CALICE prototypes beam tests integration into Geant-val

(The SiW calorimeter example)

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on behalf of the GEANT4 Collaboration

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Geant4 validation program exploiting beam tests

In May 2021, the Geant4 Collaboration started a new validation program on test beam data targeting both hadronic and electromagnetic calorimeters.

- Lead by the EP-SFT Group under the supervision of Alberto Ribon.

- Four/five beam tests selected:
  - ATLAS Hadronic Endcap Calorimeter (HEC) — *Completed*
  - ATLAS Tile Calorimeter (TileCal) — *To be done*
  - The 2020 Dual-Readout fiber calorimeter (em-sized) — *Ongoing*
  - CALICE SiW (2008 beam test involving π^-) — *Completed, today's topic*
  - A CALICE hadronic prototype (*to be agreed on - maybe at this meeting…*) — *To be done*

Some good rules

To ensure the long-term maintenance we try to build each simulation according to few general rules:

- Less (env) is more: try to use as few libraries (env) as possibile.
  → So far we managed to migrate simulations from experiments to standalone Geant4 code making future maintenance straightforward.
- Ensure multi-threading: try to design multi-threaded simulation from day-one according to the Geant4 rules (G4MTRunManager, G4Analysis, G4ActionInitialization, …).
  → Migrating a single-threaded code to a multi-threaded one *a posteriori* can be painful!
- Building code: try to build code with *vanilla* CMAKE (find_package()) and avoid ad-hoc make files from mini-frameworks.
- Make results comparison easy: deploy results on the Geant-val database for automatic physics list comparison and Geant4 regression testing.
  → the first example with CALICE will be presented today.

Geant Val - https://geant-val.cern.ch/

Geant-val is the Geant4 validation and testing suite.

It contains ~40 Geant4 *tests* over several research fields (nuclear physics, HEP, biomedical, …).

In a nutshell, it allows to:

- Create multiple jobs over beam energies, particle types, physics lists, …, and automatically submit them on HTConcord(lxplus).
- Encapsulate variables in json files.
- Run (the same!) analysis over the full set of variables with no additional user effort.
- Deploy results on the Geant-val database and allow fetching them through the website.

Geant val config files example

params.conf

```
!PHYSLIST=FTFP_BERT, QGSP_BERT
!CONST:ENERGY_UNIT=GeV
PARTICLE | ENERGY | PHYSLIST | NEVENTS
pi- | 20. | PHYSLIST | 50000
pi- | 30. | PHYSLIST | 50000
pi- | 40. | PHYSLIST | 50000
pi- | 50. | PHYSLIST | 50000
pi- | 60. | PHYSLIST | 50000
pi- | 80. | PHYSLIST | 50000
pi- | 100. | PHYSLIST | 50000
pi- | 120. | PHYSLIST | 50000
pi- | 150. | PHYSLIST | 50000
pi- | 180. | PHYSLIST | 50000
pi- | 200. | PHYSLIST | 50000
e- | 20. | PHYSLIST | 50000
e- | 40. | PHYSLIST | 50000
e- | 50. | PHYSLIST | 50000
e- | 80. | PHYSLIST | 50000
e- | 100. | PHYSLIST | 50000
e- | 119.1 | PHYSLIST | 50000
e- | 147.8 | PHYSLIST | 50000
```

template.conf

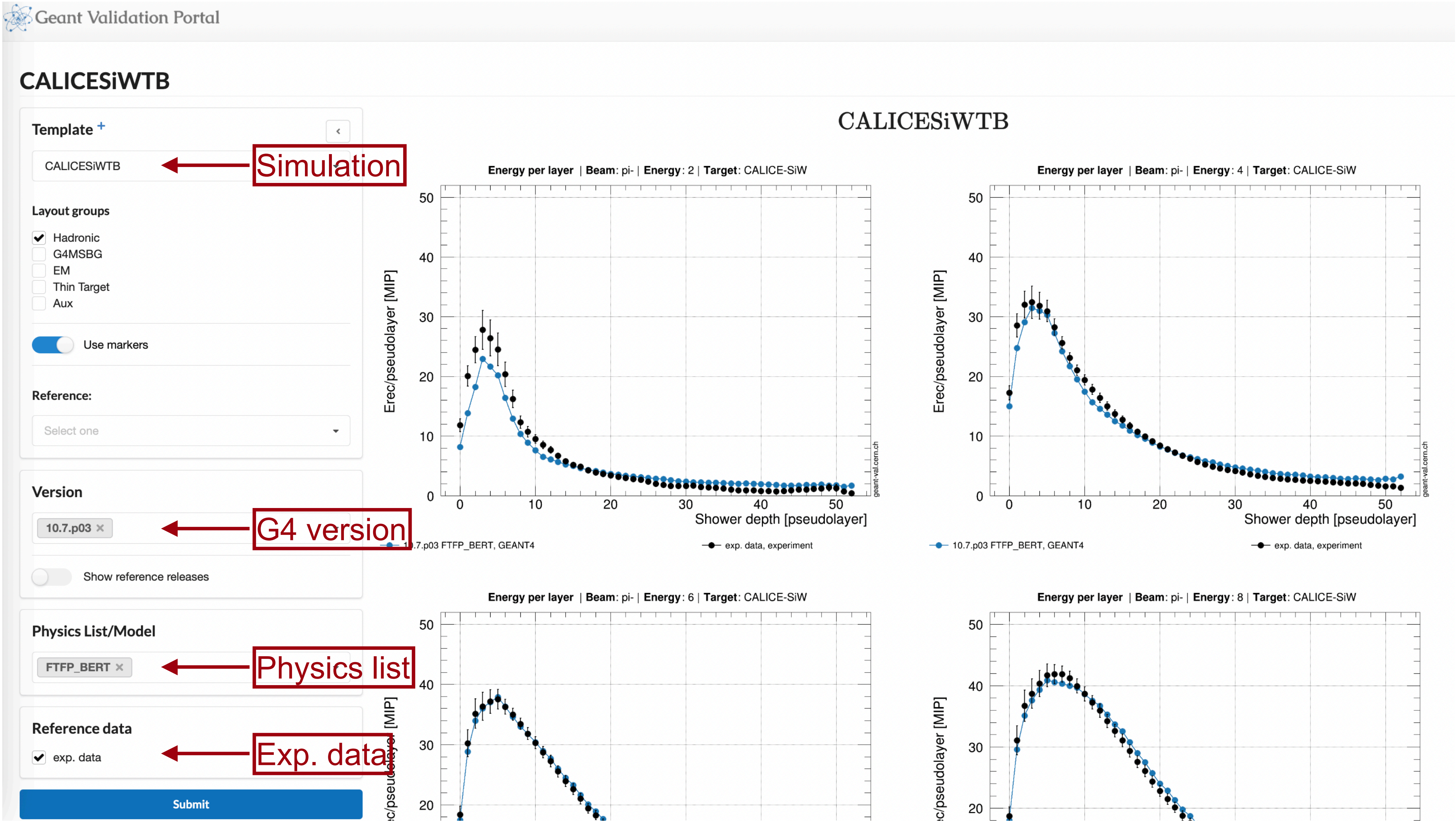
```
/run/initialize
/gun/position -9 172 0 cm
/gun/direction 0 0 1
/gun/particle %PARTICLE%
/gun/energy %ENERGY% %ENERGY_UNIT%
/run/setCut 1.0 mm
/run/beamOn %NEVENTS%
```

run.sh

```
#!/bin/bash

# Environment variables
export PHYSLIST="%PHYSLIST%"

# Execute
./sim -m run.mac -pl %PHYSLIST%
-t 2
```

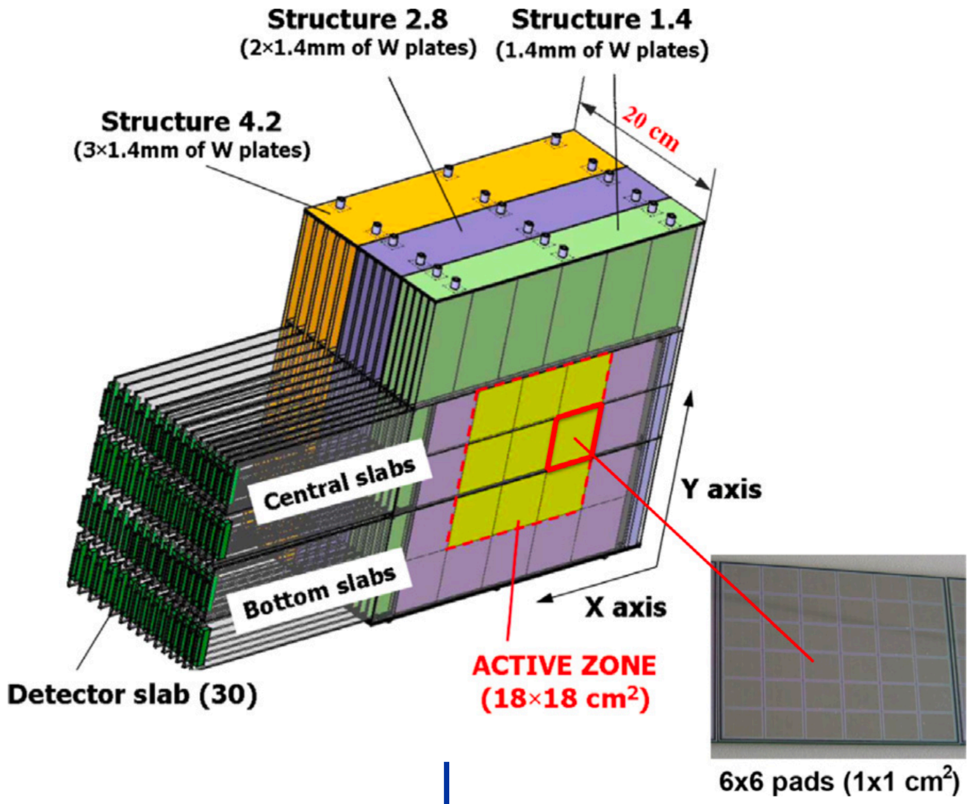

Geant Validation Portal
CALICESiWTB
Template +
CALICESiWTB
Simulation
Layout groups
Hadronic
G4MSBG
EM
Thin Target
Aux
Use markers
Reference:
Select one
Version
10.7.p03
G4 version
Show reference releases
Physics List/Model
FTFP_BERT
Physics list
Reference data
exp. data
Exp. data
Submit
CALICESiWTB
Energy per layer | Beam: pi- | Energy: 2 | Target: CALICE-SiW
Energy per layer | Beam: pi- | Energy: 4 | Target: CALICE-SiW
Energy per layer | Beam: pi- | Energy: 6 | Target: CALICE-SiW
Energy per layer | Beam: pi- | Energy: 8 | Target: CALICE-SiW
Erec/pseudolayer [MIP]
Shower depth [pseudolayer]
10.7.p03 FTFP_BERT, GEANT4
exp. data, experiment
geant-val.cern.ch

The CALICE SiW 2008 test beam

- Beam tests performed in 2008 at the FNAL beam line,
  involving 2, 4, 6, 8 and 10 GeV π^-.

- The CALICE SiW prototype is ECAL-sized.
  It features:
  - 30 longitudinal layers,
  - each layer readout by 36x9 Si cells. Active area is 18x18 cm^2, thickness is 24 X_0 ($\simeq 1\lambda$).
  - Tungsten slabs used as absorbers with different thicknesses (1.4, 2.8 and 4.2 mm). Sampling fraction decreasing with shower depth.

