Hadronic Highlights of G4 10.5

Alberto Ribon
CERN PH/SFT

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Hadronic Data Sets

- New :
  - G4PARTICLEXS**1.1** (mandatory for FTFP_BERT)
    - replaces G4NEUTRONXS2.0 ; pointed by **G4PARTICLEXSDATA**
  - G4INCL**1.0**
    - new, needed only by INCLXX ; pointed by **G4INCLDATA**
- Updated :
  - G4SAIDDATA**2.0** (mandatory for FTFP_BERT)
  - PhotonEvaporation**5.3** (mandatory for FTFP_BERT)
  - RadioactiveDecay**5.3**
- Unchanged :
  - G4ENSDFSTATE**2.2** (mandatory for FTFP_BERT)
  - G4NDL**4.5**
  - G4ABLA**3.1**
  - G4TENDL**1.3.2**

String models (1/3)

- For both **FTF** (Fritiof) & **QGS** (Quark Gluon String)
  - Released the latest version - developed since G4 10.2 but not included in 10.3 and 10.4, to keep hadronic showers stable
    - Note that snapshots of these developments have been made available in previous beta releases: G4 10.3.beta, 10.4.beta and 10.5.beta
    - Development driven to improve the desciption of thin-target data
    - No problems found in the π° production which could explain the observed higher energy response of hadronic showers in calorimeters
    - Reviewed Birks quenching : inconsistent use of Birks coefficient taken from publications where no-delta-ray emissions were assumed...
  - First implementation of alpha cluster structure of carbon nuclei (affecting only h − C interactions)

String models (2/3)

- **FTF** (Fritiof) model
  - New **tuning** of the model parameters, for both string formation and string fragmentation
  - Introduced smearing of delta-isobar mass and improved di-quark fragmentation into baryons in Lund string fragmentation
  - First implementation of **rotating strings**, at the level of string fragmentation, with introduction of Mt distribution of hadrons
  - Improved process probability parameterizations for **π-nucleon** interactions; corrected calculation of nuclear residual excitation energy

String models (3/3)

- **QGS** (Quark Gluon String) model
  - Major revision of the **final-state model** :
    implemented Reggeon cascading and "Fermi motion";
    new algorithm for the determination of the kinematical properties of partons; improved formation of the residual nucleus
  - Improved cross-sections of K-meson - nucleon interactions in QGS: Pomeron and 2 non-vacuum exchanges are taken into account
  - Gamma-nucleon cross sections are improved by parameter tuning
  - Improved **string fragmentation** : new algorithm for last string decay *a-la* Lund; refined algorithm to stop the fragmentation
  - **Tuning** the parameters related to both string formation and string fragmentation to improve the description of thin-target data

Intra-nuclear Cascade models

- Bertini-like (BERT)
  - Extended strange pair production channels to multibody final states
    - 6,7,8 and 9 bodies
  - A few important fixes (affecting the physics results)
- Binary (BIC)
  - Stable, no developments
- Liege (INCLXX)
  - Improved strangeness and the few-nucleon-removal
  - Fixed various bugs
  - New data-set : G4INCL**1.0**

Precompound / de-excitation models

- Coherent use of the same parameterisation of level density and pairing correction between all models in de-excitation and precompound
- Several code improvements
- New data-set : PhotonEvaporation**5.3**

Radioactive Decay model

- Improved electron capture
- New data-set : RadioactiveDecay**5.3**

ParticleHP & LEND models

- Bug fixes, no new development

Others

- ABLA
  - Extended to hypernuclei
  - Can be used as an alternative de-excitation model for INCLXX
- Elastic scattering
  - Extended the high-energy applicability of G4DiffuseElastic and G4NuclNuclDiffuseElastic up to 100 TeV
- *"Extensions"*
  - Made easier to change the high-energy limit of applicability of hadronic physics (which is still 100 TeV by default)
    - Requested by a cosmic ray experiment (DAMPE)
  - Possible to run Geant4, in the whole energy range of applicability, for transuranic elements
    - Interest from an ADS (Accelerator Driven System) project (MYRRHA)

Cross Sections

- Replaced environment variable G4NEUTRONXSDATA with G4PARTICLEXSDATA
- Several technical improvements
- New class G4NeutrinoElectronTotXsc for total cross-section of neutrino − electron interactions
  - Neutral + charged currents
- Improved Barashenkov-Glauber-Gribov (BGG) elastic, inelastic and total cross sections
  - For pions, kaons and protons
  - In particular for Hydrogen target
  - Extended also for hyperon projectiles

Physics Lists & Validation

- For pions, FTF / QGS / INCLXX physics-lists builders use Barashenkov-Glauber-Gribov inelastic cross-section
  - Avoiding to use Gheisha cross sections for inelastic π± H
- Both QGSP_BIC_HP and QGSP_BIC_AllHP use EM Opt4
  - Instead of EM Opt0 as before
- **geant-val.cern.ch**
  - Our validation and regression testing tool which we rely on for all Geant4 releases (public, patches, development)
  - Started with the hadronic showers in SimplifiedCalo, and then extended to many other applications, such as:
    - Thin-target testing-suite for string models, cross sections, TARC, FragTest (hadron-therapy), simplified CMS ECAL+HCAL, *etc.*
    - Many EM tests : fluctuation, bremsstrahlung, electron scattering, dE/dx, multiple scattering, attenuation, Bragg peak, Fano cavity, medical physics, simplified EM calorimeters, *etc.*

Hadronic showers *(see plots in backup slides)*

- Hadronic showers in G4 **10.5** change significantly
  - Few per-cent higher energy response
  - Smaller fluctuations of energy response
  - Wider lateral shapes

  mostly due to the **development in string models** (improved description of thin-target data)

- The first two aspects (energy response – mean and fluctuations) are affected by the **Birks quenching** : we recommend a new treatment
  - Fit the Birks coefficient from the h/e test-beam data at one beam energy, arbitrarily chosen
    - See next presentation

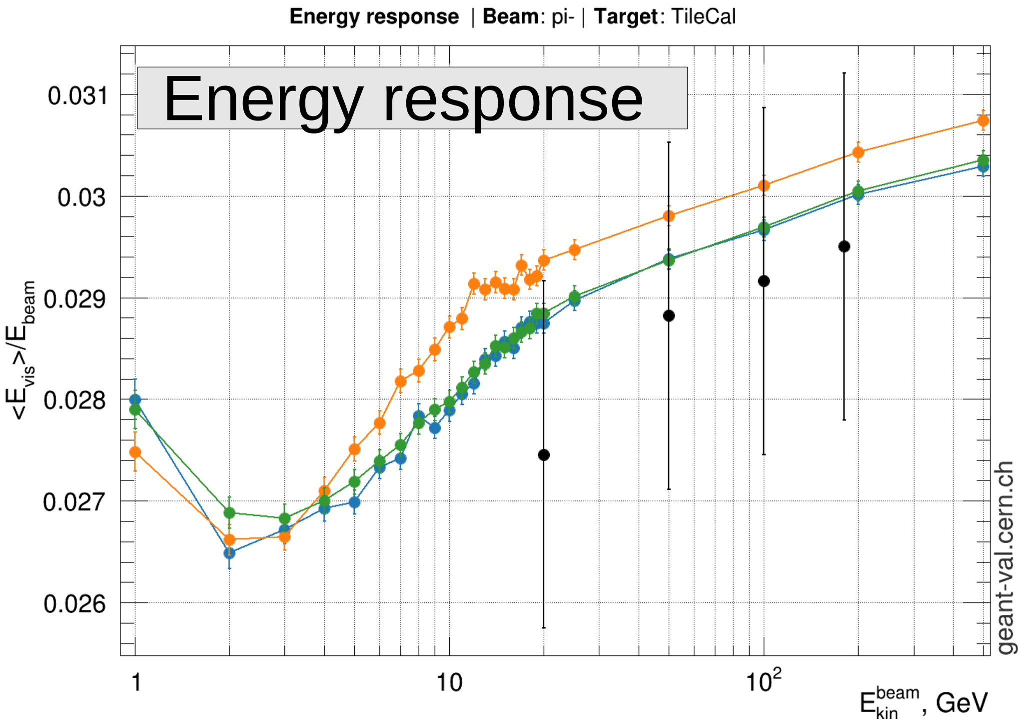
Backup slides

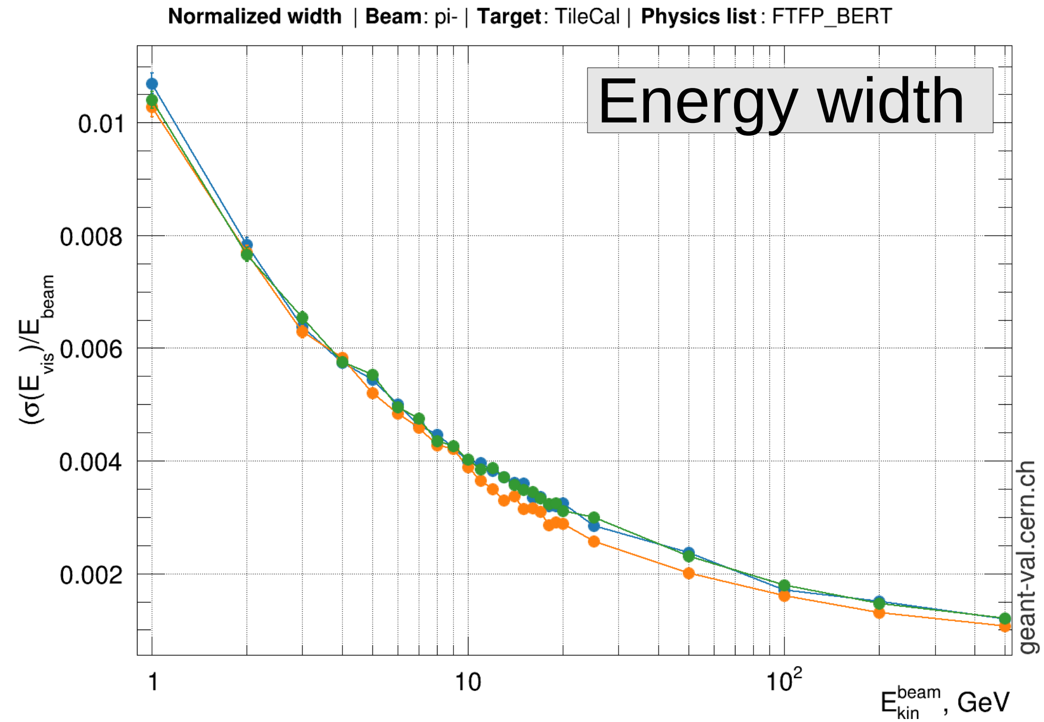
Pion showers
in Simplified Calorimeters
FTFP_BERT
Comparing G4 versions:
10.5 , 10.4.p02 , 10.3.p03

