

Beam Test and Simulation Results with Highly Granular Calorimeters for the ILC

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15th October 2009



- CALICE & detectors
- analysis techniques
- hadron profiles – comparing data and simulation
- hadrons in the ECAL
- other observables
- conclusions

The CALICE Collaboration



297 physicists/engineers from 53 institutes and 17 countries coming from the 4 regions (Africa, America, Asia and Europe)

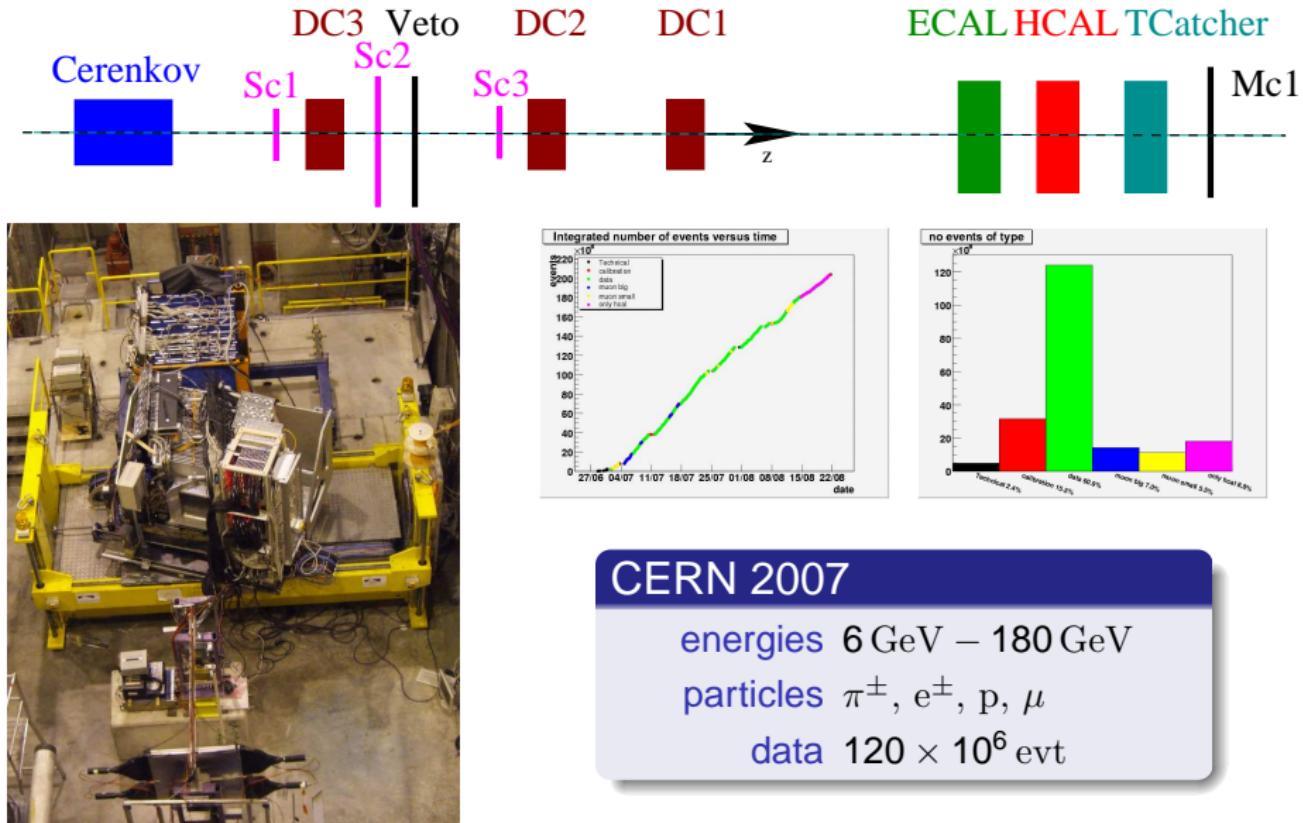
The CALICE Collaboration



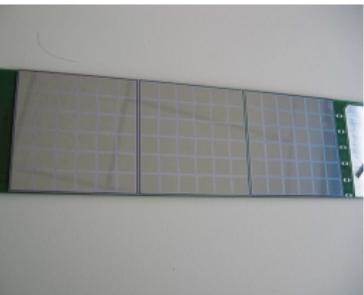
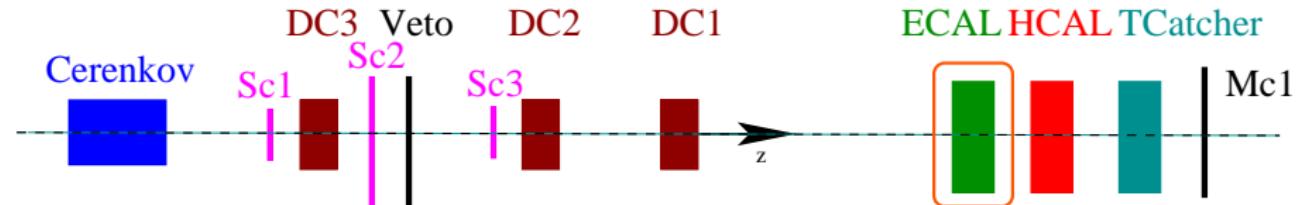
- Develop highly granular calorimeters for particle flow.
- Establish technologies for the ILC.
- Validation of hadronic interaction models in simulation.

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Test-Beam and Prototypes



Test-Beam and Prototypes



materials Silicon – Tungsten

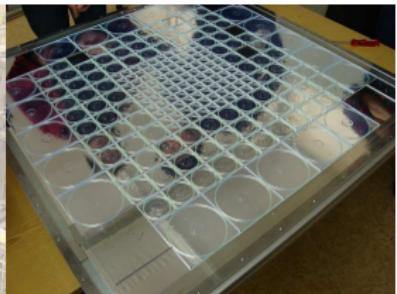
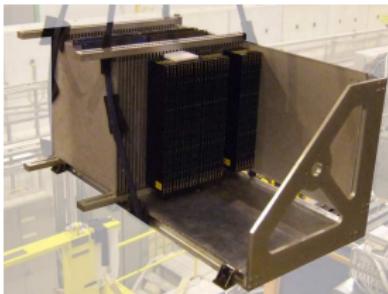
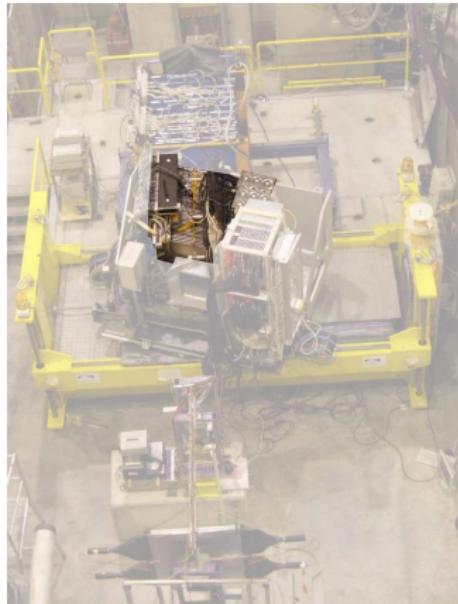
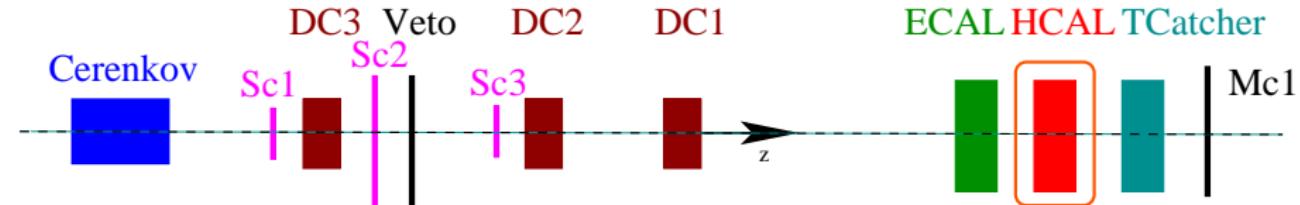
cell size $1 \times 1 \text{ cm}^2$