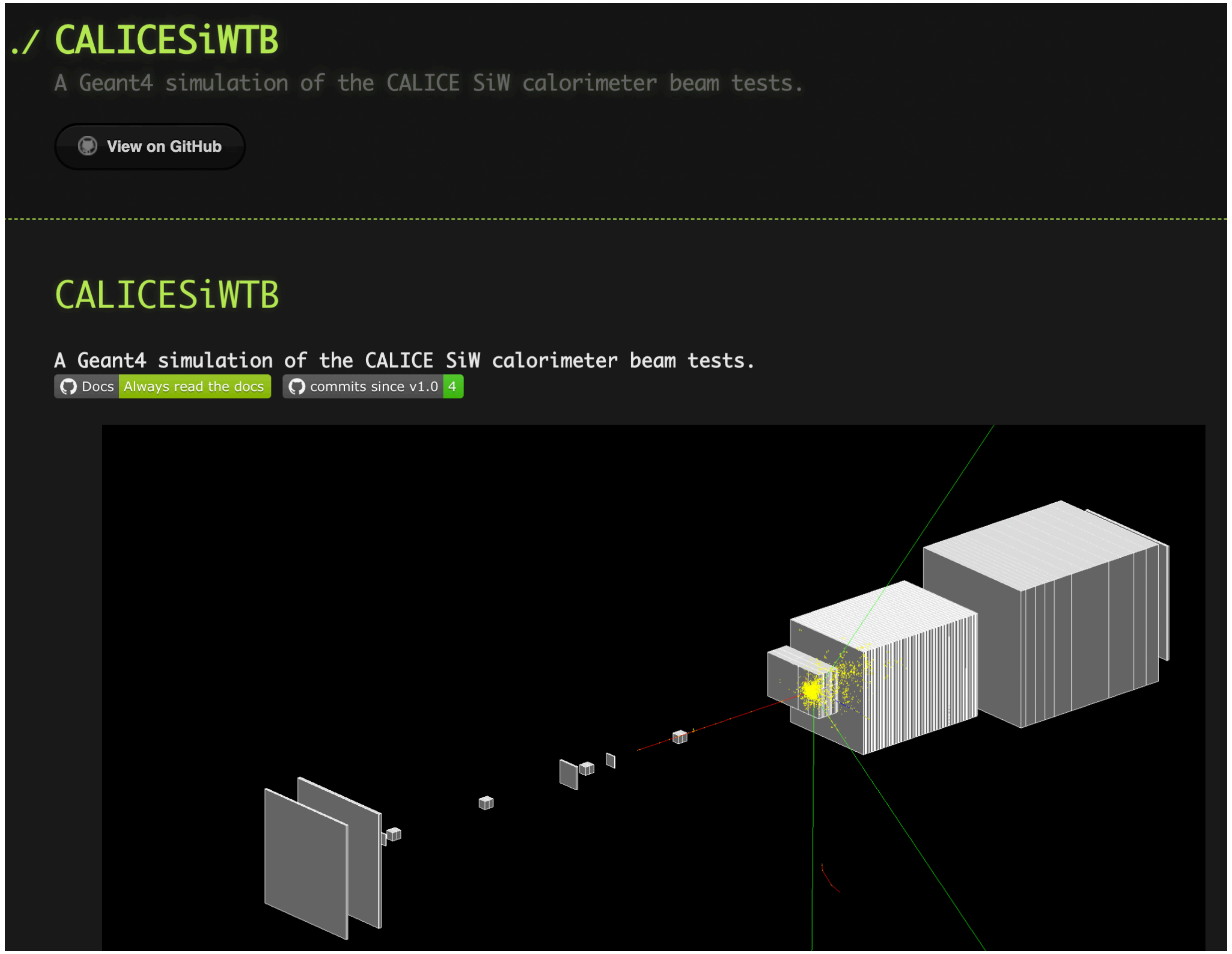
- Reference paper from 2015: NIM A 794 (2015) [link].



9720 sensitive volumes

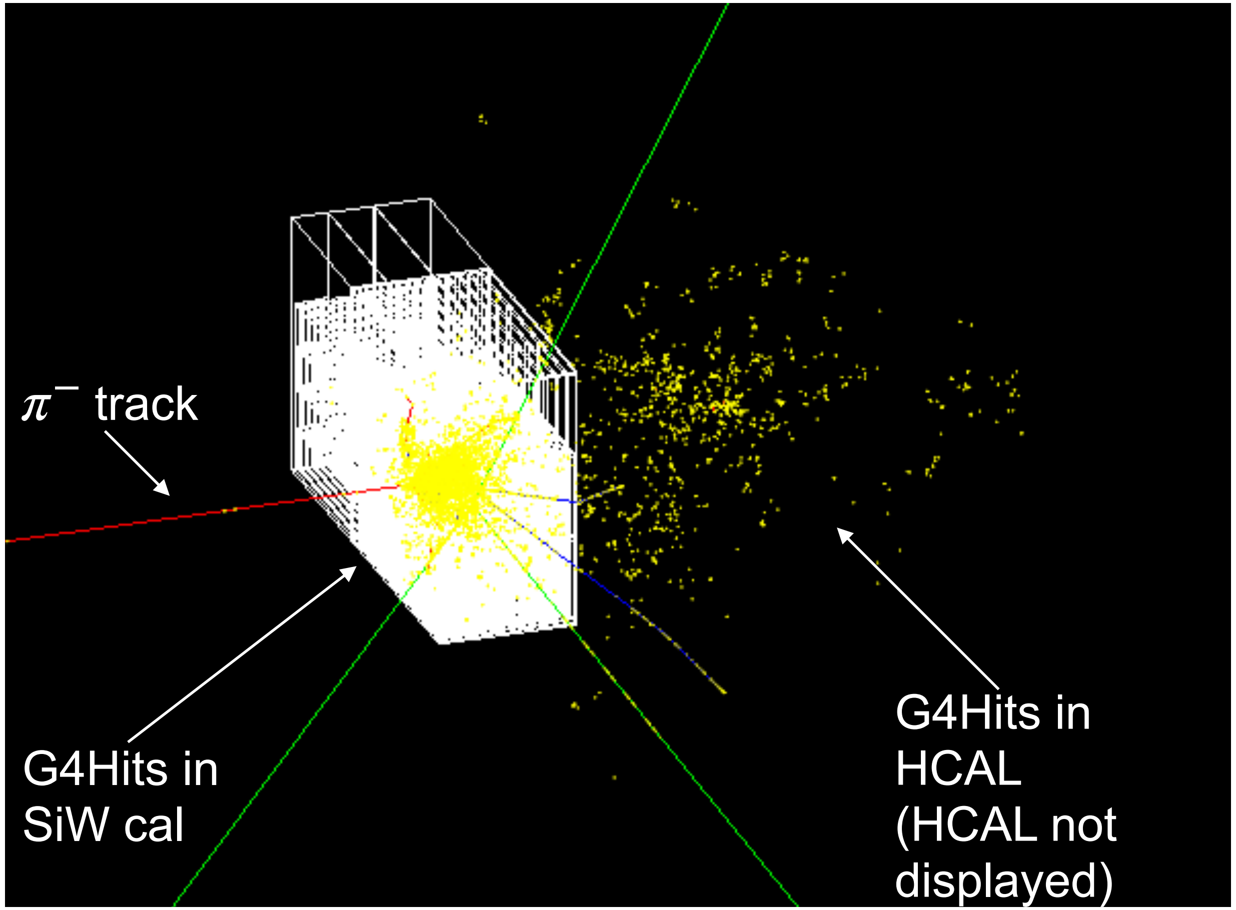
CALICESiWTB

- A standalone Geant4 simulation of the CALICE SiW 2008 beam test.
  - Based on the Geant4 env. Works easily on lxplus+HTCondor.
  - Geometry and sensitive detectors extracted from a GDML file from a previous attempt around 2018. Remaining parts rewritten as an advanced Geant4 example.
  - Open code [Github]
  - [Documentation]
  - First CALICE simulation within Geant-val. From v1.0 it can be used with Geant-val and (some) results are already available on the Geant-val website.



Selecting events

- Only π^- events with a nuclear breakup are considered in the analysis.
- Each cell is calibrated with MIPs: energy deposits are expressed in MIP units.
  Each Si-cell is associated to a single hit (G4VHit).
- First interaction layer (i) is selected if:
  - three consecutive layers have an energy > 8 MIPS, or,
  - $\frac{E_i + E_{i+1}}{E_{i-1} + E_{i-2}} > 6$ and, $\frac{E_{i+1} + E_{i+1}}{E_{i-1} + E_{i-2}} > 6$
- Setting the interaction layer as layer 0, it is possible to extract the longitudinal energy distribution (in MIPS) as a function of the beam energy, *regardless of the depth of the first interaction*.



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Conclusion from CALICE 2015 paper:

"… the physics observables which take into account the energy deposition are not reproduced well by the Monte Carlo. The reconstructed energy is too low due to a lower number of hits. Combining the longitudinal and radial energy profiles it seems that especially the Fritiof model deposits too much energy near the interaction region."

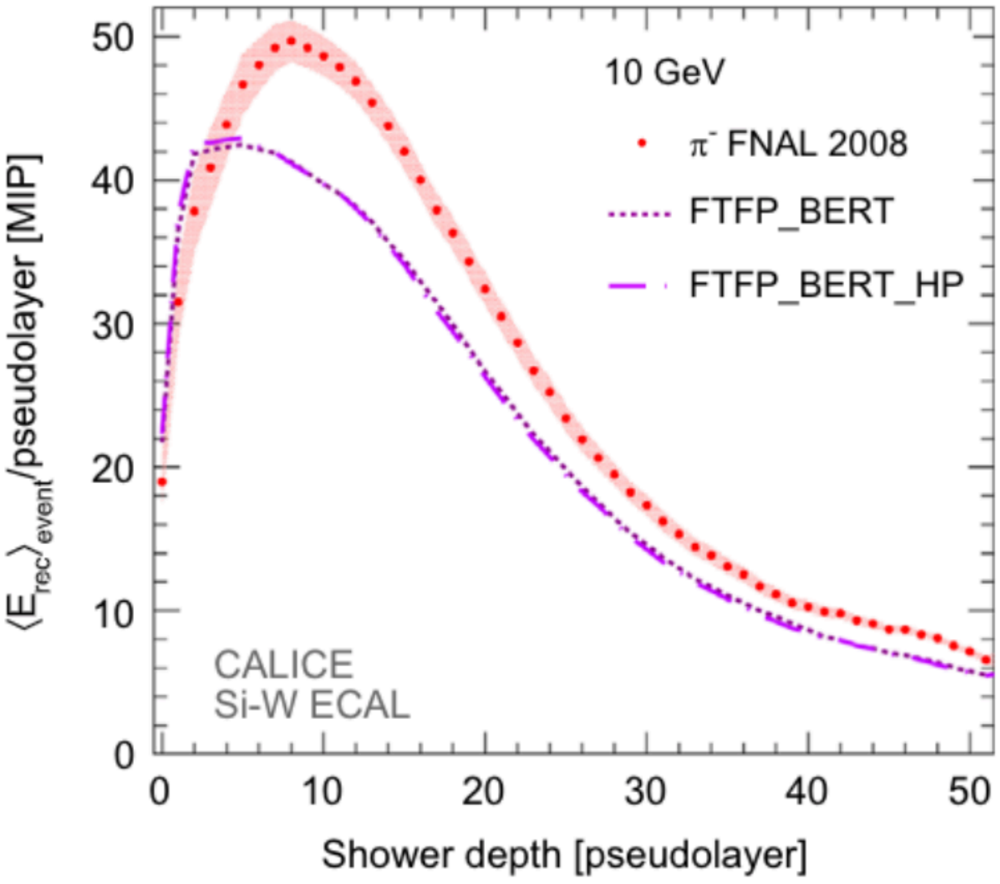
Longitudinal energy distributions

Geant4 regression testing and physics lists comparison

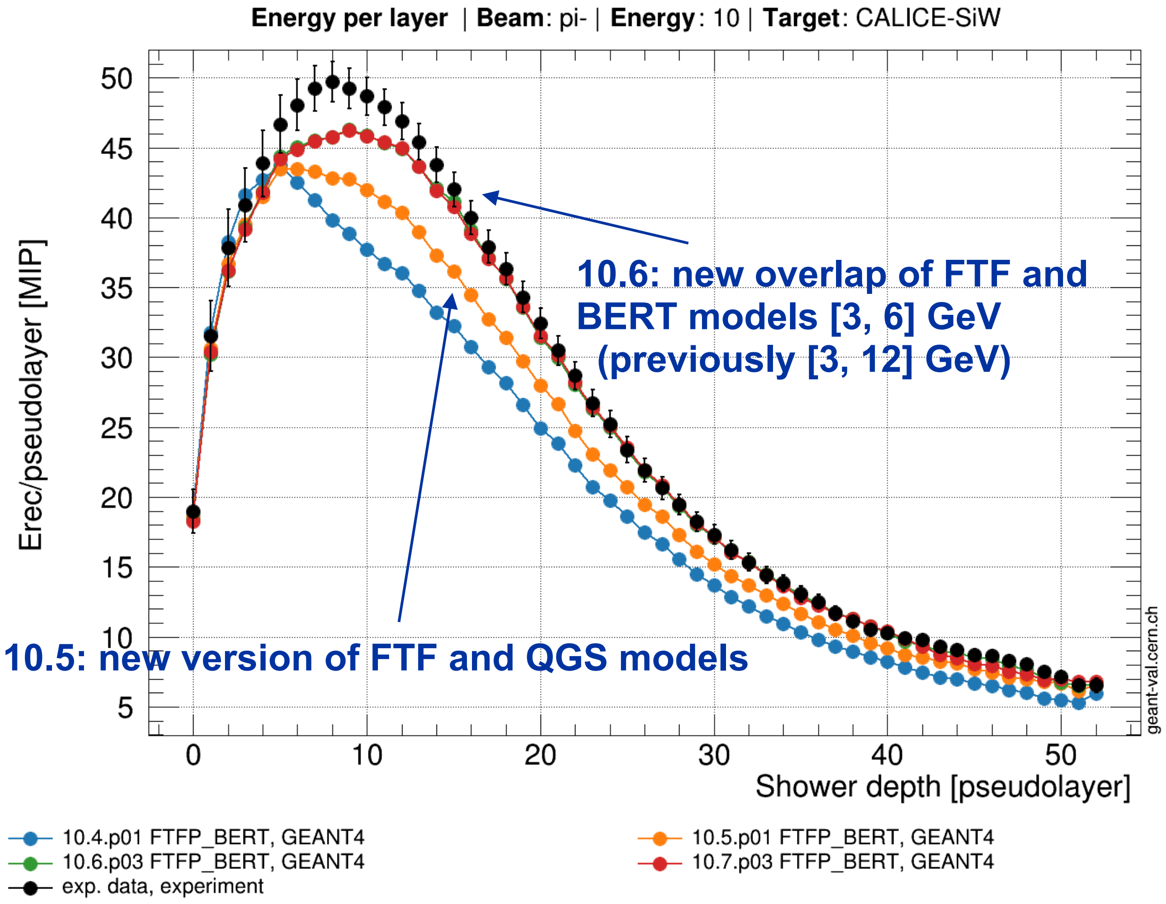
Longitudinal energy distribution - regression testing

