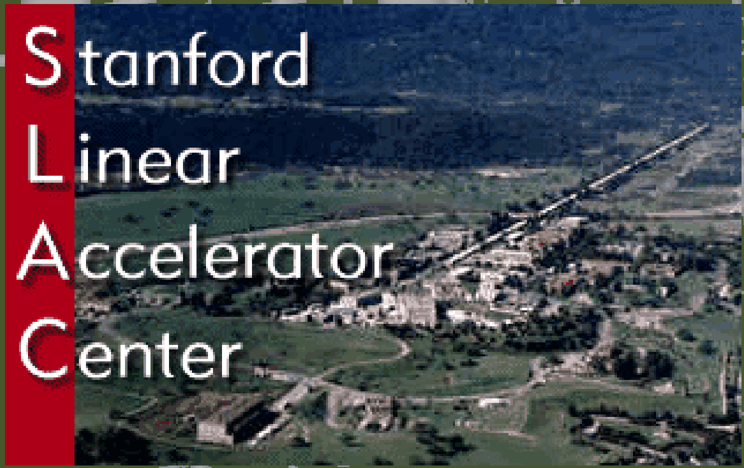


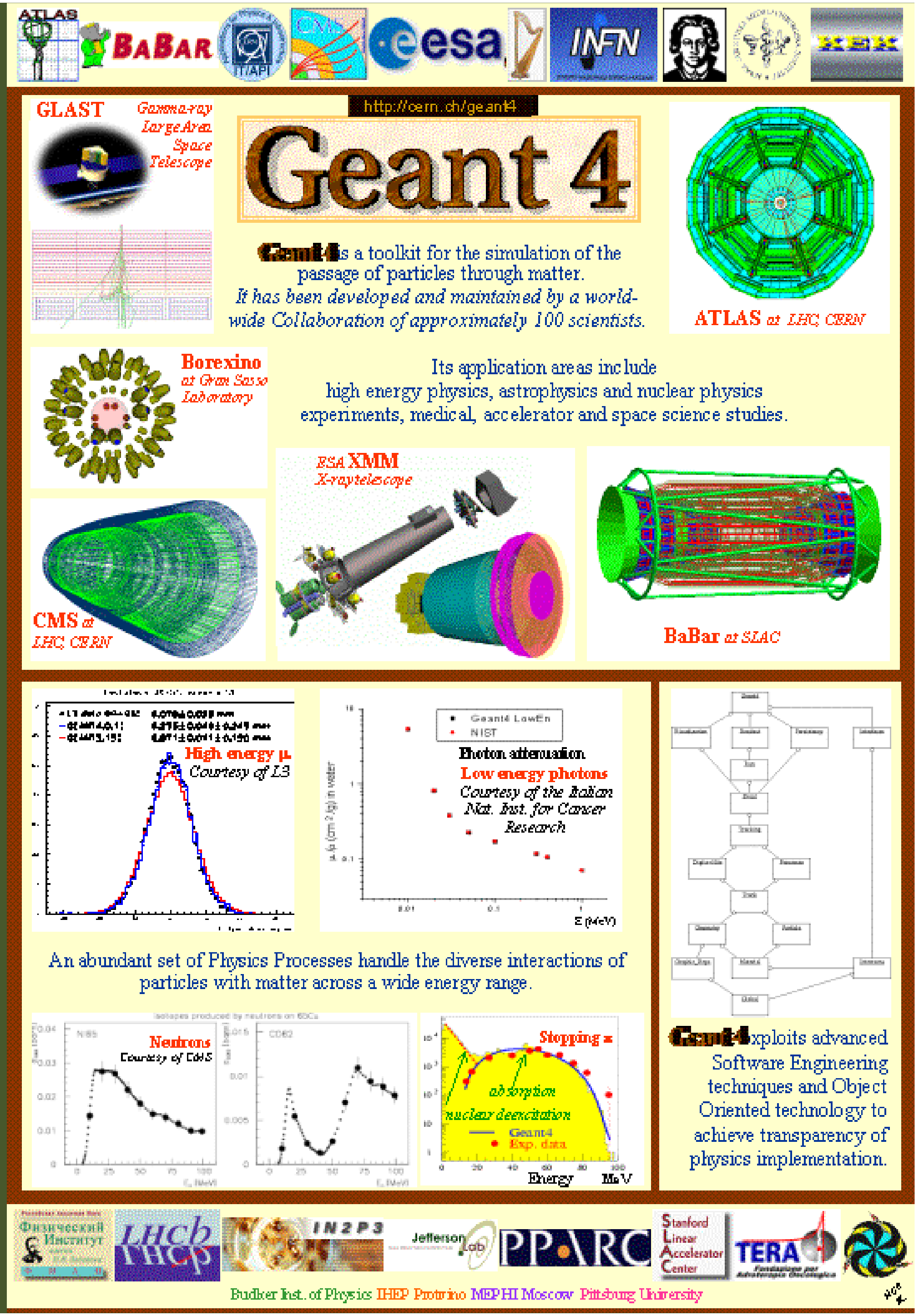
Kernel I

Makoto Asai (SLAC)

Geant4 Tutorial Course

Contents

- General introduction and brief history
- Geant4 license
- Geant4 kernel
  - Basic concepts and kernel structure
  - User classes



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

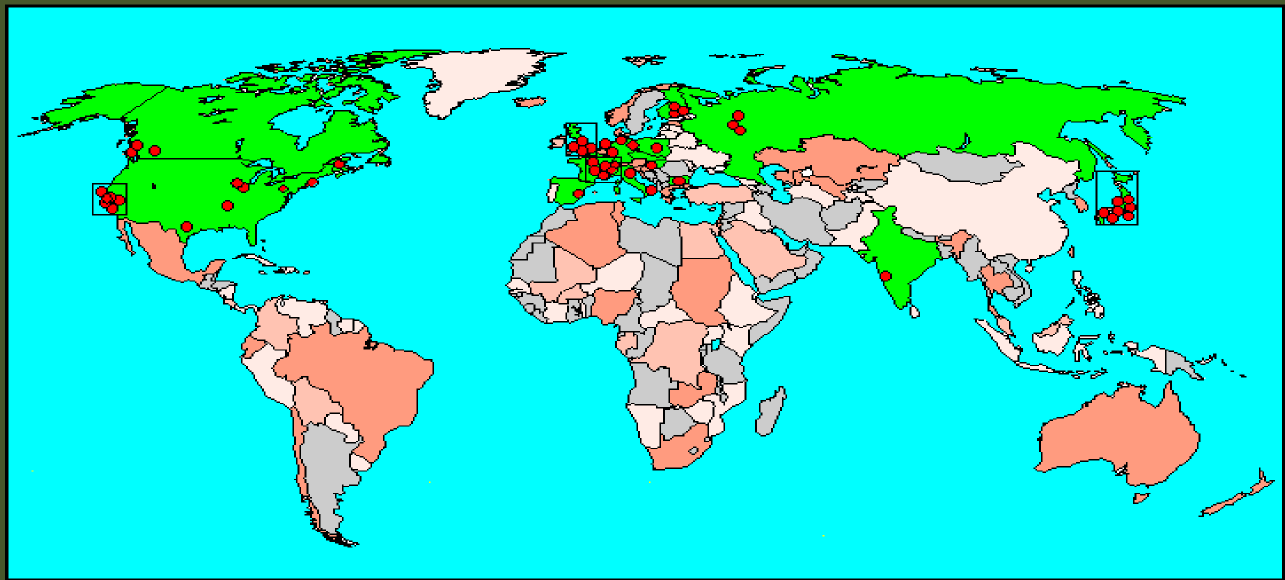
Physics in Geant4

- 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
- …
- June 30th, ’06 - Geant4 version 8.1 release
  - July 27th, ’06 - Geant4 8.1-patch01 release
- Dec 15th, ’06 - Geant4 version 8.2 release
  - Feb 23rd, ’07 - Geant4 8.2-patch01 release
- May 11th, ’07 - Geant4 version 8.3 release ← Current version
- June 29th, ’07 - Geant4 version 9.0 release (planned)
- We currently provide two to three public releases every year.
  - Bimonthly beta releases are available to the registered beta-testers.

