Search for R-parity violating Squark production at HERA

Julia Furletova

on behalf of H1 and ZEUS collaborations

EPS 2005 conference in Lisbon

(21-27 July) 2005

- $\not{R}_p$ **SUSY in** $e^{\pm}p$ **scattering**
- **Search for Squarks at HERA**
- **Bosonic stop decay**
- **Summary and outlook**

Supersymmetry and R-Parity

Supersymmetry is a promising candidate for a theory beyond the SM.

SM particles	spin	SUSY partners	spin
q_L,q_R	1/2	$\tilde{q}_L$,$\tilde{q}_R$	**0**
l_L,l_R	1/2	$\tilde{l}_L$,$\tilde{l}_R$	**0**
$\gamma, Z^0, W^\pm$	1	$\tilde{\chi}^0_1, \tilde{\chi}^0_2, \tilde{\chi}^0_3, \tilde{\chi}^0_4$	1/2
$h^0, H^\pm, H^0, A^0$	0	$\tilde{\chi}^\pm_1, \tilde{\chi}^\pm_2$	1/2
g	1	$\tilde{g}$	1/2

In the minimal supersymmetric model (MSSM) the quantum number R-parity is conserved:

$$R_P = (-1)^{2S+3B+L}$$

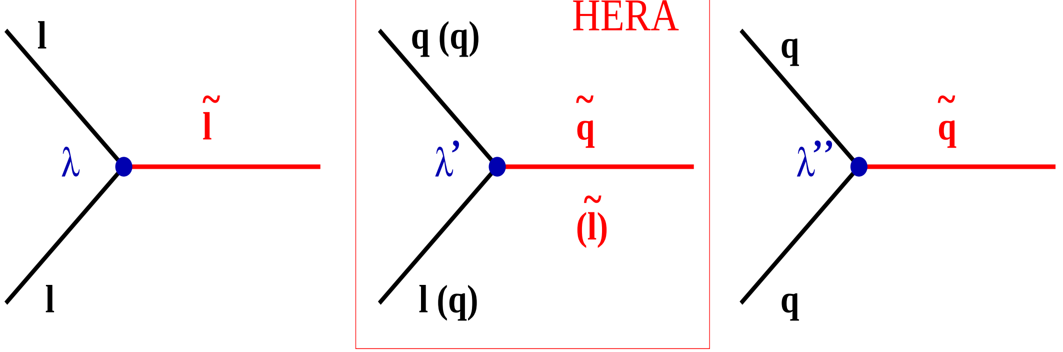
$R_P = \ \ 1$ **for all SM particles**
$R_P = -1$ **for all SUSY particles**

- **All SUSY paricles are produced in pairs**
- **Ligtest Supersymmetric particle (LSP) is stable**
- **Experimental signature of SUSY is** E_T^{miss}

Phenomenology of $\not{R}_p$ SUSY in $e^{\pm}p$ scattering

Additional $\not{R}_p$ term in general MSSM superpotential:

$$W_{\not{R}_p} = \lambda_{ijk} L_i L_j \bar{e}_k \; + \; \lambda'_{ijk} L_i Q_j \bar{d}_k \; + \; \lambda''_{ijk} \bar{u}_i \bar{d}_j \bar{d}_k \ldots..$$



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

- **Allows Single Production of SUSY particles;**
- **Resonant production of SUSY particles in $e^{\pm}p$ scattering possible via λ'_{ijk} with squark masses upto $\sqrt{s}$**
- **Narrow Width Approximation:**

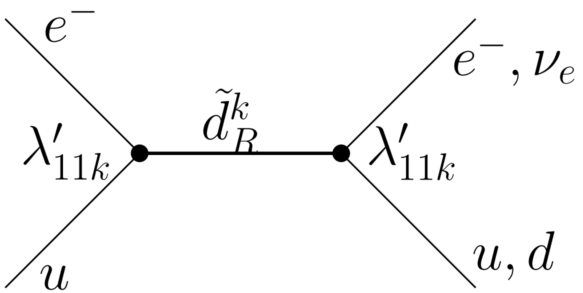
$$\sigma(e^+p \to \tilde{u}^j_L) \sim \lambda'^2_{1jk} \cdot d^k(x = \frac{M^2_{\tilde{q}}}{s})$$

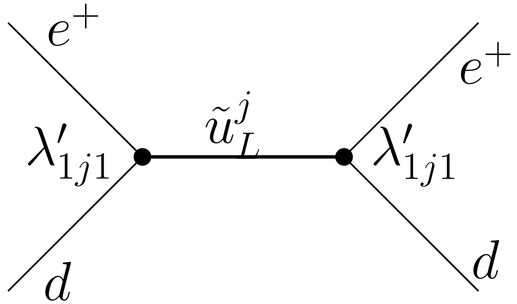
$$\sigma(e^-p \to \tilde{d}^k_R) \sim \lambda'^2_{1jk} \cdot u^j(x = \frac{M^2_{\tilde{q}}}{s})$$

- **Allows the decay of LSP to the SM particles**

Squark decays

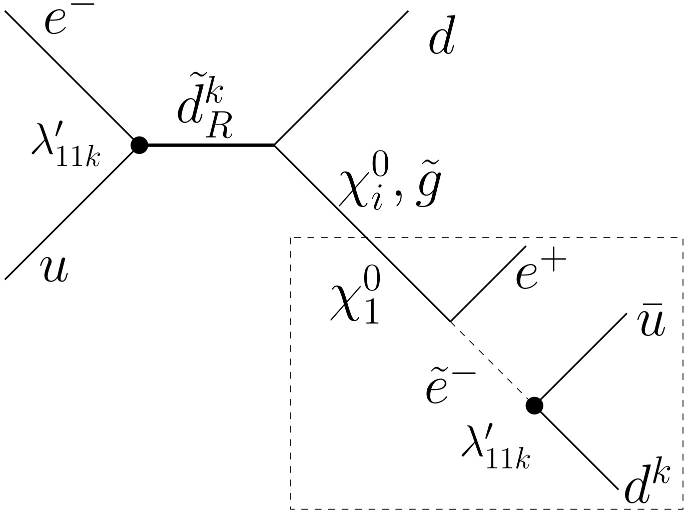
- **Direct $\not R_p$ decays:**
  (Leptoquark-like)

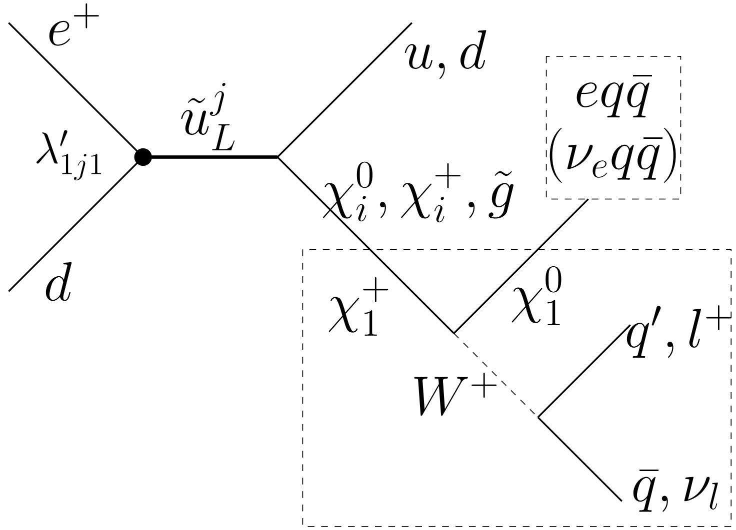




- **Signature:**
  high P_T $e(\nu)$+ jet $\Rightarrow$ Background: DIS NC(CC).
- **only $\tilde{d}^k_R$ (e^-p collisions) can decay to νq.**

