Identification and energy calibration of hadronically decaying tau leptons with the ATLAS experiment.

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Physics with Taus

Higgs → ττ

Charged Higgs search

Z′ → ττ search

SM physics: Z→ττ, ttbar, tau polarization in W→τν, ...
Beyond SM: SUSY searches, charged Higgs, Z′, ...

See backup for documentation of performance and physics results
Hadronic Tau Decays in ATLAS

Discrimination against electrons

Discrimination against QCD jets

Reconstruction

Discrimination against muons

Energy calibration

Trigger

T&P measurements

Electron Veto suppression of electron fakes additional to electron overlap removal

Muon Veto suppression of muon fakes additional to muon overlap removal

Tau Object

Tau Identification (tau ID) discrimination against QCD jets

Tau Energy Scale (TES) calibration of energy, eta tag&probe analyses tests and measurements of efficiencies and TES, using Wtaunu, Ztautau and ttbar events from data

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Tau Lepton

- $m_\tau = 1.777$ GeV
- Most taus decay inside beam pipe
- Hadronic decays: 65%
  - Mainly charged + neutral pions
  - 1 or 3 tracks
  - Energy deposits in EM and HAD calorimeters
- Main background: QCD jets
- Reconstruction:
  - Seeded by anti-$k_T$ jets ($R < 0.4$)
  - Tracks: $p_T > 1$ GeV, $dR < 0.2$
Hadronic Tau Decay Characteristics

- Isolation
- Lateral shape
  - Narrow energy deposition
  - Small track to jet axis distance
- Leading track momentum fraction
- Secondary vertex
- Invariant mass
- $\pi^0$ information
- Longitudinal shower shape
- Transition radiation in TRT

Centrality fraction

$\int L \, dt = 740 \, pb^{-1}, \sqrt{s} = 8 \, TeV$
1-prong, $p_T > 15 \, GeV$

$\text{ATLAS Preliminary}$
Tau Identification

- Boosted Decision Trees (BDTs)
- Separately for jets (tau ID) and electrons (e-veto)
- Separately for 1-prong and 3-prong taus
- Minimum tau $p_T : 15$ GeV
- Pile-up corrected input variables → pile-up robust

Signal efficiency vs number of vertices

- 1 Prong $p_T > 15$ GeV, $|\eta| < 2.5$
- TauBDT loose
- TauBDT medium
- TauBDT tight

Background rejection vs signal efficiency

- 1 Prong $p_T > 15$ GeV, $|\eta| < 2.5$
- TauBDT Summer 2012
- TauBDT Winter 2013

Simulation 2012, $\sqrt{s} = 8$ TeV

ATLAS Preliminary

Data+Simulation 2012, $\sqrt{s} = 8$ TeV

ATLAS Preliminary
Tau Energy Scale (TES)

- Energy scales for taus:
  - EM scale $\rightarrow$ LC scale $\rightarrow$ TES
- TES: compensate differences of reconstructed and true visible energy (MC based)
  - Specific hadron mix
  - Energy loss on the way
  - Pile-up contributions
- Specific for number of tracks $=1$ and $>1$, different $\eta$-regions
Performances Measurements

- $Z \rightarrow \tau_{e/\mu} \tau_{\text{had}}$ tag-and-probe analysis on 2012 data
- Requirements on
  - visible mass $m_{\text{vis}}(e/\mu, \tau_{\text{had-vis}})$
  - missing $E_T$ (direction, transverse mass)

  to suppress $Z \rightarrow ll, W \rightarrow l\nu$
Performance Measurements

- $Z \to \tau_e/\mu \tau_{had}$ tag-and-probe analysis on 2012 data
- Requirements on
  - visible mass $m_{vis}(e/\mu, \tau_{had-vis})$
  - missing $E_T$ (direction, transverse mass) to suppress $Z \to ll$, $W \to l\nu$
- Data-driven background estimation for jet background: Template fit of extended track multiplicity
Performance Measurement: tau ID

- Data/MC correction factors:
  - Combination of $Z \rightarrow \tau_\mu \tau_{\text{had}}$ and $Z \rightarrow \tau_e \tau_{\text{had}}$ results
  - No $p_T$ dependence, small $\eta$ dependence (barrel/end-cap)
  - Uncertainties: (2 – 6)%
- Cross check: $W \rightarrow \tau \nu$ and $t\bar{t}$: Consistent results in all channels
- Outlook: “Continuous” Data/MC correction factors
  → explore full BDT score in physics analysis
Performance Measurement: TES

- (a): Deconvolution method
  - Single particle response
  - Low pileup data taking, MC
- (b): $Z \rightarrow \tau_\mu \tau_{\text{had}}$ tag-and-probe
  - Invariant mass distribution
  - 2012 data
- Uncertainties on total TES (a), Data/MC differences (a,b)
- Uncertainties: $(2 - 4)\%$, depending on $\eta$, $E_T$, number of tracks

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Summary

• BDTs for discrimination of hadronic tau decays from jets and electrons
• Tau energy scale to restore the true visible energy
• Performance measurements on data for validation
  – MC/Data scale factors around 1
  – Uncertainties < 6% (ID) and < 4% (TES)
• All algorithms / measurements are stable with changing pile-up conditions!
-> Visit also the poster on “Identification of hadronically decaying tau leptons with the ATLAS experiment” by Dirk Duschinger!