Geant4 Collaboration



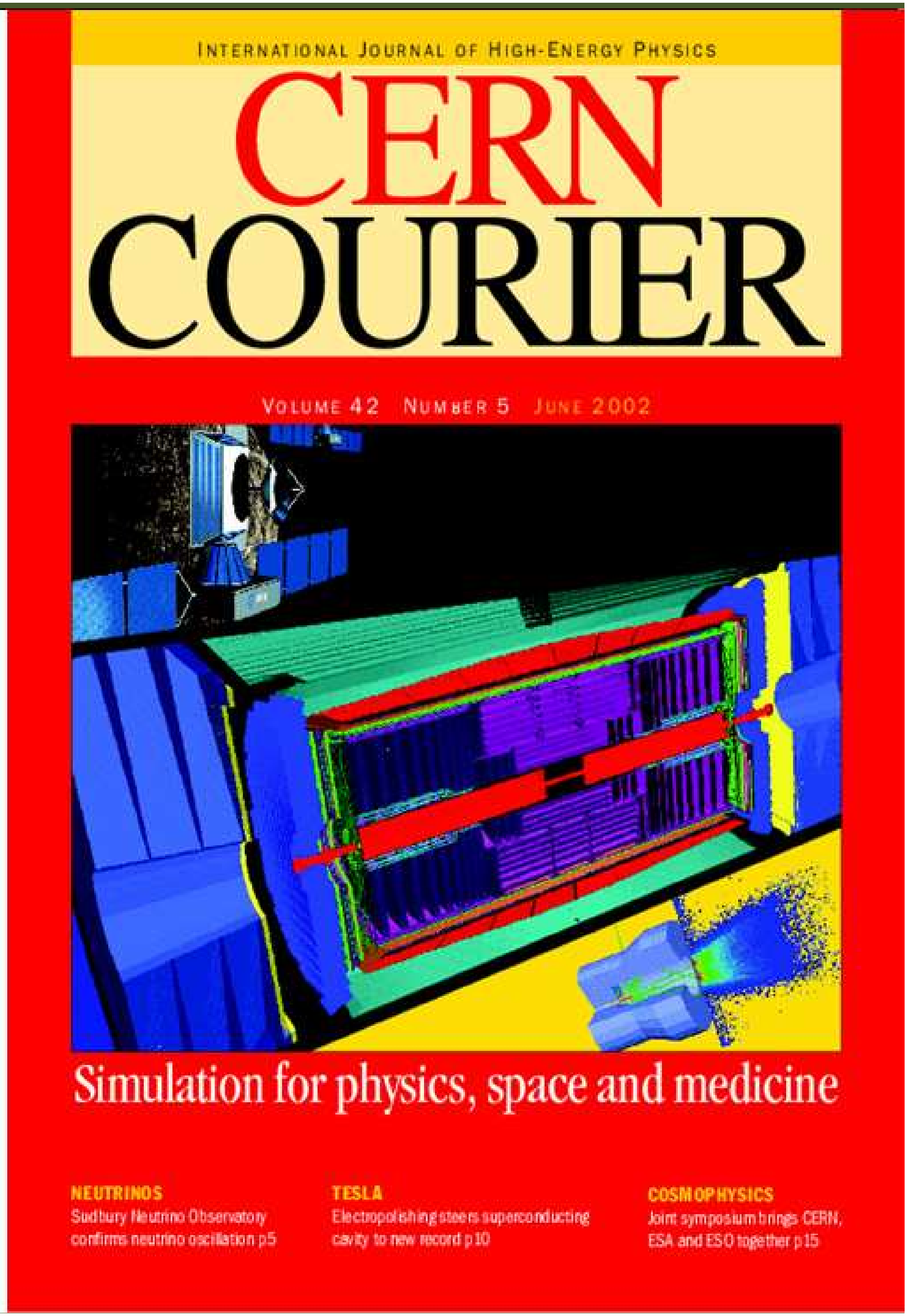
TRIUMF

Lebedev

J.W.Goethe Universität

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

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   Chong, K.P.
2. Geant4-a simulation toolkit • **Article**
   Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 506, Issue 3, 1 July 2003, Pages 250-303
   Agostinelli, S.; Allison, J.; Amako, K.; Apostolakis, J.; Araujo, H.; Arce, P.; Asai, M.; Axen, D.; Banerjee, S.; Barrand, G.; Behner, F.; Bellagamba, L.; Boudreau, J.; Broglia, L.; Brunengo, A.; Burk
3. Radiation pneumonitis and pulmonary fibrosis in non-small-cell lung cancer: Pulmonary function,

