Study of tau-pair production at HERA

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Lepton-pair production at HERA

- Lepton-pair production at ep collision
  - 27.5 GeV electron or positron + 920 GeV proton
  - Main process: photon-photon collision
  - Can be test of electroweak interaction in SM
  - Deviation from SM → hint for new physics

Bethe-Heitler
γ (Z⁰) - γ (Z⁰) collision

Cabbibo-Parisi
QED-Compton

Drell-Yan
Pair production from radiated photon

Lepton-pair production cross-section at HERA
tau-pair production at HERA

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- tau channel
  - Signal: combinations of e, $\mu$ and jet from $\tau$ decay

$\tau^+ \tau^- \rightarrow \begin{cases} 
  e^+ + e^- + \nu' s + \cdots \quad (BR: 3\%) \\
  \mu^+ + \mu^- + \nu' s + \cdots \quad (BR: 3\%) \\
  e^+ + \mu^- + \nu' s + \cdots \quad (BR: 7\%) \\
  e^+ + h^\mp + \nu' s + \cdots \quad (BR: 23\%) \\
  \mu^+ + h^\mp + \nu' s + \cdots \quad (BR: 22\%) \\
  h^\pm + h^\mp + \nu' s + \cdots \quad (BR: 42\%) 
\end{cases}$

Hardly distinguishable from di-electron and di-muon

$\sigma \sim 10$ pb ($p_T^{\tau} > 5$ GeV)
tau-pair study at ZEUS

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- Study at ZEUS
  - 0.33 fb$^{-1}$ HERA II data (2004-2007)
    - electron + proton: 0.18 fb$^{-1}$
    - positron + proton: 0.15 fb$^{-1}$

Hardly distinguishable from di-electron and di-muon

\[
\begin{align*}
\tau^+\tau^- & \rightarrow e^+e^- + \nu's + \cdots \quad (BR: 3\%) \\
& \quad \mu^+\mu^- + \nu's + \cdots \quad (BR: 3\%) \\
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& \quad \mu^+h^- + \nu's + \cdots \quad (BR: 22\%) \\
& \quad h^+h^- + \nu's + \cdots \quad (BR: 42\%)
\end{align*}
\]
tau-pair selection

(1) Low track multiplicity
- Number of tracks: $2 \leq N_{trk} \leq 7$

(2) (Quasi-)elastic selection
- No energy deposit ($<1\text{GeV}$) in forward calorimeter
- Suppress NC DIS ($e p \rightarrow eX$) and photoproduction ($\gamma p \rightarrow X$) BG

(3) Identification of tau decay
   (3a) tau-jet identification
     - Multi variable discrimination
   (3b) Electron identification
     - Track and calorimeter matching
   (3c) Muon identification
     - Track, calorimeter and muon chamber matching

(4) Charge cut
- Two decay candidates should have opposite charge
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tau-jet identification

- **tau-jet**
  - Low multiplicity
  - Pencil-like shape
  - Track charge = ±1

- **QCD jet**
  - High multiplicity
  - Broad shape

→ Identify hadronic tau decay by a multi-variable discrimination technique based on the characteristics.
**tau-jet identification**

1. **1st and 2nd moment of radial extension**

   \[
   R_{\text{mean}} = \langle R \rangle = \frac{\sum_i \{E_i \cdot R_i\}}{\sum_i E_i}, \quad R_{\text{rms}} = \sqrt{\frac{\sum_i E_i \cdot (\langle R \rangle - R_i)^2}{\sum_i E_i}}
   \]

2. **1st moment of longitudinal extension**

   \[
   L_{\text{mean}} = \langle L \rangle = \frac{\sum_i E_i \cdot \cos \alpha_i}{\sum_i E_i}
   \]

3. **Invariant mass clustered CAL cells**

   \[
   M_{\text{jet}} = \sqrt{\left(\sum_i E_i\right)^2 - \left(\sum_i p_{i,x}\right)^2 - \left(\sum_i p_{i,y}\right)^2 - \left(\sum_i p_{i,z}\right)^2}
   \]

