Highlights from High-Energy Hadronic Physics

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Geant4 Collaboration Meeting, Lund, August 2018

Outline

- Status of String models
  - FTF
  - QGS
- Status of Intranuclear Cascade models
  - BERT
  - BIC : no development
  - INCLXX
- Others
  - Cross sections
  - Upper energy limit of hadronic physics
  - Transuranic elements

String models

Status of **FTF** (Fritiof) Model

- Changes on FTF after Wollongong and included in 10.5β
  - Corrected calculation of nuclear residual excitation energy
  - New tuning of the model parameters
  - Improved version and tuning of Lund string fragmentation
  - First implementation of alpha cluster structure of carbon nuclei (affecting only hadron – C12 interactions, for both FTF & QGS)
  - Fix on antiproton annihilation at rest to get flat *cos(θ)* and *φ*
  - Code improvements, without effects on the physics
    - Classes: G4FTFModel, G4DiffractiveExcitation, G4FTFAnnihilation
    - Changes in the random sequence only due to re-ordering of operations
  - Start trying to use Professor for tuning FTF parameters... (Julia)

==> Slightly better thin-target agreement, but small impact on hadronic showers: still higher energy response and smaller energy fluctuations *vs.* production/stable version of FTF

FTF dilemma: thin-target vs. showers

- Comparing FTF with:
  - Charged pions (projectile and/or production) thin-target data
  - Fluka simulations
  - Calorimeter test-beams
- And observing that using FTF together with better models:
  - Binary (instead of Bertini) cascade for nucleons below ~1.5 GeV
  - Better elastic scattering

  increases further the calorimeter energy response
- We suspect that the main problem is not the string model (FTF) but a **strong underestimation of Birks' quenching**
  - Not yet managed to show this from “first principles”, based on the available published data on quenching in scintillators...

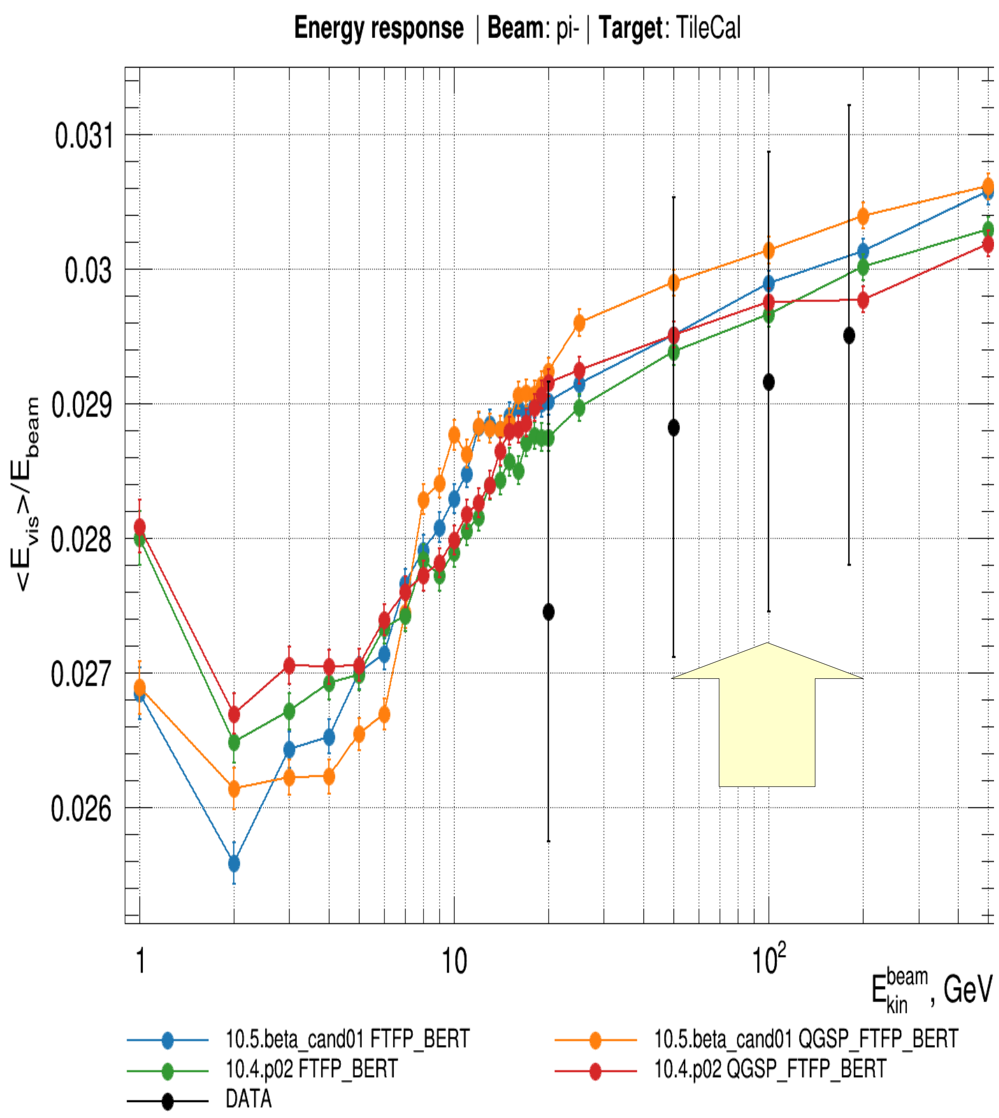
Status of **QGS** (Quark-Gluon-String) Model

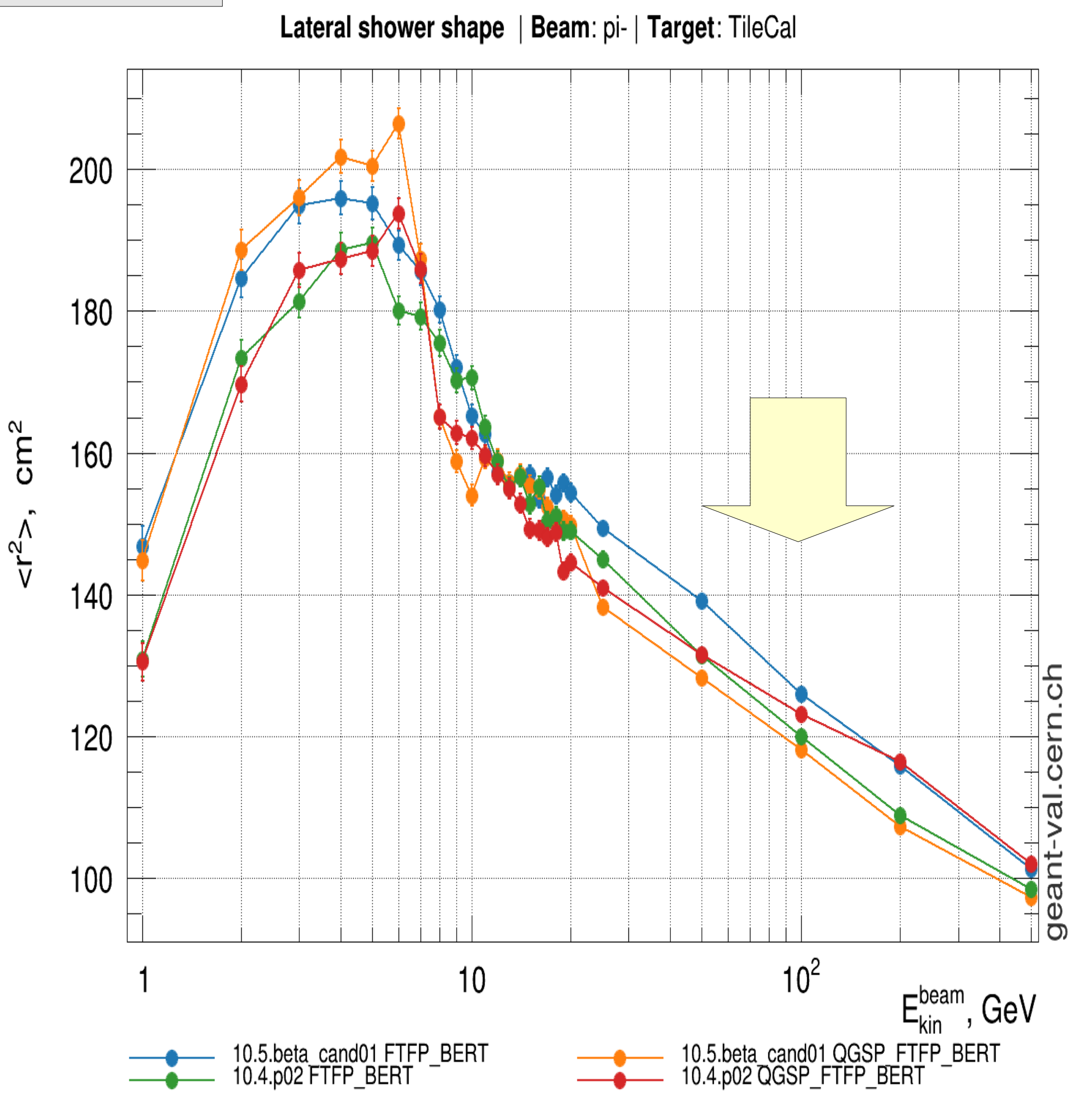
- Changes on QGS after Wollongong and included in 10.5β
  - New tuning of the model parameters
  - Improved version and tuning of QGS string fragmentation
  - First implementation of alpha cluster structure of carbon nuclei (affecting only hadron – C12 interactions, for both FTF & QGS)
  - Fix rare crashes
  - Fixed event reproducibility problem in gamma-nuclear

