Searches for Isolated Leptons, Multileptons and Leptoquarks at HERA

Judith Katzy (DESY)
Status: 1-July-2007

Total luminosity collected:

H1: 478 pb⁻¹
  294 pb⁻¹ e⁺
  184 pb⁻¹ e⁻

Zeus: 492 pb⁻¹
  286 pb⁻¹ e⁺
  206 pb⁻¹ e⁻

~ 1 fb⁻¹
DU1

- roughly 0.5 fb⁻¹ per event
- combined data set roughly 1 fb⁻¹
- roughly 2/3 e+, a little more than 1/3 e-

Hera mainly e+

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Events with isolated $e$ or $\mu$ and $P_T^{\text{miss}}$

HERA I:
H1 observed 11 events at $P_T^{X}>25$ GeV
at SM expectation $3.5\pm0.6$

ZEUS in agreement with SM expectation

Both experiments performed search in complete HERA data set
Real $W$ production in photoproduction with $W$ decay into leptons
main process for this event topology
Hadronic system with typically low $p_T^X$

$\sigma_W \sim 1.3 \text{ pb}^{-1}$
$W$ decay branching ratio into $e$ or $\mu \sim 20\%$

Other signal processes:
CC $W$ production $\sim 7\%$
Cabbibo-Parisi $Z0$ production $\sim 3\%$ (only $e$ channel)

Modelled using EPVEC generator with NLO QCD correction:
Modifies cross section by $\sim 10\%$, reduces theoretical uncertainty to $\sim 15\%$
photoproduction therefore scattered e undetected
independent on incoming electron charge (e+ and e-)

CC W production similar feynman graph only changes: outgoing is nu instead of e, exchanged boson is W instead of gamma

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Background processes

- **e: Neutral Current**
  - Real electron and fake $P_T^{\text{miss}}$ from mismeasurement

- **e,μ: Charged Current**
  - Misidentified e or $\mu$ and real $P_T^{\text{miss}}$

- **μ: Lepton Pair Production**
  - Real $\mu$ and fake $P_T^{\text{miss}}$ from mismeasurement
NC: fake $p_{\text{miss}}$ due to fluctuations in detector response or lost particles due to limited acceptance

CC: misidentify e or mu from hadronic state or radiated photon

LP in photoproduction: second mu undetected fakes $p_{\text{miss}}$

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H1 isolated leptons

Excess at high $p_T^X$

Agreement with SM

<table>
<thead>
<tr>
<th>H1 HERA I+II</th>
<th>$e$ channel obs. / exp. (signal)</th>
<th>$\mu$ channel obs. / exp. (signal)</th>
<th>$e$ and $\mu$ channels obs. / exp. (signal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_T^X &gt; 25$ GeV</td>
<td>$e^+p$ data (294 $pb^{-1}$) 11 / 4.7 ± 0.9 (75%)</td>
<td>$\mu$ channel obs. / exp. (signal) 10 / 4.2 ± 0.7 (85%)</td>
<td>$e$ and $\mu$ channels obs. / exp. (signal) 21 / 8.9 ± 1.5 (80%)</td>
</tr>
<tr>
<td>$e^-p$ data (184 $pb^{-1}$) 3 / 3.8 ± 0.6 (61%)</td>
<td>0 / 3.1 ± 0.5 (74%)</td>
<td>3 / 6.9 ± 1.0 (67%)</td>
<td></td>
</tr>
</tbody>
</table>
ZEUS isolated leptons

\[15^\circ < \theta_l < 120^\circ\]

41 events observed in 492 pb\(^{-1}\) of data

<table>
<thead>
<tr>
<th>HERA I+II P_{T_x}&gt;25\text{GeV}</th>
<th>e channel Obs/exp(signal)</th>
<th>\mu channel Obs/expt.(signal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>e(^+) data</td>
<td>3/3.9 ±0.5(81%)</td>
<td>3/3.6±0.5(81%)</td>
</tr>
<tr>
<td>e(^-) data</td>
<td>3/3.2±0.6(69%)</td>
<td>2/2.4±0.4(85%)</td>
</tr>
</tbody>
</table>

Good agreement between data and Standard Model for both data sets

No Excess seen at high \(P_{T^X}\) as seen by H1
e+p data from 1996-2007

H1 acceptance bigger but almost all events from excess are also in the ZEUS acceptance
H1 and Zeus combined

87/92.7±11.2 events with isolated leptons and $P_T^{\text{miss}}$ observed in 0.97fb$^{-1}$

