XXXVIIIth Rencontres de Moriond
ElectroWeak Interactions and Unified Theories
$15^{th} - 22^{nd}$ March 2003

Searches for new physics

at HERA

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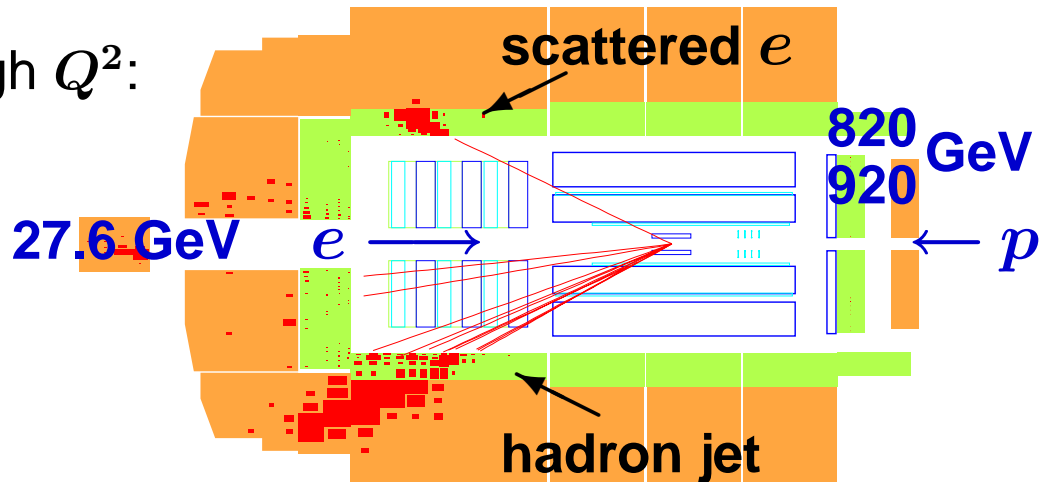
On behalf of H1 and ZEUS

Outline:

★ **DIS at high Q^2**

★ **Contact Interactions, Compositeness,**

 Large Extra Dimensions

★ **Leptoquarks**

★ **R_p violating SUSY**

★ **Excited Fermions**

★ **FCNC, Single Top Production**

★ **Conclusion and Outlook**

Introduction to HERA

- **HERA:** ep **collider at** $\sqrt{s} \approx 300/320\,\mathrm{GeV}$

NC event at high Q^2:

$$ep \rightarrow eX$$

scattered e

820 **GeV**
920

27.6 GeV $\quad e \longrightarrow$ $\qquad\qquad p$

hadron jet

two detectors:

ZEUS

H1

HERA luminosity

intergrated luminosity (1/pb)

e^+

— E_P = 920 GeV
- - - E_P = 820 GeV

99-00

93-97

100

50

e^-

98-99

H1

0

0   500   1000

days of running
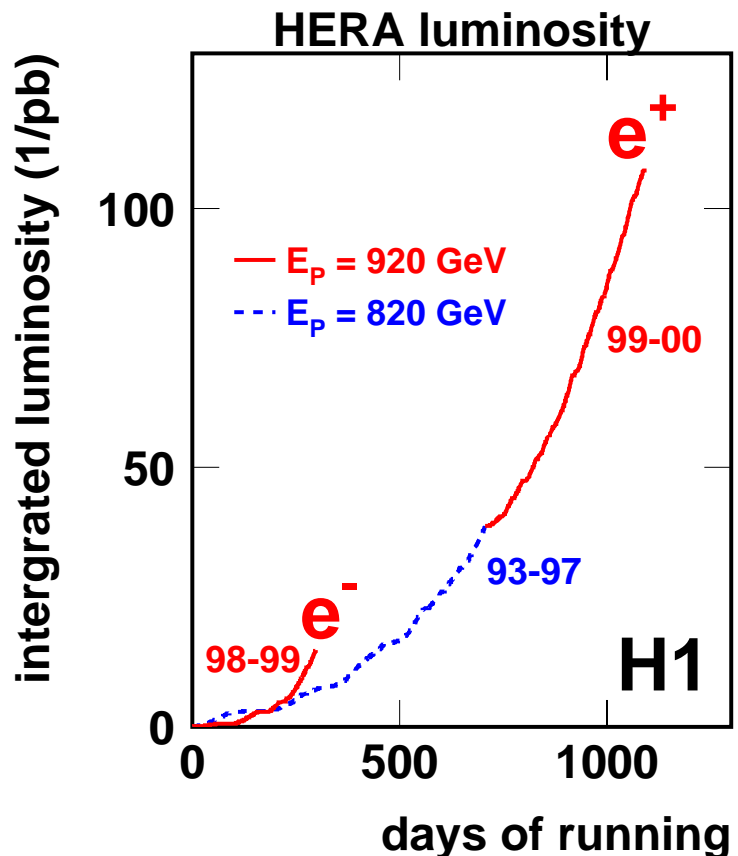
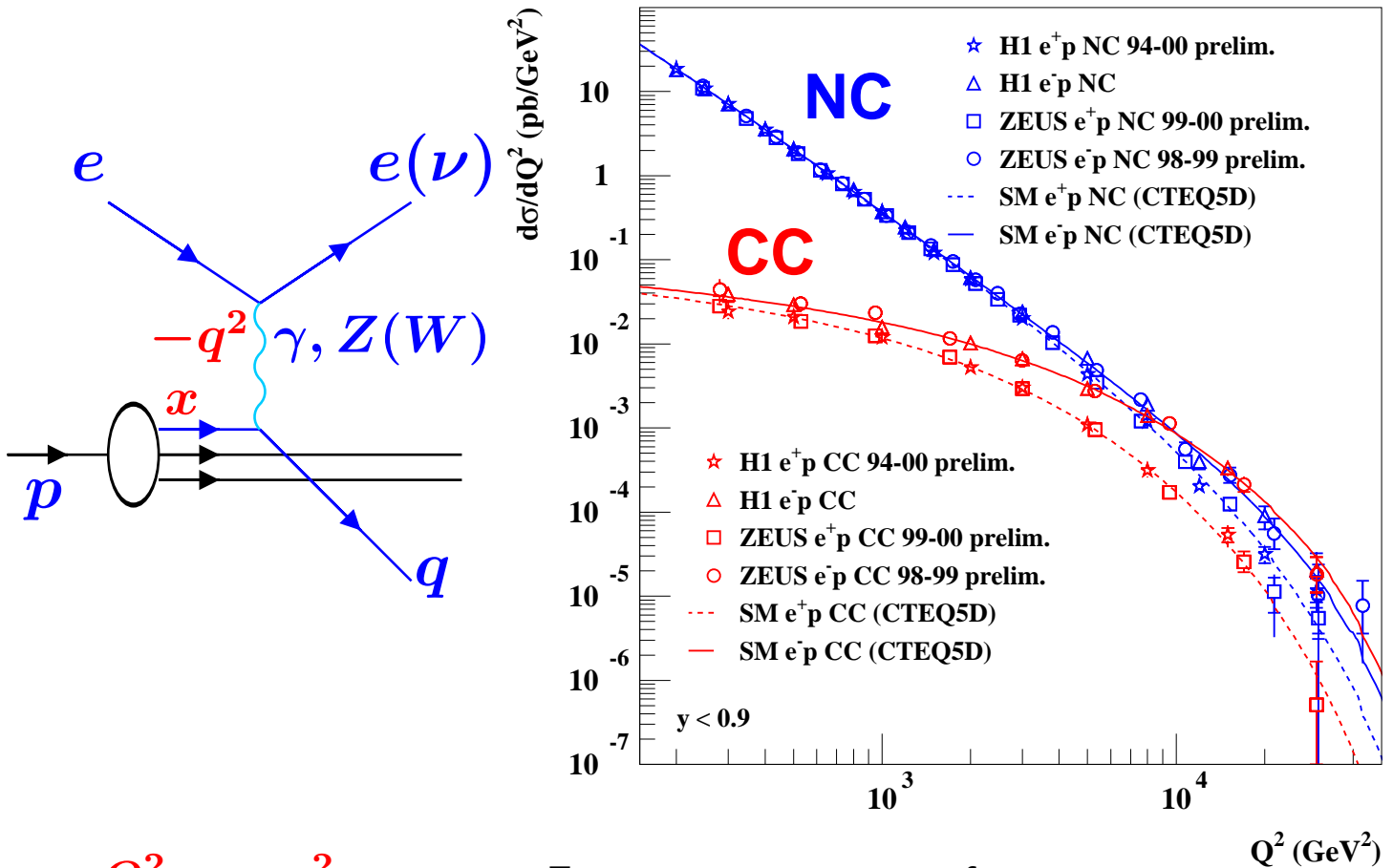$\Rightarrow$ **very good performance of HERA until shutdown in fall 2000**

