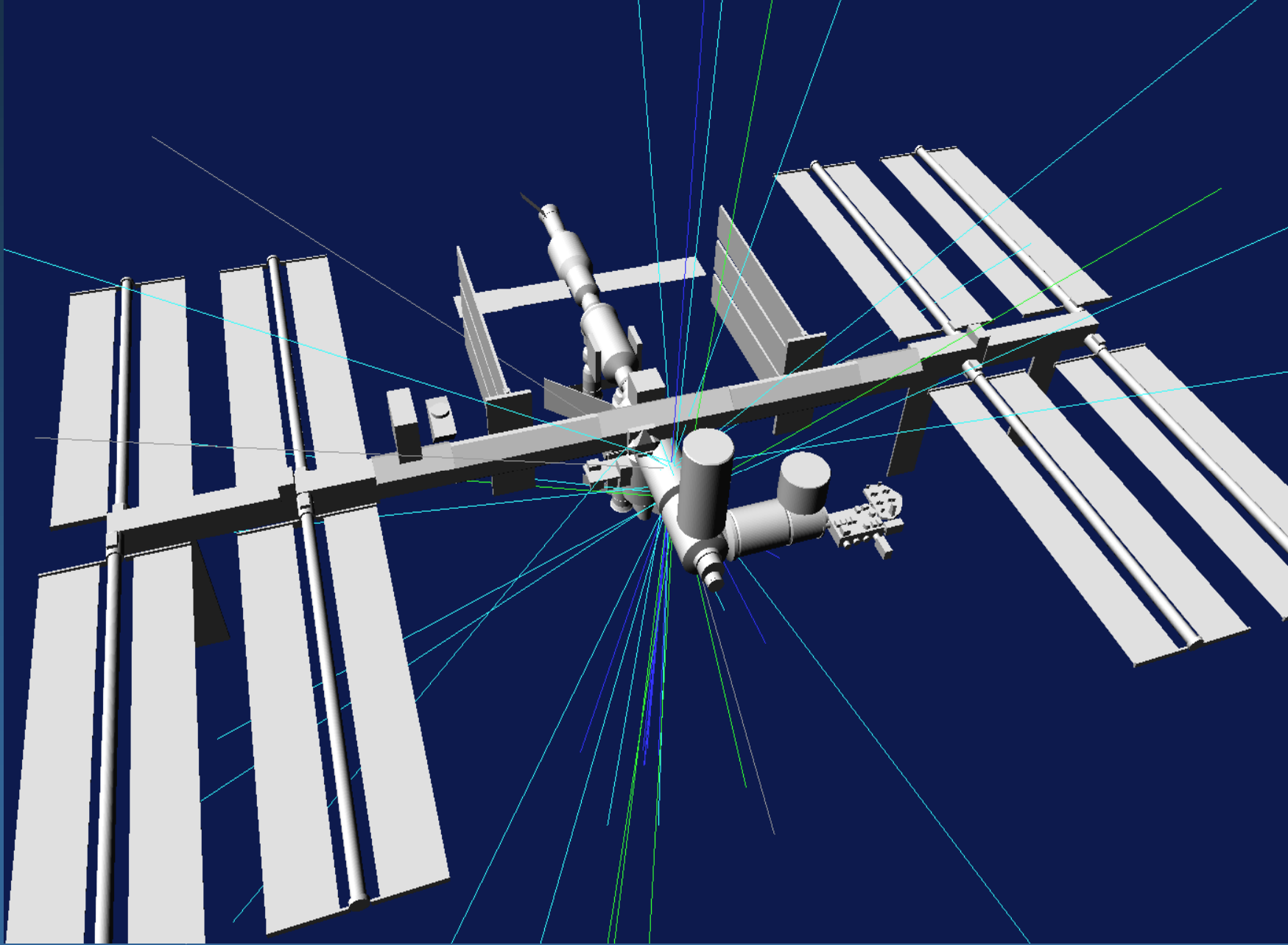
1 GeV proton in the Earth's geomagnetic field



MOKKA

Linear
Collider
Detector



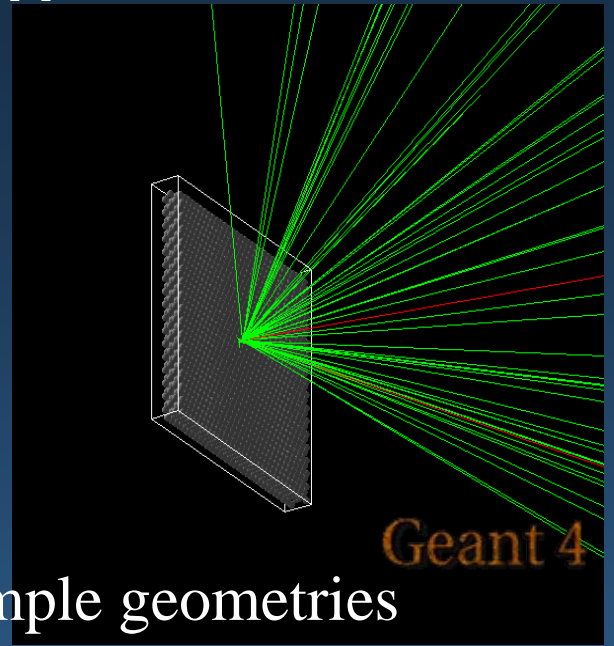
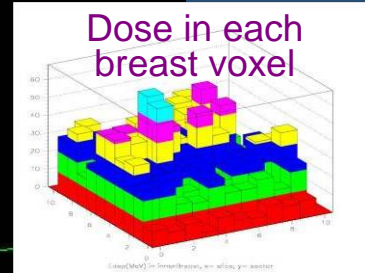


Not only large scale, complex detectors....

Analytical breast

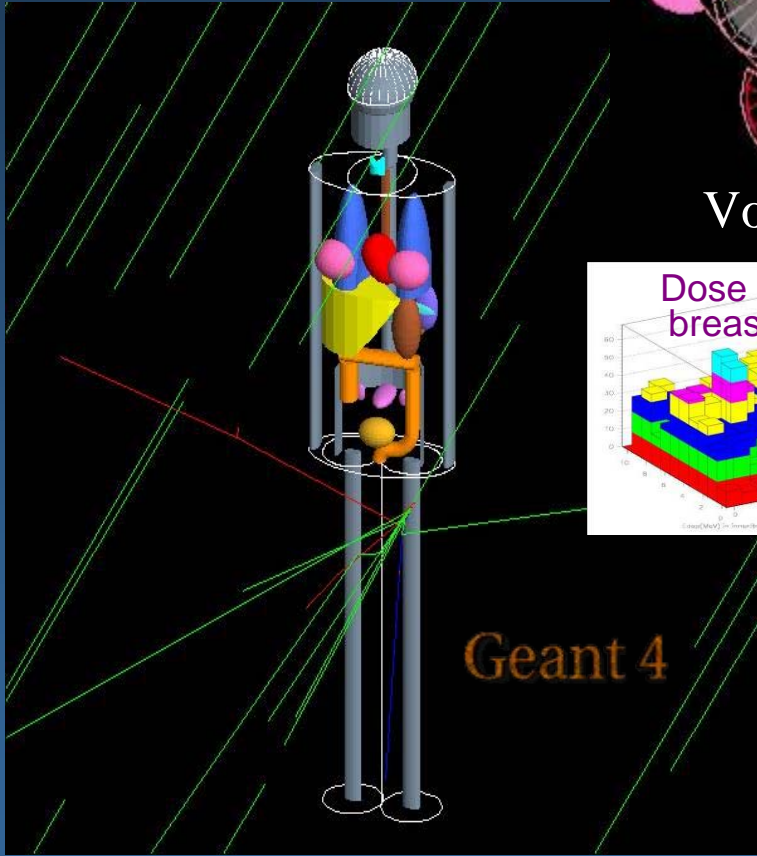


Voxel breast

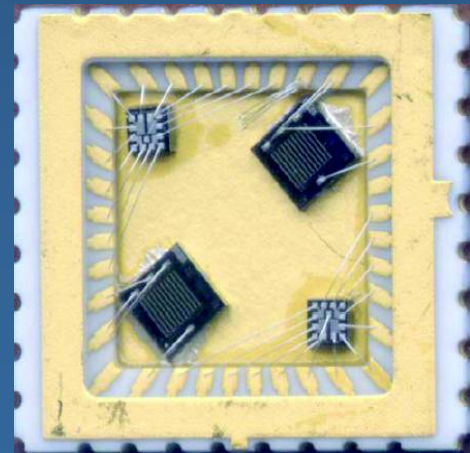


simple geometries

small scale components



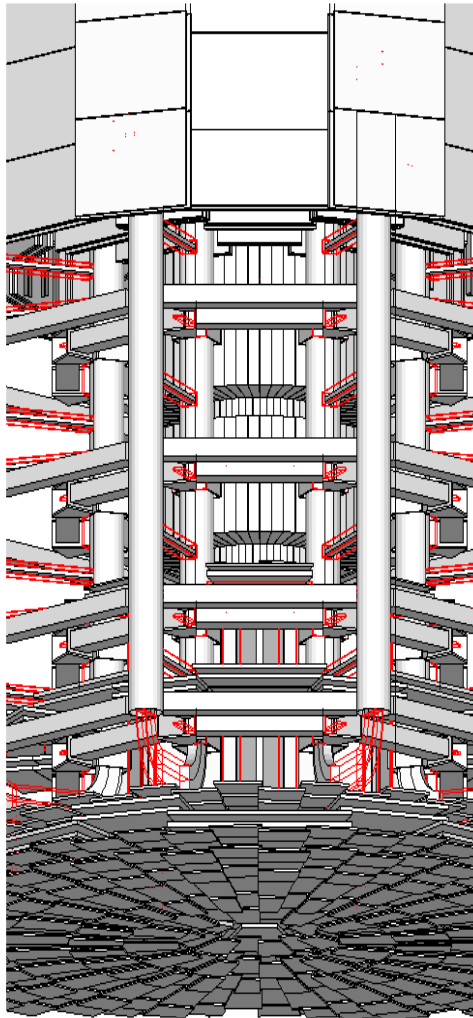
Geant 4



Geant 4

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] ...

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
- γ , X-ray and optical photons
- muons
- charged hadrons
- ions

Comparable to Geant3 already in the α release (1997)

Further extensions (*facilitated by the OO technology*)

energy
loss

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

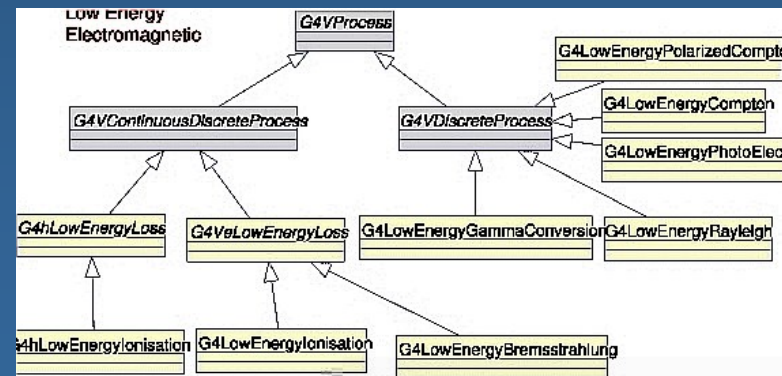
High energy extensions

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

Low energy extensions

- fundamental for space and medical applications, dark matter and ν experiments, antimatter spectroscopy etc.

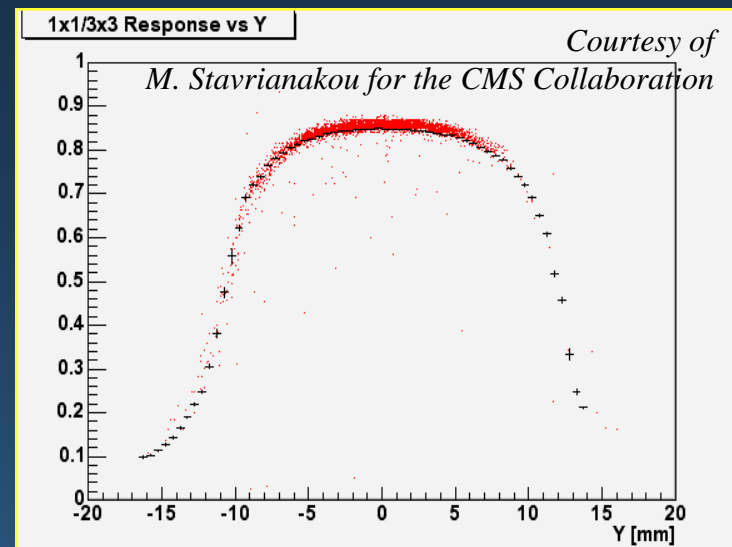
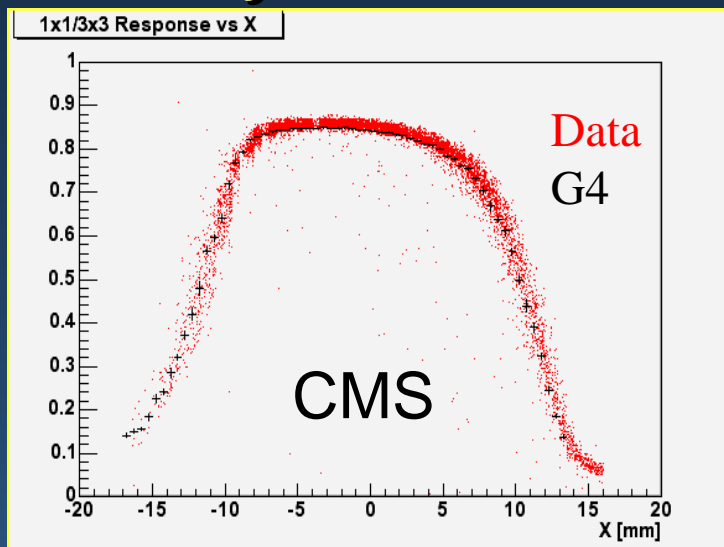
Alternative models for the same process



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

Calorimetry

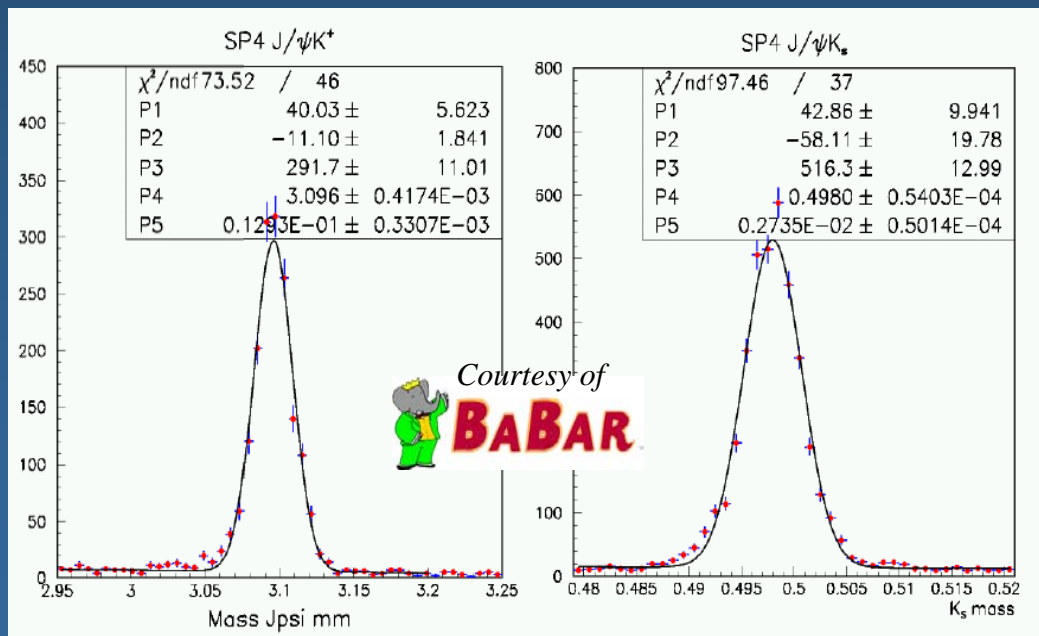
Single crystal containment: E_{1x1}/E_{3x3} versus position

