CALICE – test beam analysis and software

David Ward

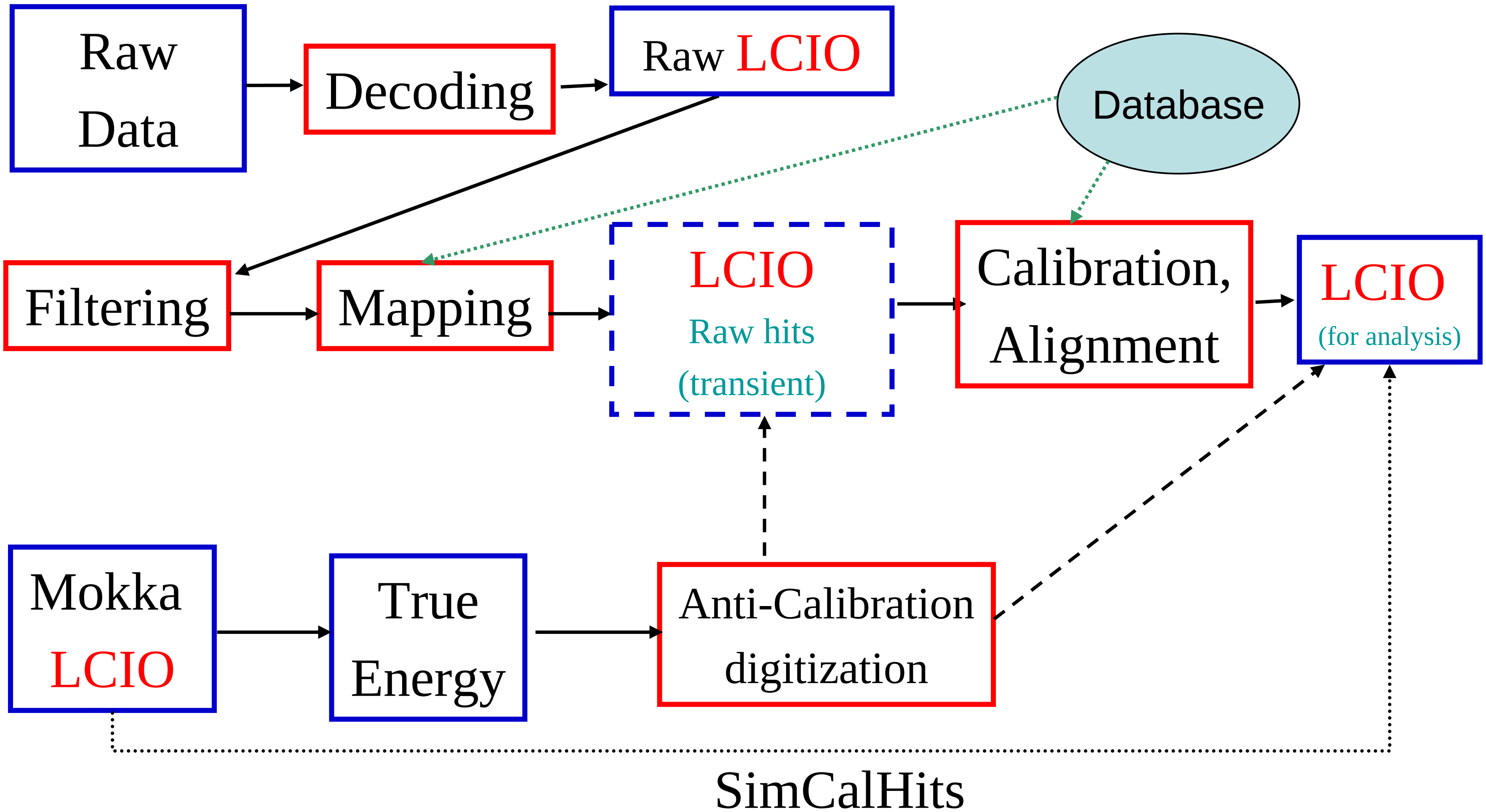
- Brief overview of analysis software
- Results from 2006 test beams @ DESY/CERN
  - ECAL analysis (Si-W and Scintillator)
  - Analogue HCAL (AHCAL)
  - Tail Catcher and combined hadron response.
- Snapshot of work in progress.
- All results are PRELIMINARY.

More details in talks in Calorimetry session by A-M.Magnan, C.Carloganu, D.Jeans, N.Meyer, D.Chakraborty etc.

Software framework

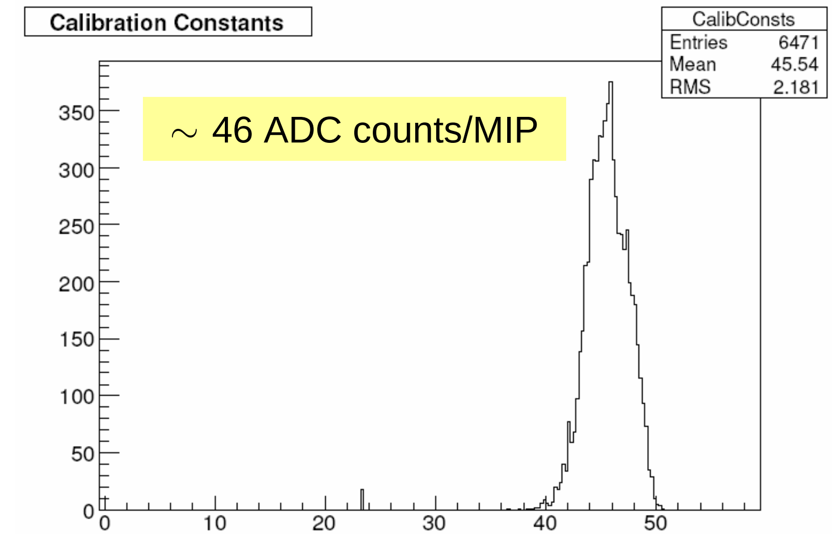
- Decision to use ILC tools for data analysis. Namely:
  - Mokka (Geant4) Monte Carlo. Same program used for test beam setups as for (some) full detector simulations. Code shared where feasible.
  - LCIO data format used for data reconstruction and analysis. Same as created by Mokka.
  - Raw data stored in DESY dCache and converted to LCIO immediately. Replicated at IN2P3 Lyon. Registered on the Grid.
  - MARLIN framework for reconstruction/analysis code. Modules coupled via LCIO objects.
  - LCCD conditions data base (calibration constants), over MySQL.
  - Use of Grid resources for data access, reconstruction, analysis, Monte Carlo production.
  - Analysis can use Root (main choice so far) or JAS3/Wired.

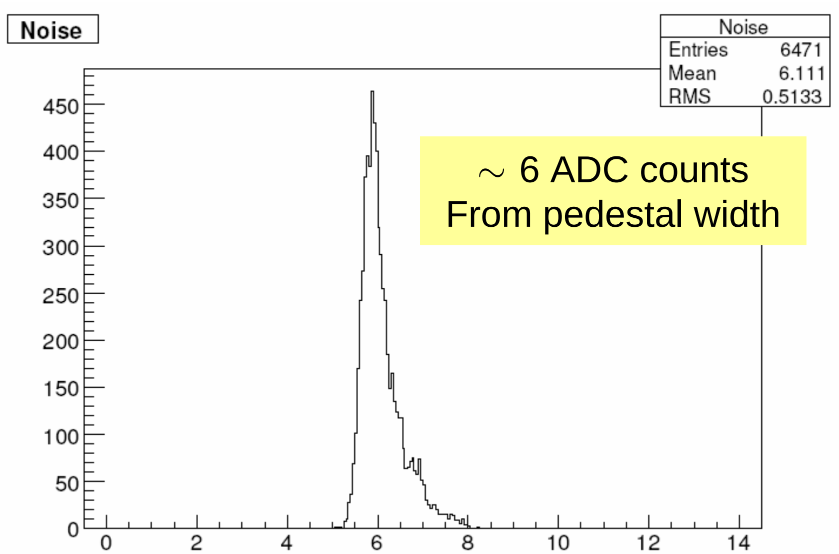
Software – data flow

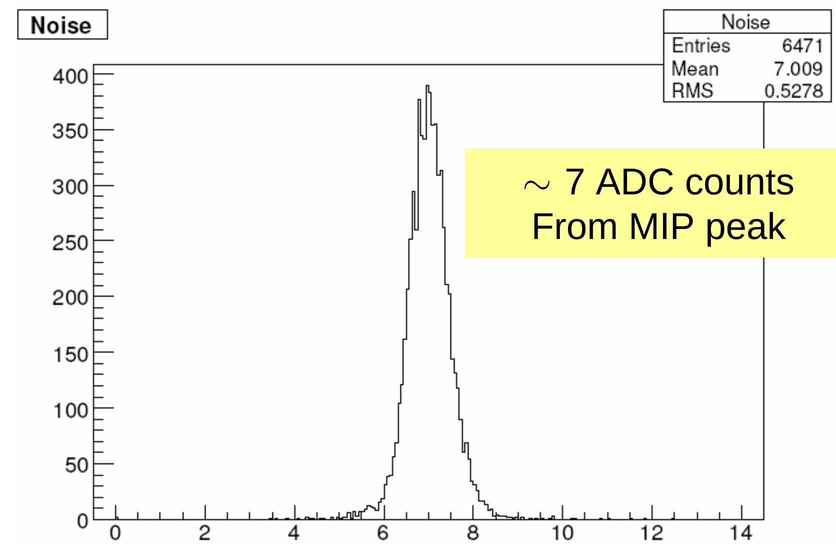


Si-W ECAL Calibration

- Pedestal data interspersed in normal data taking ⇒ running pedestal subtraction.
- Muon beam data from CERN used for calibration. Fit pedestal-subtracted MIP peak to Landau⊗Gaussian for each pad.
- MPV of Landau yields the gain value (ADC counts/MIP).
- Only 9/6480 pads dead. ~1% problematic (e.g. high noise).





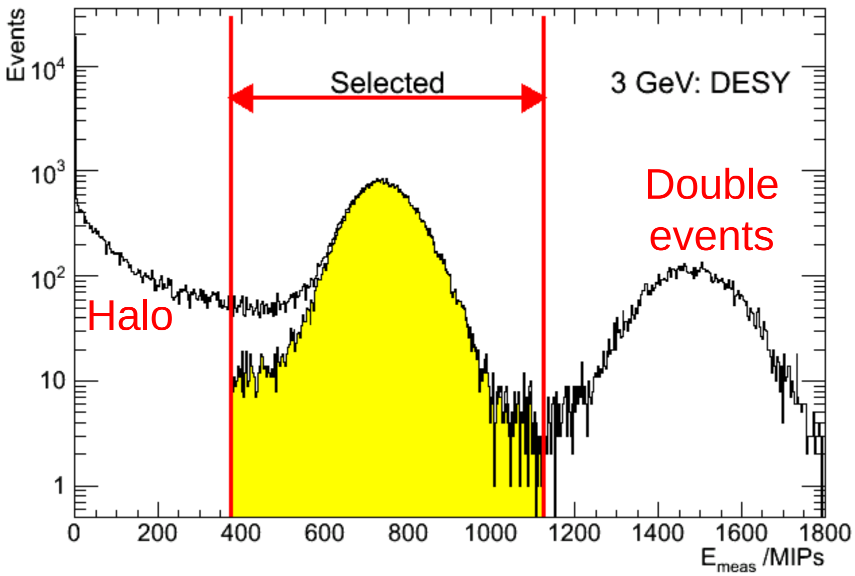


Si-W ECAL analysis

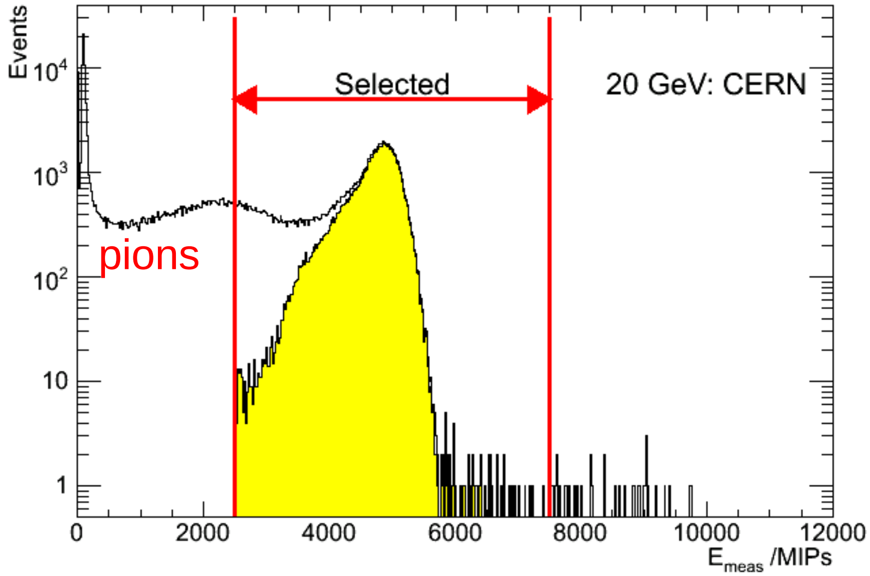
Electron selection.

Main cut is on Emeas=E(1-10)+2*E(11-20)+3*E(21-30)

1:2:3 reflects sampling fractions in three ECAL stacks.

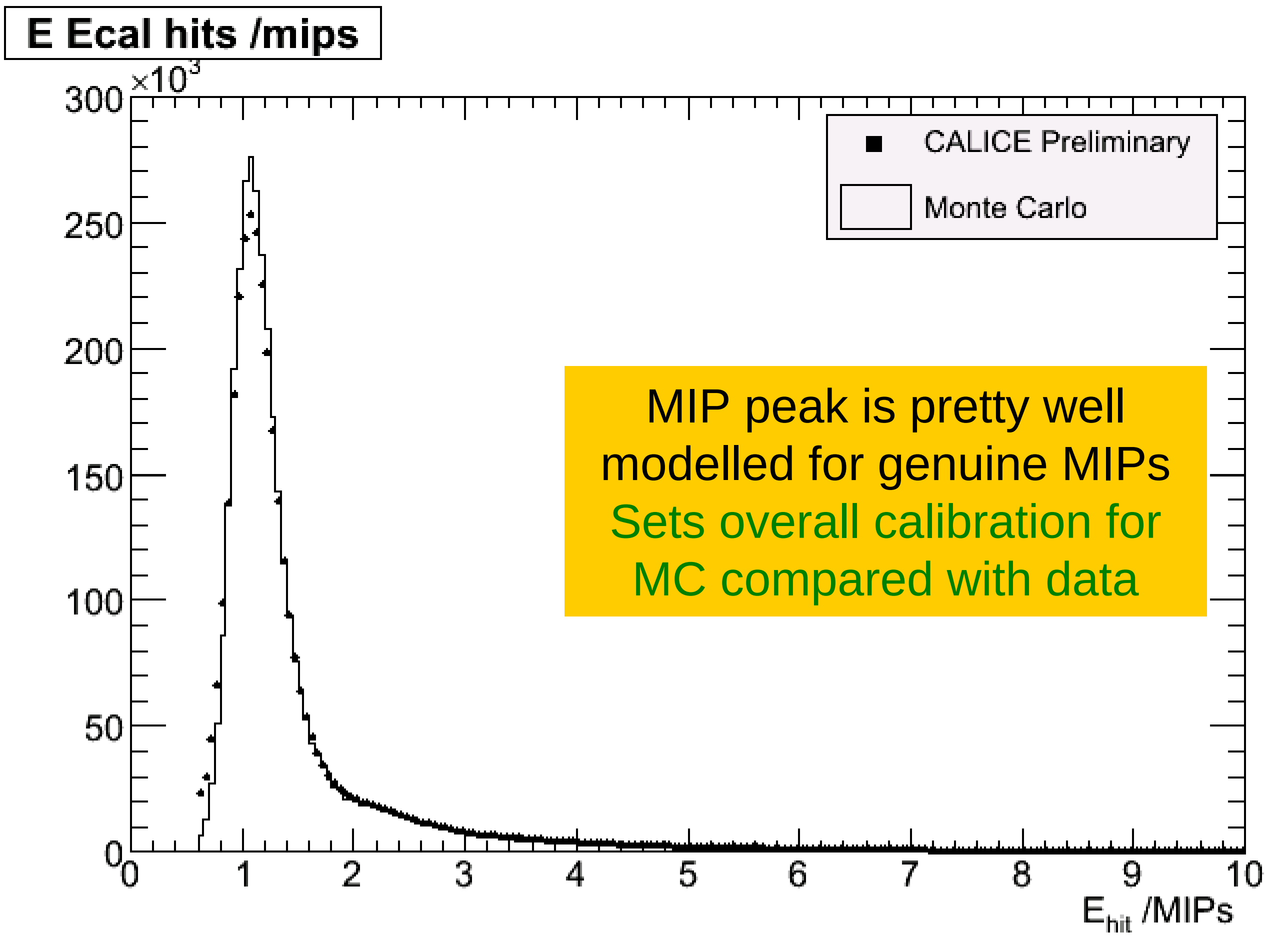


Cut against beam halo based on position of shower barycentre reduces low energy tail



