Tau leptons at HERA

S. Xella
University of Zurich
Switzerland

On behalf of the H1 collaboration

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Production of $\tau$ leptons in $e^\pm p$ collisions at HERA

$\tau$ lepton pair production

Events with large missing $p_T$ and a high $p_T$ isolated $\tau$

Dominant source of $\tau$ leptons within SM: $\sigma (p_T^{\tau} > 2\text{ GeV}) \approx 20\text{ pb}$

Very rare process within SM: $\sigma \cdot \text{Br}(W \rightarrow \tau \nu) \approx 0.1\text{ pb}$

In this talk:
- Final results on study of tau lepton production on HERA I data:
  hep-ex/0604022 , DESY-06-029 , H1-150
- Preliminary results on HERA II data

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# Properties of $\tau$ leptons

<table>
<thead>
<tr>
<th>Mass</th>
<th>1777.0 ± 0.3 MeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>$c\tau$</td>
<td>87.11 ± 0.33 $\mu$m</td>
</tr>
</tbody>
</table>

**Leptonic decay modes**

- $\tau \rightarrow e\nu$: 17%
- $\tau \rightarrow \mu\nu$: 18%

**Hadronic 1-prong decay modes**

- $\tau \rightarrow \pi^\pm \nu$: 11%
- $\tau \rightarrow \rho^\pm \nu \rightarrow \pi^\pm \pi^0 \nu$: 25%
- $\tau \rightarrow \pi^\pm \pi^0 \pi^0 \nu$: 9%

**Hadronic 3-prong decay modes**

- $\tau \rightarrow \pi^\pm \pi^\pm \pi^\pm \nu$: 10%
- $\tau \rightarrow \pi^\pm \pi^\pm \pi^0 \nu$: 4%

Only decay products observed in detector, Decay vertex difficult to reconstruct

Very difficult to distinguish from $e/\mu$ from primary interaction

Collimated jets of low particle multiplicity

Non isolated $\tau$ leptons experimentally not accessible

$\tau \equiv \text{Isolated } \tau$
Study of $\tau^+\tau^-$ production:

**Strategy**

Study *elastic* production of $\tau^+\tau^-$ events

Use the following decay modes:

- $\tau \rightarrow e \rightarrow \mu$ (leptonic) $\approx 6\%$
- $\tau \rightarrow e/\mu \rightarrow$ hadrons (semileptonic) $\approx 45\%$, clean
- $\tau \rightarrow$ hadrons $\rightarrow$ hadrons (hadronic) $\approx 42\%$, adds statistics, less clean $\rightarrow$ tau identification

For $\tau$ hadronic decay modes use a Neural Network analysis to distinguish:

- Hadronic 1-prong and 3-prong $\tau$ decays from quark/gluon jets ($L_{1\text{-prong}}, L_{3\text{-prong}}$)
- Hadronic 1-prong $\tau$ decays from unidentified electrons and muons ($L_e, L_\mu$)

$L \in [0,1]$ with Background $\rightarrow 0$ and Signal ($\tau$) $\rightarrow 1$
## Study of $\tau^+\tau^-$ production: Selection

<table>
<thead>
<tr>
<th>Selection</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isolated e</td>
<td>$20^\circ &lt; \theta_e &lt; 140^\circ$</td>
</tr>
<tr>
<td></td>
<td>$p_T^e &gt; 3$ GeV</td>
</tr>
<tr>
<td>Isolated $\mu$</td>
<td>$20^\circ &lt; \theta_\mu &lt; 140^\circ$</td>
</tr>
<tr>
<td></td>
<td>$p_T^\mu &gt; 2$ GeV</td>
</tr>
<tr>
<td>Isolated jet</td>
<td>$20^\circ &lt; \theta_{\text{jet}} &lt; 120^\circ$</td>
</tr>
<tr>
<td></td>
<td>$p_T^{\text{jet}} &gt; 2$ GeV</td>
</tr>
<tr>
<td></td>
<td>$L_{1\text{-prong}} \parallel L_{3\text{-prong}} &gt; 0.75$</td>
</tr>
<tr>
<td>$\tau^+\tau^-$ pair</td>
<td>Two isolated e or $\mu$ or jets of opposite charges</td>
</tr>
<tr>
<td>Elastic Production</td>
<td>Nothing else</td>
</tr>
<tr>
<td>Veto NC DIS</td>
<td>$E-P_z &lt; 50$ GeV</td>
</tr>
<tr>
<td>Veto $e^+ e^-$</td>
<td>$L_e &gt; 0.75$ if final state has isolated e and 1-prong jet</td>
</tr>
<tr>
<td>Veto $\mu^+ \mu^-$</td>
<td>$L_\mu &gt; 0.75$ if final state has isolated $\mu$ and 1-prong jet</td>
</tr>
</tbody>
</table>