channels 9760

size $20 \times 20 \times 30 \text{ cm}^3$

interaction length $1 \lambda_I$

Test-Beam and Prototypes



materials Iron – Scintillator

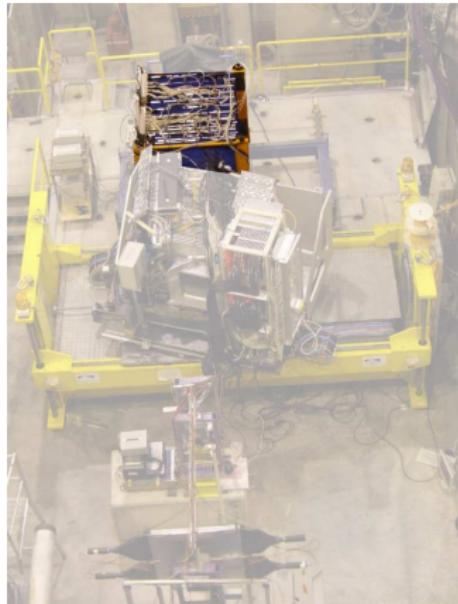
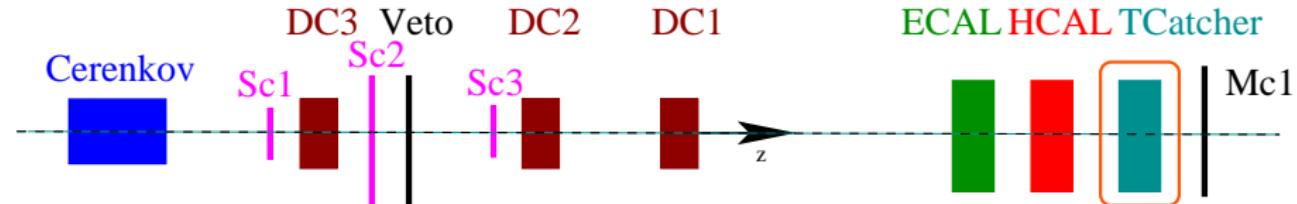
cell size $3 \times 3 / 6 \times 6 / 12 \times 12 \text{ cm}^2$

channels 7608

size $90 \times 90 \times 120 \text{ cm}^3$

interaction length $5 \lambda_I$

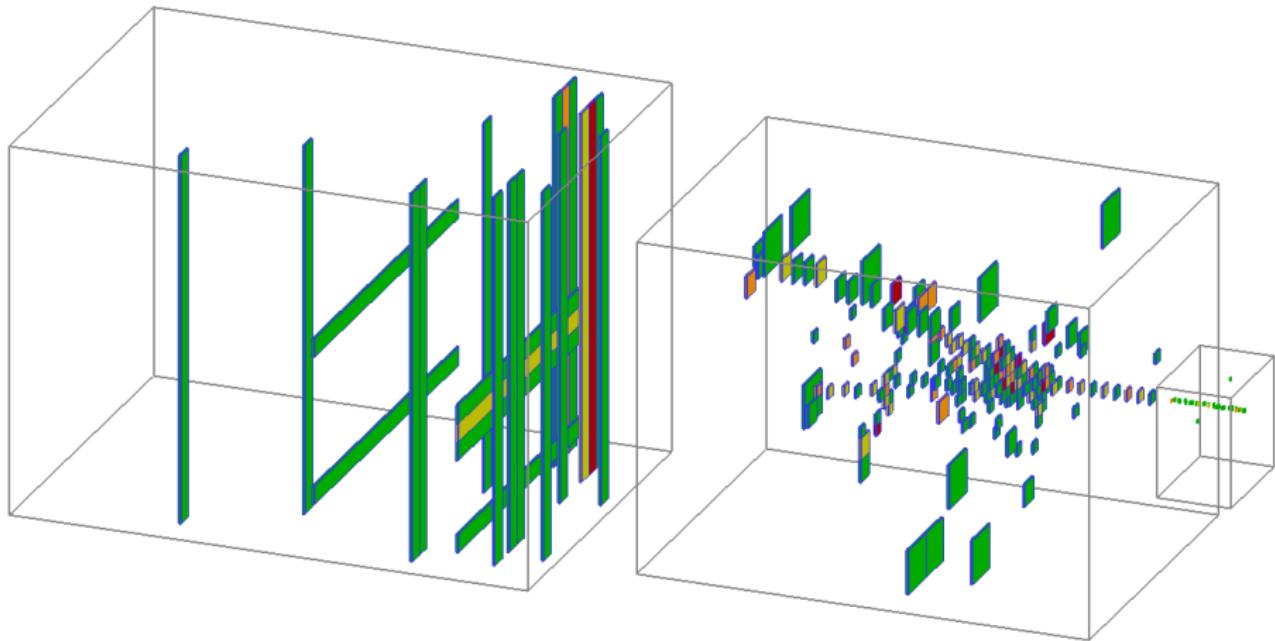
Test-Beam and Prototypes



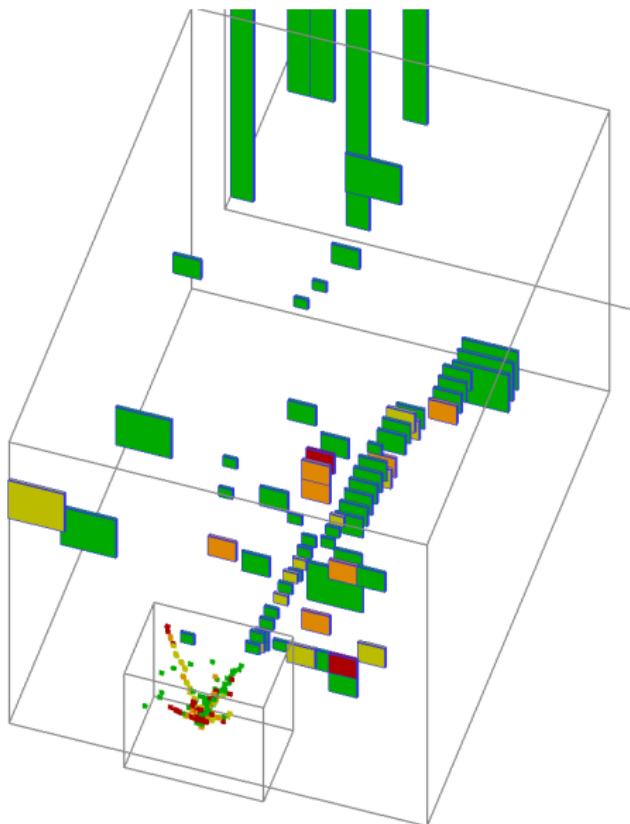
materials Iron – Scintillator
cell size $5 \times 100 \text{ cm}^2$
channels 320
size $100 \times 100 \times 140 \text{ cm}^3$

interaction length $5.5 \lambda_I$

Imaging Calorimeter



Imaging Calorimeter



Detector Characteristics

High spacial segmentation – our strength

- smaller than shower sizes
 - basis for shower separation – particle flow
 - allows to measure hadron profiles on reasonable scale
- enables us to use new analysis approaches
 - identify first hard interaction
 - energy density weighting
 - find tracks inside shower
 - correct leakage