<table>
<thead>
<tr>
<th>H1+ZEUS HERA I+II</th>
<th>e channel</th>
<th>$\mu$ channel</th>
<th>$e$ and $\mu$ channels</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_T^{X} &gt; 25$ GeV</td>
<td>obs. / exp. (signal)</td>
<td>obs. / exp. (signal)</td>
<td>obs. / exp. (signal)</td>
</tr>
<tr>
<td>$e^+p$ data (0.58 fb$^{-1}$)</td>
<td>12 / 7.4 ± 1.0 (70%)</td>
<td>11 / 7.2 ± 1.0 (85%)</td>
<td>23 / 14.6 ± 1.9 (81%)</td>
</tr>
<tr>
<td>$e^-p$ data (0.39 fb$^{-1}$)</td>
<td>4 / 6.0 ± 0.8 (67%)</td>
<td>2 / 4.8 ± 0.7 (87%)</td>
<td>6 / 10.6 ± 1.4 (76%)</td>
</tr>
<tr>
<td>$e^++e^-$ data (0.97 fb$^{-1}$)</td>
<td>4/6.0 ± 0.8 (67%)</td>
<td>2/4.8 ± 0.7 (87%)</td>
<td>29/25.3 ± 3.2 (79%)</td>
</tr>
</tbody>
</table>

Excess in $e^+$ data has significance of 1.8 σ based on data of both experiments (2.9σ H1 data only)
Cross section measurements

H1 data only

$$\sigma_{Iso\text{Lep}} = \frac{N_d - N_{bg}^{MC}}{L \epsilon}$$

$$\epsilon = \frac{N_{rec}^{MC}}{N_{gen}^{MC}}$$

<table>
<thead>
<tr>
<th>$\sigma_{Iso\text{Lep}}(\text{pb})$</th>
<th>Measured±stat±sys</th>
<th>SM±th.sys</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\int$</td>
<td>0.24±0.05±0.05</td>
<td>0.26±0.04</td>
</tr>
</tbody>
</table>

Branching ratio $W \rightarrow e, \mu$ ~21%

Subtract $Z^0$ processes

<table>
<thead>
<tr>
<th>$\sigma_{W}(\text{pb})$</th>
<th>Measured±stat±sys</th>
<th>SM±th.sys</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\int$</td>
<td>1.23±0.25±0.22</td>
<td>1.31±0.20</td>
</tr>
</tbody>
</table>

Both measured cross sections are in good agreement with the SM
Measurement of W polarisation fraction

\[ F_+ = 1 - F_- - F_0 \]

right \hspace{1cm} left \hspace{1cm} longitudinal polarisation fraction

\[
\frac{dN}{d\cos \theta^*} \propto (1 - F_ - F_0) \cdot \frac{3}{8} (1 + \cos \theta^*)^2 \\
+ F_0 \cdot \frac{3}{4} (1 - \cos^2 \theta^*) \\
+ F_- \cdot \frac{3}{8} (1 + \cos \theta^*)^2.
\]

Fit H1 measured cross section to \( \frac{dN}{d\cos \theta^*} \) and extract \( F_0 \) and \( F_- \) simultaneously.
W polarisation fraction

Good agreement with the SM found compatible with Single top production within 1σ

Single parameter fit (other parameter at SM value)

<table>
<thead>
<tr>
<th></th>
<th>HERA I+II data</th>
<th>SM</th>
</tr>
</thead>
<tbody>
<tr>
<td>( F_\perp )</td>
<td>0.58 ±0.15(stat) ±0.12(sys)</td>
<td>0.61 ±0.01(stat)</td>
</tr>
<tr>
<td>( F_0 )</td>
<td>0.15 ±0.21(stat) ±0.09(sys)</td>
<td>0.19 ±0.01(stat)</td>
</tr>
</tbody>
</table>
Anomalous single top production

SM single top production $\sigma<1\text{fb}$

Top production via flavor changing NC in BSM
Candidate process for excess
But: same rate for $e^+$ and $e^-$

Search for FCNC based on isolated lepton events of HERAI+II
additional good top quark reconstruction and positive lepton charge requirement (if possible)

24 events selected, 26 events SM prediction

No significant signal found using multi variant analysis
previous (heral) analysis also considered hadronic W decays
Single top results

Limits on FCNC cross section derived using maximum likelihood:

\( \sigma(\text{ep} \rightarrow \text{etX}) < 0.16 \) (95% CL)

