RPV SUSY searches at HERA

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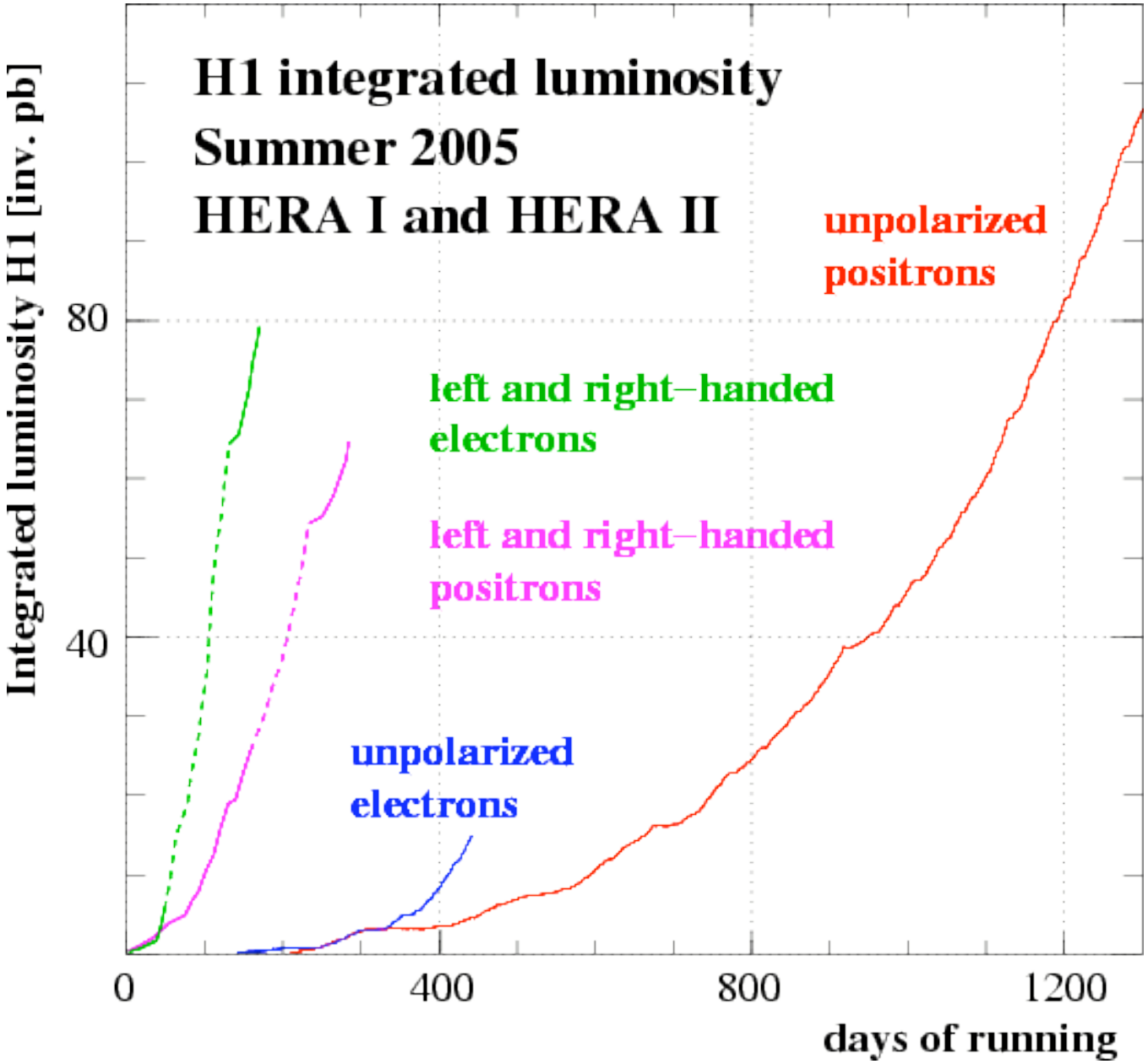
on behalf of the

ZEUS and H1 Collaborations

Contents

- HERA II $e^{\pm}p$ collider, now polarized: 25-40%
- R-Parity violation leads to production of Squarks, Gauginos subsequent decay also through other channels
- ZEUS: light stop decaying to chargino
- H1: light stop decaying to sbottom
- H1, ZEUS: GMSB Neutralino decaying to photon + Gravitino
- ZEUS: Neutralino or Chargino with RPV decay
- H1: more general squark search
- Conclusion, outlook

HERA I/II Data 'on tape'



HERA II

- 2001 upgrade
- 2002+2003 struggling
- 2004+2005 good!
- Polarized $e^{\pm}$!
- $e^{+}p$: 0.7/0.35 × Hera I
- $e^{-}p$: 4.5 × HERA I !!!!

Status Analyses:

- HERA I data only..
- H1 published in 2004
- ZEUS preliminary

RPV Production: squark or gaugino

R-parity violation:

$$\lambda'_{ijk} L^i_L Q^j_L \bar{D}^k_R =$$

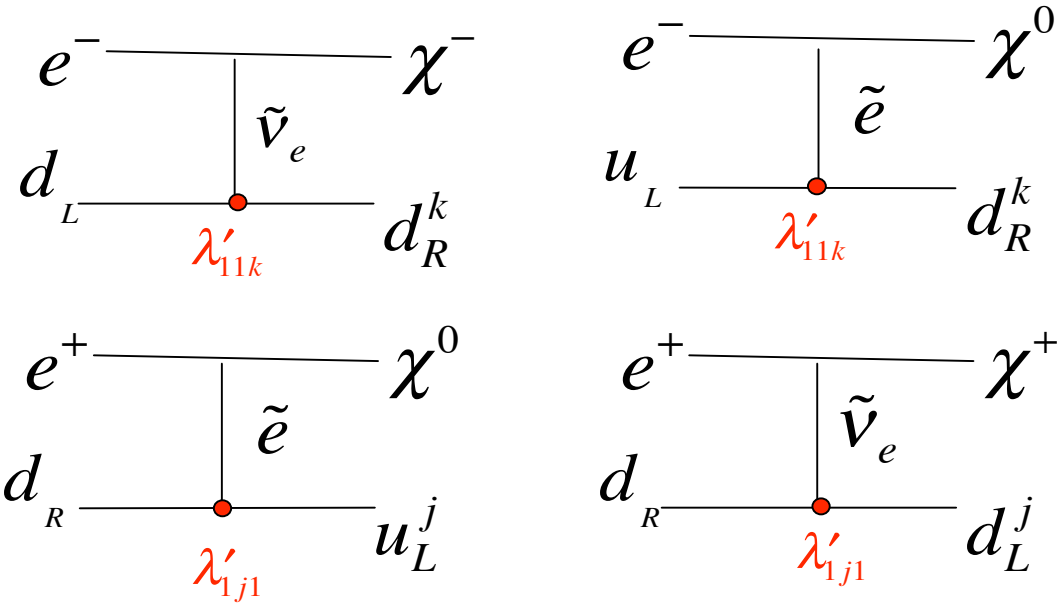
$$\lambda'_{ijk} \cdot \left(-\tilde{e}^i_L u^j_L \bar{d}^k_R - e^i_L \tilde{u}^j_L \bar{d}^k_R - (\bar{e}^i_L)^c u^j_L \tilde{d}^{k*}_R - \tilde{\nu}^i_L d^j_L \bar{d}^k_R - \nu^i_L \tilde{d}^j_L \bar{d}^k_R - (\bar{\nu}^i_L)^c u^j_L \tilde{d}^{k*}_R \right) + \text{c.c.}$$

- valence *u*, *d* in proton dominate, $u \geq 2 \cdot d$ at high x_{BJ}
- s-channel single squark production, like a leptoquark
  - ✓ $\lambda'_{11k} : e^- + u \rightarrow \tilde{d}^k$
  - ✓ $\lambda'_{1j1} : e^+ + d \rightarrow \tilde{u}^j_L$
- assume only one $\lambda'_{ijk} > 0$

- t-channel slepton exchange

➔ gaugino production

  ✓ slepton masses low?



