Search for R-Parity Violating Gaugino and Gravitino Production at HERA

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*on behalf of the **H1** and **ZEUS** collaboration*

- Introduction
- Gaugino Production (RPV-MSSM) at HERA
- Gravitino Production (RPV-GMSB) at HERA
- Summary & Outlook

Introduction

$e^{\pm}p$ Collisions at HERA

HERA:

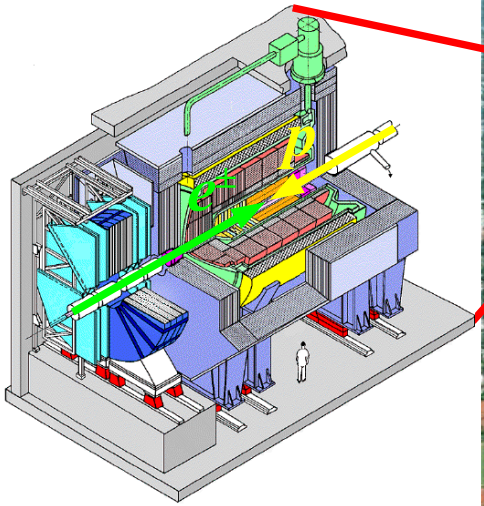
$e^{\pm}p$ storage ring to explore the p structure with:

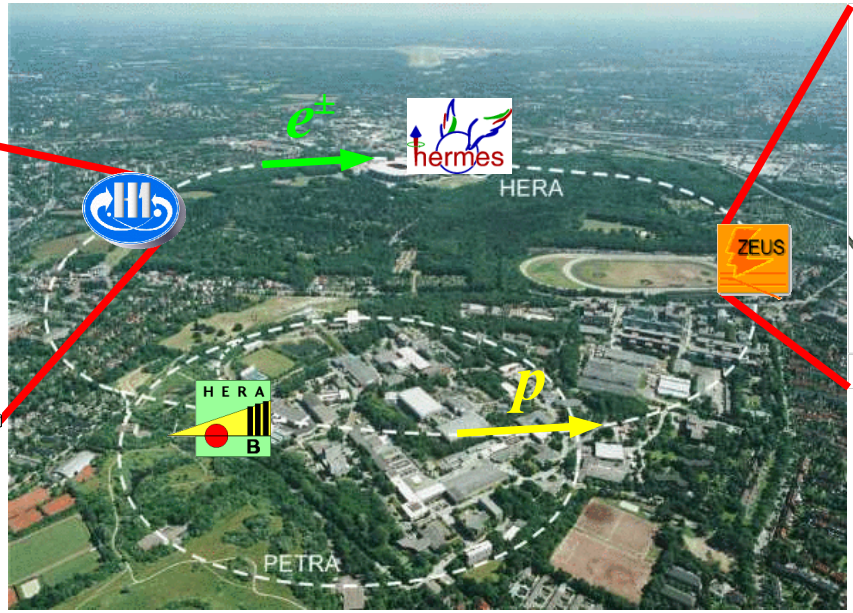
- $\sqrt{s}$ = 300 - 318 *GeV*
  → p: 820 - 920 *GeV*, $e^{\pm}$: 27.5 *GeV* *)
- L = 15 - 75 $nb^{-1}\ s^{-1}$ **)
- U = 6336 *m*
- 4 experiments
  → H1, ZEUS, HERMES, HERA-B

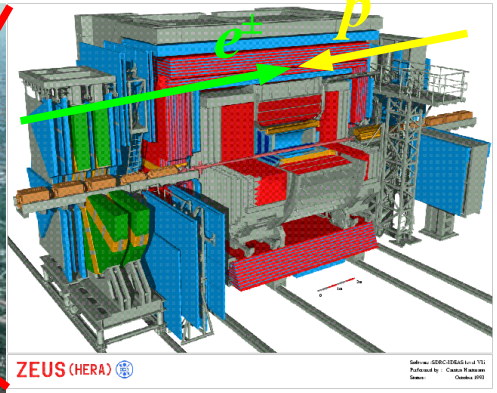
H1 & ZEUS:

HEP multi-purpose detectors with:

- asymmetric design
- typical components:
  - tracking detectors
  - calorimeters
  - myon system
- $\mathcal{L} > 120\ pb^{-1}$ per experiment in HERA I







*) p energy increased in 1998

**) luminosity increased in upgrade 2000 - 2002 (HERA I → HERA II)

Introduction

Supersymmetry

New physics beyond the Standard Model (SM) are expected to arise at ca. **1 *TeV***.

Supersymmetry (SUSY)

is a promising model for such an extension of the SM.

- new **superpartners** of SM particles ("sparticles"):
  - S differs by ½ (boson-fermion-symmetry)
  - unobserved so far

  ⇒ SUSY broken at low energies
- minimum number of sparticles and interactions

  → **Minimal Supersymmetric SM (MSSM)**
- assumption on SUSY breaking mechanism e.g.:
  - Gauge-Mediated SUSY Breaking (GMSB):
    - $\tilde{G}$ expected as lightest sparticle (LSP)
    - $\tilde{\chi}^0$ often next to LSP (NLSP)
  - Minimal Supergravity (mSUGRA)
- new **discrete, multiplicative quantum number R-parity:**

  $R_P = (-1)^{3B+L+2S}$ { **+1** for SM particles; **- 1** for sparticles
- R-parity conserving (RPC) models often favoured:
  - reduced phenomenology
  - LSP candidate for cold dark matter

  but...
- **R-parity violating (RPV) models not excluded** explicitely by most general Langrangian

  ⇒ so ...