==> Significant **better thin-target** agreement – vs. previous versions of QGS, and now comparable to the development version of FTF – but **worse showers** (higher energy response and narrower shape) with respect to the production/stable version of QGS, and both versions (development and production/stable) of FTF

Energy Response & Lateral Shape

π⁻ on Fe-Sci





String Models for G4 10.5

- V. Uzhinsky is starting this year only on 1st September to work at CERN. His main task will be to improve the QGS model, but some developments in FTF could be possible...
- We don't expect major changes, so for December release G4 **10.5** we are facing to the "usual" dilemma: *do we want to release the latest* ***development version*** *of the string models – which gives better description of* ***thin-target data*** *– or the* ***production/stable version*** *– which gives better description of* ***hadronic showers*** *in calorimeters ?*
- The conservative, safer option is the second, as we did already for G4 **10.3** & **10.4** (as well as **10.2** for QGS)
- We prefer the first one – together with using BIC (instead of BERT) for nucleons below 1.5 GeV, and with the new elastic – pushing the experiments (during the pause at the end of Run 2) to apply a **stronger Birks' quenching**... Alternative: wait for G4 **11.0**

Intranuclear Cascade models

Bertini-like (BERT) model

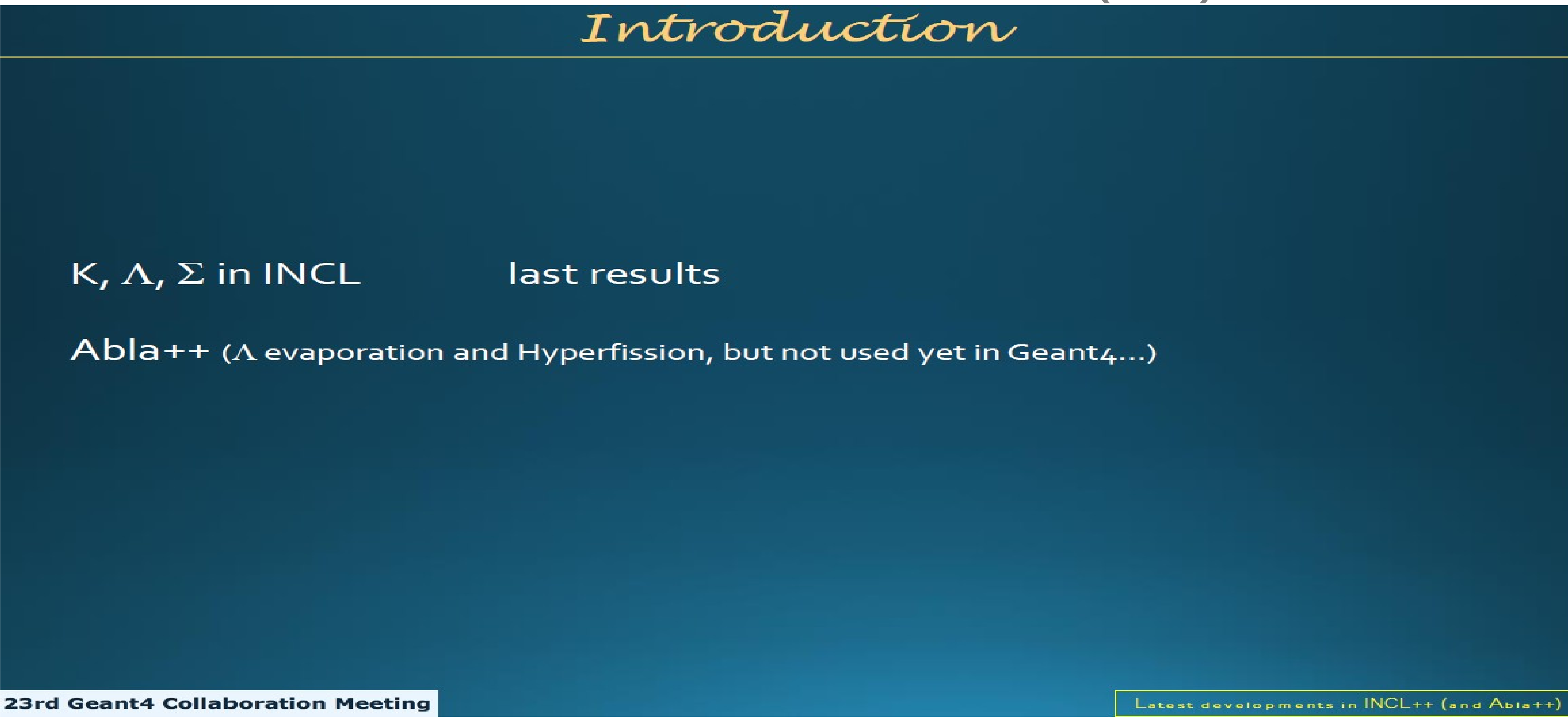
- Added strange pair production channels to the list of 6, 7, 8 and 9-body final states of pion – nucleon
  - $\pi^+ p$, $\pi^- p$, $\pi^\circ p$, $\pi^+ n$, $\pi^- n$, $\pi^\circ n$
  - Solved the problem of unphysical peaks in pion – nucleon reaction cross sections, due to missing channels
  - More kaons & hyperons and less pions are produced now
  - Affects hadron showers: smaller energy response below ~ 20 GeV

- Improved pion – quasideuteron reaction
  - Before, the charge of the projectile was ignored, leading to charge non-conservations for incident $\pi^\pm$
  - More neutrons are now produced for incident π^- , less neutrons are now produced for incident π^+
  - Affects hadrons showers: smaller (higher) energy response and wider (narrower) for π^- (π^+) showers

INCLXX model

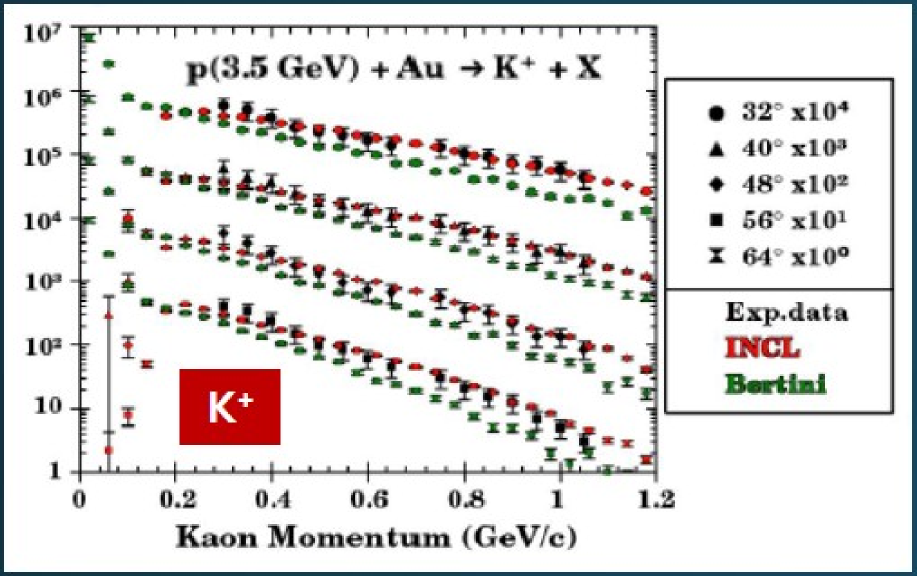
- FTFP_INCLXX is now the preferred physics list for ALICE
  - It gives the best description of light ion production (d, t, 3He, α) by ~GeV pion interactions on the beam pipe & tracker

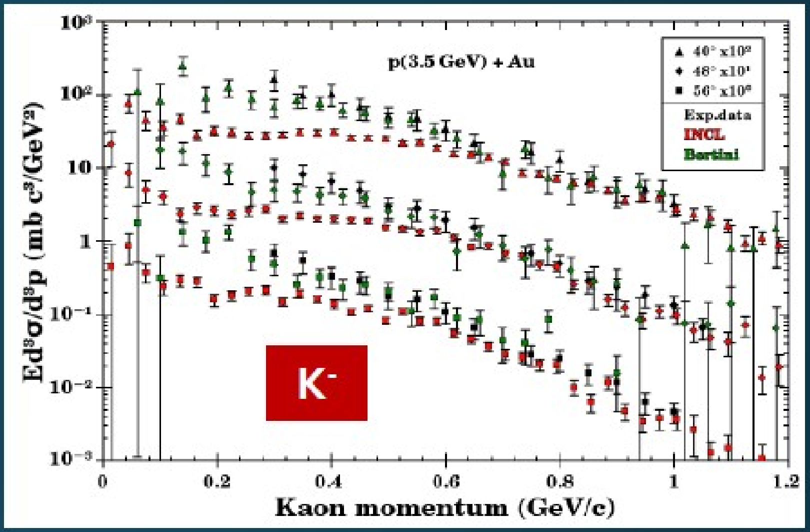
Slides from J.C. David (1/5)



