Introduction to Geant 4

http://cern.ch/geant4/

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

These slides are available at
http://www.ge.infn.it/geant4/training/

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Technology transfer

Particle physics software aids space and medicine

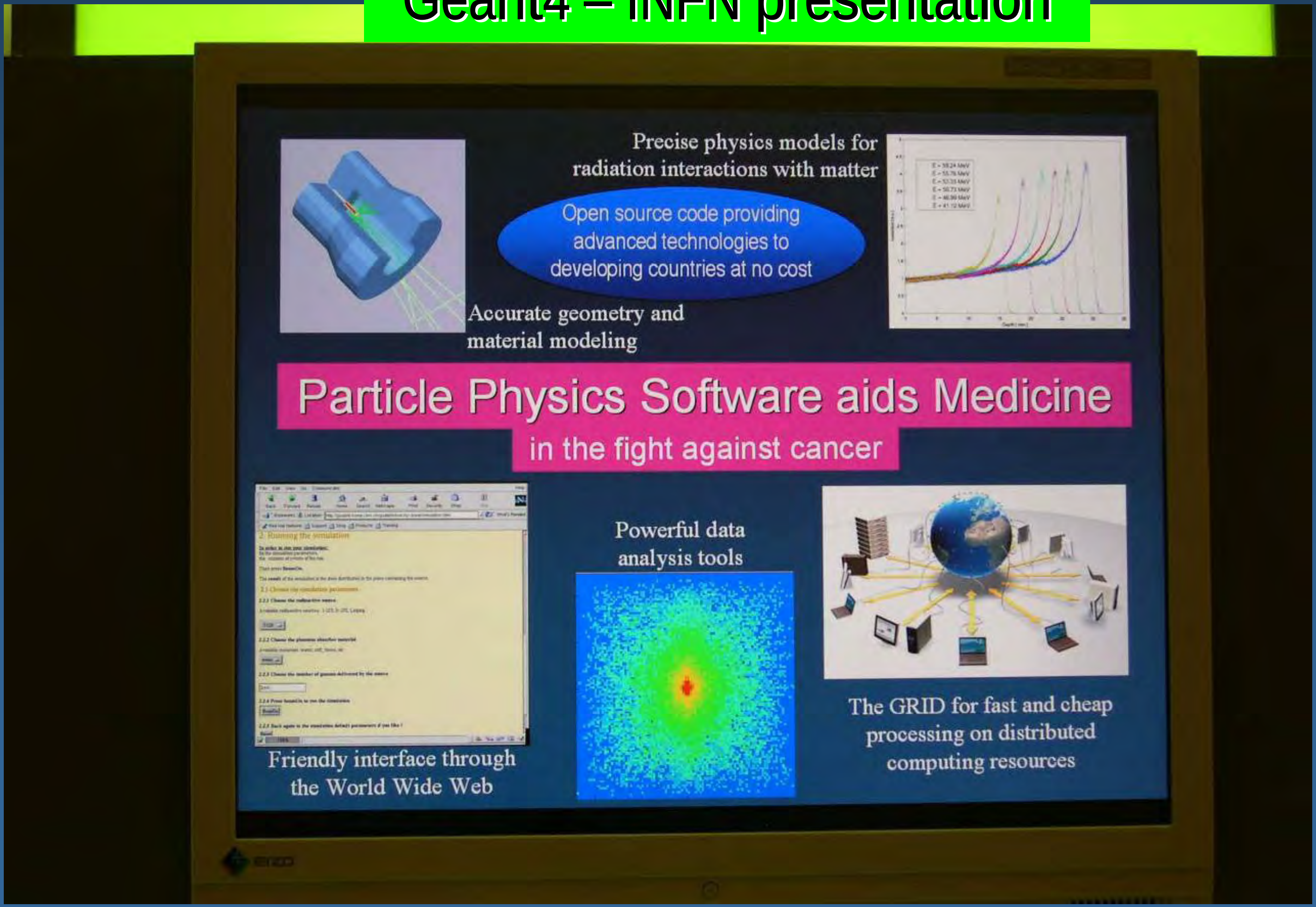
Geant4 is a showcase example of technology transfer from particle physics to other fields such as space and medical science [...].

CERN Courier, June 2002

Maria Grazia Pia, *INFN Genova*

United Nations
World Summit on Information Society
Geneva, December 2003

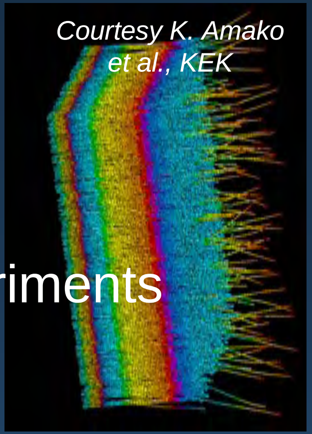
Geant4 – INFN presentation

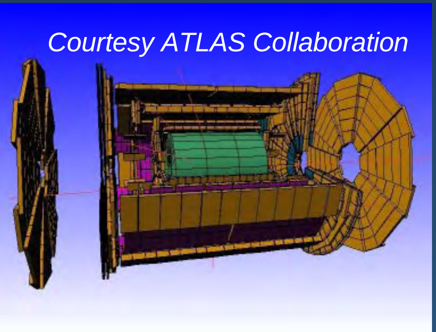



Courtesy CMS Collaboration

Geant 4

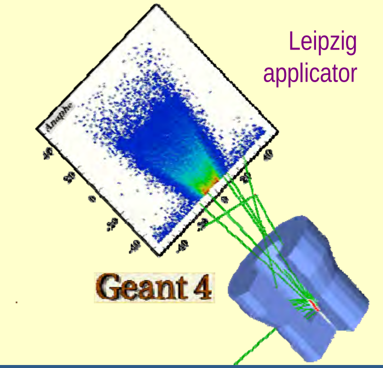
Born from the requirements of large scale HEP experiments

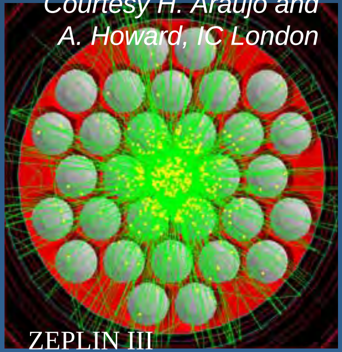

Courtesy K. Amako et al., KEK


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…

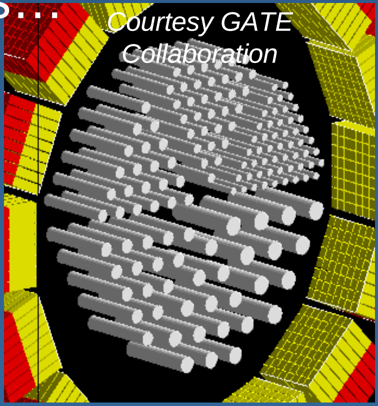


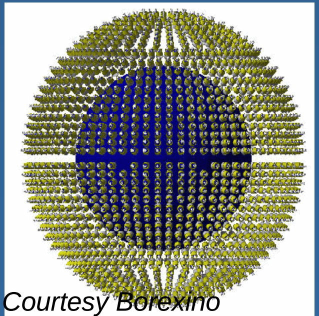


Courtesy H. Araujo and A. Howard, IC London


Courtesy R. Nartallo et al.,ESA

Most cited "engineering" publication in the past 2 years!


Courtesy GATE Collaboration

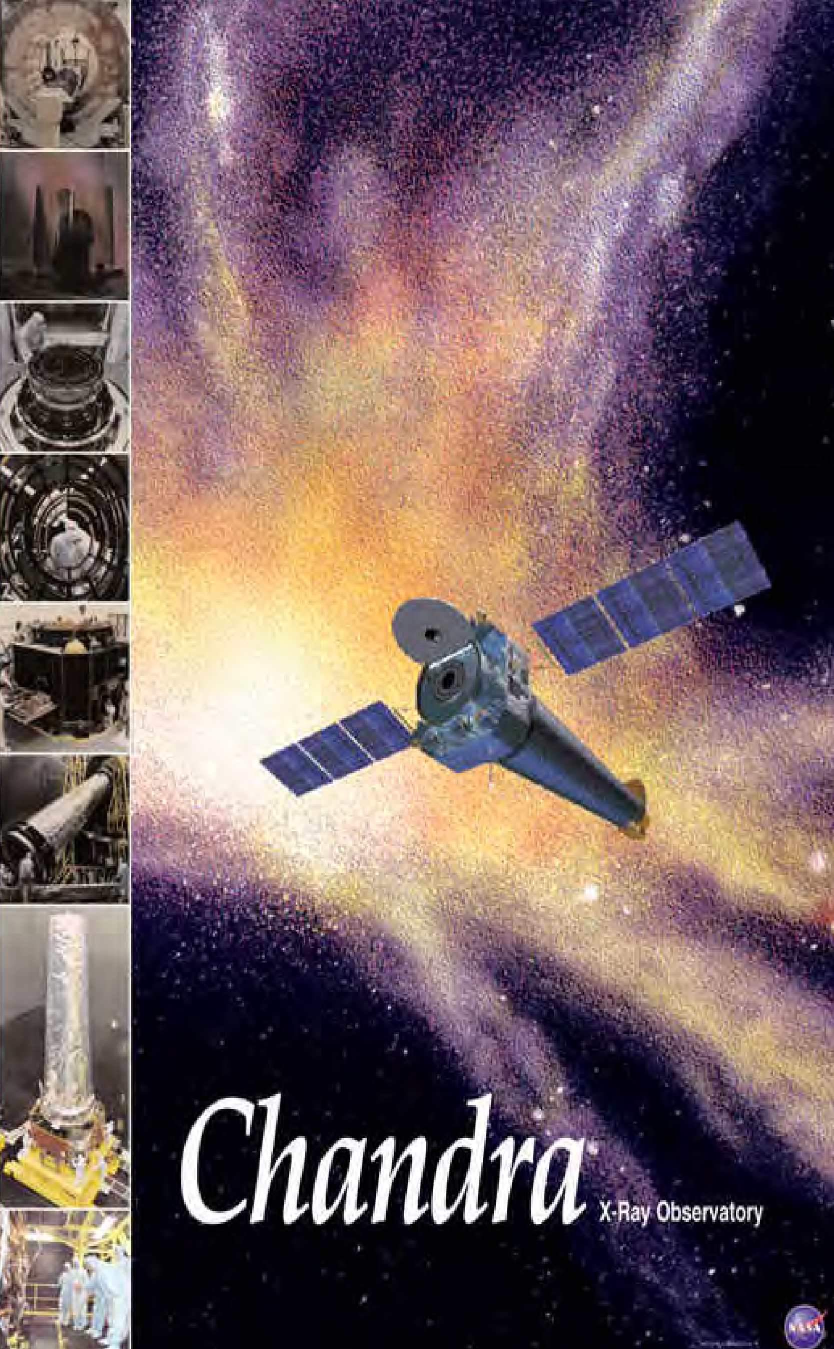

Courtesy Borexino

INFN Genova

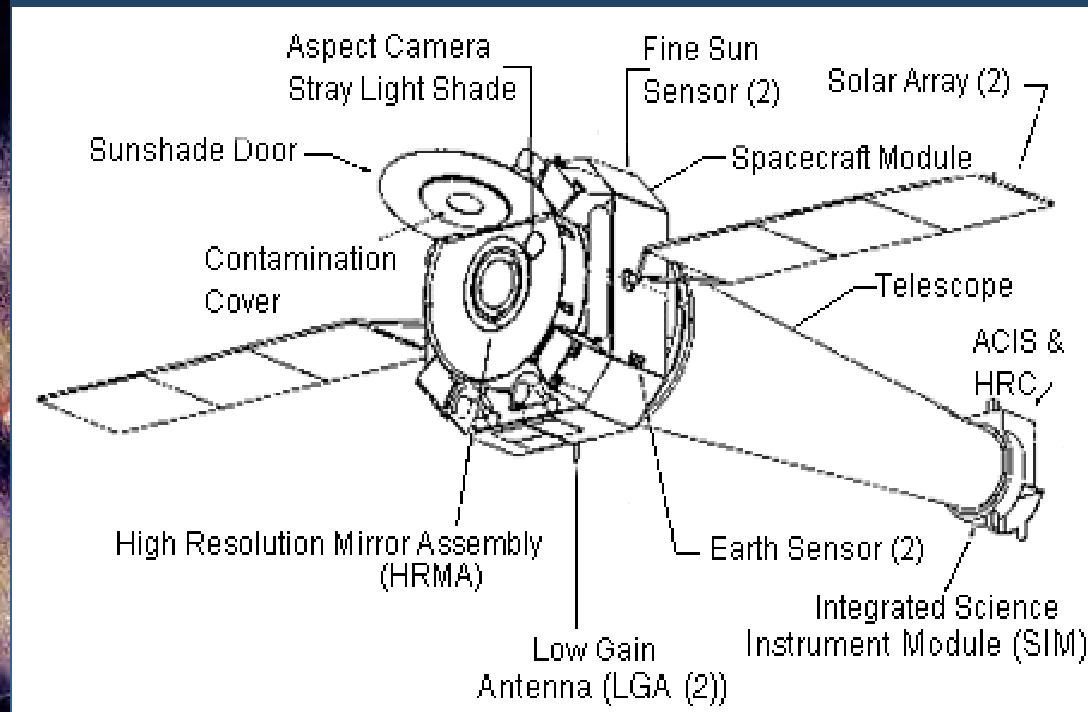
scientific…

Globalisation

Sharing requirements and functionality across diverse fields



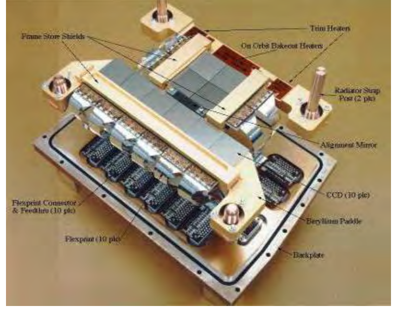
Once upon a time there was a X-ray telescope...



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

GEANT4 LOW ENERGY
ELECTROMAGNETIC PHYSICS

User Requirements Document

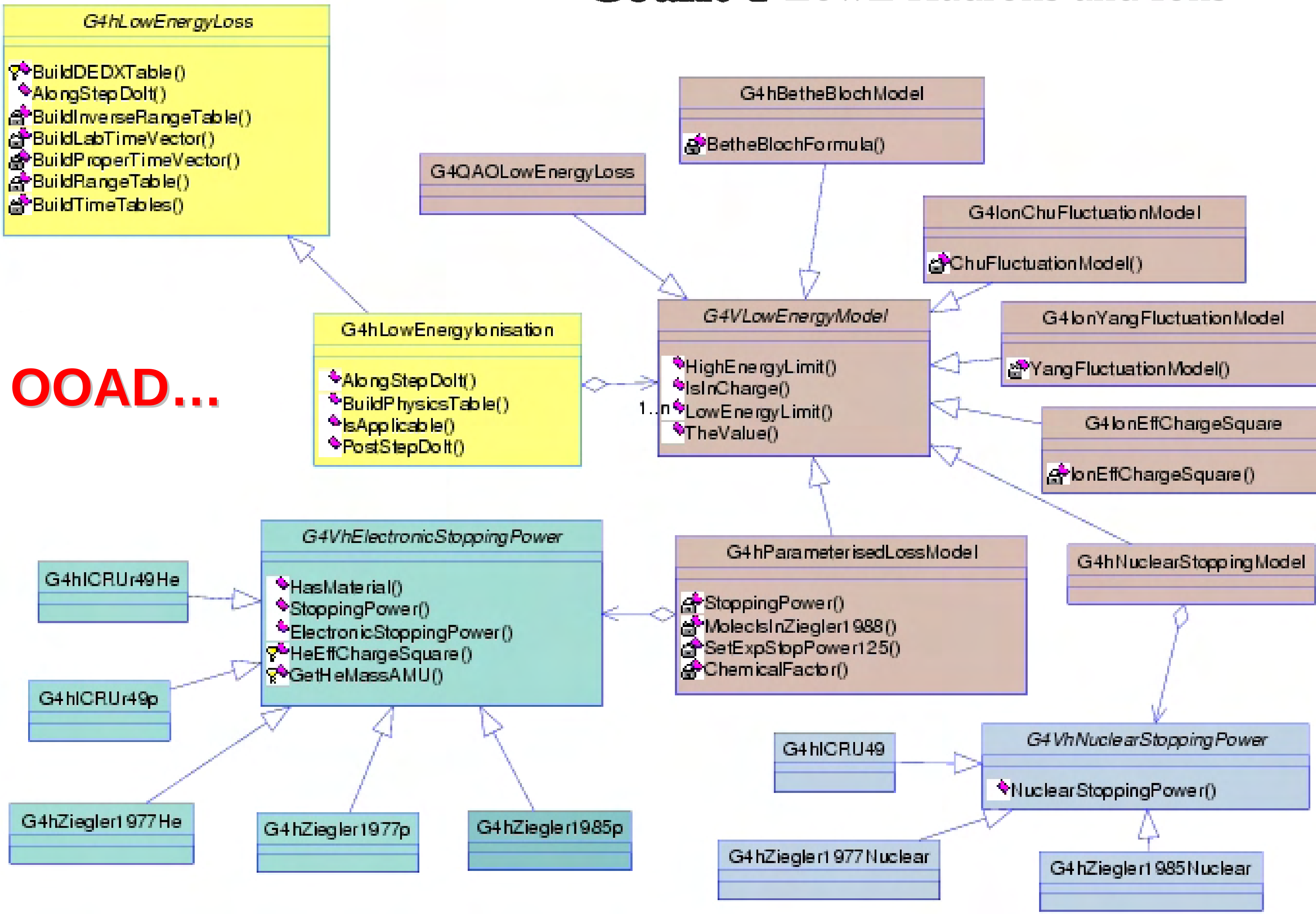
Status: in CVS repository

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)

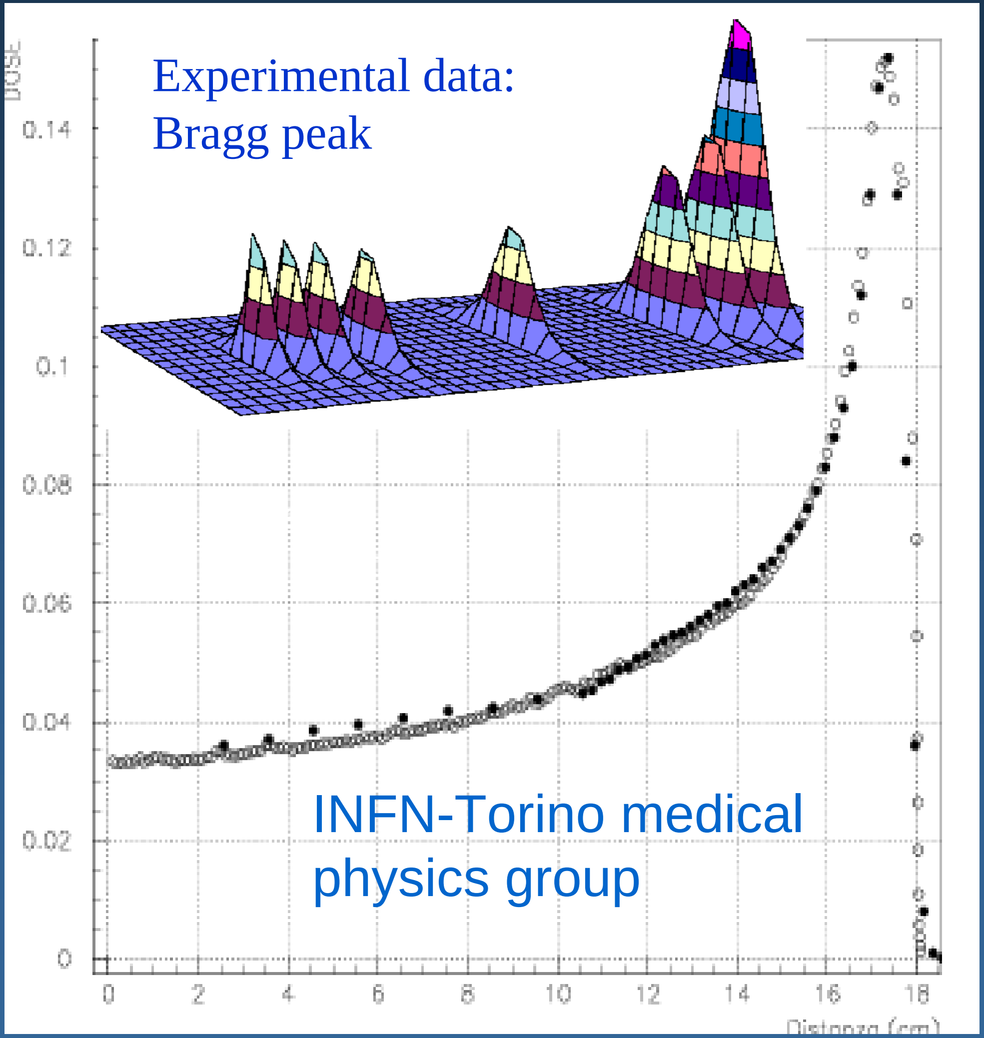
- **UR 2.1** The user shall be able to simulate electromagnetic interactions of positive charged hadrons down to < 1 KeV.
- **Need**: *Essential*
- **Priority**: *Required by end 1999*
- **Stability**: *Stable*
- **Source**: *Medical physics groups, PIXE*
- **Clarity**: *Clear*
- **Verifiability**: *Verified*

Geant 4 LowE Hadrons and Ions

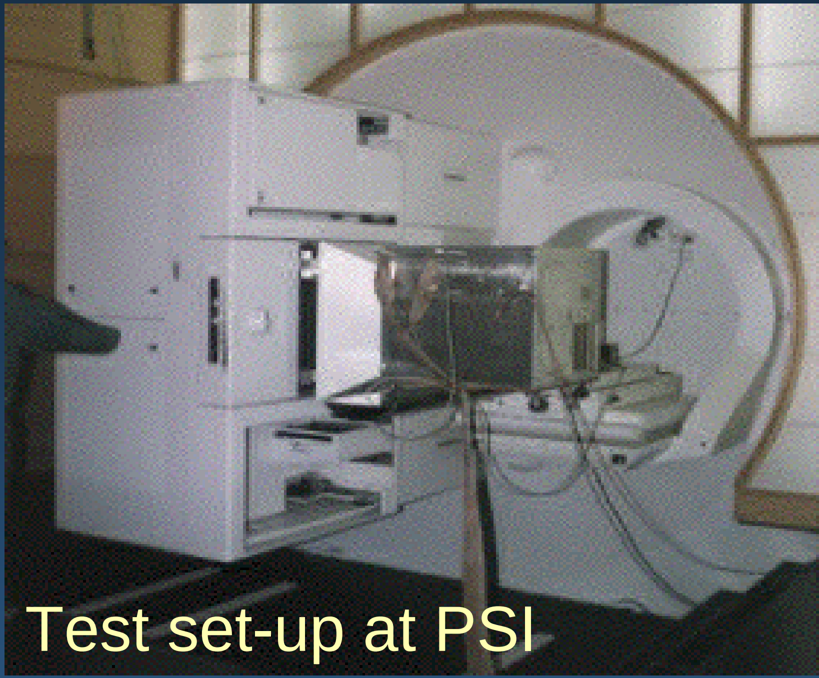
OOAD…



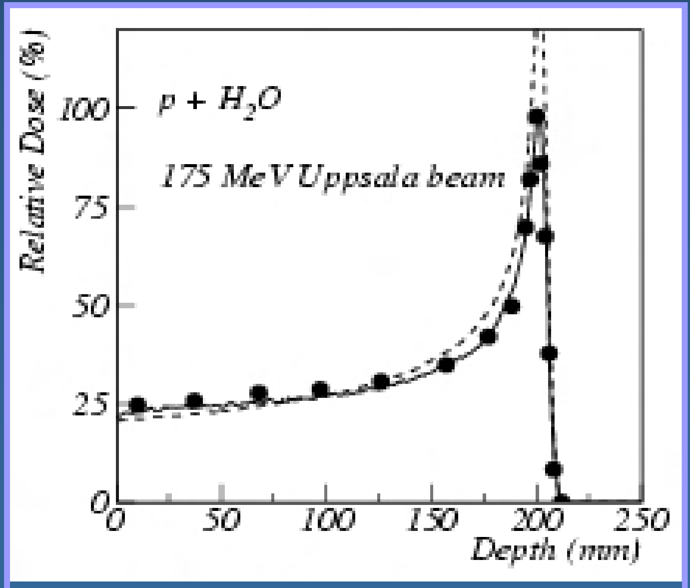
…and validation



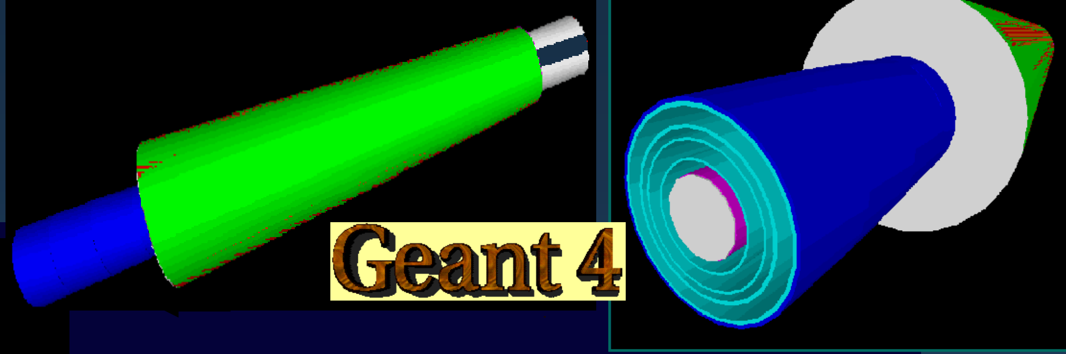
Courtesy of R. Gotta, Thesis



Test set-up at PSI

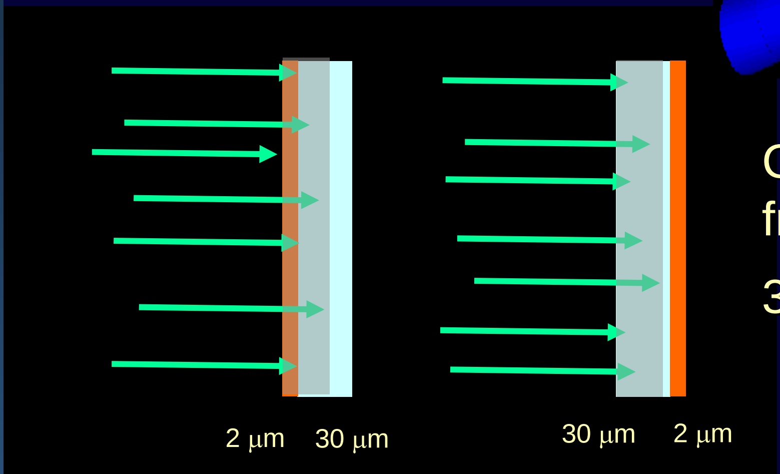


Geant4 LowE Working Group



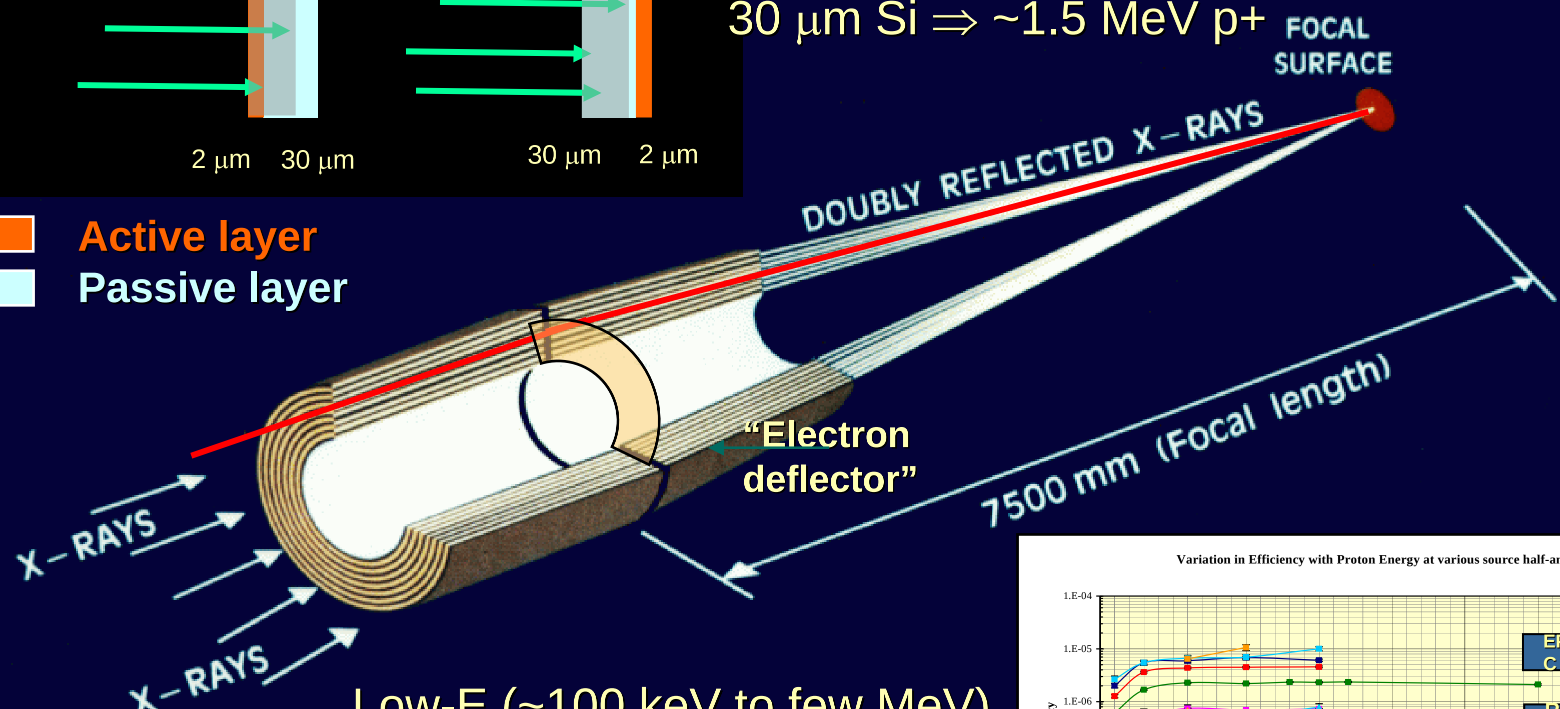
CCD displacement damage: front vs. back-illuminated

30 μm Si $\Rightarrow$ ~1.5 MeV p+

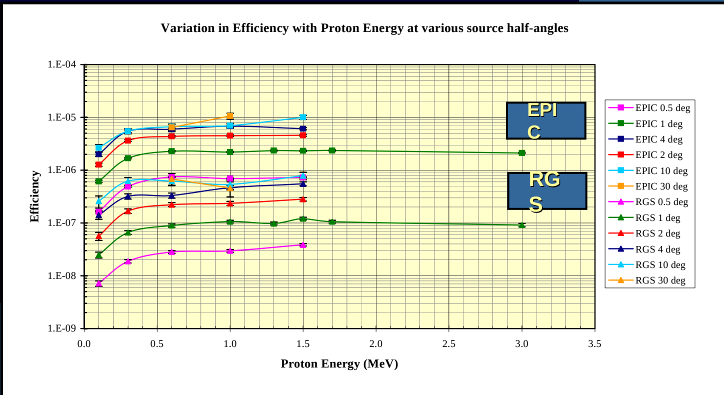


Active layer

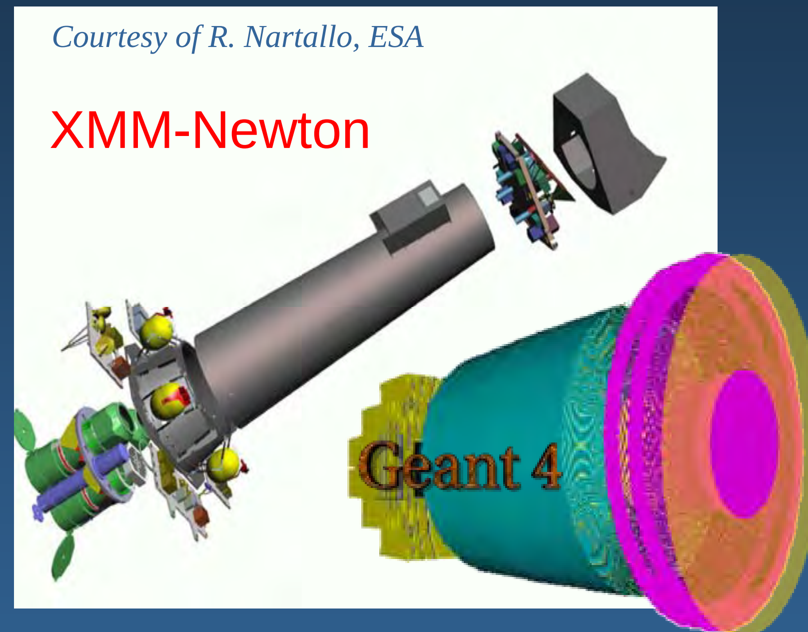
Passive layer

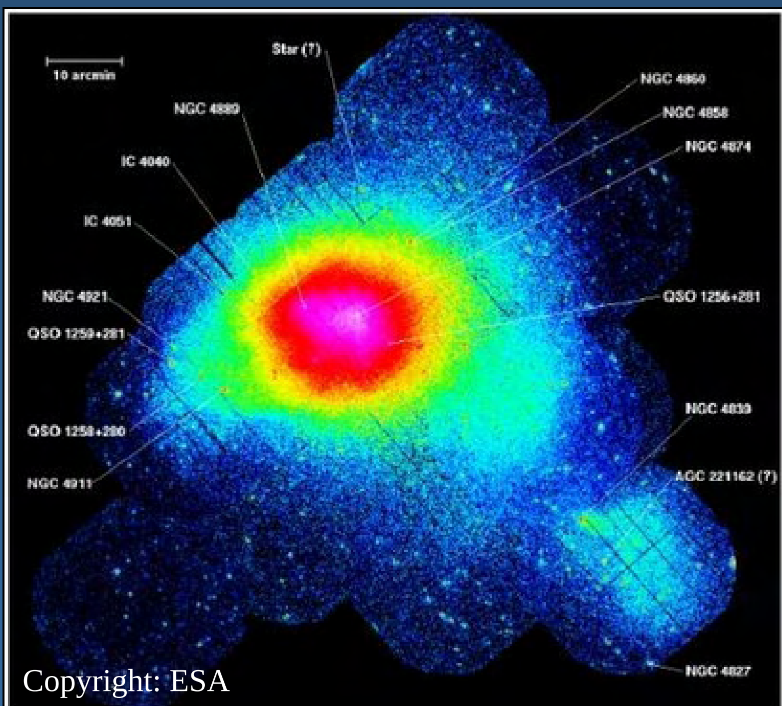


Low-E (~100 keV to few MeV), low-angle (~0°-5°) proton scattering



XMM-Newton was launched on 10 December 1999





Simulation can be mission-critical!

