Analysis of CALICE W-AHCAL Data

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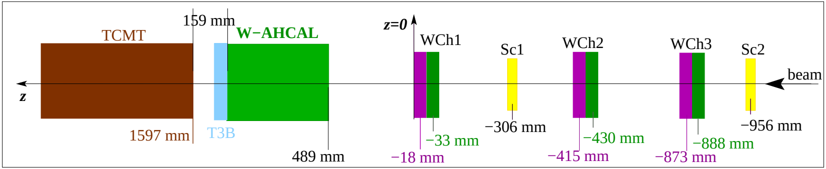
on behalf of the CERN and DESY W-AHCAL groups

CALICE collaboration meeting
March 21, 2014, Argonne

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)

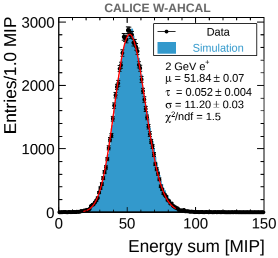
→ Note CAN-036

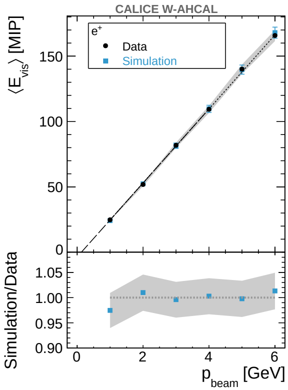
→ Publication JINST 9 (2014) 01004

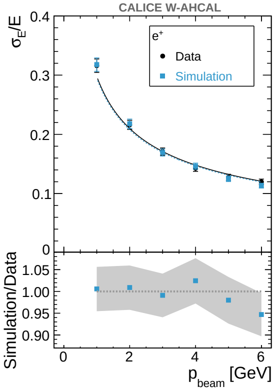
- 2011 at CERN SPS
- $10 \leq p_{\text{beam}} \leq 300\,\text{GeV}$
- Mixed beam of $e^{\pm}$, $\mu^{\pm}$, $\pi^{\pm}$, p, $K^{\pm}$
- **W-AHCAL** (38 layers) + **TCMT**

