Status Report on the W-AHCAL+TCMT Analysis

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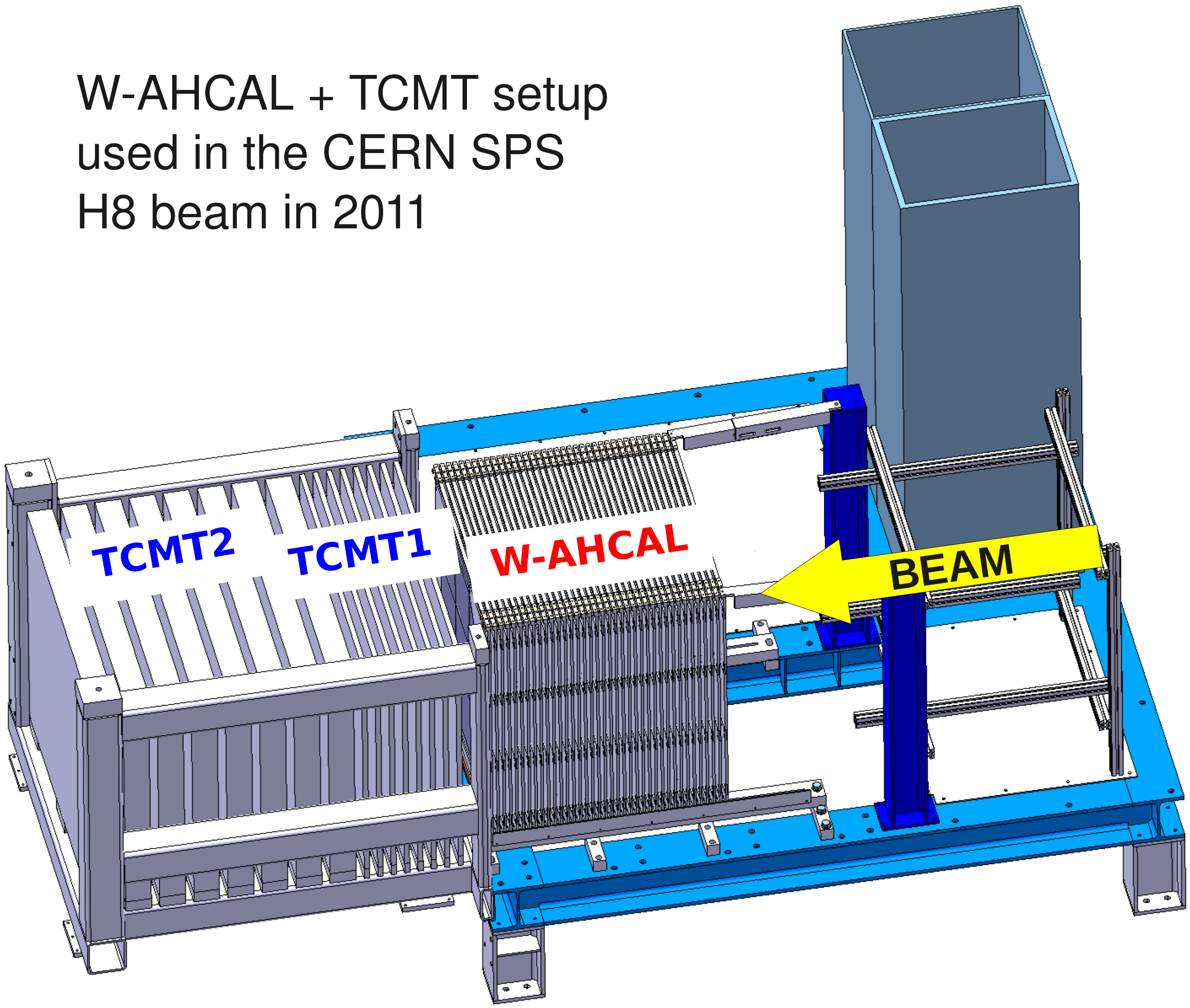
Introduction

- Test beam experiments of CALICE W-AHCAL and Tail Catcher Muon Tracker (TCMT) at CERN SPS in 2011

- Purpose of TCMT:
  - At SPS energies, hadronic shower can leak out of W-AHCAL of 4λ
  - TCMT of 5.5λ can catch the tail of these showers
  - Expect that combination of W-AHCAL and TCMT will give improvement of energy resolution for high energy data

W-AHCAL + TCMT

W-AHCAL + TCMT setup used in the CERN SPS H8 beam in 2011



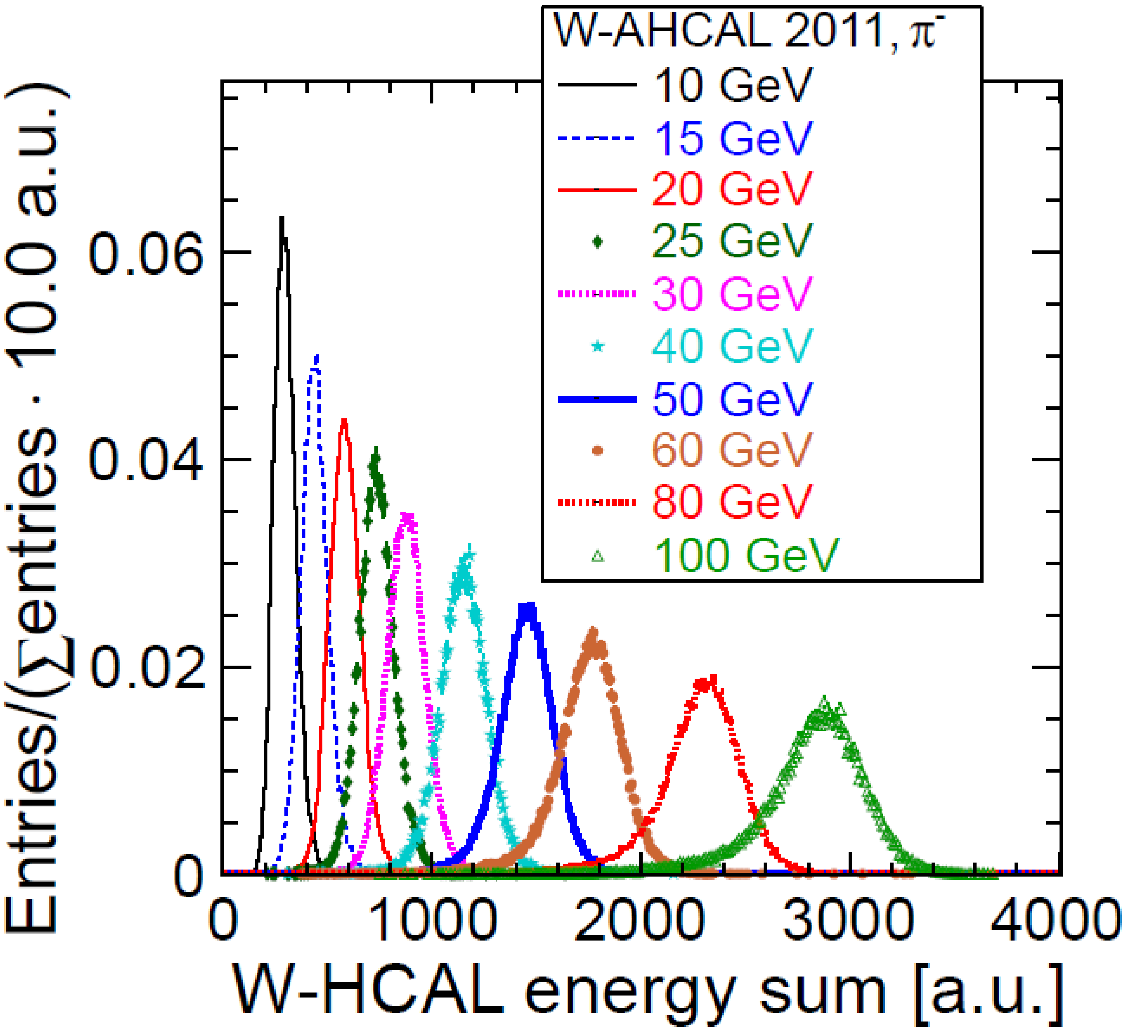
LCD Note 2012-002
https://edms.cern.ch/file/1211436/1/LCDnote_WAHCAL_testbeam.pdf

- W-AHCAL: 38 tungsten layers, each 1cm thick, corresponding to $\sim 4\lambda_I$
- TCMT1: 8 Fe layers, each 19 mm thick
- TCMT2: 8 Fe layers, each 102 mm thick
- Distance between layers 31.5 mm leaving space for sensor layers
- TCMT read-out: scintillator strips and SiPM

