Searches for new Physics in ep Collisions at HERA

XXXXth Rencontres de Moriond
Electroweak Interactions and Unified Theories
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on behalf of the

Collaborations
New Physics Searches at HERA

Searches for new Resonances or Contact interactions:
- Lepton Flavor Violation
- Leptoquarks
- Contact Interactions
- Extra Dimensions
- Quark Radius
- Excited Fermions
- SUSY in MSSM
- R-Parity-violating SUSY Searches

Exclusive Final States:
- Isolated Leptons and missing pT (HERA II)
- Single Top Production
- Multi-Lepton Events (HERA II)
- Double-charged Higgs
- Superlight Gravitinos
- Magnetic Monopoles
- General Search (HERA II)
- Pentaquarks

➡ What is new compared to summer (ICHEP)
HERA: ep Collider and Experiments

$E_e = 27.6 \text{ GeV}$

$E_p = 920 \text{ GeV}$

$318 \text{ GeV}$

$42 \text{ GeV}$

$7 \text{ GeV}$

HERA

ZEUS

PETRA
HERA Delivered Luminosities

HERA I
analysed here: H1 118 pb\(^{-1}\)
ZEUS 130 pb\(^{-1}\)

\[ \sqrt{s} = 320 \text{ GeV:} \]
\[ e^+ p \ (65 \text{ pb}^{-1}) \]
\[ e^- p \ (17 \text{ pb}^{-1}) \]

\[ \sqrt{s} = 300 \text{ GeV:} \]
\[ e^+ p \ (48 \text{ pb}^{-1}) \]

steady progress year by year

HERA II
analysed here: H1 53 pb\(^{-1}\)

\[ \sqrt{s} = 320 \text{ GeV:} \]
\[ e_L^+ p \]
\[ e_R^+ p \]

very good year 2004!
longitudinally polarised positron beam
Lepton Flavor Violation

- Neutrino oscillation: lepton flavor not conserved
- Many extensions from SM:
  - GUT, SUSY, compositeness, technicolor predict $e \rightarrow \mu$, $e \rightarrow \tau$
- Charged leptons: very stringent limits from rare decays, especially for $e \rightarrow \mu$

- At HERA: LFV can be mediated by LQs which couple to different generations
- At HERA: LFV can be mediated by R-parity-violating SUSY
Leptoquarks

- Extensions from SM:
couple to leptons and quarks, carry $B, L \neq 0$

**Buchmüller-Rückel-Wyler (BRW) Minimal Model:**
- Chiral coupling invariant under SM gauge transformation
- 7 scalar and 7 vector leptoquarks with fermion number:
  $$F = -(3B + L) = 0 \text{ or } 2$$
- decays: e.g. $\text{BR}(LQ \rightarrow lq) = \beta(lq) = 1, 1/2, 0$

Low mass $M_{LQ} < \sqrt{s}$

High mass $M_{LQ} \gg \sqrt{s}$

Narrow Width Approximation

Contact Interaction Approximation
$e \rightarrow \mu$ Transition (leptonic $\tau$ decays similar)

- $P_T^{\text{miss}} > 15$ GeV
- Isolated, in direction of $P_T^{\text{miss}}$
- No electron

$\rightarrow$ 0 event, $0.87 \pm 0.15$ expected
$e \rightarrow \tau$ Transition (hadronic decays)

- $E_\tau > 45$ GeV
- $15 < E - P_z < 60$ GeV
- Energy deposit in RCAL less than 7 GeV
- No electron with energy larger 10 GeV
- Discriminant of 6 jet shape variables:

$\rightarrow 0$ event, $1.1 \pm 0.5$ expected
Limits for F=0 Low Mass LQs for $\mu$ Channel

(130 pb$^{-1}$)

**scalar**

**vector**

**ZEUS**

Indirect constraints from low energy experiments

$\Rightarrow$ for couplings of em strength: LQs of mass 257-299 GeV excluded
Limits for F=0 Low Mass LQs for $\tau$ Channel

(130 pb$^{-1}$)

**ZEUS**

**scalar**

**vector**

Indirect constraints from low energy experiments

$\Rightarrow$ more stringent than from rare B, K, $\tau$ decays for $M_{LQ} = 250$-$280$ GeV
R-Parity

discrete multiplicative symmetry in SUSY mode is:

\[ R_P = (-1)^{3B+L+2S} \]

- \( R_P = 1 \) for SM particles
- \( R_P = -1 \) for SUSY particles

R-Parity conservation:

- SUSY particles produced in pairs
- LSP is stable
- experimental signature of SUSY: \( E_T^{\text{miss}} \)
$R_P$ can explicitly be broken by trilinear couplings in superpotential

$$W_{R_P} = \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$$

- single sparticle production
- unstable LSP
- final states with large multiplicity