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Engineering

Previous | Field Menu 2006 | Field Menu 2005 | Field Menu 2004
"Super Hot" Papers in Science Published Since 2003

Engineering

(Sorted by citations. 3 of 128)

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

Geant4 license

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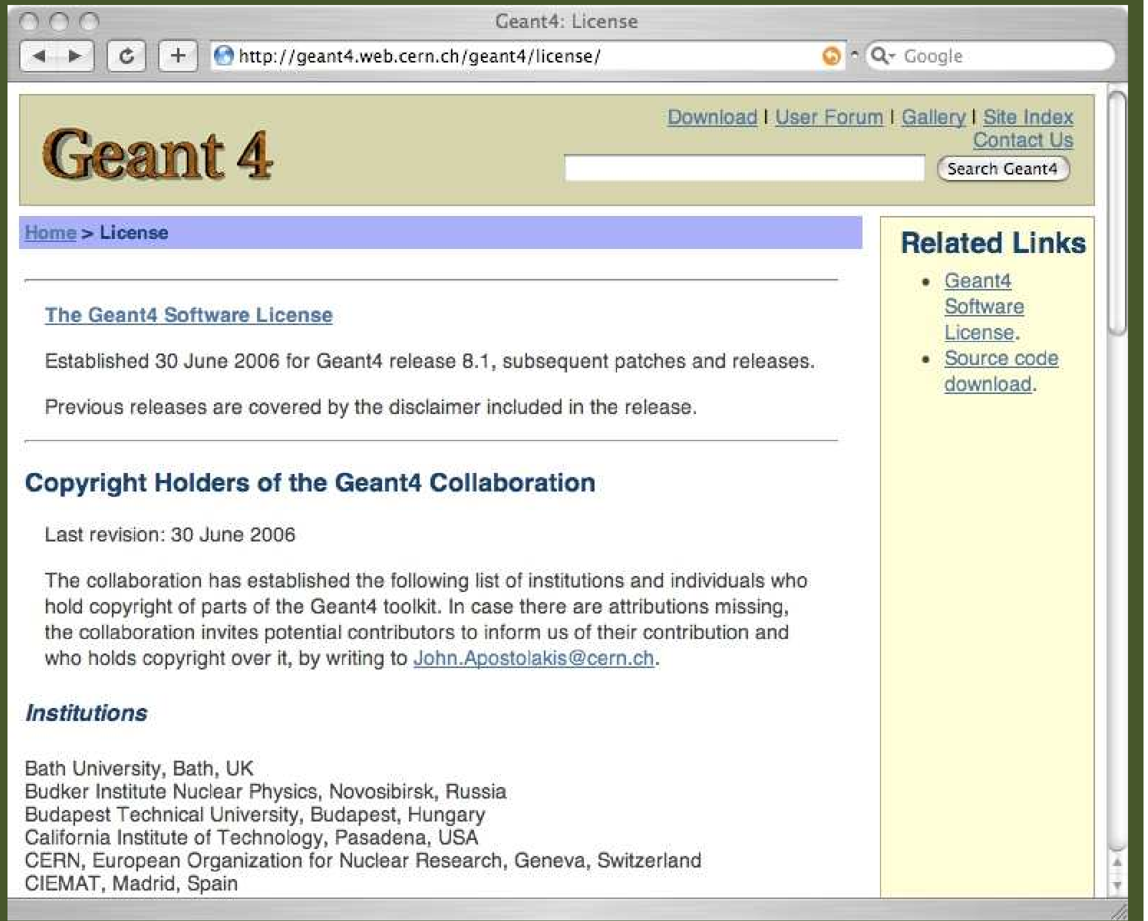
In response to user requests for clarification of Geant4's distribution policy, the collaboration recently announced a new license.