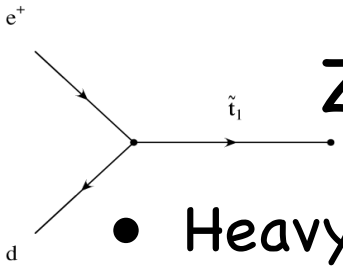
Gaugino decays

- Heavy gaugino cascades down to lighter χ_1^0
  - $\chi^+ \to W^+ \chi_1^0$
  - $\chi_2^0 \to e^+ \tilde{e}^-$, $\tilde{e}^- \to e^- \chi_1^0$
  - ... depends strongly on mass spectrum ...
- RPV 3-body decay through virtual slepton or squark
  - $\chi_1^0 \to e^+ \tilde{e}^-$, $\tilde{e}^- \xrightarrow{\lambda'} \bar{u} d^k$
  - $\chi_1^0 \to \bar{u} \tilde{u}$, $\tilde{u} \xrightarrow{\lambda'} e^+ d^k$
  - ...
- Alternative: Gauge Mediated Susy Breaking with Gravitino LSP, low mass, invisible
  - $\chi_1^0 \to \tilde{G} \gamma$
  - Signature: photon + missing P_t

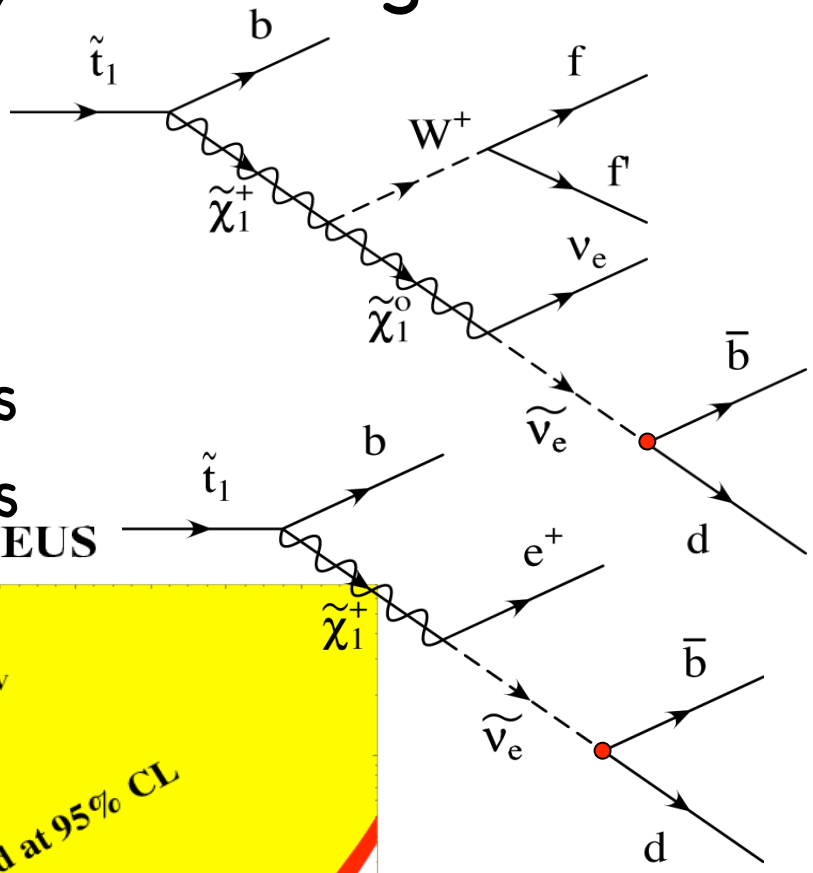
Squark decays

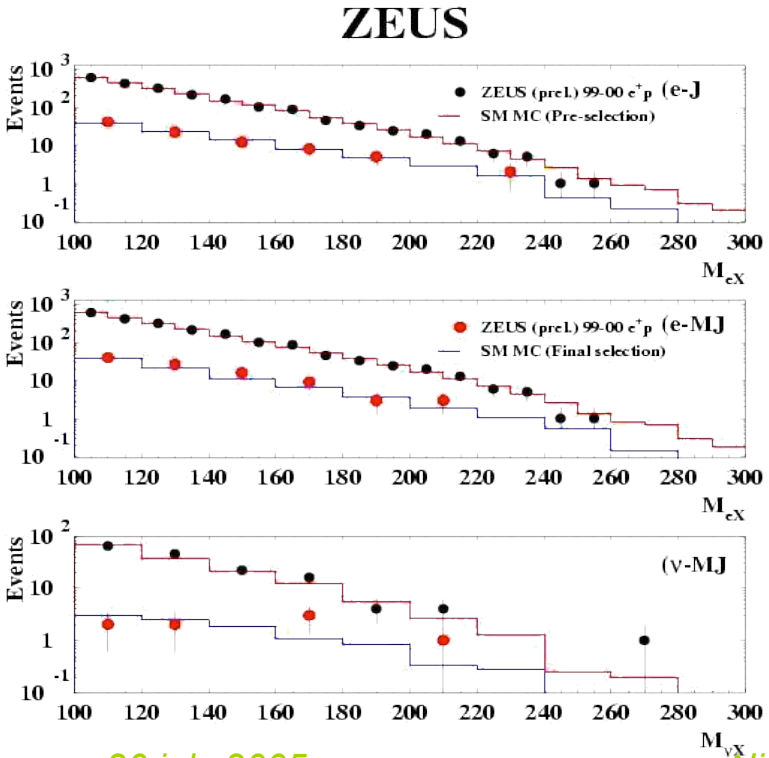
- Direct RPV decay: like leptoquark
  - ✓ B.R. large for massive gaugino and large λ'
  - ✓ ➔ Contribute to limit at highest squark mass
  - ✓ Final state like SM NC or CC DIS
  - ✓ Invariant mass peak
  - ✓ Angular distributions differ
- MSSM Gauge decays
  - ✓ 1 or 2-step cascade to ever lighter gluino, chargino, neutralino
    e.g $\tilde{u}_L^j \to \chi_2^0 u_L^j, \chi_2^0 \to Z\chi_1^0$
  - ✓ RPV 3-body decay through virtual slepton or squark:
    e.g. $\chi_1^0 \to e^+\tilde{e}^-$, $\tilde{e}^- \to \bar{u}d^k$
  - ✓ Final state differs from SM NC or CC DIS:
    1. One or more leptons, neutrinos (missing P_t)
    2. Electron from neutralino can have wrong sign (majorana fermion)
    3. Multiple high-Et jets, high circularity
    4. Invariant mass peak

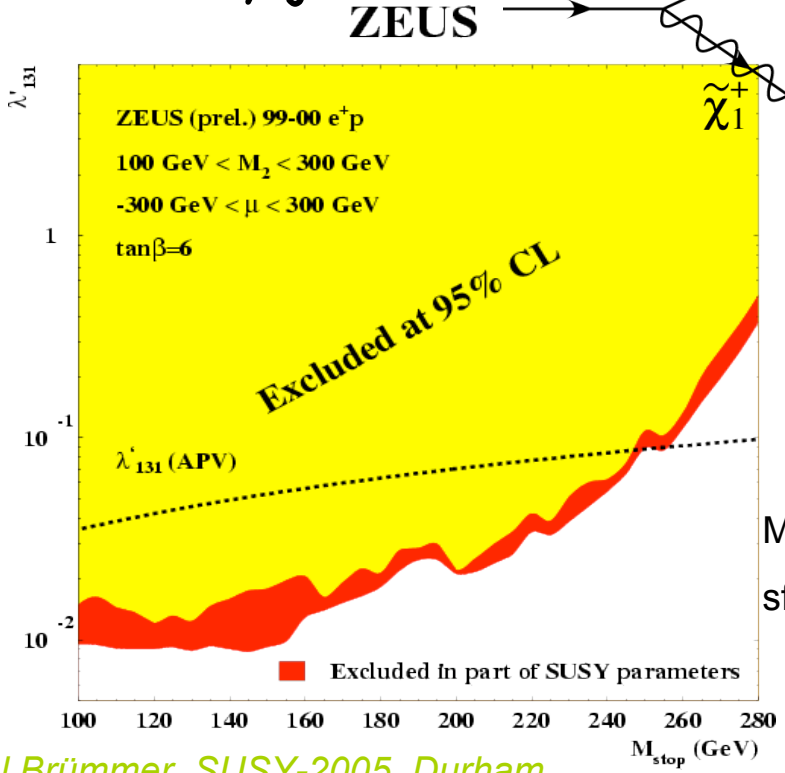
ZEUS: light stop decay via chargino



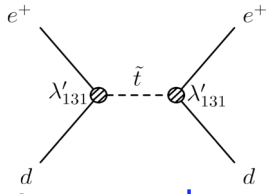
- Heavy $\tilde{b}$ and $\tilde{g}$
- Direct RPV decay $\tilde{t} \to e^+ d$
- Decay via chargino + beauty
- Ignore $\tilde{t} \to t\chi_1^0, t\tilde{g}, \tilde{b}W^+$ final states
- Final state like NC or CC DIS, jets





