CALICE beam tests

in relation to Particle Flow and Geant4 validation

David Ward

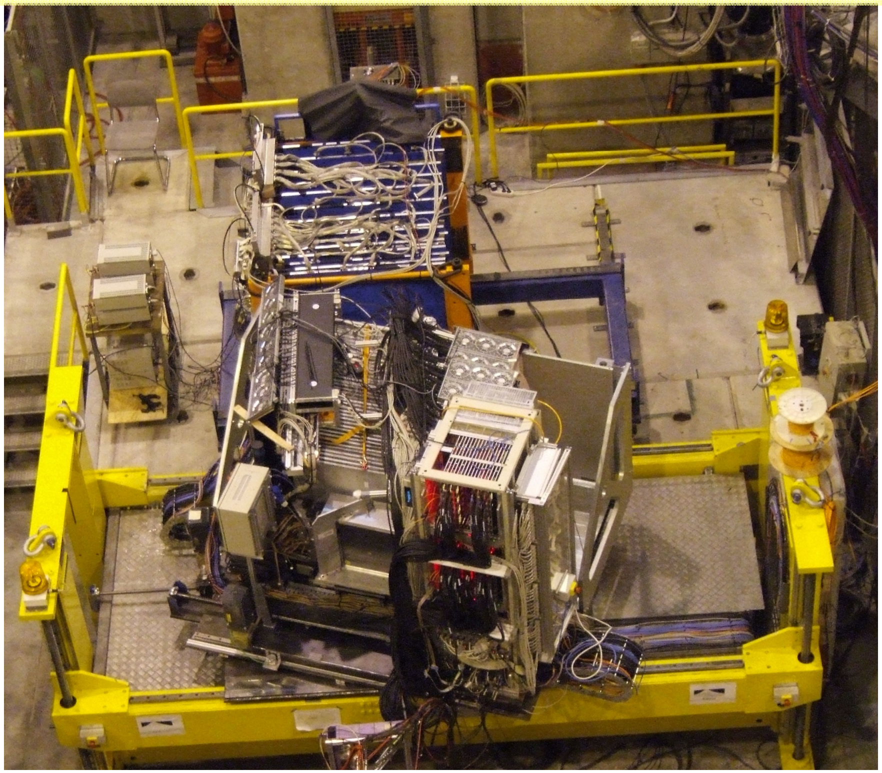
- Introduce CALICE – its aims and objectives
- Outline test beam work
- Mainly discuss measurements of electromagnetic and hadronic showers
  - Lessons for detector design
  - Tests of GEANT4

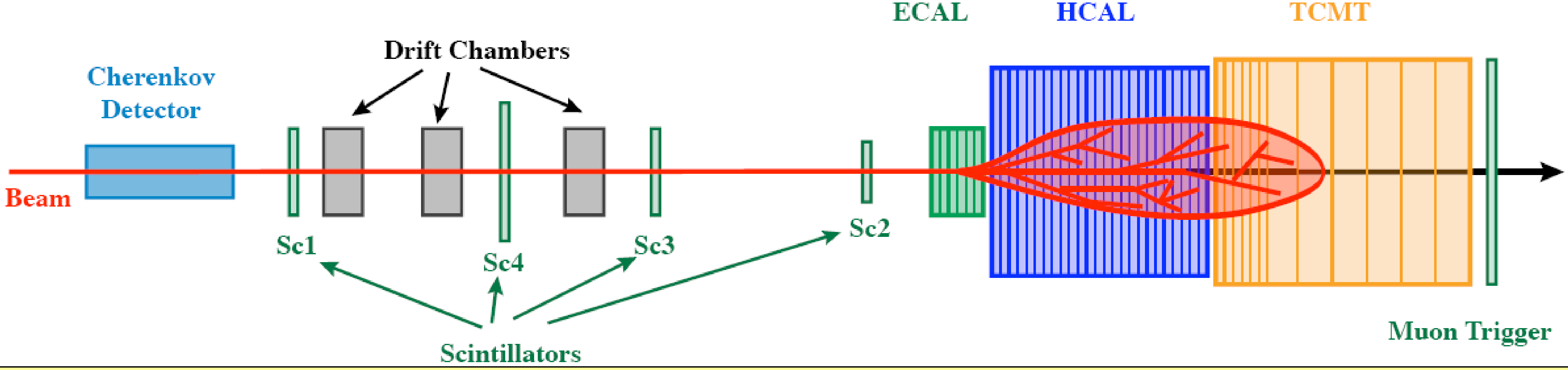
CALICE

- CALICE ~300 people/53 groups/17 countries
- Various projects aimed towards aspects of highly segmented calorimetry for a future Linear Collider detector, motivated by Particle Flow.
- Given focus by common test beams, combining ECAL/HCAL/tail catcher (TCMT); common DAQ/analysis.
- First round – small "physics prototypes"
  - Evaluate technologies; identify problem areas.
  - Validate Monte Carlo simulations, especially for hadronic showers, so that results can feed into full detector simulations.
  - Still sizeable systems with ~20K channels.
- Second phase – "technological prototypes" (mainly under aegis of EUDET).
  - More realistic technological solutions; module dimensions etc.
  - e.g. minimise thickness of sensitive layers; power pulsing.
- Will discuss some results of physics prototypes today.

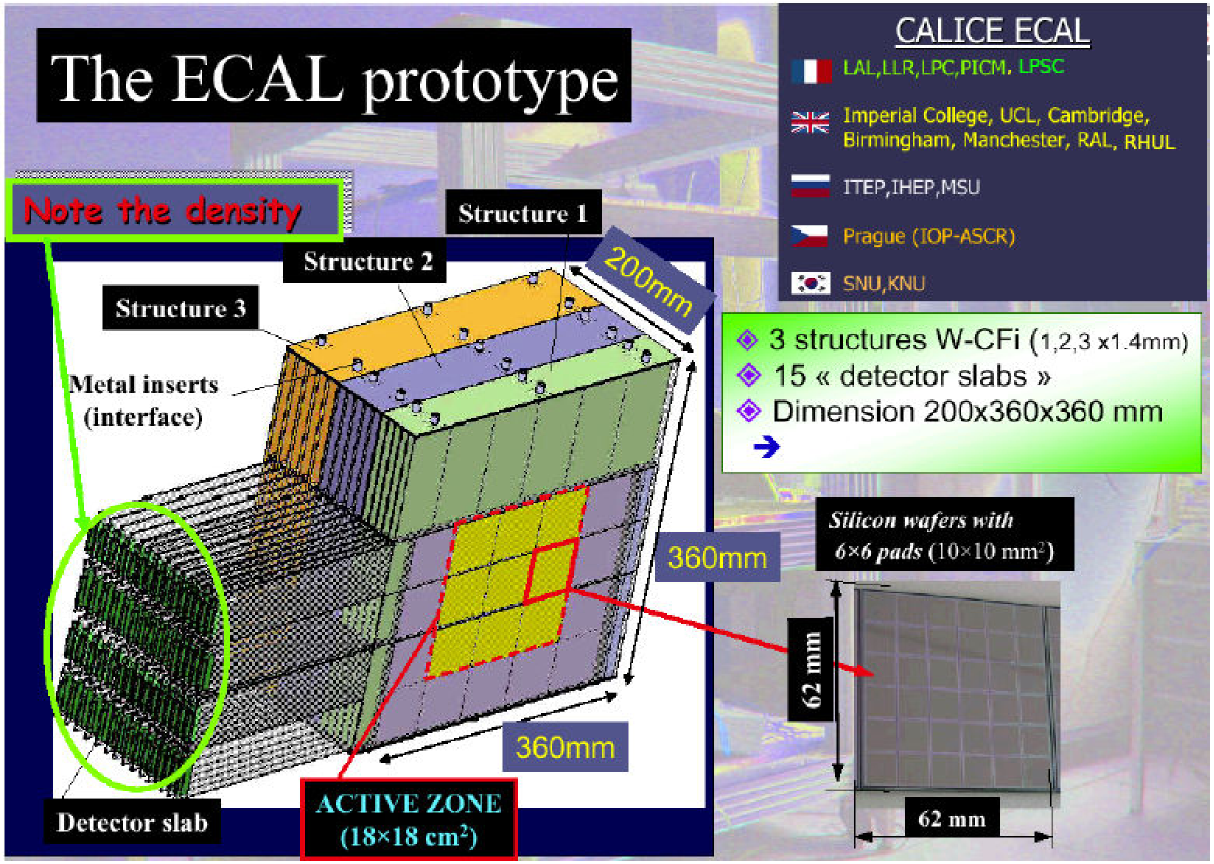
CALICE test beams

- Main beam tests, using π, μ, e beams:
- 2006-7
  - SiW ECAL + AHCAL + TCMT @ CERN
- 2007
  - Small DHCAL test @ Fermilab
- 2008
  - SiW ECAL + AHCAL + TCMT @ Fermilab
- 2009
  - Scint-W ECAL + AHCAL + TCMT @ Fermilab
  - Standalone RPC and Micromegas tests @ CERN
- 2010 planned
  - SiW ECAL + DHCAL + TCMT @ Fermilab

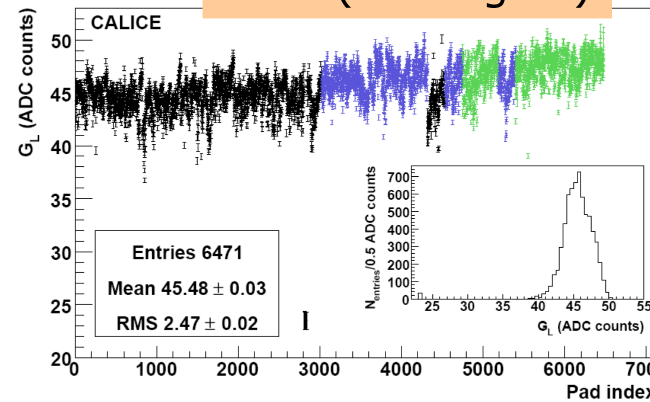




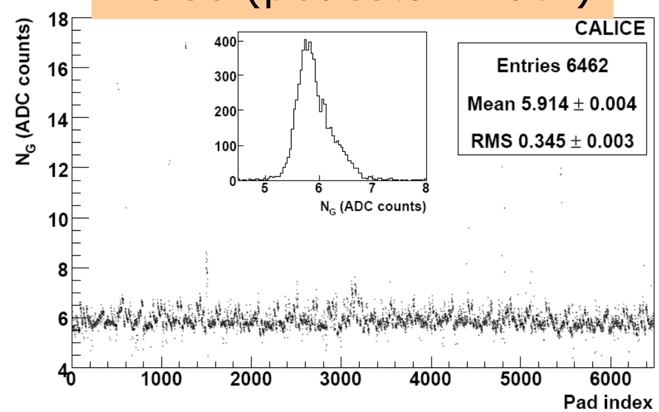
SiW ECAL



Gain (MIP signal)

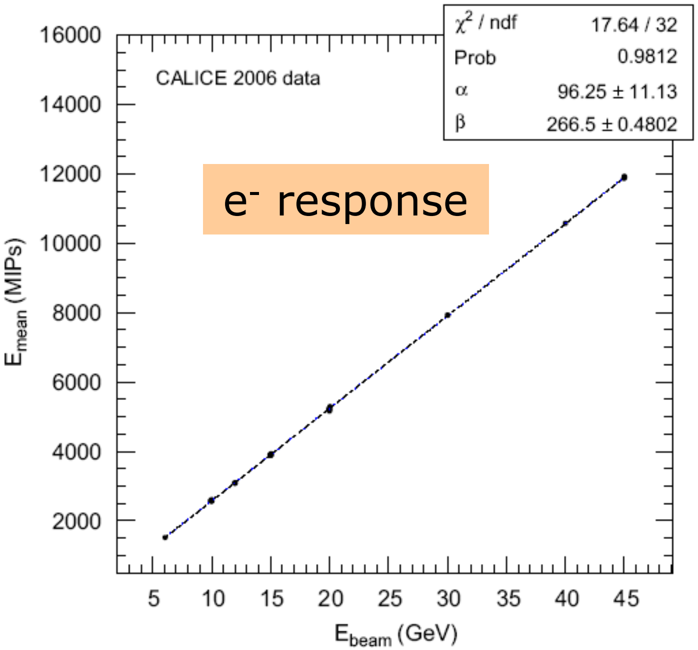


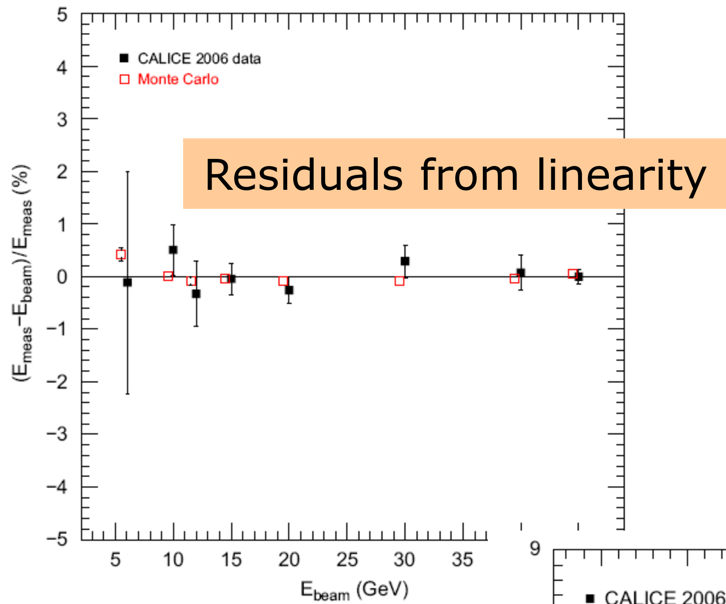
Noise (pedestal width)



Good uniform response across ~6500 Si pads (calibrated using muons).
Signal/noise ~7-8.

