An Introduction to the Geant4 toolkit & collaboration

J. Apostolakis, CERN

for the Geant4 collaboration

Overview

- Simulation packages/toolkits
  - Key capabilities and concepts
- What it can do - highlights
  - Application areas
- What is inside – lightning tour
  - Brief highlights of capabilities
- Transparency of results
  - Open source
- GEANT4: the collaboration

What can a simulation package or toolkit do ?

- A Package provides 'general' tools to undertake (some or all) of the key tasks:
  - tracking, and geometrical propagation
  - modelling of physics interactions,
  - visualization, persistency

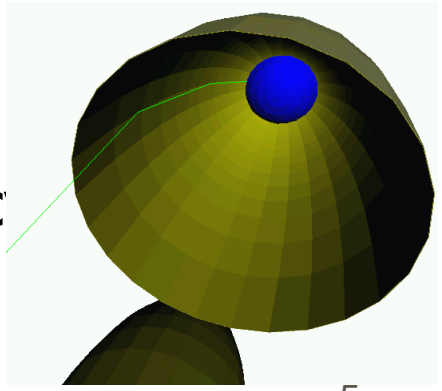
  and enable you to describe your setup's
  - detector geometry,
  - radiation source,
  - details of sensitive regions

GEANT 4

- Detector simulation tool-kit from HEP
  - full functionality: geometry, tracking, physics, I/O
  - offers alternatives, allows for tailoring
- Software Engineering and OO technology
  - provide the architecture & methods for maintaining it
- Requirements from:
  - current and future HEP experiments
  - medical and space science applications
- World-wide collaboration

Key Capabilities

- 'Kernel': create, manage, move tracks
  - tracking, stacks, geometry, hits, …
    - Extensible, flexible
- Physics Processes X-section, final-state
  - models for electromagnetic, hadronic, …
    - Can be 'assembled' for use in an application area
- Tools for faster simulation
  - 'Cuts', ramework shower parameterisation
  - Event biasing, variance reduction.
- Open interfaces for input/output
  - User commands, visualization, persistenc



Brief History

- Geant4 started as RD44 project (1994-98)
  - Amongst first OO in HEP, 1st for simulation
  - Dec 1998: 1st supported release Geant4.0.0
- First uses in production in several fields
  - Space: 1999 XMM (X-ray telescope)
  - HEP: 2001 BaBar, 2004 ATLAS/CMS/LHCb
- Regular public releases (1-2 per year)
  - Geant4 release 9.0 (Jun 07), 9.3 (Dec 09)

APPLICATION AREAS

Application domains

- High Energy Physics
  - Collider Experiments
  - Rare Event Experiments
- Nuclear Physics Experiments
  - Diverse small experiments
- Medical Physics
- Space: radiation environments, satelite science

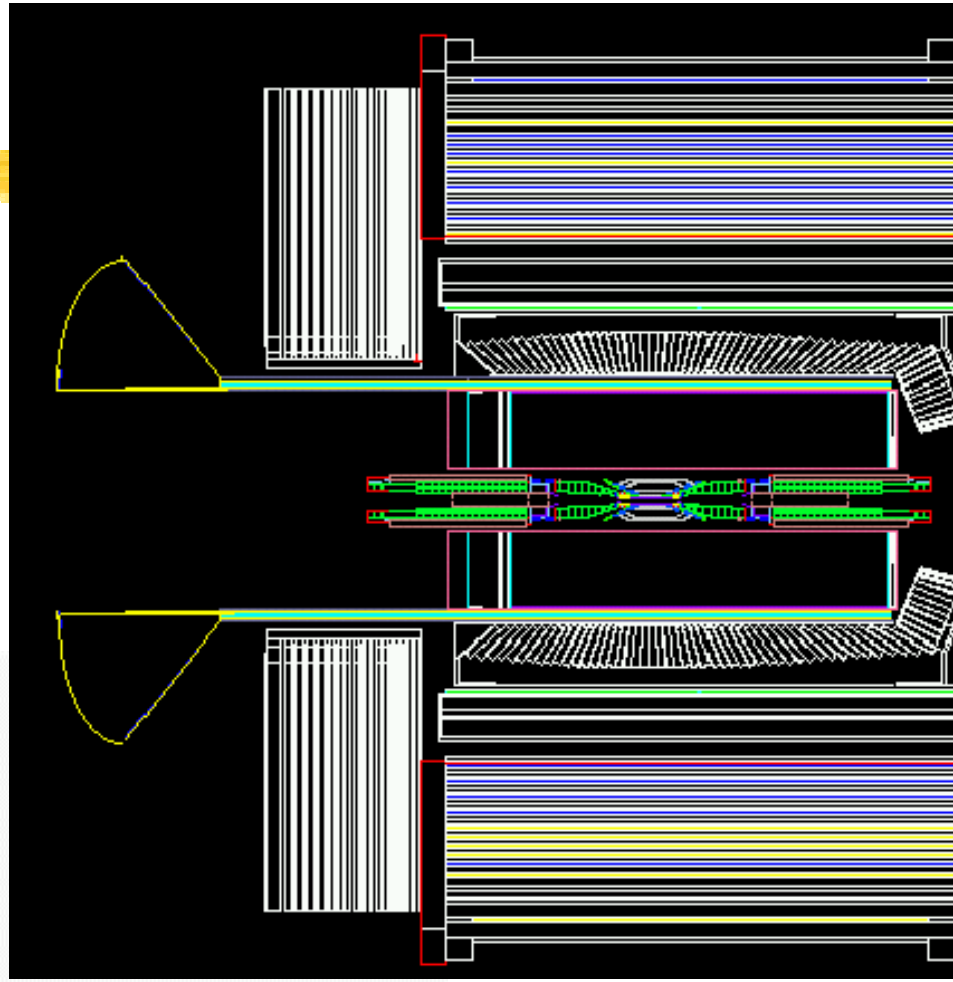
HIGH ENERGY PHYSICS

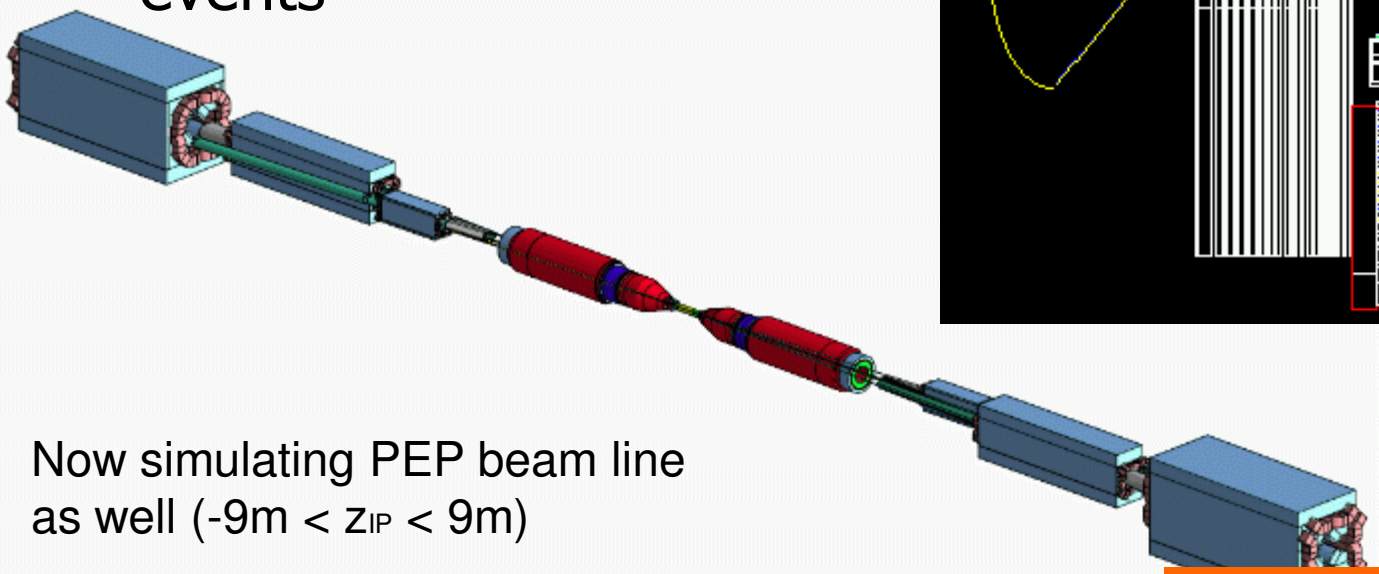
High Energy Physics Uses

- Collider Experiments
  - BaBar has Geant4-based production simulation (since ca 2002)
  - ATLAS, CMS, LHCb's detector simulation in production since early 2004
- Rare Event Experiments
  - Borexino, KAMland, …

BaBar

- BaBar at SLAC was the pioneer experiment in HEP in use of Geant4
  - Started in 2000
  - Simulated several x 10^{10} events

