Searches for Excited Fermions at HERA
-- Final Results from H1

Z. Zhang (LAL, Orsay) on behalf of the H1 Collaboration

$p$: 820/920 GeV
$\epsilon$: 27.5 GeV
HERA:
- Unique $e^\pm p$ collider of the world (1992-2007)
- High c.m. energy up to 320GeV for direct searches
- Integrated luminosity/experiment: $\sim 0.5 \text{ fb}^{-1}$

Excited fermions ($\nu^*$, $e^*$ and $q^*$)
Very actively searched for at HERA (& elsewhere):
8 (H1) + 4 (ZEUS) publications
of which 3 from H1 based on full HERA data
$\Rightarrow$ subject of this talk
Motivation & the Model

- 3 family & mass hierarchy ⇔ Composite Model of fermions

Excited fermions

- The effective Lagrangian:

$$\mathcal{L}_{GM} = \frac{1}{2\Lambda} \tilde{F}_R^a \sigma^{\mu\nu} \left[ g f \frac{\tau^a}{2} W_{\mu\nu}^a + g' f' \frac{Y}{2} B_{\mu\nu} + g_s f_s \frac{\lambda^a}{2} G_{\mu\nu}^a \right] F_L$$

SU(2) \hspace{1cm} U(1) \hspace{1cm} SU(3)

Λ: Compositeness scale

f, f', f_s: relative strength to Z/W, γ, g

Excited fermions of $1^{\text{st}}$ generation: singly produced at HERA

Decays to standard fermions and gauge bosons
with $Z \rightarrow ee, \mu\mu, qq$, and $W \rightarrow e\nu_e, \mu\nu_\mu, qq'$

- Experimental signature:
  - isolated lepton(s), $\gamma$, missing energy + jets
Excited Neutrinos

- Use all HERA-2 e-\(p\) data (184 pb\(^{-1}\))
  (cross section much larger than in e\(^+\)p data)

- Model Assumption:
  \(f = -f'\) or \(f = +f'\) (insensitive to \(f_s\))
  ~90\%, 85\% decay modes investigated

- No evidence for \(\nu^*\) found, mass dependent exclusion limits derived

![Graph](image)

<table>
<thead>
<tr>
<th>Channel</th>
<th>Data</th>
<th>SM</th>
<th>Signal efficiency [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\nu^* \rightarrow \nu \gamma)</td>
<td>7</td>
<td>12.3 ± 3.0</td>
<td>50-55</td>
</tr>
<tr>
<td>(\nu^* \rightarrow eW \rightarrow eqq)</td>
<td>220</td>
<td>223 ± 47</td>
<td>40-65</td>
</tr>
<tr>
<td>(\nu^* \rightarrow eW \rightarrow ev\mu)</td>
<td>0</td>
<td>0.40 ± 0.05</td>
<td>35</td>
</tr>
<tr>
<td>(\nu^* \rightarrow eW \rightarrow ev\nu)</td>
<td>0</td>
<td>0.7 ± 0.1</td>
<td>45</td>
</tr>
<tr>
<td>(\nu^* \rightarrow \nu Z \rightarrow \nu qq)</td>
<td>89</td>
<td>95 ± 21</td>
<td>25-55</td>
</tr>
<tr>
<td>(\nu^* \rightarrow \nu ee)</td>
<td>0</td>
<td>0.19 ± 0.05</td>
<td>45</td>
</tr>
</tbody>
</table>
Excited Neutrinos (continued)

Limits at 95% CL and all channels combined

If $f/\Lambda = 1/M_{\nu^*}$, $M_{\nu^*} < 213$ excluded

Best sensitivity achieved for mass beyond the LEP reach

HERA1 limits improved by a factor of 3-4

(scan in $f'/f$)
Excited Electrons

- Use full HERA data (475 pb$^{-1}$)
  (Four-fold increase in stat vs. HERA-1)

- Model Assumption:
  $f=+f'$ (cross section small for $f=-f'$)
  80-90% decay modes investigated