- **Squark R_P conserving gauge decay**





Signature:

- e (**"right" charge**) + **MJ**
- e (**"wrong" charge**)+ **MJ**
- ν + **MJ**
- e + l + **MJ**
- ν + l + **MJ**

Introduction to HERA

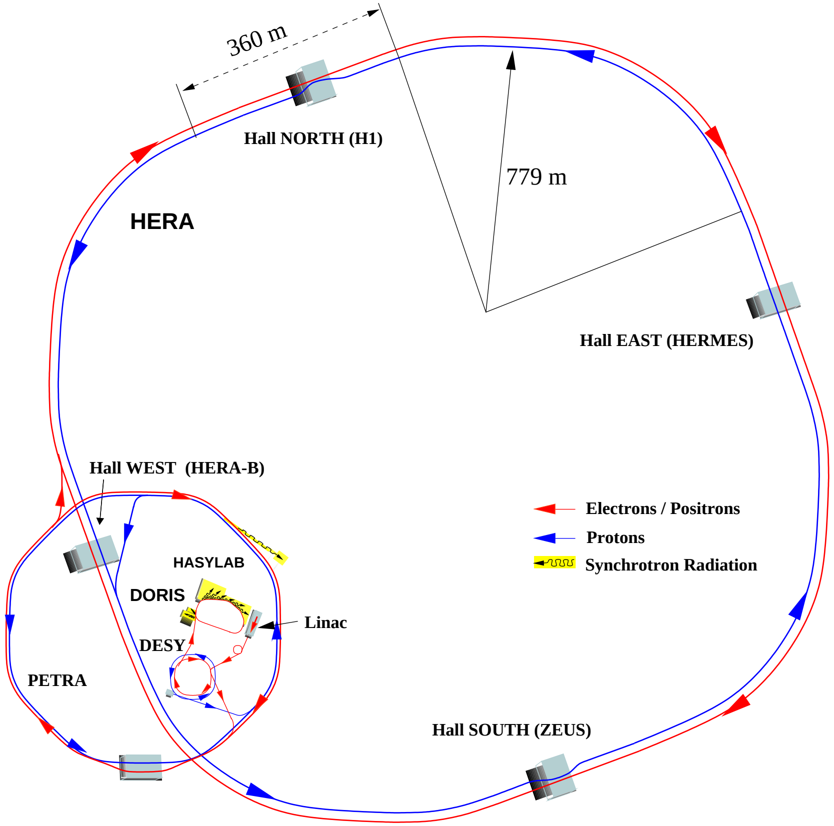
HERA **ep** **collider at** $\sqrt{s} \sim 318(300)\ GeV$.

Tunnel: 6.34 **km long,** 10 **to** 25 **meters underground.**

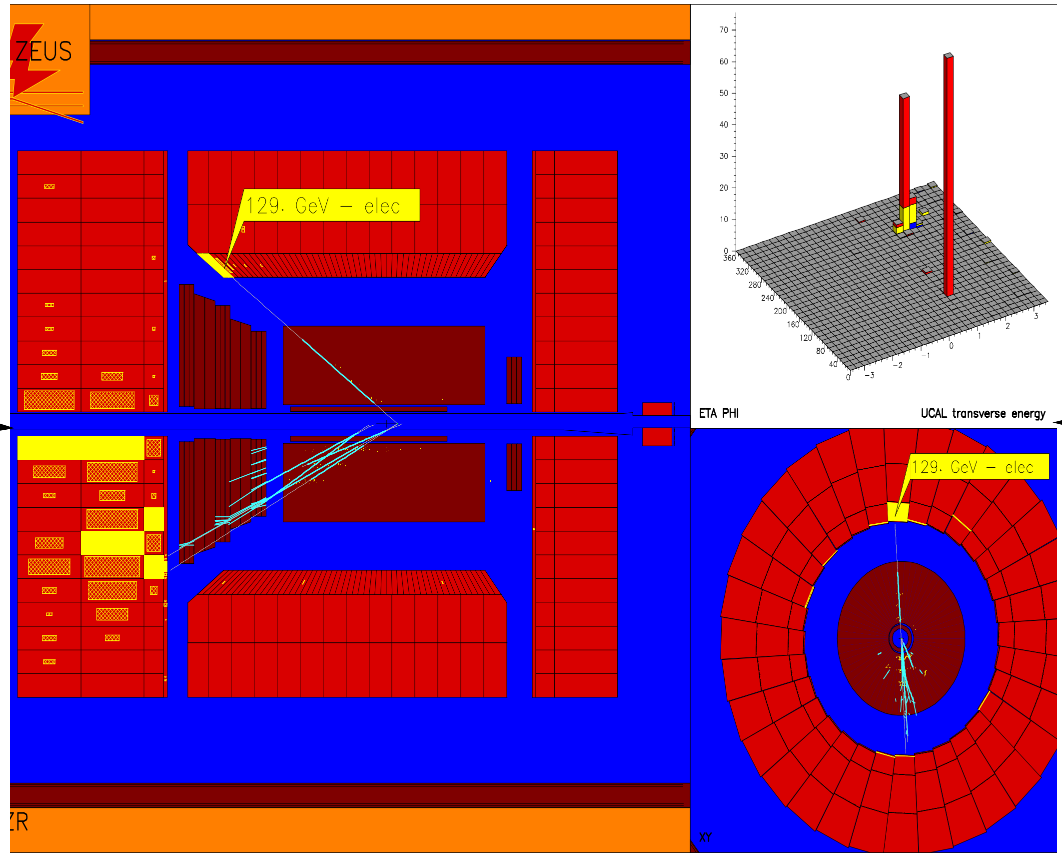
$E_e = 27.5$ **GeV,** $E_p = 920(820)$ **GeV**

Two detectors:

H1 and ZEUS



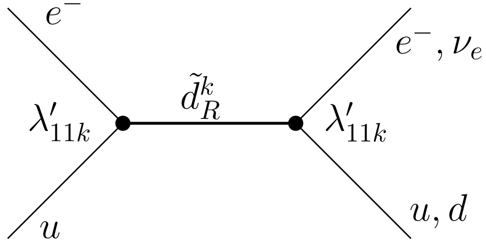
e



p

Data selection and results for direct $\not{R}_p$ decays

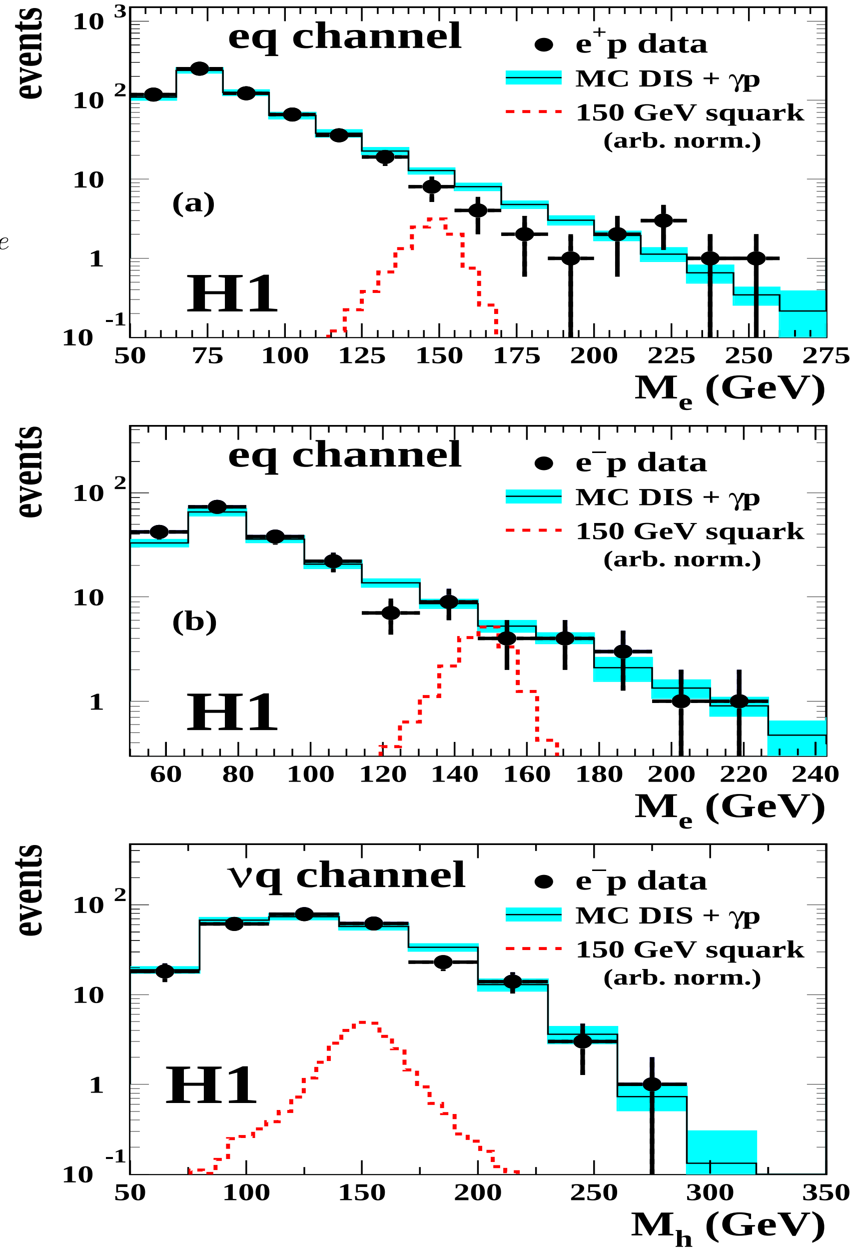
- **H1 Data:**
  64.3 $\mathbf{pb}^{-1} e^+p$ **and** 13.5 $\mathbf{pb}^{-1} e^-p$
- **Selection:**

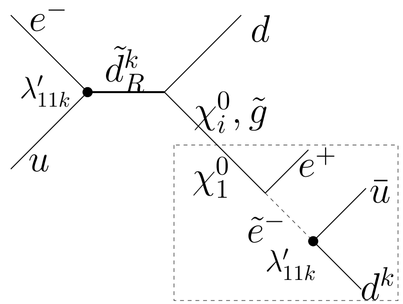


- eq **channel:**
  - * $P_T^e > 16$ **GeV**
  - * $P_T^{miss} < 15$ **GeV**
  - * $40 < \Sigma(E - p_z) < 70$ **GeV**
  - * $Q_e^2 > 2500$ **GeV**^{2} **and** $y_e < 0.9$
- νq **channel:**
  - * $P_T^{miss} > 30$ **GeV**
  - * $Q_{JB}^2 > 2500$ **GeV**^{2} **and** $y_{JB} < 0.9$
  - * **No** e **or** μ **with** $P_T > 5$ **GeV**

Ch	e^+p collisions		e^-p collisions		Efficiency
	Data	SM exp	Data	SM exp	
eq	632	628 ± 46	204	192 ± 14	$30 - 50\%$
νq	–	–	261	269 ± 21	$40 - 60\%$

No deviation from SM expectation





Data selection and results for Squark R_P conserving gauge decay

- **Selection:**

  $\geqslant 2$ **jets with** $P_T^{jet} > 15$ **GeV**

  $e + MJ + X$ **channels:**

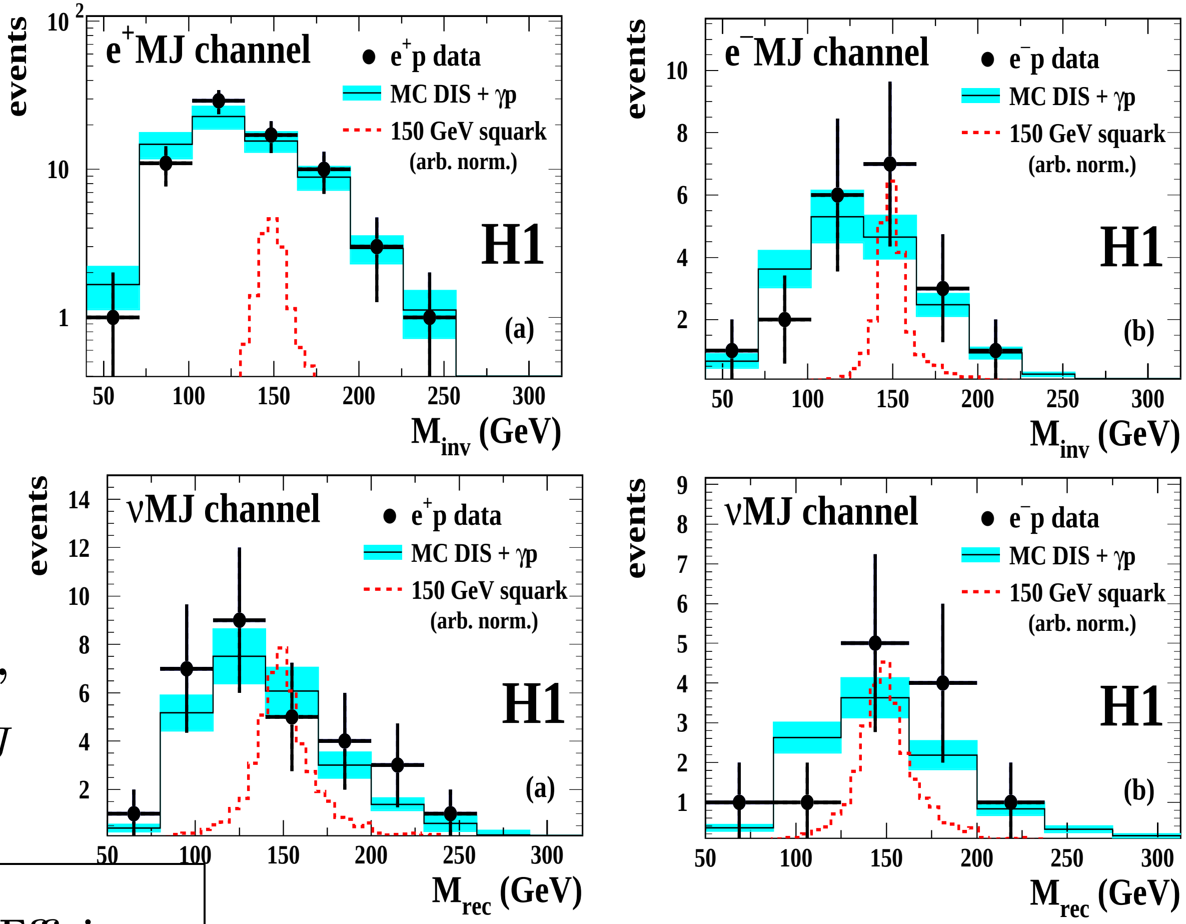
  $(e^+MJ, e^-MJ, eeMJ, e\mu MJ, e\nu MJ)$