HERA 1 results:
H1: \( \sigma(\text{ep} \rightarrow \text{etx}) < 0.55 \text{ pb} \)
Zeus: \( \sigma(\text{ep} \rightarrow \text{etX}) < 0.23 \text{ pb} \)

Upper bound on the anomalous coupling:
\( \kappa_{\tau u \gamma} < 0.14 \)

New limit extends into region of phase space uncovered by other colliders
Isolated $\tau$ leptons + $p_T^{\text{miss}}$

$H1$  $\tau + p_T^{\text{miss}}$ candidate with large $P_X^T$

Look for events with $P_T^{\text{miss}}$ and a narrow hadronic jet in complete HERA data set

$P_T^{\text{miss}} = 59$ GeV  $P_T^\tau = 14$ GeV  $P_X^T = 51$ GeV

• 45% of $\tau$ decay into 1 charged particle (“1-prong-decay”) giving a narrow, pencil like jet
• main (and large!) background CC events with narrow jets
• complementary results to those in electron and muon channel
• enhanced $\tau$ production above SM predicted by some $R_p$ violating SUSY models
• HERA I data ZEUS observed 3 events over SM expectation 0.4±0.12, 2 events at $P_T^X>$25GeV, SM expectation 0.2±0.05
**τ results**

**τ + P^miss_τ events at HERA I + II (e^±p, 184 pb^{-1})**

- H1 Data (prelim.)
- All SM
- Signal

<table>
<thead>
<tr>
<th>Events</th>
<th>N_{Data}</th>
<th>N_{SM}</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1 Data (prelim.)</td>
<td>10</td>
<td>8.6 ± 1.5</td>
</tr>
</tbody>
</table>

**τ + P^miss_τ events at HERA I + II (e^±p, 287 pb^{-1})**

- H1 Data (prelim.)
- All SM
- Signal

<table>
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<tr>
<th>Events</th>
<th>N_{Data}</th>
<th>N_{SM}</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1 Data (prelim.)</td>
<td>10</td>
<td>10.8 ± 1.8</td>
</tr>
</tbody>
</table>

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20 events observed
Good agreement with the SM prediction for e^+ and e^- data set
Only 1 event at high P_T^{X} – in the e-p data!
Dominated by background processes – only 14% signal (other channels up to 85%)
Multi-Leptons

Search for topologies with 2 or 3 high $p_T$ leptons

$p_T^{1l}>10\text{GeV, } p_T^{2l}>5\text{GeV, } 20^\circ<\theta<160^\circ$

Third lepton:
$E_e>5\text{GeV or } p_T^{\mu}>2\text{GeV, } 5^\circ<\theta<175^\circ$

**ZEUS:** ee, eee

**H1:** ee, $e\mu$, $\mu\mu$, eee, $e\mu\mu$
QED processes well understood - deviations at high mass directly sign of new physics

background processes:
NC DIS where part of the hadronic is misidentified as electron
QED Compton with gamma misidentified as e
QED processes with multi-lepton final state

$\gamma\gamma$ process dominant

CC W production (7%)

Cabbibo-Parisi Z0 production
~3%, only in electron channel
QED processes well understood - deviations at high mass directly sign of new physics

background processes:
NC DIS where part of the hadronic is misidentified as electron
QED Compton with gamma misidentified as e
2 lepton results

H1 Multi-lepton analysis HERA I+II (459 pb$^{-1}$)

- **ee**
  - Events: 446 evts
  - $M_{ee}$ [GeV]

- **$\mu\mu$**
  - Events: 185 evts
  - $M_{\mu\mu}$ [GeV]

- **e$\mu$**
  - Events: 201 evts
  - $M_{e\mu}$ [GeV]

Overall good agreement with SM

- **H1**: 3 ee events observed at $M>100$GeV
  - (all hera1 $e^+p$ data)

- **ZEUS**: 2 ee event observed at $M>100$GeV
3 lepton event

\( \mu_1 \) (\( P_T = 62 \text{ GeV} \))

\( \mu_2 \) (\( P_T = 2.7 \text{ GeV} \))

\( e \) (\( P_T = 64 \text{ GeV} \))
H1 3 lepton results

H1 Multi-lepton analysis HERA I+II (459 pb$^{-1}$)