Data & Event Selection

- π, K, p data
  - Reconstructed CERN 2011 test beam data of W-AHCAL+TCMT
  - Data at beam energies from **10 GeV to 300 GeV** for positive and negative particles
- π, K, p simulations
  - Geant4 Simulation
  - Physics List: QGSP_BERT_HP
  - Calibration as in real data
- Same selection cuts as used in W-AHCAL analysis
  - Check if energy-sum is within reasonable limits
  - Muon & electron rejection
  - Rejection of empty events,
  - Rejection of events with pre-shower
  - **Shower must start in one of the first three W-AHCAL layers**
- Same event selection for data and simulation

CALICE W-AHCAL Test Beam 2011

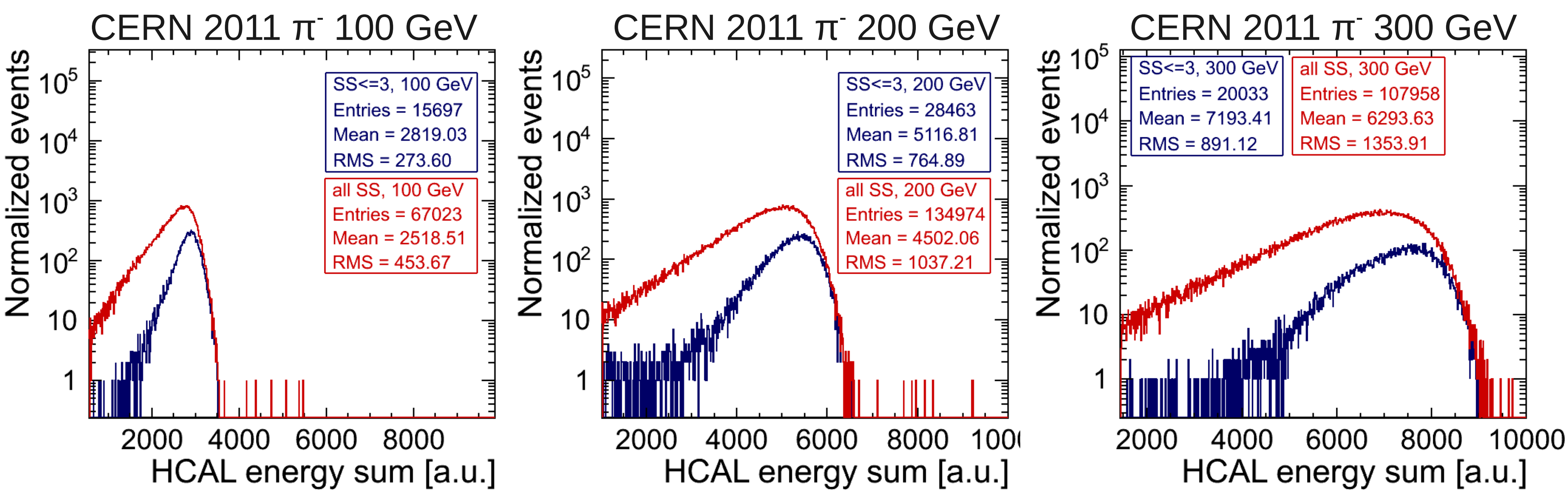


- W-AHCAL of 38 layers
- Only very small leakage effects are visible in W-AHCAL up to highest presented energies (here: $p_{beam} \leq 100$ GeV)
  - Selected only those events in which the shower starts in the first three layers of the W-AHCAL
- Leakage effects for very high energies $p_{beam} > 100$ GeV or for events with late shower start

LCD Note 2013-002

W-AHCAL at High Energies

- Leakage effects grow
  - with increasing energy and
  - when accepting all showers no matter in which layer the shower starts
- W-AHCAL: Shower start ≤ 3
- W-AHCAL: All shower start layers



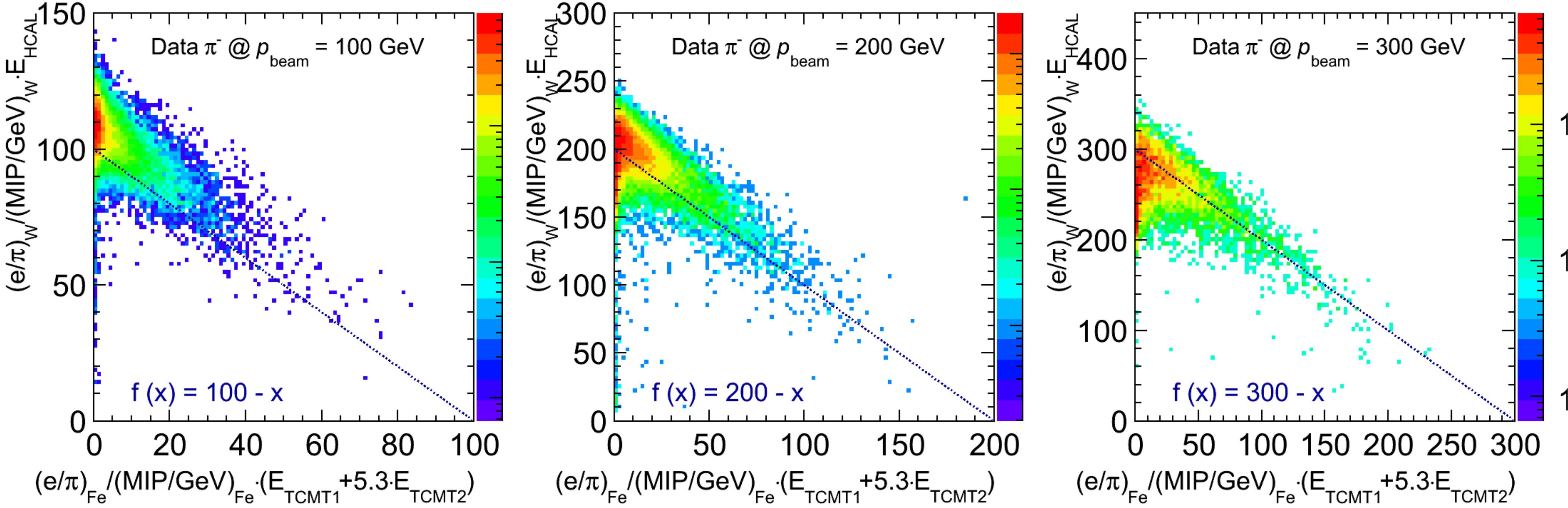
How to combine W-AHCAL and TCMT?

- Known detector response of W and Fe calorimeters
  - e over π ratios
    - $(e/\pi)_W \approx 1.0$, $(e/\pi)_{Fe} \approx 1.2$
  - MIP to GeV factors
    - $(MIP/GeV)_W \approx 27$ MIP/GeV
    - $(MIP/GeV)_{Fe} \approx 42$ MIP/GeV
  - Ratio of TCMT layer thicknesses: 5.3
    - TCMT1: 1.9 cm,
    - TCMT2: 10.2 cm
- Weighted energies
  - $\mathbf{E_{W\text{-}AHCAL,weighted} = (e/\pi)_W * (MIP/GeV)^{-1}_W * E_{W\text{-}AHCAL}}$
  - $\mathbf{E_{Fe\text{-}TCMT1,weighted} = (e/\pi)_{Fe} * (MIP/GeV)^{-1}_{Fe} * E_{TCMT1}}$
  - $\mathbf{E_{Fe\text{-}TCMT2,weighted} = (e/\pi)_{Fe} * (MIP/GeV)^{-1}_{Fe} * 5.3 * E_{TCMT2}}$

From CALICE publications
2011 JINST 6 P04003, 2012 JINST 7 P09017, 2012 JINST 7 P04015