Cerenkov used to reduce pion content

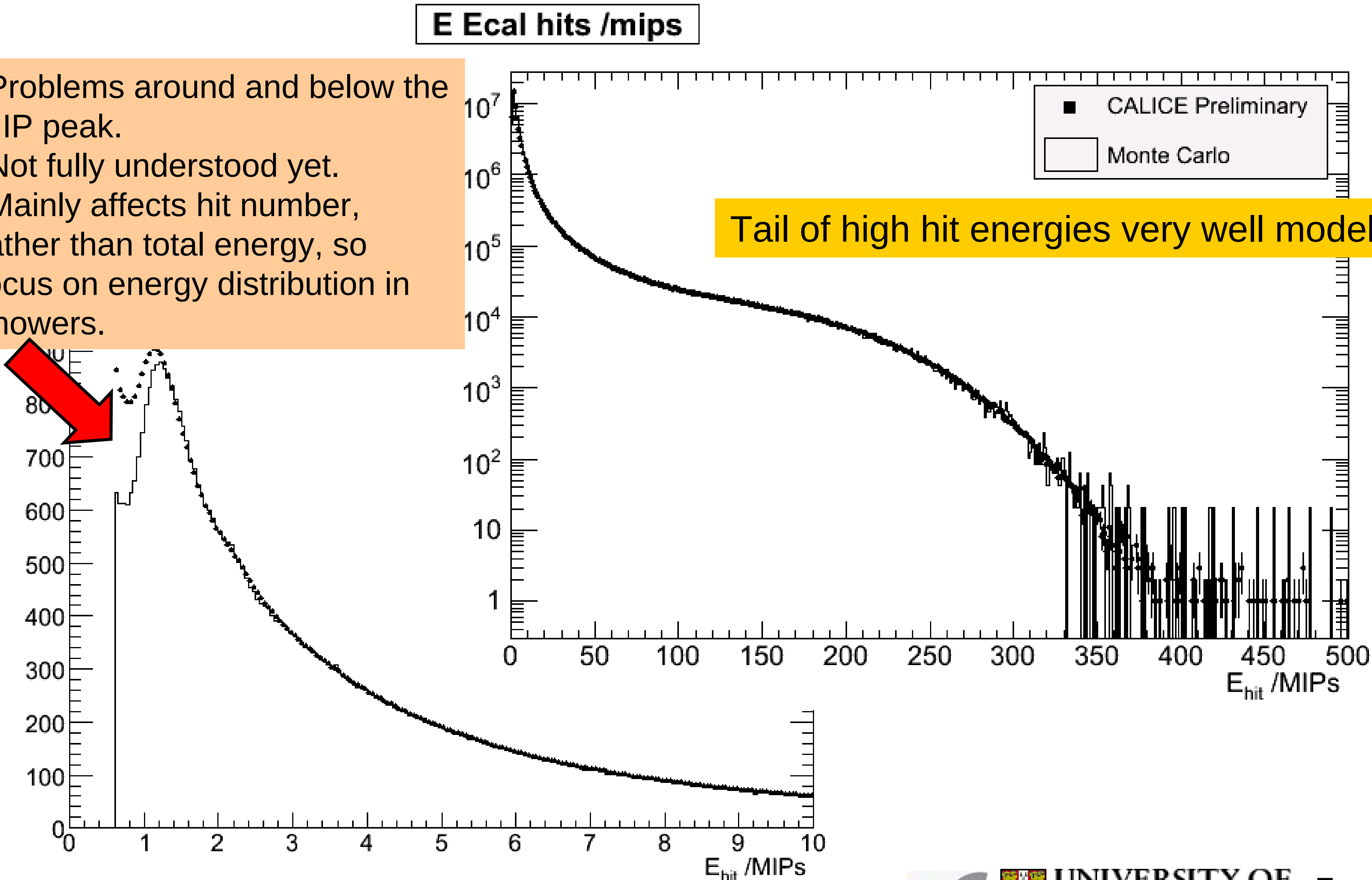
Hit energies – non-showering π^-



MIP peak is pretty well modelled for genuine MIPs

Sets overall calibration for MC compared with data

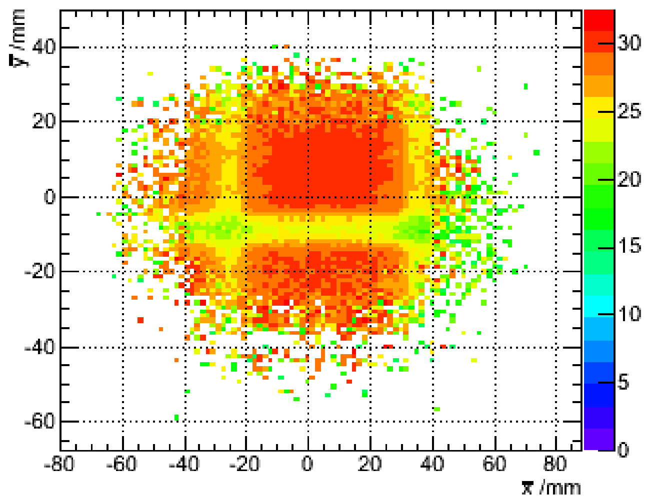
Hit energies – 30 GeV e^-

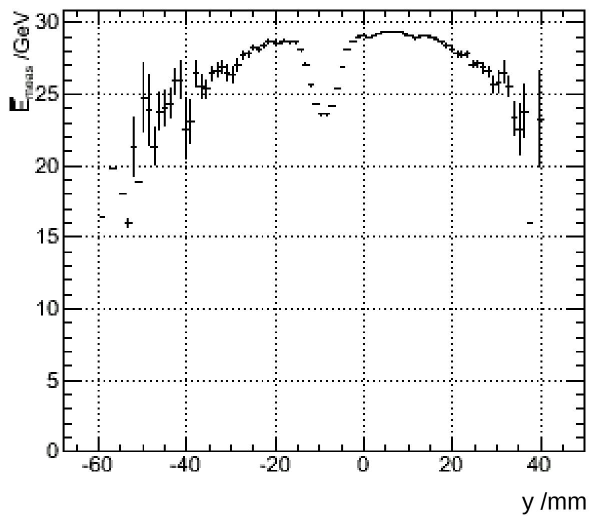


- Problems around and below the MIP peak.
- Not fully understood yet.
- Mainly affects hit number, rather than total energy, so focus on energy distribution in showers.

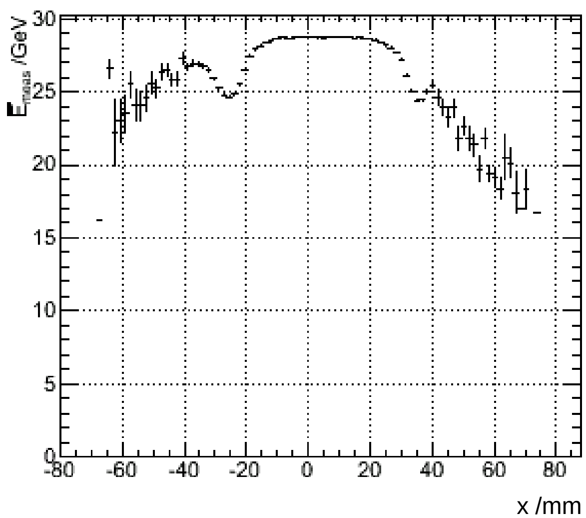
Tail of high hit energies very well modelled

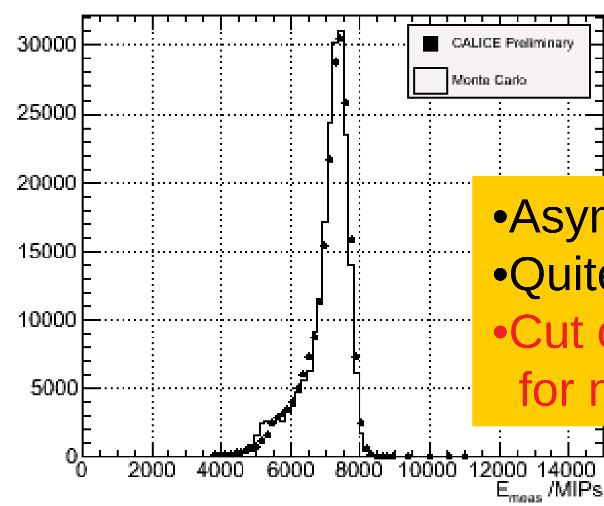
Effect of inter-wafer gaps (30 GeV e$^-$)





Guard rings $\rightarrow$ 2mm gaps between
6×6 cm^2 sensitive areas.
Corresponds to 7% of area.

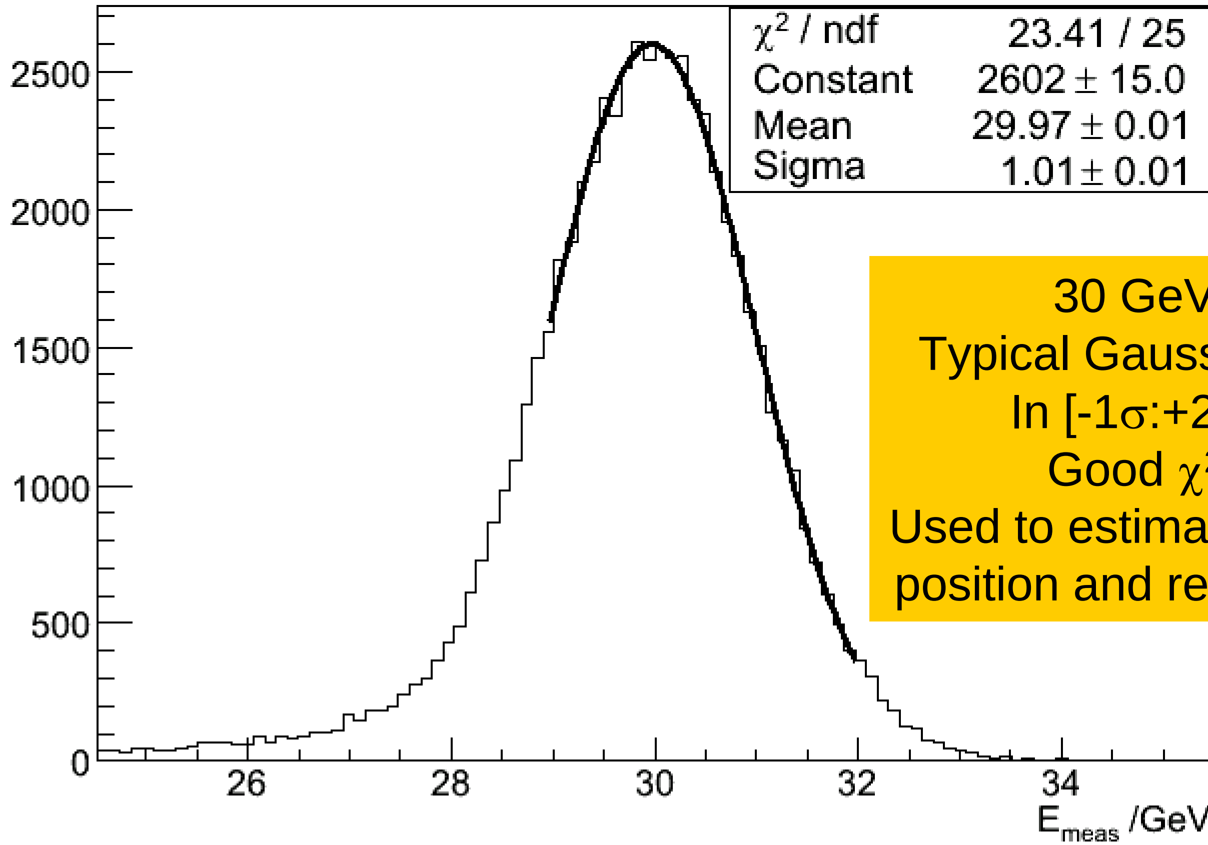




- Asymmetry caused by gaps.
- Quite well modelled by MC.
- Cut out showers near gaps for now…

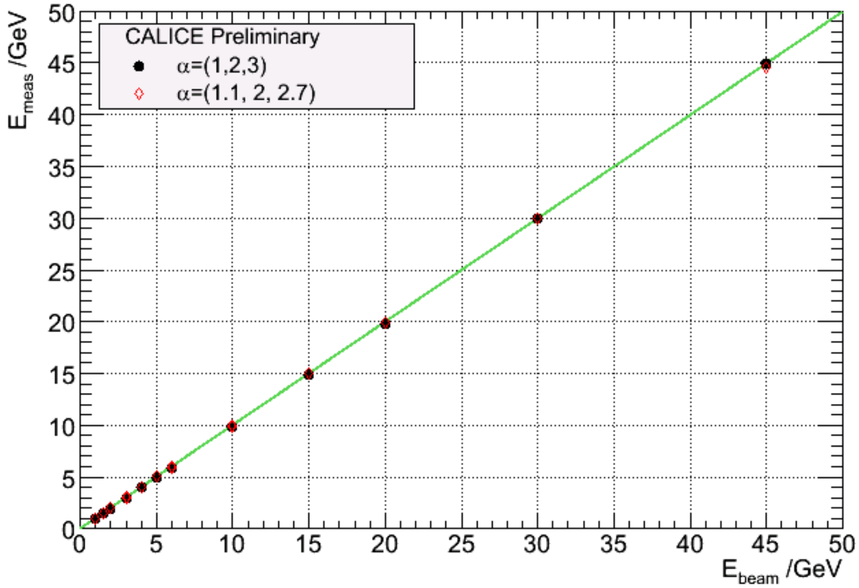
Fit to determine response+resolution

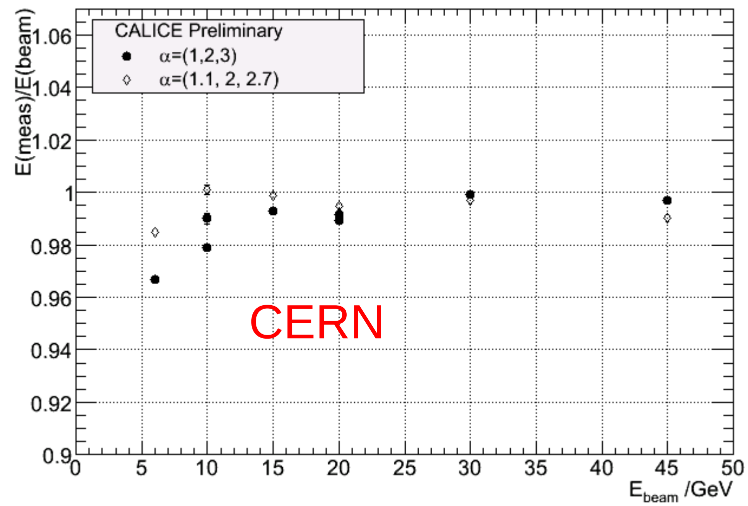
$E_{meas}=(\alpha_1 E(1\text{-}10)+\alpha_2 E(11\text{-}20)+\alpha_3 E(21\text{-}30)/\beta$
$(\alpha_1,\alpha_2,\alpha_3)=(1,2,3)$; $\beta=250.$

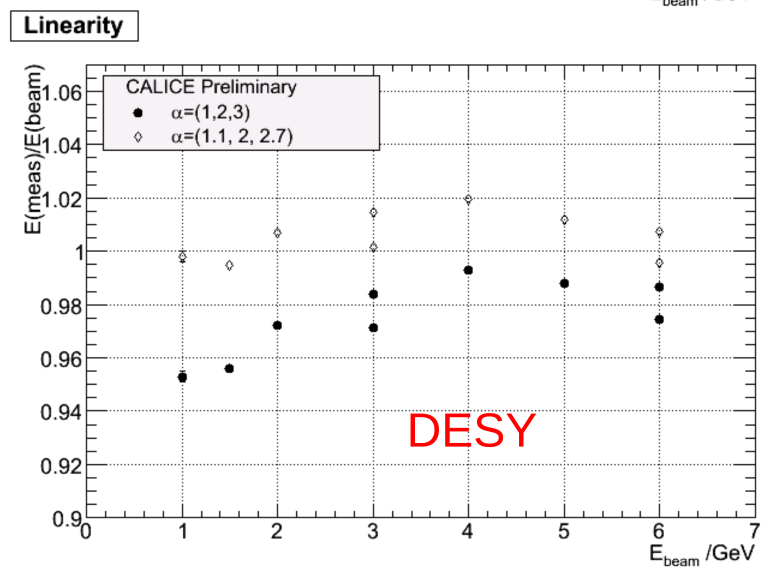


30 GeV
Typical Gaussian fit
In $[-1\sigma:+2\sigma]$
Good χ^2
Used to estimate peak position and resolution

ECAL Linearity (CERN+DESY data)