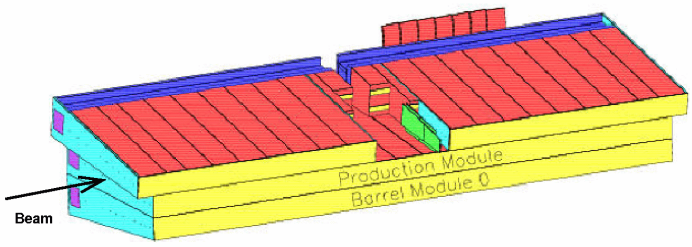




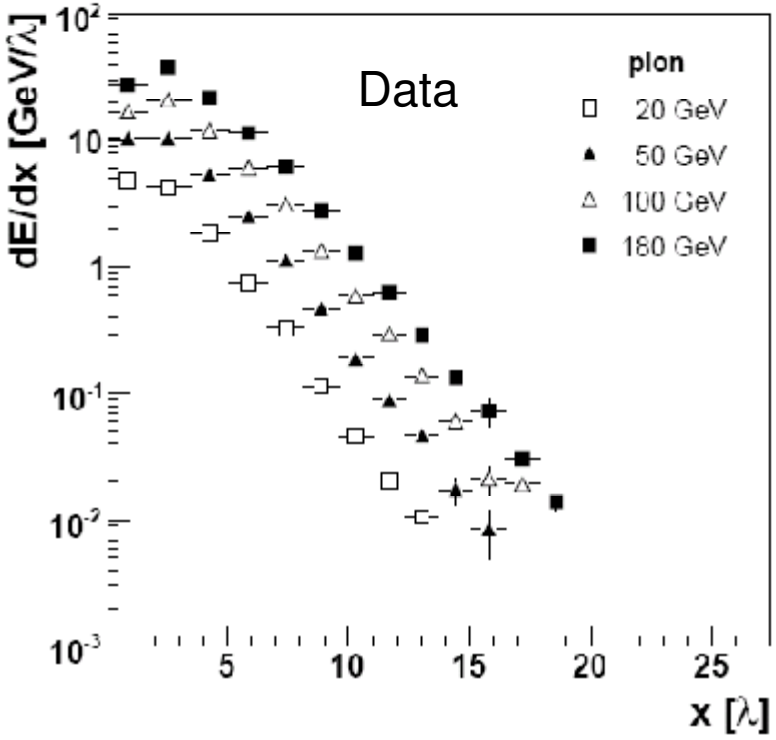
Now simulating PEP beam line as well ($-9m < z_{IP} < 9m$)

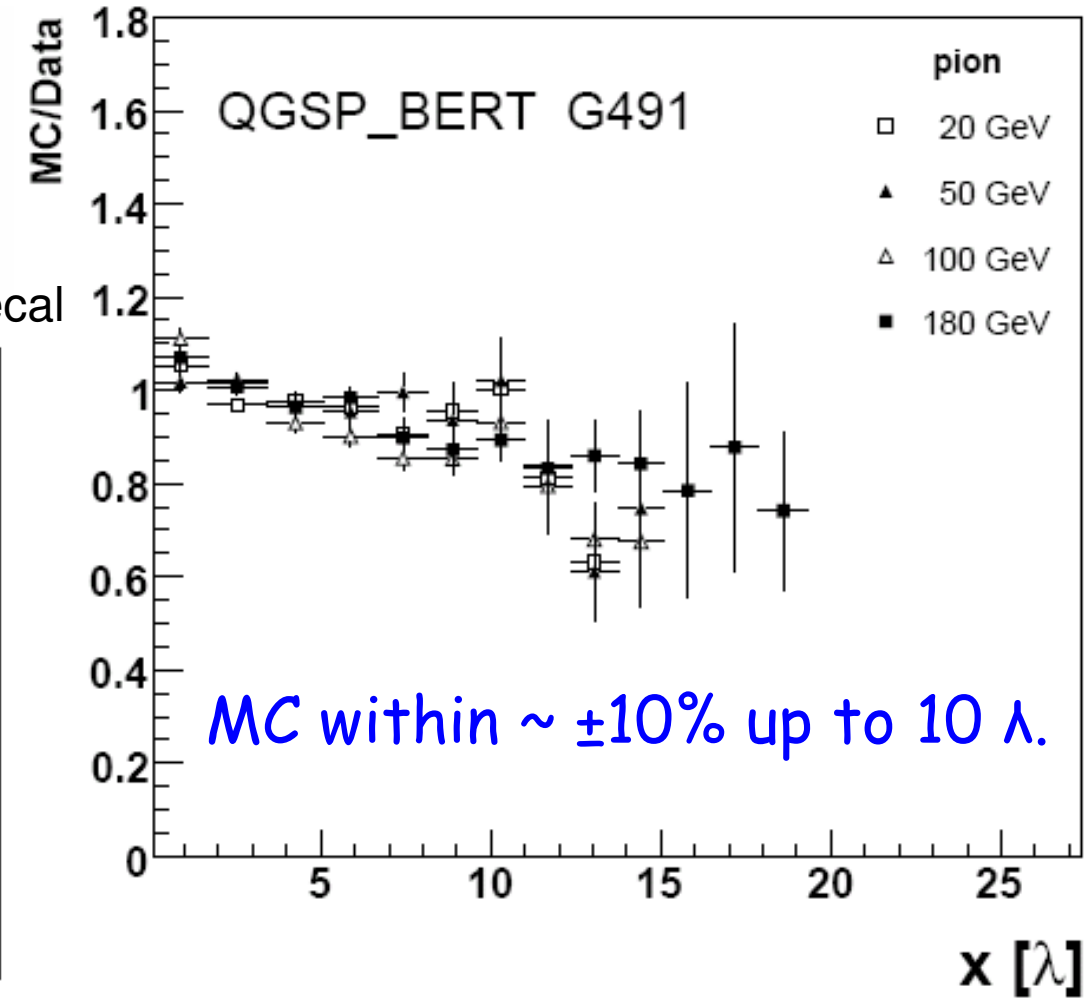
Courtesy of D.Wright (SLAC)

Pion longitudinal shower profile in stand-alone ATLAS TileCal test-beam at 90°



Thanks to Atlas Tilecal

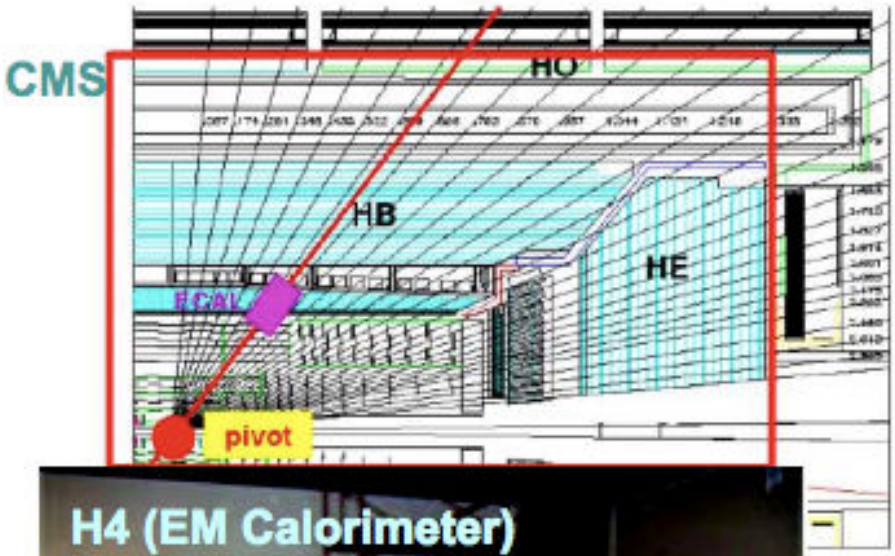


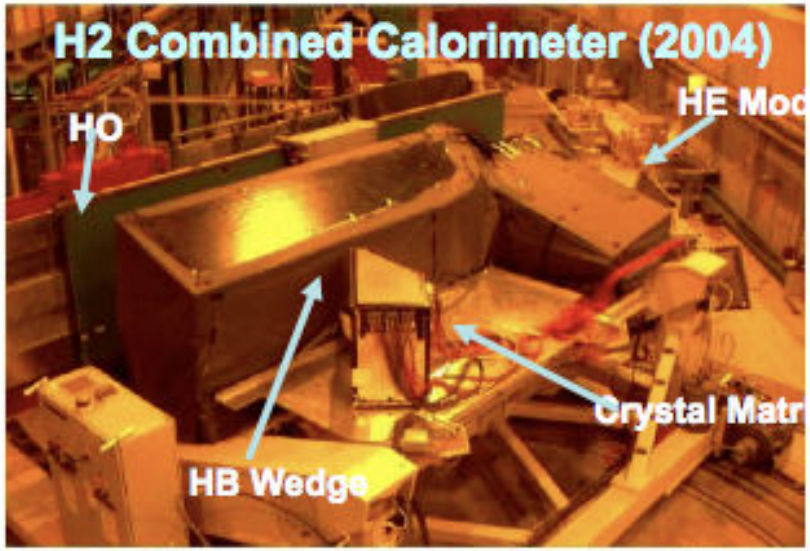


MC within ~ ±10% up to 10 λ.

