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

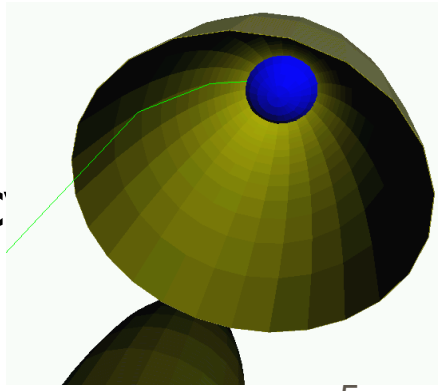
  and enable you to describe your setup's
  - detector geometry,
  - radiation source,
  - details of sensitive regions

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

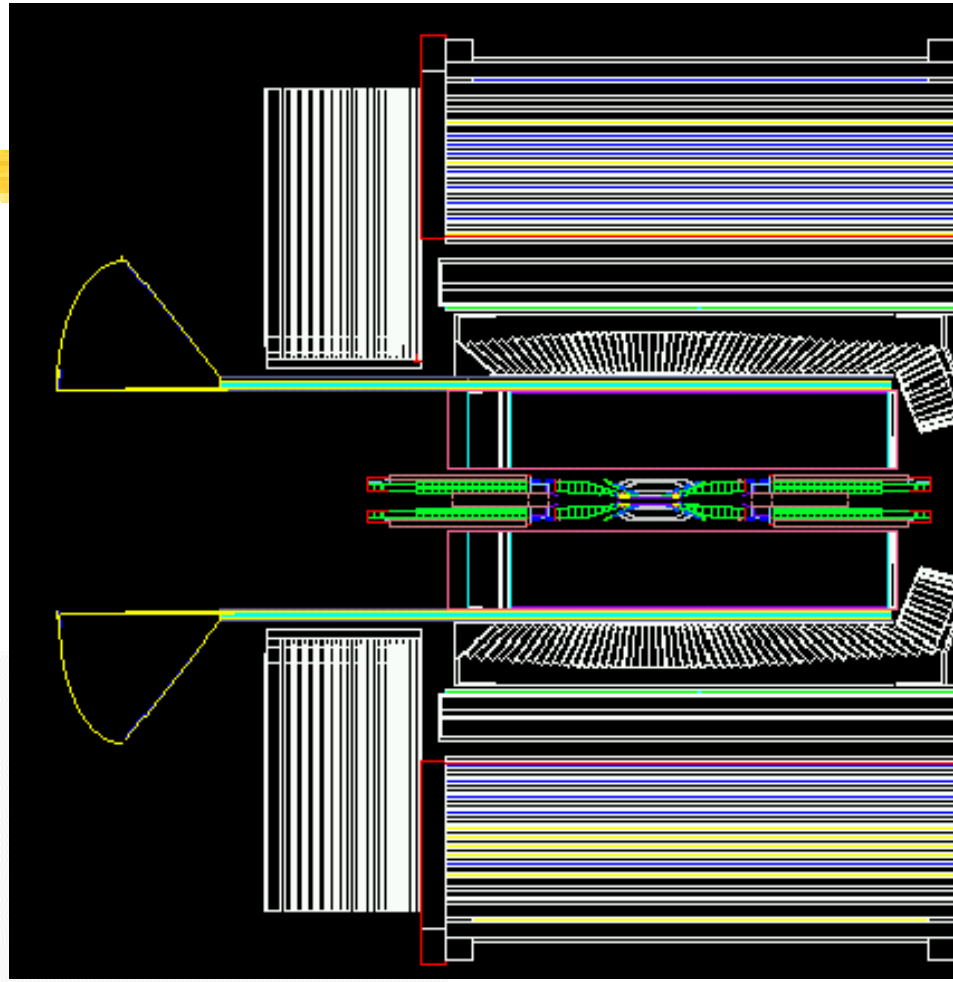
HIGH ENERGY PHYSICS

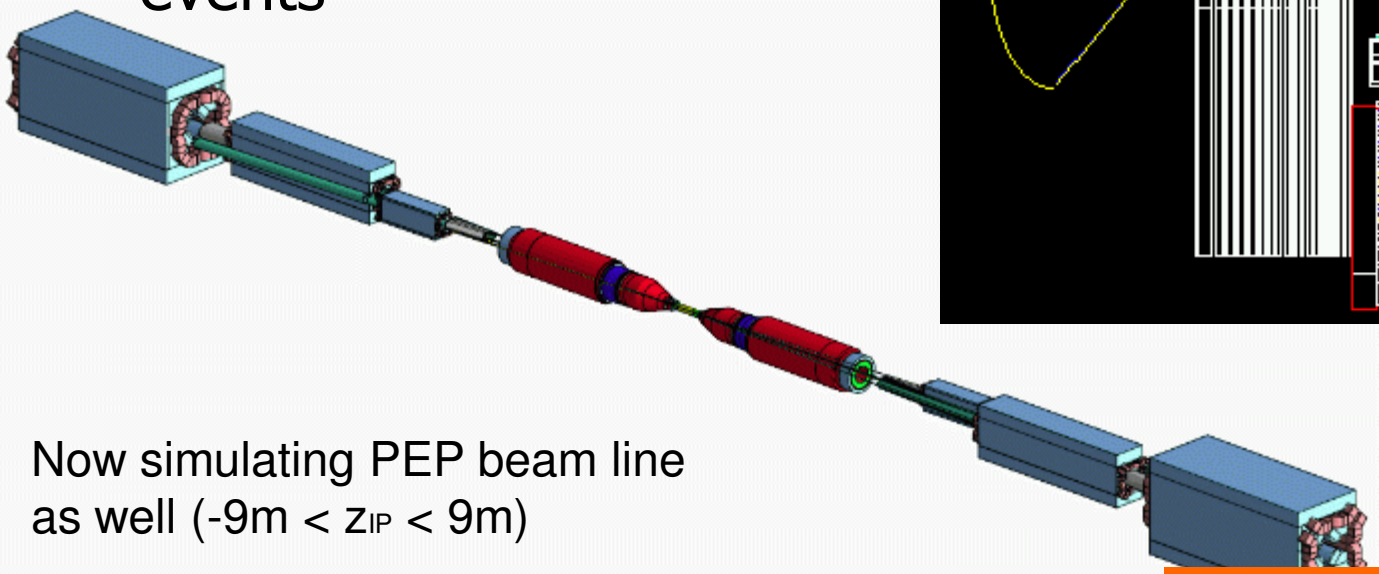
High Energy Physics Uses

- 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

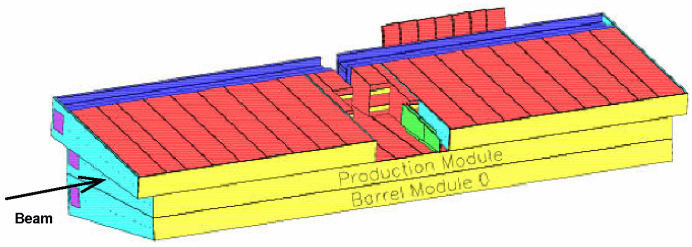




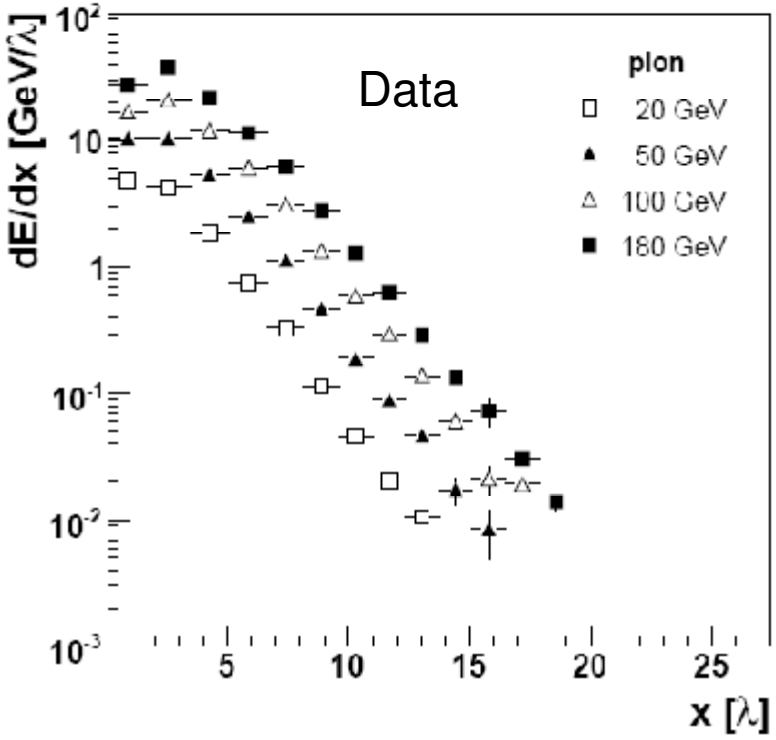
Now simulating PEP beam line as well ($-9m < z_{IP} < 9m$)

