Highlights from High-Energy Hadronic Physics

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Outline

- Status of String models
  - FTF
  - QGS
- Status of Intranuclear Cascade models
  - BERT
  - BIC
  - INCLXX
- String−Cascade Transition Region
- Others
  - Interface to Fortran EPOS
  - Hadronic models per Region
  - Neutrino Interactions

String models

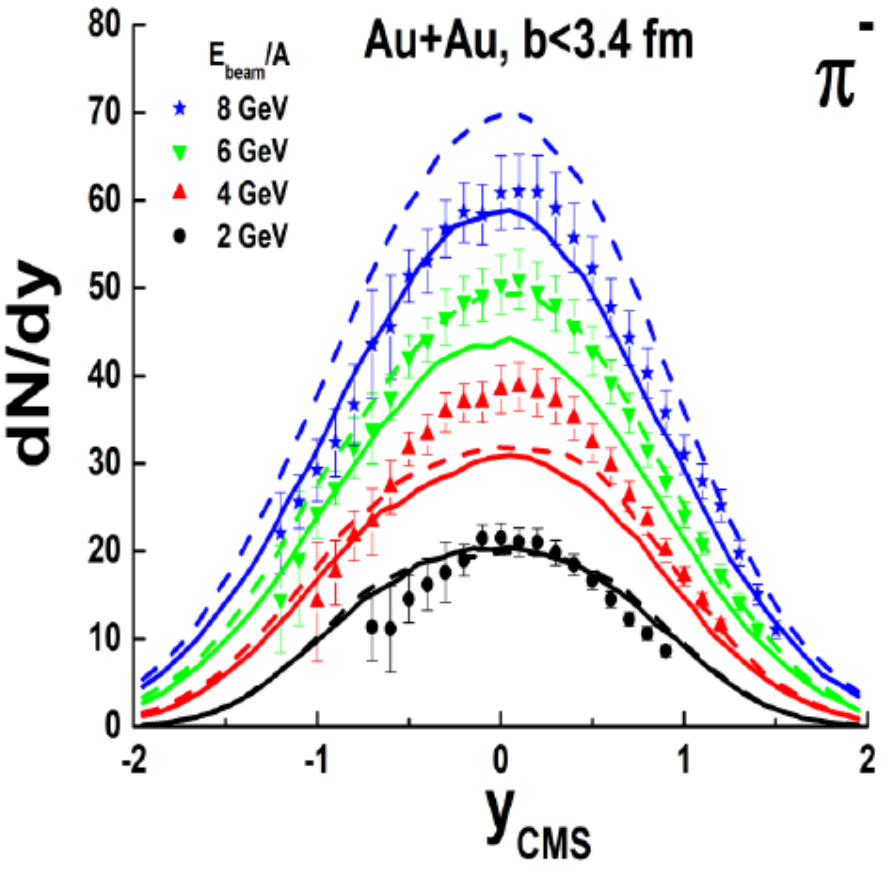
Status of **FTF** (Fritiof) model

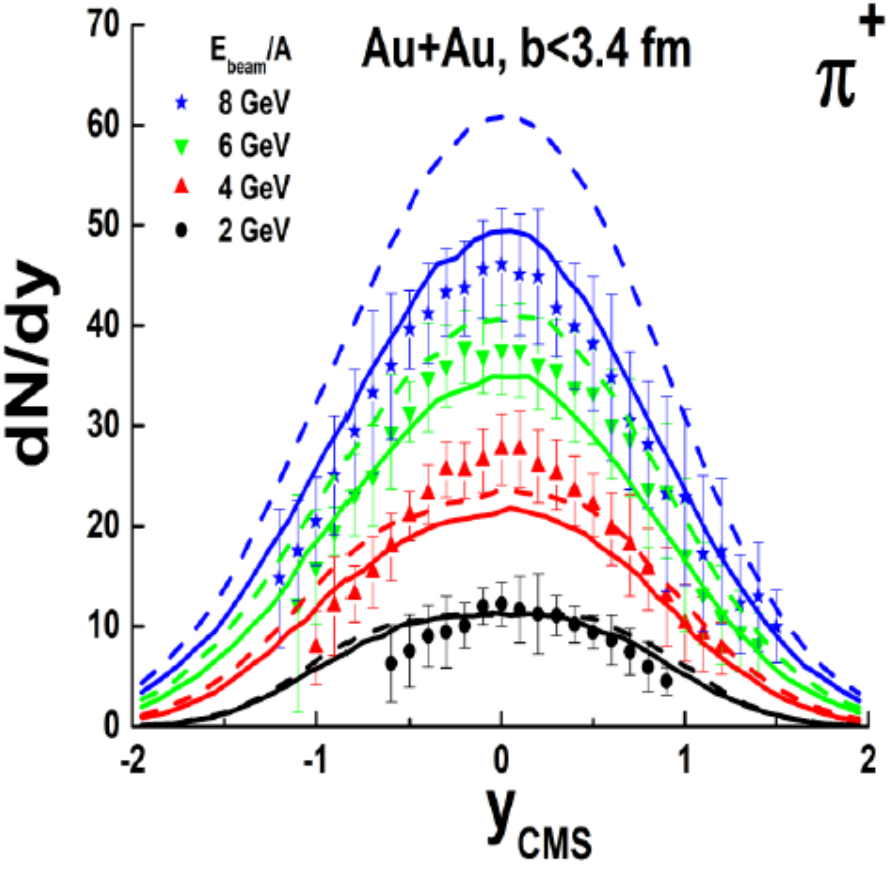
- FTF in G4 10.5
  - Decided to release the **development version**
  - Improved thin-target description and wider hadronic showers, while our suggested new treatment of Birks quenching (i.e. fitting the Birks parameter from e/π data) can cope with the increased visible energy
  - After the 2018 Collaboration meeting, retuning of the strange quark sector of the Lund string fragmentation

- Changes on FTF after G4 10.5
  - Validation and refinement of nucleus-nucleus interactions *(see an example in the next page)*
  - Improved annihilation at rest of light anti-ions
  - Extended configuration interface for pion projectile parameters
  - Fixed a memory leak

Results of the improvements for E895 exp.

J. L. Klay et al., Phys. Rev C 68, 054905 (2003)
Charged pion production in 2A to 8A GeV central Au+Au Collisions,





Dashed lines are previous calculations, solid ones – current results.

Results become better for high energies, T > 6 GeV.

Status of **QGS** (Quark-Gluon-String) model

- QGS in G4 10.5
  - Decided to release the **development version**
  - Improved thin-target description, although narrower hadronic showers and increased visible energy
    - The increased visible energy can be compensated with our suggested new treatment of Birks quenching, i.e. fitting the Birks parameter from e/π
  - After the Collaboration meeting, improved the kaon treatment and performed further validation

- Changes on QGS after G4 10.5
  - Further validation
  - On-going code review
  - Fixed a bug in the computation of the transverse mass

FTF *vs.* QGS

- In Geant4 version 10.5, from thin-target data, we can generally conclude that QGS becomes **competitive** with FTF roughly above **~ 15 – 20 GeV** (lab. projectile Ekin) whereas below this energy FTF is better
  - In the QGS-based physics lists, the transition between FTF and QGS is currently in the region [12 , 25] GeV
- QGS model is more theory-based than FTF, therefore QGS is expected to be more reliable at high energies
  - Above about ~0.5 TeV, where there are no clean thin-target data
  - But both models cannot be valid above few TeV
    - Because of the lack of gluon-jet production
    - Likely acceptable for LHC experiments, but not for FCC...
- QGS hadronic showers are narrower and with higher energy response than those of FTF
  - FTF hadronic showers expected to agree better with test-beam data

String models for G4 10.6

- V. Uzhinsky is now working at CERN – since 1st August, for 4 months – on the string models. His current main task is to **extend the string models to charm and bottom hadrons** i.e. transporting and/or producing heavy hadrons
  - Interest in FCC (as well as LHC) experiments to simulate hadronic interactions of highly boosted charmed and bottom hadrons in the beam pipe and first layers of the silicon tracker
  - Grichine's Glauber-Gribov nuclear cross sections for heavy hadrons will be available in the coming release G4 10.6
    - Unfortunately, no experimental data is available !
- This extension will be common for FTF and QGS for the **string fragmentation** part, whereas the **string formation** part will be done separately for FTF and QGS
  - Starting first with FTF ; not yet clear how much will go in G4 10.6
  - Aida Galoyan will collect experimental data on charm production

Intranuclear Cascade models

Bertini-like (BERT) model

- A few bug fixes
- Investigating possible improvements in multi-body phase generation

See Dennis' talks (plenary & parallel) for more details on Bertini

Binary Cascade (BIC) model

- Stable, no development

INCLXX (Liege) model

- Main physics developments included in G4 10.5 : improved strangeness and few nucleon removal
  - Introduced a new environmental variable G4INCLDATA, which should point to G4INCL1.0
- Several technical fixes included in G4 10.5
  - MT-irreproducibility fixed in the patch, G4 10.5.p01
- No new development expected for G4 10.6
  - Due to lack of man-power
  - Pending fixes on memory leaks

- FTFP_INCLXX is the preferred physics list for ALICE
  - It gives the best description of light ion production (d, t, 3He, α) by ~GeV pion and nucleon interactions on the beam pipe & tracker
  - But it is CPU costly (see later...)

Transition Region between String and Cascade models

Status up to G4 10.5.ref07

- **[3, 12] GeV** transition region between FTFP and BERT in FTFP_BERT physics list
  - Since G4 10.3 (December 2016)
  - The main motivation was to use more BERT and less FTFP to have lower energy response and wider hadronic showers
  - But thin-target data (HARP) prefer FTFP to BERT above ~ 5 GeV
  - This transition region is for the main hadrons − pions, kaons, and nucleons − but for the other hadron types, different regions were used (mainly for historical reasons):
    - [2, 6] GeV for hyperons (Λ , Σ , Ξ , Ω)
    - [2, 4] GeV/nucleon for light ions (d , t , He3, α)
  - Transition region between BIC and FTFP was also different (again, mainly for historical reasons):
    - [9.5, 9.9] GeV for nucleons
    - For pions, either BERT, or BIC < 1.3 GeV, or BIC < 1.5 GeV was used depending on the physics list

Change in G4 10.5.ref08

- **[3, 6] GeV** new transition region between FTFP and BERT in FTFP_BERT physics list
  - Requested by CMS and supported by thin-target experimental data
  - Discussed and agreed at the Hadronic Group meeting on July 24th
  - Took the occasion to set consistently the same transition region for all hadrons (i.e. also for hyperons and light ions)
  - Reviewed also the transition for **BIC** (Binary Cascade model), for the physics list where it is used
    - **[3, 6] GeV** between FTFP and BIC for proton and neutron
    - For pions, **BIC < 1.5 GeV** , 1 GeV < BERT < 6 GeV , FTFP > 3 GeV
  - Left unchanged the transition region QGSP − FTFP : **[12, 25] GeV**
  - Left unchanged the transition region in these 4 special P.L. : **FTFP_BERT_ATL** , **INCLXX**-based P.L. , **NuBeam** , **ShieldingM**
  - *See back up slides for the effects on hadronic showers*

Others

Interface to Fortran EPOS

- The hadronic extended example **Hadr02** in G4 **10.5** includes an interface to **CRMC** (Cosmic Ray Monte Carlo) – which offers the possibility to use generators like **EPOS** for final-state hadron-nucleus (and nucleus-nucleus) inelastic collisions at very high energies – and created a (local) physics list which uses this interface
  - The Physics List is called CRMC_FTFP_BERT and the transition between CRMC and FTFP is currently set to be [100, 110] GeV
  - Main interest for **FCC**, to simulate **jets above ~ 10 TeV**
    - Hadron-nucleus interactions up to at least ~ 1 TeV (projectile kinetic energy in the Lab frame) are expected to be well described by the Geant4 string models (FTF & QGS); above this, missing gluon-jet production
  - Currently under testing in the context of FCC
    - At model-level we see fewer and more energetic secondaries in G4 FTF & QGS with respect to EPOS due to the lack of gluon-jet emissions
  - Needs a special version of CRMC adapted for Geant4 use...

