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Calorimeter for ILC

Update: Analysis of low-energetic electron and pion data collected with the AHCAL at Fermilab

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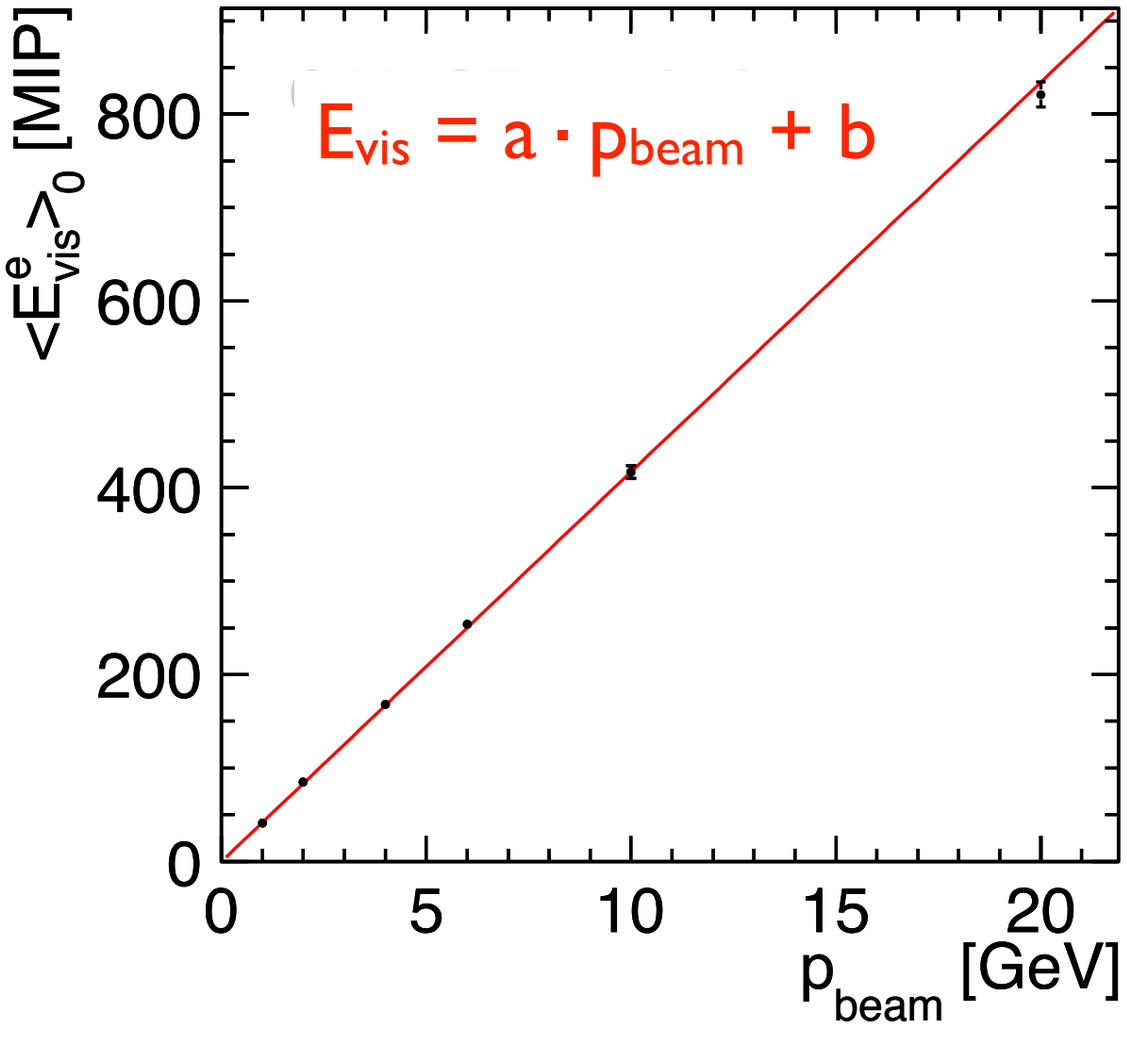
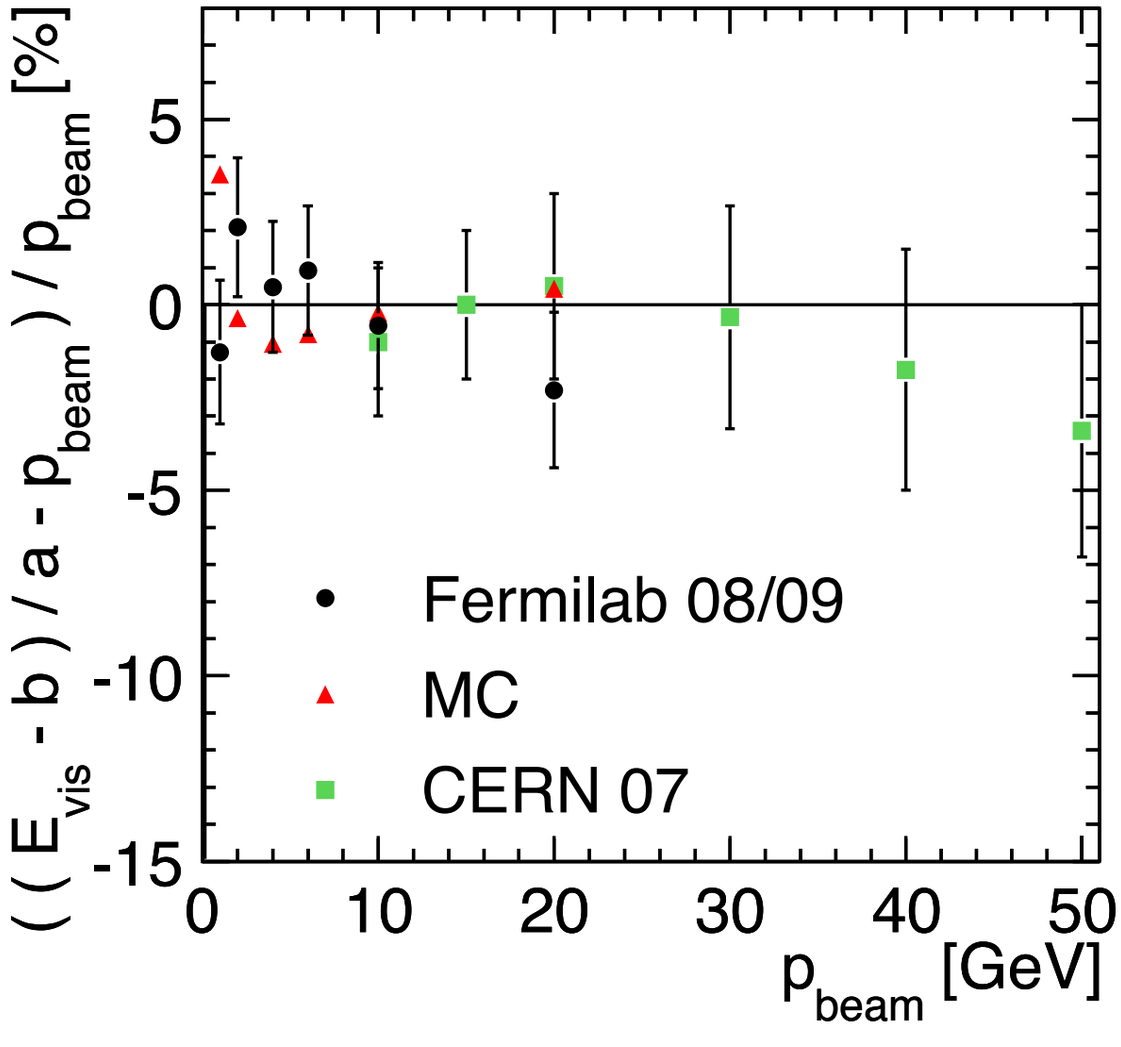
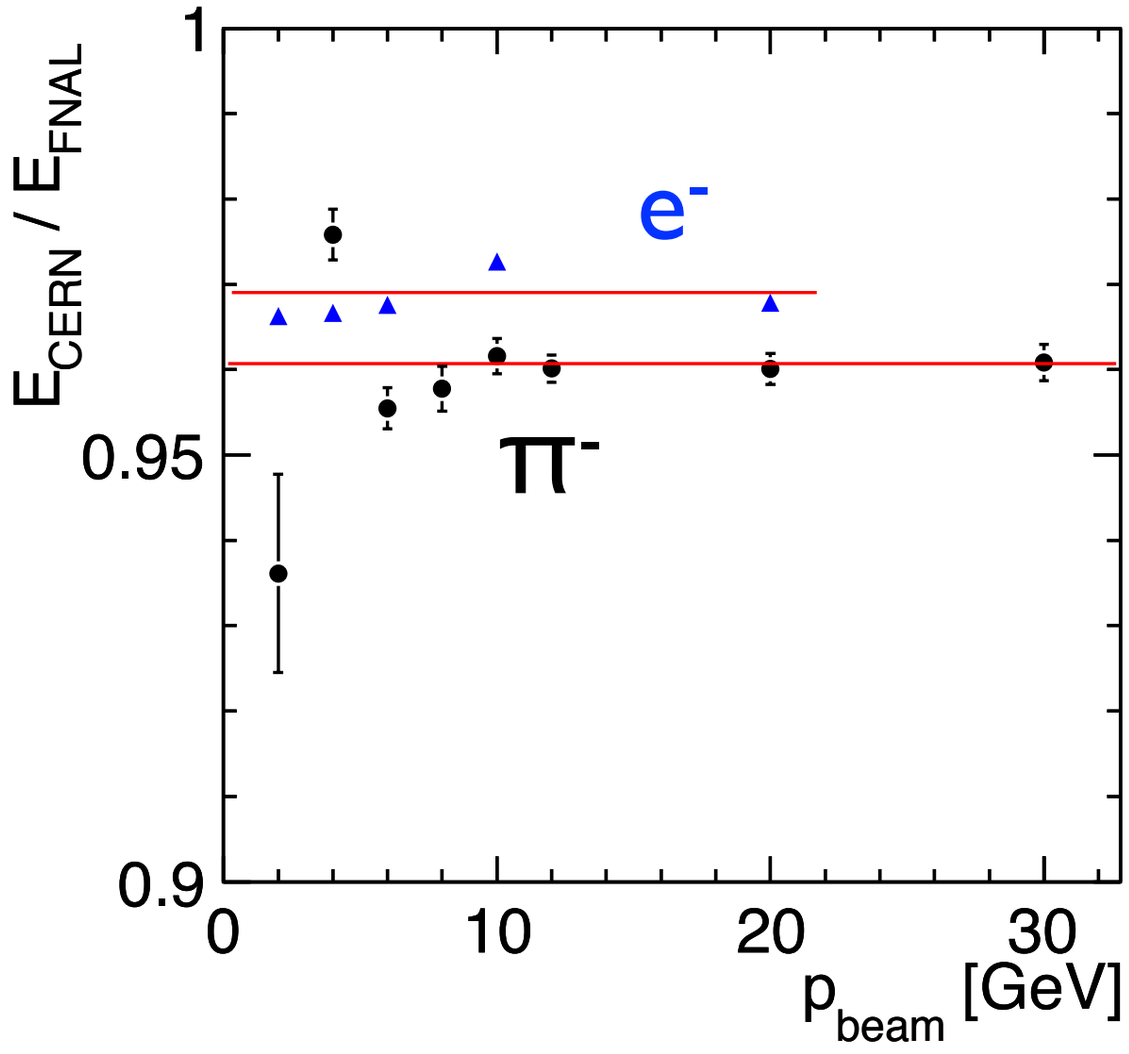
Electron response: MIP / GeV energy scale in data and simulation agrees

	FNAL	CERN	MC (FNAL)	MC (CERN)
a [MIP/GeV]	42.0 ± 0.5	42.4 ± 0.6	42.1 ± 0.0	42.6 ± 0.6
b [MIP]	-0.8 ± 1.0	-1.4 ± 7.0	-6.4 ± 0.1	-10.3 ± 7.4





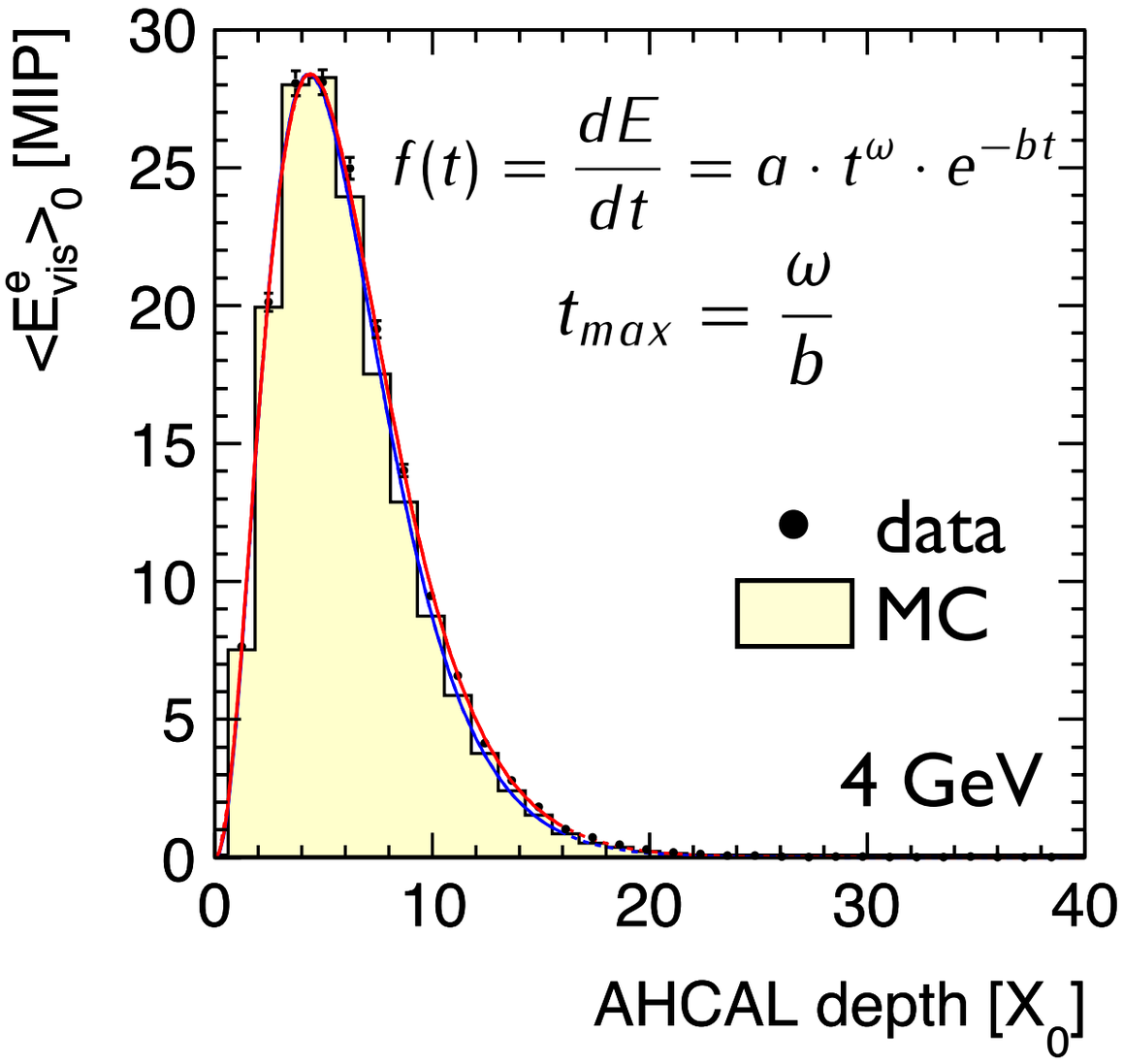
Applying CERN calibration to FNAL data shifts MIP scale down by 4%

