Kernel I

Makoto Asai (SLAC)
Geant4 Tutorial Course
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• Geant4 kernel
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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, space science and medical applications.
• In order to meet such requirements, a large degree of functionality and flexibility are provided.
• G4 is not only for HEP but goes well beyond that.
Flexibility of Geant4

- In order to meet wide variety of requirements from various application fields, a large degree of functionality and flexibility are provided.
- Geant4 has many types of geometrical descriptions to describe most complicated and realistic geometries
  - CSG, BREP and Boolean solids
  - Placement, replica, divided, parameterized, reflected and grouped
  - XML interface
- Everything is open to the user
  - Choice of physics processes/models
  - Choice of GUI/Visualization/persistency/histogramming technologies
Physics in Geant4

• It is rather unrealistic to develop a uniform physics model to cover wide variety of particles and/or wide energy range.

• Much wider coverage of physics comes from mixture of theory-driven, parameterized, and empirical formulae. Thanks to polymorphism mechanism, both cross-sections and models (final state generation) can be combined in arbitrary manners into one particular process.

• Geant4 offers
  – EM processes
  – Hadronic processes
  – Photon/lepton-hadron processes
  – Optical photon processes
  – Decay processes
  – Shower parameterization
  – Event biasing techniques
  – And you can plug-in more
Physics in Geant4

• Each cross-section table or physics model (final state generation) has its own applicable energy range. Combining more than one tables / models, one physics process can have enough coverage of energy range for wide variety of simulation applications.

• Geant4 provides sets of alternative physics models so that the user can freely choose appropriate models according to the type of his/her application.
  – 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.
Geant4 – Its history

- Dec ’94 - Project start
- Apr ’97 - First alpha release
- Jul ’98 - First beta release
- Dec ’98 - First Geant4 public release - version 1.0
- ...
- Dec 19th, ’08 - Geant4 version 9.2 release
  - Feb 19th, ’10 - Geant4 9.2-patch03 release
- Dec 18th, ’09 - Geant4 version 9.3 release
  - Apr 21st, ’10 - Geant4 9.3-patch01 release
- We currently provide one to three public releases every year.
  - Beta releases are also available to the registered beta-testers.

Current version
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
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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Read more about how the TOP25 is generated and what it reflects.

Highlights of Users Applications

To provide you some ideas how Geant4 would be utilized...
BaBar

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

Now simulating PEP beam line as well ($-9 \text{m} < z_{IP} < 9 \text{m}$)
Now Geant4 has become the standard simulation for ATLAS, LHCB, and CMS.

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

⇒ 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

Albert De Roeck (CERN)
Geant4 Setups (2)

Forward Calorimeter (FCal) Testbeam Setup

Electromagnetic Barrel Accordion Calorimeter

10 GeV Electron Shower
Geant4 at the LHC Today

Complicated geometry
Details are very important

Geant4 can handle it!!

LHCb Vertex Locator description

Albert De Roeck (CERN)
Pushing G4 to the limits: Heavy Ions

Events with > 50000 particles/event in detector acceptance
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

<table>
<thead>
<tr>
<th>Program</th>
<th>CPU (2.8GHz) (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMSIM</td>
<td>230</td>
</tr>
<tr>
<td>OSCAR 2_4_5</td>
<td>320</td>
</tr>
<tr>
<td>OSCAR 3_4_0</td>
<td>180</td>
</tr>
</tbody>
</table>

The first CMS PbPb event with OSCAR/G4
Boulby Mine dark matter search
Prototype Simulation

Courtesy of H. Araujo, A. Howard, IC London
Geant4 for beam transportation

Example: Helical Channel
72 m long solenoidal + dipole field with wedge absorbers and thin cavities

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

\[ B_{xy} = B_T \cos \sin \left( \frac{2p}{L} z \right) \]
\[ B_z = B_0 \]

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 Workshop, CERN 2001
- Cooling Experiment (MICE) Simulation (in progress)

