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Supersymmetry at HERA :

Results and Prospects

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On behalf of
H1 and ZEUS Collaborations

Outline:

- ★ HERA Results in the MSSM
- ★ $(\not{R}_p)$–SUSY and Results of H1 and ZEUS
- ★ Limits in various SUSY Models
- ★ Future Prospects
- ★ Conclusion

R–Parity

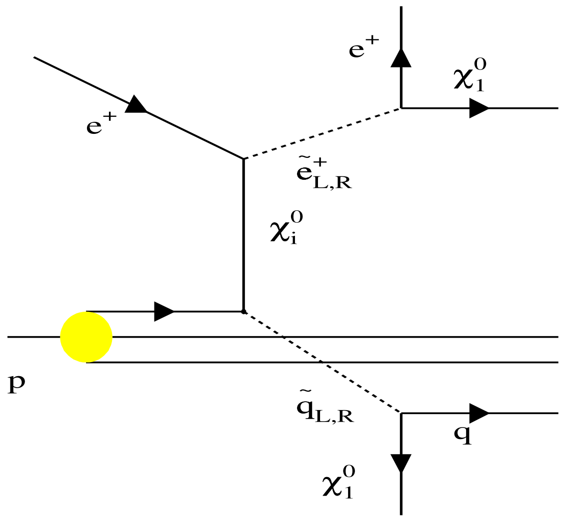
Definition: $$\boxed{R_p = (-1)^{3B+L+2S}}$$

- $R_p = 1$ for all SM particles , $R_p = -1$ for all SUSY sparticles
- The MSSM is R_p–conserving (i.e. B and L conservation)

$\longrightarrow$ all SUSY–particles are pair produced

$\longrightarrow$ LSP is stable $\rightarrow$ candidate for CDM

Dominant R_p-conserving process at HERA: $\boxed{eq \rightarrow \tilde{e}\tilde{q}}$



LSP = χ_1^0 $\Rightarrow$ undetected

Signature:

e + jet + P_T^{miss}

ZEUS: Phys. Lett. B 434 (1998) 214. **H1:** Phys. Lett. B 380 (1996) 461.

$\Longrightarrow$ $\boxed{(M_{\tilde{e}} + M_{\tilde{q}})/2 \quad >\sim 77 \text{ GeV}}$

$\Longrightarrow$ HERA no more competitive to LEP and Tevatron

R-parity violating ($\not{R}_p$) SUSY

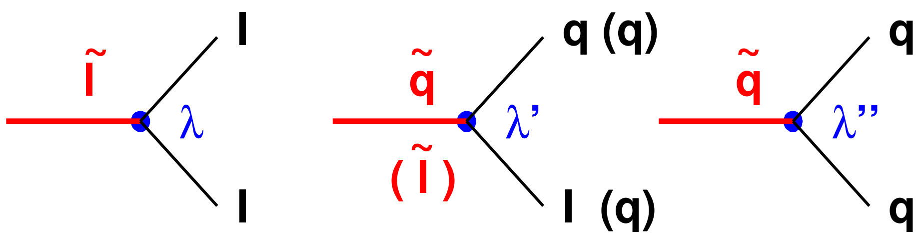
But: most general theory that is supersymmetric, gauge-invariant and renormalizable **has additional term:**

$\not{R}_p$ part of SUSY superpotential:

$$\boxed{W_{\not{R}_p} = \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k}$$

$$\hookrightarrow \not{L} \qquad \hookrightarrow \not{L} \qquad \hookrightarrow \not{B}$$

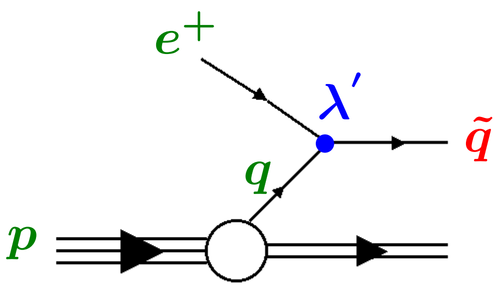
$\Longrightarrow$



- **Resonant production of single SUSY particles**
- **SUSY particles can decay into standard particles**

($\Rightarrow$ LSP no more stable)

HERA:



Initial state with leptonic and baryonic quantum numbers

$\Rightarrow$ **ideally suited to look for particles with coupling to eq-pairs**

$\Rightarrow$ **look for singly produced squarks ($\tilde{q}$) in s-channel via λ'_{ijk}**

ZEUS: ICHEP00 Osaka Abs.1042 **H1:** Eur. Phys. J. C20 (2001) 4, 639.