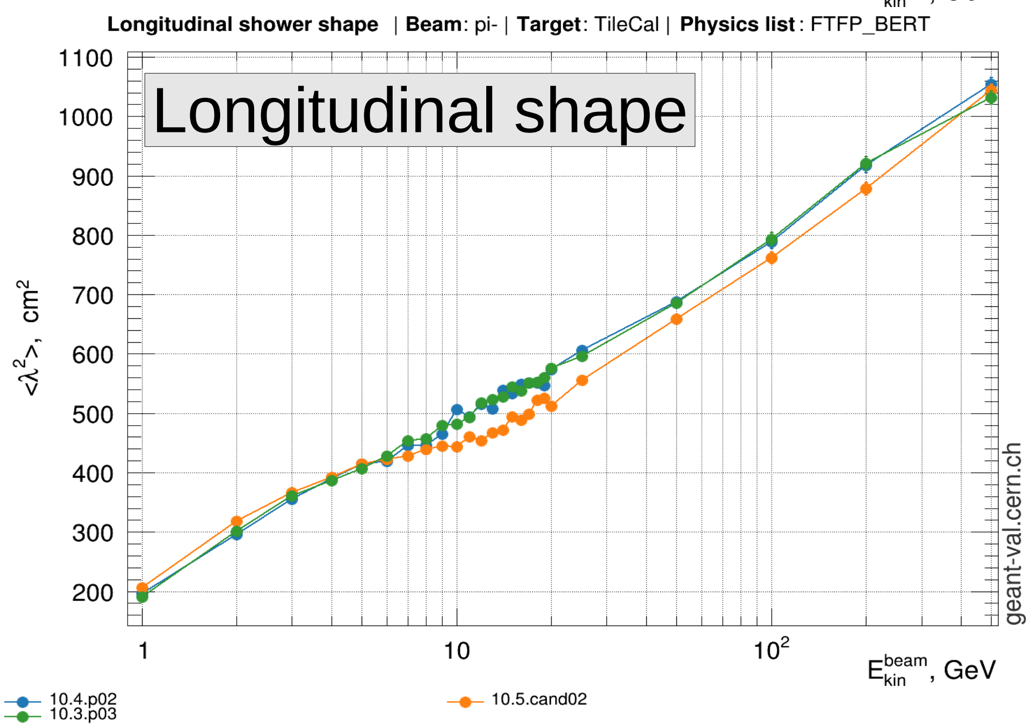
Note : conventional Birks treatment

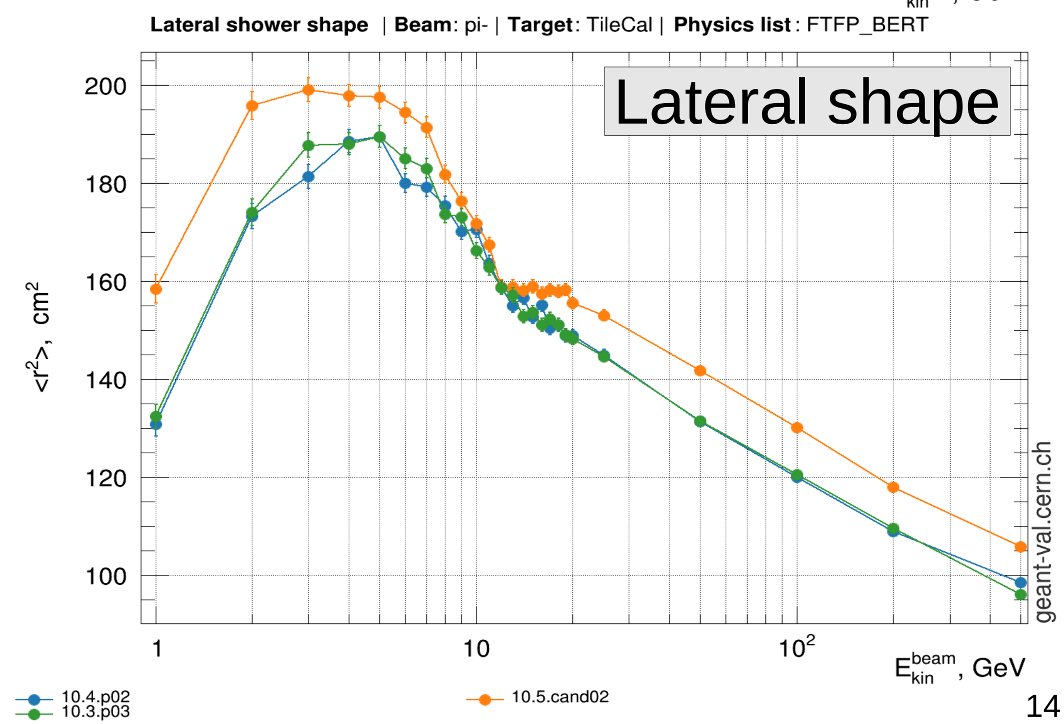
FTFP_BERT

π^- on **Fe-Sci**



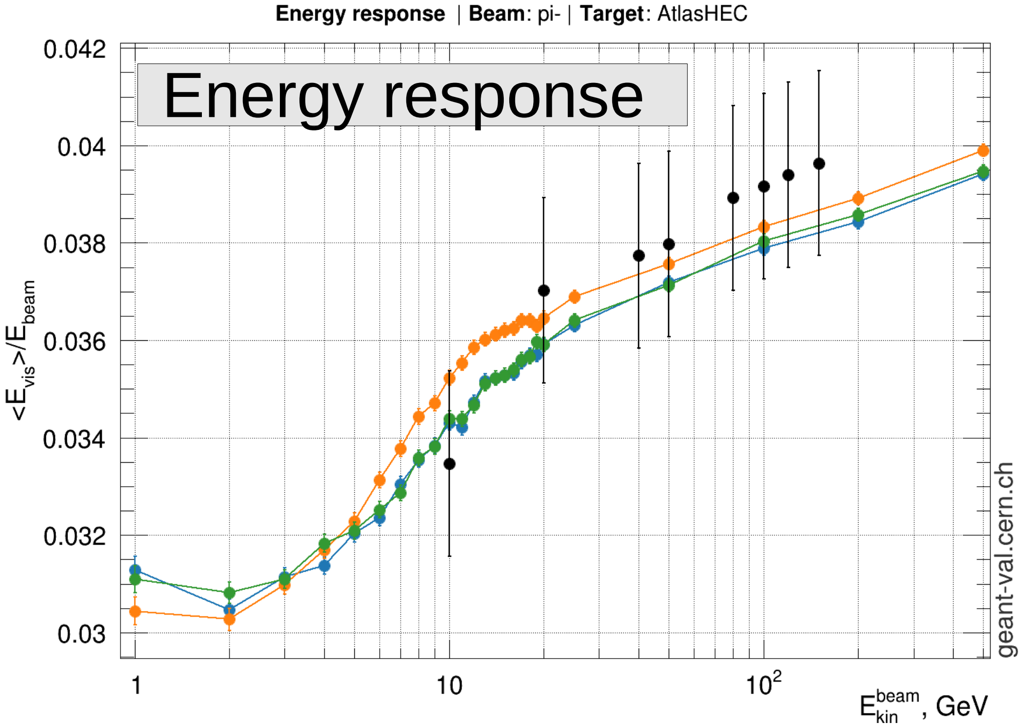


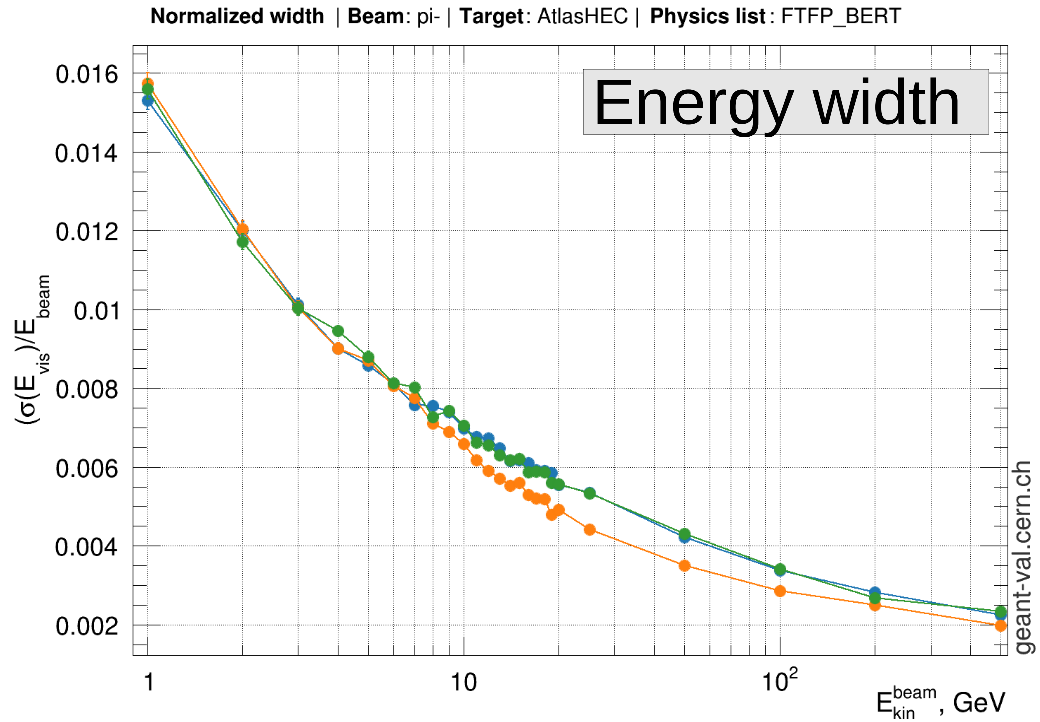


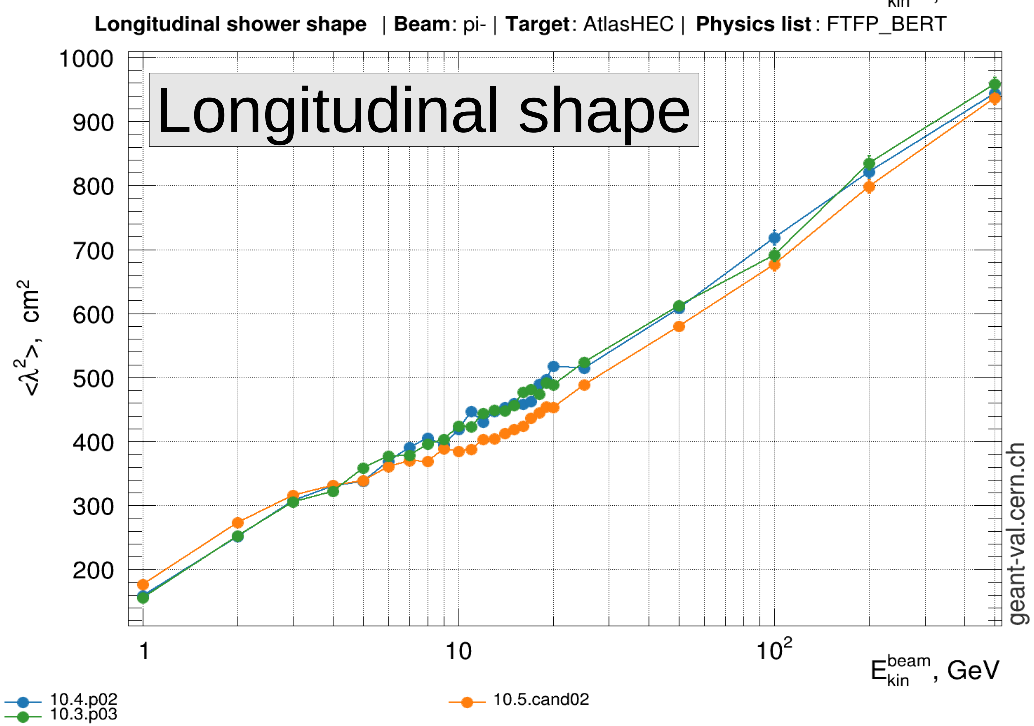


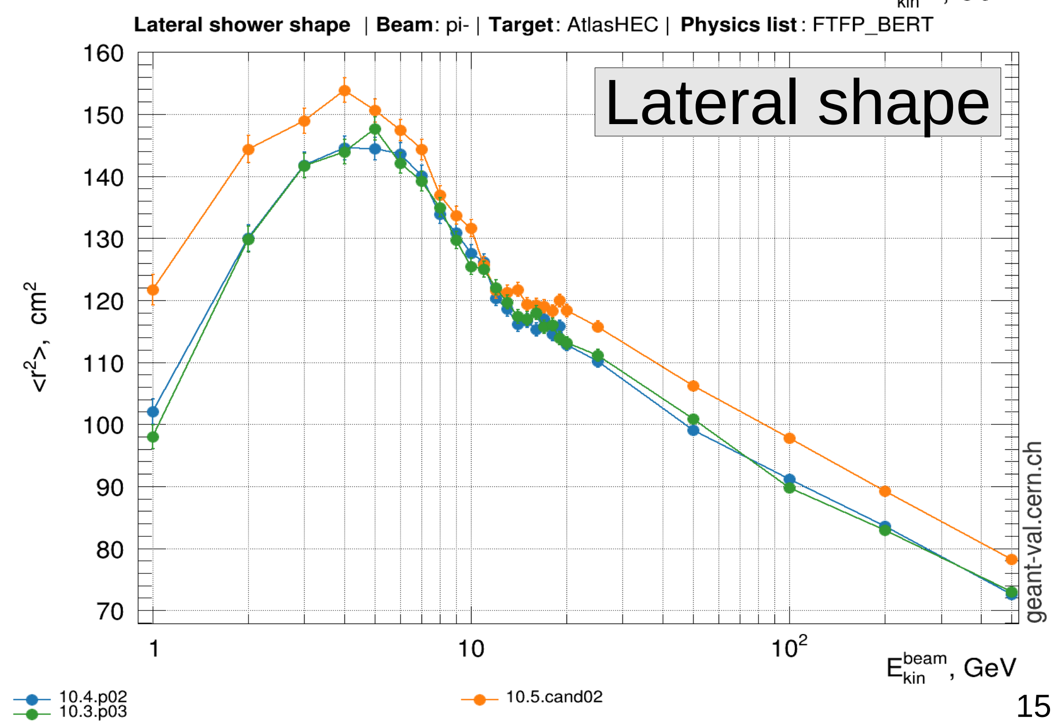
FTFP_BERT

π^- on Cu-LAr