Deep Inelastic Scattering at high Q^2

- $Q^2 = -q^2 = xys$ **Four momentum transfer**

  $\Rightarrow$ spatial resolution $\Delta r = 10^{-16}\,\mathrm{cm}$

- $x = \frac{Q^2}{2p\cdot q}$ **quark momentum fraction of the proton**

  $\Rightarrow$ lepton-quark invariant mass $M = \sqrt{xs}$

  $\Rightarrow$ direct production up to $M = \sqrt{s} = 320\,\mathrm{GeV}$

- $y = \frac{p\cdot q}{p\cdot l} = \frac{1}{2}(1 + \cos\theta^{\star})$ **inelasticity**

  $\Rightarrow$ polar angle of scattered electron

  $\Rightarrow$ distinguish DIS (t-channel) and res. produc. (s-channel)

$\Longrightarrow$ **unique at HERA:**   ● eq **interactions at high energies**

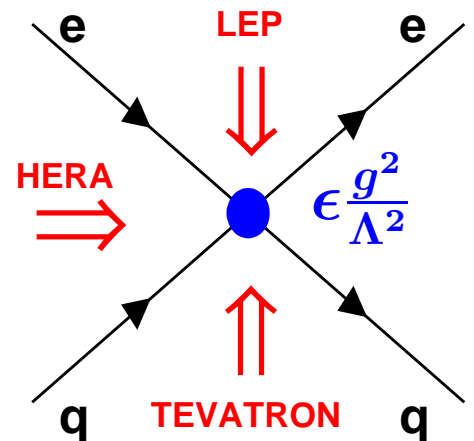   ● **particles coupling to eq pairs**

New physics at high Q^2 – Contact Interaction

- **New physics** with $\Lambda \gg \sqrt{s}$ observable as **deviations from SM at high Q^2** because of virtual processes.

- **parametrization as effective theory:**

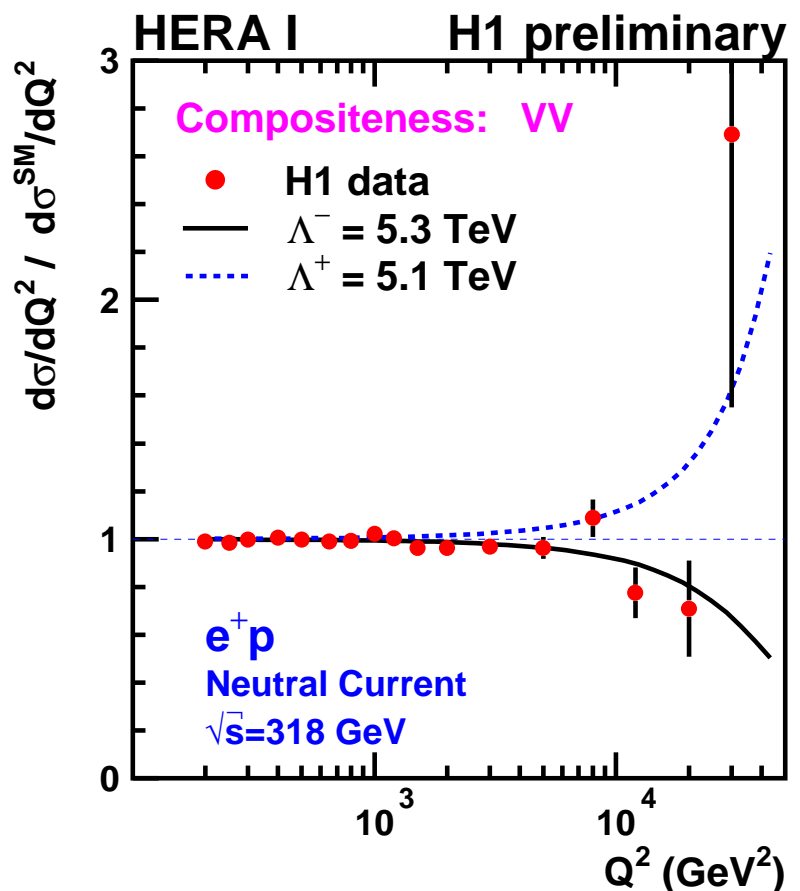 [e.g. Nucl. Phys. B234 (1984) 91.]