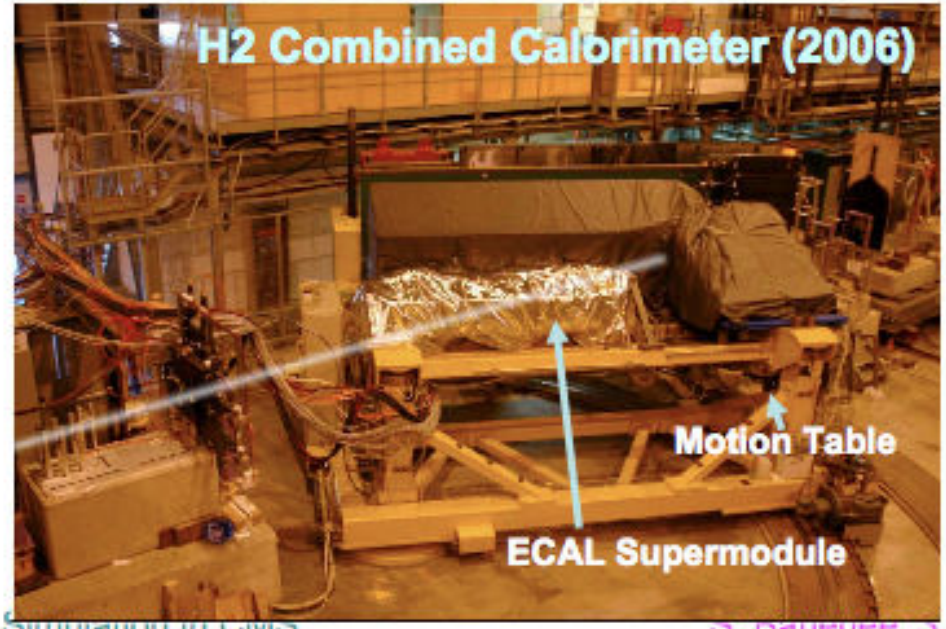
For Protons : -(20%-40%) at 10 λ.

CMS Test Beam Efforts



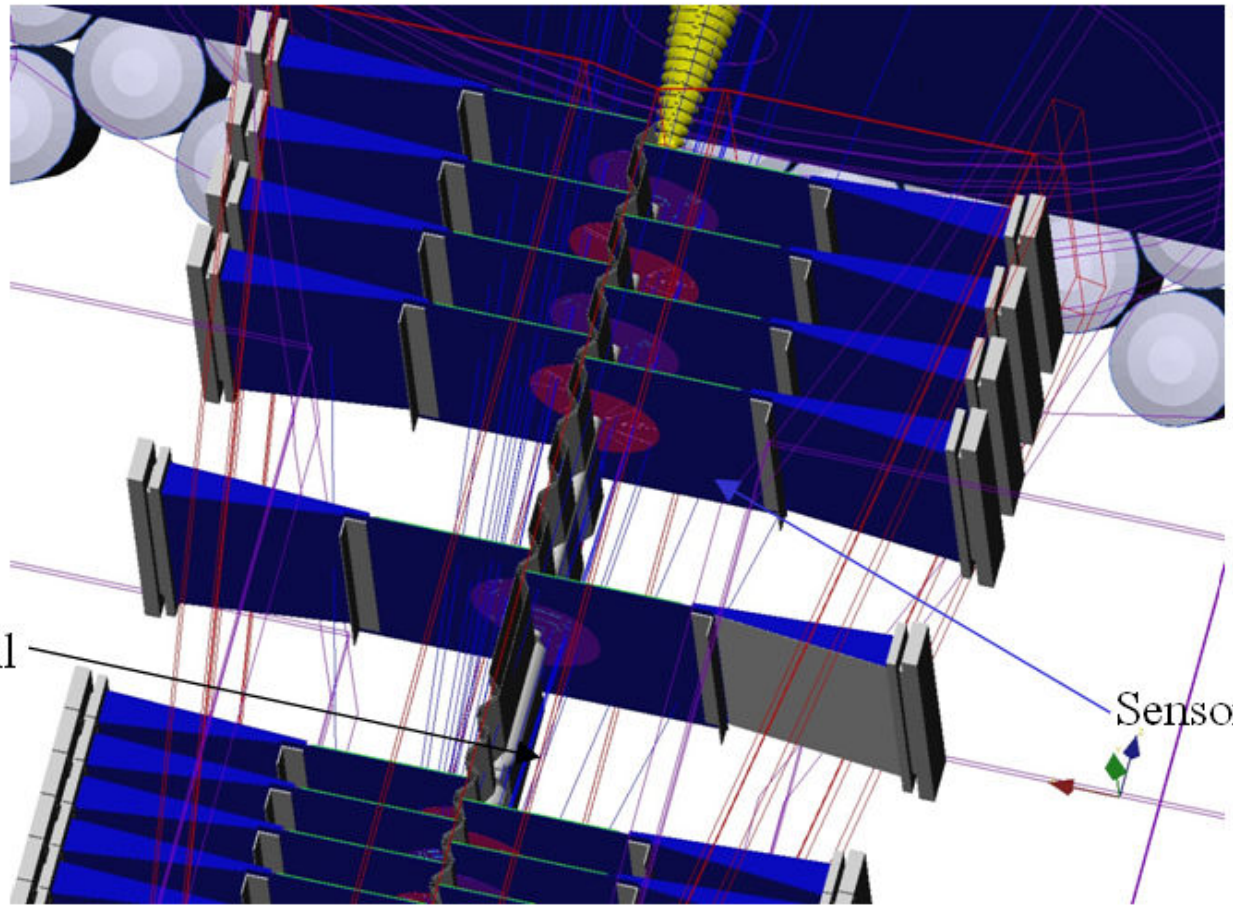


Courtesy: CMS



Talk of S. Banerjee, Geant4 Workshop 2009

Geant4 at the LHC Today



LHCb Vertex Locator description

Complicated geometry
Details are very important

Geant4 can handle it!!

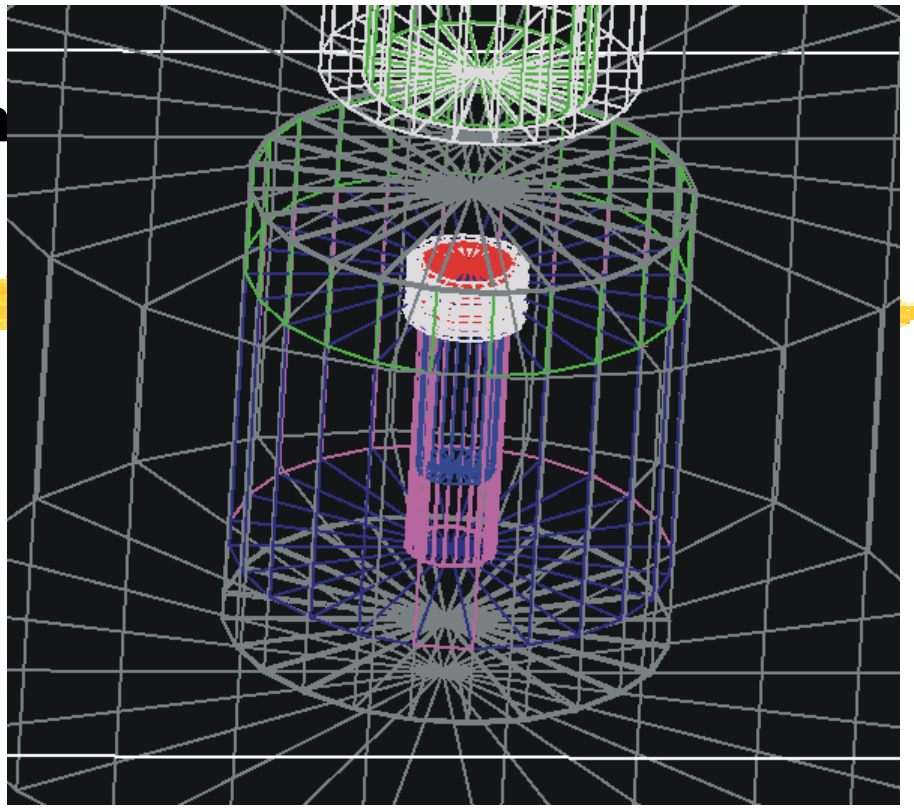
HEP: Key strengths

- Flexible geometry
  - Able to cope with deep hierarchies, many volumes (for big experiments)
  - Fast, easy to create & revise (for small experiments)
- Open, Solid Physics
  - Solid EM physics models
  - Hadronic models that can describe test beam results (typically to 10% for resolution)
  - Can try from variety of models
    - Trade accuracy for speed
- Transparency of results