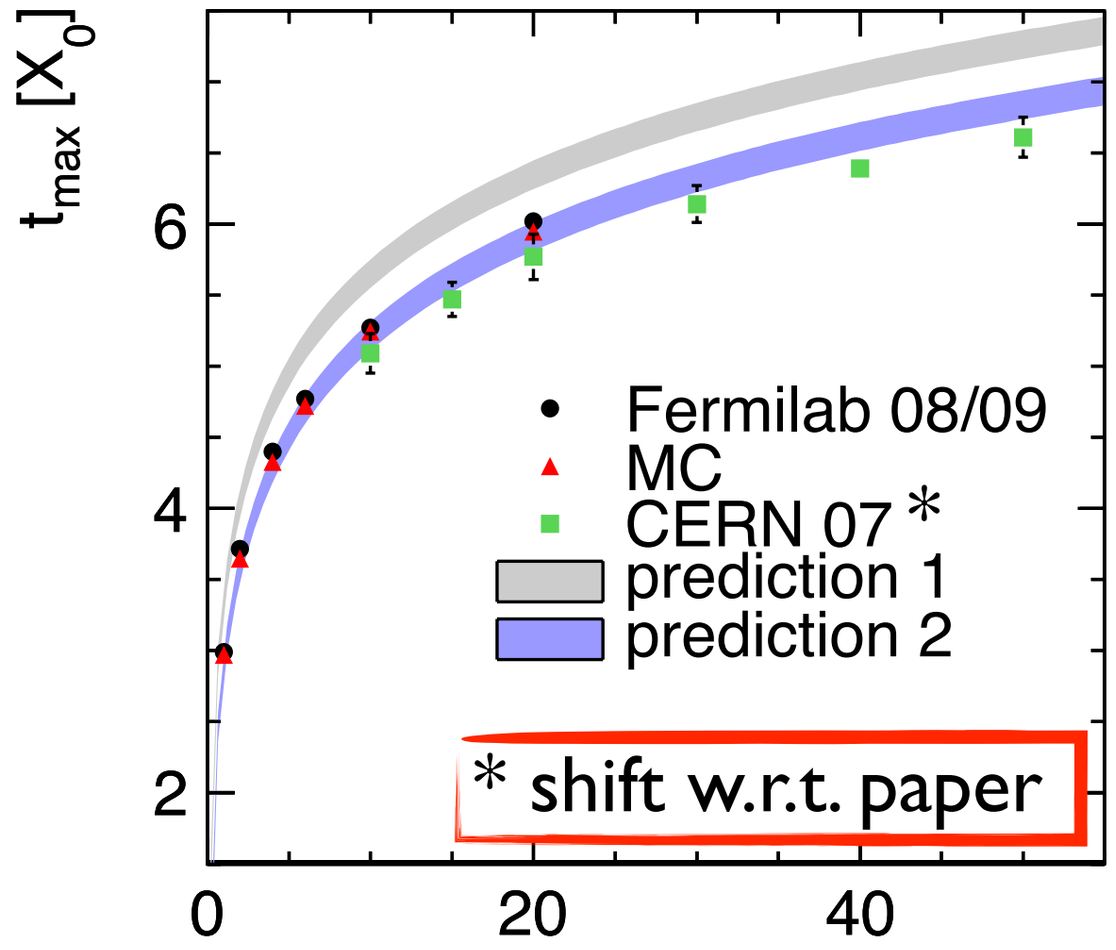


$$E_{CERN} = \frac{E[ADC]}{A^{MIP}_{CERN}} \qquad E_{FNAL} = \frac{E[ADC]}{A^{MIP}_{FNAL}}$$

- $A^{FNAL}_{MIP} < A^{CERN}_{MIP}$ (voltage and temperature correction applied)
- Shift expected to disappear when calibrating to GeV
- 5% limit of level for data / MC comparisons at MIP scale

Longitudinal electron profiles: Different data sets and simulations agree



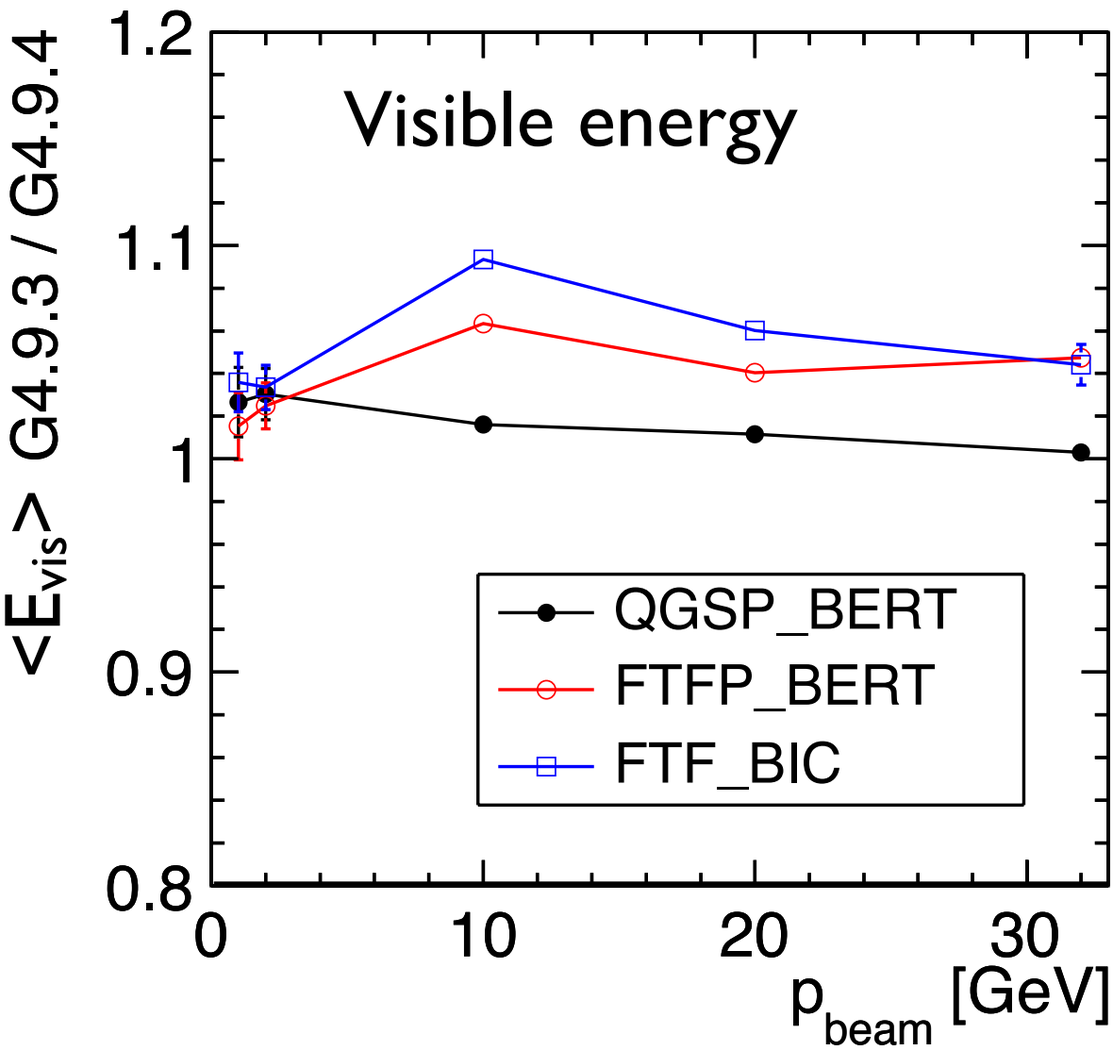


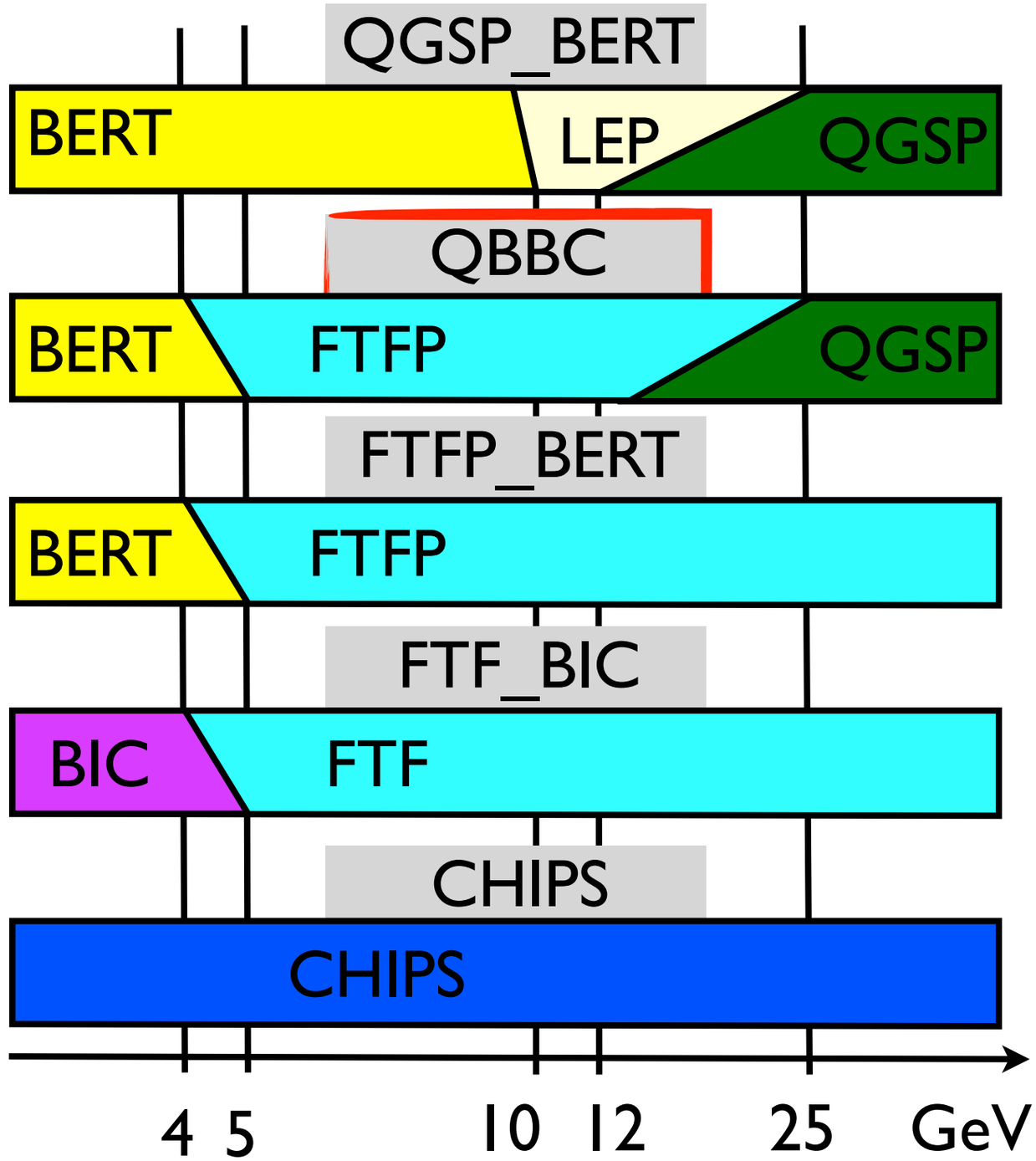
EM paper: 0.5 X_0 offset
in conversion mm → X_0

$$t_{max} = \ln \frac{E}{\epsilon_c} - 0.5$$

$$t_{max} = 1.01 \cdot \ln \frac{E}{\epsilon_c} - 1.0$$

Pion analysis: Going from Geant4 version 4.9.3 to version 4.9.4

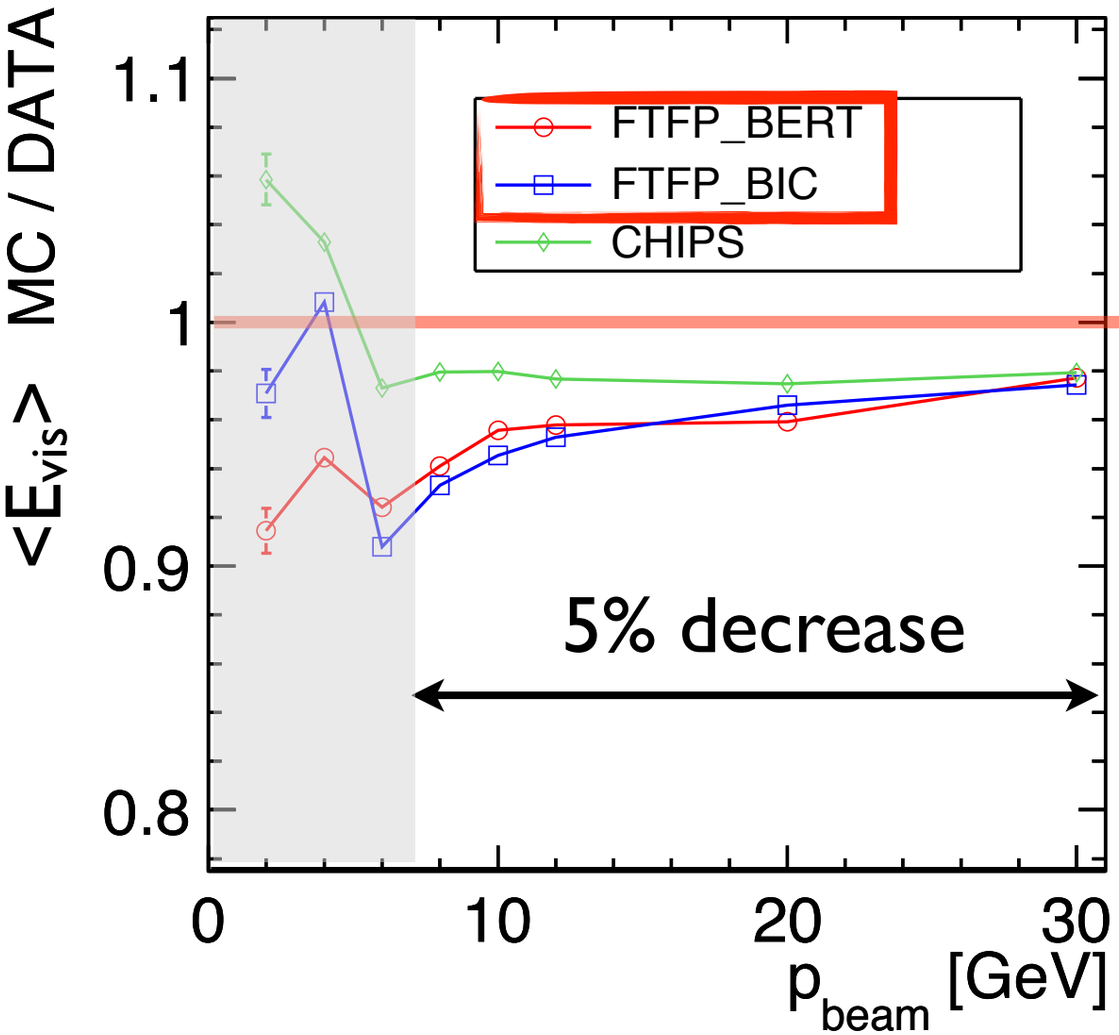




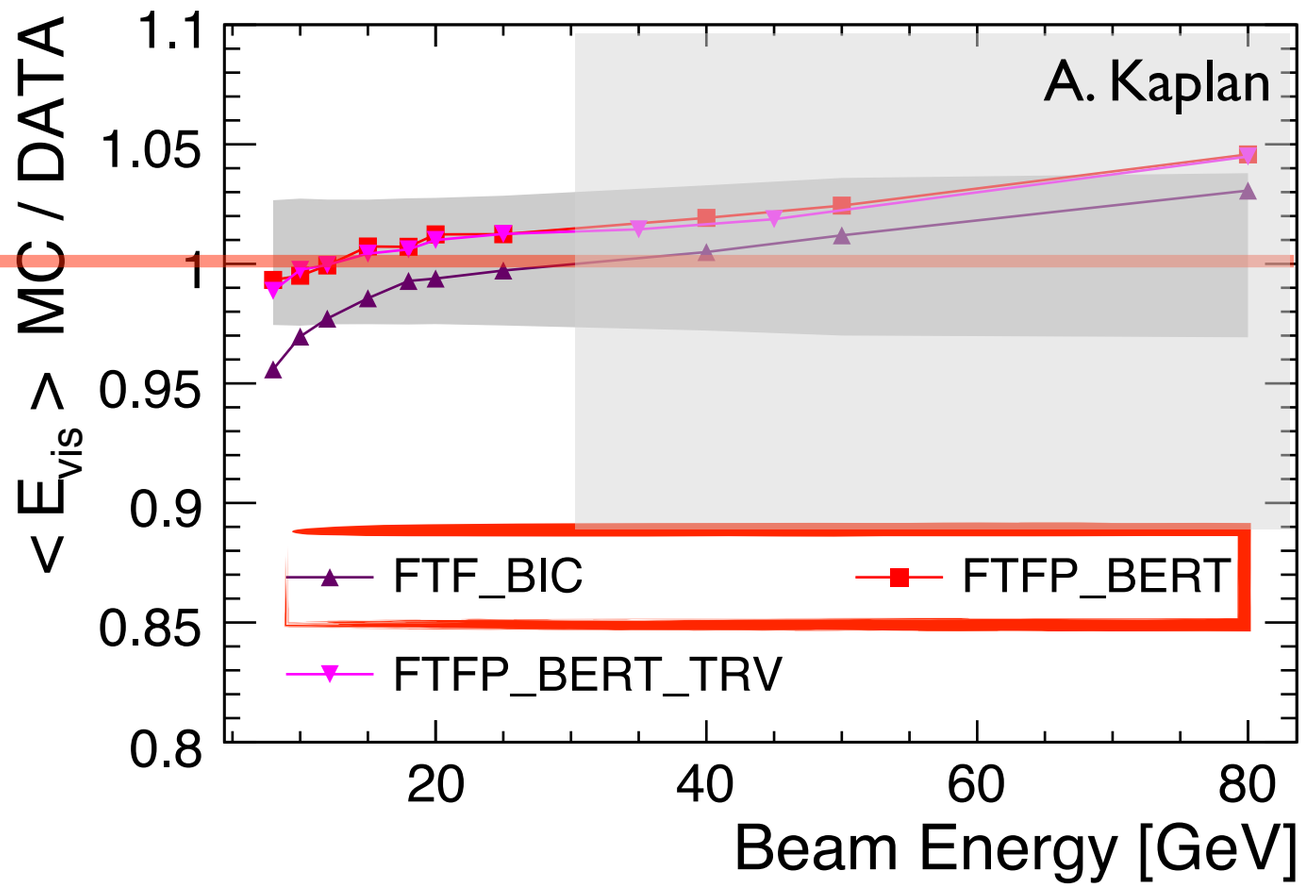
- Muon response not changed

Visible energy: Same trend of MC / data agreement for CERN and FNAL analysis

FNAL (Geant 4.9.4)



