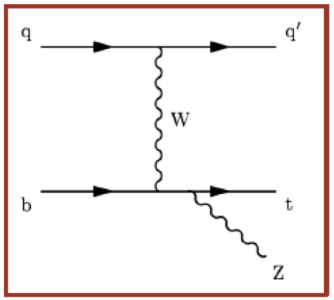
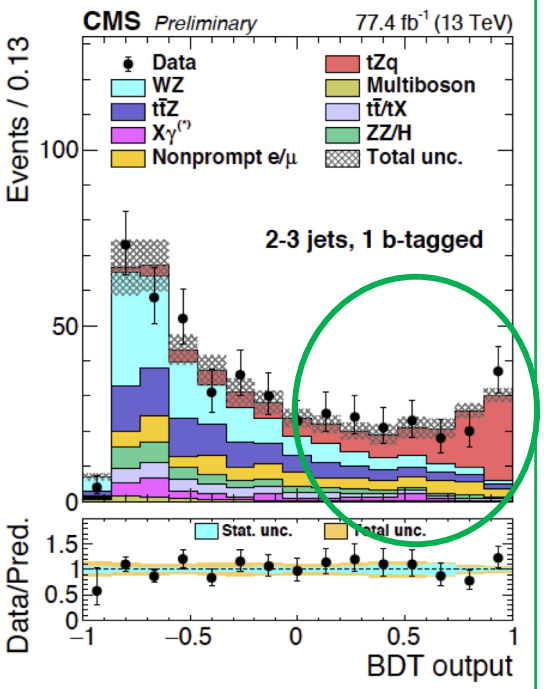
# Artificial Intelligence

- Machine learning algorithms (aka Artificial Intelligence) have been used in particle physics analyses for decades
- First in a limited capacity, but now extensively!
- Most Higgs boson measurements make extensive use of machine learning.
- Algorithms include “Boosted Decision Trees”, and neural networks
- Even starting to be incorporated into the computing and electronics of the experiment

# CMS Example: Observation of tZq production

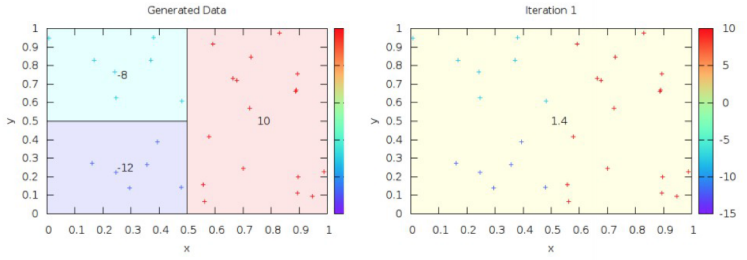


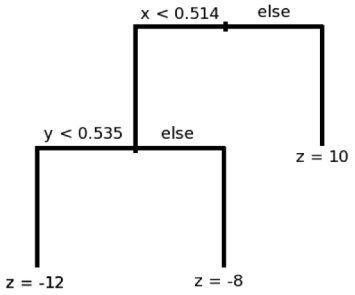

- Rare process sensitive to top quark and Z boson coupling
- Selection:
  - 3 leptons (e, $\mu$), with Z candidate
  - At least 2 jets with 1 b-tag jet
  - Use machine learning discriminate (BDT) to distinguish signal from background processes
- Result:
  - $\sigma(\mathrm{pp} \to \mathrm{tZq} \to \mathrm{t}\ell^+\ell^-\mathrm{q}) = 111\ ^{+13}_{-13}\,(\mathrm{stat})\ ^{+11}_{-9}\,(\mathrm{syst})\,\mathrm{fb}$
  - SM exp: 94.2±3.1 fb
  - Significance well over 5 $\sigma$ → Discovery! ☺



# Boosted Decision Trees

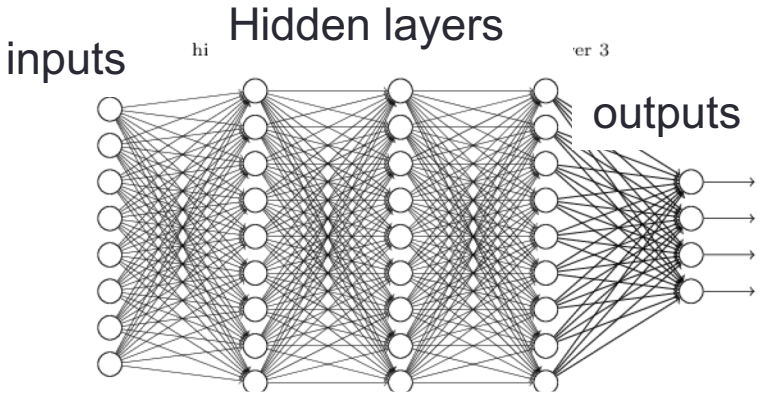
- A decision tree repeatedly splits a dataset into smaller subregions based on features in that dataset
  - Similar to what particle physicists were doing already by hand (“cuts” on the data set)
  - Kind of like “20 questions”: Does it have 4 legs? Does it have stripes?
- Ultimately you want to divide the data set into the correct classifications (which ones are cat, dog, etc.)
- The Boosting takes an ensemble of decision trees, where each subsequent tree tries to improve upon the error from the previous one
  - Each tree gets a weight, and the ensemble gets the weighted sum

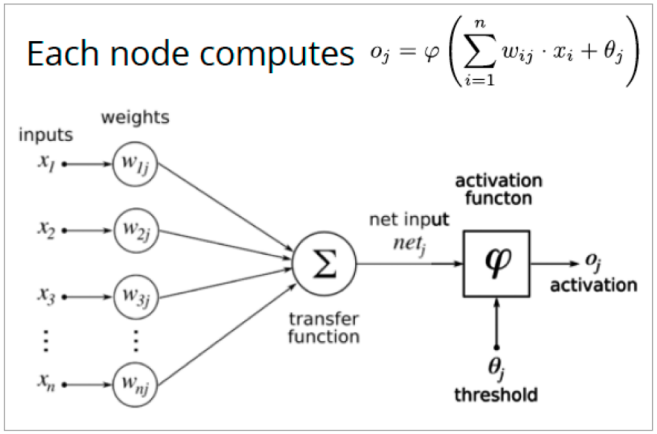


# Neural Network Machine Learning

- Loosely inspired by how neurons work in the brain
  - Neurons fire signals to other connected neurons, amplifying the signal to some degree in the process
- In a neural network, the inputs are multiplied by a set of weights, and the product is sent to a nonlinear activation function
- A Deep Neural Network has many hidden layers
  - e.g. Convolutional neural nets for image recognition



# Training and Inference

- The Neural Network, or AI algorithm in general, must be trained with large sample of examples of desired classification (just as with the BDT algorithm)
  - Cat vs. not a cat; Higgs boson vs. not a Higgs boson; momentum =10 vs. momentum =100
  - Weights are determined from back propagation and using a specific loss function (penalty)
- This is very similar to the process of fitting mathematical functions to describe some data, where the function gives the output we want
  - Like regression, where a minimization of least squares determines the parameters
  - But neural networks can have a very large set of parameters!
- The application of trained network is known as inference