

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:

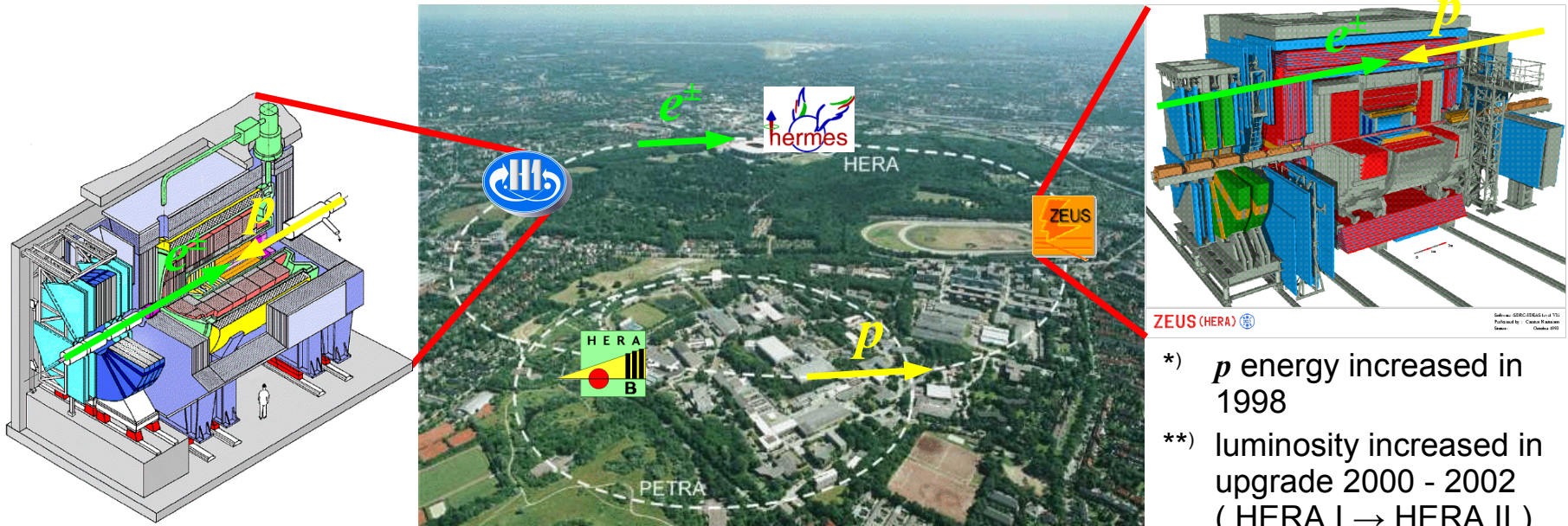
$e^\pm p$ storage ring to explore the p structure with:

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

H1 & ZEUS:

HEP multi-purpose detectors with:

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



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 $\frac{1}{2}$ (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**:

$$R_p = (-1)^{3B+L+2S} \quad \begin{cases} +1 & \text{for SM particles} \\ -1 & \text{for sparticles} \end{cases}$$
- R-parity conserving (RPC) models often favoured:
 - reduced phenomenology
 - LSP candidate for cold dark matter

but...
- **R-parity violating (RPV) models not excluded** explicitly by most general Lagrangian
 - ⇒ **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:

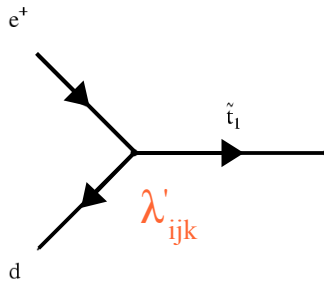
at LO:

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



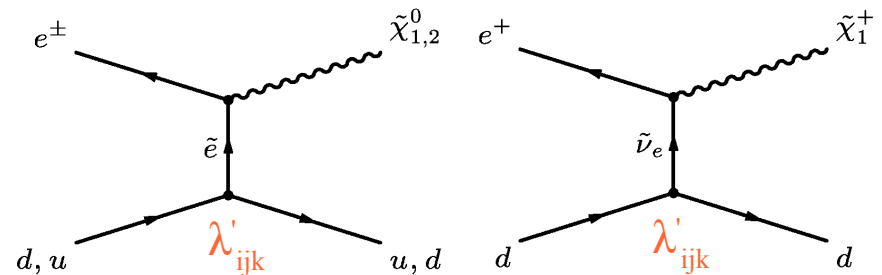
lepton-hadron colliders

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

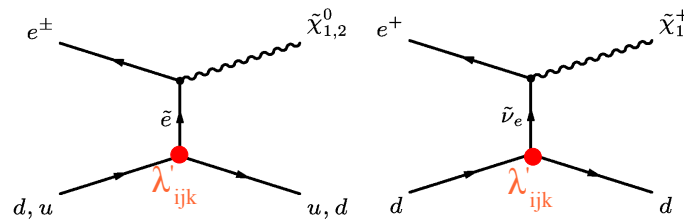


- independent of squark sector
- depends on m_l and m_χ
- recent HERA searches:
subjects of this talk

Gaugino Production (RPV-MSSM) at HERA

Introduction

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

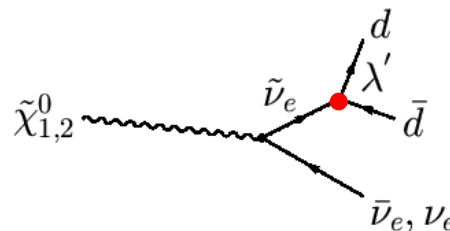
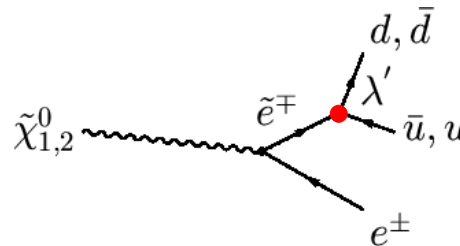


