Software Compensation in the AHCAL with Machine Learning

April 12th, 2019

CALICE Meeting
- Utrecht -

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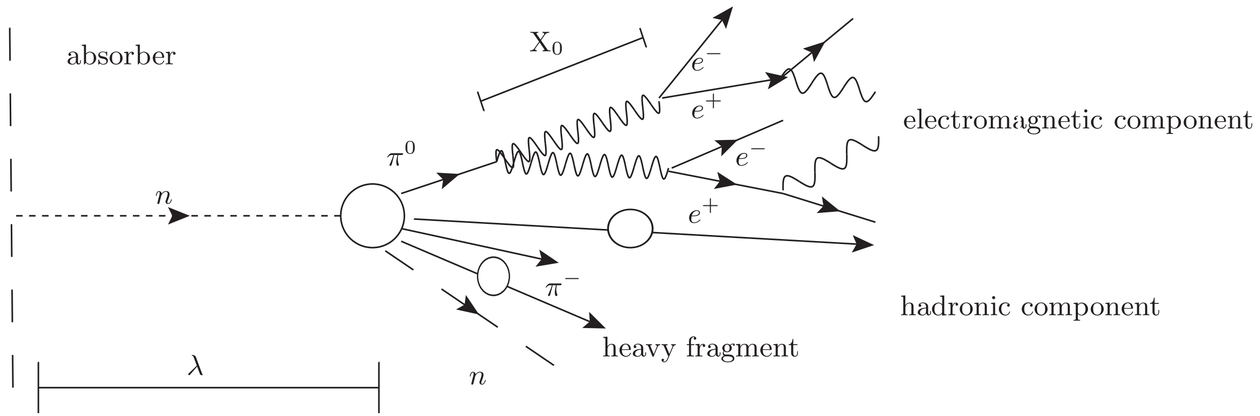
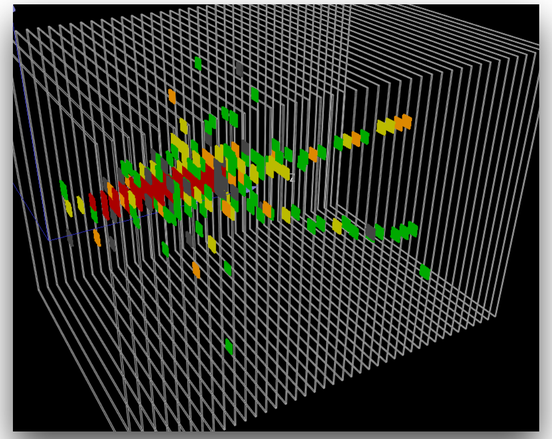
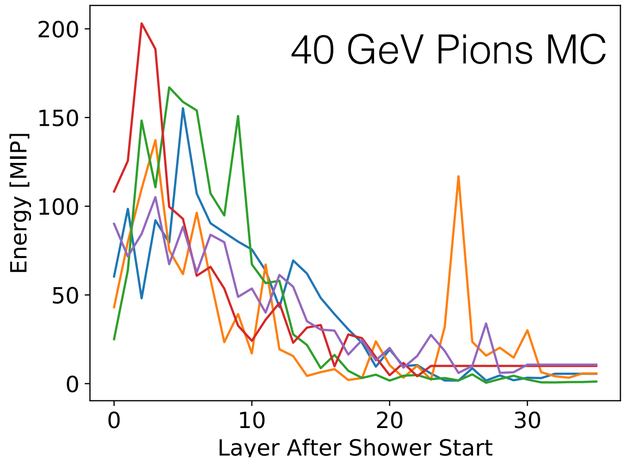
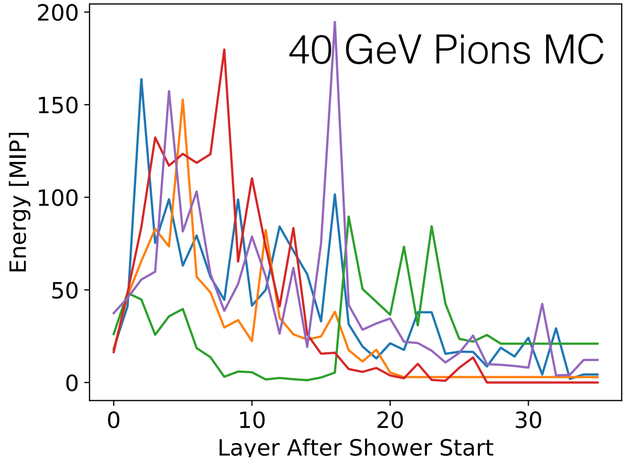
Motivation

- Fluctuations of a hadronic shower in calorimeter:
  - Measurement effects
  - **EM fraction**
  - Invisible energy
  - Sampling fluctuations
  - Catastrophic events
  - …



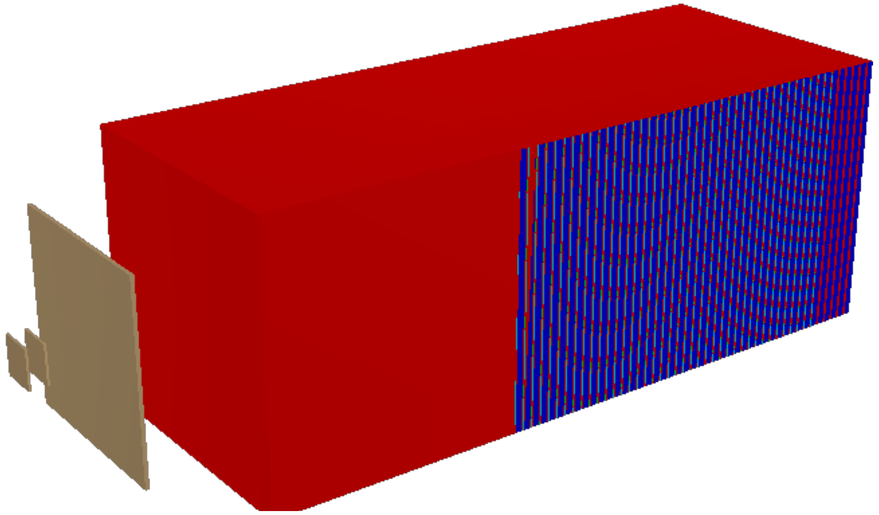


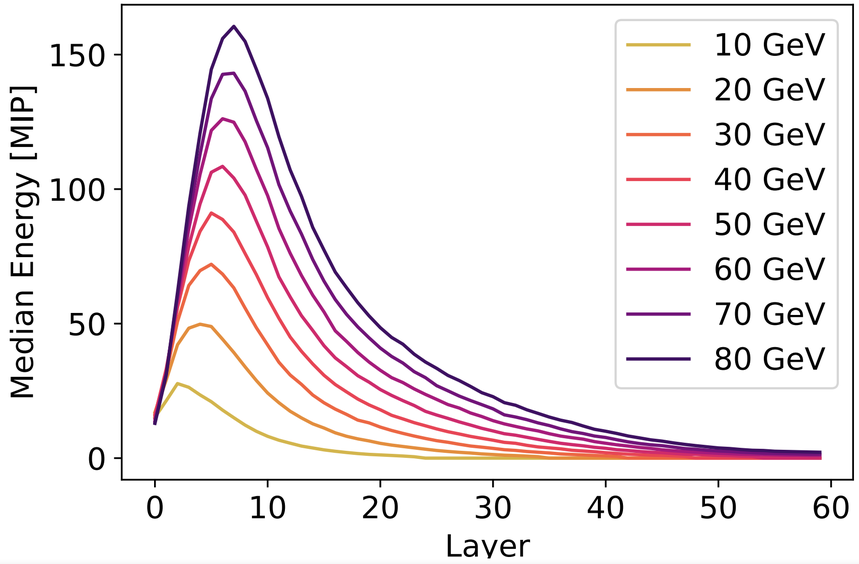




Simulation

- CALICE AHCAL test beam geometry with 60 layers
- 10 - 85 GeV Pions in 1GeV steps
- 10,000 events per Energy
- 1ns gaussian time smearing

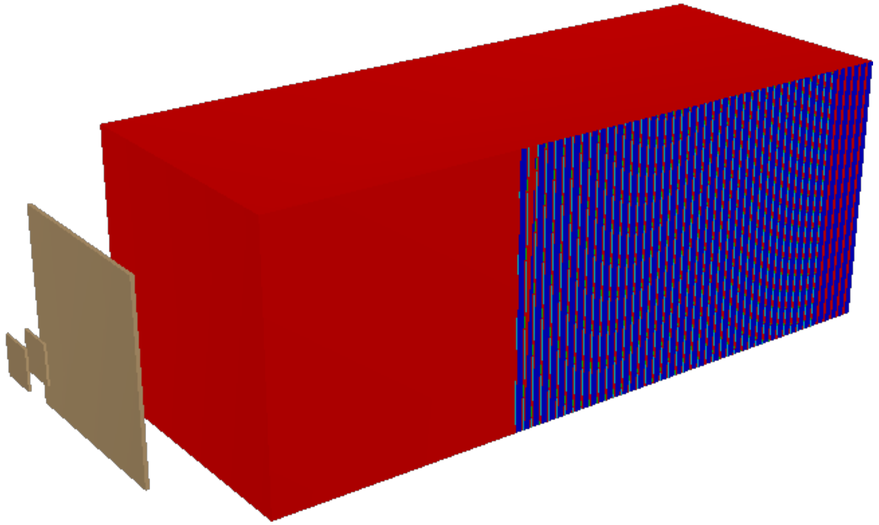


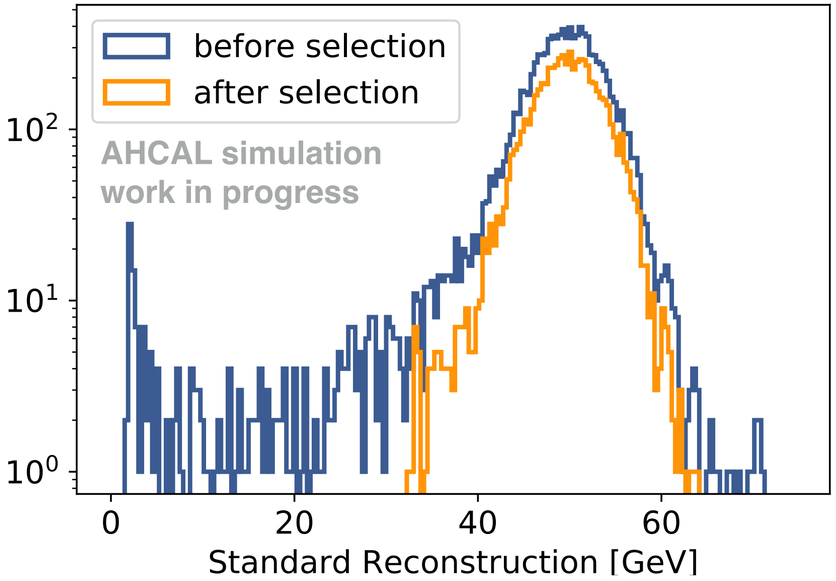


Simulation

- CALICE AHCAL test beam geometry with 60 layers
- 10 - 85 GeV Pions in 1GeV steps
- 10,000 events per Energy
- 1ns gaussian time smearing

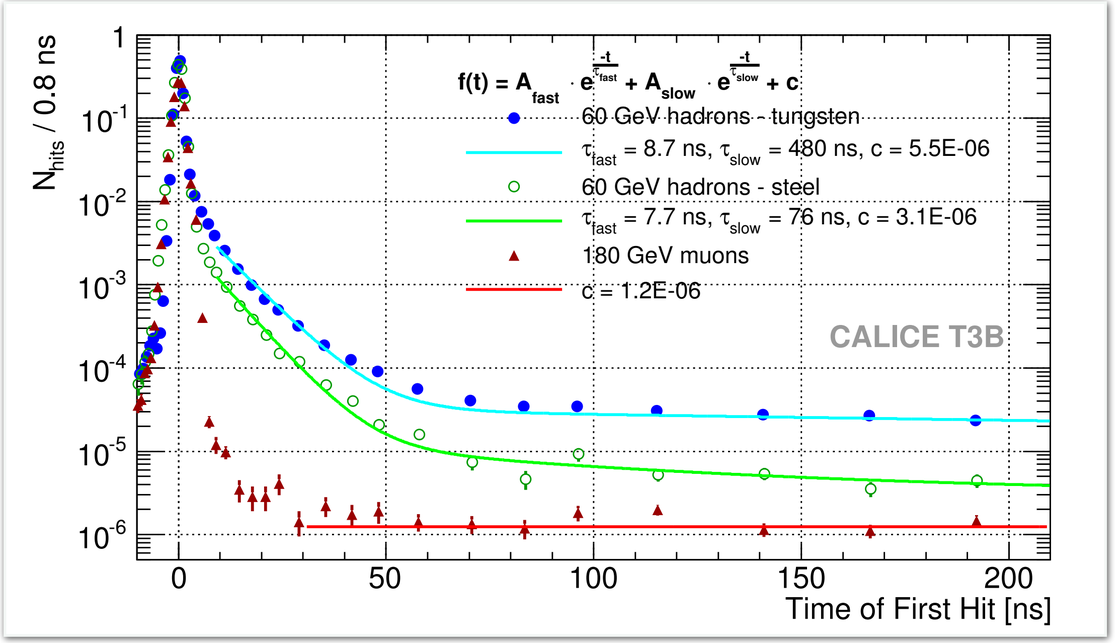
- Event selection:
  - Shower start before layer 15
  - Cut on +- 2.5sigma

