Hadronic Highlights of Geant4 11.1

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Geant4 Technical Forum, 2 February 2023

Particles & Tracks

- Consistent treatment of half-lives and mean-lifetimes for isomers; default mean lifetime threshold for isomers is now **1 ns** in all cases
- Corrected triton and anti-triton lifetimes
  - Half-live used instead of mean-lifetime; anti-triton set as stable
    - Need patch G4 11.1.p01 (in a few weeks) to get correctly the radioactive decay of triton, while the anti-triton still does not have radioactive decay (but acceptable in practice)
- Introduced new methods in the *G4Track* class to provide information on eventual short-lived parent hadronic resonances
  - Such as ρ , ω , K* , Δ , *etc.* which do not have track objects
  - Possible now to know if two or more tracks are the daughters of the same resonance
  - Requested by NA61/SHINE Collaboration, and likely useful also to other fixed-target experiments

Hadronic Data Sets

- Updated :
  - G4NDL**4.7**
    - Updated the ThermalScattering component, obtained from the thermal scattering data of JEFF-3.3, and adding the ENDF/BVIII-0 materials not already present in JEFF-3.3

- Unchanged :
  - G4PARTICLEXS**4.0** (mandatory for FTFP_BERT)
  - G4SAIDDATA**2.0** (mandatory for FTFP_BERT)
  - G4ENSDFSTATE**2.3** (mandatory for FTFP_BERT)
  - PhotonEvaporation**5.7** (mandatory for FTFP_BERT)
  - RadioactiveDecay**5.6**
  - G4TENDL**1.4**
  - G4INCL**1.0**
  - G4ABLA**3.1**

Cross Sections

- Implemented the *integral method* in hadronics
  - To take into account the change of hadronic cross-sections along a step for charged hadrons due to the decrease of hadron's kinetic energy by ionization loss
    - Negligible effects for hadronic showers (whereas it is important for EM showers)
- Extended the Glauber-Gribov elastic and inelastic nuclear cross sections for light hypernuclei and anti-hypernuclei projectiles
  - Simplified treatment
- Introduced new cross sections for tau-neutrinos
  - Based on energy scaled cross sections of muon-neutrinos

FTF (Fritiof) string model (1/2)

- Improved string fragmentation in FTF
  - To better describe the production of strange mesons and baryons in proton-proton interactions, as measured by the NA61/SHINE Collaboration
  - Also improved leading particle spectra in meson-nucleon interactions
- Improved production of vector mesons and pseudo-scalar mesons
  - For both FTF and QGS string fragmentation, to improve the description of NA61/SHINE experimental data
    - Revised the mixing probability between vector mesons (ρ° and ω), as well as the probabilities for the ratios between pseudo-scalar and vector mesons
- Extended and revised treatment of FTF annihilation (at all energies)
  - To deal with the annihilation of light anti-hypernuclei
  - General improvement of the algorithm used to sample kinematical variables

FTF (Fritiof) string model (2/2)

- Alternative sets of FTF “tunes”
  - New singleton class *G4FTFTunings* to allow to specify alternative sets of FTF parameters, called "tunes"; added also specific UI messenger
    - Currently, the feature is mostly meant for use in internal tests, further study and development; in the future, such tunes may be offered to users for specific studies
- Control of nucleon diffraction dissociation
  - Added option to *G4HadronicParameters* to control the diffraction dissociation for nucleon projectile on target nucleus with baryon number greater than 10
    - By default, both projectile and target diffraction are switched off (but they are both active in the case of target nucleus with baryon number below or equal to 10; if instead the flag is set to "true", then both projectile and target diffraction are activated regardless of the target nucleus).

