Choosing a Physics List

Based on `Geant4-11.0` - Based on material from previous 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 thresholds, …)

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, …)
- 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

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

- Reference physics lists are modular physics lists `(: public G4VModularPhysicsList)`
  - Modular physics lists implement a granular approach to physics via *constructors*

```
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));
}
```

Recapitulation: **Naming conventions**

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

Had options   Em options

- 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**) standard EM i.e. the default G4EmStandardPhysics constructor
  - **EMV** G4EmStandardPhysics_option1 constructor (HEP, fast but less precise)
  - **EMY** G4EmStandardPhysics_option3 constructor (medical, space science, precise)
  - **EMZ** G4EmStandardPhysics_option4 constructor (most precise EM physics)

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

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

Reference physics lists (2/4)

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

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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 [3,12] 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)

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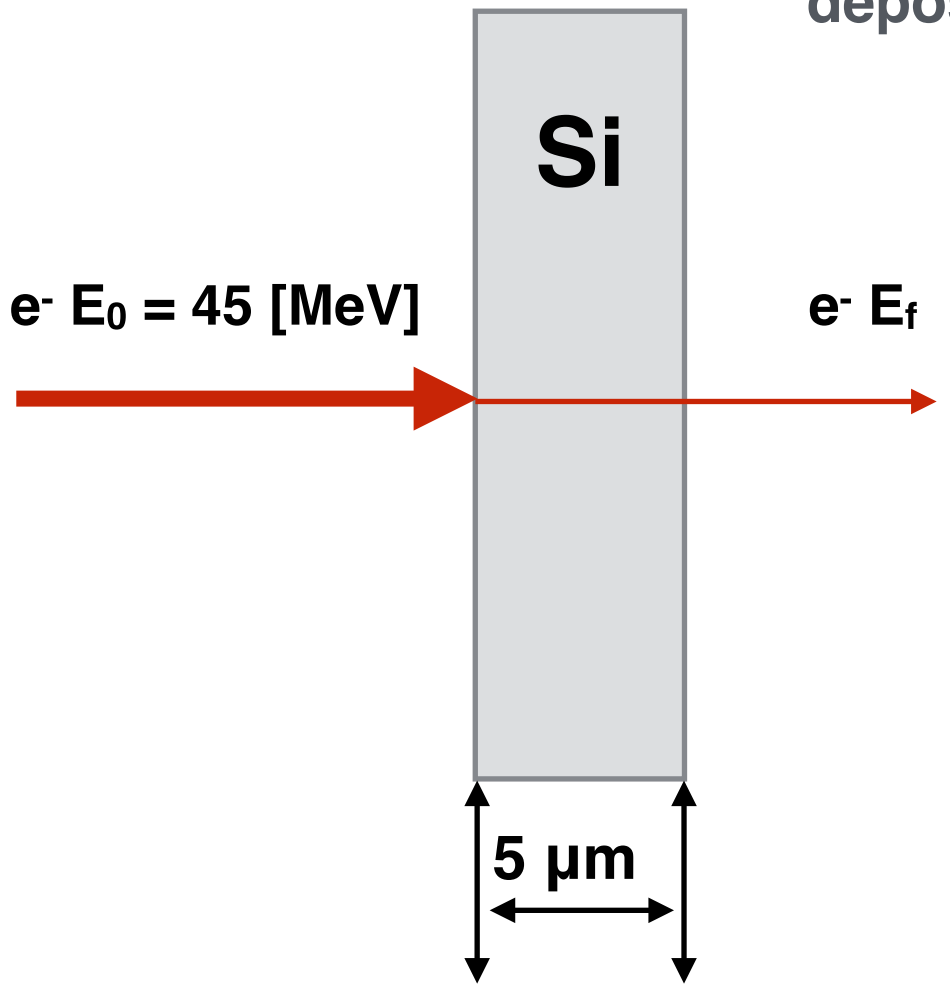
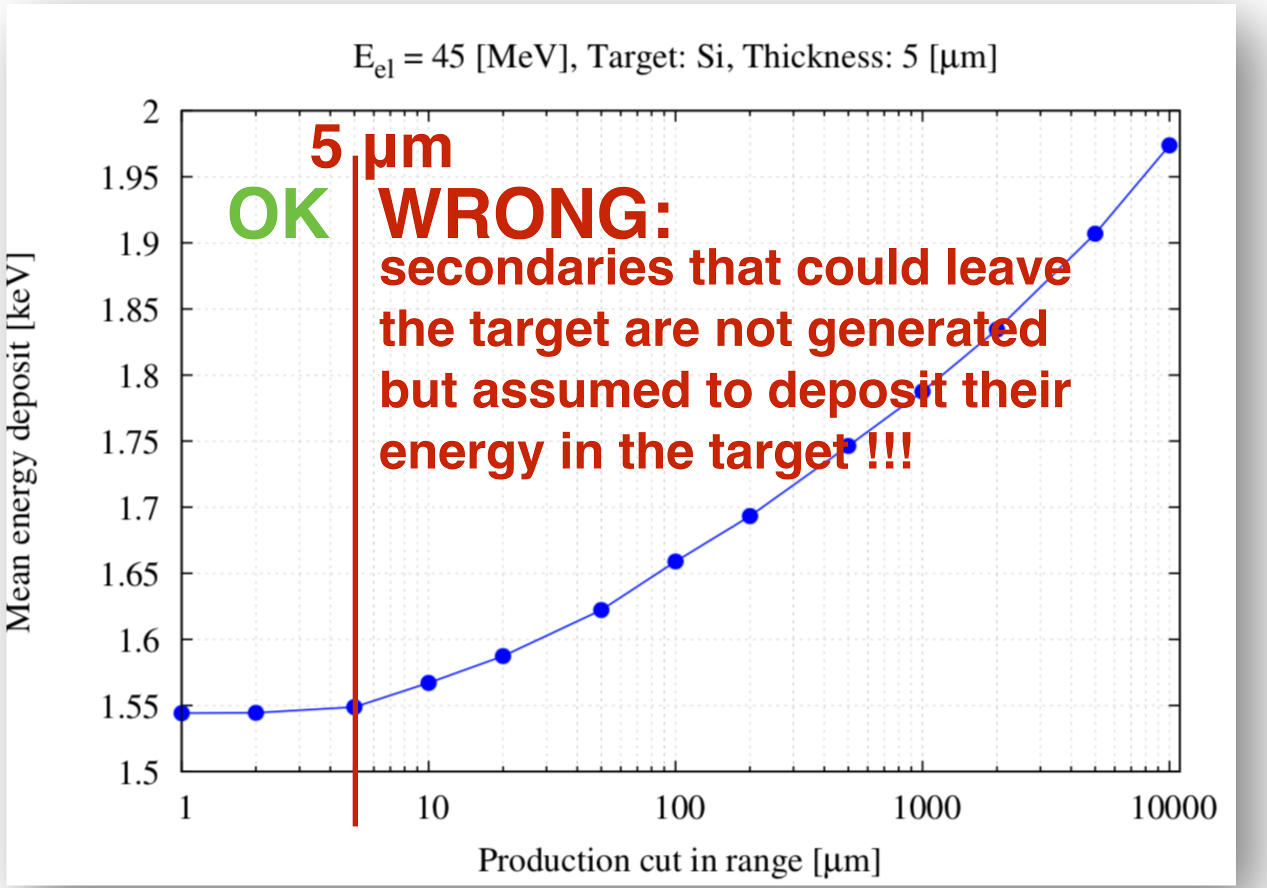
- The **FTFP_INCLXX** PL: uses the INCLXX model for the inelastic process of protons, neutrons and charged pions. The INCLXX and the FTF models intersect in the energy range [15,20] GeV ← Alternative for `FTFP_BERT` at low energies (<20 GeV)

