

# R-parity violation searches at HERA

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*on behalf of H1 and ZEUS collaborations*

## Outline:

- Introduction
- Analysis / Event Selections / Final Events
- Limits on couplings in :
  - unconstrained MSSM
  - constrained MSSM
  - mSUGRA
- Conclusion

## R-Parity Violating Squark Production

- $R_p$  violating term of SUSY superpotential:

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

- $L, Q$  = left-handed lepton, quark doublet superfields,
- $\bar{E}, \bar{D}, \bar{U}$  = right-handed charged lepton,  $d$  and  $u$ -type quark singlet superfields.
- $i, j, k$  = generation indices.

- Expand the  $\lambda'_{ijk} L_i Q_j \bar{D}_k$  term:

$$\lambda'_{ijk} [ -\tilde{e}_L^i u_L^j \bar{d}_R^k - e_L^i \tilde{u}_L^j \bar{d}_R^k - (\tilde{e}_L^i)^c u_L^j (\bar{d}_R^k)^* + \tilde{\nu}_L^i d_L^j \bar{d}_R^k + \nu_L^i \tilde{d}_L^j \bar{d}_R^k + (\tilde{\nu}_L^i)^c d_L^j (\bar{d}_R^k)^* ] + \text{h. c.}$$

$$-e^+ d^k \rightarrow \tilde{u}^j$$

$$-e^- u^j \rightarrow \tilde{d}^k$$

- Strong limits on  $\lambda'_{111}$  from neutrinoless double beta decay.

 *only 1st generation*

**Yukawa vertex which couples  
a squark with a lepton-quark pair**



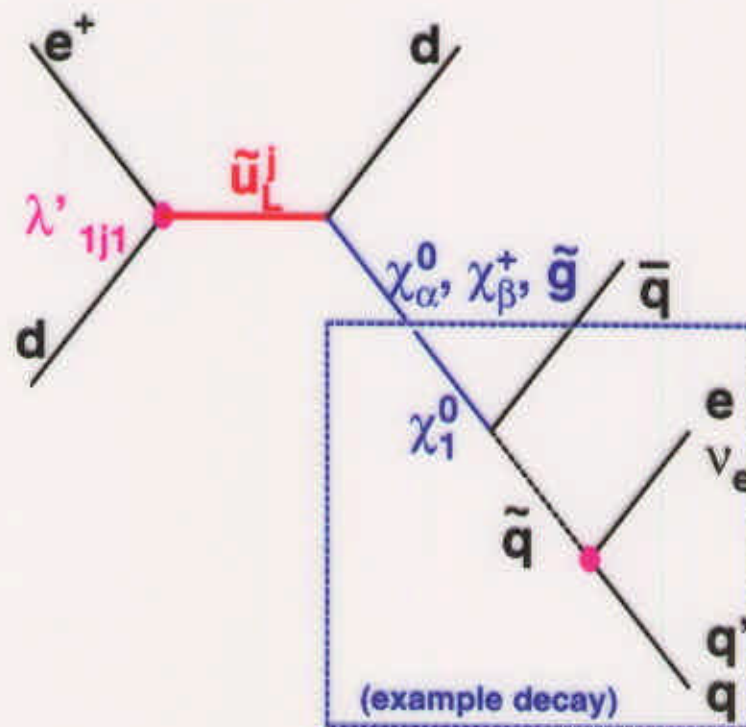
**HERA**



*positron / electron beam*

# Gauge and RPV decays

*via gauginos*



*Typical decay* 

**Multi-jets in the final state**

# Assumptions

- at most one of the couplings  $\lambda'_{ijk}$  is non-zero
- limits only valid for 1st and 2nd generation squarks

and the usual ones :

- GUT unification:  $M_1 = (5/3) \tan^2 \theta_W M_2$
- slepton mass = squark mass  
= 90 GeV  
or common scalar mass at high scale

and as usual :

$$\sigma(e^+ p \rightarrow \tilde{u}^j) \propto \lambda'_{ijk}{}^2 d^k \left( x = \frac{M_{\tilde{q}}^2}{s} \right)$$

pdf of quark-d in proton

e.g.  $M = 200 \text{ GeV} \Rightarrow x = 0.44$

NC-like  
CC-like

1-gauge decay

2-gauge decay

decay	ZEUS	H1
$\bar{q} \rightarrow e^+ q'$	•	•
$\bar{d} \rightarrow \nu + d$		•
$\bar{q} \rightarrow \chi^0 q \rightarrow e^+ q \bar{q}$	•	•
$\bar{q} \rightarrow \chi^0 q \rightarrow e^- q \bar{q}$	•	•
$\bar{q} \rightarrow \chi^0 q \rightarrow \nu q \bar{q}$	•	•
$\bar{q} \rightarrow \chi^+ q' \rightarrow e^+ q \bar{q}$	•	•
$\bar{q} \rightarrow \chi^+ q' \rightarrow \nu q \bar{q}$	•	•
$\bar{q} \rightarrow \chi_2^0 q \rightarrow \chi_1^0 Z^0 \rightarrow e^+ q \bar{q} q \bar{q}$	•	•
$\bar{q} \rightarrow \chi_2^0 q \rightarrow \chi_1^0 Z^0 \rightarrow e^- q \bar{q} q \bar{q}$	•	•
$\bar{q} \rightarrow \chi_2^0 q \rightarrow \chi_1^0 Z^0 \rightarrow \nu q \bar{q} q \bar{q}$	•	•
$\bar{q} \rightarrow \chi^+ q' \rightarrow \chi_1^0 W^+ \rightarrow e^+ q \bar{q} q \bar{q}$	•	•
$\bar{q} \rightarrow \chi^+ q' \rightarrow \chi_1^0 W^+ \rightarrow e^- q \bar{q} q \bar{q}$	•	•
$\bar{q} \rightarrow \chi^+ q' \rightarrow \chi_1^0 W^+ \rightarrow \nu q \bar{q} q \bar{q}$	•	•
$\bar{q} \rightarrow \chi_3^0 q$		•
$\bar{q} \rightarrow \chi_4^0 q$		•
$\bar{q} \rightarrow \chi_2^+ q$		•
<b>Any decay with a final state Higgs.</b>		• (if $h \rightarrow b\bar{b}$ )
<b>Decays with leptonic <math>W</math> and <math>Z^0</math> decays.</b>		• also via slepton

