W-AHCAL+TCMT Analysis

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on behalf of the CALICE W-AHCAL group

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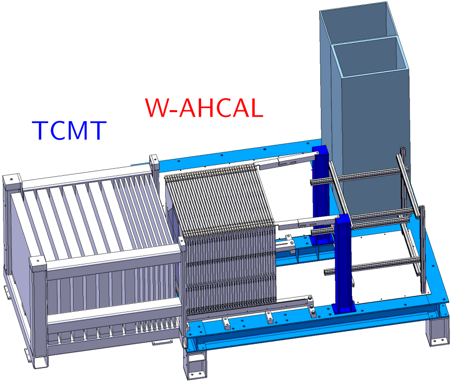
Content

CALICE W-AHCAL + TCMT

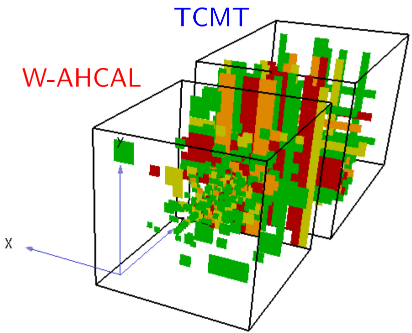
- Test beam experiments of W-AHCAL and TCMT at CERN SPS in 2011
- Purpose of TCMT
  - At SPS energies, hadronic shower can leak out of the W-AHCAL ($\sim 4\lambda$)
  - Catch tail of shower using dedicated tail catcher ($\sim 5.5\lambda$)
  - Combination of W-AHCAL + TCMT → expect improved energy resolution

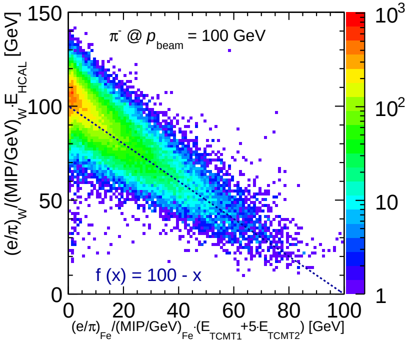


- W-AHCAL:
  38 tungsten layers,
  each 10 mm thick
- TCMT_1: 8 steel layers,
  each 20 mm thick
- TCMT_2: 8 steel layers,
  each 100 mm thick
- TCMT readout:
  scintillator strips
  and SiPM

Hadron showers in W-AHCAL + TCMT

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

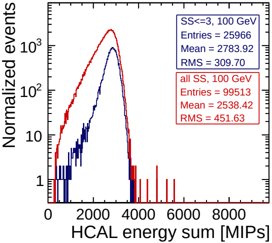


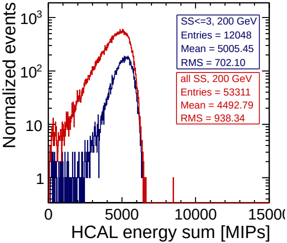


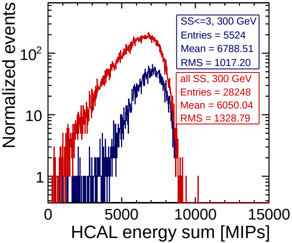
- W-AHCAL: scintillator tiles
- TCMT: scintillator strips

W-AHCAL at High Energies and Late Showers

- Leakage effects in W-AHCAL-only grow
  - with increasing energy:
    here, 100, 200, and 300 GeV
  - when accepting events with late shower starts:
    here, "only early shower starts" or "all shower starts"