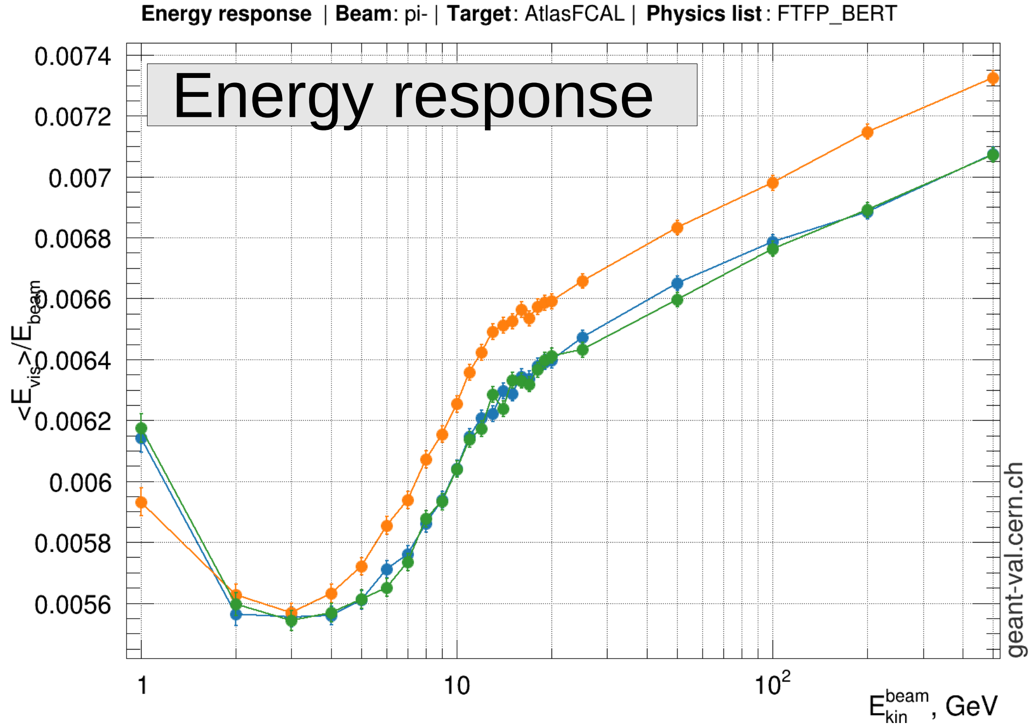


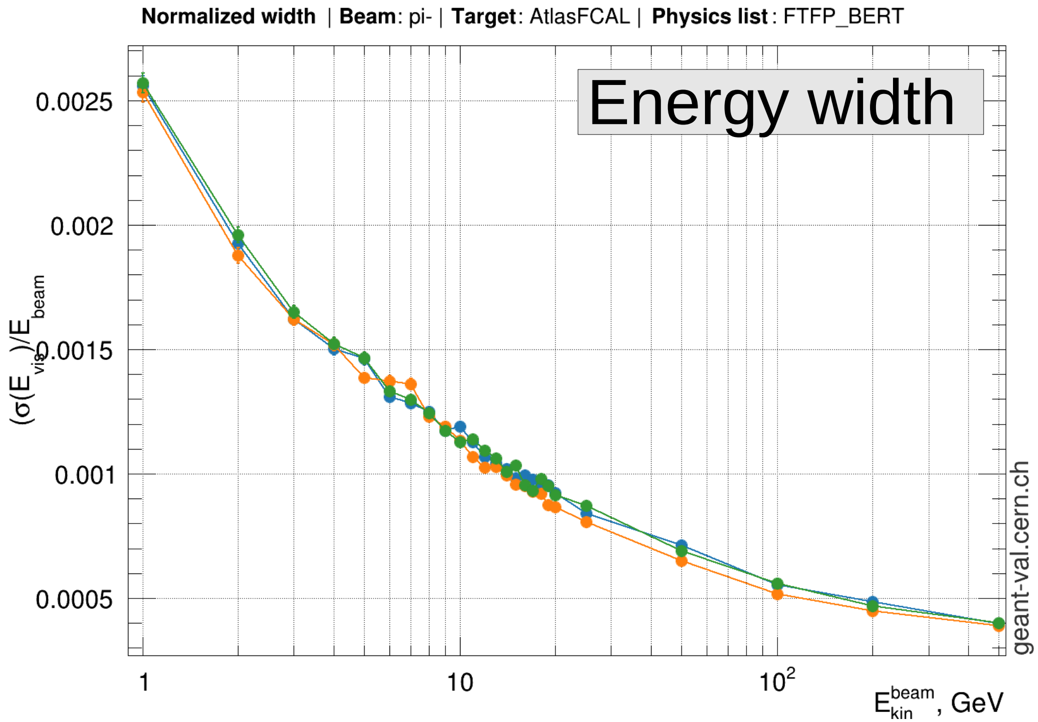


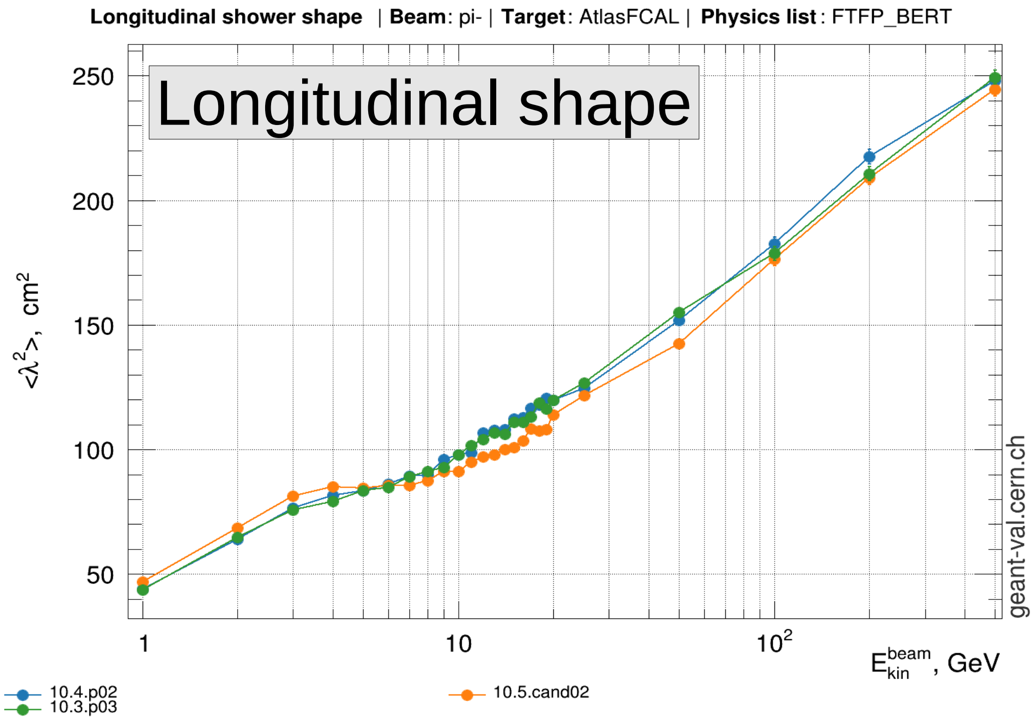


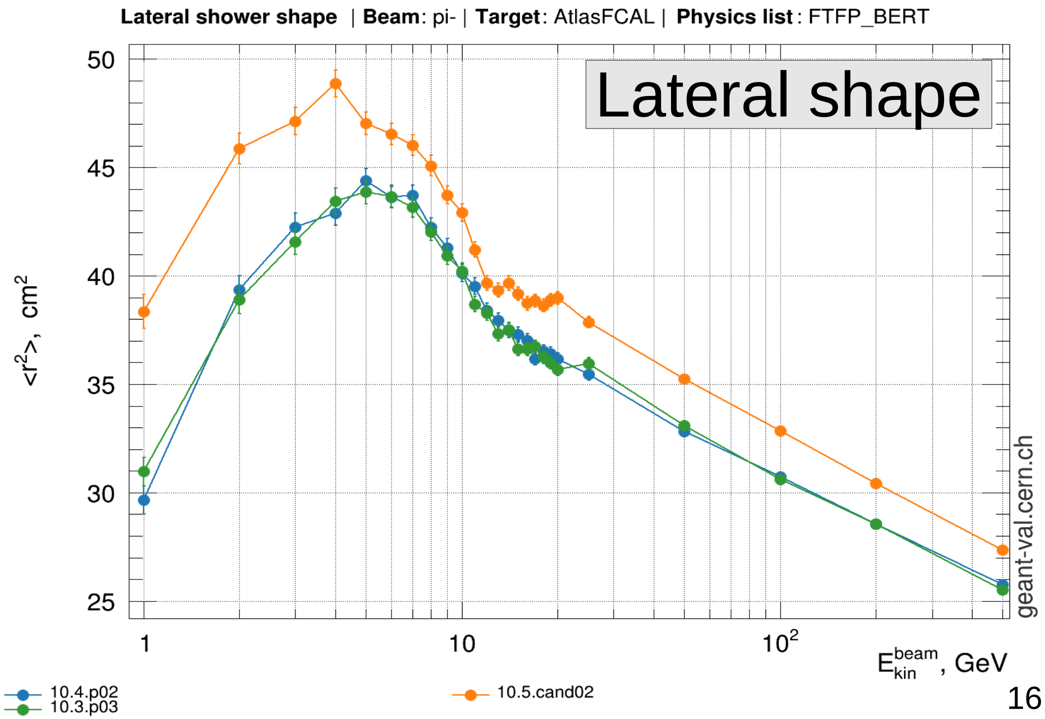
FTFP_BERT

π^- on **W-LAr**



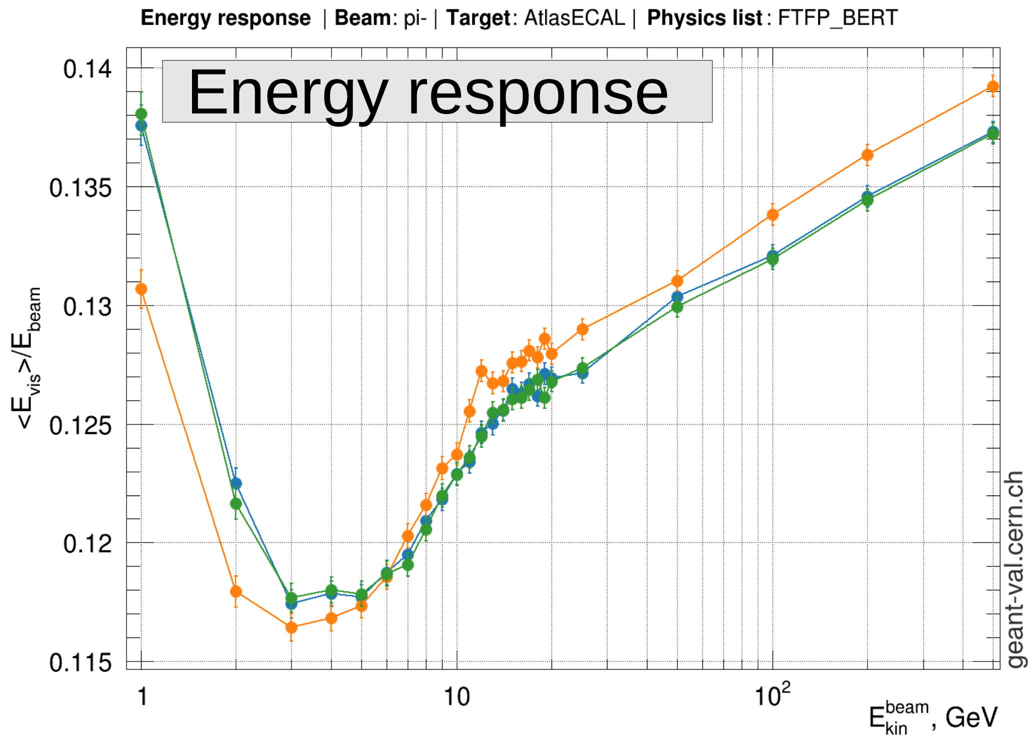


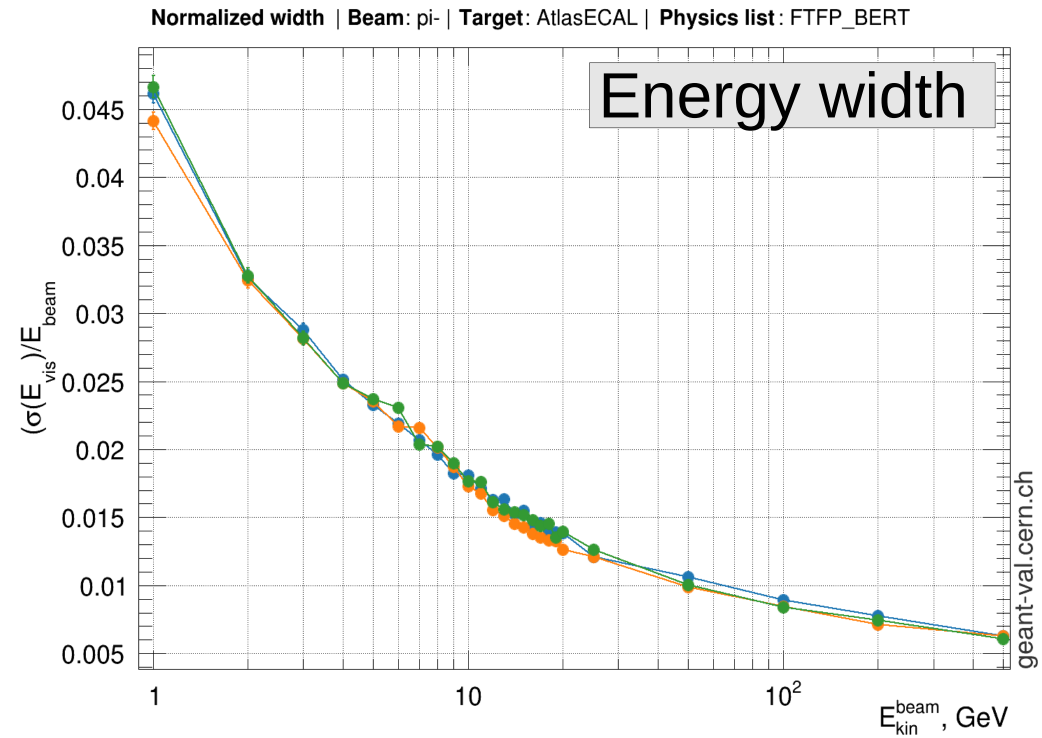


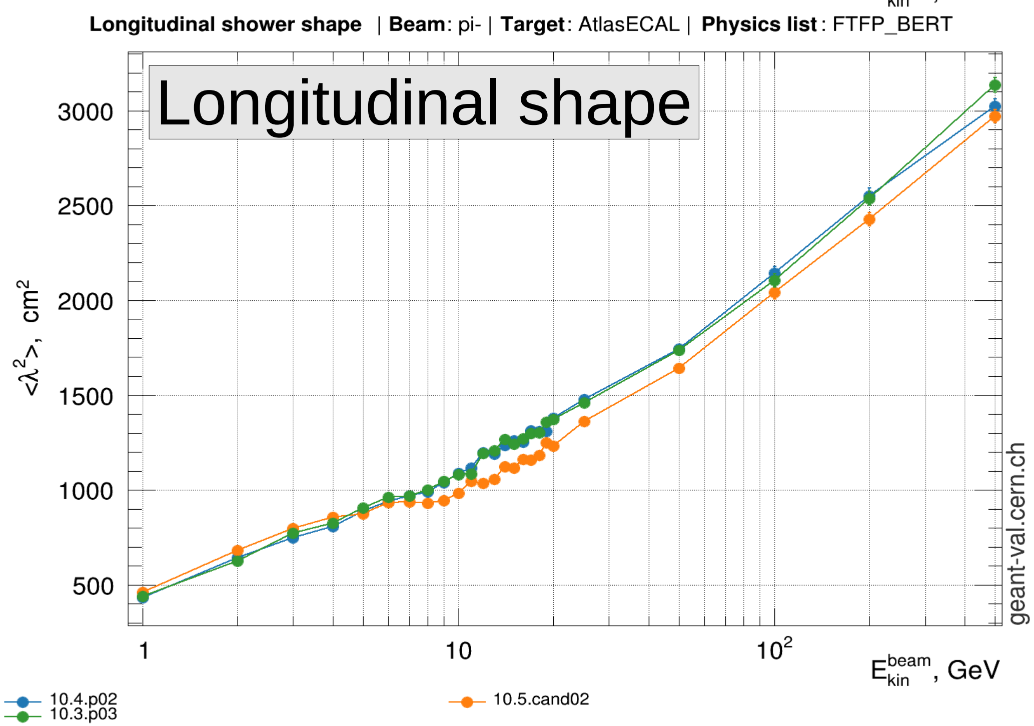


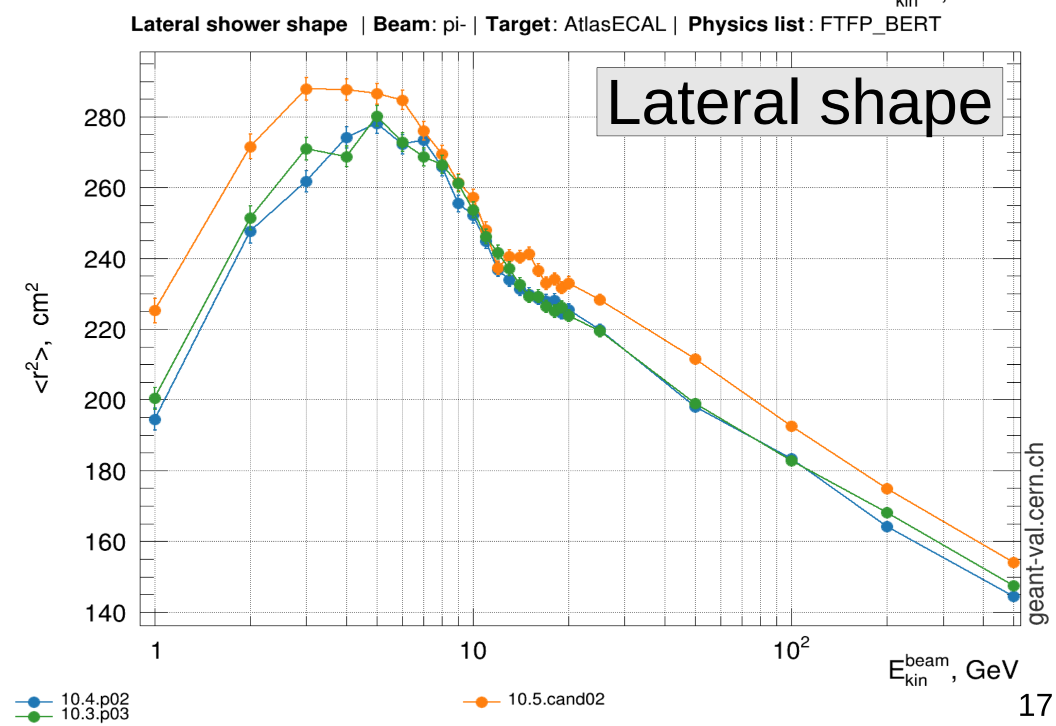