Overall good agreement with SM

Data slightly exceed SM prediction at high mass

3 eee events
Observed in hera 1 e$^+$p

2 eμμ events observed in Hera 2 e$^+$p
Zeus 3 lepton results

![Graph showing data for ZEUS (prel.) 478 pb$^{-1}$, SM, Pair production, QEDC, and NC with 2 events at high mass.](image)

- Events vs. $M_{12}(\text{GeV})$
Results on 2+3 leptons

H1 Multi-lepton analysis  HERA I+II (459 pb$^{-1}$)

$e^+p$ (286 pb$^{-1}$)  2+3 leptons

3 events with high $\Sigma P_T$

$e^-p$ (173 pb$^{-1}$)  2+3 leptons

1 $\mu\mu$ event with $M_{12}>100$ GeV

SM expectation $1.9\pm0.4$

4 events with high $\Sigma P_T$

ZEUS

3 events with high $\Sigma P_T$

SM expectation $1.58^{+0.16}_{-0.12}$
H±± search

H++/H-- exists in some left-right symmetric extensions to SM and SUSY models

Search for resonances in mass spectra of multi lepton sample

Additional charge and $P_T$ cut for ee, $e\mu$ channel, $P_T^{\text{miss}}$ cut for $\tau$

<table>
<thead>
<tr>
<th>Events $M_{ll}&gt;65\text{GeV}$</th>
<th>SM</th>
</tr>
</thead>
<tbody>
<tr>
<td>ee</td>
<td>3</td>
</tr>
<tr>
<td>$e\mu$</td>
<td>1</td>
</tr>
<tr>
<td>$e\tau$</td>
<td>1</td>
</tr>
</tbody>
</table>
feynman graph is example
- 2 more graphs with H++ production
- charge conjugate also exist
- lepton can be e, mu, tau
- production might be lepton helicity dependent but here not examined because it's hera1 sample
- elastic and inelastic p scattering possible
- signature: 2 same charged leptons with charge of incoming lepton, 1 opposite charge lepton, pt of H decay leptons higher than 1-
- experimental selection: as multilepton analysis
  2 highest pt leptons are assigned to H
  if there charge is measureable must be same as the charge of the incoming lepton
- background misid jets as lepton in nc dis, converted photon of compton events
- candidate for explanation of multi-lepton events
- check mass spectrum 2 highest pt leptons
- Mee dependent pt cut?

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Limit on $H^{±±}$ cross section

![Graph showing the cross section for different decay modes of $H^{±±}$](graph.png)

Best sensitivity for $H^{±±}\rightarrow eμ$: $σ_{H^{±±}\rightarrow eμ} < 0.05pb$
H1 sets most stringent limits on $M_H$ for $H^{±±}$ coupling to $eμ$ and $eτ$ at coupling of electromagnetic strength:

$$h_{eμ} = 0.3 \quad M_H > 141 \text{ GeV}$$

$$h_{eτ} = 0.3 \quad M_H > 112 \text{ GeV}$$
set limits for the case that the H++ only couples to the channel under investigation i.e. only to ee or only to em or only to et.

there are also limits ofopal on hee independent of decay mode which can explain why H1 doesn't see anything in the mm and tt channel.
Leptoquarks at HERA

Leptoquarks: color triplet boson with leptonic and baryonic quantum number:
Fermion number: \( F = L + 3B \)
- \( F = 2 \) (e–p)
- \( F = 0 \) (se+p)

Buchmüller-Rückl-Wyler (BRW) model: LQ classified into 14 types (7 vector, 7 scalar) depending on spin, isospin, chirality

LQ at HERA: single production from incoming particles

LQ decay lepton flavor conserving (LFC): LQ→eq, νq
or lepton flavor violating (LFV): LQ→μq, τq

H1 and ZEUS search for LQ in inclusive NC and CC event sample of 2004/05 data
Limits on 1\textsuperscript{st} generation $M_{LQ}$

No enhancement
No evidence for LQ signal

At $\lambda \sim 0.3$ exclude $M_{LQ} > 276\text{-}304$ GeV
Heavy Leptoquarks

- Possible new interaction between e and q can modify DIS cross section at high $Q^2$ via virtual effects
- Search for virtual LQ exchange using 4 fermion eeqq contact interaction method
  -> report by P. Schleper in Alternatives

Lower limits on $M_{LQ}/\lambda$ derived for all LQ
$M_{LQ} >> 300$ excluded for all LQ for $\lambda \sim 1$
Comparison with LEP and Tevatron

