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

H1 Collaboration, Eur.Phys.J.C71:1572,2011 [arXiv:1011.6359]

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On behalf of the H1 Collaboration

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HERA collider and experiments

HERA $\sqrt{s}$

HERA: 318 GeV

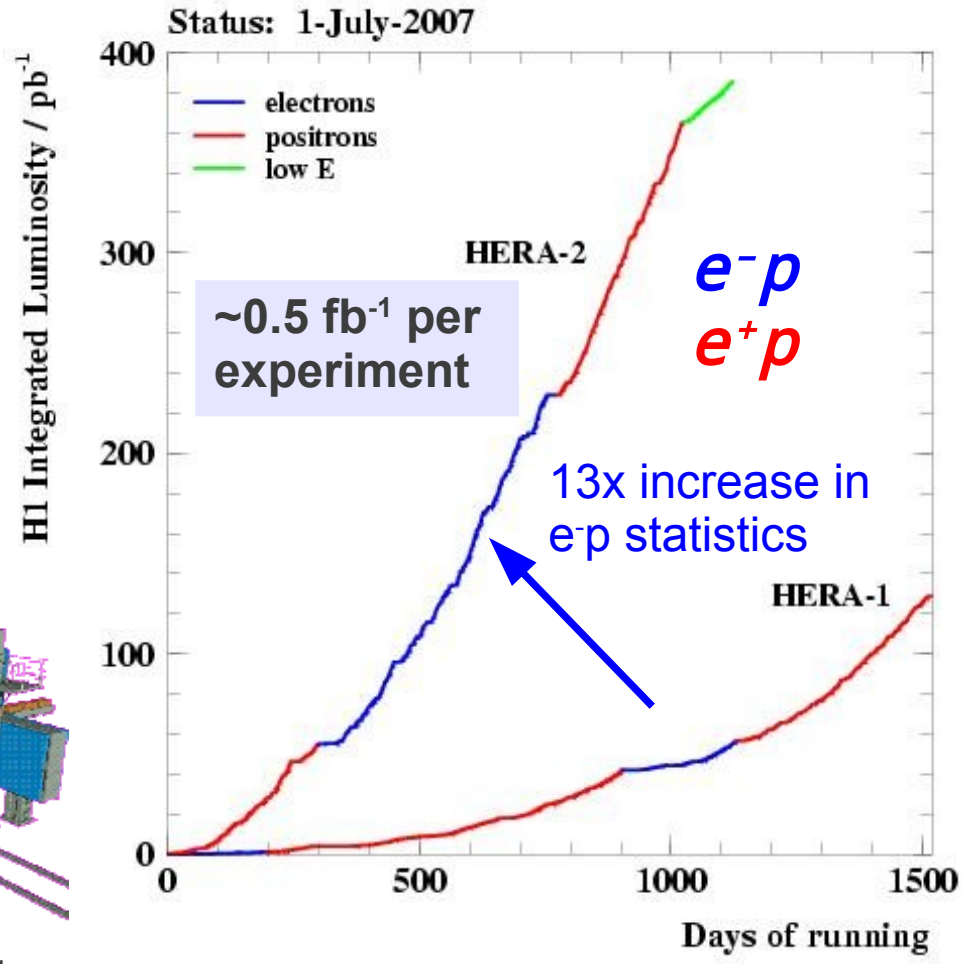
p (920 GeV) e (27.6 GeV)

World's only *ep* Collider at DESY,Hamburg
Active 1991-2007
H1 and ZEUS Experiments

HERA-I (1994-00)
~130 pb^{-1} per exp., (90% e^+p)

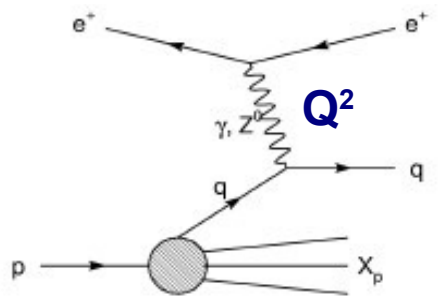
HERA-II (2003-07)
Luminosity upgrade
Long. *e* polarisation (avg. 40%)