  - $P_T^e > 6$ **GeV** ($P_T^\mu > 5$ **GeV**)
  - $P_T^{miss} < 15$ **GeV**
  - $P_T^{miss} > 15$ **GeV** $(e\nu MJ)$
  - $40 < \Sigma(E - p_z) < 70$ **GeV**

  $\nu + MJ + X$ **channel:** $(\nu MJ, \nu\mu MJ)$

  - $P_T^{miss} > 26$ **GeV,** $P_T^\mu > 5$ **GeV.**

- **No events found in** eMJ **"wrong" charge,** $eeMJ$, $e\mu MJ$, νeMJ, $\nu\mu MJ$ **channels.**



Ch	e^+p collisions		e^-p collisions		Efficiency
	Data	SM exp	Data	SM exp	
eMJ	72	67.5 ± 9.5	20	17.9 ± 2.4	$15 - 50\%$
νMJ	30	24.3 ± 3.6	12	10.1 ± 1.4	$10 - 60\%$

No evidence for squark production

Stop decays in $\not{R}_p$ SUSY

- **ZEUS data:** 65.5 $\mathbf{pb}^{-1}$ e^+p

▷ $e^+q \overset{\lambda'_{131}}{\longrightarrow} \tilde{t} \rightarrow \tilde{\chi}_1^+ b$;
$\hookrightarrow e^+\bar{b}d$ **(eMJ)**

▷ $e^+q \overset{\lambda'_{131}}{\longrightarrow} \tilde{t} \rightarrow \tilde{\chi}_1^+ b$;
$\hookrightarrow \tilde{\chi}_1^0 W^+$
$\hookrightarrow qq'$
$\hookrightarrow \nu_e \bar{b} d$ **(νMJ)**

▷ $e^+d \overset{\lambda'_{131}}{\longrightarrow} \tilde{t} \overset{\lambda'_{131}}{\longrightarrow} e^+d$ **(eJ)**

- **NC Preselection:**
  - $E_e > 8$ **GeV** ($E_e > 20$ **GeV**, $\theta_e < 0.3$)
  - $50 < \Sigma(E - P_Z) < 65$ **GeV**
- **CC preselection:** **No e;** $P_T^{miss} > 20$ **GeV**

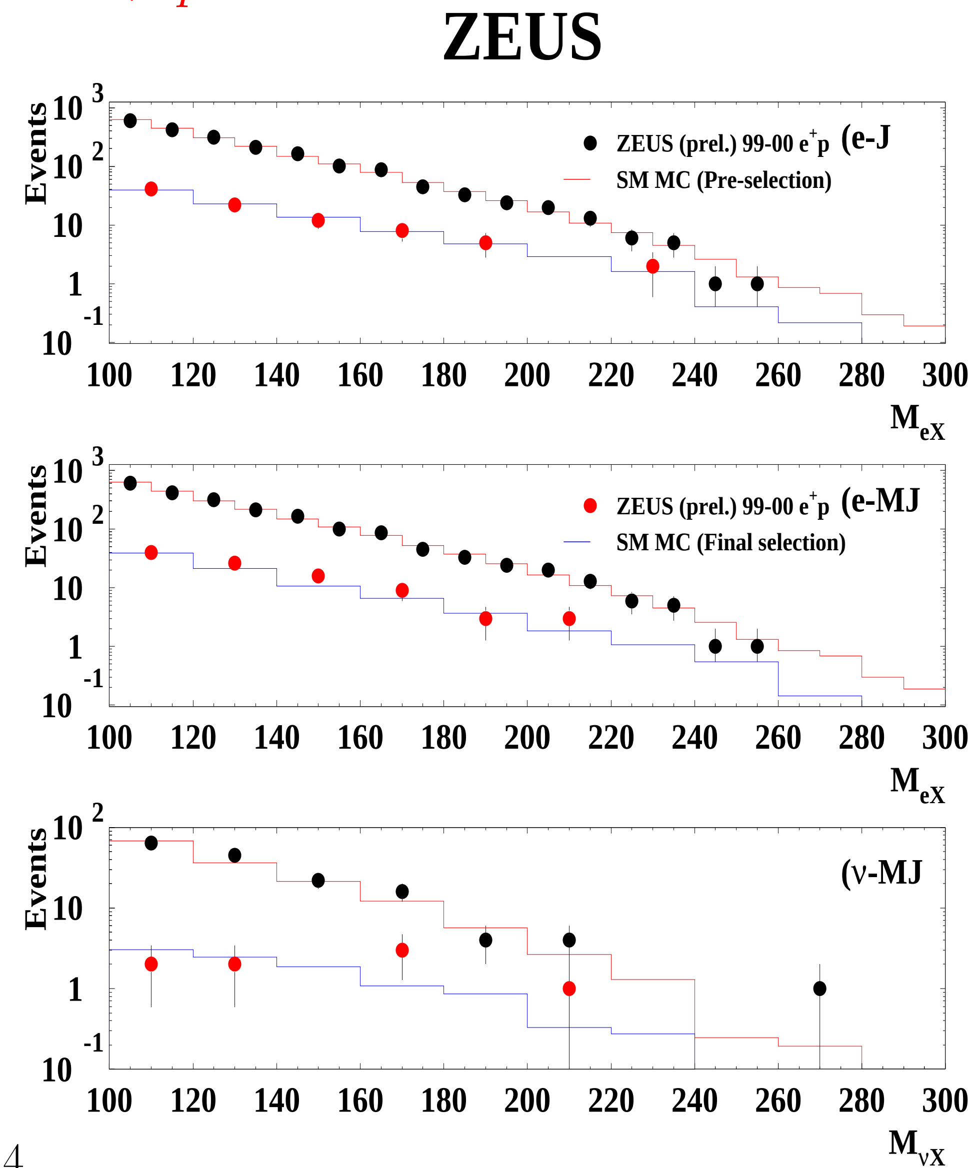
- **Final Selection:**

NC:

- $Q^2_{DA} > 3000$ $\mathbf{GeV}^2$
- $(0.8 - 0.2) < y_{DA} < 0.98$
- **eJ (eMJ):** $P_T^{had}/E_T^{had} > (<) 0.8$

CC:

- $y_{JB} > 0.42$
- **ν-MJ:** $P_T^{had}/E_T^{had} < 0.4$



No significant deviation from SM.

