Results on tau physics from HERA

Junpei Maeda
(Tokyo Institute of Technology)

On behalf of
the H1 and ZEUS collaborations

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Novosibirsk, Russia
HERA: World’s Only ep Collider

\[ \sqrt{s} \sim 318 \text{ GeV} \]

\[ e^+/e^- \quad 27.6 \text{ GeV} \]

\[ p \quad 920 \text{ GeV} \]

HERA–I (1992~2000) : \( L \sim 120 \text{ pb}^{-1}/\text{exp.} \)

HERA–II (2002~2007) : \( L \sim 350 \text{ pb}^{-1}/\text{exp.} \)

- luminosity upgraded
- longitudinally polarized lepton beam
- detector upgrades

\( \rightarrow 0.5 \text{ fb}^{-1} \) data for each experiment!

HERA laid to rest on 30 June 2007.

HERA delivered
**H1 and ZEUS detector**

- **Liquid Argon Calorimeter**
  - fine granularity, excellent tracking
  - $\sigma(E)/E = 12\%/\sqrt{E}$ for electrons
  - $\sigma(E)/E = 50\%/\sqrt{E}$ for hadrons

- **Uranium–scintillator Calorimeter**
  - good hadronic energy resolution
  - $\sigma(E)/E = 18\%/\sqrt{E}$ for electrons
  - $\sigma(E)/E = 35\%/\sqrt{E}$ for hadrons
Tau Production at HERA

*Tau lepton production is a rare process at HERA!*

- $\tau^+\tau^-$ pair–production events
- Isolated $\tau$ lepton with missing transverse momentum ($P_T^{\text{miss}}$) events
- Double charged Higgs Search
- Lepton Flavour Violation

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*Tau lepton is important in exotic search.*
Tau Production at HERA

- $\tau^+\tau^-$ pair-production events
  - Leptonic channel ($\tau^+\tau^- \rightarrow e^+\mu^+$)
  - Semi-leptonic channel ($\tau^+\tau^- \rightarrow e^{\pm}\text{had}^\mp, \mu^{\pm}\text{had}^\mp$)
  - Hadronic channel ($\tau^+\tau^- \rightarrow \text{had}^{\pm}\text{had}^\mp$)
- Isolated $\tau$ lepton with missing transverse momentum ($P_T^{\text{miss}}$) events
- Double charged Higgs Search
- Lepton Flavour Violation
**τ⁺τ⁻ pair–production (only leptonic) @ ZEUS**

\[ ep \rightarrow \tau^+\tau^- (ep) \]

HERA–II e–p data \( L=135 \text{ pb}^{-1} \)

searched for \( \tau^+\tau^- \rightarrow e^\pm \mu^\mp \)

(leptonic decay)

**selection criteria**

<table>
<thead>
<tr>
<th>electron</th>
<th>muon</th>
</tr>
</thead>
<tbody>
<tr>
<td>( E_e &gt; 4 \text{ GeV} )</td>
<td>( p_{T\mu} &gt; 2 \text{ GeV} )</td>
</tr>
<tr>
<td>( \theta_e &lt; 2.6 \text{ rad} )</td>
<td>0.6 rad ( \lesssim \theta_{\mu} \lesssim 2.8 \text{ rad} )</td>
</tr>
</tbody>
</table>

(Acceptance of central tracking detector)

**elastic requirements**

– Number of tracks in event : 1~3
– No energy deposit in ”forward” calorimeter region

**Data**

<table>
<thead>
<tr>
<th>( \tau^+\tau^- )</th>
<th>( \mu^+\mu^- )</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>( 2.0 \pm 0.8 )</td>
</tr>
</tbody>
</table>

\[ \rightarrow \text{Data agree with SM expectation.} \]
\( \tau^+\tau^- \) pair–production (incl. hadronic) @ ZEUS

\[ ep \rightarrow \tau^+\tau^- (ep) \]

HERA–II e\(^{\pm}\)p data \( L = 364 \text{ pb}^{-1} \)

To study hadronically–decayed \( \tau \) identification, searched for:

\[ \tau^+\tau^- \rightarrow \begin{cases} e^\pm + h^\pm + \nu_\tau + \cdots & (\text{BR} : \sim 23\%) \\ h^\pm + h^\pm + \nu_\tau + \cdots & (\text{BR} : \sim 42\%) \end{cases} \]

more statistics than \( \text{e}\mu \) channel (~6%)

Hadrons from \( \tau \) decay is identified by ”jet”.

