POLARIZATION IN $W \rightarrow \tau \nu$ DECAYS AT ATLAS

Jane Cummings, Yale University
on behalf of the ATLAS Collaboration
longitudinal tau polarization: relative production of positive (right-handed) and negative (left-handed) chiral (helicity) states (in relativistic limit) for $\tau^-$

$$P_{\tau} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$$

motivations
- tests of Standard Model
- searches for new physics
- reject irreducible backgrounds

LHC measurements
- $W\rightarrow\tau\nu$ at ATLAS

<table>
<thead>
<tr>
<th>Process</th>
<th>$P_\tau$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W\rightarrow\tau\nu$</td>
<td>-1</td>
</tr>
<tr>
<td>$H\rightarrow\tau\tau$</td>
<td>0</td>
</tr>
<tr>
<td>$H^\pm\rightarrow\tau\nu$</td>
<td>+1</td>
</tr>
<tr>
<td>$Z\rightarrow\tau\tau$</td>
<td>$\approx-0.15$</td>
</tr>
</tbody>
</table>
tau decays

- taus are only leptons on which spin analyses can be performed

<table>
<thead>
<tr>
<th>Channel</th>
<th>Dominant Decay Mode</th>
<th>BR [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e^- \bar{\nu} \nu$</td>
<td>$e^- \bar{\nu}<em>e \nu</em>\tau$</td>
<td>17.82 ± .04</td>
</tr>
<tr>
<td>$\mu^- \bar{\nu} \nu$</td>
<td>$\mu^- \bar{\nu}<em>\mu \nu</em>\tau$</td>
<td>17.39 ± .04</td>
</tr>
<tr>
<td>$h^- \nu$</td>
<td>$\pi^- \nu_\tau$</td>
<td>11.61 ± .06</td>
</tr>
<tr>
<td>$h^- \pi^0 \nu$</td>
<td>$\rho^- \nu_\tau \rightarrow \pi^- \pi^0 \nu_\tau$</td>
<td>25.94 ± .09</td>
</tr>
<tr>
<td>$h^- \pi^0 \pi^0(\pi^0) \nu$</td>
<td>$a_1^- \nu_\tau \rightarrow \pi^- \pi^0 \pi^0 \nu_\tau$</td>
<td>10.85 ± .11</td>
</tr>
<tr>
<td>$h^- h^- h^+(\pi^0) \nu$</td>
<td>$a_1^- \nu_\tau \rightarrow \pi^- \pi^- \pi^+ \nu_\tau$</td>
<td>14.56 ± .07</td>
</tr>
</tbody>
</table>

- measurement restricted to hadronic tau decay channels with a single charged hadron

- maximal parity violation in tau decay: spin orientation strongly correlated with angular decay distributions
polarization observables

• \( \cos \Theta \) – angle between tau line of flight and charged hadron \((\pi, \rho, a_1)\) direction in tau rest frame
  -- cannot reconstruct tau rest frame
  -- \( \cos \Theta \) related to hadronic energy fraction in the lab frame \((E >> m_\tau)\)

\[
\cos \theta = \frac{2E_{\text{vis}}/E_\tau - 1 - m_{\text{vis}}^2/m_\tau^2}{1 - m_{\text{vis}}^2/m_\tau^2}
\]

Not directly observable in \(W\rightarrow\tau\nu\) decays at hadron collider

• Spin analysis on intermediate vector meson \((\rho, a_1)\) yields a second observable:
  \( \cos \Psi \) – angle between vector meson line of flight and charged pion direction in meson rest frame
  -- related to energy sharing between charged and neutral pions in lab frame

\[
\cos \psi = \frac{m_\nu}{\sqrt{m_\nu^2 - 4m_\pi^2}} \frac{E_{\pi} - E_{\pi^0}}{||p_\pi - p_{\pi^0}||}
\]