can also proceed via real/virtual sfermion

if  $\leq 2$  SUSY fermions

Final state topologies

Channel	Decay processes	Signature
S1	$\bar{q} \xrightarrow{X} e^+ q$	High $P_T$ $e^+$ + 1 jet
S2	$\bar{d}_R \xrightarrow{X} \nu_e d$	Missing $P_T$ + 1 jet
S3	$\bar{q} \rightarrow q \begin{cases} X \rightarrow e^+ \bar{q} q \\ X \rightarrow q \bar{q} Y \\ X \rightarrow e^+ \bar{q} q \end{cases}$	$e^+$ + multiple jets
S4	$\bar{q} \rightarrow q \begin{cases} X \rightarrow e^- \bar{q} q \\ X \rightarrow q \bar{q} Y \\ X \rightarrow e^- \bar{q} q \end{cases}$	$e^-$ (i.e. wrong sign lepton) + multiple jets
S5	$\bar{q} \rightarrow q \begin{cases} X \rightarrow \nu(\bar{\nu}) \bar{q} q \\ X \rightarrow q \bar{q} Y \\ X \rightarrow \nu(\bar{\nu}) \bar{q} q' \end{cases}$	Missing $P_T$ + multiple jets
S7	$\bar{q} \rightarrow q \begin{cases} X \rightarrow l \nu Y \\ X \rightarrow e^+ \bar{q} q \end{cases}$	$e$ + $e$ or $\mu$ + Missing $P_T$ + multiple jets
S8	$\bar{q} \rightarrow q \begin{cases} X \rightarrow l \nu Y \\ X \rightarrow \nu \bar{q} q \end{cases}$	$e$ or $\mu$ + Missing $P_T$ + multiple jets

X, Y = any  $\chi^0$  or  $\chi^+$  or gluino

# Analysis

1994-1997 e+ Data Samples

**ZEUS 48 pb<sup>-1</sup>**

**H1 37 pb<sup>-1</sup>**

*simulation of the signal:*

large scan of the  
SUSY parameter space  
on  $M_2, \mu, \tan\beta$

any gauge decay generated (H1)  
but the gluinos (ZEUS)

# Event selection

## H1

- $Q^2(\text{electron})$
- $y(\text{ele}), y(\text{h})$

optimized cut on  $y$   
+ specific angular cuts

## ZEUS

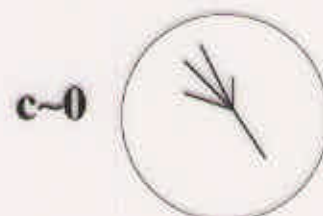
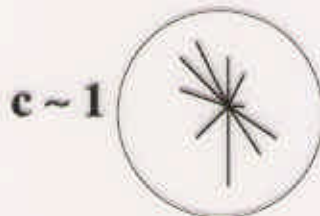
- $Q^2(\text{DA})$
- $y(\text{DA}), y(\text{h})$

optimized cut on:

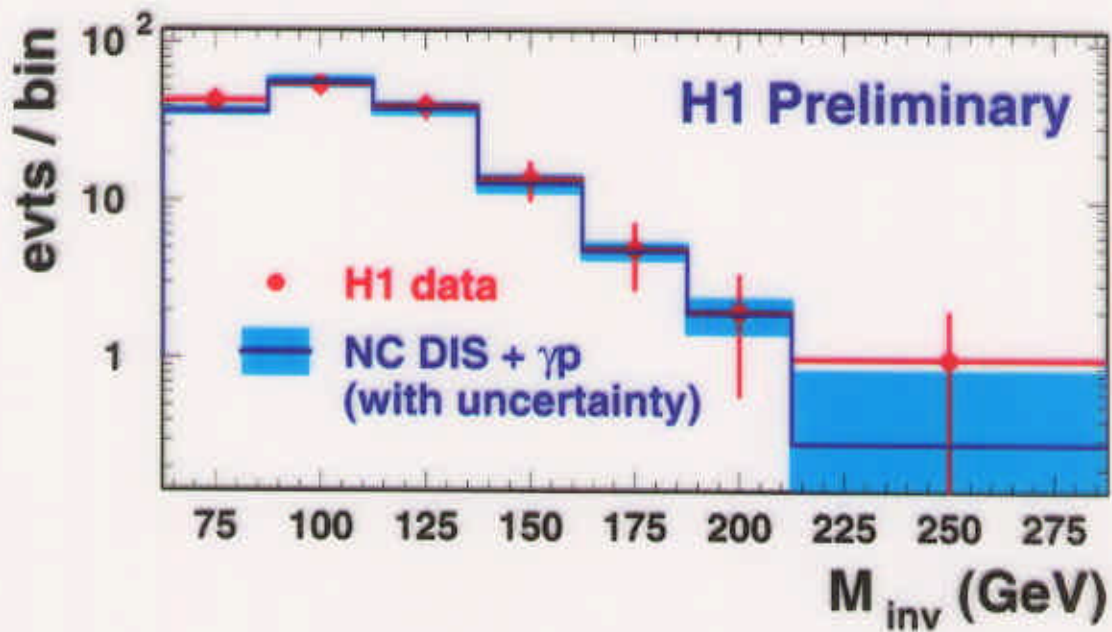
- $y$
- $M(1+\text{jets})=2E_e(E+p_z)$
- **circularity**



