Energy Reconstruction using Convolutional Neutral Networks in High Energy Calorimetry

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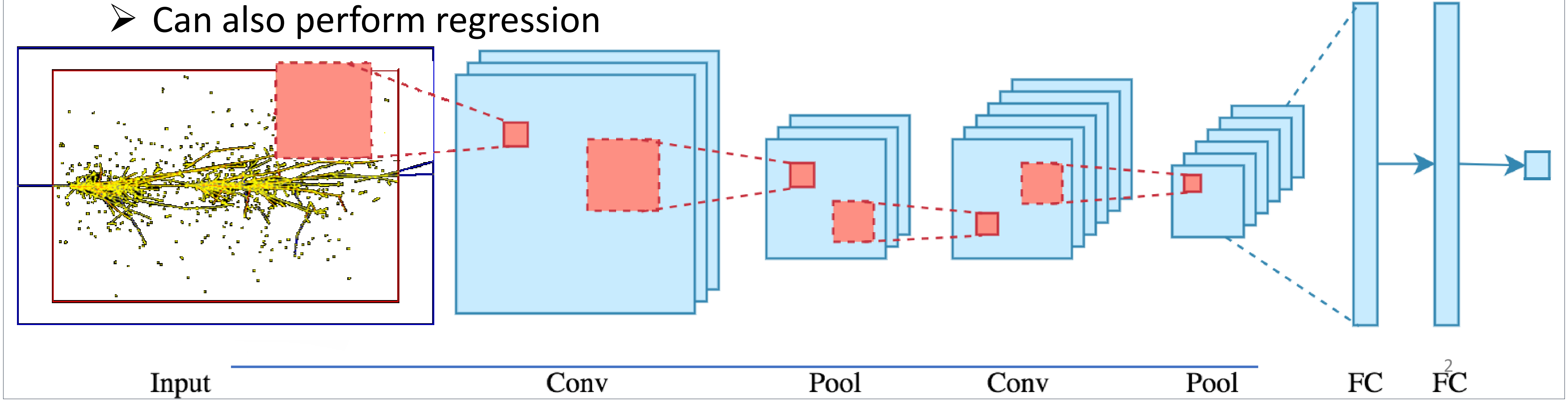
Convolutional Neural Network for energy reconstruction

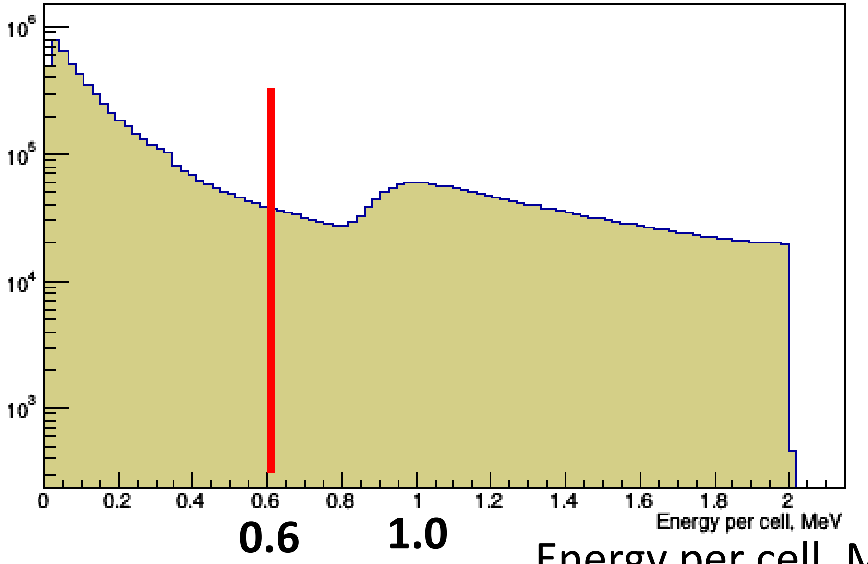
- The showers in high granularity calorimeters can be viewed as 3D images
  - Fiber calorimeters with depth segmentation by timing
- From the visible signal detailed information on *multiplicity and production angle of the secondaries* can be extracted and used to improve the energy reconstruction

- Convolutional Neural Networks(CNN) are very good at image classification
  - Raw images are used
  - Extract higher level features using sequential convolutional operations
  - Can also perform regression

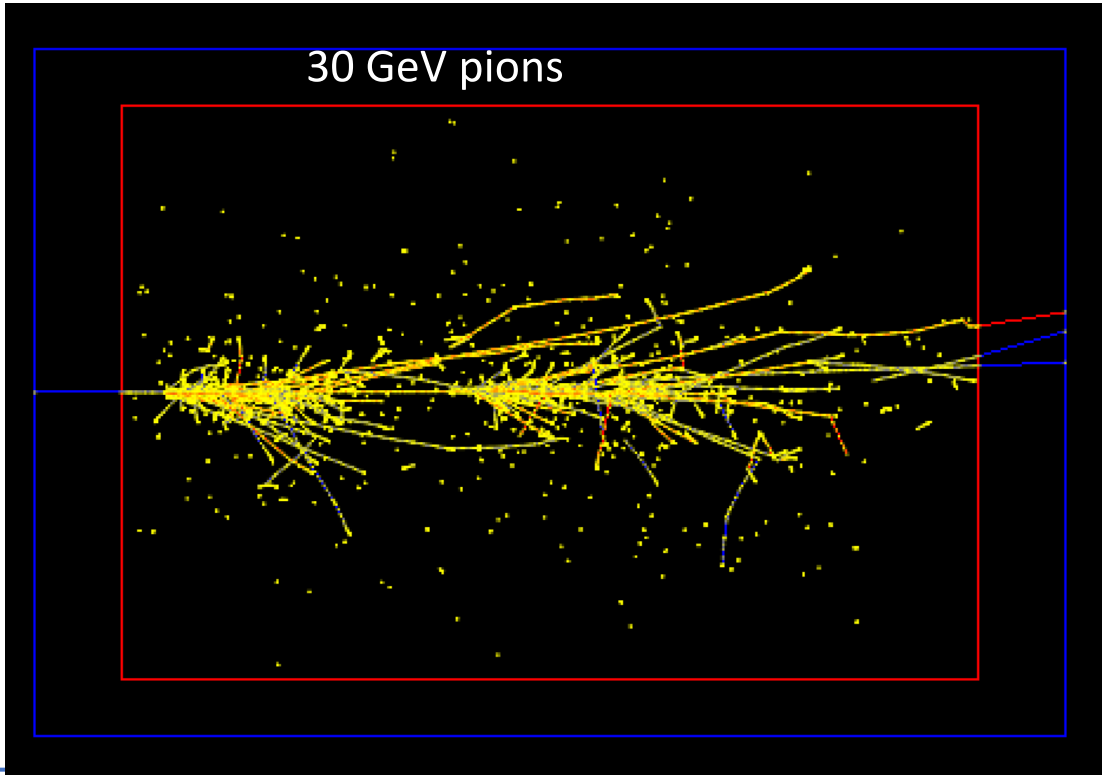


Standalone calorimeter setup (simulation)

