Electron Vetos for Tau Signatures at ATLAS

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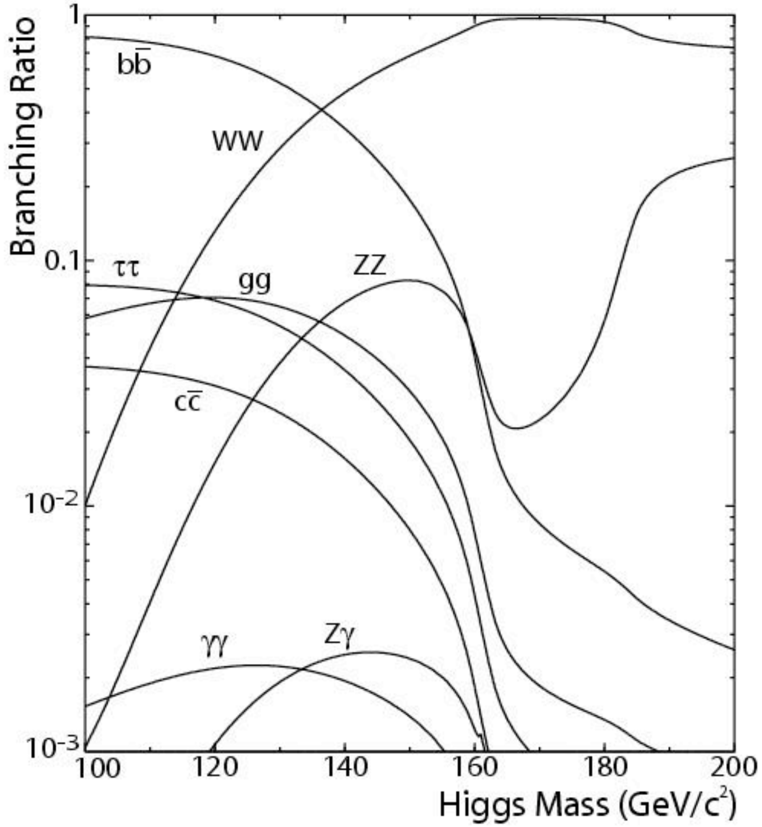
Why taus?

- Heaviest lepton
  - Is being used to probe the phase space of, for example:
    - SM low mass Higgs
      - $H \rightarrow \tau\tau$
    - MSSM Higgs
      - Dominant production channel: $t \rightarrow H + b, \ with\ H \rightarrow \tau + \nu$
- Measure properties of
  - Electroweak bosons
  - Top quarks



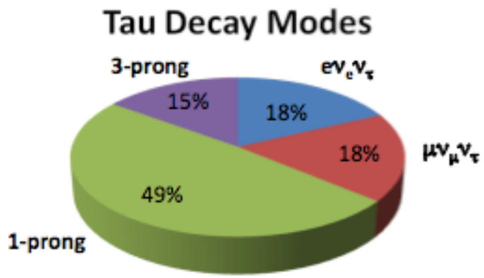
Hadronically Decaying Taus

Decay properties:

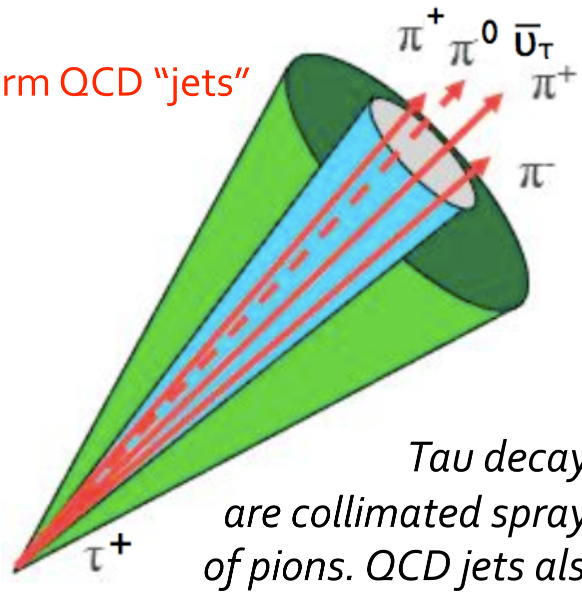
– 10^{-13} s lifetime, can only observe the decay products: (some or none) neutral & charged pion(s)
  - **1 Prong (i.e. one track)** or 3 Prong (3 tracks)