Introduction

R-Parity Violating SUSY in $e^{\pm}p$ Collisions

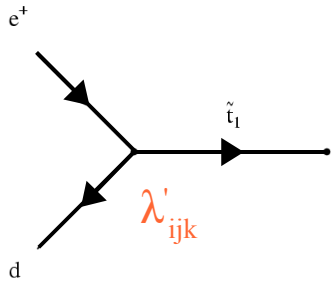
RPV allows **production of single sparticles** and the **decay of the LSP to SM particles** via additional terms in the superpotential:

at LO:

$$W_{RPV} = \lambda_{ijk} L_i L_j \bar{E}_k + \boxed{\lambda'_{ijk} L_i Q_j \bar{D}_k} + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k + \ldots$$

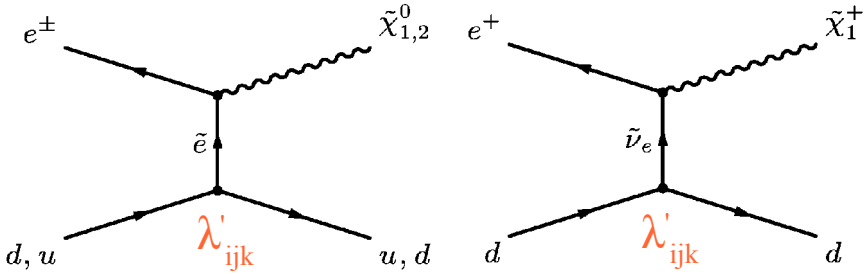
lepton-hadron colliders

s-channel: squark production



no deviations from the SM at HERA so far
(H1: Eur.Phys.J. **C36**, 425 (2004)
Phys.Lett. **B599**, 159 (2004)
ZEUS Coll.: presented at DIS05
→ v. next talk)

t-channel: gaugino production



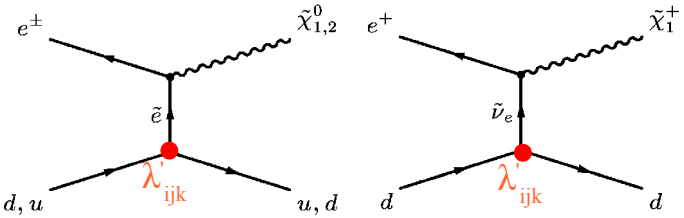
- independent of squark sector
- depends on m_l and m_χ

→ recent HERA searches:
subjects of this talk

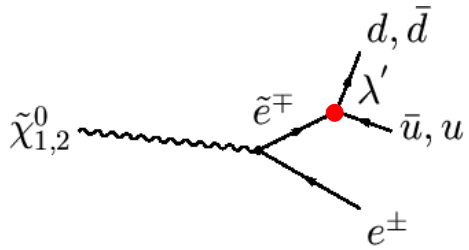
Gaugino Production (RPV-MSSM) at HERA

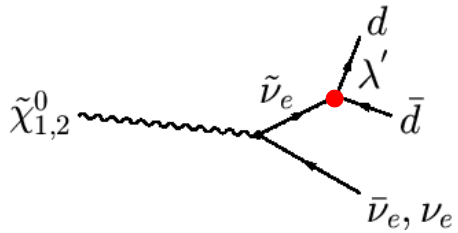
Introduction

- $\tilde{\chi}$ production assumed to be dominated by λ'_{111}



- $\tilde{\chi}$ decay to $qq + e^{\pm}/\nu_e/\bar{\nu}_e$
- this search:
  $e^{\pm}$-channel
  (BR: 30 - 70%)
  ⇓
- search strategy:
  - ≥ 2 jets with high p_T
  - high E_T
  - ≥ 1 $e^{\pm}$-candidate

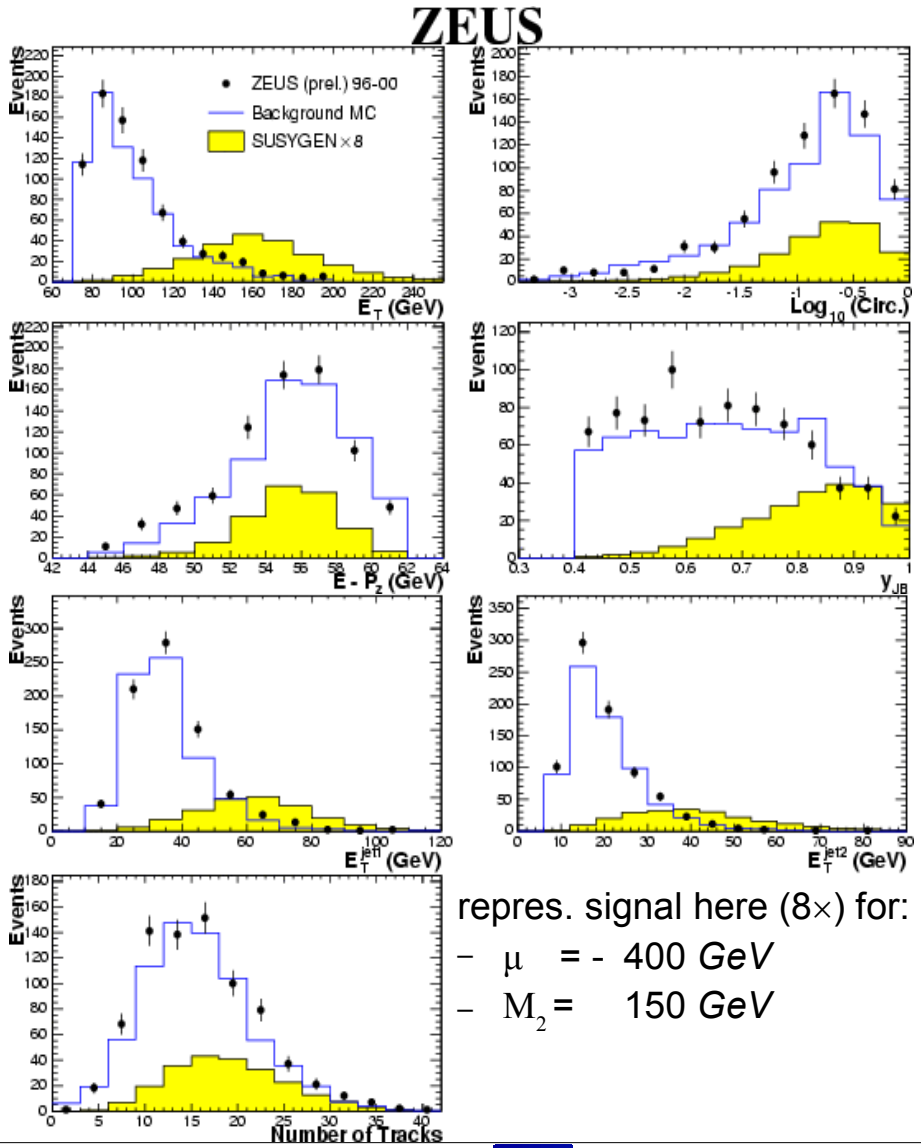




- signal assumptions:
  - large squark masses
    $M_{\tilde{q}}$ = 1 TeV
  - degenerate slepton masses
    $M_{\tilde{l}}$ = 100 GeV
  - $\tan(\beta)$ = 30
  - λ'_{111} = 1.0
- main SM background:
  - NC DIS di-jet events