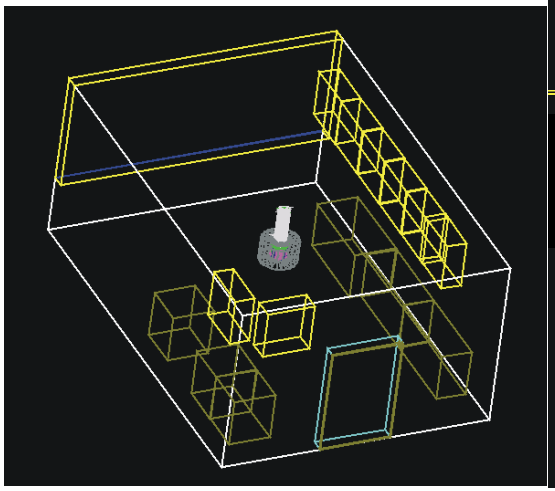
‘Near’ HEP: Experiments and accelerators

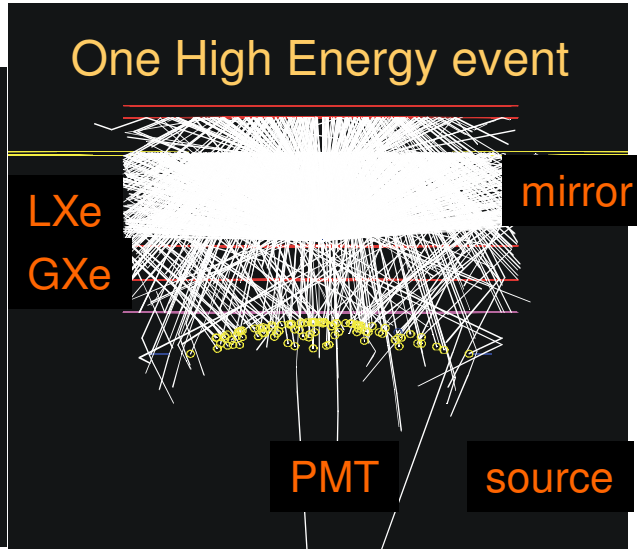
- Diverse small(er) experiments
  - Rare-Event (typically underground)
  - Nuclear
    - Model detector response
- Modeling accelerator beams
  - Effects of interactions with collimators

Boulby Mine dark matter search Prototype Simulation



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



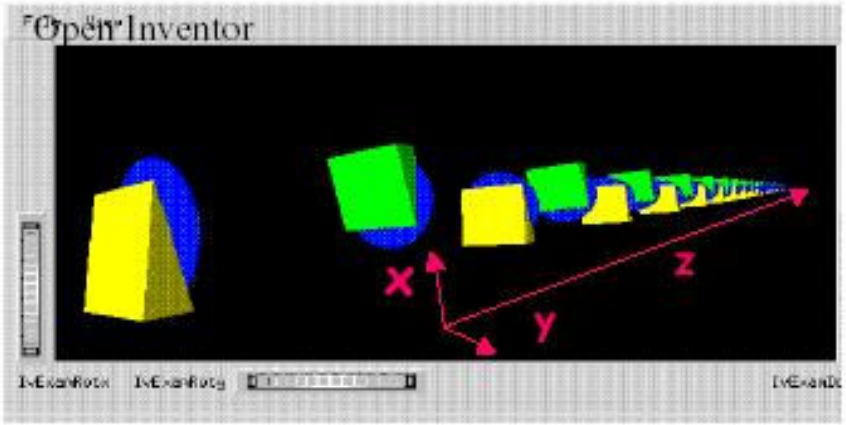


Geant4 for beam transportation

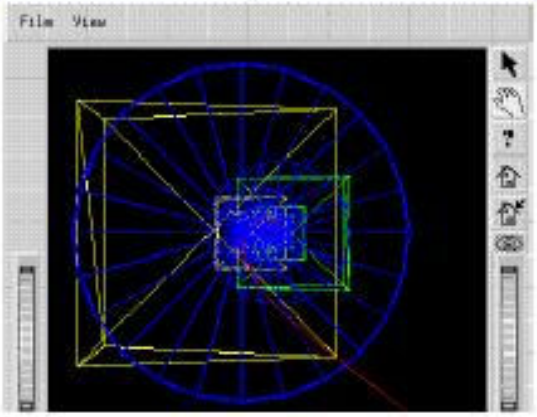
Example: Helical Channel

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)

Courtesy of V.D.Elvira (FNAL)

Alternative/Beam Transport

Geant4 extensions for beam transport

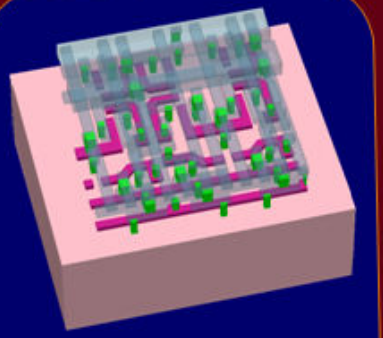
- BeamTools (FNAL, revised to 2003)
- Microbeam studies (Bordeaux)
- BDSIM
  - http://flc.pp.rhul.ac.uk/bdsim.html
- G4Beamline
  - http://www.muonsinc.com/tiki-index.php?page=G4beamline

AEROSPACE

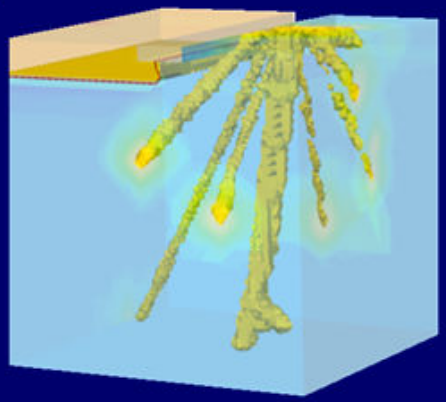
Space Applications

- Model radiation environments
  - Effect on satellite electronics
    - Numerous ESA missions
  - Planetary radiation environments
    - Mars, Mercury, .. (Planetocosmics)
- Science
  - γ-radiation produced by incoming cosmic ray protons

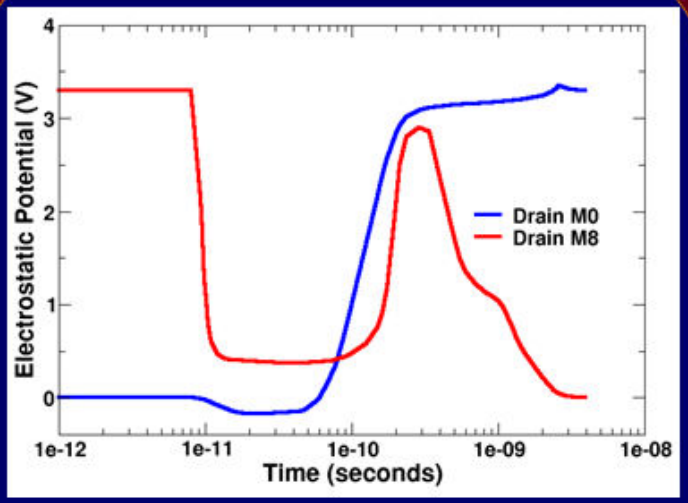
RADSAFE on SEE in SRAMs



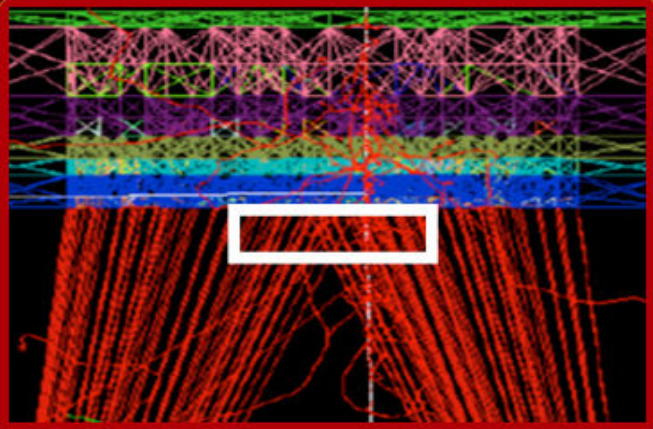
TCAD Cell Structure: SRAM Cell



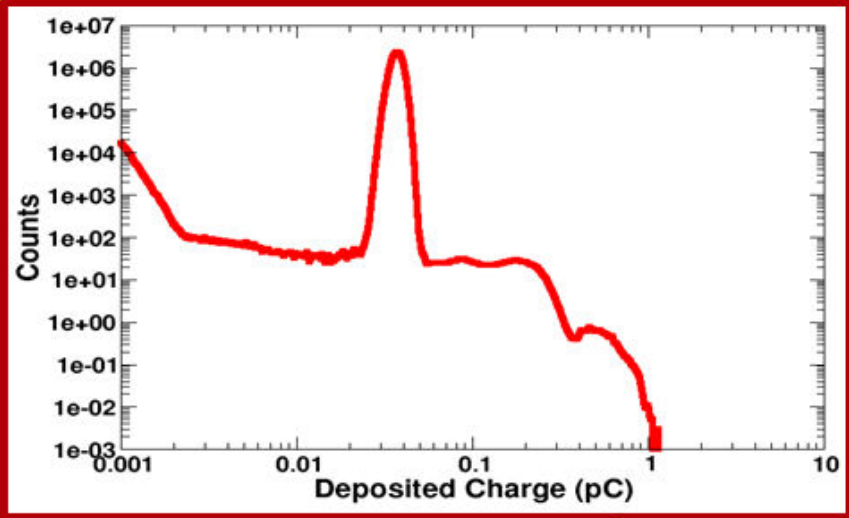
Single Charge Deposition in TCAD: Ne+W Event