Signal eff. 50%  
Background rej. 0.5%, 4%
Study of $\tau^+\tau^-$ production: Backgrounds

- **q/g jet misidentified as $\tau$ jet**
- **unidentified e misidentified as 1-prong $\tau$ jet**
- **unidentified $\mu$ misidentified as 1-prong $\tau$ jet**
- **e/\mu interpreted as $\tau \rightarrow e/\mu$**

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Study of $\tau^+\tau^-$ production: Background control samples

Main backgrounds: $\gamma\gamma \rightarrow e^+e^-, \mu^+\mu^-$ NC, $\gamma p$

Dedicated control samples selected to study background description and tau identification

- $e^+ e^-$ control
  - $N_{data} = 115$
  - $N_{SM} = 133.1 \pm 19.5$
  - $N_{e^+e^-} = 126.9 \pm 19.4$

- $\mu^+ \mu^-$ control
  - $N_{data} = 20$
  - $N_{SM} = 14.1 \pm 1.4$
  - $N_{\mu^+\mu^-} = 7.1 \pm 1.3$

- $\gamma p$ control
  - $N_{data} = 21$
  - $N_{SM} = 13.3 \pm 4.0$
  - $N_{\gamma p} = 7.8 \pm 4.0$

- $\gamma p$ control
  - $N_{data} = 14$
  - $N_{SM} = 18.6 \pm 7.4$
  - $N_{\gamma p} = 14.6 \pm 7.4$

Graphs showing $\tau$ jet candidates with various backgrounds for $e^+ e^-$, $\mu^+ \mu^-$, and $\gamma p$ channels.
Study of $\tau^+\tau^-$ production: Results Hera I (106 pb$^{-1}$)

Number of events passing $\tau^+\tau^-$ selection

<table>
<thead>
<tr>
<th>Decay channel</th>
<th>Leptonic $e\mu$</th>
<th>Semileptonic $e\tau$-jet</th>
<th>$\mu\tau$-jet</th>
<th>Hadronic $\tau$-jet $\tau$-jet</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1 Data</td>
<td>7</td>
<td>2</td>
<td>10</td>
<td>11</td>
<td>30</td>
</tr>
<tr>
<td>SM</td>
<td>2.9±0.4 56%</td>
<td>6.3±0.9 47%</td>
<td>7.0±1.3 85%</td>
<td>11.0±2.0 50%</td>
<td>27.1±4.1 59%</td>
</tr>
<tr>
<td>$\tau^+\tau^-$</td>
<td>2.9±0.4 56%</td>
<td>6.3±0.9 47%</td>
<td>7.0±1.3 85%</td>
<td>11.0±2.0 50%</td>
<td>27.1±4.1 59%</td>
</tr>
</tbody>
</table>

Purest final state

Total number of events observed is in agreement with SM expectation
H1

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$\tau^+\tau^-$ Production Cross Section

Phase space definition: elastic events with two $\tau$ leptons of

- $p_{\tau T} > 2$ GeV  
  acceptance $\approx 1\%$
- $20^\circ < \theta_\tau < 140^\circ$

First time at HERA!

