Hadronic Physics Highlights of Geant4 11.3

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Hadronic Data Sets (1/2)

- Updated the main hadronic data sets
  - G4ENSDFSTATE**3.0** , PhotonEvaporation**6.1** , RadioactiveDecay**6.1.2**
    - Updated with the ENSDF (Evaluated Nuclear Structure Data File) data from March 2024
    - **More consistent treatment of nuclides with incomplete information, and with fewer unphysical states**
- Others
  - Updated G4PARTICLEXS**4.1**
    - Updated cross sections for all isotopes for neutron, proton, and light ion projectiles
    - Fixed cross sections for Argon, Promethium, Astatine, Radon, and Francium
    - Fixed low-energy limits of cross sections
  - New, optional data sets : G4NUDEXLIB**1.0** , G4URRPT**1.1**
    - The first is used by the new model NuDEX, through the environmental variable G4NUDEXLIBDATA
    - The second is used by the new URR treatment of low-energy neutrons, through the environmental variable G4URRPTDATA

Hadronic Data Sets (2/2)

- Updated :
  - G4ENSDFSTATE**3.0** (mandatory for FTFP_BERT)
  - PhotonEvaporation**6.1** (mandatory for FTFP_BERT)
  - RadioactiveDecay**6.1.2** (mandatory for FTFP_BERT)
  - G4PARTICLEXS**4.1** (mandatory for FTFP_BERT)
- Unchanged :
  - G4SAIDDATA**2.0** (mandatory for FTFP_BERT)
  - G4INCL**1.2**
  - G4ABLA**3.3**
  - G4NDL**4.7.1**
  - TENDL**1.4**
- New, optional :
  - G4NUDEXLIB**1.0**
  - G4URRPT**1.1**

Hadronic Cross Sections

- Updated cross section classes to rationalise initialisation of data in MT mode
  - In view of the parallelisation of physics initialisation planned for next year
- New class *G4InterfaceToXS* , to compute inverse cross sections based on G4PARTICLEXS cross sections for neutron and light ions
  - Used to evaluate evaporation probabilities in nuclear de-excitation
- Optimised *G4ChargeExchangeXS* , by switching computations from isotopes to elements and making the code running faster without loss of accuracy
  - Used in the physics list constructor *G4ChargeExchangePhysics* – currently utilised only in the QBBC reference physics list

String Models

- Fritiof (**FTF**) model
  - No physics development after G4 11.2
  - On-going physics validation

- Quark-Gluon String (**QGS**) model
  - No physics development after G4 11.2
  - On-going physics validation

Intra-nuclear Cascade Models

- **BERT** (Bertini-like cascade)
  - **Improved angular emissions for 4-body and higher-body generation**
    - BERT becomes closer to FTFP, and this has an impact on hadronic showers
    - Reminder: BERT is the most used, workhorse cascade model in HEP
- **BIC** (Binary Cascade)
  - Stable
    - Reminder: used in medical physics, and sometimes in HEP for evaluating systematic errors
- **INCLXX** (Liege cascade)
  - Consolidation of the antiproton physics introduced in 11.2
    - Great interest in this recent development from the antiproton physics experiments at CERN, as well as in astroparticle experiments (*e.g.* GAPS)
    - Reminder: INCLXX is used in production by ALICE;
      moreover, there is a growing interest by the neutrino community...

PreCompound

- Changed treatment of inverse cross sections
  - From Kalbach's parameterisation (Option 3)
    to *G4NeutronInelasticXS* & *G4ParticleInelasticXS* (Option 1)

Nuclear De-excitation

- Several technical changes, a few physics fixes and improvements
  - Fixed usage of pairing corrections, with better agreement with experimental data
  - Fixed computation of the minimal kinetic energy of fragments and use of Coulomb barrier
  - Simplified computation of corrections and probabilities
  - Introduced a new class, *G4InterfaceToXS*, to compute the inverse cross sections
    - Based on G4PARTICLEXS for neutron and light ions
  - ...

Including NuDEX in Geant4

- New alternative and more sophisticated nuclear de-excitation model, for the emission of gammas and internal conversion electrons
  - Useful for more precise simulations of gamma and electron emissions in nuclear reactions
  - Relies on a new hadronic data set, G4NUDEXLIB1.0 (~80 MB, ascii files)
    - Various parameters from ENSDF, BrICC, RIPL-3, and IAEA
    - Pointed by the environmental variable **G4NUDEXLIBDATA**
  - When it cannot be applied, it relies on *G4PhotonEvaporation*
  - For the time being, it can be used only for neutron capture when ParticleHP is utilised in the QGSP_BERT_HP physics list
    - To enable it, use the following C++ interface:
      G4HadronicParameters::Instance()->SetEnableNUDEX(true);
    - In the future, it will be possible to use it more generally, as an alternative evaporation model, as well as in other physics lists