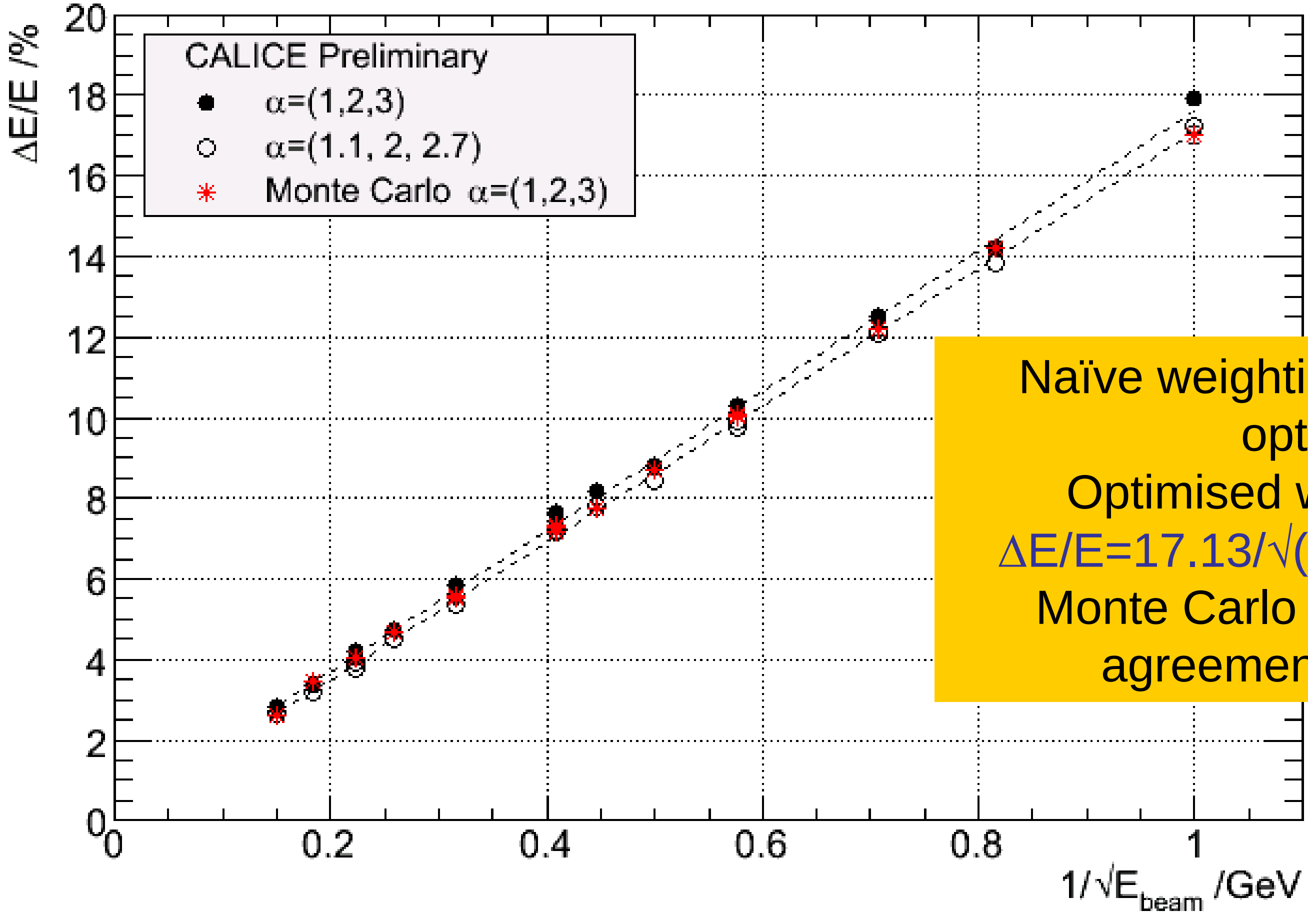




Compare two possible weighting schemes
Non-linearities at $\sim$ 1% level

n.b. missing layers in DESY data

ECAL Resolution (CERN+DESY)



Naïve weighting not far from optimal

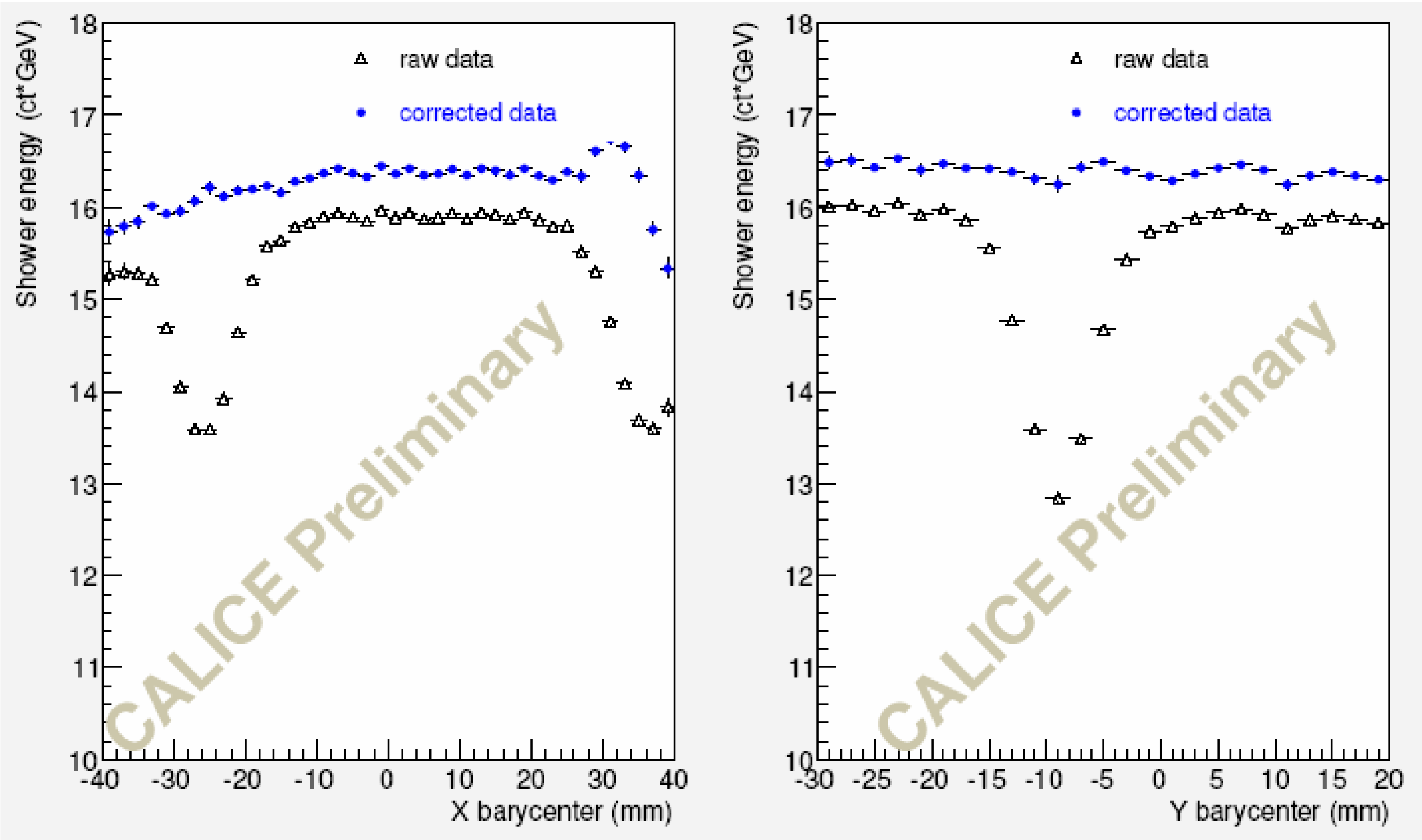
Optimised weights yield

$\Delta E/E = 17.13/\sqrt{(E/\mathrm{GeV})} \oplus 0.54\%$

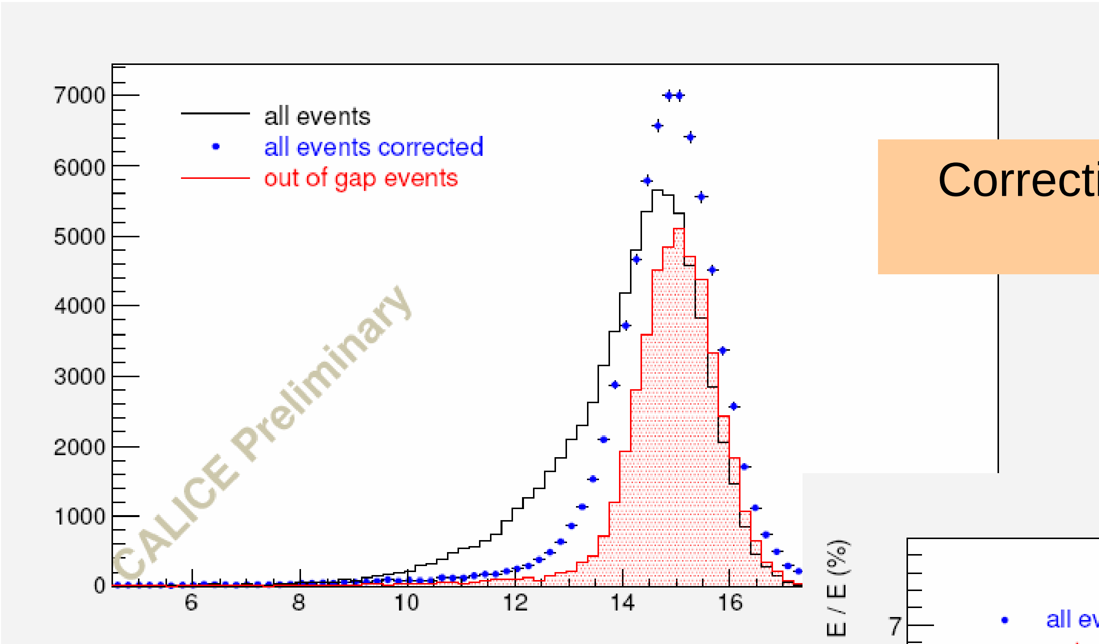
Monte Carlo in pretty good agreement with data

Gap correction (global)

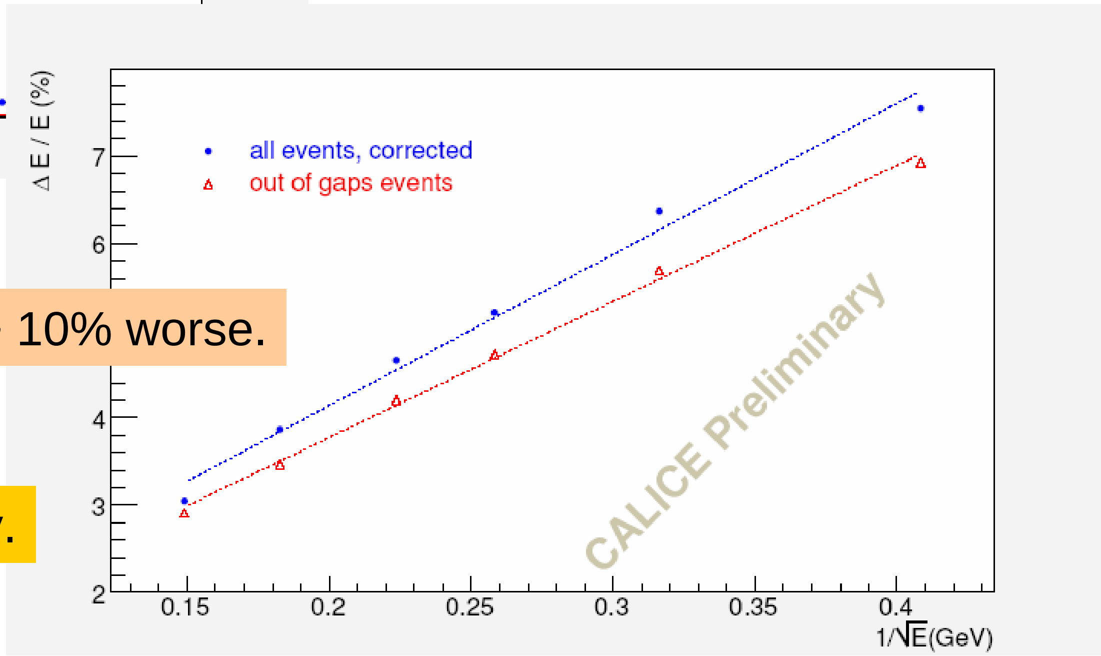
Gaussian parametrisation of energy loss close to gaps.
Enables a good smoothing of the dips (at normal incidence)



Effect of gap correction



Correction largely removes asymmetry in reconstructed energy

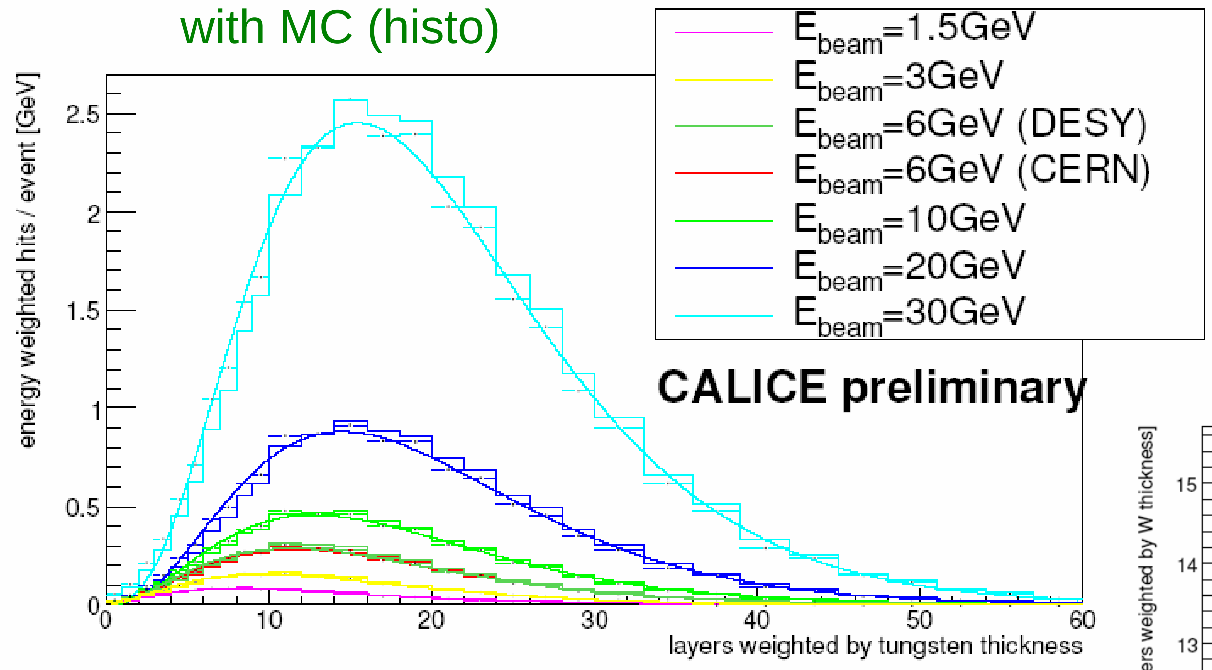


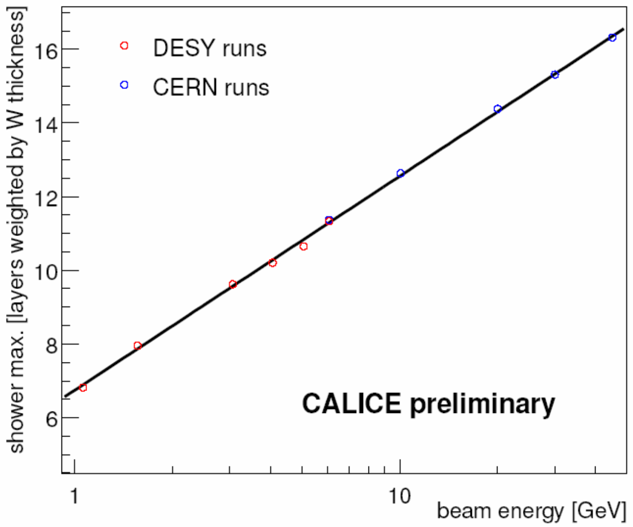
Resolution is ~ 10% worse.

