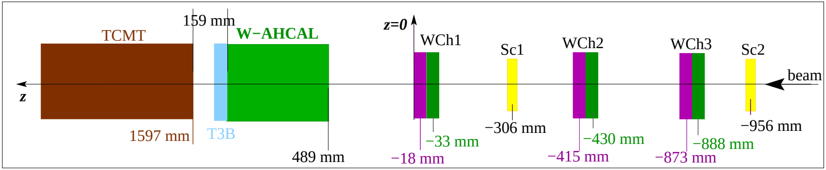
Analysis of CALICE W-AHCAL Data

Eva Sicking (CERN)

on behalf of the CALICE W-AHCAL group and the CLIC detector and physics study

February 5, 2014,
CLIC workshop – CERN

Test Beam Experiments in 2010/2011 at CERN PS/SPS



- 2010 at CERN PS
- $1 \leq p_{\text{beam}} \leq 10\,\text{GeV}$
- Mixed beam of $e^{\pm}$, $\mu^{\pm}$, $\pi^{\pm}$, p
- **W-AHCAL** (30 layers)

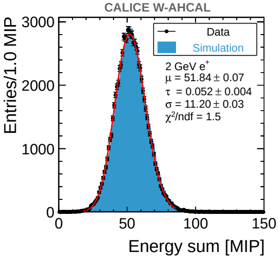
→ Note CAN-036

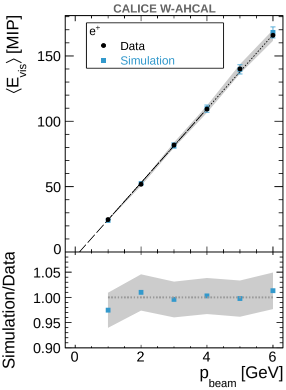
→ Publication JINST 9 (2014) 01004

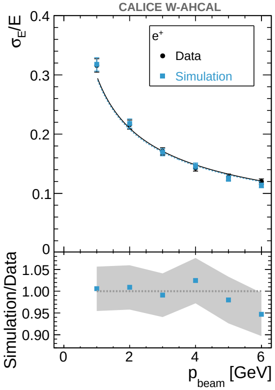
- 2011 at CERN SPS
- $10 \leq p_{\text{beam}} \leq 300\,\text{GeV}$
- Mixed beam of $e^{\pm}$, $\mu^{\pm}$, $\pi^{\pm}$, p, $K^{\pm}$
- **W-AHCAL** (38 layers) + **TCMT**

→ Note CAN-044 ($\leq 100\,\text{GeV}$)

