Tau Energy Scale at the ATLAS Detector

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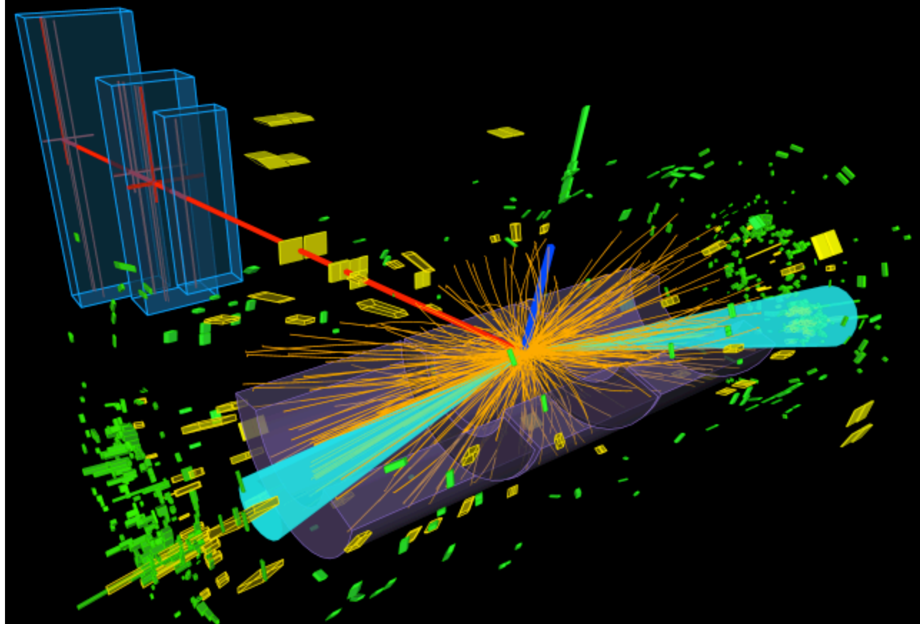
Yale

ATLAS EXPERIMENT

Why study taus?



Higgs boson candidate decaying into 2 tau leptons

- Many analyses use tau leptons: Standard Model Processes, Higgs boson searches, new physics phenomena searches (heavy gauge bosons, leptoquarks)
- Higgs boson to $\tau\tau$
- I work on Associated Production of the Higgs boson with a W or Z boson, where the Higgs boson decays to two τ $\rightarrow$ currently unmeasured channel!
- ATLAS needs an excellent and robust tau reconstruction and calibration to complete these studies

Calibration of Particles in ATLAS

- Need to calibrate the energy of many particles in the detector
- Why do we calibrate?
  - Detector issues: dead material in detector, incomplete coverage of detector, non-uniformity across detector
  - Some particles do not deposit enough energy into calorimeter to be included in clustering algorithm
  - Other particles decay and lose energy before reaching the calorimeter
  - Pileup effects – overlapping particles
- First Calibration: LC (local calibration) scale – applied to all jet-like objects to compensate for above issues