Hadronic models per Region

- Geant4 physics list is defined globally, not per region
- Sometimes users would like to use a reference physics list, e.g. FTFP_BERT, but replacing a hadronic physics model in a region with a more precise model
  - Recent request from ALICE : to be able to use INCLXX in the Tracker region, while using BERT elsewhere
    - INCLXX describes better the production of light ions by primary pions and nucleons interacting in the beam pipe and silicon tracker
    - The overhead in CPU time for ALICE of using FTFP_INCLXX instead of FTFP_BERT if about a factor of 2
- An elegant and efficient solution is provided by the "**Generic Biasing**" capability of Geant4
  - It naturally allows a treatment per-region and per-particle
  - No "occurrence" biasing, only "final-state operation" biasing
    - Kept the natural cross sections, but changed final-state hadronic model
    - It is "biasing" but with weight = 1.0 (as in analogous simulations)

Neutrino Interactions

- Progress in modelling neutrino interactions inside Geant4
  - Alternative to the interface to external GENIE package
- Neutrino – electron interactions included in G4 10.5
  - Neutral- and charged-current for neutrinos and anti-neutrinos of all 3 flavours (ν_e , ν_μ , ν_τ)
  - Included in the gamma-lepto-nuclear physics constructor G4EmExtraPhysics (present in all physics lists); it can be activated and steered via UI commands
- ν_μ – nuclear interactions will be included in G4 10.6
  - Including also "anti_nu_mu"
  - Included in the gamma-lepto-nuclear physics constructor G4EmExtraPhysics (present in all physics lists); it can be activated and steered via UI commands
  - In the future (after G4 10.6), can be extended to electron and tau neutrinos (and anti-neutrinos)

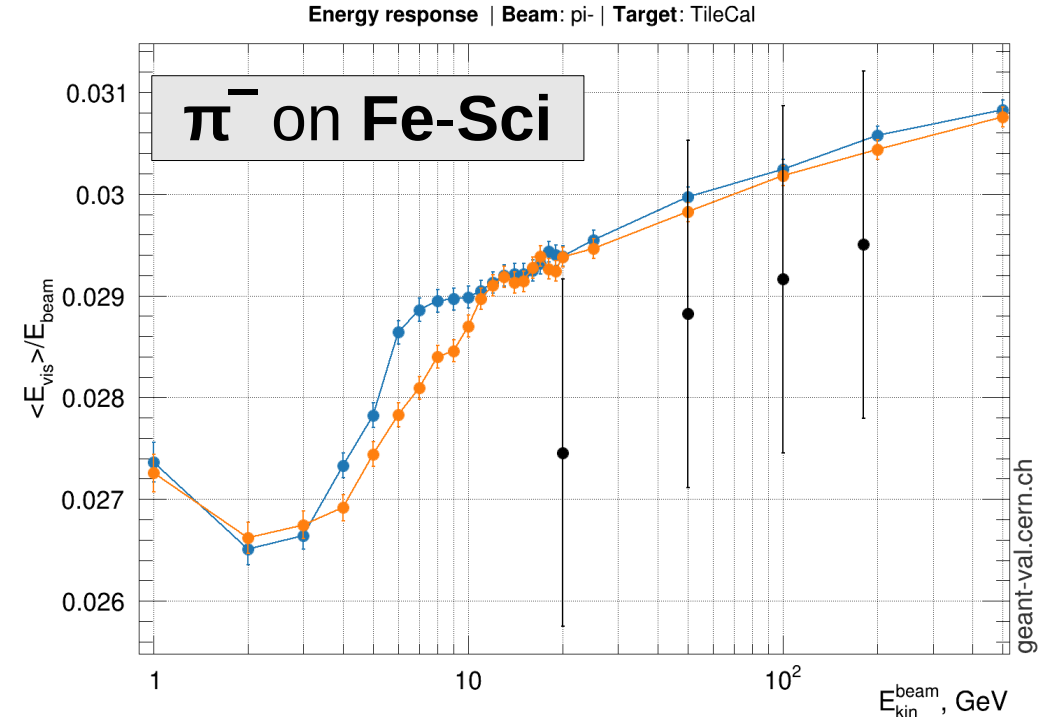
Back up

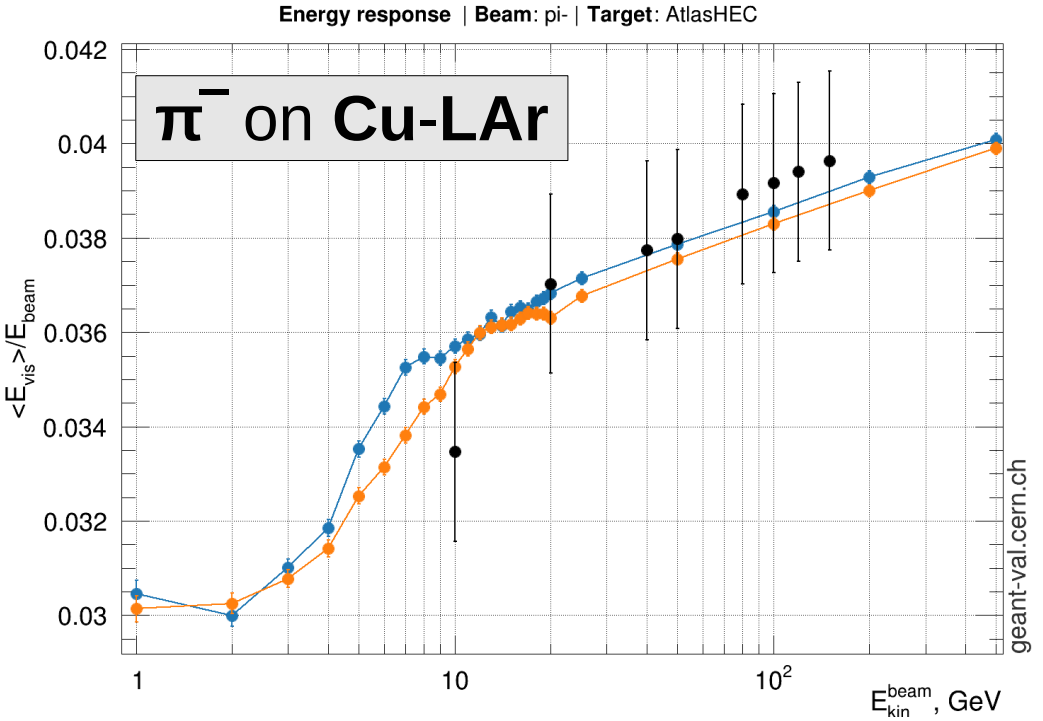
Pion- showers: FTFP_BERT

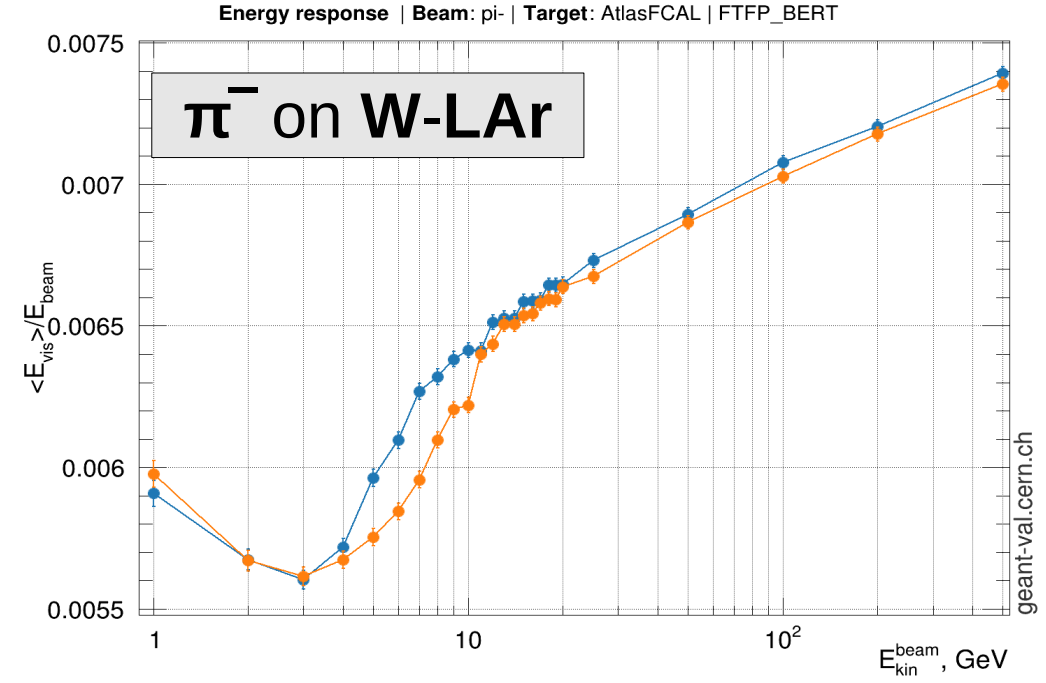
G4 “10.5.ref07.tr3_6gev”
10.5.ref07

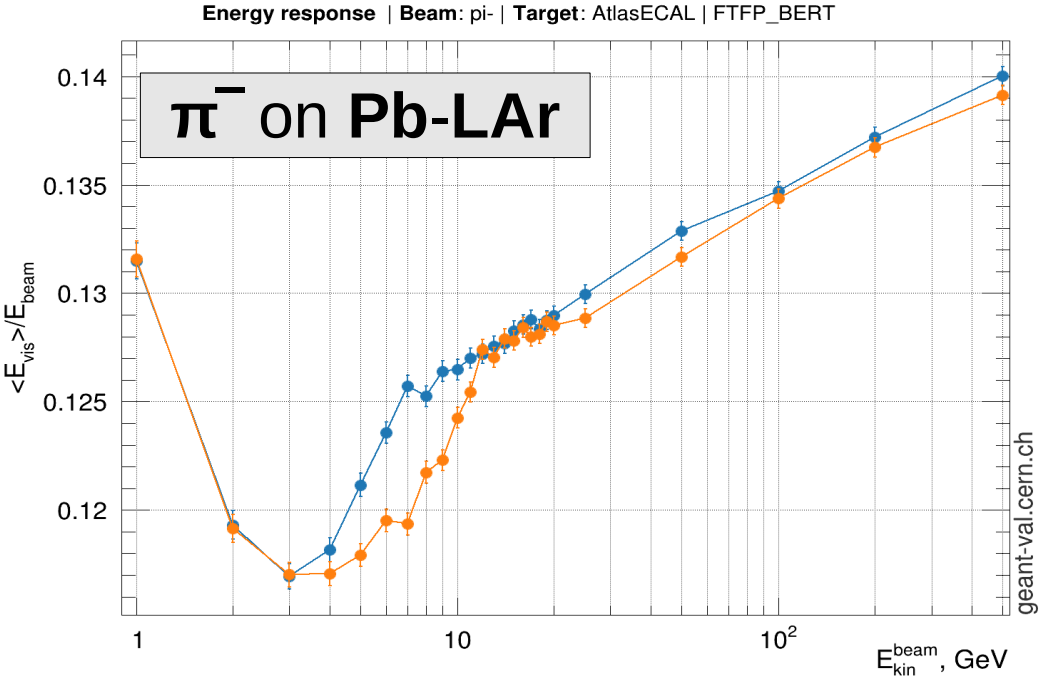
Note : conventional Birks treatment
(easier and no experimental h/e to fit !)

