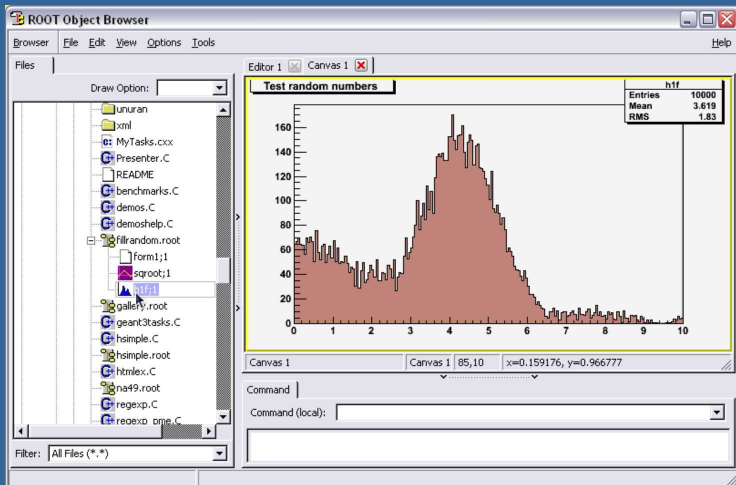
Пакеты моделирования и обработки данных

Мачулин Игорь Николаевич

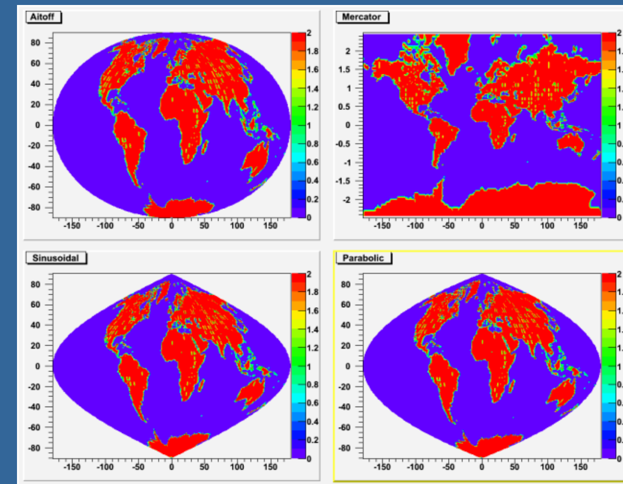
Программное обеспечение для физики элементарных частиц и ядра.

- •Разработчик – ЦЕРН
- •ОС – Линукс
- •Язык программирования – C++
- •Пакеты на основе C++ :
- 1) Root – обработка больших массивов информации с детекторов, проведение статистического анализа, проверка гипотез, представление результатов
- 2) Geant4 – моделирование методом Монте-Карло физических процессов в детекторах частиц

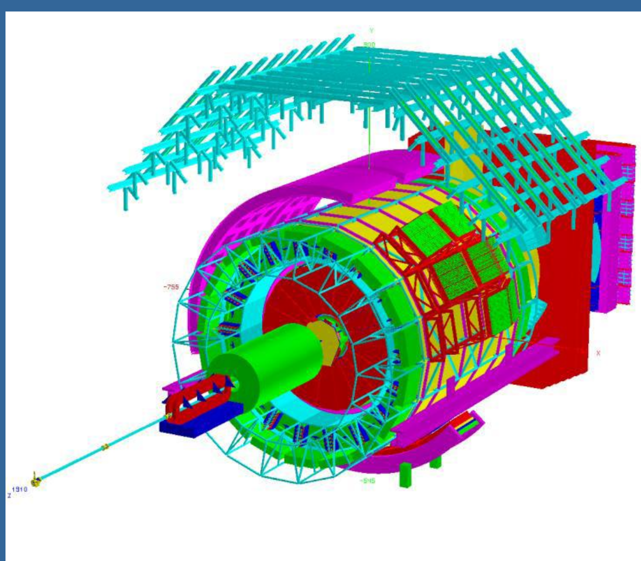
Root – data analyses framework



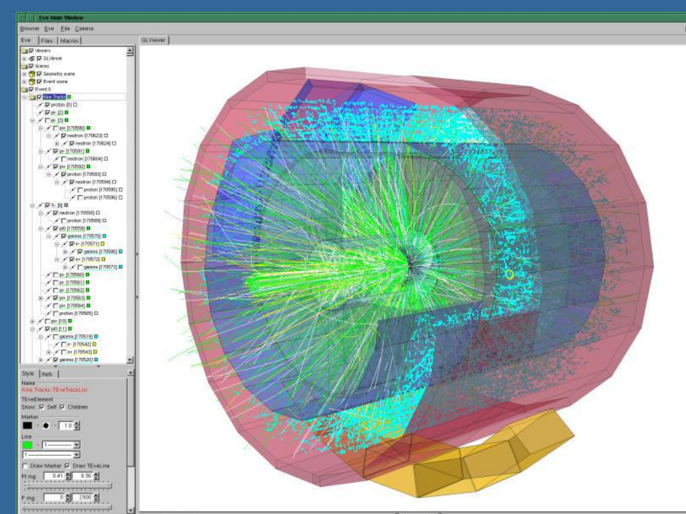
ROOT Browser



Various Projections



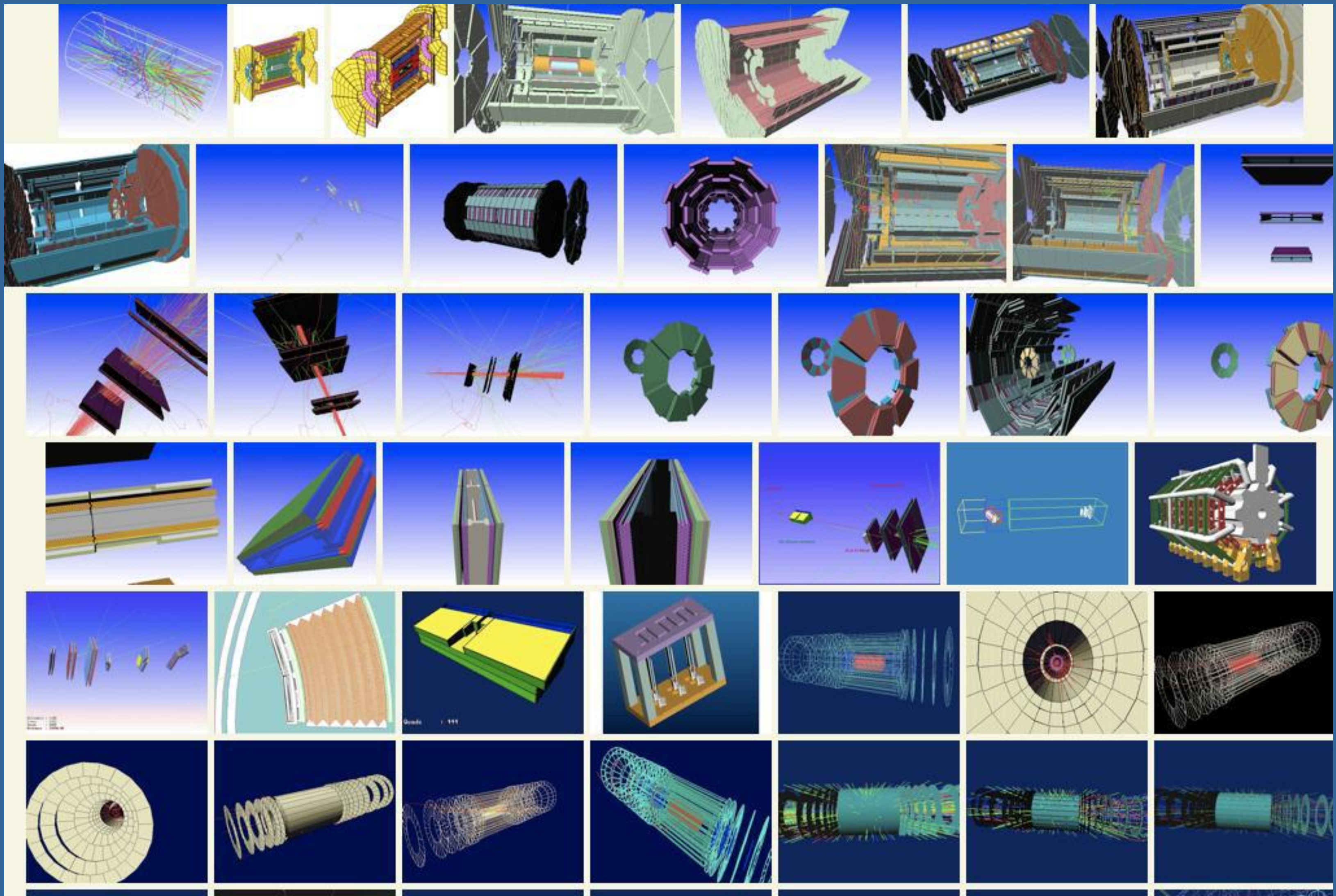
ALICE



Simulated Pb-Pb event in ALICE detector

Geant4 – simulation toolkit for particles

High Energy Physics Experiments



Операционная система

- • **Операционная система , сокр. ОС (англ.** ***operating system, OS) — комплекс управляющих и обрабатывающих программ, которые, с одной стороны, выступают как интерфейс между устройствами вычислительной системы и прикладными программами, а с другой стороны — предназначены для управления устройствами, управления вычислительными процессами, эффективного распределения вычислительных ресурсов между вычислительными процессами и организации надёжных вычислений. Это определение применимо к большинству современных ОС общего назначения.***

- •В логической структуре типичной вычислительной системы ОС занимает положение между устройствами с их микроархитектурой, машинным языком и, возможно, собственными (встроенными) микропрограммами — с одной стороны — и прикладными программами с другой.
- •Разработчикам программного обеспечения ОС позволяет абстрагироваться от деталей реализации и функционирования устройств, предоставляя минимально необходимый набор функций.
- •В большинстве вычислительных систем ОС является основной, наиболее важной (а иногда и единственной) частью системного ПО. С 1990-х наиболее распространёнными операционными системами являются ОС семейства Microsoft Windows и системы класса UNIX (особенно Linux и Mac OS).

Linux

- **Linux— общее название Unix-подобных операционных систем на основе одноимённого ядра, библиотек и системных программ, разработанных в рамках проекта GNU, а так же другого программного обеспечения.**
- ***•GNU's Not UNIX — «GNU — не UNIX» — свободная Unix-подобная операционная система, разрабатываемая Проектом GNU.***

- В отличие от большинства других операционных систем, Linux не имеет единой «официальной» комплектации. Вместо этого Linux поставляется в большом количестве так называемых дистрибутивов, в которых ядро Linux соединяется с утилитами GNU и другими прикладными программами (например, X.org), делающими её полноценной многофункциональной операционной средой.
- •Наиболее известными и используемыми дистрибутивами Linux в физике элементарных частиц (ЦЕРН) являются: Debian, Fedora, ScientificLinux, Ubuntu.

Язык программирования C++

- •C++ — компилируемый статически типизированный язык программирования общего назначения. Поддерживая разные парадигмы программирования, сочетает свойства как высокоуровневых, так и низкоуровневых языков.
- В сравнении с его предшественником — языком C, — наибольшее внимание уделено поддержке объектно-ориентированного и обобщённого программирования.
- Название «C++» происходит от названия языка C, в котором унарный оператор ++ обозначает инкремент переменной.

- Являясь одним из самых популярных языков программирования, C++ широко используется для разработки программного обеспечения. Область его применения включает создание операционных систем, разнообразных прикладных программ, драйверов устройств, приложений для встраиваемых систем, высокопроизводительных серверов, а также развлекательных приложений (например, видеоигры). Существует несколько реализаций языка C++ — как бесплатных, так и коммерческих. Их производят Проект GNU, Microsoft, Intel и Embarcadero (Borland).

Основная литература

- http://www.cern.ch
- http://geant4.web.cern.ch/geant4/
- http://root.cern.ch/

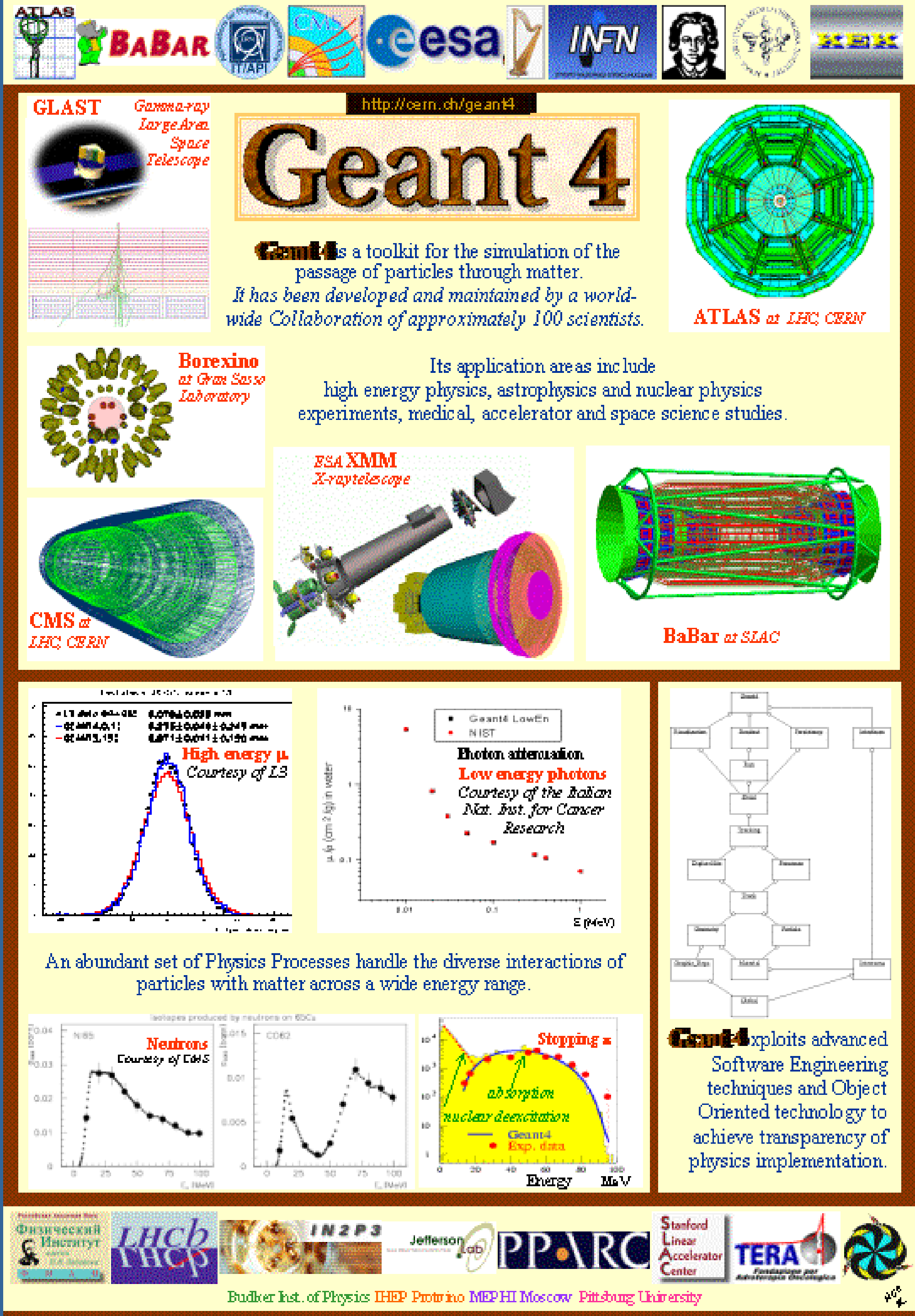
- С.М. Ермаков. Метод Монте-Карло и смежные вопросы. Наука. 1975.
- И.М. Соболь. Метод Монте-Карло. Наука. 1985.
- Х. Гульд, Я. Тобочник. Компьютерное моделирование в физике. Мир. 1990.

- Р. Лафоре, Объектно-ориентированное программирование в С++, из-во Питер, СПб, 2011.
- Г. Шилдт, Самоучитель С++

Geant4
General introduction and brief history

Contents

- General introduction and brief history
- Highlights of user applications
- Geant4 kernel
  - Basic concepts and kernel structure
  - User classes
  - Primary particle generation



What is Geant4?

- Geant4 is the successor of GEANT3, the world-standard toolkit for HEP detector simulation.
- Geant4 is one of the first successful attempt to re-design a major package of HEP software for the next generation of experiments using an Object-Oriented environment.
- A variety of requirements also came from heavy ion physics, CP violation physics, cosmic ray physics, astrophysics, space science and medical applications.
- In order to meet such requirements, a large degree of functionality and flexibility are provided.
- G4 is not only for HEP but goes well beyond that.

Flexibility of Geant4

- In order to meet wide variety of requirements from various application fields, a large degree of functionality and flexibility are provided.
- Geant4 has many types of geometrical descriptions to describe most complicated and realistic geometries
- Everything is open to the user
  - Choice of physics processes/models
  - Choice of GUI/Visualization/persistency/histogramming technologies

Physics in Geant4

- It is rather unrealistic to develop a uniform physics model to cover wide variety of particles and/or wide energy range.
- Much wider coverage of physics comes from mixture of theory-driven, parameterized, and empirical formulae. Thanks to polymorphism mechanism, both cross-sections and models (final state generation) can be combined in arbitrary manners into one particular process.
- Geant4 offers
  - EM processes
  - Hadronic processes
  - Photon/lepton-hadron processes
  - Optical photon processes
  - Decay processes
  - Shower parameterization
  - Event biasing techniques
  - And you can plug-in more

Physics in Geant4

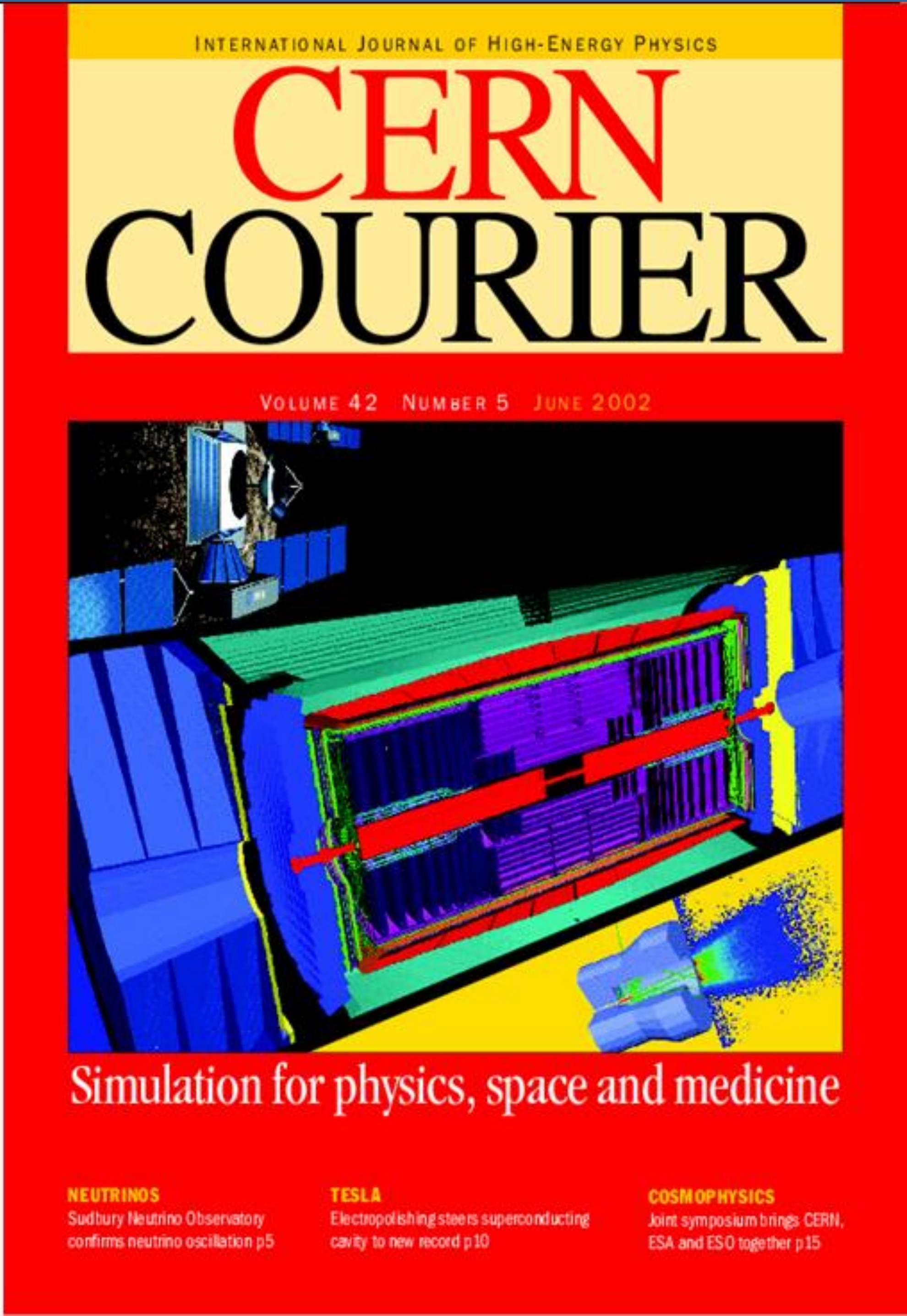
- Each cross-section table or physics model (final state generation) has its own applicable energy range. Combining more than one tables / models, one physics process can have enough coverage of energy range for wide variety of simulation applications.
- Geant4 provides sets of alternative physics models so that the user can freely choose appropriate models according to the type of his/her application.
- Several individual universities / physicists groups are contributing their physics models to Geant4. Given the modular structure of Geant4, developers of each physics model are well recognized.