Gaugino Production (RPV-MSSM) at HERA

Event Selection



repres. signal here (8×) for:

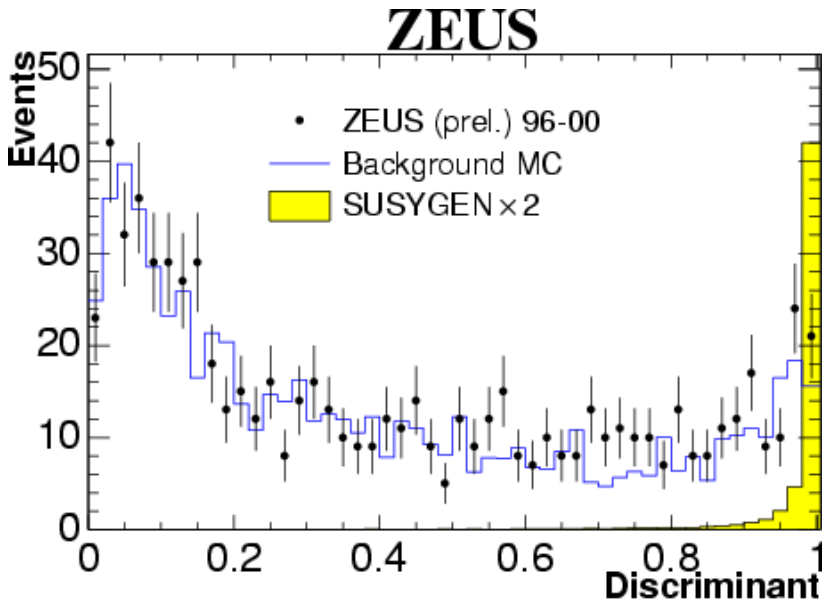
- μ = - 400 *GeV*
- M_2 = 150 *GeV*

ZEUS: 121 pb^{-1} $e^{\pm}p$ data

- $Q_{JB}^2 > 100$ *GeV²*, $y_{JB} > 0.4$, 45 *GeV* < $E\text{-}p_z$ < 62 *GeV*
- $E_T > 75$ *GeV*
- ≥ 2 jets ($E_T^{jet} > 10$ *GeV*, $-0.5 < \eta^{jet} < 2.7$)
- ≥ 1 $e^{\pm}$-candidate ($p_T^e > 6$ *GeV*, $\theta^e < 90°$)

⇒ **signal efficiency × BR: ~30%**

multi-variate discriminant method:

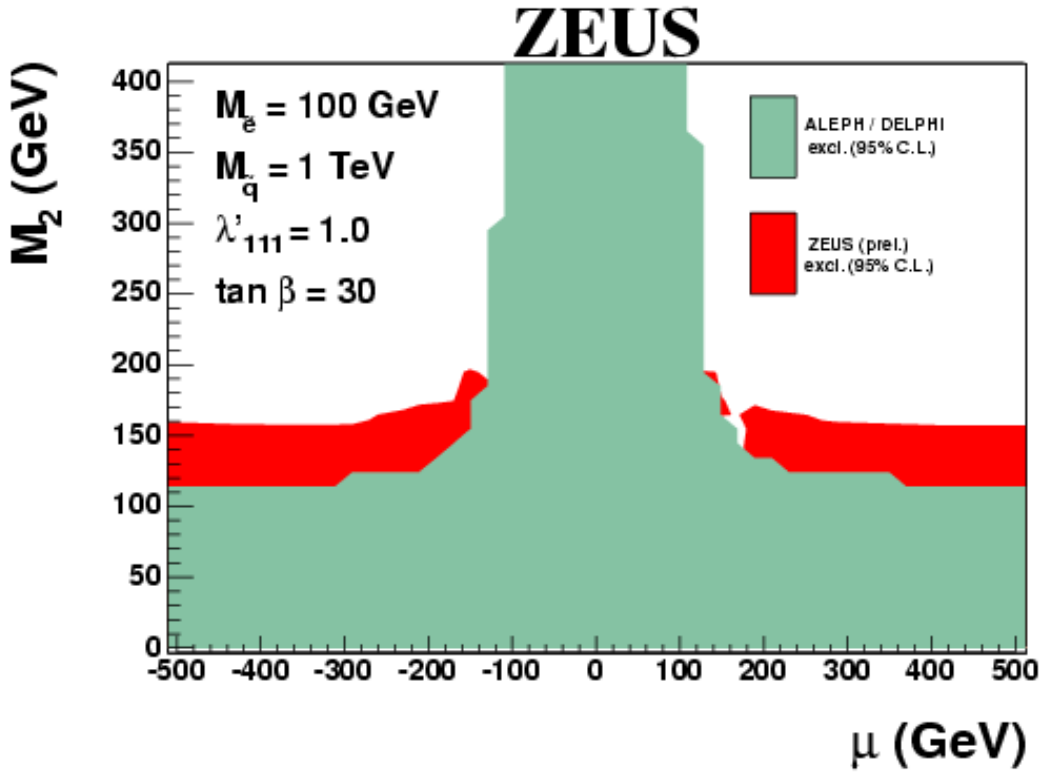


Gaugino Production (RPV-MSSM) at HERA

Results

No deviations from SM are observed in high discriminant region.

$\Rightarrow$ limits in μ-M_2 plane improved compared to LEP results



parameter scan:

- $|\mu| < 500$ *GeV*
- $M_2 < 250$ *GeV*

Systematic uncertainties are included in numerical calculation of the limits as uncorrelated Gaussian fluctuations in the number of signal and background events.

