Deep Learning for Event Classification with CTA

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Fermi Summer School
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Cherenkov Telescope Array (CTA)

The next-generation Imaging Air Cherenkov Telescope (IACT) array

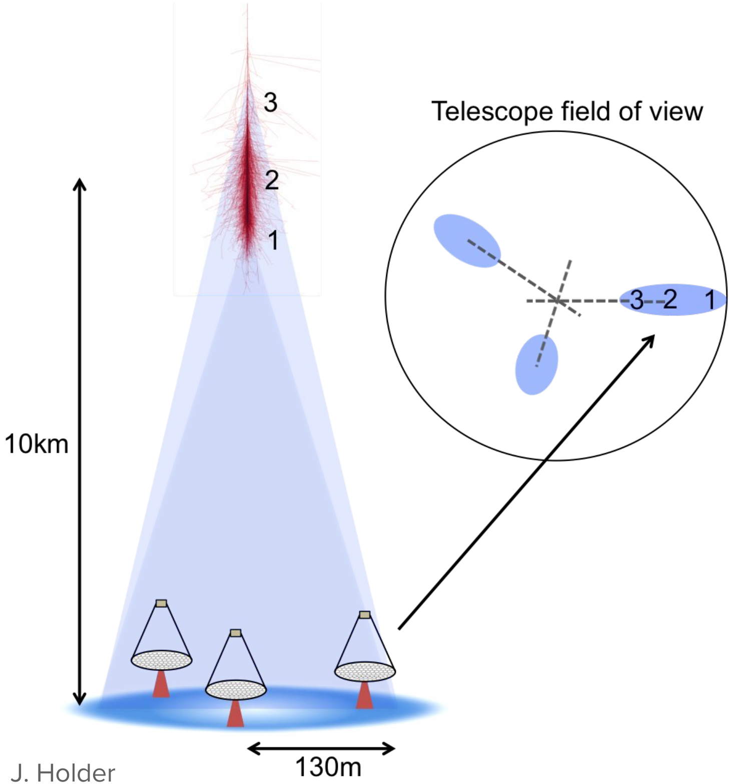
Small, Medium, and Large Size Telescopes