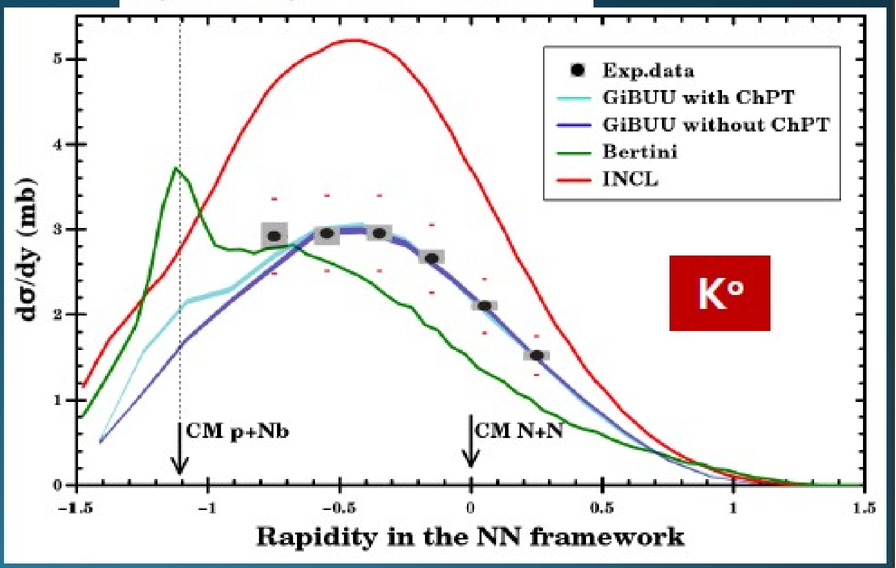
INCLXX model – Slides from J.C. David (2/5)

Results - K production





p(3.5GeV) + Nb → K^0_S + X



K⁺

quite good (even at high energy)
forward angle?
ΔN important but improvable at high energy

K⁻

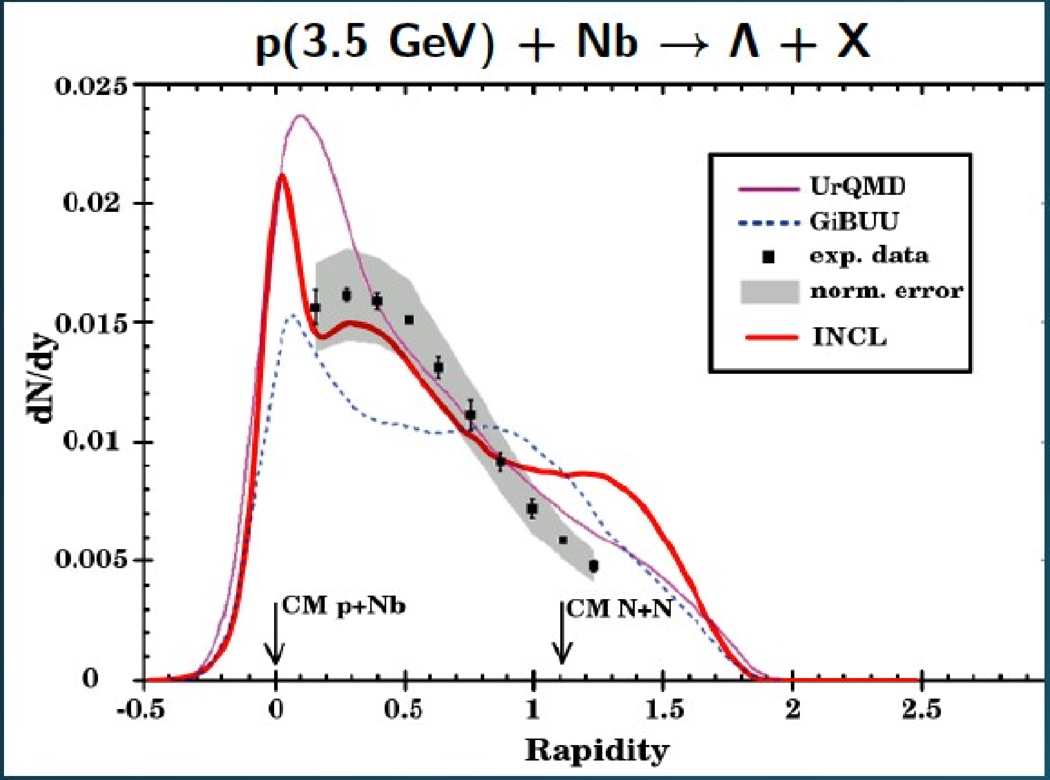
less good, some channels are missing

K°

roughly Ok, but exp. data needed

INCLXX model – Slides from J.C. David (3/5)

Results – Λ production

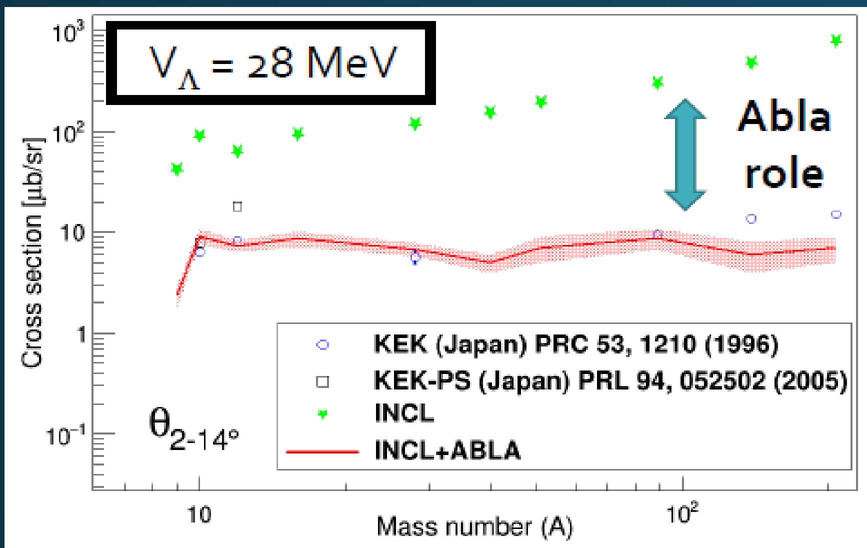


Too few exp. data to get a clear idea, but first results rather good (especially compared to other models)

HADES Collaboration, Eur. Phys. J. A (2014) 50:81

INCLXX model – Slides from J.C. David (4/5)