- 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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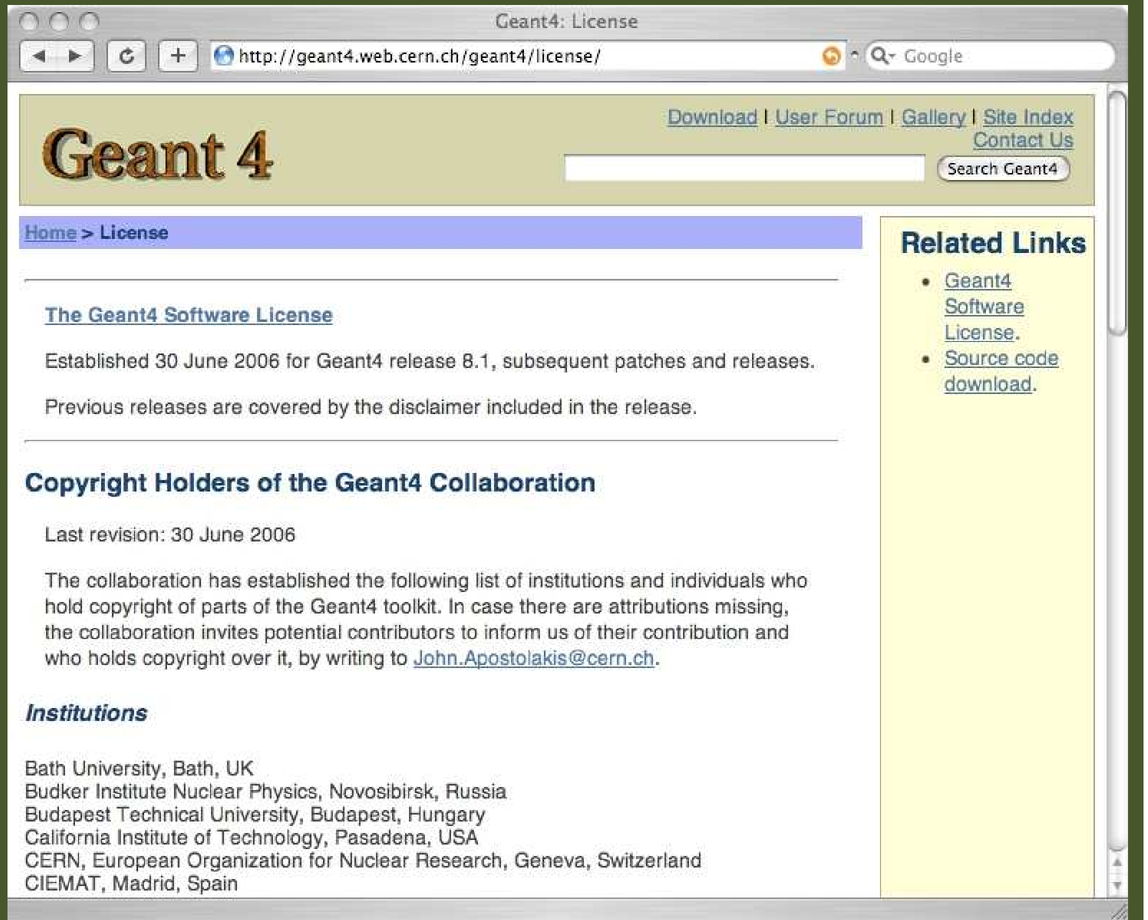
- Through the generous support of many governments and institutions, you, the community, have already paid for Geant4.
- We, the Geant4 collaboration, want you to enjoy the software and use it where ever you can.



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Basic concepts
and kernel structure

Terminology (jargons)

- Run, event, track, step, step point
- Track ←→ trajectory, step ←→ trajectory point
- Process
  - At rest, along step, post step
- Cut = production threshold
- Sensitive detector, 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