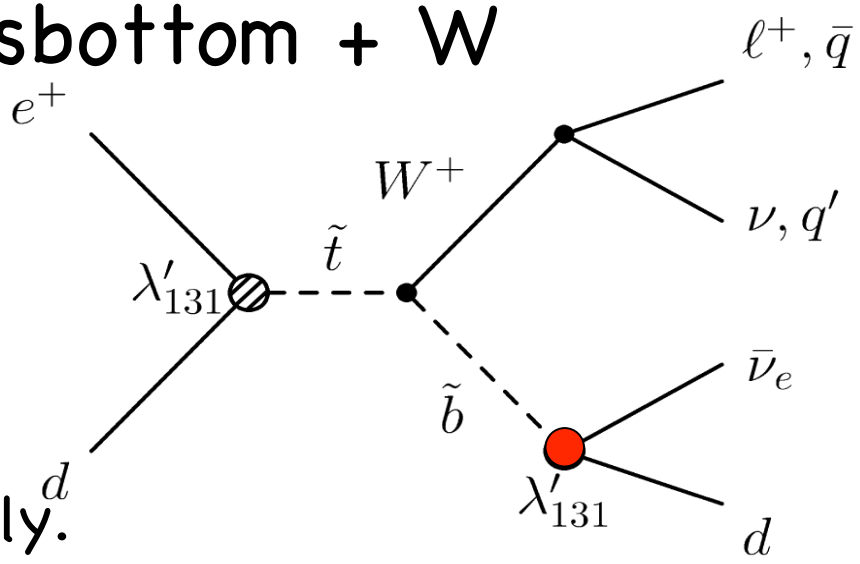


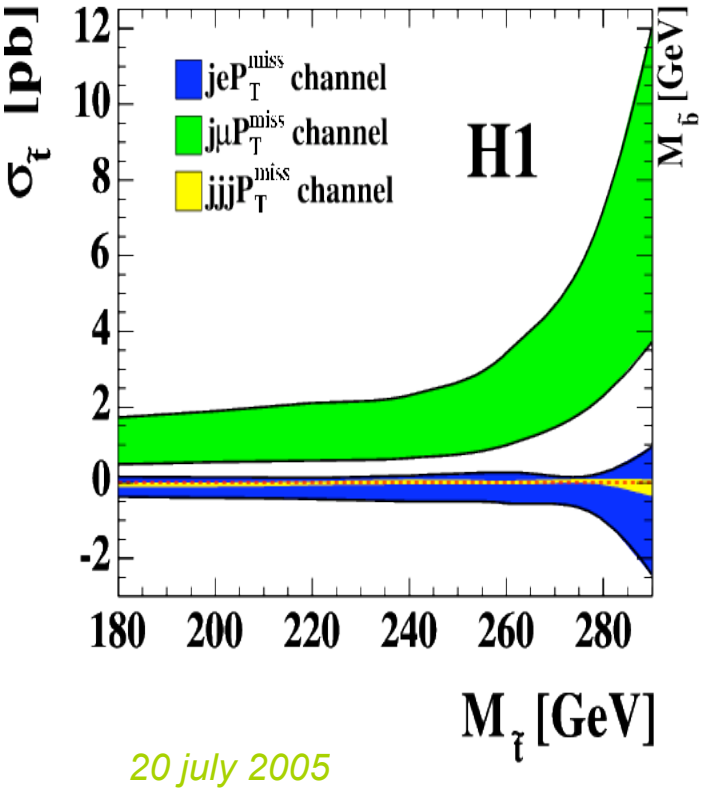
$M_1=M_2=M_3$ at GUT scale, sfermion masses free

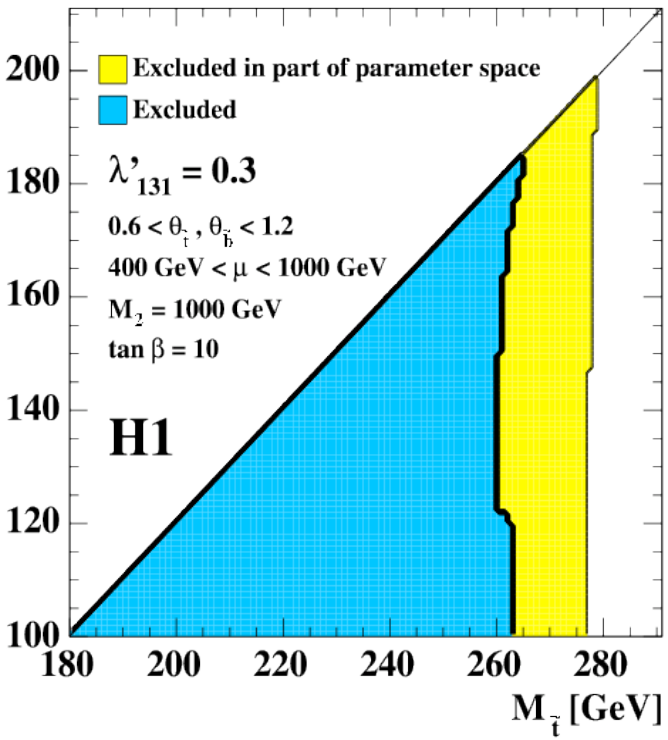


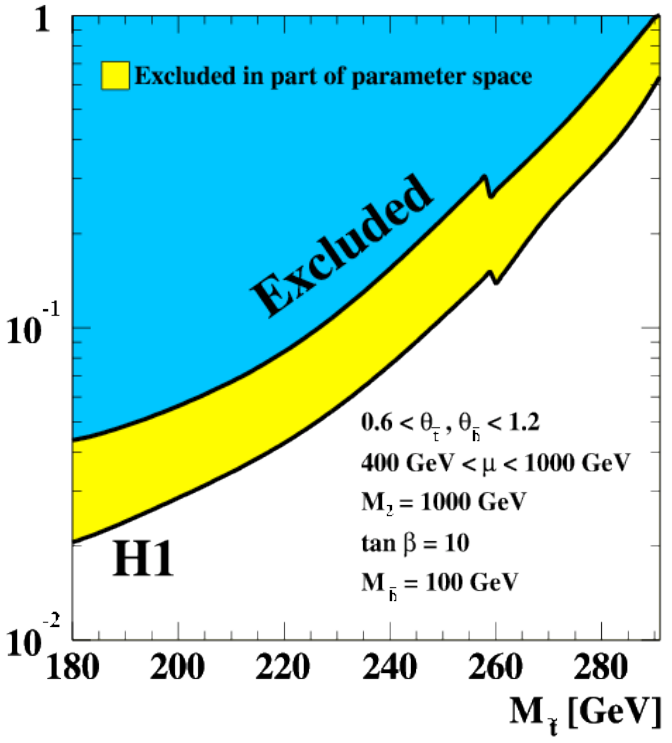
H1: stop decay to sbottom + W

- $m_{\tilde{b}_1} + m_W < m_{\tilde{t}_1} < m_{\chi^+} + m_b, m_{\chi^0} + m_t$
- Cannot explain H1 excess events with lepton + $P_{t,miss}$ + jet
- Limits given for this decay and direct RPV `leptoquark'-decay only.



