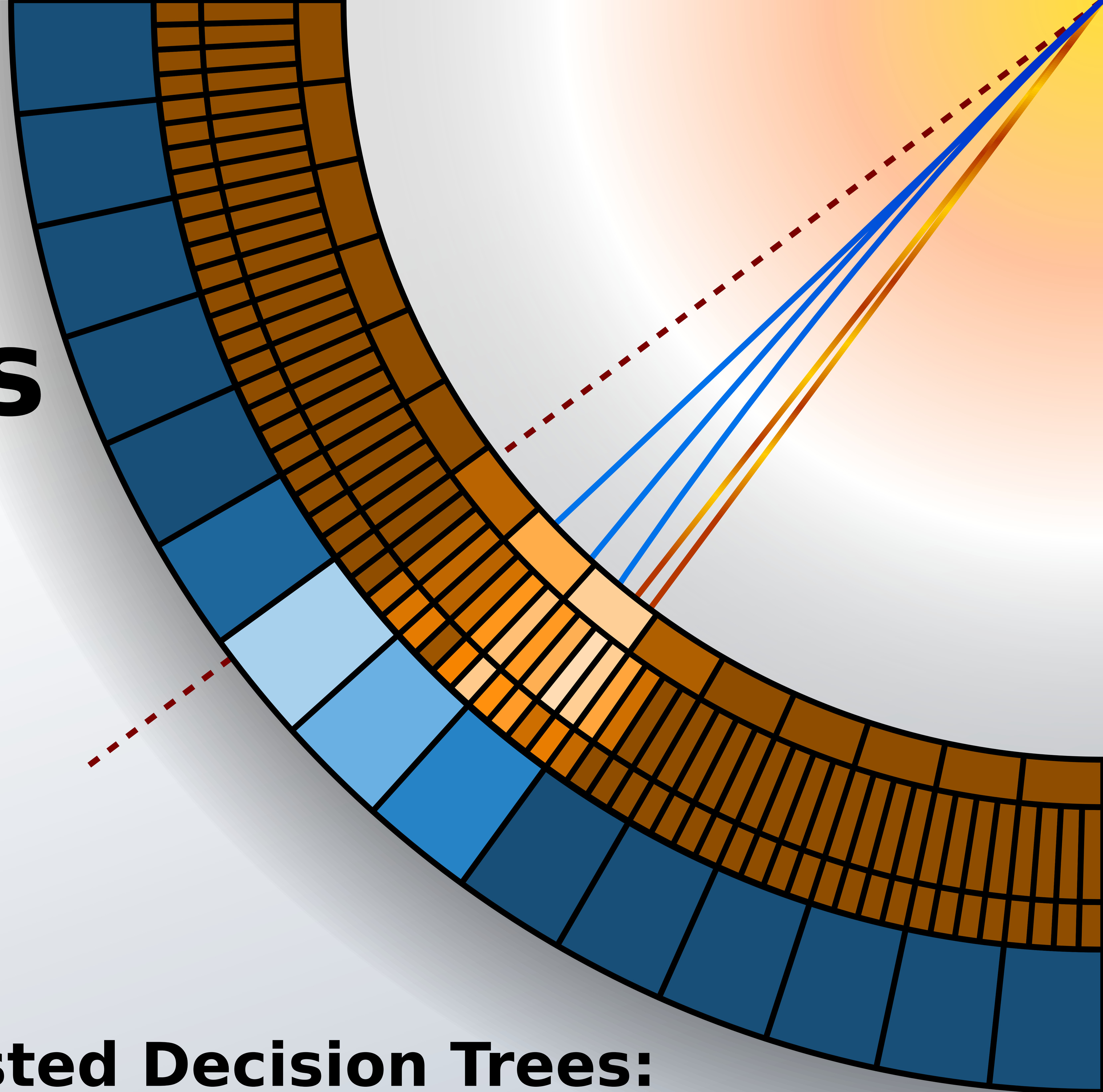
Neutral Pion Reconstruction in Hadronic Tau Decays