Courtesy of V.D. Elvira (FNAL)
Synchrotron Radiation

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

Courtesy of G. Blair (CERN)
Ray tracing in perfect quadrupoles

In our microbeam line, four quadrupoles to focus the beam:
- Focus, Defocus, $F_2, D_1$ “Russian” configuration
- Quad length = 15 cm, gap radius = 1 cm, distance between quads = 4 cm
  $G_1 = -G_4 = 5.8928 \text{ T/m}$ and $G_2 = -G_3 = -14.6466 \text{ T/m}$
- proton or alpha beam
- gaussian $T = 8 \text{ MeV or 2 MeV (standard deviation is 4 keV)}$
- angular divergence : 0.5 m rad
- gaussian position distribution of $10 \mu \text{m FWMH}$

$B_z = G_y$
$B_x = G_x$
$B_z = 0$

$G$ is the field gradient

GEANT4.1+P01 predicts:
- Focus plane position : $230.15 \pm 0.05 \text{ mm}$
- FWHM of beam in image plane : $1.3 \mu \text{m}$
- same prediction as the OXRAY code:
  focus plane position : $230.1 \pm 0.1 \text{ mm}$
  FWHM = $1.1 \mu \text{m}$

Centre d’Études Nucléaires de Bordeaux-Gradignan

November 2002

Courtesy of S.Incerti (IN2P3/CNRS)
X-ray Multi-Mirror mission (XMM)

- Chandra X-ray observatory, with similar orbit, experienced unexpected degradation of CCDs
- Possible effects on XMM?

Launch December 1999
Perigee 7000 km
Apogee 114000 km
Flight through the radiation belts
γ astrophysics

γ-ray bursts

BeppoSAX Observation of Gamma-Ray Burst on February 28, 1997

 Courtesy of Fabrizio Fiore and the BeppoSAX Team

Typical telescope:
- Tracker
- Calorimeter
- Anticoincidence

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

GLAST

GLAST Hits Display

Previous
View XZ
View YZ
Zoom
Unzoom
New Center
Reset 3D
Marker +
Marker -
Save as Gif
View X3D

File Name: HT8_00.dat
Event ID: 15
Hits N: 72

Download

Kernel I - M.Asai

GLAST 4 x 4 Array of Towers

Some Dimensions are Distorted for Clarity of Presentation

Gamma Ray

Tracker
Calorimeter
Anticoincidence Shield

9.5 cm

Si Strip Detector
208 mm Strip
16 Gaps of 0.035 cm lead equivalent
2 Gaps without Converters
Imaging Calorimeter (1/4 length)

SLAC
NATIONAL ACCELERATOR LABORATORY
Induced X-ray line emission: indicator of target composition
(~100 μm surface layer)
Bepi Colombo: X-Ray Mineralogical Survey of Mercury

BepiColombo
ESA cornerstone mission to Mercury

Spettro di Fluorescenza di Basalto Islandese Simulato
En. Incidente 6.5 KeV

PlanetoCosmics
Geant4 simulation of Cosmic Rays in planetary Atmosphere/Magneto-spheres

28th International Cosmic Ray Conference

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

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

Cutoff Rigidities vs position
PlanetoCosmics
Mars field and atmosphere

- MGS observation Br @ 400 km
- Cain 50-degree spherical harmonic model (2003)
- NASA Mars GRAM2001 model
  - p, n, T in function of:
    - Lat., long. (topography from MOLA)
    - Altitude, season, local time, F10.7
- Dust models
  - Based on:
    - NASA MGCM 0-80 km
    - Univ. of Arizona MTGCM 80-170 km

Geant4 implementation courtesy L. Desorgher, University of Bern
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
Geometry examples of GATE applications

Multi-ring PET

D. Strul
IPHE Lausanne

Triple-head gamma camera

S. Staelens
Uni Ghent
GEANT4 based proton dose calculation in a clinical environment: technical aspects, strategies and challenges
Screen shots of gMocren
Comparison with commercial treatment planning systems

M. C. Lopes¹, L. Peralta², P. Rodrigues², A. Trindade²
¹ IPOFG-CROC Coimbra Oncological Regional Center - ² LIP - Lisbon

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

CT images used to define the geometry:
a thorax slice from a Rando anthropomorphic phantom

Agreement better than 2% between GEANT4 and TLD dosimeters
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
Geant4 license
The New 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.

