GEANT4-DNA
A SIMULATION TOOLKIT

Introduction to Geant4

geant4-dna.org

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Geant4-DNA tutorial
Thaïlande
18-20/3/2026

Geant4 version 11.4
Released in December 2025

Contents of this talk

- Aim of this Lecture
- Particle Transport in Geant4
- Geant4 Implementation (simulation management)
- Geometry
- Physics
- Incident Particle
- Scoring and User Hook
- Tips

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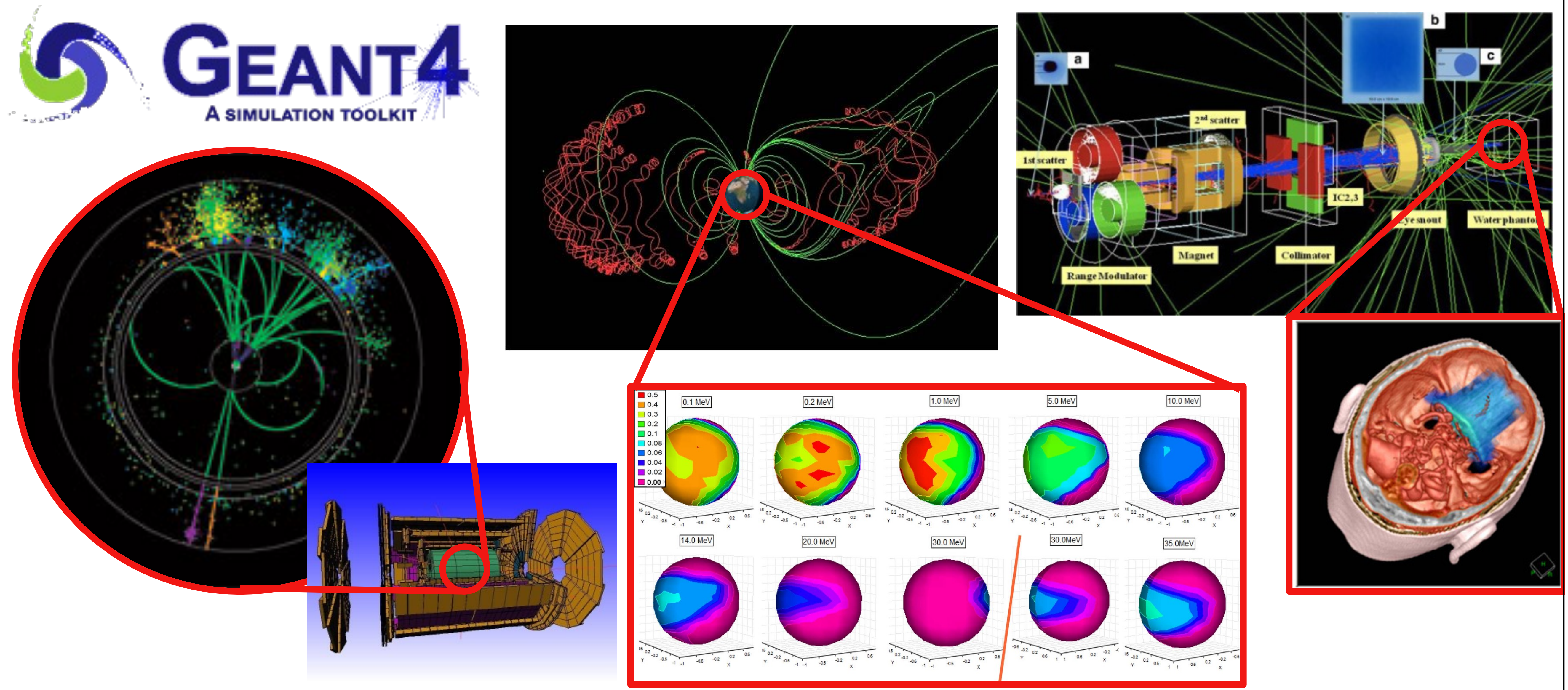
Geometry ANd Tracking 4 (Geant4)



Aim of this lecture and note

- Geant4 is designed as a toolkit.
- Thus, Geant4 has very high scalability,

  although the implementation could be a bit difficult.

- The aim of this lecture is to **understand the concept of the Geant4 simulations**.

- We explain only basic,

  simple,

  general,

  and, easy things.

  But, Geant4 provides numerous functionalities

  which is not introduced in this lecture.

Acknowledgement: This slide partially takes inspiration from the Geant4 lecture materials provided by KEK.

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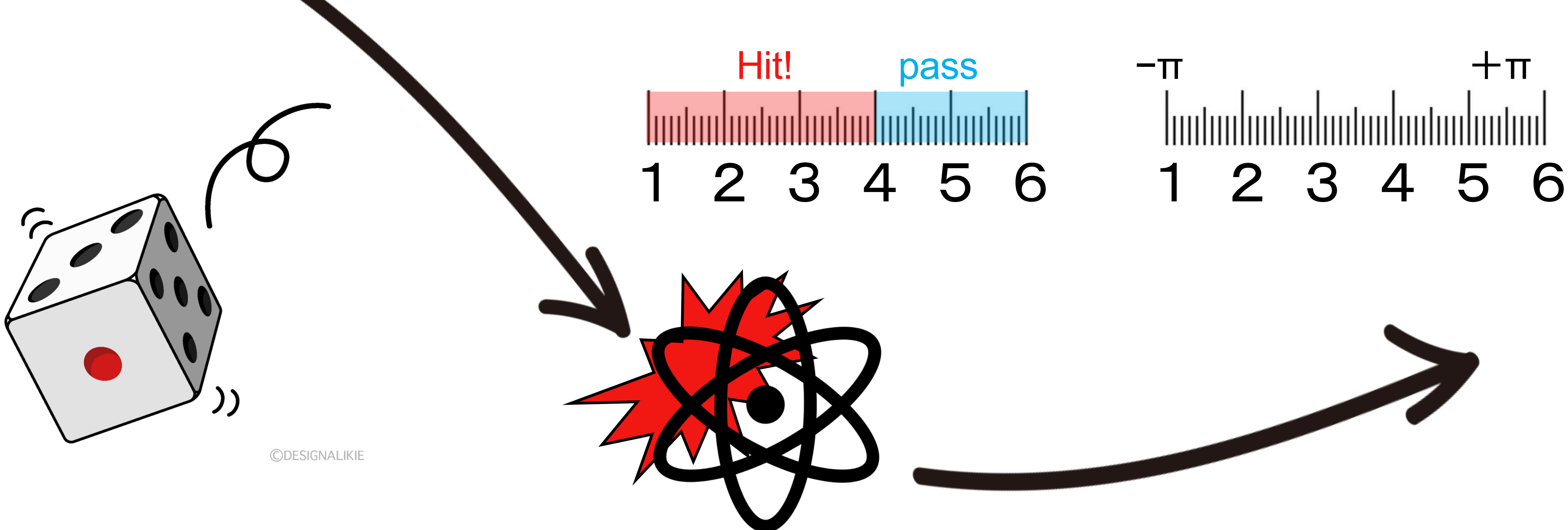
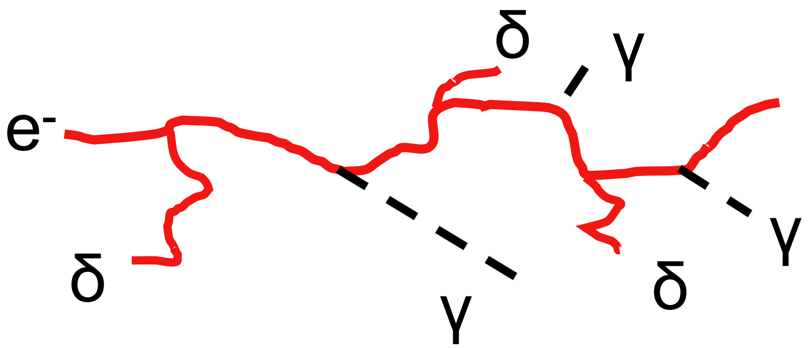
Monte Carlo Methods in Particle Transport

Monte Carlo simulation:
A method to predict the probability of various events when the potential for random variable is present .

We can extend this MC method for particle transport
(such as particle hists, deflection etc…).



Charged Particle Transport in Geant4



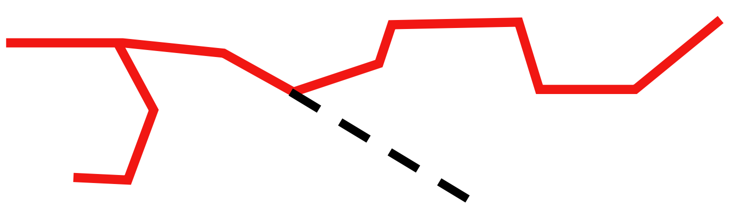
Trajectory in real world

High accuracy/Slow computing

Track-Structure approach

- Sequential interaction calculation

[Geant4-DNA, PARTRAC, RITRACKS, TRACION, KURBUC, PHITS(-TS)]

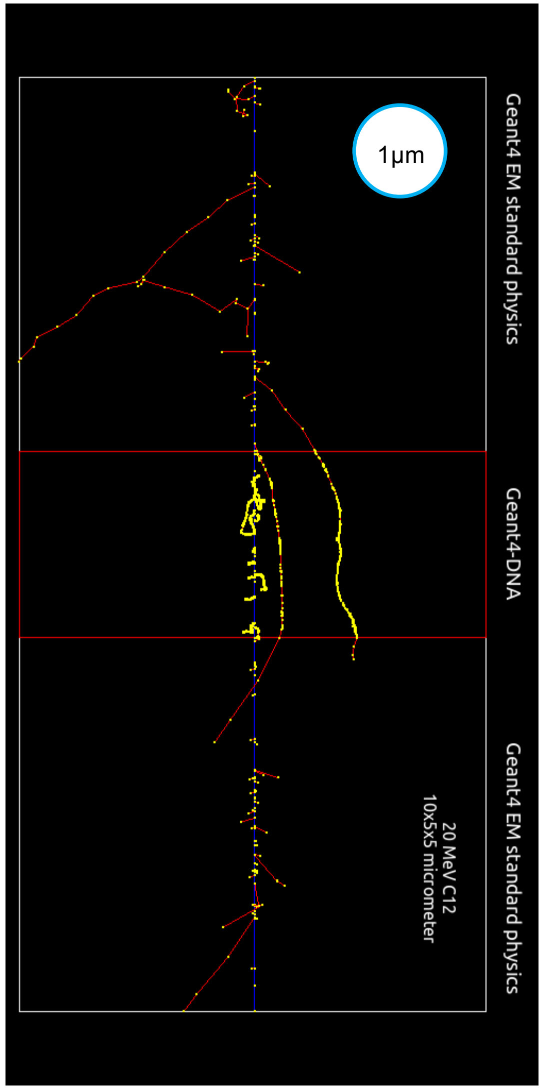


Low accuracy /**Fast computing**

Condensed-History approach

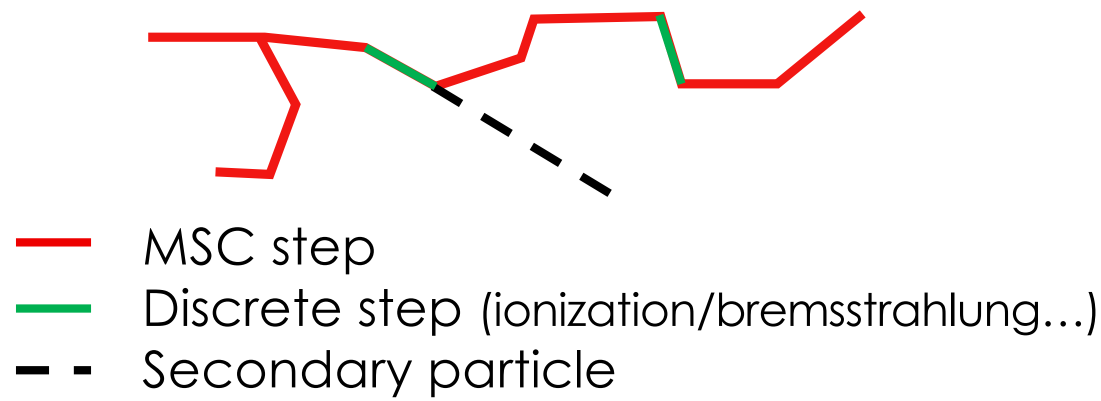
- Multiple-scattering approximation
- Continuous slowing down approximation