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



Geant 4

Geant4 Collaboration

Stanford Linear Accelerator Center

HARP

Applications for Physics & Infrastructure CERN IT/API

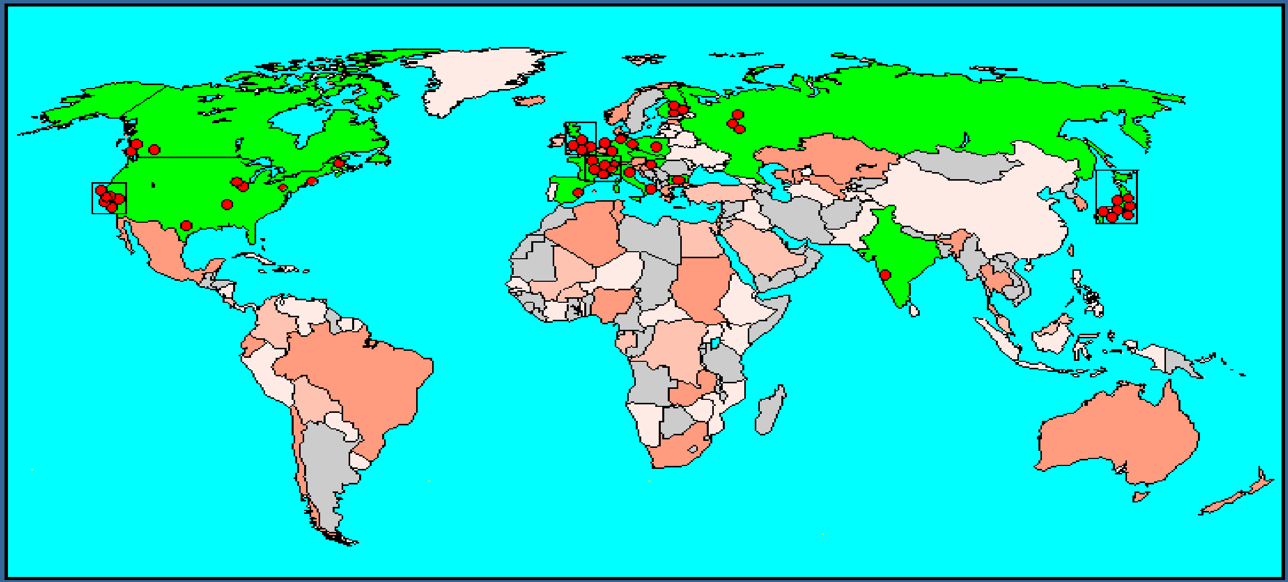
KEK

esa

BABAR

TERA Fondazione per Adroterapia Oncologica

ATLAS



INFN ISTITUTO NAZIONALE DI FISICA NUCLEARE

CMS

Российская Академия Наук
Физический Институт имени П.Н.Лебедева
Ф И А Н

Lebedev

LHCb

IN2P3

Univ. Barcelona

PPARC

Helsinki Inst. Ph.

Jefferson Lab
Thomas Jefferson National Accelerator Facility

Collaborators also from non-member institutions, including
Budker Inst. of Physics
IHEP Protvino
MEPHI Moscow
Pittsburg University

Highlights of
Users Applications

http://www.in-cites.com/hotpapers/2004/november04-eng.html

– http://www.in-cites.com/hotpapers/2005/jan05-eng.html

– http://www.in-cites.com/hotpapers/2005/mar05-eng.html

– http://www.in-cites.com/hotpapers/2005/may05-eng.html

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Published In The Last 2-Years For: Engineering

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"Super Hot" Papers in Science Published Since 2003

Engineering
(Sorted by citations, 3 of 128)

1 Citations: 133
Title: GEANT4-A SIMULATION TOOLKIT
Authors: AGOSTINELLI S; ALLISON J; AMAKO K; APOSTOLAKIS J; ARAUJO H; ARCE P; ASAI M; AXEN D; BANERJEE S; BARRAND G; BEHNER F; BELLAGAMBA L; BOUDREAU J; BROGLIA L; BRUNENGO A; BURKHARDT H; CHAUVIE S; CHUMA J; CHYTRACEK R; COOPERMAN G; COSMO G; DEGTYARENKO P; DELL'ACQUA A; DEPAOLA G; DIETRICH D; ENAMI R; FELICIELLO A; FERGUSON C; FESEFELDT H; FOLGER G; FOPPIANO F; FORTI A; GARELLI S; GIANI S; GIANNITRAPANI R; GIBIN D; CADENAS JJG; GONZALEZ I; ABRIL GG; GREENIAUS G; GREINER W; GRICHINE V; GROSSHEIM A; GUATELLI S; GUMPLINGER P; HAMATSU R; HASHIMOTO K; HASUI H; HEIKKINEN A; HOWARD A; IVANCHENKO V; JOHNSON A; JONES FW; KALLENBACH J; KANAYA N; KAWABATA M; KAWABATA Y; KAWAGUTI M; KELNER S; KENT P; KIMURA A; KODAMA T; KOKOULIN R; KOSSOV M; KURASHIGE H; LAMANNA E; LAMPEN T; LARA V; LEFEBURE V; LEI F; LIENDL M; LOCKMAN W; LONGO F; MAGNI S; MAIRE M; MEDERNACH E; MINAMIMOTO K; DE FREITAS PM; MORITA Y; MURAKAMI K; NAGAMATU M; NARTALLO R; NIEMINEN P; NISHIMURA T; OHTSUBO K; OKAMURA M; O'NEALE S; OOHATA Y; PAECH K; PERL J; PFEIFFER A; PIA MG; RANJARD F; RYBIN A; SADILOV S; DI SALVO E; SANTIN G; SASAKI T; SAVVAS N; SAWADA Y; SCHERER S; SEIL S; SIROTENKO V; SMITH D; STARKOV N; STOECKER H; SULKIMO J; TAKAHATA M; TANAKA S; TCHERNIAEV E; TEHRANI ES;

Top 25 Hottest Articles

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment

January to December 2011 full year

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1. **Geant4-a simulation toolkit**
   Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 506, Issue 3, July 2003, Pages 250-303
   Agostinelli, S.; Allison, J.; Amako, K.; Apostolakis, J.; Araujo, H.; Arce, P.; Asai, M.; Axen, D.; Banerjee, S.; Barrand, G.; Behner, F.; Bellagamba, L.; Boudreau, J.; Broglia, L.; Brunengo, A.; Burkhardt, H.; Chauvie, S.; Chuma, J.; Chytracek, R.; Coope
   Cited by SciVerse Scopus (3266)

2. **Big-bang nucleosynthesis: A probe of the early Universe**
   Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 611, Issue 2-3, December 2009, Pages 224-230
   Coc, A.
   Cited by SciVerse Scopus (1)

3. **Neutron detection gamma ray sensitivity criteria**
   Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 654, Issue 1, October 2011, Pages 412-416
   Kouzes, R.T.; Ely, J.H.; Lintereur, A.T.; Mace, E.K.; Stephens, D.L.; Woodring, M.L.

4. **Application of PWO crystals for detection of low-activity gamma-radiation in the energy range above 3MeV**
   Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 537, Issue 1-2, January 2005, Pages 439-442
   Drobychev, G.Y.; Baryshevsky, V.G.; Fedorov, A.A.; Khruschinsky, A.A.; Korjik, M.V.; Lecoq, P.; Missevitch, O.V.

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[GEANT4—a simulation toolkit](#) [PDF] from kobe-u.ac.jp
S Agostinelli, J Allison, K Amako… - Nuclear Instruments and …, 2003 - Elsevier
Geant4 is a toolkit for simulating the passage of particles through matter. It includes a complete range of functionality including tracking, geometry, physics models and hits. The physics processes offered cover a comprehensive range, including electromagnetic, ...
Cited by 5000 - Related articles - All 29 versions

[Geant4 developments and applications](#) [PDF] from neu.edu
J Allison, K Amako, J Apostolakis… - Nuclear Science, …, 2006 - ieeexplore.ieee.org
Abstract **Geant4** is a software toolkit for the simulation of the passage of particles through matter. It is used by a large number of experiments and projects in a variety of application domains, including high energy physics, astrophysics and space science, medical physics ...
Cited by 929 - Related articles - BL Direct - All 16 versions

[CITATION] **Geant4**: a simulation toolkit
J **Geant4** Collaboration - Nucl. Instr. and Methods A, 2003
Cited by 70 - Related articles

[Geant4 low energy electromagnetic physics](#) [PDF] from infn.it
S Chauvie, S Guatelli, V Ivanchenko… - … Record, 2004 IEEE, 2004 - ieeexplore.ieee.org
Abstract The **Geant4** simulation toolkit includes a specialised package, implementing a precise treatment of electromagnetic interactions of particles with matter below 1 keV. The **Geant4** low energy electromagnetic package provides a variety of models describing the ...
Cited by 98 - Related articles - All 7 versions

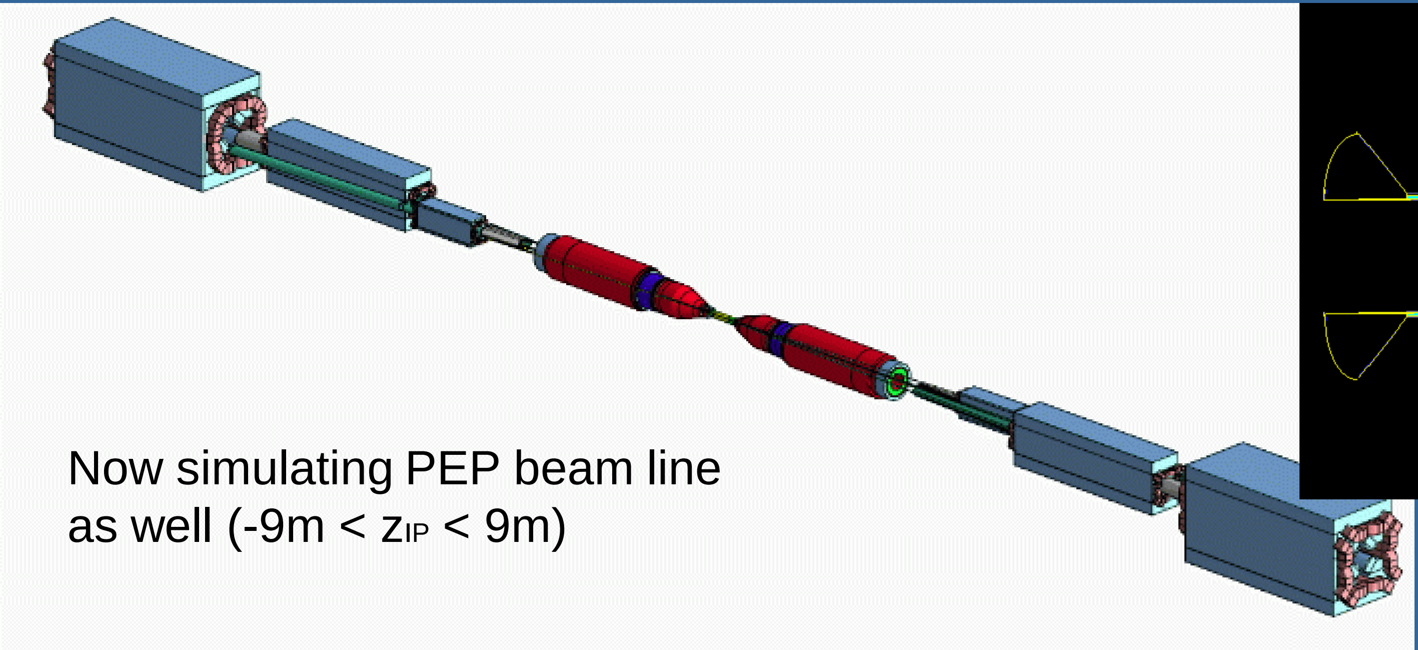
[GATE: A Geant4-based simulation platform for PET and SPECT integrating movement and time management](#) [RTF] from ciemat.es
G Santin, D Strul, D Lazaro, L Simon… - Nuclear Science, …, 2003 - ieeexplore.ieee.org
Abstract GATE, the **Geant4** application for tomographic emission, is a simulation platform developed for PET and SPECT. It combines a powerful simulation core, the **Geant4** toolkit, with newly developed software components dedicated to nuclear medicine. In particular, it ...
Cited by 92 - Related articles - BL Direct - All 11 versions

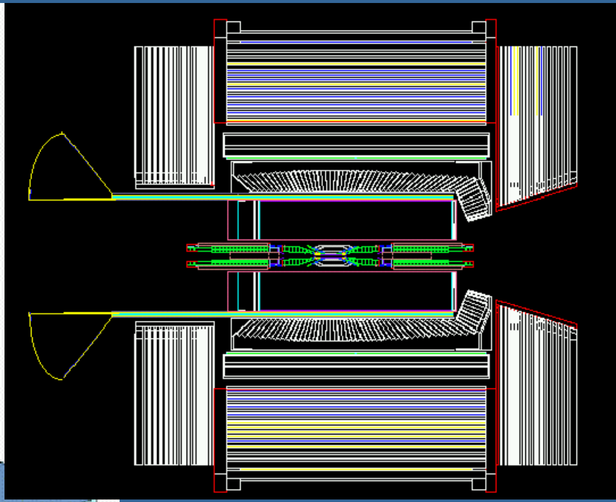
Highlights of Users Applications

To provide you some ideas how Geant4 would be utilized…

BaBar

- BaBar at SLAC is the pioneer experiment in HEP in use of Geant4
  - Started in 2000
  - Simulated ~$2*10^{10}$ events so far
  - Produced at 20 sites in North America and Europe

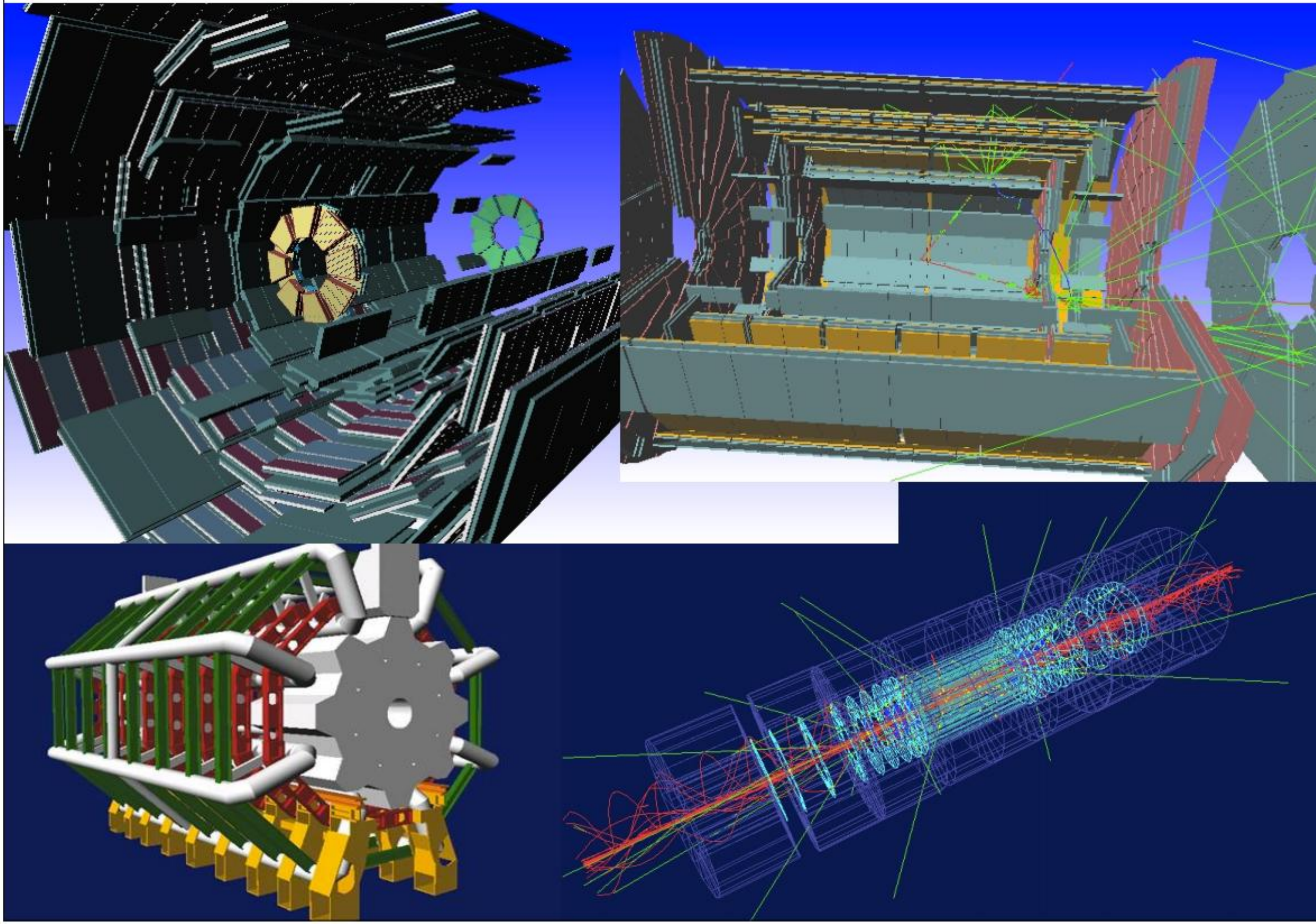




Courtesy of D.Wright (SLAC)

Large Hadron Collider (LHC) @ CERN

Geant4 in High Energy Physics (ATLAS at LHC)

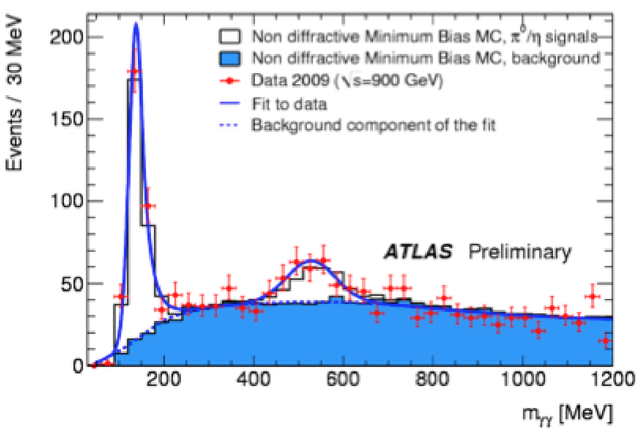


Geant4 has been successfully employed for

- Detector design
- Calibration / alignment

T. LeCompte (ANL)

GEANT4 Comparisons with the Calorimeters



Invariant mass of pairs of well-isolated electromagnetic clusters.