  (only vector-like terms considered)

$$\mathcal{L}_{CI} = \sum_{i,j=L,R} \epsilon_{ij}^{eq} \frac{g^2}{\Lambda^2} (\bar{e}_i \gamma^\mu e_i)(\bar{q}_j \gamma_\mu q_j)$$

- **compositeness:**

  $\epsilon = \pm 1, \quad g^2 = 4\pi$

- **several chiral combinations**

Large Extra Dimensions

- **hierarchy problem "solved" by extra dimensions**

- **Arkani-Hamed et al.** [hep-ph/9803315]**:**

  - **propagation: SM particles in 4-D; gravitons in (4+n)-D**

  - $M_P^2 = R^n M_s^{2+n}$ $R =$ **size of n compact extra dim.**

    $M_s^{2+n} \sim \mathcal{O}(1\,\mathrm{TeV})$**: eff. Planck scale**

  - **virtual KK "graviton" exchange interferes with** γ, Z

  - **effective coupling** $\eta_G = \pm 1/M_s^4$

$\Rightarrow$ **contribution to** $eq \rightarrow eq$ **at high** Q^2
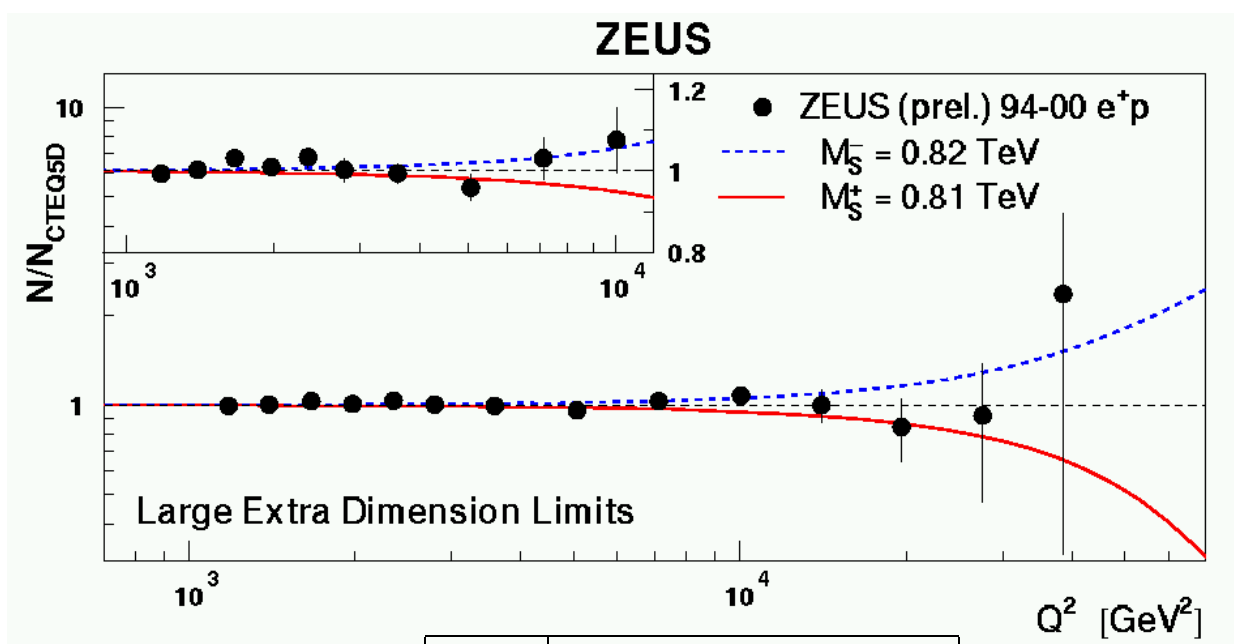
95% CL on M_S

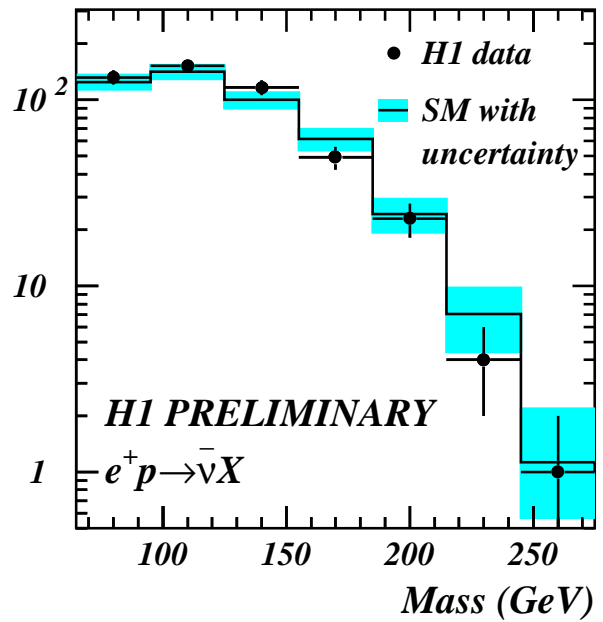| λ	ZEUS	H1
$+1$	**0.81 TeV**	**0.83 TeV**
-1	**0.82 TeV**	**0.79 TeV**

Leptoquarks

Leptoquarks considered as extension of SM

carry $B, L \neq 0$ and couple to leptons and quarks:

s-channel   **u-channel**

e l_k e l_k

LQ λ_{1j}

λ_{1i} λ_{jk} LQ

q_i q_j q_i λ_{ki} q_j
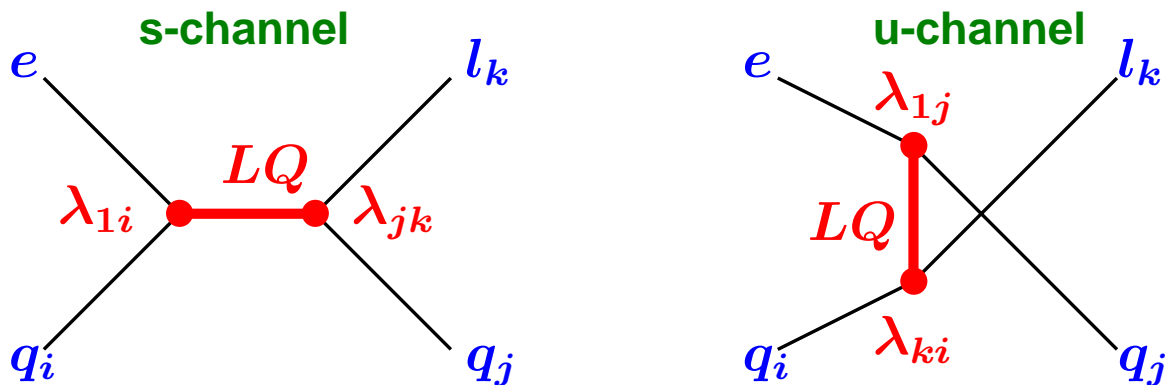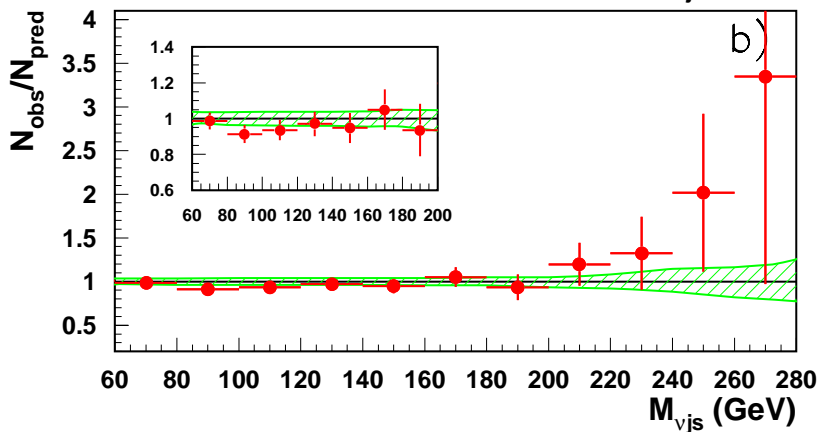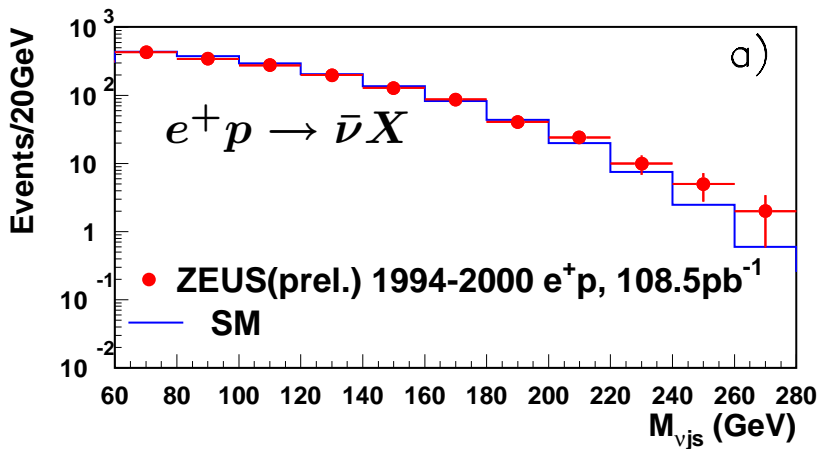
direct search: resonance peak