Intra-nuclear Cascade models

- Bertini-like (BERT)
  - Stable, no developments
- Binary (BIC)
  - Stable, no developments
- Liege (INCLXX)
  - Stable, no developments
    - *But on-going work, not yet released (expected for G4 11.2), to extend the model to anti-proton annihilation (at rest and in-flight)*

Nuclear de-excitation

- Added limitation on the decays of unphysical fragments, allowing for removal of light unphysical states and providing improved isotope production for the spallation fragments
  - In particular, better and more consistent treatment of floating levels
- Better treatment of Coulomb barrier
- Extended upper limit of atomic de-excitation from Z=100 to Z=104
- Extended nuclear de-excitation for hyper-fragments (*i.e.* fragments with Lambdas inside)
  - Do not perform pre-compound emission but only equilibrium emission
  - Simplified treatment for equilibrium emission

Others

- New *G4NeutronGeneralProcess* combined process; enabled in the reference physics list QBBC
  - Similar to the *G4GammaGeneralProcess* , the physics remain unchanged but can speed-up the simulation by reducing the number of cross section evaluations (in particular for granular geometries)
- Extended atomic de-excitation in radioactive decays
  - In *G4ECDecay* and *G4ITDecay* , extended upper limit of atomic de-excitation from Z=100 to Z=104
- Tau-neutrino nuclear interactions
  - New final-state models for tau and anti-tau neutral and charged current neutrino-nucleus interactions
- Extended nuclear elastic scattering for light hypernuclei and anti-hypernuclei projectiles on target nuclei
  - Simplified treatment

Light Hypernuclei and Anti-hypernuclei

- Complete (but simplified) treatment of light (anti-)hypernuclei
  - By default, no light hypernuclei and anti-hypernuclei
  - If enabled, via:
    - *G4HadronicParameters::Instance()→SetEnableHyperNuclei(true);*

    then, the following interactions are included in all reference physics lists:
    - simplified treatment of weak decays
    - ionization and multiple scattering for the charged particles

    moreover, only for FTFP_BERT and FTFP_INCLXX physics lists, also the following hadronic interactions are included:
    - nuclear elastic scattering
    - nuclear inelastic scattering, handled by either the FTF string model or by the INCL intranuclear cascade model, with a very simplified treatment of nuclear de-excitation
      - INCL is applicable only to hypernuclei, not to anti-hypernuclei;
        FTF is applicable to both hypernuclei and anti-hypernuclei (at all energies for the latter);
        note that QGS is not applicable to ion projectiles (of any kind)

Hadronic showers *(see plots in backup slides)*

- Small changes in hadronic showers in G4 **11.1**, with FTF- and QGS-showers getting a bit closer to each other
  - With respect to G4 11.0.p03
    - FTFP_BERT pion showers have slightly (~0.5%) higher energy response and (~2%) narrower lateral shapes
    - QGSP_BERT pion showers have slightly (~0.5%) lower energy response and (~2%) wider lateral shapes
  - QGSP_BERT showers with respect to FTFP_BERT ones:
    - ~ 1-2% higher energy response
    - ~ 10% wider (*i.e.* less optimistic) energy resolution
    - ~ 5% longer showers
    - ~ 7% narrower showers

Reminder: we recommend to fit the Birks quenching coefficient from the h/e test-beam data !

