Improving High-Energy Particle Detectors with Machine Learning

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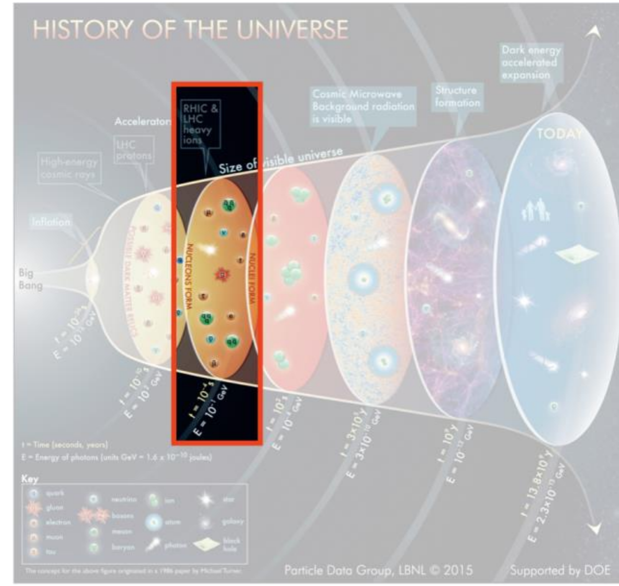
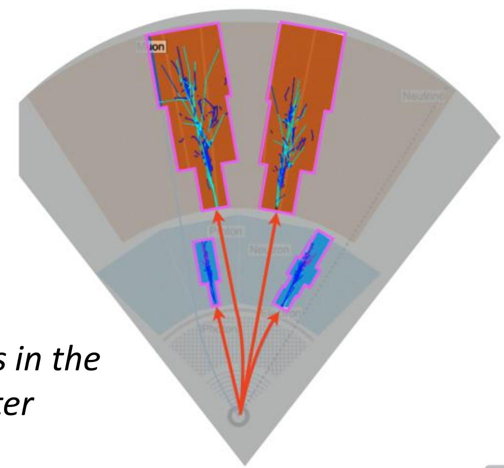
Motivations and Objectives

- What did the universe look like after the Big Bang?
  - Quark-gluon plasma (QGP) microseconds after the Big Bang
- Use heavy ion collisions at the LHC to recreate QGP and study its properties
  - QGP produces thousands of particles, and we record energy deposition of these particles in the calorimeter system
- Want to reconstruct particles from the energy deposition
  - 1. classify the particles correctly
  - 2. recalibrate deposited energy to the true energy
- Objective: Use techniques from machine learning to improve reconstruction of particles
  - Treat energy deposition like a 3D image

