Hadronic Highlights of Geant4 10.7

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On behalf of the Geant4 Hadronic Physics Working Group

Geant4 Technical Forum, 21 January 2021

Hadronic Data Sets

- Updated :
  - G4PARTICLEXS**3.1** (mandatory for FTFP_BERT)
  - PhotonEvaporation**5.7** (mandatory for FTFP_BERT)
  - G4ENSDFSTATE**2.3** (mandatory for FTFP_BERT)
  - RadioactiveDecay**5.6**
- Unchanged :
  - G4SAIDDATA**2.0** (mandatory for FTFP_BERT)
  - G4NDL**4.6**
  - G4INCL**1.0**
  - G4ABLA**3.1**
  - G4TENDL**1.3.2**

Hadronic String models (1/2)

- For both **FTF** (Fritiof) & **QGS** (Quark Gluon String)
  - Completed the extension to charm and bottom hadron projectiles
    - To deal with charm and bottom quarks and diquarks carried out by the heavy projectile hadron, as well as with the possibility of creating charm – anti_charm and bottom – anti_bottom pairs from the vacuum during string fragmentation
    - Simplified approach at low energies – below 100 MeV – because our intra-nuclear cascade models do not handle charm and bottom hadrons
  - Simplified treatment of the decays of secondary charm and bottom hadrons (*i.e.* created by inelastic nuclear interactions of primary hadrons)
    - Cannot use the “pre-assigned decay” from MC generators as usually done for the primary heavy hadrons (because secondaries are created after the event generation)
    - One single, fully hadronic decay is defined for each “long”-lived charm and bottom hadron, with a simple multi-body phase-space treatment of the decay kinematics

Hadronic String models (2/2)

- **FTF** model
  - Improved agreement of FTF simulations with NA49 experimental data
    - On Pt-Xf correlations of secondaries produced in pp collisions at 158 GeV/c
  - Corrected treatment of string direction
  - Retuning of Pt in the string fragmentation
  - Added protections against numerical instabilities
  - Extended FTF configuration interface to include parameters of quark exchange with and without excitation, for baryon and pion projectiles
- **QGS** model
  - Improved treatment of antibaryon interactions
    - Better handling of low-mass strings
  - Added protections against numerical instabilities

Intra-nuclear Cascade models

- Bertini-like (BERT)
  - Stable, no developments; a few fixes:
    - Fixed non-conservation warnings in sub-threshold reactions
    - Fixed compilation warnings
- Binary (BIC)
  - Stable, no developments, one fix:
    - Fixed memory leak at exit
- Liege (INCLXX)
  - Stable, no developments, one fix:
    - Fixed compilation warnings

Precompound / de-excitation models

- Improved *G4NuclearLevelData* ; more consistent UI commands
- New data-set : PhotonEvaporation**5.7**

Radioactive Decay model

- Deprecated old UI commands *grdm/...*
  and introduced new, equivalent ones */process/had/rdm/...*
- New data-set : RadioactiveDecay**5.6**

ParticleHP & LEND models

- Stable, no developments; a few fixes
- Deprecated environmental variables, recommended UI commands
  - Introduced new CMake option *GEANT4_BUILD_PHP_AS_HP*
    (replacing the deprecated environmental variable *PHP_AS_HP*)

Elastic & Quasi-Elastic scattering

- Numerical protection against precision loss in elastic scattering
- Extension for charm and bottom hadrons of :
  - Simple treatment of elastic scattering
  - Chips quasi-elastic (used only in QGS model)

Neutrino interactions

- Added $\nu_e - A$ and $\underline{\nu}_e - A$ total cross sections
- Improved $\nu_\mu - A$ final-state model
  - For both neutral and charged current
- Added $\underline{\nu}_\mu - A$, $\nu_e - A$, $\underline{\nu}_e - A$ final-state models
  - For both neutral and charged current

Others

- Introduced optional coalescence model, useful in particular for Cosmic Ray applications
  - Form deuteron and anti-deuteron from, respectively, proton-neutron and antiproton-antineutron pairs with close momenta
  - To switch it on: */process/had/enableCRCoalescence true*
- New UI command to change the default upper energy limit
  - Default: 100 TeV , to change it: */process/had/maxEnergy …*
- New UI command to switch off printing of hadronic information
  - */process/had/verbose 0*
- Replaced where possible the use of environmental variables in hadronic models with appropriate UI commands
  - Using consistently the prefix: */process/had/*

Cross Sections

- Corrected threshold in gamma-proton cross section
- Added protections in EM dissociation cross section
- Extended *G4ParticleInelasticXS* to gamma cross section
- New G4PARTICLEXS**3.1**
  - More accurate cross sections for fusion reactions and for inelastic interactions of neutron, proton, light ions and gamma, for the full energy range
- Introduced optional scaling factors for elastic and inelastic cross sections of hadrons for systematic studies
  - 3 categories: nucleons (p, n), pions (π±), all others
  - New methods in *G4HadronicParameters* to scale the cross sections
  - ±10% for nucleons & pions; ±15-20% for kaons; ±20-30% for others
    - Bigger variations might be considered at low energies to account for the uncertainties on the shape of the cross section in the threshold and resonance region