FTFP_BERT

π¯ on Pb-LAr



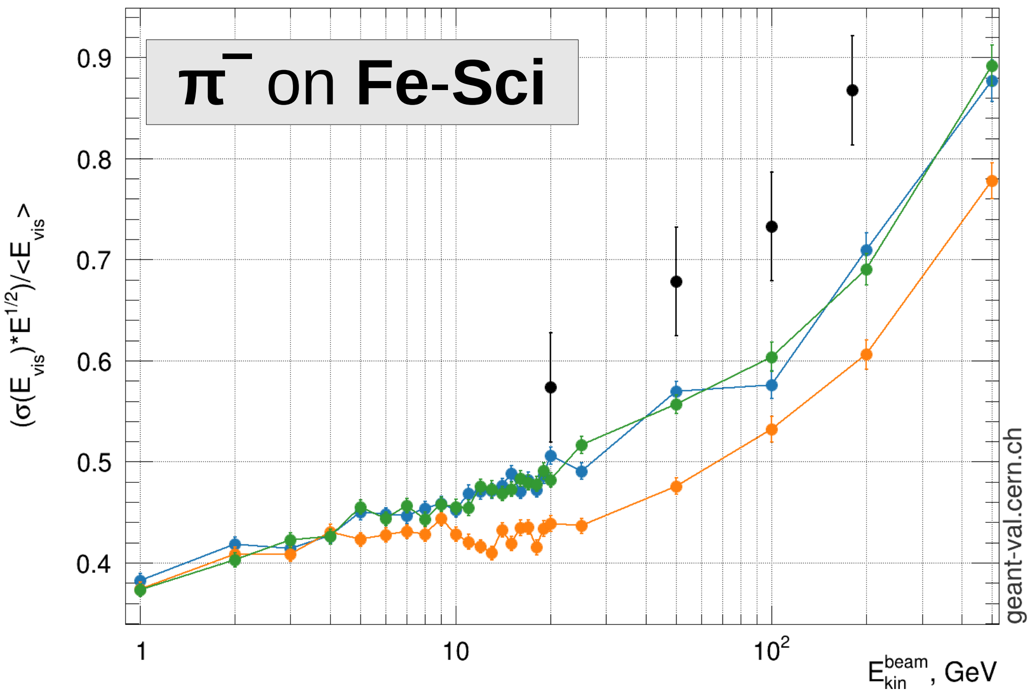




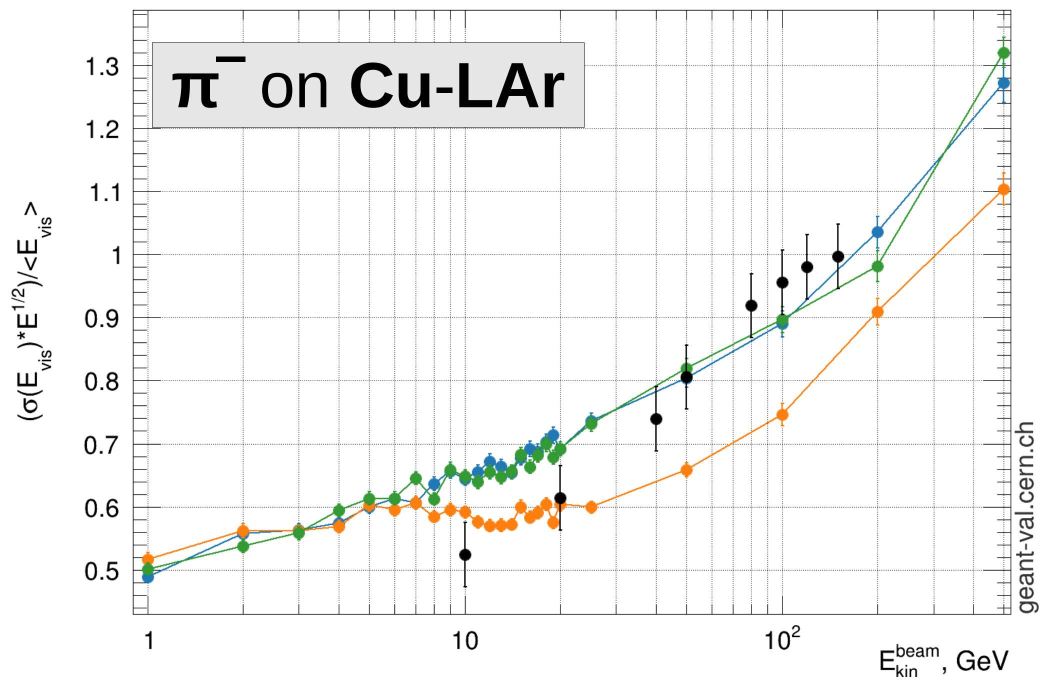


FTFP_BERT : Energy Resolution

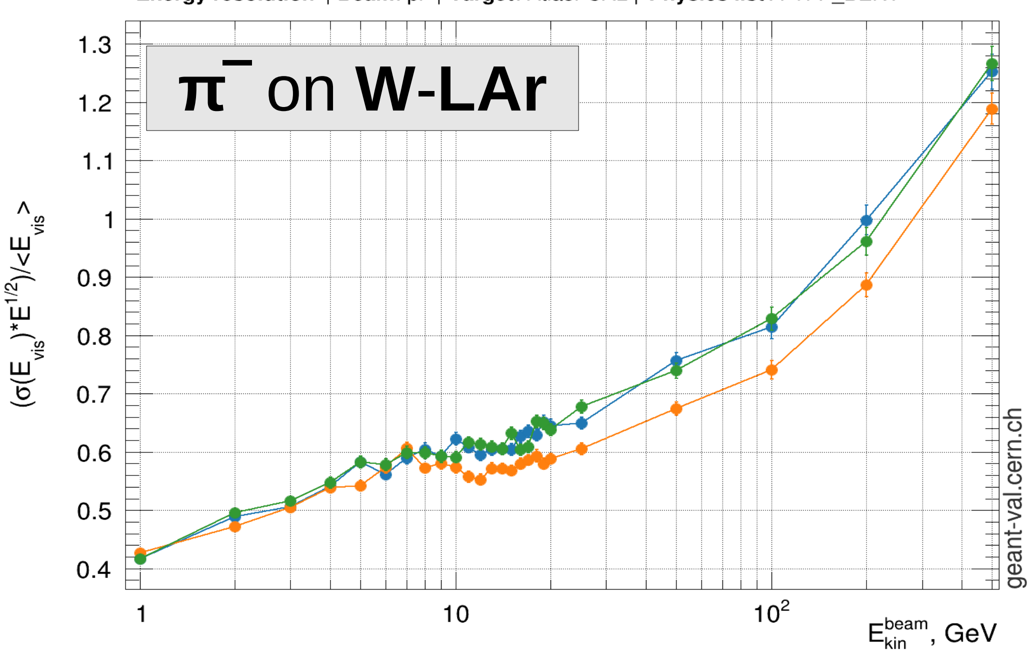
Energy resolution | **Beam**: pi- | **Target**: TileCal



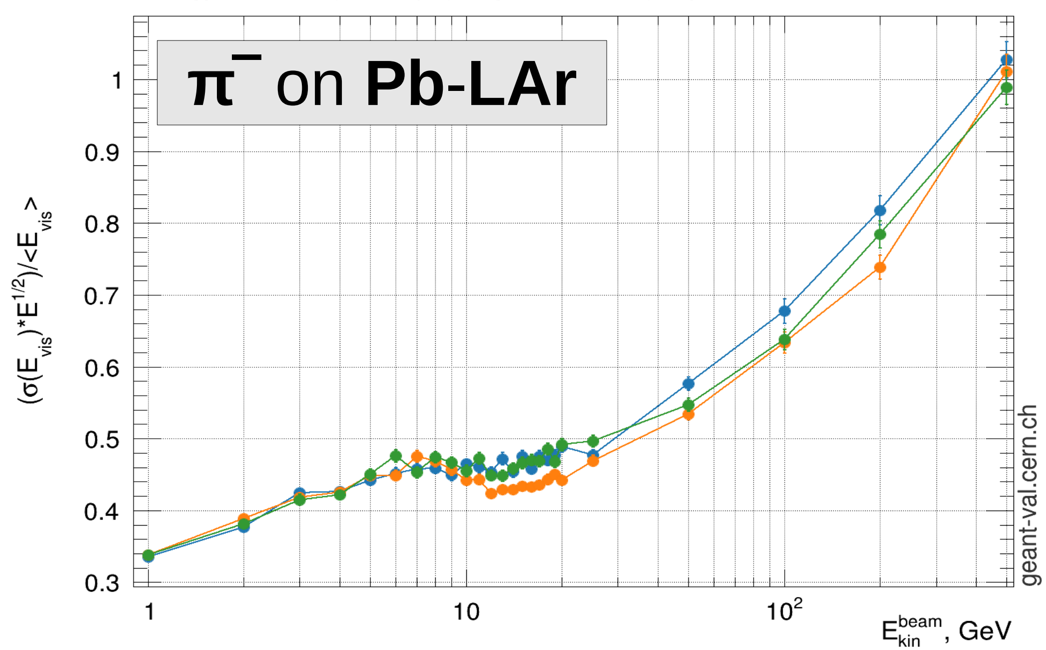
Energy resolution | **Beam**: pi- | **Target**: AtlasHEC