- $\lambda_i = \text{the eigenvalues of } M_{ij} = \frac{\sum_{k=1}^N p_{1,k} p_{2,k}}{\sum_{k=1}^N (p_{1,k}^2 + p_{2,k}^2)}$
- $\lambda_1 + \lambda_2 = 1$  and both  $\lambda_i$  are in the range  $[0, 1]$ .
- Define the circularity as  $c = 2(1 - \max(\lambda_1, \lambda_2))$ .



$e^+$  multijets final states (**160 events in DATA**):

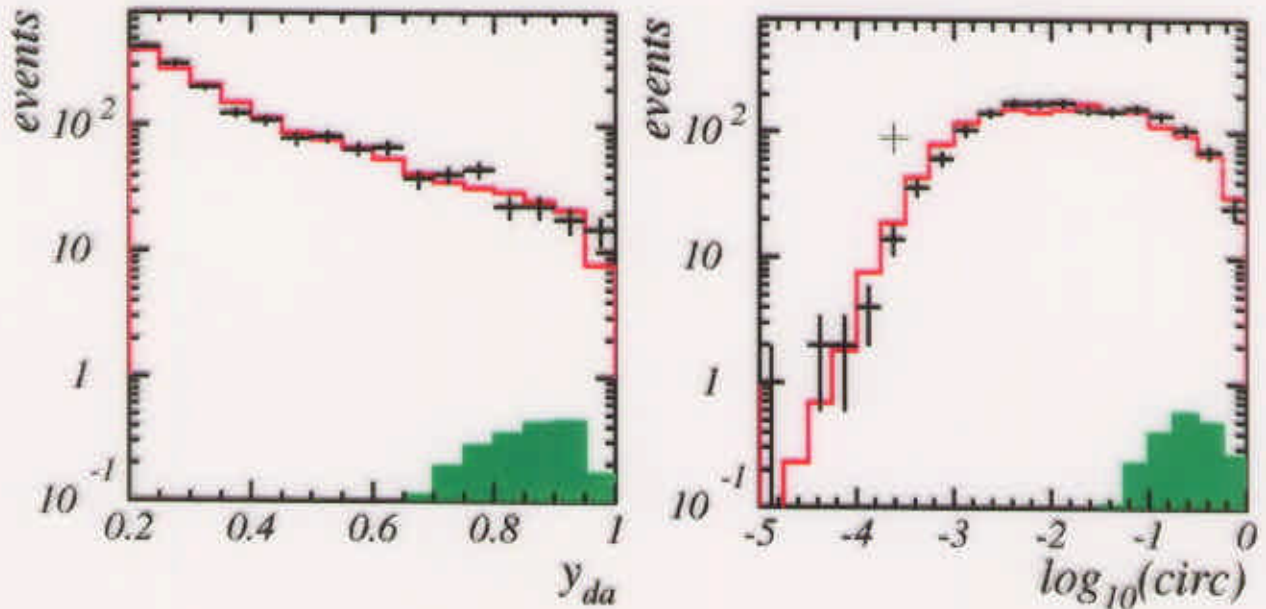


Good agreement with SM expectation:  $152.6 \pm 13.4$

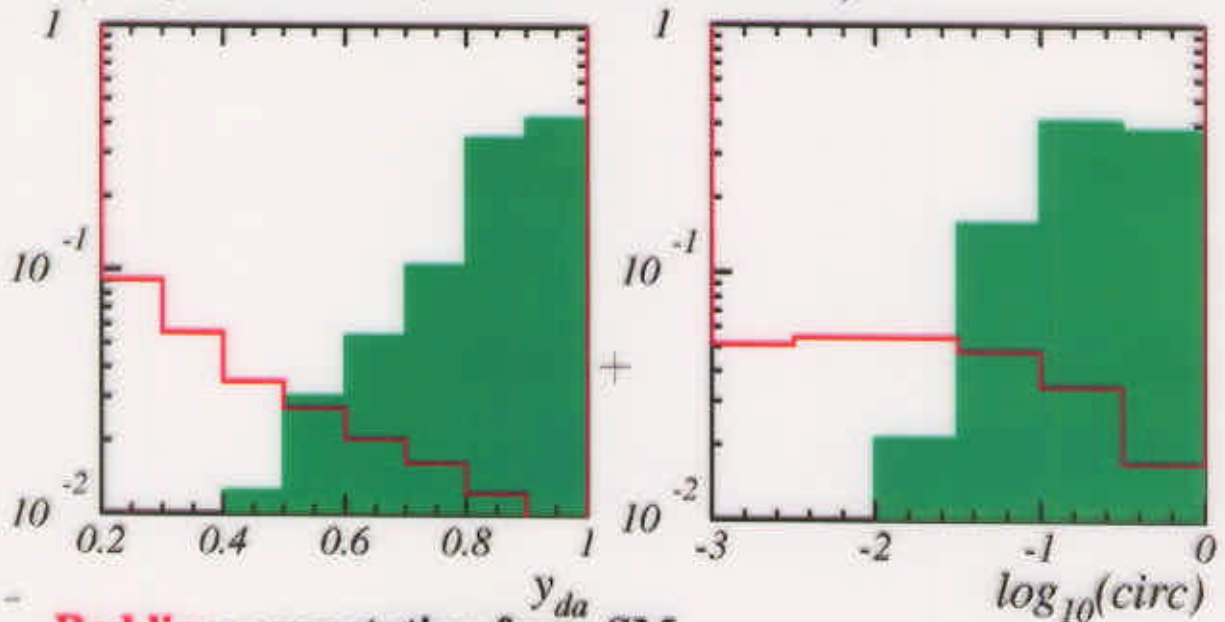


$e^+$  multijets final states:

**ZEUS Preliminary**



$e^-$  multijets final states ( **0** events in DATA ):



**Red line:** expectation from SM

**Green histogram:** hypothetical signal of 220 GeV,  
 $\mu=-180, M_2=100, \tan\beta=2$ , normalized to expected sensitivity

# Compute limits on $\lambda'_{1j1}$ couplings

- unconstrained MSSM
- constrained MSSM
- mSUGRA

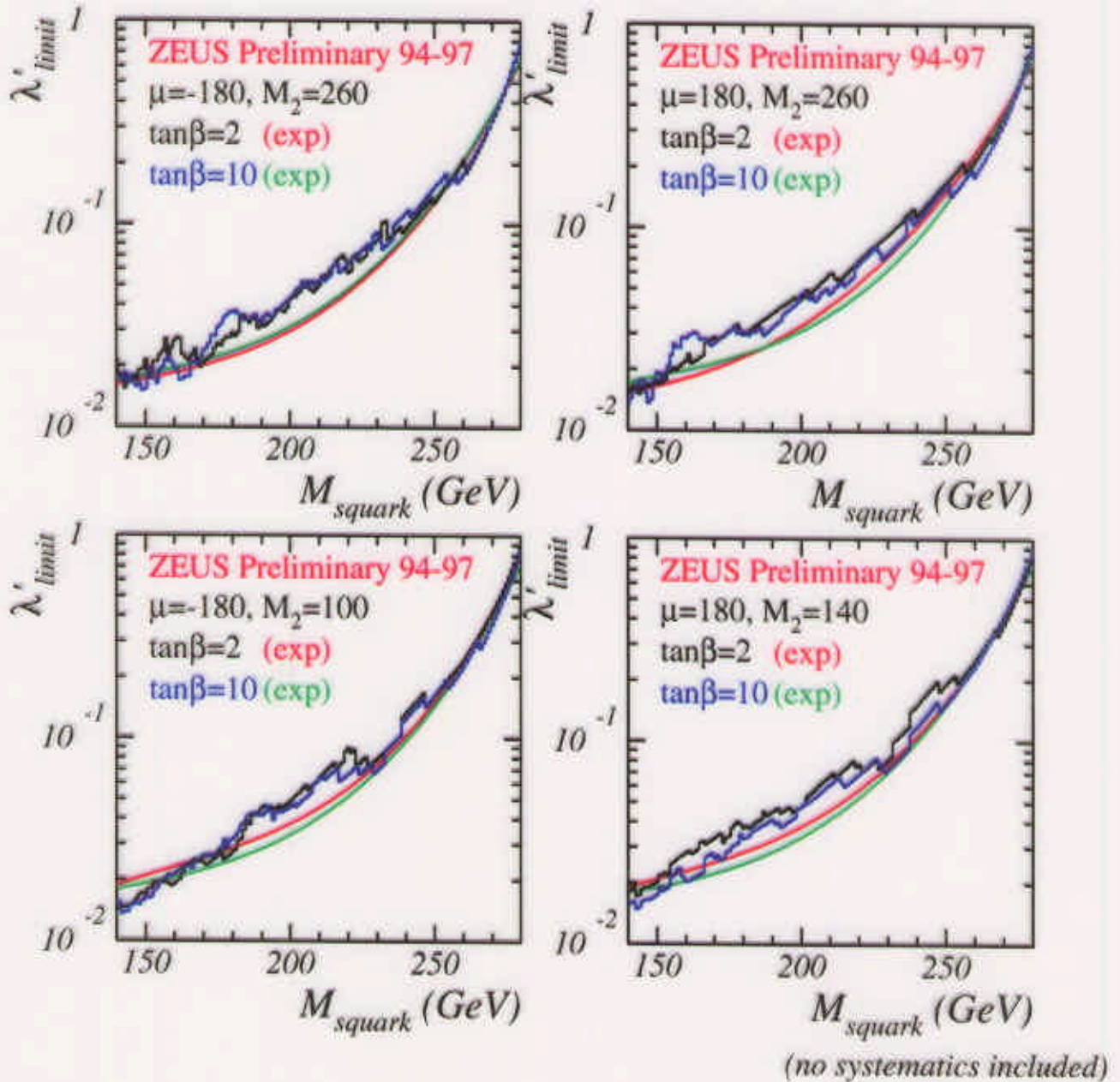
+ breaking mechanism REWSB

+ common mass  $m_0$  for all sfermions at high scale

basic assumpt.

