Searches for **Excited Fermions**
in **ep** collisions

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On behalf of the H1 collaboration
The HERA collider

\[ e^\pm (27.6 \text{ GeV}) \]

\[ p (820/920 \text{ GeV}) \]

\[ \sqrt{s} = 300,320 \text{ GeV} \]

HERA I : 1992-2000
(120 pb\(^{-1}\) per experiment)

HERA II :
- Lumi upgrade
- Polarised leptons beams

All HERA I+II data :
- \( e^- p : 184 \text{ pb}^{-1} \)
- \( e^\pm p : 475 \text{ pb}^{-1} \)
Excited fermion states generalities

- **Excited fermion states** should be a signal for substructure at a characteristic scale $\mathcal{O}(\Lambda)$ (Actual experimental constraints lead to a scale $\Lambda > \sim 1$ TeV)

- If known quarks and leptons are composite they should be considered, as the ground state to a rich spectrum of excited states

- **Composite models of fermions**:
  - should explain the threefold “replica” of fermion generation
  - should be possible alternatives to the conventional SM description of EW symmetry breaking.

- The ways to couple fermions and excited fermions:
  - **Gauge mediated interactions (GM)**:
    
    $f^* \leftrightarrow f$ transitions described by an effective lagrangian:
    
    $$\mathcal{L}_{\text{eff}}^{GM} = \sum_{V=\gamma,Z,W} e \sqrt{2} c_{Vf* f} \sigma^{\mu \nu} (c_{Vf* f} - d_{Vf* f} \gamma_5) f \partial^\mu V^\nu + \text{h.c.}$$

  - or **Contact interactions** (not considered here, an H1 paper in preparation)


Basic elements of the *gauge mediated* theory

- **f** can carry different spin/isospin values  
  (Kuhn & Zerwas, Phys. Lett B 147, 189, 1984)

  Assume that **f** have spin $\frac{1}{2}$ - isospin $\frac{1}{2}$ and are organised in left/right weak doublet

- Lagrangian should respect a *chiral symmetry*
  → Only right-handed part of **F*** involved in **f**F*V couplings

- Interactions described in a SU(2)XU(1) invariant form

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

- \( g, g', g_s \): usual weak and strong coupling constants
- \( W_{\mu\nu}, B_{\mu\nu}, G_{\mu\nu} \): field-strength tensors
Expression of the $V_{ff^*}$ couplings ($V = \gamma, Z, W$)

- **$ff^*\gamma$ vertex**
  \[ C_{\gamma ff^*} = \frac{1}{2} (f I_3 + f' \frac{Y}{2}) \]

- **$ff^*Z$ vertex**
  \[ C_{Z ff^*} = \frac{1}{2} (f I_3 \cot \theta_W - f' \frac{Y}{2} \tan \theta_W) \]

- **$ff^*W$ vertex**
  \[ C_{W ff^*} = \frac{f}{2\sqrt{2} \sin \theta_W} \]

$I_3$: third isospin component

$Y$: hypercharge ($\pm 1$ for $\ell^*$)

$\theta_W$: Weinberg angle
Excited fermions: production and decay at ep colliders

Produced via t-channel
\( W \) boson exchange

\[ \frac{\sigma(e^-p)}{\sigma(e^+p)} \sim 100 \]  
(“charged current” like production)

H1 analysis: use all \( e^-p \) data (184 pb^{-1})

Under the assumption \( f_s = 0 \)

(q* production via \( qg = 0 \))

(q* decay into \( qg = 0 \))

\( q^* \) produced via t-channel \( \gamma/Z/W \) bosons exchange

\( q^* \) de-excitation by emission of \( \gamma, Z, W \)

Produced via t-channel
\( \gamma/Z \) bosons exchange

H1 analysis: use (almost) all \( e^\pm p \) data (435 pb^{-1})

\( f^* \) de-excitation by emission of \( \gamma, Z, W \)

H1 analysis on \( e^+p \) data (37 pb^{-1})

(plan to analyse all the H1 data)
### Searches for $v^*$ with H1

<table>
<thead>
<tr>
<th>decay</th>
<th>MC events</th>
<th>results</th>
</tr>
</thead>
<tbody>
<tr>
<td>$v^* \rightarrow v \gamma$</td>
<td>$P_T^{\text{miss}} &gt; 20$ GeV, 1 $\gamma$ candidate</td>
<td>data SM sig. $\epsilon$ (%)</td>
</tr>
<tr>
<td></td>
<td>1 jet with $P_T^{\text{jet}} &gt; 5$ GeV</td>
<td>7 $12.3 \pm 3.0$ 50-55</td>
</tr>
<tr>
<td></td>
<td>Reduce CC DIS : $P_T^{\gamma} &gt; 20$ GeV</td>
<td></td>
</tr>
<tr>
<td>$v^* \rightarrow eW$</td>
<td>1 isolated electron , $P_T^e &gt; 25$ GeV</td>
<td>data SM sig. $\epsilon$ (%)</td>
</tr>
<tr>
<td>$\rightarrow eqq$</td>
<td>at least 2 jets, $P_T^{\text{jets}} &gt; 20,15$ GeV</td>
<td>220 $223 \pm 47$ 40-65</td>
</tr>
<tr>
<td></td>
<td>Reduce NC DIS : W candidate is formed from 2 highest $P_T$ jets</td>
<td></td>
</tr>
<tr>
<td>$v^* \rightarrow v Z$</td>
<td>$P_T^{\text{miss}} &gt; 20$ GeV</td>
<td>data SM sig. $\epsilon$ (%)</td>
</tr>
<tr>
<td>$\rightarrow vqq$</td>
<td>at least 2 jets, $P_T^{\text{jets}} &gt; 20,15$ GeV</td>
<td>89 $95 \pm 21$ 25-55</td>
</tr>
<tr>
<td></td>
<td>Reduce CC DIS : Z candidate is formed from 2 highest $P_T$ jets</td>
<td></td>
</tr>
</tbody>
</table>