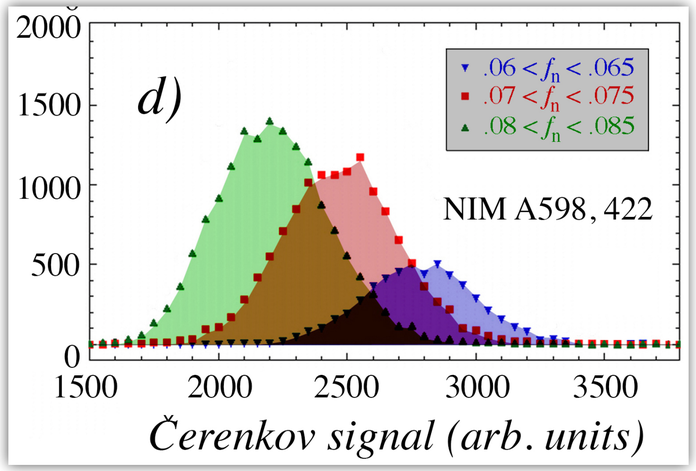


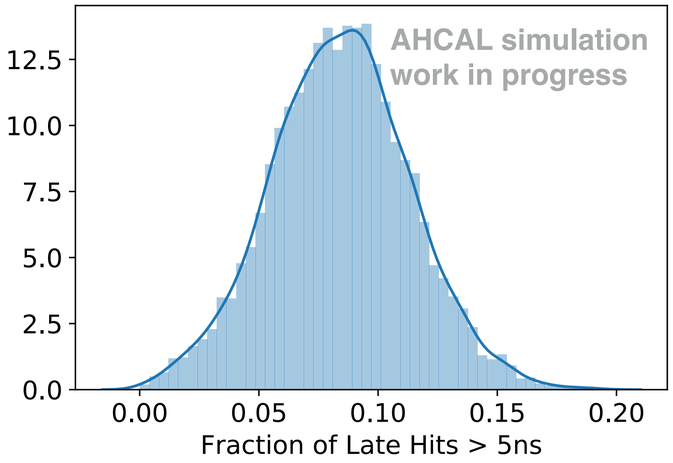


Timing

- Timing capabilities with technological prototype
- Slow neutrons created in hadronic processes —> late hits
- **May help energy reconstruction?**
  - Correlation between neutron content and em-fraction observed in dual read-out calorimeter
- Problem: Not many neutrons in steel absorber!





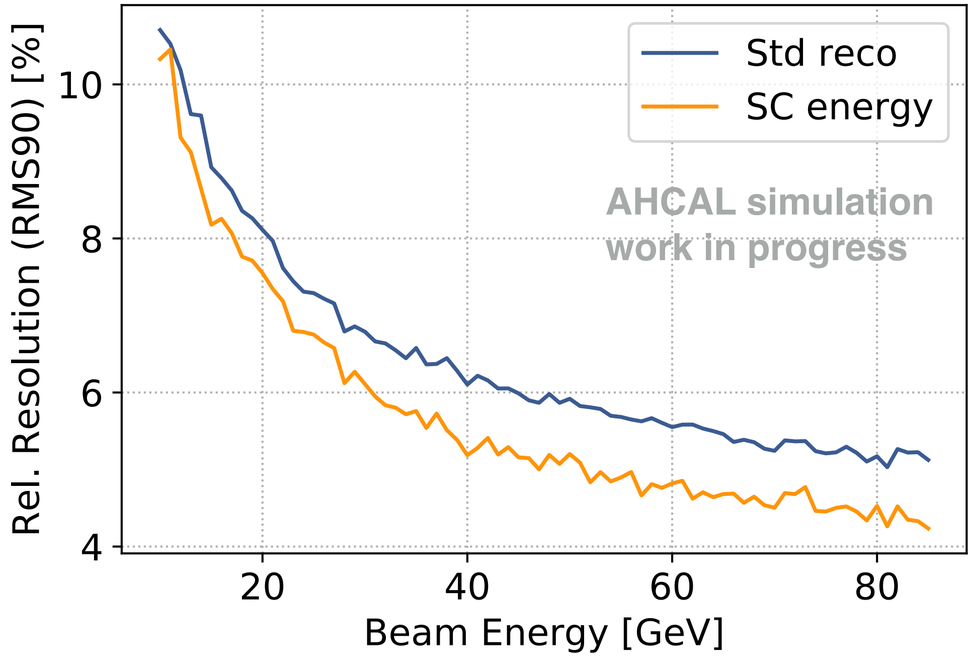


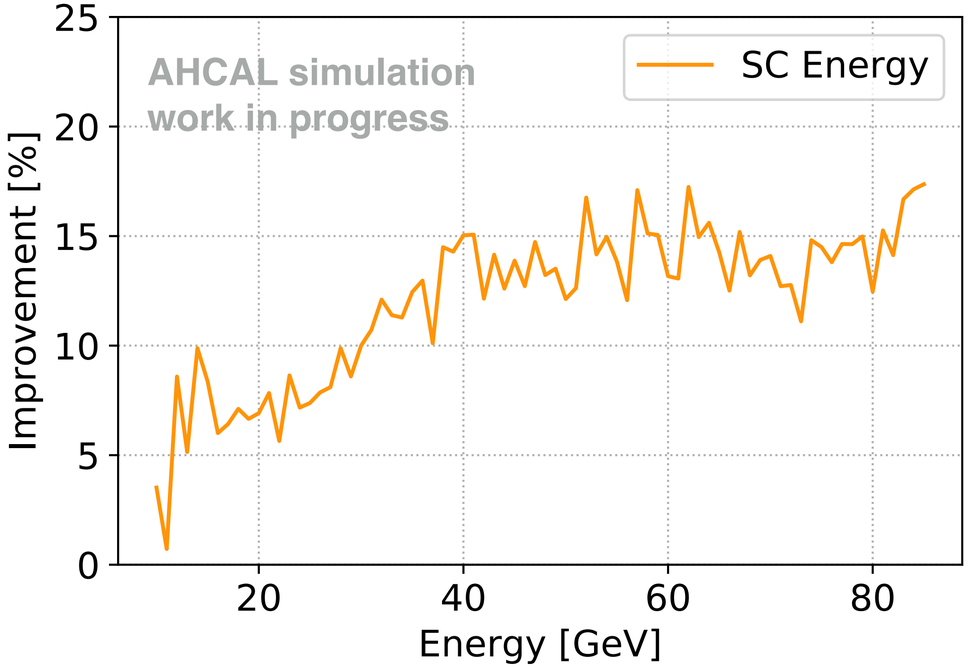
Software Compensation - Energy

- Global software compensation approach yields **~15%** improvement over std reco
- Using Fraction of hits **> 5 MIP**

Optimize:

$$E_{\mathrm{reco}} = a + b * f_{\mathrm{HighEnergyHits}} + c * f^2_{\mathrm{HighEnergyHits}}$$



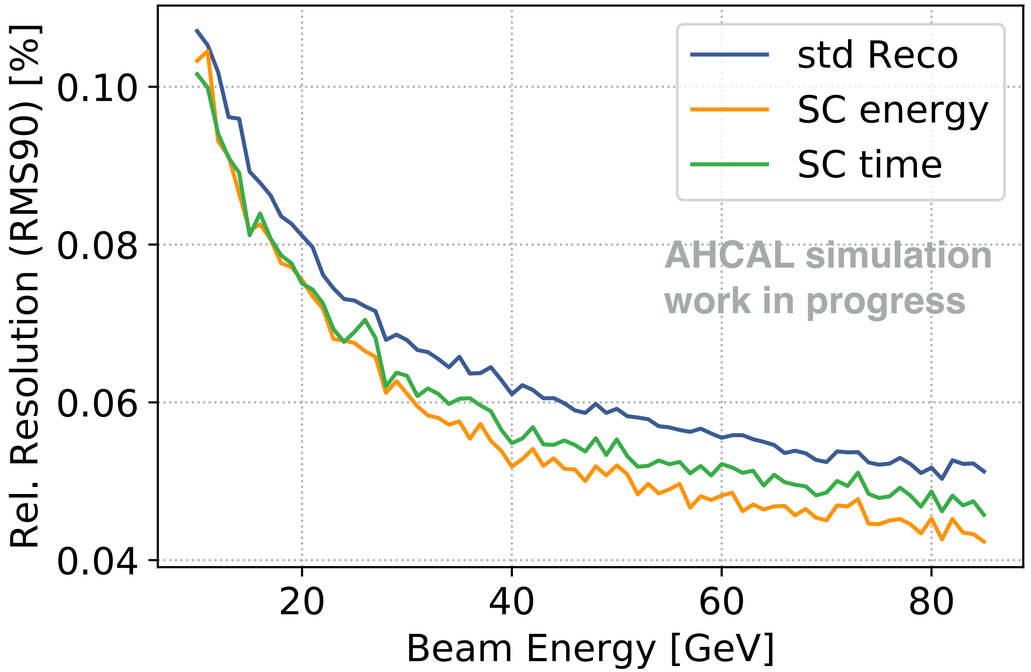


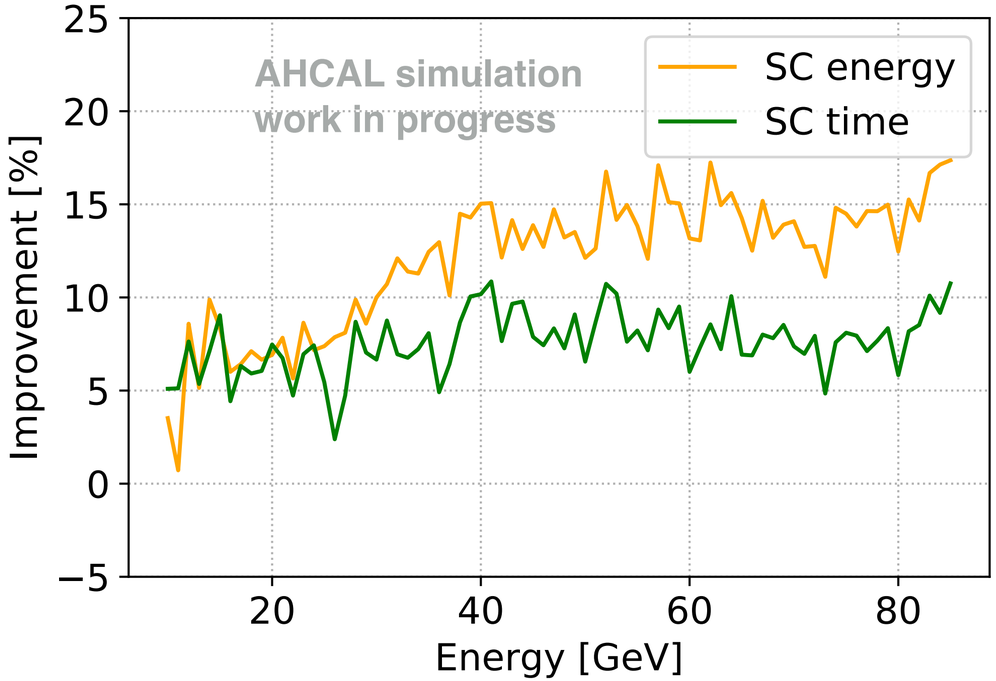
Software Compensation - Time

- Global software compensation approach with **time** yields **~8%** improvement over std reco
- Using fraction of late hits **> 5ns**

Optimize:

$$E_{\mathrm{reco}} = a + b * f_{\mathrm{LateHits}} + c * f^2_{\mathrm{LateHits}}$$





Software Compensation - Time

- Global SC approach with **energy and time** yields **~17%** improvement over std reco
- Using fraction of late hits **> 5ns** and hits **> 5 MIP**

Optimize:

$$E_{\mathrm{reco}} = a + b * f_{\mathrm{HighEnergyHits}} + c * f_{\mathrm{LateHits}} + d * f_{\mathrm{LateHits}} * f_{\mathrm{HighEnergyHits}}$$

