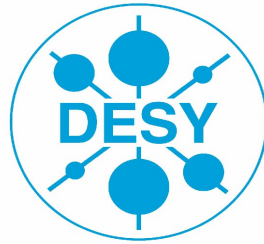
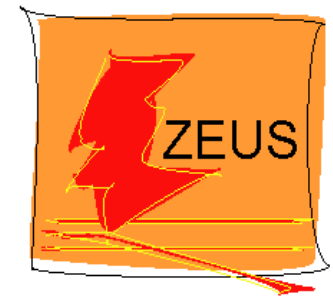


# Searches for New Physics Using Combined H1 and ZEUS Data



Antje Hüttmann (DESY)  
for the H1 and ZEUS collaborations



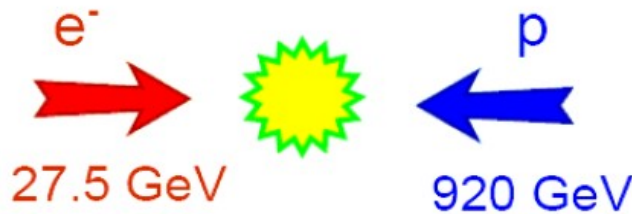
Lake Louise Winter Institute  
February 20, 2010

# Outline

- Contact interactions
- Leptoquarks
- Squark production in RPV SUSY
- Excited fermions
- Isolated leptons and missing  $p_T$
- Anomalous single top production
- Multi-leptons
- General searches

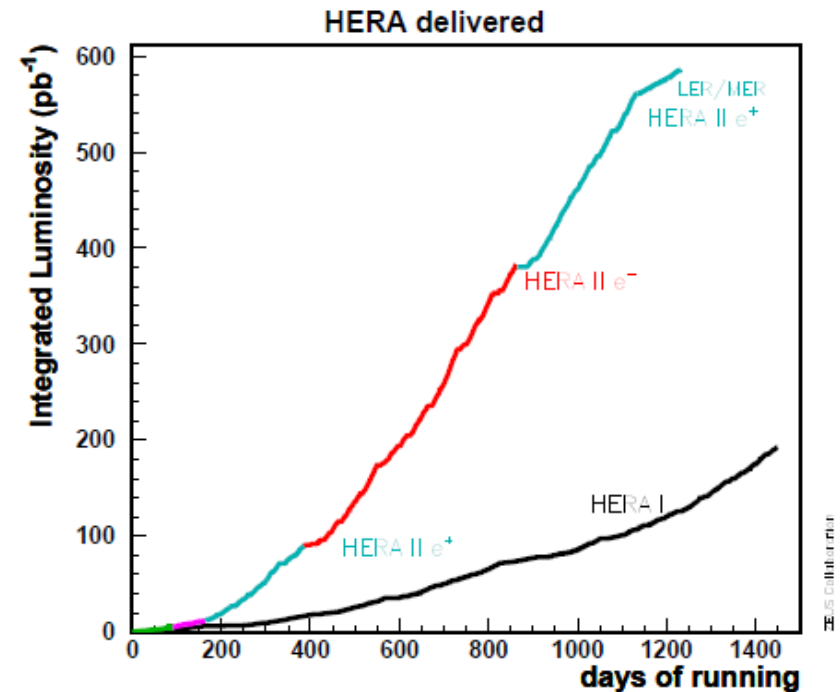
# The HERA Collider

- World's only *ep collider*, located at DESY in Hamburg
- In operation from 1992-2007