Data and Event Selection

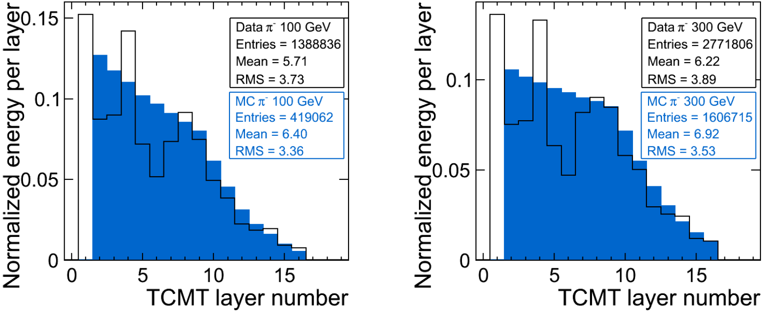
- Full statistic of runs with TCMT
  - π^+ at $p_{\text{beam}} = 50$, 60, 80, 100, 120, and 180 GeV
  - π^- at $p_{\text{beam}} = 50$, 60, 80, 100, 120, 150, 180, 200, 250, and 300 GeV

- Data
  - CERN SPS 2011 test beam data of W-AHCAL + TCMT
- Simulation
  - Mokka simulation of W-AHCAL + TCMT using GEANT4
  - Physics list QGSP_BERT_HP
  - Calibration and noise as in real data

- Event selection (same for data and simulation)
  - Shower start selection using Cluster Shower Start finder: shower start in first 3 layers
  - Muon and electron rejection
  - Rejection of empty events
  - Rejection of events with pre-showers

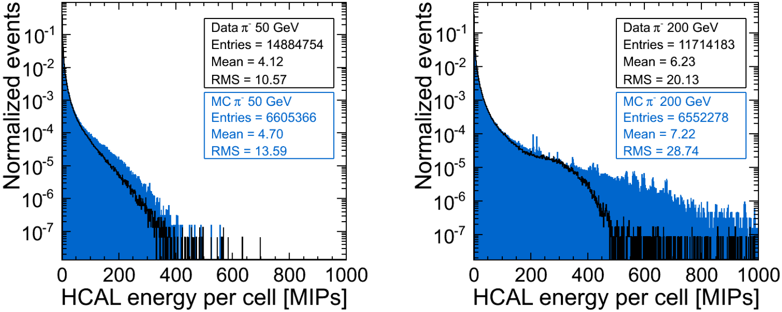
Longitudinal Shower Profile in TCMT

- 3 issues discovered in longitudinal shower profile of TCMT
  - TCMT layer counting is not the same in data and MC: layer number is shifted by 2 layers in MC (not shown) → corrected
  - So far, first TCMT layer was not included in the simulation → corrected
  - Spikes/dips in data not visible in MC: Problem of noisy/blind $TCMT_1$ strips in data? → under investigation



Saturation Effects in W-AHCAL at High p_{beam}

- At low p_{beam}, hit energy reach in MC and data agree well
- At high p_{beam}, MC and data start to differ
  → MC reaches much higher energy depositions per cell
- Sign of saturation effect in data which is not accounted for in MC
  → under investigation, see last part of the presentation



How to combine W-AHCAL and TCMT

- Known detector response of W and Fe calorimeters
  - e/π-ratios
    - $(e/\pi)_{\mathrm{W}} = 1.0$
      $(e/\pi)_{\mathrm{Fe}} = 1.2$[1]
  - MIP/GeV factors
    - $(\mathrm{MIP/GeV})_{\mathrm{W}} = 27\,\mathrm{MIP/GeV}$
      $(\mathrm{MIP/GeV})_{\mathrm{Fe}} = 42\,\mathrm{MIP/GeV}$
  - Ratio of TCMT layer thicknesses: 5
    - TMCT_1: 20 mm
    - TMCT_2: 100 mm

First approximation: Weighted energies in GeV

- $E_{\text{W-AHCAL, weighted}} = (e/\pi)_{\mathrm{W}}/(\mathrm{MIP/GeV})_{\mathrm{W}} \cdot \quad E_{\text{W-AHCAL}}$
- $E_{\text{Fe-TMCT}_1\text{, weighted}} = (e/\pi)_{\mathrm{Fe}}/(\mathrm{MIP/GeV})_{\mathrm{Fe}} \cdot \quad E_{\text{Fe-TCMT}_1}$
- $E_{\text{Fe-TMCT}_2\text{, weighted}} = (e/\pi)_{\mathrm{Fe}}/(\mathrm{MIP/GeV})_{\mathrm{Fe}} \cdot 5 \cdot E_{\text{Fe-TCMT}_2}$

