Geant4 validation on AHCAL data

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on behalf of the FLC HCAL group

Event Sample

- Data
  - $\pi^{\pm}$
  - 8 GeV – 80 GeV
  - $\approx$ 100 000 events per energy
- Simulation
  - 200 000 events per list and energy
  - Digitisation simulating detector effects
- Measurements:
  - Nuclear interaction length
  - Leakage corrected response and resolution
  - Longitudinal and radial shower shape

Highly granular Scintillator-Fe Calorimeter ~ 5.3 λ_{int}
- Longitudinal segmentation:
  38 layers à 3 cm
- Transverse:
  216 cells from 3x3 cm^2 to 12x12 cm^2
- 7608 channels readout with Silicon Photomultipliers

The analysis shown here was done by B.Lutz (DESY / Universität Hamburg) in the framework of his Ph.D. thesis

All data shown here acquired with the CALICE AHCAL prototype during test beam 2007 at CERN SPS H6

Physics Lists

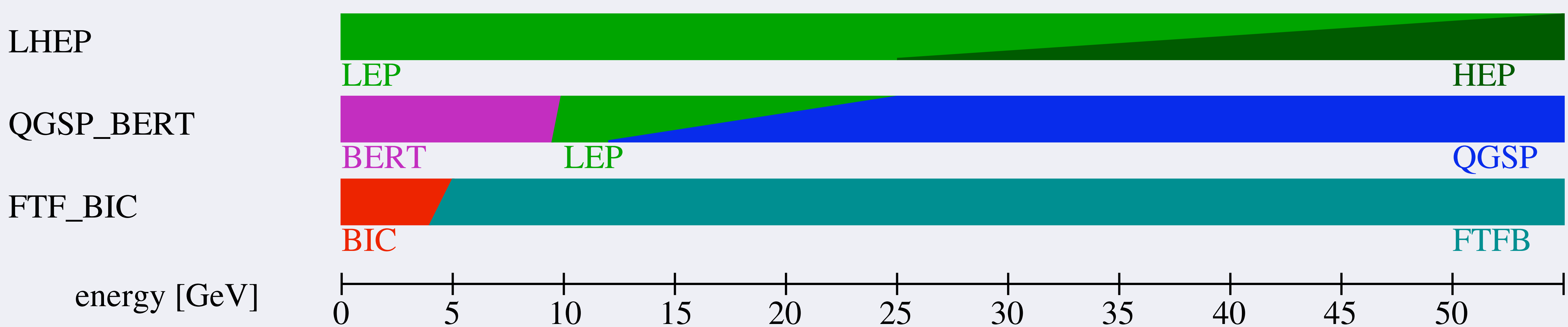
- Geant4 organises models in "physics lists"
- $>$ 20 different hadron lists
- 13 tested
- Will show 4 representative
  - LHEP
  - QGSP_BERT
  - FTF_BIC
  - CHIPS

- Random selection of model in transition region
- LEP stop gap in case low an high energy models cannot be matched

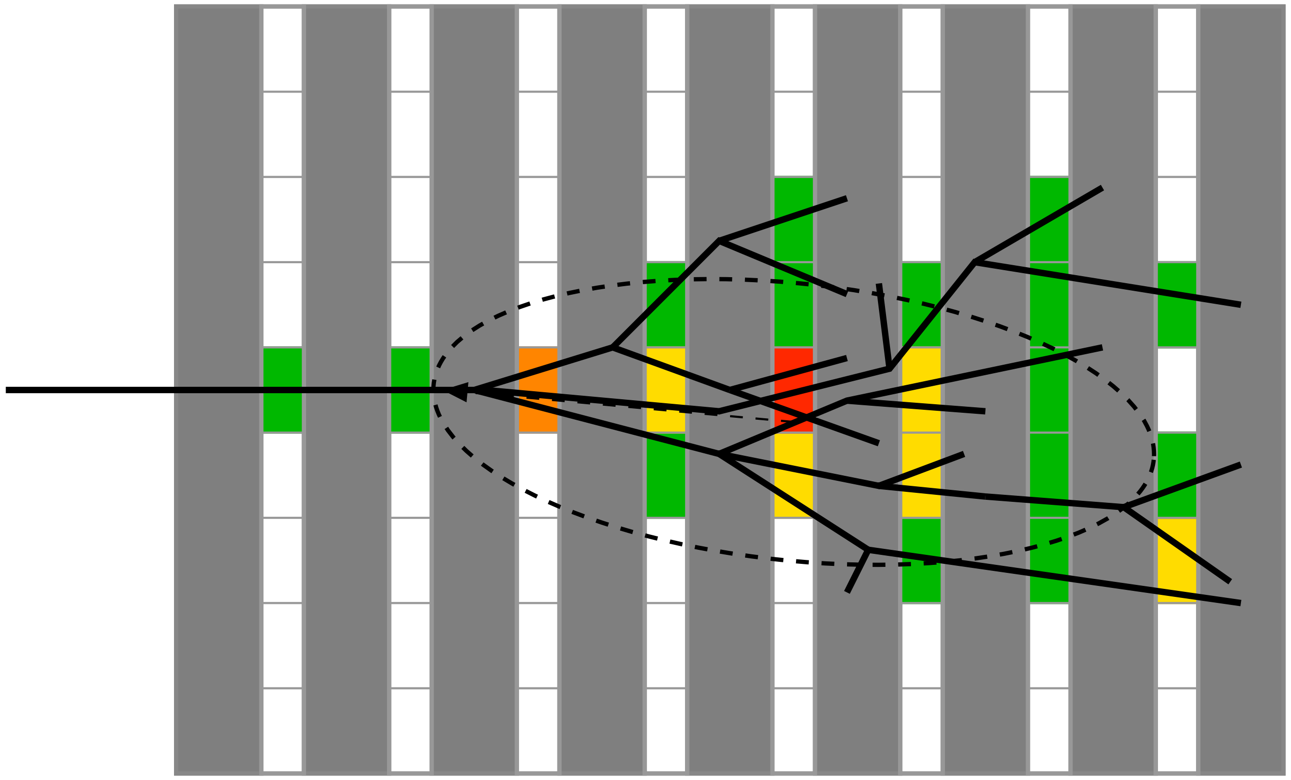
Geant 4.9.3 final version (12/2009)

