

Further Studies of Hadronic Showers in Geant4 10.6.ref09

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Main Changes in Hadronics vs. 10.6.ref08

- Changes only in the FTF string model
 - Bug-fix in quasi-elastic to avoid double counting of elastic on Hydrogen
 - Thanks to NA61/SHINE ! Expected no impact on hadronic showers
 - Extended FTF configuration interface for quark exchange
 - With and without excitation, for baryon and pion projectiles
 - No changes in the random sequence !
 - Improved description of Pt-Xf correlations in 158 GeV/c pp NA49 data
 - **String formation** : implemented new splitting of excited hadrons into quark-antiquark or quark-diquark (in the method **G4DiffractiveExcitation::CreateStrings**)
 - **String fragmentation (G4LundStringFragmentation)** : two independent changes:
 1. The string direction (one of string's properties, whose value can be either +1 for projectile-like strings or -1 for target-like strings) is now treated correctly and used to invert the results of the string fragmentation (in the string rest frame) when the string direction is -1
 2. Introduced a new parameter, a kind of "temperature" for sampling the Pt of produced hadrons; this parameter has been tuned for different fragmentation processes

Pion- showers: FTFP_BERT

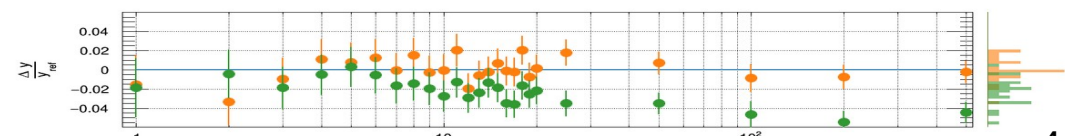
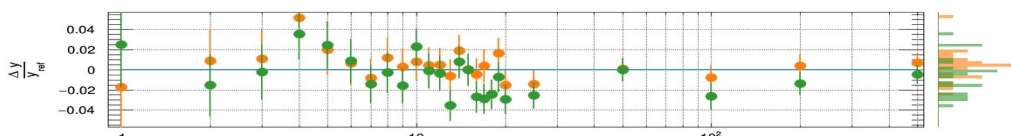
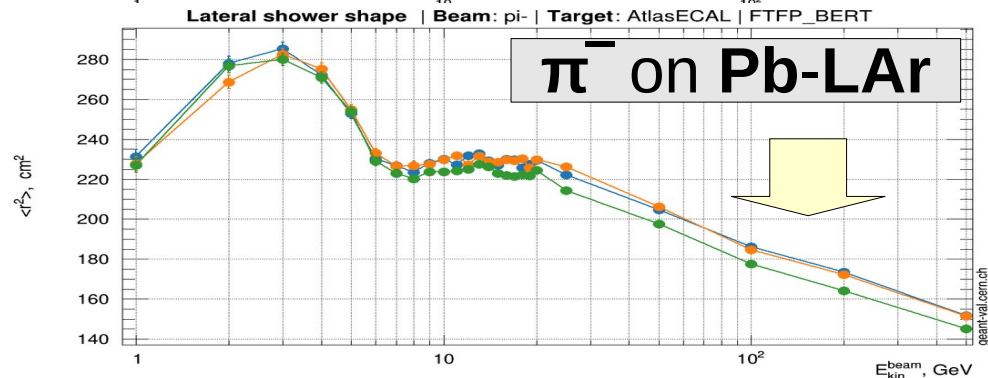
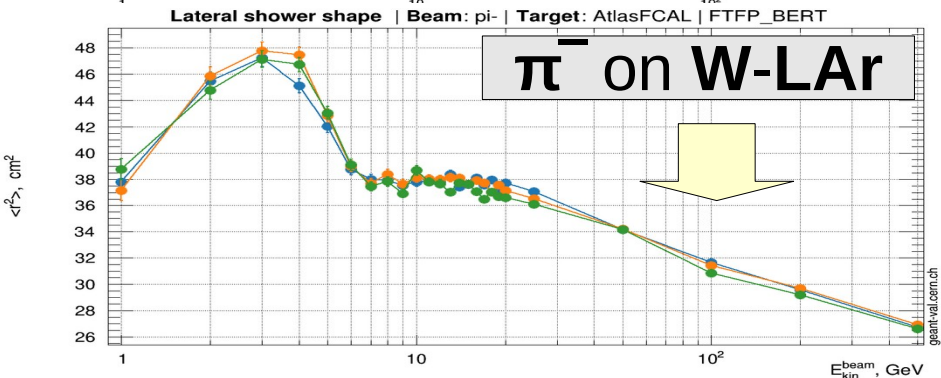
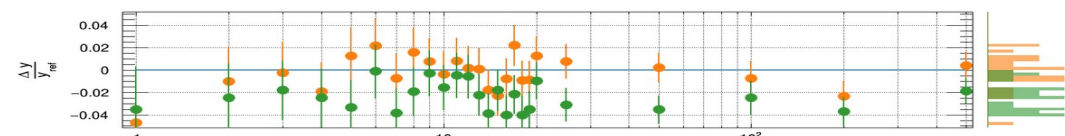
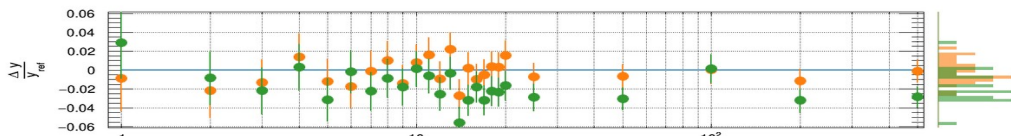
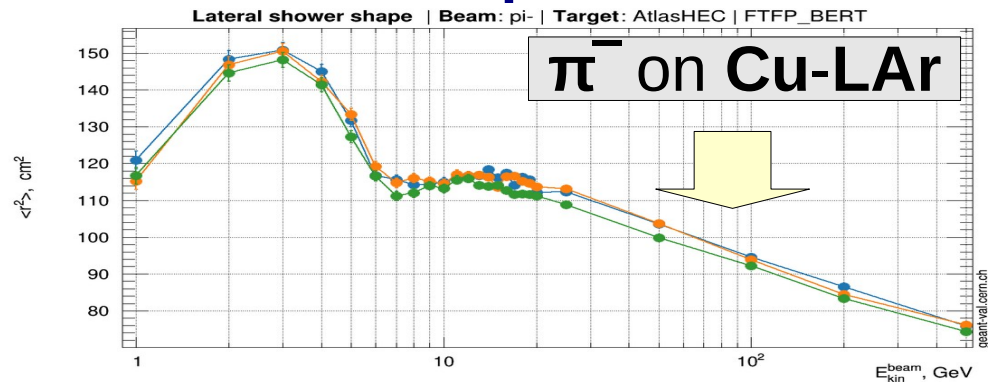
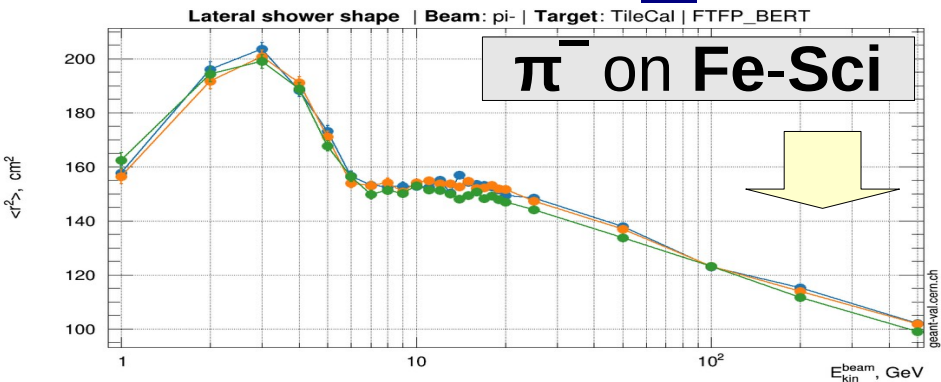
G4 10.6.ref09

G4 10.6.ref08

G4 10.6.p02

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

FTFP_BERT : Lateral Shape



10.6.p02.cand00
10.6.ref09

10.6.ref08

10.6.p02.cand00
10.6.ref09

10.6.ref08

Pion- showers: FTFQGSP_BERT

G4 10.6.ref09

G4 10.6.ref08

G4 10.6.ref08a (rolled back QGS hadronization)

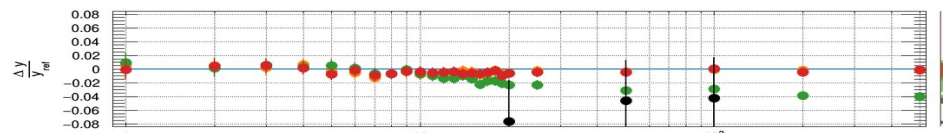
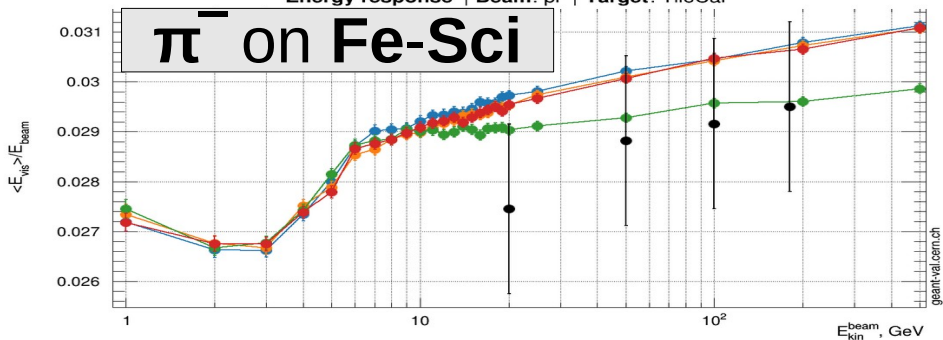
G4 10.6.ref07

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

FTFQGSP_BERT : Energy Response

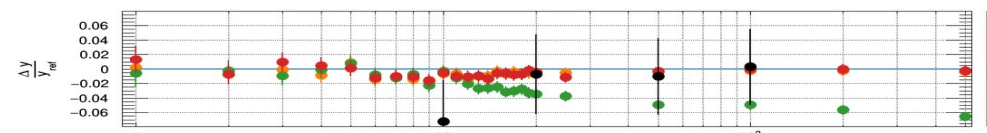
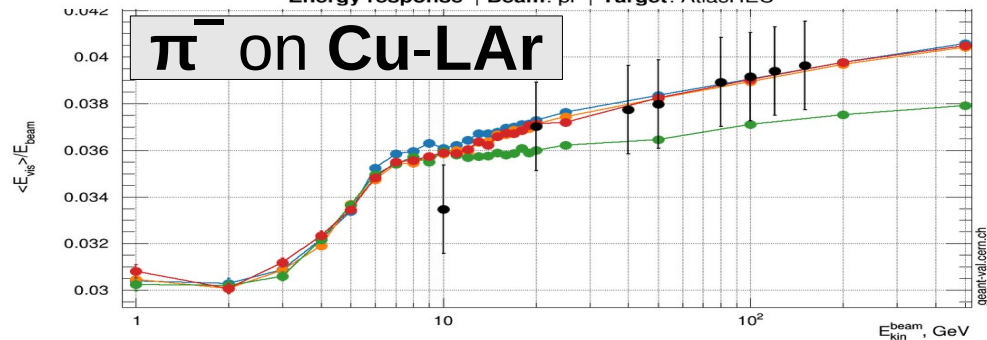
Energy response | Beam: pi- | Target: TileCal

π^- on Fe-Sci



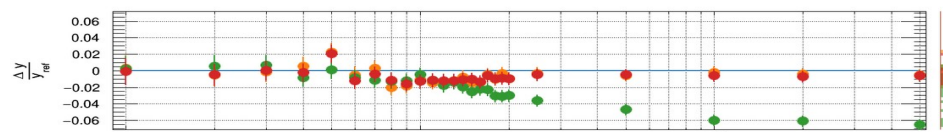
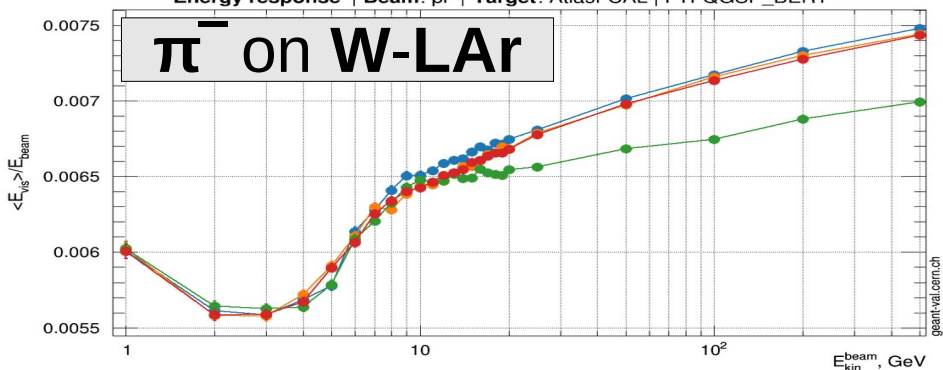
Energy response | Beam: pi- | Target: AtlasHEC

π^- on Cu-LAr



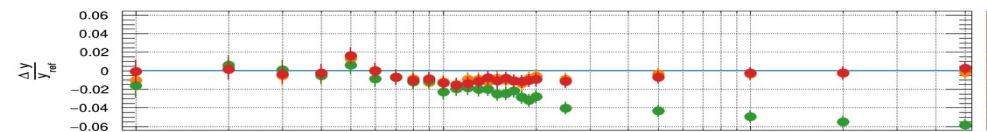
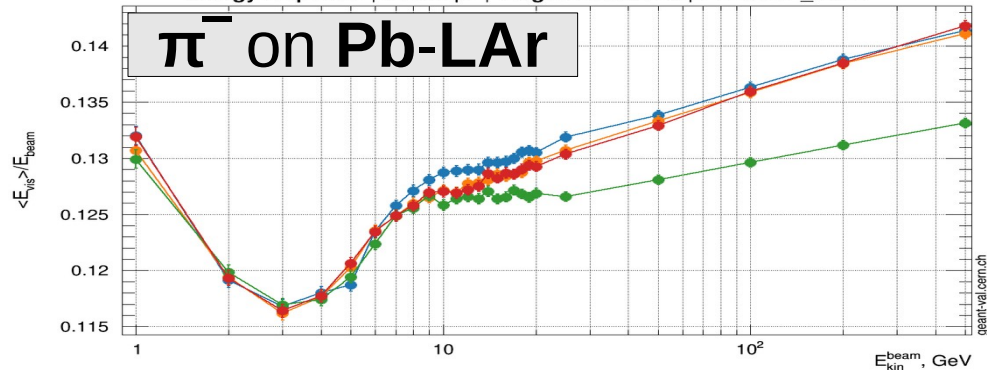
Energy response | Beam: pi- | Target: AtlasFCAL | FTFQGSP_BERT

π^- on W-LAr



Energy response | Beam: pi- | Target: AtlasECAL | FTFQGSP_BERT

π^- on Pb-LAr

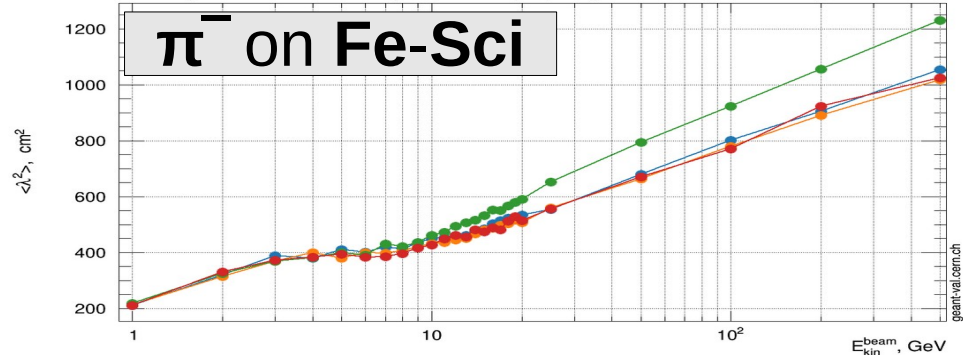


10.6.ref08 (blue), 10.6.ref07 (red), 10.6.ref09 (green)

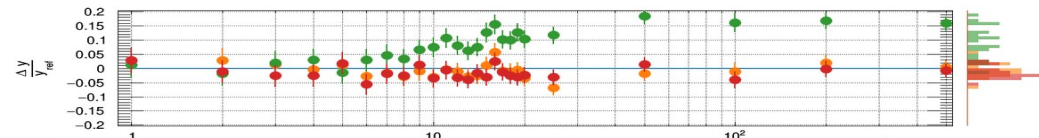
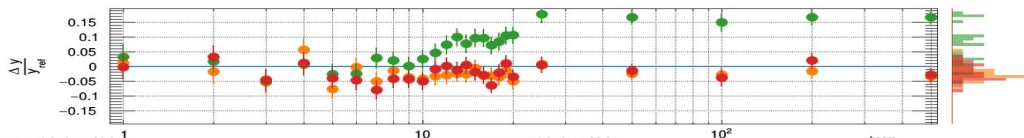
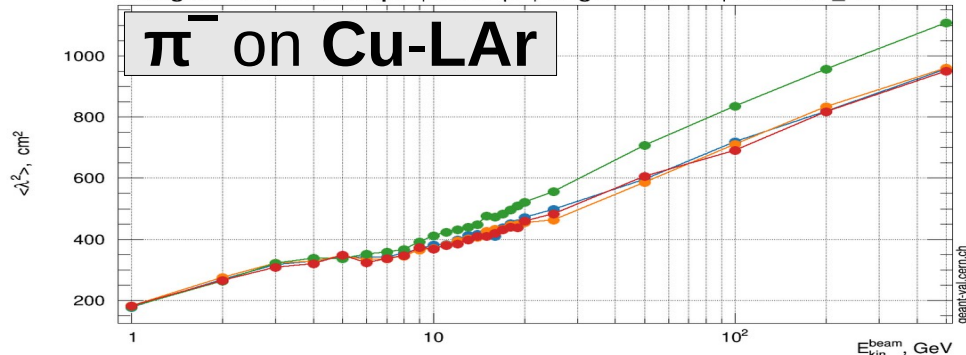
10.6.ref08 (blue), 10.6.ref07 (red), 10.6.ref09 (green)