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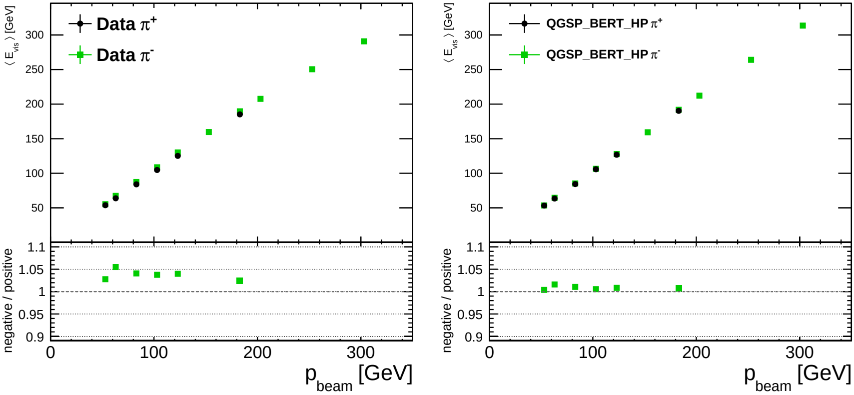
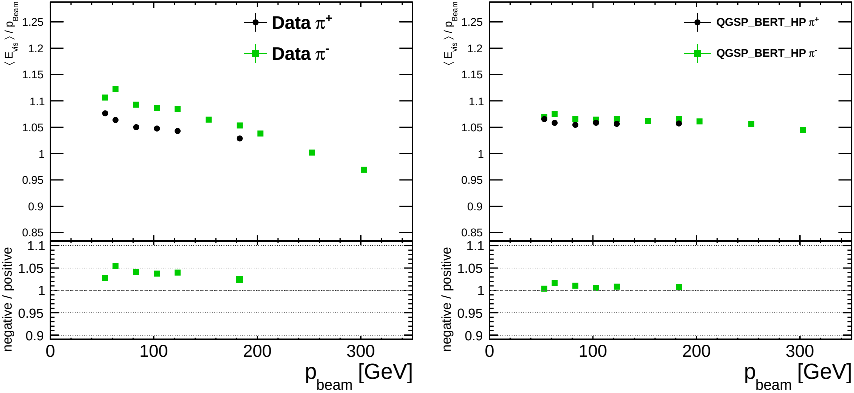
[1] Attention: (e/π) needs to be adjusted to TMCT layer thicknesses.

E_{vis} in W-AHCAL+TCMT



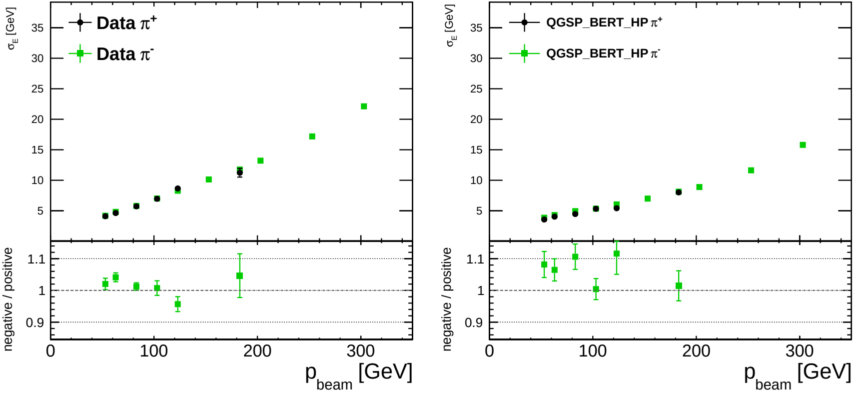
- Data:
  - Response for π^- is up to 5 % higher than for π^+
  - Effect discussed already in CAN-044

