Searches for Supersymmetry at HERA

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Outline

- HERA status
- RPV supersymmetry
- Searches for squarks
- Stop decays
- Search for gaugino production
- Searches for gravitinos
- Conclusions

Focus on recent results and updates since SUSY05.

For non-SUSY searches at HERA see talk by Linus Lindfeld
HERA Running

$e^{\pm} \ 27 \ \text{GeV} \ \Rightarrow \ \sqrt{s}=320 \ \text{GeV} \ \Rightarrow \ p \ 920 \ \text{GeV}$

**HERA I**: 1993-2000  
Luminosity: $\sim 130 \ \text{pb}^{-1}$  
85% $e^+$, 15% $e^-$

**HERA II** since 2002:  
Instant. luminosity increased by factor 3  
Polarised $e^{\pm}$ beam: $P_e \sim 36\%$  
Luminosity: $\sim 240 \ \text{pb}^{-1}$ until now  
15% $e^+$, 85% $e^-$

Very efficient running in 2004+2005+2006 (on-going)

HERA II data analysis started. (This talk only HERA I data.)
RPV Supersymmetry

Multiplicative, discreet Symmetry: \( R_p = (-1)^{3B+L+2S} +1 \) for SM particles
\(-1\) for SUSY particles

RPV: Allows single sparticle production; LSP can decay to SM particles

Additional trilinear terms in superpotential:

\[
W_{R_P} = \lambda_{ijk} L_i L_j \tilde{e}_k + \lambda'_{ijk} L_i Q_j \tilde{d}_k + \lambda''_{ijk} u_i \tilde{d}_j \tilde{d}_k + \ldots
\]

Leading order diagrams at HERA from \( \lambda'_{ijk} \) term.

- Squark production
- Gaugino production
Reminder: H1 Squark Searches

Resonant squark production in s-channel. Squark masses up to $\sqrt{s}=320\text{GeV}$.

$R_p$-violating decay:

Example of gauge decays:

- Many final states considered:
  
  $eq, vq, eMJ, eeMJ, \mu\mu MJ, \nu eMJ, \nu \nu MJ$ \hspace{0.5cm} $\sum BR \sim 100\%$

- No deviation from SM observed in any of these channels.

$\rightarrow$ Large region of SUSY parameter space can be excluded.
Examples for $\lambda'_{l1j1}$:

For strength $\lambda'=0.3$ squark masses up to 275 GeV excluded at 95% CL.
**ZEUS Stop Search**

**MSSM parameter space:**
- $100 \text{ GeV} < M_2 < 300 \text{ GeV}$
- $-300 \text{ GeV} < \mu < 300 \text{ GeV}$
- $\tan(\beta) = 6$

Stop is lightest squark in most of parameter space.
**Dominant decay channels:**

**Electron channels**
- $e^+$-jet channel
- $e^+$-multi jet channel

**Neutrino channel**
- $\nu$-multi jet channel
ZEUS Stop Search: Results

No deviation from Standard Model was found.
Calculate combined limits for three channels.
For $\lambda=0.3$ values up to $M_{\text{stop}}=270$ GeV can be excluded at 95% CL.
Scenarios where $\tilde{\chi}^0_1$ is not the LSP or $m_{\chi^0} < 30$ GeV were discarded.

Limit for mSUGRA:

Small influence of $M_2$ and $\mu$ (red region).
H1: Bosonic Stop Decay

Mass spectrum complementary to previous squark search:
\[ m(\tilde{b}) + m(W^\pm) < m(\tilde{t}_1) < m(\tilde{\chi}_0^0) + m(t), \quad m(\tilde{\chi}_+^+) + m(b) \]

Signatures:
- \( \text{jet} + l + p_T, \text{miss} \)
- \( 3\text{jets} + p_T, \text{miss} \)

Excess in \( \text{jet} + \mu + p_T, \text{miss} \) (obs/exp=8 / 2.7±0.5)
not confirmed by other channels.

Limits in \( m(\tilde{b}) - m(\tilde{t}) \) plane:
\( m(\tilde{t}) \) up to 275 GeV excl. at 95% CL

Reminder:

Excess seen by H1/ZEUS

- [H1, prelim., DIS04]

Used data set: 68 pb\(^{-1}\) (\( \sqrt{s}=319 \) GeV) + 38 pb\(^{-1}\) (\( \sqrt{s}=301 \) GeV)
If $M_\text{squark} \gg M_\text{slepton}$:

s-channel suppressed $\Rightarrow$ t-channel dominant, probing $\lambda'_{ijk}$

Gaugino production:

$\sigma \sim (\lambda')^2$

Independent of squark masses!

Gaugino Decay:

Electron channel

BRs add up to almost 100%.

Neutrino channel

$\tilde{\chi}^\pm$ decay to same final states
Gaugino Search: Selection

Electron channel shown at SUSY2005.

Neutrino channel:
- $E_T > 50$ GeV
- $P_T > 20$ GeV
- $\geq 1$ jet ($p_T>10$ GeV)
- reject events with electron

Analysed ZEUS data: 121pb$^{-1}$

Discriminant method used to optimise signal-to-background.

Data shows no signal.
Excluded region from scan with $m_{\chi^\pm} \leq 103$ GeV (LEP limit).

Results from both channels combined to calculate limits in MSSM:

new results!
**H1: Gravitino Search**

**MSSM → GMSB: LSP is gravitino**

**Signature:**
isol. $\gamma^+p_{T,m_{\text{miss}}} + 1\text{jet}$

No deviation from SM observed.

**Used Lumi:**
e$^+p$: 64 pb$^{-1}$
e$^-p$: 14 pb$^{-1}$

High squark masses → no constraints from APV, CCU → $\lambda'$ can be large!
Gravitino Search by ZEUS

Using multivariate discriminant method to optimise signal-to-background.

Variables used for discriminant:

Used Lumi: 121 pb$^{-1}$ ($e^{+}p$ and $e^{-}p$ !)

No excess in signal region.
Gravitino Search by ZEUS

Limits for different strength of $\lambda'$ coupling:

\[
\begin{aligned}
&\chi_1^0 \to G\gamma \\
\sqrt{s}=233 \text{ GeV}, N=1 \\
&M/\Lambda=1.1, \tan\beta=2, \mu<0
\end{aligned}
\]

For $\lambda'_{111}=1$ masses up to $m(\tilde{e})<260$ GeV, and $m(\tilde{\chi})<150$ GeV can be excl. at 95% CL.

Compared to H1 result:
- More luminosity used
- Also $e^-p$ data included (larger coupling)
- Use of discriminant gives higher sensitivity
- Slightly different parameters
Gravitino Search by ZEUS

Limits for different couplings:

Limits for different $N$:

Limits for different $M/\Lambda$, $\text{sign}(\mu)$ and $\tan\beta$:

Limits valid in large part of GMSB parameter space!
Conclusions

• HERA is an ideal place to search for RPV supersymmetry

• Many searches for supersymmetry have been performed with HERA I data
  - Squark production in MSSM and mSUGRA
  - Gaugino production in MSSM
  - Gravitinos in GMSB
  ➔ No evidence for supersymmetry was found.

• HERA II running very efficiently
  - Collected HERA II luminosity already twice of HERA I!
  - Search results from HERA II expected soon!