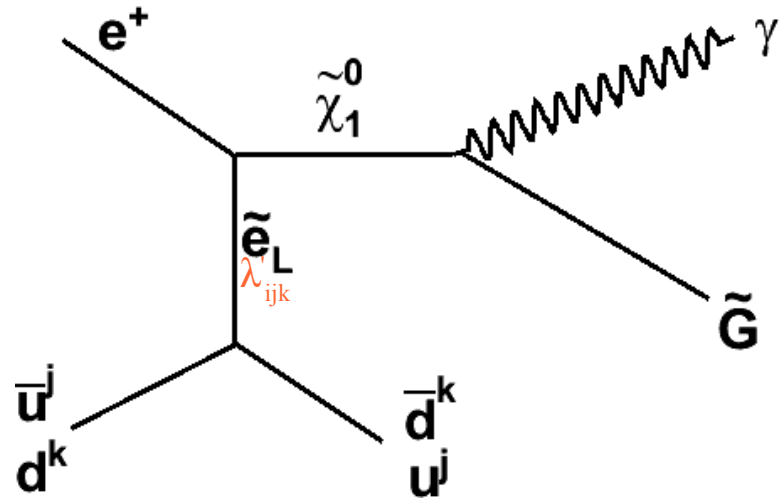
Gravitino Production (RPV-GMSB) at HERA

Introduction

- $\tilde{\chi}_1^0$ production via t-channel $\tilde{e}_L$-exchange
- $\tilde{l}$ masses independent **of squark sector** here
  $\Rightarrow \Delta m = m(\tilde{e}_L) - m(\tilde{\chi}_1^0)$ can be small
- $\tilde{\chi}_1^0$ (NLSP) decays to $\tilde{G}$ (LSP) + γ

$\Downarrow$

- search strategy:
  - missing p_T (from undetected $\tilde{G}$)
  - isolated γ with high E_γ
  - ≥ 1 jet
- accessable Yukawa couplings:
  - e^+p scattering: λ'_{1j1}, j = 1,2
    (j=3 suppressed due to high top quark mass)
  - e^-p scattering: λ'_{11k}, k = 1,2,3



- main SM background:
  - CC DIS events with real (radiative) and fake γ

This final state has not been analysed at HERA before.

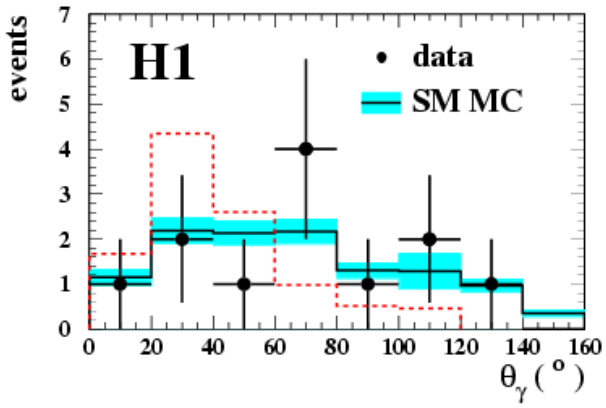
Gravitino Production (RPV-GMSB) at HERA

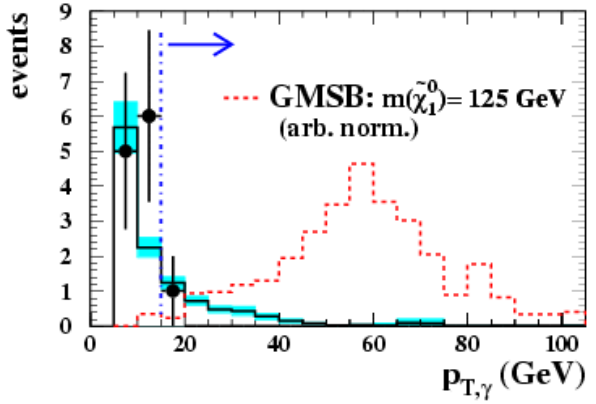
Control Selection (H1)

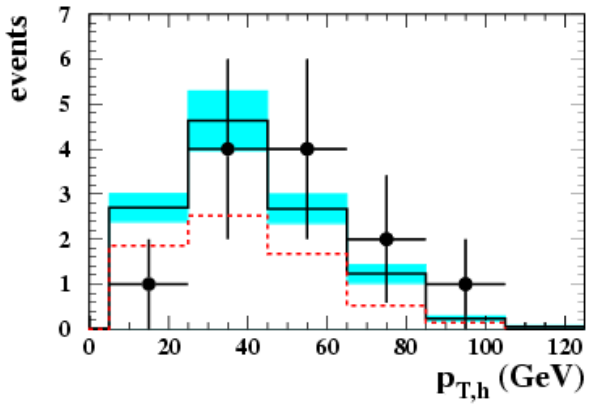
H1: 64.3 pb^{-1} e^+p data
13.5 pb^{-1} e^-p data
(Phys.Lett.B61:31-42(2005))

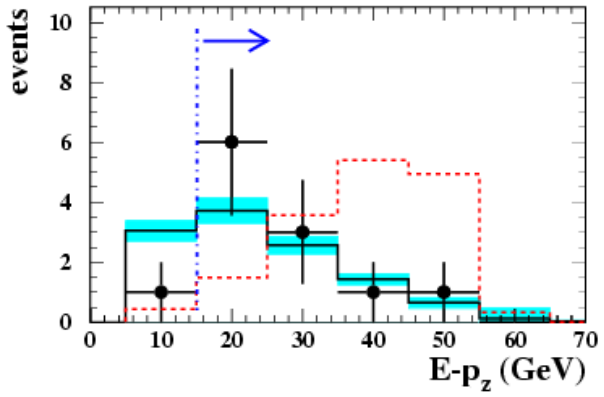
repr. signal here for:
– $m(\tilde{\chi}_1^0)$ = 125 *GeV*

– missing p_T > 25 *GeV*
– ≥ 1 jet
($10° < \theta^{jet} < 145°$,
$p_T^{jet} > 5$ *GeV*)
– ≥ 1 isolated γ
($10° < \theta^{\gamma}$,
$p_T^{\gamma} > 5$ *GeV*)