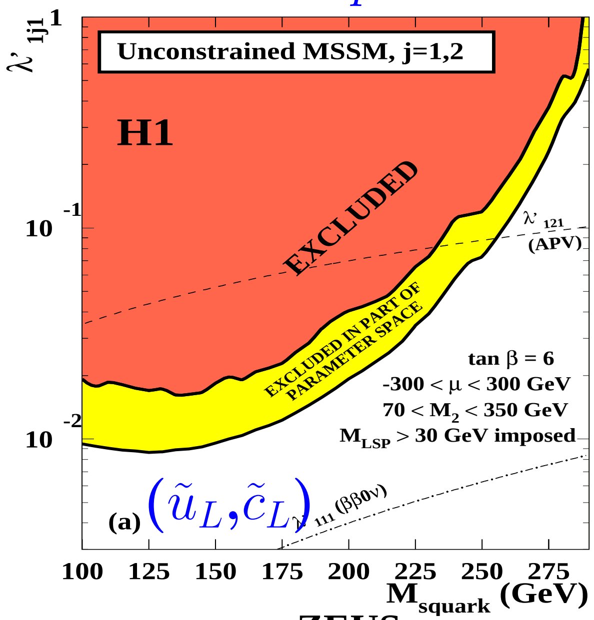
Coupling limits in the MSSM

- No evidence for resonance was found ⇒ Limit
- SUSY parameters scan (H1 and ZEUS):
  - $\tan\beta = 6$, $M_{\tilde{l}} = 90$ GeV
  - $M_{LSP} > 30$GeV
  - 70GeV $< M_2 <$ 350GeV (H1)
  - 100GeV $< M_2 <$ 300GeV (ZEUS)
  - -300GeV $< \mu <$ 300GeV
- 95% CL mass limits

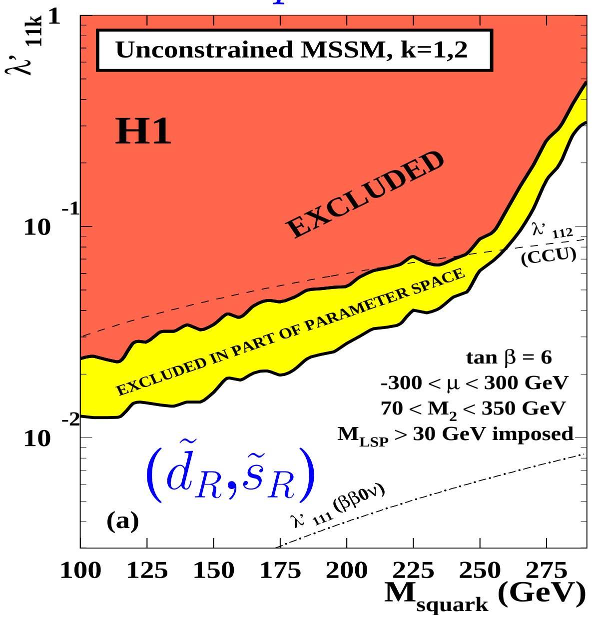
$\lambda'_{1j1} = 0.3$	$M(\tilde{u}_L, \tilde{c}_L, \tilde{t}_L) <$ 275 GeV
$\lambda'_{11k} = 0.3$	$M(\tilde{d}_R, \tilde{s}_R, \tilde{b}_R) <$ 280 GeV

- HERA results improve the limits on $\lambda'_{121}, \lambda'_{131}, \lambda'_{112}, \lambda'_{113}$ for masses up to ~ 255 GeV