Physics Lists (1/2)

- Enabled charm and bottom hadronic physics in nearly all physics lists (in particular those of interest for HEP)
  - Main exceptions: QGSP_BIC , QGSP_BIC_HP , QGSP_BIC_AllHP
  - QGS-based physics lists use QGSP above 12 GeV also for charm and bottom hadrons (and FTFP below 25 GeV)
  - FTF-based physics lists use FTFP for all energies for charm and bottom hadrons, with a simplified approach below 100 MeV
    - No cascade model works for charm and bottom hadrons
- QGS-based physics lists use now QGS above 12 GeV also for hyperons, anti-hyperons, antiproton and antineutron
  - And FTFP below 25 GeV
    - For hyperons, FTFP is used down to 3 GeV, and BERT below 6 GeV

Physics Lists (2/2)

- Physics lists that include *G4EmExtraPhysics* use now the new low-energy gamma-nuclear final-state model : *G4LowEGammaNuclearModel*
  - Below 200 MeV ; BERT is used above 199 MeV and below 6 GeV ; QGSP is used above 3 GeV
  - This model is based on precompound de-excitation, and produces isomers and gamma transitions
- Cleanup destruction of physics processes at the end of job; reviewed ownership/deletion of physics models at the end of the run

Hadronic showers *(see plots in backup slides)*

- Stable hadronic showers in G4 **10.7**
  - With respect to G4 10.6.p03
    - Few percent narrower showers for FTF-based physics lists
    - No changes for QGS-based physics lists
  - QGSP_BERT with respect to FTFP_BERT
    - Few percent higher energy response
    - Wider energy fluctuations and worse energy resolution
    - Few percent longer showers
    - 5-10% 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 internal (reference tags) versions
- The only validation tool in Geant4
- On-going work to extend its coverage
- Under evaluation also by the Fluka-CERN team

Backup slides

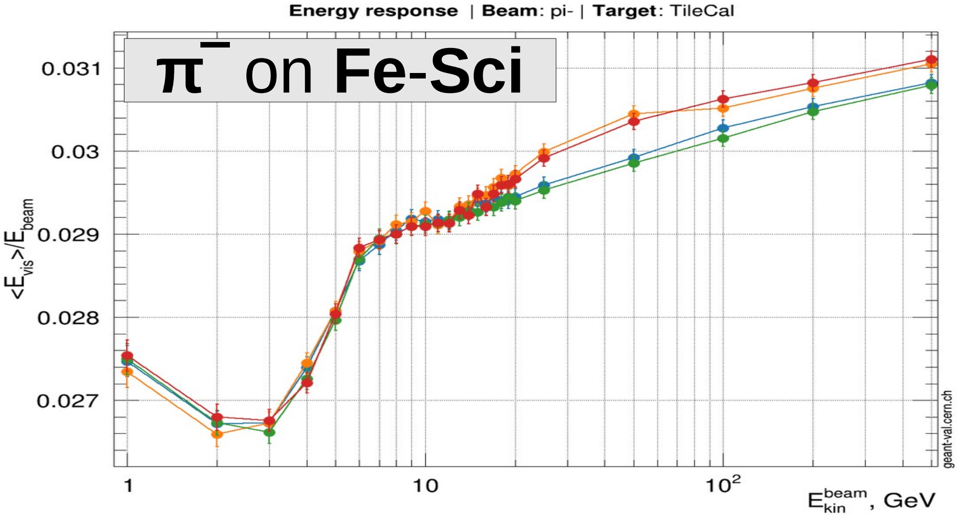
Pion– showers:

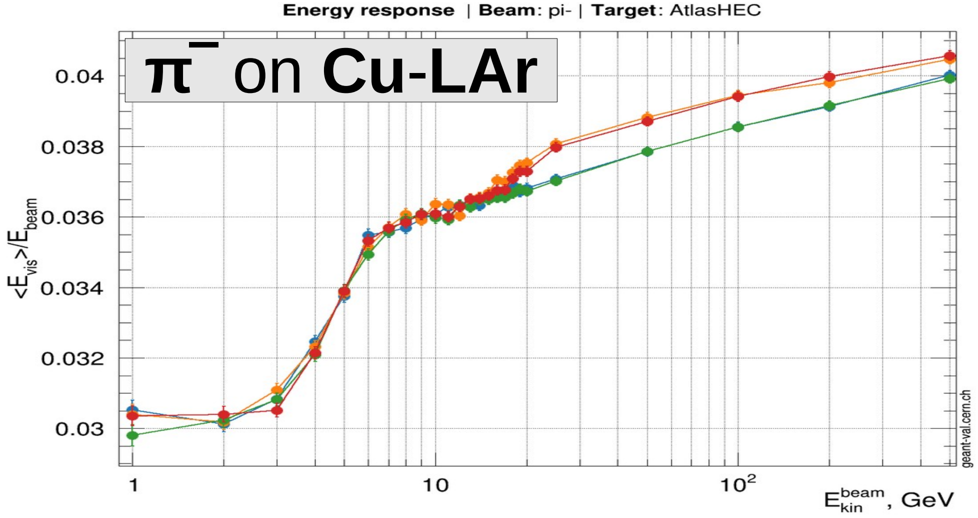
G4 10.7 FTFP_BERT
G4 10.6.p03 FTFP_BERT

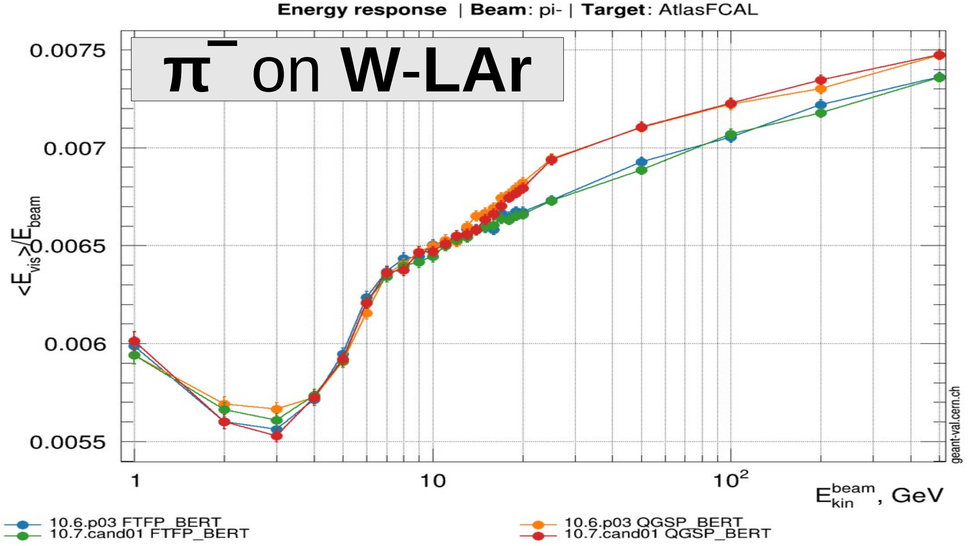
G4 10.7 QGSP_BERT
G4 10.6.p03 QGSP_BERT

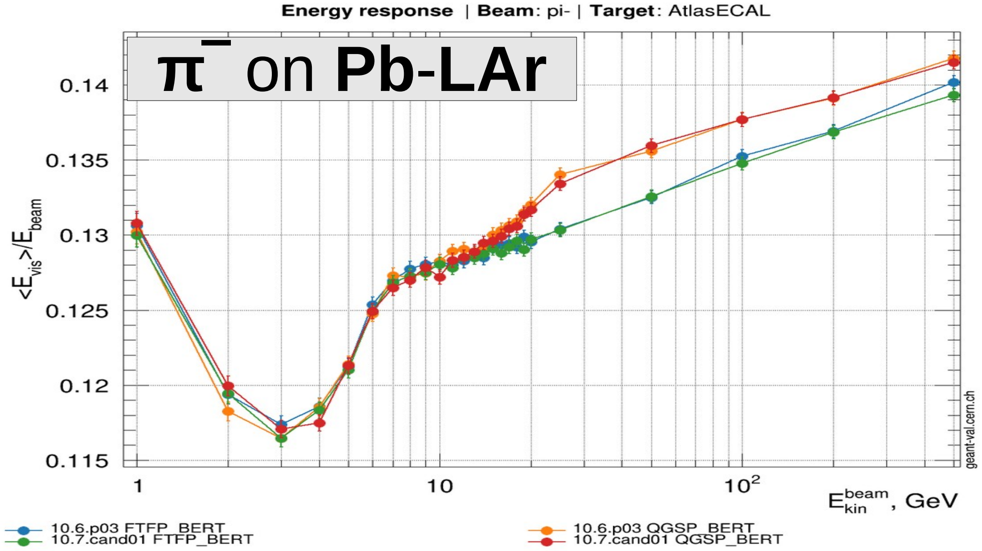
Note : conventional Birks treatment
(easier and no experimental h/e to fit !)