FTFQGSP_BERT : Longitudinal Shape

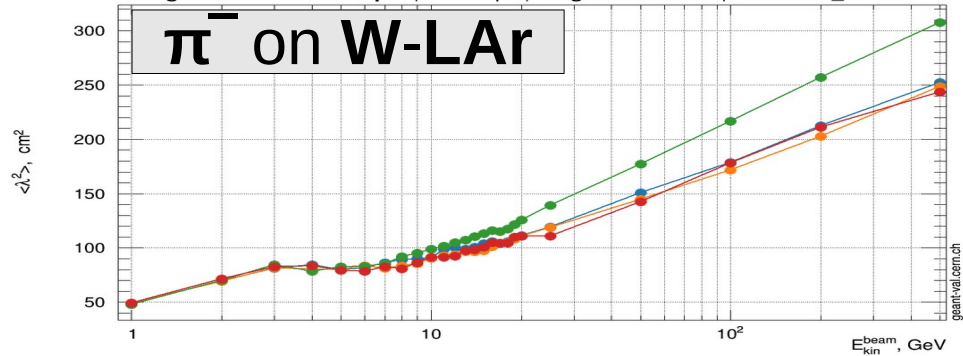
Longitudinal shower shape | Beam: pi- | Target: TileCal | FTFQGSP_BERT



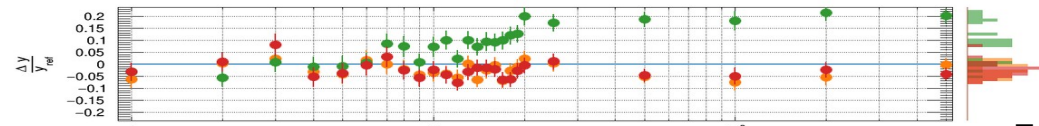
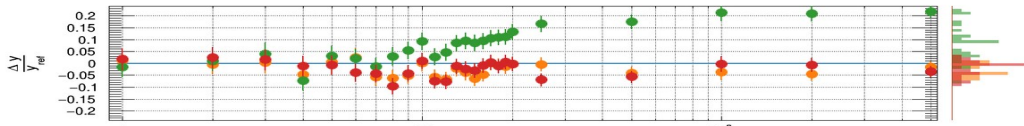
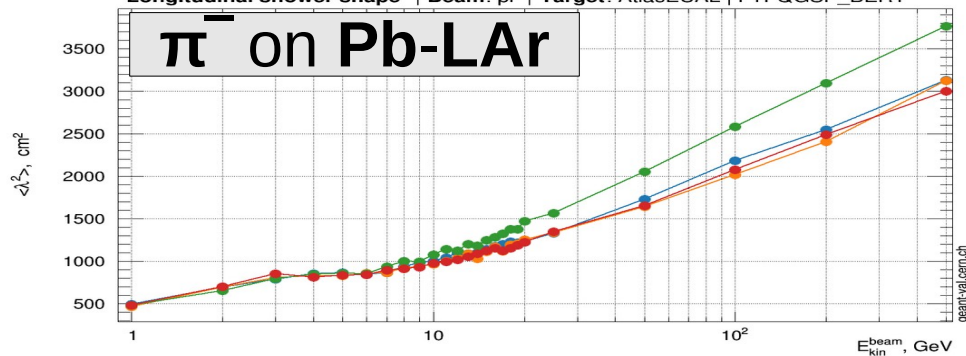
Longitudinal shower shape | Beam: pi- | Target: AtlasHEC | FTFQGSP_BERT



Longitudinal shower shape | Beam: pi- | Target: AtlasFCAL | FTFQGSP_BERT



Longitudinal shower shape | Beam: pi- | Target: AtlasECAL | FTFQGSP_BERT



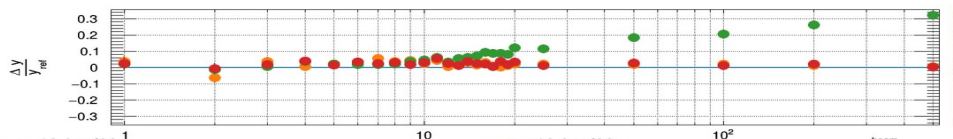
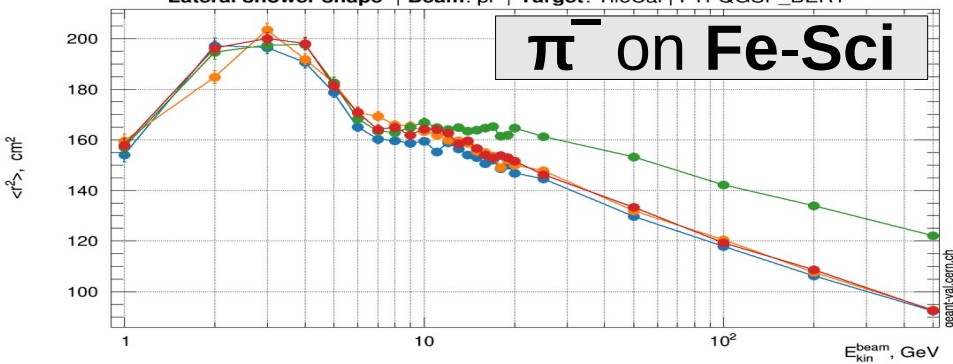
10.6.ref08 10.6.ref09 10.6.ref07

10.6.ref08 10.6.ref09 10.6.ref07

FTFQGSP_BERT : Lateral Shape

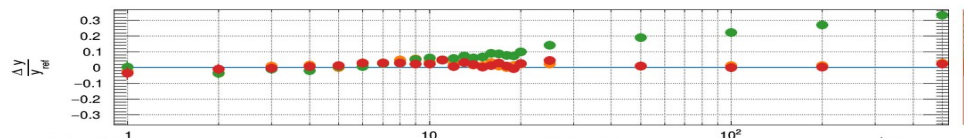
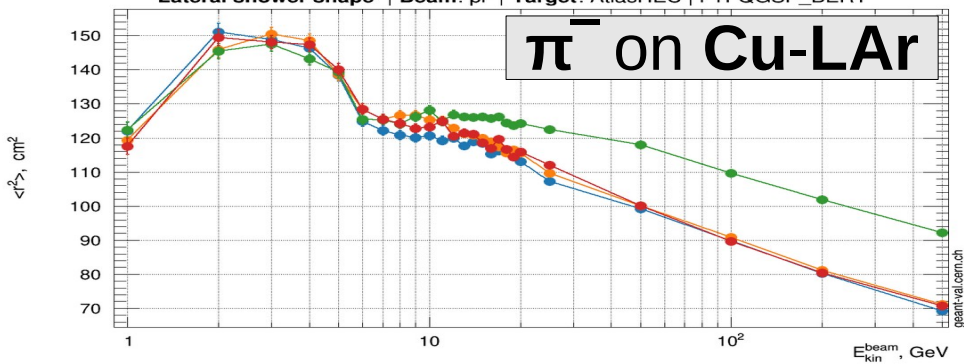
Lateral shower shape | Beam: pi- | Target: TileCal | FTFQGSP_BERT

π^- on Fe-Sci



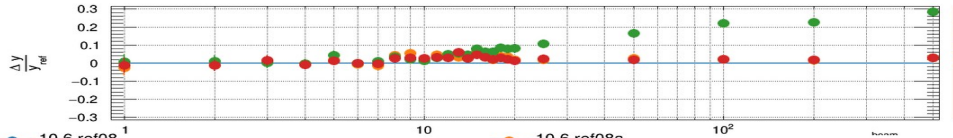
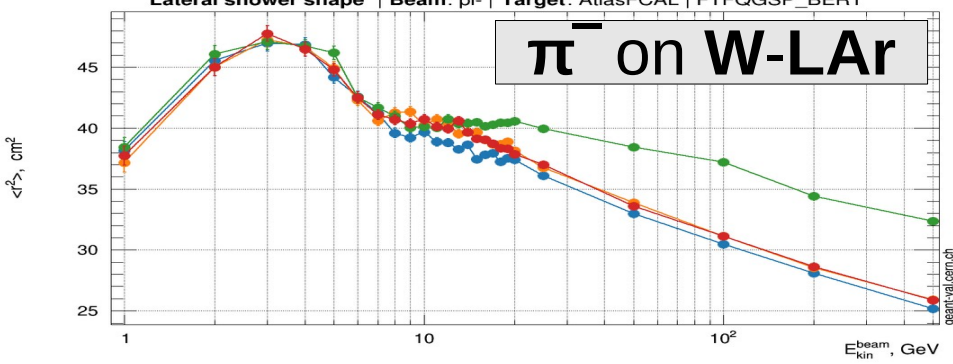
Lateral shower shape | Beam: pi- | Target: AtlasHEC | FTFQGSP_BERT

π^- on Cu-LAr



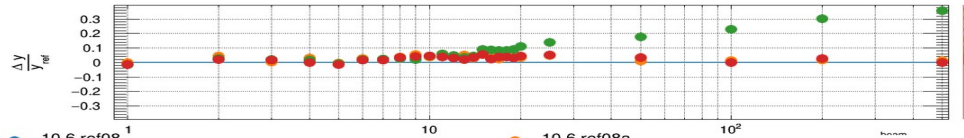
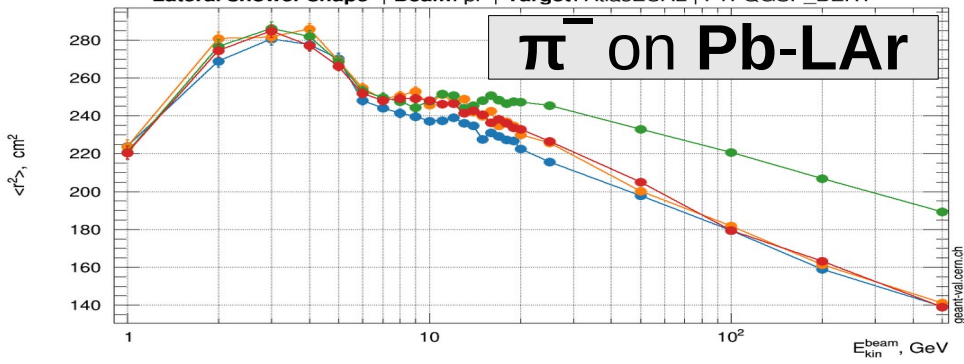
Lateral shower shape | Beam: pi- | Target: AtlasFCAL | FTFQGSP_BERT

π^- on W-LAr



Lateral shower shape | Beam: pi- | Target: AtlasECAL | FTFQGSP_BERT

π^- on Pb-LAr



Hadronic Showers : Summary for 10.6.ref09

- Few % narrower showers for FTF-based physics lists
- Stable showers for QGS-based physics lists
- **Surprising big changes in FTFQGSP_BERT showers!**
 - Few % lower energy response; quasi stable energy resolution; 10-20% longer showers and 10-30% wider showers
 - Appears in *Ref09*, where only FTF has changed

Particle-level Study of **FTFQGSP** π^- - projectile on **Cu** target vs. beam energy

(similar conclusions for other projectile – target combinations)

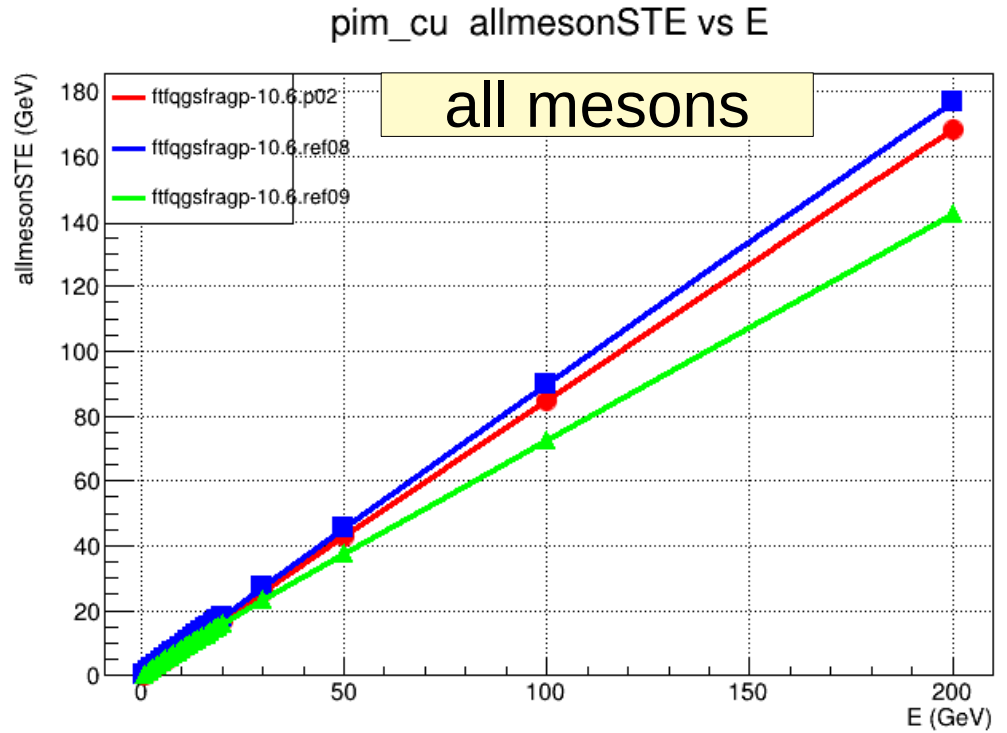
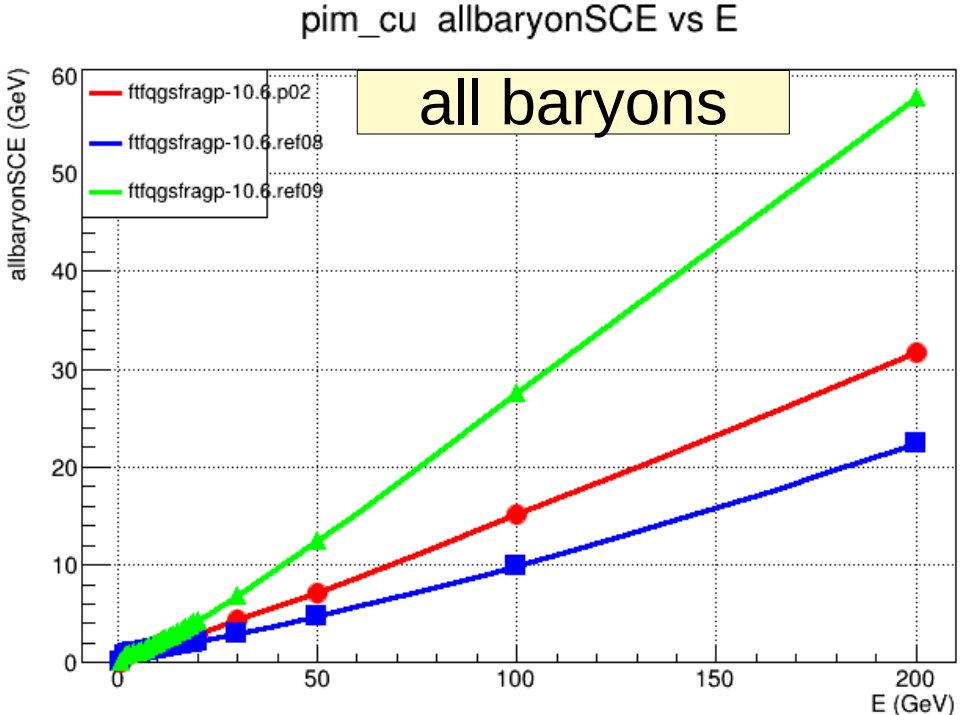
G4 **10.6.ref09**

G4 **10.6.ref08**

G4 **10.6.p02**

Energy Flow

π^- on Cu

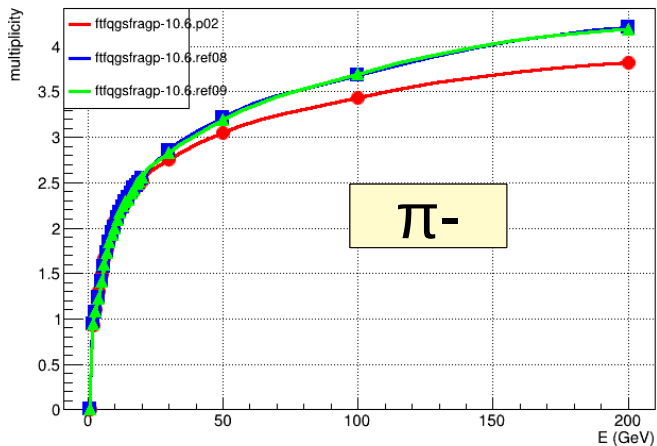


Energy flow in *Ref09*
decreases for mesons and
increases for baryons
w.r.t. *Ref08*
==> higher energy reponse
and bigger showers !