CHIPS: no transition region, only available from version 4.9.3.p01

Content for $\pi^{\pm}$



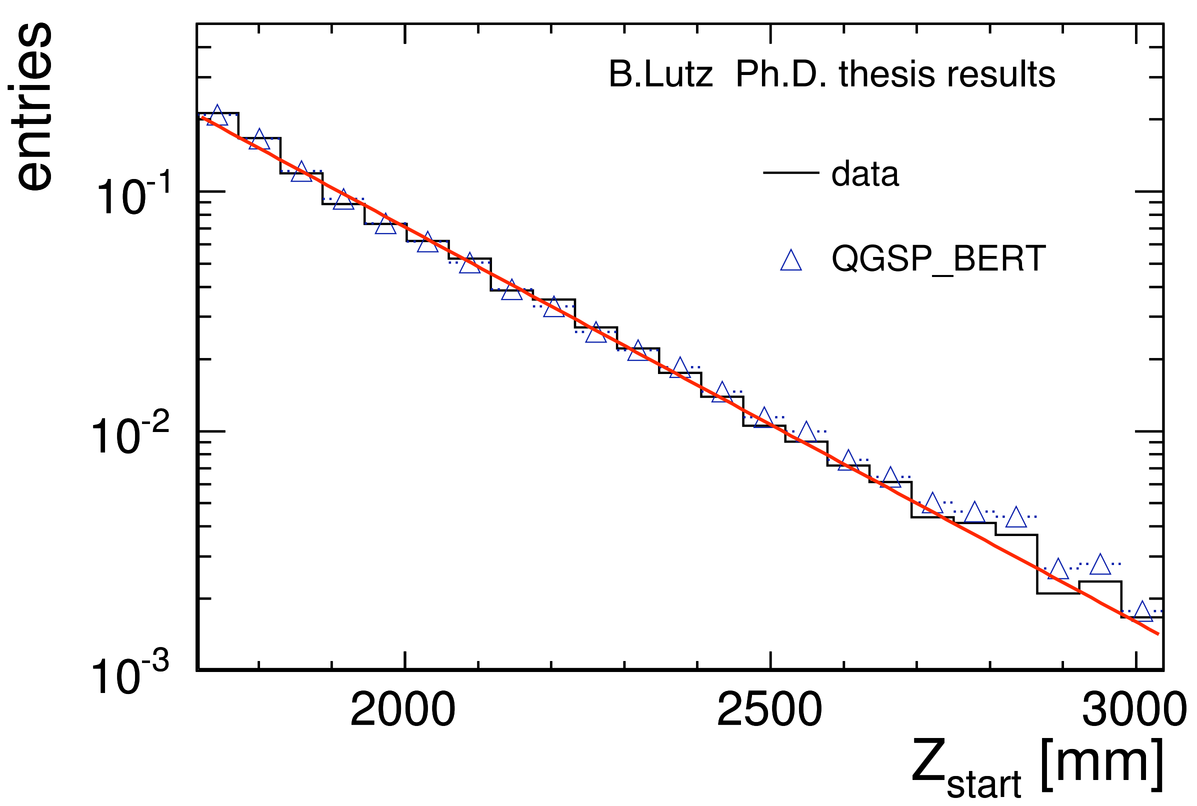
Identifying the First Hadronic Interaction

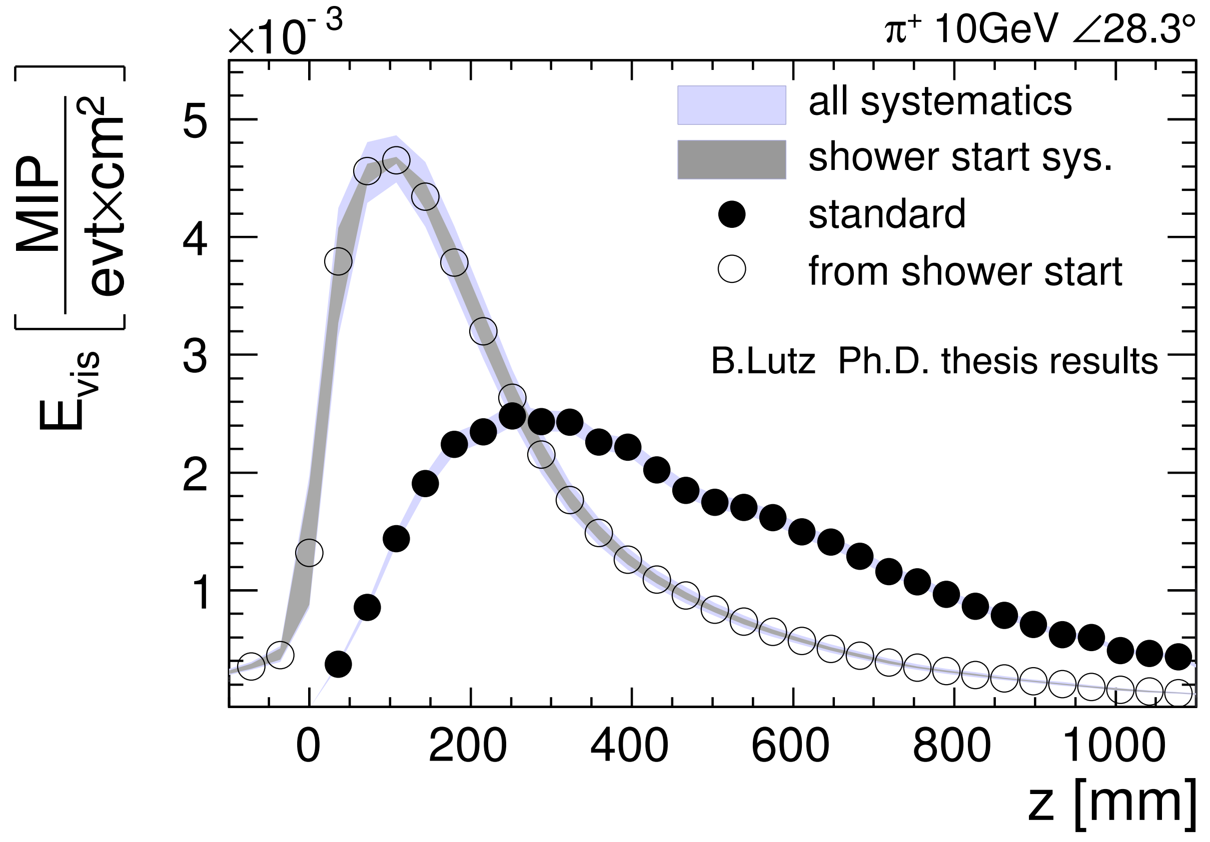


- 1 MIP signal
- 2 MIP signal
- 3 MIP signal
- larger signal

- Cluster based
- Seeded by hits $>$ 1 MIP
- Optimised thresholds with simulation
  - Cluster energy
  - Cluster hits
  - Cluster angle
- One threshold set for all beam energies
- Simulation model dependent
  - Position resolution
  - Systematic z-shift
- z-resolution typically one layer distance
- Estimated systematic z-uncertainty from different simulation models

Nuclear Interaction Length of π





- Measured nuclear interaction length $\lambda_{\mathrm{I},\pi}$ consistent within fit systematics
- Agreement between simulation and data
- Method allows to measure longitudinal profile without fluctuations in first interaction