** increased sensitivity in \(\tau \rightarrow \rho \nu\) channel + experimentally accessible observables
Charged Asymmetry

\[ E_{T}^{\pi^{-}} - E_{T}^{\pi^{0}} \approx 2 \frac{p_{T}^{\text{trk}}}{p_{T}} - 1 = \Upsilon \]

* optimized for \( \tau \rightarrow \rho \nu \) decay mode

Right-Handed distribution: asymmetric energy sharing (longitudinal \( \rho \))

Left-Handed distribution: symmetric energy sharing (transverse \( \rho \))
event selection

- 24 pb^{-1} collected (2010) with combined tau (p_T>16 GeV) and missing transverse energy (E_T^{miss}>22 GeV) trigger

1. one identified jet-seeded tau with transverse momentum in range [20 GeV,60 GeV] with a single reconstructed track
2. missing transverse energy E_T^{miss}>30 GeV
3. reject events with jet activity in the barrel – end-cap transition region
4. reject events with an identified electron or muon with p_T>15 GeV
5. reject events with jet activity along the direction of reconstructed E_T^{miss}
6. missing transverse energy significance: $S_{E_T^{miss}} = \frac{E_T^{miss}}{\sigma(E_T^{miss})} = \frac{E_T^{miss}}{0.5 \sqrt{\sum E_T}} \geq 6$

## Sample Composition

<table>
<thead>
<tr>
<th>Sample</th>
<th>Number of Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>1136</td>
</tr>
<tr>
<td>Electroweak Background</td>
<td>138 ± 4</td>
</tr>
<tr>
<td><em>EW background estimated from simulation</em></td>
<td></td>
</tr>
<tr>
<td>Left-Handed Signal</td>
<td></td>
</tr>
<tr>
<td>( W \rightarrow \tau_L \nu )</td>
<td>1002 ± 16</td>
</tr>
<tr>
<td><em>Multijet background estimated from control sample in data and corrected for EW contamination – results in polarization-dependent normalization</em></td>
<td></td>
</tr>
<tr>
<td>Right-Handed Signal</td>
<td></td>
</tr>
<tr>
<td>( W \rightarrow \tau_R \nu )</td>
<td>1523 ± 22</td>
</tr>
<tr>
<td><em>Multijet background</em></td>
<td>79 ± 4</td>
</tr>
</tbody>
</table>

Kinematics in left- and right-handed tau decays yield greater acceptance for right-handed taus which tend to be harder than left-handed taus.
kinematic distributions

**Tau Transverse Momentum**

* normalized to integrated luminosity; decay kinematics affect the shape and acceptance in left-handed and right-handed simulated distributions

RED: simulated right-handed tau decay distributions
BLACK: simulated left-handed tau decays

---

**Electromagnetic Radius**

---

OCT 09 2012 -- EWWG

J Cummings, Yale University
MISSING TRANSVERSE ENERGY

* tau $p_T$ and missing $E_T$ cuts increase sensitivity to tau polarization measurement in $W$-$\tau\nu$ decays by rejecting $\tau$-$\pi\nu$ decay modes for which $Y$ is not optimized; more pronounced in left-handed signal
Extraction of Tau Polarization

- Fit observed charged asymmetry in data to linear combination of right-handed and left-handed templates w. simulated samples and EW backgrounds plus multijet data
- Maximize binned log-likelihood (constructed as product of poisson terms w. fit parameters for overall Monte Carlo samples normalization and multijet normalization)

Fit Result: $P_\tau = -1.06 \pm 0.04\text{(stat)}$
systematic uncertainty

• ‘shifted’ templates produced for each source of systematic uncertainty and new fit value – nominal fit value gives $\Delta P_\tau$