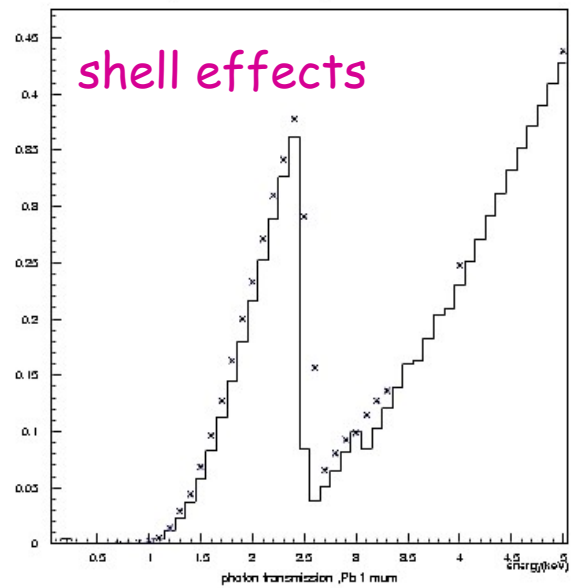


Tracking

Geant4
Standard
Electromagnetic
Physics

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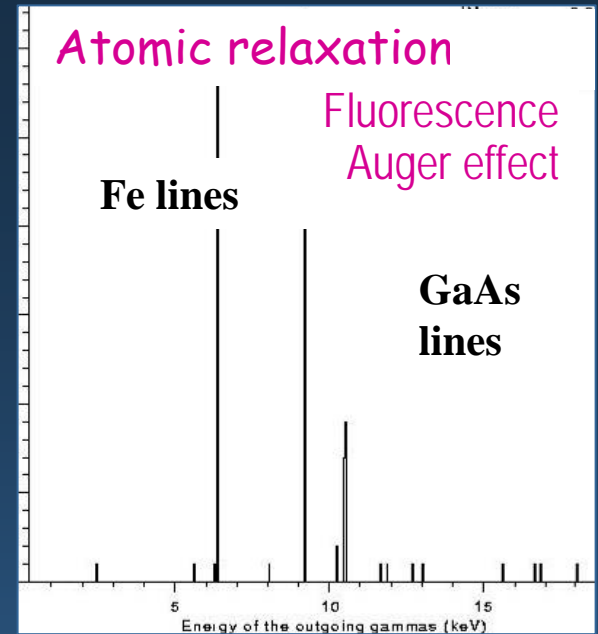




Geant 4

e, γ 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

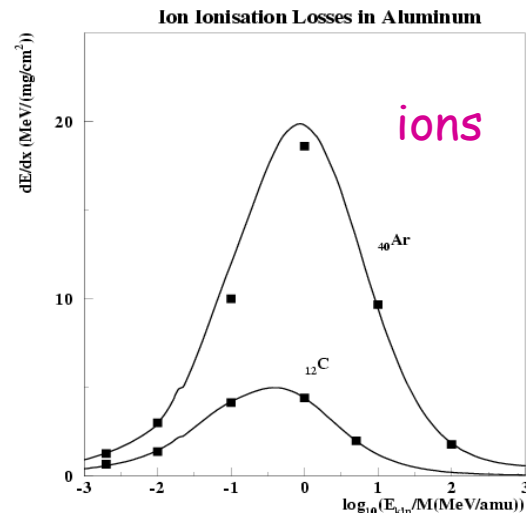
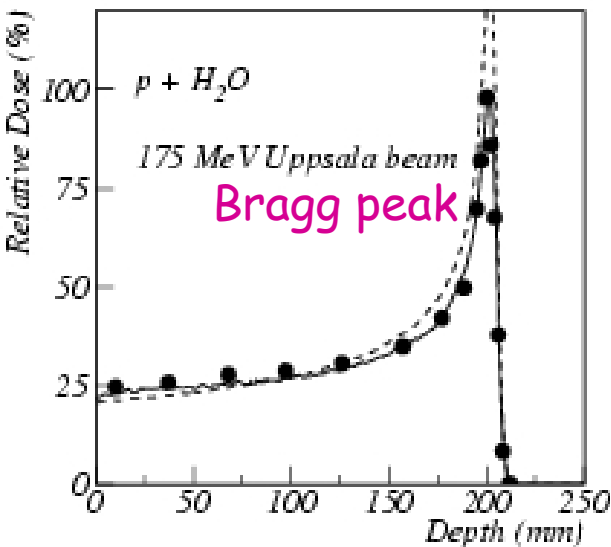
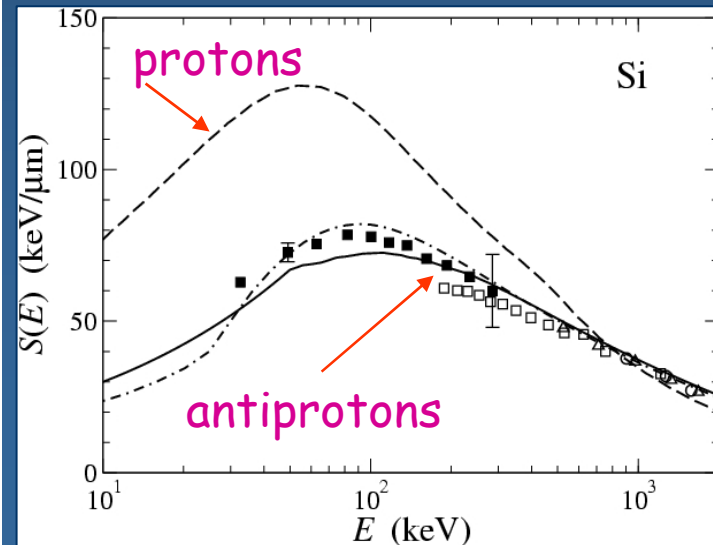


Figure 9: Ion electronic stopping power in aluminum. Points - the best fit on the data from Ref.[12], solid line - GEANT4 parameterisation. The accuracy of the data is about 5 %.

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



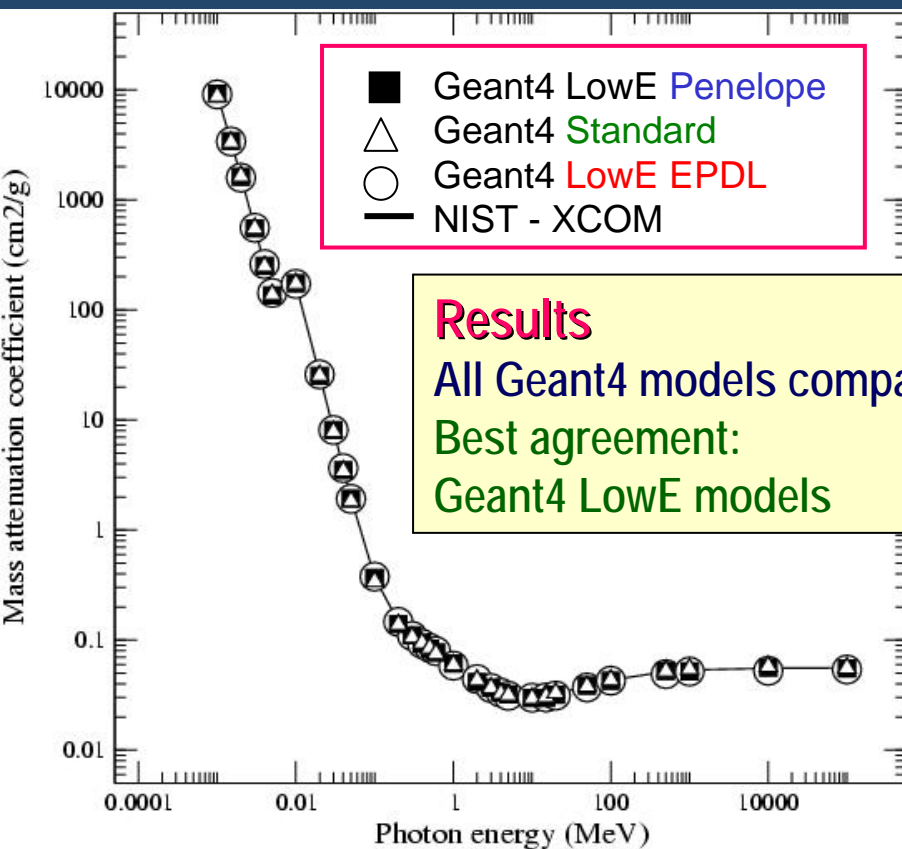
“Comparison of Geant4 electromagnetic physics models against the NIST reference data”

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

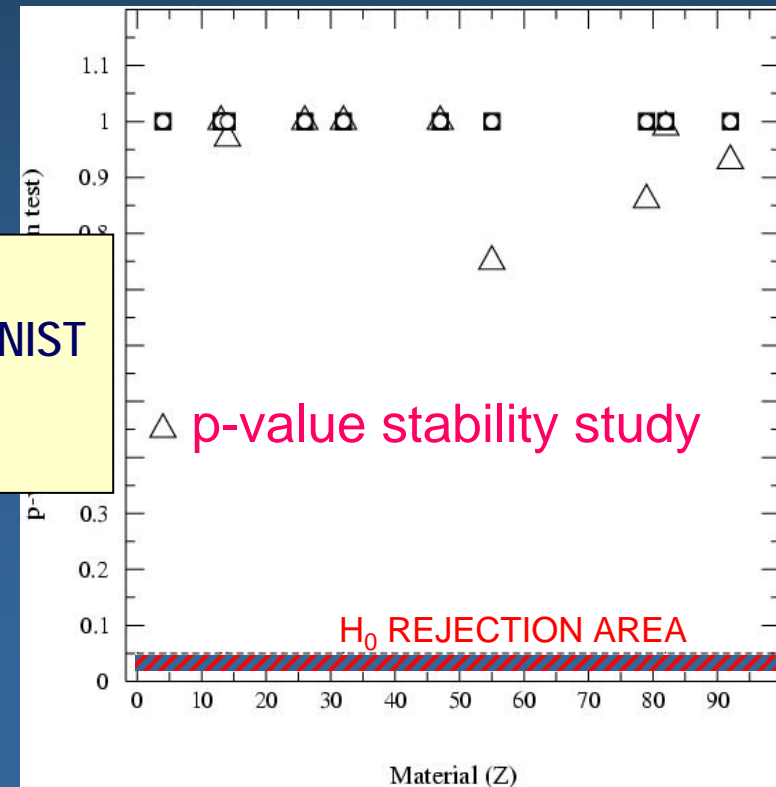


Results

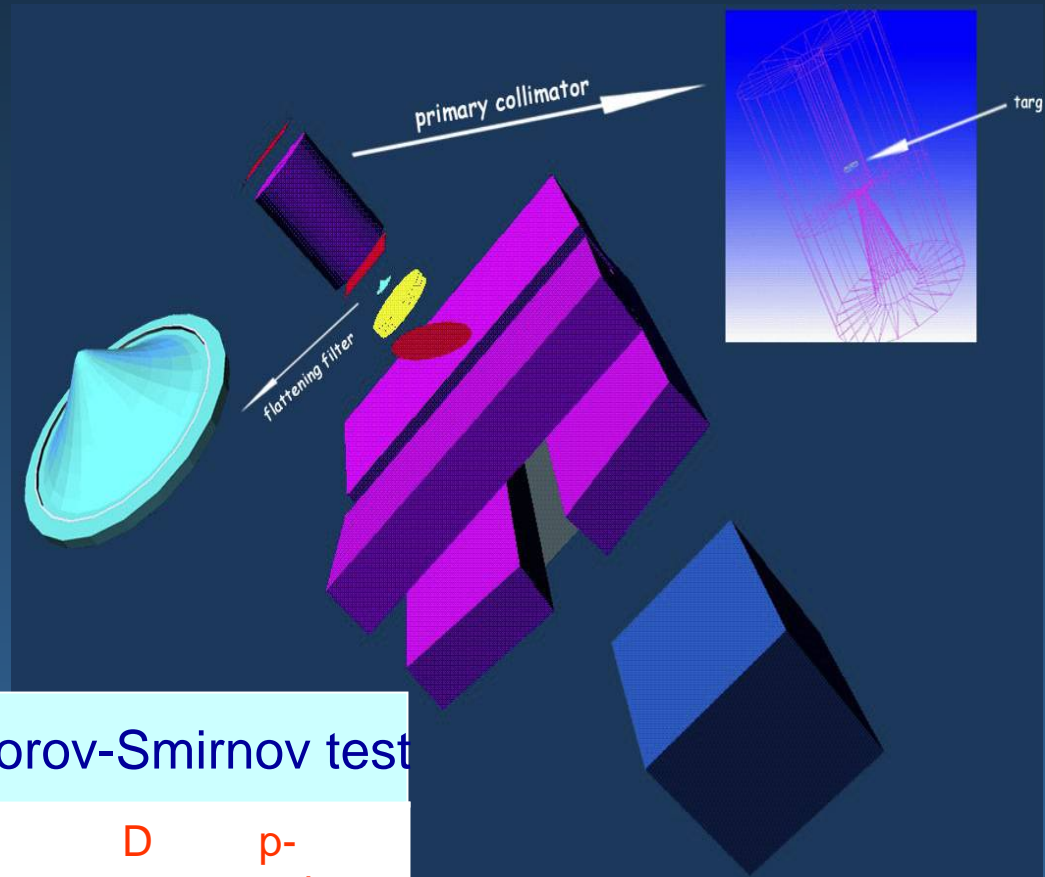
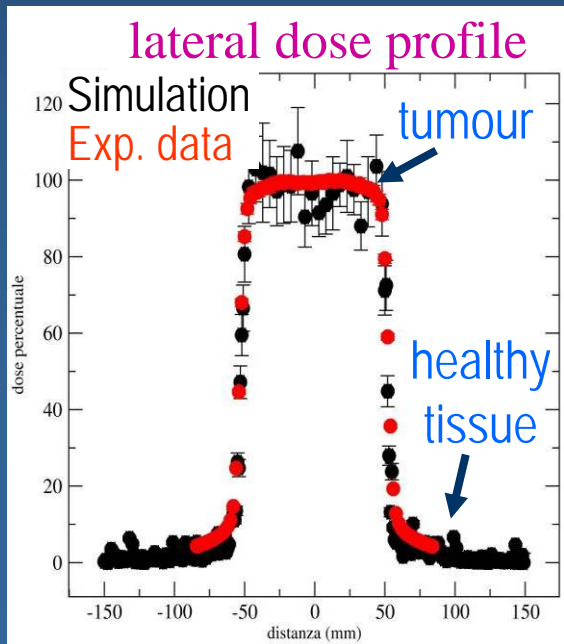
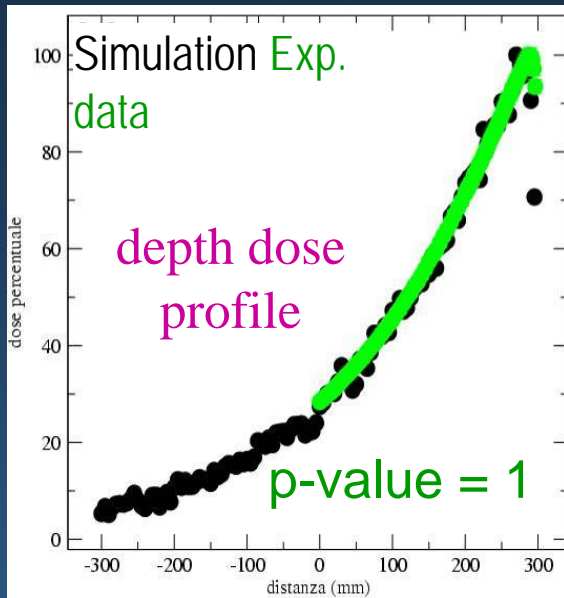
All Geant4 models compatible with NIST