Energy Response

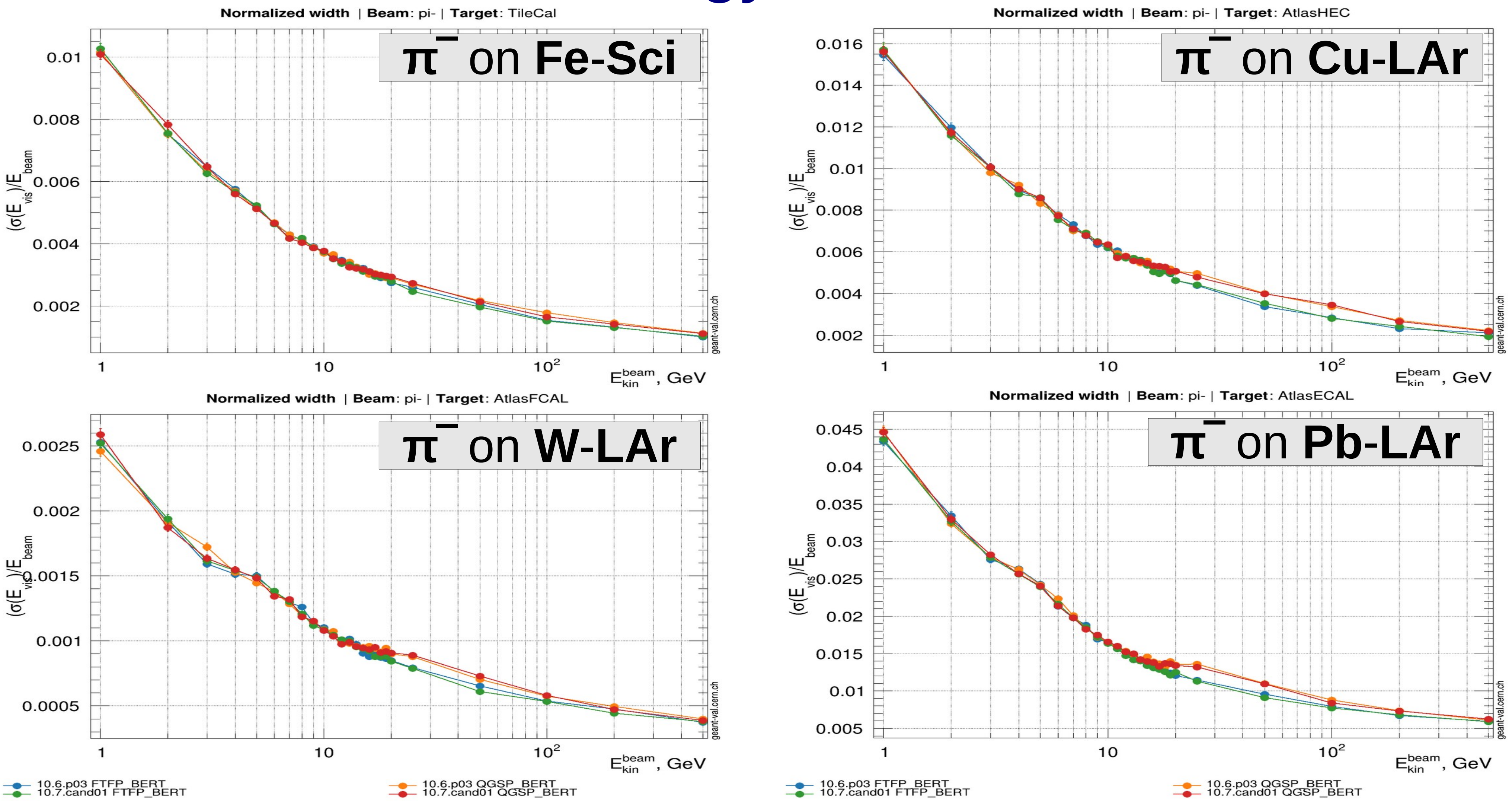




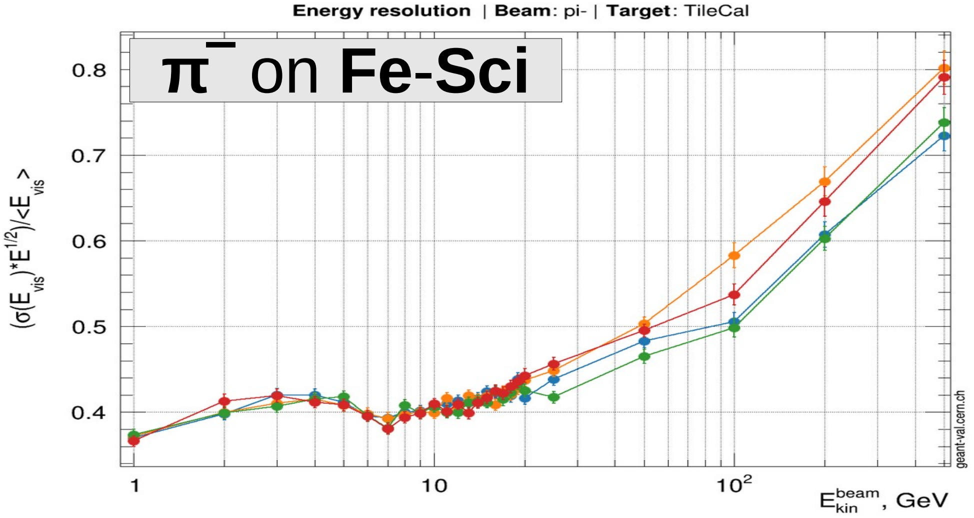


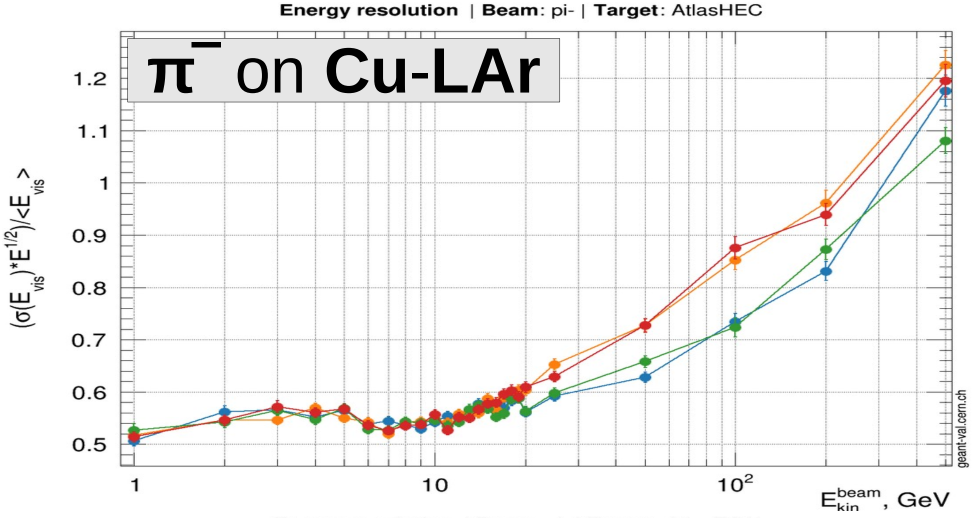