<table>
<thead>
<tr>
<th>Source</th>
<th>$+\Delta P_\tau$</th>
<th>$-\Delta P_\tau$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy scale central</td>
<td>0.042</td>
<td>0.063</td>
</tr>
<tr>
<td>Energy scale forward</td>
<td>0.007</td>
<td>0.002</td>
</tr>
<tr>
<td>$E_T^{\text{miss}}$ resolution</td>
<td>0.014</td>
<td>–</td>
</tr>
<tr>
<td>No FCAL</td>
<td>0.003</td>
<td>–</td>
</tr>
<tr>
<td>$\tau$ identification</td>
<td>0.005</td>
<td>0.006</td>
</tr>
<tr>
<td>Trigger</td>
<td>0.007</td>
<td>0.006</td>
</tr>
<tr>
<td>MC model</td>
<td>0.020</td>
<td>0.020</td>
</tr>
<tr>
<td>W cross-section</td>
<td>0.005</td>
<td>0.005</td>
</tr>
<tr>
<td>Z cross-section</td>
<td>0.006</td>
<td>0.006</td>
</tr>
<tr>
<td>Combined</td>
<td>0.05</td>
<td>0.07</td>
</tr>
</tbody>
</table>

scale factors applied to jet energy calibration and tau energy scales for all clusters in central region

nominal templates produced with HERWIG++ generated signal samples; comparison to PYTHIA6
Bayesian 95% credibility interval restricted to physically allowed range [-1,-0.91]

\[ P_{\tau} = -1.06 \pm 0.04 \text{ (stat)}^{+0.05}_{-0.07} \text{ (syst)} \]
“Measurement of τ polarization in W→τν decays with the ATLAS detector in pp collisions at \( \sqrt{s}=7\,\text{TeV} \)” EPJC 72 (2012) 2062
http://www.springerlink.com/content/3h24r0j573181876/

*generic method for measuring tau polarization
& systematic uncertainties are relatively small
& first measurement of tau polarization at a hadron collider
& first probe of helicity structure in Wτν coupling at high \( Q^2 \)
& results consistent with Standard Model

* measure tau polarization in any tau production mechanism
& characterize coupling to taus in event of discovery
& use as discriminating variable in searches
Fitting Method

\[ T_i(N_{MC}, P_\tau, N_{MJ}) = N_{MC} \left[ \left( \frac{1 + P_\tau}{2} \right) S_i^L \mu_{s_i^L} + \left( \frac{1 + P_\tau}{2} \right) S_i^R \mu_{s_i^R} \right] + N_{MC} \cdot \left[ \sum_j b_j \mu_{b_j} \right] + N_{MJ} \cdot q_i \]

- Tau Polarization parameter of interest – weights the relative contributions of left- and right-handed signals
- Parameters for the left-handed and right-handed signal contributions scaled to cross section x integrated luminosity
- Parameters for the EW background process contributions scaled to cross section x integrated luminosity
- Normalization parameter for the Monte Carlo (signals and EW backgrounds)
- Normalization parameter for the multijet background
- Multijet background parameter corrected for EW contamination

Maximize binned log-likelihood for likelihood constructed per bin i:

\[ \mathcal{L}[i] = \frac{e^{-T_i(T_i)} N_i}{N_i!} \cdot \prod_{k=L,R} \frac{e^{-s_k^i} (s_k^i)^{S_i^k}}{S_i^k!} \cdot \prod_j \frac{e^{-b_j^i} (b_j^i)^{B_j^i}}{B_j^i!} \cdot \frac{e^{-q_i} (q_i)^{Q_i}}{Q_i!} \]

- \( N_i, S_i^L, S_i^R, B_j^i, Q_i \): number of events* per bin in data, left-handed (right-handed) signal, \( j \)th EW background, and multijets (*prior to scaling for MC samples)
**MULTIJET BACKGROUND**

- Shape of multijet contribution to charged asymmetry distributions taken from region D
- Correction factors applied for EW contamination per bin
- Overall multijet background normalization included as fit parameter

EW Corrections:

\[
N_{\text{corrected}}^i = N^i - c_i (N^A - N_{QCD}^A)
\]

\[
c_i = \frac{N_{\text{sig}}^i + N_{EW}^i}{N_{\text{sig}}^A + N_{EW}^A}
\]

\[
N_{QCD}^A = N^B \times \frac{N^C}{N^D}
\]