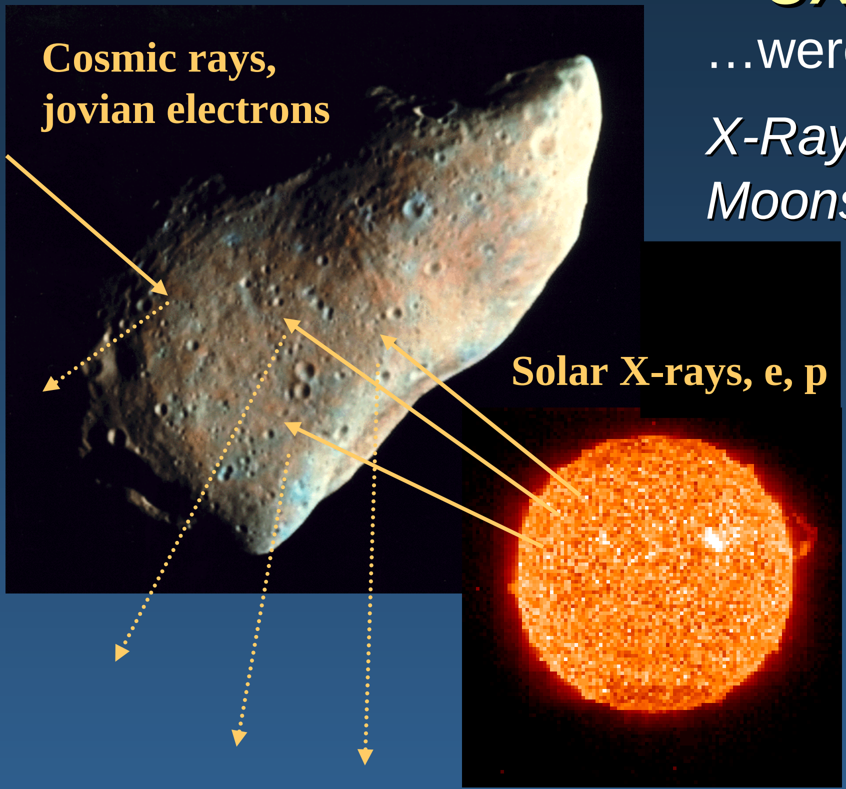
EPIC-PN image of the Coma Cluster

…and the other way round

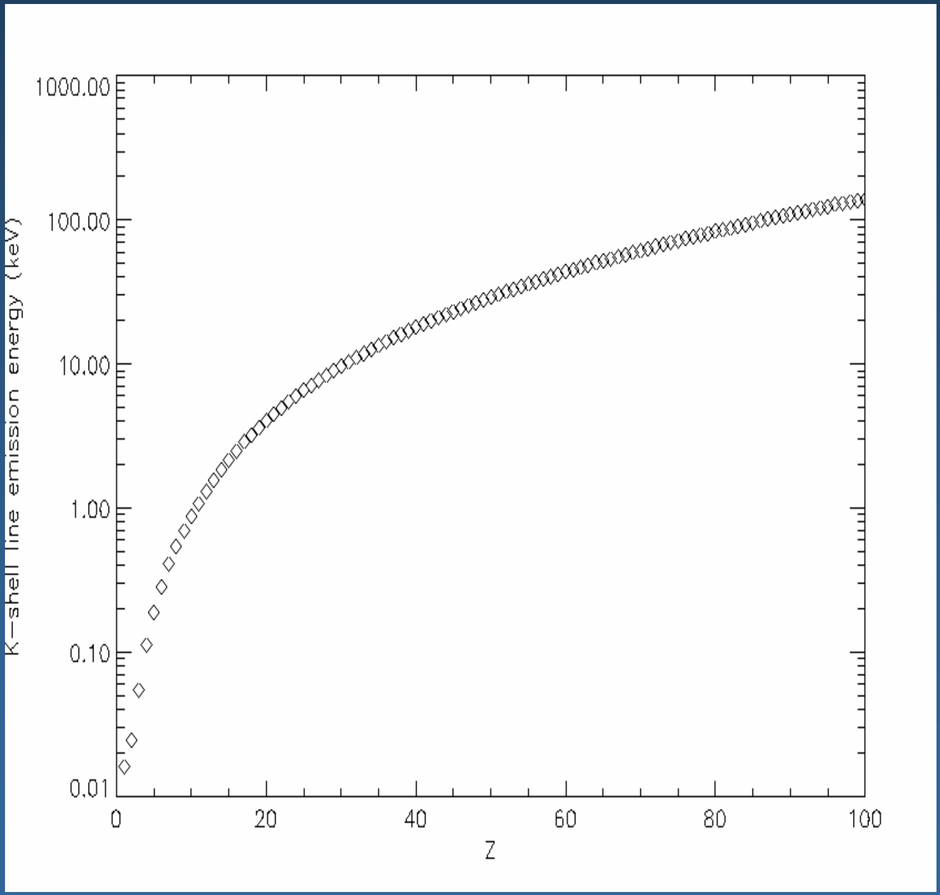
Geant4 low energy e, γ extensions

…were triggered by astrophysics requirements

X-Ray Surveys of Planets, Asteroids and Moons



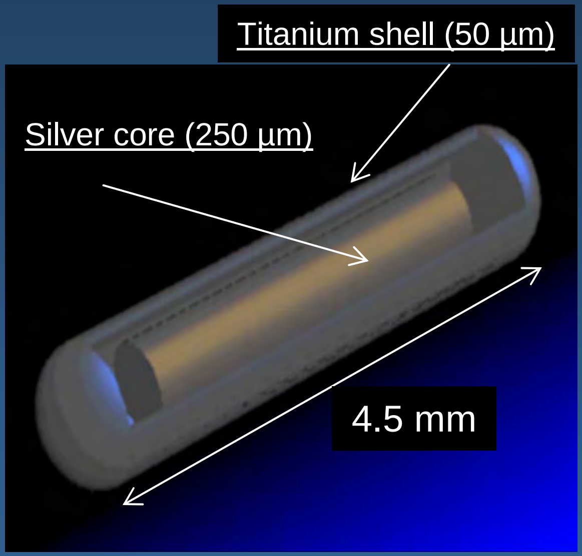
Courtesy SOHO EIT

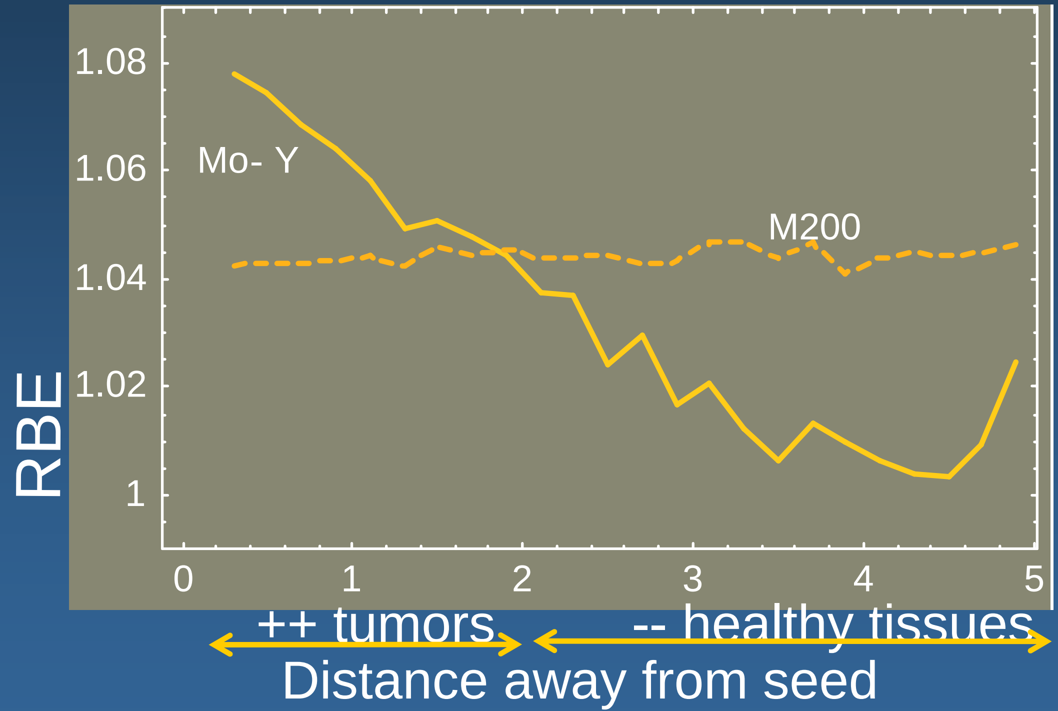


Induced X-ray line emission: indicator of target composition (~100 μm surface layer)

…the first user application

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



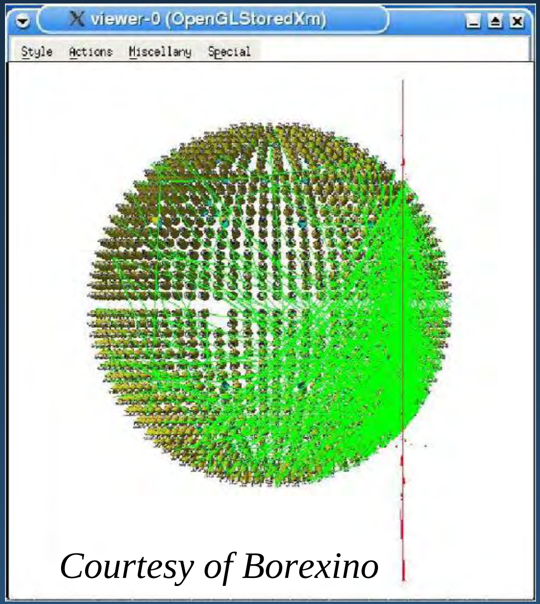


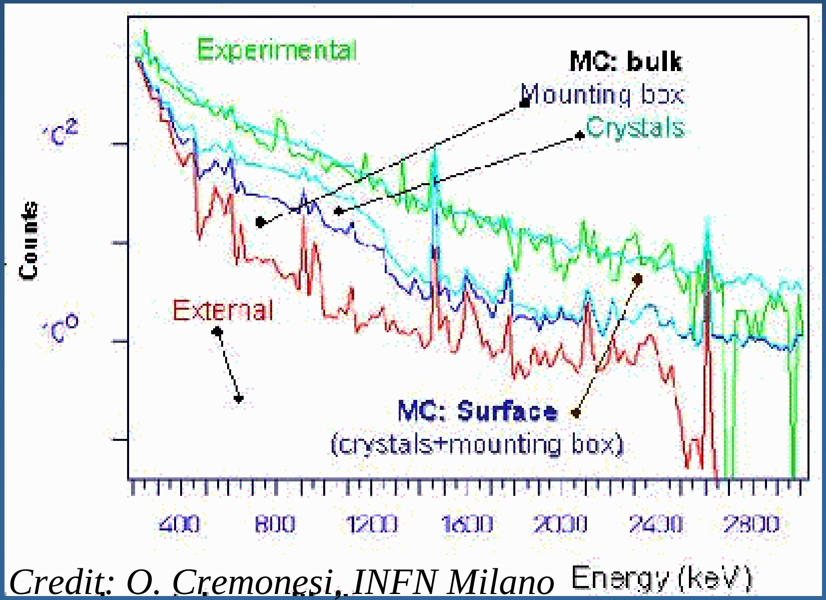
R. Taschereau, R. Roy, J. Pouliot

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





...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 Molloi, 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 Quailty 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, Lartizien, 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 Schmidtlein, 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…

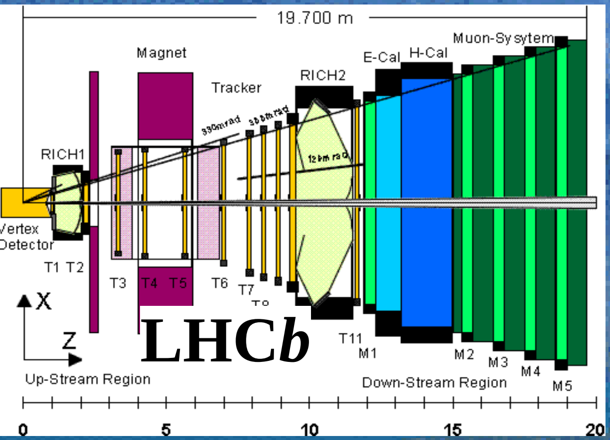
An experiment of distributed software production and management

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

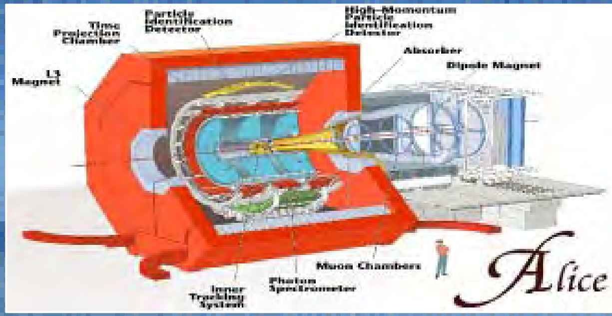
R&D phase: **RD44**, 1994 - 1998

1st release: December 1998

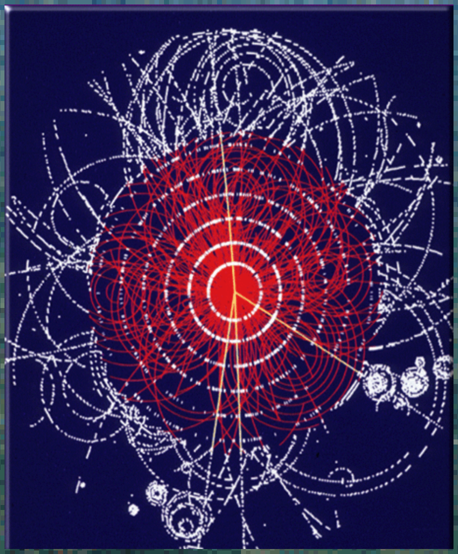
2 new releases/year since then

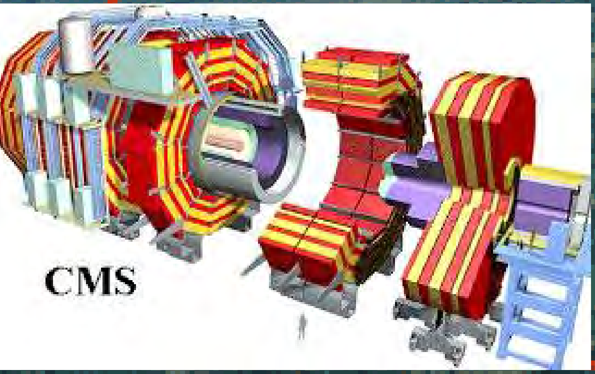


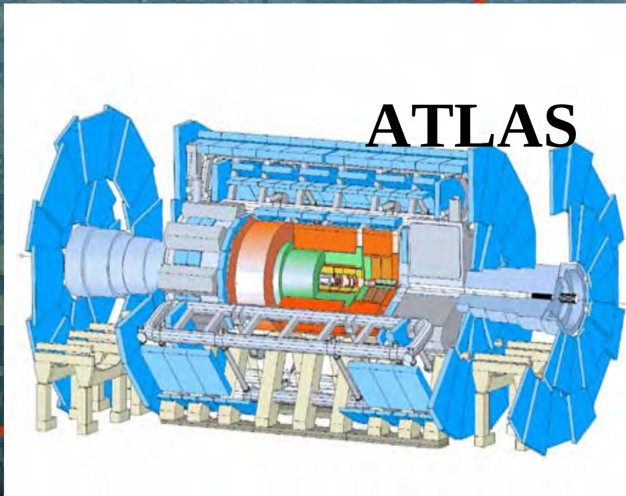
Complex physics
Complex detectors
20 years software life-span



LHC



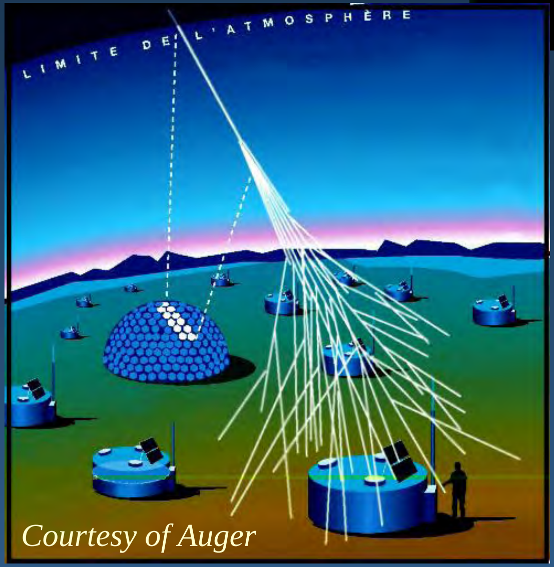




From deep underground...

...to space

Dark matter and ν experiments



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

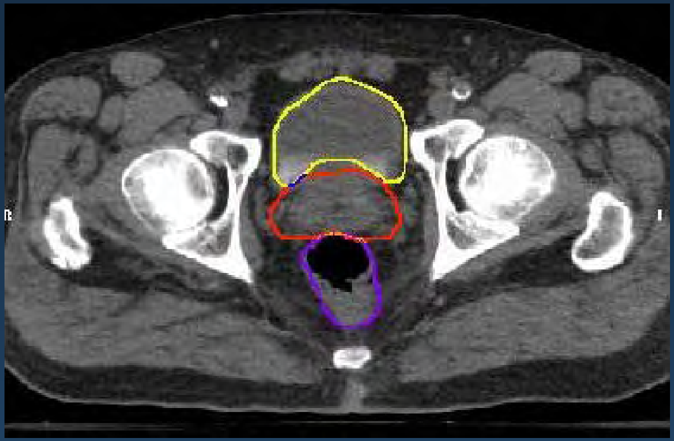
Cosmic ray experiments

Variety of requirements from diverse applications

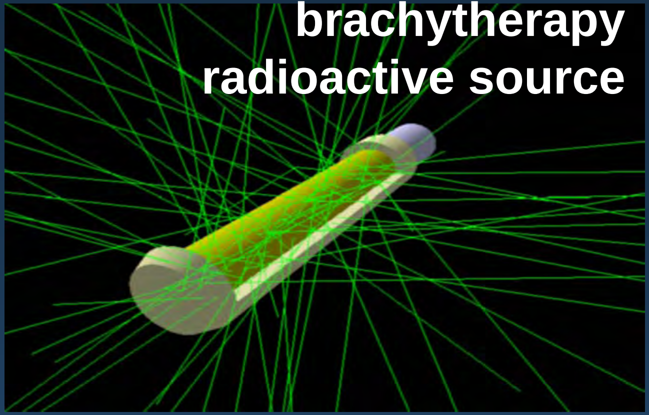
Physics from the eV to the PeV scale	Detectors, spacecrafts and environment

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

Require reliability, rigorous software engineering standards



Medical Physics

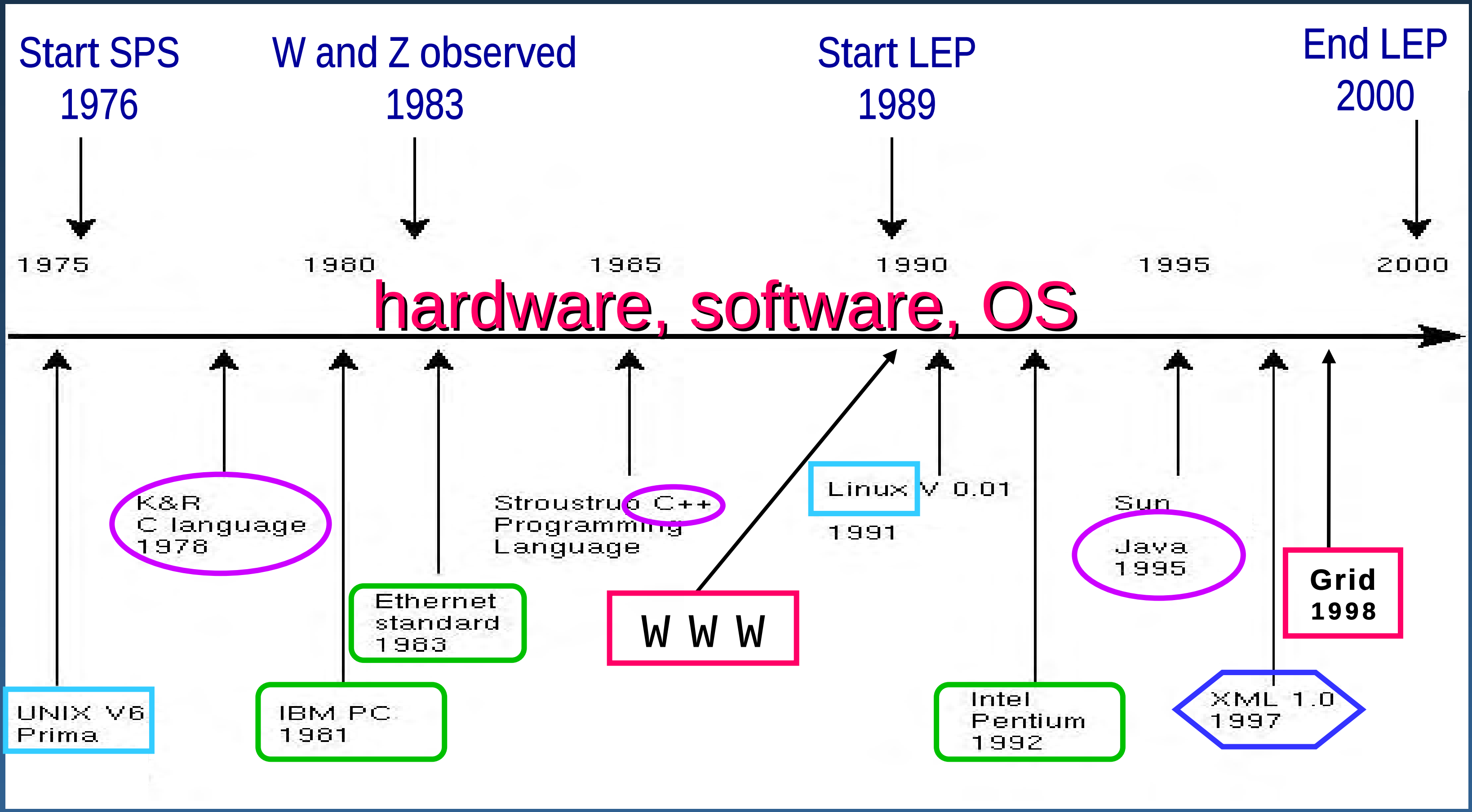


from hospitals…

…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**

Strategic vision

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

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

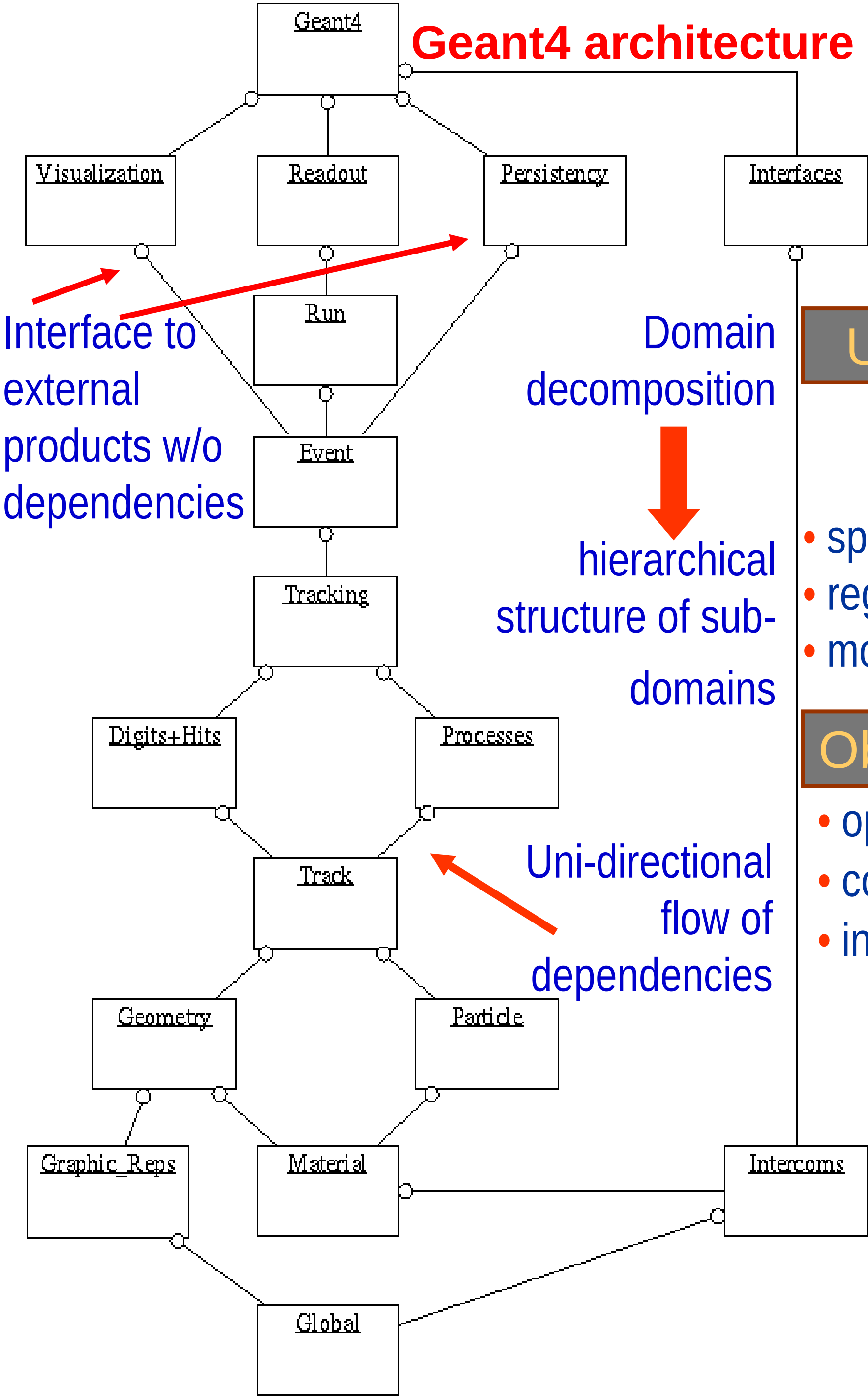
From the Minutes of LCB (LHCC Computing Board) meeting on 21 October, 1997:

"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

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.

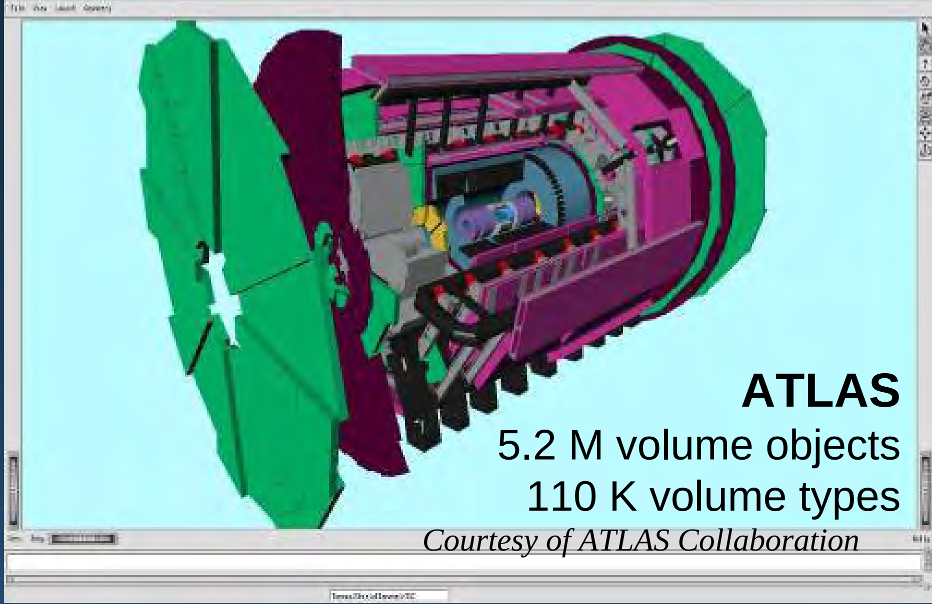
Tracking

- 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**

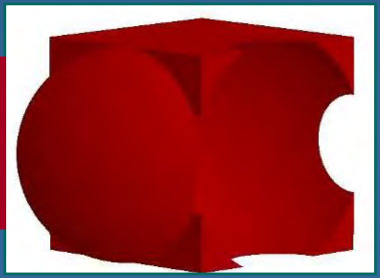
- all particles are tracked down to zero range
- energy, TOF ... cuts can be defined by the user

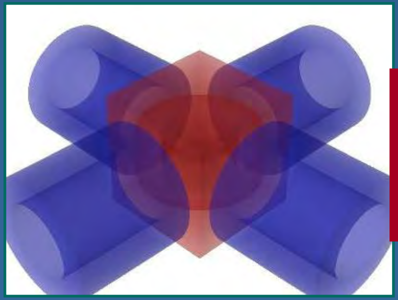
Geometry



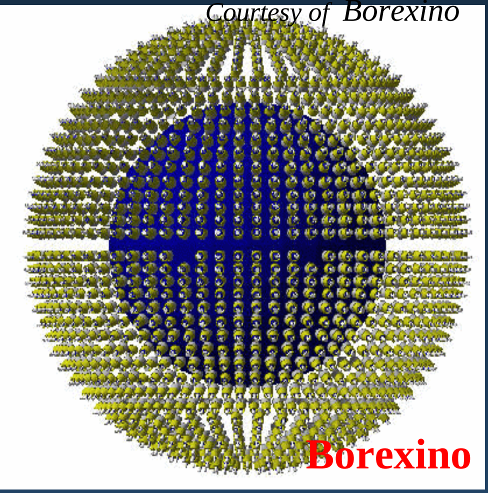
- Role
  - detailed detector description
  - efficient navigation
- Three conceptual layers
  - Solid: shape, size
  - LogicalVolume: material, sensitivity, daughter volumes, etc.
  - PhysicalVolume: position, rotation
- One can do fancy things with geometry…

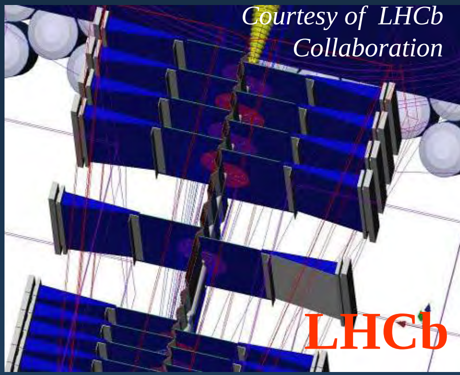
Boolean operations





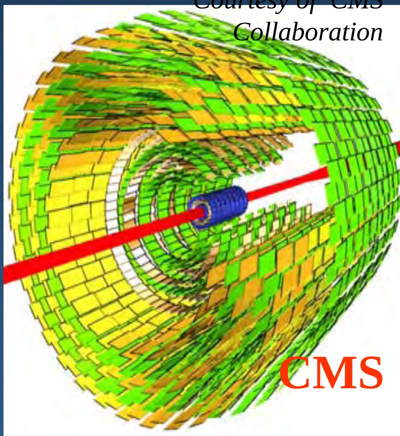
Transparent solids

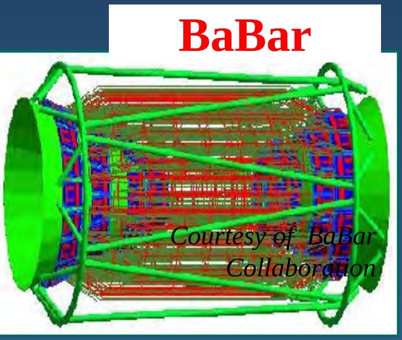




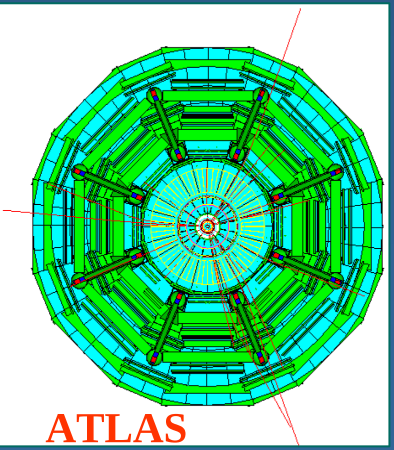
Solids

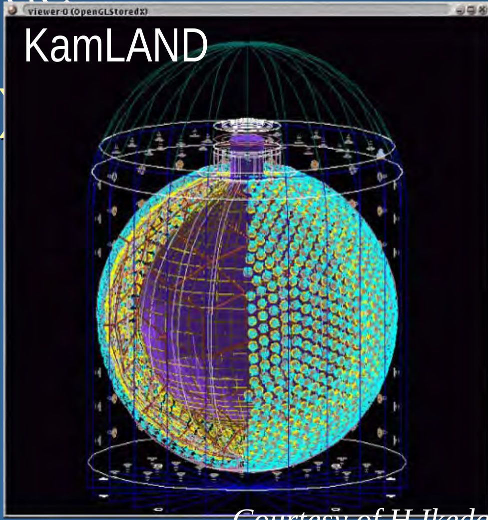
Multiple representations
Same abstract interface





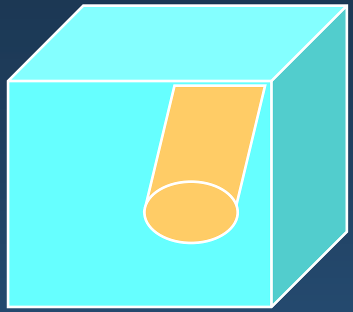
- CSG (**C**onstructed **S**olid **G**eometries)
  - simple solids
- STEP extensions
  - polyhedra, spheres, cylinders, cones, toroids, etc.
- BREPS (**B**oundary **REP**resented **S**olids)
  - volumes defined by boundary surfaces