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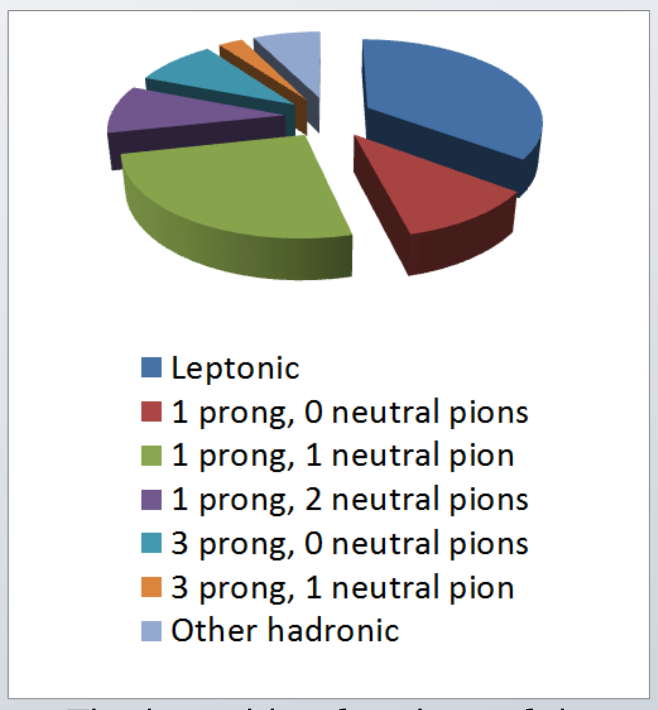
Introduction:

As the most massive of the leptons, tau particles are of particular interest to many particle physics analyses, especially the observation and measurement of the Higgs Boson. Due to the large tau mass of about 1.78 GeV, the tau gives the best opportunity to observe leptonic Higgs decays. As such, accurate measurement of the properties of the tau are essential.

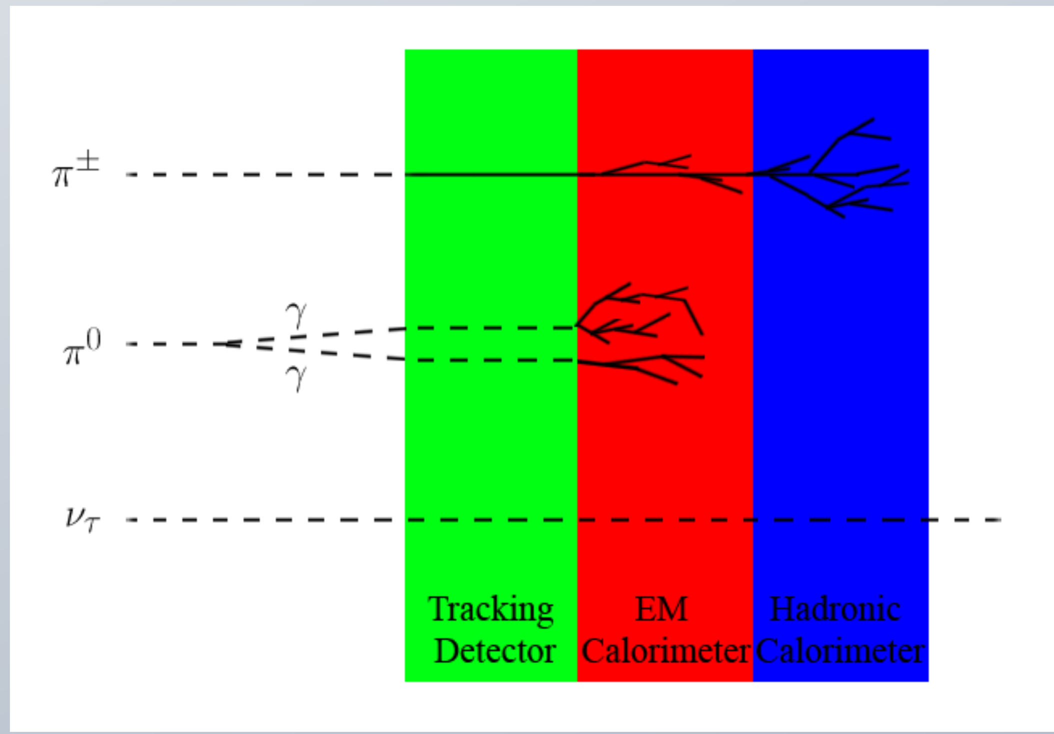
Taus have a mean lifetime of about 2.91 x 10^{-13} s eliminating the possibility of direct detection, meaning they must be detected via their decay products. The main decay modes of the tau are shown in the chart to the right. The hadronic decays are grouped according to number of charged decay products (prongs). The main hadronic decay modes involve a mixture of charged and neutral pions. The neutral pions have a mean lifetime of just 8.4 x 10^{-17} s, decaying almost exclusively into pairs of photons.



The branching fractions of the main tau decay modes.

