W-HCAL+TCMT Analysis Status Report

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DESY

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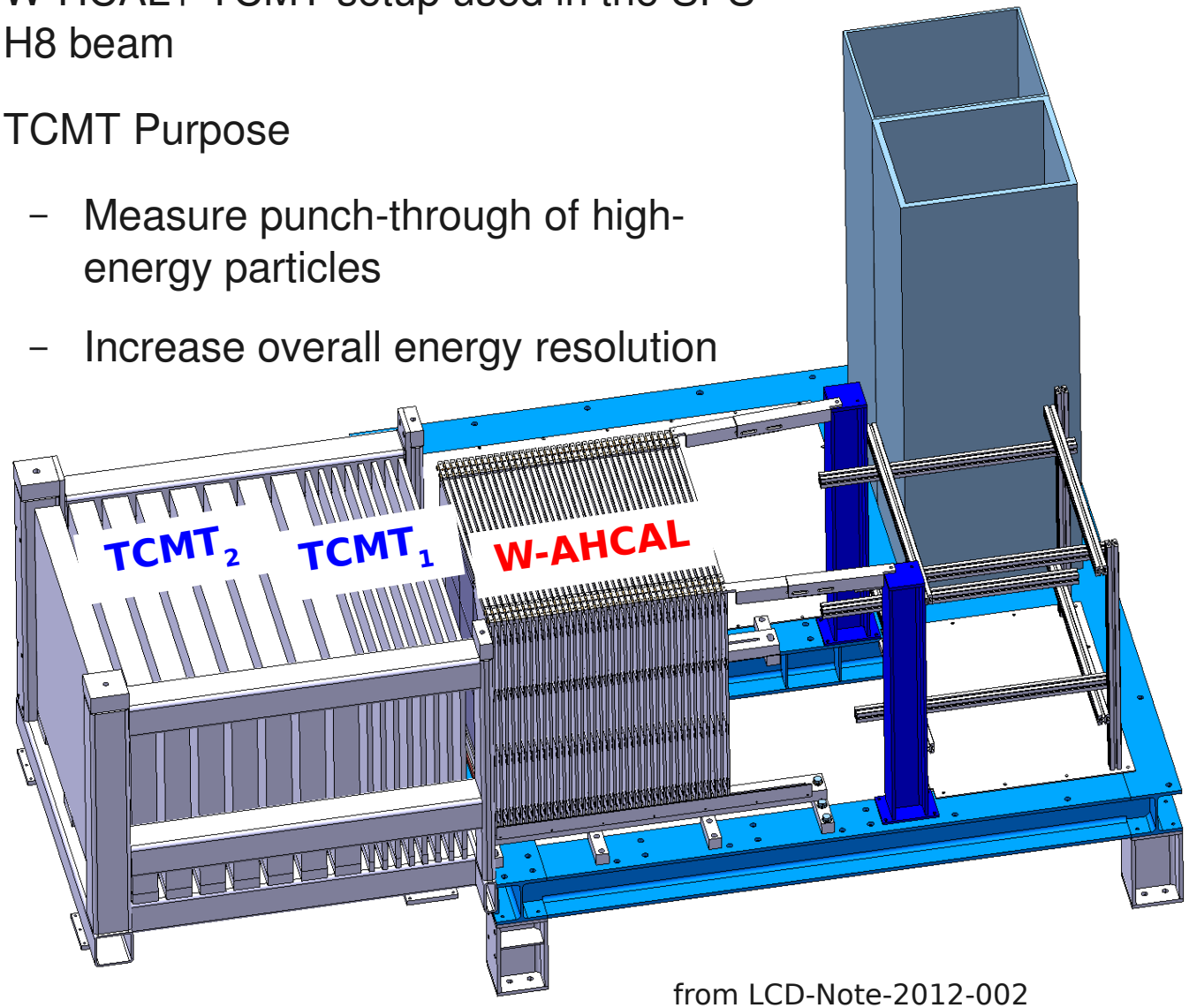
Content

- Data sets and event selection
- Determination of energy resolution $\sigma_E/\langle E \rangle$
- Determination of sampling fraction
  - Naive approach: one weight for each detector part
  - “Uncorrected” approach: only one weight combined with knowledge of the detector: e/π ratios, MIP/GeV factors
- Comparison of
  - Energy resolution
  - Sampling weights
    - Shower start cut dependence

W-AHCAL + TCMT

- W-HCAL+ TCMT setup used in the SPS H8 beam
- TCMT Purpose
  - Measure punch-through of high-energy particles
  - Increase overall energy resolution



from LCD-Note-2012-002

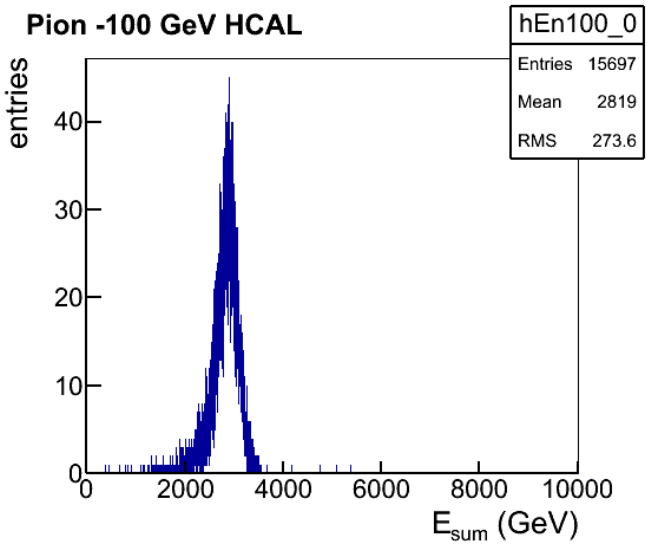
- HCAL: 38 tungsten layers, each 1cm thick, corresponding to ~4λ_I
- $TCMT_1$: 8 Fe layers, each 2cm thick
- $TCMT_2$: 8 Fe layers, each 10cm thick
- Distance between layers 32mm leaving space for sensor layers
- TCMT read-out: scintillator strips and SiPM

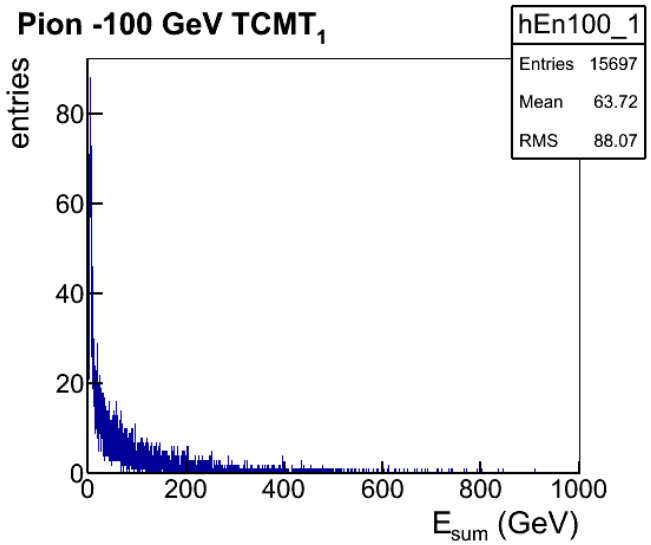
Data Sets & Events Selection

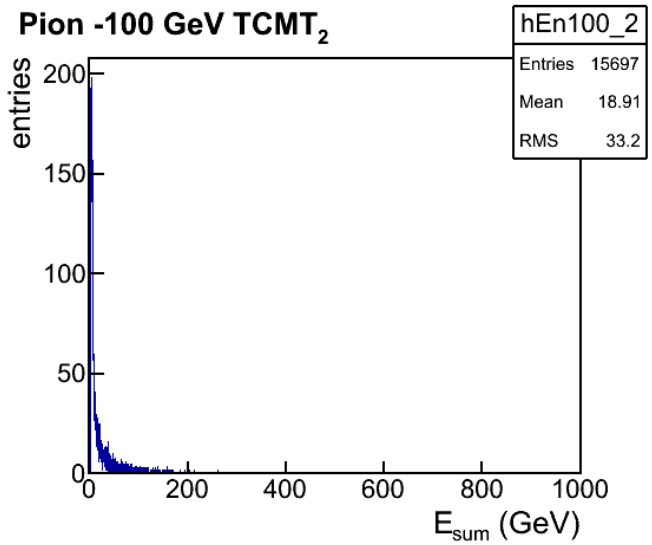
- Reconstructed CERN 2011 test beam data of HCAL+TCMT
- Data at beam energies from **10 GeV to 300 GeV** for positive and negative particles
- Here: Analysis of pion event sample

- Pion events selection based on HCAL-selection cuts
  - Check if energy-sum is reasonable for pions
  - Muon & electron rejection
  - Empty event rejection, pre-shower rejection
  - Shower should start in one of the first 4 layers

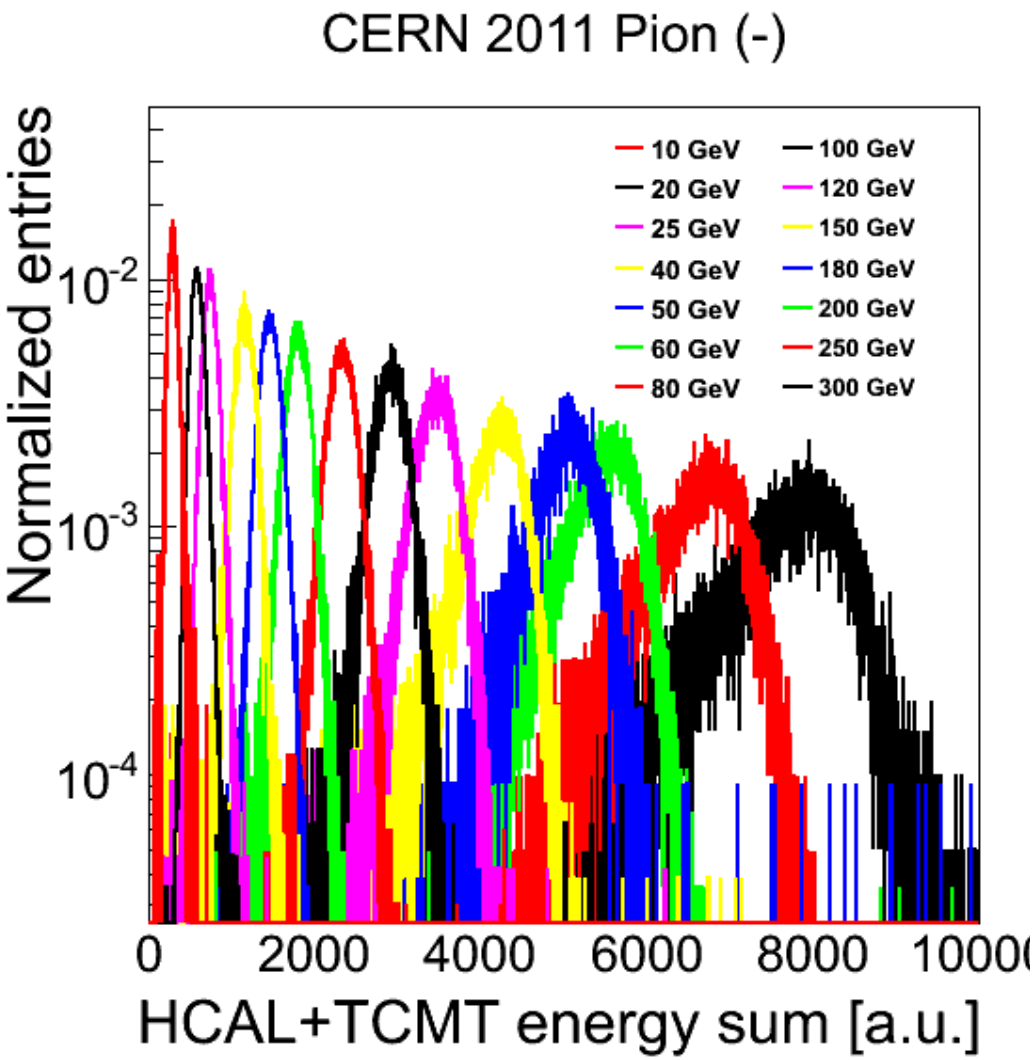
Example: 100 GeV, negative pions

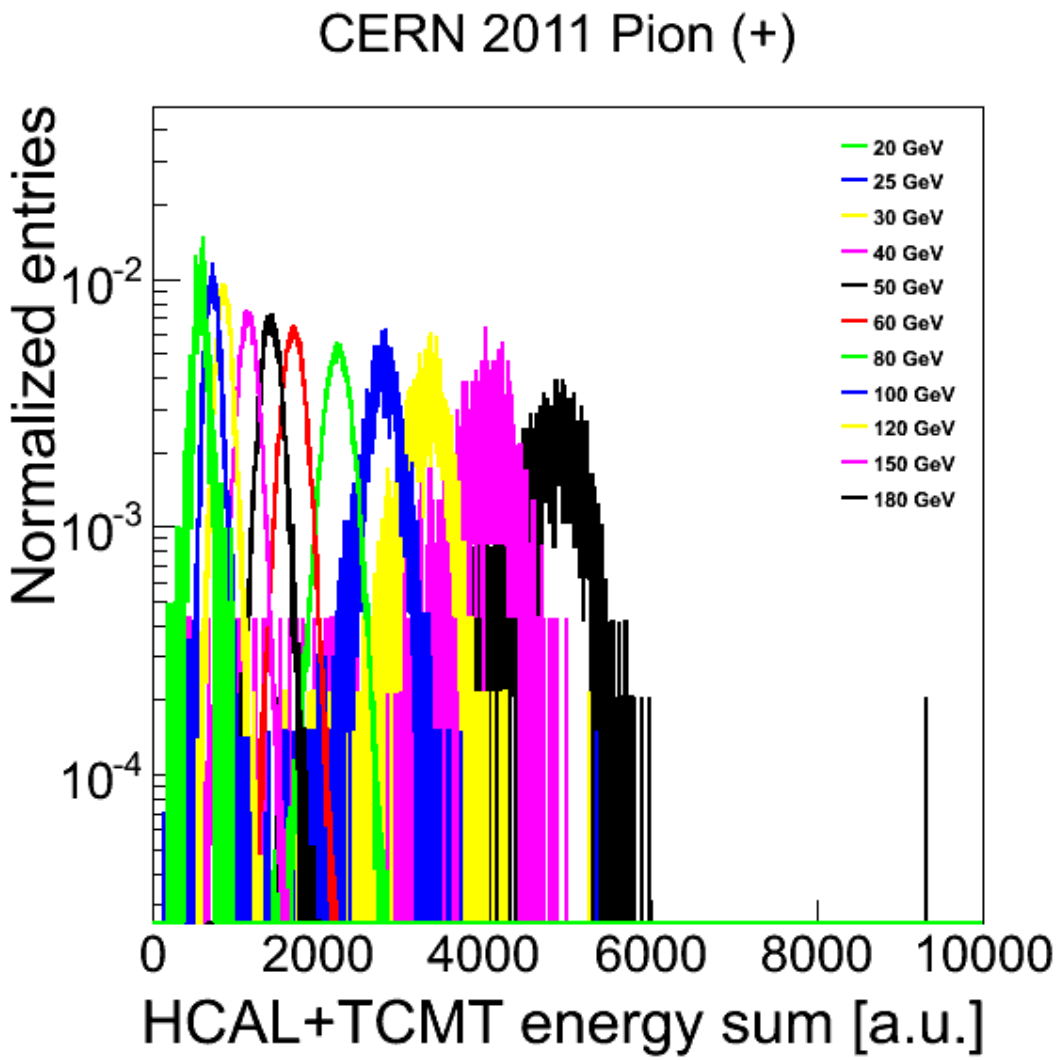






Control histograms: $E_{\text{sum HCAL+TCMT}}$

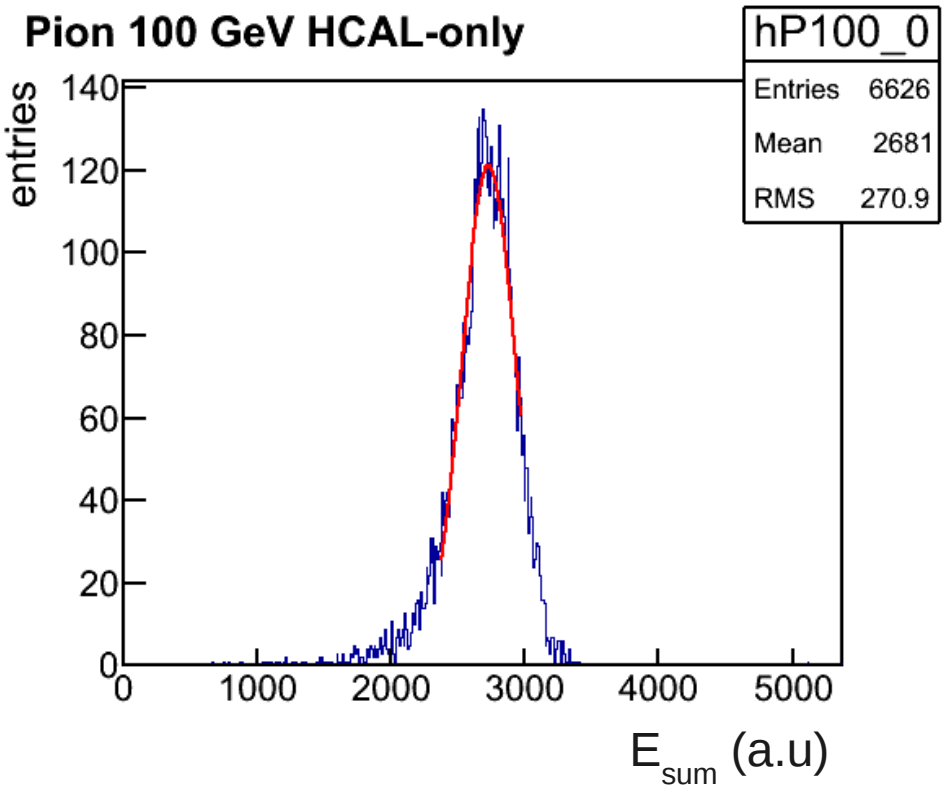




Estimation of Energy Resolution

- Determine energy sum distribution
- Use only 80% of most central entries of the E_{sum} peak for a fit with a Gaussian function
- Extract mean $\langle E \rangle = \langle E_{80\%} \rangle$