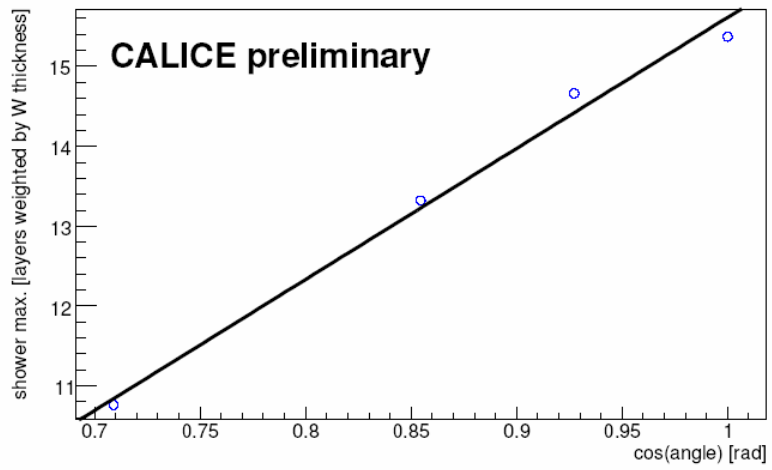
Other approaches also under study.

Longitudinal Profile

Compare data (points+errors) with MC (histo)



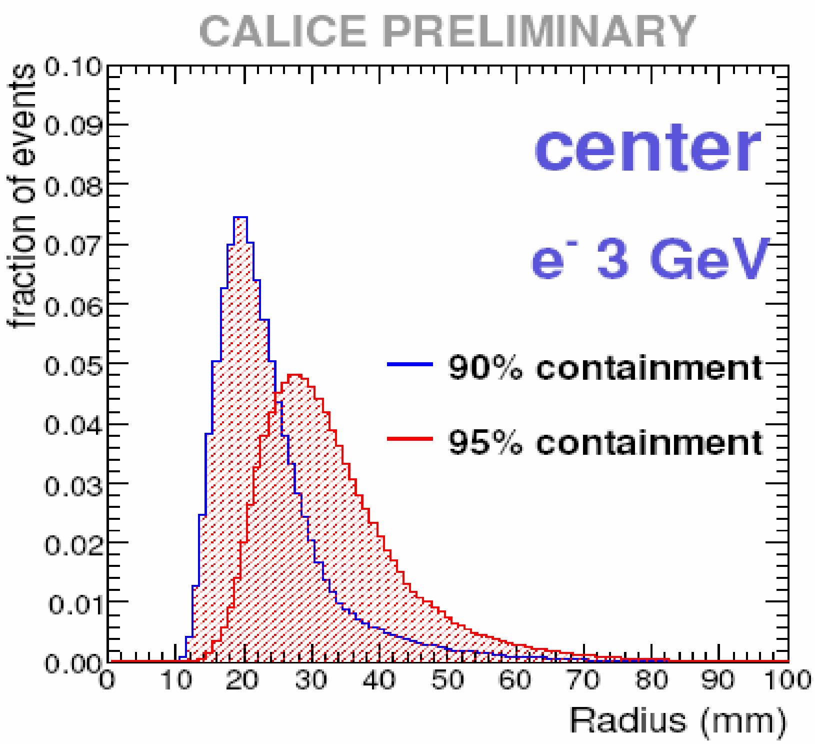


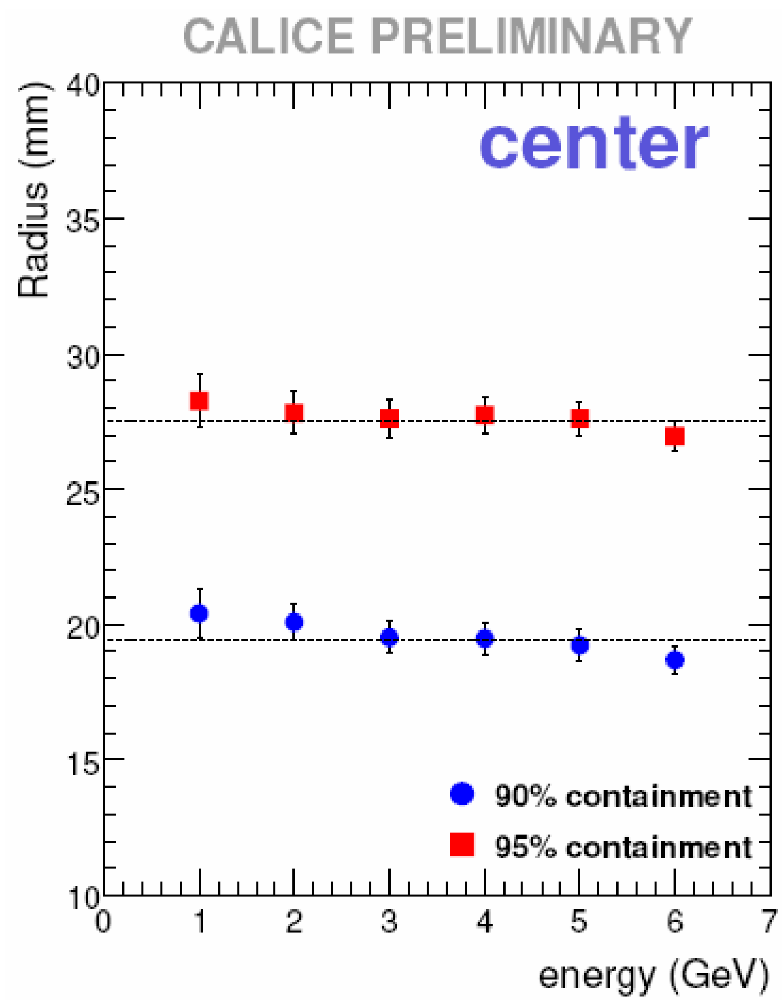


Expected logarithmic growth of shower max with energy;
Increases with cosθ

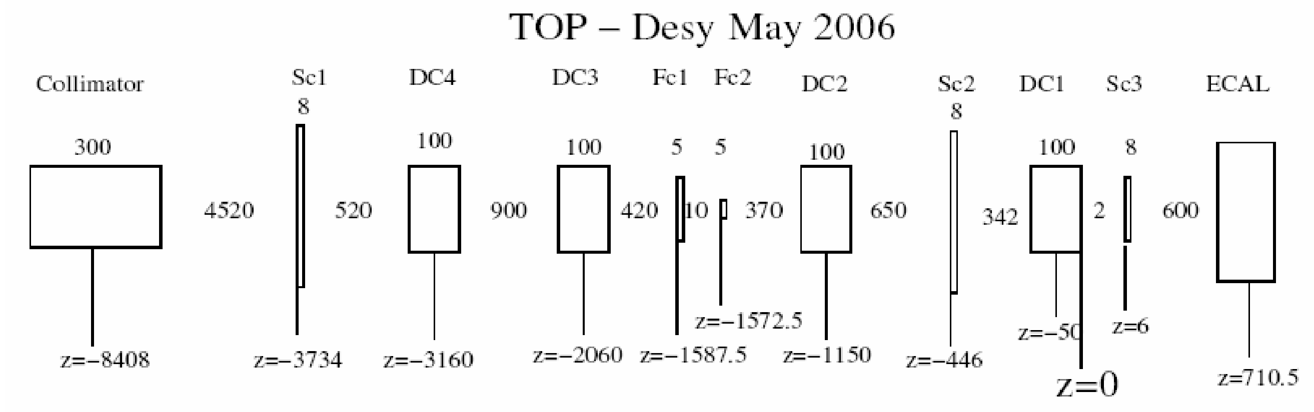
Transverse profile

- •Molière radius for W $\sim$ 9mm
- •About 84 mm of total 200 mm depth of ECAL is W
- •Expect 90% of energy contained in effective Molière radius

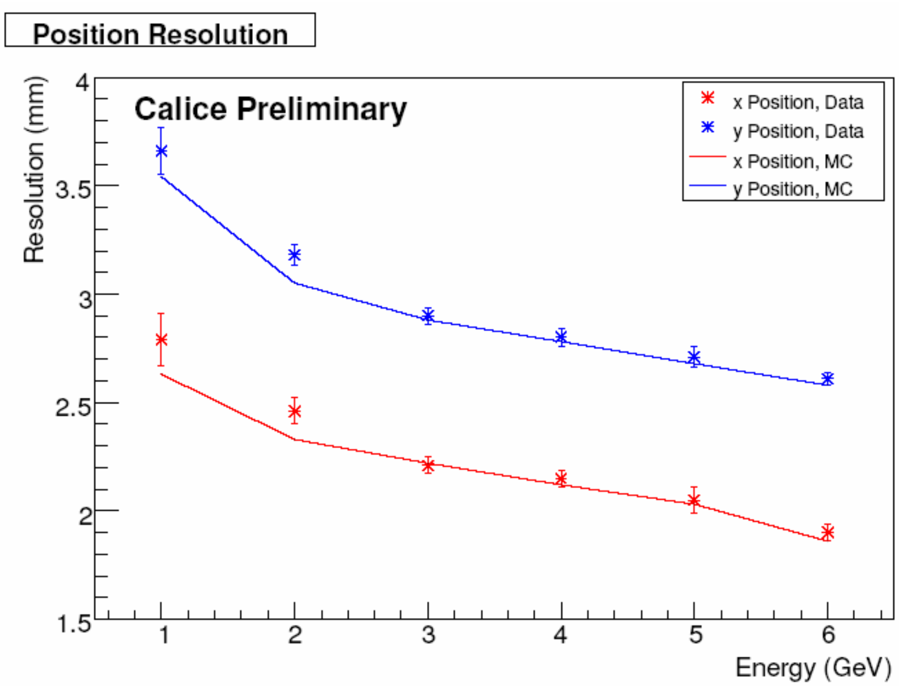


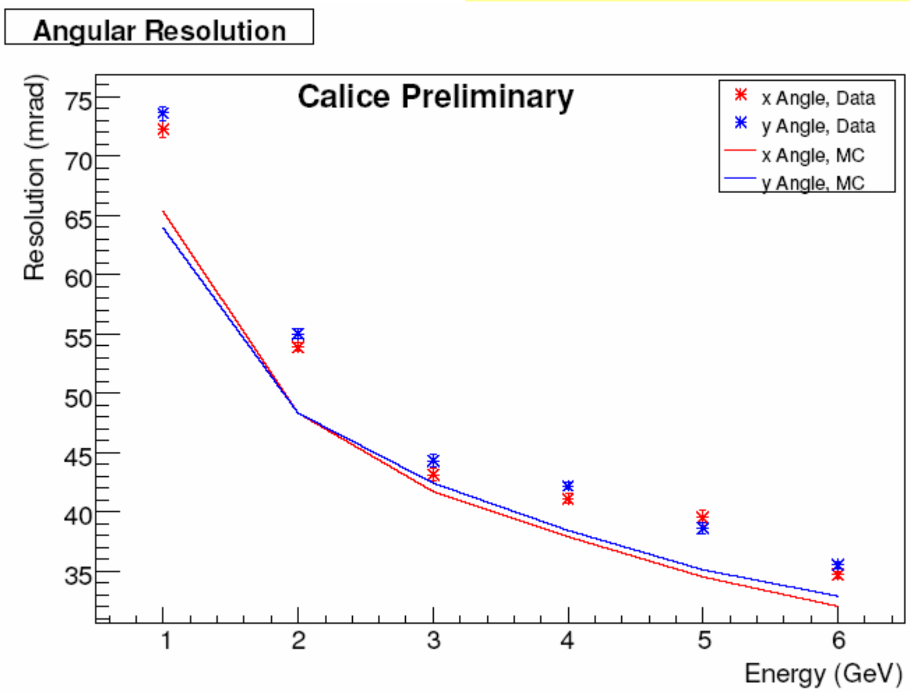


Position and angular resolution



Drift chambers in beam line used to reconstruct electron position and angle at ECAL; compare with reconstructed shower.

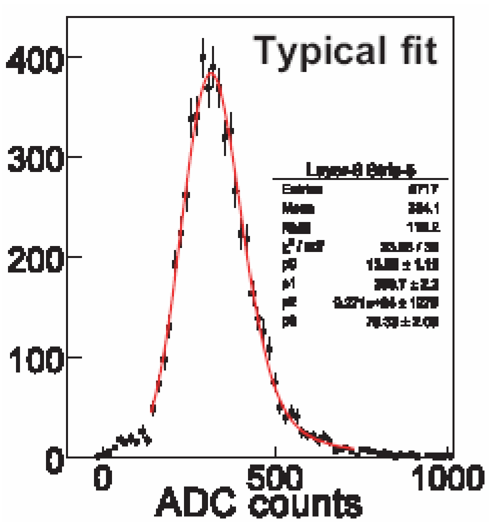




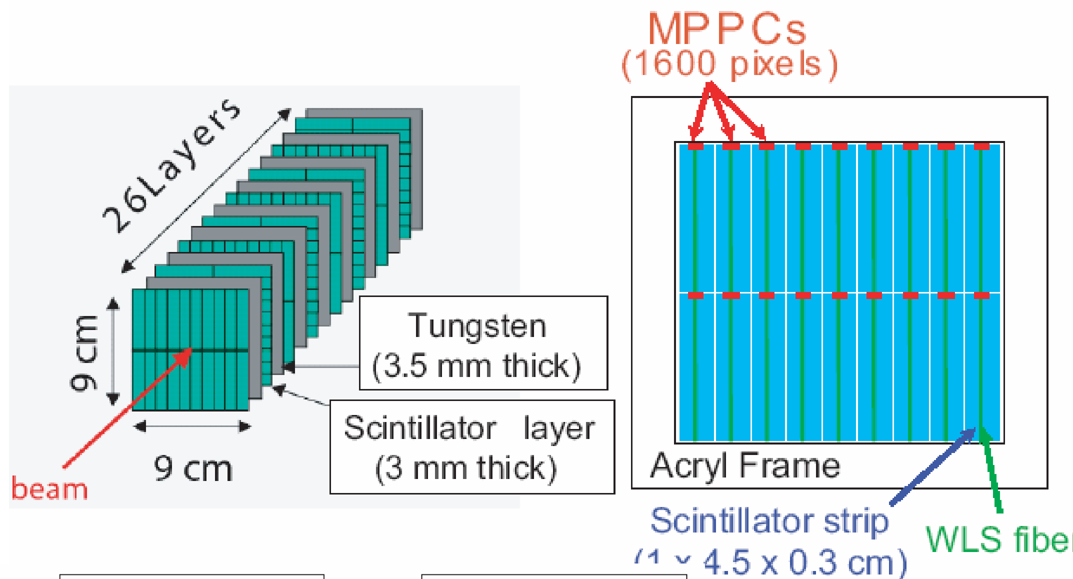
Scintillator-Tungsten ScECAL

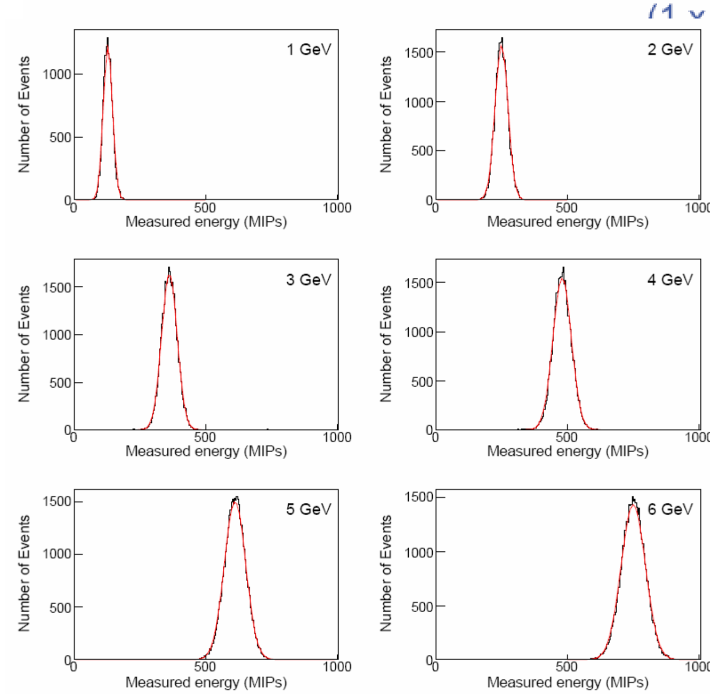
Data recorded March 2007 @ DESY

See talk by T.Takeshita



Calibration – use MIPs in positron beam runs without absorber layers. Typical (Landau⊗Gaussian) fit.