- **production at HERA :** $\sigma_{ep}^{\mathrm{prod}} = f(M_{LQ}, \lambda)$

- **Buchmüller-Rückl-Wyler:** [Phys. Lett. B191 (1987) 442.]

  – **couplings to chiral SM fermions and invariant under SM gauge group**

  $\Rightarrow$ **7 Scalar and 7 Vector Leptoquarks with fermion number** $F = -(3B + L) = 0$ or 2

  $\Rightarrow$ **decays: fixed branching** $1, \frac{1}{2}, 0$ **into** eq **and/or** νq

- **seperate from DIS by** $\frac{d\sigma}{dy}$
  DIS: $\propto 1/y^2$; **Scalar LQ: flat;** **Vector LQ:** $\propto (1 - y)^2$

Leptoquarks – Resonance scan

H1 data

SM with uncertainty

H1 PRELIMINARY

$e^+p \rightarrow e^+X$

H1 data

SM with uncertainty

H1 PRELIMINARY

$e^+p \rightarrow \bar{\nu}X$

ZEUS

a)

$e^+p \rightarrow \bar{\nu}X$

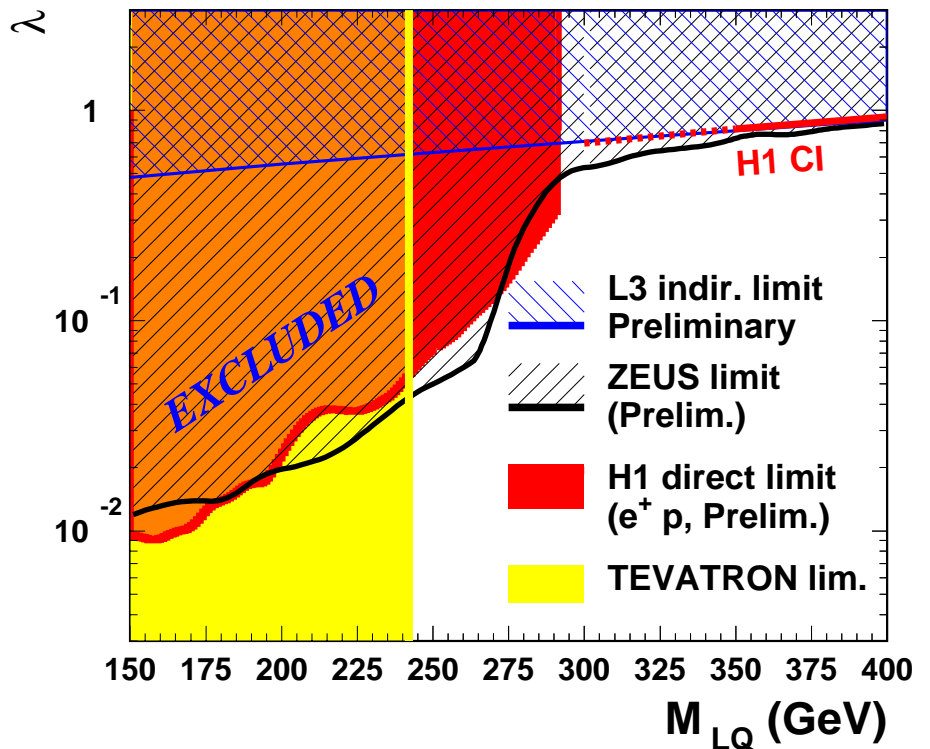● ZEUS(prel.) 1994-2000 e^+p, 108.5pb^{-1}

— SM

b)
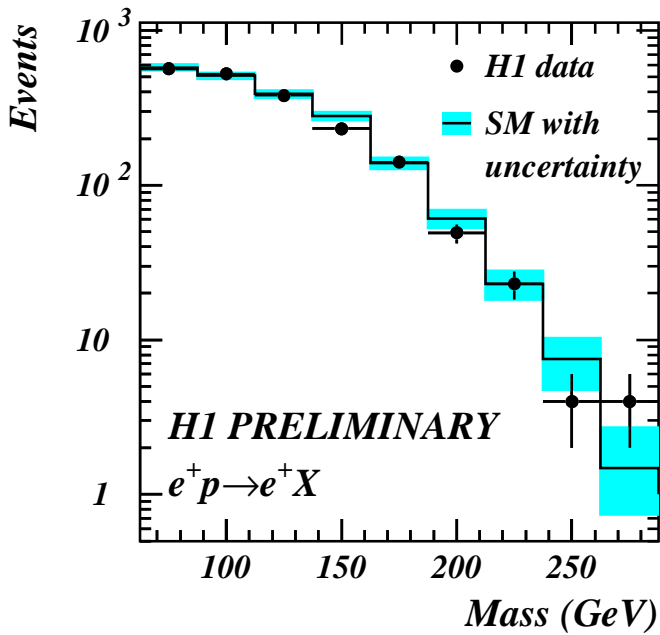
- **excess in 94–97 $e+$jet data not confirmed.**

