

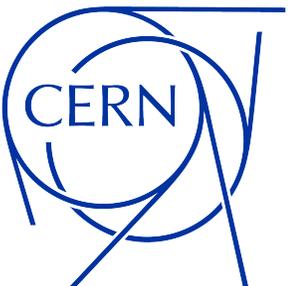
Choosing a Physics List

Geant4-11.1 reference - Based on previous Geant4 courses

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Covered topics

- ◆ **Recapitulation on physics list**
 - ✿ *Reference physics list*
 - ✿ *Modular physics list*
 - ✿ *Physics list naming convention*
 - ✿ *Using reference physics lists*
- ◆ **(Some) reference physics lists**
- ◆ **Do not forget about cuts!**
- ◆ **Validation & geant-val**
- ◆ **Example(s)**

Recapitulation: 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, ...)

Recapitulation: 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* [\[link\]](#)

Recapitulation: 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));
    // Synchrotron 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));
}
```

Recapitulation: 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**

Recapitulation: Using reference physics lists (1/2)

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
}
```

Recapitulation: Using reference physics lists (2/2)

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

```
#include "G4RunManagerFactory.hh"
#include "G4PhysListFactory.hh"

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

(1/5)

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

(2/5)

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- ◆ 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*, ...)

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

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

(3/5)

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

(4/5)

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
 - ♣ 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← Recommended for medical applications (also QGSP_BIC_HP)

Reference physics lists

(5/5)

Relevant physics list options for *electromagnetic physics* are

- ◆ PL+(**No suffix** or **_EM0**): uses the G4EmStandardPhysics constructor, implements default em physics
← Recommended em option for HEP applications (sampling calorimeters, ...)