Motivation:

In order to optimize the hadronic tau energy resolution, a method can be used which takes advantage of the improved resolution of the tracking system for charged particles, and the calorimeter system for the remaining neutral particles. This gives rise to the following algorithm:



A rough illustration of the detector signatures of each of the three most common particles in hadronic tau decays.

1. Determine the number of neutral pions (π^0's) in the decay.
2. Select the most likely calorimeter energy clusters associated with these particles.
3. Correct these clusters for hadronic energy deposits to get the energy of just the neutral particles.
4. Sum the energy of the charged particles as determined by the tracking system with that of the neutral particles as determined in the previous step.

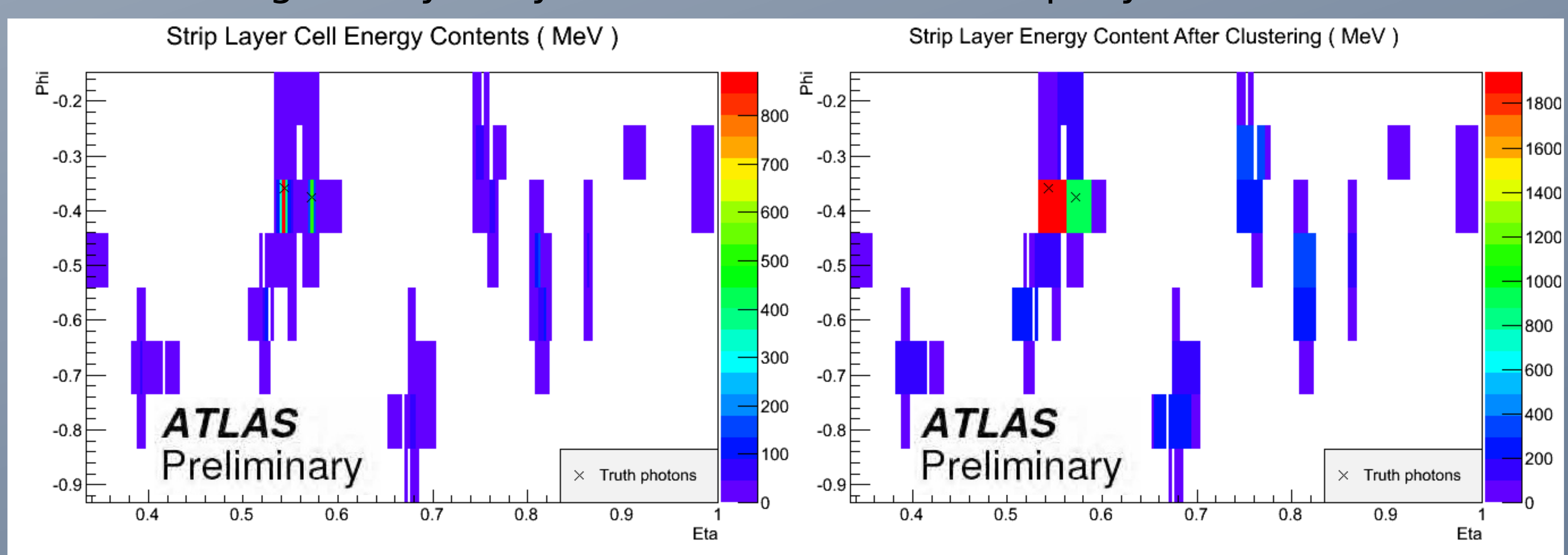
My goal has been to improve the method used for the first of these steps.

ATLAS Detector:

The ATLAS experiment is a particle detector situated on the main ring of the Large Hadron Collider (LHC) at the CERN laboratory in Geneva, Switzerland. The detector has a cylindrical structure with many different layers, including multiple tracking detectors, and calorimeters.

The tracking detectors measure the curvature of a particle's path through a strong magnetic field in order to measure the particle's momentum. This measurement is very precise due to the fine resolution of the detectors.

The calorimeters absorb a particle's energy in order to measure the total energy associated with it. There are several layers to the calorimeter system, varying in both spatial and energy resolution. The best spatial resolution is given by a layer referred to as the strip layer.