– Conserve lepton number: tau (anti) neutrino produced

– Observe a "jet" originating from the τ decay.
  That tau jet is typically, at a given energy:
  - wider than that of electrons
  - narrower than that from bare quarks that hadronize to form QCD "jets"



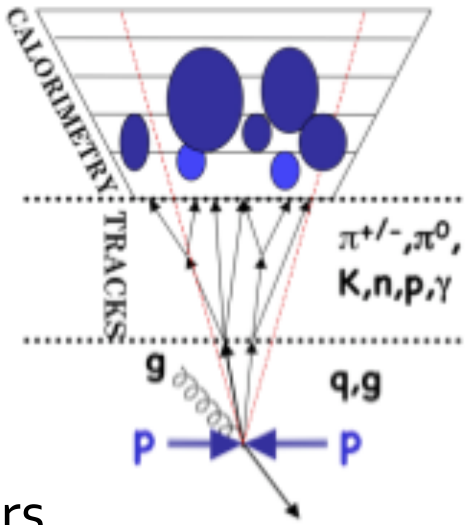
Many objects that are not true τs are reconstructed as τs! We want to place loose requirements initially, as statistics are already low for processes with τs.
The next slide describes reconstruction and identification(ID).



Tau decays are collimated sprays of pions. QCD jets also produce these sprays…

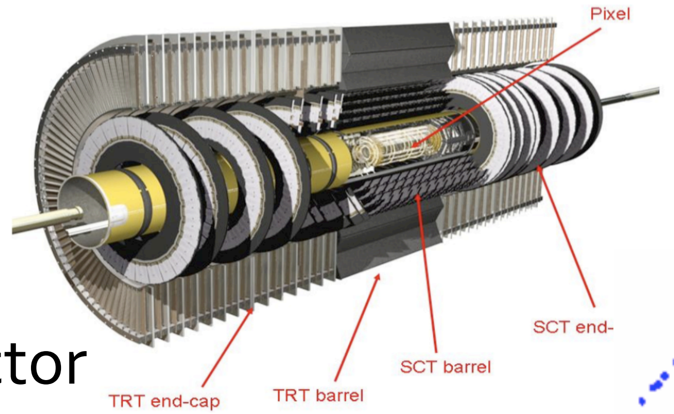
Tau Reconstruction & ID

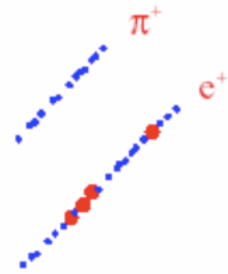
- Reconstructed through tracks and energy deposits
  - Candidates are reconstructed as calo-seeded and/or track- seeded



- Use the Calorimeter and Tracker together:
  - Calorimeter information:
    Energy: τs deposit in both Hadronic (HCal) and Electromagnetic (ECal) Calorimeters, while electrons primarily in latter.
    Shape of energy deposit: collimated energy deposits
  - Tracking information: **Transition Radiation** & **Track Width**

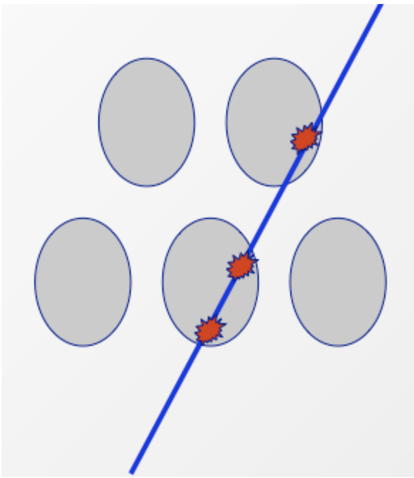
The Transition Radiation Tracker (TRT)