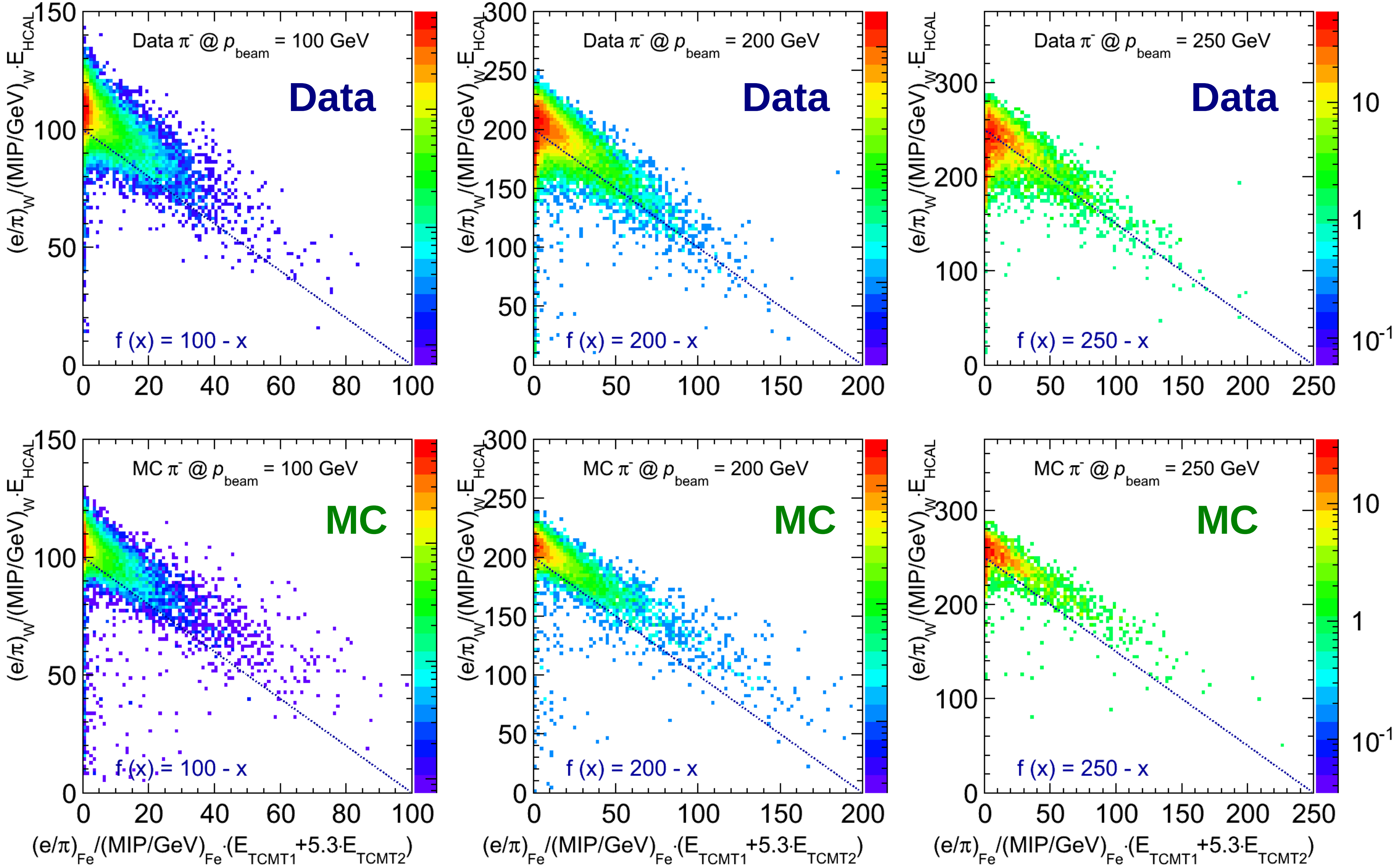
Consistency Check: $E_{W\text{-}AHCAL}$ versus E_{TCMT}

- Build correlation of weighted energy deposition in W-AHCAL and TCMT taking into account detector knowledge

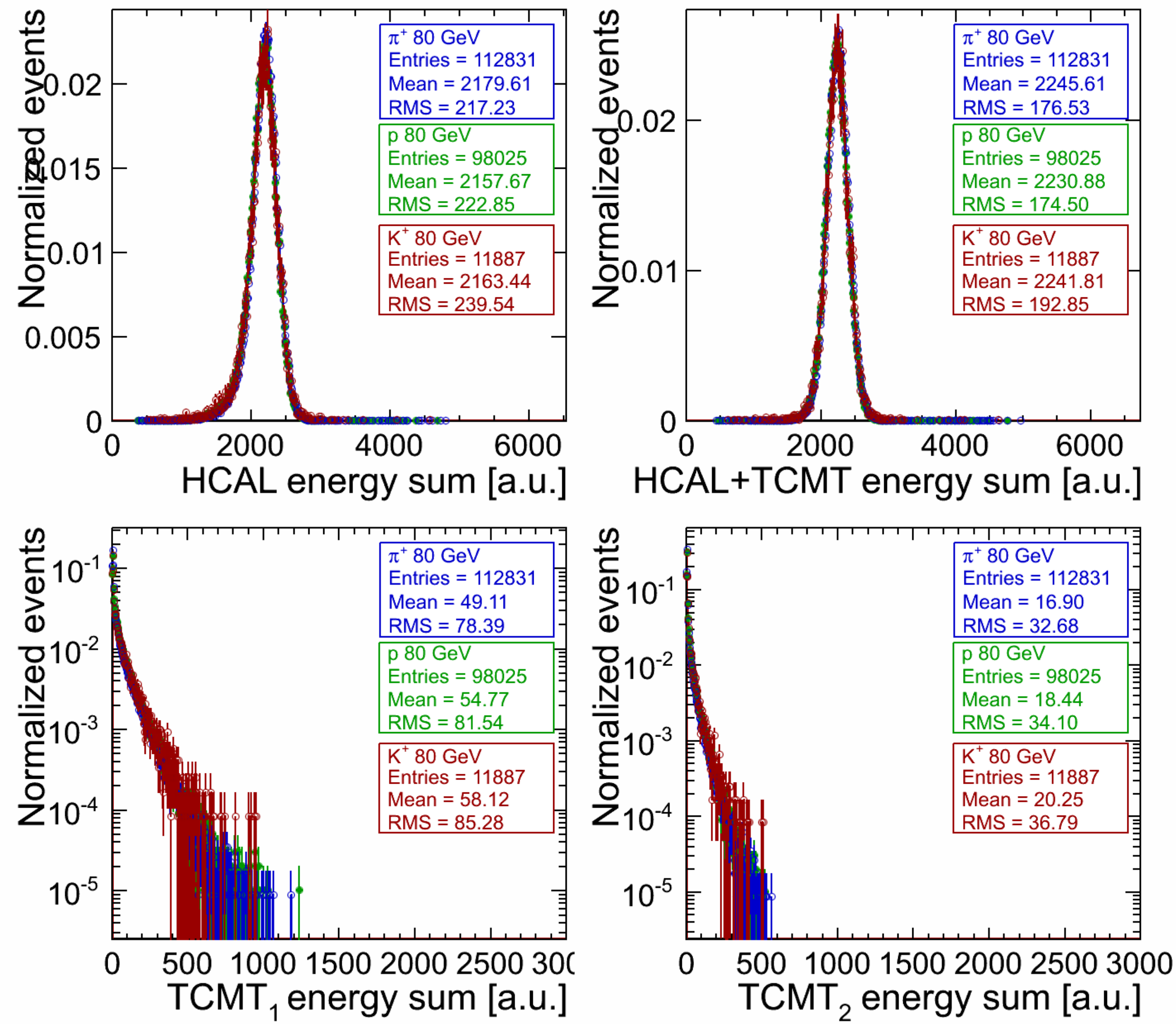


- Almost linear dependence
  - Energy lost in the W-AHCAL is recovered in the TCMT