Unresolved Resonance Region (URR) treatment via Probability Tables (PT)

- Major physics improvement in the treatment of low-energy (< 20 MeV) neutrons
  - Relevant for more precise simulations of nuclear reactor criticality and shielding applications
    - Making Geant4 another step closer to MCNP and TRIPOLI
  - Relies on a new data set, G4URRPT1.1 (~290 MB, compressed files)
    - Probability tables at temperature 293.15 K processed with both NJOY and CALENDF, from the JEFF-3.3 library and consistent with G4NDL4.7.1
    - Pointed by the environmental variable **G4URRPTDATA**
  - By default, it is not included
    - It can be activated on top of any reference physics list based on HP (or HPT) by using the new physics list constructor class ***G4URRNeutrons***
    - The choice of the type of PT between NJOY or CALENDF is done via C++ interface, *e.g.* ***G4HadronicParameters::Instance()->SetTypeTablePT("calendf");***

Notes

- QGSP_BERT_**HP**
  - Since Geant4 version 11.2, the physics list QGSP_BERT_HP has a treatment of low energy (< 20 MeV) neutrons which is not the same as for the other HP-based reference physics lists (FTFP_BERT_HP, QGSP_BIC_HP, Shielding, *etc.*)
  - QGSP_BERT_HP is still under validation, therefore it is not recommended for physics studies, but users are welcome to try out and provide feedback

- Radioactive Decay
  - *G4RadioactiveDecay* has been renamed ***G4VRadioactiveDecay*** , and *G4Radioactivation* has been renamed ***G4RadioactiveDecay***
  - The header for *G4Radioactivation* is preserved to provide backward compatibility

Hadronic showers *(see plots in backup slides)*

- For nearly all reference physics lists, hadronic showers in G4 **11.3** have
  ~ 1-2% higher energy response and
  ~ 5% narrower lateral showers
  than those of G4 11.2
  - Due to the improvement in the angular emission of ≥ 4 bodies in BERT, reducing the differences between this model and FTFP
  - QGSP_BERT showers with respect to FTFP_BERT ones in G4 11.3 :
    - ~ 1-2% higher energy response
    - **~ 10% wider (*i.e.* less optimistic) energy resolution**
    - ~ 5% longer showers
    - ~ 4% narrower showers

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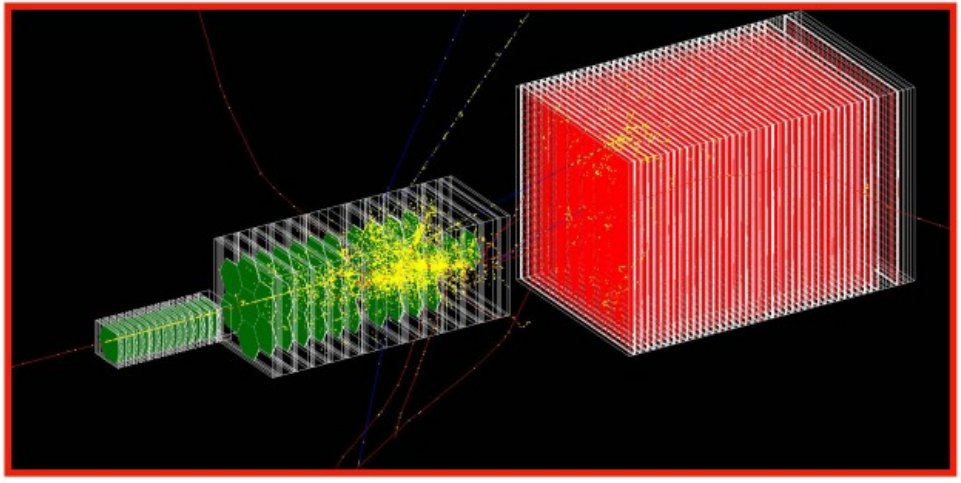
- The validation and testing suite of Geant4
- We rely heavily on it for all releases
  - For major, minor, patches and monthly development versions
- On-going work to extend its coverage
  - Added in 2024 the CMS HGCal test-beam set-up, important for both physics validation and computing performance studies
  - On-going work to include benchmarks for low-energy neutrons, comparing with reference codes – MCNP & Tripoli