$(\not{R}_p)$ Production of Squarks at HERA

94 – 97: 40 pb^{-1} e^+p

for each experiment

e^+ **beam and proton PDF**

$\Rightarrow$ mainly probing λ'_{1j1}:

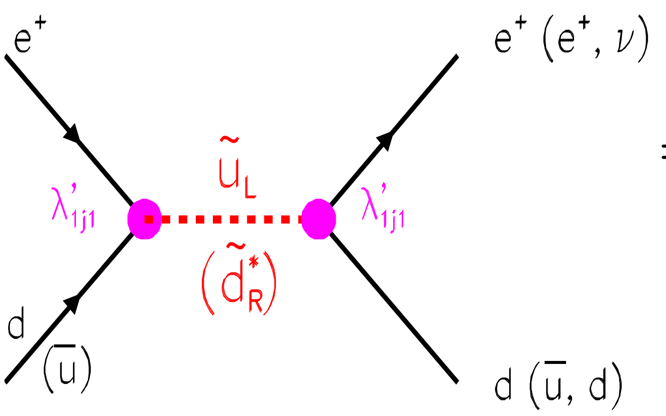
$e^+d \longrightarrow \tilde{u}_L, \tilde{c}_L, \tilde{t}_L$

λ'_{1jk}	production process	
111	$e^+ + \bar{u} \to \bar{\tilde{d}}_R$	$e^+ + d \to \tilde{u}_L$
112	$e^+ + \bar{u} \to \bar{\tilde{s}}_R$	$e^+ + s \to \tilde{u}_L$
113	$e^+ + \bar{u} \to \bar{\tilde{b}}_R$	$e^+ + b \to \tilde{u}_L$
121	$e^+ + \bar{c} \to \bar{\tilde{d}}_R$	$e^+ + d \to \tilde{c}_L$
122	$e^+ + \bar{c} \to \bar{\tilde{s}}_R$	$e^+ + s \to \tilde{c}_L$
123	$e^+ + \bar{c} \to \bar{\tilde{b}}_R$	$e^+ + b \to \tilde{c}_L$
131	$e^+ + \bar{t} \to \bar{\tilde{d}}_R$	$e^+ + d \to \tilde{t}_L$
132	$e^+ + \bar{t} \to \bar{\tilde{s}}_R$	$e^+ + s \to \tilde{t}_L$
133	$e^+ + \bar{t} \to \bar{\tilde{b}}_R$	$e^+ + b \to \tilde{t}_L$

Cross section in NWA: $\sigma(e^+p \longrightarrow \tilde{u}^j_L) \propto \lambda'^2_{1jk} \cdot d^k\left(x = \frac{M^2_{\tilde{q}}}{s}\right)$

Squark Decay Modes in $(\not{R}_p)$ SUSY

1) direct $\not{R}_p$ Decays (Leptoquark-like):



Signature : High P_T $e(\nu)$ + jet

$\Rightarrow$ Look for NC (CC)–like events at high E_T

★ this channel is dominant at high masses (for higher λ'_{1j1})

$\Rightarrow$ **see Jolanta Sztuk's talk** 'Leptoquarks at HERA' **for details**

Squark Decay Modes in $(\not{R}_p)$ SUSY (cont.)

2) Gauge Decay Chain:

- **the squark first decays into quark + gaugino:**
  - $\tilde{q} \longrightarrow \chi_i^0 + q\,,\quad i = 1, 2, 3, 4$
  - $\tilde{q} \longrightarrow \chi_i^\pm + q,\quad i = 1, 2$
  - $\tilde{q} \longrightarrow \tilde{g} + q,$ dominant if kinematically allowed