Asymmetric Design
4π Coverage
Excellent Lepton ID + HFS Reconstruction

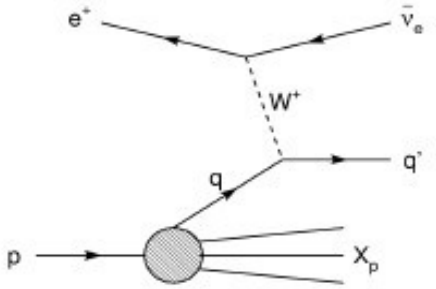


Deep-inelastic scattering at high Q^2

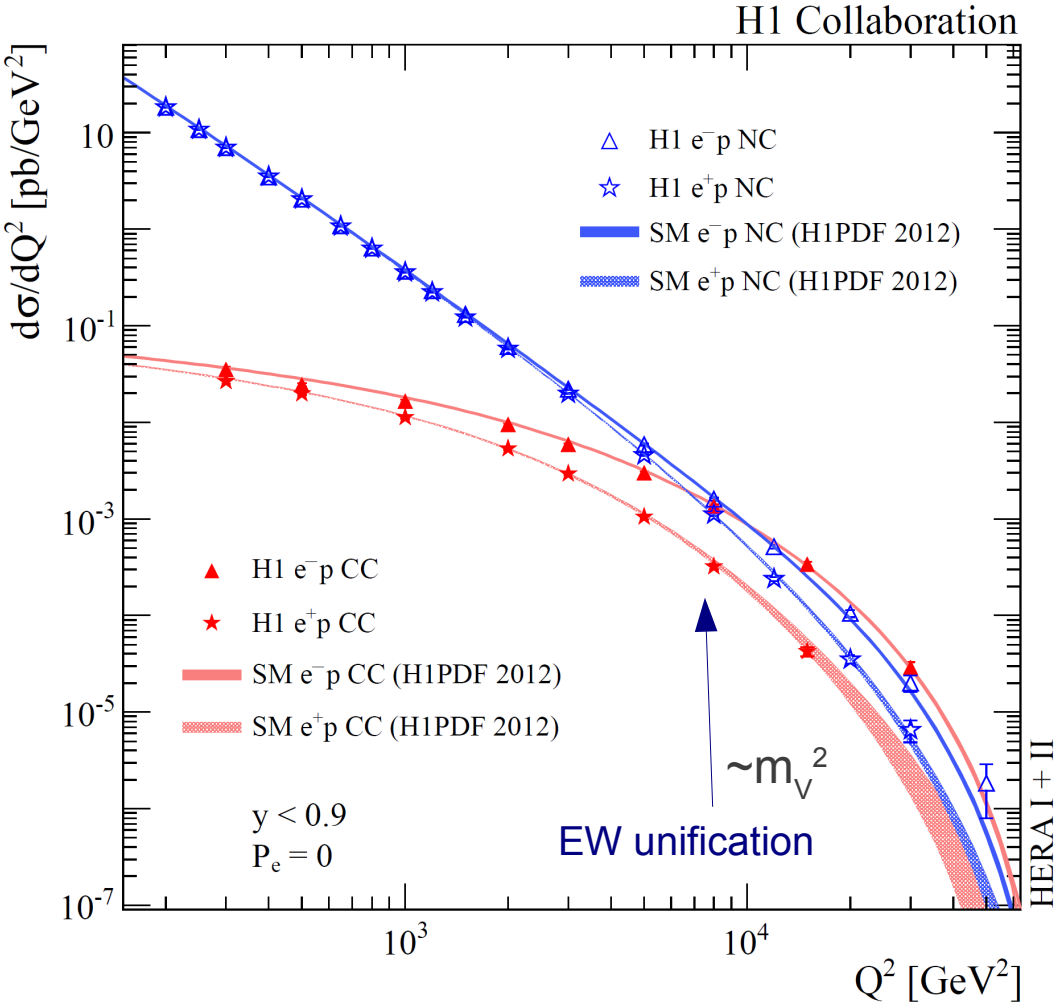
- Main Standard Model processes in *ep* collisions



Neutral Current



Charged Current



see talk by Z. Zhang – TR6

- Q^2 up to 40.000 GeV^2
- Spatial resolution ~ $1/Q^2 = 10^{-18}$ m - can probe small distances
- Resonant production of particles up to sqrt(s) = 319 GeV possible

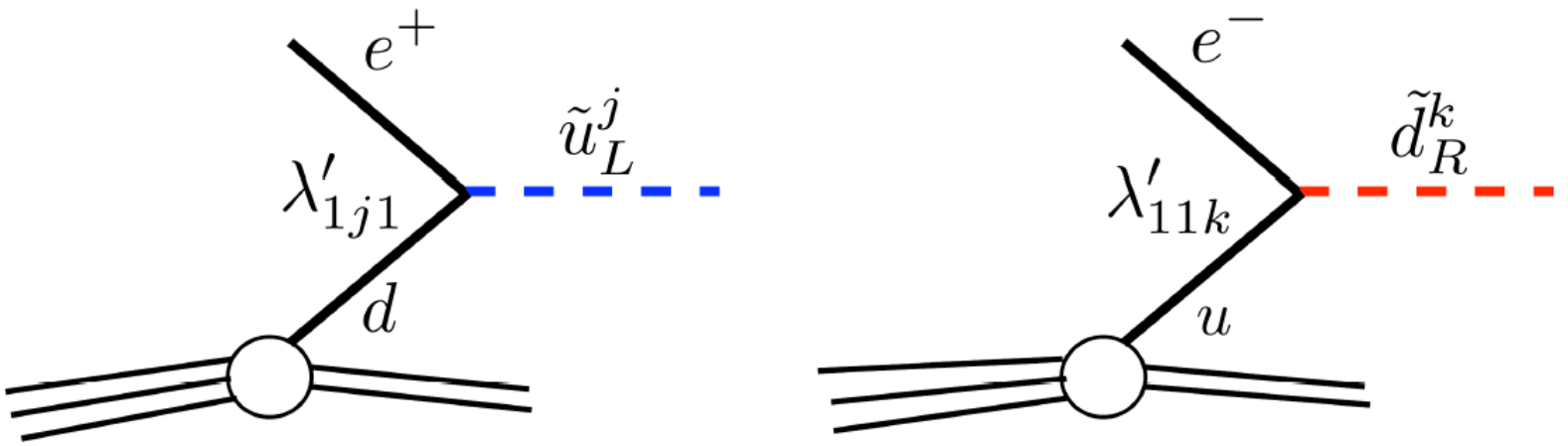
Resonant squark production in *ep* collisions