  and width $\sigma_E = \sigma_{E80\%}$ of peak based on Gaussian fit function results
- Energy resolution: $\sigma_E / \langle E \rangle = \sigma_{E80\%} / \langle E_{80\%} \rangle$



Comparison of Energy Resolutions

- $E_{sum,HCAL}$
- $E_{sum,HCAL,TCMT} = 1 * E_{sum,HCAL} + 1 * E_{sum,TCMT1} + 1 * E_{sum,TCMT2}$
- Sampling: χ^2 minimization of difference in E_{input} and $E_{reco,corrected}$
  - E_{input} is chosen here to $E_{beam,}$ use full 100% of the E_{sum} peak
  - **"Naive/simple":** simultaneous minimization of several weights

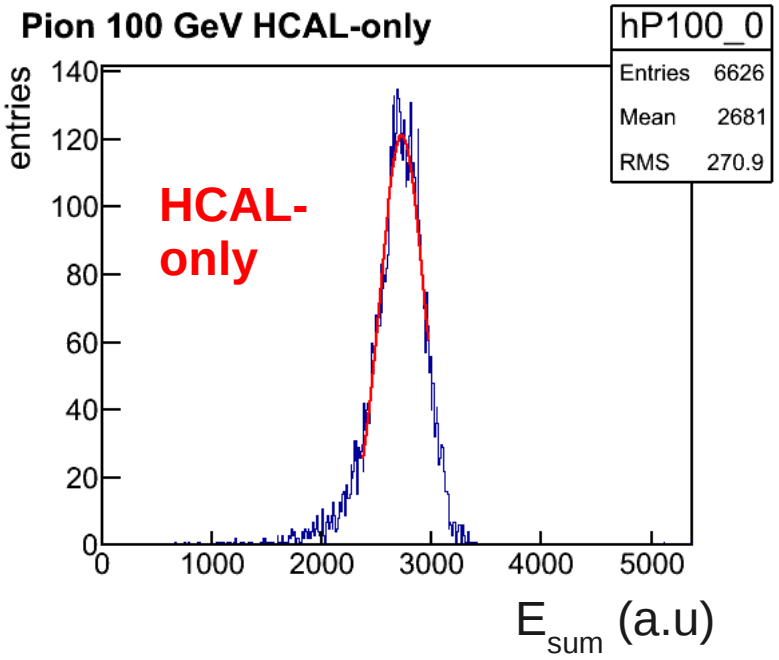
$$E_{input} = \mathbf{w_H} * E_{HCAL} + \mathbf{w_{T1}} * E_{TCMT1} + \mathbf{w_{T2}} * E_{TCMT2}$$

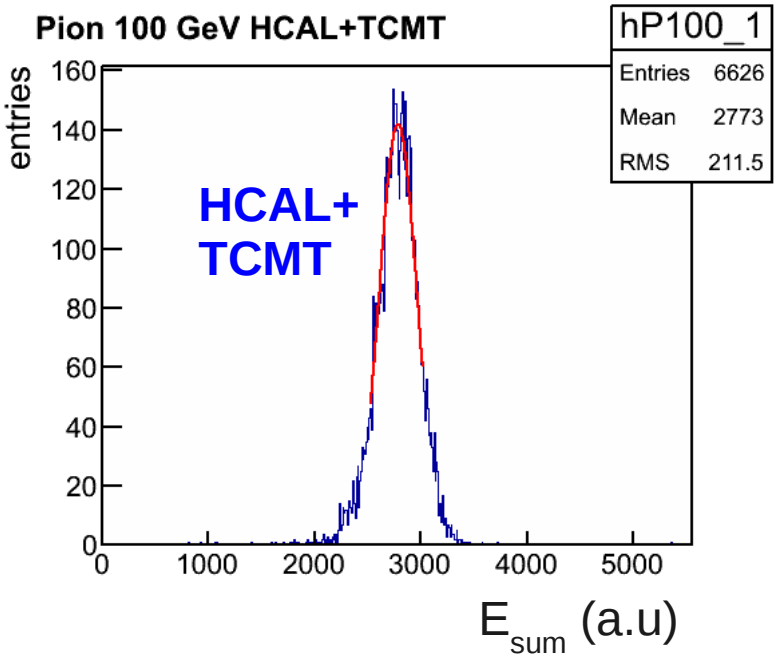
  - **"Uncorrected":** use known properties of calorimeter and 1 scaling factor

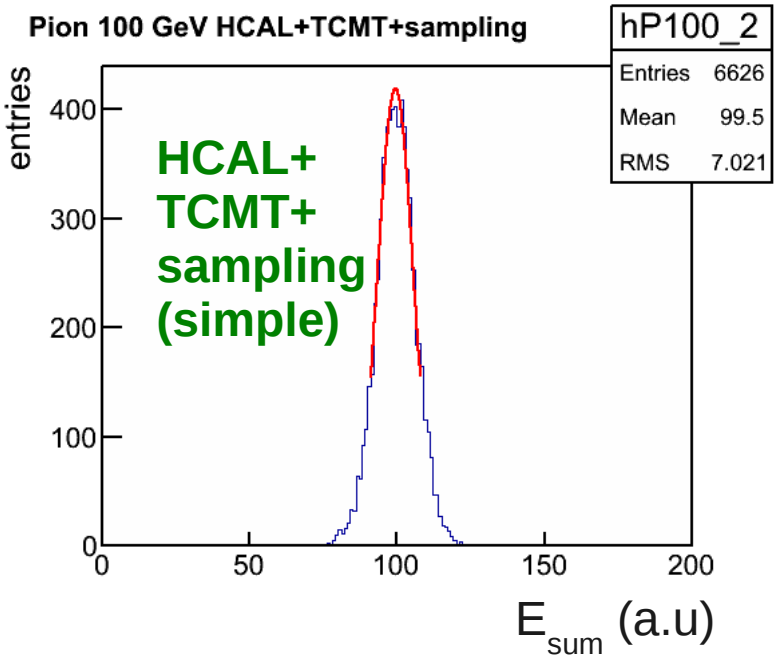
$$E_{input} = \mathbf{w_{global}} * (e/\pi)_W * (MIP/GeV)^{-1}_W * E_{HCAL} + \mathbf{w_{global}} * (e/\pi)_{Fe} * (MIP/GeV)^{-1}_{Fe} * E_{TCMT1} + \mathbf{w_{global}} * (e/\pi)_{Fe} * (MIP/GeV)^{-1}_{Fe} * 4 * E_{TCMT2}$$

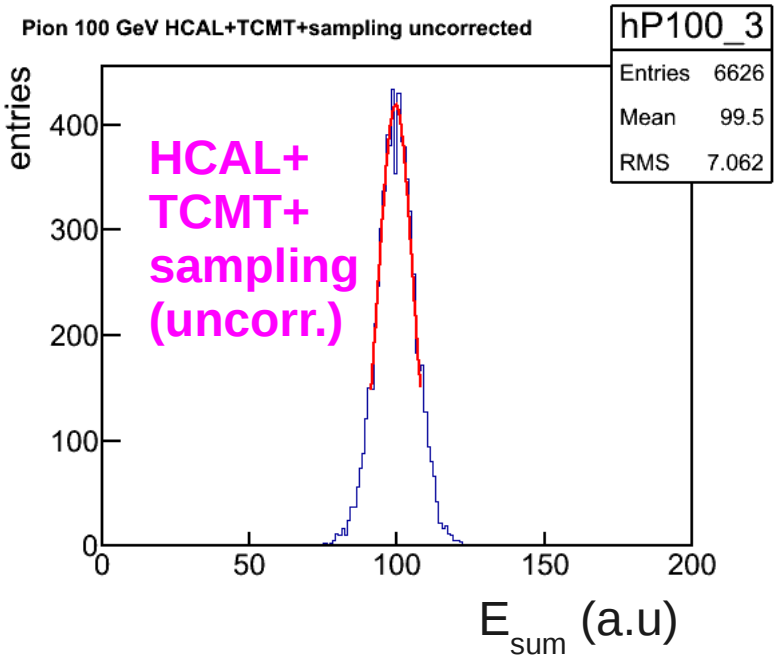
  - For current setup: $(e/\pi)_W = 1.0$, $(e/\pi)_{Fe} = 1.19$, $(MIP/GeV)_W = 27.0$ MIP/GeV $(MIP/GeV)_{Fe} = 42.3$ MIP/GeV