Backup slides

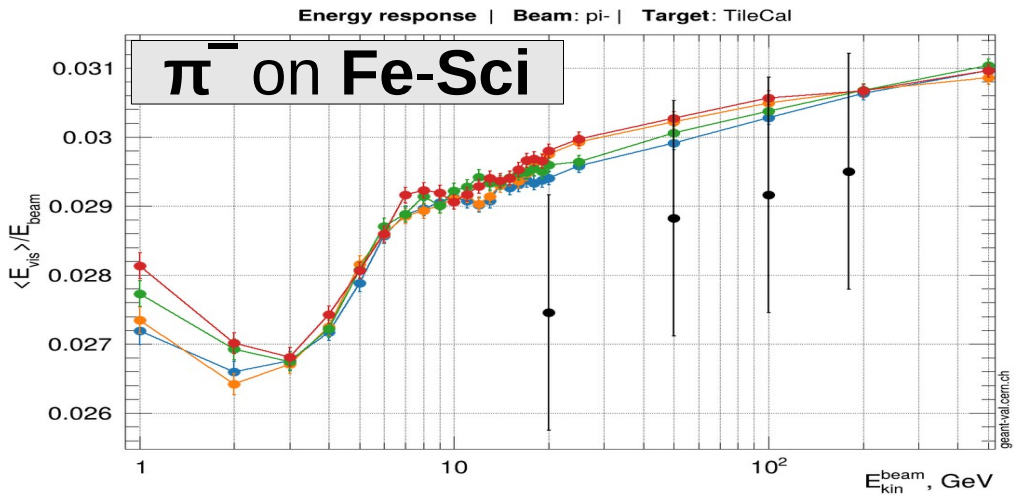
Pion− showers:

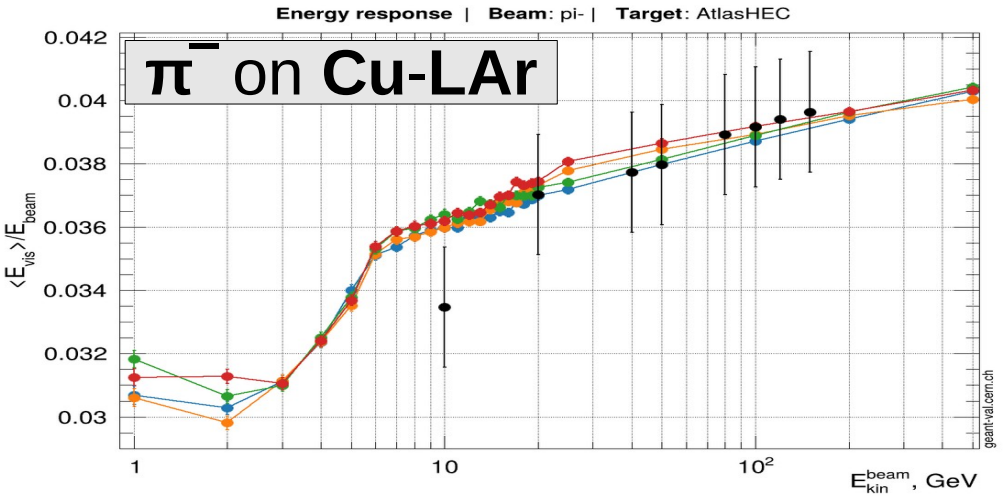
G4 11.3 FTFP_BERT
G4 11.2.p02 FTFP_BERT

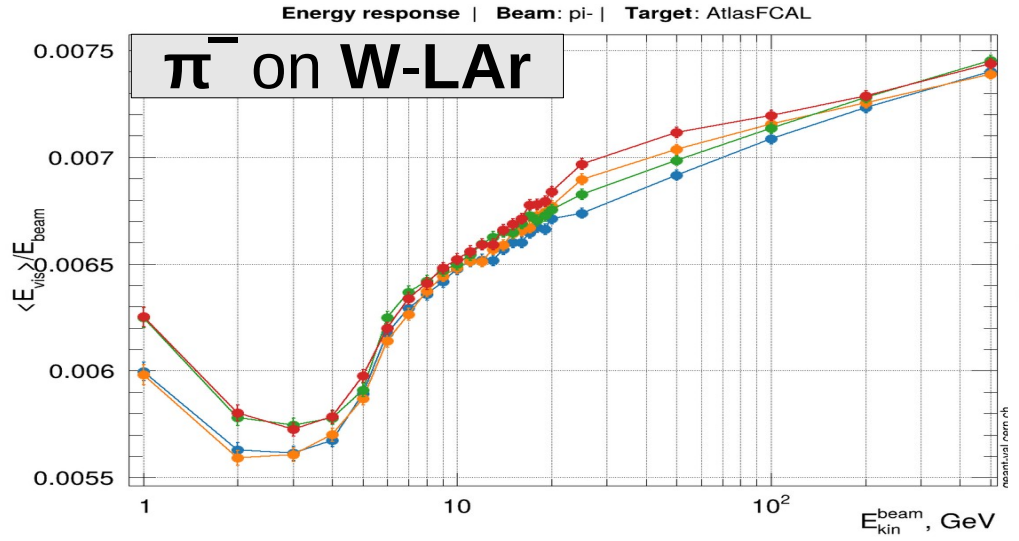
G4 11.3 QGSP_BERT
G4 11.2.p02 QGSP_BERT

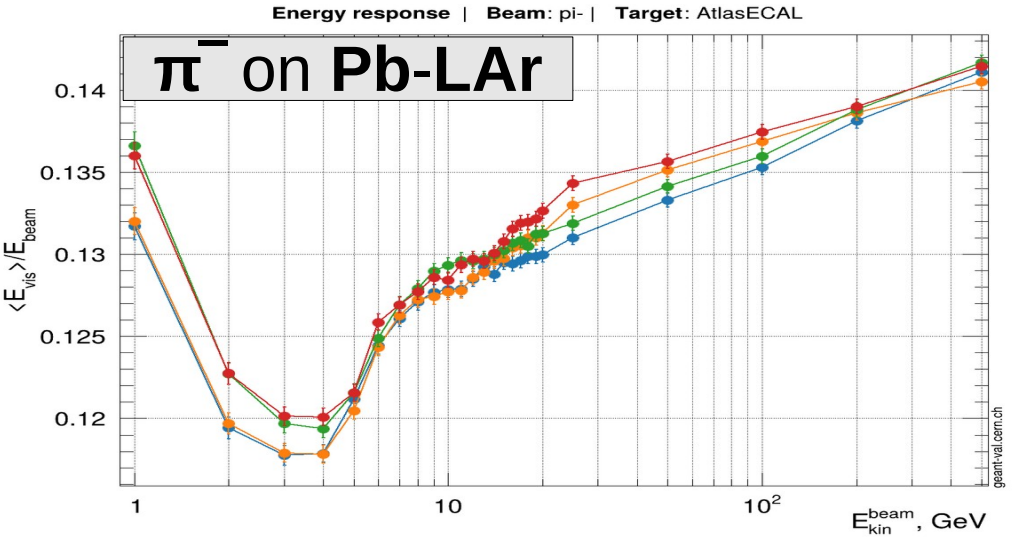
Note : conventional Birks treatment
(easier and no experimental h/e to fit !)