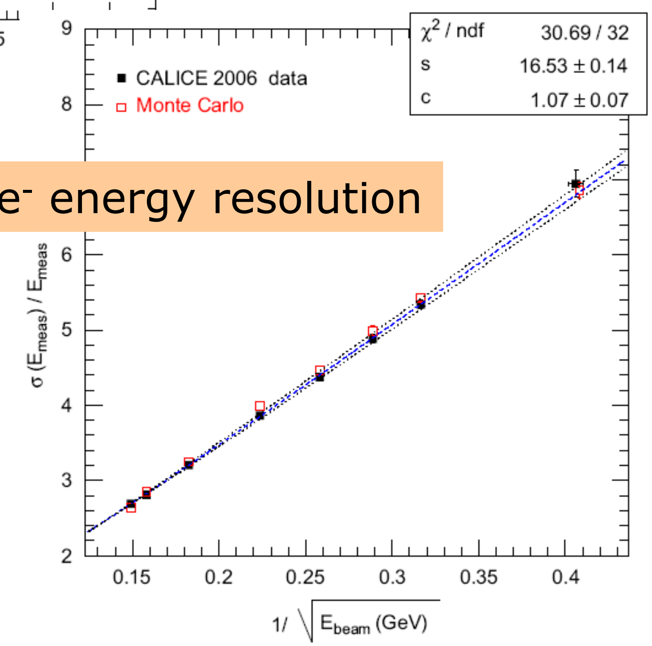
SiW ECAL results



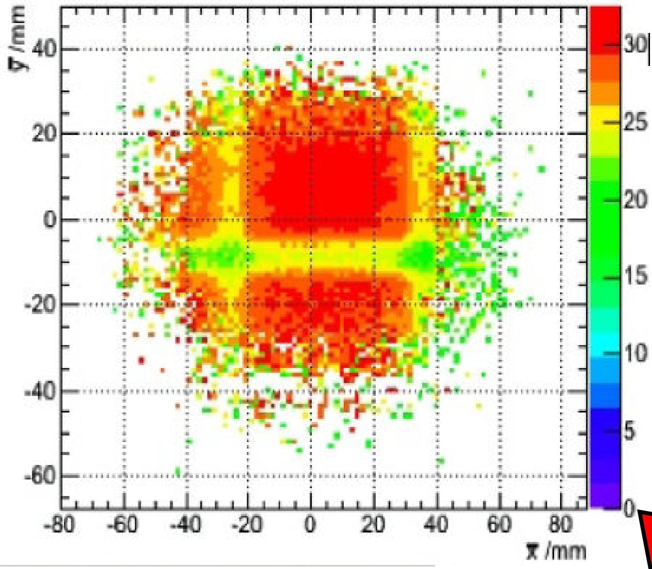


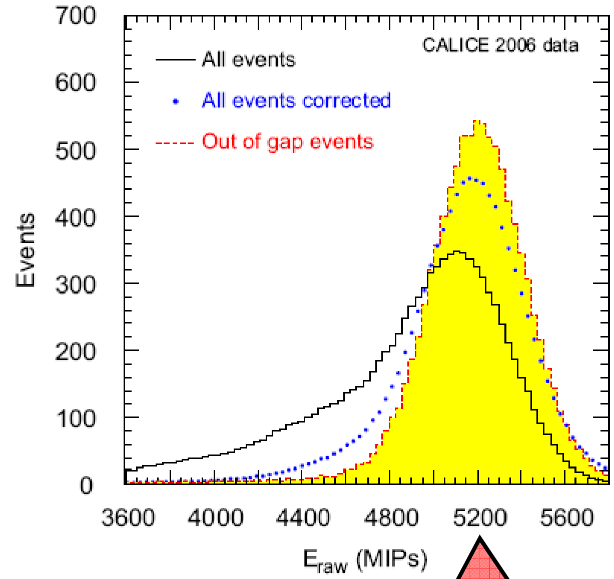
Linearity of response is good to ~1% (though small offset from zero in test beam setup; largely simulated)

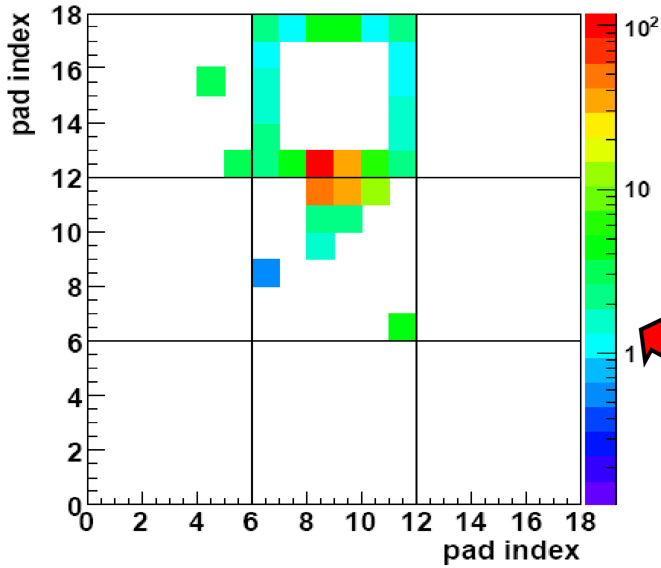
Energy resolution: $16.5\%/\sqrt{E} \oplus 1.1\%$
Well modelled by Monte Carlo



SiW ECAL problem issues

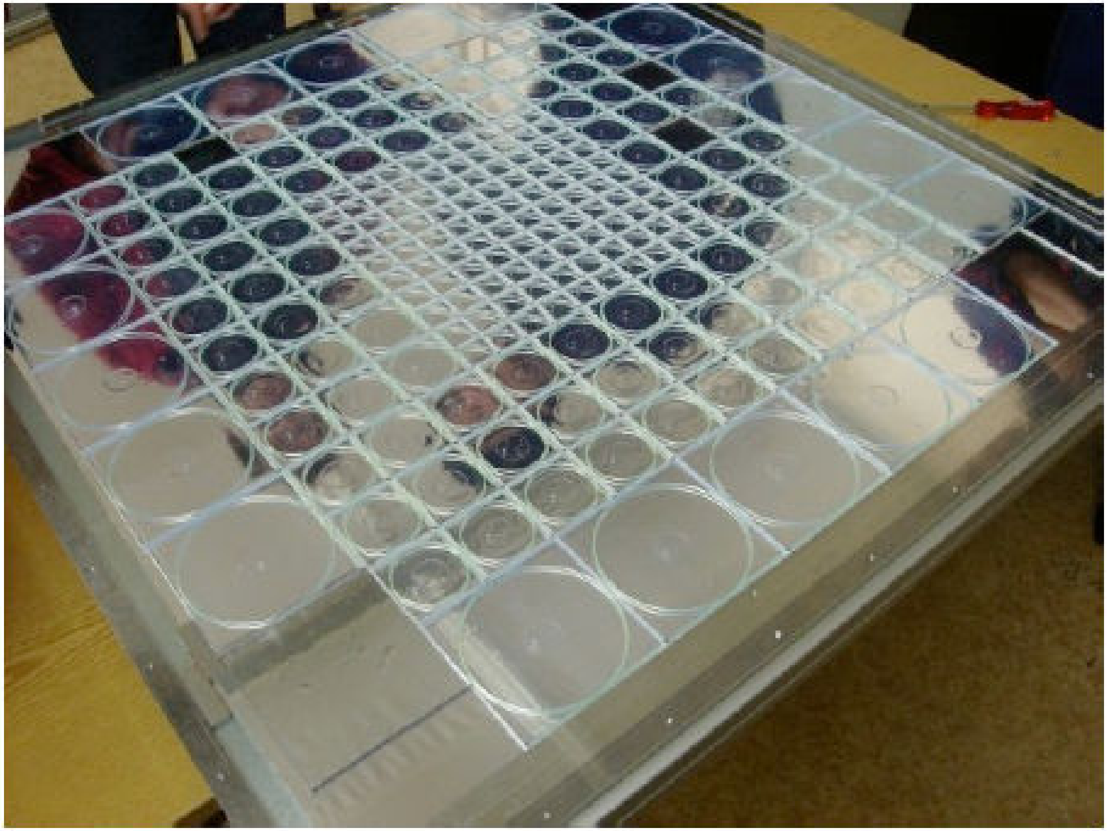




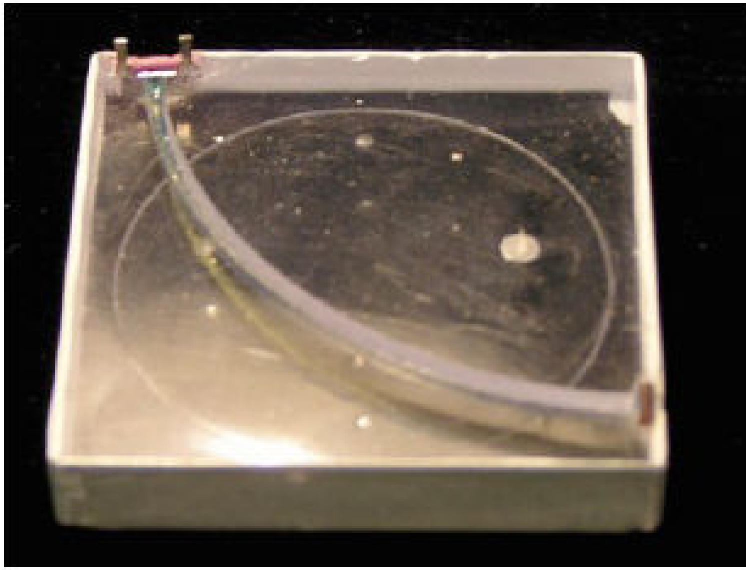


- Guard rings create dead areas around wafers.
- Simulated OK.
- Can (largely) correct response, but causes some degradation in resolution.
- Large energy deposited in guard ring ⇒ correlated crosstalk around edge of wafer ⇒ square pattern of hits.
- Aim to alleviate this in the next generation of sensors (larger wafers; segmented guard rings)