$E_{\mathrm{vis}}/p_{\mathrm{beam}}$ in W-AHCAL+TCMT



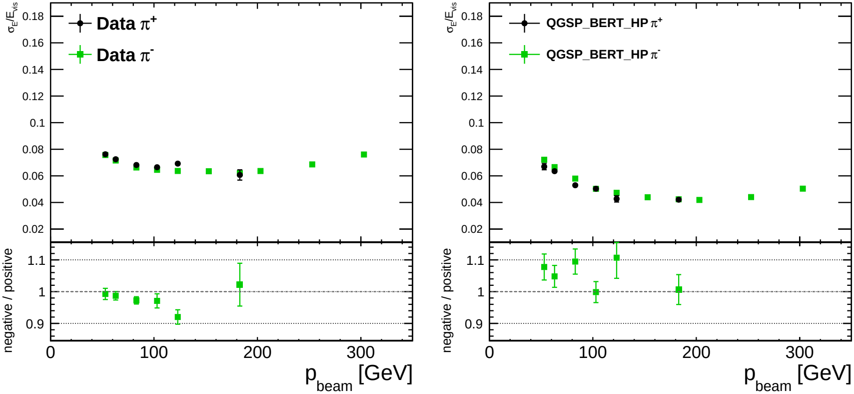
- Data:
  - Response for π^- is up to 5 % higher than for π^+
  - Effect discussed already in CAN-044
- MC results are linear in p_{beam}, data falls as a function of p_{beam}

$\sigma_{E_{\text{vis}}}$ in W-AHCAL+TCMT



- Width of energy sum distribution grows as a function of p_{beam}
- Width of energy sum distribution is smaller in MC than in data

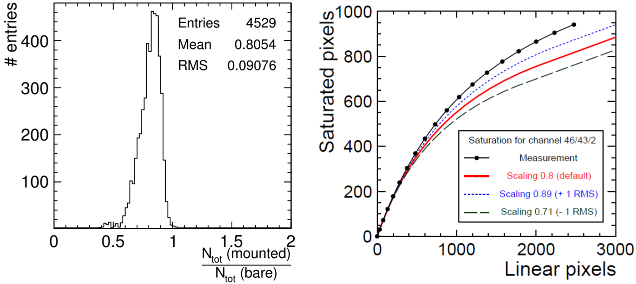
$\sigma_{E_{\text{vis}}}/E_{\text{vis}}$ in W-AHCAL+TCMT



- Expectation: $\sigma_{E_{\text{vis}}}/E_{\text{vis}}$ should fall as a function of p_{beam}
- Observation: $\sigma_{E_{\text{vis}}}/E_{\text{vis}}$ grows with p_{beam} at high p_{beam}
  - Data: Saturation effect and/or leakage?
  - MC: Effect of the missing first layer in simulation?

Systematic Study of Saturation Effects

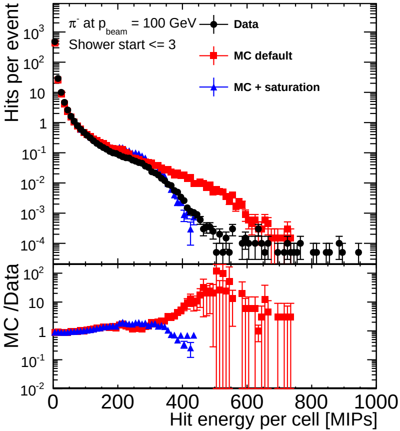
- Scaling and saturation curve used in reconstruction



Figures from paper on el.-m. response of Fe-AHCAL and talk by Angela Lucaci-Timoce