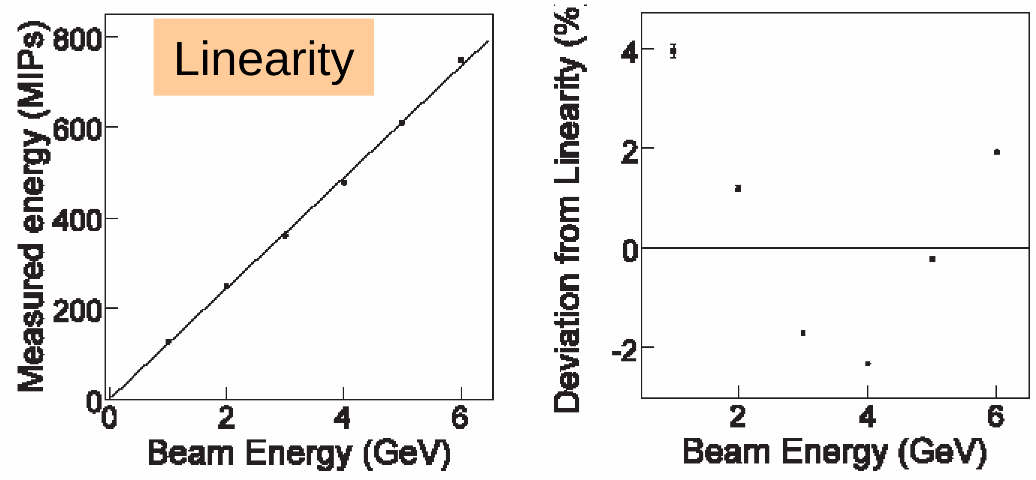




Fits to calorimeter response

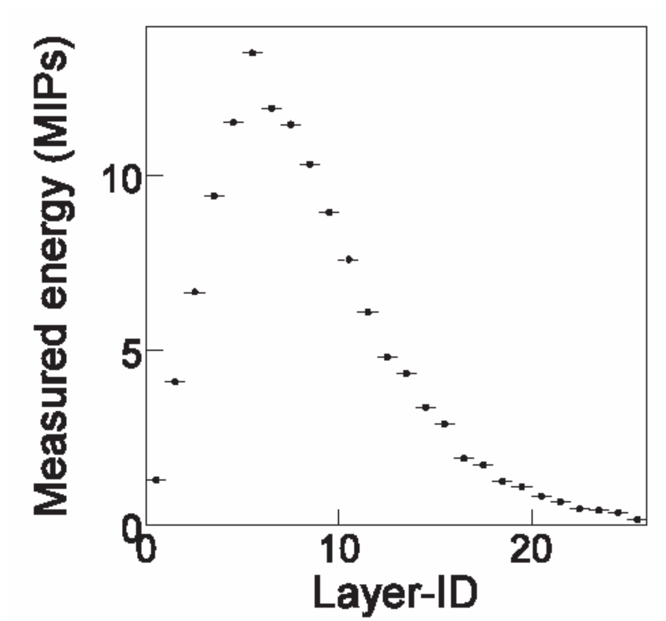
Calorimeter Review:
LCWS'07 DESY 31/05/07

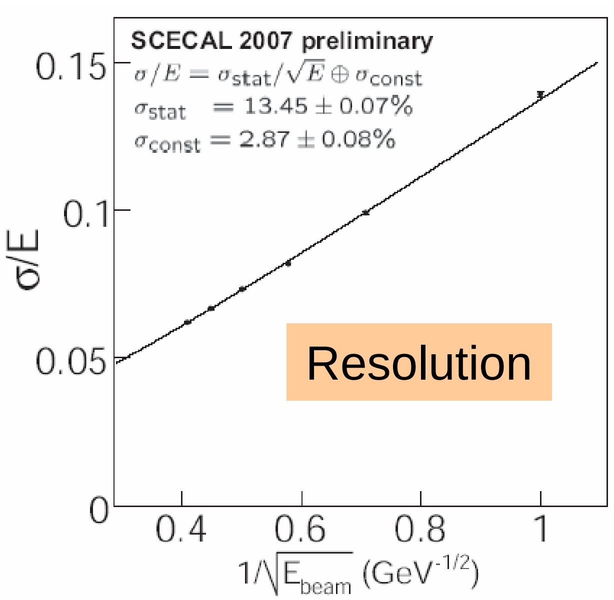
First ScECAL results



Some non-linearity seen.
n.b. no corrections for
MPPC non-linearity yet.

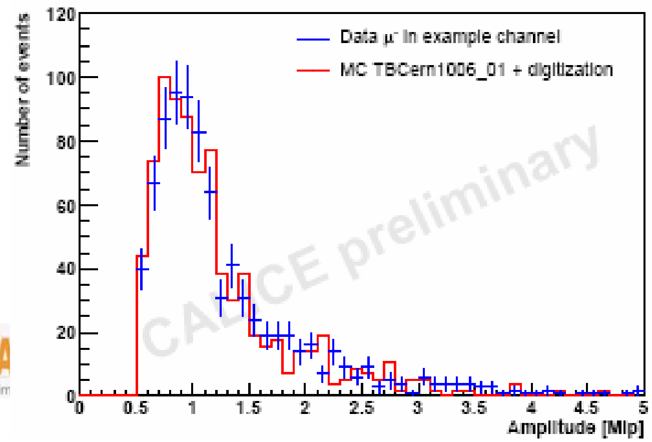
Longitudinal profile



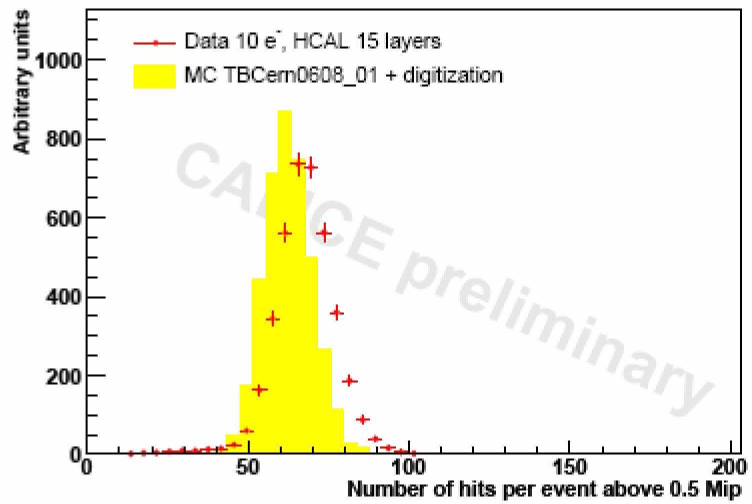


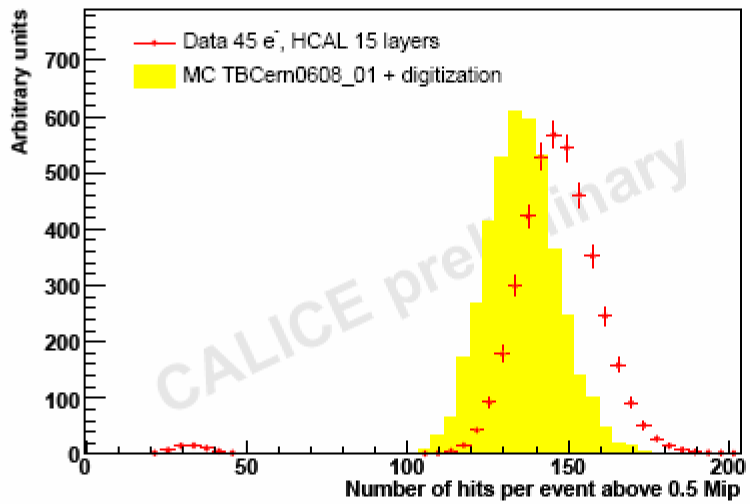
AHCAL analysis

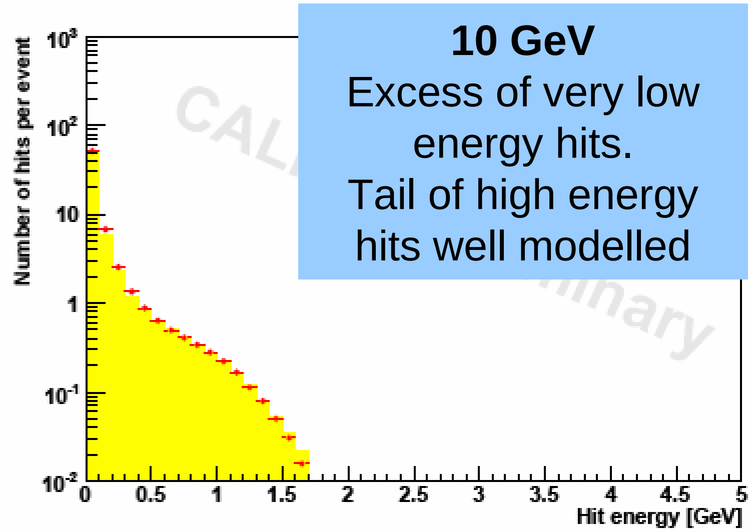
- Electromagnetic showers (electrons+muons) important for evaluation of calibration corrections, monotoring performance of detector.
- Then move on to hadrons, whose simulation is more uncertain.
- Calibration is much more complicated than Si-W ECAL.
  - Muons to get MIP calibration; equalise response, zero suppression
  - SiPM non-linearity corrections. Lab calibration and LED light injection system. Electron showers especially sensitive
  - Temperature – 1°C $\rightarrow$ 3% systematic uncertainty
  - Only 3.7% of channels not calibrated; of which about half dead.
- Look at early data (August 2006) with 15 planes – adequate to contain electromagnetic showers (29 X_0). Though there was correlated noise (now fixed).
- Monte Carlo digitization is needed to approach agreement between data and MC.
  - Cross talk; non-linearity + Poisson statistics at pixel level; noise; kill dead channels.



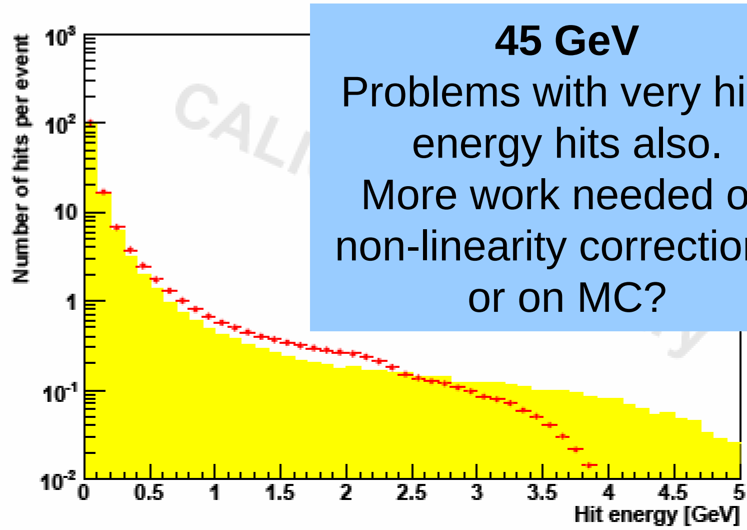
AHCAL electrons







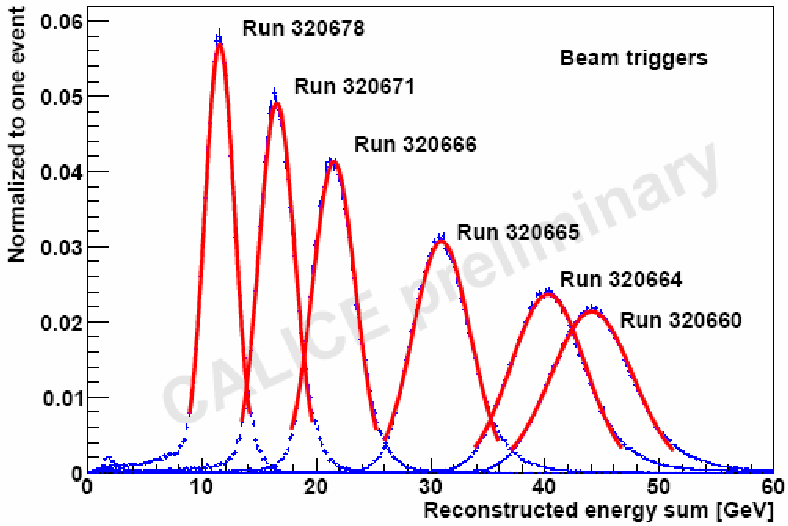
10 GeV
Excess of very low energy hits.
Tail of high energy hits well modelled



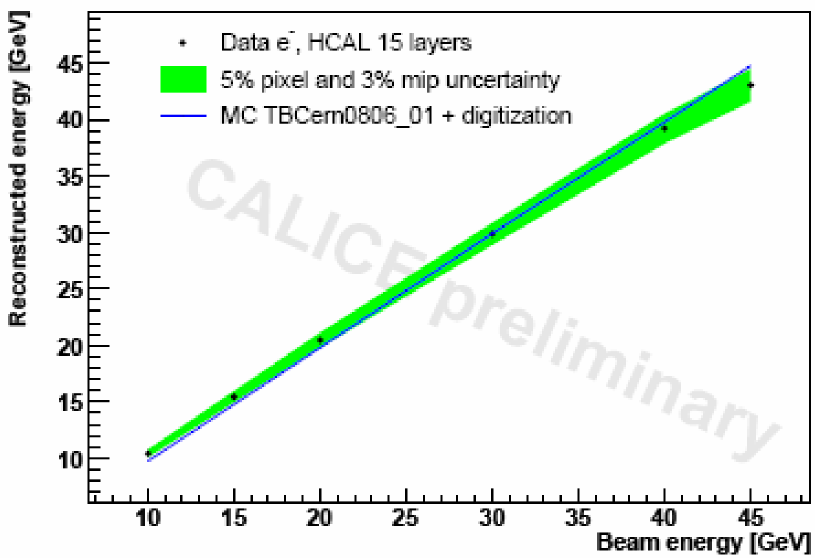
45 GeV
Problems with very high energy hits also.
More work needed on non-linearity corrections, or on MC?