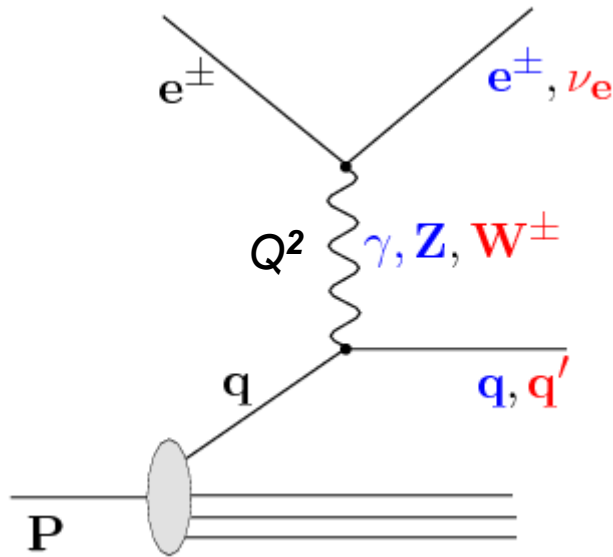


Center of mass energy:  
 $\sqrt{s} = 318 \text{ GeV}$

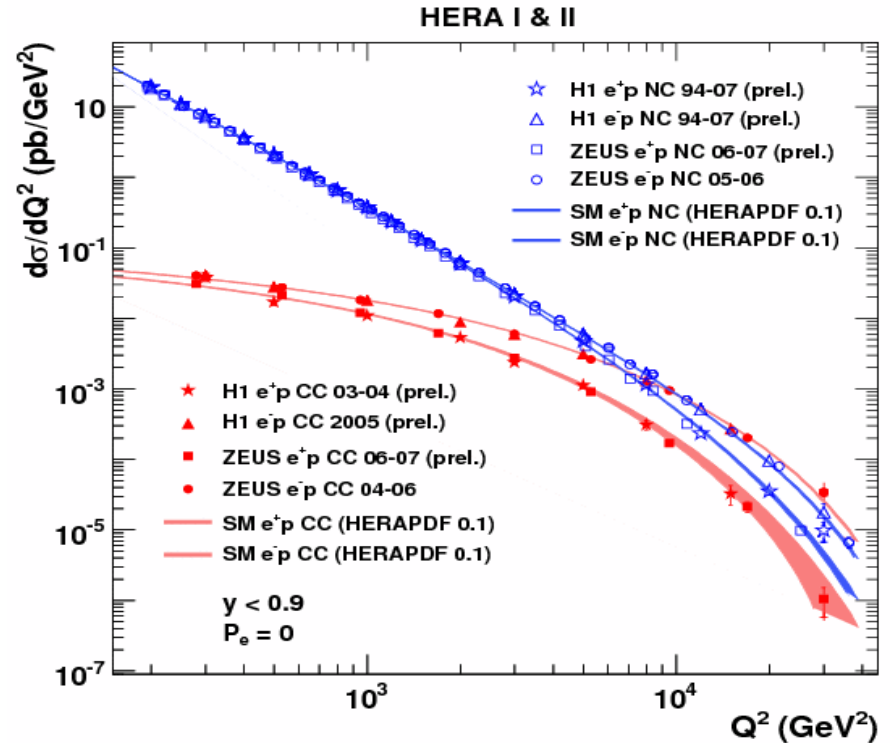
- Lepton beam longitudinally polarized in HERA-II running period (since 2002,  $P \approx 30\text{-}40\%$ )
- Two colliding experiments: H1 and ZEUS
- $0.5 \text{ fb}^{-1}$  of data collected by each experiment



# Deep Inelastic Scattering (DIS)



- **NC:**  $\gamma$  or  $Z$  exchanged,  $e^\pm$  in final state
- **CC:**  $W^\pm$  exchanged,  $\nu_e$  in final state
- $Q^2$  gives the resolving power
- New physics would appear at high  $Q^2$  (i.e. small scale)



- Excellent agreement between data and MC predictions over many orders of magnitude

# Contact Interactions

- **Effective theory** describing low energy effects from physics at much higher energy scales  $\Lambda \gg \sqrt{s}$
- Could **alter SM DIS distributions** at high  $Q^2$
- Vector-type **eeqq CI** described by effective Lagrangian:

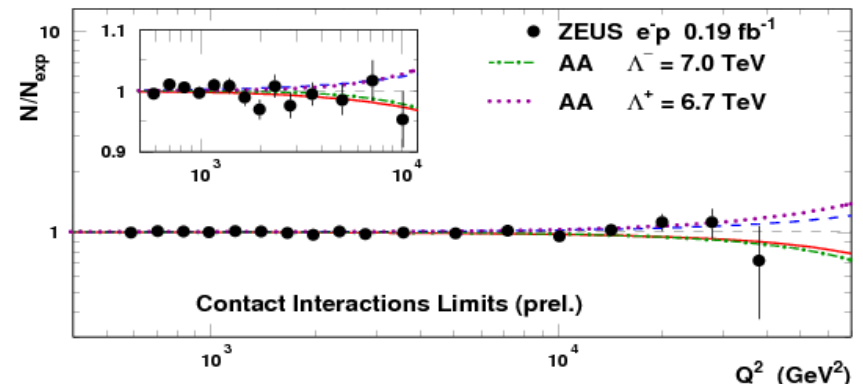
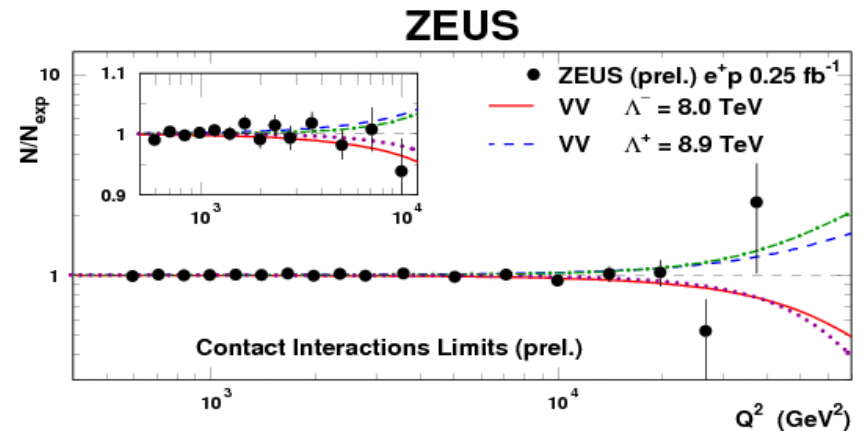
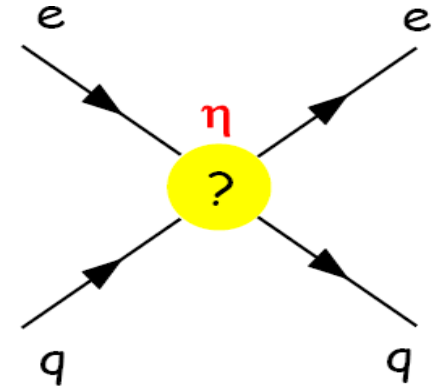
$$\mathcal{L}_{\text{CI}} = \sum_{a,b=L,R}^{q=u,d} \eta_{ab}^q (\bar{e}_a \gamma_\mu e_a) (\bar{q}_b \gamma^\mu q_b)$$

where

$$\eta_{ab}^q = \pm 4\pi / \Lambda^2$$

- Many models possible, depending on **chiral structure**
- No deviations from NC DIS  $\rightarrow$  ZEUS set **limits on 19 models** with different helicity structure ( $L=0.44 \text{ fb}^{-1}$ , prel.):