E_{HCAL} versus E_{TCMT}: Data and MC



Example: π, p, K at 80 GeV

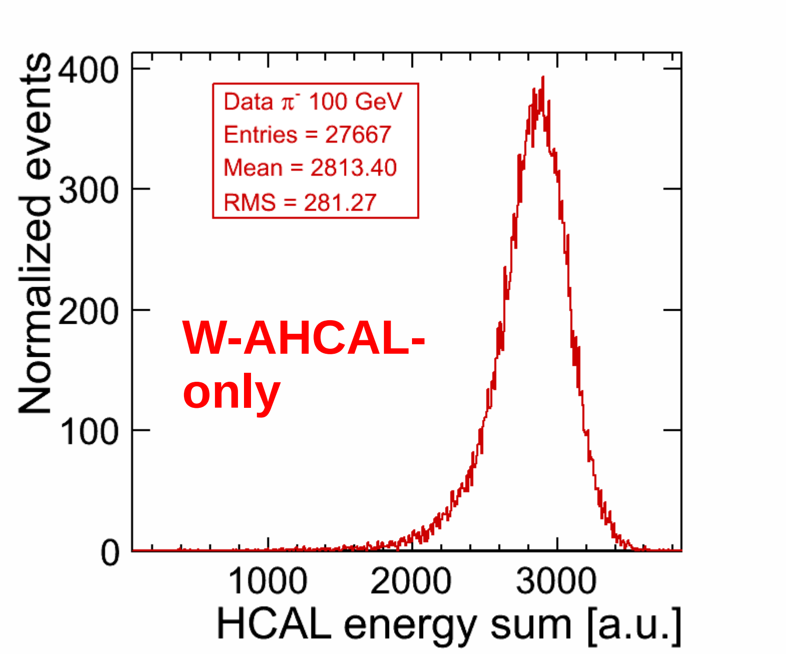


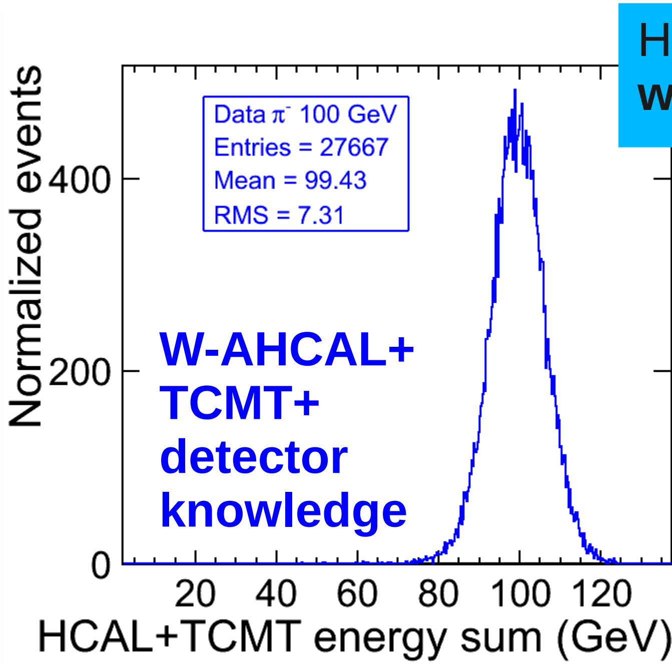
- Comparison of π, p, and K data
- Similar results for all hadrons

Optimization of Energy Resolution

- **First step**: Instead of W-AHCAL-only, use weighted sum of W-AHCAL and TCMT using detector knowledge and one scaling factor
  - **"Detector knowledge":**

$$
\begin{aligned}
E_{input} = & \; \mathbf{w_{global}} * (e/\pi)_{W} * (MIP/GeV)^{-1}_{W} * E_{W\text{-}AHCAL} \\
& + \mathbf{w_{global}} * (e/\pi)_{Fe} * (MIP/GeV)^{-1}_{Fe} * E_{TCMT1} \\
& + \mathbf{w_{global}} * (e/\pi)_{Fe} * (MIP/GeV)^{-1}_{Fe} * \mathbf{5.3} * E_{TCMT2}
\end{aligned}
$$



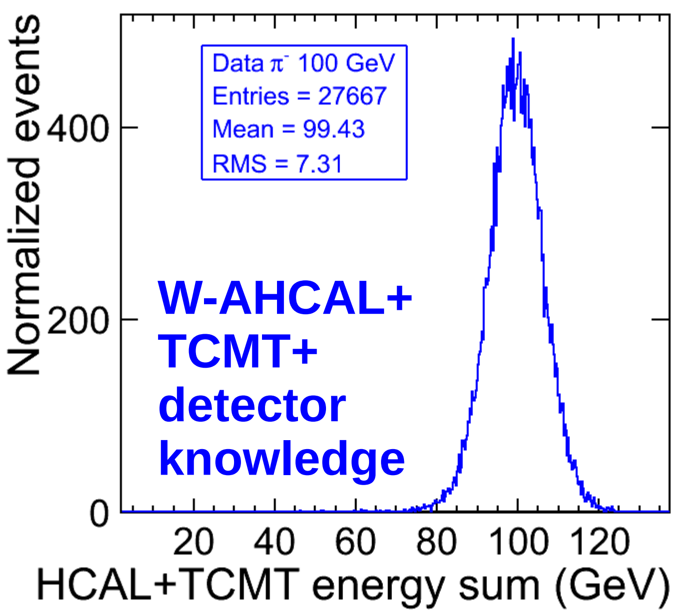


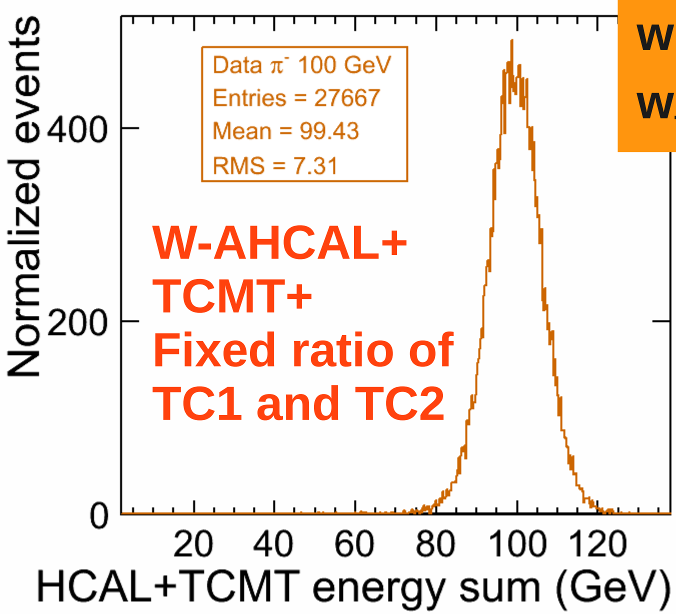
Here $\mathbf{w_{global}} \approx 0.91$

Optimization of Energy Resolution

- **Second step**: Try to optimize the resolution by fitting 2 independent weights for W-AHCAL and TCMT using a χ^2-minimization

$$E_{input} = \mathbf{w_H} * E_{W\text{-}AHCAL} + \mathbf{w_T} * E_{TCMT1} + \mathbf{w_T} * 5.3 * E_{TCMT2}$$





Here:
$\mathbf{w_H} \approx 0.034$
$\mathbf{w_T} \approx 0.026$

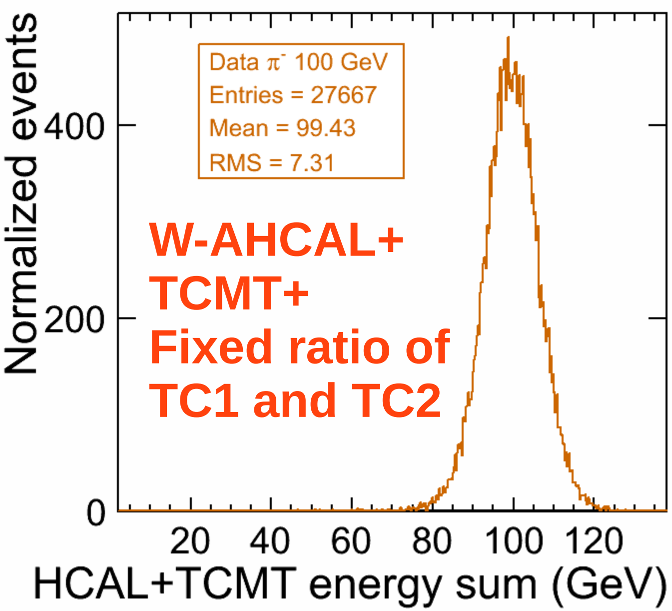
Optimization of Energy Resolution

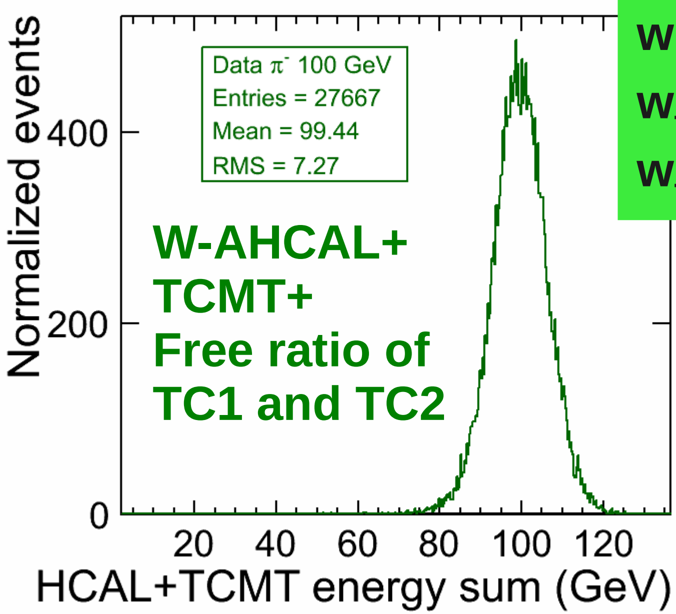
- **Third step**: Try to further optimize the resolution by fitting 3 independent weights for W-AHCAL, TCMT1 and TCMT2 using a χ^2-minimization

$$E_{input} = \mathbf{w_H} {*} E_{W\text{-}AHCAL} + \mathbf{w_{T1}} {*} E_{TCMT1} + \mathbf{w_{T2}} {*} E_{TCMT2}$$