FTFP_BERT : Energy Response

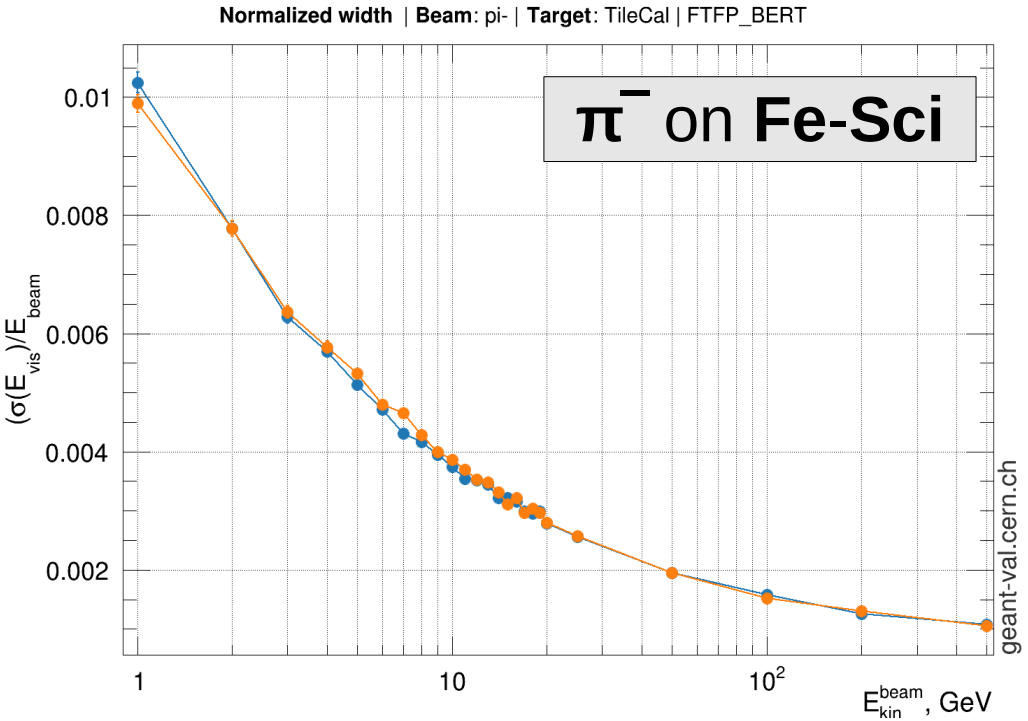


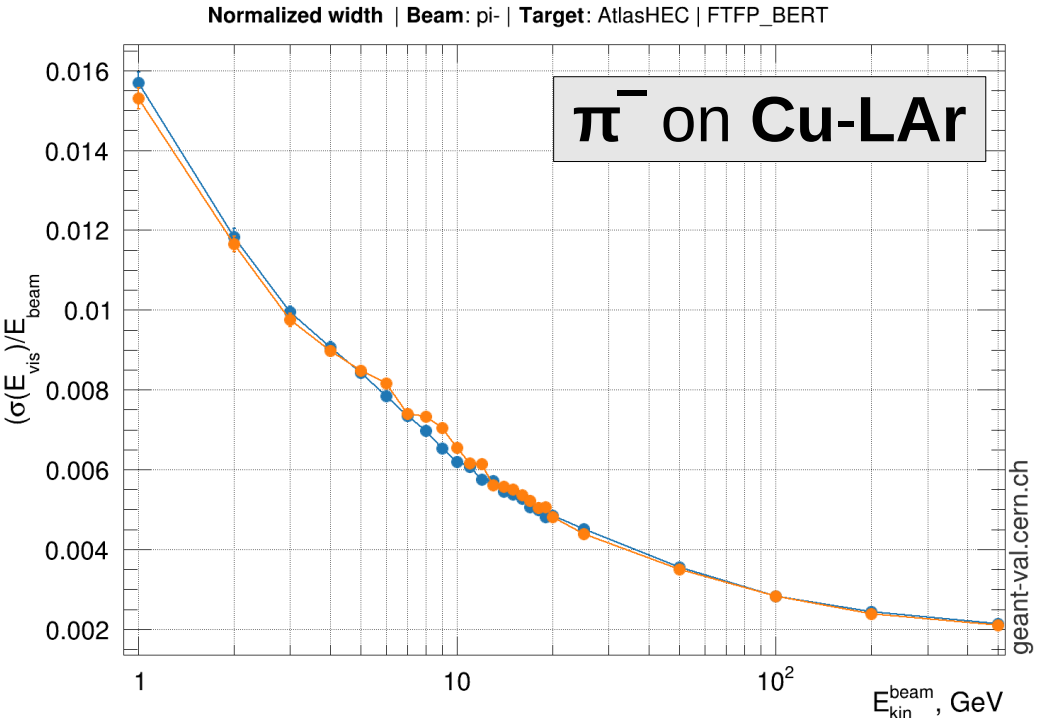


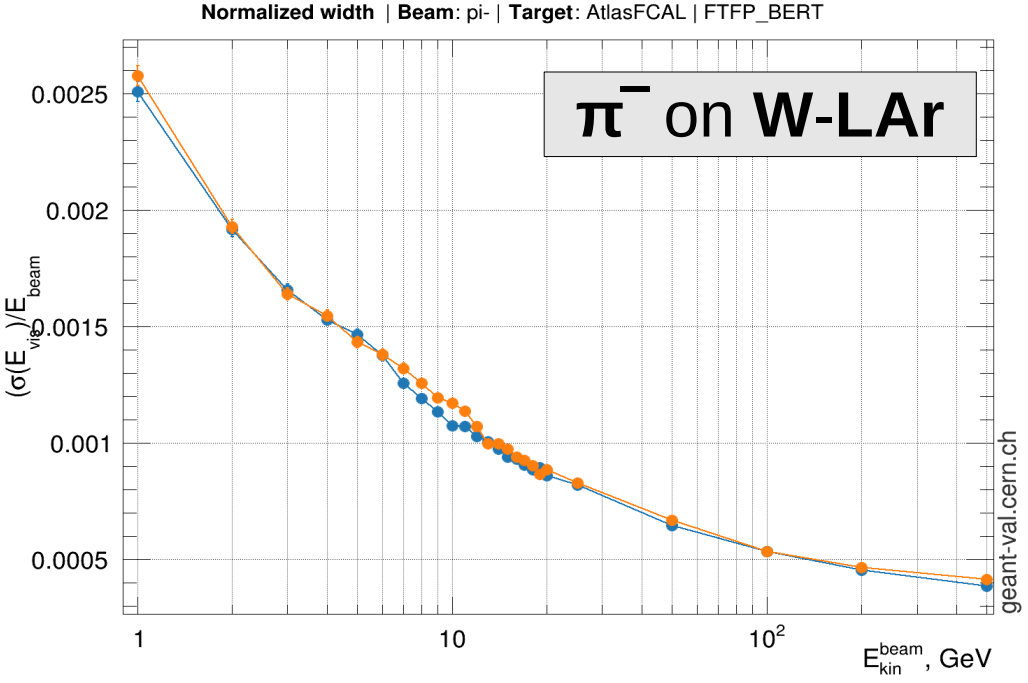


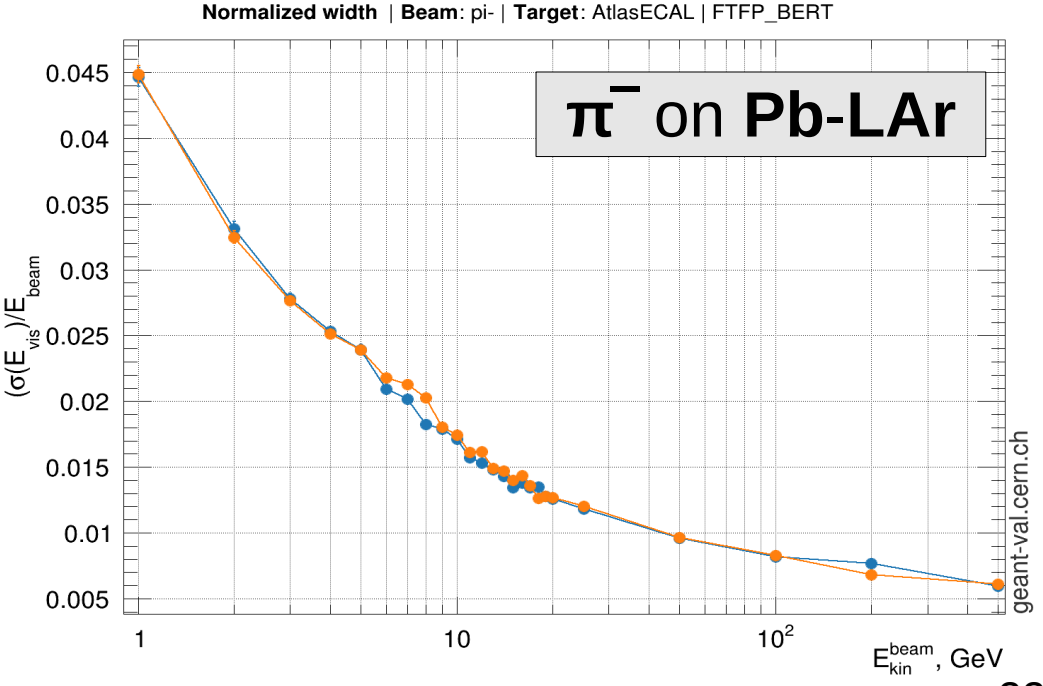


FTFP_BERT : Energy Width









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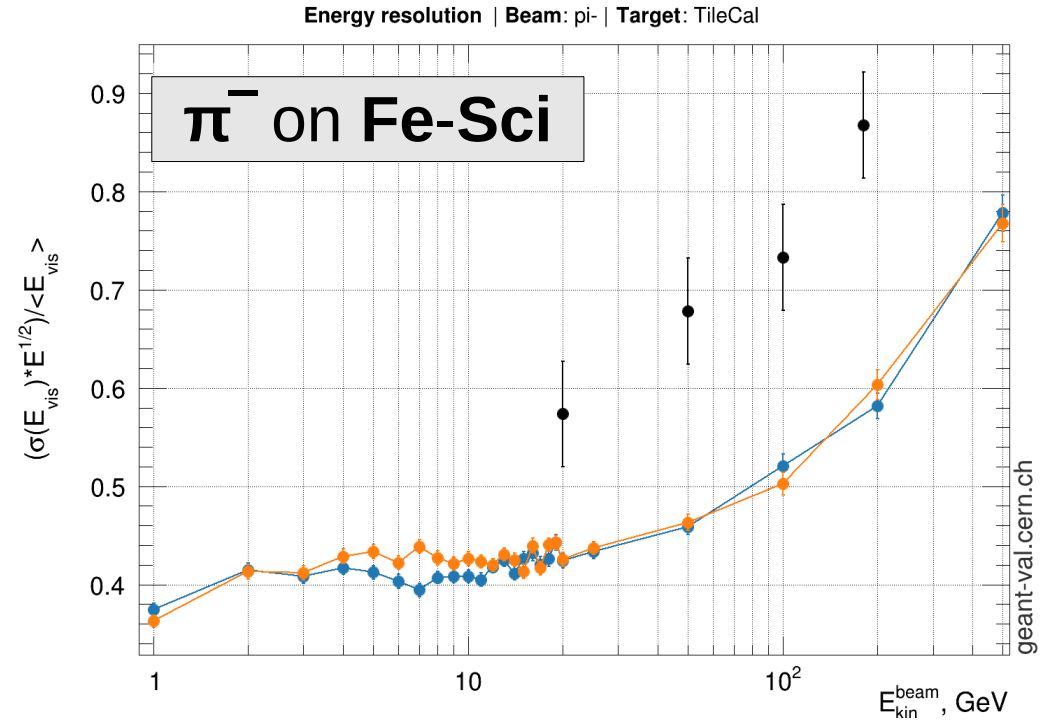
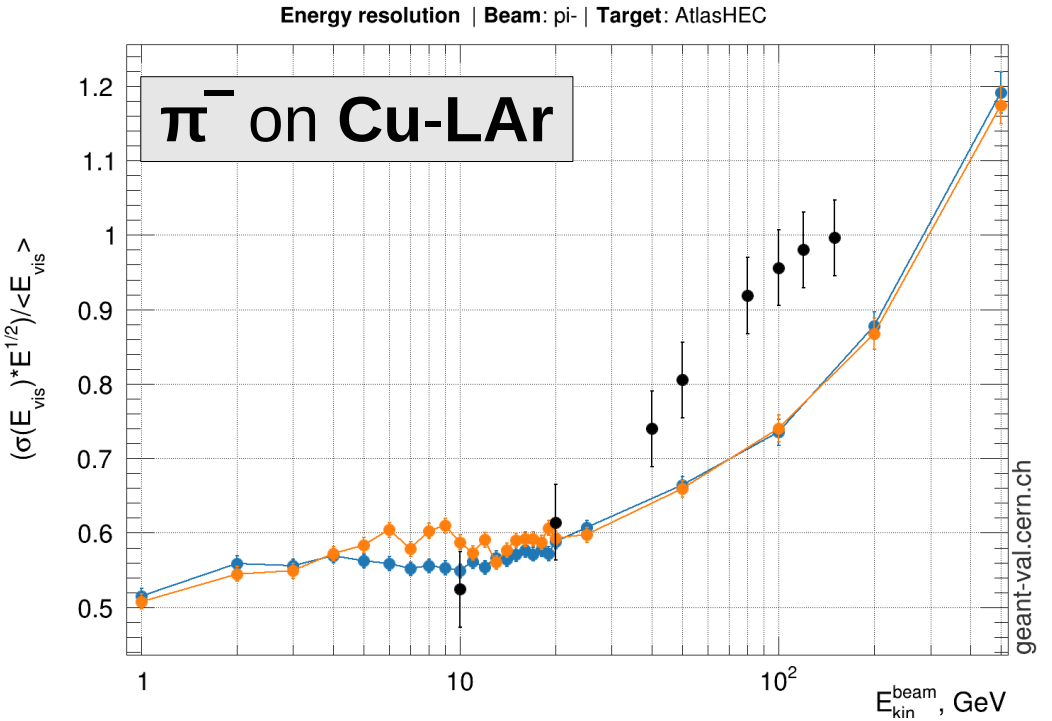
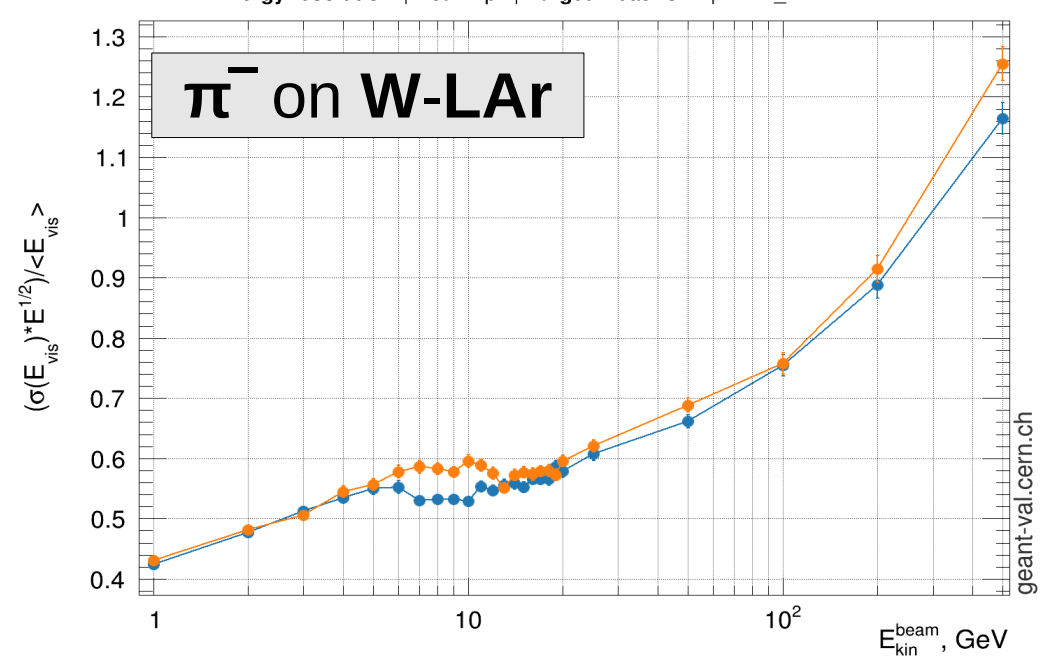
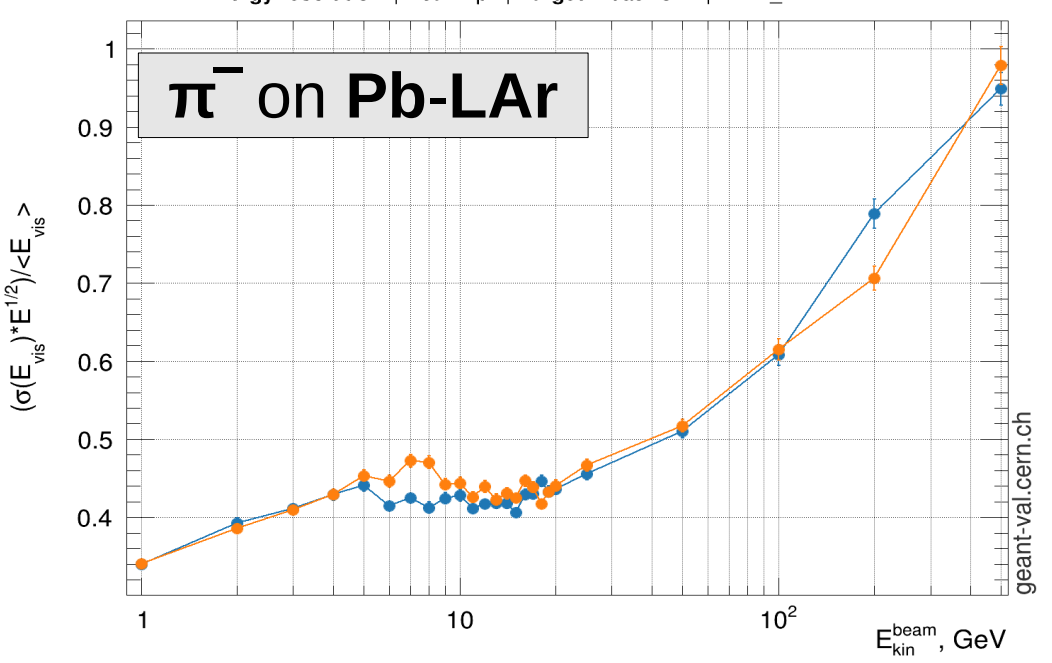
FTFP_BERT : Energy Resolution