Software Compensation - Time

- Global SC approach with **energy and time** yields **~17%** improvement over std reco
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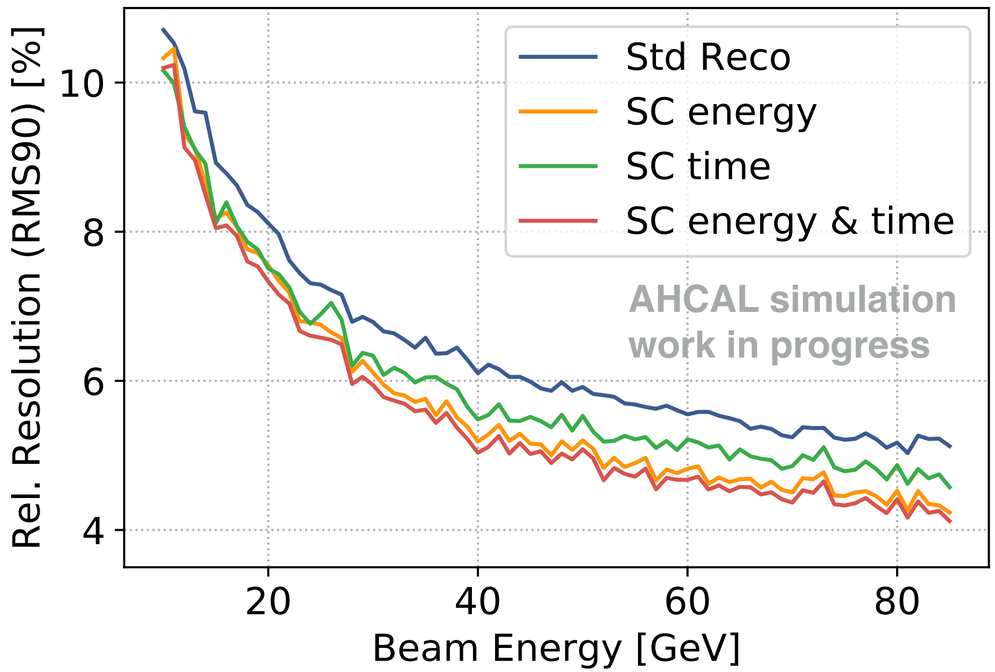
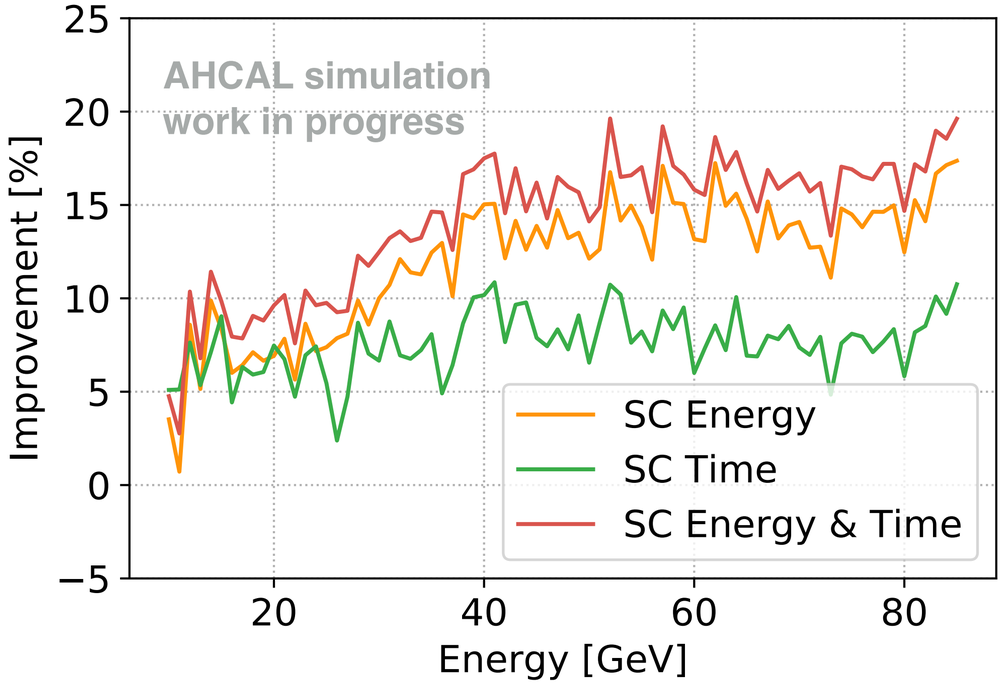
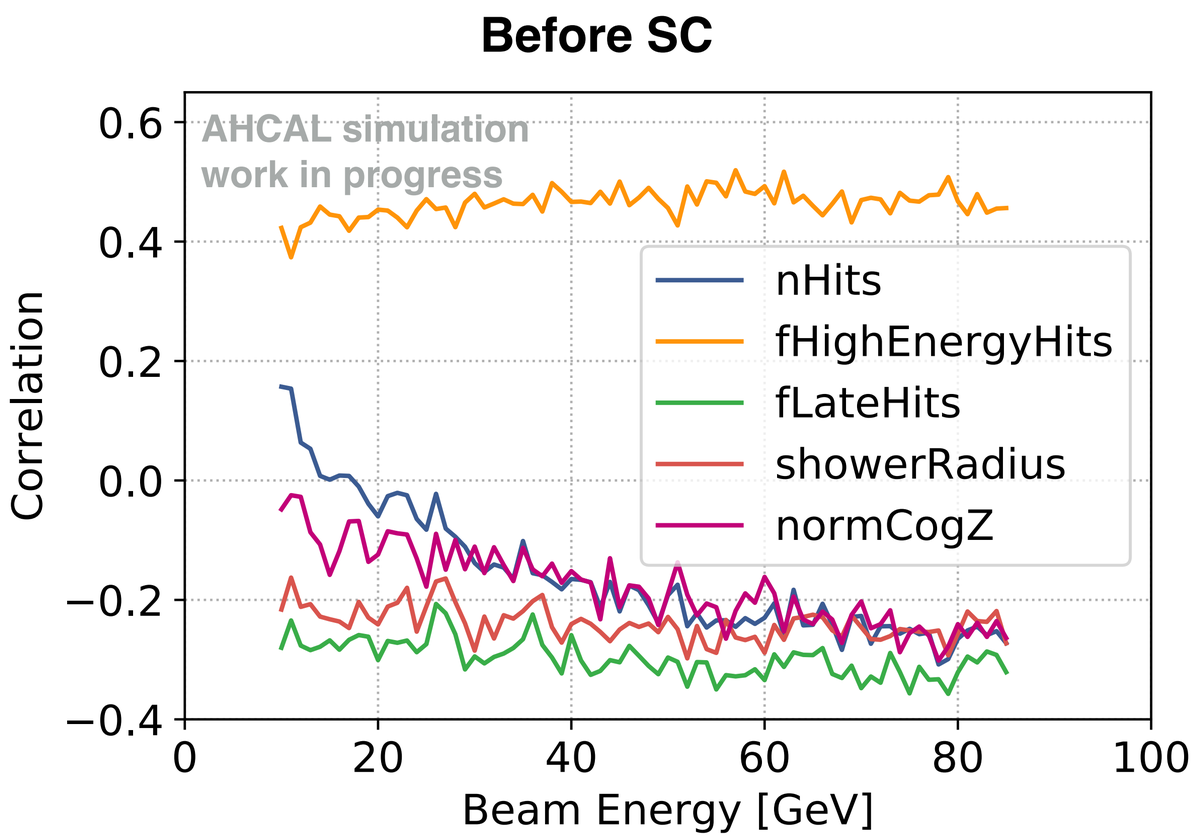




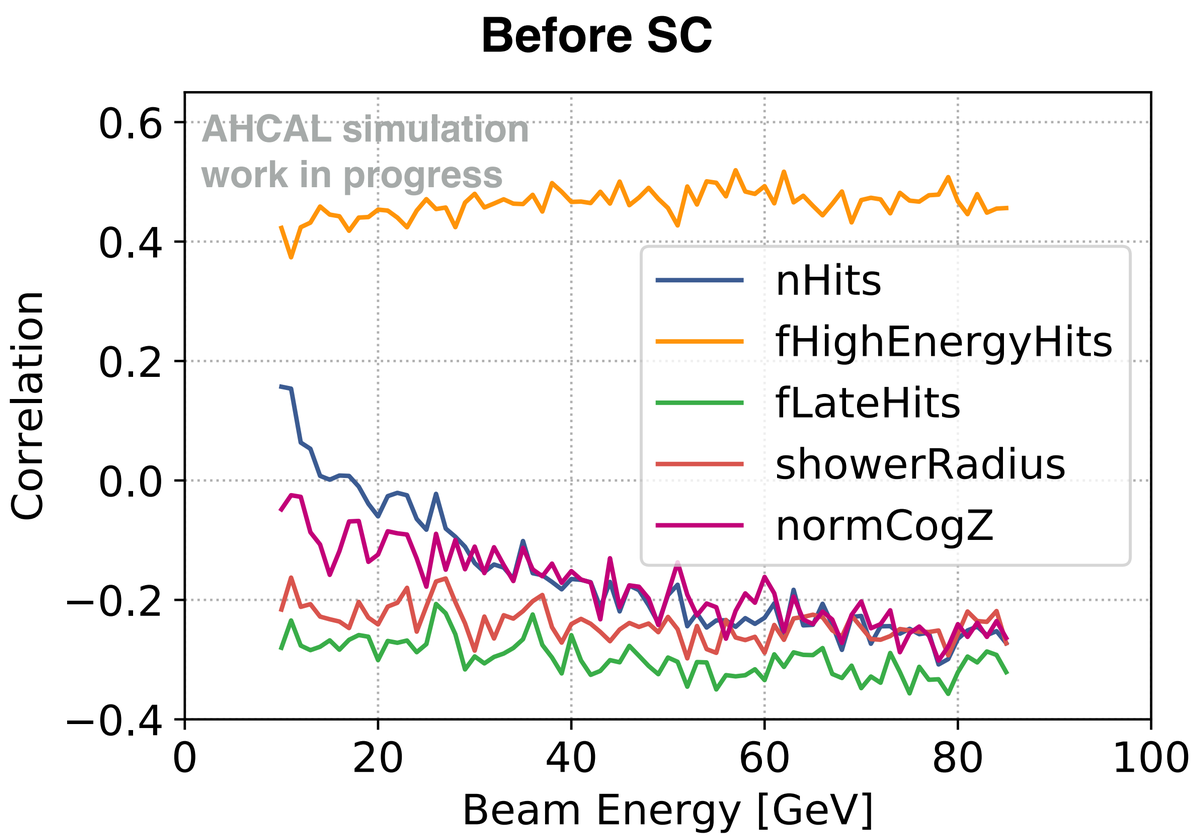
Correlations

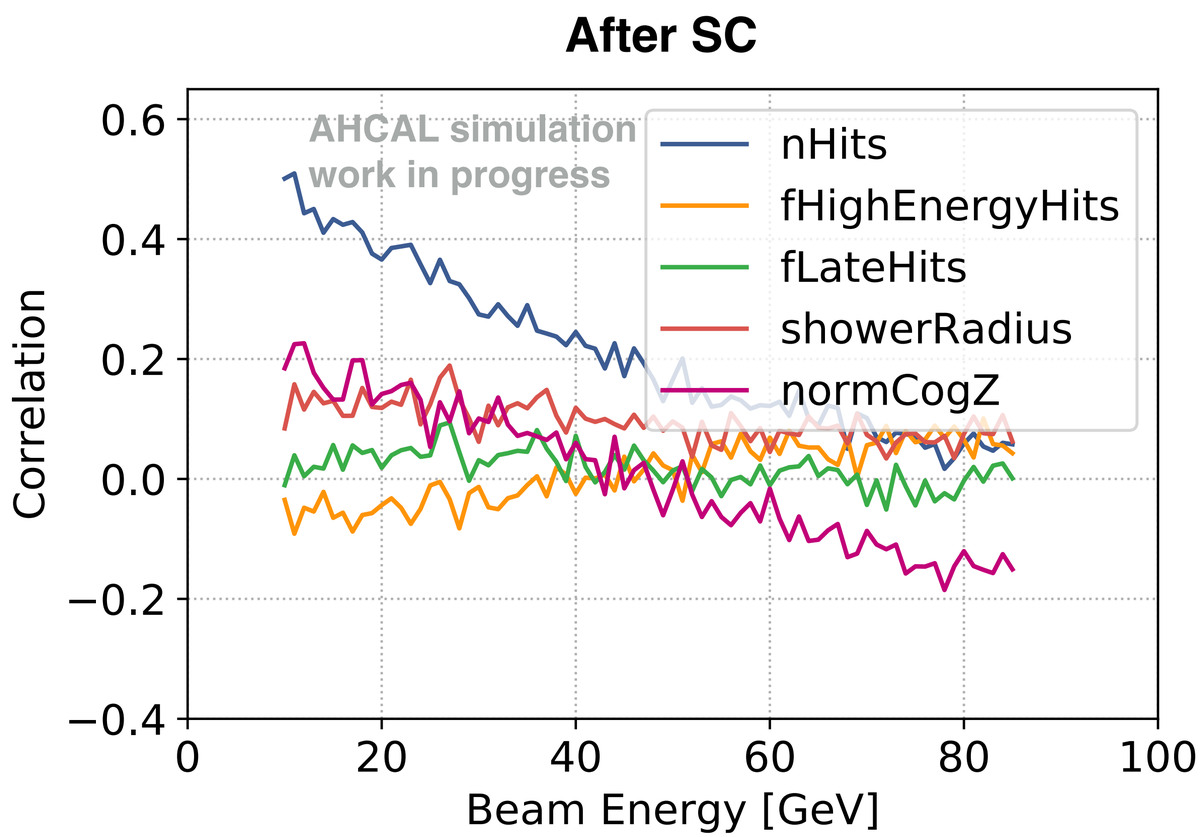
- Correlation coefficients of features with reconstructed energy



