Searches for SUSY at HERA

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On behalf of the

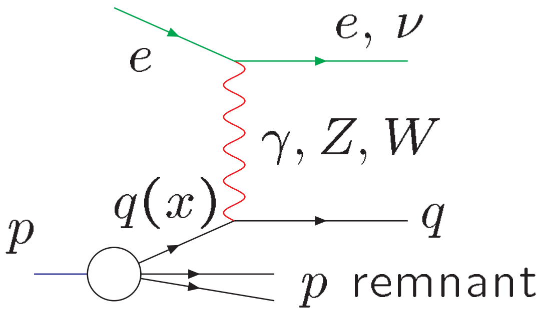
H1 and ZEUS Collaborations

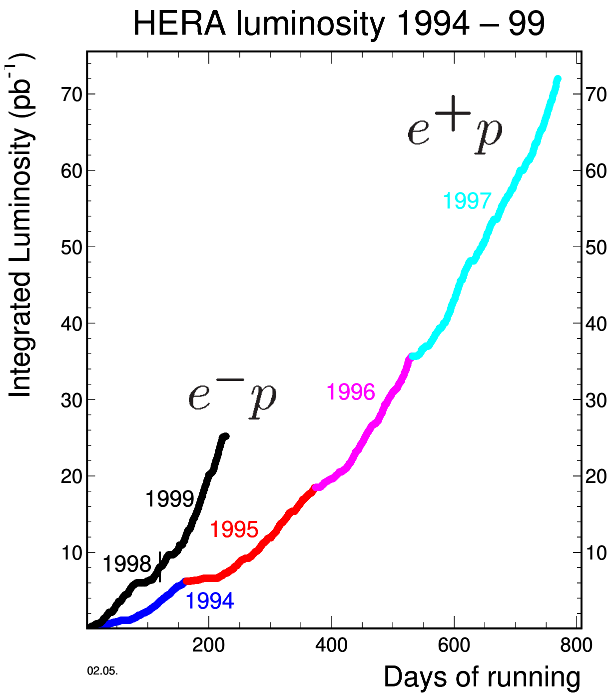
- → Introduction
- → Squarks in $\not{R}_P$ MSSM
- → Events with high p_t lepton and $P_{T,miss}$
- → Conclusion and Outlook

Tampere, Finland
July 15–21 1999

Introduction

HERA: the first electron–proton collider



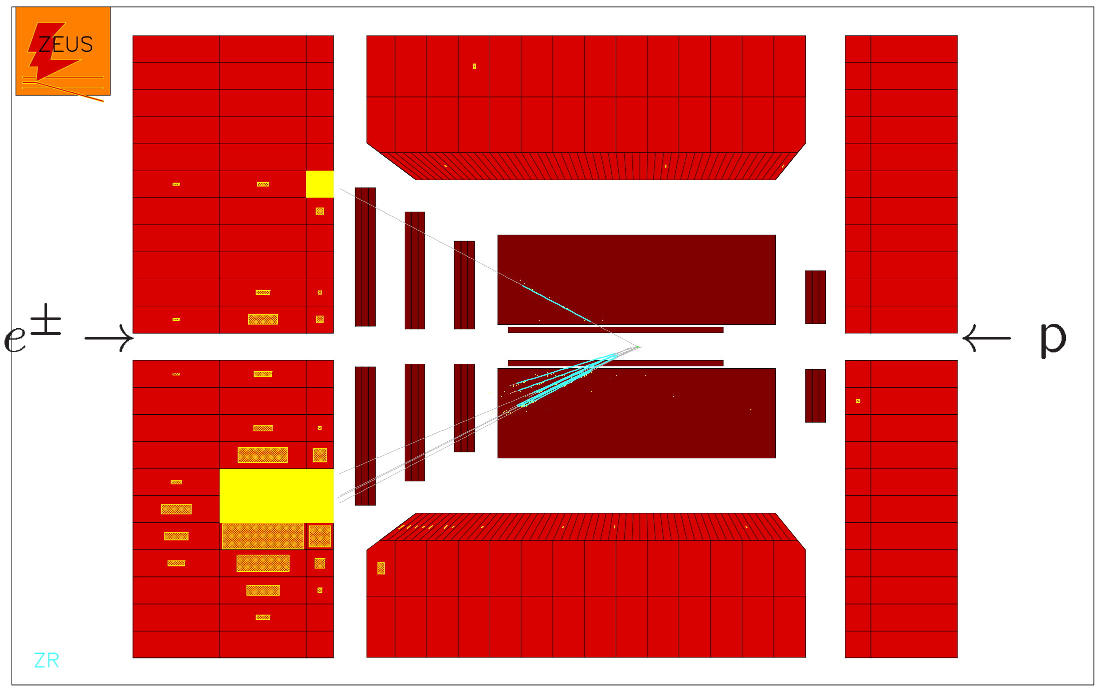


$Q^2 =$ (4 momentum transfer)^2
$x =$ parton momentum fraction
$y = (1 + \cos\theta^*)/2$
$M = \sqrt{xs}$

ep centre–of–mass energy = 300 → 320 GeV

	ZEUS	H1
→ 1993–1994 e^-p	1 pb^{-1}	1 pb^{-1}
→ 1994–1997 e^+p	48 pb^{-1}	37 pb^{-1}
→ 1998–1999 e^-p	16 pb^{-1}	14 pb^{-1}
→ 1999–2000 e^+p		

A NC Event in the ZEUS Detector



Uranium-Scintillator Calorimeter

6000 Cells, each read out by 2 PMTs

$$\sigma_{\theta_{\mathbf{e}}} = 3\text{mrad}$$

$$\sigma(\boldsymbol{E})(\text{em}) = 18\%\sqrt{E} \oplus 1\%E$$

$$\sigma(\boldsymbol{E})(\text{had}) = 35\%\sqrt{E} \oplus 1\%E$$

Scale Uncertainty:

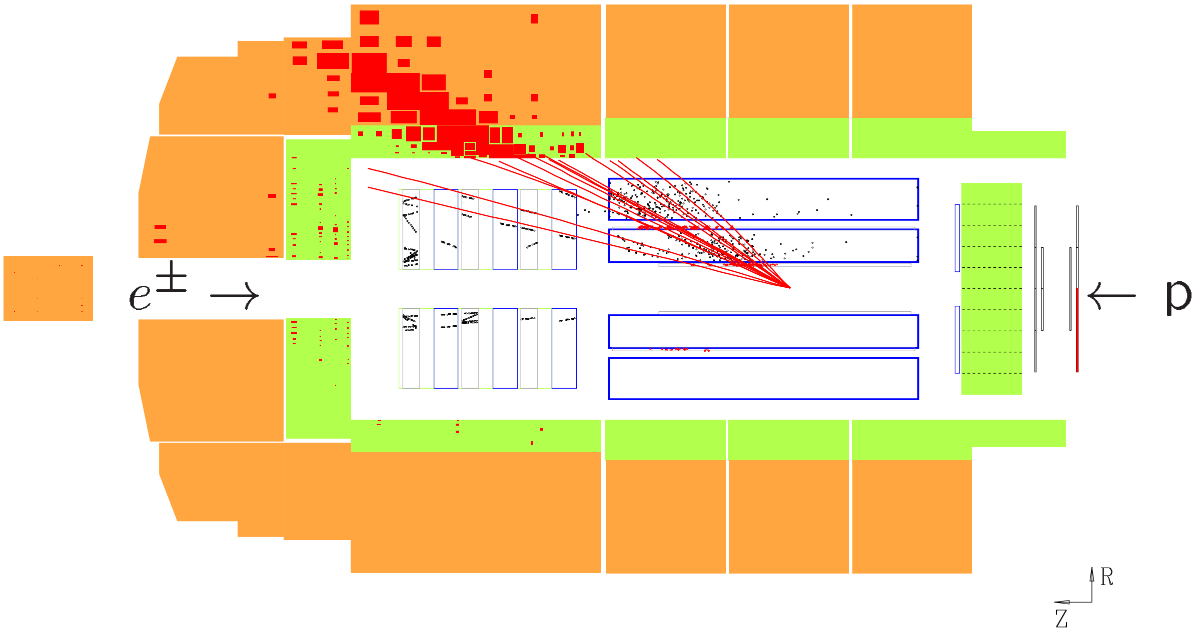
	FCAL	BCAL	RCAL
em	3%	1%	2%
had	3%	3%	3%