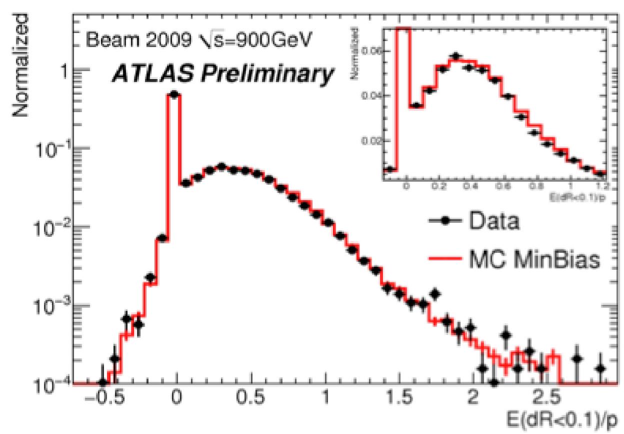
The π^0 mass is within 0.8 ± 0.6% of expectations.

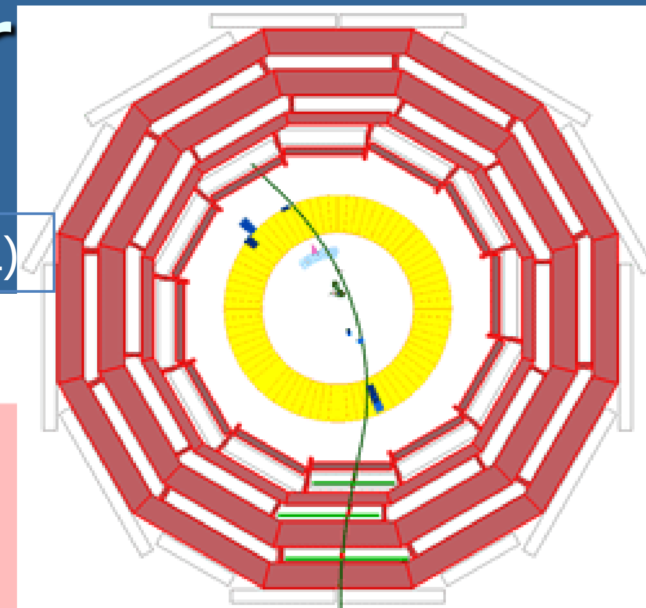
The η^0 mass is within 3 ± 2% of expectations.

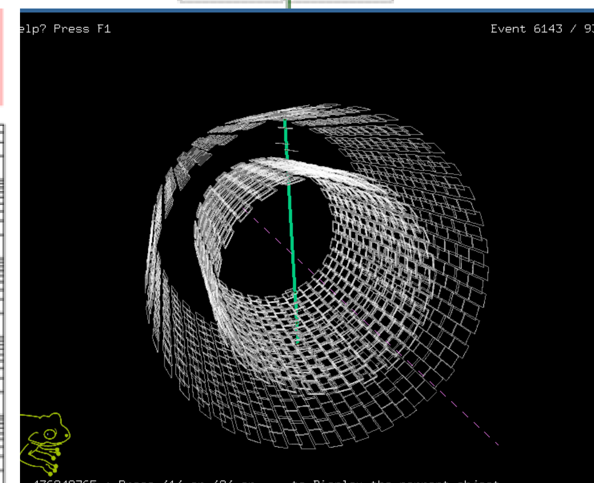
The detector uniformity is better than 2%.

Response of the calorimeter to single isolated tracks. To reduce the effect of noise, topological clusters are used in summing the energy.

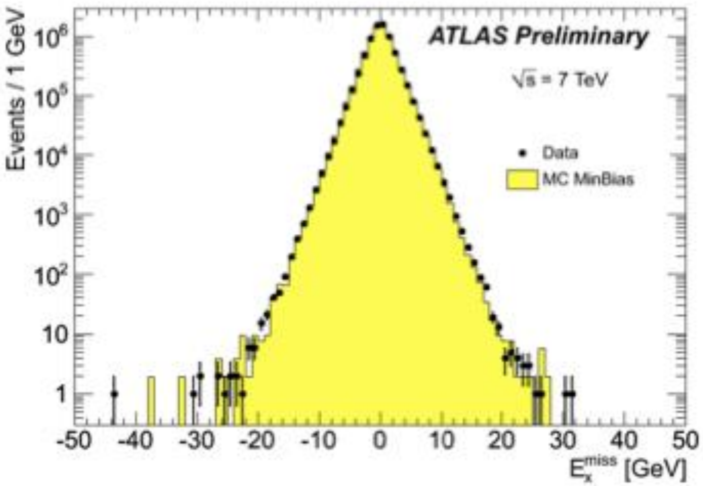
This plot agreed better than we ever expected. (I sent the student who made it back to make sure that they didn't accidentally compare G4 with G4.

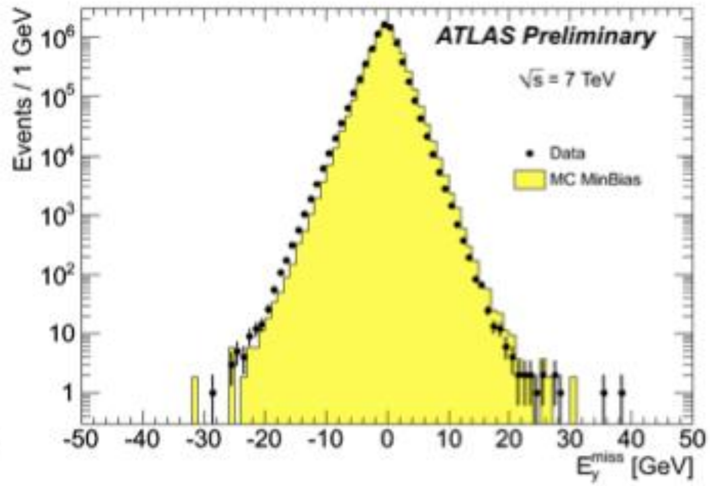






Figures from CMS

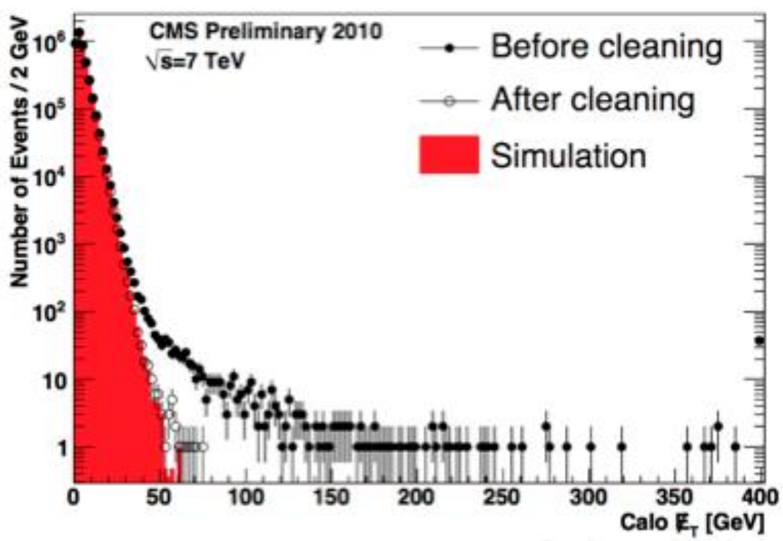


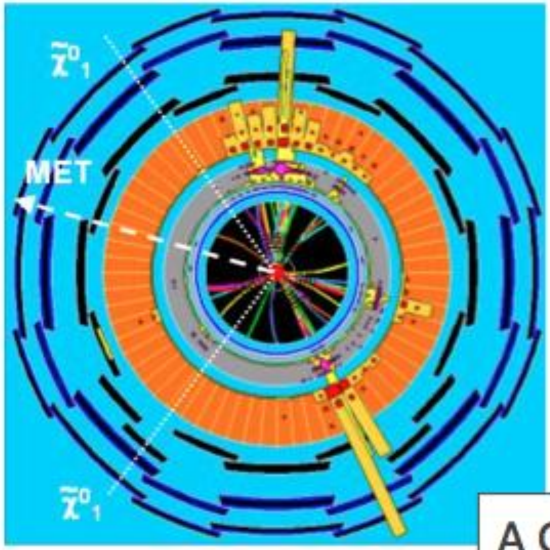


This is one of the hardest things to get right. MET incorporates everything measured in the detector and attempts to identify non-interacting particles, such as neutrinos or dark matter.

Agreement is astounding.

You can even see that the ATLAS detector is not quite centered – in both data and MC.

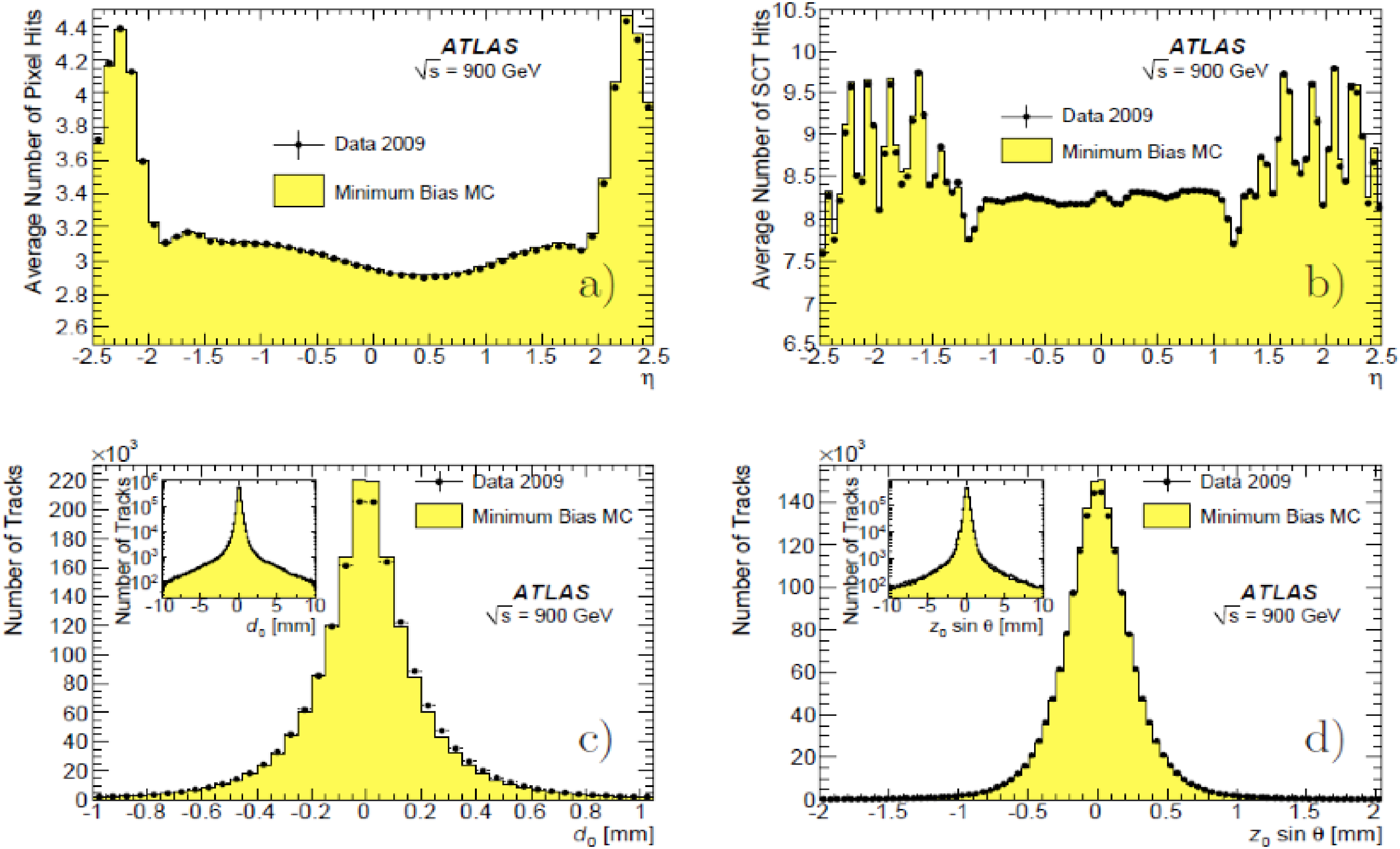




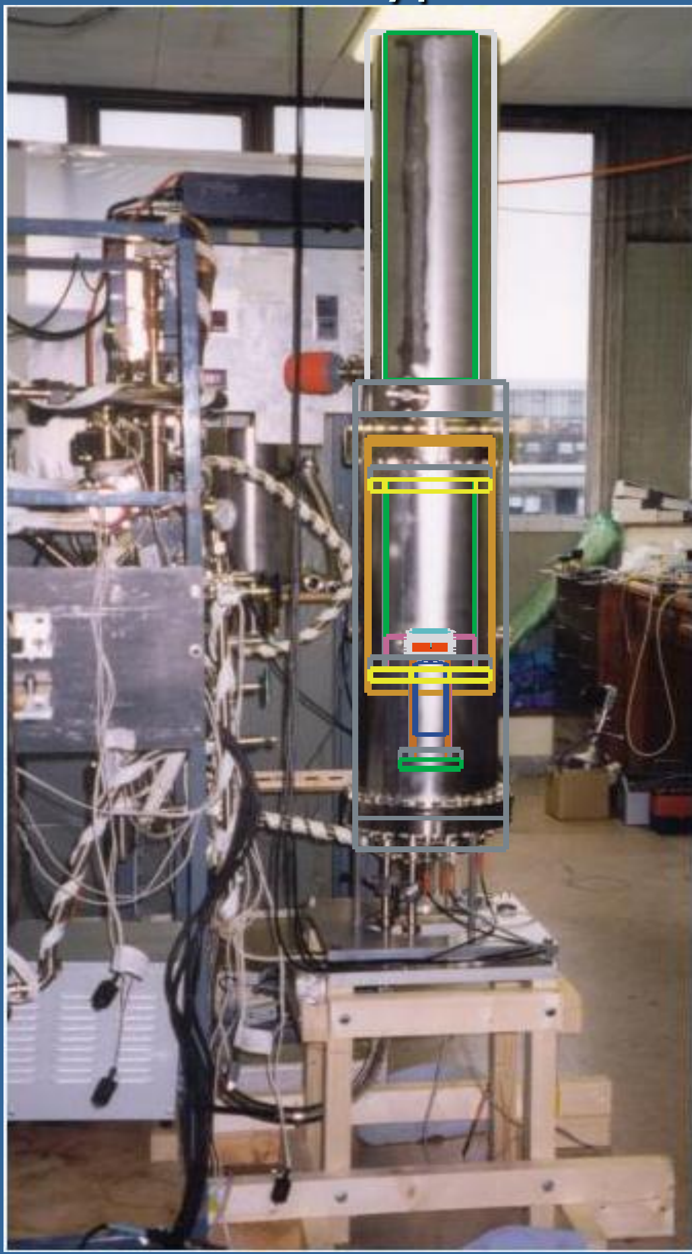
A GEANT4 event.

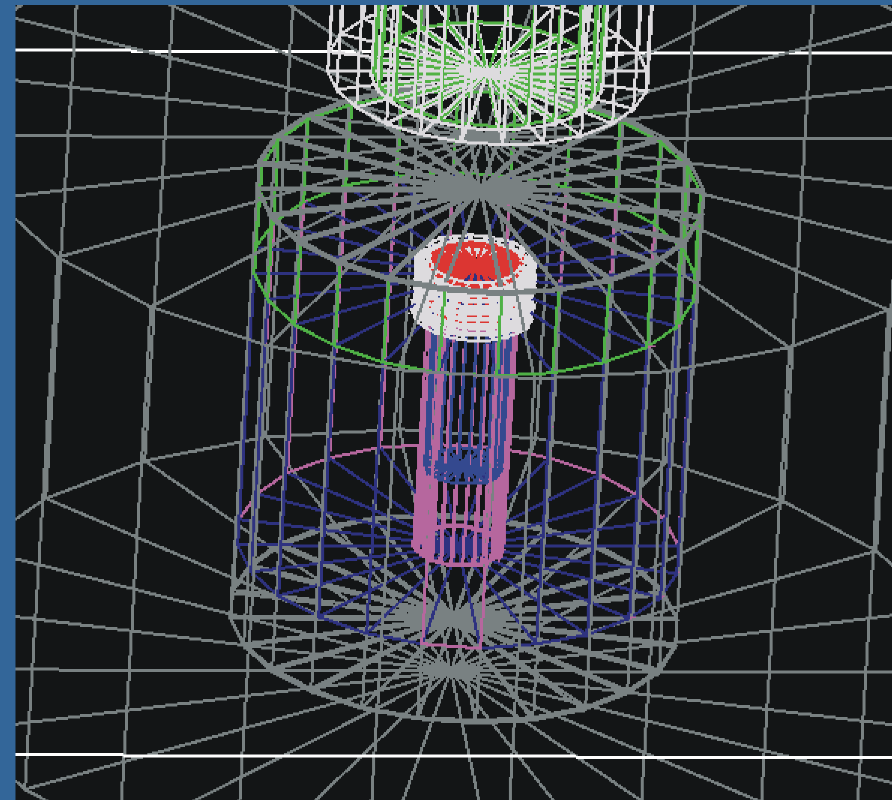
Both ATLAS and CMS plots are made from a tiny piece of the very earliest data.