[Geant4, PHITS, EGS]

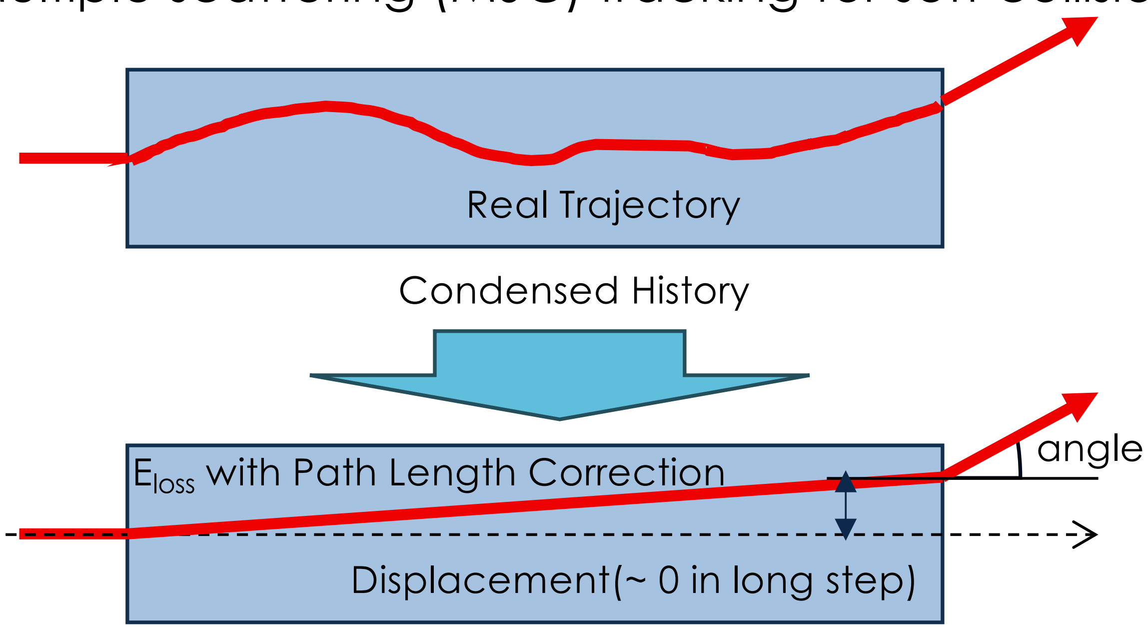


Condensed History Tracking for charged particles

Geant4 tracking



Multiple scattering (MSC) tracking for soft collisions



CH tracking handles 3 types of interactions

Soft collision

Typically, charged particle interacts 10^3 – 10^5 times with Coulomb effects (Elastic/semi-elastic) in 1 mm. Scattering angle of each interaction is very small. This type of interactions are model as a multiple scattering. Basically, continuous (restricted; neglect energy loss by hard collisions) energy loss and multiple scattering angle are sampled in the step.

Hard collision

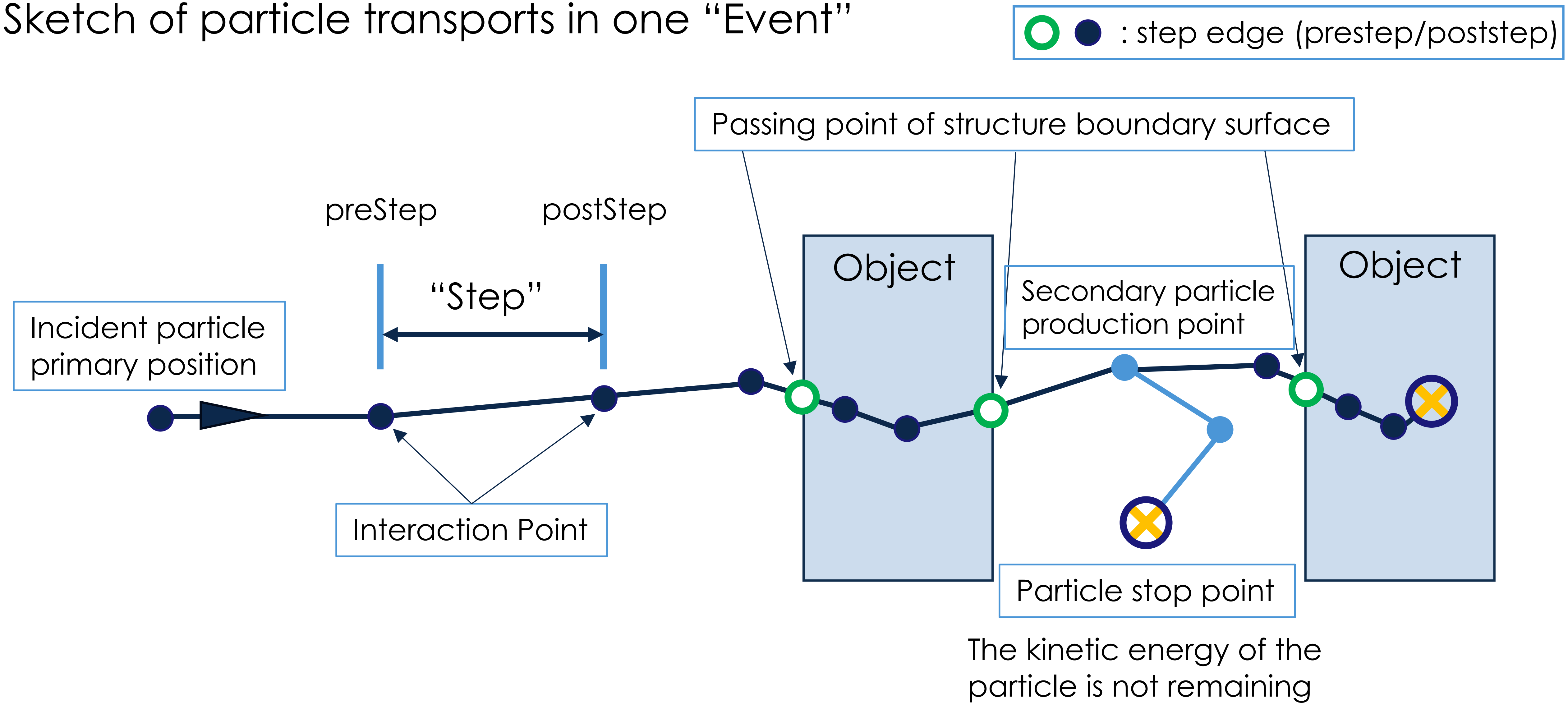
It is inelastic collisional interaction. Such as Ionization and nuclear fragmentation are categorized into hard collisions. This process needs to be modeled in a discrete manner.

Radiation

Charged particles lose energy via emission of radiation while interacting with electromagnetic or color fields in a medium (e.g., Bremsstrahlung). This process needs to be modeled in a discrete manner.

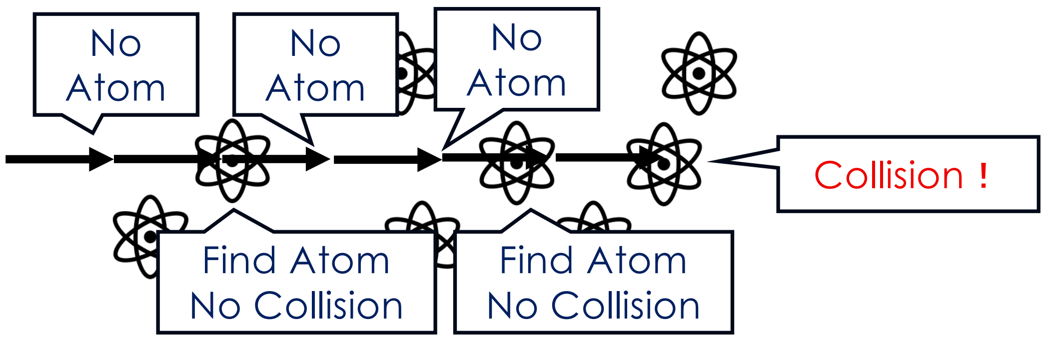
Geant4 Particle Transport

Sketch of particle transports in one "Event"



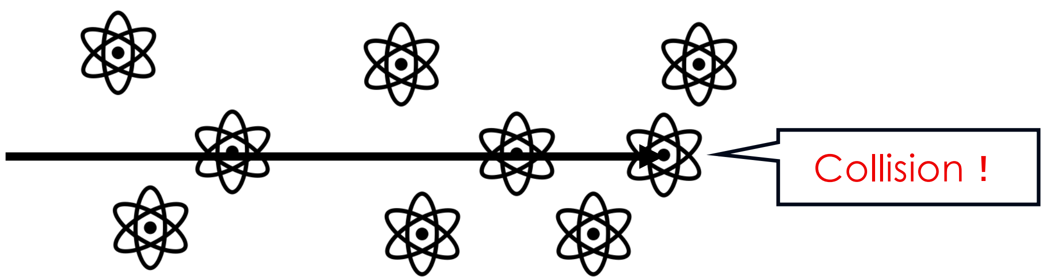
How manage "step"?

(A) Short step approach with hit probability ~ 33 %: an average of one hit per three atoms



High computing cost…

(B) Calculate distance to a collision

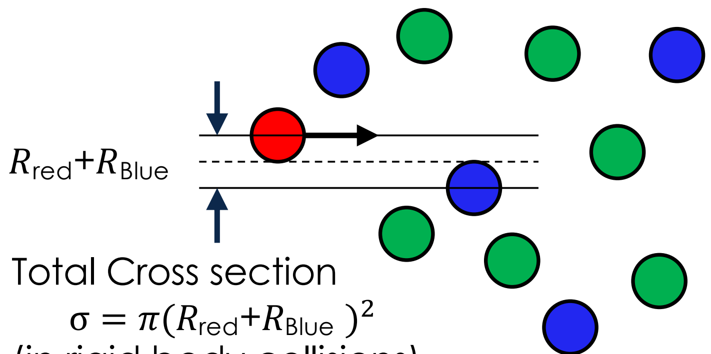


Low computing cost !

Sampling "Step" 1 : Cross Section and Mean Free Path

Geant4 samples step length based on mean free path (MFP) for each interaction.

Cross section (cm²): interaction probability

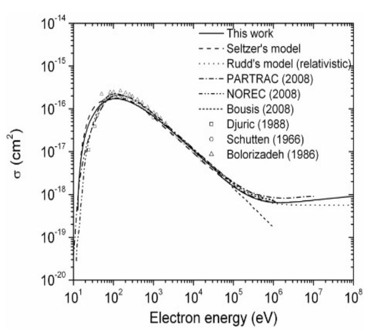


Total Cross section

$\sigma = \pi(R_{\text{red}}+R_{\text{Blue}})^2$

(in rigid body collisions)

It depends on particle, energy, process...
e.g.)Total electron ionization cross section for water



I. Plante et. al.
2009 New J. Phys. 11 063047

The average of mean free path (MFP) is related by $\lambda(E) = 1/(n \cdot \sigma(E))$.