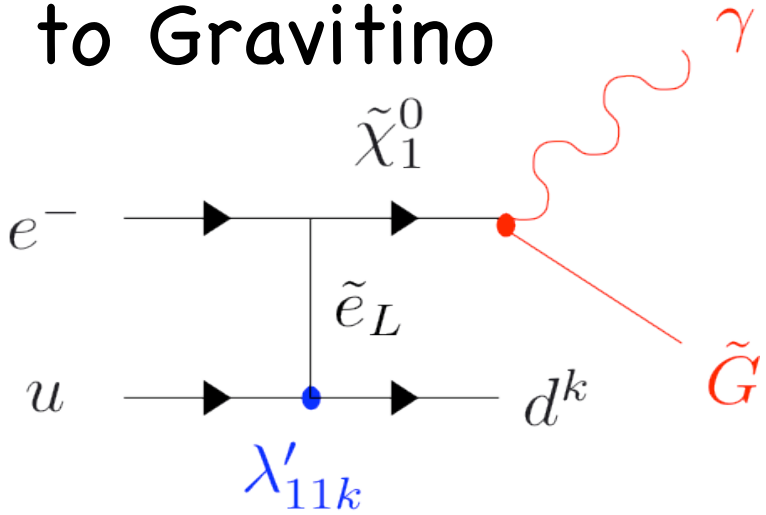


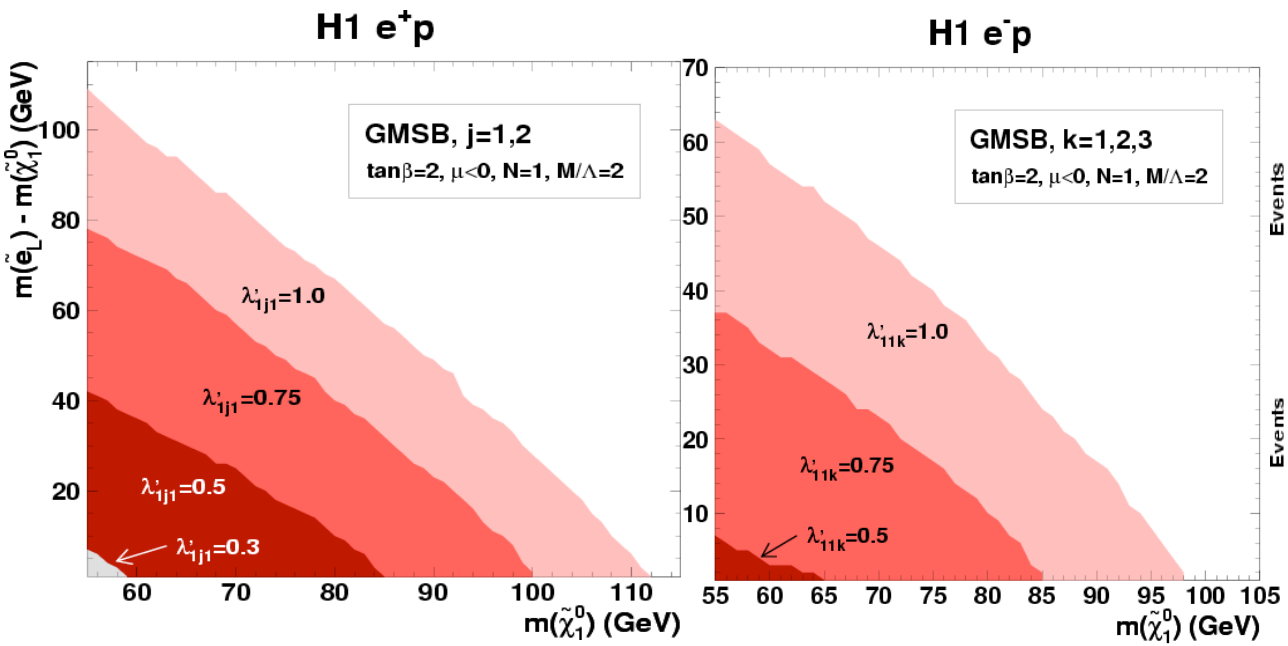


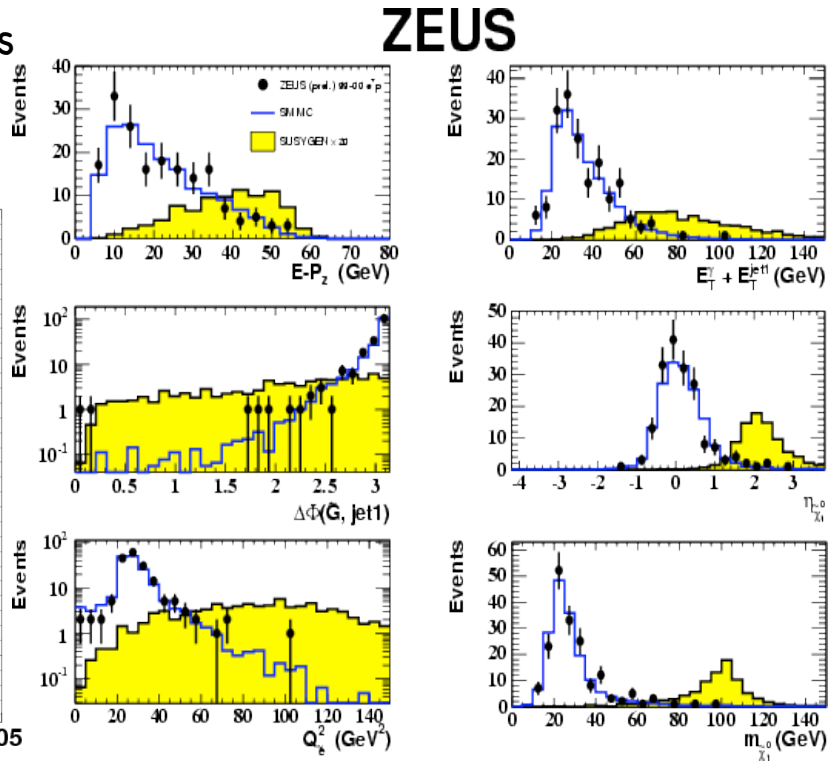


GMSB Gaugino decay to Gravitino

- Signature: $P_{T,miss}$ and photon
- Slepton exchange only
- Heavy squarks avoid APV, CCU
  $\Rightarrow \lambda'_{11k}, \lambda'_{1j1}$ as large as 1 for j,k≠1
- $M_{\gamma\tilde{G}}$ using constraints of E-P_z, $P_{T,miss}$