# Unconstrained MSSM

(specific SUSY parameters)



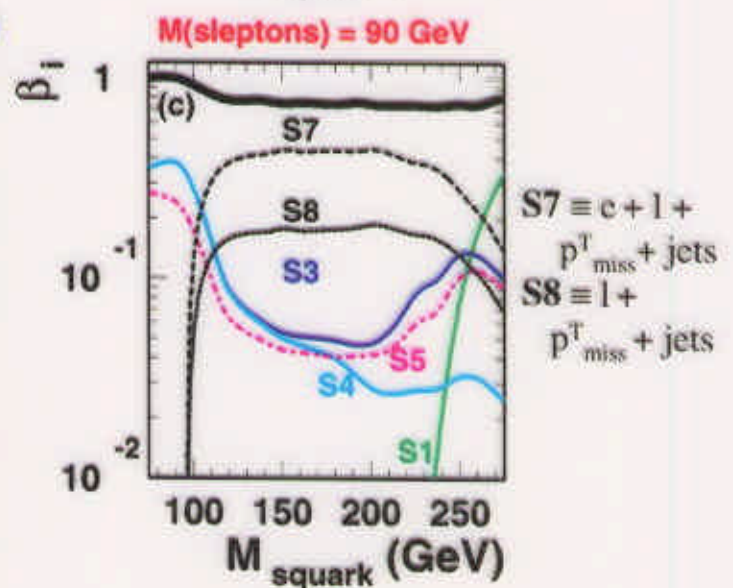
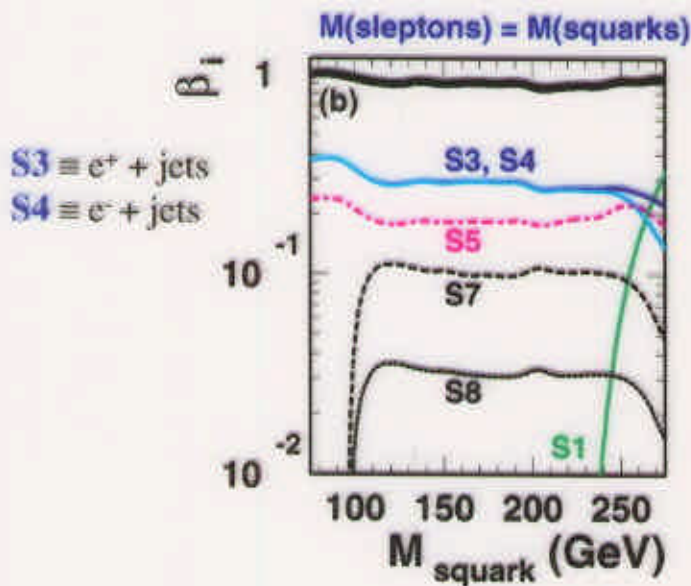
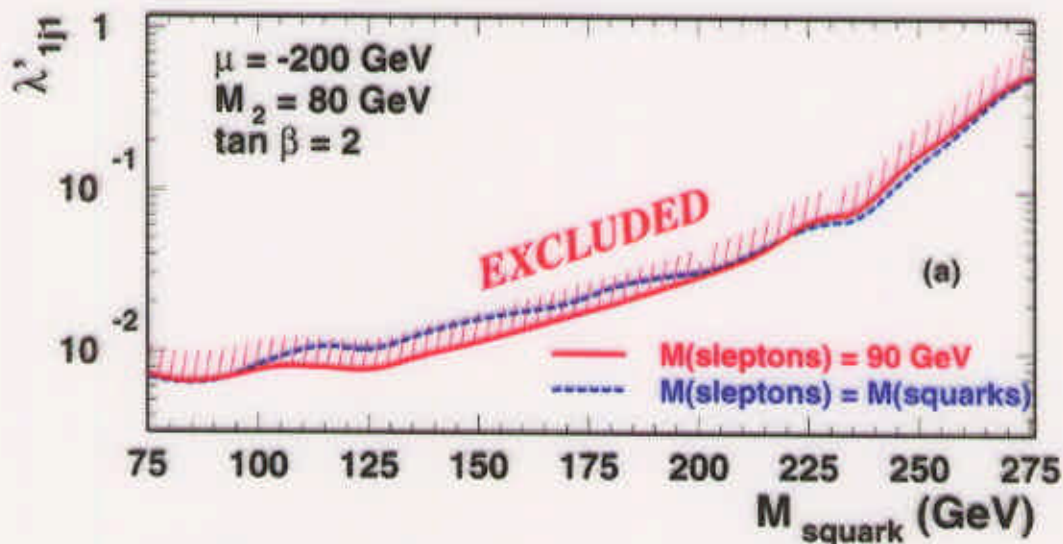
**Typical exclusion limits :**

at 95% C.L.  $\lambda'$  upper limit goes from  
0.02 @  $m=140$  GeV to 0.8 @  $m=280$  GeV