Data and simulation agreements

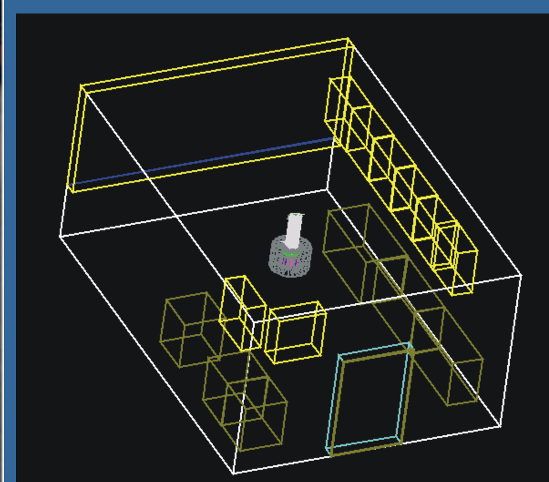


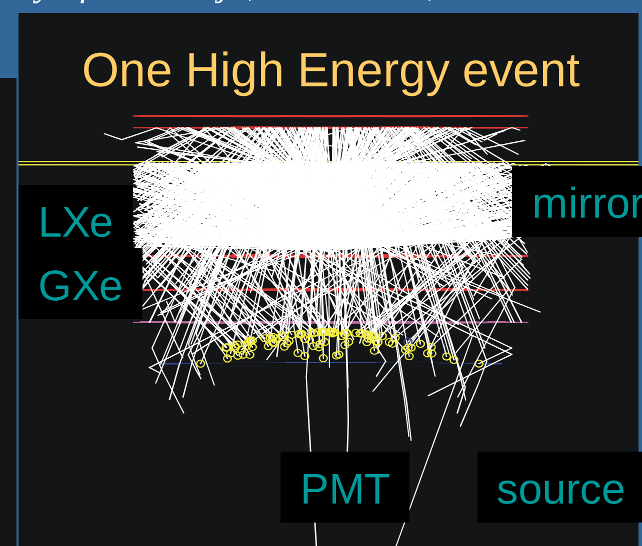
Boulby Mine dark matter search
Prototype Simulation





Courtesy of H. Araujo, A. Howard, IC London





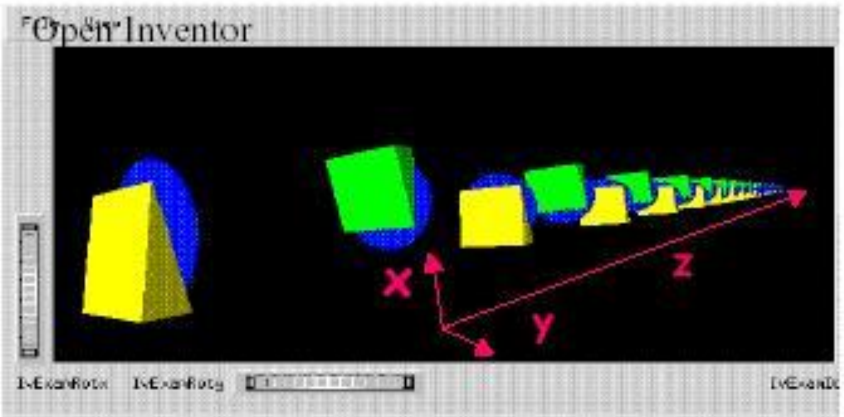
Geant4 for beam transportation

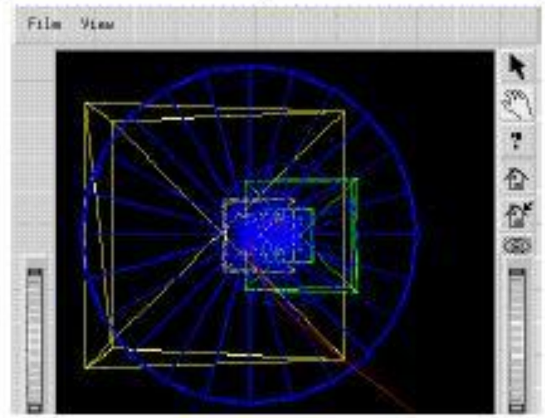
Example: Helical Channel

Published in proc. of PAC 2001 (Fermilab-Conf-01-182-T)

72 m long solenoidal + dipole field with wedge absorbers and thin cavities

$$B_{x,y} = B_T \cos,\sin\left(\frac{2p}{L} z\right) \qquad B_z = B_0$$





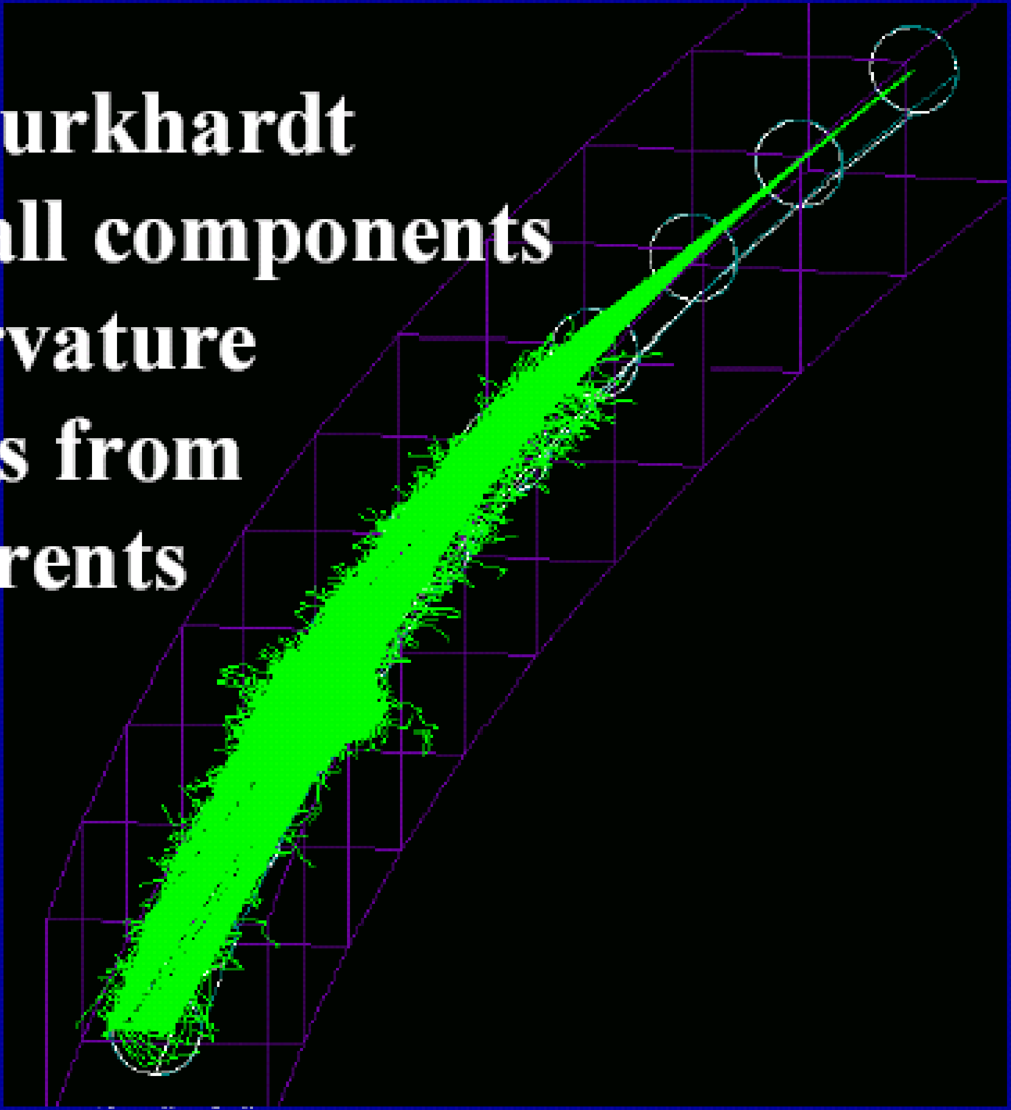
Other simulations:

- Alternate Solenoid Channel (sFoFo), published in proceedings of PAC2001 and Feasibility Study II for a Neutrino Factory at BNL (2001)
- Bent Solenoid Channel, presented at Emittance Exchange Workshop, BNL 2000
- Low Frequency r.f. Cooling Channel, presented at International Cooling Experiment Workship, CERN 2001
- Cooling Experiment (MICE) Simulation (in progress)

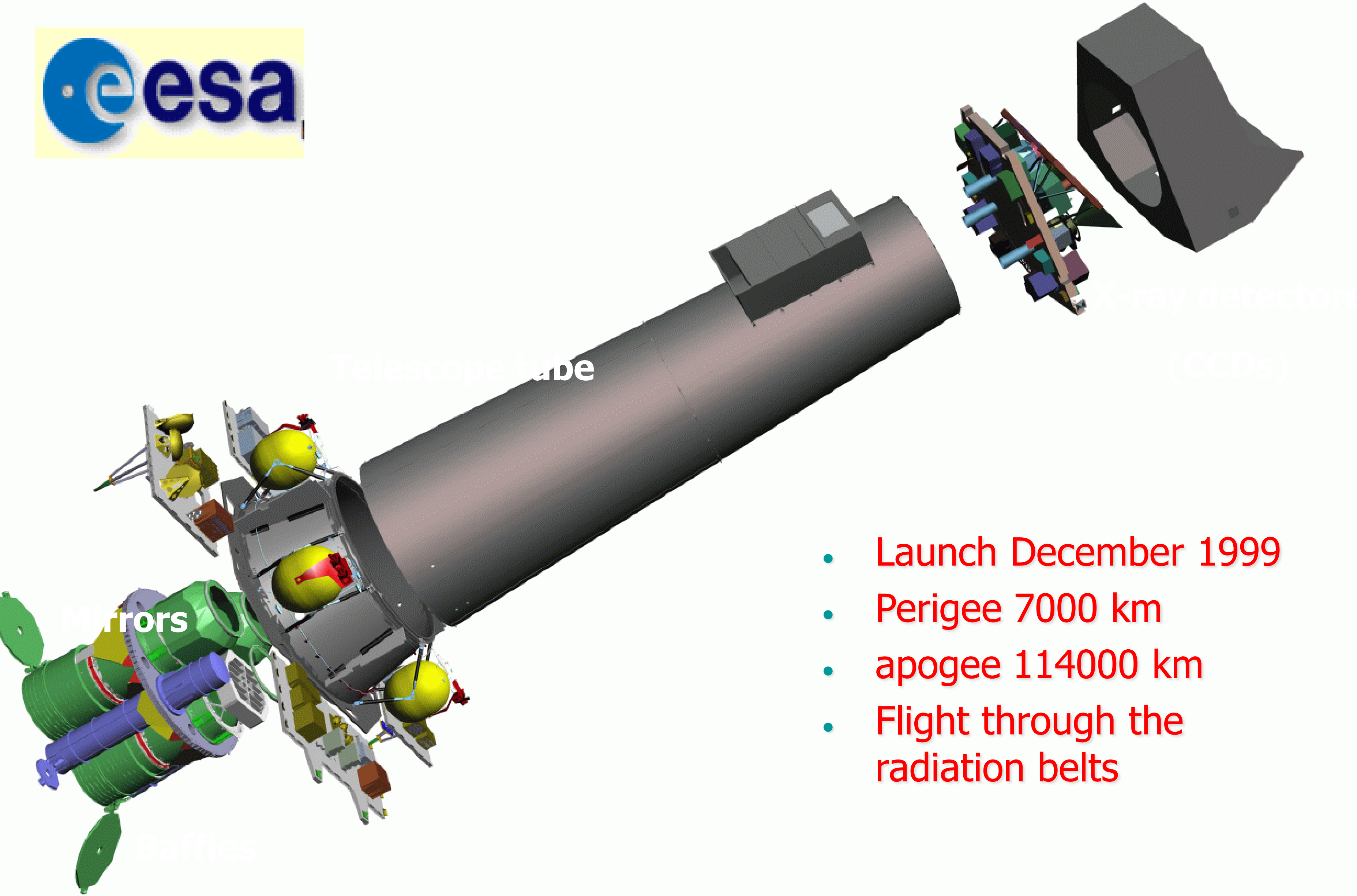
G4 Users Meeting, February 21st, 2002 *V. Daniel Elvira, Fermilab*

Synchrotron Radiation

Generator of H. Burkhardt
Implemented for all components
Based on local curvature
Individual photons from
individual parents



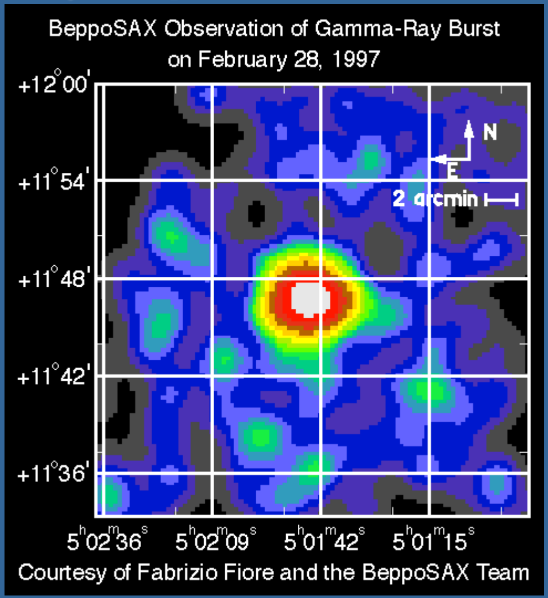
Courtesy of G.Blair (CERN)

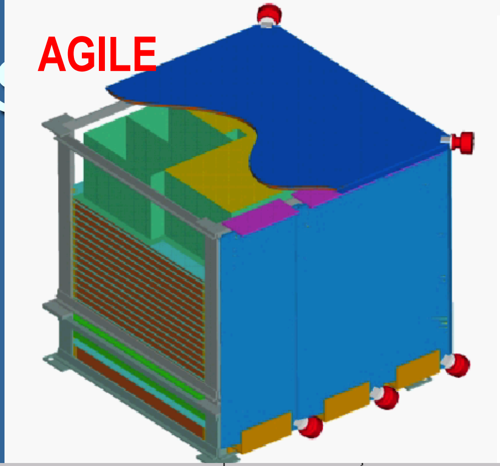


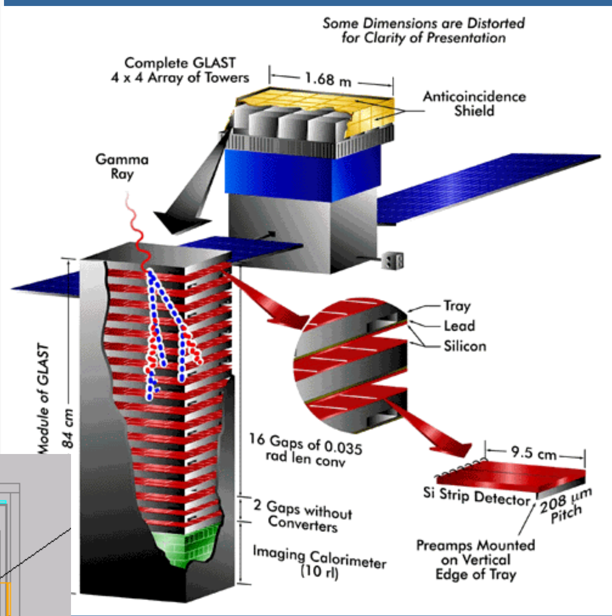
- Launch December 1999
- Perigee 7000 km
- apogee 114000 km
- Flight through the radiation belts