Central Tracking Detector

Angular acceptance: $15^{\circ} < \theta < 164^{\circ}$

Momentum: $\sigma(p_t)/p_t = (0.005\text{GeV}^{-1}p_t) \oplus 0.016$

A CC Event in the H1 Detector



Liquid Argon Calorimeter

44000 Cells

$$\sigma_{\theta_e} = \text{2-5 mrad}$$

$$\sigma/\sqrt{E}\ \text{(e)} = 12\ \%$$

$$\sigma/\sqrt{E}\ \text{(had)} = 50\ \%$$

$$\boldsymbol{\Delta E/E_{em}} = 1\text{ - }3\ \%$$

$$\boldsymbol{\Delta E/E_{had}} = 4\ \%$$

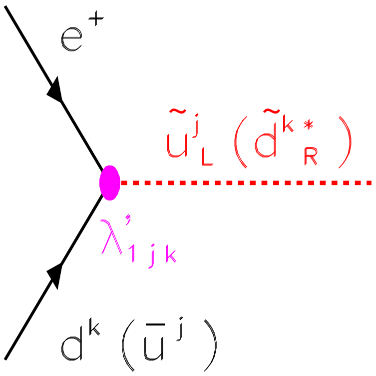
R_P violating MSSM at HERA

- $R_P = (-1)^{3B+L+2S}$ particles ↔ sparticles
- $\not{R}_P \rightarrow$ single sparticle production
  decay of LSP
- General MSSM with R_P violation:

$$W_{SUSY} = W_{MSSM} + W_{\not{R}_P}$$
$$W_{\not{R}_P} = \tfrac{1}{2}\lambda_{ijk}L_iL_j\bar{E}_k + \lambda'_{ijk}L_iQ_j\bar{D}_k + \tfrac{1}{2}\lambda''_{ijk}\bar{U}_i\bar{D}_j\bar{D}_k$$

- The term with λ'_{ijk} is relevant for ep:

$$W_{LQD} = \lambda'_{ijk}\Big[-\tilde{e}^i_L u^j_L \bar{d}^k_R - e^i_L \tilde{u}^j_L \bar{d}^k_R - (\bar{e}^i_L)^c u^j_L (\tilde{d}^k_R)^* \\ +\tilde{\nu}^i_L d^j_L \bar{d}^k_R + \nu^i_L \tilde{d}^j_L \bar{d}^k_R + (\bar{\nu}^i_L)^c d^j_L (\tilde{d}^k_R)^*\Big]$$



production $\not{R}_P$:

e^+p mainly λ'_{1j1}:$e^+d^k \rightarrow \tilde{u}^j_L$

e^-p mainly λ'_{11k}:$e^-u^j \rightarrow (\overline{\tilde{d}^{k*}_R})$

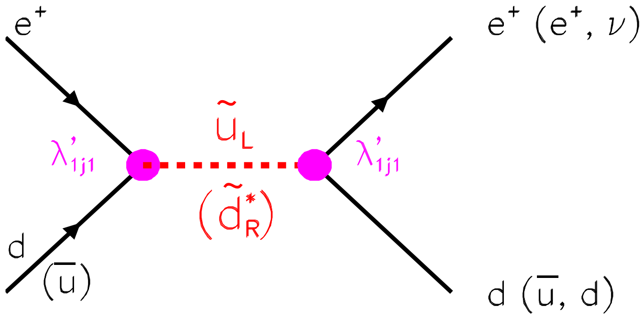
decays both $\not{R}_P$ and Gauge:

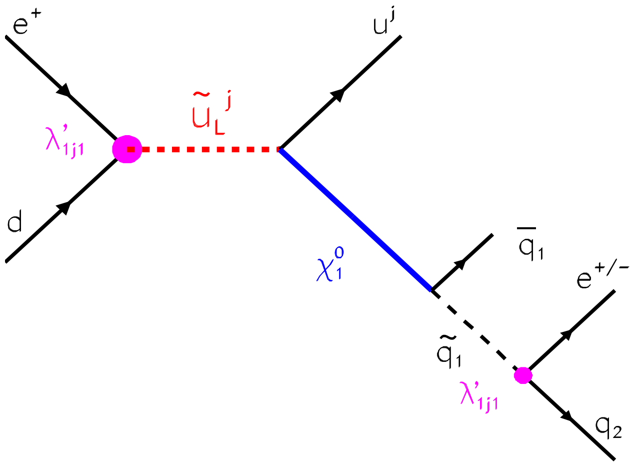
$\tilde{u}^j_L \rightarrow e^+d^k_L,\ u^j_L\tilde{\chi}^0_i,\ d^j_L\tilde{\chi}^+,\ \ldots$

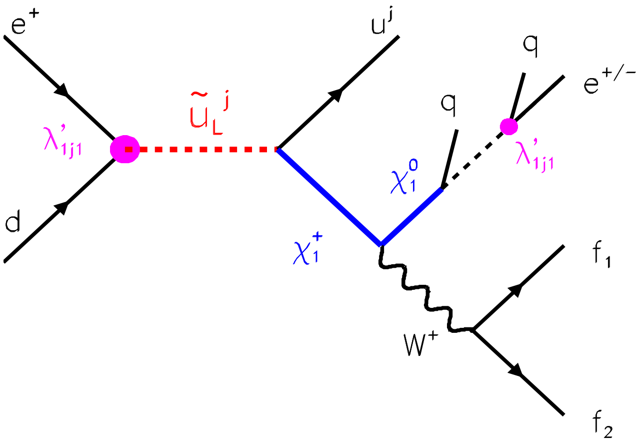
$\overline{\tilde{d}^{j*}_R} \rightarrow e^-u^k_L,\ \bar{\nu}d^k_R,\ d^j_R\tilde{\chi}^0_i,\ \ldots$