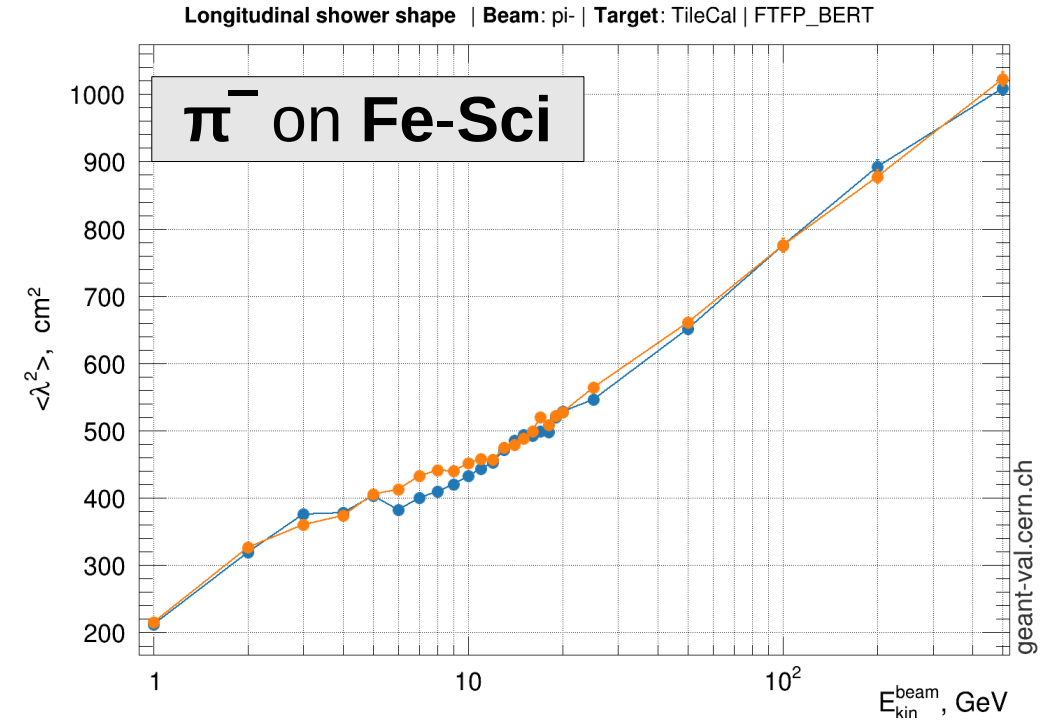


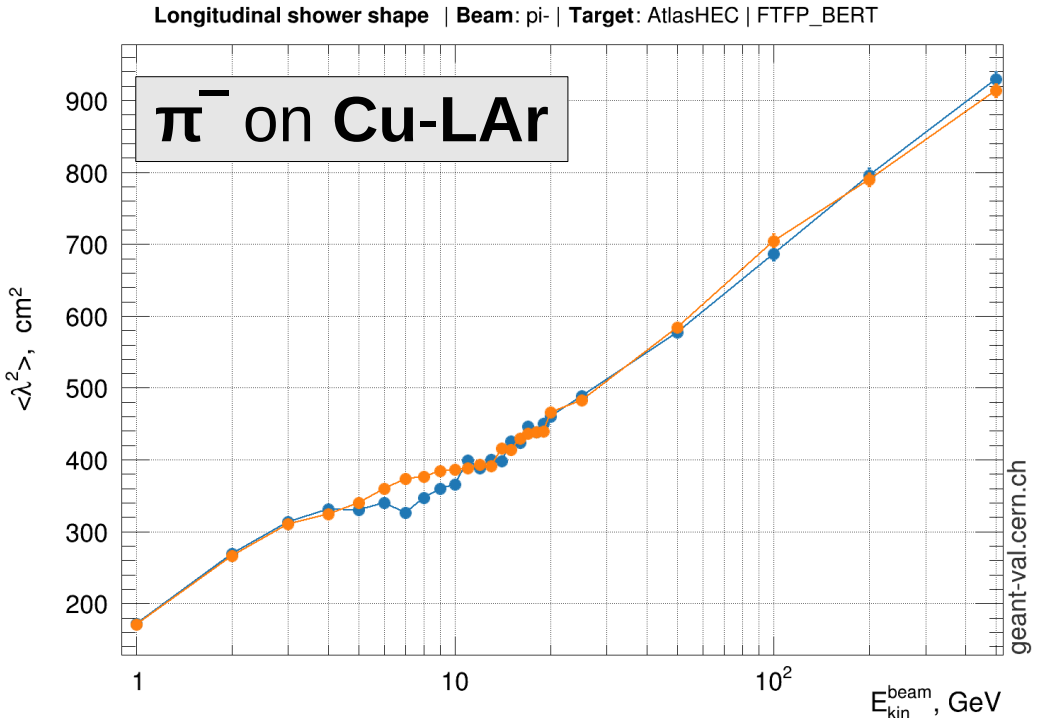


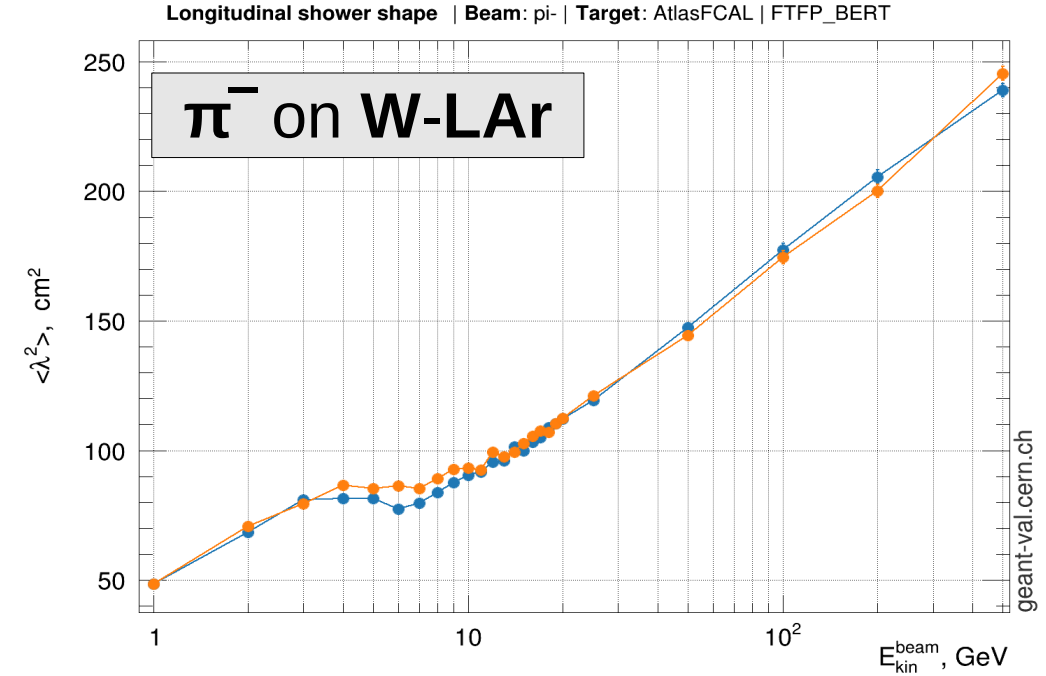


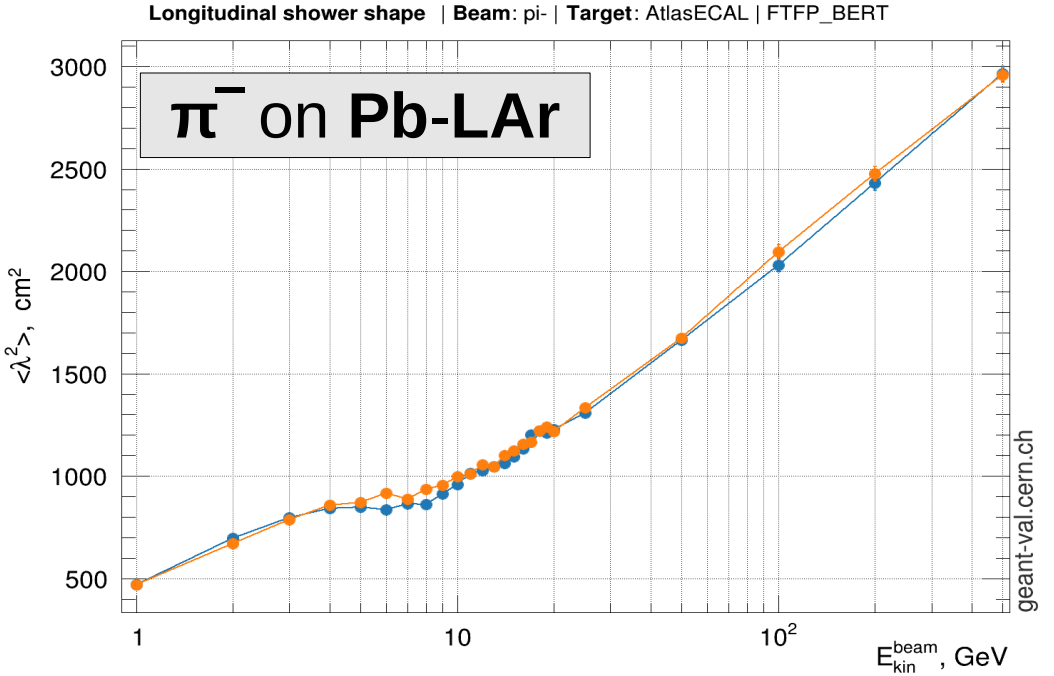


FTFP_BERT : Longitudinal Shape