Comparison of Resolution: Example



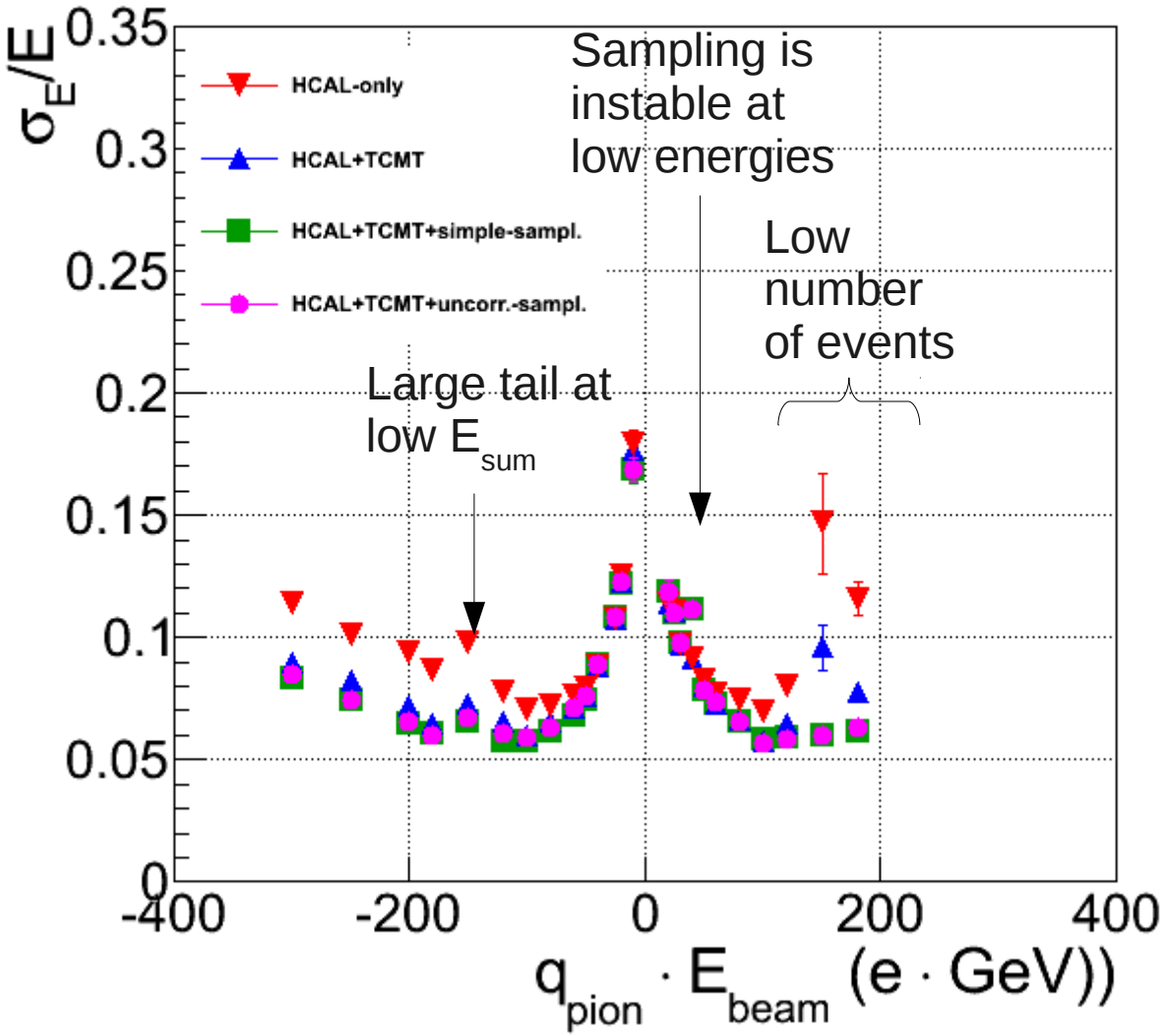






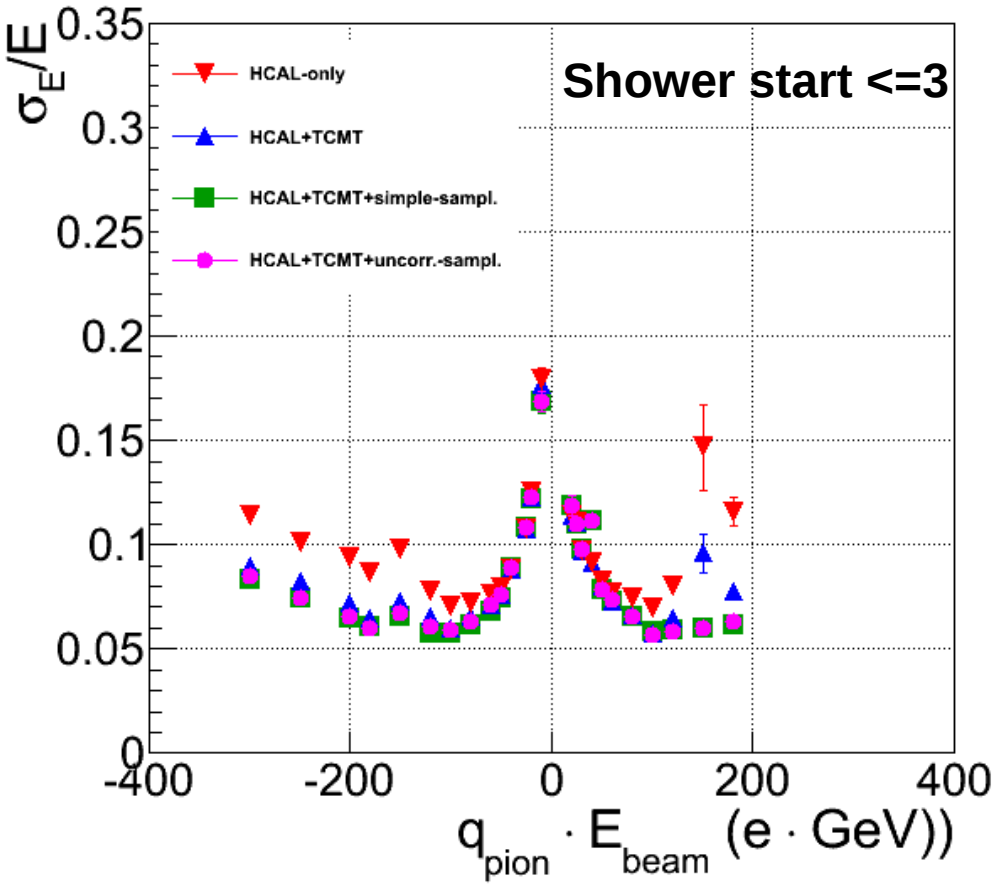
Beam Energy Dependence

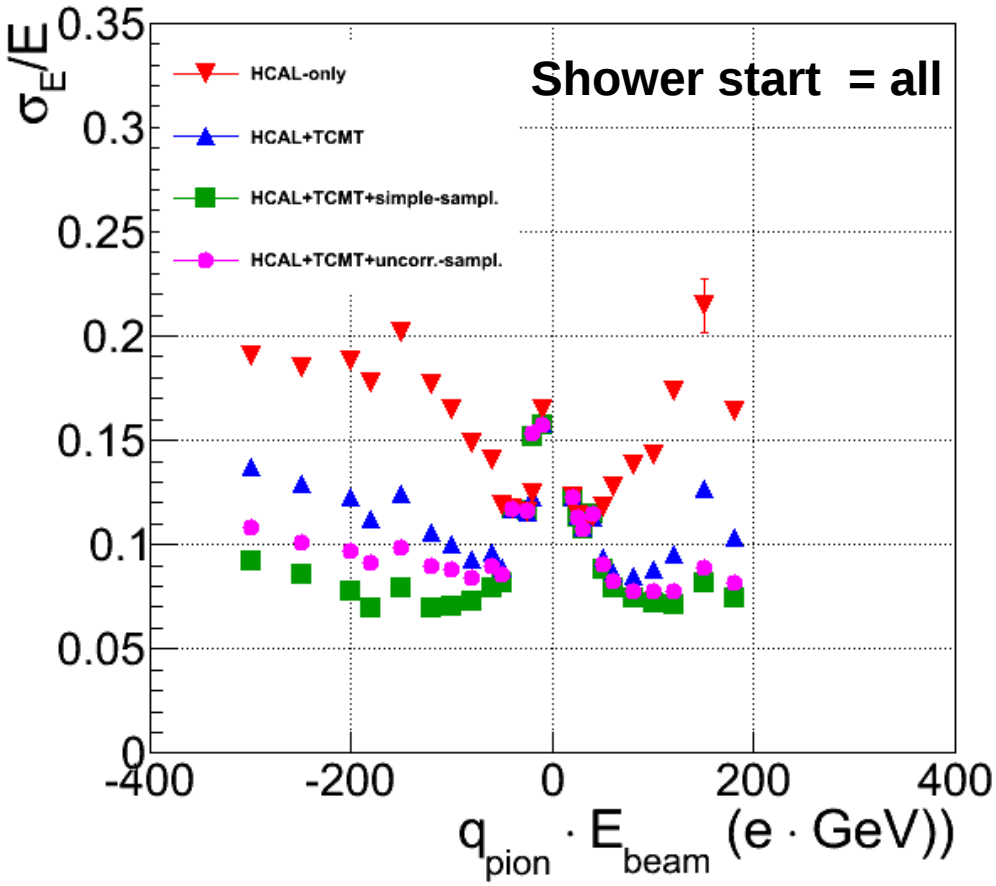
Energy Resolution versus Beam Energy



- Estimated for HCAL-only, HCAL+TCMT, HCAL+TCMT+simple-sampling, HCAL+TCMT+ uncorr-sampling
- Sampling: Weights are optimized for each energy separately
- For high energy runs, σ_E/E decreases when using information of TCMT
- Increase of σ_E/E at high E due to tail at low E_{sum} → peak appears to be broader
- Both sampling approaches give similar results
- Sampling further decreases σ_E/E

Shower Start Dependence



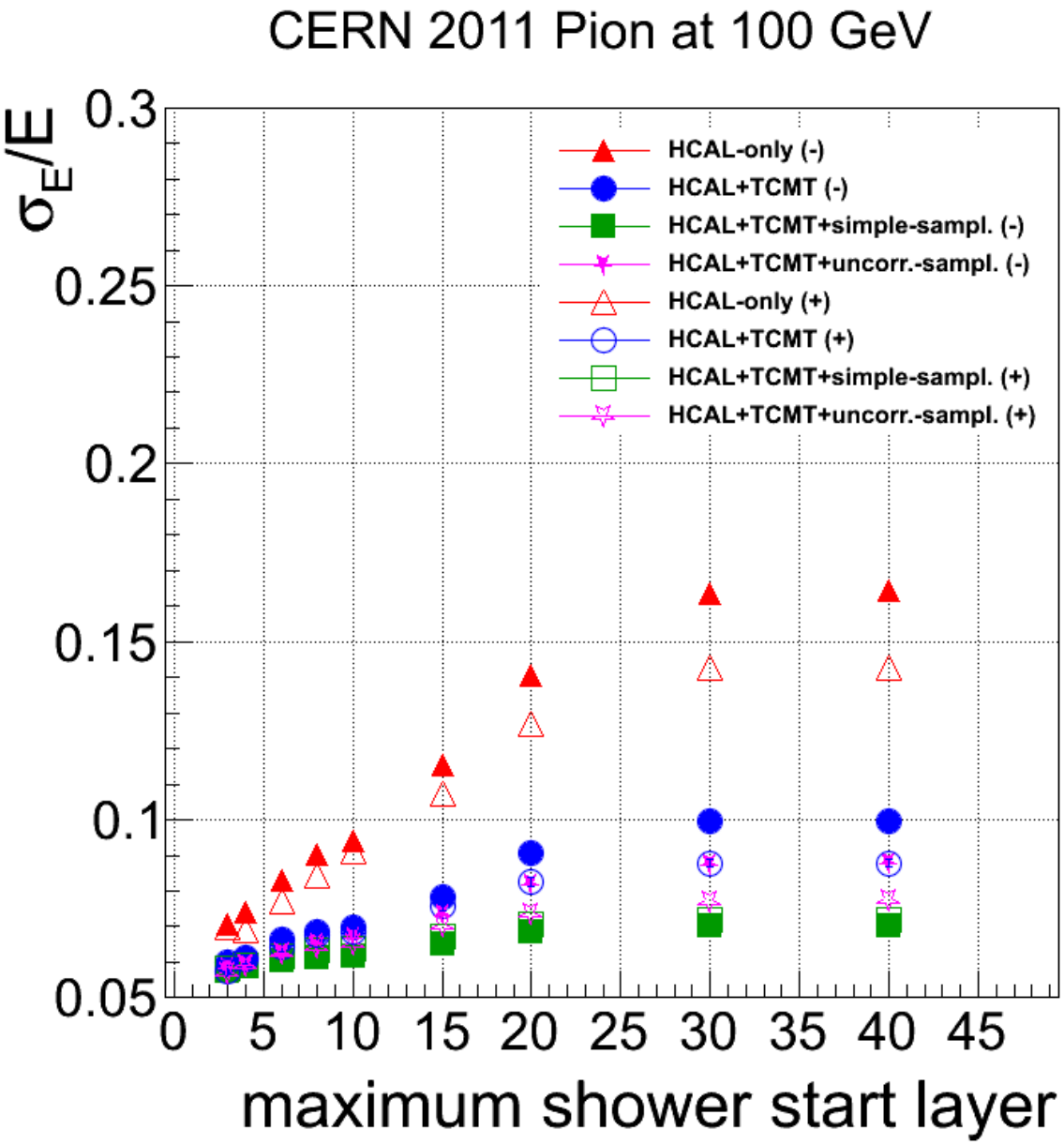


- σ_E/E increases when allowing the shower to start in all layers
  → Leakage effects at high energies are more pronounced
  → Larger leakage → lager tails at low E_{sum}
  → Larger difference between two sampling approaches

Shower Start Dependence

- Introduction
- Energy scan

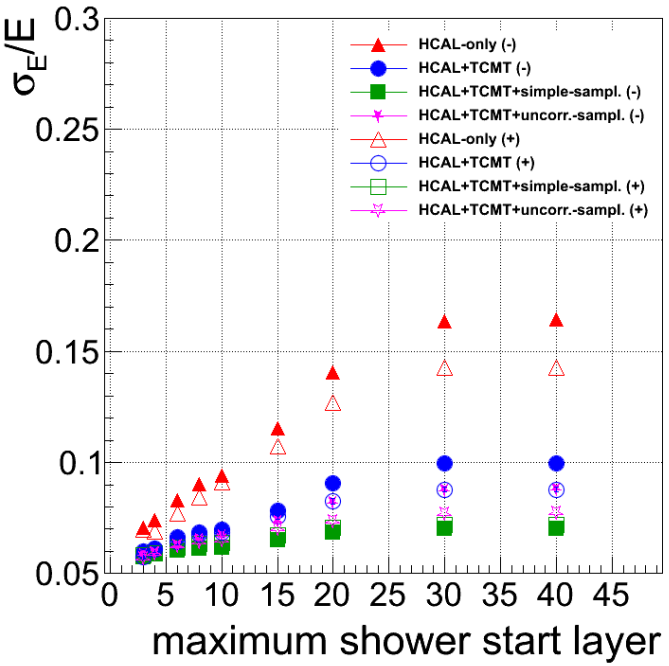
Shower-Start Dependence @ 100 GeV



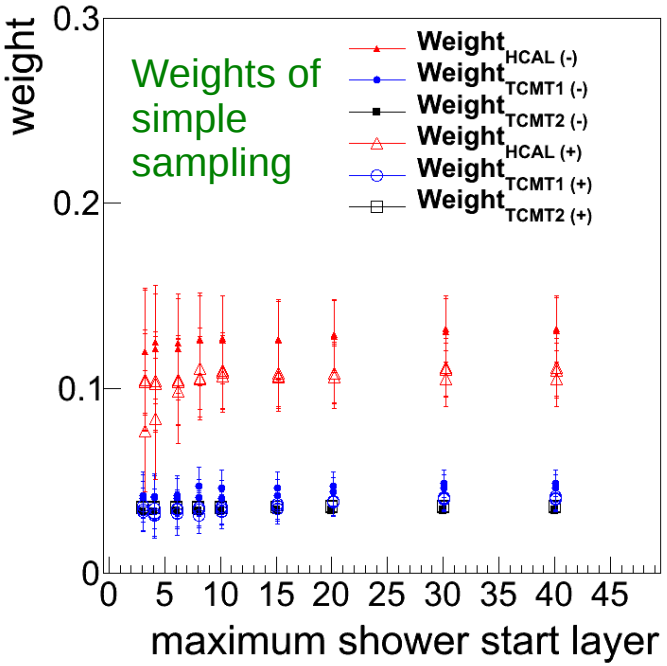
- Increased resolution when using only first layers for shower start
- Impact on shower start cut is less obvious when using TCMT(+sampling)
- How do the sampling weights look like?
  - Note: Sampling has been done for each run separately.
    To do: combine files per energy and perform the sampling on complete data sample

Shower-Start Dependence @ 100 GeV

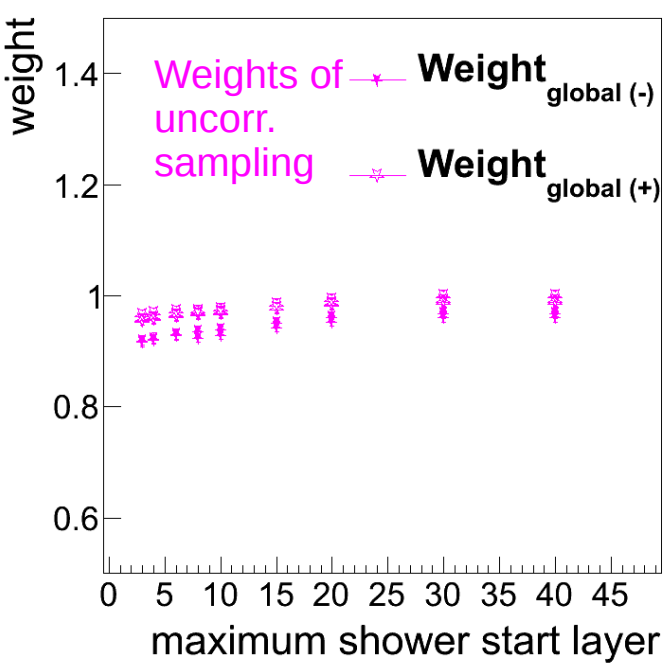
CERN 2011 Pion at 100 GeV



CERN 2011 Pion at 100 GeV



CERN 2011 Pion at 100 GeV



$$E_{input} = w_H * E_{HCAL} + w_{T1} * E_{TCMT1} + w_{T2} * E_{TCMT2}$$

$$E_{input} = w*(e/\pi)_W*(M/G)^{-1}_W * E_{HCAL} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * E_{TCMT1} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * 4 * E_{TCMT2}$$

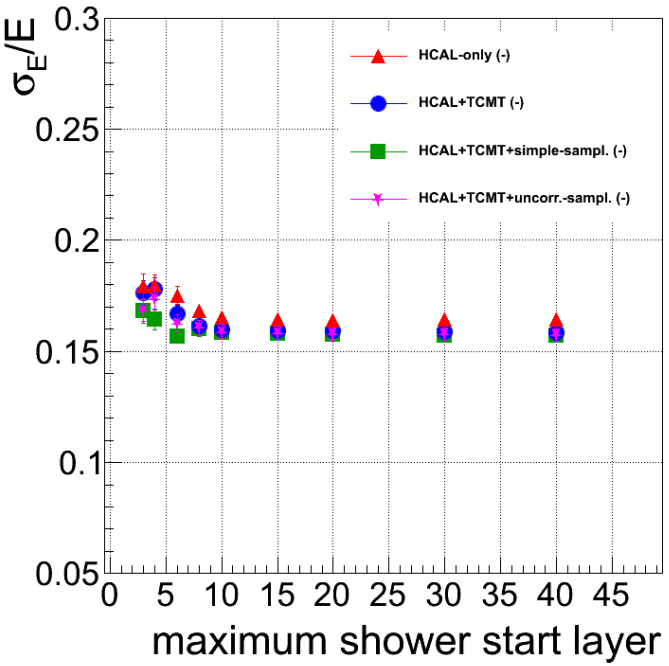
- Independent weights w_H,w_{T1},w_{T2}, do not have expected values from "uncorrected sampling" approach, e.g. w_{T2} should be 4 times w_{T1}
  - Simple method has many degrees of freedom. Favor "uncorrected sampling" approach with only one degree of freedom but slightly worse resolution
- Weights dependent only slightly on shower start

Energy Scan

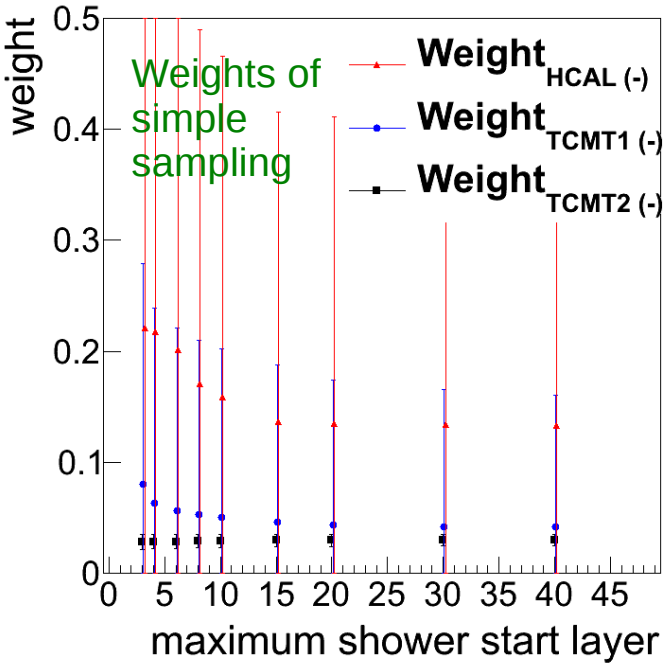
(all energies in backup slides)