The most difficult thing: separate a \( \tau \)–jet from quark/gluon induced jets

There are many kinds of large background…

e.g.) diffractive–photoproduction

\[ \sigma \sim 300 \text{ nb} \ (2 \text{ jets w/ } E_T > 4 \text{ GeV}) \]

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<table>
<thead>
<tr>
<th>electron</th>
<th>jet</th>
</tr>
</thead>
</table>
| \( p_T^e > 5 \text{ GeV} \) & \( -2 < \eta_e < 2 \)  
matched track (\( p_T^\text{track} > 3 \text{ GeV} \)) | \( p_T^{\text{jet}} > 5 \text{ GeV} \) & \( -2 < \eta^{\text{jet}} < 2 \)  
at least one associated tracks, electron rejection cut |

**elastic requirements** : No energy deposit in forward calorimeter region, Low track multiplicity
τ–jet ID for $\tau^+\tau^−$ pair–production @ ZEUS

τ–ID using PDE Range Searching (discriminant)

• Generalization of one–dimensional PDE approach to $n$ dimensions
  – Counts number of signal and background events (training sample) in "vicinity" $V$ of the test event
  – Implemented in TMVA

\[
D(i_{\text{event}}, V) = \frac{\text{#signal events in } V}{\text{#all signal events}} = \frac{n_s(i_{\text{event}}, V) / N_s}{n_s(i_{\text{event}}, V) / N_s + n_b(i_{\text{event}}, V) / N_b}
\]

– 6 variables are inputted to discriminant, then evaluate discrimination value. (next slide)
**τ–jet ID for \( \tau^+\tau^- \) pair–production @ ZEUS**

6 variables are prepared for discriminant.

- **Rmean, Rrms**: 1\(^{\text{st}}\) and 2\(^{\text{nd}}\) moment of radial extension
  
  \[
  Rmean = \langle R \rangle = \frac{\sum_i E_i \cdot R_i}{\sum_i E_i}, \quad Rrms = \sqrt{\frac{\sum_i E_i \cdot (R - \langle R \rangle)^2}{\sum_i E_i}}
  \]

- **Mass**: invariant mass of clustered CAL cells
  
  \[
  Mass = \sqrt{\left(\sum_i E_i\right)^2 - \left(\sum_i p_{i,x}\right)^2 - \left(\sum_i p_{i,y}\right)^2 - \left(\sum_i p_{i,z}\right)^2}
  \]

- **Lmean**: 1\(^{\text{st}}\) moment of longitudinal extension
  
  \[
  Lmean = \langle L \rangle = \frac{\sum_i E_i \cdot \cos \alpha_i}{\sum_i E_i}
  \]

- **Rtrak**: The sum of distance between the jet axis and the tracks associated with the jet
  
  \[
  Rtrak = \sum_{i \in Ntrk} \left(\Delta \eta_i^2 + \Delta \phi_i^2\right)
  \]

- **Nsubj**: Number of subjets \((y_{\text{cut}}=5 \times 10^{-4})\)

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**ZEUS–prel–08–009**

25 Sep 2008

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Results of $\tau^+\tau^-$ pair-production @ ZEUS

$ep \rightarrow \tau^+\tau^- (ep)$ HERA–II $e^\pm p$ data $L=364$ pb$^{-1}$

Large uncertainty due to

- MC statistics
- PHP scale normalization

Discriminant threshold is given for each topology.