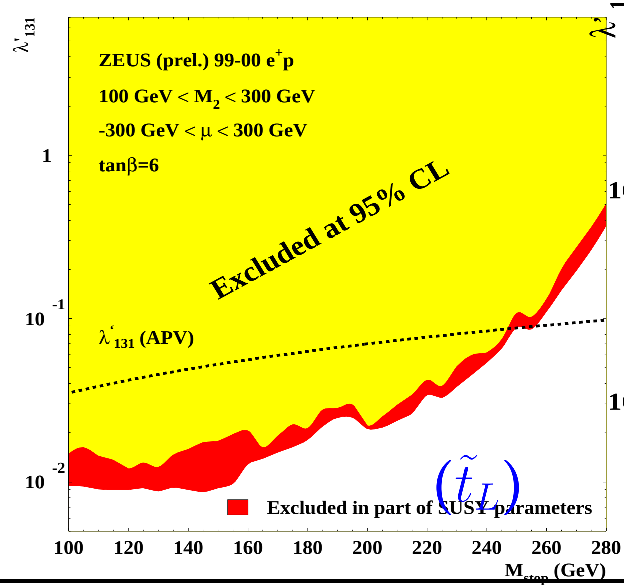
e^+p data

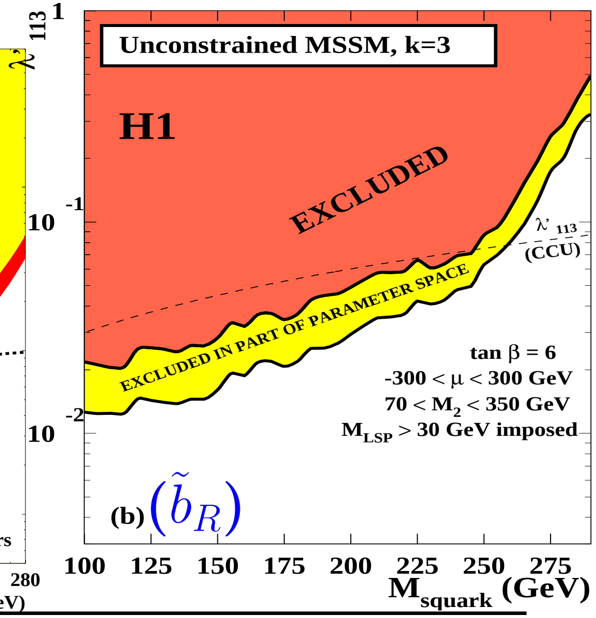


e^-p data



ZEUS





Limits in the minimal Supergravity model

- **in mSUGRA only 5 parameters:**

  $\tan\beta = 6$; **sign**$(\mu) = -1$

  m_0 **- common scalar mass**

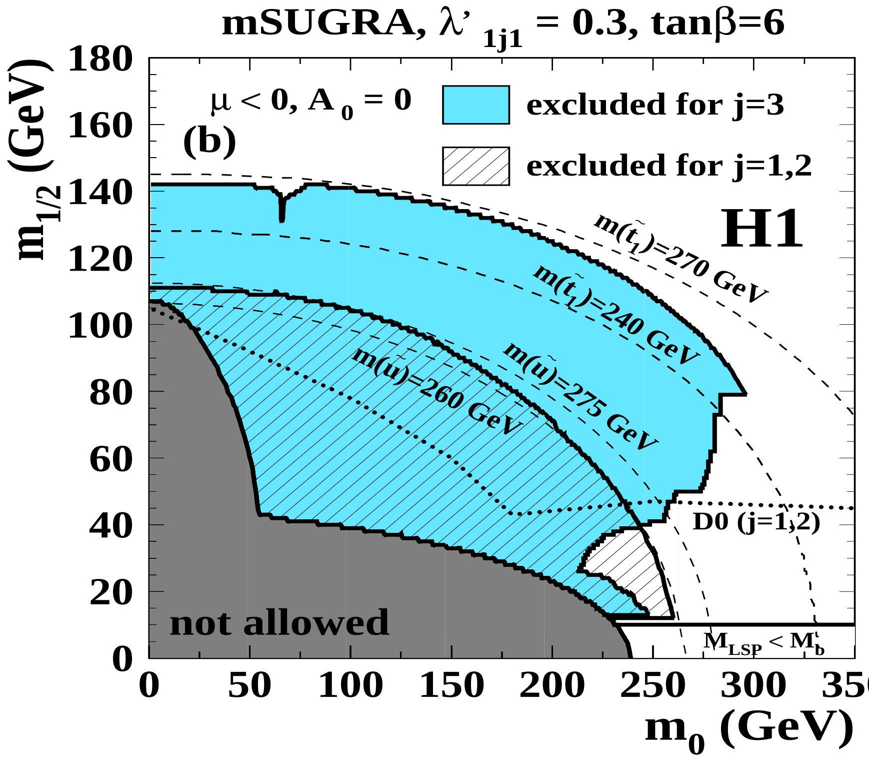
  $m_{1/2}$ **- common gaugino mass**

  $A_0 = 0$ **- common trilinear coupling**

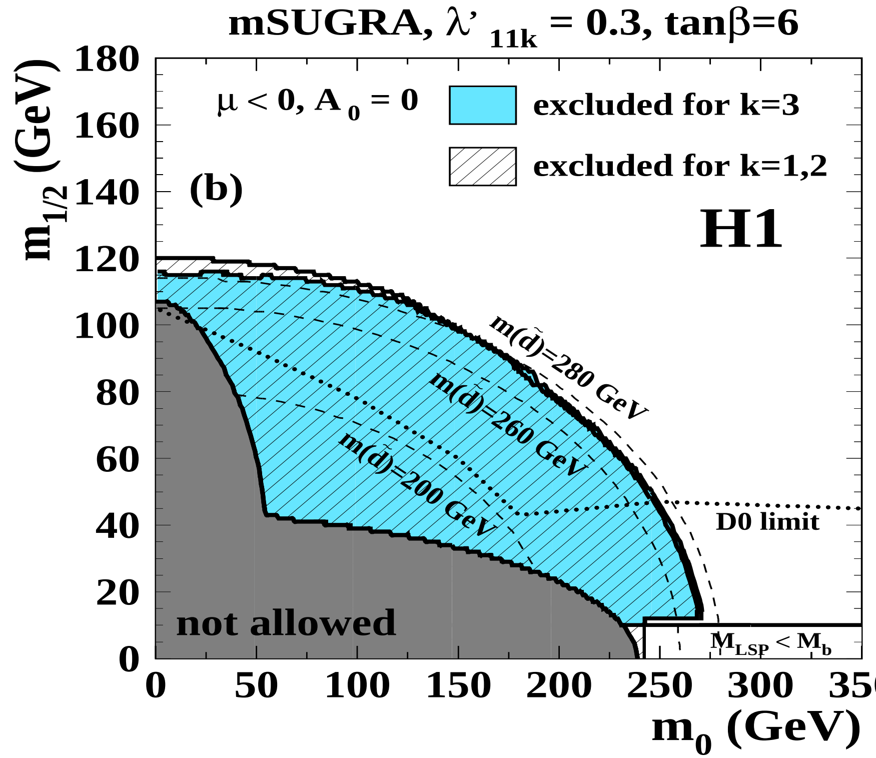
  For $\lambda'_{1j1}(\lambda'_{11k}) = 0.3$ **limit in** $(m_0, m_{1/2})$ **plane**

- **Limits follow curves of constant squark mass.**
- **For** $\lambda'_{1j1}(\lambda'_{11k}) = 0.3$ **the parameter space defined by** $M_{\tilde{q}} < 275(285)$ **GeV is nearly fully excluded.**

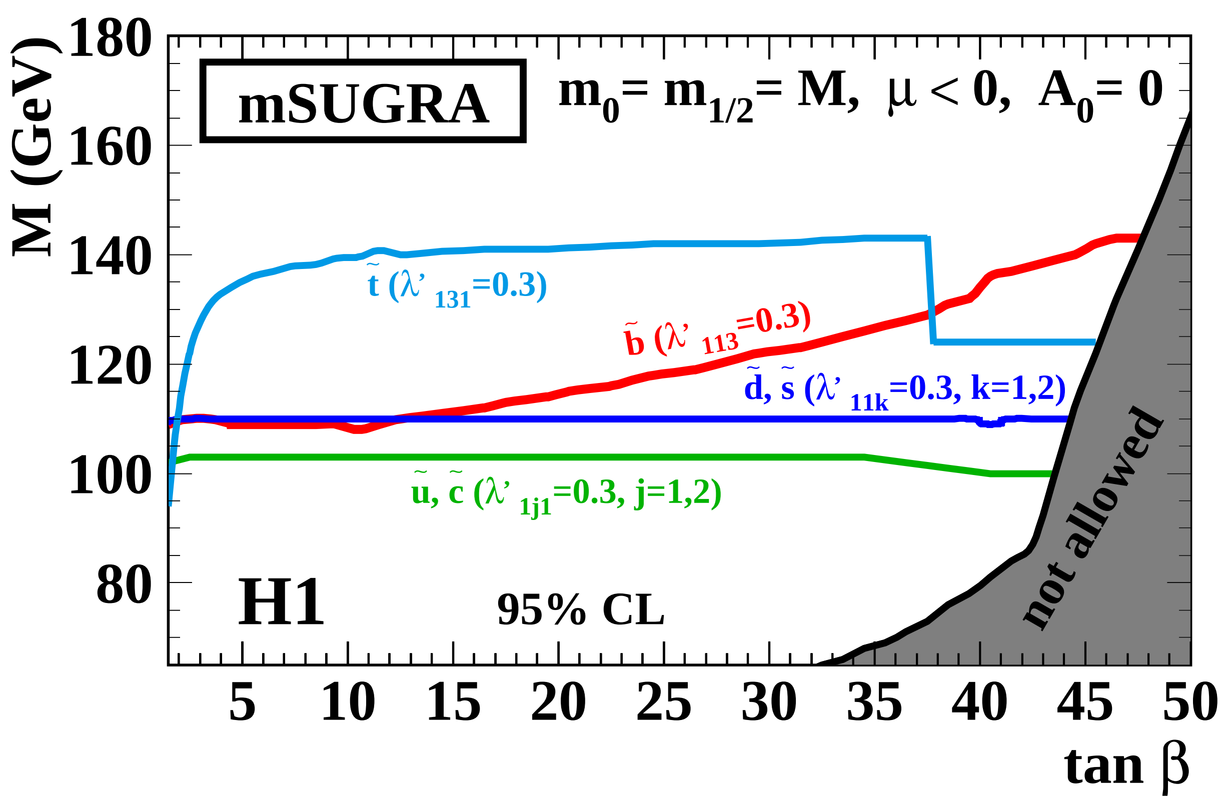
e^+p **data** ($\tilde{t}_L$ **and** $\tilde{u}_L, \tilde{c}_L$)



e^-p **data** ($\tilde{b}_R$ **and** $\tilde{d}_R, \tilde{s}_R$)