MSSM parameters: M_1, M_2, μ, $\tan\beta$
and $M_{\tilde{q}}$

$e^+p \to \not{R}_P$ squark final states



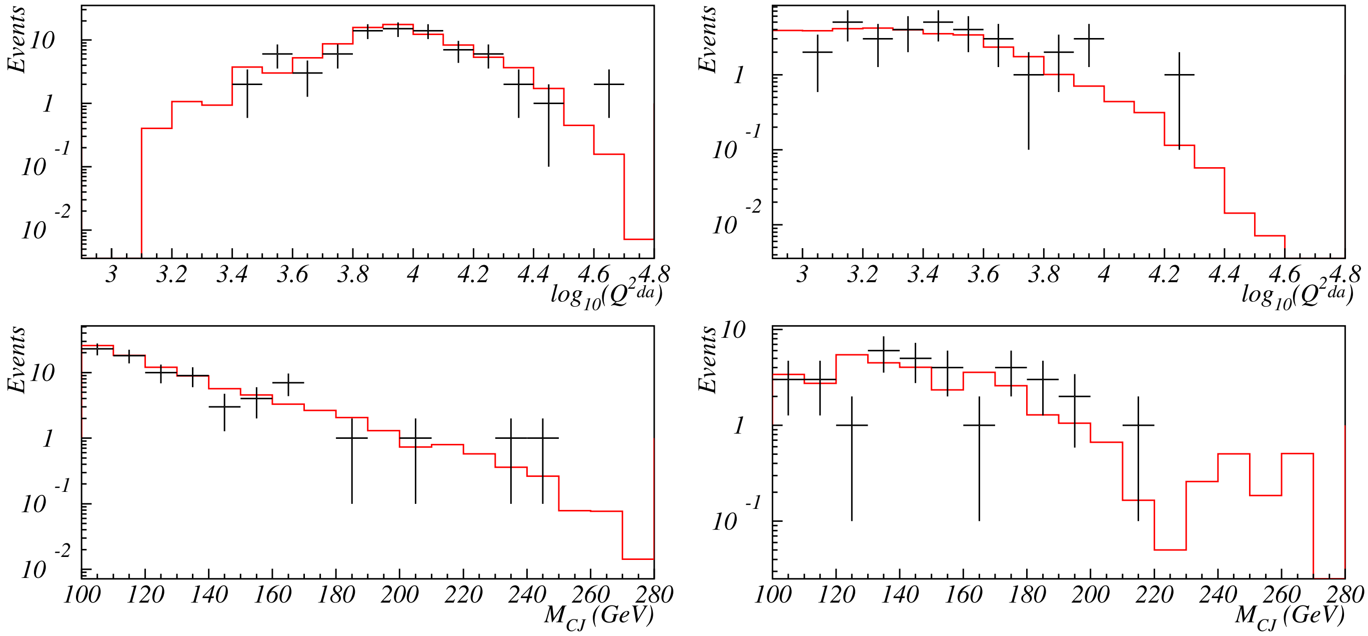




. . . and many more

ZEUS $e^+p \to \tilde{q} \to e^\pm + jets$ search

preselection: high Q^2 NC DIS



e^+, jet

- $E_{T,jet} > 30$ GeV, $\eta < 2.5$
- $P_{T,e} > 30$, $y_{da} > y_{cut}(M)$
- DATA: 78, expect: 88.3

$e^\pm$, multi-jet

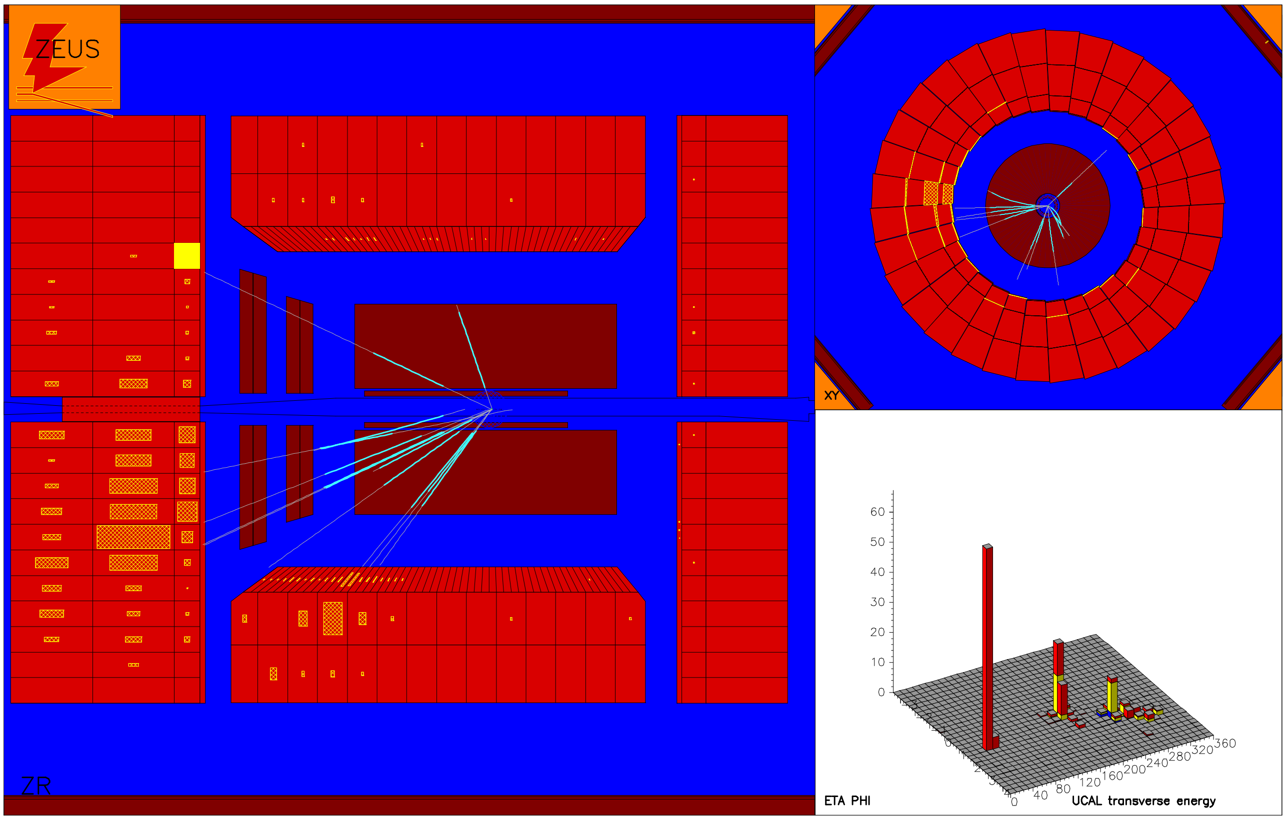
- $E_{T,jet1,2} > 40, 20$; $\eta < 2.5$
- DATA: 33, expect: 33.6