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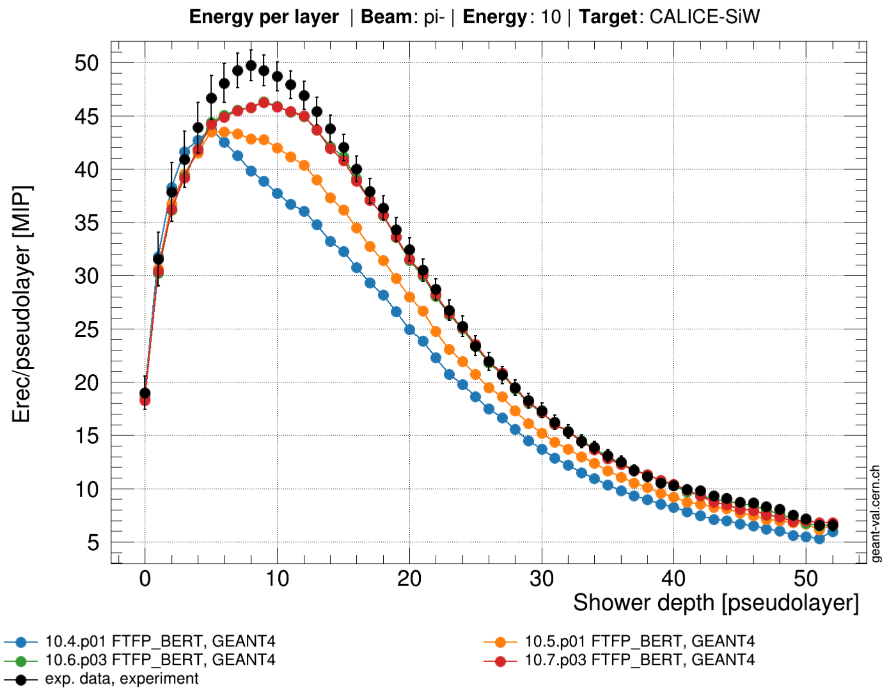
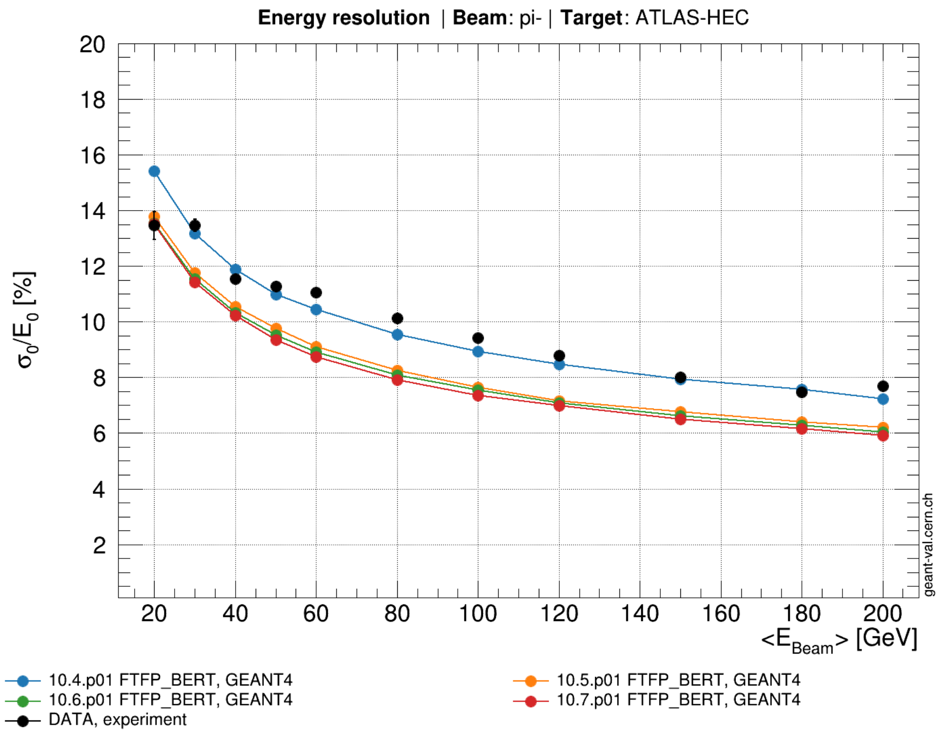
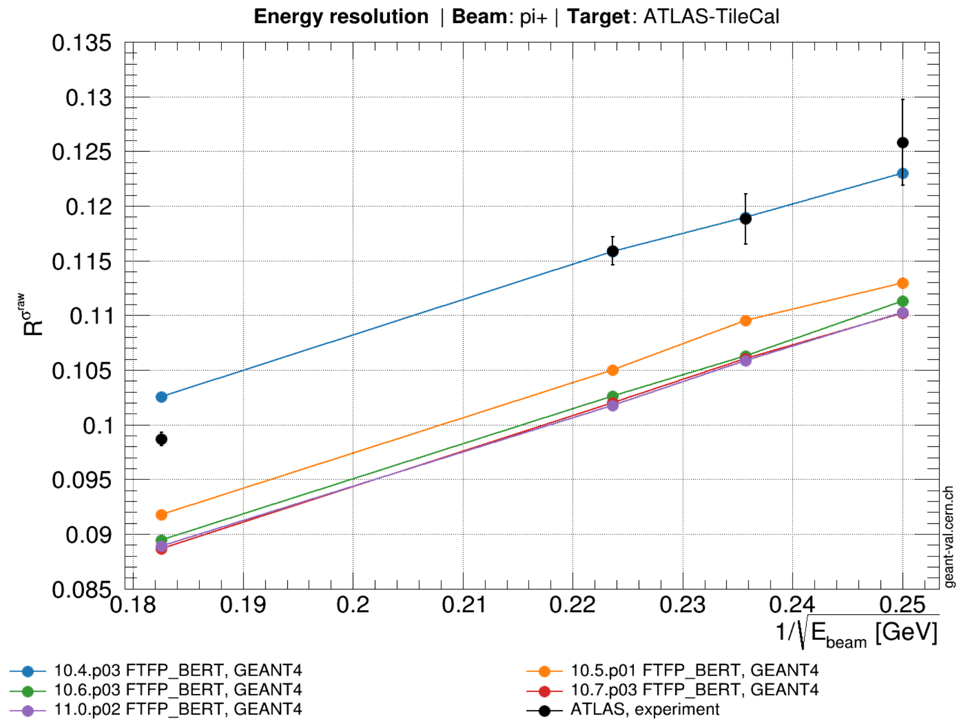
- We rely heavily on this tool for testing and validating Geant4
  - For major, minor, patches and monthly development versions
- The only validation tool in Geant4
- On-going work to extend its coverage
  - In particular, by importing calorimeter test-beams, *e.g.* **ATLAS HEC**, **ATLAS TileCal**, **CALICE SiW**, new **Dual-Readout** calorimeter, *etc.*