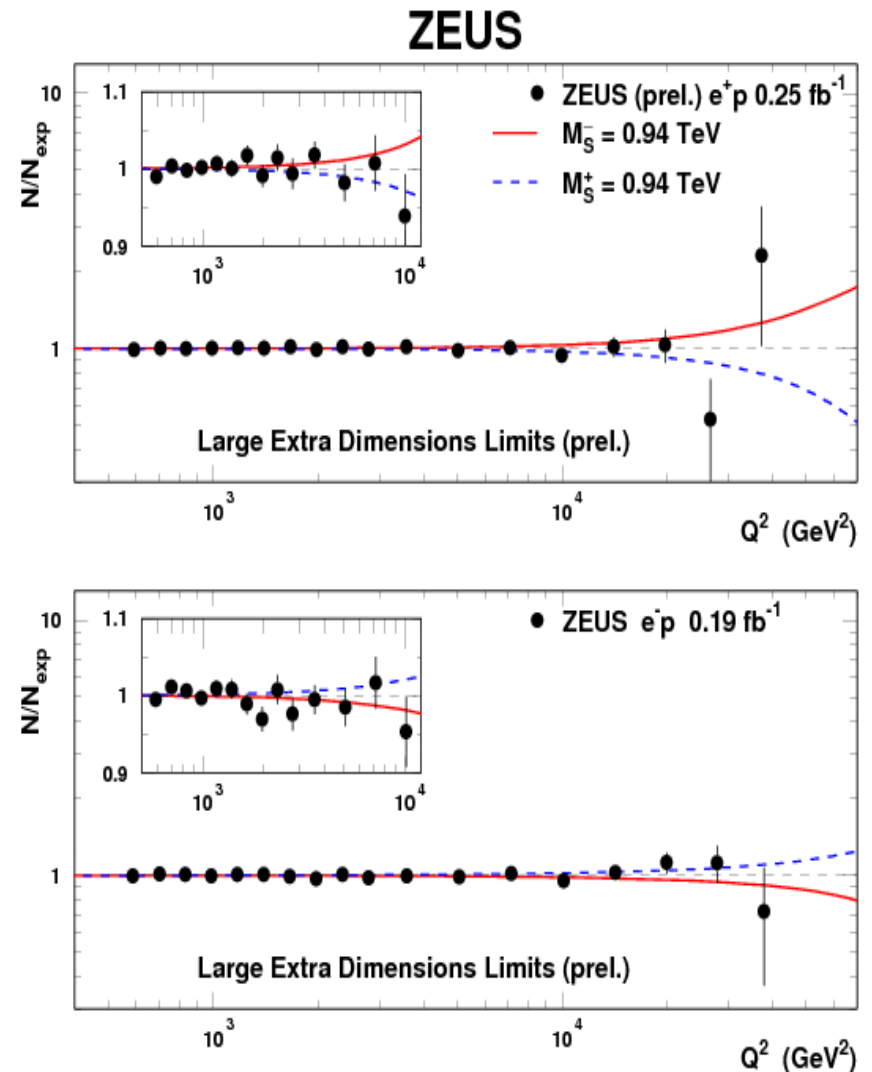
$$\Lambda > 3.8 - 8.9 \text{ TeV} \quad (95\% \text{ CL})$$



# Large Extra Dimensions

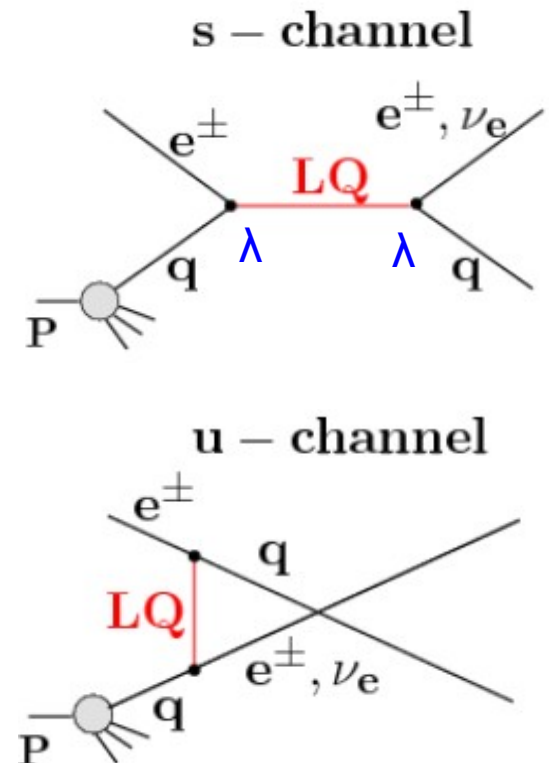
- ADD (Arkani-Hamed, Dimopoulos, Dvali) model: **space time is  $4+n$  dimensional**
- SM particles confined to 4 dimensions, **gravity can propagate into the extra dimensions**
- Fundamental Planck scale  $M_S$  in  $4+n$  dimensions can be of the order of 1TeV
- ➡ **Strength of gravitational and electroweak interactions comparable** at high energies, hierarchy problem solved
- Virtual graviton exchange contribution to  $eq \rightarrow eq$  scattering can be described by a **contact interaction with effective coupling  $\eta_G \sim \pm 1/M_S$**
- ZEUS limit ( $L=0.44 \text{ fb}^{-1}$ , prel.):