Energy resolution | **Beam**: pi- | **Target**: AtlasFCAL | **Physics list**: FTFP_BERT



Energy resolution | **Beam**: pi- | **Target**: AtlasECAL | **Physics list**: FTFP_BERT



10.4.p02
10.3.p03
10.5.cand02

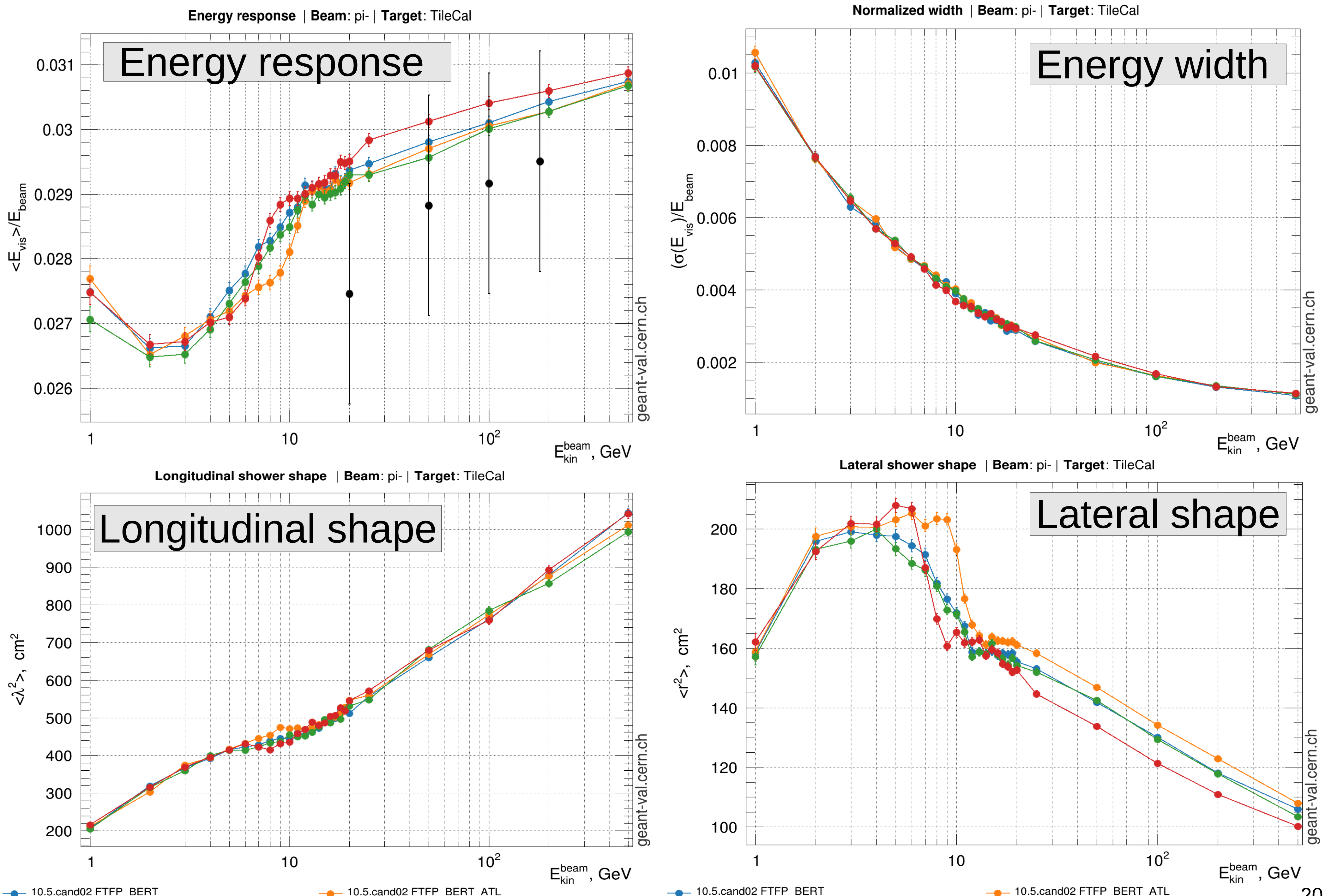
10.4.p02
10.3.p03
10.5.cand02

Pion showers
in Simplified Calorimeters
G4 10.5
Comparing Physics Lists:

FTFP_BERT , FTFP_BERT_ATL ,
FTFP_BERT_HP , QGSP_FTFP_BERT

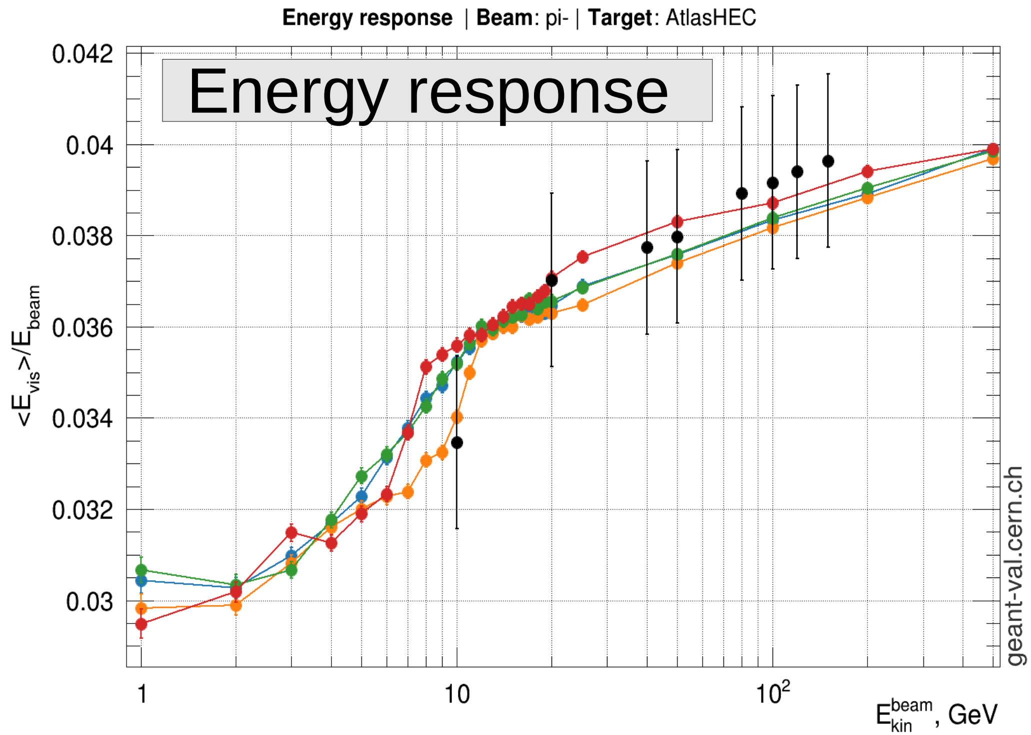
Note : conventional Birks treatment

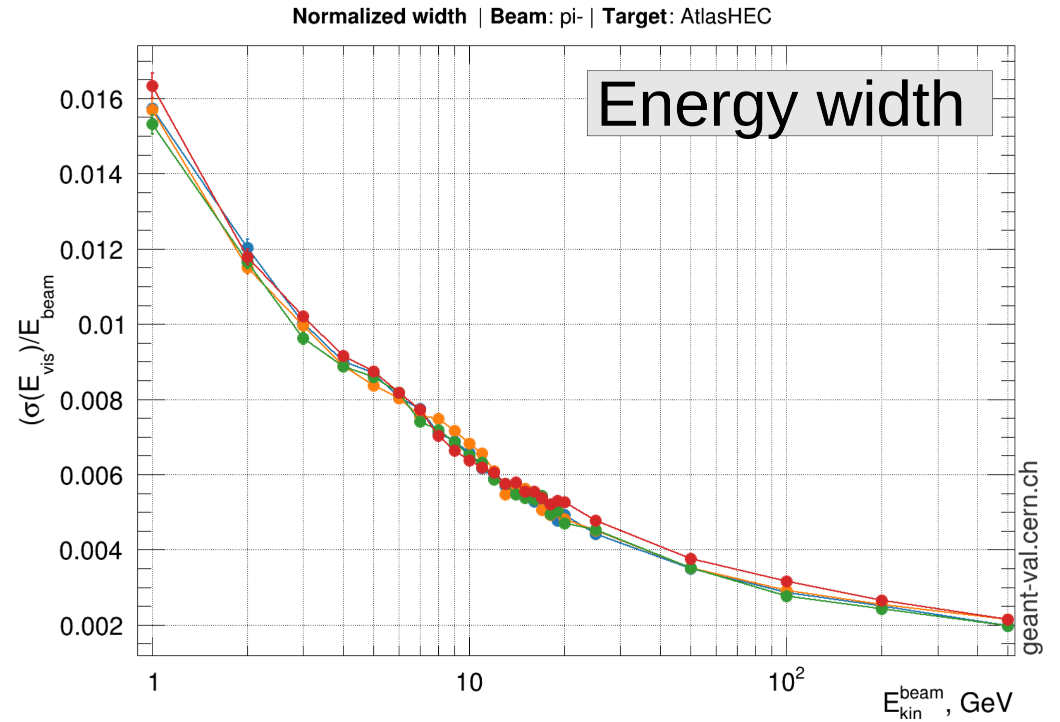
π⁻ on Fe-Sci

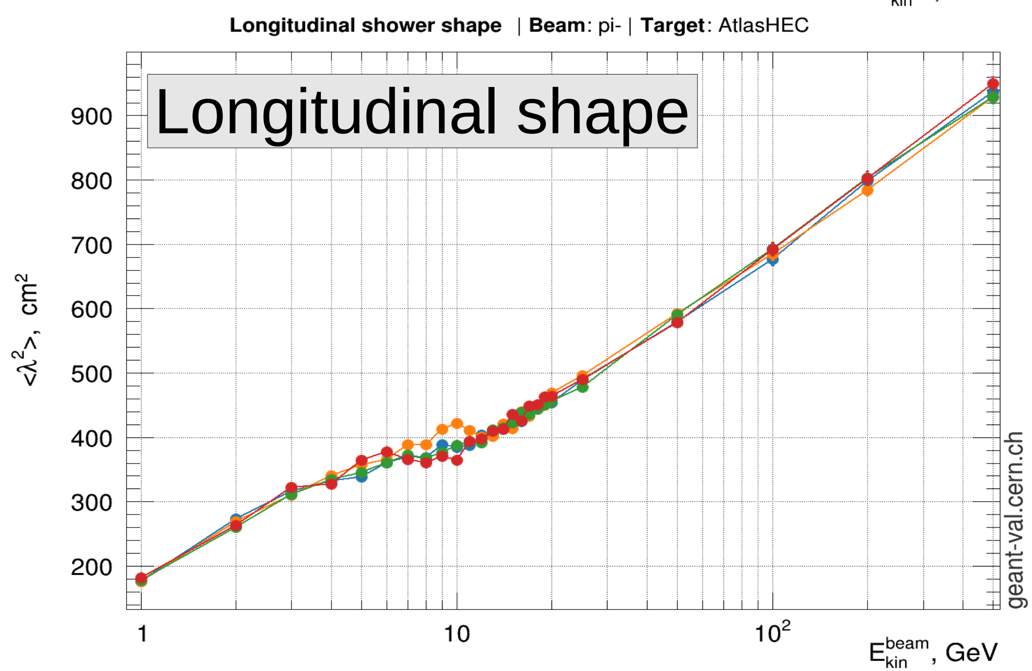


Energy response | Beam: pi- | Target: TileCal
Energy response
$<E_{vis}>/E_{beam}$
E_{kin}^{beam}, GeV
Normalized width | Beam: pi- | Target: TileCal
Energy width
$(\sigma(E_{vis})/E_{beam}$
Longitudinal shower shape | Beam: pi- | Target: TileCal
Longitudinal shape
$<\lambda^2>$, cm^2
Lateral shower shape | Beam: pi- | Target: TileCal
Lateral shape
$<r^2>$, cm^2
geant-val.cern.ch
10.5.cand02 FTFP_BERT
10.5.cand02 FTFP_BERT_HP
10.5.cand02 FTFP_BERT_ATL
10.5.cand02 QGSP_FTFP_BERT