Correlations

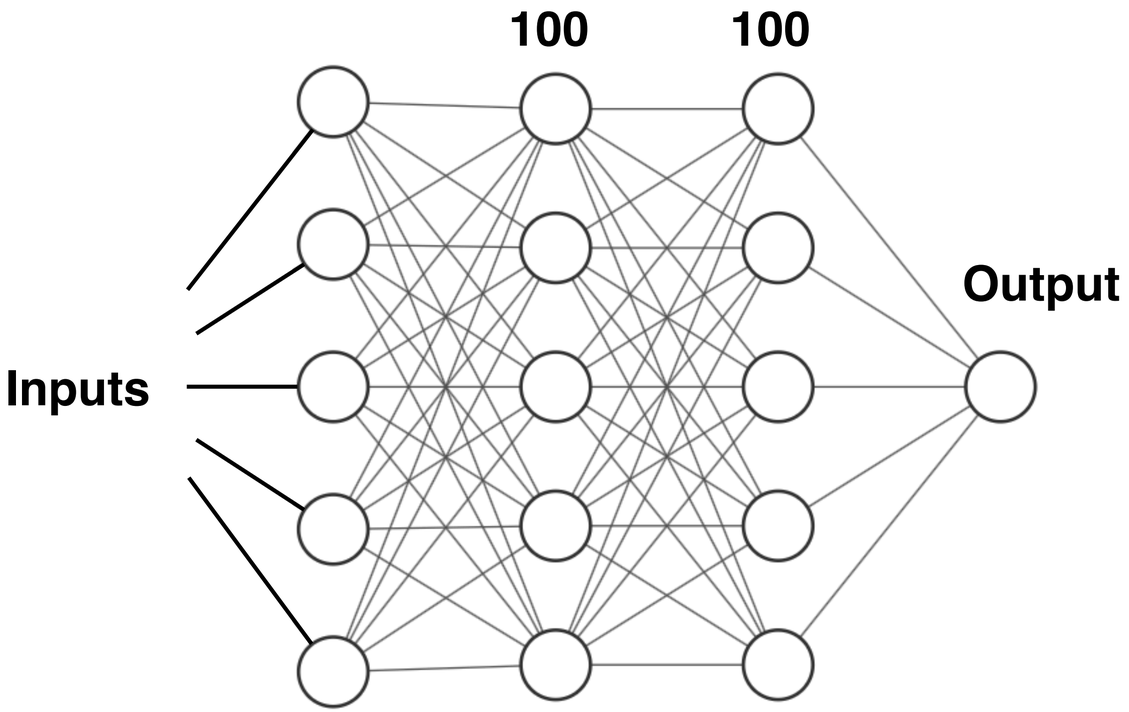
- Correlation coefficients of features with reconstructed energy
- After software compensation: still some correlation left





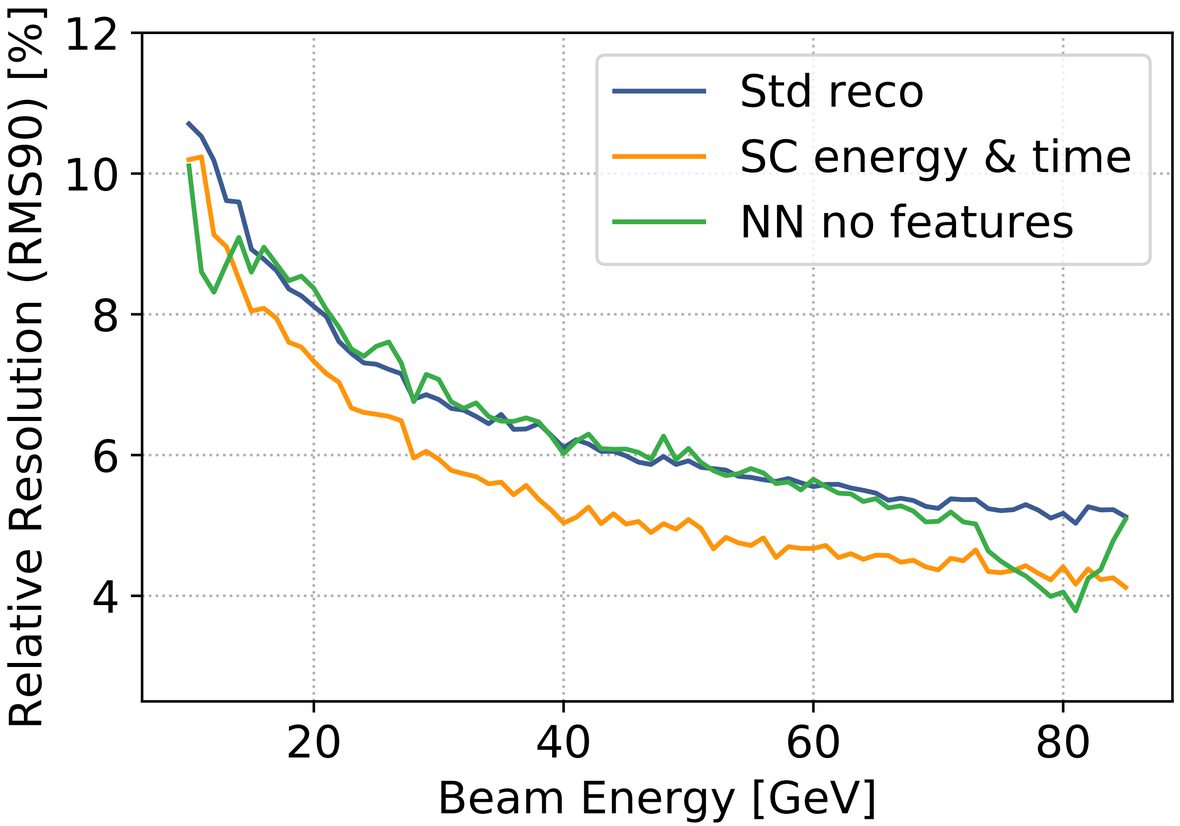
Neural Networks

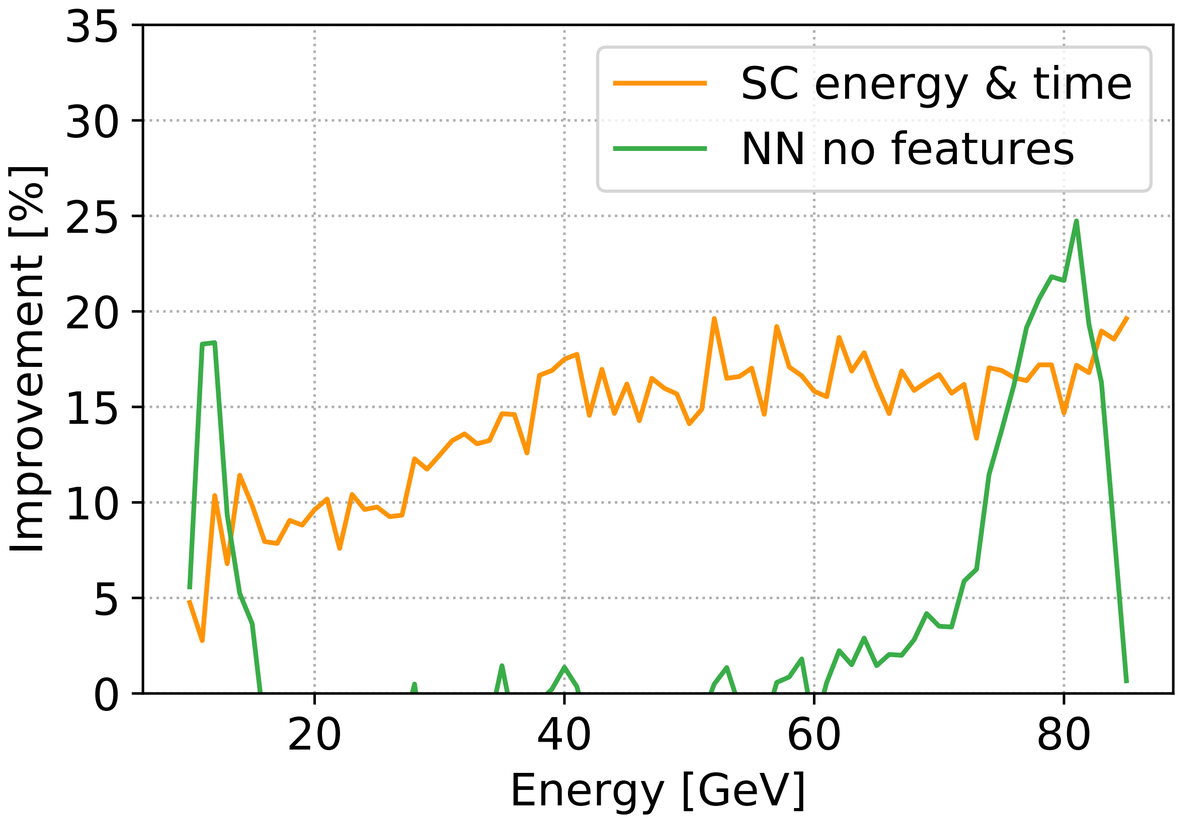
- Continuous training energies (1GeV steps)
- Splitting data in train and test data set (70/30)
- Event selection must not depend on true energy
- Scaling of features (mean = 0, var = 1)
- Learning on $dE = E_{stdReco} / E_{true}$
- Simple architecture:
  - 2 fully connected layers
  - 100 neurons each
- Prevent overfitting
  (small network size, dropout, l2 regularization)
- Loss function: Mean squared error



Neural Networks

- **Input:** Only energy sum





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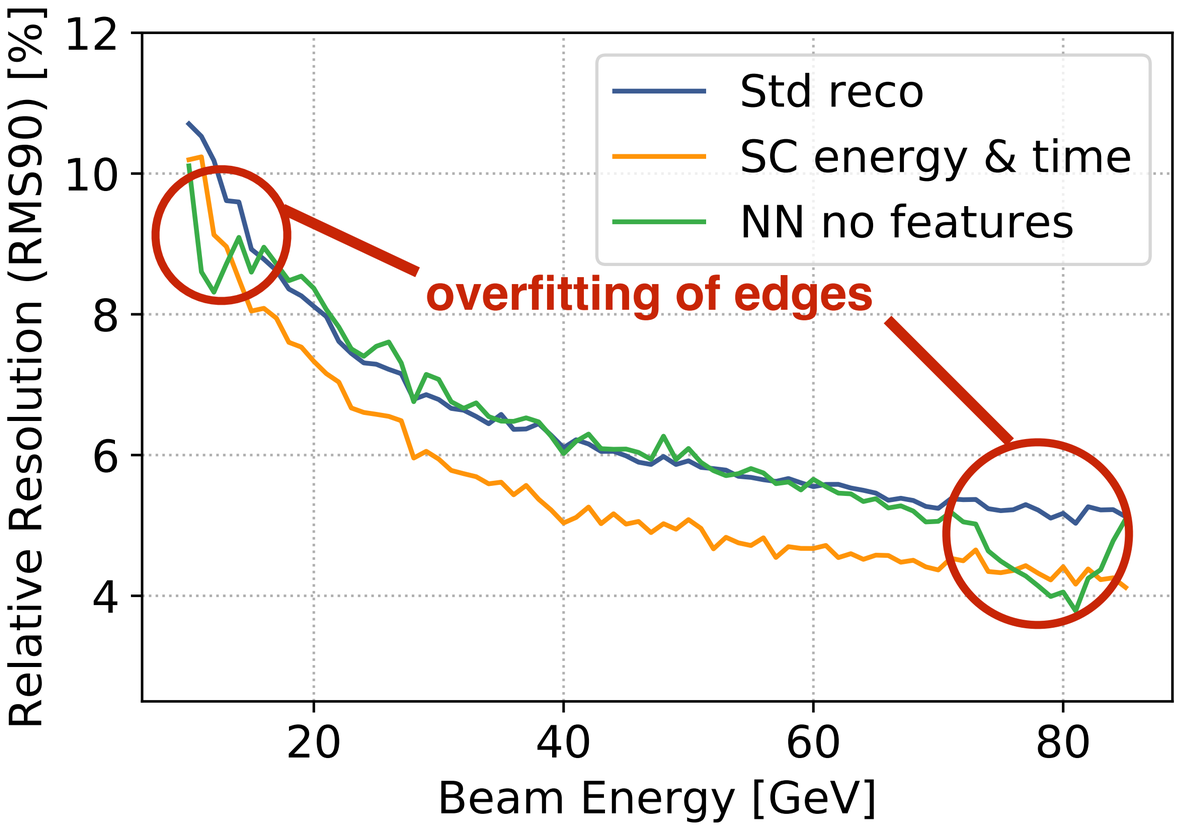
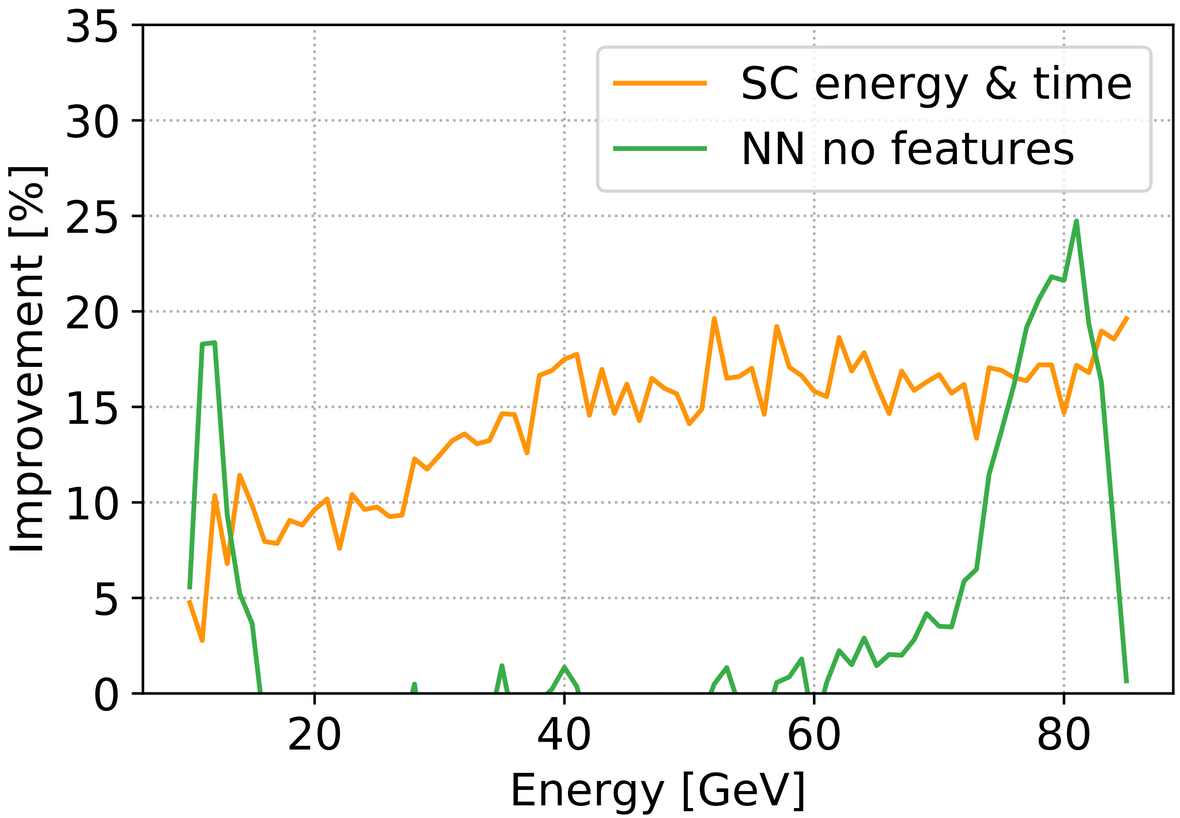
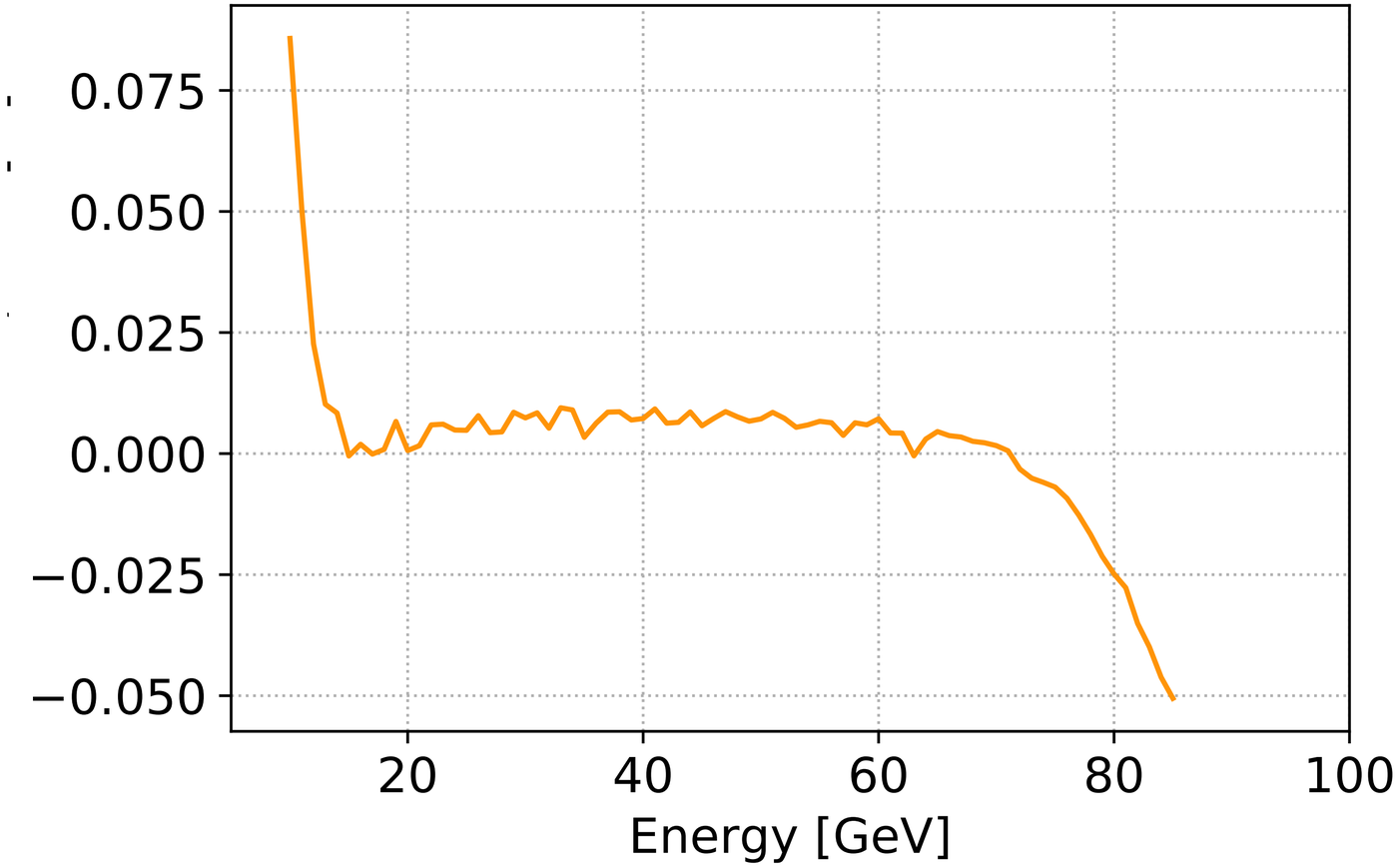




