Introduction to Geant4

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Geant4 Seminar

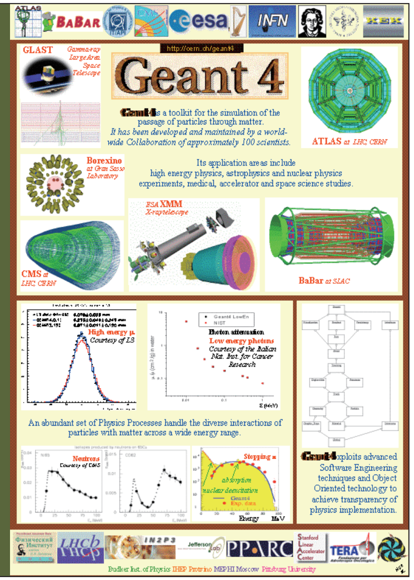
5th Geant4 Space Users Workshop

12/Feb/2008

Geant 4

Contents

- General introduction and brief history
- Highlights of user applications
- Geant4 kernel
  - Overview
  - Geometry
  - Tracking and physics process
  - Event biasing
  - Scoring
- Geant4 license
- Geant4 user support processes



General introduction and brief history

What is Geant4?

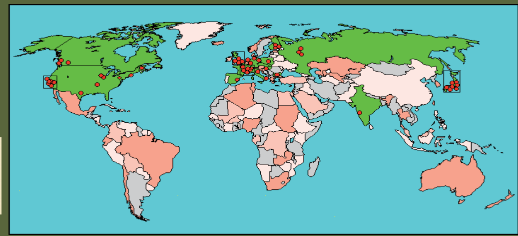
- Geant4 is the successor of GEANT3, the world-standard toolkit for HEP detector simulation.
- Geant4 is one of the first successful attempt to re-design a major package of HEP software for the next generation of experiments using an Object-Oriented environment.
- A variety of requirements have also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

Geant4 – Its history

- Dec '94 - Project start
- Apr '97 - First alpha release
- Jul '98 - First beta release
- Dec '98 - First Geant4 public release
- ...
- May 4th, '07 - Geant4 version 8.3 release
  - Aug 17th, '07 - Geant4 8.3-patch01 release
  - Feb 5th, '08 - Geant4 8.3-patch02 release
- June 29th, '07 - Geant4 version 9.0 release
  - Aug 28th, '07 - Geant4 9.0-patch01 release
  - Feb 5th, '08 - Geant4 9.0-patch02 release
- Dec 14th, '07 - Geant4 version 9.1 release
  - Feb 5th, '08 - Geant4 9.1-patch01 release ← Current version
- We currently provide two to three public releases every year.
  - Bimonthly beta releases are available to the registered beta-testers.

Geant4 Collaboration

IT/API
esa
INFN
KEK
Stanford Linear Accelerator Center
TRIUMF



LIP
Jefferson Lab
Lebedev
IN2P3
HELSINKI INSTITUTE OF PHYSICS
J.W.Goethe Universität
PPARC
UNIVERSITAT DE BARCELONA

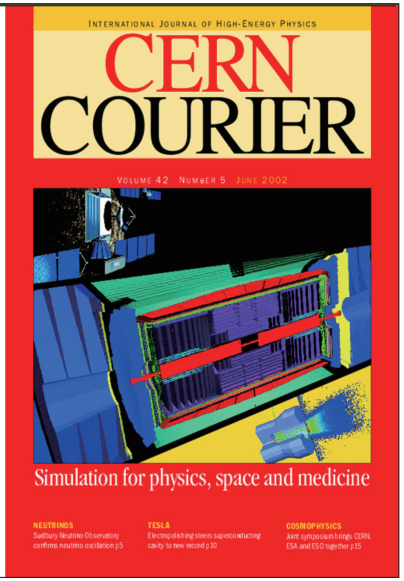
Collaborators also from non-member institutions, including
Budker Inst. of Physics
IHEP Protvino
MEPHI Moscow
Pittsburg University

Technology transfer

Particle physics software aids space and medicine

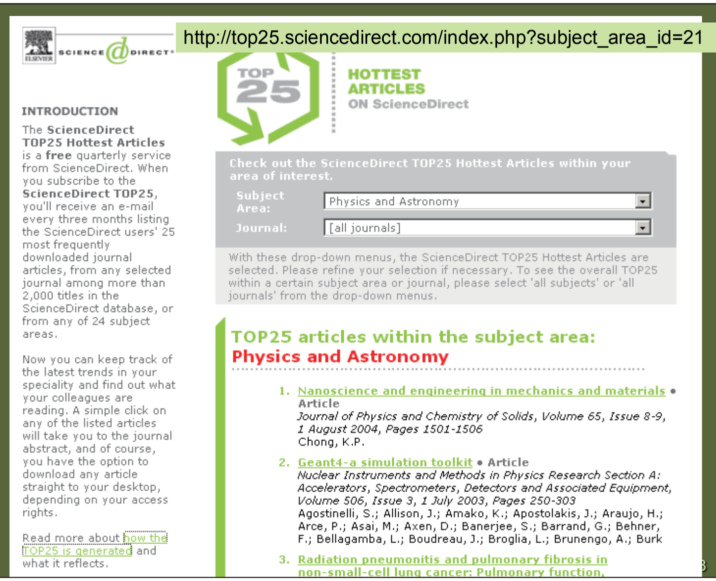
Geant4 is a showcase example of technology transfer from particle physics to other fields such as space and medical science [...].

CERN Courier, June 2002



Geant 4

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




http://www.in-cites.com/hotpapers/2004/november04-eng.html
The Top 3 Hot Papers
Engineering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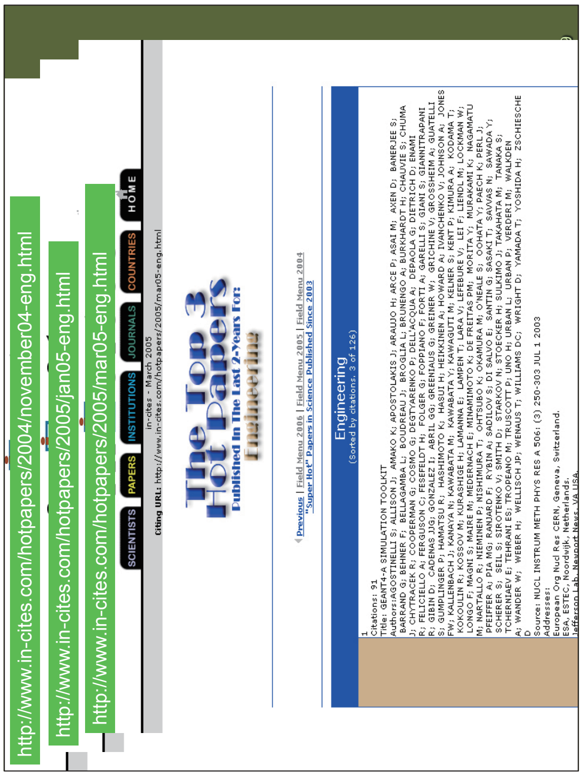
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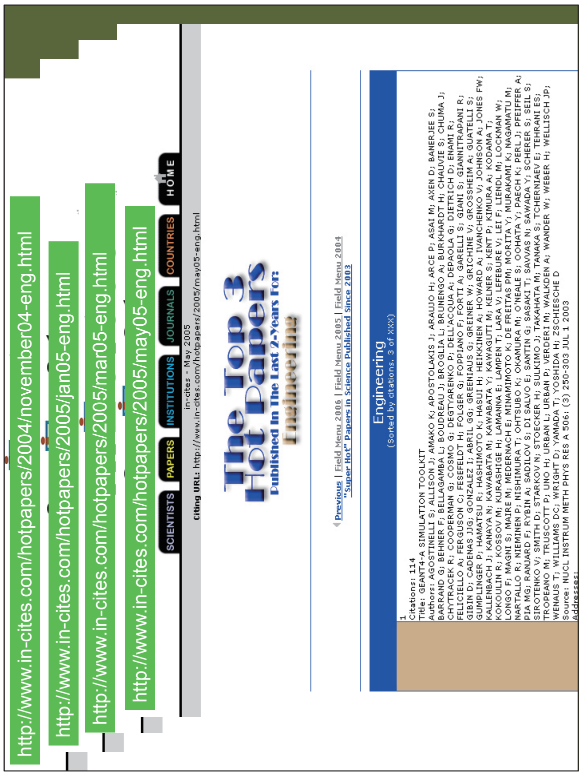
The Top 3 Hot Papers
Engineering


http://www.in-cites.com/hotpapers/2004/november04-eng.html
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http://www.in-cites.com/hotpapers/2005/july05-eng.html

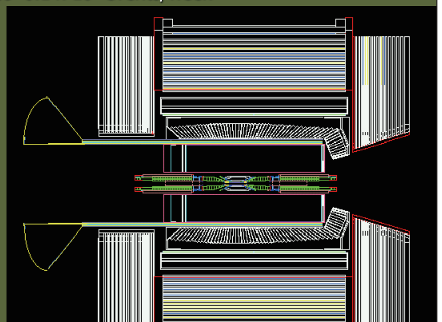
Highlights of Users Applications

To provide you some ideas how Geant4 would be utilized…

Introduction to Geant4 (SLAC) M.Asai

BaBar

- BaBar at SLAC is the pioneer experiment in HEP in use of Geant4
  - Started in 2000
  - Simulated 10^{10} events so far
  - Produced at 20 sites in North America and Europe
  - Current average production rate 6.1 x 10^7 events/week



Courtesy of D.Wright (SLAC)

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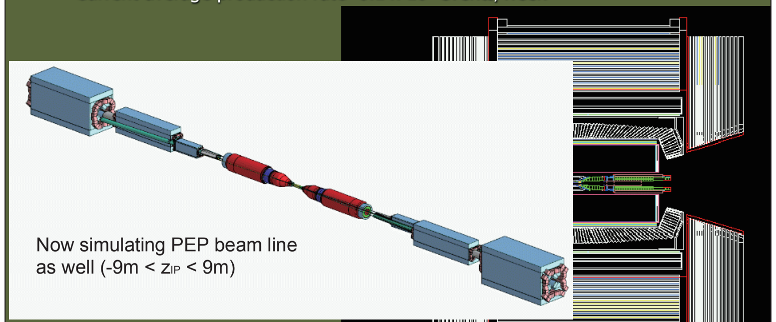

Courtesy of D.Wright (SLAC)

Geant 4

Geant4 at the LHC Today

Now Geant4 has become the standard simulation for ATLAS, LHCB, and CMS

	ATLAS	CMS	LHCb
Transition to Geant4 (G3 stopped)	DC02 '04	Nov '03	May '04
Produced # of events in DC	12 M	40 M	80 M
CPU time (sec)/ event (2.8 Ghz)	600 (pp→Z→ee) 700 (SUSY)	200 (QCD jets) 60 (min bias)	22-65
Memory used	400 Mb	220 Mb	220 Mb
# of placed volumes	5 M	1.2 M	18 M

No memory leaks!!

⇒ Observations:

- Geant4 in production is running now very stable/very few problems (~ 10^{-5})
- Transition to Geant4 has been a very smooth process for all experiments

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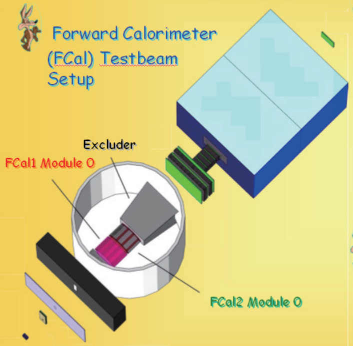
Geant 4 — Slide 7 — Geant4 Workshop September 30, 2002 — Status of the GEANT4 Physics Evaluation in ATLAS

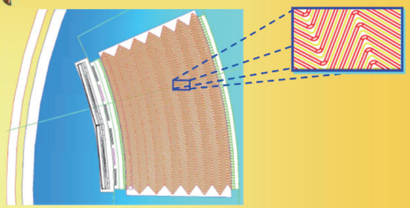
Peter Loch
University of Arizona
Tucson, Arizona 85721

Geant4 Setups (2)

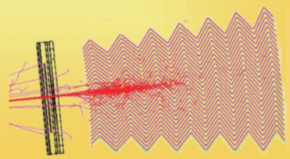
Forward Calorimeter (FCal) Testbeam Setup



Electromagnetic Barrel Accordion Calorimeter

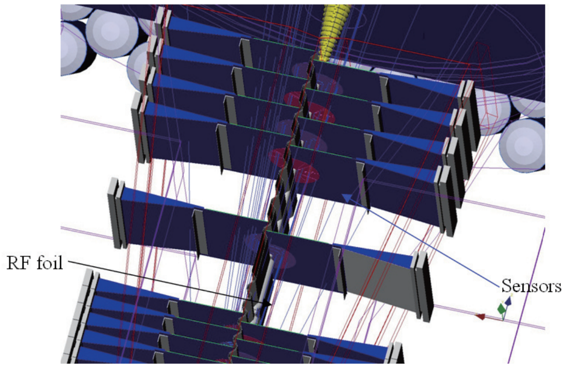


10 GeV Electron Shower



Geant 4

Geant4 at the LHC Today



Complicated geometry Details are very important

Geant4 can handle it!!