Best agreement:

Geant4 LowE models



A medical accelerator for IMRT



Kolmogorov-Smirnov test

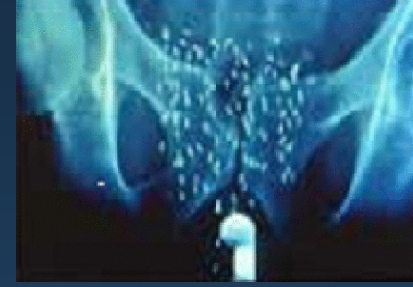
range	D	p-value
-84 ÷ -60 mm	0.385	0.23
-59 ÷ -48 mm	0.27	0.90
-47 ÷ 47 mm	0.43	0.19
48 ÷ 59 mm	0.30	0.82
60 ÷ 84 mm	0.40	0.10



Dosimetry

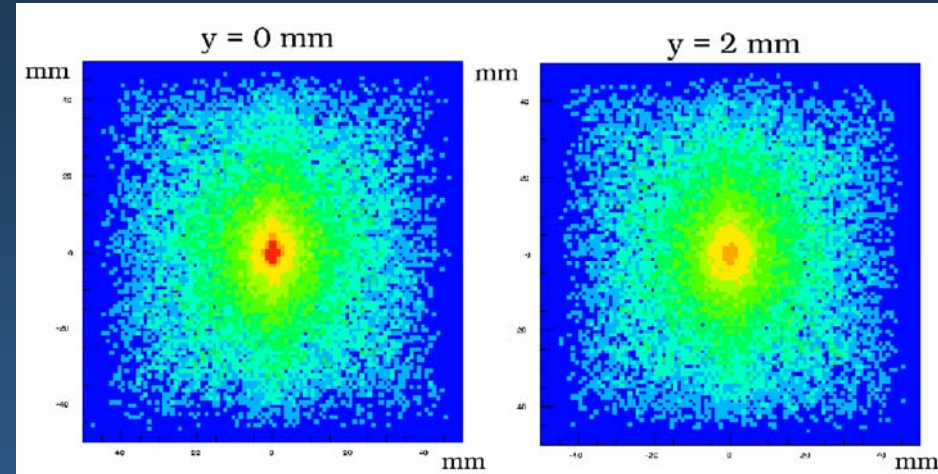
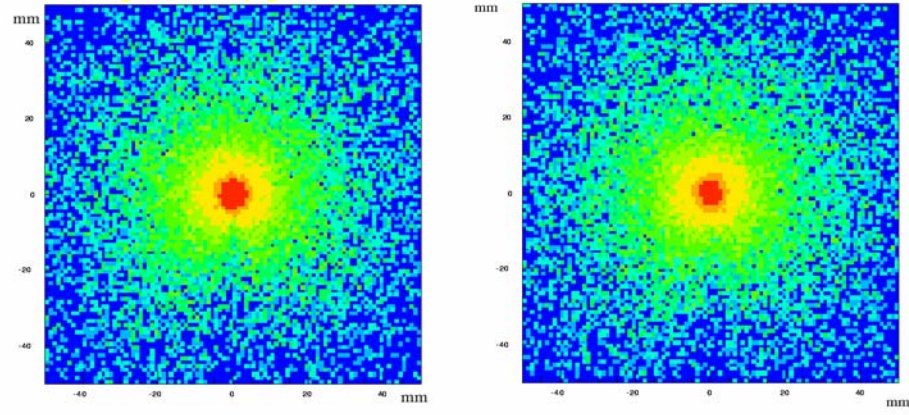
Endocavitary

brachytherapy MicroSelectron-HDR source



Dosimetry

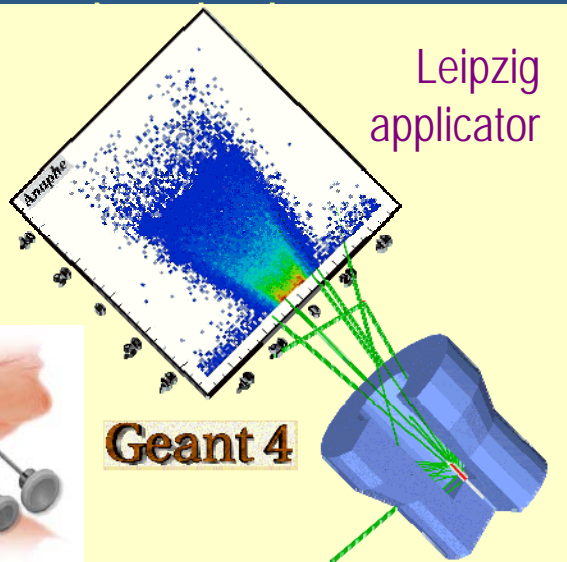
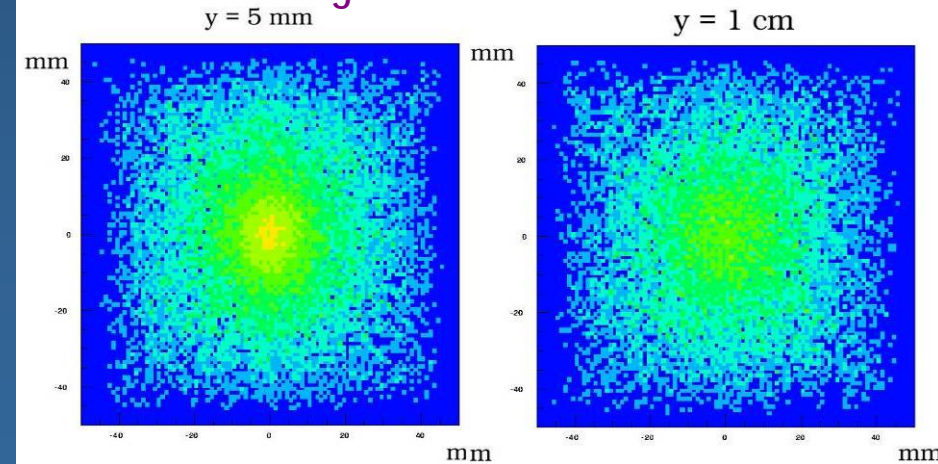
Interstitial



Dosimetry

Superficial

Bebig Isoseed I-125 source



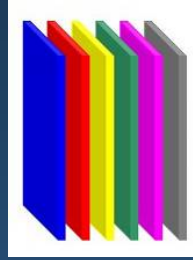
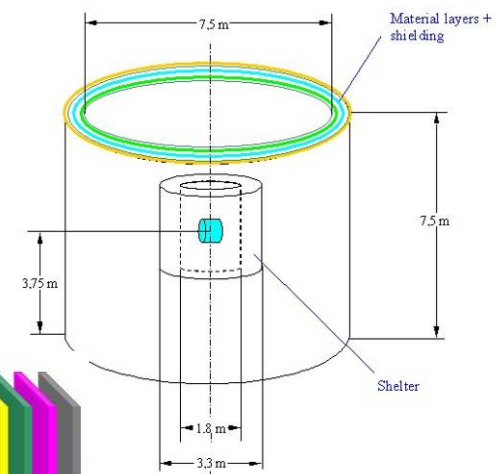
Dosimetry in interplanetary missions



Aurora Programme



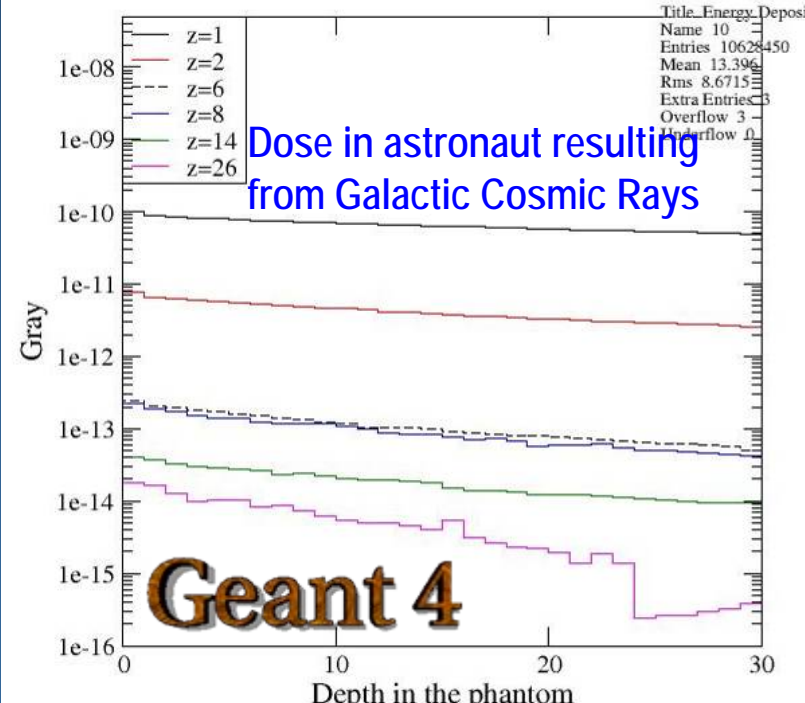
Courtesy of ESA



Courtesy of Alenia Spazio vehicle concept

Dose in the phantom

GCR - EM Physics - 10 cm polyethylene



Cosmic rays,
jovian electrons

Solar system explorations

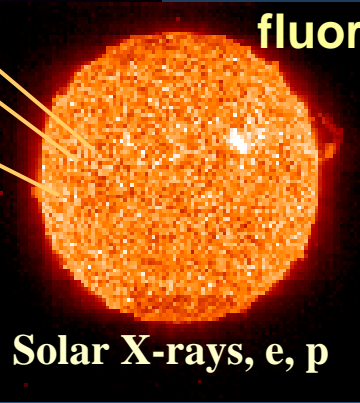
Study of the elemental composition of planets, asteroids and moons → clues to solar system formation

X-ray fluorescence

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

PIXE

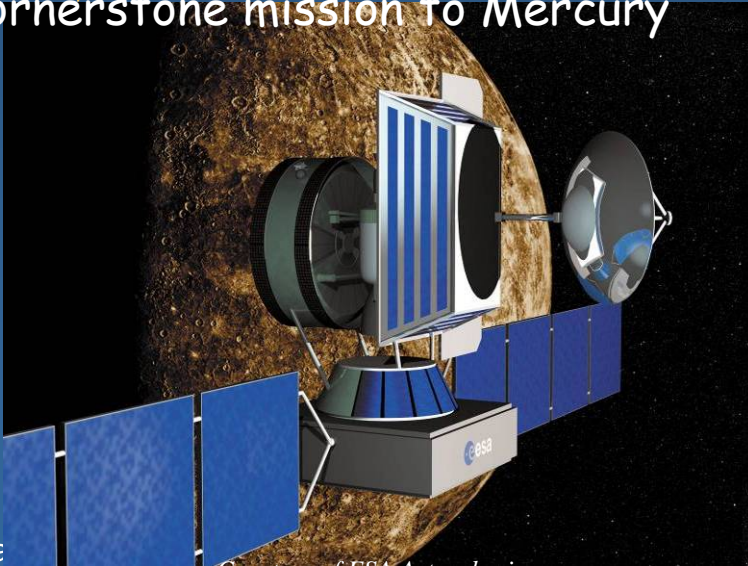
Significant only during particle events, during which it can exceed XRF



Solar X-rays, e, p

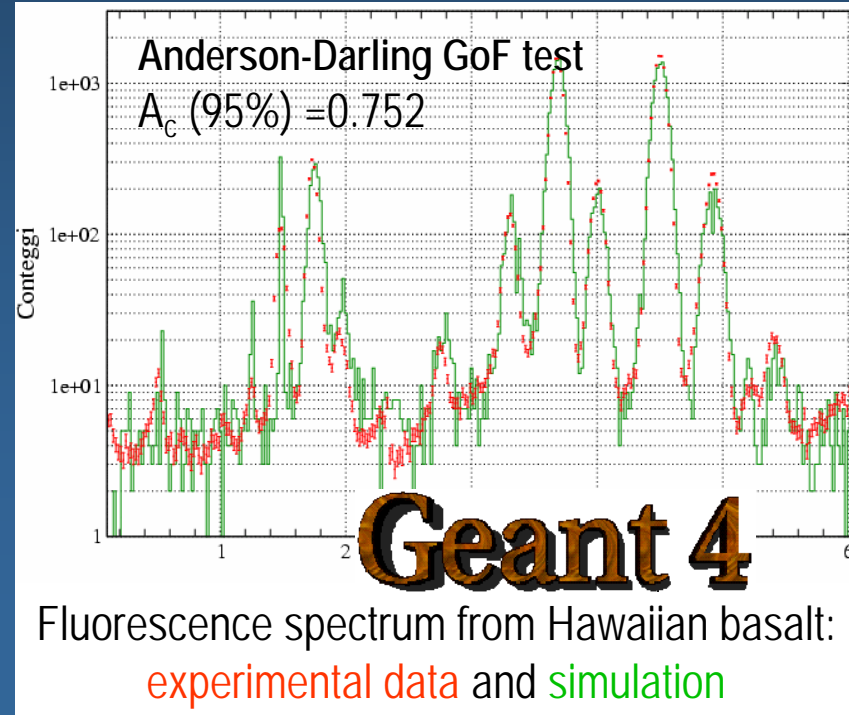
Courtesy SOHO EIT

BepiColombo
ESA cornerstone mission to Mercury



Maria

Courtesy of ESA Astrophysics

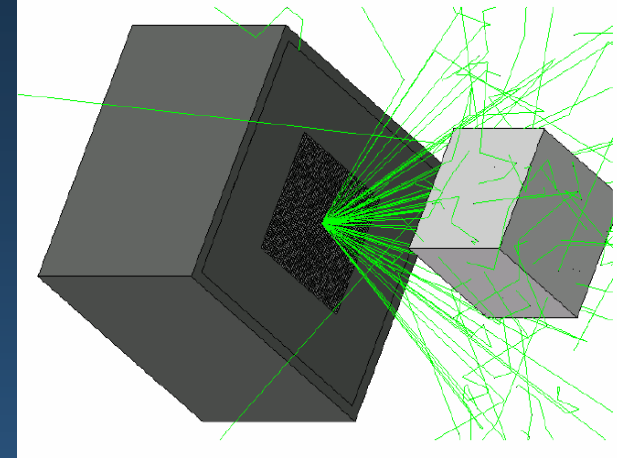




Detection of Landmines using Radiation Based Techniques

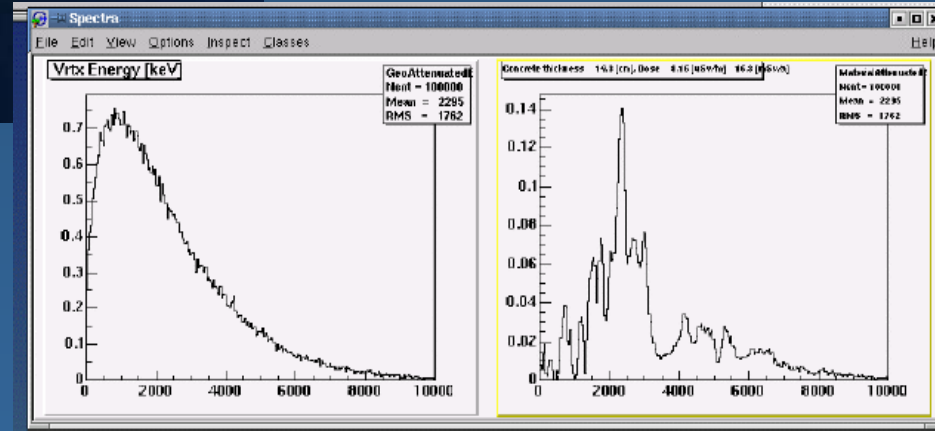
Geant4 User's Workshop, SLAC 2002 02 21

Dr Anthony A. Faust
Threat Detection Group
Defence Research Establishment Suffield