Thus, in general, MFP of processes can be calculated as follows,

$$\lambda(E) = \left(\sum_i [n_i \cdot \sigma_i(E)]\right)^{-1}$$

where, E is kinetic energy of incident particle, n_i is number of atoms per volume (*i*-th *material*: blue, green in the left sketch).

Let's think, the survival probability of the particle at x: $P(x)$

$$P(x + dx) = P(x)(1 - \lambda(E)^{-1} dx)$$

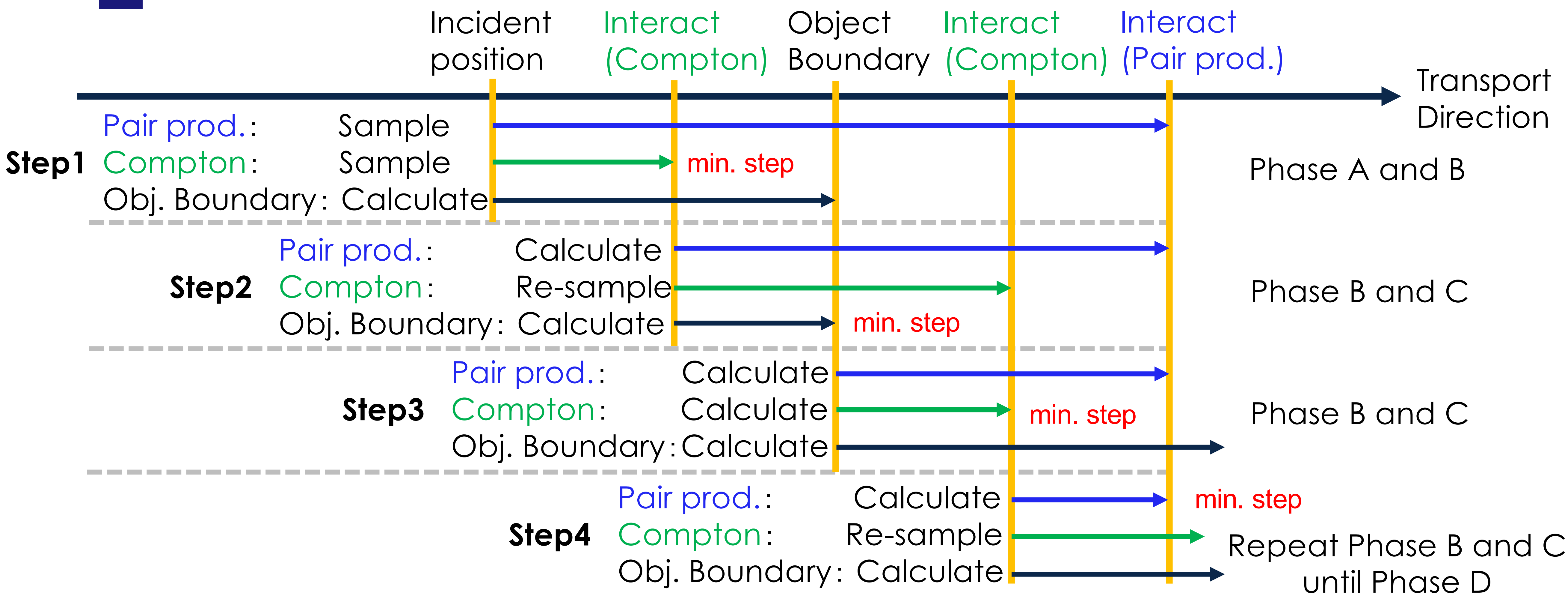
$P(x)$: prob. of no interaction until x

$(1 - \lambda^{-1} dx)$: prob. of no interaction until dx

$$P(x) = exp(-x/\lambda(E))$$ number of MFP

Geant4 samples number of MFP (x: step length) for each process

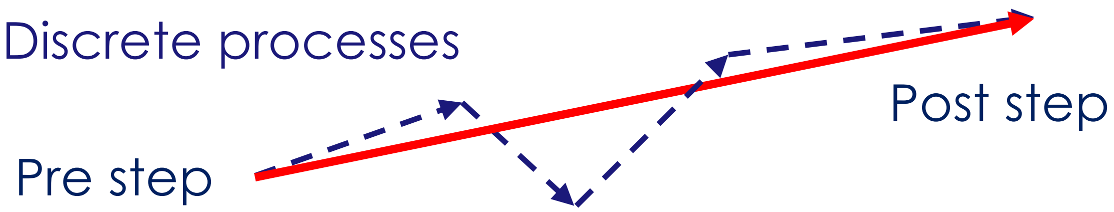
Sampling "Step" 2 : Step Selection Algorithm



Phase A: Sample step length for each process
Phase B: Chose minimum step length one of the evaluated step lengths or distance to the object boundary.
Phase C: Re-sample step length for the selected interaction
Phase D: Stop calculation until either particle energy is zero or achieving to the end of "world"

Interaction in “Step” 1 : Scattering Angle in Multiple Scattering

Multiple-scattering (MSC) approximation



$\frac{x}{\lambda} < 1$: Single Scattering

1 MeV photon in water : λ ~ 10 cm

Geant4 transport photon in SS

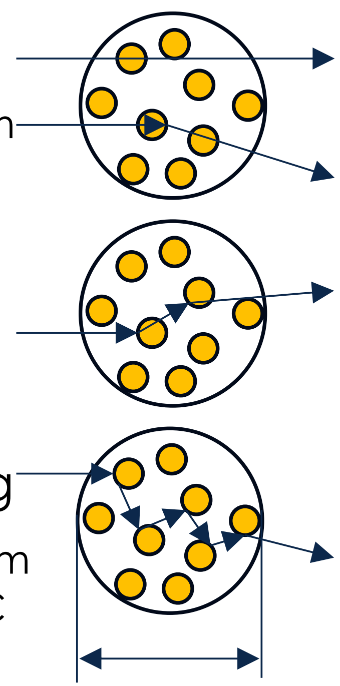
$1 < \frac{x}{\lambda} < 10$: Intermediate

$10 < \frac{x}{\lambda}$: Multiple Scattering

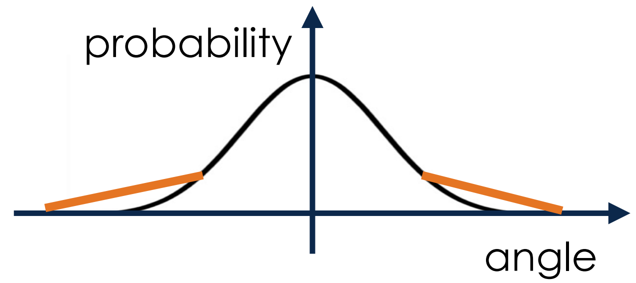
10 keV electron in water: λ ~ 10 nm

Geant4 transport electron in MSC

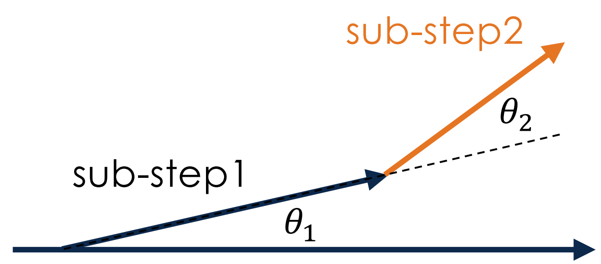
Number of MFP : $\frac{x}{\lambda}$

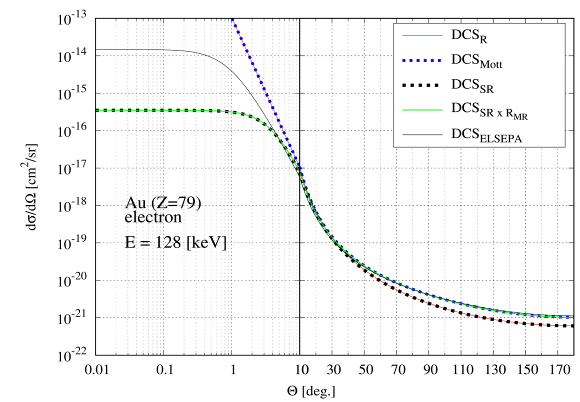


- Conventional approach
  Urban model: central (~ gaussian)
  + tail correction



- Recent approach
  Goudsmit-Saunderson model:
  Multiple elastic scattering approach

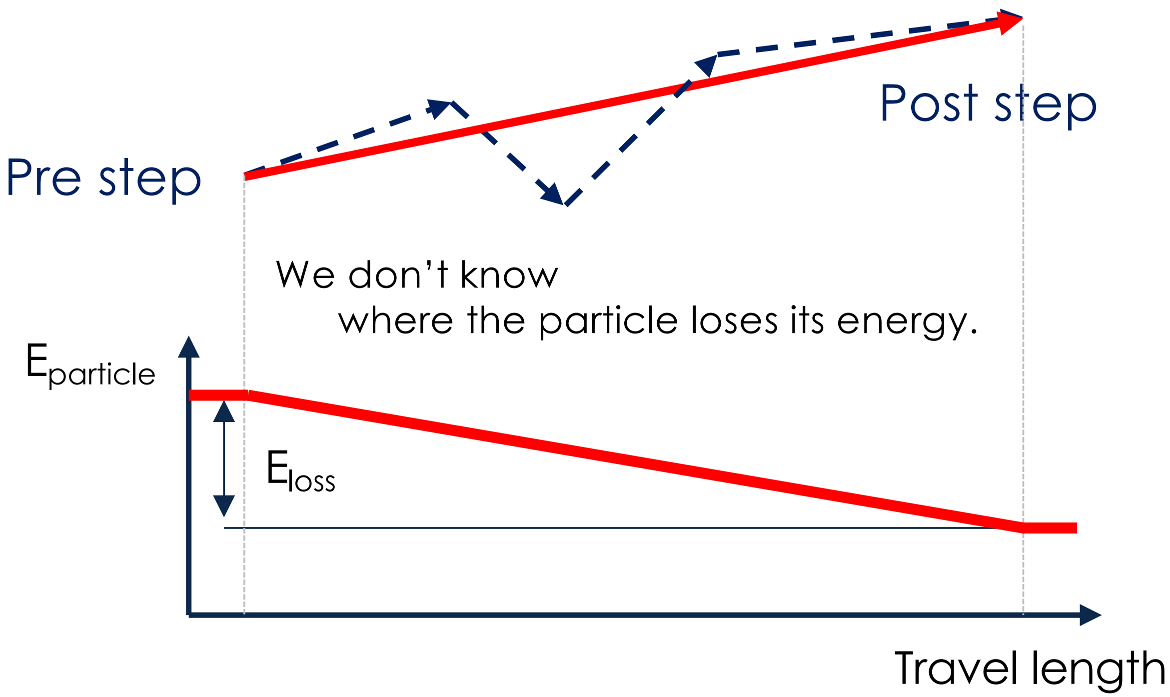




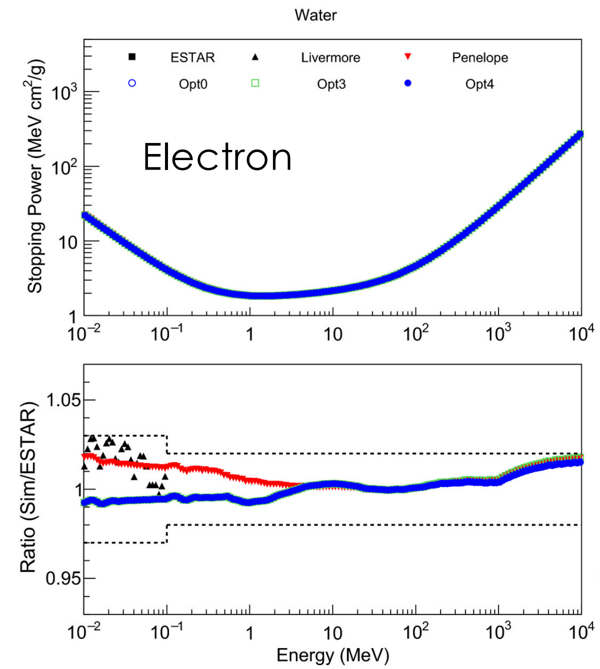
arXiv:2410.13361v1 [physics.comp-ph] 17 Oct 2024

Interaction in “Step” 2 : Energy Loss and Secondary Production

Continuous Slowing Down approximation



Energy loss is evaluated by energy loss table, based on either free-gas model, ICRU, or the Bethe-Bloch.