- Copper / Silicon sampling calorimeter is simulated with GEANT4
  - Alternating Cu 17mm(absorber), Si 3mm (active) layers, with size of 1.0x1.0x1.5m^3
  - Readout granularity is cells of 2x2x2cm^3
  - Signal is integrated over 5ns with correction for the longitudinal propagation time.
  - Energy threshold of 0.6 MeV per cell is applied, with MIP MPV at about 1.0 MeV.
  - No electronics/noise is simulation



Energy per cell, MeV



Convolutional Neural Network model

- **Input1 (50,50,75) in X,Y, and Z with beam being along Z**
- *Conv3D: 64 kernels, 5x5x5, ReLU*
- *Conv3D: 32 kernels, 3x3x3, ReLU*
- MaxPool3D, 2x2x2
- *Conv3D: 32 kernels, 3x3x3, ReLU*
- *Conv3D: 32 kernels, 3x3x3, ReLU*
- MaxPool3D, 2x2x2
- *Conv3D: 32 kernels, 3x3x3, ReLU*
- *Conv3D: 6 kernels, 3x3x3, ReLU*
- MaxPool3D, 5x5x2
- *Flatten +* **Input2(simple energy sum over the calorimeter volume)**
- Dense layers: (256,ReLU), (128,ReLU), (32,ReLU,dropout=0.3)
- Output 1, linear

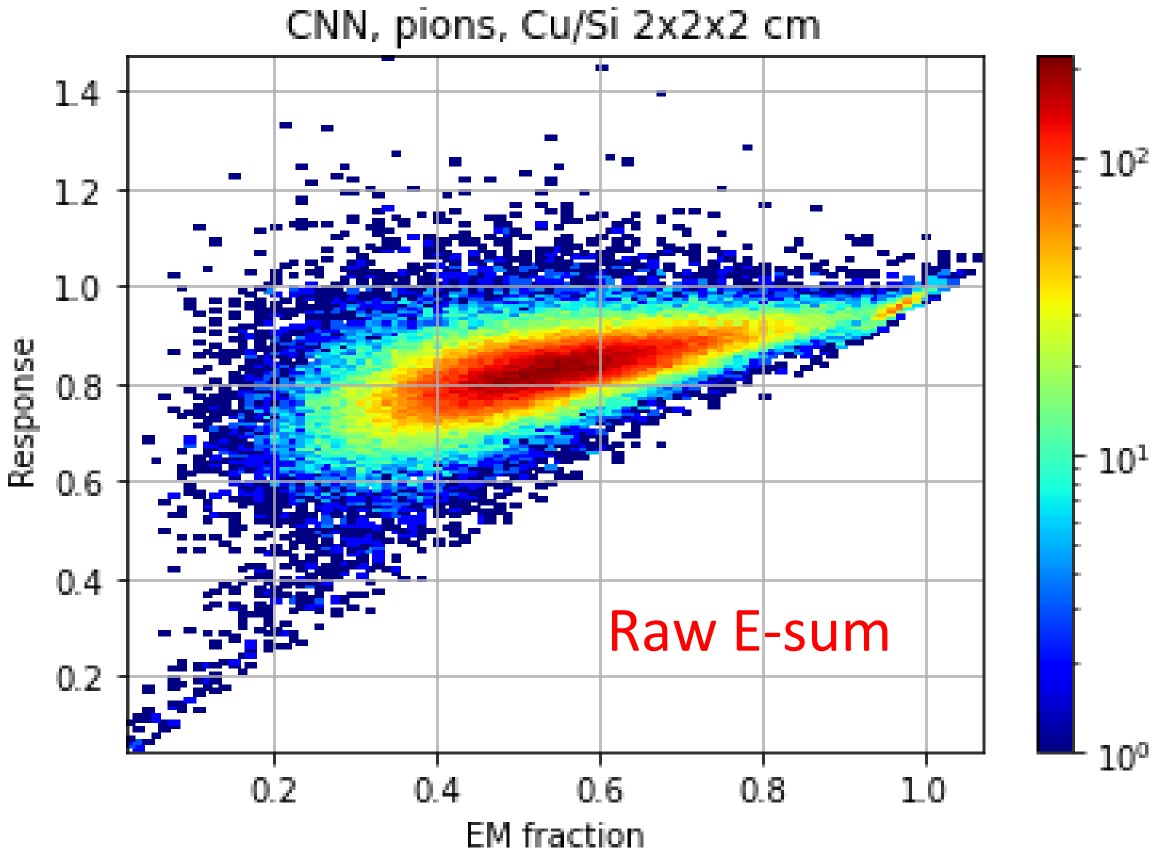
Loss function:
Mean squared logarithmic error

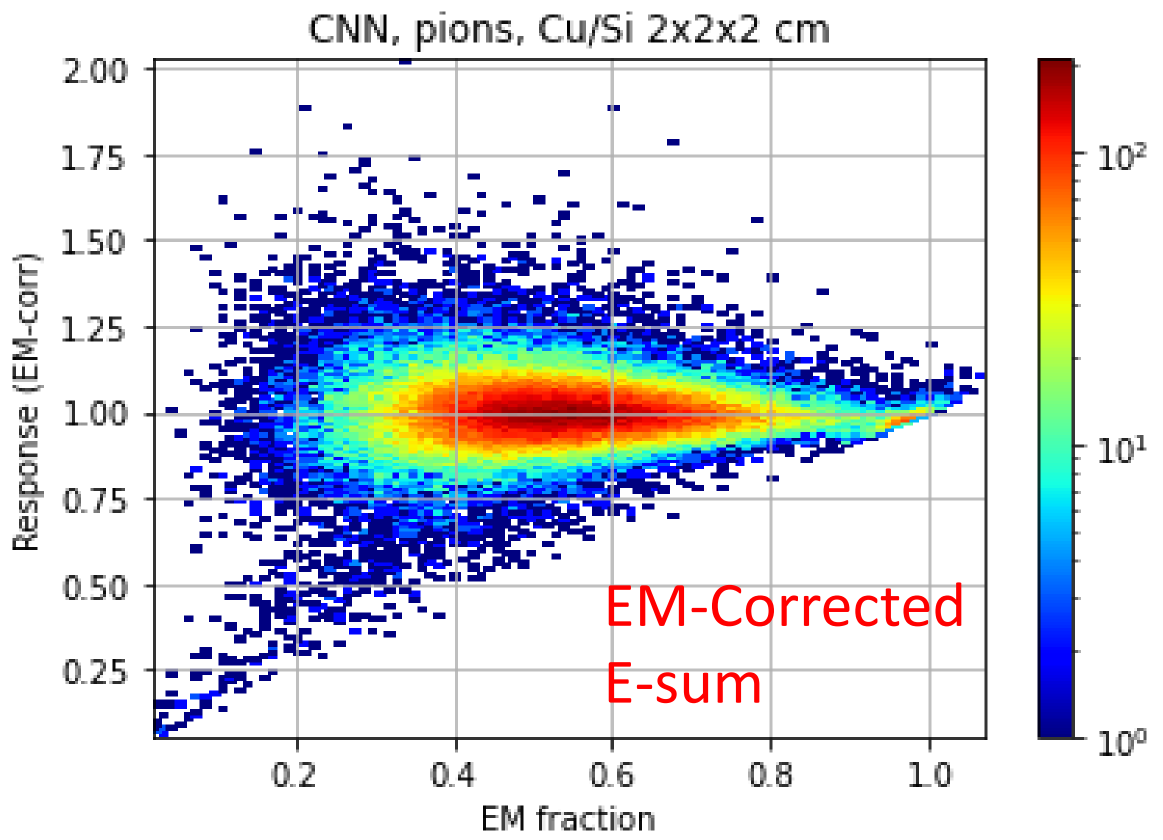
Trained on 800k single pions 0.5-150 GeV, validation on 100k, test 100-300k samples.