- **LEP**: contact interaction (indirect constraints from $e^- e^+ \rightarrow q\bar{q}$)
- **TEVATRON**: pair production ($\lambda$ independent)
- **HERA**: single production ($M_{LQ} < 300$ GeV) and contact interaction ($M_{LQ} > 300$ GeV)

~ factor 2 more lumi to be added using full HERA II data
Limits on LFV Leptoquarks

Signature ep->μX

Low background, good sensitivity

Typical selection:
Back-to-back topology, $P_{T}^{\text{calo}}>20\text{GeV}$

Assume:
No evidence for Signal found

Exclude $M_{LQ}>300\text{ GeV}$ for $\lambda \sim 0.3$
Summary

• Results for isolated leptons with $p_T^\text{miss}$ shown for complete HERA data sample and for the first time with H1+ZEUS combination ~1fb$^{-1}$:
  – In e+p data: H1 observed 21 events where 8.9 were expected in complete data and even stronger signal in e+p data
  – ZEUS observed 6 events where 7.4 expected

• All HERA data analysed by H1 and ZEUS multi-lepton events
  – At high $\Sigma p_T$ H1 observes 4 events, expectation is 1.9±0.4
    ZEUS observes 3 events, expectation is 1.58$^{+0.12}_{-0.16}$
  – Combined results expected soon

• Limits for LQ updated – improvement with full HERA data sample to come
extras
### Isolated lepton event selection

<table>
<thead>
<tr>
<th>Variable</th>
<th>Electron</th>
<th>Muon</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\theta_1$</td>
<td>$5^\circ &lt; \theta_1 &lt; 140^\circ$ (H1), $15^\circ &lt; \theta_1 &lt; 120^\circ$ (ZEUS)</td>
<td></td>
</tr>
<tr>
<td>$P_T$</td>
<td>$&gt; 10$ GeV</td>
<td></td>
</tr>
<tr>
<td>$P_{T,calo}$</td>
<td>$&gt; 12$ GeV</td>
<td></td>
</tr>
<tr>
<td>$P_{T,miss}$</td>
<td>$&gt; 12$ GeV</td>
<td></td>
</tr>
<tr>
<td>$P_{T,X}$</td>
<td>-</td>
<td>$&gt; 12$ GeV</td>
</tr>
<tr>
<td>$D_{jet}$</td>
<td>-</td>
<td>$&gt; 1.0$</td>
</tr>
<tr>
<td>$D_{track}$</td>
<td>$&gt; 0.5$ for $\theta_e \geq 45^\circ$</td>
<td>$&gt; 0.5$</td>
</tr>
<tr>
<td>$z^2$</td>
<td>$&gt; 5000$ GeV$^2$ for $P_{T,calo} &lt; 25$ GeV</td>
<td>-</td>
</tr>
<tr>
<td>$V_{ap}/V_p$</td>
<td>$&lt; 0.5$ ($&lt; 0.15$ for $P_{T,\mu} &lt; 25$ GeV)</td>
<td>$&lt; 0.5$ ($&lt; 0.15$ for $P_{T,calo} &lt; 25$ GeV)</td>
</tr>
<tr>
<td>$\Delta \phi_{1,X}$</td>
<td>$&lt; 160^\circ$</td>
<td>$&lt; 170^\circ$</td>
</tr>
<tr>
<td>$\delta_{miss}$</td>
<td>$&gt; 5$ GeV$^*$</td>
<td>-</td>
</tr>
<tr>
<td># isolated $\mu$</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

- **H1**: only if one e candidate is detected, with the same charge as the beam lepton

#### Analysis phase space selection.
H1: extended polar angle range

#### Isolation of lepton

#### Cuts designed to reduce SM background, whilst preserving large signal purity
Multi-lepton event yields at $M_{ll}>100$GeV