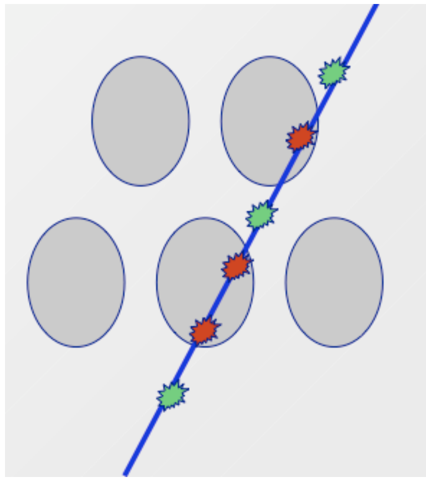


- Outermost layer of inner detector
  - Continuous tracking for particle ID
  - Straws composed with Xenon gas mixture
- Transition radiation: radiation produced by highly relativistic charged particles when they cross the boundary between two mediums of different dielectric constants
  - The High to Low threshold ratio can be used to identify electrons

Non-electrons produce hits mostly inside the straws. Minimum interaction otherwise



Electrons additionally undergo interactions with the inter-straw material. The extra interactions lead to a larger response, "high threshold hits" (HT).



Understanding electrons & Constructing an electron veto as part of a τ ID

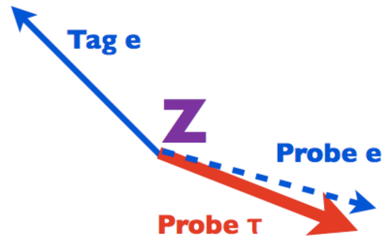
- The Goal: Maximize τ acceptance & Minimize electron fake rate:
  - A looser electron veto optimizes the former
  - A tighter electron veto optimizes the latter
- 70% of electrons are reconstructed as hadronic τ decays by the τ reconstruction algorithm, with no electron veto. We need a way to veto these electrons!

Where does the electron veto fit in?

- Without the electron veto the background contamination would dwarf the signal.
  - Makes it possible to search for low cross-section signals.
- The electron veto is used alongside a QCD jet discriminator for $\boldsymbol{\tau}$ ID
- Electron Vetos are used as part of the $\boldsymbol{\tau}$ ID in many channels with $\boldsymbol{\tau}$s, including
  - ***ttbar*** $\rightarrow \tau^{+/-}_{had} + \mu/e^{-/+}$ + 2 *b-quark jets* + $\nu_\tau + \nu_{\mu/e}$
  - **W$^{+/-}$** $\rightarrow \tau^{+/-}_{had} + \nu_\tau$
  - **Z** $\rightarrow \tau^{+/-}_{had} + \tau^{-/+}_{lep}$
  - **Charged Higgs H$^{+/-}$** $\rightarrow \tau^{+/-}_{had} + \nu_\tau$
  - **(MSSM Higgs) H** $\rightarrow \tau^{+} + \tau^{-}$

Cut-based electron veto in Data

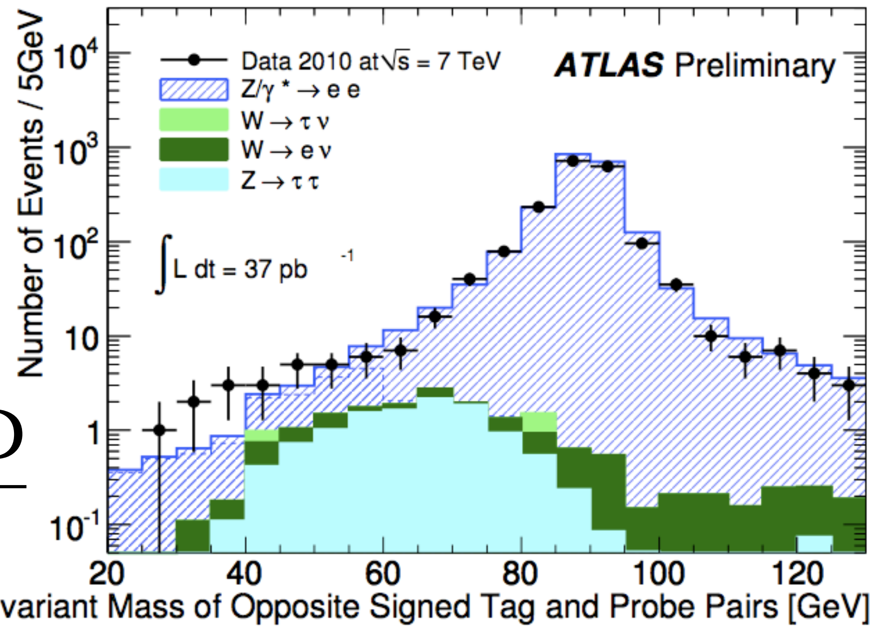
- Extract electron sample in data using Tag & Probe method with Z→ee events as signal
  - Isolate one tight electron as the *Tag*
  - Subject **unbiased** object to the *Probe* cuts