$\Rightarrow$ assume that one $R_P$ coupling dominates
$R_p$-violating Neutralino Production at HERA

so far: s channel squark

new: t channel selectron

NEW:
⇒ analyse SUSY independent of TeVatron mass bounds on squarks
⇒ set first limits on $\lambda'_{121}$ for low selectron mass & large squark mass
Gravitino Production via $t$ Channel Selectron Exchange

\[ e^+, e^- \rightarrow \tilde{\chi}_1^0 (NLSP) \]

\[ d, u \rightarrow \tilde{\chi}'_{1j1}, \tilde{\chi}'_{11k} \rightarrow u^j, d^k \rightarrow \tilde{G} \text{ (LSP)} \]

- $p_T^\gamma > 5$ GeV
- Isolated
- Good tracking acceptance
- $p_T^{miss} > 25$ GeV
- $p_T^{jet} > 5$ GeV
- Good tracking acceptance

$\Rightarrow$ study of $R_p$ SUSY independent of squark mass, dependent on $m_{\tilde{e}_L}, m_{\chi^0}$

$\Rightarrow$ Gauge Mediated SUSY Breaking: slepton masses lower than squark masses

$\Rightarrow$ analyse gravitino ($= p_T^{miss}$) + photon decay of neutralino for the first time
Distributions and Final Selection Cuts

64.3pb\(^{-1}\) of e\(^+\)p data, 13.5pb\(^{-1}\) of e\(^-\)p data

1 event, 2.9 \(\pm\) 0.3 expected (radiative CC)
Limits on Cross Section

\[ \Rightarrow \lambda'_{121} < 0.5 \text{ for } m(\tilde{\chi}_1^0) \approx 80 \text{ GeV} \]

\[ (\tan \beta = 2, \mu < 0, N = 1, M/\Lambda = 2) \]

\[ \Rightarrow \lambda'_{11k} < 0.75 \text{ for } m(\tilde{\chi}_1^0) \approx 81 \text{ GeV} \]

\[ (\tan \beta = 2, \mu < 0, N = 1, M/\Lambda = 2) \]

\[ \Rightarrow \text{first limits independent of squark masses} \]
Limits in $R_p$-violating GMSB ($e^+p$)

H1 $e^+p$

$GMSB, j=1,2$
$\tan\beta=2, \mu<0, N=1, M/\Lambda=2$

$$m(\tilde{e}_L) - m(\tilde{\chi}^0_1) \geq 112 \text{ GeV for } \lambda'_{ij1} = 1$$
$$m(\tilde{e}) < 164 \text{ GeV for } \lambda'_{ij1} = 1$$

$R_P$ conserving SUSY

LEP:

Tevatron:

$\Rightarrow$ HERA is complementary and competitive for $\lambda \approx 1$
High $p_{T}$ Lepton Events at HERA

$e^+ p \rightarrow \mu^+ X + P_{Tmiss}$

- isolated lepton
- high hadronic $p_T$
- missing calorimeter $p_T$

Possible other explanations:

Anomalous top production, RPV SUSY: e.g. $ep \rightarrow \tilde{t} \rightarrow \tilde{b}W$ (no deviation)

Standard Model:
dominated by $W$ production
High $p_T$, Lepton Events at HERA

Example of Tau Candidate

$P_T^{CAL} = 39$ GeV  $P_T^X = 37$ GeV  $M_T = 68$ GeV

$\tau$ jet: collimated "pencil like"
Isolated Lepton Results at HERA I

<table>
<thead>
<tr>
<th></th>
<th>Electron</th>
<th>Muon</th>
<th>Tau_{prelim.}</th>
<th>W contrib.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>obs./exp.</td>
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<td>e\mu(\tau)</td>
</tr>
<tr>
<td><strong>H1 1994-2000</strong></td>
<td></td>
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<td>$\mathcal{L}(e^\pm p) = 118 \text{ pb}^{-1}$</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Full sample</td>
<td>11 / 11.5 ±1.5</td>
<td>8 / 2.94 ±0.51</td>
<td>5 / 5.81 ±1.36</td>
<td>≈ 75(15)%</td>
</tr>
<tr>
<td>$P_T^X &gt; 25 \text{ GeV}$</td>
<td>5 / 1.76 ±0.29</td>
<td>6 / 1.68 ±0.30</td>
<td>0 / 0.53 ±0.10</td>
<td>≈ 85(50)%</td>
</tr>
<tr>
<td>$P_T^X &gt; 40 \text{ GeV}$</td>
<td>3 / 0.66 ±0.13</td>
<td>3 / 0.64 ±0.14</td>
<td>0 / 0.22 ±0.05</td>
<td>≈ 90(55)%</td>
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<td><strong>ZEUS 1994-2000</strong></td>
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<td>24 / 20.6 ±3.2</td>
<td>12 / 11.9 ±0.6</td>
<td>3 / 0.4 ±0.12</td>
<td>≈ 17(48)%</td>
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<td>$P_T^X &gt; 25 \text{ GeV}$</td>
<td>2 / 2.9 ±0.46</td>
<td>5 / 2.75 ±0.21</td>
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<td>$P_T^X &gt; 40 \text{ GeV}$</td>
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<td>1 / 0.07 ±0.02</td>
<td>≈ 60(70)%</td>
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W contribution is NLO: Diener, Schwanenberger, Spira