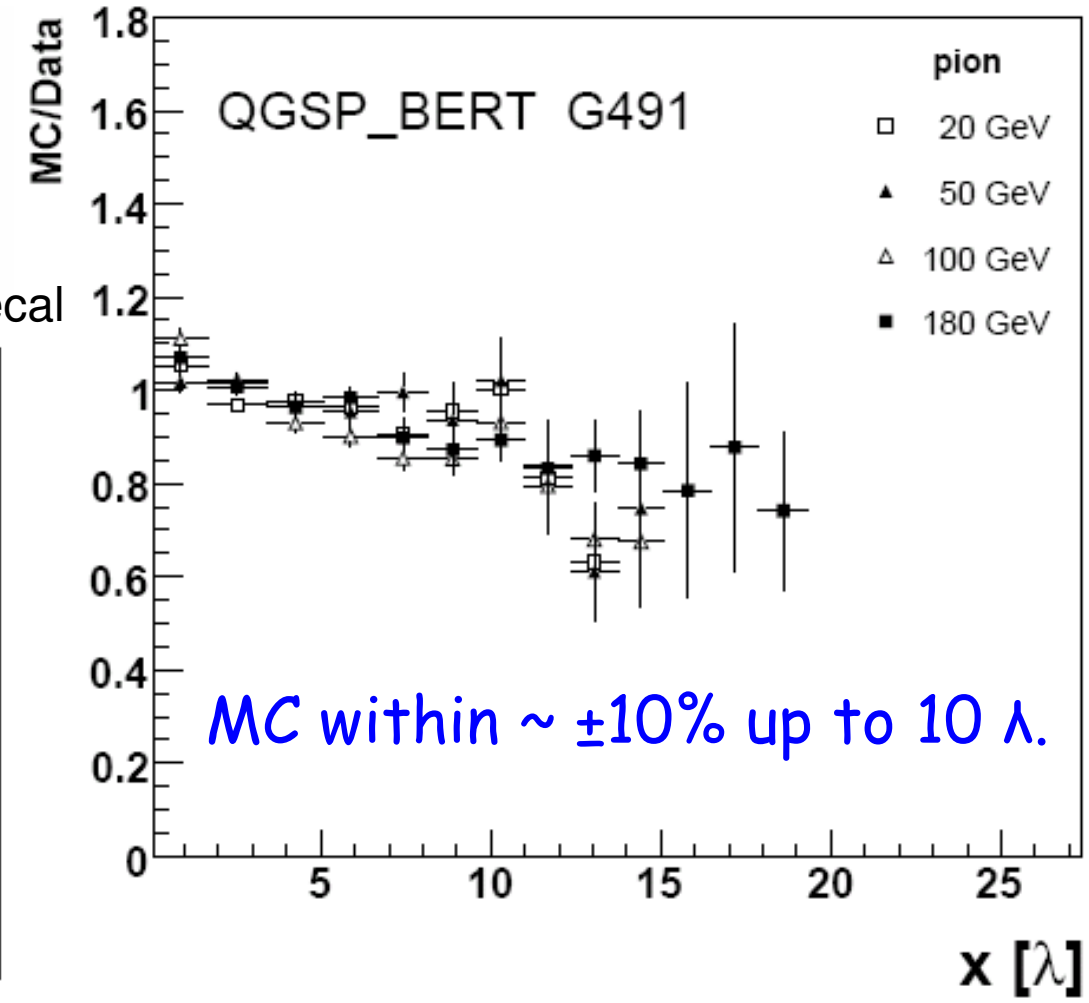
Courtesy of D.Wright (SLAC)

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



Thanks to Atlas Tilecal

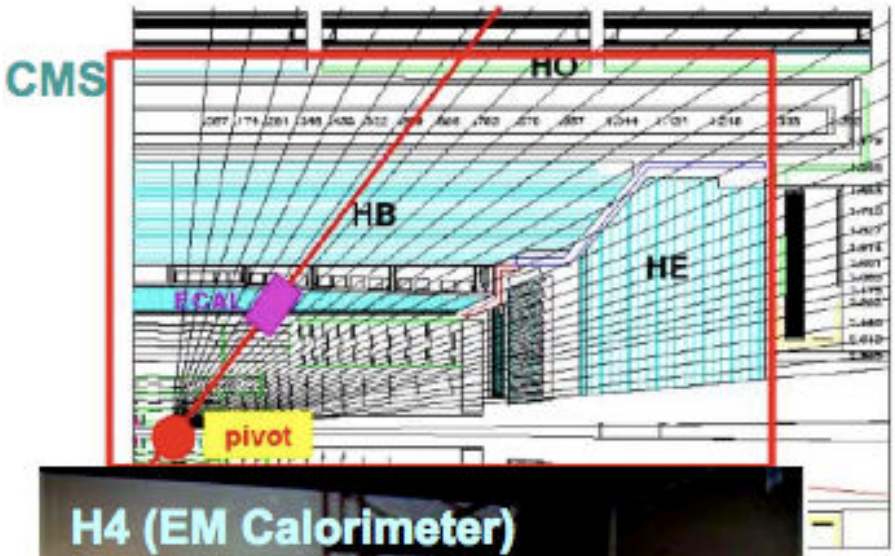


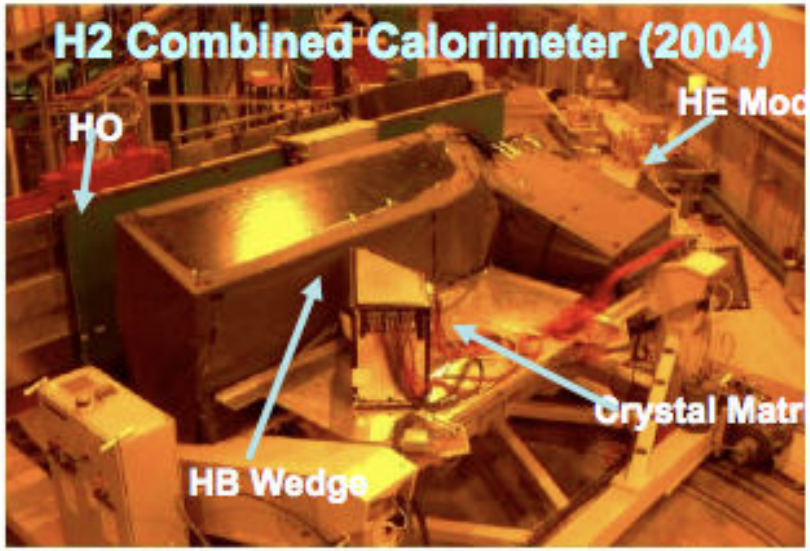


MC within ~ ±10% up to 10 λ.