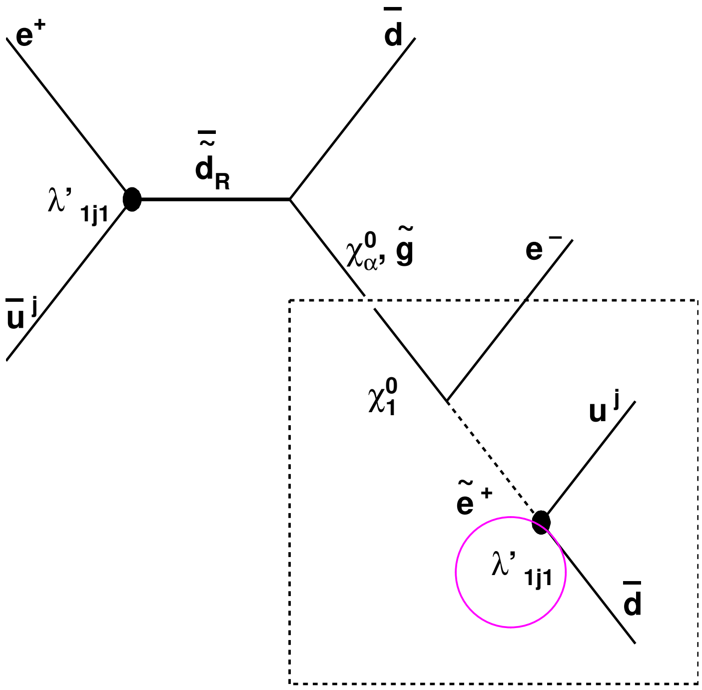
- **subsequent gaugino decay:**

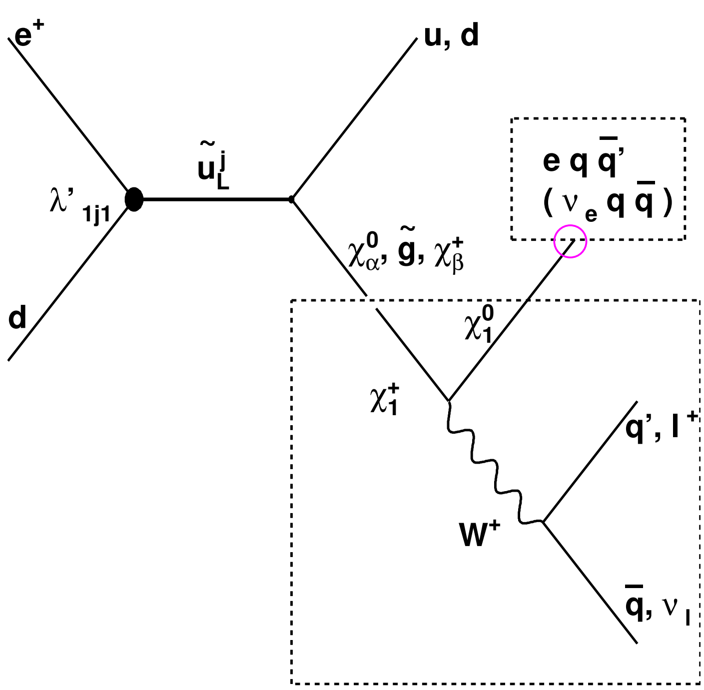
or

both finally R_p violating

gaugino decays $(\not{R}_p)$ violating into 2 quarks + ($e^\pm$ or ν_e):

χ_i^0 with i>1, $\chi_i^\pm$, $\tilde{g}$ decays into lighter χ and two fermions:





large variety of decay modes with lepton(s) + multiple jets

very striking channels: e^- (wrong charge), multi leptons

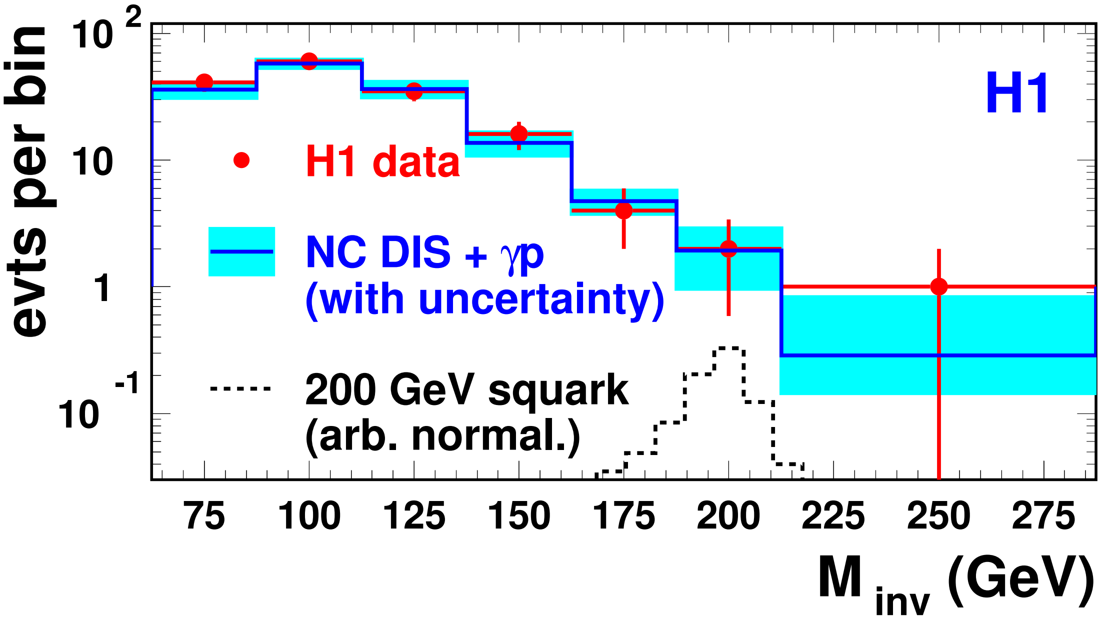
The analyses cover $\sim$ 100 % of the $\tilde{q}$ branching ratio

H1: Gauge Decays into $e + \text{jets} + X$

Selection cuts:

- $P_T^e > 5$ GeV , high y_e, angular cuts
- ≥ 2 high P_T jets , $E_T^{\text{jet 1}} > 15$ GeV , $\theta_{\text{jet 1}} > 10^\circ$

Mass spectrum:



typical efficiencies: $\epsilon = 30 - 50\%$

variety of lepton sub–channels checked in detail

i.e.: $e^+, e^-, ee, e\mu, \nu e$

$\Longrightarrow$ $\boxed{\text{no deviation from SM in channels } e \text{ + jets + X}}$

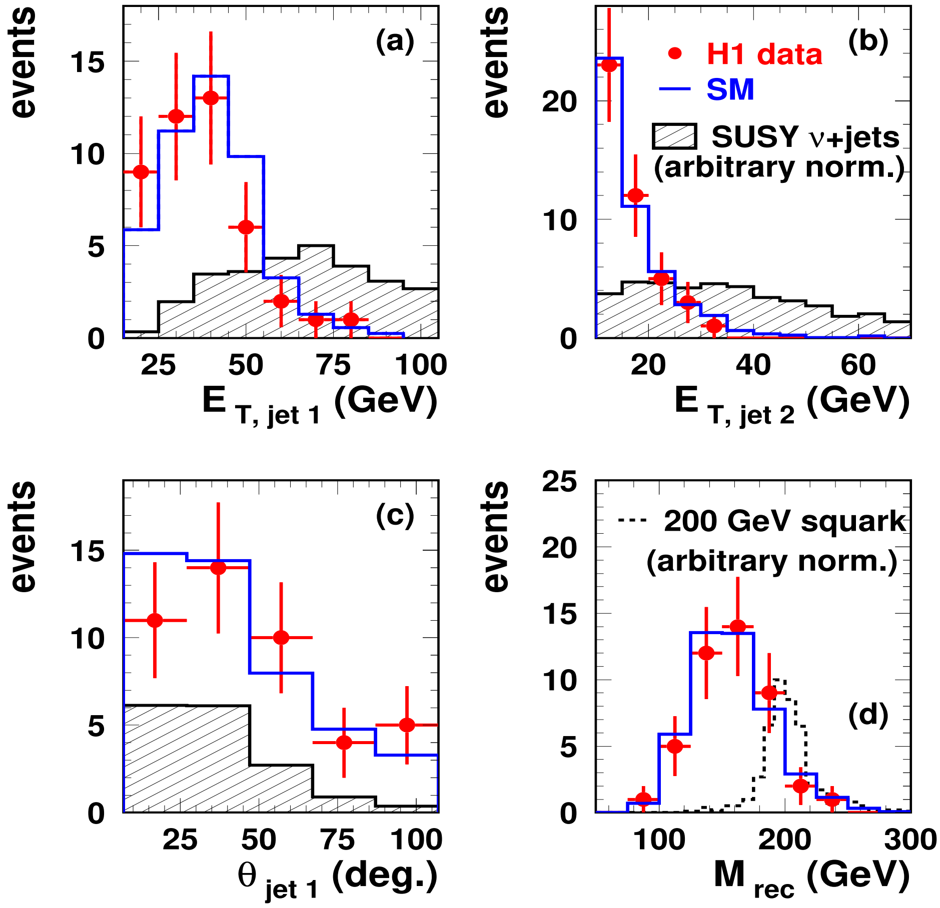
ZEUS: consistent with SM as well

No wrong-charge electron event found by ZEUS and H1 !