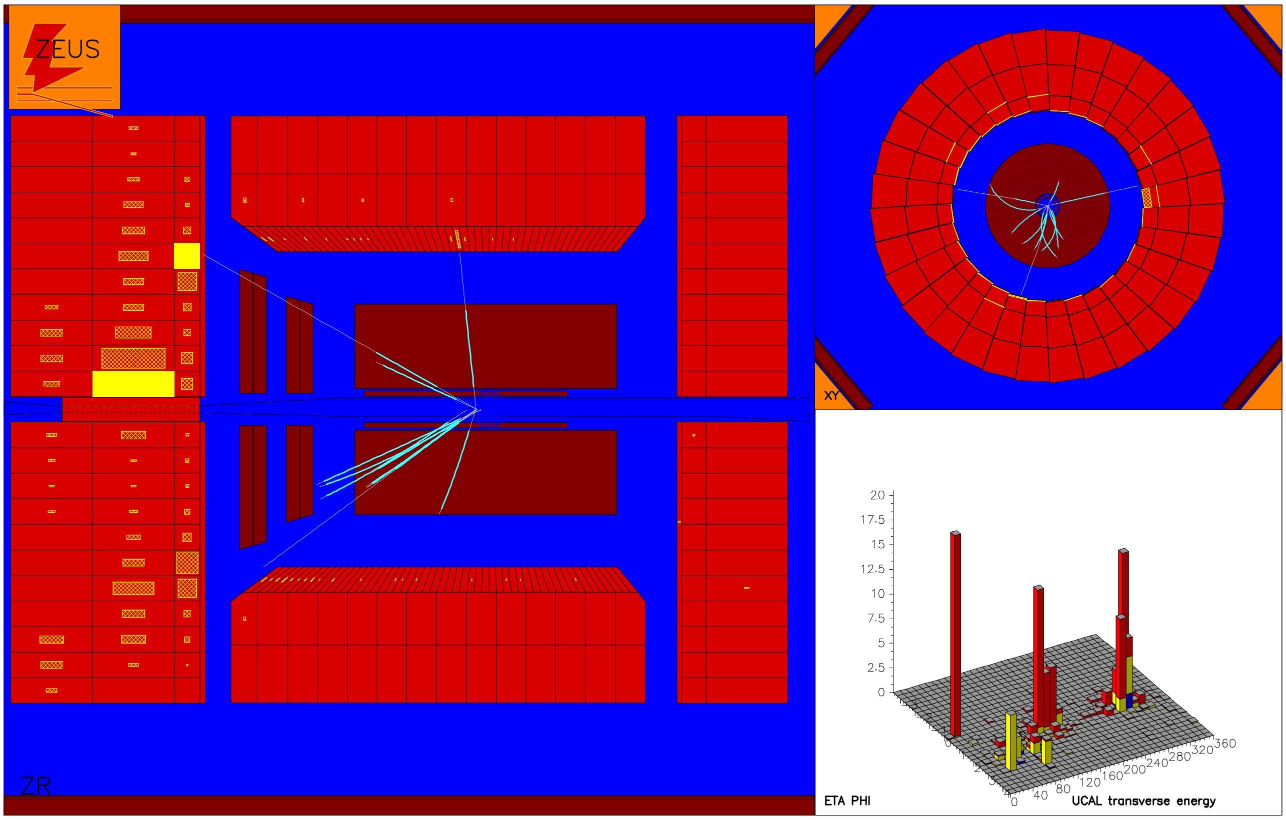
e^-, multi-jet

- e^- with 3σ negative track
- DATA: 0, expect: 0.06

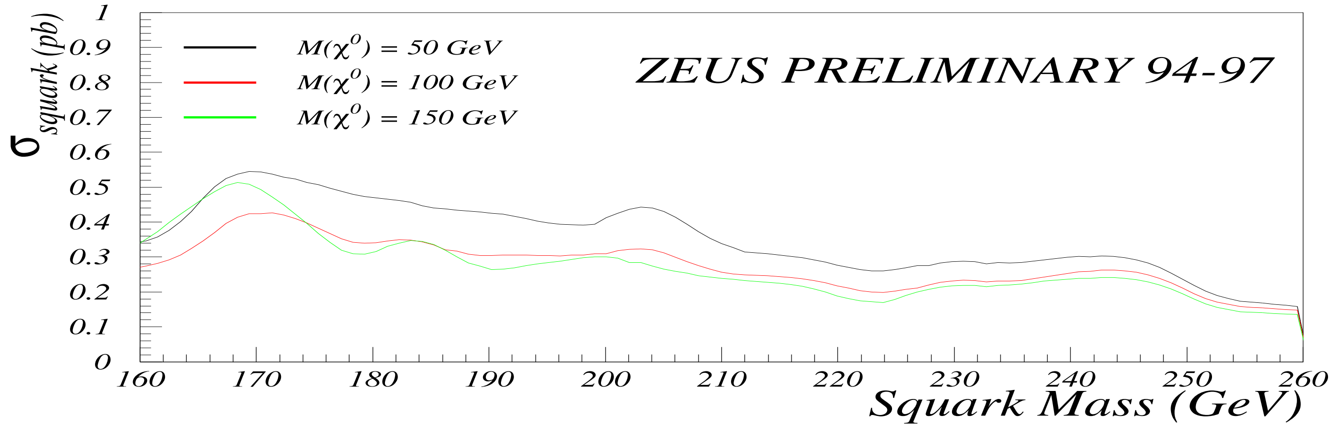
No significant excess observed ...
→ derive limits on σ, λ_{1j1} vs. $M_{\tilde{q}}$
(using likelihood method with sliding mass window)

