Search for R-Parity Violating Supersymmetry in *ep* Collisions

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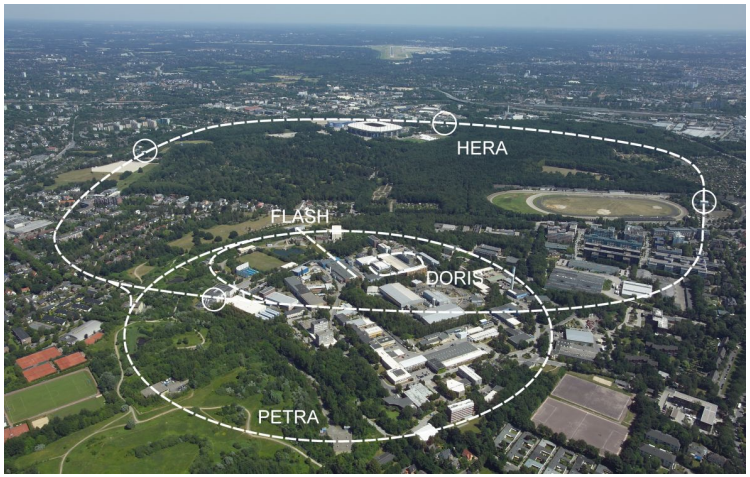
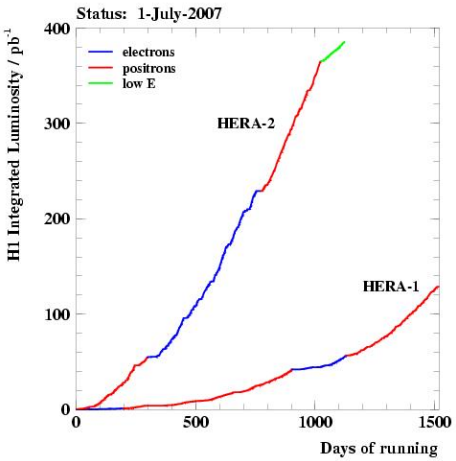
HERA *ep* collider

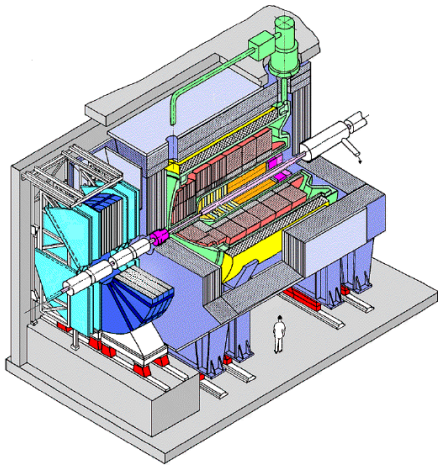
- At DESY, Hamburg 1992-2007
- Data for this analysis from 1998-2007 (HERA I+II)
- $e^{\pm}p$ collisions at $\sqrt{s} = 318$ GeV
- Integrated Luminosity:
  - $e^{-}p : \int \mathcal{L} = 183$ pb^{-1}
  - $e^{+}p : \int \mathcal{L} = 255$ pb^{-1}

H1 Experiment

- Asymmetric design
- Excellent lepton (e,μ) id
- 4π coverage - detect ν
- Good hadronic final state reconstruction via energy flow algorithm







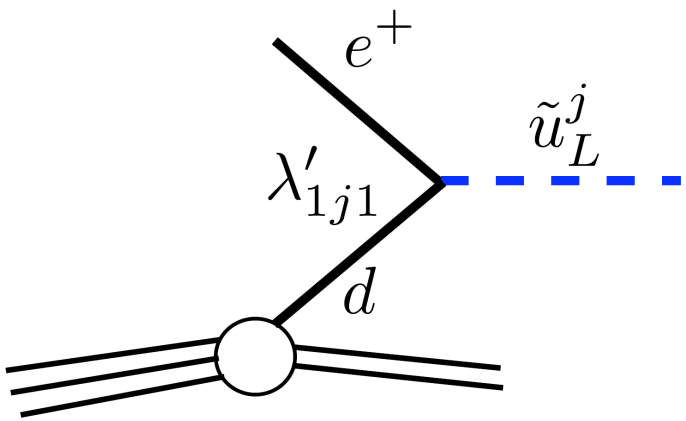
Squark Production in RPV SUSY

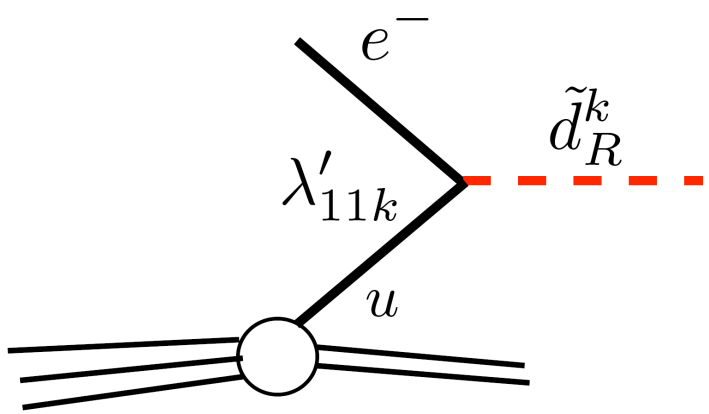
RPV SUSY

- Violation of R-Parity $R_P = -1^{3B-L+2S}$ leads to extra terms in superpotential

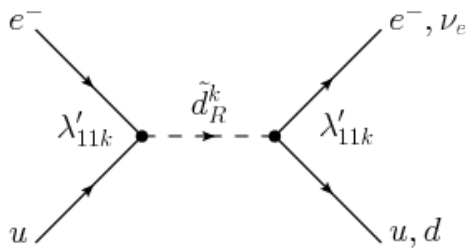
$$\lambda_{ijk} L_i L_j \overline{E}_k + \underbrace{\lambda'_{ijk} L_i Q_j \overline{D}_k}_{\text{Relevant at HERA}} + \lambda''_{ijk} \overline{U}_i \overline{D}_j \overline{D}_k$$

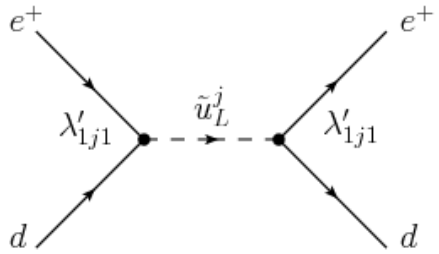
  where i, j, k generation indices
- Our model: Only one λ' coupling non-zero, proton decay still forbidden
- Allows resonant production of squarks from lepton+quark initial state.
- Squark masses up to $\sqrt{s} = 319$ GeV accessible.