CTA North: La Palma, Canary Islands, Spain

CTA South: Paranal, Atacama Desert, Chile

Operations planned to start in 2020s

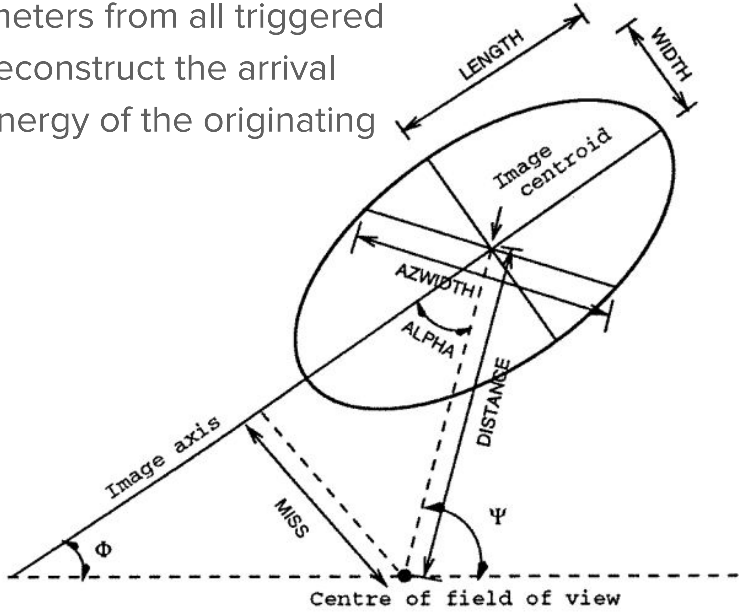
IACT Event Reconstruction

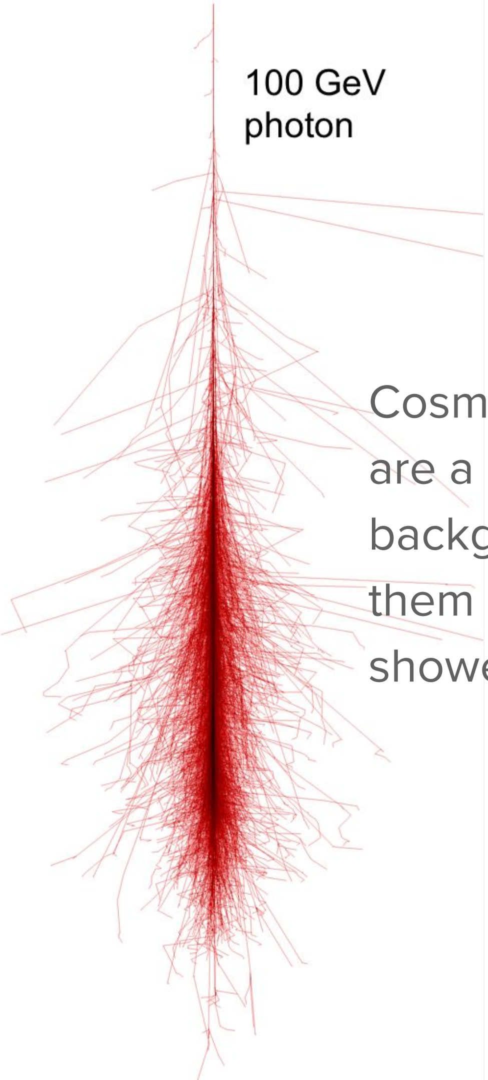


J. Holder

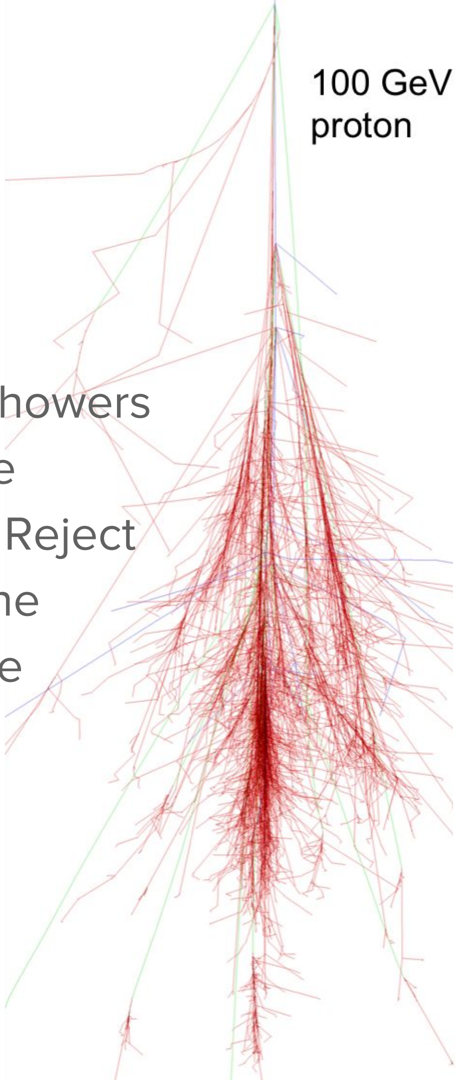
Model each shower image as an ellipse and parametrize by its moments

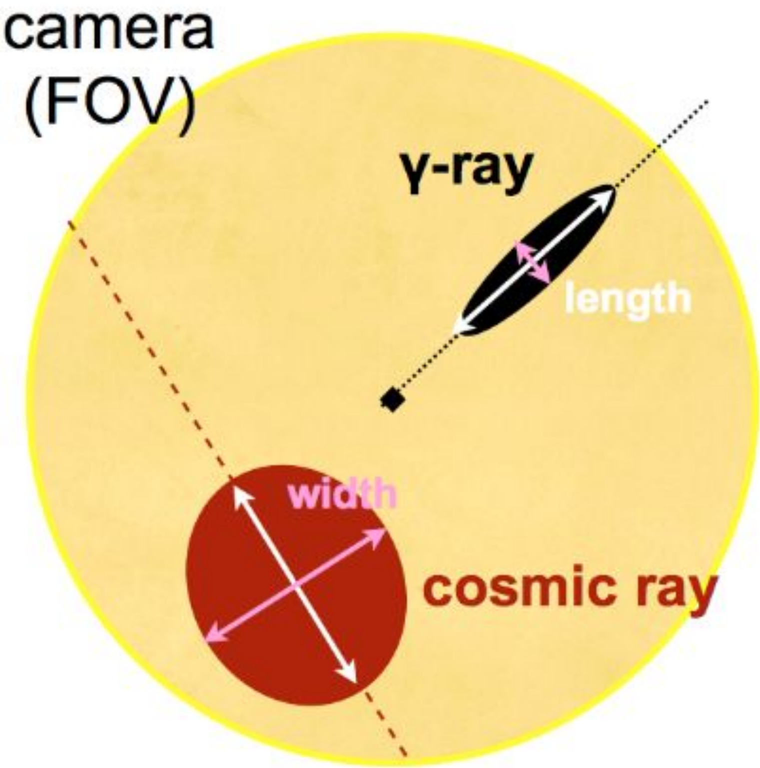
Combine parameters from all triggered telescopes to reconstruct the arrival direction and energy of the originating gamma ray