Shower-Start Dependence @ 10 GeV

CERN 2011 Pion at 10 GeV

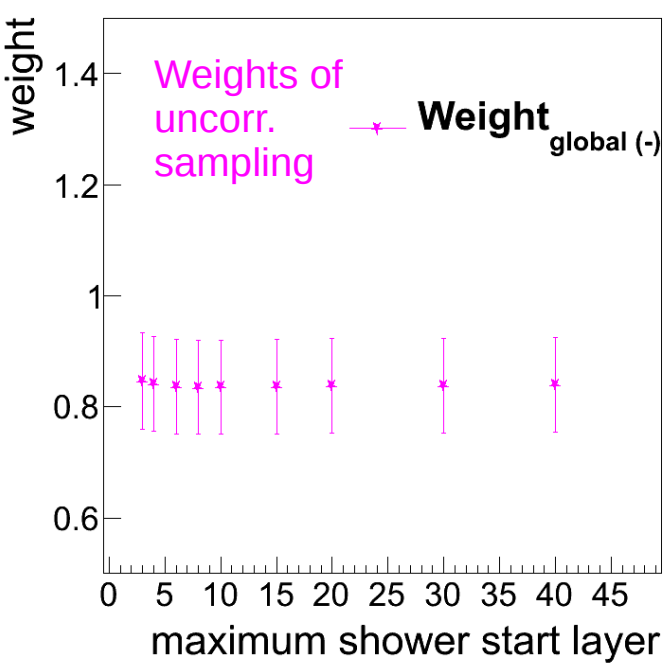


CERN 2011 Pion at 10 GeV



$$E_{input} = w_H * E_{HCAL} + w_{T1} * E_{TCMT1} + w_{T2} * E_{TCMT2}$$

CERN 2011 Pion at 10 GeV

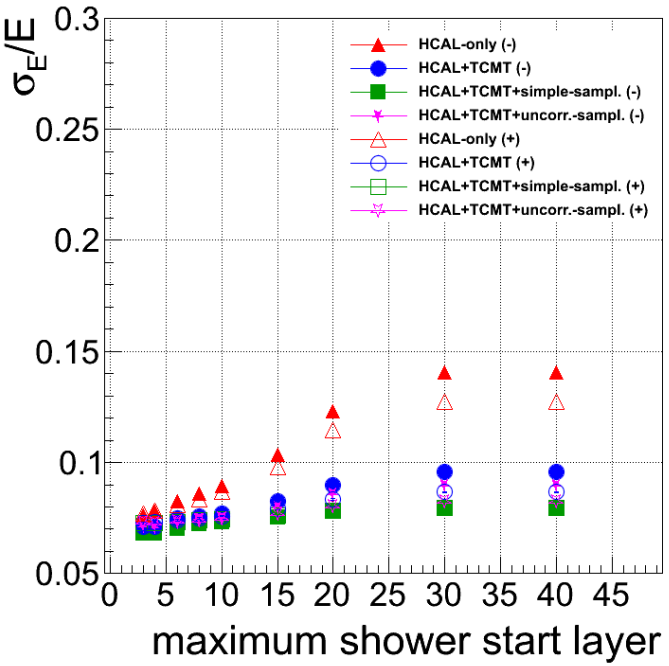


$$E_{input} = w*(e/\pi)_W*(M/G)^{-1}_W * E_{HCAL} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * E_{TCMT1} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * 4 * E_{TCMT2}$$

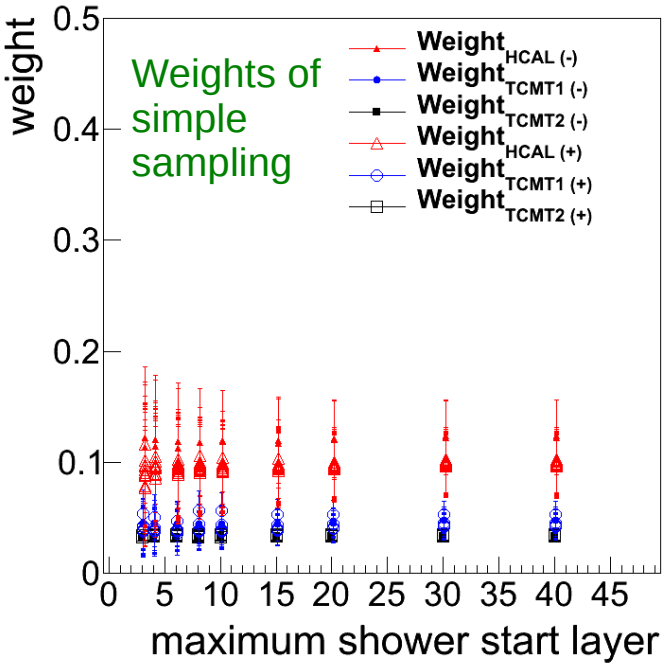
- Results of HCAL and HCAL+TCMT are almost the same
- Sampling does not working properly as there are almost no hits in the TC
  - Large uncertainties of weights

Shower-Start Dependence @ 60 GeV

CERN 2011 Pion at 60 GeV

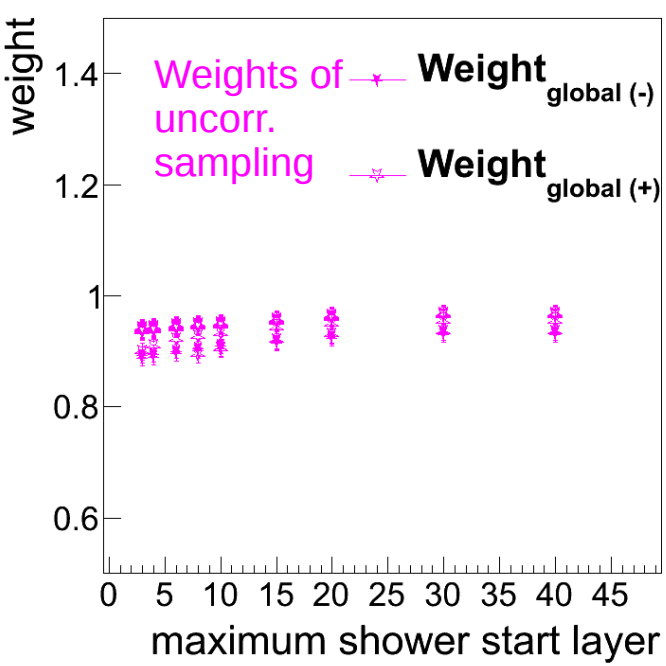


CERN 2011 Pion at 60 GeV



$$E_{input} = w_H * E_{HCAL} + w_{T1} * E_{TCMT1} + w_{T2} * E_{TCMT2}$$

CERN 2011 Pion at 60 GeV

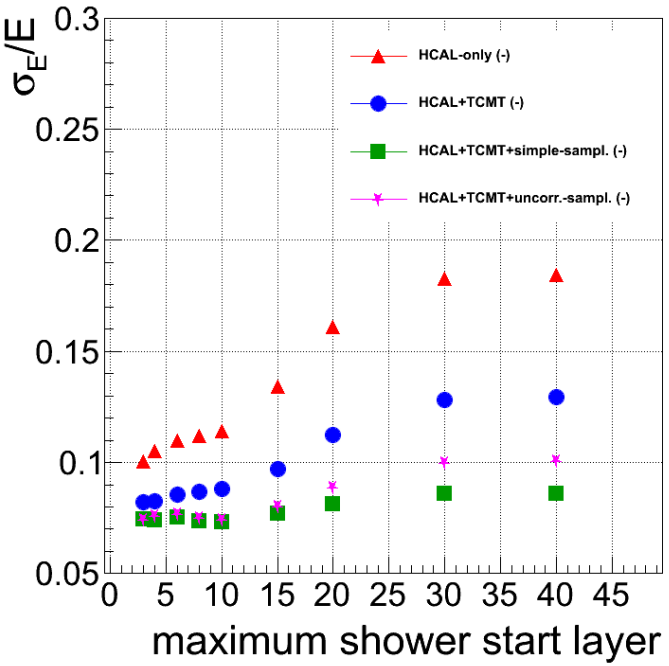


$$E_{input} = w*(e/\pi)_W*(M/G)^{-1}_W * E_{HCAL} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * E_{TCMT1} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * 4 * E_{TCMT2}$$

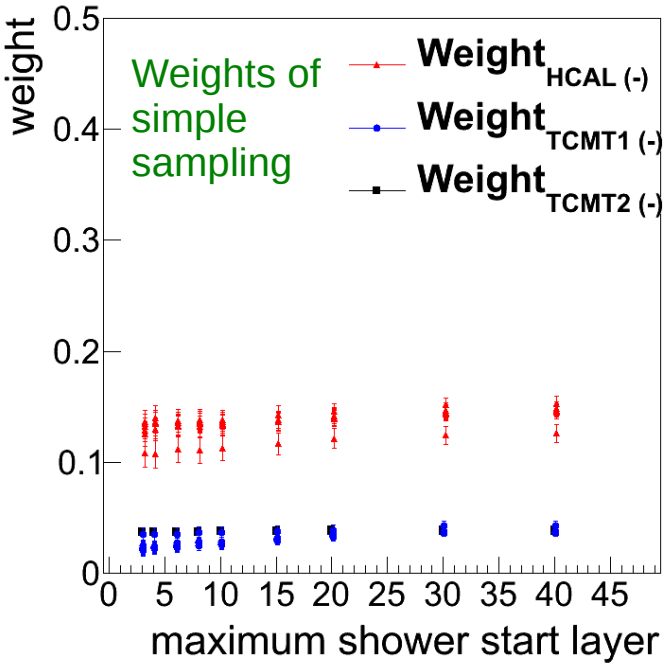
- Here, the sampling starts to work, as enough hits reaches the TC
  - Sampling gives stable results
- Weights are almost independent of shower start cut

Shower-Start Dependence @ 250 GeV

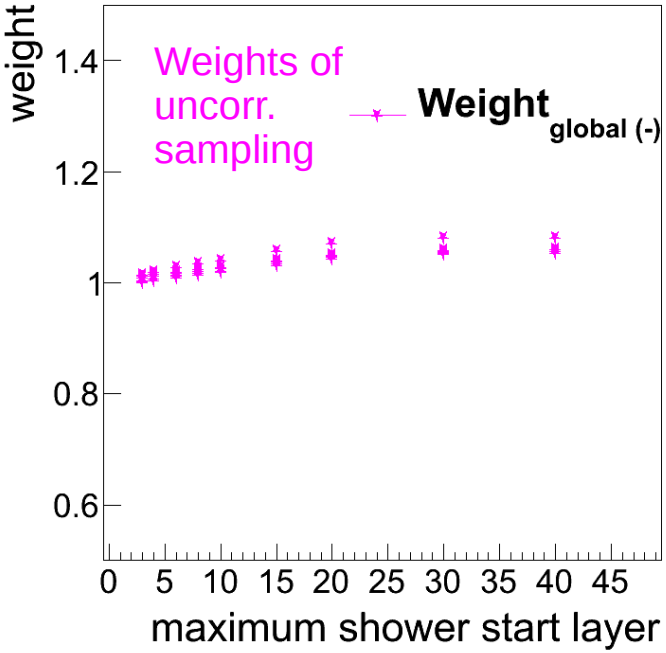
CERN 2011 Pion at 250 GeV



CERN 2011 Pion at 250 GeV



CERN 2011 Pion at 250 GeV



$$E_{input} = w_H * E_{HCAL} + w_{T1} * E_{TCMT1} + w_{T2} * E_{TCMT2}$$

$$E_{input} = w*(e/\pi)_W*(M/G)^{-1}_W * E_{HCAL} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * E_{TCMT1} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * 4 * E_{TCMT2}$$

- Sampling works, gives good resolution also at higher shower start values
- Weights are almost independent on shower start
- Weights of “uncorrected sampling” approach is close to 1 but grows with energy

Summary

- Energy resolution of HCAL, HCAL+TCMT, HCAL+TCMT+simple-sampling, HCAL+TCMT+uncorr.-sampling
- Low energy runs
  - No difference in resolution when adding TCMT
  - Sampling does not work as too few hits are in the TCMT
  - Weights have large uncertainties
- High energy runs
  - Increased resolution when adding TCMT(+sampling)
  - Sampling works fine and gives stable results
- Shower start dependence of energy resolution
  - Strongest in HCAL-only data
  - Only slight dependence in HCAL+TCMT(+sampling)
- Shower start dependence of sampling weights
  - Weights seems to depend only slightly on shower start
- Weights of “uncorrected” sampling increase slightly with energy

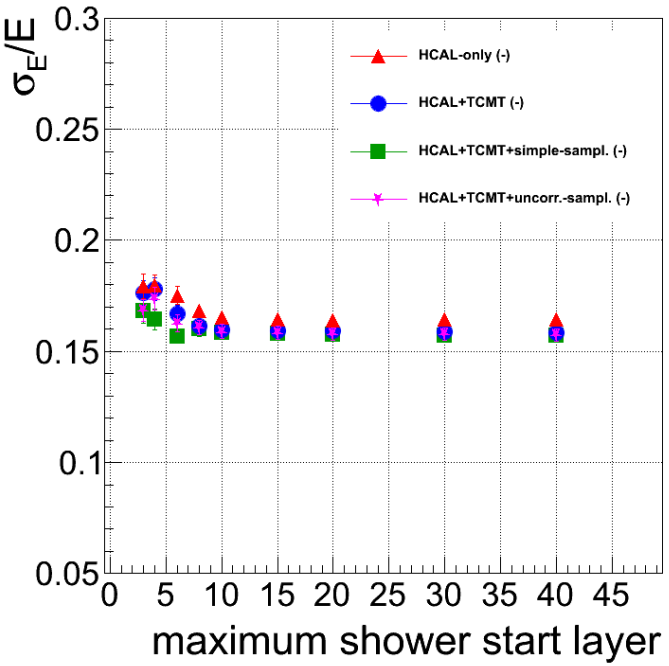
Outlook

- Comparison of data and simulations
- Study E_{Input} dependence of weights and energy resolution
- Study linearity of response
- Choose one energy for the determination of the sampling weights and use these for all data
  - Data or MC
- Study impact of noise