# Unconstrained MSSM

*no big dependence on slepton mass assumption :*

**H1 Preliminary**

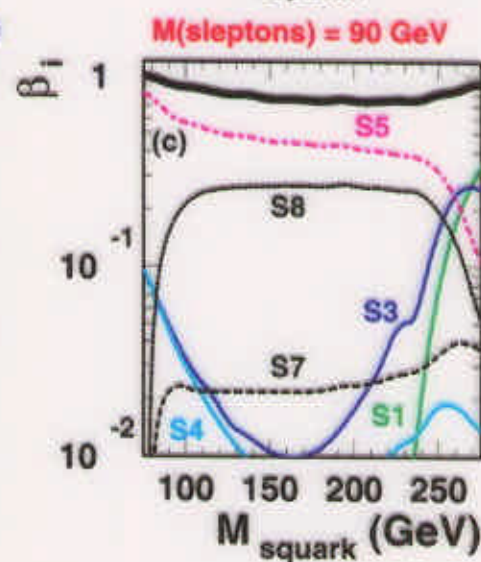
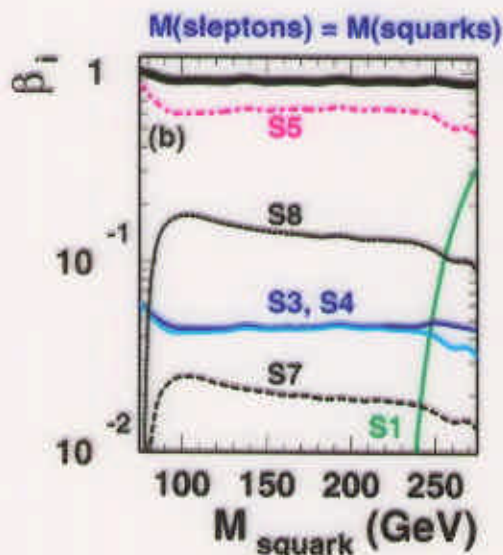
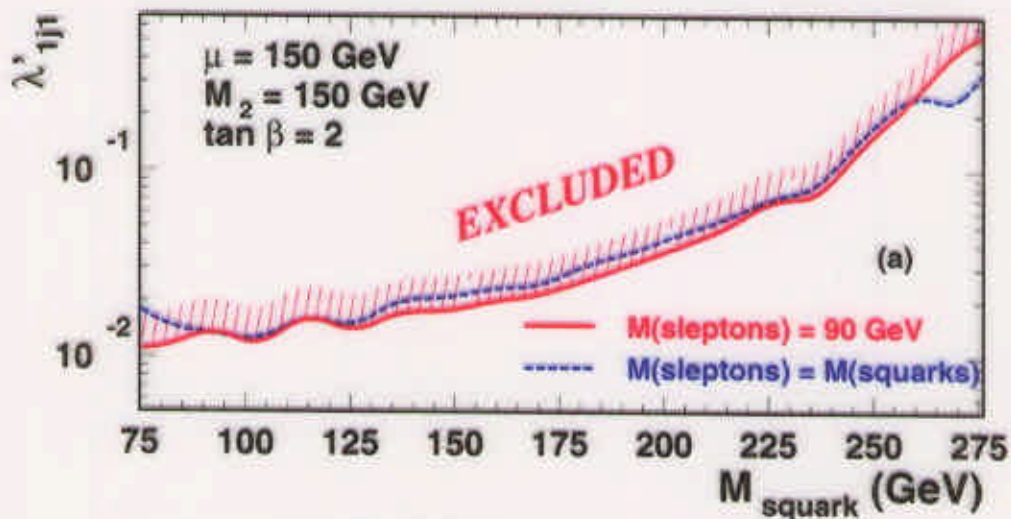


**~ all B.R. covered !**

# Unconstrained MSSM

$\chi_1^0$  dominated by its **zino** component :