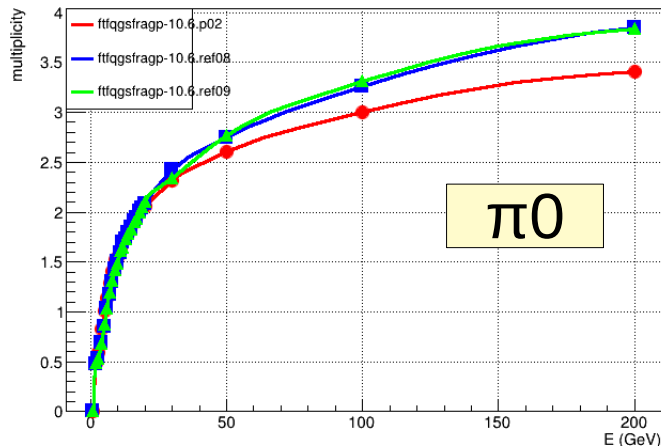
Particle Multiplicity

π^- on Cu

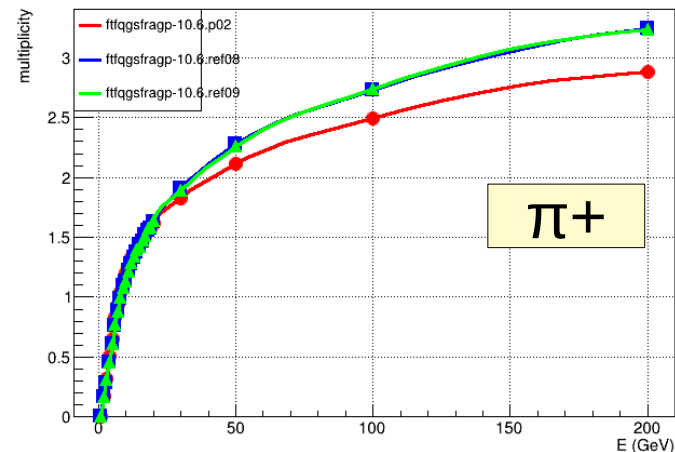
multiplicity_pim_cu pim vs E



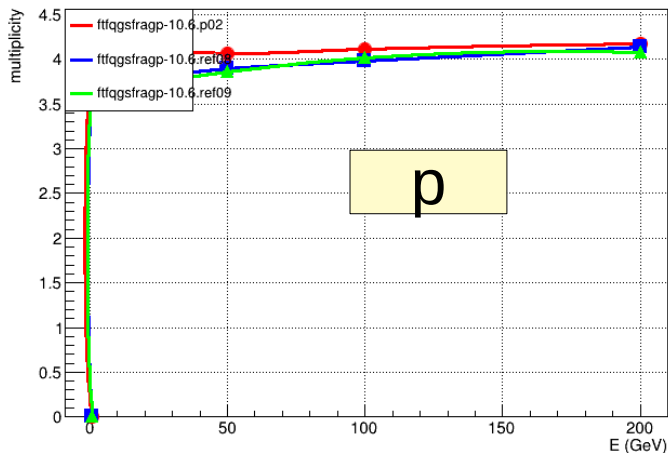
multiplicity_pim_cu piz vs E



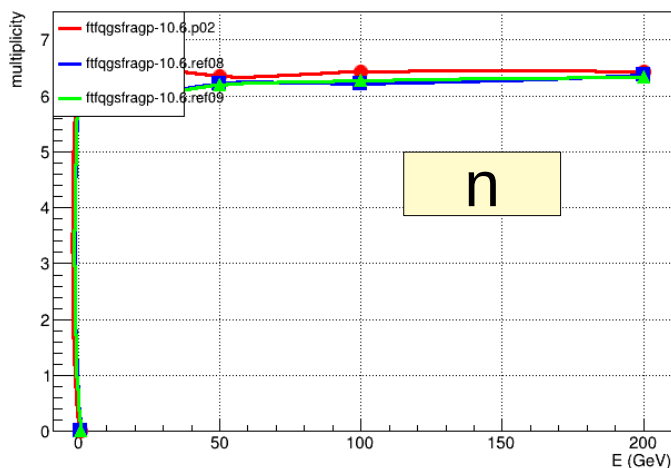
multiplicity_pim_cu pip vs E



multiplicity_pim_cu p vs E



multiplicity_pim_cu n vs E

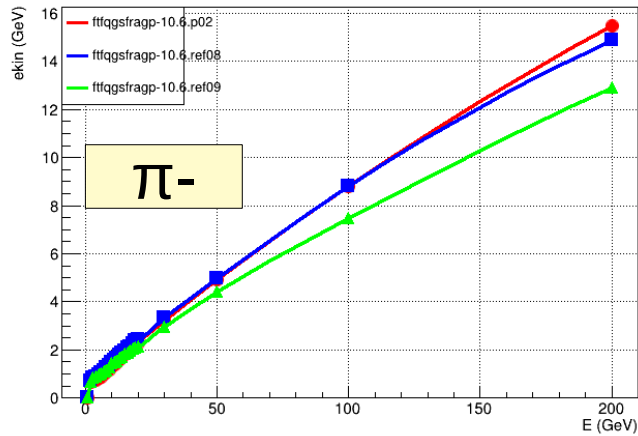


Multiplicity of secondaries in *Ref09* is the **same** as in *Ref08*

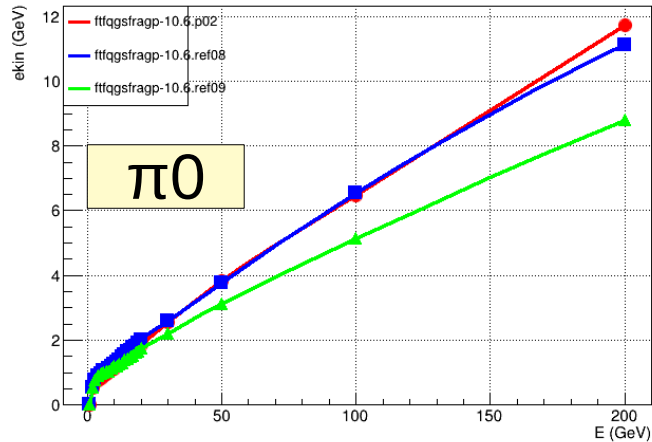
Kinetic Energy Spectra

π^- on Cu

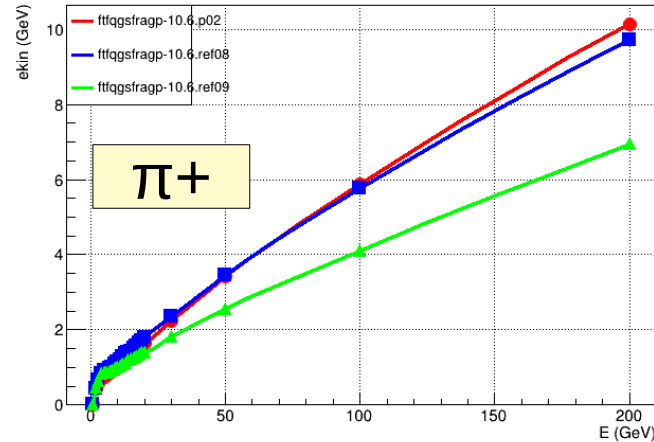
ekin_pim_cu pim vs E



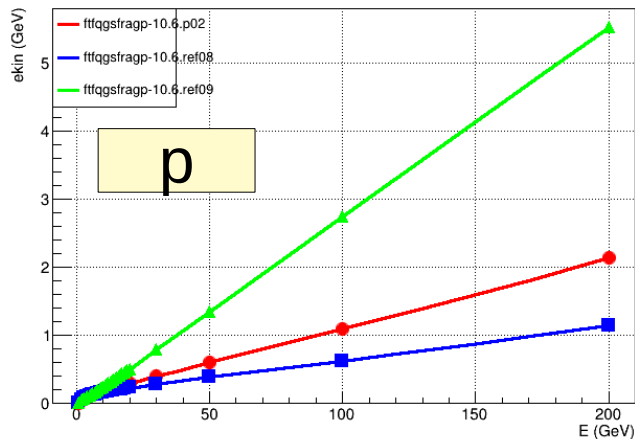
ekin_pim_cu piz vs E



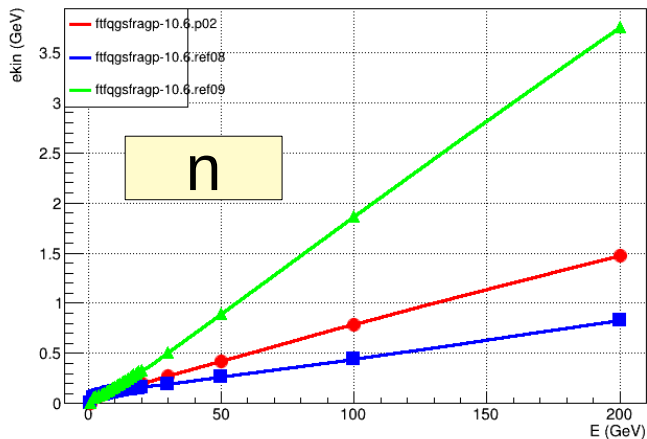
ekin_pim_cu pip vs E



ekin_pim_cu p vs E



ekin_pim_cu n vs E



Spectra becomes
softer for pions and
harder for nucleons
in Ref09 w.r.t. Ref08

Pion- showers: FTFQGSP_BERT

G4 10.6.ref09

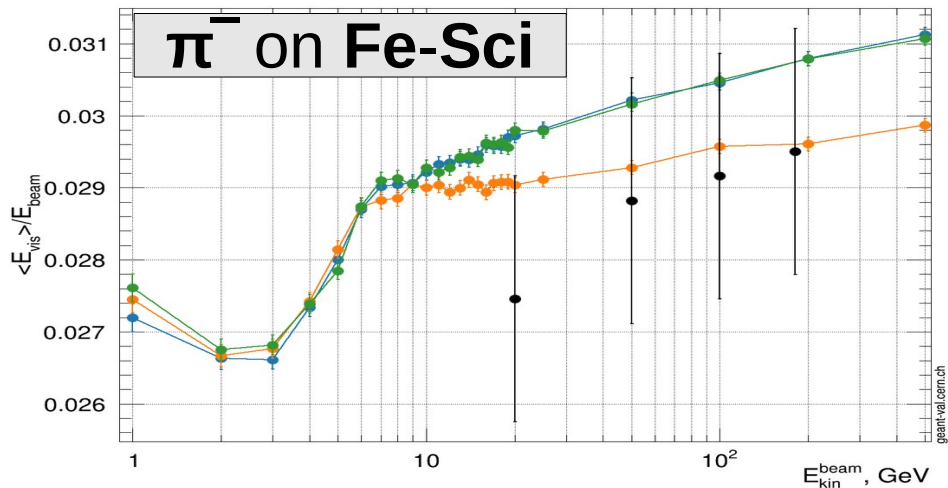
G4 10.6.ref09a

G4 10.6.ref08

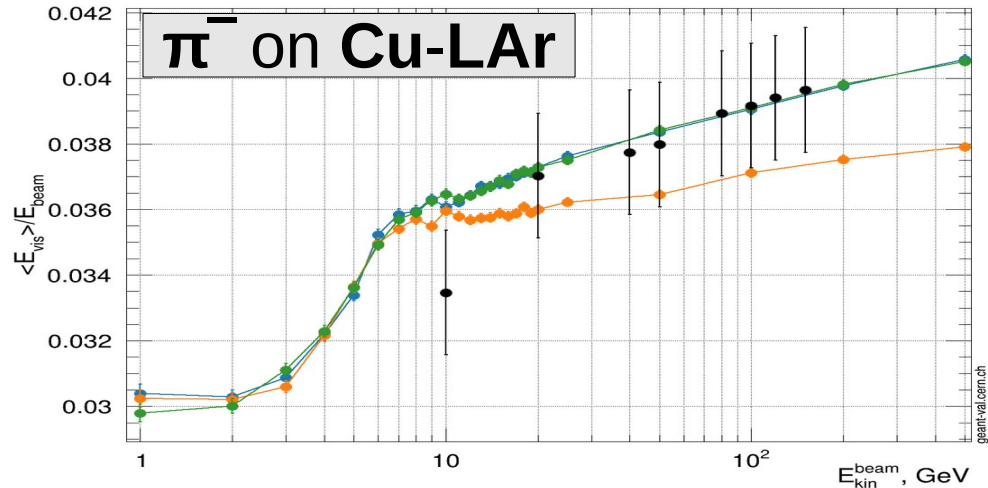
Note : “10.6.ref09a” is as *Ref09*, but rolling back (as it was in *Ref08*)
the method **G4DiffractiveExcitation::CreateStrings**

FTFQGSP_BERT : Energy Response

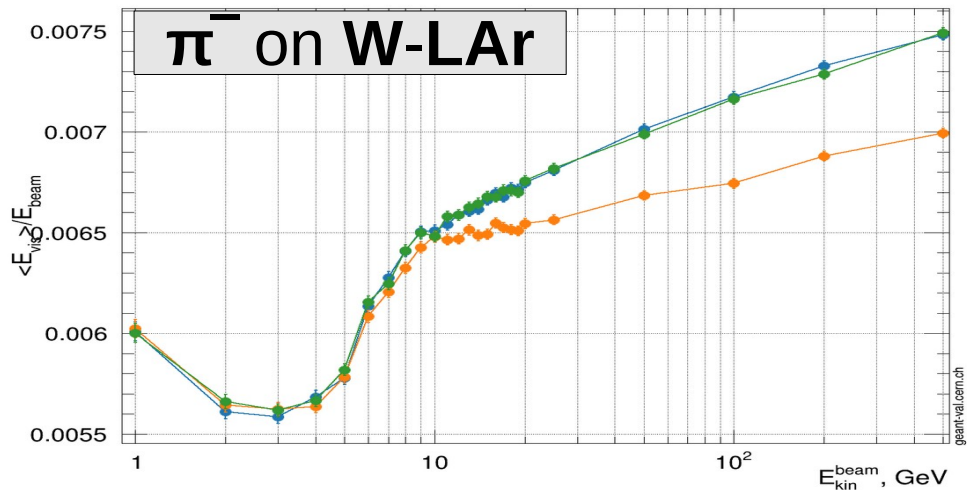
Energy response | Beam: pi- | Target: TileCal



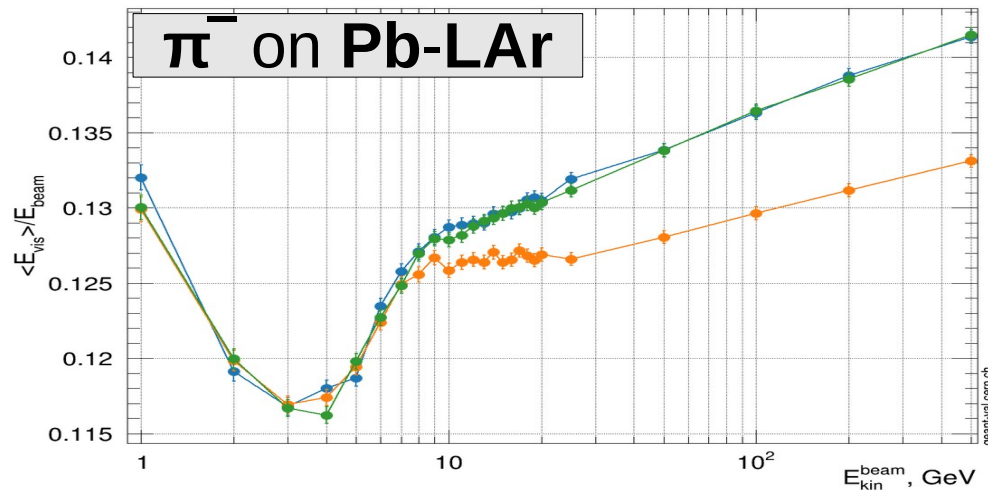
Energy response | Beam: pi- | Target: AtlasHEC