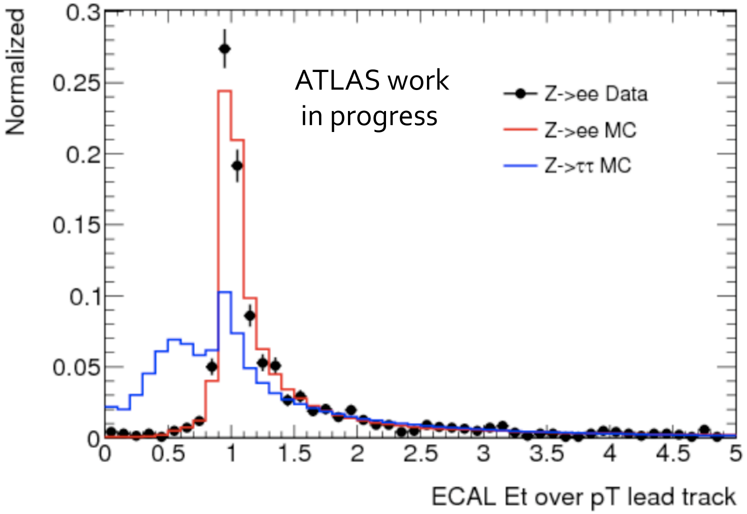
- Invariant Mass Spectrum: 80-100 GeV
- Opposite Sign between pair objects

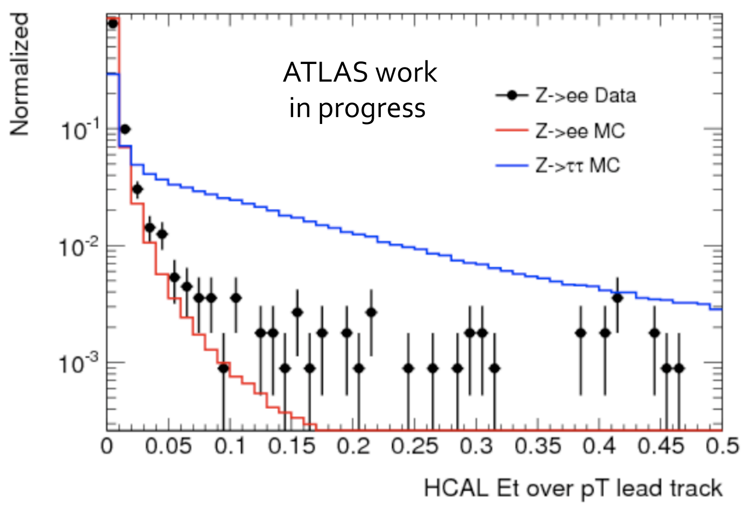
"Fake Rate"

$$\text{Mis-ID Probability} \equiv \frac{\#\ \tau\text{'s passing eVeto}\ \&\ \tau\text{-ID}}{\#\ \text{reconstructed}\ \tau\text{'s}}$$