| $v^* \rightarrow v Z \rightarrow vee$ | $P_T + 2e$ | bkg : NC - DIS |
| $v^* \rightarrow eW \rightarrow eev$ | $P_T^{\text{miss}} + 2e$ | bkg : W production |
| $v^* \rightarrow eW \rightarrow e\mu\nu$ | $P_T + e + \mu$ | bkg : $\mu$-pairs |
Invariant mass distributions in the 3 main channels:

Search for $\nu^*$ at HERA (e$p$, 184 pb$^{-1}$)

- $\nu^* \rightarrow \nu \gamma$
- $\nu^* \rightarrow \nu Z$
- $\nu^* \rightarrow eW$

**Good agreement data / SM, no resonance observed**

$\nu^*$ branching ratio

(almost all $\nu^*$ decay topologies are investigated)

Total BR analysed

$C_{\nu^*\gamma}^\gamma = \frac{1}{4} (f-f') = 0$
Limits on $f/\Lambda$ from $\nu^*$ production

Limits at 95% C.L. on $f/\Lambda$ from all channels combined

If $f/\Lambda = 1/M_{\nu^*}$ and $f = -f'$

$M_{\nu^*} < 213 \text{ GeV}$ excluded

For masses beyond the LEP reach, best sensitivity achieved so far
<table>
<thead>
<tr>
<th>decay</th>
<th>Searches for $e^*$ with H1</th>
<th>MC events</th>
<th>results</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e^* \rightarrow e\gamma$</td>
<td>• 2 electromagnetic clusters with $P_T &gt; 20,15$ GeV</td>
<td></td>
<td>data SM sig. $\varepsilon$ (%)</td>
</tr>
<tr>
<td></td>
<td>• Reduced QED Compton</td>
<td></td>
<td>112 125 ± 19 60-70</td>
</tr>
<tr>
<td></td>
<td>$\left{ \begin{array}{l} e_{m1} + e_{m2} &gt; 75$ GeV  \ $E_1 + E_2 &gt; 100$ GeV \end{array} \right.$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$e^* \rightarrow eW$</td>
<td>• $P_T^{\text{miss}} + 2$ jets ,</td>
<td></td>
<td>data SM sig. $\varepsilon$ (%)</td>
</tr>
<tr>
<td>\quad $\rightarrow e\bar{q}q$</td>
<td>same as $e^* \rightarrow eZ \rightarrow e\bar{q}q$</td>
<td></td>
<td>172 175 ± 39 40</td>
</tr>
<tr>
<td>$e^* \rightarrow eZ$</td>
<td>• 1 electron + 2 jets ,</td>
<td></td>
<td>data SM sig. $\varepsilon$ (%)</td>
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<td></td>
<td>351 318 ± 64 45</td>
</tr>
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Invariant mass distributions in the 3 main channels:

- $e^* \rightarrow e\gamma$
- $e^* \rightarrow eZ$
- $e^* \rightarrow VW$

Good agreement data / SM, no resonance observed

$e^*$ branching ratio

(almost all $e^*$ decay topologies are investigated)

$$C_{ee\gamma} = \frac{1}{2} (f_{+} + f_{-}) = 0 \text{ for } f = -f'$$

Cross section very small in that case:

- $\sigma(f_{+}f_{+}) = 7.3 \times 10^{-3} \text{ pb}^{-1}$
- $\sigma(f_{-}f_{-}) = 7.8 \times 10^{-6} \text{ pb}^{-1}$

Only the case $f = +f'$ will be studied
Limits at 95% C.L. from all channels combined

**Limits on** $f/\Lambda$ **from e* production**

**Excited Electron Searches** ($f = +f'$)

- **e* D0** (1 fb$^{-1}$)
  - $qq \rightarrow \gamma, Z \rightarrow ee^*$
  - $e^* \rightarrow e\gamma$

- If: $f/\Lambda = 1/M_{e^*}$ and $f = +f'$
- $M_{e^*} < 273$ GeV excluded

**Best sensitivity achieved for intermediate e* mass ranges**

(e* at HERA have a unique sensitivity up to $M_{e^*} \sim 300$ GeV and $f/\Lambda \sim 10^{-3}$ GeV$^{-1}$)
Summary

All the H1 data at $E_{cm} = 300, 320$ GeV have been used:

- $e^-p : 184 \text{ pb}^{-1}$ to look for excited neutrino (published)
- $e^\pm p : 435 \text{ pb}^{-1}$ to look for excited electrons (preliminary)

No signal found and upper limits have been derived:

For $e^*: if \ f/\Lambda = 1/M_{e^*} and f = +f', M_{e^*} < 273 \text{ GeV} \ excluded$
For $\nu^*: if \ f/\Lambda = 1/M_{\nu^*} and f = -f', M_{\nu^*} < 213 \text{ GeV} \ excluded$

In the mass range $200 \text{ GeV} < M_{\ell^*} < 300 \text{ GeV}$, HERA has the best sensitivity.