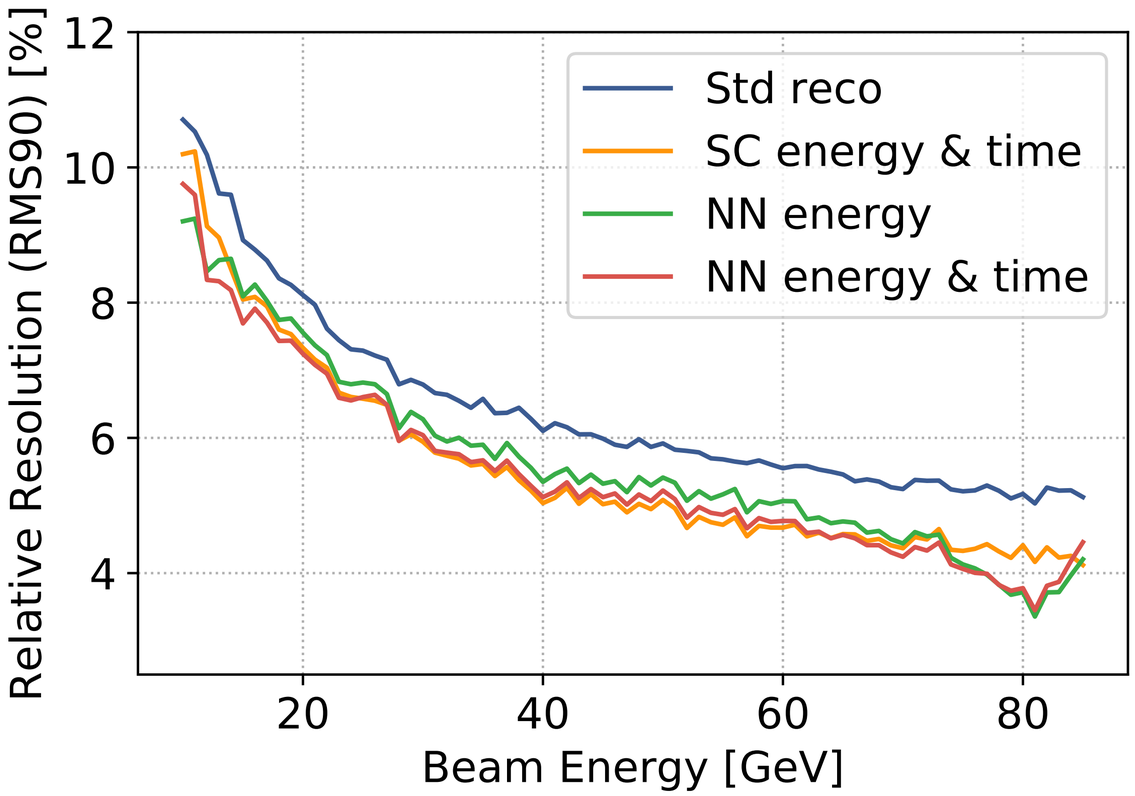
Neural Networks - Linearity

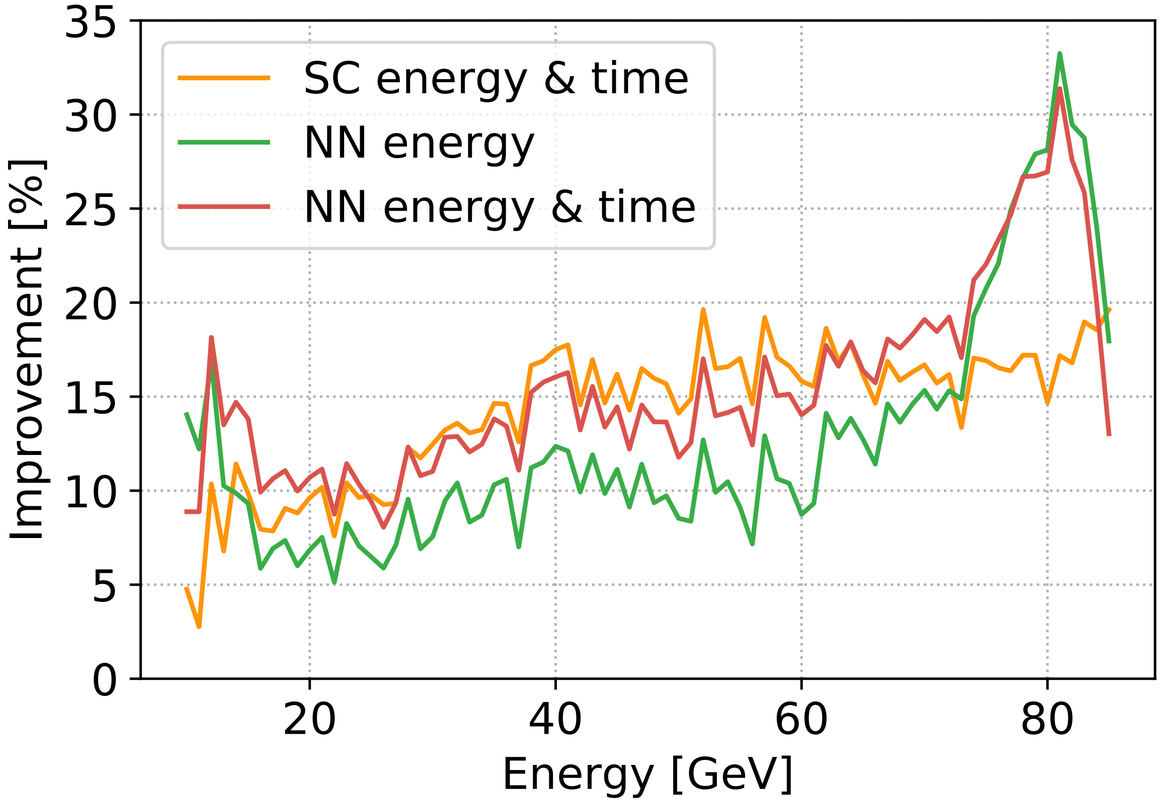
- Non-linearity at the edges



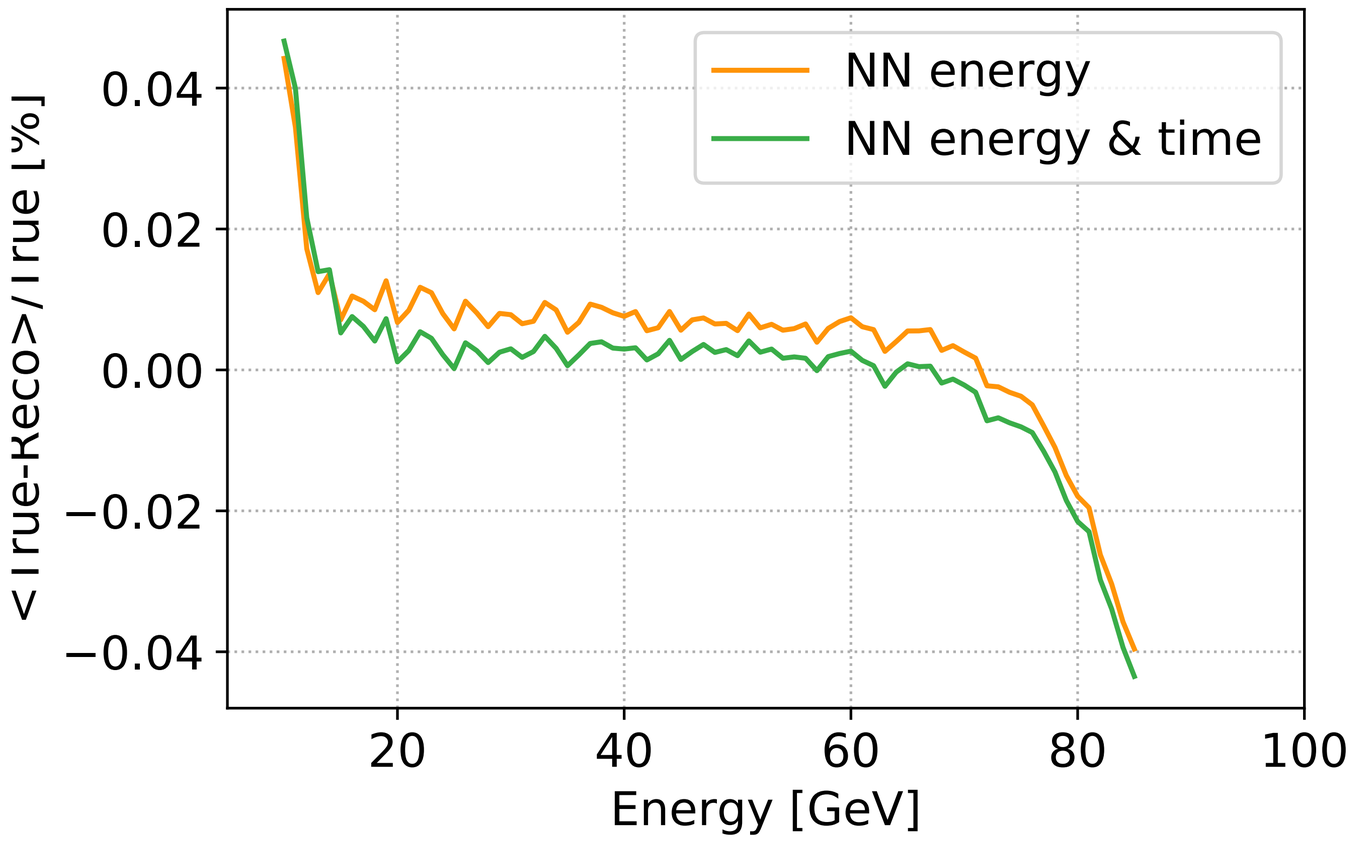
NN Energy & Time

- **Input**: energy (#hits > 5mip), time (#hits > 5ns)