• http://cern.ch/geant4/license/
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Basic concepts and kernel structure
Terminology (jargons)

- Run, event, track, step, step point
- Track $\leftrightarrow$ trajectory, step $\leftrightarrow$ trajectory point
- Process
  - At rest, along step, post step
- Cut = production threshold
- Sensitive detector, score, hit, hits collection,
Run in Geant4

• As an analogy of the real experiment, a run of Geant4 starts with “Beam On”.

• Within a run, the user cannot change
  – detector setup
  – settings of physics processes

• Conceptually, a run is a collection of events which share the same detector and physics conditions.
  – A run consists of one event loop.

• At the beginning of a run, geometry is optimized for navigation and cross-section tables are calculated according to materials appear in the geometry and the cut-off values defined.

• **G4RunManager** class manages processing a run, a run is represented by **G4Run** class or a user-defined class derived from G4Run.
  – A run class may have a summary results of the run.

• **G4UserRunAction** is the optional user hook.
Event in Geant4

- An event is the basic unit of simulation in Geant4.
- At beginning of processing, primary tracks are generated. These primary tracks are pushed into a stack.
- A track is popped up from the stack one by one and “tracked”. Resulting secondary tracks are pushed into the stack.
  - This “tracking” lasts as long as the stack has a track.
- When the stack becomes empty, processing of one event is over.
- G4Event class represents an event. It has following objects at the end of its (successful) processing.
  - List of primary vertices and particles (as input)
  - Hits and Trajectory collections (as output)
- G4EventManager class manages processing an event. G4UserEventAction is the optional user hook.
Track in Geant4

- Track is a **snapshot** of a particle.
  - It has physical quantities of **current instance** only. It does not record previous quantities.
  - Step is a “delta” information to a track. Track is not a collection of steps. Instead, a track is being updated by steps.

- Track object is deleted when
  - it goes out of the world volume,
  - it disappears (by e.g. decay, inelastic scattering),
  - it goes down to zero kinetic energy and no “AtRest” additional process is required, or
  - the user decides to kill it artificially.

- No track object persists at the end of event.
  - For the record of tracks, use trajectory class objects.

- **G4TrackingManager** manages processing a track, a track is represented by **G4Track** class.

- **G4UserTrackingAction** is the optional user hook.
Step in Geant4

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

- Track does not keep its trace. No track object persists at the end of event.
- **G4Trajectory** is the class which copies some of G4Track information. **G4TrajectoryPoint** is the class which copies some of G4Step information.
  - G4Trajectory has a vector of G4TrajectoryPoint.
  - At the end of event processing, G4Event has a collection of G4Trajectory objects.
    - /tracking/storeTrajectory must be set to 1.
- Keep in mind the distinction.
  - G4Track $\leftrightarrow$ G4Trajectory, G4Step $\leftrightarrow$ G4TrajectoryPoint
- Given G4Trajectory and G4TrajectoryPoint objects persist till the end of an event, you should be careful not to store too many trajectories.
  - E.g. avoid for high energy EM shower tracks.
- G4Trajectory and G4TrajectoryPoint store only the minimum information.
  - You can create your own trajectory / trajectory point classes to store information you need. G4VTrajectory and G4VTrajectoryPoint are base classes.
Particle in Geant4

• A particle in Geant4 is represented by three layers of classes.

• **G4Track**
  – Position, geometrical information, etc.
  – This is a class representing a particle to be tracked.

• **G4DynamicParticle**
  – "Dynamic" physical properties of a particle, such as momentum, energy, spin, etc.
  – Each G4Track object has its own and unique G4DynamicParticle object.
  – This is a class representing an individual particle.

• **G4ParticleDefinition**
  – "Static" properties of a particle, such as charge, mass, life time, decay channels, etc.
  – G4ProcessManager which describes processes involving to the particle
  – All G4DynamicParticle objects of same kind of particle share the same G4ParticleDefinition.
Tracking and processes

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

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

- At the end of each step, according to the processes involved, the state of a track may be changed.
  - The user can also change the status in `UserSteppingAction`.
  - Statuses shown in **green** are artificial, i.e. Geant4 kernel won’t set them, but the user can set.

- `fAlive`
  - Continue the tracking.

- `fStopButAlive`
  - The track has come to zero kinetic energy, but still AtRest process to occur.