Energy Response

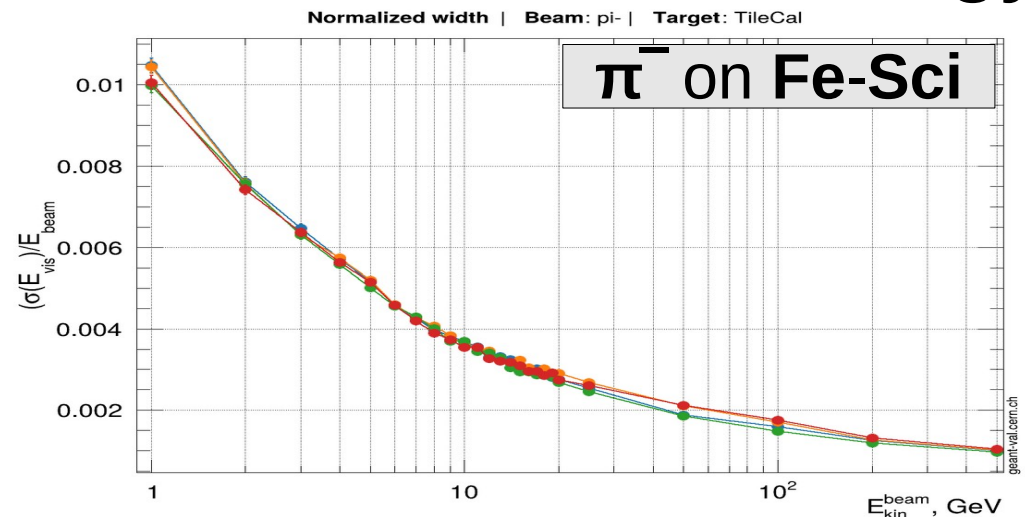


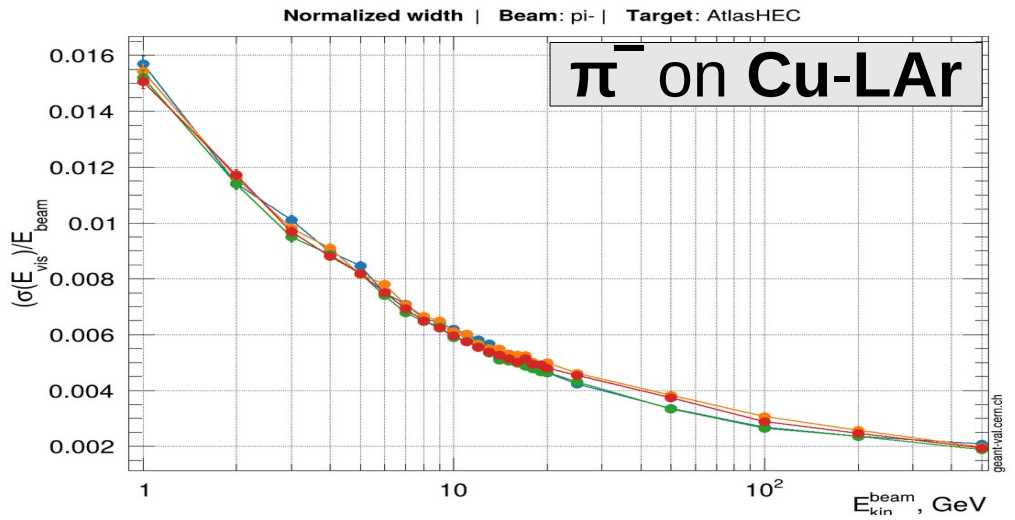


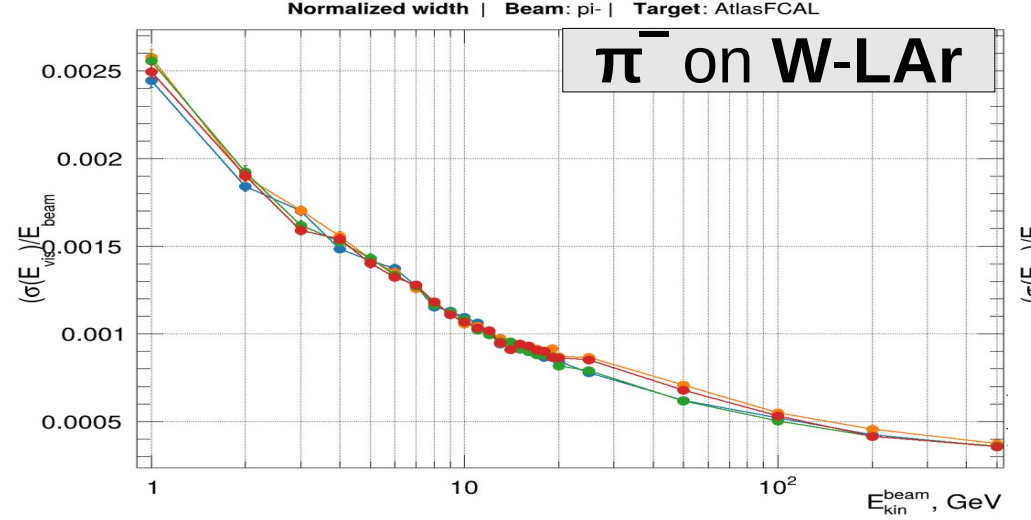