- ◆ PL+ **_EMV**: uses the G4EmStandardPhysics_option1 constructor, implements fast but less precise em physics due to simple multiple scattering step limitation
← Recommended em option for fast HEP applications (homogenous calorimeters, ...)
- ◆ PL+ **_EMY**: uses the G4EmStandardPhysics_option3 constructor, implements Urban MSC model for all particles (medical, space science, precise)
← Recommended em option for medical applications (proton/ion therapy, ...)
- ◆ PL+ **_EMZ**: uses the G4EmStandardPhysics_option4 constructor, implements the most accurate em physics, e.g. an error-free stepping for e^{\pm}
← The most accurate em physics description. Can be used as a reference for all the cases above

Do not forget about cuts!

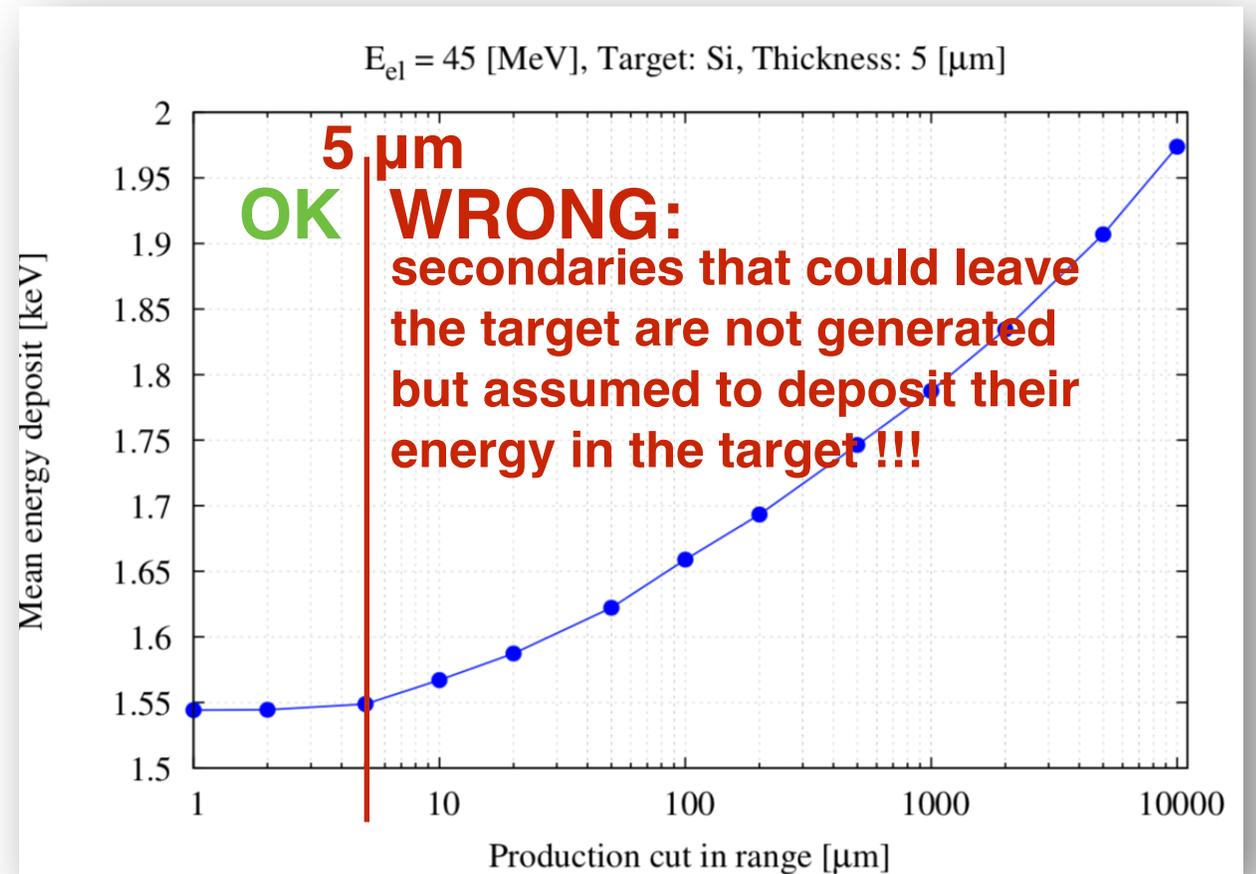
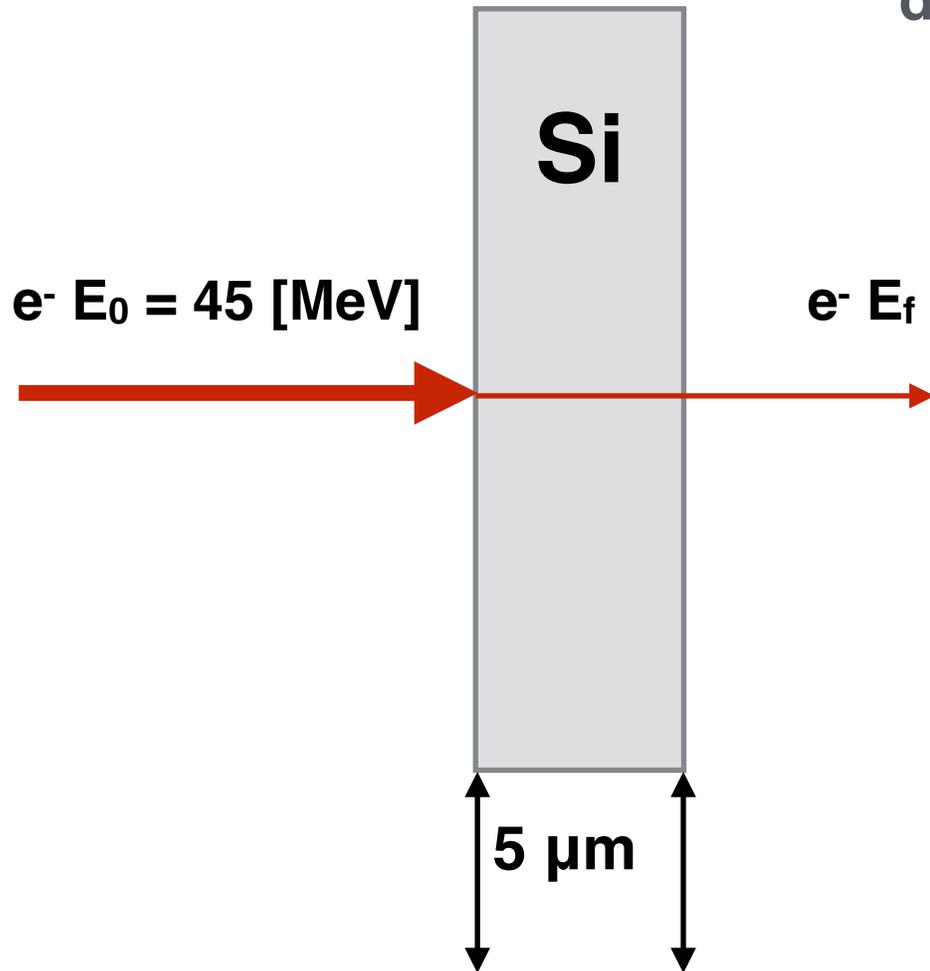
(1/2)

- ◆ 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 $100 \text{ KeV} \times \text{production_cut_in_mm}$

Do not forget about cuts!

(2/2)

Compute the mean of the energy deposit in the target



Validation & geant-val

(1/2)