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 ϕ

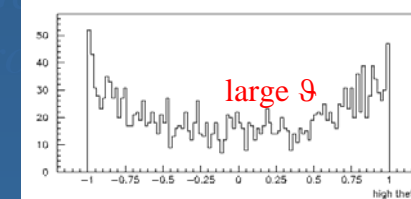
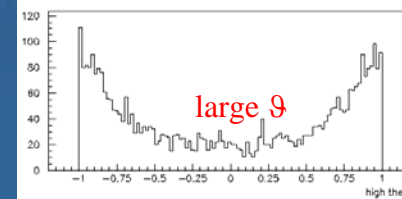
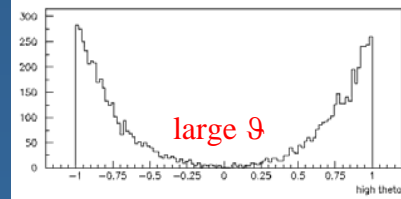
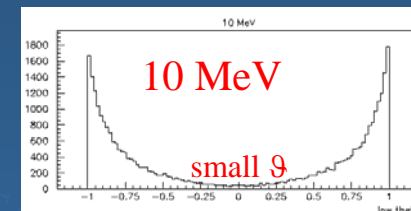
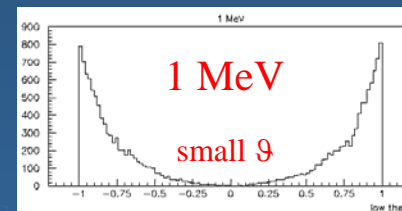
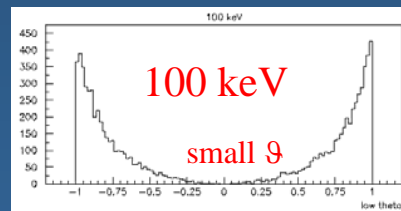
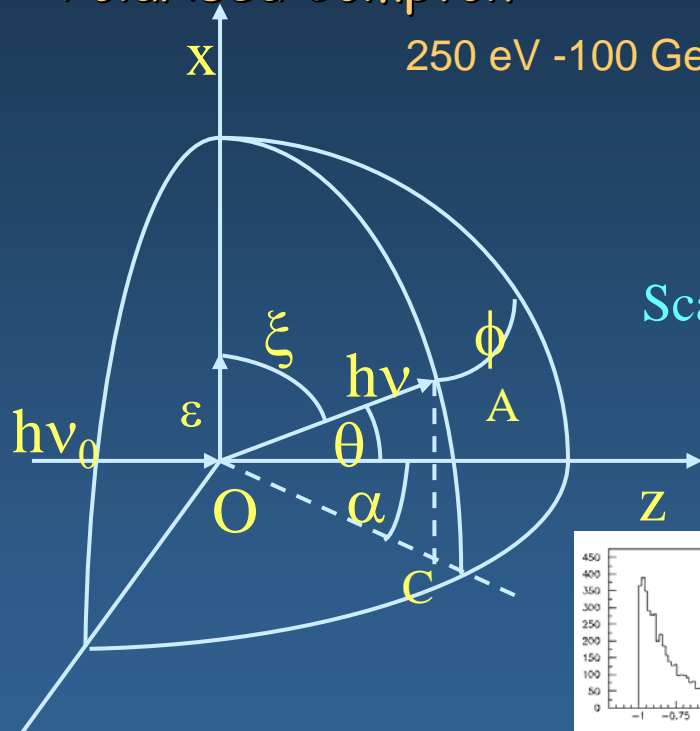
- Sample θ
- θ - Energy Relation \Rightarrow Energy
- Sample of ϕ from $P(\phi) = a (b - c \cos^2 \phi)$ distribution

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

Scattered Photon Polarization

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

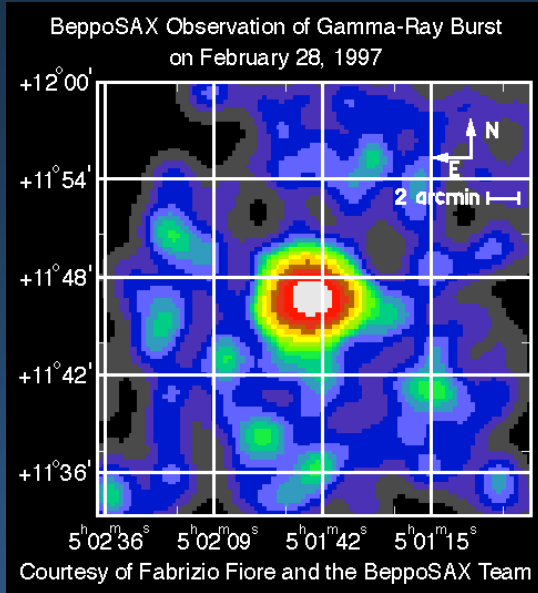
$$\overline{\varepsilon_{\parallel}} = \left(N \hat{i} - \frac{1}{N} \sin^2 \theta \sin \phi \cos \phi \hat{j} - \frac{1}{N} \sin \theta \cos \theta \cos \phi \hat{k} \right) \cos \beta$$



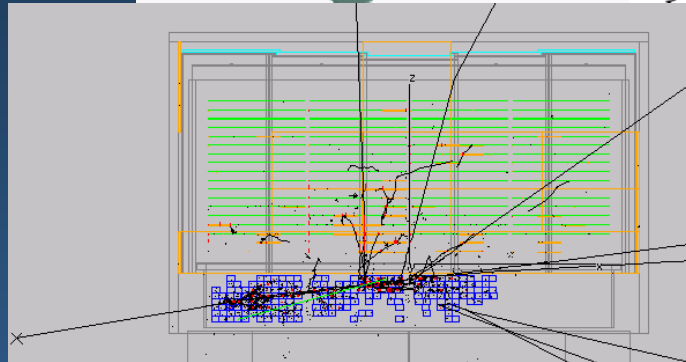
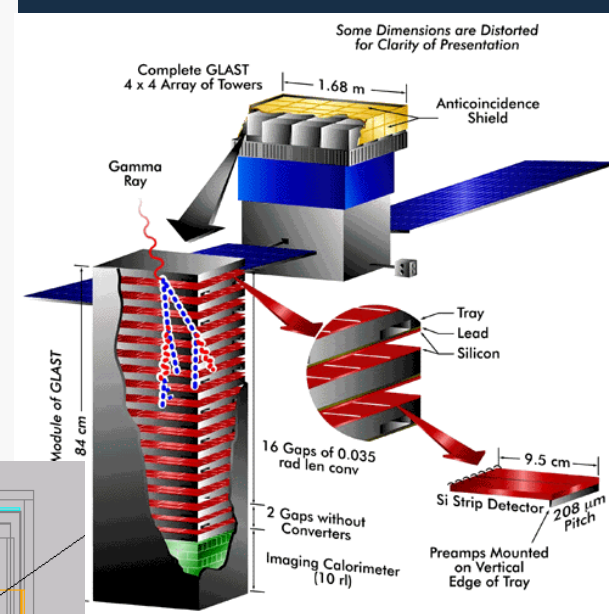
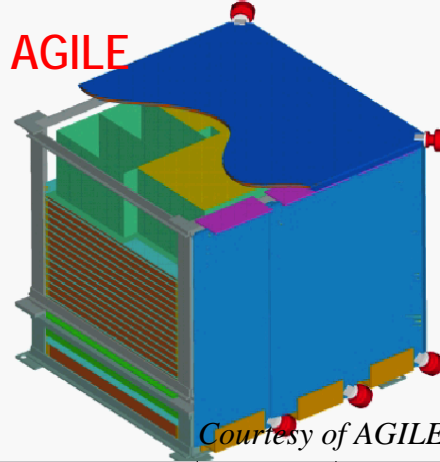
- θ Polar angle
- ϕ Azimuthal angle
- ε Polarization vector

γ astrophysics

γ -ray bursts

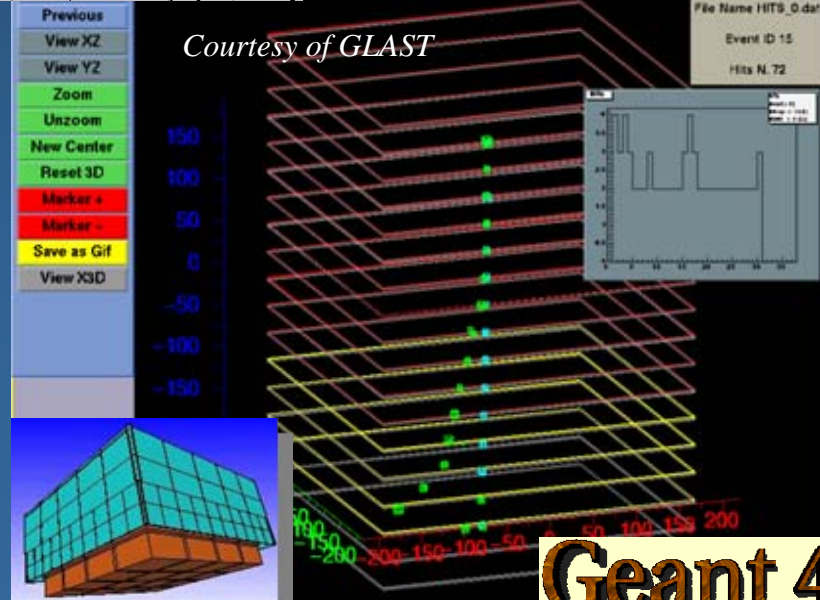


AGILE



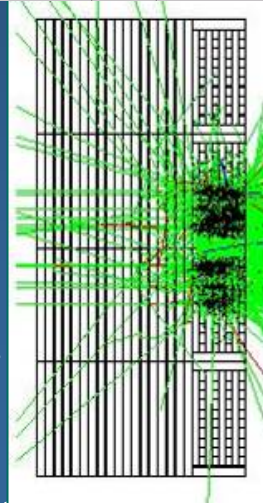
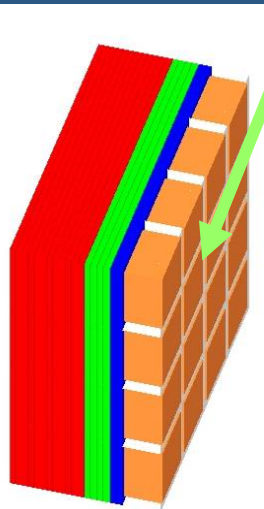
GLAST

GLAST Hits Display



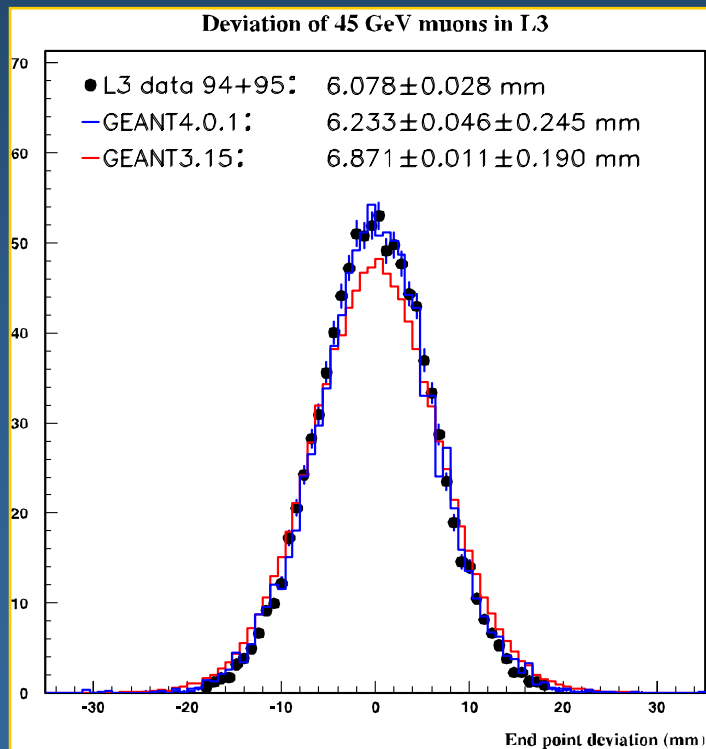
Typical telescope:
Tracker
Calorimeter
Anticoincidence

- γ conversion
- electron interactions
- multiple scattering
- δ -ray production
- charged particle tracking



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

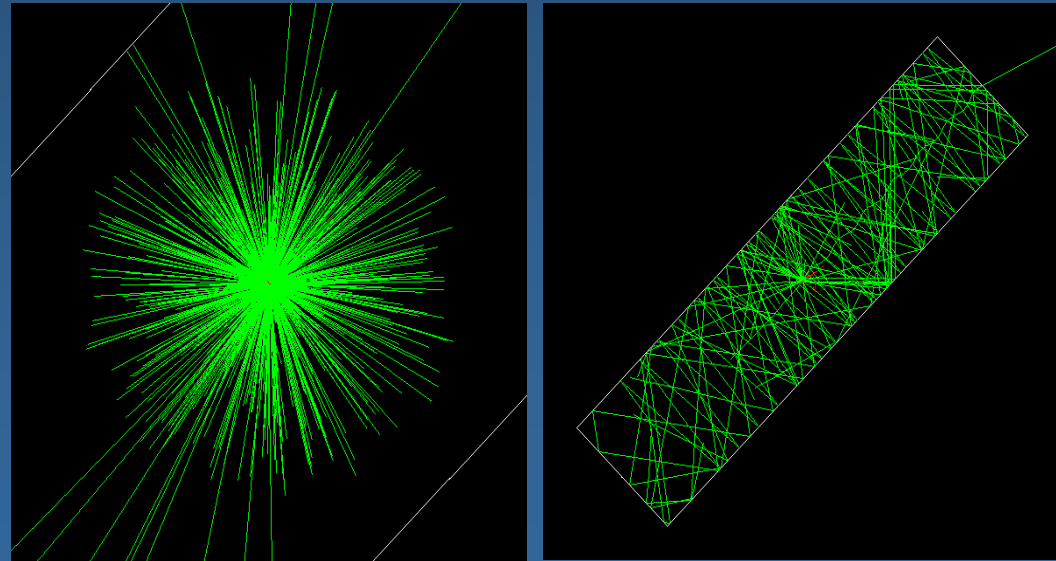
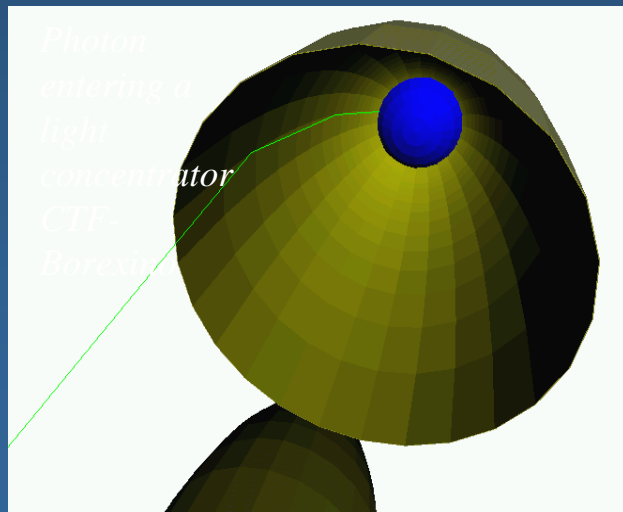
Optical photons