RPV SUSY

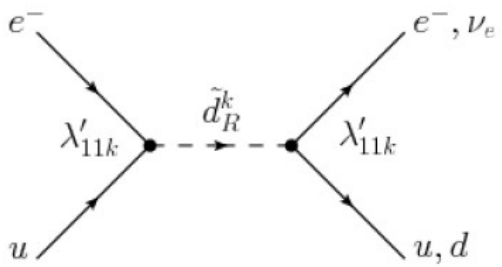
- Violation of R-Parity $R_P = -1^{3B-L+2S}$ leads to extra terms in superpotential

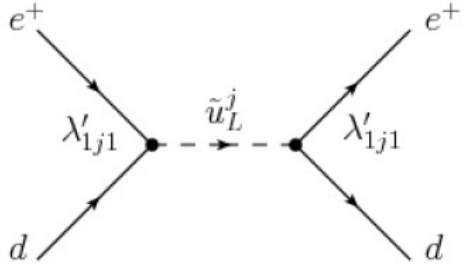
$$\lambda_{ijk} L_i L_j \overline{E}_k + \underbrace{\lambda'_{ijk} L_i Q_j \overline{D}_k}_{\text{Relevant at HERA}} + \lambda''_{ijk} \overline{U}_i \overline{D}_j \overline{D}_k$$

  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.



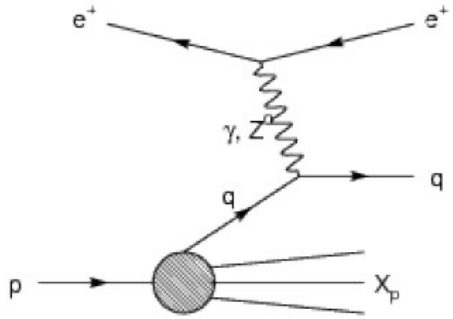
Direct squark decays

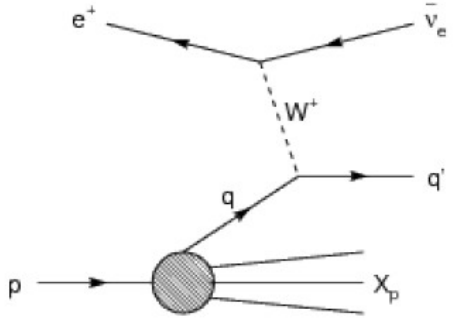




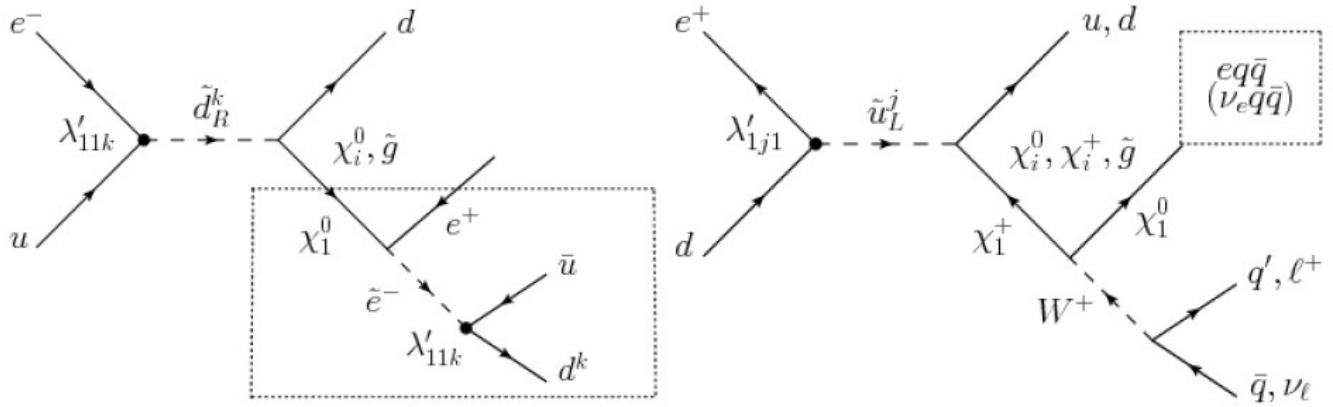
- Production and decay via same RPV coupling
- eq,νq final states: NC and CC-like – irreducible background
- Exploit heavy mass of squarks
- Decay products boosted forward, high p_T
- Mass reconstruction: $M_{e,h} = \sqrt{x_{e,h} \cdot s}$

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

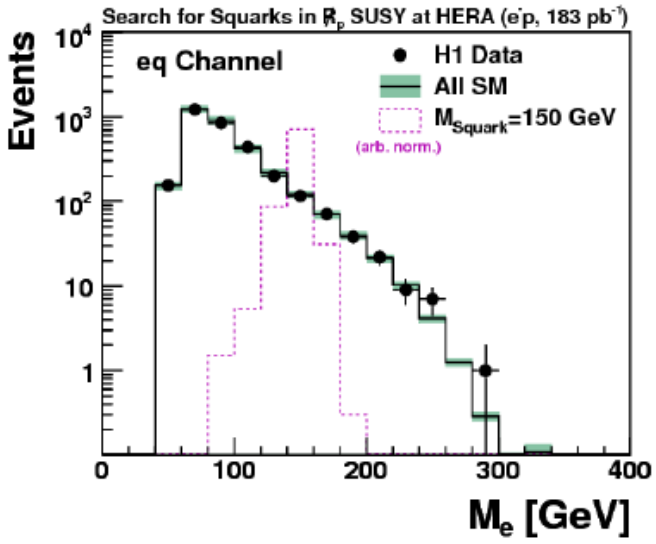
H1 Search for Squarks in $R\!\!\!/_p$ SUSY