- **full data set in good agreement with SM**
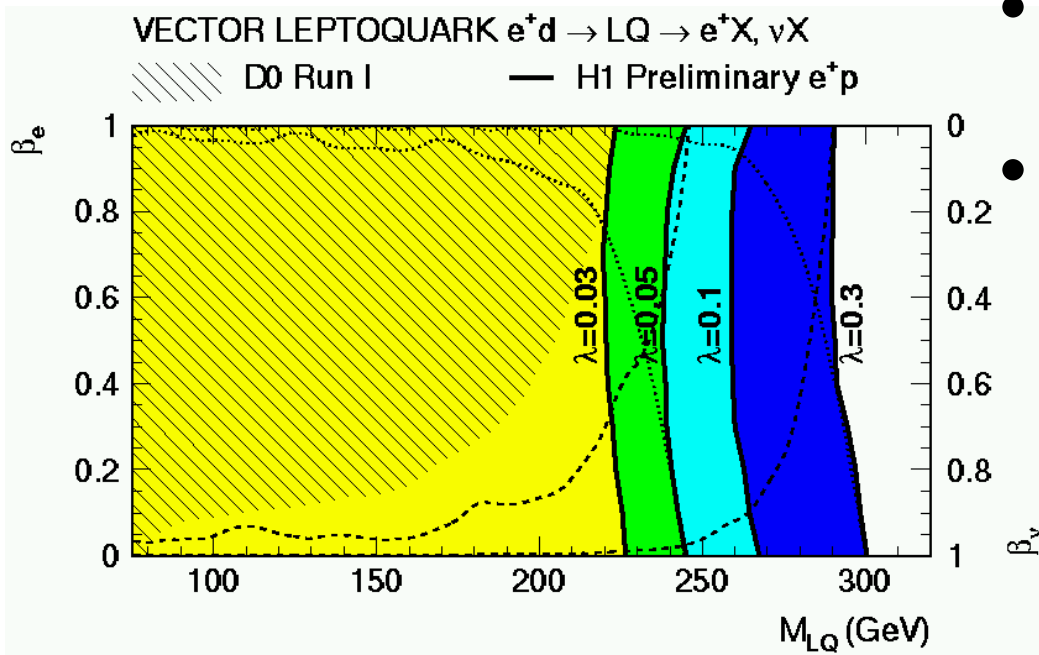
Leptoquarks – Limits

BRW model (β fixed):

- **TeVatron** pair production, independent of λ

- **LEP** t-channel contribution to $e^+ e^- \to$ hadrons, strongly dependent on λ

SCALAR LEPTOQUARKS WITH F=0 ($\tilde{S}_{1/2,L}$)

more general model : β **free,** $\beta(eq) + \beta(\nu q) = 1$
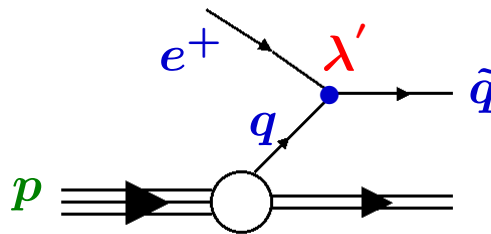

- **limits almost independent of β**

- **HERA limits very stringent for small $\beta(eq)$**

R–Parity violating Supersymmetry

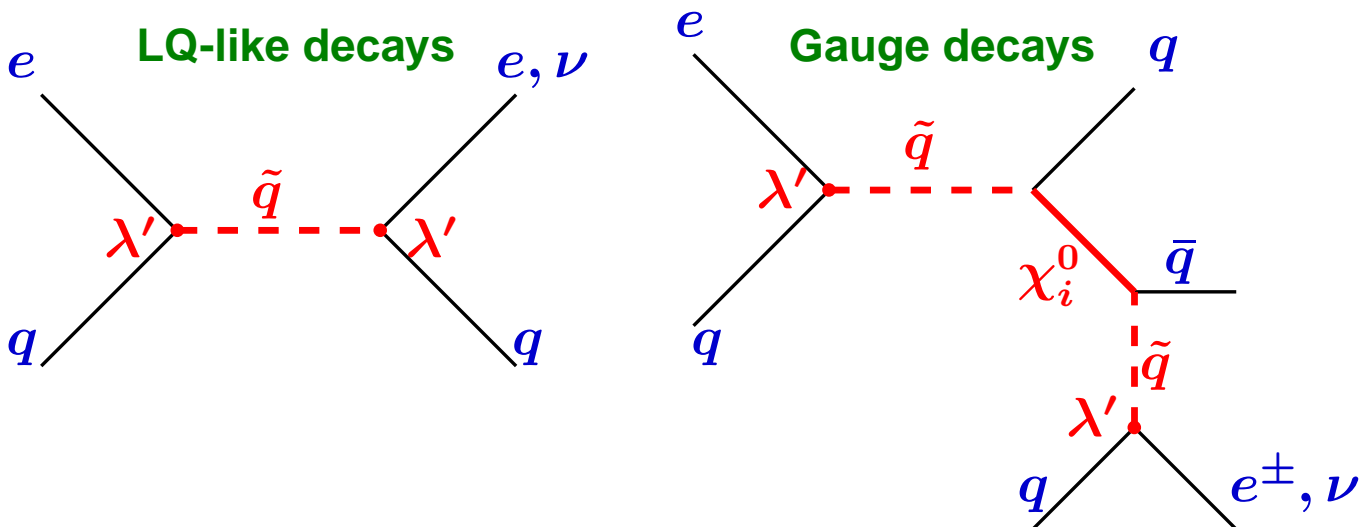- $R_p = (-1)^{3B+L+2S}$ $R_p = +1$: SM particles

                                                $R_p = -1$: SUSY particles

- **most general theory has $\not{R}_p$ term:**

[hep-ex/9211204 and ref. therein]

$$W_{\not{R}_p} = \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$$
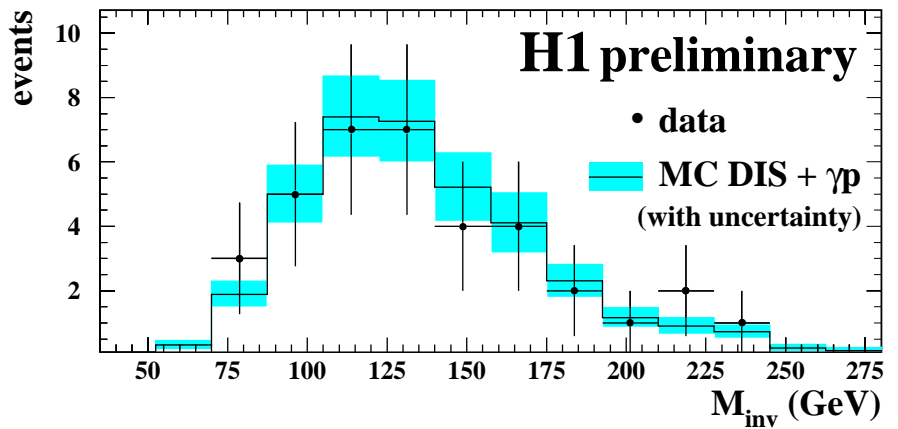