Energy response | Beam: pi- | Target: AtlasFCAL | FTFQGSP_BERT

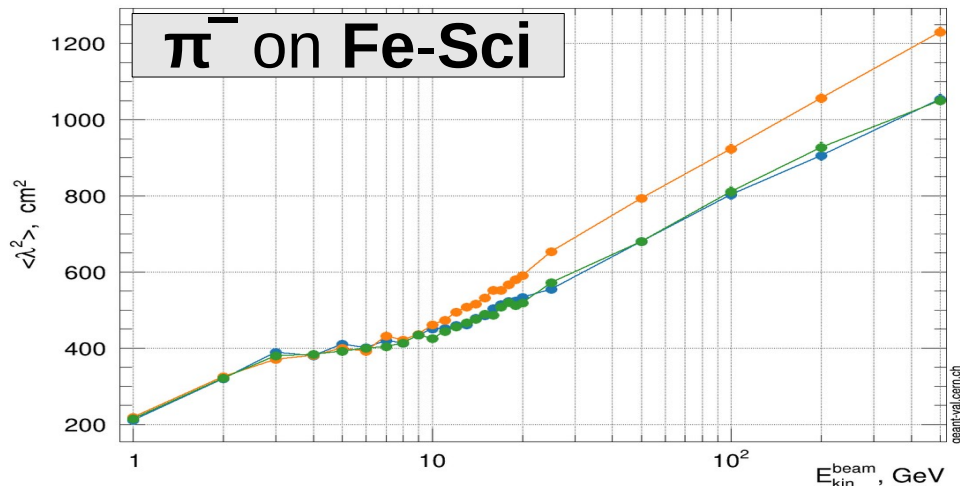


Energy response | Beam: pi- | Target: AtlasECAL | FTFQGSP_BERT

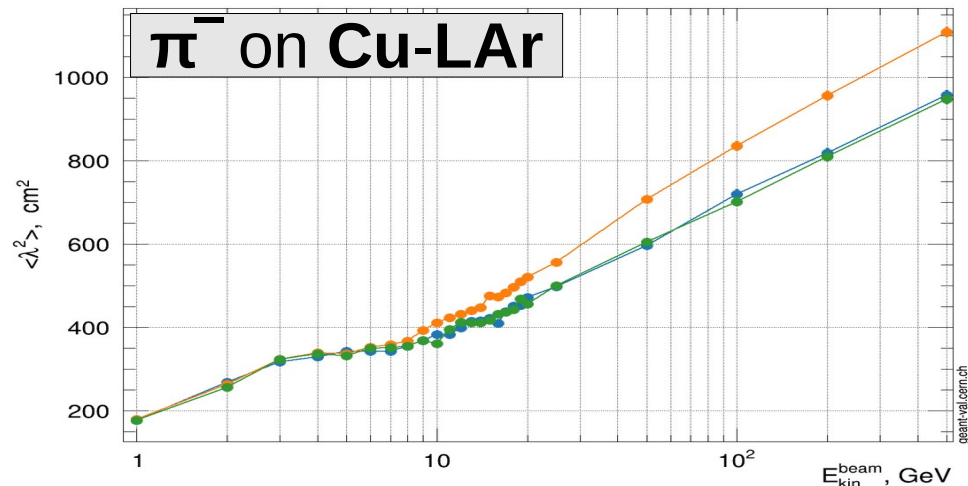


FTFQGSP_BERT : Longitudinal Shape

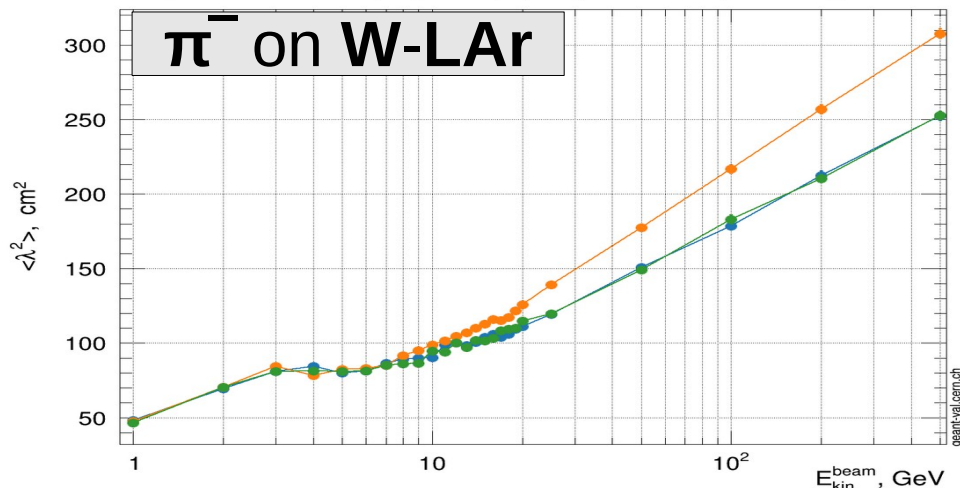
Longitudinal shower shape | Beam: pi- | Target: TileCal | FTFQGSP_BERT



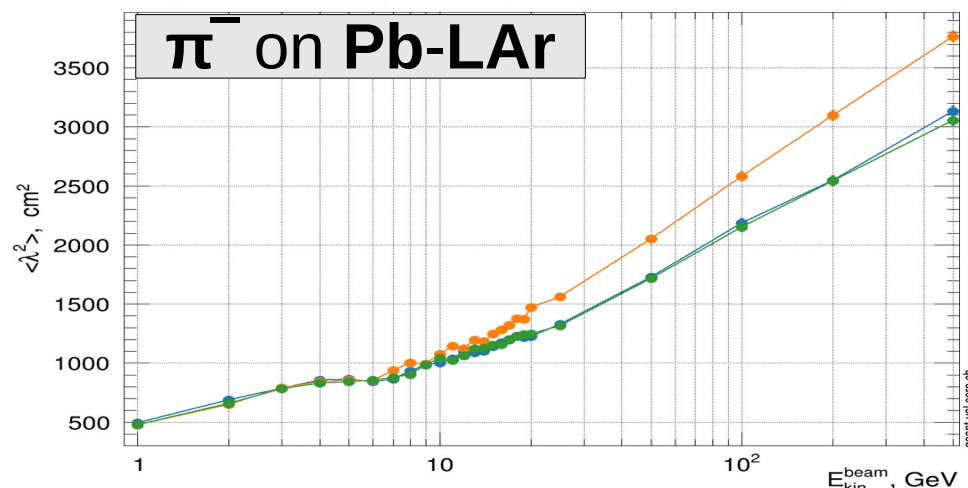
Longitudinal shower shape | Beam: pi- | Target: AtlasHEC | FTFQGSP_BERT



Longitudinal shower shape | Beam: pi- | Target: AtlasFCAL | FTFQGSP_BERT

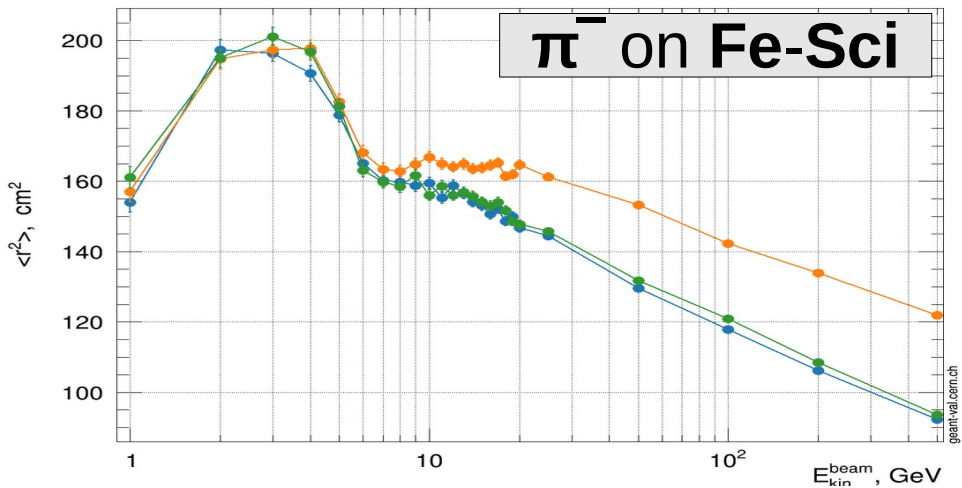


Longitudinal shower shape | Beam: pi- | Target: AtlasECAL | FTFQGSP_BERT

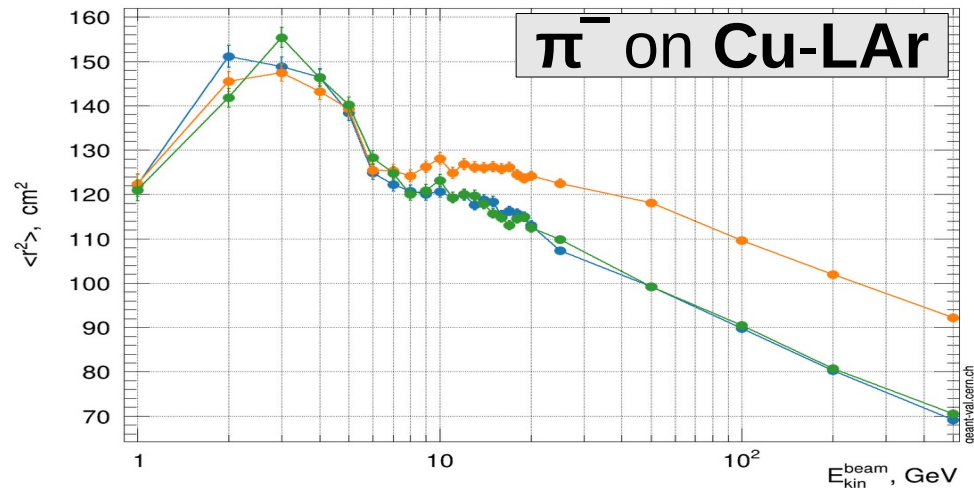


FTFQGSP_BERT : Lateral Shape

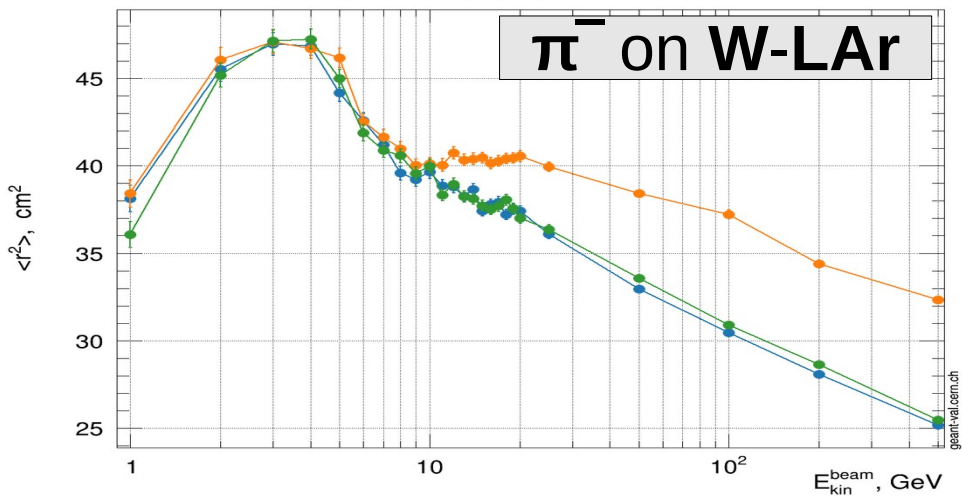
Lateral shower shape | Beam: pi- | Target: TileCal | FTFQGSP_BERT



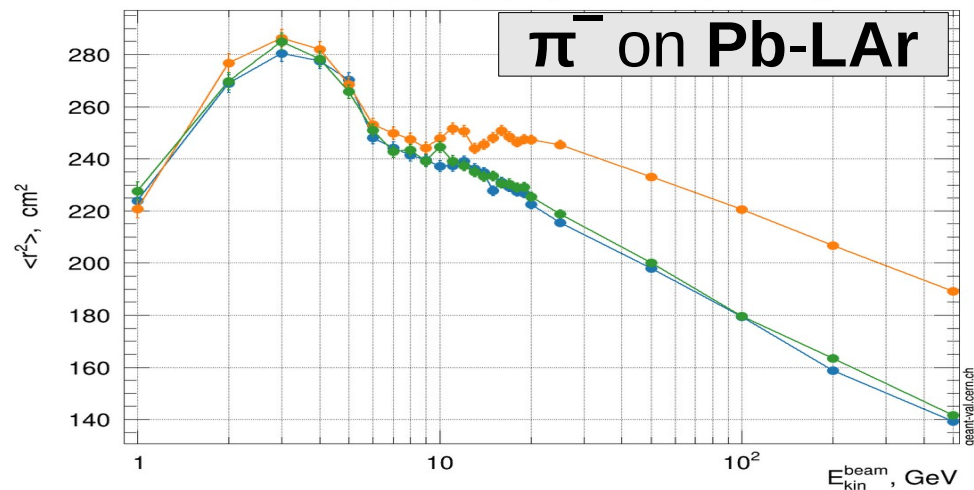
Lateral shower shape | Beam: pi- | Target: AtlasHEC | FTFQGSP_BERT



Lateral shower shape | Beam: pi- | Target: AtlasFCAL | FTFQGSP_BERT



Lateral shower shape | Beam: pi- | Target: AtlasECAL | FTFQGSP_BERT



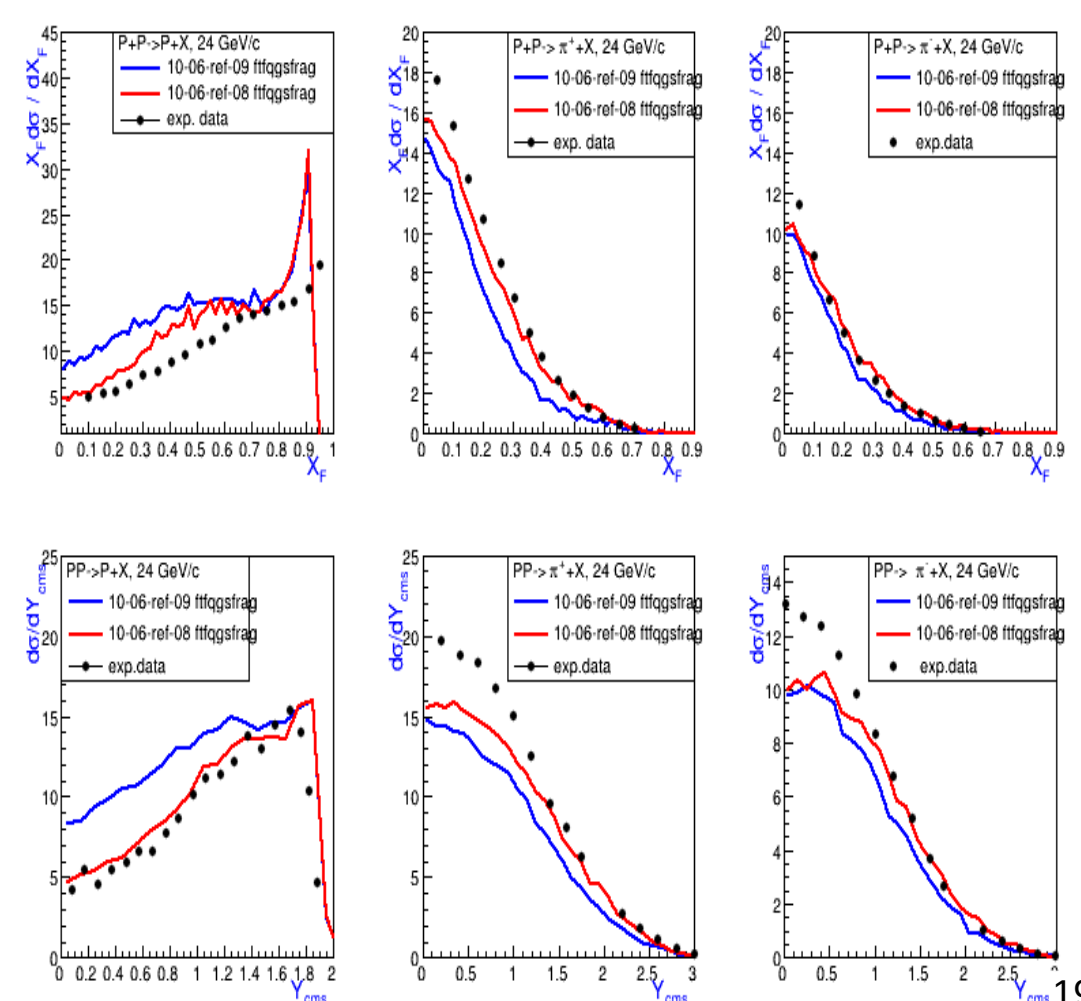
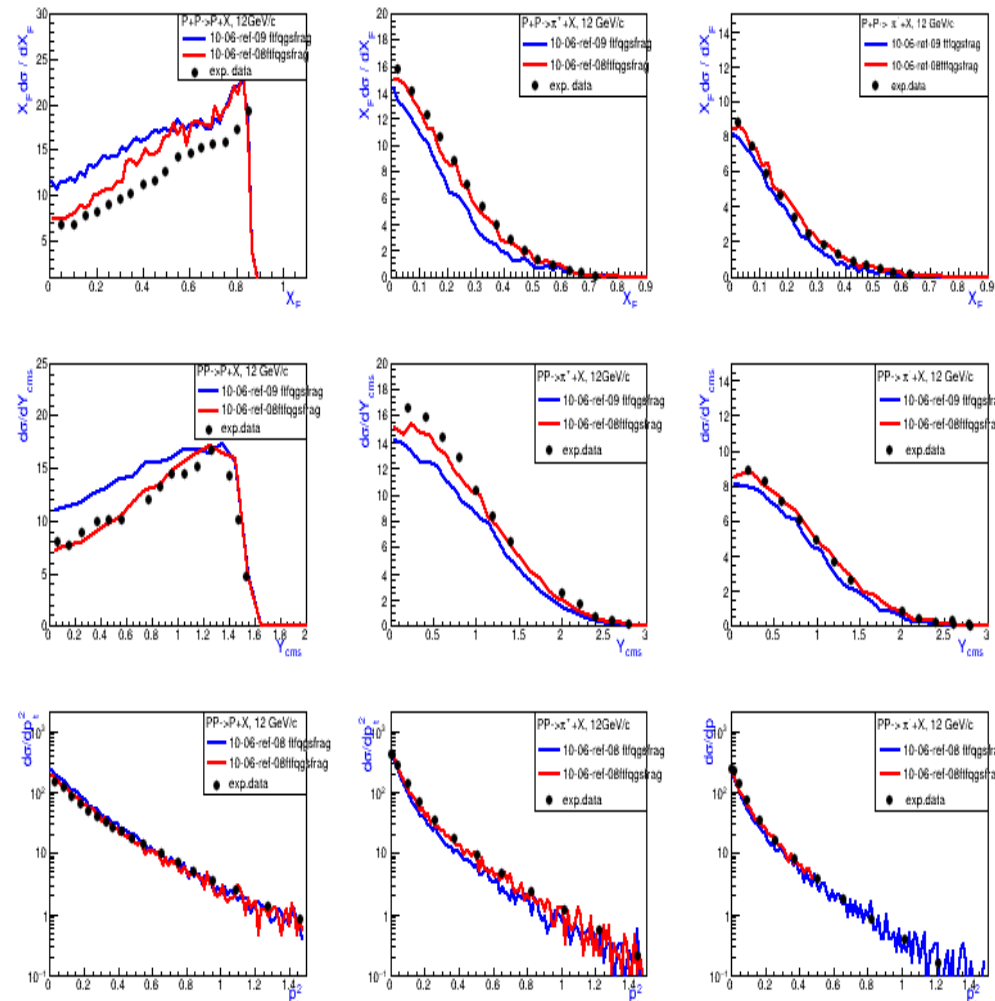
Thin-target (test22) Validation of FTFQGSP