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<tr>
<td>$e^* \rightarrow e\gamma$ (ela.)</td>
<td>42</td>
<td>$48 \pm 4$</td>
<td>60–70</td>
</tr>
<tr>
<td>$e^* \rightarrow e\gamma$ (inel.)</td>
<td>65</td>
<td>$65 \pm 8$</td>
<td>60–70</td>
</tr>
<tr>
<td>$e^* \rightarrow \nu W \rightarrow \nu q\bar{q}$</td>
<td>129</td>
<td>$133 \pm 32$</td>
<td>20–55</td>
</tr>
<tr>
<td>$e^* \rightarrow \nu W \rightarrow \nu e\nu$</td>
<td>4</td>
<td>$4.5 \pm 0.7$</td>
<td>60</td>
</tr>
<tr>
<td>$e^* \rightarrow eZ \rightarrow e\nu\nu$</td>
<td>286</td>
<td>$277 \pm 62$</td>
<td>35</td>
</tr>
<tr>
<td>$e^* \rightarrow eZ \rightarrow e\bar{q}\bar{q}$</td>
<td>0</td>
<td>$0.72 \pm 0.06$</td>
<td>60</td>
</tr>
<tr>
<td>$e^* \rightarrow eZ \rightarrow eee$</td>
<td>0</td>
<td>$0.52 \pm 0.05$</td>
<td>40–15</td>
</tr>
</tbody>
</table>

⇒ No evidence for $e^*$ found, mass dependent exclusion limits derived
Excited Electrons (continued)


Limits at 95% CL and all channels combined

→ If $f/\Lambda = 1/M_{e^*}$, $M_{e^*} < 272$ excluded

→ The results extend previously excluded domain at LEP, Tevatron

$\Rightarrow$ GM interactions dominate

GM: Gauge Mediated interactions
CI: Contact Interactions
Excited Quarks

- Use full HERA data (475 pb$^{-1}$)
  (12-fold increase in stat vs. prev. results)

- Model Assumption:
  $f = + f'$  ($f_s = 0$ or $f_s \neq 0$)
  s, u channels + interference
  (previously only s-channel with NWA considered)

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<th>Channel</th>
<th>Data</th>
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<th>Signal Efficiency [%]</th>
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<tr>
<td>$q^* \rightarrow q\gamma$</td>
<td>44</td>
<td>$46 \pm 4 \pm 7$</td>
<td>35 – 45</td>
</tr>
<tr>
<td>$q^* \rightarrow qW/Z \rightarrow qq\bar{q}$</td>
<td>341</td>
<td>$326 \pm 48 \pm 62$</td>
<td>5 – 55</td>
</tr>
<tr>
<td>$q^* \rightarrow qW \rightarrow qe\nu$</td>
<td>6</td>
<td>$6.0 \pm 0.2 \pm 0.8$</td>
<td>20 – 30</td>
</tr>
<tr>
<td>$q^* \rightarrow qW \rightarrow q\mu\nu$</td>
<td>5</td>
<td>$4.4 \pm 0.2 \pm 0.7$</td>
<td>20 – 40</td>
</tr>
<tr>
<td>$q^* \rightarrow qZ \rightarrow q\ell\ell$</td>
<td>0</td>
<td>$0.44 \pm 0.06 \pm 0.04$</td>
<td>15 – 30</td>
</tr>
<tr>
<td>$q^* \rightarrow qZ \rightarrow q\mu\mu$</td>
<td>0</td>
<td>$0.87 \pm 0.10 \pm 0.04$</td>
<td>15 – 30</td>
</tr>
</tbody>
</table>

→ No evidence for $q^*$ found, mass dependent exclusion limits derived
Excited Quarks (continued)

Limits at 95% CL and all channels combined

\( f / \Lambda = 1 / M_{q^*}, M_{q^*} < 252 \) excluded

The results extend
- beyond the kinematical limits
- previously excluded domain at LEP

\( \Lambda = M_{q^*}, f = f' \)

\( f_s = 0.1 \)

\( f_s = 0.01 \)

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\( f_s = 0.01 \)

\( f_s = 0.1 \)
Summary

- H1 has given the final word on the searches for \( f^* \):
  
  If \( f/\Lambda = 1/M_{f^*} \), \( M_{f^*} < 213, 272, 252 \text{GeV} \) excluded at 95\%CL
  for \( \nu^* \), \( e^* \), and \( q^* \), respectively

- The HERA limits with the full data sample
  - improve significantly previous HERA results
  - extend/compete/complement those at LEP/Tevatron