LHCb Vertex Locator description

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Geant 4

Heavy-Ion Collisions

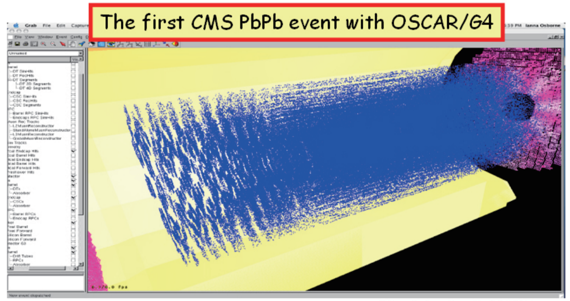
OSCAR/Geant4 can run full heavy ion events.

- Timing is good/Memory > 500 Mbyte (2GB memory machines used)
- Have now run > 100 events without problems

~ Timing for the first event with 55K generator tracks

Program	CPU (2.8GHz) (min)
CMSIM	230
OSCAR 2_4_5	320
OSCAR 3_4_0	180

The first CMS PbPb event with OSCAR/G4



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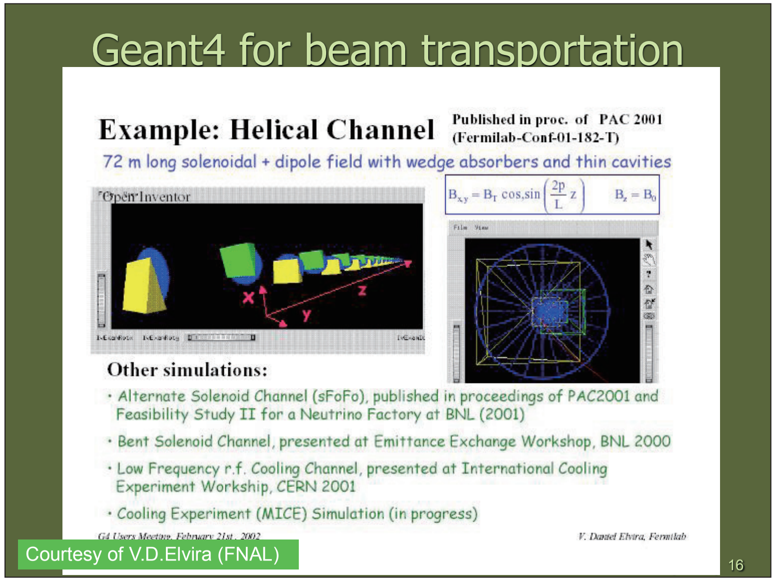
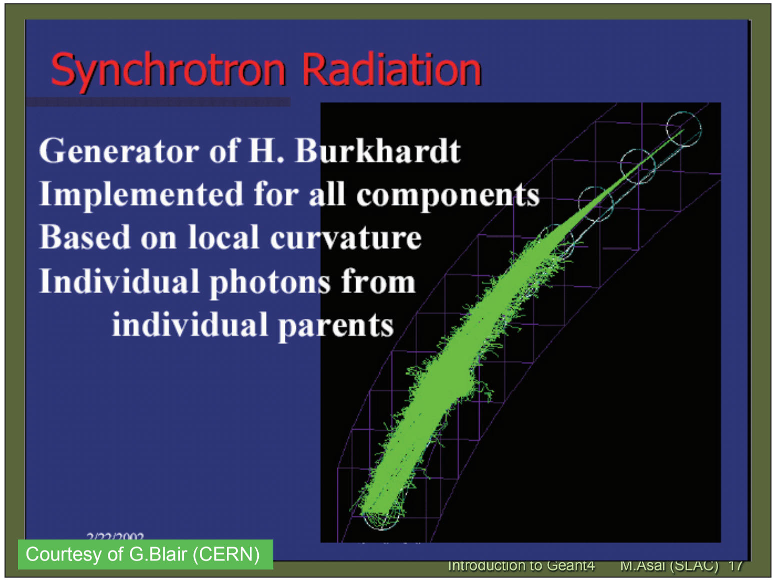
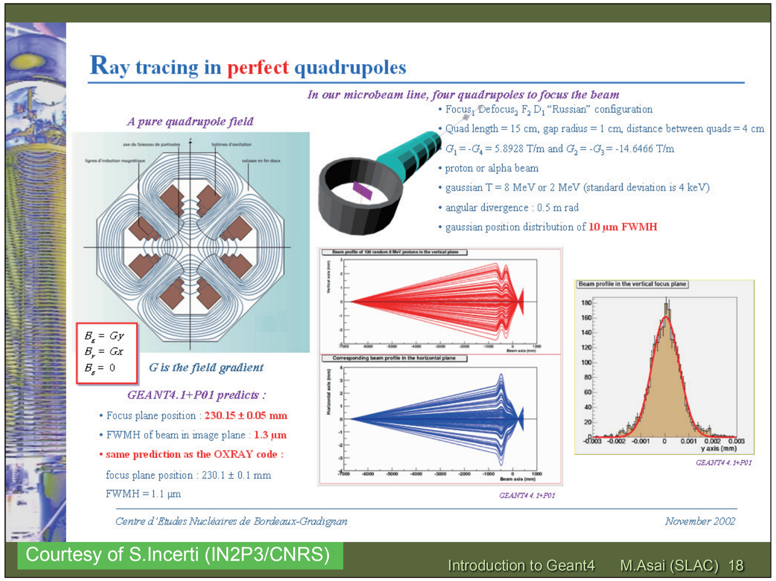

Geant4 for beam transportation
Example: Helical Channel
Published in proc. of PAC 2001 (Fermilab-Conf-01-182-T)
72 m long solenoidal + dipole field with wedge absorbers and thin cavities
Other simulations:
Alternate Solenoid Channel (sFoFo), published in proceedings of PAC2001 and Feasibility Study II 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)
V. Daniel Elvira, Fermilab
Courtesy of V.D.Elvira (FNAL)
16


Synchrotron Radiation
Generator of H. Burkhardt
Implemented for all components
Based on local curvature
Individual photons from individual parents
Courtesy of G.Blair (CERN)
Introduction to Geant4 M.Asai (SLAC) 17


Ray tracing in perfect quadrupoles
In our microbeam line, four quadrupoles to focus the beam
A pure quadrupole field
G is the field gradient
Focus, Defocus, F, D, "Russian" configuration
Quad length = 15 cm, gap radius = 1 cm, distance between quads = 4 cm
proton or alpha beam
gaussian T = 8 MeV or 2 MeV (standard deviation is 4 keV)
angular divergence : 0.5 m rad
gaussian position distribution of 10 µm FWHM
GEANT4.1+P01 predicts :
Focus plane position : 230.15 ± 0.05 mm
FWHM of beam in image plane : 1.3 µm
same prediction as the OXRAY code :
focus plane position : 230.1 ± 0.1 mm
FWHM = 1.1 µm
Centre d'Etudes Nucléaires de Bordeaux-Gradignan
November 2002
Courtesy of S.Incerti (IN2P3/CNRS)
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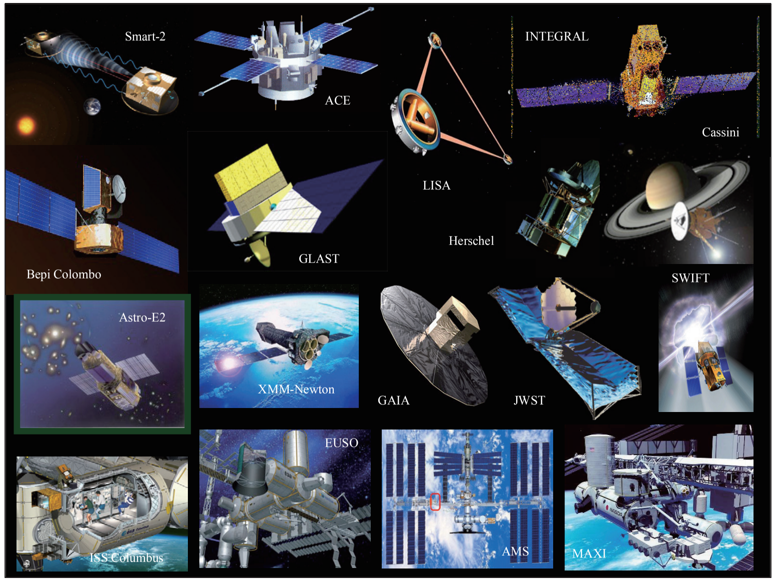
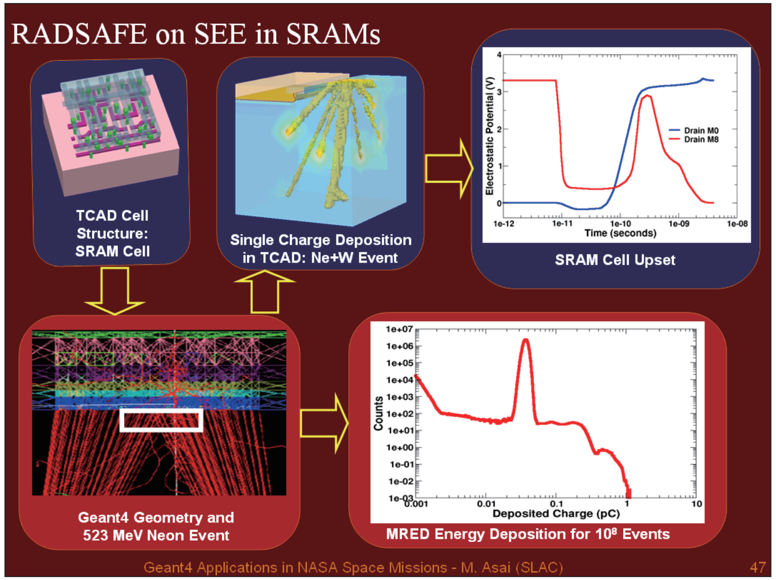
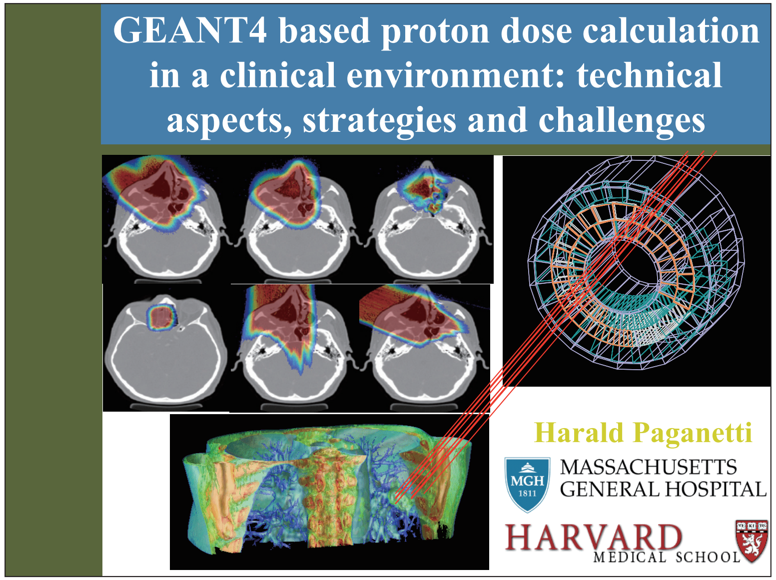
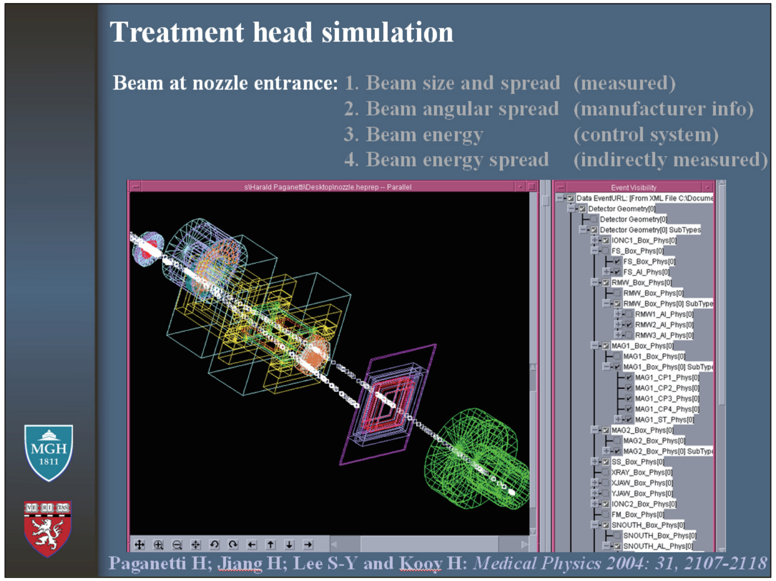
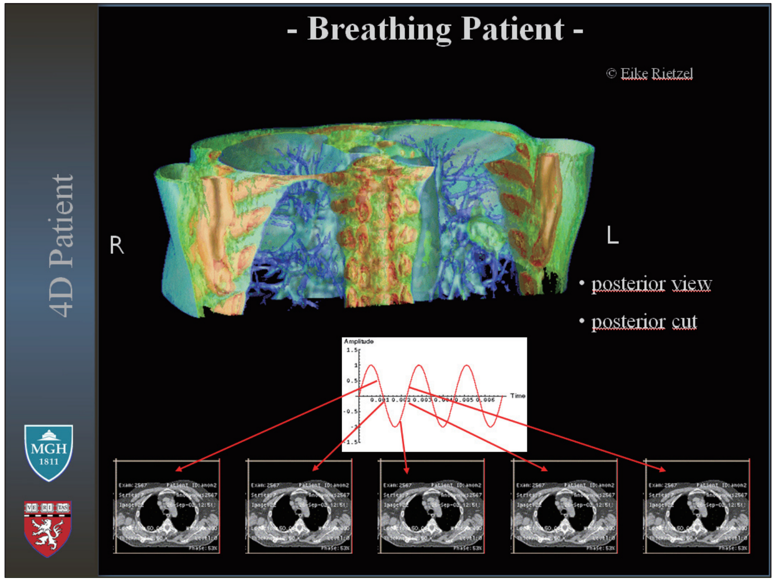
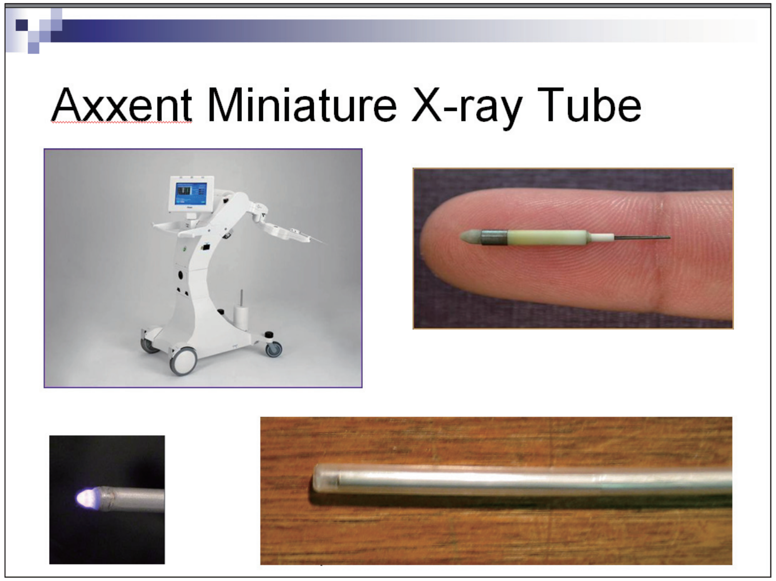