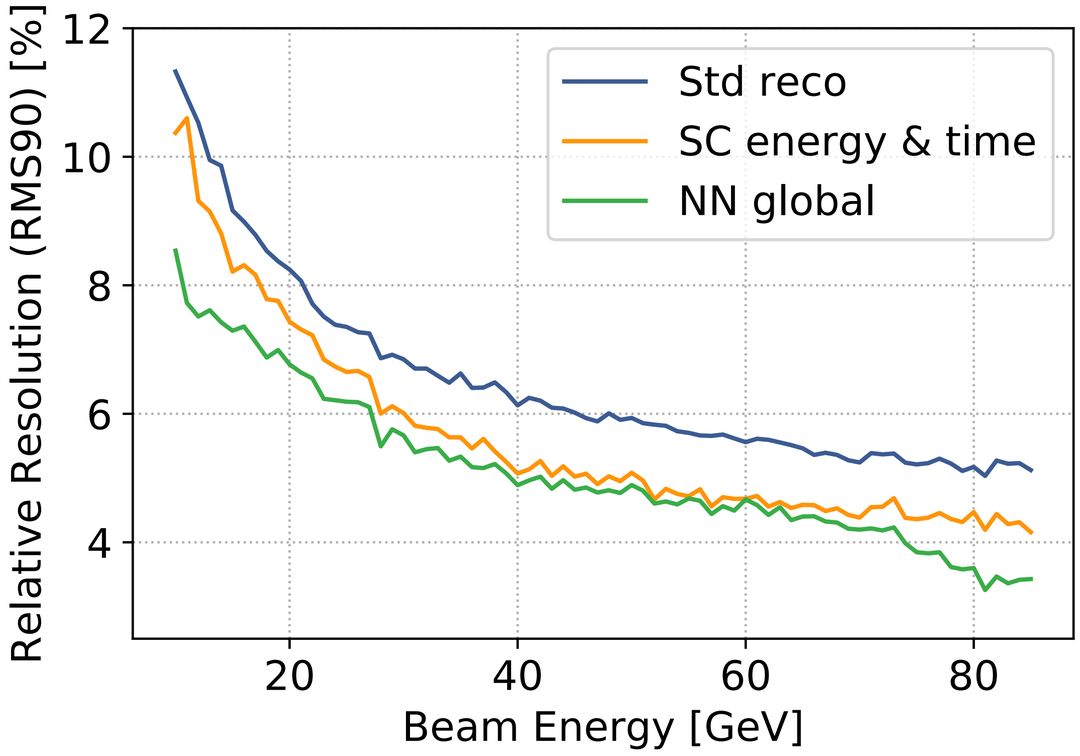


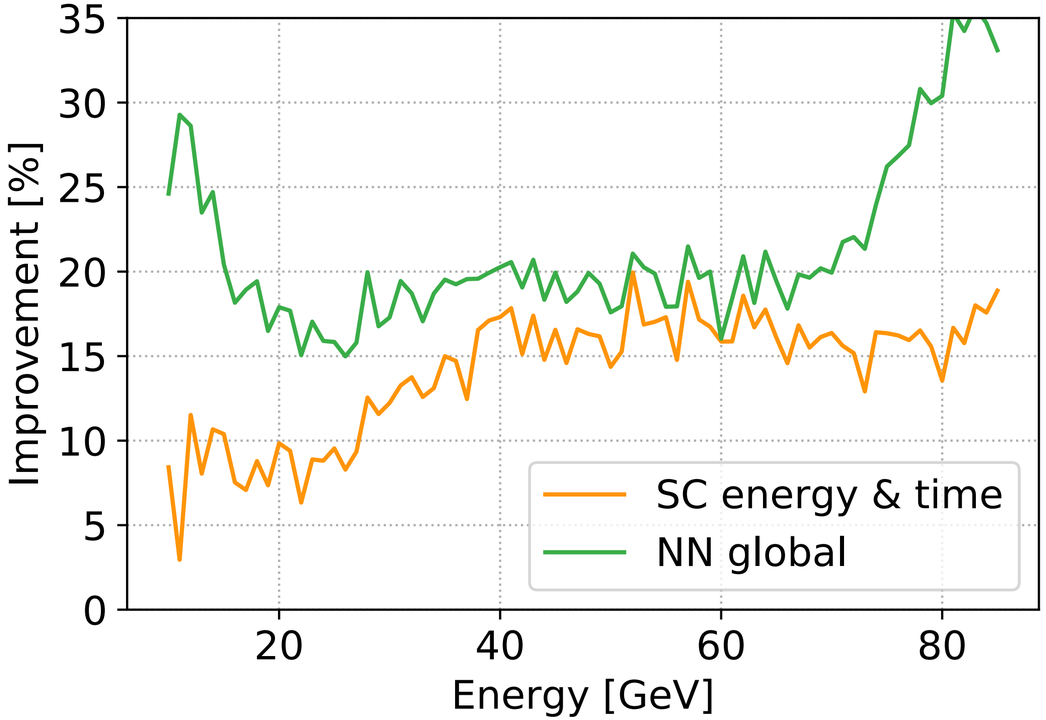
NN Energy & Time - Linearity



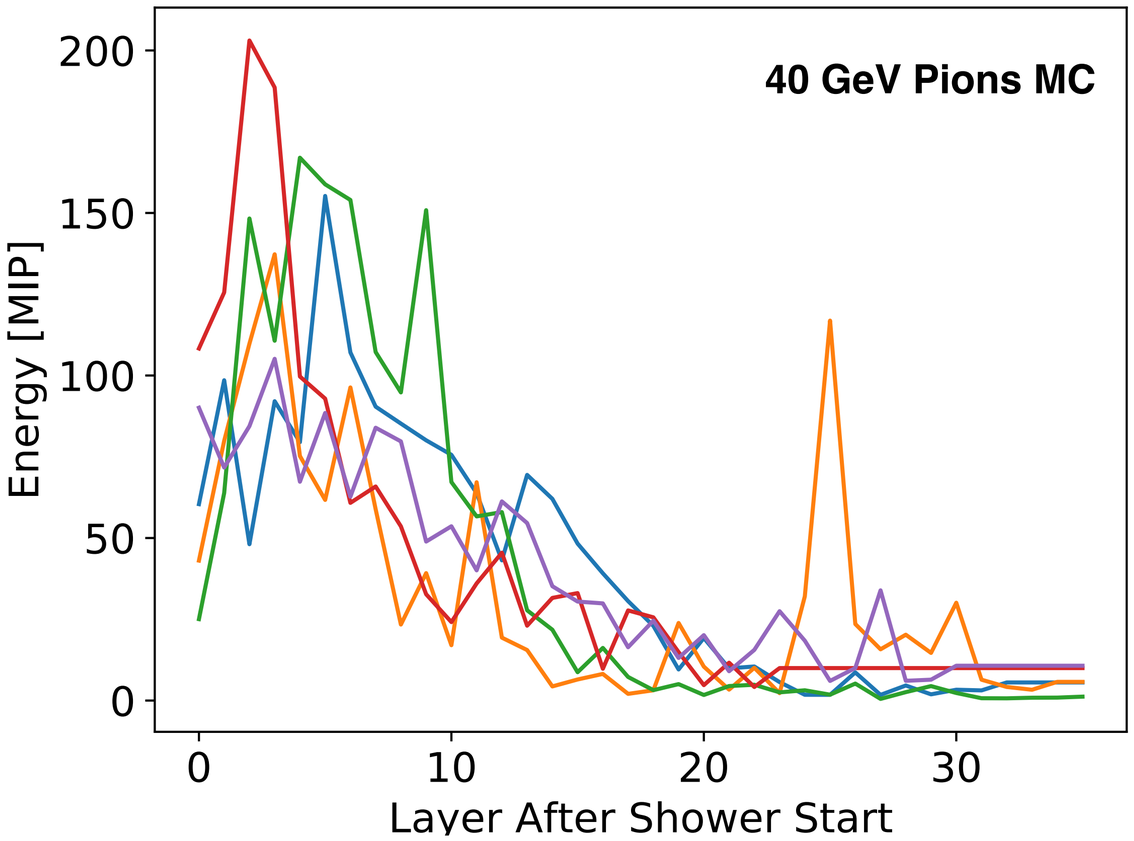
Neural Networks

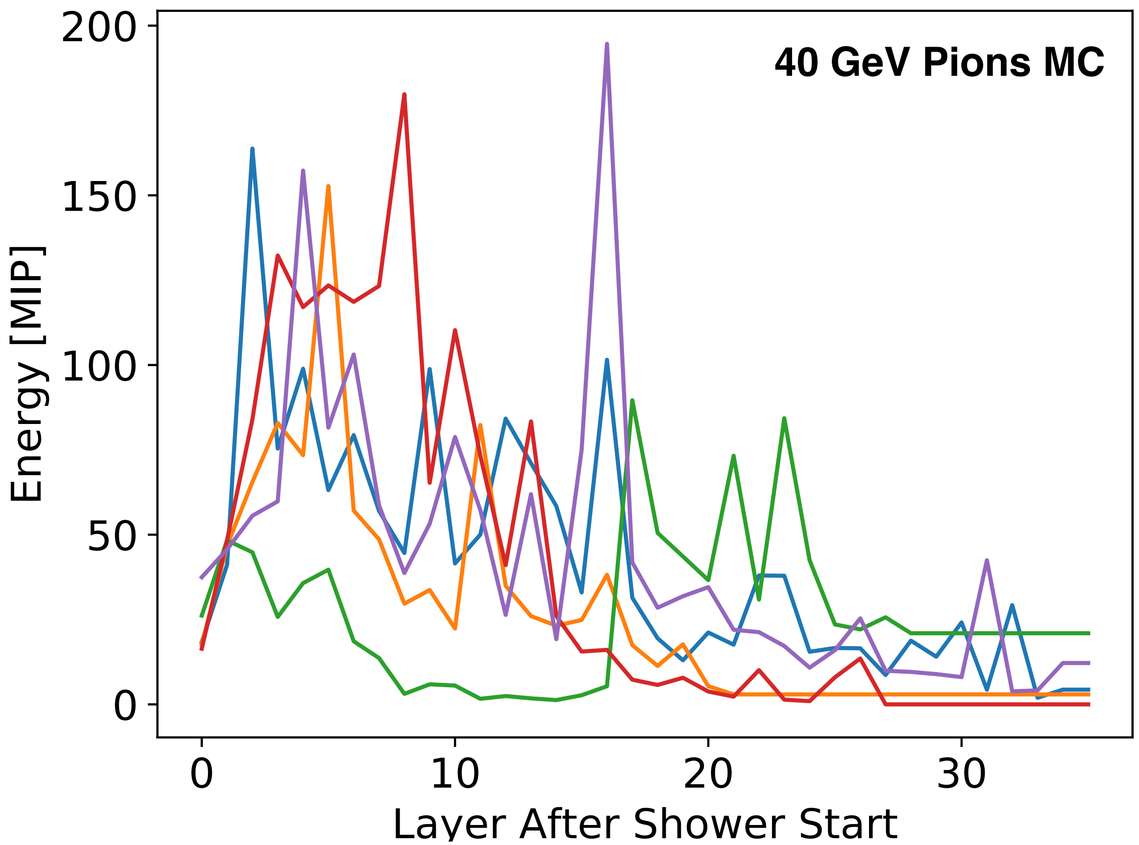
- **Input:** energy (3 thresholds), time, #hits, radius, cogZ





Shower Profiles





Neural Networks

- **Input:** global, energy per layer, #hits per layer (total: 8+80 inputs)