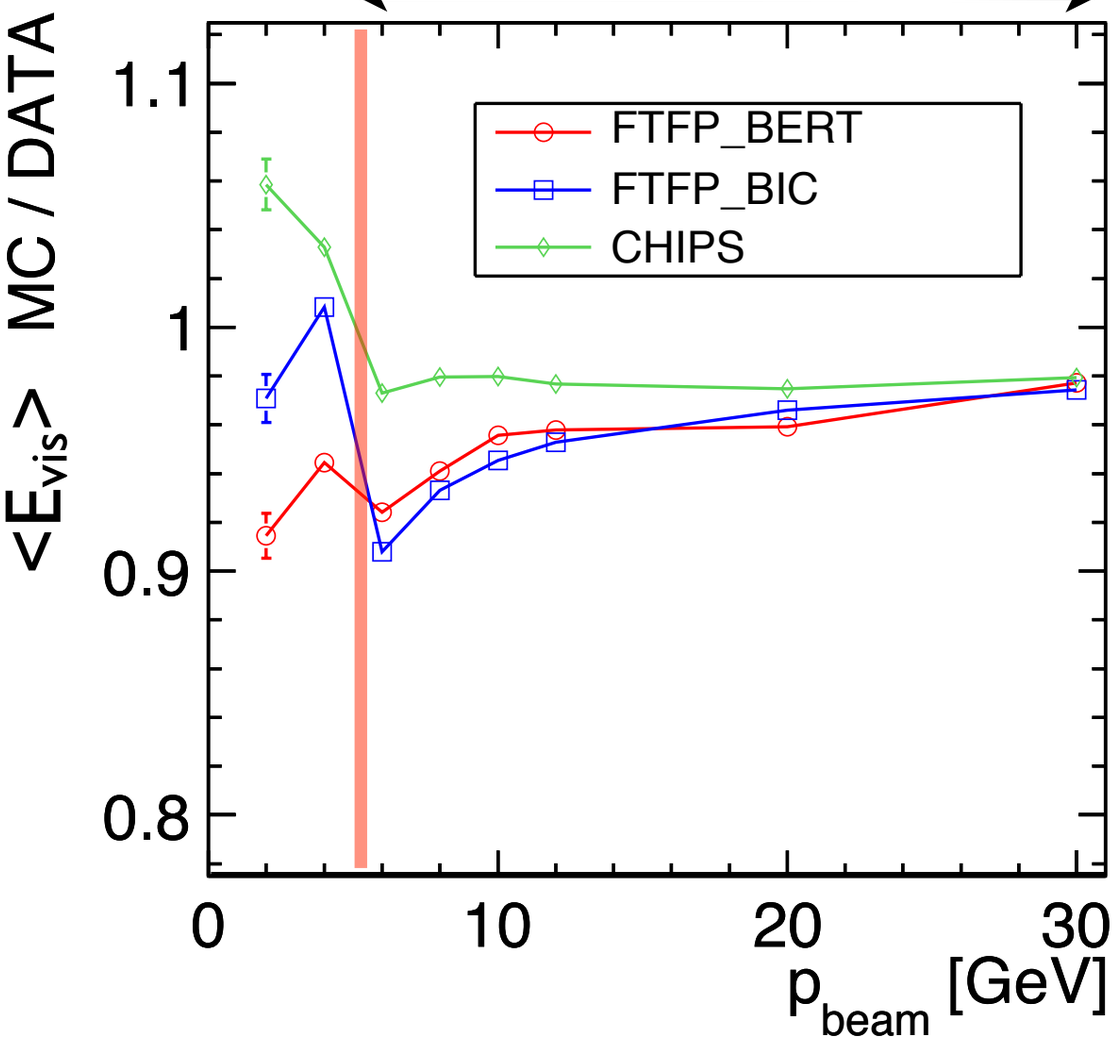
CERN (Geant 4.9.3)



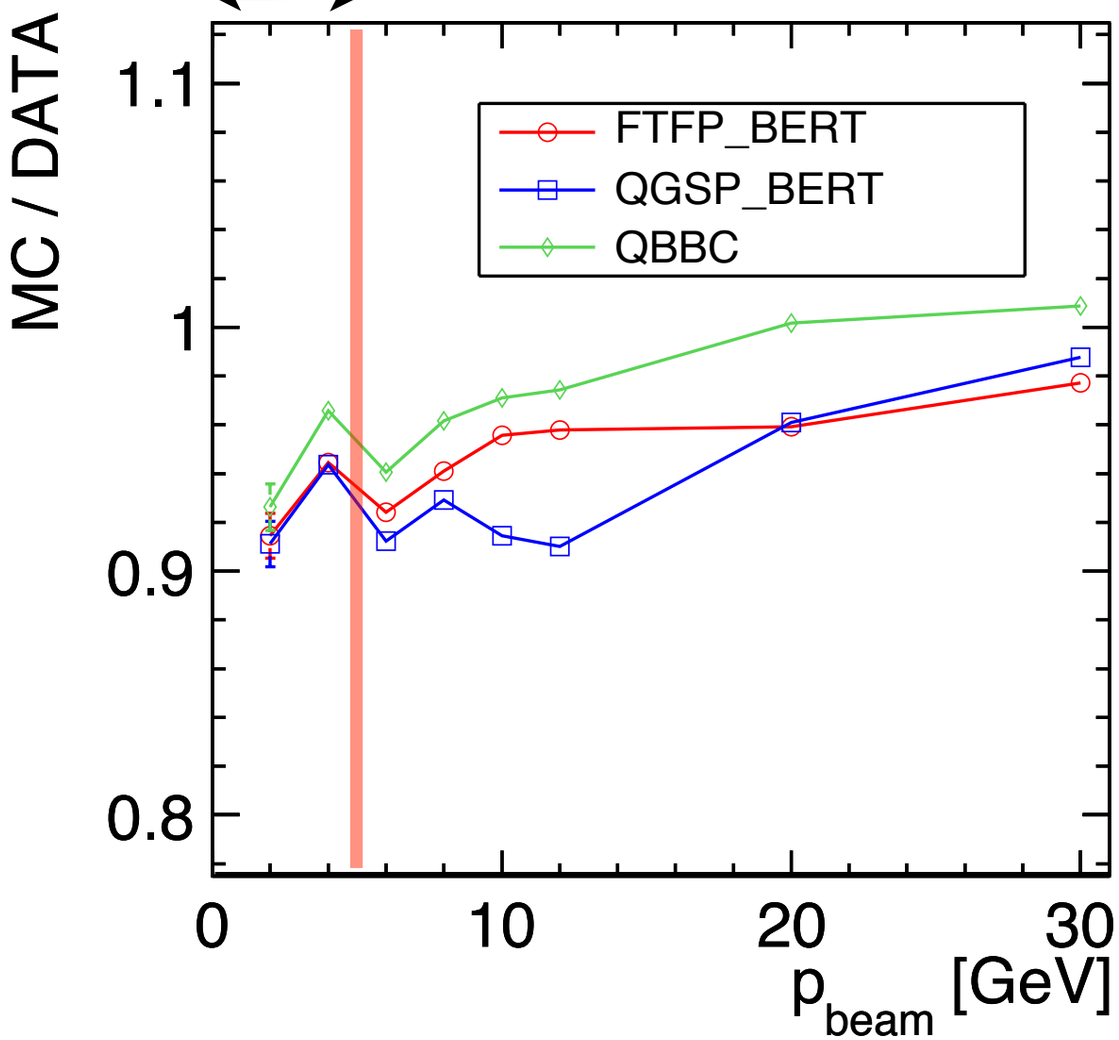
- FNAL vs CERN: Different calibration, event selection, Geant4 version.

Extension to low beam energies: Crossing model transitions reveals model features

FTF dominates
FTFP_BERT and FTF_BIC

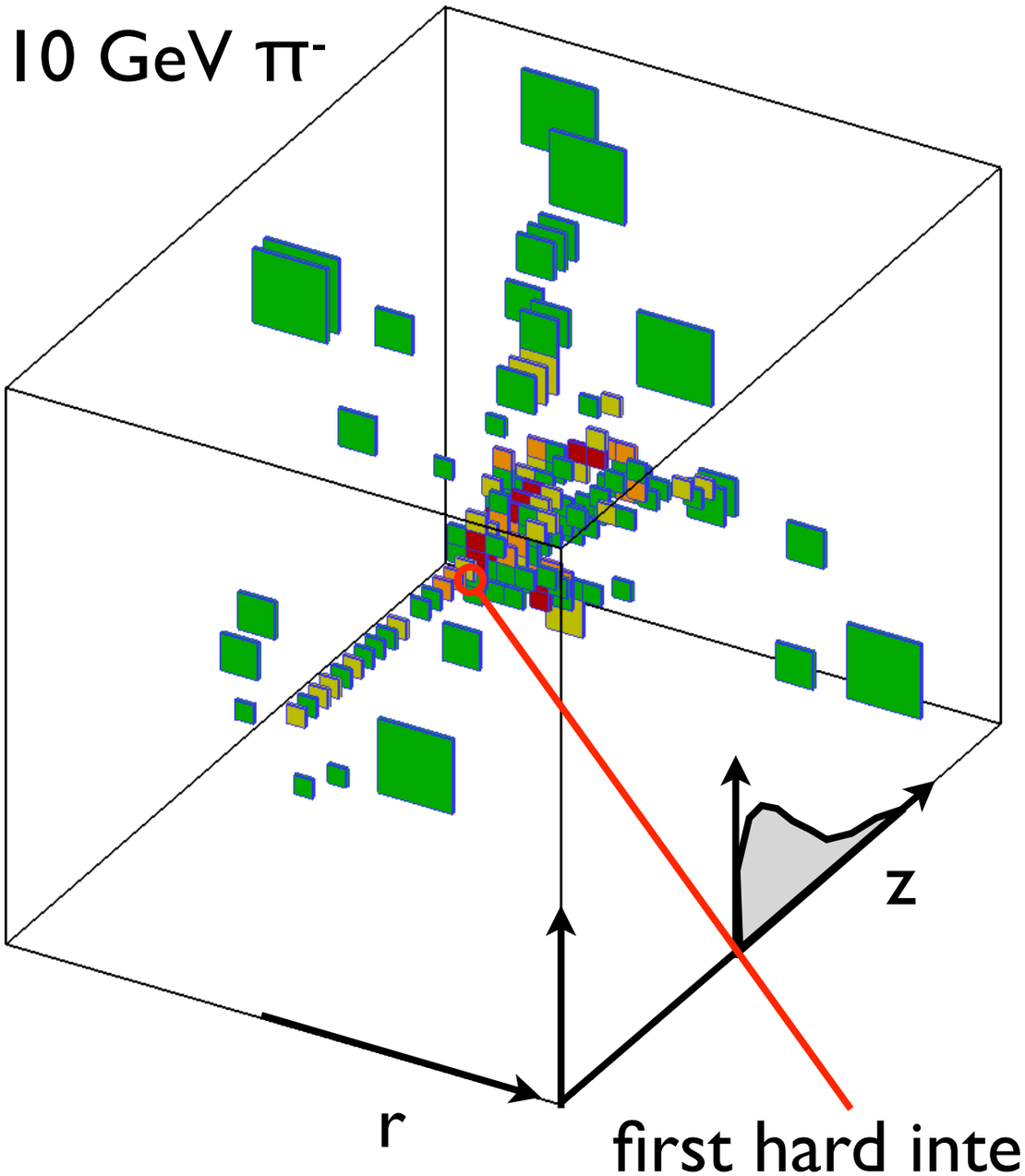


BERT dominates



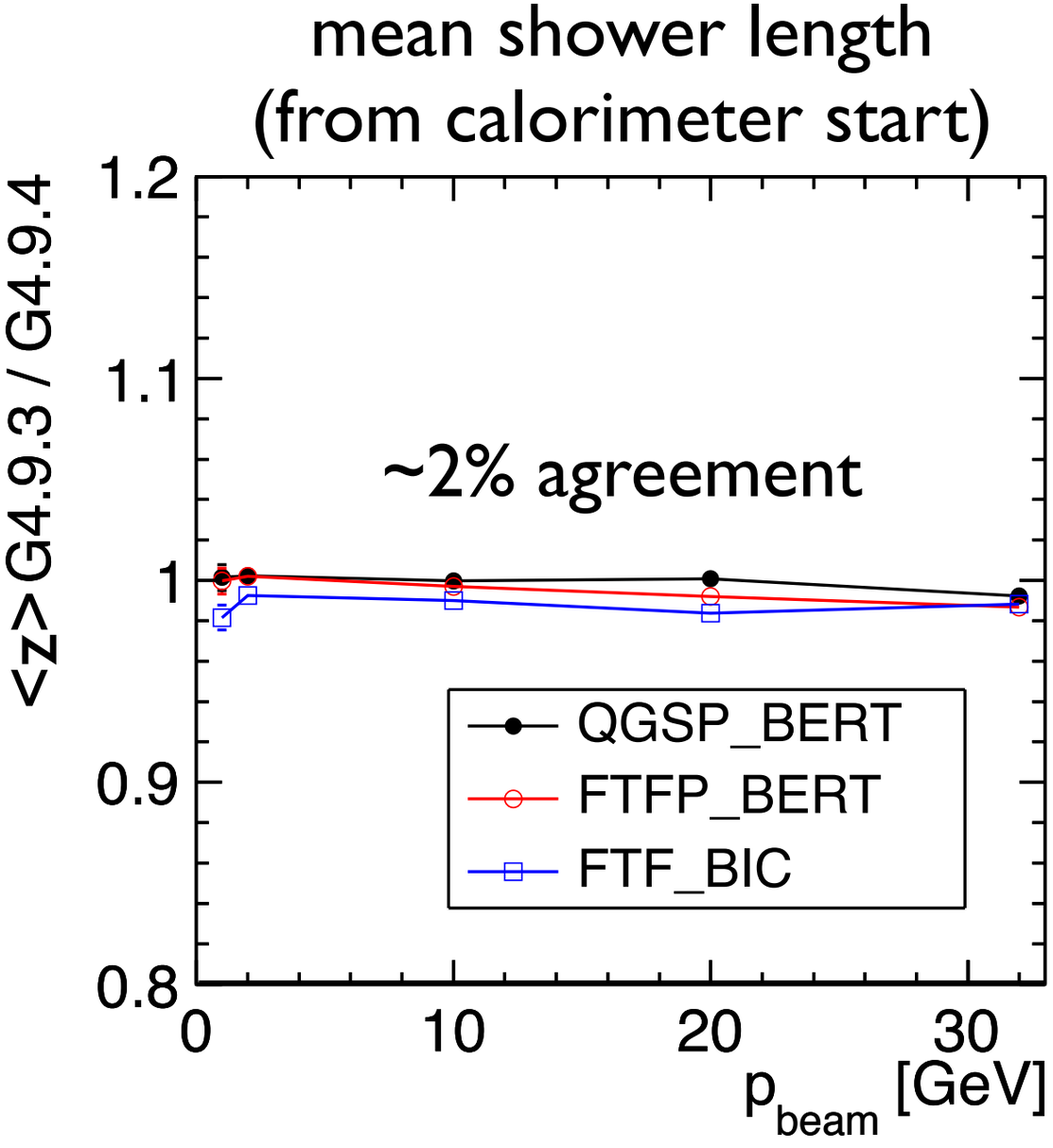
- Using HP for QGSP_BERT does not affect E_{vis}