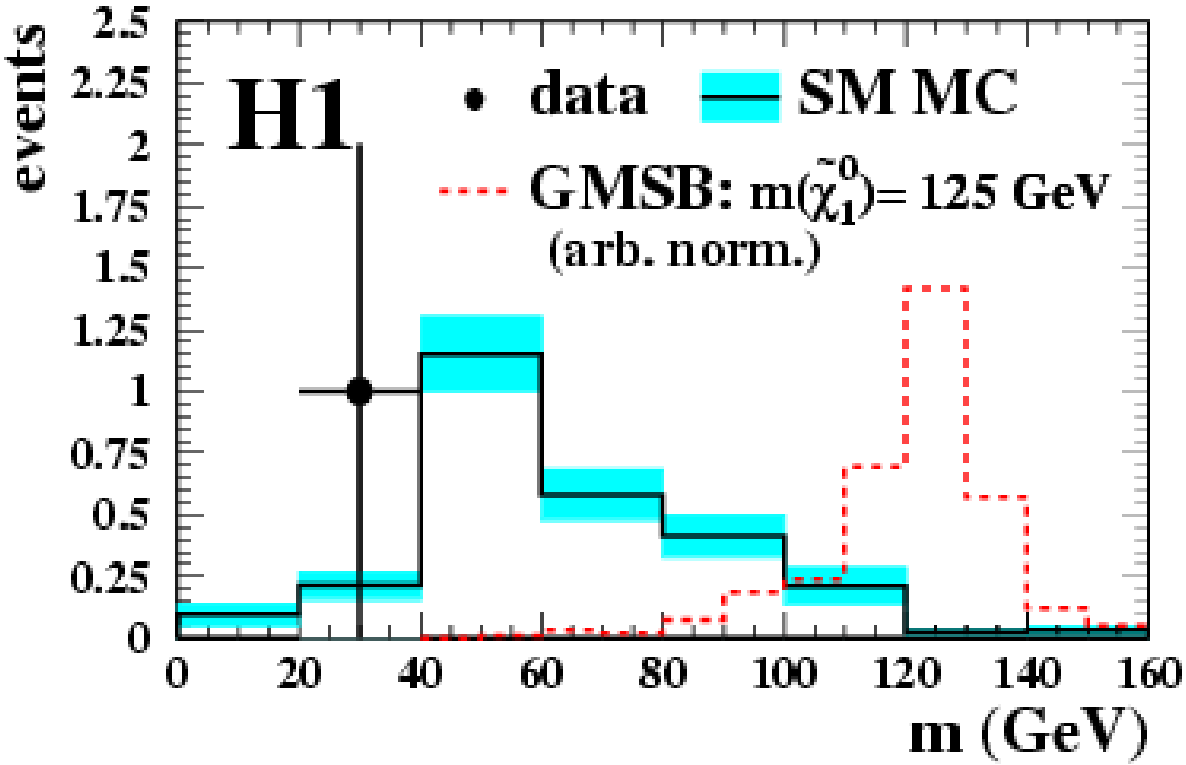


Gravitino Production (RPV-GMSB) at HERA

Final Selection (H1)

- p_T^{γ} > 15 *GeV*
- $E - p_z$ > 15 *GeV*

$\Rightarrow$ **signal efficiency: 10 – 35%**



e+p data:
- expected (SM): 1.8±0.2
- data: 0

e-p data:
- expected (SM): 1.1±0.2
- data: 1

candidate event:
- $m(\tilde{\chi}_1^0)$ = 36±4 *GeV*

Systematic uncertainties are included in numerical calculation of the limits as uncorrelated Gaussian fluctuations in the number of signal and background events.