Comparing Data and Simulation

FTF_BIC

⊕

QGSP_BERT

⊕

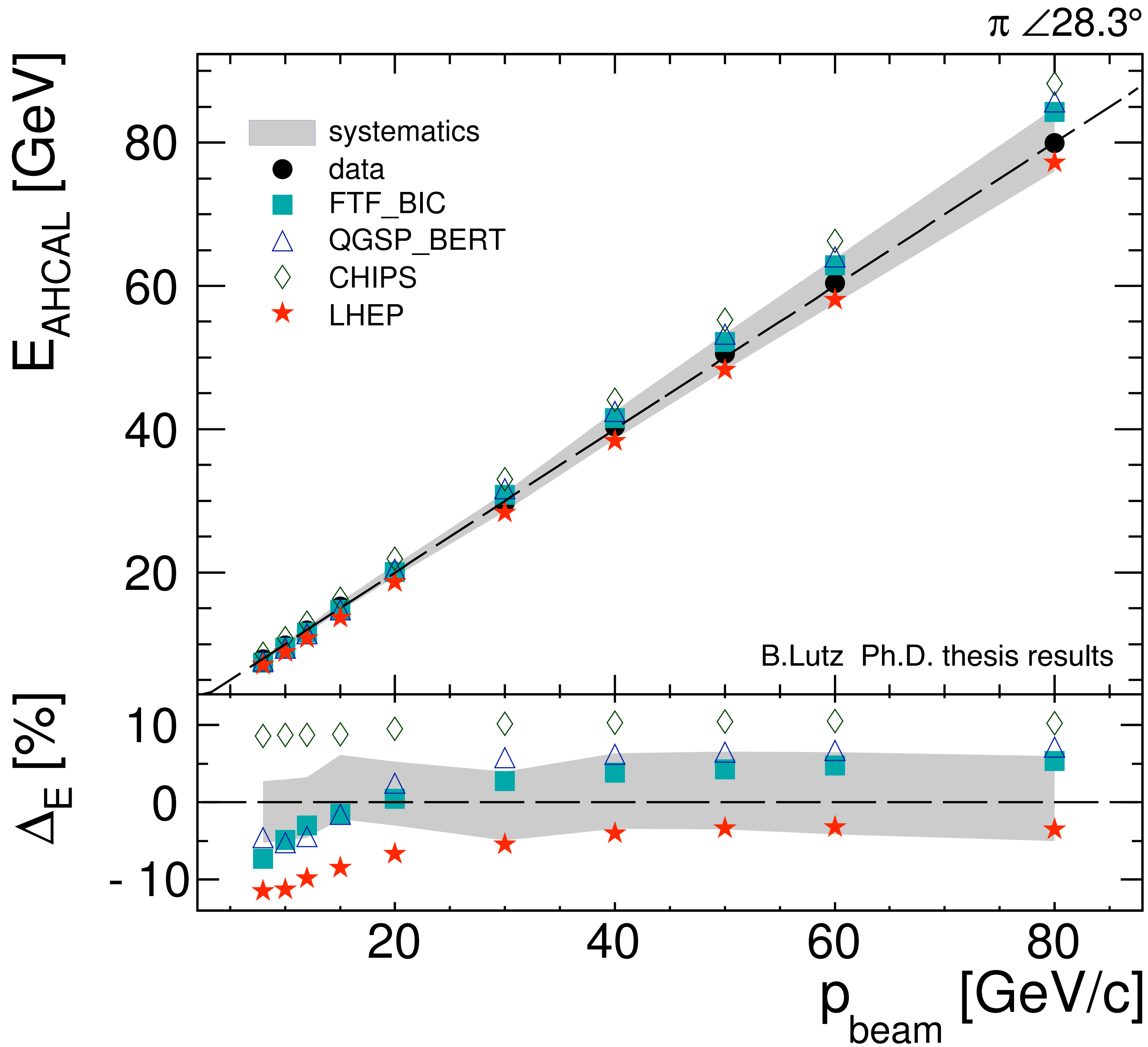
CHIPS

⊖⊖

LHEP

⊖

Leakage Corrected Response



string+cascade within errors — only CHIPS flat like data

Comparing Data and Simulation

FTF_BIC

⊕ ⊕

QGSP_BERT

⊕ ○

CHIPS

⊖⊖ ⊖⊖

LHEP

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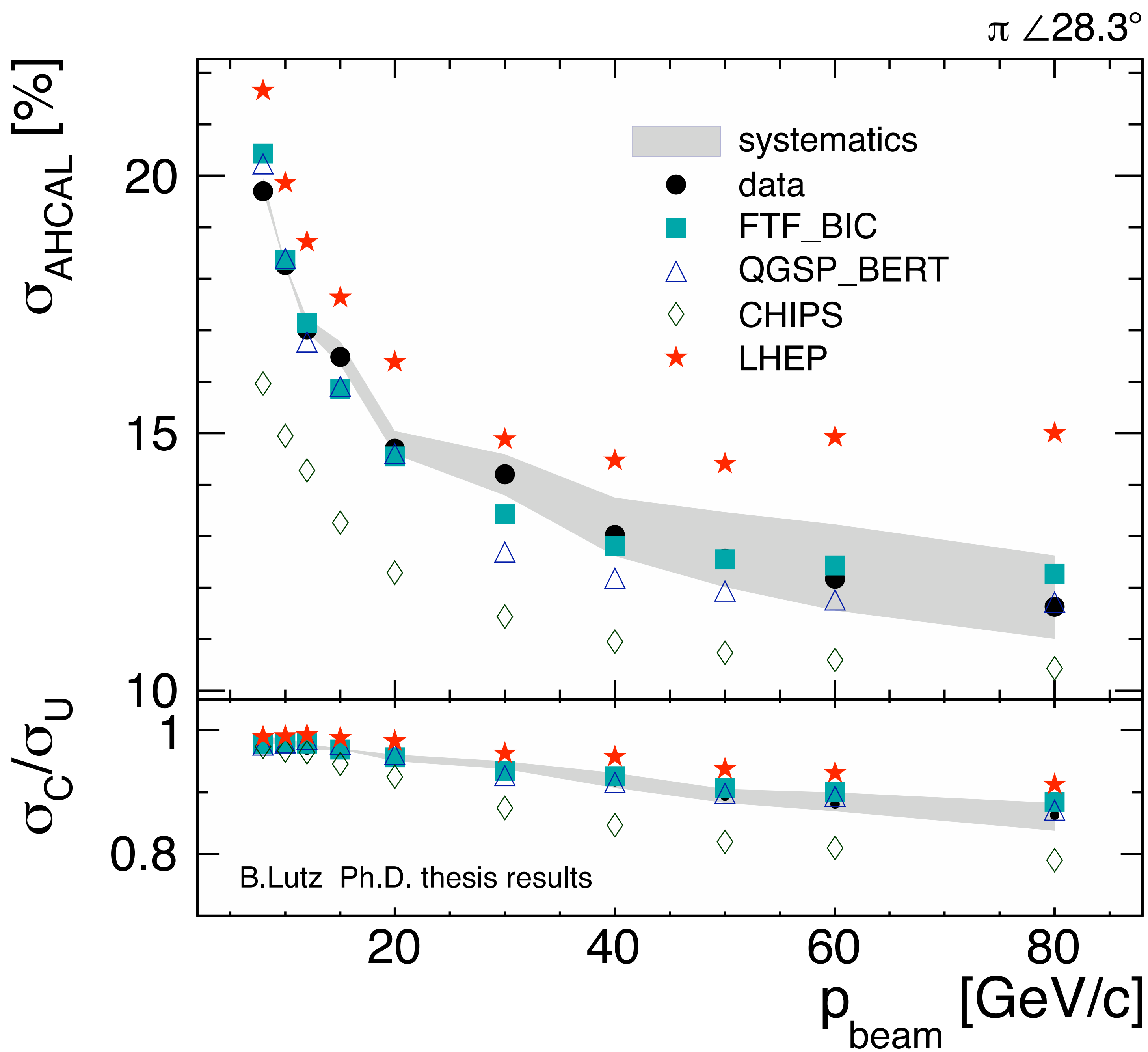
Leakage Corrected Resolution