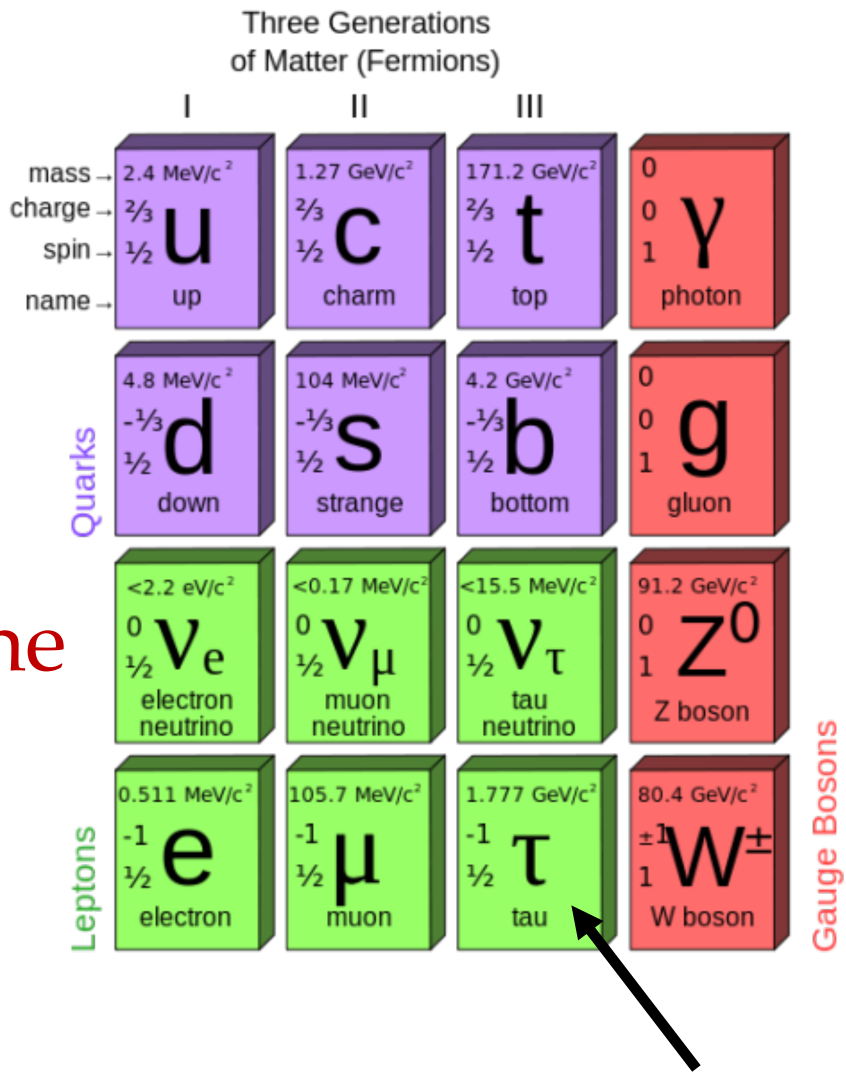
Taus!

Mass: $1776 \pm 0.12\ MeV$ most massive lepton

Lifetime: $(290.3 \pm 0.5) \times 10^{-15}$s very short!

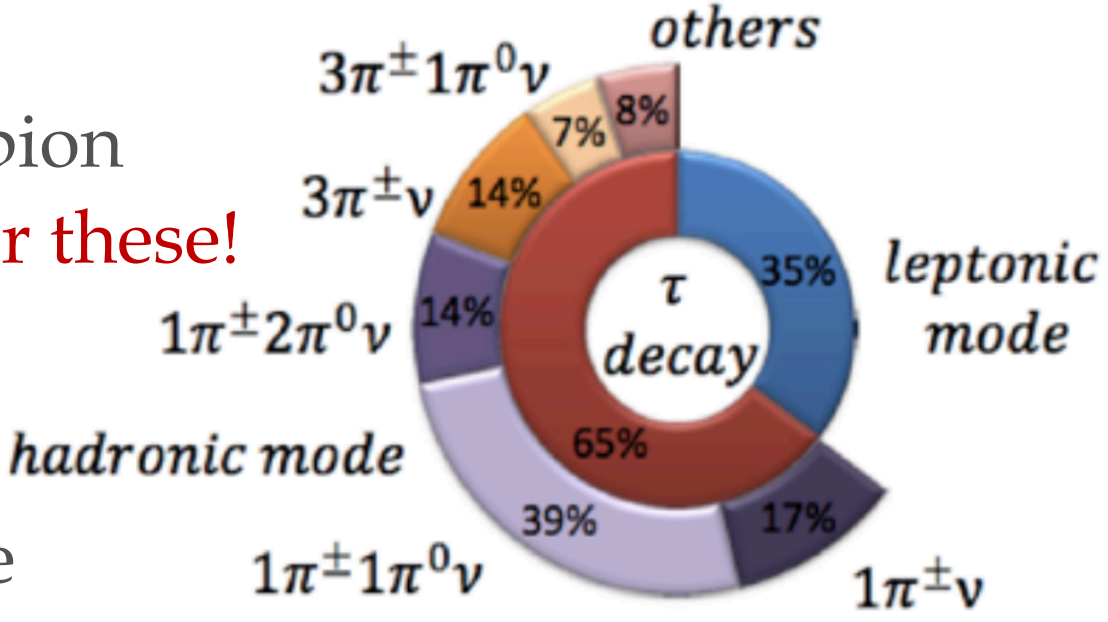
Decay length: $87 \mu m$ inside the LHC beamline