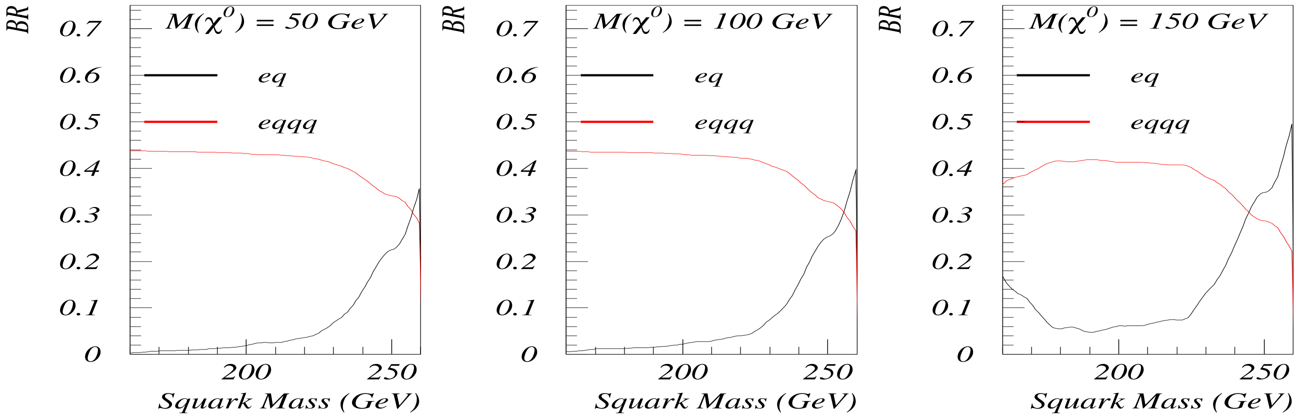
e-multijet with mass 214, 200 GeV

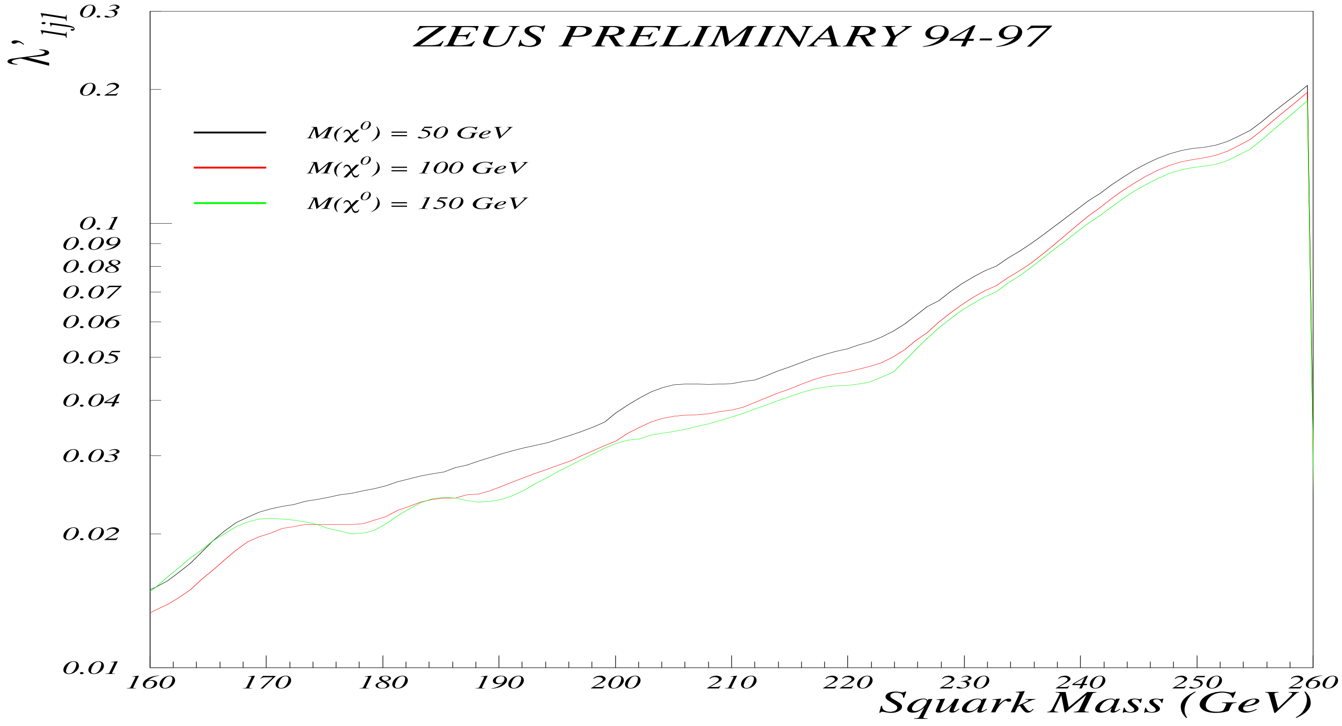




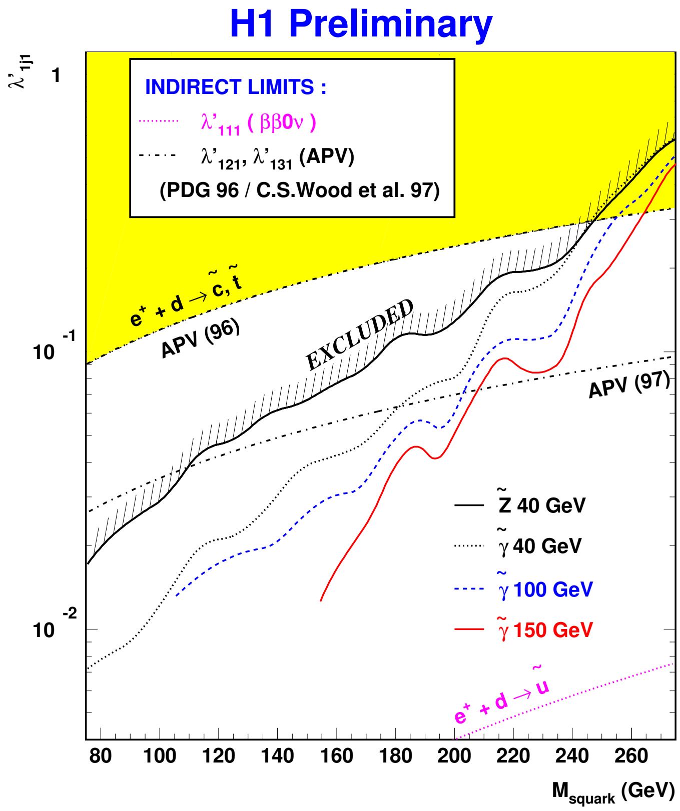
ZEUS squark limits





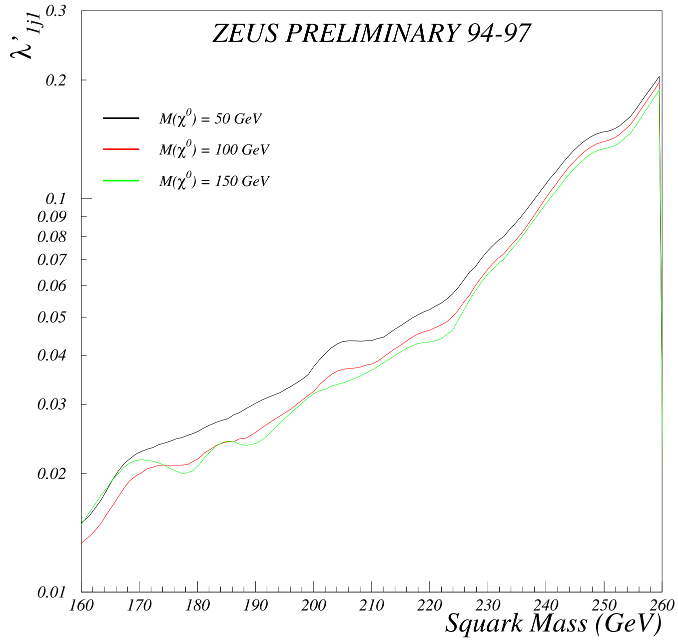


H1, ZEUS, low energy limits on λ'_{1j1}



ICHEP98

- 94–97 e^+p: 37 pb^{-1}
- use e^+ jet, $e^\pm$ multijet
- unseen χ^+ final states
  ⇒ lower efficiency
- limit procedure includes
  e^+q, $\nu_e a$, $e^\pm qqq$, $e^\pm qqqqq$

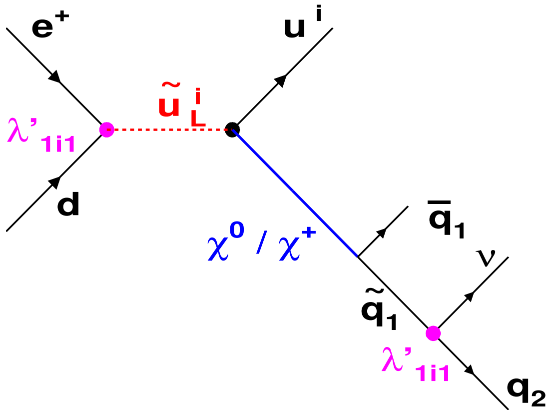


EPS-HEP 99

- 94–97 e^+p: 47 pb^{-1}
- use e^+ jet, $e^\pm$ multijet
- ignore χ^+, χ^0_2, χ^0_3, χ^0_4
  final states
- limit procedure includes
  e^+q, $\nu_e a$, $e^\pm qqq$
- χ^0_1 pure photino

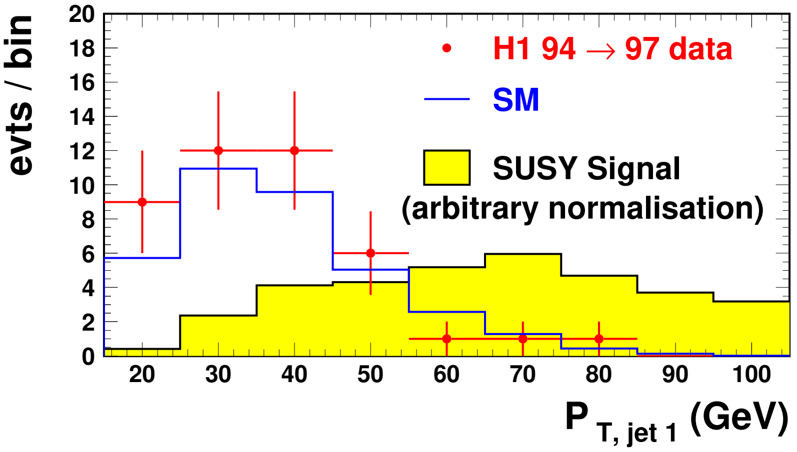
beat APV limits for $M_{\tilde{q}} \gtrsim 200$

H1: Channels with several jets and $P_{T,miss}$



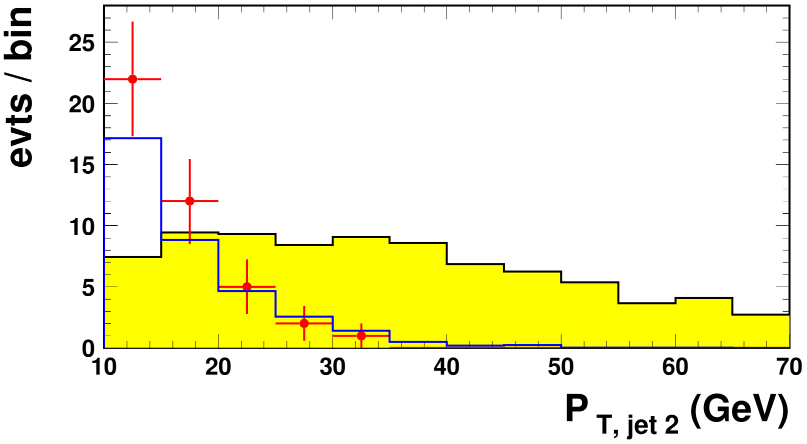
Main Preselection Cuts :

- $P_{T,miss} > 25$ GeV
- $P_{T,jet,1,2} > 15$GeV, 10 GeV



SUSY signal shown merging several $(M_{\tilde{q}}, M_{\chi})$

Final selection :



P_T(both jets) > 15 GeV

⇓

$N_{obs} = 20$ evts,

$N_{SM} = 18.5 \pm 2.8$ evts

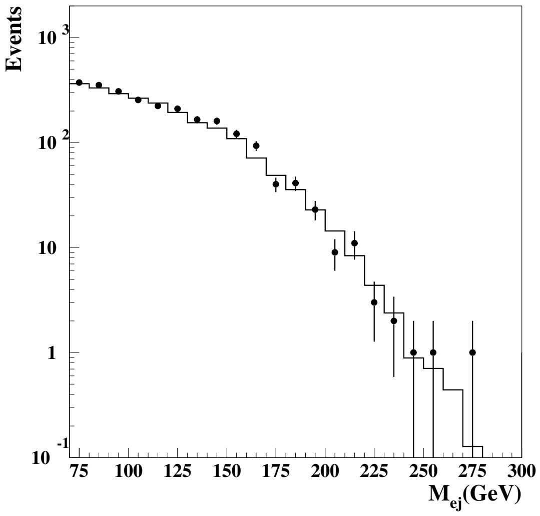
(mainly CC DIS)