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

Processes in Geant4:

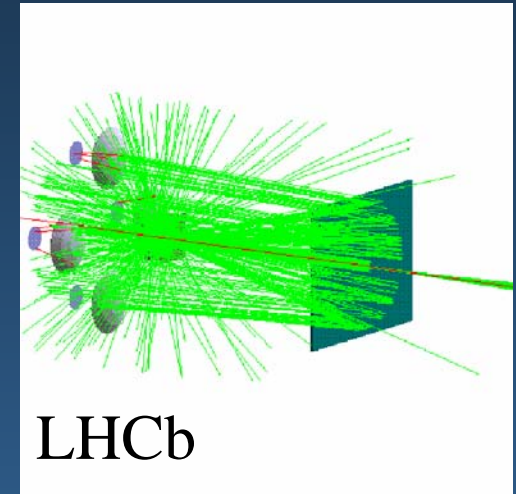
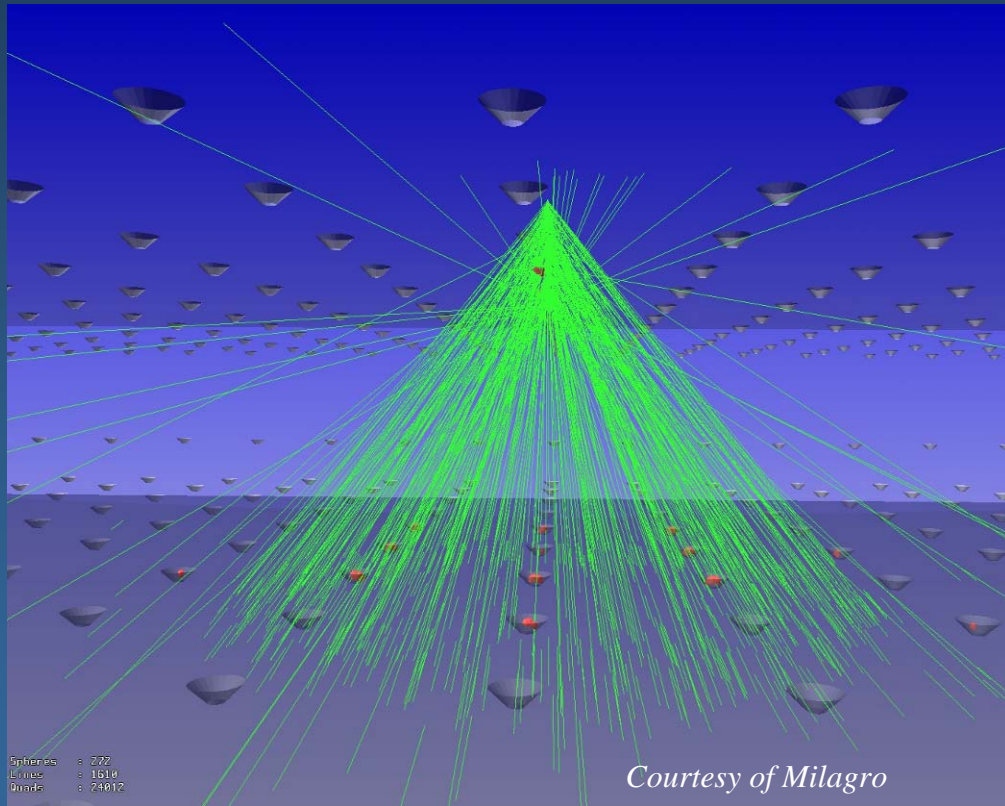
- in-flight absorption
- Rayleigh scattering
- medium-boundary interactions (reflection, refraction)

Geant4 Optical Processes : Scintillating Cells and WLS Fibers



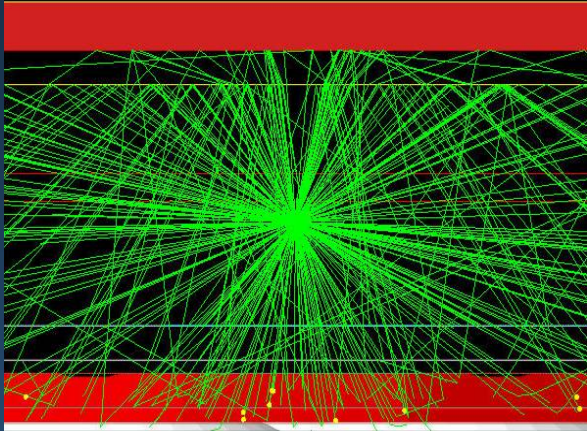
Cherenkov

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



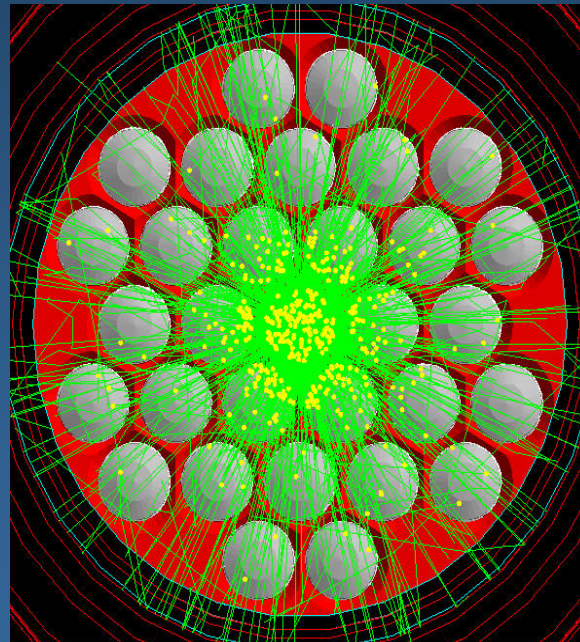
Aerogel Thickness	Yield Per Event	Cherenkov Angle mrad
4 cm DATA	6.3 ± 0.7	247.1 ± 5.0
MC	7.4 ± 0.8	246.8 ± 3.1
8 cm DATA	9.4 ± 1.0	245.4 ± 4.8
MC	10.1 ± 1.1	243.7 ± 3.0

prompt scintillation

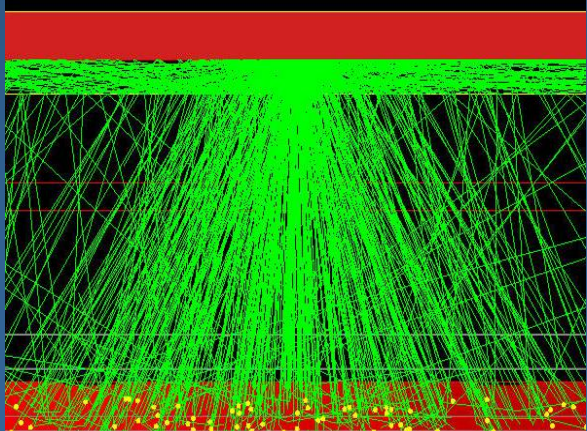


ZEPLIN III
Dark Matter Detector

signal in PMT

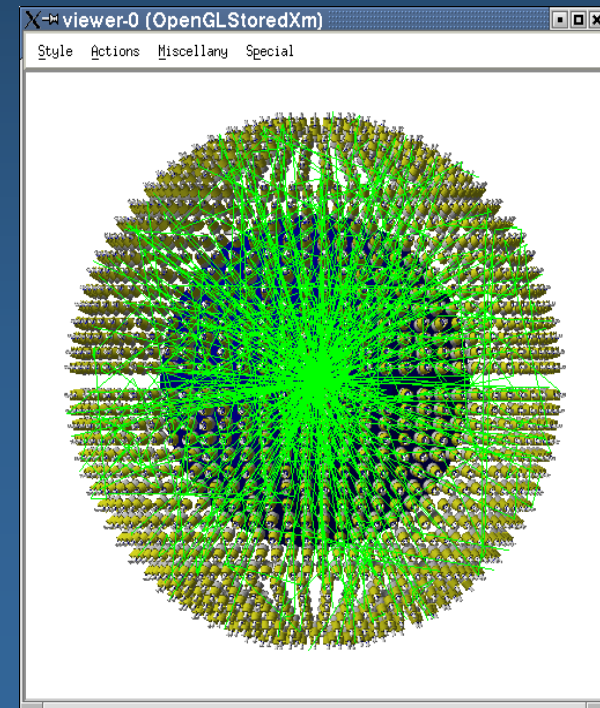


termoluminescence



Scintillation

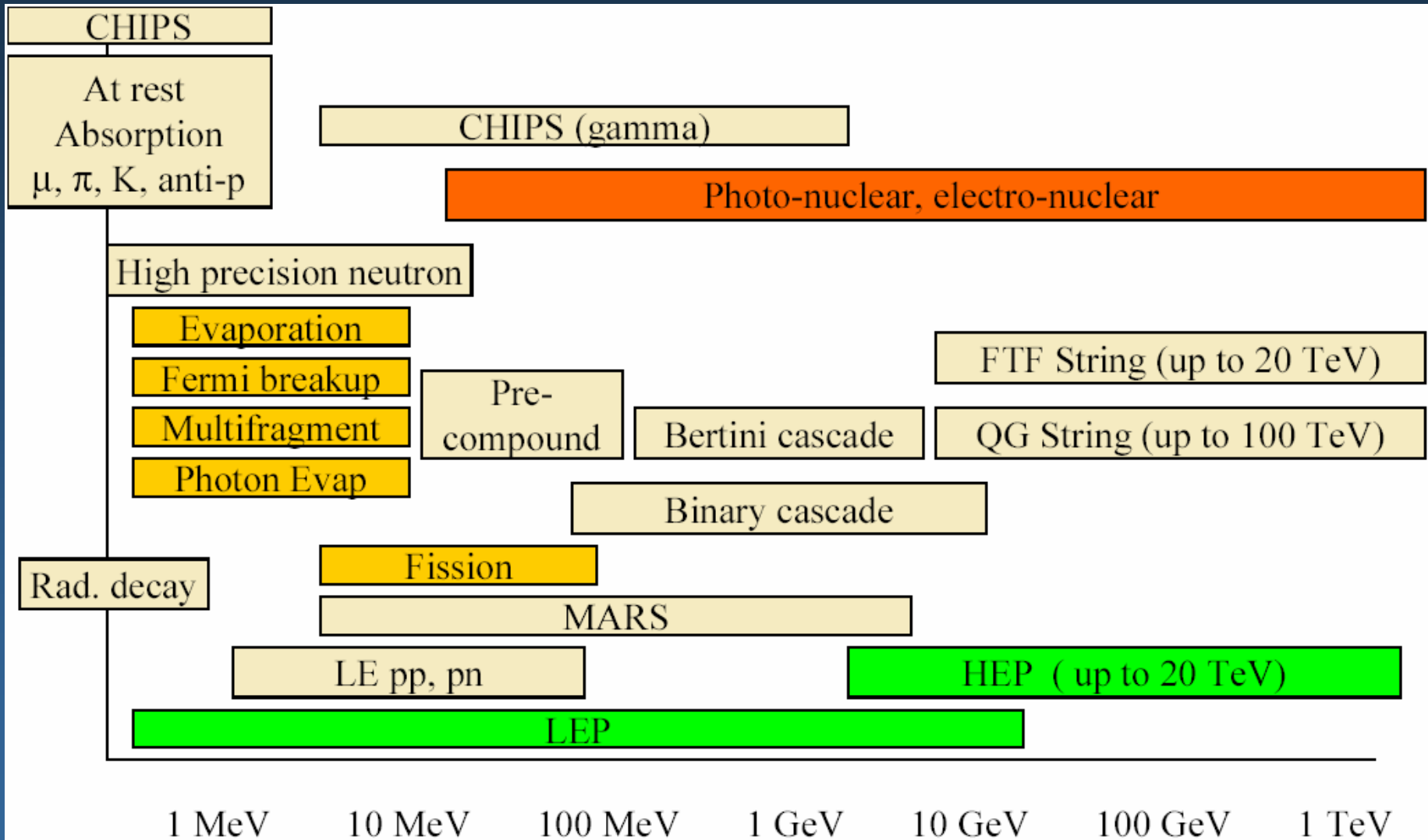
GEANT4 Scintillation
Event in BOREXINO



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

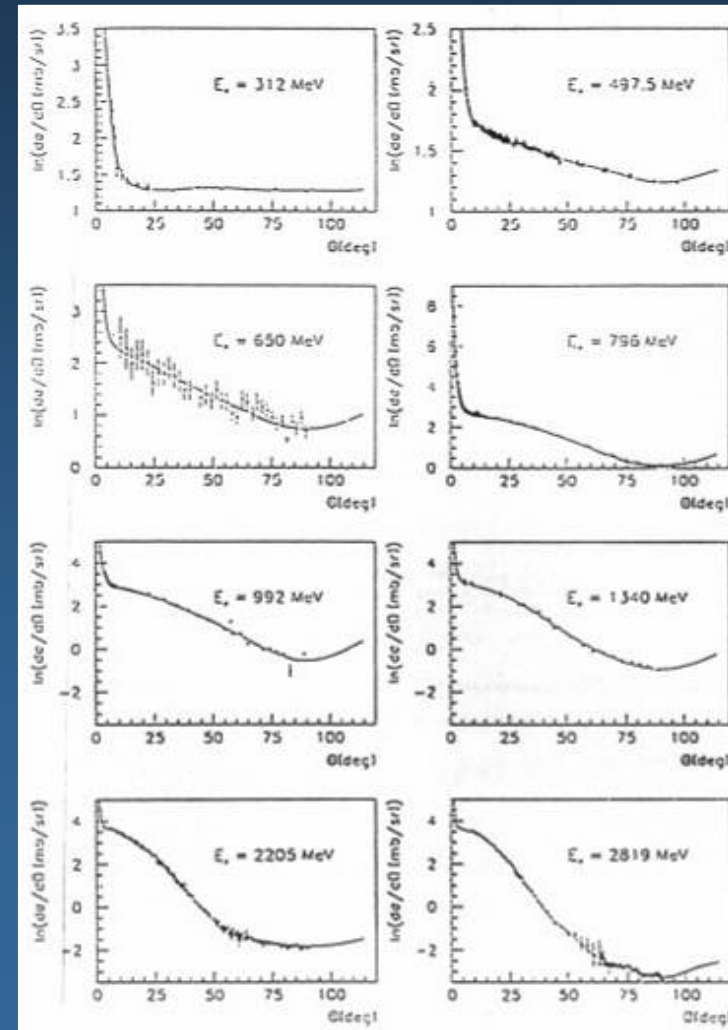
Some models originally from GHEISHA

- completely reengineered into OO design
- refined physics parameterisations

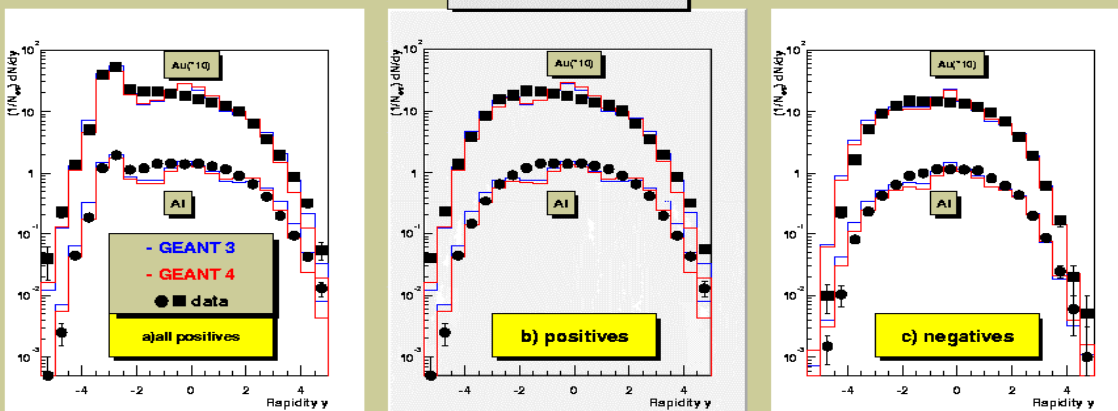
New parameterisations

- pp, elastic differential cross section
- nN, total cross section
- pN, total cross section
- np, elastic differential cross section
- π N, total cross section
- π N, coherent elastic scattering

