Geant4 11.3.2

Choosing a Physics List

Geant4 Tutorial at Jefferson Lab

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21 August 2025

Outline

- Review
  - physics lists, reference physics lists, naming convention
- Considerations for choosing a physics list
- Some application-based recommendations
- Choosing physics lists from the examples

Physics List

- An object responsible for:
  - specifying all particles to be used in a simulation application
  - specifying physics processes and assigning them to each particle type
- One of three mandatory objects that the user must provide to the G4RunManager in any application
  - tells run manager what physics needs to be invoked and when
- Provides a very flexible way to set up the physics environment
  - user can choose and specify particles he wants
  - user can choose the physics (processes) to assign to each particle
- BUT, user must have a good understanding of the physics required to describe the problem
  - omission of relevant particles and/or physics interactions could lead to poor modeling results

Reference Physics Lists

- Also called "Production Physics Lists"
  - used by larger groups like ATLAS, CMS, etc.
  - well-maintained and tested
  - very stable: not often changed and usually updated only for bug fixes
  - extensively validated inside and outside of Geant4
  - FTFP_BERT, QGSP_BERT, QGSP_FTFP_BERT_EMV, FTFP_BERT_HP, QGSP_BIC_EMY, QGSP_BIC_HP, QBBC, Shielding
- Caveats:
  - these are provided as a "best guess" of the physics needed in certain use cases
  - intended as templates or starting points
  - if you decide to use them, you are responsible for validating them for your application
  - this may mean adding or removing physics or changing settings

Reference Physics List Naming Convention

- Hadronic options
  - “QGS” Quark Gluon String model (>~ 15 GeV)
  - ”FTF” FRITIOF String Model (>~ 5 GeV)
  - “BIC” Binary Cascade model (<~ 10 GeV)
  - “BERT” Bertini Cascade model (<~ 15 GeV)
  - “P” G4Precompound model used for de-excitation
  - “HP” High precision particle (neutrons and some charged particles (<~ 20 MeV)

- Electromagnetic options
  - no suffix: standard EM (default G4EmStandardPhysics constructor)
  - “EMV” G4EmStandardPhysics_option1 (fast, less precise)
  - “EMY” G4EmStandardPhysics_option3 (precise, used for medical and space)
  - “EMZ” G4EmStandardPhysics_option4 (most precise, slower)

- Name decoding: String_Cascade_Neutron_EM
- Complete list of pre-packaged physics lists (with detailed descriptions) at
  - http://geant4-userdoc.web.cern.ch/geant4-userdoc/UsersGuides/PhysicsListGuide/html/index.html

Packaged Physics Lists: Naming Convention Examples

- FTFP_BERT
  - includes standard EM physics models
  - FTF – FRITIOF string model (> ~4 GeV) +
  - P – G4Precompound deexcitation model
  - Bertini cascade (< ~12 GeV)

- QGSP_BIC_HP
  - QGS – quark gluon string model (> 12 GeV)
  - FTF – FRITIOF string model (9.5 - 25 GeV)
  - P – G4Precompound deexcitation model
  - BIC – Binary interaction cascade (200 MeV – 9.9 GeV)
  - HP – high precision neutron, proton, d, t, ^{3}He, alpha interaction model (< 20 MeV)

Physics List Considerations

- Application
- Precision vs. CPU
- Validation
- Degree of customization

Application Determines Energy and Particle Types Needed

- HEP
  - keV < E < TeV
  - all particle types (except optical photons, phonons)
- Nuclear
  - keV < E < few GeV
  - all particle types (except optical, phonons, exotics)
- Space
  - keV < E < 1 GeV
  - mostly e^-, e^+, γ, p, n, light ions
- Shielding
  - eV < E < few GeV
  - p, n, ions

Application Determines Energy and Particle Types Needed

- Medical
  - keV < E < 1 GeV
  - e^-, e^+, γ, p, n, light ions
- Micro-biology
  - meV < E < few GeV
  - e^-, e^+, p, n, light ions, chemical species
- Micro-electronics
  - meV < E < few GeV
  - e^-, e^+, p, n light ions, phonons