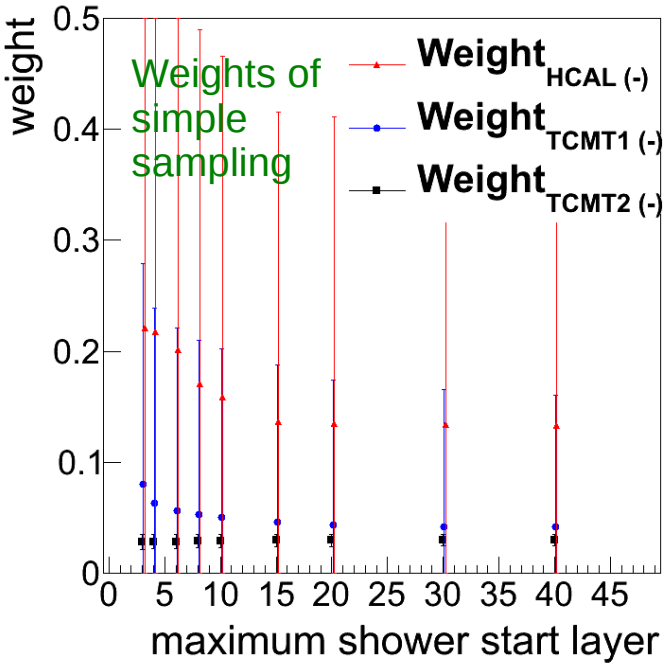
Backup

Shower-Start Dependence @ 10 GeV

CERN 2011 Pion at 10 GeV

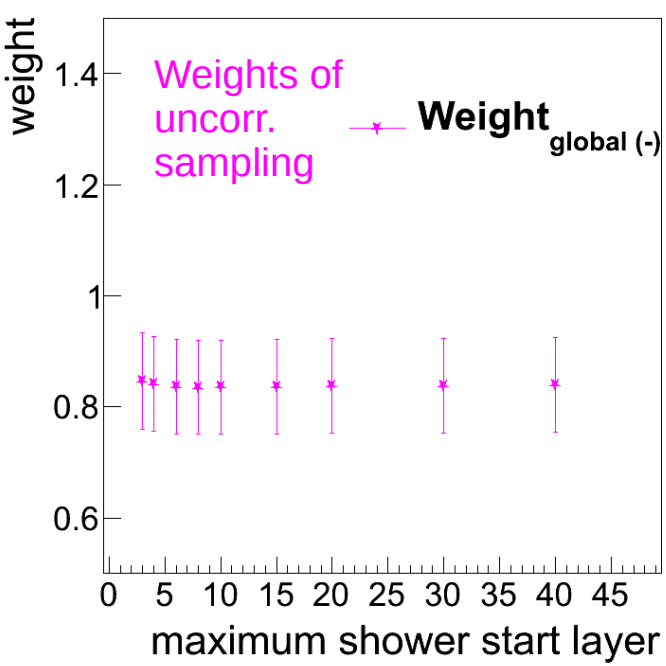


CERN 2011 Pion at 10 GeV



$$E_{input} = w_H * E_{HCAL} + w_{T1} * E_{TCMT1} + w_{T2} * E_{TCMT2}$$

CERN 2011 Pion at 10 GeV

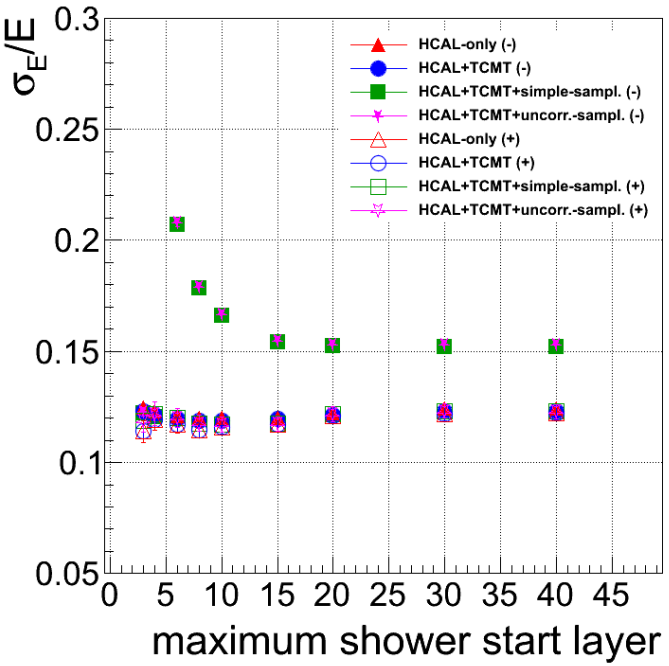


$$E_{input} = w*(e/\pi)_W*(M/G)^{-1}_W * E_{HCAL} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * E_{TCMT1} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * 4 * E_{TCMT2}$$

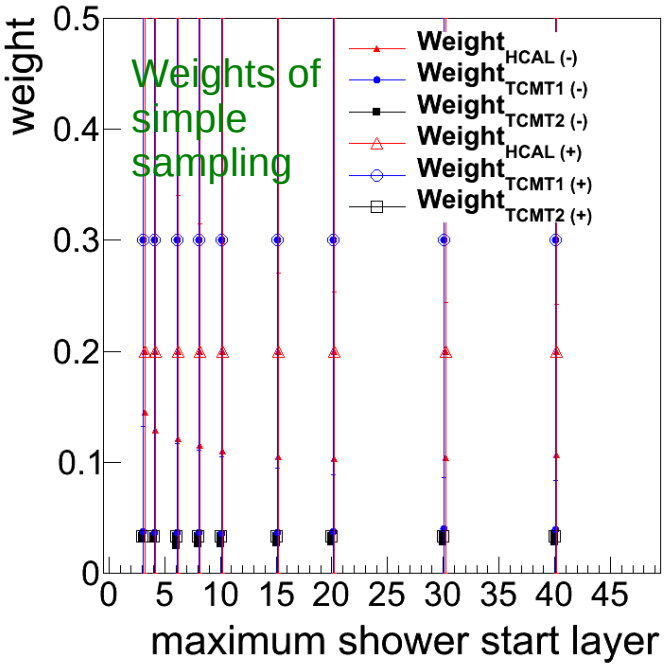
- Results of HCAL and HCAL+TCMT are almost the same
- Sampling does not working properly as there are almost no hits in the TC
  - Large uncertainties of weights

Shower-Start Dependence @ 20 GeV

CERN 2011 Pion at 20 GeV

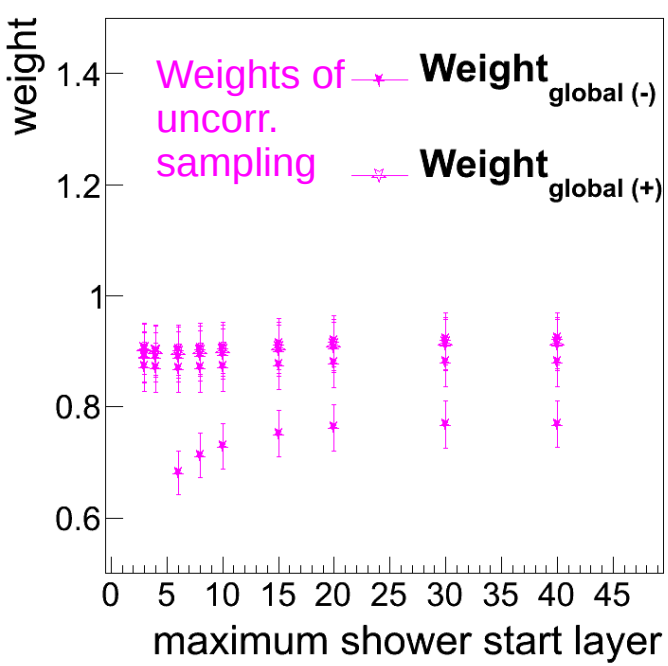


CERN 2011 Pion at 20 GeV



$$E_{input} = w_H * E_{HCAL} + w_{T1} * E_{TCMT1} + w_{T2} * E_{TCMT2}$$

CERN 2011 Pion at 20 GeV

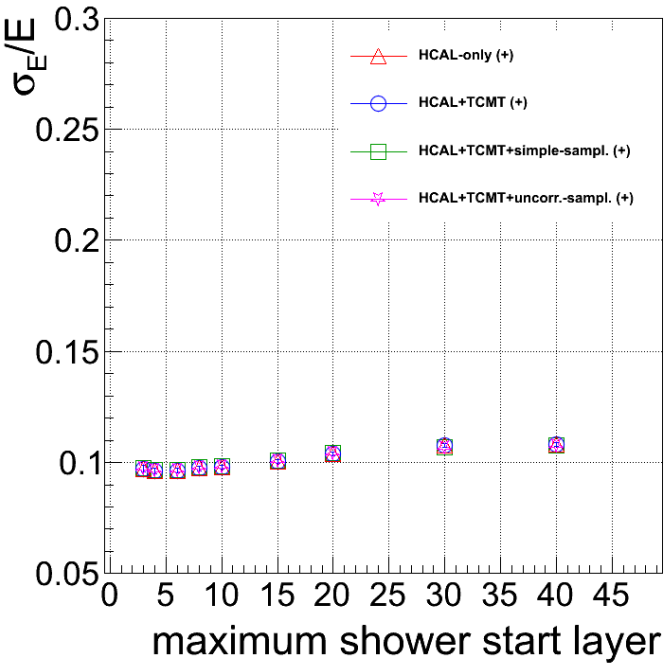


$$E_{input} = w*(e/\pi)_W*(M/G)^{-1}_W * E_{HCAL} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * E_{TCMT1} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * 4 * E_{TCMT2}$$

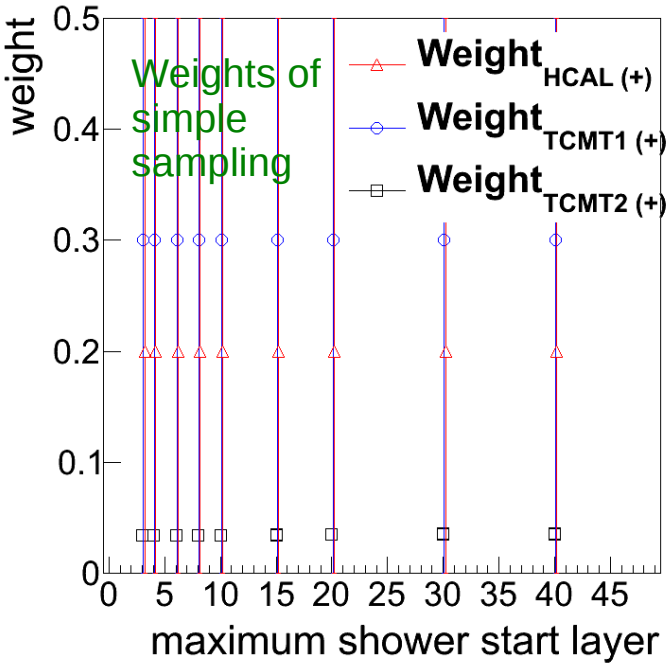
- Results of HCAL and HCAL+TCMT are almost the same
- Sampling does not working properly as there are almost no hits in the TC
  - Large uncertainties of weights

Shower-Start Dependence @ 30 GeV

CERN 2011 Pion at 30 GeV

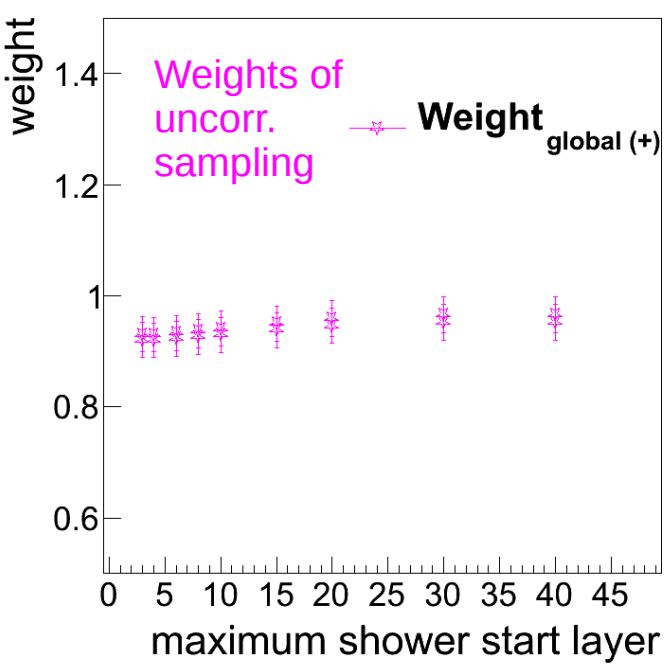


CERN 2011 Pion at 30 GeV



$$E_{input} = w_H * E_{HCAL} + w_{T1} * E_{TCMT1} + w_{T2} * E_{TCMT2}$$

CERN 2011 Pion at 30 GeV

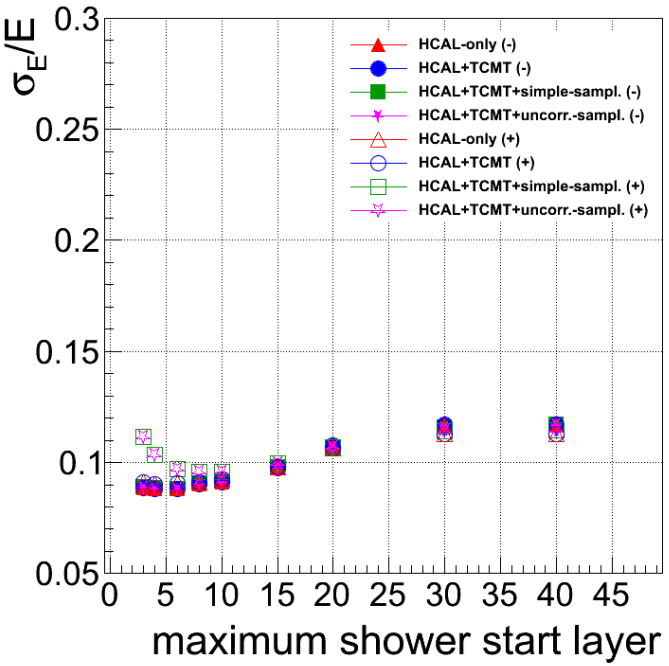


$$E_{input} = w*(e/\pi)_W*(M/G)^{-1}_W * E_{HCAL} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * E_{TCMT1} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * 4 * E_{TCMT2}$$

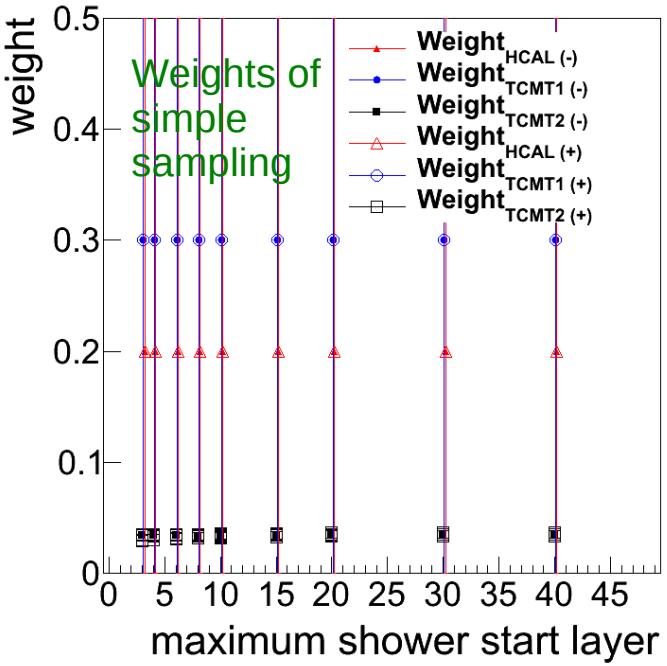
- Results of HCAL and HCAL+TCMT are almost the same
- Sampling does not working properly as there are almost no hits in the TC
  - Large uncertainties of weights

Shower-Start Dependence @ 40 GeV

CERN 2011 Pion at 40 GeV

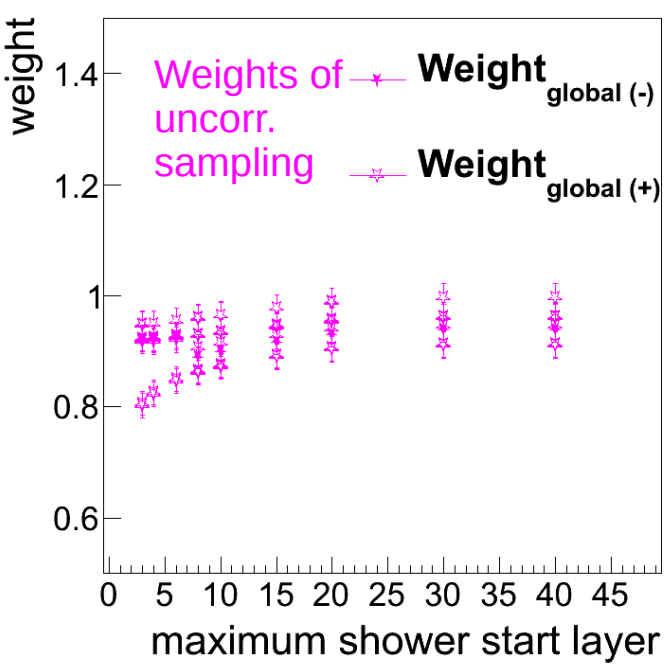


CERN 2011 Pion at 40 GeV



$$E_{input} = w_H * E_{HCAL} + w_{T1} * E_{TCMT1} + w_{T2} * E_{TCMT2}$$

CERN 2011 Pion at 40 GeV

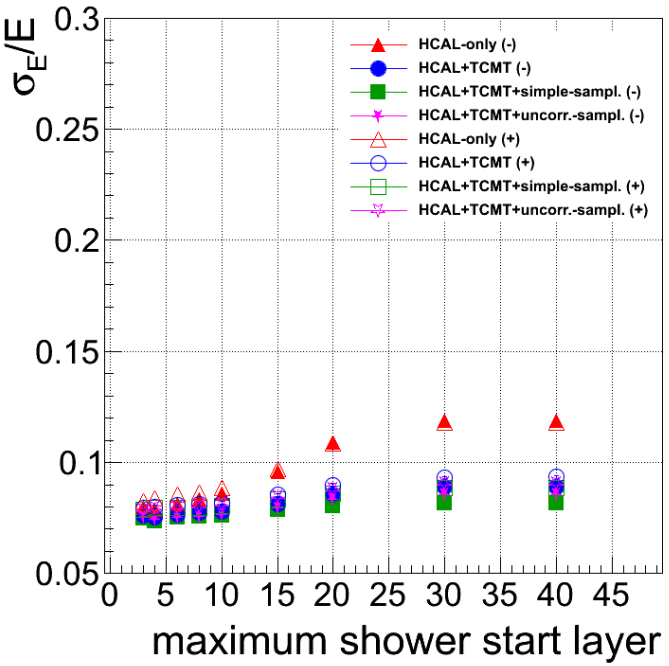


$$E_{input} = w*(e/\pi)_W*(M/G)^{-1}_W * E_{HCAL} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * E_{TCMT1} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * 4 * E_{TCMT2}$$

