



Choosing a Physics List

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This talk is based on Geant4 tutorial materials from past events, especially slides by **Lorenzo Pezzotti** (CERN)

Physics List

The physics list

- is one of the mandatory classes (in every simulation there must one and one only physics list).
- It determines the physics environment to be simulated, i.e.
 - ❖ the particles simulated, and
 - ❖ the associated processes together with their parameters (cuts, energy ranges for hadronic models, ...).

Reference physics lists

Geant4 provides ready-to-use physics lists, known as *reference physics lists*

- They are located under `/geant4/source/physics_lists/lists`,
e.g. FTFP_BERT, QGSP_BERT, FTFP_BERT_HP, QGSP_BIC, QGSP_BIC_HP, QBBC, Shielding, ...
- They are *validated* by the Geant4 community and represent best guesses on the physics needed in a certain domain (HEP, biomedical physics, radiation shielding, ...)
- They are adopted (with mild variants) by the vast majority of HEP experiments (ATLAS, CMS, ALICE, LHCb, ...)
- **Users are responsible for validating the physics lists** (and the entire simulation) on their data
 - ❖ It means either changing settings or adding/removing certain constructors (see next slide)
- **PL documentation**: the complete list of reference physics lists together with their properties is described in the *Guide for Physics List* [[link](#)]

Modular physics list

Reference physics lists are modular physics lists

```
( : public G4VModularPhysicsList)
```

- Modular physics lists implement a granular approach to physics via *constructors*

```
geant4/source/physics_lists/lists/src/FTFP_BERT.cc
```

```
FTFP_BERT::FTFP_BERT(G4int ver){
    if(ver > 0) {
        G4cout << "<<< Geant4 Physics List simulation
engine: FTFP_BERT" << G4endl;
        G4cout << G4endl;
    }
    defaultCutValue = 0.7*CLHEP::mm;
    SetVerboseLevel(ver);
    // EM Physics
    RegisterPhysics( new G4EmStandardPhysics(ver));
    // Synchroton Radiation & GN Physics
    RegisterPhysics( new G4EmExtraPhysics(ver) );
    // Decays
    RegisterPhysics( new G4DecayPhysics(ver) );
    // Hadron Elastic scattering
    RegisterPhysics( new
G4HadronElasticPhysics(ver) );
    // Hadron Physics
    RegisterPhysics( new
G4HadronPhysicsFTFP_BERT(ver));
    // Stopping Physics
    RegisterPhysics( new G4StoppingPhysics(ver) );
    // Ion Physics
    RegisterPhysics( new G4IonPhysics(ver));
    // Neutron tracking cut
    RegisterPhysics( new G4NeutronTrackingCut(ver));
}
```

Naming conventions

Physics lists names are given as **String(s)_Cascade_Neutron_EM**



➤ Hadronic options

- ❖ **QGS** Quark Gluon String model (> ~15-20 GeV)
- ❖ **FTF** FRITIOF String model (> ~3 GeV)
- ❖ **BIC** Binary Cascade model (< ~6 GeV)
- ❖ **BERT** Bertini Cascade model (< ~6 GeV)
- ❖ **P** G4Precompound model used for de-excitation
- ❖ **HP** High Precision neutron model (< ~20 MeV)

➤ Electromagnetic options

- ❖ (**No suffix** or **EM0**)
- ❖ **EMV**
- ❖ **EMY**
- ❖ **EMZ**

Using reference physics lists

Reference physics lists are straightforward to use, *e.g.*

`main()` - Use a reference physics list (FTFP_BERT)

```
#include "G4RunManagerFactory.hh"
#include "FTFP_BERT.hh"
int main(int argc, char** argv) {
    // some code

    // Run manager
    auto* runManager = G4RunManagerFactory::CreateRunManager();
    // Physics list
    G4VModularPhysicsList* physicsList = new FTFP_BERT();
    physicsList->SetVerboseLevel(1);
    runManager->SetUserInitialization(physicsList);
    // some code
}
```