Precision vs. CPU

- Are computing resources (CPU time) an issue?
  - Use physics list that has biasing
  - Use physics list that has fast, but usually less precise models
- Do you need the most precise physics?
  - Use the most complete physics lists, no biasing
  - In some cases, biasing can still be used, if the biased physics does not directly affect the final results (physics lists by region)
- The right balance must be found by validating against data

Validation

- Physics list must always be chosen based on how well its components perform in your specific case
  - always balance physics accuracy with CPU performance
- Geant4 provides validation (comparison to data) for most of its physics codes
  - validation is a continuing task
  - performed at least once per release
  - more validations added with time
- User must do the same
  - validate against data from your experiment or application

Customization

- Physics lists provided by Geant4 may not meet your needs
  - may not reproduce your data
  - may not have precise enough physics in your energy range
  - may be missing specialized physics

- What to do?
  - write your own from scratch
  - use Geant4-supplied physics lists and switch in and out various physics modules
    - with modules supplied by physics list factory, or
    - write your own physics module
  - then you must validate

Customization: Changing EM Physics in a Reference Physics List

- QGSP_BIC_HP_EMZ
  - QGSP_BIC_HP is a reference physics list with standard EM
  - you can change this by using the G4PhysListFactory
    - knows all available reference physics lists and makes EM substitutions easy

```
// IM YOUR MAIN APPLICATION
//
  // create your run manager
#ifdef G4MULTITHREADED
  G4MTRunManager* runManager = new G4MTRunManager;
  // number of threads can be defined via macro command
  runManager->SetNumberOfThreads(4);
#else
  G4RunManager* runManager = new G4RunManager;
#endif
  //
  // create a physics list factory object that knows
  // everything about the available reference physics lists
  // and can replace their default EM option
  G4PhysListFactory physListFactory;
  // obtain the QGSP_BIC_HP_EMZ reference physics lists
  // which is the QGSP_BIC_HP refrence list with opt4 EM
  const G4String plName = "QGSP_BIC_HP_EMZ";
  G4VModularPhysicsList* pList = physListFactory.GetReferencePhysList(plName);
  // (check that pList is not nullptr, that I skipp now)
  // register your physics list in the run manager
  runManager->SetUserInitialization(pList);
  // register further mandatory objects i.e. Detector and Primary-generator
  ...
```

Choosing Your Physics List

- Ideally, user has a good understanding of the physics relevant to a given application
  - user can then build his own or decide on a pre-built one
  - in either case the physics list must be validated for the application
  - during the validation, some changes to the physics list may be required

- If your application fits within a well-defined area (e.g. medical)
  - user may choose a physics list used in that area as a starting point
  - validation, once again, is required

- Procedure that always works, but is time-consuming
  - start with most accurate physics (e.g. EMZ for EM)
  - run the simulation with lower statistics to obtain the most accurate result
  - if desired, choose a less accurate, but faster, physics list and run some more simulation statistics
  - modify in a granular way the first physics list using the most accurate results as a guide

Recommended Physics Lists for Some Applications

- FTFP_BERT
  - HEP applications
  - FRITIOF string + Precompound deexcitation + Bertini cascade + standard EM
  - can add _HP if neutron flux is important
- Shielding
  - for shielding and space applications
  - very similar to FTFP_BERT_HP, but with better ion-ion interactions
- QGSP_BIC_HP
  - medical applications
  - Quark Gluon String + FRITIOF + Precompound + Binary cascade + high precision neutron + standard EM
  - can add best precision EM by appending "EMZ"

Physics Lists From the Examples

- Advanced
  - many have physics lists custom-designed for a particular area
  - if you are working that area try that list
    - space telescope
    - microelectronics
    - radioprotection
    - composite calorimeter
    - ….
    - ….
- Extended
  - Several physics lists testing specific aspects of Geant4
    - optical
    - medical
    - electromagnetic
    - ….
    - ….