p elastic scattering on Hydrogen



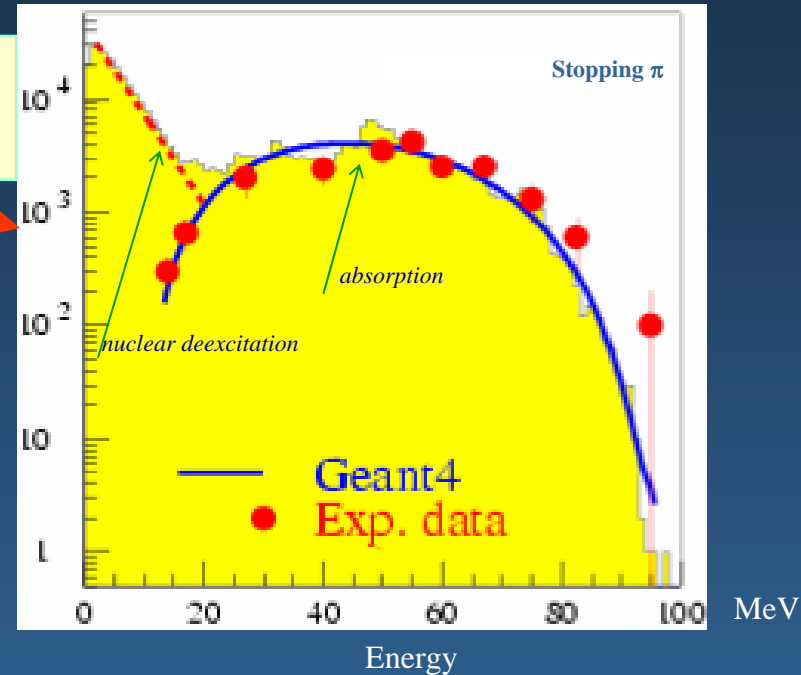
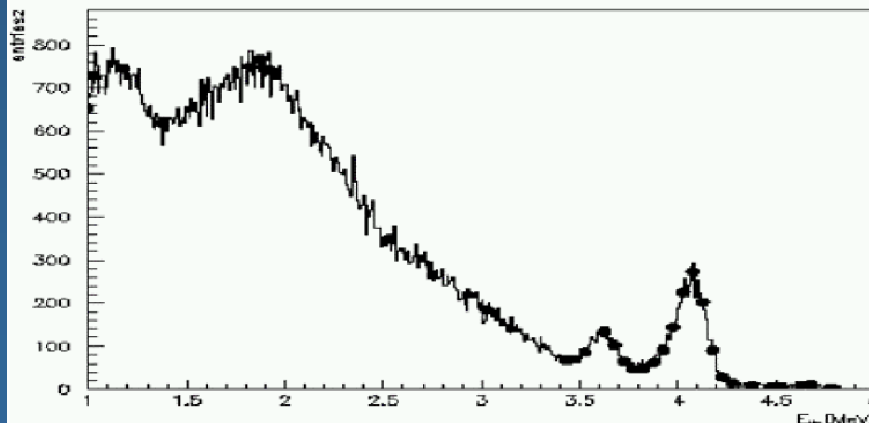
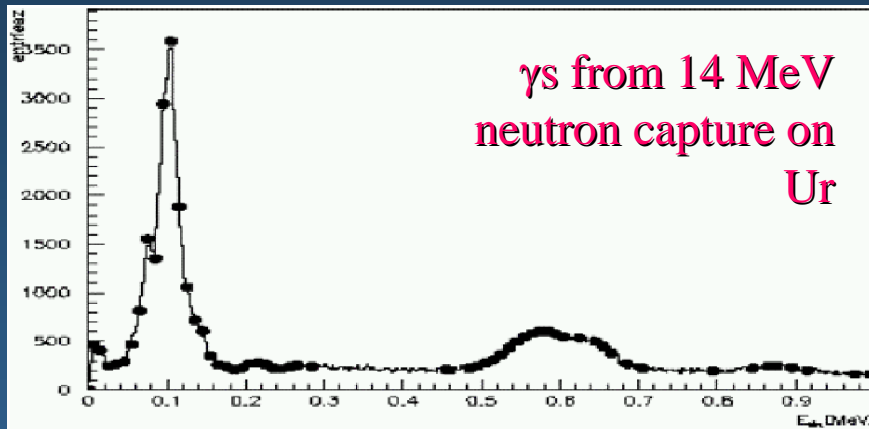
$(\pi^+, K^+)A$ at 250 GeV/c



Parameterised and data-driven hadronic models (2)

Other models are completely new, such as:

stopping particles: π^- , K^-
(relevant for μ/π PID detectors)

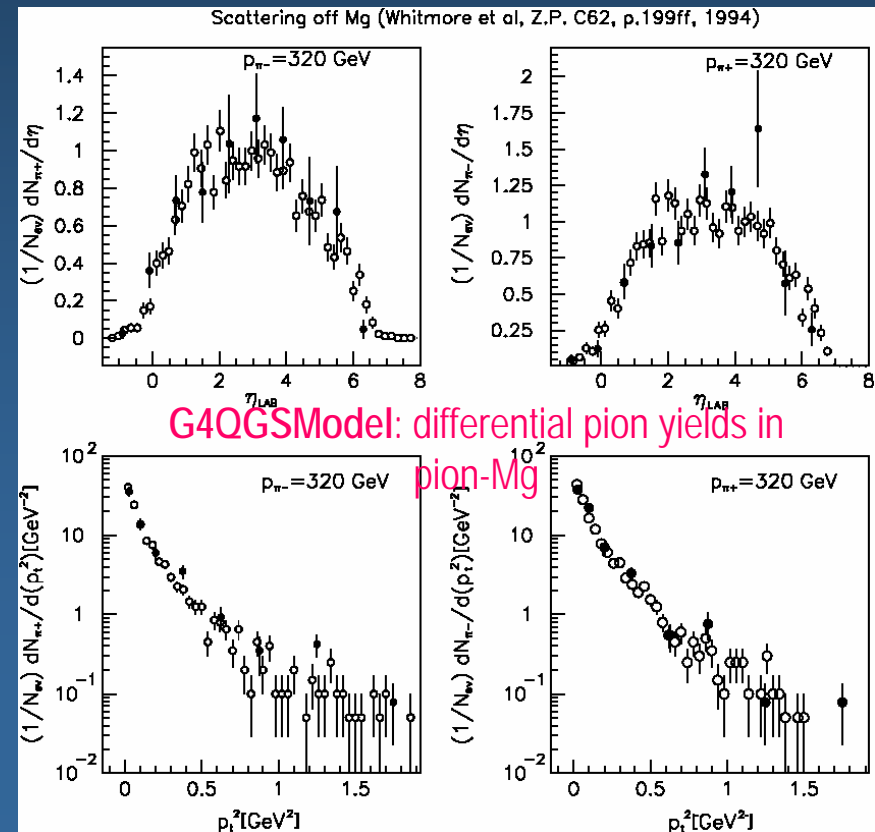
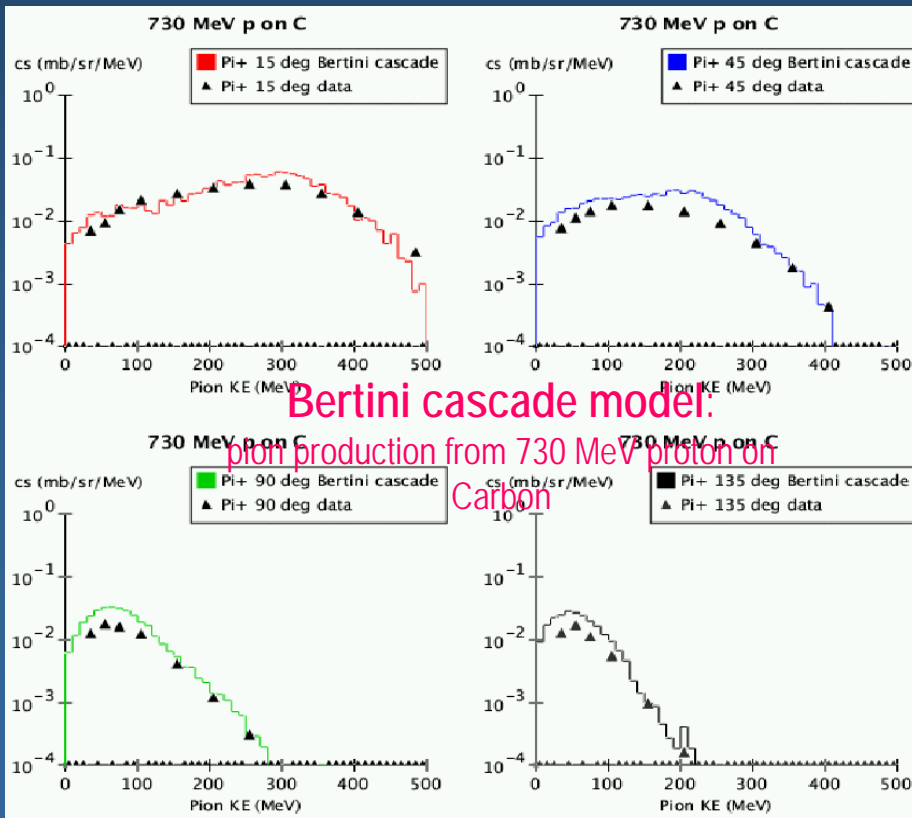


neutrons

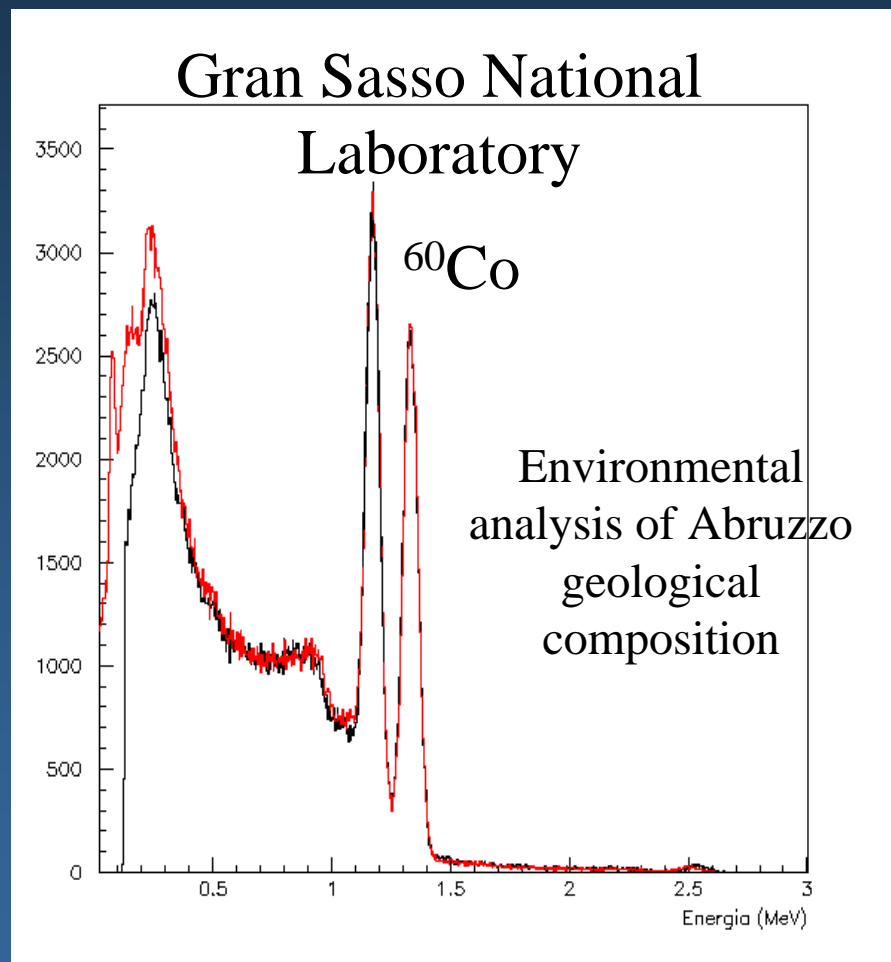
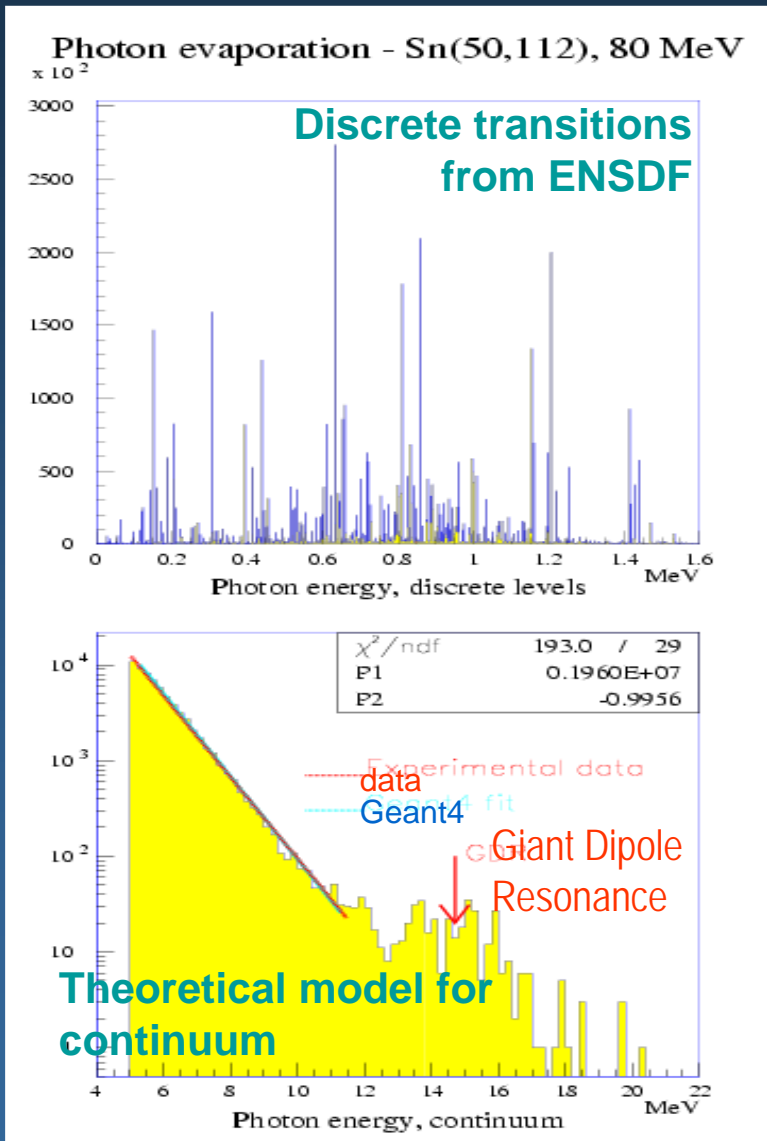
All worldwide existing databases
used in neutron transport
Brond, CENDL, EFF, ENDFB, JEF,
JENDL, MENDL etc.