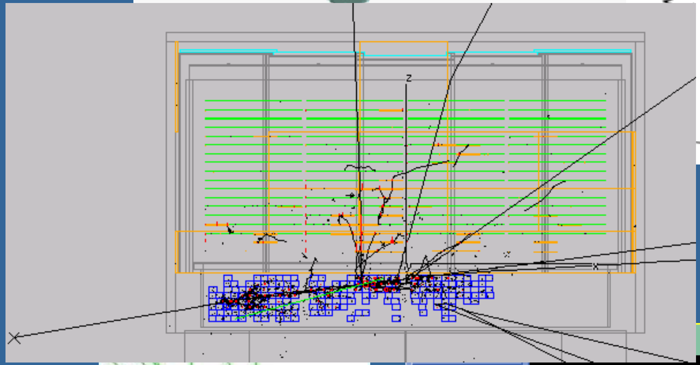
γ astrophys

γ-ray bursts

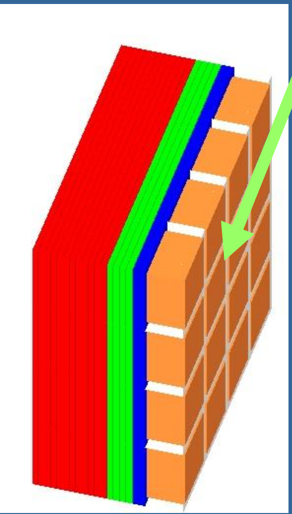






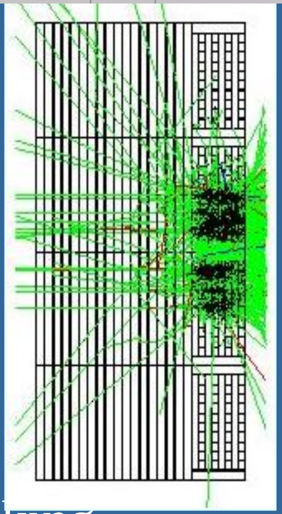


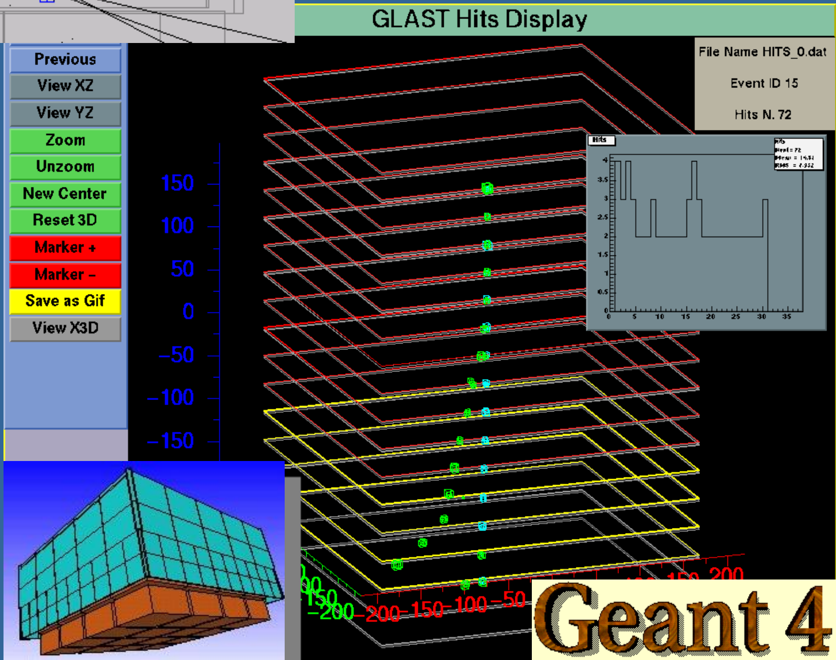
GLAST

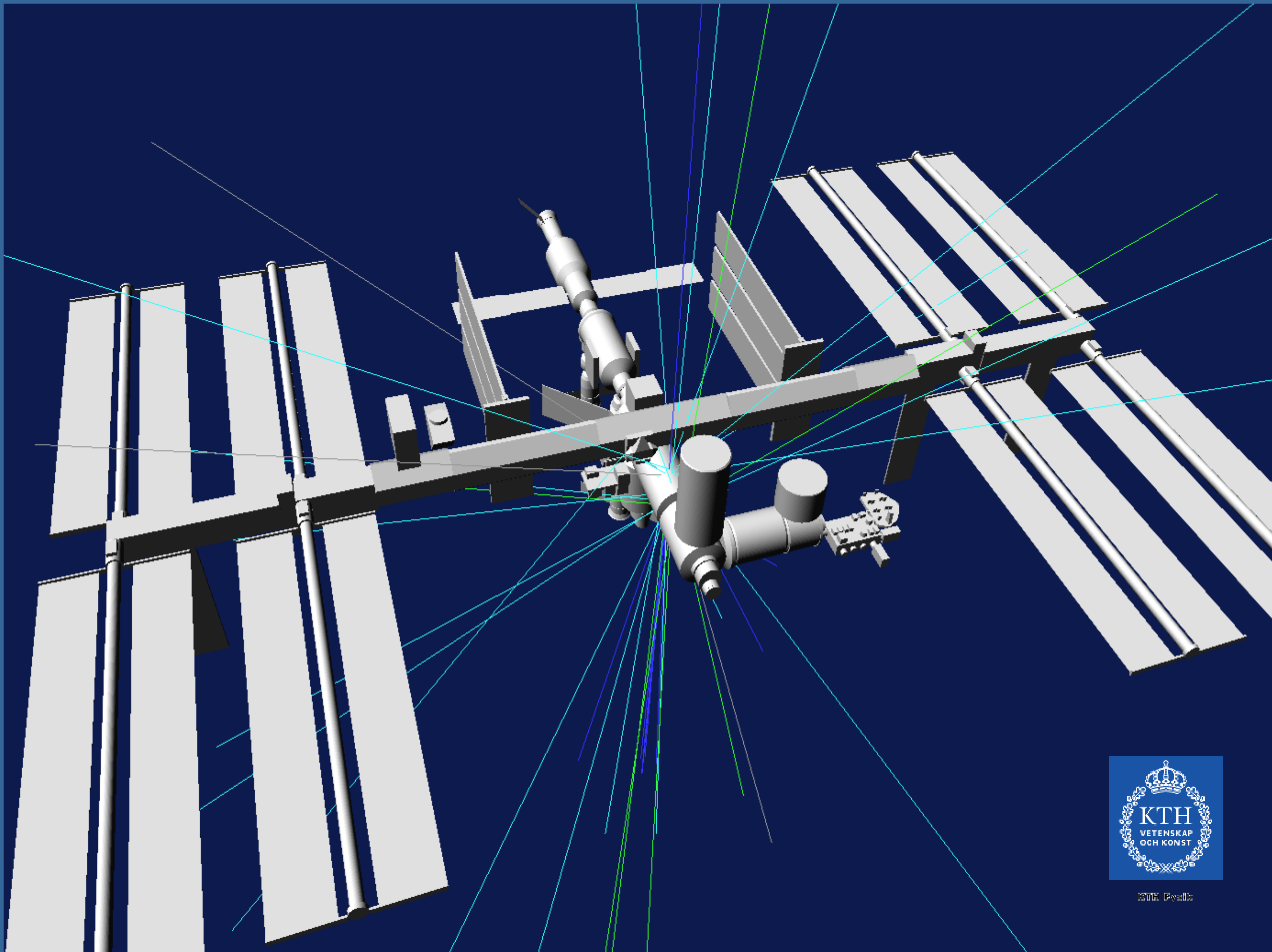


Typical telescope:
Tracker
Calorimeter
Anticoincidence

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





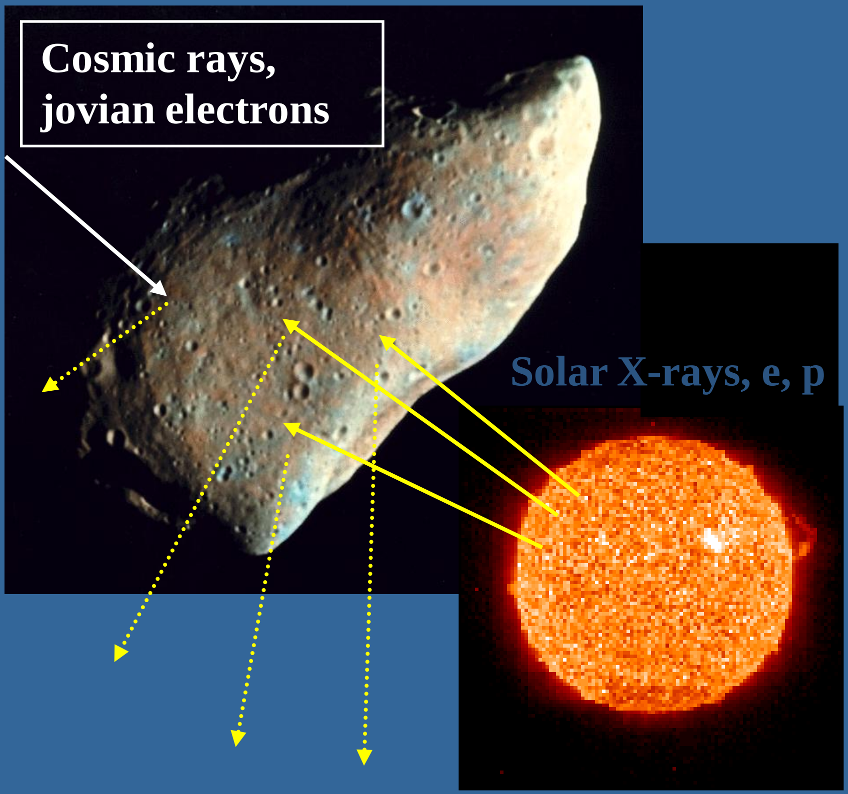


Courtesy T. Ersmark, KTH Stockholm

Geant4 in space science

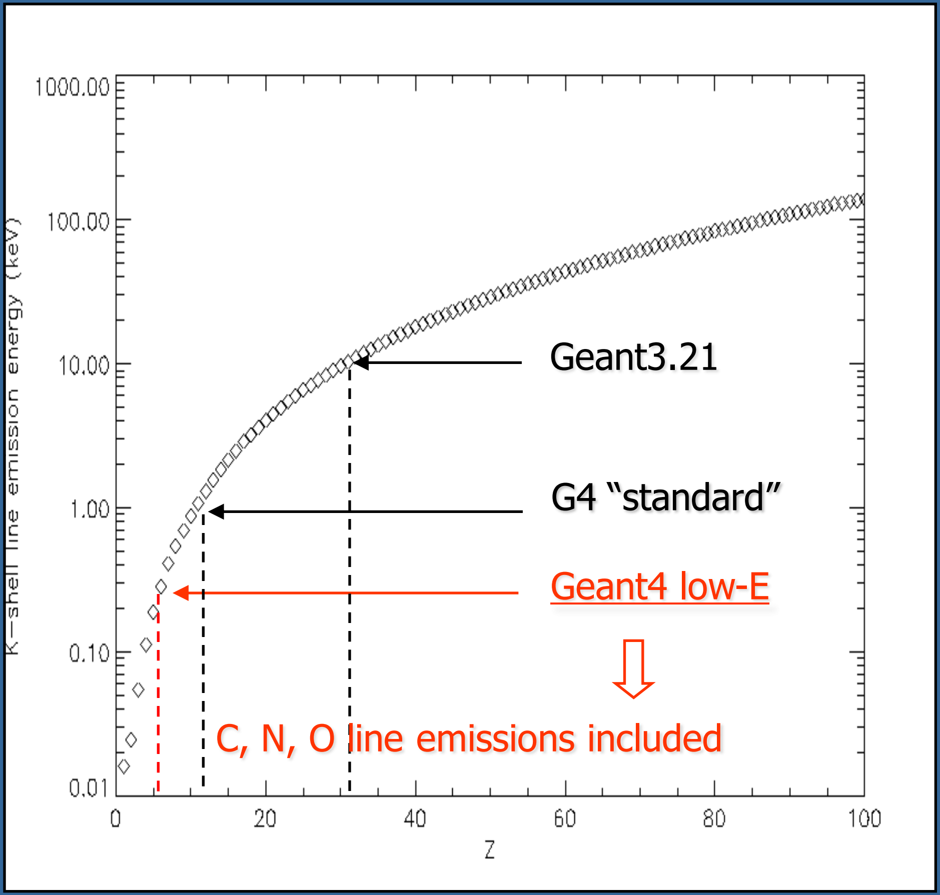
ESA Space Environment & Effects Analysis Section

X-Ray Surveys of Asteroids and Moons

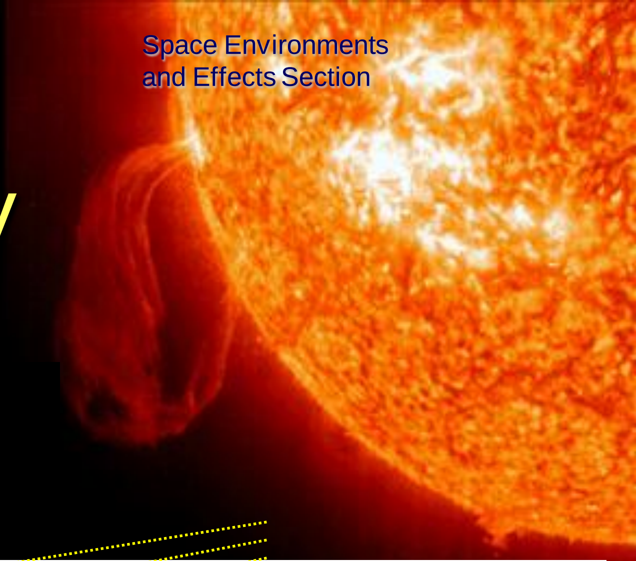


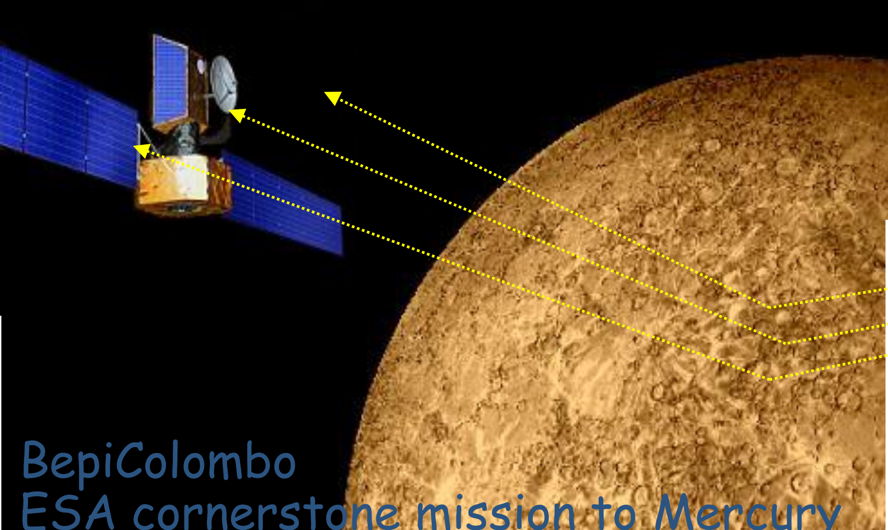
Courtesy SOHO EIT

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

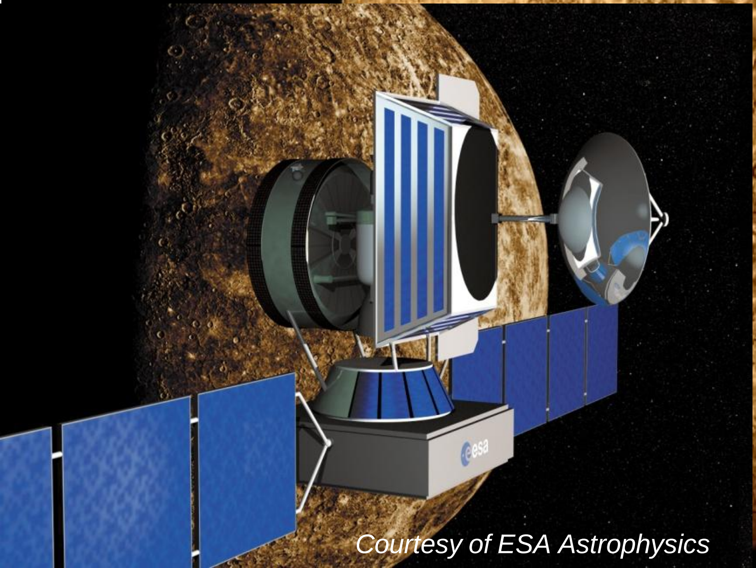


Bepi Colombo: X-Ray Mineralogical Survey of Mercury

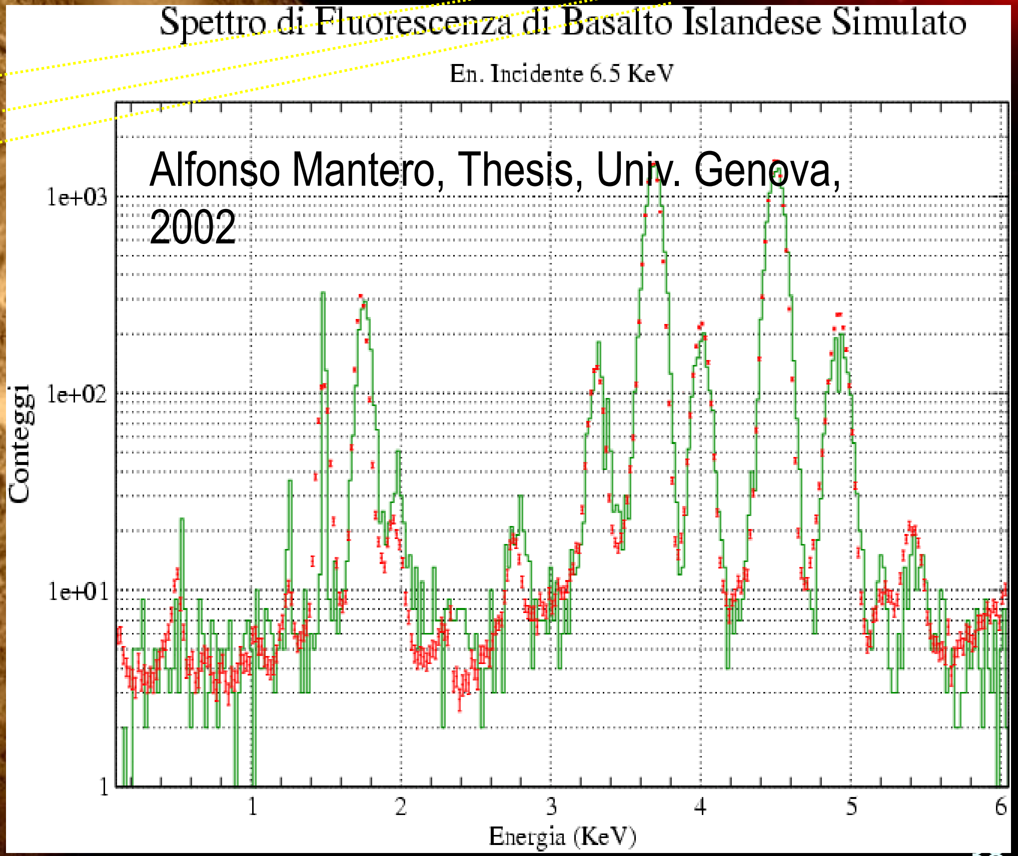




BepiColombo
ESA cornerstone mission to Mercury



Courtesy of ESA Astrophysics



PlanetoCosmics

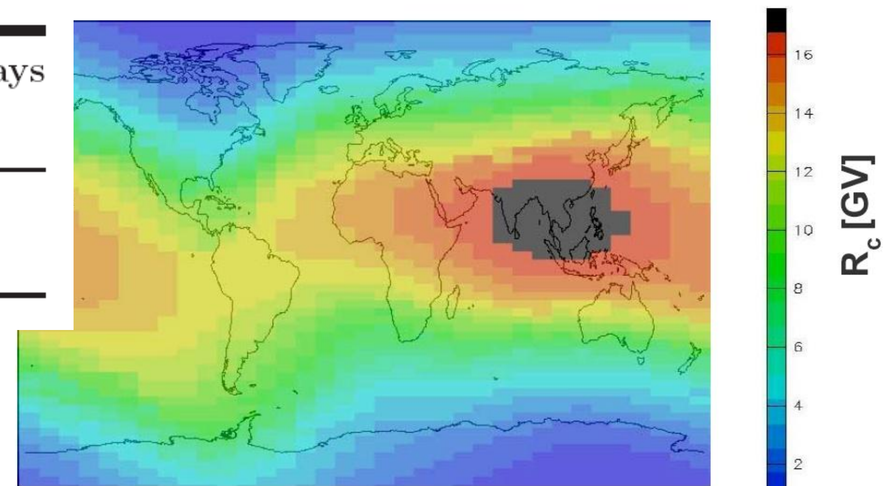
Geant4 simulation of Cosmic Rays in planetary Atmo-/Magneto- spheres

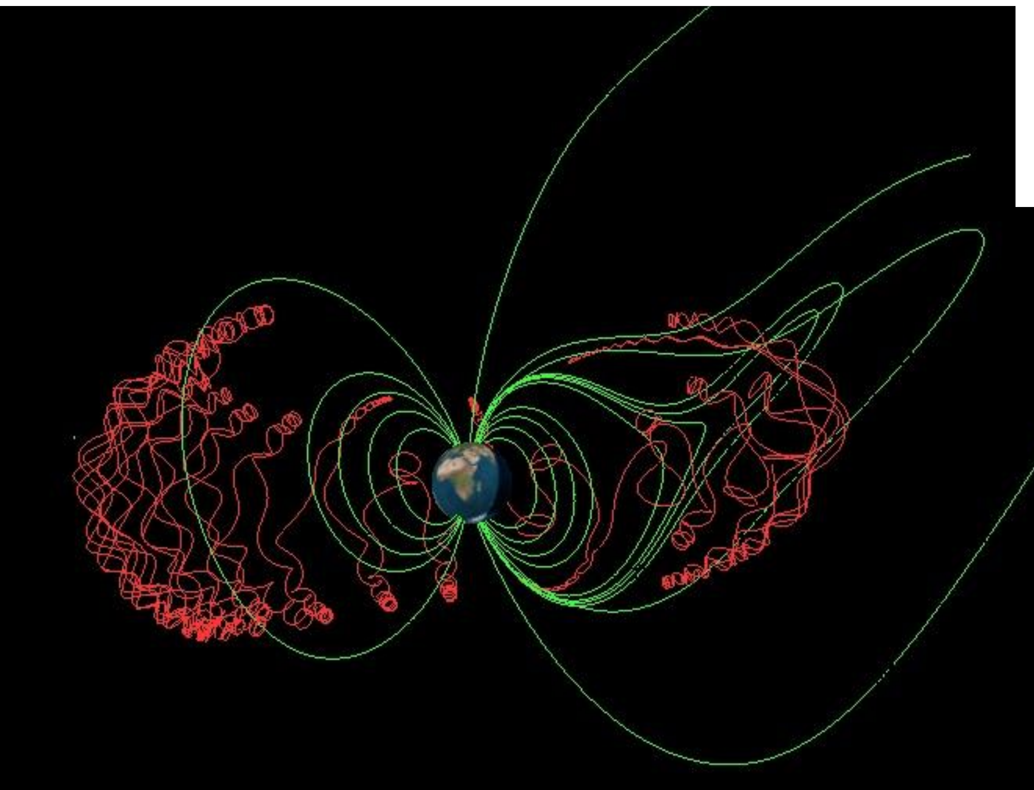
28th International Cosmic Ray Conference — 4277

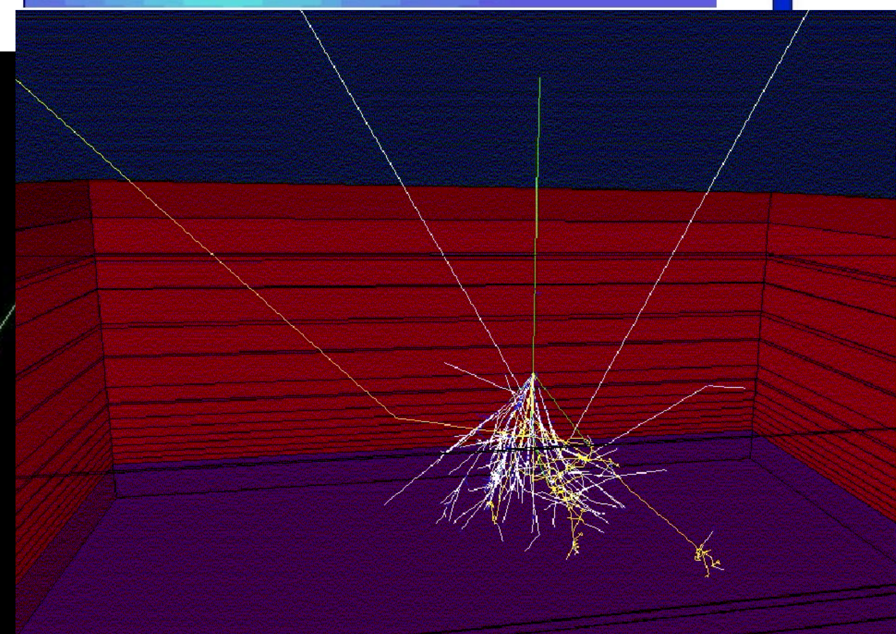
Geant4 Simulation of the Propagation of Cosmic Rays through the Earth's Atmosphere

L. Desorgher, E. O. Flückiger, M. R. Moser, and R. Bütikofer
Physikalisches Institut, University of Bern, CH-3012 Bern, Switzerland