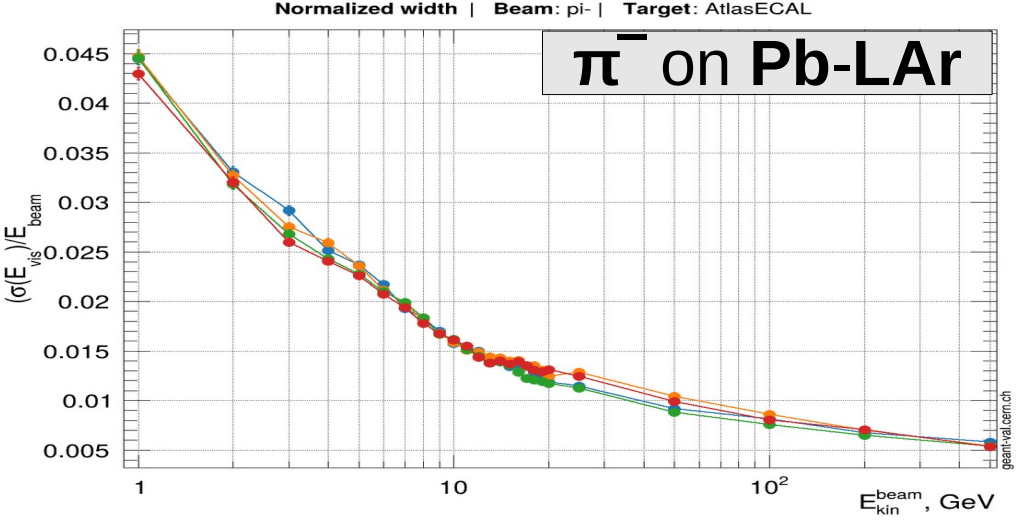


Energy Width

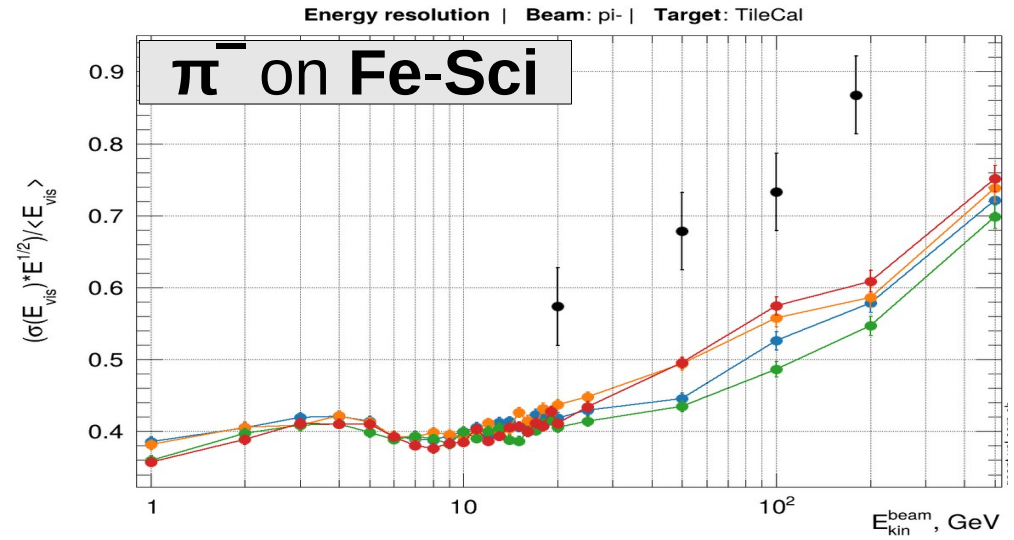


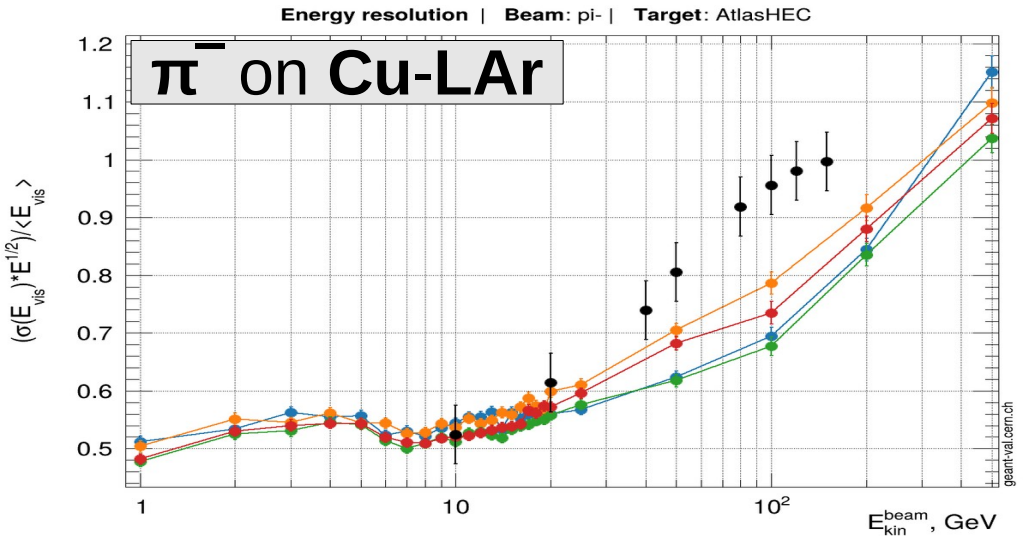