CAD exchange

Physical Volumes



placemen
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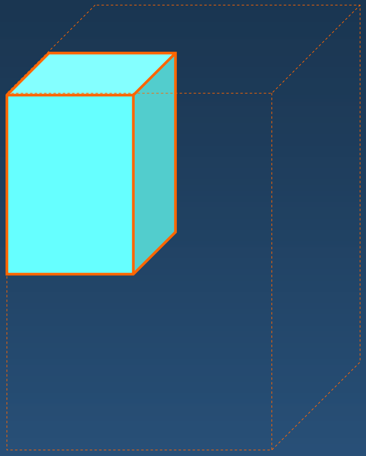
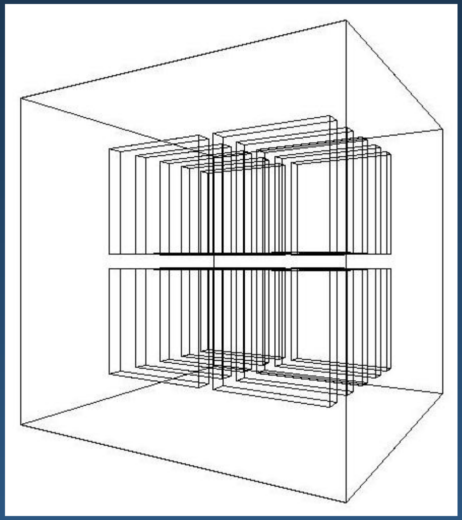
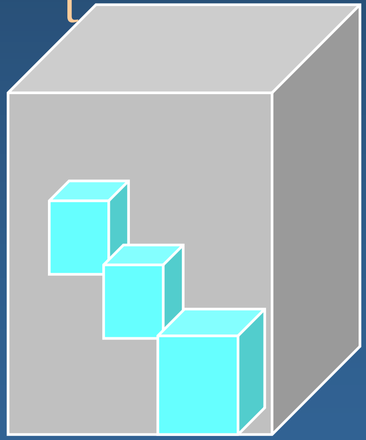
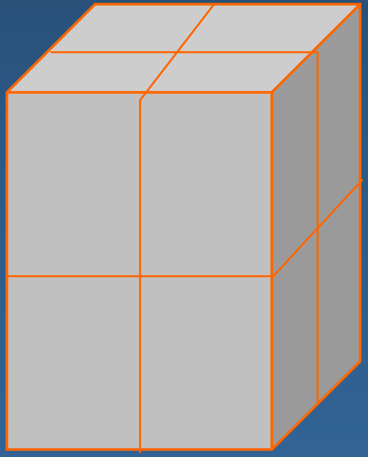




assembled



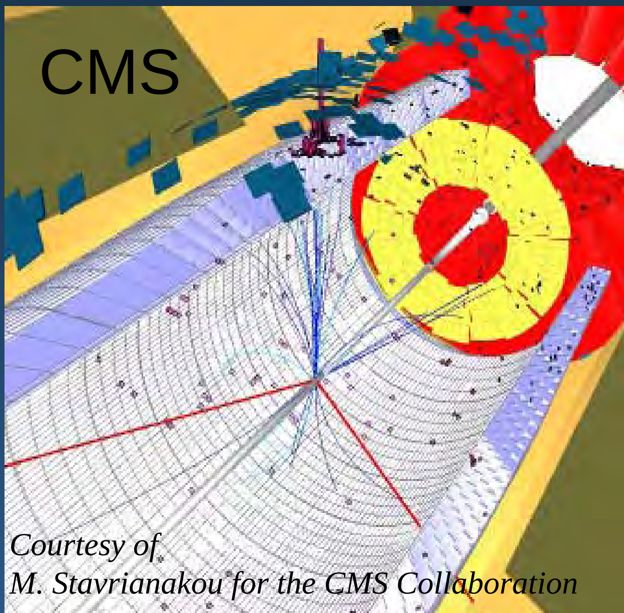
parameterised



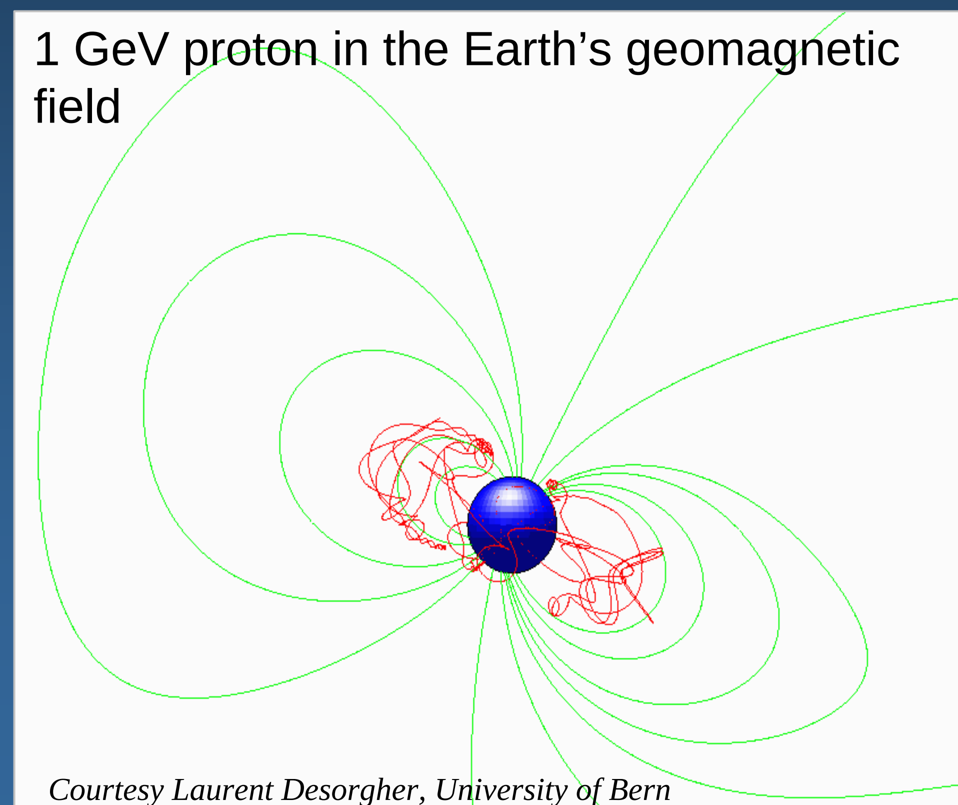
replica

Versatility to describe complex geometries

Electric and magnetic fields of variable non-uniformity and differentiability

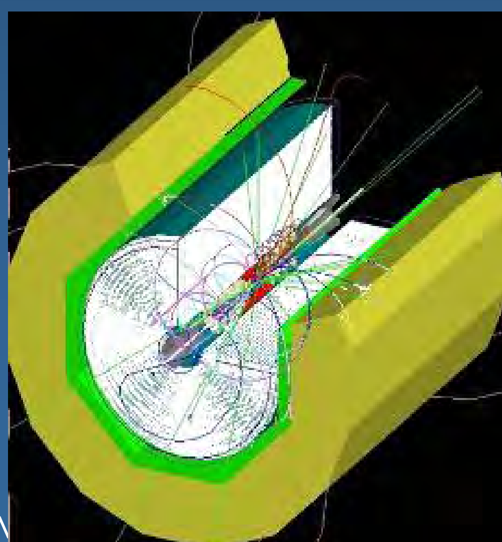


Geant4 field ~ 2 times faster than FORTRAN/GEANT3



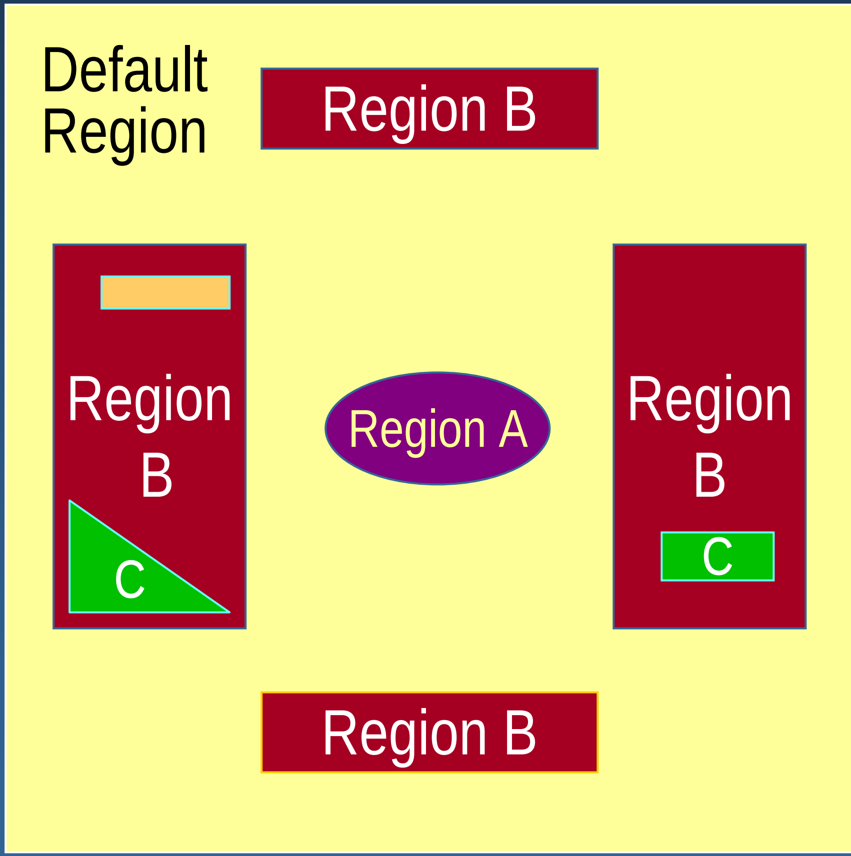
MOKKA

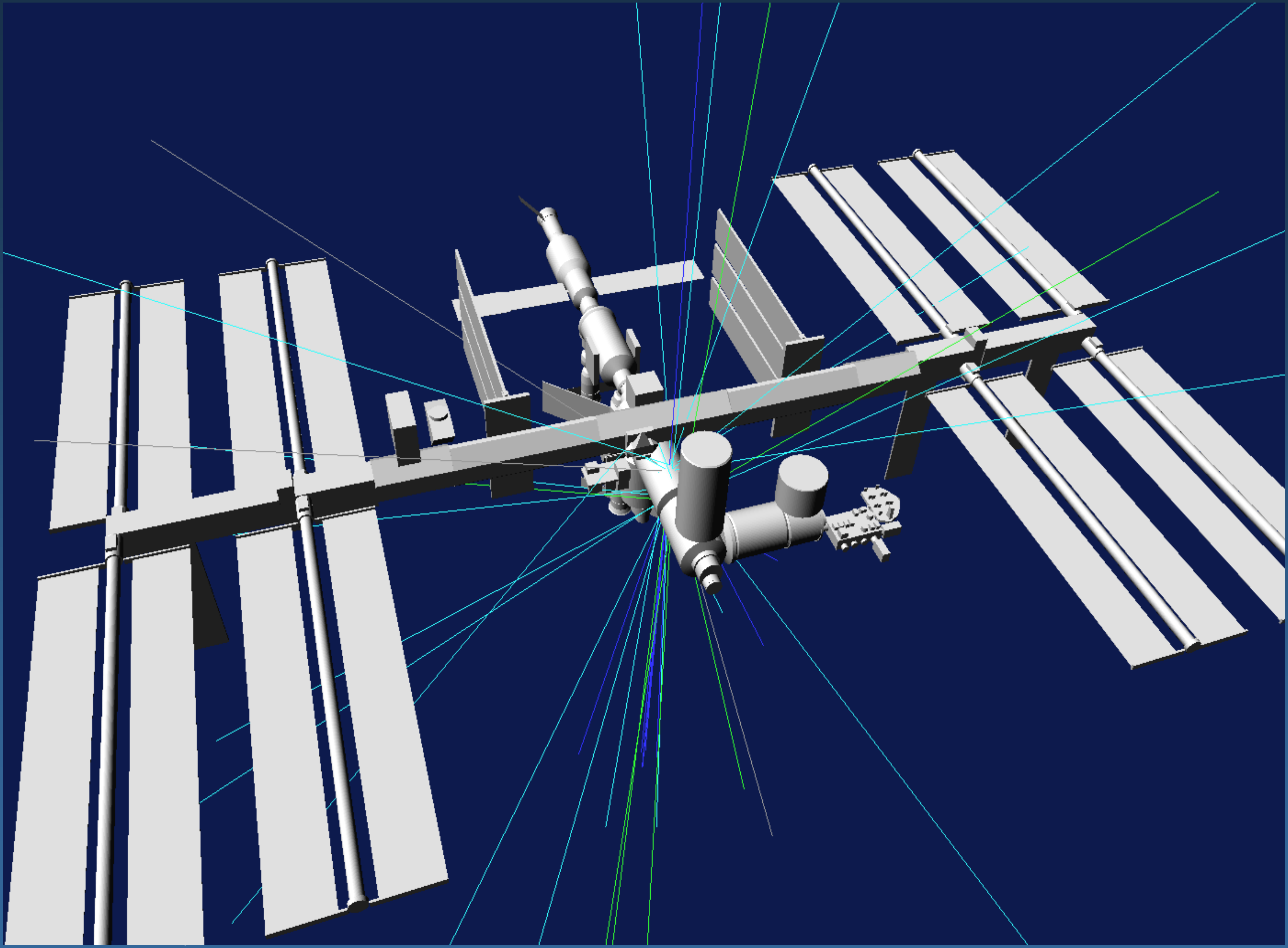
Linear Collider Detector



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



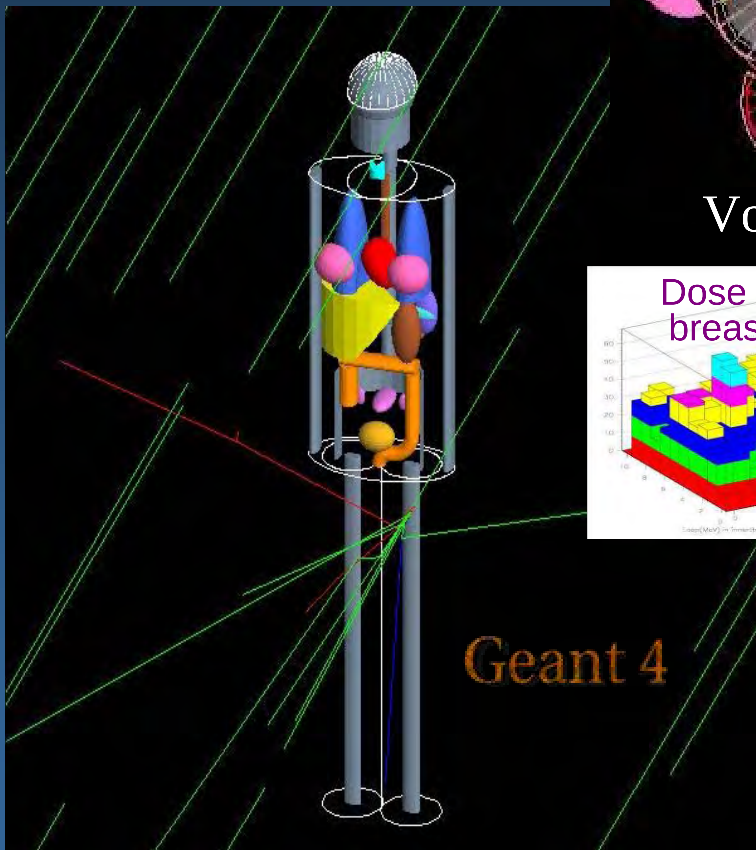


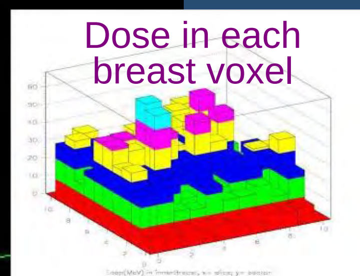
Courtesy T. Ersmark, KTH Stockholm

Not only large scale, complex detectors….

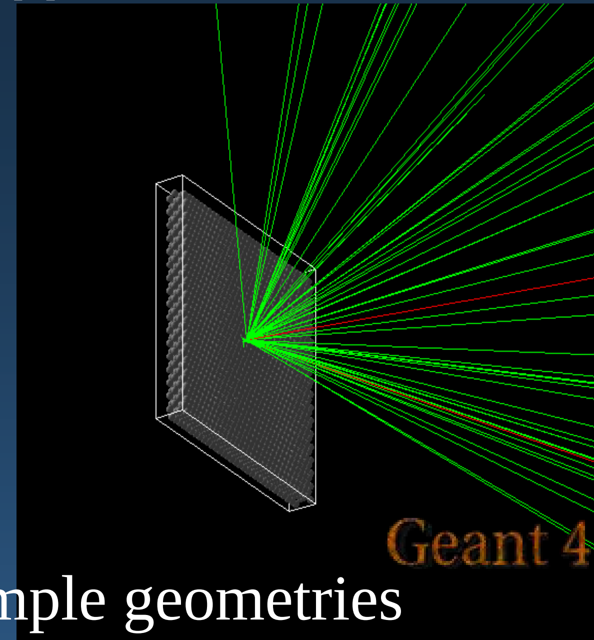
Analytical breast

Voxel breast



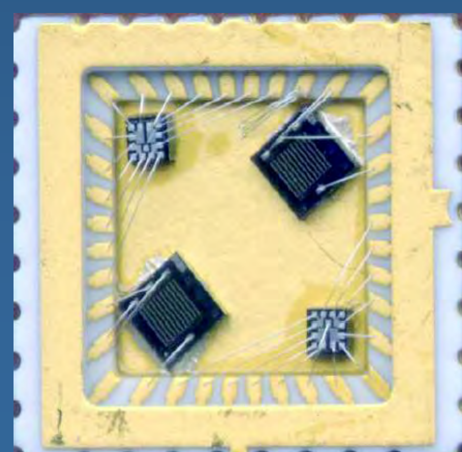


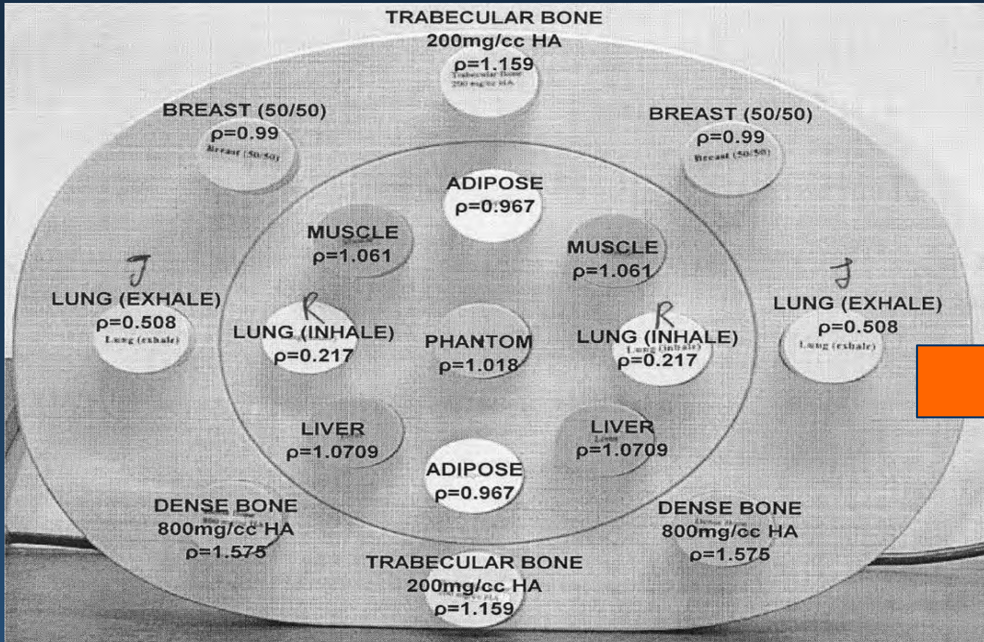
Geant4 anthropomorphic phantoms

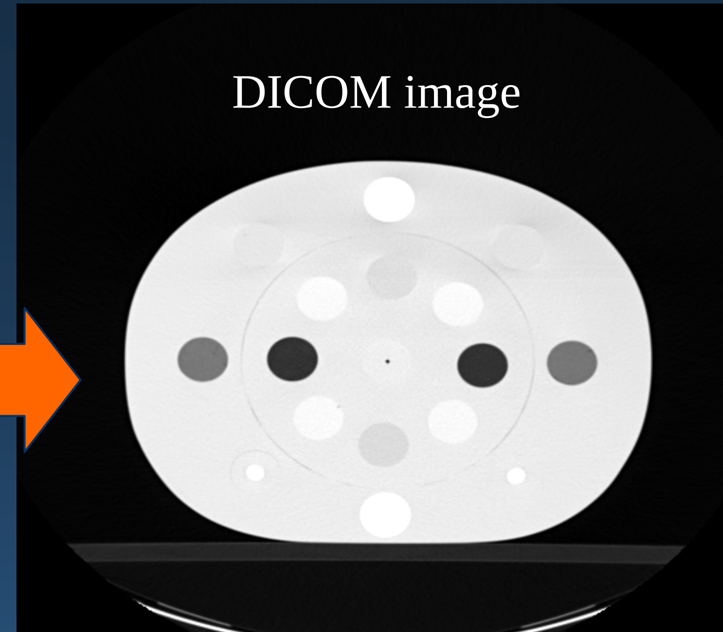


simple geometries

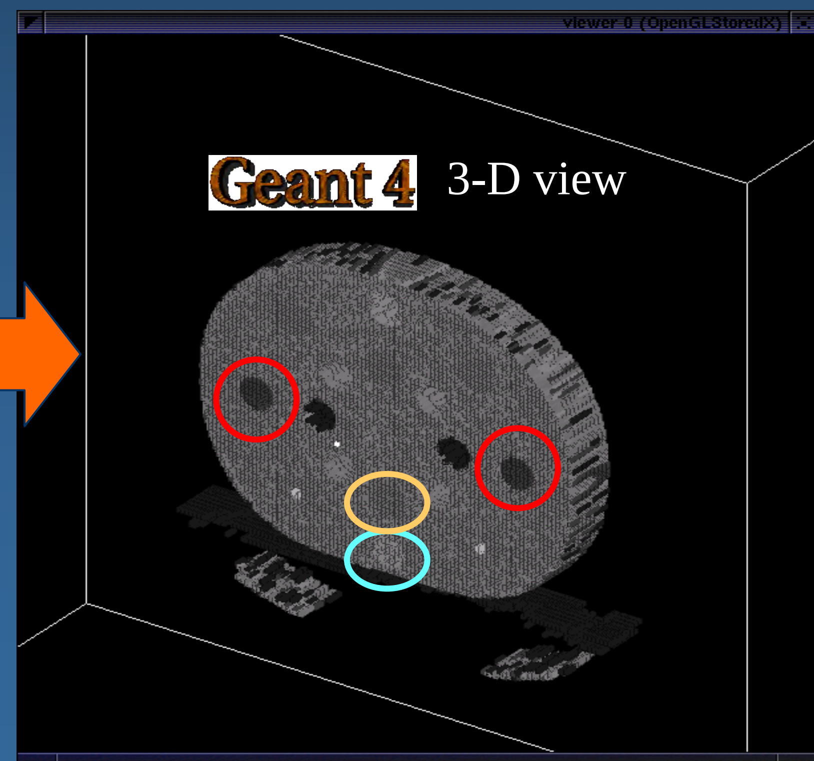
small scale components





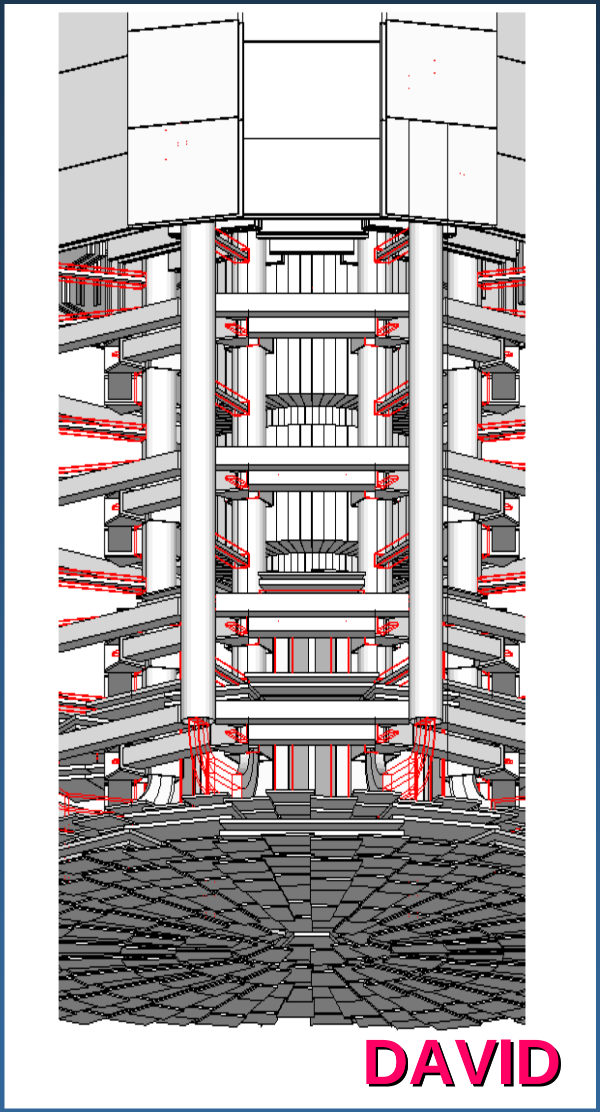


- Reading image information
- Transformation of pixel data into densities
- Association of densities to a list of materials
- Defining the voxels
  - Geant4 parameterised volumes
  - parameterisation function: material

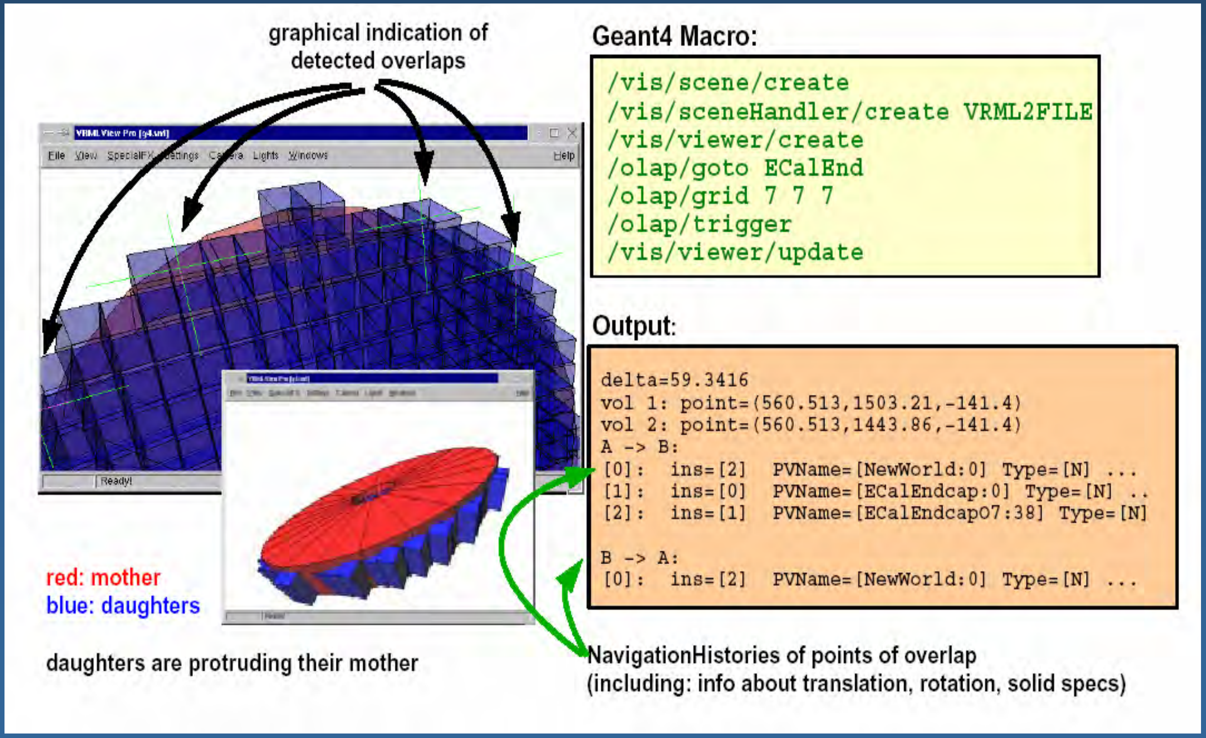


CENTRE DE RECHERCHE
Pavillon L'Hôtel-Dieu
Centre hospitalier universitaire de Québec
UNIVERSITÉ LAVAL
L. Archambault, L. Beaulieu, V.-H. Tremblay

You may also do it wrong…



Tools to detect badly defined geometries



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

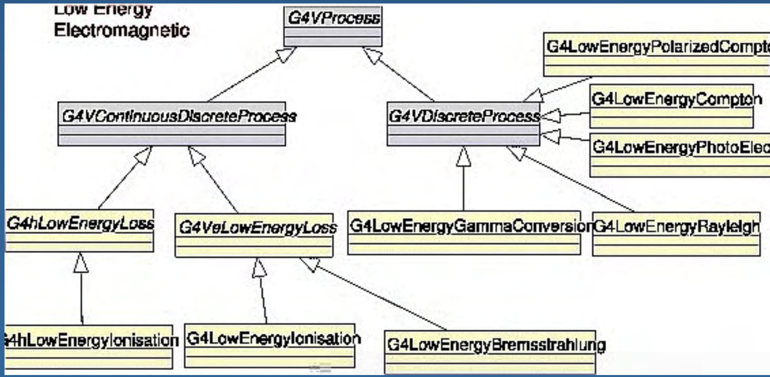
energy loss { Bremsstrahlung, Ionisation }

- 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

Comparable to Geant3 already in the α 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 ν experiments, antimatter spectroscopy etc.
- Alternative models for the same process



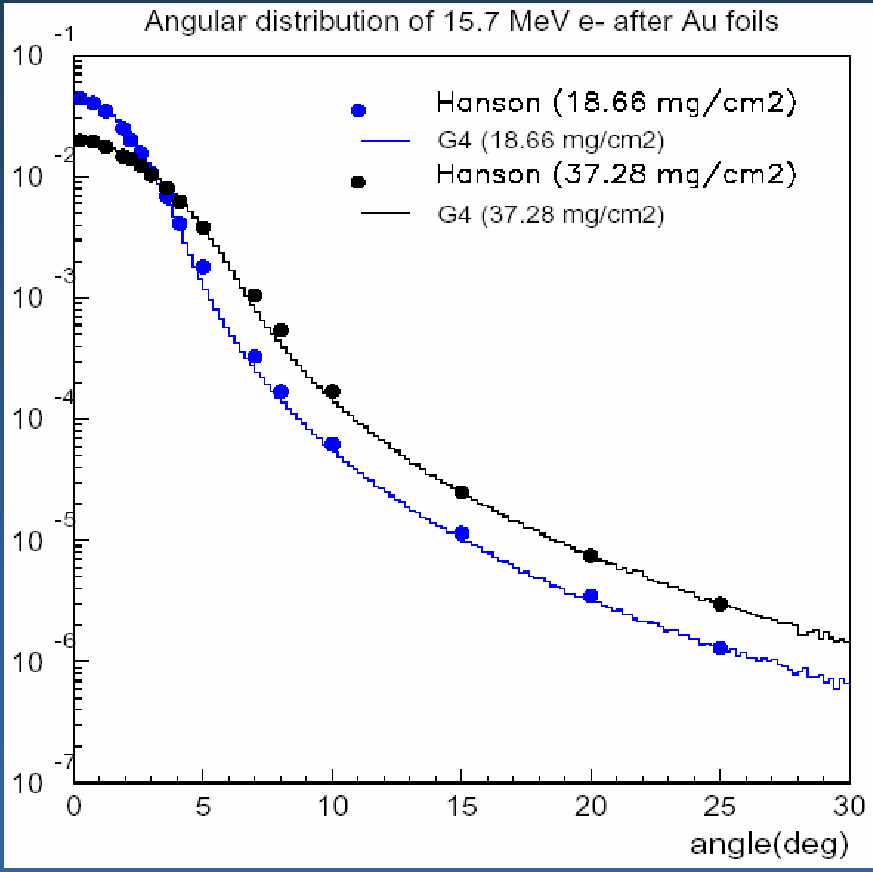
All obeying to the same abstract Process interface <u>transparent to tracking</u>

Standard electromagnetic processes

1 keV up to O(100 TeV)

- Multiple scattering
  – model based on Lewis theory
  – 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



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 ν factory or μ collider

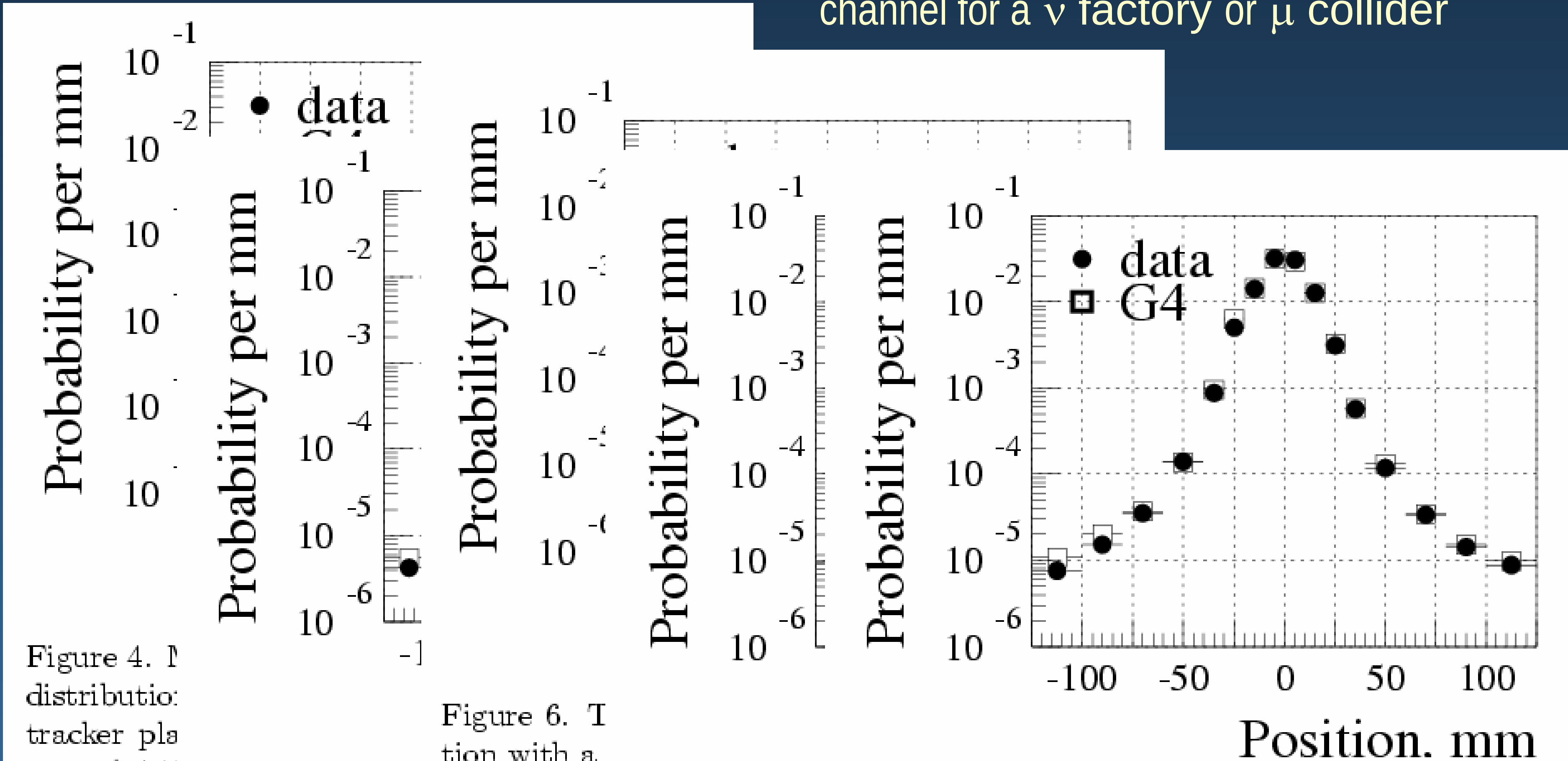


Figure 4. ... distributio... tracker pla... central ±1...

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

Figure 6. T... tion with a ...

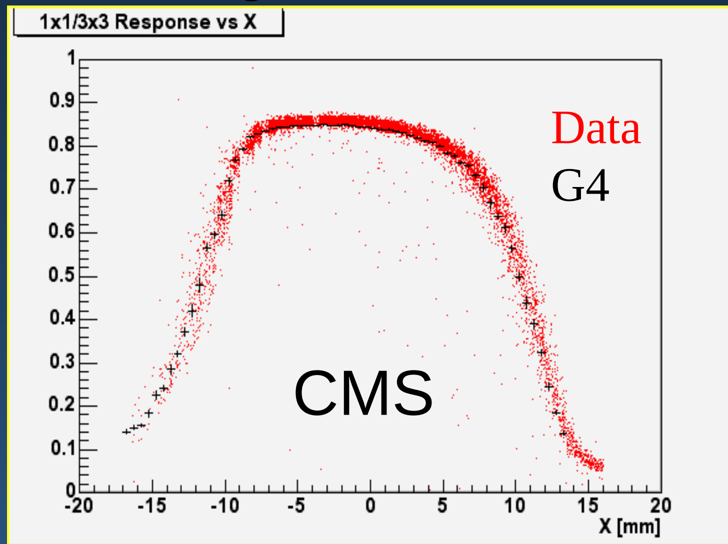
Figure 7. The ... tion with a 3. ...

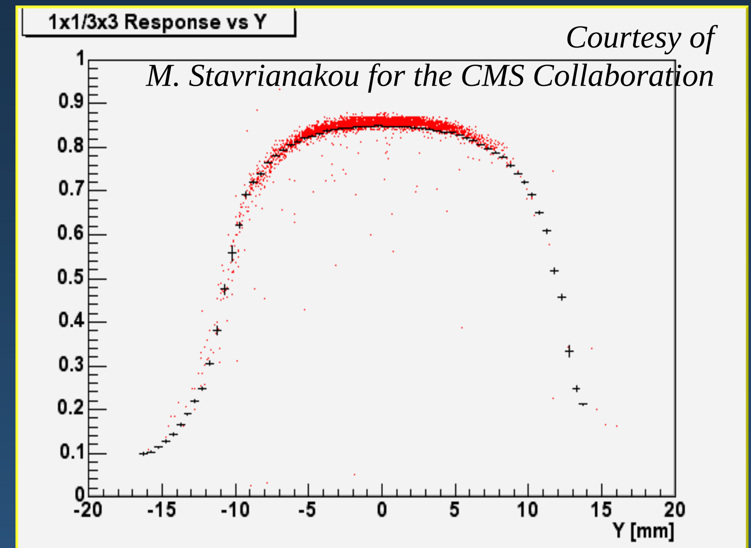
Figure 8. The measured and simulated arrival position distributions with a 150 mm liquid hydrogen target.