10 GeV π^-

CALICE 2015 - Geant4.9.6 NIMA794



Geant4 Collaboration 2022

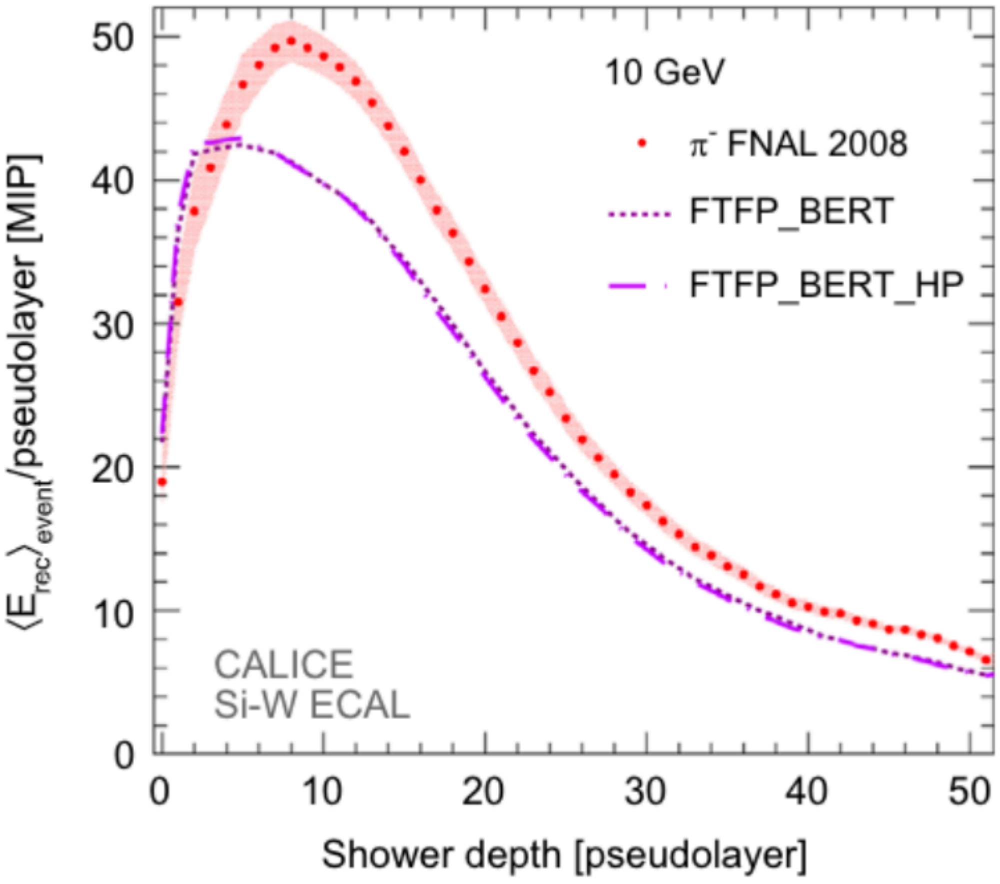


From 2017 to 2021

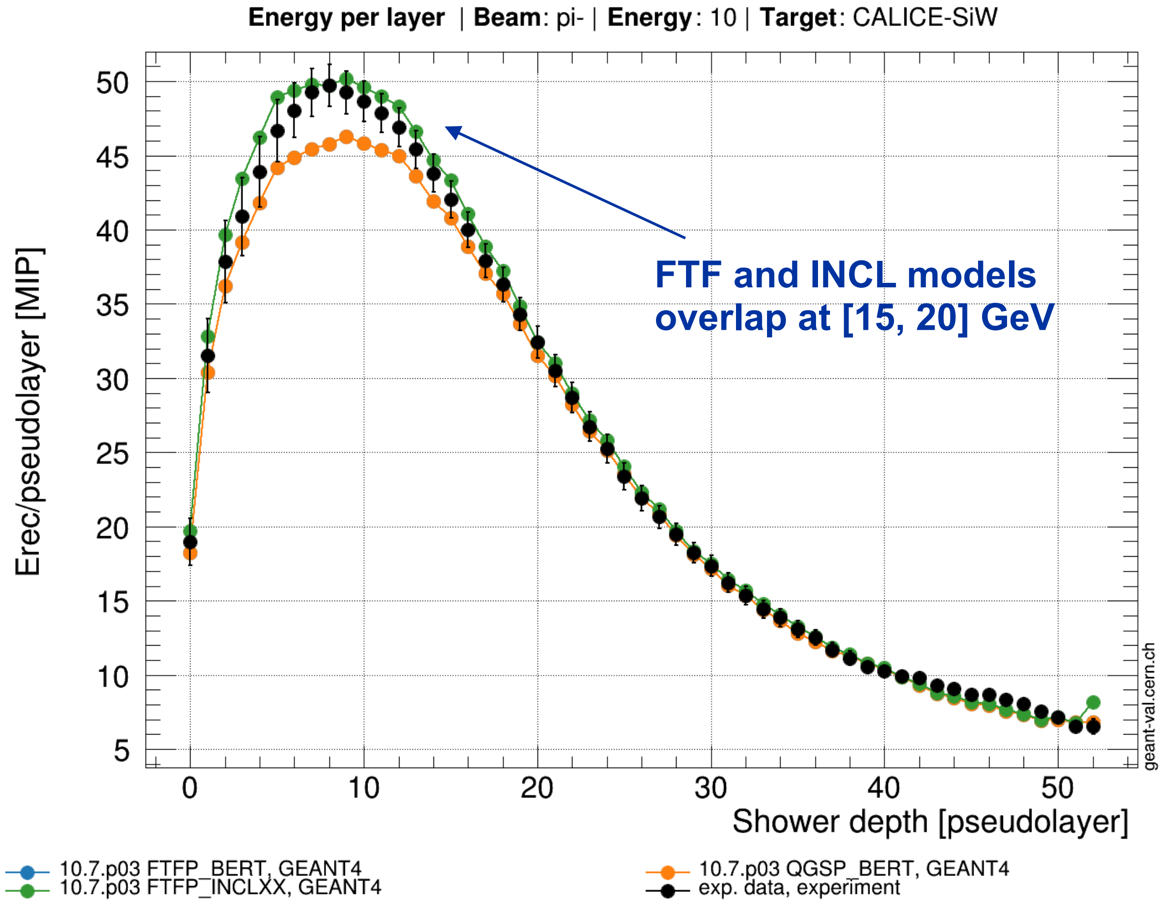
Longitudinal energy distribution - PL comparison