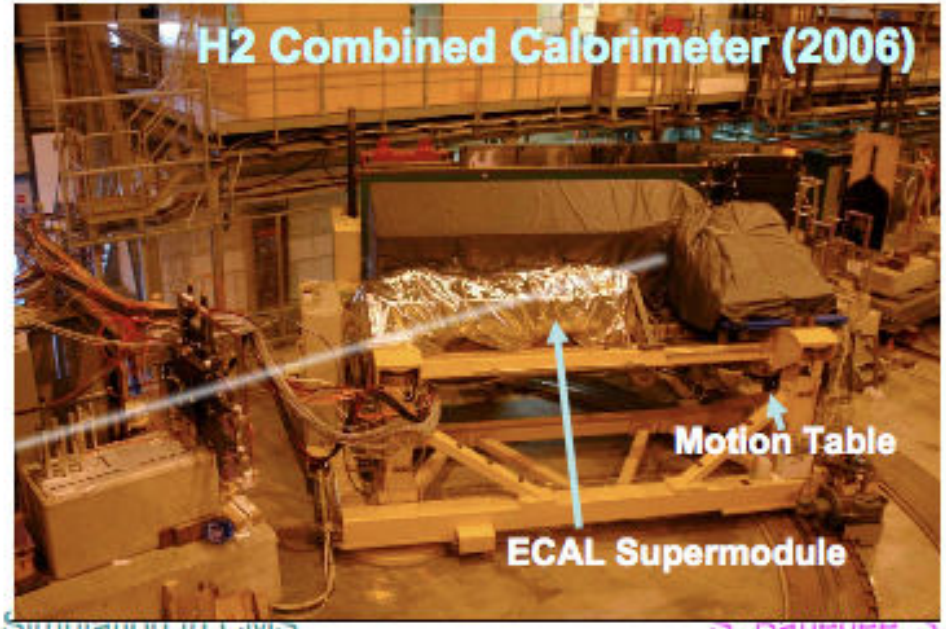
For Protons : -(20%-40%) at 10 λ.

CMS Test Beam Efforts



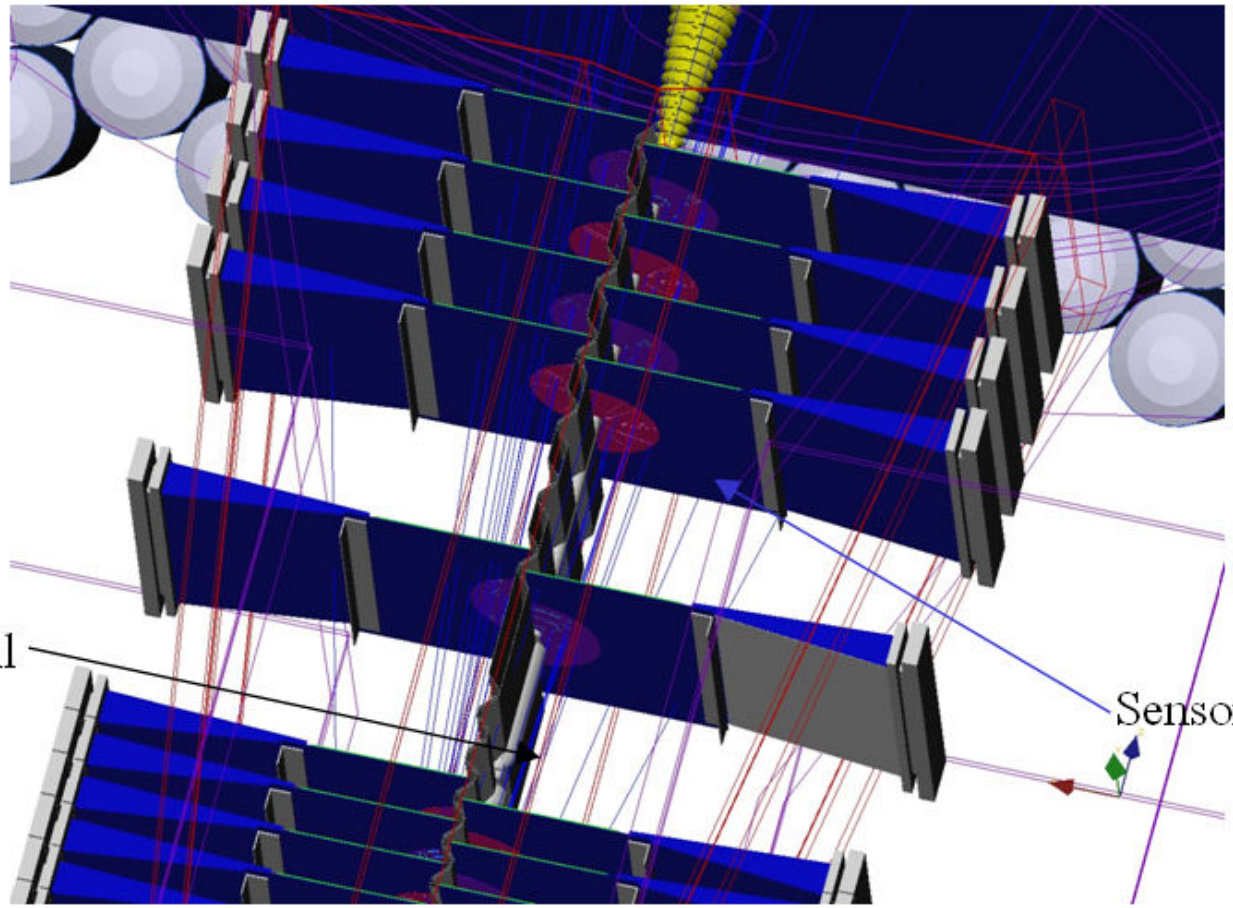


Courtesy: CMS



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!!

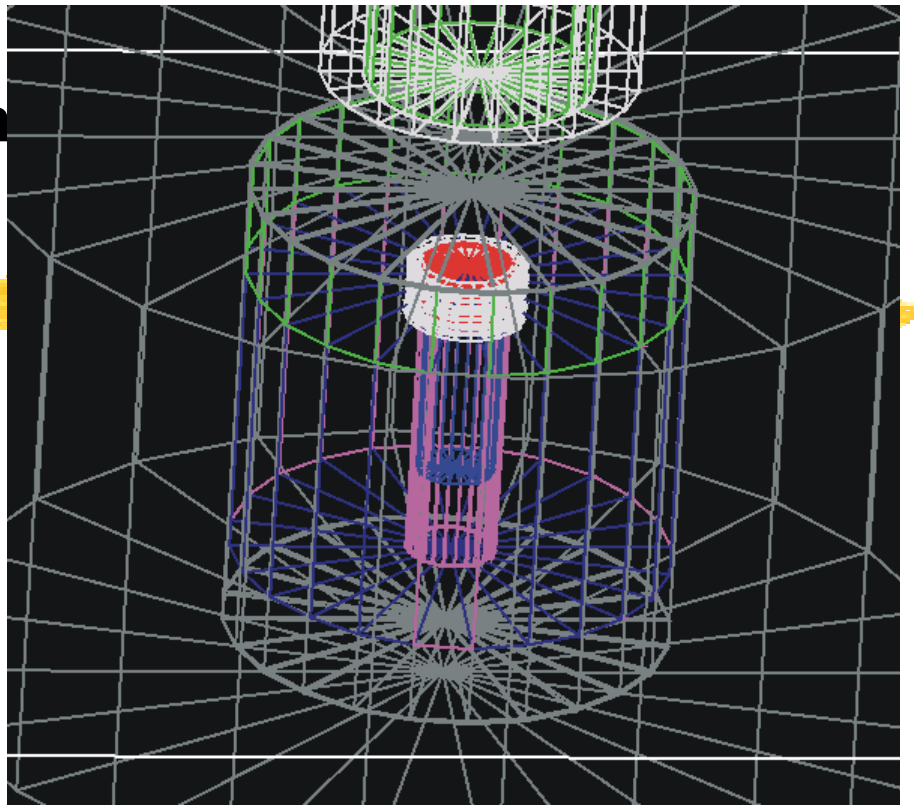
HEP: Key strengths

- 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

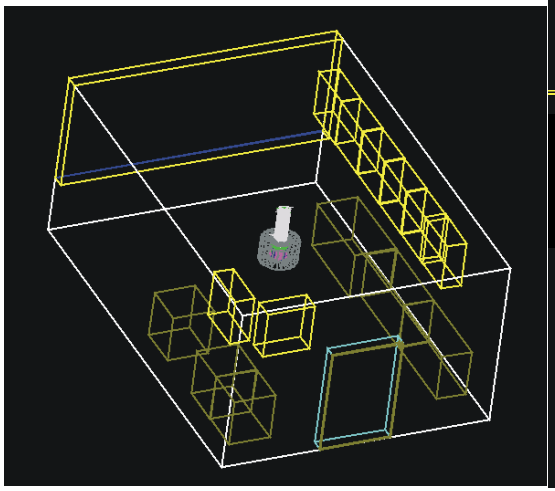
‘Near’ HEP: Experiments and accelerators