- 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

Do not forget about cuts!

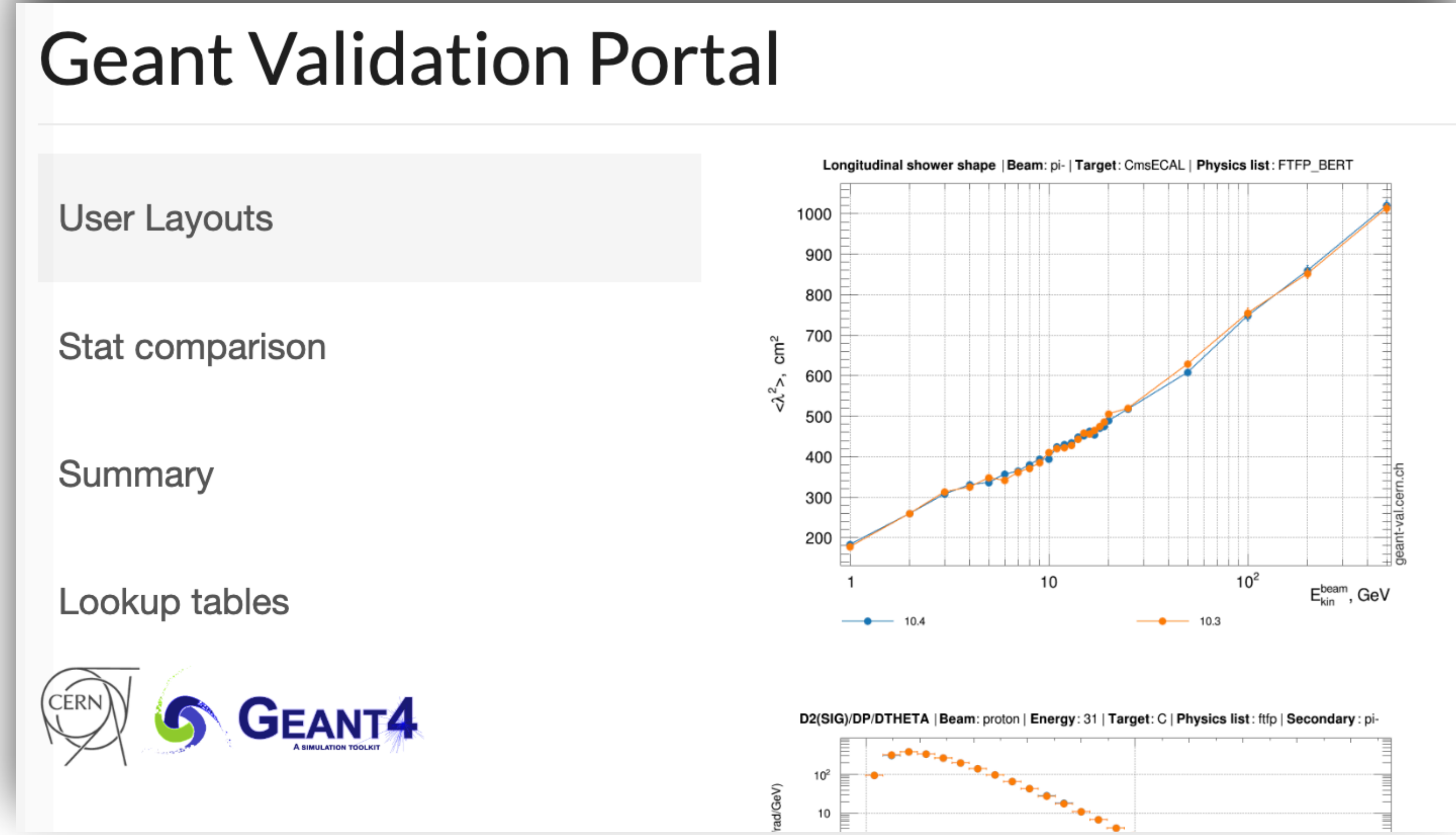


Compute the mean of the energy deposit (E_f-E_0) in the target



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



Validation & geant-val (2/2)

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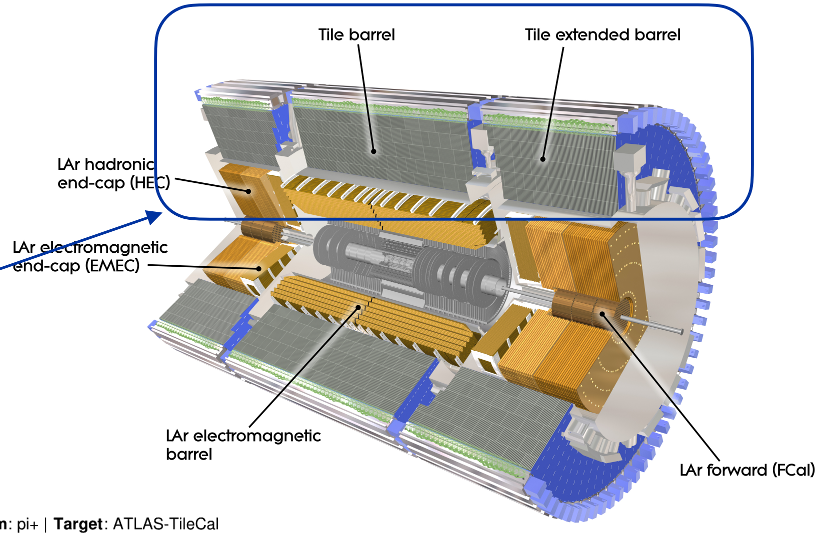
Geant Validation Portal