Smart-2
ACE
LISA
INTEGRAL
Cassini
Bepi Colombo
GLAST
Herschel
SWIFT
Astro-E2
XMM-Newton
GAIA
JWST
ISS Columbus
EUSO
AMS
MAXI

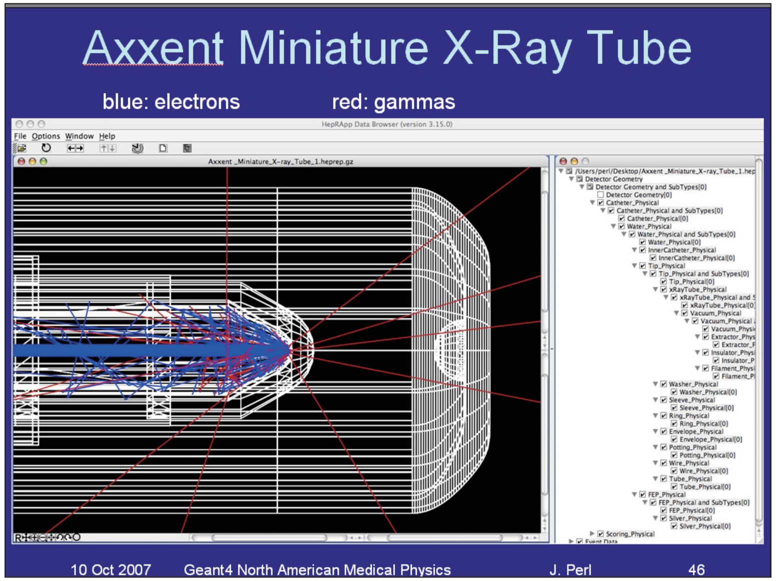

RADSAFE on SEE in SRAMs
TCAD Cell Structure: SRAM Cell
Single Charge Deposition in TCAD: Ne+W Event
Electrostatic Potential (V)
Time (seconds)
Drain M0
Drain M8
SRAM Cell Upset
Geant4 Geometry and 523 MeV Neon Event
Counts
Deposited Charge (pC)
MRED Energy Deposition for 10^8 Events
Geant4 Applications in NASA Space Missions - M. Asai (SLAC)
47

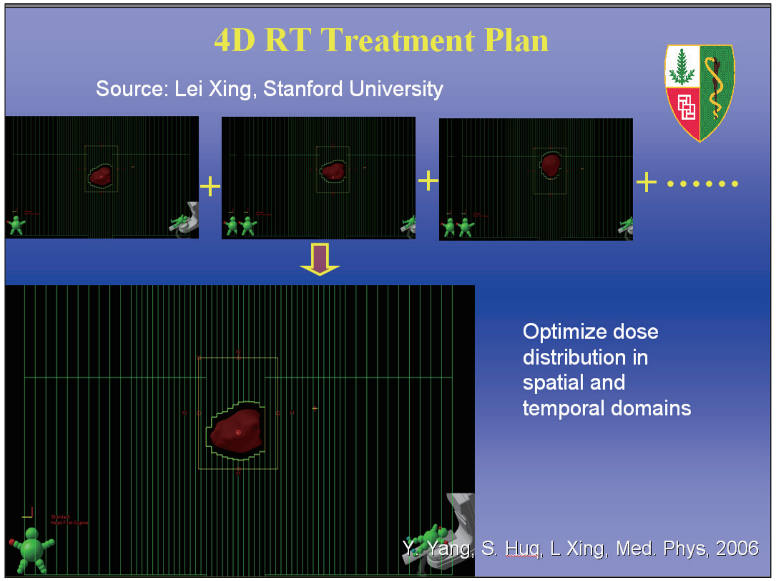

GEANT4 based proton dose calculation in a clinical environment: technical aspects, strategies and challenges
Harald Paganetti
MASSACHUSETTS GENERAL HOSPITAL
HARVARD MEDICAL SCHOOL

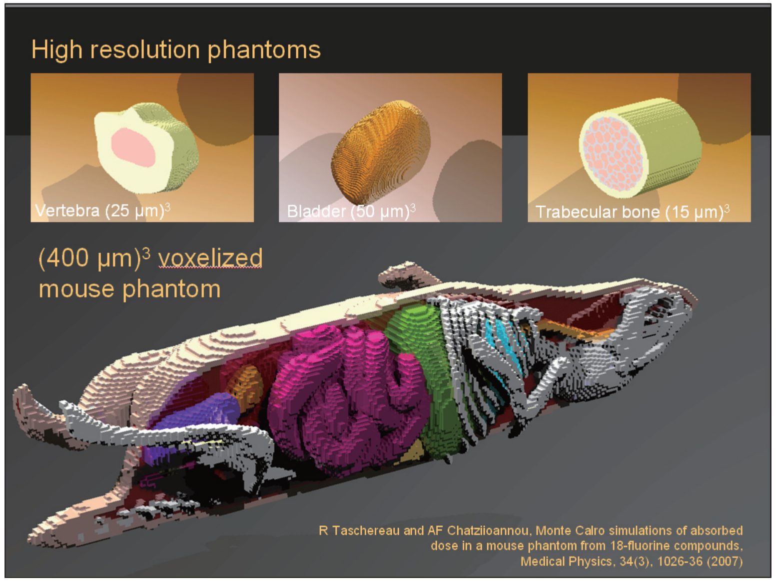

Treatment head simulation
Beam at nozzle entrance: 1. Beam size and spread (measured)
2. Beam angular spread (manufacturer info)
3. Beam energy (control system)
4. Beam energy spread (indirectly measured)
Paganetti H; Jiang H; Lee S-Y and Kooy H: Medical Physics 2004: 31, 2107-2118


4D Patient
- Breathing Patient -
© Eike Rietzel
R
L
• posterior view
• posterior cut

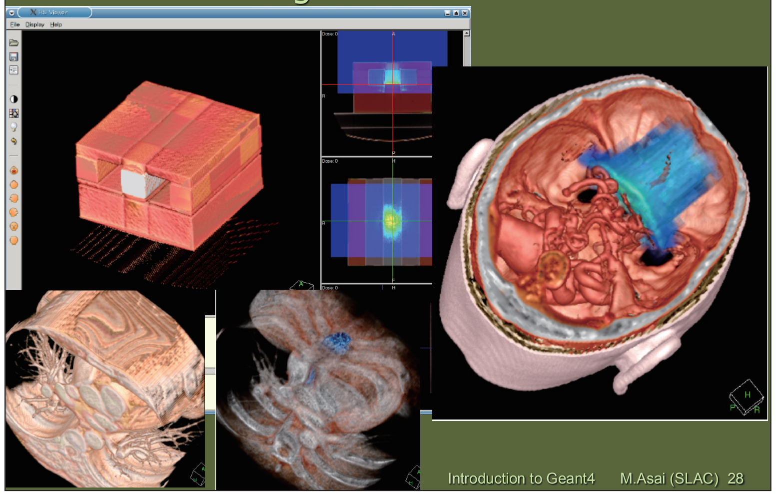

Axxent Miniature X-ray Tube


Axxent Miniature X-Ray Tube
blue: electrons
red: gammas
10 Oct 2007
Geant4 North American Medical Physics
J. Perl
46


4D RT Treatment Plan
Source: Lei Xing, Stanford University
Optimize dose distribution in spatial and temporal domains
Y. Yang, S. Huq, L Xing, Med. Phys, 2006

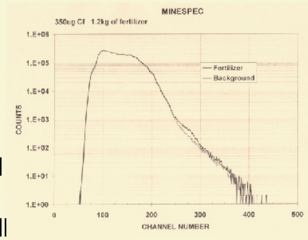

High resolution phantoms
Vertebra (25 μm)³
Bladder (50 μm)³
Trabecular bone (15 μm)³
(400 μm)³ voxelized mouse phantom
R Taschereau and AF Chatziioannou, Monte Calro simulations of absorbed dose in a mouse phantom from 18-fluorine compounds, Medical Physics, 34(3), 1026-36 (2007)

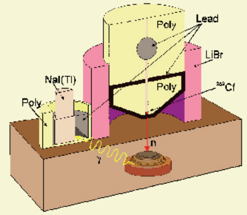
Screen shots of "gMocren" viewer of DICOM image and dose distribution



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





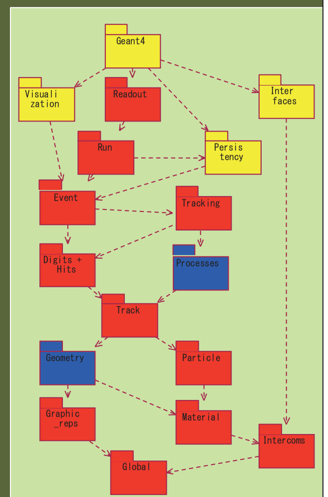
Defence Research Establishment Suffield • Centre de recherches pour la défense, Suffield

A. A. Faust, Geant4 User's Workshop, SLAC 2002 02 21

Geant4 kernel
- overview -

Geant4 structure

- Geant4 consists of 17 categories.
  - Developed and maintained by Working Groups responsible for each category.
  - Interfaces between categories largely stable, with some evolution.
- Geant4 Kernel
  - Handles run, event, track, step, hit, trajectory, etc.
  - Provides frameworks of geometrical representation and physics processes.
  - Interfaces to visualization and GUI.