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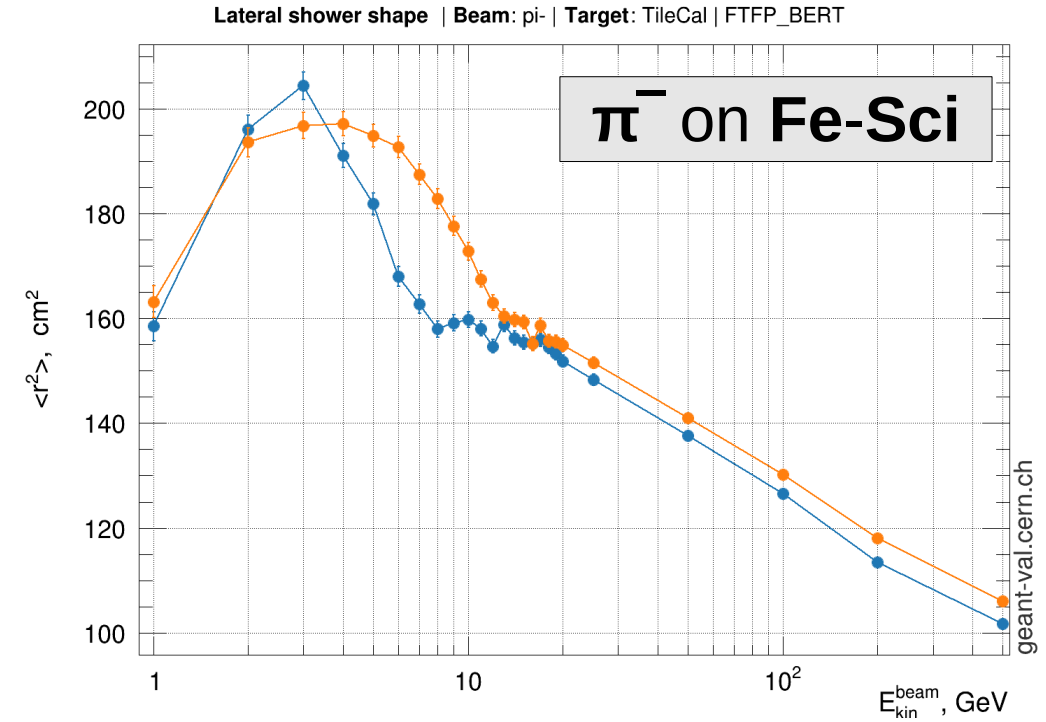
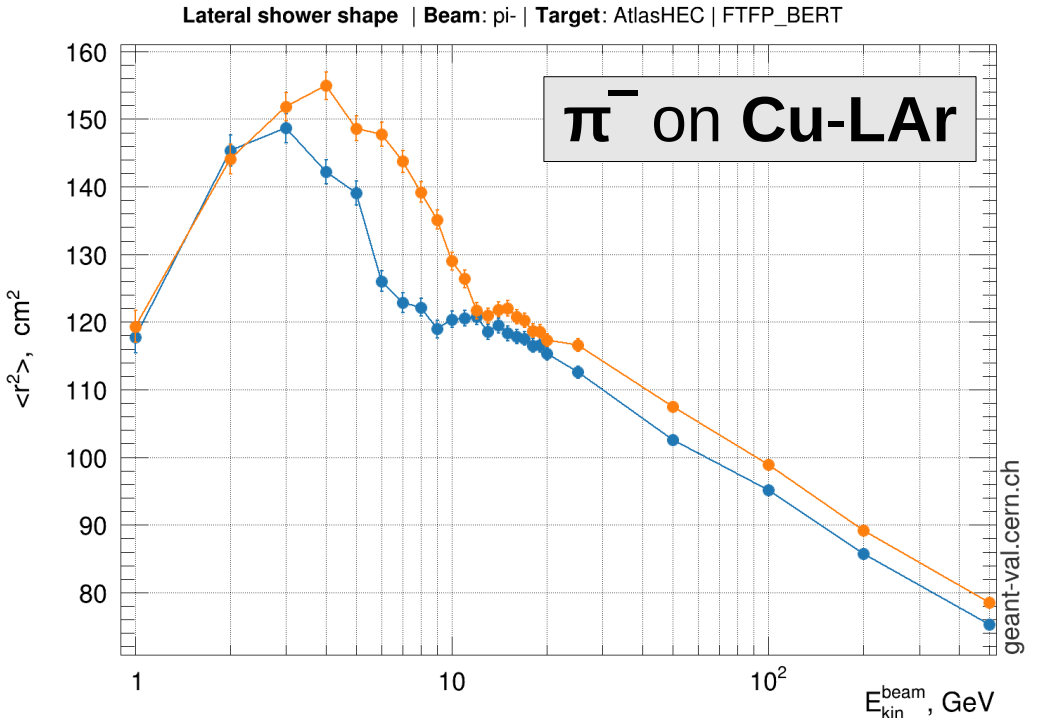
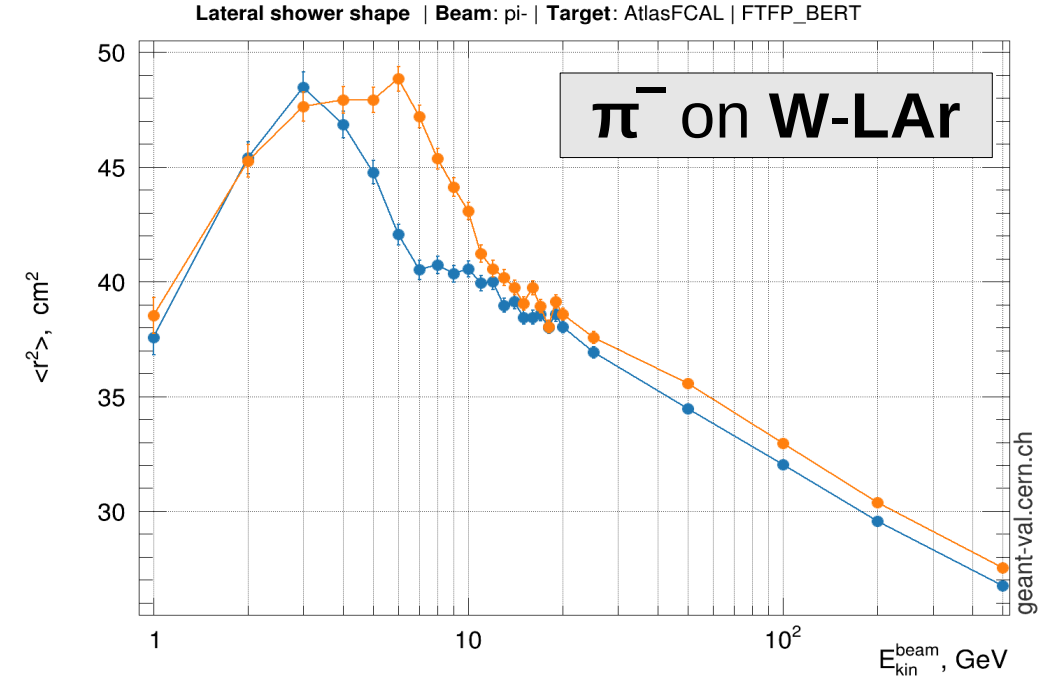
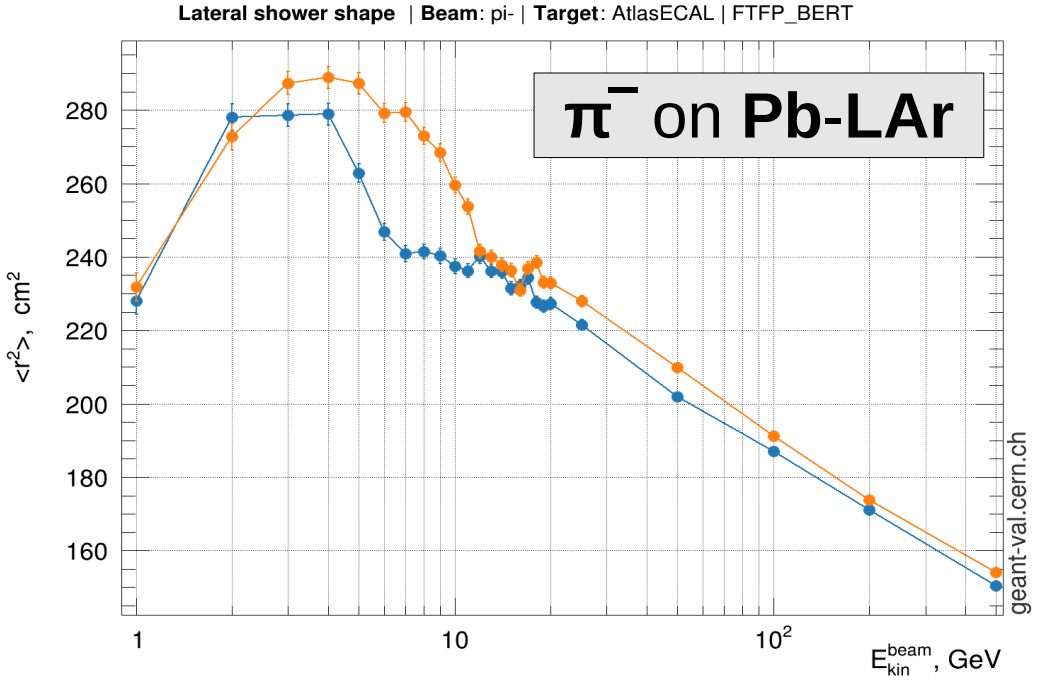
FTFP_BERT : Lateral Shape