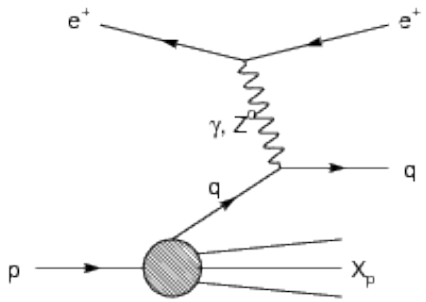
Direct Squark Decays

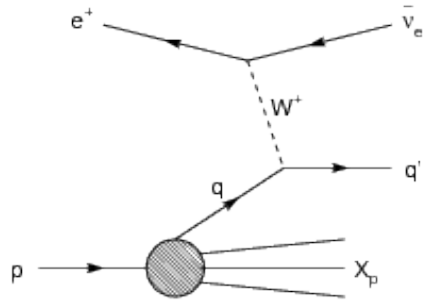




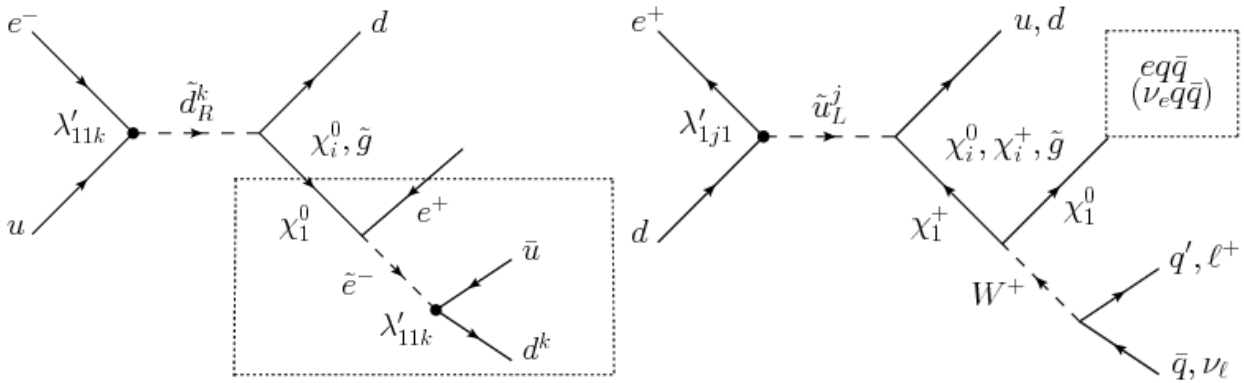
- Production and decay via same RPV coupling
- eq,νq final states: NC and CC-like – irreducible background
- Exploit heavy mass of squarks
- Decay products boosted forward, high p_T
- Mass reconstruction: $M_{e,h} = \sqrt{x_{e,h} \cdot s}$

Background: Standard Model Deep-Inelastic Scattering





Cascade decays



- R_P conserving decay, followed by RPV $\chi^0/\chi^\pm$decay
- Final states with lepton(s) (e, μ), ν and jets (MJ)
- Look at 14 relevant, exclusive channels
- Topologies: eMJ,$eeMJ$,$e\mu MJ$,νMJ,νeMJ,$\nu\mu MJ$
- Mass reconstruction: $M_{rec} = \sqrt{4E_e^0 \sum_i (E_i - E_e^0)}$ where i runs over all j,ν
  $\sigma_{M_{rec}} \sim 10 - 20$ GeV
- Exploit energy/momentum conservation