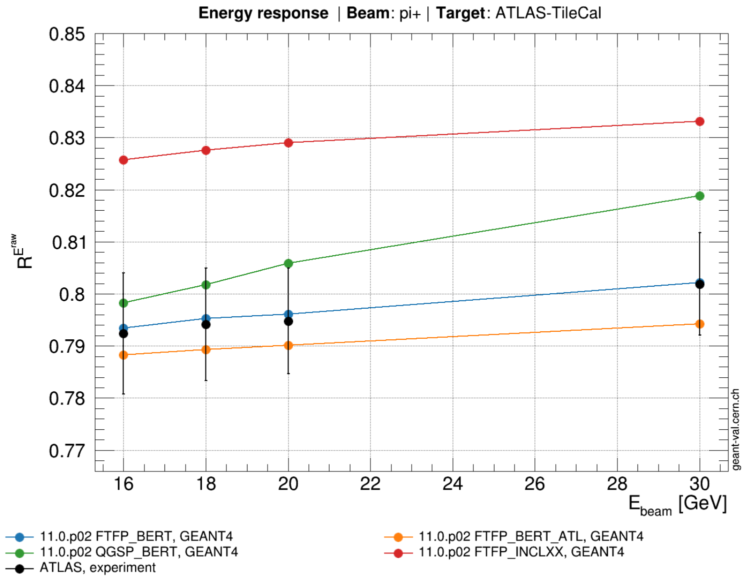
Available tests

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

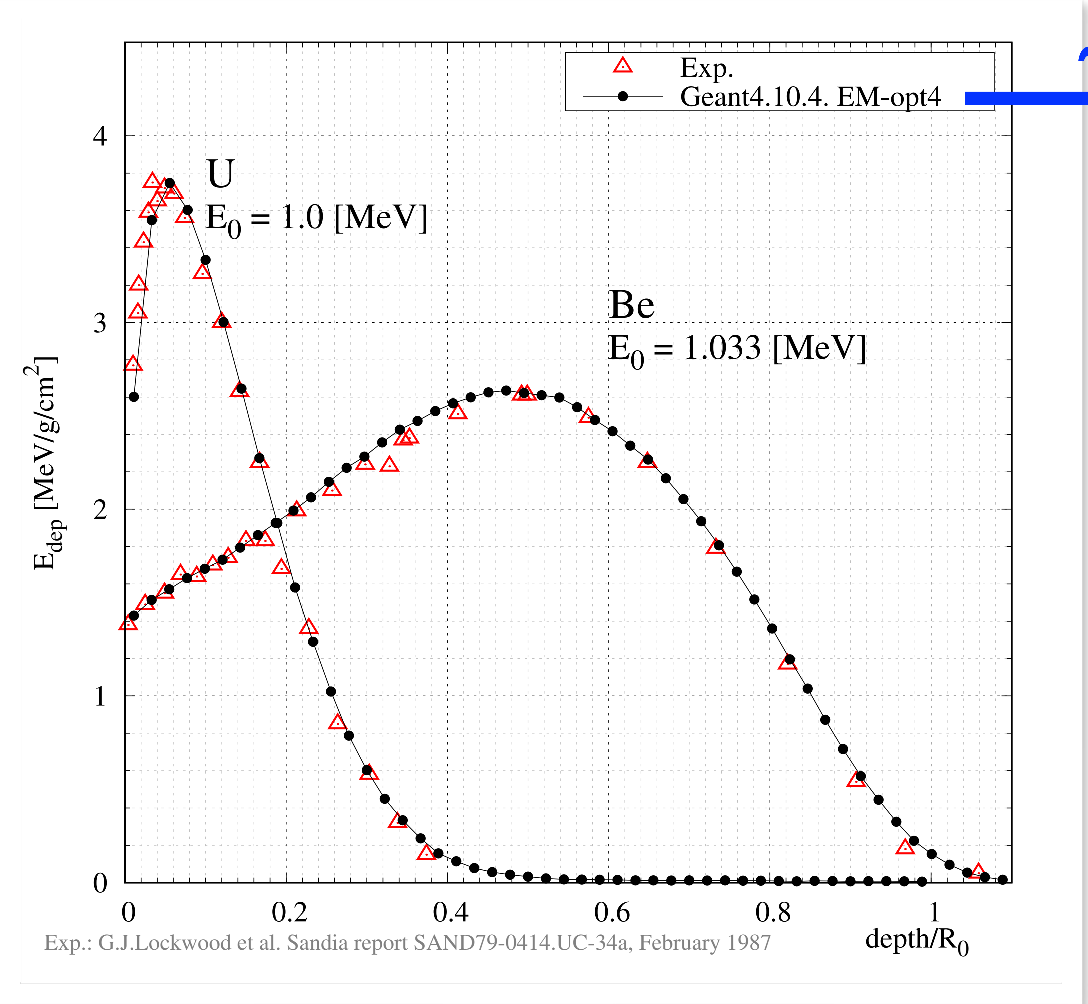




Example #2: **EM dose-depth profile** (1/2)

- 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