- ◆ 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

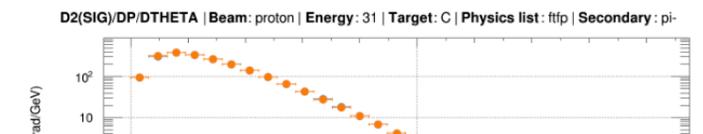
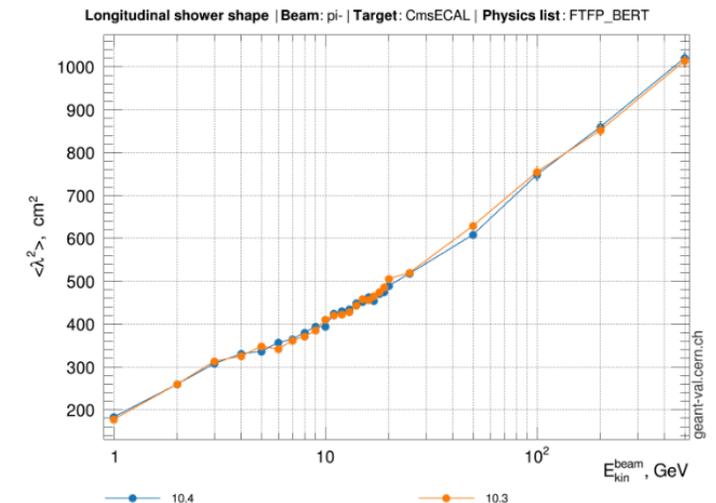
Geant Validation Portal

User Layouts

Stat comparison

Summary

Lookup tables



Validation & geant-val

(2/2)

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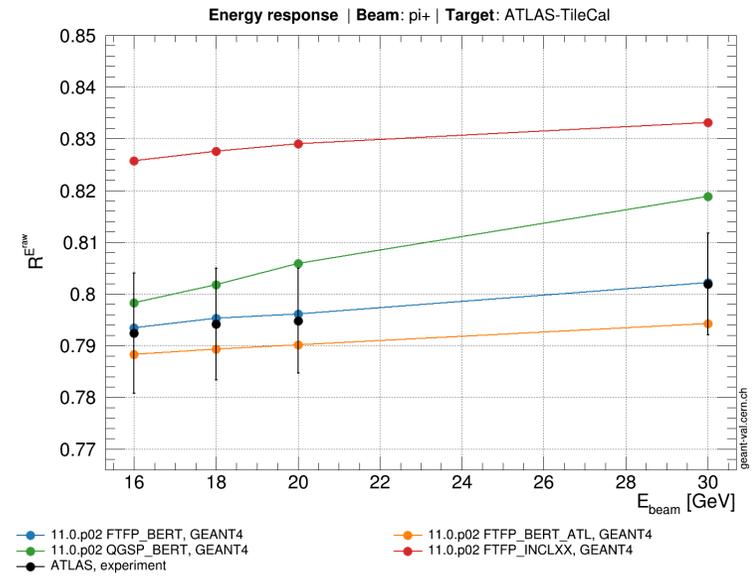
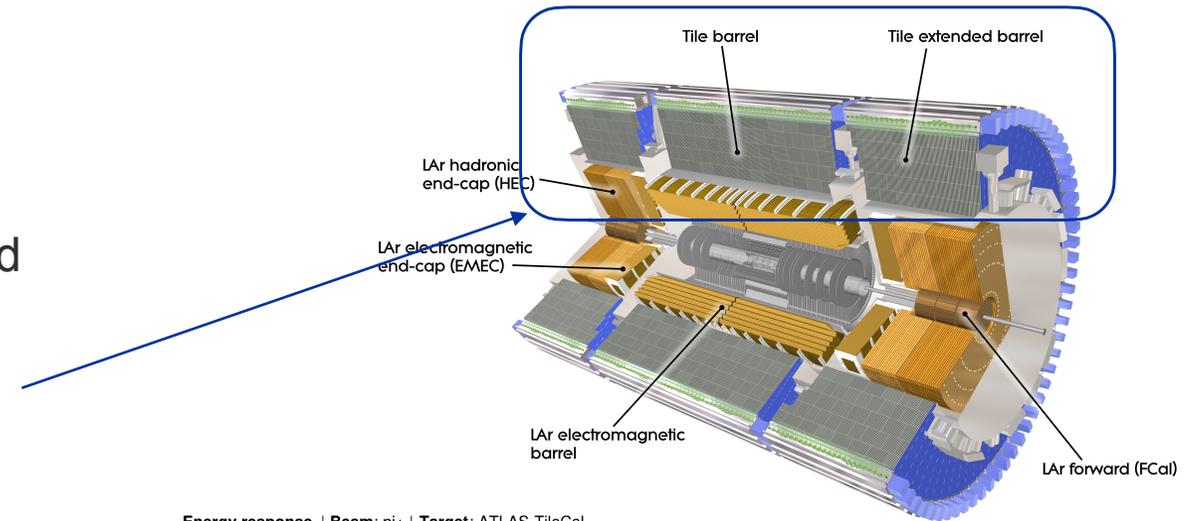
Geant Validation Portal

Available tests

Test	Project	Author	Description
ATLHECTB	GEANT4	Lorenzo Pezzotti, Alberto Ribon	A simulation of the ATLAS hadronic end-cap calorimeter beam tests. It features a detailed geometry description, Birks quenching treatment, and readout channels selection. Source code: github.com/lopezzot/ATLHECTB , Documentation: lopezzot.github.io/ATLHECTB/
ATLTileCalTB	GEANT4	Lorenzo Pezzotti, Stephan Lachnit, Alberto Ribon	A standalone Geant4 simulation of the ATLAS tile calorimeter test-beam. Source Code: https://github.com/lopezzot/ATLTileCalTB
BraggPeakGSI_MT	GEANT4		
Bremsstrahlung	GEANT4	B. Faddegon	Bremsstrahlung yield