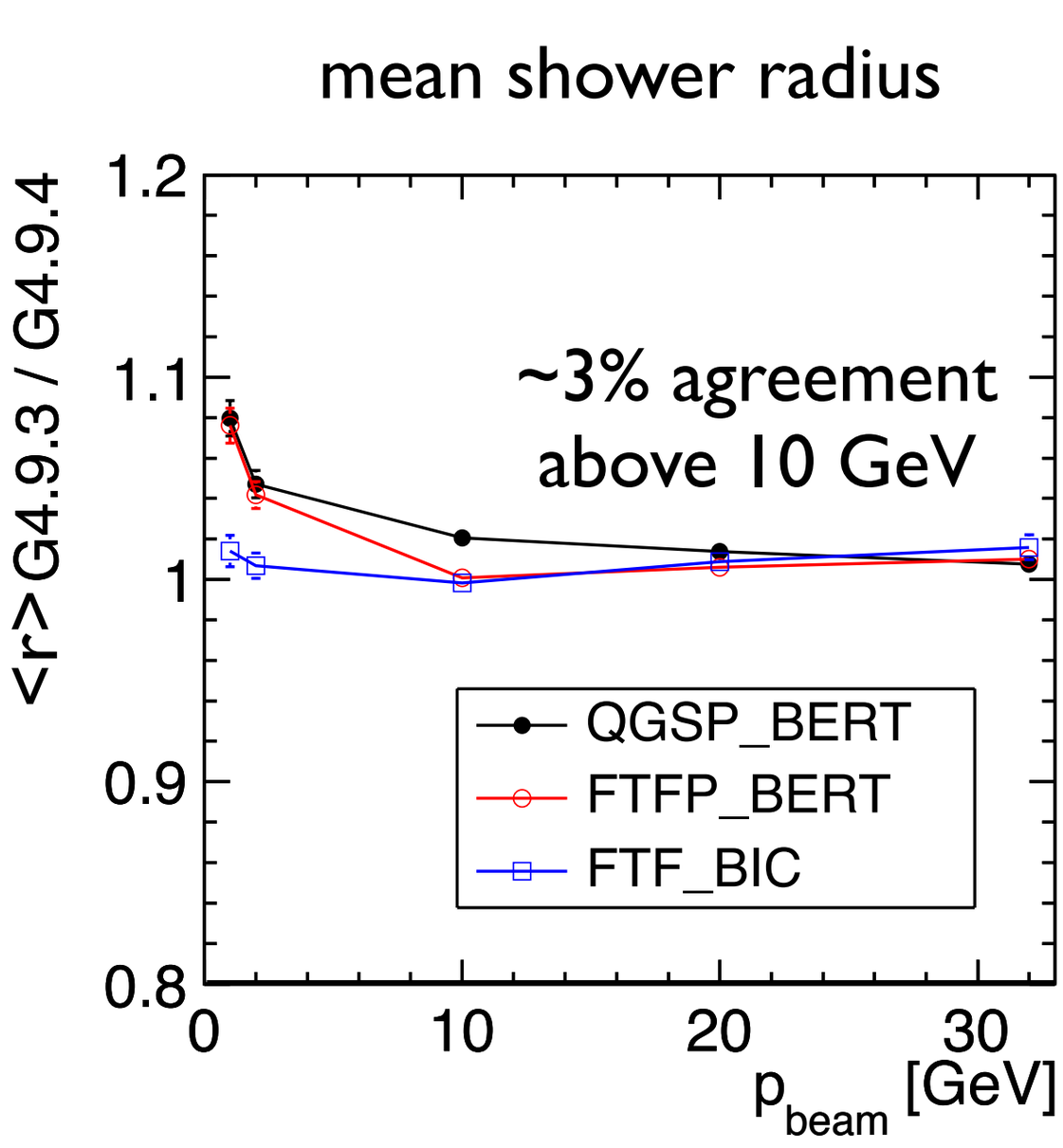
Analysis of pion shower topology



- Signal in single cell: E_i
- Total response E_{vis} = ΣE_i
- Shower depth <z> = $\frac{\Sigma(E_i \cdot z_i)}{\Sigma E_i}$
- Shower radius <r> = $\frac{\Sigma(E_i \cdot r_i)}{\Sigma E_i}$

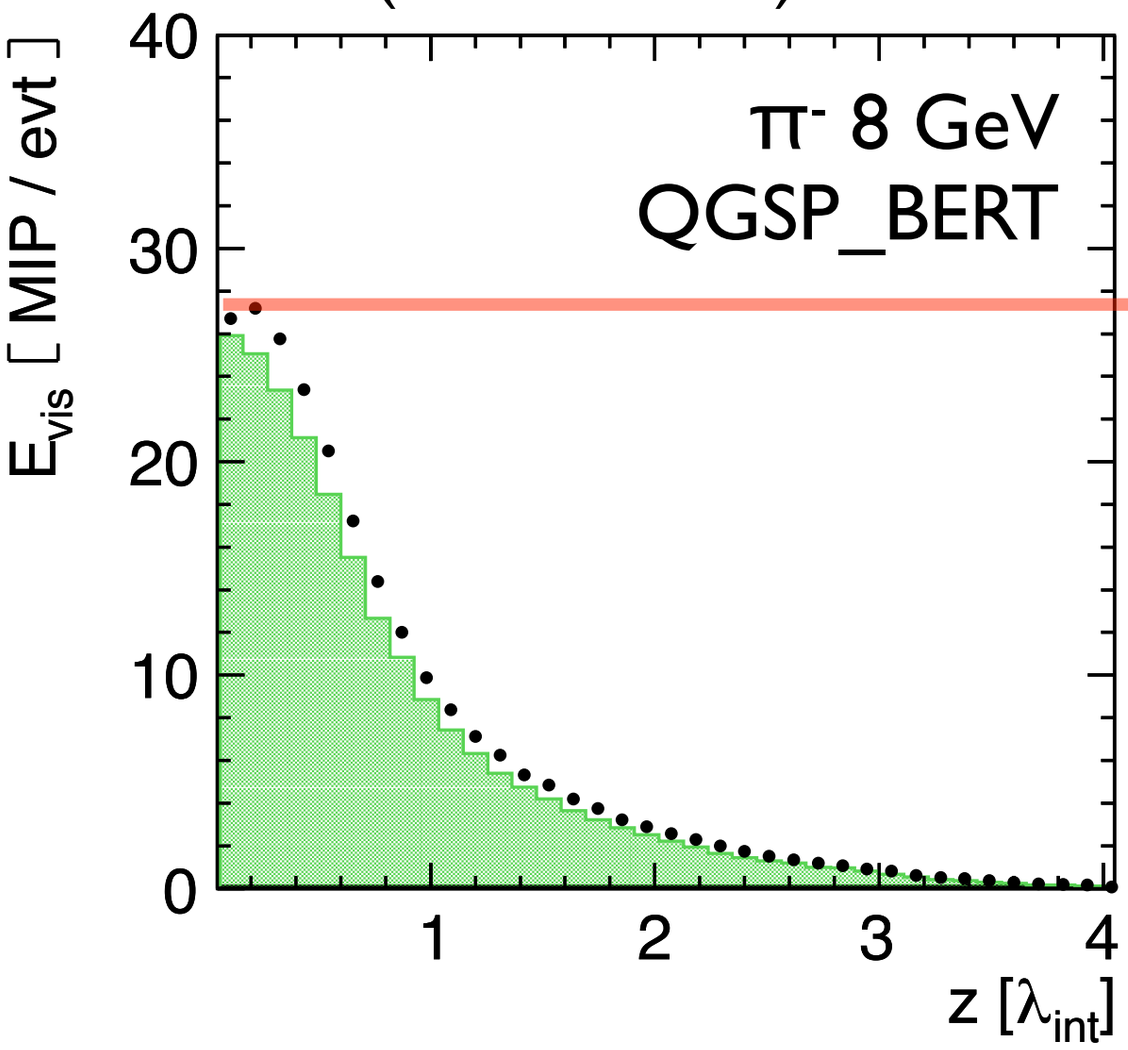
Different Geant4 versions predict similar shower topologies above 10 GeV



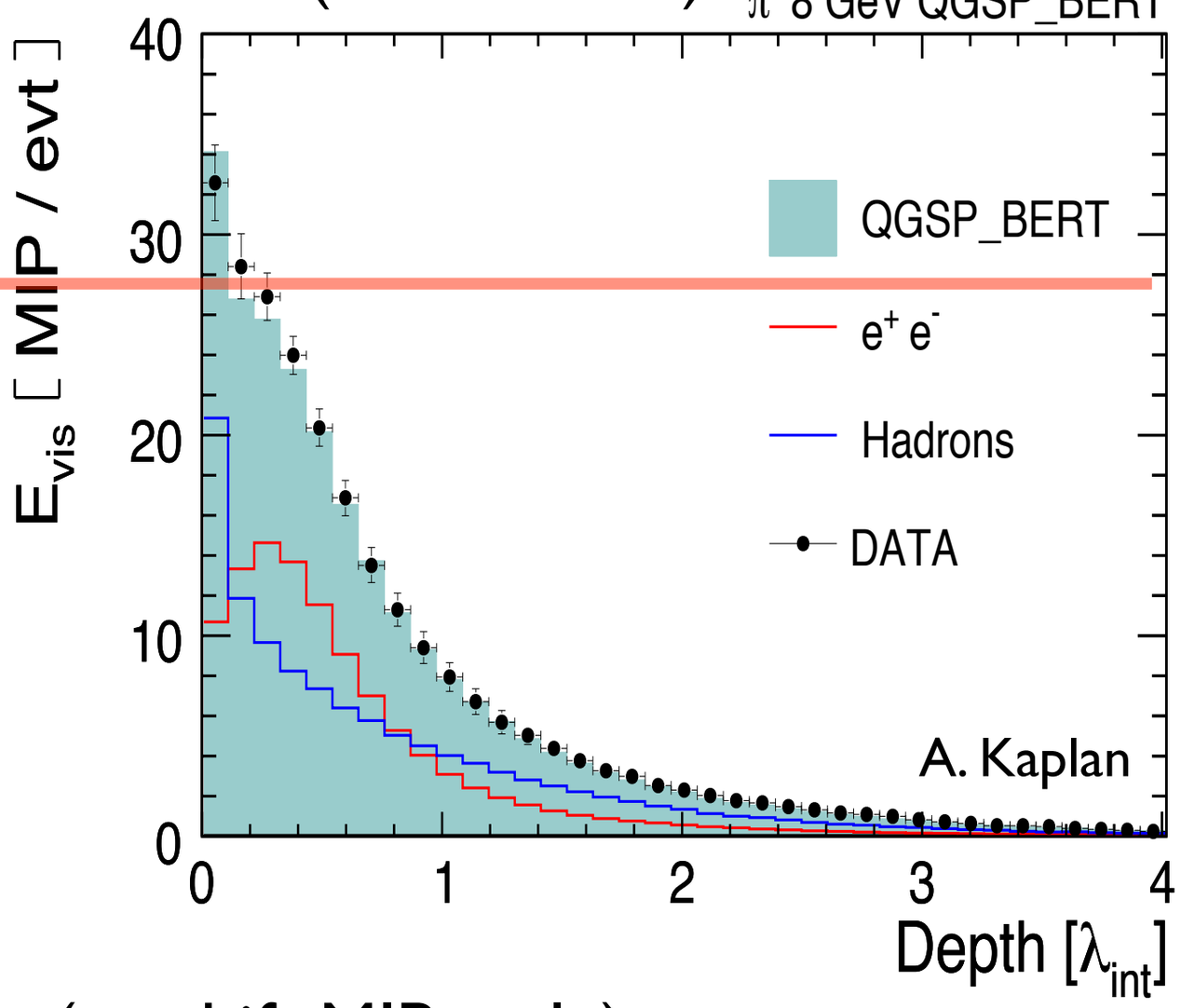


Shapes of longitudinal pion profiles for CERN and FNAL analysis agree

FNAL (Geant 4.9.4)



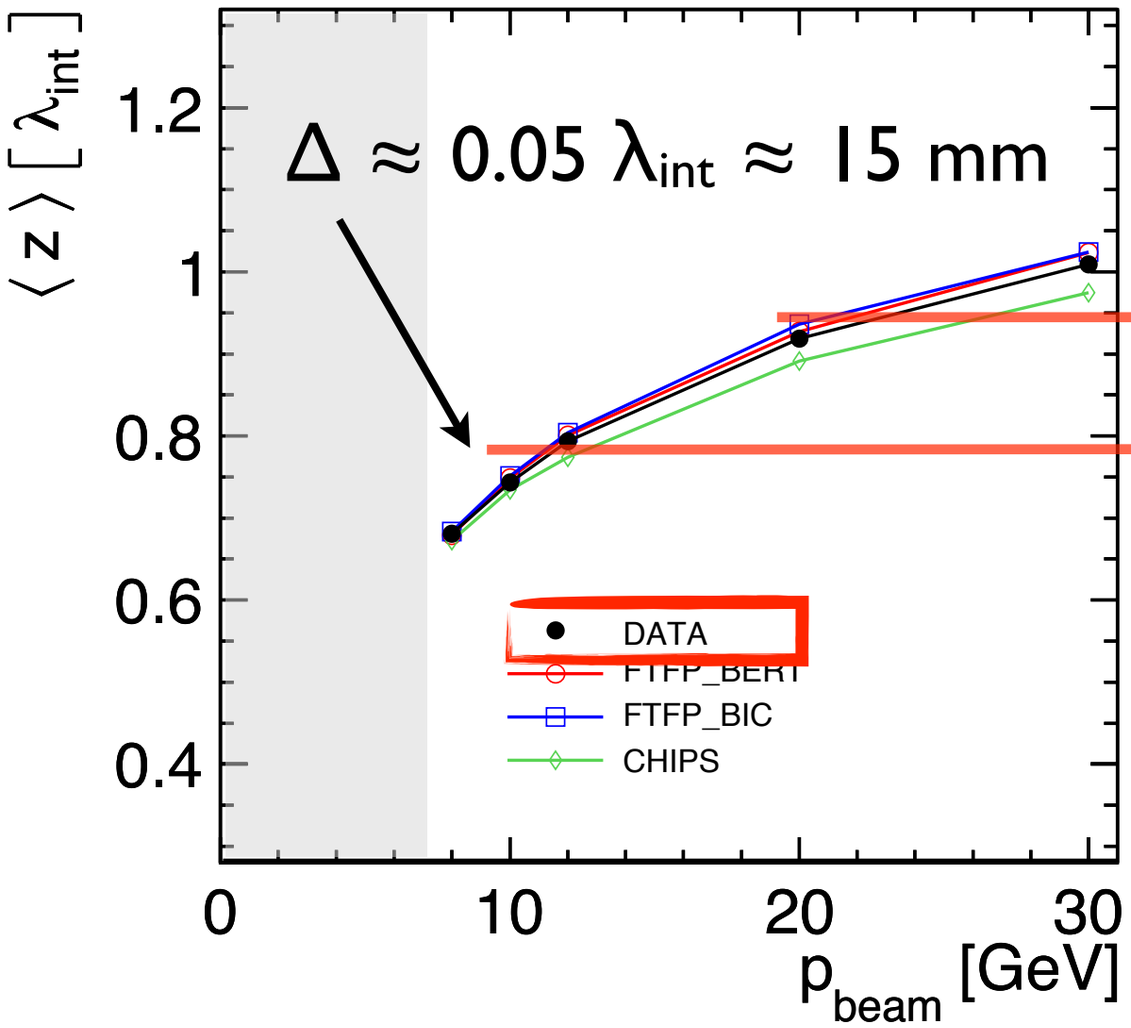
CERN (Geant 4.9.3)