SRAM Cell Upset



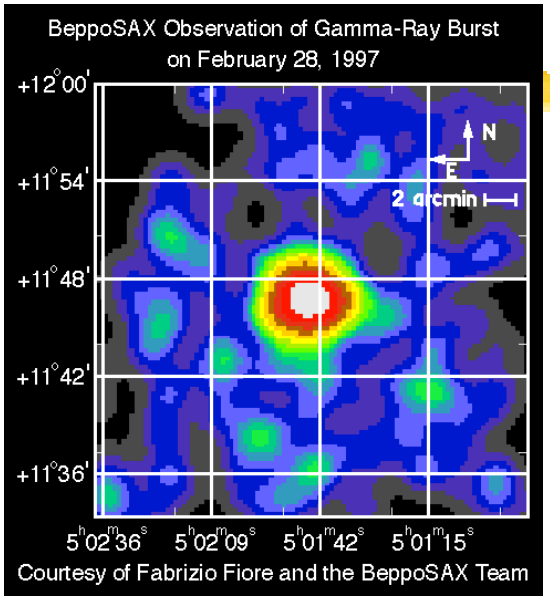
Geant4 Geometry and 523 MeV Neon Event



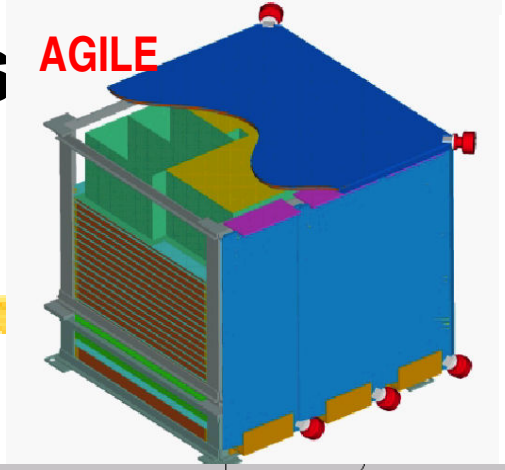
MRED Energy Deposition for 10^8 Events

γ astrophysics

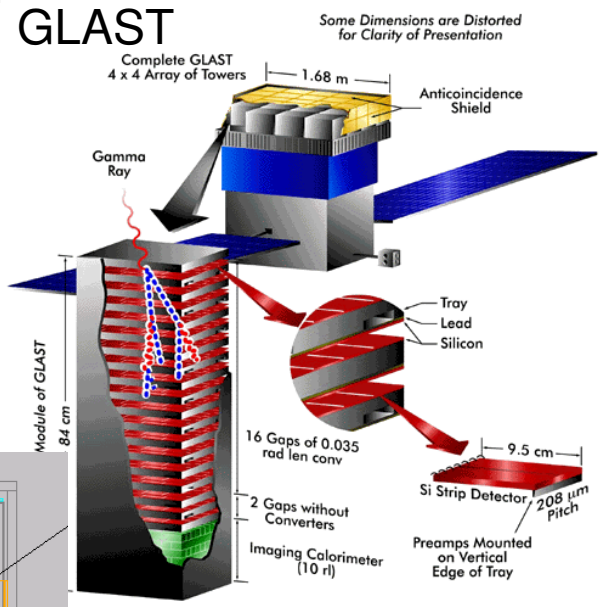
γ-ray bursts



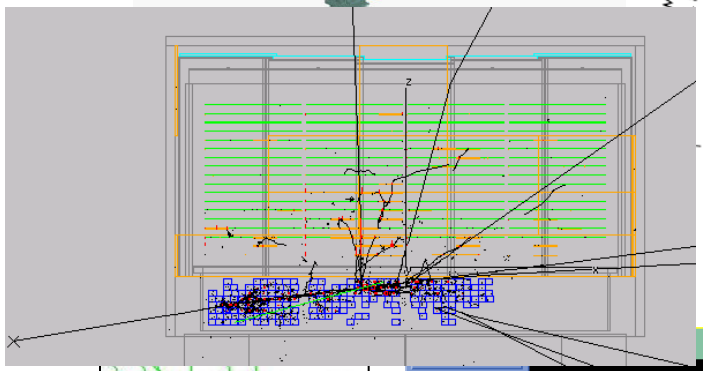
AGILE

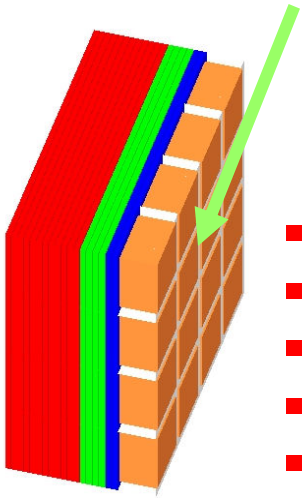


GLAST



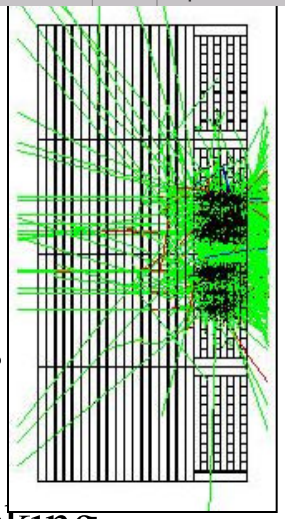
GLAST

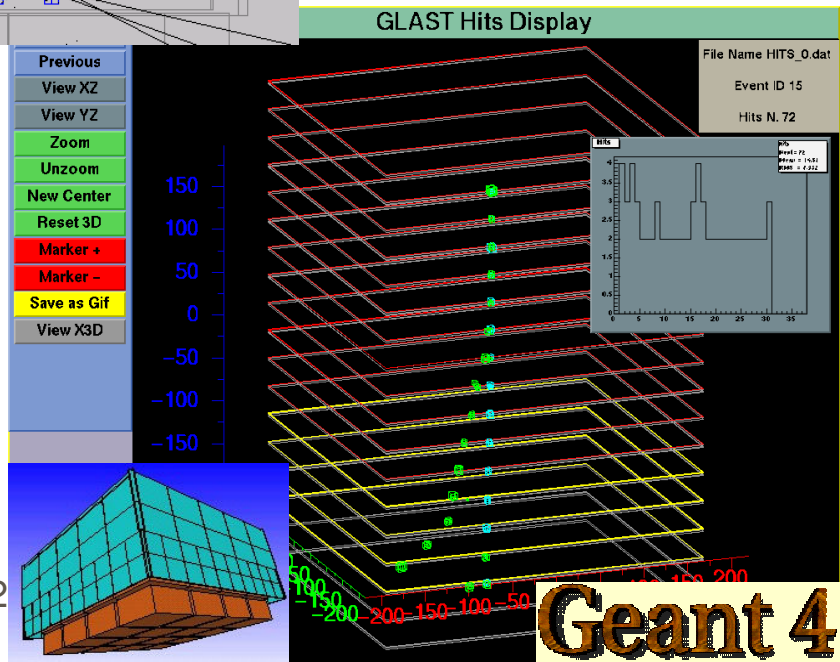




Typical telescope:
Tracker
Calorimeter
Anticoincidence

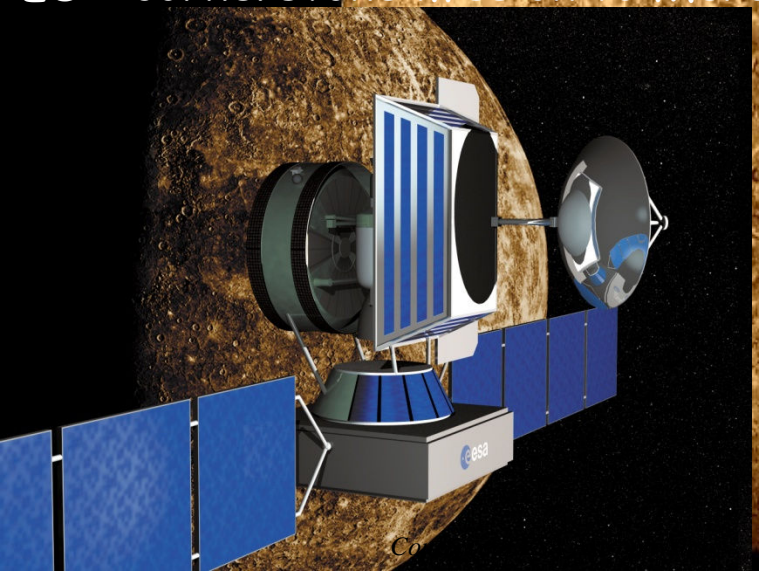
- γ conversion
- electron interactions
- multiple scattering
- δ-ray production
- charged particle tracking