Cosmic-ray showers are a massive background! Reject them using the shower shape





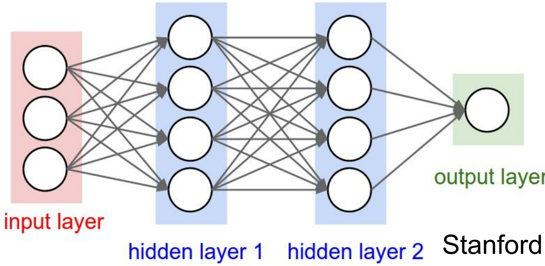
M. Santander

Deep Learning

Convolutional Neural Network (CNN): machine learning technique that can directly classify camera images, with no explicit intermediate parameterization

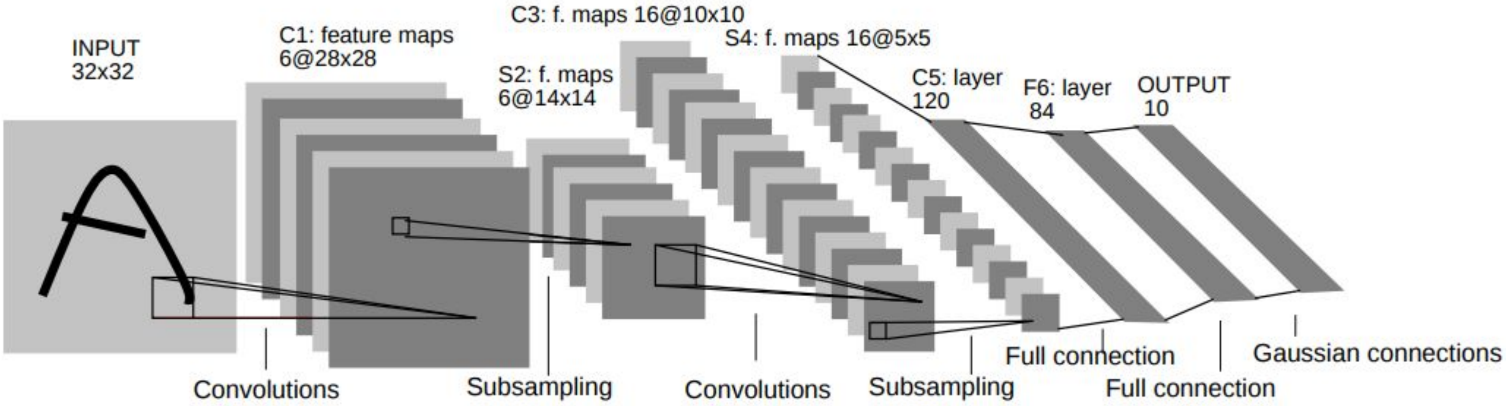
Needs lots of training data and parallel processing using graphics cards (~10x speedup)

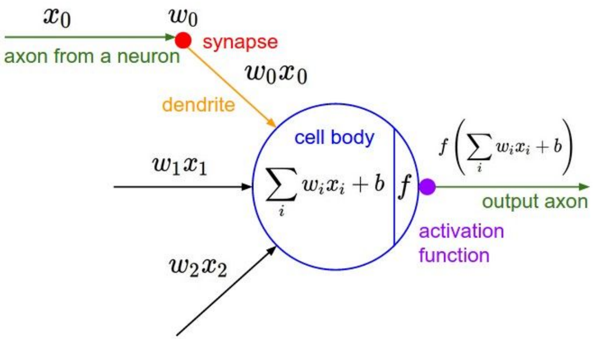
CNNs have been used to classify gamma-ray and muon images (HESS, VERITAS) and are currently being studied by many groups in CTA