10 GeV π^-

CALICE 2015 - Geant4.9.6 NIMA794



Geant4 Collaboration 2022 - Geant4.10.7.p03

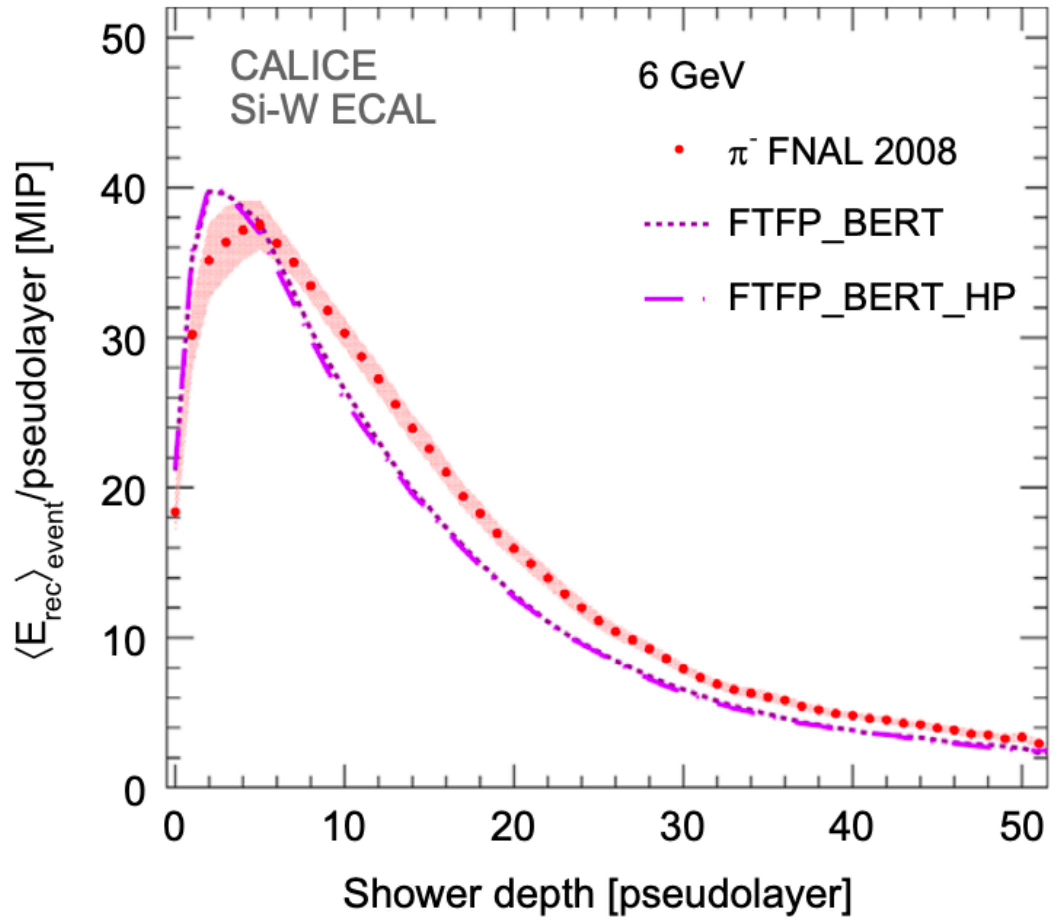


Below 12 GeV FTFP_BERT and QGSP_BERT are identical

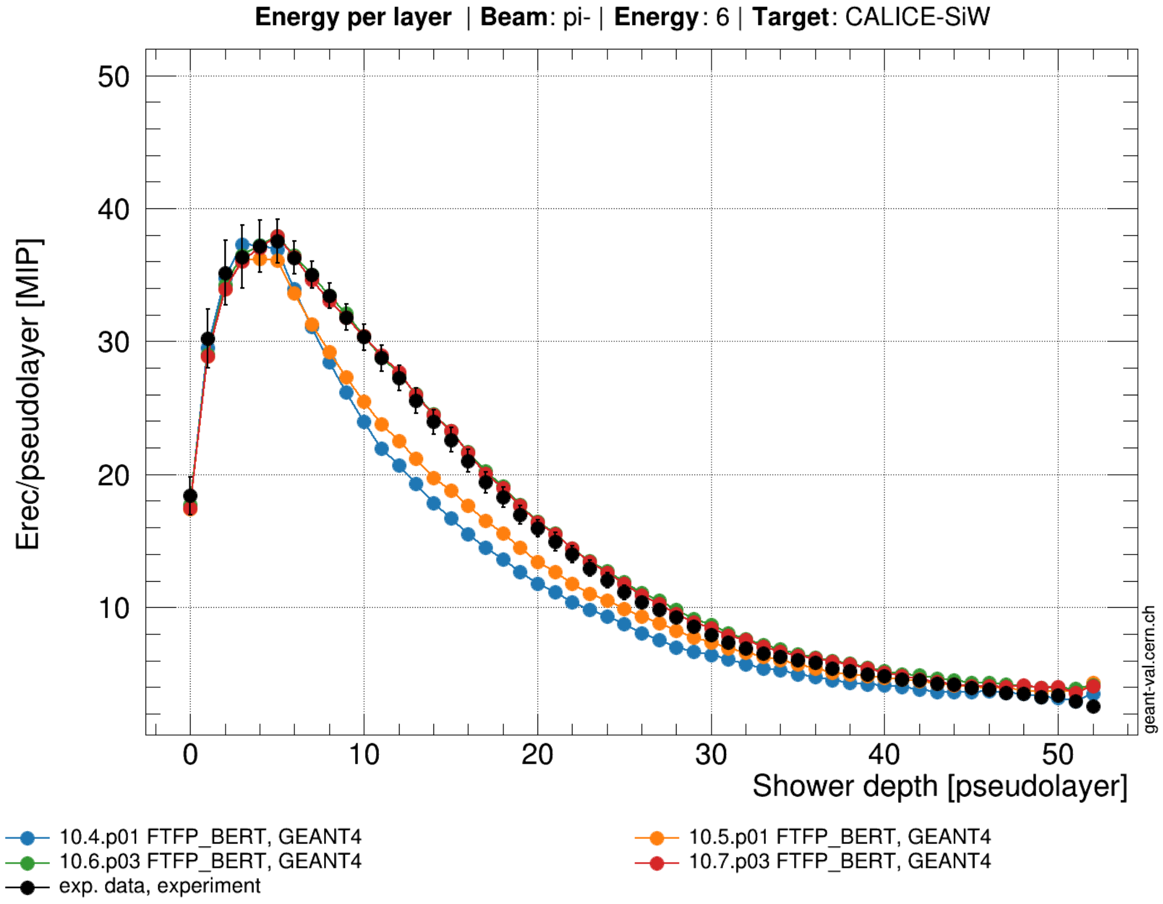
Longitudinal energy distribution - regression testing

6 GeV π^-

CALICE 2015 - Geant4.9.6 NIMA794



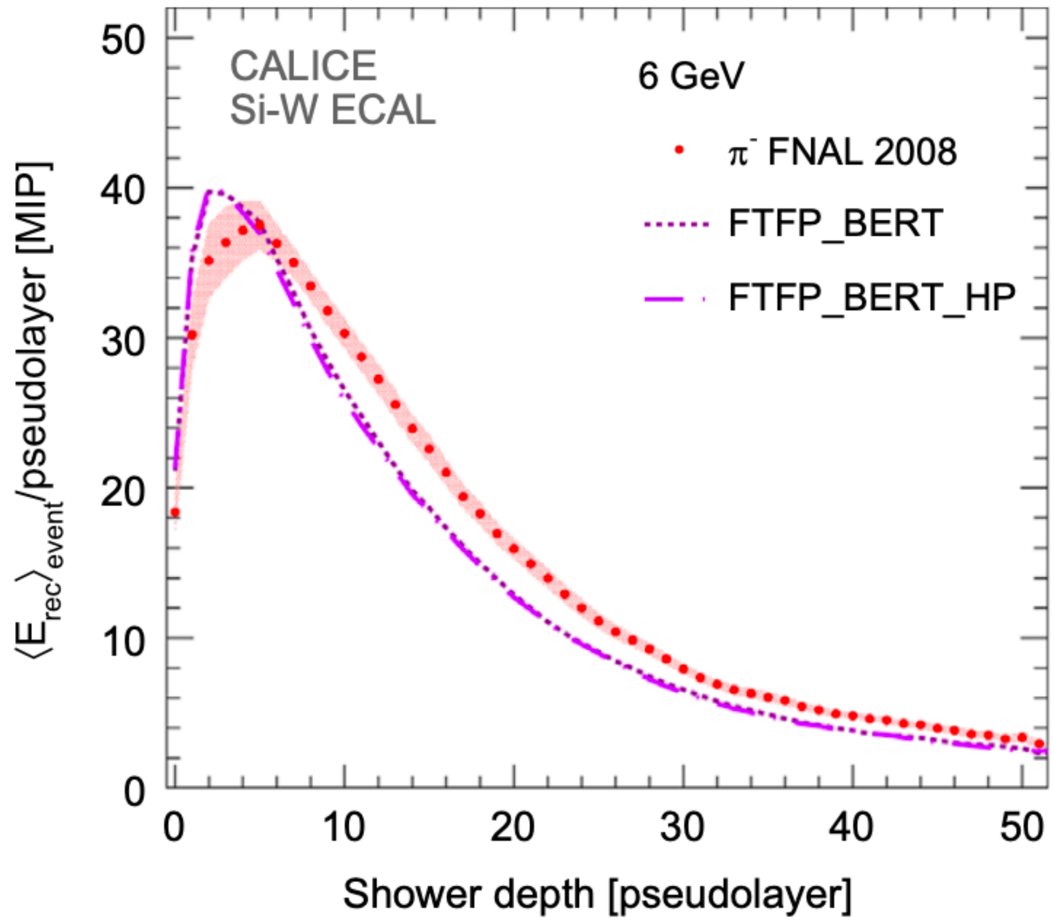
Geant4 Collaboration 2022



Longitudinal energy distribution - PL comparison

6 GeV π^-

CALICE 2015 - Geant4.9.6 NIMA794



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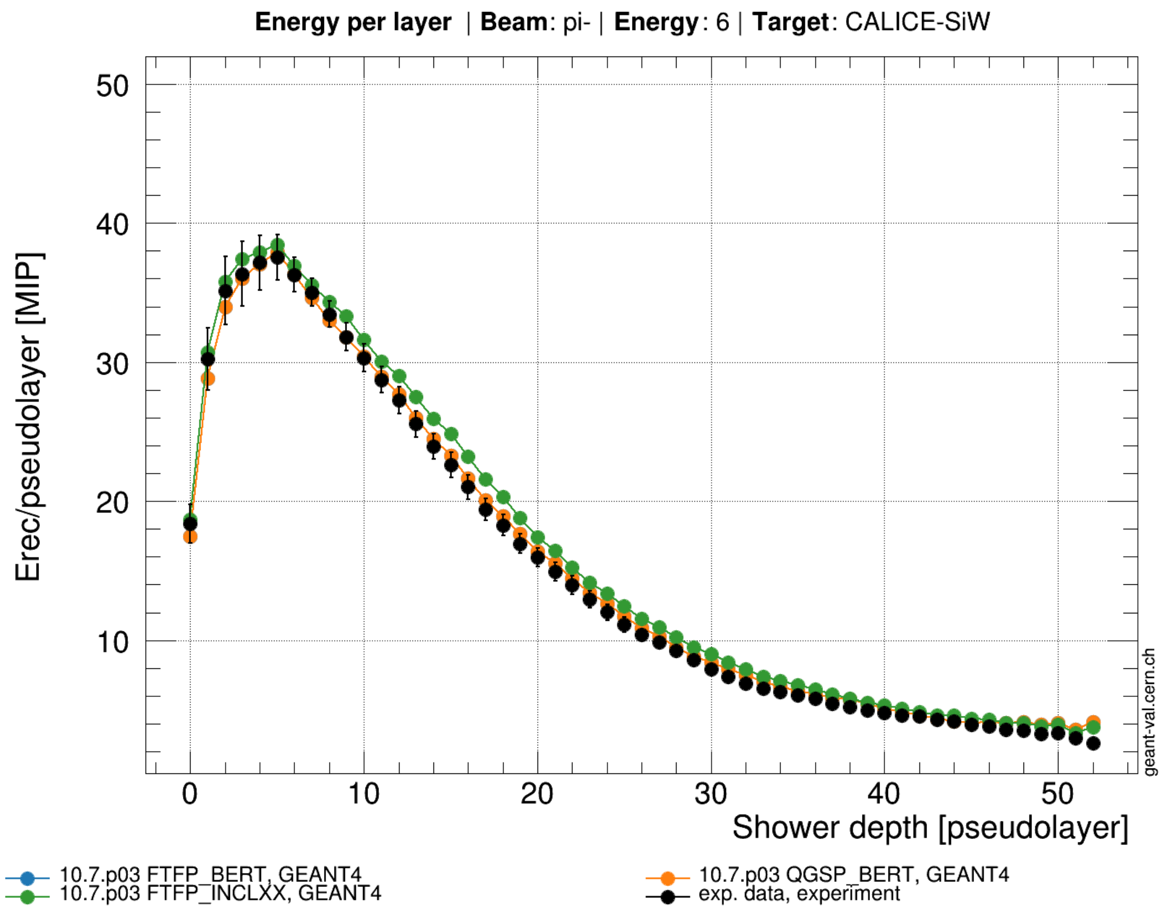
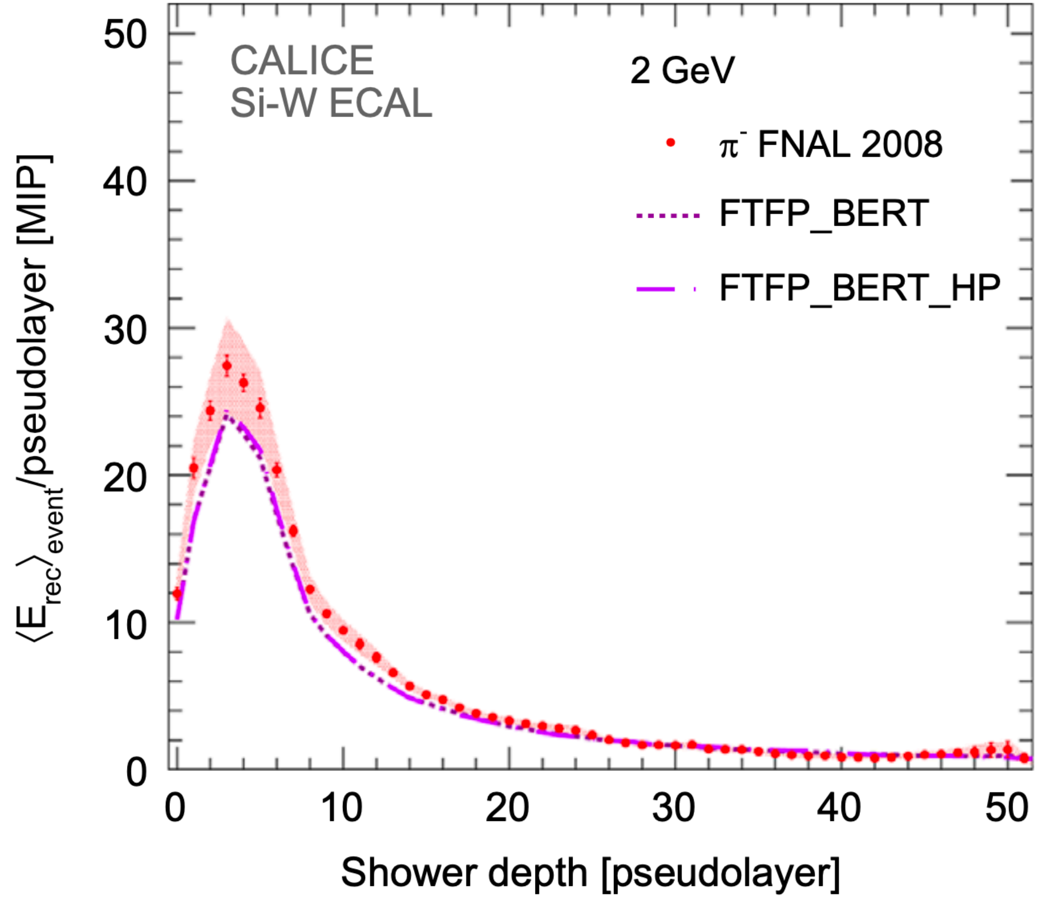