\[ \sigma_{\text{measured}} = 13.6 \pm 5.7 \text{ pb} \]
\[ \sigma_{\text{expected}} = 11.2 \pm 0.3 \text{ pb} \]
Search for events with an isolated $\tau$ and large missing $p_T$

Search motivated by excess observed at high $p_T^X$ in the search for Isolated electrons and muons (see D.South, this conference)

An excess at high $p_T^X$ could be a sign of new physics
E.g. Single top production

Additional high $p_T$ jet $\rightarrow$ Large $p_T^X$
## Search for $\tau + \text{large } p_T^{\text{miss}}$

### Selection

<table>
<thead>
<tr>
<th>Large missing momentum</th>
<th>$P_T^{\text{miss}} &gt; 12 \text{ GeV}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isolated jet</td>
<td>$20^\circ &lt; \theta_{\text{jet}} &lt; 120^\circ$  $p_{\text{jet}}^T &gt; 7 \text{ GeV}$</td>
</tr>
<tr>
<td>Veto NC DIS</td>
<td>$E-Pz &lt; 50 \text{ GeV}$</td>
</tr>
<tr>
<td>Veto NC and $\gamma P$</td>
<td>$\Delta \phi (\tau - X) &lt; 170^\circ$  $V_{\text{ap}}/V_{\text{p}} &lt; 0.5$ ($V_{\text{ap}}/V_{\text{p}} &lt; 0.15$ if $P_{\text{Calo}} &lt; 25 \text{ GeV}$)</td>
</tr>
<tr>
<td>$\tau$ Identification Veto CC</td>
<td>Only 1 charged track in isolated jet  $R_{\text{jet}} &lt; 0.12$  $p_{T}^{\text{track}} &gt; 5 \text{ GeV}$</td>
</tr>
</tbody>
</table>

**Signal eff. $\approx 80\%$**  
**Background rej $\approx 1\%$**

$R_{\text{jet}} = \text{Radius of the jet = Energy weighted distance in } (\eta, \phi)$ of each hadron in the jet from the jet axis
Search for $\tau +$ large $p_T^{\text{miss}}$:

**Backgrounds**

<table>
<thead>
<tr>
<th>Charged Current</th>
<th>$\gamma p$</th>
<th>Neutral Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e (k^e)$</td>
<td>$e$</td>
<td>$e'(k'^e)$</td>
</tr>
<tr>
<td>$\nu (k'^\nu)$</td>
<td>$q$</td>
<td>$\gamma, Z^0$</td>
</tr>
<tr>
<td>$W^\pm (q''^\pm)$</td>
<td>$q$</td>
<td>$q'$</td>
</tr>
<tr>
<td>$p (p^h)$</td>
<td>$p$</td>
<td>$p (p^h)$</td>
</tr>
<tr>
<td>$X$</td>
<td>$X$</td>
<td>$X$</td>
</tr>
</tbody>
</table>

Main background

- q/g jet misidentified as $\tau$ jet
- e misidentified as 1-prong $\tau$ jet
- $p_T^{\text{miss}}$ due to mismeasurement

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Search for $\tau + \text{large } p_T^{\text{miss}}$: Background control samples

Main backgrounds: CC, $\gamma P$, NC

Dedicated control samples selected to study background description and tau identification.
Search for $\tau + \text{large } p_T^{\text{miss}}$: Results Hera I (115 pb$^{-1}$)

Number of events passing $\tau + \text{large } p_T^{\text{miss}}$ selection

<table>
<thead>
<tr>
<th></th>
<th>H1 Data</th>
<th>Total SM expectation</th>
<th>SM signal (W)</th>
<th>Other SM Processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>6</td>
<td>9.9 ± 3.0</td>
<td>0.89 ± 0.20</td>
<td>9.0 ± 3.0</td>
</tr>
<tr>
<td>$p_T^X &gt; 25$ GeV</td>
<td>0</td>
<td>0.39 ± 0.10</td>
<td>0.20 ± 0.05</td>
<td>0.19 ± 0.09</td>
</tr>
</tbody>
</table>