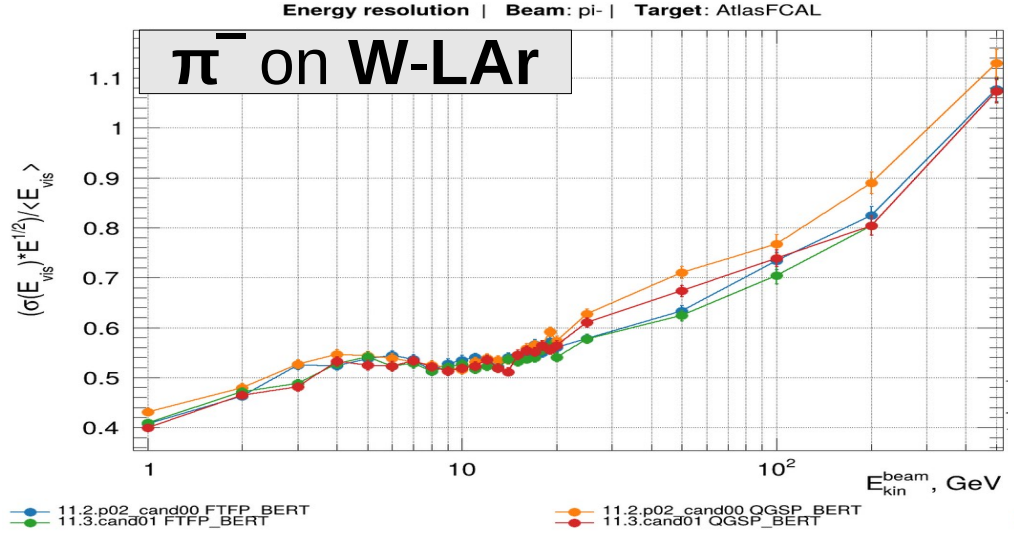


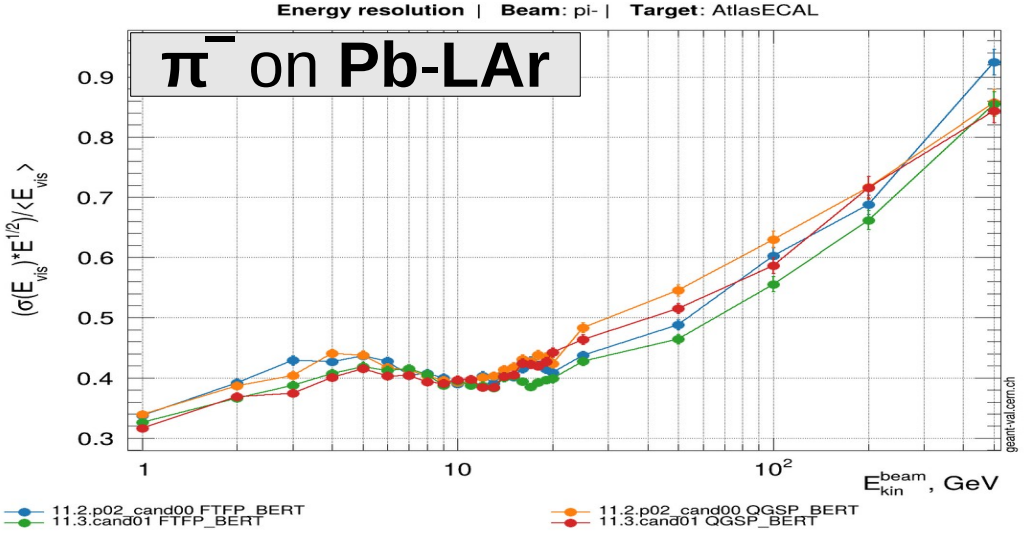


Energy Resolution

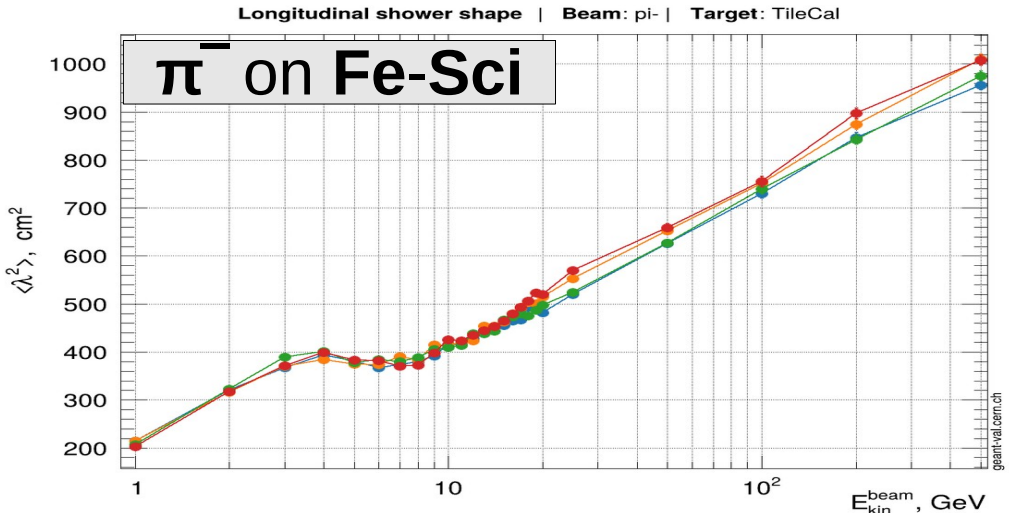