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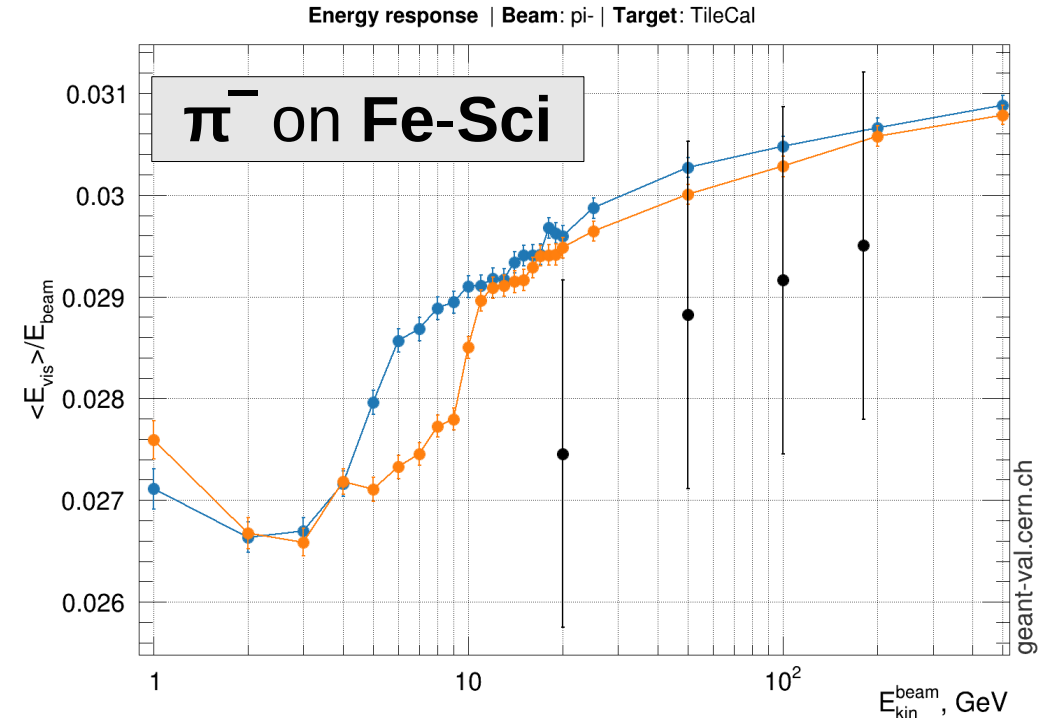
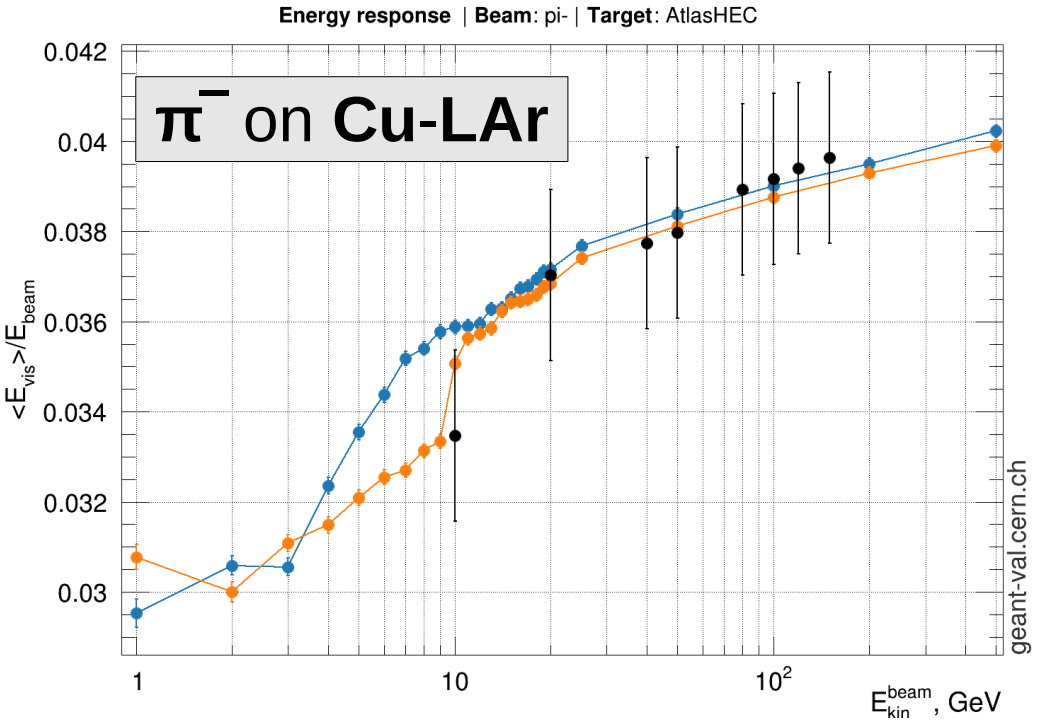
Pion- showers: QGSP_BERT

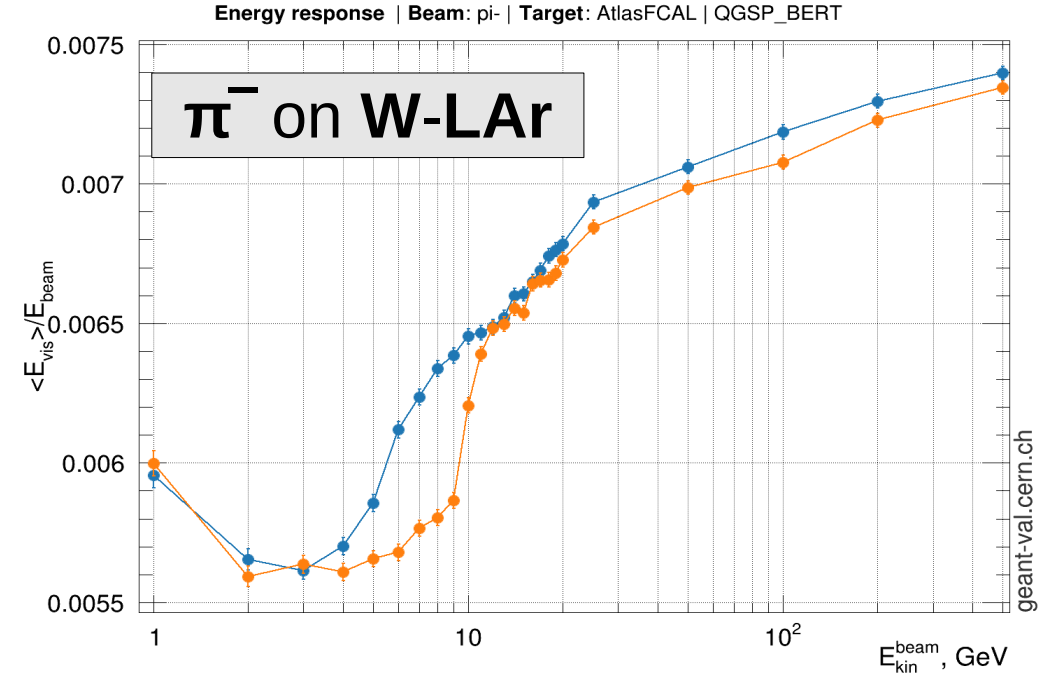
G4 “10.5.ref07.tr3_6gev”
10.5.ref07

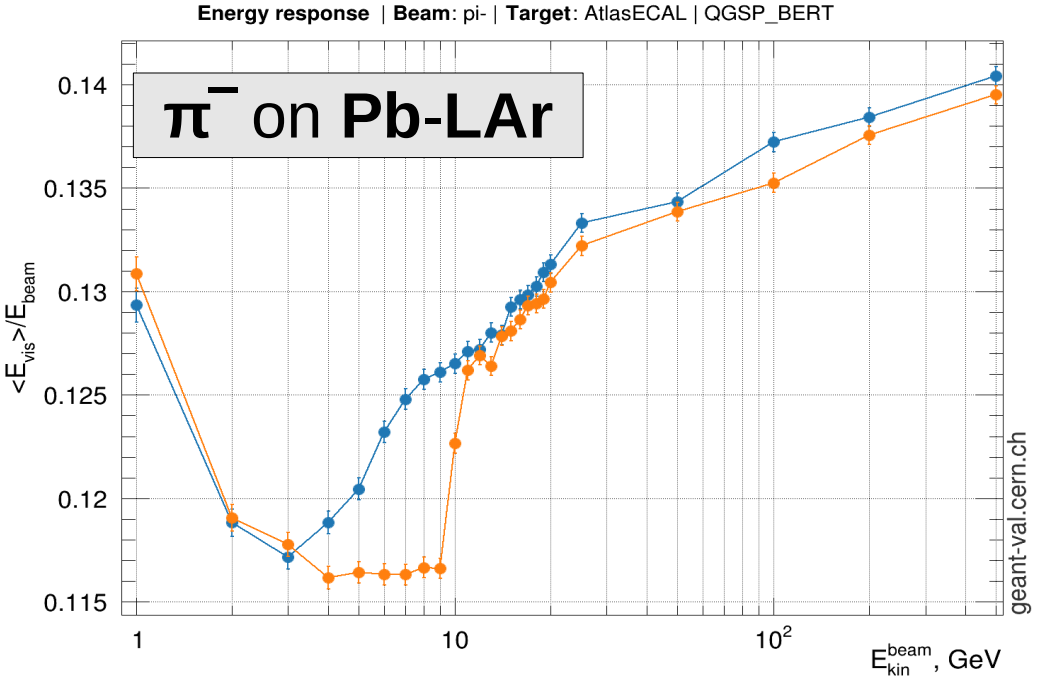
Note : conventional Birks treatment
(easier and no experimental h/e to fit !)