4. **No. of subjets \((y>5 \times 10^{-4})\)**

   \[
   N_{\text{subjets}}
   \]

5. **Sum of distance between jet axis and tracks associated with jet**

   \[
   R_{\text{trk}} = \sum_i^{N_{\text{trk}}} \sqrt{(\Delta \eta_i^2 + \Delta \phi_i^2)}
   \]

Signal: tau-jet
Background: QCD-jet
tau-jet identification

- 1st and 2nd moment of radial extension
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- 1st moment of longitudinal extension
  \[ L_{\text{mean}} = \langle L \rangle = \frac{\sum_i E_i \cdot \cos \alpha_i}{\sum_i E_i} \]

- Invariant mass clustered CAL cells
  \[ M_{\text{jet}} = \sqrt{\left( \sum_i E_i \right)^2 - \left( \sum_i p_{i,x} \right)^2 - \left( \sum_i p_{i,y} \right)^2 - \left( \sum_i p_{i,z} \right)^2} \]

- No. of subjets \((y>5 \times 10^{-4})\) \(N_{\text{subjets}}\)

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  \[ R_{\text{trk}} = \sum_i^{N_{\text{trk}}} \sqrt{(\Delta \eta_i^2 + \Delta \phi_i^2)} \]
tau-jet identification

- 1\textsuperscript{st} and 2\textsuperscript{nd} moment of radial extension

\[ R_{\text{mean}} = \langle R \rangle = \frac{\sum_i \{ E_i \cdot R_i \}}{\sum_i E_i} \quad \text{and} \quad R_{\text{rms}} = \sqrt{\frac{\sum_i E_i \cdot (\langle R \rangle - R_i)^2}{\sum_i E_i}} \]

- 1\textsuperscript{st} moment of longitudinal extension

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- **No. of subjets (y>5×10^{-4})** \[ N_{\text{subjets}} \]

- **Sum of distance between jet axis and tracks associated with jet**
  \[ R_{\text{trk}} = \sum_i^{N_{\text{trk}}} \sqrt{(\Delta \eta_i^2 + \Delta \phi_i^2)} \]
tau-jet identification

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No. of subjets \((y > 5 \times 10^{-4})\) \(N_{\text{subjets}}\)

Sum of distance between jet axis and tracks associated with jet
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- No. of subjets \((y>5\times10^{-4})\) \(N_{\text{subjets}}\)

- Sum of distance between jet axis and tracks associated with jet

\[
R_{\text{trk}} = \sum_i^{N_{\text{trk}}} \sqrt{(\Delta \eta_i)^2 + (\Delta \phi_i)^2}
\]
Discriminant for tau jets

- Expansion of likelihood approach to n-dimensions
- Count number of signal and background events (training sample) nearby test event

\[ D(\tilde{x}) = \frac{\rho_{\text{sig}}(\tilde{x})}{\rho_{\text{sig}}(\tilde{x}) + \rho_{\text{bkg}}(\tilde{x})} \]

(e)-jet-jet channel (BR: 42%)

Selection criteria
- Jet
  - $p_T > 5\text{ GeV}$
  - $|\eta| < 2$
  - $D > 0.8$
- Opposite charge for two jets

Results
- $14.4^{+2.2}_{-3.5}$ events expected
- $9.0^{+0.4}_{-0.3}$ tau-pair (purity 63%)
- BG: photoproduction
- 10 events observed
(e)-e-jet channel (BR: 23%)

Selection criteria

- **Electron**
  - $p_T > 2$ GeV, $17^\circ < \theta < 160^\circ$
  - Opposite charge to beam ($\theta > 1$)

- **Jet**
  - $p_T > 5$ GeV, $|\eta| < 2$
  - $D > 0.8$

- Opposite charge for e and jet

Results

- $8.8^{+1.8}_{-0.8}$ events expected
  - $5.3^{+0.3}_{-0.2}$ tau-pair (purity 60%)
  - BG: di-electron, DIS