- `fStopAndKill`
  - The track has lost its identity because it has decayed, interacted or gone beyond the world boundary.
  - Secondaries will be pushed to the stack.

- `fKillTrackAndSecondaries`
  - Kill the current track and also associated secondaries.

- `fSuspend`
  - Suspend processing of the current track and push it and its secondaries to the stack.

- `fPostponeToNextEvent`
  - Postpone processing of the current track to the next event.
  - Secondaries are still being processed within the current event.
Step status

• Step status is attached to G4StepPoint to indicate why that particular step was determined.
  – Use “PostStepPoint” to get the status of this step.
  – “PreStepPoint” has the status of the previous step.

• fWorldBoundary
  – Step reached the world boundary

• fGeomBoundary
  – Step is limited by a volume boundary except the world

• fAtRestDoItProc, fAlongStepDoItProc, fPostStepDoItProc
  – Step is limited by a AtRest, AlongStep or PostStep process

• fUserDefinedLimit
  – Step is limited by the user Step limit

• fExclusivelyForcedProc
  – Step is limited by an exclusively forced (e.g. shower parameterization) process

• fUndefined
  – Step not defined yet

• If you want to identify the first step in a volume, pick fGeomBoudary status in PreStepPoint.
• If you want to identify a step getting out of a volume, pick fGeomBoundary status in PostStepPoint
Cuts in Geant4

• 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.
Extract useful information

- Given geometry, physics and primary track generation, Geant4 does proper physics simulation “silently”.
  - You have to add a bit of code to extract information useful to you.

- There are two ways:
  - Use user hooks (G4UserTrackingAction, G4UserSteppingAction, etc.)
    - You have an access to almost all information
    - Straight-forward, but do-it-yourself
  - Use Geant4 scoring functionality
    - Assign G4VSensitiveDetector to a volume
    - Hits collection is automatically stored in G4Event object, and automatically accumulated if user-defined Run object is used.
    - Use user hooks (G4UserEventAction, G4UserRunAction) to get event / run summary
Unit system

- Internal unit system used in Geant4 is completely hidden not only from user’s code but also from Geant4 source code implementation.
- Each hard-coded number must be multiplied by its proper unit.
  \[
  \text{radius} = 10.0 \times \text{cm};
  \]
  \[
  \text{kineticE} = 1.0 \times \text{GeV};
  \]
- To get a number, it must be divided by a proper unit.
  \[
  \text{G4cout} \ll e\text{Dep} / \text{MeV} \ll " [\text{MeV}]" \ll \text{G4endl};
  \]
- Most of commonly used units are provided and user can add his/her own units.
- By this unit system, source code becomes more readable and importing / exporting physical quantities becomes straightforward.
  - For particular application, user can change the internal unit to suitable alternative unit without affecting to the result.
G4cout, G4cerr

• G4cout and G4cerr are *ostream* objects defined by Geant4.
  – G4endl is also provided.

```cpp
G4cout << "Hello Geant4!" << G4endl;
```

• Some GUIs are buffering output streams so that they display print-outs on another window or provide storing / editing functionality.
  – The user should not use std::cout, etc.

• The user should not use std::cin for input. Use user-defined commands provided by intercoms category in Geant4.
  – Ordinary file I/O is OK.
Geant4 kernel

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

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

- Geant4 is a toolkit. You have to build an application.
- To make an application, you have to
  - Define your geometrical setup
    - Material, volume
  - Define physics to get involved
    - Particles, physics processes/models
    - Production thresholds
  - Define how an event starts
    - Primary track generation
  - Extract information useful to you
- You may also want to
  - Visualize geometry, trajectories and physics output
  - Utilize (Graphical) User Interface
  - Define your own UI commands
  - etc.
User classes

• **main()**
  – Geant4 does not provide `main()`.

• **Initialization classes**
  – Use `G4RunManager::SetUserInitialization()` to define.
  – Invoked at the initialization
    • `G4VUserDetectorConstruction`
    • `G4VUserPhysicsList`

• **Action classes**
  – Use `G4RunManager::SetUserAction()` to define.
  – Invoked during an event loop
    • `G4VUserPrimaryGeneratorAction`
    • `G4UserRunAction`
    • `G4UserEventAction`
    • `G4UserStackingAction`
    • `G4UserTrackingAction`
    • `G4UserSteppingAction`

Note: classes written in red are mandatory.
The main program

• Geant4 does not provide the `main()`.