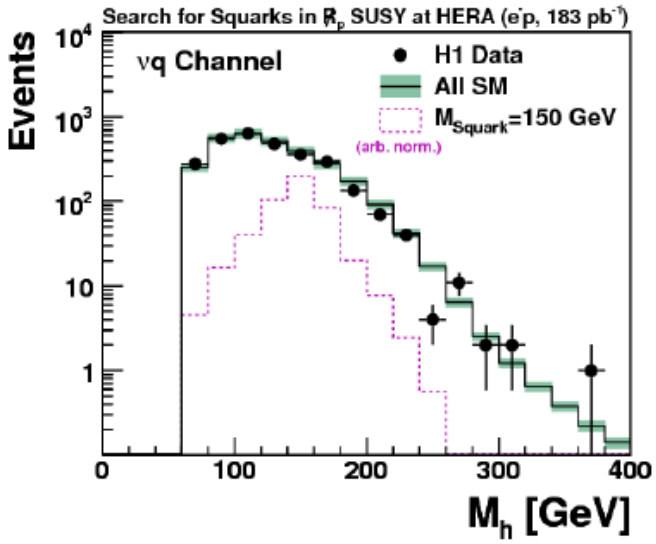
Selection Channel	$e^- p$ (183 pb^{-1}) Data	SM Expectation	$e^+ p$ (255 pb^{-1}) Data	SM Expectation	Range of Signal Efficiencies
eq	3121	3215 ± 336	2946	2899 ± 302	30% – 40%
νq	2858	2983 ± 358	–	–	50% – 60%
eMJ (RC)	147	158.3 ± 23.9	140	146.0 ± 21.4	10% – 40%
eMJ (WC)	0	1.3 ± 0.3	1	0.6 ± 0.4	5% – 20%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

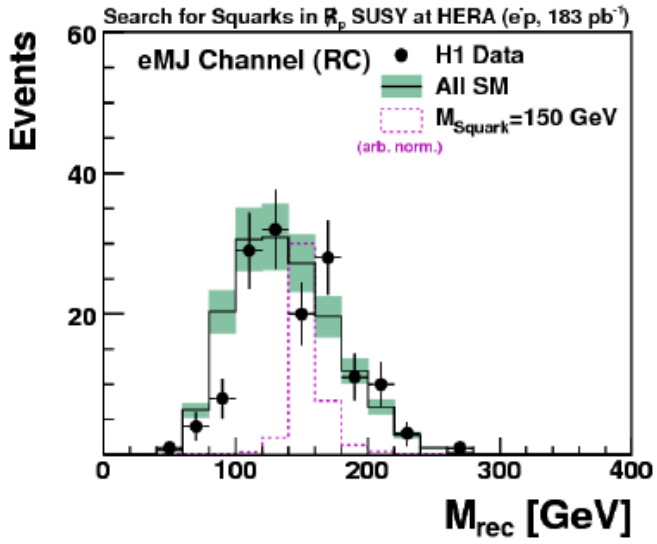
- All channels agree with the SM prediction within uncertainties
- SM Background Predictions from MC: PYTHIA, DJANGO, RAPGAP
- Signal Generator: SUSYGEN3
- Uncertainties considered:
  em. scale (0.7% – 2%), JES (2%), Lumi (3%), model (3% – 20%)

Some invariant mass distributions

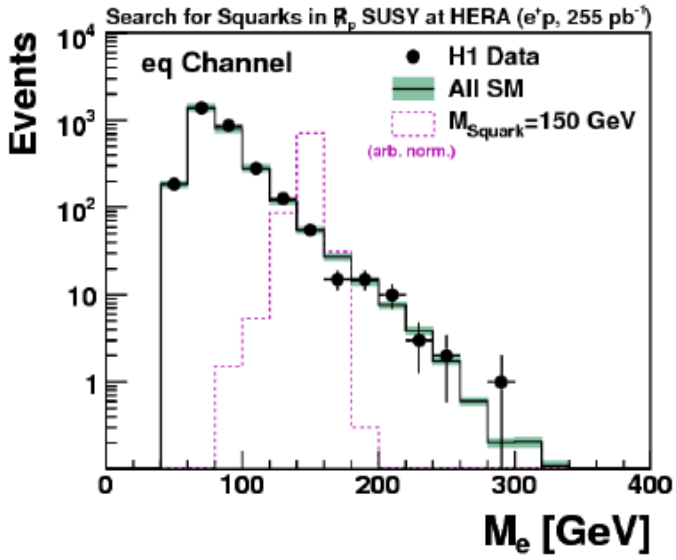
e^-p collisions 183 pb^{-1} (x 13 larger than previous analysis)