Cutoff Rigidities vs position

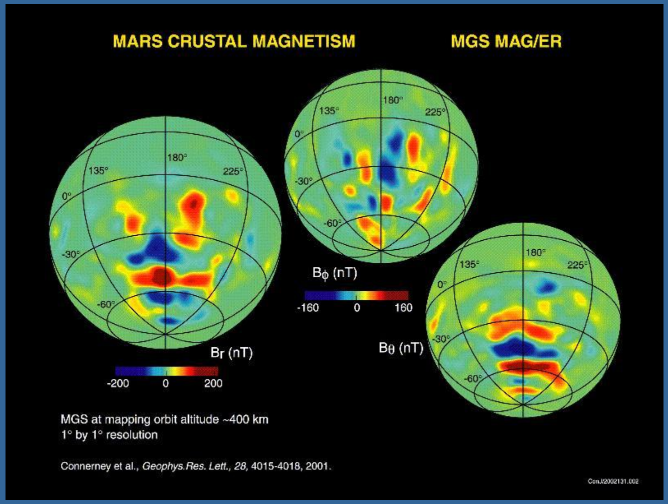


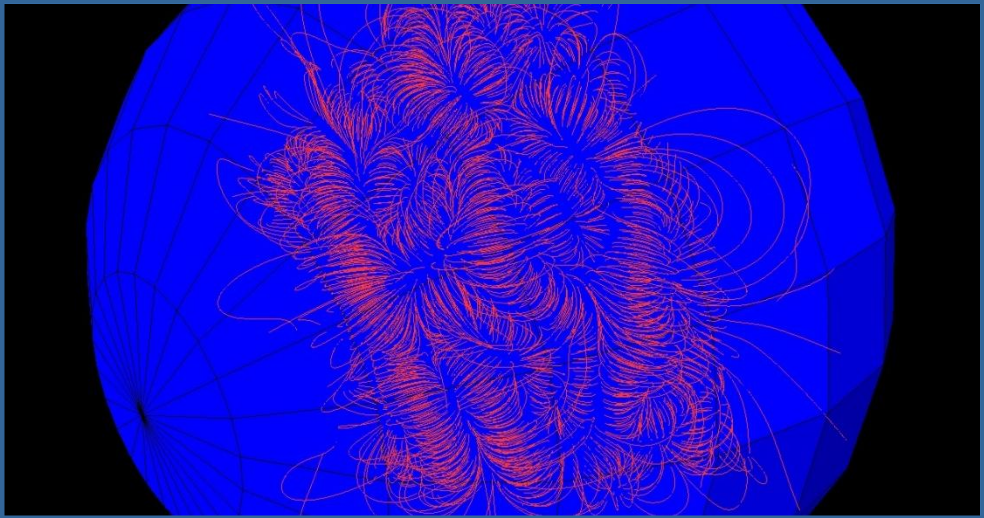




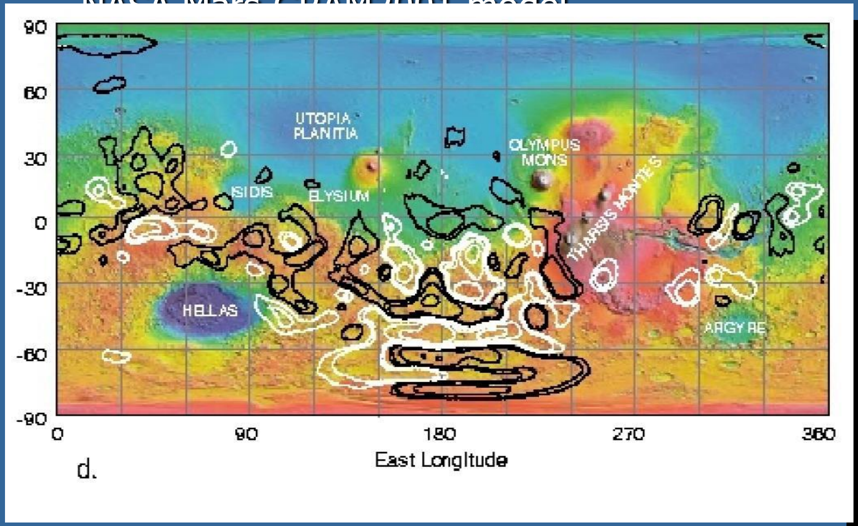
PlanetoCosmics

Mars field and atmosphere

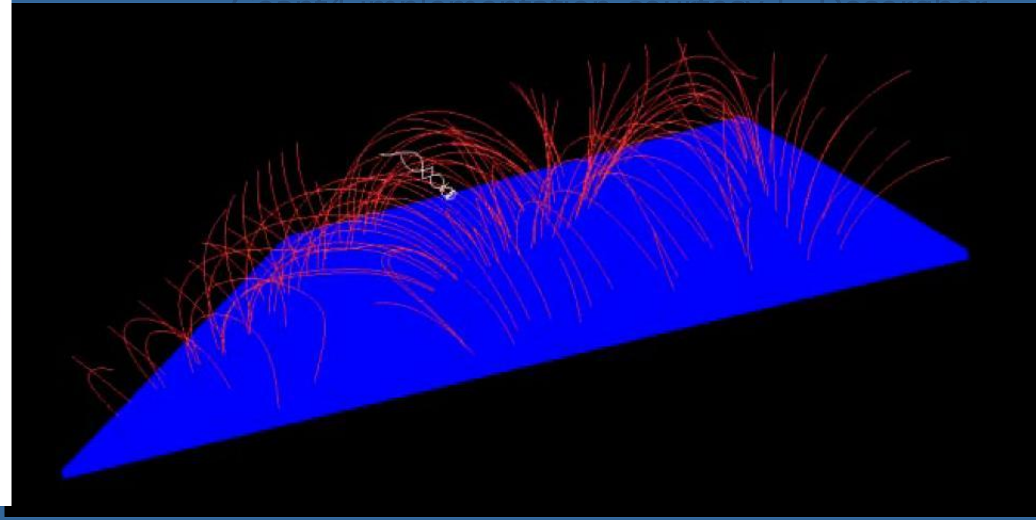




NASA Mars-GRAM2001 model



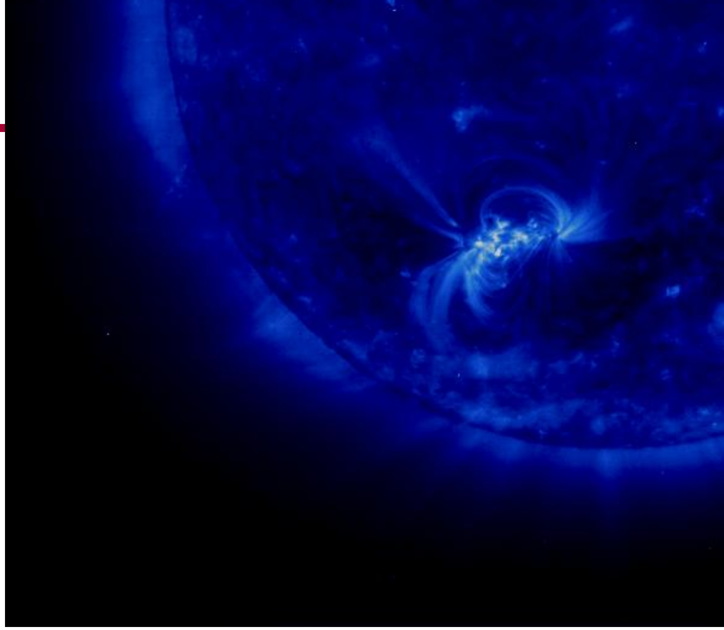
Geant4 implementation courtesy L. Desorgher

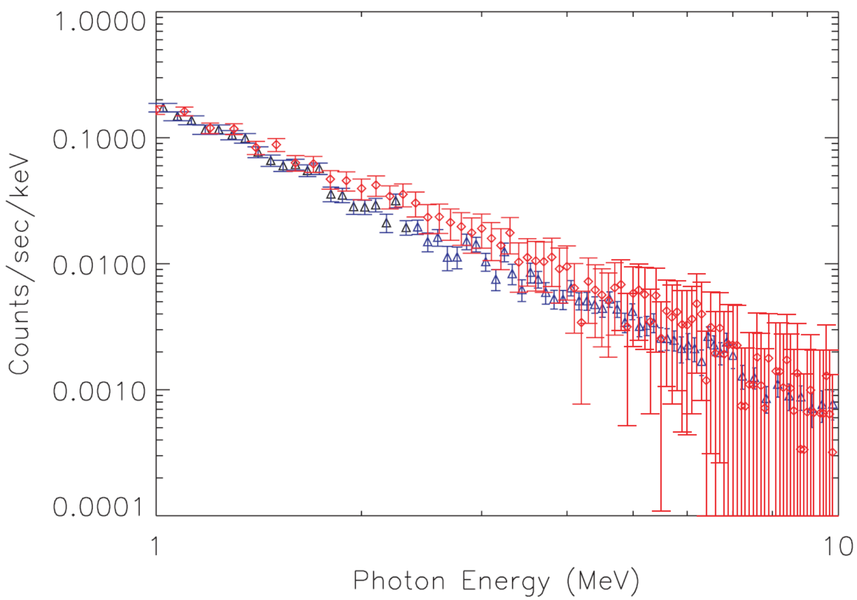


Solar event gamma-rays

- Electron Bremsstrahlung – induced gammas in solar flares
- Compton back-scattering

  ✐ observable gamma-ray spectrum much softer than predicted by simple analytic calculations





Effects of Compton scattering on the Gamma Ray Spectra of Solar flares

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junichi.kotoku@nao.ac.jp
Kazuo MAKISHIMA[1] and Yukari MATSUMOTO[2]
Department of Physics, University of Tokyo, Bunkyo-ku, Tokyo, 113-0022
and
Mitsuhiro KOHAMA, Yukikatsu TERADA and Toru TAMAGAWA
RIKEN (Institute of Physical and Chemical research), Wako-shi, Saitama
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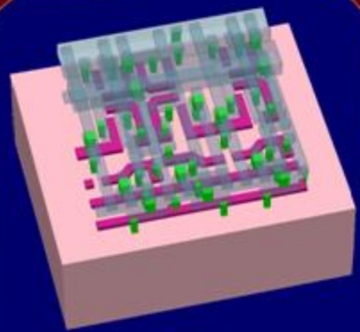
(Received ; accepted)

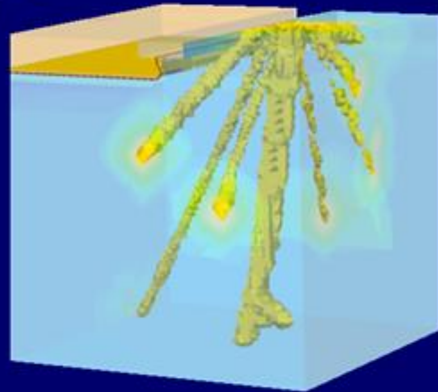
Abstract

Using fully relativistic GEANT4 simulation tool kit, the transport of energetic electrons generated in solar flares was Monte-Carlo simulated, and resultant bremsstrahlung gamma-ray spectra were calculated. The solar atmosphere was ap-

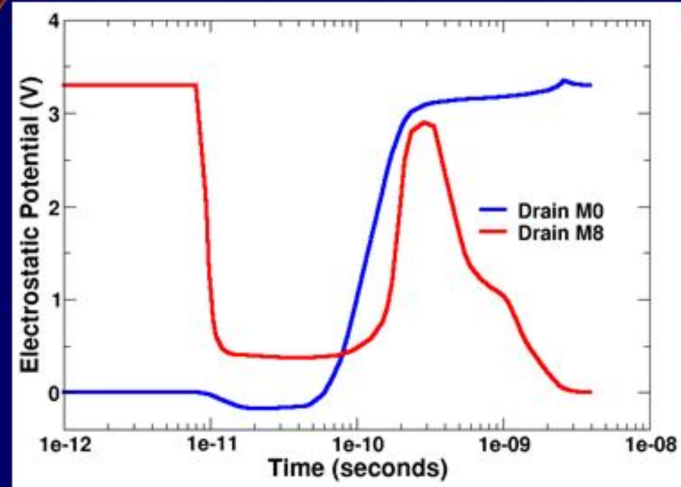
RADSAFE on SEE in SRAMs



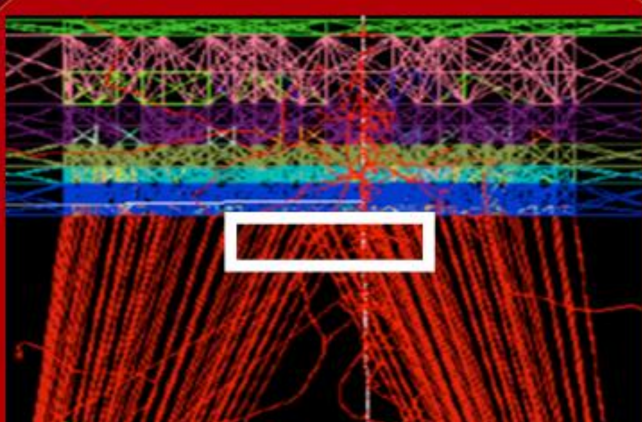
TCAD Cell Structure: SRAM Cell



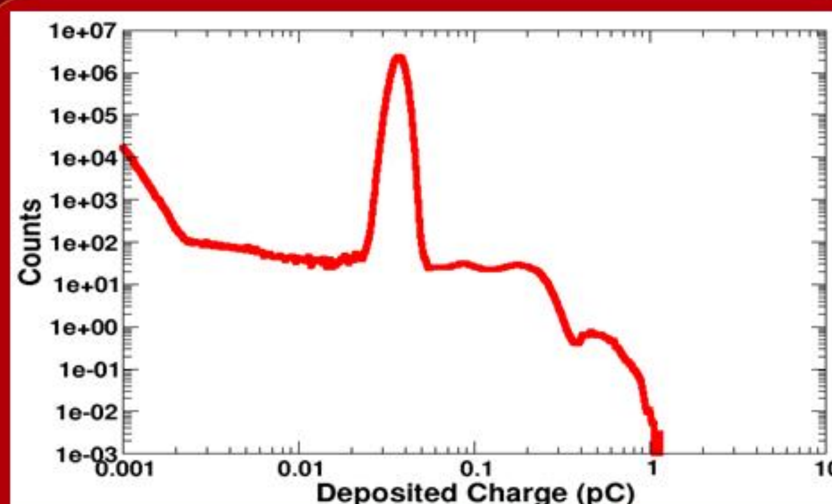
Single Charge Deposition in TCAD: Ne+W Event



SRAM Cell Upset

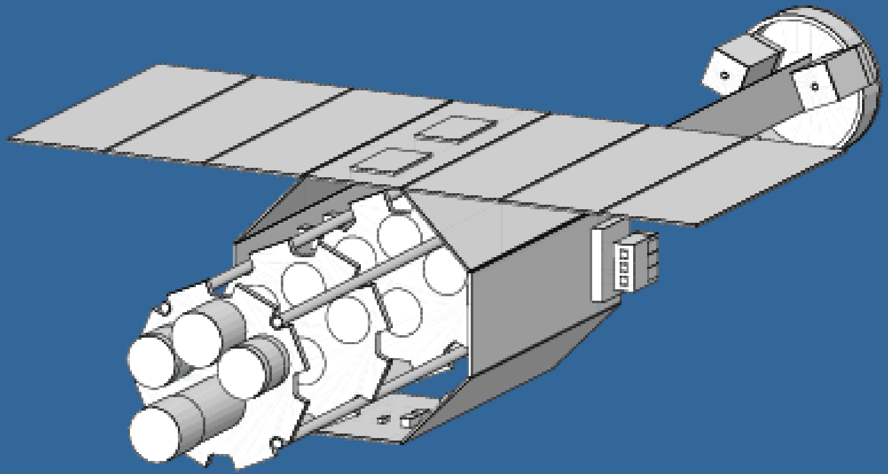


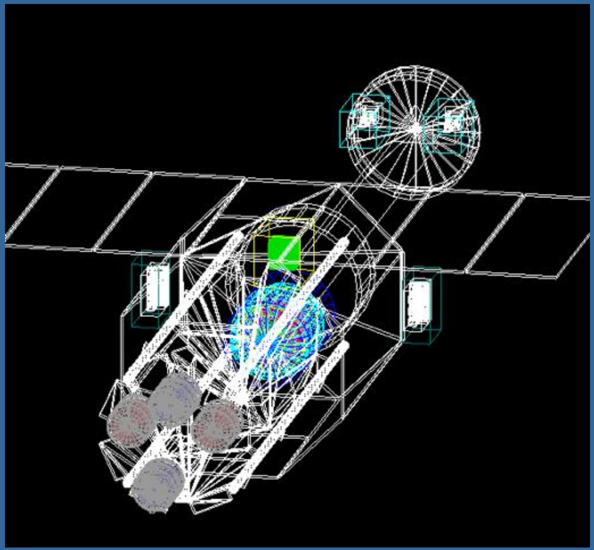
Geant4 Geometry and 523 MeV Neon Event

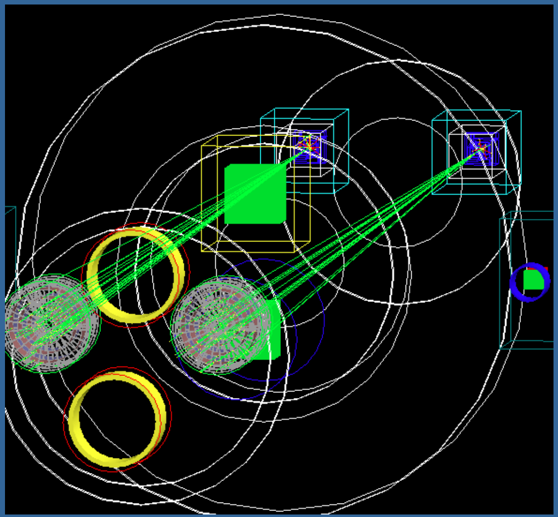


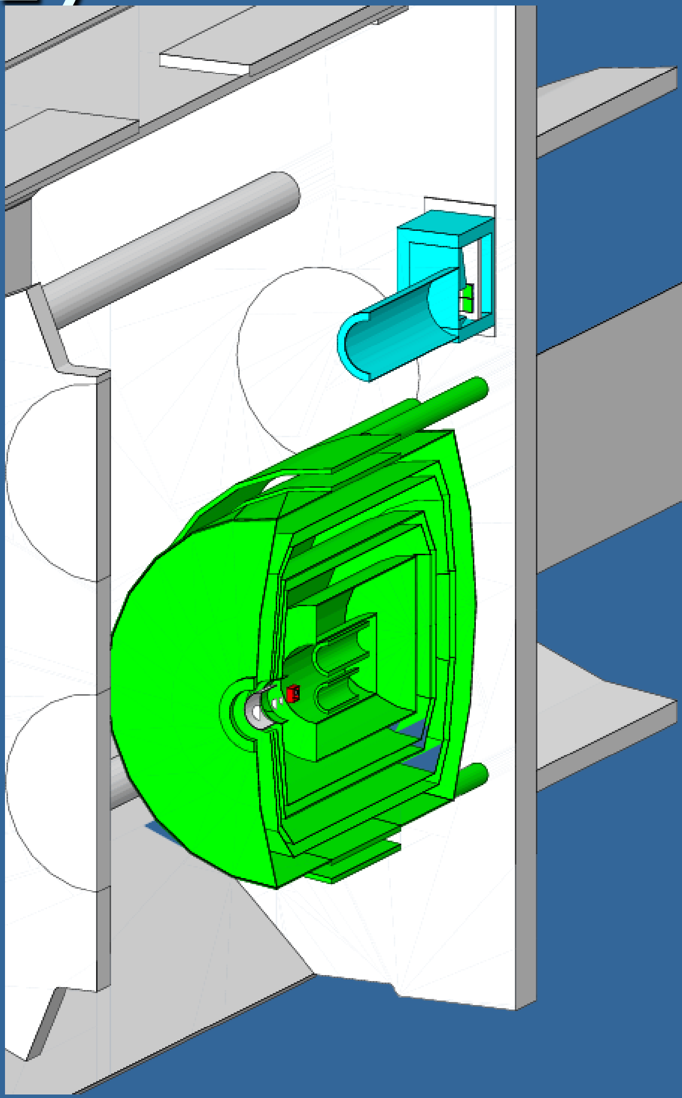
MRED Energy Deposition for 10^8 Events

ASTRO-H (1)