Using reference physics lists

NOTE: Physics lists with non standard EM physics constructors (e.g. FTFP_BERT_EMZ) can be used via the *physics list factory*

main() - Use FTFP_BERT_EMZ via G4PhysListFactory

```
int main(int argc, char** argv) {
    // some code
    // Run manager
    //
    auto* runManager = G4RunManagerFactory::CreateRunManager();
    //Physics list
    G4PhysListFactory PLFactory;
    const G4String PLName = "FTFP_BERT_EMZ";
    G4VModularPhysicsList* PL = PLFactory.GetReferencePhysList( PLName );
    runManager->SetUserInitialization(PL);
    // some code
}
```

Reference physics lists

The **FTFP_BERT PL** is the recommended one for high-energy physics simulations. It adopts the models:

- **FTF**: (Fritiof) hadronic string model for hadron inelastic process > 3 GeV
- **P**: Precompound model for nucleus de-excitation
- **BERT**: (Bertini) intra-nuclear cascade model for the hadron inelastic process < 6 GeV
- Plus: neutron radiative capture, nuclear capture at rest for negatively charged hadrons, elastic scattering for hadrons, lepto-nuclear and gamma-nuclear processes and standard em physics (*Compton, pair-production, photoelectric effect, ...*)

NOTE: The energy range transition between cascade and string models is typically chosen with thin target data

NOTE: Hadronic showers are (often) quite sensitive to it *e.g.*

ATLAS changed the energy range between FTFP and BERT to [9,12] GeV while

CMS changed the energy range between FTFP and BERT only for pions to [3,12] GeV

Reference physics lists

The **FTFP_BERT_PL** is the recommended one for high-energy physics simulations. It adopts the models:

Recommended PL for HEP applications
(calorimeters, collider physics, ...)

- **FTF**: (Fritiof) hadronic string model for hadron inelastic process > 3 GeV
- **P**: Precompound model for nucleus de-excitation
- **BERT**: (Bertini) intra-nuclear cascade model for the hadron inelastic process < 6 GeV
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NOTE: Hadronic showers are (often) quite sensitive to it *e.g.*

ATLAS changed the energy range between FTFP and BERT to [9,12] GeV while

CMS changed the energy range between FTFP and BERT only for pions to [3,12] GeV

Reference physics lists

Other relevant reference physics lists for hadronic physics are

- The **FTFP_BERT_HP** PL: same as FTFP_BERT but using the high-precision neutron treatment for low energy neutrons (< 20 MeV)
- The **QGSP_BERT** PL: same as FTFP_BERT but uses the QGS (Quark Gluon String) model for the hadron inelastic process with an energy transition range with FTF of [12,25] GeV

NOTE: Below 12 GeV QGSP_BERT and FTFP_BERT are identical

- The **FTFP_INCLXX** PL: uses the INCLXX model for the inelastic process of protons, neutrons and charged pions. The INCLXX and the FTF models intersect in the energy range [15,20] GeV
- The **QGSP_BIC** PL: uses both FTF and QGS models for high-energy interactions and both BERT and BIC (Binary Cascade) models for low-energy interactions, as
 - ❖ Protons, neutrons: BIC < 6 GeV, FTFP [3, 25] GeV and QGSP > 12 GeV
 - ❖ Pions and kaons: BERT < 6 GeV, FTFP [3, 25] GeV and QGSP > 12 GeV