G4 10.6.ref09

G4 10.6.ref08

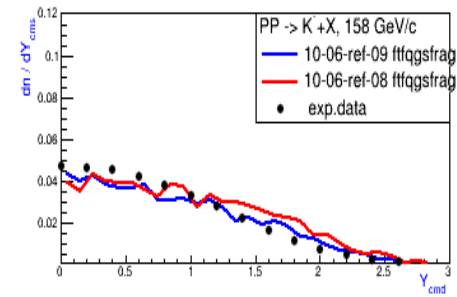
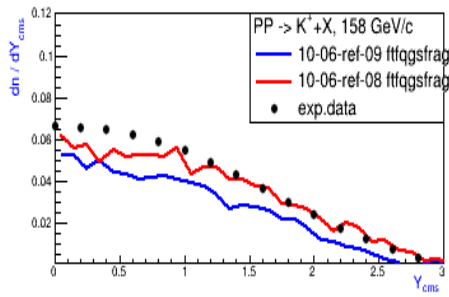
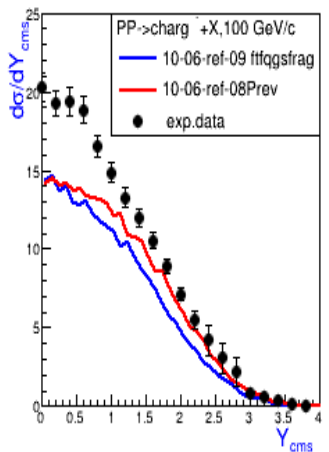
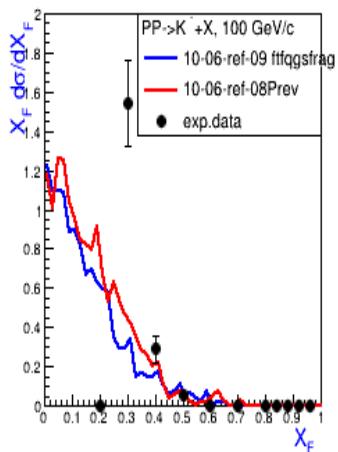
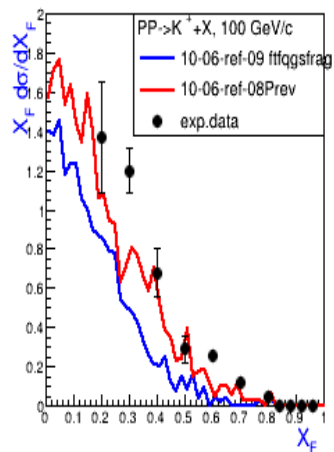
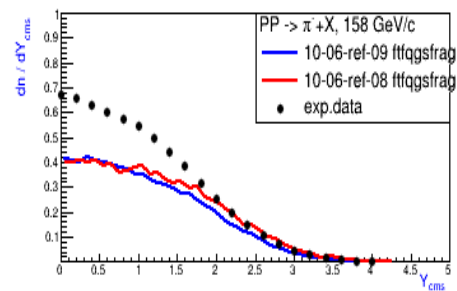
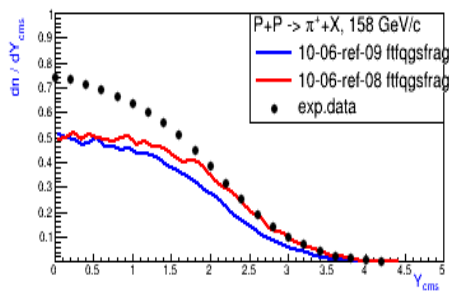
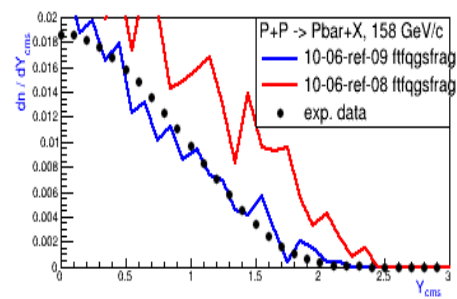
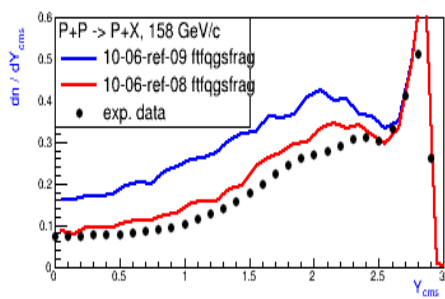
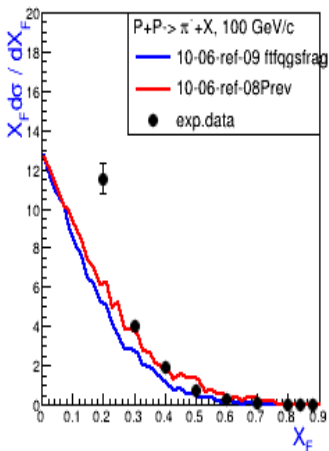
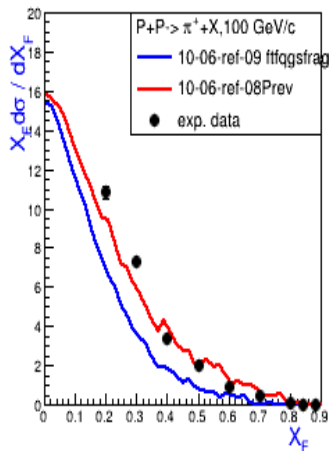
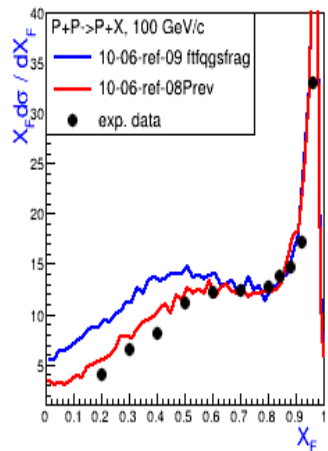
12 GeV/c $p p \rightarrow h + X$

24 GeV/c $p p \rightarrow h + X$



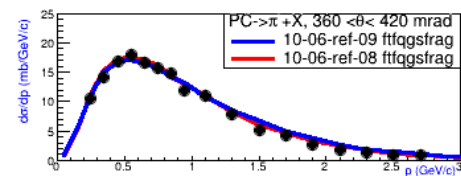
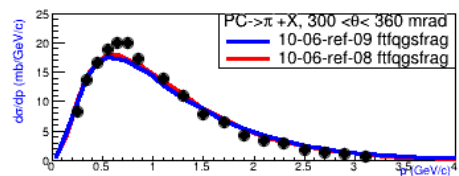
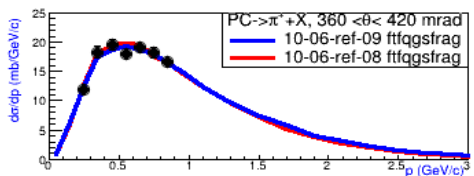
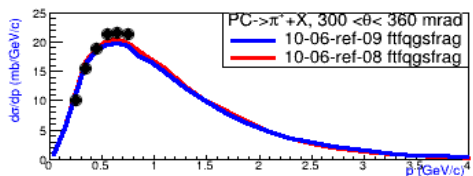
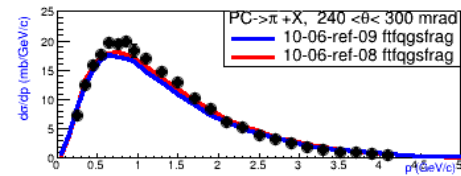
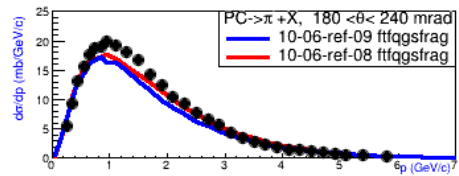
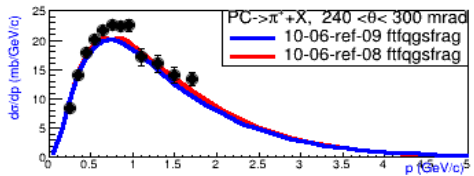
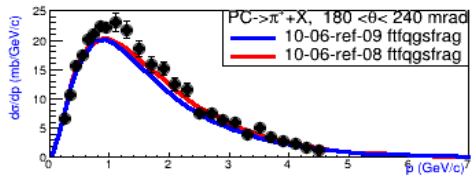
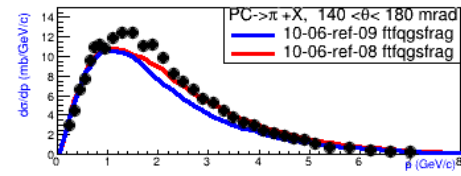
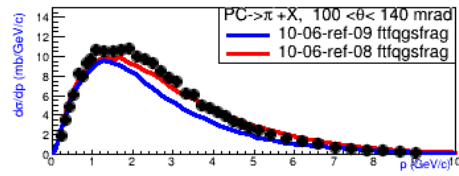
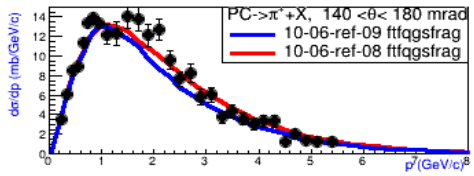
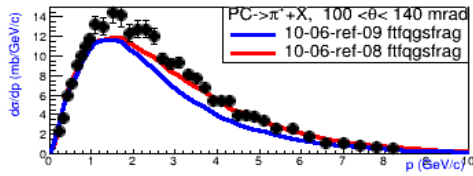
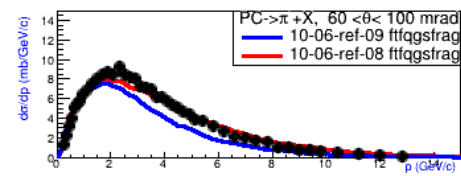
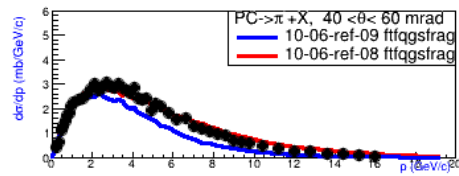
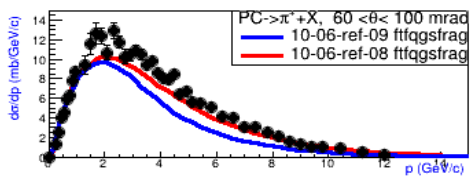
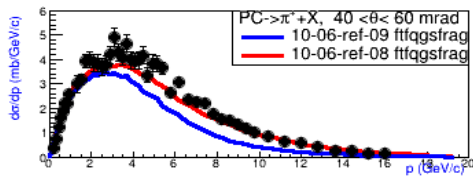
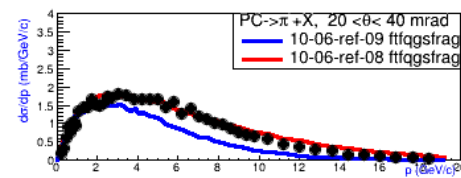
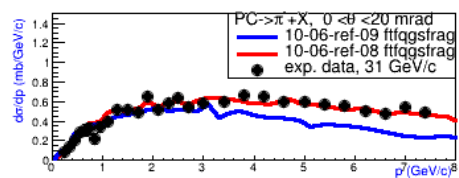
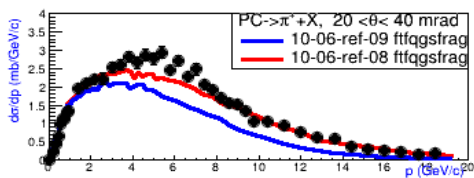
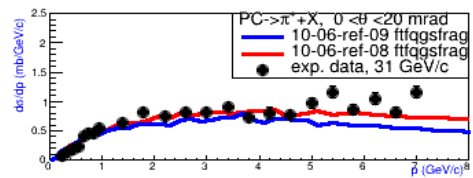
100 GeV/c $p p \rightarrow h + X$

158 GeV/c $p p \rightarrow h + X$



31 GeV/c $p C \rightarrow \pi^+ + X$

31 GeV/c $p C \rightarrow \pi^- + X$



Summary for FTFQGSP_BERT

- The big change in *Ref09* for FTFQGSP_BERT is due to the **new splitting** of excited hadrons into quark-antiquark and quark-diquark in **G4DiffractiveExcitation::CreateStrings**
 - Rolling back this method we get the same hadronic showers as in *Ref08*
- Multiplicity of secondaries produced by FTFQGSP in *Ref09* is the same as in *Ref08*, while the kinetic spectra in *Ref09* become **softer for pions** and **harder for nucleons**
 - Because of this, FTFQGSP_BERT showers in *Ref09* have **higher energy response** and are **bigger** than in *Ref08*
- Thin-target data show that *Ref09* is **worse** than *Ref08*
 - Because of the inconsistent treatment of the **string direction** between FTF string formation and QGS fragmentation

FTFP_BERT Pion- showers

G4 10.6.ref09

G4 10.6.ref09d

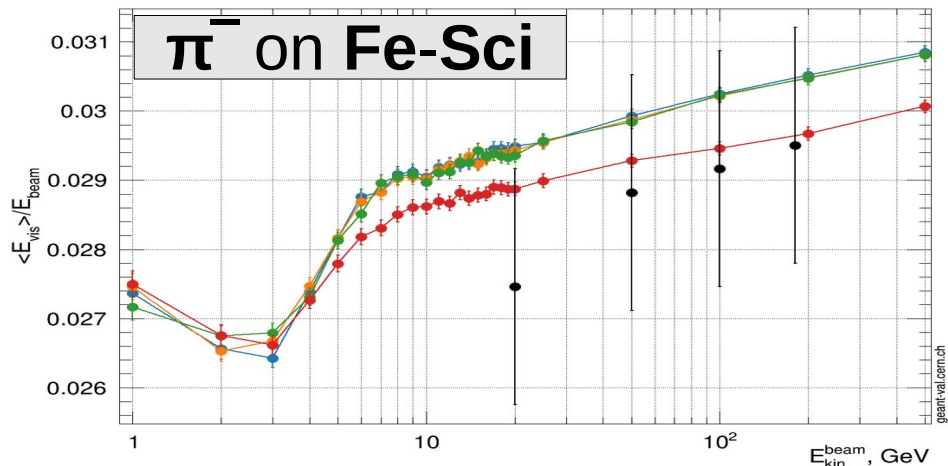
G4 10.6.ref09e

G4 10.6.ref08

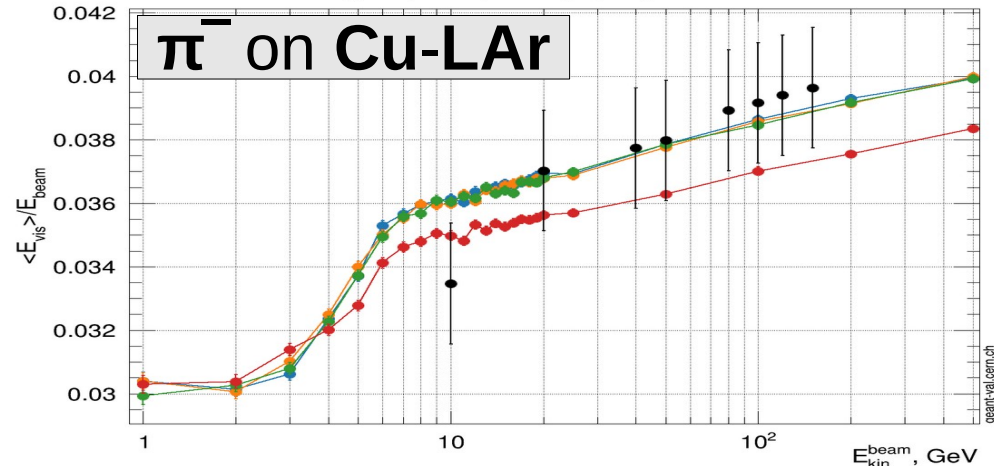
- Notes :
- “10.6.ref09d” is as *Ref09*, but rolling back (as it was in *Ref08*) the re-tuning of Pt in class **G4LundStringFragmentation**
 - “10.6.ref09e” is as *Ref09*, but rolling back (as it was in *Ref08*) the treatment of String Direction in **G4LundStringFragmentation**

