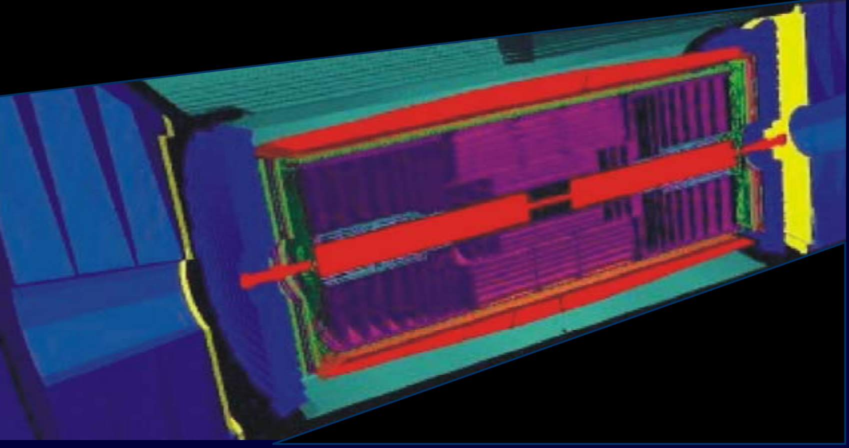
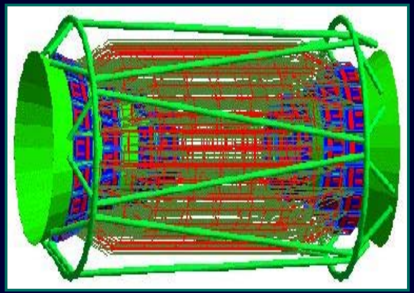
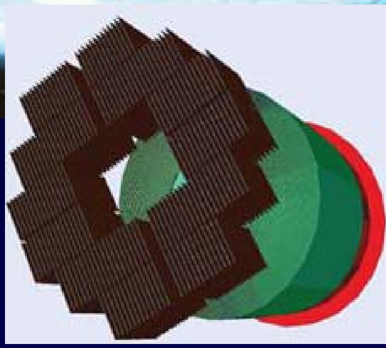
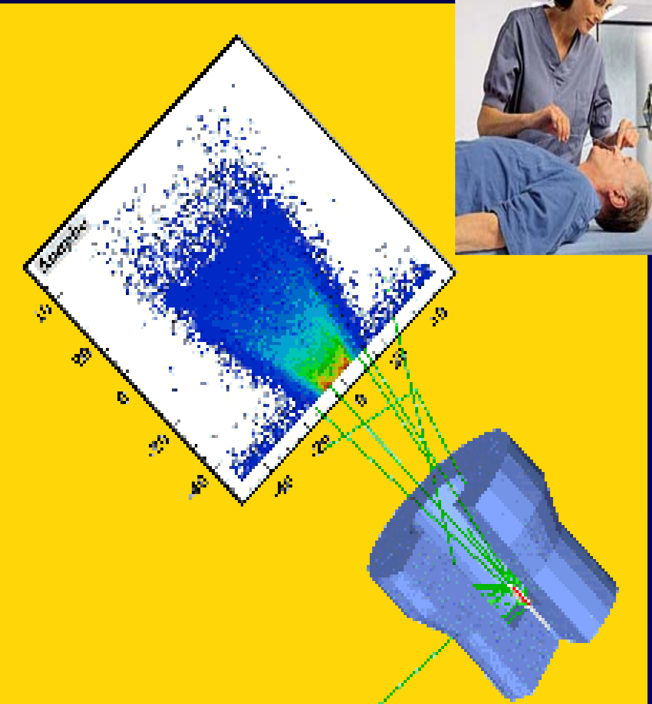






http://cern.ch/geant4/geant4.html
http://www.ge.infn.it/geant4/



Geant 4

Susanna Guatelli
INFN Genova
guatelli@ge.infn.it

17th March 2004,

NPL Workshop,Teddington, England

Contents

- Introduction to Geant4 Simulation Toolkit
- Why Geant4 for Medical Physics
- Geant4 toolkit functionality
- Geant4 physics models
- Validation of Geant4 physics models
- Exploration of the use of geographically distributed computing resources

What is Geant 4 ?

- OO Toolkit for the simulation of next generation HEP detectors
  - ...of the current generation too
  - ...not only of HEP detectors
  - already used also in nuclear physics, medical physics, astrophysics, space applications, radiation background studies etc.

- It is also an experiment of distributed software production and management, as a large international collaboration with the participation of various experiments, labs and institutes

- It is also an experiment of application of rigorous software engineering methodologies and Object Oriented technologies to the HEP environment

The Geant 4 kit

- Code
  - ~1M lines of code
  - continuously growing
  - publicly downloadable from the web
- Documentation
  - 6 manuals
  - publicly available from the web
- Examples
  - distributed with the code
  - navigation between documentation and examples code
  - various complete applications of (simplified) real-life experimental set-ups
- Platforms
  - Linux, SUN
  - Windows-NT: Visual C++
- Commercial software
  - None required
  - Can be interfaced
- Free software
  - CVS
  - gmake, g++
  - CLHEP
- Graphics & (G)UI
  - OpenGL, X11, OpenInventor, DAWN, VRML...
  - OPACS, GAG, MOMO...

Geant4 Collaboration

MoU based
Distribution, Development and User Support of Geant4

- Atlas, BaBar, CMS, HARP, LHCB
- CERN, JNL, KEK, SLAC, TRIUMF
- ESA, INFN, IN2P3, PPARC
- Frankfurt, Barcelona, Karolinska, Lebedev
- Serpukov, Novosibirsk, Pittsburg, Northeastern, Helsinki

- Collaboration Board
  - manages resources and responsibilities
- Technical Steering Board
  - manages scientific and technical matters
- Working Groups
  - do maintenance, development, QA, etc.

Budker Inst. of Physics
IHEP Protvino
MEPHI Moscow
Pittsburg University

The foundation

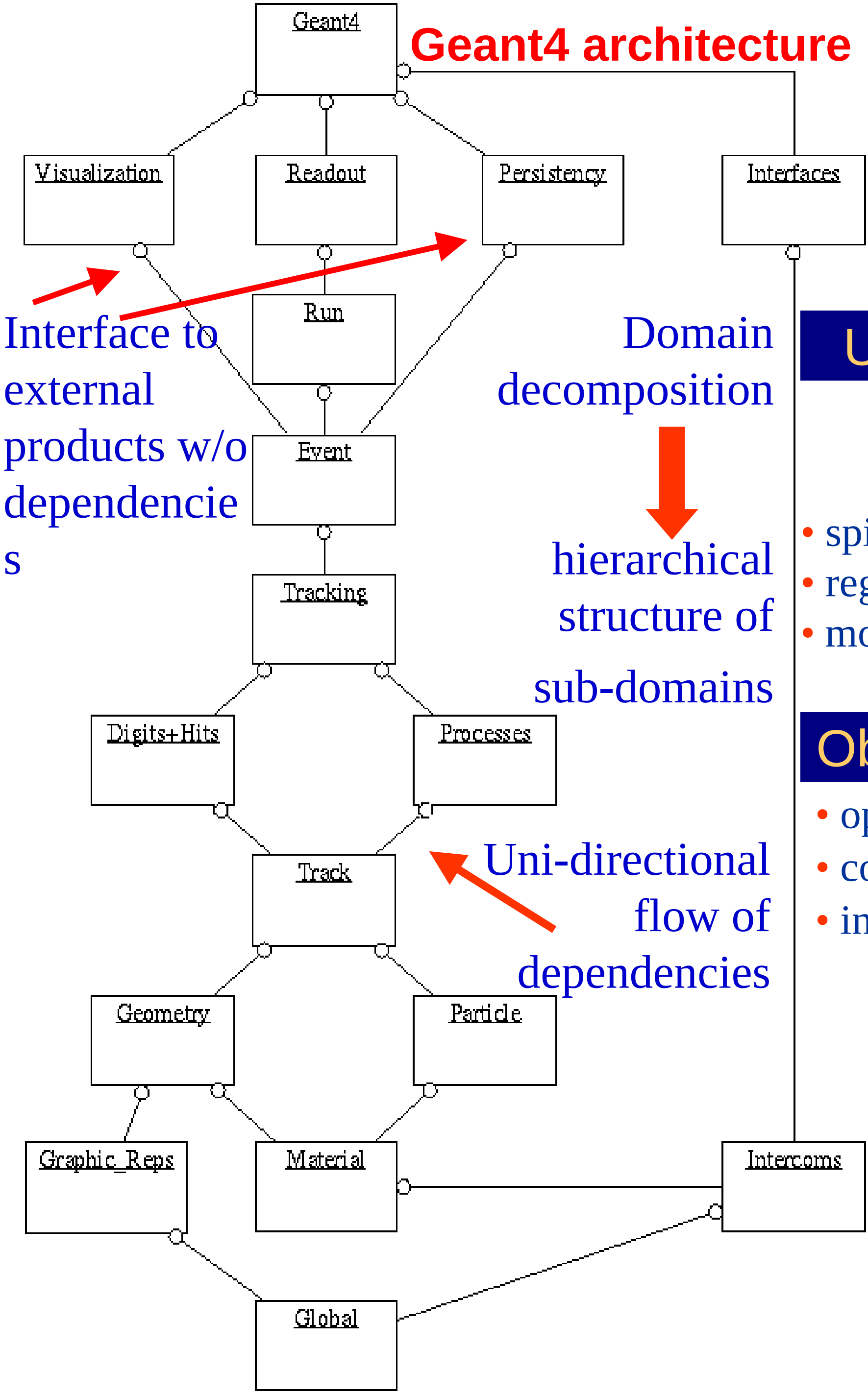
What characterizes Geant4

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, <u>differently from the concept of packages</u>, 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

Why Geant4 for Medical Physics

Advanced **functionality**
in geometry, physics, visualisation etc.

Specific facilities
controlled by a friendly UI

A rigorous
software process

Extensibility
to accomodate new user requirements

What in HEP software is relevant to the bio-medical community?

Quality Assurance
based on sound software engineering

Transparency
of physics

Independent validation
by a large user community worldwide

User support
from experts

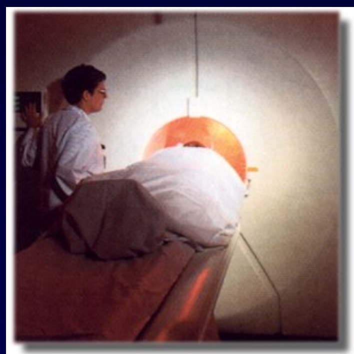
Adoption of **standards**
wherever available

Use of **evaluated data libraries**

Geant4 applications in Medical Physics

- Verification of conventional radiotherapy treatment planning (as required by protocols)
- Investigation of innovative methods of radiotherapy
- Radiodiagnostic
- Dosimetric studies at cellular level