CALICESIWTB	GEANT4	Lorenzo Pezzotti, Alberto Ribon	A standalone Geant4 simulation of the CALICE SiW calorimeter beam tests involving charged pions. Code: https://github.com/lopezzot/CALICESIWTB
CCCStest	GEANT4	Chihiro Omachi	
ElecBackScat	GEANT4		

Example #1: 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



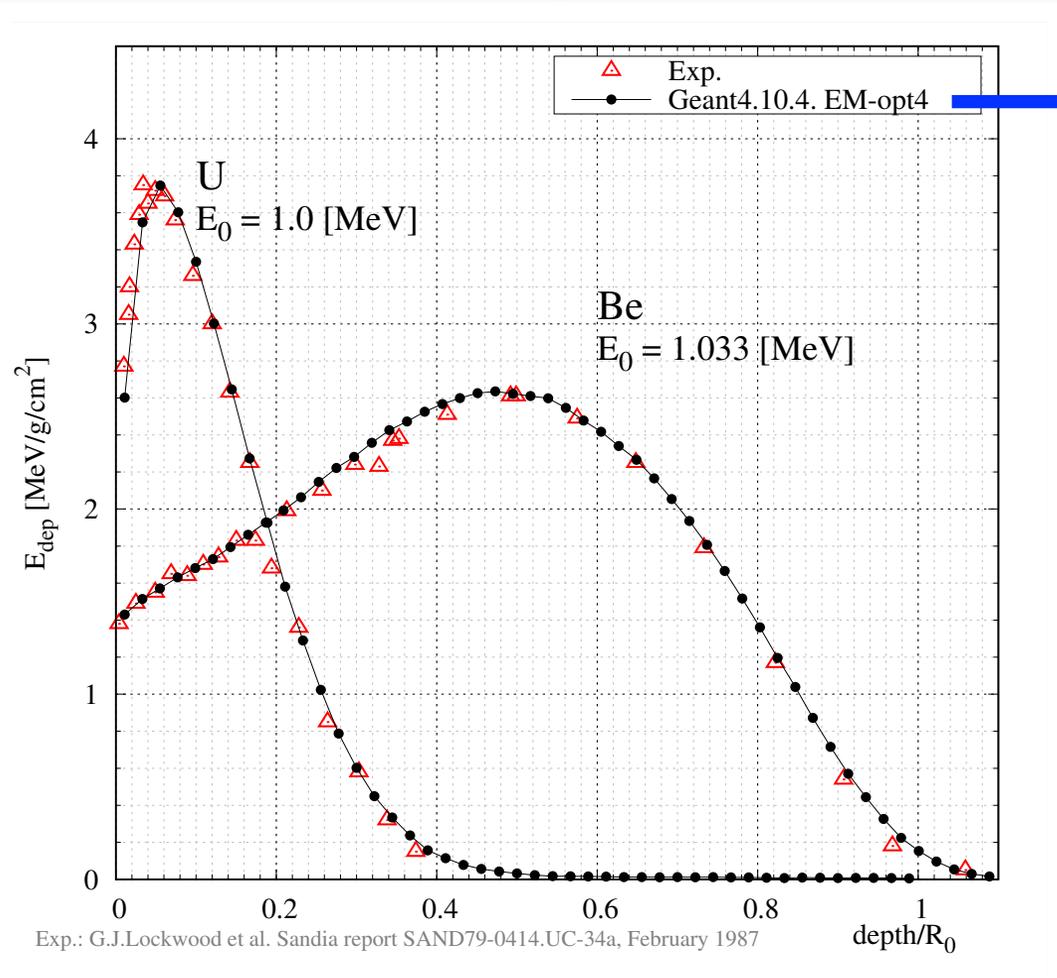
Example #2: EM dose-depth profile

(1/2)

- ◆ Something that *almost always* works:
 - ❖ the user can take **the most accurate physics settings** (e.g. EMZ for EM), run some simulation with lower statistics to obtain the *most accurate result*, then
 - ❖ take **a less accurate but faster physics setting** (e.g. G4EmStandardPhysics for EM) as a starting point and obtain some simulation results, and granularly **extend the initial physics list by using the accurate results as reference**
- ◆ **Example:** simulation of energy deposit by energetic e^- as a function of the penetration depth, for both lighter and heavier materials (see next slide)

Example #2: EM dose-depth profile

(2/2)



~ 15-20 % faster