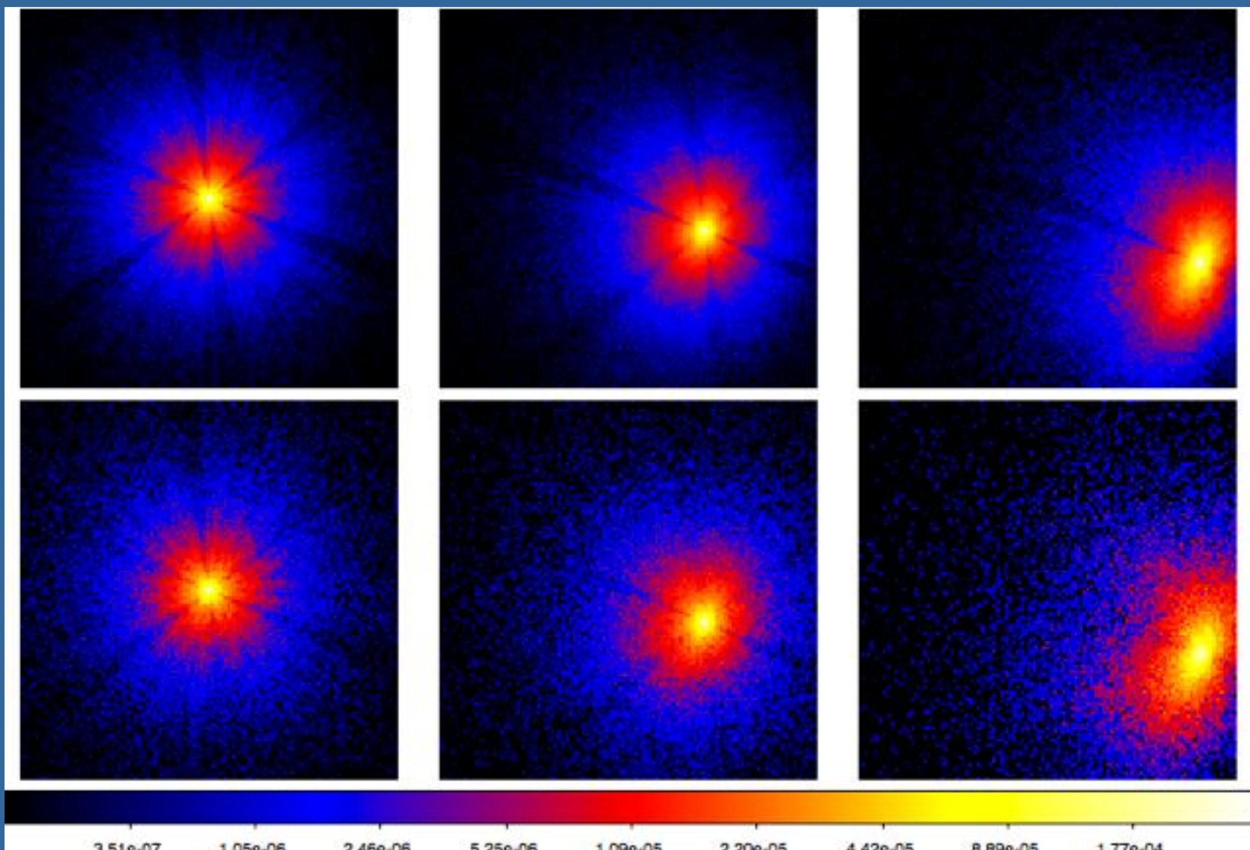




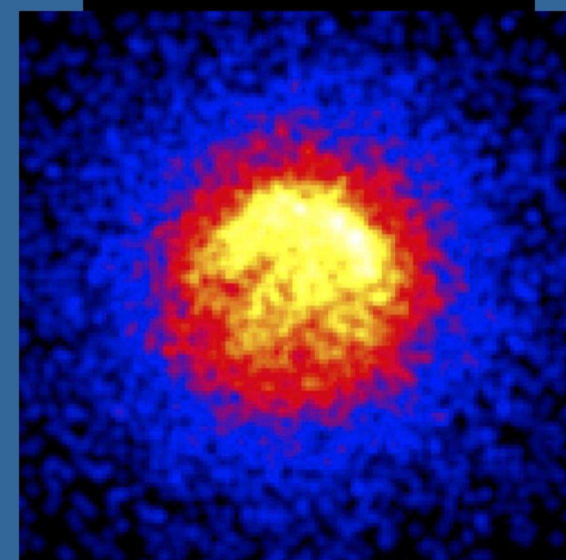
SXI and SXS

ASTRO-H (2)

Point source on HXI
Left; center; right - 0arcmin; 2arcmin; 4arcmin
top; bottom - 10keV; 30keV

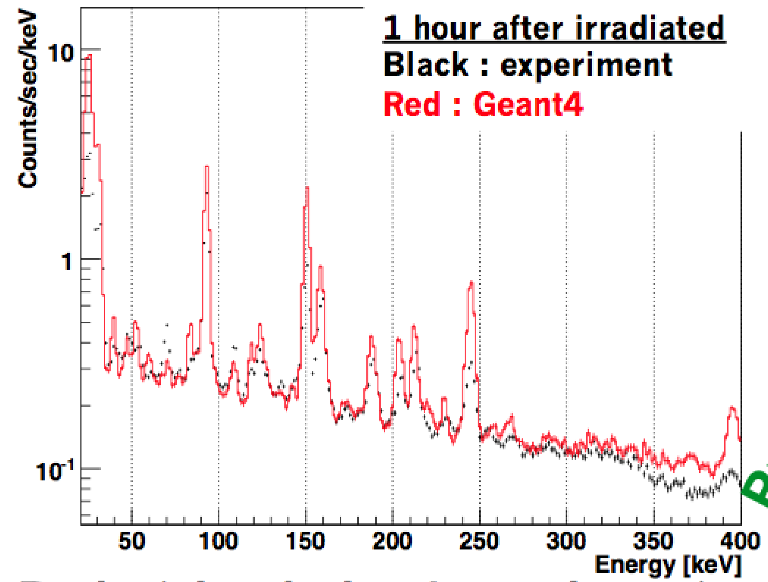


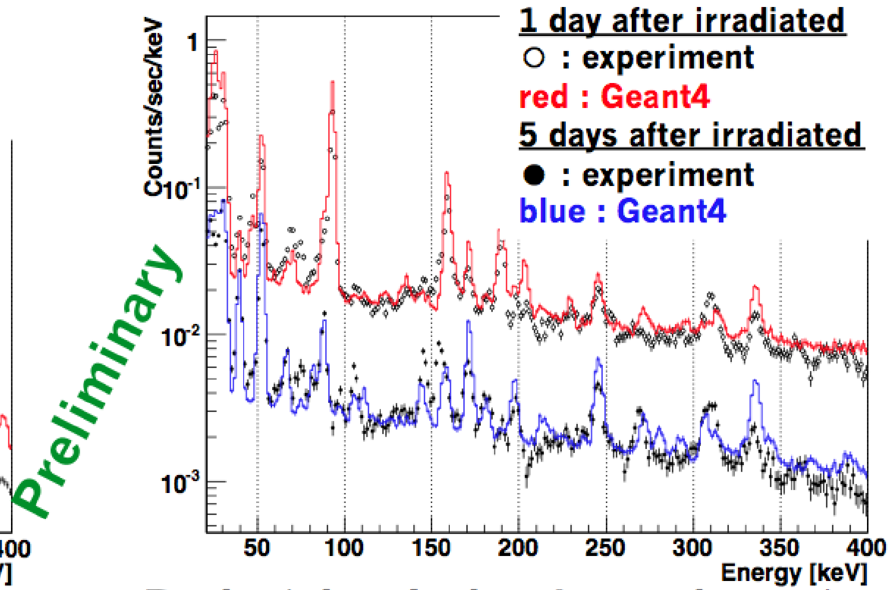
Kepler SNR on HXI
(very preliminary)



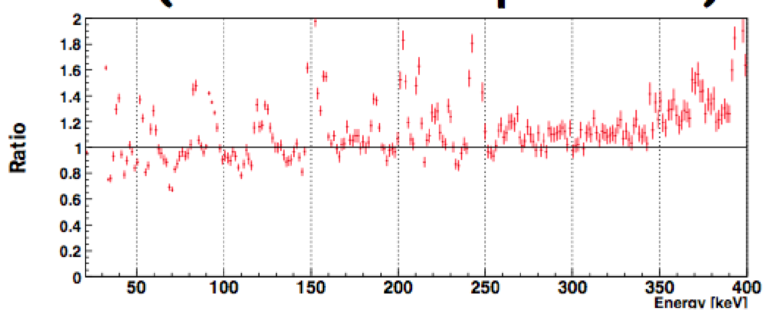
Time evolution of the activation background

Comparison with Geant4

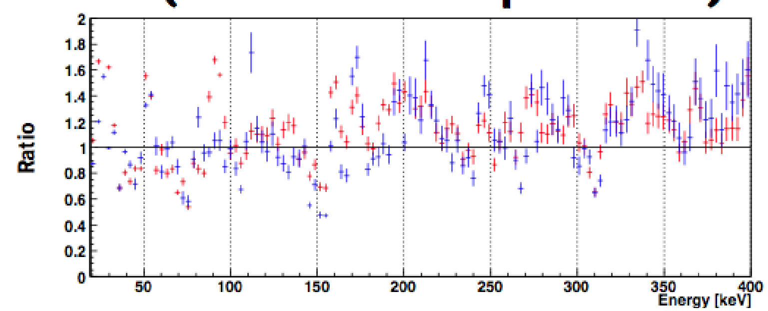




Ratio (simulation/experiment)

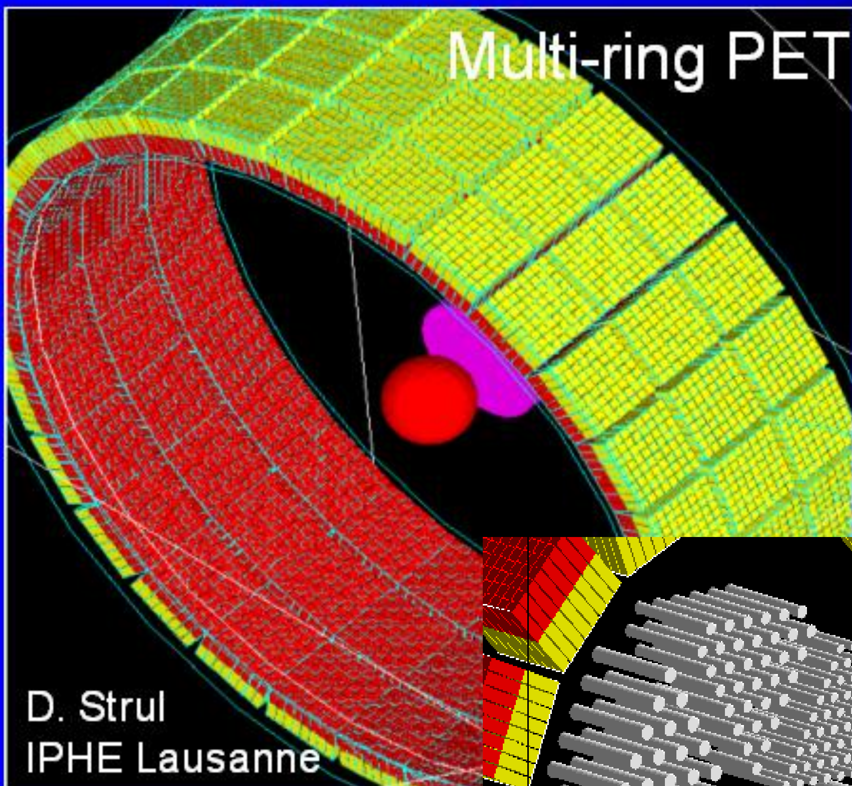


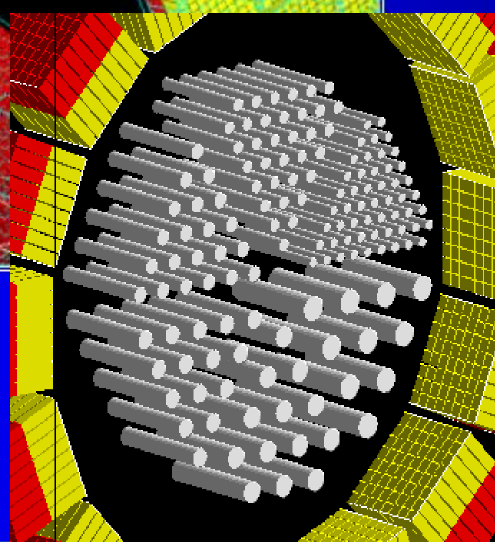
Ratio (simulation/experiment)

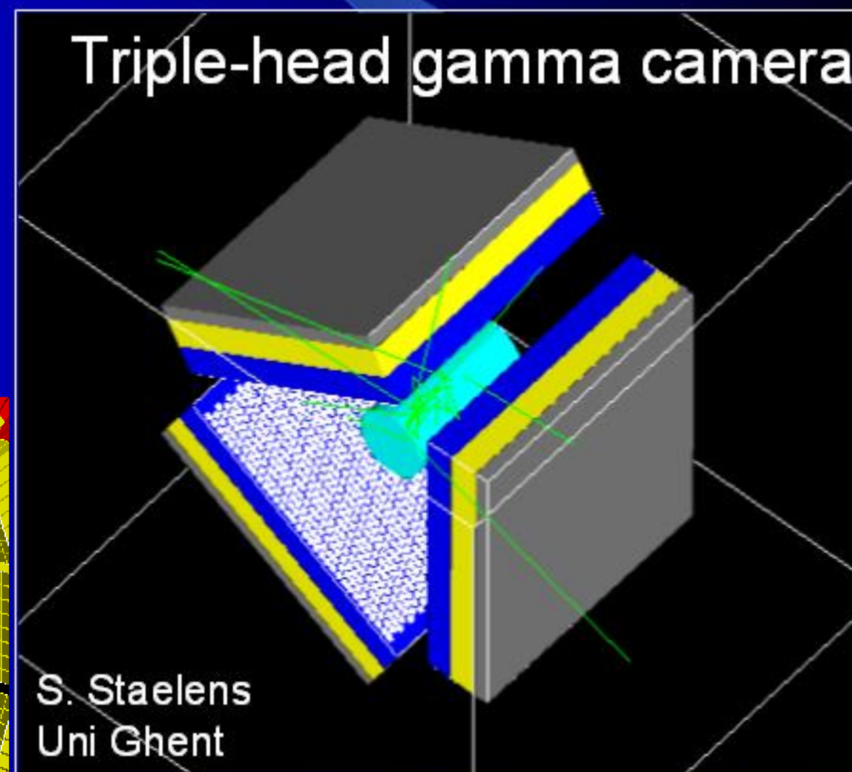


❖ Simulation results agrees with experimental data within a factor of two in terms of the line intensities

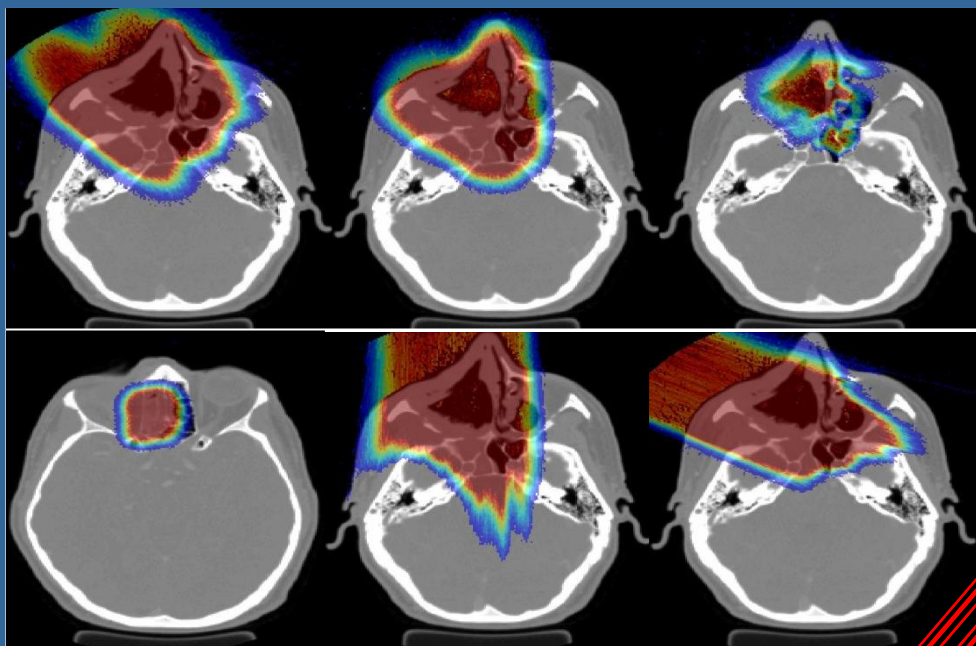
Geometry examples of GATE applications

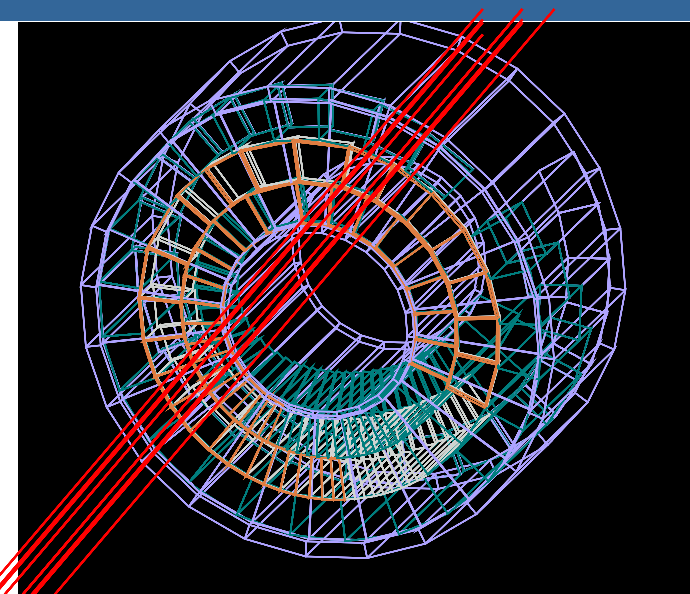


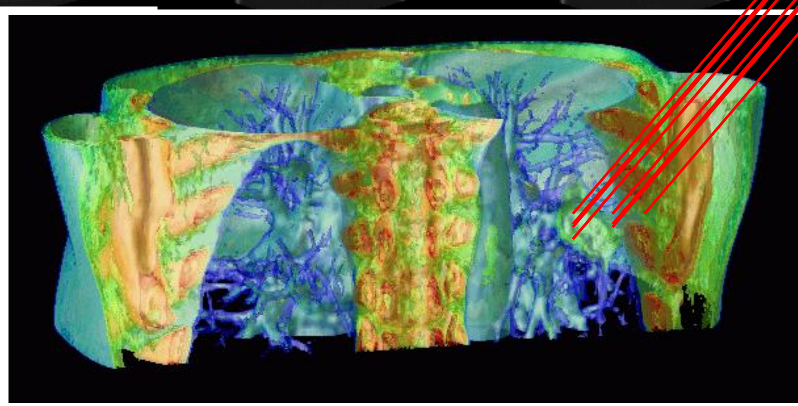




GEANT4 based proton dose calculation in a clinical environment: technical aspects, strategies and challenges