FTF_BIC slightly better

Comparing Data and Simulation

FTF_BIC

⊕ ⊕ ⊕

QGSP_BERT

⊕ ○ ⊕

CHIPS

⊖⊖ ⊖⊖ ⊖

LHEP

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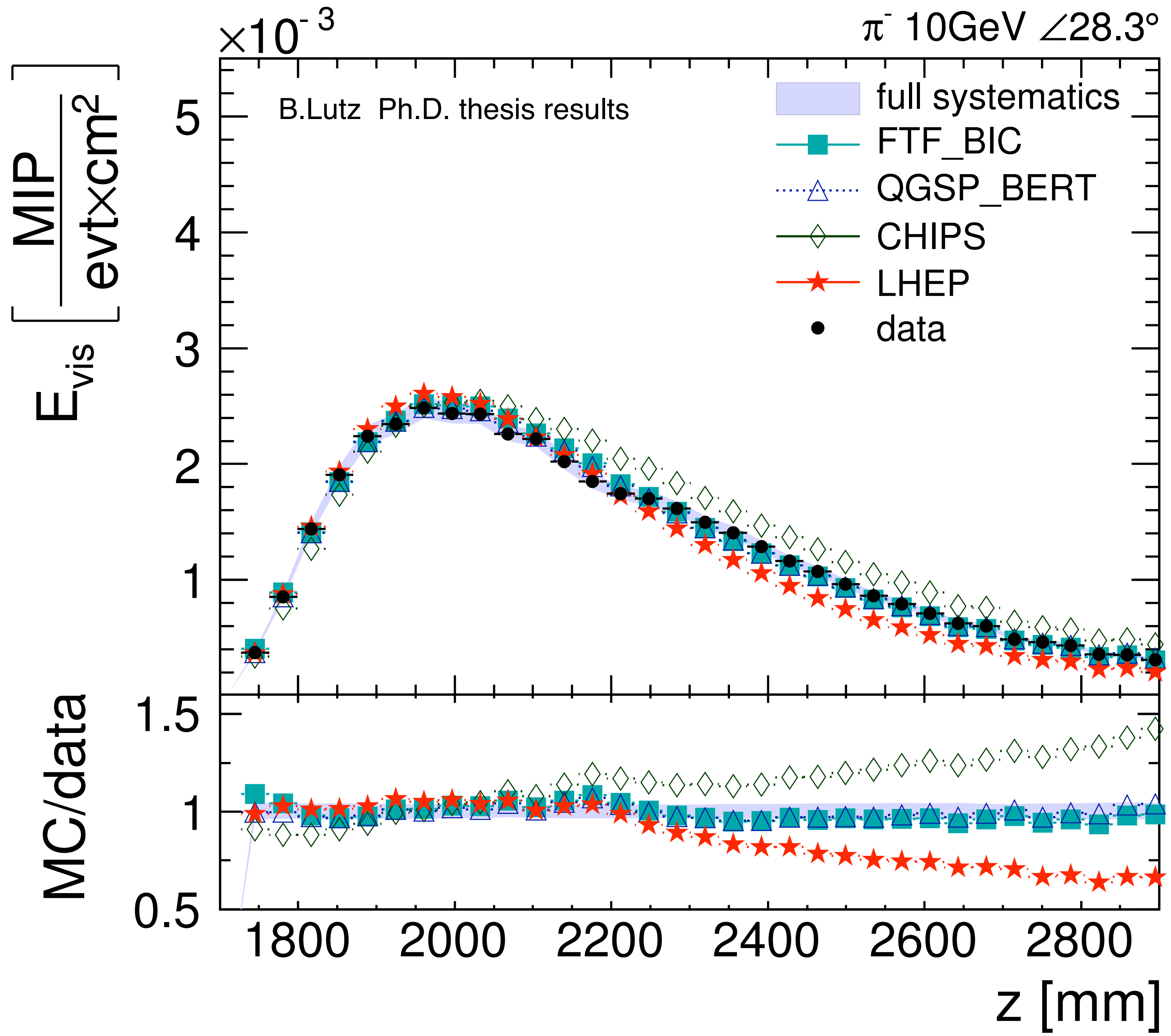
Longitudinal Shape



cascade models good — CHIPS/LHEP wrong tails

Comparing Data and Simulation

FTF_BIC

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QGSP_BERT

⊕ ○ ⊕ ⊕

CHIPS

⊖⊖ ⊖⊖ ⊖ ⊖

LHEP

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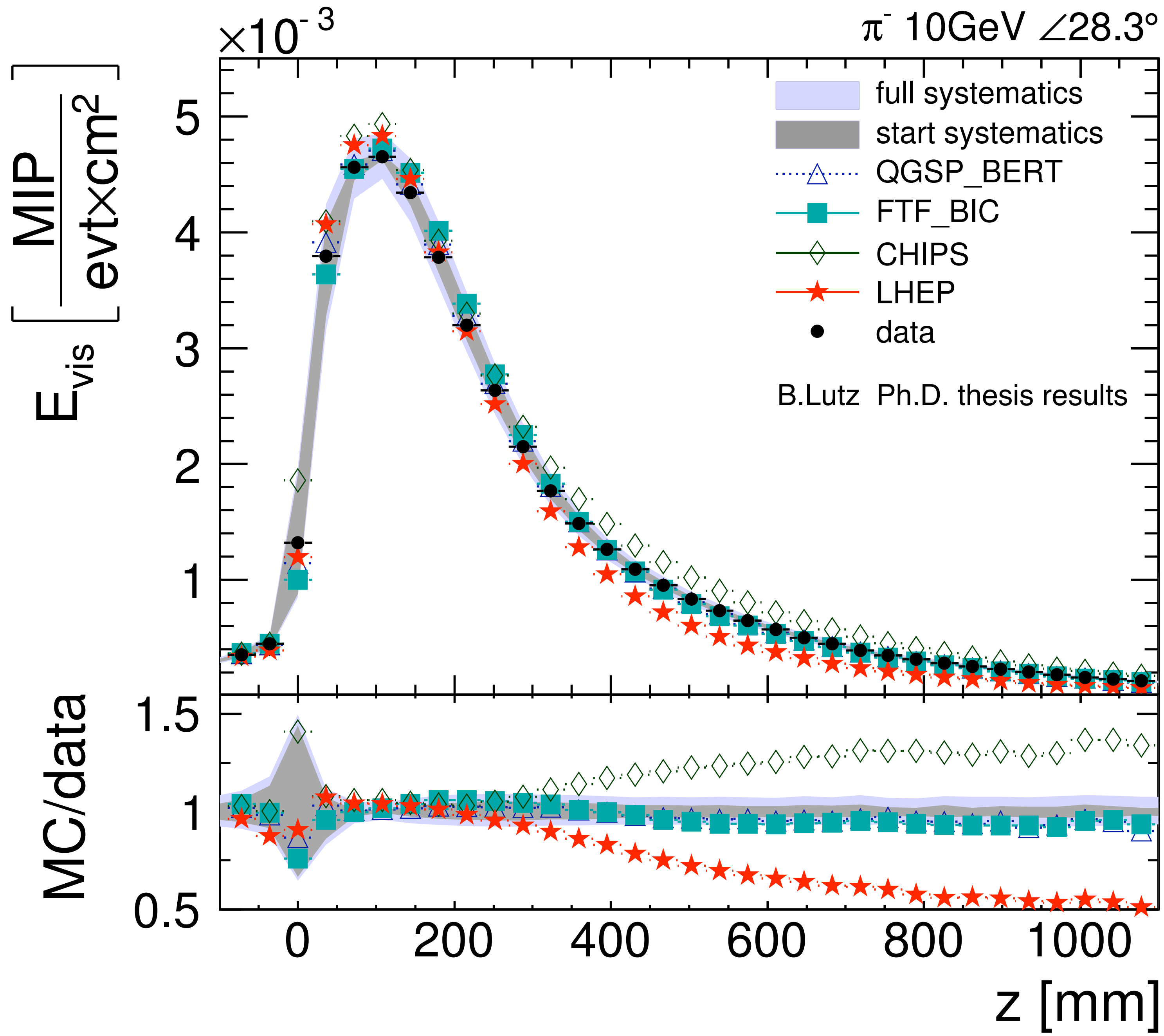
Longitudinal Shape from Start