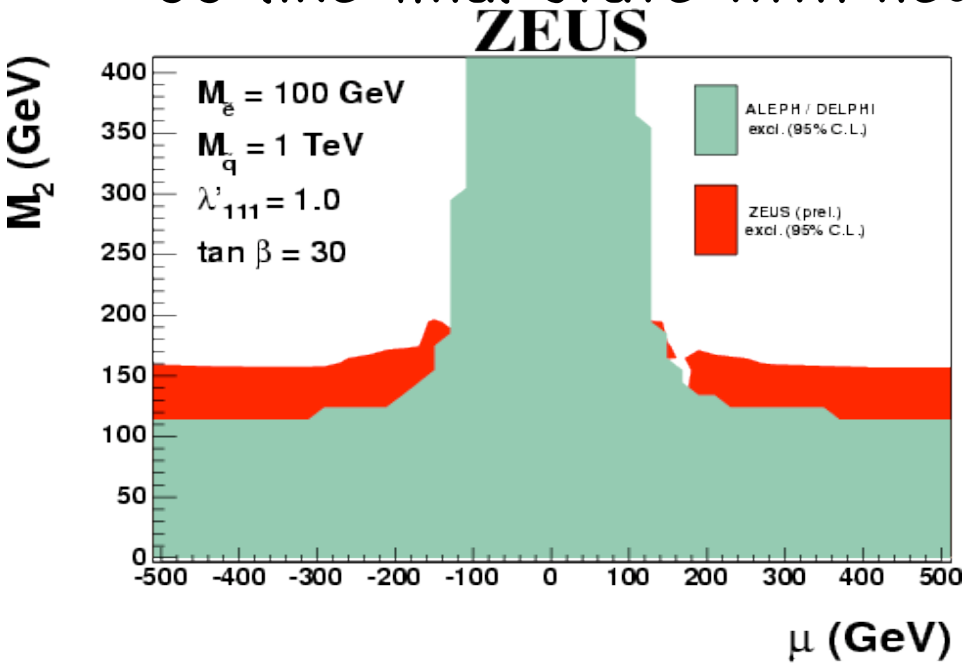


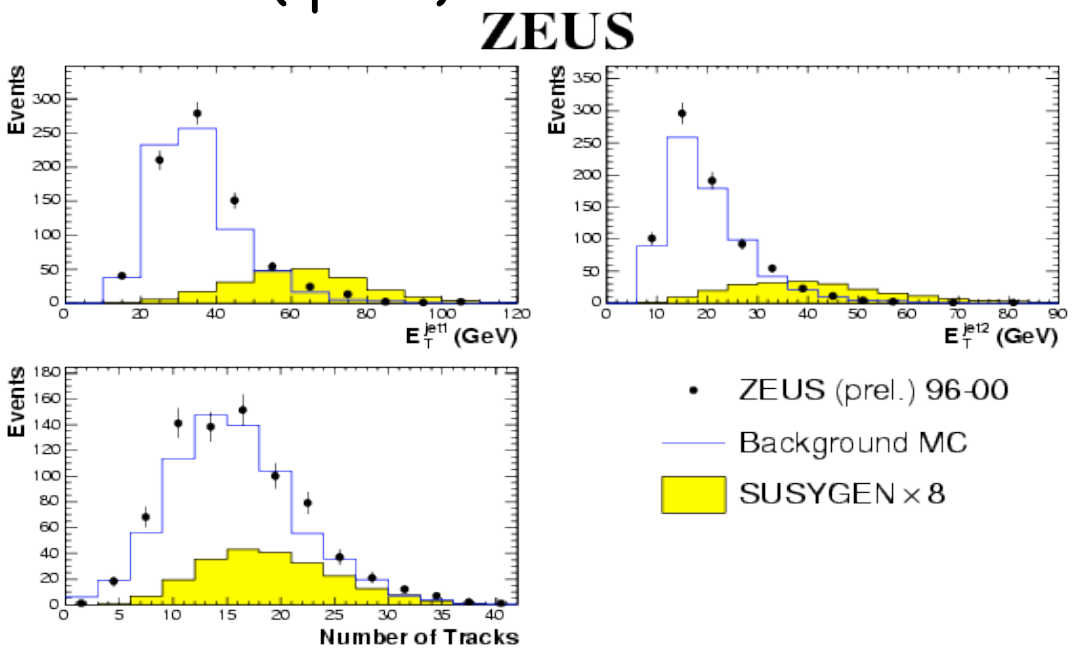




ZEUS: RPV decay of Gaugino

- Assume squarks heavy, sleptons 100 GeV, $\lambda'_{111} = 1$
- Use 121 pb^{-1} of e^+p collisions from 1996-2000
- Final state has positron or neutrino and 3 jets
- Wrong sign electron too forward to distinguish..
- Define discriminant-function of 6 variables
- CC-like final state with neutrino not (quite) done



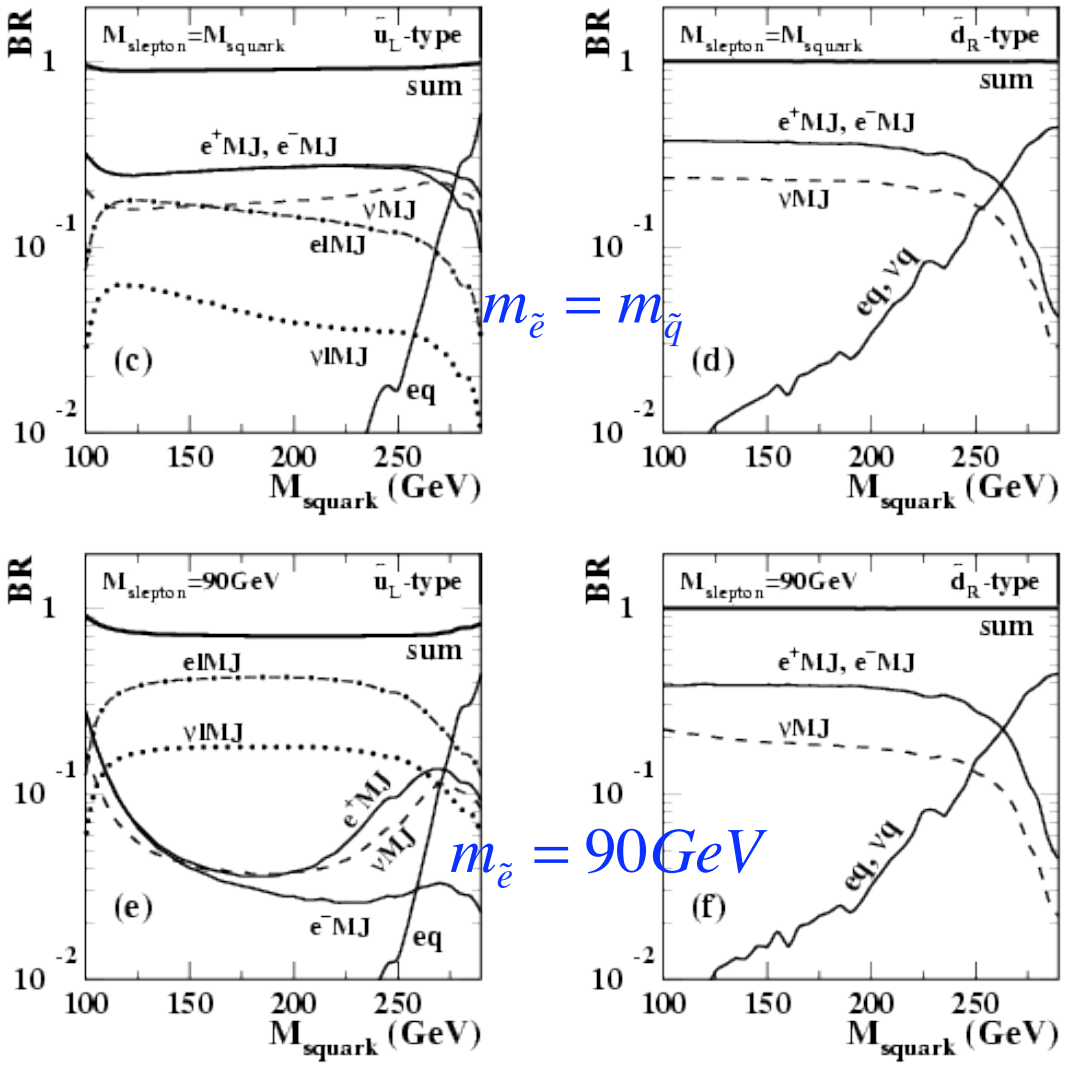


H1: comprehensive squark search

Channel	e^+p collisions		e^-p collisions		Eff.
	DATA	SM exp.	DATA	SM exp	
eq	632	628±46	204	192±14	30-50%
$e\nu$	-	-	261	269±21	40-60%
e + jets	72	67.5±9.5	20	17.9±2.4	15-50%
wrong e + jets	0	0.20±0.14	0	0.06±0.02	10-30%
ee + jets	0	0.91±0.51	0	0.13±0.03	15-45%
$e\mu$ + jets	0	0.91±0.38	0	0.20±0.04	15-35%
νe + jets	0	0.74±0.26	0	0.21±0.07	15-40%
ν + jets	30	24.3±3.6	12	10.1±1.4	10-60%
$\nu\mu$ + jets	0	0.61±0.12	0	0.16±0.03	15-50%

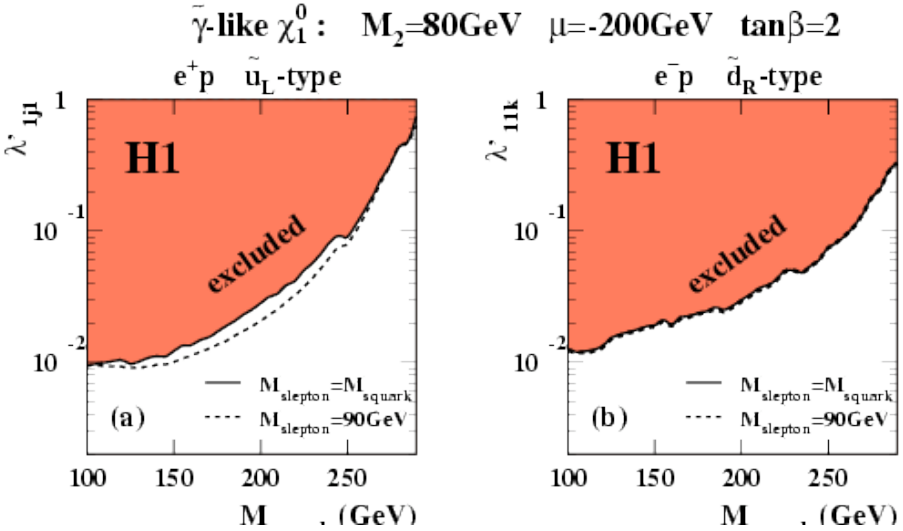
H1: important to cover final states!