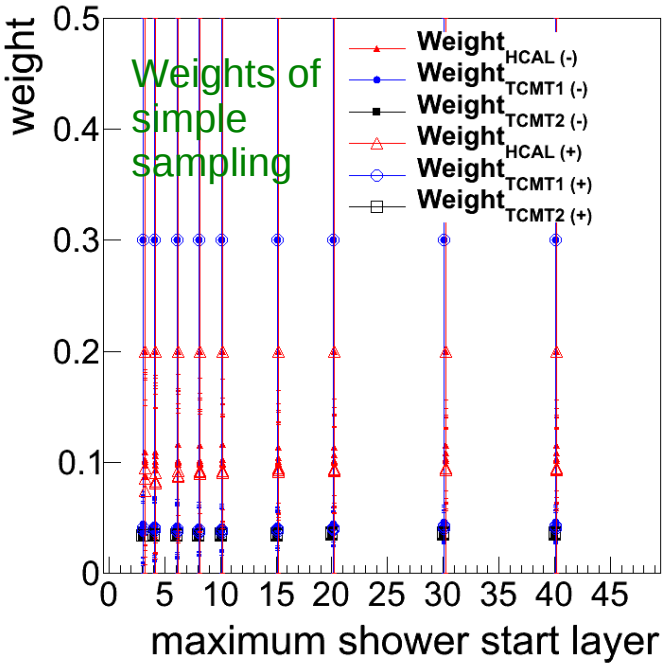
- Results of HCAL and HCAL+TCMT are almost the same
- Sampling does not working properly as there are almost no hits in the TC
  - Large uncertainties of weights

Shower-Start Dependence @ 50 GeV

CERN 2011 Pion at 50 GeV

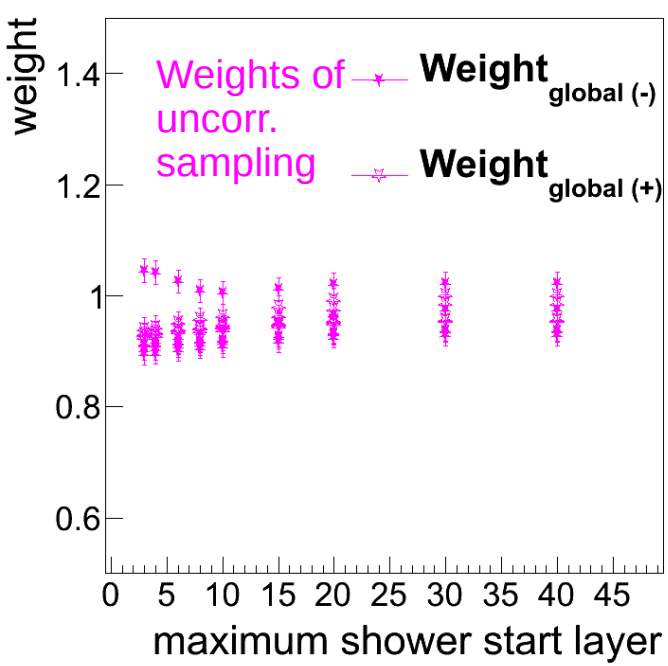


CERN 2011 Pion at 50 GeV



$$E_{input} = w_H * E_{HCAL} + w_{T1} * E_{TCMT1} + w_{T2} * E_{TCMT2}$$

CERN 2011 Pion at 50 GeV

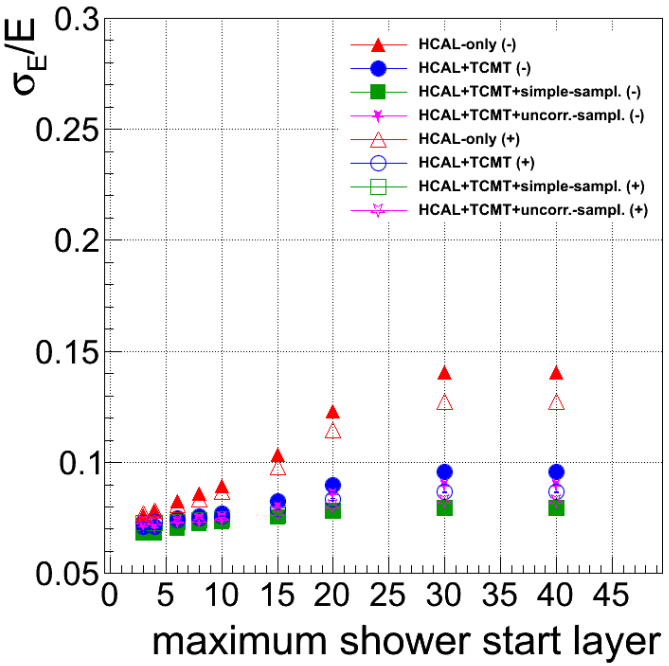


$$E_{input} = w*(e/\pi)_W*(M/G)^{-1}_W * E_{HCAL} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * E_{TCMT1} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * 4 * E_{TCMT2}$$

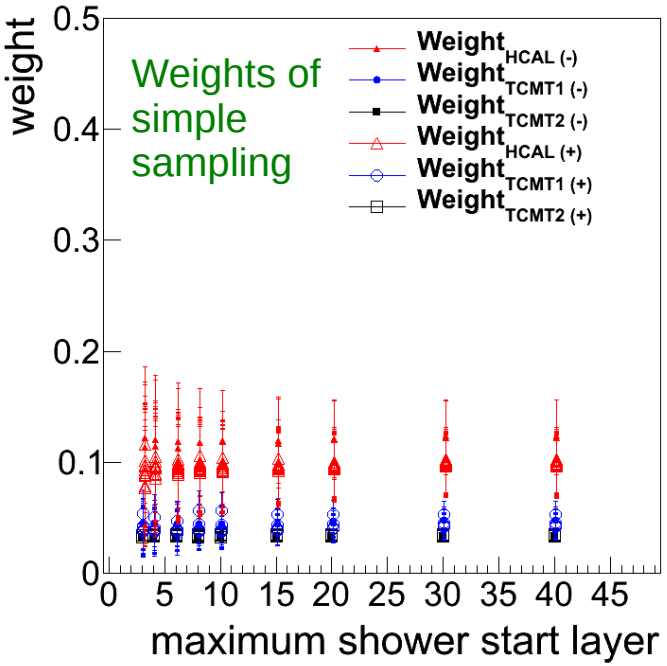
- Results of HCAL and HCAL+TCMT are almost the same
- Sampling does not working properly as there are almost no hits in the TC
  - Large uncertainties of weights

Shower-Start Dependence @ 60 GeV

CERN 2011 Pion at 60 GeV

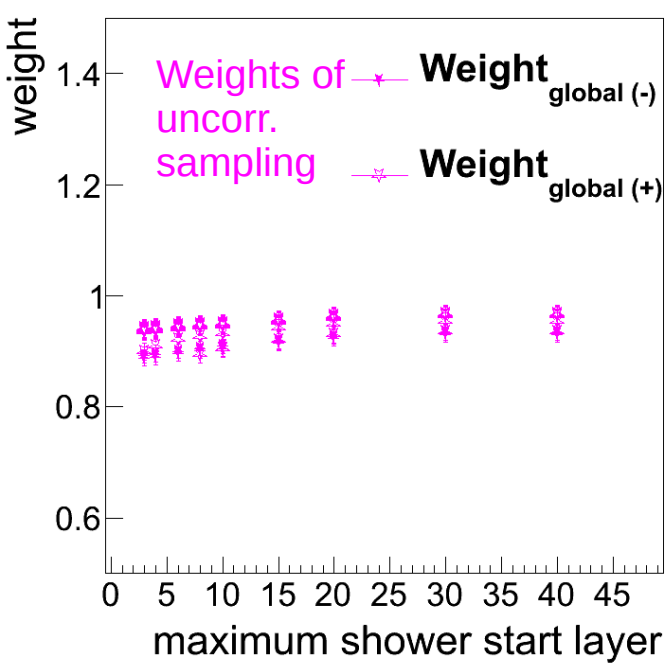


CERN 2011 Pion at 60 GeV



$$E_{input} = w_H * E_{HCAL} + w_{T1} * E_{TCMT1} + w_{T2} * E_{TCMT2}$$

CERN 2011 Pion at 60 GeV

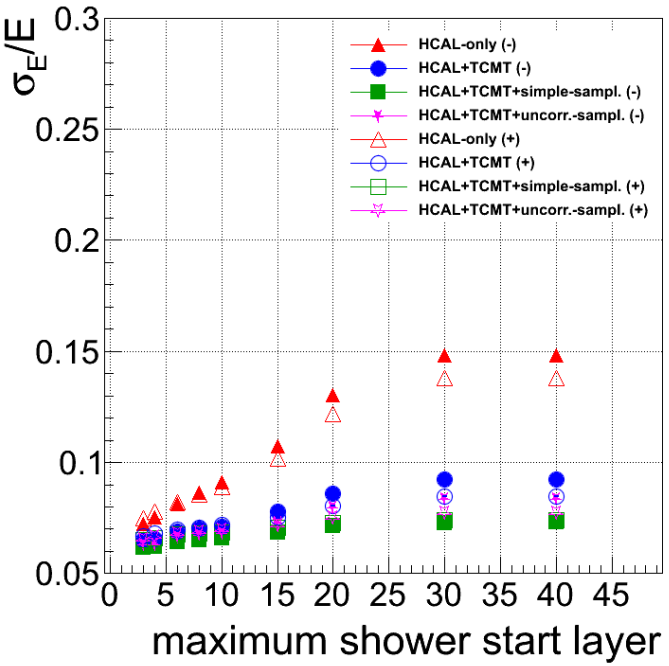


$$E_{input} = w*(e/\pi)_W*(M/G)^{-1}_W * E_{HCAL} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * E_{TCMT1} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * 4 * E_{TCMT2}$$

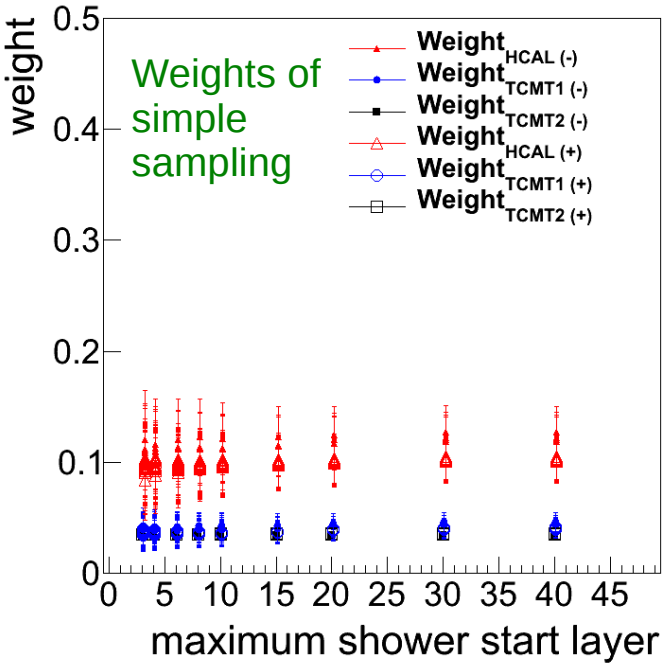
- Here, the sampling starts to work, as enough hits reaches the TC
- Weights are almost independent on shower start

Shower-Start Dependence @ 80 GeV

CERN 2011 Pion at 80 GeV

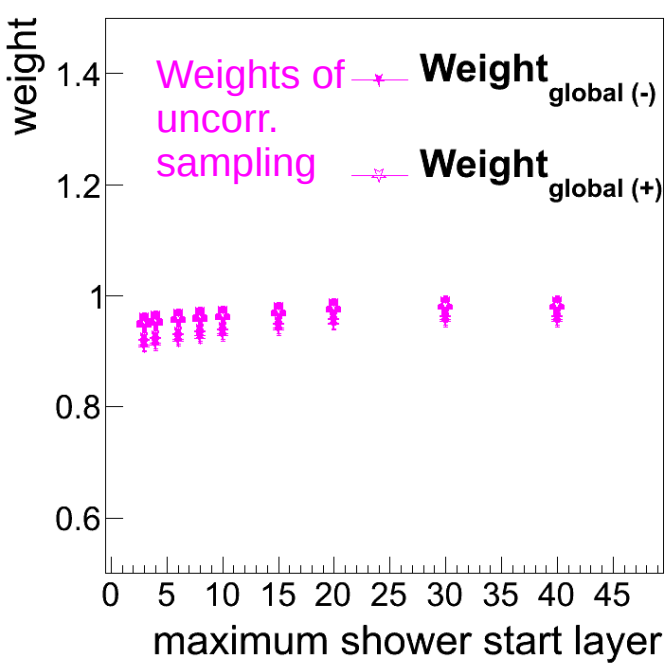


CERN 2011 Pion at 80 GeV



$$E_{input} = w_H * E_{HCAL} + w_{T1} * E_{TCMT1} + w_{T2} * E_{TCMT2}$$

CERN 2011 Pion at 80 GeV

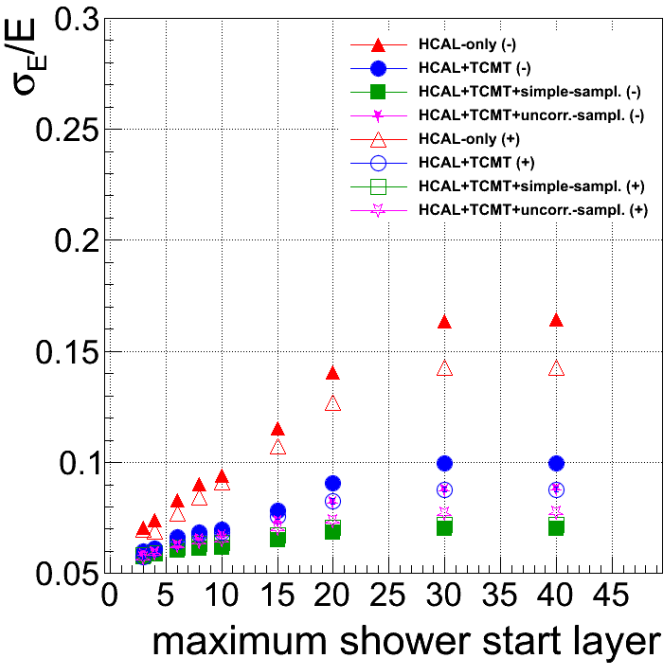


$$E_{input} = w*(e/\pi)_W*(M/G)^{-1}_W * E_{HCAL} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * E_{TCMT1} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * 4 * E_{TCMT2}$$