Energy reconstruction with more tradition techniques

The performance of the energy reconstruction with CNN is compared to:

1. Simple energy sum over all channels in the volume
2. Reconstruction with correction for the fluctuations in the EM-fraction

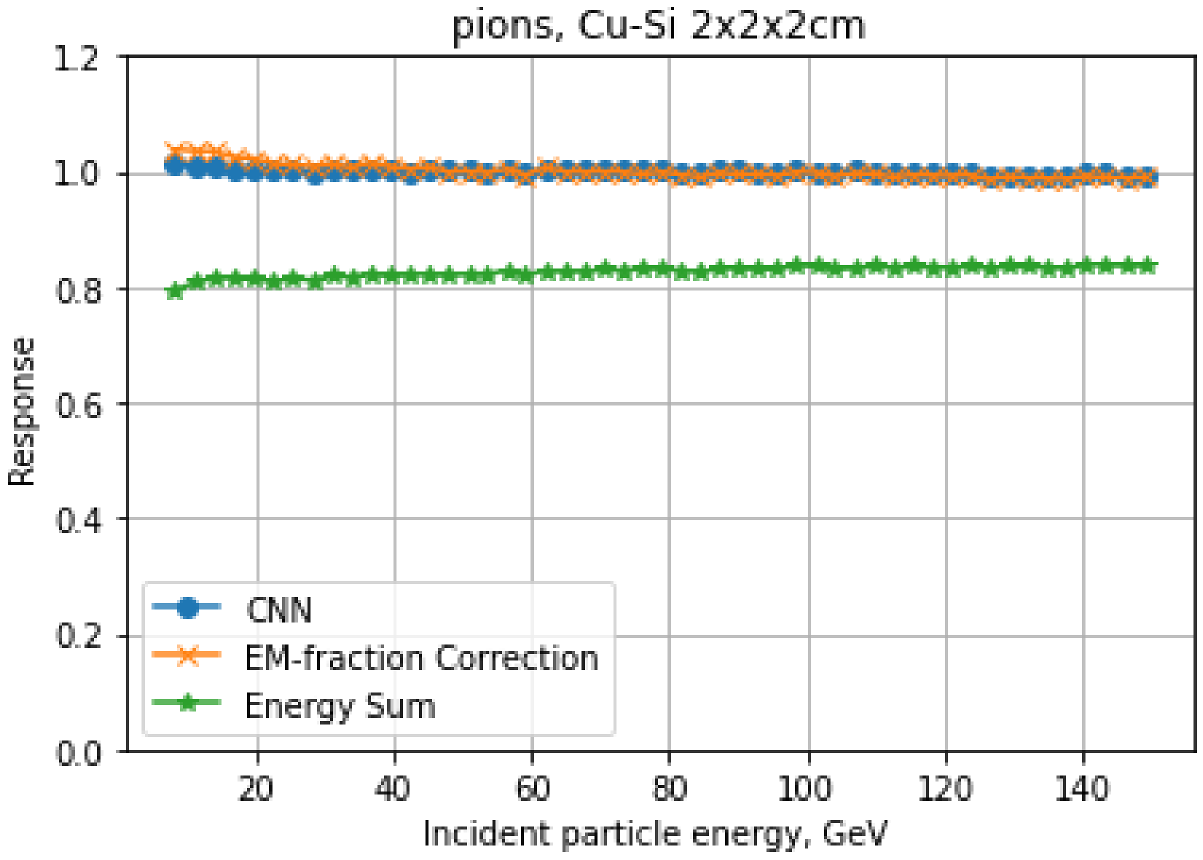


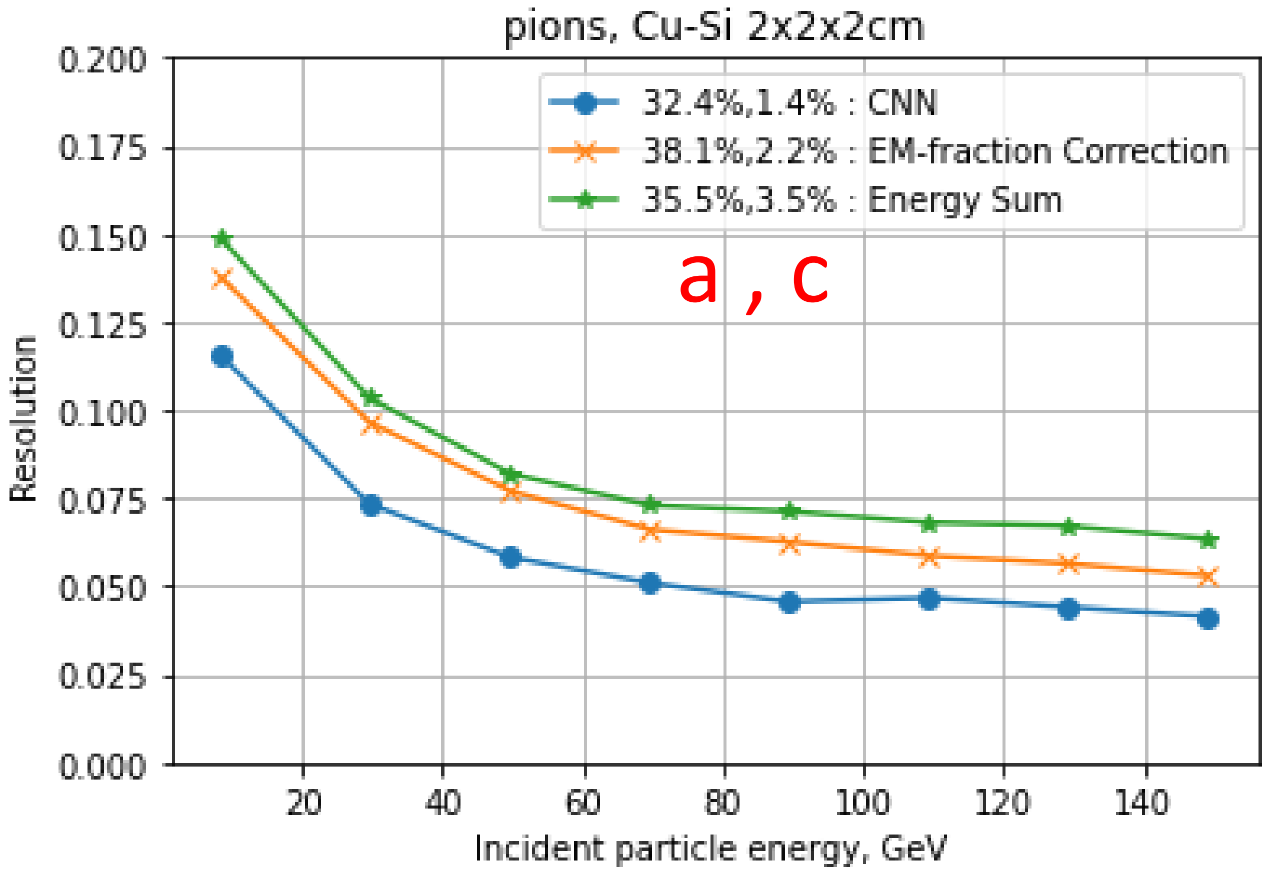


CNN performance – single hadron, Cu/Si

CNN trained with **single pions** outperforms other conventional methods for energy reconstruction.

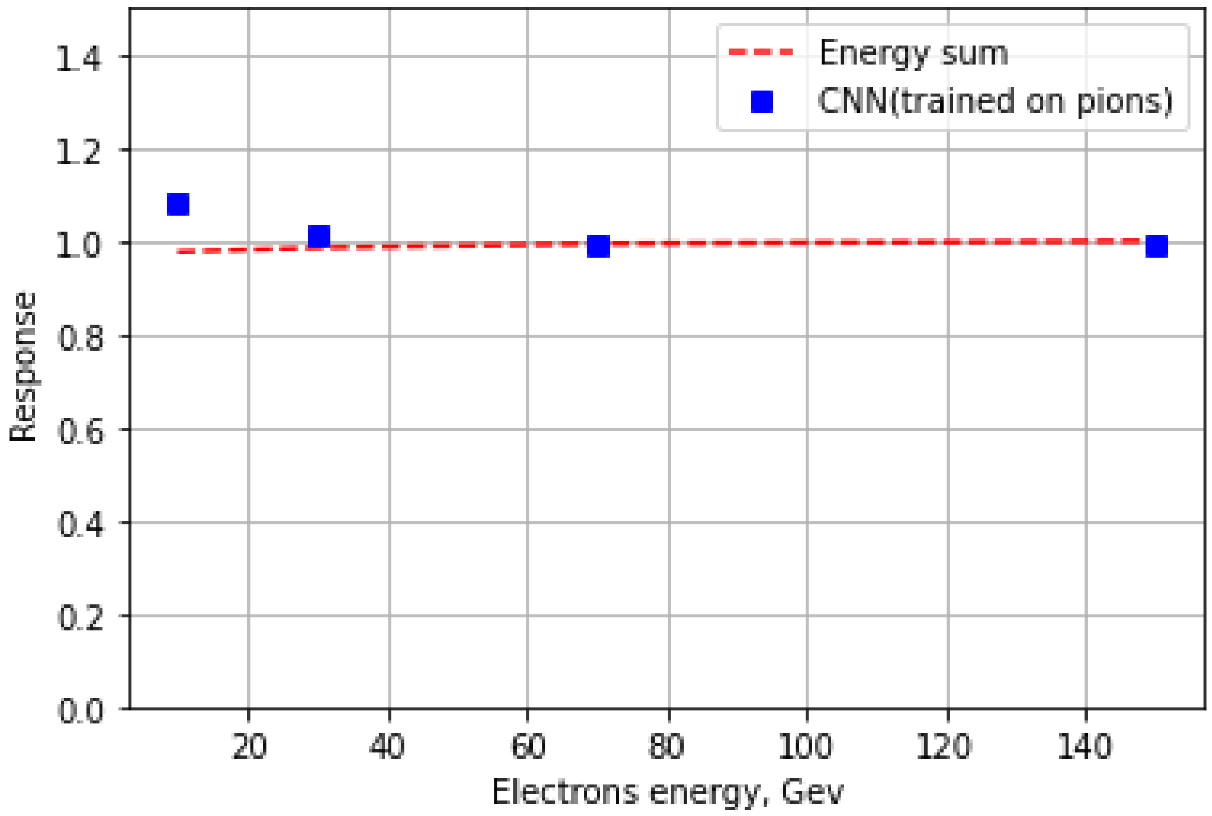
$$\frac{\sigma}{E} = \frac{a}{\sqrt{E}} \oplus c$$