increased sensitivity with profile from starting point

Comparing Data and Simulation

FTF_BIC

⊕ ⊕ ⊕ ⊕ ⊖

QGSP_BERT

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CHIPS

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LHEP

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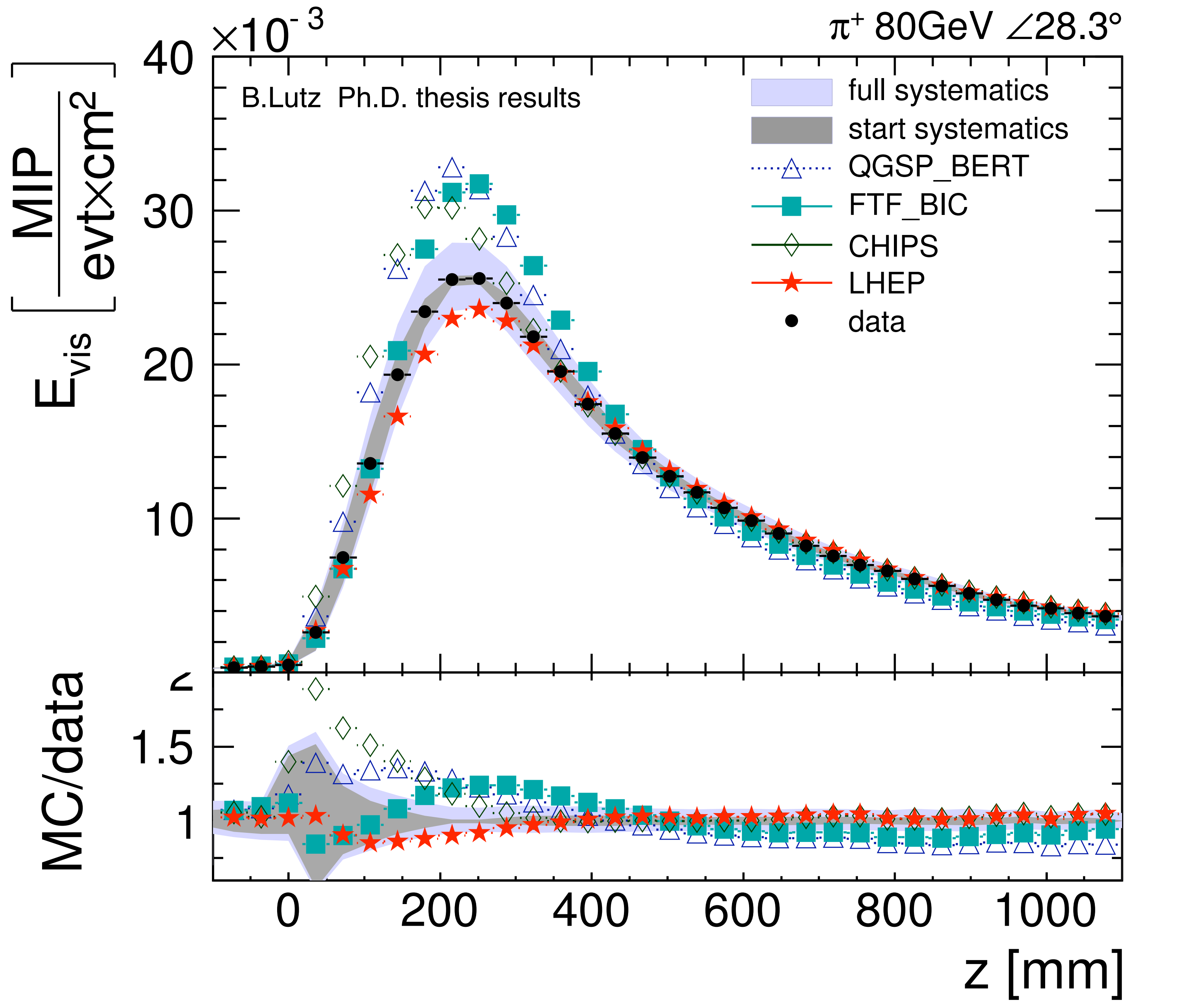
Longitudinal Shape from Start