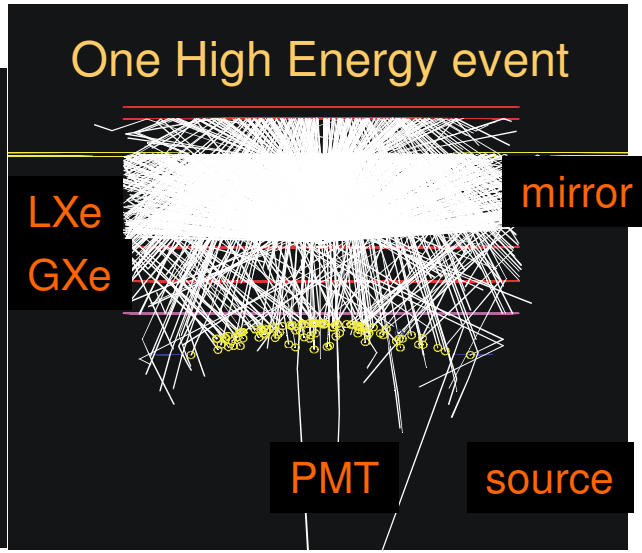
- Diverse small(er) experiments
  - Rare-Event (typically underground)
  - Nuclear
    - Model detector response
- Modeling accelerator beams
  - Effects of interactions with collimators

Boulby Mine dark matter search Prototype Simulation



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



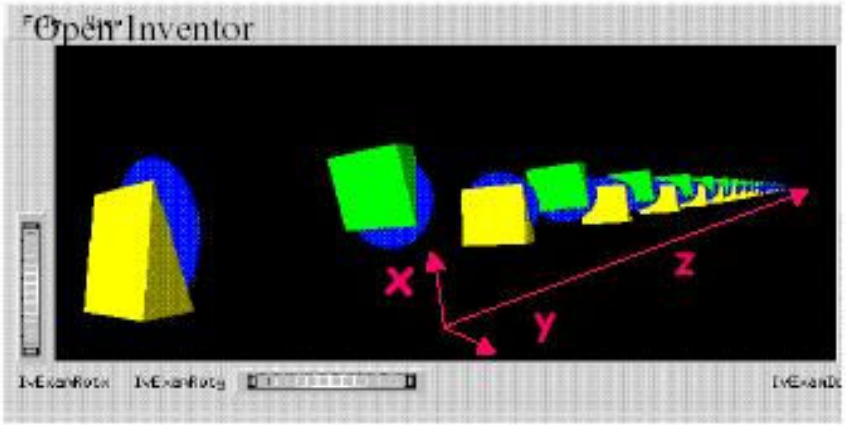


Geant4 for beam transportation

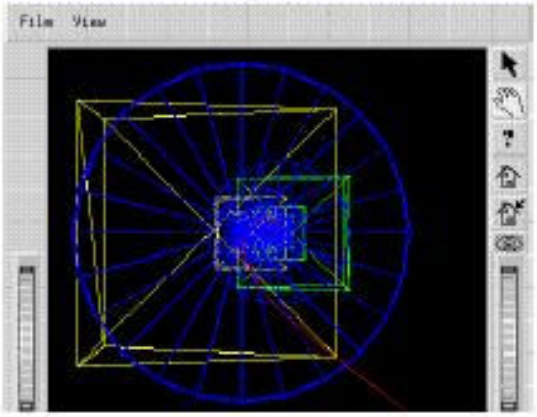
Example: Helical Channel

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

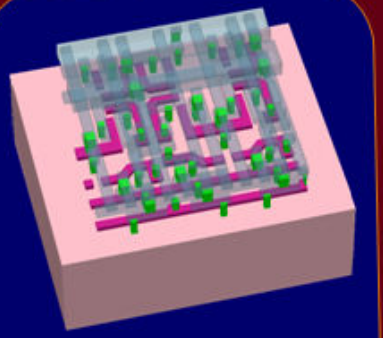
- BeamTools (FNAL, revised to 2003)
- Microbeam studies (Bordeaux)
- BDSIM
  - http://flc.pp.rhul.ac.uk/bdsim.html
- G4Beamline
  - http://www.muonsinc.com/tiki-index.php?page=G4beamline