Courtesy of W.J. Murray (RAL)

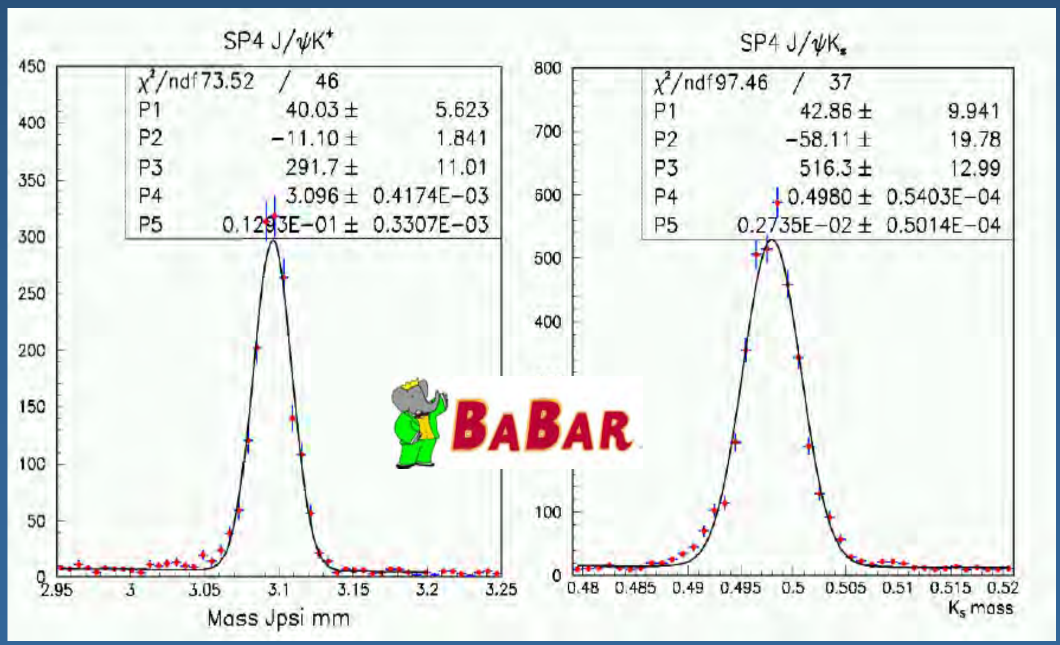
Calorimetry

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

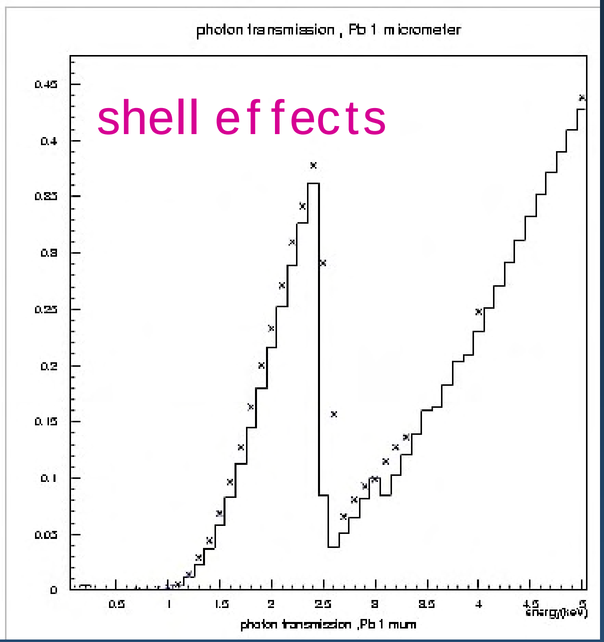




Tracking



Geant4
Standard
Electromagnetic
Physics

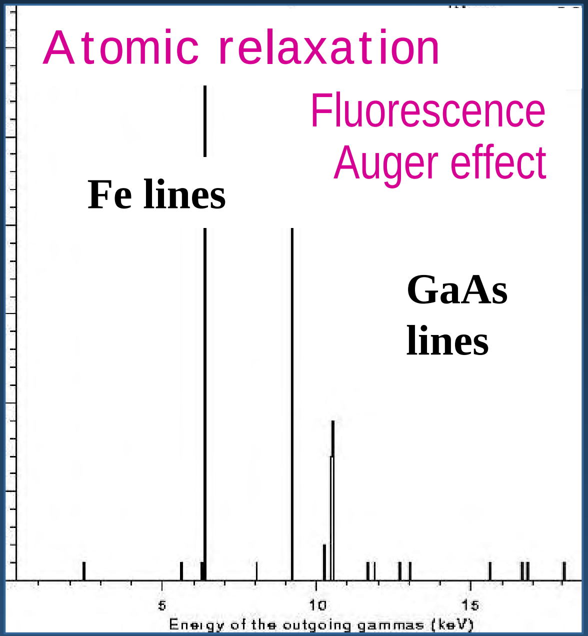


Geant 4

e,γ down to 250/100 eV
EGS4, ITS to 1 keV
Geant3 to 10 keV

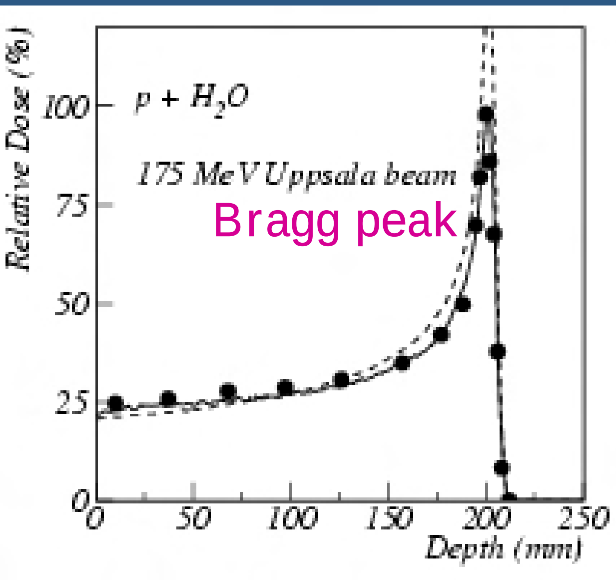
① Based on EPDL97, EEDL and EADL evaluated data libraries

② Based on Penelope analytical models



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

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



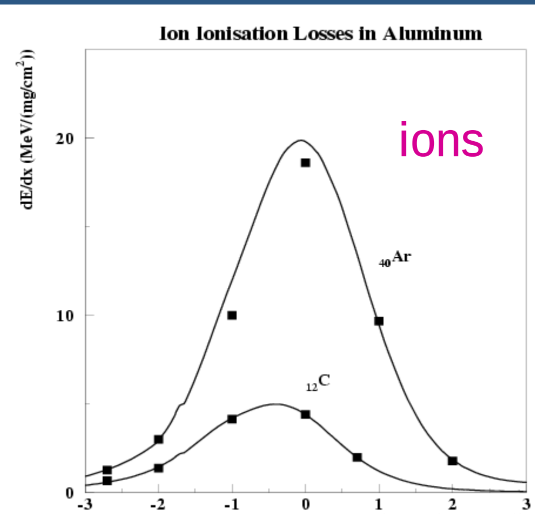
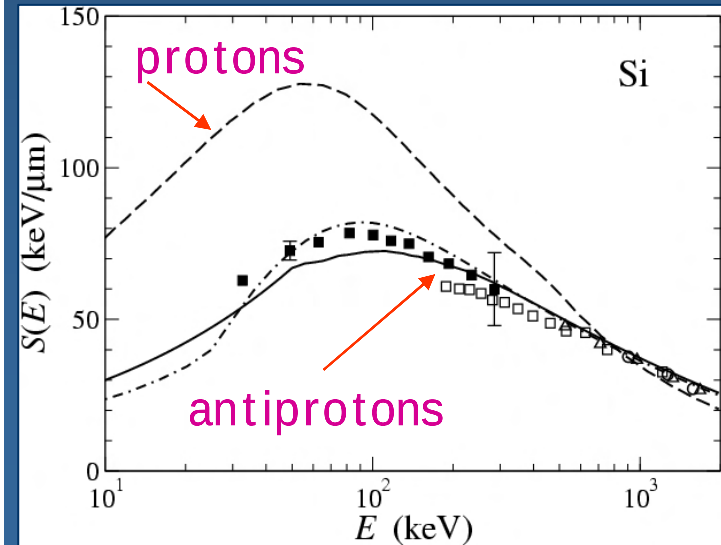


Figure 9: Ion electronic stopping power in aluminum. Points - the best fit on the data from Ref.[12], solid line - GEANT4 parameterisation. The accuracy of the data is about 5 %.



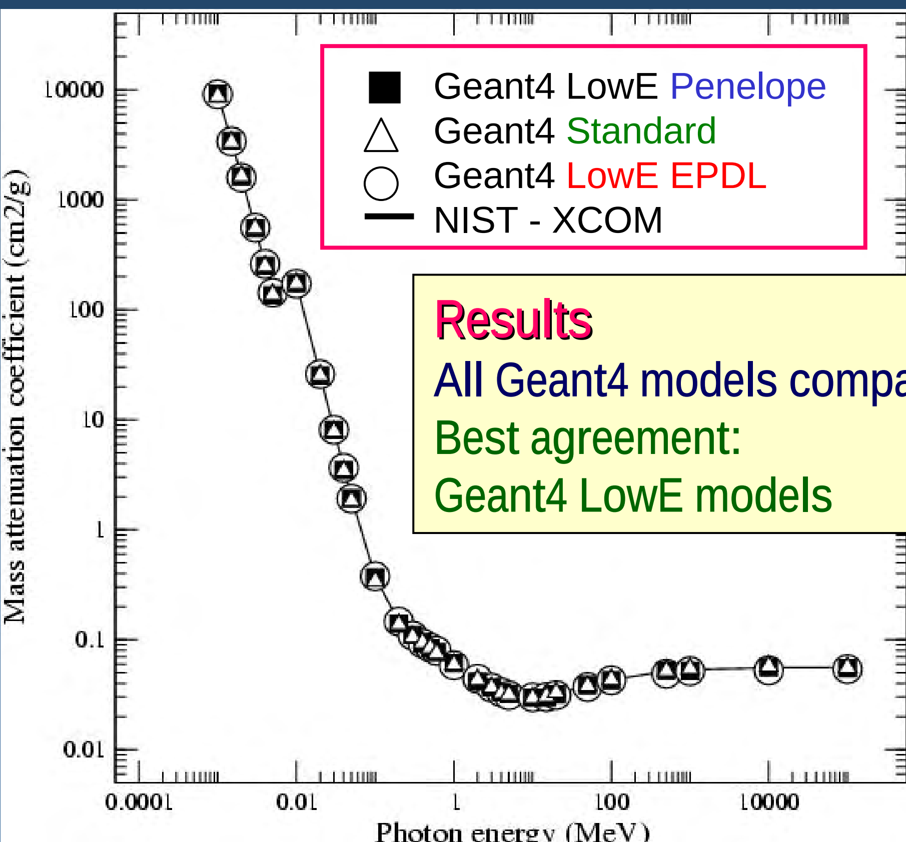
“Comparison of Geant4 electromagnetic physics models against the NIST reference data”

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

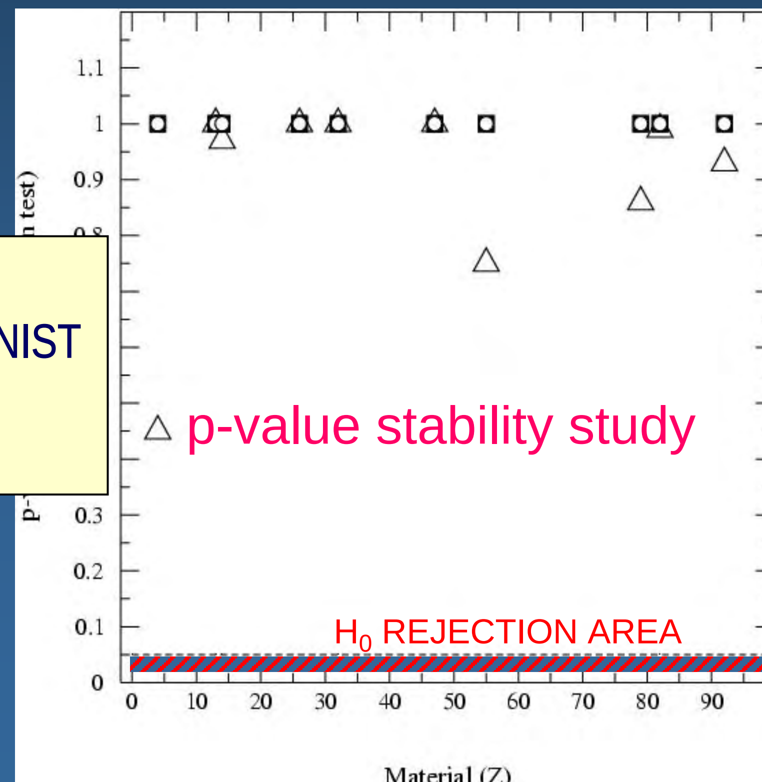


Results

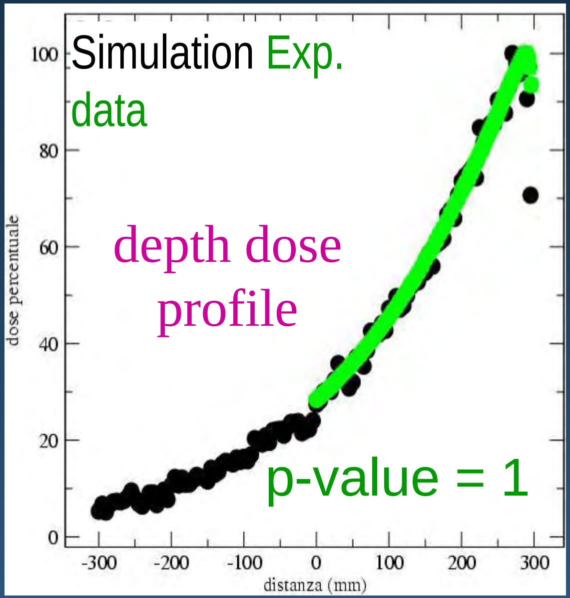
All Geant4 models compatible with NIST

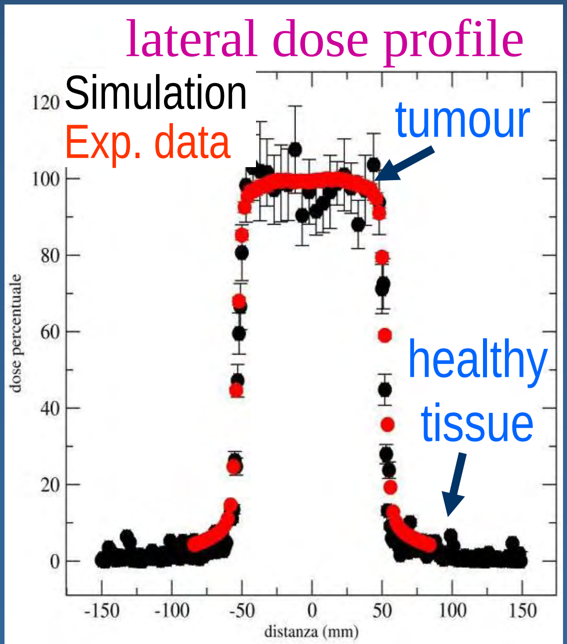
Best agreement:

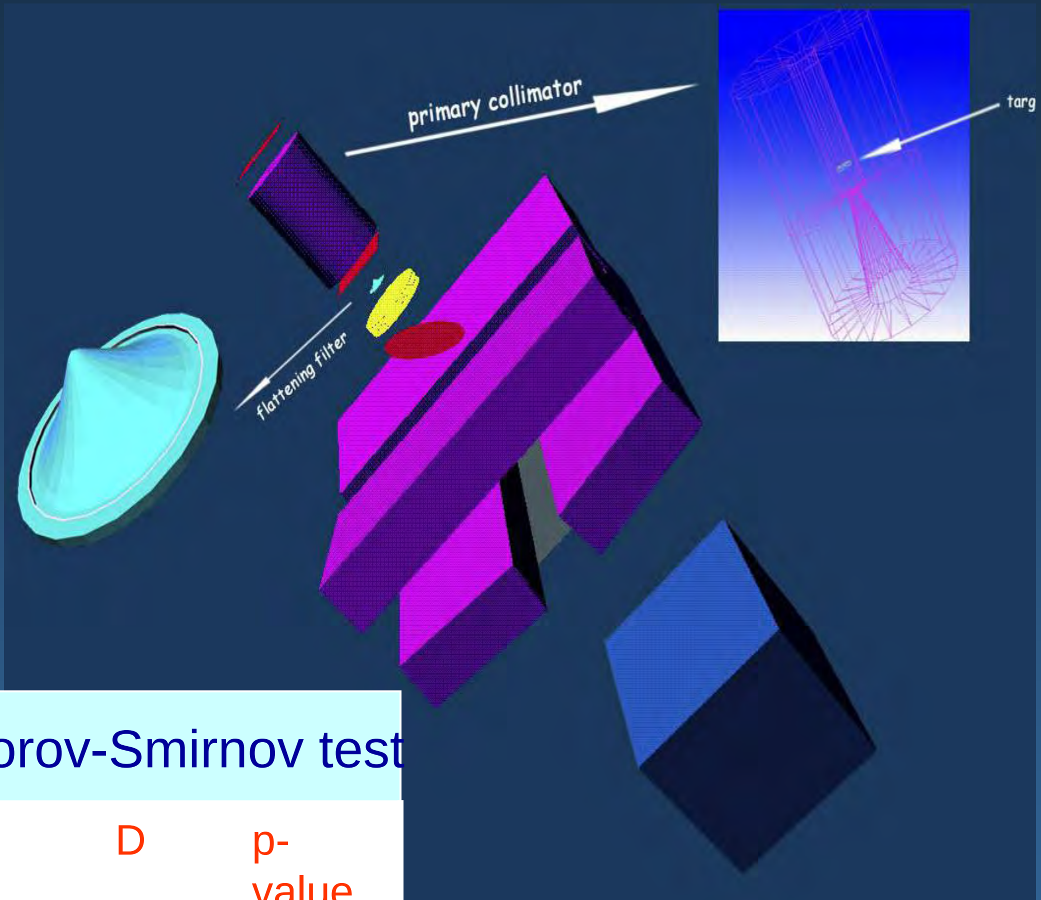
Geant4 LowE models



A medical accelerator for IMRT







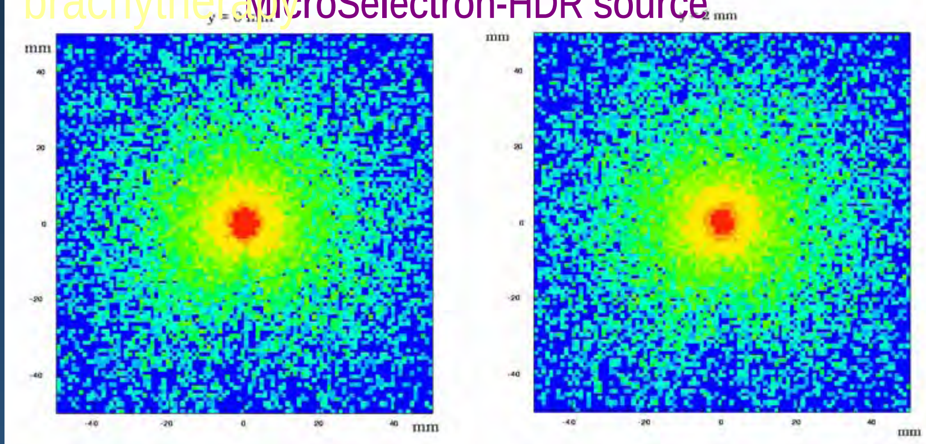
Kolmogorov-Smirnov test

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

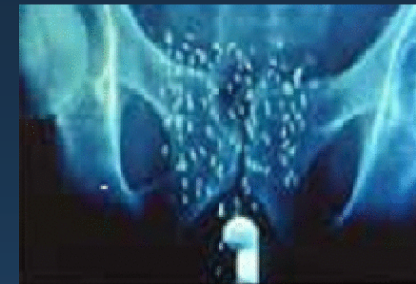
IST Genova and S. Paolo Hospital Savona

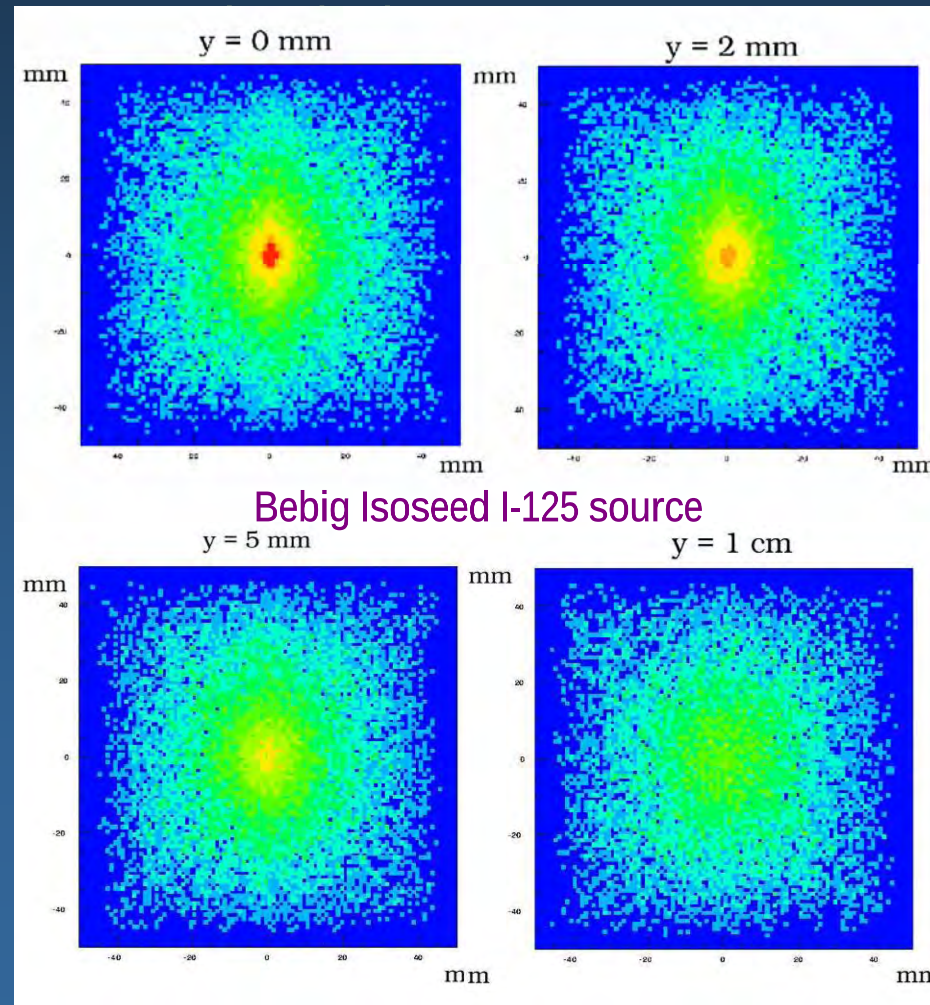
Dosimetry
Endocavitary
brachytherapy

MicroSelectron-HDR source

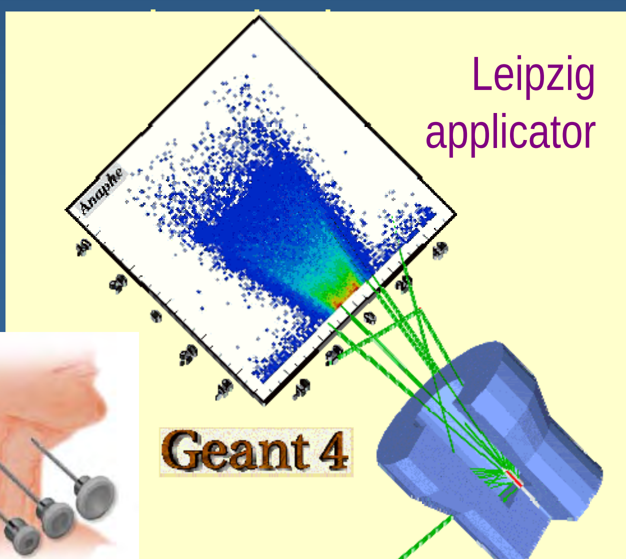


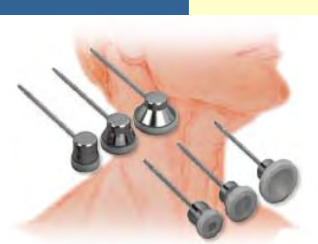
Dosimetry
Interstitial





Dosimetry
Superficial



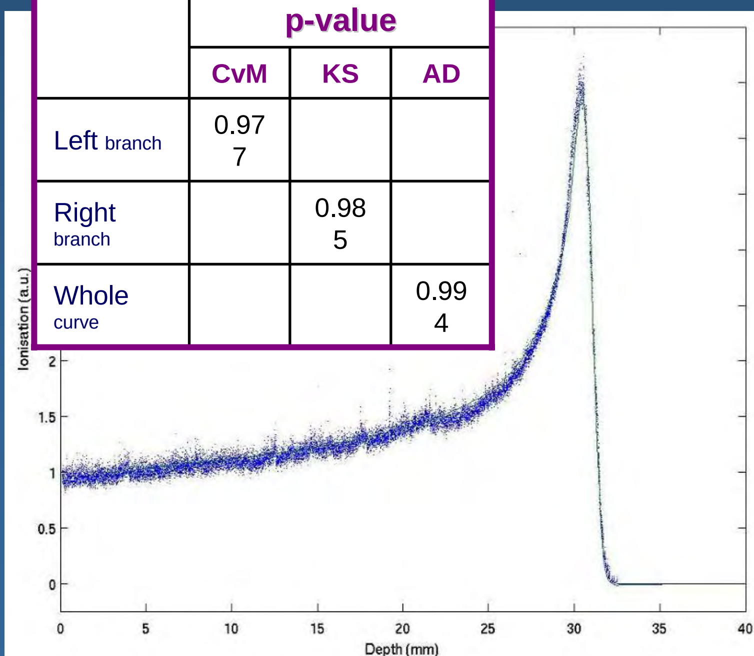


F. Foppiano, IST and INFN Genova Geant4 team

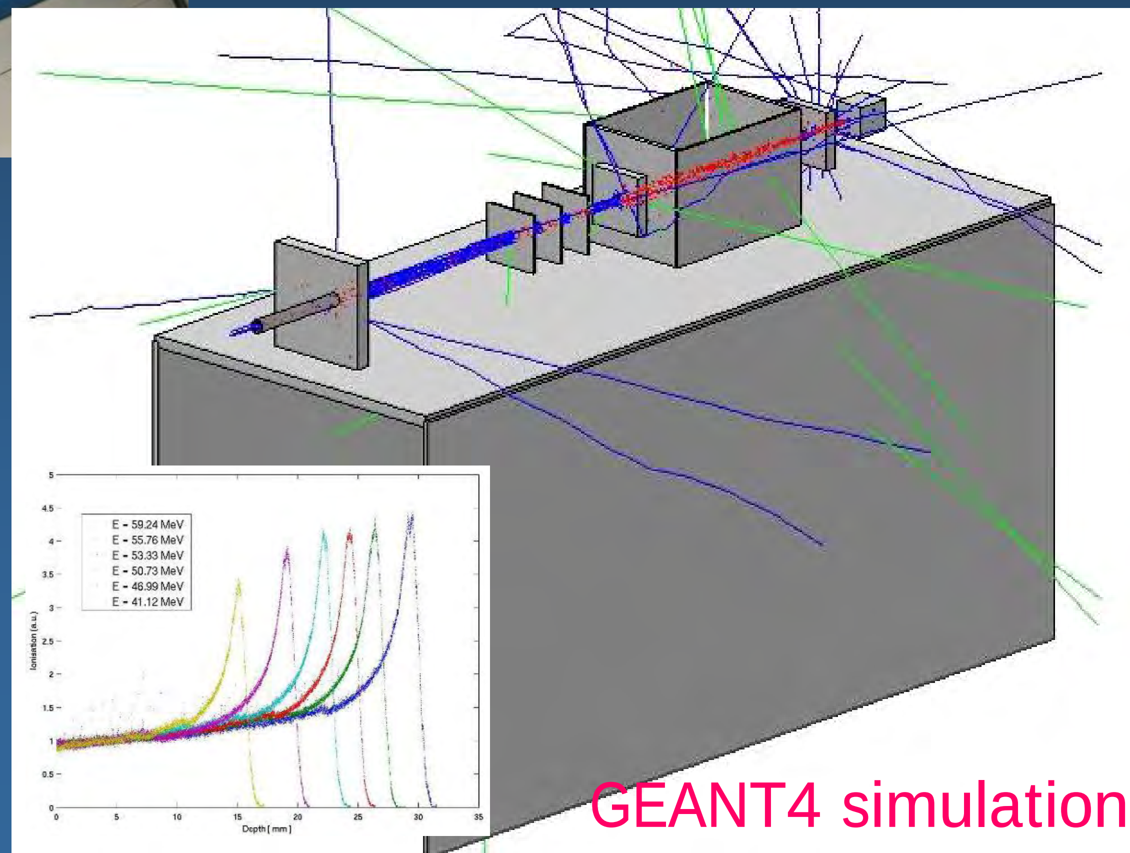
Real hadrontherapy beam line

CATANA hadrontherapy at INFN LNS

Paper to be submitted to
IEEE Trans. Nucl. Sci.

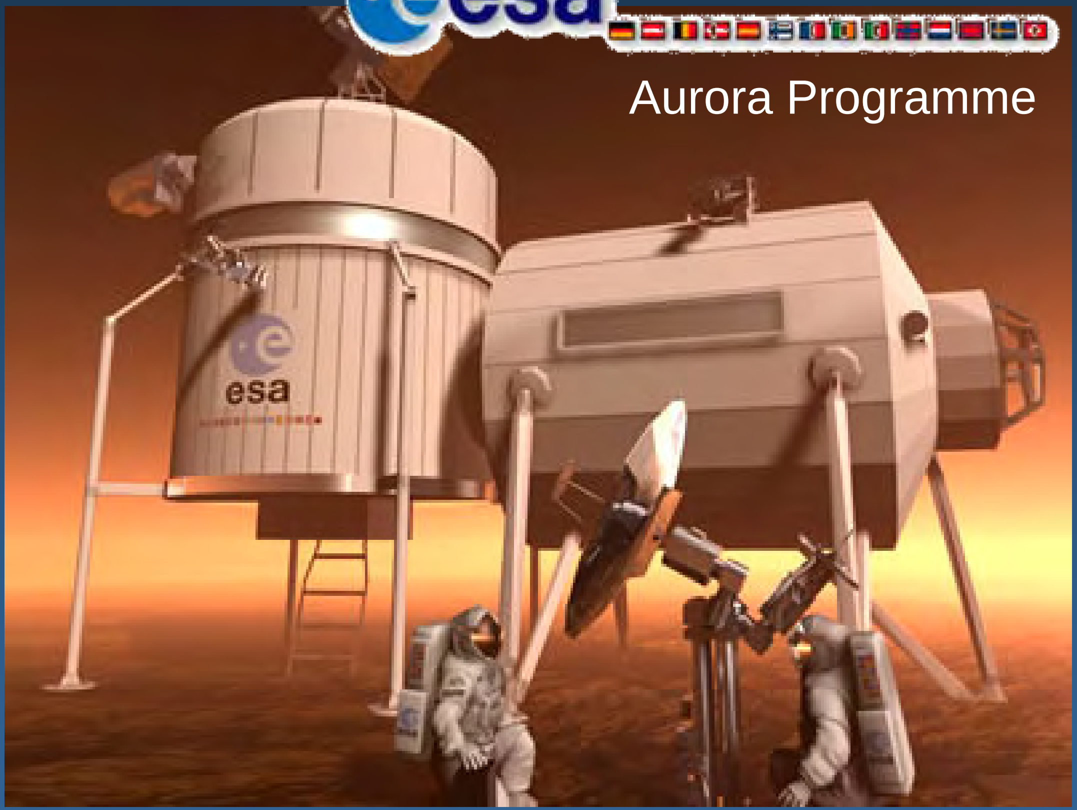


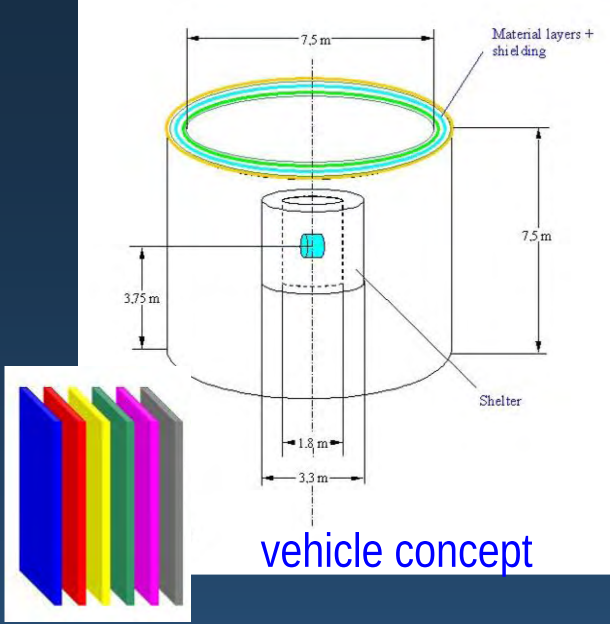
	p-value		
	CvM	KS	AD
Left branch	0.977		
Right branch		0.985	
Whole curve			0.994

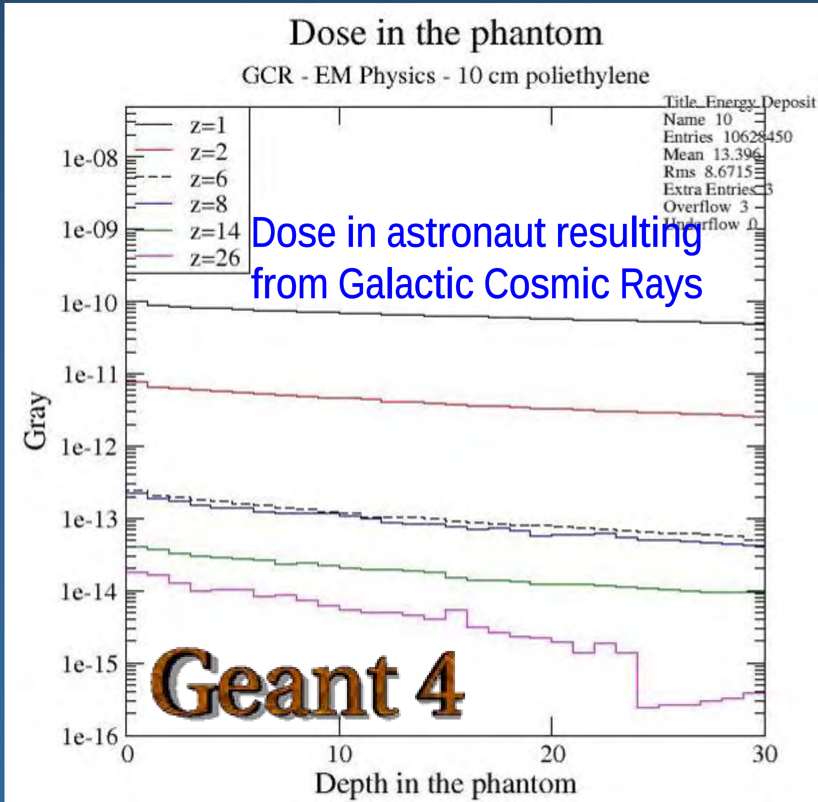


GEANT4 simulation

Dosimetry in interplanetary missions



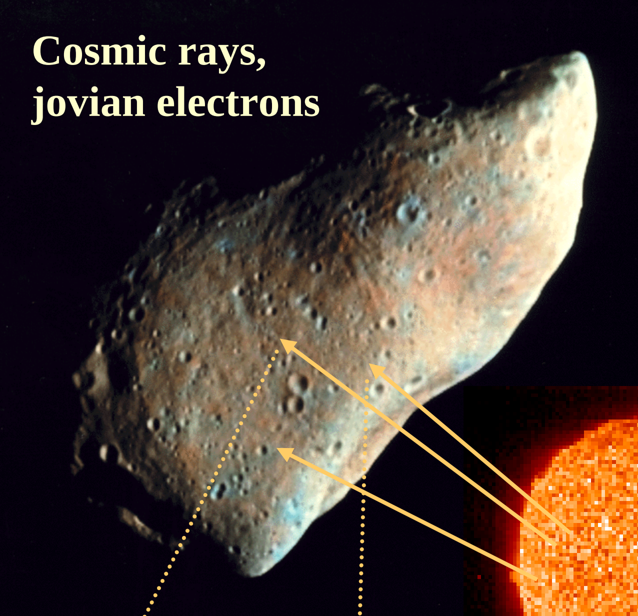


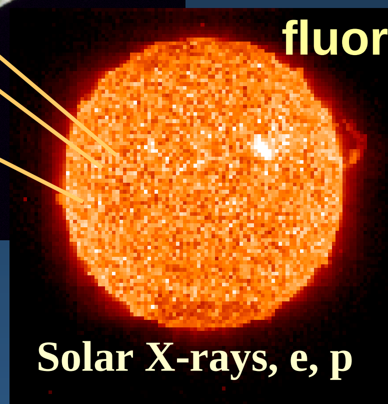


Maria Grazia Pia, *INFN Genova*

Solar system explorations

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





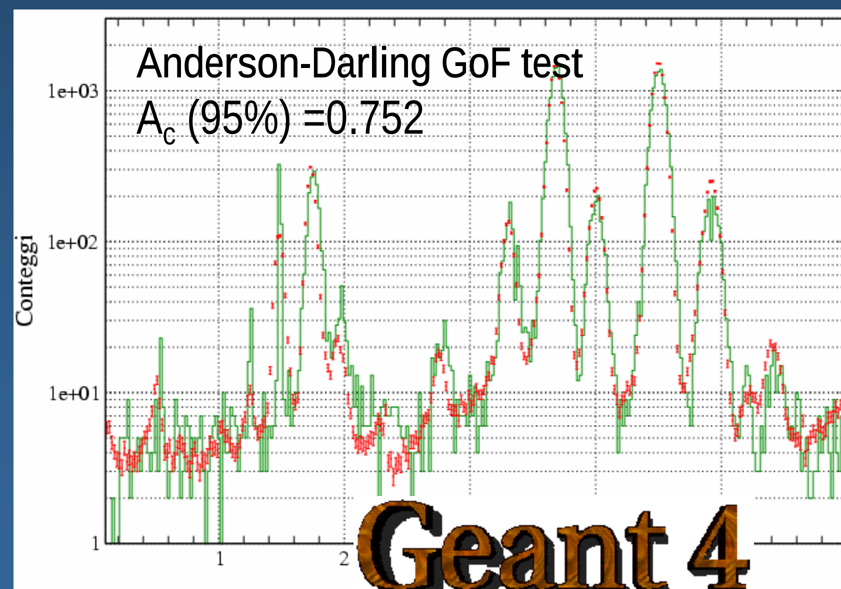
Courtesy SOHO EIT

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

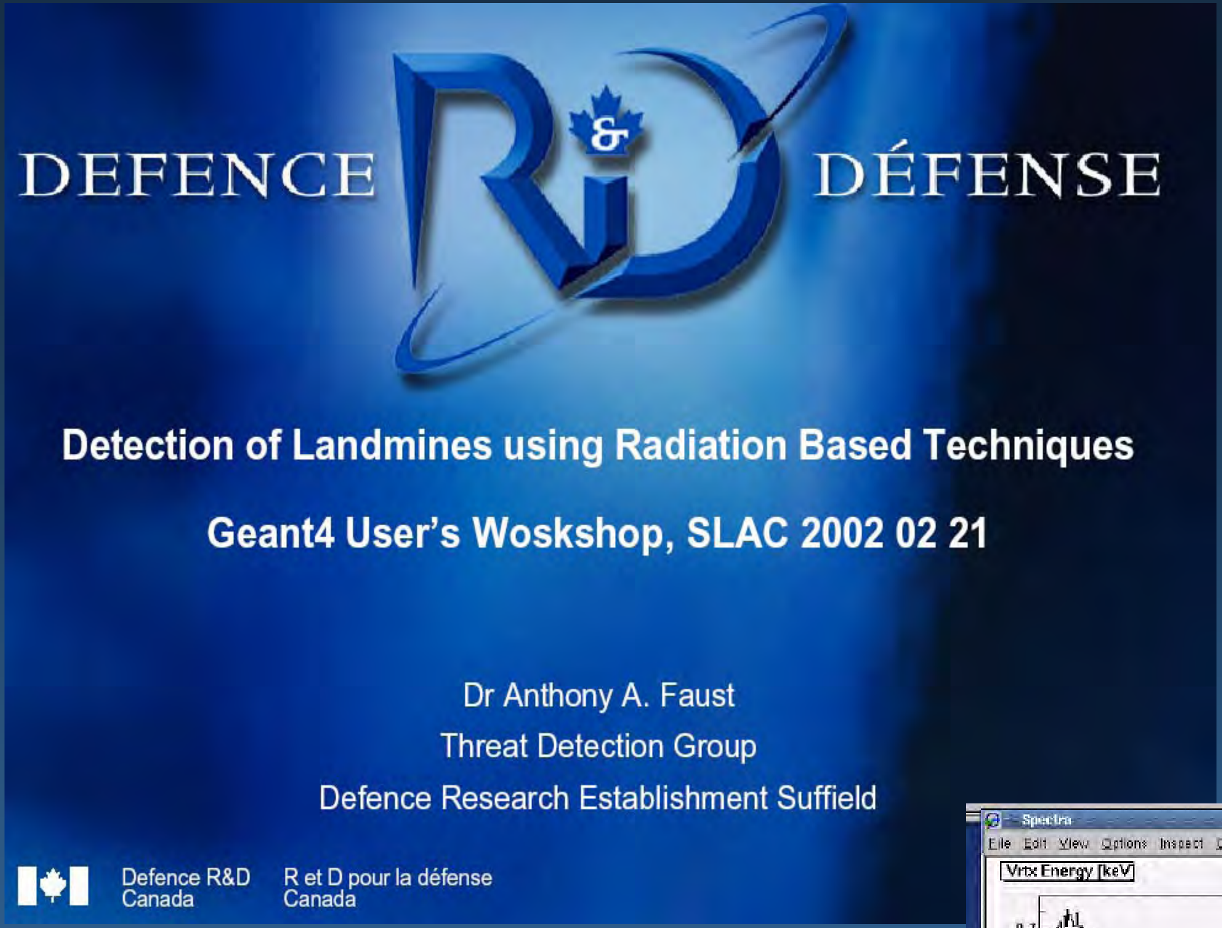
BepiColombo
ESA cornerstone mission to Mercury