2010 electron results

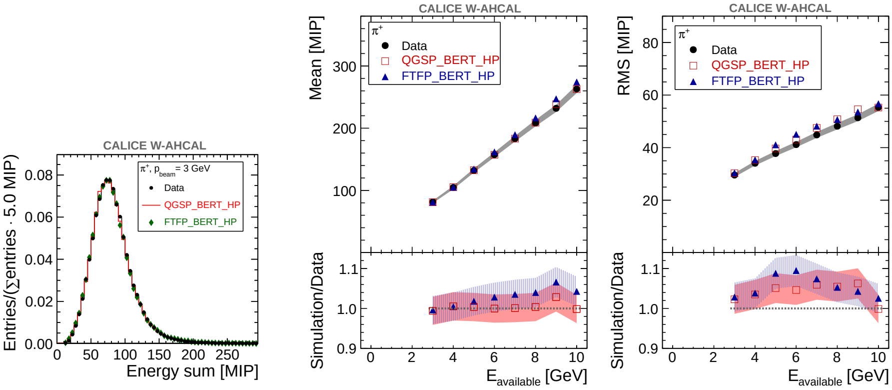






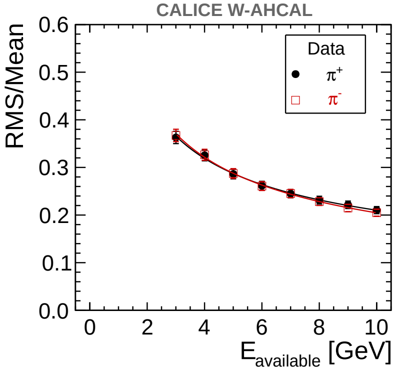
- Calorimeter response (visible energy) increases with p_{beam} following linear fit
- Resolution descreases with p_{beam} following $\frac{\sigma_E}{E} = \frac{a}{\sqrt{E[\text{GeV}]}} \oplus b \oplus \frac{c}{E[\text{GeV}]}$
- W-AHCAL: $a = (29.6 \pm 0.5)\,\%/\sqrt{E} \rightarrow 2.8\,X_0$ per layer
- Fe-AHCAL: $a = (21.5 \pm 1.4)\,\%/\sqrt{E} \rightarrow 1.2\,X_0$ per layer

2010 π results



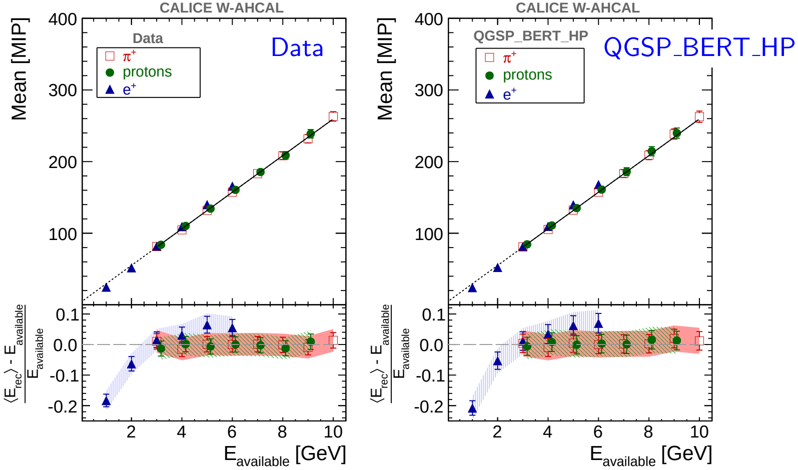
- Analysis as a function of $E_{\text{available}} = \sqrt{p_{\text{beam}}^2 + m_\pi^2}$
- QGSP_BERT_HP describes mean best, both MCs give slightly broader RMS
- Description of GEANT4 physics list in backup slides
  - HP = **H**igh **P**recision needed for accurate neutron simulation

2010 π results



- Energy resolution for $\pi^{\pm}$ follows $\frac{\sigma_E}{E} = \frac{a}{\sqrt{E[\mathrm{GeV}]}} \oplus b \oplus \frac{c}{E[\mathrm{GeV}]}$
- Stochastic term:
  - W-AHCAL (π^+)
    $a = (61.8 \pm 2.5)\,\%/\sqrt{E[\mathrm{GeV}]}$
    $\rightarrow$ Fit range 1-10 GeV
    $\rightarrow$ RMS and mean
    $\rightarrow$ 2.8 X_0 per layer important for el.-m. fraction of shower
  - Fe-AHCAL
    $a = (57.6 \pm 0.4)\,\%/\sqrt{E[\mathrm{GeV}]}$
    $\rightarrow$ Fit range 10-100 GeV
    $\rightarrow$ Gaussian fit function
    $\rightarrow$ 1.2 X_0 per layer

Combined results



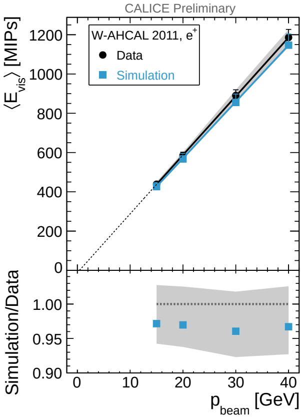
- Reconstructed energy as a function of the available energy
- e^+ shows steeper slop than hadrons; also predicted by MC
- Bottom panels: residuals of linear fit to pion data points