- Different muon calibration (→ shift MIP scale)
- Different algorithms for finding the first hard interaction
- CERN: require first hard interaction in layers 1-5

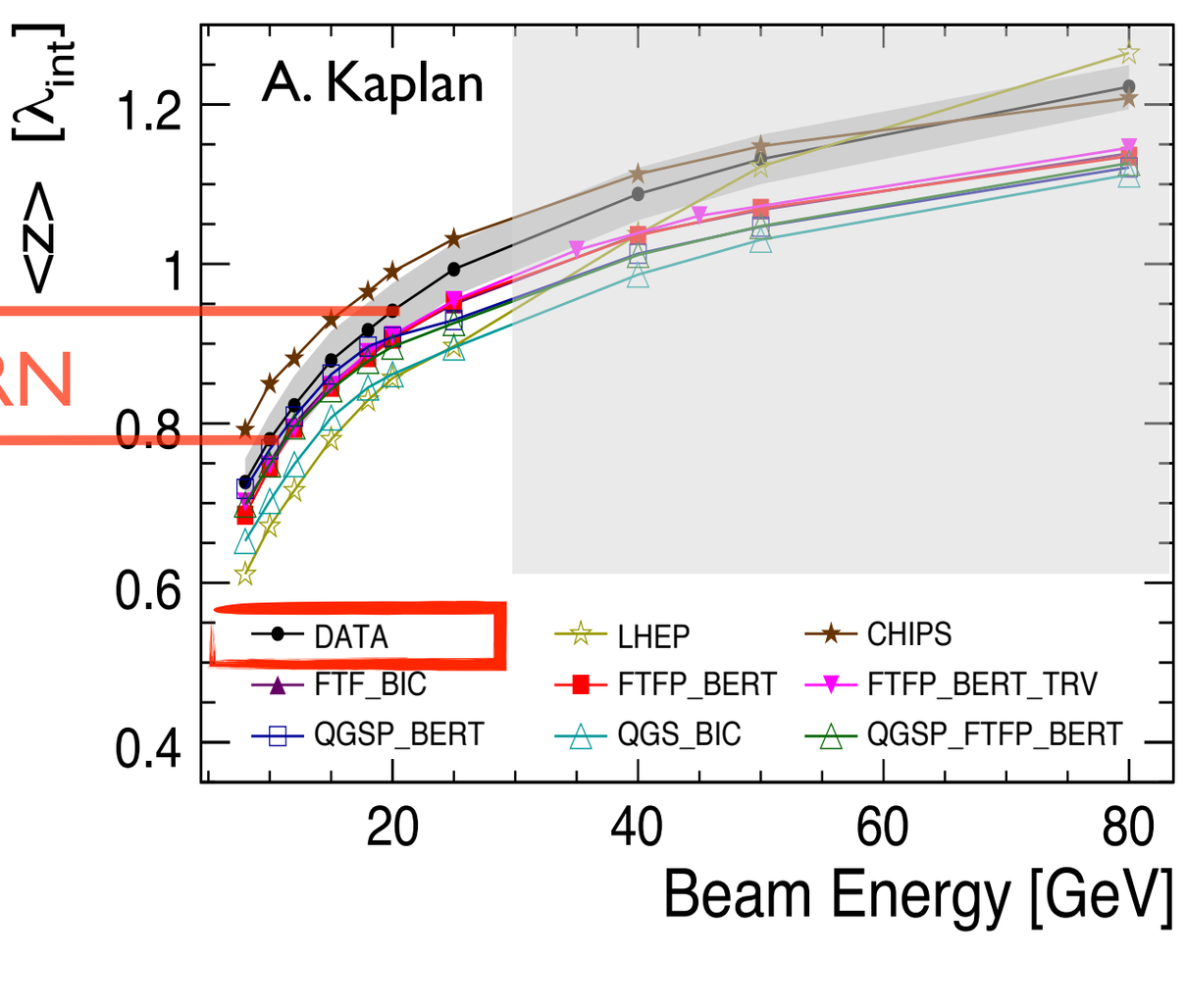
Shower length from first hard interaction: Agreement CERN / FNAL analysis within 6%

FNAL (Geant 4.9.4)



CERN

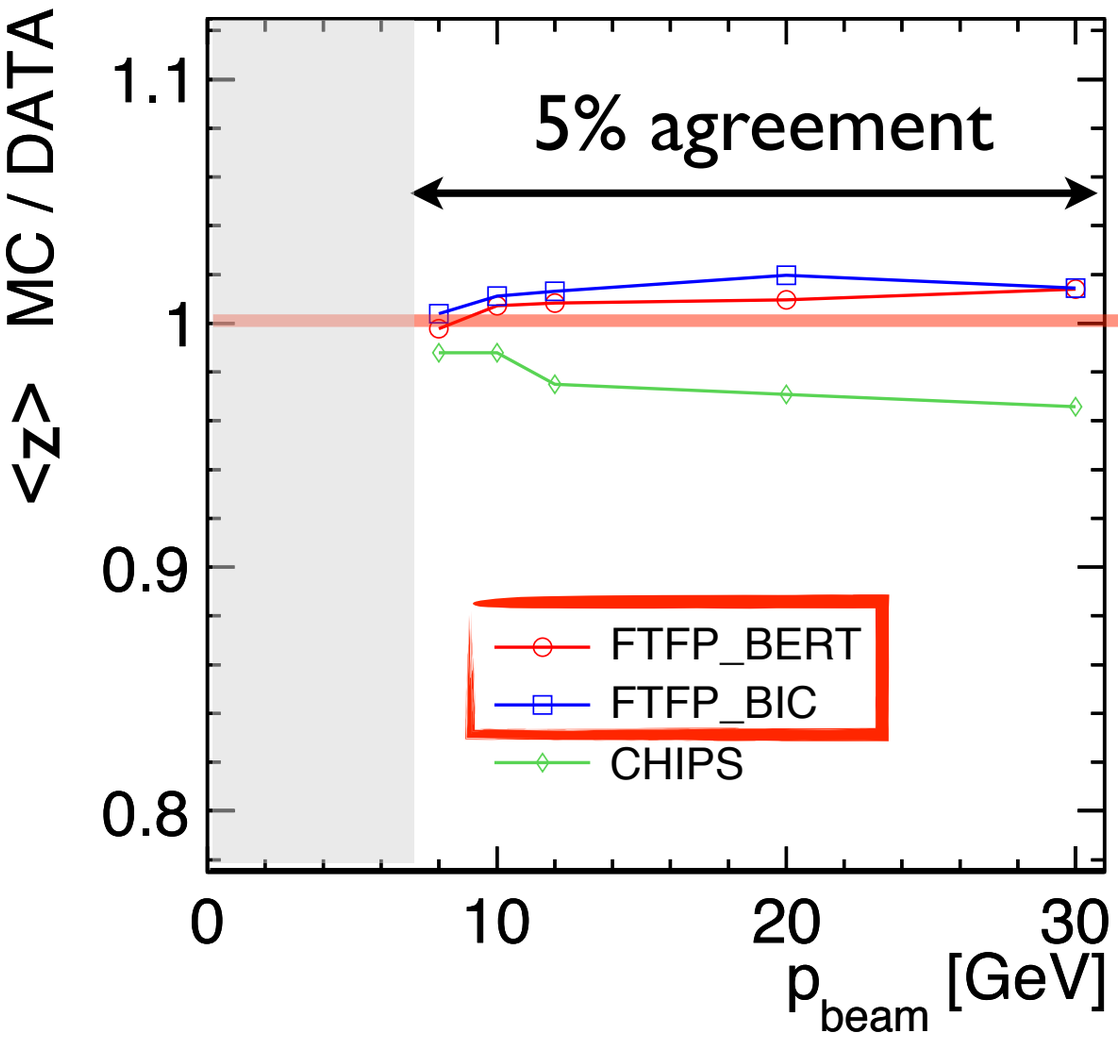
CERN (Geant 4.9.3)



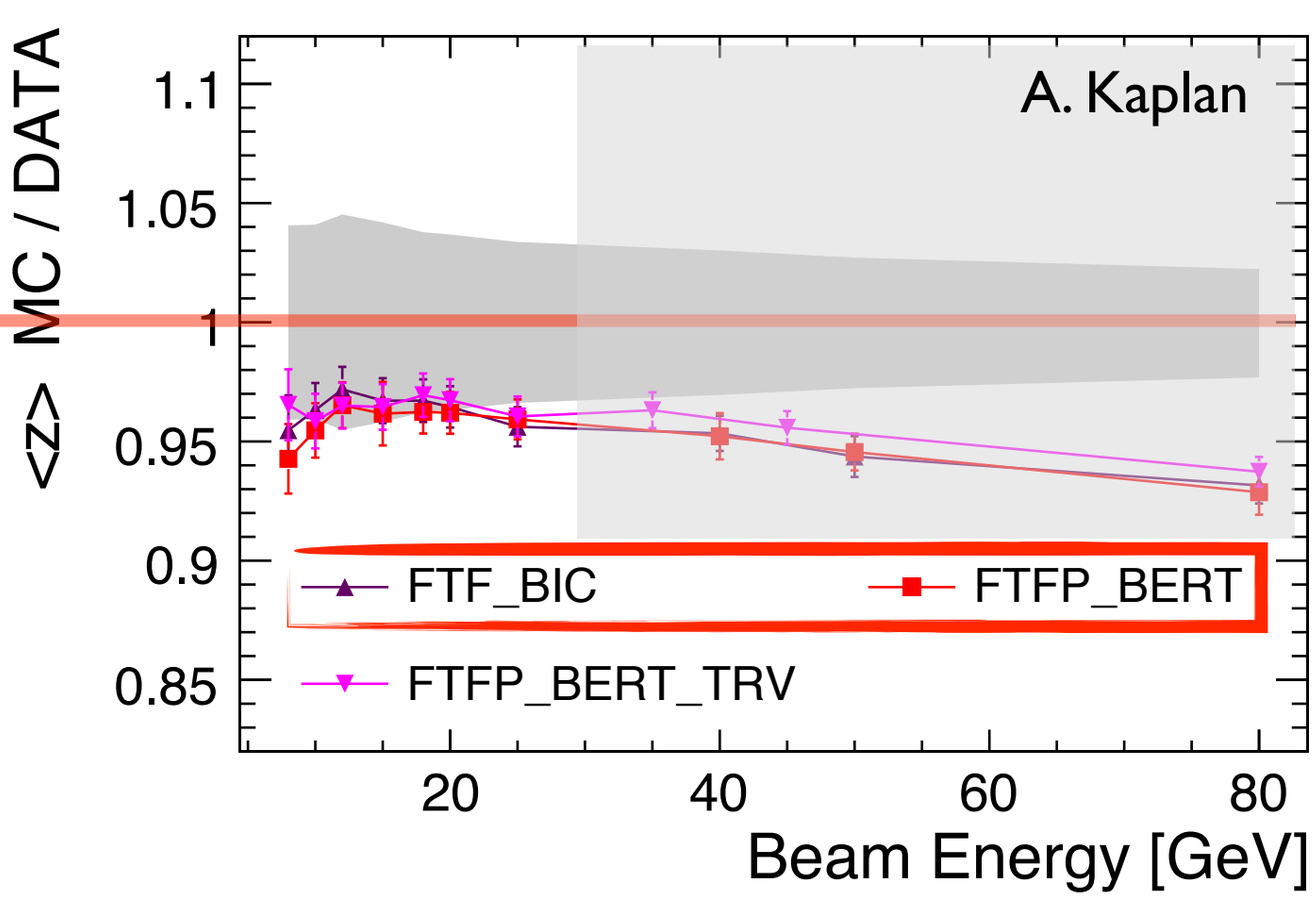
- Different algorithms for finding the first hard interaction
- CERN: require first hard interaction in layers 1-5

Shower length: Same trend of MC / data agreement for CERN and FNAL analysis

FNAL (Geant 4.9.4)



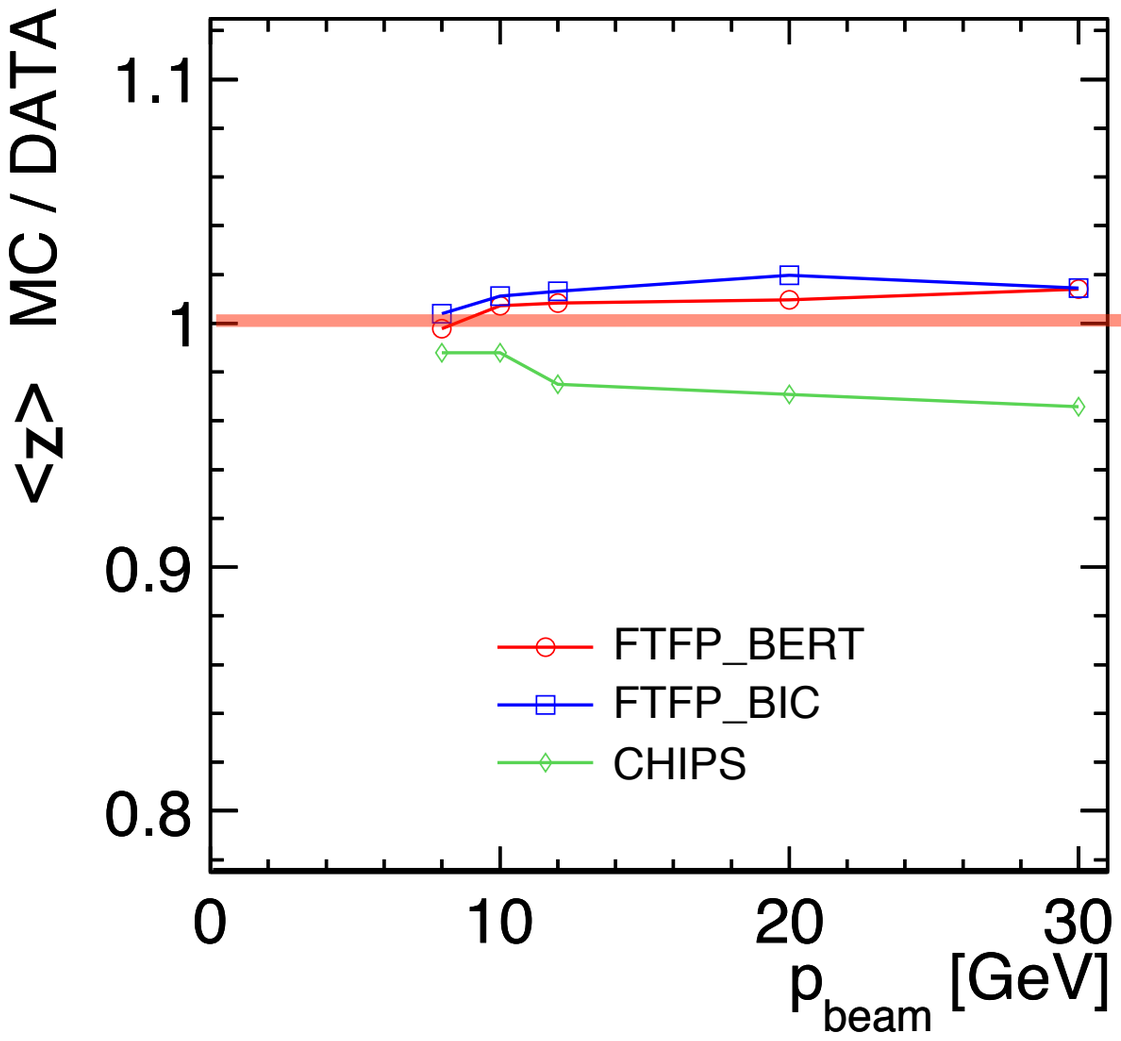
CERN (Geant 4.9.3)