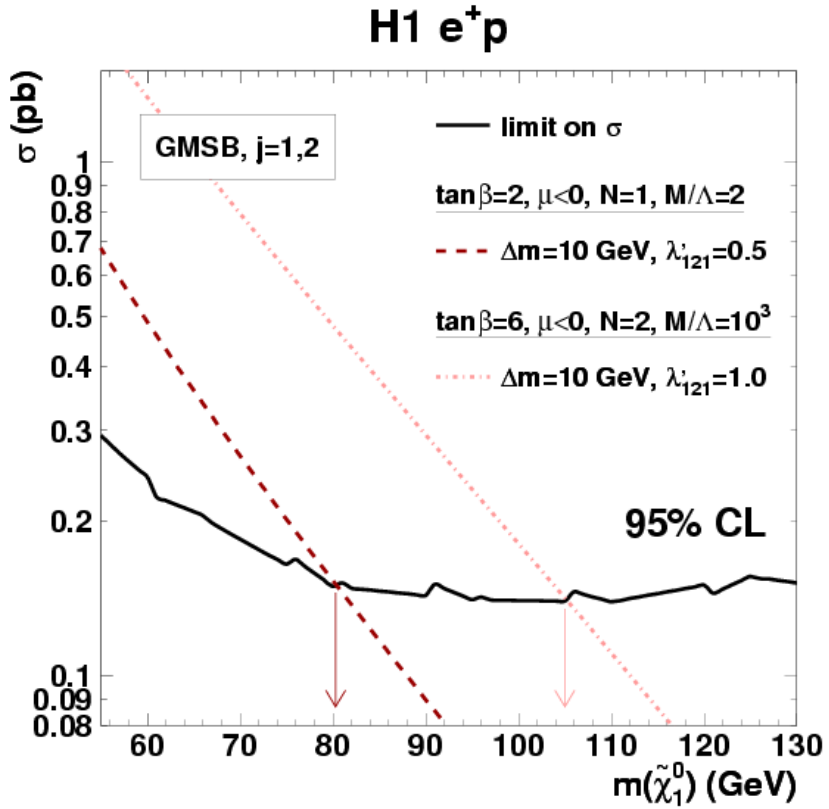
Gravitino Production (RPV-GMSB) at HERA

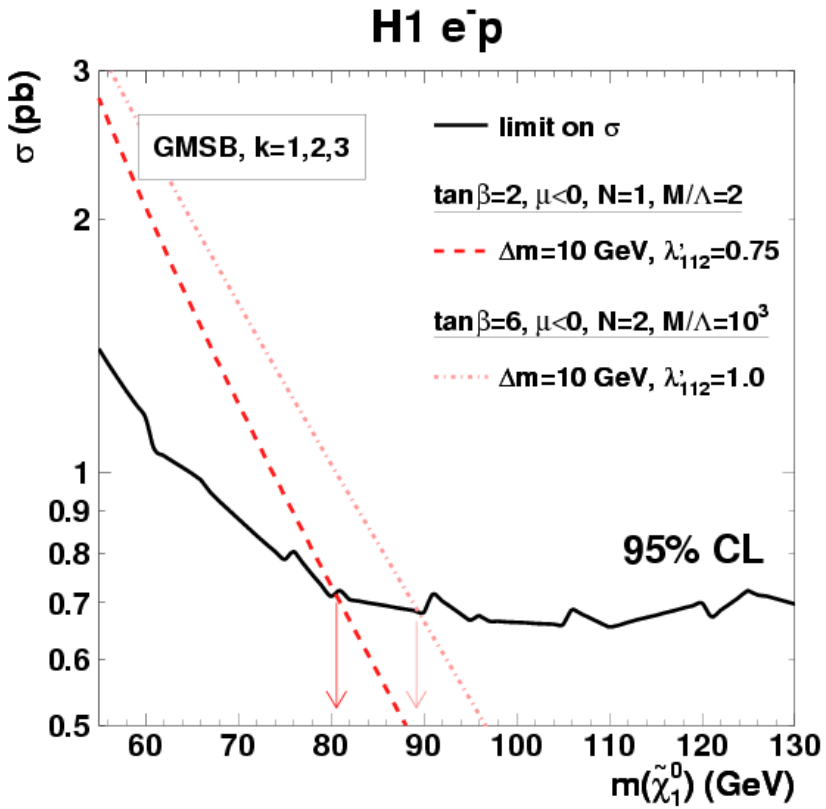
Results I (H1)

No deviations from SM are observed.

⇒ **first** limits from HERA, which are independent on squark sector

here: cross section





Gravitino Production (RPV-GMSB) at HERA

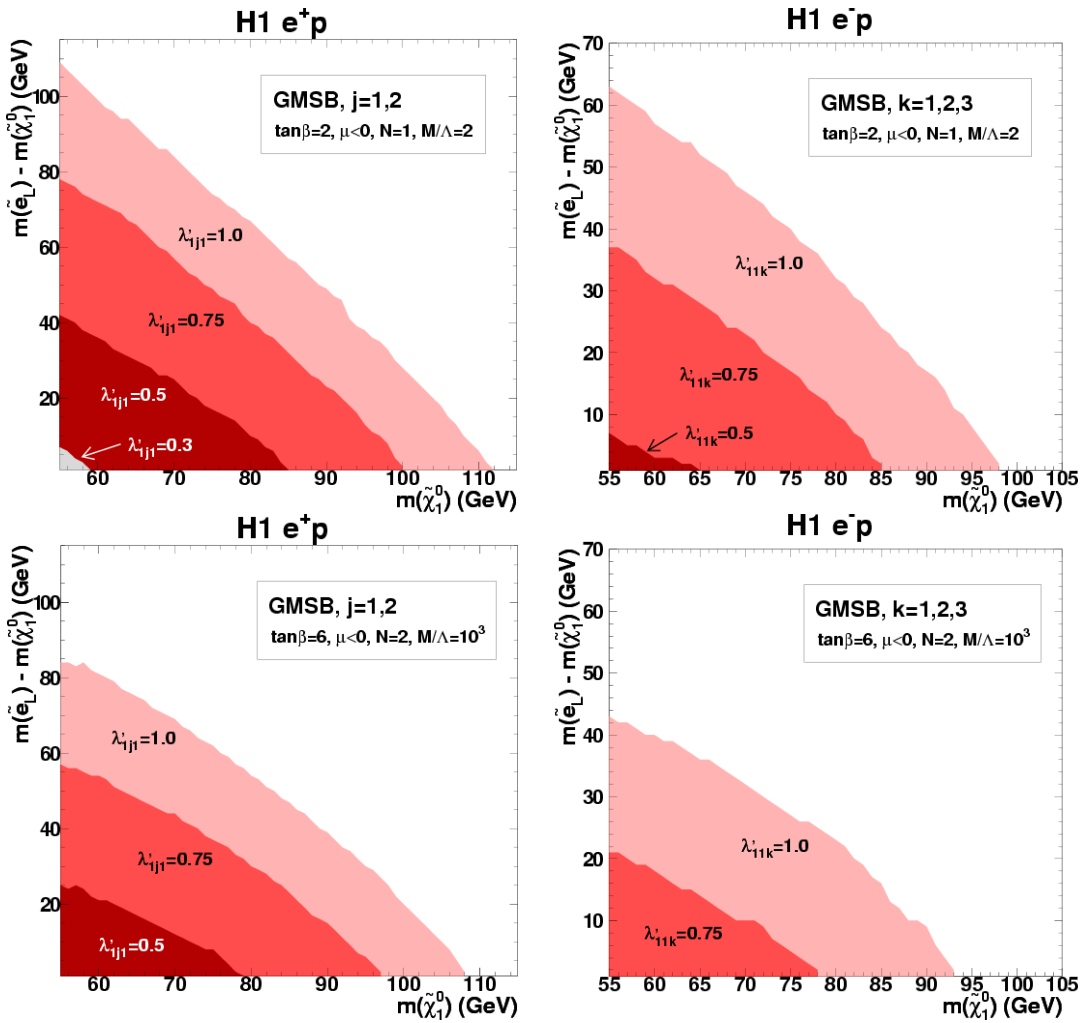
Results II (H1)

here:

- mass difference
- Yukawa coupling

Limits:

- $m(\tilde{e}_1^0) > 164\ GeV$
  for **large** Δm and $\lambda' = 1.0$
- $m(\tilde{\chi}_1^0) > 112\ GeV$
  for **small** Δm and $\lambda' = 1.0$
- $\lambda'_{1j1} > \mathcal{O}(\alpha_{EM})$
  for **small** $m(\tilde{\chi}_1^0)$ and Δm