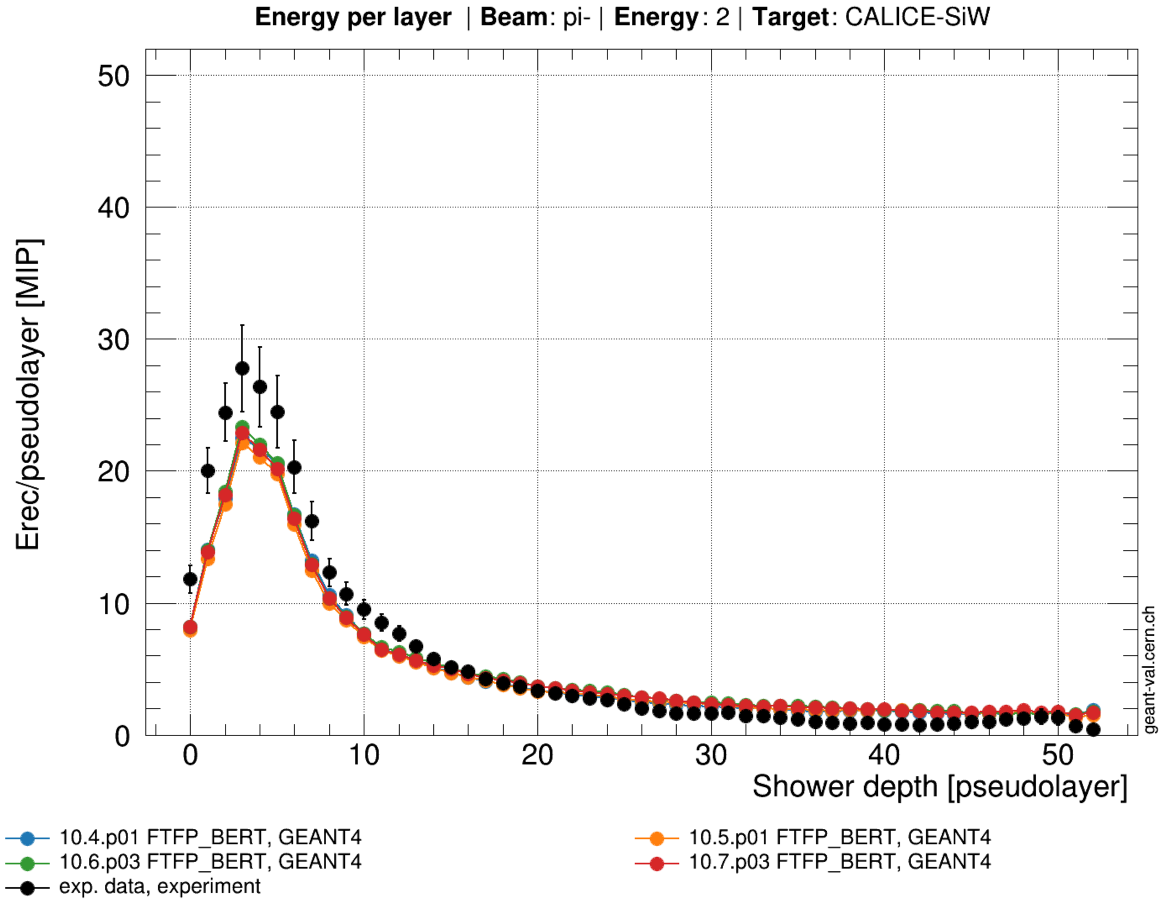
Longitudinal energy distribution - regression testing

2 GeV π^-

CALICE 2015 - Geant4.9.6 NIMA794



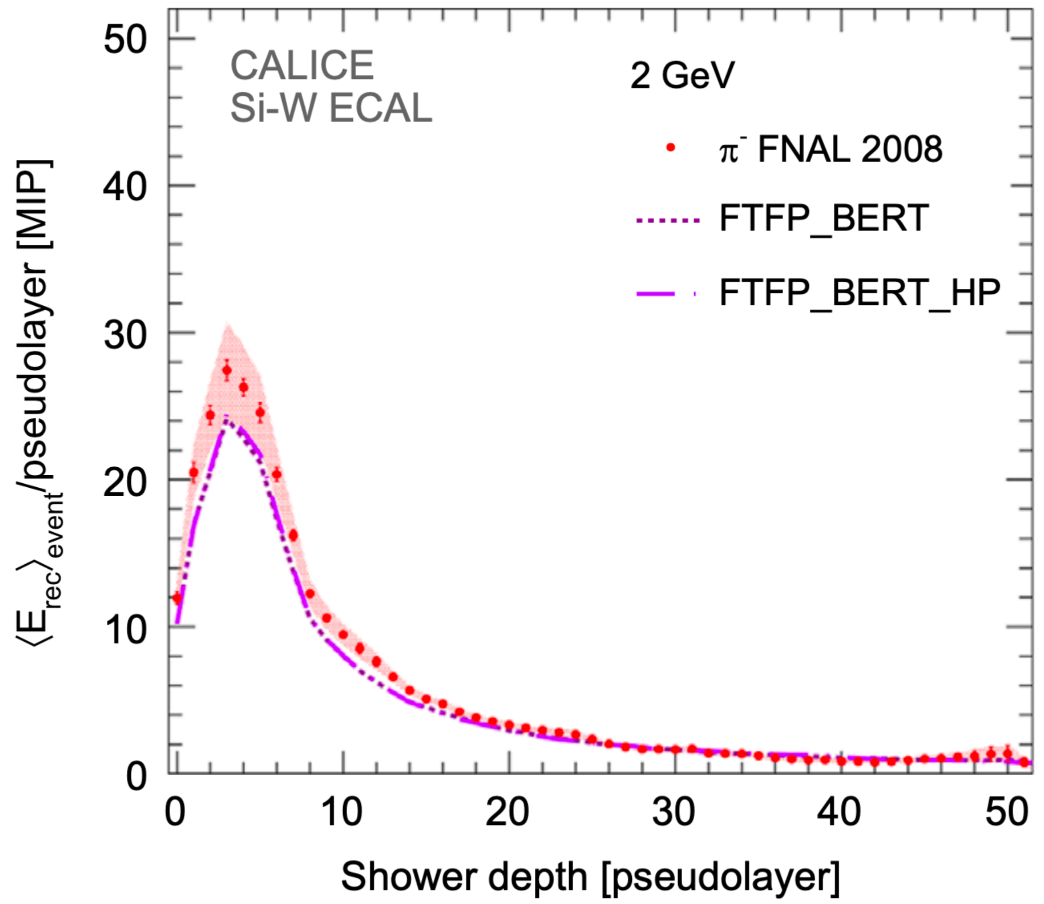
Geant4 Collaboration 2022



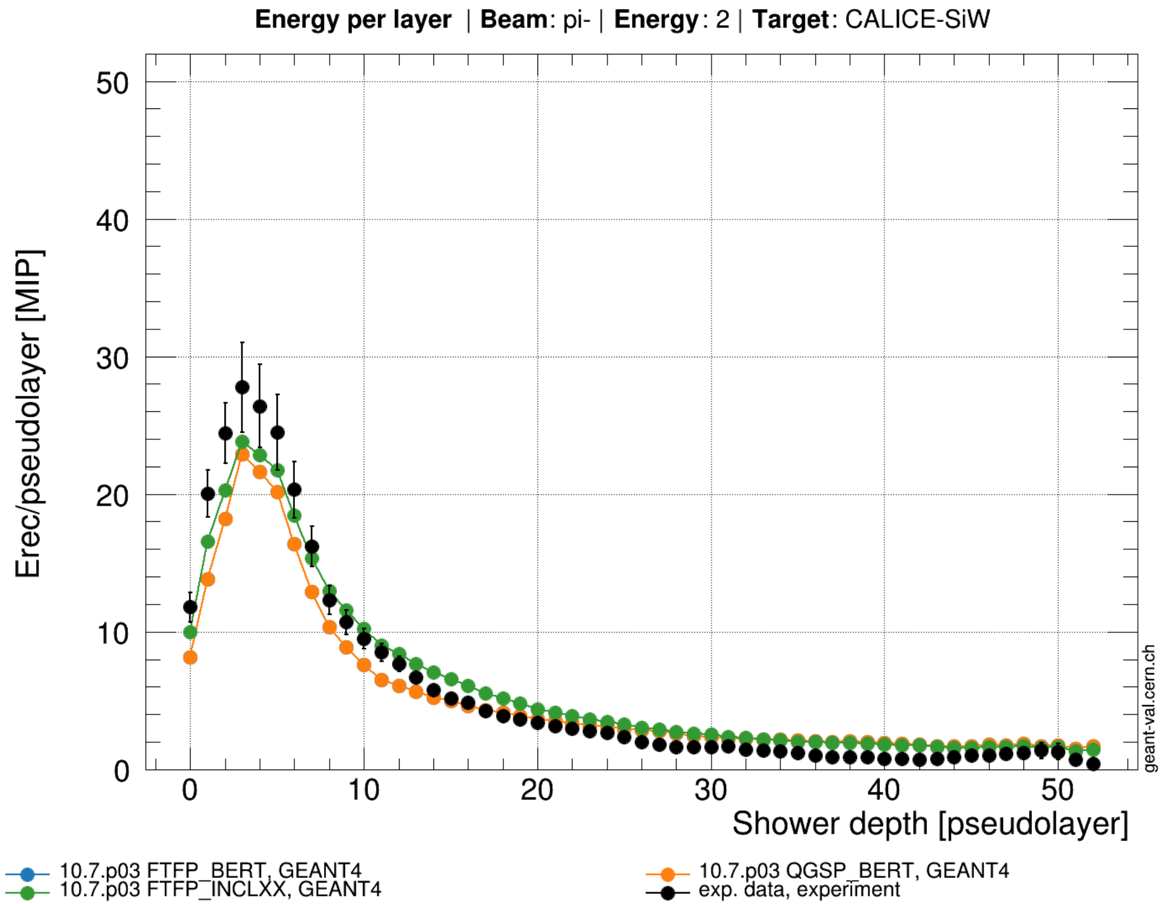
Longitudinal energy distribution - PL comparison