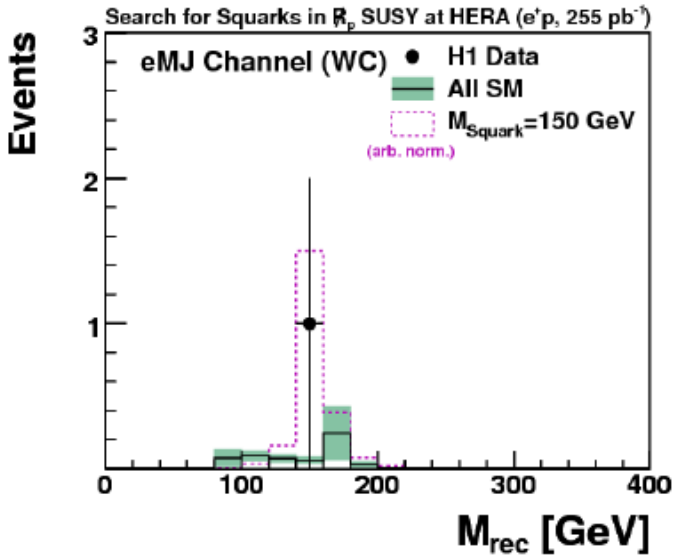


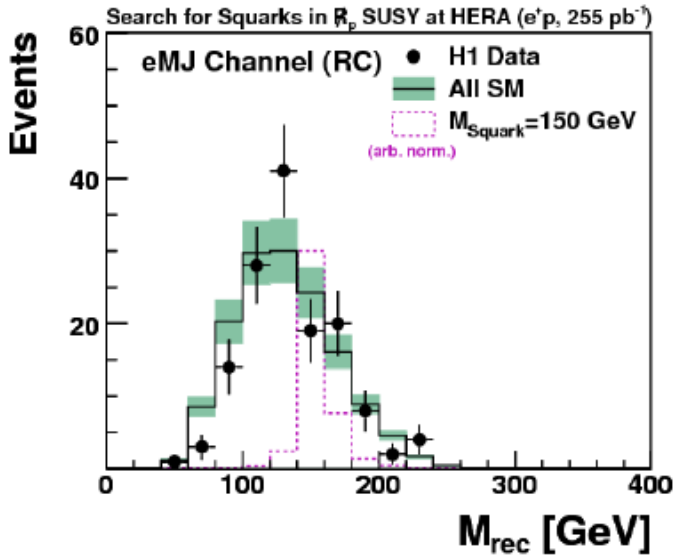




e^+p collisions 255 pb^{-1} (x 4 larger than previous analysis)







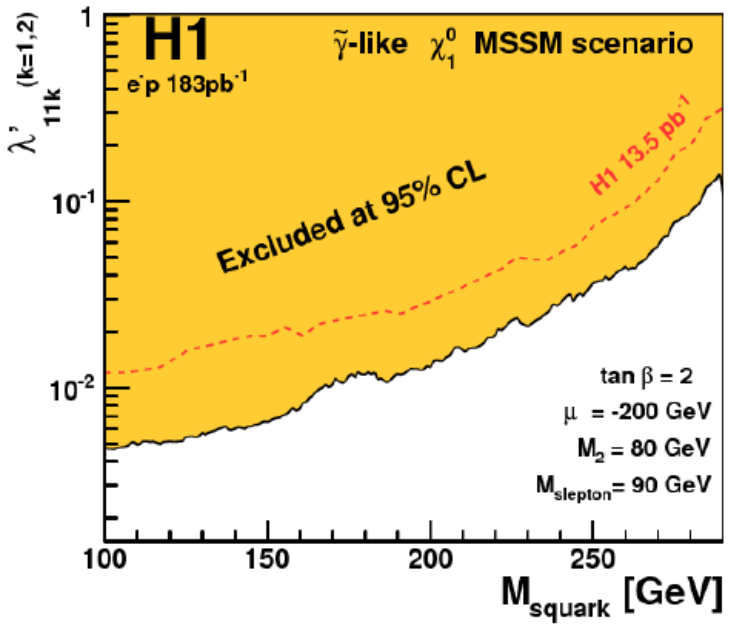
- All distributions well described by SM prediction – No sign of squark production in *ep*

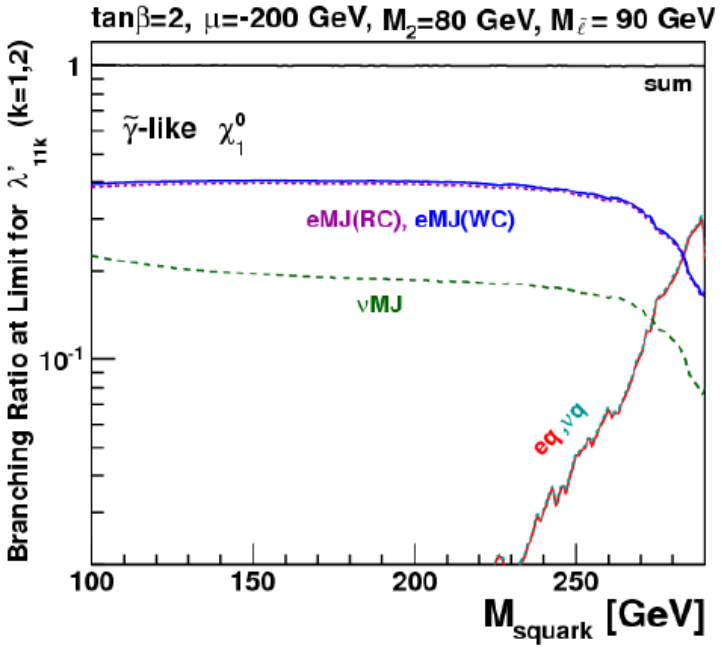
Limit setting method

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 for on scenario in the parameter space