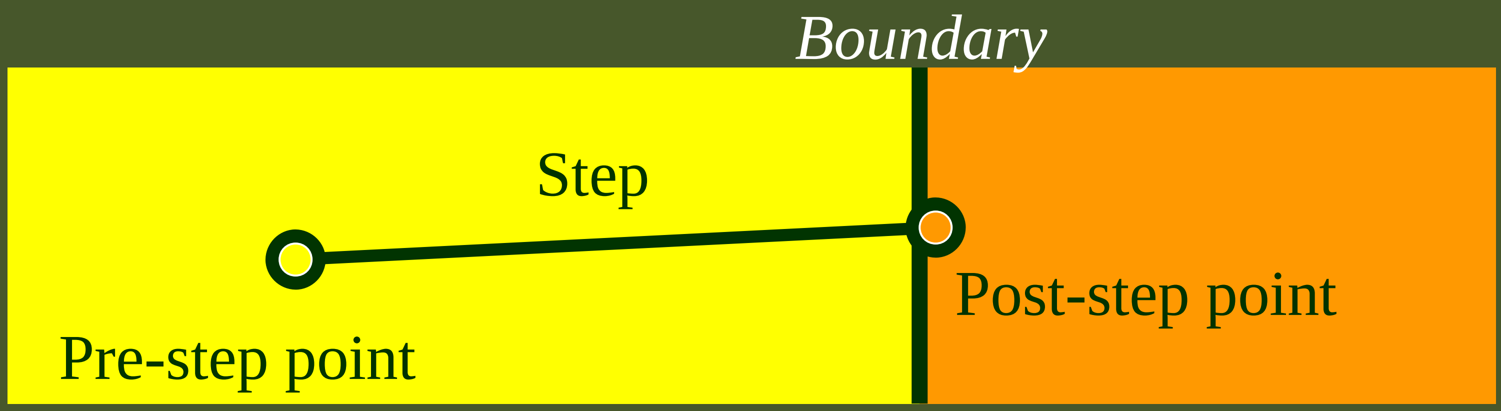
- An event is the basic unit of simulation in Geant4.
- At beginning of processing, primary tracks are generated. These primary tracks are pushed into a stack.
- A track is popped up from the stack one by one and "tracked". Resulting secondary tracks are pushed into the stack.
  - This "tracking" lasts 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 ←→ G4Trajectory, G4Step ←→ 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

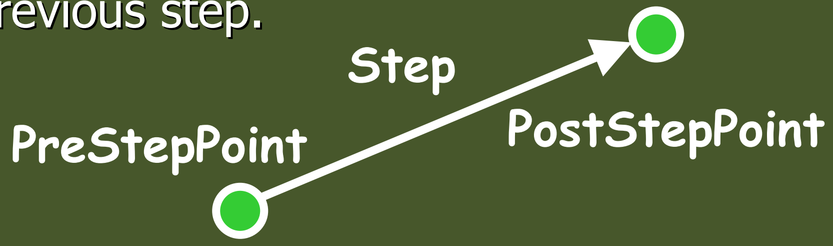
Track status

- 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 yellow 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.

```
radius = 10.0 * cm;
kineticE = 1.0 * GeV;
```

- To get a number, it must be divided by a proper unit.

```
G4cout << eDep / MeV << " [MeV]" << 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

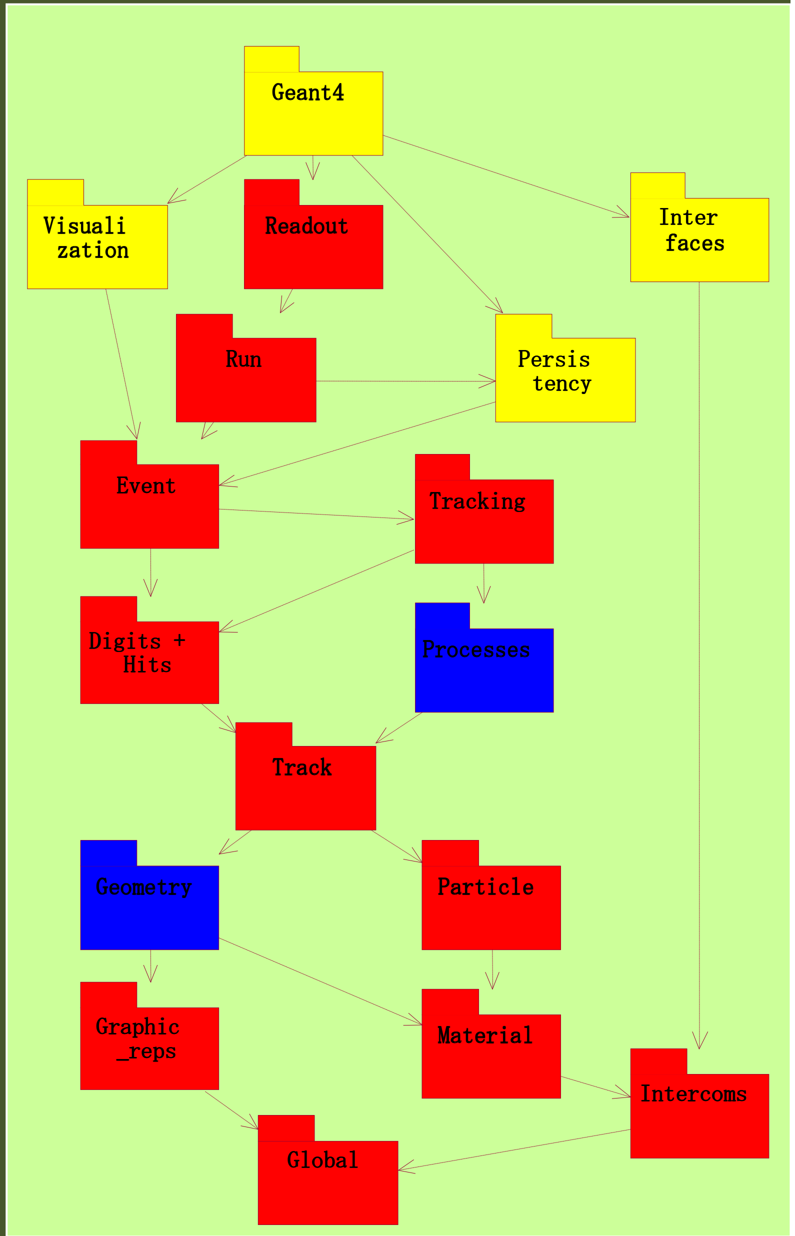
- G4cout and G4cerr are *ostream* objects defined by Geant4.
  - G4endl is also provided.