Geant4 kernel
- geometry -

Introduction to Geant4 (SLAC) M.Asai

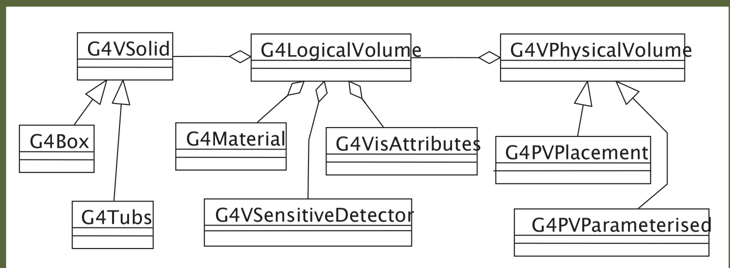
Key geometry capabilities

- Describing a setup as hierarchy or "flat" structure
  - Describing setups up to billions of volumes
  - Tools for creating & checking complex structures
  - Interface to CAD
- Navigating fast in complex geometry model
  - Automatic optimization
    - in some cases 20 times or more faster than GEANT 3.21
- Geometry models can be 'dynamic'
  - Changing the setup at run-time, e.g. "moving objects"
- Parallel virtual geometries
  - For hits/readout, biasing/scoring, fast simulation.
- Defining geometrical "regions"
  - For physics optimization: choice of production threshold, triggering of fast simulation, user limits, etc.

Introduction to Geant4 M.Asai (SLAC) 33

Define detector geometry

- Three conceptual layers
  - G4VSolid -- shape, size
  - G4LogicalVolume -- daughter physical volumes, material, sensitivity, user limits, etc.
  - G4VPhysicalVolume -- position, rotation



Introduction to Geant4 M.Asai (SLAC) 34

Define detector geometry

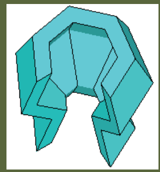
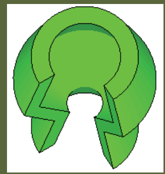
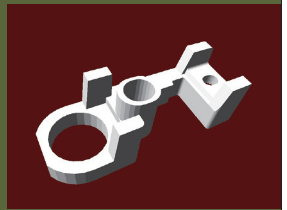
- Basic strategy

```
G4VSolid* pBoxSolid =
  new G4Box("aBoxSolid", 1.*m, 2.*m, 3.*m);
G4LogicalVolume* pBoxLog =
  new G4LogicalVolume( pBoxSolid, pBoxMaterial,
                       "aBoxLog", 0, 0, 0);
G4VPhysicalVolume* aBoxPhys =
  new G4PVPlacement( pRotation,
    G4ThreeVector(posX, posY, posZ), pBoxLog,
    "aBoxPhys", pMotherLog, 0, copyNo);
```

Introduction to Geant4 M.Asai (SLAC) 35

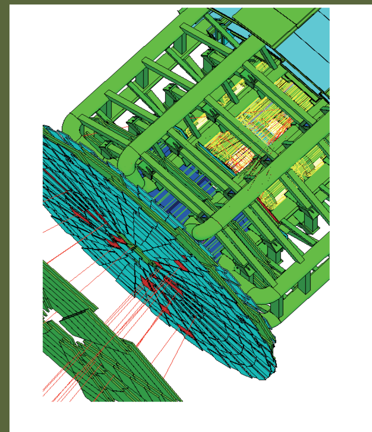
Solids

- Solids defined in Geant4:
  - CSG (Constructed Solid Geometry) solids
    - G4Box, G4Tubs, G4Cons, G4Trd, …
    - Analogous to simple GEANT3 CSG solids
  - Specific solids (CSG like)
    - G4Polycone, G4Polyhedra, G4Hype, …
  - BREP (Boundary REPresented) solids
    - G4BREPSolidPolycone, G4BSplineSurface, …
    - Any order surface
  - Tessellated solid
    - A generic solid defined by a number of facets
    - Facets can be triangular or quadrangular
  - Boolean solids
    - G4UnionSolid, G4SubtractionSolid, …

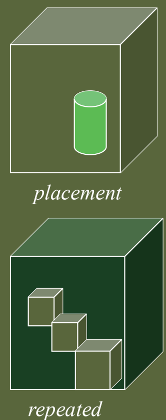

Various ways of placing

- Simple placement volume
- Parameterized volume
- Nested-parameterized volume
- Replicated volume
- Divided volume
- Reflected volume
- Assembly volume



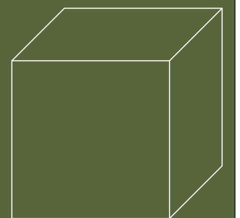
Physical Volumes

- Placement volume : it is one positioned volume
  - One physical volume object represents one "real" volume.
- Repeated volume : a volume placed many times
  - One physical volume object in memory represents any number of "real" volumes.
  - Greatly reduces use of memory.
  - Parameterised
    - repetition w.r.t. copy number
  - Replica and Division
    - simple repetition along one axis
- A mother volume can contain either
  - many placement volumes
  - or, one repeated volume



Physical volume

- G4PVPlacement
  - 1 Placement = One Placement Volume
  - A volume instance positioned once in its mother volume
- G4PVParameterised
  - 1 Parameterized = Many Repeated Volumes
  - Parameterized by the copy number
    - Shape, size, position, rotation, material, sensitivity and vis attributes can be parameterized by the copy number.
    - The user has to implement a concrete class of G4VPVParameterisation to indicate how it is parameterized.
  - Reduction of memory consumption
  - Typical use-cases
    - Complex detectors
      - with large repetition of volumes, regular or irregular
    - Medical applications
      - the material in animal tissue is measured as cubes with varying material



Physical volume

- G4PVPlacement
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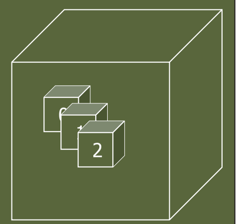

Introduction to Geant4 M.Asai (SLAC) 39

Physical volume

- G4PVPlacement
  - 1 Placement = One Placement Volume
  - A volume instance positioned once in its mother volume
- G4PVParameterised
  - 1 Parameterized = Many Repeated Volumes
  - Parameterized by the copy number
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    - The user has to implement a concrete class of G4VPVParameterisation to indicate how it is parameterized.
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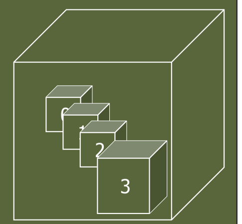

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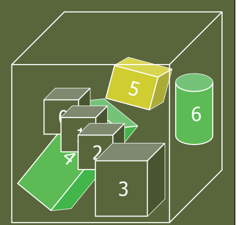

Introduction to Geant4 M.Asai (SLAC) 39

Physical volume

- G4PVReplica
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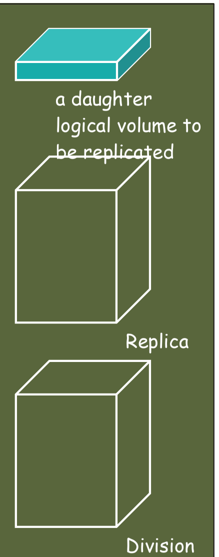
  - Daughters of same shape are aligned along one axis
  - Daughters completely fill the mother without gap in between.
- G4PVDivision
  - 1 Division = Many Repeated Volumes
  - Daughters of same shape are aligned along one axis and fill the mother.
  - There can be gaps between mother wall and outmost daughters.
  - No gap in between daughters.
    - In future release, we will extend G4PVDivision to allow gaps between daughters.



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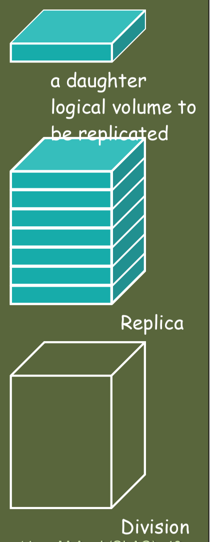

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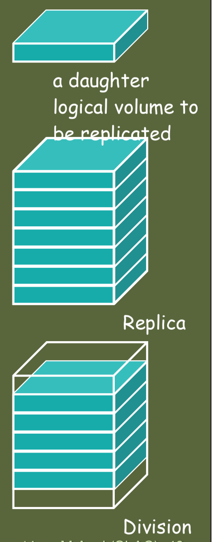

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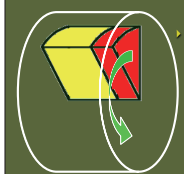
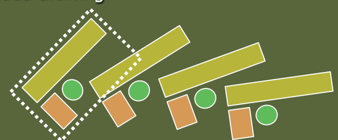
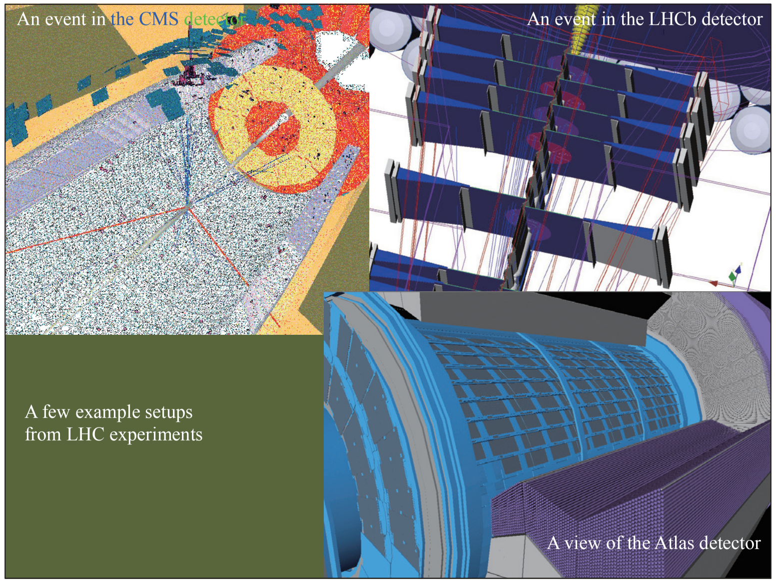


- G4ReflectionFactory
  - 1 Placement = a pair of Placement volumes
  - Generating a set of placements of a volume and its reflected volume
  - Useful typically for end-cap calorimeter in HEP detector

- G4AssemblyVolume
  - 1 Placement = a set of Placement volumes
  - Position a group of volumes
  - Analogies to a computer-aided drawing



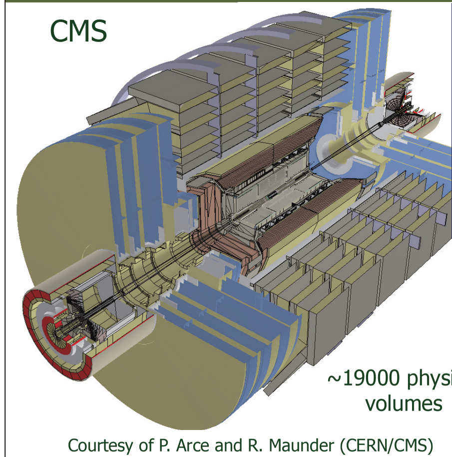


A few example setups from LHC experiments

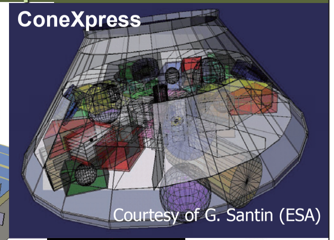
GDML

- GDML is defined through XML Schema (XSD)
  - XSD = XML based alternative to Document Type Definition (DTD)
  - defines document structure and the list of legal elements
  - XSD are in XML -> they are extensible
- GDML can be written by hand or generated automatically
  - 'GDML writer' allows writing-out GDML file
- Initially developed as an alternative geometry description format for Geant4
  - to move away from hard-coded geometry
- Now, playing also an important role of geometry interchange format
  - possibility to export geometries from experiment-specific frameworks
    - allows physics validation/comparison, visualization, debugging

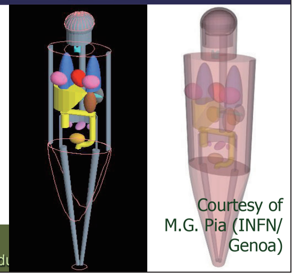
GDML examples



Courtesy of P. Arce and R. Maunder (CERN/CMS)



Courtesy of G. Santin (ESA)


Courtesy of M.G. Pia (INFN/ Genoa)

Tessellated solids

- Tessellated solid is a generic solid defined by a number of facets
  - Facets can be triangular or quadrangular
- Constructs solids for conversion of complex geometrical shapes imported from CAD systems
- But can also be explicitly defined:
  - By providing the vertices of the facets in anti-clock wise order, in absolute or relative reference frame
- GDML binding