LHEP matches — others overestimate shower maximum

Comparing Data and Simulation

Differential longitudinal shape

FTF_BIC

$\oplus$ $\oplus$ $\oplus$ $\oplus$ $\ominus$

QGSP_BERT

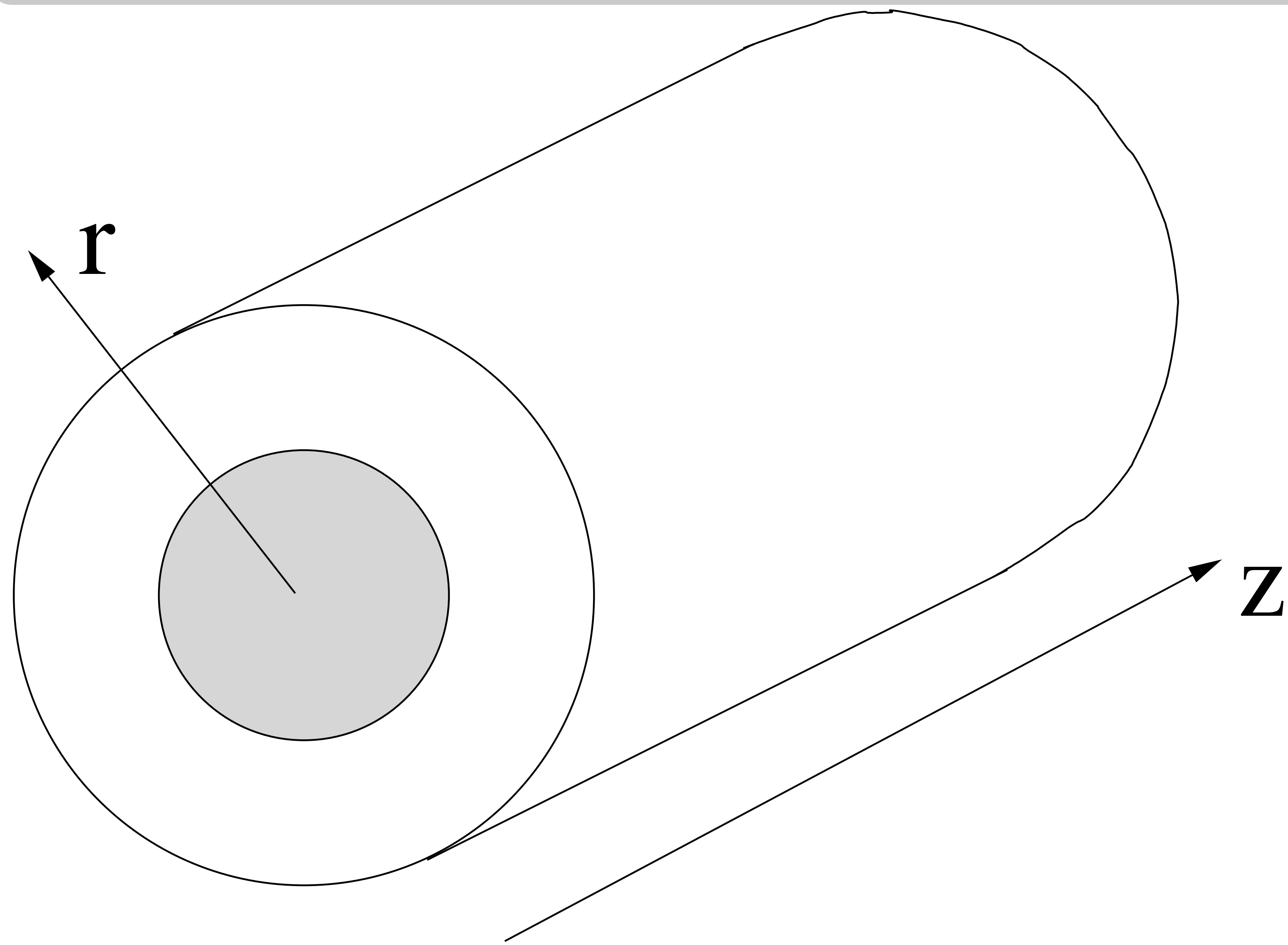
$\oplus$ $\bigcirc$ $\oplus$ $\oplus$ $\ominus$

CHIPS

$\ominus\ominus$ $\ominus\ominus$ $\ominus$ $\ominus$ $\ominus$

LHEP

$\ominus$ $\ominus\ominus$ $\ominus$ $\ominus$ $\oplus$



Longitudinal profile within a cylinder at radius r

Comparing Data and Simulation

FTF_BIC

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QGSP_BERT

⊕ ○ ⊕ ⊕ ⊖ ⊖

CHIPS

⊖⊖ ⊖⊖ ⊖ ⊖ ⊖ ⊖

LHEP

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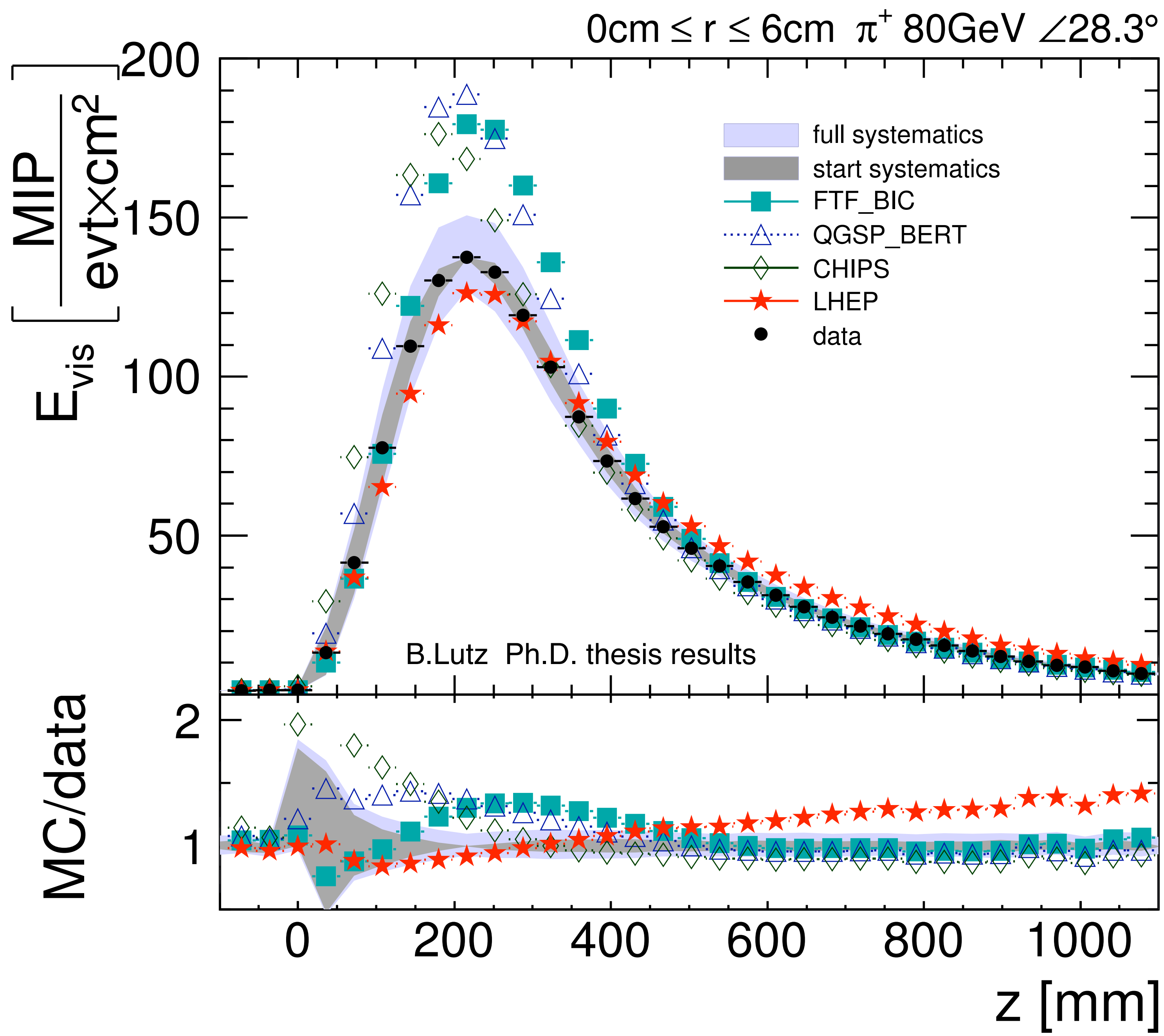
Longitudinal at $0 < r \leq 6$ cm