Geant4
DICOM Interface



file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....................DICM....UL......
....OB............UI..1.2.840.10008.
5.1.4.1.1.2.....UI..1.3.12.2.1107.5.
1.4.40238.5.0.14178572411846....UI..
1.2.840.10008.1.2.1.....UI..1.3.12.2
.1107.5.1.4.....SH..SIEMENS_S5VA30A
....CS..ISO_IR 100....CS˝.ORIGINAL\P
RIMARY\AXIAL\CT_SOM5 SPI....UI..1.2.
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0 ..2.TM..094324.432987 ..3.TM..0943
24.432987 ..P.SH....'.CS..CT..p.LO..
SIEMENS ....LO..HOTEL-DIEU DE QUEBEC
....ST$.COTE DU PALAIS.QUEBEC.QUEBEC
.CANADA ....PN......SH..HNCT40238 ..
```


Developed by L. Archambault, L. Beaulieu, V.-H. Tremblay
(Univ. Laval and l'Hôtel-Dieu, Québec)

Model of complex structures

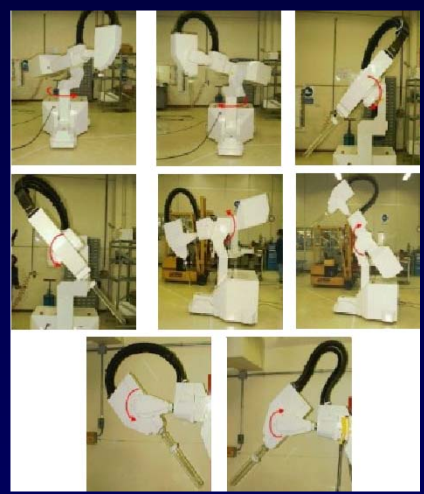
Model patient's anatomy in A Geant4 application

Model of beam lines

IntraOperative Radiation Therapy (IORT)

- Electron beam

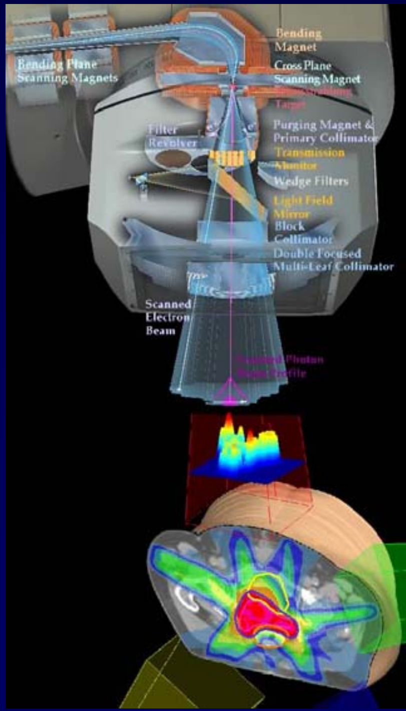
IORT Novac7



G. Barca*, F. Castrovillari**, D. Cucè**,
E. Lamanna**, M. Veltri*
** Azienda Ospedaliera (Hospital) of Cosenza*
***Physics Dep., UNICAL & INFN, Cosenza*

Treatment Head

- High energy electron beam, 50 MeV



IST, INFN Genova
F. Foppiano,
M. G. Pia,
M. Piergentili

Geant4 applications in radiodiagnostic

GATE Collaboration

- Geant4 application for tomographic emission (GATE) is a recently developed simulation platform based on Geant4, specifically designed for PET and SPECT studies.

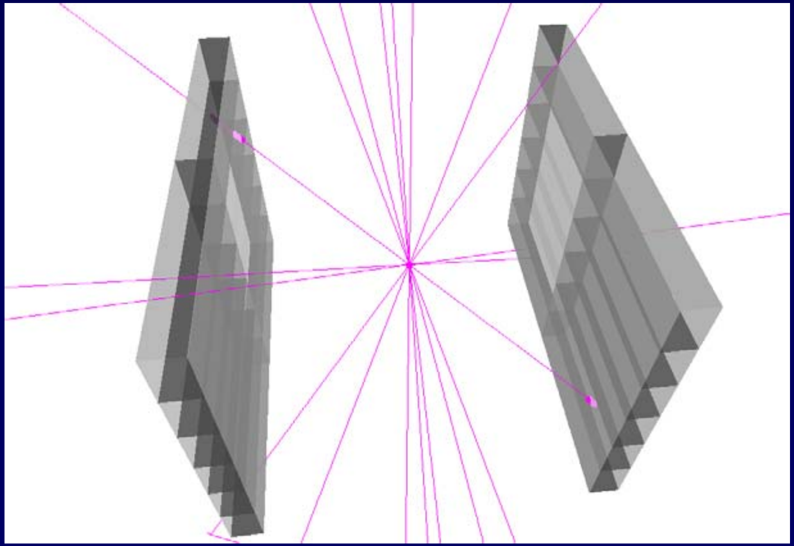
Experimental set-up changing with time

PEM

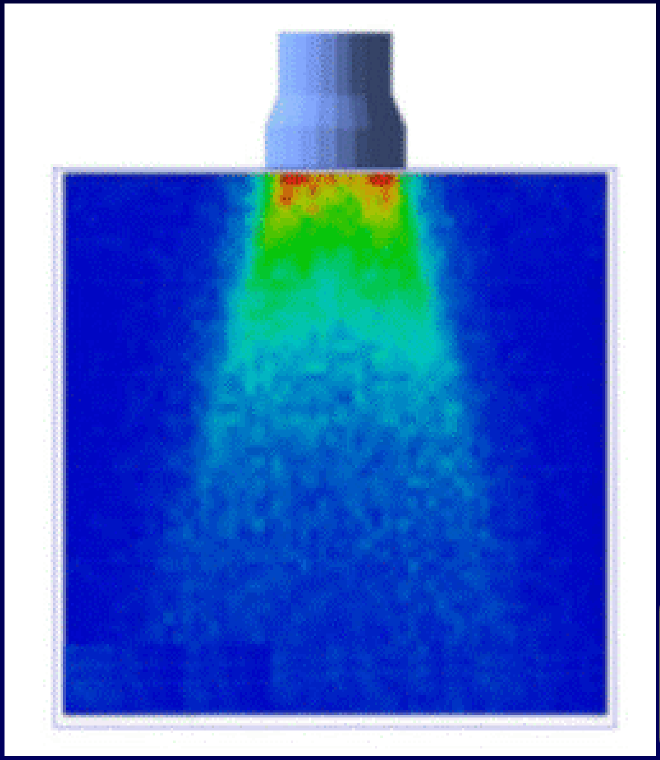
- Positron Emission Mammography (PEM)

M. C. Lopes[1], L. Peralta[2], P. Rodrigues[2], A. Trindade[2]

[1] IPOFG-CROC Coimbra Oncological Regional Center - [2] LIP - Lisbon



Dosimetric system for brachytherapy



Low Energy Physics for accurate dosimetry

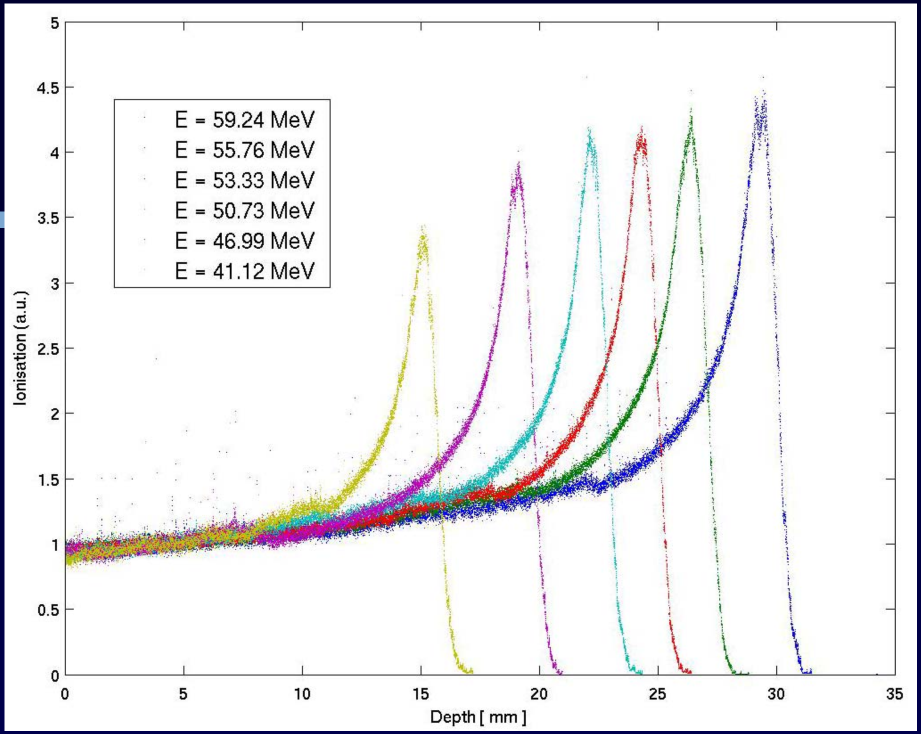
Collaboration of frameworks

Analysis, UI, Visualisation,
Access to distributed computing resources

Dosimetry for all brachytherapic devices

F. Foppiano[1], S. Guatelli[2], M.G. Pia[2], J. Moscicki[3]
1. IST Genova, 2. INFN Genova, 3. CERN

Geant4 Hadrontherapy Application



Electromagnetic and hadronic Interactions for protons and ions (and secondaries particles)

Proton beam line

G.A.P.Cirrone, G.Cuttone, S.Lo Nigro, L.Raffaele, G.M.Sabini (LNS, INFN, IT)

Shielding and radioprotection in space missions

- Collaboration ESA, ALENIA SPAZIO, INFN Genova in AURORA project context

G.Brambati1,V.Guarnieri1, S.Guatelli2, C. Lobascio1,P.Parodi1, M. G. Pia2, R. Rampini
1.ALENIA SPAZIO, Torino, Italy,2.INFN Genova, Italy

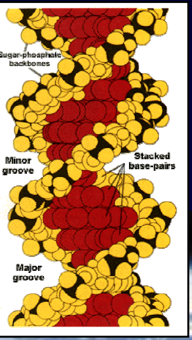
- Geant4 application for shielding and astronauts' radioprotection studies

AURORA
explore the solar system and the Universe

Geant4 application in Medical Physics not only in hospitals treatments

Geant4-DNA

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



Geant4 application in Radiobiology

CERN

IST

INFN
ISTITUTO NAZIONALE DI FISICA NUCLEARE

KONGL. CAROLINSKA MEDICO CHIRURGISKA INSTITUTET

The functionality

What Geant4 can do
How well it does it

Tutorial material

- Geant4 User Documentation and further training material can be found at Geant4 web site: http://cern.ch/geant4

- After this course, you may profit of Geant4 user support, provided by the Geant4 Collaboration
  - including a User Forum accessible through HyperNews (link from Geant4 homepage)

- Geant4 Course

  IEEE Nuclear Science Symposium and Medical Imaging Conference, Rome, October 2004
  www.ge.infn.it/geant4/events

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
  - tracking is independent from particle type
  - it is possible to add new physics processes without affecting the 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*