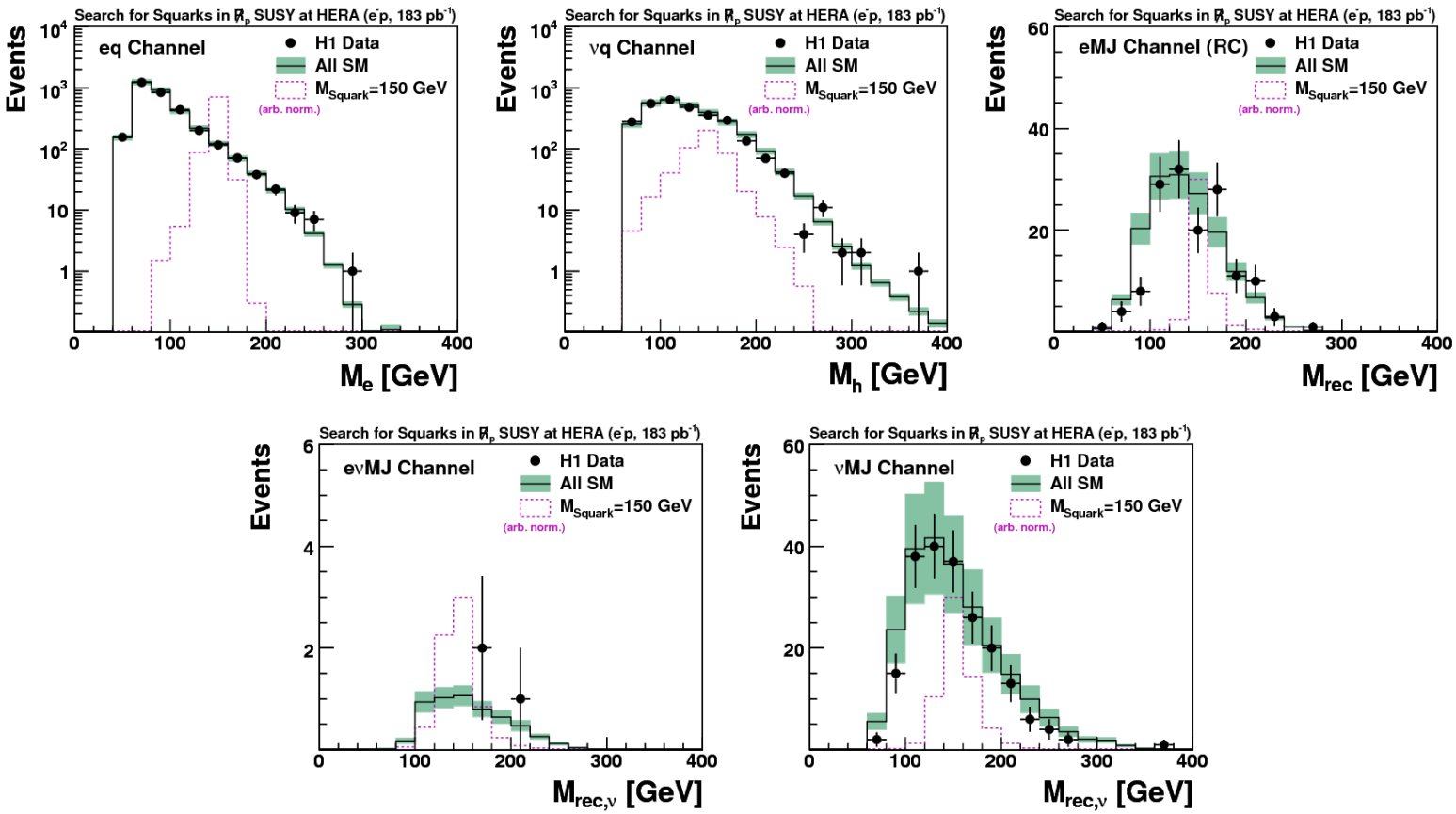
Selection Results

H1 Search for Squarks in $R\!\!\!/_p$ SUSY

Selection Channel	$e^- p$ (183 pb^{-1}) Data	SM Expectation			$e^+ p$ (255 pb^{-1}) Data	SM Expectation			Range of Signal Efficiencies		
eq	3121	3215	$\pm$	336	2946	2899	$\pm$	302	30%	–	40%
νq	2858	2983	$\pm$	358	–		–		50%	–	60%
eMJ (RC)	147	158.3	$\pm$	23.9	140	146.0	$\pm$	21.4	10%	–	40%
eMJ (WC)	0	1.3	$\pm$	0.3	1	0.6	$\pm$	0.4	5%	–	20%
$eeMJ$	0	1.5	$\pm$	0.5	2	1.7	$\pm$	0.5	5%	–	35%
$e\mu MJ$	0	0.03	$\pm$	0.02	0	0.03	$\pm$	0.03	5%	–	15%
$e\nu MJ$	3	5.6	$\pm$	1.2	5	8.2	$\pm$	2.0	5%	–	40%
νMJ	204	235.5	$\pm$	63.3	113	134.0	$\pm$	33.8	5%	–	15%
$\nu\mu MJ$	0	0.04	$\pm$	0.02	0	0.06	$\pm$	0.03	5%	–	20%

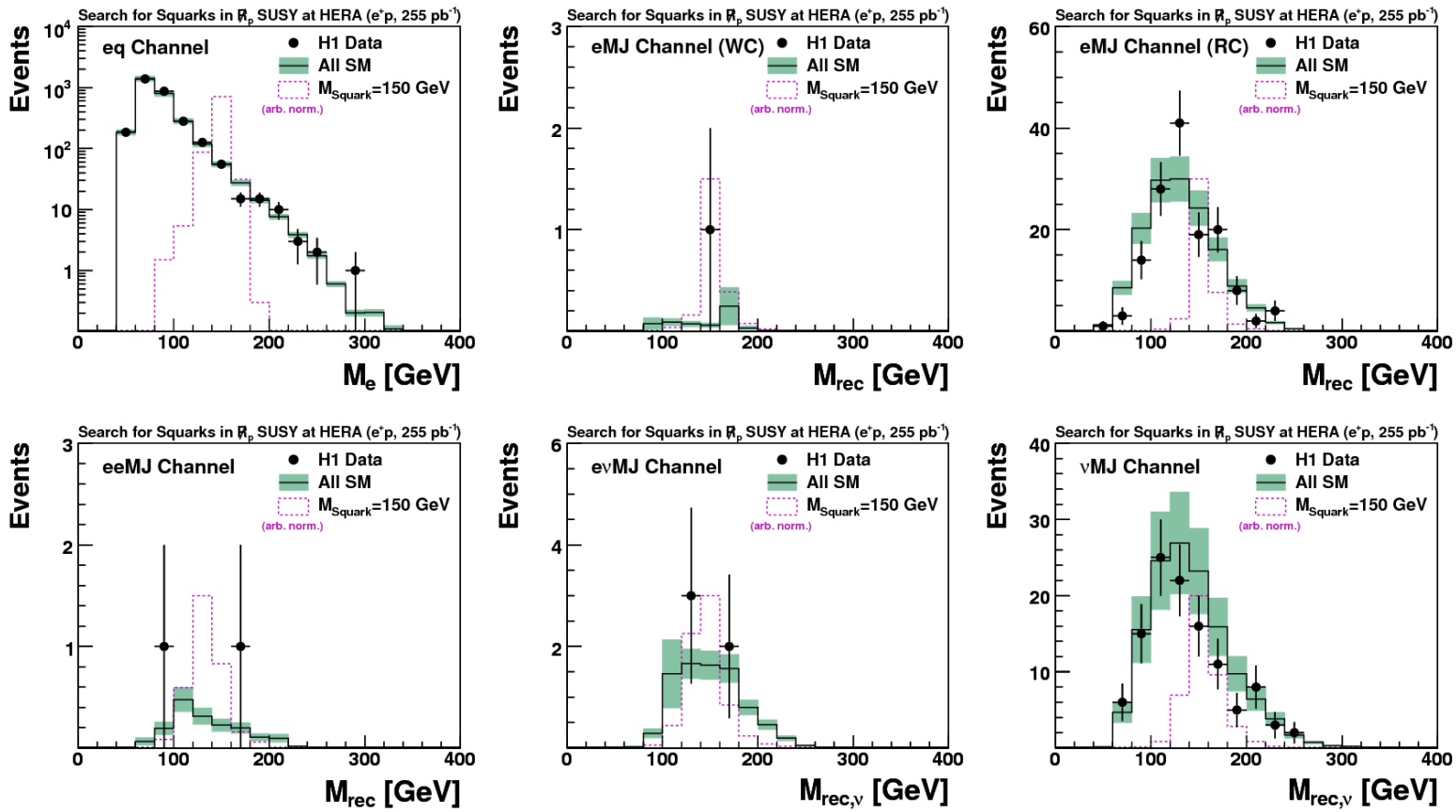
- All channels agree with the SM prediction within uncertainties
- SM Background Predictions from MC: PYTHIA, DJANGO, RAPGAP
- Signal Generator: SUSYGEN3
- Uncertainties considered:
  em. scale ($0.7\% - 2\%$), JES (2%), Lumi (3%), model ($3\% - 20\%$)