Data are in reasonable agreement with SM expectation.
The highest $M_{\tau\tau}^{\text{visible}}$ event ($M_{\tau\tau}^{\text{visible}}=40$ GeV)
\( \tau^+ \tau^- \) pair–production \( \oplus \) H1

\[ ep \rightarrow \tau^+ \tau^- (ep) \] HERA–I e\( ^\pm \)p data \( L=106 \) pb\(^{-1}\)

look for all topologies to be able to identify \( \tau^+ \tau^- \) events

- leptonic(e\( \mu \)), semi–leptonic(e–jet, \( \mu \)–jet), hadronic(jet–jet) decay
- look at the jets from low \( P_T \)
  - exactly required 1 or 3–tracks in the jet
  - using neural network to identify \( \tau \)–jet
  - the first measurement of \( \tau^+ \tau^- \) cross section at \( ep \)–collider

Neural Network based tau–ID

- To distinguish hadronic 1–prong, 3–prong \( \tau \) decays from quark/gluon jets \( (L_{1\text–prong}, L_{3\text–prong}) \)
- To distinguish hadronic 1–prong \( \tau \) decays from misidentified electrons/muons \( (L_{\text{veto} e}, L_{\text{veto} \mu}) \)
  - multiplicities of neutral clusters / invariant mass / number of tracks / 1st moment of energy deposits…

<table>
<thead>
<tr>
<th>electron</th>
<th>muon</th>
<th>jet</th>
</tr>
</thead>
<tbody>
<tr>
<td>( p_T^e &gt; 3 ) GeV</td>
<td>( p_T^\mu &gt; 2 ) GeV</td>
<td>( p_T^{\text{jet}} &gt; 2 ) GeV</td>
</tr>
<tr>
<td>( L_{1\text–prong} \parallel L_{3\text–prong} &gt; 0.75 )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Two isolated e or \( \mu \) or jets of opposite charges

**signal efficiency = 50%**

**misidentified probability = 0.5\% (4\%)**

**elastic requirements**: No additional tracks/clusters, No activity in forward regions

**NC/di–e/di–\( \mu \) rejection**: \( E–P_z < 50 \) GeV, \( L_{\text{veto} e} > 0.75, L_{\text{veto} \mu} > 0.75 \)
Results of $\tau^+\tau^-$ pair–production @ H1

$ep \rightarrow \tau^+\tau^- (ep)$  \hspace{1cm} HERA–I $e^\pm p$ data $L=106$ pb$^{-1}$


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### Phase space definition

- Elastic events with two $\tau$ leptons of 
  \begin{align*}
  & p_T^\tau > 2 \text{ GeV} \\
  & 20^\circ < \theta_\tau < 140^\circ
  \end{align*}

(acceptance $\approx 1\%$)

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### Purest final state

- First measurement at HERA!!

### First measurement at HERA!!

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### $\tau^+\tau^-$ Results

<table>
<thead>
<tr>
<th>Decay Channel</th>
<th>Leptonic</th>
<th>Semi–leptonic</th>
<th>Hadronic</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$e, \mu$</td>
<td>$e\tau$-jet</td>
<td>$\mu\tau$-jet</td>
<td>$\tau$-jet $\tau$-jet</td>
</tr>
<tr>
<td>H1 Data</td>
<td>7</td>
<td>2</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>SM $\tau^+\tau^-$</td>
<td>2.9 $\pm$ 0.4</td>
<td>6.3 $\pm$ 0.9</td>
<td>7.0 $\pm$ 1.3</td>
<td>11.0 $\pm$ 2.0</td>
</tr>
<tr>
<td>$\pi^0\nu$</td>
<td>56%</td>
<td>47%</td>
<td>85%</td>
<td>50%</td>
</tr>
</tbody>
</table>

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### Results

- $\sigma_{\text{measured}} = 13.6 \pm 4.4 \pm 3.7$ pb
- $\sigma_{\text{theory}} = 11.2 \pm 0.3$ pb (GRAPE)

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### Good agreement with SM expectation!

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\( \tau^+ \tau^- \) candidate @ H1

H1

TAU PAIR CANDIDATE

\[ e^+ p \rightarrow e^+ \tau^- \tau^+ p \]

\[ \mu^- \bar{\nu}_\mu \nu_\tau \quad h^+ h^+ h^- \quad \bar{\nu}_\tau \]
Tau Production at HERA

• $\tau^+\tau^-$ pair–production events

• Isolated $\tau$ lepton with missing transverse momentum ($P_T^{\text{miss}}$) events

• Double charged Higgs Search

• Lepton Flavour Violation
Isolated tau leptons + $P_T^{\text{miss}}$ physics

$$ep \rightarrow W(eX) \rightarrow \tau\nu$$

Rare process, but sensitive to new physics
- SM signal is single W boson production with subsequent decay $W \rightarrow \tau\nu$.
- Main background is CC events with narrow jets.
- A complement to isolated $e(\mu) + P_T^{\text{miss}}$ analysis
  (There is a slight excess for $e(\mu)$ channel at H1.)