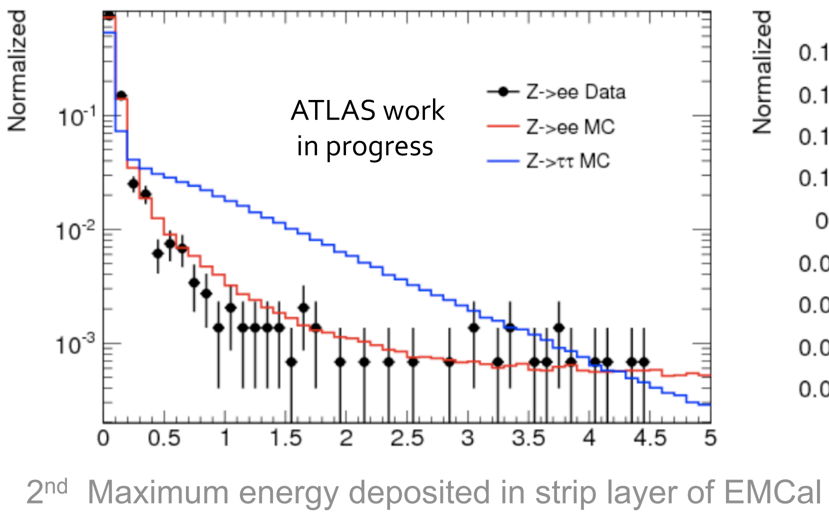
Cut Based Electron Veto Variables

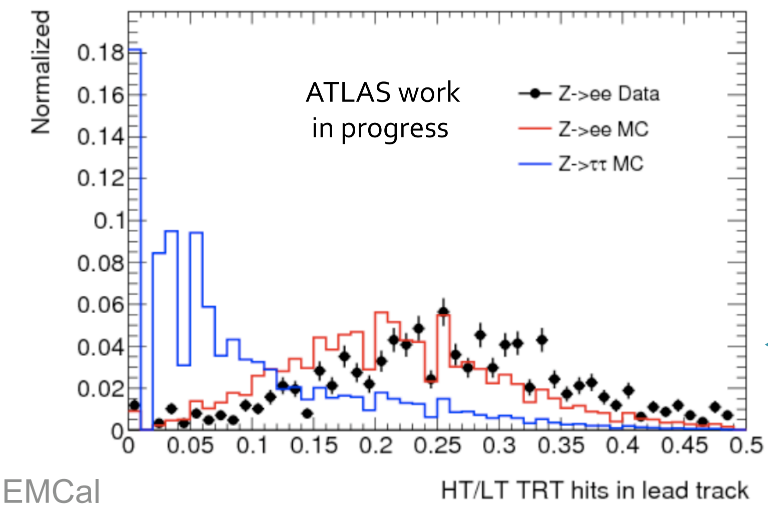




Truth Electrons reconstructed as τ candidates

Truth Taus reconstructed as τ candidates

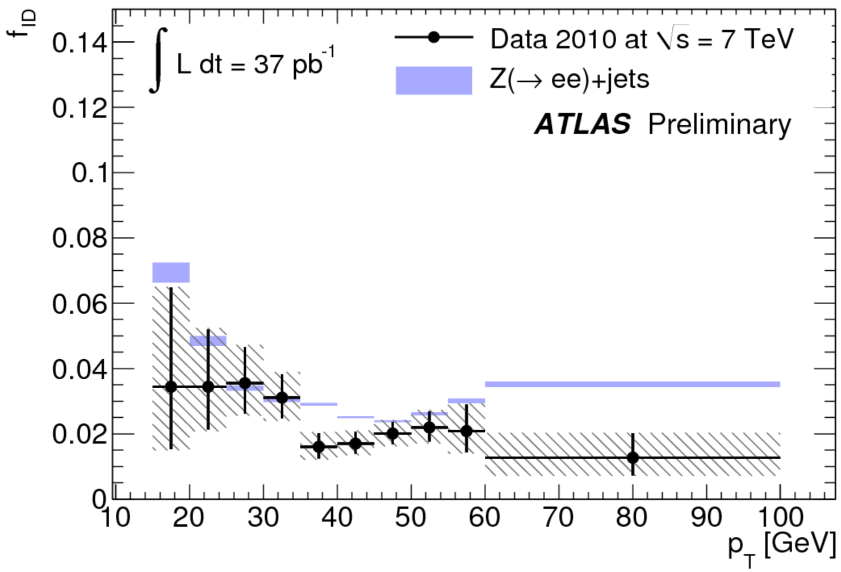




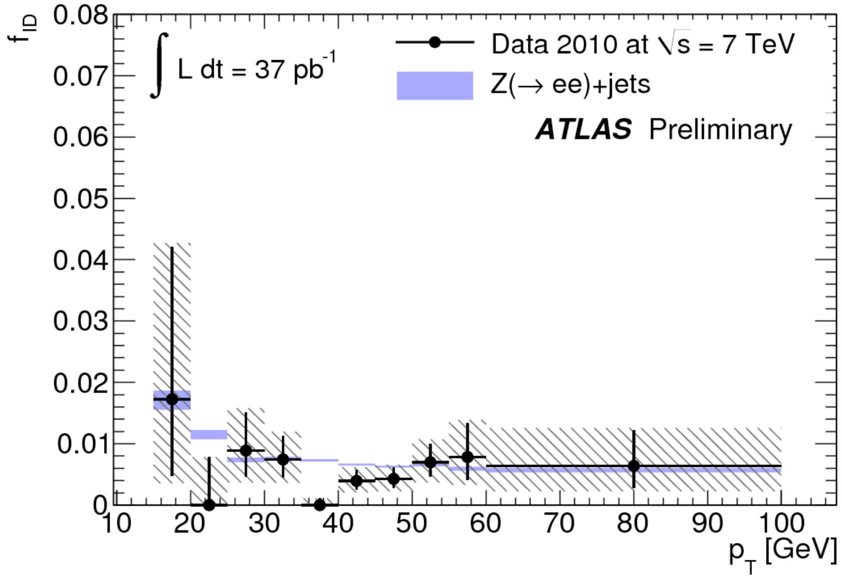
The TRT High to Low Threshold Ratio is the most powerful discriminator of all the variables between τ's and electrons