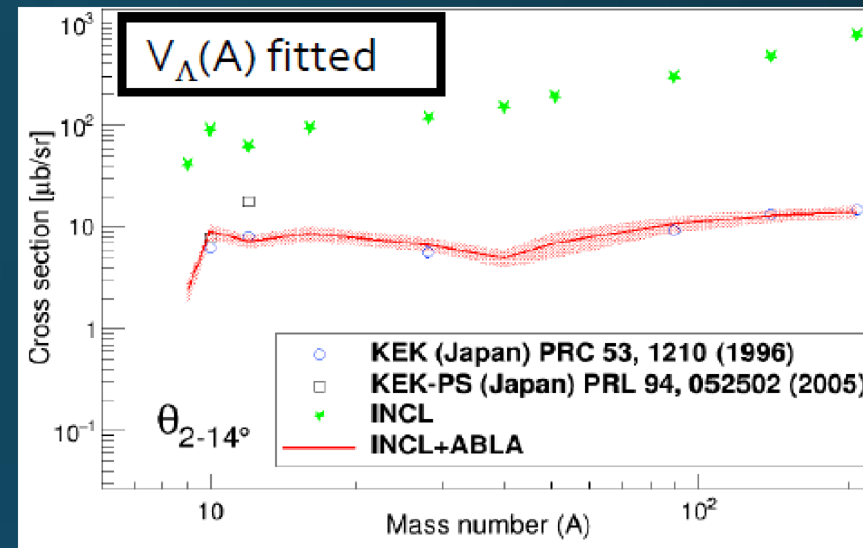
Results ~ Hypernuclei



1^{st}

Role of Abla important! And good results

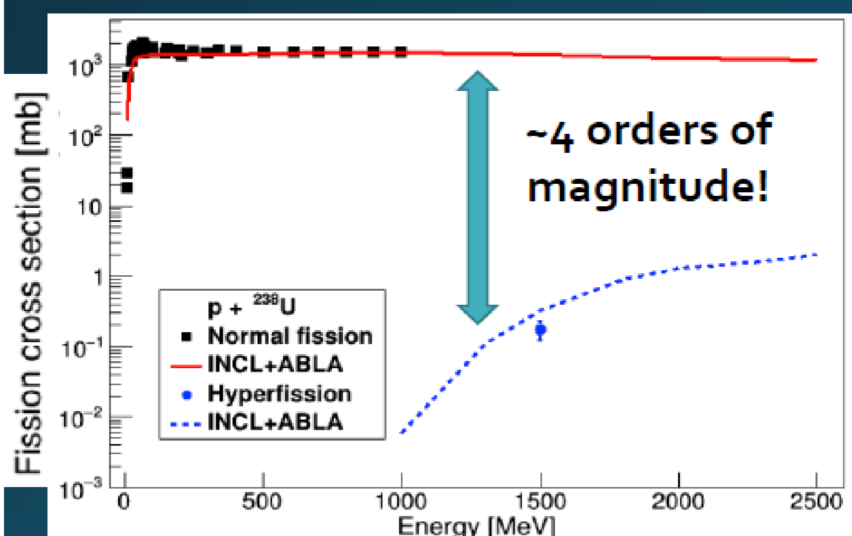
$(\pi^+,K^+)_\Lambda X$ ~1.05 GeV/c



$V_\Lambda(A)$ fitted on those cross sections

2^{nd}

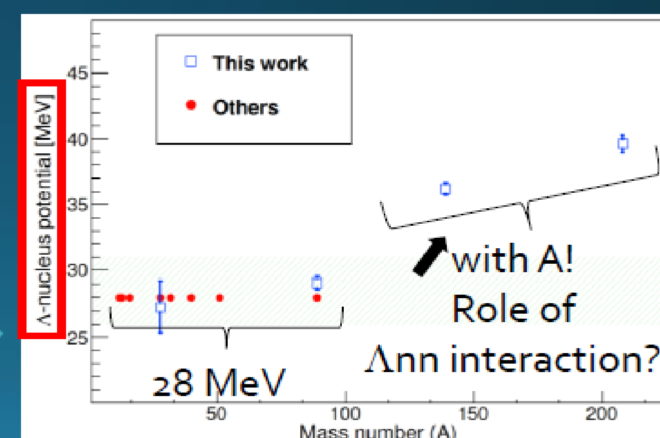
INCL-Abla as a tool



3^{rd}

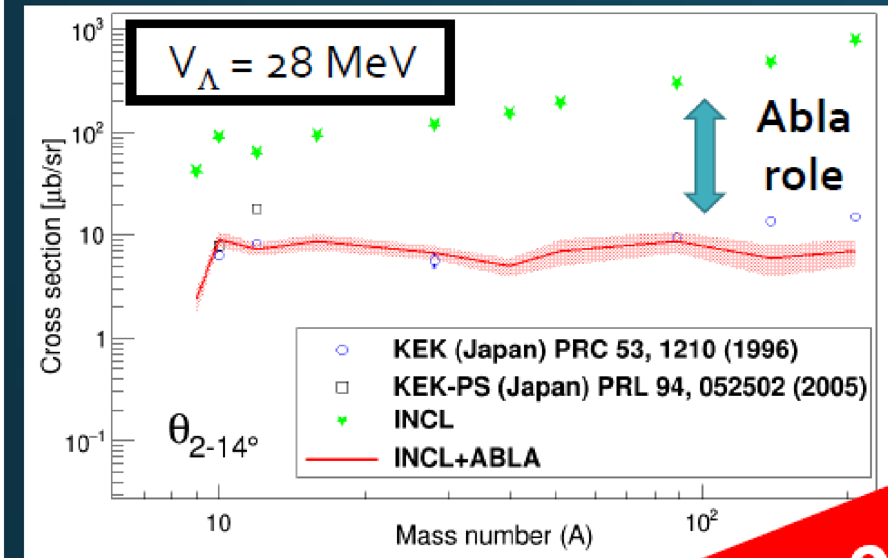
Even hyperfission seems well reproduced!!!

p(1.5 GeV) + U



INCLXX model – Slides from J.C. David (5/5)

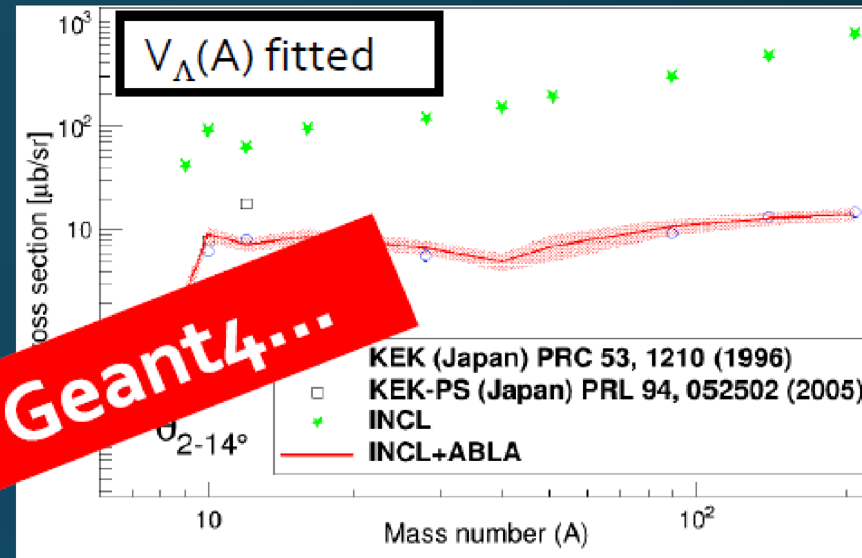
Results - Hypernuclei



1st

Role of Abla important! And good results

…eV/c

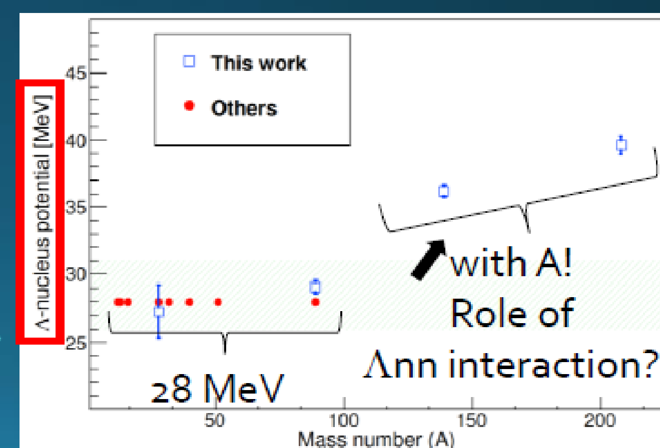


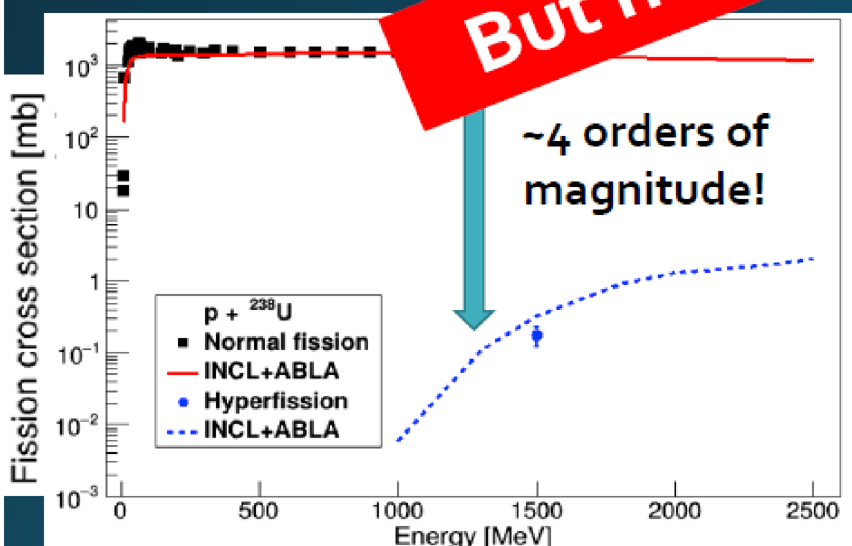
But no hypernuclei in Geant4…

V_Λ(A) fitted on those cross sections

INCL-Abla as a tool

2nd





3rd

Even hyperfission seems well reproduced!!!