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

2010 electron results

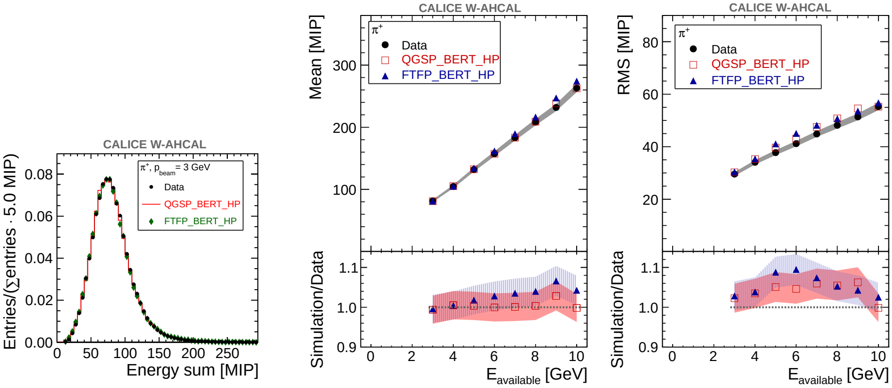






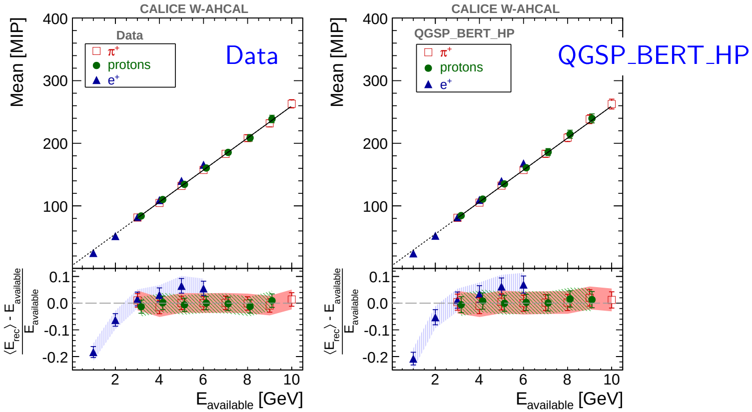
- Calorimeter response (visible energy) increases with p_{beam} following linear fit
- Resolution descreases with p_{beam} following $\frac{\sigma_E}{E} = \frac{a}{\sqrt{E[\text{GeV}]}} \oplus b \oplus \frac{c}{E[\text{GeV}]}$
- W-AHCAL: $a = (29.6 \pm 0.5)\,\%/\sqrt{E} \rightarrow 2.8\,X_0$ per layer
  - constant term b not well constrained
- 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
- Range too small for a meaningful resolution fit

Comparison for different particle types



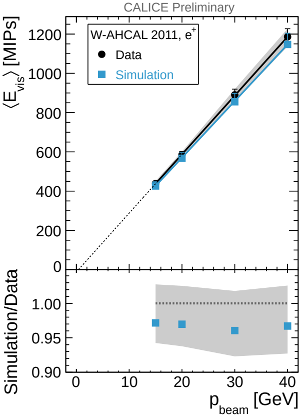
- Reconstructed energy as a function of the available energy
- Bottom panels: residuals of linear fit to pion data points
- Almost compensating - small differences as predicted by MC

Towards publication of 2011 data analysis

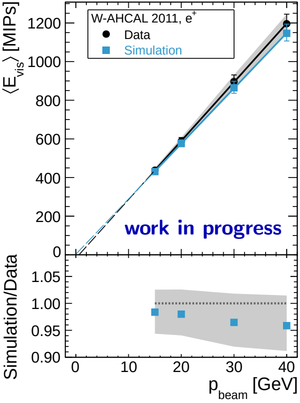
- Paper being drafted, based on analysis note CAN-044
- Recent improvements:
  - Software and calibration updates, to be consistent with 2010 paper
  - Use of cell-wise saturation scaling factors for better precision at higher energy
- Open items:
  - Combination of 2010+2011 data for energy resolution fits
  - Completion of systematic uncertainties

New software and calibration – e^+ linearity

CAN-044



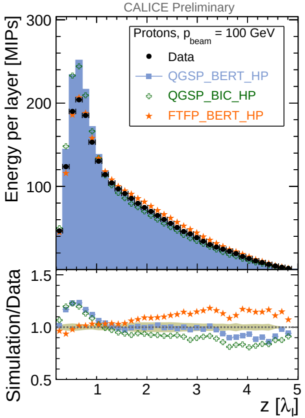
New



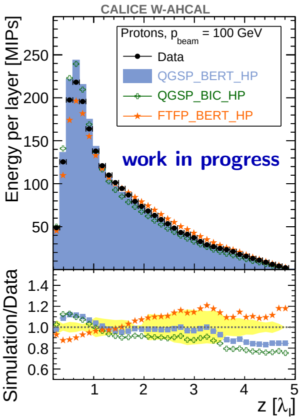
- Only small variations in linearity of e^+

New software and calibration – p longitudinal profiles

CAN-044

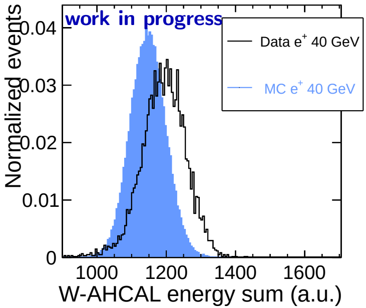


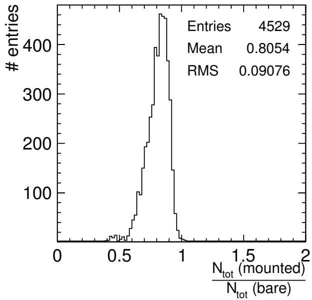
New



- Only small variations in the longitudinal profiles of protons

e^+ analysis: Saturation scaling





- Some disagreement between electromagnetic data and simulation at high energy
- Could be related to saturation
- SiPM max. response scaled to account for variations in optical coupling