Neural Networks

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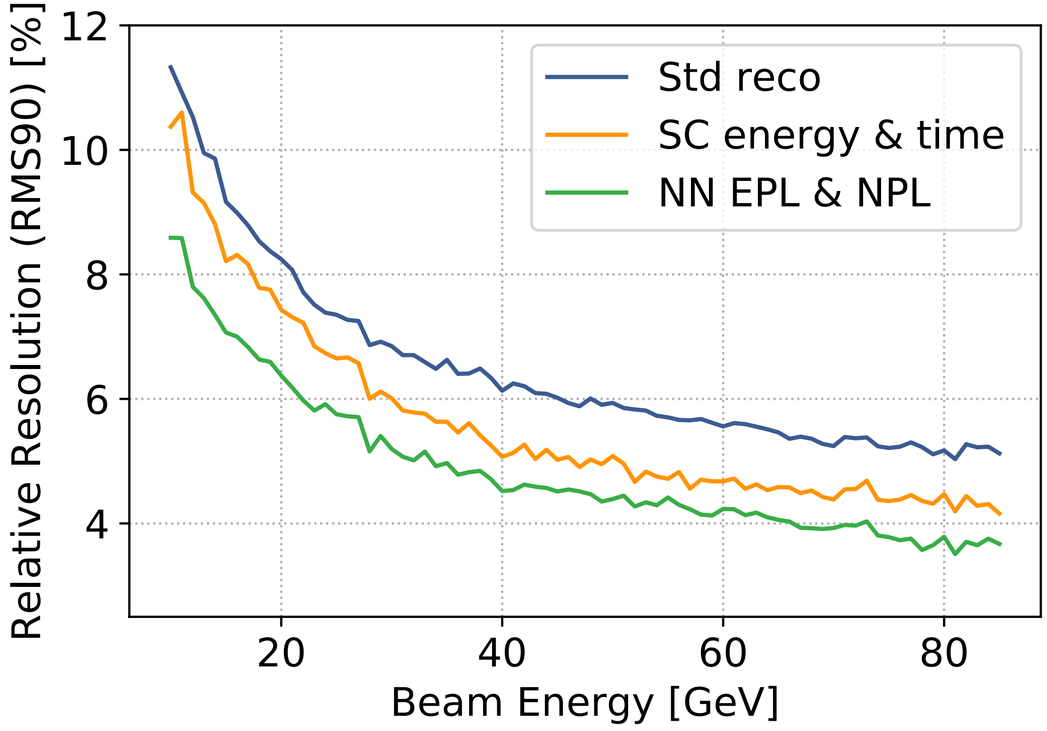
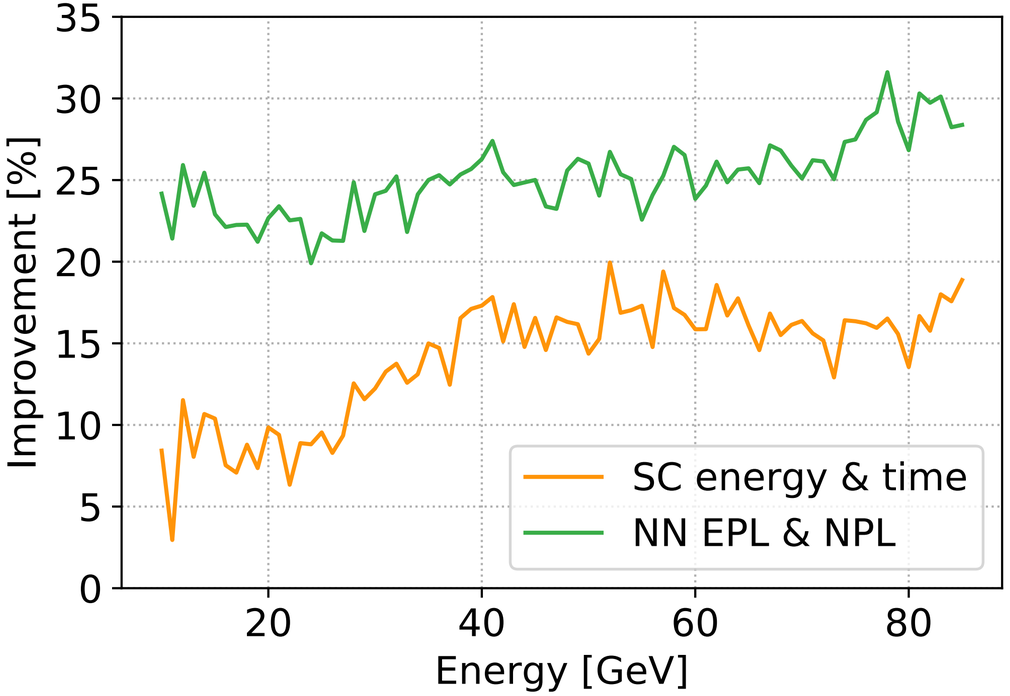
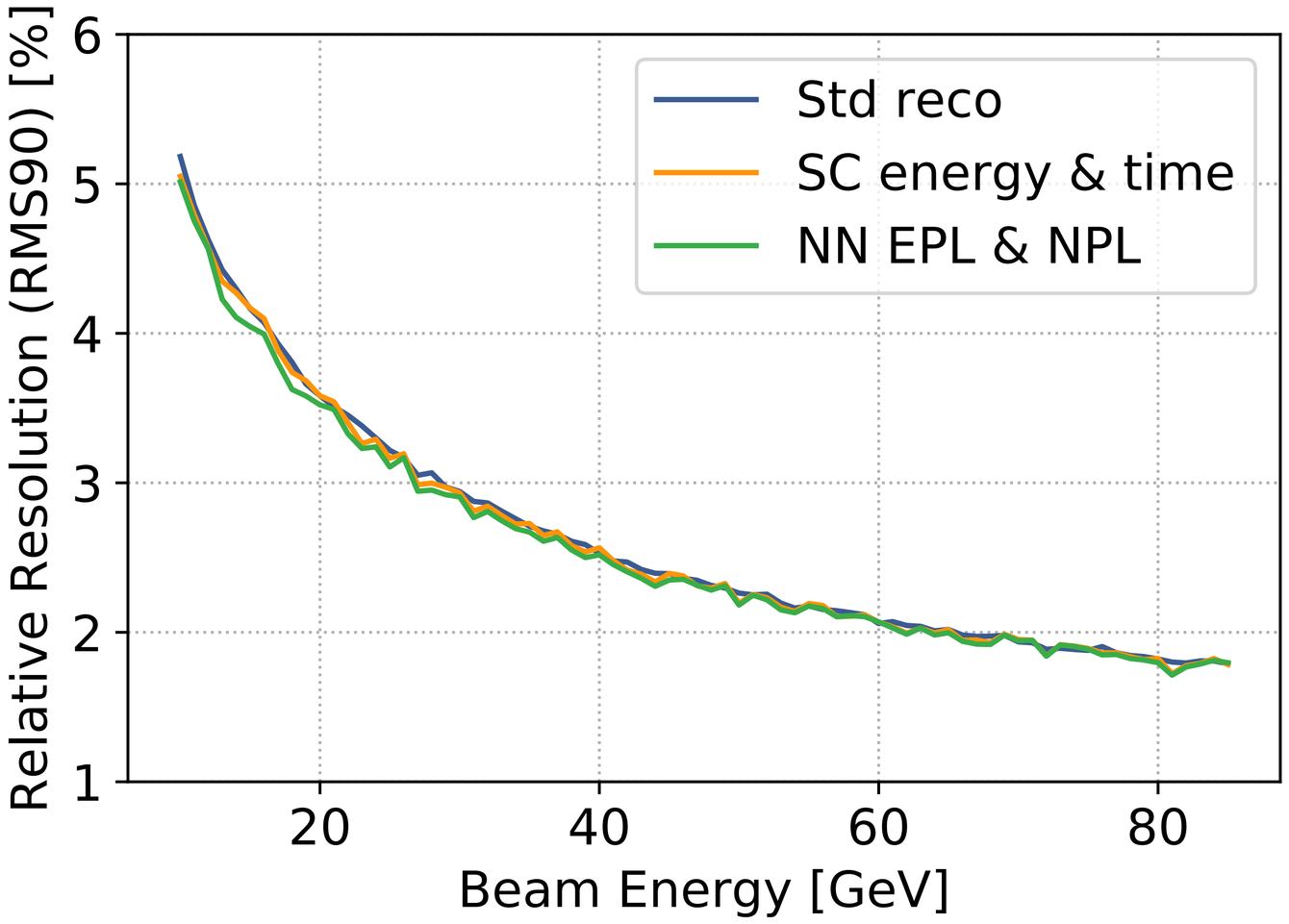




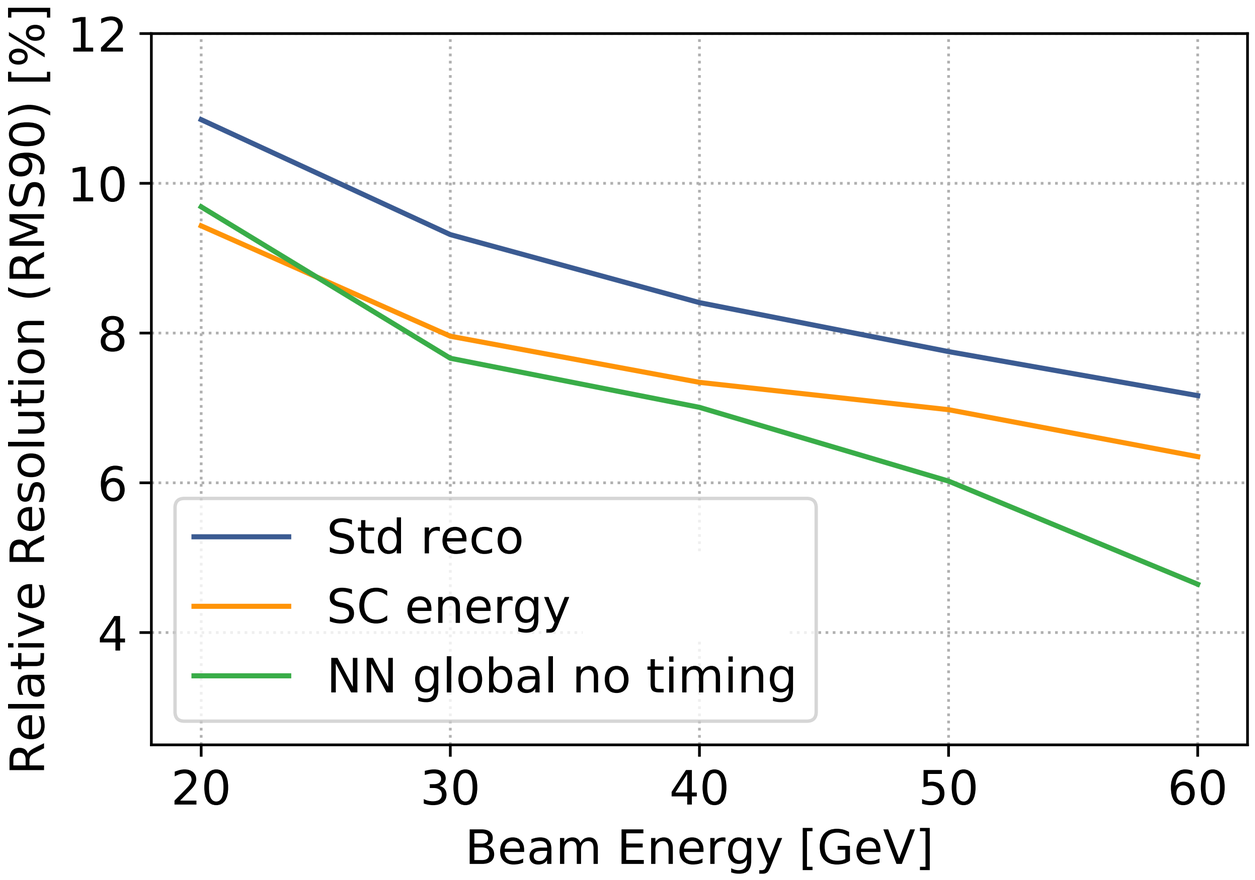
Neural Networks

- Cross check with electrons
- No improvement visible



Does it work on data?

- Training on 60 layers simulation, applying to data (20, 30, 40, 50, 60 GeV)
- Very preliminary: Insufficient event selection
- **Clear improvement observed**



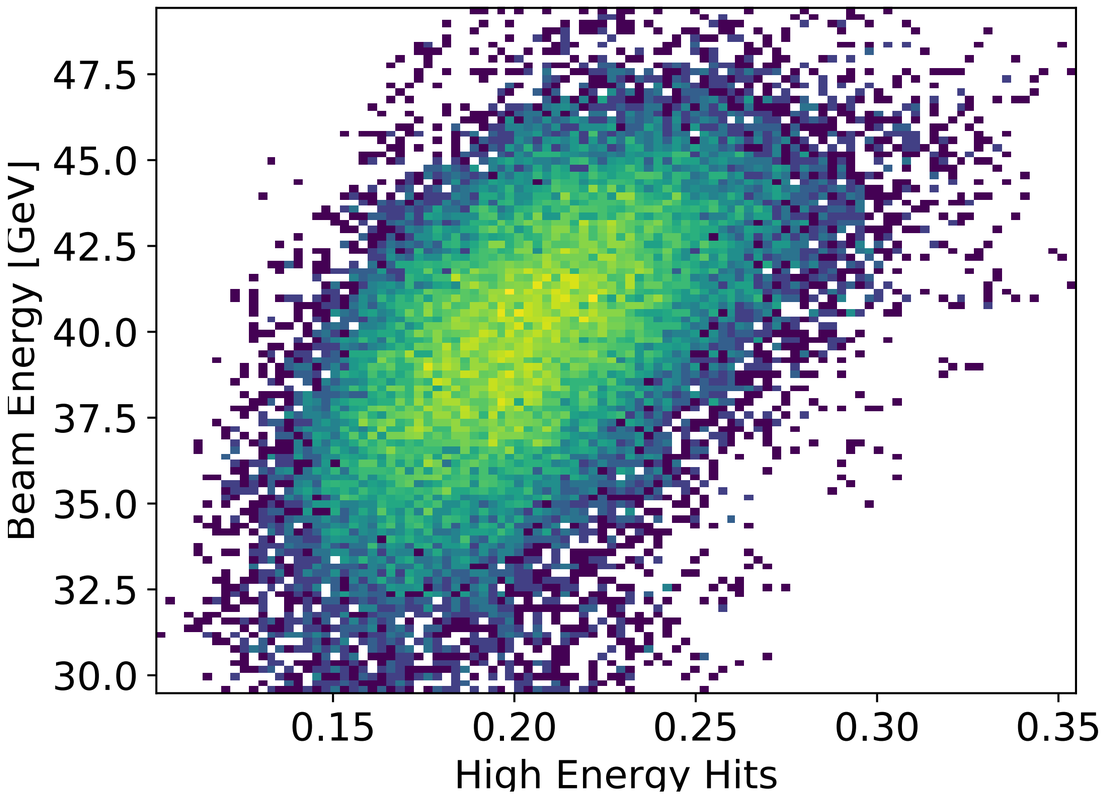
Summary & Outlook

- Correlation of timing with energy visible in simulation
- Slight improvement in energy reconstruction in SC scheme
  - Good time resolution needed
  - Even harder in real-life: clustering
- Machine learning algorithms are capable of using much more information
  - Significant improvement for using energy profile of each event
  - Adding information improves energy reconstruction
  - First check on data looks promising
- **Outlook:**
  - Timing in tungsten?
  - Better architecture, better features, better event selection?
  - Deep learning (Erik)