AEROSPACE

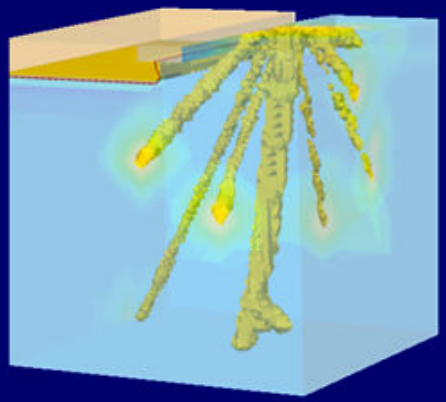
Space Applications

- 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

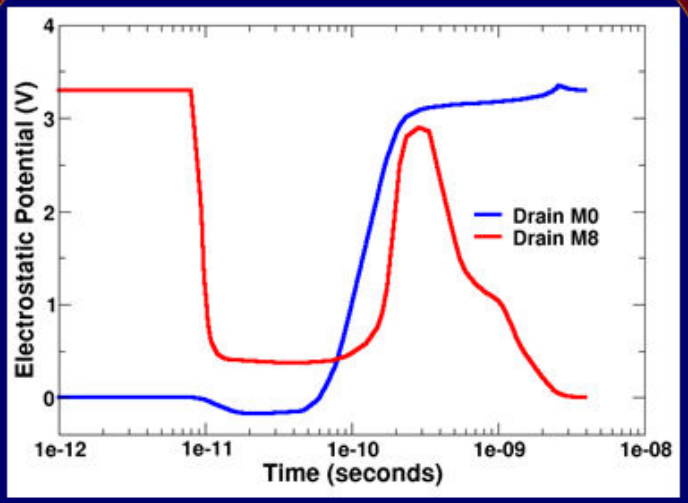
RADSAFE on SEE in SRAMs



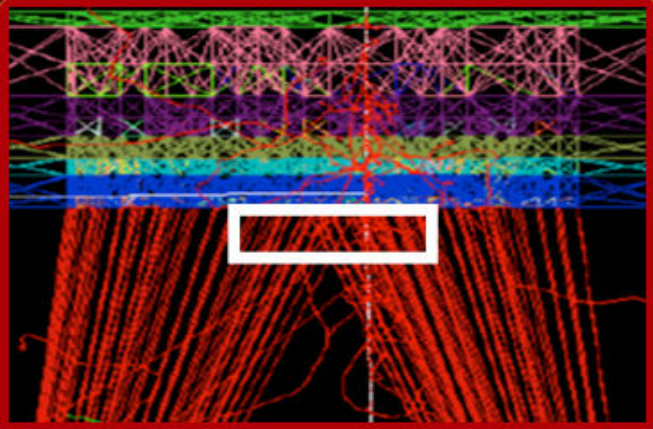
TCAD Cell Structure: SRAM Cell



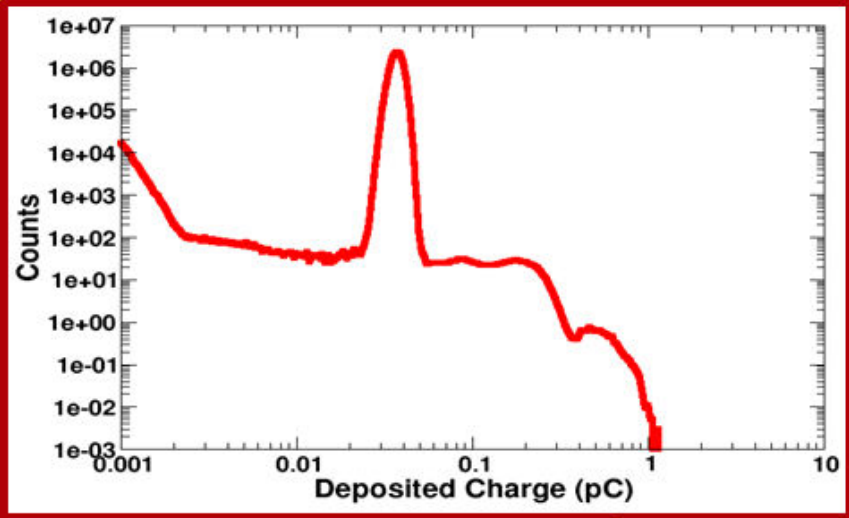
Single Charge Deposition in TCAD: Ne+W Event