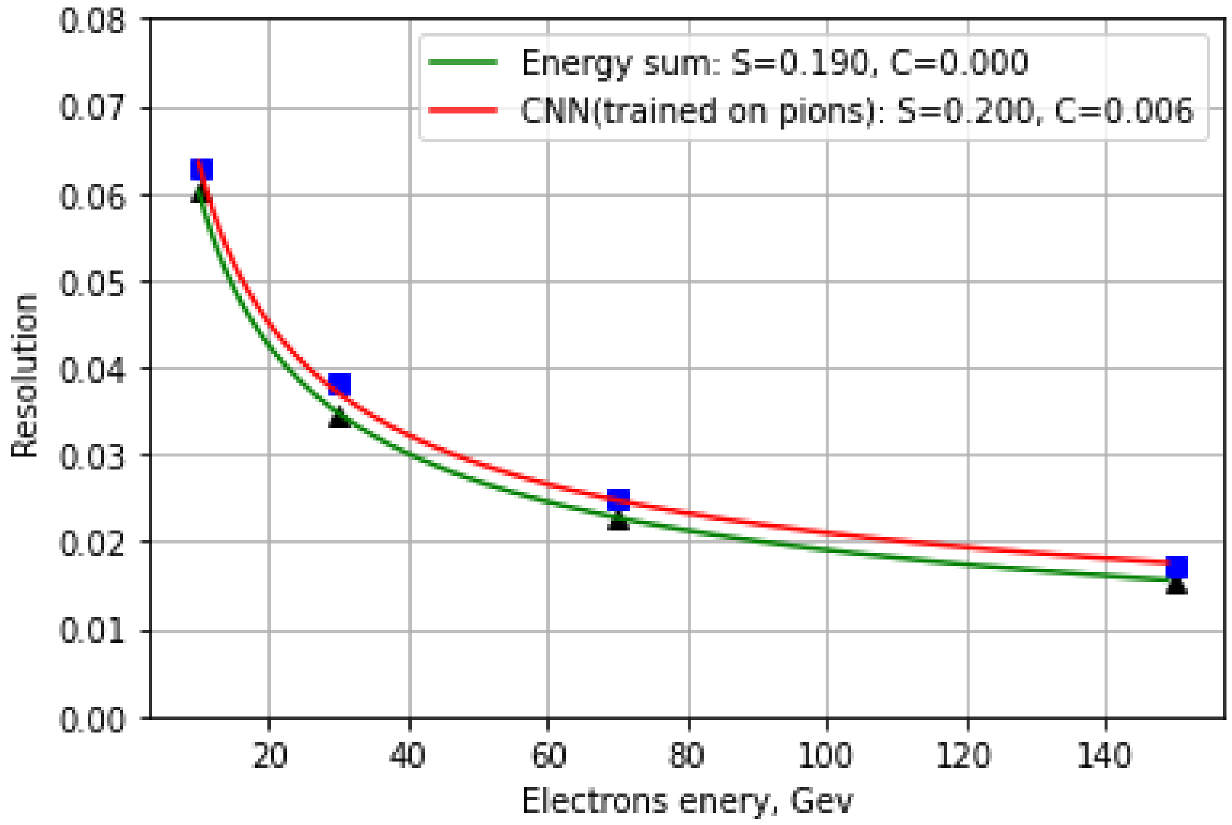




CNN test with electrons

Electron reconstruction with CNN ***trained on single pions***.