- Distribution of scaling factors has a large channel-to-channel spread, available for about 60 % of the channels
- In previous AHCAL analyses, all saturation curves scaled with a mean value of 0.8

Cell-wise 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

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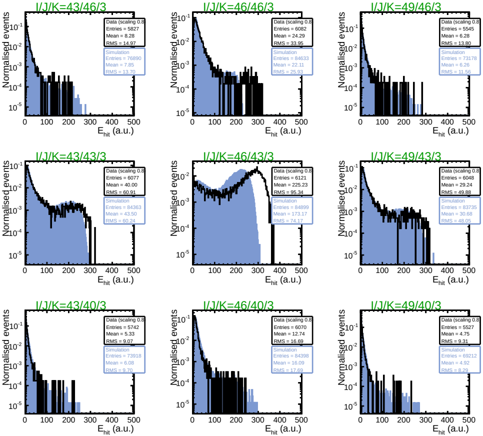
- E_{hit} per cell for data and MC
- **Data scaling=0.8**, MC

work in progress



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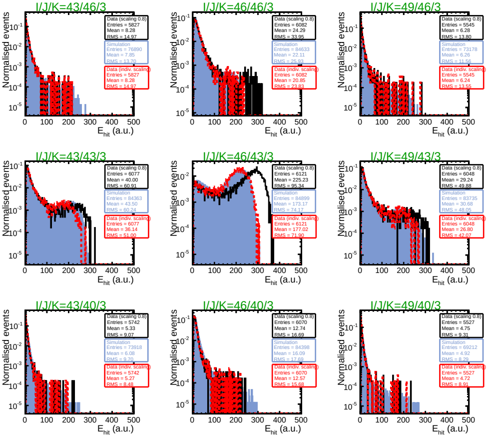
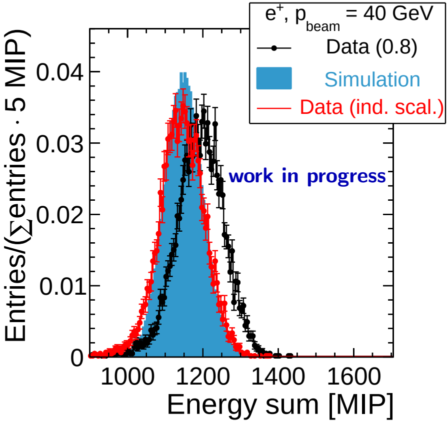
- E_{hit} per cell for data and MC
- **Data with individual scaling factors**