Special Low Energy Physics Lists: DNA

- examples/advanced/dna/moleculardna/
  - physics, physico-chemistry, chemistry processes

- Physics constructors
  - RegisterPhysics(new G4EmDNAPhysics_optionN());
  - RegisterPhysics(new G4RadioactivePhysics());
  - RegisterPhysics(new G4DecayPhysics());
  - RegisterPhysics(new ChemistryList());

- Energy scale
  - GetProductionCutsTable()->SetEnergyRange(100*eV, 1*GeV);
- Physical scale is that of molecules
  - but with parallel world physics at larger scale

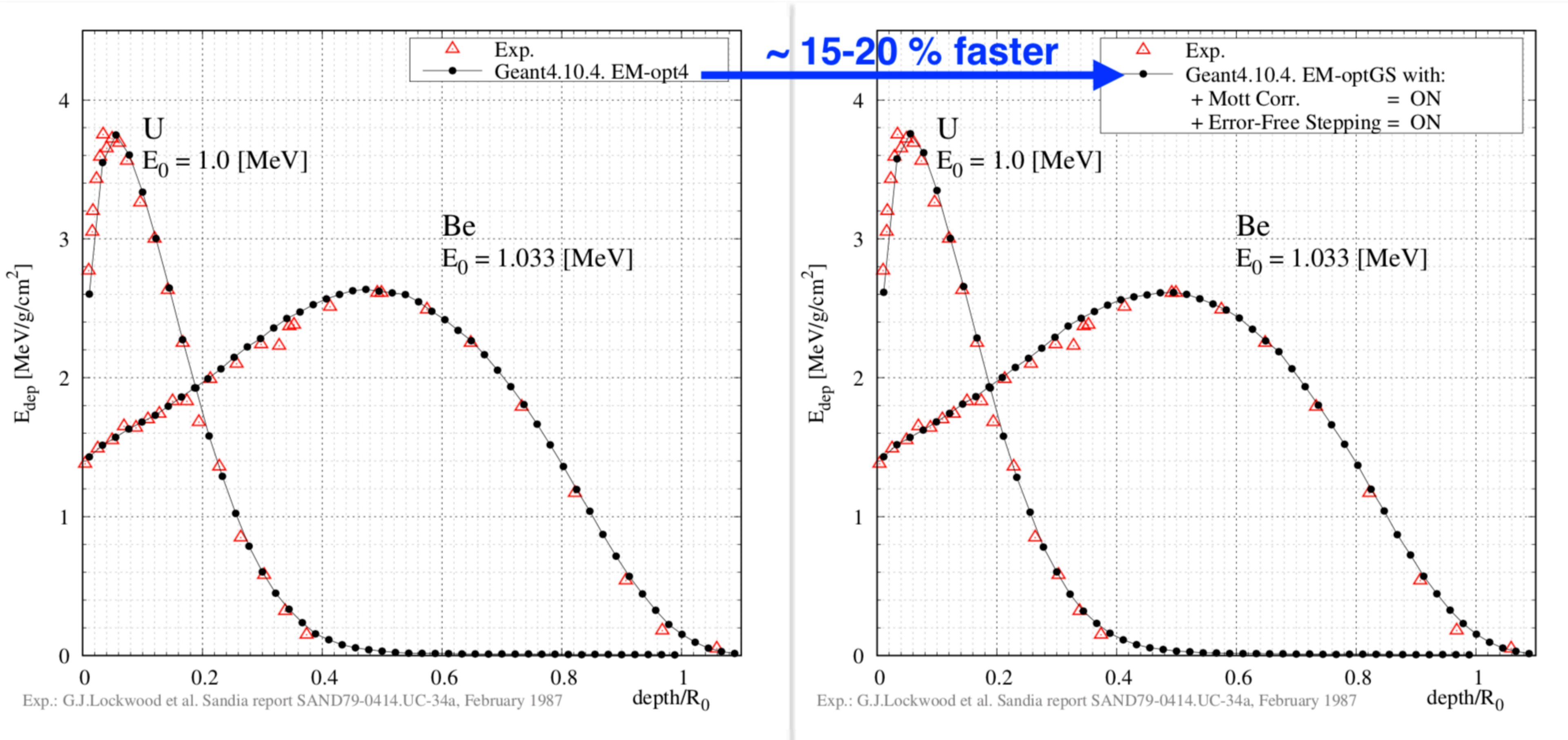
Special Low Energy Physics Lists: Microelectronics