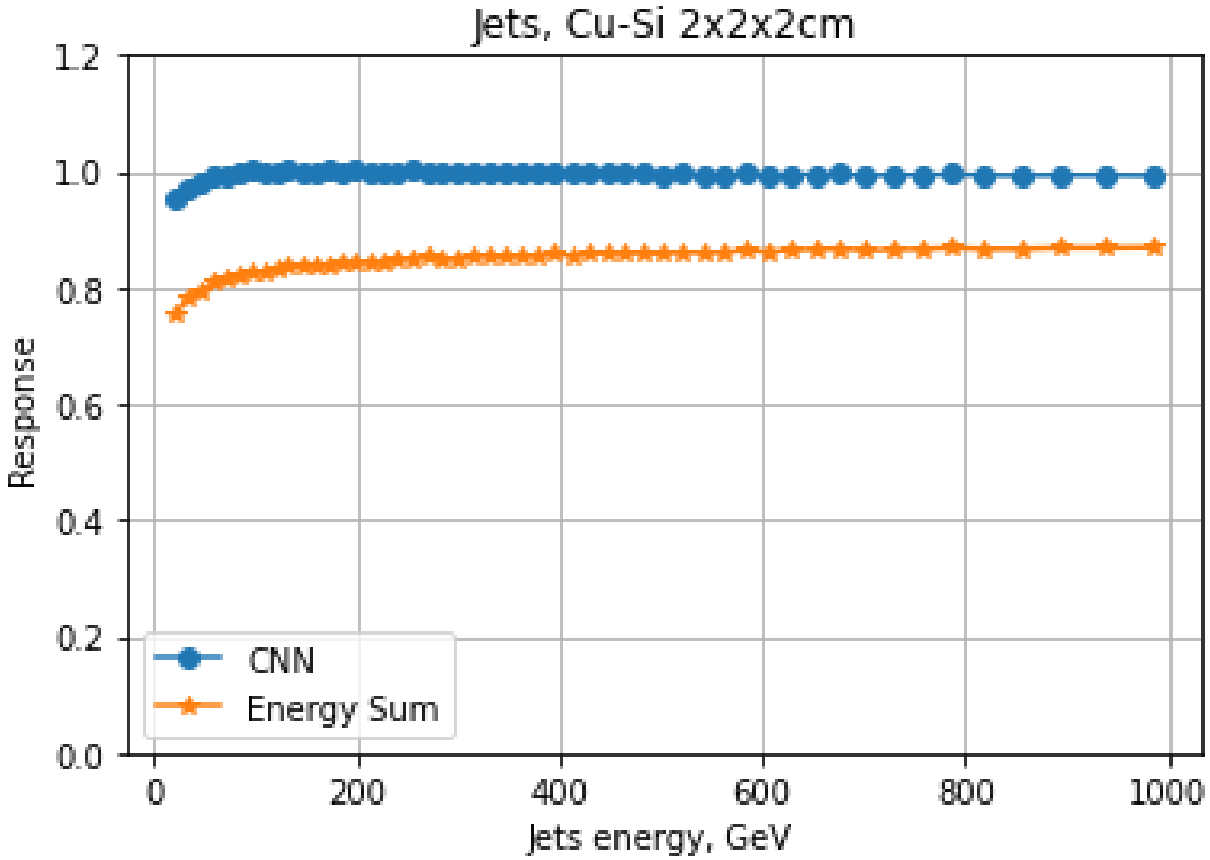


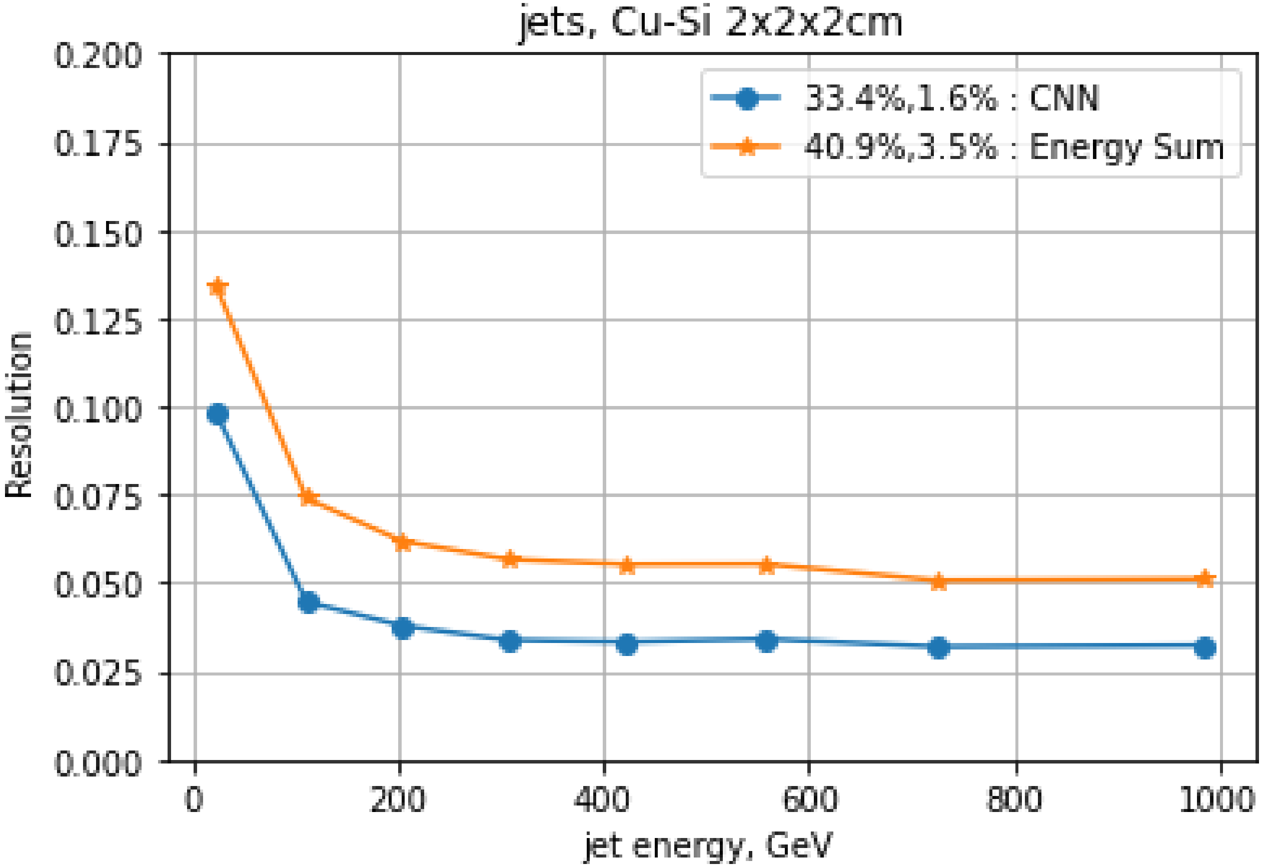


CNN maintains good performance for electrons reconstruction – comparable to the traditional technique.