FTFP_BERT : Energy Response

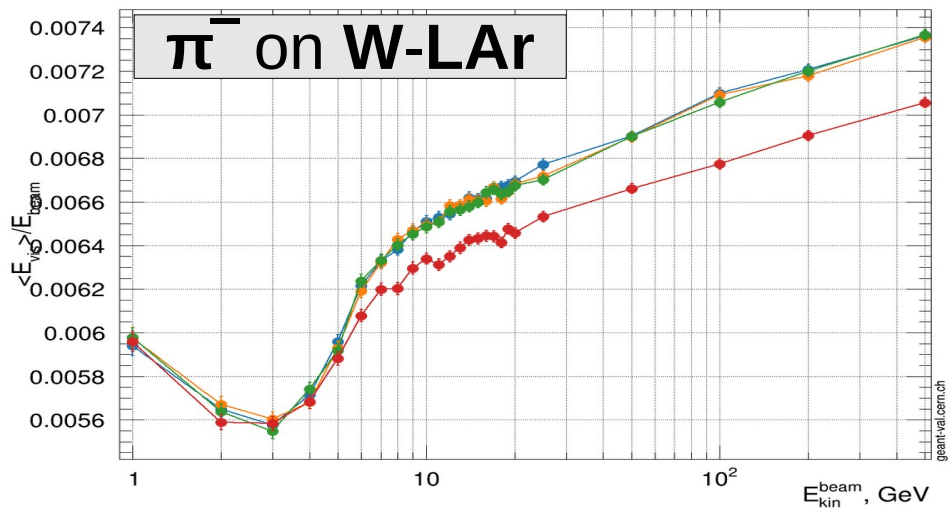
Energy response | Beam: pi- | Target: TileCal



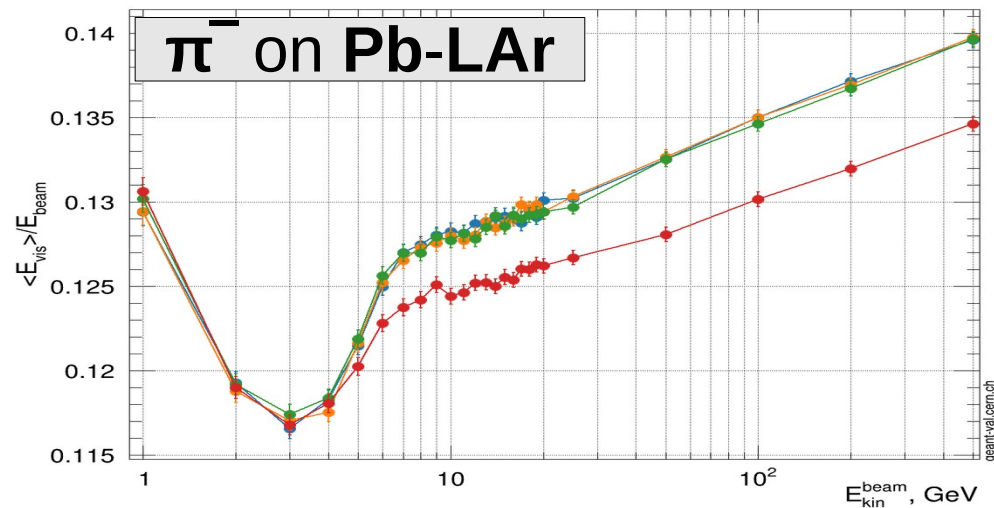
Energy response | Beam: pi- | Target: AtlasHEC



Energy response | Beam: pi- | Target: AtlasFCAL | FTFP_BERT



Energy response | Beam: pi- | Target: AtlasECAL | FTFP_BERT

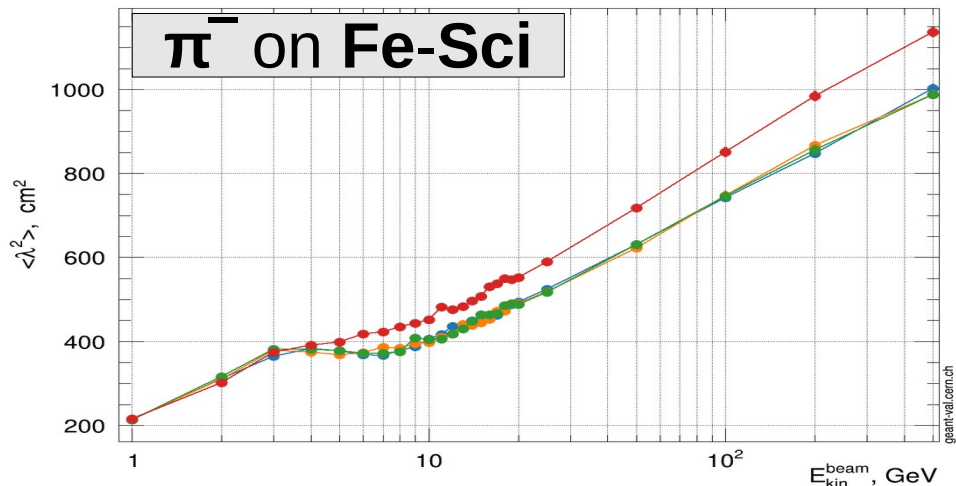


10.6.ref08
10.6.ref09d
10.6.ref09
10.6.ref09e

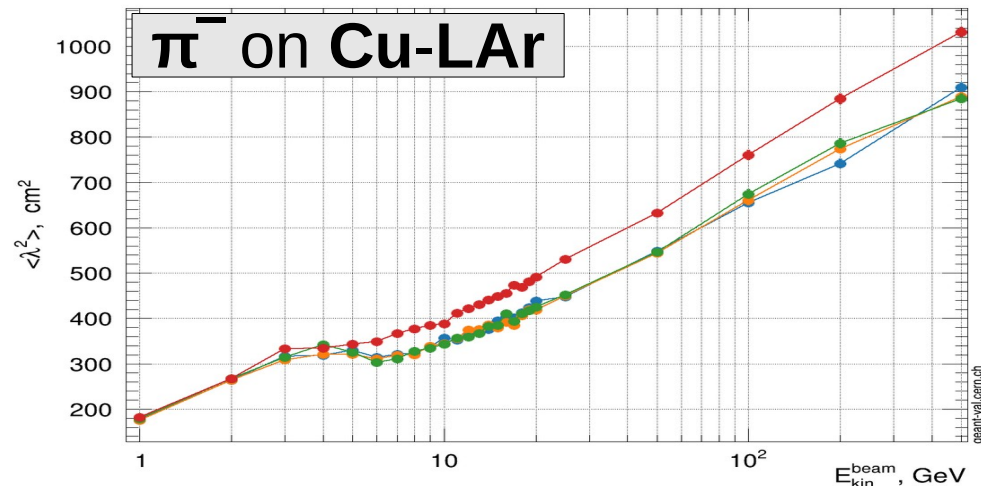
10.6.ref08
10.6.ref09d
10.6.ref09
10.6.ref09e

FTFP_BERT : Longitudinal Shape

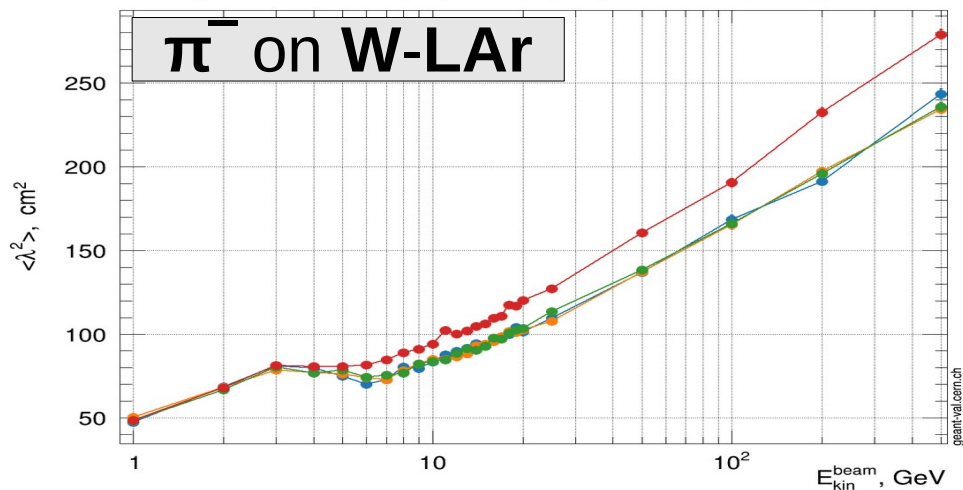
Longitudinal shower shape | Beam: pi- | Target: TileCal | FTFP_BERT



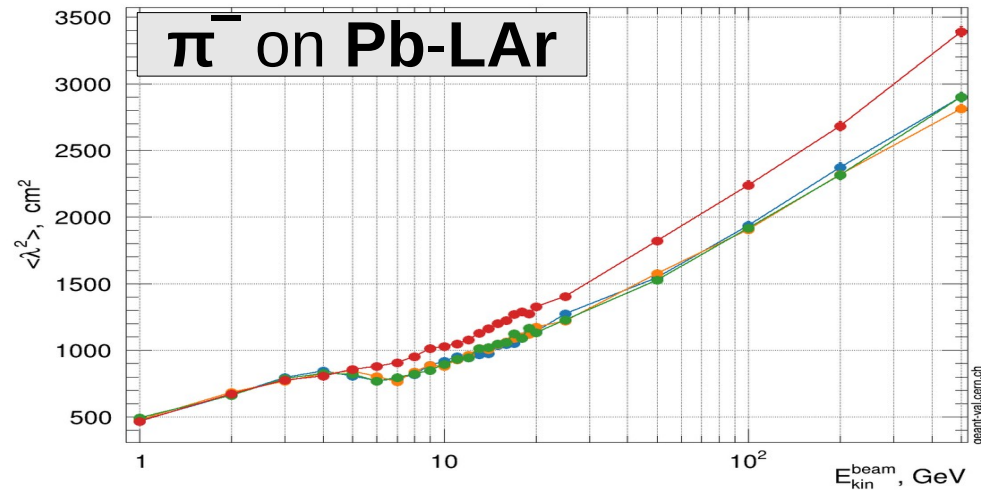
Longitudinal shower shape | Beam: pi- | Target: AtlasHEC | FTFP_BERT



Longitudinal shower shape | Beam: pi- | Target: AtlasFCAL | FTFP_BERT

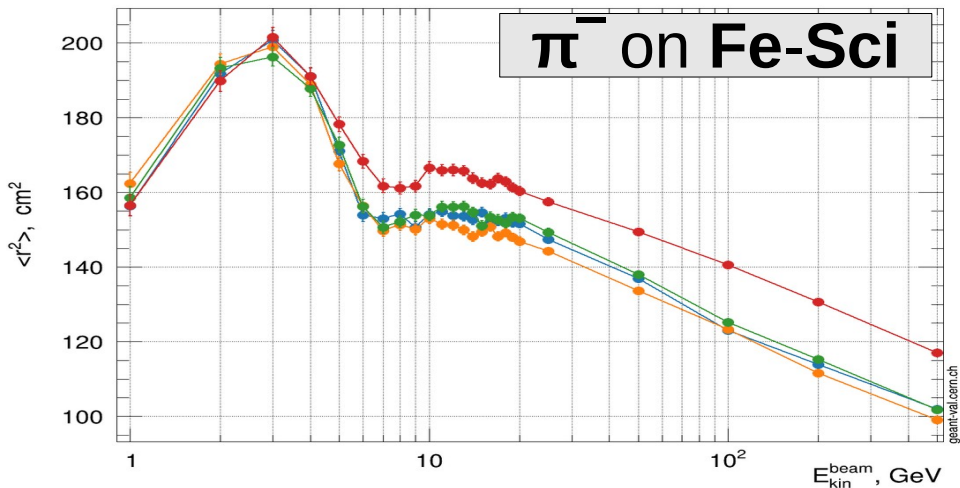


Longitudinal shower shape | Beam: pi- | Target: AtlasECAL | FTFP_BERT

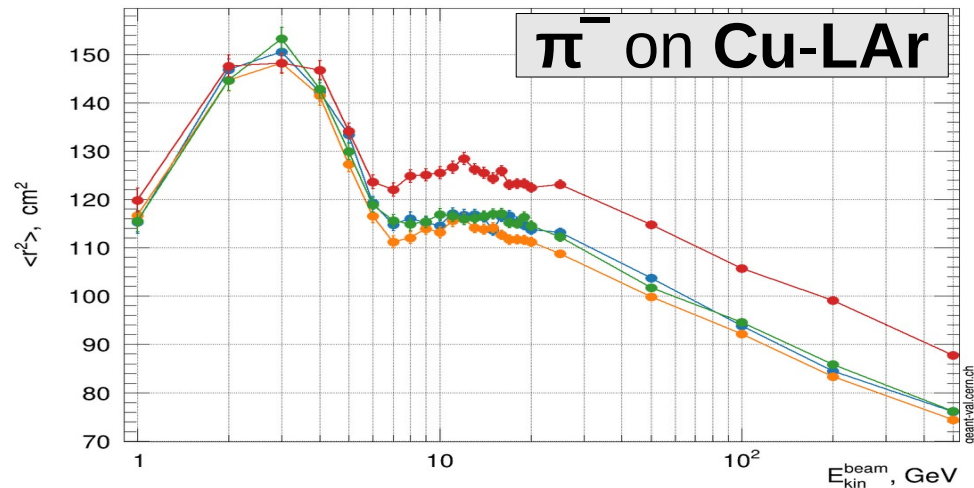


FTFP_BERT : Lateral Shape

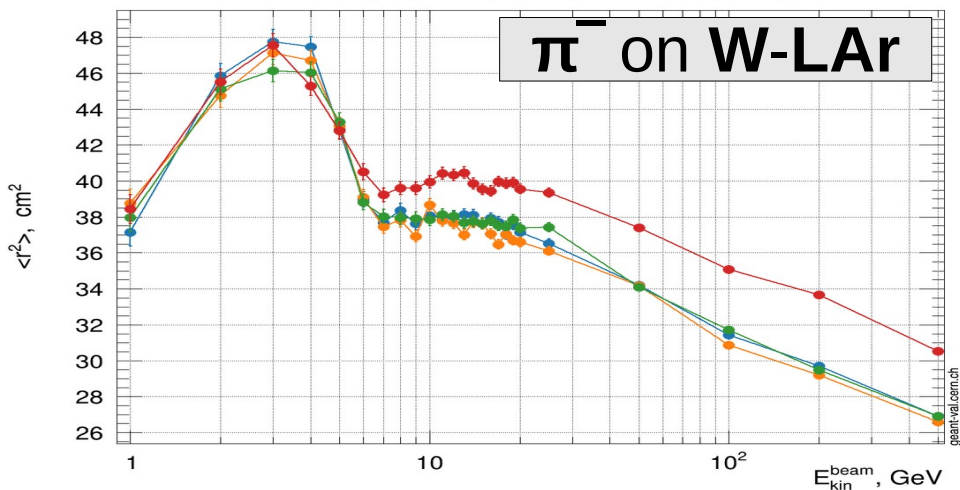
Lateral shower shape | Beam: pi- | Target: TileCal | FTFP_BERT



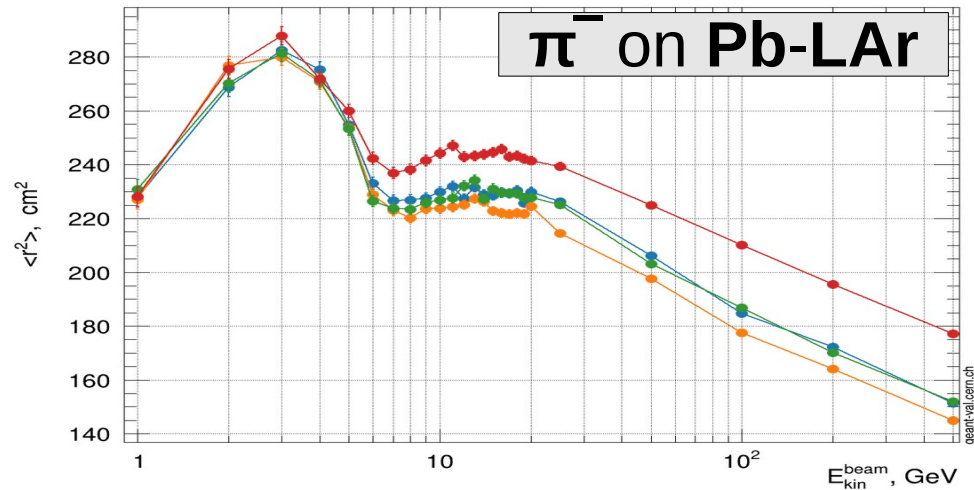
Lateral shower shape | Beam: pi- | Target: AtlasHEC | FTFP_BERT



Lateral shower shape | Beam: pi- | Target: AtlasFCAL | FTFP_BERT



Lateral shower shape | Beam: pi- | Target: AtlasECAL | FTFP_BERT



Summary for FTFP_BERT

- **No changes** when rolling back (as in *Ref08*) the method **G4DiffractiveExcitation::CreateStrings**
- The **Pt** re-tuning in **G4LundStringFragmentation** is responsible of the change of lateral shapes in *Ref09*
- Rolling back (as in *Ref08*) the string direction treatment of **G4LundStringFragmentation** produces **big changes**
 - "10.6.ref09e" showers have lower energy response and are bigger (*i.e.* longer & wider) than those of *Ref09*, becoming similar to those of FTFPQGSP_BERT in *Ref09*
 - Also in this case, the big changes are due to an inconsistent treatment of the **string direction** between string formation and string fragmentation (both by FTF model)

Conclusions

- We have understood the hadronic shower changes (small for FTFP_BERT, big for FTFQGSP_BERT) in *Ref09*
- We have seen spectacular hadronic showers (low energy response and wide shape) in two cases
 - FTFQGSP_BERT in *Ref09*, FTFP_BERT in between *Ref08-09*
 - Due to an exchange of kinetic energy between mesons – that become softer – and baryons – that become harder

due to a “fortuitous”, unphysical inconsistency between string formation and string fragmentation, rejected by thin-target data !