Ref: Med Phys. 2021 Jan;48(1):19-56

In naive, E_{loss} is calculated by

$$E_{loss} = \frac{dE}{dx}\Delta s$$

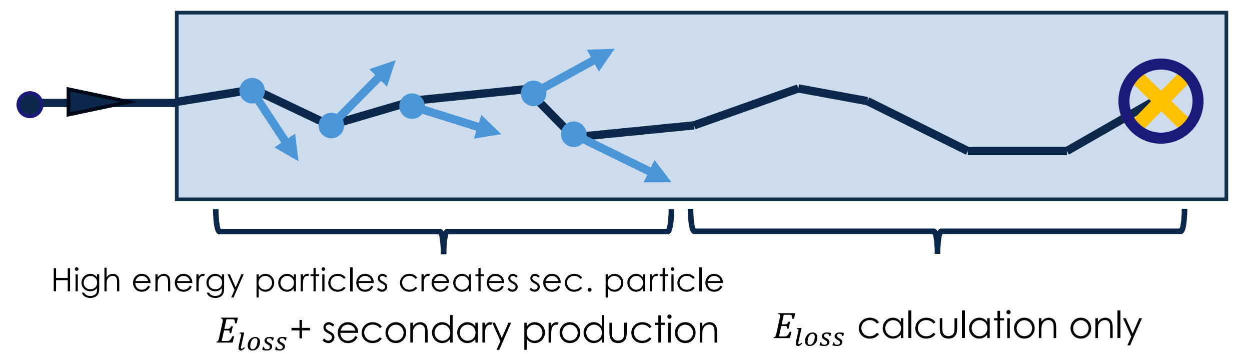
$\frac{dE}{dx}$: energy loss in unit length

Δs: step size

If step size is large compared to range, the E_{loss} calculation will be less accurate. So, step size is automatically limited.

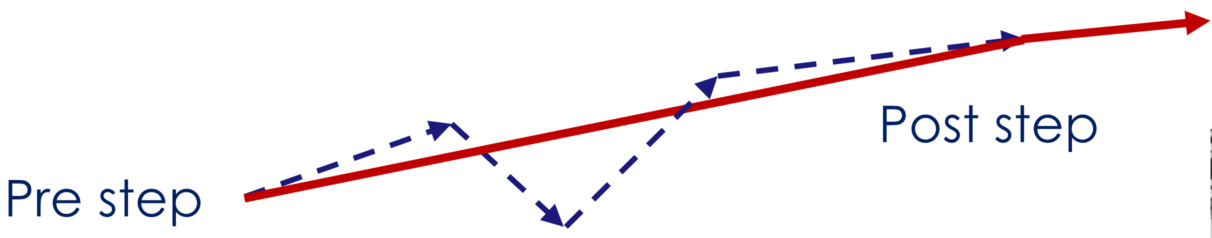
The E_{loss} is a stochastic quantity, therefor, the fluctuation is also sampled by one of the implemented models.

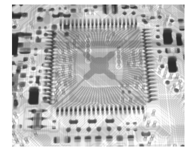
Geant4 controls the production of secondary particles using the *range cut* . This means that Geant4 does not generate secondary particles where its range is smaller than the cut-off value.



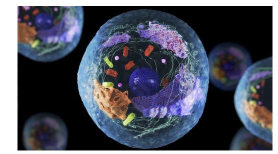
Limitation of condensed history approach
~ Can we simulate with microscopic volumes? ~

Condensed-History approach





Micro-electronics
→ MicroElec extension



Biological applications
→ Geant4-DNA

$\frac{x}{\lambda} < 1$: Single Scattering

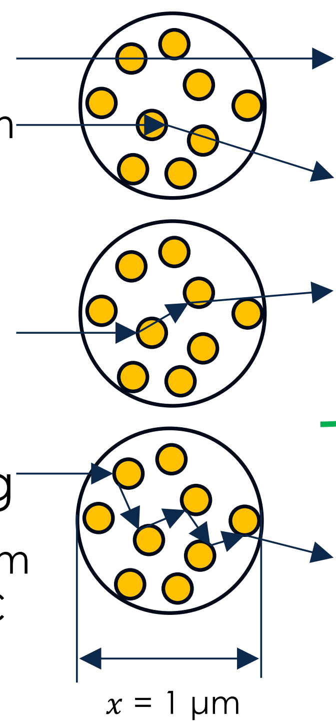
1 MeV photon in water : λ ~ 10 cm
Geant4 transport photon in SS

$1 < \frac{x}{\lambda} < 10$: Intermediate

$10 < \frac{x}{\lambda}$: Multiple Scattering

10 keV electron in water: λ ~ 10 nm
Geant4 transport electron in MSC

Number of MFP : $\frac{x}{\lambda}$



Ag, Be, Fe, Si, W, Al,
Ge, C, Ti, Cu, Au, Ni,
BORON_NITRIDE
SILICON_DIOXIDE,
ALUMINUM_OXIDE,
KAPTON,
TITANIUM_NITRIDE

WATER, Au
Other density scaled water

Available materials are limited

Geant4 with track structure approach

Other Applications (1 µm or lager)

Geant4 with condensed history approach

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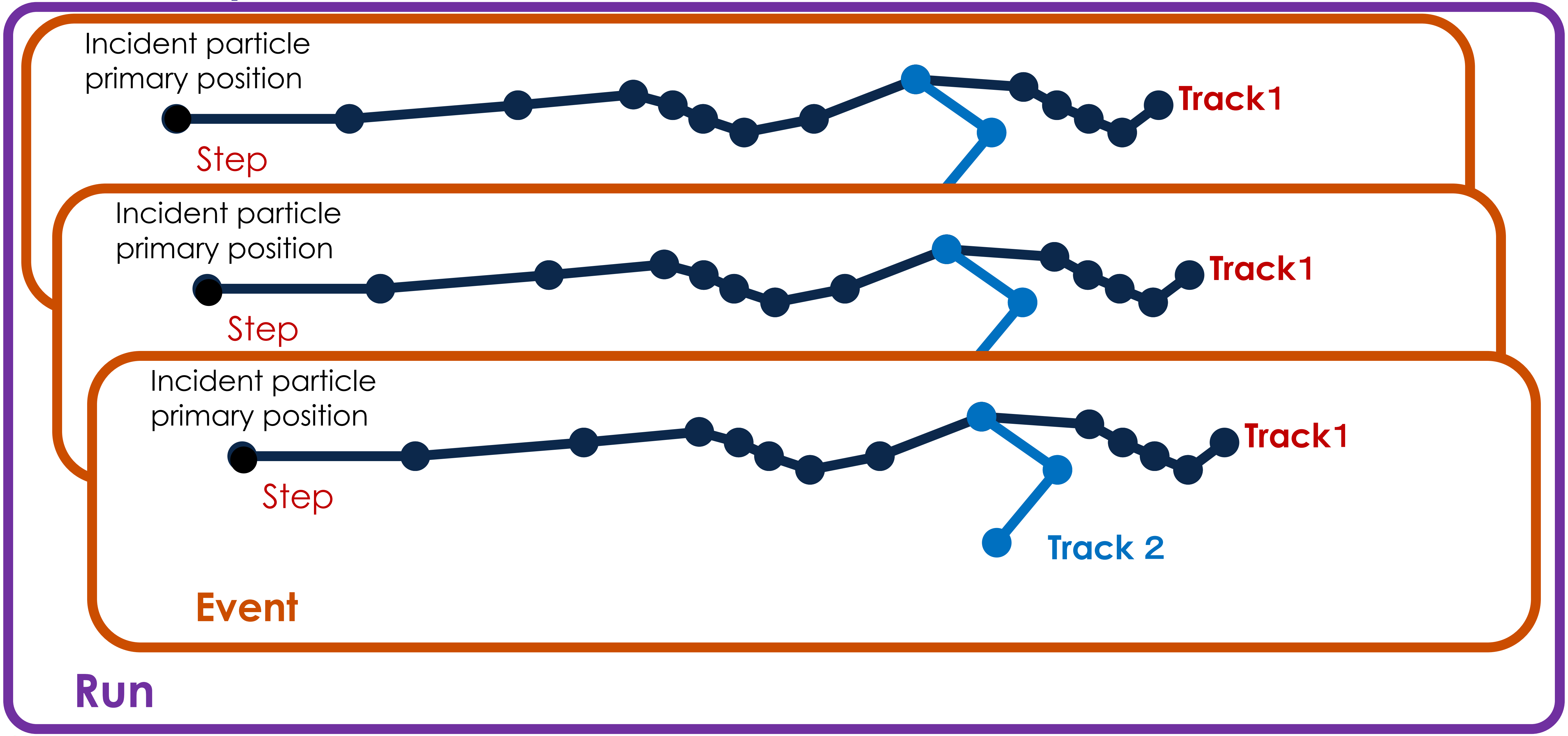
Step, Track, Event, Run



Essential information that required for simulations

PrimaryGeneratorAction

Incident particle primary position

- Particle type (e^-, γ, …)
- Energy
- Direction, Distribution, …

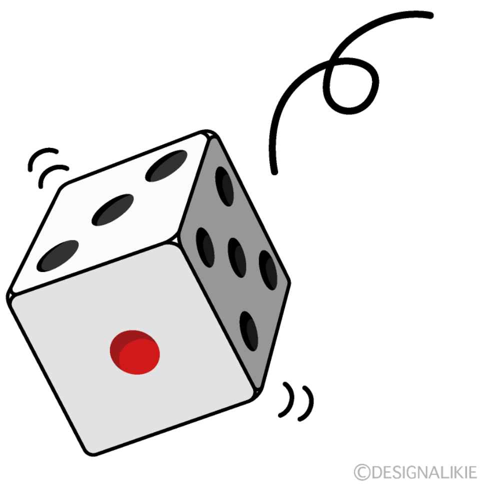
RunManager

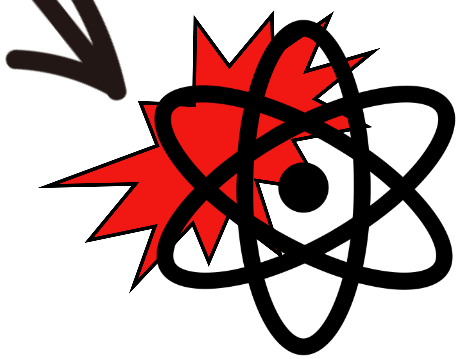
The class for managing a whole simulation