2 GeV π^-

CALICE 2015 - Geant4.9.6 NIMA794



Geant4 Collaboration 2022 - Geant4.10.7.p03



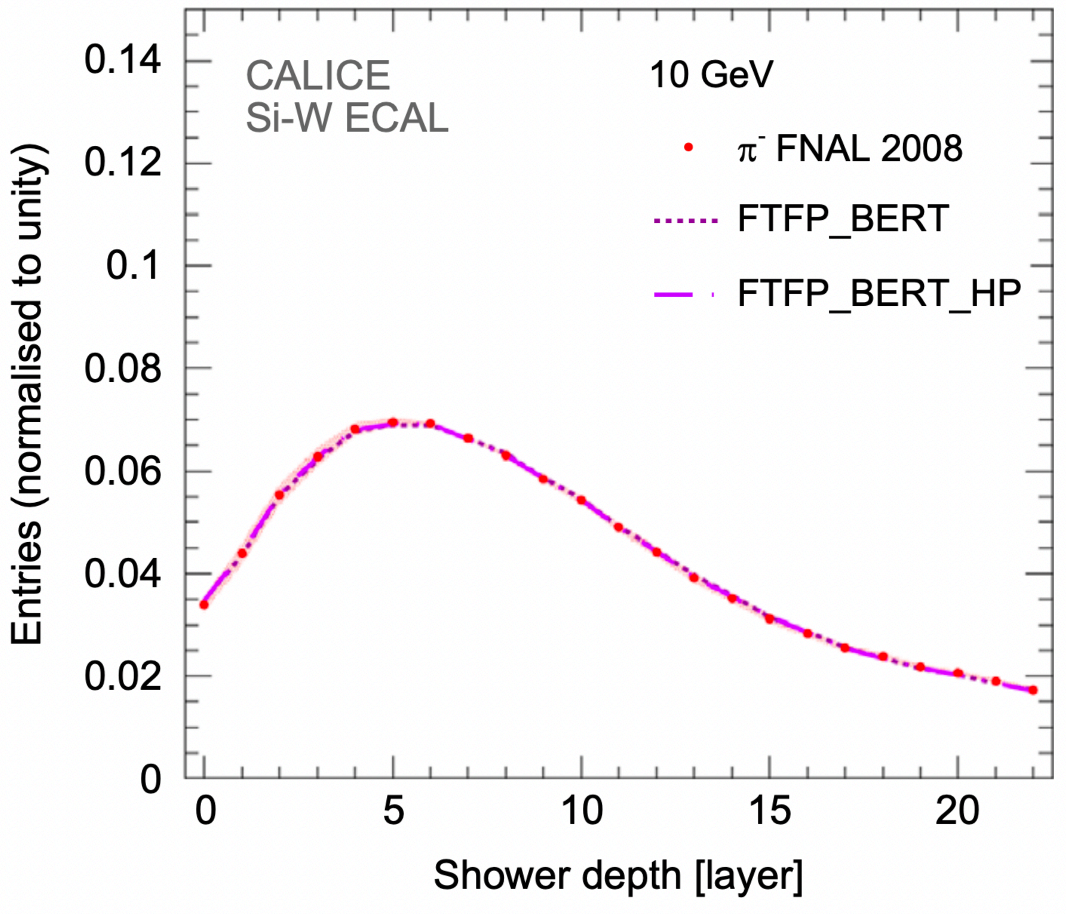
Longitudinal hit distributions

Geant4 regression testing and physics lists comparison

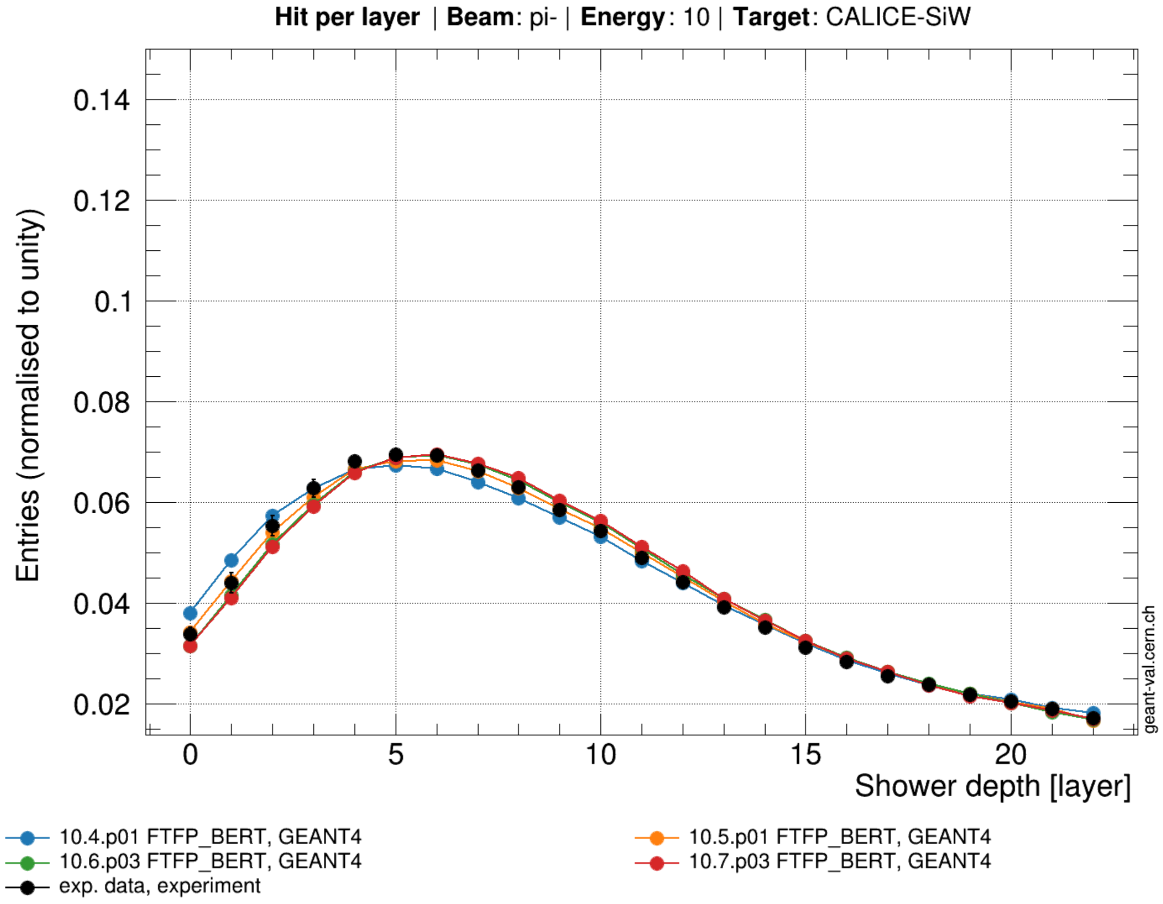
Longitudinal hit distribution - regression testing

10 GeV π^-

CALICE 2015 - Geant4.9.6 NIMA794



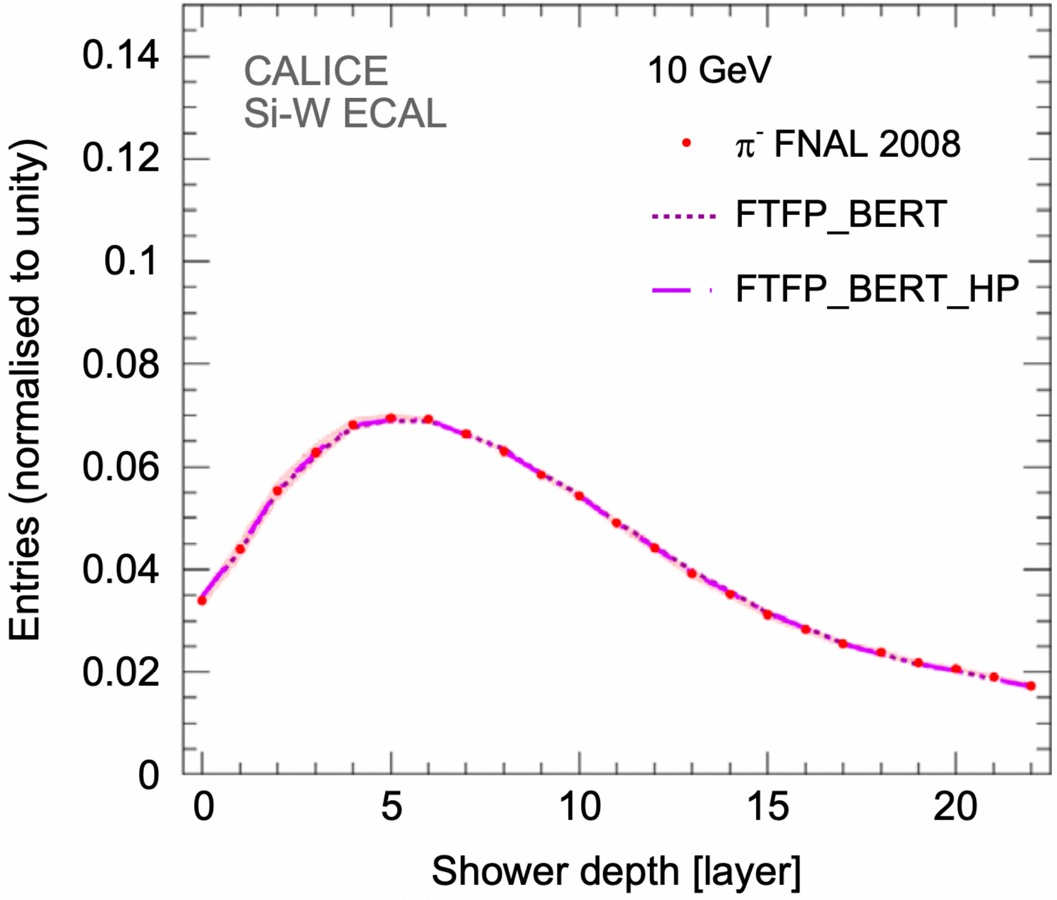
Geant4 Collaboration 2022



Longitudinal hit distribution - PL comparison

10 GeV π^-

CALICE 2015 - Geant4.9.6 NIMA794



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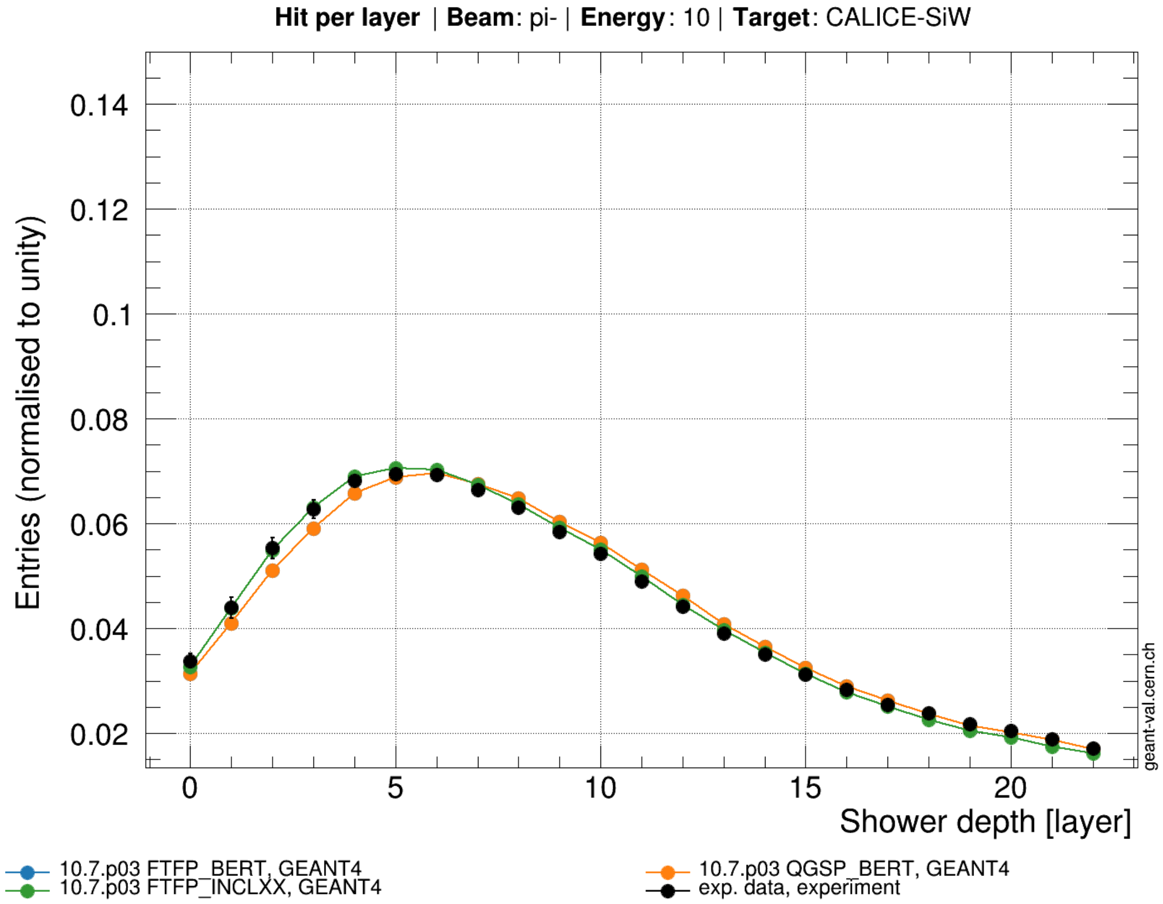

Longitudinal hit distribution - regression testing

6 GeV π^-

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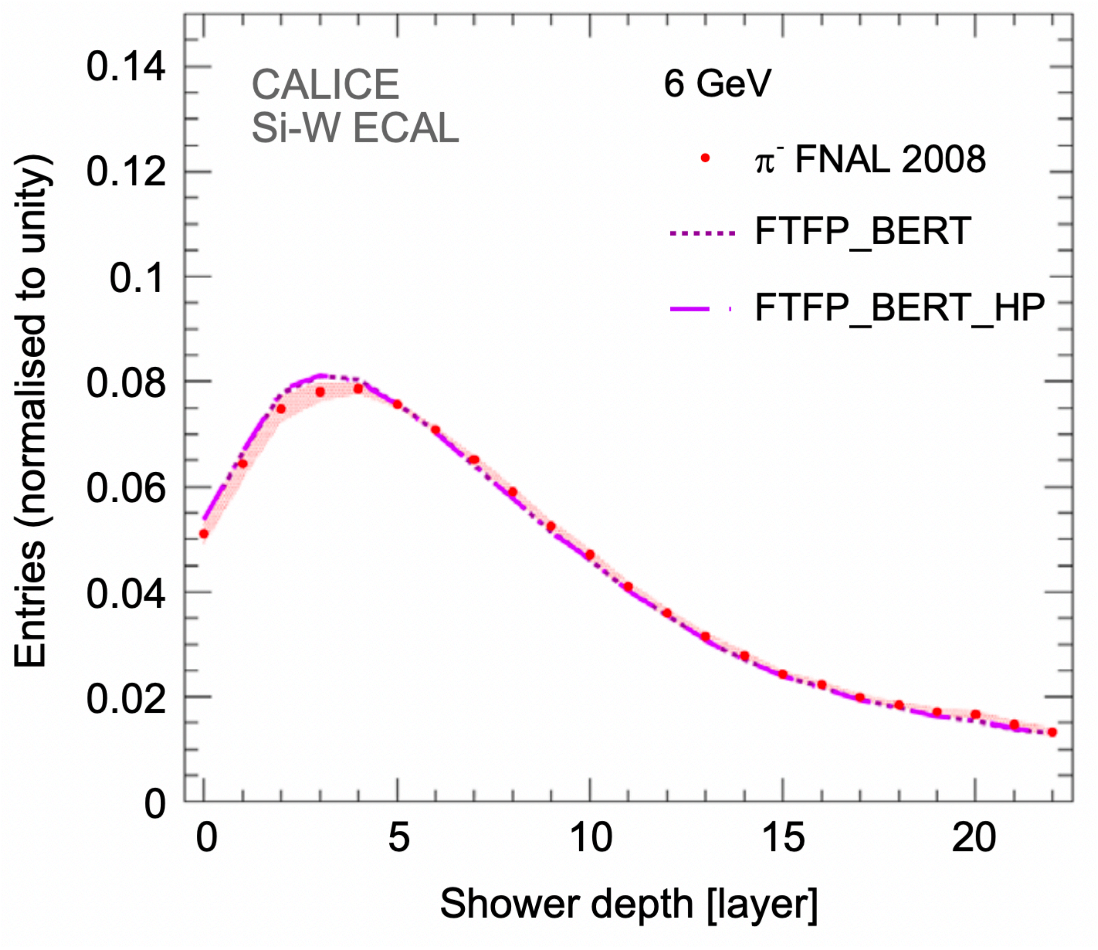