CNN performance – multi-particle showers: jets

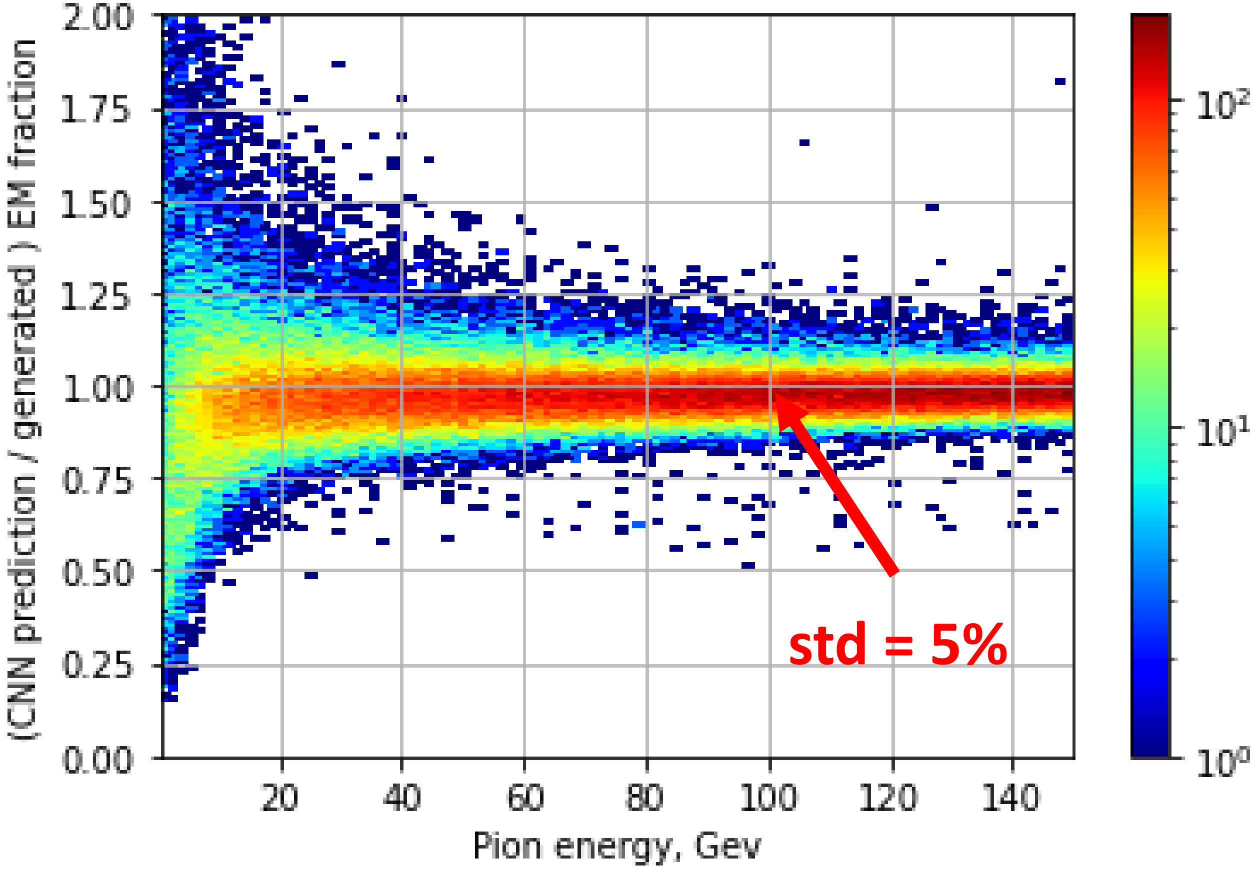
CNN trained on ***single pions*** (0.5-150 GeV) performs very well on **jet reconstruction** in extended energy range – up to 1 TeV