$e^+ p \to \tilde{u}_L^{j=1,2}$ $e^- p \to \tilde{d}_L^{k=1,2}$



$m_{\tilde{e}} = m_{\tilde{q}}$

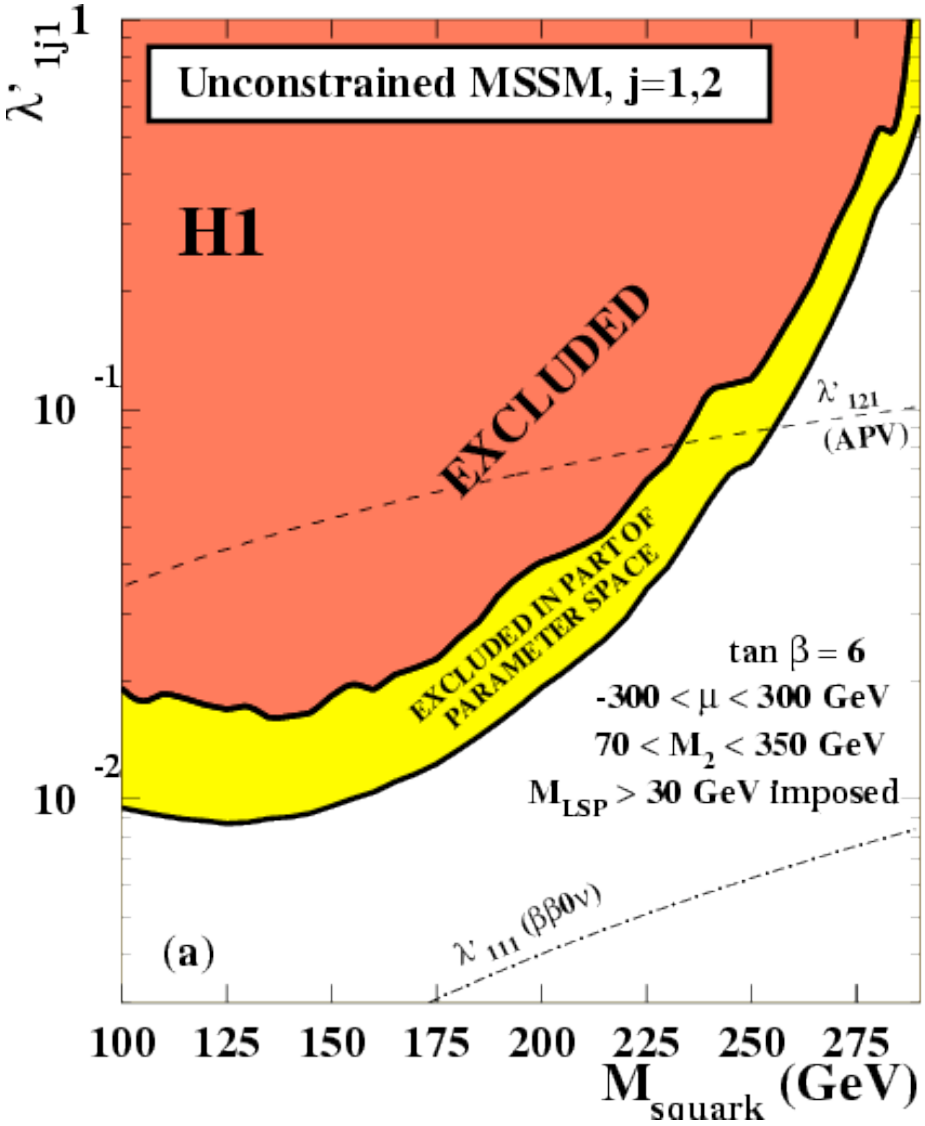
$m_{\tilde{e}} = 90GeV$



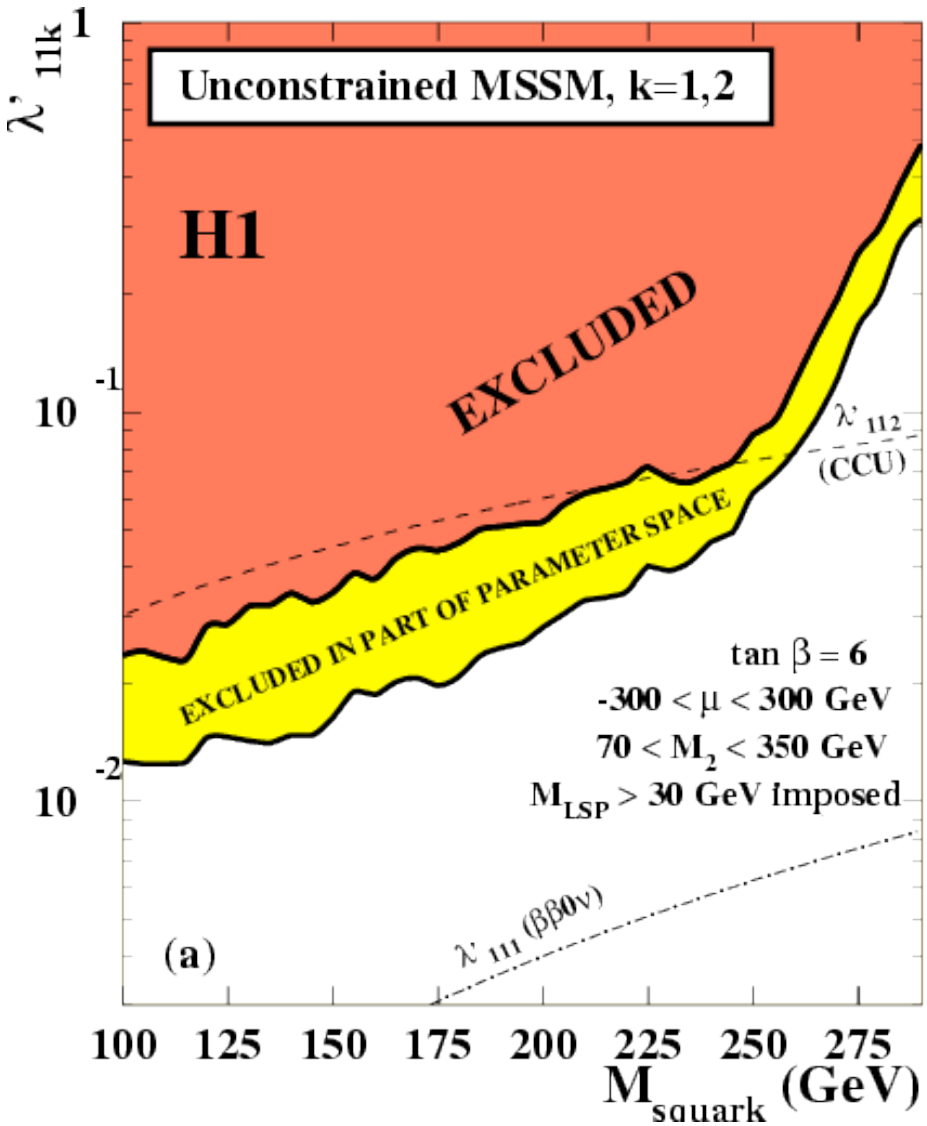
B.R. Of considered states Sum to nearly 100% for Different Model assumptions. Example here: sleptons with mass equal to squarks or much lighter, 90 GeV. Final limit nearly the same!