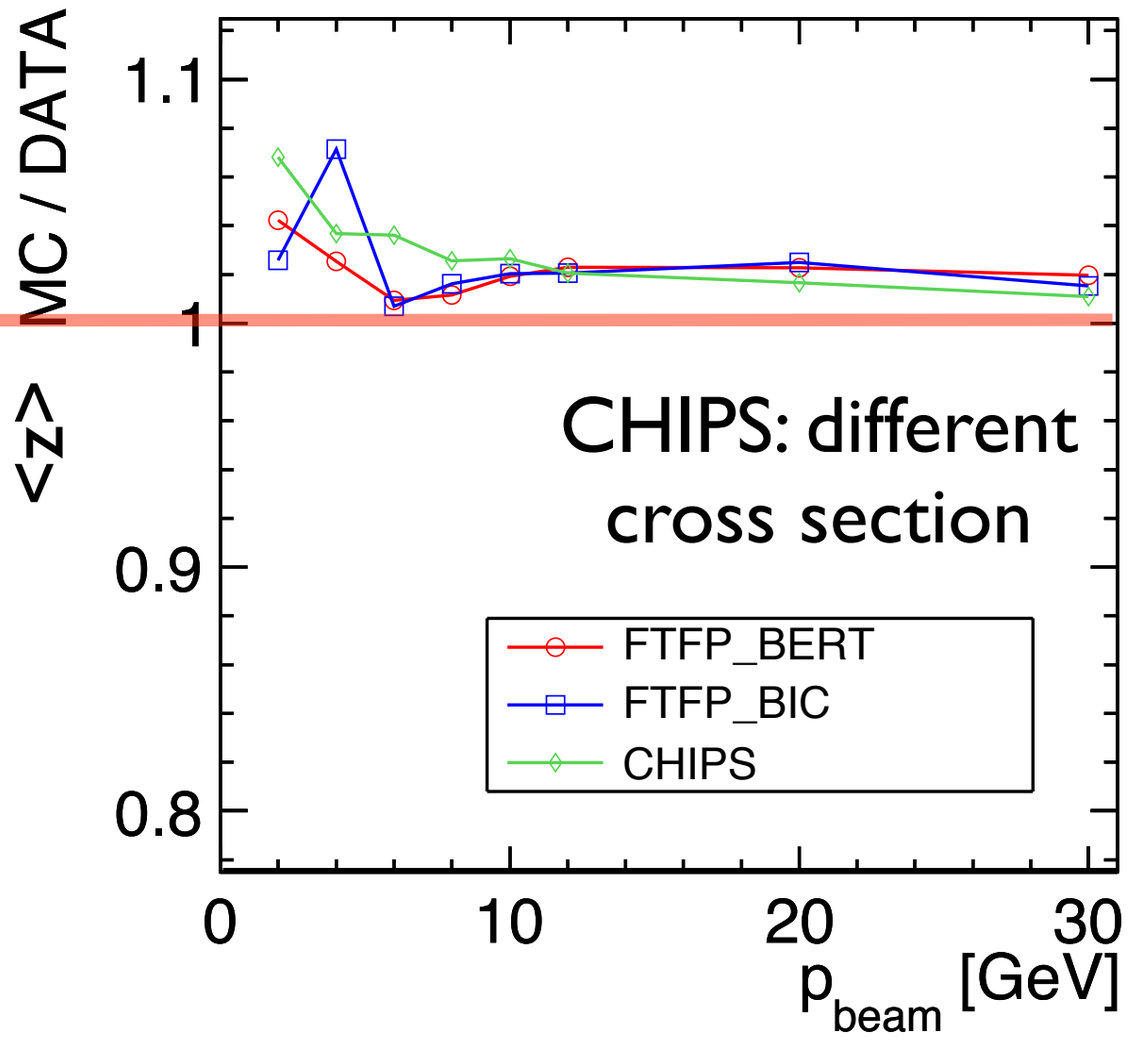
Shower length from AHCAL start: Same trends, MC / data ratios shifted

mean shower length

from first hard interaction



from calorimeter start

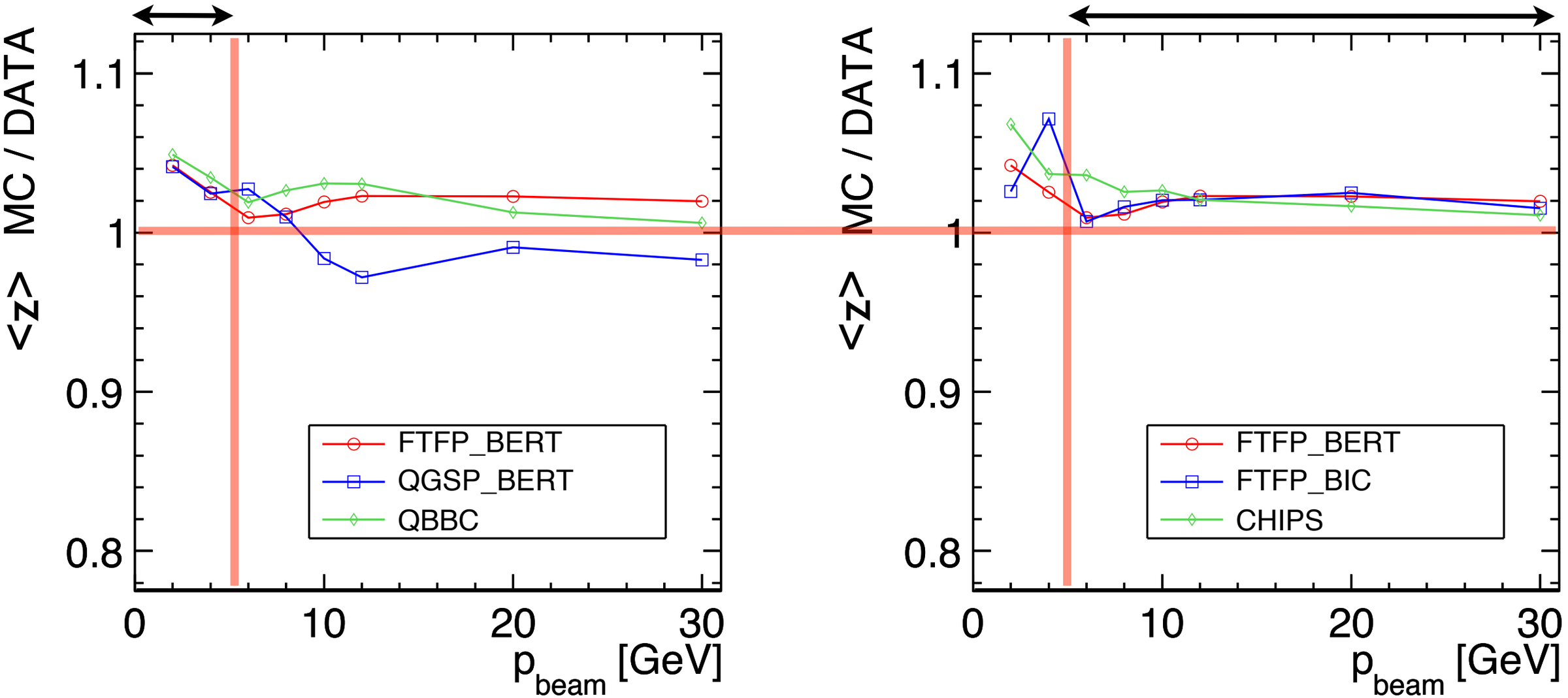


- Below 6 GeV: Worse performance of algorithm for locating first hard interaction

Extension to low beam energies: Crossing model transitions reveals model features