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Thank you 😊
BACKUP
Tau Performance

- https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TauPublicCollisionPlots
Physics with Taus (CONF notes)

- Higgs $\rightarrow \tau\tau$: ATLAS-CONF-2013-108, [https://cds.cern.ch/record/1632191](https://cds.cern.ch/record/1632191)
- Charged Higgs: ATLAS-CONF-2013-090, [https://cds.cern.ch/record/1595533](https://cds.cern.ch/record/1595533)
- SUSY with taus: ATLAS-CONF-2013-026, [https://cds.cern.ch/record/1525882](https://cds.cern.ch/record/1525882)
- ttbar: ATLAS-CONF-2012-032, [https://cds.cern.ch/record/1432198](https://cds.cern.ch/record/1432198)
- Tau polarization in $W \rightarrow \tau\nu$ events, ATLAS-CONF-2012-009, [https://cds.cern.ch/record/1428549](https://cds.cern.ch/record/1428549)
- Z $\rightarrow \tau\tau$: ATLAS-CONF-2012-006, [https://cds.cern.ch/record/1426991](https://cds.cern.ch/record/1426991)

Complete list: [https://twiki.cern.ch/twiki/bin/view/AtlasPublic/CONFnotes](https://twiki.cern.ch/twiki/bin/view/AtlasPublic/CONFnotes)

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Physics with Taus (published)


Complete list: [https://twiki.cern.ch/twiki/bin/view/AtlasPublic/Publications](https://twiki.cern.ch/twiki/bin/view/AtlasPublic/Publications)
Electron Veto

- Signal eff. (taus) vs background efficiency (electrons)
- Candidates pass loose BDT tau ID and are not overlapping with tight electrons

[Graph showing the relationship between signal efficiency and background efficiency, with different markers for different $|\eta|$ ranges and labels indicating ATLAS Preliminary Simulation $\sqrt{s} = 8$ TeV.]
• Cut-based veto
• Candidates not overlapping with reconstructed muons
• Muons fake taus by failing muon reconstruction
  – Inefficient detector regions
  – Low momentum muons
  – Significant energy loss in HAD calorimeter
Performance Measurement: Trigger

- $Z \rightarrow \tau_\mu \tau_\text{had}$ events
- Efficiency wrt. offline identified taus (BDT medium)
- 20 GeV tau trigger
  - Plateau: $p_T > 35$ GeV
- Uncertainty: $(2 - 8)\%$

- Combined triggers to achieve low $p_T$ thresholds
  - Higgs $\rightarrow \tau \tau$: Di-tau trigger
  - Charged Higgs: tau + $E_T^{\text{miss}}$

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Performance Measurement: Tau ID

- $m_T = \sqrt{2 \cdot p_T(\text{lep}) \cdot E_T^{\text{miss}} \cdot (1 - \cos \Delta \phi(\text{lep}, E_T^{\text{miss}}))}$
- No additional leptons in event
- $42 \text{ GeV} < m_{\text{vis}}(\text{lep}, \tau) < 82 \text{ GeV}$
- $\cos \Delta \phi(\text{lep}, E_T^{\text{miss}}) + \cos \Delta \phi(\tau, E_T^{\text{miss}}) > -0.15$
- OS charge (lep, tau)
- $m_T < 50 \text{ GeV}$
- $\Delta \phi(\tau, \text{lep}) > 2.4$
Extended Track Multiplicity

Tracks are added to the core tracks if they satisfy:

- \( 0.2 < dR(\text{track}, \tau \text{ axis}) < 0.6 \)
- \( p_T(\text{track}) > 500 \text{ MeV} \)
- \( p_T(\text{core track}) / p_T(\text{track}) \cdot dR(\text{core track}, \text{track}) < 0.4 \)
  for at least one of the core tracks

Core tracks satisfy:

- \( p_T(\text{track}) > 1 \text{ GeV}, \ dR(\text{track}, \tau \text{ axis}) < 0.2 \)

General track requirements (distances wrt tau vertex):

- \# \text{ pixel hits} \geq 2, \# \text{ pixel + SCT hits} \geq 7
- \( |d_0| \leq 1.0 \text{ mm} \) (transverse distance of closest approach)
- \( |z_0 \cdot \sin \theta| \leq 1.5 \text{ mm} \) (longitudinal distance of closest appr.)
Outlook

Many studies ongoing:

• Refine reconstruction of decay products (tracks, neutral pions, tau decay substructure)
• Improve energy and position resolution
• Better reject jets, electrons, muons
• Update identification at trigger level
• Provide “continuous” MC/Data correction factors
  → explore full BDT score in physics analysis (instead of pre-defined working points)