(syst : ±1.5% on $\mathcal{L}$, ±7% on pdf, ±2% on ε_{trigg}, ±4% on had scale)

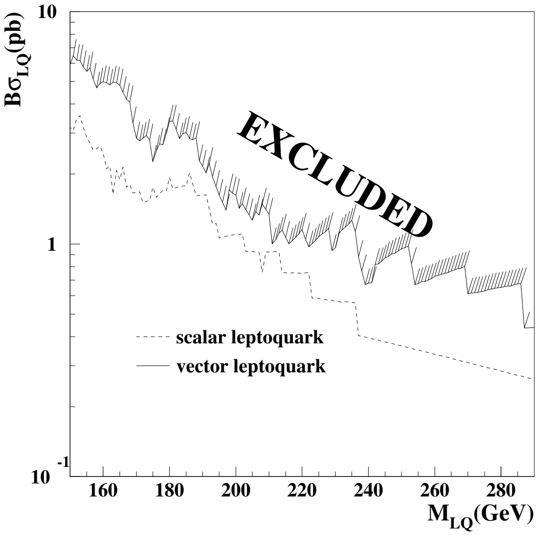
Efficiencies on SUSY Signal : $\varepsilon \sim 10 - 60\%$ depending on $M_{\tilde{q}}$, M_{χ}

⇒ No signal observed in this channel

ZEUS $e^+p \to \bar{\nu}q$, $e^-p \to e^-q$



ZEUS 1998-99 Preliminary



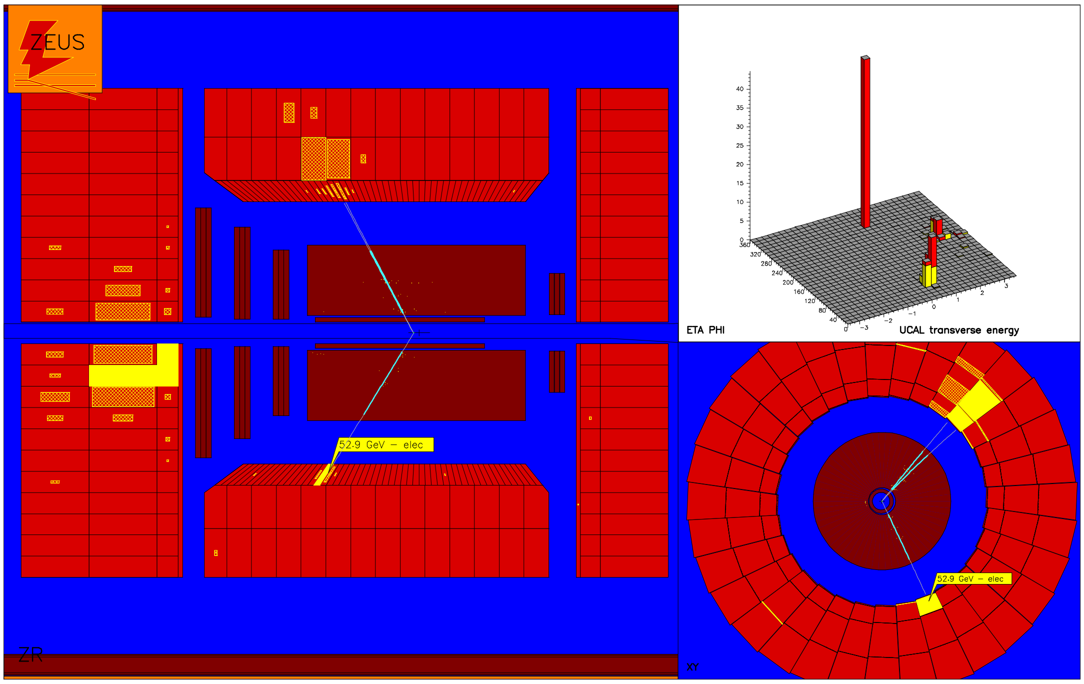
ZEUS 1998-99 Preliminary

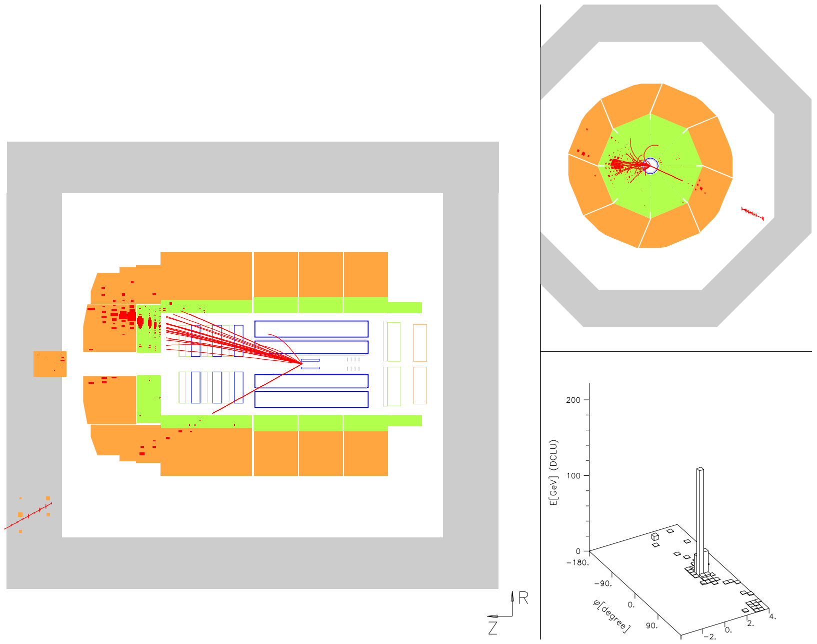
→ First look at 16.6 pb^{-1} of e^-p from 98–99

● No signal observed in $e^-p \to \overline{\tilde{d}^*_R} \to e^-$ jet

→ Also no signal observed in $e^+p \to \tilde{d}^*_R \to \bar{\nu}$ jet

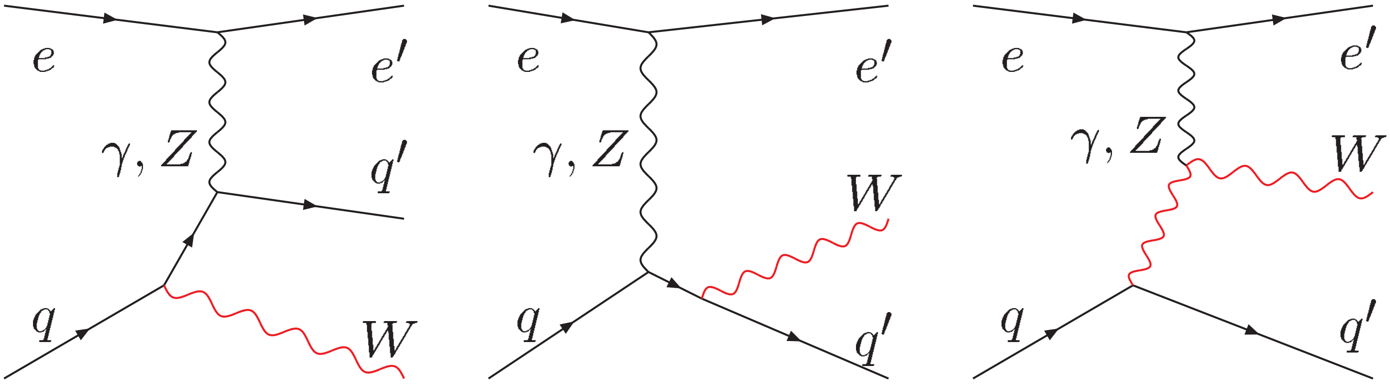
Isolated Lepton + Missing Pt





→ Standard Model W production?