An excess at high $p_T^X$ could be a sign of new physics.
  $\rightarrow$ single top production via FCNC etc.

$\sigma \times \text{BR} \sim 0.1\text{pb}$

$> 12$ GeV (H1)
$> 20$ GeV (ZEUS)

Additional high $p_T$ jet
$\tau$–ID for Isolated $\tau + P_T^{\text{miss}}$ analysis @ ZEUS

HERA–I $e^+p$ data $L=130 \text{ pb}^{-1}$

had $\tau$–ID

$\tau$–ID using PDE Range Searching

– Same method as $\tau^+\tau^-$ analysis. (see above)

– Variable set is different.

$$\log(R_{trk}) \rightarrow -\log(L_{\text{rms}})$$

$L_{\text{rms}}$: 2nd moment of longitudinal extension

$$L_{\text{rms}} = \sqrt{\frac{\sum_i E_i (L_{\text{mean}} - \cos \alpha_i)^2}{\sum_i E_i}}$$

required $D > 0.95$

Good separation of signal from background!
**Result of isolated $\tau + P_T^{\text{miss}}$ @ ZEUS**

Interesting $\tau + P_T^{\text{miss}}$ events at large $P_T^X$ are observed at ZEUS!

<table>
<thead>
<tr>
<th>ZEUS 1994–2000 e±p</th>
<th>ZEUS data</th>
<th>SM expectation</th>
<th>$W \rightarrow \tau\nu$ Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>3</td>
<td>$0.40 \pm 0.12$</td>
<td>43%</td>
</tr>
<tr>
<td>$P_T^{\text{had}} &gt; 25 \text{ GeV}$</td>
<td>2</td>
<td>$0.20 \pm 0.05$</td>
<td>49%</td>
</tr>
<tr>
<td>$P_T^{\text{had}} &gt; 40 \text{ GeV}$</td>
<td>1</td>
<td>$0.07 \pm 0.01$</td>
<td>71%</td>
</tr>
</tbody>
</table>

New physics signal
Isolated tau leptons + $P_T^{\text{miss}}$ @ H1

$ep \rightarrow W(eX) \rightarrow \tau \nu$

- ZEUS HERA–I result has a slight excess for $\tau + P_T^{\text{miss}}$ events.
- H1 analyzed all HERA data. \rightarrow 471 pb$^{-1}$

**Cut–based tau–ID**

- look for jet in LAr calorimeter (cone radius = 1.0)
  $P_T^{\text{jet}} > 7$ GeV, $20^\circ < \theta^{\text{jet}} < 120^\circ$

- Isolation: Distance to other e, $\mu$, jet in $\eta–\phi > 1.0$

Radial shower shape ("Jet radius") < 0.12

$$R_{\text{jet}} = \frac{1}{E_{\text{jet}}} \sum_h E_h \sqrt{\Delta \eta(jet, h)^2 + \Delta \phi(jet, h)^2}$$

- $N_{\text{jet}}^{\text{tracks}} = 1$ (only 1–prong jet)

\rightarrow misidentification probability : < 1%

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Data in good agreement with SM prediction!
τ + P_T^{miss} candidate event

H1 τ + P_T^{miss} candidate with large P_T^X

P_{miss}^{X} = 59 \text{ GeV} \quad P_T^{\tau} = 14 \text{ GeV} \quad P_T^{X} = 51 \text{ GeV}
Tau Production at HERA

• $\tau^+\tau^-$ pair-production events

• Isolated $\tau$ lepton with missing transverse momentum ($P_T^{\text{miss}}$) events