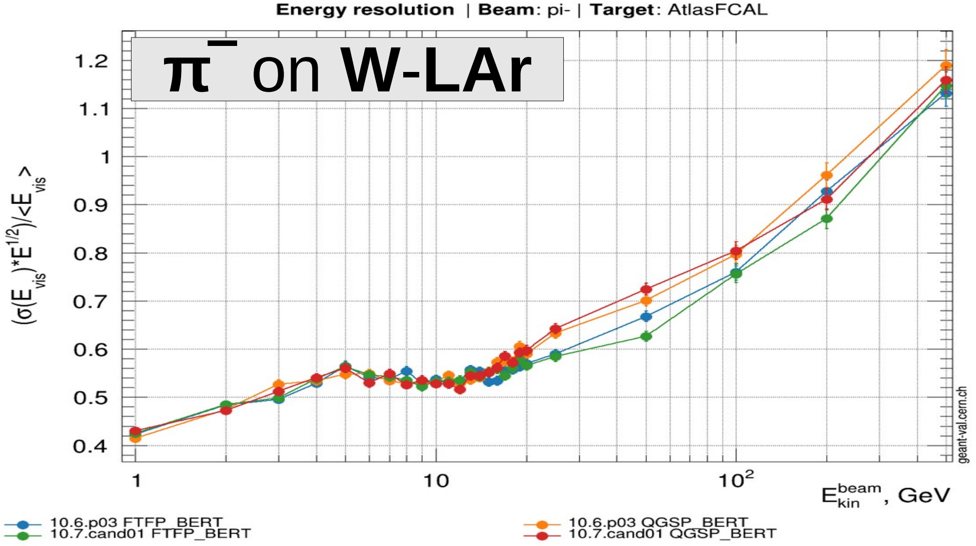
Energy Width

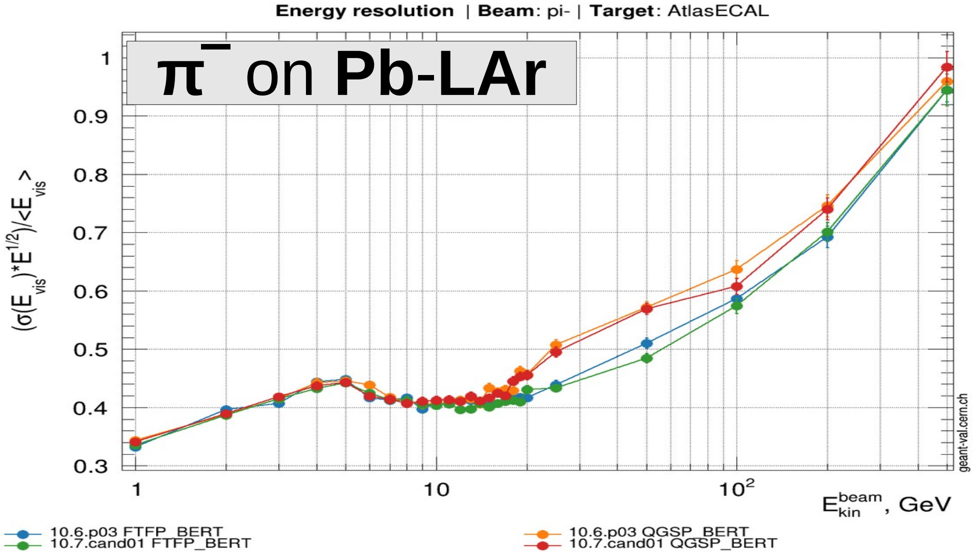


Energy Resolution

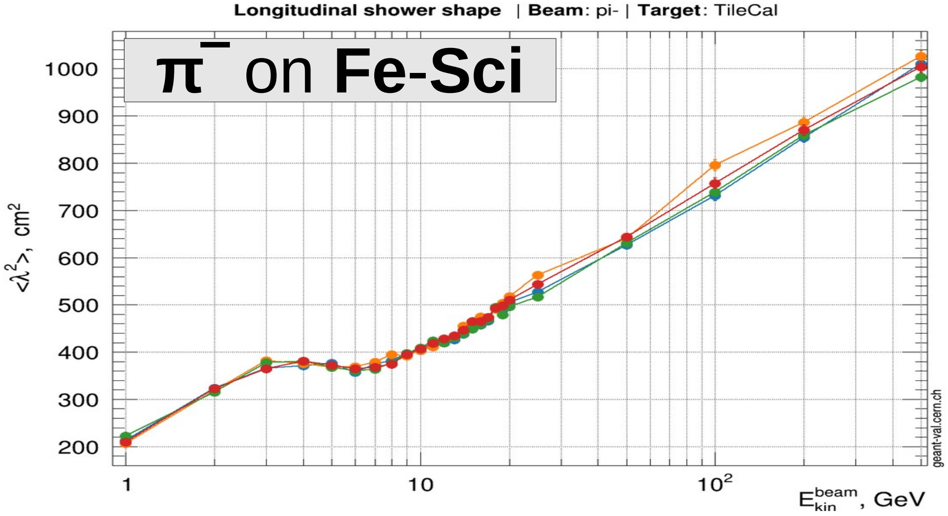