QGSP_BERT : Energy Response

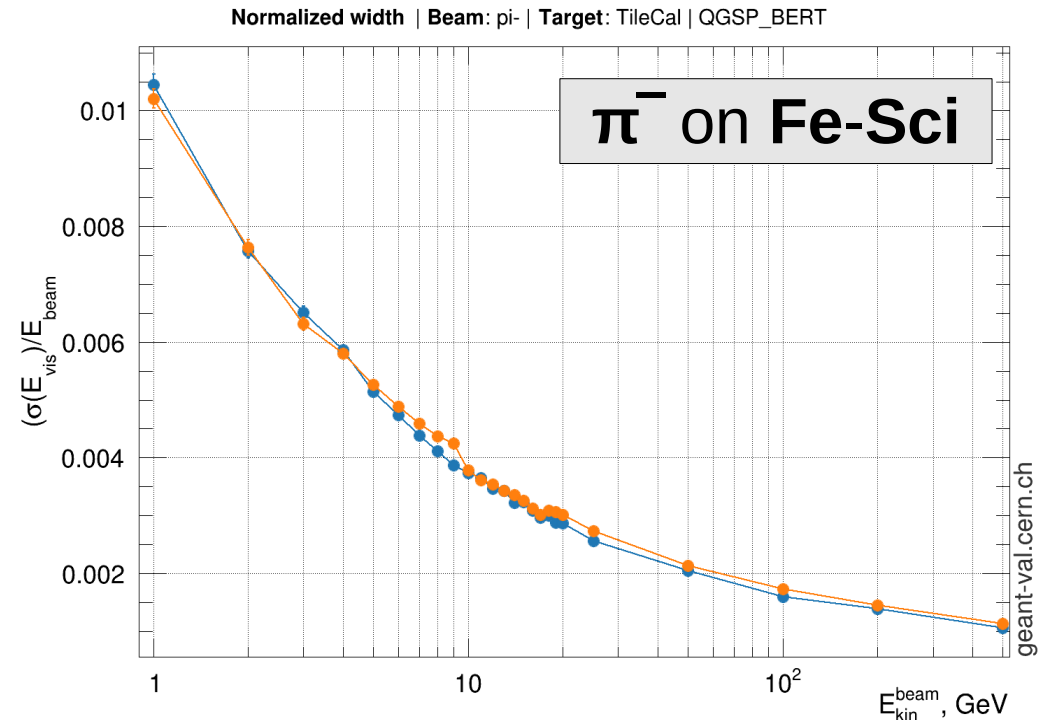


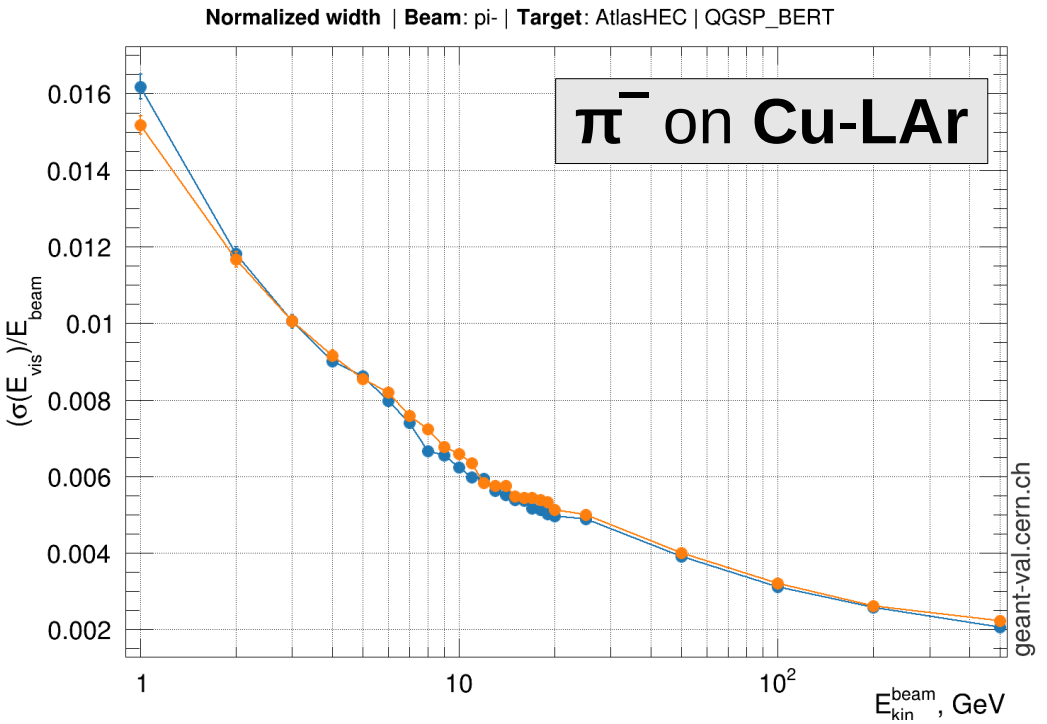


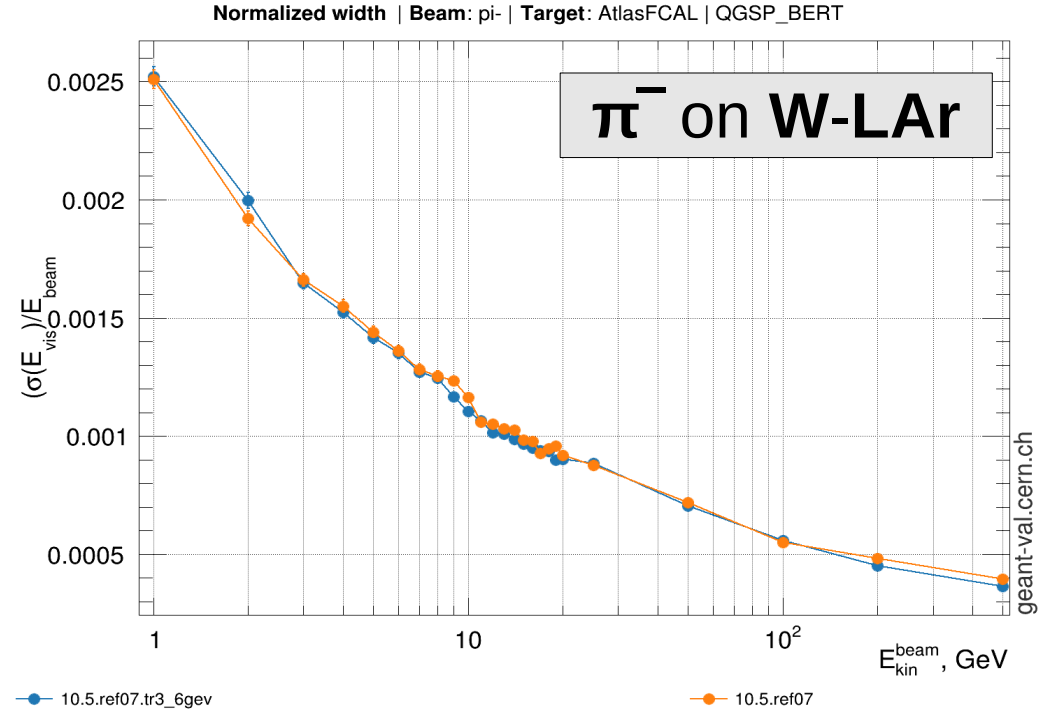


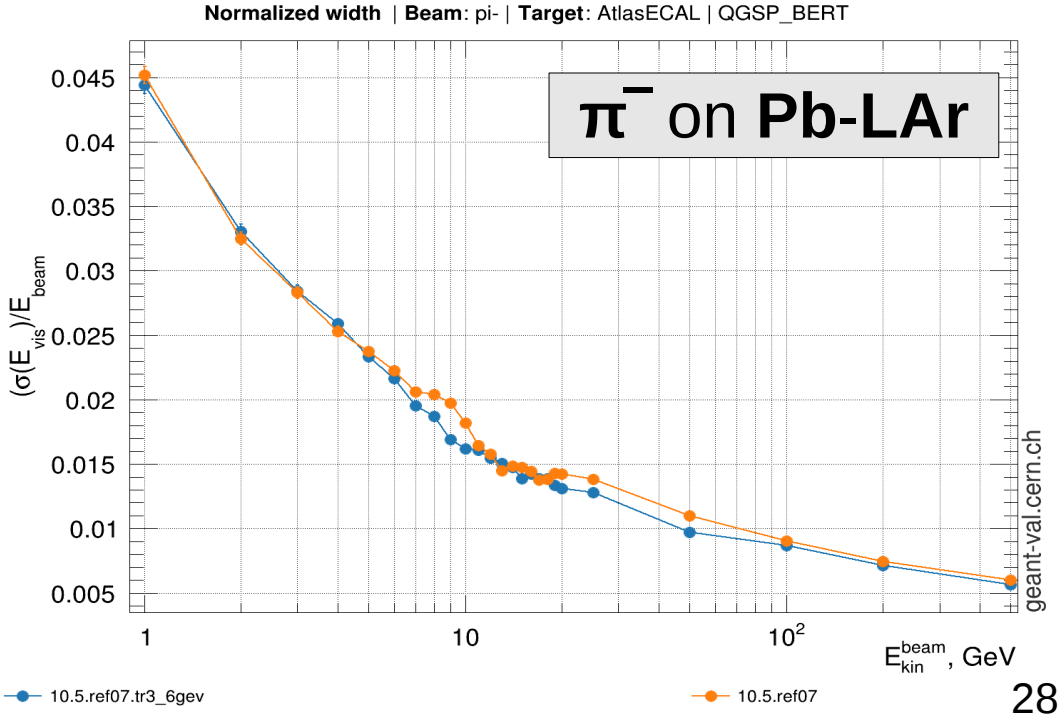


QGSP_BERT : Energy Width

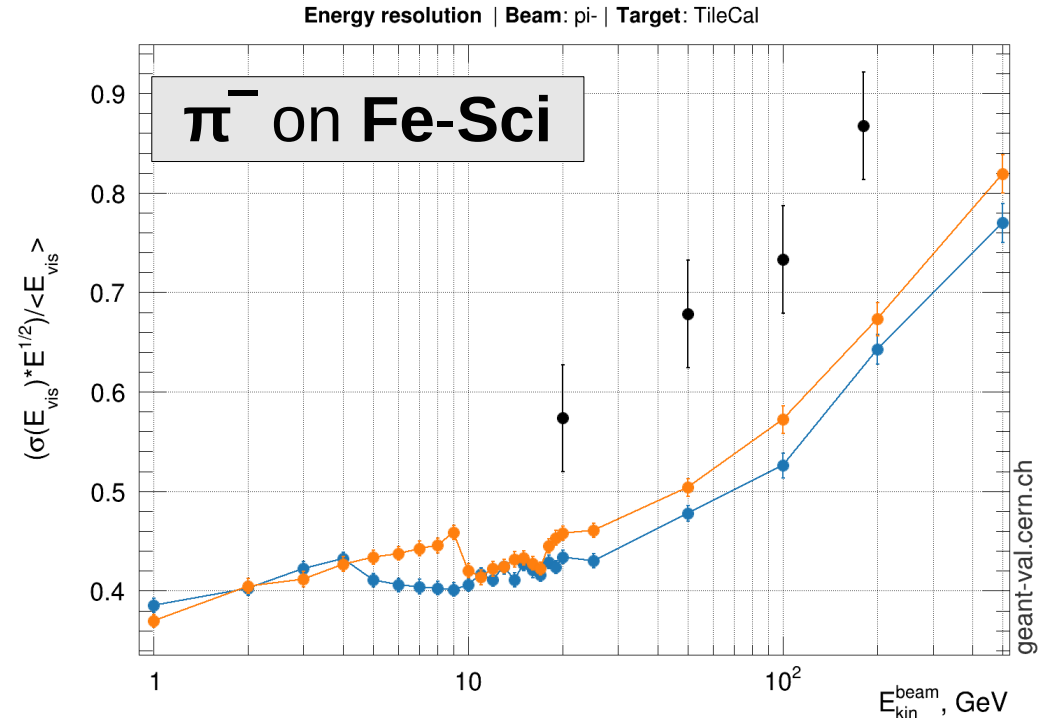


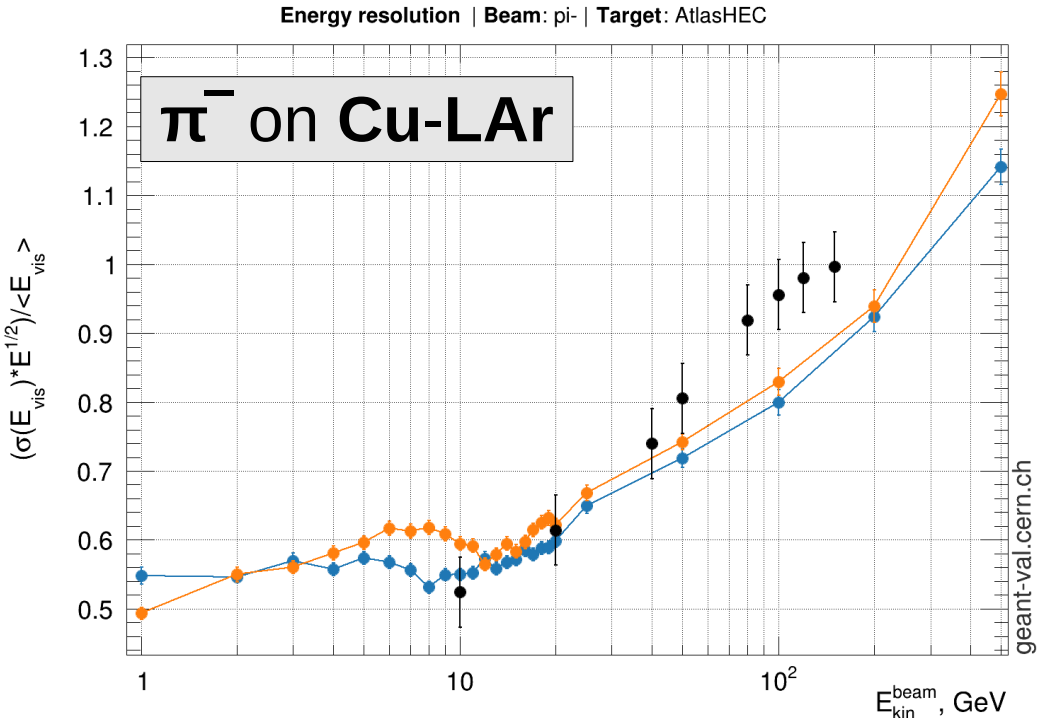


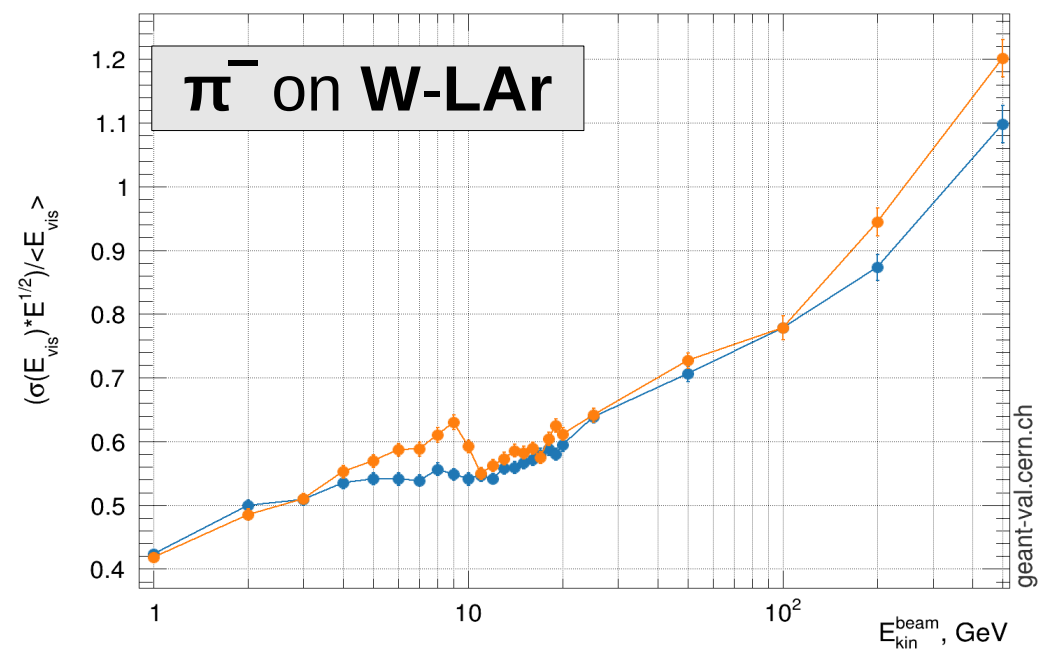