p(1.5 GeV) + U

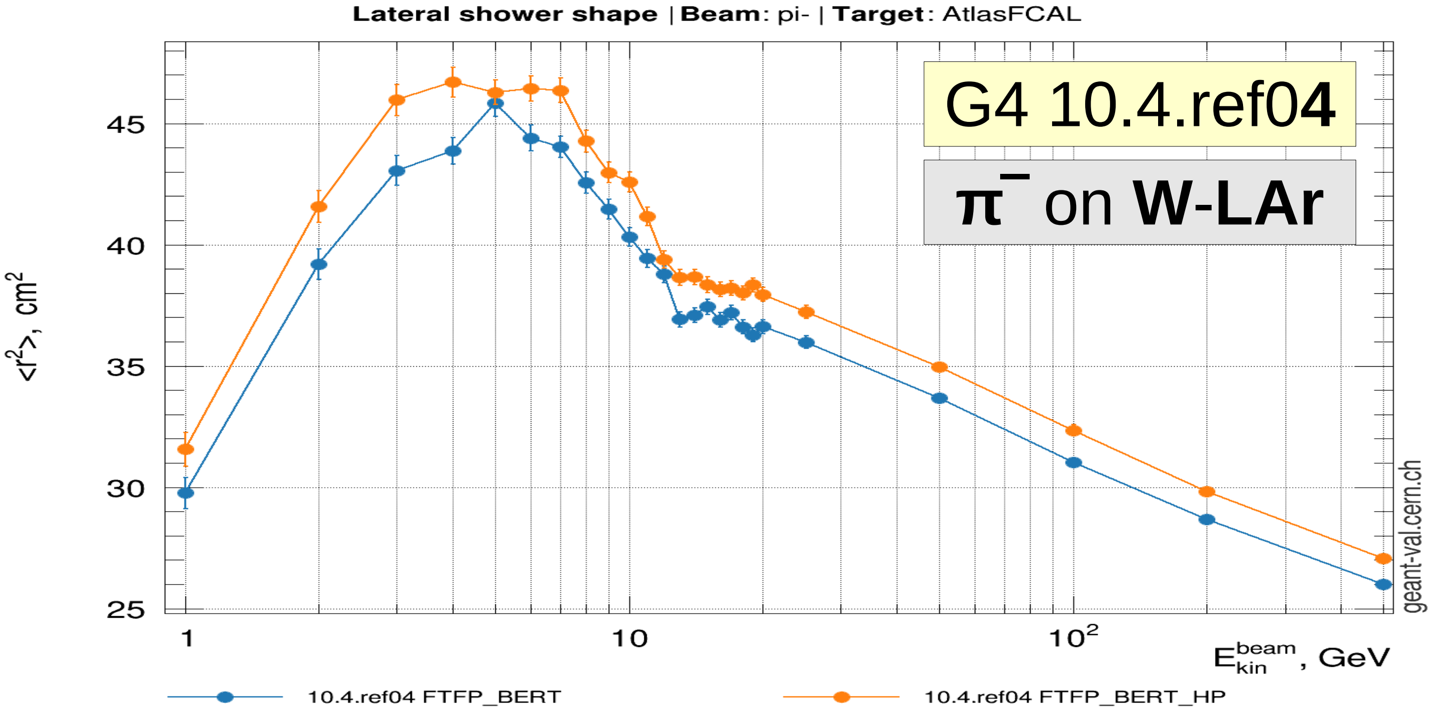
Others

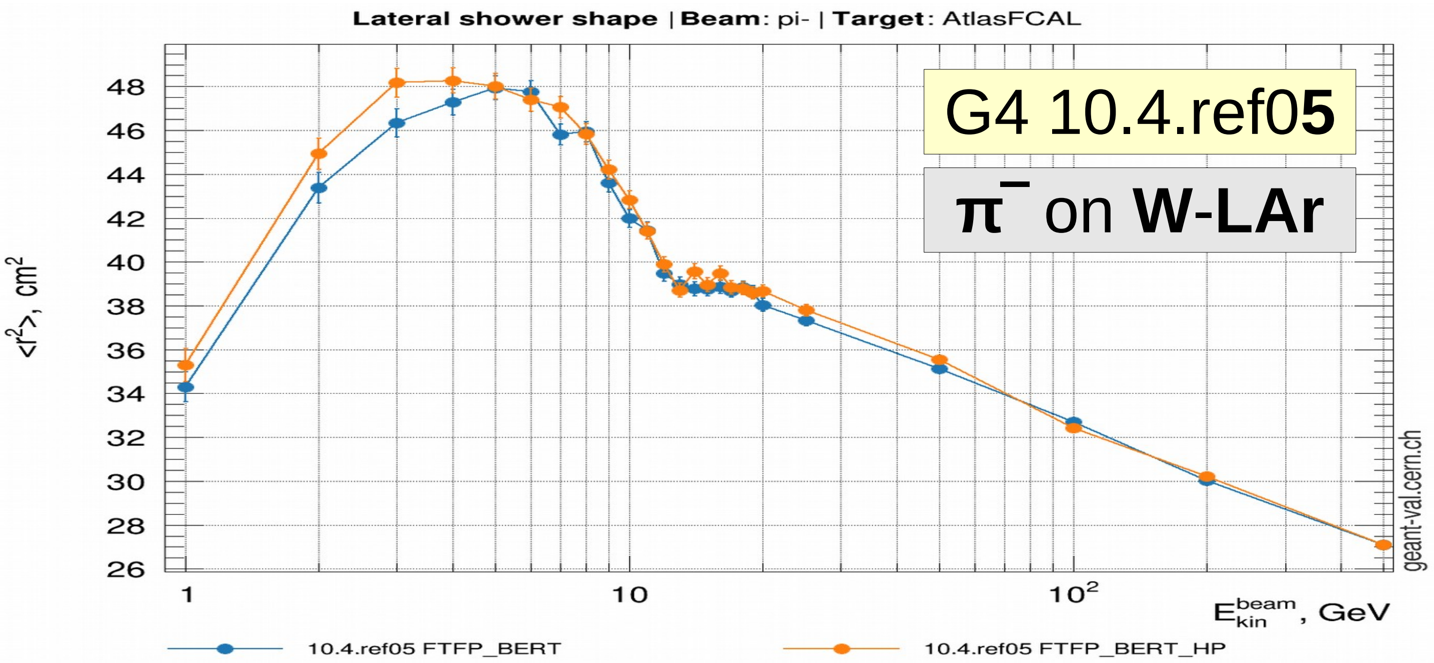
Cross Sections

- Several improvements
  - Update NeutronXS cross sections: G4NEUTRONXS2.0
  - In preparation, update of SAID cross sections
  - Selection of isotopes
  - Improved computation of kaon cross sections
  - Use of faster math functions G4Log, G4Exp, G4Pow
  - Updated hadron-nucleon cross sections from PDG 2016/2017
  - Removed Gheisha cross sections when (in most cases) better alternatives are available

==> Improved hadron lateral shapes in Tungsten
(see next slide)

Lateral Shape : FTFP_BERT *vs* FTFP_BERT_HP





FTFP_BERT is closer to FTFP_BERT_HP in Ref05 than in Ref04

Upper Energy Limit of Hadronic Physics

- Default "100 TeV" , hardwired in many different files
  - Limit for final-state models, not for cross sections
- Introduced a new, read-only singleton:

  G4HadronicParameters

  meant to keep all global hadronic parameters
- For the time being, it has only the upper energy limit:

  G4HadronicParameters::Instance()->GetMaxEnergy()

  which is used in many places in Geant4
  - *source/process/hadronic/* , *source/physics_lists/* , *examples/* , *tests/*
  - Now (G4 10.4.ref07) you can change the limit, e.g. "1000 TeV" by changing one value in a single file

Please avoid to put "100 TeV" by hand in your code, use instead the above method !

Transuranic Elements

- ADS (Accelerator Driven System) nuclear applications need to run Geant4 for transuranic elements, for "high" energies (i.e. above 20 MeV, so involving more than neutronHP)
  - This was not possible because of several protections in the code:
    if (Z > 92) { // Error, or warning, or skipping }
- In the beta-release, we introduced a boolean flag "*isHeavyElementAllowed*" to allow or not the use of transuranic elements
  - Currently set "true" by default
    - Is it ok for the release ?
  - Currently set in different classes, for flexibility
    - Should it be factorized in the class G4HadronicParameters ?

Back up

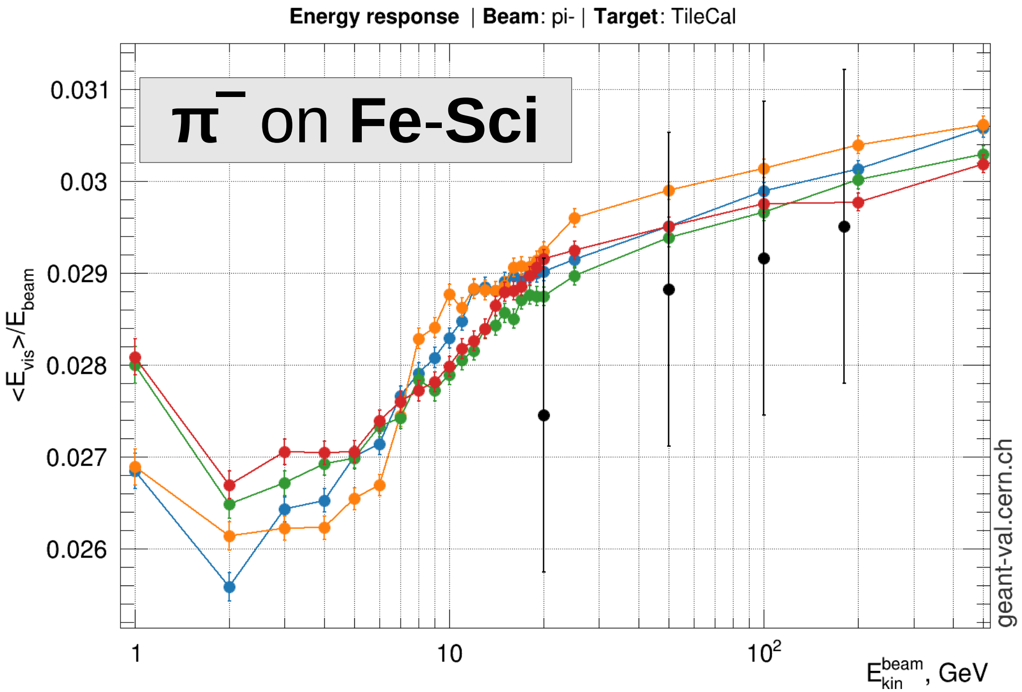
Pion- showers:

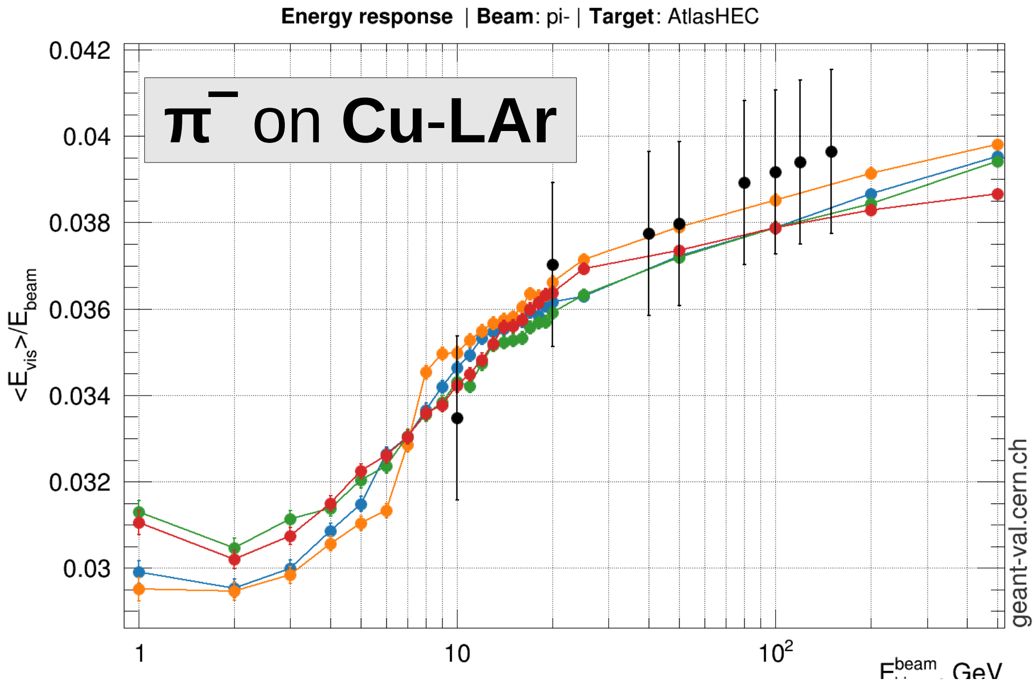
FTFP_BERT G4 10.5β
FTFP_BERT G4 10.4.p02