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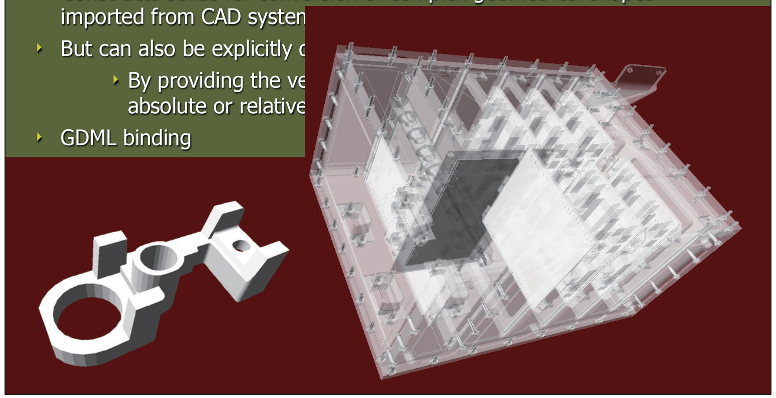
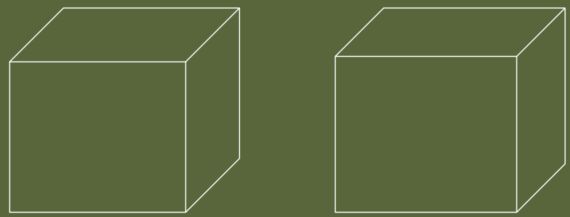


Nested parameterization



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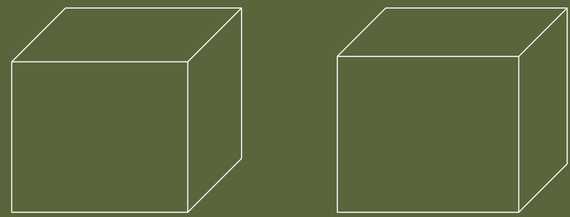

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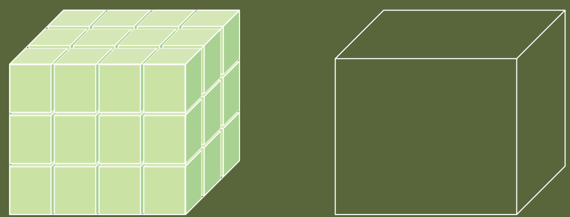

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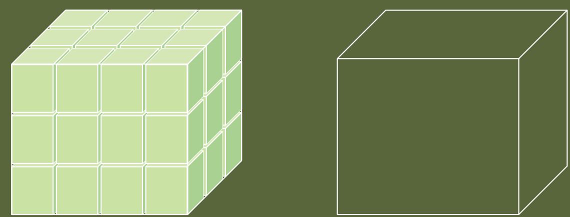

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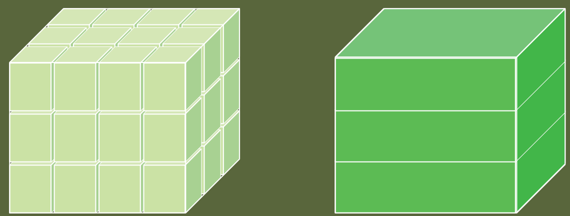

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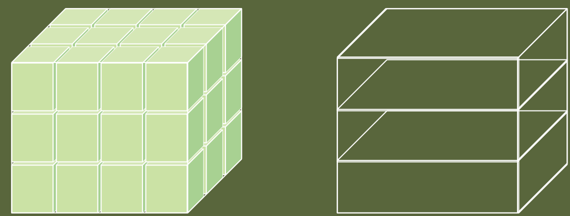

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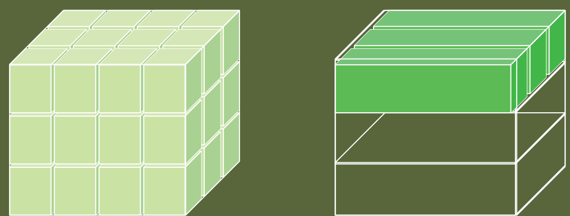

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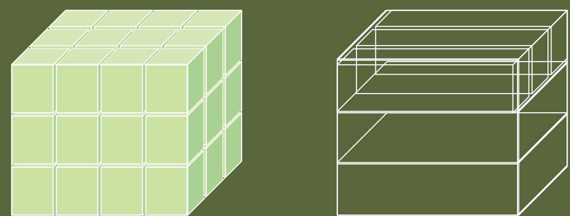

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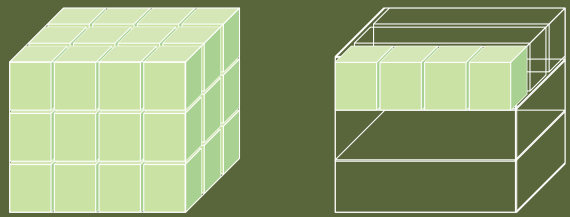

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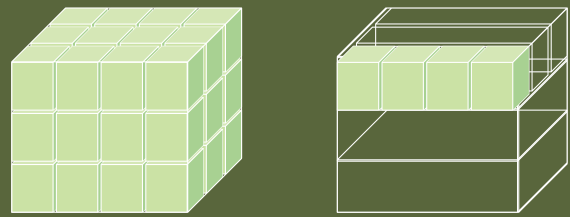

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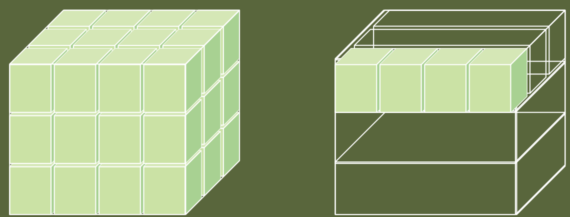
  The user may use replicas for the first and second axes sequentially, and then use one-dimensional parameterization along the third axis.



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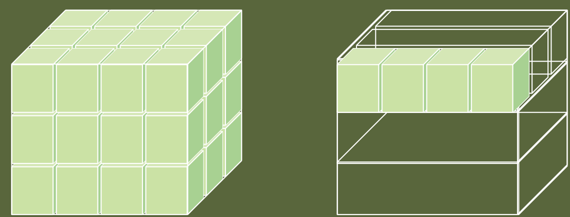

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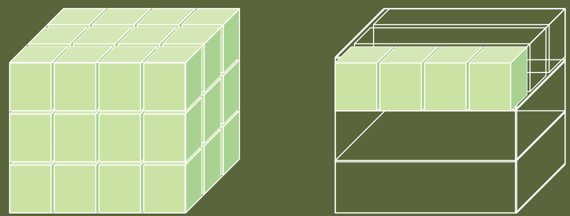
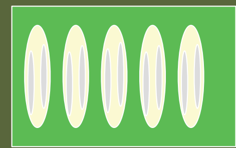


- For ultra-large number of voxels, it requires much less memory compared to placement volumes and gives much faster navigation compared to ordinary parameterized volume.
  - Material is index by three indices.

Alternative geometries

- Geant4 can handle 'dynamic' geometries which vary in time,
  - Modifying just a portion of a single 'active' geometry setup
    - E.g. rotating one or more elements

- Geant4 also allows a parallel (artificial) geometry description
  - to define scoring volumes
  - to trigger shower parameterizations
  - to steer biasing with volumes 'carrying' importance values



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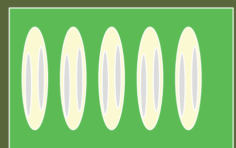

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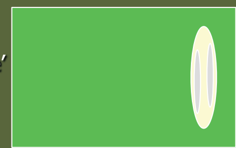

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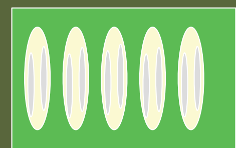

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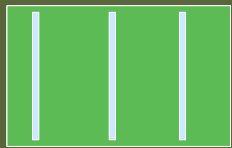

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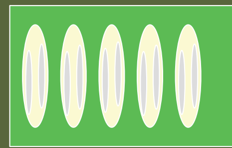
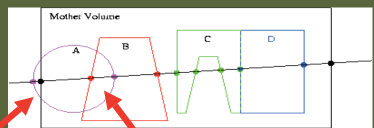


Debugging geometries

- An protruding volume is a contained daughter volume which actually protrudes from its mother volume.
- Volumes are also often positioned in a same place with the intent of not provoking intersections between themselves. When volumes in a common mother actually intersect themselves are defined as overlapping.
- Geant4 does not allow for malformed geometries, neither protruding nor overlapping.
  - The behavior of navigation is unpredictable for such cases.
- The problem of detecting protrusions or overlaps between volumes is bounded by the complexity of the solid model description.
- Utilities are provided for detecting wrong positioning
  - Optional checks at construction
  - Kernel run-time commands
  - Graphical tools (DAVID, OLAP)



protruding overlapping

Geant4 kernel
- tracking and physics process -

Physics in Geant4

- Each cross-section table or physics model (final state generation) has its own applicable energy range. By combining more than one tables / models, one physics process can have enough coverage of energy range for wide variety of simulation applications.
  - Thanks to polymorphism mechanism, both cross-sections and models can be combined in arbitrary manners into one particular process.
- Geant4 provides sets of alternative physics models so that the user can freely choose appropriate models according to the type of his/her application.
  - In other words, it is the user's responsibility to choose reasonable set of physics processes/models that fits to his/her needs.
  - For example, some models are more accurate than others at a sacrifice of speed.

Physics 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, for example, can take over from the ordinary transportation without modifying the transportation 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

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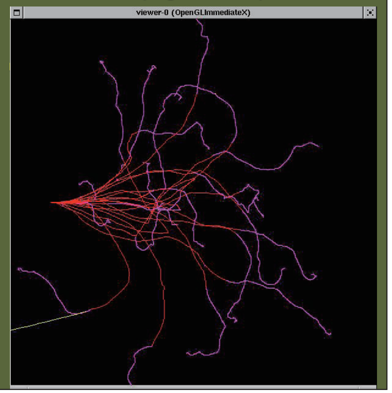

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- Note : Geant4 itself has no concrete interface to external physics model.

Tracking and processes

- Geant4 tracking is general.
  - It is independent to the particle type or 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.
- A Cut in Geant4 is a production threshold.
  - Not tracking cut, which does not exist in Geant4 as default.
    - All tracks are traced down to zero kinetic energy.
  - It is applied only for physics processes that have infrared divergence
  - Much detail will be given at later talks on physics.

Geant4 kernel
- event biasing -

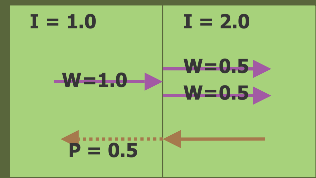
Event biasing in Geant4

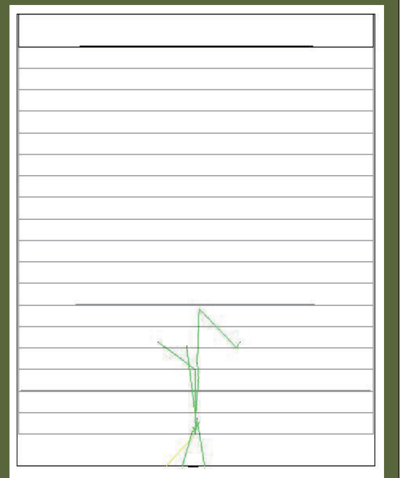
- Event biasing (variance reduction) techniques are a vital requirement for many applications
- These feature could be utilized by many application fields such as
  - Shielding
  - Radiation environment assessment
  - Dosimetry
- Since Geant4 is a toolkit and also all source code is open, the user can do whatever he/she wants.
  - Capable users in experiments/institutions created their own implementations of event biasing.
- For the user's convenience Geant4 itself provides most commonly used event biasing techniques.

Event biasing techniques

- Production cuts / threshold
  - This is a biasing technique – most popular for many applications
- Geometry based biasing
  - Importance weighting for volume/region
- Energy weight window
  - Importance weighting for energy range
- Leading particle biasing
  - Taking only the most energetic (or most important) secondary
- Primary event biasing
  - Biasing primary events and/or primary particles in terms of type of event, momentum distribution, etc.
- Enhanced process or channel
  - Increasing cross section for a process
- Physics based biasing
  - Biasing secondary production in terms of particle type, momentum distribution, cross-section, etc.

