Tau Lepton Reconstruction and ID with the ATLAS Detector at the LHC

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Outline

- Motivation
- ATLAS detector
- Hadronic tau decays reconstruction
- Hadronic tau decays identification
- Plans for the First Data
- Summary
Physics involving tau's

- Standard Model: large number of $\tau$ from decays of Z and W bosons already with 100 pb$^{-1}$
- Important for the discovery of MSSM Higgs bosons
- Polarisation sensitive to SUSY parameters
- Used in many new physics searches

![Graph of ATLAS results with L = 100 pb$^{-1}$](image)

ATLAS

L = 100 pb$^{-1}$

![Graph of Z' mass distribution](image)

ATLAS Preliminary

$Z' \rightarrow \tau \tau$

L = 1 fb$^{-1}$
ATLAS detector

Muon Detectors

Electromagnetic Calorimeters

Solenoid

Forward Calorimeters

End Cap Toroid

Barrel Toroid

Inner Detector

Hadronic Calorimeters

Shielding
ATLAS Inner Detector

ATLAS Tracking: $|\eta|<2.5$
Detector Intrisic accuracy [\mu m]
Pixel 10 (R-\phi)x115(z)
SCT Barrel 17(R-\phi)x570 (z)
SCT Encap 17(R-\phi)x580(r)
TRT 130(R-\phi)
ATLAS Calorimetry: EM

Liquid Argon EM Calorimeter: $|\eta|<3.2$
- Layer
  - Granularity ($\Delta\eta \times \Delta\phi$)
    - Pre-sampler: 0.025x0.1
    - $\eta$ strips layer: 0.003x0.1
    - Middle layer: 0.025x0.025
    - Back layer: 0.05x0.025

\[ \frac{\sigma_E}{E} = 10.1\% / \sqrt{E} \otimes 0.17\% \]
- Data
Hadronic Calorimeter: $|\eta| < 3.2$

Layer | Granularity ($\Delta \eta \times \Delta \phi$)
--- | ---
0 | 0.1x0.1
1 | 0.1x0.1
2 | 0.2x0.1

$\sigma_{E'/E} = 56.4\% / \sqrt{E} \oplus 5.5\%$
Tau lepton reconstruction

- two complementary reconstruction algorithms:
  - track-based:
    uses tracks as initial reconstruction seed
  - calorimeter-based:
    uses calorimeter clusters as initial seed
- due to the use of tracking reconstruction constrained to $|\eta|<2.5$

Main sources of fake taus:
- QCD jets
- electrons
- muons
Merged reconstruction

1) for each track seed, a jet is searched for within 0.2 cone radius

2) jet is found, then calorimeter-based reconstruction is also run

3) if no jet found within $\Delta R < 0.2$ of track seed, the candidate is track-seed only

4) use remaining jets for the calorimeter-based reco only

- the $(\eta, \phi)$ position of candidate is defined by position of the track-based candidate
- energy of candidate is defined by the calorimeter-based candidate
- the track multiplicity is defined by the track-based candidate
1) seed: high quality leading hadronic track: $p_T > 6$ GeV, requirement for min. number of hits in the SCT and TRT, and $\chi^2$/ndf cuts

2) look for other tracks with $p_T > 1$ GeV in cone $dR < 0.2$ around the leading track:
   a) no additional tracks - single prong candidate
   b) up to two additional tracks - three prong candidate
3) the $(\eta, \phi)$ position of candidate is defined by position at perigee of the leading track, or barycentre of the n-tracks system.

4) the tau candidate energy is estimated using the energy-flow approach:

I. the calo deposits from charged particles are replaced by the tracks momenta.

II. the contribution from $\pi^0$ included, and the effects of $\pi^0$ and $\pi^\pm$ depositing energy in the same calorimeter cells are corrected.

\[ \mu = 1.0 \]
\[ \sigma = 0.08 \]

\[ \mu = 0.97 \]
\[ \sigma = 0.03 \]
Track-based reconstruction

Fine granularity of the ATLAS EM calorimeter allows for identification of the isolated subclusters from $\pi^0$

