Identifying mass composition of ultra high energy cosmic rays using deep learning

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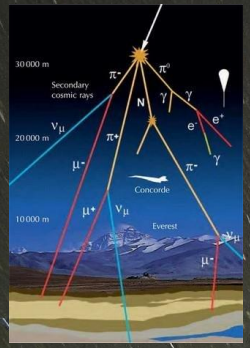
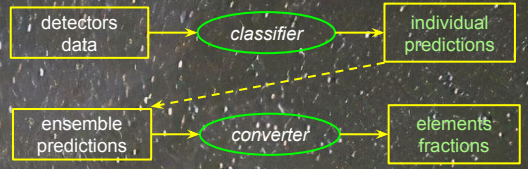


Goal: identify mass composition of ultra-high-energy cosmic rays

Problem: Air showers, initiated by cosmic rays, are *highly stochastic*. Hence very difficult to identify primary particle.

Solution: use two neural networks:
1) predict primary particles for individual events
2) estimate mass composition for ensembles of events based on the inference of the first nn

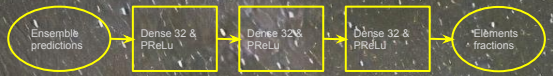


Telescope Array Surface Detector (covers ~700km^2, 1.2km spacing of detectors)

The method is general:
if individual events are subject to high variability, introduce a chain of two neural networks for obtaining accurate predictions for ensembles of events.

Classifier: individual predictions

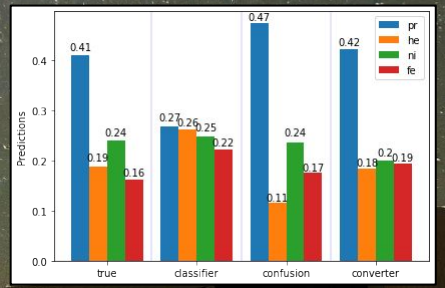
Converter: ensemble predictions



Data: Monte-Carlo simulation for TA SD with 4 primary particles: protons, helium, nitrogen, and iron; QGSJET-II-3 hadronic interaction model.

Classifier: has 4 blocks, responsible for analyzing different kinds of data.

Converter: trained on 10 000 ensembles of 5 000 events.
Input - averaged predictions of the classifier for the ensemble and their dispersion.
Output - fractions of elements in ensemble.



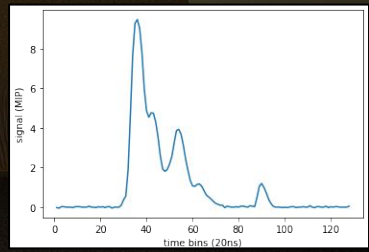
Example of predictions obtained by different methods

Each detector has 2 layers of 1.2cm thick plastic scintillator. Real-time calibration.

To improve accuracy, train in 2 steps:
1) on all events
2) in specific energy bin

energy bin, log scale	18-18.25	18-18.25	18-18.25	18-18.25	18-18.25
Averaged MAE	0.072	0.053	0.048	0.043	0.038

MAE between true and reconstructed fractions of elements, averaged over the elements for different energy bins.



Detector's reading reduced to 128 time bins.