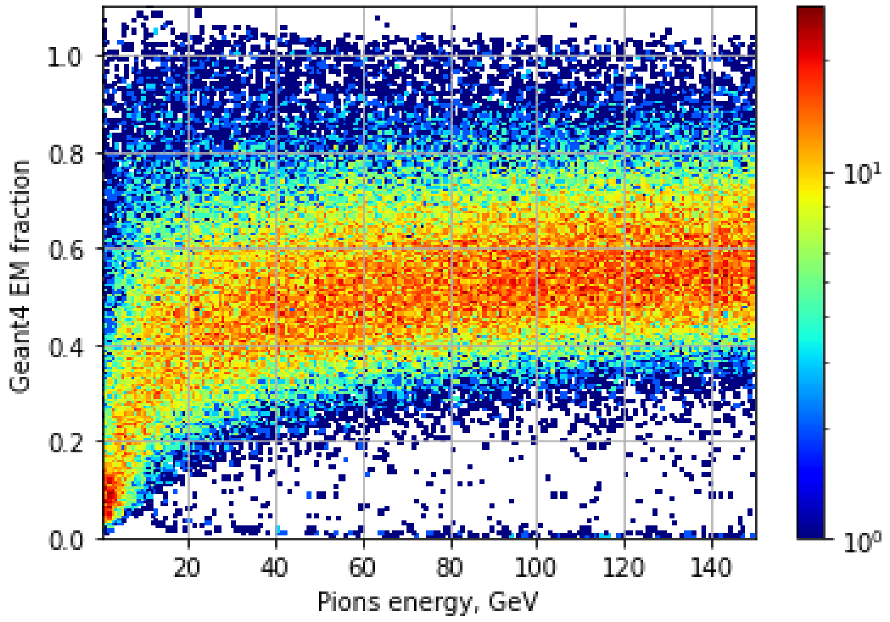


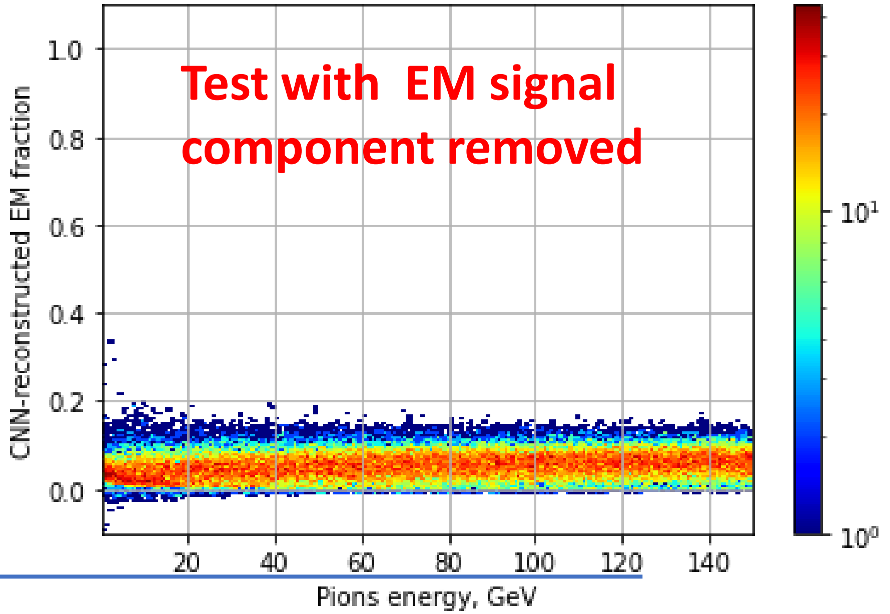


Reconstructing the EM fraction with CNN

CNN can also be trained to reconstruct the EM-fraction in the hadron showers



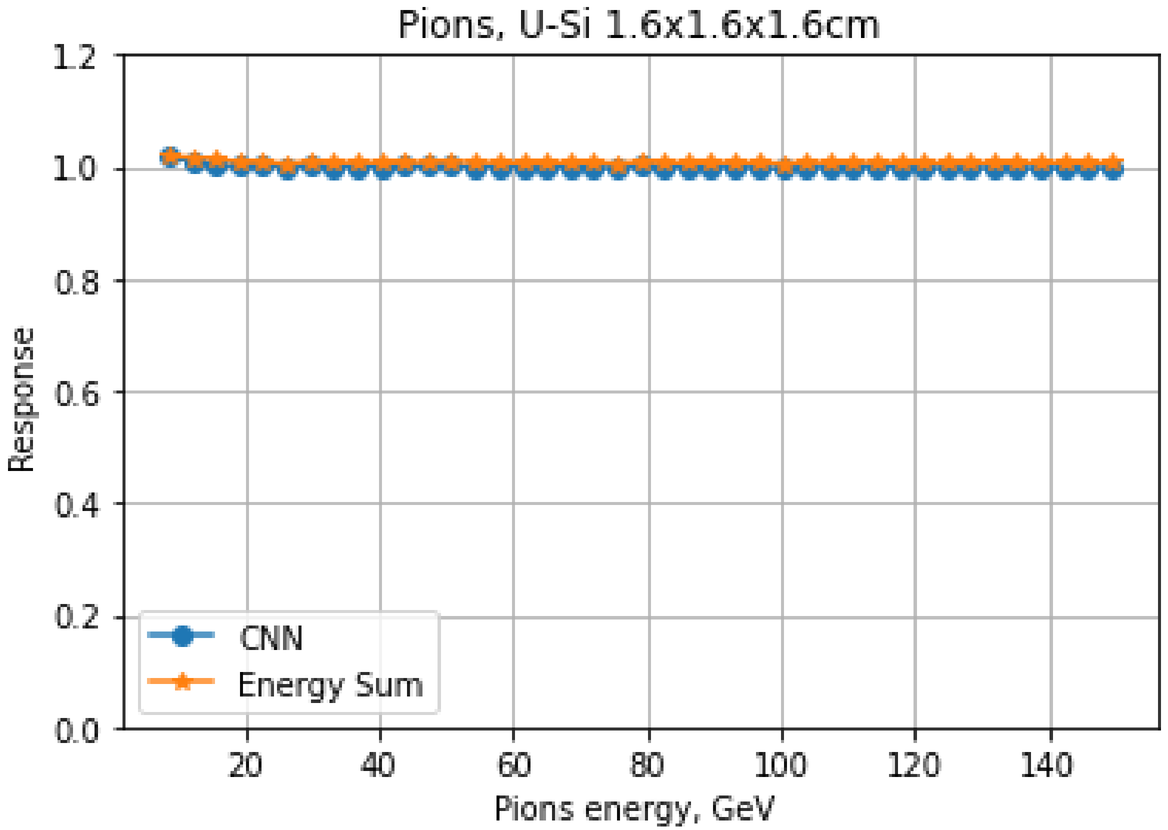


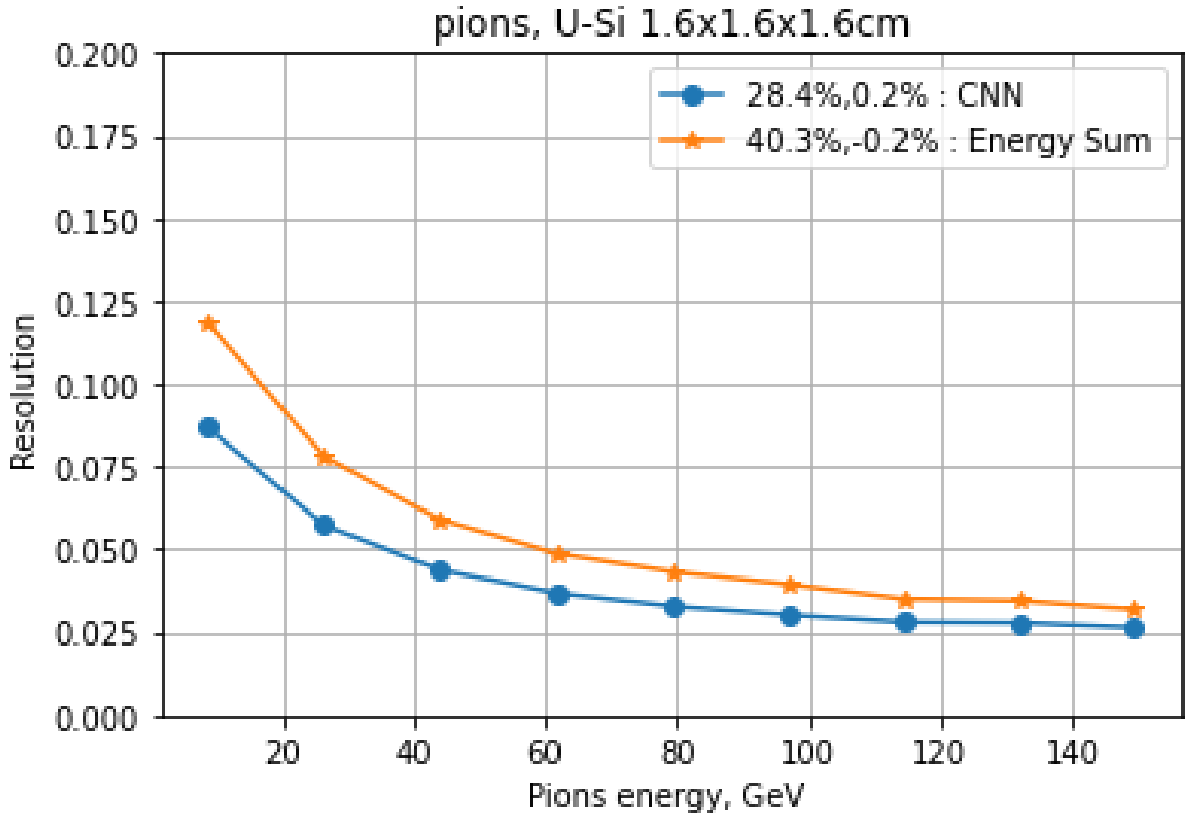


CNN performance – compensating calorimeter

Uranium – Silicon sampling calorimeter. U-3.3mm, Si-0.7mm

Signal is integrated in 5ns and the cells are combined in 1.6x1.6x1.6cm^3 channels for the CNN reconstruction. CNN is trained on single pions 0.5-150 GeV.





Depth segmentation with timing

- Fast timing gives opportunity to explore timing-based depth segmentation in fiber calorimeters.
- CNN-like energy reconstruction techniques may contribute for further improvement in performance, using the 3D image of the showers

FEATURES	AARDVARC V3 [1]
SAMPLE BUFFER	32 k
CHANNEL	4-8 CHANNEL
BANDWIDTH	2 GHZ ANALOG
TIMING RESOLUTION	4-8 ps
SAMPLE RATE	10-14 GSa/s