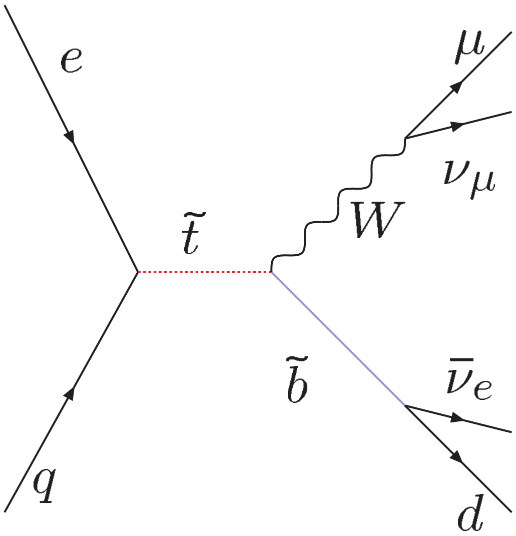
Standard Model W Production



W candidates in 94–97 e^+p:

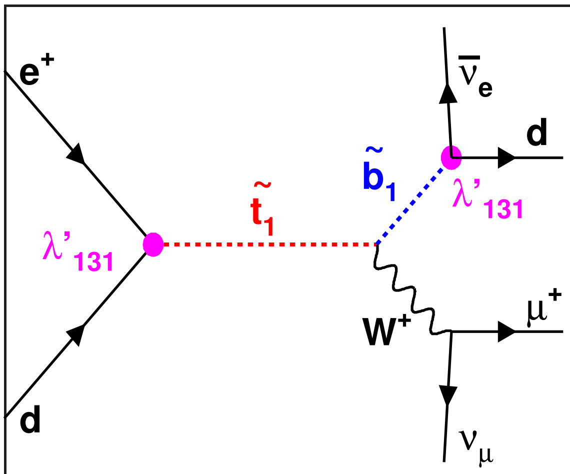
	Channel	SM W	eff.	SM DIS, γp
H1	$1e^-$, 0 e^+	1.65 ± 0.47		< 0.75
	1μ, $2\mu^+$, $1\mu^-$, $1\mu^-e^+$	0.53 ± 0.11		< 0.31
ZEUS	$3e^+$	2.10	38%	1.10 ± 0.30
	0μ	0.76	13%	0.65 ± 0.22

W candidates in 98–99 e^-p H1 0, expect 1.0 e, 0.4 μ



- High hadronic P_t!
- Could it be $R\!\!\!/_P\ \tilde{t}$?

H1: reject $\tilde{t} \to \tilde{b}$ + W explanation



Model : $\not{R}_P$ SUSY, $\lambda'_{131} \neq 0$

Assumptions :
$\tilde{b}_1$ is the LSP
$M_{\tilde{b}_1} < M_{\tilde{t}_1} < M_{\chi_1^+}$

cf T.Kon et al

Existing limits ⇒ $M_{\tilde{b}_1} \gtrsim 90$ GeV, real W ⇒ $M_{\tilde{t}_1} \gtrsim 180$ GeV
Only decay mode for $\tilde{b}_1$: $\tilde{b}_1 \to d\bar{\nu}_e$
Original theoretical motivation: “explain”
HERA high Q^2 NC DIS and high p_T lepton events

- $W \to e\nu$: 1 event in H1 (e^-)
- $W \to \mu\nu$: 4 events in H1 (2 μ^+, 1 μ^-, 1 $\mu^\pm$)
  $\mu^- e^+$ event fails selection due to e^+
- $W \to had.$: demand $P_{T,miss} > 25$ GeV, $P_{T,jet,1,2} > 25$ GeV

$$\boxed{N_{had,obs} = 3 \text{ evts}, \; N_{had,SM} = 4.7 \pm 0.7 \text{ evts (CC DIS)}}$$

No excess had. channel ⇒ Cannot “explain” μ events!

Quantitatively, for $M_{\tilde{t}} \sim 200$ GeV, $M_{\tilde{b}} \sim 100$ GeV:
- efficiencies: $\varepsilon(W \to had.) \simeq \varepsilon(W \to \mu\nu) \simeq 50\%$
- SM: $BR(W \to \mu\nu) = \mathbf{0.15} \cdot BR(W \to had.)$

→ Upper limit on additional μ events from $\tilde{b}W$:
$N_{obs,\tilde{b}W}(W \to \mu) < 0.36$ at 90% C.L

Conclusion and Outlook

New at EPS-HEP99

→ new limits on $\not{R}_P$ squarks:

- ZEUS: $\lambda'_{1j1} < 0.02$ for $M_{\tilde{q}} = 160$ GeV,
  $\lambda'_{1j1} < 0.2$ for $M_{\tilde{q}} = 260$ GeV
  beat APV limits for $M_{\tilde{q}} \lesssim 200$ GeV
- H1: no signal in $e^+p \rightarrow \tilde{u}_L \rightarrow jets + P_{T,miss}$
- ZEUS: no signal in $e^-p \rightarrow \tilde{d}_R \rightarrow e^-jet$

→ Intriguing high P_T muon events with $P_{T,miss}$

- SUSY $\tilde{t} \rightarrow \tilde{b}W$ explanation unlikely

1999–2000: 50 pb^{-1} e^+p

→ Let's hope for more puzzling events!

2001– . . . HERA upgrade

- polarised $e^\pm$ beam
- 170 pb^{-1} per year
- ultimate integrated luminosity $\mathcal{O}(1\mathrm{fb}^{-1})$

HERA has unique potential
to study $\not{R}_P$ squark final states

ZEUS event selection

→ Preselection: 46.8 pb^{-1} $e^{+}p$, 94–97

- $z_{vtx}| < 50$cm
- $|E - P_z| > 44$GeV, a good electron found
- At least one jet with $E_{t,j} > 30 GeV$, $\eta_j < 2.5$
- $Q^2_{DA} > 800$GeV^2, Mass $>$ 100 GeV

→ e^- multijet sample (DATA: 33, expect: 33.6)

- Electron track is negative at 3σ level
- $E_{t,j1} > 40$ GeV, $E_{t,j2} > 20$ GeV, $\eta_{j1,2} < 2.5$
- Electron track is negative at 3σ level
- $P_{t,had}/E_{t,had} < 0.75$
- $0.4 < y_{da} < 0.95$ to suppress NC DIS, γp

→ e^+ multijet sample (DATA: 78, expect: 88.3)