Updates for 2011 data analysis

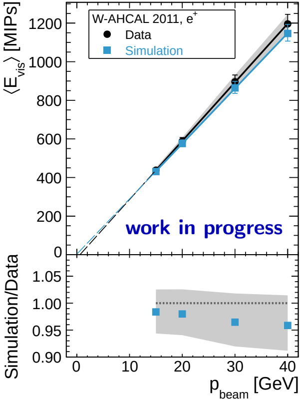
- Paper draft based on analysis note ▸ CAN-044
- Recent updates
  - Software updates
  - Calibration updates
- Open items
  - Combination of 2010+2011 data for energy resolution fit
  - Use of individual saturation scaling factors

New software and calibration – e^+ linearity

CAN-044



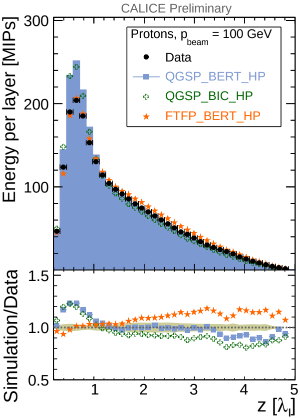
New



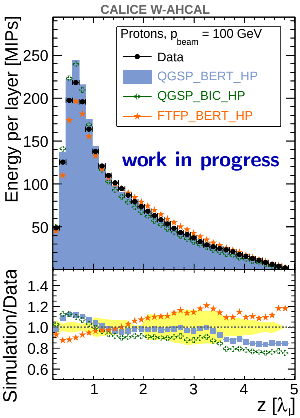
- Only small variations in linearity of e^+

New software and calibration – p longitudinal profiles

CAN-044

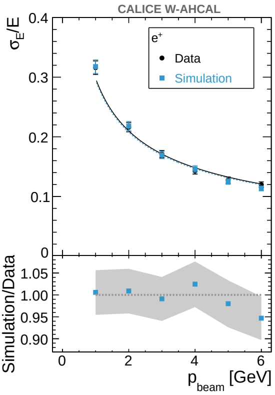


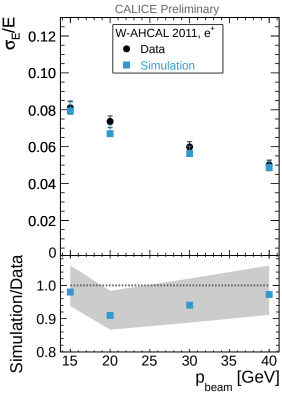
New



- Only small variations in the longitudinal profiles of protons

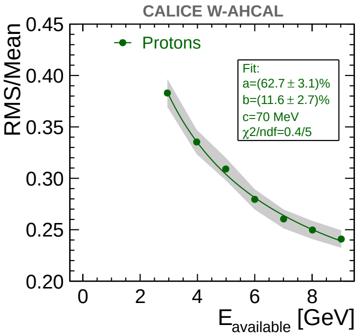
Outlook: Combined energy resolution for e^+ 2010+2011

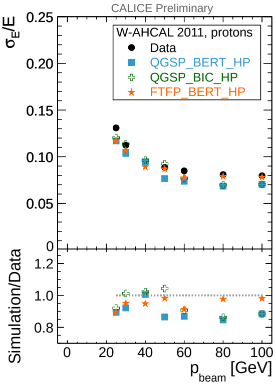




- Resolution estimation only for 2010, not yet for 2011
- Outlook
  - Combine 2010 and 2011 data points
  - Adding 2011 to 2010 does not change the *a* term much, while the *b* term can be better constrained than in 2010 only