- $\tilde{\chi}$ decay to $qq + e^\pm/\nu_e/\bar{\nu}_e$

- 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
 $M_{\tilde{q}} = 1 \text{ TeV}$

- degenerate slepton masses

- $M_{\tilde{l}} = 100 \text{ GeV}$

- $\tan(\beta) = 30$

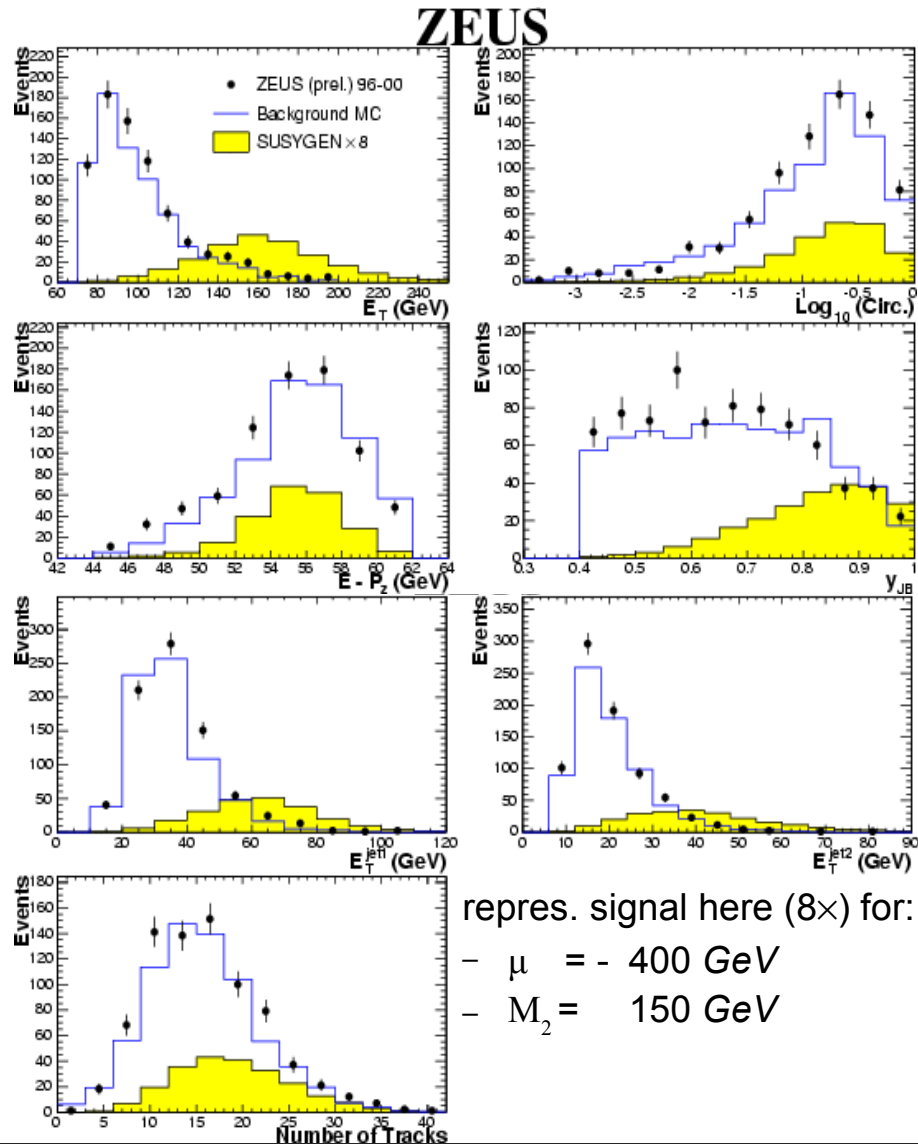
- $\lambda'_{111} = 1.0$

- main SM background:

- NC DIS di-jet events

Gaugino Production (RPV-MSSM) at HERA

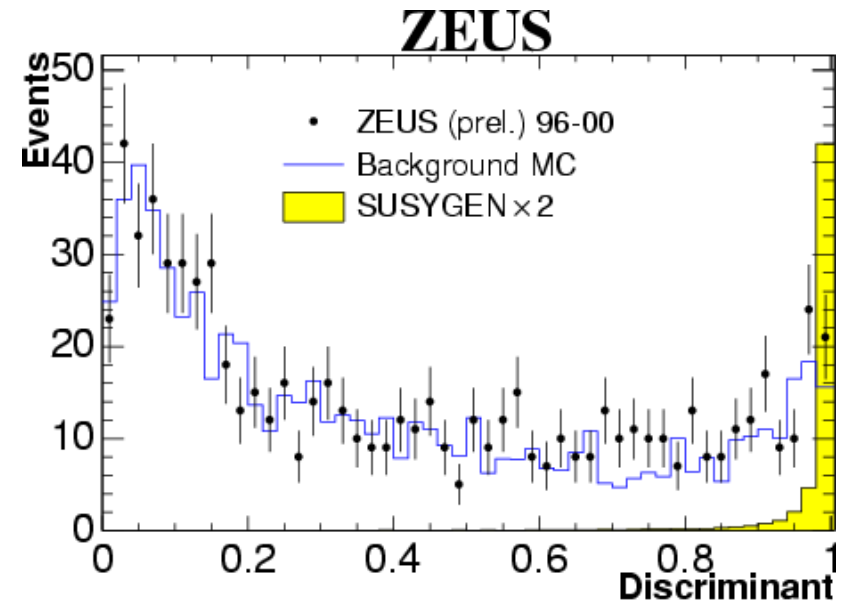
Event Selection



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

- $Q_{\text{JB}}^2 > 100 \text{ GeV}^2$, $y_{\text{JB}} > 0.4$,
 $45 \text{ GeV} < E_{\text{p}_z} < 62 \text{ GeV}$
 - $E_{\text{T}} > 75 \text{ GeV}$
 - ≥ 2 jets ($E_{\text{T}}^{\text{jet}} > 10 \text{ GeV}$, $-0.5 < \eta^{\text{jet}} < 2.7$)
 - ≥ 1 e^\pm -candidate ($p_{\text{T}}^e > 6 \text{ GeV}$, $\theta^e < 90^\circ$)
- \Rightarrow **signal efficiency \times BR: $\sim 30\%$**

multi-variate discriminant method:

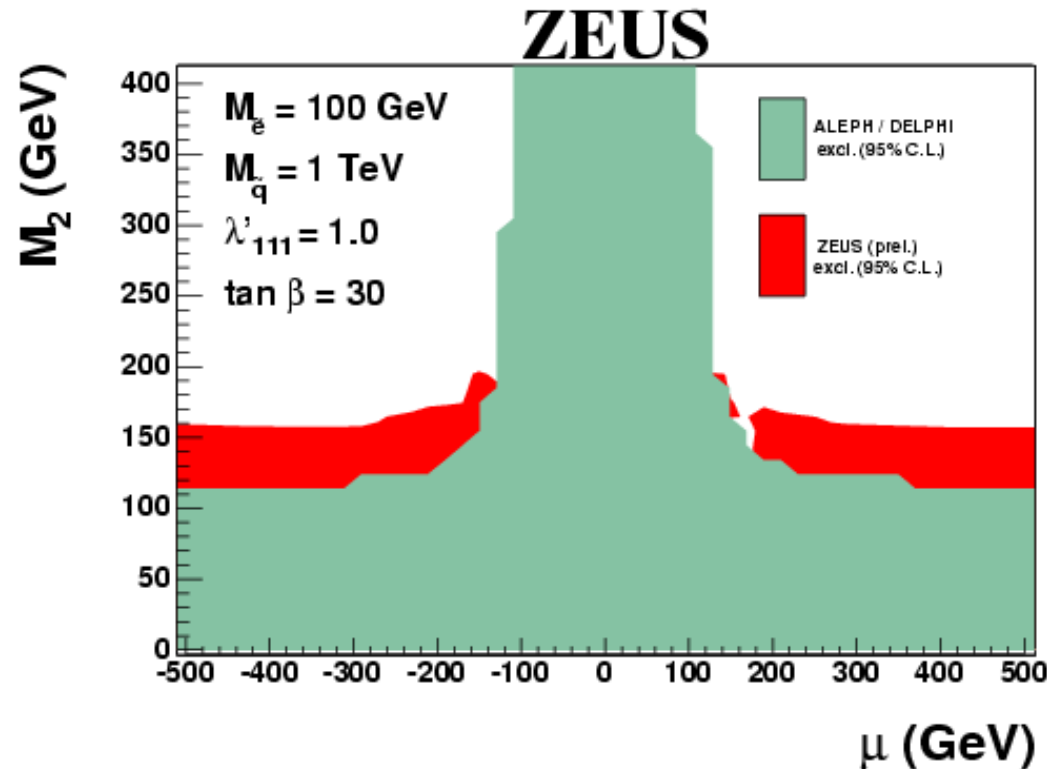


Gaugino Production (RPV-MSSM) at HERA

Results

No deviations from SM are observed in high discriminant region.

⇒ limits in μ - M_2 plane improved compared to LEP results



parameter scan:

- $|\mu| < 500 \text{ GeV}$
- $M_2 < 250 \text{ GeV}$

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

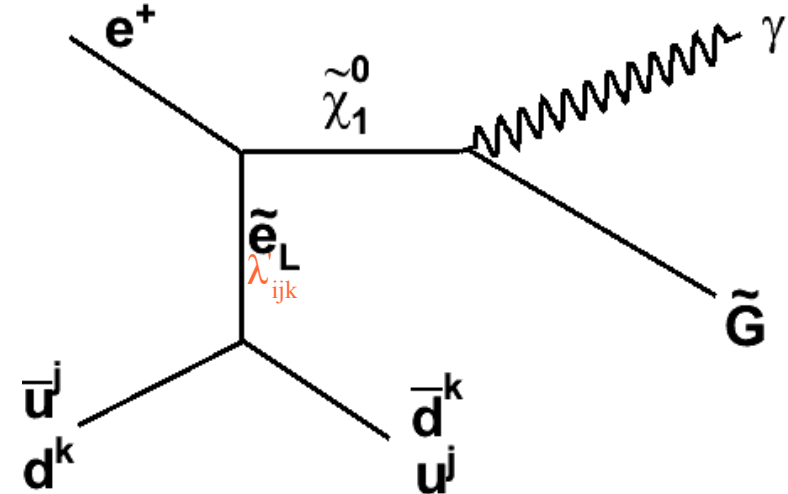
Gravitino Production (RPV-GMSB) at HERA

Introduction

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



- search strategy:
 - missing p_T (from undetected \tilde{G})
 - isolated γ with high E_γ
 - ≥ 1 jet
- accessible Yukawa couplings:
 - e^+p scattering: λ'_{1j1} , $j = 1, 2$
 (j=3 suppressed due to high top quark mass)
 - ep 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: $64.3 \text{ pb}^{-1} e^+p$ data
 $13.5 \text{ pb}^{-1} ep$ data
 (Phys.Lett.B61:31-42(2005))