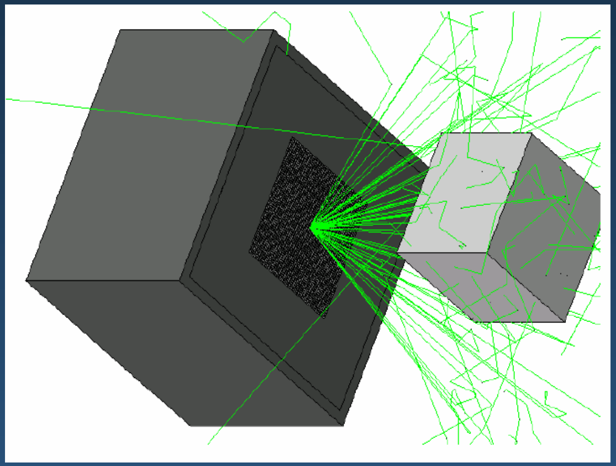
Courtesy of ESA Astrophysics

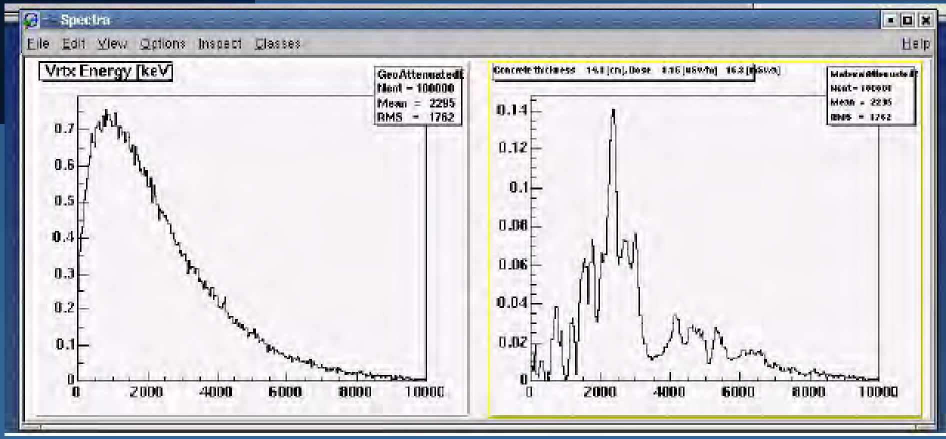


Fluorescence spectrum from Hawaiian basalt: experimental data and simulation

Maria







X-ray Backscatter Imaging

- Exploit Z dependent differences in Compton/Photoelectric cross-sections
- Z^{mine}_{eff} ~8 and Z^{soil}_{eff} ~14

Used Low Energy packages

Polarisation

Cross section:

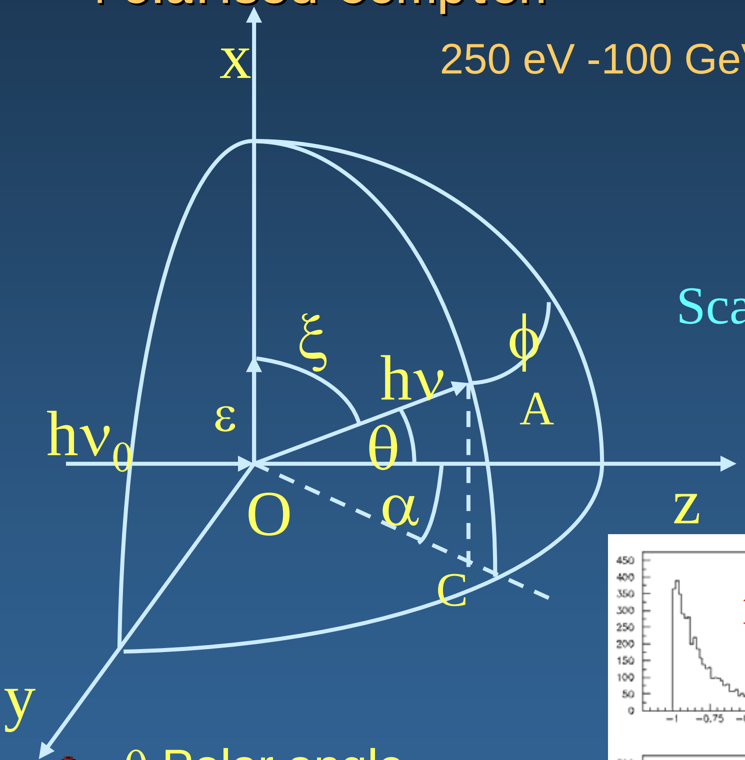
$$\frac{d\sigma}{d\Omega} = \frac{1}{2} r_0^2 \frac{h\nu^2}{h\nu_0^2}\left[\frac{h\nu_0}{h\nu} + \frac{h\nu}{h\nu_0} - 2\sin^2\theta\cos^2\phi\right]$$

Sample Methods:

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

Low Energy Polarised Compton

250 eV -100 GeV

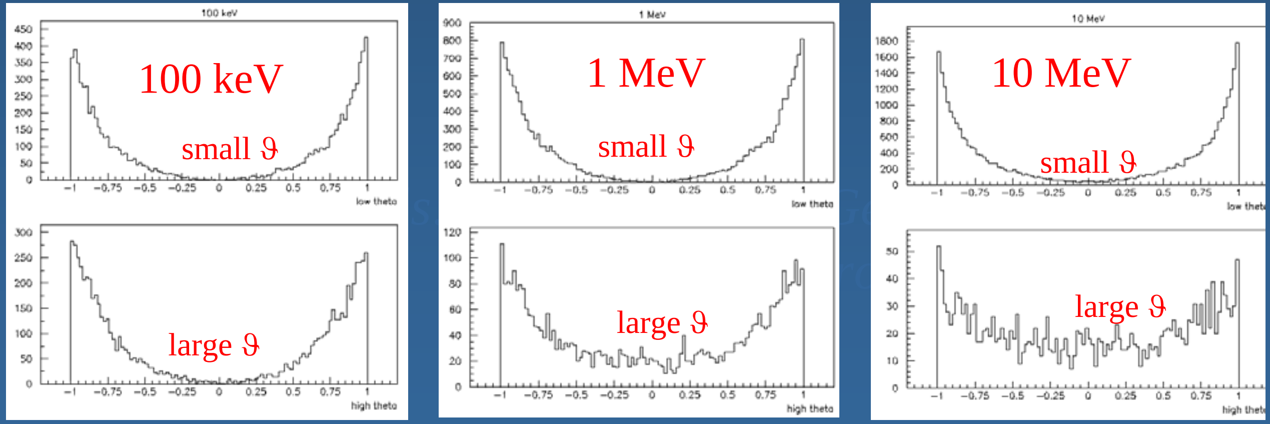


$$\cos\xi = \sin\theta\cos\phi \quad \Rightarrow \quad \sin\xi = \sqrt{1-\sin^2\theta\cos^2\phi} = N$$

Scattered Photon Polarization

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

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



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

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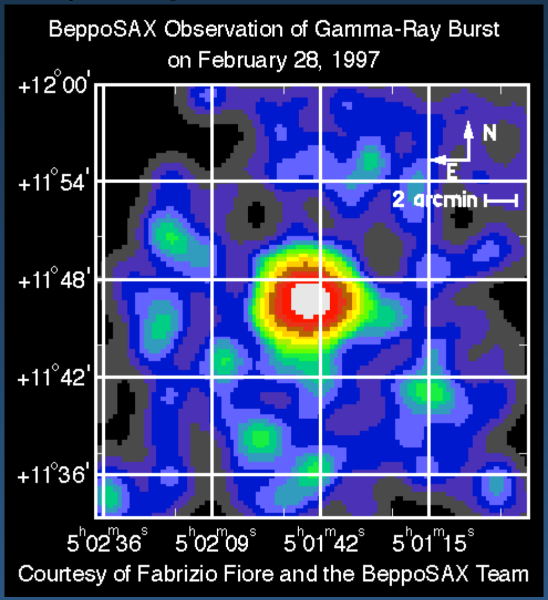
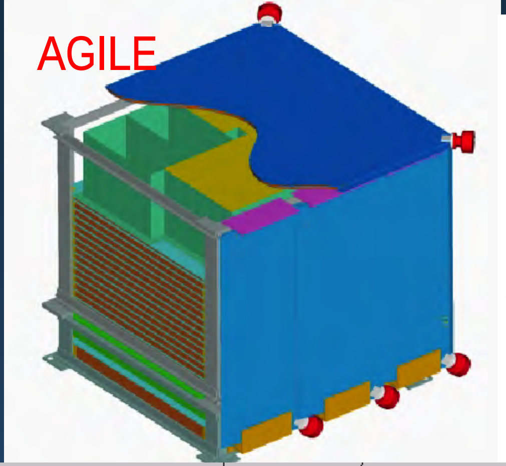
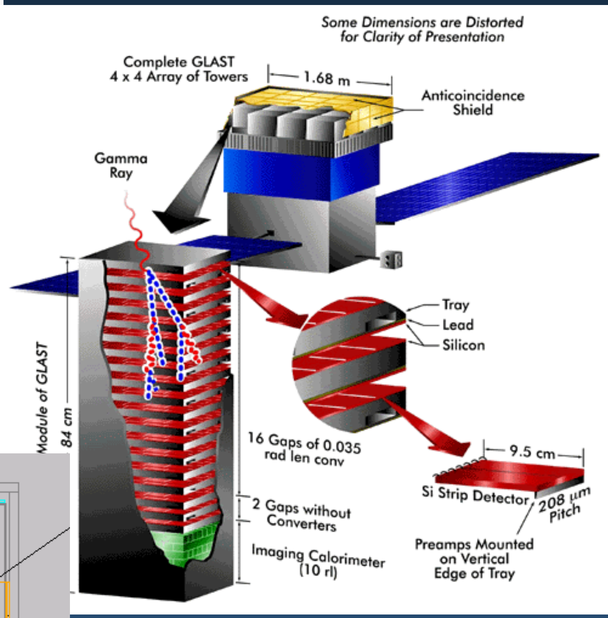
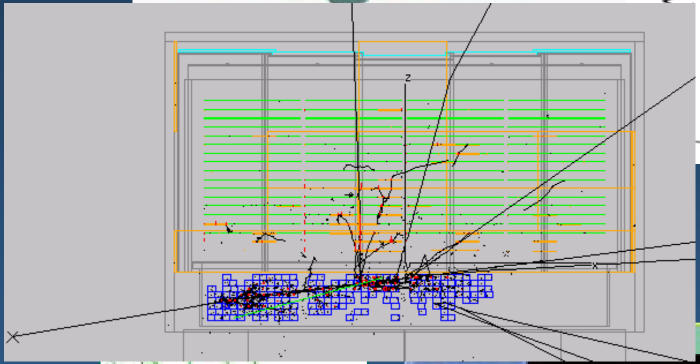
γ astrophysics

γ-ray bursts

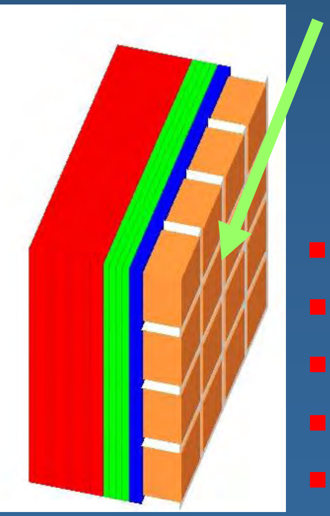








GLAST



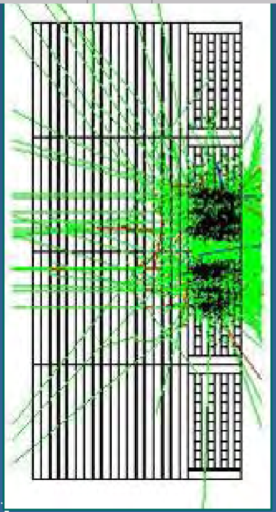
Typical telescope:

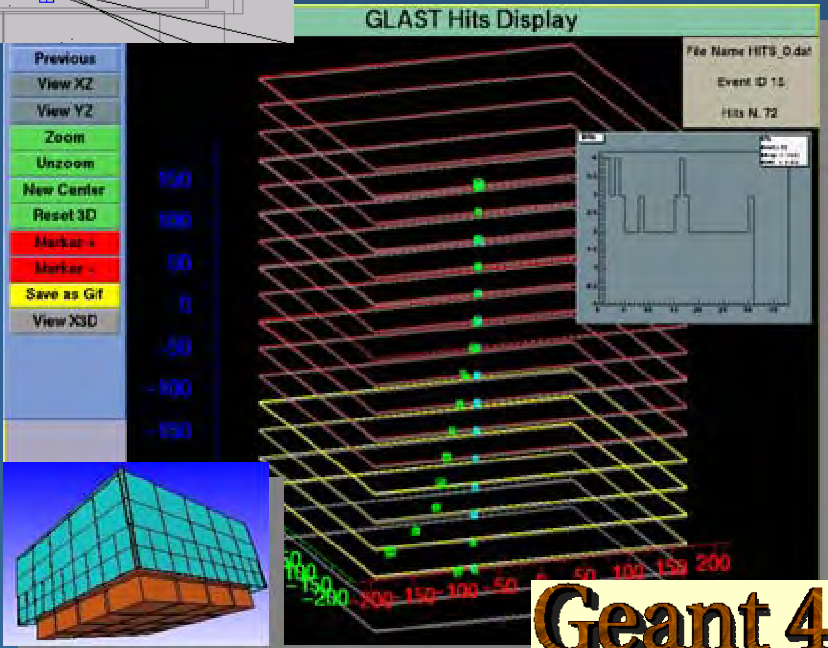
Tracker

Calorimeter

Anticoincidence

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

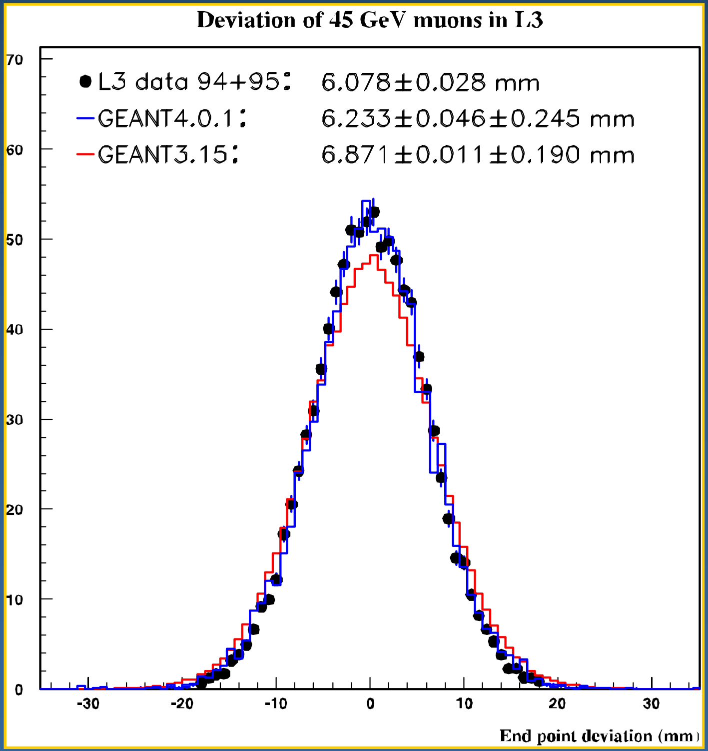




Geant 4

Muons

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



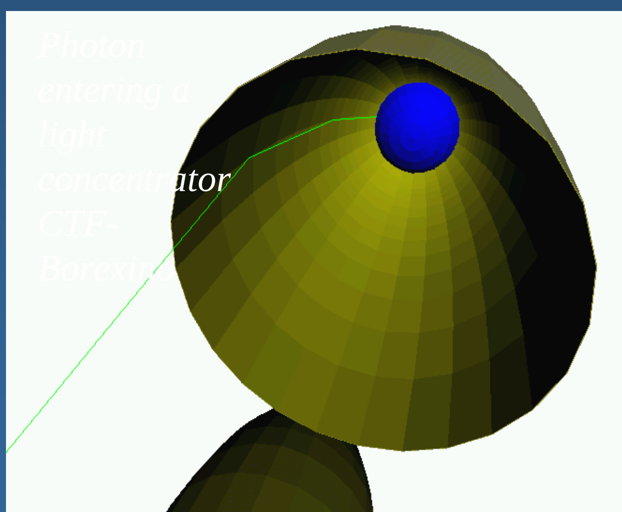
- Muon Muon energy loss
- Muon radiation processes
- Gamma conversion to muon pair
- Positron annihilation to muon pair
- Positron annihilation into hadrons

Optical photons

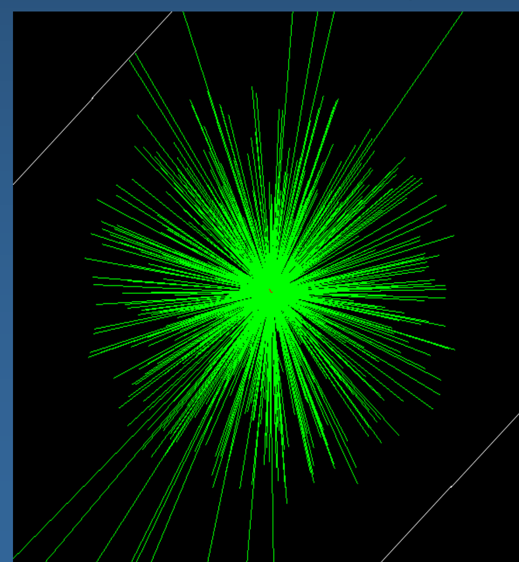
Production of optical photons in HEP detectors is mainly due to Cherenkov effect and scintillation

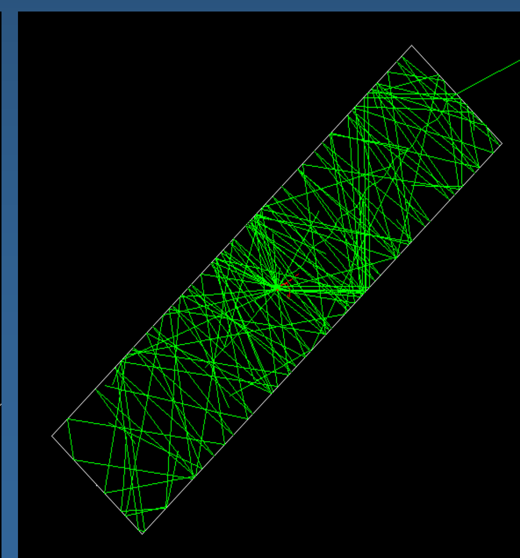
Processes in Geant4:

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



Geant4 Optical Processes : Scintillating Cells and WLS Fibers

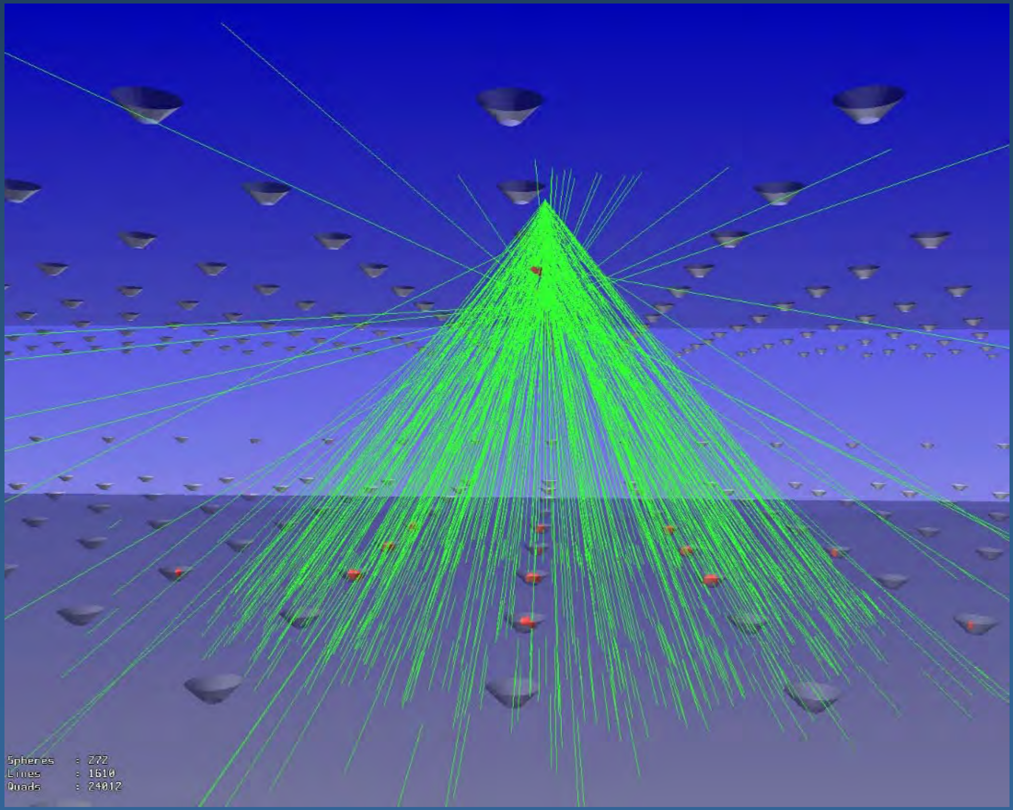


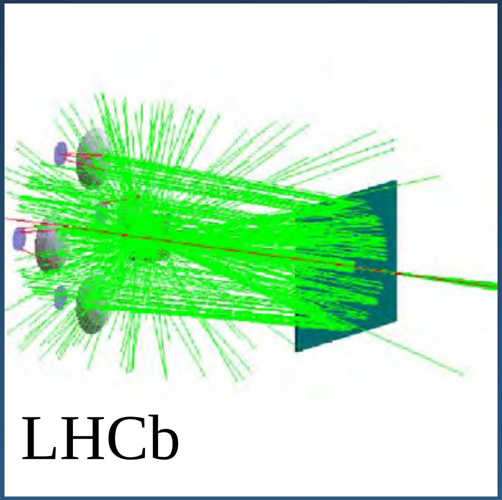


Courtesy of J. Mc Cormick (SLAC)

Cherenkov

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

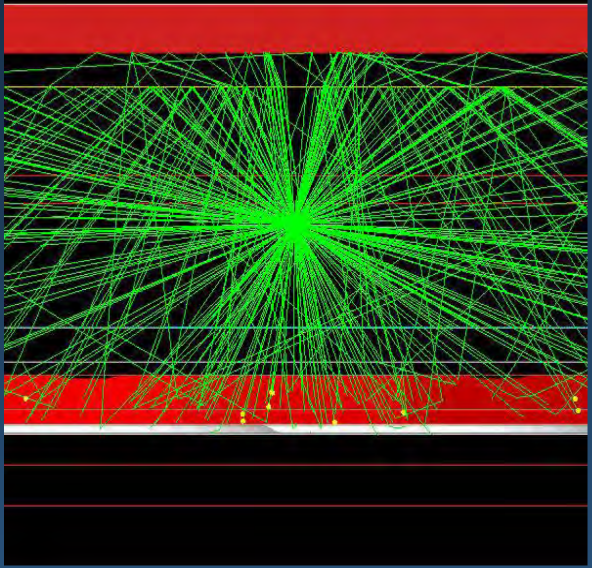




Aerogel Thickness		Yield Per Event	Cherenkov Angle mrad
4 cm	DATA	6.3 ± 0.7	247.1+-5.0
	MC	7.4 ± 0.8	246.8+-3.1
8 cm	DATA	9.4 ± 1.0	245.4+-4.8
	MC	10.1 ±1.1	243.7+-3.0

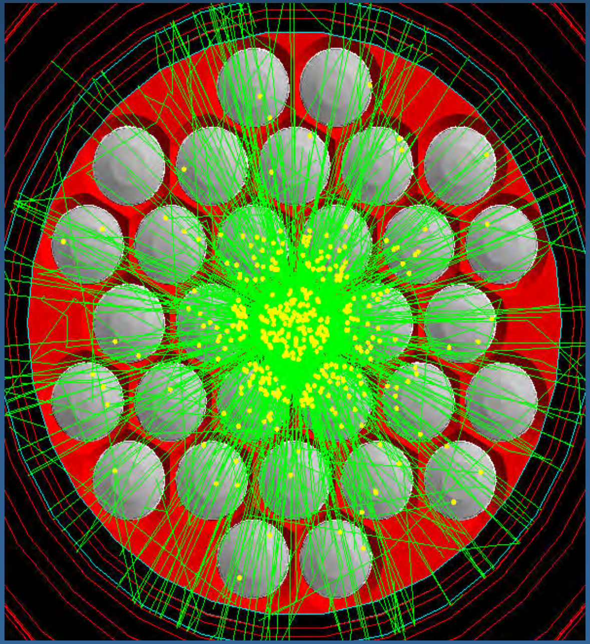
Scintillation

prompt scintillation

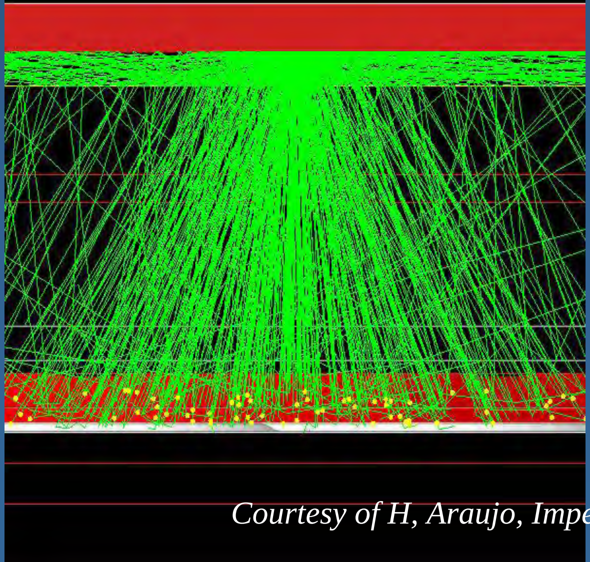


ZEPLIN III
Dark Matter Detector

signal in PMT

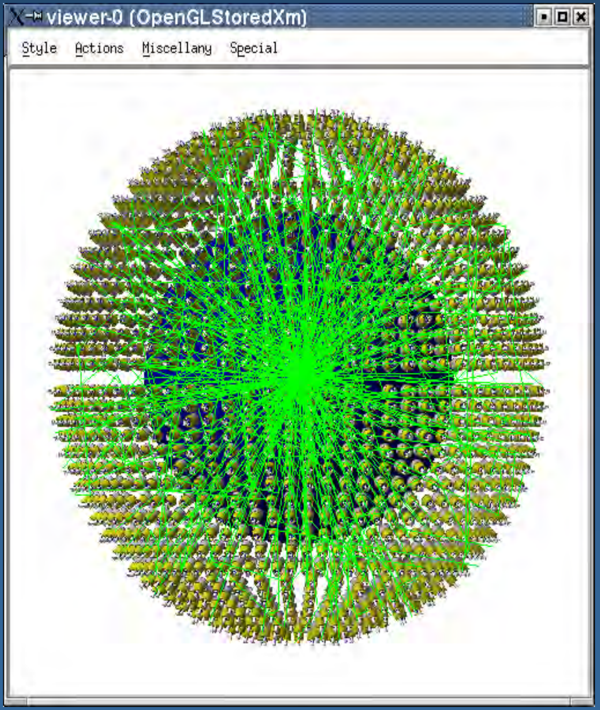


termoluminescense



Courtesy of H, Araujo, Imperial College London

GEANT4 Scintillation
Event in BOREXINO



Courtesy of Borexino

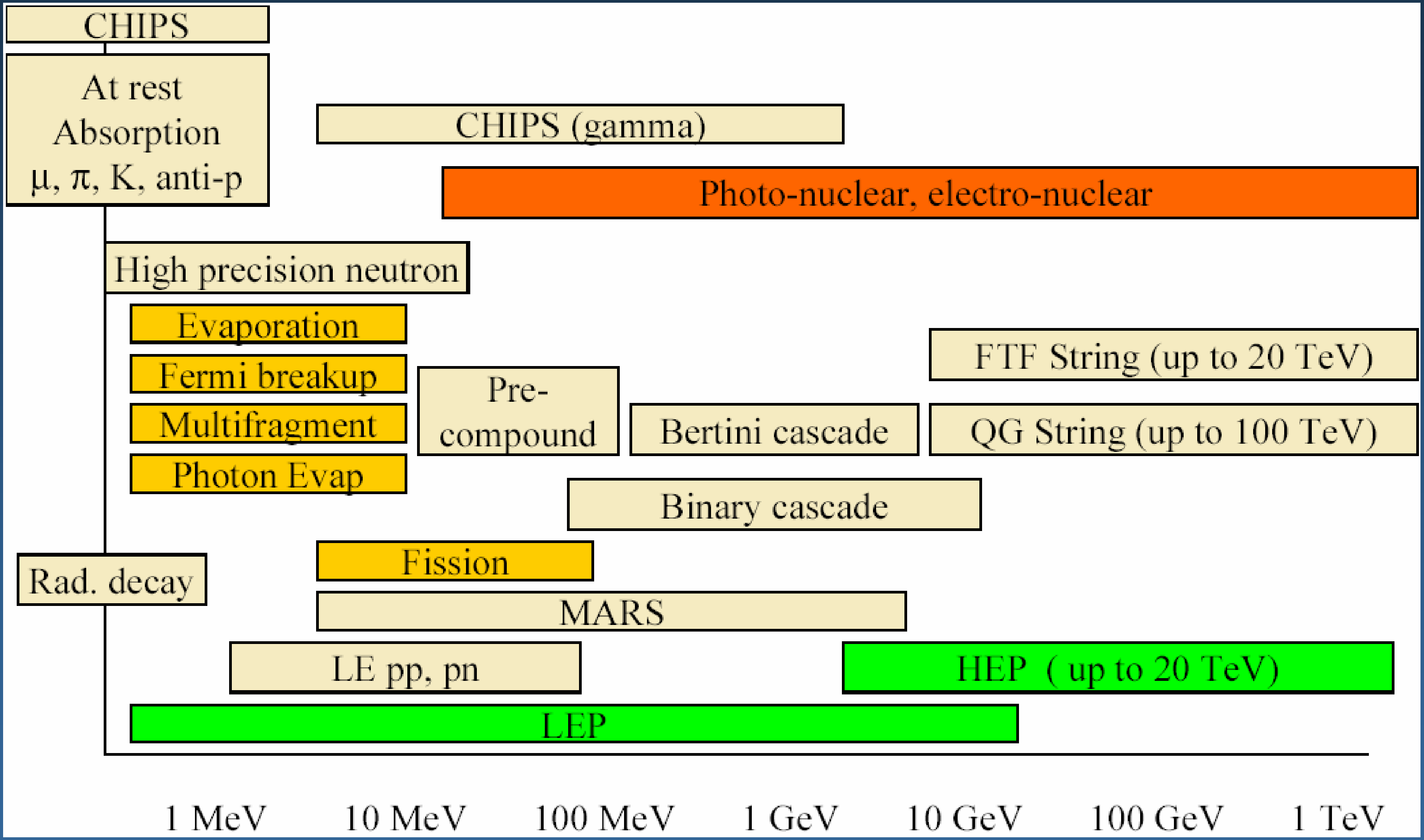
Hadronic physics

- 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

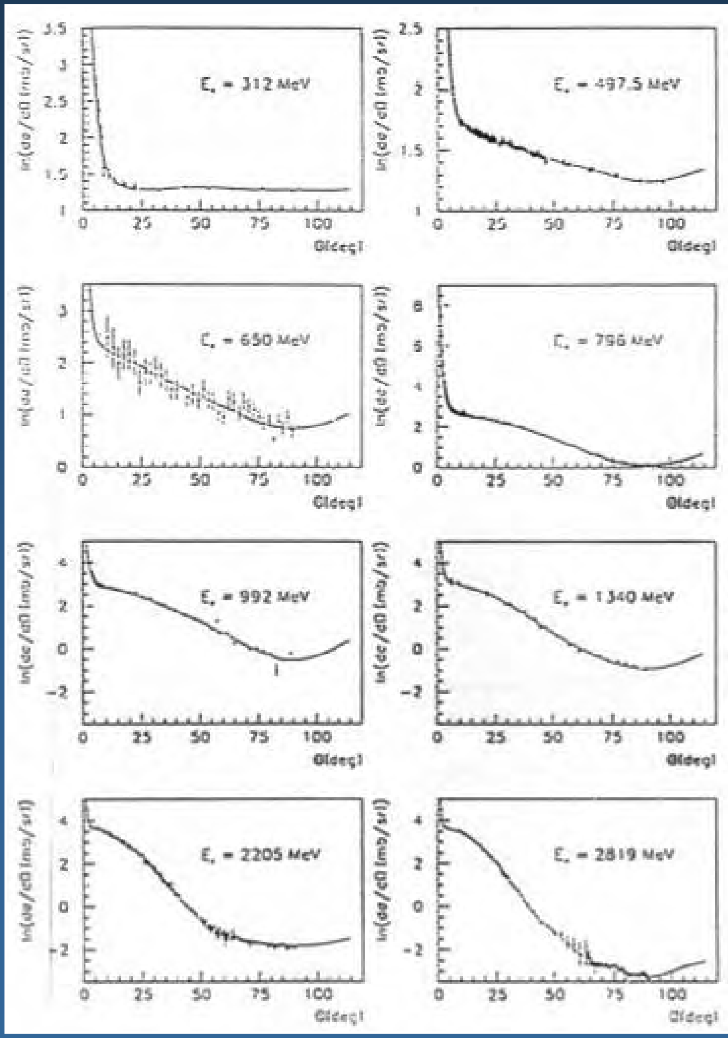


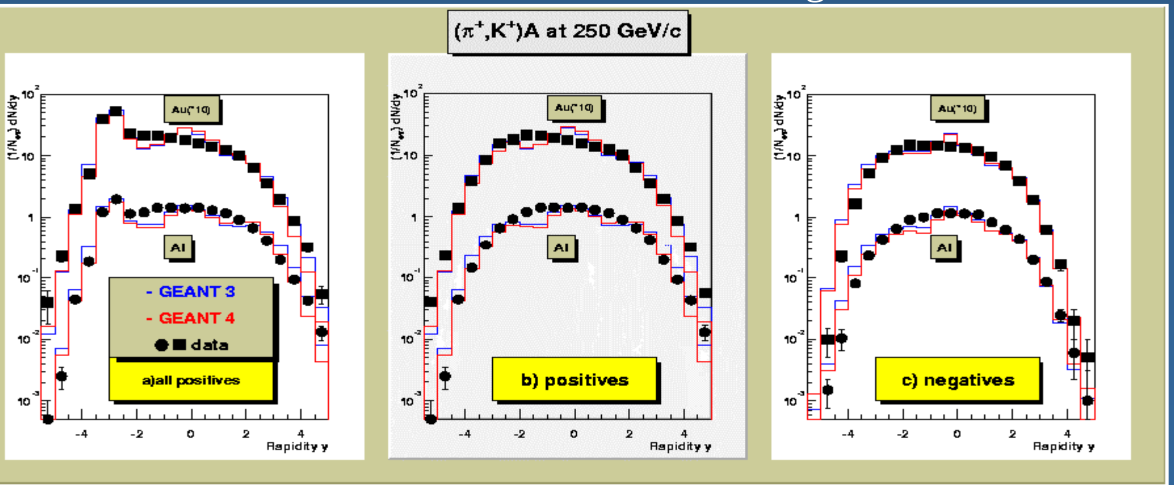
Parameterised and data-driven hadronic models (1)