• In your `main()`, you have to
  
  – Construct G4RunManager (or your derived class)
  
  – Set user mandatory classes to RunManager
    
    • G4VUserDetectorConstruction
    
    • G4VUserPhysicsList
    
    • G4VUserPrimaryGeneratorAction
  
• You can define VisManager, (G)UI session, optional user action classes, and/or your persistency manager in your `main()`.
Describe your detector

- Derive your own concrete class from `G4VUserDetectorConstruction` abstract base class.
- In the virtual method `Construct()
  - Instantiate all necessary materials
  - Instantiate volumes of your detector geometry
  - Instantiate your sensitive detector classes and set them to the corresponding logical volumes
- Optionally you can define
  - Regions for any part of your detector
  - Visualization attributes (color, visibility, etc.) of your detector elements
Select physics processes

- Geant4 does not have any default particles or processes.
  - Even for the particle transportation, you have to define it explicitly.

- Derive your own concrete class from `G4VUserPhysicsList` abstract base class.
  - Define all necessary particles
  - Define all necessary processes and assign them to proper particles
  - Define cut-off ranges applied to the world (and each region)

- Geant4 provides lots of utility classes/methods and examples.
  - "Educated guess" physics lists for defining hadronic processes for various use-cases.
Generate primary event

- Derive your concrete class from `G4VUserPrimaryGeneratorAction` abstract base class.
- Pass a `G4Event` object to one or more primary generator concrete class objects which generate primary vertices and primary particles.
- Geant4 provides several generators in addition to the `G4VPrimaryParticleGenerator` base class.
  - `G4ParticleGun`
  - `G4HEPEvtInterface, G4HepMCIInterface`
    - Interface to `/hepevt/` common block or HepMC class
  - `G4GeneralParticleSource`
    - Define radioactivity
Optional user action classes

- All user action classes, methods of which are invoked during “Beam On”, must be constructed in the user’s `main()` and must be set to the RunManager.

- **G4UserRunAction**
  - `G4Run* GenerateRun()`
    - Instantiate user-customized run object
  - `void BeginOfRunAction(const G4Run*)`
    - Define histograms
  - `void EndOfRunAction(const G4Run*)`
    - Analyze the run
    - Store histograms

- **G4UserEventAction**
  - `void BeginOfEventAction(const G4Event*)`
    - Event selection
  - `void EndOfEventAction(const G4Event*)`
    - Output event information
Optional user action classes

- **G4UserStackingAction**
  - `void PrepareNewEvent()`
    - Reset priority control
  - `G4ClassificationOfNewTrack ClassifyNewTrack(const G4Track*)`
    - Invoked every time a new track is pushed
    - Classify a new track -- priority control
      - Urgent, Waiting, PostponeToNextEvent, Kill
  - `void NewStage()`
    - Invoked when the Urgent stack becomes empty
    - Change the classification criteria
    - Event filtering (Event abortion)
Optional user action classes

• **G4UserTrackingAction**
  – void PreUserTrackingAction(const G4Track*)
    • Decide trajectory should be stored or not
    • Create user-defined trajectory
  – void PostUserTrackingAction(const G4Track*)
    • Delete unnecessary trajectory

• **G4UserSteppingAction**
  – void UserSteppingAction(const G4Step*)
    • Kill / suspend / postpone the track
    • Draw the step (for a track not to be stored as a trajectory)
Let me remind you…

- Define material and geometry
  - G4VUserDetectorConstruction
    Material and Geometry lectures
- Select appropriate particles and processes and define production threshold(s)
  - G4VUserPhysicsList
    Physics lectures
- Define the way of primary particle generation
  - G4VUserPrimaryGeneratorAction
    Primary particle lecture
- Define the way to extract useful information from Geant4
  - G4UserSteppingAction, G4UserTrackingAction, etc.
  - G4VUserDetectorConstruction, G4UserEventAction, G4Run, G4UserRunAction
  - G4SensitiveDetector, G4VHit, G4VHitsCollection
    Scoring lectures