Limits in the mSUGRA

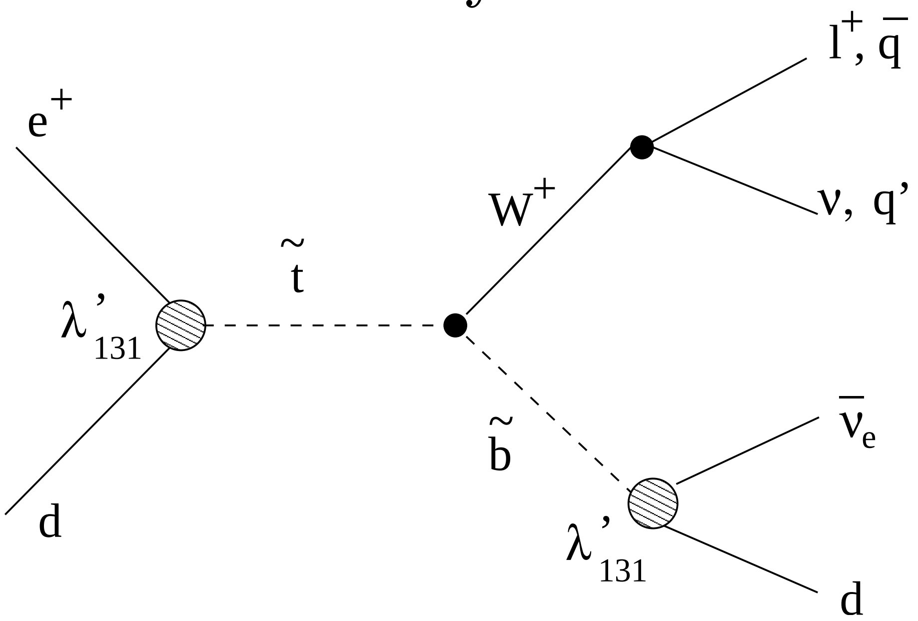


- For $(\tilde{u}, \tilde{c}, \tilde{d}, \tilde{s})$ curves are flat (small mixing).
- For $(\tilde{d}, \tilde{s})$ limit higher then for $(\tilde{u}, \tilde{c})$ because of larger production cross section.
- Mixing is higher in stop sector.
- At value of $\tan\beta > 37$ stop decay to $\tilde{\tau}$ become important, but was not searched for.

Bosonic Stop decays in $\not{R}_p$ SUSY

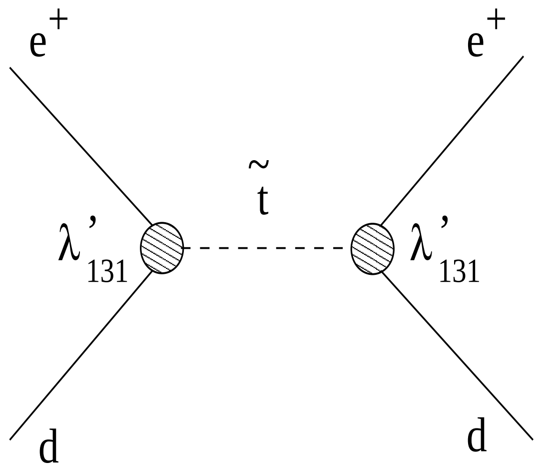
- $e^+ q \xrightarrow{\lambda'} \tilde{t} \rightarrow \tilde{b} W$; $\tilde{b} \xrightarrow{\lambda'} \bar{\nu}_e d$
  - experimentally investigated for the first time
- **Complementary to the previous SUSY searches:**
  $M(\tilde{b}) < M(\tilde{t})$; $\tilde{q} \not\rightarrow q' \tilde{\chi}$
- $M_{\tilde{t}} < \sqrt{s}$, **at HERA** $\sqrt{s} \sim 300(319) GeV$.

Dominant decay channels:



Signature:

$J + e + P_T^{miss}$
$J + \mu + P_T^{miss}$
$3J + P_T^{miss}$
$J + e$

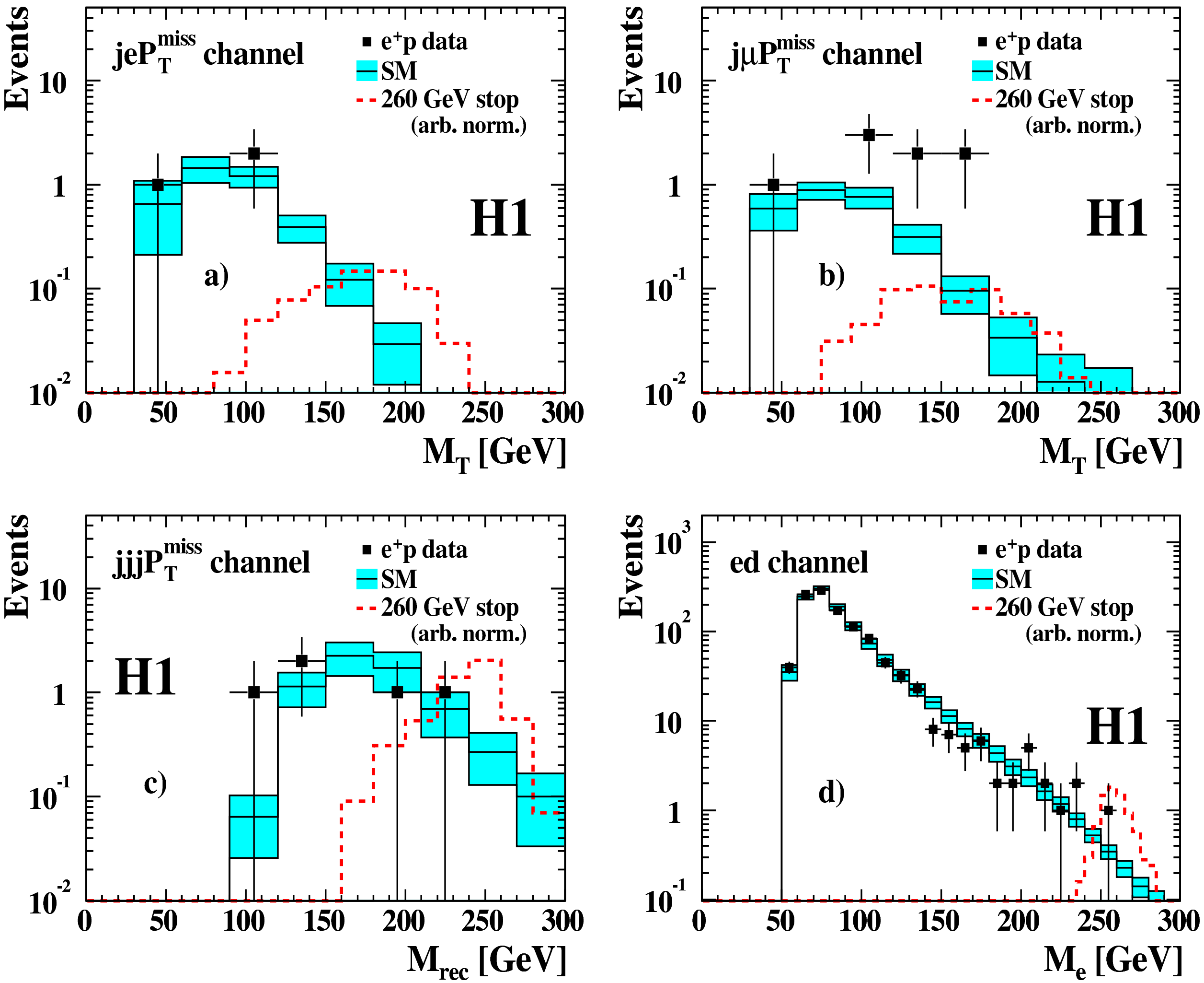


Bosonic stop decay

- **Total** 106 **pb**$^{-1}$ e^+p **H1 data**
- **Selection cuts:**
  - **Bosonic Stop Decay Channels** (JeP_T^{miss}, $J\mu P_T^{miss}$, $3J+P_T^{miss}$)**:**
    - $P_T^l > 10$ **GeV**
    - $P_T^{Jet} > 10\ (20, 15, 10)$ **GeV**
    - $P_T^{miss} > 12\ (25)$ **GeV**
  - $\not{R}_p$ $\tilde{t} \rightarrow ed$ **Channel** ($J+e$)**:**
    - $P_T^{Jet} > 20$ **GeV**
    - $P_T^l > 20$ **GeV**
    - $Q_e^2 > 2500$ **GeV**^{2}