work in progress

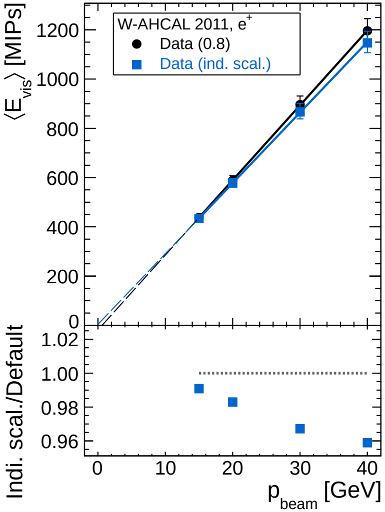


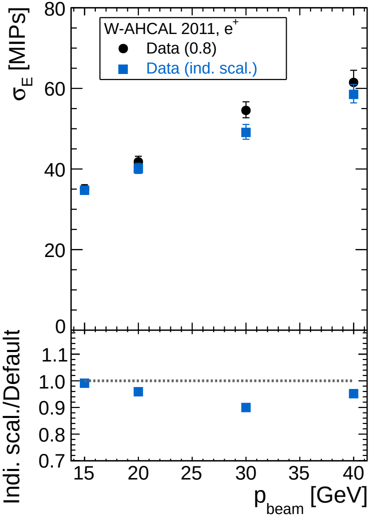
Individual saturation scaling factors



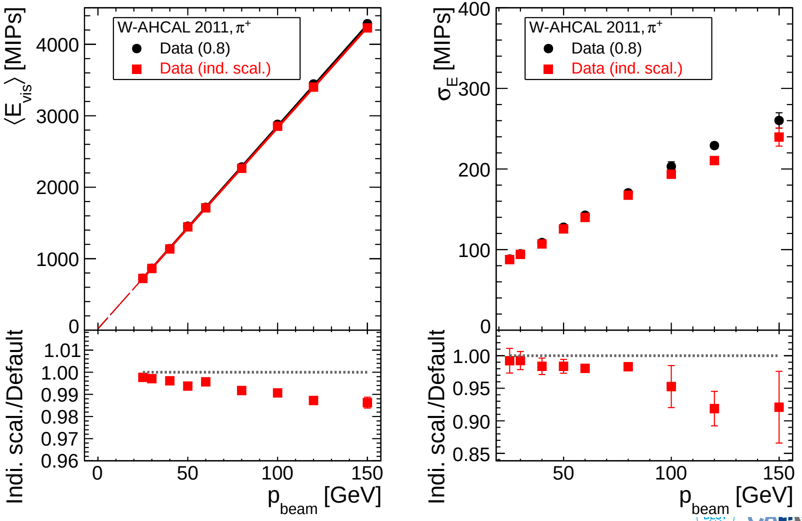
- $e^{\pm}$ showers in tungsten are very dense
- Up to 25 % of total energy sum is contained in only one cell in this particular data set
- Saturation scaling factor has a significant impact on the final calorimeter response
- Cell-wise scaling factors give improved agreement between data and MC
- Use individual scaling factors from now on as default, also for hadron reconstruction