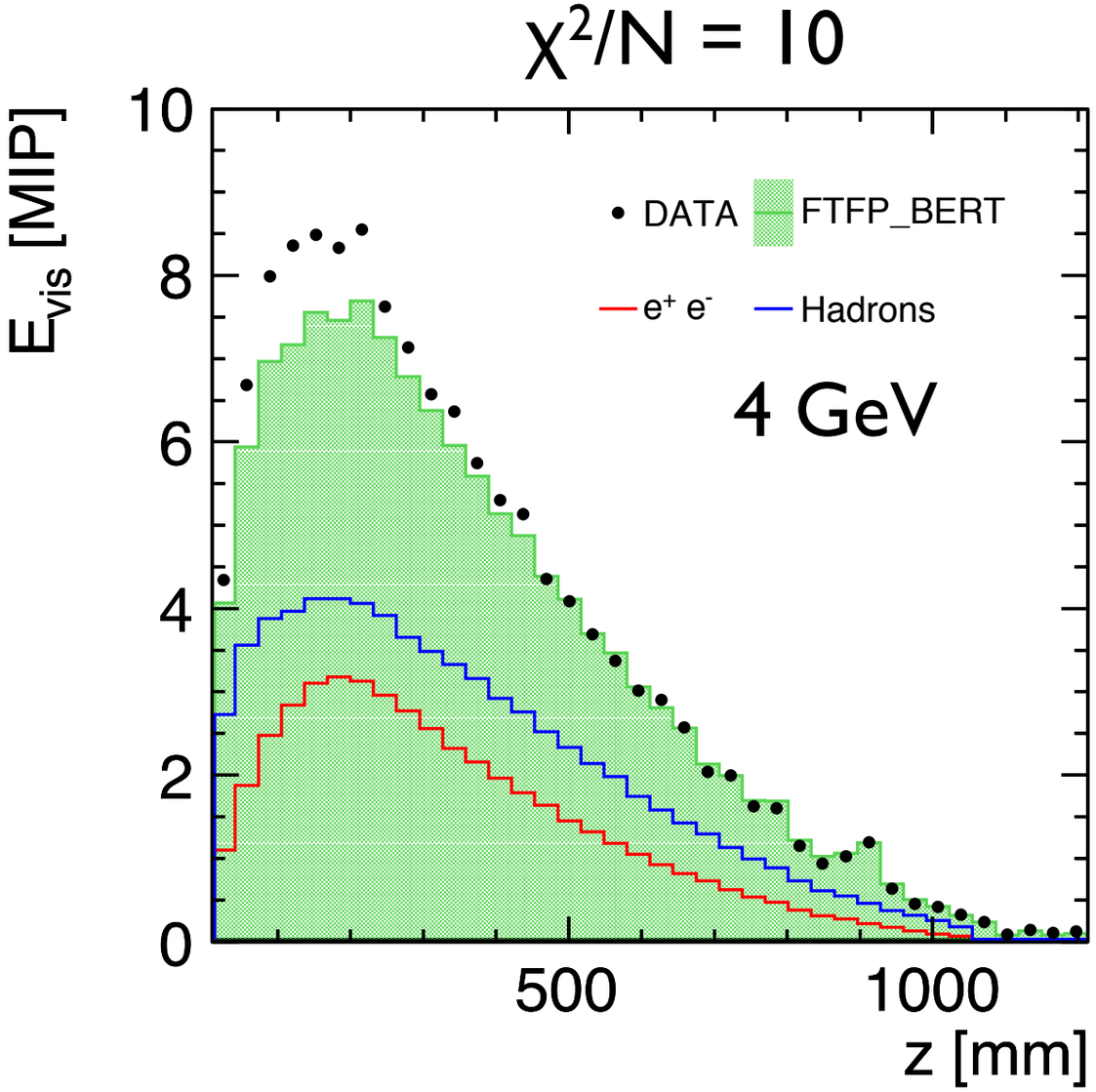
BERT dominates

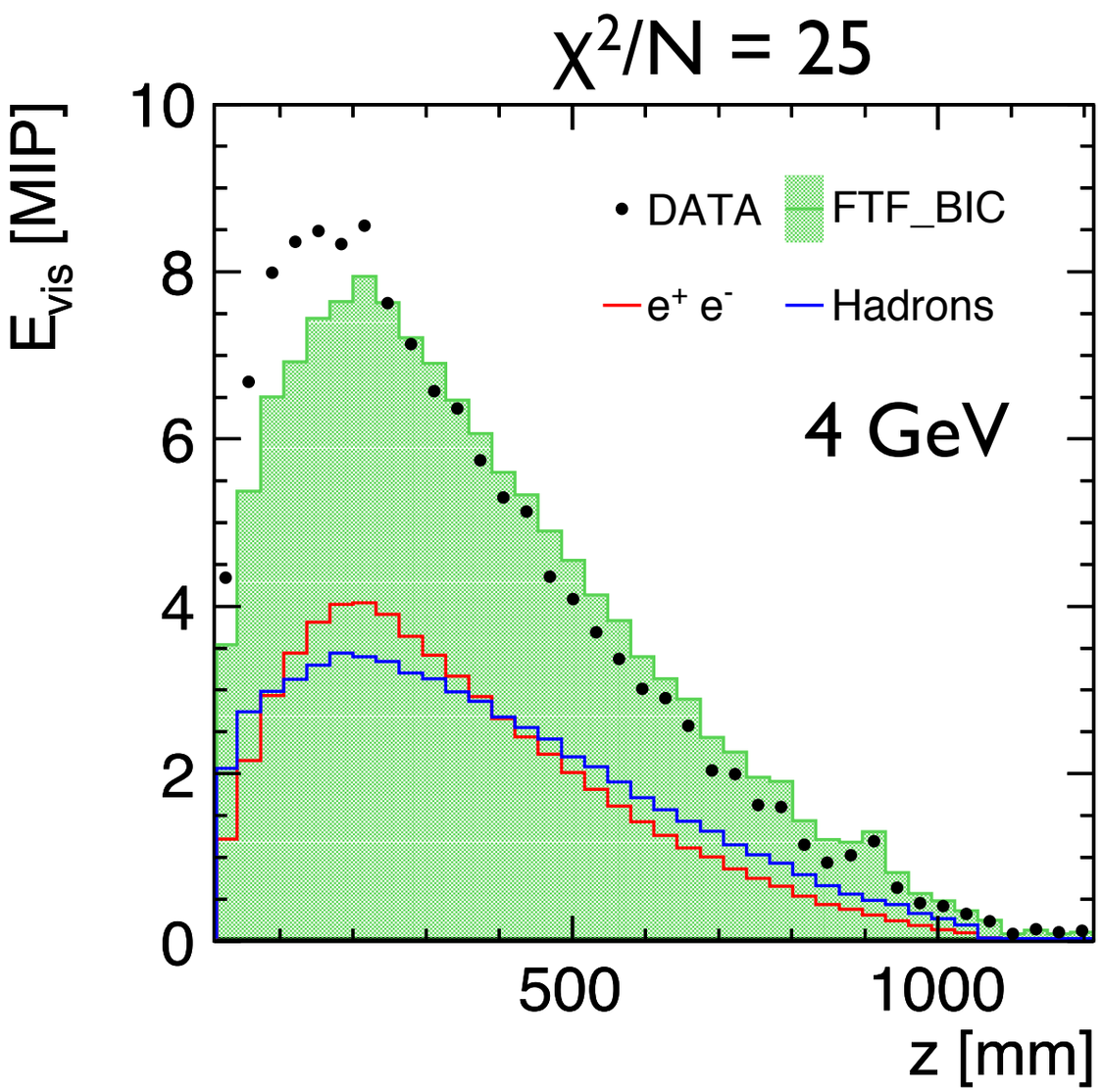
FTF dominates
FTFP_BERT and FTF_BIC



- Using HP package for QGSP_BERT does not affect <z>

Comparing χ^2 / N allows to quantify the overall profile shape agreement

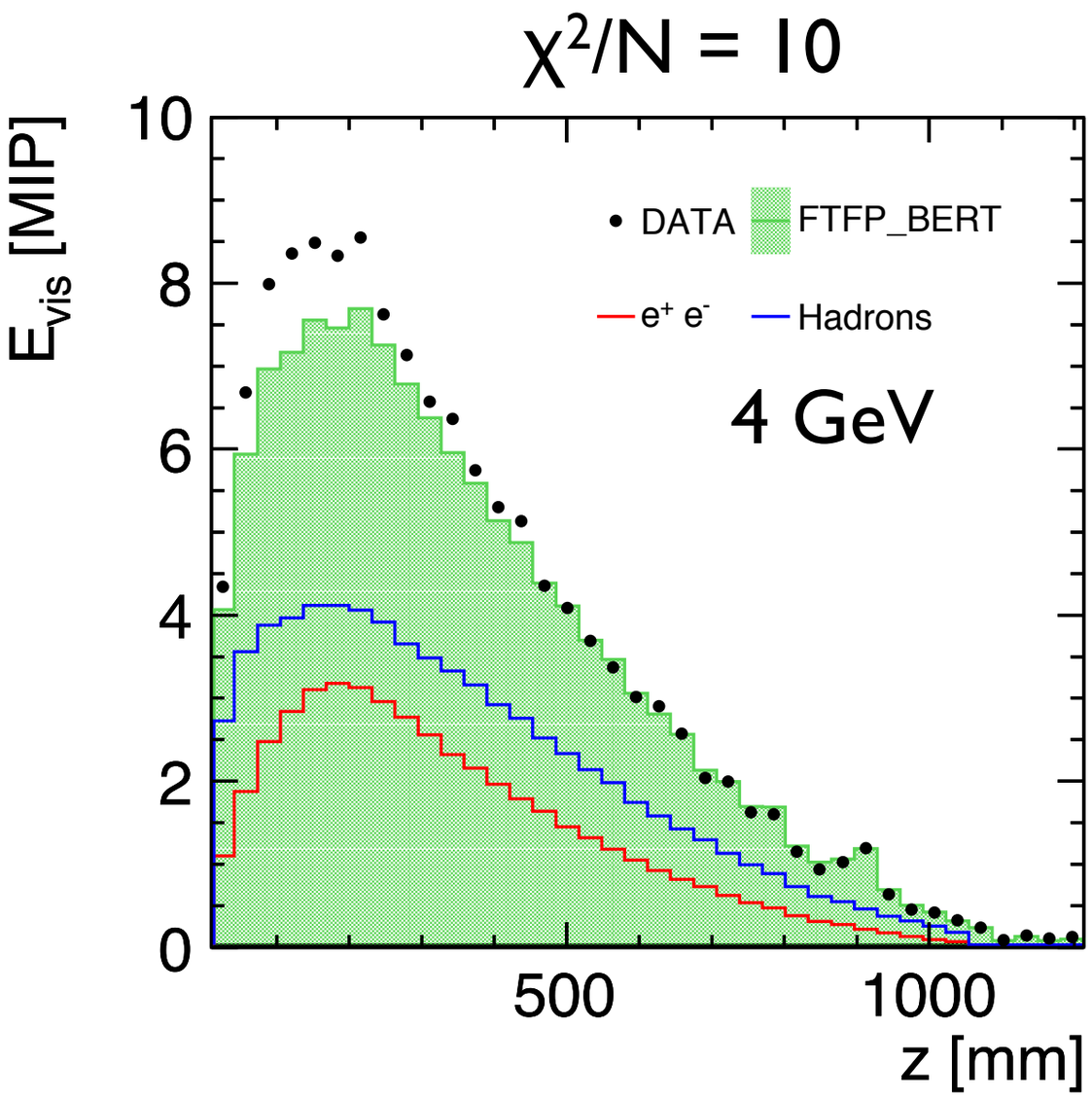


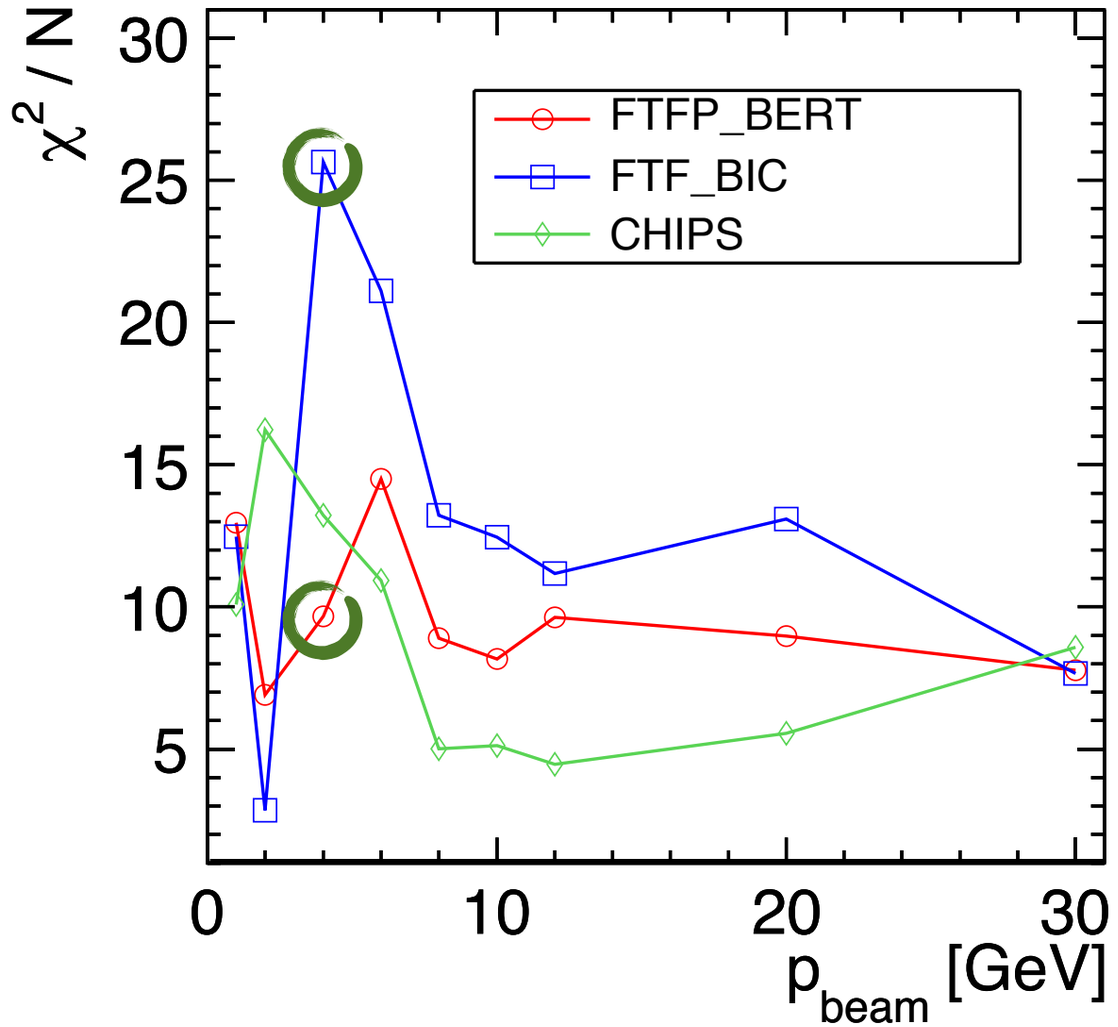


$$\chi^2 = \frac{\Sigma\,(\Delta E_i{}^2)}{\Sigma\,(\sigma_i{}^2)} \quad , \quad N = \text{number of layers}$$

Up to now: Only statistical uncertainties taken into account

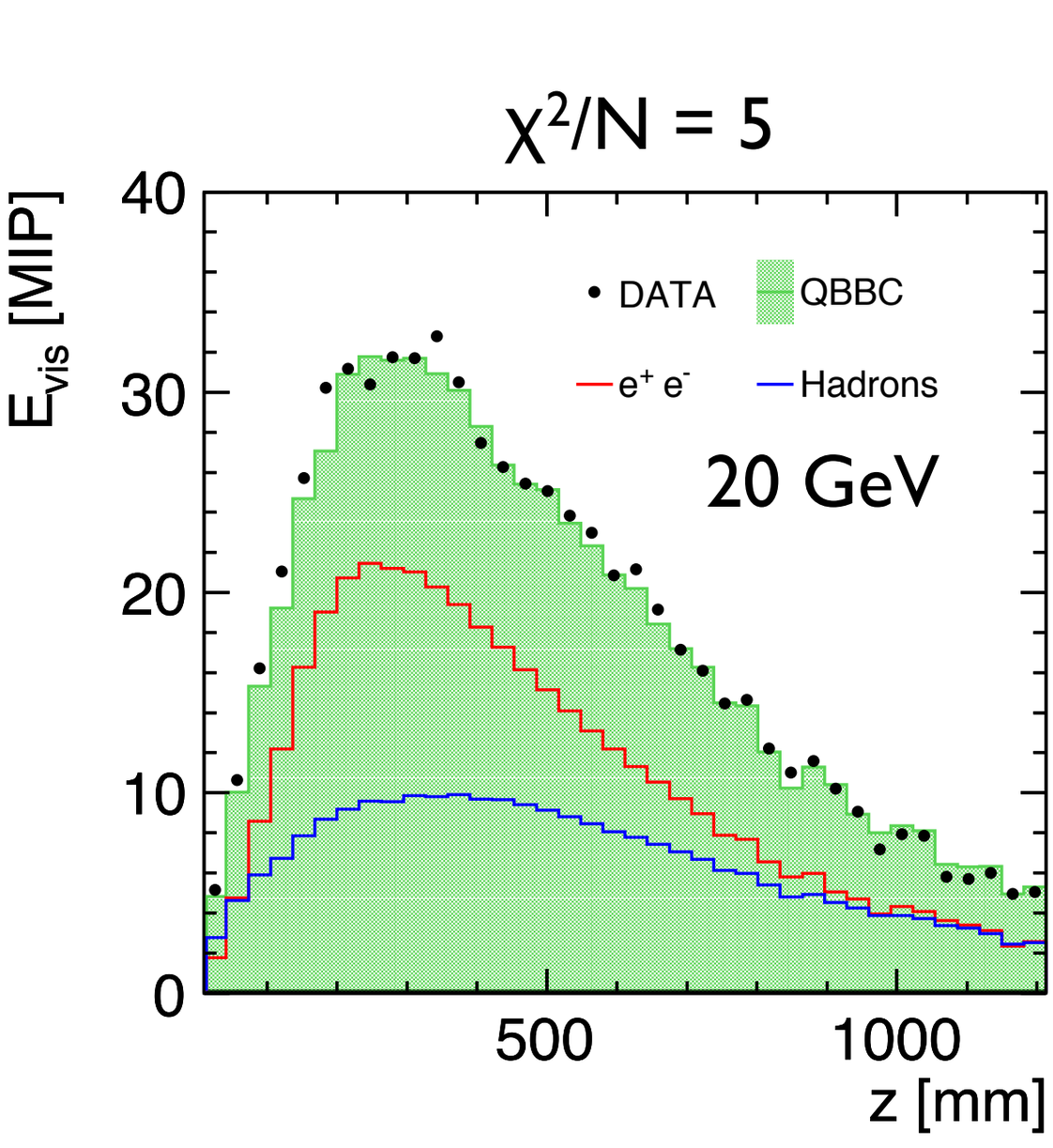
Momentum dependence of χ^2 / N

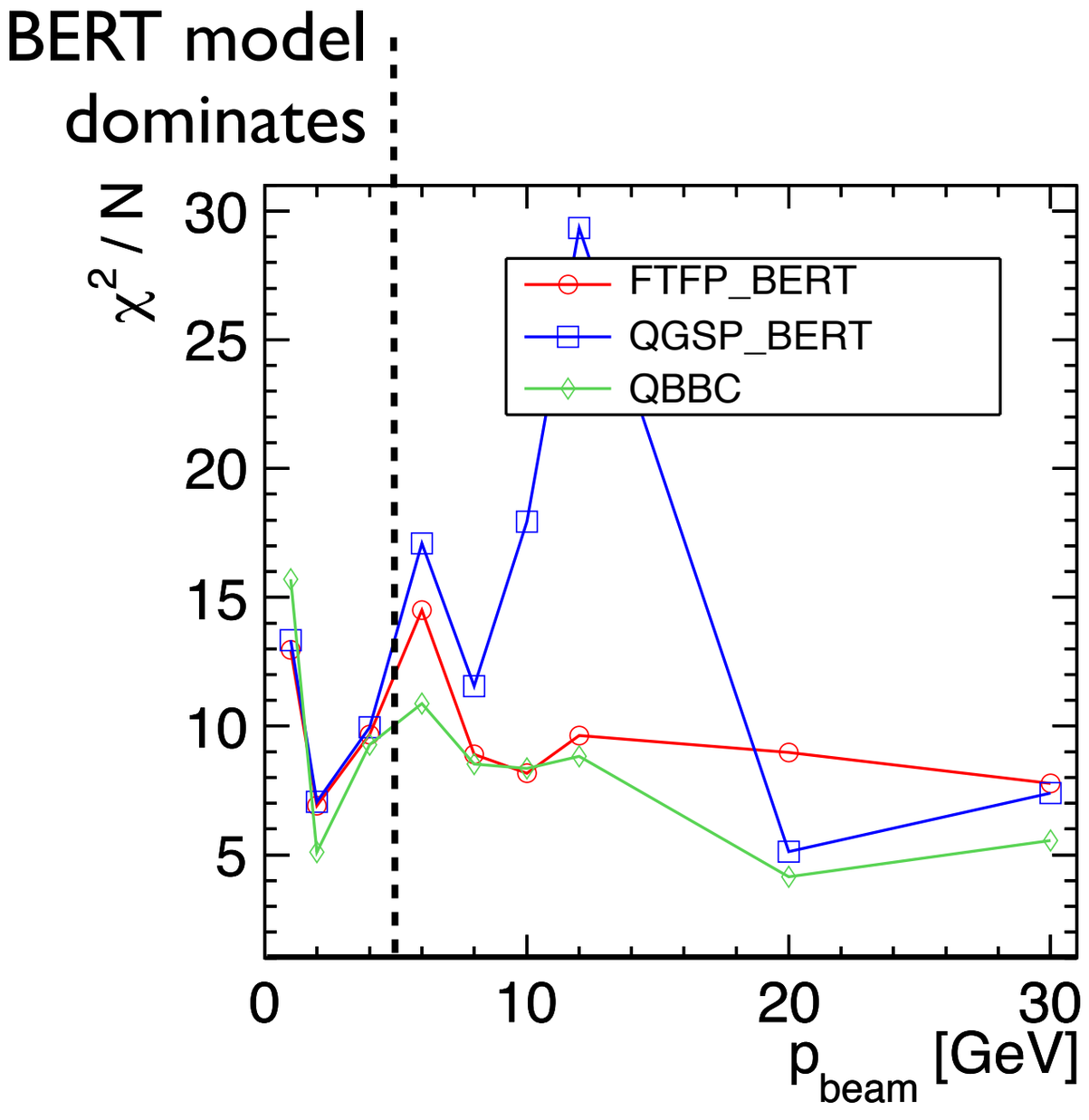




$$\chi^2 = \frac{\Sigma\,(\Delta E_i{}^2)}{\Sigma\,(\sigma_i{}^2)} \quad , \quad N = \text{number of layers}$$

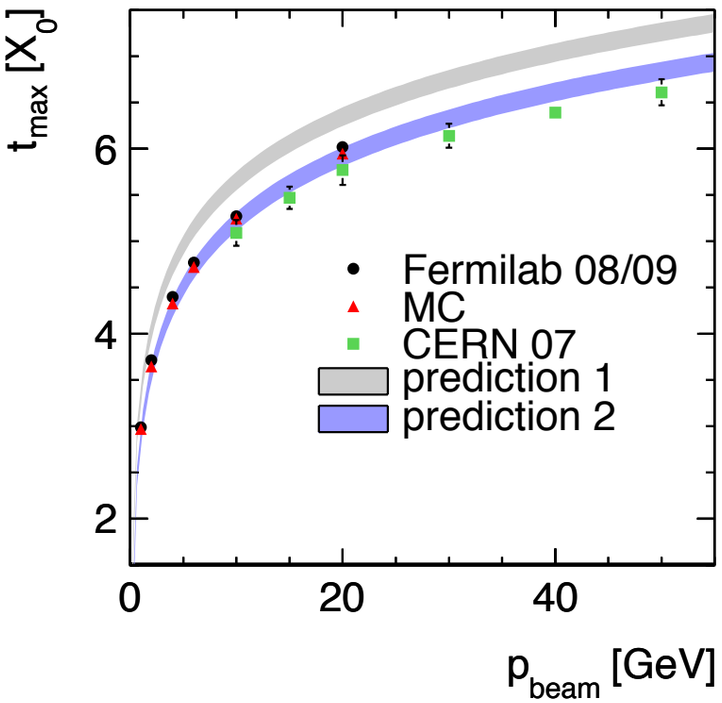
χ^2 / N reflects model transitions in physics lists