PhysicsList

Information of Interaction

- Electromagnetic Interactions
- Hadronic Interactions
- Nuclear/Atomic Decay, optical, …



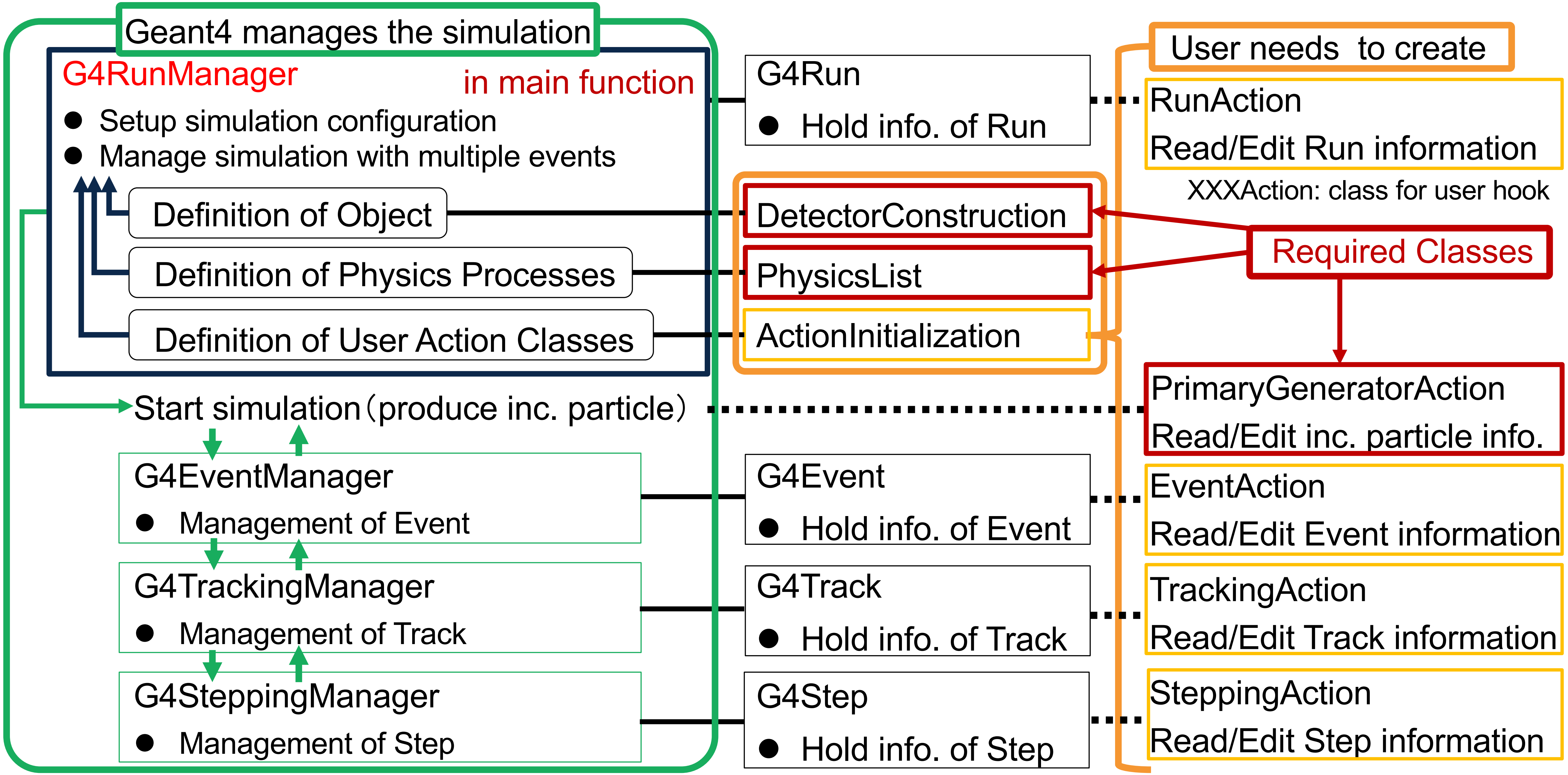


DetectorConstruction

Object Property

- Object Shape
- Atomic number
- Density, …

Simulation Management and Implementation



Contents of Application (advanced/medical_linac)

see examples/advanced/medical_linac

Application descriptions	README History	
Setup file to compile	CMakeLists.txt	
Main source	medical_linac.cc **src** **include**	DetectorConstruction.hh/cc DetectorMessenger.hh/cc PhysicsList.hh/cc PhysicsListMessenger.hh/cc ActionInitialization.hh/cc PrimaryGeneratorAction.hh/cc PrimaryGeneratorMessenger.hh/cc RunAction.hh/cc SteppingAction.hh/cc StackingAction.hh/cc StepMax.hh/cc StepMaxMessenger.hh/cc
Macro commands	run.mac vis.mac	

macro command definition (→ DetectorMessenger.hh/cc, PhysicsListMessenger.hh/cc, PrimaryGeneratorMessenger.hh/cc)

Build/Execute Application

```
$ cp –r path/to/examples/advance/medical_linac .
$ cd medical_linac
$ mkdir build
$ cd build
$ cmake ../
$ make

$ ./medical_linac
            or
$ ./medical_linac run.mac
```

execute medical_linac with user interface panel

execute medical_linac with macrofile

Order of Execution ①

see examples/advanced/medical_linac/medical_linac.cc

```
int main(int argc, char** argv)
{
  G4UIExecutive* ui = nullptr;
  if (argc == 1){
     ui = new G4UIExecutive(argc, argv);
   }

  //construct the run manager
  auto* runManager = G4RunManagerFactory::CreateRunManager();

  runManager -> SetUserInitialization(new PhysicsList());
  runManager -> SetUserInitialization(new DetectorConstruction());
  runManager -> SetUserInitialization(new ActionInitialization());
  G4ScoringManager::GetScoringManager();

  // Initialize visualization
  G4VisManager* visManager = new G4VisExecutive;
  visManager->Initialize();

  // Get the pointer to the User Interface manager
  G4UImanager* UImanager = G4UImanager::GetUIpointer();

  if ( ! ui ){
     // batch mode
     G4String command = "/control/execute ";
     G4String fileName = argv[1];
     UImanager->ApplyCommand(command+fileName);
  }else {
    // interactive mode
    UImanager->ApplyCommand("/control/execute vis.mac");
    ui->SessionStart();
    delete ui;
  }

  // Job termination
  delete visManager;
  delete runManager;
  return 0;
}
```

```
$ ./medical_linac
$ ./medical_linac run.mac
```

:argc = 1
:argc = 2

If argc==1, user interface window will be popped up

Create RunManager

Register PhysicList
DetectorConstruction
PrimaryGeneratorAction and the other action classes via ActionInitialization

Register built-in scoring class

Initialize visualization

Create User Interface (Command) Manager

if argc != 1 Execute "/control/execute XXX.xxx" by UI manager

if argc == 1 Execute "/control/execute vis.mac" by UI manager

Clean the job

Order of Execution ②

After /control/execute run.mac (see run.mac in medical_linac)

```
#### verbosities
/control/verbose 1
/material/verbose 0
/run/verbose 0
/process/em/verbose 0

/run/numberOfThreads 4

/physics/addPhysics standard_opt3

/run/initialize

/score/create/boxMesh boxMesh_1
/score/mesh/translate/xyz 0 0 130 mm
/score/mesh/boxSize 127.5 127.5 127.5 mm  # half dim
/score/mesh/nBin 51 51 51
/score/quantity/doseDeposit dDep
/score/close
/score/list

/run/printProgress 100000
/run/beamOn 5000000

#/score/drawProjection boxMesh_1 dDep
/score/dumpQuantityToFile boxMesh_1 dDep dDep.txt
```

Set verbose (log output) level

Set number of threads for the job

Select EM physics

Initialize run

G4RunManager::Initialize() will be called
→ G4RunManager:: InitializeGeometry()
→ DetectorConstruction:: Construct()
→ G4RunManager:: InitializePhysics()
→ PhysicsList:: Construct()

Setup Scoring (boxMesh_1)
G4Box: 255 mm × 255 mm × 255 mm (nbins 51 × 51 × 51)
Placed at (0 , 0 , 130 mm)
Dose deposit will be scored for each voxel

Run 5000000 events

Save scored result in dDep.txt

GEANT4-DNA

Order of Execution ③

After /run/BeamOn

RunAction::GenerateRun()

RunAction::BeginOfRunAction

Loop of Event ==

PrimaryGeneratorAction::GeneratePrimaries

EventAction::BeginOfEventAction

Loop of Tracks ==================================

TrackingAction:: BeginOfTrackingAction

Loop of Steps ===========================

SteppingAction::BeginOfSteppingAction

SteppingAction:: EndOfSteppingAction

TrackingAction:: EndOfTrackingAction

EventAction::EndOfEventAction

RunAction:: EndOfRunAction

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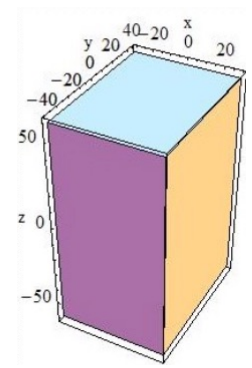
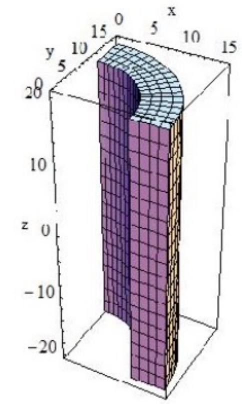
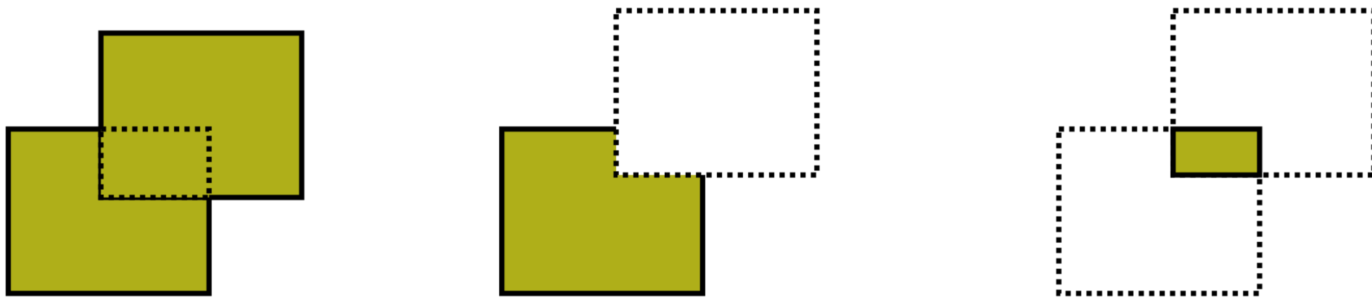
Geometry 1: Solid Geometry

- Catalog of Solid Geometry
  - CSG (Constructive Solid Geometry) classes
  - 3D representation of simple shapes
  - (G4Box, G4Tubs, G4Sphere,…)