Outlook: Combined energy resolution for p 2010+2011

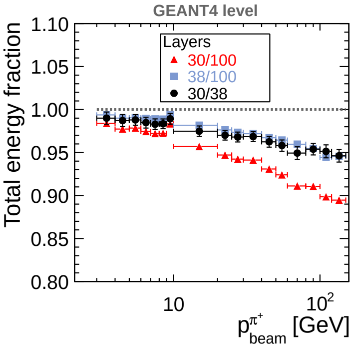


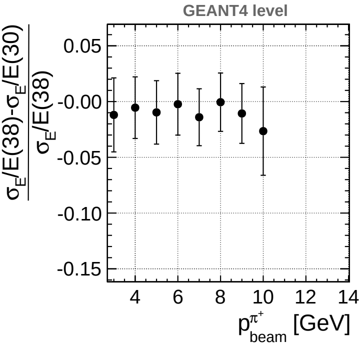


- Resolution estimation only for 2010, not yet for 2011
- Outlook
  - Combine 2010 and 2011 data points
  - Attention: 2010 setup has 30 layers, 2011 setup has 38 layers → Add systematic uncertainty due to leakage effects

Systematic uncertainty of leakage effects

- Study based on Geant4 simualtions
- Calorimeter with 100 layers contains full shower
- Energy fraction is energy integral in longitudinal profile from shower start

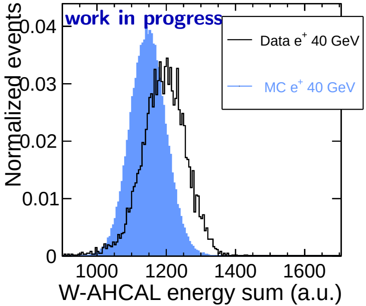


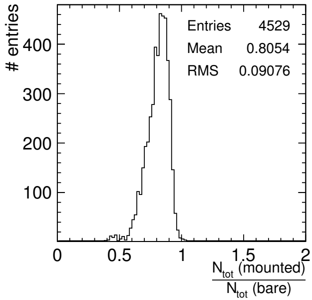


- With 38 layers, up to **5 %** energy leakage despite the shower start cut
- Study selection to reduce leakage

- With 30 layers, energy resolution at most **2 %** larger in comparison to 38 layers ($\leq$ 10 GeV)

e^+ analysis: Saturation scaling





- Distribution of individual scaling factors has a large spread, available for about 60 % of the channels
- So far, all saturation curves scaled with a mean value of 0.8

- Problem: disagreement between electromagnetic data and simulation
- Could this be related to saturation?

Individual saturation scaling factors

- e^+ beam in region around tiles I=43,46,49, J=40,43,46
- e^+ longitudinal profile has maximum in layer 3
- Cross-check scaling factors for all central cells for this specific data set

- Finding: The central cell
  - has individual factor 10 % larger than average: 0.91 instead of 0.8
  - contains up to 25 % of total energy sum

→ Big effect on energy sum

Individual saturation scaling factors

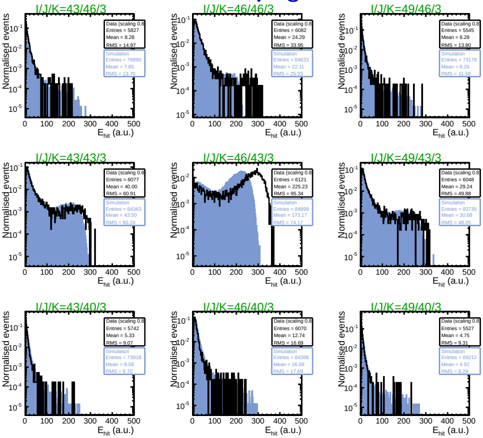
- e^+ beam in region around tiles I=43,46,49, J=40,43,46
- e^+ longitudinal profile has maximum in layer 3
- Cross-check scaling factors for all central cells for this specific data set

- Finding: The central cell
  - has individual factor 10 % larger than average: 0.91 instead of 0.8
  - contains up to 25 % of total energy sum