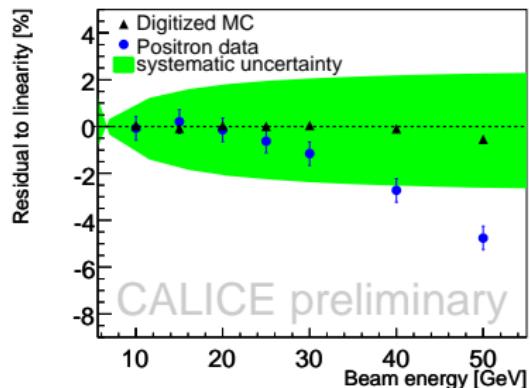
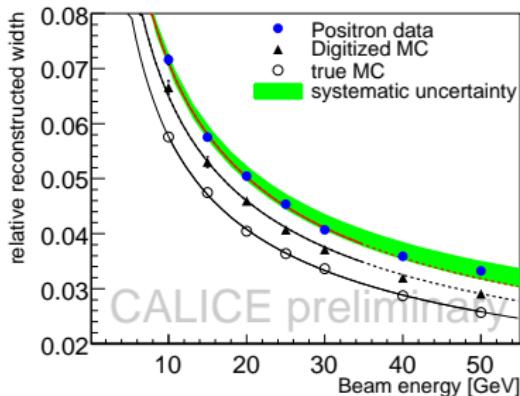
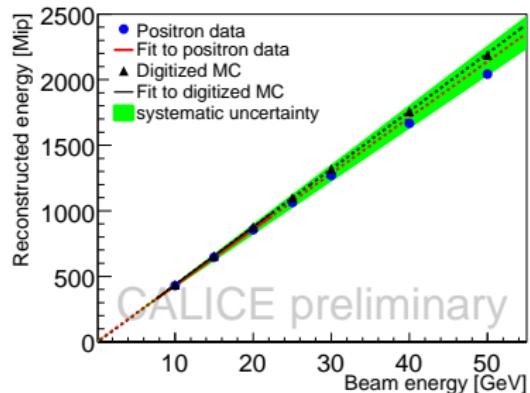
New technologies – our challenge

- Si-Wafers
 - dead zones
 - electrical coupling
- SiPM & scintillator tiles
 - saturation correction
 - temperature dependent calibration
 - light crosstalk

Simulation

- software
 - Geant4 9.2 (standard physics lists)
 - Geant4 9.3 (new physics lists)
 - Mokka 7.0
- simulation
 - absorber thickness variations
 - saturation effects in the scintillator (Birks' law)
 - electronic gate width
- digitisation
 - light crosstalk between scintillator tiles
 - non-linearity of the SiPM
 - superposition of SiPM and DAQ noise
 - statistical fluctuations in the photon detection
 - variation of detector calibration with temperature

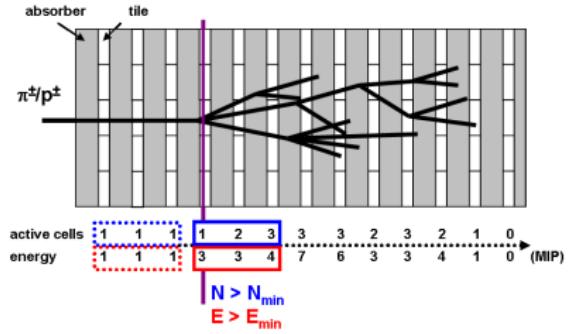
HCAL Electromagnetic Response



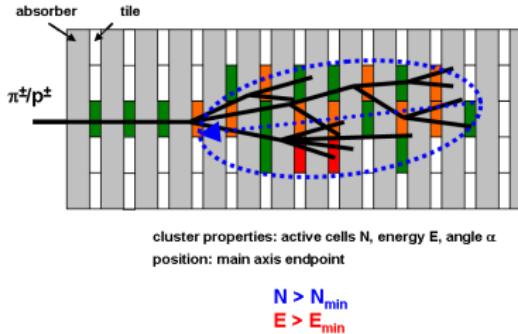
- linearity within 1% up to 30 GeV
- stochastic term
data $22.5 \pm 0.4_{\text{syst.}} \pm 0.1_{\text{stat.}} \left[\%/\sqrt{E} \right]$
MC $20.4 \pm 0.2_{\text{stat.}} \left[\%/\sqrt{E} \right]$
- constant term
data $0 \pm 0.1_{\text{syst.}} \pm 0.1_{\text{stat.}} \left[\% \right]$
MC $0 \pm 0.6_{\text{stat.}} \left[\% \right]$
- ⇒ total agreement within 10%

Finding the First Hard Interaction

Method 1



Method 2



moving layer sum

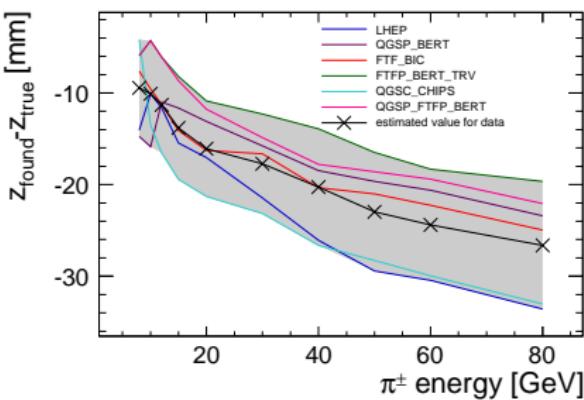
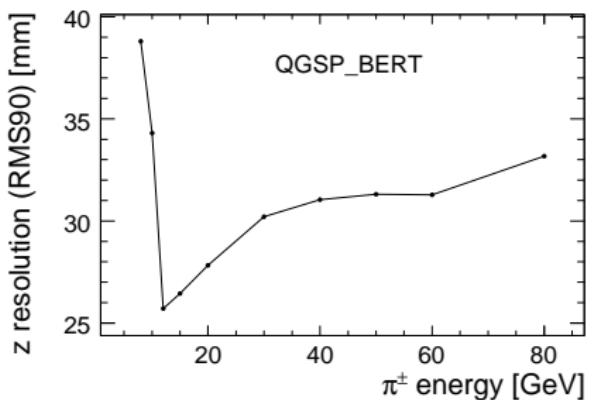
- simple
- fast
- only z position

activity based clustering

- complex implementation
- 3D position
- works in arbitrary detector configuration

accuracy within one layer

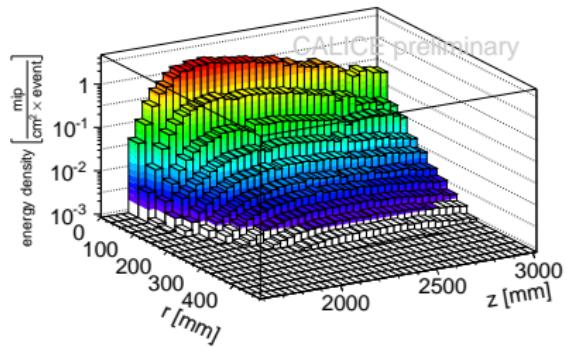
Cluster Based Method – Accuracy



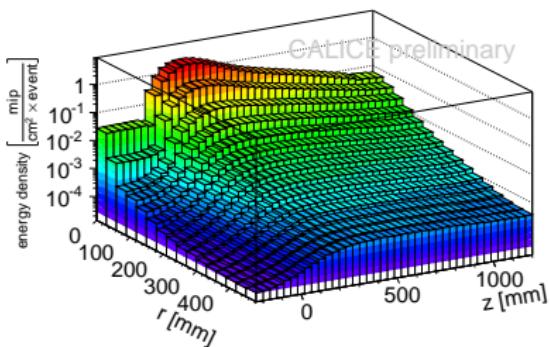
- energy dependence
- model dependence
- but resolution approx. within one layer