Parameter scan

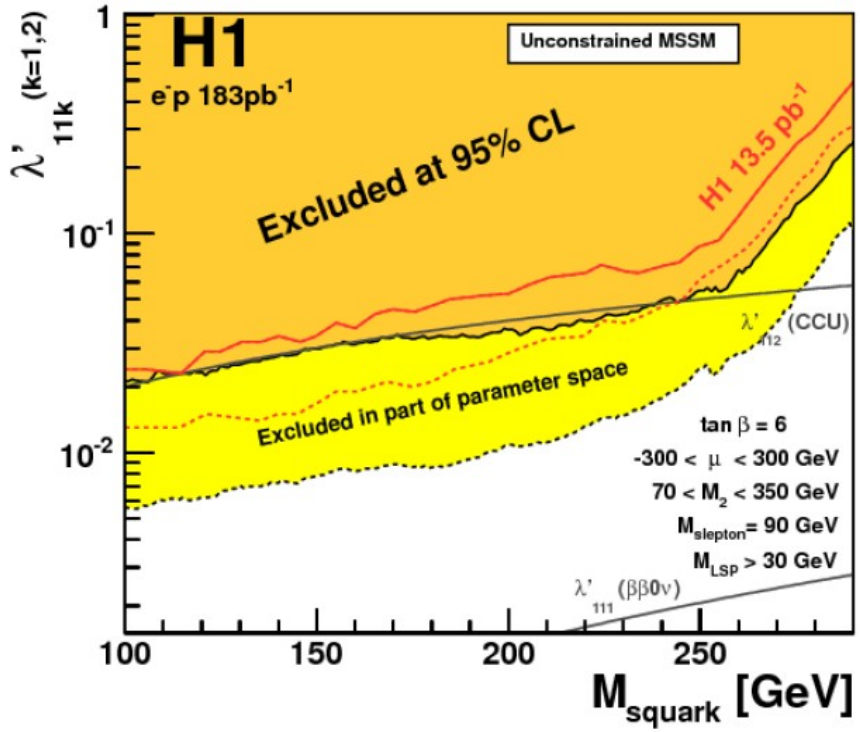
- Separate scans for $\tan\beta = 2, 6$ and $\lambda'_{1j1}, \lambda'_{11k} (j, k = 1, 2 \text{ or } 3)$.
- For couplings of em. strength ($\lambda' \simeq 0.3$)
  - $M_{\tilde{u},\tilde{c},\tilde{t}} \geq 275$ GeV at 95% CL.
  - $M_{\tilde{d},\tilde{s},\tilde{b}} \geq 290$ GeV at 95% CL.

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

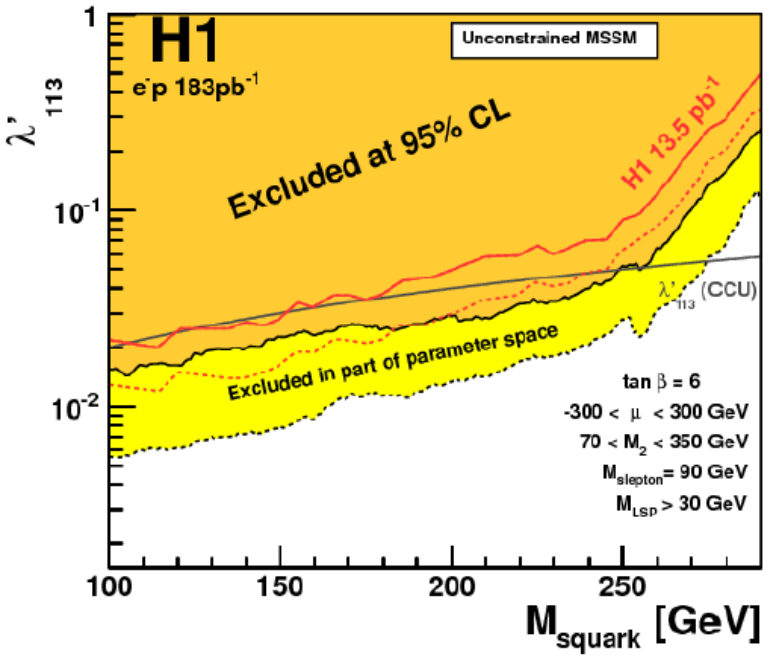
- Scan $-300 < \mu < 300$ GeV and $70 < M_2 < 350$ GeV
- Weakest limit (all scenarios)

  ———————
- Best limit (one scenario)

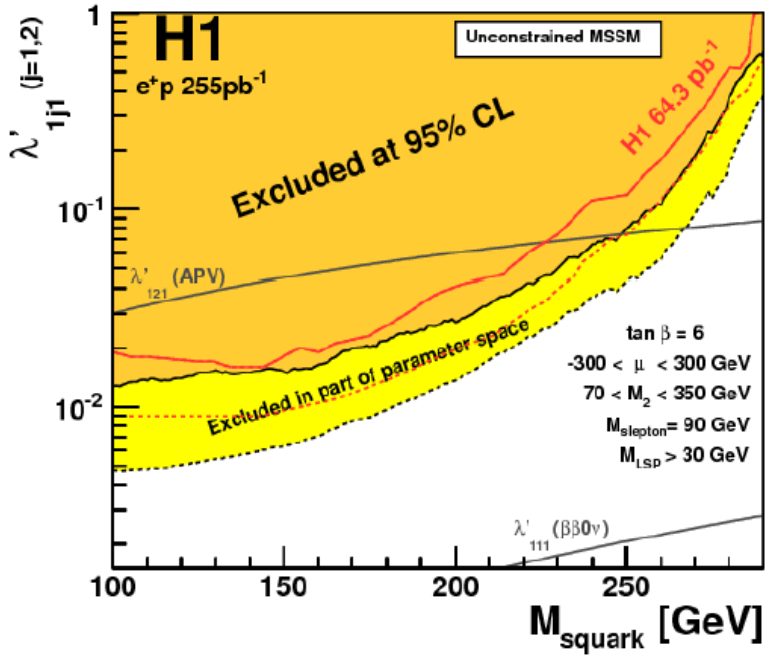
  - - - - - - - - - -
- Previous limits (H1 2004 13.5 pb^{-1}) ——— - - - - - - - - -
- Compare to indirect limits from CCU, $\beta\beta0\nu$, APV