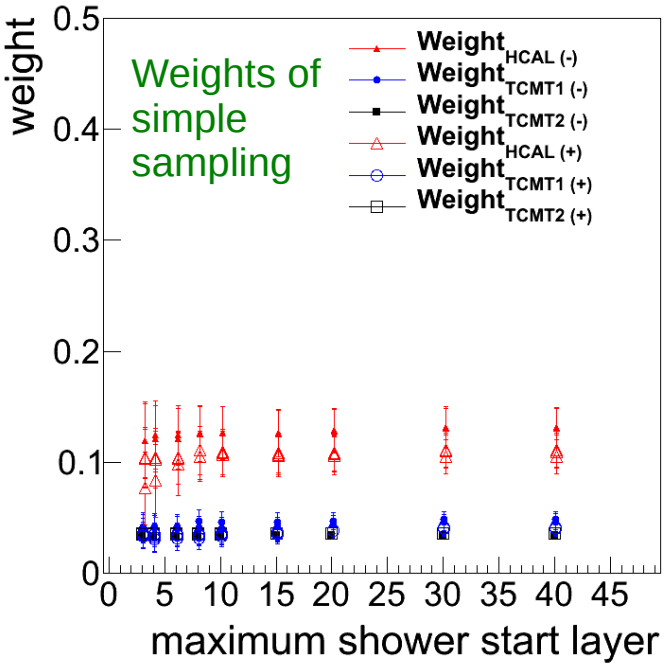
- Sampling works, gives good resolution also at higher shower start values
- Weights are almost independent on shower start

Shower-Start Dependence @ 100 GeV

CERN 2011 Pion at 100 GeV

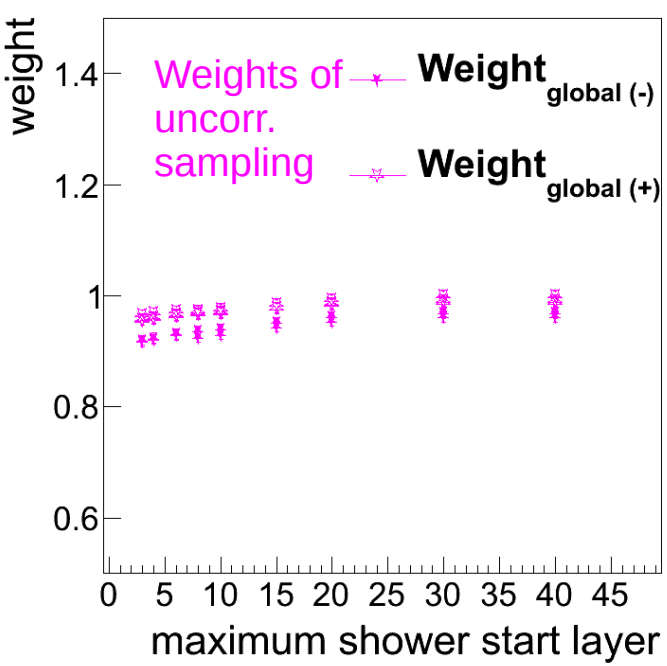


CERN 2011 Pion at 100 GeV



$$E_{input} = w_H * E_{HCAL} + w_{T1} * E_{TCMT1} + w_{T2} * E_{TCMT2}$$

CERN 2011 Pion at 100 GeV

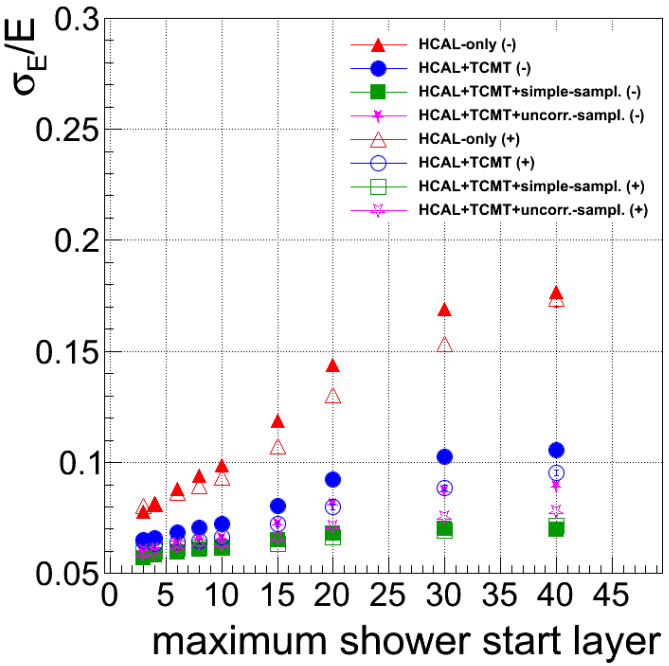


$$E_{input} = w*(e/\pi)_W*(M/G)^{-1}_W * E_{HCAL} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * E_{TCMT1} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * 4 * E_{TCMT2}$$

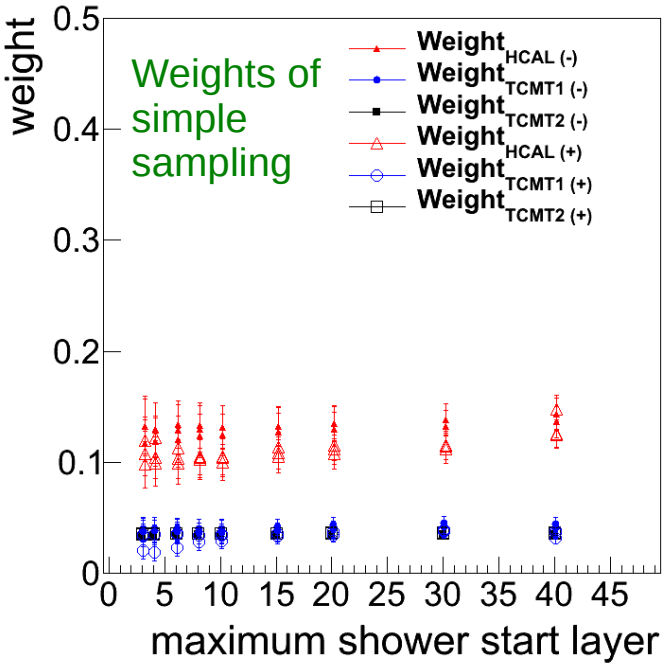
- Sampling works, gives good resolution also at higher shower start values
- Weights are almost independent on shower start

Shower-Start Dependence @ 120 GeV

CERN 2011 Pion at 120 GeV

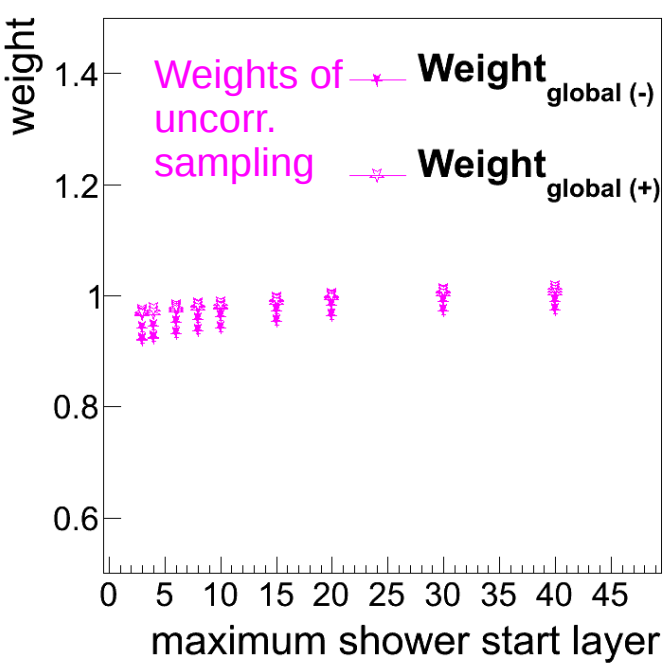


CERN 2011 Pion at 120 GeV



$$E_{input} = w_H * E_{HCAL} + w_{T1} * E_{TCMT1} + w_{T2} * E_{TCMT2}$$

CERN 2011 Pion at 120 GeV

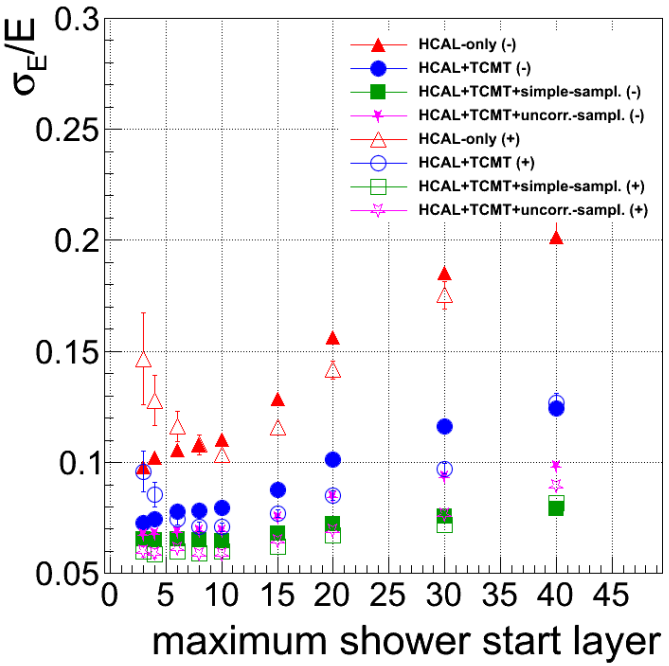


$$E_{input} = w*(e/\pi)_W*(M/G)^{-1}_W * E_{HCAL} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * E_{TCMT1} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * 4 * E_{TCMT2}$$

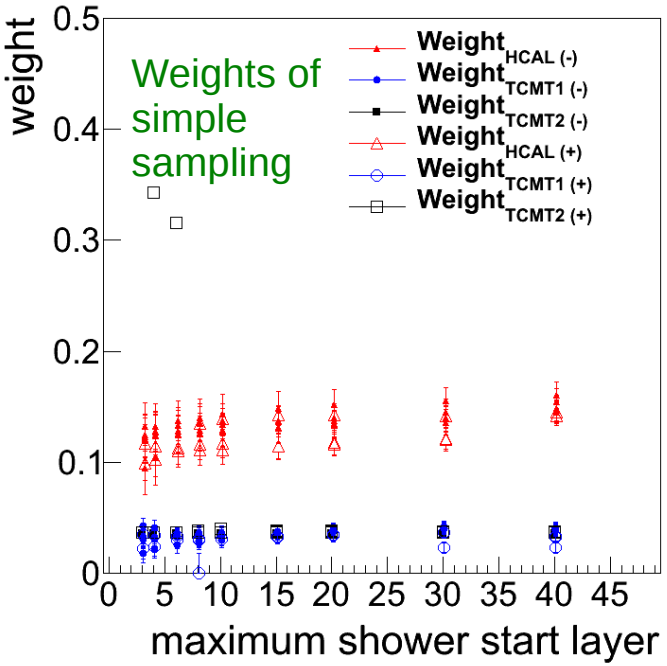
- Sampling works, gives good resolution also at higher shower start values
- Weights are almost independent on shower start

Shower-Start Dependence @ 150 GeV

CERN 2011 Pion at 150 GeV

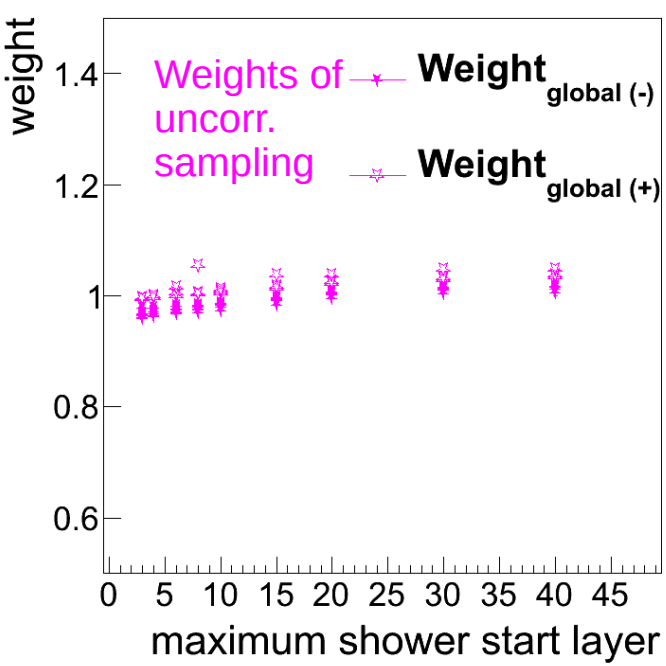


CERN 2011 Pion at 150 GeV



$$E_{input} = w_H * E_{HCAL} + w_{T1} * E_{TCMT1} + w_{T2} * E_{TCMT2}$$

CERN 2011 Pion at 150 GeV

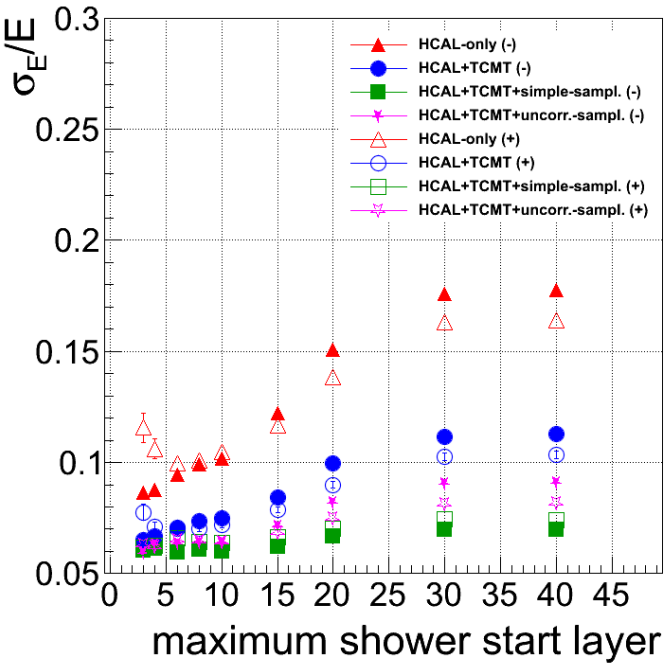


$$E_{input} = w*(e/\pi)_W*(M/G)^{-1}_W * E_{HCAL} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * E_{TCMT1} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * 4 * E_{TCMT2}$$

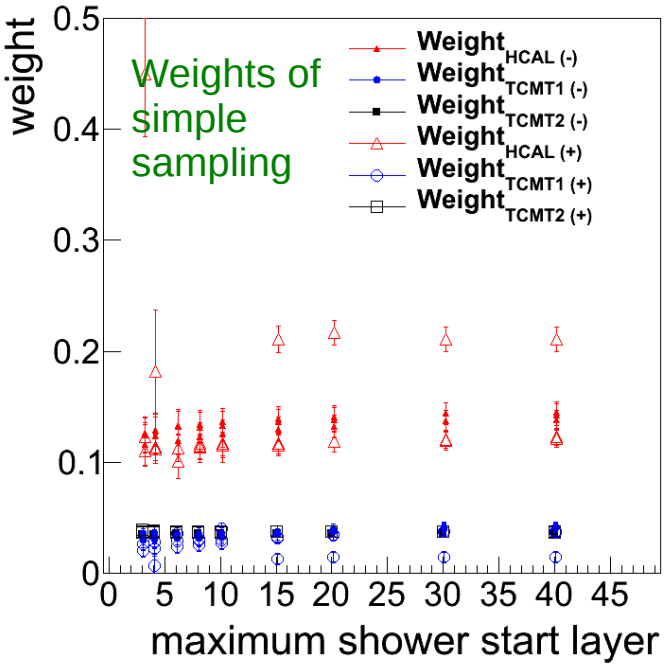
- Sampling works, gives good resolution also at higher shower start values
- Weights are almost independent on shower start