Analogue HCAL

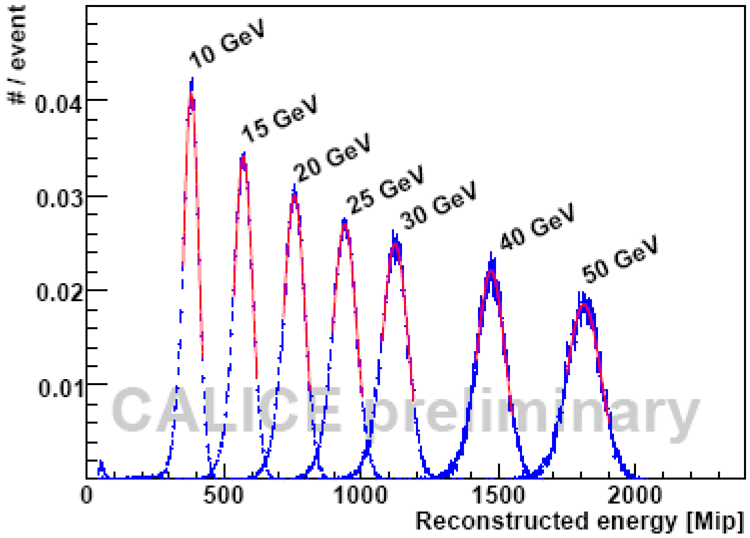


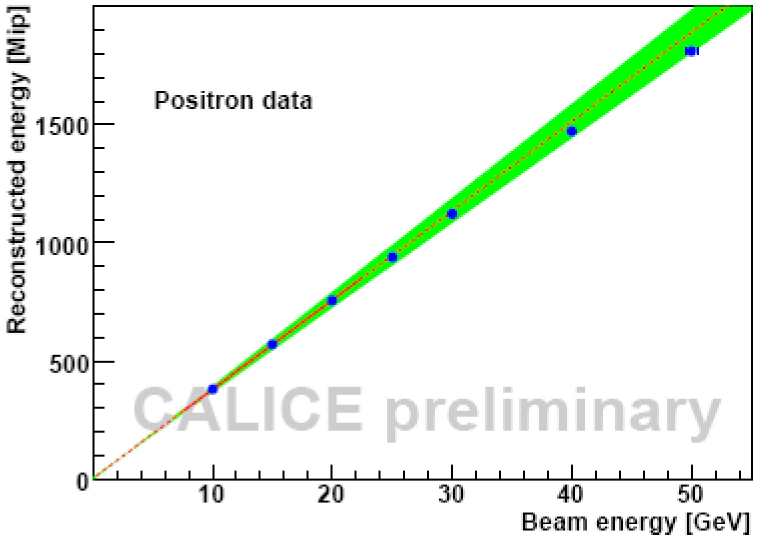
- Steel absorber structure:
  - 38 layers
  - 2 cm total absorber thickness per layer (1.1 X_0, 0.12 λ)
  - total ~ 4.5 λ

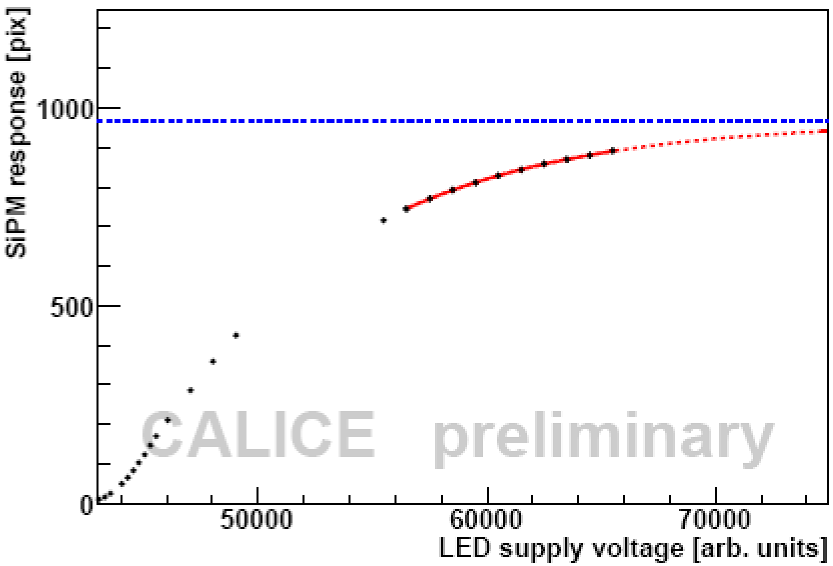


- Active layers: Scintillator tiles
  - high granularity in the layer center: 100 3x3 cm^2 tiles, then 6x6 cm^2 and 12 x12 cm^2
  - light collection via wls fiber, read out with SiPM

AHCAL electron data

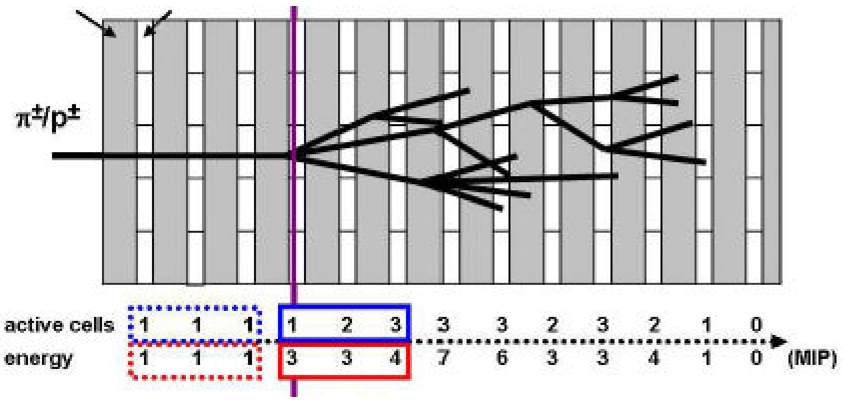




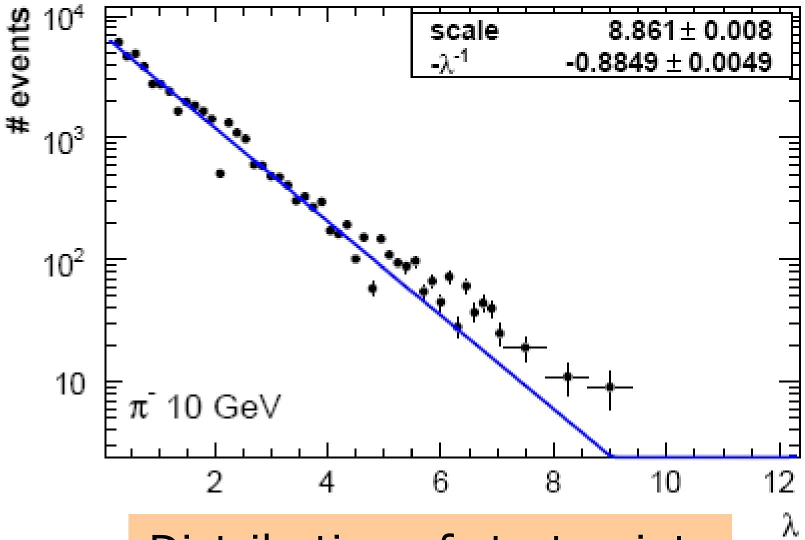


- Understanding electron (and muon) response is an important prerequisite to studying hadron showers.
- Non-trivial – need good control of corrections (e.g. temperature) and non-linear response of SiPMs.
- Currently linearity OK to ~4% up to 50 GeV, and further improvements in the pipeline.
- Good enough to proceed to study hadrons

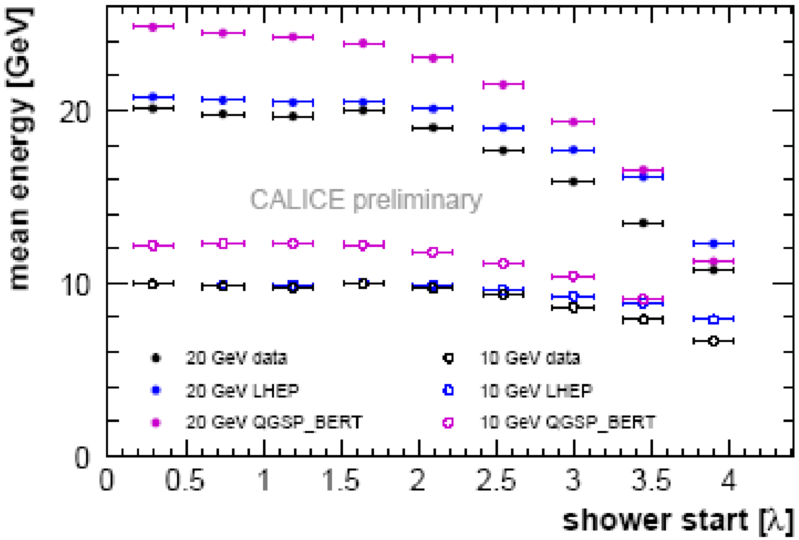
AHCAL hadronic showers



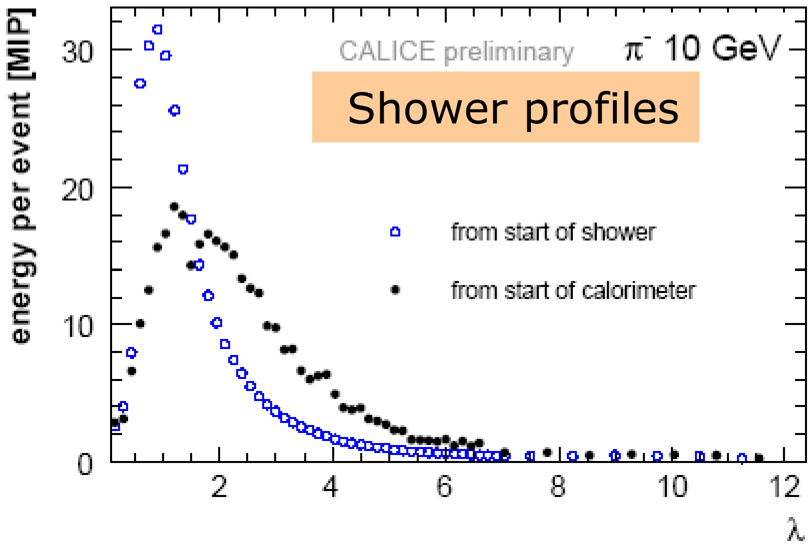
Identify shower start point



Distribution of start points



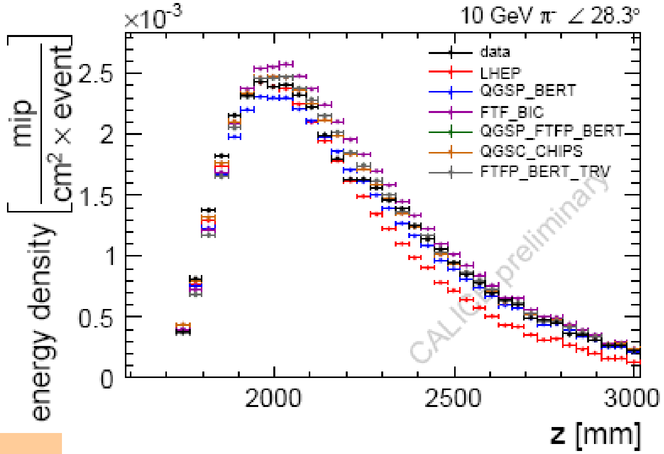
Energy leakage vs. start point



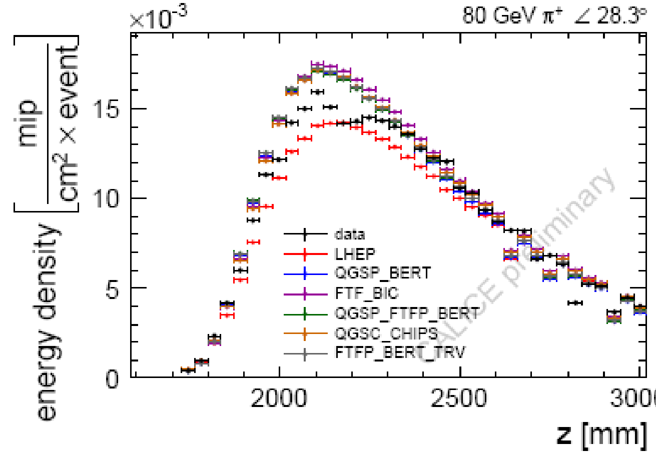
Shower profiles

Comparisons with Geant4

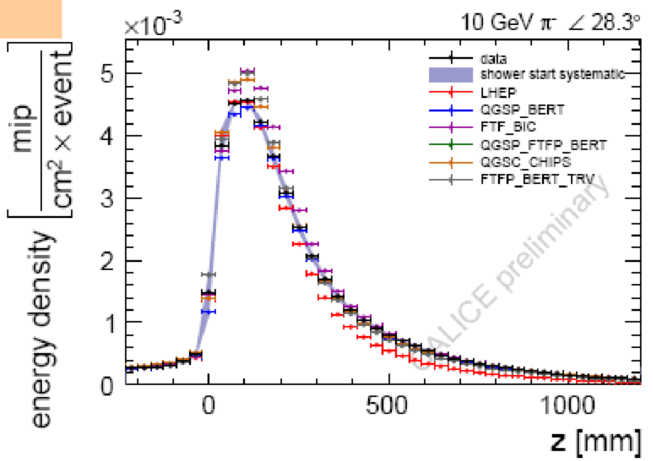
Shower profiles compared with Geant4 physics lists