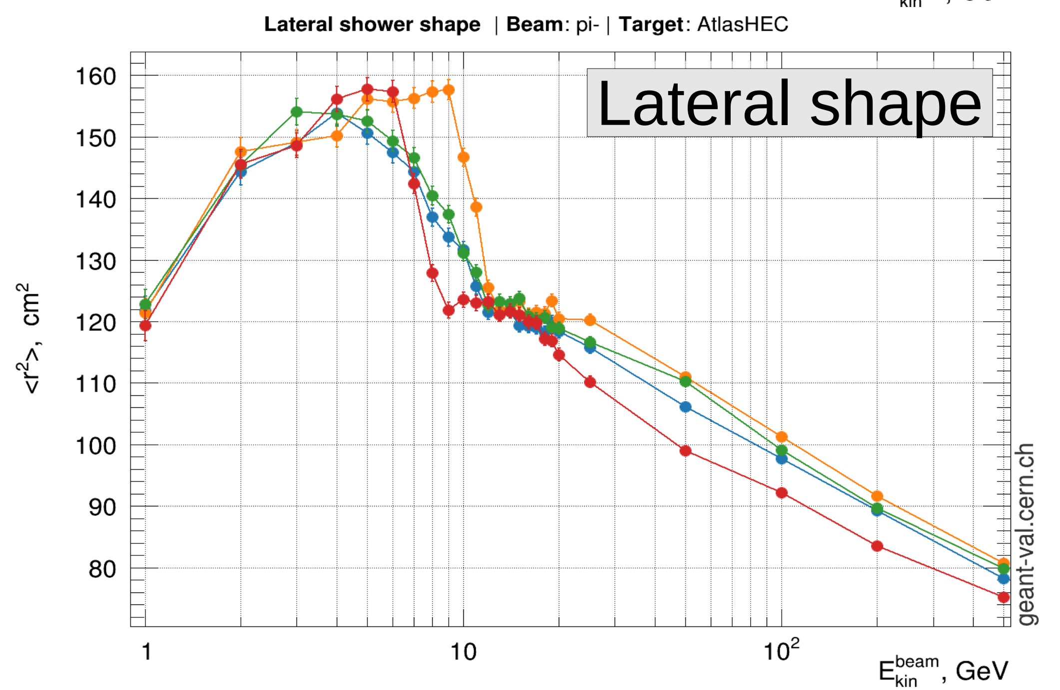
π^- on Cu-LAr





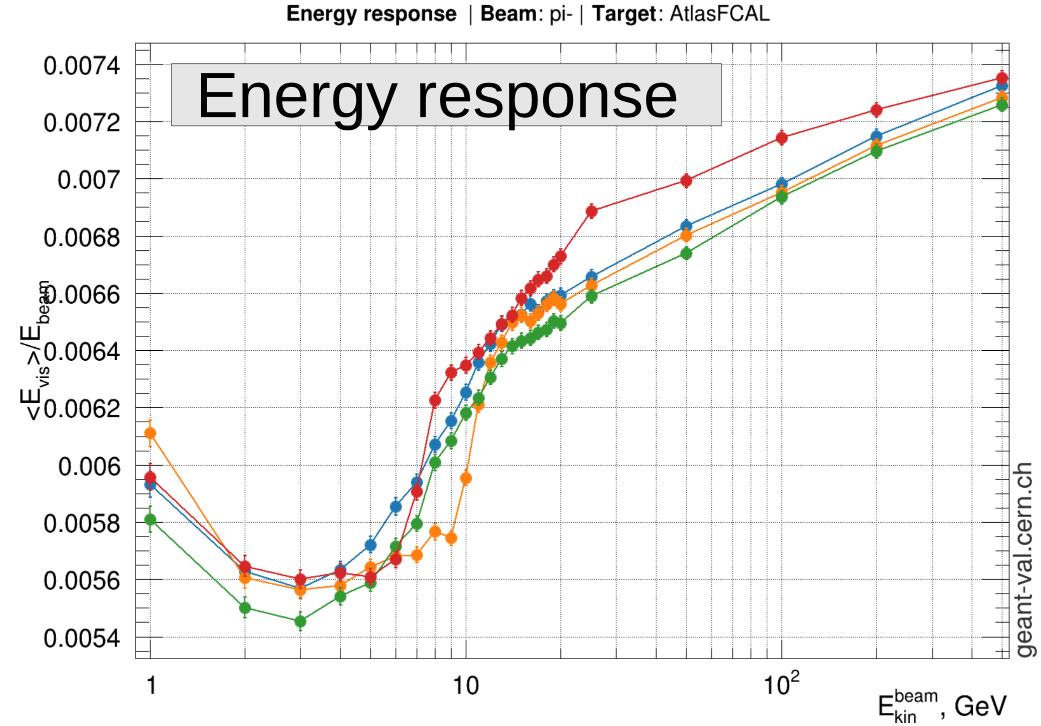


10.5.cand02 FTFP_BERT
10.5.cand02 FTFP_BERT_HP
10.5.cand02 FTFP_BERT_ATL
10.5.cand02 QGSP_FTFP_BERT

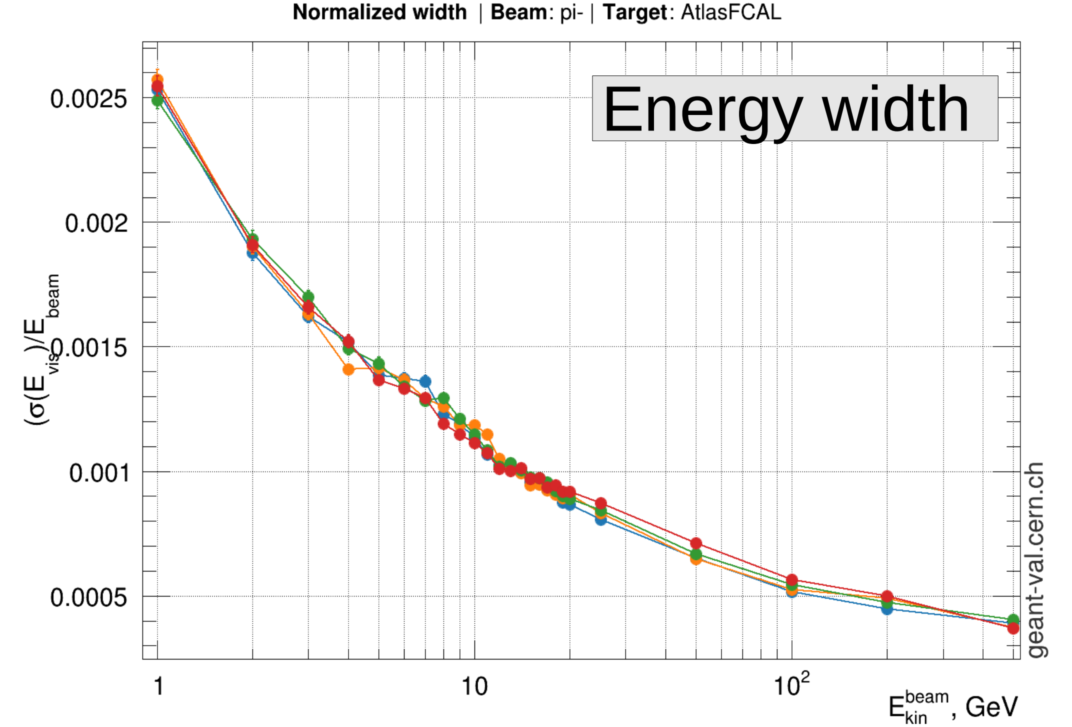


10.5.cand02 FTFP_BERT
10.5.cand02 FTFP_BERT_HP
10.5.cand02 FTFP_BERT_ATL
10.5.cand02 QGSP_FTFP_BERT

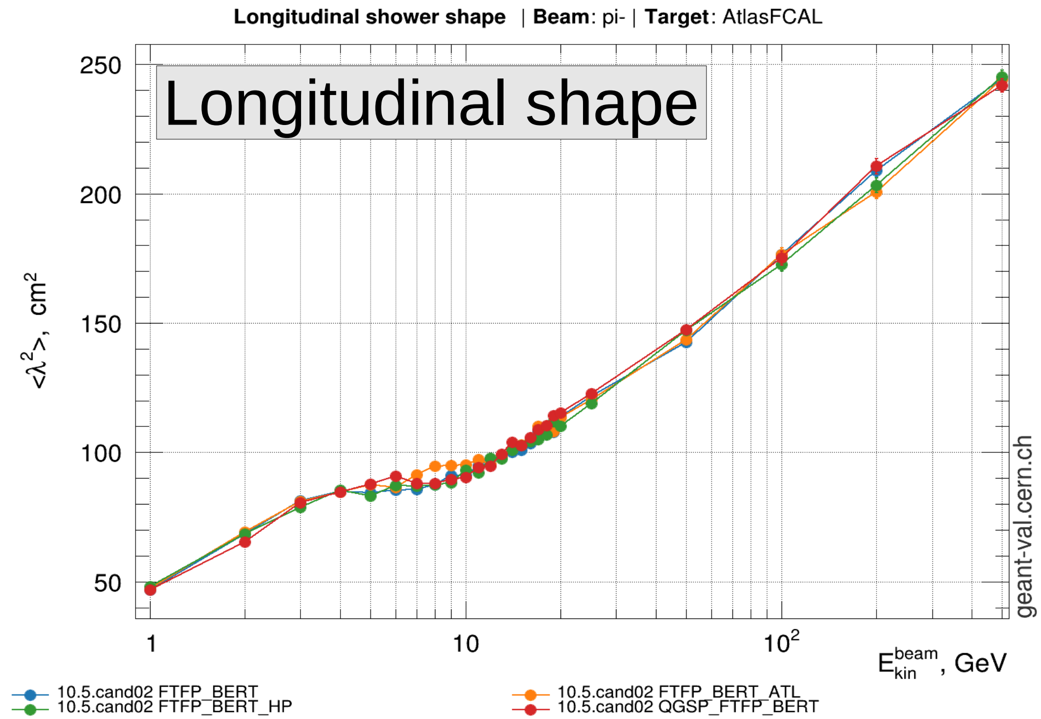
π^- on W-LAr



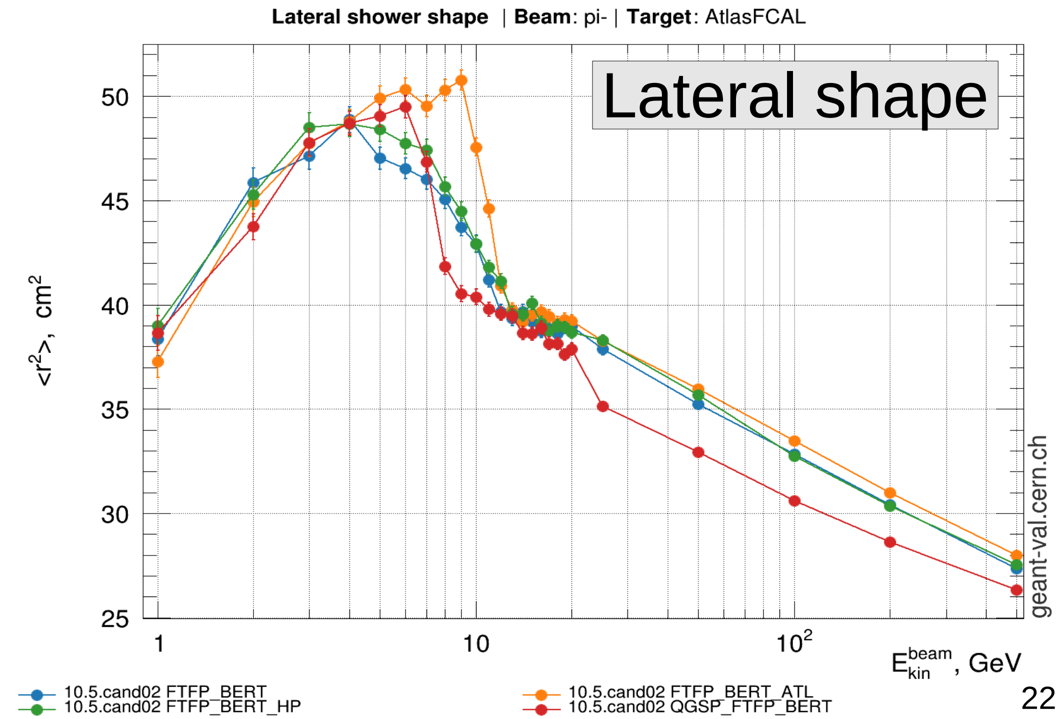
Energy response | Beam: pi- | Target: AtlasFCAL
Energy response
$<E_{vis}>/E_{beam}$
E_{kin}^{beam}, GeV
geant-val.cern.ch



Normalized width | Beam: pi- | Target: AtlasFCAL
Energy width
$(\sigma(E_{vis})/E_{beam}$
E_{kin}^{beam}, GeV
geant-val.cern.ch