Reference physics lists

Other relevant reference physics lists for hadronic physics are

- The **FTFP_BERT_HP** PL: same as FTFP_BERT but using the high-precision neutron treatment for low energy neutrons (< 20 MeV)
Recommended PL for shielding and space application
- The **QGSP_BERT** PL: same as FTFP_BERT but uses the QGS (Quark Gluon String) model for the hadron inelastic process with an energy transition range with FTF of [12,25] GeV
Alternative for FTFP_BERT at high energies (> 25 GeV)
NOTE: Below 12 GeV QGSP_BERT and FTFP_BERT are identical
- The **FTFP_INCLXX** PL: uses the INCLXX model for the inelastic process of protons, neutrons and charged pions. The INCLXX and the FTF models intersect in the energy range [15,20] GeV
Alternative for FTFP_BERT at low energies (< 20 GeV)
- The **QGSP_BIC** PL: uses both FTF and QGS models for high-energy interactions and both BERT and BIC (Binary Cascade) models for low-energy interactions, as
Recommended for medical applications (also QGSP_BIC_HP)
 - ❖ Protons, neutrons: BIC < 6 GeV, FTFP [3, 25] GeV and QGSP > 12 GeV
 - ❖ Pions and kaons: BERT < 6 GeV, FTFP [3, 25] GeV and QGSP > 12 GeV

Reference physics lists

Relevant physics list options for electromagnetic physics are

- PL+(**No suffix** or **_EMO**): uses the G4EmStandardPhysics constructor, implements default EM physics
- PL+**_EMV**: uses the G4EmStandardPhysics_option1 constructor, implements fast but less precise EM physics due to simple multiple scattering step limitation
- PL+**_EMY**: uses the G4EmStandardPhysics_option3 constructor, implements Urban MSC model for all particles (medical, space science, precise)
- PL+**_EMZ**: uses the G4EmStandardPhysics_option4 constructor, implements the most accurate em physics, e.g. an error-free stepping for e^{\pm}

Recommended EM option
for HEP applications
(sampling calorimeters, ...)



Recommended EM option
for HEP applications
(homogeneous calorimeters, ...)



Recommended em option for
medical applications
(proton/ion therapy, ...)



The most accurate em physics
description. Can be used as a
reference for all the cases above.