SRAM Cell Upset



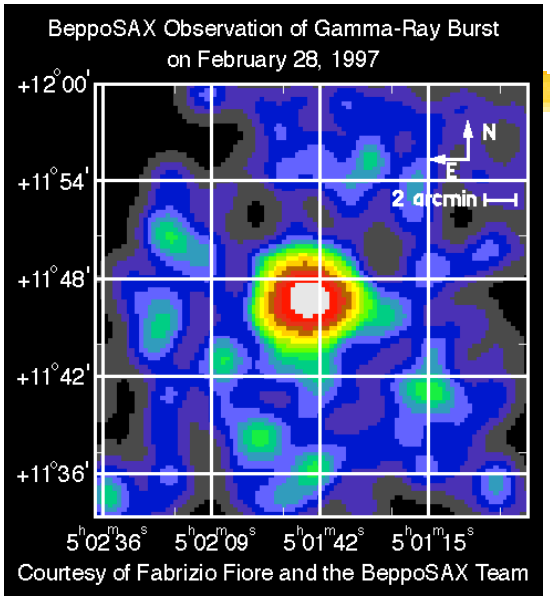
Geant4 Geometry and 523 MeV Neon Event

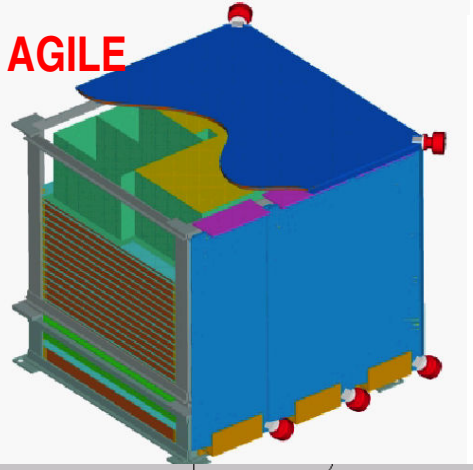


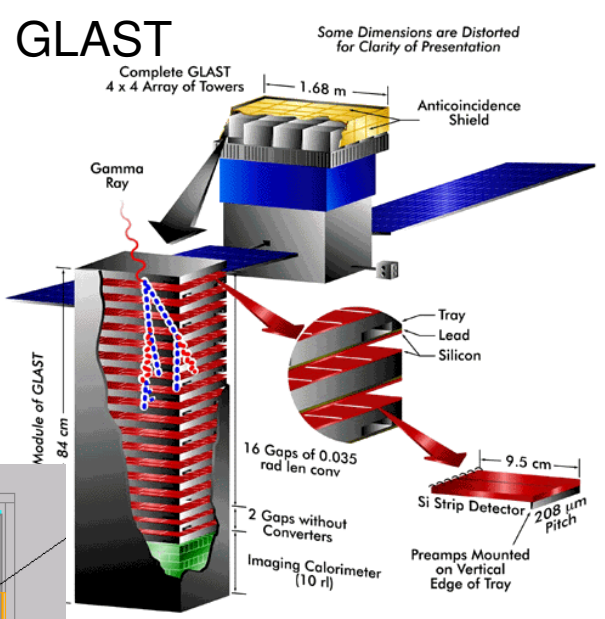
MRED Energy Deposition for 10^8 Events

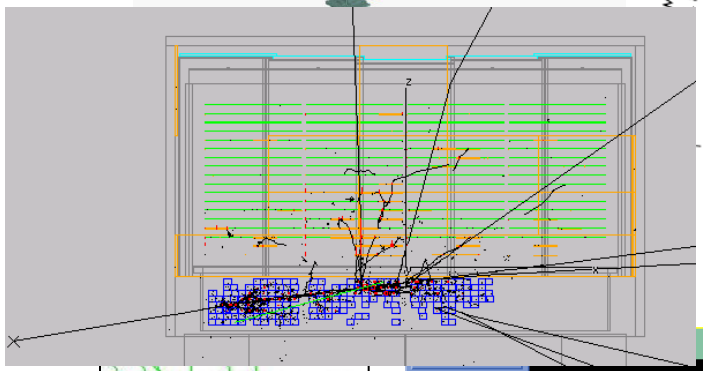
γ astrophysics

γ-ray bursts

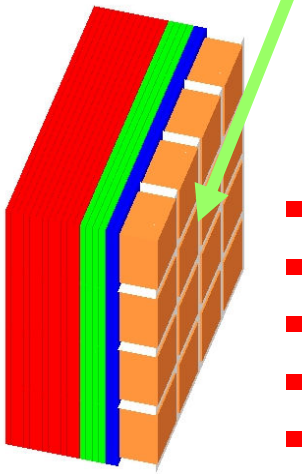






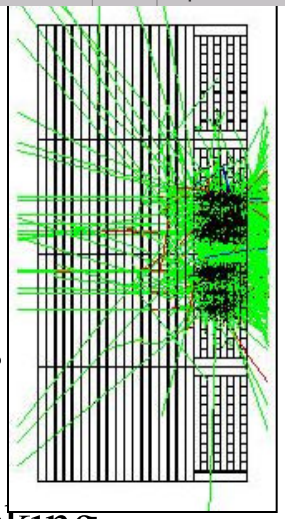


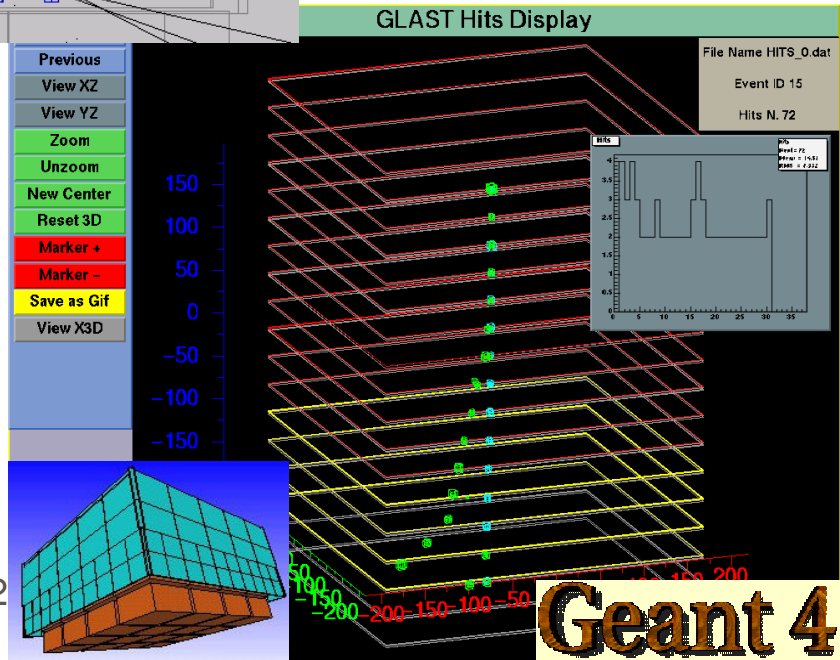
GLAST



Typical telescope:
Tracker
Calorimeter
Anticoincidence

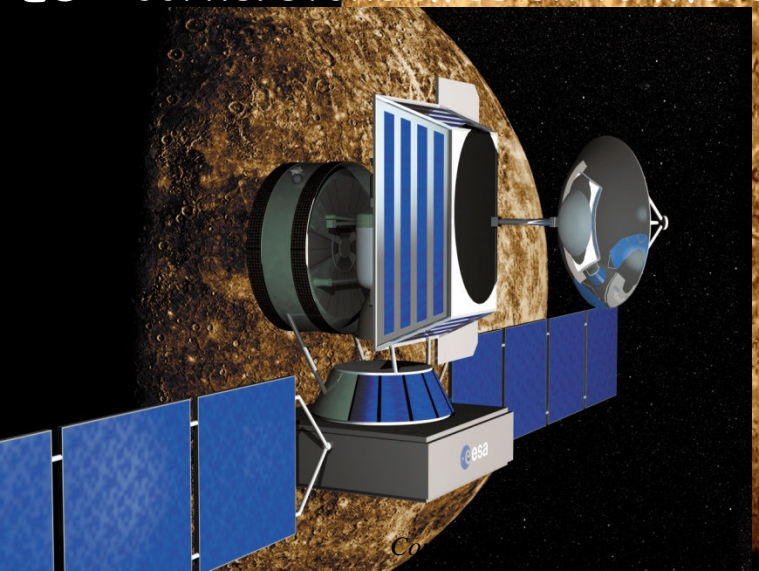
- γ conversion
- electron interactions
- multiple scattering
- δ-ray production
- charged particle tracking

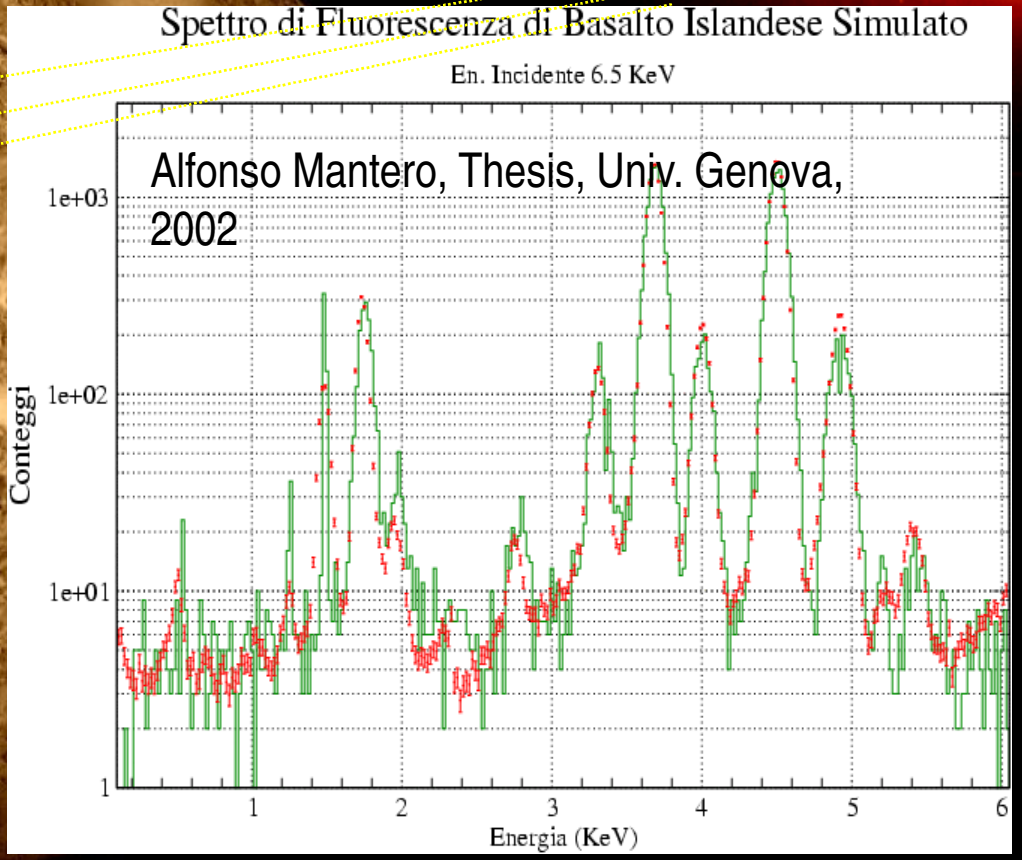




Bepi Colombo: X-Ray Mineralogical Survey of Mercury

BepiColombo
ESA cornerstone mission to Mercury





PlanetoCosmics

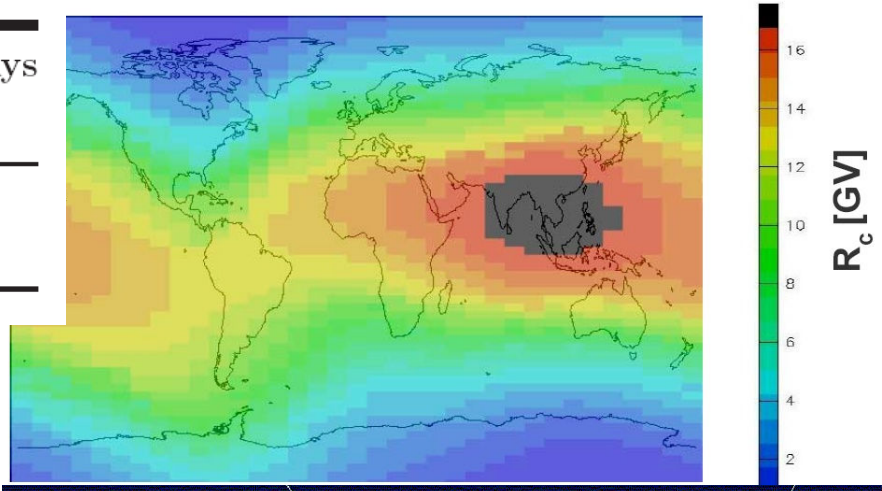
Geant4 simulation of Cosmic Rays in planetary Atmo-/Magneto- spheres

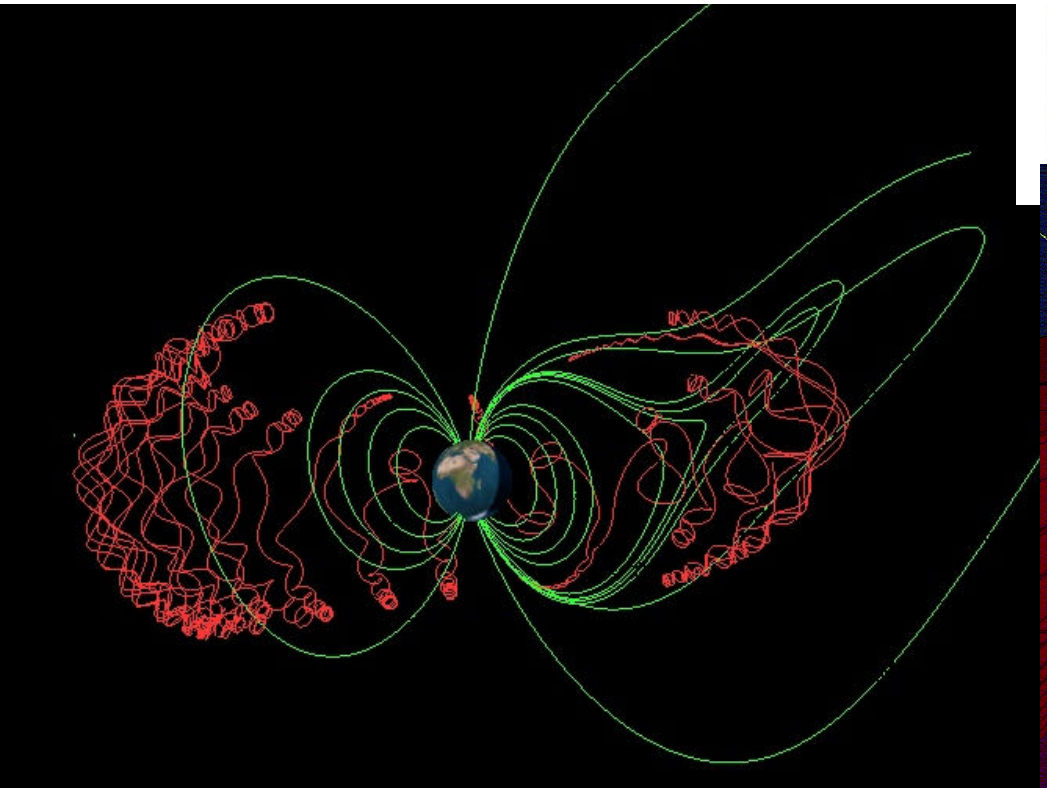
28th International Cosmic Ray Conference — 4277