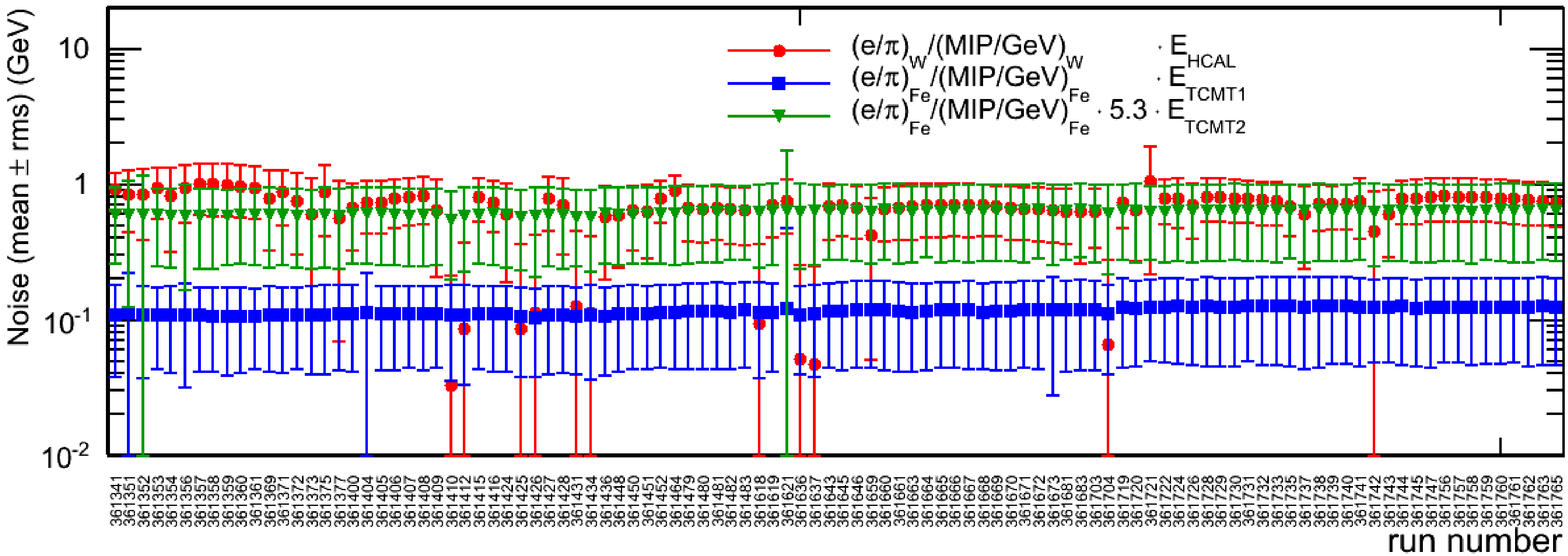
- Drawbacks
  - Possible domination by fluctuations in TCMT
  - Weights might converge at physically incorrect values

Here:
$\mathbf{w_H} \approx 0.034$
$\mathbf{w_{T1}} \approx 0.035$
$\mathbf{w_{T2}} \approx 0.12$





Outlook: Noise Subtraction

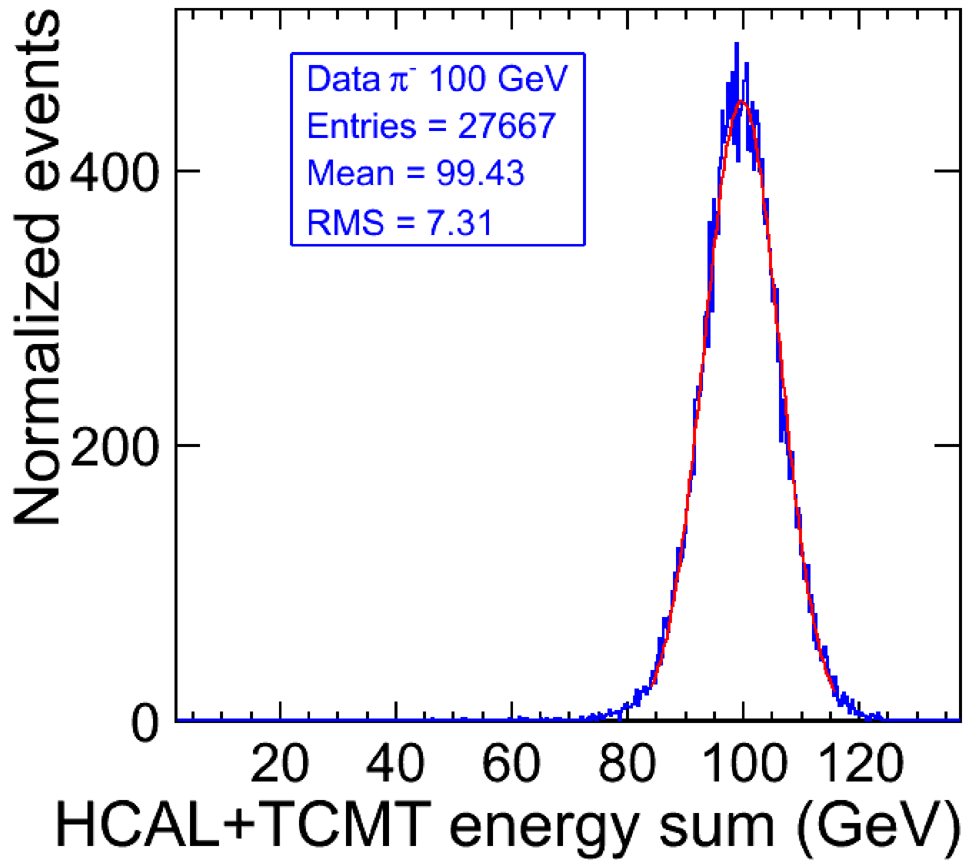


- Select noise events with noise trigger
  `(!beamBit&&(pedestalBit||purePedBit))&&(eHcal<100,000)`
- Measure noise per run **scaled by e/π and MIP/GeV factors**
- Noise seems stable over all runs for TCMT1 and TCMT2
- Outlook: repeat determination of energy sum and energy resolution after noise subtraction