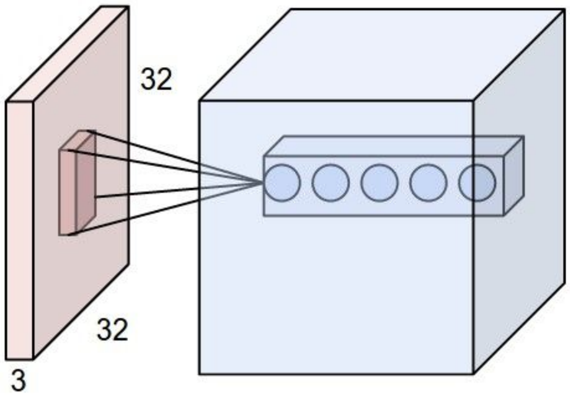


Stanford CS231n

Convolutional Neural Networks







Schwarzschild-Couder Telescope (SCT)

Prototype under construction at VERITAS site in Arizona

Dual-mirror optics and high-resolution camera improve sensitivity, angular resolution, and field of view compared to standard medium size telescopes

SCT images have high resolution and square pixels, making them well suited for analysis with neural networks

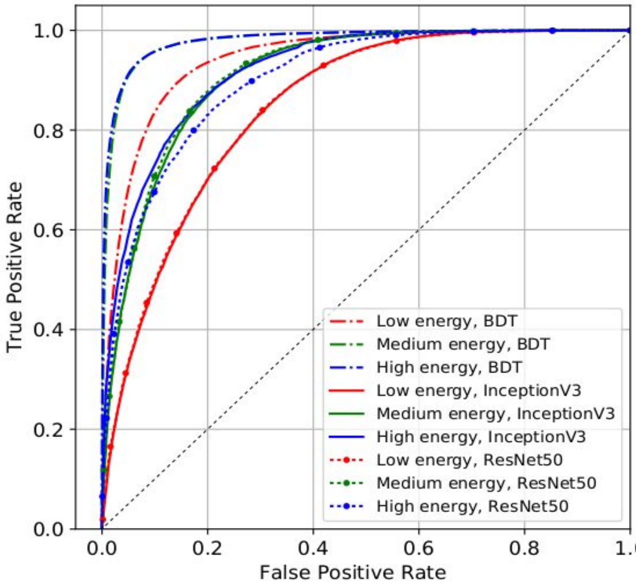
Proof of Concept: SCT Gamma/Hadron Classification

Trained on single telescope SCT images of diffuse gammas and protons

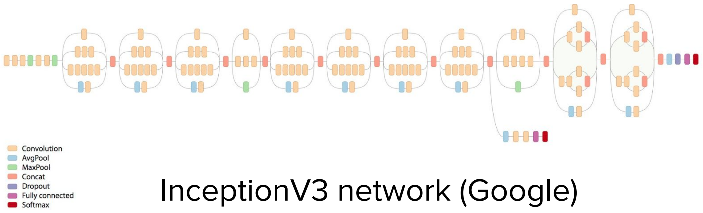
Used slightly modified well-known CNN models, InceptionV3 (Google) and ResNet50 (Microsoft)

Neural networks work, but need stereo reconstruction to match existing analysis methods

Nieto, Brill, Kim, Humensky: arXiv:1709.05889

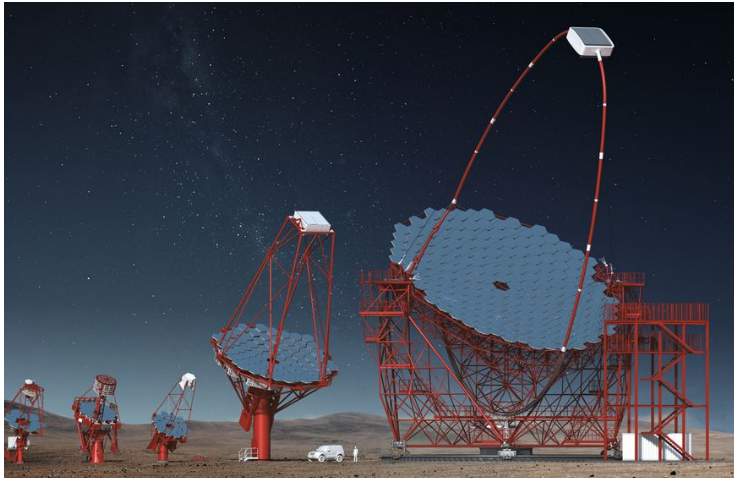


Model	Low E.	Med. E.	High E.
ResNet50	81.1%	90.1%	91.2%
Inception V3	81.4%	90.1%	91.6%