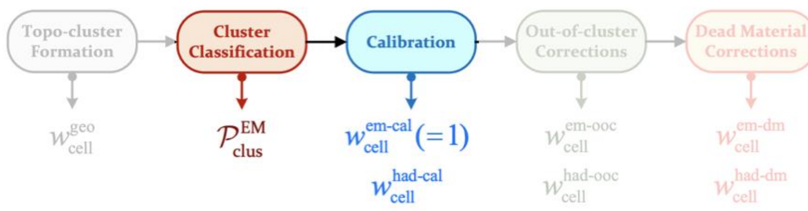




Particle showers in the ATLAS calorimeter

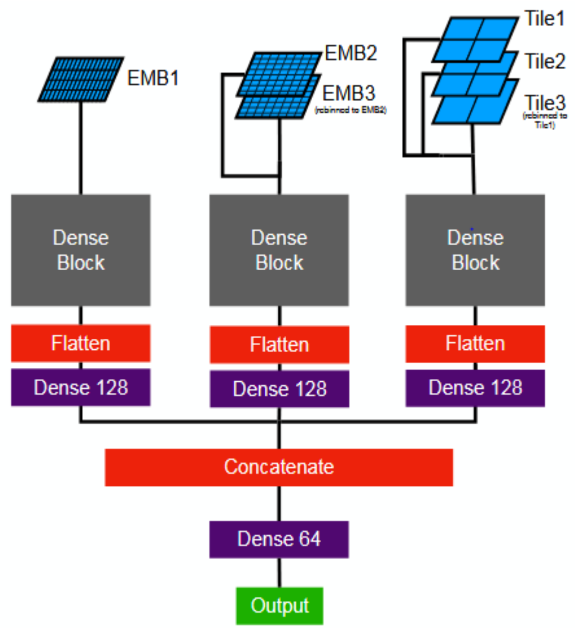
Methods

- Form “topoclusters” from cells (pixels) in the calorimeter
  - Find the cluster energy
- Classify whether the cluster comes from an electromagnetic or hadronic shower
- Calibrate cluster energy (regression)
- <u>Current method</u>: uses hand-picked properties of clusters for classification and calibration
  - Uses “local cell weighting” (LCW) for calibration
- <u>New method</u>: use DenseNet neural network for classification and regression
  - Treat energy deposition as 3D image
- <u>Goal</u>: Apply classification and regression in succession to correctly calibrate the energy of particles produced by a nuclear collision



Sequence of calibration steps.

Ref: Eur. Phys. J. C 77 (2017) 490

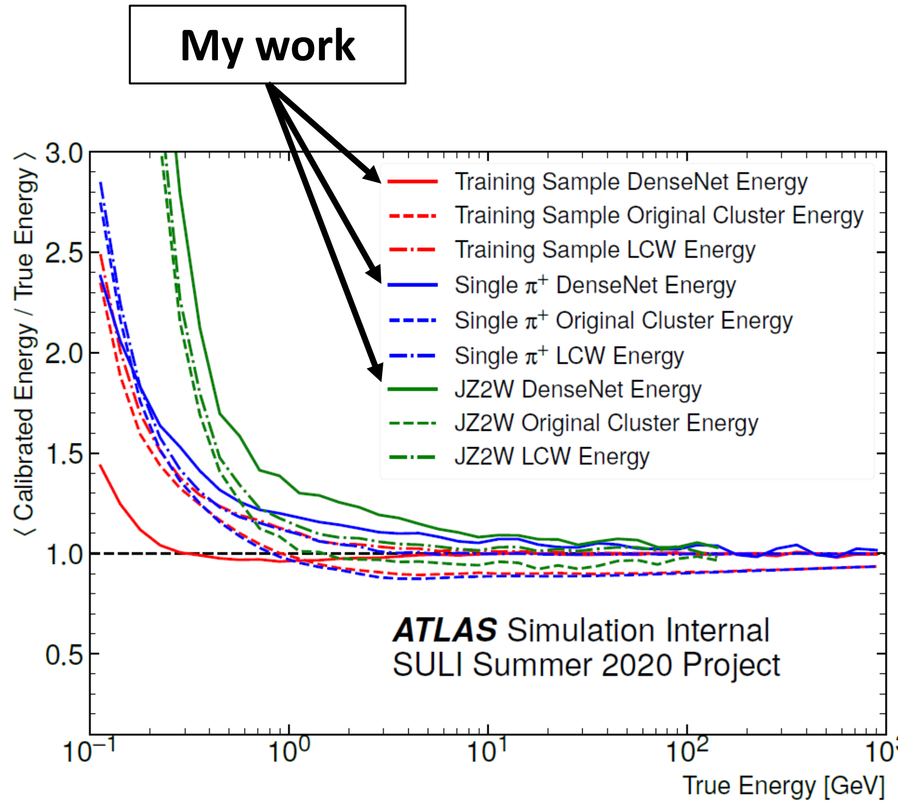


Sketch of DenseNet neural network.

Ref: ATL-PHYS-PUB-2020-018, https://cds.cern.ch/record/2724632

Results and Conclusions

- Trained classification and regression with 5-fold validation
  - Large improvement in calibrated energy compared to LCW
- Used trained calibration models to predict calibrated energies for new data sets
  - The training sample is idealized, whereas the single π^+ and JZ2W samples are affected differently by noise
  - Also, the JZ2W sample contains multiple types of particles
- <u>Conclusion</u>: The model still predicts relatively well even though the training sample doesn't include complex effects
- <u>Next step</u>: try to properly account for these effects



The ratio between the calibrated and true energy, as a function of true energy.

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