Invariant Mass Distributions in $e^- p$ (183 pb^{-1})



- Showing SM background processes, squark signal $M_{\tilde{q}} = 150$ GeV.
- Lumi 13$\times$ larger than previous analysis
- SM well described – No sign of squark production in $e^- p$ collisions

Invariant Mass Distributions in e^+p (255 pb^{-1})



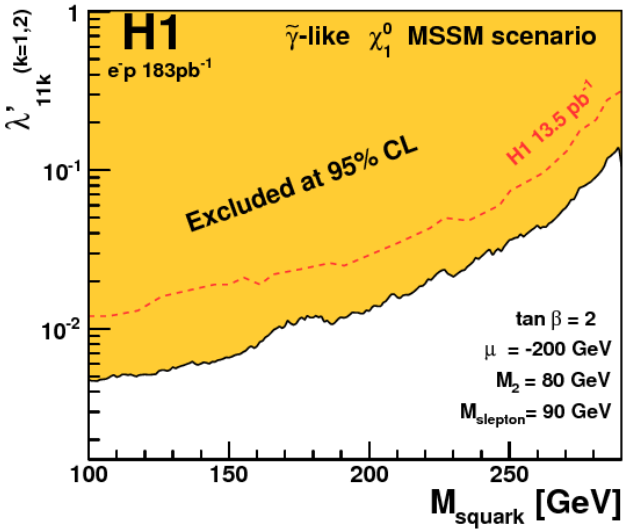
- Showing SM background processes, squark signal $M_{\tilde{q}} = 150$ GeV.
- Lumi 4$\times$ larger than previous analysis
- SM well described – No sign of squark production in e^+p collisions