Back-up

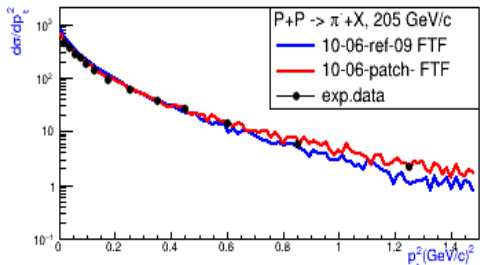
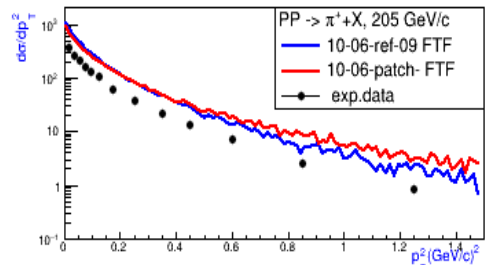
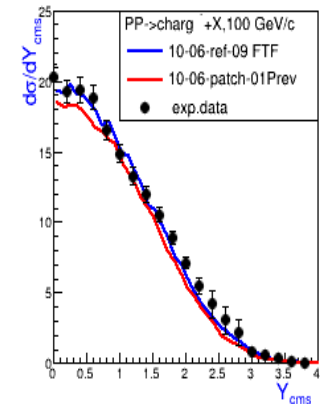
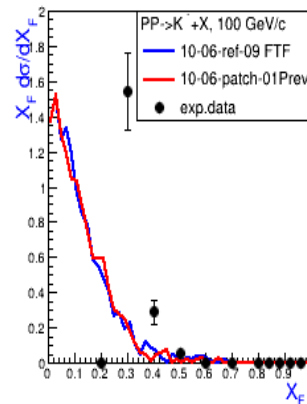
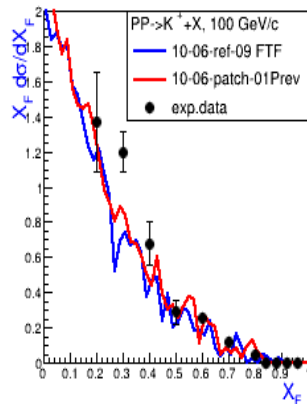
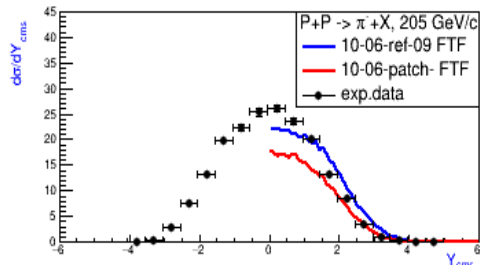
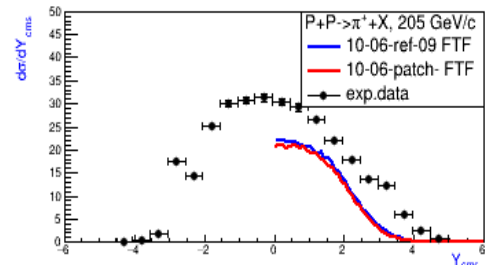
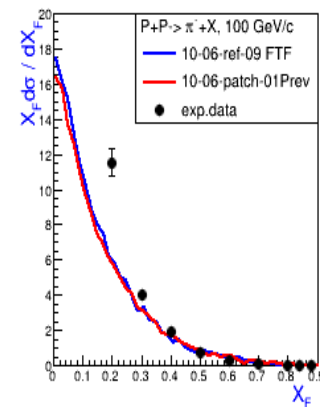
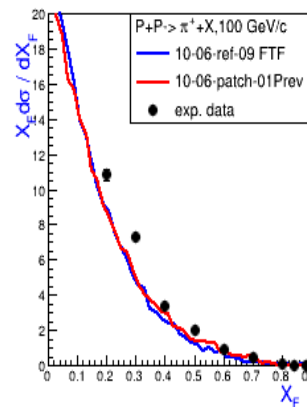
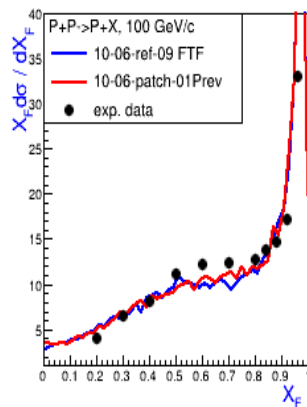
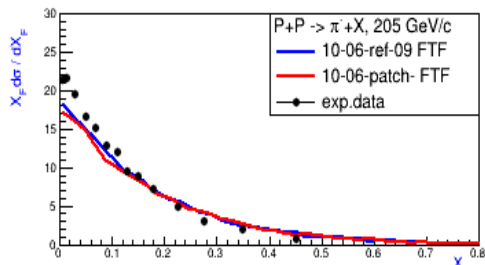
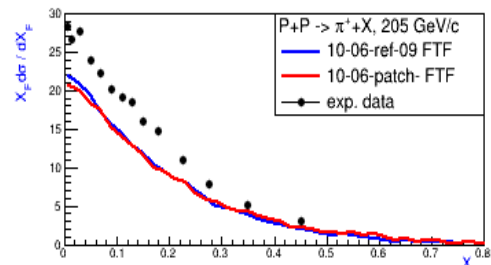
Thin-target (test22) Validation of FTFP

G4 10.6.ref09

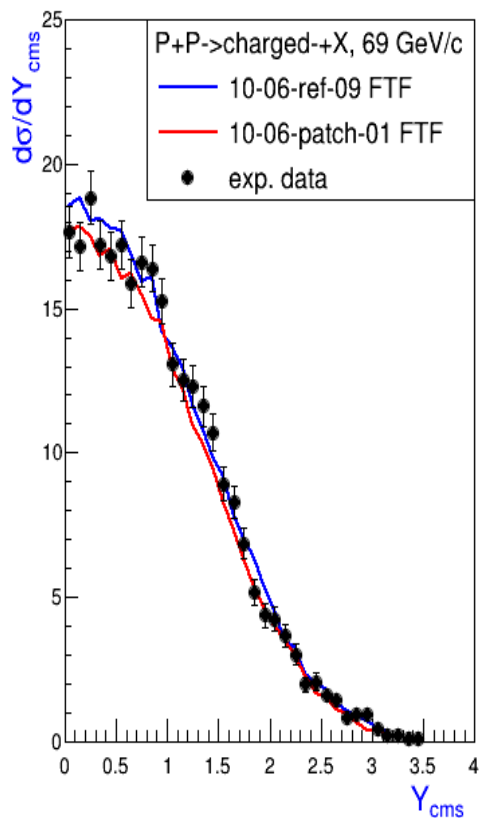
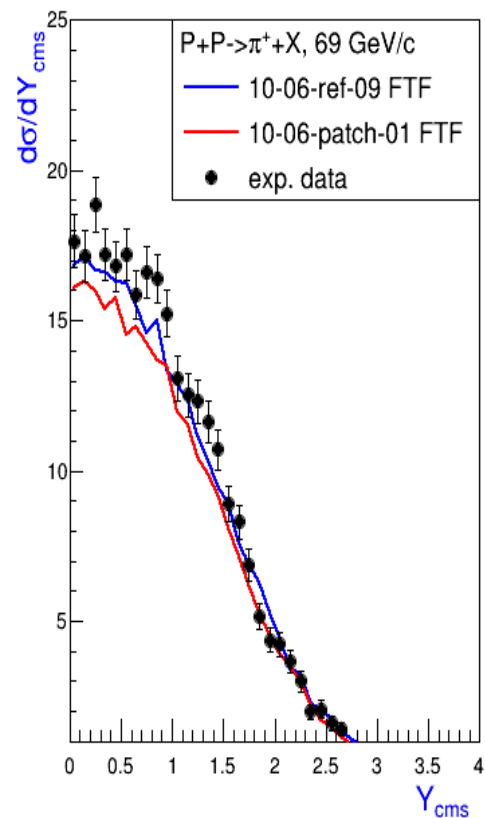
G4 10.6.p01

205 GeV/c $p p \rightarrow \pi^\pm + X$

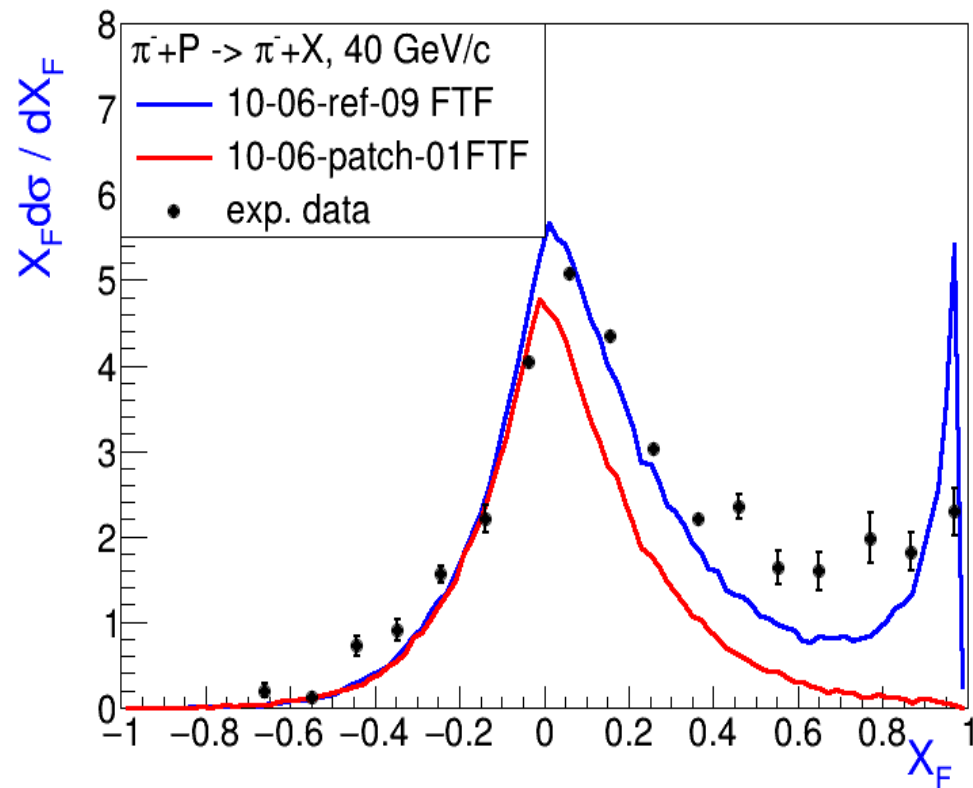
100 GeV/c $p p \rightarrow h + X$



69 GeV/c $p p \rightarrow h^+ + X$

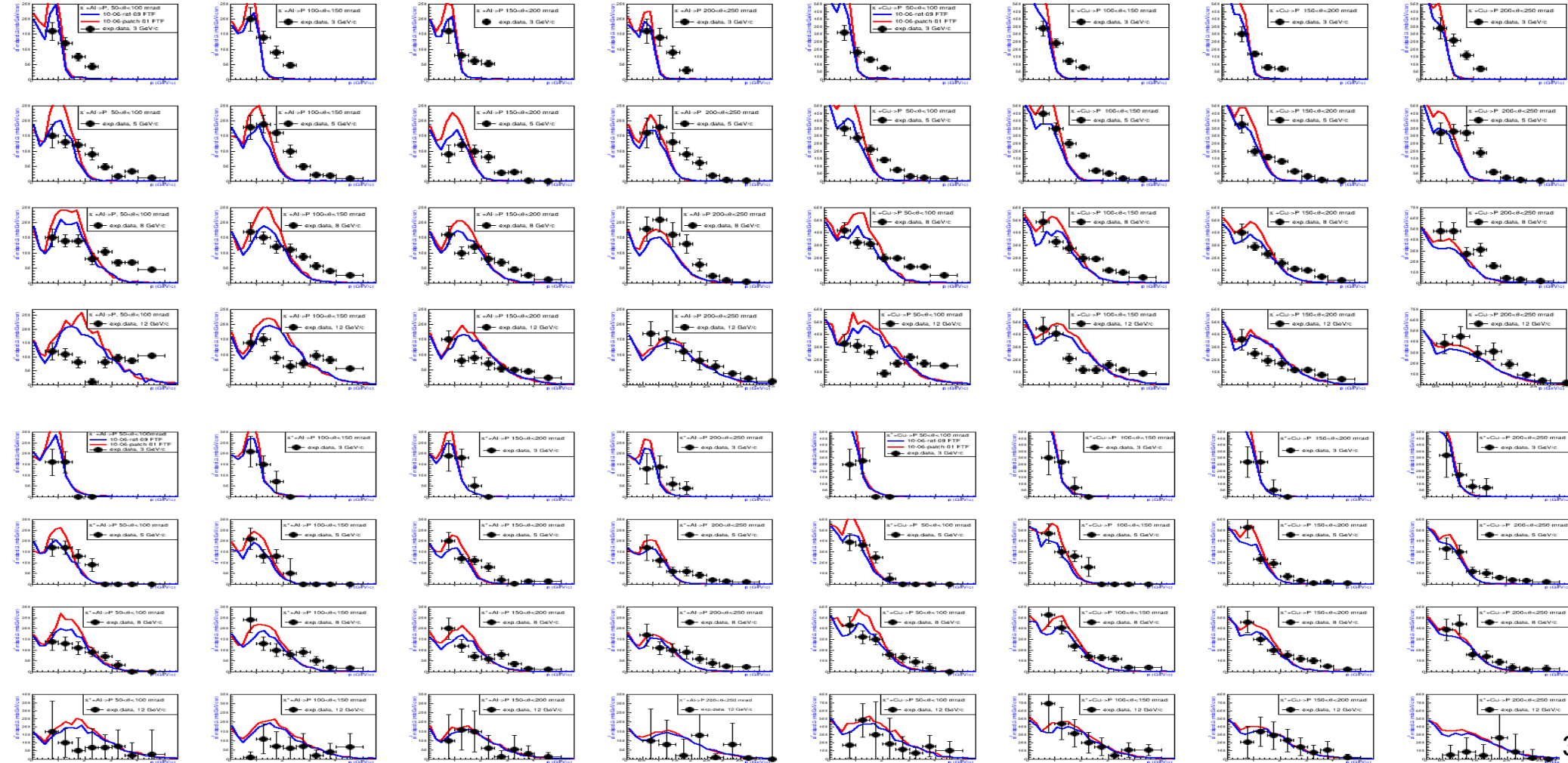


40 GeV/c $\pi^- p \rightarrow \pi^- + X$



3÷12 GeV/c π^\pm Al \rightarrow p + X

3÷12 GeV/c π^\pm Cu \rightarrow p + X



Pion- showers

G4 10.6.ref09 FTFP_BERT

G4 10.6.ref09a FTFP_BERT

G4 10.6.ref09c FTFP_BERT

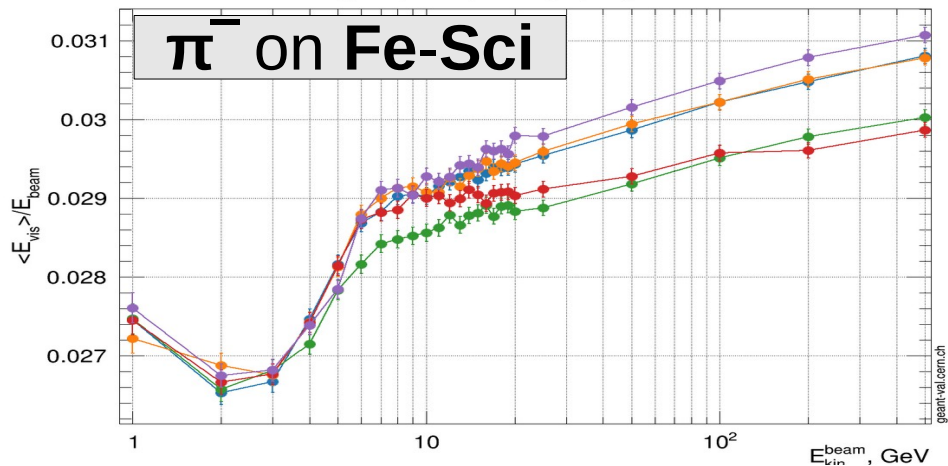
G4 10.6.ref09 FTFQGSP_BERT

G4 10.6.ref09a FTFQGSP_BERT

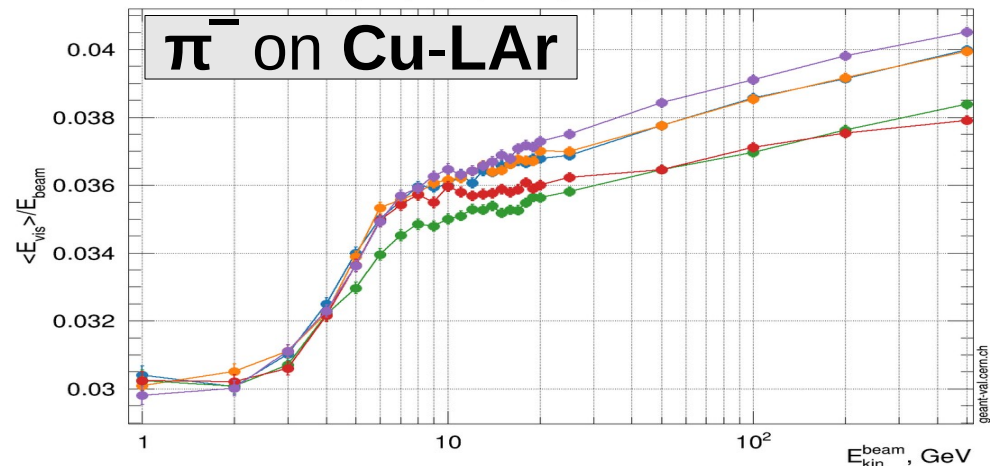
- Notes :
- “10.6.ref09a” is as *Ref09*, but rolling back (as it was in *Ref08*) the method **G4DiffractiveExcitation::CreateStrings**;
 - “10.6.ref09c” is as *Ref09*, but rolling back (as it was in *Ref08*) the class **G4LundStringFragmentation**