Positrons: Linearity and Sigma

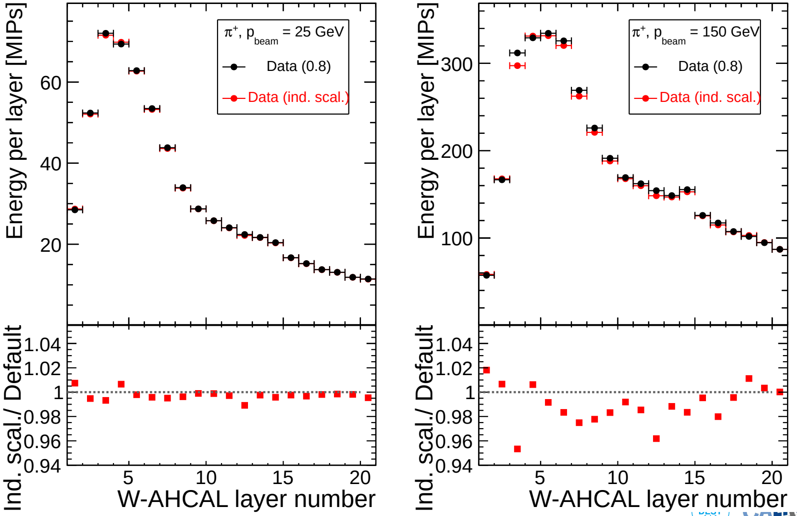




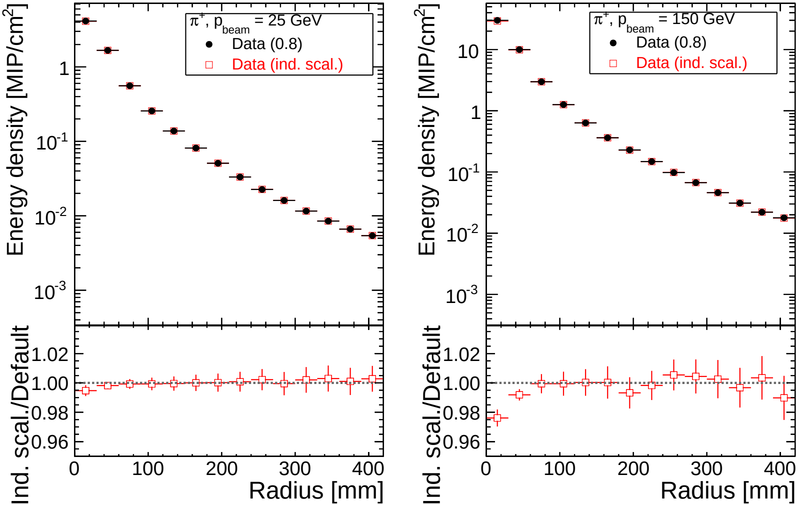
Pions: Linearity and Sigma



Pions: Longitudinal Profile



Pions: Radial Profile



Towards combination of 2010 and 2011 data

- Reconstruct 2010 (and 2011) data with 2011 reconstruction cuts
- Check for consistency with published results
- For hadrons, need to account for different longitudinal containment

Electron selection

2010 event selection

- Cherenkov trigger
- $z_{cog} < 400\,\mathrm{mm}$

2011 event selection

- Cherenkov trigger
- $z_{cog} < 650\,\mathrm{mm}$
- One cluster only
- No tracks
- Number of hits inside momentum dependent range (defined only for 10-40 GeV)