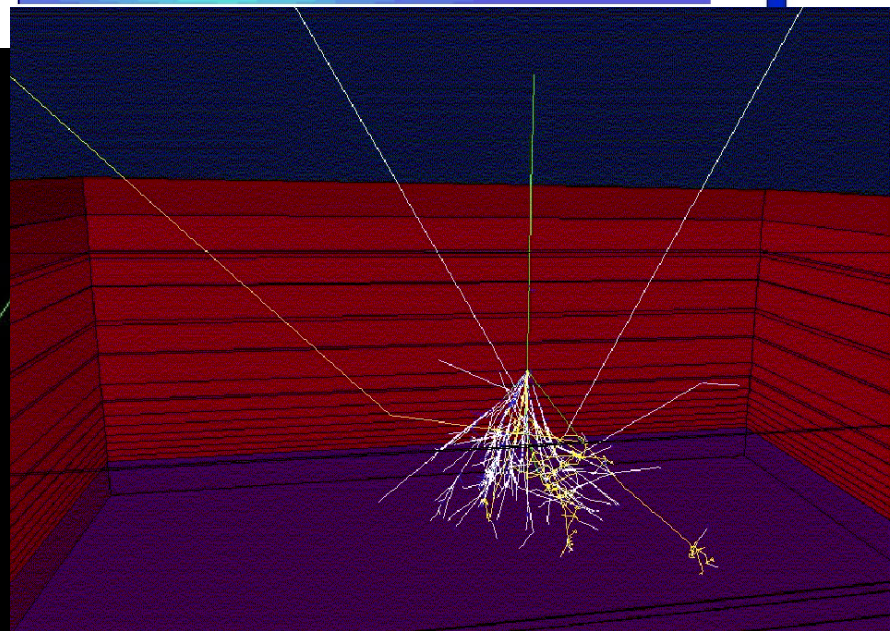
Geant4 Simulation of the Propagation of Cosmic Rays through the Earth's Atmosphere