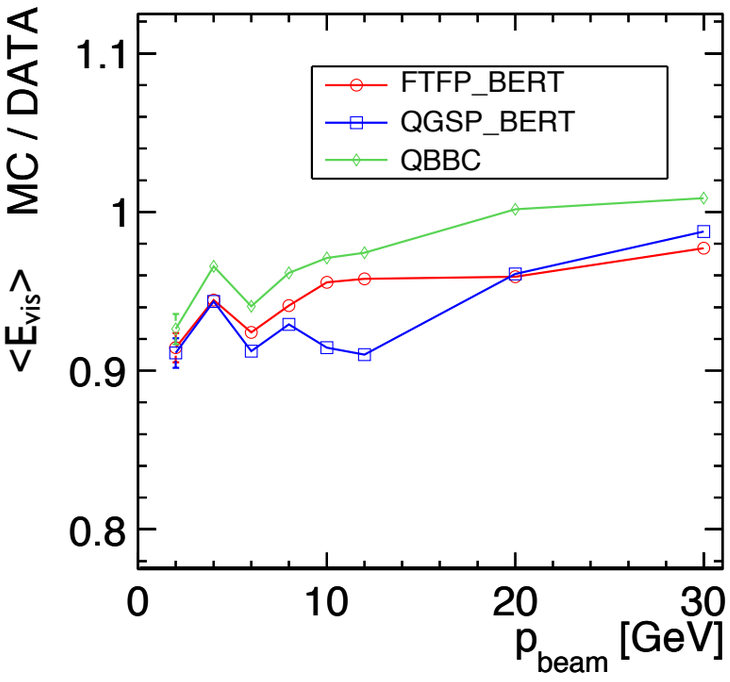




$$\chi^2 = \frac{\Sigma\,(\Delta E_i{}^2)}{\Sigma\,(\sigma_i{}^2)} \quad , \quad N = \text{number of layers}$$

Summary

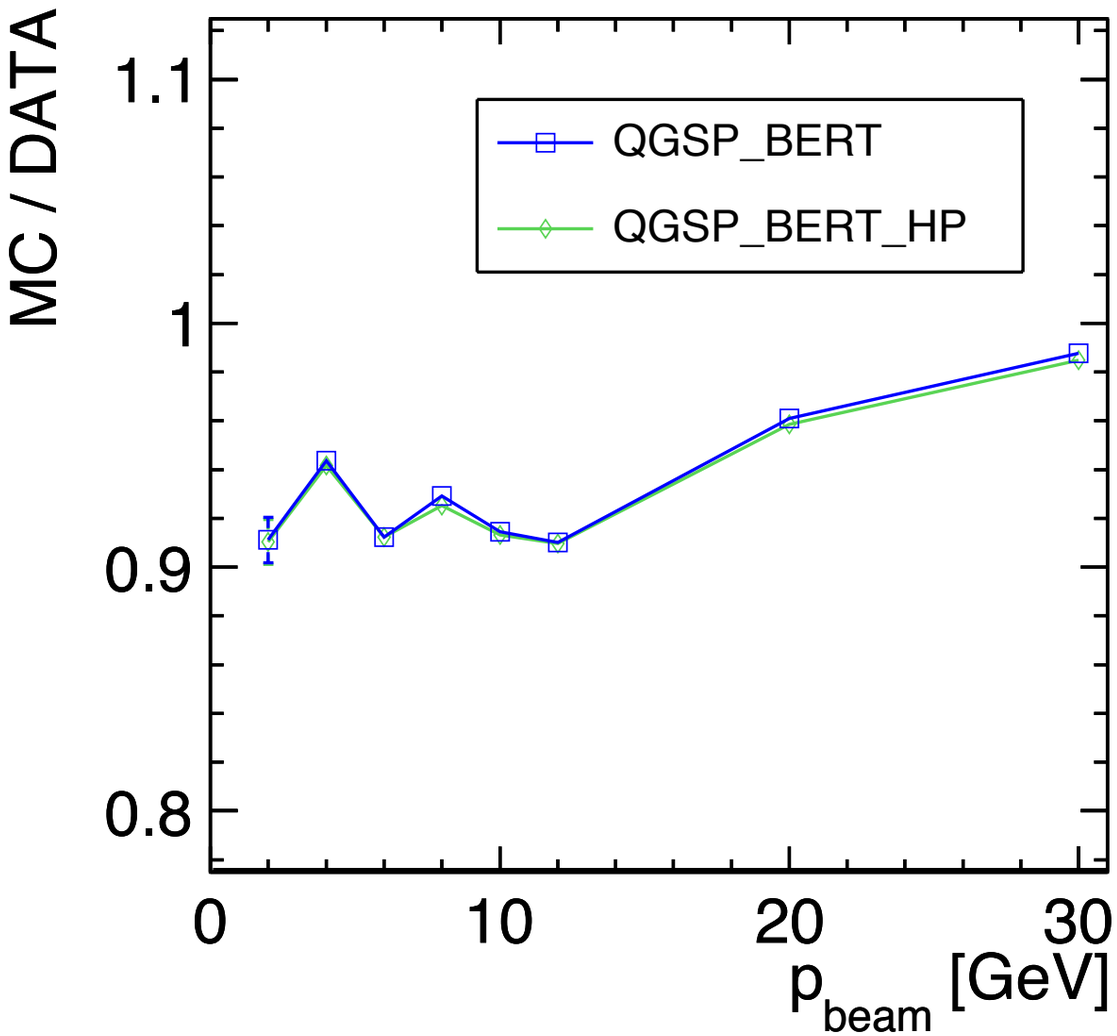




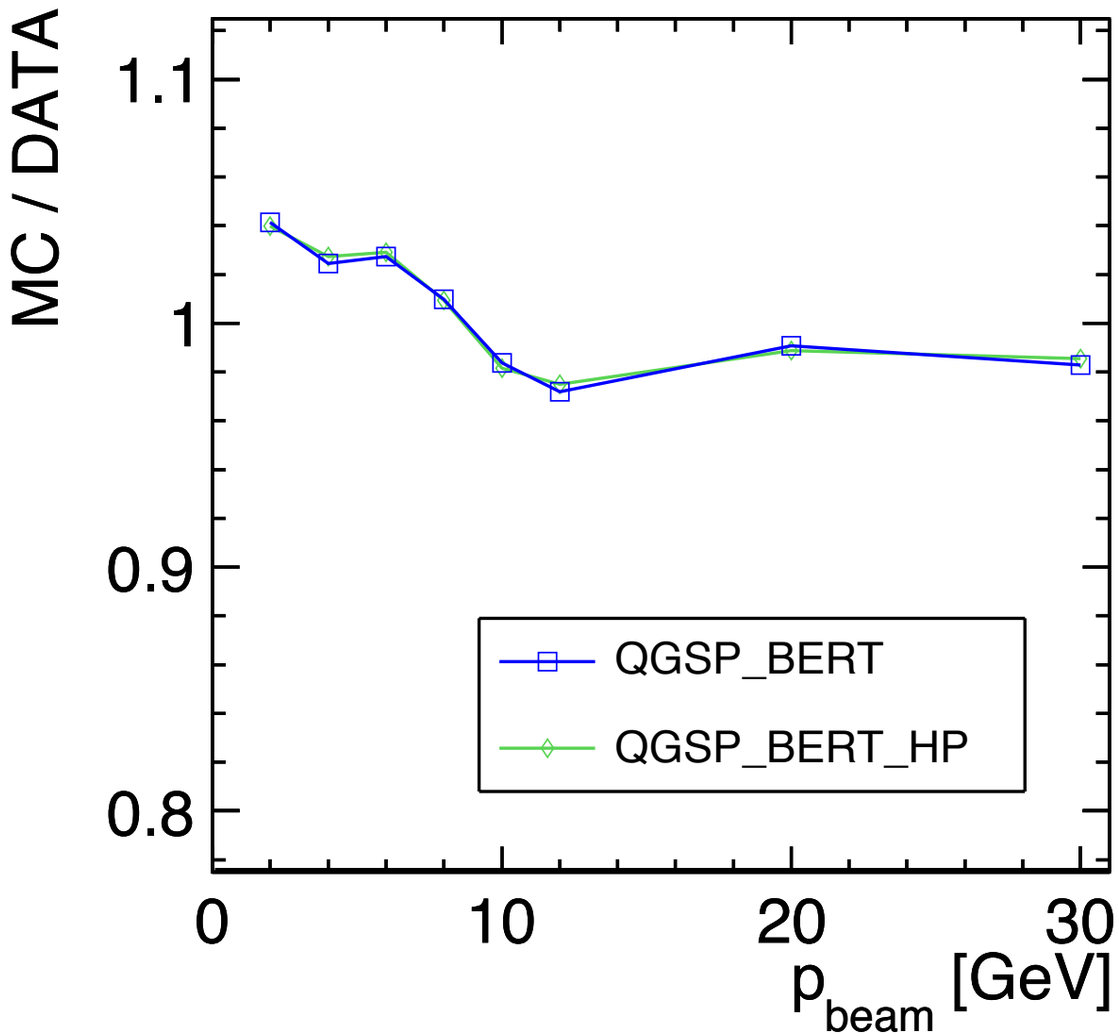
- Electrons:
  - Data and simulation consistent between 2 GeV and 50 GeV.
- Pions:
  - Predictions from different Geant4 versions (4.9.3 and 4.9.4) vary by up to 10%.
  - Data / MC comparisons below 5% need improved understanding of energy scale.
  - FNAL data allow extension of CERN analysis to low energies. Consistent results (5% level) at overlap energies.

Using HP shows no effect on Fe-AHCAL simulation

visible energy



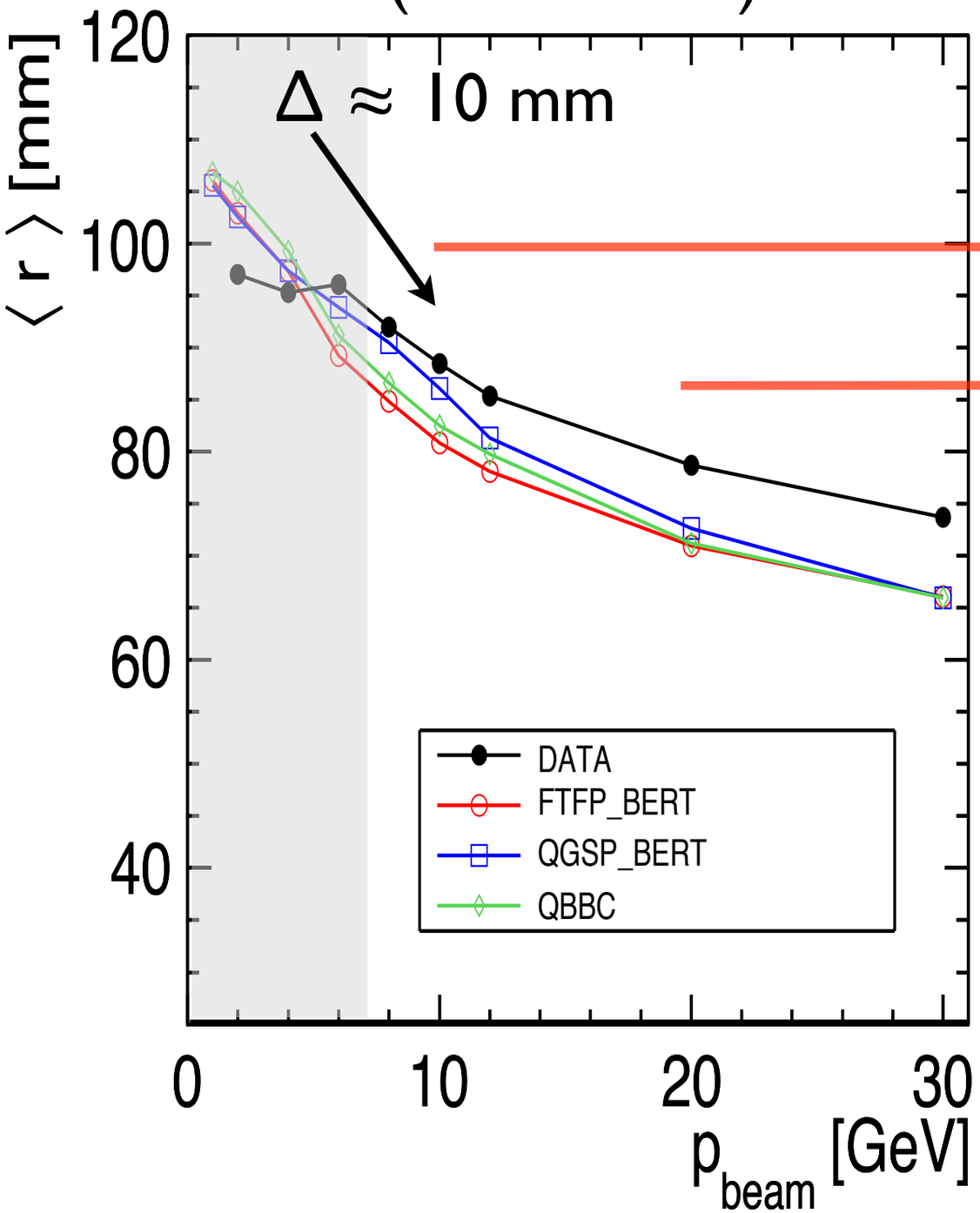
mean shower length



- Digitization includes time-cut.

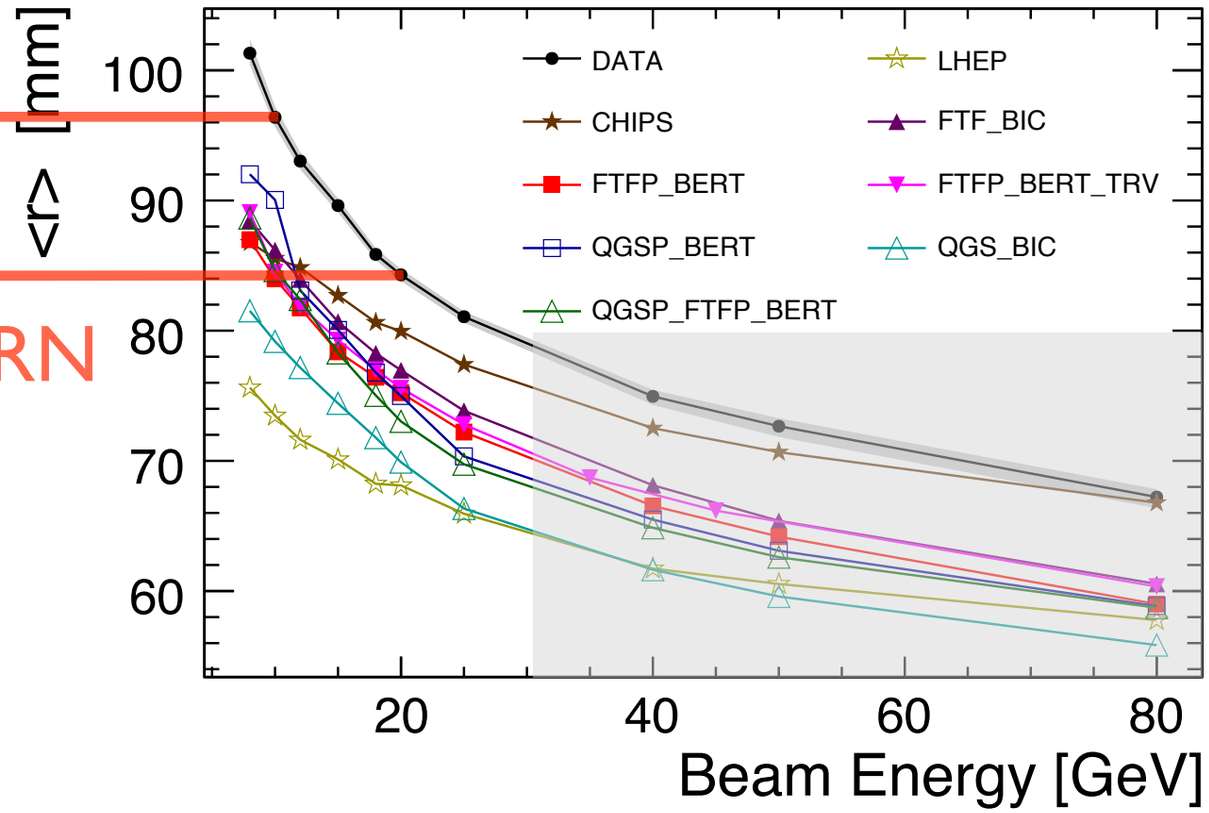
Shower radius

FNAL (Geant 4.9.4)



CERN

CERN (Geant 4.9.3)



Hits before first hard interaction included?