Misidentification Probability Results

These are two of of the six Tau ID and Electron Veto combinations



After the application of the medium-tightness electron veto and tau-ID



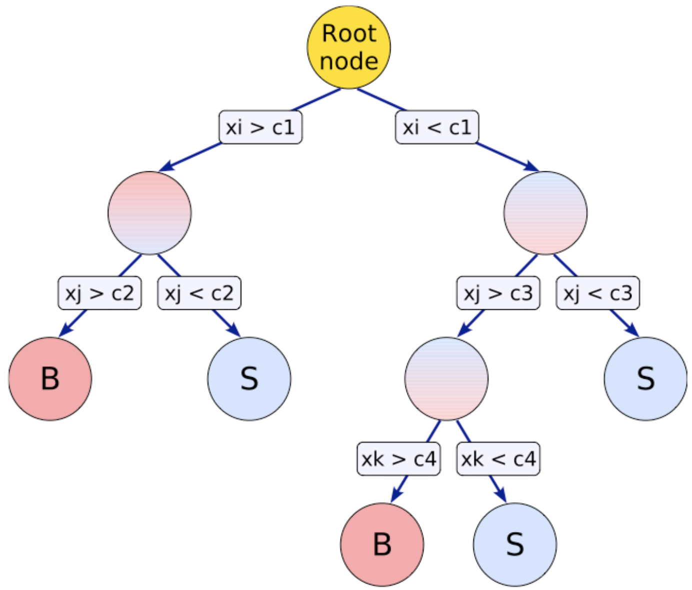
After the application of the Tightest electron veto and tau-ID: the rate of electrons mis-identified as taus is shown to be < 1%.

Boosted Decision Trees for Electron Veto: A Multivariate Technique

- Sequence of binary splits:

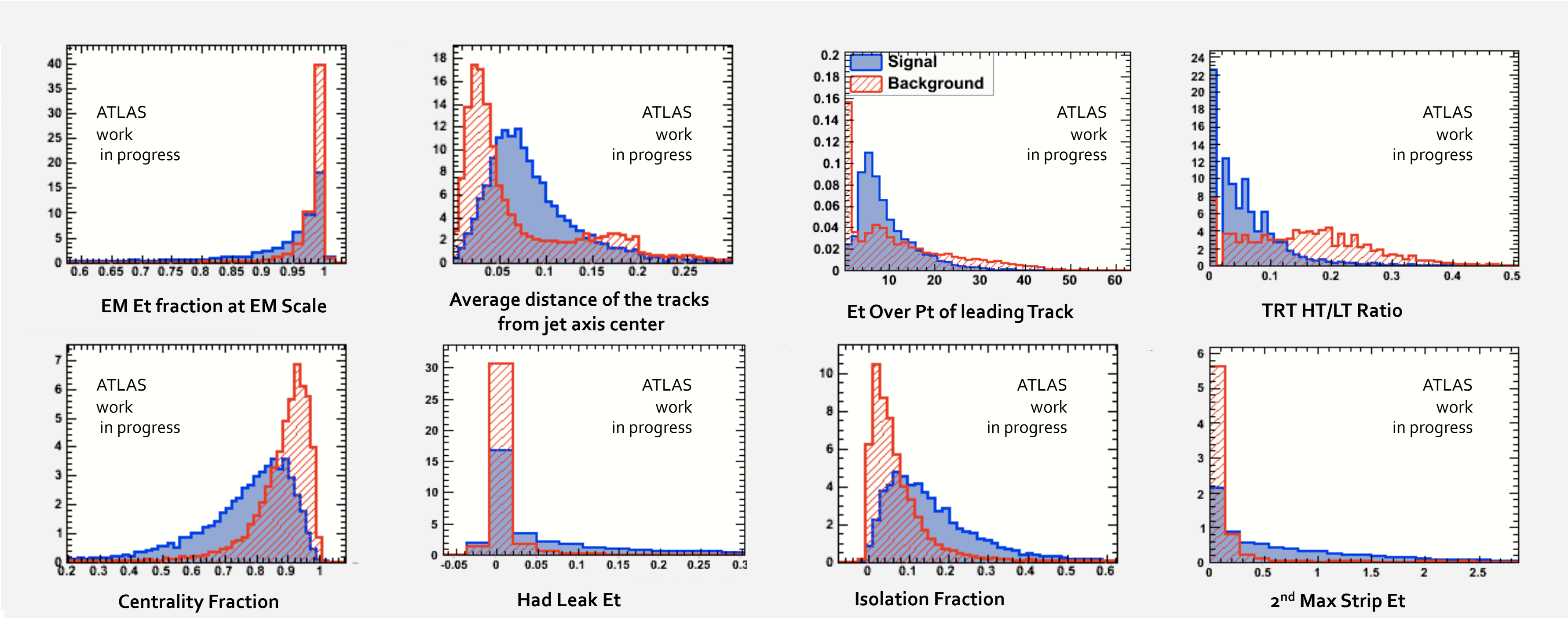
  Repeated yes/no decisions are taken until a stop criterion is fulfilled.

- Phase space divided into many regions eventually classified as signal or background.
  - Where as cut based electron veto considers a single phase space region.



Source: [TMVAUsersGuide]

BDT Electron Veto(BDTe) 2011



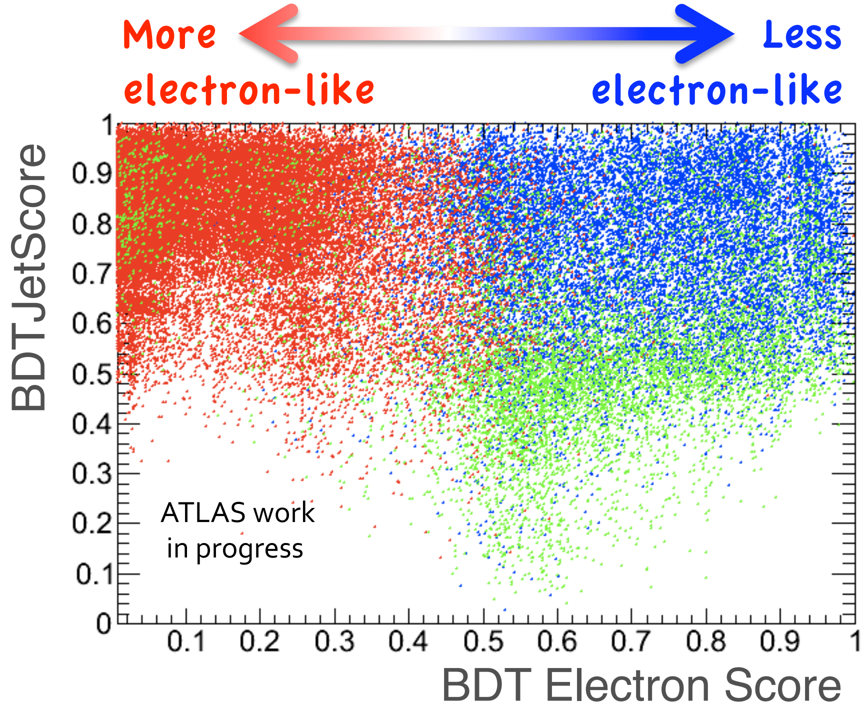
True τs are the Signal, they are properly reconstructed as τ candidates