$\hookrightarrow$ **Resonant production of $\tilde{q}$** $\hookrightarrow$ **LSP no more stable**

cascade decays via $\chi^{\pm}/\tilde{g}$ taken into account

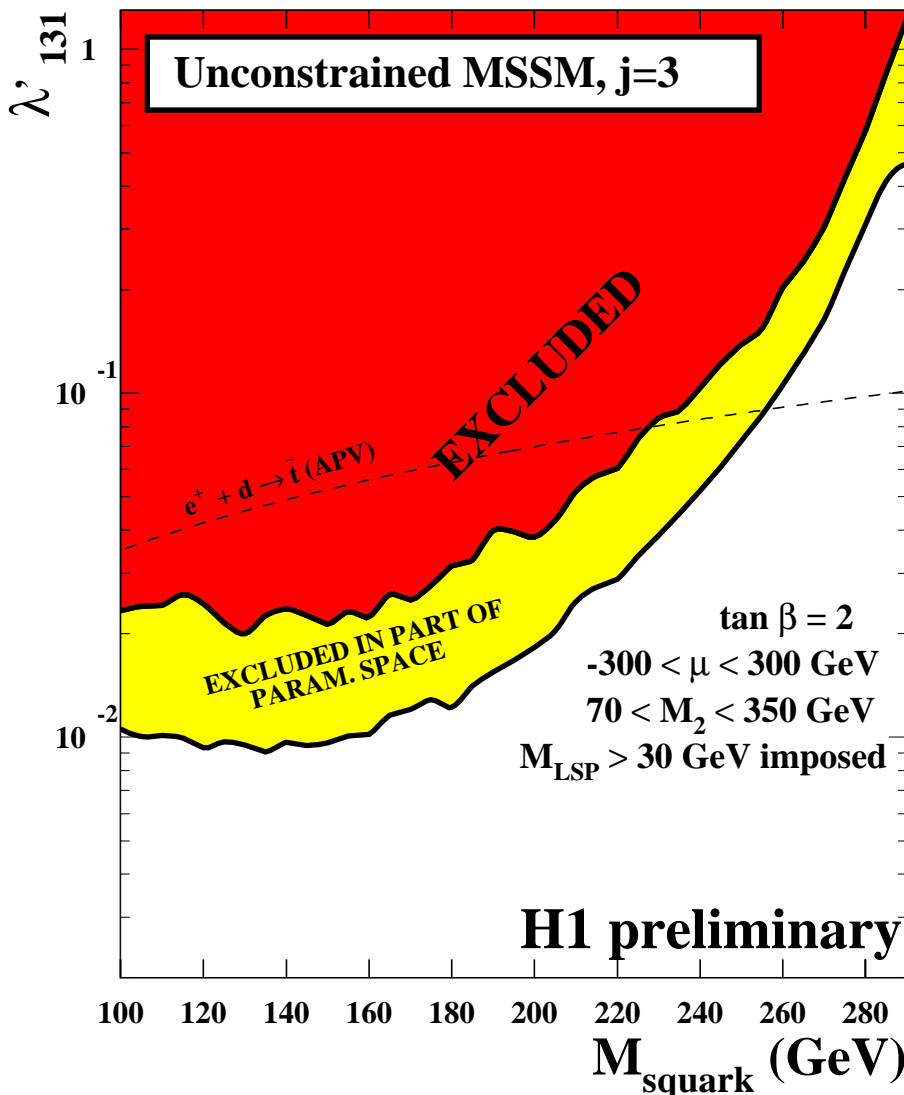$\Rightarrow$ **large variety of final states**

R–Parity violating Supersymmetry

Searches for squarks in R_P viol. SUSY: νMJ channel

- **check all channels:**

  e.g. $\nu + \geq 2$ **jets**

$\Rightarrow$ **no deviation from SM**

H1 preliminary

- data
- MC DIS + γp (with uncertainty)

events

M_{inv} (GeV)

Searches for squarks in R_P viol. SUSY

λ'_{131}

Unconstrained MSSM, j=3

$e^+ + d \rightarrow \tilde{t}$ (APV)

EXCLUDED

EXCLUDED IN PART OF PARAM. SPACE

$\tan \beta = 2$
$-300 < \mu < 300$ GeV
$70 < M_2 < 350$ GeV
$M_{LSP} > 30$ GeV imposed

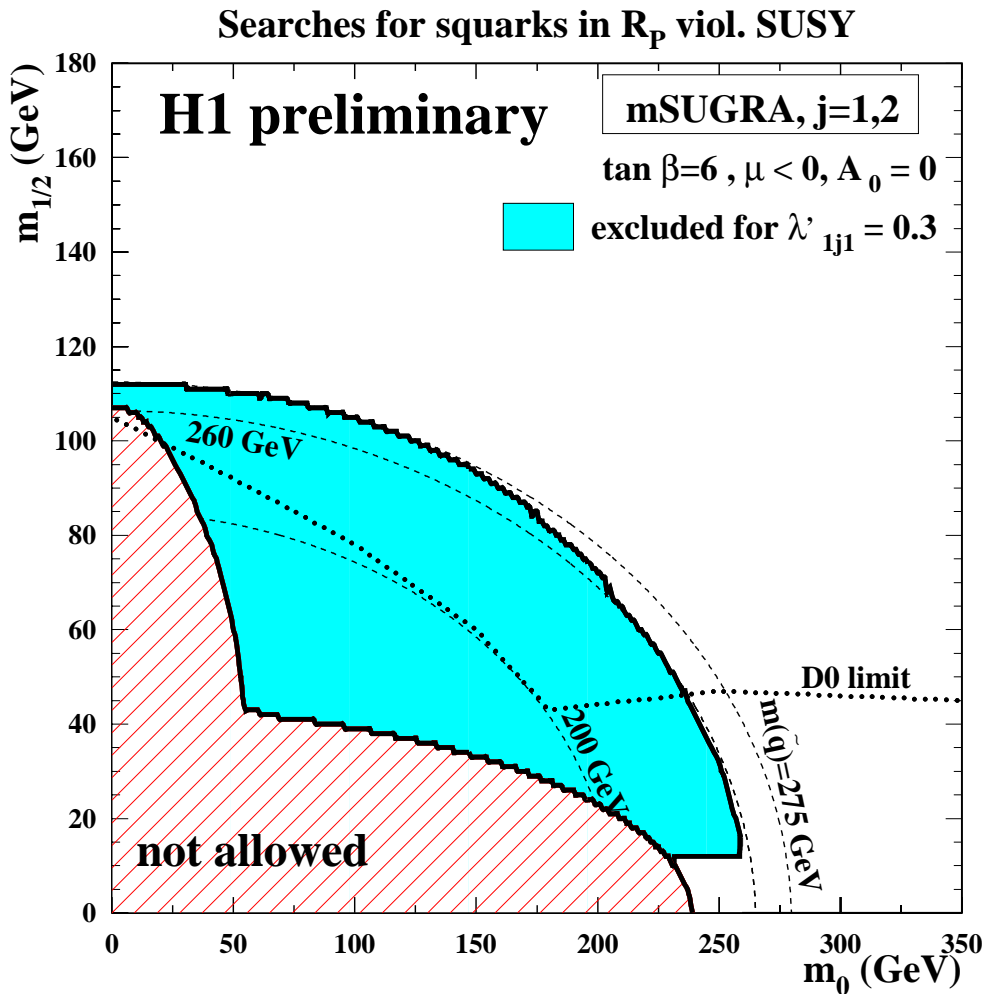**H1 preliminary**

M_{squark} (GeV)

unconstrained MSSM:

sfermion masses free

- **e.g.** $j = 3 \Rightarrow$ **stop**

- **limits widely para-meter independent**

- **masses up to 270 GeV ruled out for $\lambda' = 0.3$**

Limits in $\not{R}_p$ mSUGRA

minimal SUperGRAvity:

- common sfermion (gaugino) mass m_0 ($m_{1/2}$) at GUT scale

Searches for squarks in R_P viol. SUSY

- **HERA sensitivity follows squark mass isocurve**

- **HERA constraints depend on λ'**

- searches at LEP very sensitive. HERA competitive for intermediate values of m_0 for $\lambda'_{131} \neq 0$.