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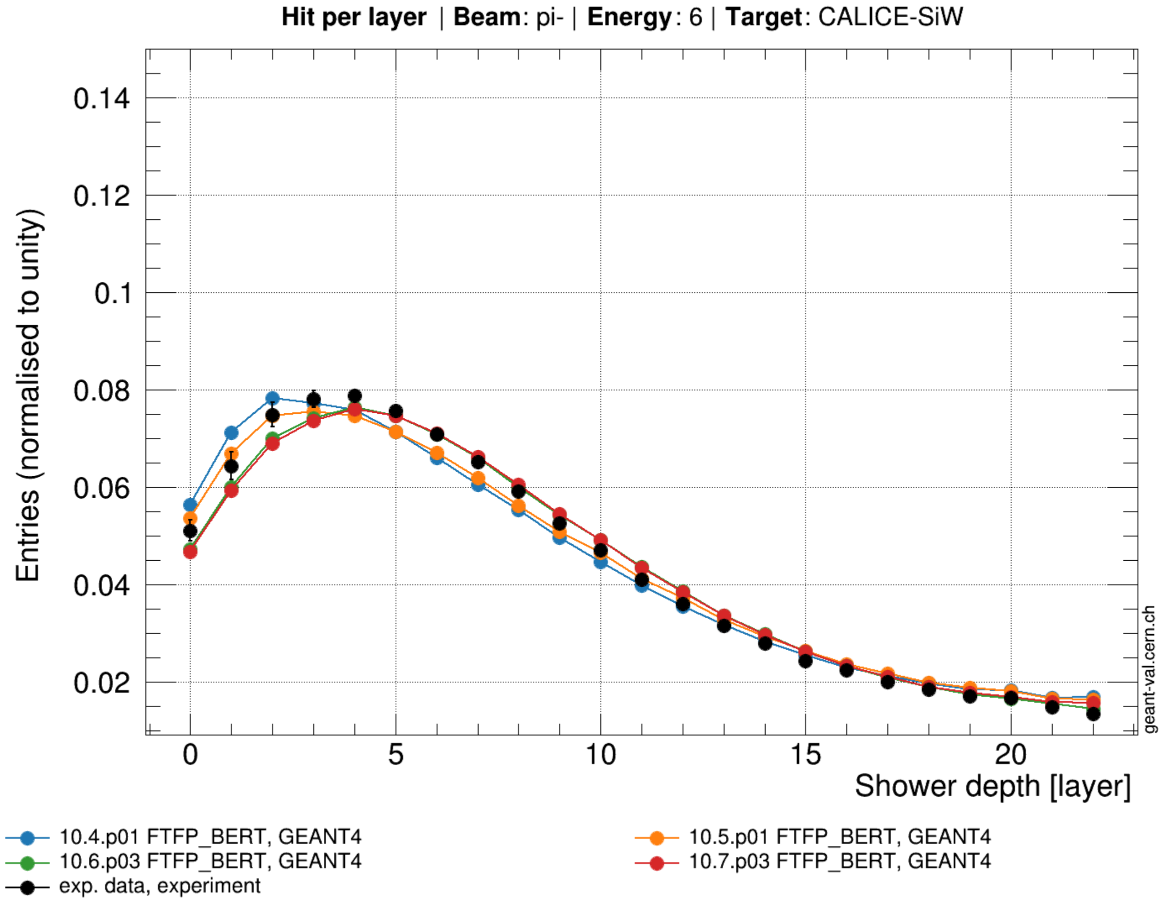

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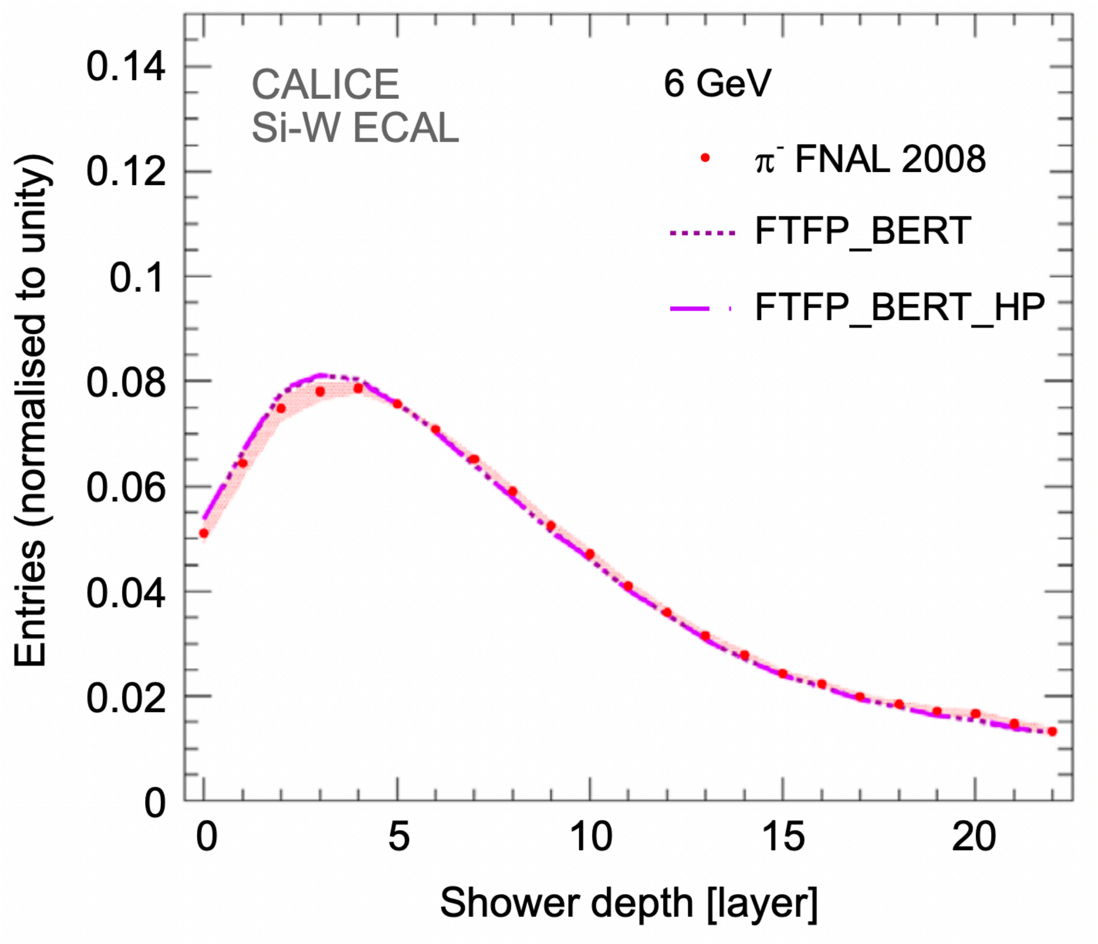

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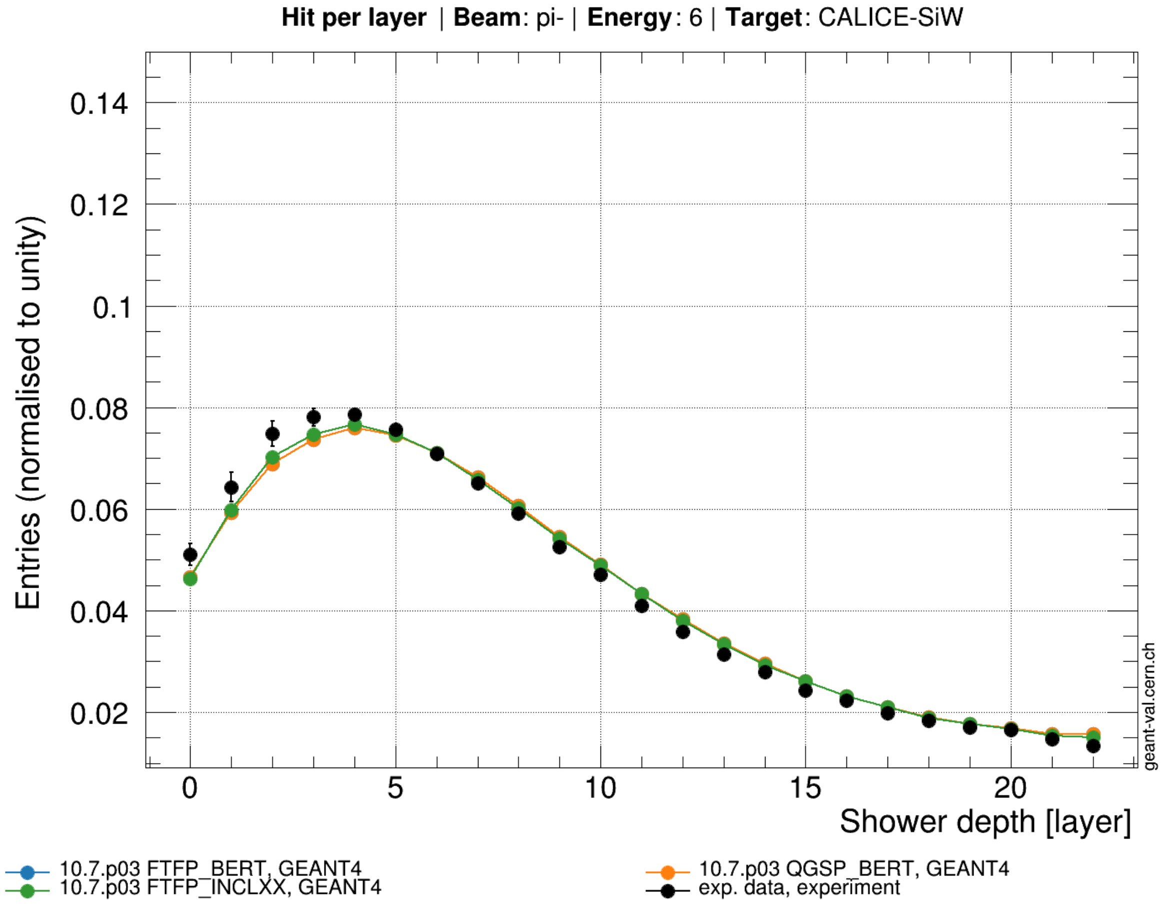