2D Profiles (HCAL)

80 GeV π^+ standard profile

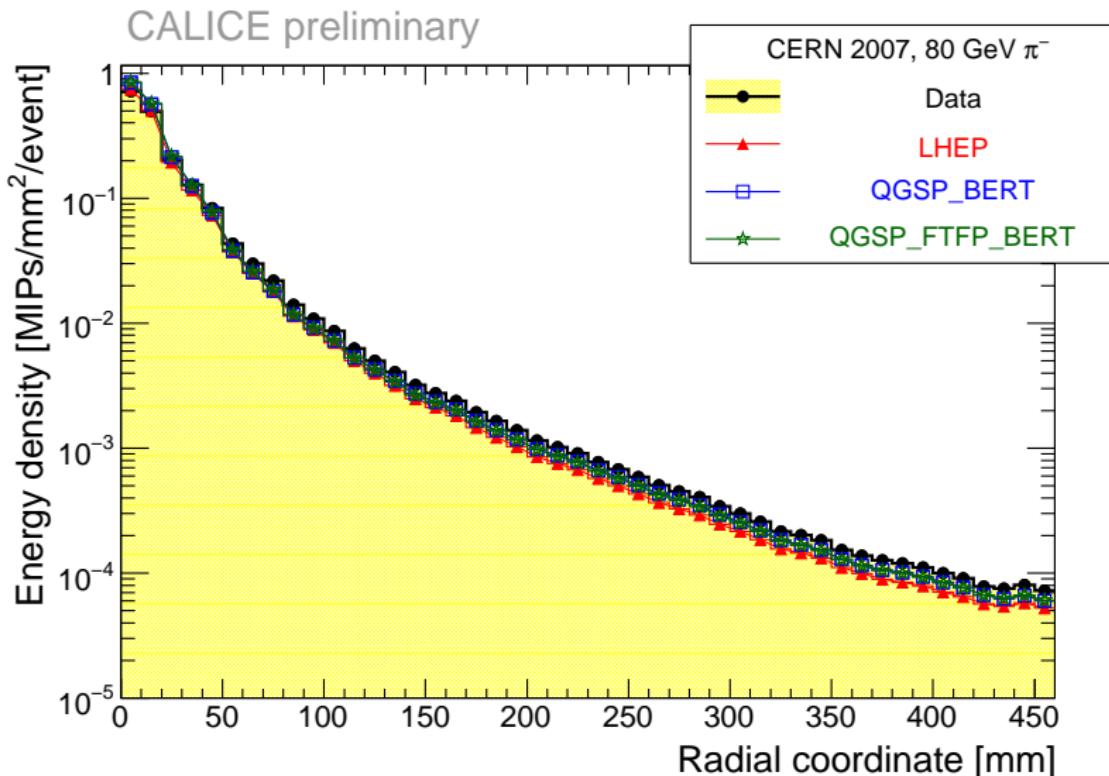


80 GeV π^+ from shower start

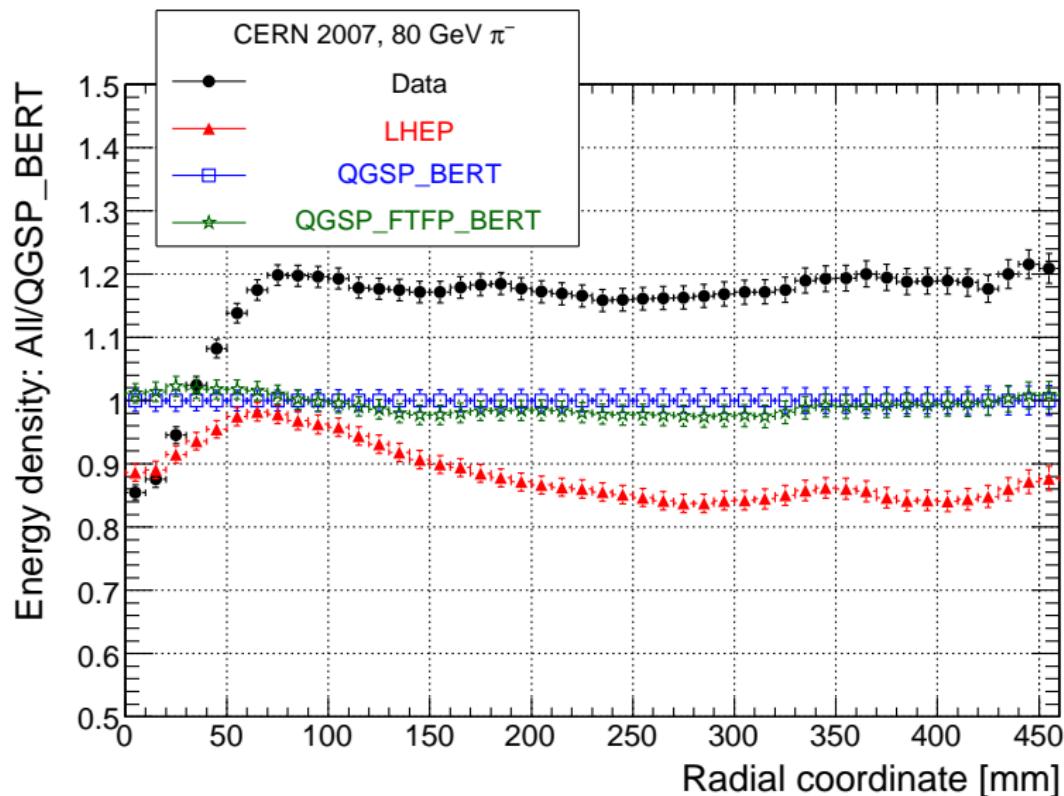


- two dimensional energy density
- lateral: radial ring with centre r
- longitudinal: position z