→ observed excesses in H1 + Zeus do not match channels
**Isolated Leptons at HERA II**

**H1 Collaboration (updated since ICHEP)**

**HERA II: complete data sample**

Search for $l + p_T^{\text{miss}}$ events at HERA II (53 pb$^{-1}$)

- H1 Data (prelim.) $N_{\text{Data}} = 10$
- All SM $N_{\text{SM}} = 6.1 \pm 0.9$

- Slight excess at high $p_T^X$

**HERA I+II combined**

Search for $l + p_T^{\text{miss}}$ events at HERA (171 pb$^{-1}$)

- H1 Data (prelim.) $N_{\text{Data}} = 29$
- All SM $N_{\text{SM}} = 20.6 \pm 2.9$

- Clear excess at high $p_T^X$
### Updated Isolated Lepton Results at HERA II

#### H1 1994-2004

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<td><strong>Full sample</strong></td>
<td>20/16.3 ± 2.2</td>
<td>9/4.3 ± 0.7</td>
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#### ZEUS 1994-2000

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$W$ contribution is NLO: Diener, Schwanenberger, Spira

⇒ **combined electron+muon:**

- full sample : **29 / 20.6 ± 2.9 (74%)**
- $P_T^X>25$ GeV : **16 / 5.1 ± 1.0 (85%)**
General Search

Objects: $e, \mu, \gamma, \nu, \text{jet}$

- **Common phase space:**
  - $P_T^{\text{(object)}} > 20 \text{ GeV}$
  - $10^\circ < \Theta^{\text{(object)}} < 140^\circ$
  - Isolation: $R_{\eta\phi^{\text{(object)}}} > 1.0$

- Consider topologies with 2 or more objects
- Search for deviation from SM

HERA II: no deviation from SM
Magnetic Monopoles

- **Dirac**: Existence of Magnetic Monopoles leads naturally to an explanation of charge quantisation.
- Also predicted from theories which unify the fundamental forces.
- Formation of a monopole condensate provides a possible mechanism for quark confinement.

Quantisation of angular momentum of a system with electric charge $e$ and a monopole with magnetic charge $g$ leads to charge quantisation condition (Dirac):

$$\frac{eg}{\hbar c} = n$$

- $n = 1 \rightarrow$ minimum magnetic charge $g_d$
- Down quark: $e = -1/3 \rightarrow$ fundamental magnetic charge $3g_d$
- Dirac: $n$ is even if particle has electric and magnetic charge $\rightarrow$ fundamental magnetic charge $> 3g_d$
Magnetic Monopoles

- Heavily ionising magnetic monopoles produced in $e^+p$ collisons may stop in Al beam pipe around interaction point
- Binding energy in Al is expected to be large → permanently trapped if stable
- Data from 1995-1997: 62 pb$^{-1}$, $\sqrt{s} = 300$ GeV

- beam pipe cut in long thin strips and analysed in Superconducting Quantum Mechanical Interference Device (SQUID)

Fluctuations not reproducible

$\Rightarrow$ sensitive down to 0.1g$_D$

$\Rightarrow$ no monopoles were found
Summary

- **HERA** performs a wide range of searches for physics beyond the SM
- No evidence for new physics found yet
- Limits on Lepton Flavor Violation and Leptoquarks
- Limits on Superlight Gravitino Production
- Limits on Magnetic Monopoles
- Still very interesting excesses in $e\nu + \mu\nu$ by H1, in $\tau\nu$ by ZEUS
  - and also in recent data $e\nu$ by H1

⇒ more luminosity needed to solve “Isolated Lepton Puzzle”

Outlook

- **HERA** provides now $e^-p$ collisions (only $\approx 20$ pb$^{-1}$ from 1998/99)

⇒ interesting potential for more “New Physics from HERA”