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

Cutoff Rigidities vs position

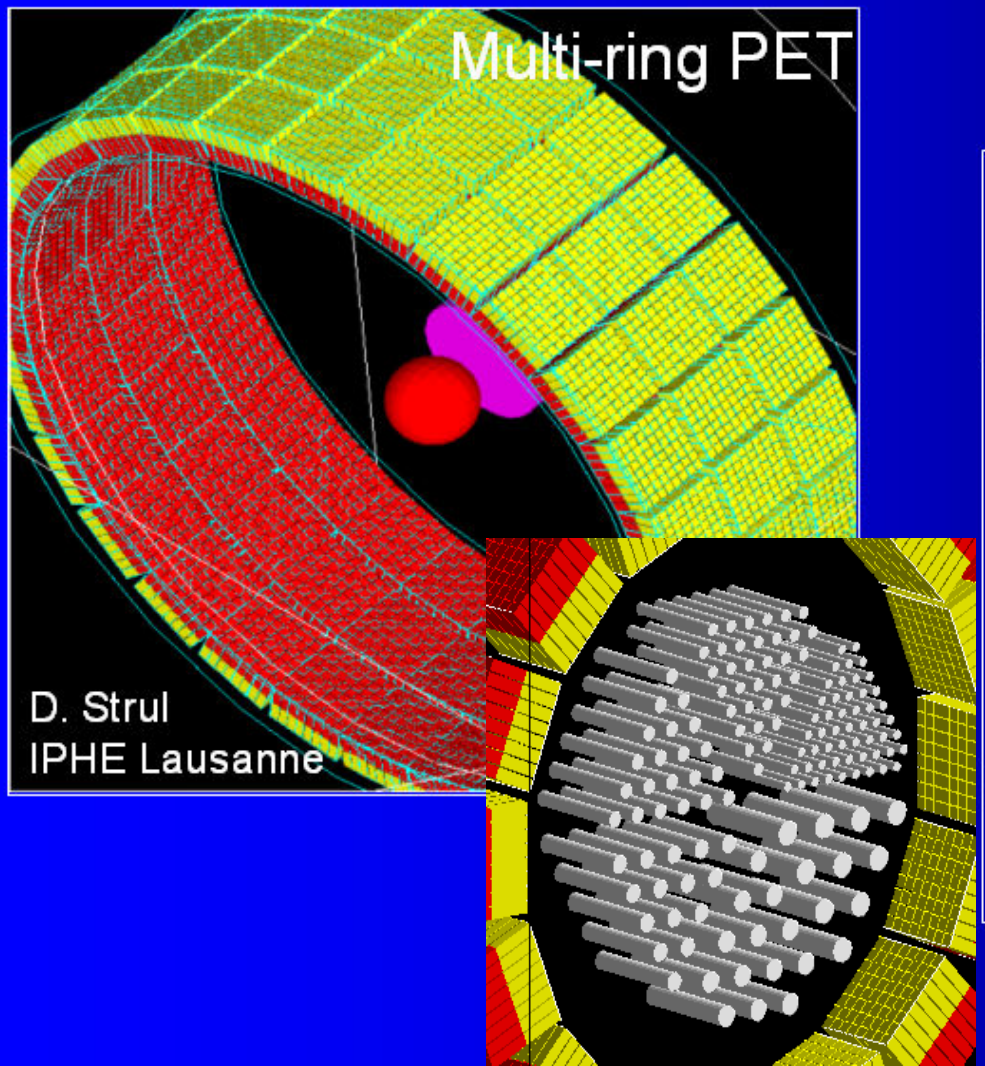


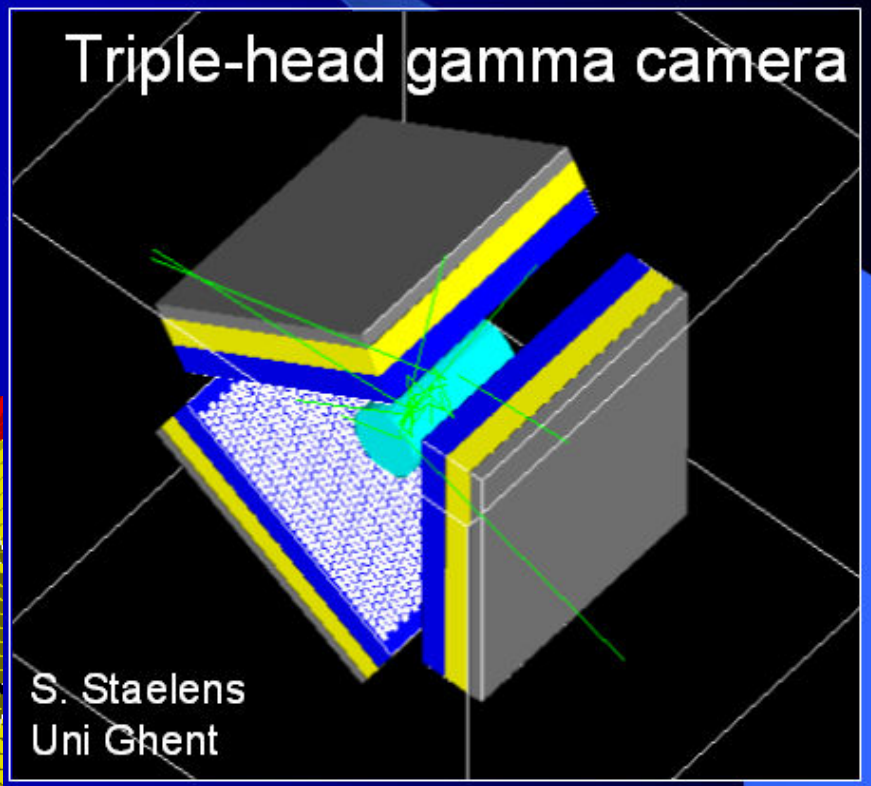




MEDICAL PHYSICS

Geometry examples of GATE applications





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

SCIENCE DIRECT

TOP 25 HOTTEST ARTICLES ON ScienceDirect

INTRODUCTION

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Journal: [all journals]

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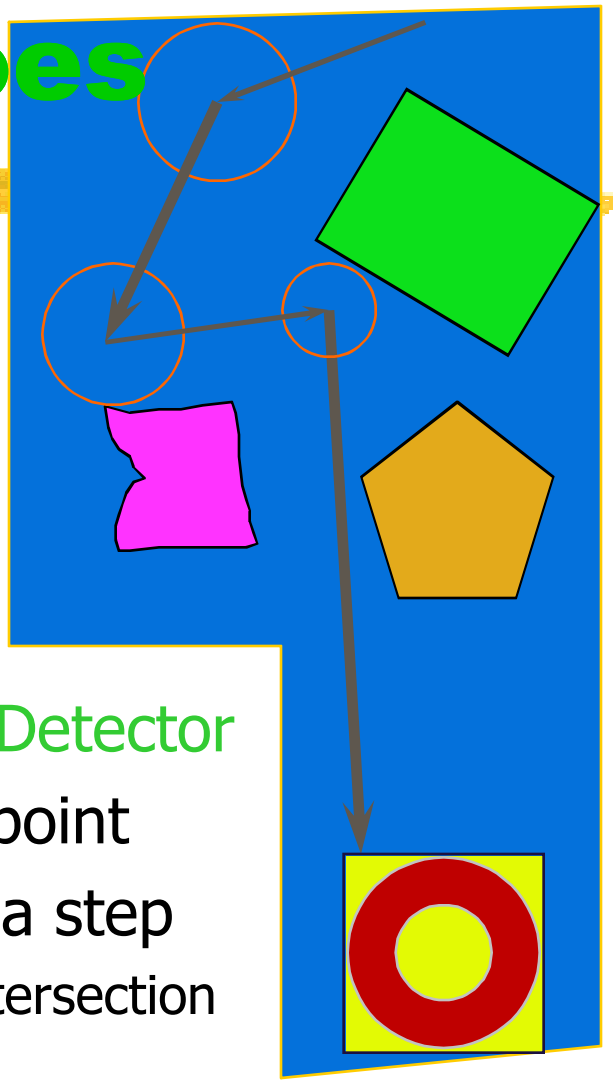
TOP25 articles within the subject area: Physics and Astronomy

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

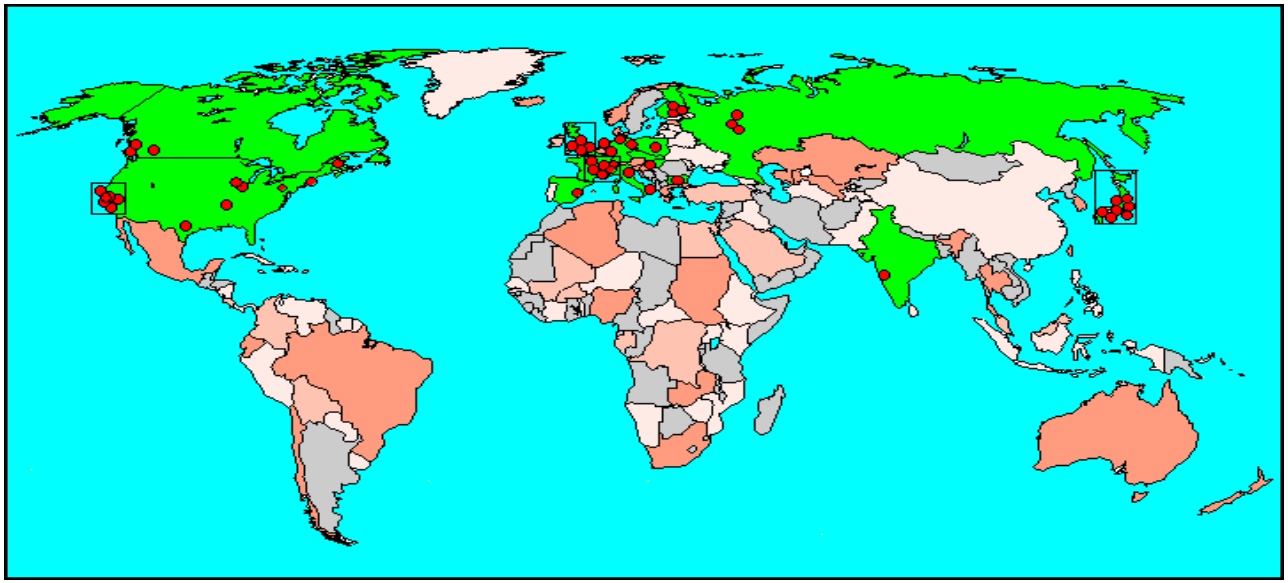
- Hadronic physics is included in Geant4
  - a powerful and flexible framework and
  - implementations of physics X-sections & models.
- A variety of models and cross-sections
  - for each energy regime, particle type, material
  - alternatives with different strengths and computing resource requirements
- 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)

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

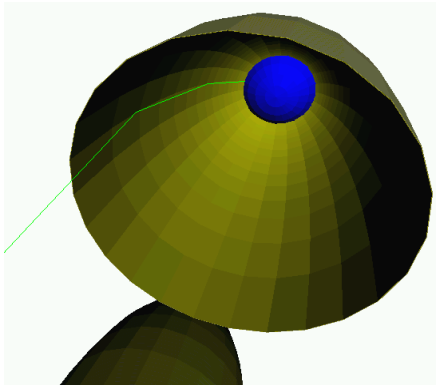
Note: "Training" page is also directly accessed at http://cern.ch/geant4/milestones/training/training-milestone.html

- 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



Practical considerations

- Starting off / Installation
  - Need CLHEP, vis 'drivers'
  - Compatible platform
- Interacting with an application
  - Command line interface
    - /gun/particle proton
    - /run/beamOn 10
  - GUI
- 'Coding' (if necessary)
  - Modifying existing C++ 'code' to describe your setup
  - For advanced uses, creating you own class to describe eg a magnetic field.

Platforms

- What works 'best'
  - Linux and gcc 3.2.3
    - most developers & HEP institutions use this
    - Today Jan 2005 'Scientific Linux' 3 and 4
  - Windows (XP) & Vis C++ 7.1
    - numerous users
- What we expect to work
  - Other Linux flavours with
    - Gcc 3.2.3, 3.4.6, 4.1.1
    - Possibly with fewer options, eg missing some visualisation
- What others 'ported' and check
  - Mac OS X, Sun Solaris

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

Before: Two public releases per year.

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

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

MoU-based Collaboration

G4 license, New G4 collaboration

Acknowledgements

Thanks to those who have contributed

-to creating slides for tutorials / talk, that I borrowed

Thanks to all those who have contributed

-to the development of Geant4,

-to its validation for these and other application areas,

-to those who have applied it

-particularly those who have given feedback.

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