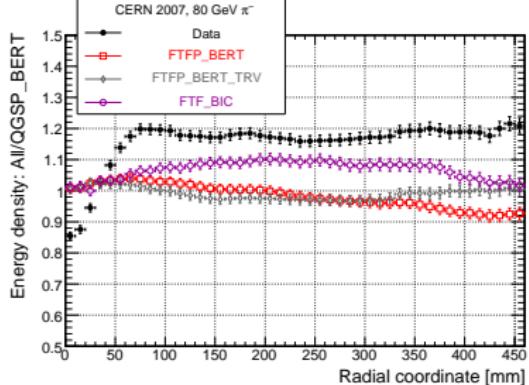
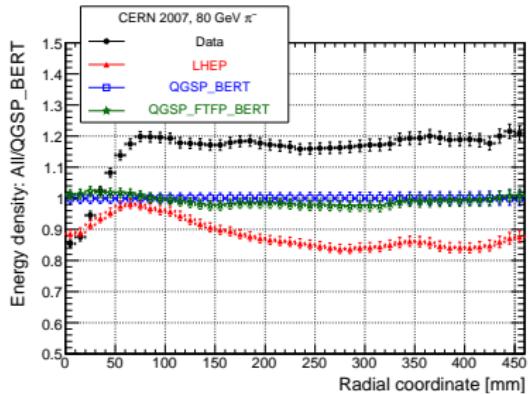
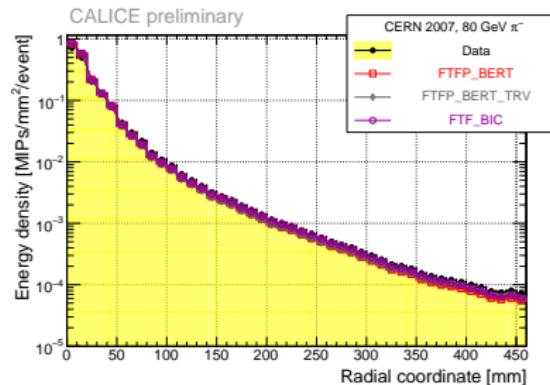
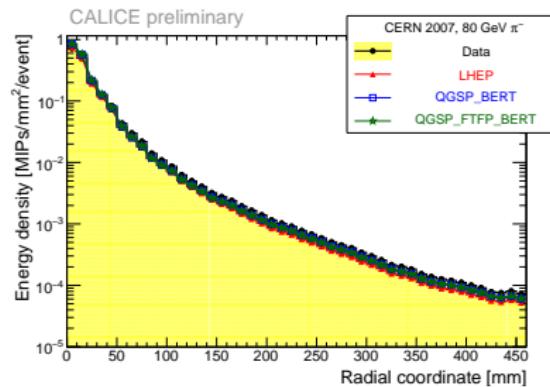
Lateral Profiles – Measurement and Simulation



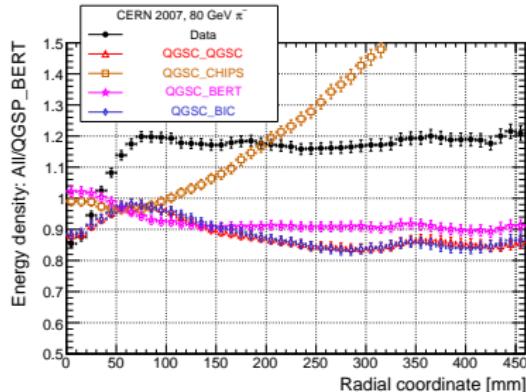
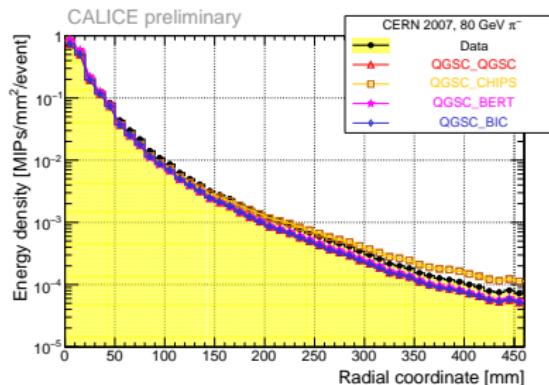
Lateral Profiles – Measurement and Simulation



Lateral Profiles – Measurement and Simulation

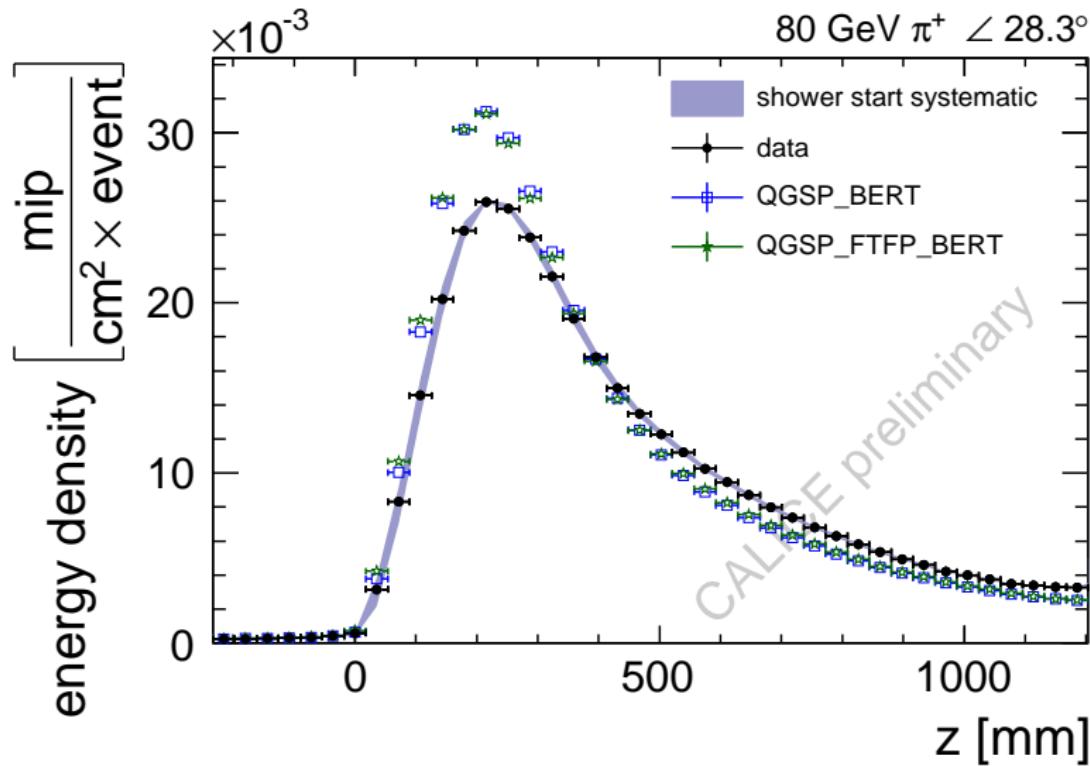


Lateral Profiles – Measurement and Simulation

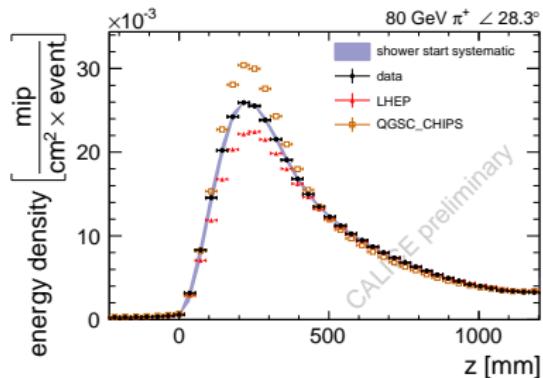
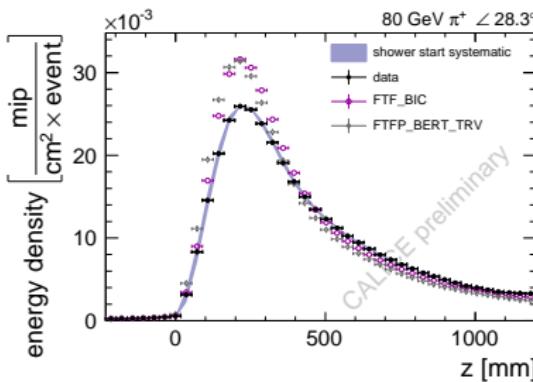
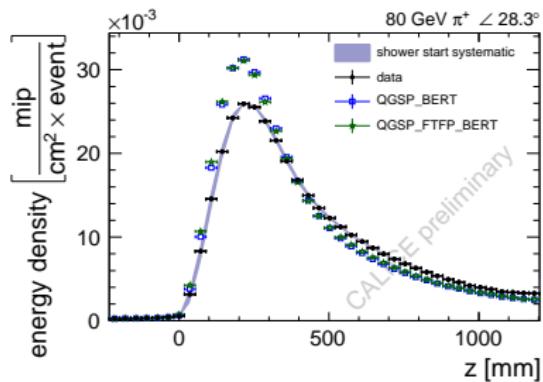