H1: MSSM with degenerate sfermions

$\lambda'_{1j1} : e^+ p \to \tilde{u}_L^{j=1,2}$

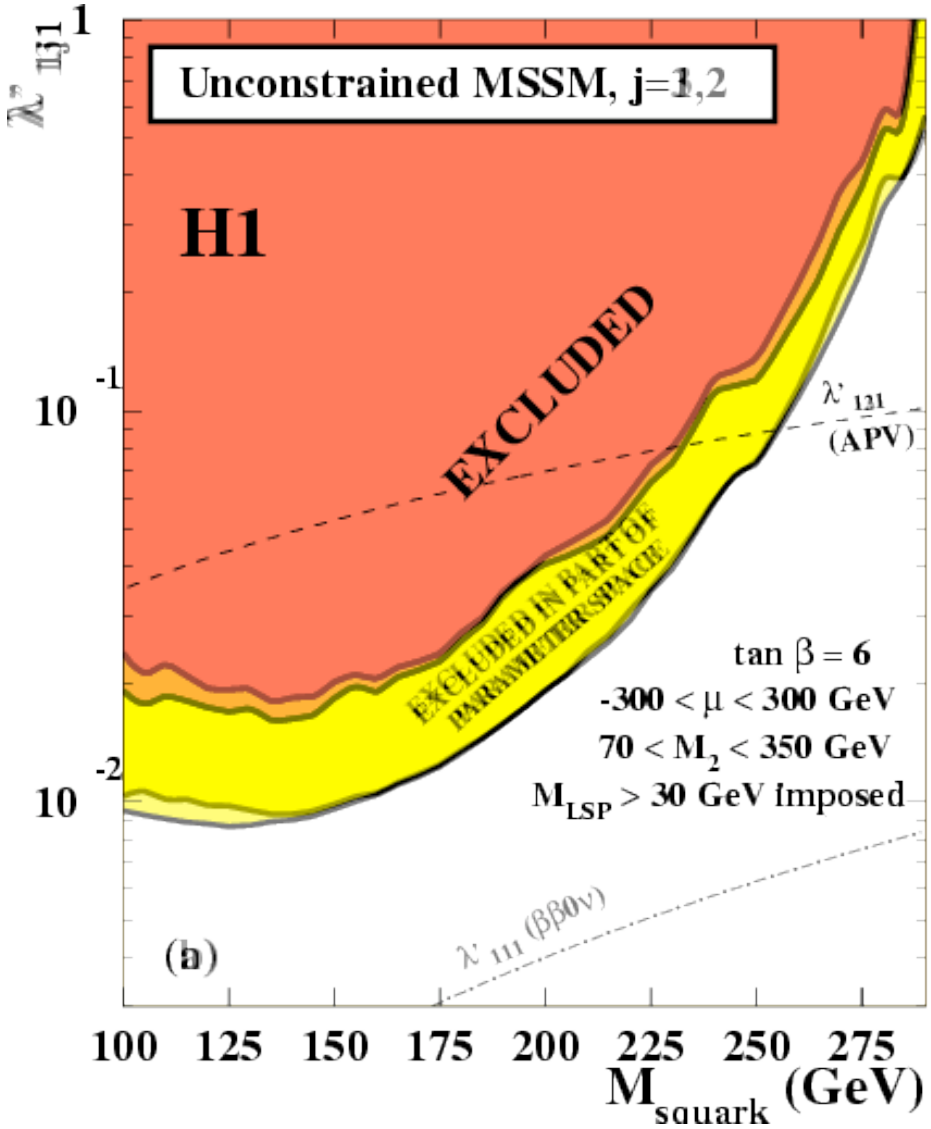


$\lambda'_{11k} : e^- p \to \tilde{d}_R^{k=1,2}$

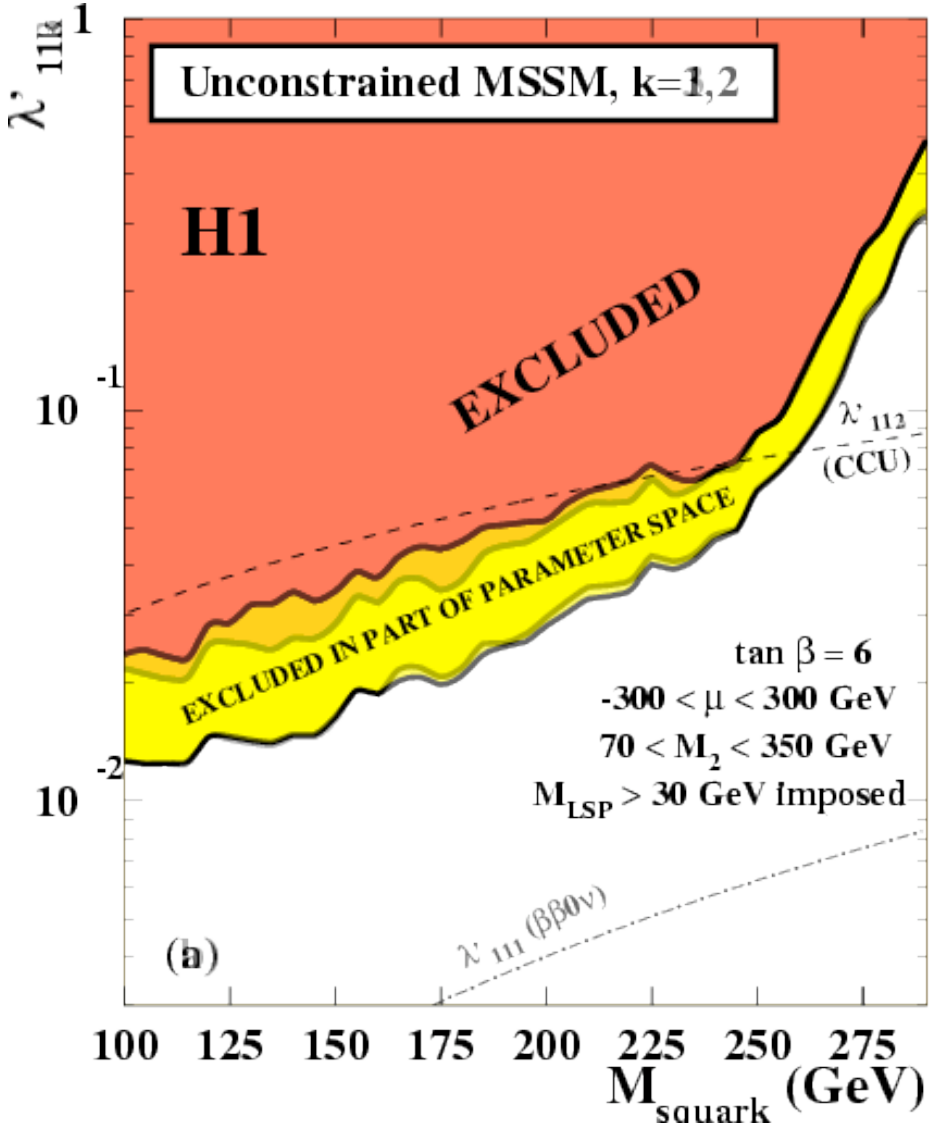


H1: MSSM with degenerate sfermions

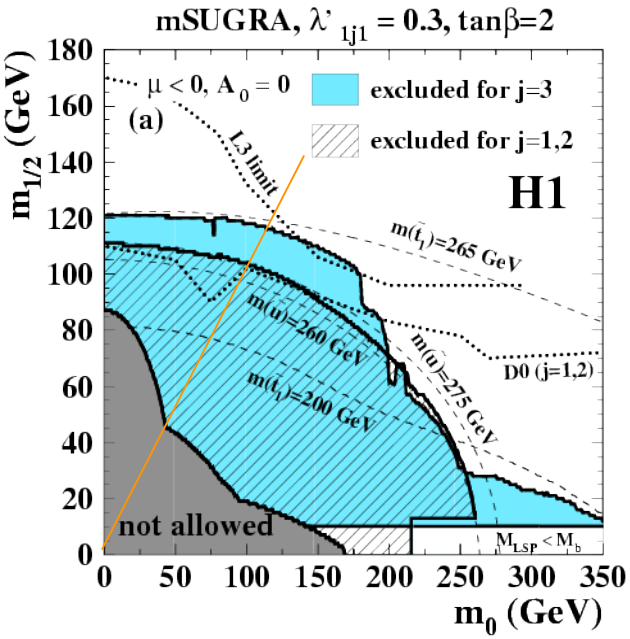
$\lambda'_{1j1} : e^+ p \to \tilde{u}_L^{j=1,2}, \tilde{t}_L$