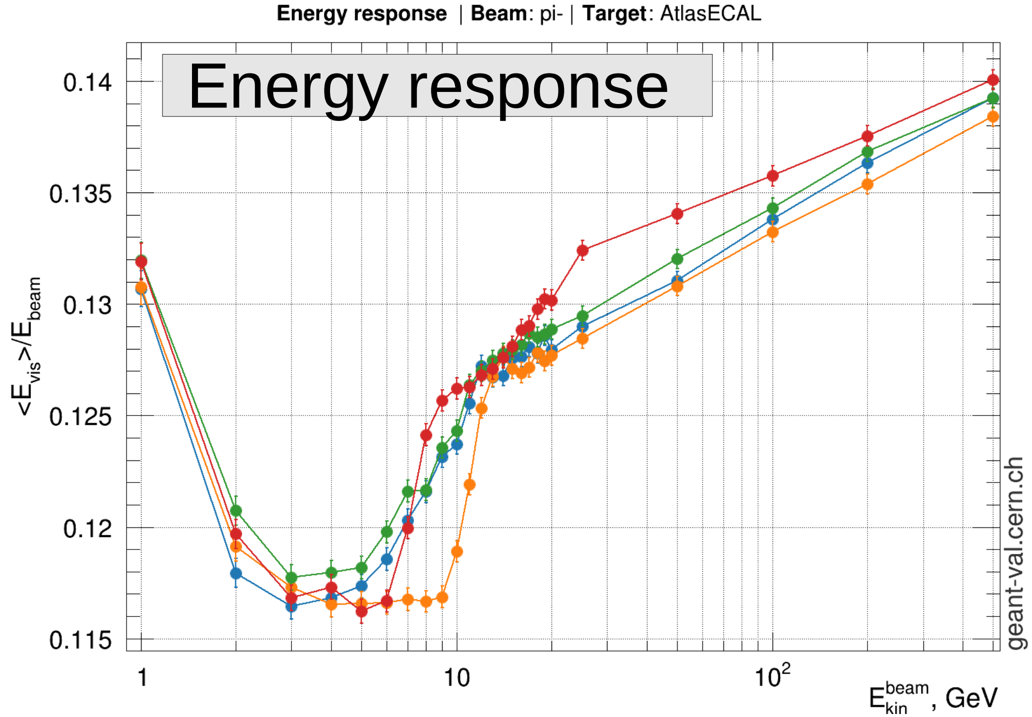


Longitudinal shower shape | Beam: pi- | Target: AtlasFCAL
Longitudinal shape
$<\lambda^2>$, cm^2
E_{kin}^{beam}, GeV
geant-val.cern.ch
10.5.cand02 FTFP_BERT
10.5.cand02 FTFP_BERT_HP
10.5.cand02 FTFP_BERT_ATL
10.5.cand02 QGSP_FTFP_BERT

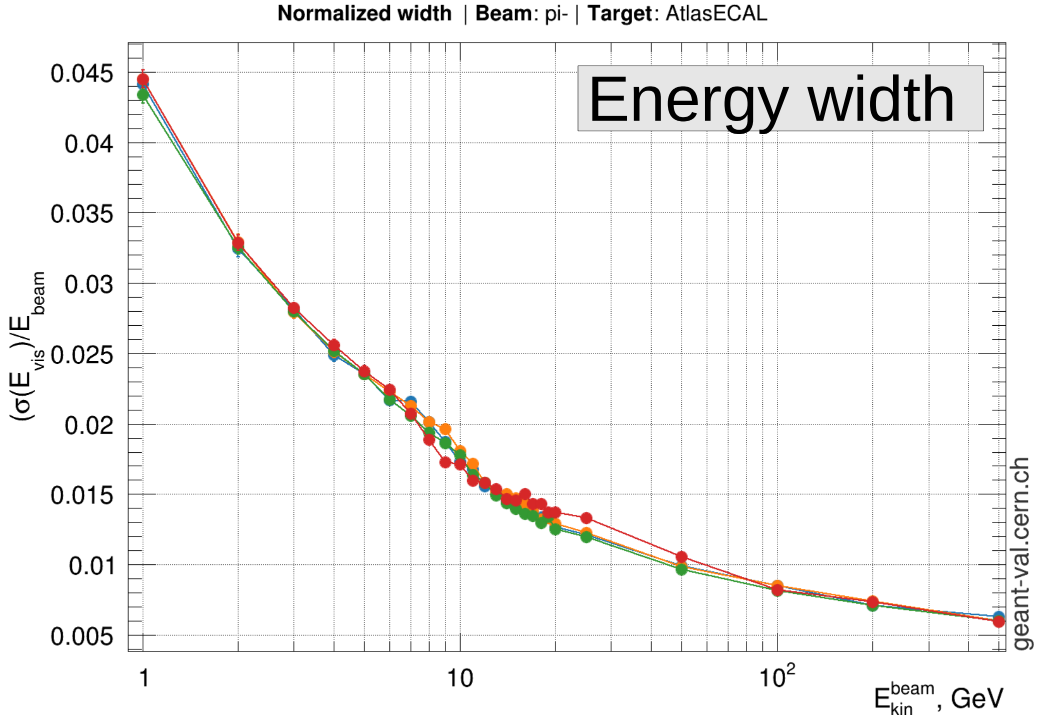


Lateral shower shape | Beam: pi- | Target: AtlasFCAL
Lateral shape
$<r^2>$, cm^2
E_{kin}^{beam}, GeV
geant-val.cern.ch
10.5.cand02 FTFP_BERT
10.5.cand02 FTFP_BERT_HP
10.5.cand02 FTFP_BERT_ATL
10.5.cand02 QGSP_FTFP_BERT

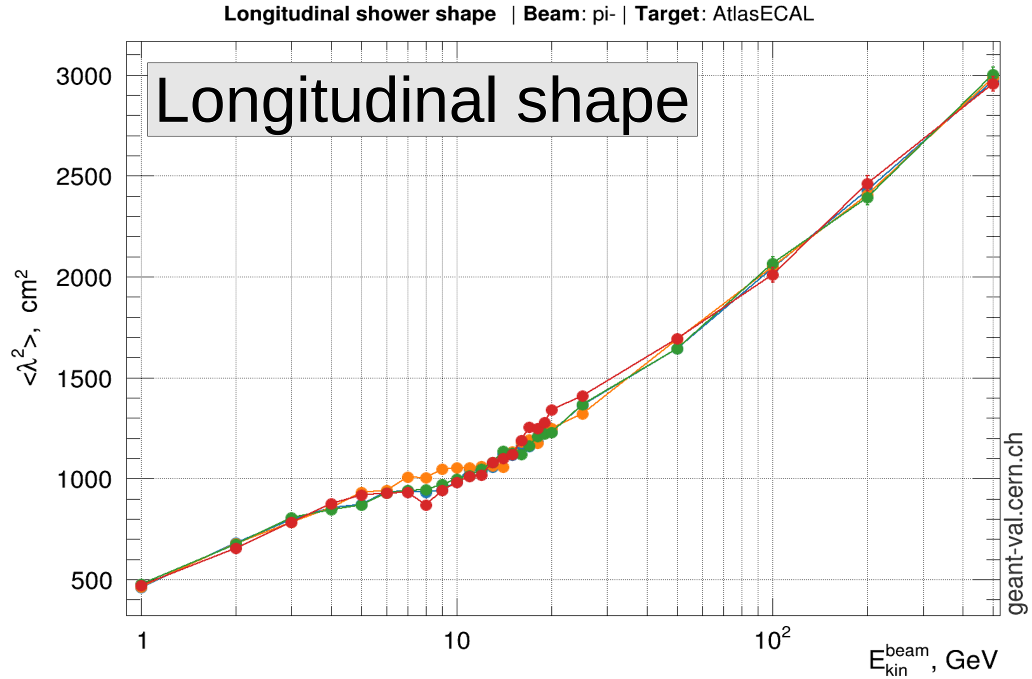
π⁻ on Pb-LAr



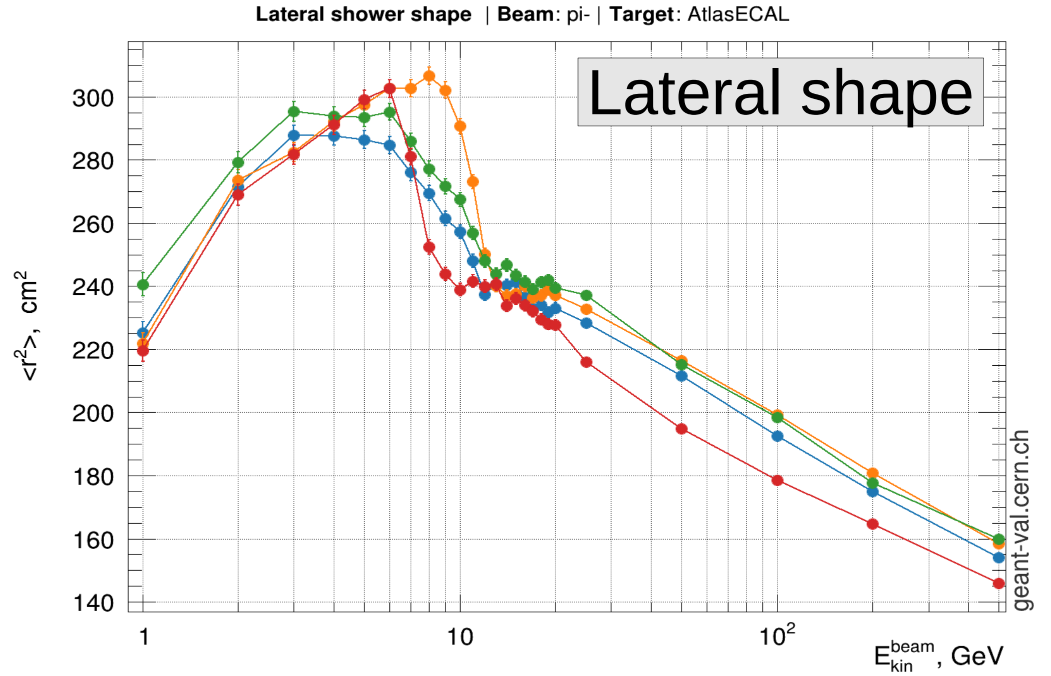
Energy response | Beam: pi- | Target: AtlasECAL
Energy response
$<E_{vis}>/E_{beam}$
E_{kin}^{beam}, GeV
geant-val.cern.ch



Normalized width | Beam: pi- | Target: AtlasECAL
Energy width
$(\sigma(E_{vis})/E_{beam}$
E_{kin}^{beam}, GeV
geant-val.cern.ch



Longitudinal shower shape | Beam: pi- | Target: AtlasECAL
Longitudinal shape
$<\lambda^2>$, cm^2
E_{kin}^{beam}, GeV
geant-val.cern.ch
10.5.cand02 FTFP_BERT
10.5.cand02 FTFP_BERT_HP
10.5.cand02 FTFP_BERT_ATL
10.5.cand02 QGSP_FTFP_BERT



Lateral shower shape | Beam: pi- | Target: AtlasECAL
Lateral shape
$<r^2>$, cm^2
E_{kin}^{beam}, GeV
geant-val.cern.ch
10.5.cand02 FTFP_BERT
10.5.cand02 FTFP_BERT_HP
10.5.cand02 FTFP_BERT_ATL
10.5.cand02 QGSP_FTFP_BERT

Energy Resolution