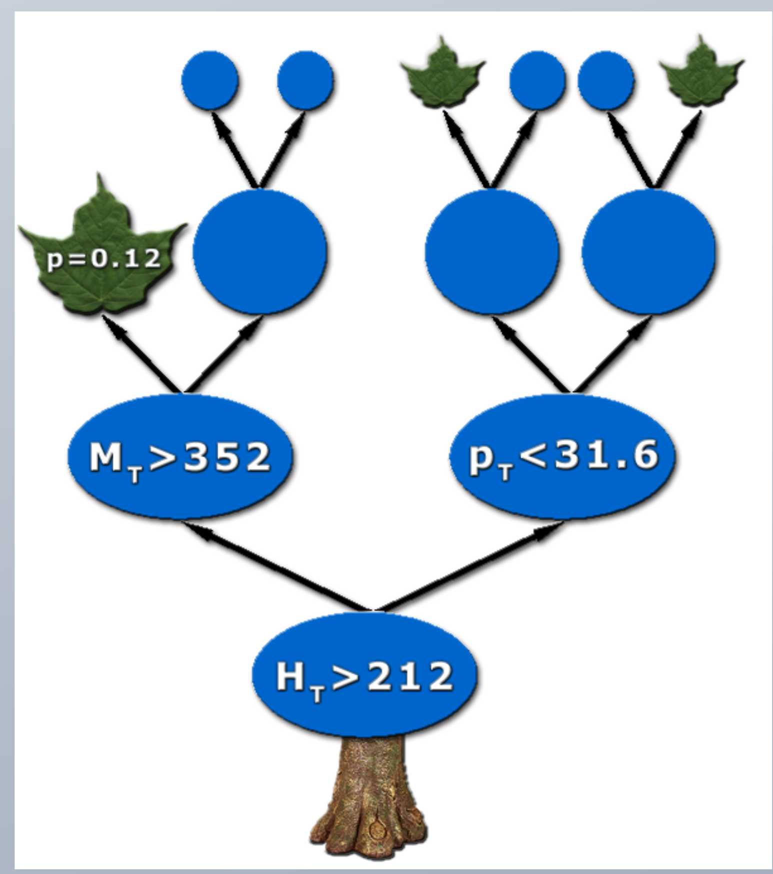
The strip layer of the ATLAS detector has fine enough resolution to distinguish between the photons emitted by neutral pion decays allowing for improved tau reconstruction. (Simulation)

Boosted Decision Trees:

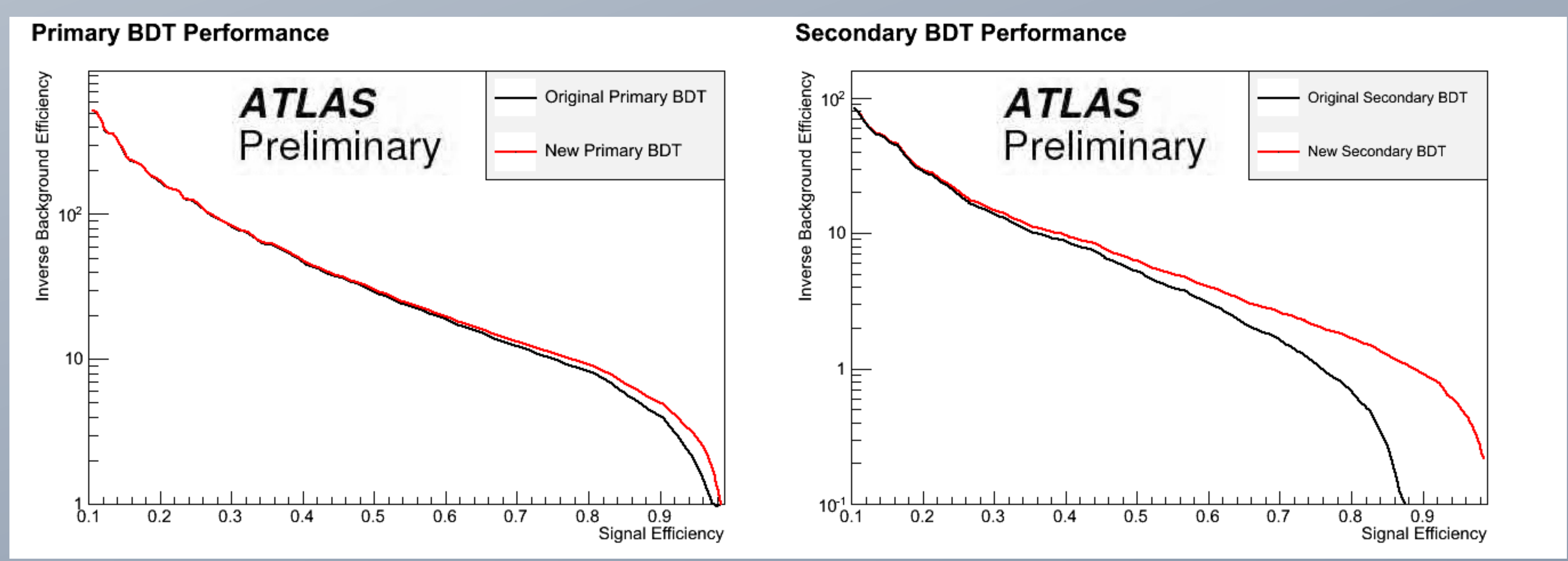
A decision tree is a classifier which sorts input events into two categories, referred to as signal and background. A decision tree uses a series of optimized cuts to divide the sample into various regions which are then classified as either signal or background according to the region's composition.