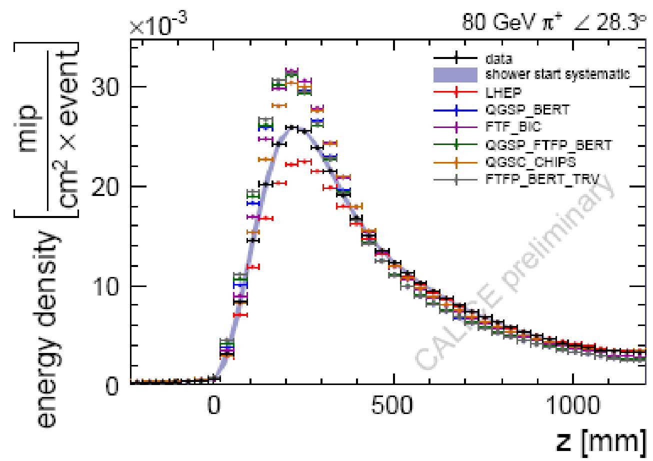
(a) standard profile 10 GeV



(b) standard profile 80 GeV

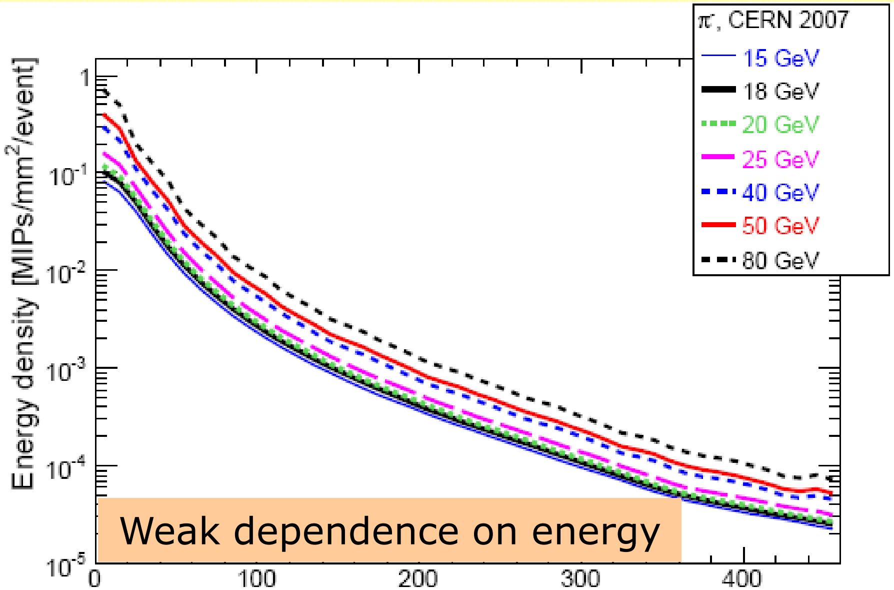


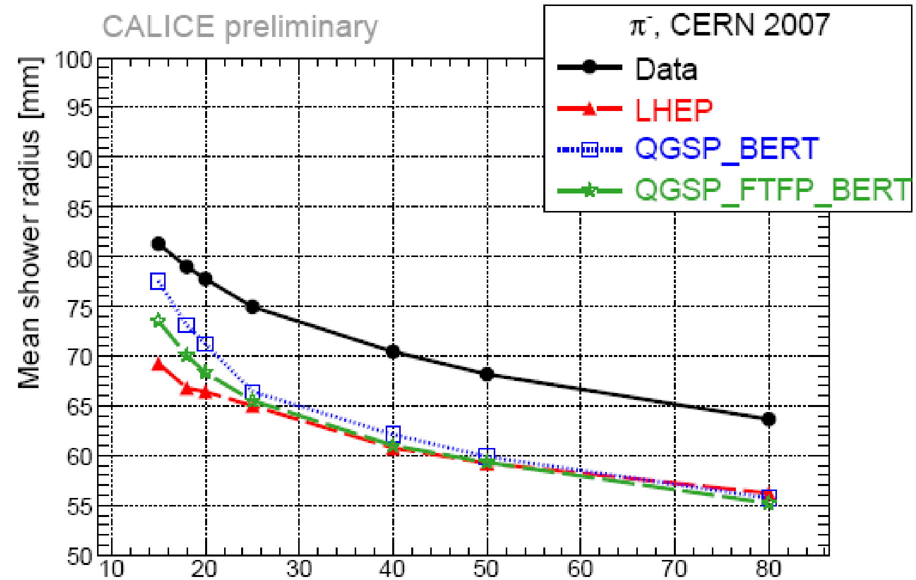
(c) profile from shower start 10 GeV

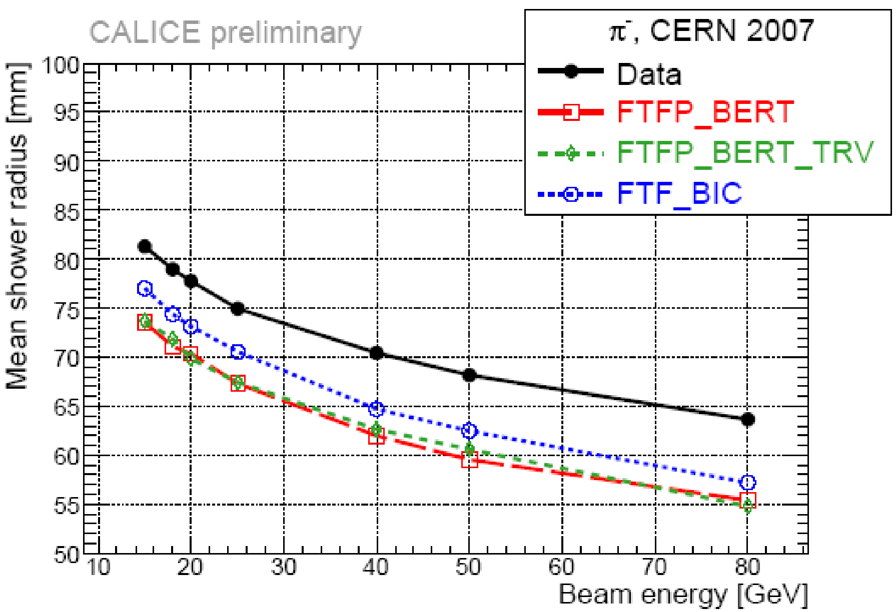


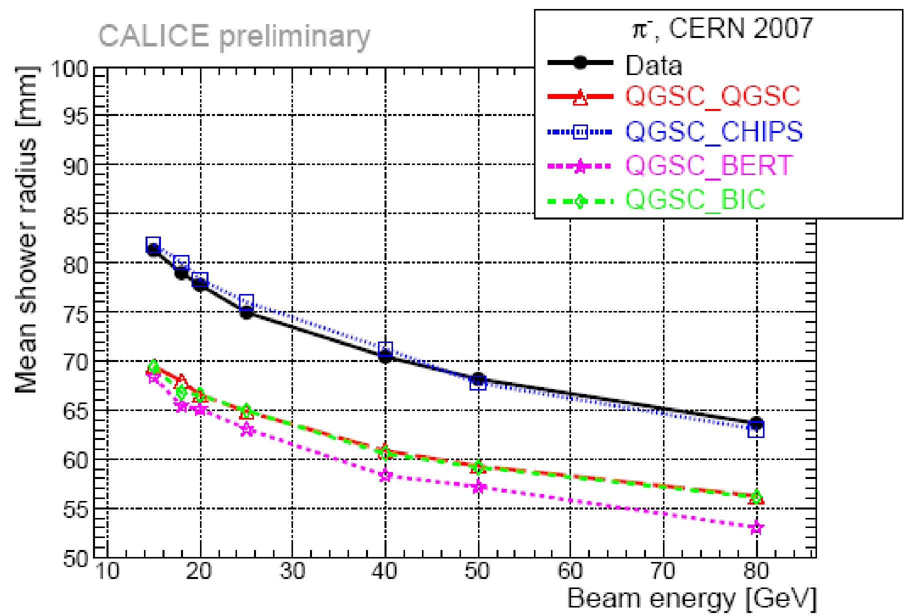
(d) profile from shower start 80 GeV

AHCAL transverse shower profiles



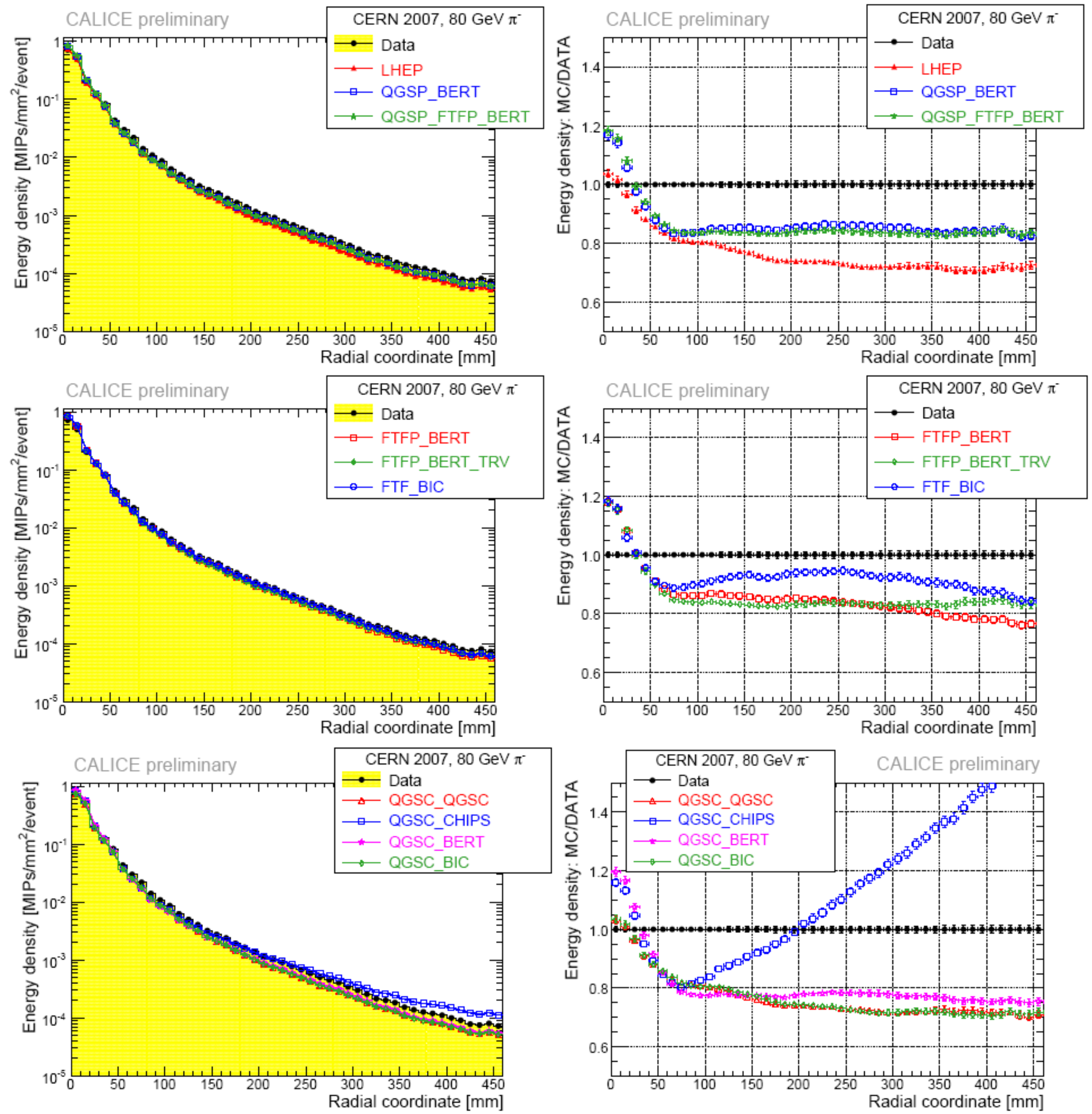




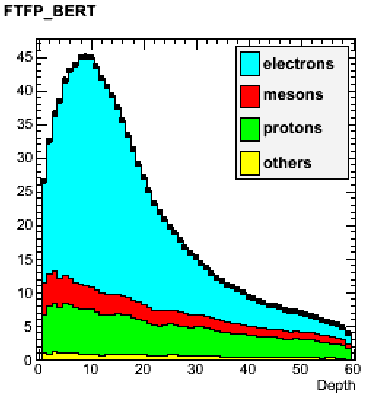


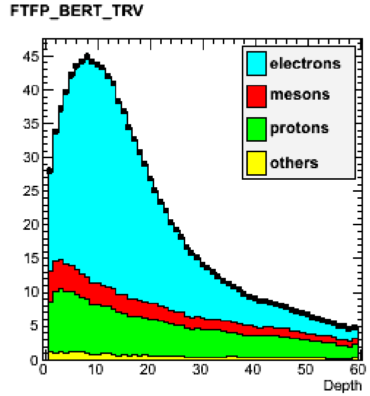
Transverse profiles contd.