Excited Fermions

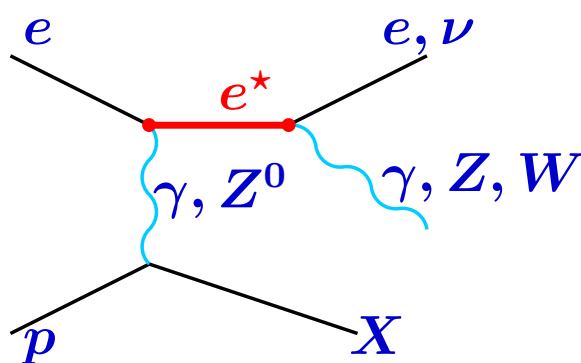- **compositeness of fermions would manifest in excited states** $f^\star$.

- **(De-)excitation of states described by effective Lagrangian:**

  Hagiwara et al.   [Z. Phys. C29 (1985) 115.]

$$\mathcal{L} \propto \tfrac{1}{\Lambda}(f \cdot \mathrm{SU}(2) + f' \cdot \mathrm{U}(1) + f_s \cdot \mathrm{SU}(3))$$
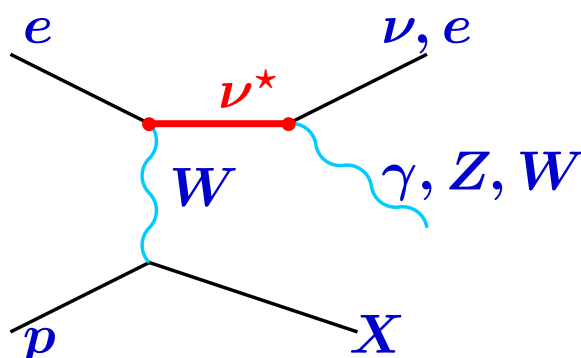
Λ: **Compositeness scale** f, f', f_s: **gauge group weights**

$e^\star$:

- $e^\star \rightarrow e\gamma$
- $e^\star \rightarrow eZ^0_{\hookrightarrow q\bar{q}}$
- $e^\star \rightarrow \nu W_{\hookrightarrow q\bar{q}'}$

$\nu^\star$:

- $\nu^\star \rightarrow \nu\gamma$
- $\nu^\star \rightarrow \nu Z^0_{\hookrightarrow q\bar{q}}$
- $\nu^\star \rightarrow eW_{\hookrightarrow q\bar{q}'}$

$\Rightarrow$ **much higher X-section for** $e^- p$
(W exchange)

Limits on Excited Fermions

- **cross section depends on f, f' and Λ.**

- **usually used:**

$$f = -f'$$

or $f = +f'$

Excited Electron Limits
f = f'
excluded
ZEUS prel.
H1
ADLO (indirect)
LEP preliminary
Delphi, OPAL (direct)

H1 ν^* limits
f=-f'
e^+p
e^-p
LEP (L3)
(a)
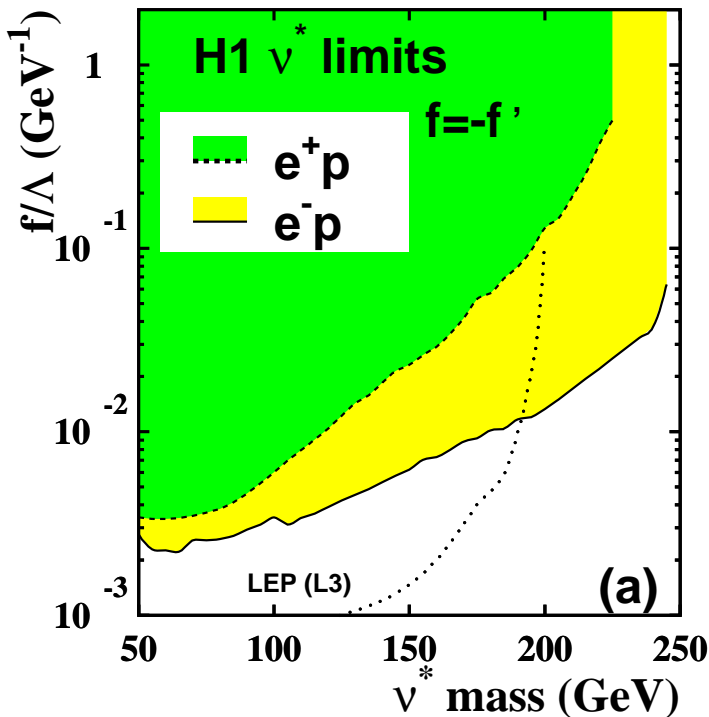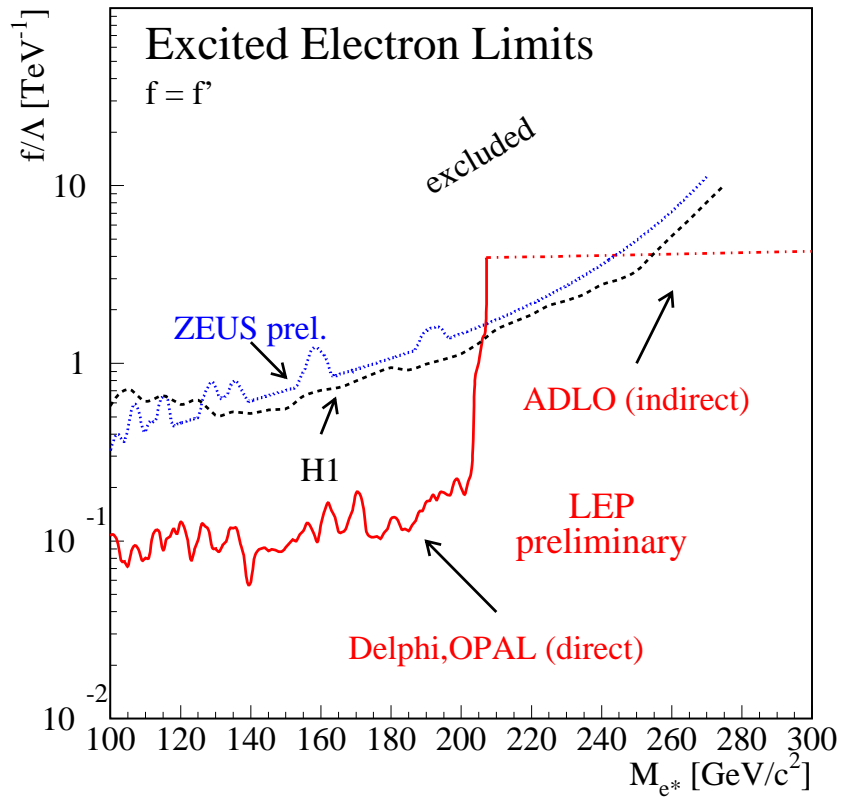
for $\nu^\star$: e^-p data (just $15\,\mathrm{pb}^{-1}$) **give a much larger contribution**