Recently developed ***Waveform Digitizer***

By NALU Scientific

Summary

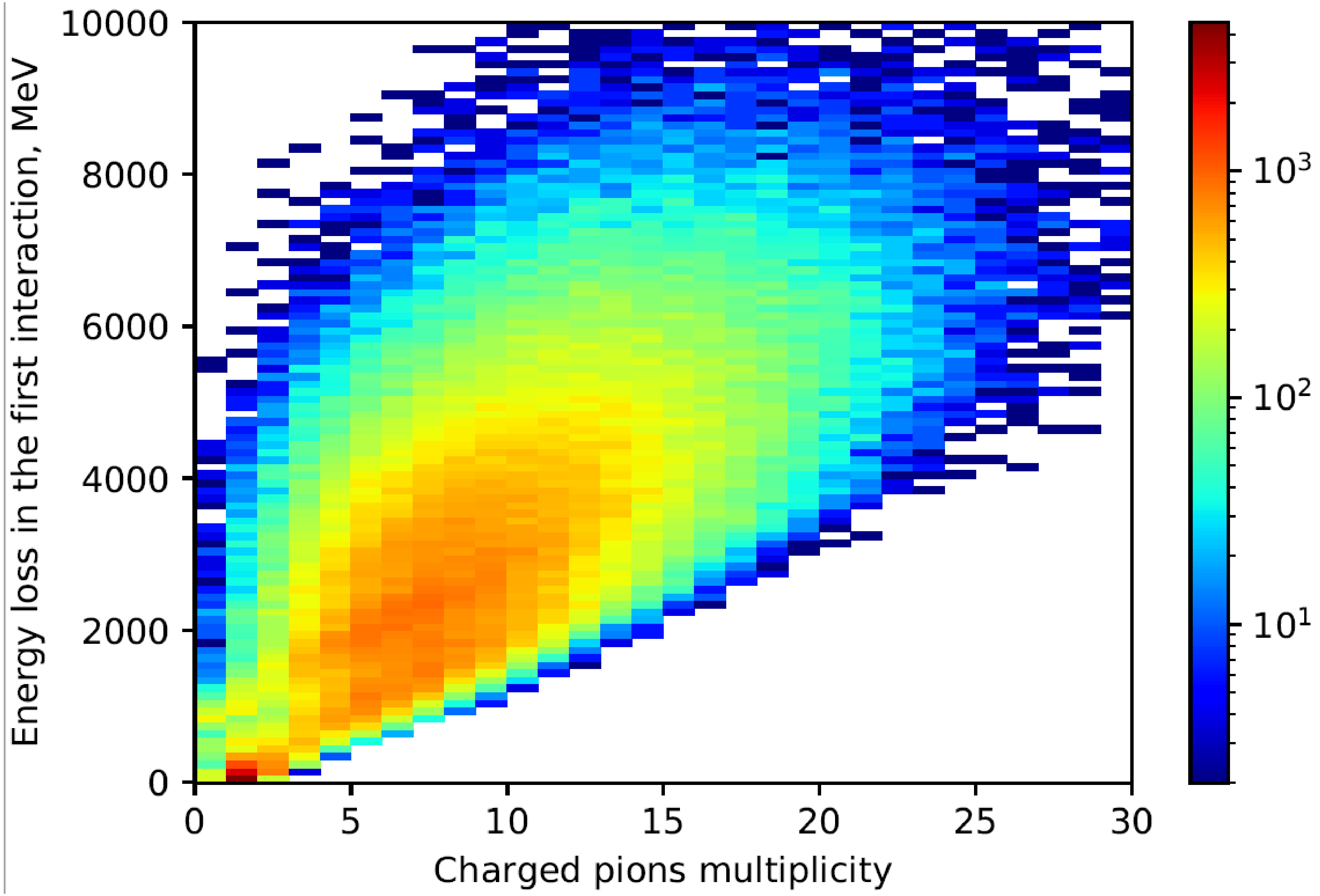
- We studied energy reconstruction in high granularity hadron calorimeters with Convolutional Nural Network (CNN)

- We achieved improved precision of the energy reconstruction beyond the reach of commonly used techniques
  - The CNN performance was demonstrated on **Ci/Si (non-compensating) and U/Si (compensating) calorimeters**, using GEANT4 simulation.
  - CNN trained on examples with simulated **single hadron showers** performs well in a broader range of energy reconstruction tasks and can reconstruct energy of the **multi-particle showers from jets** and **EM-showers from photons**
  - CNN based algorithm also correctly **reconstructs the electromagnetic component** in hadron showers

- *Looking to expand the study to fiber calorimeters with **time-based longitudinal segmentation***

BACKUP

Energy loss vs charged pion multiplicity



First hadronic interaction