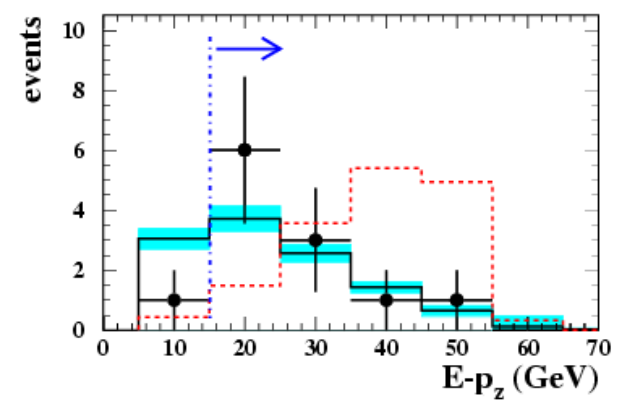
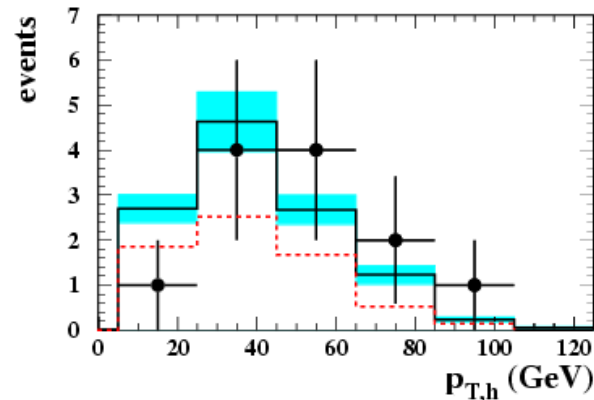
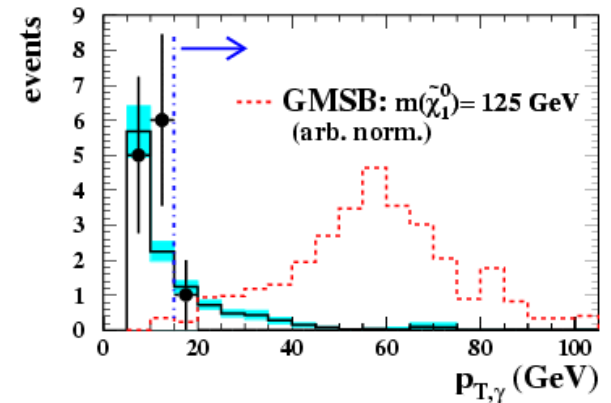
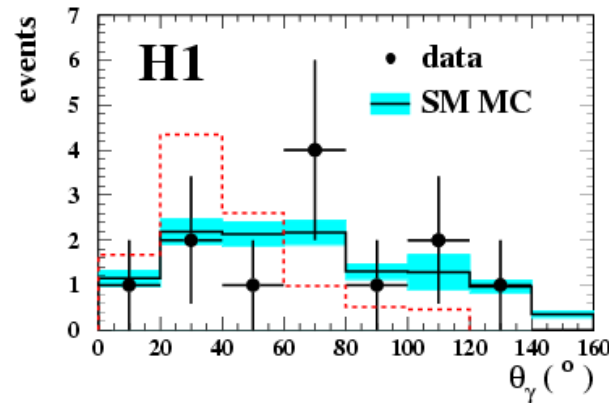
repr. signal here for:

– $m(\tilde{\chi}_1^0) = 125 \text{ GeV}$

– missing $p_T > 25 \text{ GeV}$

– ≥ 1 jet
 $(10^\circ < \theta^{\text{jet}} < 145^\circ,$
 $p_T^{\text{jet}} > 5 \text{ GeV})$

– ≥ 1 isolated γ
 $(10^\circ < \theta^\gamma,$
 $p_T^\gamma > 5 \text{ GeV})$



Gravitino Production (RPV-GMSB) at HERA

Final Selection (H1)

- $p_T^\gamma > 15 \text{ GeV}$
 - $E - p_z > 15 \text{ GeV}$
- \Rightarrow **signal efficiency: 10 – 35%**

e+p data:

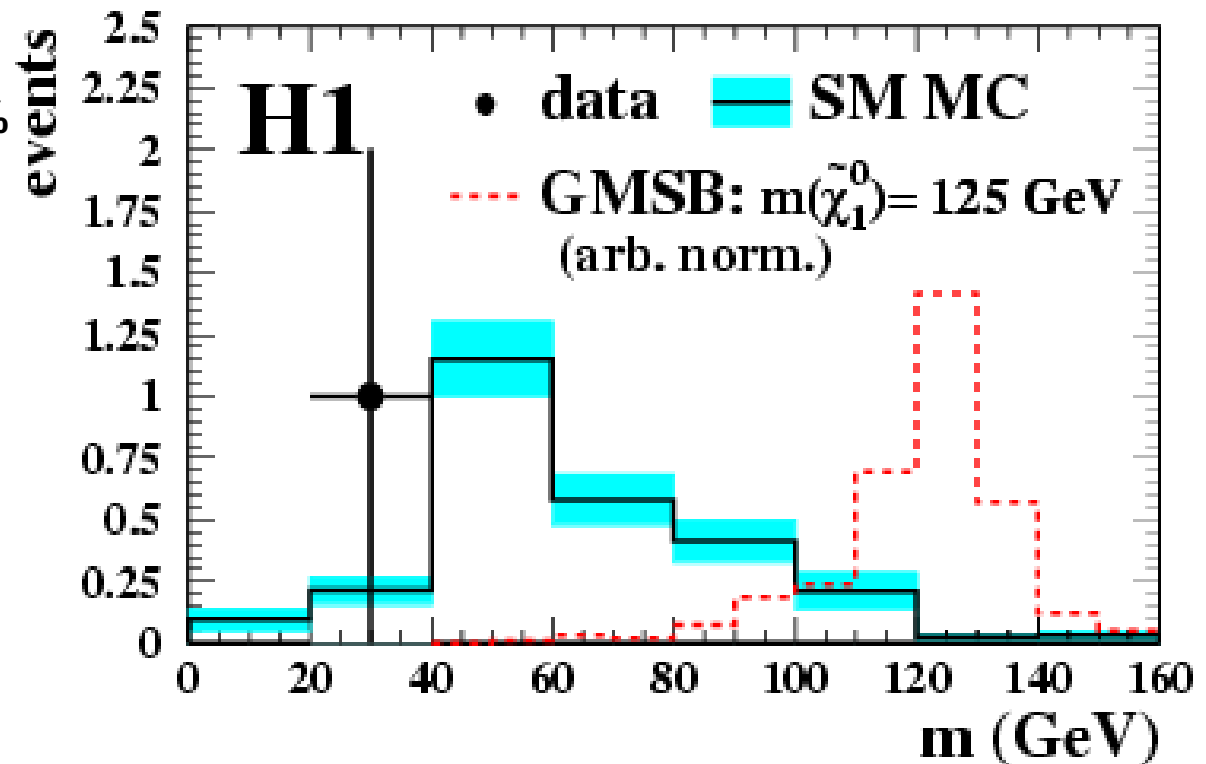
- expected (SM): 1.8 ± 0.2
- data: 0

e-p data:

- expected (SM): 1.1 ± 0.2
- data: 1

candidate event:

- $m(\tilde{\chi}_1^0) = 36 \pm 4 \text{ GeV}$



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

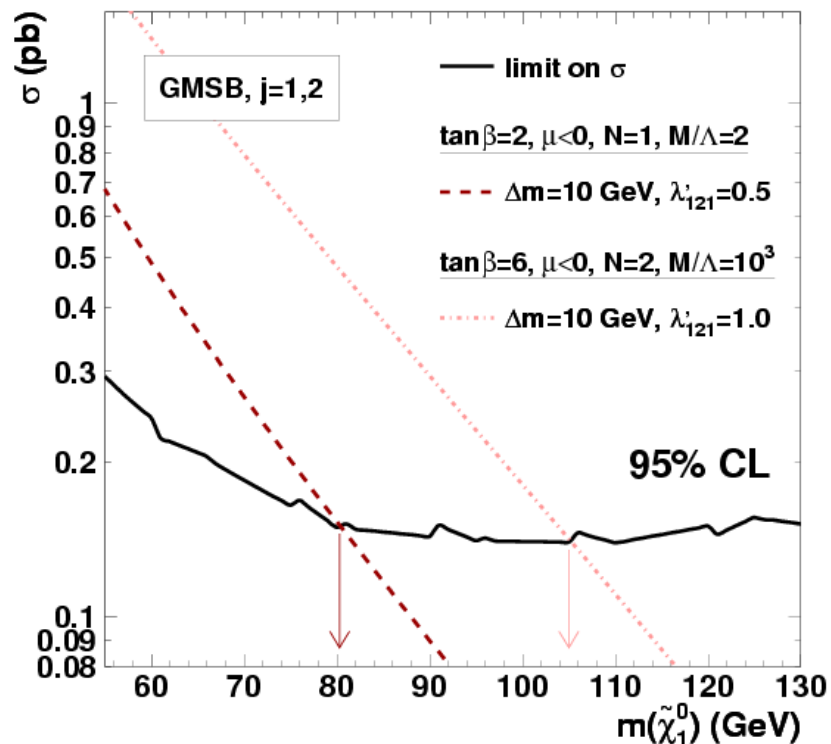
Results I (H1)

No deviations from SM are observed.

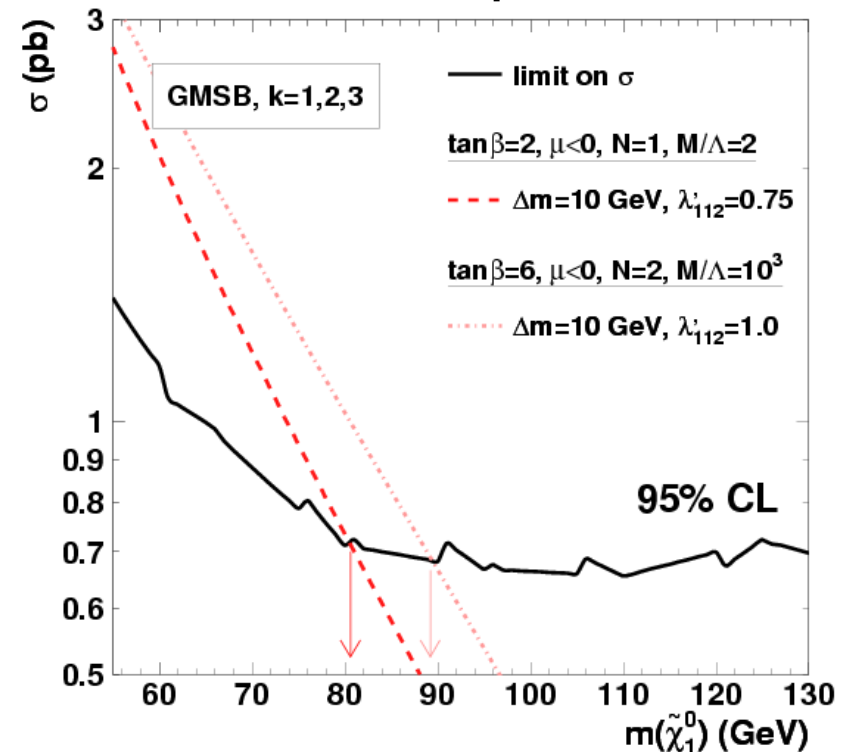
⇒ **first** limits from HERA, which are independent on squark sector