$\Rightarrow$ **substantial improvement expected with HERA II**
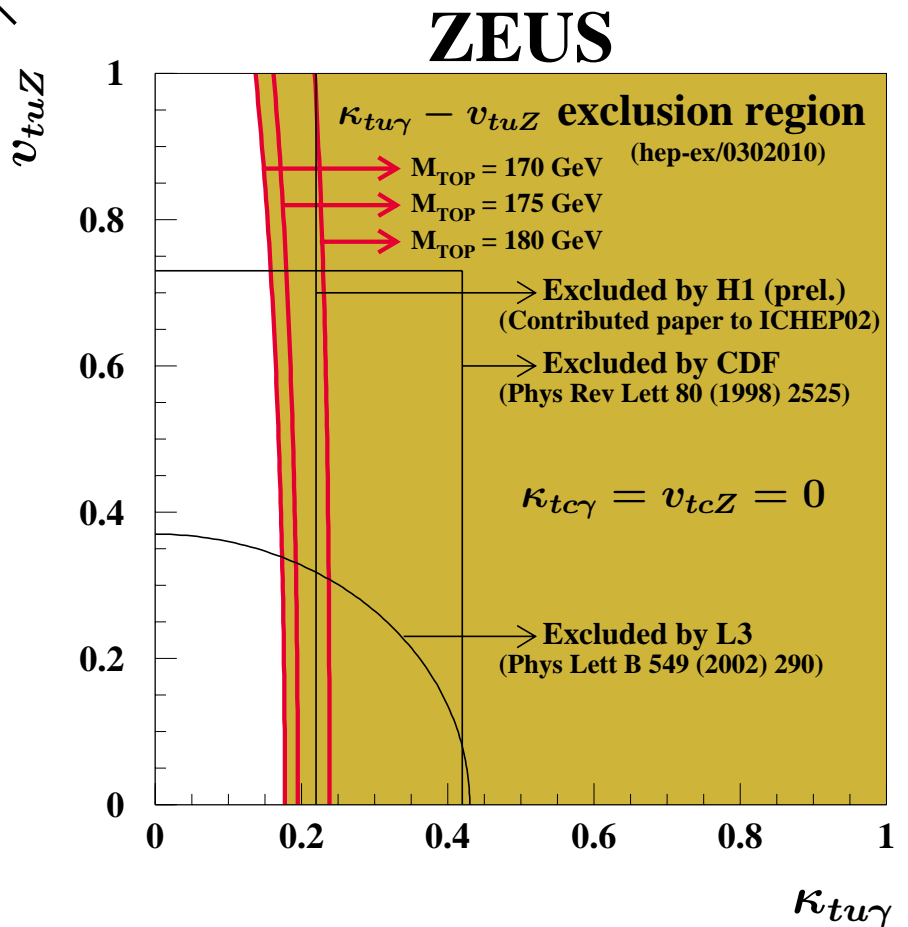
Anomalous (FCNC) single top production

- **H1: excess of events with isolated leptons, p_t^{miss} and hard jet**

  (not confirmed by ZEUS)
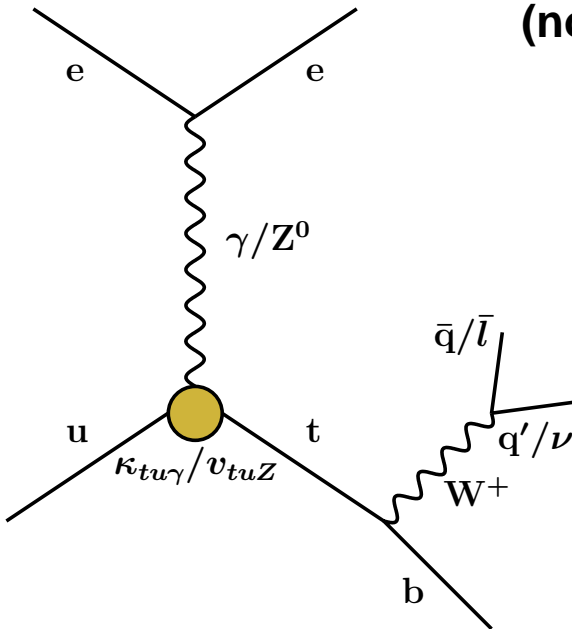
$\Rightarrow$ **signature for top**

- **FCNC vertex $\kappa_{tu\gamma}, v_{tuZ}$**

- **hadr. decay of W conside-red as well (in agreement with SM)**

- **very sensitive to $\kappa_{tu\gamma}$**

- **LEP:**

  $e^+e^- \to \gamma Z \to tu$

- **TeVatron:** rare top decays: $t \to \gamma q, Zq$

ZEUS

$\kappa_{tu\gamma} - v_{tuZ}$ exclusion region

(hep-ex/0302010)

$M_{\mathrm{TOP}} = 170$ GeV
$M_{\mathrm{TOP}} = 175$ GeV
$M_{\mathrm{TOP}} = 180$ GeV

Excluded by H1 (prel.)
(Contributed paper to ICHEP02)

Excluded by CDF
(Phys Rev Lett 80 (1998) 2525)

$\kappa_{tc\gamma} = v_{tcZ} = 0$

Excluded by L3
(Phys Lett B 549 (2002) 290)

Conclusion and Outlook

★ **no signal found and limits derived for several models beyond the SM at HERA**

    ★ **Contact Interaction, Compositeness, Large Extra Dimensions**

    ★ **Leptoquarks**

    ★ **Lepton Flavour Violation**

    ★ R_P **violating supersymmetric models**

    ★ **Excited Fermions**

    ★ **anomalous top production and FCNC**

but: some outstanding events – **multi–leptons and isolated leptons** **– are still puzzling and very exciting !**

    $\longrightarrow$ see talk of T. Carli

★ **prospects for HERA II**

    – **polarisation helps to test specific chiral properties of models beyond the SM**

    – **higher luminosity (in particular $e^- p$) will give significant improvement of limits (e.g. excited neutrinos)**