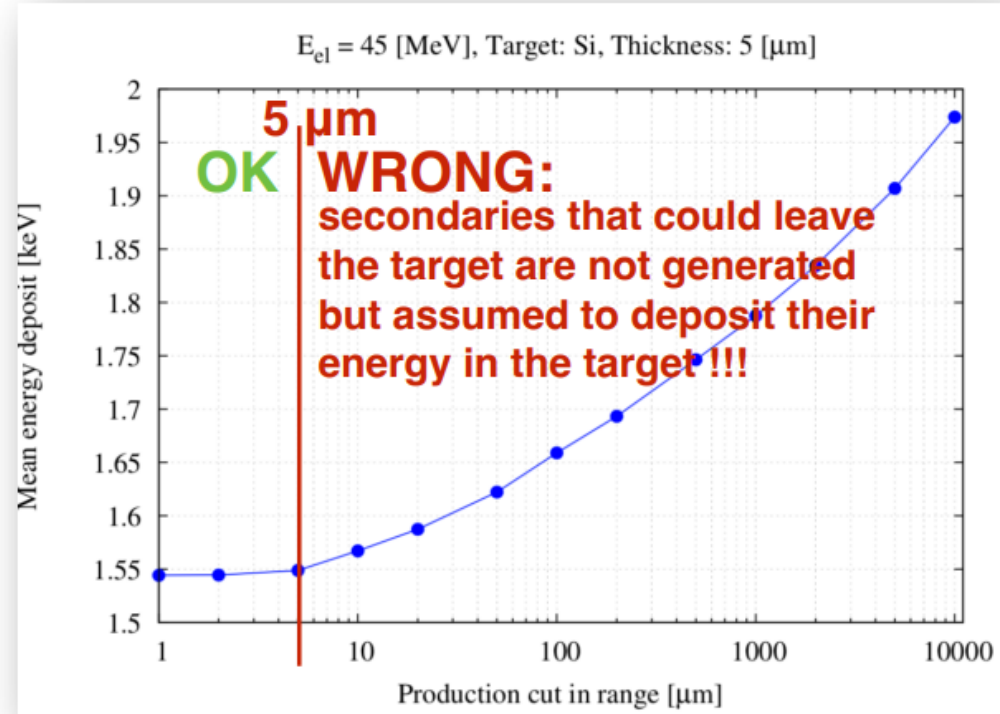
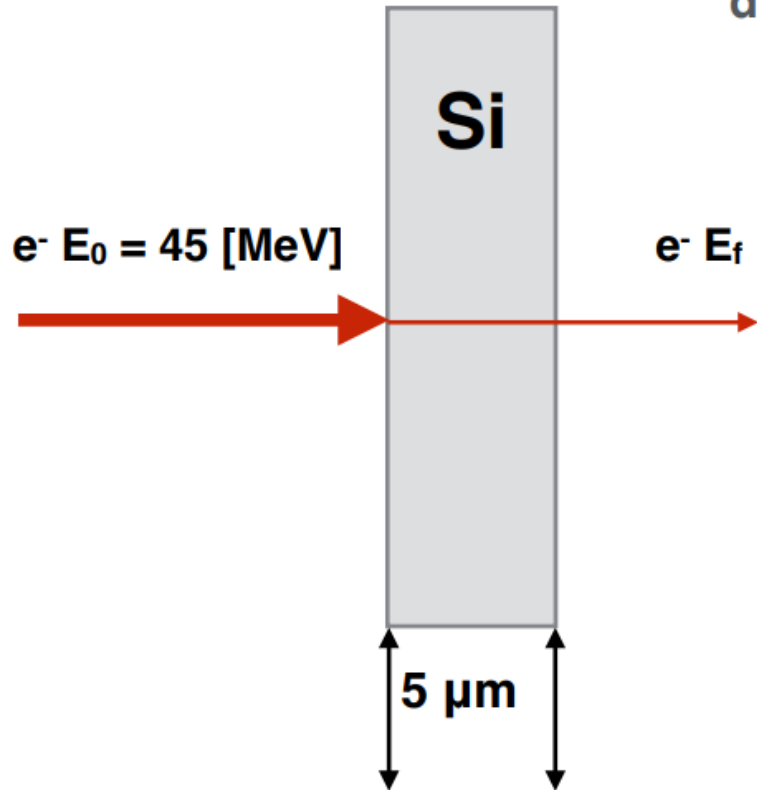


Do not forget about cuts!

- Geant4 uses **secondary production thresholds in length**
 - ❖ The default value is 0.7 mm for reference physics lists
 - ❖ UI commands to select cuts: `/run/setCut 0.1 mm`
or `/run/setCutForAGivenParticle e- 0.1 mm`
 - ❖ Internally, cuts are converted to energy values depending on the material and particle type. The corresponding energy has a minimum value (default is 1 keV) and the user can set it with UI command: `/cuts/setLowEdge 100 eV`
 - ❖ γ production thresholds are used in bremsstrahlung and e^- are used in ionization
 - ❖ e^+ production thresholds are almost always ignored as they annihilate and produce two photons that can fly away. They are used only for very high cuts on γ (at least higher than the electron mass, which is the minimal energy of each of the two photons generated)
 - ❖ **Proton** production thresholds mean that if a hadron scatters elastically on a nucleus (of the material), the (recoiling) nucleus becomes a new G4Track only if its kinetic energy is above the value *100 KeV x production_cut_in_mm*

Do not forget about cuts!