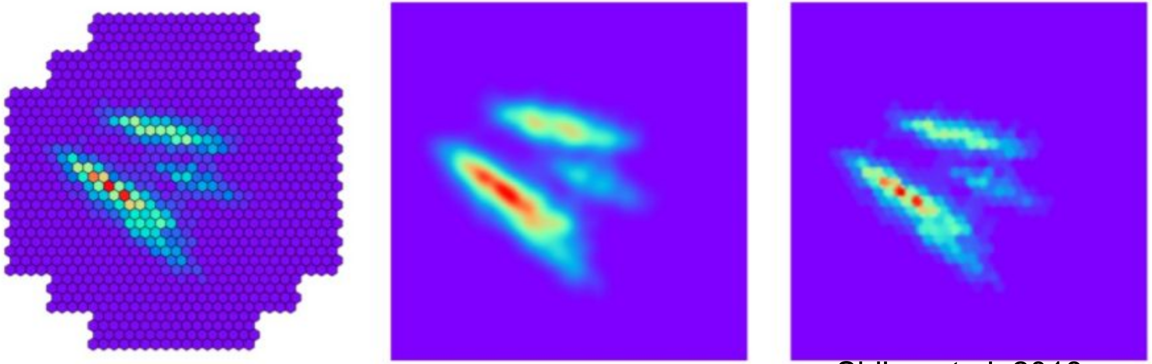
InceptionV3 network (Google)

IACT Deep Learning Challenges



Combine images from a telescope array containing many different telescopes which may or may not have triggered ➔ best results so far achieved with recurrent neural networks, but still preliminary

Process **hexagonally spaced pixels** into a square matrix ➔ many methods under study, no consensus yet



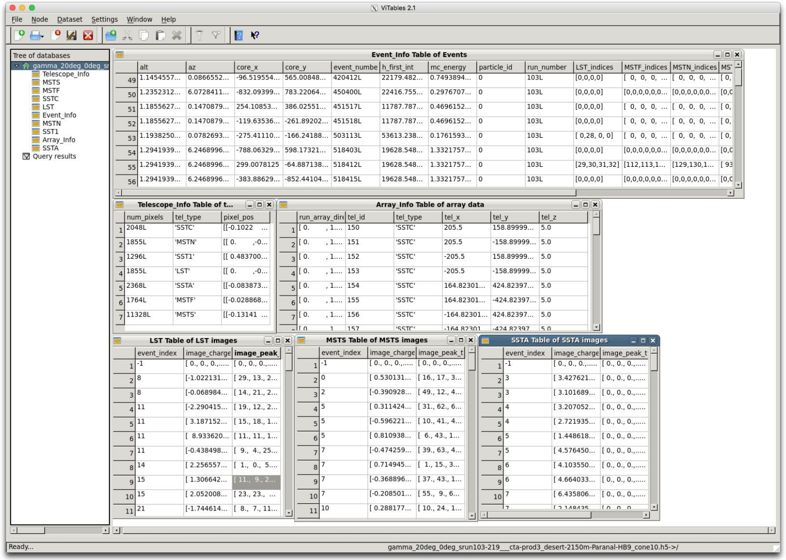
Shilon et al. 2018

Get lots of **labeled training data**:

1. Reprocess MC simulations ➔ ImageExtractor
2. Understand effect of subtle differences between sims and data ➔ not there yet