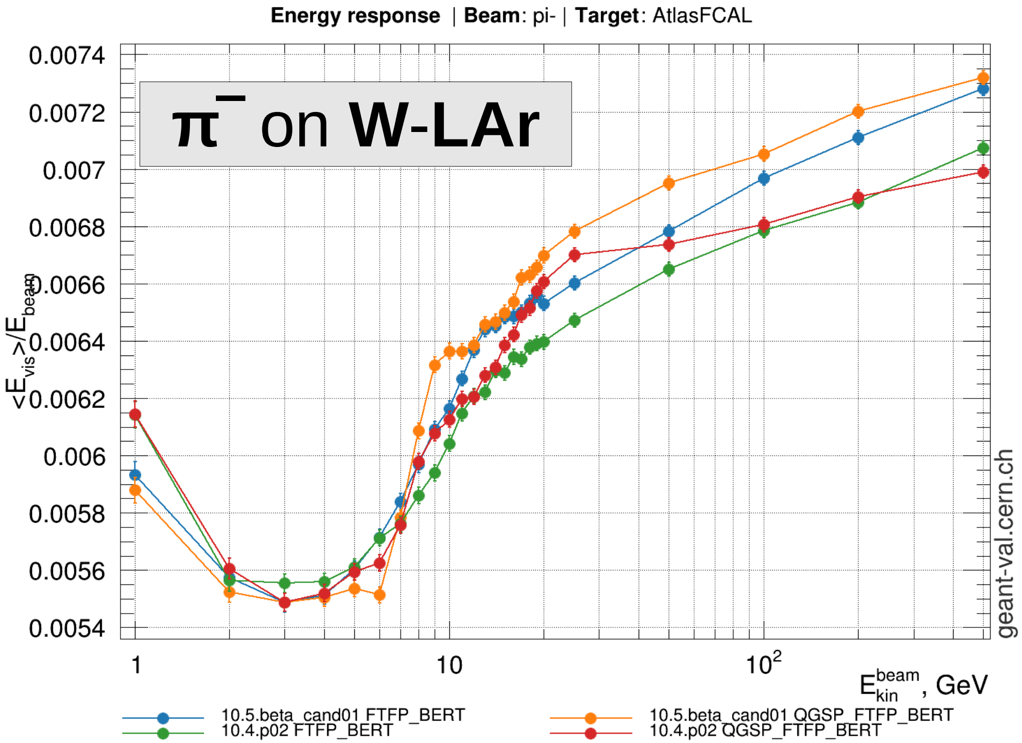
QGSP_FTFP_BERT G4 10.5β
QGSP_FTFP_BERT G4 10.4.p02

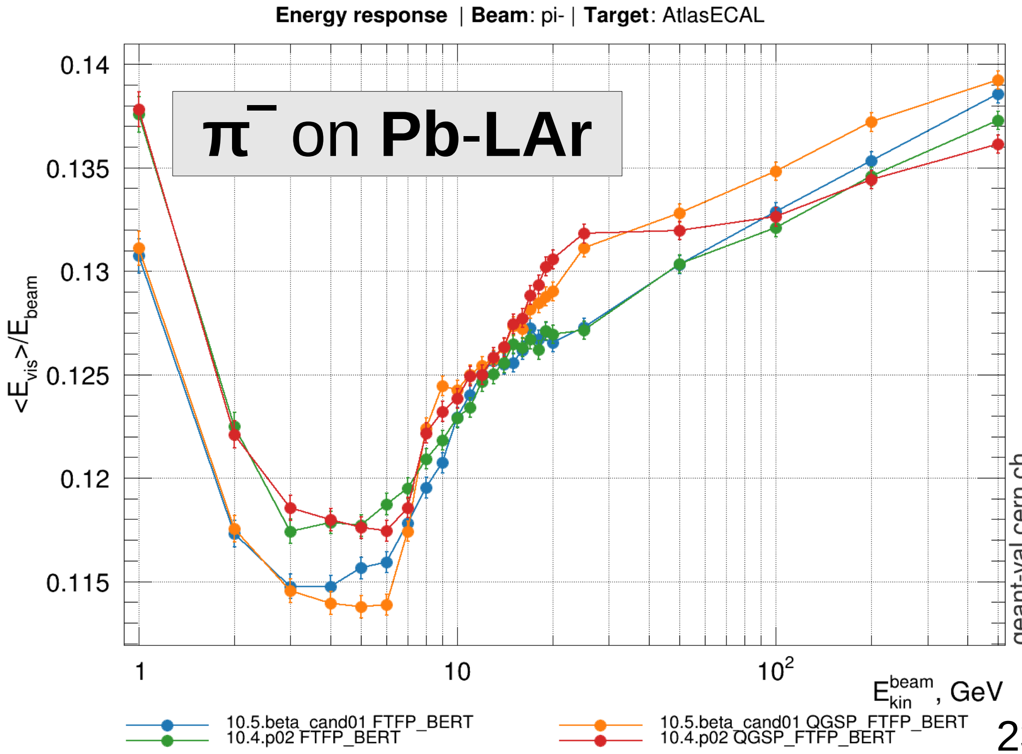
Note: FTFP_BERT : BERT > 3 GeV
FTFP < 12 GeV
QGSP_FTFP_BERT : BERT < 8 GeV
FTFP [6, 25] GeV
QGSP > 12 GeV