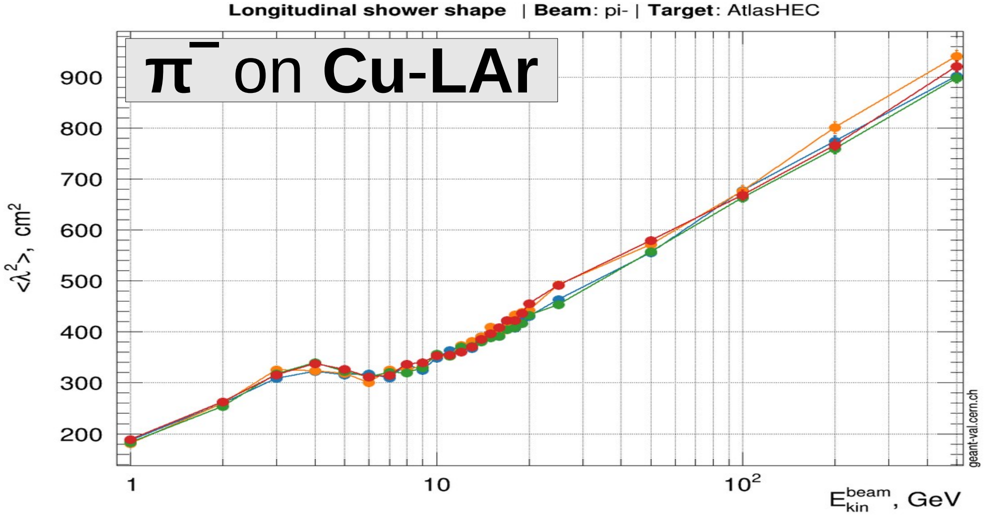


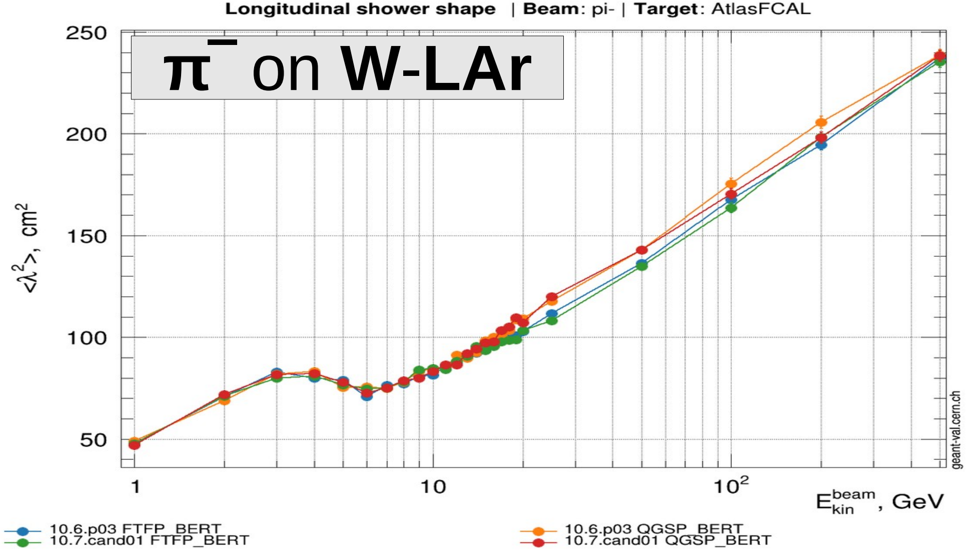


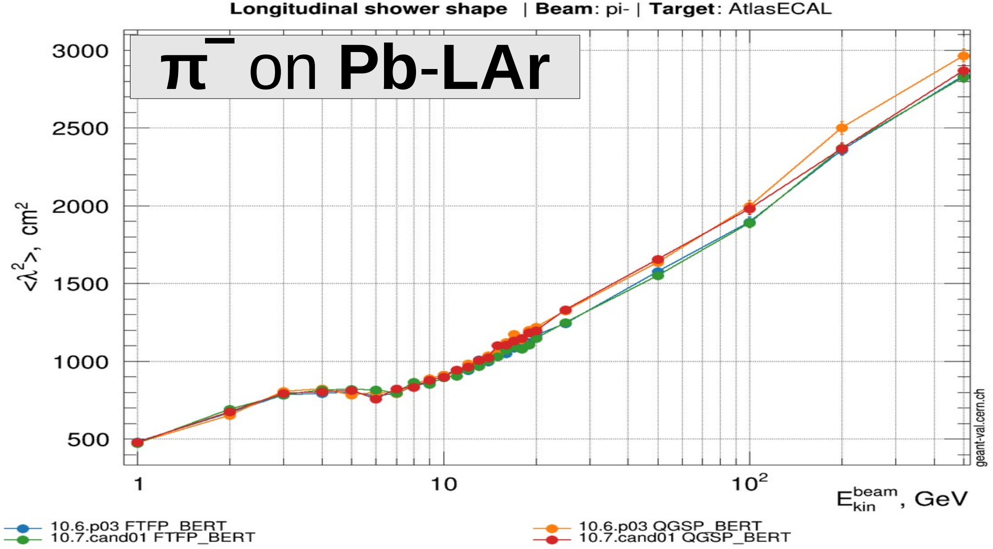


Longitudinal Shape