• Double charged Higgs Search

• Lepton Flavour Violation
Doubly–charged Higgs search @ H1

searched for $H^{++}$ bosons using HERA–I $e^+p$ data $L=88\text{ pb}^{-1}$

\[ H^{++} \rightarrow e^+\tau^+ \] final selection

<table>
<thead>
<tr>
<th>Event class</th>
<th>$N_{\text{obs}}$</th>
<th>$N_{\text{bkg}}$</th>
<th>Signal fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e\mu$</td>
<td>0</td>
<td>$0.27 \pm 0.02$</td>
<td>6 %</td>
</tr>
<tr>
<td>$eh$</td>
<td>1</td>
<td>$1.66 \pm 0.48$</td>
<td>12 %</td>
</tr>
<tr>
<td>$ee$</td>
<td>0</td>
<td>$0.14 \pm 0.04$</td>
<td>7 %</td>
</tr>
<tr>
<td>total</td>
<td>1</td>
<td>$2.07 \pm 0.54$</td>
<td>25 %</td>
</tr>
</tbody>
</table>

SM signal efficiency

CDF ($M_H > 114$ GeV)
(c.f. hep-ex/0808.2161)

No evidence for $H^{++} \rightarrow e^+\tau^+$ decays
Lepton Flavour Violation @ H1/ZEUS

searched for Lepton Flavour Violation

\[ e \rightarrow e(v) \]

\[ \gamma/Z(W^\pm) \]

\[ q \rightarrow q \]

SM DIS

s–channel

Leptoquark (LQ)s couple to both quarks and leptons.

\[ \tau \rightarrow X + e \]

had \( \tau \)-ID

Neural Network based tau–ID

80% signal efficiency

95% quark/gluon induced jet rejection

\[ N_{\text{events}} \]

\[ \tau \]–ID using PDE Range Searching

same discriminant as in ZEUS \( \tau + P_T \) miss search

\[ \tau \]

\[ \lambda_{eq} \]

\[ \lambda_{(\tau)} \]

\[ q_{\alpha} \]

\[ q_{\beta} \]

\[ LQ \]

\[ \tau \rightarrow X + e \]

REQUIRED:

\[ P_T^{\text{jet1}} > 25 \text{GeV}, P_T^{\text{jet2}} > 15 \text{GeV} \]

exactly 1 or 3 tracks in the jet

\[ D_{NN} > 0.8 \]

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Limits for LQs in the $\tau$ channel @ H1/ZEUS

No significant deviation from SM found. Limits were set on coupling to LQ leading to Lepton Flavour Violation.

\[ \begin{array}{c|c|c}
\text{H1} & \text{e}^+\text{p: }13.7 \text{ pb}^{-1}, \text{e}^-\text{p: }66.5 \text{ pb}^{-1} \\
\hline
\text{Data} & \text{SM MC} \\
\hline
\text{ep} \rightarrow \tau X & \text{0} & 0.75 \pm 0.21 \\
\text{e}^+\text{p} & \text{1} & 4.90 \pm 0.85 \\
\end{array} \]

HERA–I $\text{e}^\pm\text{p}$ data $L=80.2$ pb$^{-1}$

No evidence for LFV

\[ \begin{array}{c|c}
\text{Data} & 0 \\
\text{SM} & 2.3 \pm 0.5 \\
\text{sel. eff.} & 22\sim30\% \left( M_{LQ} < \sqrt{s} \right) \\
\end{array} \]

HERA–I $\text{e}^\pm\text{p}$ data $L=130$ pb$^{-1}$

No candidate was found. Limits on LQ were set.

\[ \begin{array}{c|c}
\text{Data} & 0 \\
\text{No evidence for LFV} & \text{No evidence for LFV} \\
\end{array} \]
Summary

• Only a few taus have been seen at HERA.
  – Detecting taus at HERA is a challenging task.
• They are an important signature for new physics.
• Many tools for the identification of hadronically–decayed taus have been developed by H1 and ZEUS.