Energy Response

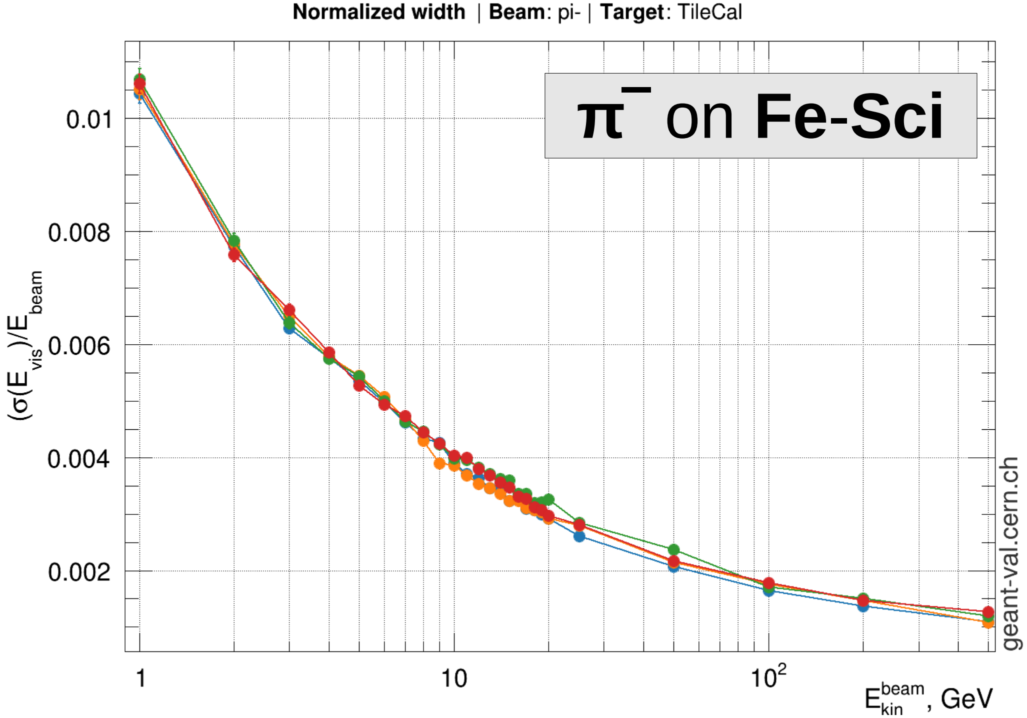


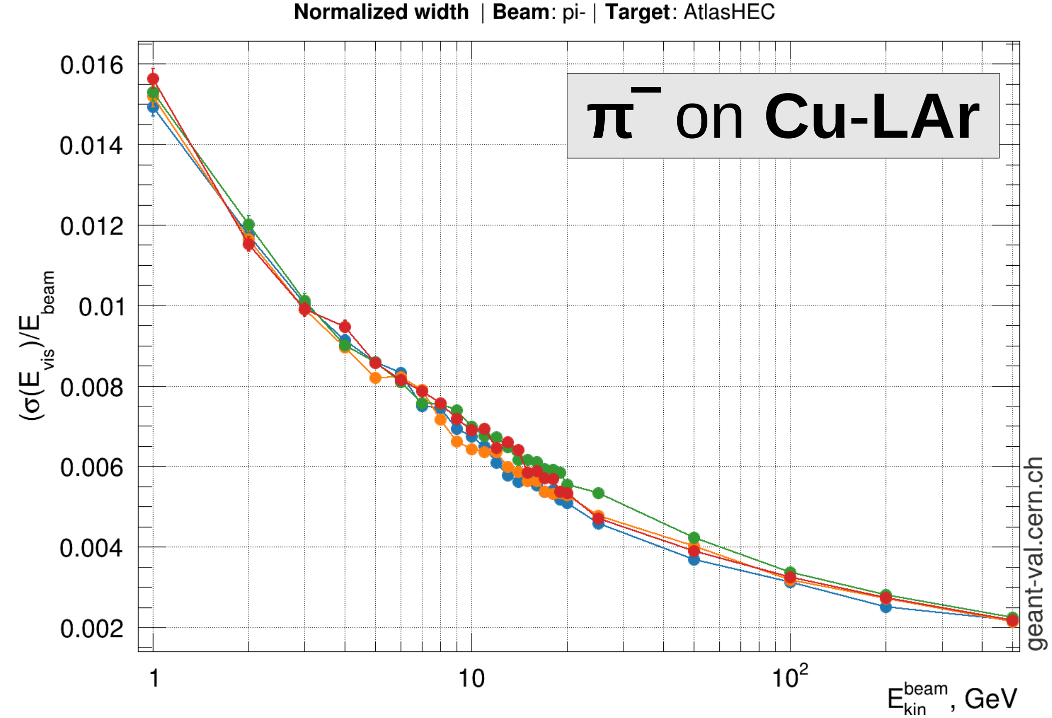


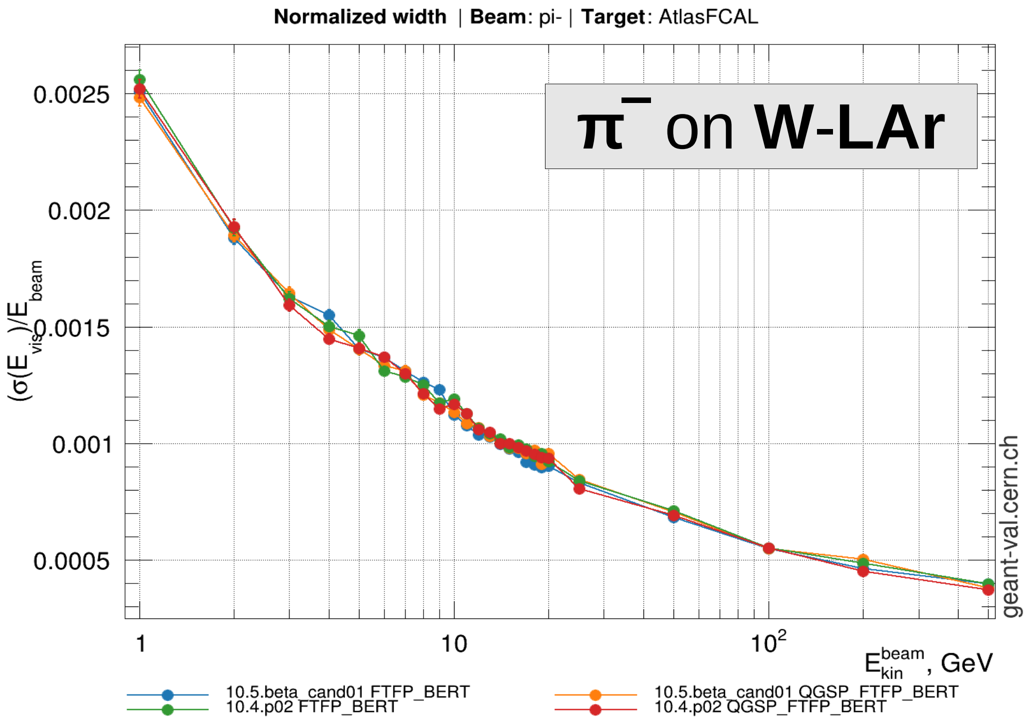


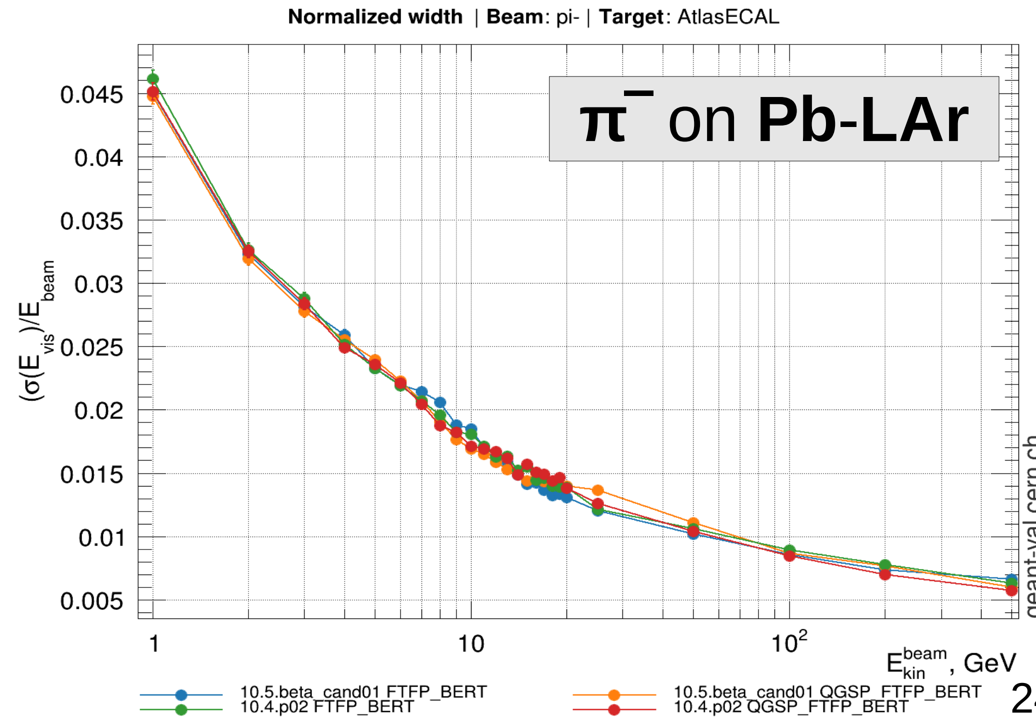


Energy Width

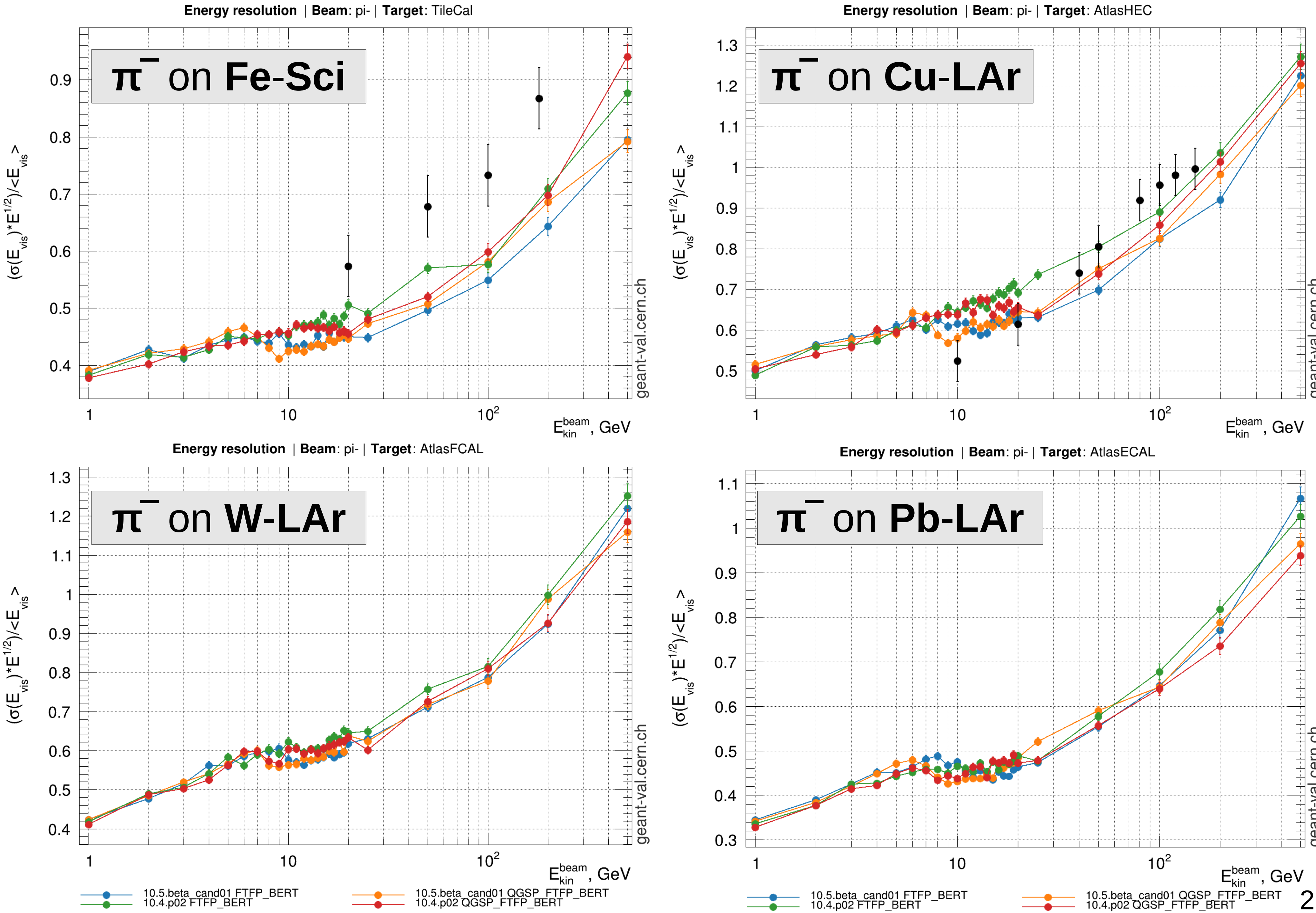