Describe the experimental set-up

- construct all necessary materials
- define shapes/solids required to describe the geometry
- construct and place volumes of your detector geometry
- define sensitive detectors and identify detector volumes to associate them to
- associate magnetic field to detector regions
- define visualisation attributes for the detector elements

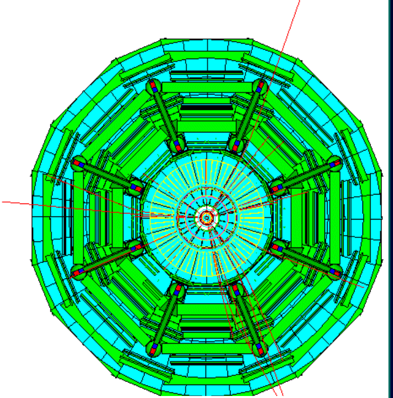
Materials

- Different kinds of materials can be defined
  - isotopes ⟺ G4Isotope
  - elements ⟺ G4Element
  - molecules ⟺ G4Material
  - compounds and mixtures ⟺ G4Material

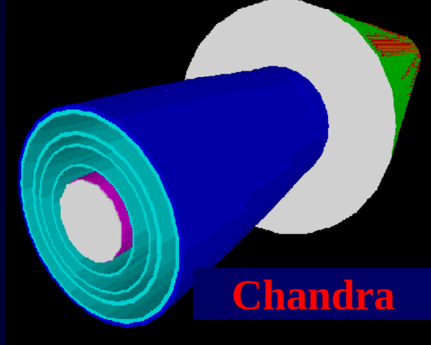
- Attributes associated:
  - temperature
  - pressure
  - state
  - density

It is possible to define homogeneous and heterogeneous materials

Geometry



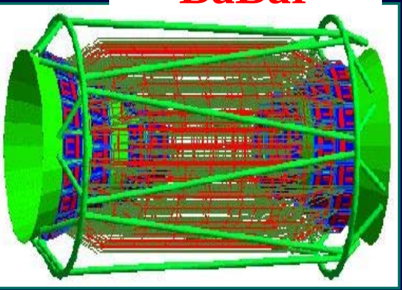
ATLAS



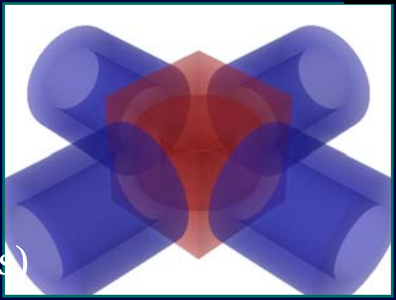
Role: detailed detector description
and efficient navigation

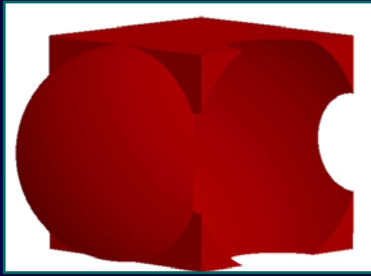
Multiple representations

(same abstract interface)

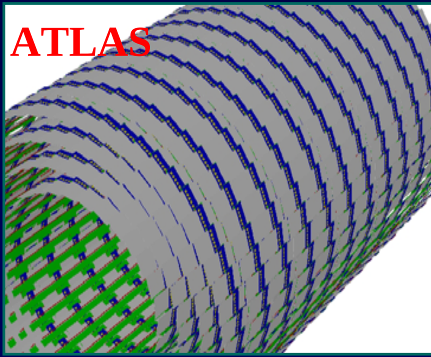


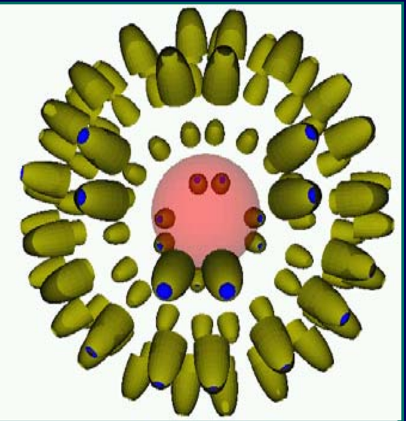
BaBar





- **CSG** (**C**onstructed **S**olid **G**eometries)
  - simple solids
- **STEP extensions**
  - polyhedra,, spheres, cylinders, cones, toroids, etc.
- **BREPS** (**B**oundary **REP**resented **S**olids)
  - volumes defined by boundary surfaces
  - include solids defined by NURBS *(Non-Uniform Rational B-Splines)*



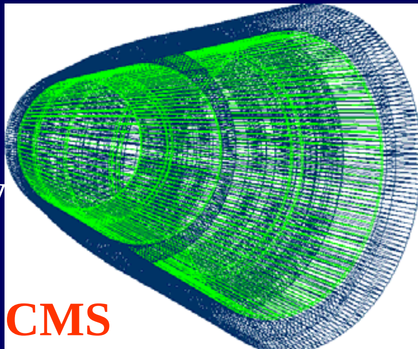


Borexino

CAD exchange: ISO STEP interface

Fields: of variable non-uniformity and differentiability

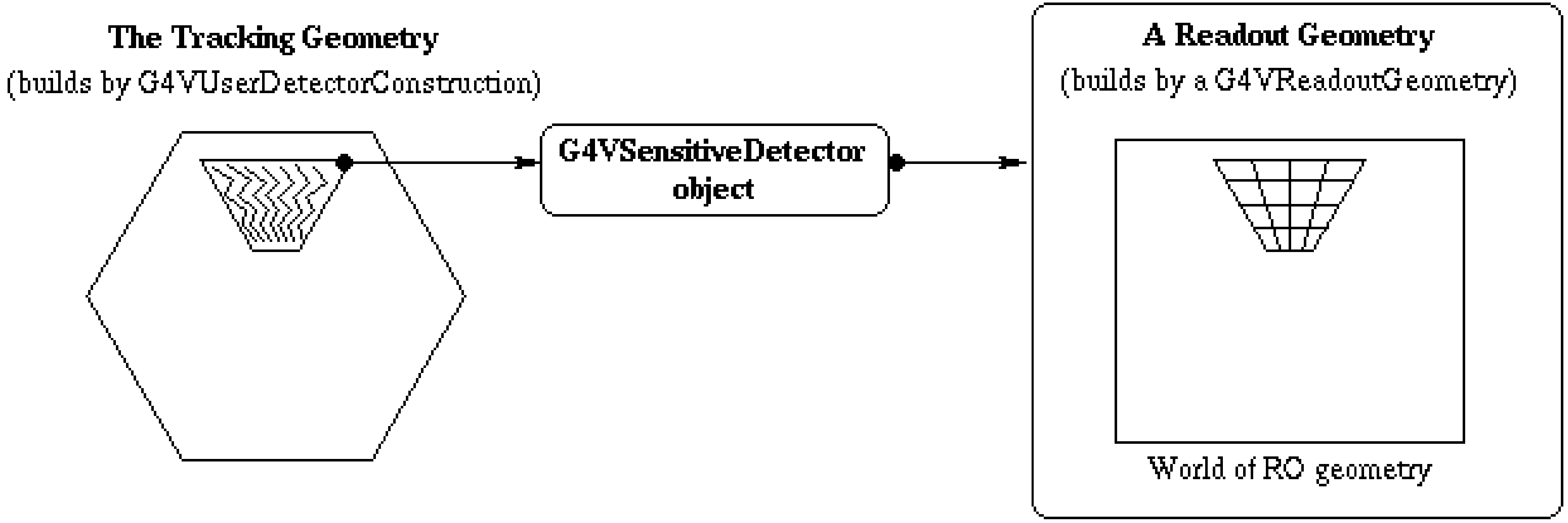
External tool for g3tog4 geometry conversion



Read-out Geometry

Readout geometry is a virtual and artificial geometry

- it is associated to a *sensitive detector*
- can be defined in parallel to the real detector geometry
- helps optimising the performance



Hits and Digis

- A sensitive detector creates hits using the information provided by the G4Step
- One can store various types of information in a hit
  - position and time of the step
  - momentum and energy of the track
  - energy deposition of the step
  - geometrical information
  - etc.
- A Digi represents a detector output
  - e.g. ADC/TDC count, trigger signal
- A Digi is created with one or more hits and/or other digits
- Hits collections are accessible
  - through G4Event at the end of an event
  - through G4SDManager during processing an event

Generating primary particles

- Interface to Event Generators
  - through ASCII file for generators supporting /HEPEVT/
  - abstract interface to Lund++

- Various utilities provided within the Geant4 Toolkit
  - ParticleGun
    - beam of selectable particle type, energy etc.
  - GeneralParticleSource
    - provides sophisticated facilities to model a particle source
    - used to model space radiation environments, sources of radioactivity in underground experiments etc.
  - you can write your own, inheriting from *G4VUserPrimaryGeneratorAction*

G4GeneralParticleSource

2D Surface sources	3D Surface sources	Volume sources	Angular distribution	Energy spectrum
• circle • ellipse • square • rectangle • Gaussian beam profile	• sphere • ellipsoid • cylinder • paralellapiped (incl. cube & cuboid)	• sphere • ellipsoid • cylinder • paralellapiped (incl. cube & cuboid)	• isotropic • cosine-law • user-defined (through histograms)	• mono-energetic • Gaussian • Linear • Exponential • power-law • bremsstrahlung • black-body • CR diffuse • user-defined (through histograms or point-wise data)

Physics: general features

- Ample variety of physics functionalities
- Uniform treatment of electromagnetic and hadronic processes
- Abstract interface to physics processes