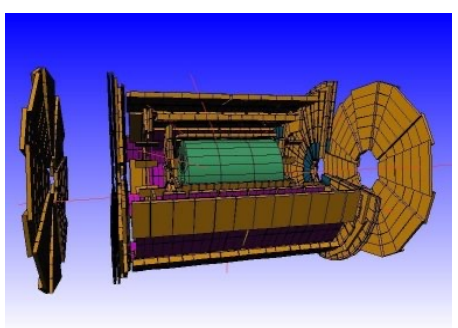




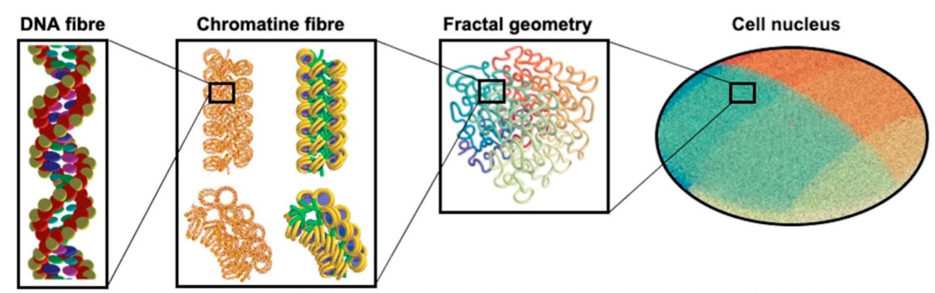
- Boolean operation
  - G4UnionSolid, G4SubtractionSolid, G4IntersectionSolid



- Example



ATLAS detector @ LHC



DNA and cell nucleus
(available in moleculardna)

Geometry 2: Material – NIST Database

You can call the material information from NIST database

- Simple Materials (Elements)

Z	Name	density(g/cm^3)	I (eV): mean excitation energy
1	G4_H	8.3748e-05	19.2
2	G4_He	0.000166322	41.8
3	G4_Li	0.534	40

Bethe-Bloch formula

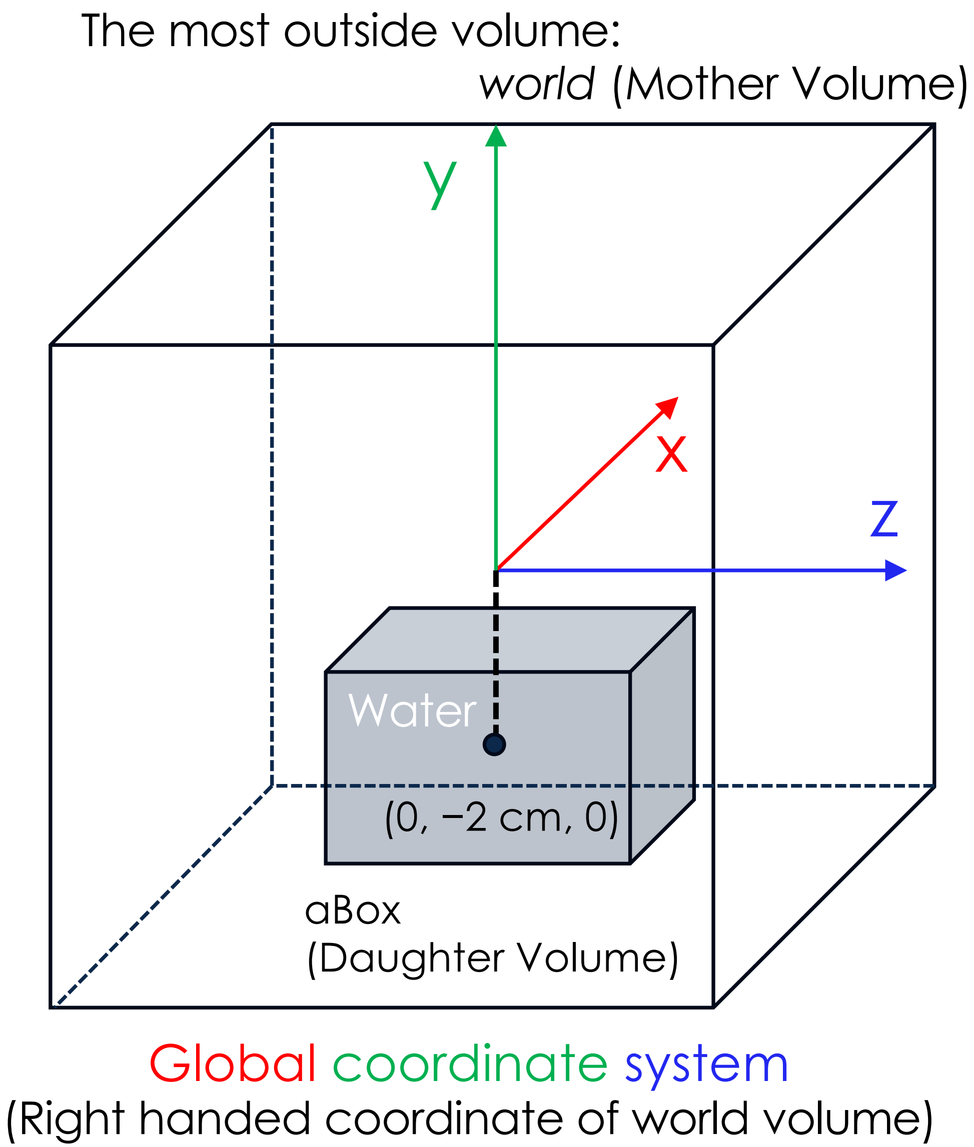
$$-\left\langle \frac{dE}{dx} \right\rangle = \frac{4\pi}{m_e c^2} \cdot \frac{nz^2}{\beta^2} \cdot \left(\frac{e^2}{4\pi\varepsilon_0}\right)^2 \cdot \left[\ln\left(\frac{2m_e c^2\beta^2}{I\cdot(1-\beta^2)}\right) - \beta^2\right]$$

- NIST Compounds

Gas: G4_AIR, G4_Galactic, G4_ETHANE
Liquid: G4_WATER, G4_ETHYL_ALCOHOL
Plastic: G4_KAPTON, G4_NYLON-8062, G4_MYLAR, G4_TEFLON
Tissue: G4_ADIPOSE_TISSUE_ICRP, G4_LUNG_ICRP
DNA: G4_DNA_ADENINE, G4_DNA_MONOPHOSPHATE

see more detail: https://geant4-userdoc.web.cern.ch/UsersGuides/ForApplicationDeveloper/html/Appendix/materialNames.html

Geometry 3: Definition of Geometry (in DetectorConstruction)



How to define geometry

- Procedure 1 : Define *Solid* (set shape and size)
  Select/combine shape from the catalog of volumes
  ex) one Box, 2 cm × 2 cm × 5cm

half lengths

```
G4VSolid* pBoxSolid = new G4Box("aBoxSolid", 1.*cm, 1.*cm, 2.5 *cm);
```

- Procedure 2 : Define *Logical Volume* (set material Info.)
  Select/combine shape from the catalog of volumes
  ex) H_2O (liquid), density 1g/cm^3 (standard given by NIST database)

```
G4NistManager* nistMan = G4NistManager::Instance();
G4Material* pWater = nistMan->FindOrBuildMaterial( "G4_WATER" );
G4LogicalVolume* pBoxLog =
        new G4LogicalVolume(pBoxSolid, pWater, "aBoxLog", 0, 0, 0);
```

- Procedure 3 : Define *Physical Volume* (place volume)
  Place Logical Volume with position and rotation information
  ex) place pBoxLog in mother volume (world) at (0, -2 cm, 0) without rotation

```
G4ThreeVector boxPos = {0., − 2*cm, 0.};
G4VPhysicalVolume* pBoxPhys =
       new G4PVPlacement(nullptr, boxPos, pBoxLog,
                                          "aboxPhys", pMotherLog,0,0);
```

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Physics

☐ Electromagnetic Physics

Geant4 provides physics model sets (constructors) for each target energy range

e.g.) G4EmStandardPhysics_option4 : e-msc | e-ioni | e-brems | phot-elec | photo-Comp …

G4EmLivermorePhysics (low energy) : e-msc | e-ioni | e-brems | phot-elec | photo-Comp …

G4EmDNAPhysics_option4 (down to a few eV) : e-elast | e-ioni | e-excit | e-solv | e-brems | phot-elec …

☐ Hadronic Physics

Geant4 provides models for each process, and user select a combination

Parton
- Parton String
- Fritiof String

Intra-nuclear
- INCL++
- Binary cascade
- QMD

Relaxation
- Pre-compound
- Fermi breakup
- Fission

Low energy
- Model driven
- Data driven

How to chose?
→ Reference Physics List
(see later slide)

☐ Decay Physics

Geant4 provides models for particle decay, radioactive decay, positronium decay

☐ Optical Physics

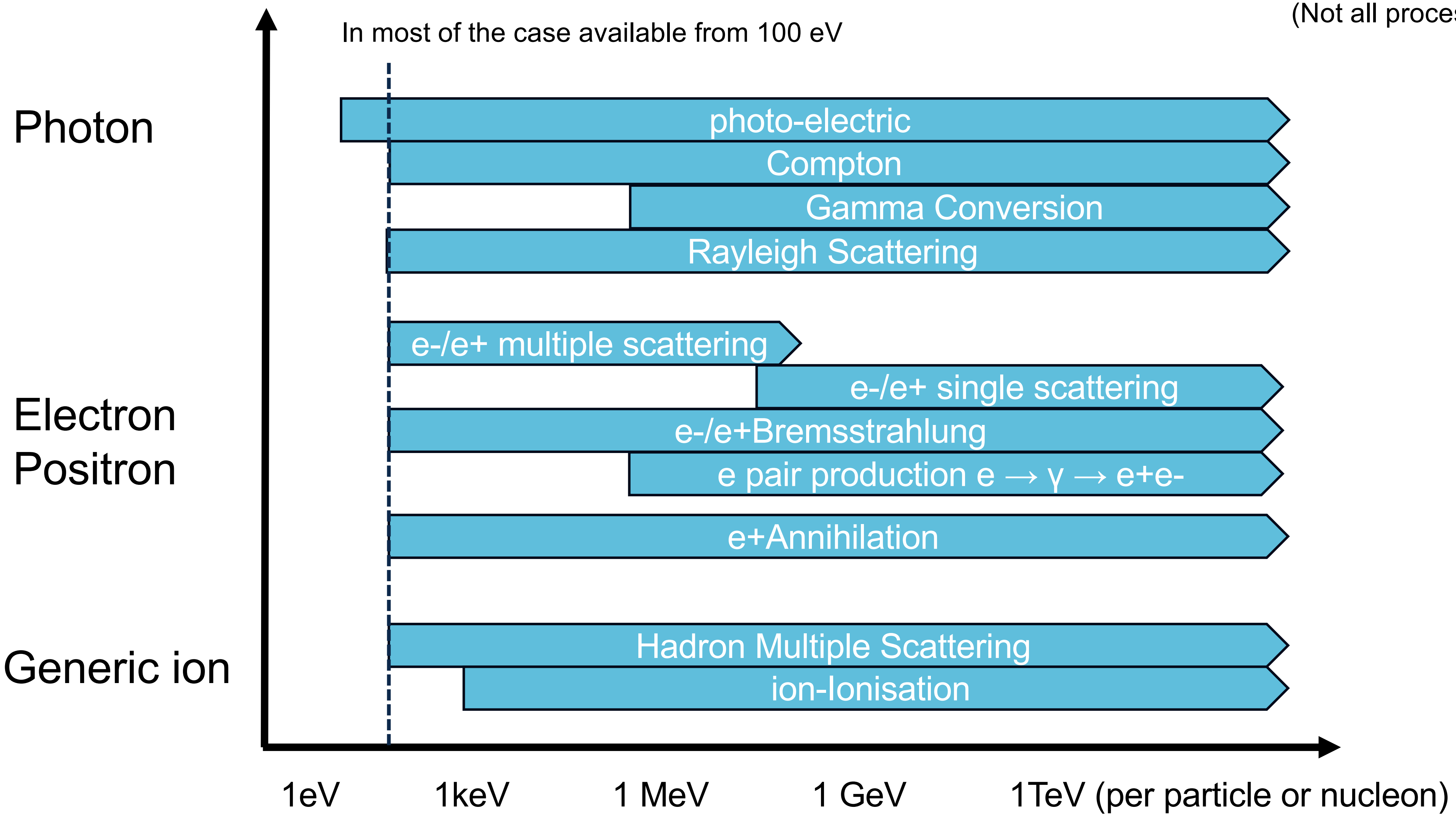
Geant4 provides models for scintillation emission, wavelength shift, reflection, refraction etc.