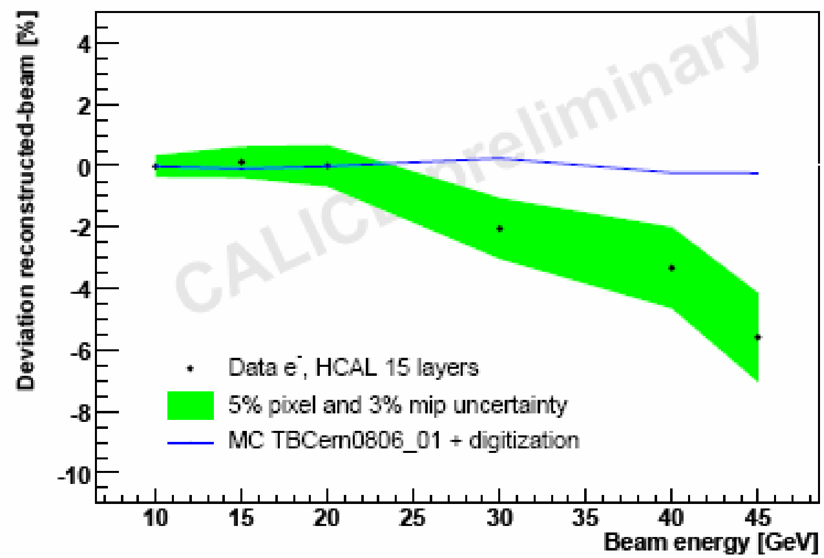
David Ward

AHCAL – e⁻ linearity

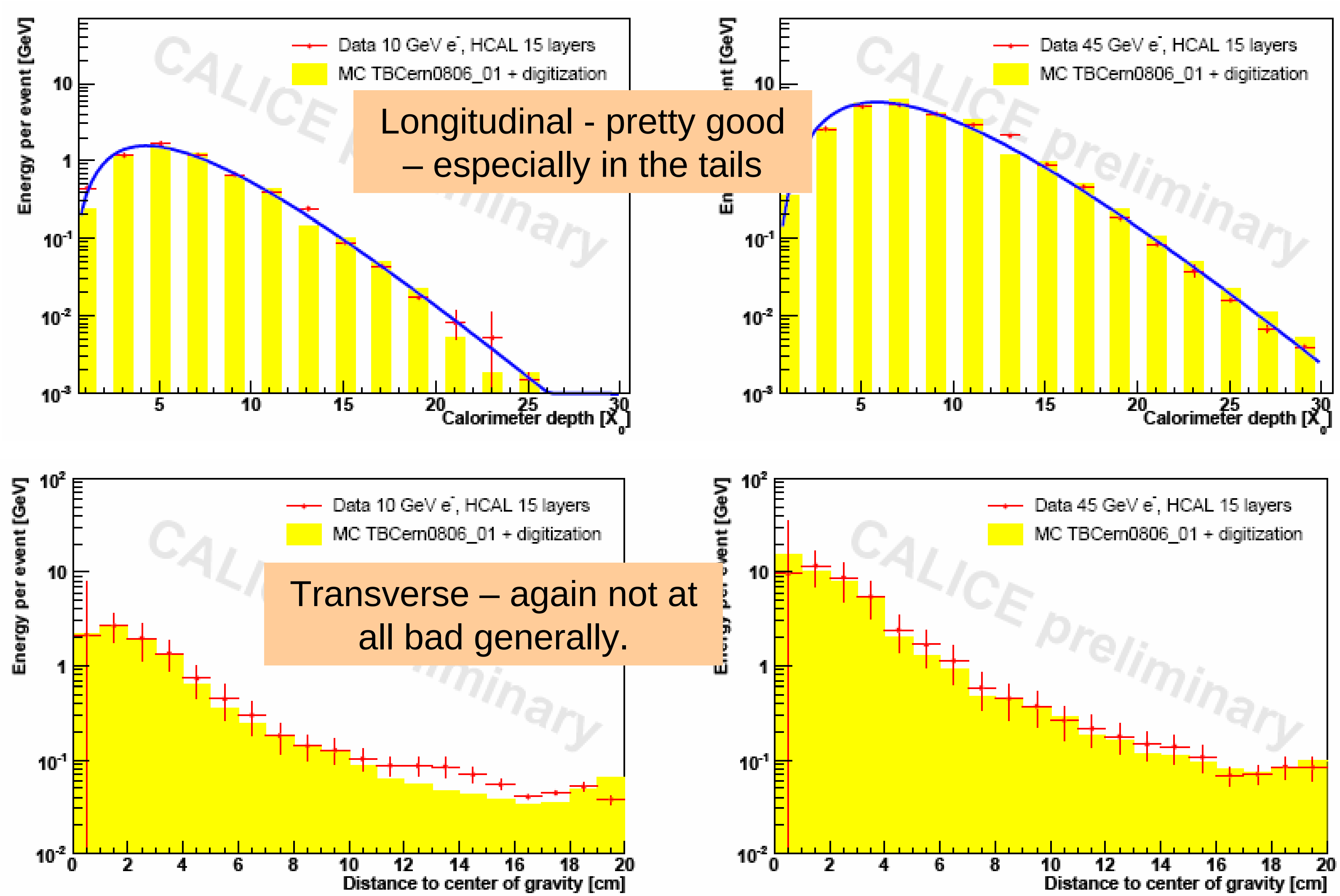


- Gaussian fits to determine response and resolution.
- Response: linearity pretty good up to 20 GeV, but deviation by ~ 5% by 45 GeV in data.
- MC is better – suggests non-linearity corrections not quite under control yet.





AHCAL e$^-$ shower profiles

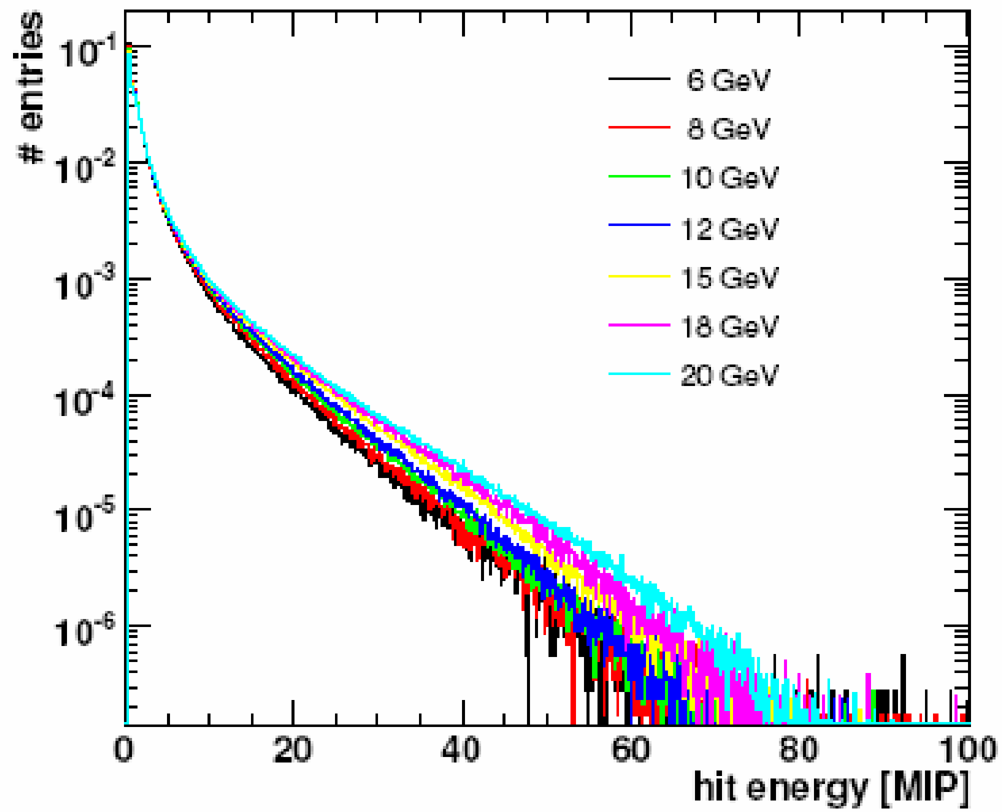


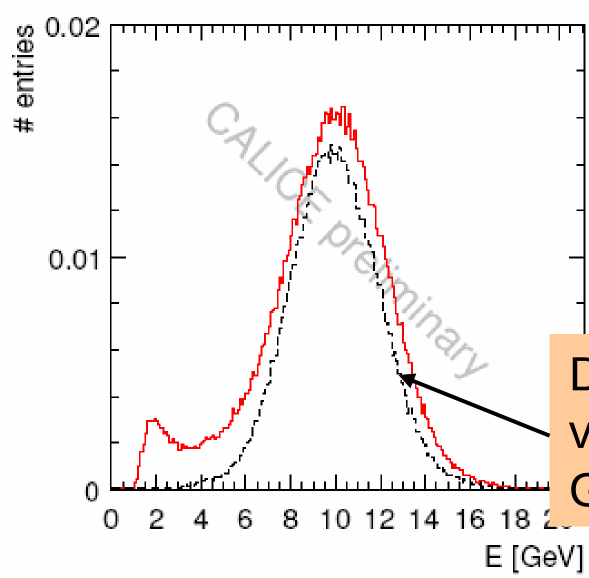
Longitudinal - pretty good – especially in the tails

Transverse – again not at all bad generally.

AHCAL – look at pions?

- Actually less sensitive than electrons to SiPM non-linearity corrections.
- E.g. 20 GeV pion, only 3% of hits > 20 MIP, at which point non-linearity = 10%.
- Data taken from 6-50 GeV. Just looking at a fraction of the data here, taken in a short time period.



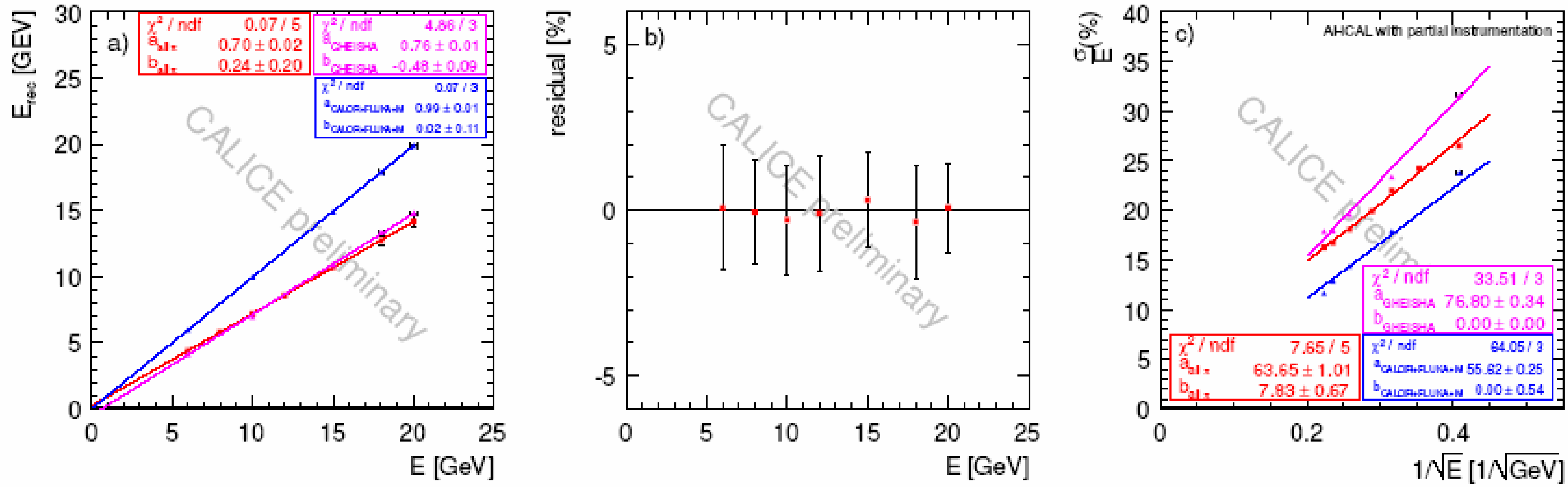


Demand minimal ECAL energy. Then use TCMT to veto leakage; select contained showers (black curve). Gaussian fit in $\pm 1.5\sigma$ to get response + resolution

AHCAL pion linearity + resolution

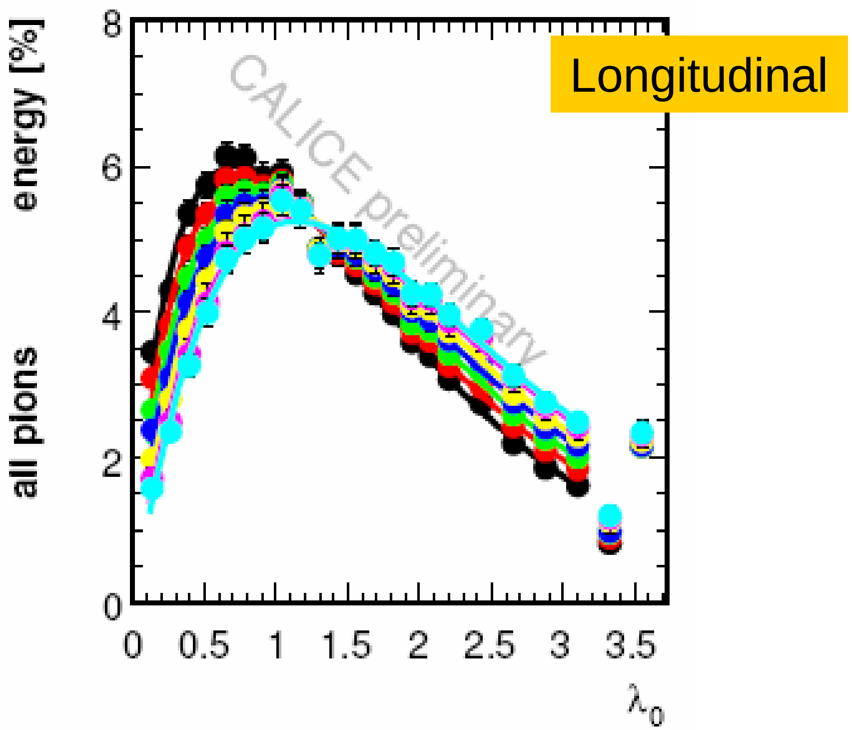
Linearity + residuals

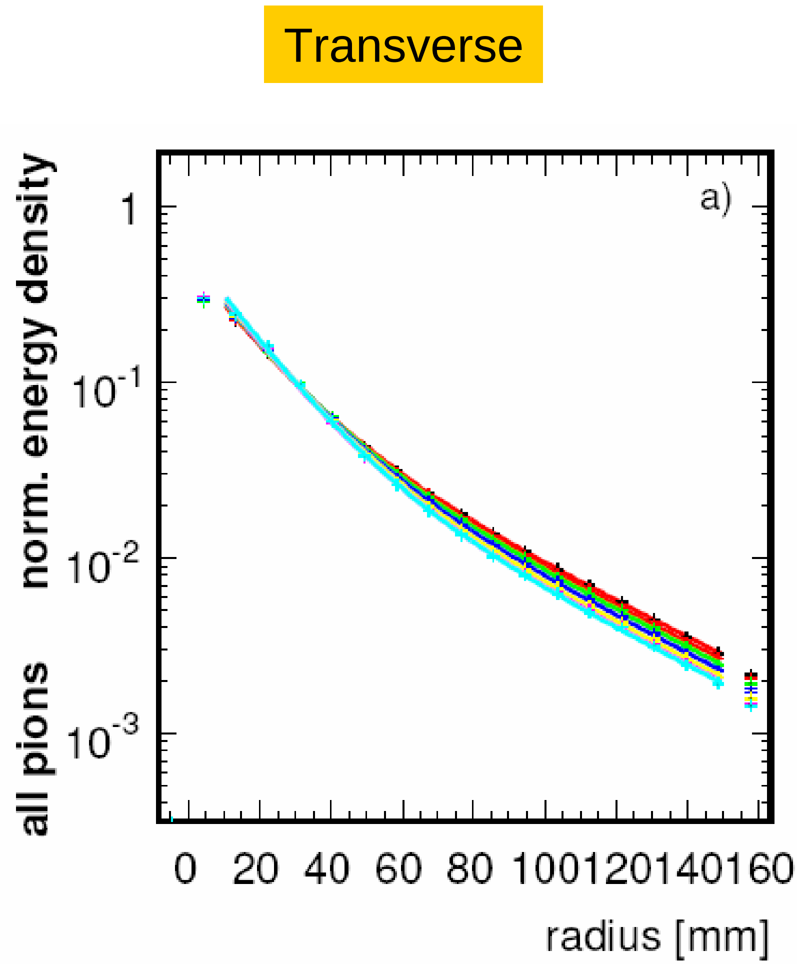
Resolution

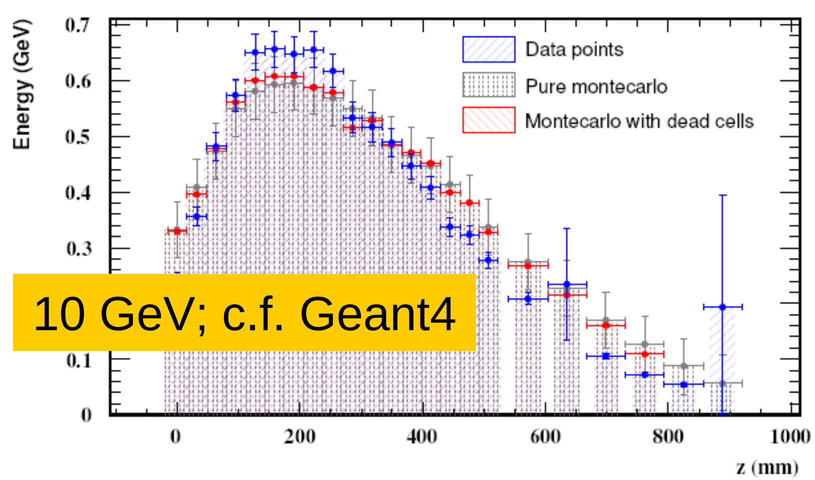


Data (red) compared with two Monte Carlo models (both GEANT3 in this case).
Resolution in the range indicated by MC predictions.
Clearly will tell us something useful about Monte Carlo models.
Not drawing any conclusions yet.