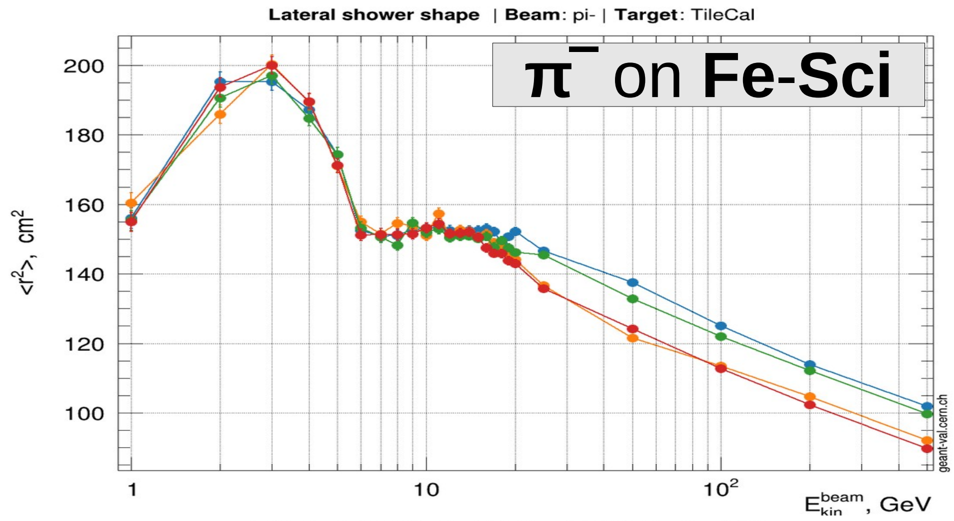


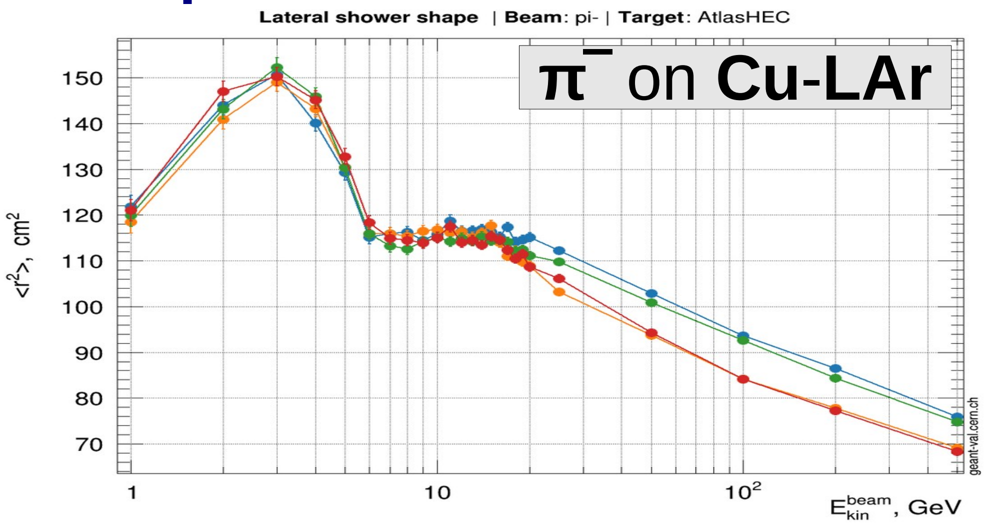


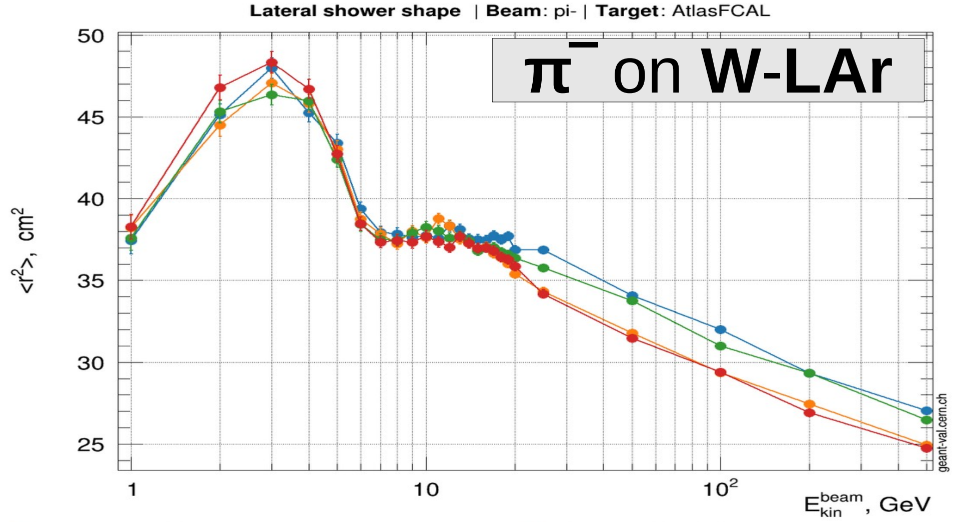


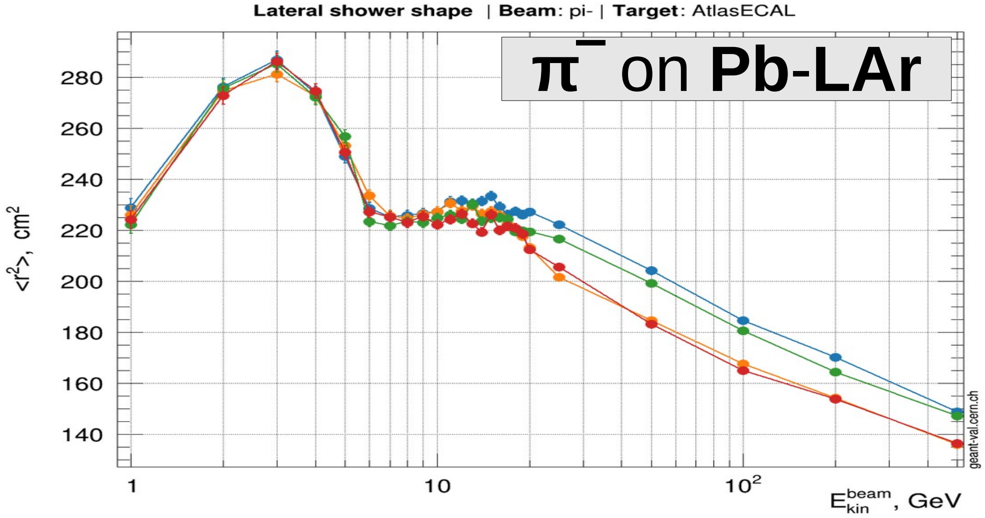


Lateral Shape









10.6.p03 FTFP_BERT
10.7.cand01 FTFP_BERT
10.6.p03 QGSP_BERT
10.7.cand01 QGSP_BERT

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