• Results for $\tau^+\tau^−$ pair–production are in agreement with SM prediction (H1/ZEUS).
• New result of isolated $\tau + P_T^{miss}$ from H1 is in agreement with SM expectation.
  – ZEUS result using HERA–I data has a slight excess.
• No evidence for $H^{++}\rightarrow e^+\tau^+$ decays (H1) and lepton flavour violation (H1/ZEUS)

• HERA data taking ended on June 30 2007 after 15 years successful operation:
  – Each experiment has collected $\sim$500 pb$^{-1}$ data.
  – Tau analyses have not finalized yet, still more to come for the next years!
backup slides
Background control sample for $\tau^+\tau^-$ pair–production @ H1

$e^+ e^-$

$\mu^+ \mu^-$

$\gamma p$

$\nu\bar{\nu}$

Jet Candidates

$1$-prong

$3$-prong

H1 Data

All SM Processes

$\gamma\gamma \rightarrow \tau^+\tau^-$
Event selection for isolated tau + \( P_T^{\text{miss}} \) @ H1

**CC selection**

\( P_T^{\text{miss}} > 12 \text{ GeV} \)

the ratio of the anti-parallel and parallel components of the hadronic \( P_T \)

**Tau–jet selection (cut–based)**

look for jet in LAr calorimeter (cone radius = 1.0)

\( P_T^{\text{jet}} > 7 \text{ GeV}, \, 20^\circ < \theta^{\text{jet}} < 120^\circ \)

Isolation : Distance to other e, \( \mu \), jet in \( \eta–\phi > 1.0 \)

Radial shower shape ("Jet radius")

\[
R_{\text{jet}} = \frac{1}{E_{\text{jet}}} \sum_h E_h \sqrt{\Delta \eta(jet,h)^2 + \Delta \phi(jet,h)^2}
\]

only 1–prong jet → (misidentification probability : < 1%)
**Isolated tau leptons + $P_T^{\text{miss}}$ @ H1**

$\tau + P_T^{\text{miss}}$ events at HERA I + II (e$^+$p, 287 pb$^{-1}$)

<table>
<thead>
<tr>
<th>$e^+p$</th>
<th>Full Sample</th>
<th>$P_T^X &gt; 25$ GeV</th>
<th>H1 Data</th>
<th>SM Expectation</th>
<th>SM Signal $W \rightarrow \tau \nu$</th>
<th>Other SM Processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>287 pb$^{-1}$</td>
<td>10</td>
<td>10.8 ± 1.8</td>
<td>1.6 ± 0.3</td>
<td>9.2 ± 1.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>184 pb$^{-1}$</td>
<td>10</td>
<td>8.6 ± 1.5</td>
<td>1.0 ± 0.2</td>
<td>7.6 ± 1.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>471 pb$^{-1}$</td>
<td>20</td>
<td>19.5 ± 3.2</td>
<td>2.7 ± 0.4</td>
<td>16.8 ± 2.8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$\tau + P_T^{\text{miss}}$ events at HERA I + II (e$^-$p, 184 pb$^{-1}$)

<table>
<thead>
<tr>
<th>$e^-p$</th>
<th>Full Sample</th>
<th>$P_T^X &gt; 25$ GeV</th>
<th>H1 Data</th>
<th>SM Expectation</th>
<th>SM Signal $W \rightarrow \tau \nu$</th>
<th>Other SM Processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>184 pb$^{-1}$</td>
<td>1</td>
<td>0.47 ± 0.07</td>
<td>0.25 ± 0.04</td>
<td>0.22 ± 0.03</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

H1 Data (prelim.) $N_{\text{Data}} = 10$

All SM $N_{\text{SM}} = 10.8 ± 1.8$

All SM $N_{\text{SM}} = 8.6 ± 1.5$

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Lepton Flavour Violation @ ZEUS

ZEUS

(a) -log(R_{mean})

(b) -log(R_{rms})

(c) -log(1-L_{mean})

(d) -log(L_{rms})

(e) N_{subj}

(f) M_{jet} (GeV)

ZEUS e^+p 94-00
Background MC
LFV τ M_{LO}=240 GeV

- Background MC
Limits for LQs in the $\tau$ channel @ H1/ZEUS


**HERA–I $e^\pm p$ data $L=80.2$ pb$^{-1}$**

No significant deviation from SM found.

Limits were set on coupling to LQ leading to Lepton Flavour Violation.

**HERA–I $e^\pm p$ data $L=130$ pb$^{-1}$**

No candidate was found.

Limits on LQ were set.

→ No evidence for LFV