Too optimistic energy resolution for pion showers in ATLAS calorimeters

- ~20% disagreement since G4 10.5, seen in both ATLAS HEC and TileCal





Examples related to hadronics

- ***ParticleFluence***
  - New set of examples implementing different setups − Sphere, Concentric Spheres, Layer, Calo − for scoring particle fluences
- *Hadr**01***
  - Extended to charm and bottom hadrons projectiles
  - Extended to light hypernuclei and anti-hypernuclei projectiles
- *Hadr**09***
  - Extended to light hypernuclei and anti-hypernuclei inelastic nuclear interactions

Backup slides

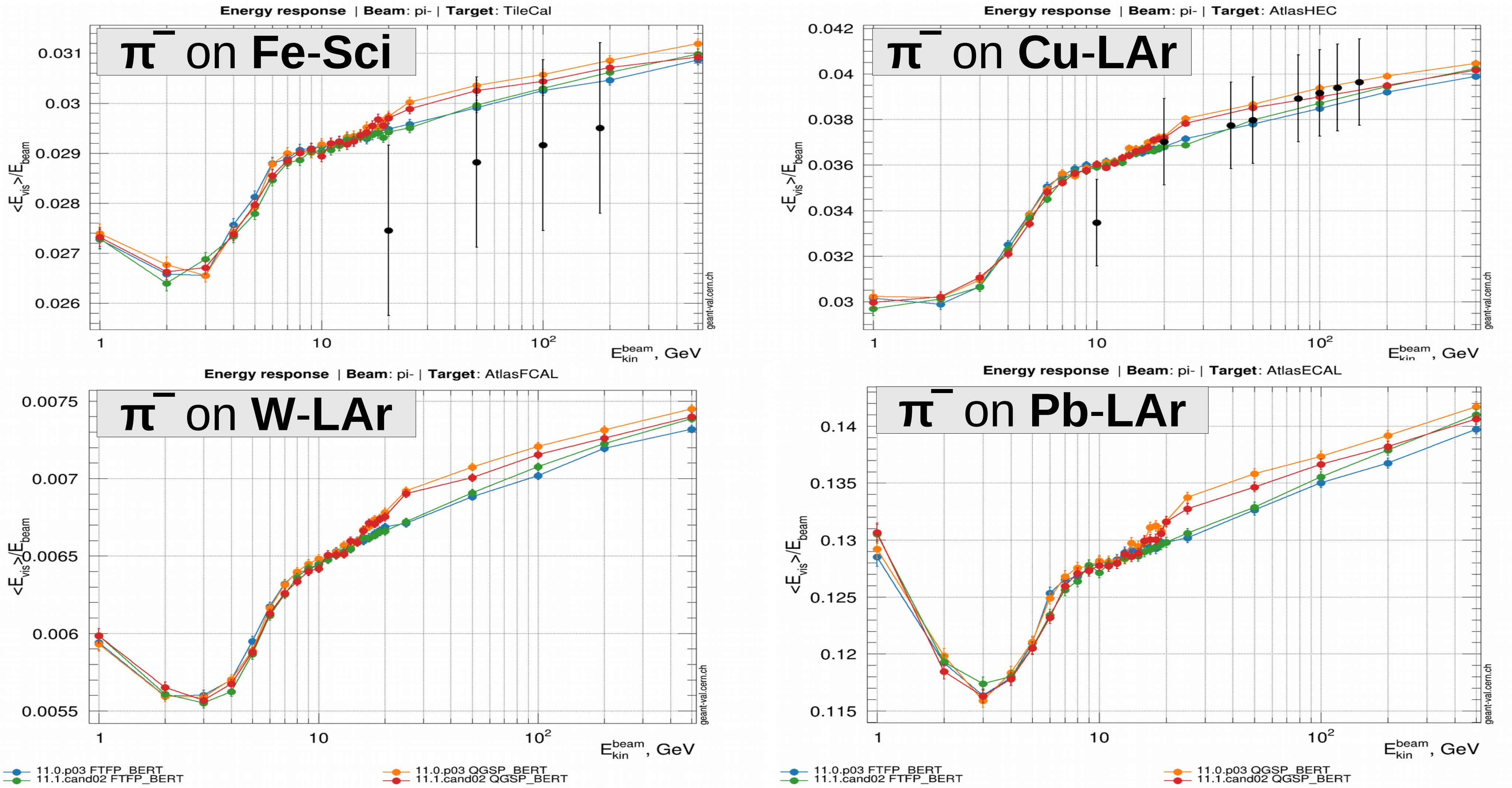
Pion– showers:

G4 11.1 FTFP_BERT
G4 11.0.p03 FTFP_BERT

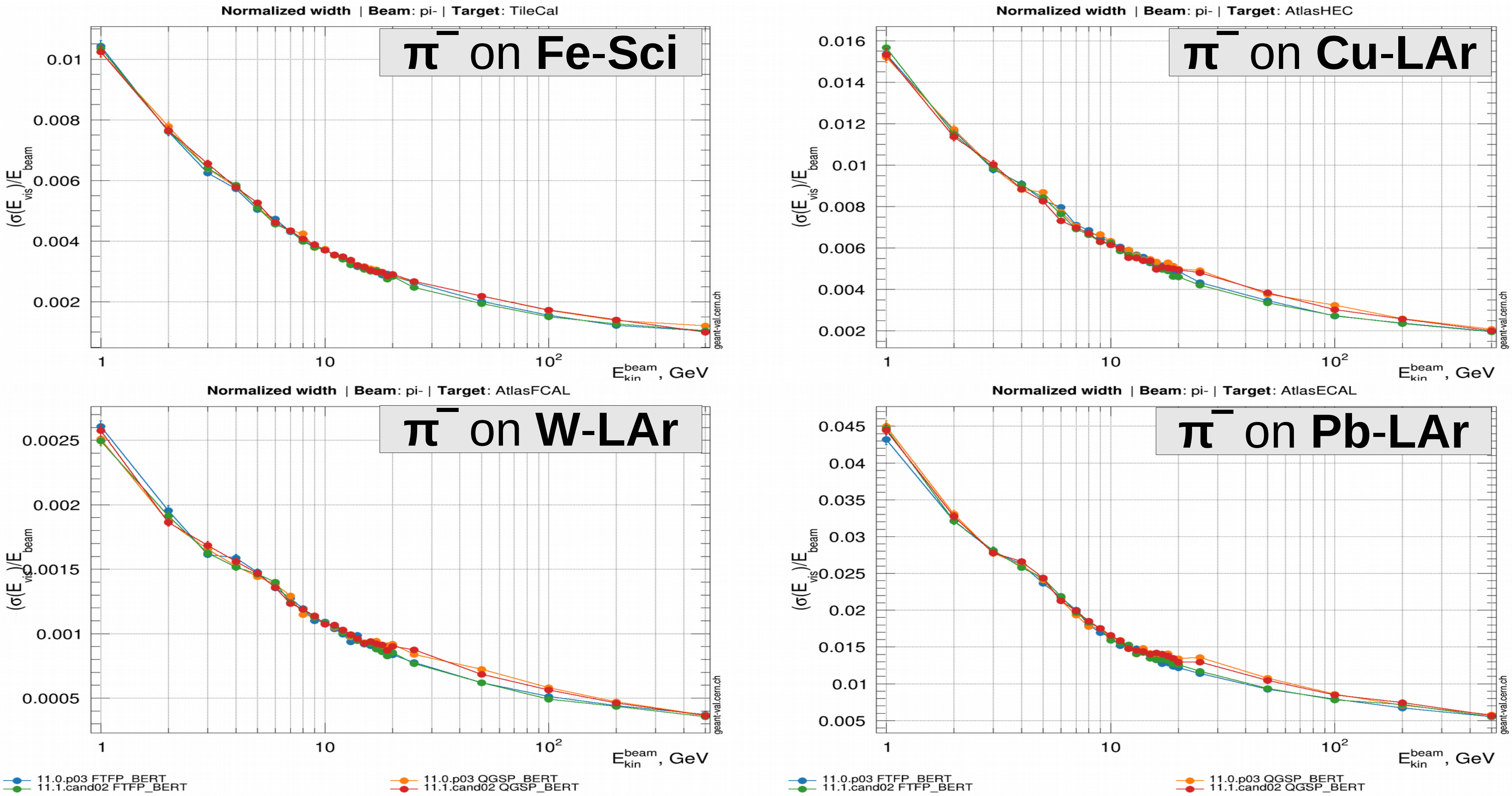
G4 11.1 QGSP_BERT
G4 11.0.p03 QGSP_BERT

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

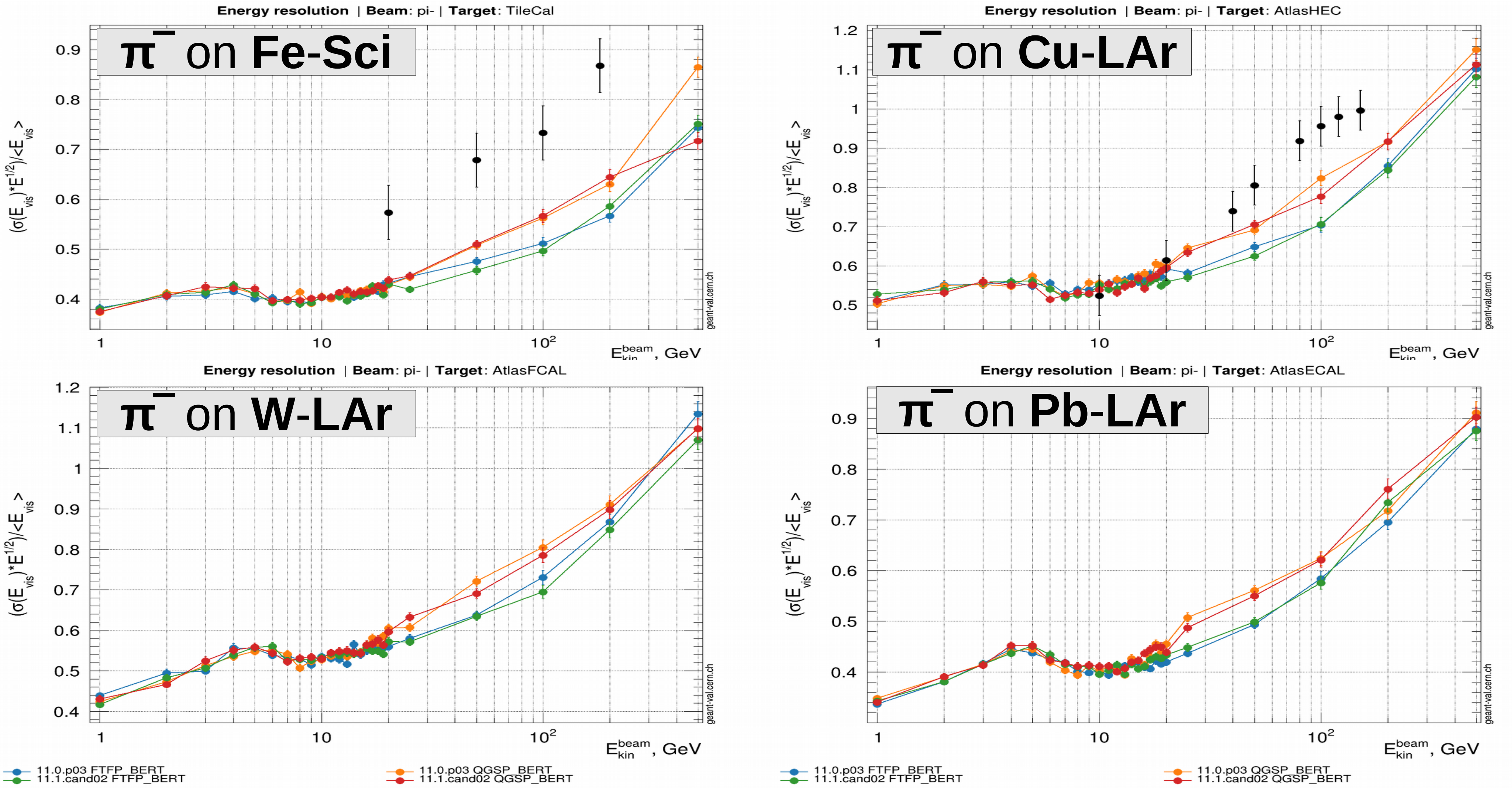