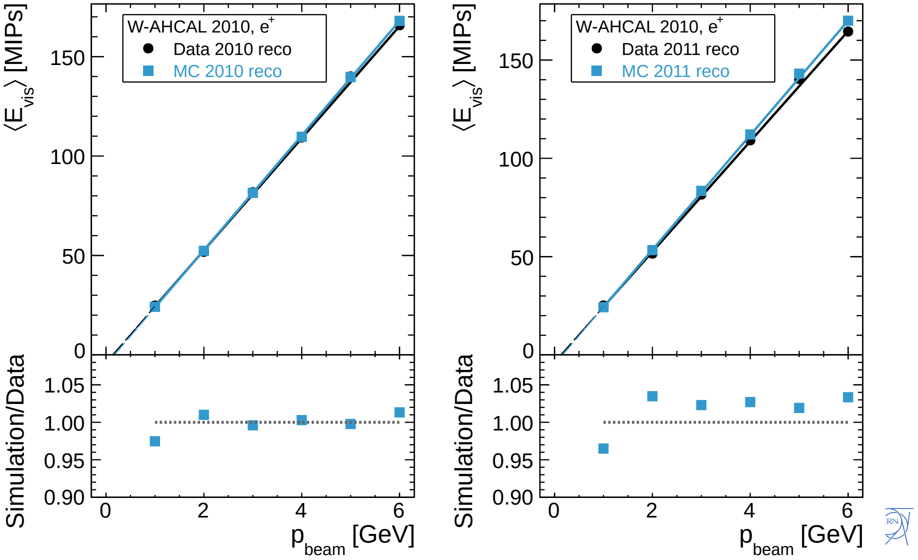
2010 E_{vis} and width

- Novosibirsk function

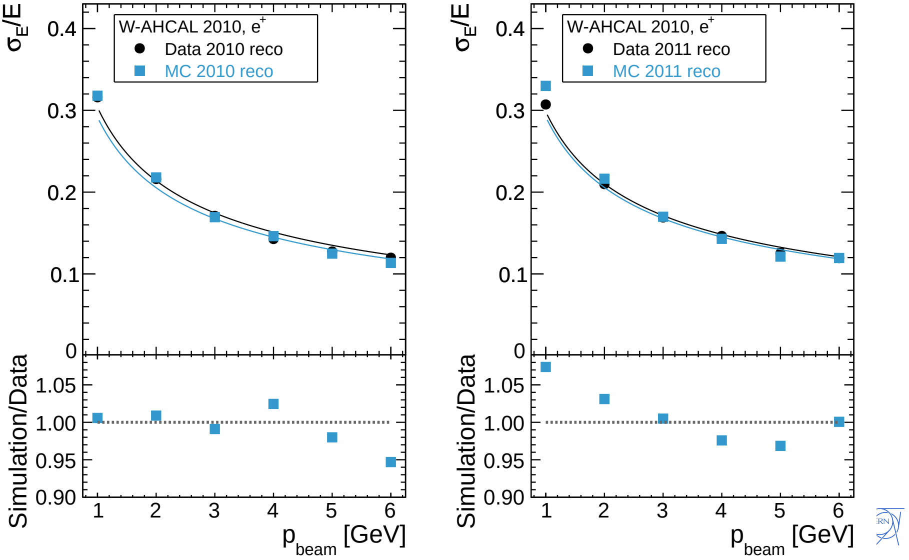
2011 E_{vis} and width

- Novosibirsk function

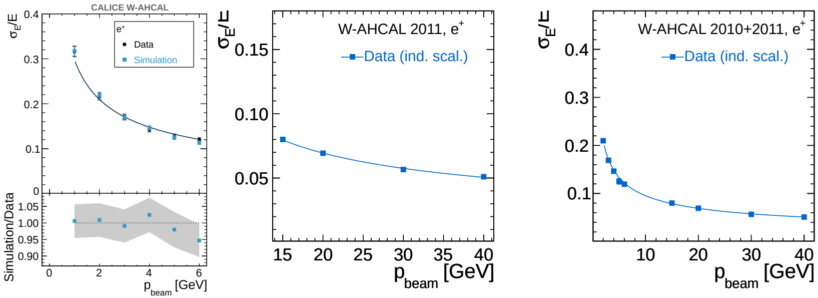
Linearity of e^+ 2010



Resolution of e^+ 2010



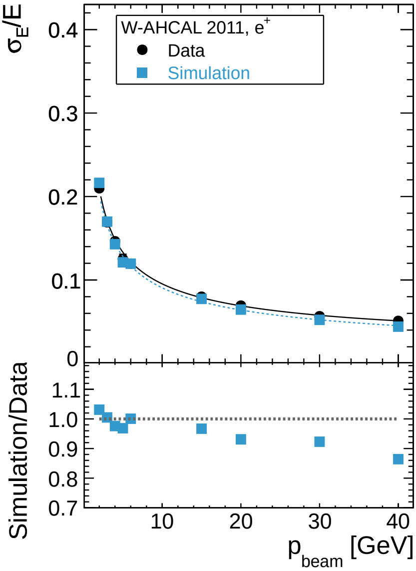
Energy resolution fit e^+



	2010 only (paper)	2011 only	2010+2011
a (%)	29.6 ± 0.5	30.1 ± 0.4	29.4 ± 0.2
b (%)	0.0 ± 2.1	1.7 ± 0.3	2.1 ± 0.1
c (GeV)	0.036	0.035	0.035
χ^2/NDF	5.3/4	3.91/2	12.70/7

- Combination of 2010 and 2011 better constrains fit results

Energy resolution fit e^+: 2010 and 2011, data and MC



- 2010 data with 2011 reconstruction

	data (ind. scal)	Simulation
$a(\%)$	29.4 ± 0.2	28.6 ± 0.0
$b(\%)$	2.1 ± 0.1	0.0 ± 3.8
$c(\mathrm{GeV})$	0.035	0.035
χ^2/NDF	12.70/7	507.50/7

Hadron selection

2010 event selection

- Cherenkov trigger
- Cuts on the number of found tracks and their length
- Cuts on number of clusters and their position in the calorimeter

2011 event selection

- Cherenkov trigger
- Layer of primary interaction ≤ 3
  - Not available in 2010 default reconstruction
  - Need to re-run 2010 reconstruction
  - Use 2010 reconstruction in the meantime