→ Big effect on energy sum

- E_{hit} per cell for data and MC
- **Data scaling=0.8**, MC

work in progress



Calorimeter for ILC

Individual saturation scaling factors

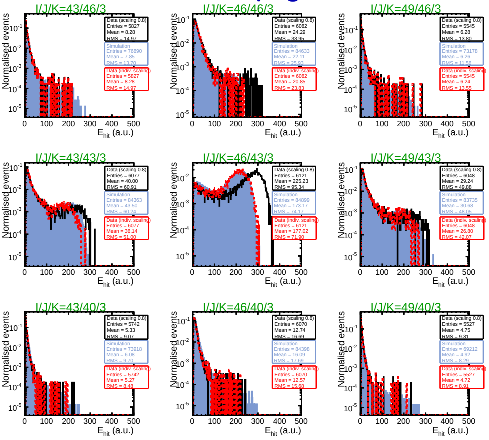
- e^+ beam in region around tiles I=43,46,49, J=40,43,46
- e^+ longitudinal profile has maximum in layer 3
- Cross-check scaling factors for all central cells for this specific data set

- Finding: The central cell
  - has individual factor 10 % larger than average: 0.91 instead of 0.8
  - contains up to 25 % of total energy sum

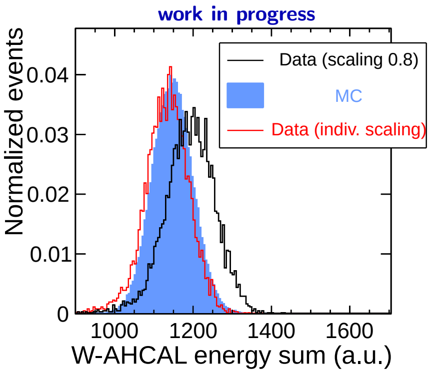
→ Big effect on energy sum

- E_{hit} per cell for data and MC
- **Data with individual scaling factors**

work in progress



Individual saturation scaling factors

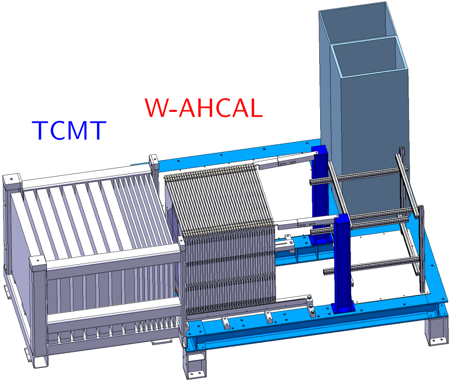


- $e^{\pm}$ showers are very dense
- Up to 25 % of total energy sum is contained in only one cell in this particular data set
- Saturation scaling factor has a significant impact on the final calorimeter response

- Individual scaling factors give improved agreement between data and MC
- Idea: Use individual scaling factors from now on as default, also for hadron reconstruction

High Energy Hadron Showers: Tail Catcher (TCMT)

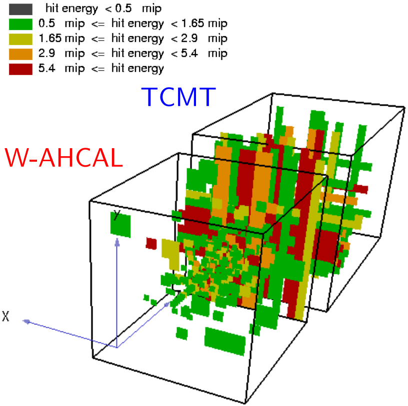
- Test beam experiments at CERN SPS using W-AHCAL+TCMT
- Purpose of TCMT
  - At SPS energies, hadronic shower can leak out of the W-AHCAL of $\sim 4\lambda_I$
  - Catch tail of shower using additional $\sim 5.5\lambda_I$ of tail catcher
  - Combination of W-AHCAL + TCMT $\rightarrow$ improve energy resolution

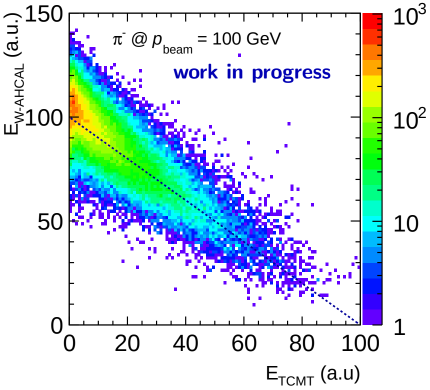


- W-AHCAL: 38 tungsten layers, each 10 mm thick
- TCMT_1: 8 steel layers, each 20 mm thick
- TCMT_2: 8 steel layers, each 100 mm thick
- TCMT readout: scintillator strips and SiPM