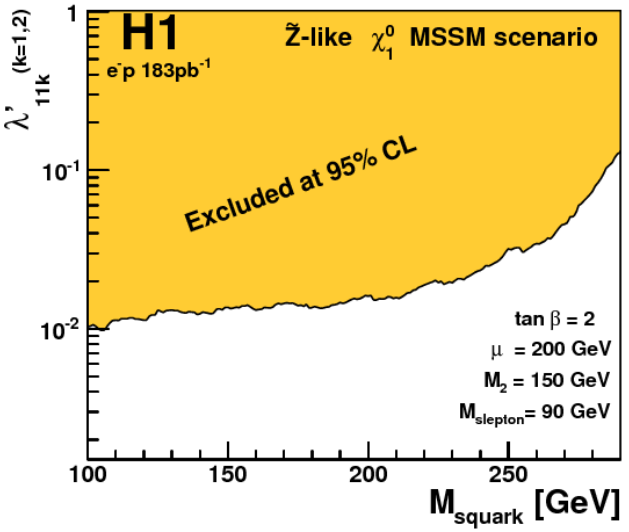
Parameter Scan and Limit Method

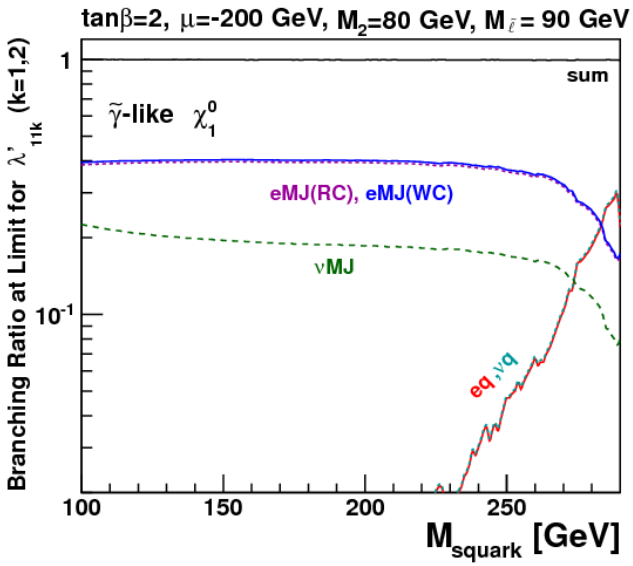
MSSM Parameters

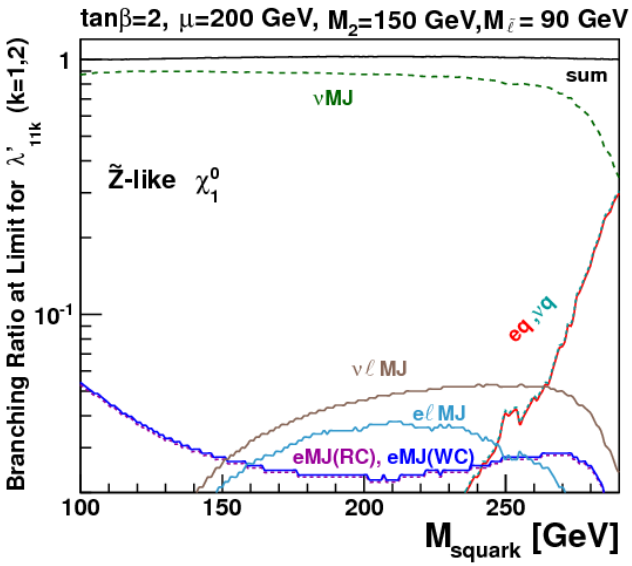
- Consider phenomenological MSSM model (LSP: χ_1^0)
- One scenario defined by $\tan\beta$, μ, M_2
- Determines particle masses and branching fractions
- Fix slepton masses $M_{\tilde{\ell}}$ at 90 GeV (LEP constraints)
- Generate spectrum and determine signal efficiencies using SUSYGEN3
- Set limit on last free parameter λ'
- Compare observed rate (simultaneously in all channels) to predicted rate at given λ'
- Use modified frequentist approach based on Likelihood Ratio (CL_{s+b} *method*) to find confidence limits at 95%.

Example: Limits on couplings in two scenarios ($e^- p$ data)









- Similar sensitivity in each scenario ($\lambda < 10^{-2}$), but from different channels

Parameter Scan

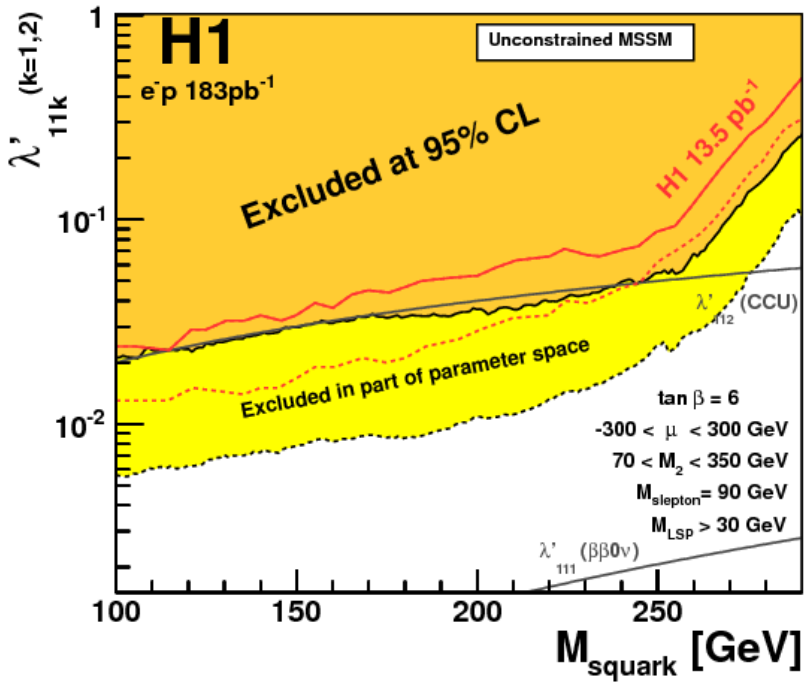
- Separate scans for $\tan\beta = 2, 6$ and $\lambda'_{1j1}, \lambda'_{11k} (j, k = 1, 2 \text{ or } 3)$.
- For couplings of em. strength ($\lambda' \simeq 0.3$)
  - $M_{\tilde{u},\tilde{c},\tilde{t}} \geq 275$ GeV at 95% CL.
  - $M_{\tilde{d},\tilde{s},\tilde{b}} \geq 290$ GeV at 95% CL.

$e^- p(\lambda'_{11k})$ for $\tan\beta = 6$

- Scan $-300 < \mu < 300$ GeV and $70 < M_2 < 350$ GeV
- Weakest limit (all scenarios)

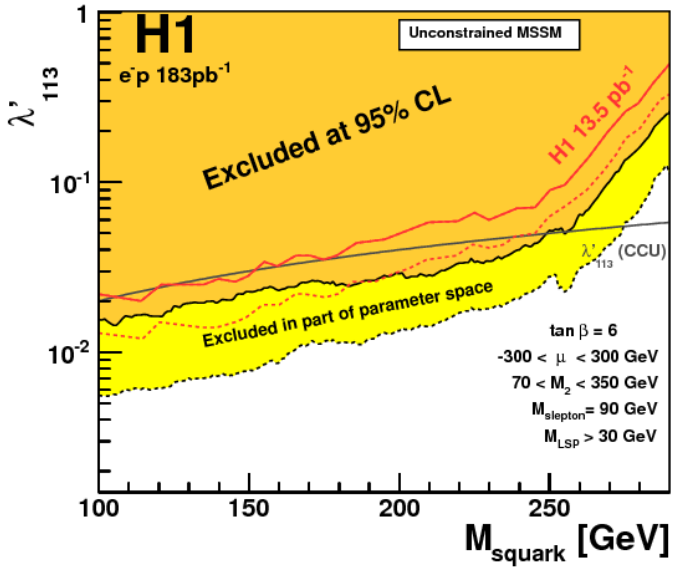
  ———————
- Best limit (one scenario)

  - - - - - - - - - -
- Previous limits (H1 2004 13.5 pb^{-1}) ———— - - - - - - - - - -
- Compare to indirect limits from CCU, $\beta\beta0\nu$, APV



