CaloX – Extreme Calorimetry

Nural Akchurin, Chris Cowden, Jordan Damgov, and Shuichi Kunori
Texas Tech University

We explore ways of taking advantage of advances in image processing algorithms in high-energy calorimetry. This Letter of Interest (LoI) provides highlights from one of our recent feasibility studies and serves as the beginning of a potential roadmap for future studies.

The development of showers in materials is complex: the choices we make determine the precision with which shower energy and its spatial and temporal distributions are reconstructed. For example, a coarsely segmented calorimeter might be simple to calibrate, operate, and used to achieve a reasonable energy resolution and response linearity, but it may be unable to say much about the finer features of a shower that is rich in information. It is precisely this information and correlations within it that we aim to better characterize.

With this LoI, we propose exploring the benefits of extreme calorimetry, in which every interaction is simulated and the showers are analyzed with image-analysis algorithms in a highly segmented calorimeter. If properly designed, high granularity calorimeters can offer spatially and temporally detailed pictures of hadronic showers. These details can be used to improve the energy measurement over the existing reconstruction techniques in that they reveal the energy-space attributes of a shower. A class of computer vision algorithms are able to extract valuable high-level properties of a shower from the raw signals on an event-by-event basis and improve reconstruction performance in a wide range of em and hadronic interactions.

As a demonstration case, a sampling calorimeter with 17-mm thick copper (absorber) plates interleaved with 3 mm silicon (active) was simulated. The granularity of the calorimeter was set to $2\times2\times2$ cm^3, which is slightly larger than the radiation length of the copper. This calorimeter was intrinsically undercompensating.

We trained a shallow Convolutional Neural Network (CNN) to perform energy reconstruction using the deposited energy in individual cells. The CNN architecture included 6 convolutional and 3 fully connected layers. The training was accomplished by a large (800,000 events) data sample of π^+ in the range of 0.5-150 GeV. The CNN-based energy reconstruction was compared to two traditional methods: a simple energy sum and another technique, akin to dual-readout, in which the EM fraction, $f_{em,}$ information of the deposited energy is used. In addition to better energy reconstruction, the CNN-based method also provided response linearity within 1% from 5 to 150 GeV. The energy resolution was also good: a stochastic(constant) term of 32(1.4) %. For the method with a correction based on the $f_{em,}$ the energy resolution was 38(2.2) %, and the simple energy sum technique resulted in 35.5(3.5) %.

The CNN-based reconstruction algorithm trained with single hadrons also showed very good performance for jets and electrons. This suggests that to a large degree, the CNN correctly identifies and utilizes the local features (e.g. f_{em} and f_{had}) of the shower. The linearity was consistent with unity ($\pm$1%) for jets within a larger momentum range of 50-1,000 GeV (Figure

1.a), and the energy resolution (Figure 1.b) was at least as good as it was for single hadrons using the same method of reconstruction. We are in the process of evaluating the potential benefits of precision time measurement that is an additional feature to augment traditional reconstruction methods as well as the CNN-based approach described above.

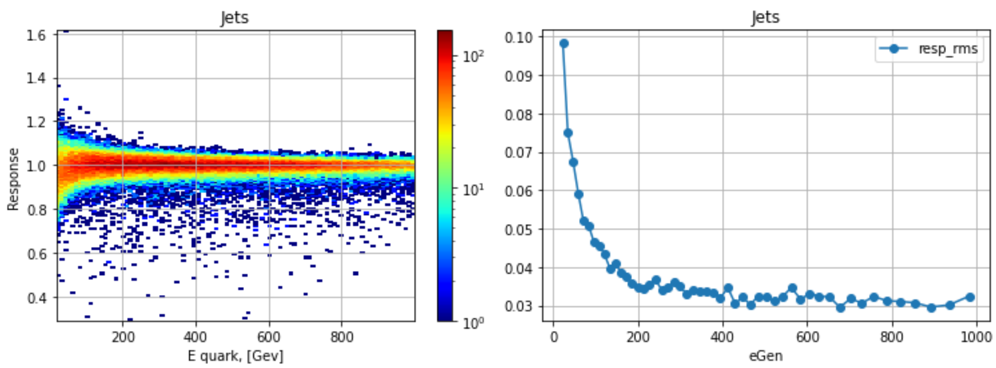

Figure 1. The response (a) and the energy resolution (b) for jets from a CNN-based reconstruction algorithm using the single hadron training sample.

We intend to further analyze practical application and adoption of these advanced methodologies by exploring their implementation in a large volume (realistic) detector with non-uniform cell geometries. Although reconstructed energy resolution is our primary goal, in our analysis we adopt jet-mass reconstruction as a secondary target since jet-mass is an important feature of boosted objects in high energy colliders. We also intend to study the impact of mis-calibration on the CNN performance as well as develop and study some potential calibration techniques.

We invite interested colleagues to join us in developing a comprehensive program to realize the next generation calorimeters for future experiments. Contacts are nural.akchurin@ttu.edu, chris.cowden@gmail.com, jordan.damgov@ttu.edu, and shuichi.kunori@ttu.edu.