Number of events observed is compatible with SM expectation
No event observed at high $p_T^X$

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Cross section limit for $\tau + p_T^{\text{miss}}$ processes

Cross section upper limit at 95\% C.L. for $p_T^X > 25$ GeV

Phase space definition
- $p_\tau > 10$ GeV
- $5^\circ < \theta_\tau < 140^\circ$
- $p_T^{\text{miss}} > 12$ GeV

Accept. $\approx$ 8\%

$\sigma(p_T^X > 25 \text{ GeV}) < 0.31$ pb


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Search for $\tau + \text{large } p_T^{\text{miss}}$:
Results Hera I + II (278 pb$^{-1}$)

e$^+p$ and e$^-p$ samples, 278 pb$^{-1}$

New H1 preliminary result on Hera I and Hera II data
→e$^+p$ and e$^-p$ samples have now comparable sizes

<table>
<thead>
<tr>
<th>H1 Preliminary</th>
<th>H1 Data</th>
<th>Total SM expectation</th>
<th>SM signal (W)</th>
<th>Other SM Processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>94–05 e$^{\pm}$p 278 pb$^{-1}$</td>
<td>Total</td>
<td>25</td>
<td>$24.2 \pm 5.0$</td>
<td>$2.0 \pm 0.37$</td>
</tr>
<tr>
<td></td>
<td>$P_T^X &gt; 25 \text{ GeV}$</td>
<td>3</td>
<td>$0.74 \pm 0.18$</td>
<td>$0.44 \pm 0.08$</td>
</tr>
</tbody>
</table>
Search for $\tau +$ large $p_T^{\text{miss}}$:
Results Hera I + II, $e^+ p$ and $e^- p$

<table>
<thead>
<tr>
<th>H1 Preliminary</th>
<th>H1 Data</th>
<th>Total SM expectation</th>
<th>SM signal (W)</th>
<th>Other SM Processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>94–04 $e^+ p$ 153 pb$^{-1}$</td>
<td>Total</td>
<td>8</td>
<td>$10.6 \pm 2.9$</td>
<td>$1.1 \pm 0.23$</td>
</tr>
<tr>
<td></td>
<td>$P_T^X &gt; 25$ GeV</td>
<td>0</td>
<td>$0.40 \pm 0.10$</td>
<td>$0.24 \pm 0.05$</td>
</tr>
<tr>
<td>98–05 $e^- p$ 125 pb$^{-1}$</td>
<td>Total</td>
<td>17</td>
<td>$13.5 \pm 2.6$</td>
<td>$0.9 \pm 0.15$</td>
</tr>
<tr>
<td></td>
<td>$P_T^X &gt; 25$ GeV</td>
<td>3</td>
<td>$0.35 \pm 0.09$</td>
<td>$0.19 \pm 0.03$</td>
</tr>
</tbody>
</table>
H1 preliminary

H1 $\tau + P_T^{\text{miss}}$ candidate with large $P_T^X$

$P_T^{\text{miss}} = 28$ GeV  $P_T^\tau = 13$ GeV  $P_T^X = 39$ GeV

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Summary

The production of tau pairs in ep collisions has been studied for the first time at HERA, with 106 pb$^{-1}$ of data. The measured cross section is

$$\sigma_{\tau^+\tau^-} = 13.6 \pm 5.7 \text{ pb}$$
compatible with the expected value of 11.2 ± 0.3 pb

The search for isolated tau leptons in events with large missing momentum has been finalized on 115 pb$^{-1}$ of data.

Both results are summarized in the publication hep-ex/0604022, DESY-06-029 , H1-150

Preliminary results on 278 pb$^{-1}$ of data on the search for isolated $\tau^+p_T^{\text{miss}}$ are also reported.
At $p_T^{X}>25$ GeV , 3 events are observed, for 0.74 ± 0.18 expected from SM processes
backup
A hadronic $\tau$ decay originates a jet with very specific characteristics: *collimated energy deposits in Calorimeter and few charged particles in Tracking detectors*. 

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