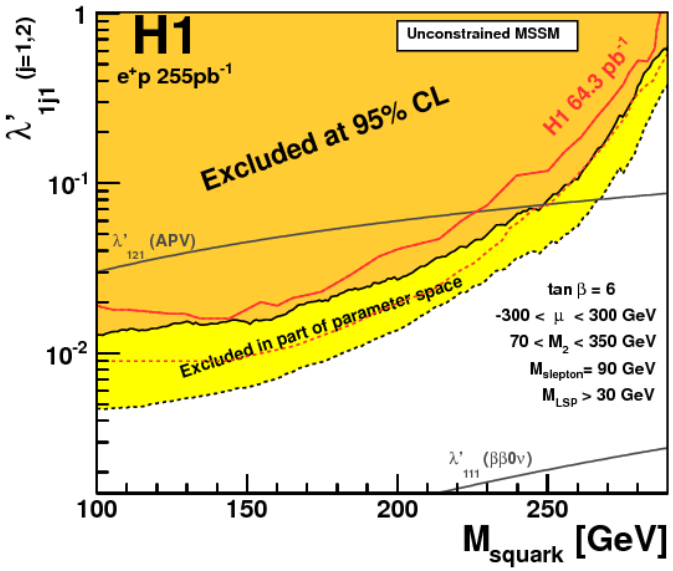
Exclusion limits

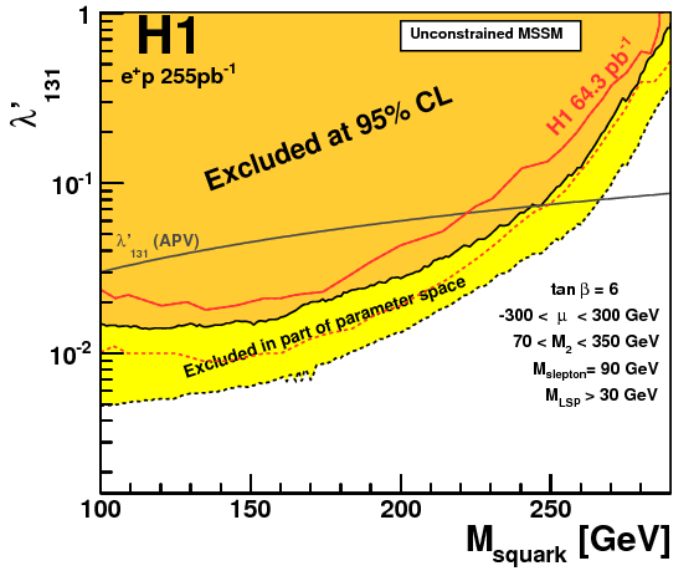
$e^- p$



- For $j, k = 3$ mixing in $\tilde{t}$ sector leads to different final states
- Conservatively assume no sensitivity (top signal would show up in covered channels)