overshoot stronger — LHEP too long

Comparing Data and Simulation

Longitudinal at 12$< r \leq$18 cm

FTF_BIC

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QGSP_BERT

⊕ ○ ⊕ ⊕ ⊖ ⊖

CHIPS

⊖⊖ ⊖⊖ ⊖ ⊖ ⊖ ⊖ ⊖

LHEP

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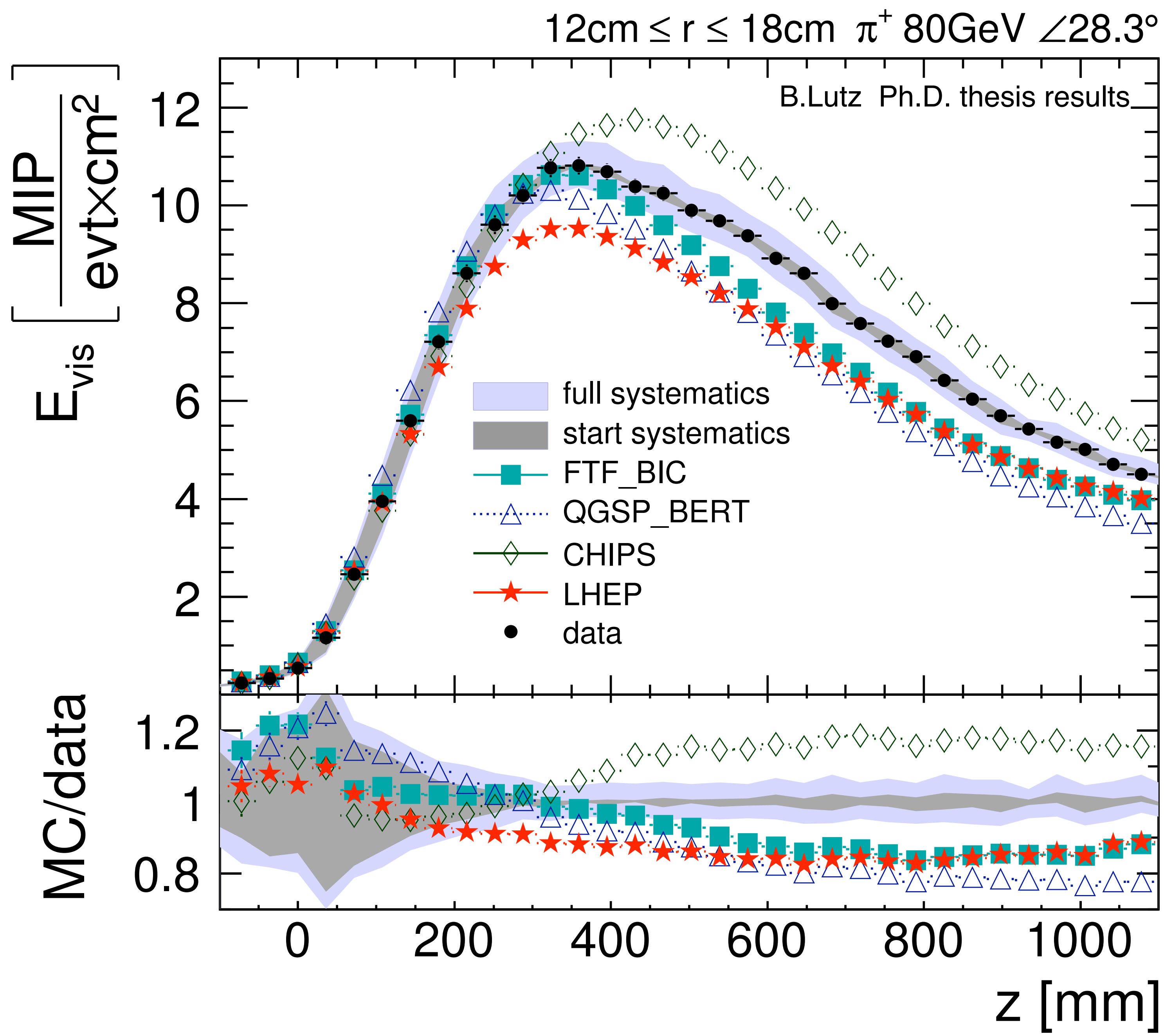