Compute the mean of the energy deposit in the target



Validation & geant-val

- Geant4 provides validation (i.e. comparison to data) for most of its physics codes
- ❖ Validation is a continuous task, performed at least as often as each release
- ❖ More validation tests added as time goes on ...
- [Geant-val](#) is our validation and testing suite
- ❖ It includes a database with a [web interface](#) for the community

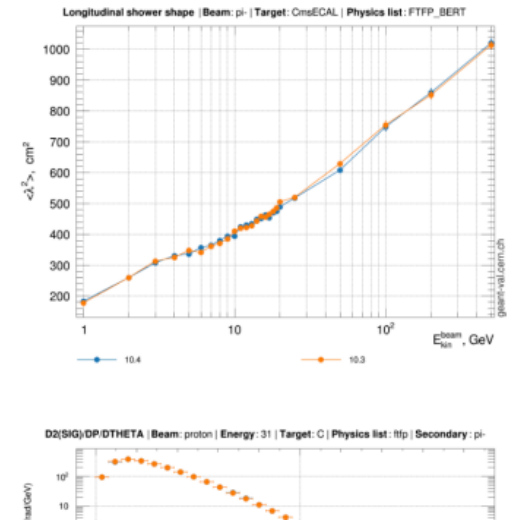
Geant Validation Portal

User Layouts

Stat comparison

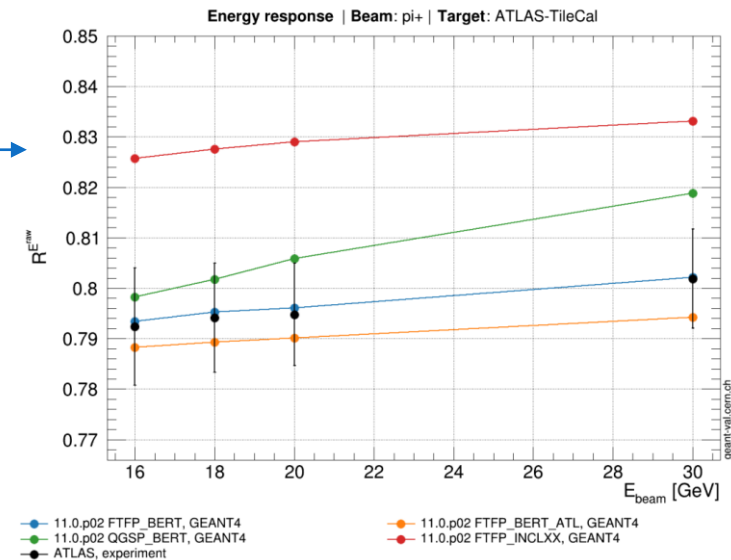
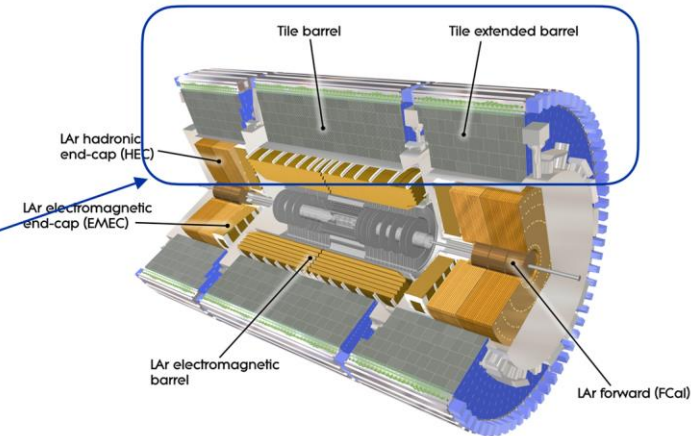
Summary

Lookup tables



Example: PL for hadronic calorimeter simulation

- Suppose you want to simulate an iron-based hadronic calorimeter using geant4-11.0
- On geant-val, geant4-11.0 has been validated on the ATLAS tile calorimeter test beam data
 - ❖ It is made of iron and scintillating plastic tiles
- Go to geant-val
 - ❖ select ATLTileCalTB and geant4-11.0.p02
 - ❖ Compare several physics lists to the ATLAS data
 - ❖ Currently FTFP_BERT is the best (and recommended) physics list for such detectors



Thank you!