AHCAL pion energy profiles





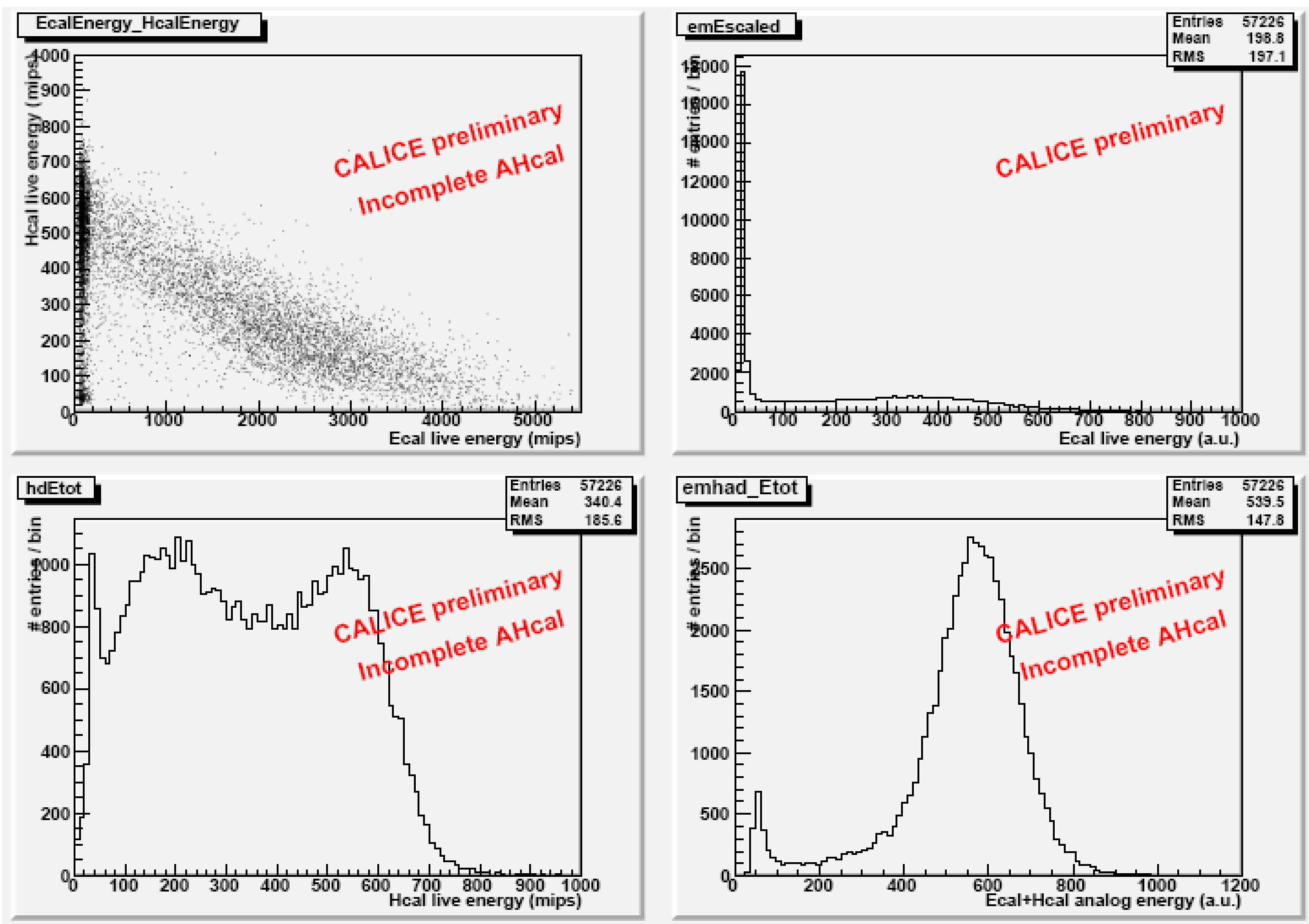


HCAL – longer term plans

- Important feature in future will be “deep analysis”.
- i.e. explore substructure in hadronic showers (electromagnetic component, MIP-like, neutrons etc.)
- This will certainly be sensitive to hadronic Monte Carlo models.
- Also important for particle flow – algorithms like PandoraPFA exploit substructure in showers to improve pattern recognition – need to compare these aspects between Monte Carlo and data.
- Will include all calorimeters, not just HCAL.
- Work started, but no public results yet.

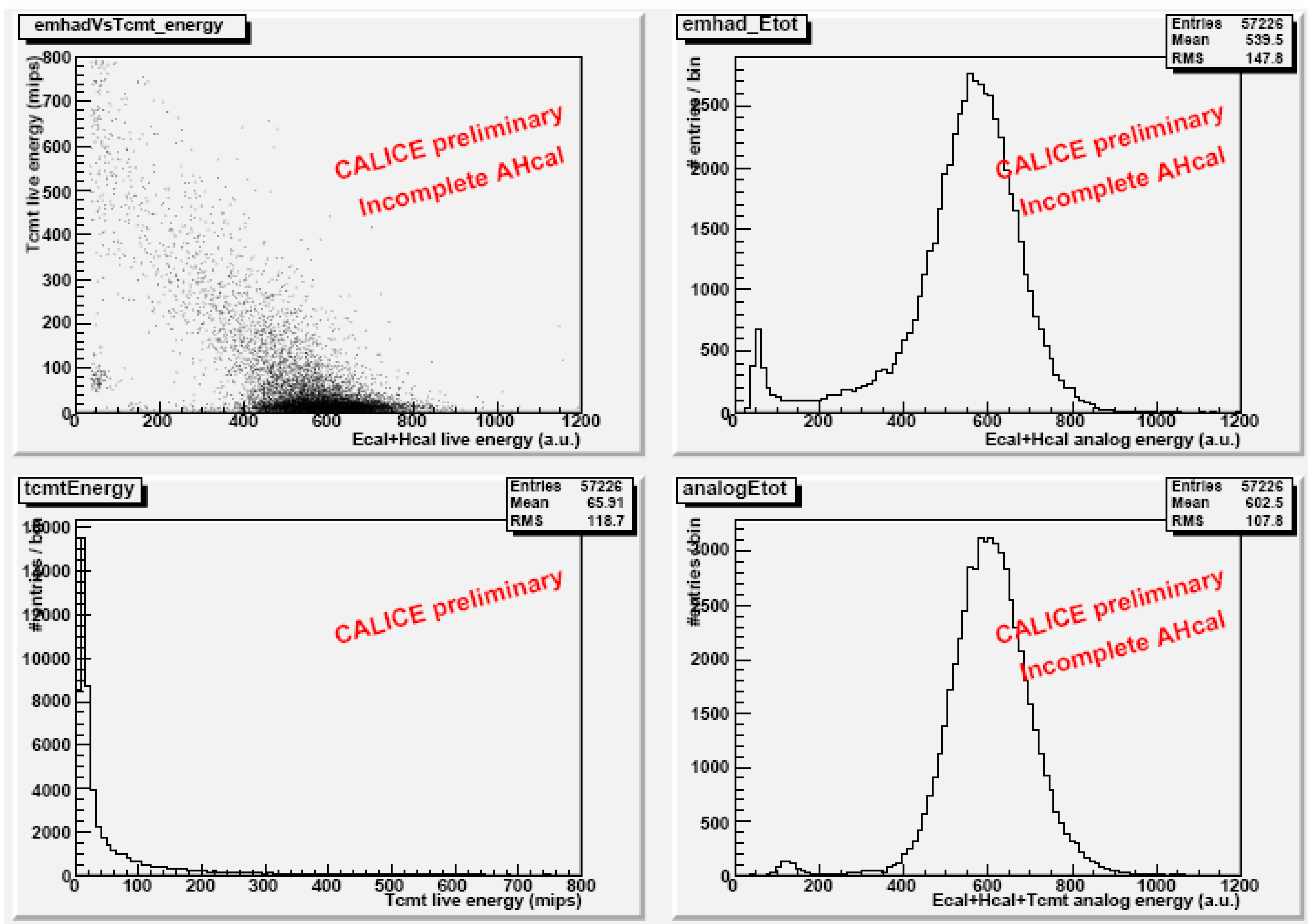
Combined ECAL/AHCAL/TCMT analysis

Correlate ECAL and AHCAL energies. 20 GeV π^-

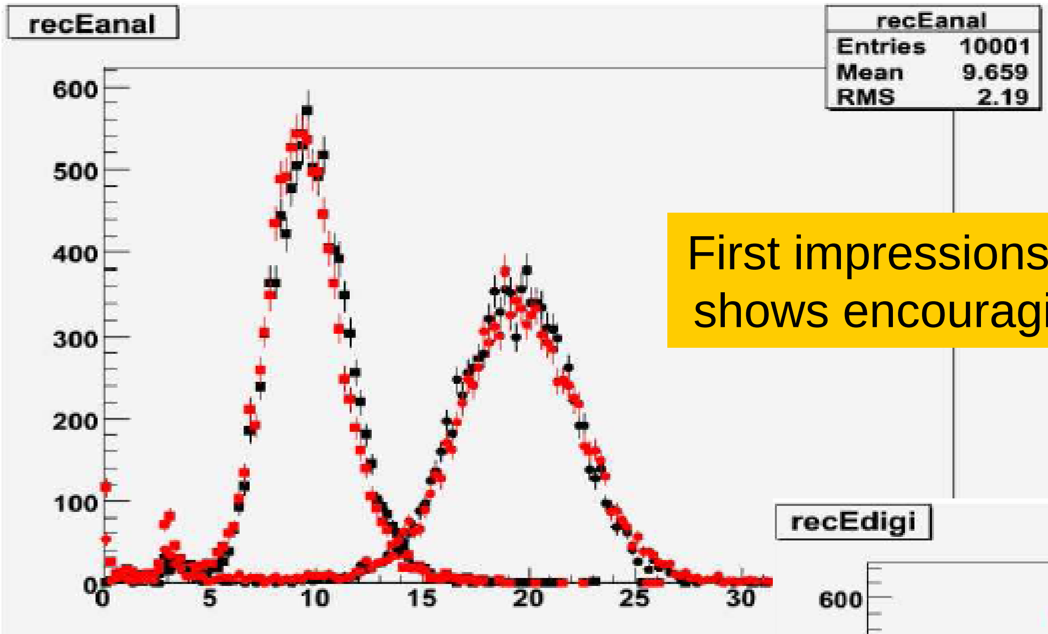


Combined ECAL/AHCAL/TCMT analysis

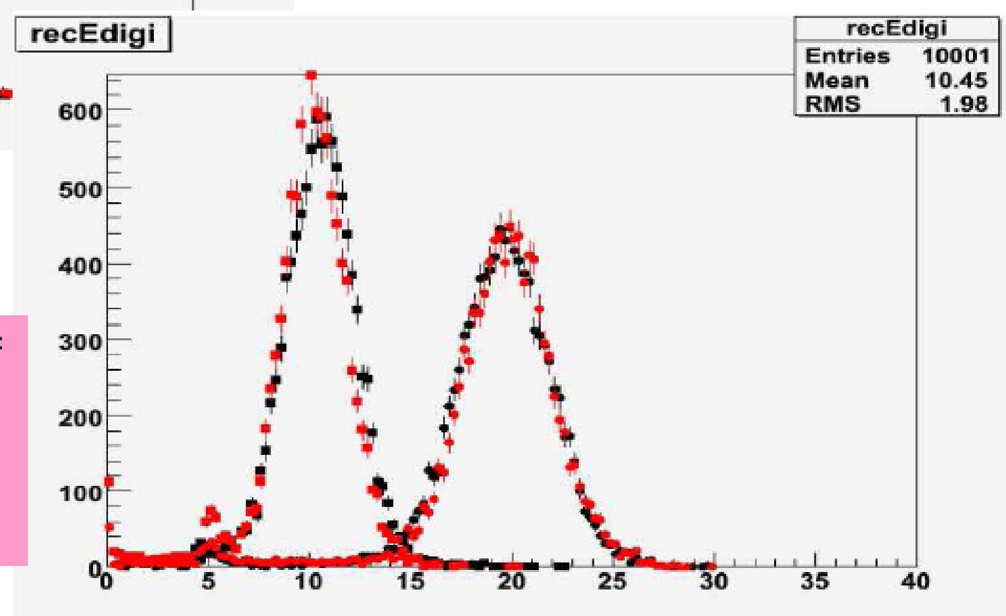
Now correlate ECAL+AHCAL energy with TCMT 20 GeV π^-



Compare with Monte Carlo



First impressions – Geant 4 Monte Carlo shows encouraging agreement with data



Can also explore other ways of using the data. For example, emulate (semi-)digital treatment of data.

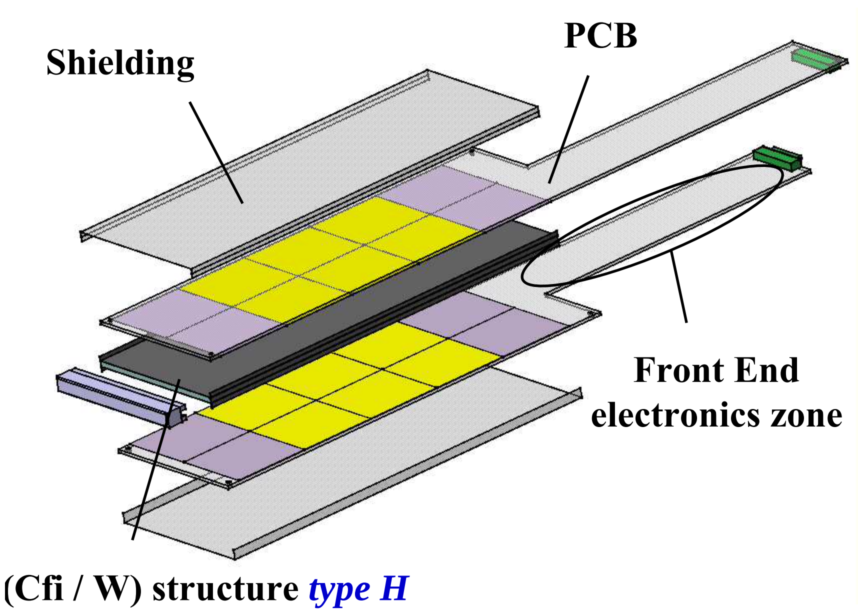
Summary

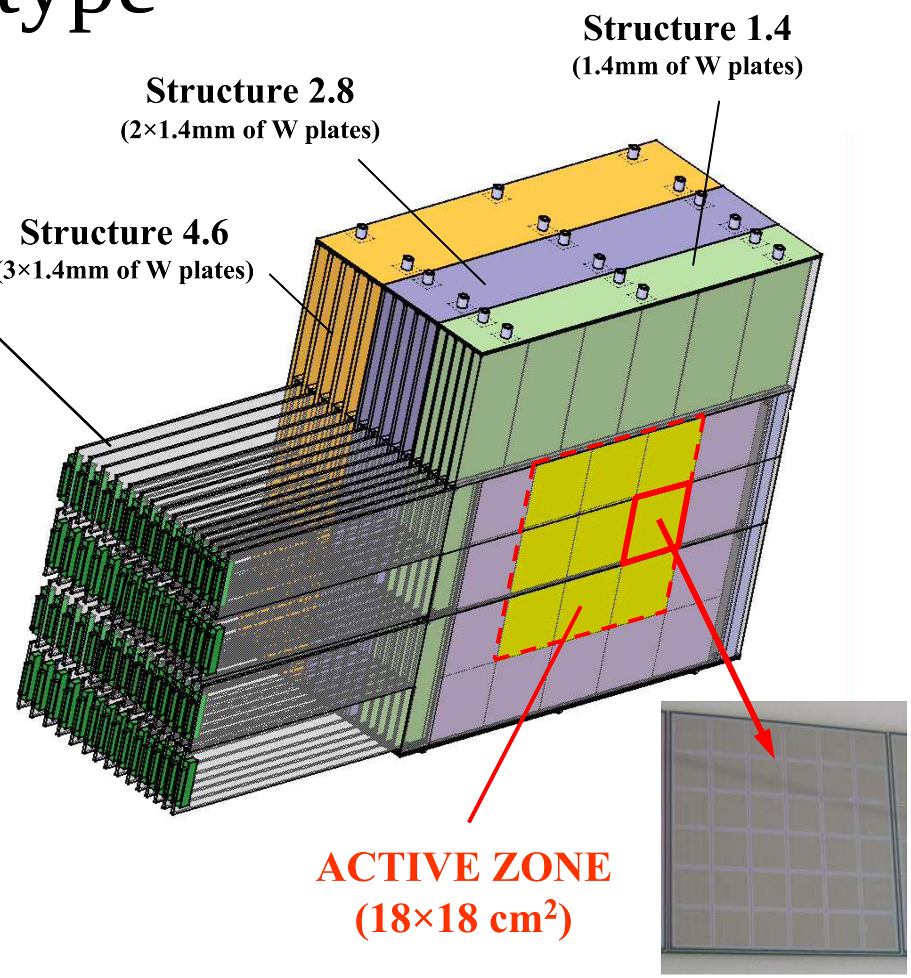
- 6 months since CERN test beam ended (and 2 months since ScECAL tests); good progress in understanding detectors.
- Initial work technical - focussed on electromagnetic processes; understanding calibration, hardware effects.
- First look at hadronic showers already encouraging.
- Rich source of information for many interesting studies.
- Longer term objective – our results provide key inputs to ILC detector optimisation studies:
  - Understand Monte Carlo digitization issues of realistic detectors, operated jointly in beams.
  - Validate Monte Carlo models, especially of hadronic physics, characterise their systematic uncertainties. Using detectors of unprecedented spatial granularity.