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 Toolkit
 - 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/ γ 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

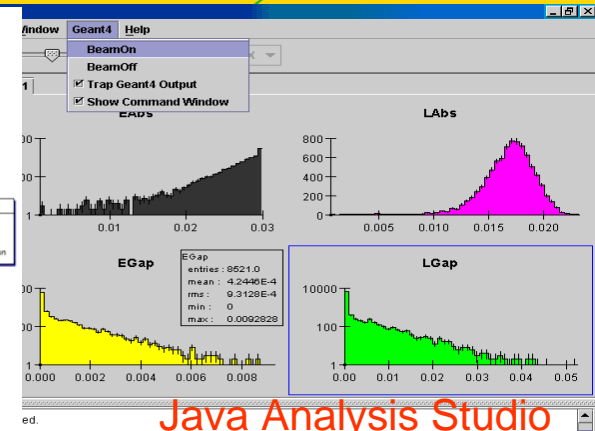
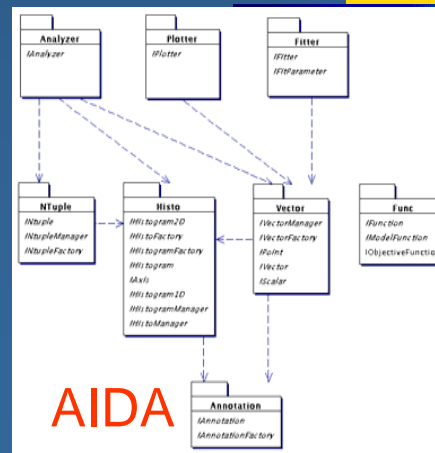
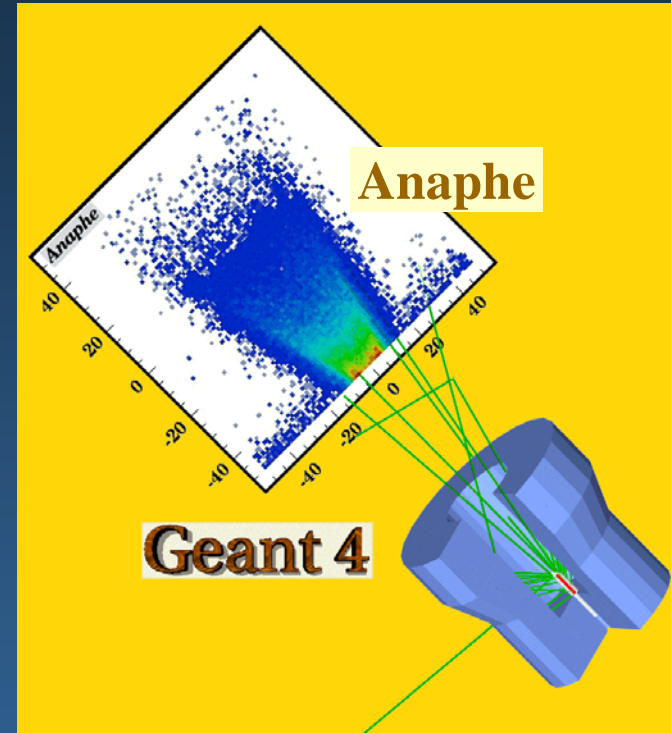
Through abstract interfaces

no dependence
minimize coupling of components

Similar approach

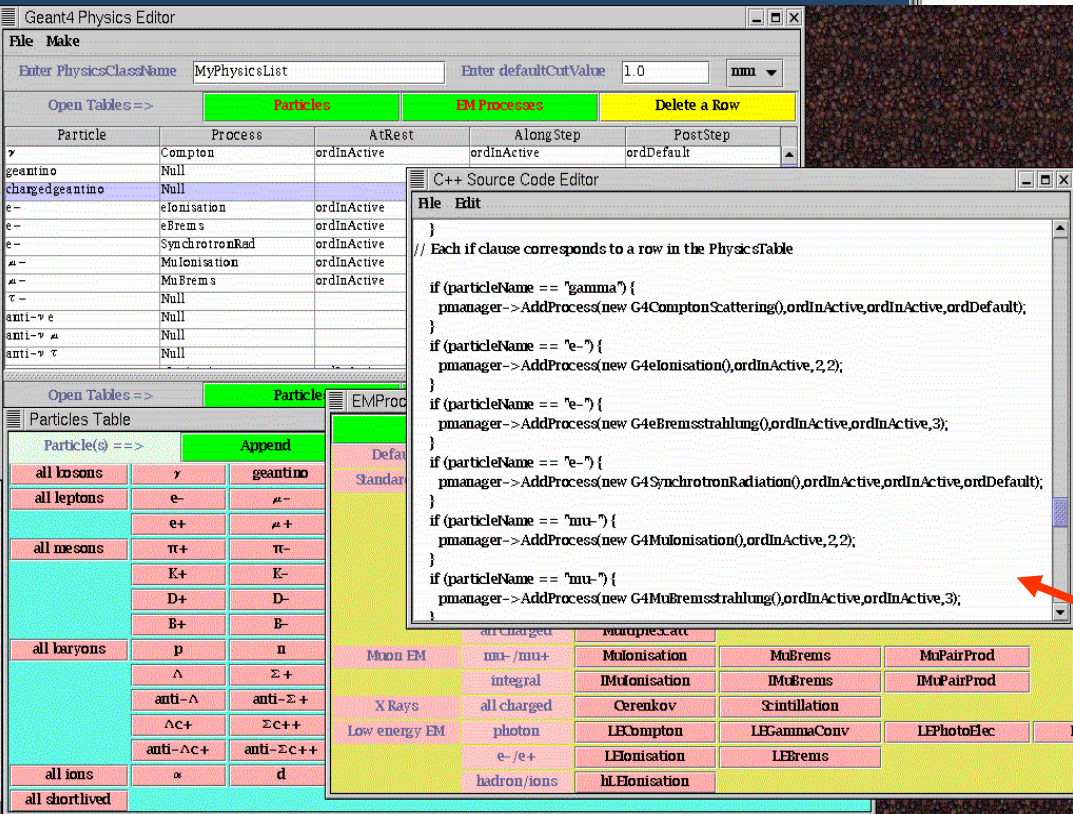
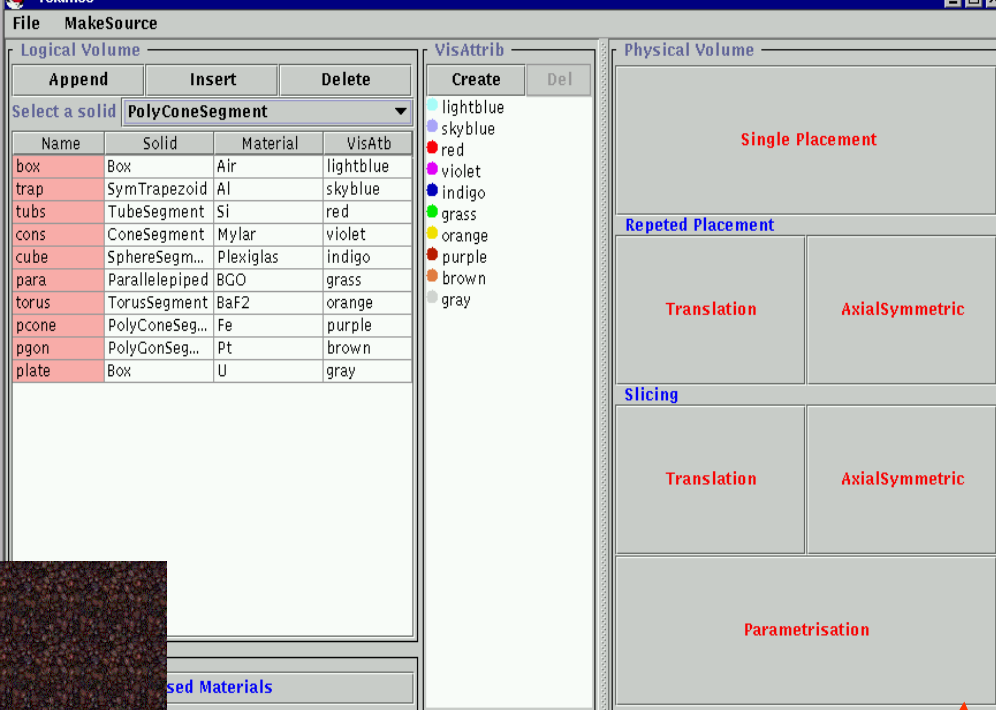
- Visualisation
- (G)UI
- Persistency
- Analysis

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

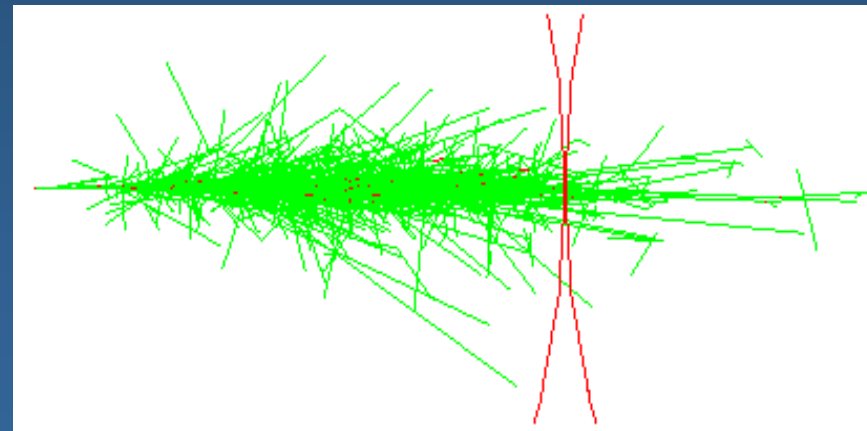
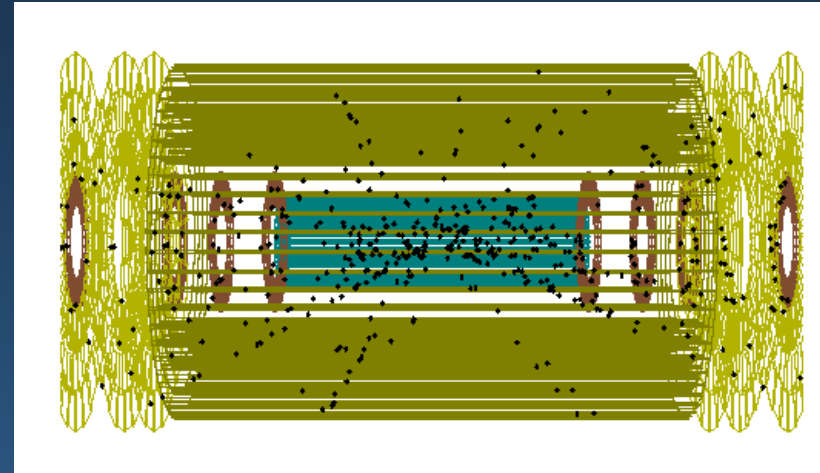
■ Control of several kinds of visualisation

- detector geometry
- particle trajectories
- hits in the detectors

■ Various drivers

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

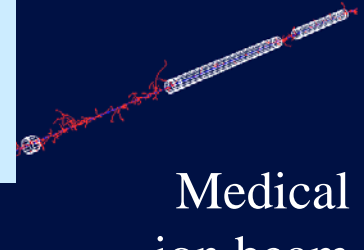
■ all handled through abstract interfaces



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

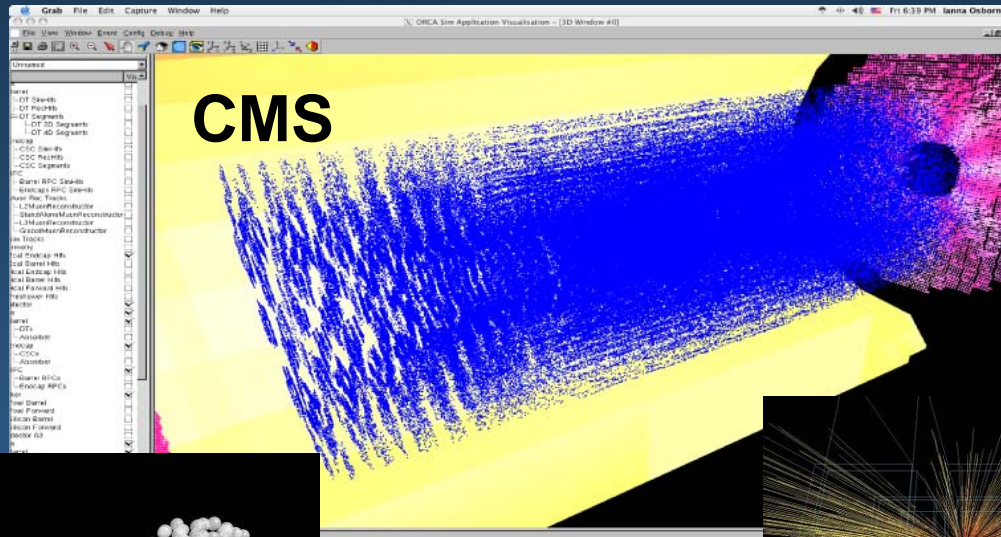


Medical ion beam

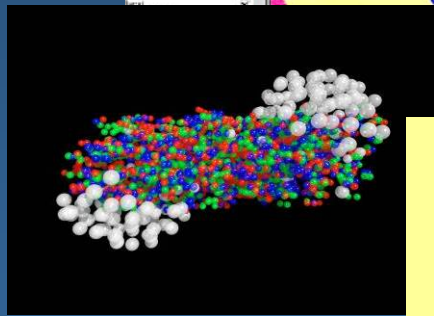
Geant4 simulation

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

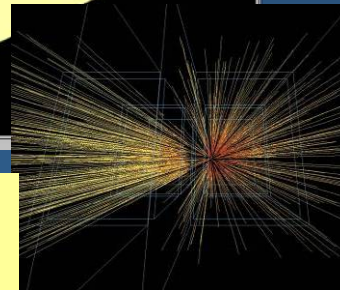
Cylinders : 14
Cubes : 6226
Lines : 51678