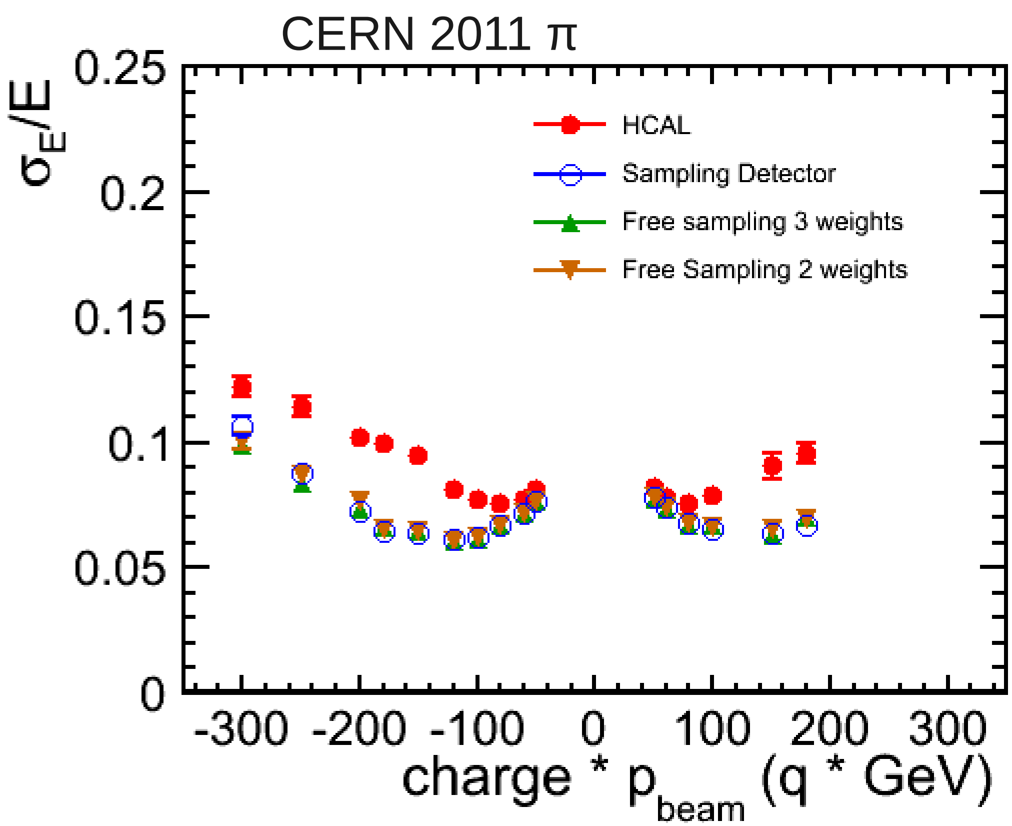
Quantify Resolution

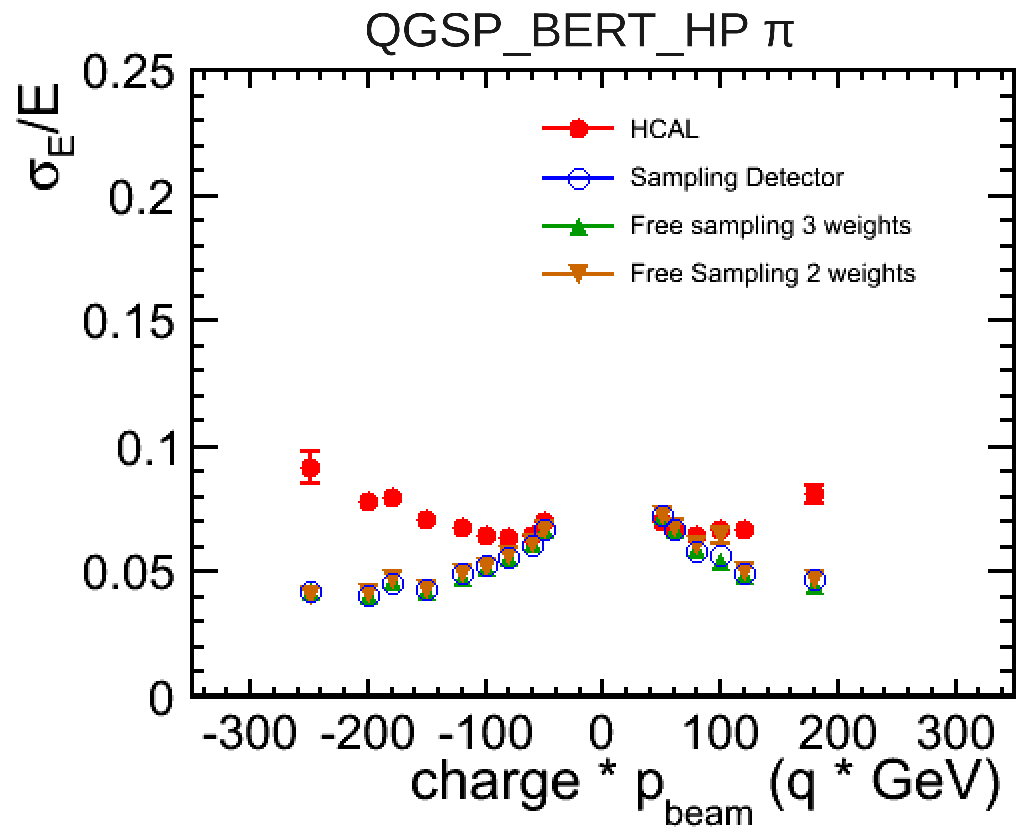
- Determine energy sum distribution
- Use only 90% of most central entries of the E_{sum} peak for a fit with a Gaussian function
- Extract mean $<E> = <E_{90\%}>$

  and width $\sigma_E = \sigma_{E,90\%}$ of peak based on Gaussian fit function results
- Energy resolution: $\sigma_E / <E> = \sigma_{E,90\%} / <E_{90\%}>$



Resolution

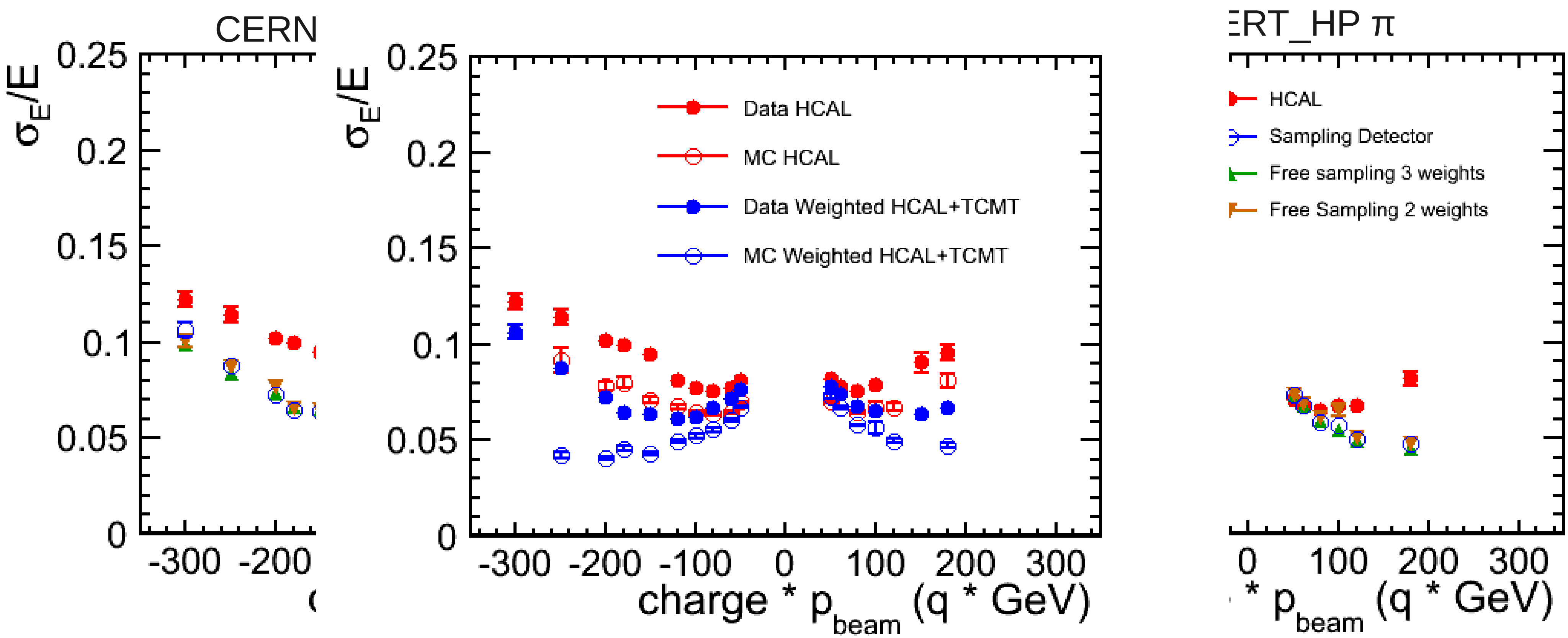




- TCMT improves resolution
- Different sampling methods give similar results

- Adding of TCMT gives larger improvement in MC than in data, especially in high energy data