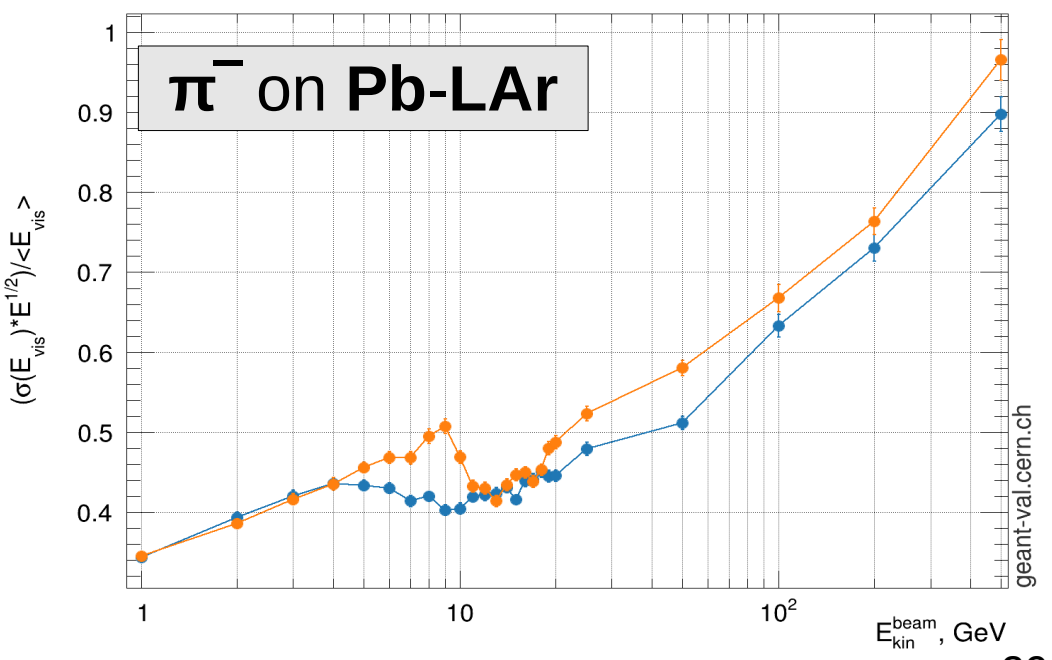


QGSP_BERT : Energy Resolution

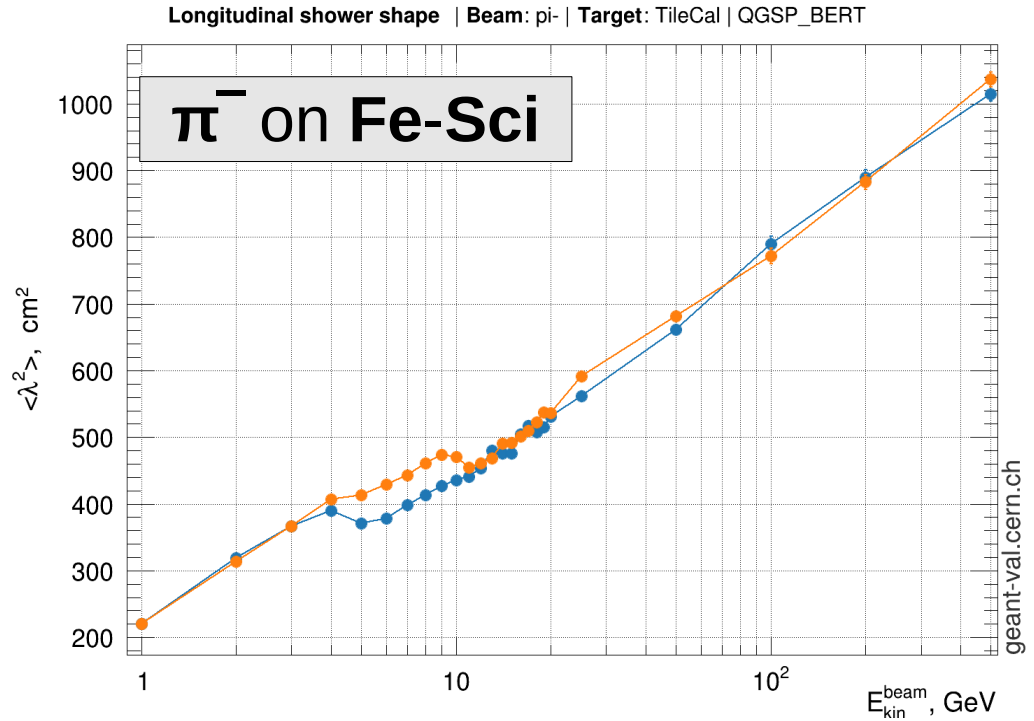


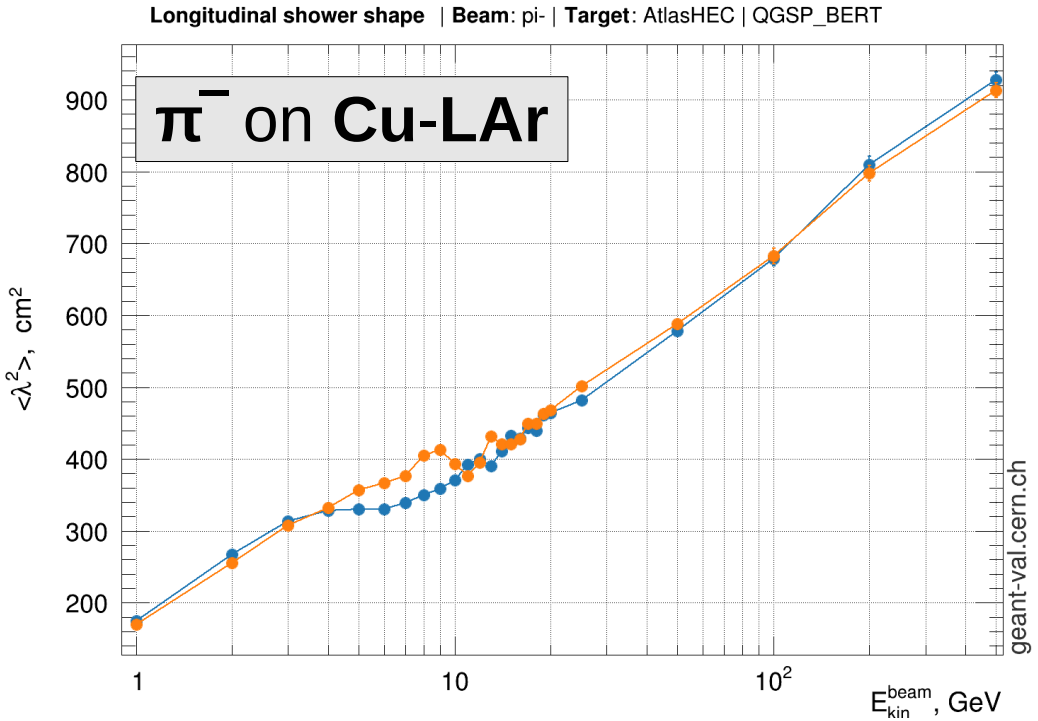


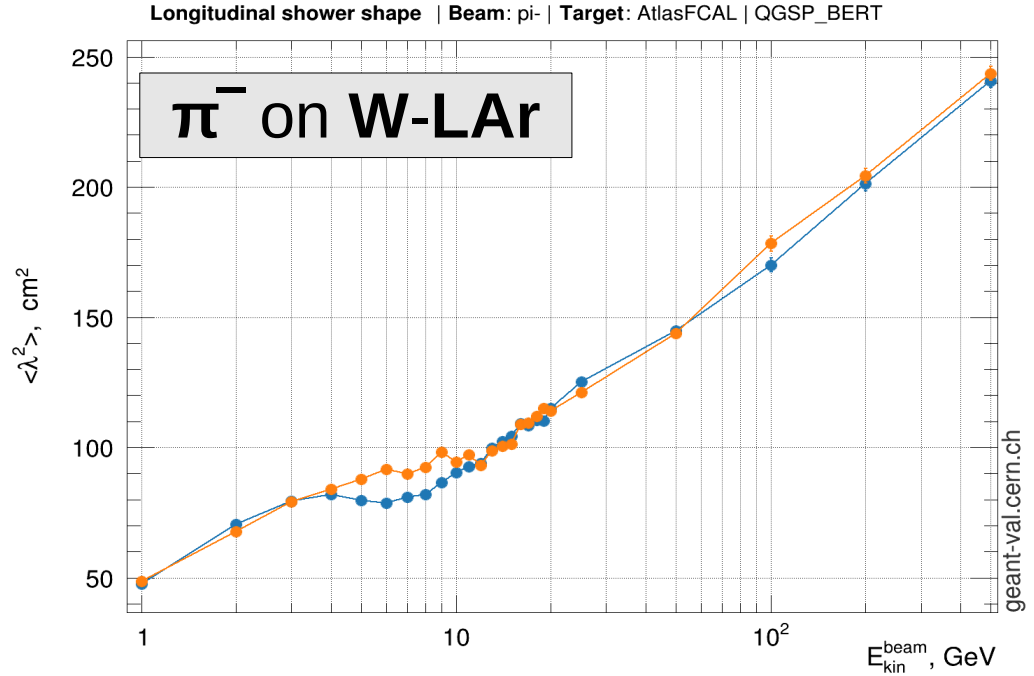


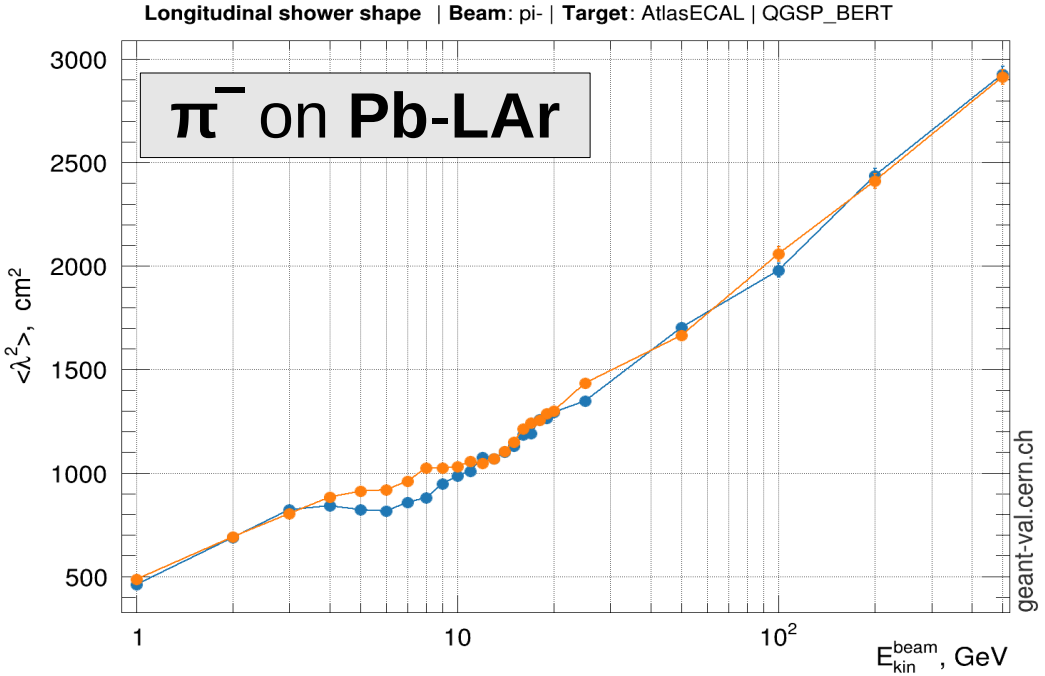


QGSP_BERT : Longitudinal Shape









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