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# Charged pion energy reconstruction in HGCAL TB prototype using graph neural networks

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**Abstract**

The CMS Collaboration is preparing to replace its endcap calorimeters for the HL-LHC era with a high-granularity calorimeter (HGCAL). The HGCAL will have fine segmentation in both the transverse and longitudinal directions, and will be the first such calorimeter specifically optimized for particle-flow reconstruction to operate at a colliding-beam experiment. The proposed design uses silicon sensors as active material in the regions of highest radiation and plastic scintillator tiles equipped with on-tile silicon photomultipliers (SiPMs), in the less-challenging regions. The unprecedented transverse and longitudinal segmentation facilitates particle identification, particle-flow reconstruction and pileup rejection.A prototype of the silicon-based electromagnetic and hadronic sections along a section of the CALICE AHCAL prototype was exposed to muons, electrons and charged pions in beam test experiments at the H2 beamline at the CERN SPS in October 2018 to study the performance of the detector and its readout electronic components. Given the complex nature of hadronic showers, energy reconstruction is expected to benefit from detailed information of energy deposits and its spatial distribution of the individual showers in the detector, which can be well utilized by advanced machine learning algorithms. Here we present reconstruction of hadronic showers created by charged pions of momenta 20-300 GeV using a dynamic reduction network (DRN) based on graph neural networks (GNNs).

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# Charged pion energy reconstruction in HGCAL TB prototype using graph neural networks

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**Abstract**

The CMS Collaboration is preparing to replace its endcap calorimeters for the HL–LHC era with a high-granularity calorimeter (HGCAL). The HGCAL will have fine segmentation in both the transverse and longitudinal directions, and will be the first such calorimeter specifically optimized for particle-flow reconstruction to operate at a colliding-beam experiment. The proposed design uses silicon sensors as active material in the regions of highest radiation and plastic scintillator tiles equipped with on-tile silicon photomultipliers (SiPMs), in the less-challenging regions. The unprecedented transverse and longitudinal segmentation facilitates particle identification, particle-flow reconstruction and pileup rejection. A prototype of the silicon-based electromagnetic and hadronic sections along a section of the CALICE AHCAL prototype was exposed to muons, electrons and charged pions in beam test experiments at the H2 beamline at the CERN SPS in October 2018 to study the performance of the detector and its readout electronic components. Given the complex nature of hadronic showers, energy reconstruction is expected to benefit from detailed information of energy deposits and its spatial distribution of the individual showers in the detector, which can be well utilized by advanced machine learning algorithms. Here we present reconstruction of hadronic showers created by charged pions of momenta 20-300 GeV using a dynamic reduction network (DRN) based on graph neural networks (GNNs).

# 1 Introduction

In the high luminosity LHC (HL–LHC) phase, starting end of the decade, the Large Hadron Collider (LHC) at CERN, Geneva will operate at the instantaneous luminosity of around $5 \times 10^{34}\text{cm}^{-2}\ \text{s}^{-1}$ to $7.5 \times 10^{34}\text{cm}^{-2}\ \text{s}^{-1}$. To withstand the high radiation exposure and pileup conditions, the CMS experiment [1] is replacing its endcap calorimeters with a high granularity sampling calorimeter called HGCAL [2] based on silicon sensors and scintillator tiles directly readout by SiPMs for the active media with very fine transverse and longitudinal granularity. A prototype HGCAL detector setup comprised of Si-based electromagnetic (CE–E) and a hadronic (CE–H) sections [3] followed by scintillator-tile based CALICE AHCAL [4] was exposed to $e^+$ and $\pi^-$ beams of energies ranging from 20–300 GeV.

# 2 Energy reconstruction of charged pions showers

The resolution (response) is defined as $\sigma/\mu$ ($\mu/E_{True}$) of a Gaussian function fitted to the distribution of the reconstructed energy at a given incident energy. Two methods to reconstruct pion energies are compared. A $\chi^2$–method [5] has been used to combine the energy measured in CE–E, CE–H, and AHCAL using scale factors that minimize the resolution. A dynamic reduction network (DRN) [6] based on a graph representation of data was trained with a list of energies along with their x, y, and z positions of reconstructed hits (rechits) as input and $E_{true}/E_{raw}$ as a target, where $E_{true}$ was pion true energy and $E_{raw}$ is total energy measured in three sections. More details are documented in [7]. Figure 1 (left) shows the distribution of energy reconstructed in data and simulation for 200 GeV pions. Comparison of resolution using $\chi^2$ and DRN in data and simulation are presented in figure 1 (middle). The performance of the DRN trained on simulation is reproduced in the data. We observe an improvement by a factor of two in energy resolution using DRN for all the energies compared to that obtained using the $\chi^2$-method. A comparison of the performance of three DRNs using rechit energies (DRN (E)), including longitudinal positions (DRN (E,z)) and transverse positions (DRN (E,x,y,z)) of rechits is shown in figure 1 (right).

To summarize, we presented the performance of HGCAL prototype detector to charged pions in the beam test experiments carried out in 2018 at CERN H2 beamline area. The DRN is able to learn the complex structure of hadron showers with the highly granular information provided by the HGCAL, and results in improved resolution unforeseen in previous hadron calorimeters. A journal publication documenting the detailed studies corresponding to the results presented in this note is under preparation.

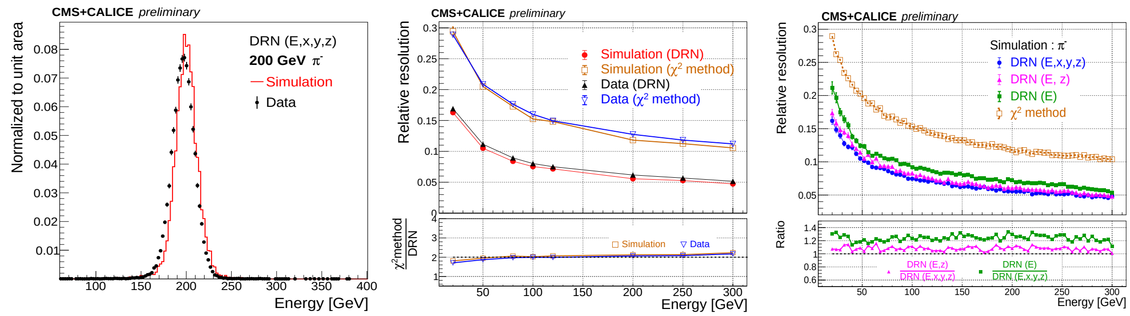


Figure 1: Distribution of reconstructed energy for 200 GeV $\pi^-$ using DRN in data and simulation (left), energy resolution as a function of beam energy using $\chi^2$ and DRN methods (middle), and comparisons of resolution obtained using DRNs trained with different input features (right).

# References


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