Resolution: π



- TCMT improves resolution
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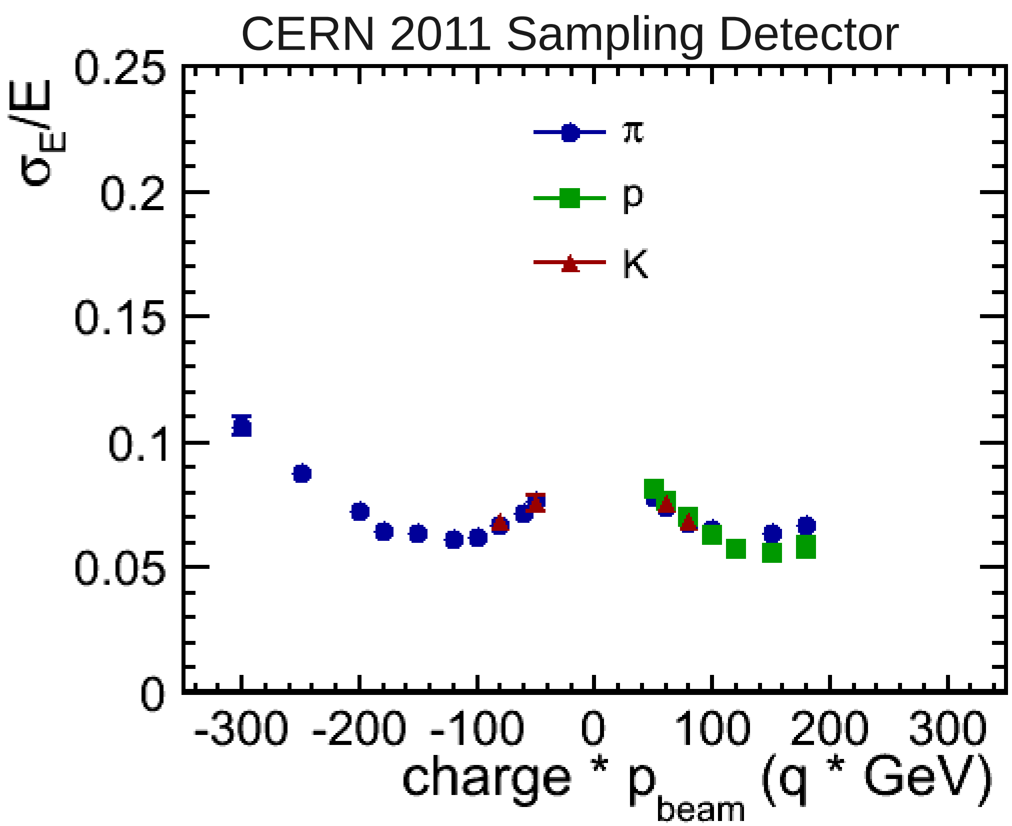
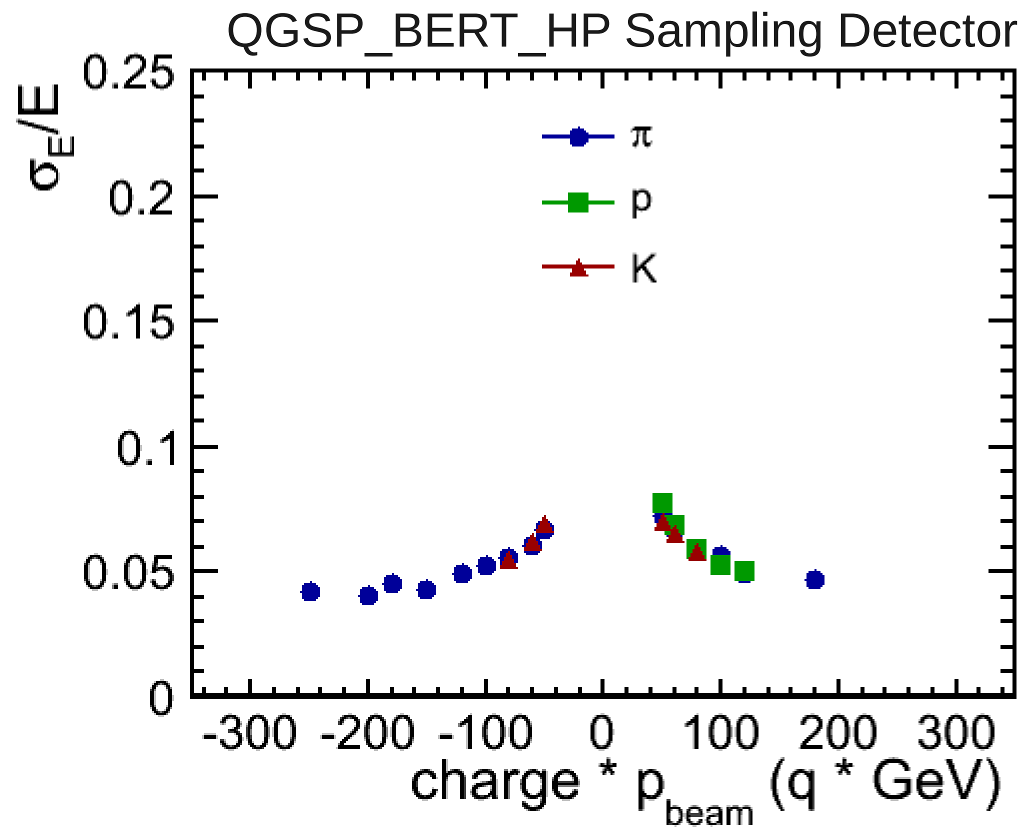
Resolution: π, p, K

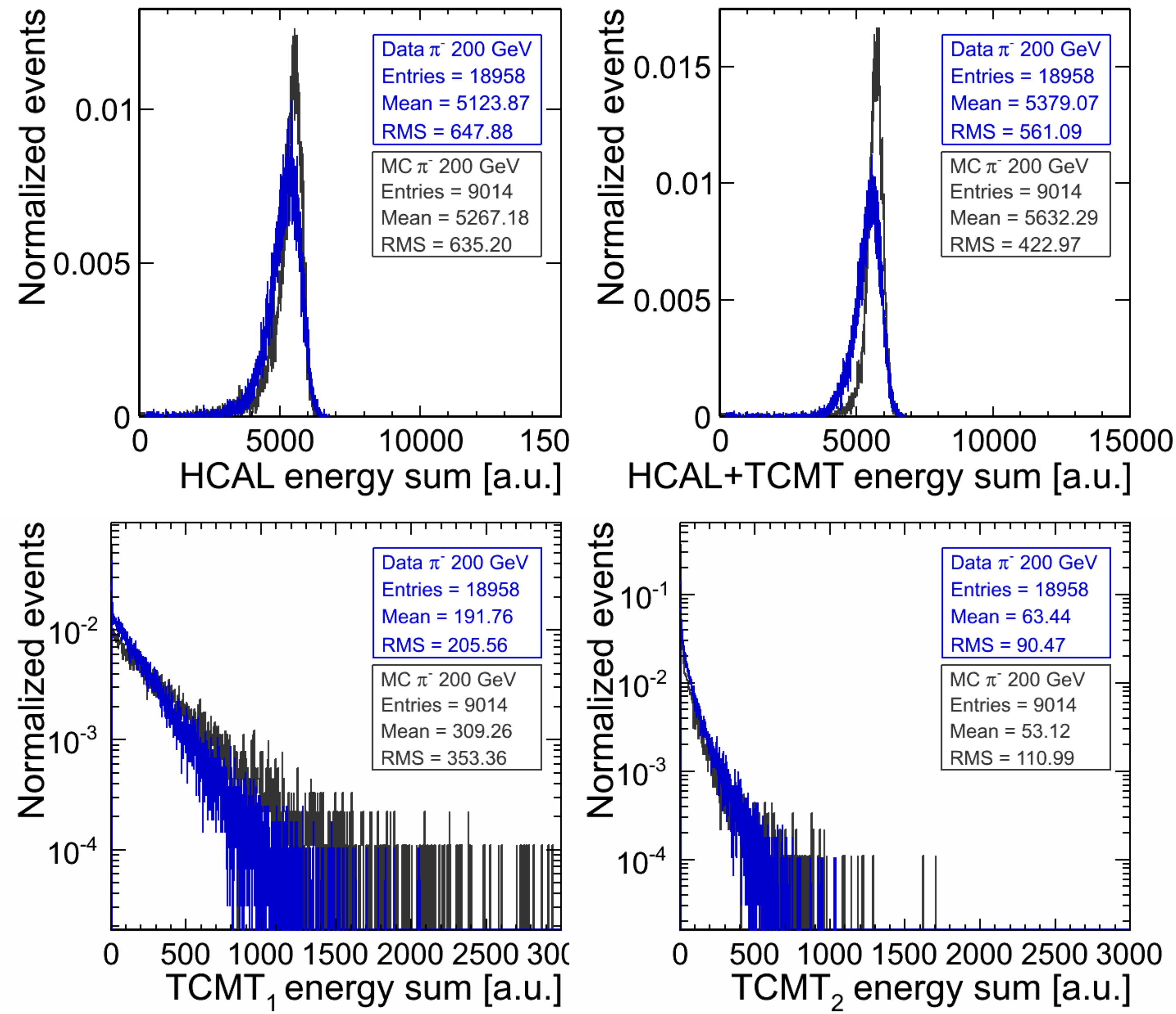




- Use weighted energy sum of W-AHCAL and TCMT according to detector knowledge
- Resolution is similar for π, K, and p data