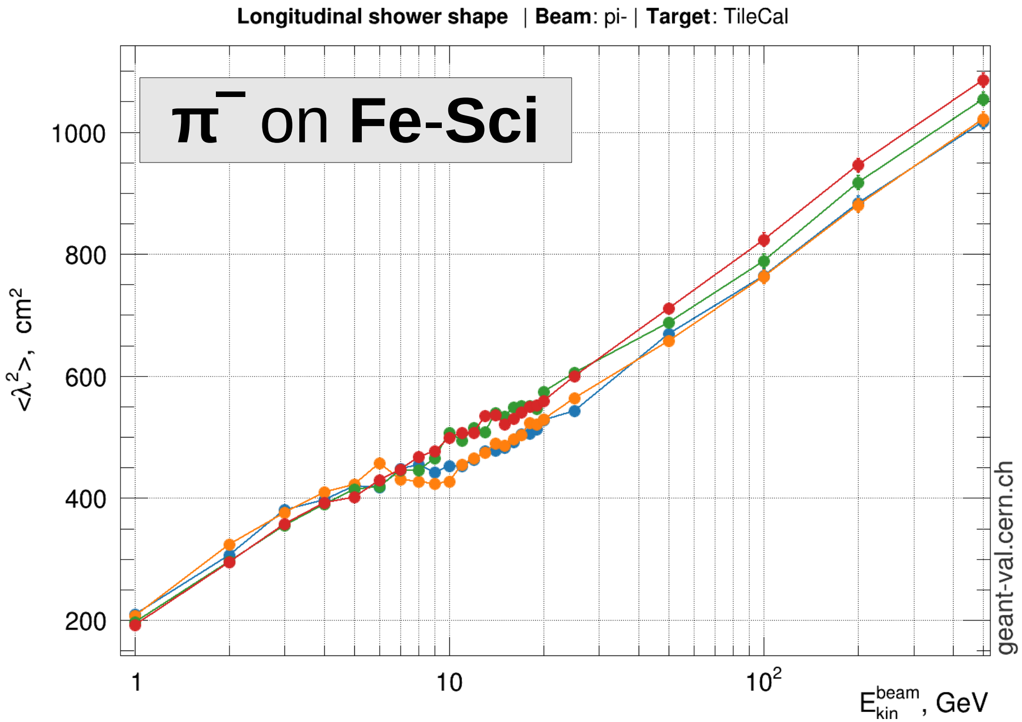


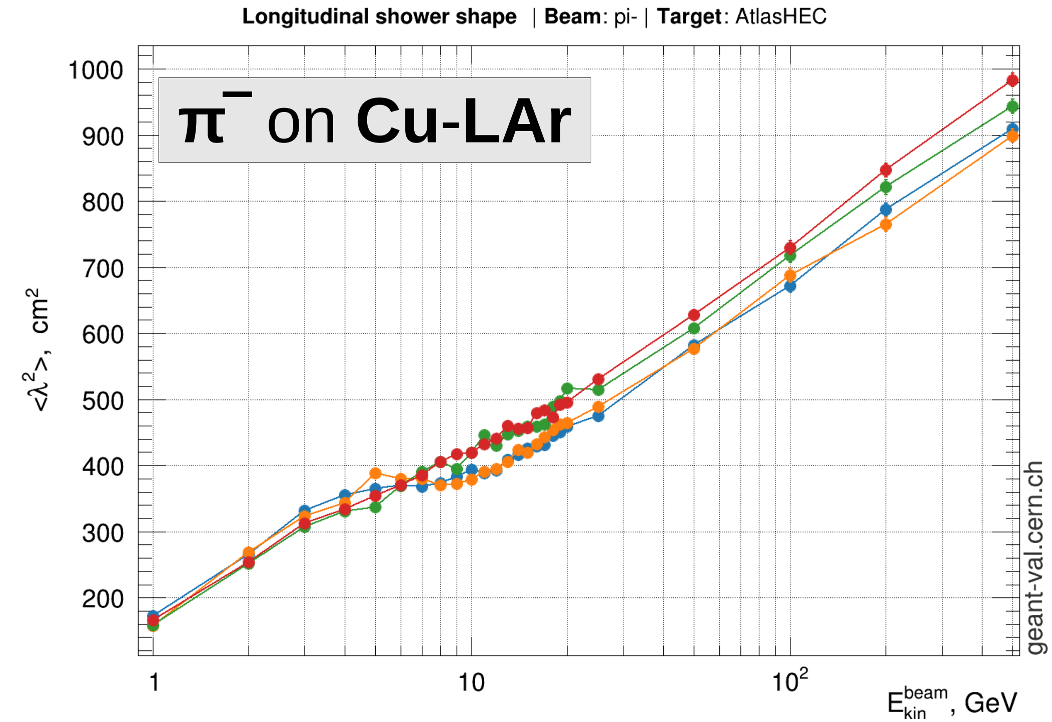


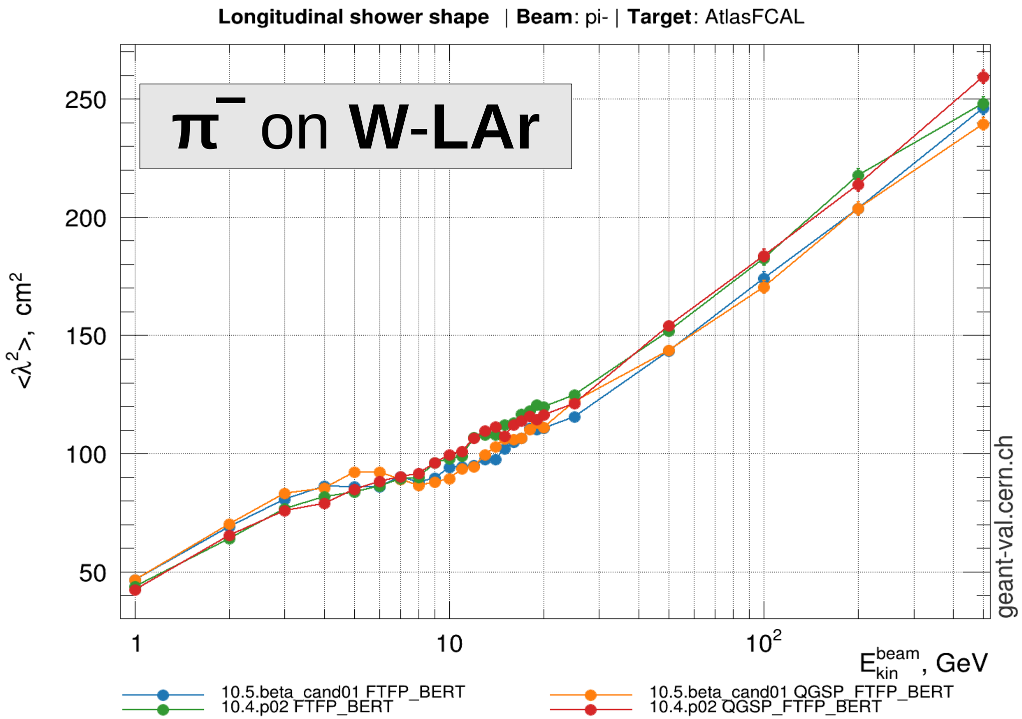
Energy Resolution

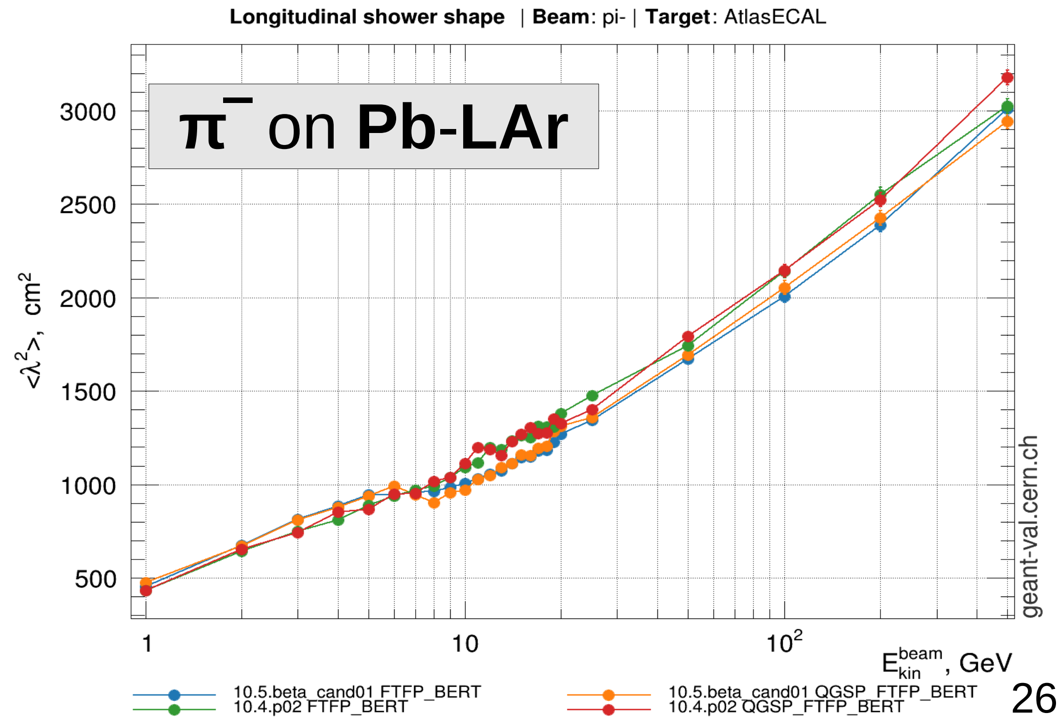


Longitudinal Shape









Lateral Shape