Shower-Start Dependence @ 180 GeV

CERN 2011 Pion at 180 GeV

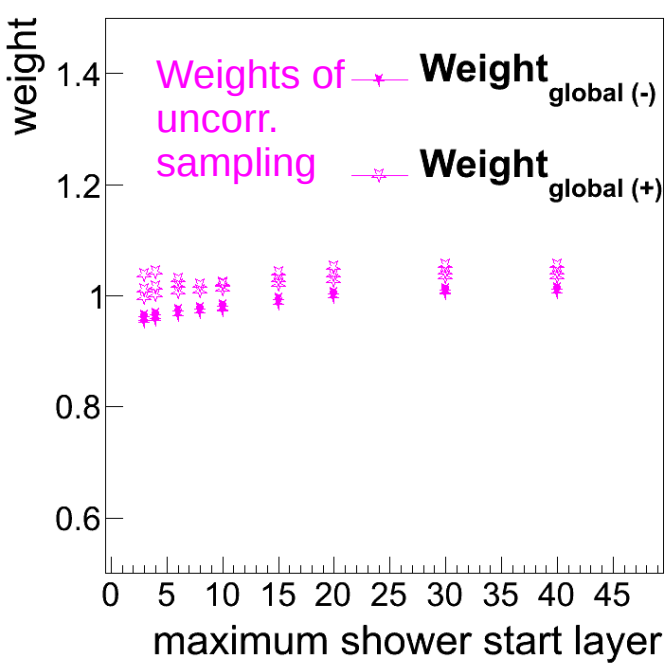


CERN 2011 Pion at 180 GeV



$$E_{input} = w_H * E_{HCAL} + w_{T1} * E_{TCMT1} + w_{T2} * E_{TCMT2}$$

CERN 2011 Pion at 180 GeV

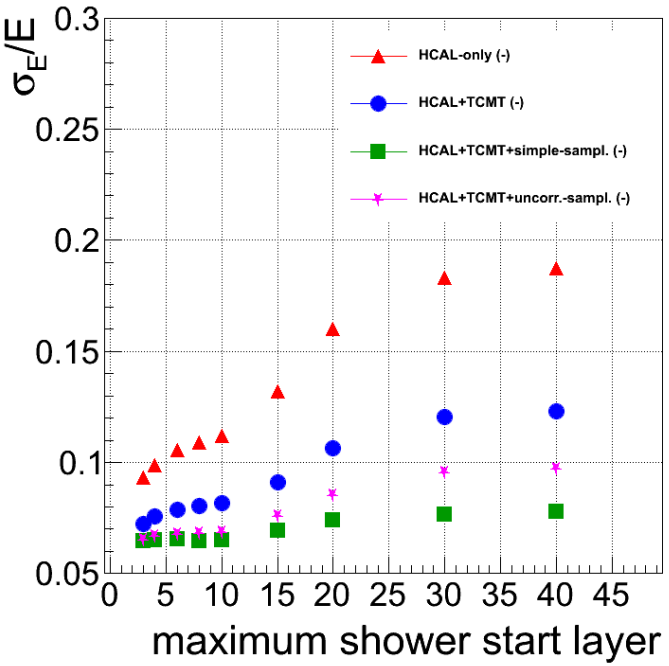


$$E_{input} = w*(e/\pi)_W*(M/G)^{-1}_W * E_{HCAL} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * E_{TCMT1} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * 4 * E_{TCMT2}$$

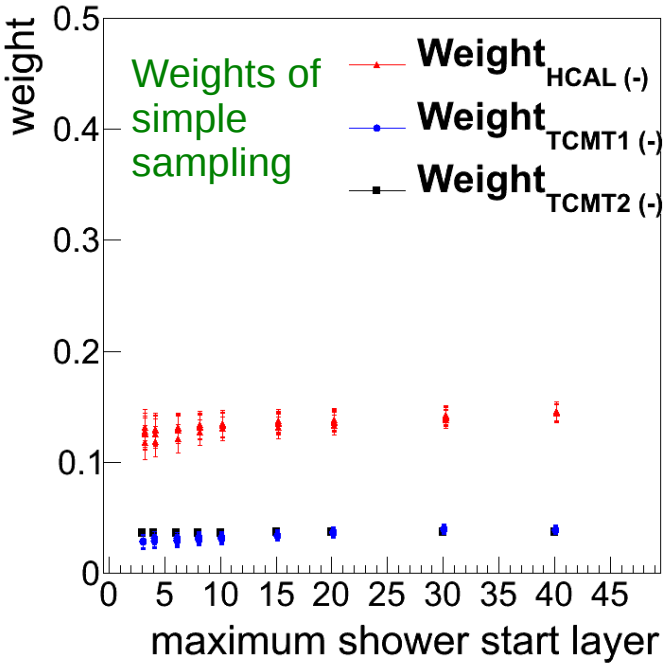
- Sampling works, gives good resolution also at higher shower start values
- Weights are almost independent on shower start

Shower-Start Dependence @ 200 GeV

CERN 2011 Pion at 200 GeV

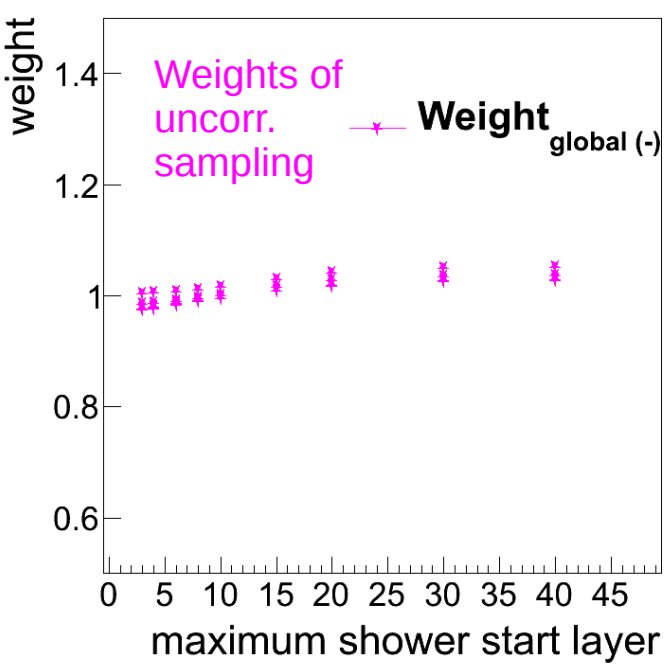


CERN 2011 Pion at 200 GeV



$$E_{input} = w_H * E_{HCAL} + w_{T1} * E_{TCMT1} + w_{T2} * E_{TCMT2}$$

CERN 2011 Pion at 200 GeV

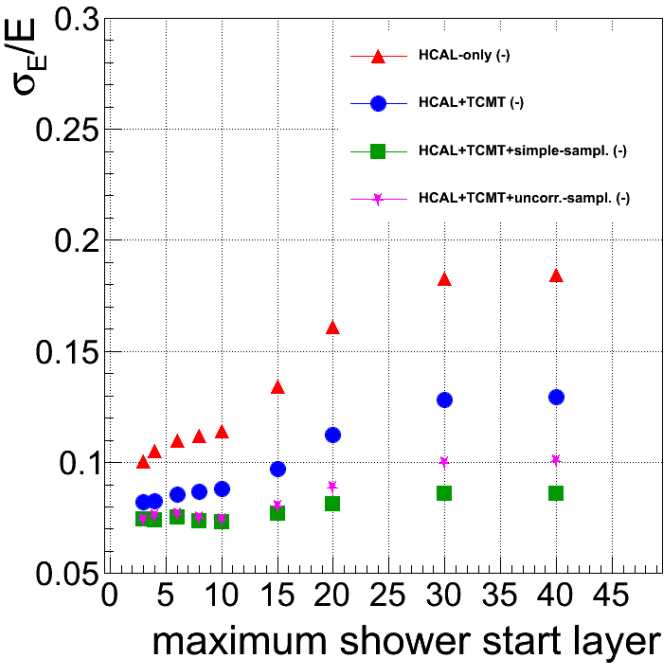


$$E_{input} = w*(e/\pi)_W*(M/G)^{-1}_W * E_{HCAL} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * E_{TCMT1} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * 4 * E_{TCMT2}$$

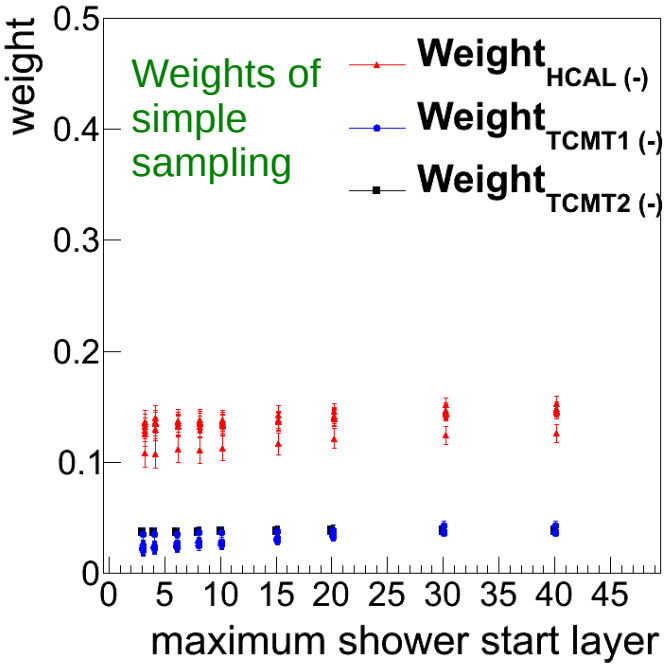
- Sampling works, gives good resolution also at higher shower start values
- Weights are almost independent on shower start

Shower-Start Dependence @ 250 GeV

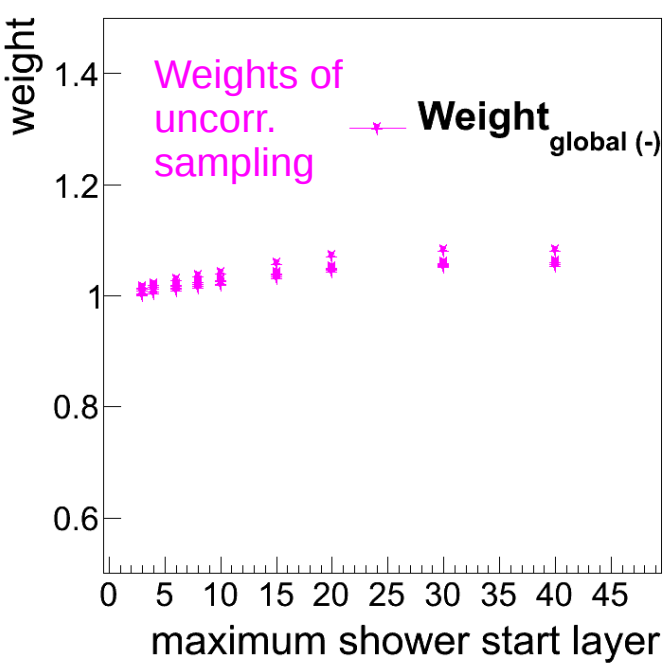
CERN 2011 Pion at 250 GeV



CERN 2011 Pion at 250 GeV



CERN 2011 Pion at 250 GeV



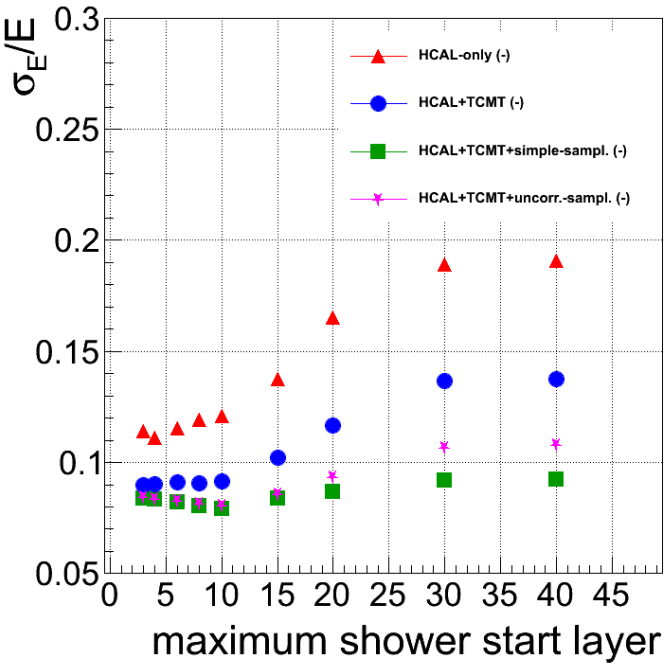
$$E_{input} = w_H * E_{HCAL} + w_{T1} * E_{TCMT1} + w_{T2} * E_{TCMT2}$$

$$E_{input} = w*(e/\pi)_W*(M/G)^{-1}_W * E_{HCAL} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * E_{TCMT1} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * 4 * E_{TCMT2}$$

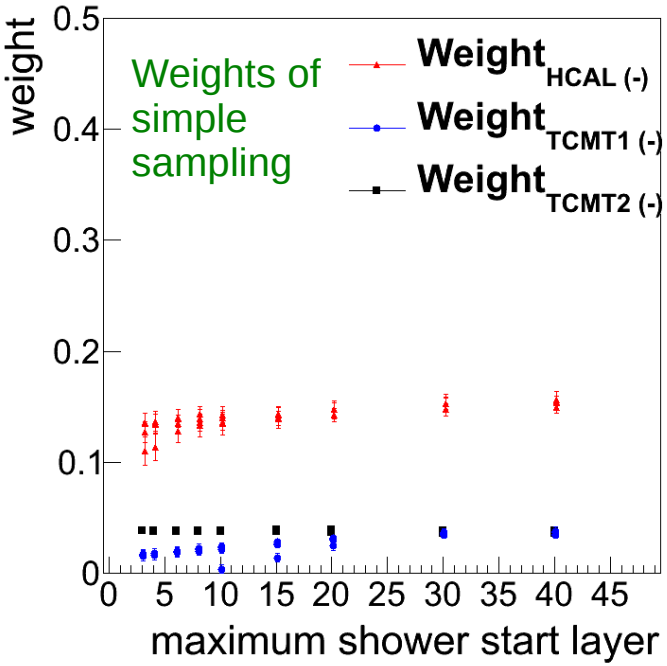
- Sampling works, gives good resolution also at higher shower start values
- Weights are almost independent on shower start

Shower-Start Dependence @ 300 GeV

CERN 2011 Pion at 300 GeV

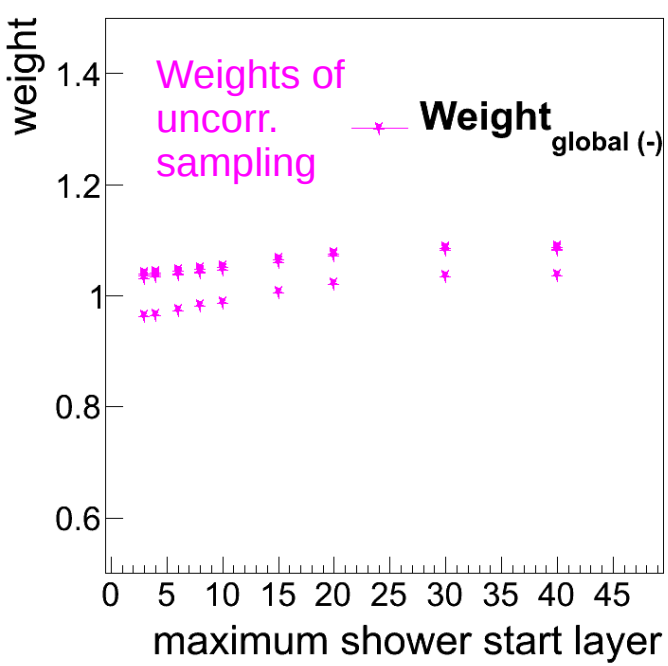


CERN 2011 Pion at 300 GeV



$$E_{input} = w_H * E_{HCAL} + w_{T1} * E_{TCMT1} + w_{T2} * E_{TCMT2}$$

CERN 2011 Pion at 300 GeV



$$E_{input} = w*(e/\pi)_W*(M/G)^{-1}_W * E_{HCAL} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * E_{TCMT1} + w*(e/\pi)_{Fe}*(M/G)^{-1}_{Fe} * 4 * E_{TCMT2}$$

- Sampling works, gives good resolution also at higher shower start values
- Weights are almost independent on shower start

Shower Start