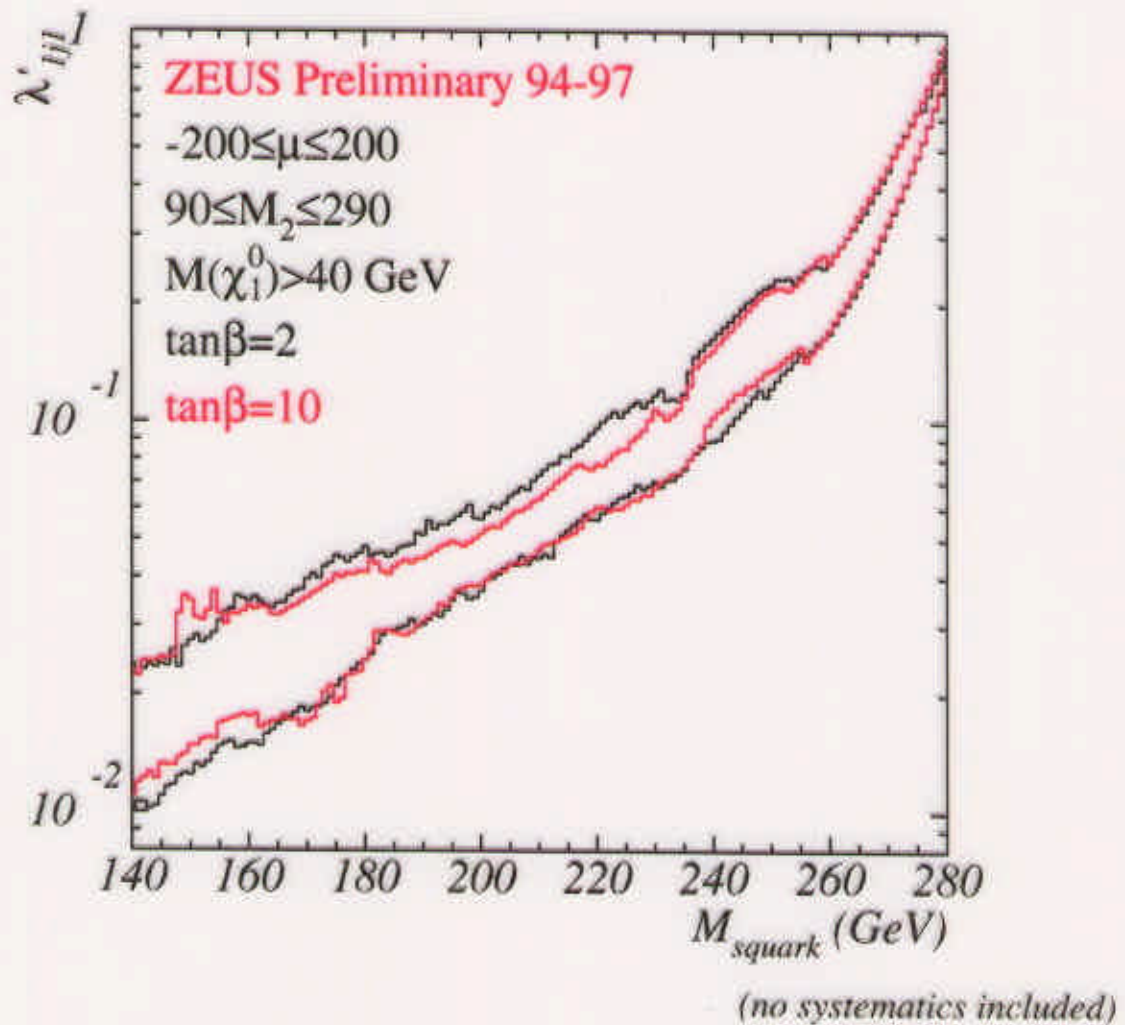
## H1 Preliminary



similar results to  $\chi_1^0$  when dominated by its **photino** component

# Unconstrained MSSM

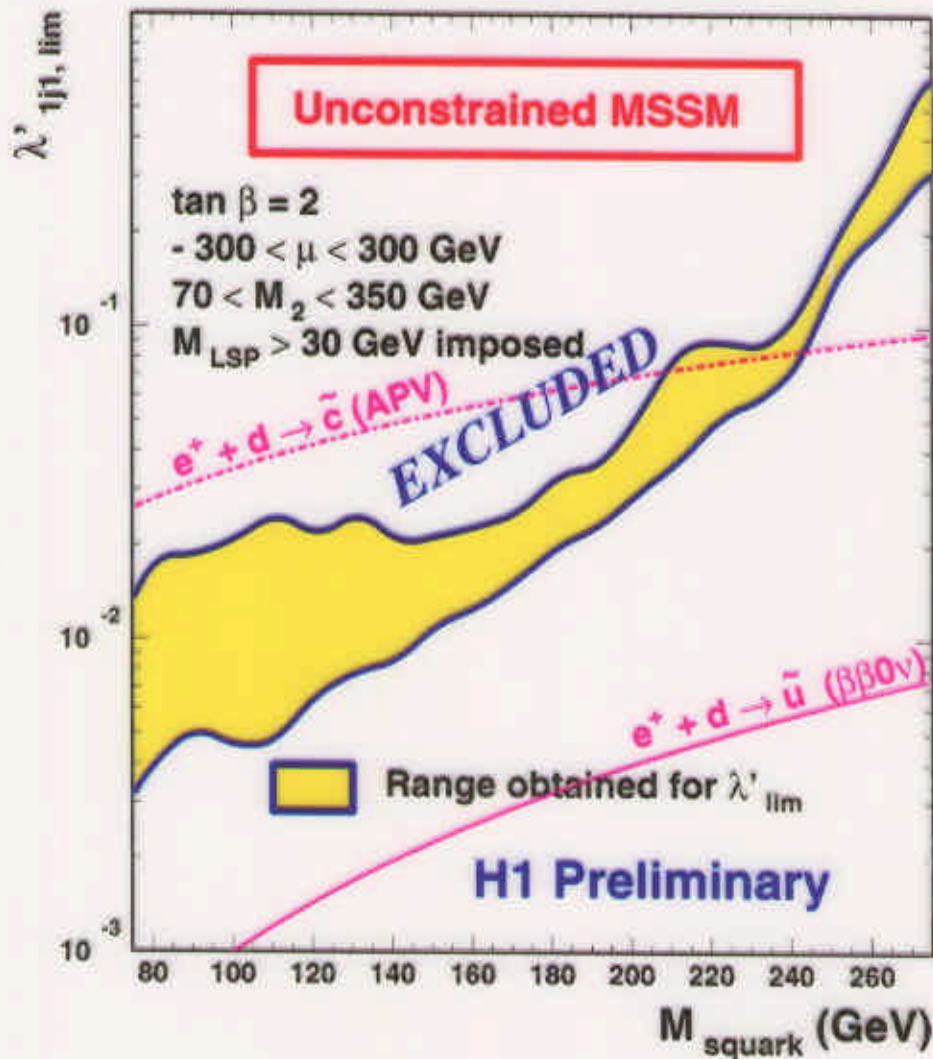
scanning the  $\mu$ ,  $M_2$  range...



as a result:

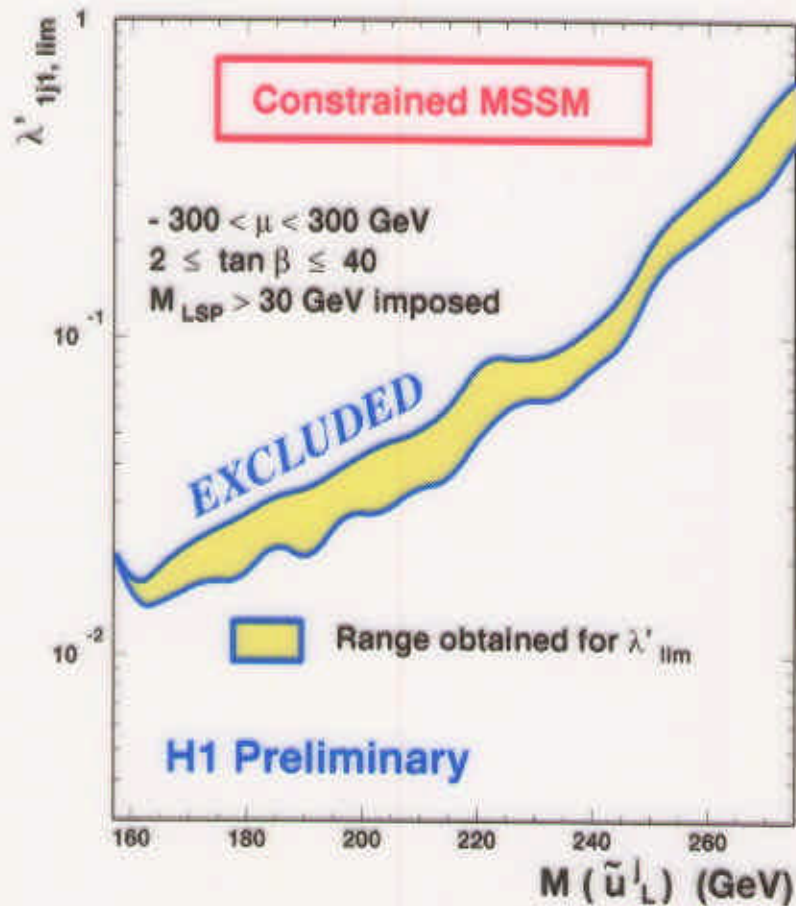
**no strong variation with SUSY parameters**