<table>
<thead>
<tr>
<th>$\tau \to a_1(2\pi^0\pi^\pm)\nu$</th>
<th>no $\pi^0$ subclusters</th>
<th>1 $\pi^0$ subcluster</th>
<th>$\geq 2 \pi^0$ subclusters</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau \to \rho \nu$</td>
<td>9%</td>
<td>34%</td>
<td>57%</td>
</tr>
<tr>
<td>$\tau \to \pi^\pm \nu$</td>
<td>15%</td>
<td>50%</td>
<td>35%</td>
</tr>
</tbody>
</table>

**Table:**

- For $\tau \to a_1(2\pi^0\pi^\pm)\nu$, the probabilities are: 9% for no $\pi^0$ subclusters, 34% for 1 $\pi^0$ subcluster, and 57% for $\geq 2 \pi^0$ subclusters.
- For $\tau \to \rho \nu$, the probabilities are: 15% for no $\pi^0$ subclusters, 50% for 1 $\pi^0$ subcluster, and 35% for $\geq 2 \pi^0$ subclusters.
- For $\tau \to \pi^\pm \nu$, the probabilities are: 65% for no $\pi^0$ subclusters, 20% for 1 $\pi^0$ subcluster, and 15% for $\geq 2 \pi^0$ subclusters.

**Graphs:**

- **Top Graph:**
  - $\tau \to \rho \nu$ with mean = −(2.4 ± 0.2)% and $\sigma = (4.6 ± 0.2)%$.
- **Bottom Graph:**
  - $\tau \to a_1(\to 2\pi^0\pi)\nu$.

**Other Diagram:**

- **ATLAS**
  - One $\pi^0$ subcluster
  - At least one $\pi^0$ subcluster

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1) seed: jets, with $E_T > 10$ GeV
2) all cells with $\Delta R < 0.4$ around the barycentre are H1-style calibrated for energy estimation
3) tracks within $\Delta R < 0.3$ and $p_T > 1$ GeV from the cluster centre are assigned to candidate
Reconstructed candidates matched with truth taus:

- Track seed only - 1%
- Both seeds - 75%
- Calo seed only - 24%
Charge and prong ID

Charge mis-ID $\Delta Q(\text{reco,truth})$

Candidates reconstructed as 1P (one track) and matched with truth tau (had):

$\Delta Q = 0 \rightarrow 98.3\%$

$\Delta Q = 2 \rightarrow 1.7\%$

Candidates reconstructed as 3P (3 tracks, cut on $Q=\pm 1$ on package level) and matched with truth tau (had):

$\Delta Q = 0 \rightarrow 96.4\%$

$\Delta Q = 2 \rightarrow 3.6\%$

Mis-reconstruction

<table>
<thead>
<tr>
<th></th>
<th>1P decay</th>
<th>3P decay</th>
</tr>
</thead>
<tbody>
<tr>
<td>reco as 1 track</td>
<td>96.1%</td>
<td>3.9%</td>
</tr>
<tr>
<td>reco as 2 track</td>
<td>23.8%</td>
<td>76.2%</td>
</tr>
<tr>
<td>reco as 3 track</td>
<td>3.9%</td>
<td>96.2%</td>
</tr>
</tbody>
</table>
Identification

- Both tau reconstruction algorithms provide a large range of identification variables.
- There are many ID methods implemented:
  - Cut based identification
  - Logarithmic likelihood
  - Neural Network
  - Boosted Decision Tree
  - Probability Density Estimators with Range Searches (PDRS)
  - $R_{EM}$ - radius of EM cluster
  - Isolation Fraction – transverse energy deposited in isolation region ($0.1 < \Delta R < 0.2$) divided by the energy in cone $\Delta R < 0.4$
  - EM and Hadronic energies of cluster
  - $\eta$-strip width - width of cluster in the $\eta$-strip layer of EM calorimeter
  - $N_{strip-cells}$ - # of strip cells over energy threshold
  - $N_{track}$ - track multiplicity of tau candidate
Identification variables

\[ R_{EM} = \sum_{i=1}^{n} E_{T,i} \sqrt{(\eta_i - \eta_{\text{cluster}})^2 + (\phi_i - \phi_{\text{cluster}})^2} \]

\[ \Delta \eta = \sqrt{\frac{\sum_{i=1}^{n} E_{T,i}^{\text{strip}} (\eta_i - \eta_{\text{cluster}})^2}{\sum_{i=1}^{n} E_{T,i}^{\text{strip}}}}. \]