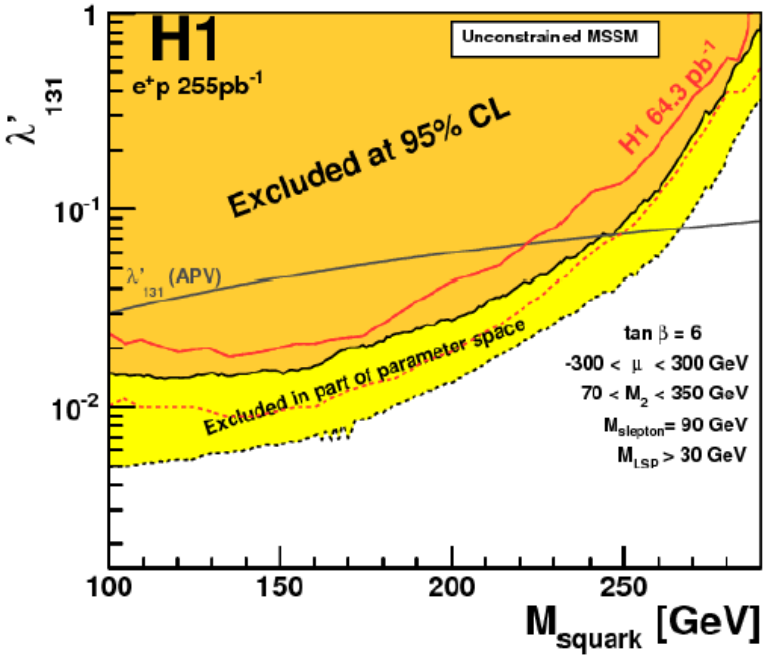


Exclusion limits



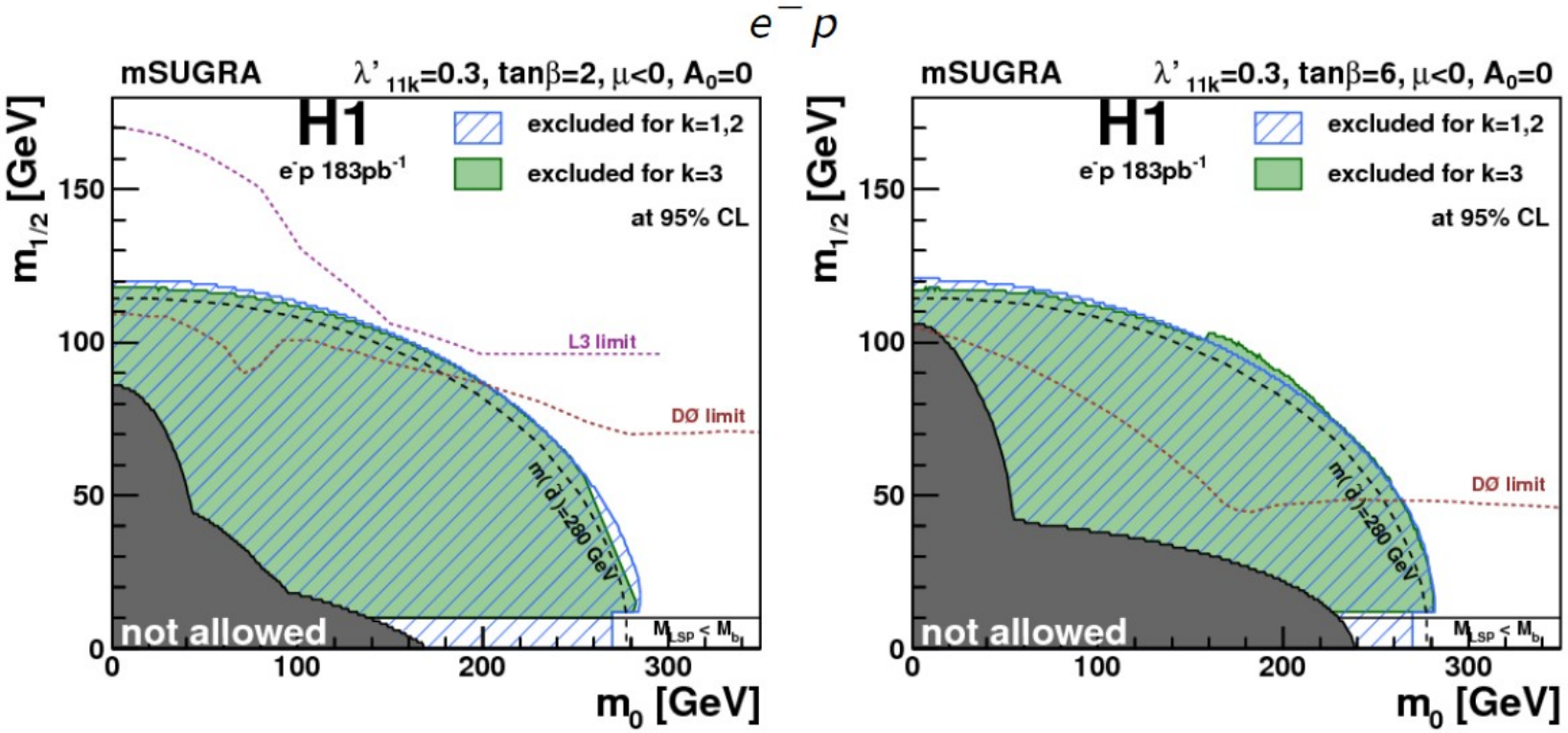
- For $j, k = 3$ mixing in $\tilde{t}$ sector leads to different final states
- Conservatively assume no sensitivity (top signal would show up in covered channels)