# Unconstrained MSSM



→ better than indirect Atomic Parity Violation limits  
up to  $m \sim 240 \text{ GeV}$

# Constrained MSSM



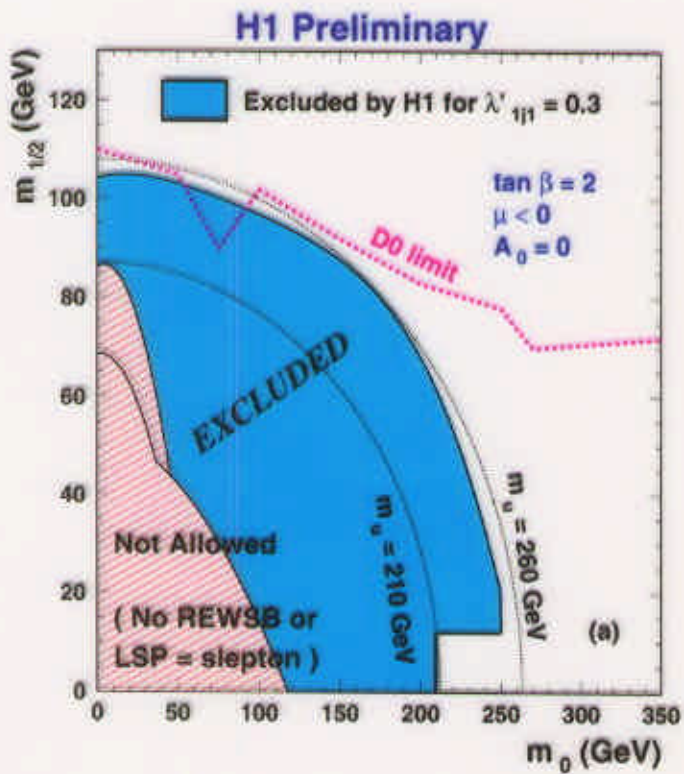
## Results similar to unconstrained

For a Yukawa coupling of the electromagnetic strength ( $\lambda'_{1j1} = 0.3$ ), squark masses up to 258 GeV are ruled out at 95% C.L.

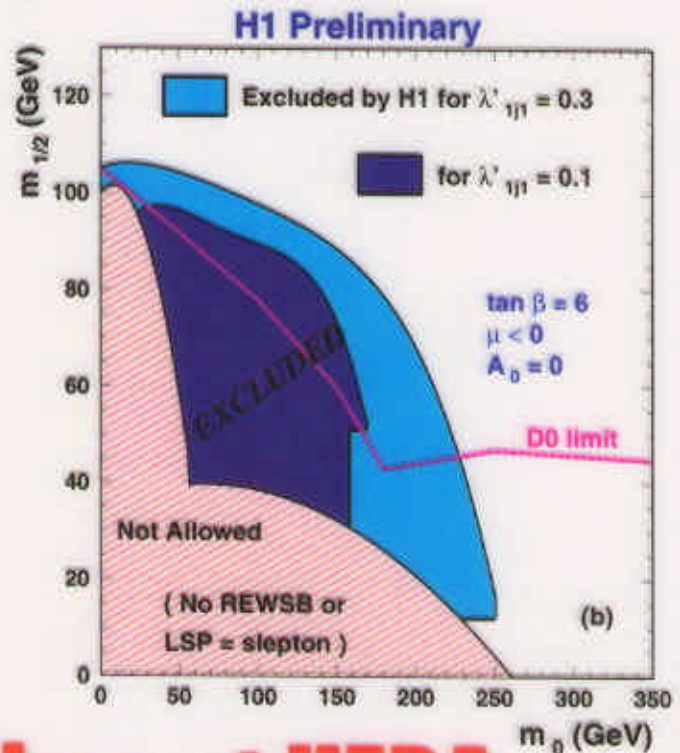
*no strong variation with SUSY parameters*



# mSUGRA



increase  $\tan \beta$



**First time at HERA**

# Conclusions.

- Search for u-type squark resonant production at HERA in RPV processes
- $e^+$  data (48+37  $pb^{-1}$ )
- No excess observed

- Limits on  $\lambda'$  couplings with MSSM assumptions for  $e^+d$  pair coupling (scanning of SUSY parameter space)
- No strong variation with SUSY parameter space
- ~ all Br.Ratio covered

- Results ~ model independent:  
usual assumptions for MSSM  
constrained MSSM }  
mSUGRA }



allows comparison with other collider results

- *More data are available:*  
~ 30  $pb^{-1}$  of  $e^-$   
present data taking with  $e^+$  ( $\geq 100 pb^{-1}$ )
- *More data will be available from 2001:*  
150  $pb^{-1}/year$