here: cross section

H1 e^+p



H1 e^-p



Gravitino Production (RPV-GMSB) at HERA

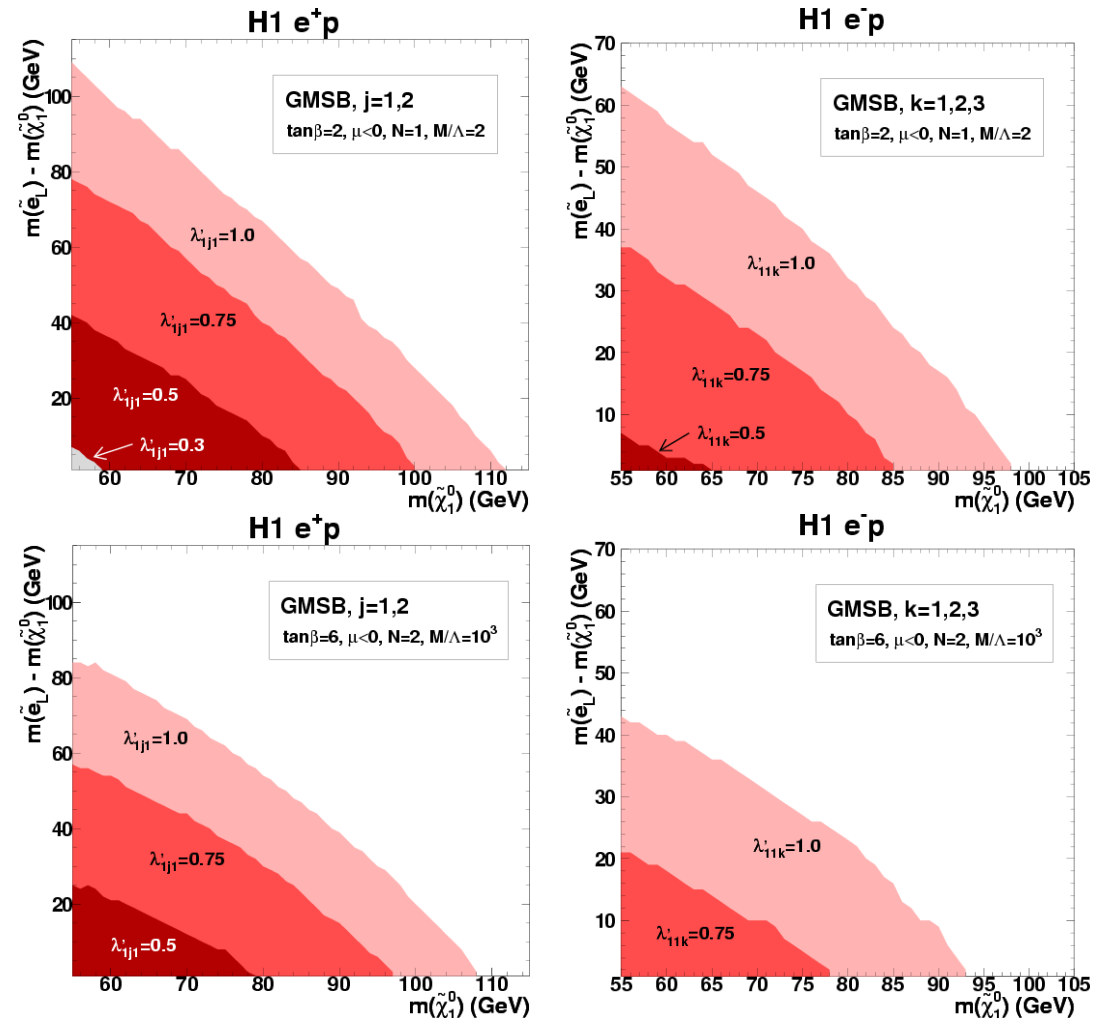
Results II (H1)

here:

- mass difference
- Yukawa coupling

Limits:

- $m(\tilde{e}_L^0) > 164 \text{ GeV}$
for **large** Δm and $\lambda' = 1.0$
- $m(\tilde{\chi}_1^0) > 112 \text{ GeV}$
for **small** Δm and $\lambda' = 1.0$
- $\lambda'_{ij1} > O(\alpha_{EM})$
for **small** $m(\tilde{\chi}_1^0)$ and Δm