H1: Gauge Decays into $\nu + \text{jets} + \text{X}$

Selection cuts:

- $P_T^{\text{miss}} > 25$ GeV
- ≥ 2 high P_T jets , $E_T^{\text{jet 1}} > 15$ GeV , $\theta_{\text{jet 1}} > 10^\circ$



typical efficiencies: $\epsilon = 30 - 60\%$

variety of lepton sub–channels checked in detail (i.e.: ν, $\nu\mu$, νe)

$\Longrightarrow$ **no deviation from SM in channels ν + jets + X**

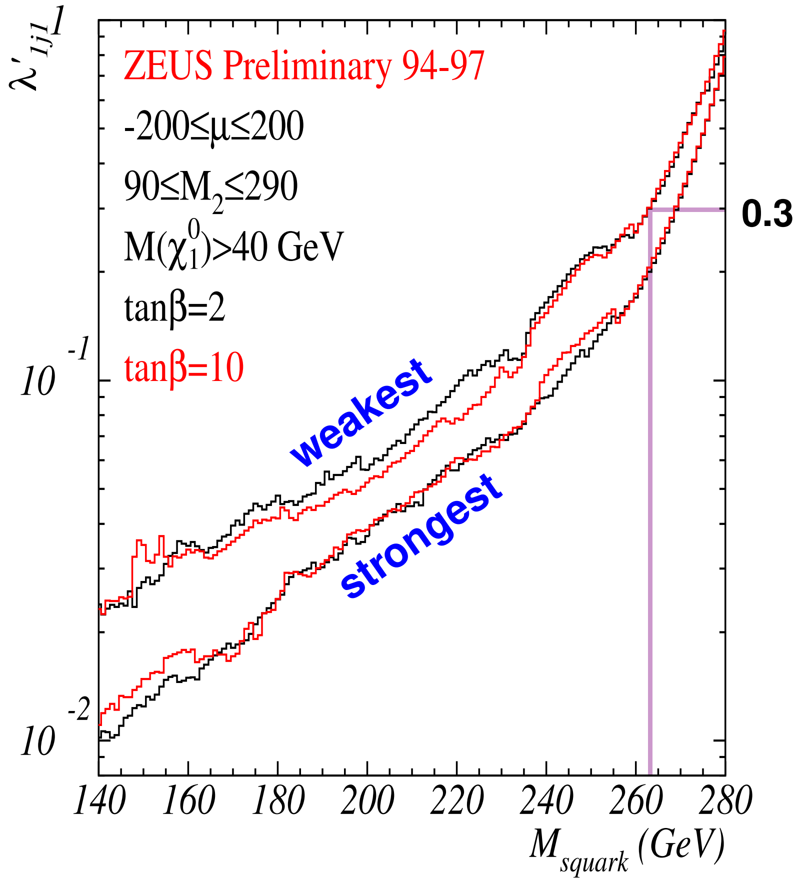
ZEUS: excess at high masses, that is not confined to signal region $\longrightarrow$ still under investigation !