Training Pipeline: ImageExtractor and CTALearn

myfile.simtel.gz ⇒ **image-extractor** [ctapipe, pytables] ⇒ myfile.h5 ⇒ **CTALearn** [TensorFlow]



https://github.com/cta-observatory/image-extractor

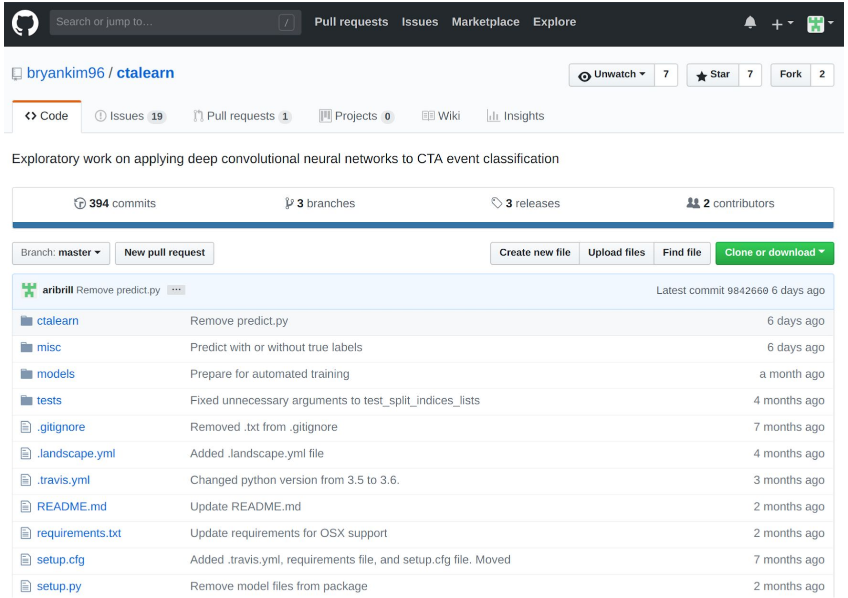
Daniel Nieto (UCM); Bryan Kim, Ari Brill (Columbia)

CTALearn

High-level Python library for doing deep learning with IACT image data

Includes modules for loading and manipulating ImageExtractor HDF5 data and for running machine learning models with TensorFlow