  - Tracking independent from physics
- Distinction between processes and models
  - often multiple models for the same physics process (complementary/alternative)
- Open system
  - Users can easily create and use their own models
- <u>Transparency</u> *(supported by encapsulation and polymorfism)*
  - Calculation of cross-sections independent from the way they are accessed (data files, analytical formulae etc.)
  - Distinction between the calculation of cross sections and their use
  - Calculation of the final state independent from tracking
- Modular design, at a fine granularity, to expose the physics
- Explicit use of units throughout the code
- Public distribution of the code, from one reference repository worldwide

Select physics processes

- **Geant4 does not have any default particles or processes**
  - even for the particle transportation, one has to define it explicitly

This is a ***mandatory*** and ***critical*** user's task

- Derive your own concrete class from the G4VUserPhysicsList abstract base class
  - define all necessary particles
  - define all necessary processes and assign them to proper particles
  - define production thresholds (in terms of range)

Read the Physics Reference Manual !

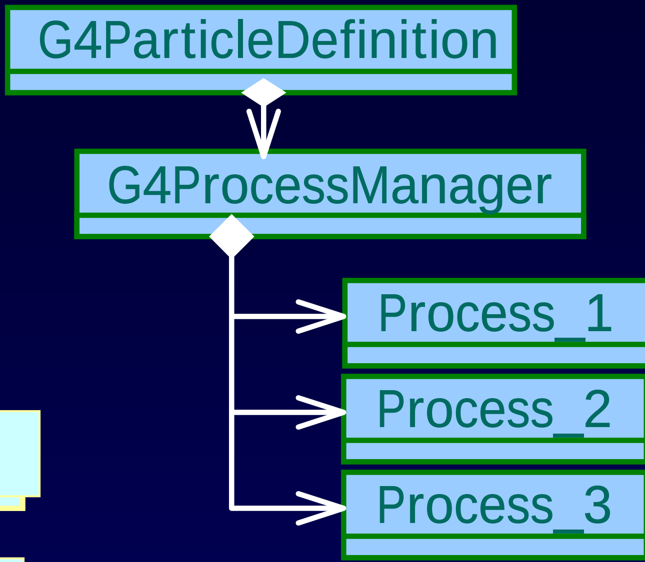
The Advanced Examples offer a guidance for various typical experimental domains

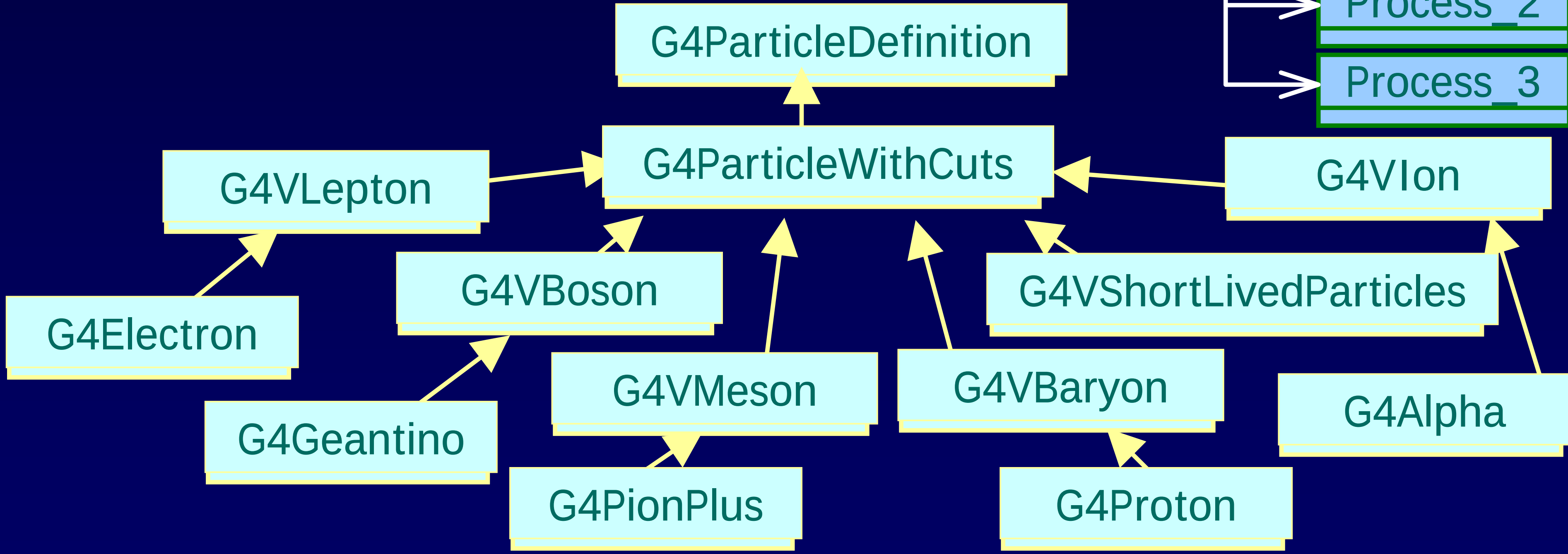
G4ParticleDefinition

- intrisic particle properties: *mass, width, spin, lifetime…*
- sensitivity to physics

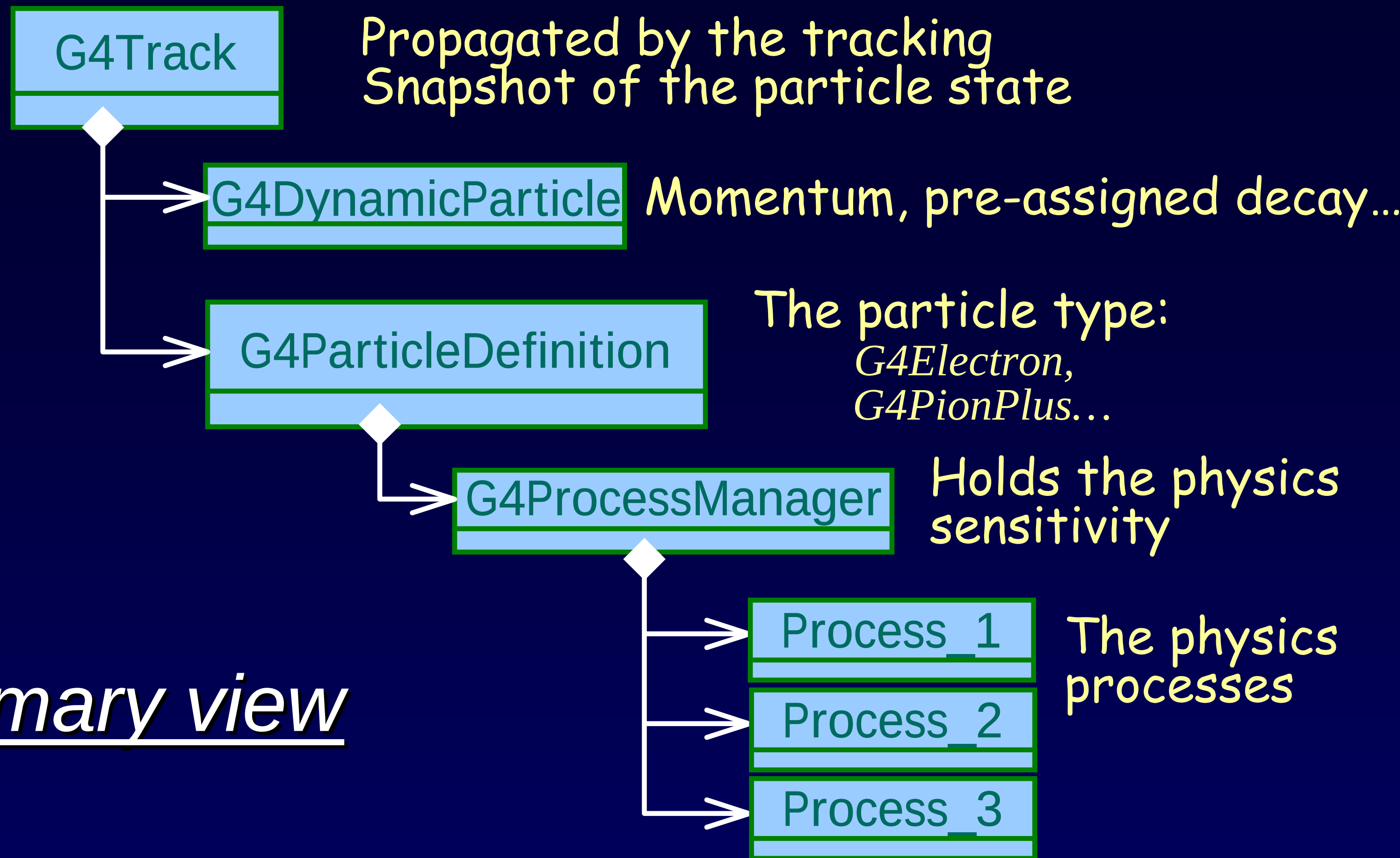
– This is realized by a G4ProcessManager attached to the G4ParticleDefinition

– The G4ProcessManager manages the list of processes the user wants the particle to be sensitive





G4ParticleDefinition is the base class for defining concrete particles



Summary view

The classes involved in building the PhysicsList are:

- the G4ParticleDefinition concrete classes
- the G4ProcessManager
- the processes

Cuts in Geant4

- In Geant4 there are no tracking cuts
  - particles are tracked down to a zero range/kinetic energy
- Only production cuts exist
  - i.e. cuts allowing a particle to be born or not
- Why are production cuts needed ?
- Some electromagnetic processes involve infrared divergences
  - this leads to an infinity [huge number] of smaller and smaller energy photons/electrons *(such as in Bremsstrahlung, δ-ray production)*
  - production cuts limit this production to particles above the threshold
  - the remaining, divergent part is treated as a continuous effect (i.e. *AlongStep* action)
- Fix the cut: compromise between calculation accuracy and CPU performance

Control, monitor and analyse the simulation

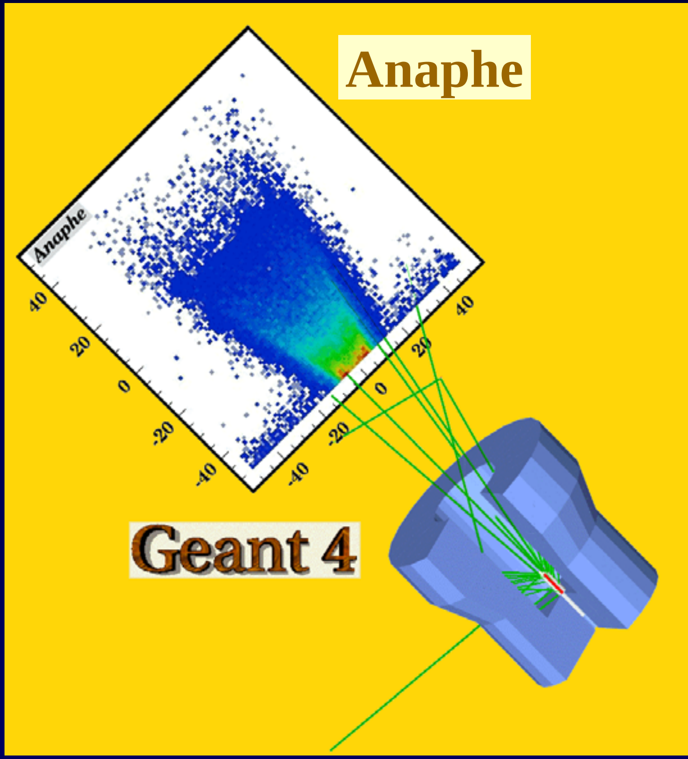
Interface to external tools in Geant4

Through <u>abstract interfaces</u>

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

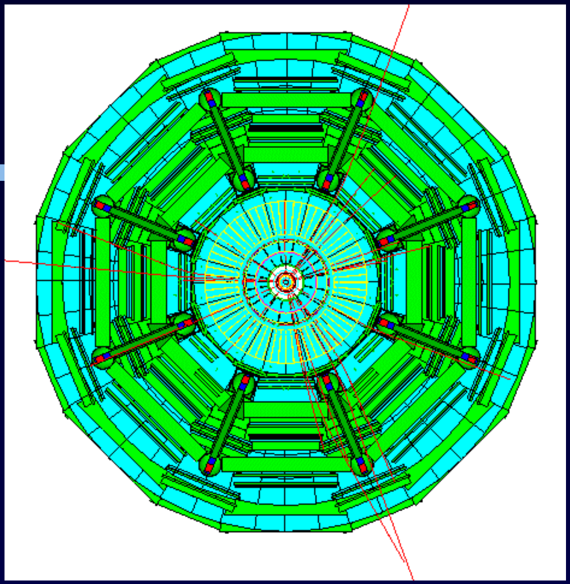
User Interface in Geant4

- Two phases of user actions
  - setup of simulation
  - control of event generation and processing
- Geant4 provides interfaces for various (G)UI:
  - G4UIterminal: C-shell like character terminal
  - G4UItcsh: tcsh-like character terminal with command completion, history, etc
  - G4UIGAG: Java based GUI
  - G4UIOPACS: OPACS-based GUI, command completion, etc
  - G4UIBatch: Batch job with macro file
  - G4UIXm: Motif-based GUI, command completion, etc

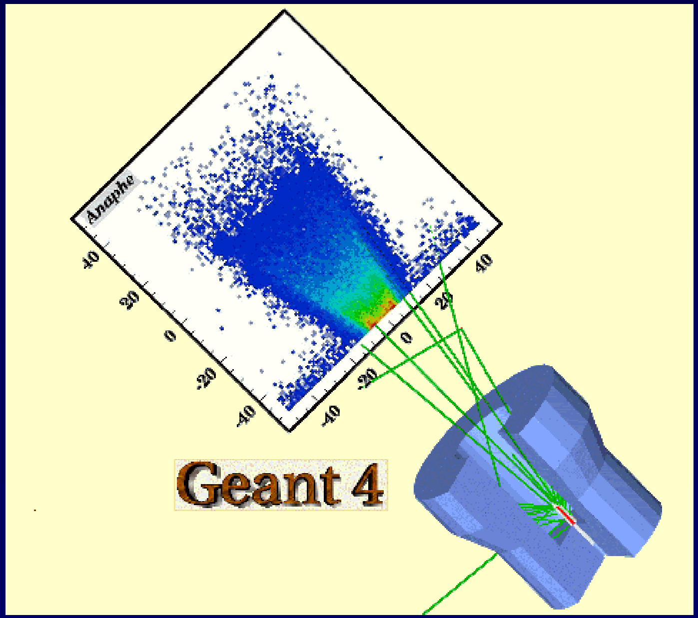
Visualisation

- Geant4 Visualisation must respond to varieties of user requirements
  - Quick response to survey successive events
  - Impressive special effects for demonstration
  - High-quality output to prepare journal papers
  - Flexible camera control for debugging geometry
  - Highlighting overlapping of physical volumes