Ch	Data	SM exp
JeP_T^{miss}	3	3.84 ± 0.92
$J\mu P_T^{miss}$	8	2.69 ± 0.47
$3JP_T^{miss}$	5	6.24 ± 1.74
ed	1100	1120 ± 131

typical efficiencies: $30 - 50\%$

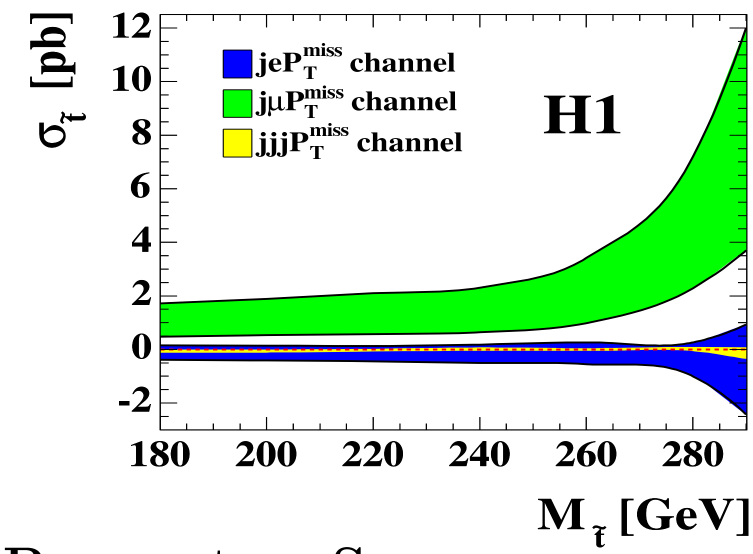


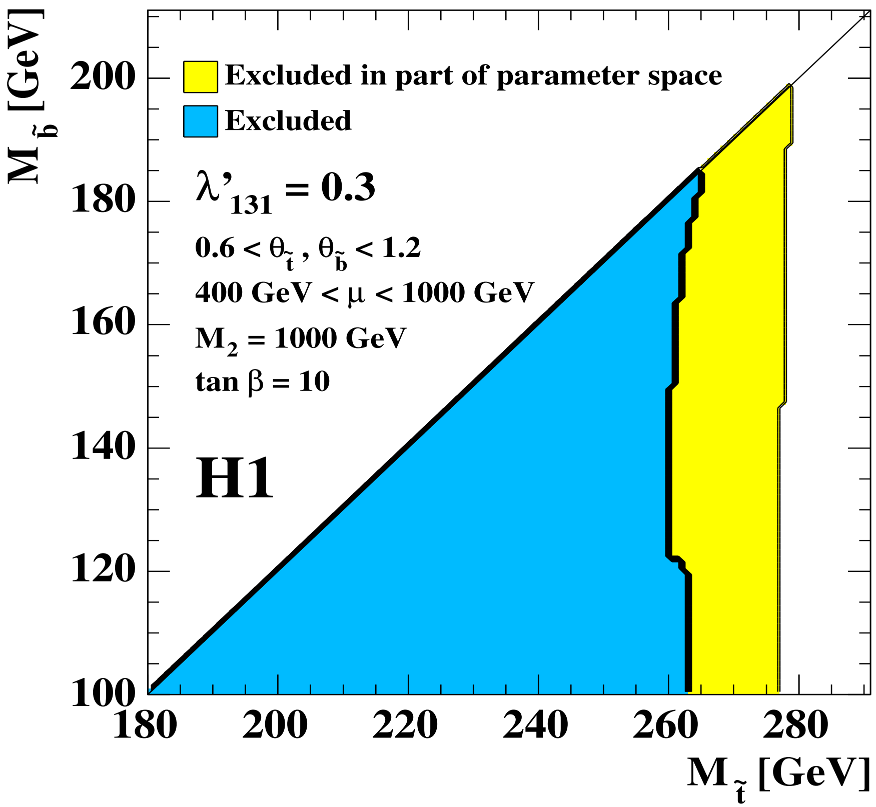
Slight excess in $J\mu P_T^{miss}$ **channel but**
no significant deviation from SM expectation

Bosonic stop decay: Limits

- For each channel: $\sigma_{\tilde{t}}(M_{\tilde{t}}) = \frac{N_{data} - N_{SM}}{\varepsilon \cdot \mathrm{BR} \cdot \mathcal{L}}$

- Excess seen in the $J\mu P_T^{miss}$ channel is not supported by the other decay channels.





- MSSM Parameters Scan:
  - ∘ $\tan\beta = 10$
  - ∘ $M_2 = 1000$ GeV
  - ∘ $400 < \mu < 1000$ GeV
  - ∘ $0.6 < \theta_{\tilde{t},\tilde{b}} < 1.2$
  - ∘ $A_t = A_b = -100$ GeV
- Stop masses $\lesssim 275$ GeV for $\lambda'_{131} = 0.3$ are excluded.
- Similar results for $\tan\beta = 2$ and $M_2 = 400$.

Summary

- **Squarks in $\not{R}_p$ SUSY have been searched for in many decay channels using ~ 64 pb^{-1} e^+p and ~ 13 pb^{-1} e^-p data at $\sqrt{s} \sim 319$ GeV.**
- **No evidence for squark production found**
- **Limits were derived in the SUSY parameter space**
  For $\lambda'_{1jk} = 0.3$ squark masses up to ~ 280 GeV are excluded.
- **Complementary analysis: bosonic stop decay using ~ 106 pb^{-1} e^+p at $\sqrt{s} \sim 319$ and 301 GeV.**
  - ▷ **A slight excess in the $J\mu P_T^{miss}$ channel is not confirm by the other decay channels.**
  - ▷ **For $\lambda'_{131} = 0.3$ stop masses up to ~ 275 GeV are excluded.**

Outlook

- **HERA II data are coming:**
  - ▷ **New data: ~ 150 pb^{-1} per experiment.**
  - ▷ **The goal is ~ 700 pb^{-1} per experiment until July 2007.**
  - ▷ **polarised $e^{\pm}$ beams:**

$$e_R^+ + d_L \to \tilde{u}_L, \tilde{c}_L, \tilde{t}_L$$
$$e_L^- + u_L \to \tilde{d}_R, \tilde{s}_R, \tilde{b}_R$$