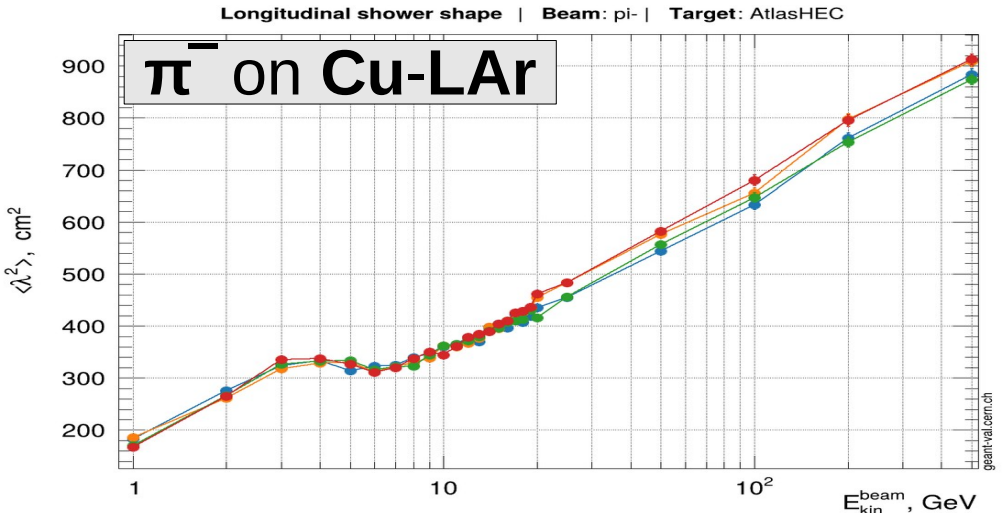


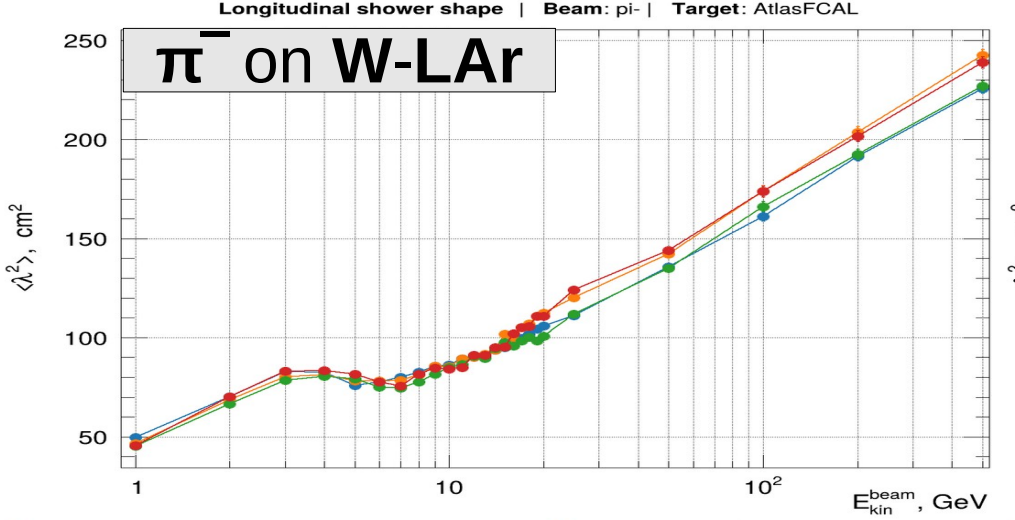


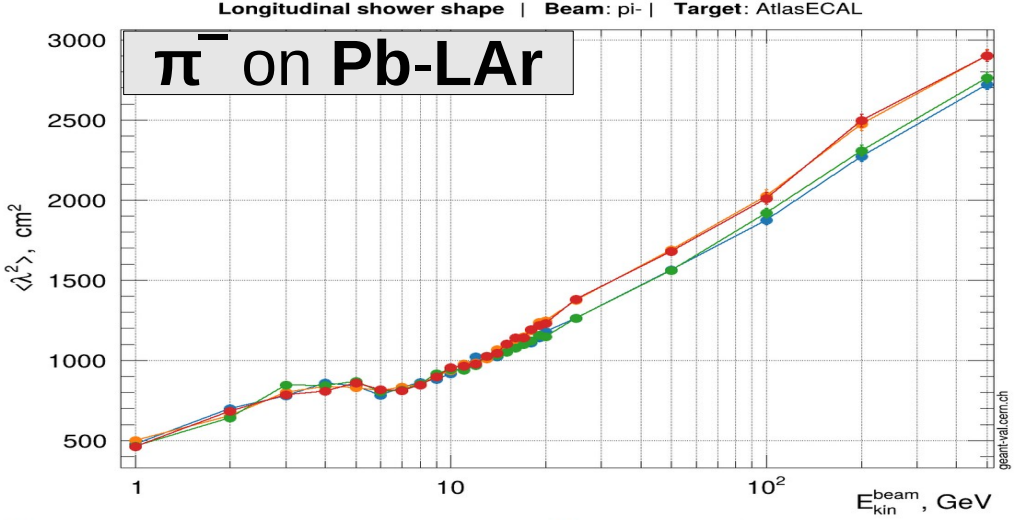


Longitudinal Shape









Lateral Shape