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

p elastic scattering on Hydrogen

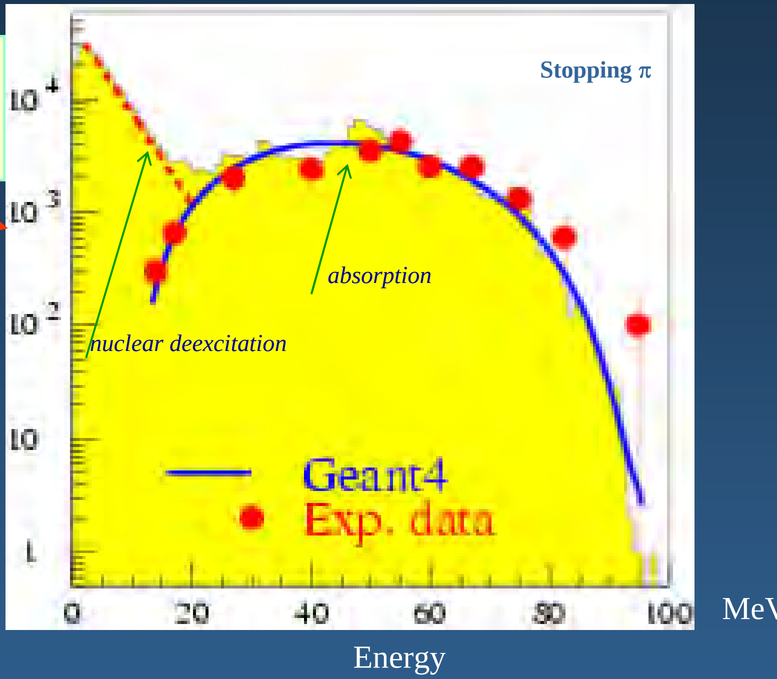


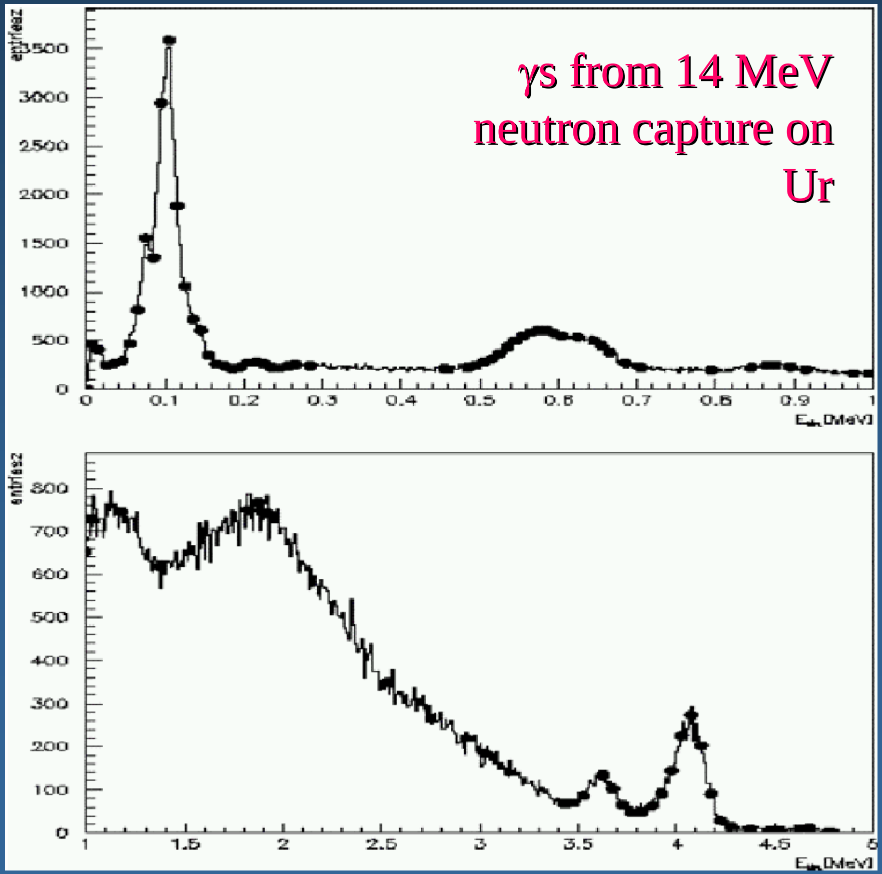


Parameterised and data-driven hadronic models (2)

Other models are completely new, such as:

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





neutrons

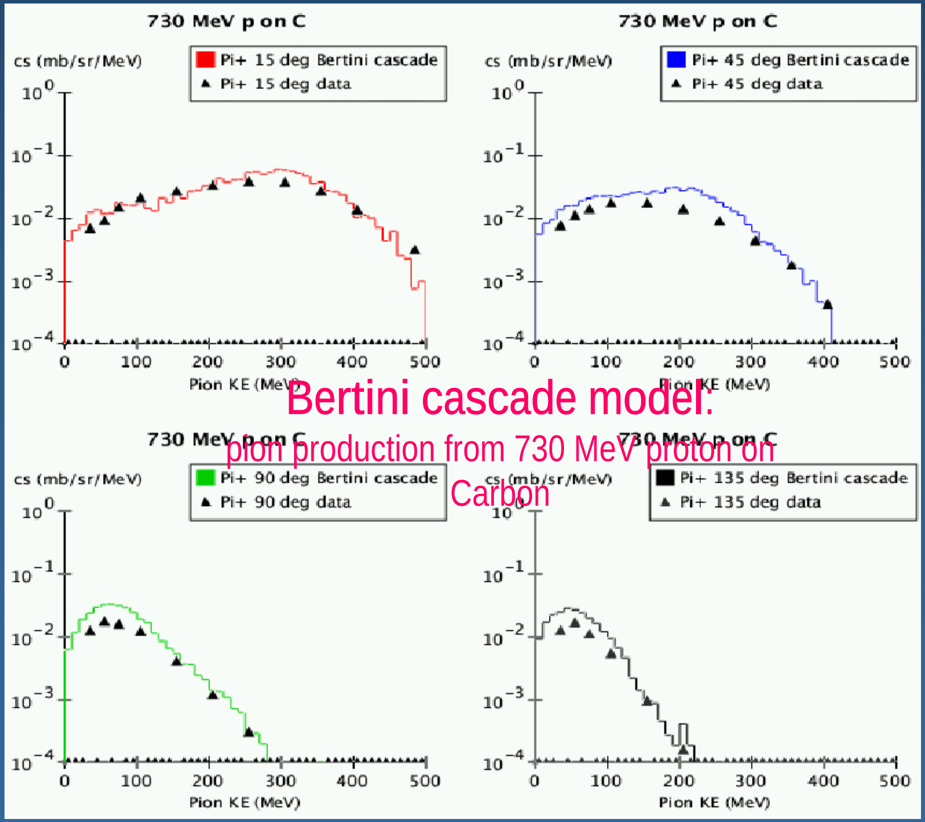
All worldwide existing databases used in **neutron** transport

Brond, CENDL, EFF, ENDFB, JEF, JENDL, MENDL etc.

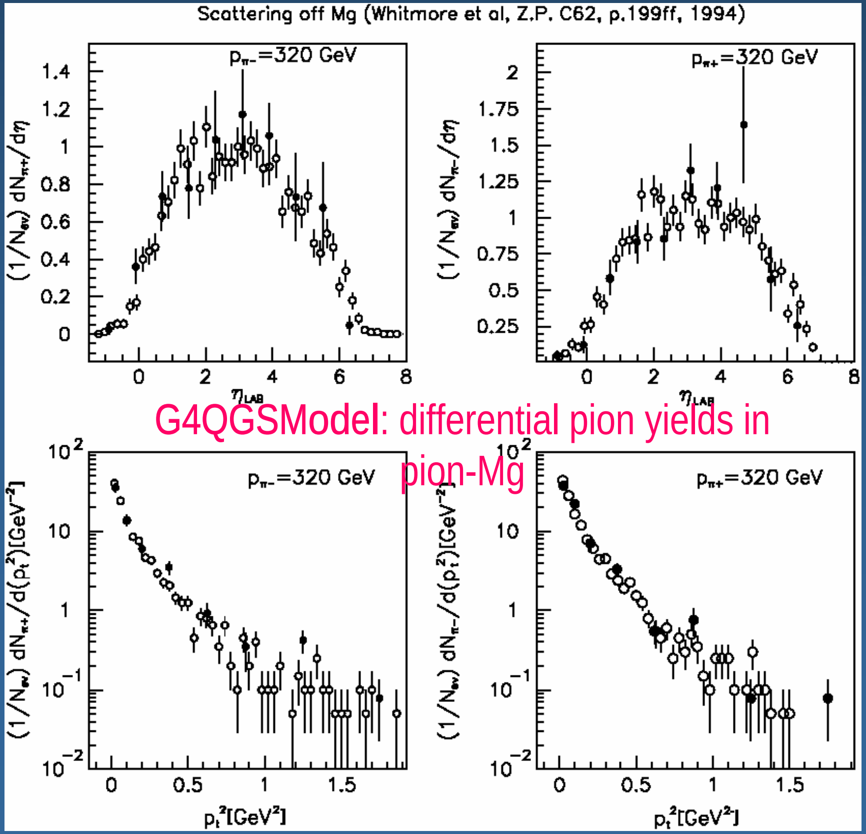
Maria Grazia Pia, *INFN Genova*

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

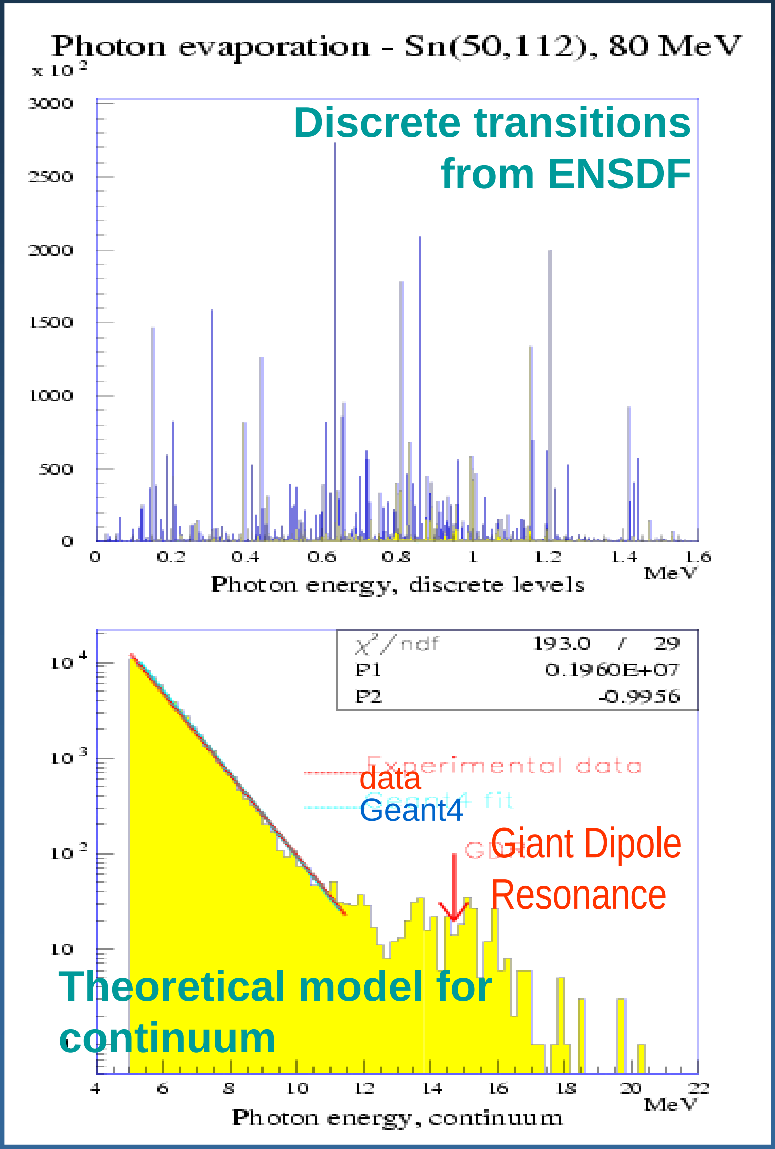


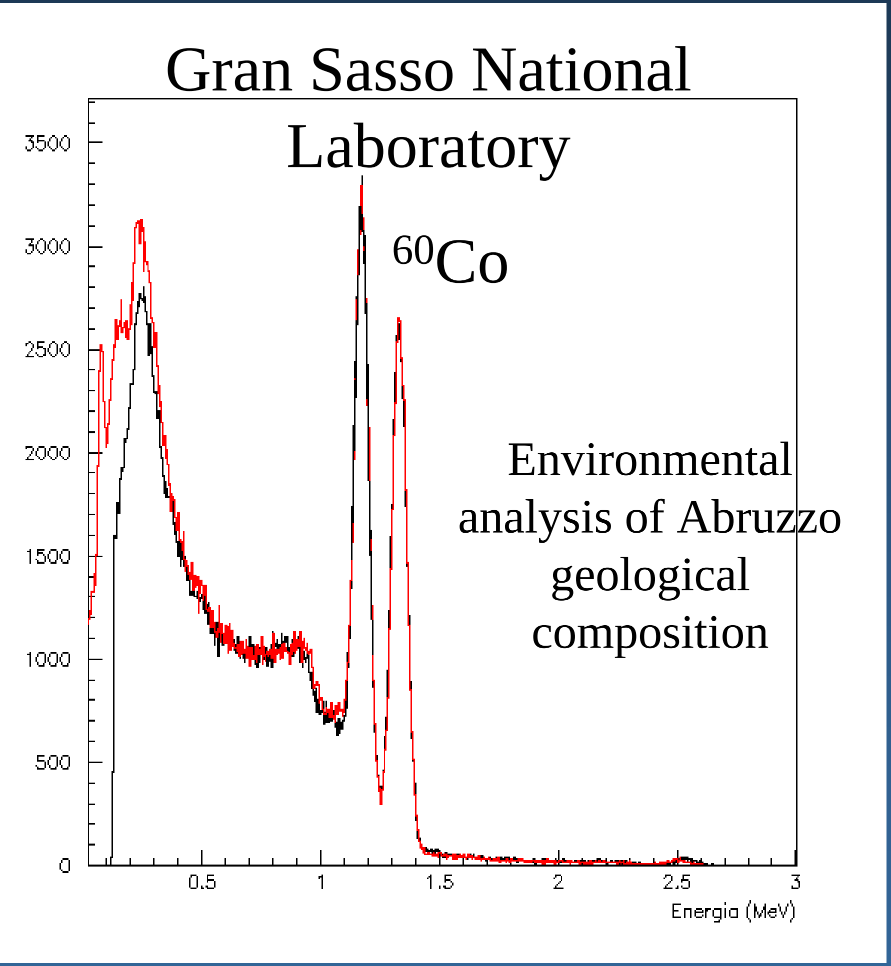
Bertini cascade model: pion production from 730 MeV proton on Carbon



G4QGSModel: differential pion yields in pion-Mg

The two worlds can be mixed…





Other components

- Materials
  - elements, isotopes, compounds, chemical formulae
- Particles
  - all PDG data
  - and more, for specific Geant4 use, like ions
- Hits & Digi
  - to describe detector response
- Primary event generation
  - some general purpose tools provided within the To
    - eg. GeneralParticleSource

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

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

Interface to external tools in Geant4

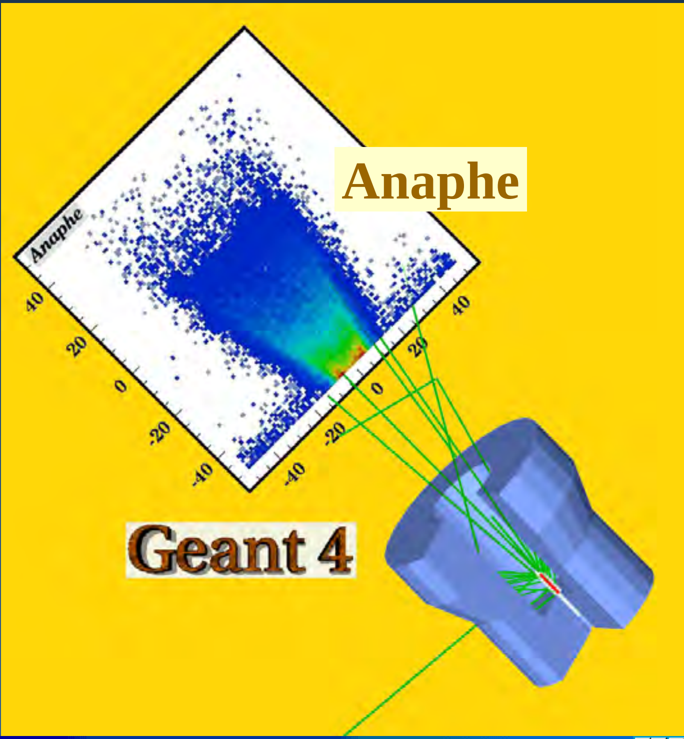
Through abstract interfaces

no dependence

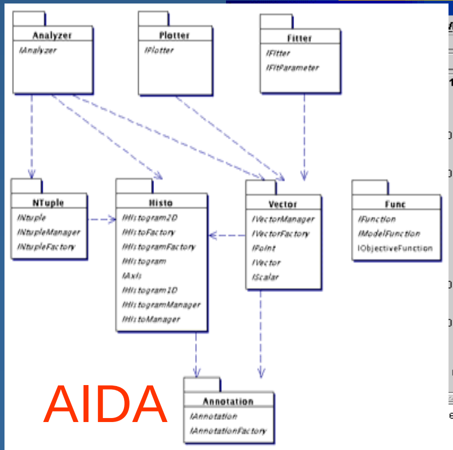
minimize coupling of components

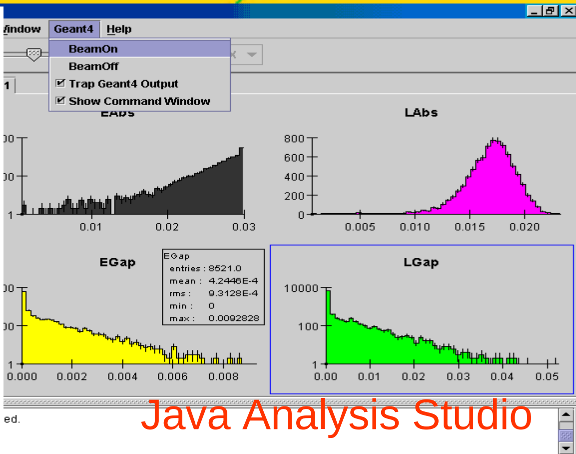
Similar approach

- Visualisation
- (G)UI
- Persistency
- Analysis



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





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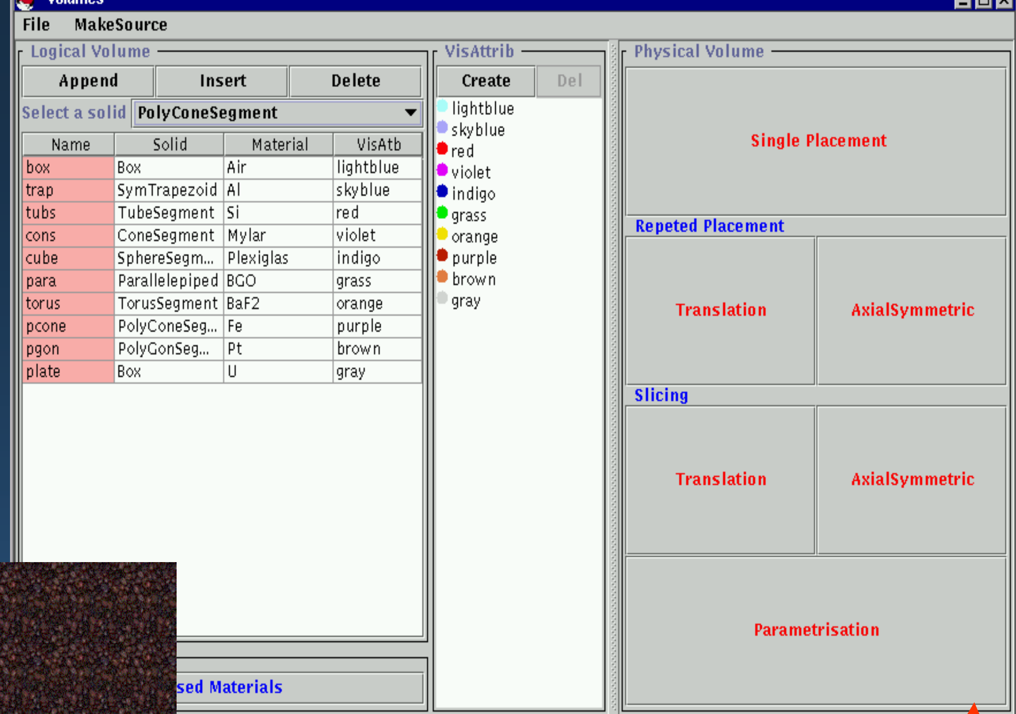
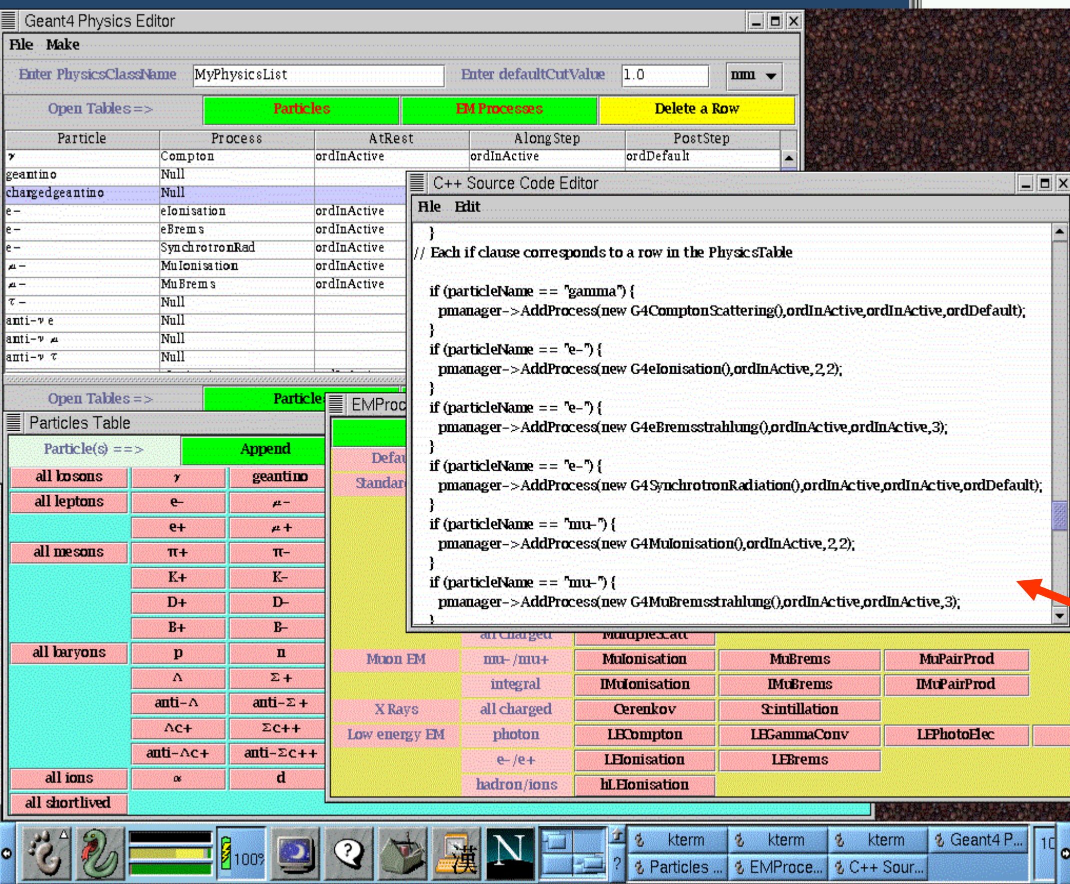
User Interface

- Several implementations, all handled through abstract interfaces
- Command-line (batch and terminal)
- GUIs
  - X11/Motif, GAG, MOMO, OPACS, Java



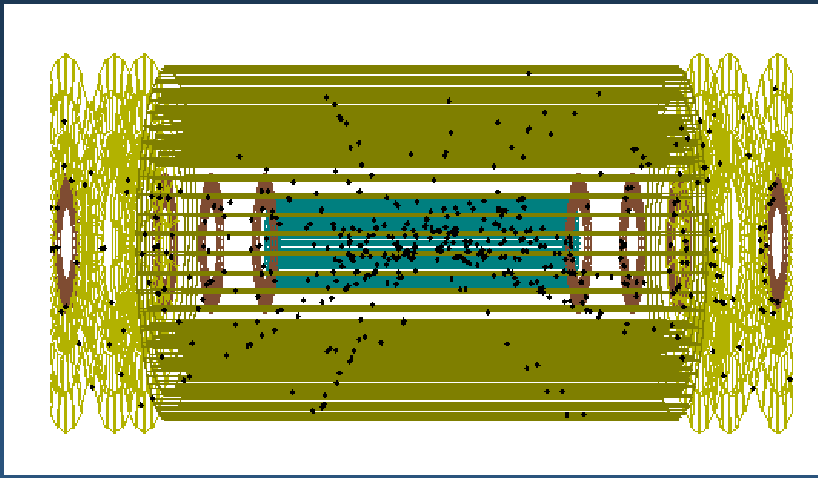


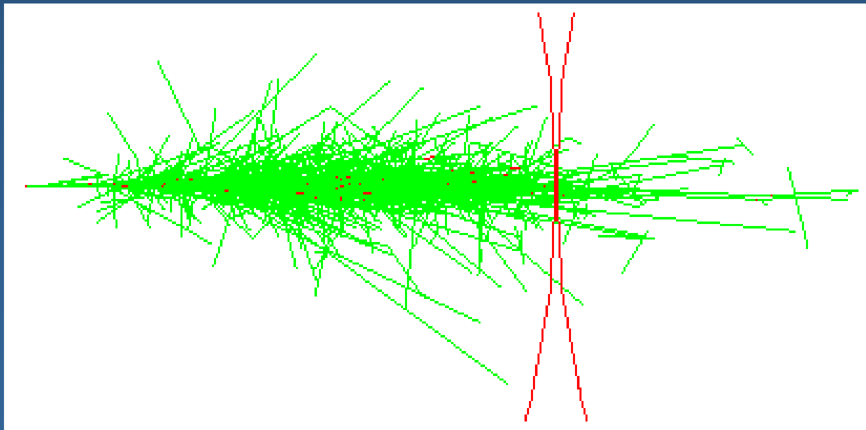
Automatic code generation for geometry and physics through a GUI

- GGE (Geant4 Geometry Editor)
- GPE (Geant4 Physics Editor)

Visualisation

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



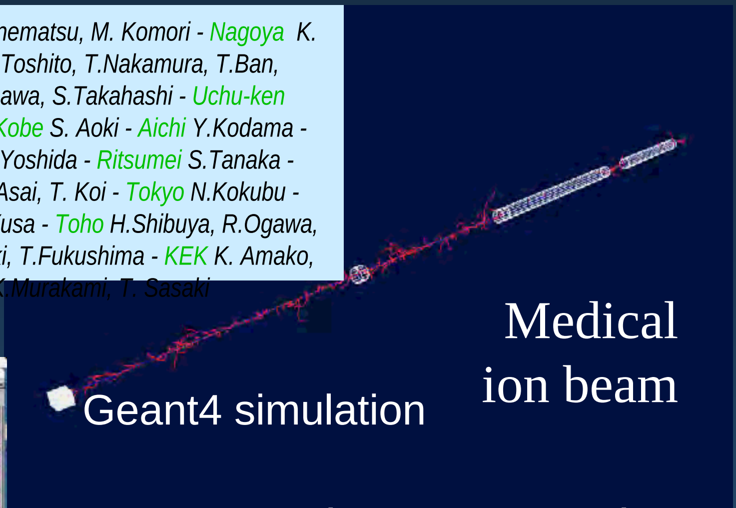


- Various drivers
  - OpenGL
  - OpenInventor
  - X11
  - Postscript
  - DAWN
  - OPACS
  - HepRep
  - VRML…
- all handled through abstract interfaces

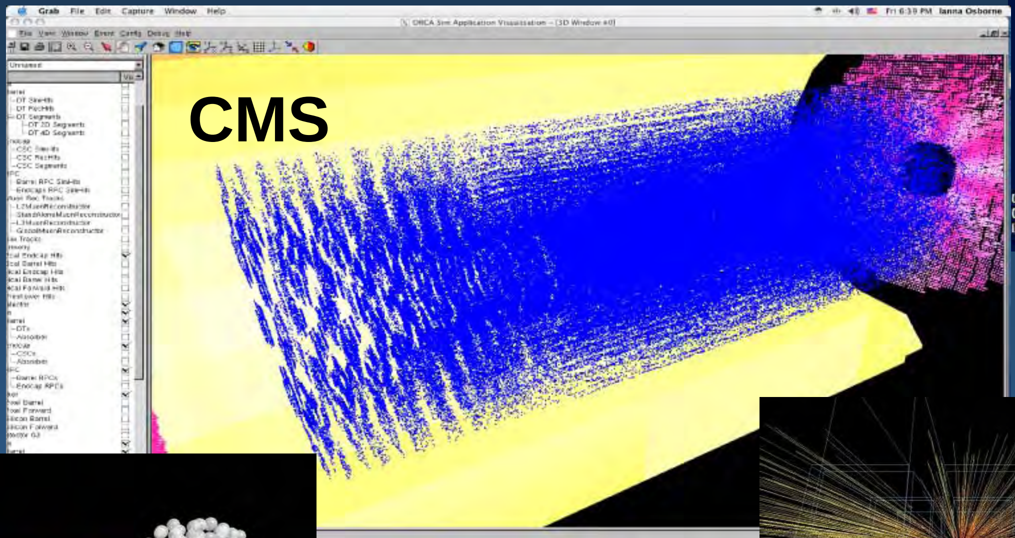
Pushing Geant4 to the limit

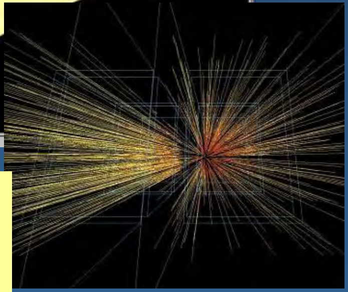
Heavy ion beams

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

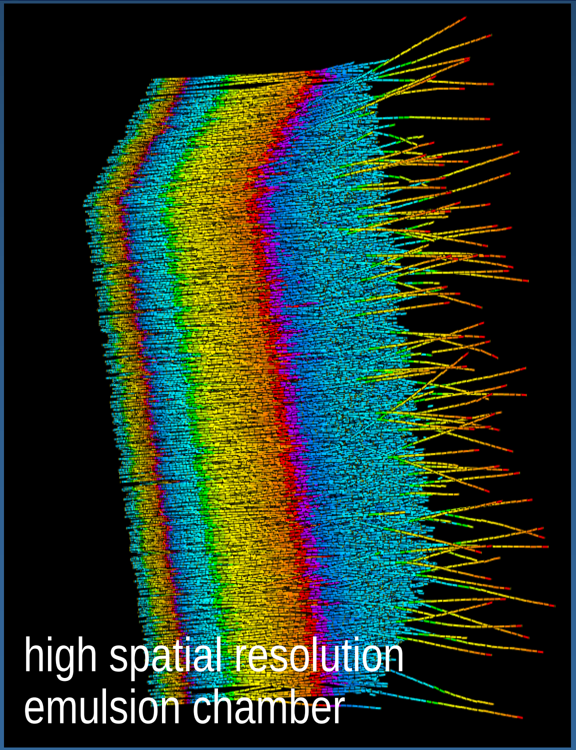


Beam Track Reconstruction
135 MeV/u ^{12}C beam





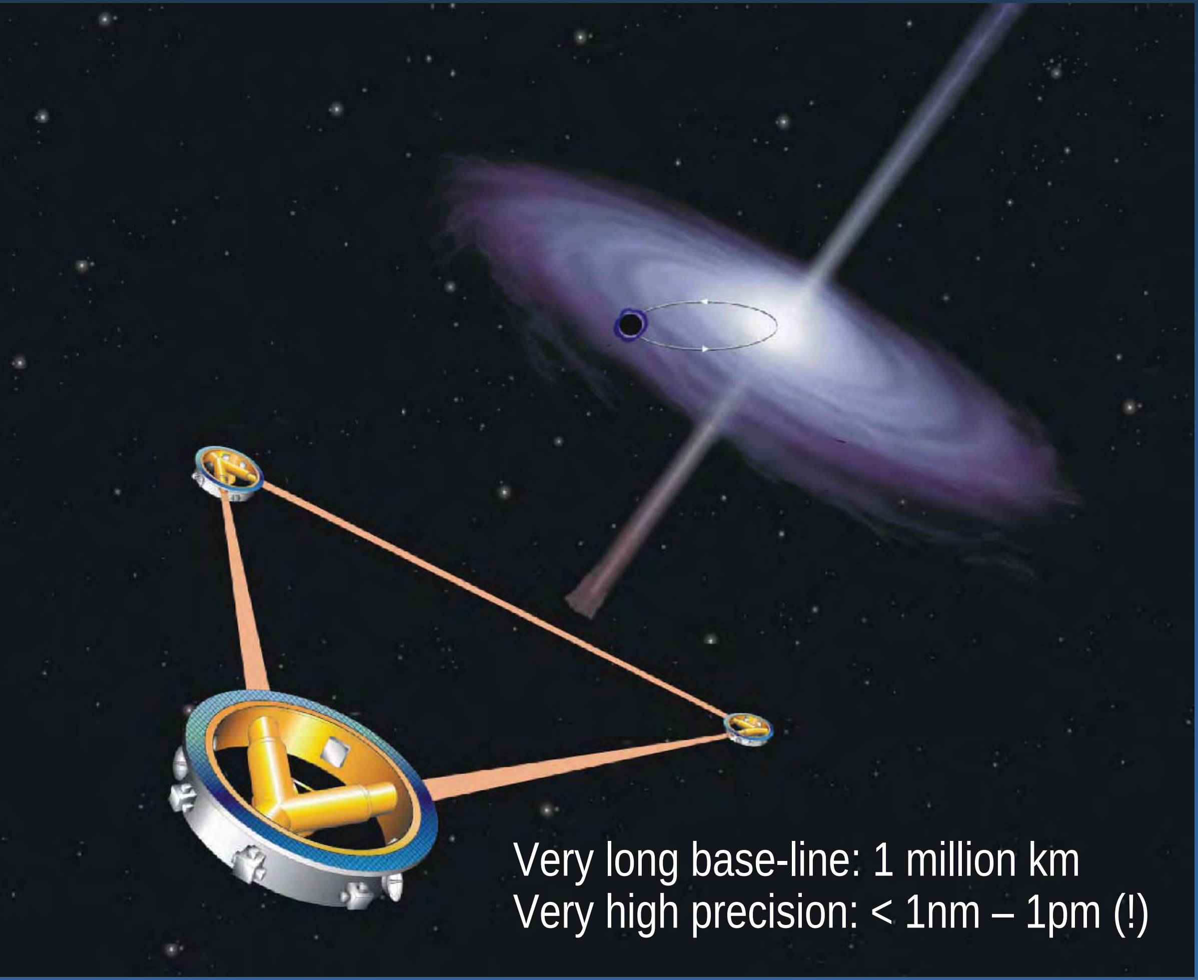
Events with > 50000 particles/event in detector acceptance