Spares

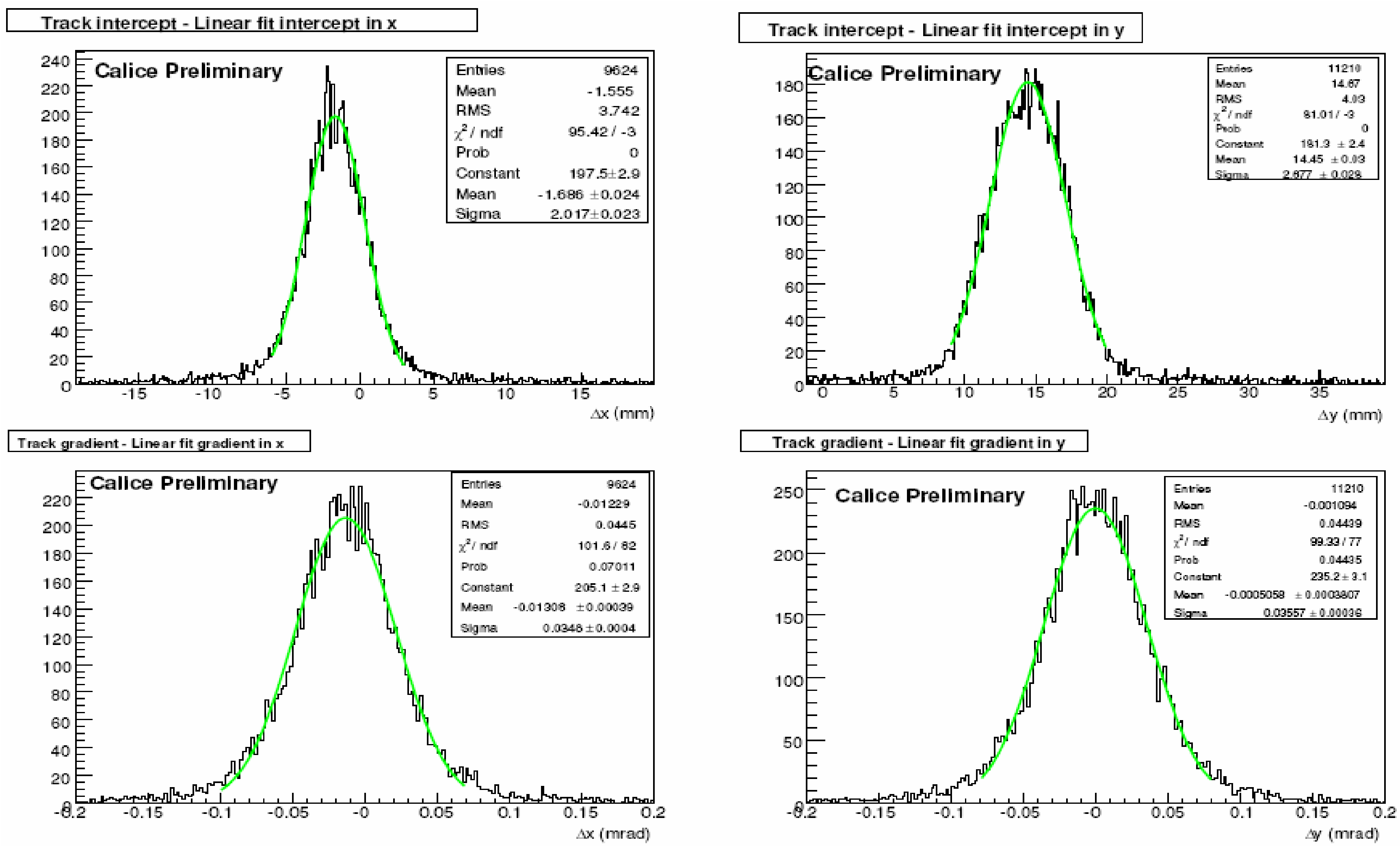
Figure 1: General layout of the Calice Si/W ECAL prototype

CALICE ECAL Prototype

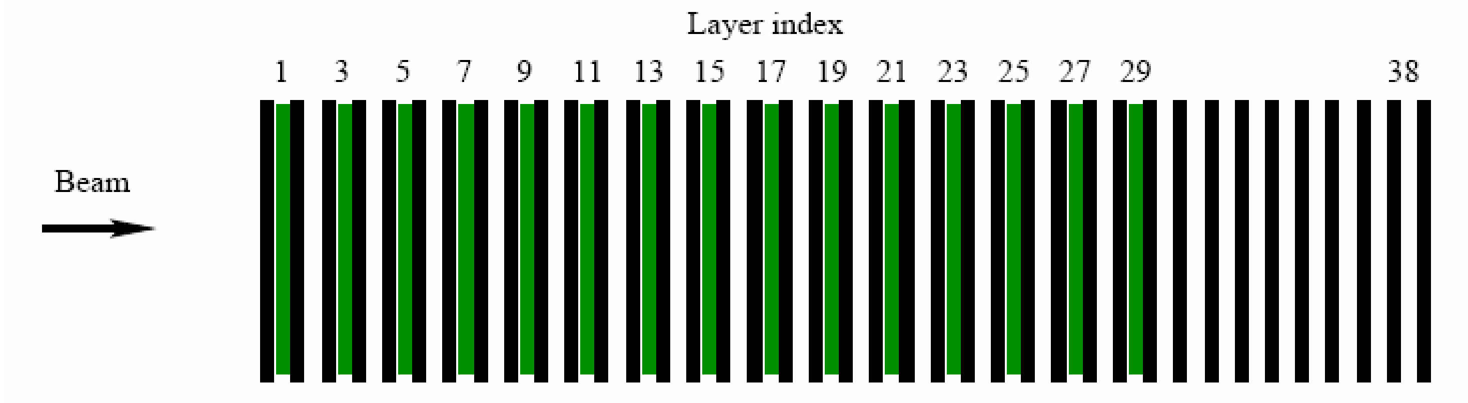




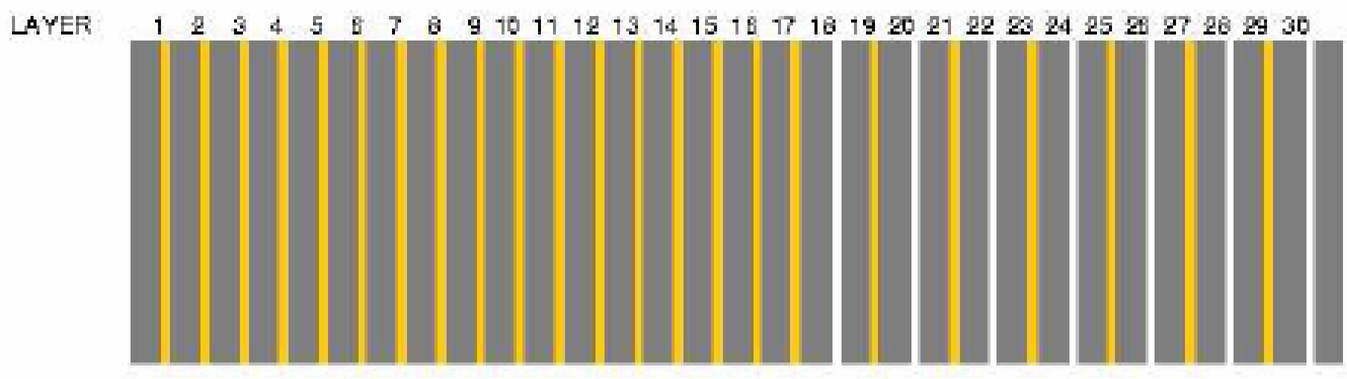
Tracking-ECAL correlation



HCAL Layouts

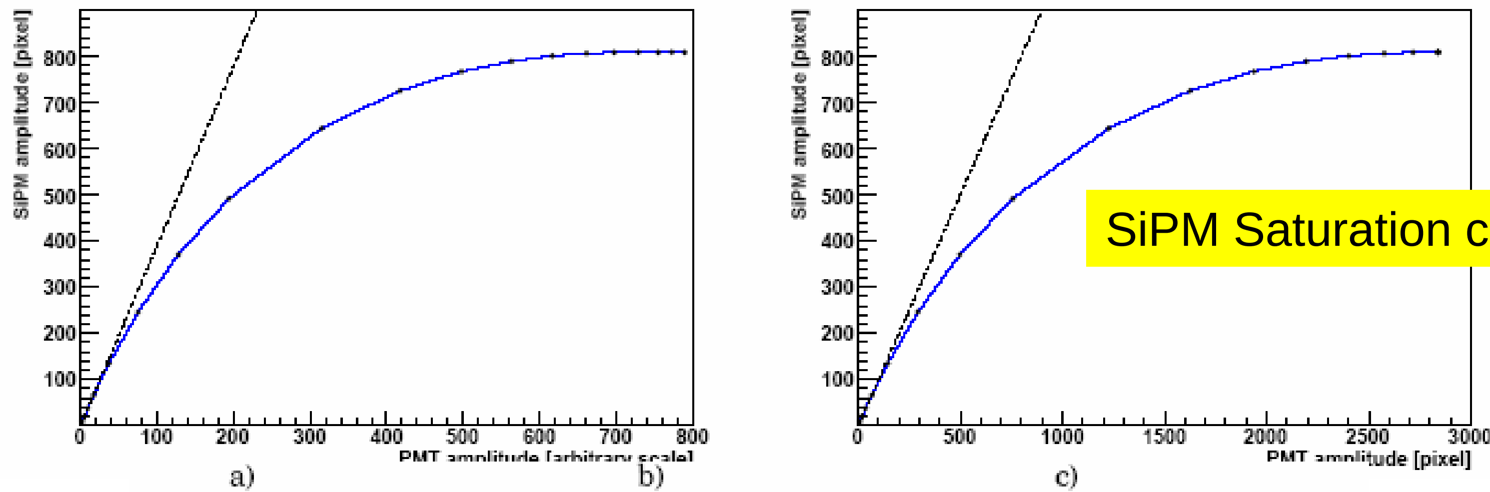


August'06

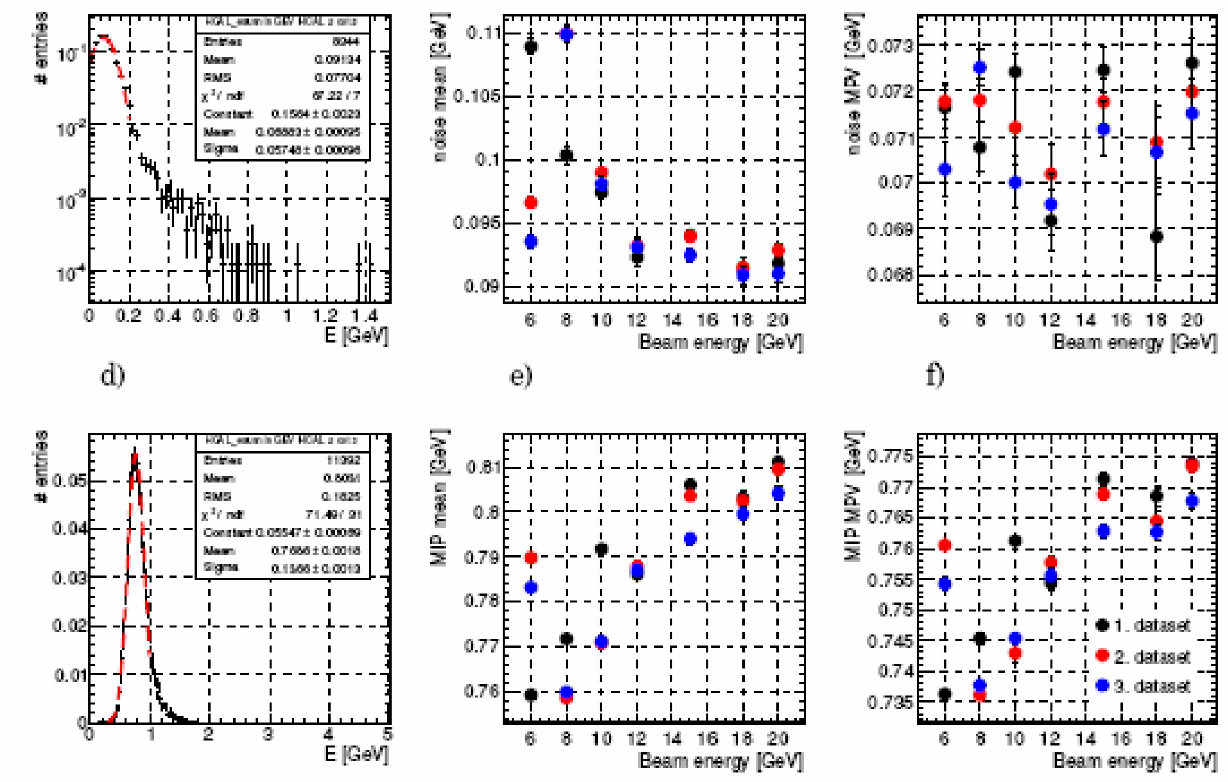


October'06

SiPM Saturation curves

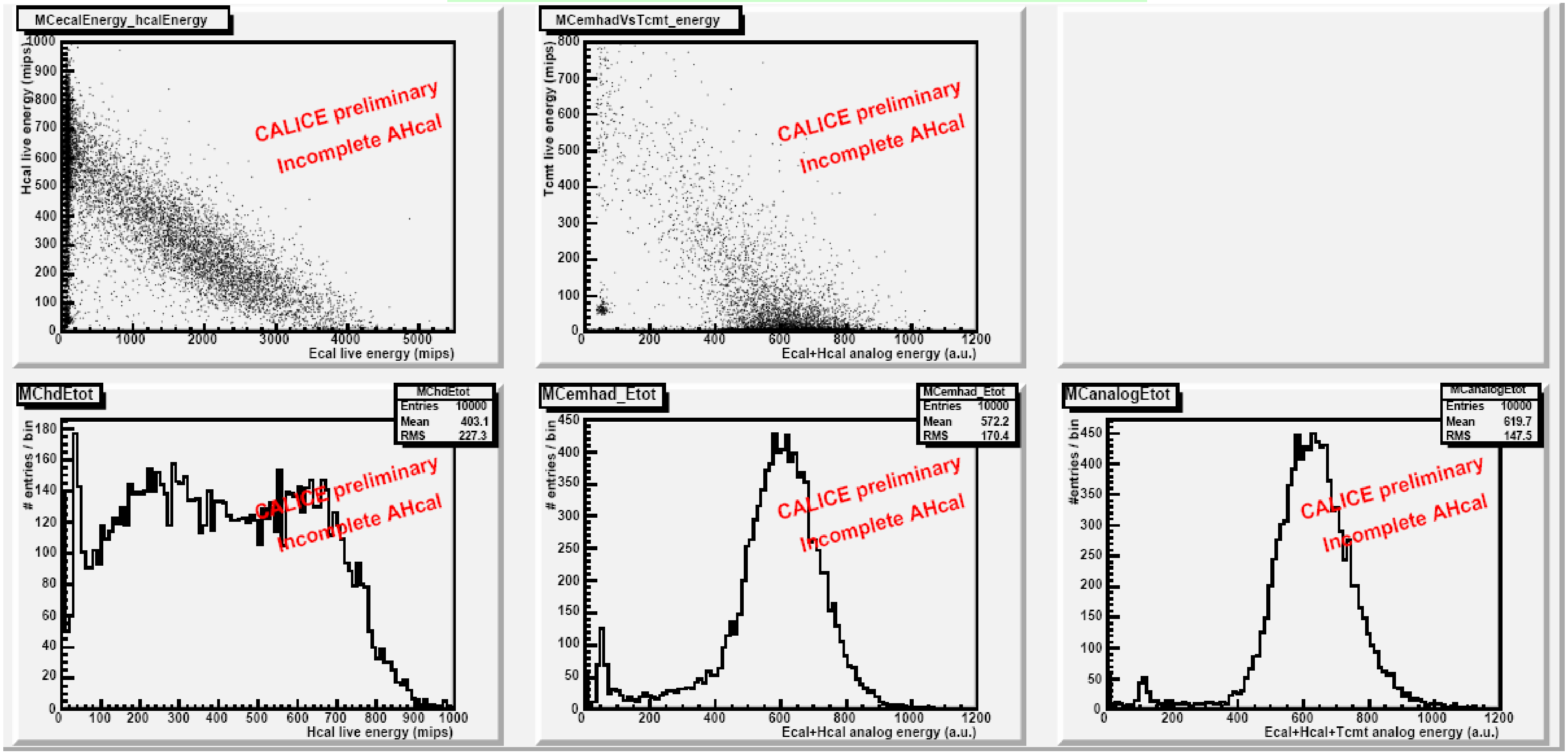


HCAL noise



Combined ECAL/AHCAL/TCMT analysis

Monte Carlo using analogue method…



Too early to make quantitative statements, but looks very encouraging.

Combined ECAL/AHCAL/TCMT analysis

Similar study using digital approach