H1 preliminary HERA I+II

<table>
<thead>
<tr>
<th>Selection</th>
<th>Data</th>
<th>SM</th>
<th>Pair Production</th>
<th>NC-DIS + Compton</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e^+p$ $M_{ll}&gt;100$ GeV 3</td>
<td>3.0 ± 0.2</td>
<td>0.6 ± 0.2</td>
<td>0.4 ± 0.1</td>
<td></td>
</tr>
<tr>
<td>$\mu\mu$ $M_{ll}&gt;100$ GeV 0</td>
<td>0.06 ± 0.03</td>
<td>0.06 ± 0.03</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>$e\nu$ $M_{ll}&gt;100$ GeV 1</td>
<td>0.53 ± 0.05</td>
<td>0.53 ± 0.05</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>$e\mu\mu$ $M_{ll}&gt;100$ GeV 3</td>
<td>0.6 ± 0.1</td>
<td>0.6 ± 0.1</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>$e\mu\mu$ $M_{ll}&gt;100$ GeV 1</td>
<td>0.04 ± 0.02</td>
<td>0.04 ± 0.02</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>$e\mu\mu$ $M_{ll}&gt;100$ GeV 1</td>
<td>0.007 ± 0.005</td>
<td>0.007 ± 0.005</td>
<td>—</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Selection</th>
<th>Data</th>
<th>SM</th>
<th>Pair Production</th>
<th>QEDC</th>
<th>NC</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e^+p$ $M_{ll}&gt;100$ GeV 0</td>
<td>0.55 ± 0.1</td>
<td>0.3 ± 0.1</td>
<td>0.25 ± 0.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\mu\mu$ $M_{ll}&gt;100$ GeV 0</td>
<td>0.03 ± 0.02</td>
<td>0.03 ± 0.02</td>
<td>—</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$e\nu$ $M_{ll}&gt;100$ GeV 0</td>
<td>0.3 ± 0.05</td>
<td>0.3 ± 0.05</td>
<td>—</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$e\mu\mu$ $M_{ll}&gt;100$ GeV 0</td>
<td>0.32 ± 0.06</td>
<td>0.32 ± 0.06</td>
<td>—</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$e\mu\mu$ $M_{ll}&gt;100$ GeV 0</td>
<td>0.04 ± 0.01</td>
<td>0.04 ± 0.01</td>
<td>—</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$e\mu\mu$ $M_{ll}&gt;100$ GeV 0</td>
<td>0.006 ± 0.004</td>
<td>0.006 ± 0.004</td>
<td>—</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ZEUS preliminary HERA I+II

<table>
<thead>
<tr>
<th>Type</th>
<th>DATA</th>
<th>SM</th>
<th>Pair production</th>
<th>QEDC</th>
<th>NC</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e^+p$</td>
<td>2e</td>
<td>1</td>
<td>0.5±0.1</td>
<td>0.5±0.1</td>
<td>0.4±0.1</td>
</tr>
<tr>
<td></td>
<td>3e</td>
<td>2</td>
<td>0.6±0.07±0.5</td>
<td>0.6±0.07</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>$e^-p$</td>
<td>2e</td>
<td>1</td>
<td>0.6±0.1</td>
<td>0.4±0.04</td>
<td>0.39±0.3</td>
</tr>
<tr>
<td></td>
<td>3e</td>
<td>0</td>
<td>0.4±0.1±0.5</td>
<td>1.0±0.1</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>
2 lepton mass spectra, $H^{±±}$ search (backup)

H1 HERA I data, $H^{±±}$ preselection

6 evts obs. 0.53±0.06 expt.

1 event after final selection (charge+ $P_T$ cuts)
Leptoquark search all mass spectra
H$^{±±}$ production

H1 HERA I data
feynman graph is example
- 2 more graphs with H++ production
- charge conjugate also exist
- lepton can be e, mu, tau
- production might be lepton helicity dependent but here not examined because it's hera1 sample
- elastic and inelastic p scattering possible
- signature: 2 same charged leptons with charge of incoming lepton, 1 opposite charge lepton, pt of H decay leptons higher than l-
- experimental selection: as multilepton analysis
  - 2 highest pt leptons are assigned to H
    - if there charge is measureable must be same as the charge of the incoming lepton
- background misid jets as lepton in nc dis, converted photon of compton events
- candidate for explanation of multi-lepton events
- check mass spectrum 2 highest pt leptons
- Mee dependent pt cut?
CC and NC cross section

HERA II

\begin{align*}
\frac{d\sigma}{dQ^2} (pb/GeV^2) & \approx 10^0 \\
& \approx 10^{-1} \\
& \approx 10^{-3} \\
& \approx 10^{-5} \\
& \approx 10^{-7}
\end{align*}

\begin{align*}
Q^2 (GeV^2) & \approx 10^3 \\
& \approx 10^4
\end{align*}

- H1 e^+p NC 03-04 (prel.)
- H1 e^+p NC 2005 (prel.)
- ZEUS e^+p NC 2004
- ZEUS e^+p NC 04-05 (prel.)
- SM e^+p NC (CTEQ6M)
- SM e^+p NC (CTEQ6M)

\[ y < 0.9 \]
\[ P_T = 0 \]