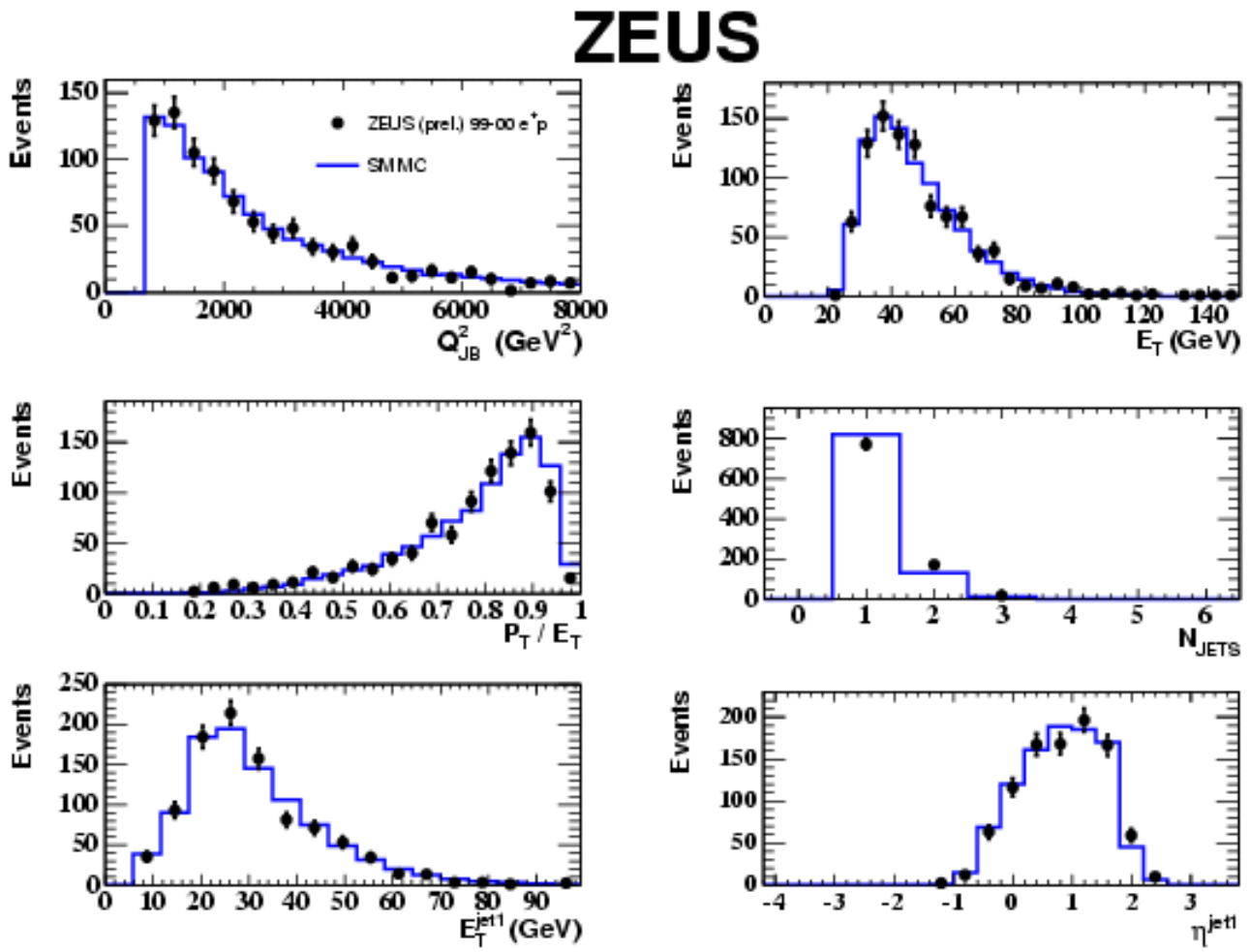
Gravitino Production (RPV-GMSB) at HERA

Control Selection (ZEUS)

ZEUS:
65.5 pb^{-1} e^+p data

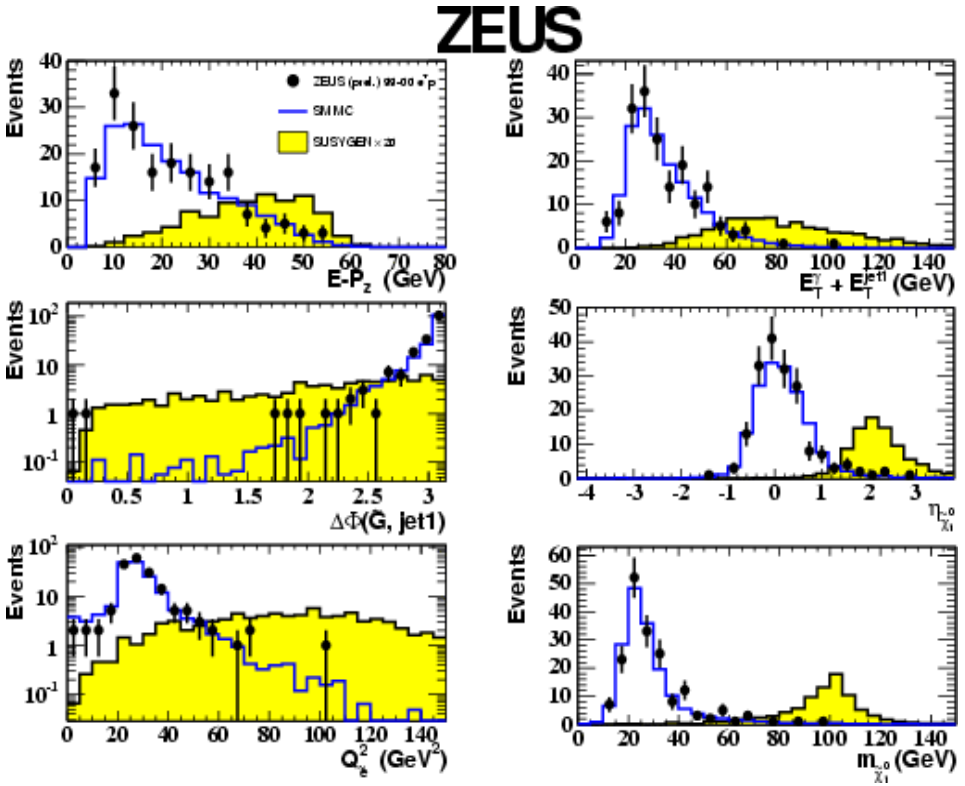
- Q_{JB}^2 > 700 *GeV²*,
  y_{JB} > 0.1,
  $E\text{-}p_z$ < 65 *GeV*
- missing p_T > 20 *GeV*
- ≥ 1 jet
  (-1.5 < η^{jet} < 2.5,
  p_T^{jet} > 6 *GeV*)

⇒ **signal efficiency: 66 - 79%**



Gravitino Production (RPV-GMSB) at HERA

Final Selection (ZEUS)