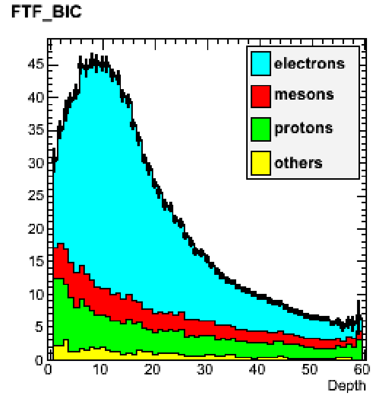
- Most G4 models predict too narrow showers (by ~10%), as judged from shower radius.
- One pre-release physics list (QGSC_CHIPS) looks much better.
- However, it doesn't actually get the shape right.
- Emphasises the need for great caution in drawing conclusions about MC models.



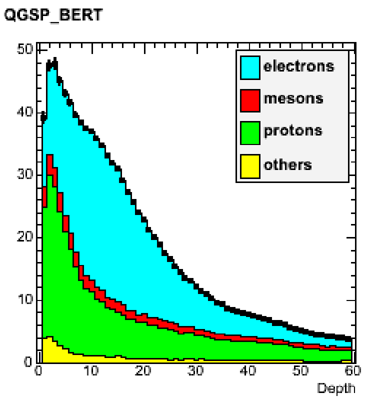
Hadrons in the SiW ECAL (MC only)

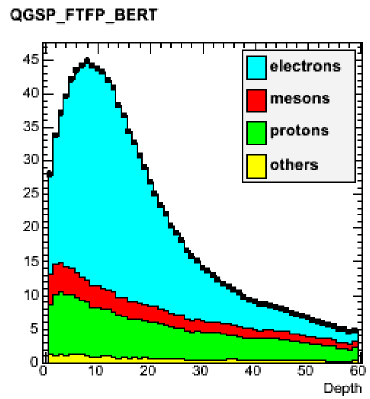


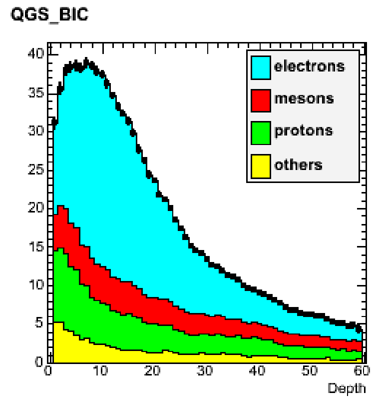


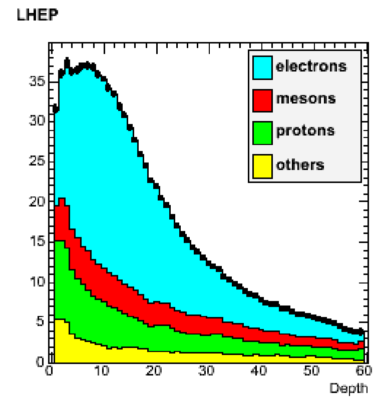


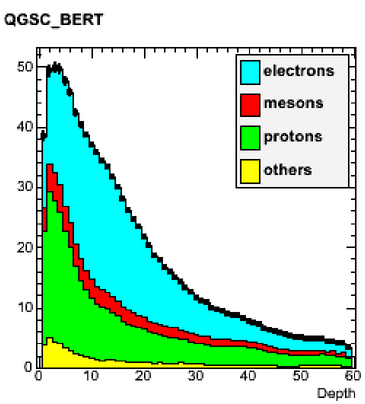
- Hadron showers not contained in ECAL (~1λ_{int})
- However, many showers start there.
- Different target material
- High granularity;
- High X_0/λ_{int}

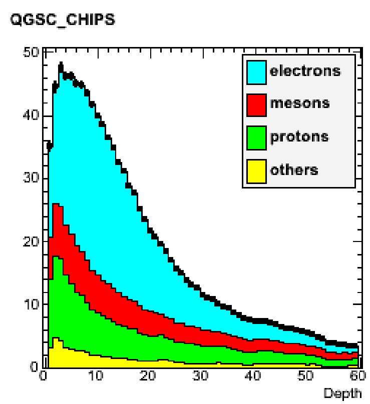


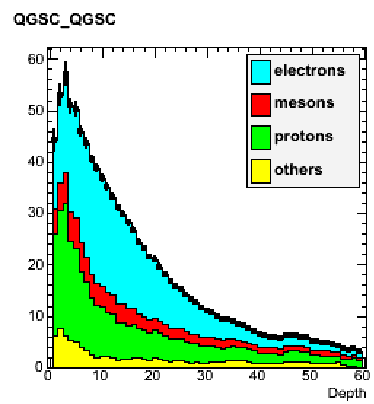








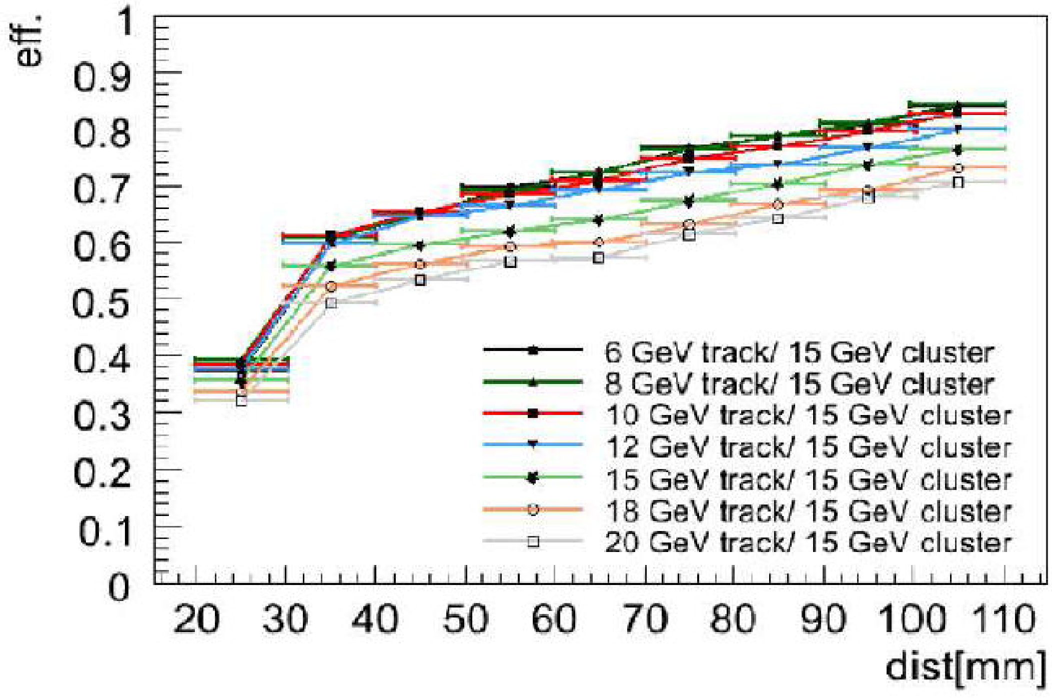




- 8 GeV π^- : long. profile w.r.t. shower start
- c.f. 10 G4 physics lists
- sensitive to different particle components in initial interaction.

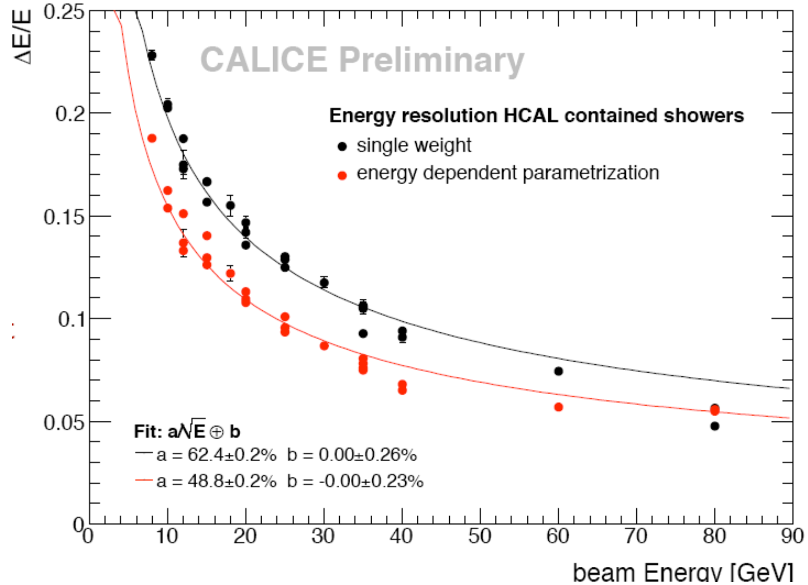
Two-particle separation (AHCAL)

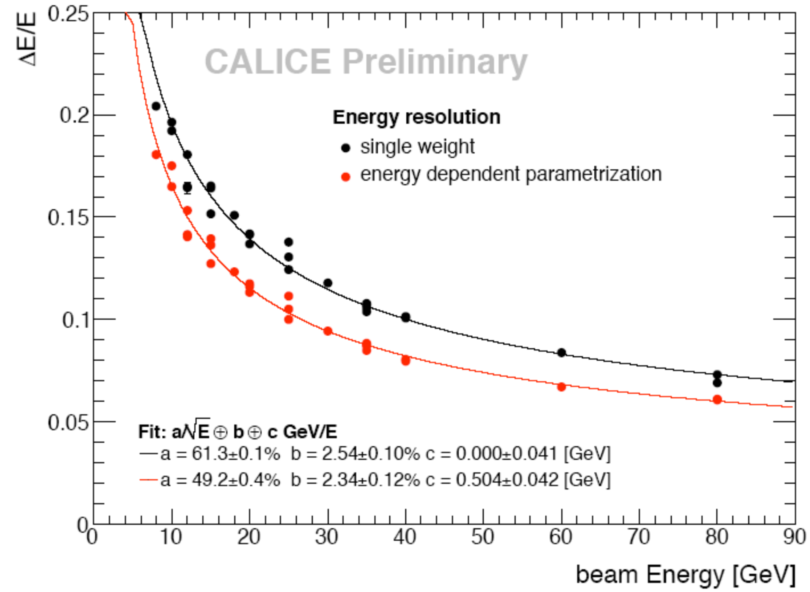
- Emulate particle flow.
- Superimpose two test beam pion events.
- Run Pflow clustering (not Pandora (yet))
- Pretend one was associated with charged track and other a neutral
- Calculate "efficiency"
  - Exactly two clusters
  - Neutral reconstructed correctly within $\pm 3\sigma$
- Show vs separation
- Scope for many similar studies in future.