$\lambda'_{11k} : e^- p \to \tilde{d}_R^{k=1,2}, \tilde{b}_R$



H1: mSUGRA limits in plane $m_{1/2}$ vs. m_0

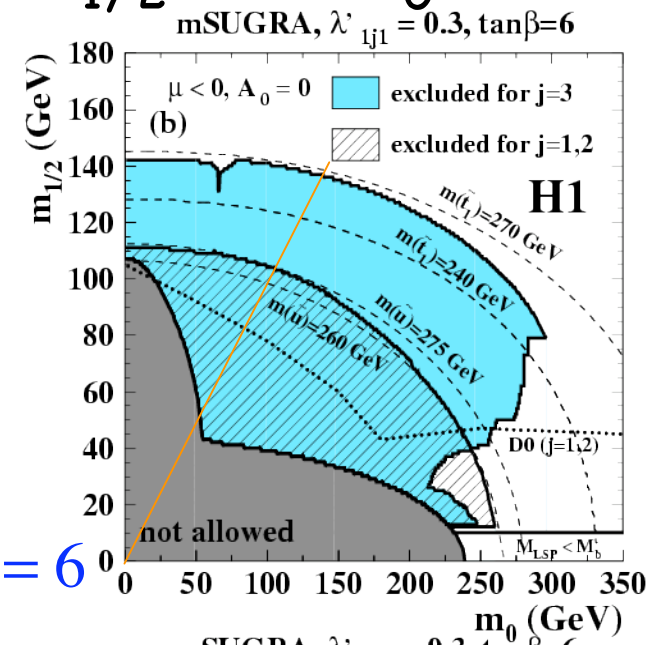


$\lambda'_{1j1} : e^+ p \to \tilde{u}, \tilde{c}, \tilde{t}$

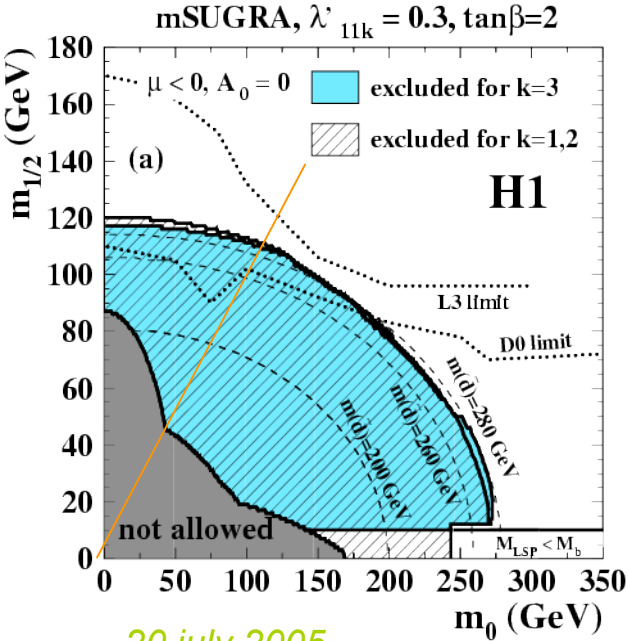
$\tilde{t}$

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

$\tan\beta = 2$



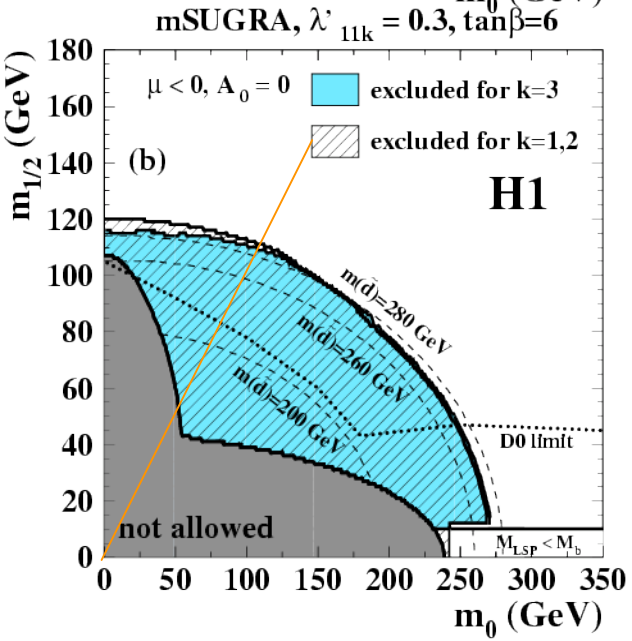
$\tan\beta = 6$



$\lambda'_{11k} : e^- p \to \tilde{d}, \tilde{s}, \tilde{b}$

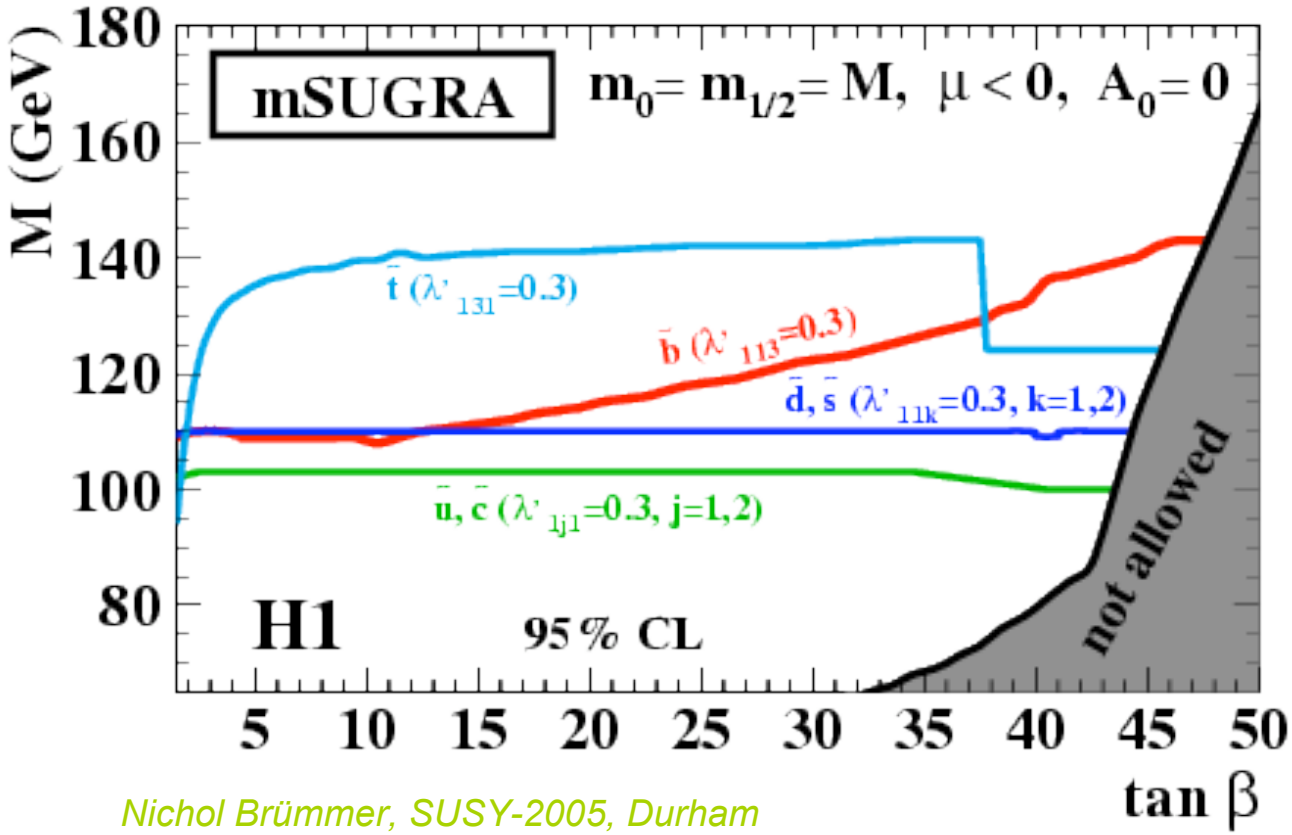
$\tilde{b}$

$\tilde{d}, \tilde{s}$



H1: mSUGRA limit on $m_{1/2} = m_0$ vs $\tan\beta$

- Finally constrain to diagonal $m_{1/2} = m_0 = M$
- Mixing of stop sbottom states depends on $\tan\beta$
  ➔ mass of light state decreases at high $\tan\beta$
  ➔ can exclude higher values of M for same squark mass
- For $\tan\beta > 37$ final states with light stau contribute



Conclusion

- HERA results on RPV-SUSY
  - complementary, competitive to LEP, Tevatron, low energy limits
  - ZEUS light stop search beats APV limits when $m_{\tilde{t}} < 250 GeV$
  - H1: light stop $\rightarrow$ sbottom + W, if λ'_{131}=0.3, then $m_{\tilde{t}} > 260 - 275\,\mathrm{GeV}$
  - GMSB neutralino $\rightarrow$ Gravitino + γ, for λ'_{1j1}=1,
    $m_{\chi_1^0} > 112\mathrm{GeV}$ if $m_{\tilde{e}} \approx m_{\chi_1^0}$ or $m_{\tilde{e}} > 164\ \mathrm{GeV}$ if $m_{\chi_1^0} \approx 55\ \mathrm{GeV}$
  - ZEUS: RPV-decaying gauginos: M_2> 160 GeV if λ'_{111}=1, $m_{\tilde{e}} = 100 GeV$
  - H1: combine many channels, MSSM, mSUGRA limits,
    if λ'_{1jk}=0.3, squark masses up to 280 GeV are excluded,
    with some dependence on the SUSY-parameters.
- HERA II is producing good data
  - Polarized $e^{\pm}$ beam: RPV couplings are chiral
  - HERA II total luminosity already equals that of HERA I
  - The HERA II e^-p sample already 4.5 $\times$ HERA I !!