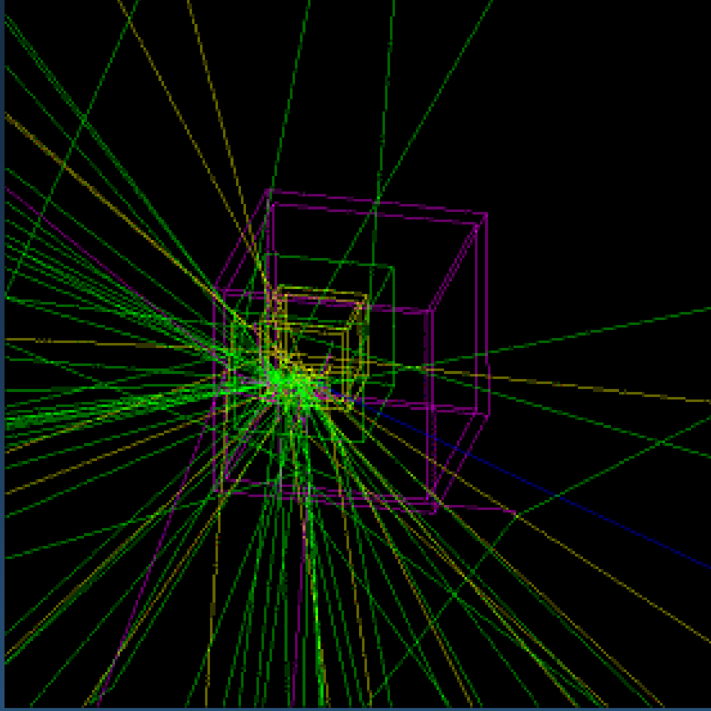


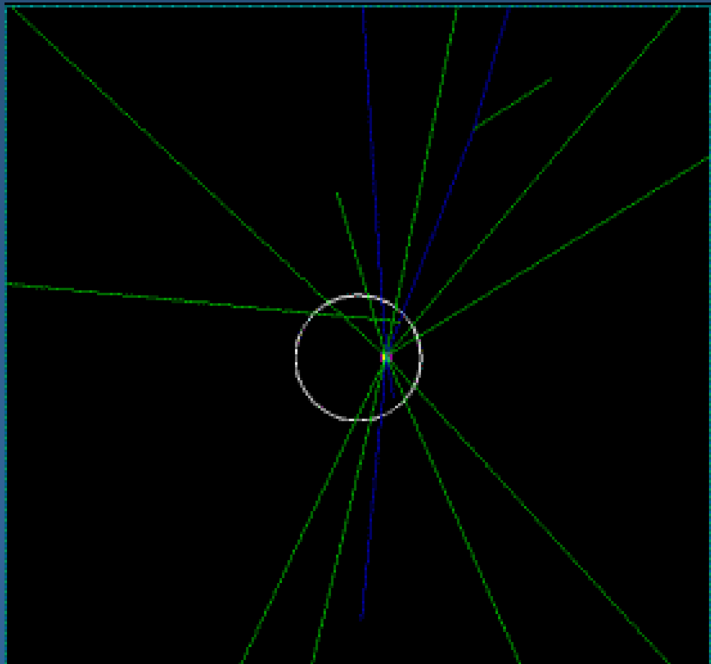
~ 180 minutes to simulate 1 event with 55K generator tracks

LISA (gravitational waves)

Geant4 relevant for evaluation of space charging effects





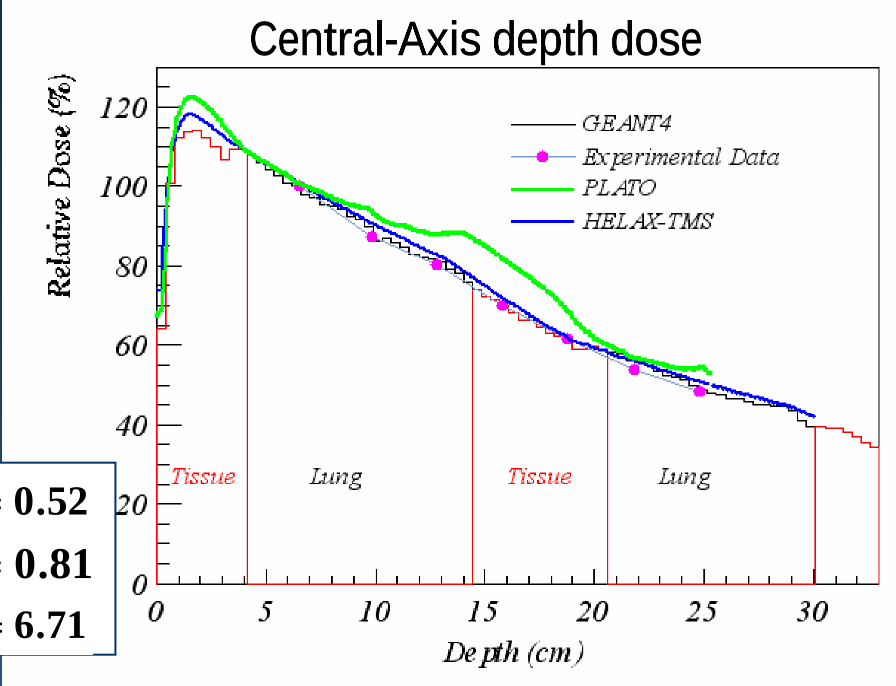


Courtesy H. Araujo, A. Howard, IC London

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

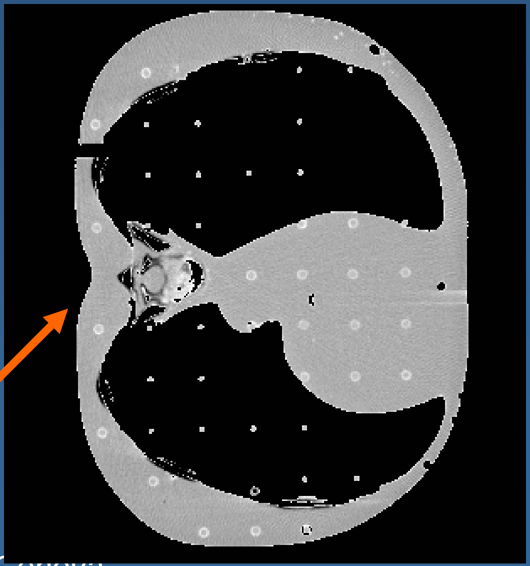


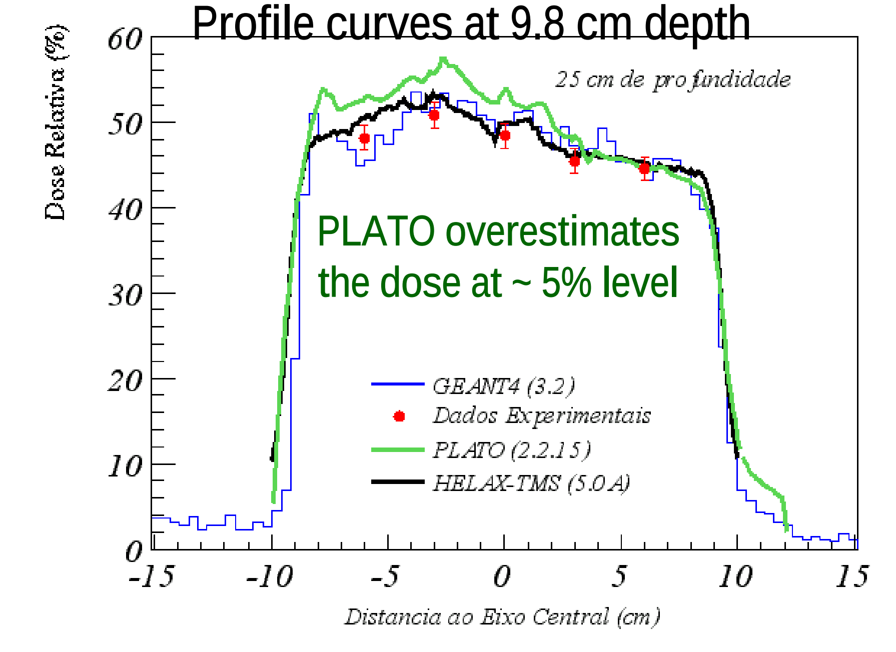
$$\chi^2/ndf\ (GEANT\ 4) = 0.52$$
$$\chi^2/ndf\ (TMS) = 0.81$$
$$\chi^2/ndf\ (PLATO) = 6.71$$

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

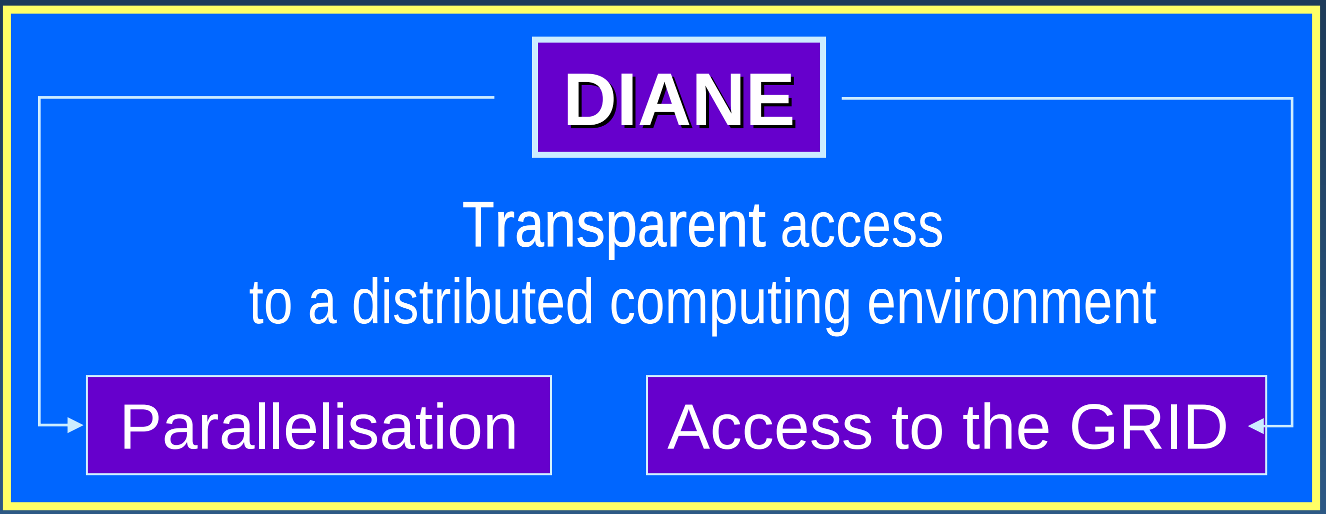
CT images used to define the geometry:

a thorax slice from a Rando anthropomorphic phantom

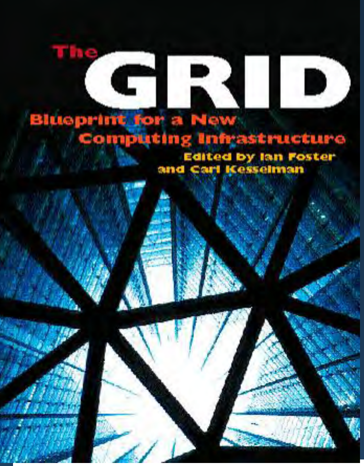




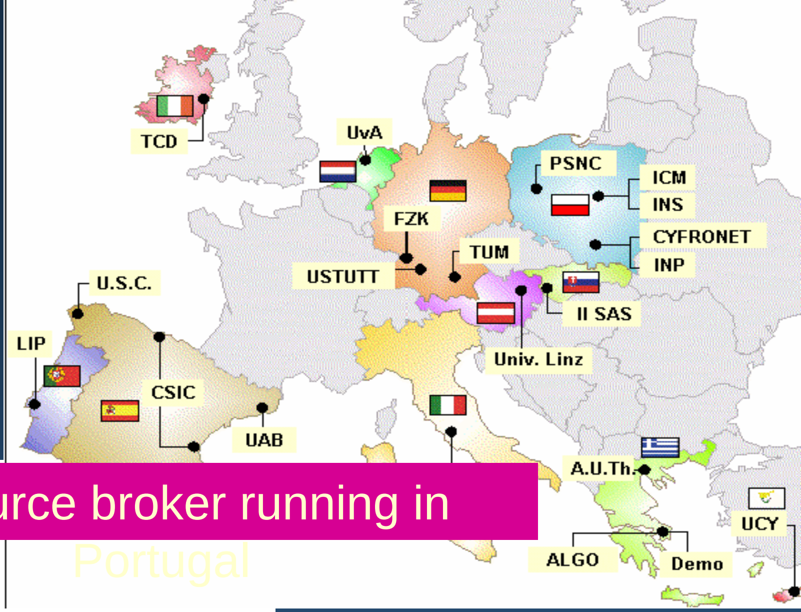
Access to distributed computing



- Local computing farm
- Geographically distributed grid



Traceback from a run on CrossGrid testbed



Current #Grid setup (computing element

Resource broker running in Portugal

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

“Fast” use case: brachytherapy

Period of testing	3weeks
Number of runs performed	50
Number of events simulated (per run)	$2 \cdot 10^7$
Number of DIANE workers applied (per run)	40
Number of tasks (per run)	10^3
Number of events per task	$2 \cdot 10^4$

40 DIANE workers

Sequential

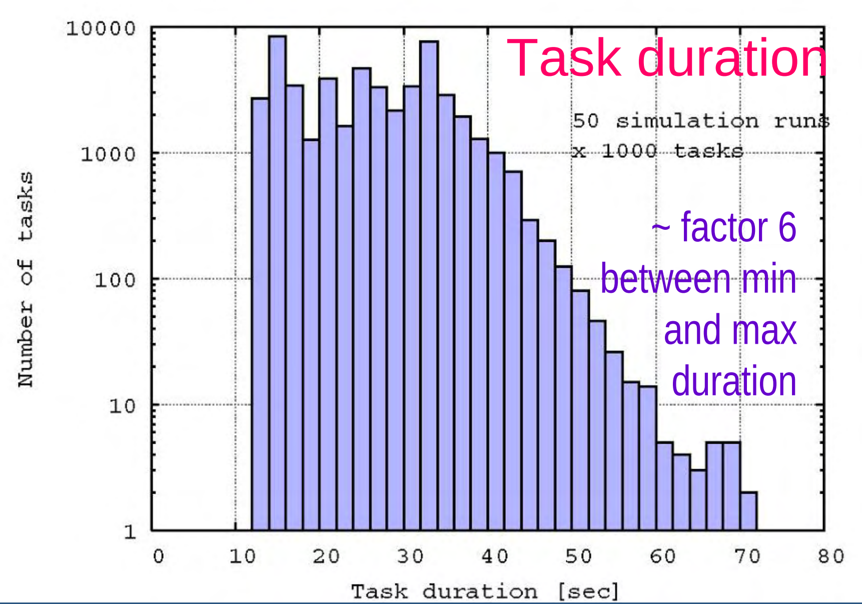
1 task = 25 ± 0.5 CPU s

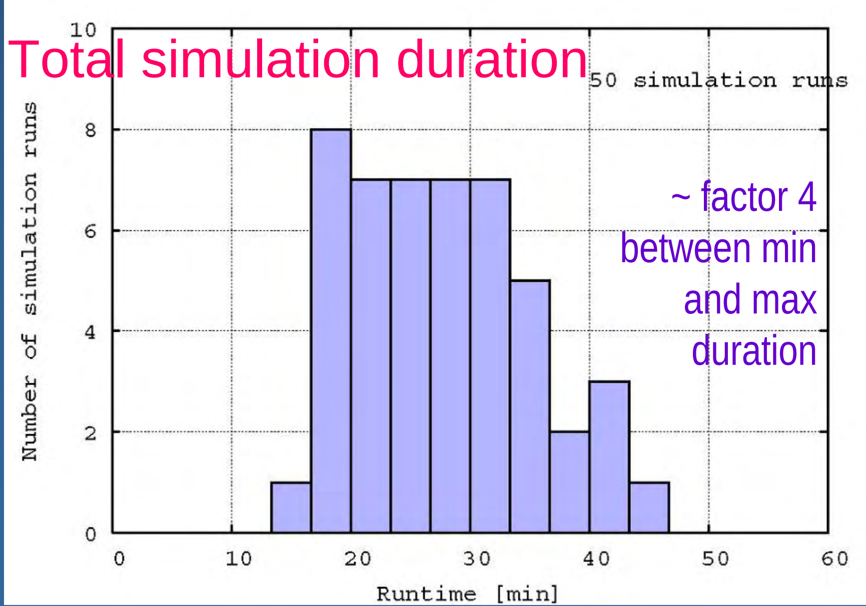
Total simulation = 417 ± 8 min on lcgui003

Ideal expectation with 40 workers: ~10 min for the whole simulation

On the grid

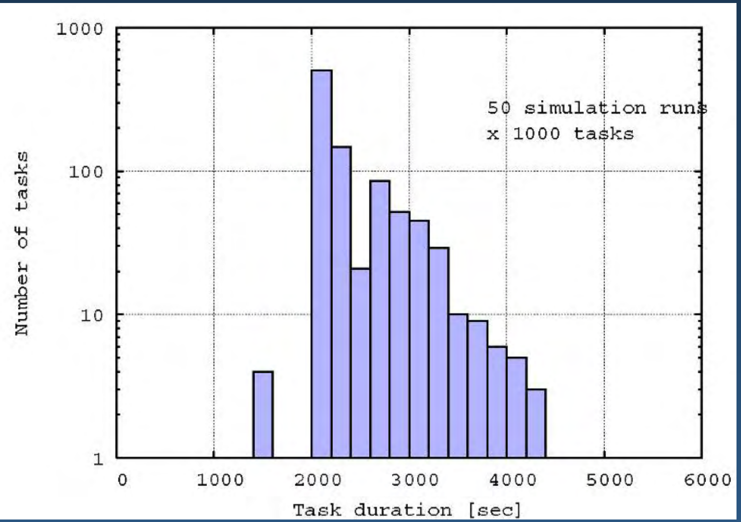
64% runs terminated < 30 min
96% runs terminated < 40 min





More computationally intensive use case: hadrontherapy

Period of testing	5weeks (with breaks)
Number of runs performed	50
Number of events simulated (per run)	10^5
Number of DIANE workers applied (per run)	20
Number of tasks (per run)	20
Number of events per task	$5 \cdot 10^3$



20 DIANE workers

Sequential

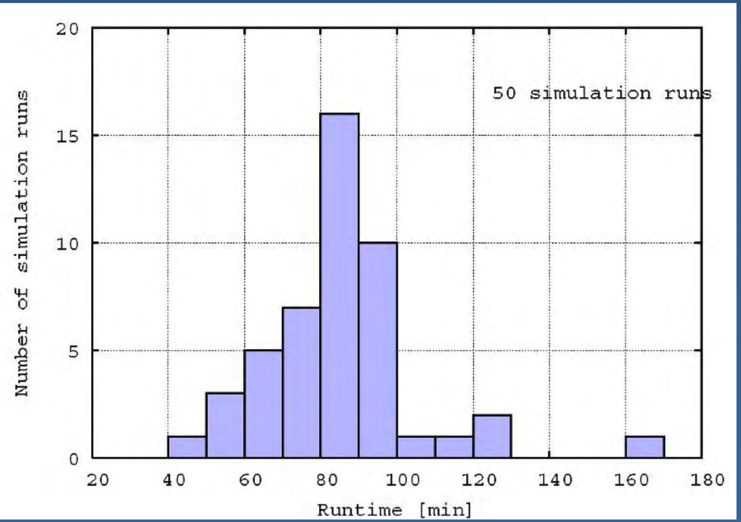
1 task = 50’ ± 50 s CPU time

Total simulation = 16.7 h ± 17 min

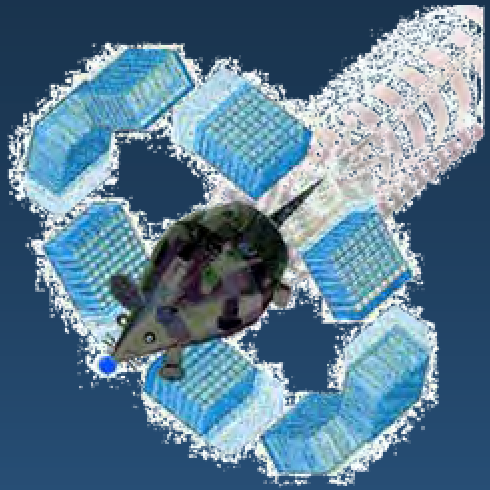
Ideal expectation with 20 workers:
~50 min for the whole simulation

On the grid

84% runs terminated < 100 min

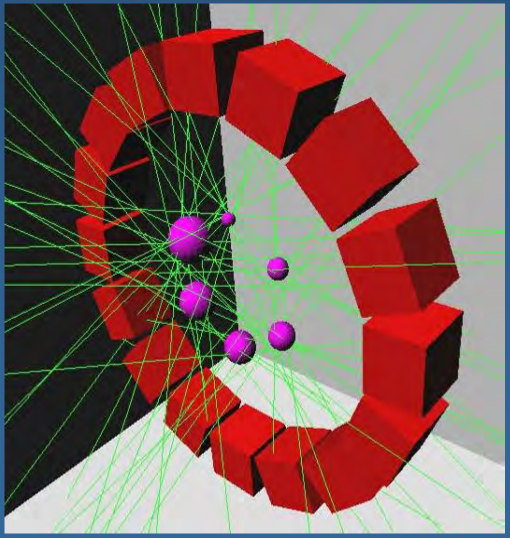


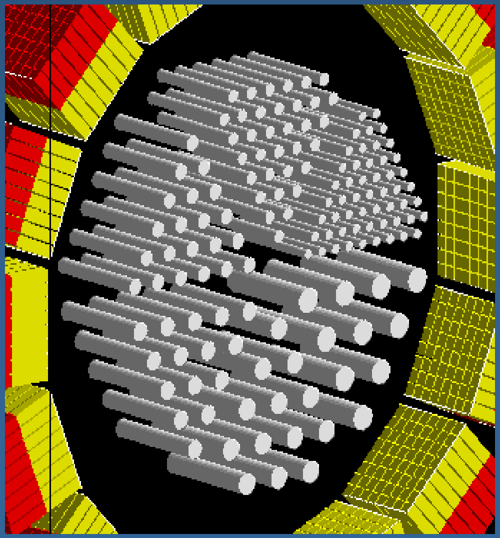
GATE
a Geant4 based simulation platform, designed for PET and SPECT



GATE Collaboration

Recently released as an open source software system under GPL





Robustness

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

European Space Agency:

ESA

National Institutes:

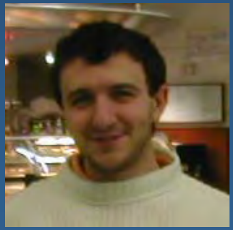
INFN, IN2P3, PPARC

Universities:

Frankfurt Univ., Helsinki Univ. *etc.*

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













The next frontier

The power of abstract interfaces

Geant 4 geometry: a cell
Geant 4 process: mutagenesis

Geant4-DNA - Microsoft Internet Explorer

File Edit View Favorites Tools Help

Back Search

Address D:\Users\pia\wwwG4infn\dna\index.htm Go Links

esa

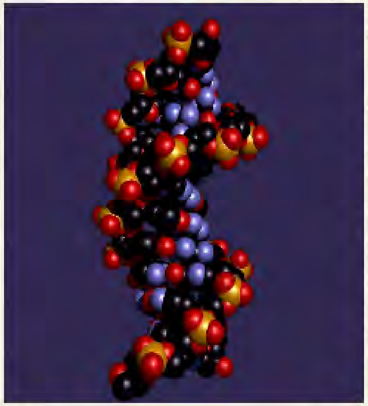
Geant 4 DNA

INFN Istituto Nazionale di Fisica Nucleare

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

- Home
- Requirements
- Documents
- Talks
- Papers
- Meetings
- Team
- Geant4
- Geant4-INFN
- Geant4 LowE Physics
- Useful links

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



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

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

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

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

Pictures courtesy of ESA

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)

User Support

See http://cern.ch/geant4

Geant4 User Forum: link from Geant4 web

Geant4 Technical Forum

Training Courses *(no charge: only travel expenses for instructors)*

Feel free to contact us!

User Organizations

Geant4 North American Medical Users Organization - G4NAMU

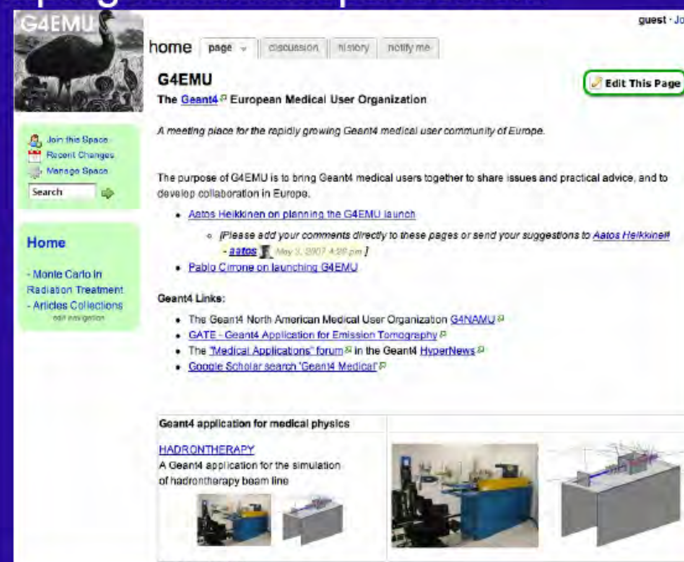
Launched in May of 2005 to provide a meeting place for the rapidly growing Geant4 medical user community of North America

- Bring this community together to share issues and advice, to develop regional collaboration and to communicate as a group to the Geant4 developers.
- Current membership includes 95 members from 44 institutions throughout Canada and the United States

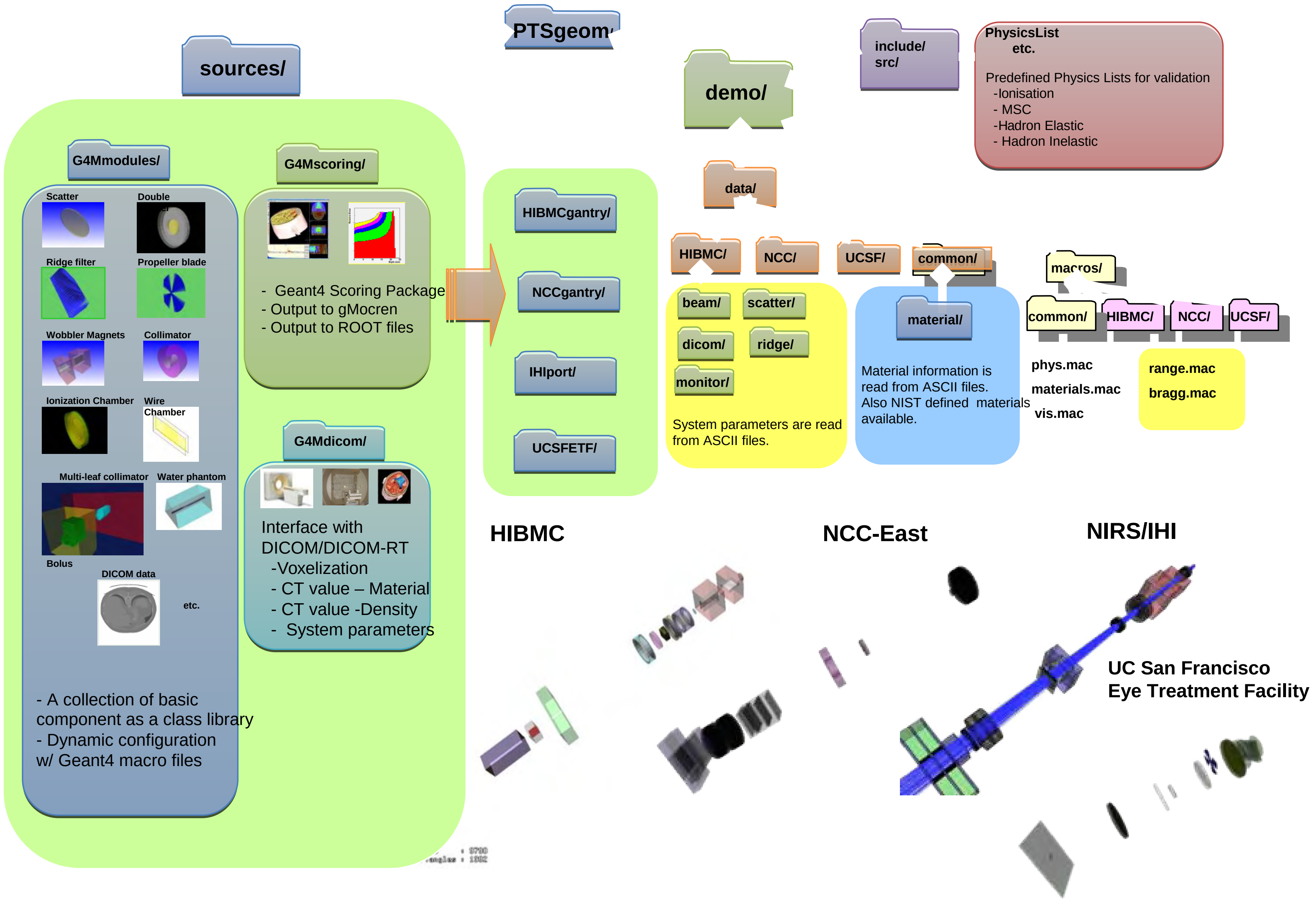
- http://geant4.slac.stanford.edu/g4namu/

Geant4 European Medical User Organization

- http://g4emu.wikispaces.com



Software Structure for Particle Therapy Simulation

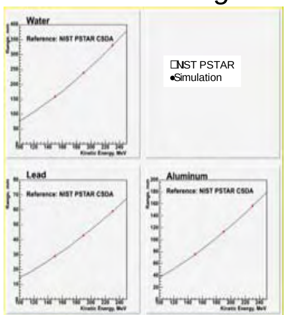


Validation Activities

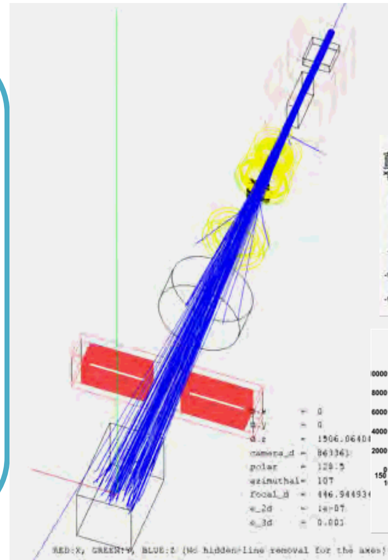
for Proton Therapy

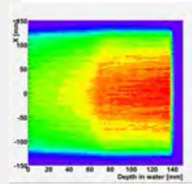
Material Properties

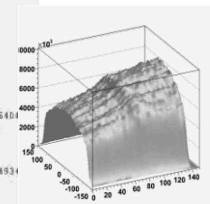
Proton range



Stopping Power/Range ,
checked with NIST data

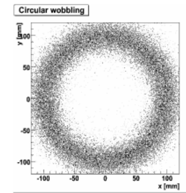




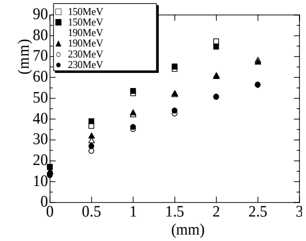


Beam Delivery system validation

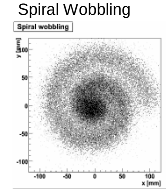
Wobbler Magnet



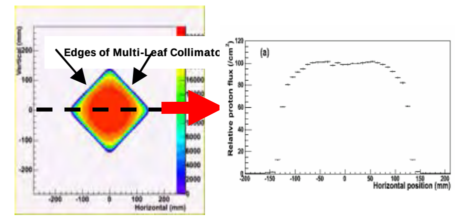
Lead Scatterer



Wobbler demonstration:
Spiral Wobbling



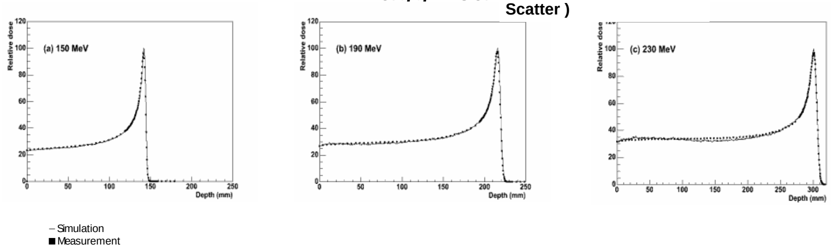
Uniform Irradiation Field



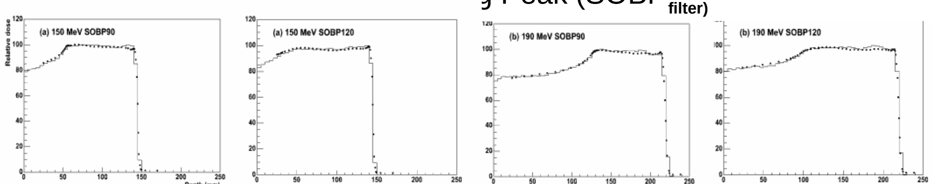
Depth-Dose distribution

IEEE TNS V52,Issue4,(2005)pp.896-901

Bragg Peak (with Wobbler and Scatter)



Spread Out Bragg Peak (SOBP) (with Wobbler, Scatter, and Ridge filter)

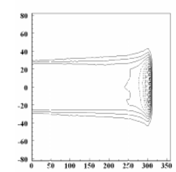


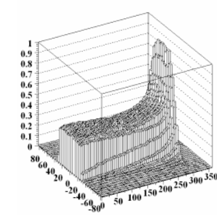
Nuclear Interaction Effect

by T.Akagi (HIBMC)

beam

MLC Water phantom

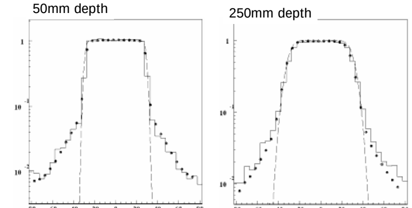




Measurements
TPS calculations
G4 (histograms)

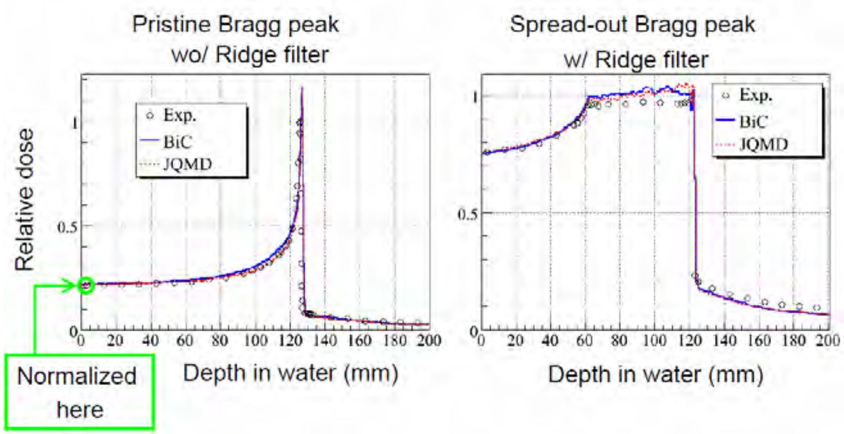
50mm depth

250mm depth

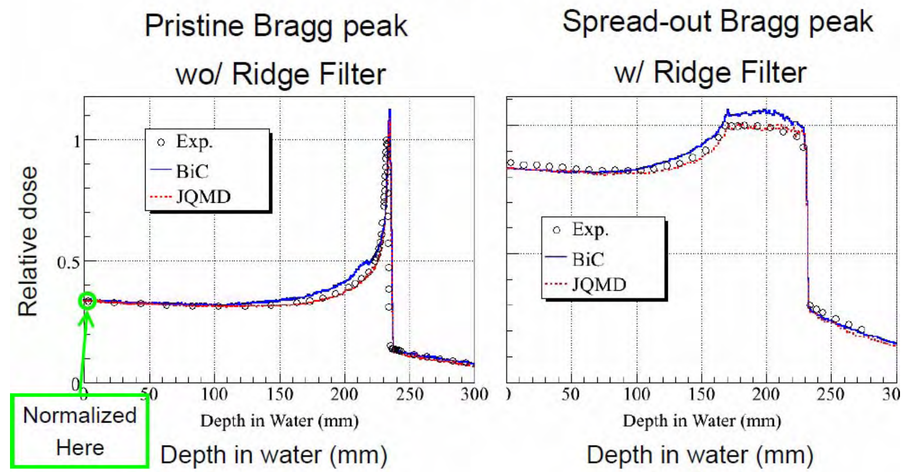


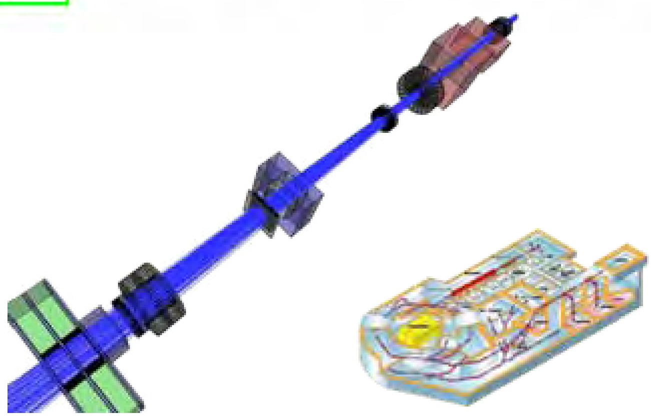
also for Carbon Therapy

Depth-dose distribution
(^{12}C 290 MeV/n)



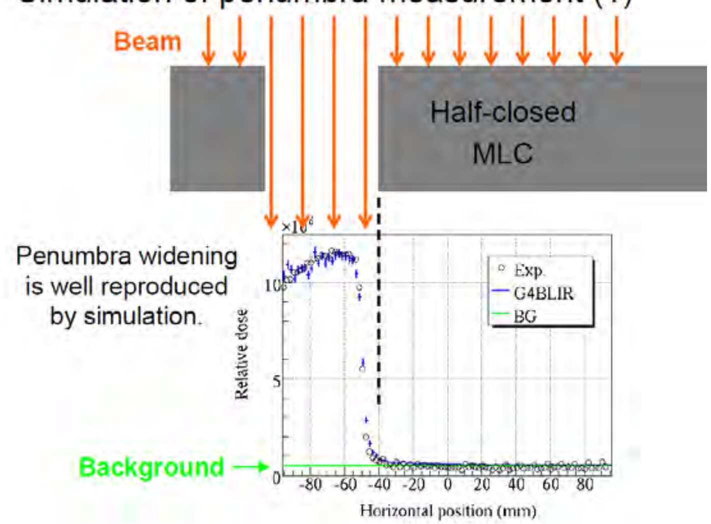
Depth-dose distribution
(^{12}C 400 MeV/n)





NIRS /
IHI experimental beam line

Simulation of penumbra measurement (1)



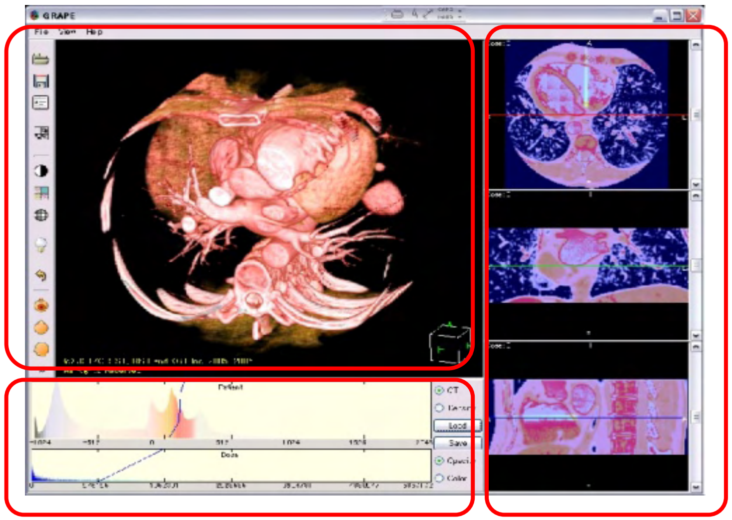
gMocren : A Visualization Tool

http://geant4.kek.jp/gMocren/

gMocren and utility softwares are freely available.