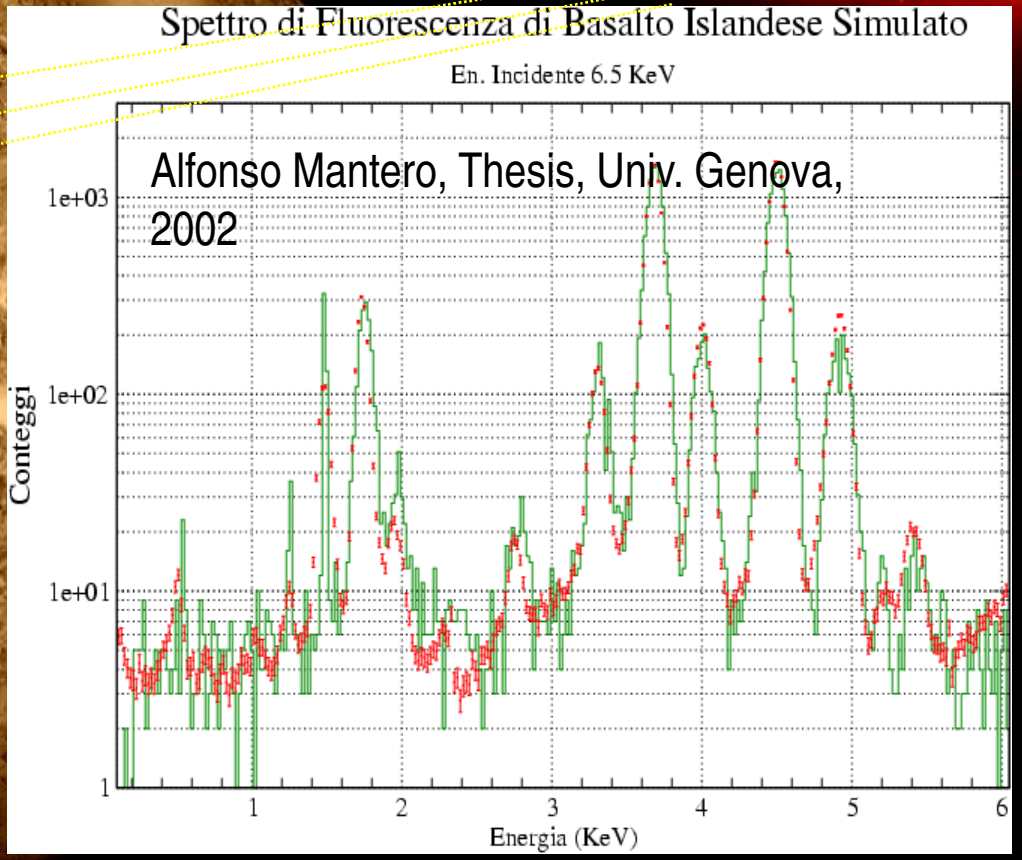




Bepi Colombo: X-Ray Mineralogical Survey of Mercury

BepiColombo
ESA cornerstone mission to Mercury





PlanetoCosmics

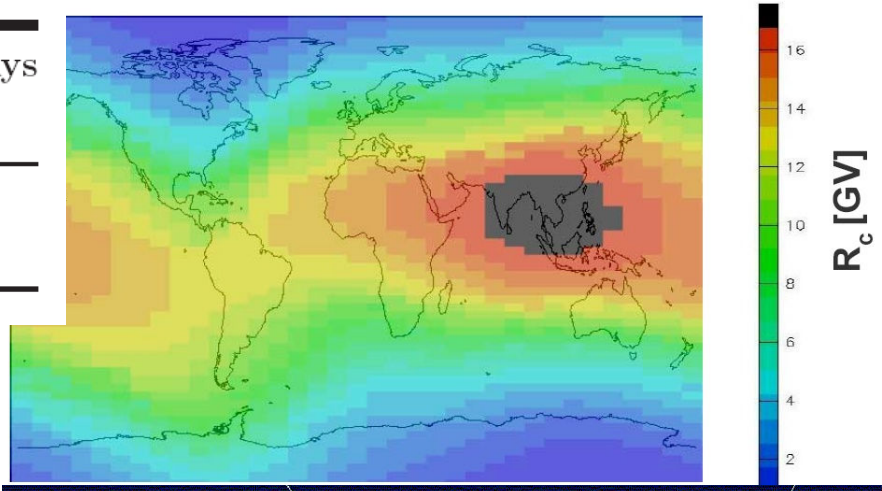
Geant4 simulation of Cosmic Rays in planetary Atmo-/Magneto- spheres

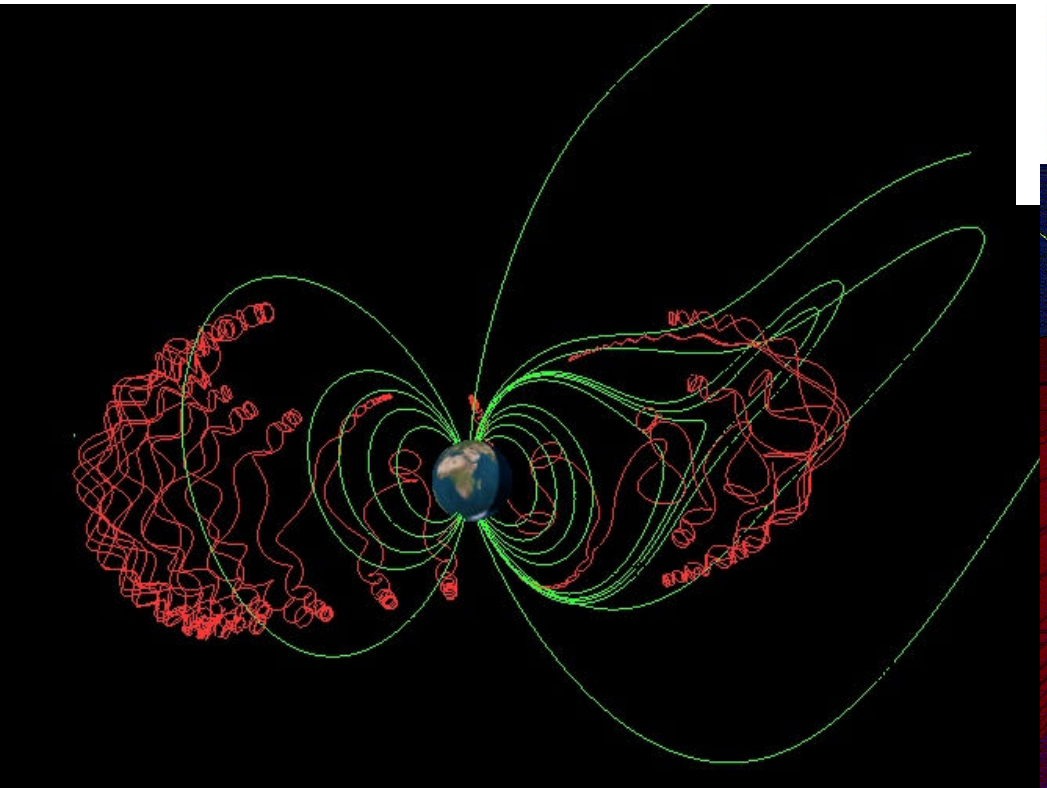
28th International Cosmic Ray Conference — 4277

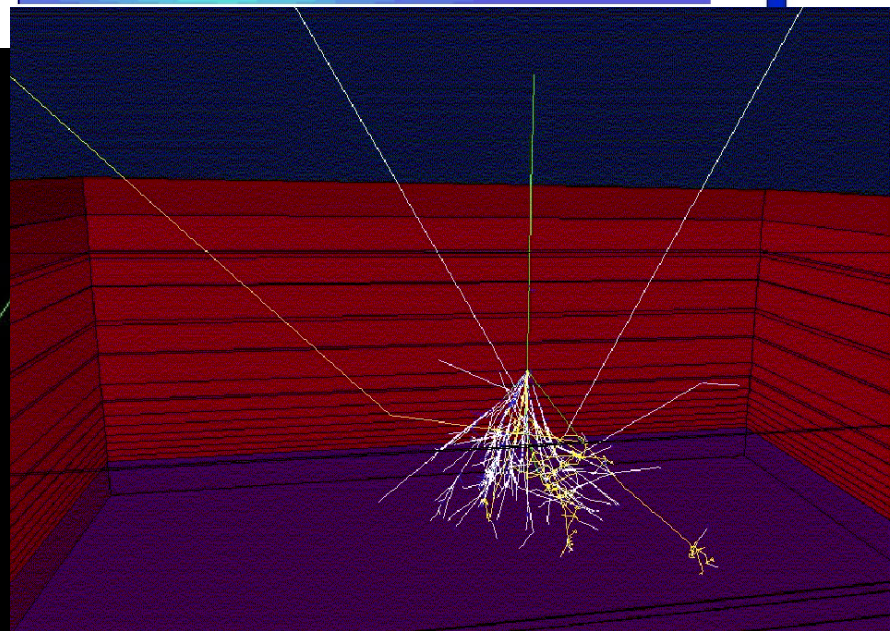
Geant4 Simulation of the Propagation of Cosmic Rays through the Earth's Atmosphere