☐ Ttransportation

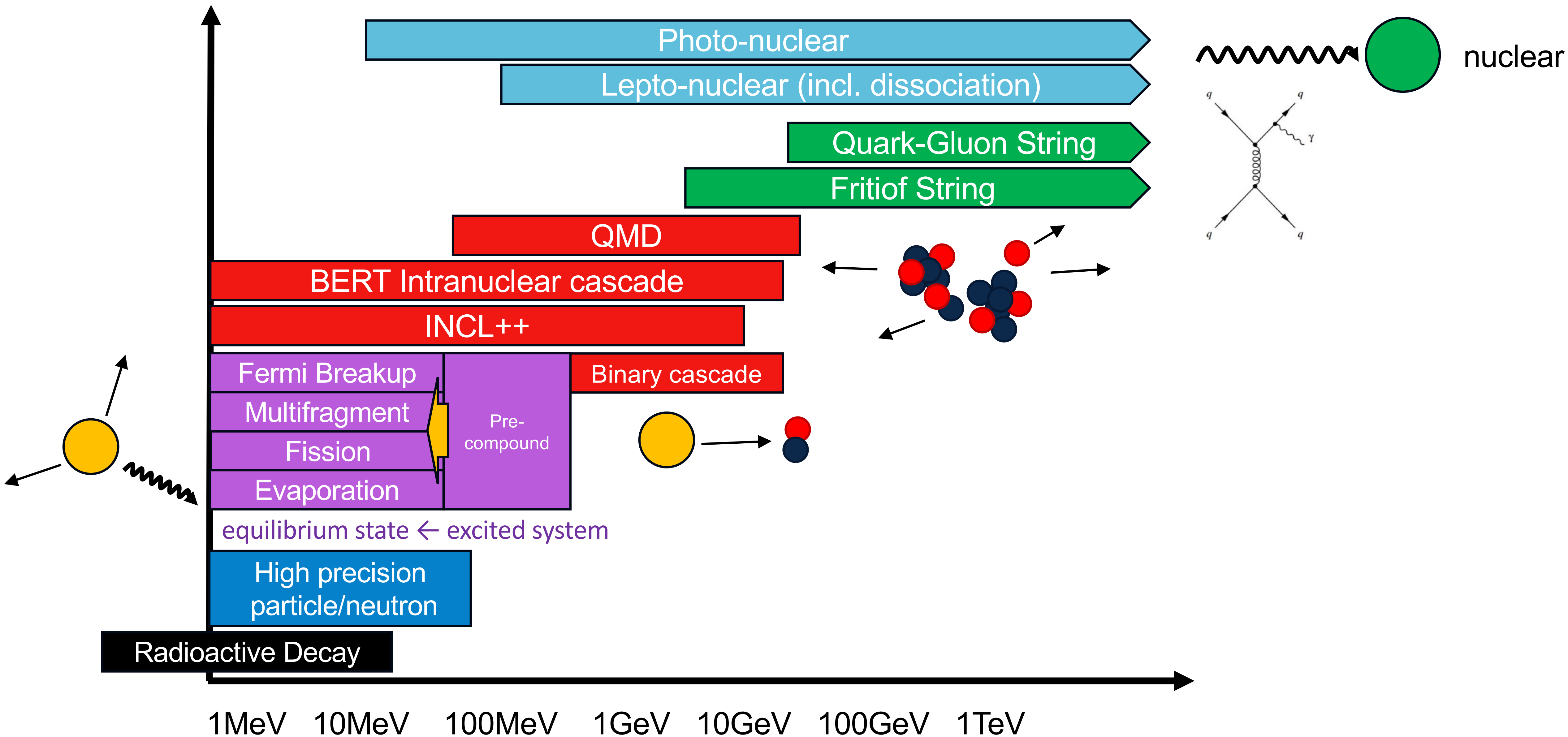
Geant4 also simulates particle transport to object boundary, and transportation in magnetic field, etc.

Geant4 Electromagnetic Physics Overview (G4EmStandard_option3)

(Not all process shown)



Geant4 Hadronic Physics Overview



Reference Physics List

Name scheme of the hadronic physics in Reference Physics List

- FTF → Fritiof Parton String Model: 4 GeV < E
- QGS → Quark Gluon String Model: 12 GeV <E
- BERT → Bertini Intranuclear Cascade Model: E < 10 GeV
- BIC → Binary Intranuclear Cascade Model: E < 10 GeV
- INCLXX → Liege Intranuclear Cascade Model (INCL): E < 10 GeV
- P → Precompound Model (Nuclear relaxation after string interaction, e.g; FTFP, QGSP)
- HP → Neutron High Precision Model: E < 20 MeV

Name scheme of the electromagnetic physics in Reference Physics List

- _EM0 → Standard EM physics (G4EmStandardPhysics)
- _EMV, _EMX → Standard EM physics Option 1, 2 (High computing speed etc.)
- _EMY, _EMZ → Standard EM physics Option 3, 4 (High accuracy models)
- _LIV, _PEN → Low energy EM physics (Livermore, Penelope)

Recommended Physics List for Medical Applications and Radiation Protection

For E< 200 MeV, QGSP_BIC_EMY or QGSP_BIC_HP_EMZ are well validated.

Example of Physics List

Implementation for reference physics list in main function (or in PhysicsList.cc)

```
....
#include ”G4PhysListFactory.hh”
int main( int argc,char** argv )
{

// Select Physics List
G4PhysListFactory factory;
G4VModularPhysicsList* physic =
                factory.ReferencePhysList(“QGSP_BIC_EMY”);
runManager->SetUserInitialization( physics );
....
....
```

- Include header file for G4PhyiscsFactory
- Create an object for G4PhyiscsFactory
- Select “QGSP_BIC_EMY” from reference PhysList
- Set the PhysList to RunManager

Recommended Physics List for Medical Applications and Radiation Protection

For E< 200 MeV, QGSP_BIC_EMY or QGSP_BIC_HP_EMZ are well validated.

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Generate Primary(incident) Particle

2 methods implementation for PrimaryGeneratorAction

Method 1

Implement user specific own
PrimaryGeneratorAction

Advantage:
High flexibility

Disadvantage:
Effort required

Method 2

Implement by means of build-in class
G4ParticleGun
G4GeneralParticleSource (GPS)

Advantage:
Easy implementation

Disadvantage:
Medium scalability

G4GeneralParticleSource (GPS)

Implementation for GPS in PrimaryGeneratorAction.cc

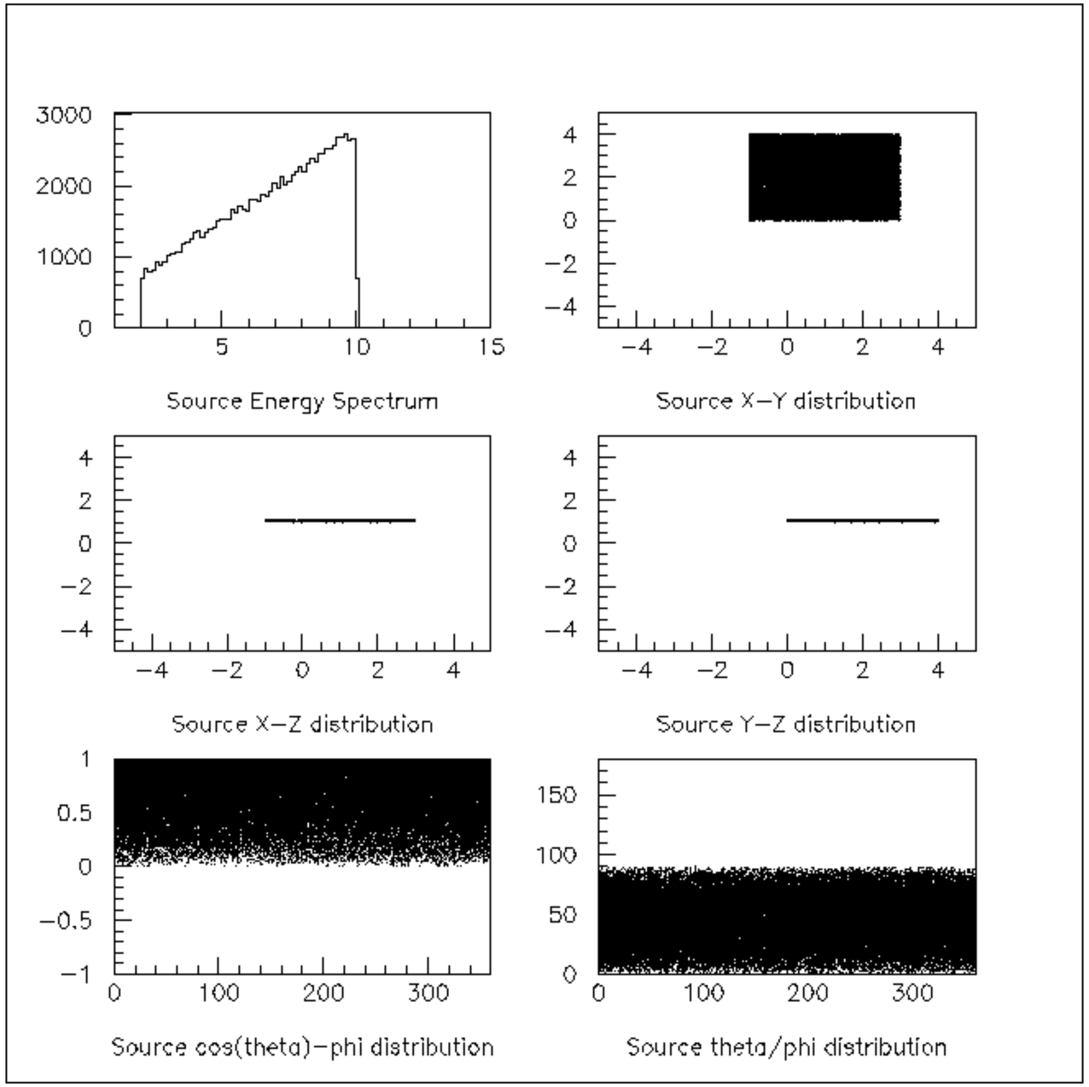
```
PrimaryGenerator::PrimaryGenerator() {
        fpGPS = new G4GeneralParticleSource();
}

void PrimaryGenerator::GeneratePrimaries(G4Event* anEvent) {
        fpGPS-> GeneratePrimaryVertex(anEvent);
}
```

fpGPS need to be definded as a member of PrimaryGenerator class

GPS Macro Commands

```
/gps/particle gamma
/gps/pos/type Plane
/gps/pos/shape Square
/gps/pos/centre 1 2 1 cm
/gps/pos/halfx 2 cm
/gps/pos/halfy 2 cm
/gps/ang/type cos
/gps/ene/type Lin
/gps/ene/min 2 MeV
/gps/ene/max 10 MeV
/gps/ene/gradient 1
/gps/ene/intercept 1
/run/beamOn 10000
```



see examples/extended/eventgenerator/exgps/macros 38 examples available!
https://geant4-userdoc.web.cern.ch/UsersGuides/ForApplicationDeveloper/html/GettingStarted/generalParticleSource.html