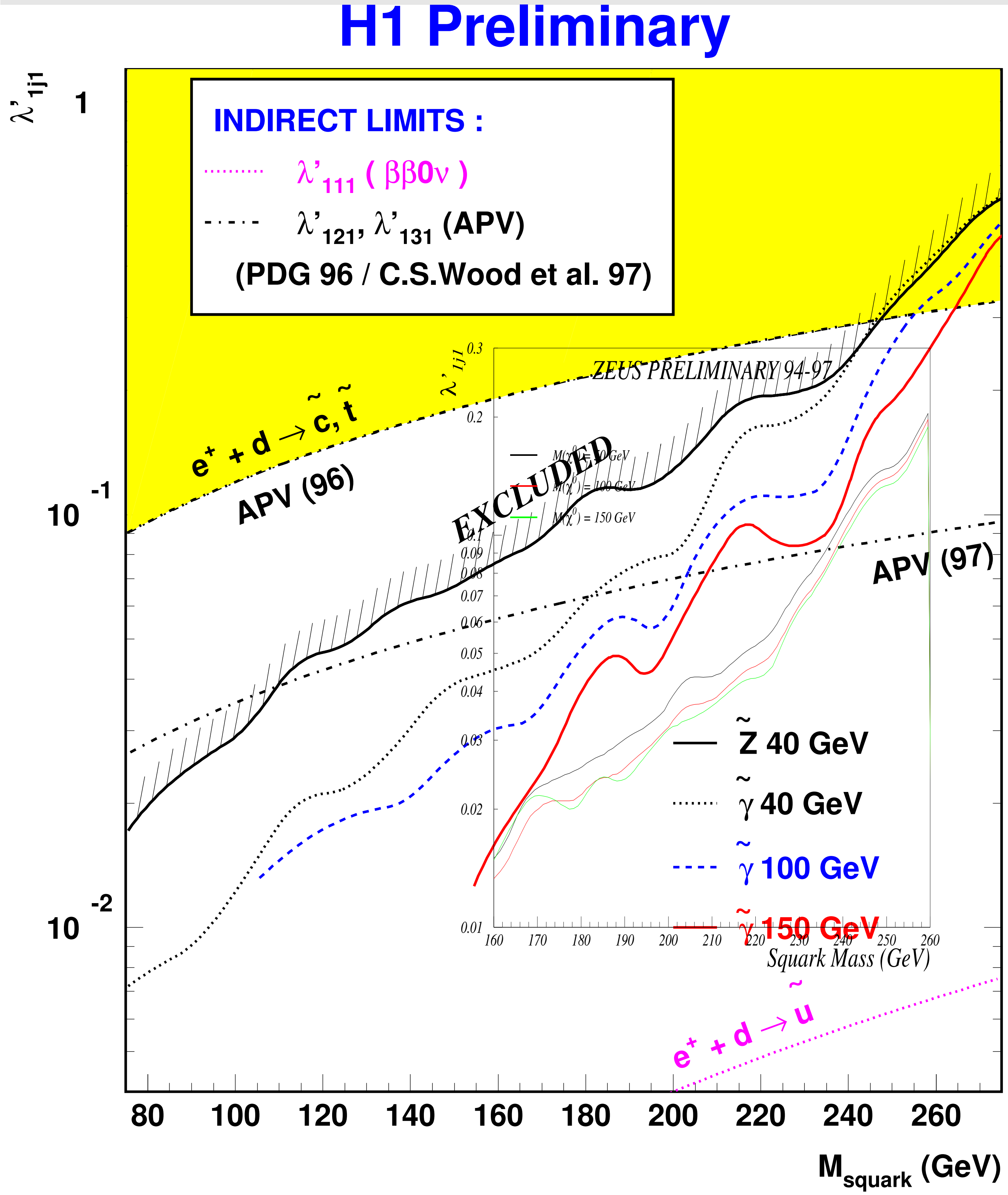
- as for e^- multijet, without 3σ e^- charge

→ e^+ jet sample (DATA: 33, expect: 33.6)

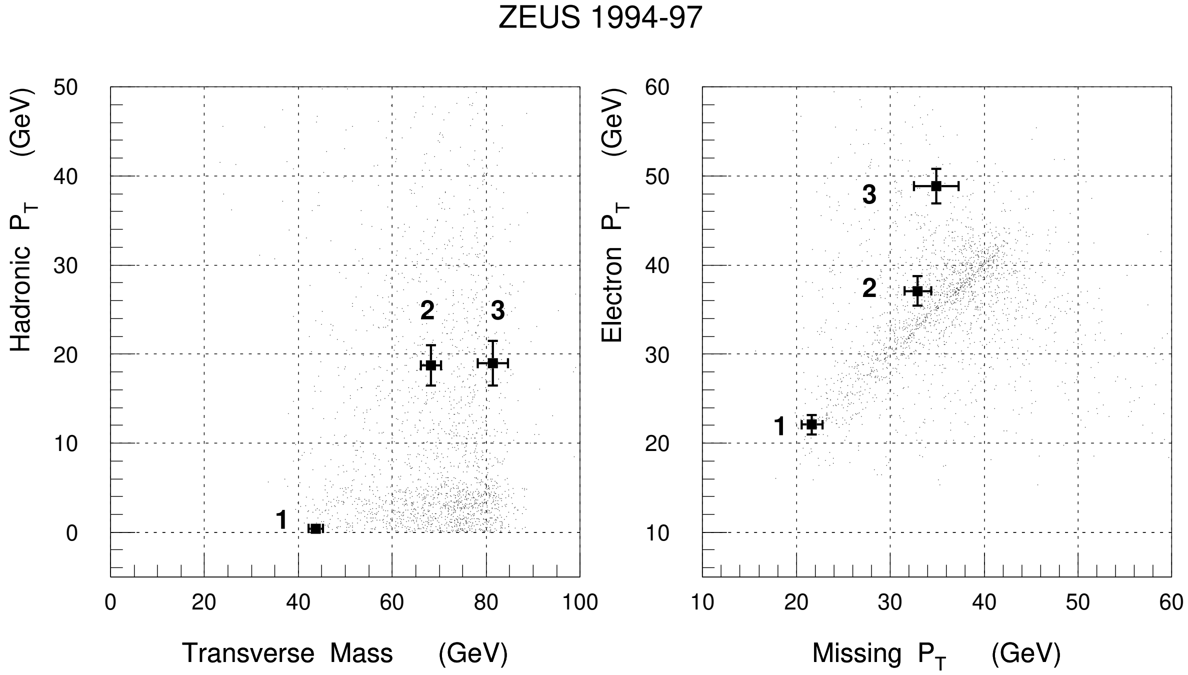
- not in the $E^{\pm}$ multijet samples
- $E_{t,j1} > 30$ GeV, $\eta_{j1,2} < 2.5$
- $P_{t,e} > 30$ GeV
- $y_{da} > y_{cut}(M)$ GeV

⟶Sliding mass window limit procedure
combining all channels, backgrounds

H1 and ZEUS limits on λ'_{1j1}



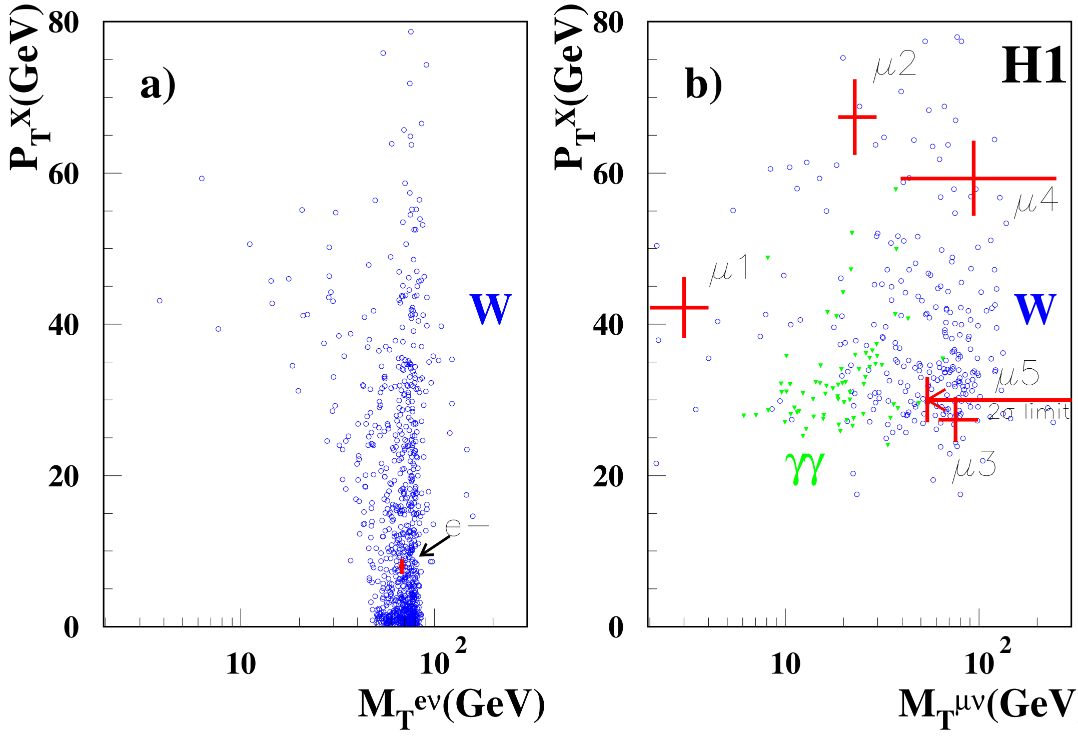
ZEUS: Positron Channel



MC sample 1000*data luminosity

$$\boxed{M_T = \sqrt{2p_T^e p_T^\nu(1 - cos\Phi^{e\nu})}}$$

H1: Electron, Muon Channel



MC sample 500*data luminosity

Future of squarks at HERA