  - Interactive picking of visualised objects
  - …

Visualisation



- Control of several kinds of visualisation
  - detector geometry
  - particle trajectories
  - hits in the detectors



- Visualisation drivers are interfaces to 3D graphics software
- You can select your favorite one(s) depending on your purposes such as
  - Demo
  - Preparing precise figures for journal papers
  - Publication of results on Web
  - Debugging geometry
  - Etc

Available Graphics Software

By default, Geant4 provides visualisation drivers, i.e. interfaces, for

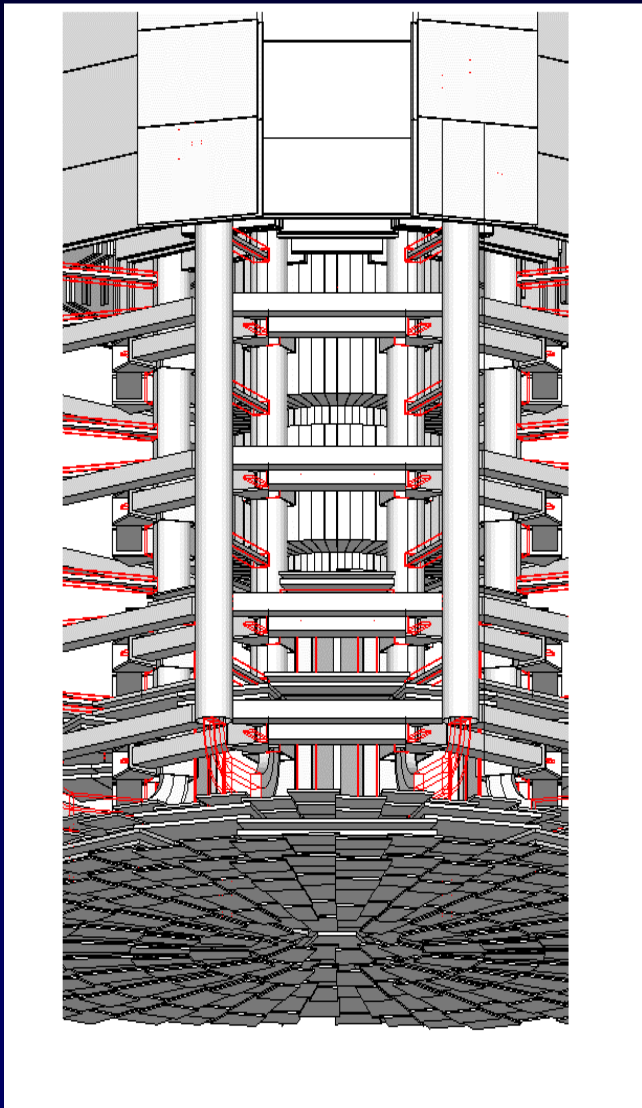
- DAWN : Technical high-quality PostScript output
- OPACS: Interactivity, unified GUI
- OpenGL: Quick and flexible visualisation
- OpenInventor: Interactivity, virtual reality, etc.
- RayTracer : Photo-realistic rendering
- VRML: Interactivity, 3D graphics on Web

Debugging tools: DAVID

- DAVID is a graphical debugging tool for detecting potential intersections of volumes

- Accuracy of the graphical representation can be tuned to the exact geometrical description
  - physical-volume surfaces are automatically decomposed into 3D polygons
  - intersections of the generated polygons are parsed
  - if a polygon intersects with another one, the physical volumes associated to these polygons are highlighted in colour (red is the default)

- DAVID can be downloaded from the web as an external tool for Geant4



Physics Models

Physics processes

Transparency

- Tracking independent from physics
- Final state independent from cross sections
- Use of public evaluated databases

- Object Oriented technology
  - implement or modify any physics process without changing other parts of the software
  - open to extension and evolution

- Electromagnetic and Hadronic Physics
  - Complementary/alternative physics models

Electromagnetic physics

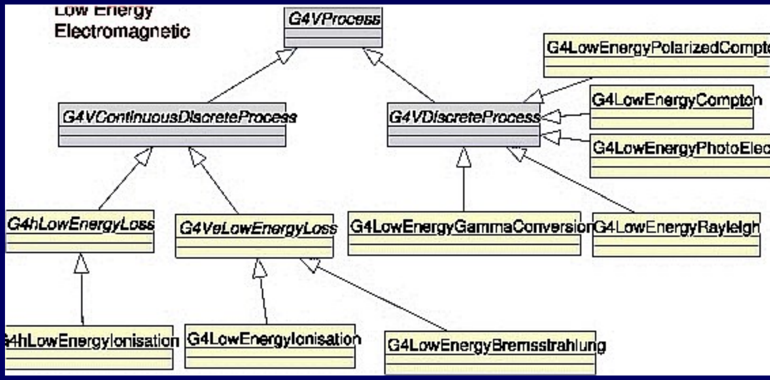
- electrons and positrons
- γ, X-ray and optical photons
- muons
- charged hadrons
- ions

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



Standard electromagnetic physics in Geant4

The model assumptions are:

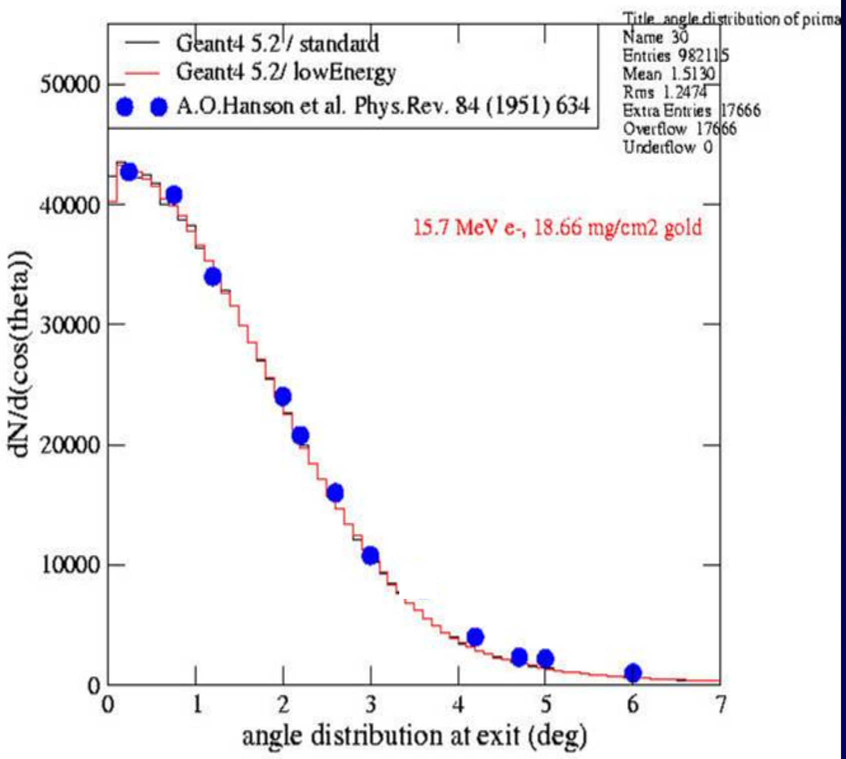
- The projectile has energy $\geq$ 1 keV
- Atomic electrons are quasi-free: their binding energy is neglected *(except for the photoelectric effect)*
- The atomic nucleus is free: the recoil momentum is neglected
- Matter is described as homogeneous, isotropic, amorphous

Standard electromagnetic processes

1 keV up to O(100 TeV)

- Multiple scattering
  - new model *(by L. Urbán)*
  - computes mean free path length and lateral displacement
- New energy loss algorithm
  - optimises the generation of δ 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



Requirements for LowE 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)

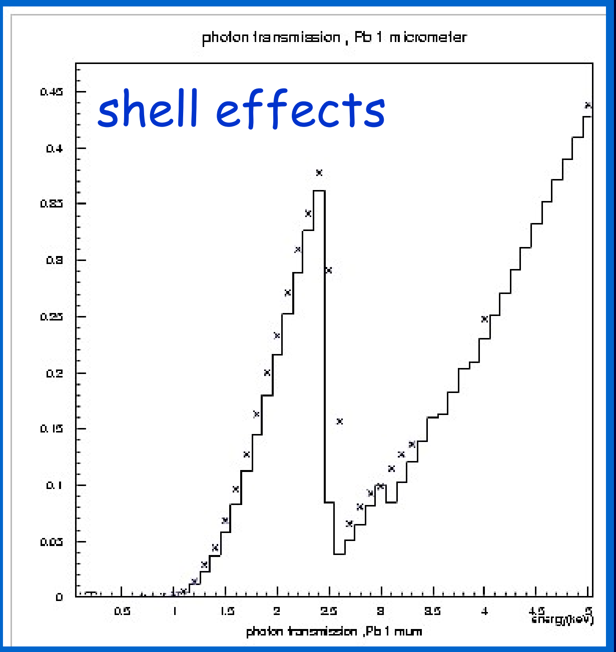
- **UR 2.1** The user shall be able to simulate electromagnetic interactions of positive charged hadrons down to < 1 KeV.
- **Need**: *Essential*
- **Priority**: *Required by end 1999*
- **Stability**: *T. b. d.*
- **Source**: *Medical physics groups, PIXE*
- **Clarity**: *Clear*
- **Verifiability**: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

Requirement from Medical Physics

The Geant4 Low Energy package

- A package in the Geant4 electromagnetic package
  - *geant4/source/processes/electromagnetic/lowenergy/*
- A set of processes extending the coverage of electromagnetic interactions in Geant4 down to "*low*" energy
  - 250 eV *(in principle even below this limit)/100* ev for electrons and photons
  - down to the approximately the ionisation potential of the interacting material for hadrons and ions
- A set of processes based on detailed models
  - shell structure of the atom
  - precise angular distributions