- examples/advanced/microelectronics
  - 5 MeV proton passing through Si
  - Standard EM in World volume (2 micrometer cube)
  - Geant4-MicroElec processes and models in target volume (1 micrometer cube)
- Physics list
  - production cut value = 1 micrometer for all particles
  - all atomic de-excitation processes turned on: fluorescence, Auger, PIXE
  - phonon scattering
- Particles
  - electrons, positrons, photons, ions only

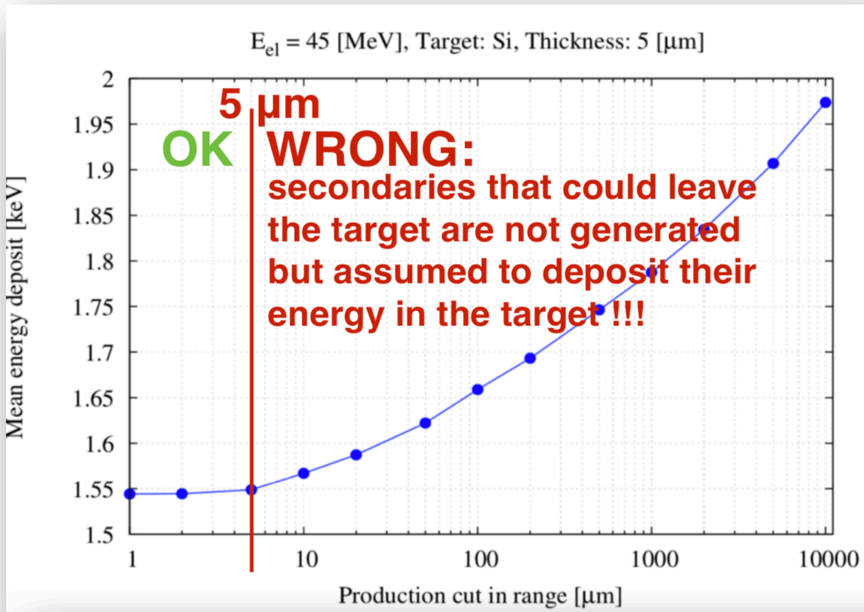
Validation Example

- Simulating (EM) depth dose profile
  - energy deposit by energetic electrons as a function of penetration depth in both lighter and heavier materials
  - use Geant4 validation results from test37, to choose an initial physics list (in this case beam is 1.033 MeV e-, targets are Be and U)
  - then adjust initial reference physics list to achieve maximum physics performance while improving computational efficiency

Validation Example



Validating the Production Threshold



cut [μm]	mean E_{dep}	rms E_{dep}	prod. thres. [keV]		mean num. sec.	
			γ	e^-	γ	e^-
1	1.54423	0.000573911	0.99	0.99	0.0006811	0.1018230
2	1.54443	0.000583879	0.99	2.9547	0.0006843	0.0316897
5	1.54882	0.000605834	0.99	13.1884	0.0006857	0.0068261
10	1.56717	0.000665733	0.99	31.9516	0.0006730	0.0028232
20	1.58734	0.000743473	1.08038	47.8191	0.0006651	0.0018811
50	1.62223	0.000912408	1.67216	80.7687	0.0006557	0.0011304
100	1.65893	0.001108240	2.32425	121.694	0.0006518	0.0007536
200	1.69338	0.001342180	3.2198	187.091	0.0006465	0.000477
500	1.74642	0.001774670	5.00023	337.972	0.0006184	0.0002617
1000	1.78751	0.002219870	6.95018	548.291	0.0006054	0.0001622
2000	1.83440	0.002861020	9.66055	926.09	0.0005786	9.3e-05
5000	1.90700	0.004243030	14.9521	2074.3	0.0005427	4.07e-05
10000	1.97378	0.006036600	20.6438	4007.59	0.000521	2.22e-05

Compute the mean of the energy deposit (E_f-E_0) in the target