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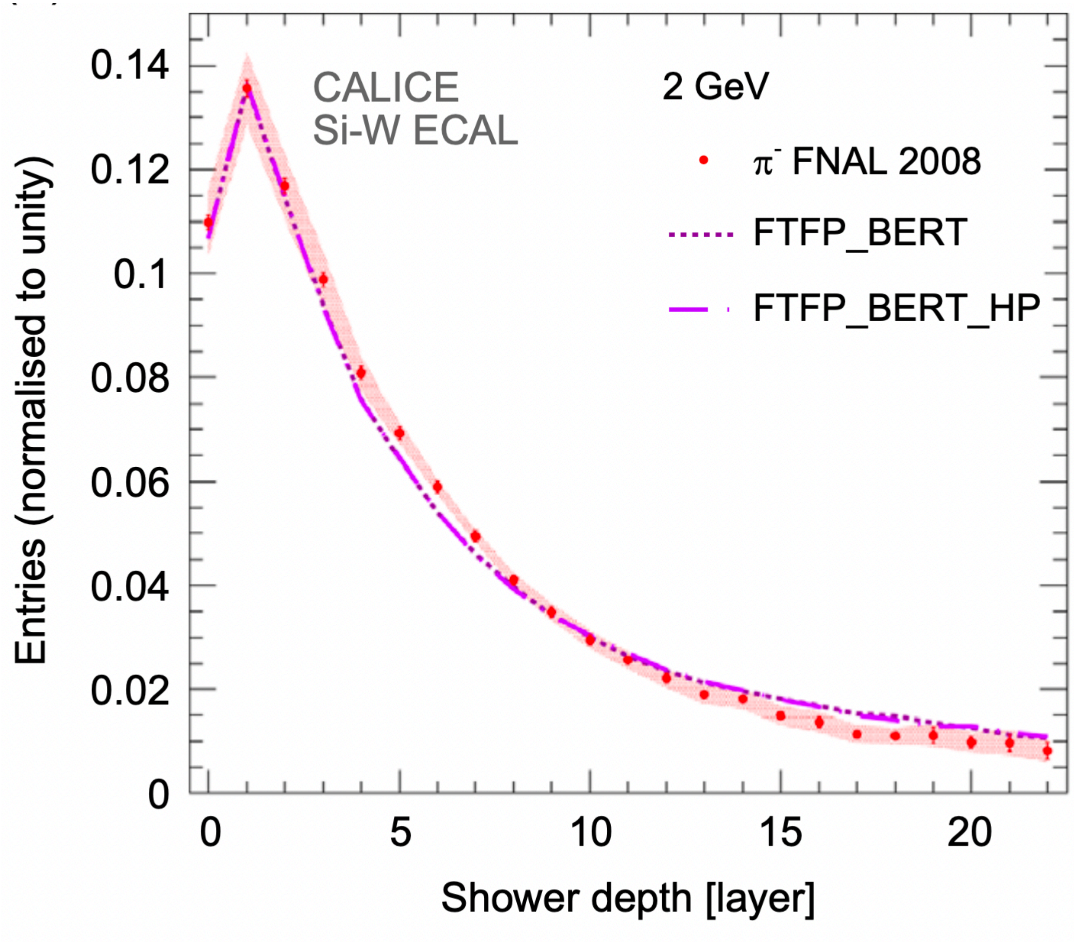
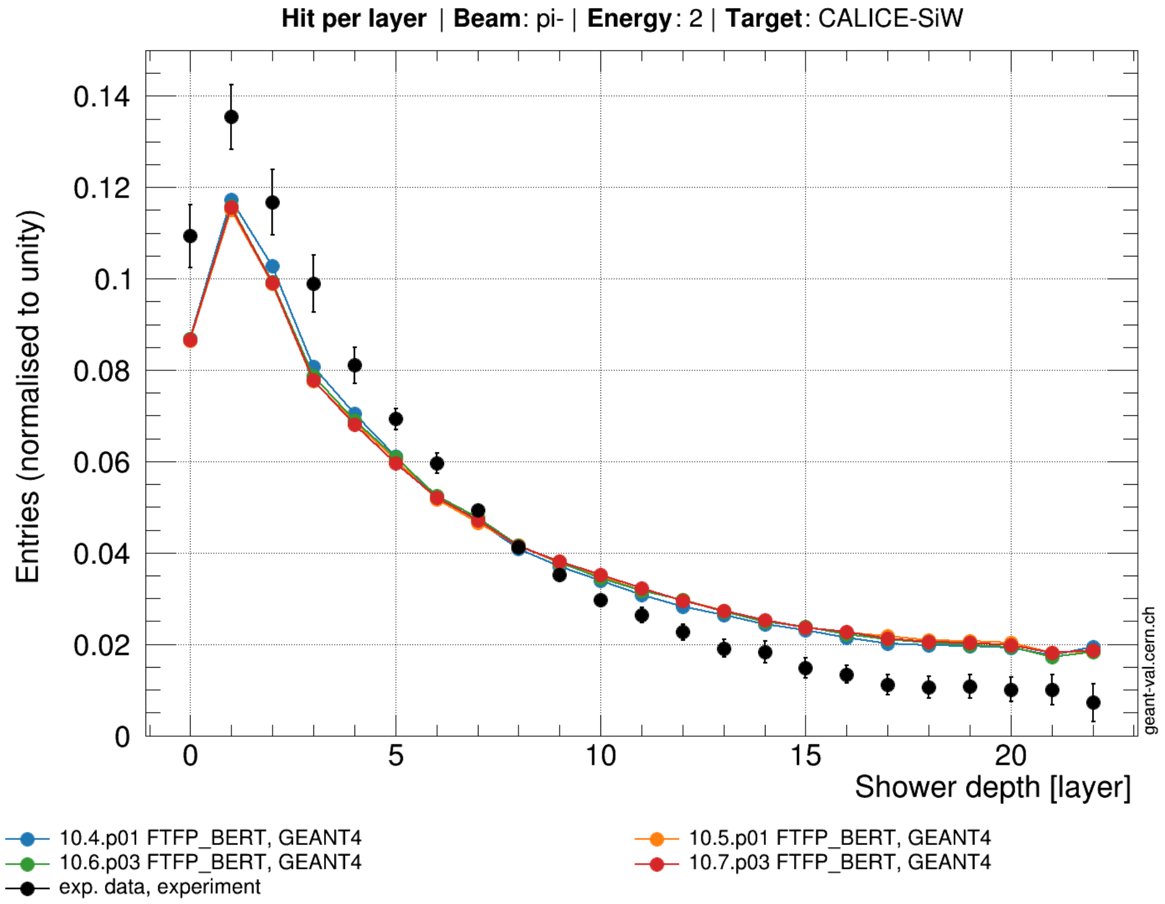


Geant4 Collaboration 2022



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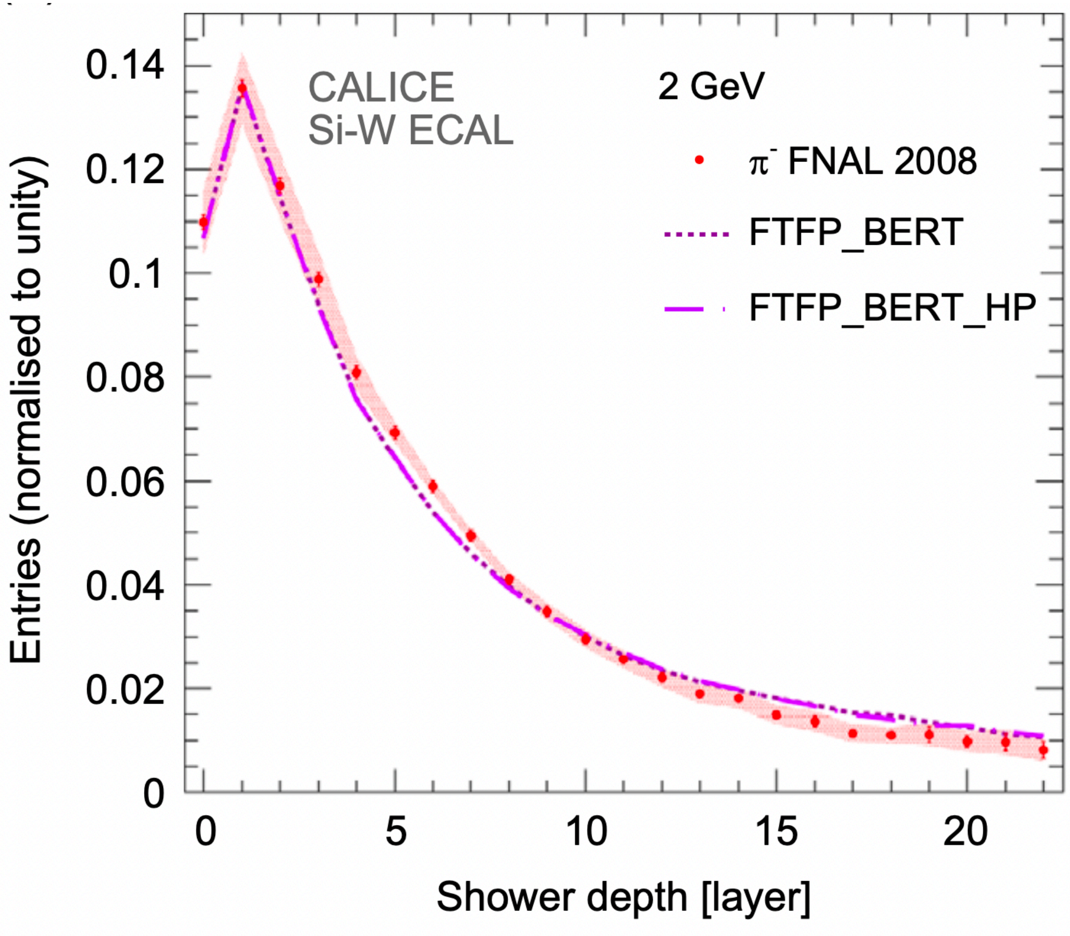

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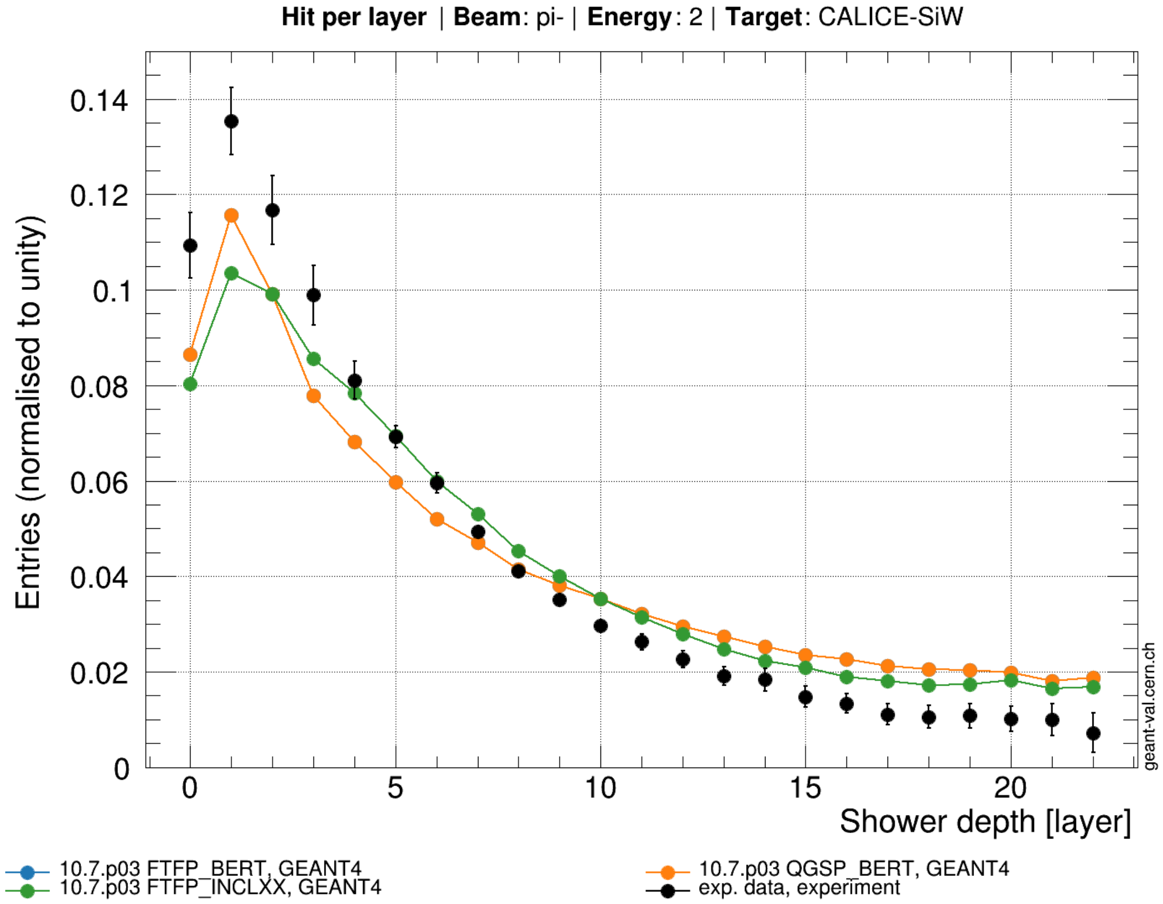

Conclusions and take home

- Geant4 validation:
  - Geant4 needs experiments and experiments need Geant4.
    → A new validation program targeting test beam results is ongoing thanks to the collaboration with ATLAS, CALICE and the Dual-Readout Calorimetry Communities.
  - CALICE is a key player: highly-granular calorimeters provide unprecedented possibilities to study shower shapes. Variables less dependent on digitization aspects are usually preferred (but not always).
  - We offer full support for results development on the Geant-val testing suite. We believe it is the best way to ensure the long term maintenance of Geant4 tests.
    → Most important for us to be able to test new Geant4 releases, pre-releases and models optimization on well established data.
- The CALICE SiW test-beam simulation:
  - A recent simulation of the CALICE SiW 2008 test beam shows nice improvement with respect to 2015 investigations.
    → It provides a good example of how to migrate CALICE-like simulation to standalone Geant4 code and to integrate it into Geant-val. See also the [geant-val-documentation].
- We are willing to collaborate with CALICE on past and future test beam simulations in the most effective way possible (lorenzo.pezzotti@cern.ch - Alberto.Ribon@cern.ch).