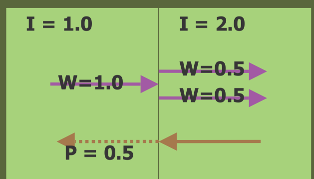
Geometrical importance biasing

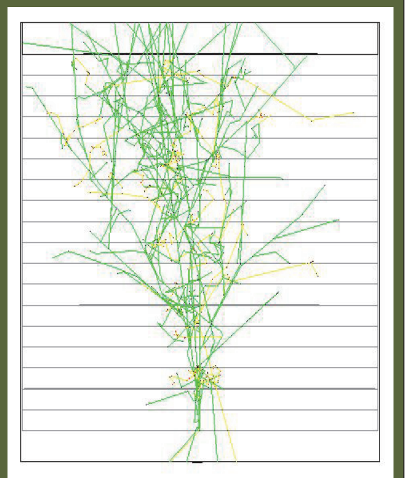




- Define importance for each geometrical region
- Splitting a track,
  - Eg creating two particles with half the 'weight' if it moves into volume with double importance value.
- Russian-roulette in opposite direction.
- Scoring particle flux with weights
  - At the surface of volumes

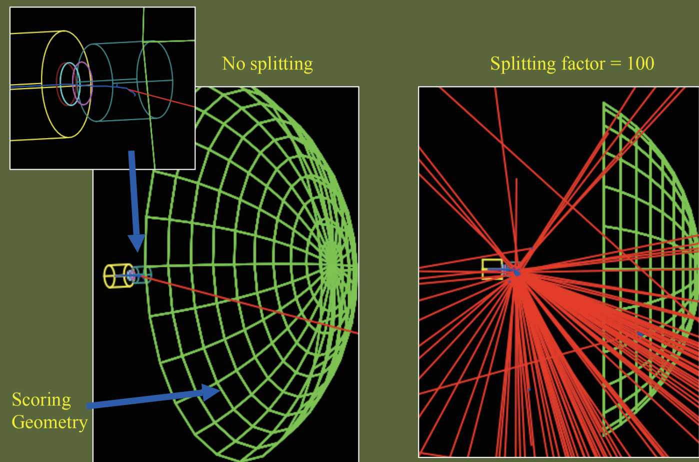
Geometrical importance biasing





- Define importance for each geometrical region
- Splitting a track,
  - Eg creating two particles with half the 'weight' if it moves into volume with double importance value.
- Russian-roulette in opposite direction.
- Scoring particle flux with weights
  - At the surface of volumes

Bremsstrahlung splitting



Geant4 kernel
- scoring -

Introduction to Geant4 M.Asai (SLAC)

Easy-to-use scoring

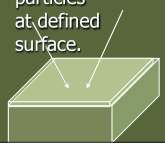
- Before Geant4 8.0 release (Dec '06), the user had to implement "sensitive detector" to score physics quantities.
  - It's a reasonable requirement for a large-scale HEP experiment, but it's too heavy for space/medical users who just want to score most common quantities such as dose or flux.
- At v8.0, we released primitive scorers for common physics quantities (see next slide), thus users were freed from implementing C++ code of "scoring detectors".
  - The user can "register" to each volume what to score.
- In next release (Dec '07), we will introduce command-base scoring functionality.
  - The user can define scoring mesh(es) completely independent to the geometrical boundaries of "mass world". The user can register provided primitive scorers to these mesh cells. (The user may add their own scorers as well).
  - It will be a beta-release with limited functionality. Full release is planed in 2008.

Introduction to Geant4 M.Asai (SLAC) 59

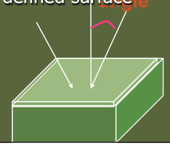
List of provided primitive scorers

- Concrete Primitive Scorers (See Application Developers Guide 4.4.6)
  - Deposited energy
    - G4PSEnergyDepsit, G4PSDoseDeposit, G4PSChargeDeposit
  - Current/Flux
    - G4PSFlatSurfaceCurrent, G4PSSphereSurfaceCurrent,G4PSPassageCurrent, G4PSFlatSurfaceFlux, G4PSCellFlux, G4PSPassageCellFlux
  - Track length
    - G4PSTrackLength, G4PSPassageTrackLength
  - Others
    - G4PSMinKinEAtGeneration, G4PSNofSecondary, G4PSNofStep

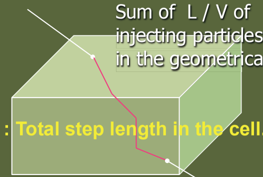
SurfaceCurrent : Count number of injecting particles at defined surface.



SurfaceFlux : Sum up 1/cos (angle) of injecting particles at defined surface



CellFlux : Sum of L / V of injecting particles in the geometrical cell.



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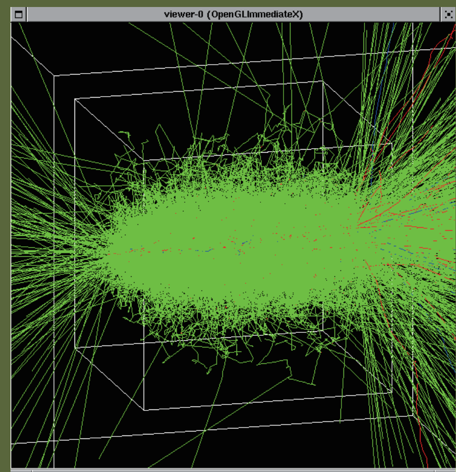
Command-based scorer



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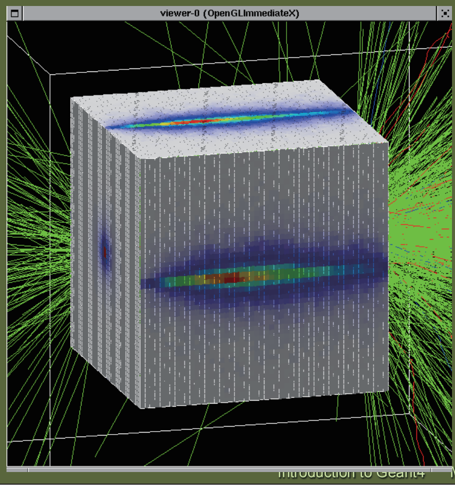
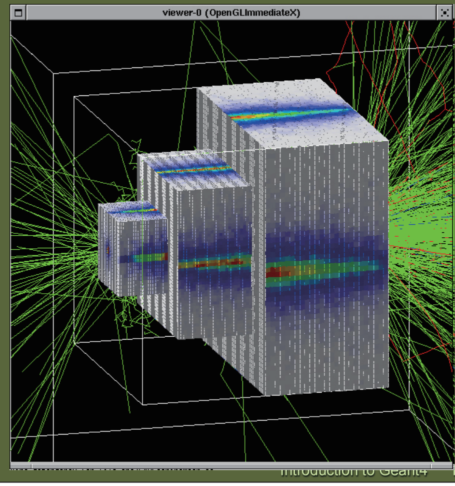
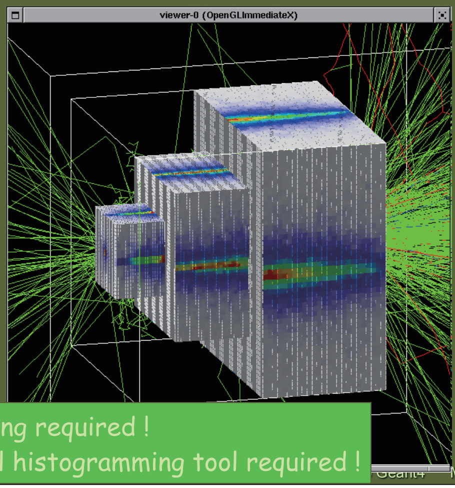
Command-based scorer



Command-based scorer



Command-based scorer



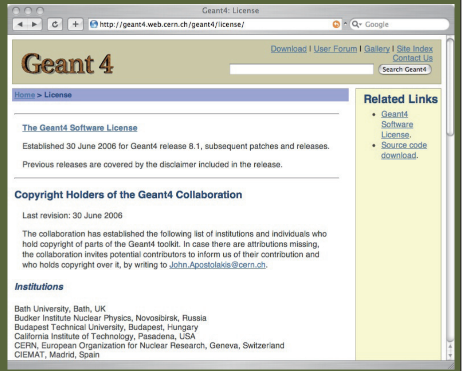
No C++ coding required !
No external histogramming tool required !

Geant4 license

The Geant4 License

In response to user requests for clarification of Geant4's distribution policy, the collaboration recently announced a new license.

- Makes clear the user's wide-ranging freedom to use, extend or redistribute Geant4, even as part of some for-profit venture.
- The license was released along with the latest Geant4 release 8.1.
- Simple enough that you can read and understand it.



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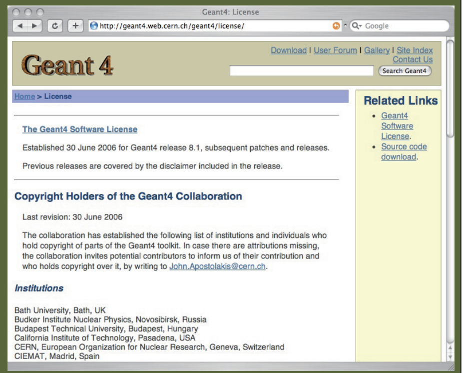


- http://cern.ch/geant4/license/

User support processes in Geant4

User Support

- Geant4 Collaboration offers extensive user supports.
  - Technical Forum
  - Users workshops
  - Tutorial courses
  - HyperNews and mailing list
  - Bug reporting system
  - Requirements tracking system
  - LXR code browser
  - Daily "private" communications

http://cern.ch/geant4/

Technical Forum

- The Technical Forum is open to all interested parties
  - To be held at least 4 times per year (in at least two locales)
- The purpose of the forum is to:
  - Achieve, as much as possible, a mutual understanding of the needs and plans of users and developers.
  - Provide the Geant4 Collaboration with the clearest possible understanding of the needs of its users.
  - Promote the exchange of information about physics validation performed by Geant4 Collaborators and Geant4 users.
  - Promote the exchange of information about user support provided by Geant4 Collaborators and Geant4 user communities.
- Consult Geant4 home page for previous and coming Technical Forums.

Geant4 users workshop

- Users workshops were held or are going to be held hosted by several institutes for various user communities.
  - KEK - Dec.2000, Jul.2001, Mar.2002, Jul.2002, Mar.2003, Jul.2003, Jul. 2004, Jan.2005, Jan.2006
  - SLAC - Feb.2002
  - Spain (supported by INFN) - Jul.2002
  - CERN - Nov.2002
  - NASA/ESA/Vanderbilt/JAXA - Jan.2003, May.2004, Oct.2005, Nov.2006,

    Feb.2008
  - Helsinki - Oct.2003, Jun.2005
  - Bordeaux - Nov.2005
  - Lisbon - Oct.2006
  - Hebden Bridge - Sep.2007
  - Local workshops of one or two days were held or are planned at several places. Refer to our web site.

Geant4 tutorials / lectures

- In addition to the users workshops, many tutorial courses and lectures with some discussion time slots were held for various user communities.
  - CERN School of Computing
  - Italian National School for HEP/Nuclear Physicists
  - MC2000
  - MCNEG workshop
  - IEEE NSS/MIC
  - KEK, SLAC, DESY, FNAL, Jefferson, ESA, INFN, Frascati, Karolinska, GranSasso, etc.
  - ATLAS, CMS, LHCb
  - Tutorials/lectures at universities
    - Japan - Ritsumeikan, Kitazato
    - Europe - Genoa, Bologna, Udine, Roma, Trieste, Imperial, Helsinki, …
    - U.S., Canada - Vanderbilt, McGill
- Geant4 collaboration is happy to offer tutorial courses if requested.

HyperNews

- HyperNews system was set up in April 2001

[Membership | Subscriptions | Recent Index | Search | Geant4 Home | Feedback | Help]

Geant 4

Geant4 HyperNews Forums

Welcome to the Geant4 HyperNews system.

The Geant4 collaboration welcomes user participation in this forum through the exchange of questions about and experiences with the Geant4 toolkit. When possible, developers will monitor these contributions and provide assistance. To report a problem or program error please use the Geant4 Problem Reporting System.

The following list is a short guide to what you can do from this page:

- To read a forum, click on the title of the forum in one of the available indices. Available indices include a Time Ordered Index, and a Recent Post Index.
- To post a new message (start a new thread) in a forum, click on the Add Message button at the bottom of the forum page. One can also use email.
- To create a membership, follow the directions here.
- To edit your membership information in the system, go to the Membership page.
- To subscribe (once you are a member) to any forum or to see what forums you are currently subscribed to, go to the Central HyperNews Subscription Page. You can also see who else is subscribed to a forum from there.
- To search the messages in the HyperNews system, go to the HyperNews Search Page.
- To request a new forum be created, use the Request a New Forum page.

HyperNews

- 24 categories
- Not only "user-developer", but also "user-user" information exchanges are quite intensive.