Configuration-file-driven workflow drives reproducible training and prediction

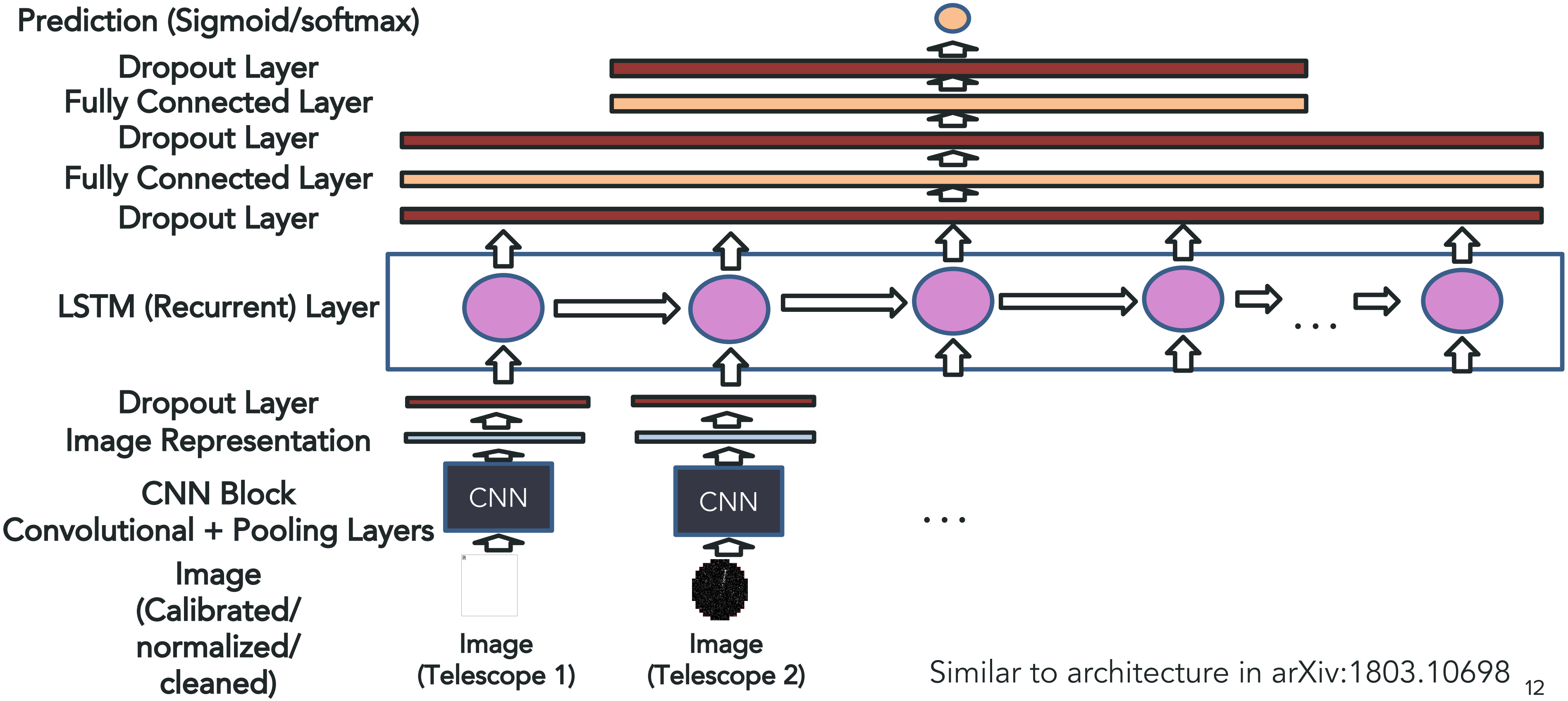


Current development version: v0.1.2

Primary developers (join us!):
Ari Brill, Bryan Kim, Qi Feng (Columbia)
Daniel Nieto (UCM)

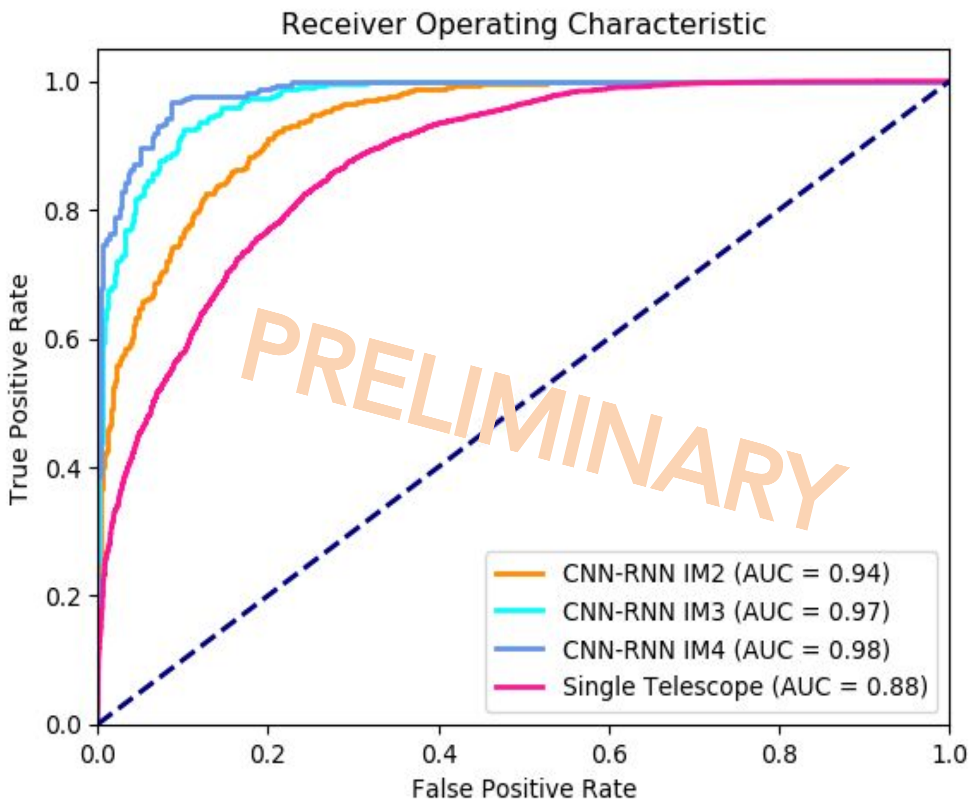
https://github.com/bryankim96/ctalearn

CNN-RNN



Similar to architecture in arXiv:1803.10698

CNN-RNN



- Trained on 200k events each of protons and diffuse gammas from ImageExtractor “ProtoML” dataset
- No quality cuts, no pre-selection of data (except for multiplicity)
- SCT images only
- Preliminary results look promising albeit no hyperparameter optimization

PRELIMINARY

Multiplicity	AUC (test)
1 (basic CNN)	88%
2 (CNN-RNN)	94%
3 (CNN-RNN)	97%
4 (CNN-RNN)	98%