string models less deviations — LHEP too short

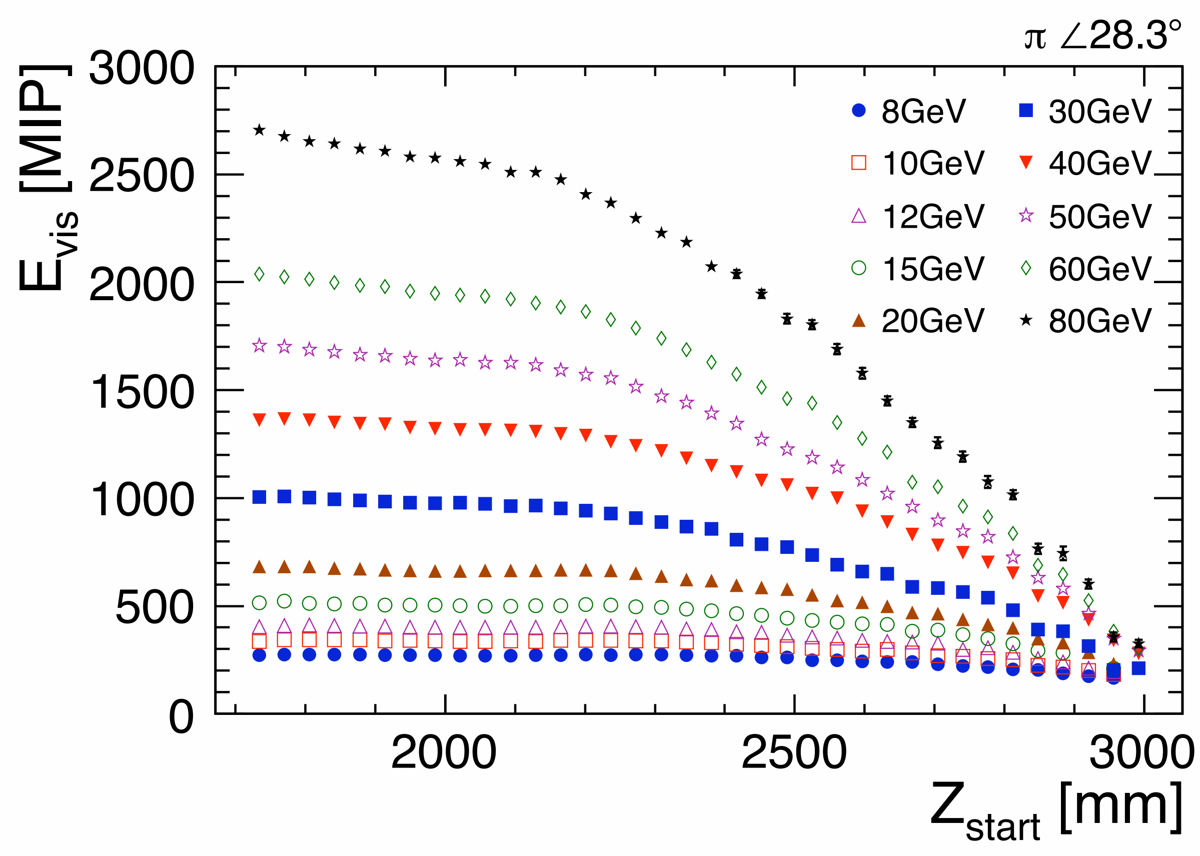
Simulation Validation Results

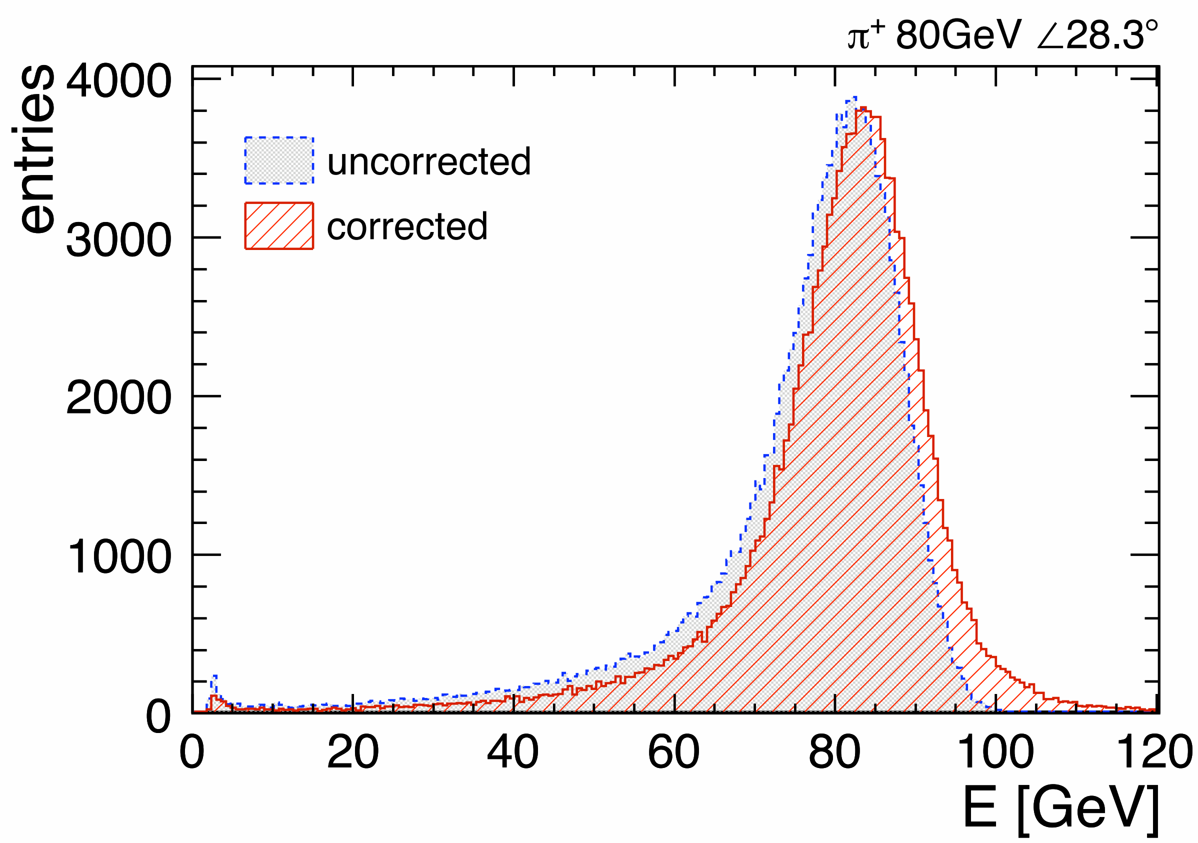
High granularity ⇒ new level of detail in test of hadron shower models

- QGSP_BERT & FTF_BIC
  - Reasonable description of response and resolution
  - Good description of low energy shower shape
  - Fail to describe high energy shower shape (String Models)
  - Largest difference in the shower core
- LHEP
  - Outperformed in almost all aspects
  - Should be replaced in other physics lists
- CHIPS
  - Least successful physics list in the tested version
  - Less artifacts than compound lists
  - Needs further development

BACKUP SLIDES

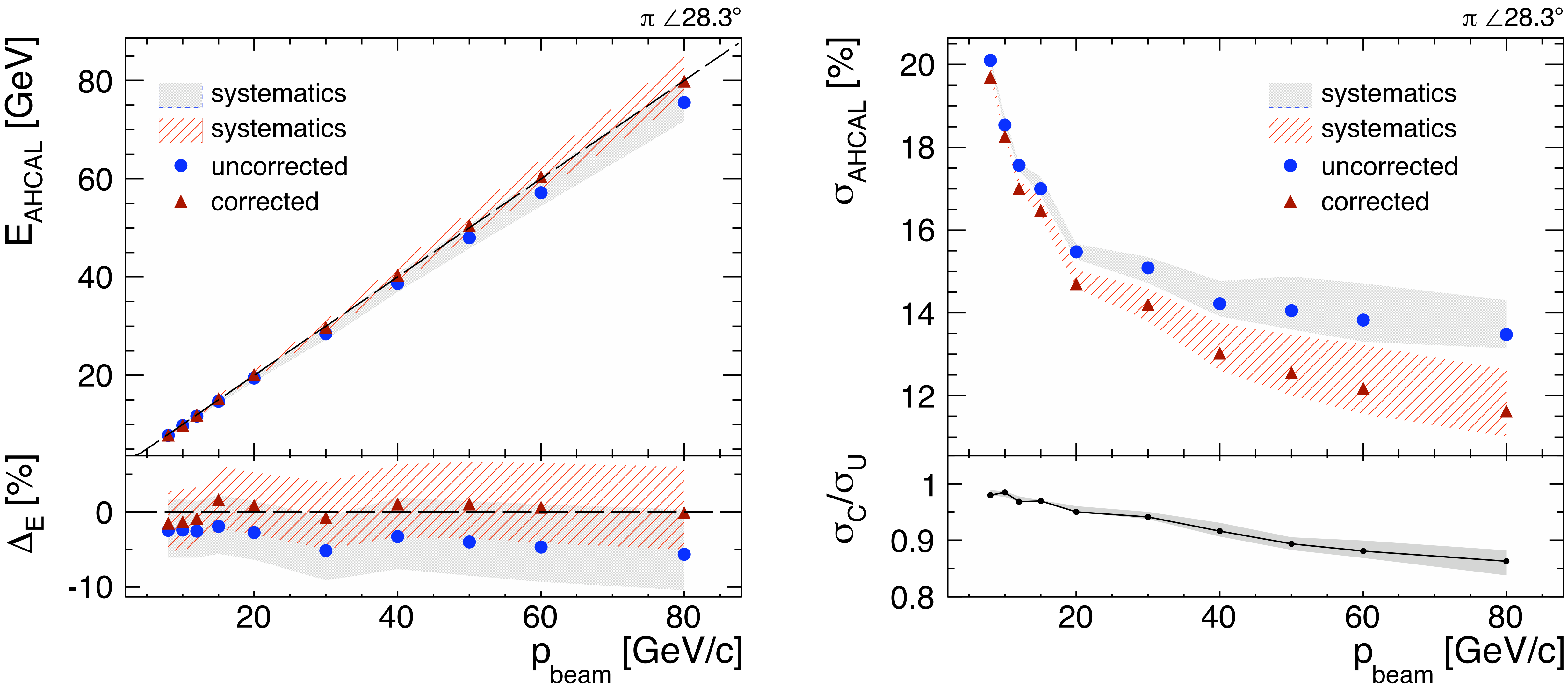
Leakage





- Depends on beam energy
  - → Non-linear detector response
- Fluctuations worsen resolution
- Depends on shower starting point
  - ⇒ Can correct average expected leakage knowing where shower starts
- Mean energy corrected
- Resolution improved

Leakage Correction Result



Linearity Improved from 5 % to 1 % at 80 GeV

Resolution Improved by more than 10 % at 80 GeV