Energy Response

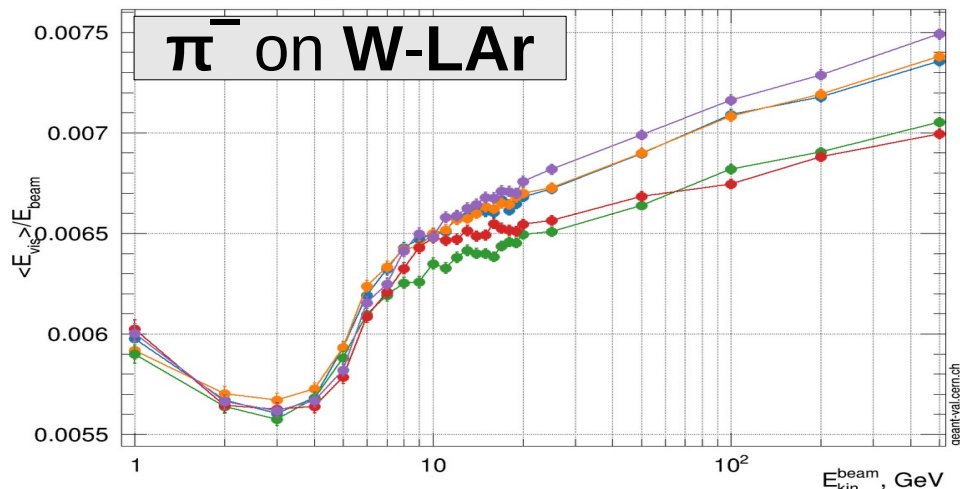
Energy response | Beam: pi- | Target: TileCal



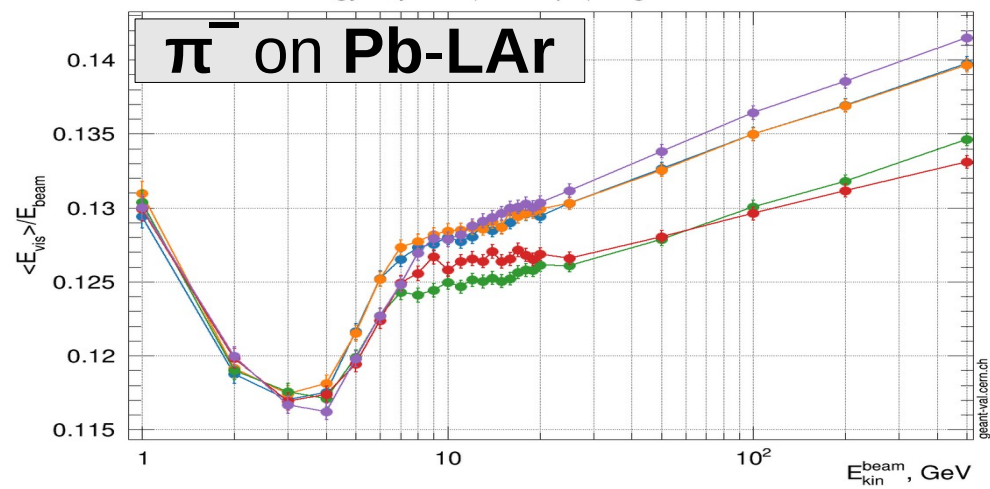
Energy response | Beam: pi- | Target: AtlasHEC



Energy response | Beam: pi- | Target: AtlasFCAL



Energy response | Beam: pi- | Target: AtlasECAL



10.6.ref09 FTFP_BERT
10.6.ref09c FTFP_BERT
10.6.ref09a FTFQGSP_BERT

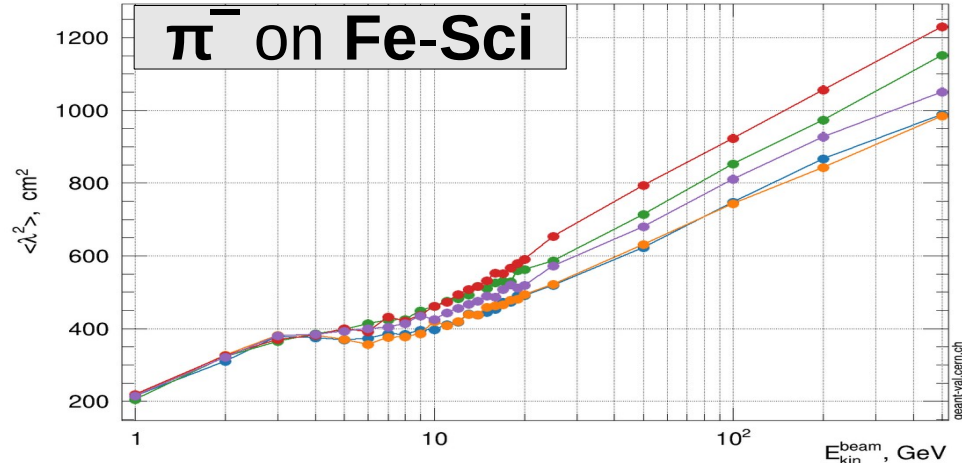
10.6.ref09a FTFP_BERT
10.6.ref09 FTFQGSP_BERT

10.6.ref09 FTFP_BERT
10.6.ref09c FTFP_BERT
10.6.ref09a FTFQGSP_BERT

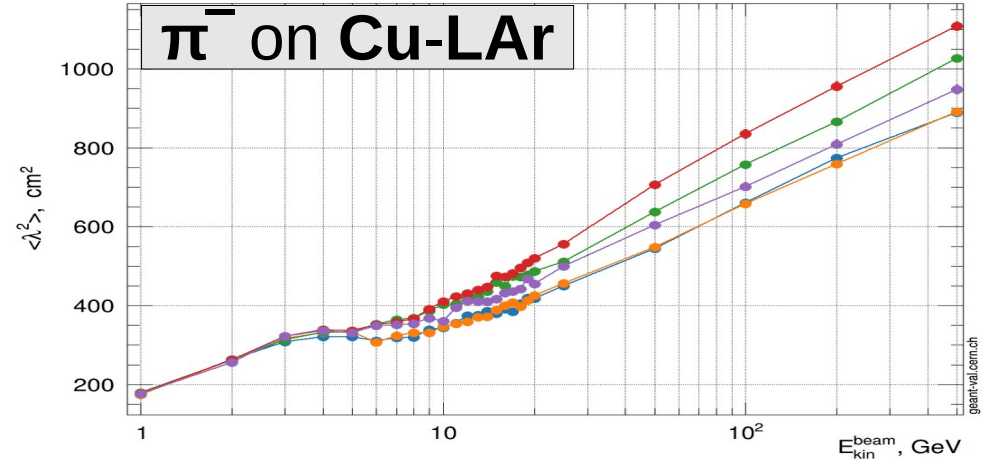
10.6.ref09a FTFP_BERT
10.6.ref09 FTFQGSP_BERT

Longitudinal Shape

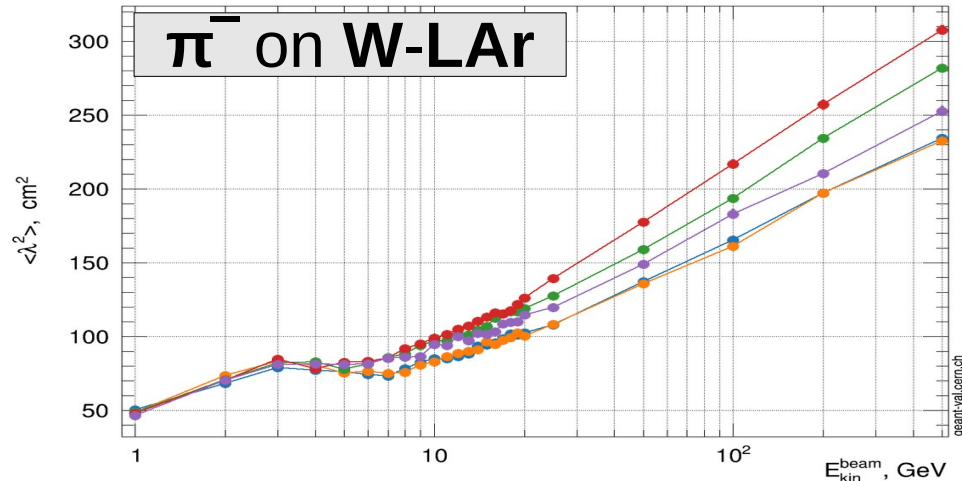
Longitudinal shower shape | Beam: pi- | Target: TileCal



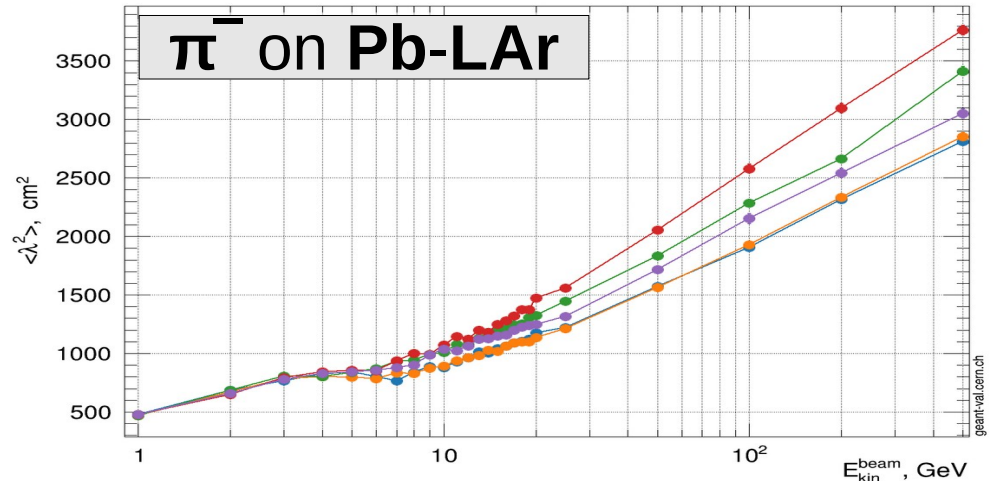
Longitudinal shower shape | Beam: pi- | Target: AtlasHEC



Longitudinal shower shape | Beam: pi- | Target: AtlasFCAL



Longitudinal shower shape | Beam: pi- | Target: AtlasECAL



10.6.ref09 FTFP_BERT
10.6.ref09c FTFP_BERT
10.6.ref09a FTFQSP_BERT

10.6.ref09a FTFP_BERT
10.6.ref09 FTFQSP_BERT

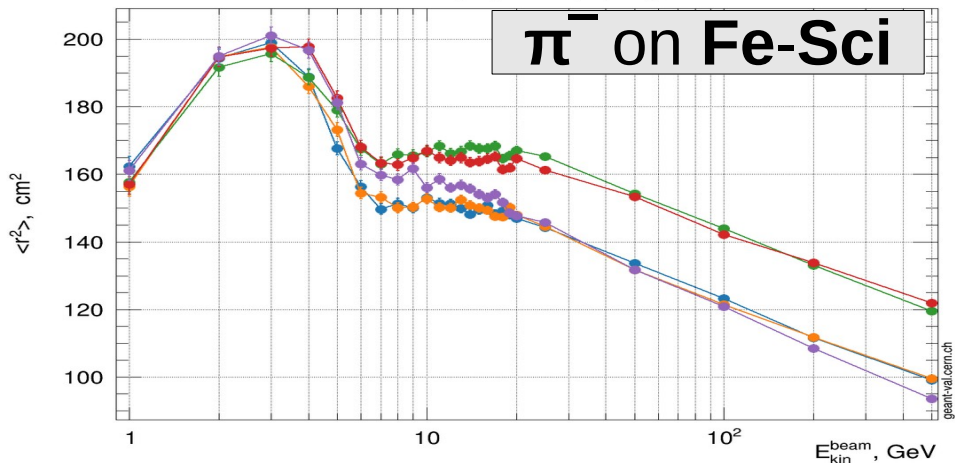
10.6.ref09 FTFP_BERT
10.6.ref09c FTFP_BERT
10.6.ref09a FTFQSP_BERT

10.6.ref09a FTFP_BERT
10.6.ref09 FTFQSP_BERT

Lateral Shape

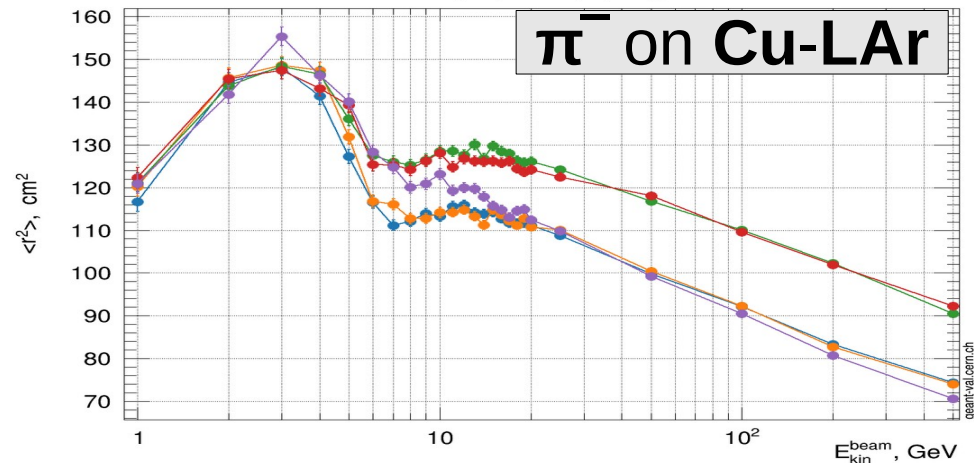
Lateral shower shape | Beam: pi- | Target: TileCal

π^- on Fe-Sci



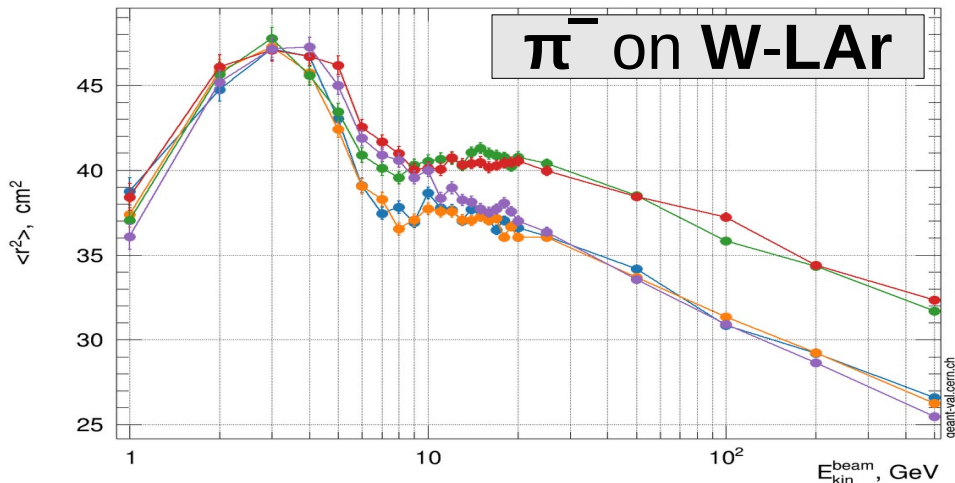
Lateral shower shape | Beam: pi- | Target: AtlasHEC

π^- on Cu-LAr



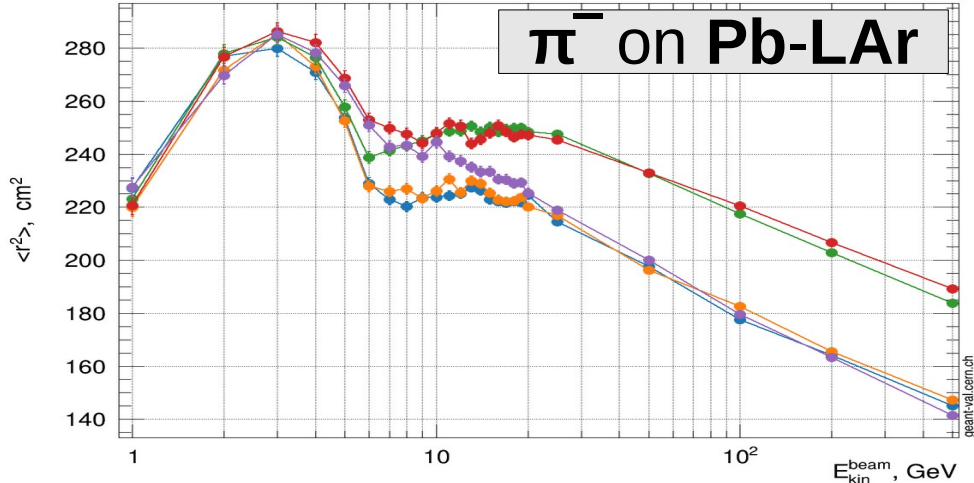
Lateral shower shape | Beam: pi- | Target: AtlasFCAL

π^- on W-LAr



Lateral shower shape | Beam: pi- | Target: AtlasECAL

π^- on Pb-LAr



10.6.ref09 FTFP_BERT
10.6.ref09c FTFP_BERT
10.6.ref09a FTFQGSP_BERT

10.6.ref09a FTFP_BERT
10.6.ref09 FTFQGSP_BERT

10.6.ref09 FTFP_BERT
10.6.ref09c FTFP_BERT
10.6.ref09a FTFQGSP_BERT

10.6.ref09a FTFP_BERT
10.6.ref09 FTFQGSP_BERT