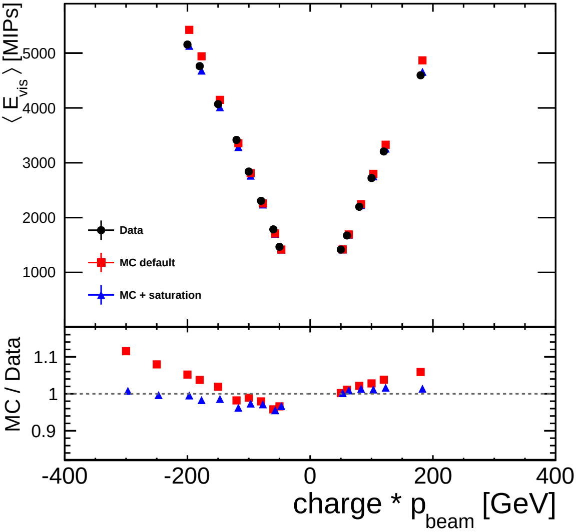
- MC: sim+reco use linear extrapolation of saturation curve
  → saturation and de-saturation cancel out each other perfectly
- Use more realistic saturation correction in MC for study of systematics of saturation correction (Sergey Morozov)
  - Simulation using asymptotic saturation curve,
    reconstruction using linear extrapolation

Hit Energy Per Cell in W-AHCAL-only



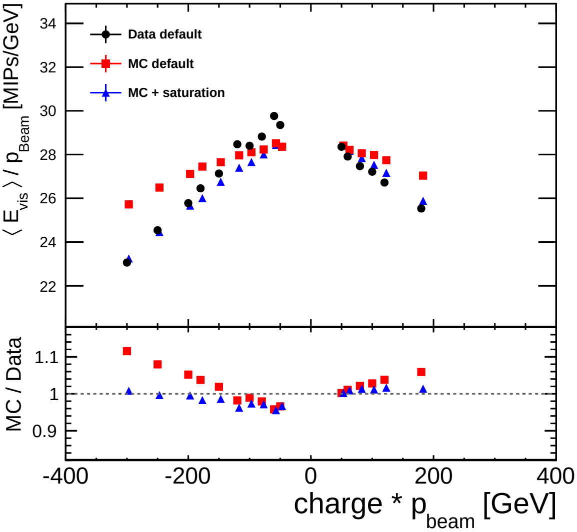
- Modified saturation correction gives hit energy distribution in MC which is in better agreement with data than default MC

Summary E_{vis} in W-AHCAL-only



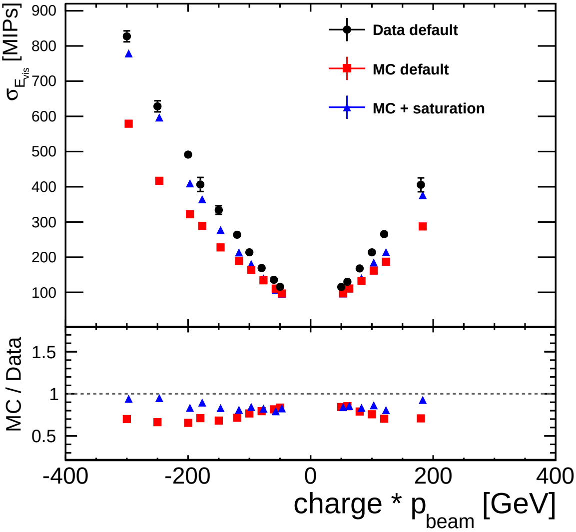
- Good agreement between data and MC using more realistic saturation correction for high p_{beam}