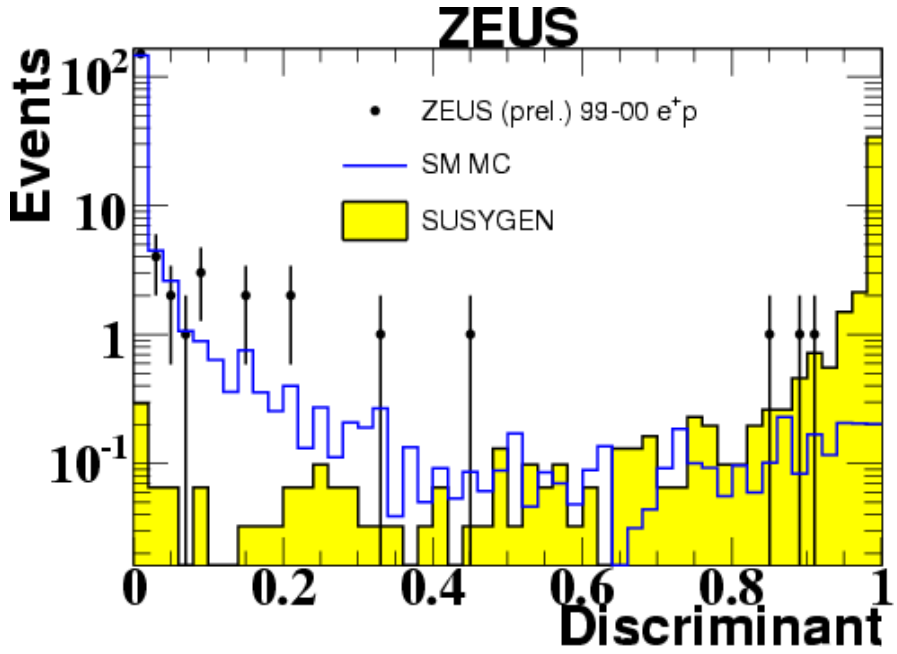
repr. signal here for:

- $m(\tilde{\chi}_1^0)$ = 100.4 *GeV*
- Δm = 40 *GeV*
- λ' = 1.0

- ≥ 1 isolated γ
- E^{γ} > 4 *GeV*
- -2.8 < η^{γ} < 2.8

⇒ **signal efficiency: 59 - 71%**

multi-variate discriminant method:



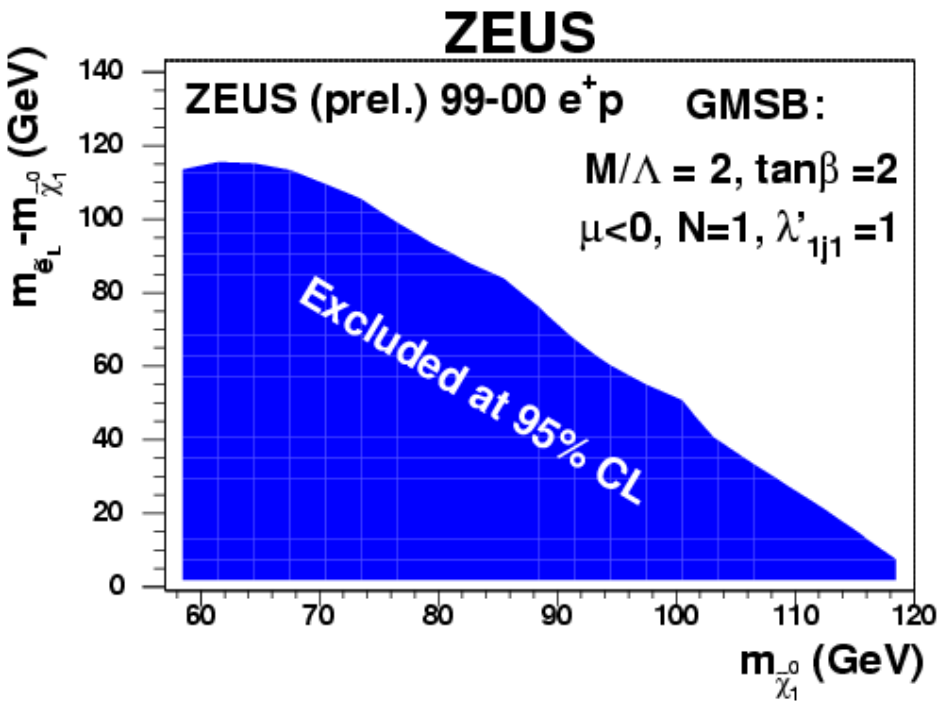
Gravitino Production (RPV-GMSB) at HERA

Results (ZEUS)

No deviations from SM are observed in high discriminant region.

$\Rightarrow$ limits in $m(\chi_1^0)$-Δm plane improved compared to particular H1 result

(modified frequentist method: NIM **A434**, 435 (1999), hep-ex/9902006)



parameter scan:

- $m(e_L)$
- $m(\chi_1^0)$

Systematic uncertainties are included in numerical calculation of the limits as uncorrelated Gaussian fluctuations in the number of signal and background events.

Summary

Squark independent searches for R-parity violating gaugino and gravitino production have been performed by H1 and ZEUS in the HERA I data set.

No deviations from the Standard Model have been found in the explored parameter spaces.

Exclusion limits have been:

- **extended** for the μ-M_2 plane **in RPV-MSSM** by ZEUS
- **set in RPV-GMSB** by H1:
  - $m(\tilde{\chi}_1^0) > 112$ *GeV* for **small** Δm and $\lambda' = 1.0$
  - $m(\tilde{e}_L) > 164$ *GeV* for **large** Δm and $\lambda' = 1.0$
  - $\lambda'_{1j1} > \mathcal{O}(\alpha_{EM})$ for **small** $m(\tilde{\chi}_1^0)$ and Δm
  - for σ and Δm depending on $m(\tilde{\chi}_1^0)$ and various parameter sets
- **extended** for the $m(\tilde{\chi}_1^0)$-Δm plane and one particular parameter set **in RPV-GMSB** by ZEUS

Outlook

- higher luminosity of HERA II
  (goal: 700 pb^{-1} by July 2007, > 110 pb^{-1} so far)
  $\Rightarrow$ much more statistics
  $\Rightarrow$ all searches benefit
- increase in fraction of e^-p data
  $\Rightarrow$ especially RPV-SUSY searches benefit
  (e^-p data more sensitive because of coupling to u-quark)

We are looking forward to first results from HERA II ...