High Energy Hadron Showers: Tail Catcher (TCMT)

- Example pion shower at $p_{\text{beam}} = 100$ GeV
- TCMT recovers energy leaked out of W-AHCAL





- W-AHCAL: scintillator tiles
- TCMT: scintillator strips
- Ongoing study on how to combine W-AHCAL and TCMT

Summary and Outlook

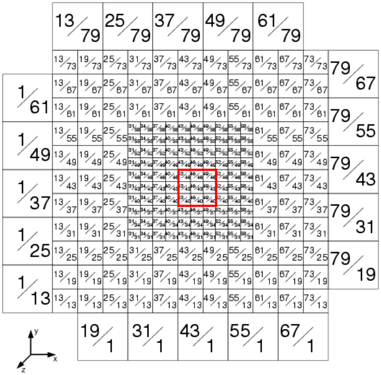
- Test beam measurements with CALICE W-AHCAL at PS and SPS
- Data at low beam momentum ($\leq 10\,\mathrm{GeV}$)
  - Results are published
- Data at intermediate beam momentum ($10 - 150\,\mathrm{GeV}$)
  - Preliminary results up to 100 GeV
  - Open issues
    - Combination of 2010+2011 data for energy resolution from 5-150 GeV
    - Improve cuts to contain shower within the W-AHCAL up to 150 GeV
    - Validate shower start finder algorithm for 5-10 GeV
    - Use of individual saturation scaling factors for all data sets
- Data at high beam momentum ($\leq 300\,\mathrm{GeV}$)
  - Measure shower tail leaked out of W-AHCAL using TCMT
  - Ongoing study on how to combine W-AHCAL and TCMT results

Backup

AHCAL geometrical indices

- AHCAL tiles identified using geometrical indices I/J/K

AHCAL fine layer



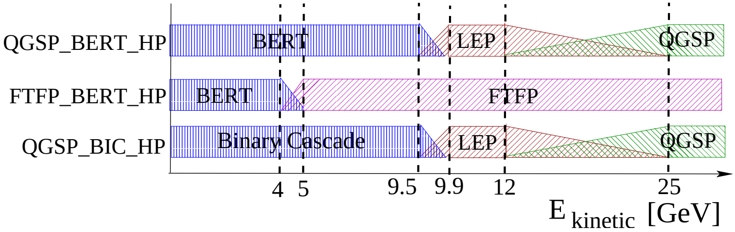
I/J/K: geometrical indices

x=I: 1..79 in steps of 3, 6, 12
y=J: 1..79 in steps of 3, 6, 12
z=K=layer: 1..38 in steps of 1

- $e^{\pm}$ beam in region around I=43,46,49, J=40,43,46

Comparison with GEANT4 Simulations

- Comparison of test beam data with GEANT4 simulations (version 9.3.4)
- Test various physics models combined to so-called physics lists
- Three example physics lists



W-AHCAL and Fe-AHCAL in Electron Analysis

- JINST 9 (2014) 01004, CAN-036
- Energy range: 1-6 GeV
- 2.8 X_0 per HCAL layer:
  4 mm Fe + 10 mm W
- Estimated visible energy using Novosibirsk fit (Gaussian with tail)

- Fe-AHCAL (1012.4343)
- Energy range 10-50 GeV
- 1.2 X_0 per HCAL layer:
  16 mm Fe
- Estimated visible energy using Gaussian fit ($\pm 2\sigma$)

W-AHCAL and Fe-AHCAL Hadron Analyses

- JINST 9 (2014) 01004, CAN-036
- Energy range: 1-10 GeV
- Estimated visible energy using RMS

- Fe-AHCAL (1207.4210)
- Energy range 10-100 GeV
- Estimated visible energy using Gaussian fit ($\pm 2\sigma$)