Summary $E_{\mathrm{vis}}/p_{\mathrm{beam}}$ in W-AHCAL-only



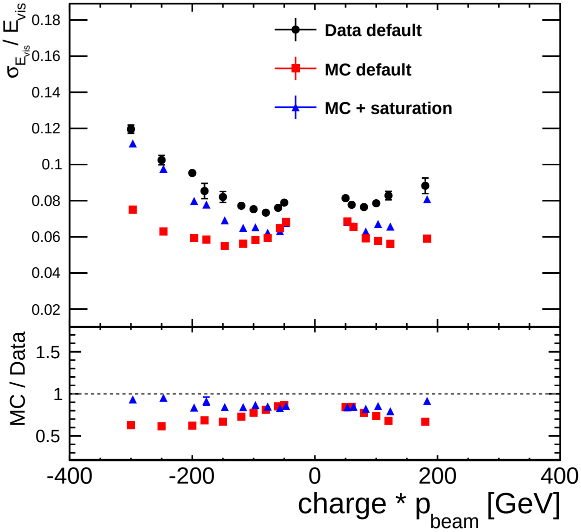
- Good agreement between data and MC using more realistic saturation correction for high p_{beam}

Summary $\sigma_{E_{\text{vis}}}$ in W-AHCAL-only



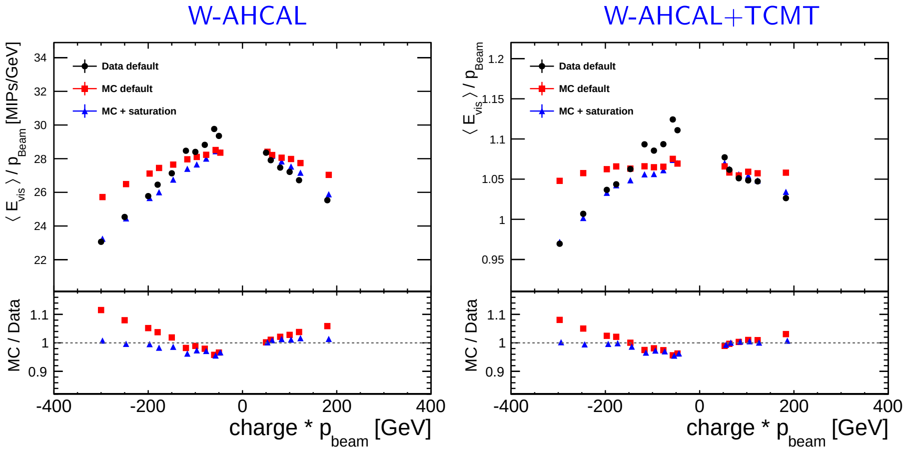
- MC with more realistic saturation correction gives broader σ_E than default MC
- Better agreement for high p_{beam}

Summary $\sigma_{E_{\text{vis}}}/E_{\text{vis}}$ in W-AHCAL-only



- MC with more realistic saturation correction gives broader σ_E than default MC
- Better agreement for high p_{beam}

Summary $E_{\text{vis}}/p_{\text{beam}}$ in W-AHCAL + TCMT



- Also W-AHCAL + TCMT results for MC after more realistic saturation correction gives good agreement with data

Summary

- Analysis of W-AHCAL + TCMT hadron data with beam momenta up to $p_{\mathrm{beam}} = 300\,\mathrm{GeV}$
- Direct comparison of results of negative pions and positive pions
  - Negative pions show higher E_{vis} than positive pions as observed in CAN-044
  - $E_{\mathrm{vis}}/p_{\mathrm{beam}}$ of W-AHCAL+TCMT is constant with p_{beam} for MC
  - $E_{\mathrm{vis}}/p_{\mathrm{beam}}$ of W-AHCAL+TCMT falls with p_{beam} for data → saturation effect
- Study of saturation effects in high energy data using MC simulations
  - More realistic saturation correction gives good agreement between MC and data response

Outlook

- Continue systematic study of saturation effects
  - So far, private implementation of modified saturation procedure implemented by Sergey Morozov
  - Now, also official implementation in newest CALICE software version v04-07
- Correction of TCMT simulations
  - Corrected layer numbering
  - Added simulation of first TCMT layer
- Correct weighting of W-AHCAL and TCMT response using e/π ratio
  - Estimate e/π ratio for fine and coarse TCMT layer in simulations