- most models predict higher density at small radii and lower density in the tails
- QGSC_CHIPS behaves most different to the other models
- differences in tails in around 20%

Longitudinal Profiles – Measurement and Simulation



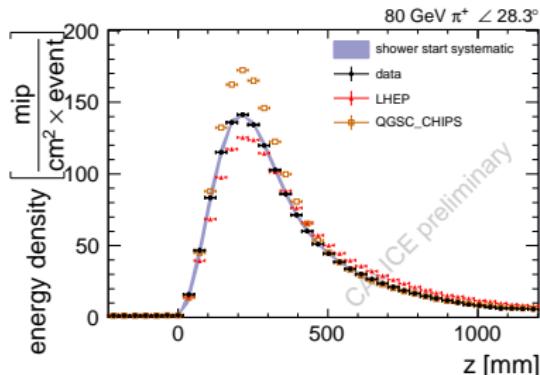
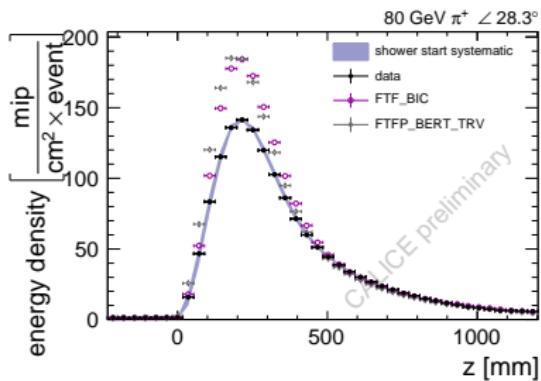
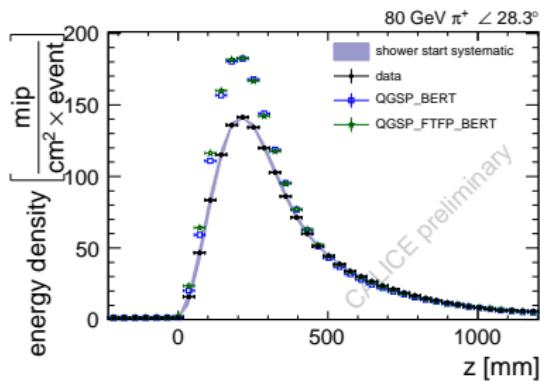
Longitudinal Profiles – Measurement and Simulation



- most models predict higher density in the shower maximum and lower density in the tails
- QGSC_CHIPS describes rise best and also better in the tail than others

Longitudinal Profiles inside Radial Cylinder (core)

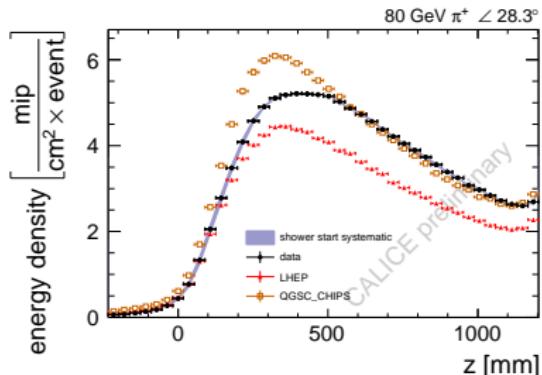
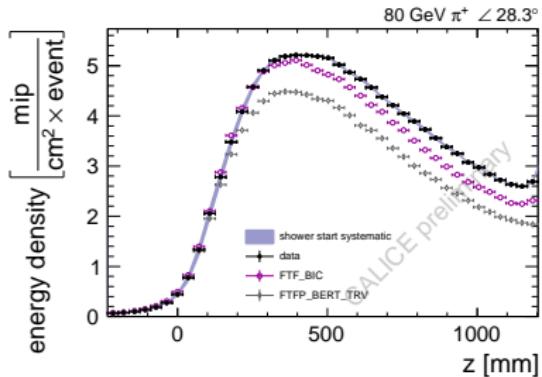
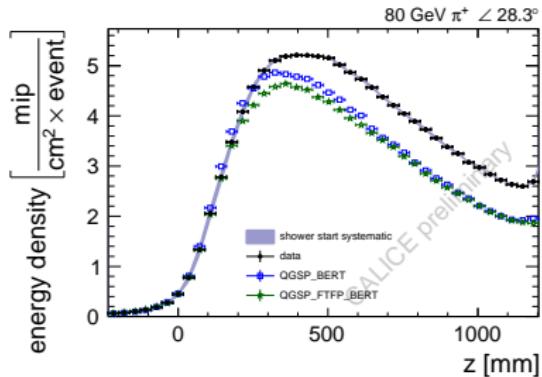
0 cm $\leq r < 6$ cm, from shower start



- tail matched quite well by all models (except LHEP)
- QGSC_CHIPS
 - describes rise best
 - smallest difference in the maximum

Longitudinal Profiles inside Radial Cylinder (medium)

$18 \text{ cm} \leq r < 24 \text{ cm}$, from shower start



- here: FTF_BIC nearest to data
- QGSC_CHIPS
 - describes rise worst
 - only model above data
 - too much backwards signal

Profiles Summary

- fine grain 2D profile measurements plus projections
 - lateral
 - longitudinal
 - longitudinal inside radial cylinders
- comprehensive set of comparisons with simulation models
 - a lot of differences between simulation and measurement visible above 20 GeV
 - differences in bins up to 20% at 80 GeV
 - more energy points available
 - we need your help to understand the differences

Can the ECAL help with Hadrons?

ECAL

- best granularity
- different (denser) material
- but very short ($1 \lambda_I$)

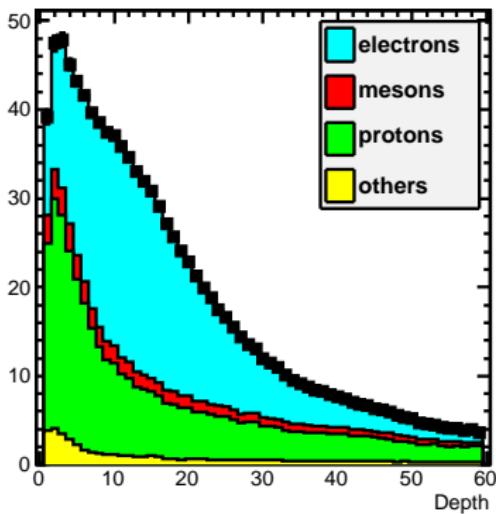
Analysis Approach

- shower start is the trick
- select events starting at the front of the calorimeter
- first lambda is sampled with very high segmentation

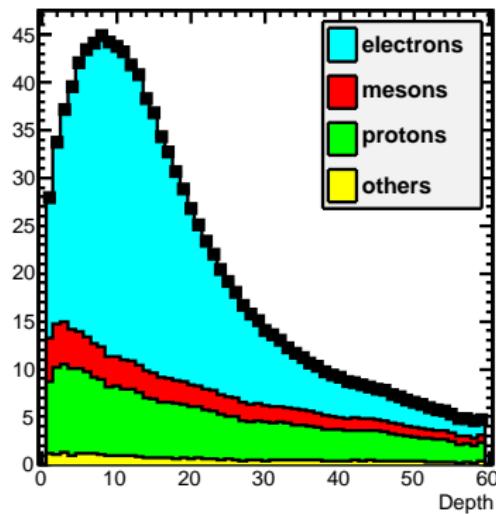
Work in Progress \Rightarrow will show only simulations today

Can the ECAL help with Hadrons?