- Complementary to the "standard" electromagnetic package

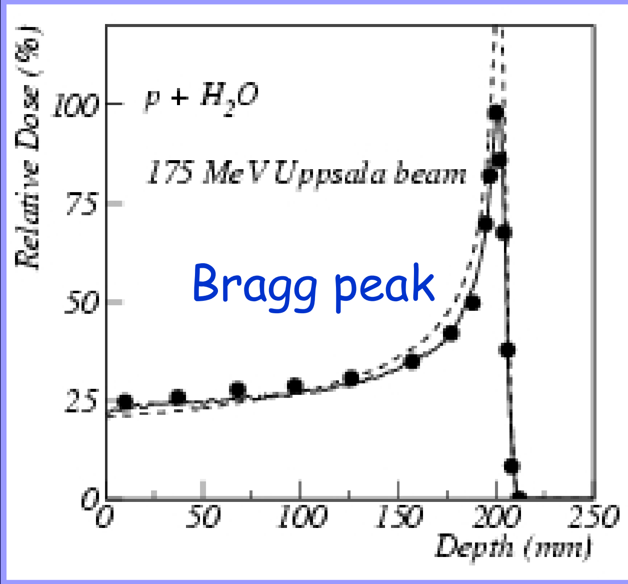
Low energy e.m. extensions



e,γ down to 250 eV

Based on EPDL97, EEDL and EADL evaluated data libraries

Fundamental for neutrino/dark matter experiments, space and medical applications, antimatter spectroscopy etc.



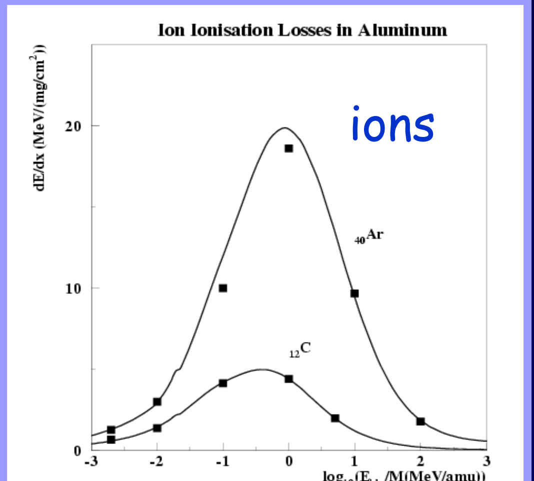
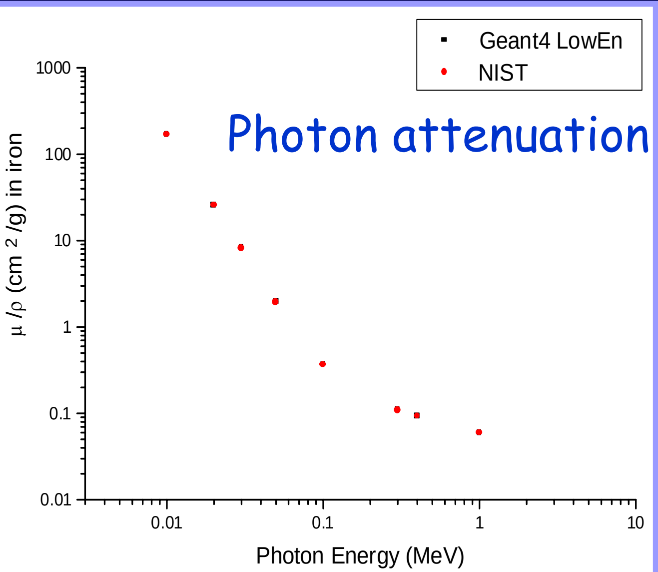
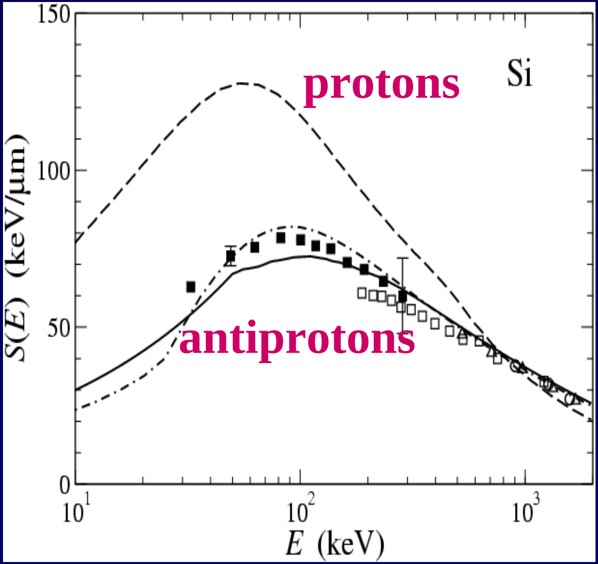


Figure 9: Ion electronic stopping power in aluminum. Points - the best fit on the data from Ref.[12], solid line - GEANT4 parameterisation. The accuracy of the data is about 5 %.

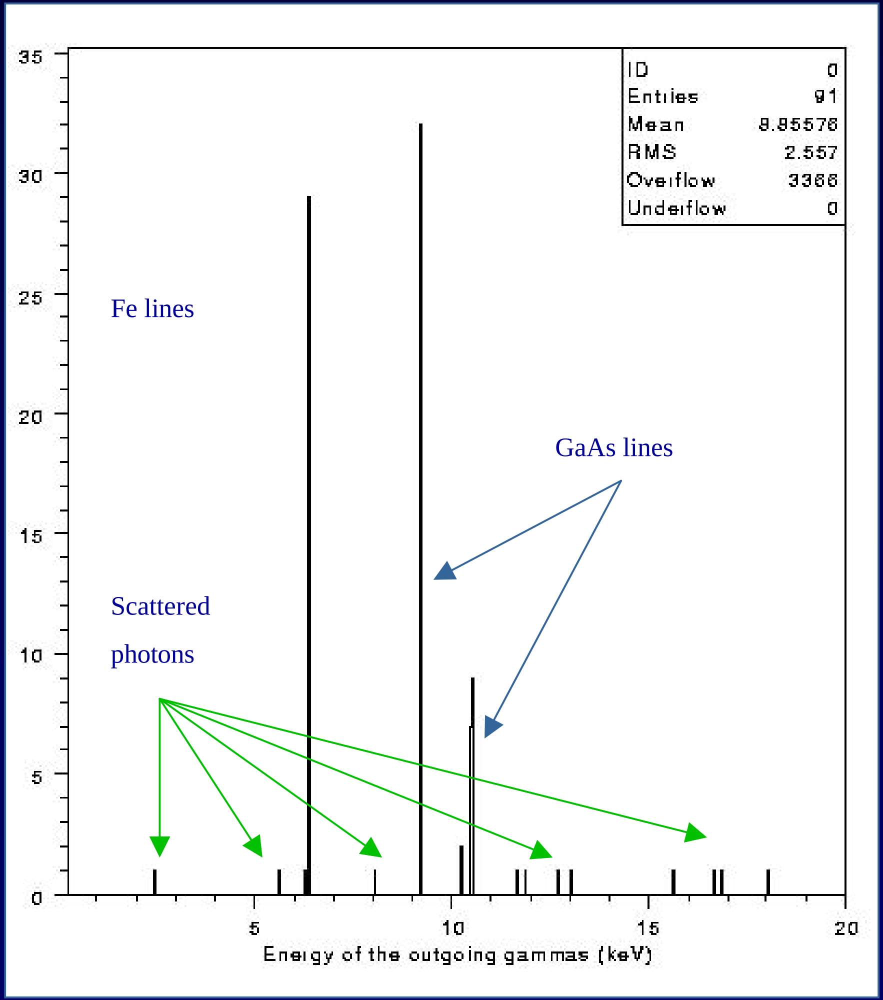
Hadron and ion models based on Ziegler and ICRU data and parameterisations



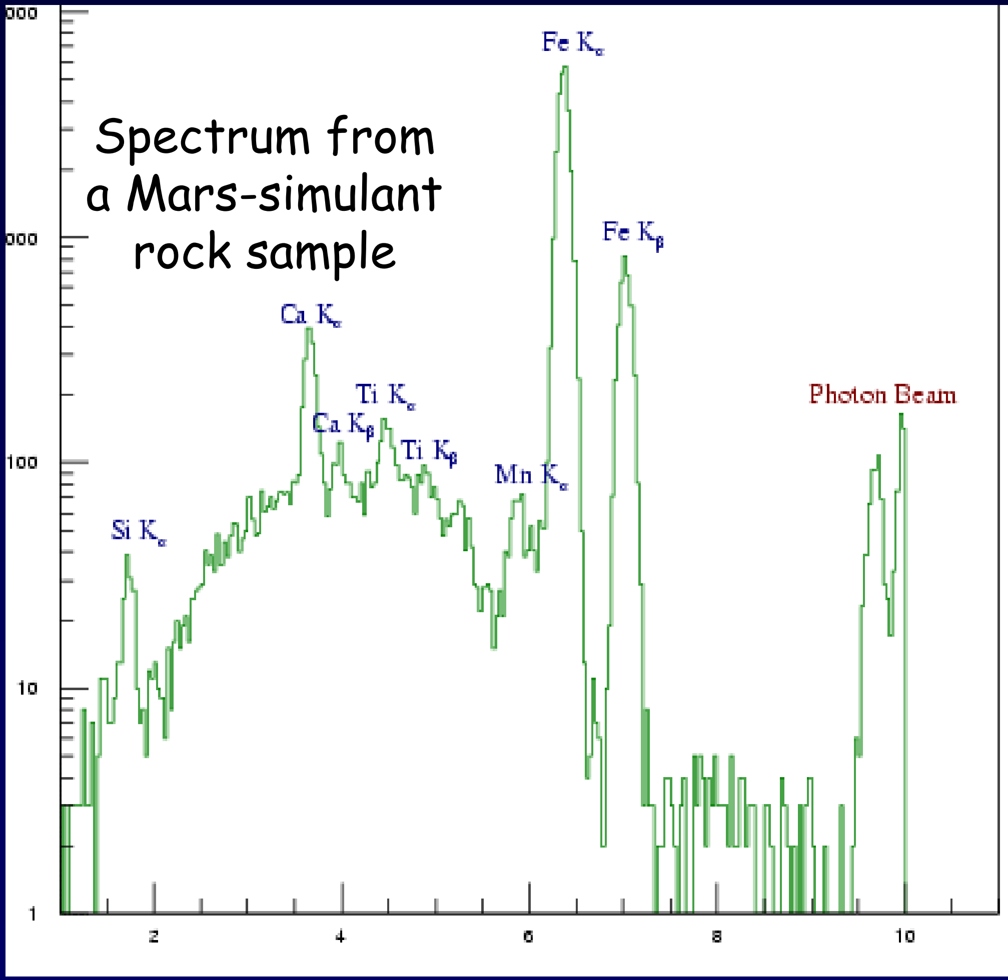


Fluorescence

Microscopic validation:
against reference data

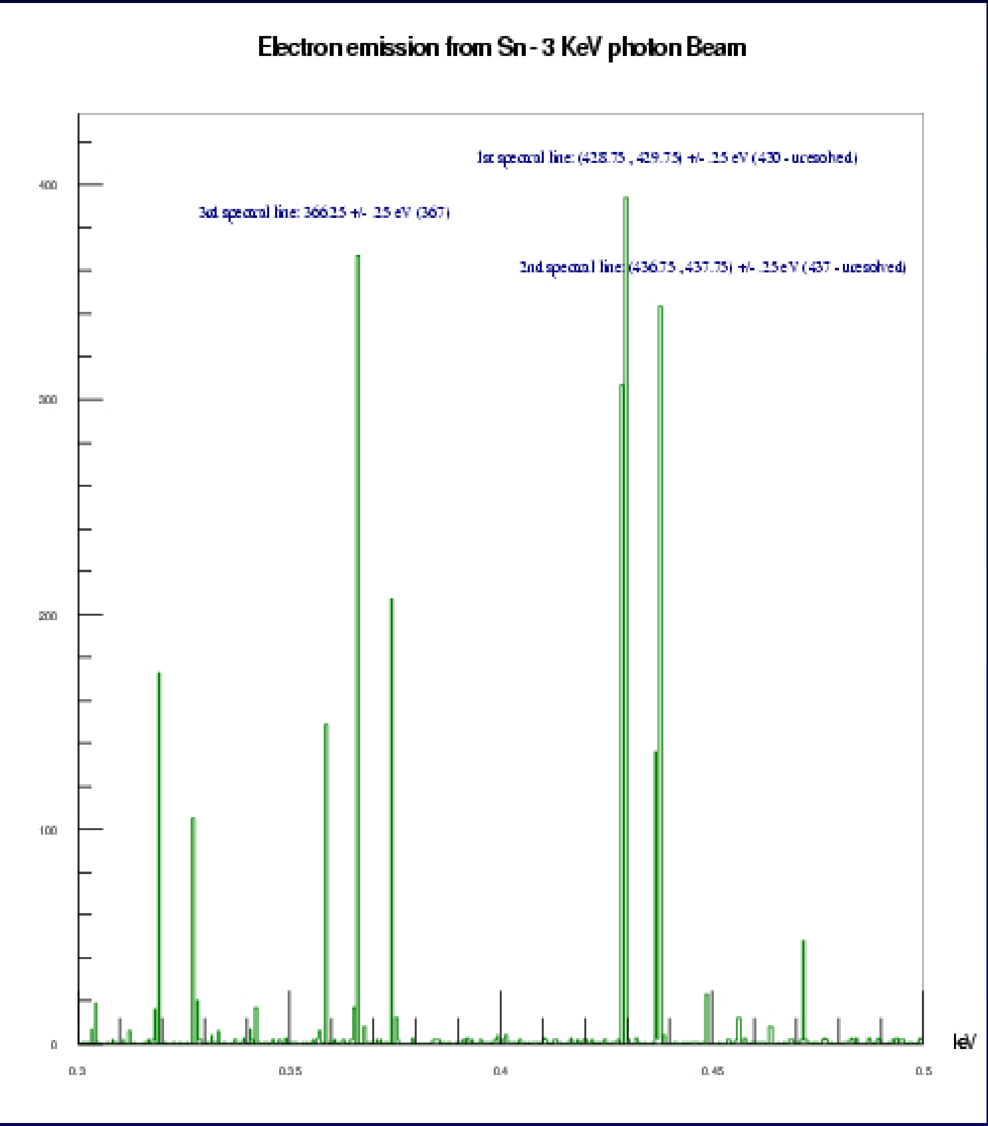


Experimental validation:
test beam data, in collaboration with
ESA Advanced Concepts & Science
Payload Division



Auger effect

Auger electron emission from various materials



Sn, 3 keV photon beam,

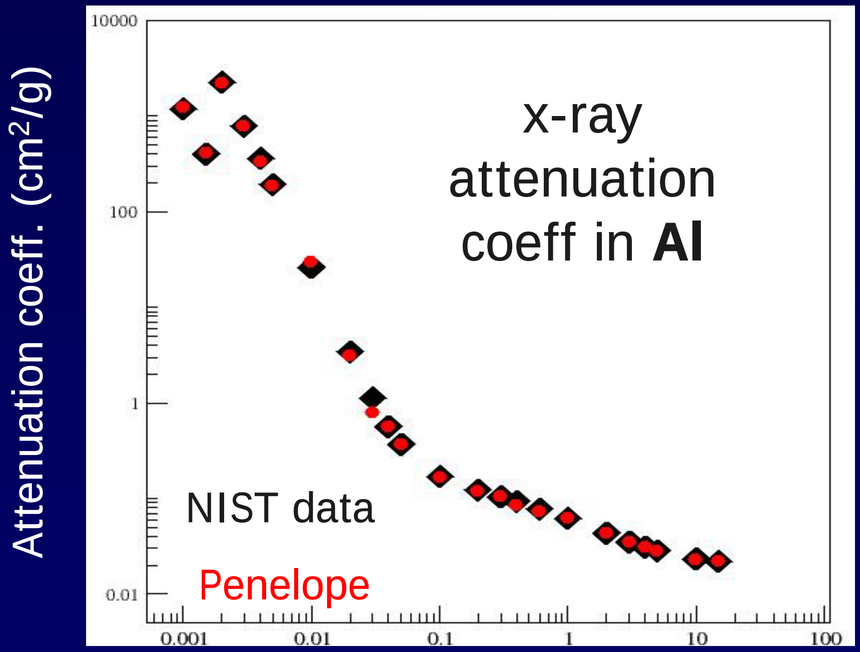
electron lines w.r.t. published experimental results

Processes à la Penelope

- The whole physics content of the Penelope Monte Carlo code has been re-engineered into Geant4 *(except for multiple scattering)*
  - processes for photons and electrons

- *Physics models by F. Salvat (University of Barcelona, Spain), J.M. Fernandez-Varea (University of Barcelona, Spain), E. Acosta (University of Cordoba, Argentina), J. Sempau (University of Catalonia, Spain)*

- Power of the OO technology:
  - extending the software system is easy
  - all processes obey to the same abstract interfaces
  - using new implementations in application code is simple



Hadronic physics (1)

- 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
  - it is possible to mix-and-match, with fine granularity
  - data-driven, parameterised and theoretical models
- Consequences for the users
  - no more confined to the black box of one package
  - the user has control on the physics used in the simulation, which contributes to the validation of experiment's results

Hadronic physics (2)

- Parameterised and data-driven models

  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
  - πN, total cross section
  - πN, coherent elastic scattering

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

Radioactive Decay Module

- Handles α, β-, β+, ν and anti-ν, de-excitation γ-rays
  - can follow all the descendants of the decay chain
  - can apply variance reduction schemes to bias the decays to occur at user-specified times of observation
- Branching ratio and decay scheme data based on the Evaluated Nuclear Structure Data File *(ENSDF)*
- Geant4 photo-evaporation model is used to treat prompt nuclear de-excitation following decay to an excited level in the daughter nucleus

- Applications:
  - underground background
  - backgrounds in spaceborne γ-ray and X-ray instruments
  - radioactive decay induced by spallation interactions
  - brachytherapy
  - etc.

E.M. Physics Validation

- Validation is fundamental in Geant4
- Validations at different levels
  - Unit, integration, system testing
  - Microscopic physics validation
  - Macroscopic validation experimental use cases
- Comparisons to experimental measurements and recognised standard references

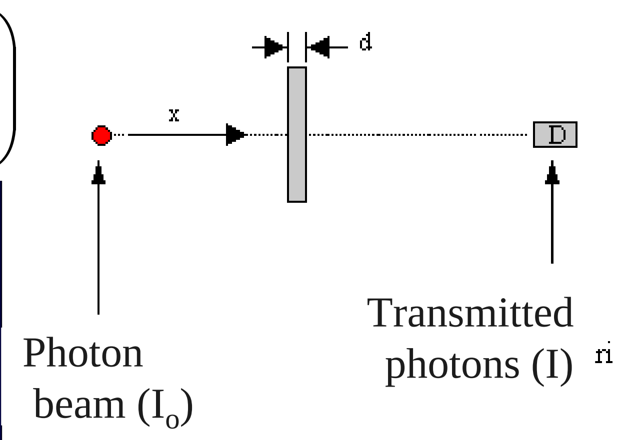
Microscopic validation

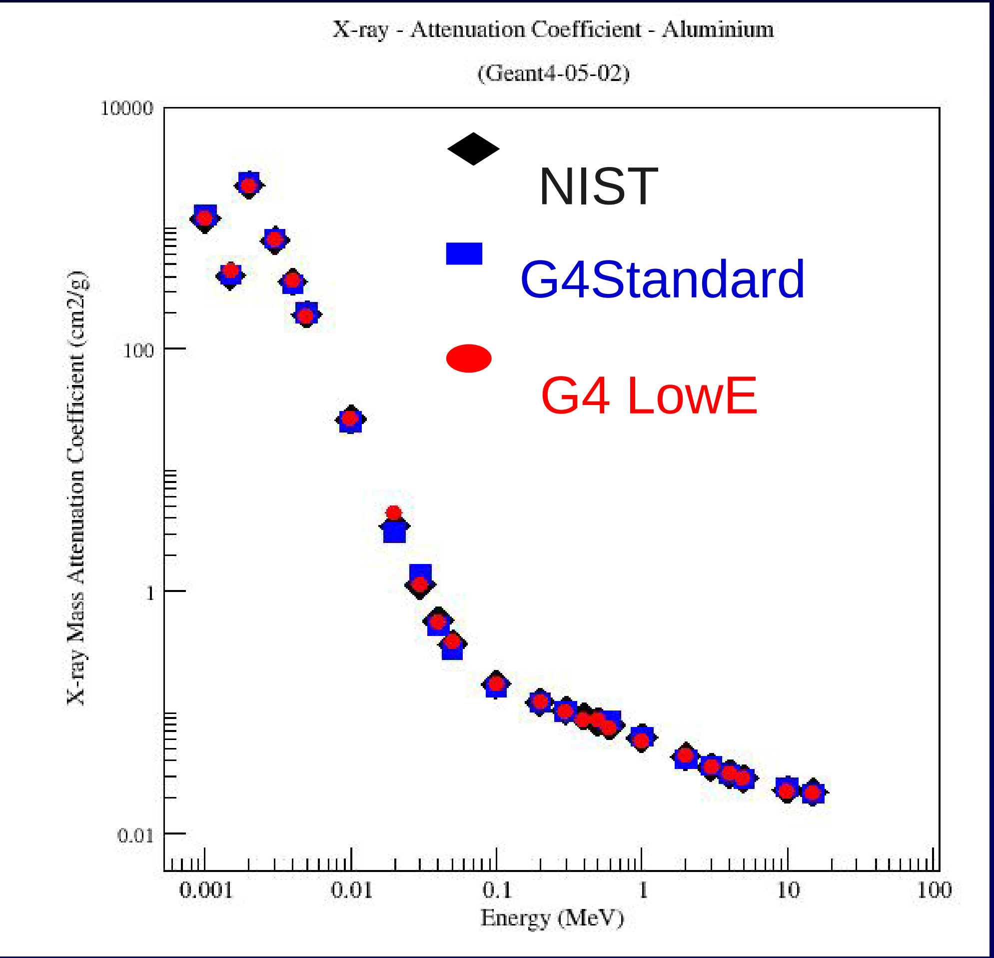
- Validation of Geant4 electromagnetic physics models
- Attenuation coefficients, CSDA ranges, Stopping Power, distributions of physics quantities
- Quantitative comparisons to experimental data and recognised standard references
- Regression test