Gravitino Production (RPV-GMSB) at HERA

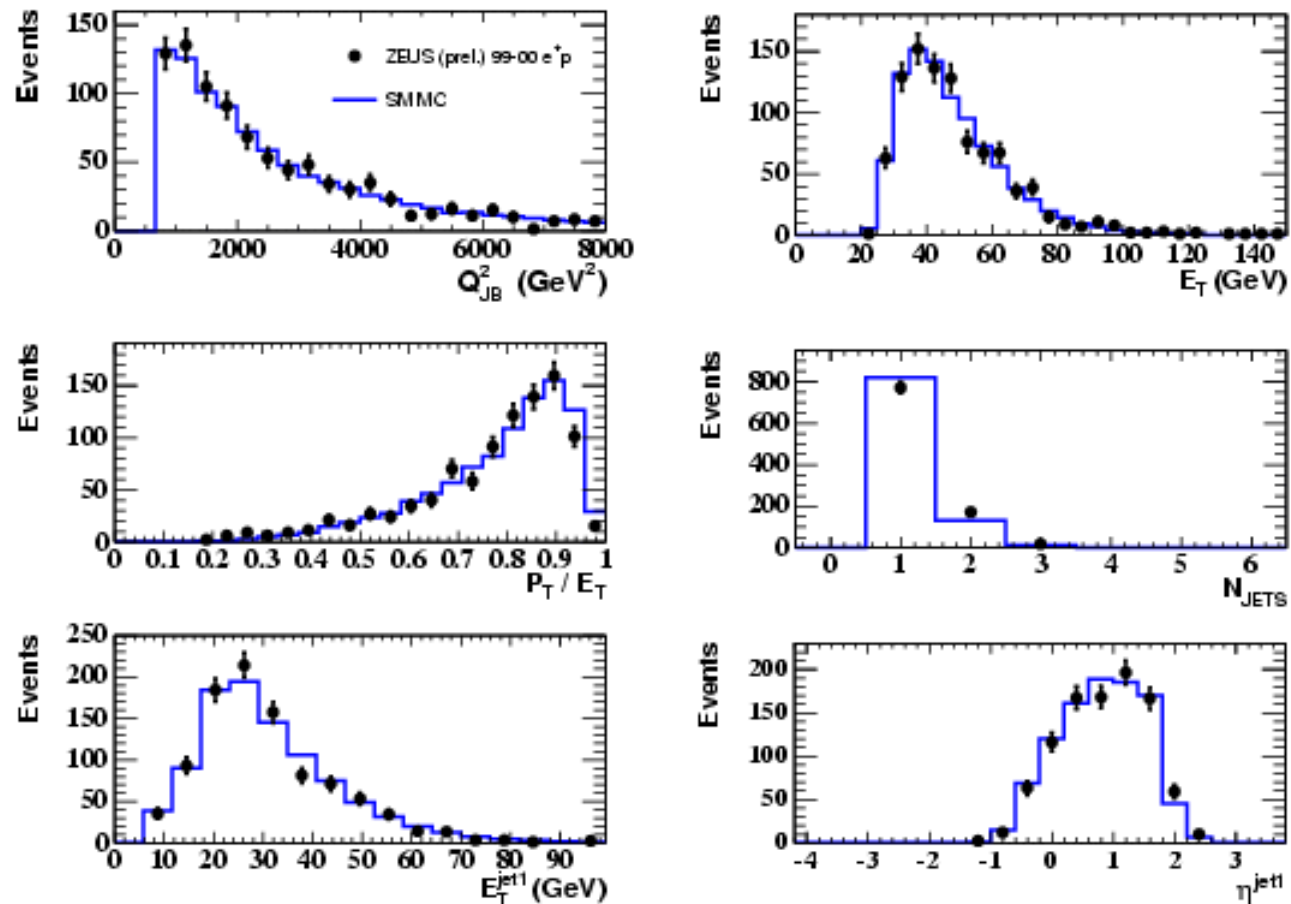
Control Selection (ZEUS)

ZEUS:

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

- $Q_{JB}^2 > 700 \text{ GeV}^2$,
 - $y_{JB} > 0.1$,
 - $E-p_z < 65 \text{ GeV}$
 - **missing** $p_T > 20 \text{ GeV}$
 - ≥ 1 **jet**
 $(-1.5 < \eta^{\text{jet}} < 2.5,$
 $p_T^{\text{jet}} > 6 \text{ GeV})$
- \Rightarrow **signal efficiency:**
66 - 79%

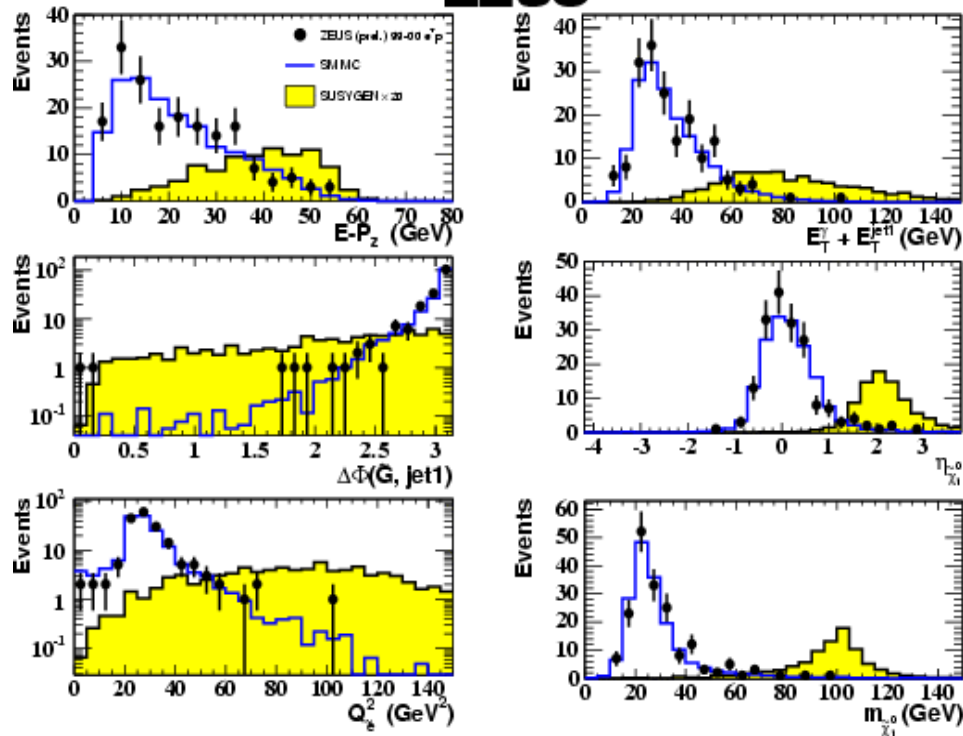
ZEUS



Gravitino Production (RPV-GMSB) at HERA

Final Selection (ZEUS)