Energy Response



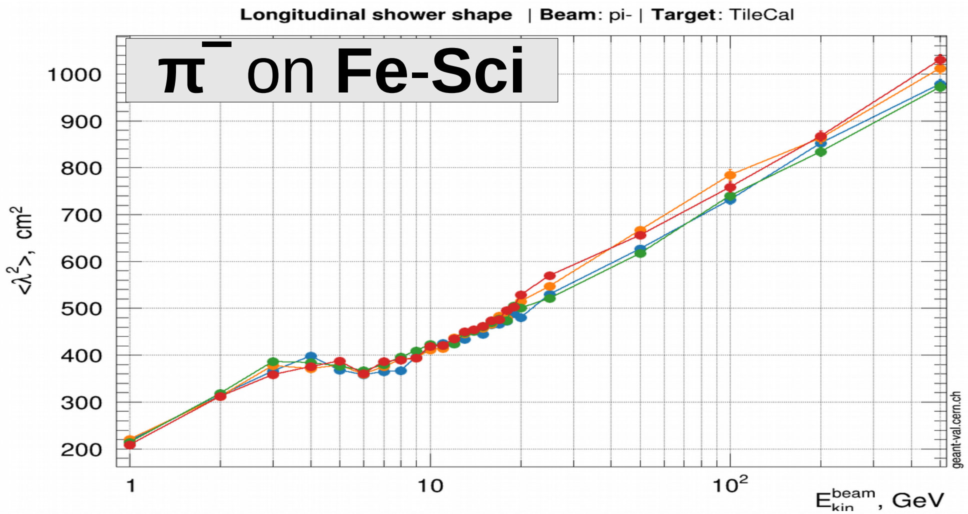
Energy Width

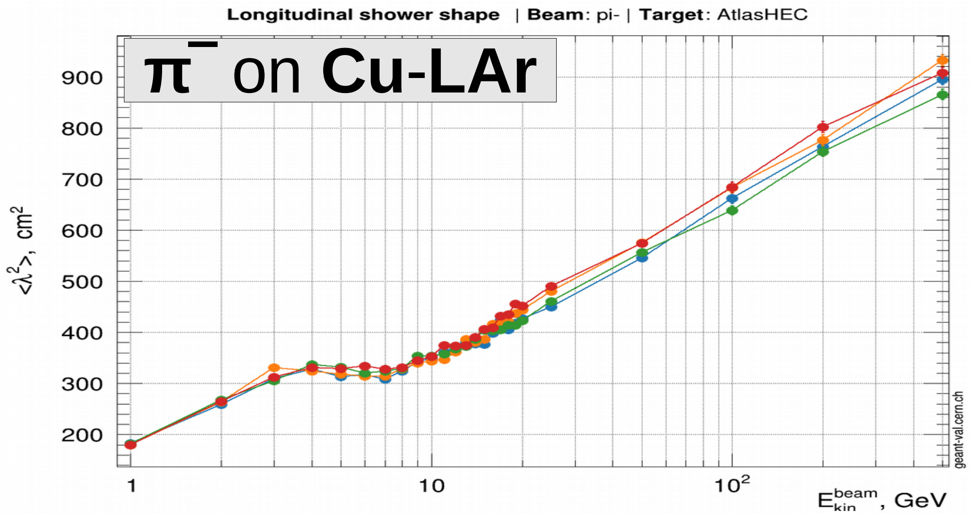


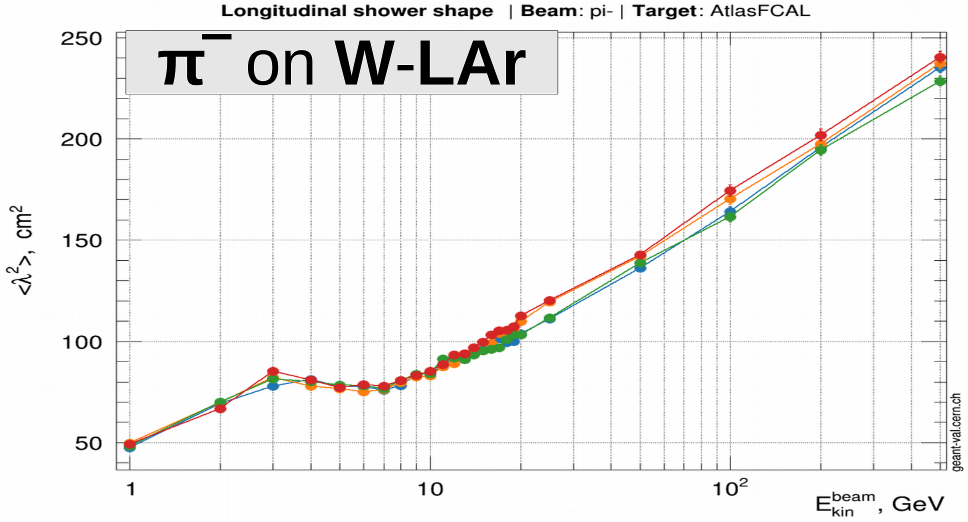
Energy Resolution

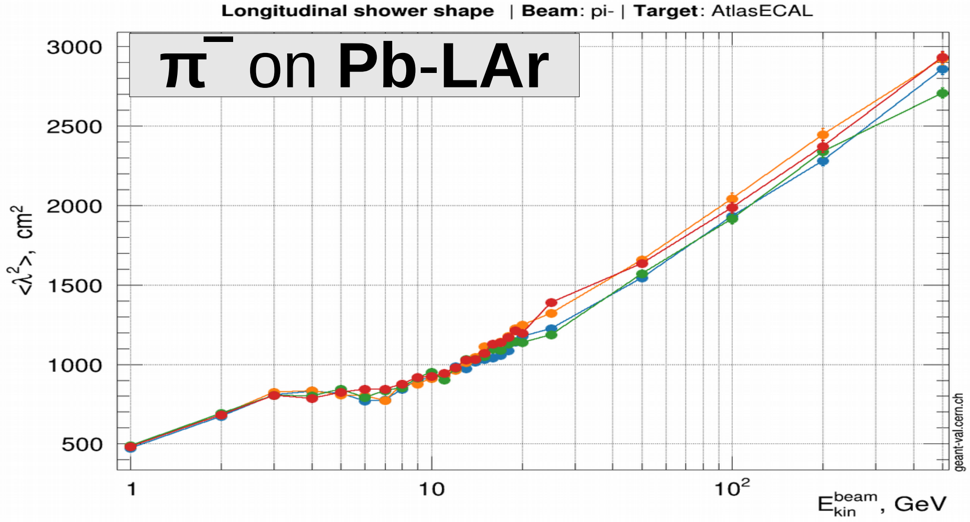


Longitudinal Shape









11.0.p03 FTFP_BERT
11.1.cand02 FTFP_BERT
11.0.p03 QGSP_BERT
11.1.cand02 QGSP_BERT

11.0.p03 FTFP_BERT
11.1.cand02 FTFP_BERT
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11.1.cand02 QGSP_BERT

Lateral Shape