$\Rightarrow$ use decay products to identify them



Tau Decays

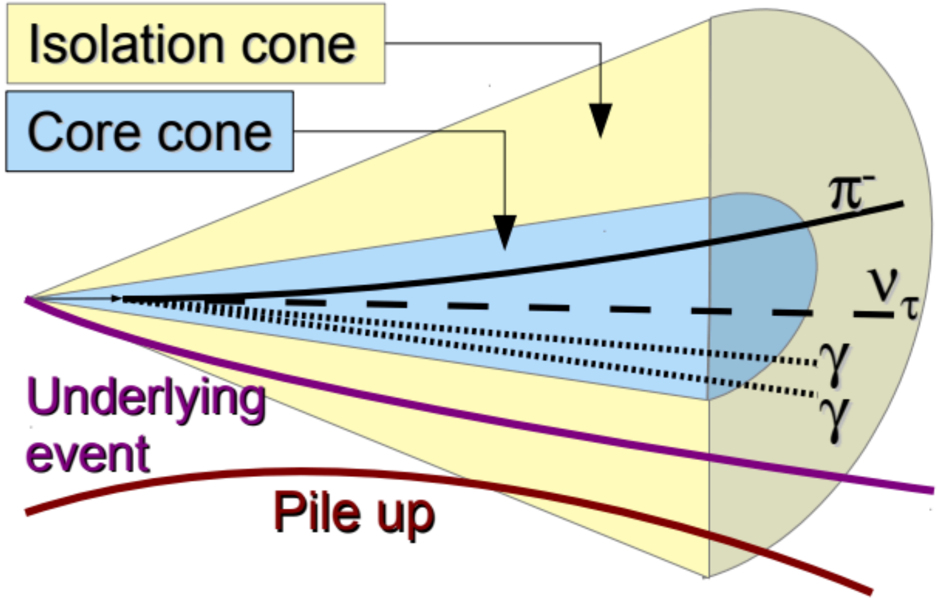
- *Hadronic*: hadrons in the final state (pions, kaons)
  - 65% of all τ decays
  - 1 or 3 charged pions in final state
  - 68% of decays also include a neutral pion
  - Need to use tau specific calibration for these!



- *Leptonic*: electrons or muons in final state
  - 35% of all τ decays
  - $\tau \rightarrow e\nu_e\nu_\tau$ or $\tau \rightarrow \mu\nu_e\nu_\tau$
  - Taken care of by muon and electron specific energy calibrations

Tau Specific Energy Calibration

- τ can lose energy before it reaches the calorimeters
- Out-of-cone effects
- Underlying event
- Pileup



- Only looking at visible decay products
- Assuming we have identified a τ

- *Goal*: Correct energy measured in detector to average value of energy of decay products at the generator level
  $\Rightarrow$ simulated (truth) information!

Baseline Tau Energy Calibration

Correction to LC-calibrated sum of energy from calorimeter clusters

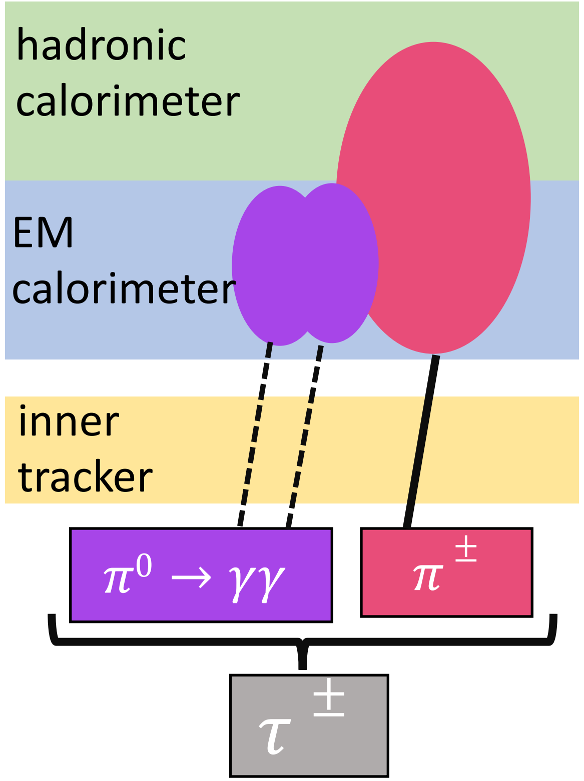
$$E_{calib} = \frac{E_{LC} - E_{pileup}}{\mathcal{R}(E_{LC} - E_{pileup}, |\eta|, n_p)}$$

Two Step Process:

1. Remove energy contribution from pileup (E_{pileup})
2. Scale to true visible momenta, in bins of # of prongs (n_p) and pseudorapidity

- Works well for high p_T τ, but not for low p_T τ
- Does not include reconstructed neutral pions or charged pion tracks

Tau Energy Scale - BRT

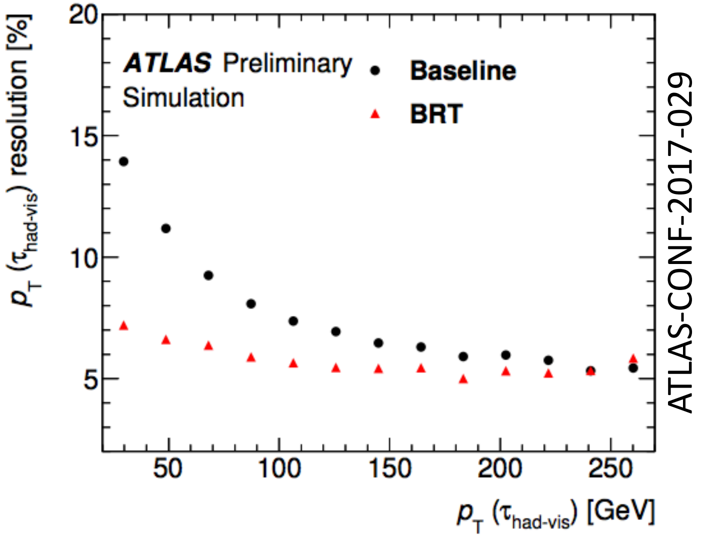


- Boosted Regression Tree (BRT) trained weight applied to visible decay products of τ
  - Multi-Variate Analysis Tau Energy Scale (**MVATES**):

$$E_T \rightarrow (1 + \alpha)E_T$$

  - Combines Tau Particle Flow (TPF) information (to get charged pion momentum in tracking system) with calorimeter information

- Figures of Merit:
  - *non-closure:* offset of ratio of calibrated τ p_T and truth τ p_T (of visible components) from 1
  - *resolution:* 68% central interval of ratio of calibrated τ p_T and truth τ p_T
- Better performance at low p_T



Current Improvements to TES

- Applying MVATES at the trigger level
- Training the BRT by including trigger level track information
- Allows for better informed decisions in the trigger
- Higher stakes ⇒ only get one shot to keep event

Summary

- We need to calibrate the τ energy in order to effectively use τ in many analyses
- The BRT calibration that includes particle tracking information improves upon the baseline calibration
- Further studies for MVATES using trigger information are ongoing
  - Optimizing the input track variables and training splits
    - Is it better to train the MVATES weights on 1 and 3 prong τ separately or together?
  - Need to re-tune for new data-taking conditions in Run 3

Sources

- http://cdsweb.cern.ch/record/2261772/files/ATLAS-CONF-2017-029.pdf
- http://cdsweb.cern.ch/record/1544036/files/ATLAS-CONF-2013-044.pdf
- https://arxiv.org/pdf/1512.05955.pdf
- https://cds.cern.ch/record/2064383/files/ATL-PHYS-PUB-2015-045.pdf
- https://cds.cern.ch/record/1954897/files/ATL-PHYS-PROC-2014-197.pdf
- https://indico.cern.ch/event/607328/contributions/2447342/attachments/1415889/2167797/CoEPP-17-02-22.pdf
- https://cds.cern.ch/record/1994460

Back-Up

Tau Identification

- Candidates: jets with p_T>10 GeV and $|\eta|$<2.5
- Track with most momentum in cone of ΔR<0.2 becomes vertex
  - $\Delta R = \sqrt{(\eta_i - \eta_j)^2 + (\phi_i - \phi_j)^2}$
  - ϕ is azimuthal axis around beamline, η is pseudorapidity ($\eta = -\ln(\tan(\frac{\theta}{2}))$)
- Tracks must have p_T >1GeV and 6 hits in the pixel and SCT
  - *core* (ΔR<0.2) and *isolation* (0.2<ΔR<0.4) tracks
- Get direction of τ from calorimeter cluster information
- Mass of τ is set to zero $\Rightarrow$ $p_T = E_T$
- Identification: Loose, Medium, and Tight
  - Efficiencies are 0.6, 0.55, and 0.45 for 1 prong taus and 0.5, 0.4, and 0.3 for 3 prong taus