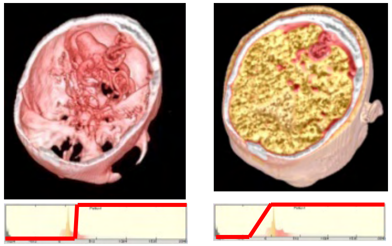
Supported system **:**
- Windows 2k/XP or PC Linux OS
- Pentium 4 or faster
- more than 1 GB (recommend)

3D (ray casting) 2D (MPR)



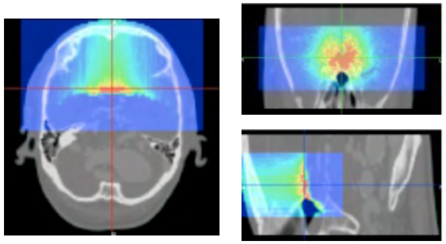
Opacity curve and color map editor

Opacity curve and color map editor

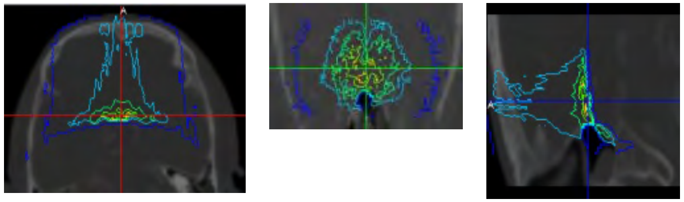


free hand or templates with WW&WL editing

Calculated dose distribution

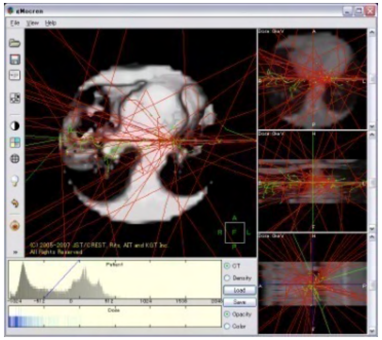


color mapping



contour plot

Particle trajectories

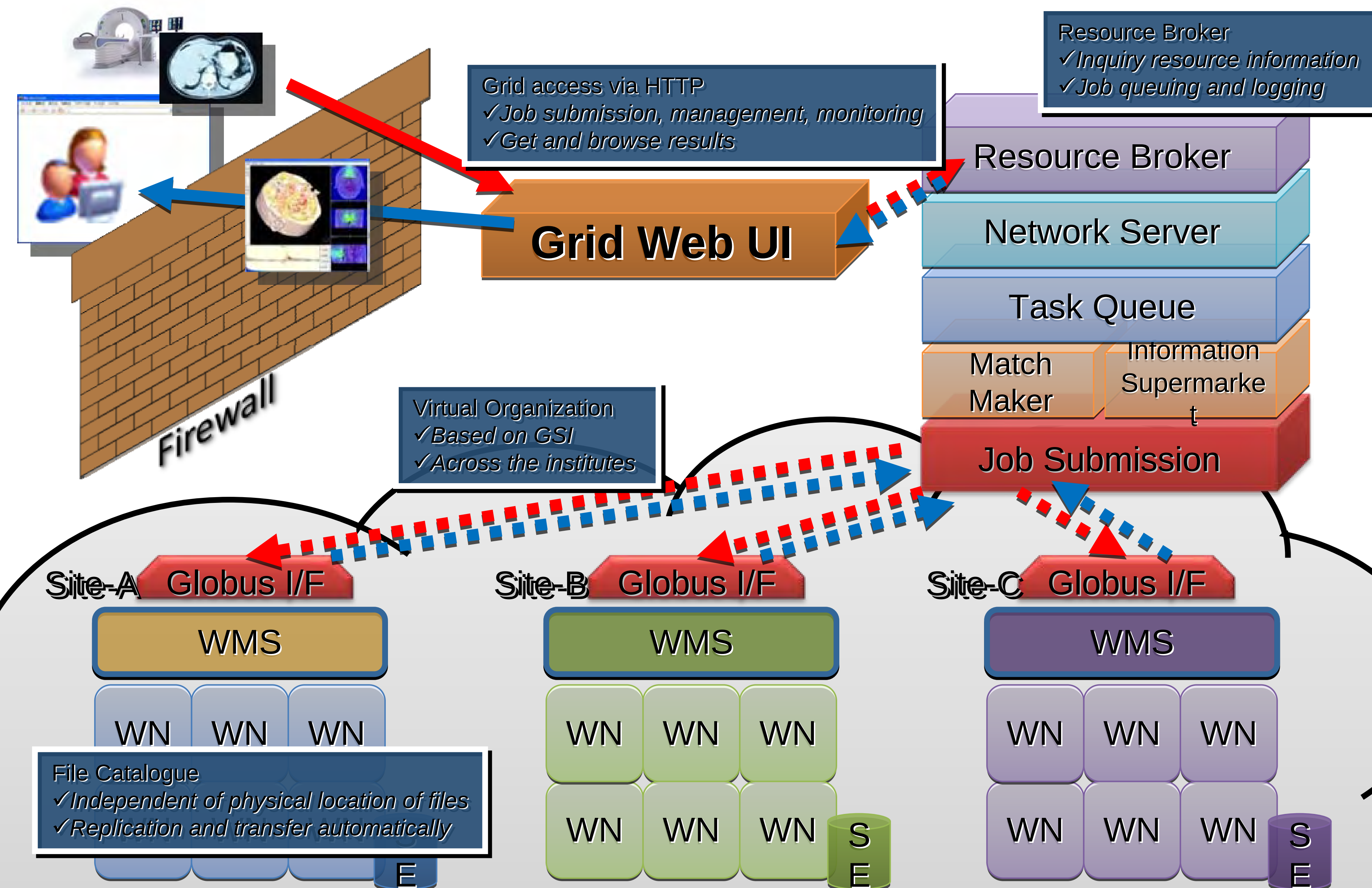


Trajectory information in the simulation is available.

Functionality Requirements :

- To visualize
  - the modality image used by the simulation,
  - the calculated dose distribution and
  - the particle trajectories
  - in an agreeable speed
- Transfer function editor
- Multi-platform

GRID Deployment and Web UI Interface



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

Geant 4

Basics of User Application

User Documentation at

http://cern.ch/geant4

Toolkit + User application

- Geant4 is a **toolkit**
  - i.e. you cannot "run" it out of the box
  - You must write an application, which uses Geant4 tools
- Consequences
  - There are no such concepts as "Geant4 defaults"
  - You must provide the necessary information to configure your simulation
  - You must deliberately choose which Geant4 tools to use
- Guidance: we provide many **examples**
  - **Novice Examples**: overview of Geant4 tools
  - **Advanced Examples**: Geant4 tools in real-life applications

Basic concepts

- What you **MUST** do:
  - Describe your **experimental set-up**
  - Provide the **primary particles** input to your simulation
  - Decide which **particles** and **physics models** you want to use out of those available in Geant4 and the precision of your simulation (cuts to produce and track secondary particles)
- You may also want
  - To interact with Geant4 kernel to **control** your simulation
  - To **visualise** your simulation configuration or results
  - To produce **histograms, tuples** etc. to be further analysed

Interaction with Geant4 kernel

- Geant4 design provides **tools** for a user application
  - To tell the kernel about your simulation configuration
  - To interact with Geant4 kernel itself
- Geant4 tools for user interaction are **base classes**
  - You create **your own concrete class** derived from the base classes
  - Geant4 kernel handles your own derived classes transparently through their base class interface (polymorphism)
- **Abstract base classes** for user interaction
  - User derived concrete classes are **mandatory**
- **Concrete base classes** (with virtual dummy methods) for user interaction
  - User derived classes are **optional**

User classes

Initialisation classes

Invoked at the initialization

- *G4VUserDetectorConstruction*
- *G4VUserPhysicsList*

Action classes

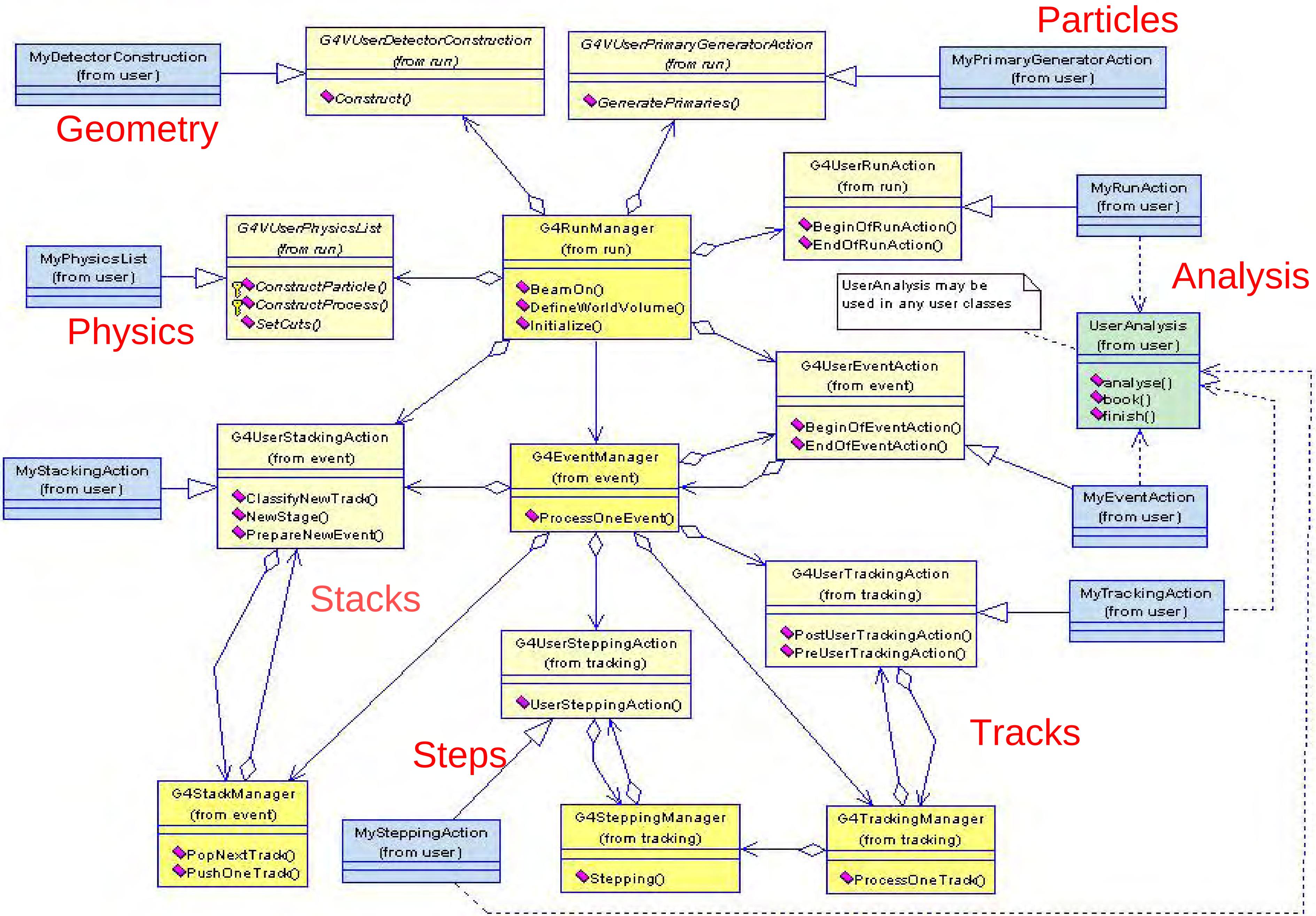
Invoked during the execution loop

- *G4VUserPrimaryGeneratorAction*
- G4UserRunAction
- G4UserEventAction
- G4UserTrackingAction
- G4UserStackingAction
- G4UserSteppingAction

Mandatory classes:

- *G4VUserDetectorConstruction*
  describe the experimental set-up
- *G4VUserPhysicsList*
  select the physics you want to activate
- *G4VUserPrimaryGeneratorAction*
  generate primary events

Overview of Geant4 advanced examples



The main program

- Geant4 does not provide the **main()**
  - Geant4 is a toolkit!
  - The main() is part of the user application

- In his/her main(), the user **must**
  - construct **G4RunManager** (or his/her own derived class)
  - notify the G4RunManager mandatory user classes derived from
    - ***G4VUserDetectorConstruction***
    - ***G4VUserPhysicsList***
    - ***G4VUserPrimaryGeneratorAction***

- The user may define in his/her main()
  - optional user action classes
  - VisManager, (G)UI session

main()

```
{
  …
  // Construct the default run manager
  G4RunManager* runManager = new G4RunManager;

 // Set mandatory user initialization classes
 runManager->SetUserInitialization(new MyDetectorConstruction);
 runManager->SetUserInitialization(new MyPhysicsList);

  // Set mandatory user action classes
  runManager->SetUserAction(new MyPrimaryGeneratorAction);

  // Set optional user action classes
  MyEventAction* eventAction = new MyEventAction();
   runManager->SetUserAction(eventAction);
  MyRunAction* runAction = new MyRunAction();
   runManager->SetUserAction(runAction);
  …
}
```

Describe the experimental set-up

- Derive your own concrete class from the ***G4VUserDetectorConstruction*** abstract base class

- Implement the **Construct()** method
  - 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

How to define materials

Different kinds of materials can be defined:

- Isotopes
- Elements
- Molecules
- Compounds and mixtures

```
PVPhysicalVolume*  MyDetectorConstruction::Construct()
 {
    …
    a = 207.19*g/mole;
    density = 11.35*g/cm3;
    G4Material* lead = new G4Material(name="Pb", z=82., a, density);

    density = 5.458*mg/cm3;
    pressure = 1*atmosphere;
    temperature = 293.15*kelvin;
    G4Material* xenon = new G4Material(name="XenonGas", z=54.,
                                       a=131.29*g/mole, density,
                                       kStateGas, temperature, pressure);
    ...
 }
```

Lead: the first block of definitions (a, density, lead).

Xenon gas: the second block of definitions (density, pressure, temperature, xenon).

How to define a compound material

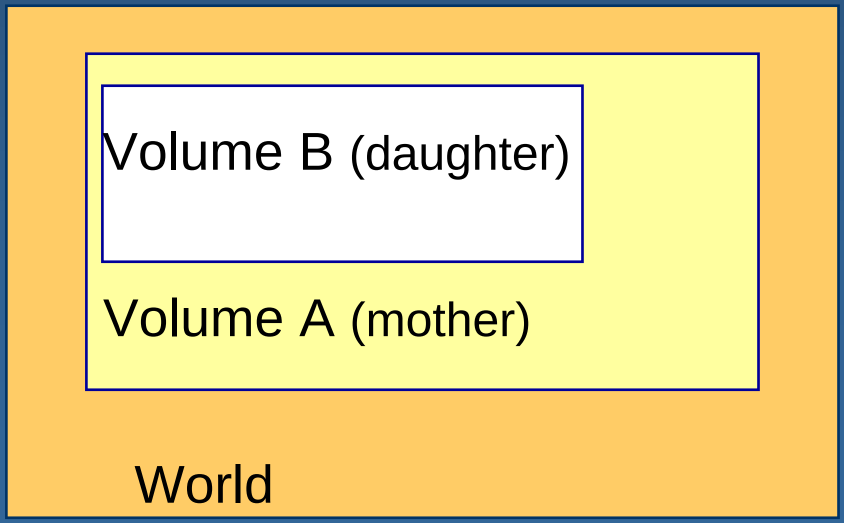
For example, a **scintillator** consisting of Hydrogen and Carbon:

```
G4double a = 1.01*g/mole;
G4Element* H  = new G4Element(name="Hydrogen", symbol="H", z=1., a);

a = 12.01*g/mole;
G4Element* C  = new G4Element(name="Carbon", symbol="C", z=6., a);

G4double density = 1.032*g/cm3;
G4Material* scintillator = new G4Material(name = "Scintillator", density,
numberOfComponents = 2);

scintillator -> AddElement(C, numberOfAtoms = 9);
scintillator -> AddElement(H, numberOfAtoms = 10);
```

Define detector geometry

- Three conceptual layers
  - G4VSolid — shape, size
  - G4LogicalVolume — material, sensitivity, magnetic field, etc.
  - G4VPhysicalVolume — position, rotation

- A unique physical volume (the world volume), which represents the experimental area, must exist and fully contain all other components



e.g.: Volume A is mother of Volume B

The mother must contain the daughter volume entirely

How to build the World

```
solidWorld = new G4Box(“World", halfWorldLength, halfWorldLength, halfWorldLength);
logicWorld = new G4LogicalVolume(solidWorld, air, "World", 0, 0, 0);
physicalWorld = new G4PVPlacement(0,                 //no rotation
                                  G4ThreeVector(),   // at (0,0,0)
                                  logicWorld,        // its logical volume
                                  "World",           // its name
                                  0,                 // its mother  volume
                                  false,             // no boolean operations
                                  0);                // no magnetic field
```

How to build a volume inside the World

```
solidTarget = new G4Box(“Target", targetSize, targetSize, targetSize);
logicTarget = new G4LogicalVolume(solidTarget, targetMaterial, "Target",0,0,0);
physicalTarget = new G4PVPlacement(0,                // no rotation
                                   positionTarget,   // at (x,y,z)
                                   logicTarget,      // its logical volume
                                   "Target",         // its name
                                   logicWorld,       // its mother  volume
                                   false,            // no boolean operations
                                   0);               // no particular field
```

Select physics processes

- Geant4 does not have any default particles or processes
- 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)
- Pure virtual methods of G4VUserPhysicsList

ConstructParticles()
ConstructProcesses()
SetCuts()

→ to be implemented by the user in his/her concrete derived class

PhysicsList: particles and cuts

```
MyPhysicsList :: MyPhysicsList():  G4VUserPhysicsList()
{
   defaultCutValue = 1.0*cm;
}
```

⟸ Define **production thresholds** (the same for all particles)

```
void MyPhysicsList :: ConstructParticles()
{
   G4Electron::ElectronDefinition();
   G4Positron::PositronDefinition();
   G4Gamma::GammaDefinition();
}
```

⟸ Define the **particles** involved in the simulation

```
void MyPhysicsList :: SetCuts()
{
   SetCutsWithDefault();
}
```

⟸ Set the **production threshold**

PhysicsList: more about cuts

```
MyPhysicsList :: MyPhysicsList():  G4VUserPhysicsList()
{
    // Define production thresholds
    cutForGamma  = 1.0*cm;
    cutForElectron = 1.*mm;
    cutForPositron = 0.1*mm;
} ;


void MyPhysicsList :: SetCuts()
{
   // Assign production thresholds
   SetCutValue(cutForGamma, "gamma");
   SetCutValue(cutForElectron, "e-");
   SetCutValue(cutForPositron, "e+");
}
```

The user can define different cuts for different particles or different regions

Physics List: processes

Select physics processes to be activated for each particle type

```
void MyPhysicsList :: ConstructParticles()
 {
   if (particleName == "gamma")
     {
         pManager->AddDiscreteProcess(new G4PhotoElectricEffect());
         pManager->AddDiscreteProcess(new G4ComptonScattering());
         pManager->AddDiscreteProcess(new G4GammaConversion());
     }
   else if (particleName == "e-")
     {
         pManager->AddProcess(new G4MultipleScattering(), -1, 1,1);
         pManager->AddProcess(new G4eIonisation(), -1, 2,2);
         pManager->AddProcess(new G4eBremsstrahlung(), -1,-1,3);
     }
   else if (particleName == "e+")
     {
         pManager->AddProcess(new G4MultipleScattering(), -1, 1,1);
         pManager->AddProcess(new G4eIonisation(), -1, 2,2);
         pManager->AddProcess(new G4eBremsstrahlung(), -1,-1,3);
         pManager->AddProcess(new G4eplusAnnihilation(),  0,-1,4);
     }
}
```

The Geant4 *Standard* electromagnetic processes are selected in this example

Primary events

- Derive your own concrete class from the ***G4VUserPrimaryGeneratorAction*** abstract base class

- Define primary particles providing:
  - Particle type
  - Initial position
  - Initial direction
  - Initial energy

- Implement the virtual member function **GeneratePrimaries()**

Generate primary particles

```
MyPrimaryGeneratorAction:: My PrimaryGeneratorAction()
{
  G4int numberOfParticles = 1;
  particleGun = new G4ParticleGun (numberOfParticles);
  G4ParticleTable* particleTable = G4ParticleTable::GetParticleTable();
  G4ParticleDefinition* particle = particleTable->FindParticle(“e-“);
  particleGun->SetParticleDefinition(particle);
  particleGun->SetParticlePosition(G4ThreeVector(x,y,z));
  particleGun->SetParticleMomentumDirection(G4ThreeVector(x,y,z));
  particleGun->SetParticleEnergy(energy);
}

void MyPrimaryGeneratorAction::GeneratePrimaries(G4Event* anEvent)
{
  particleGun->GeneratePrimaryVertex(anEvent);
}
```

Optional User Action classes

- Five concrete base classes whose virtual member functions the user may override to gain control of the simulation at various stages
  - G4User**Run**Action
  - G4User**Event**Action
  - G4User**Tracking**Action
  - G4User**Stacking**Action
  - G4User**Stepping**Action
- Each member function of the base classes has a dummy implementation
  - Empty implementation: does nothing
- The user may implement the member functions he desires in his/her derived classes
- Objects of user action classes must be registered with G4RunManager

Optional User Action classes

G4UserRunAction

- BeginOfRunAction(const G4Run*)
  - For example: book histograms
- EndOfRunAction(const G4Run*)
  - For example: store histograms

G4UserEventAction

- BeginOfEventAction(const G4Event*)
  - For example: perform and event selection
- EndOfEventAction(const G4Event*)
  - For example: analyse the event

G4UserTrackingAction

- PreUserTrackingAction(const G4Track*)
  - For example: decide whether a trajectory should be stored or not
- PostUserTrackingAction(const G4Track*)

Optional User Action classes

G4UserSteppingAction

- UserSteppingAction(const G4Step*)
  – For example: kill, suspend, postpone the track
  – For example: draw the step

G4UserStackingAction

- PrepareNewEvent()
  – For example: reset priority control
- ClassifyNewTrack(const G4Track*)
  – Invoked every time a new track is pushed
  – For example: classify a new track (priority control)
    - Urgent, Waiting, PostponeToNextEvent, Kill
- NewStage()
  – Invoked when the Urgent stack becomes empty
  – For example: change the classification criteria
  – For example: event filtering (event abortion)

Select (G)UI and visualisation

- In your **main()**, taking into account your computer environment, instantiate a **G4UIsession** concrete class provided by Geant4 and invoke its **sessionStart()** method
- Geant4 provides:
  - G4UIterminal
  - csh or tcsh like character terminal
  - G4GAG
  - tcl/tk or Java PVM based GUI
  - G4Wo
  - Opacs
  - G4UIBatch
  - batch job with macro file
  - …

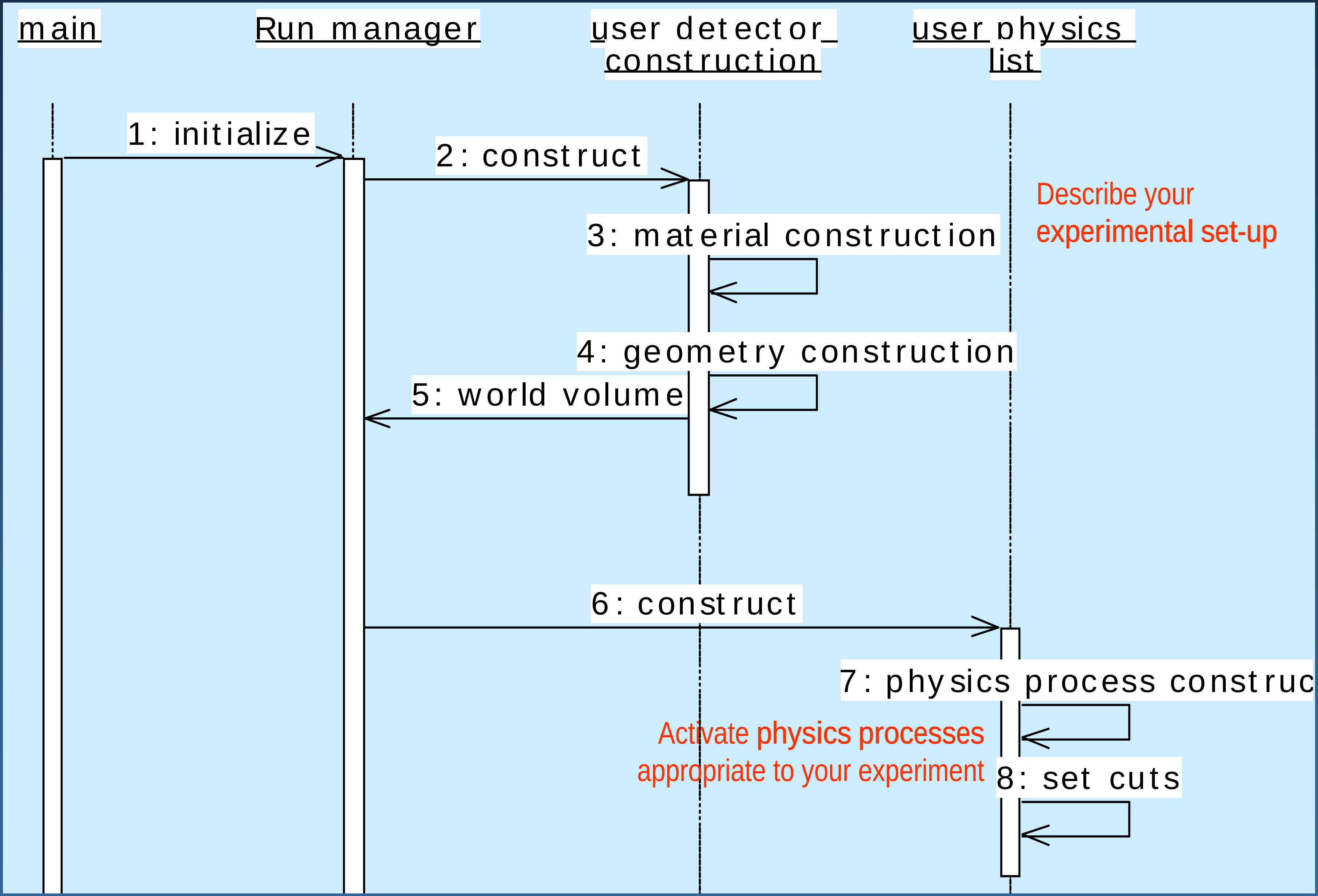
- In your **main()**, taking into account your computer environment, instantiate a **G4VisExecutive** and invoke its **initialize()** method
- Geant4 provides interfaces to various graphics drivers:
  - DAWN *(Fukui renderer)*
  - WIRED
  - RayTracer *(ray tracing by Geant4 tracking)*
  - OPACS
  - OpenGL
  - OpenInventor
  - VRML
  - …

Recipe for novice users

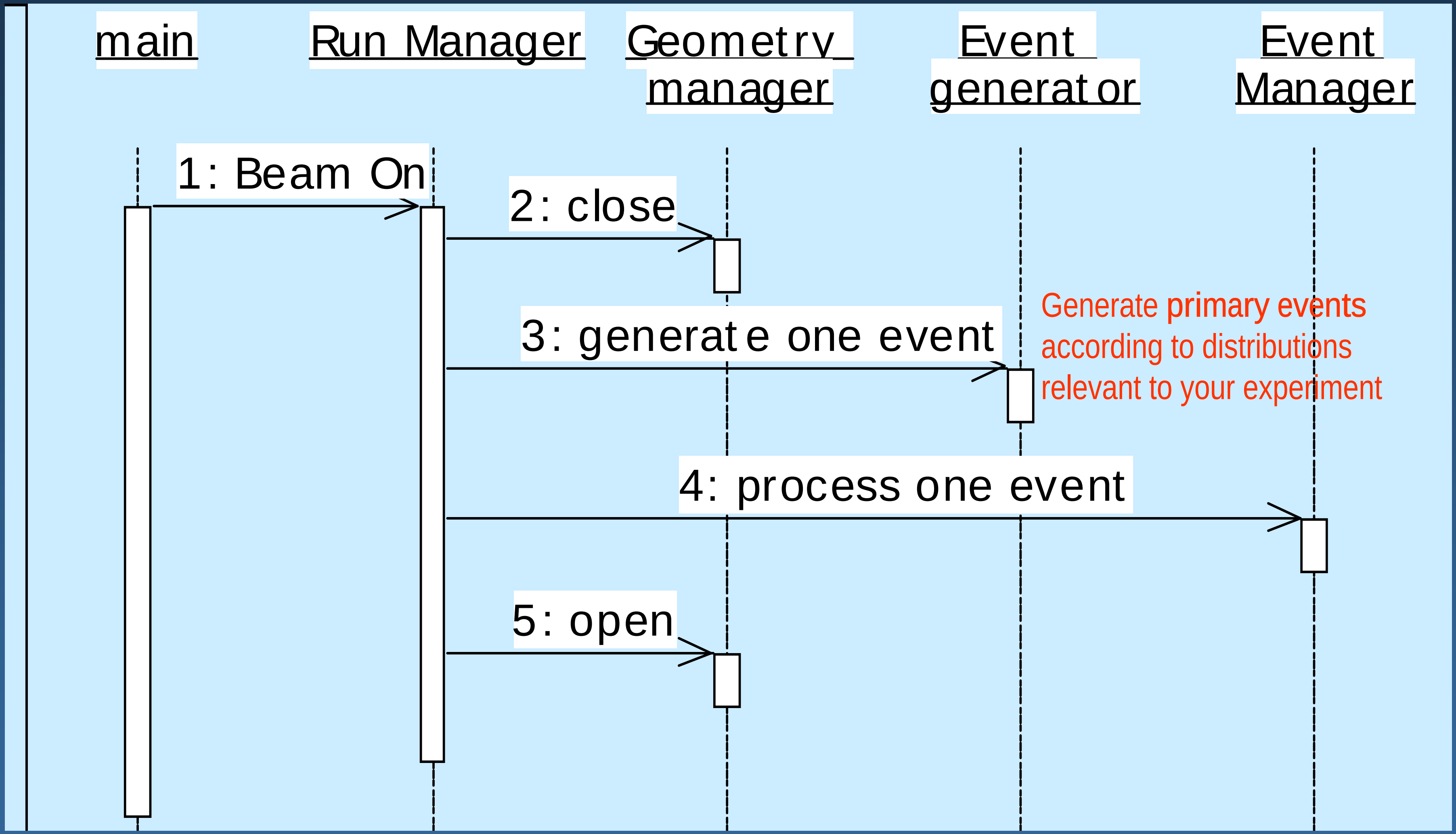
Experienced users may do much more, but the conceptual process is still the same…

- Design diagram as in generic Geant4 Advanced Example
- Create your derived mandatory user classes
  - My**DetectorConstruction**
  - My**PhysicsList**
  - My**PrimaryGeneratorAction**
- Optionally create your derived user action classes
  - MyUser**Run**Action
  - MyUser**Event**Action
  - MyUser**Tracking**Action
  - MyUser**Stacking**Action
  - MyUser**Stepping**Action
- Create your main()
  - Instantiate G4RunManager or your own derived MyRunManager
  - Notify the RunManager of your mandatory and optional user classes
  - Optionally initialize your favourite User Interface and Visualization
- That’s all!

Initialisation



Beam On


main
Run Manager
Geometry manager
Event generator
Event Manager
1: Beam On
2: close
3: generate one event
4: process one event
5: open
Generate primary events according to distributions relevant to your experiment

Event processing