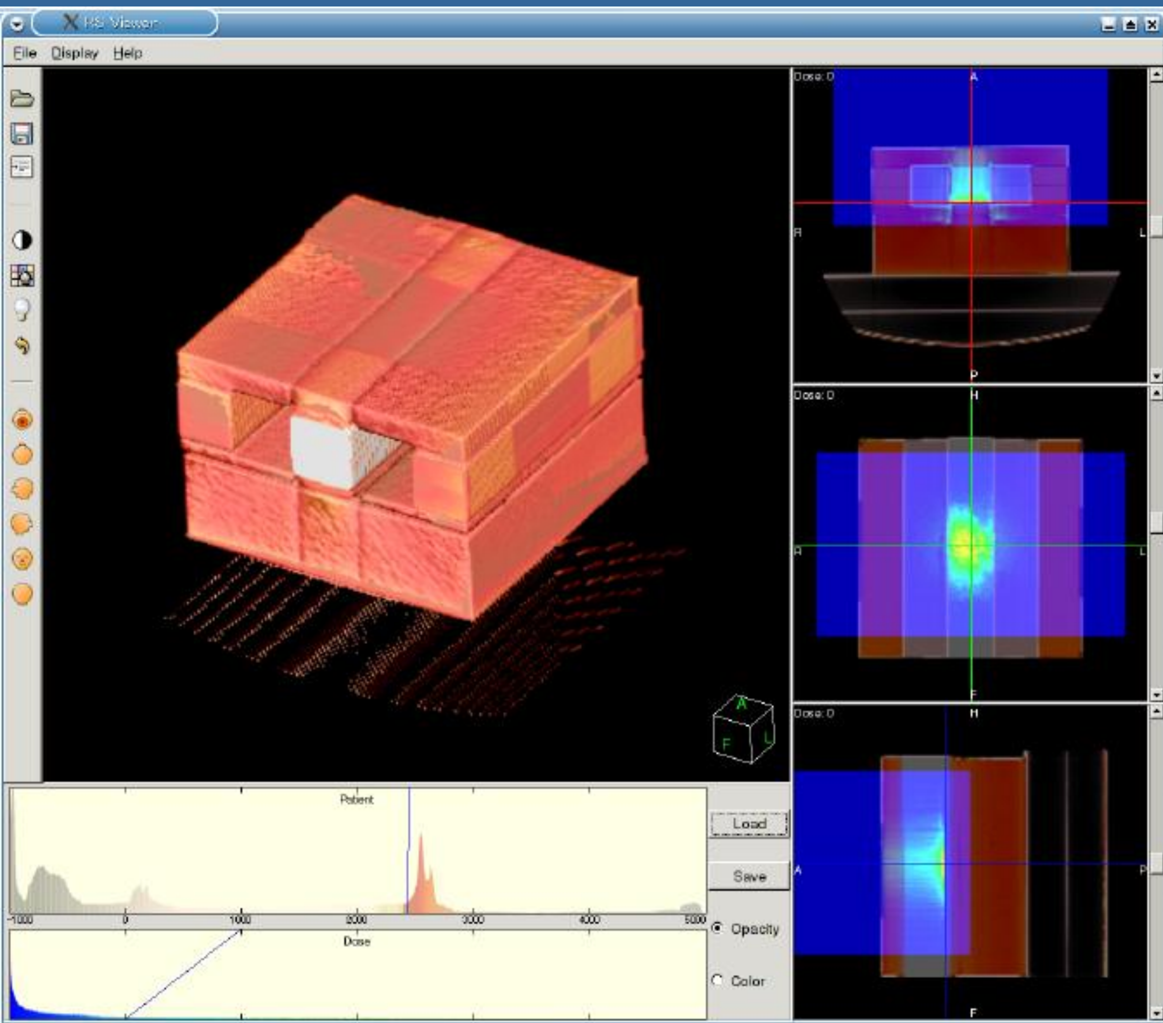


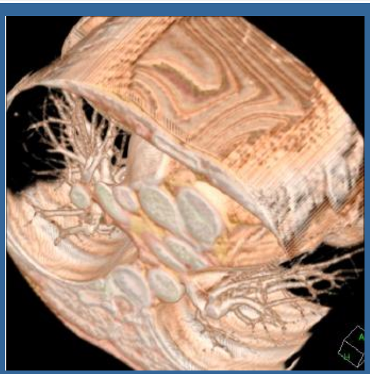
Harald Paganetti

MASSACHUSETTS GENERAL HOSPITAL

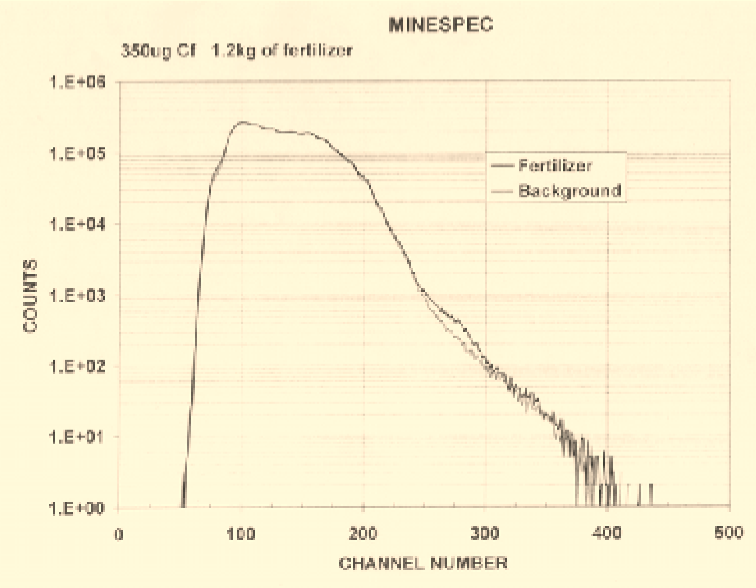
HARVARD MEDICAL SCHOOL

Screen shots of gMocren

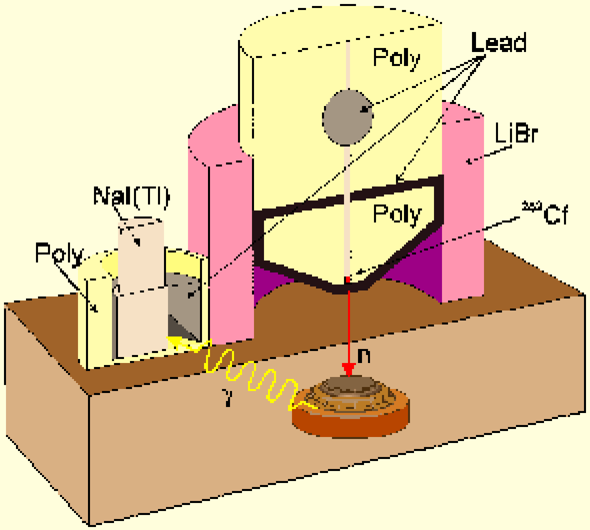




Thermal Neutron Activation



- TNA detects explosive by properties of constituents
  - High concentration of N
  - Does not ID explosive
- Can confirm presence of all surface laid or shallow AT mines in few seconds to 1 minute
- AT up to 20 cm deep and large AP mines in < 5 minutes



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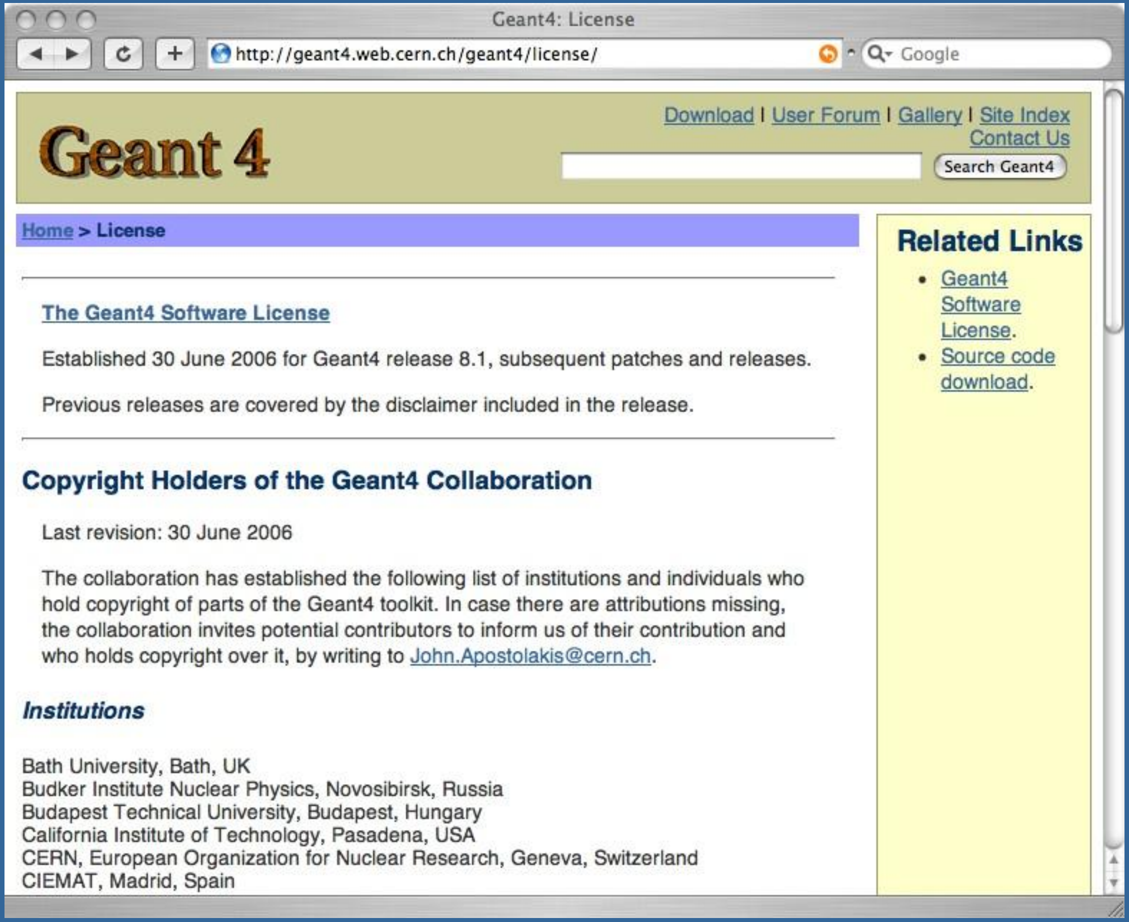
- The license was released along with the latest Geant4 release 8.1.
- Simple enough that you can read and understand it.
- http://cern.ch/geant4/license/



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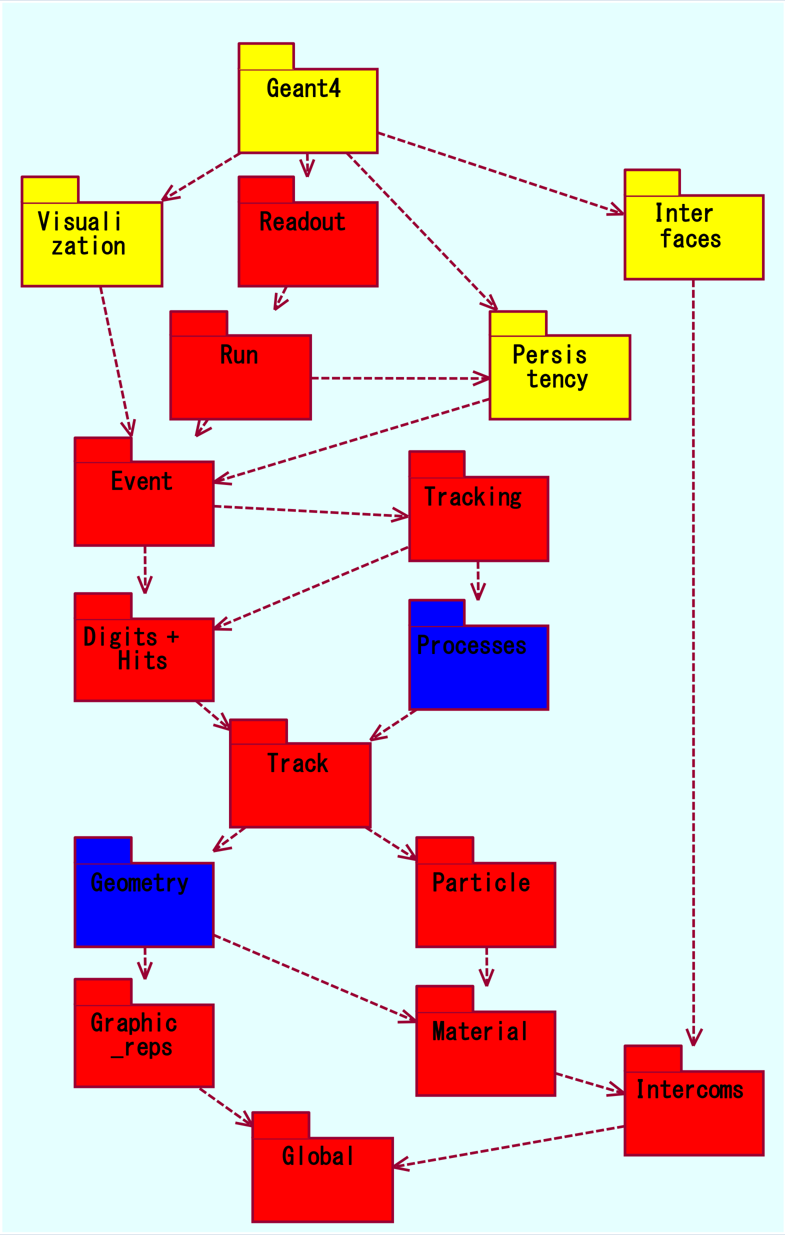
Basic concepts
and kernel structure

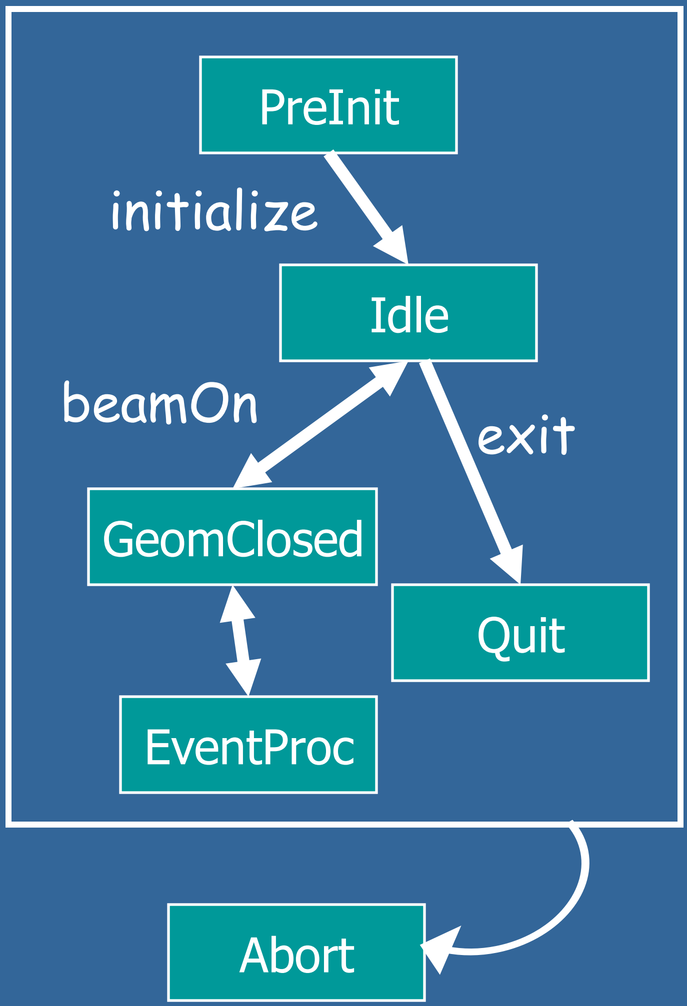
Geant4 kernel

- Geant4 consists of 17 categories.
  - Independently developed and maintained by WG(s) responsible to each category.
  - Interfaces between categories (e.g. top level design) are maintained by the global architecture WG.
- Geant4 Kernel
  - Handles run, event, track, step, hit, trajectory.
  - Provides frameworks of geometrical representation and physics processes.



Geant4 as a state machine

- Geant4 has six application states.
  - G4State_PreInit
    - Material, Geometry, Particle and/or Physics Process need to be initialized/defined
  - G4State_Idle
    - Ready to start a run
  - G4State_GeomClosed
    - Geometry is optimized and ready to process an event
  - G4State_EventProc
    - An event is processing
  - G4State_Quit
    - (Normal) termination
  - G4State_Abort
    - A fatal exception occurred and program is aborting



Run in Geant4

- As an analogy of the real experiment, a run of Geant4 starts with "Beam On".
- Within a run, the user cannot change
  - detector geometry
  - settings of physics processes

  ---> detector is inaccessible during a run
- Conceptually, a run is a collection of events which share the same detector conditions.
- At the beginning of a run, geometry is optimized for navigation and cross-section tables are calculated according to materials appear in the geometry and the cut-off values defined.
- G4RunManager class manages processing a run, a run is represented by G4Run class or a user-defined class derived from G4Run.
- G4UserRunAction is the optional user hook.

Event in Geant4

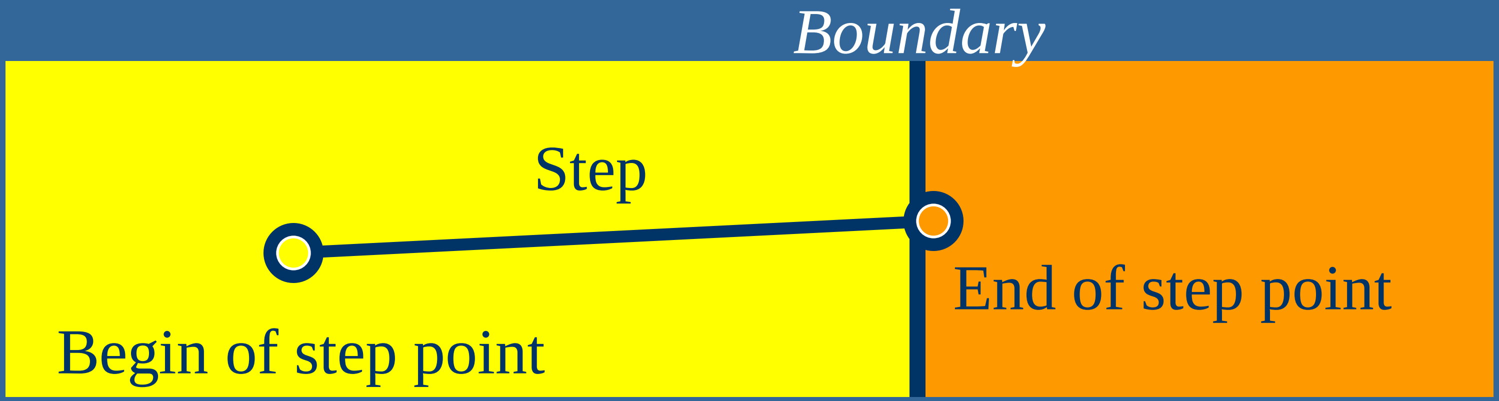
- At beginning of processing, an event contains primary particles. These primaries are pushed into a stack.
- When the stack becomes empty, processing of an event is over.
- G4EventManager class manages processing an event.
- G4Event class represents an event. It has following objects at the end of its processing.
  - List of primary vertexes and particles (as input)
  - Hits collections
  - Trajectory collection (optional)
  - Digits collections (optional)
- G4UserEventAction is the optional user hook.

Track in Geant4

- Track is a snapshot of a particle.
  - It has only position and physical quantities of current instance.
- Step is a “delta” information to a track.
  - Track is not a collection of steps.
- Track is deleted when
  - it goes out of the world volume
  - it disappears (e.g. decay)
  - it goes down to zero kinetic energy and no “AtRest” additional process is required
  - the user decides to kill it
- No track object persists at the end of event.
  - For the record of track, use trajectory class objects.
- G4TrackingManager manages processing a track, a track is represented by G4Track class.
- G4UserTrackingAction is the optional user hook.

Step in Geant4

- Step has two points and also "delta" information of a particle (energy loss on the step, time-of-flight spent by the step, etc.).
- Each point knows the volume (and material). In case a step is limited by a volume boundary, the end point physically stands on the boundary, and it logically belongs to the next volume.
  - Because one step knows materials of two volumes, boundary processes such as transition radiation or refraction could be simulated.
- G4SteppingManager class manages processing a step, a step is represented by G4Step class.
- G4UserSteppingAction is the optional user hook.



Particle in Geant4

- A particle in Geant4 is represented in three layers of classes.
- G4Track
  - Position, geometrical information, etc.
  - This is a class representing a particle to be tracked.
- G4DynamicParticle
  - "Dynamic" physical properties of a particle, such as momentum, energy, spin, etc.
  - Each G4Track object has its own and unique G4DynamicParticle object.
  - This is a class representing an individual particle (which is not necessarily to be tracked).
- G4ParticleDefinition
  - "Static" properties of a particle, such as charge, mass, life time, decay channels, etc.
  - G4ProcessManager which describes processes involving to the particle
  - All G4DynamicParticle objects of same kind of particle share the same G4ParticleDefinition.

Tracking and processes

- Geant4 tracking is general.
  - It is independent to
    - the particle type
    - the physics processes involving to a particle
  - It gives the chance to all processes
    - To contribute to determining the step length
    - To contribute any possible changes in physical quantities of the track
    - To generate secondary particles
    - To suggest changes in the state of the track
      - e.g. to suspend, postpone or kill it.

Processes in Geant4

- In Geant4, particle transportation is a process as well, by which a particle interacts with geometrical volume boundaries and field of any kind.
  - Because of this, shower parameterization process can take over from the ordinary transportation without modifying the transportation process.
- Each particle has its own list of applicable processes. At each step, all processes listed are invoked to get proposed physical interaction lengths.
- The process which requires the shortest interaction length (in space-time) limits the step.
- Each process has one or combination of the following natures.
  - AtRest
    - e.g. muon decay at rest
  - AlongStep (a.k.a. continuous process)
    - e.g. Cerenkov process
  - PostStep (a.k.a. discrete process)
    - e.g. decay on the fly