Energy measurement –software compensation

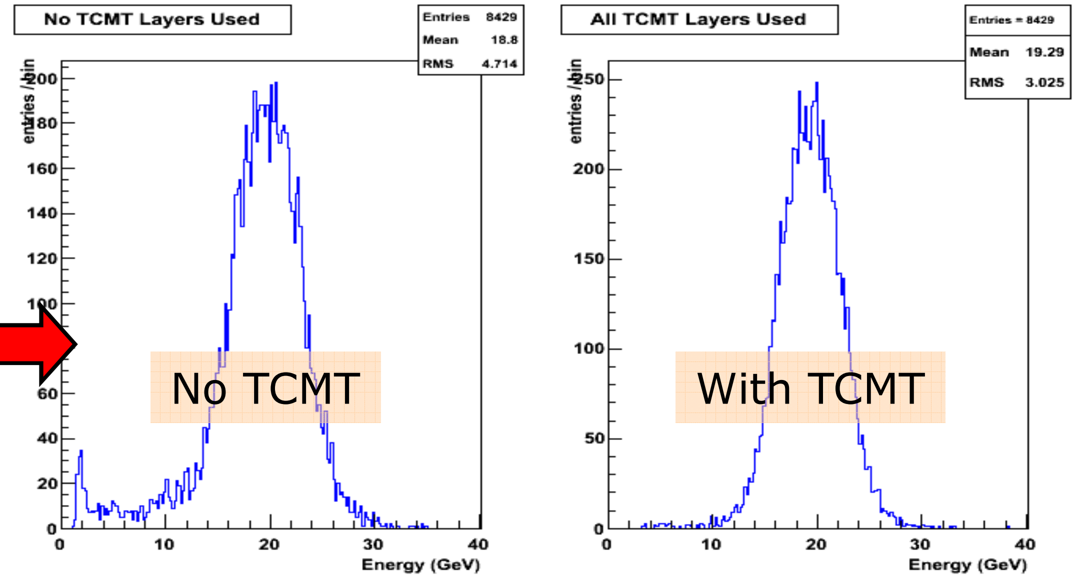
- CALICE calorimeters are not compensating (e.g. e/π~1.2 in AHCAL).
- Can exploit fine granularity to correct in software.
- e.g. parametrise weights for hits of different energies (e/m showers tend to have greater particle density). Optimise on energy resolution.
- Improve resolution from ~60%/√E to ~50%/√E
- Works equally well for HCAL alone or for combined ECAL/HCAL/TCMT system.
- No adverse effect on linearity of response. Actually improves it slightly.



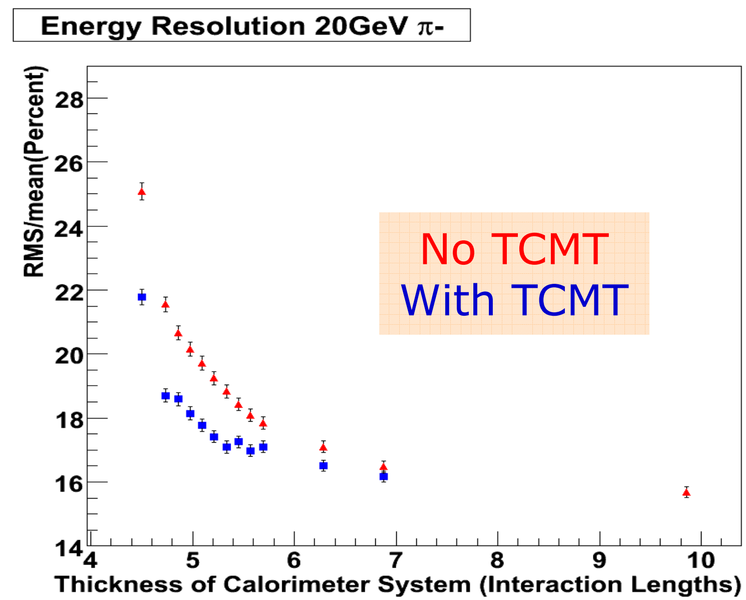


Use of tail catcher

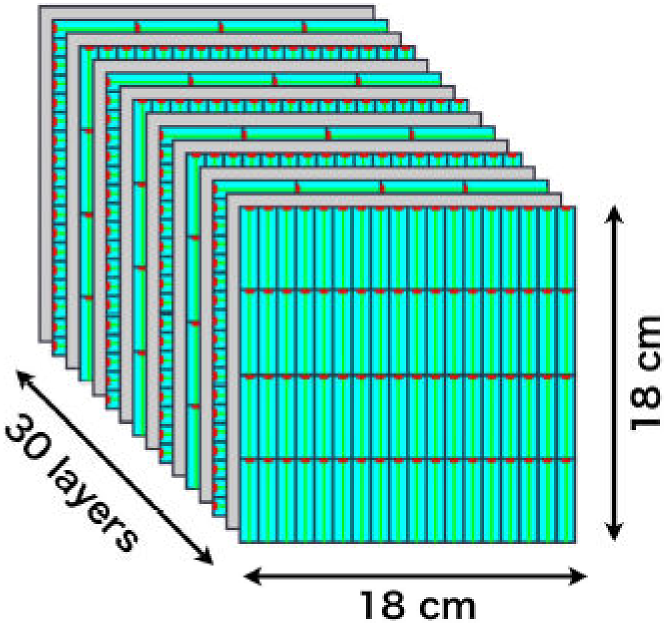
- CALICE test beam calorimeters:
  - ECAL ~1λ
  - AHCAL ~4.5λ
  - TCMT ~5λ
- Tail catcher is needed to contain hadronic showers
- ILD-like detector would have a coil of ~1.8λ behind the HCAL.
- Emulate its effect in software by omitting suitable layers of the CALICE setup.
- Study resolution as a function thickness of ECAL+HCAL, with and without use of TCMT.



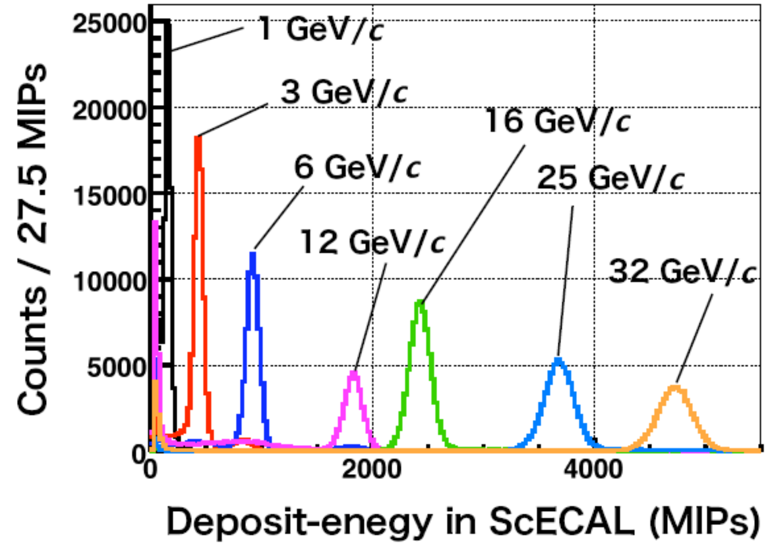
Study for 20 GeV π^-

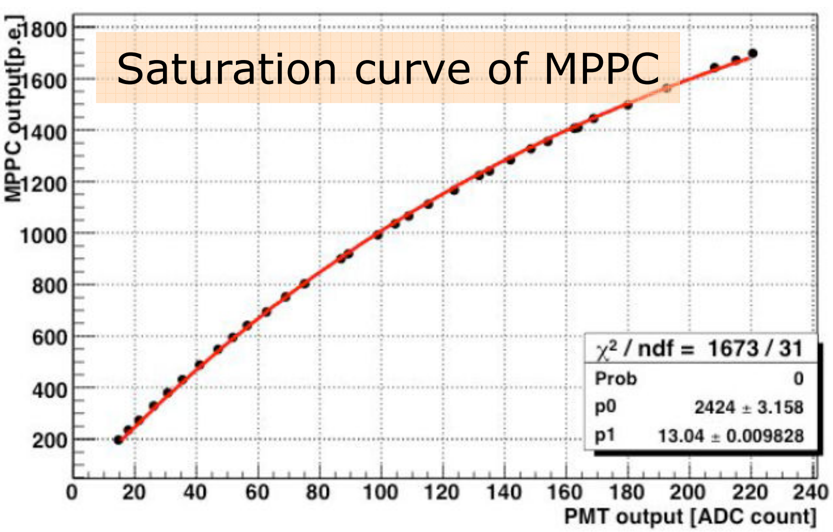


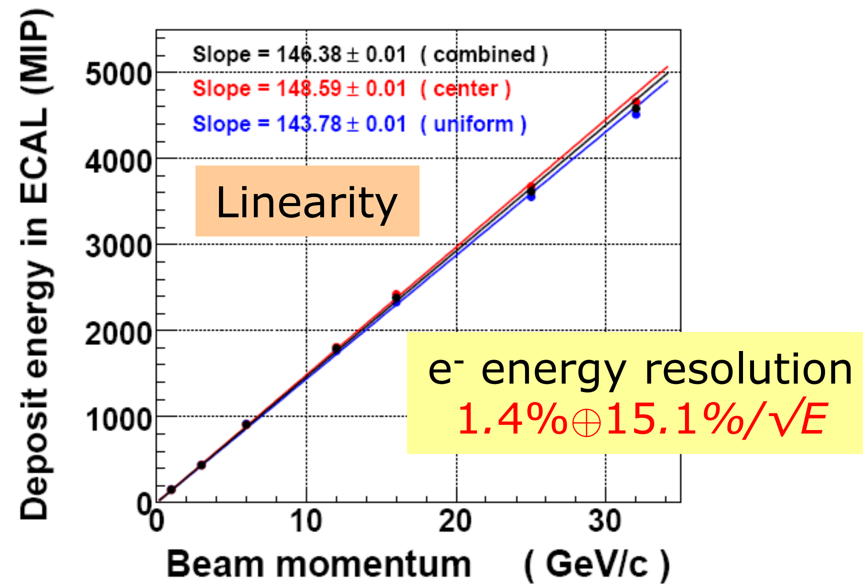
Scint-W ECAL



- Scintillator strips 1x4.5 cm
- Read out via WLS fibres and MPPCs
- Tested at Fermilab
- (see Tohru Takeshita's talk for more).

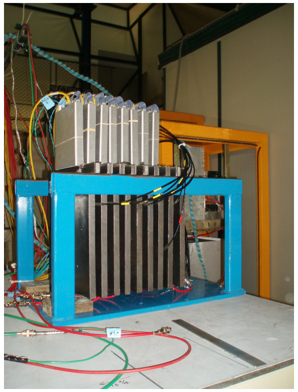


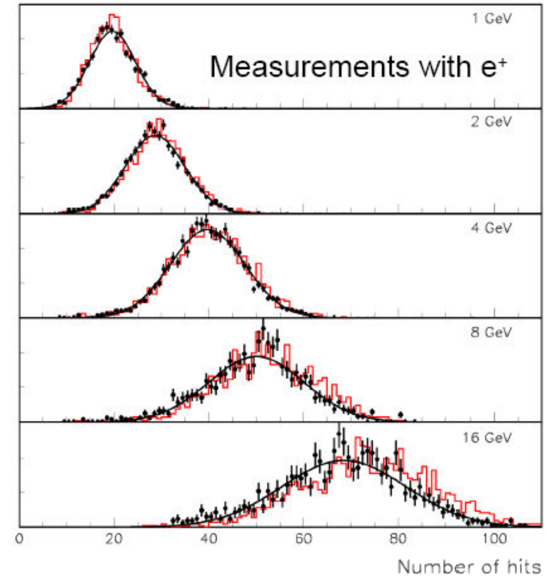


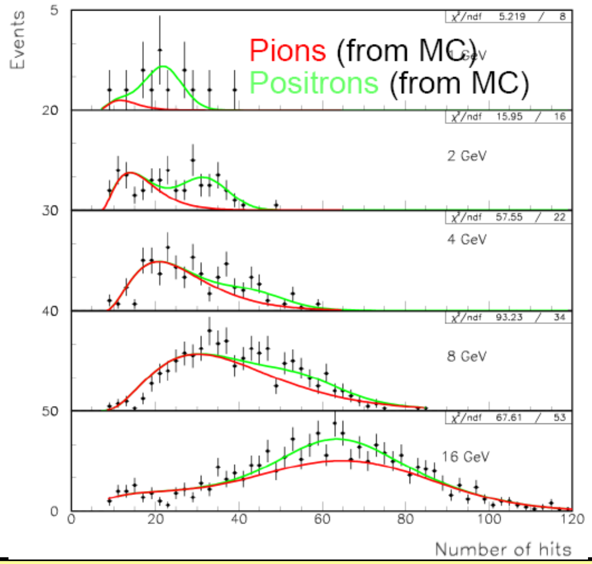


Digital HCAL

- Development and study of thin (glass) RPCs
- Development of a digital (1-bit) readout
- System for large number of channels
- Tests of a small (9-plane) prototype with cosmic rays, and in the FNAL testbeam
- Reasonable agreement between measurements and Monte Carlo simulations of the set-up
- Now moving rapidly towards a full 1 m^3 prototype, for beam tests in 2010.