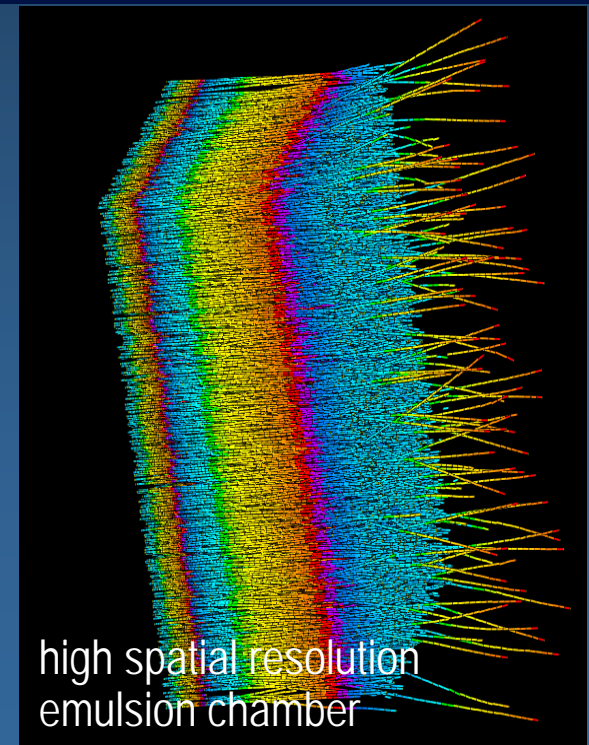
CMS



Events with > 50000 particles/event in detector acceptance



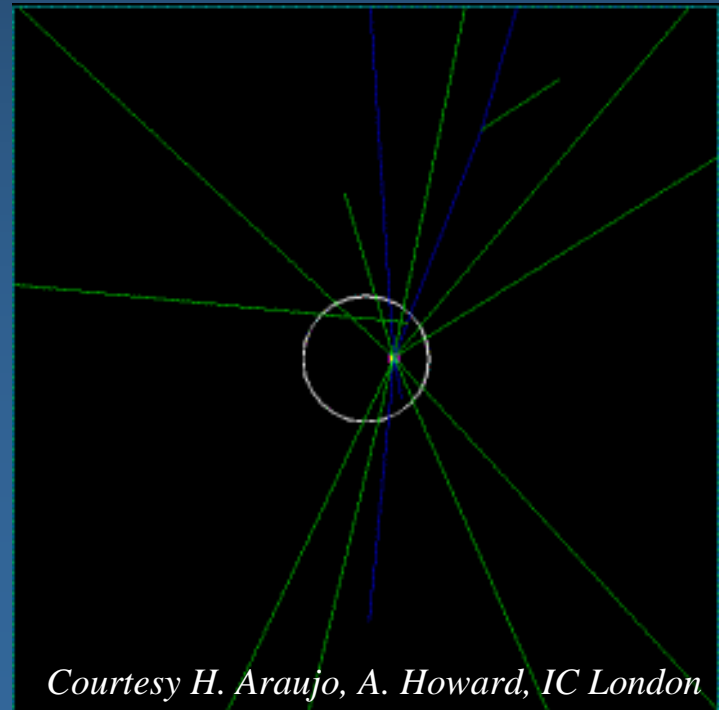
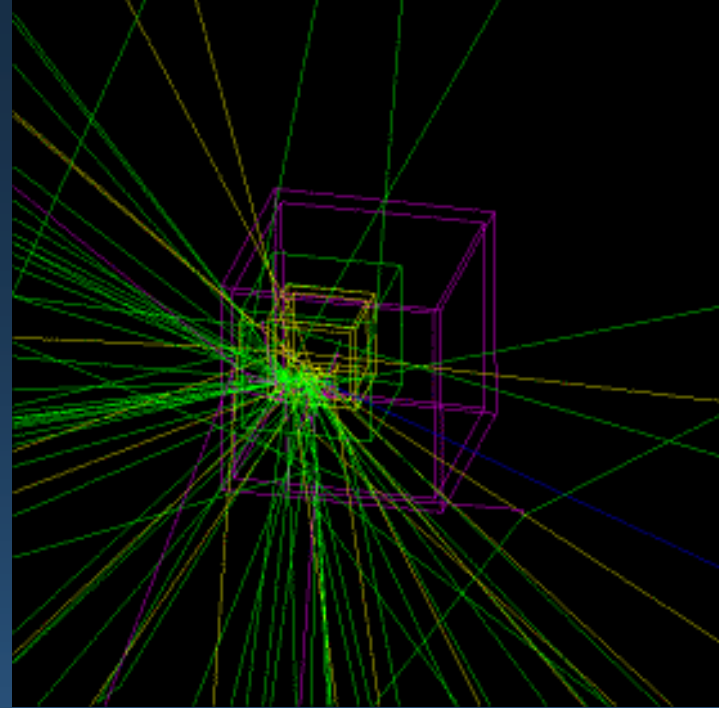
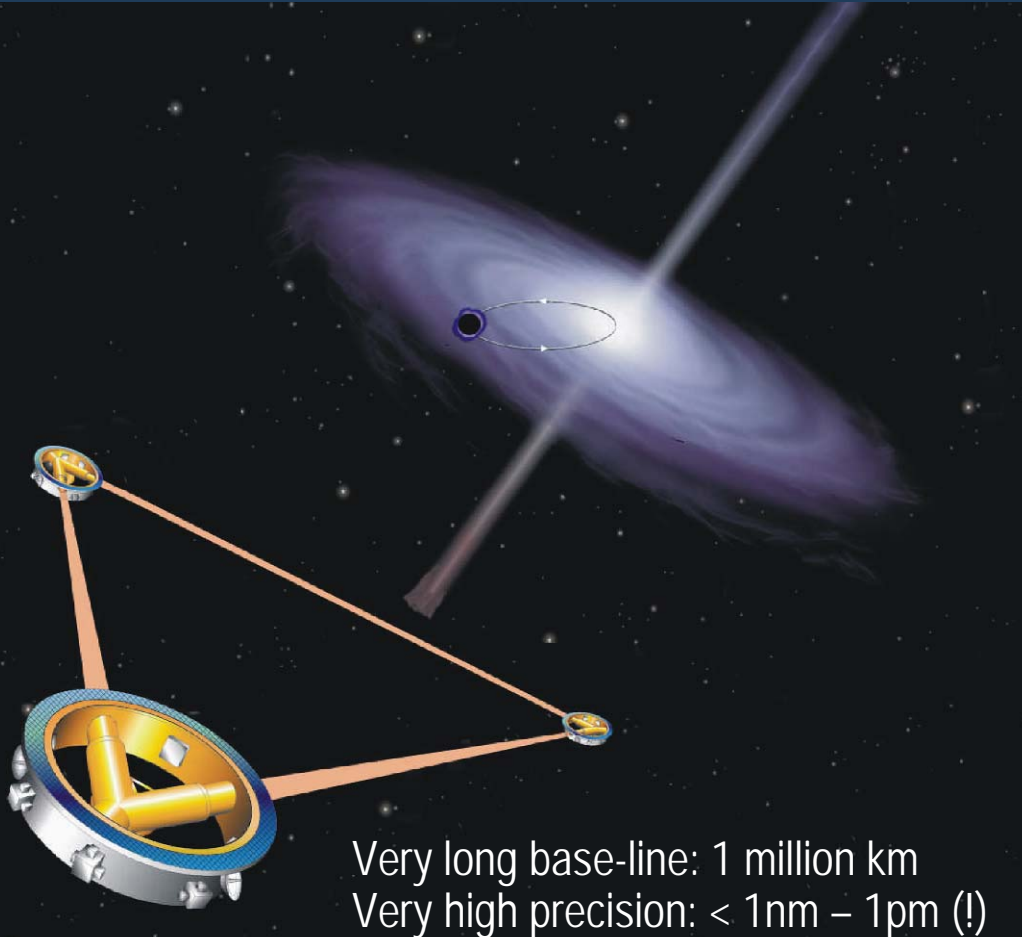
~ 180 minutes to simulate 1 event with 55K generator tracks



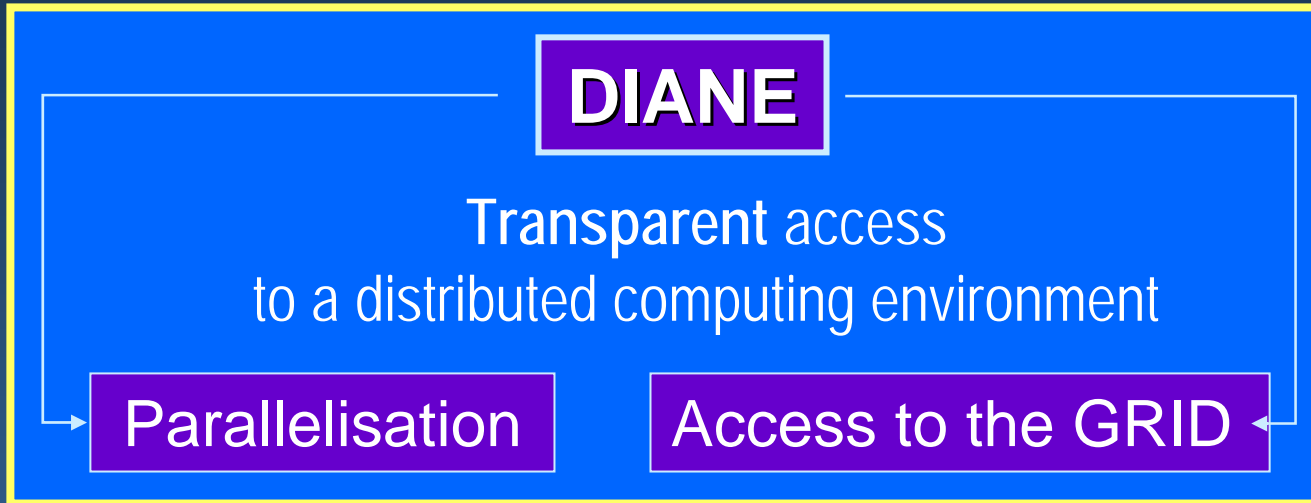
high spatial resolution emulsion chamber

LISA (gravitational waves)

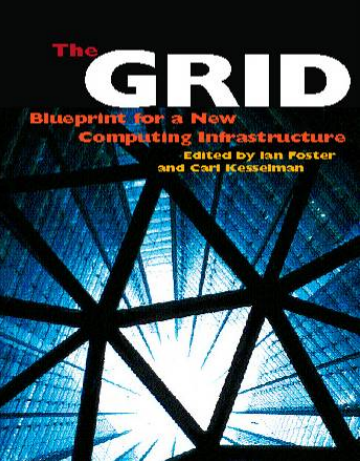
Geant4 relevant for evaluation of
space charging effects



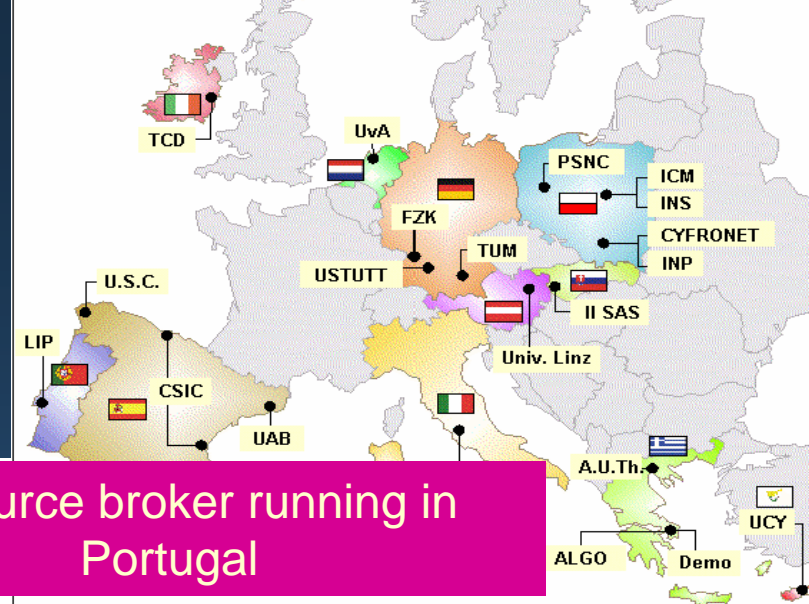
Access to distributed computing



- 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

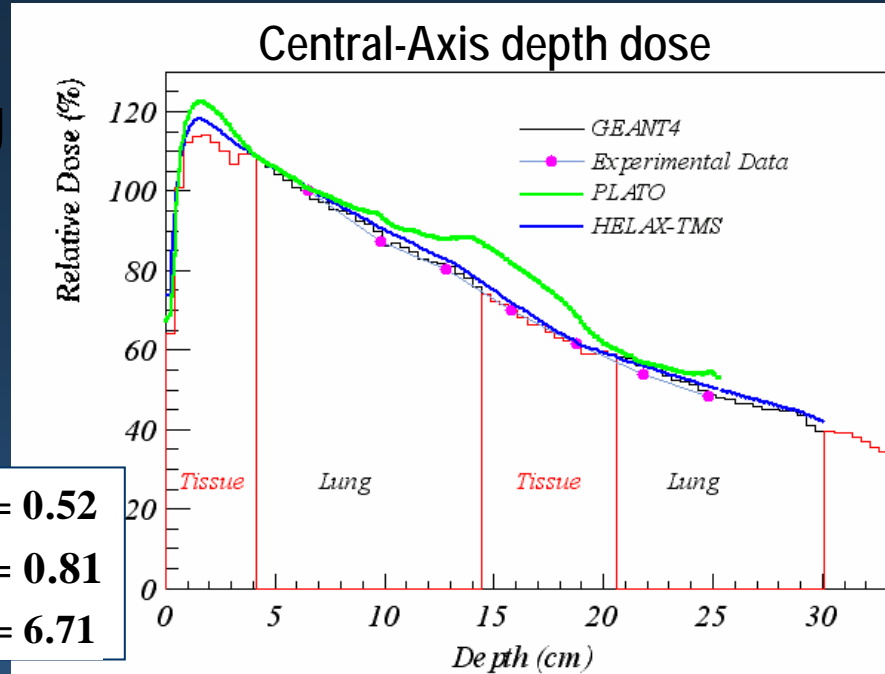
M. C. Lopes, L. Peralta, P. Rodrigues, A. Trindade

IPOFG-CROC Coimbra Oncological Regional Center
LIP - Lisbon

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

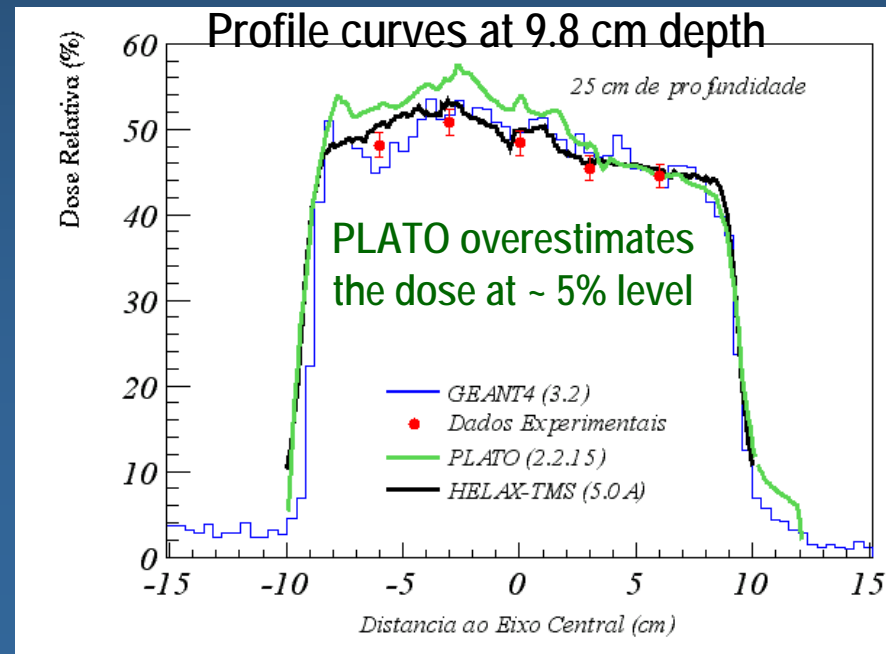
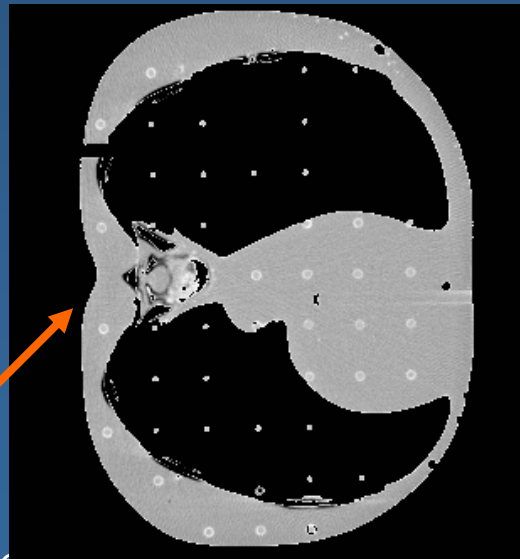
$$\chi^2 / \text{ndf (TMS)} = 0.81$$

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



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 & © Neiviana



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

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