Looking Ahead

Neural networks work well for IACT data but have many challenges remaining

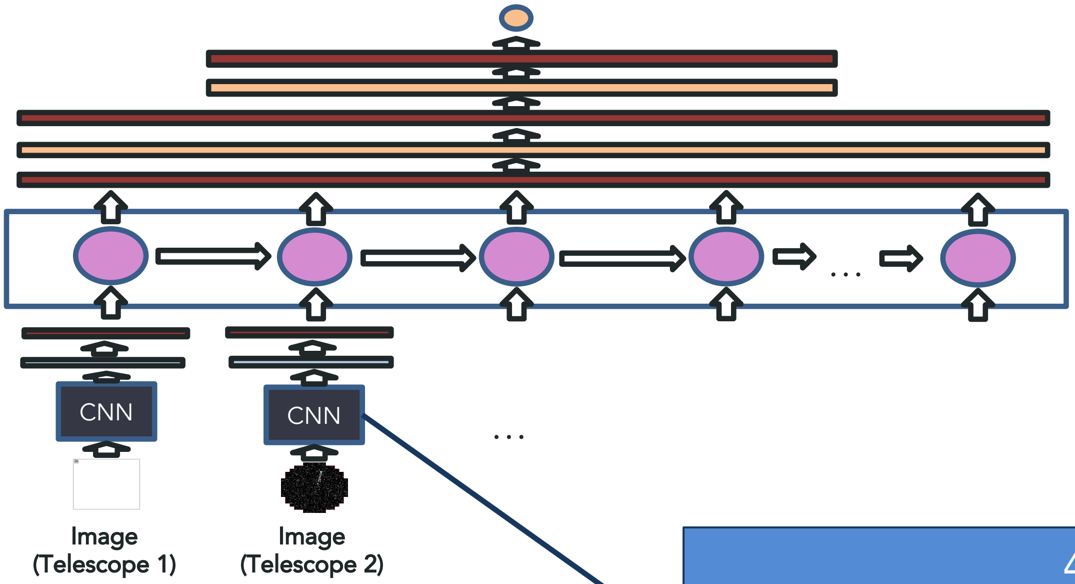
CNN-RNN architecture gives promising preliminary results on gamma/hadron classification with many improvements possible: hyperparameter optimization, inclusion of more telescope types, application to energy/direction reconstruction

CTALearn v0.2 release expected in July:

- Configure user-provided machine learning models
- Load and train with data from any CTA telescope/camera (+ VERITAS)
- Major code upgrades aimed at future use with CTA low-level analysis (ctapipe)
- Code available at github.com/bryankim96/ctalearn

Backup

CNN Block



Basic CNN

48x48x1 INPUT →
→ 3x3x32 CONV → 2x2 stride 2 MAX_POOL →
→ 3x3x64 CONV → 2x2 stride 2 MAX_POOL →
→ 3x3x128 CONV → 2x2 stride 2 MAX_POOL →

06/2017

arXiv:1709.05889

Accuracy

Model	Low E.	Med. E.	High E.
ResNet50	81.1%	90.1%	91.2%
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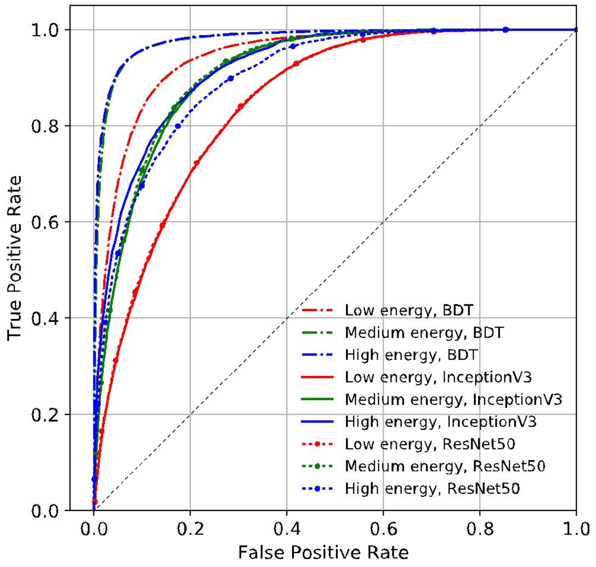
ROC



04/2018

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