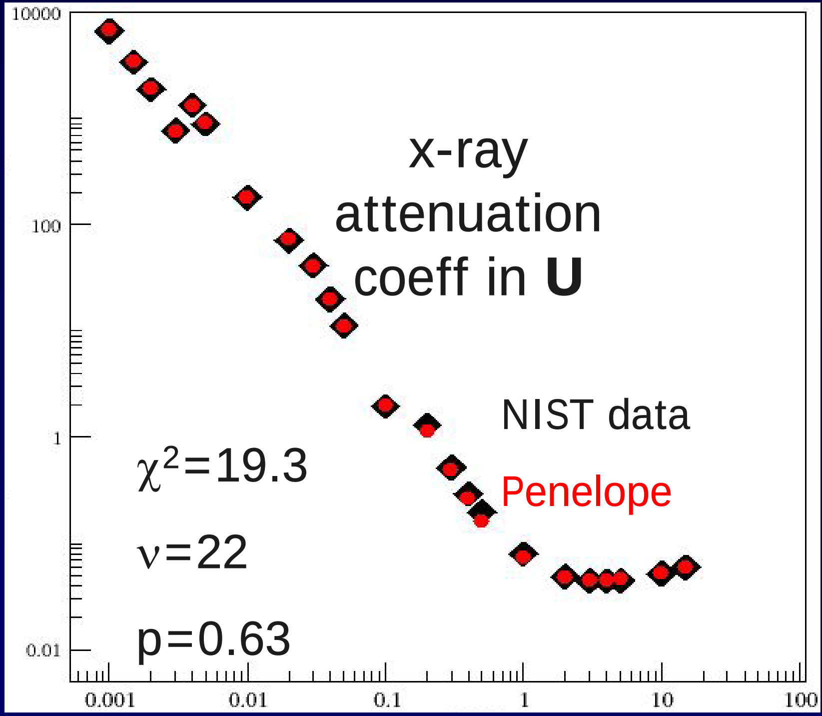
  Tests are repeated for every public release of Geant4 to control the evolution of the physics models provided to users

Photon mass attenuation coefficient

$$\frac{\mu}{\rho} = -\frac{1}{d\rho}\ln\left(\frac{I}{I_0}\right)$$

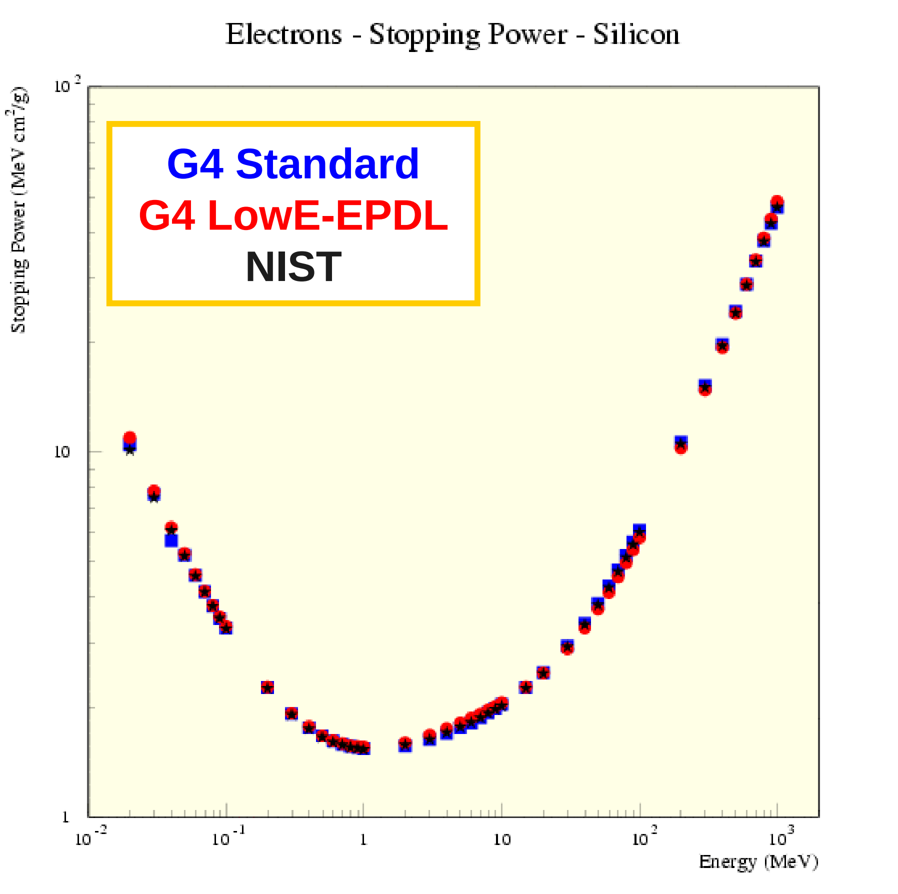






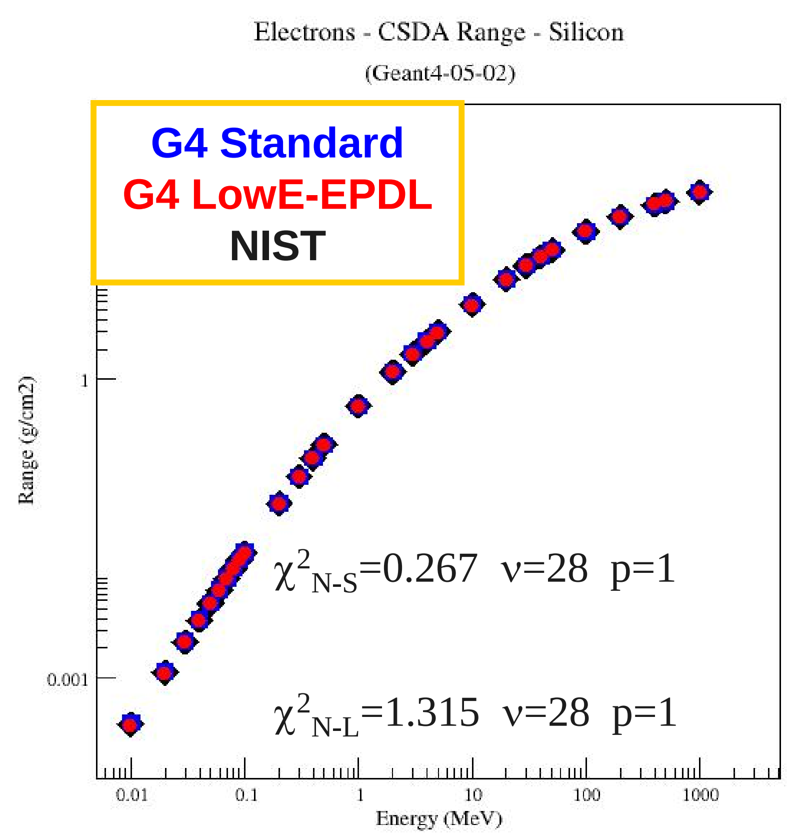
Absorber Materials:

Be, Al, Si, Ge, Fe, Cs, Au, Pb, U



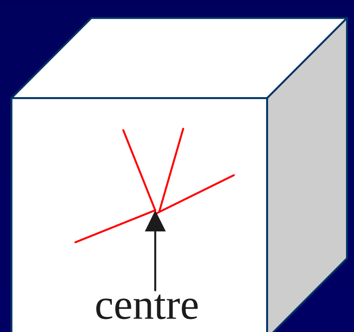
Electron stopping power And CSDA range

Absorber Materials:
Be, Al, Si, Ge, Fe, Cs, Au, Pb, U

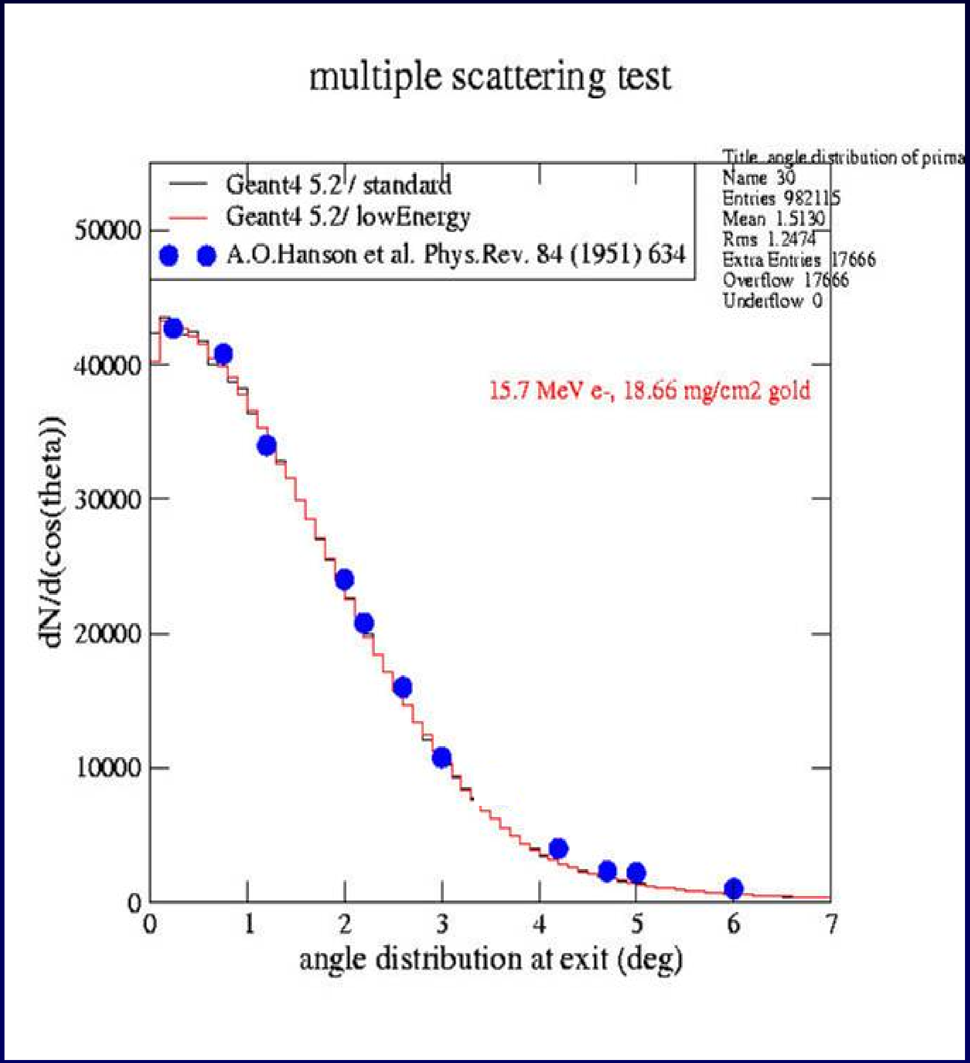


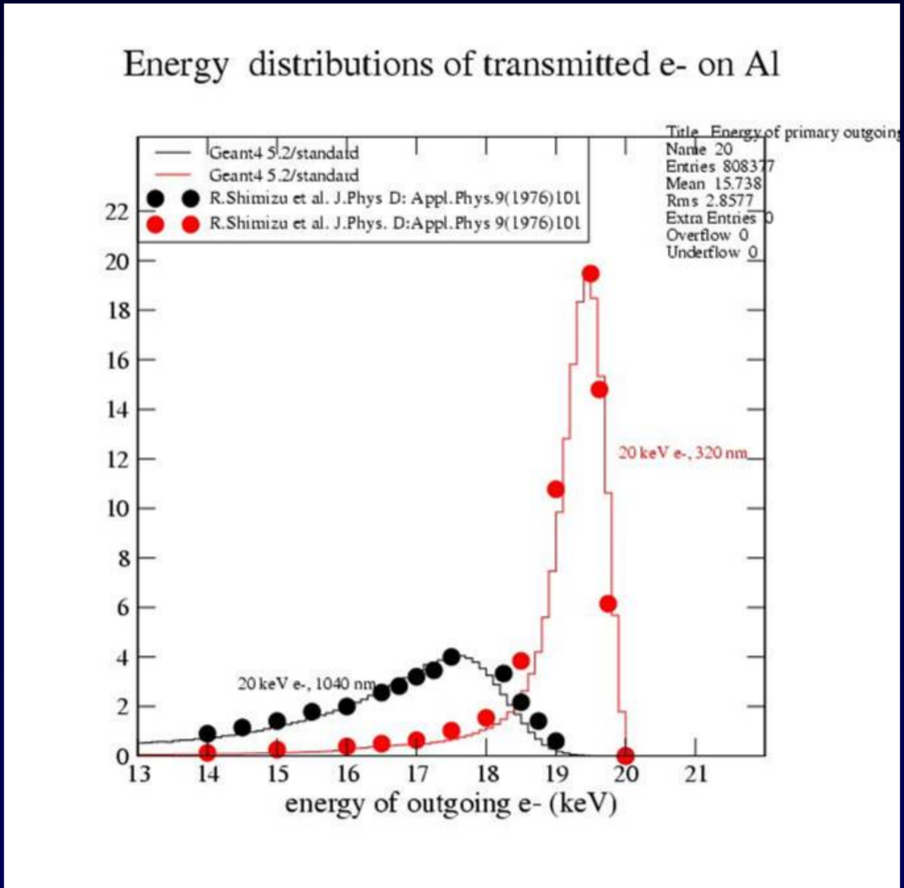
CSDA range: particle range without energy loss fluctuations and multiple scattering

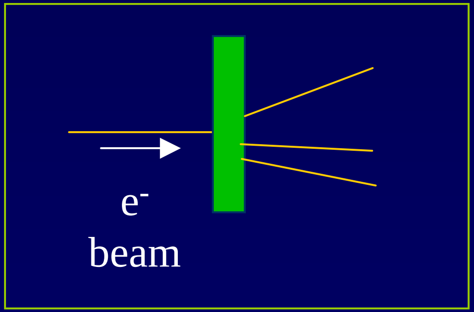
Experimental set-up



Transmission tests

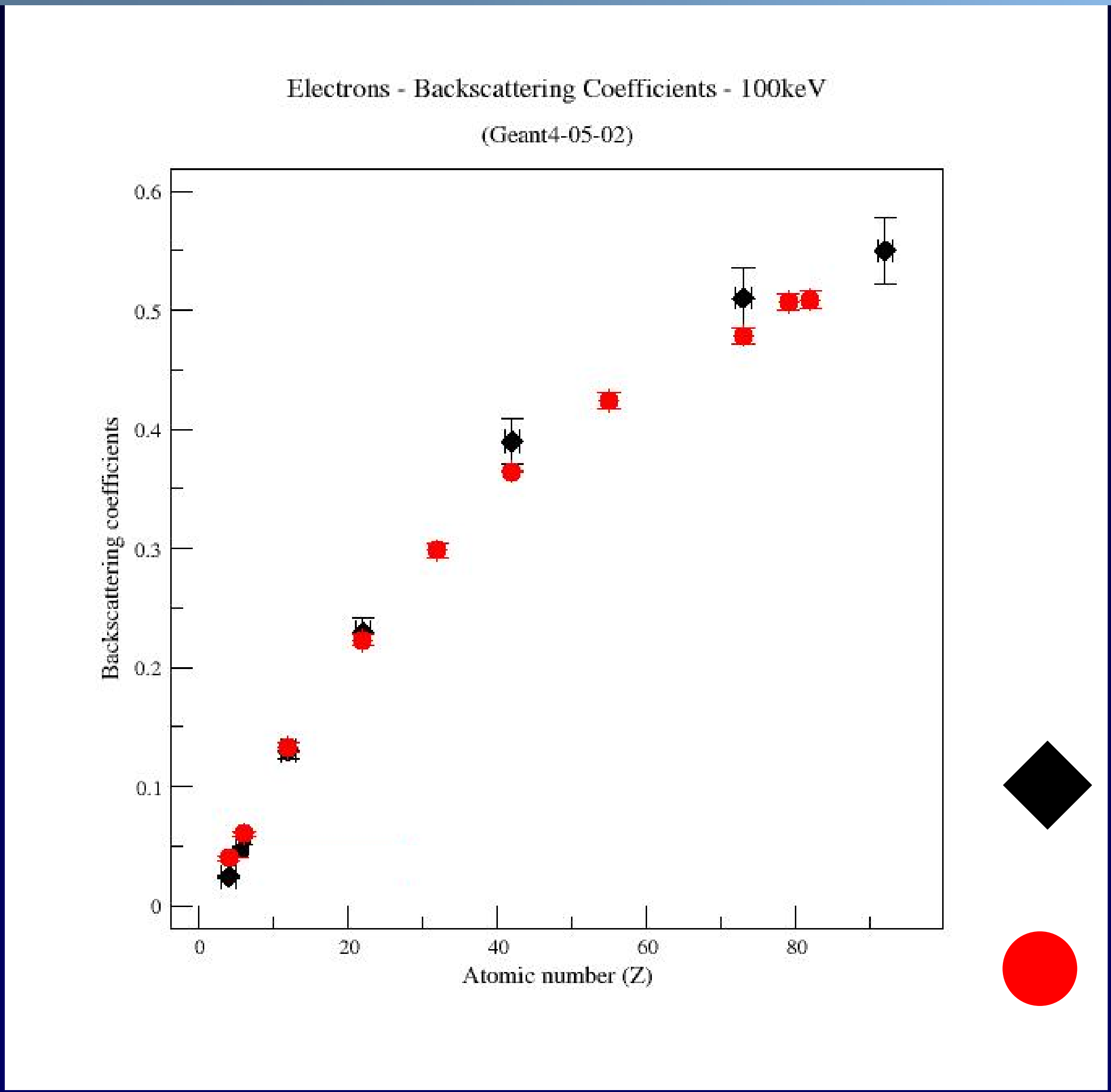


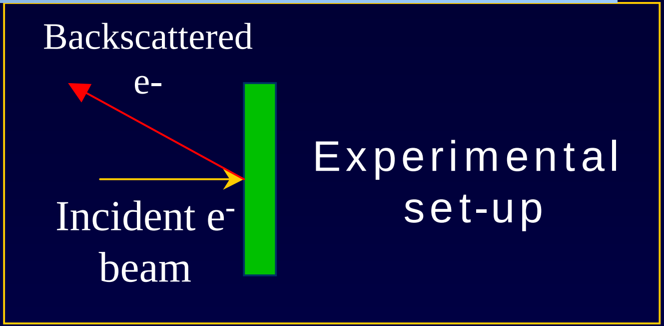




Experimental set-up

Backscattering coefficient – E=100keV



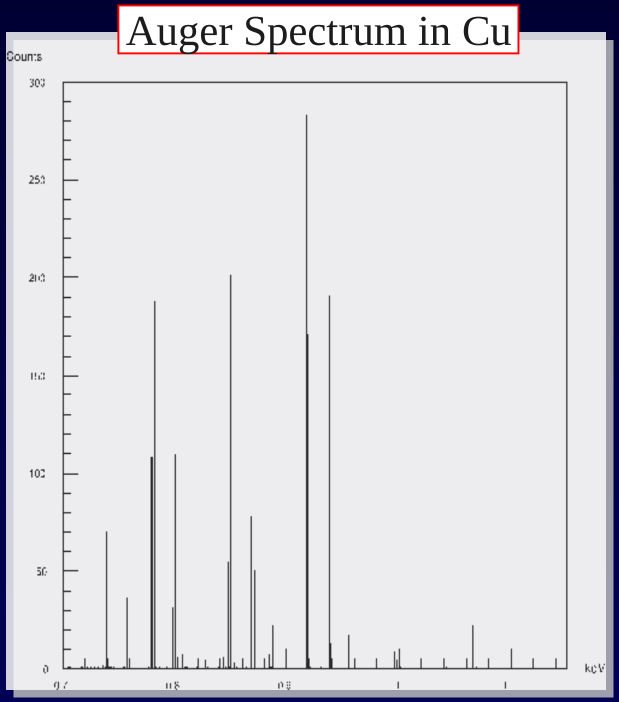


Angle of incidence (with respect to the normal to the sample surface) = 0°

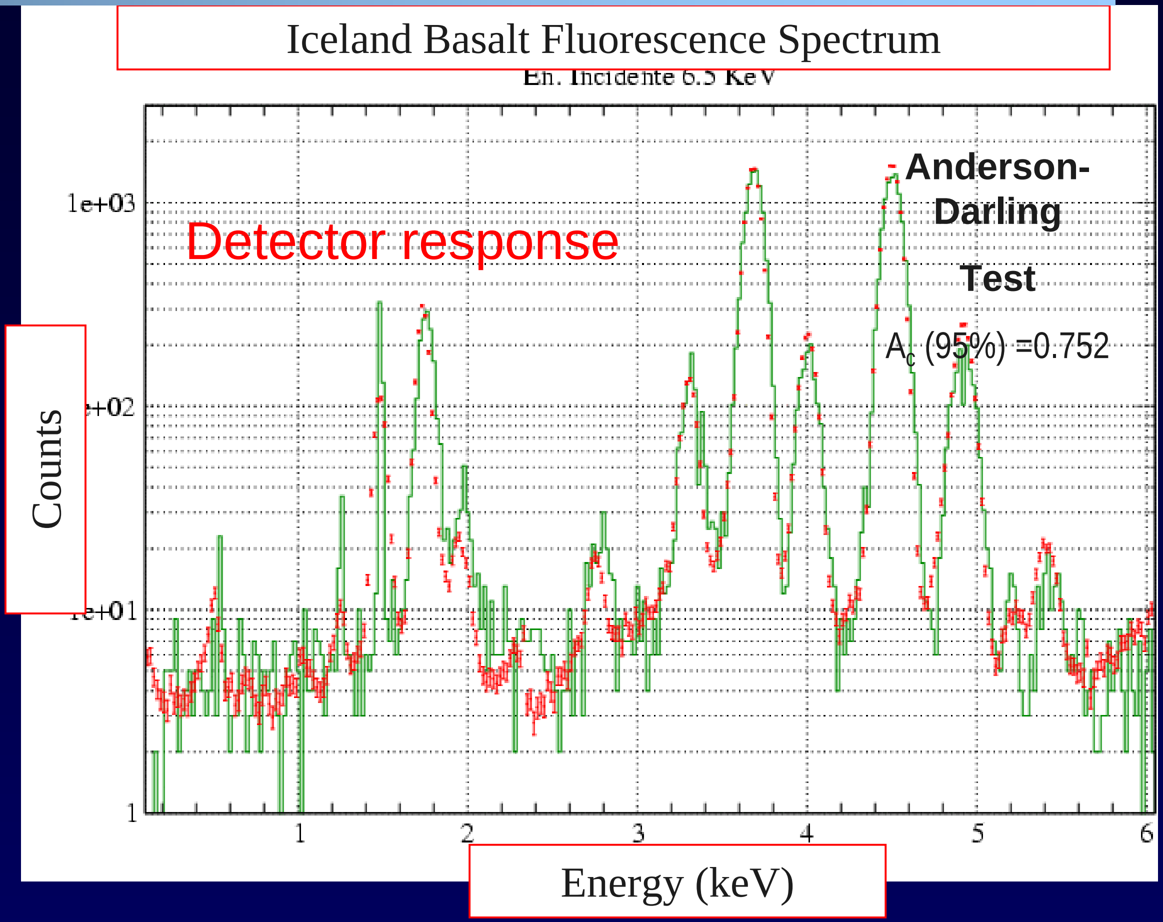
Lockwood et al. (1981)

G4 LowE

Auger Effect, X-Ray Fluorescence



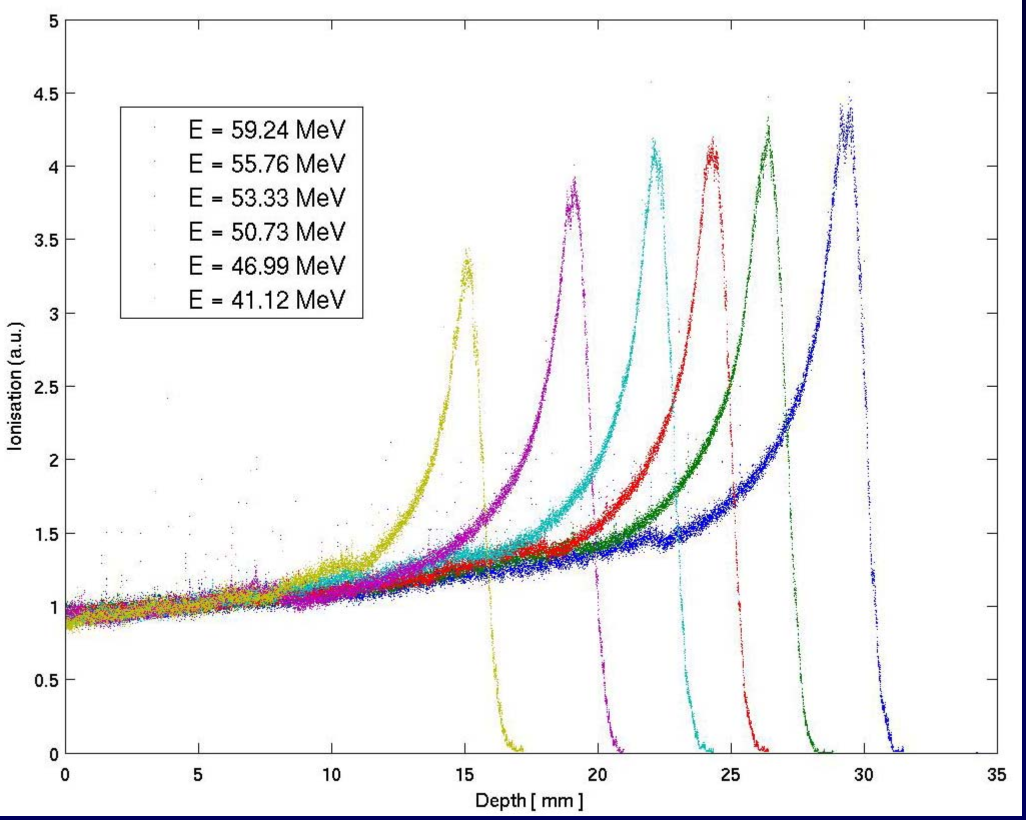
Simulation of Auger emission from pure materials irradiated by an electron beam with continuous spectrum



A.Mantero, M.Bavdaz, A.Owens, A.Peacock, M.G.Pia

Simulation of X-ray Fluorescence and Application to Planetary Astrophysics

Bragg Peak



KOLMOGOROV-SMIRNOV

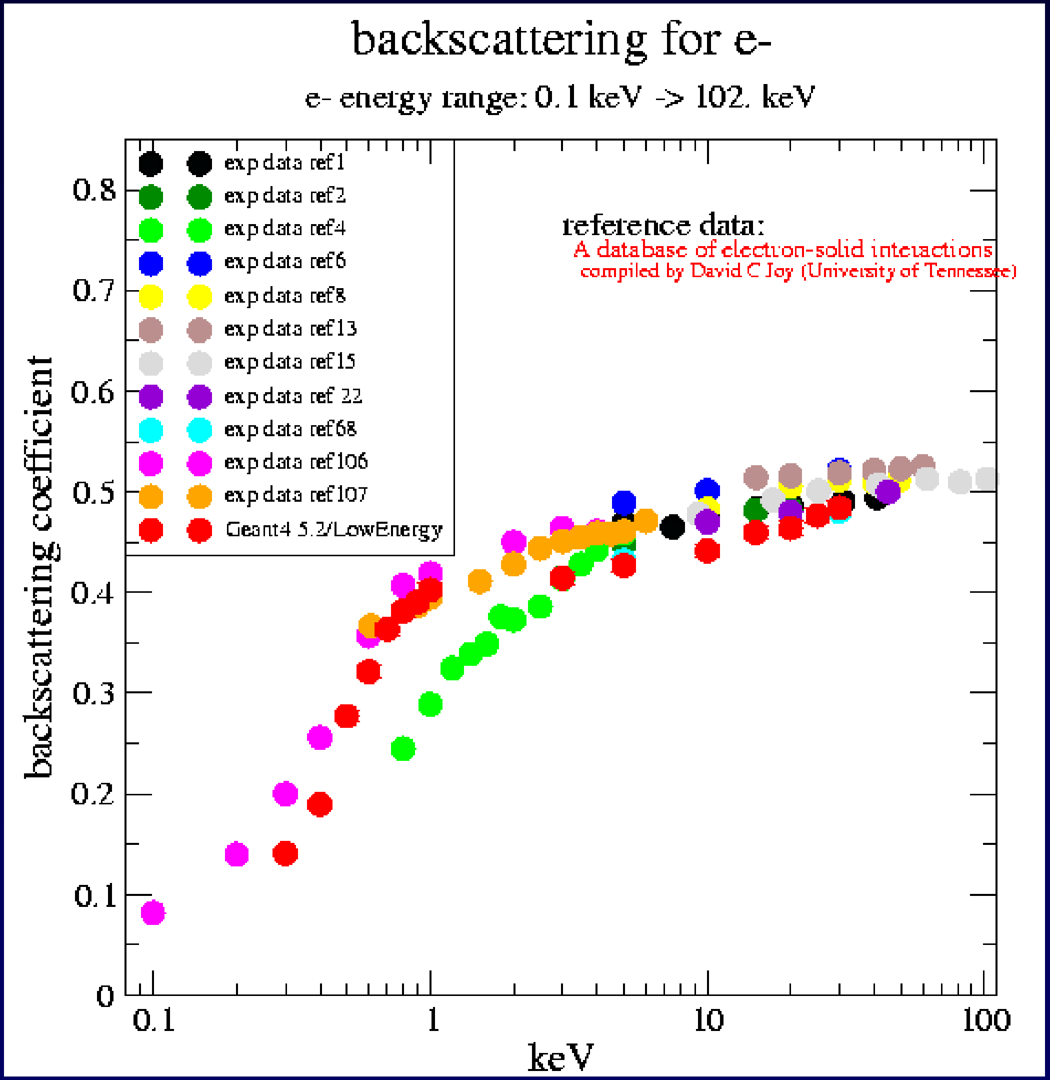
$D_{EXP\text{-}GEANT4}=0.11$ p=n.s.

Goodman approximation KOLMOGOROV-SMIRNOV

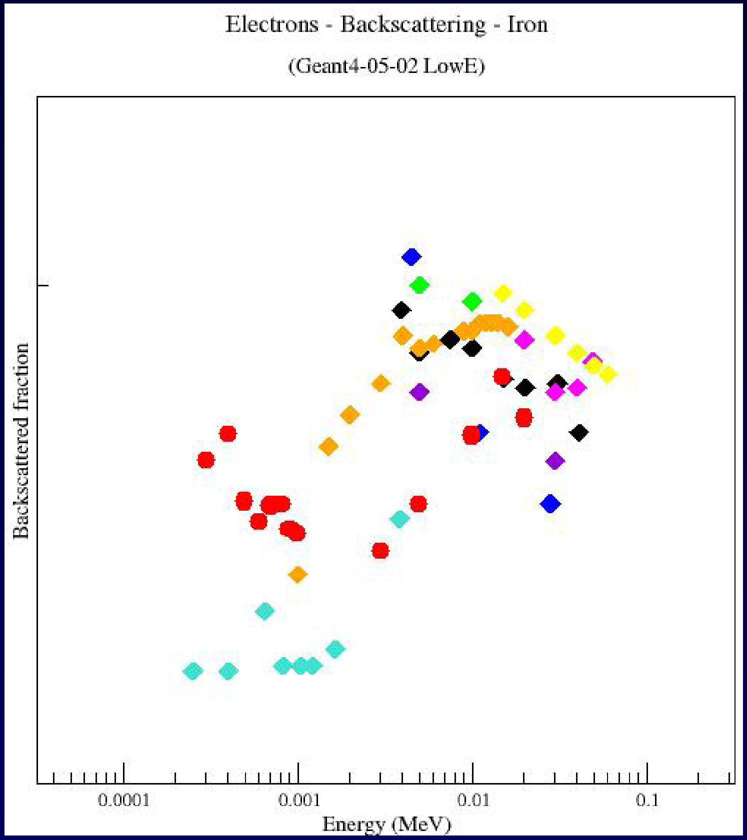
$\chi^2_{EXP\text{-}GEANT4}=3.8$ $\nu=2$ p=n.s.

G.A.P.Cirrone, G.Cuttone, S.Donadio, S.Guatelli, S.Lo Nigro, B.Mascialino, M.G.Pia, L.Raffaele, G.M.Sabini

The problem of validation: finding reliable data



Backscattering low energies - Au



Note: Geant4 validation is not always easy

experimental data often exhibit large differences!

Much more available or in progress…

- Now and next future:

-Tests on physics quantities regarding protons, alpha particles and ions

Requested by Geant4 medical physics community interested in the use of ions for oncology treatments

-Tests extended to hadronic processes

- Validation of physics models is always in progress

  - new tests
  - regression tests

- Many detailed results are available for the validation of basic physics distributions: http://www.ge.infn.it/geant4/analysis/test

Geant4 e.m. physics models are subject to a rigorous testing and validation process

Validation of physics models is fundamental for **critical application domains** such as medical physics

Access to distributed computing resources

How MC can nowadays be used
in clinical practice

Monte Carlo methods in radiotherapy

Monte Carlo methods have been explored for years as a tool for precise dosimetry, in alternative to analytical methods

de facto,

Monte Carlo simulation is not used in clinical practice

(only side studies)

- The limiting factor is the **speed**

We explored the use of distributed computing resources

Performance of the Geant4 brachytherapy application

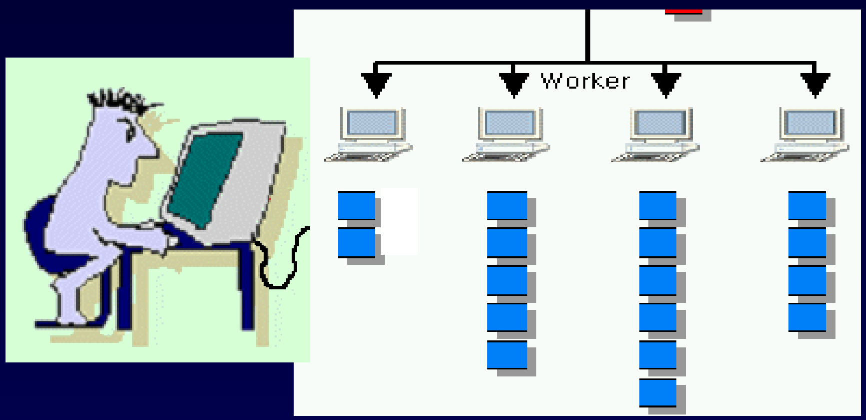
	Sequential mode	Parallel mode with about 50 computers
Endocavitary brachytherapy	1M events 61 minutes	1M events 4 minutes 34’’
Superficial brachytherapy	1M events 65 minutes	1M events 4 minutes 25’’
Interstitial brachytherapy	1M events 67 minutes	5M events 4 minutes 36’’

With parallel mode performance adequate for clinical application, but…

it is not realistic to expect any hospital to own and maintain a PC farm

Flow of the exploration

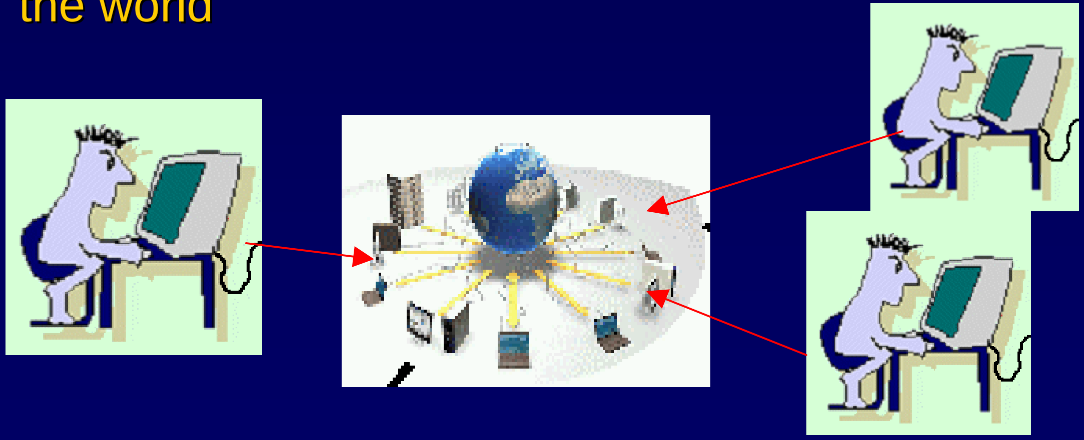
- **Parallelisation of the Geant4 application on a local cluster**