2010 E_{vis} and width

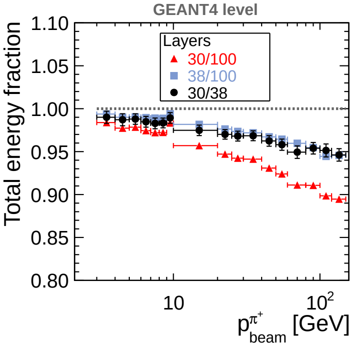
- Mean and RMS of histogram

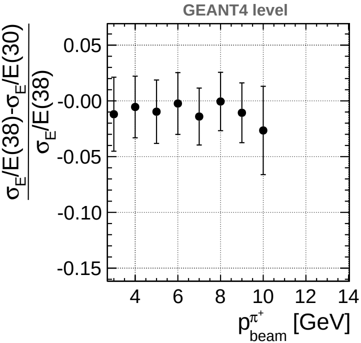
2011 E_{vis} and width

- Mean and σ of Gaussian function

2010 vs. 2011: Leakage effects for 30 and 38 layers

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

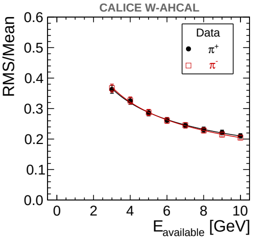


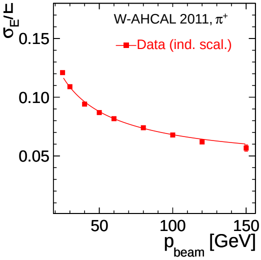


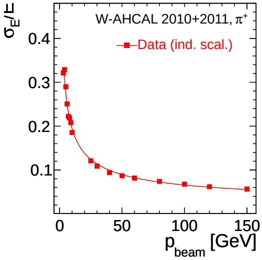
- With 38 layers, up to **5 %** energy leakage despite the shower start cut
- Study selection to reduce leakage

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

Energy resolution fit π^+







	2010 only (paper)	2011 only	2010+2011
a (%)	61.8 ± 2.5	55.4 ± 0.6	60.8 ± 0.2
b (%)	7.7 ± 3.0	4.0 ± 0.1	2.5 ± 0.1
c (GeV)	0.070	0.065	0.063
χ^2/NDF	0.5/6	19.92/7	437.23/15

- Combination of 2010 and 2011 seems to better constrain fit results
- Todo: rerun 2010 reconstruction with shower start processor

Summary and Outlook

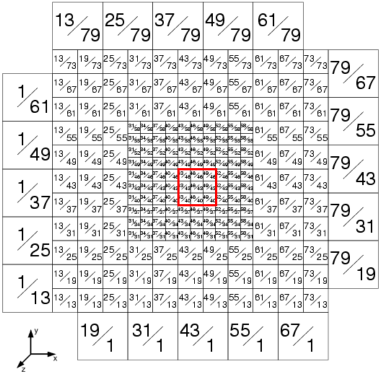
- Test beam measurements with CALICE W-AHCAL at PS and SPS
- Data at low beam momentum ($\leq 10\,\text{GeV}$): published
- Data at intermediate beam momentum ($10 - 150\,\text{GeV}$)
  - Preliminary results up to 100 GeV
  - Recent studies:
    - Software and calibration updated, 2010 paper status
    - Use of channel-wise saturation scaling factors
    - Combination of 2010+2011 data for energy resolution from 5-150 GeV
  - Open issues:
    - Improve cuts to contain shower within the W-AHCAL up to 150 GeV
    - Validate shower start finder algorithm for 5-10 GeV
- Data at high beam momentum ($\leq 300\,\text{GeV}$)
  - Ongoing study on how to combine W-AHCAL and TCMT energies
  - Limitations of saturation corrections

Backup

AHCAL geometrical indices

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

AHCAL fine layer



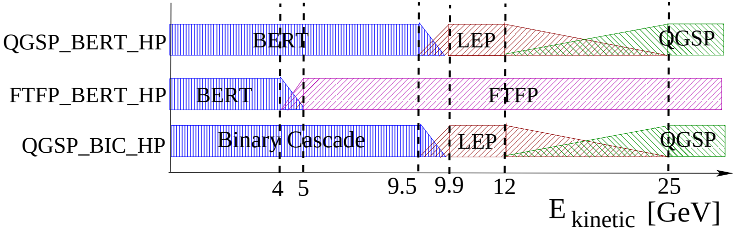
I/J/K: geometrical indices

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 ($\pm 2\sigma$)