\[ \Delta E_{T}^{12} = \frac{\sum_{0.1 < \Delta R < 0.2, j} E_{T,j}}{\sum_{j, \Delta R < 0.4} E_{T,j}} \]

\[ \frac{E_{T}}{p_{T,\text{leading track}}} \]
## Identification performance

### Neural network

<table>
<thead>
<tr>
<th>Selection</th>
<th>Efficiency</th>
<th>Rejection cuts $E_T = 10 - 30$ GeV</th>
<th>Rejection cuts $E_T = 30 - 60$ GeV</th>
<th>Rejection NN</th>
<th>Rejection PDRS</th>
</tr>
</thead>
<tbody>
<tr>
<td>One-prong</td>
<td>0.33</td>
<td>225±10</td>
<td>435±30</td>
<td>510±40</td>
<td>460±40</td>
</tr>
<tr>
<td>Three-prong</td>
<td>0.28</td>
<td>360±25</td>
<td>470±40</td>
<td>740±70</td>
<td>670±60</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.42</td>
<td>140±10</td>
<td>170±10</td>
<td>440±40</td>
<td>320±30</td>
</tr>
<tr>
<td></td>
<td>0.45</td>
<td>60±2</td>
<td>90±10</td>
<td>160±10</td>
<td>130±10</td>
</tr>
</tbody>
</table>

### Logarithmic likelihood

- One-prong, $E_T = 10 - 30$ GeV
- One-prong, $E_T > 100$ GeV
- Three-prong, $E_T = 60 - 100$ GeV
- Three-prong, $E_T > 100$ GeV
Identification performance

- the dedicated algorithm used for rejection of the fake candidates from electrons uses:
  - energy in hadronic calorimeter
  - the ratio of the associated energy in the electromagnetic calorimeter and the track momentum
  - the ratio of the number of high threshold to low threshold hits in the TRT
  - the energy not associated with a charged track in the strip part of the EM calorimeter

$\epsilon_{\text{tau}} = 94.1\%$

$\epsilon_{\text{electron}} = 1.5\%$
Prospects for first data

- selection of “safe variables” for early identification
- estimation of the tau energy scale with data
- evaluation of the Tau ID/Reco efficiencies with real tau event samples
- training of the identification tools with the real data QCD sample

Expected number of events for 100 pb$^{-1}$

<table>
<thead>
<tr>
<th>Process</th>
<th>$W \rightarrow \tau \nu$</th>
<th>$W \rightarrow e \nu$</th>
<th>$W \rightarrow \mu \nu$</th>
<th>QCD</th>
<th>$t \bar{t}$, $Z \rightarrow ee$, $Z \rightarrow \tau \tau$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1550</td>
<td>150</td>
<td>25</td>
<td>500</td>
<td>30</td>
</tr>
<tr>
<td>$Z \rightarrow \tau(-had)\tau(-l)$</td>
<td>520</td>
<td>45</td>
<td>29</td>
<td>&lt;5</td>
<td>10</td>
</tr>
</tbody>
</table>
Fake rate estimation

• Estimation of the fake rate from QCD jets:
  1. selection of $p_T$ balanced, back-to-back dijets events,
  2. one jet selected with “anti-tau” identification – $N_{\text{trk}}>3$ for $p_T<50$ GeV + each additional 50 GeV
  3. second jet used as a “probe object” - selected with default tau identification selections

\[
\text{fake rate} = \frac{\text{probe jets identified as } \tau}{\text{all probe jets}}
\]

<table>
<thead>
<tr>
<th>$p_T$ range (GeV)</th>
<th>Expected stat error for 100 pb$^{-1}$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-40</td>
<td>0.02</td>
</tr>
<tr>
<td>40-80</td>
<td>0.01</td>
</tr>
<tr>
<td>80-120</td>
<td>0.001</td>
</tr>
<tr>
<td>120-160</td>
<td>0.002</td>
</tr>
</tbody>
</table>
Conclusions

Good tau reconstruction efficiency is important for many Standard Model and New Physics analyses

- the ATLAS collaboration has developed robust algorithms for efficient tau reconstruction

- rich set of identification tools can be used to distinguish between real tau leptons and fake candidates from QCD jets and electrons

- With these first taus could be observed in the real data this year