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Scoring and User hook

Scoring is the most complex part of Geant4 implementation

Basically. 3 ways implementation

Command Based Scoring

Advantage:
Easy
manage via macro command

Disadvantage
Only simple voxel shape
Score each run (not each event, step)

User Hook via Action classes

Advantage:
Intuitively easy for scoring
Score in any level (run, event, step…)

Disadvantage:
Messy implementation required
in very complex geometry

Sensitive Detector

Advantage:
Relatively easy scoring in very complex geometry
Similar to SteppingAction

Disadvantage:
User need to make relation
between sensitivity and geometry

Easy and Simple

Run level scoring only
Only for simple voxel

Step level Scoring

Difficult handing
in complex geometry

Relatively easy handling in complex geometry

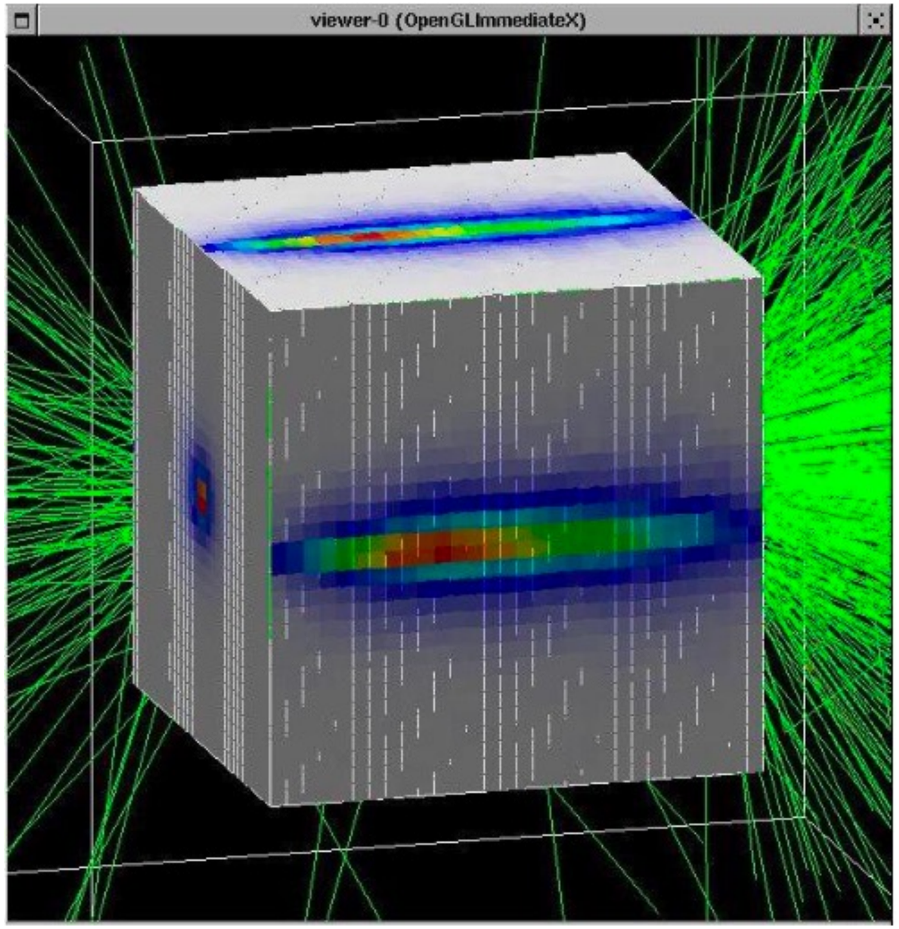
Need effort for implementation
of geometry sensitivity

Command Based Scoring

```
#include "G4RunManager.hh"
#include "G4ScoringManager.hh"
int main(int argc, char** argv)
{
G4RunManager* runManager = new G4RunManager();
G4ScoringManager::GetScoringManager();
…
```

```
/score/create/boxMesh boxMesh_1
/score/mesh/translate/xyz 0 0 130 mm
/score/mesh/boxSize 127.5 127.5 127.5 mm  # half dim
/score/mesh/nBin 51 51 51
/score/quantity/doseDeposit dDep
/score/close
/score/list

#/score/drawProjection boxMesh_1 dDep
/score/dumpQuantityToFile boxMesh_1 dDep dDep.txt
```



from examples/extended/runAndEvent/RE3

User Hook via Action Classes

Action classes for user hook

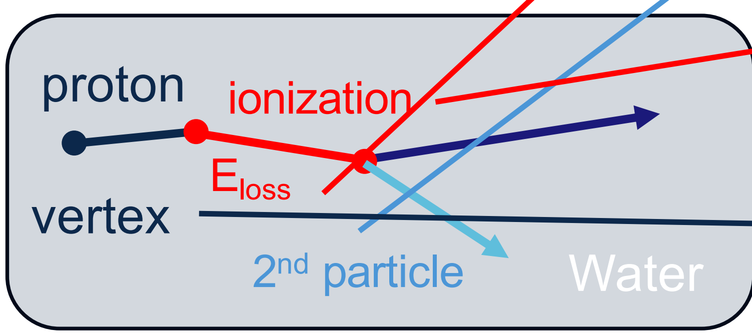
- **RunAction** — Read/Edit Run information
- **EventAction** — Read/Edit Event information
- **TrackingAction** — Read/Edit Track information
- **SteppingAction** — Read/Edit Step information

```
void SteppingAction::UserSteppingAction(const G4Step* aStep)
{
  G4double edep = aStep->GetTotalEnergyDeposit();
  ....
```

G4Step: Useful function to hook step information
- GetTrack () : get track information include this step
- GetPreStepPoint () : get pre/post step point
- GetPostStepPoint () step point holds more detail information
- GetStepLength ()
- GetSecondaryInCurrentStep ()

G4StepPoint: Useful function to hook step information
- GetKineticEnergy () : get KE of particle at the point
- GetMaterial (): get Martial information at the point
- GetProcessDefinedStep (): get physics process at the point

G4Track: Useful function to hook step information
- GetTrackID () : get track ID
- GetDefinition () : get particle definition of the track
- GetVertexPosition (): get vertex position



See class references for G4Step, G4StepPoint, G4Track,

User need to understand the information structure in Geant4 simulations

Sensitive Detector

Procedure 1: Implement SensitiveDetector class

Initialize() : called begin of event
EndOfEvent: called end of event
ProcessHits: called each step only in registered sensitive volume

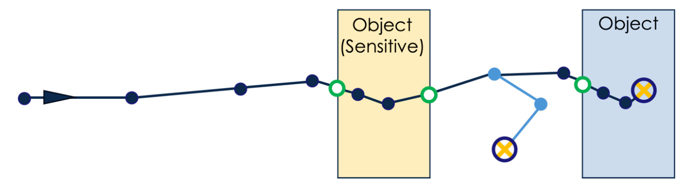
```
class SensitiveDetector : public G4VSensitiveDetector
{
  public:
    SensitiveDetector(const G4String &name);
    ~SensitiveDetector() = default;

    void Initialize(G4HCofThisEvent *aHCE) override;
    void EndOfEvent(G4HCofThisEvent *aHCE) override;
    G4bool ProcessHits(G4Step *aStep, G4TouchableHistory *aTouchable)
override;

  private:
    G4double fEdep;
}
```

```
G4bool SensitiveDetector::ProcessHits(G4Step *aStep, G4TouchableHistory* ) {
    G4double edep = aStep->GetTotalEnergy()
    if ( edep <= 0) {
        return false;
    }
    fEdep += eDep;
    return true;
};
```

ProcessHits is called for only step in registered sensitive volume



Procedure 2: Register logical volume as a SensitiveDetector

```
void DetectorConstruction::Construct( )
{
    auto aSD = new SensitiveDetector{};
    auto sm   = G4SDManager::GetSDMpointer();
    sm->AddNewDetector(aSD);

    logicalvolume -> SetSensitiveDetector( aSD  );
```

Save the Results with Action Classes or SensitiveDetector

1. **Define a file for saving results in UserRunAction::BeginOfRun()**
   - Geant4 support several file types for saving result
   - ROOT, csv, xml

```
void RunAction::BeginOfRunAction(const G4Run* aRun) {
  auto am = G4AnalysisManager::Instance();
  am->SetFileName("output.root");
  am->SetHistDirectoryName("hist");
  am->CreateH1("h1", "Edep in detector", 100, 0., 10.);
    // 1d hist id =0, name = "h1", title = "Edep in detector"
    // number of bins 100, minimum = 0, maximum = 10

  am->OpenFile();
}
```

2. **Score and Save results**
   - You can score what ever you want, but you must transfer the information to RunAction by yourself to save the results.
   - Alternatively, using AnalysisManager, Geant4 can transfer to anywhere. (call G4AnalysisManager::Instance())

```
void SteppingAction::UserSteppingAction(const G4Step* aStep)
{
  auto am = G4AnalysisManager::Instance();

  G4double edep = aStep->GetTotalEnergyDeposit();

  am->Fillh1(0, edep); // 1d hist id = 0, fill edep
}
```

3. **Write the results to the save file in UserRunAction::EndOfRunAction()**

```
void RunAction::EndOfRunAction(const G4Run* aRun) {
  auto am = G4AnalysisManager::Instance();
  am->Write();
  am->CloseFile();
}
```

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Tips for Development

To start application development: Find proper application in Geant4 examples!

Geant4 Forum
https://geant4-forum.web.cern.ch/

Users guide for application developer
https://geant4-userdoc.web.cern.ch/UsersGuides/ForApplicationDeveloper/html/index.html

Class reference
https://geant4.kek.jp/Reference/

Physics reference manual
https://geant4-userdoc.web.cern.ch/UsersGuides/PhysicsReferenceManual/html/index.html

Backup

If you don't have internet access

```
g4vm:/local1 < 63 >nmcli device
DEVICE  TYPE      STATE                   CONNECTION
lo      loopback  connected (externally)  lo
enp2s0  ethernet  disconnected            --
```

This is your network device name.

```
g4vm:/local1 < 87 >nmcli connection up enp2s0
Error: unknown connection 'enp2s0'.
g4vm:/local1 < 88 >nmcli connection show
NAME    UUID                                  TYPE      DEVICE
lo      a36a4b2f-f1ac-4dd4-8335-d15dfa929ac6  loopback  lo
ens160  7f871b38-1f33-39cb-bab8-4eda0a5ac240  ethernet  --
```

If you don't have the same device name here.
Please try following commands!

```
g4vm:/local1 < 100 >sudo nmcli connection delete ens160
Connection 'ens160' (7f871b38-1f33-39cb-bab8-4eda0a5ac240) successfully deleted.
g4vm:/local1 < 101 >sudo nmcli connection add type ethernet ifname enp2s0 con-name enp2s0 ipv4.method auto ipv6.method auto
Connection 'enp2s0' (0f5bb16d-2e3b-4cc9-b68e-67a7f23c8b21) successfully added.
g4vm:/local1 < 102 >nmcli connection up enp2s0
Connection successfully activated (D-Bus active path: /org/freedesktop/NetworkManager/ActiveConnection/3)
g4vm:/local1 < 103 >
g4vm:/local1 < 103 >ping 8.8.8.8
PING 8.8.8.8 (8.8.8.8) 56(84) bytes of data.
64 bytes from 8.8.8.8: icmp_seq=1 ttl=111 time=10.6 ms
64 bytes from 8.8.8.8: icmp_seq=2 ttl=111 time=14.7 ms
```