QGSP_BERT



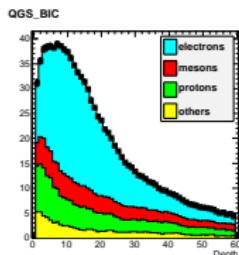
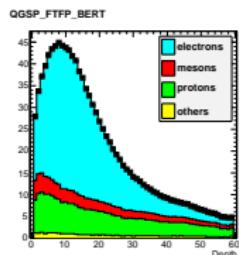
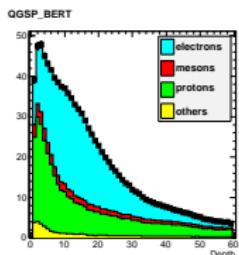
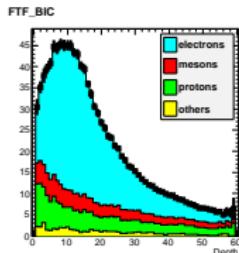
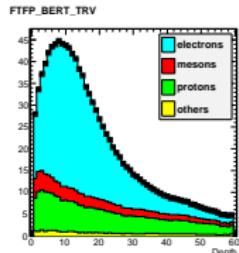
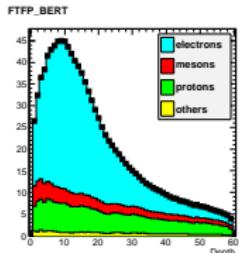
QGSP_FTFP_BERT



hadron models

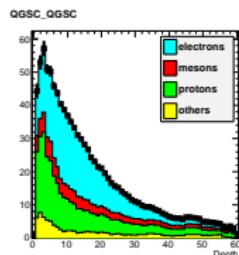
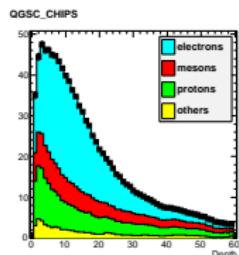
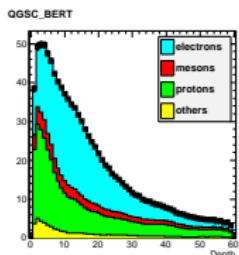
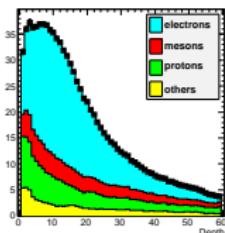
- different fraction of particle types
- different shape for different particle types

Can the ECAL help with Hadrons?



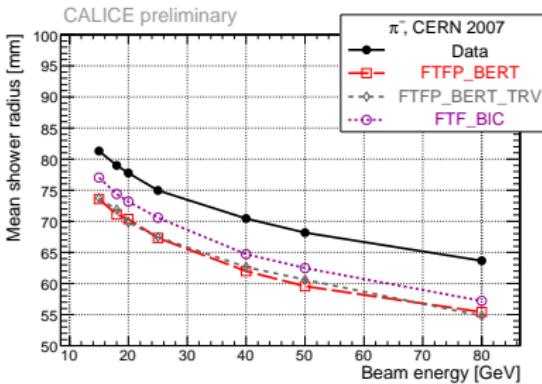
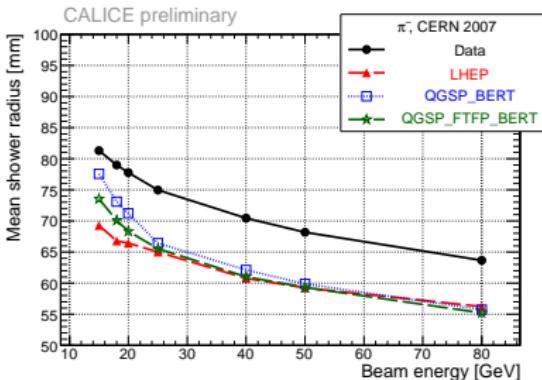
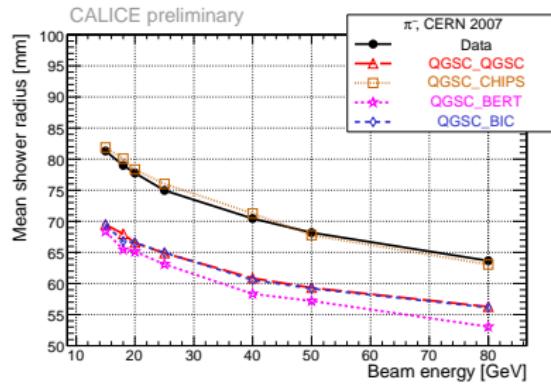
ECAL

longitudinal energy
distribution
from shower start
8 GeV π^-



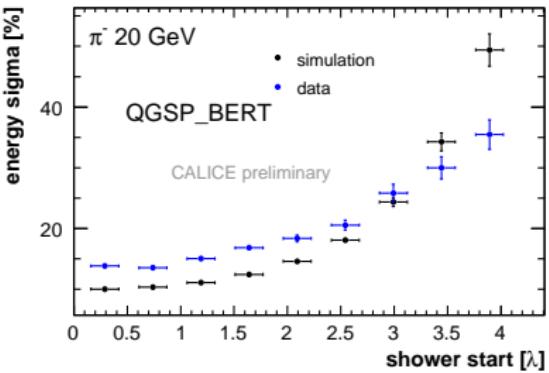
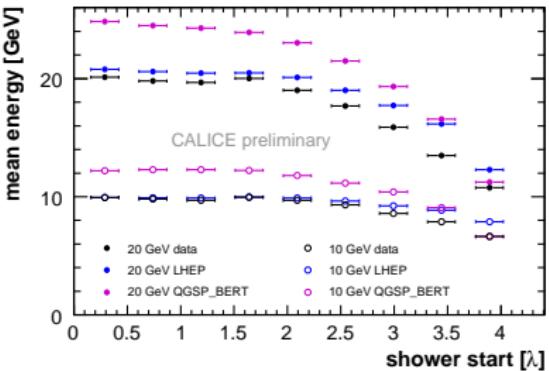
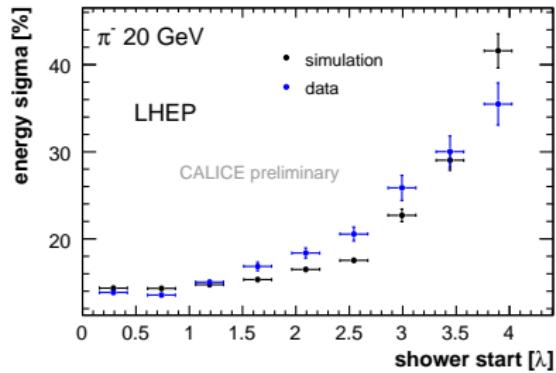
Other Observables

- **Shower Radius:** energy weighted mean distance of HCAL hits to shower axis
- Showers become narrower with increasing energy.



Other Observables

- **Leakage:** shower start dependent energy and resolution
- The later the shower starts the more likely is leakage.
- Reconstructed energy decreases and resolution worsens.