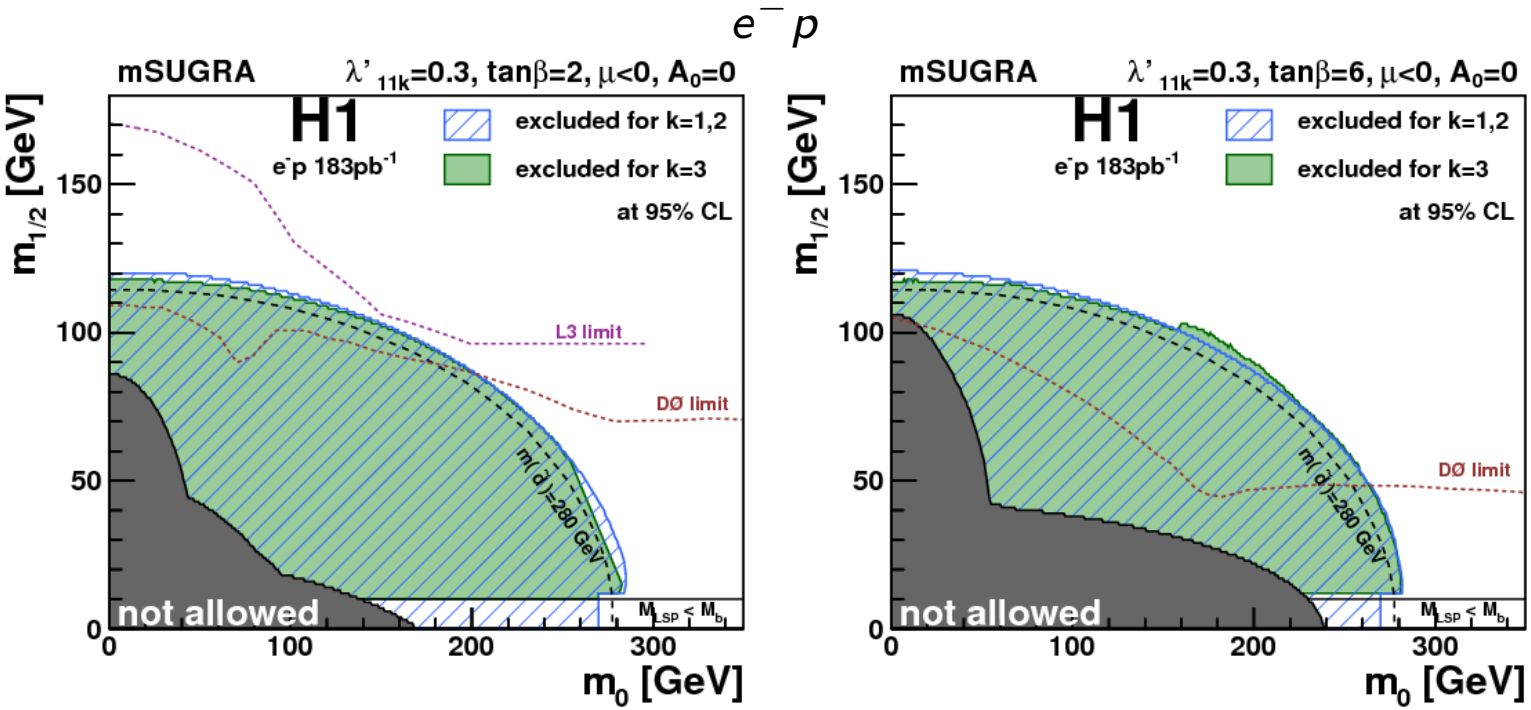
$e^+ p$





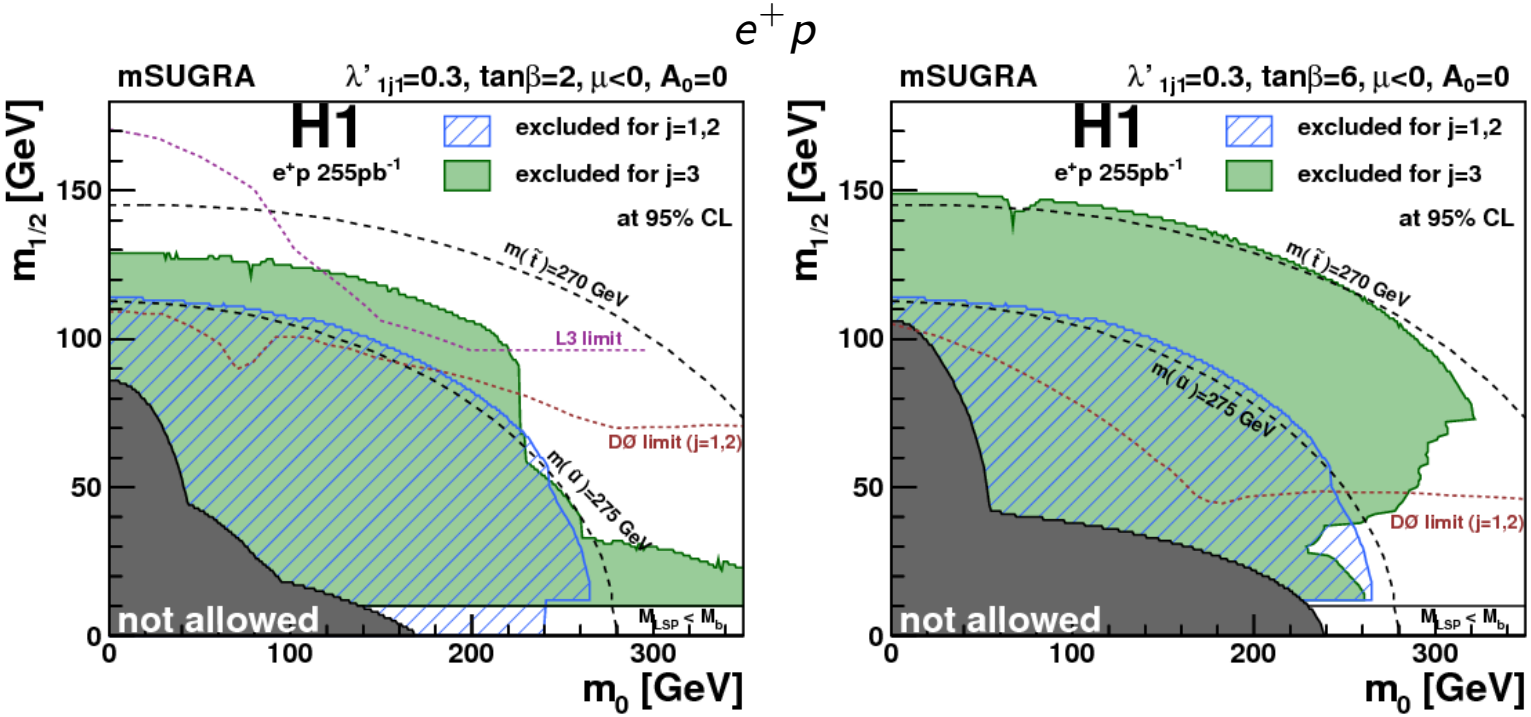
Limits in mSUGRA scenario

- Further constrain MSSM model to **mSUGRA** (GCU & REWSB)
- $M_{\tilde{q}}, M_{\tilde{\ell}}, M_{\chi_i^0,\chi_j^\pm}$ fixed by (m_0, $m_{1/2}$, $\tan\beta$, A_0, sign(μ))
- Consider $A_0 = 0$,sign(μ) < 0 and $\tan\beta = 2, 6$
- Determine limit contours at 95% CL in m_0, $m_{1/2}$ plane for couplings of em. strength $\lambda' = 0.3$