- 7 events observed
(e)- $\mu$ -jet channel (BR: 22%)

Selection criteria

- Muon
  - $p_T > 2$ GeV, $34^\circ < \theta < 157^\circ$
- Jet
  - $p_T > 5$ GeV, $|\eta| < 2$
  - $D > 0.8$
- Opposite charge for $\mu$ and jet

Results

- $8.0^{+2.2}_{-1.2}$ events expected
- $5.9^{+0.5}_{-0.5}$ tau-pair (purity 73%)
- BG: di-muon, photoproduction
- 4 events observed
(e)-e- $\mu$ channel (BR: 7\%)

Selection criteria

- **Electron**
  - $p_T > 2$ GeV, $17^\circ < \theta < 160^\circ$
  - Opposite charge to beam ($\theta > 1$)

- **Muon**
  - $p_T > 2$ GeV, $34^\circ < \theta < 157^\circ$
  - Opposite charge for e and $\mu$

Results

- $3.6^{+1.3}_{-0.3}$ events expected
- $3.0^{+0.3}_{-0.2}$ tau-pair (purity 82\%)
- BG: di-muon, DIS
- 4 events observed
Results (all channels)

- tau-pair events at HERA II (L=0.33fb\(^{-1}\))
  \[ \sigma = 3.26 \pm 1.30 \text{(stat.)} ^{+0.99}_{-0.73} \text{(syst.)} \text{ pb} \]

- Kinematic region:
  \[ p_T > 5 \text{ GeV, } 17^\circ < \theta < 160^\circ \]

- SM prediction: \(5.67 \pm 0.16 \text{ pb}\)

- Data agree with SM prediction

<table>
<thead>
<tr>
<th>Topology</th>
<th>(e-)e- (\mu)</th>
<th>(e-)e-jet</th>
<th>(e-)(\mu) -jet</th>
<th>(e-)jet-jet</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>4</td>
<td>7</td>
<td>4</td>
<td>10</td>
<td>25</td>
</tr>
<tr>
<td>Total MC</td>
<td>(3.6^{+1.3}_{-0.3})</td>
<td>(8.8^{+1.8}_{-0.8})</td>
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</tr>
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<td>(\tau^+ \tau^-) MC</td>
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</tr>
<tr>
<td>Purity</td>
<td>82%</td>
<td>60%</td>
<td>73%</td>
<td>63%</td>
<td>67%</td>
</tr>
</tbody>
</table>
Results (all channels)

- Tau-pair events at HERA II (L=0.33 fb\(^{-1}\))

- \(\sigma = 3.26 \pm 1.30 \text{(stat.)}^{+0.99}_{-0.73} \text{(syst.)} \text{ pb}\)

- Kinematic region:
  - \(p_T > 5 \text{ GeV}, \quad 17^\circ < \theta < 160^\circ\)

- SM prediction: 5.67 \(\pm 0.16 \text{ pb}\)

- Data agree with SM prediction

- No excess at high \(p_T\) and \(M_{\tau\tau}\)

- No evidence of physics beyond SM
Summary

- Tau-pair production at electron(positron)-proton collision was studied at ZEUS
  - Integrated luminosity of 0.33fb⁻¹ at HERA II
  - Beam energy: 27.5GeV (e±) and 920GeV (p)
- 25 tau-pair candidates were found with 67% purity
- Cross-section was measured in kinematic region: 
  \[ p_T(\tau) > 5\text{GeV}, \ 17^\circ < \theta(\tau) < 160^\circ \text{ (acceptance of 1.23\% due to } p_T \text{ cut)} \]
  - \( \sigma = 3.26 \pm 1.30 \text{(stat.)} ^{+0.99}_{-0.73} \text{(syst.)} \text{ pb} \)
  - (SM prediction: 5.67 ±0.16 pb (theor.))