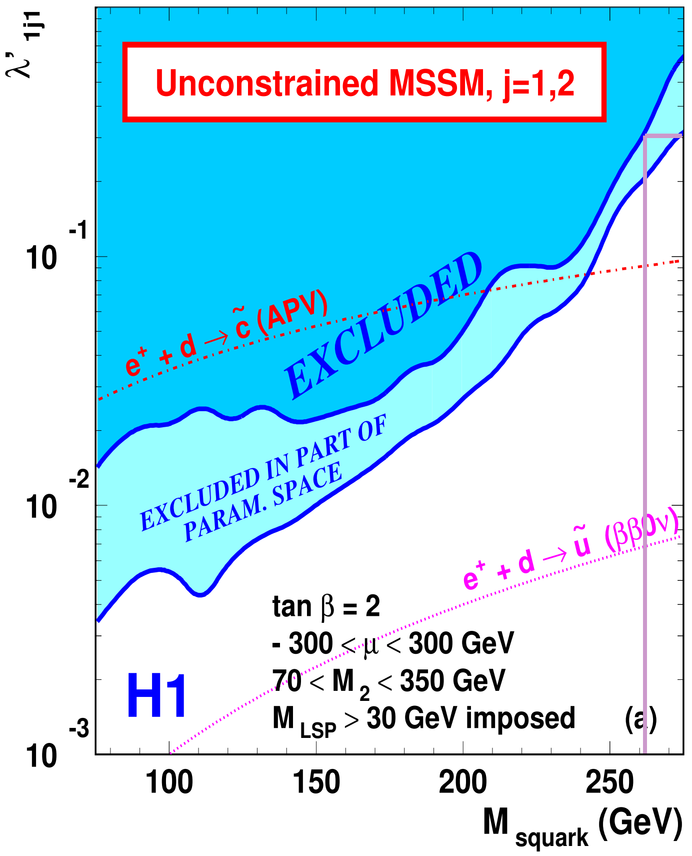
Exclusion limits in the phenomenological MSSM

Unconstrained (phenomenological) MSSM:

- gaugino masses depend on MSSM soft terms : $\tan\beta, \mu, M_2$
- BR and R_p–conserving couplings depend on : $\tan\beta, \mu, M_2$
- but: sfermion masses are free

$\Longrightarrow$ **Scan in SUSY parameter space:**





- Limits are widely model independent
- masses $M_{\tilde{q}}$ up to 260 GeV excluded for $\lambda'_{1j1} = 0.3$
- HERA's sensitivity extends beyond the indirect limits from low energy experiments for $\tilde{c}, \tilde{t}$ (see e.g.: Dreiner, hep-ph/9707435)

Results in Constrained MSSM Models

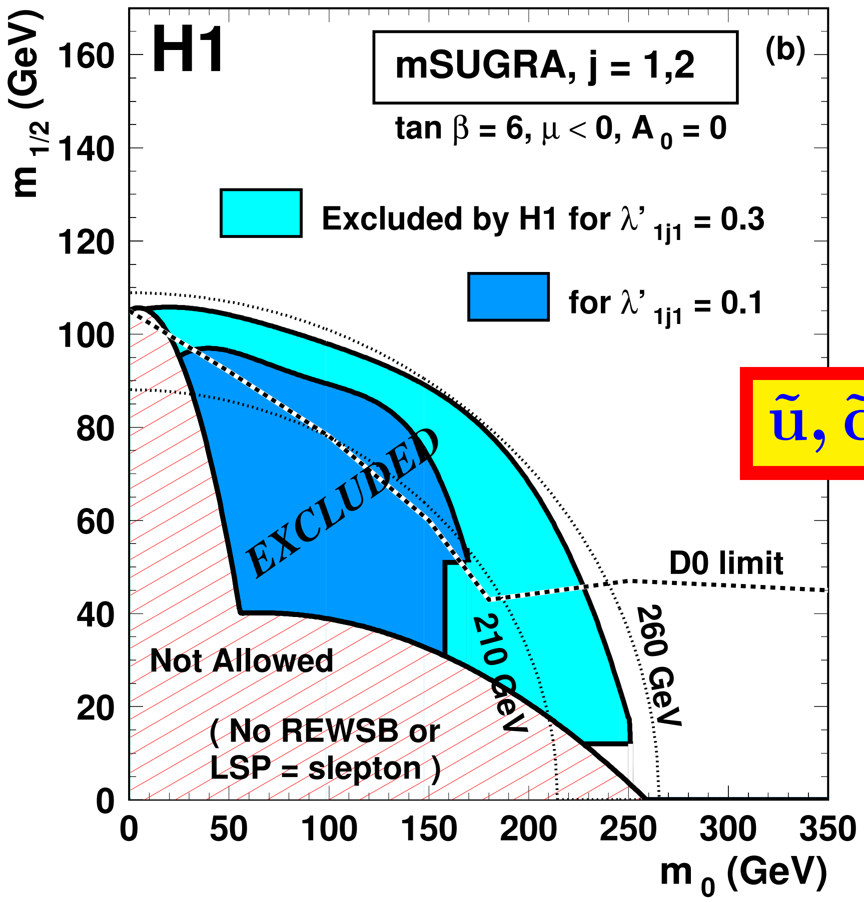
H1 gives limits in **constrained models**:

- common sfermion (gaugino) mass m_0 ($m_{1/2}$) at GUT scale
- masses at EW scale given by RGE
- Sfermion and gaugino sector are related

  $\Rightarrow$ completely determined by : $m_0, m_{1/2}, \mu$, tanβ,A_0
- minimal supergravity **(mSUGRA)**:

  in addition: radiative EW symmetry breaking (REWSB)

  $\Rightarrow |\mu|$ is related to other parameters



$\tilde{u}, \tilde{c}$

- HERA sensitivity follows isomass curve
- HERA's constraints depend on λ'

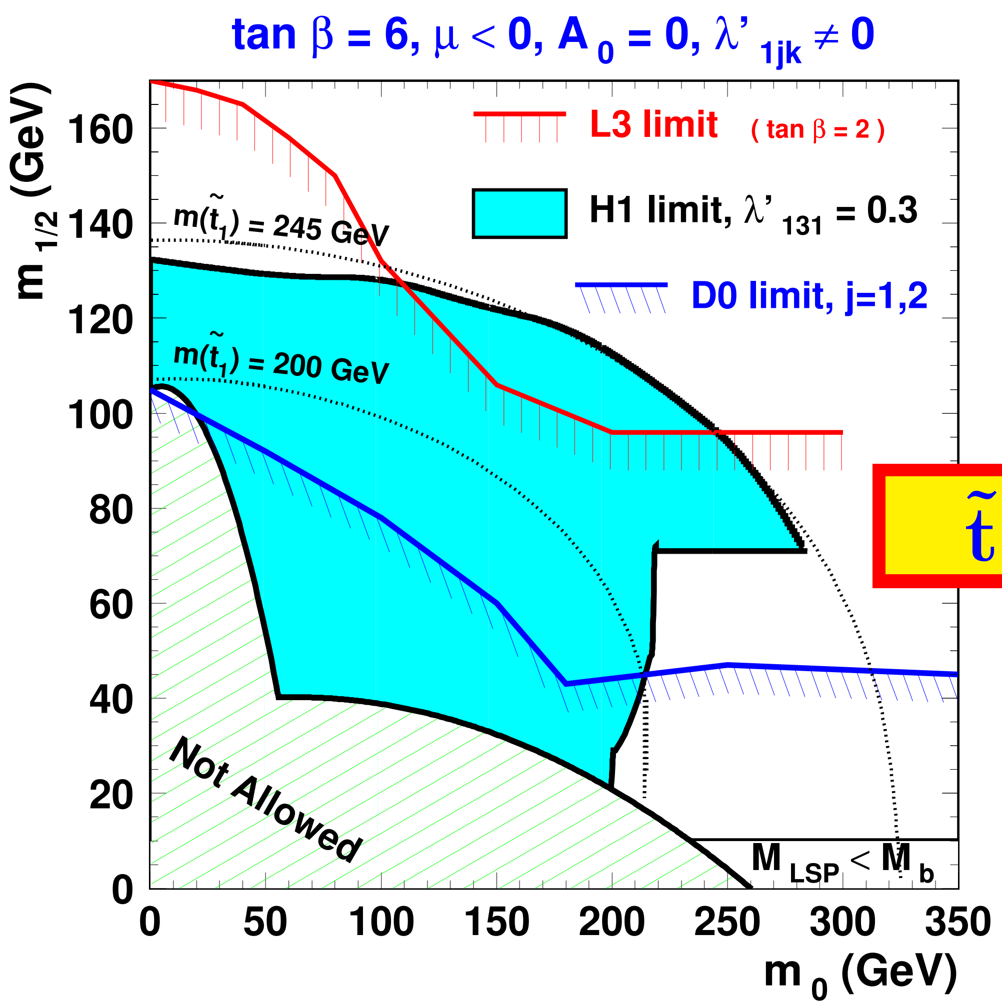
$\Rightarrow$ HERA and Tevatron complement each other

Results in Constrained MSSM Models (cont.)