But a institute or hospital may not own a sufficient computer farm …

- **Access to distributed computing resources**

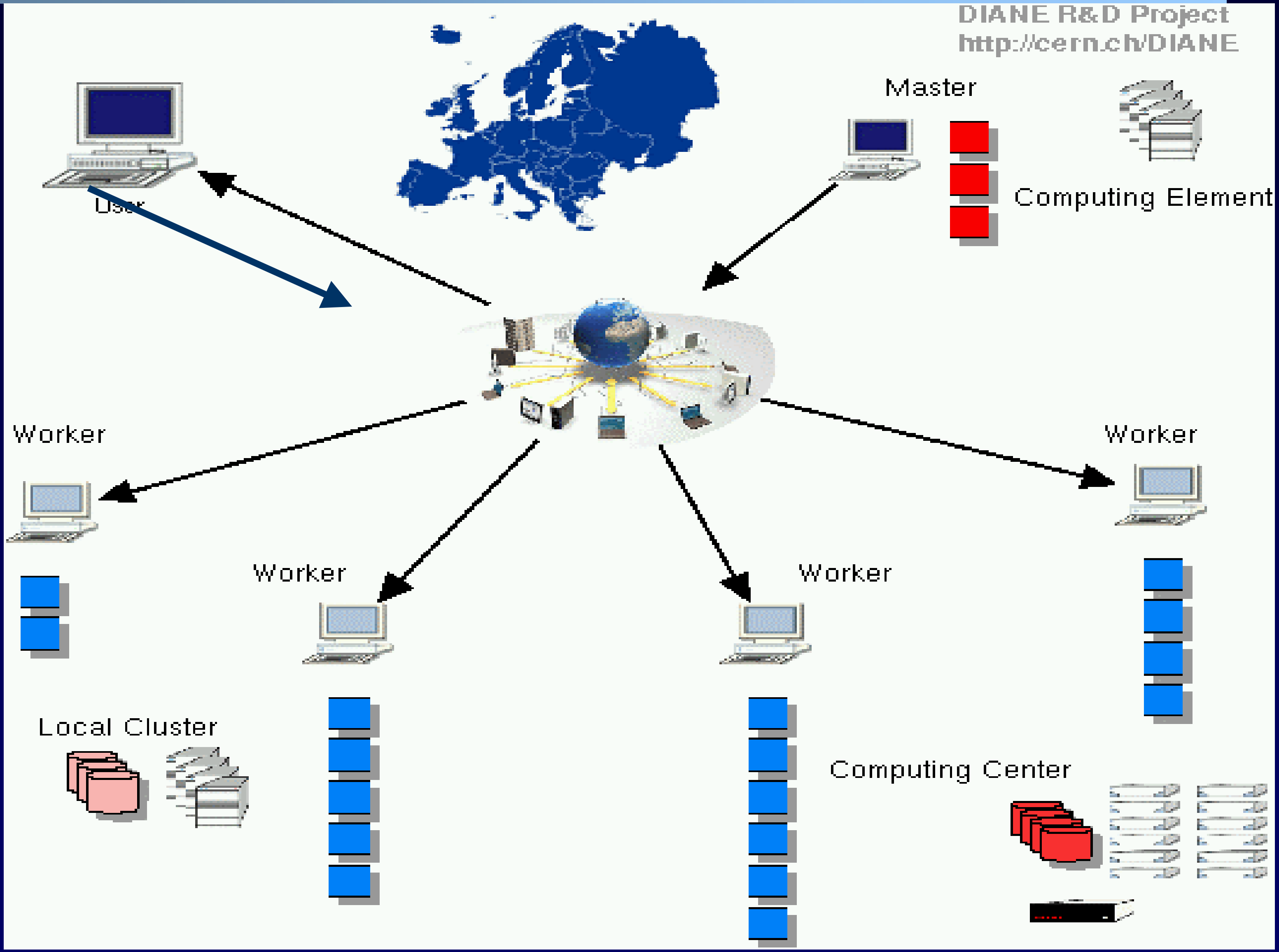
Share with other institutes computing resources geographically distributed around the world



Parallel mode: distributed resources

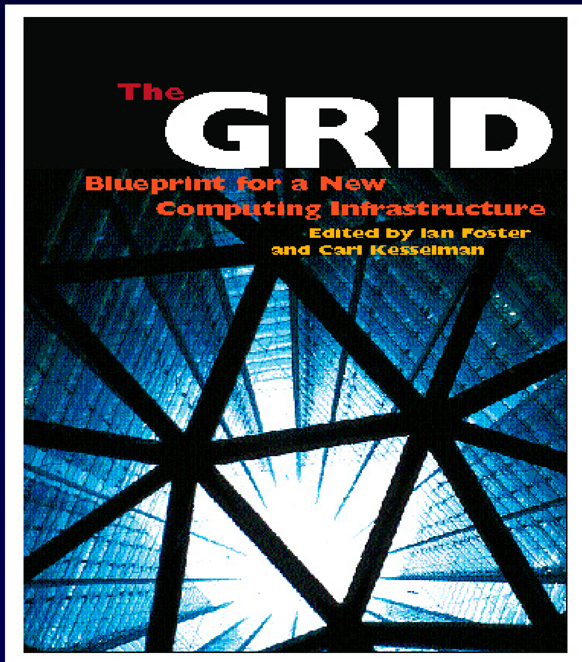
Distributed Geant 4 Simulation:

DIANE framework and generic GRID middleware



Grid

Wave of interest in grid technology as a basis for "revolution" in e-Science and e-Commerce



Ian Foster and Carl Kesselman's book:

"A computational Grid is a hardware and software infrastructure that provides dependable, consistent , pervasive and inexpensive access to high-end computational capabilities"

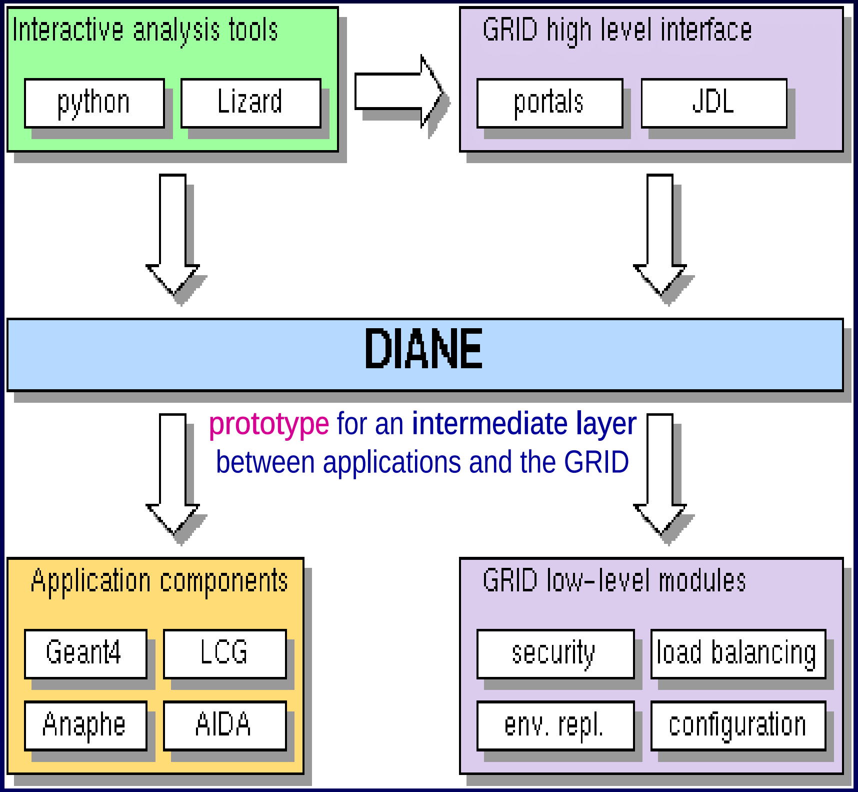
An infrastructure and standard interfaces capable of providing transparent access to geographically distributed computing power and storage space in a uniform way

Many GRID R&D projects, many related to HEP

US projects

European projects

DIANE



- DIANE is a intermediate layer between applications and a local cluster or the GRID
- Same application code as running on a sequential machine or on a dedicated cluster or on the GRID completely transparent to the user

J. Moscicki (CERN)
www.cern.ch/diane

Running on the GRID

- Via DIANE

A hospital is not required to own and maintain extensive computing resources to exploit the scientific advantages of Monte Carlo simulation for radiotherapy

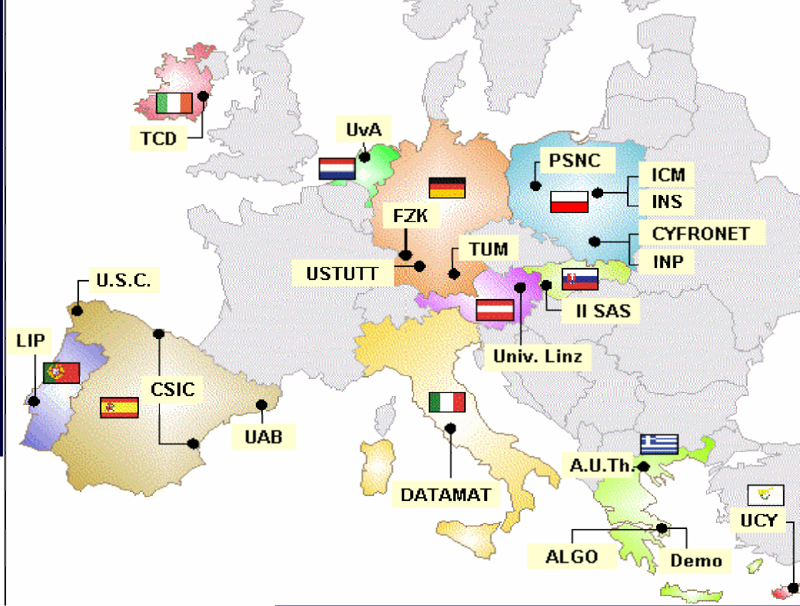
Any hospital

– even small ones, or in less wealthy countries, that cannot afford expensive commercial software systems –

may have access to

advanced software technologies and tools for radiotherapy

Traceback from a run on CrossGrid testbed



Resource broker running in Portugal

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

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

Conclusions (1)

- Geant4 Simulation Toolkit exploits modern software technologies

- Geant4 offers an ample variety of physics models
  - Both e.m. and hadronic physics models
  - Transparency of the physics
  - Penelope physics models were re-engineered in Geant4
  - The choice of physics models is user responsibility

- Validation of physics models
  - E.M. physics models are validated in comparison to experimental data or protocol data
  - Regression test: Complete control on the evolution of the models
  - Penelope physics models tested in comparison to protocol data

Conclusion (2)

- **Geant4 offers an ample variety of tools regarding**
  -Physics models
  -Geometry set-up definition
  -Tracking of particles
  -User interfaces
  -Visualisation

The responsibility of choice of the tools out of the richness offered by the toolkit is user task

- **The access to geographically distributed computing resources overcomes the problem of speed constraint**

- **Geant4 is a tool used widely in medical physics**
  -IEEE Nuclear Science Symposium and Medical Imaging Conference,Portland, Oregon, October 2003
  www.ge.infn.it/geant4/events

Conclusions (3)

- **Geant4 Collaboration releases a new public version of Geant4 toolkit every six months**
- **Geant4 is continuously enriched of new functionality**
- **Milestones and deadlines are always respected**
  - Rigorous software process
  - Large international collaboration

Conclusion(4)

Useful websites:

-www.cern.ch/geant4

-www.ge.infn.it/geant4

- **Geant4 Collaboration provides user documentation**
- **Novice and Advanced examples are released as part of the Geant4 Simulation Toolkit**
- **Hypernews service provided**
- **A User Forum for Geant4 Medical Physics Community will be created in the next future**
- **Geant4 Collaboration offers User Support**