In order to create a more statistically stable classifier, the misclassified events can be re-weighted more heavily before training an additional tree. The overall classifier given by a weighted average over the trees is known as a boosted decision tree (BDT).

The current algorithm for π^0 counting is a pair of BDT's: one to distinguish between Tau decays with and without π^0's, and the other to distinguish between those with one π^0, and those with two π^0's. My goal has been to probe the calorimeter strip layer in order to improve the performance of these BDT's through the addition of new variables.



Training a decision tree results in a branching structure as shown in the above diagram. (Image by Dag Gillberg)



The higher inverse background efficiency for a given signal efficiency given by the new BDT indicates improved performance. (Simulation)

Results:

The main approach taken was to run a clustering algorithm with very fine radius on the energy deposits in the calorimeter strip layer in hopes of reconstructing individual photons. Various scores and variables based around energy and geometry were introduced and optimized. As can be seen in the plots above, the new variables have reduced the background efficiency for a given signal efficiency when compared to the previous two BDT's. This improvement is further demonstrated in the tables below and to the right, comparing the new BDT's to the previous tau decay mode reconstruction, as well as that of the CMS experiment.

New π^0 BDTs

reconstructed τ decay mode			
$\pi\pi\pi$	0.00	0.03	0.98
$\pi\pi^0$	0.13	0.85	0.01
π	0.87	0.12	0.01
generated τ decay mode	π	$\pi\pi^0(\pi^0)$	$\pi\pi\pi$

CMS Simulation, $\sqrt{s}$ = 7 TeV

reconstructed τ decay mode			
$\pi\pi\pi$	0.02	0.01	0.91
$\pi\pi^0$	0.13	0.83	0.04
π	0.85	0.16	0.05
generated τ decay mode	π	$\pi\pi^0(\pi^0)$	$\pi\pi\pi$

The above tables compare the new BDT's performance (top) to that of the CMS experiment. It is worth noting that CMS does not distinguish between modes with 1 and 2 π^0's.

New BDT's: Reconstructed decay mode

Truth decay mode	$1\pi^\pm$	$1\pi^\pm + 1\pi^0$	$1\pi^\pm + 2\pi^0$	$3\pi^\pm$	$3\pi^\pm + 1\pi^0$
$1\pi^\pm$	86.5	10.3	3.1	0.1	0.0
$1\pi^\pm + 1\pi^0$	15.4	56.7	25.6	0.4	1.9
$1\pi^\pm + 2\pi^0$	3.1	24.3	68.9	0.1	3.6
$3\pi^\pm$	0.8	0.3	0.2	95.1	3.7
$3\pi^\pm + 1\pi^0$	0.2	1.1	2.4	51.4	44.9

Original BDT's: Reconstructed decay mode

Truth decay mode	$1\pi^\pm$	$1\pi^\pm + 1\pi^0$	$1\pi^\pm + 2\pi^0$	$3\pi^\pm$	$3\pi^\pm + 1\pi^0$
$1\pi^\pm$	81.8	12.6	4.8	0.5	0.2
$1\pi^\pm + 1\pi^0$	11.6	47.5	38.1	0.9	1.9
$1\pi^\pm + 2\pi^0$	2.6	26.5	68.9	0.5	1.4
$3\pi^\pm$	0.8	1.6	1.3	92.0	4.2
$3\pi^\pm + 1\pi^0$	0.3	1.2	3.5	50.2	44.9

The tables to the left show the truth decay mode along the left column, and reconstructed decay mode along the top. The primary BDT has improved a small amount, while the secondary has improved significantly.

[1] The ATLAS Collaboration, *Reconstruction, Energy Calibration, and Identification of Hadronically Decaying Tau Leptons*, ATLAS-CONF-2011-077, May, 2011.

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