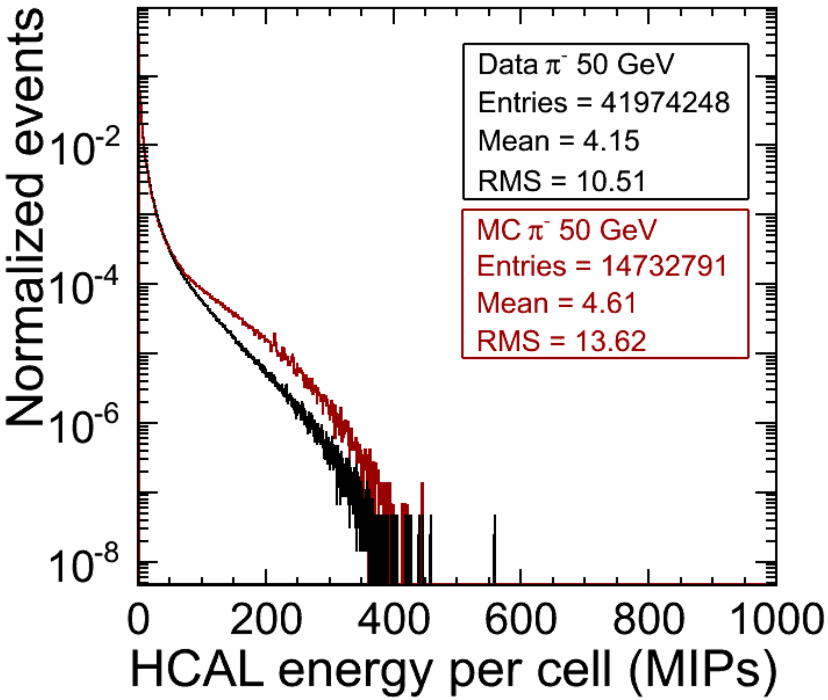
- Resolution is similar for π, K, and p also in MC
- Results are better in MC than in data, especially for high pbeam

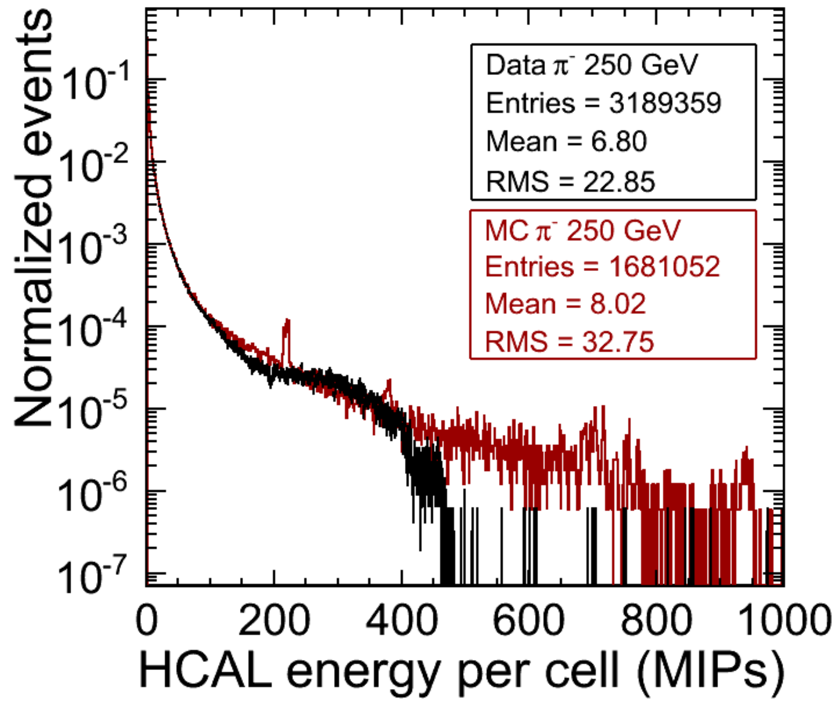
Example: π_{data} and π_{MC} at 200 GeV



- At high energies, TCMT does not improve resolution as much as at intermediate energies
- Comparison of data and MC
- **Differences already in W-AHCAL**

Comparison of Hit Distribution in W-AHCAL





- At low energy, MC and data are in fairly good agreement in terms of the energy distribution
- At high energies, MC and Data start to differ → MC reaches much higher energy deposition per cell
- Possible sign of saturation effect in data?
- This effect is not a leakage effect and could not be cured by a TC

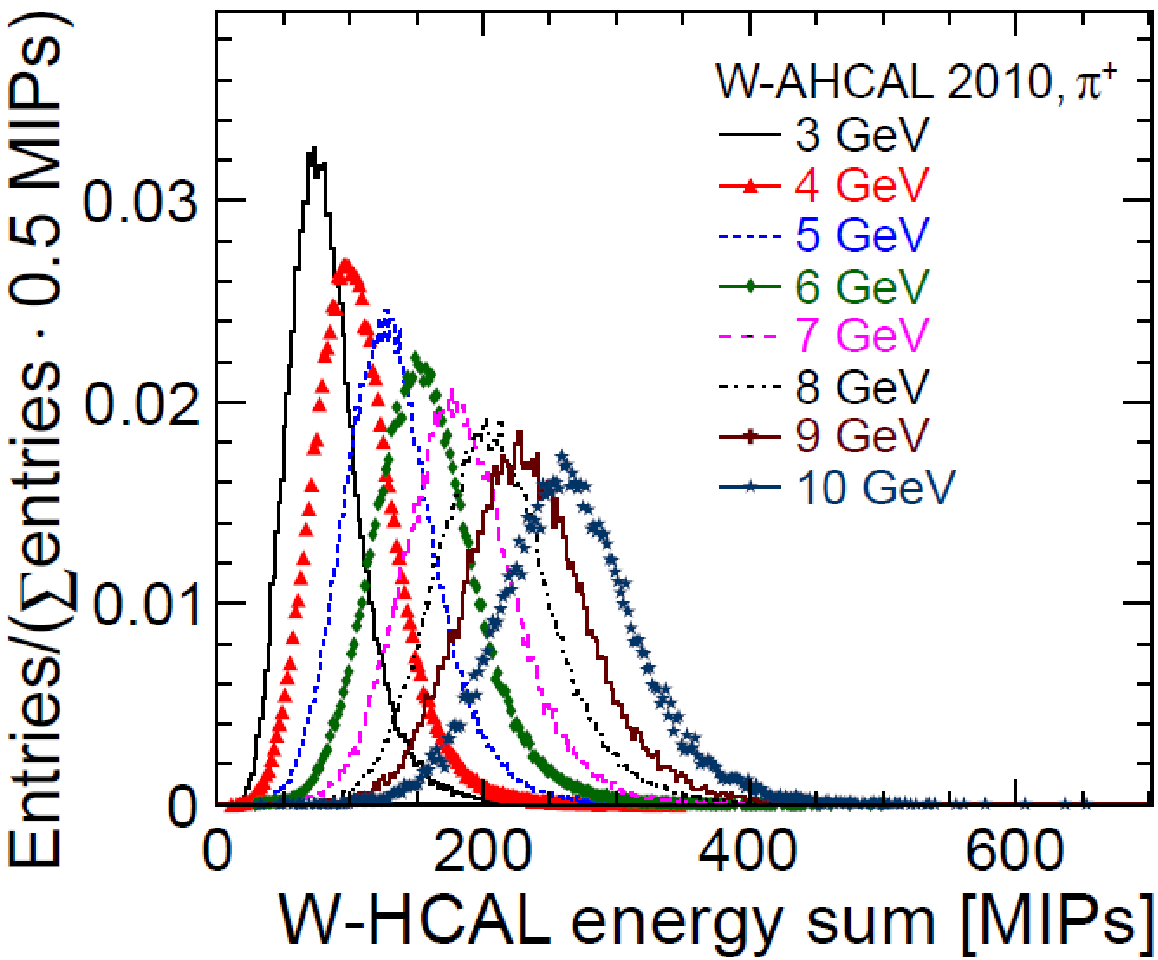
Summary & Outlook

- Start of analysis of W-AHCAL and TCMT test beam data of 2011 at CERN SPS at energies from 10 to 300 GeV
- Comparison of data and MC as well as of π, K, p
- Optimization of energy resolution for W-AHCAL+TCMT
- Measurement of noise
- Possible observation of saturation effect in W-AHCAL

- Next steps
  - Optimize event selection cuts for energies above 100 GeV
  - Noise subtraction before estimation of resolution
  - Study possible saturation effect in W-AHCAL at high energies
- Goal
  - Determine energy resolution and linearity of combined W-AHCAL+TCMT

Backup

CALICE W-AHCAL Test Beam 2010



CALICE Analysis Note 036

https://edms.cern.ch/file/1224616/1/can_note_14June2012.pdf

- Test beam with W-AHCAL at CERN PS at energies from 1 to 10 GeV
- W-AHCAL of 30 layers
- Clear pion peak at all energies in HCAL-only
- By selection, shower fully contained in W-AHCAL
  - Select events with shower start in very first W-AHCAL layers (≤3)

E_{HCAL} versus E_{TCMT}: Early and Late Shower