Categorized Index of Forums

- Applications
- Control of runs, events, tracks, particles
- Experimental Setup
- General matters
- Interfaces
- Physics

Applications
- Educational Applications
- Industrial instruments
- Medical Applications
- Space Applications

Control of runs, events, tracks, particles
- Event and Track Management
- Particles
- Run Management

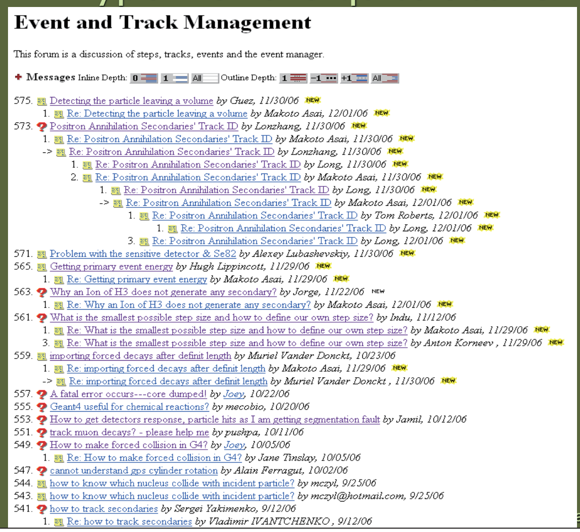
Experimental Setup
- Fields: Magnetic and Otherwise
- Geometry
- Hits, Digitization and Pileup
- Materials

General matters
- Documentation and Examples
- HyperNews System Announcements
- Hypernews Testing
- Installation and Configuration
- User Requirements

Interfaces
- (Graphical) User Interfaces
- Analysis
- Persistency
- Visualization

Physics
- Electromagnetic Processes
- Fast Simulation, Transportation & Others
- Hadronic Processes
- Physics List

HyperNews is quite active



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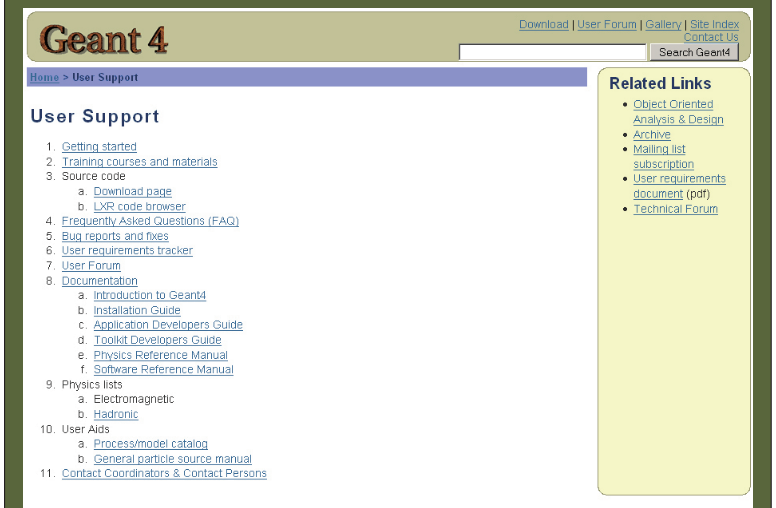


To conclude

- Geant4 is a toolkit for the simulation of elementary particles and nucleus passing through and interacting with matter, and for the simulation of detector apparatus measuring the passage of particles and scoring physical quantities.
- It provides comprehensive geometry and physics modeling capabilities embedded in its flexible kernel structure.
- In 2008, Geant4 celebrates 10 year anniversary of its public releases.
- Geant4 is nowadays well adopted to most of the current and future HEP experiments as their simulation engine.
- Use of Geant4 is rapidly expanding (rather exploding) in space and medical application domains.
  - The major developments and refinements of Geant4 are now driven by requirements from these domains.
- Geant4 collaboration offers extensive user supports.

Introduction to Geant4 Physics Overview

Koi, Tatsumi
SLAC SCCS

Based on Presentations at SLAC Geant4 Tutorial 2007

Outline

- Geant4 Physics Overview
- Process
- Physics List
- Standard EM
- Low Energy EM
- Hadron Physics
- Cuts, Decay and Optical
- Event biasing

Geant4 Physics

- Geant4 provides a wide variety of physics components for use in simulation
- Physics components are coded as processes
  - a process is a class which tells a particle how to interact
  - user may write his own processes (derived from Geant4 process)
- Processes are grouped into
  - electromagnetic, hadronic, and decay categories

Geant4 Physics: Electromagnetic

- standard – complete set of processes covering charged particles and gammas
  - energy range 1 keV to ~PeV
- low energy – specialized routines for e+, e-, g, charged hadrons
  - more atomic shell structure details
  - some processes valid down to 250 eV or below
  - others not valid above a few GeV
- optical photon – only for long wavelength photons (x-rays, UV, visible)
  - processes for reflection/refraction, absorption, wavelength shifting, Rayleigh scattering

Geant4 Physics: Hadronic

- Pure hadronic (0 - ~100 TeV)
  - elastic
  - inelastic
  - capture
  - fission
- radioactive decay
  - at-rest and in-flight
- photo-nuclear (~10 MeV - ~Tev)
- lepto-nuclear (~10 MeV - ~Tev)
  - e+, e- nuclear reactions
  - muon-nuclear reactions

Geant4 Physics Decay and Parameterized

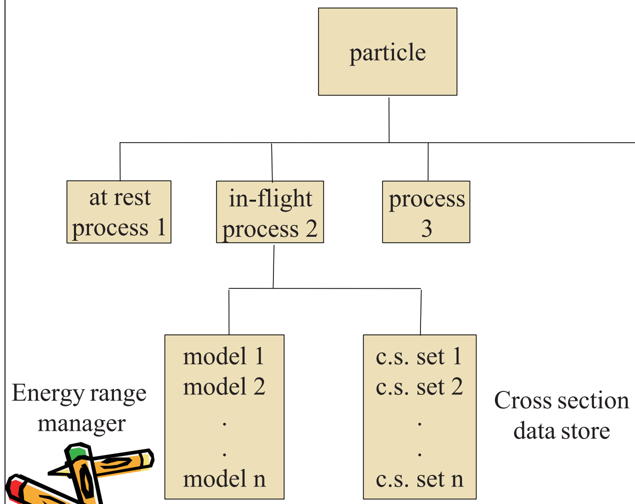
- Decay processes include
  - weak decay (leptonic decays, semi-leptonic decays, radioactive decay of nuclei)
  - electromagnetic decay (π^0 , etc. decay)
  - strong decays not included here (they are part of hadronic models)
- Parameterized processes
  - electromagnetic showers propagated according to parameters averaged over many events
  - faster than detailed shower simulation

Physics Processes

- All the work of particle decays and interactions is done by processes
  - transportation is also handled by a process
- A process does two things:
  - decides when and where an interaction will occur
    - method: GetPhysicalInteractionLength()
    - this requires a cross section, decay lifetime
    - for the transportation process, the distance to the nearest object along the track is required
  - generates the final state of the interaction (changes momentum, generates secondaries, etc.)
    - method: DoIt()
    - this requires a model of the physics

Handling Multiple Processes

- Many processes (and therefore many interactions) can be assigned to the same particle
- How does Geant4 decide which interaction happens at any one time?
  - interaction length or decay length is sampled from each process
  - shortest one happens, unless
  - a volume boundary is encountered in less than the sampled length. Then no physics interaction occurs (just simple transport).
  - the processes that were not chosen have their interaction lengths shortened by the distance traveled in the previous step
  - repeat the procedure



Summary (1)

- Geant4 supplies many physics processes which cover electromagnetic, hadronic and decay physics
- Many processes may be assigned to one particle
  - which one occurs first depends on cross sections, lifetimes, and distances to volume boundaries

Physics List

What is a Physics List?

- A class which collects all the particles, physics processes and production thresholds needed for your application
- It tells the run manager how and when to invoke physics
- It is a very flexible way to build a physics environment
  - user can pick the particles he wants
  - user can pick the physics to assign to each particle
- But, user must have a good understanding of the physics required
  - omission of particles or physics could cause errors or poor simulation

Why Do We Need a Physics List?

- Physics is physics – shouldn't Geant4 provide, as a default, a complete set of physics that everyone can use?
- No:
  - there are many different physics models and approximations
    - very much the case for hadronic physics
    - but also the case for electromagnetic physics
  - computation speed is an issue
    - a user may want a less-detailed, but faster approximation
  - no application requires all the physics and particles Geant4 has to offer
    - e.g., most medical applications do not want multi-GeV physics

Why Do We Need a Physics List? (2)

- For this reason Geant4 takes an atomistic, rather than an integral approach to physics
  - provide many physics components (processes) which are de-coupled from one another
  - user selects these components in custom-designed physics lists in much the same way as a detector geometry is built
- Exceptions:
  - a few electromagnetic processes must be used together
  - future processes involving interference of electromagnetic and strong interactions may require coupling as well

G4VUserPhysicsList

- All physics lists must derive from this class
  - and then be registered with the run manager
- Required Methods
  - ConstructParticle() - choose the particles you need in your simulation and define all of them here
  - ConstructProcess() - for each particle, assign all the physics processes important in your simulation
  - SetCuts() - set the range cuts for secondary production
  - What's a range cut?
  - => essentially a low energy limit on particle production
  - more on this later

Pre-packaged Physics Lists (1)

- Our example deals mainly with electromagnetic physics
- A complete and realistic EM physics list can be found in novice example N03
  - good starting point
  - add to it according to your needs
- Adding hadronic physics is more involved
  - for any one hadronic process, user may choose from several hadronic models to choose from
  - choosing the right models for your application requires care
  - to make things easier, hadronic physics lists are now provided according to some use cases

Pre-packaged Physics Lists (2)

- Referred to as “hadronic physics lists” but include electromagnetic physics from example N03
- Can be found on the Geant4 web page at http://geant4.web.cern.ch/geant4/physics_lists
- Caveats:
  - these lists are provided as a “best guess” of the physics needed in a given case
  - the user is responsible for validating the physics for his own application and adding (or subtracting) the appropriate physics
  - they are intended as starting points or templates

Summary (2)

- All the particles, physics processes, and production cuts needed for an application must go into a physics list
- Some pre-packaged physics lists are provided by Geant4 as starting points for users
  - electromagnetic physics lists
  - hadronic physics lists
- Care is required by user in choosing the right physics to use

Standard EM

’Standard’ em physics : the model

The projectile is assumed to have an energy ≥ 1 keV.

- The atomic electrons are quasi-free : their binding energy is neglected (except for photoelectric effect).
- The atomic nucleus is fixe : the recoil momentum is neglected.

The matter is described as homogeneous, isotropic, amorphous.

1. Common to all charged particles
   - ionization (∼ keV ⟶)
   - Coulomb scattering from nuclei (∼ keV ⟶)
   - Cerenkov effect
   - Scintillation
   - transition radiation
2. Muons
   - (e+,e-) pair production (∼ 100GeV ⟶)
   - bremsstrahlung (∼ 100GeV ⟶)
   - nuclear interaction (∼ 1TeV ⟶)
3. Electrons and positrons
   - bremsstrahlung (∼ 10MeV ⟶)
   - e+ annihilation

4. Photons
   - gamma conversion (∼ 10MeV ⟶)
   - incoherent scattering (∼ 100keV ⟶∼ 10MeV)
   - photo electric effect (⟵∼ 100keV)
   - coherent scattering (⟵∼ 100keV)
5. Optical photons
   - reflection and refraction
   - absorption
   - Rayleigh scattering

Total :∼ 15 processes ⟶ ∼ 40 classes

+ ∼ 10 classes for the materials category

Summary (3)

- Standard EM physics processes are available for gammas and charged particles from 1 keV and up
- EM processes must be ordered in the physics list
- EM processes are based on theoretical cross sections with corrections. During simulation, quantities are taken from tables calculated at initialization time
- Multiple scattering is handled by model functions which represent fits to Lewis transport theory results (not Moliere)
- Energy-range relation is used to compute energy loss, and to control step lengths and secondary production

Low Energy Electromagnetic Physics

Low Energy Electromagnetic Physics

- A package in the Geant4 electromagnetic package
  - in …geant4/source/processes/electromagnetic/lowenergy/
- A set of processes extending the coverage of electromagnetic interactions in Geant4 down to "low" energy
  - 250 eV (in principle even below this limit) / 100 eV for electrons and photons
  - down to the approximately the ionization potential of the interacting material for hadrons and ions
  - up to 100 GeV (unless specified)
  - all processes are based on theoretical models and on exploitation of evaluated data ; they involve two distinct phases :
    - calculation and use of total cross sections
    - generation of the final state
- A set of processes based on detailed models
  - shell structure of the atom
  - precise angular distributions

Overview of LowEM physics

- **Photons**
  - Compton Scattering
  - Compton Scattering by Linearly Polarized Gamma Rays
  - Rayleigh Scattering
  - Gamma Conversion
  - Photoelectric effect
- **Electrons**
  - Bremsstrahlung
  - Ionisation

Come in **two "flavours"** of models:
- based on the **Livermore Library**
- à la **Penelope** (+ positron annihilation)