```
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.

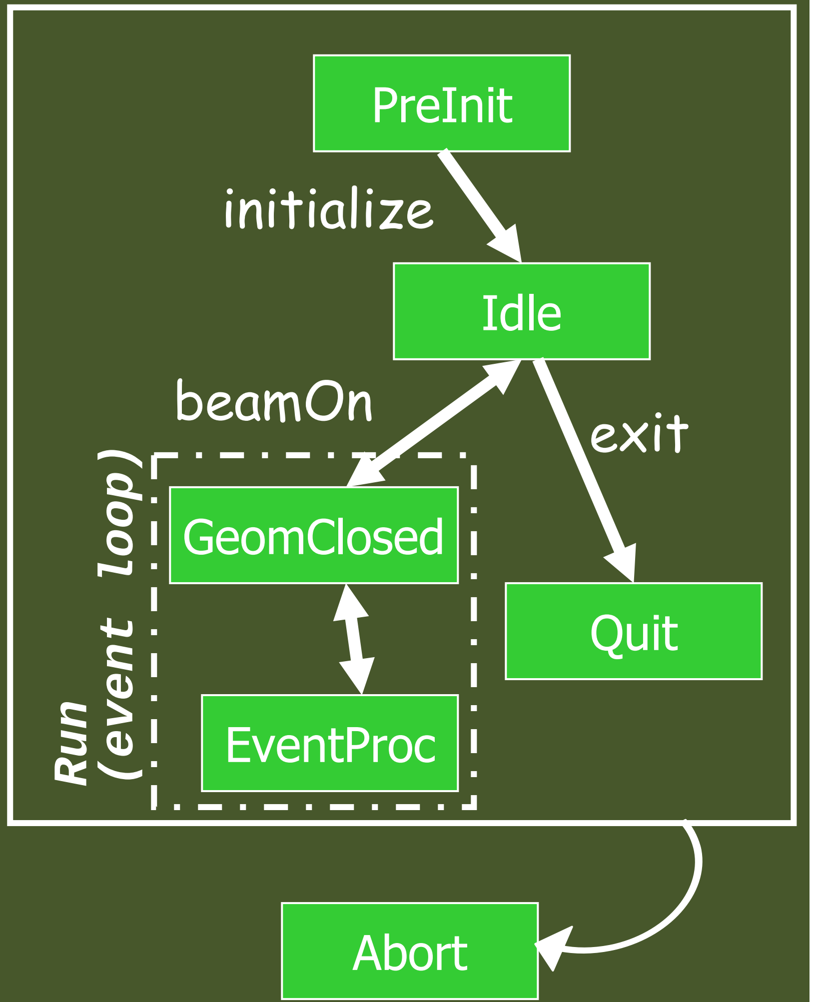
Geant4 kernel

- 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 yellow 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, G4HepMCInterface
    - 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