Special interest in stop production:

- $\tilde{t_1}$ may be the lightest squark

$\Longrightarrow$ larger part of $(m_0, m_{1/2})$–plane covered by HERA (compared to λ'_{1j1} , $j \neq 3$)



$\tilde{t}$

- Masses $M_{\tilde{t}_1}$ up to 245 GeV can be ruled out for $\lambda'_{131} = 0.3$

$\Rightarrow$ HERA competitive to LEP at intermediate m_0 for λ'_{131}

Future Prospects

HERA I: unanalysed data on tape:

- ⋆ **97/98 :** $\approx 15\,\mathrm{pb}^{-1}$ with initial e^{-}–beam !

  $\Longrightarrow$ $\boxed{\tilde{d}_R\text{–production via } \lambda'_{11k}}$

- ⋆ **99/00 :** e^{+}–beam $\int \mathcal{L}\, dt$ doubled

  important: $\sqrt{\mathrm{s}} = 300$ GeV $\rightarrow 320$ GeV

$\Longrightarrow$ Limit in $\lambda'_{1j1}(M_{\tilde{q}})$ can be improved by factor of 2 or more ! !

Extend excluded mass region by 15 GeV (mSUGRA!)

HERA II:

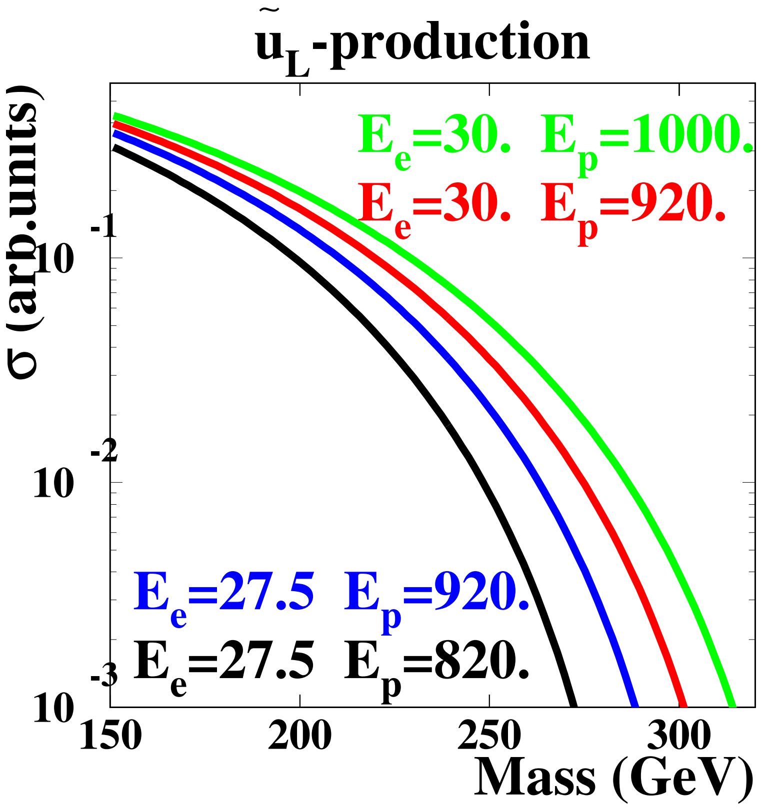
- ⋆ 5x higher luminosity:

  $\sim$ 1fb^{-1} in $\sim$ 5 years per experiment

- ⋆ polarized $e^{\pm}$ beams:

$$e_R^+ + d_L \rightarrow \tilde{u_L}^j$$

$$e_L^- + u_L \rightarrow \tilde{d_R}^k$$



$\Longrightarrow$ **We need e_R^+ or e_L^- for $(\not{R}_p)$–search at HERA II**

$\Longrightarrow$ **Crucial point for $(\not{R}_p)$–search at HERA is $\sqrt{s}$!**

Conclusion

★ HERA is ideally suited for $(\not R_p)$–SUSY via λ'.

★ So far $\sim$ 40 pb^{-1} of (e^+p) data have been analyzed by each HERA experiment.

$\Longrightarrow$ No evidence for squark production has been found.

★ Squark masses up to 260 GeV can be ruled out for λ'_{1j1}= 0.3 .

★ Limits for $\lambda'(M_{\tilde{q}})$ are better than indirect bounds from low energy experiments for $\tilde{c}$ and $\tilde{t}$.

★ mSUGRA limits are competitive/complementary to LEP and Tevatron.

... we look forward to see new exciting SUSY results from HERA ...