- **Hadrons and ion ionisation**
  - Energy loss of slow & fast hadrons
  - Energy loss in compounds
  - Delta-ray production
  - Effective charge of ions
  - Barkas and Bloch effects (hadron sign + relativistic)
  - Nuclear stopping power
  - PIXE

Atomic relaxation
- Fluorescence
- Auger process

In progress

- Extensions down to the eV scale :
  The Geant4 DNA project
  - in water (for radiobiology studies)
  - in semiconductor materials (for radiation damage to components)
- Difficult domain
  - models must be specialized by material
  - cross sections, final state generation, angular distributions

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

Summary (4)

- OO technology provides the mechanism for a rich set of electromagnetic physics models in Geant4
  - further extensions and refinements are possible, without affecting Geant4 kernel or user code
- Two main approaches in Geant4
  - standard
  - Low Energy (Livermore Library / Penelope)
- each one offering a variety of models for specialized applications
- Extensive validation activity and results
- More on Physics Reference Manual and web site

Hadron Physics

Introdcutiion to Geant4
Physics Overview T. Koi (SLAC)

Hadronic Processes, Models and Cross Sections

- In Geant4 physics is assigned to a particle through processes
- Each process may be implemented
  - directly as part of the process, or
  - in terms of a model class
- In Geant4 hadronic physics there are sometimes many models for a given process
  - user must choose
  - can have more than one per process
- A process must also have cross sections assigned
  - here too, there are options

Introdcutiion to Geant4
Physics Overview T. Koi (SLAC)

Hadronic Models – Data Driven

- Characterized by lots of data
  - cross section
  - angular distribution
  - multiplicity
  - etc.
- To get interaction length and final state, models interpolate data
  - cross section, coef of Legendre polynomials
- Examples
  - neutrons (E < 20 MeV)
  - coherent elastic scattering (pp, np, nn)
  - Radioactive decay

Introdcutiion to Geant4
Physics Overview T. Koi (SLAC)

Hadronic Models – Theory Driven

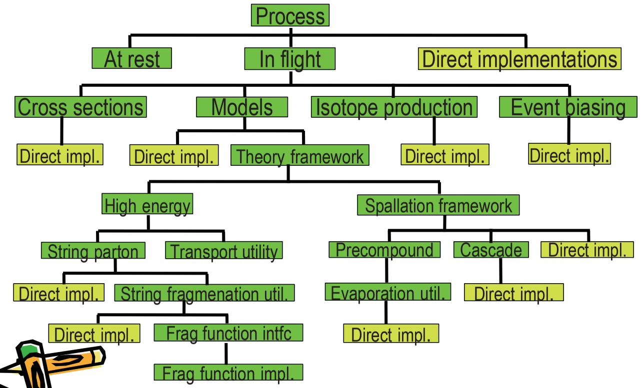
- Dominated by theory (quark-gluon strings, chiral perturbation theory, ...)
  - not as much data to tie things down
- Final states determined by sampling theoretical distributions
- Examples:
  - quark-gluon string (projectiles with E > 20 GeV)
  - intra-nuclear cascade (intermediate energies)
  - nuclear de-excitation and breakup
  - chiral invariant phase space (up to a few GeV)

Introdcutiion to Geant4
Physics Overview T. Koi (SLAC)

Hadronic Models - Parameterized

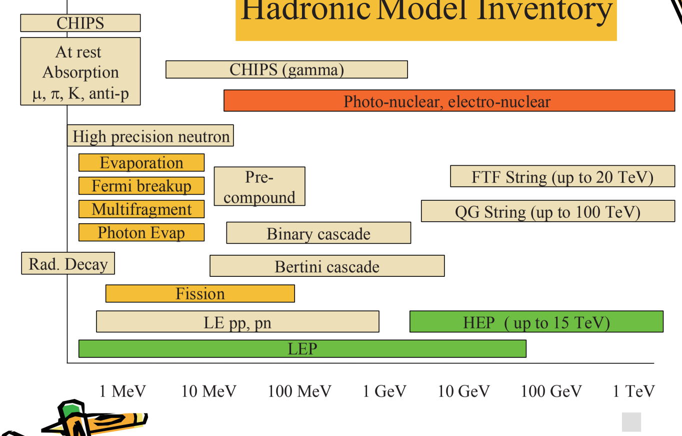
- Depend mostly on fits to data and some theoretical distributions
- Two models available:
  - Low Energy Parameterized (LEP) for < 20 GeV
  - High Energy Parameterized (HEP) for > 20 GeV
  - Each type refers to a collection of models
- Both derived from GHEISHA model used in Geant3
- Core code:
  - hadron fragmentation
  - cluster formation and fragmentation
  - nuclear de-excitation

Hadronic Model Organization



Introdcutiion to Geant4
Physics Overview T. Koi (SLAC)

Hadronic Model Inventory



Introdcutiion to Geant4
Physics Overview T. Koi (SLAC)

Low energy (< 20MeV) neutrons physics

- High Precision Neutron Models (and Cross Section Data Sets)
  - G4NDL
    - ENDF
  - Elastic
  - Inelastic
  - Capture
  - Fission
- NeutronHPorLEModel(s)
- ThermalScatteringModels (and Cross Section data Sets)
- JENDL High Energy Files (cross sections < 3GeV)

Introdcutiion to Geant4
Physics Overview T. Koi (SLAC)

Ion Physics

- Inelastic Reactions
  - Cross Sections
    - Tripathi, Shen, Kox and Sihver
    - G4GeneralSpaceNNCrossSection
  - Model
    - G4BinaryLightIon
    - G4WilsonAbrasion
    - G4QMD
- Electromagnetic Dissociation
- Radio Active Decay

Summary (5-1)

- Geant4 hadronic physics allows user to choose how a physics process should be implemented:
  - cross sections
  - models
- Many processes, models and cross sections to choose from
  - hadronic framework makes it easier for users to add more
- Two main types of elastic scattering are available:
  - GHEISHA-style
  - coherent
- Precompound models are available for low energy nucleon projectiles and nuclear de-excitation

Summary (5-2)

- Cascade models (Bertini, Binary) are valid for fewer particles over a smaller energy range
  - more theory-based
  - more detailed
  - slower
- Parameterized models (LEP, HEP) handle the most particle types over the largest energy range
  - based on fits to data and some theory
  - not very detailed
  - fast

Summary (5-3)

- High Precision Neutron models are data driven models and its used evaluated data libraries.
- However the library is not complete because there are no data for several key elements.
- Geant4 has abundant processes for Ion interactions with matter and also without matter.
- Without any extra modules, users may simulate ion transportation in the complex and realistic geometries of Geant4.
- Validation has begun and the results show reasonable agreement with data. This work continues.

Isotope Production

- Useful for activation studies
- Covers primary neutron energies from 100 MeV down to thermal
- Can be run parasitically with other models
- G4NeutronIsotopeProduction is currently available
  - G4ProtonIsotopeProduction not yet completed

Summary (5-4)

- Two string models (QGS, FTF) are provided for high energy (>20 GeV) interactions
- The Chiral Invariant Phase Space model is available for:
  - capture at rest
  - anti-baryon annihilation
  - gamma and lepto-nuclear interactions
  - nuclear de-excitation
- Other models/processes available include:
  - capture at rest and in flight
  - fission
  - neutron-induced isotope production

Cuts, Decay and Optical Processes

Threshold for Secondary Production (1)

- Every simulation developer must answer the question: how low can you go?
  - at what energy do I stop tracking particles?
- This is a balancing act
  - need to go low enough to get the physics you're interested in
  - can't go too low because some processes have infrared divergence causing CPU time to skyrocket
- The traditional Monte Carlo solution is to impose an absolute cutoff in energy
  - particles are stopped when this energy is reached
  - remaining energy is dumped at that point

Threshold for Secondary Production (2)

- But, such a cut may cause imprecise stopping location and deposition of energy
- There is also a particle dependence
  - range of 10 keV γ in Si is a few cm
  - range of 10 keV e- in Si is a few microns
- And a material dependence
  - suppose you have a detector made of alternating sheets of Pb and plastic scintillator
  - if the cutoff is OK for Pb, it will likely be wrong for the scintillator which does the actual energy deposition measurement

Threshold for Secondary Production (3)

- Geant4 solution: impose a production threshold
  - this threshold is a distance, not an energy
  - default = 1 mm
  - the primary particle loses energy by producing secondary electrons or gammas
  - if primary no longer has enough energy to produce secondaries which travel at least 1mm, two things happen:
    - discrete energy loss ceases (no more secondaries produced)
    - the primary is tracked down to zero energy using continuous energy loss
- Stopping location is therefore correct
- Only one value of production threshold distance is needed for all materials because it corresponds to different energies depending on material.

Threshold for Secondary Production (4)

- Geant4 recommends the default value of 1mm
  - user needs to decide the best value
  - this will depend on the size of sensitive elements within the simulated detector, and on available CPU
- This value is set in the SetCuts() method of your physics list.
- Instead of "secondary production threshold distance" it is more convenient to simply say "cuts"
  - but please remember that this does not mean that any particle is actually stopped before it runs out of energy

The Decay Process

- Derived from G4VRestDiscreteProcess
  - decay can happen in-flight or at rest
- Should be applied to all unstable, long-lived particles
- Different from other physical processes:
  - mean free path for most processes: $\lambda = N \rho \sigma / A$
  - for decay in-flight: $\lambda = \beta \gamma c \tau$
- Same decay process for all eligible particles
  - decay process retrieves BR and decay modes from decay table stored in each particle type

Available Decay Modes

- Phase space:
  - 2-body e.g. $\pi^0 \to \gamma\gamma$, $\Lambda \to p\,\pi^-$
  - 3-body e.g. $K^0_L \to \pi^0\,\pi^+\,\pi^-$
  - many body
- Dalitz: $P^0 \to \gamma\, l^+\, l^-$
- Muon decay
  - V – A, no radiative corrections, mono-energetic neutrinos
- Leptonic tau decay
  - like muon decay
- Semi-leptonic K decay: $K \to \pi\, l\, \nu$

Pre-assigned Decays

- Geant4 provides decay modes for long-lived particles
  - user can re-define decay channels if necessary
- But decay modes for short-lived (e.g. heavy flavor) particles not provided by Geant4
  - user must "pre-assign" to particle:
    - proper lifetime
    - decay modes
    - decay products
  - decay process can invoke decay handler from the generator
    - must use G4VExtDecayer interface
- Take care that pre-assigned decays from generators do not overlap with those defined by Geant4
  - K^0_S , τ

Optical Photons(1)

- Technically, should belong to electromagnetic category, but:
  - optical photon wavelength is >> atomic spacing
  - treated as waves -> no smooth transition between optical and gamma particle classes
- Optical photons are produced by the following Geant4 processes:
  - G4Cerenkov
  - G4Scintillation
  - G4TransitionRadiation
- Warning: these processes generate optical photons without energy conservation

Optical Photons (2)

- Optical photons undergo:
  - Rayleigh scattering
  - refraction and reflection at medium boundaries
  - bulk absorption
  - wavelength shifting
- Geant4 keeps track of polarization
  - but not overall phase -> no interference
- Optical properties can be specified in G4Material
  - reflectivity, transmission efficiency, dielectric constants, surface properties
- Photon spectrum properties also defined in G4Material
  - scintillation yield, time structure (fast, slow components)

Summary (6)

- The precision of particle stopping and the production of secondary particles are determined by a secondary production threshold
- There is one decay process for all long-lived, unstable particles
- Optical processes handle the reflection, refraction, absorption, wavelength shifting and scattering of long-wavelength photons

Event Biasing

- Geant4 simulation:
  - Analogue == regular processing
  - Non-analogue/event biased simulation == manipulated processes and/or process list
    - I.e, manipulate processing to effectively apply B(x) in place of N(x)
- Geant4 provides
  - Several built-in general use biasing techniques
  - Utility class, G4WrapperProcess to support user defined biasing
- Expect biasing to be used by experienced users
  - Should understand what a particular biasing technique does, it's constraints and side effects
  - Understand how processing works in Geant4

Built in Biasing Options

Biasing Technique	First Release Version
Primary particle biasing	3.0
Radioactive decay biasing	3.0
Mars hadronic leading particle biasing	4.0
General hadronic lead particle biasing	4.3
Hadronic cross section biasing	4.3
Geometrical Importance sampling	5.0
Geometrical weight window and weight cutoff	5.2

Summary (7)

- Number of popular event biasing techinques built into Geant4
- User defined biasing supported through G4WrapperProcess
- Ongoing developments aim to improve exiting Geant4 biasing, and provide new event biasing and scoring methods
- Documentation at
  - http://geant4.web.cern.ch/geant4/UserDocumentation/UsersGuides/ForApplicationDeveloper/html/ch03s07.html

Thank you for listening!!