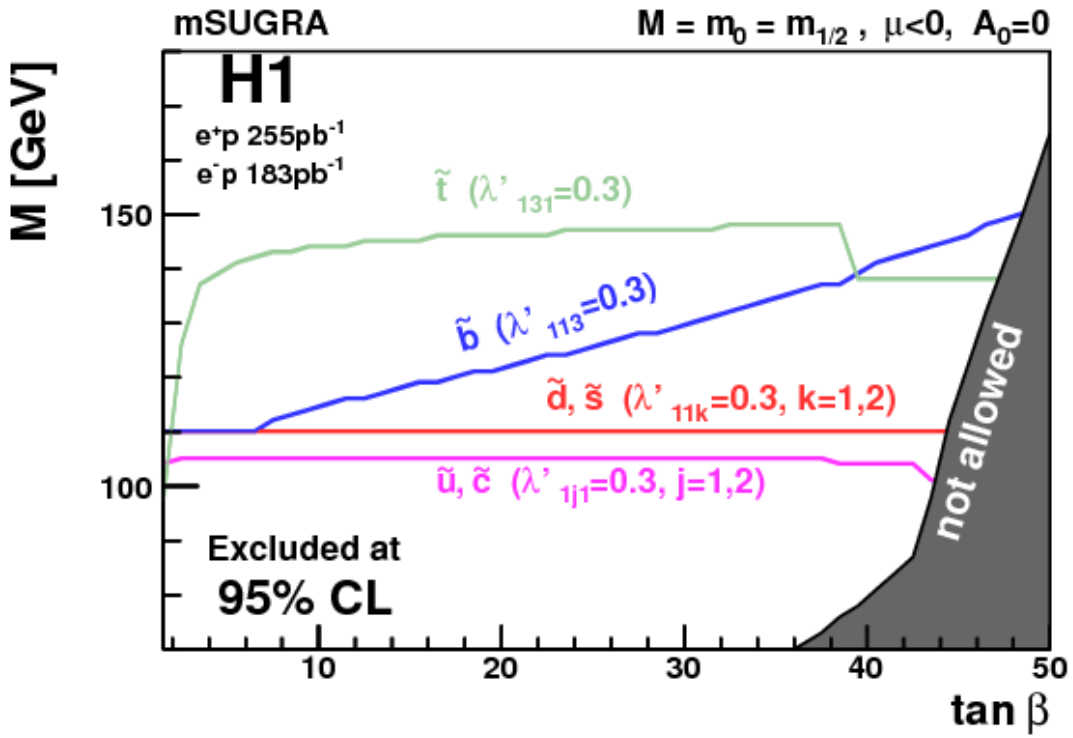
Limits in mSUGRA scenario

- $j = 1, 2$: $M_{\tilde{u},\tilde{c}} \geq 275$ GeV in whole plane.
- $j = 3$: Light $\tilde{t}$ component leads to larger area excluded in m_0, $m_{1/2}$ plane but mass limits weaker than $M_{\tilde{t}} \geq 270$ GeV ($\tan\beta = 2$)
- Limits comparable to existing LEP (L3), Tevatron (D0) limits



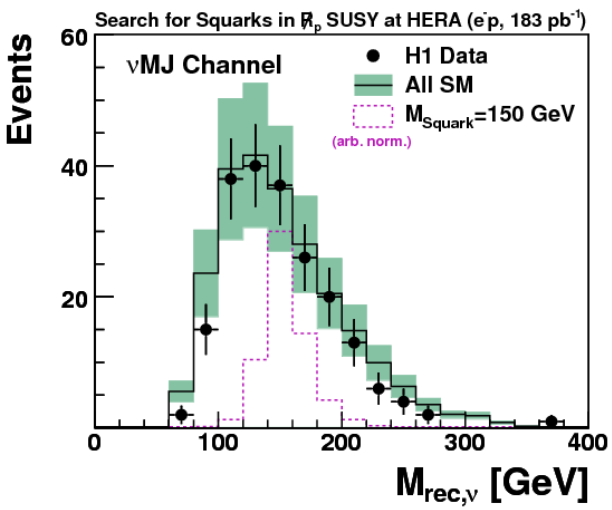
$\tan\beta$ Dependence of mSUGRA limits

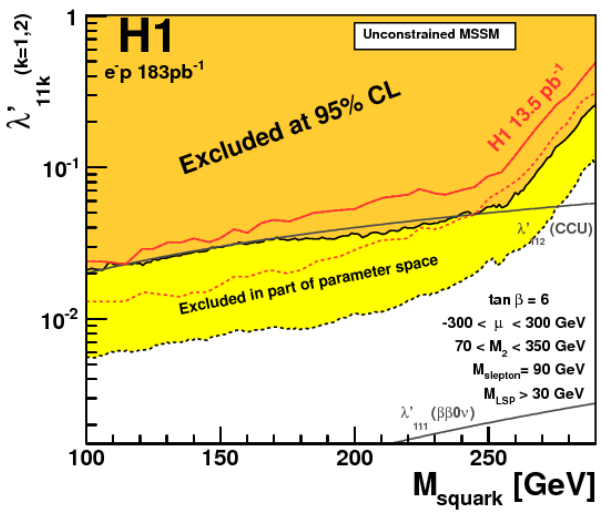
- Only small dependence of squark mass bounds for $1^{st}, 2^{nd}$ generation
- For 3^{rd} generation exclude $M = m_0 = m_{1/2}$ up to 150 GeV at high $\tan\beta$.
  - $\tilde{t}$: For $\tan\beta > 38$ $\tilde{\tau}$ component leads to τ final states - not included in analysis.

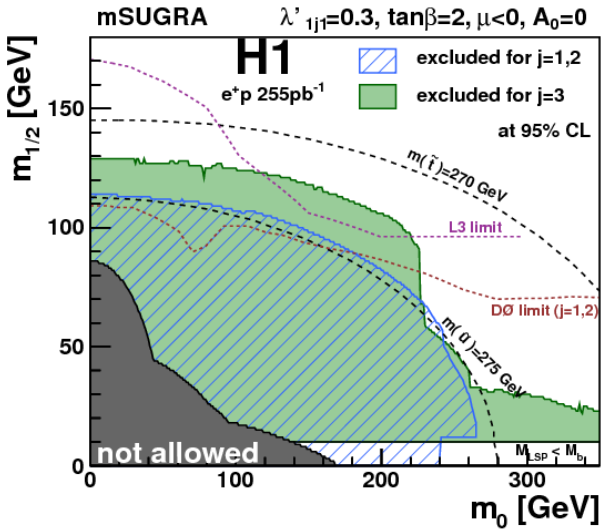


RPV SUSY at HERA - Summary

- H1 did comprehensive search for RPV SUSY in 0.5 fb^{-1} $e^{\pm}p$ data.
- HERA data well described by the Standard Model in all investigated channels
  - Even statistically limited processes
- For couplings of em. strength ($\lambda'_{1j1}, \lambda'_{11k} \simeq 0.3$)
  - $M_{\tilde{u},\tilde{c},\tilde{t}} \geq 275$ GeV at 95% CL.
  - $M_{\tilde{d},\tilde{s},\tilde{b}} \geq 290$ GeV at 95% CL.
- ep collisions best environment for searches for RPV SUSY via λ' coupling.







Backup

Limits on couplings in one scenario (e^+p)