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

Cutoff Rigidities vs position

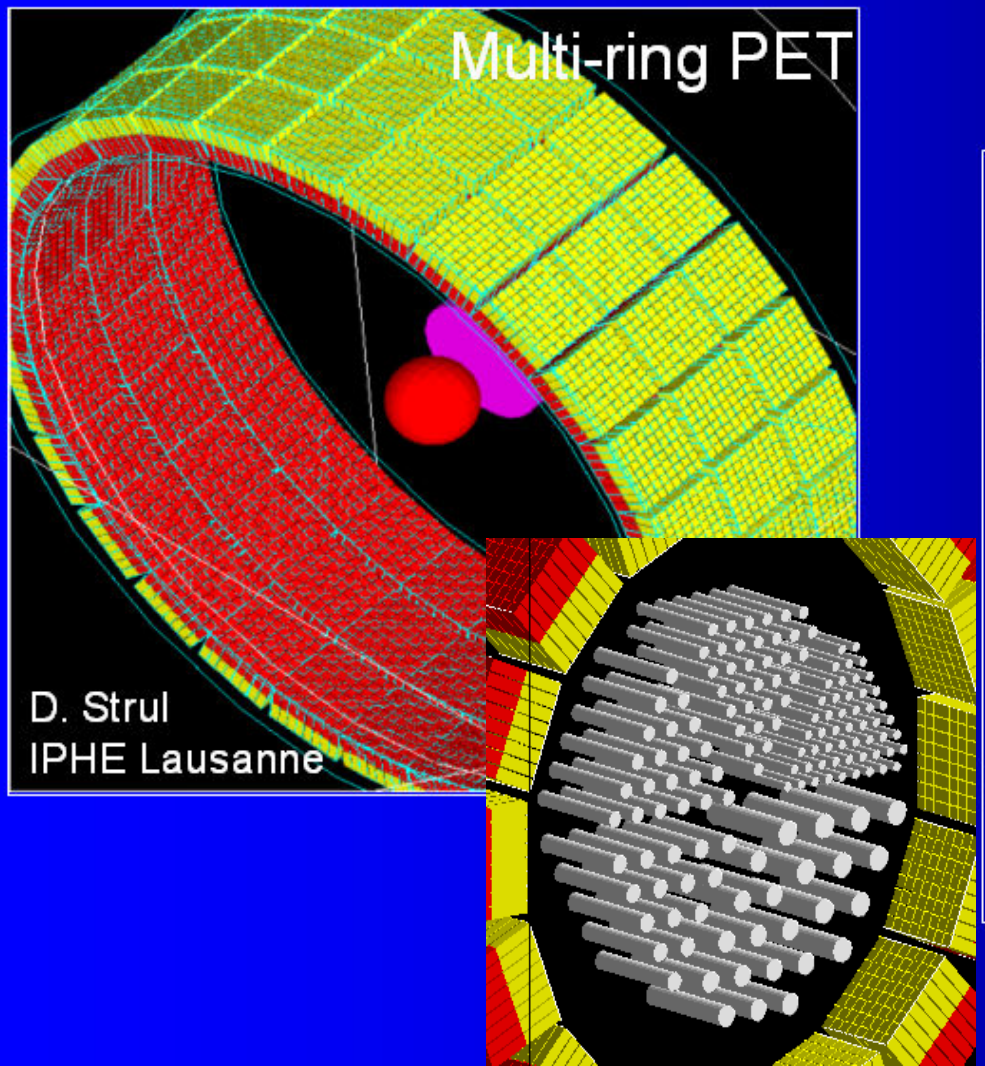


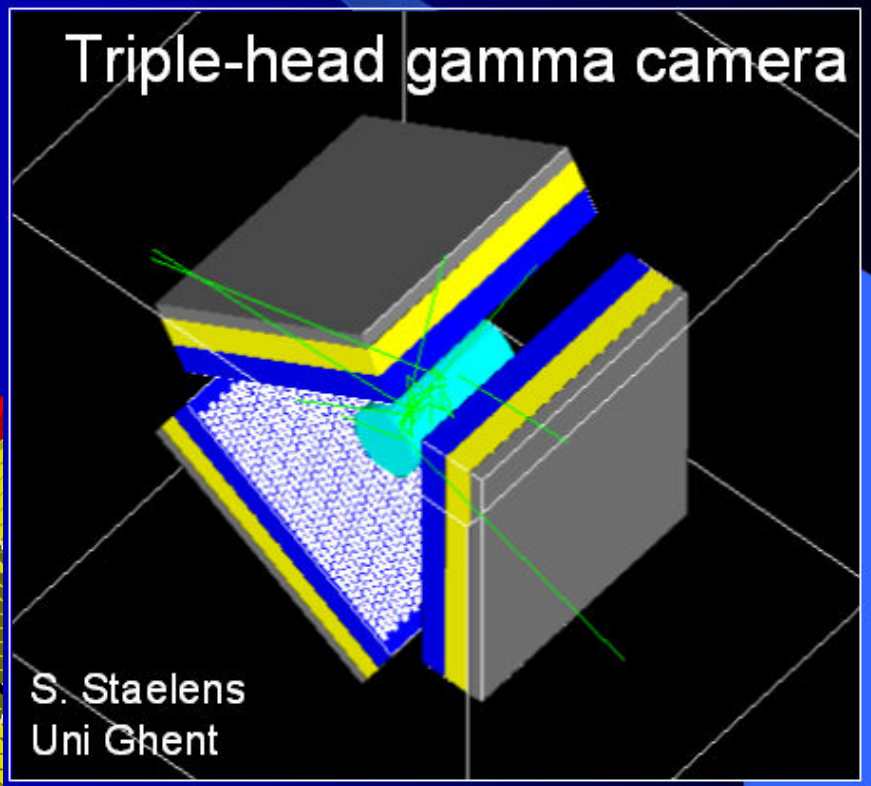




MEDICAL PHYSICS

Geometry examples of GATE applications





http://top25.sciencedirect.com/index.php?subject_area_id=21

SCIENCE DIRECT

TOP 25 HOTTEST ARTICLES ON ScienceDirect

INTRODUCTION

The **ScienceDirect TOP25 Hottest Articles** is a **free** quarterly service from ScienceDirect. When you subscribe to the **ScienceDirect TOP25**, you'll receive an e-mail every three months listing the ScienceDirect users' 25 most frequently downloaded journal articles, from any selected journal among more than 2,000 titles in the ScienceDirect database, or from any of 24 subject areas.

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Journal: [all journals]

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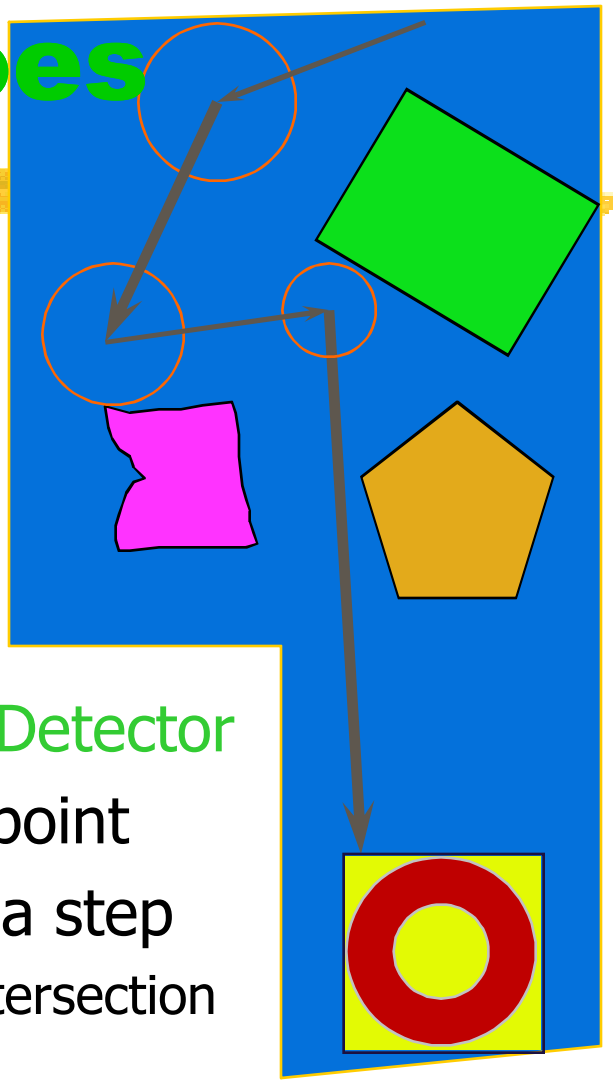
TOP25 articles within the subject area: Physics and Astronomy