Electrons are the Background, as they are also reconstructed as τ candidates

All plots are produced with Monte Carlo and normalized to unity

Testing the Performance of the BDTe in top Monte Carlo

- Sample: All ttbar decay channels except fully hadronic, at NLO
  - contains true final-state electrons, taus and QCD jets
- Reconstructed τ candidates are "matched" to true electrons, τs or neither
  - "matching" of two particles: geometrical proximity inside ATLAS



Taus: Reconstructed τs matching true τs

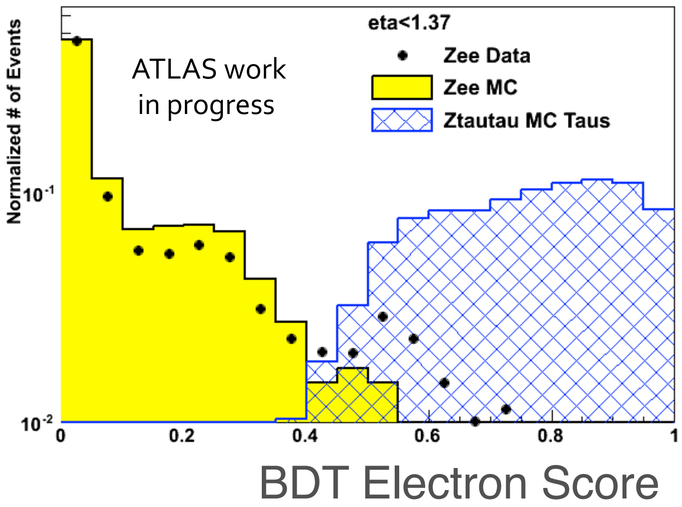
Electrons: Reco τs matching true electrons

"Jets": Reco τs that are neither truth matched to τs nor to electrons.
Many objects fall into this category (some of which are QCD Jets)!

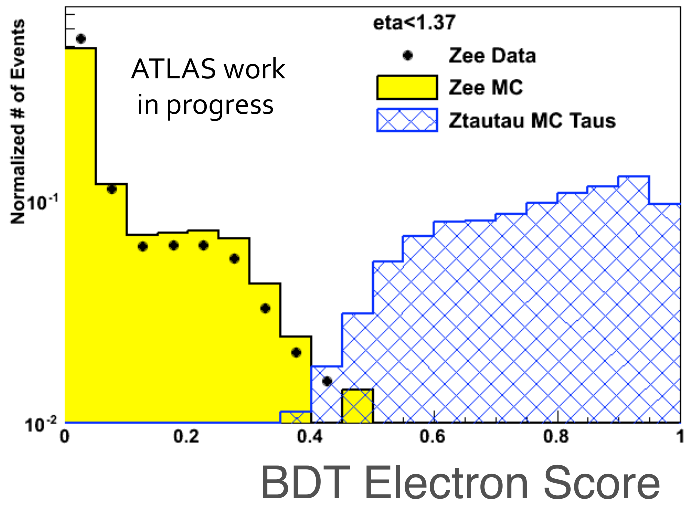
BDTe performs well in a busy environment

BDTe Performance in **2011** 7 TeV Data in Central Region of ATLAS

- A clear separation of the BDTe score for true τs & true electrons
- Good Data/MC agreement



QCD Jet Discriminator applied



Data/MC mismatch comes from QCD jets faking electrons in Z → ee enriched data sample. Once a QCD jet discriminator is applied, mismatch disappears

Conclusions

- The variables used for both electron vetos are well-modeled and exhibit good Data/MC agreement.
- The cut-based electron veto and the BDTe are both approved for use in analyses.
- The misidentification probabilities for electrons to τs after the electron veto have been calculated and used in physics analyses.
- The electron veto is a vital part of controlling backgrounds for channels with τs.

I want to acknowledge collaborators:

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…and the ATLAS Tau Working Group

Thank you.