Conclusions & Outlook

Conclusions

- CALICE had very successful test-beams
- detector understanding is steadily increasing
 - calibration
 - digitisation
- developed techniques to measure location of the first hadronic interaction
- promising measurement of shower shapes
 - improved sensitivity due to shower start
 - high granularity allows very detailed studies
 - spotted discrepancies between simulation and data
- steadily increasing set of observables with model discriminating potential

Conclusions & Outlook

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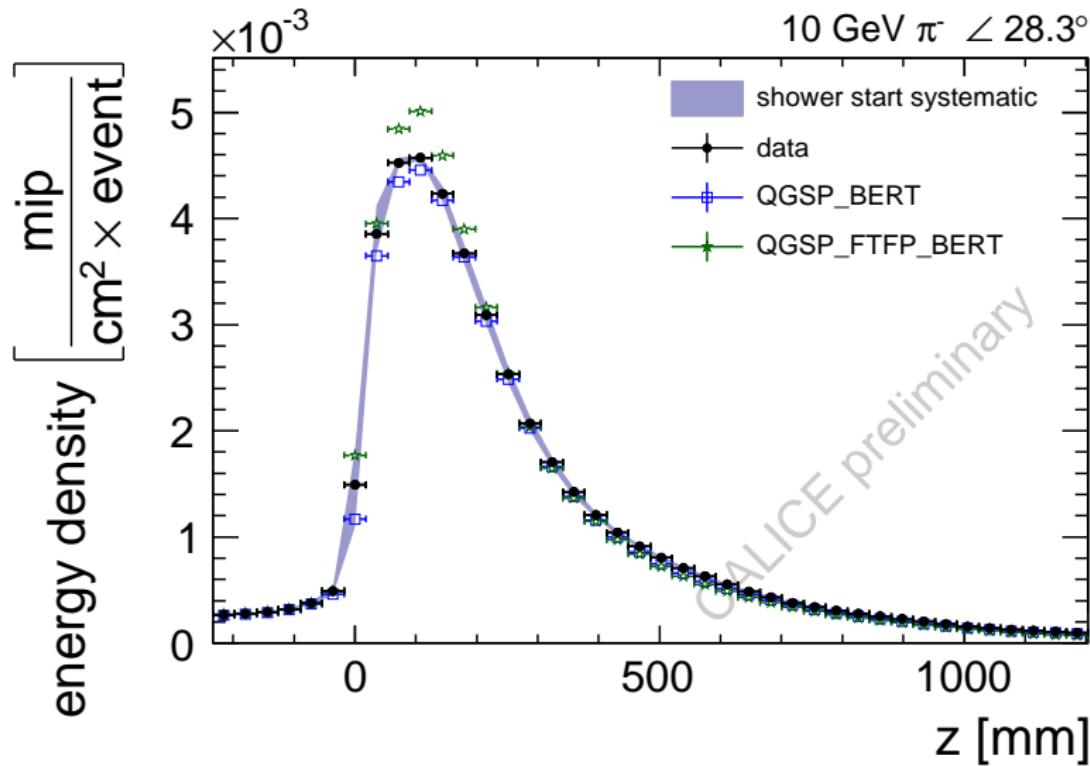
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Outlook

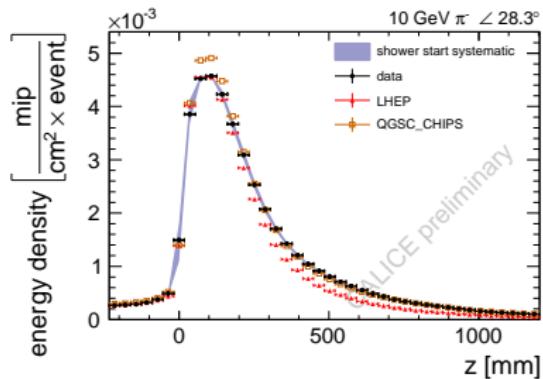
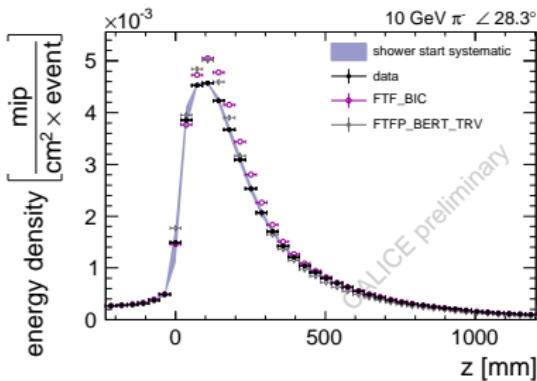
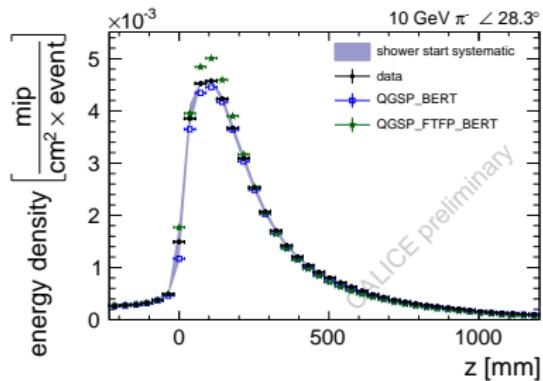
- increase of our sensitivity
- hadron showers measured with ECAL
- comparison of different particle types (π/p)
- new observables
 - e.g. no track segments inside shower
- We are waiting for your input, too.

BACKUP

Longitudinal Profiles – Measurement and Simulation

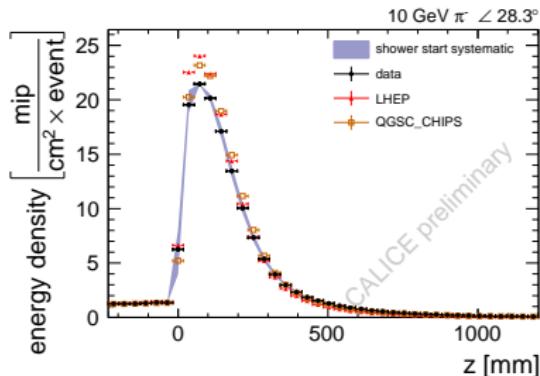
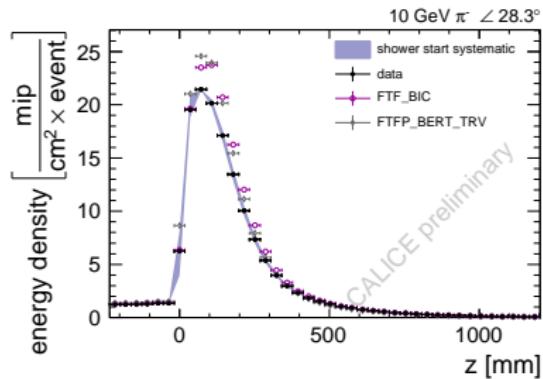
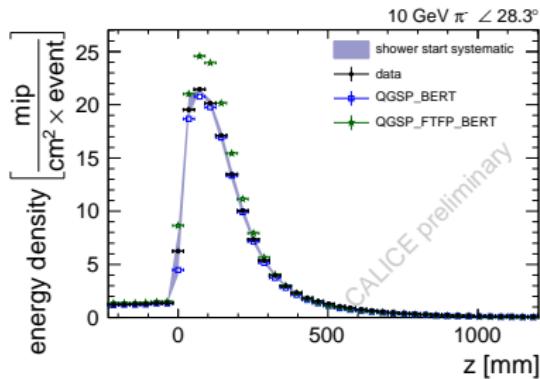


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