ZEUS

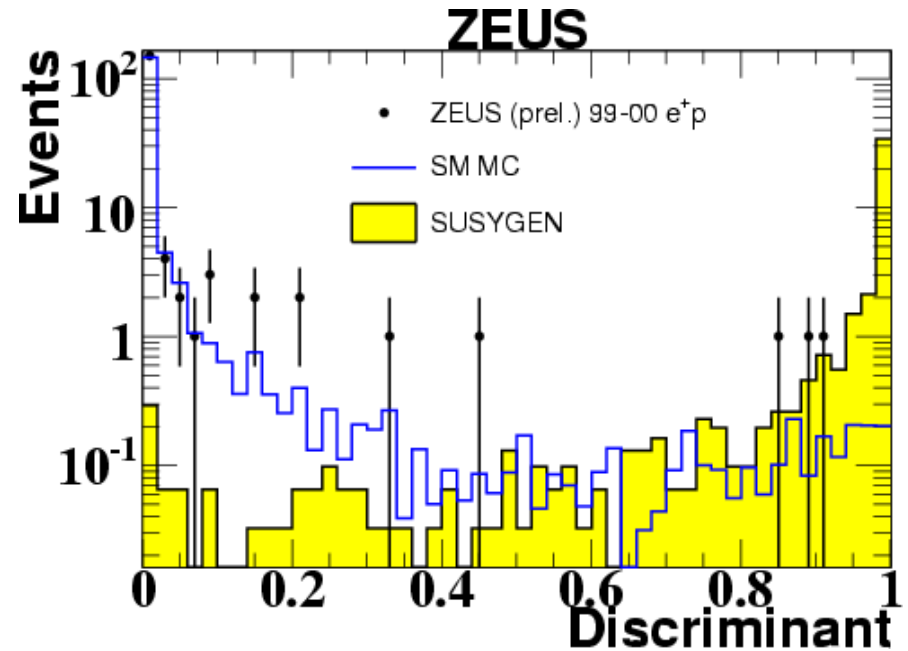


repr. signal here for:

- $m(\tilde{\chi}_1^0) = 100.4 \text{ GeV}$
- $\Delta m = 40 \text{ GeV}$
- $\lambda = 1.0$

- ≥ 1 isolated γ
 - $E_\gamma > 4 \text{ GeV}$
 - $-2.8 < \eta^\gamma < 2.8$
- \Rightarrow signal efficiency: 59 - 71%

multi-variate discriminant method:



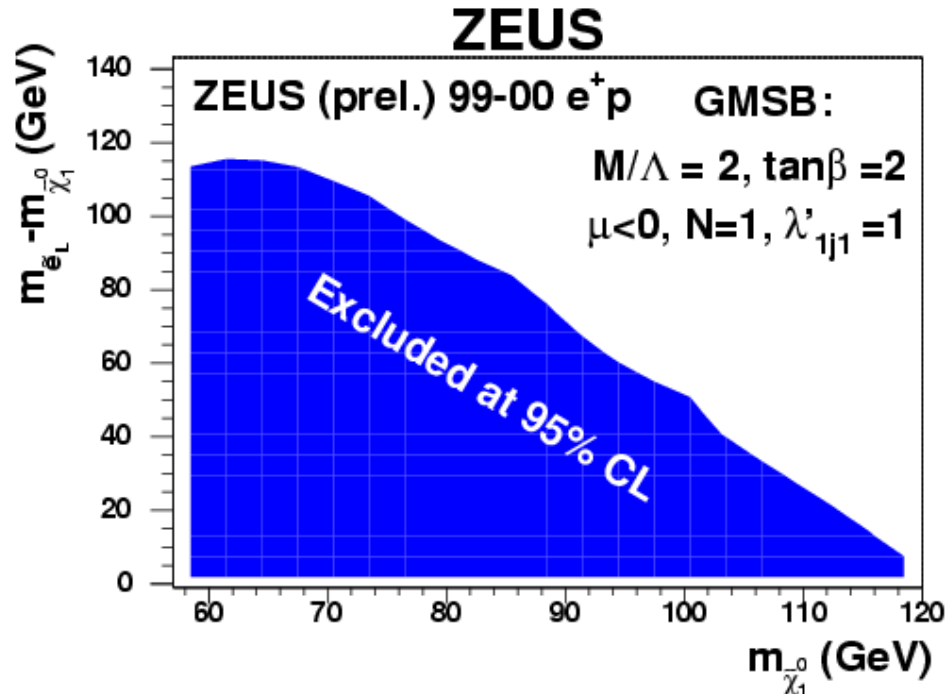
Gravitino Production (RPV-GMSB) at HERA

Results (ZEUS)

No deviations from SM are observed in high discriminant region.

⇒ 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:
 - $m(\tilde{\chi}_I^0) > 112 \text{ GeV}$ for **small** Δm and $\lambda' = 1.0$
 - $m(\tilde{e}_L) > 164 \text{ GeV}$ for **large** Δm and $\lambda' = 1.0$
 - $\lambda'_{1j1} > O(\alpha_{EM})$ for **small** $m(\tilde{\chi}_I^0)$ and Δm
 - for σ and Δm depending on $m(\tilde{\chi}_I^0)$ and various parameter sets
- **extended** for the $m(\tilde{\chi}_I^0)$ - 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, $> 110 \text{ pb}^{-1}$ so far)
 \Rightarrow much more statistics
 \Rightarrow all searches benefit
- increase in fraction of ep data
 \Rightarrow especially RPV-SUSY searches benefit
(ep data more sensitive because of coupling to u -quark)

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