Backup

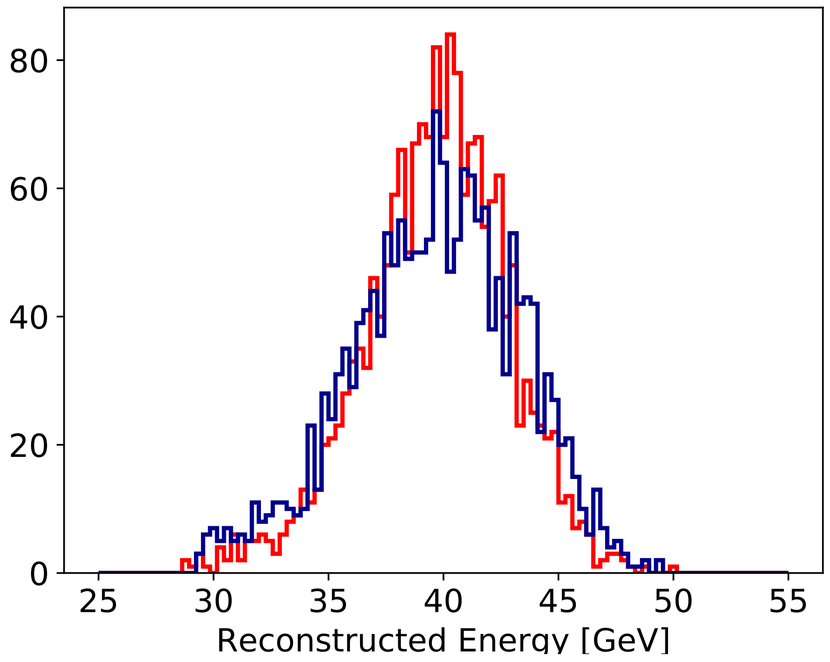
High Energy Hits Correlation

- Clear correlation of high energy hits > 5 MIPs and energy sum visible

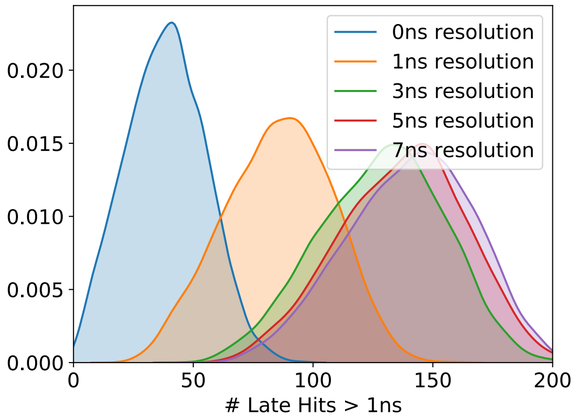


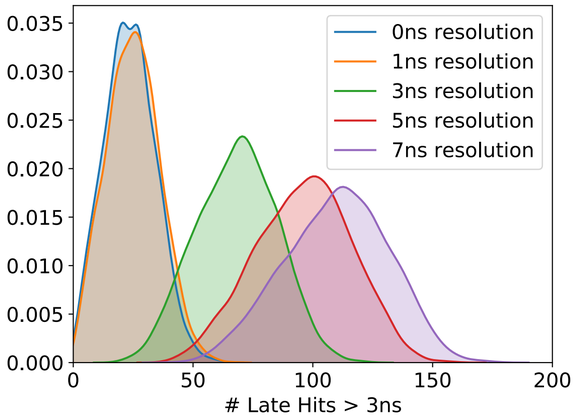
$$E_{\mathrm{reco}} = a + b * f_{\mathrm{HighEnergyHits}} + c * f^2_{\mathrm{HighEnergyHits}}$$

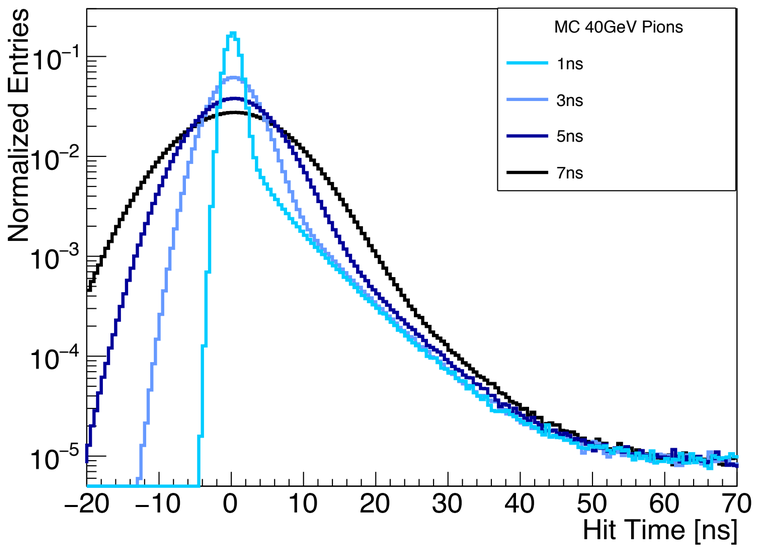
- Global software compensation approach yields **15.2%** improvement over std reco

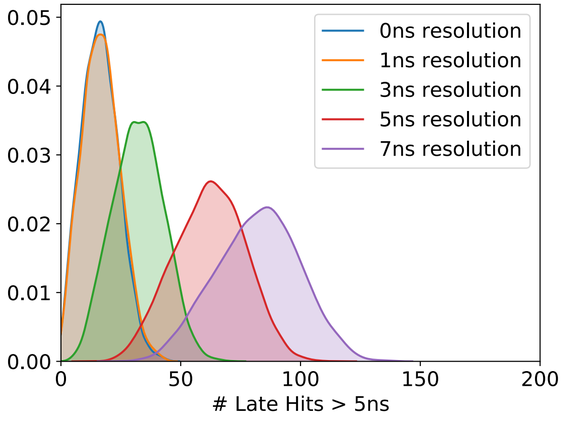


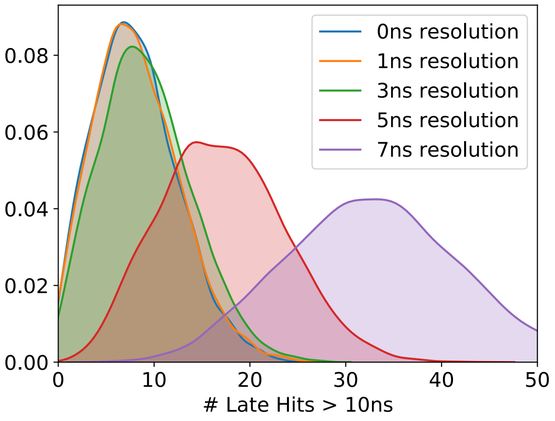
Late Hits

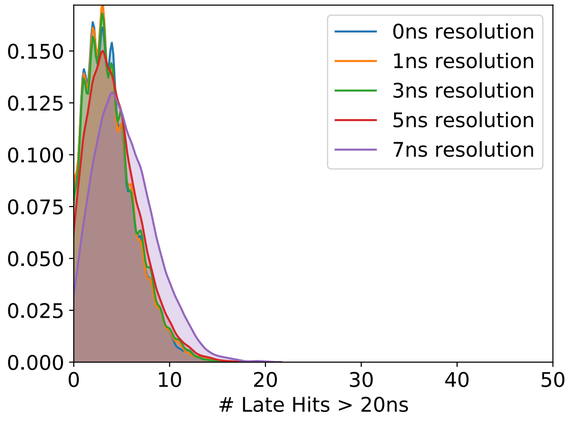

0ns resolution
1ns resolution
3ns resolution
5ns resolution
7ns resolution
Late Hits > 1ns


0ns resolution
1ns resolution
3ns resolution
5ns resolution
7ns resolution
Late Hits > 3ns


MC 40GeV Pions
1ns
3ns
5ns
7ns
Normalized Entries
Hit Time [ns]

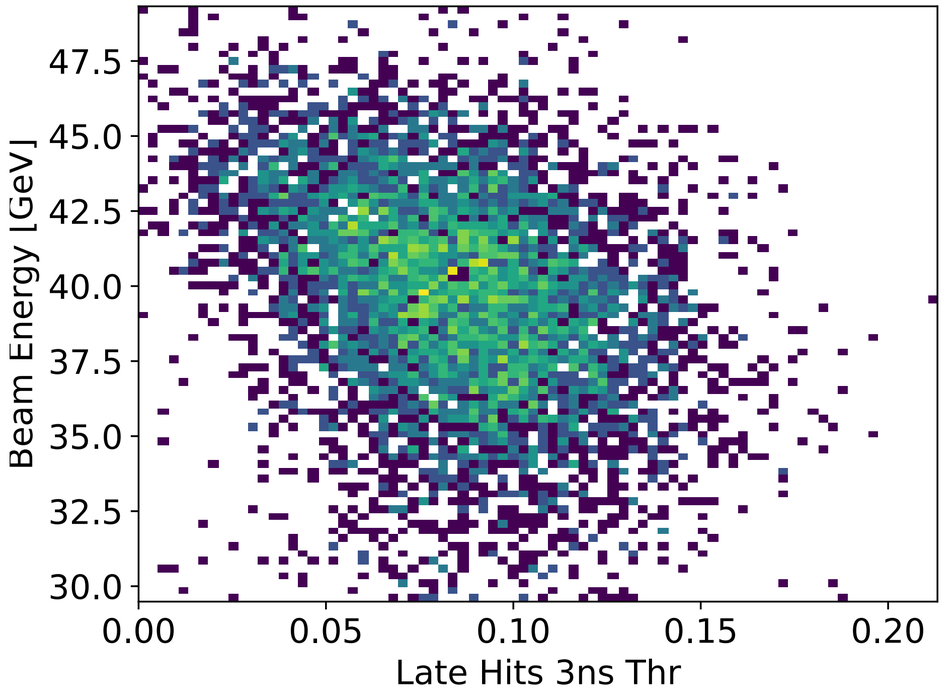

0ns resolution
1ns resolution
3ns resolution
5ns resolution
7ns resolution
Late Hits > 5ns

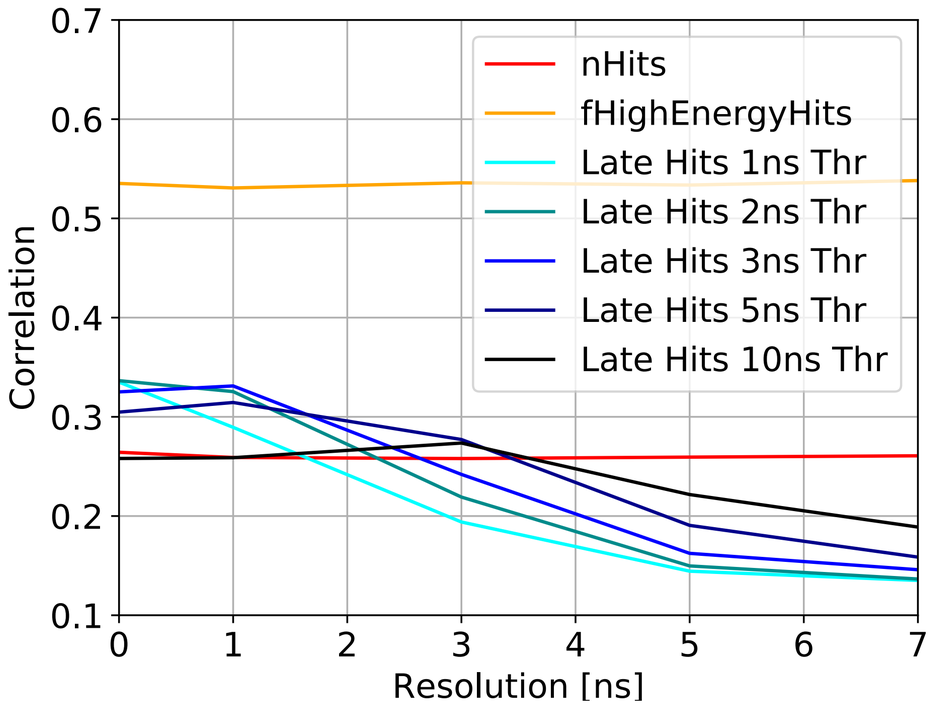

0ns resolution
1ns resolution
3ns resolution
5ns resolution
7ns resolution
Late Hits > 10ns


0ns resolution
1ns resolution
3ns resolution
5ns resolution
7ns resolution
Late Hits > 20ns

Fraction of Late Hits

- Correlation between fraction of late hits and energy sum visible





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