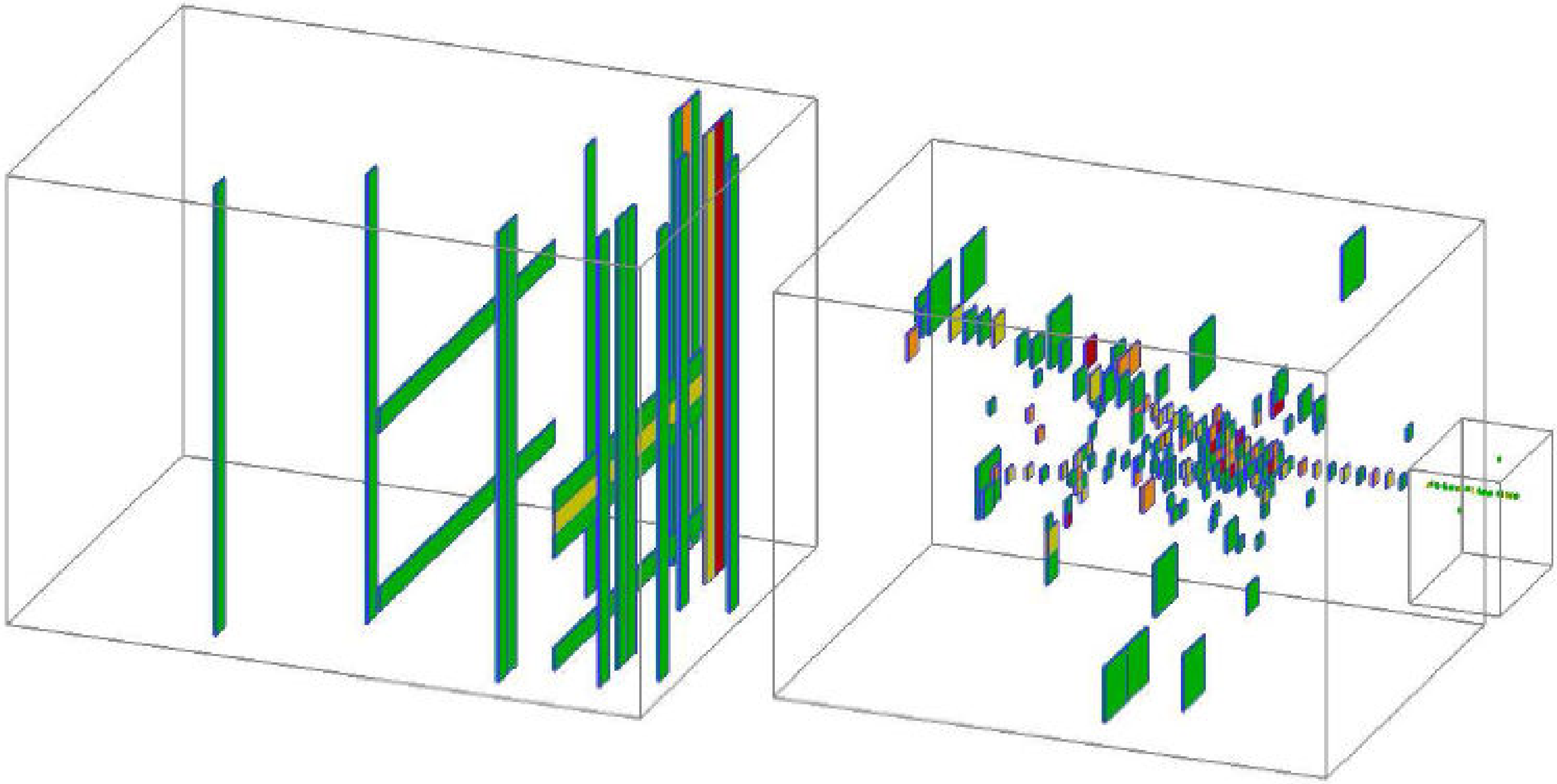


Summary

- Only touched on a few of the activities in CALICE
  - Also GEMs studied for DHCAL
  - Semi-Digital HCAL, based on RPCs, or MicroMegas
  - Digital ECAL (MAPS-based sensors)
- Understanding hadronic showers is a subtle business
  - Often dealing with novel sensor technologies – need to understand calibration, special features etc.
  - Typically use muons and electron beams for this first before moving on to hadron data.
  - Many models in Geant4; all are hybrids. None can be expected to be perfect.
  - Still learning about the best ways to compare simulations wirh data.
    - Need measurements which are both experimentally robust and sensitive to models.
    - What are the most important observables for Particle Flow?
    - What are the most informative observables to provide useful feedback to G4 developers?

Spares

Imaging calorimeter

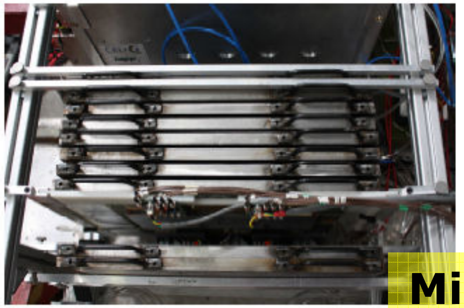


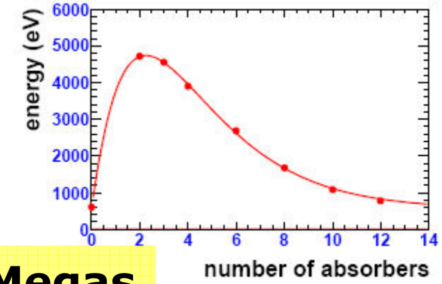
Models used in Physics Lists (for $\pi^{\pm}$)

- LHEP — LEP (<55); HEP (>25)
- QGSP_BERT — BERT (<9.9); LEP (9.5-25); QGSP (>12)
- *QGSP_FTFP_BERT* — BERT (<8); FTFP (6-25); QGSP (>12)
- QGS_BIC — BIC (<1.3); LEP (1.2-25); QGSB (>12)
- QGSC_BERT — BERT (<9); QGSC (>6)
- *QGSC_CHIPS* — QGSC_CHIPS ($\forall$ energies) “energyflow i/f to CHIPS”
- *QGSC_QGSC* — QGSC ($\forall$ energies) “multisoft i/f to CHIPS”
- FTFP_BERT — BERT (<5); FTFP (>4)
- *FTFP_BERT_TRV* — BERT (<8); FTFP (>6)
- FTF_BIC — BIC (<5); FTFB (>4)

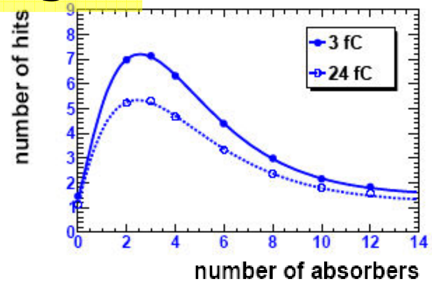
- n.b. Ranges overlap to provide smooth transitions between models. Energies in GeV
- Prerelease lists in *italics.*

Other test beam activities

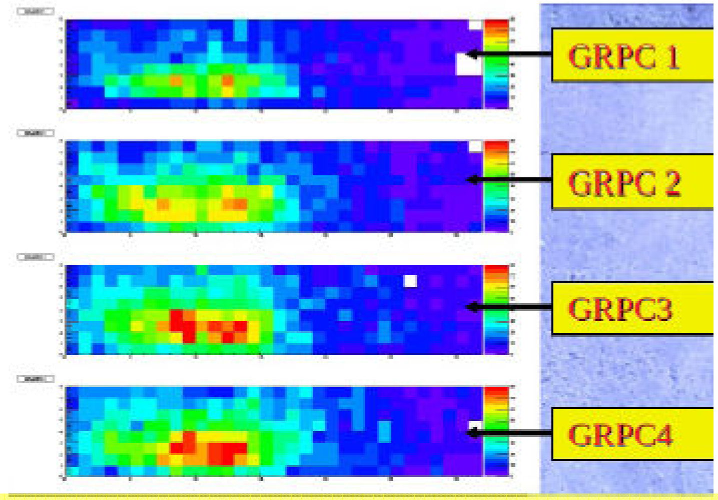




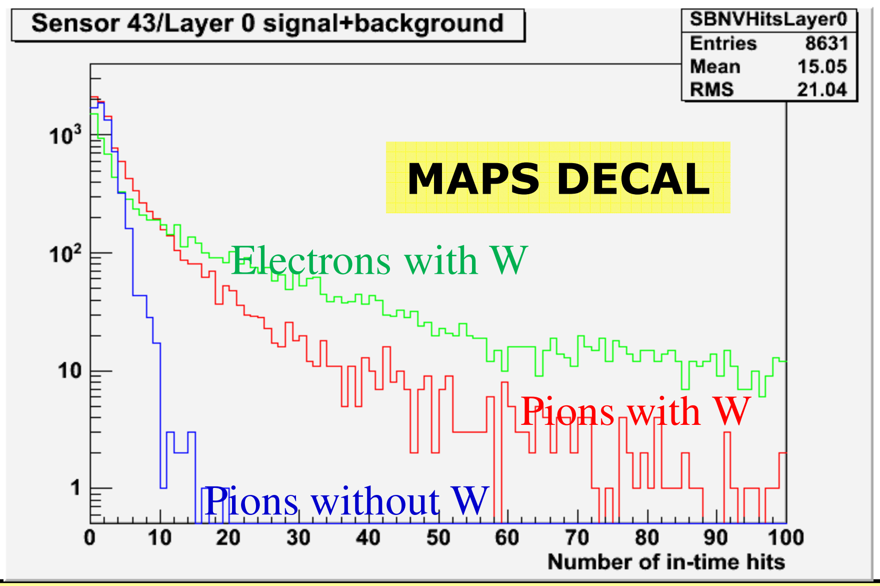
MicroMegas

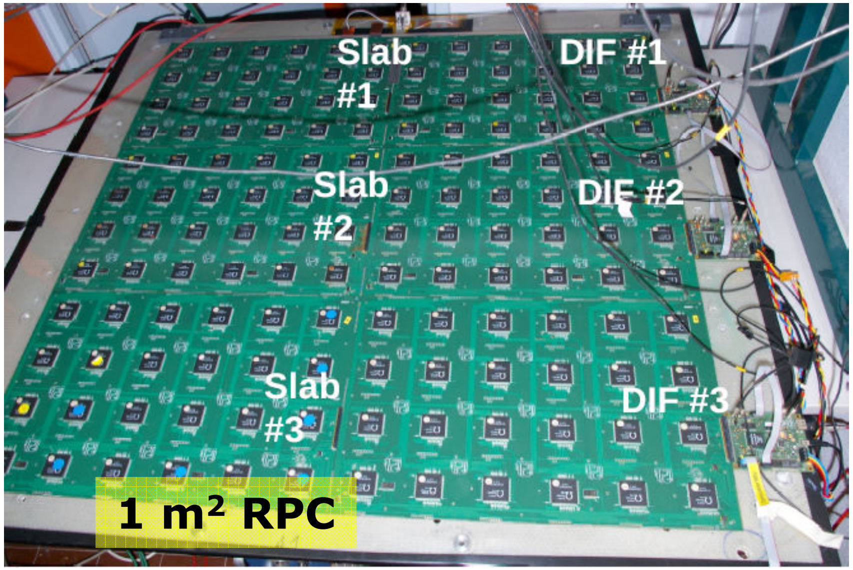


- Lateral electron shower profile
- Longitudinal electron shower profile
- Analysis of hadron showers is ongoing