1. Nanoscience and engineering in mechanics and materials • **Article**
   Journal of Physics and Chemistry of Solids, Volume 65, Issue 8-9, 1 August 2004, Pages 1501-1506
   Chong, K.P.
2. Geant4-a simulation toolkit • **Article**
   Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 506, Issue 3, 1 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.; Burk
3. Radiation pneumonitis and pulmonary fibrosis in non-small-cell lung cancer: Pulmonary function, prediction, and prevention • **Article**

A QUICK WALK THROUGH GEANT4

Geometry: what it does



Describes a Setup

- Hierarchy of volumes
- Many volumes repeat
  - Volume & sub-tree
- Up to hundreds of thousands of volumes
- Importing solids from CAD systems

Navigates in Detector

- Locates a point
- Computes a step
  - Linear intersection

Electromagnetic physics

- Gammas:
  - Gamma-conversion, Compton scattering, Photo-electric effect
- Leptons(e, μ), charged hadrons, ions
  - Energy loss (Ionisation, Bremstrahlung), Multiple scattering, Transition radiation, Synchrotron radiation, e+ annihilation.
- Photons:
  - Cerenkov, Rayleigh, Reflection, Refraction, Absorption, Scintillation
- High energy muons
- A choice of implementations for most processes
  - "Standard": performant when relevant physics above 1 KeV
  - "Low Energy": Extra accuracy for application delving below 1 KeV

Hadronic processes

- Hadronic physics is included in Geant4
  - a powerful and flexible framework and
  - implementations of physics X-sections & models.
- A variety of models and cross-sections
  - for each energy regime, particle type, material
  - alternatives with different strengths and computing resource requirements
- Components can be assembled in an optimised way for each use case.

Openness and Extensibility

- As a toolkit with open-source code, Geant4 can be extended in many ways
  - Expected/simple
    - Creating a new shape (G4VSolid)
  - Unusual, but predicted
    - New processes, for physics or user action
  - Radical extensions
    - Reversing time (two ways)
    - Creating 'on-the-fly' density for a material (future)

Practical considerations

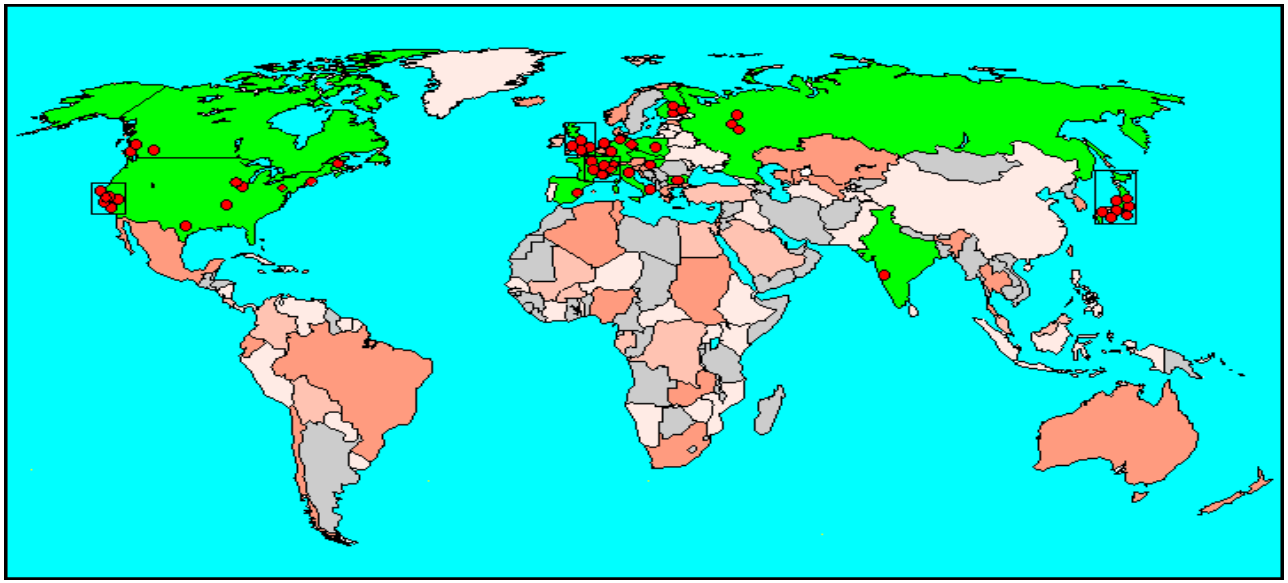
- Starting off: what you need
  - Compatible platform
  - Need CLHEP foundation class library
  - One or more visualisation libraries (possibly from system, e.g. OpenGL)
- CLHEP is used for key common classes
  - ThreeVector (G4ThreeVector is a name for CLHEP::HepThreeVector)
  - FourVector
  - Random Number Generators, ..
- Coding is needed – except if someone did it for you.
  - Modify existing C++ 'code' to describe your setup
  - Create you own class to describe eg a magnetic field.

Platforms

- What works 'best' (used by developers, main testing)
  - Scientific Linux 4 or 5 and gcc 4.3 (HEP production)
  - MacOS 10.5 Leopard
- What we also support (tested + numerous users)
  - Windows (XP) & Visual C++
    - numerous users
- What we expect to work
  - Other Linux flavours with gcc 4.1 and 4.3
    - Possibly with fewer options, eg missing some visualisation
- What others 'ported' and check
  - Sun Solaris

GEANT4 COLLABORATION

Geant4 Collaboration



TRIUMF

Lebedev

LIP

UK STFC

Collaborators also from non-member institutions, including
IHEP
MEPHI Moscow
Jefferson Laboratory

Hands on!

- Time to get your hands on Geant4
  - Copy exercises
  - Your first run of a simple example
- To start, please look at

http://www.ifh.de/geant4/g4course2010

Else, if you have difficulty to reach that use
http://www-zeuthen.desy.de/geant4/g4course2010

The END

Resources for more information

- Geant4 web site
  - http://cern.ch/geant4/
- Geant4 Training Page
  - http://cern.ch/geant4/support/ and follow "Training" link,
  - Geant4 training INFN / EM 'Low-energy'
    - http://www.ge.infn.it/geant4/training/
- Geant4 Workshops and Users Workshops presentations
  - Latest at the home page, previous at http://geant4.web.cern.ch/geant4/collaboration/meetings_minutes.html#G4workshops

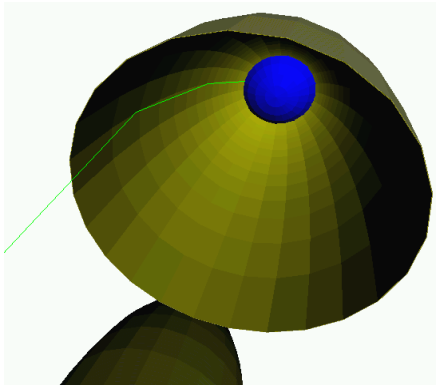
Note: "Training" page is also directly accessed at http://cern.ch/geant4/milestones/training/training-milestone.html

- Geant4 Physics WG web sites
  - Which can all be found at http://cern.ch/geant4/organisation/working_groups.html
  - Geant4 Low-Energy Electromagnetic WG web site
    - http://www.ge.infn.it/geant4/lowE/
  - Geant4 EM (standard) see below
  - Geant4 Hadronic WG home
- Papers on G4 and its validation
  - "Geant4: a simulation toolkit", Nucl Instr and Methods **A** 506 (2003), 250-303
  - "Validation of GEANT4, an object-oriented MC toolkit for simulations in medical physics" J.F. Carrier et al, Med Phys 32 (2004), p 484.

ElectroMagnetic (standard) WG home page is at http://cern.ch/geant4/working_groups/electromagnetic/electromagneticWG.html

Geant4 Capabilities & Use

- Kernel: create geometry, hits, …
- Physics Processes
  - models for EM, hadronics, …
  - ‘assembled’ into physics lists for application area
- Tools for faster simulation
  - Shower parameterisation & Event biasing.
- Open interfaces for input/output
  - User commands, visualization
- Verification and validation for use cases
- Using it
  - via ready applications (eg GATE)
  - by starting with examples & customising



Geant4 releases: 1999-2009

RD44

- Dec 1998 - Geant4.0.0 release
- June 2001 - Geant4 3.2 release
- Dec 2005 – Geant4 8.0
- Jun 2006 – *Geant4 8.1 release*
- May 2007 – Geant4 8.3
- Jun 2007 – Geant4 9.0

MoU-based Collaboration

G4 license, New G4 collaboration

Before: Two public releases per year.

- Dec 2008 – Geant4 9.2
- Dec 2009 – Geant4 9.3

Since 2008: one beta (June), one full rel.

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-to its validation for these and other application areas,

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Note that it is a large task to give credit to all of them individually.