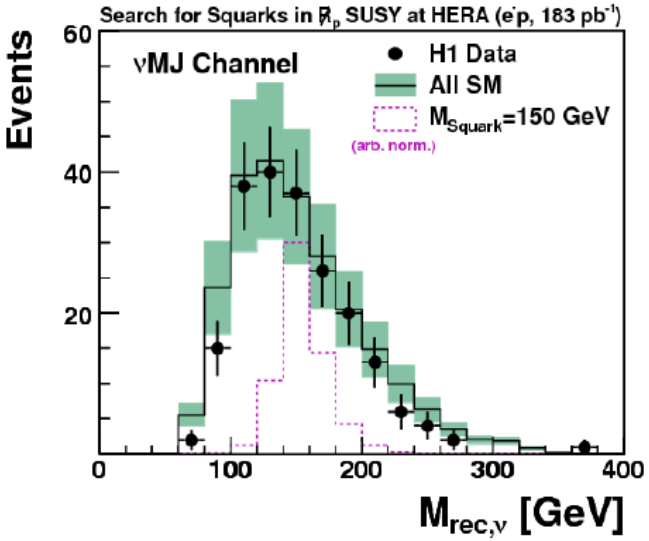
Limits in mSUGRA scenario

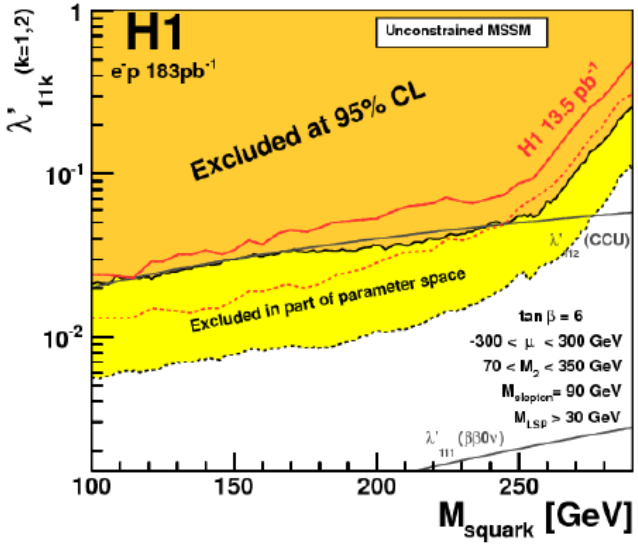
- Further constrain MSSM model to **mSUGRA** (GCU & REWSB)
- $M_{\tilde{q}}, M_{\tilde{\ell}}, M_{\chi_i^0, \chi_j^\pm}$ fixed by (m_0, $m_{1/2}$, $\tan\beta$, A_0, sign(μ))
- Consider $A_0 = 0$,sign(μ) < 0 and $\tan\beta = 2, 6$
- Determine limit contours at 95% CL in m_0, $m_{1/2}$ plane for couplings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

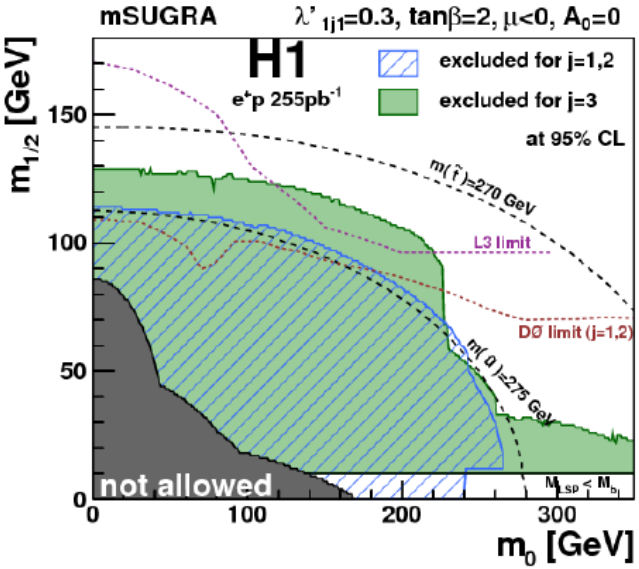


Summary

- 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.[1)]







[1)] LHC has higher mass reach in comparable scenarios (see talk by D. Pomeroy) – LHeC would be ideal for further studies