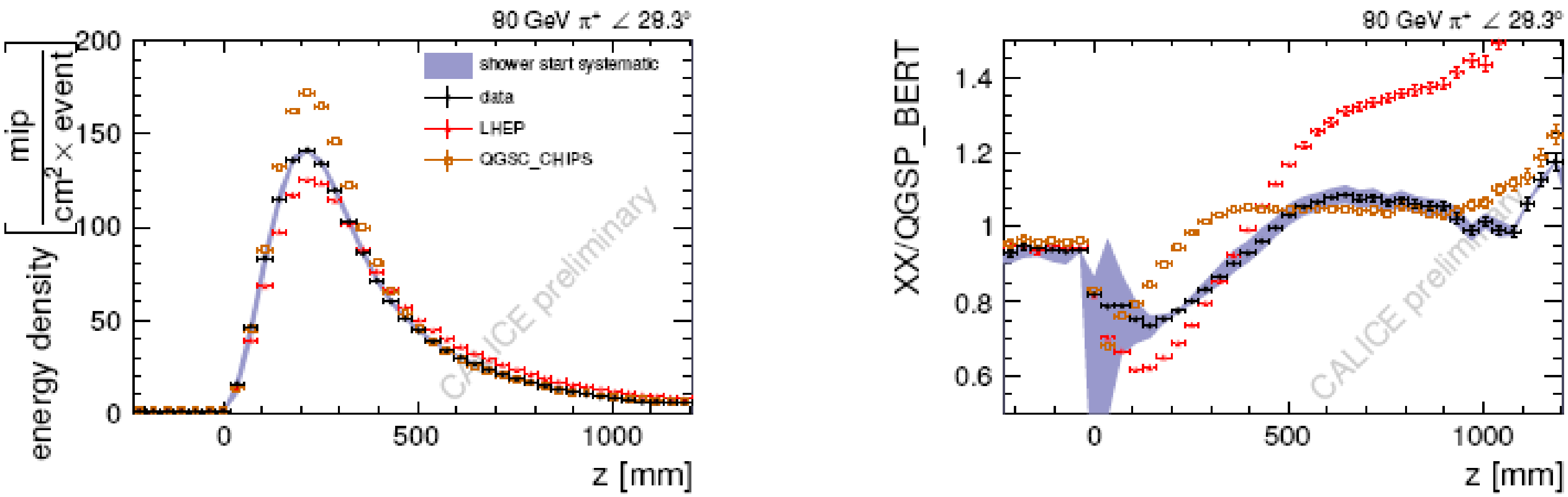
MiniDHCAL – hadronic shower development



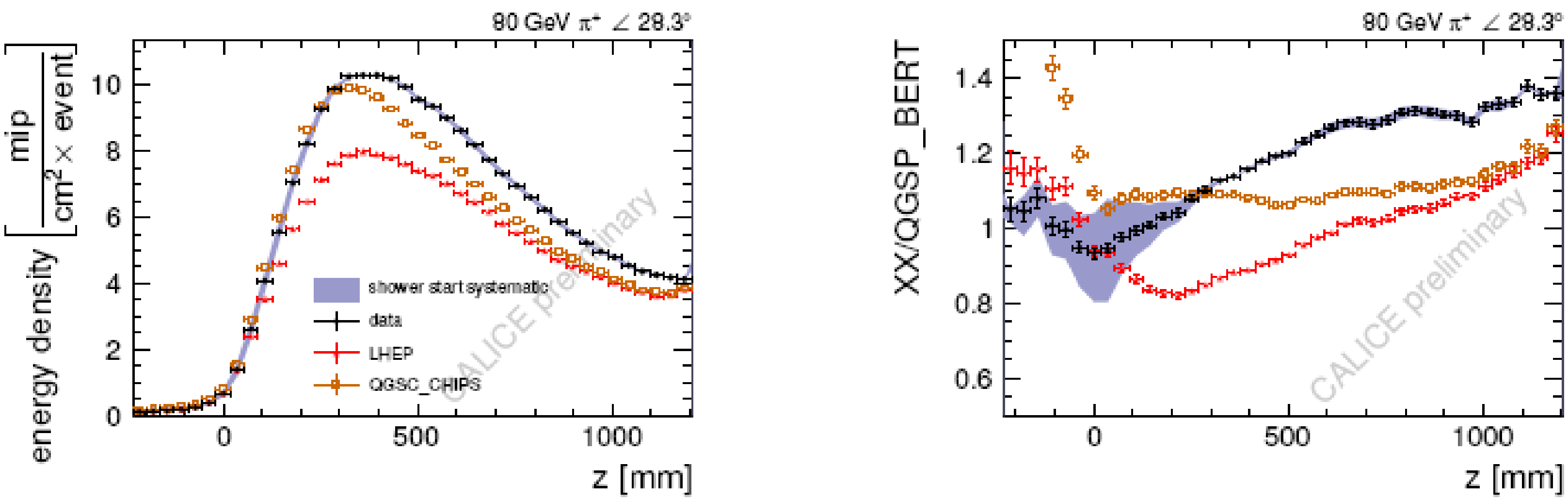


Long. Profiles vs radius

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

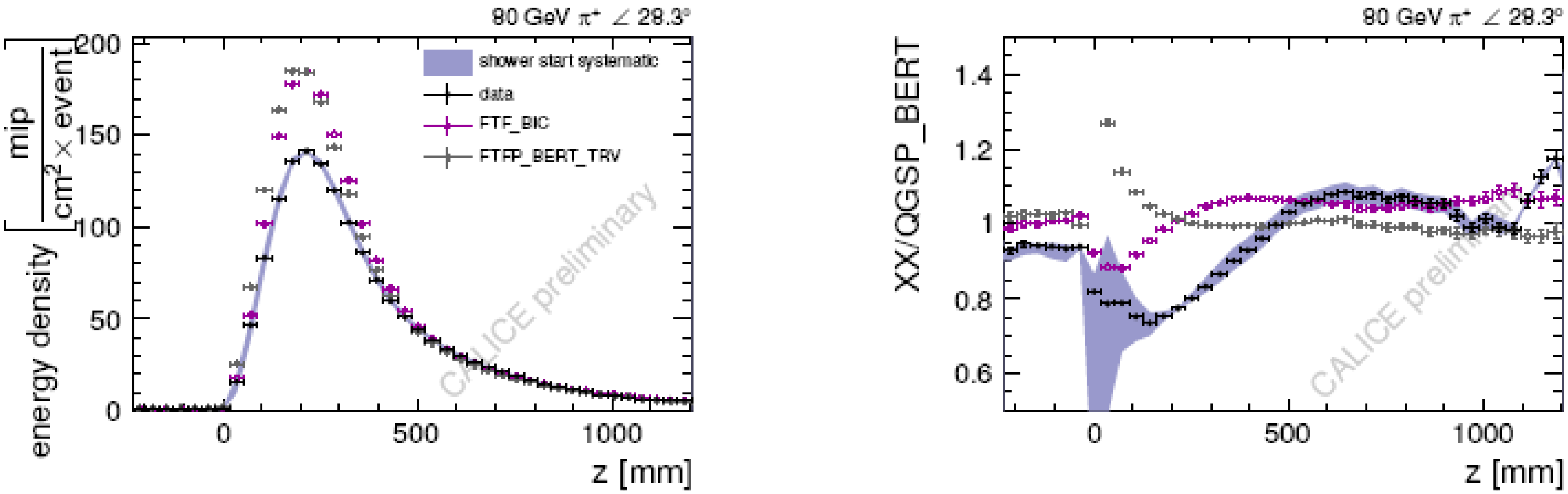


$12\,\mathrm{cm} \leq r < 18\,\mathrm{cm}$ from shower start

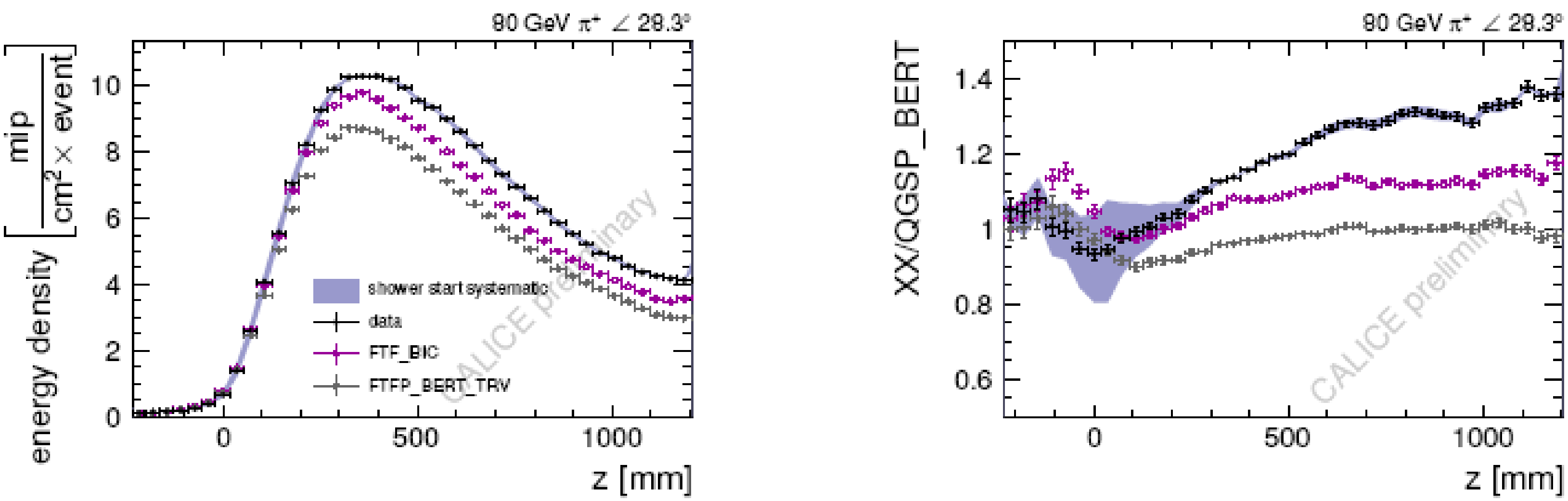


And more models

$0\,\mathrm{cm} \le r < 6\,\mathrm{cm}$ from shower start

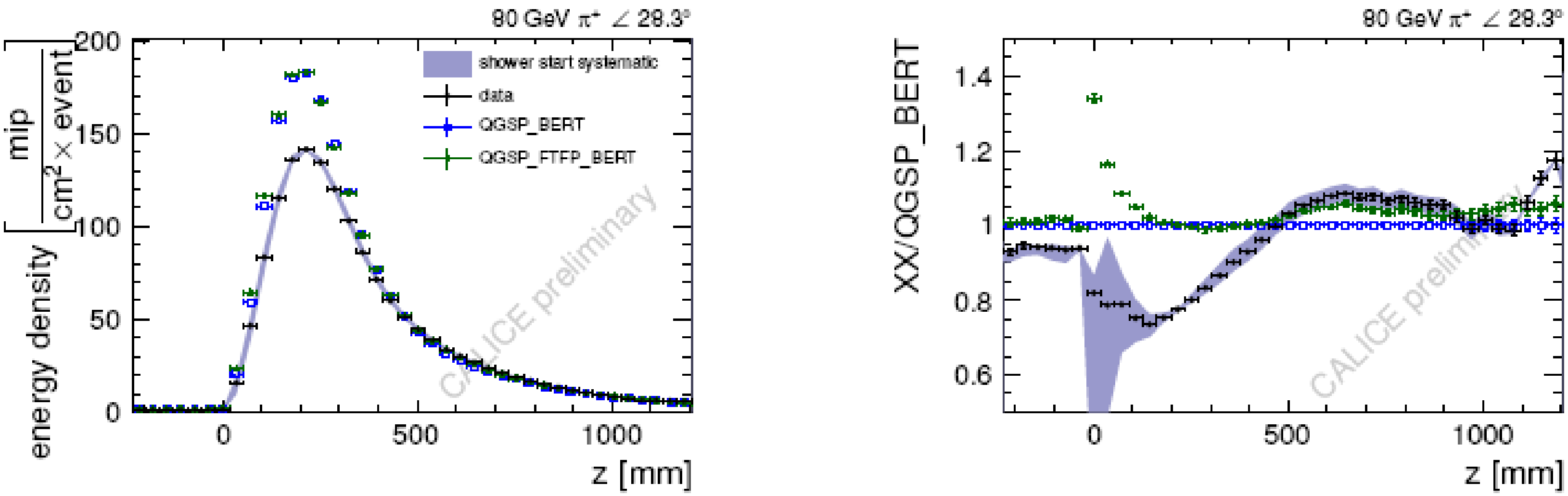


$12\,\mathrm{cm} \le r < 18\,\mathrm{cm}$ from shower start



And more…

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



$12\,\mathrm{cm} \leq r < 18\,\mathrm{cm}$ from shower start