$$M_S^+, M_S^- > 0.94 \text{ TeV} \quad \text{independent of } n$$



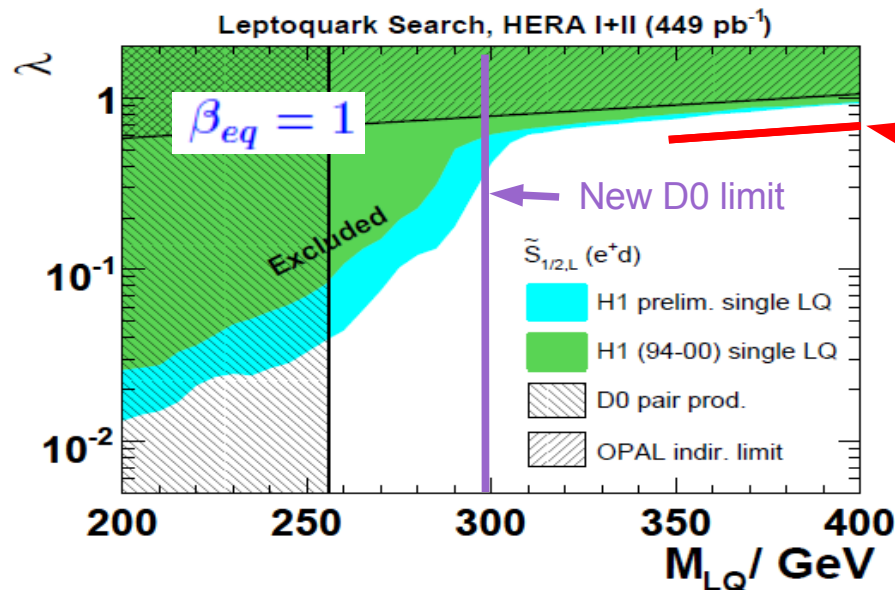
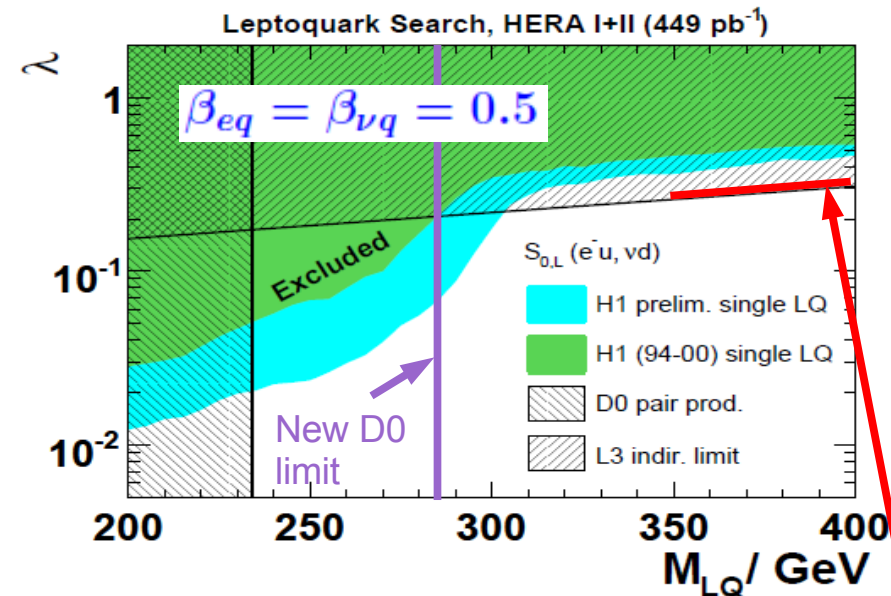
# Leptoquarks (I)

- Scalar or vector **bosons carrying both lepton and baryon number**, color charge and fractional electric charge
  - Buchmüller-Rückl-Wyler model:
    - SM symmetry conserved
    - Lepton and baryon number conserved
  - **Experimental constraints:**
    - LQ couplings flavor diagonal
    - Couple either to LH or to RH fermions
- 7 scalar and 7 vector 1<sup>st</sup> generation LQs



- Heavy LQ exchange can be described by a four fermion **contact interaction** with effective coupling  $\eta \sim \lambda^2/M_{LQ}^2$

# Leptoquarks (II)

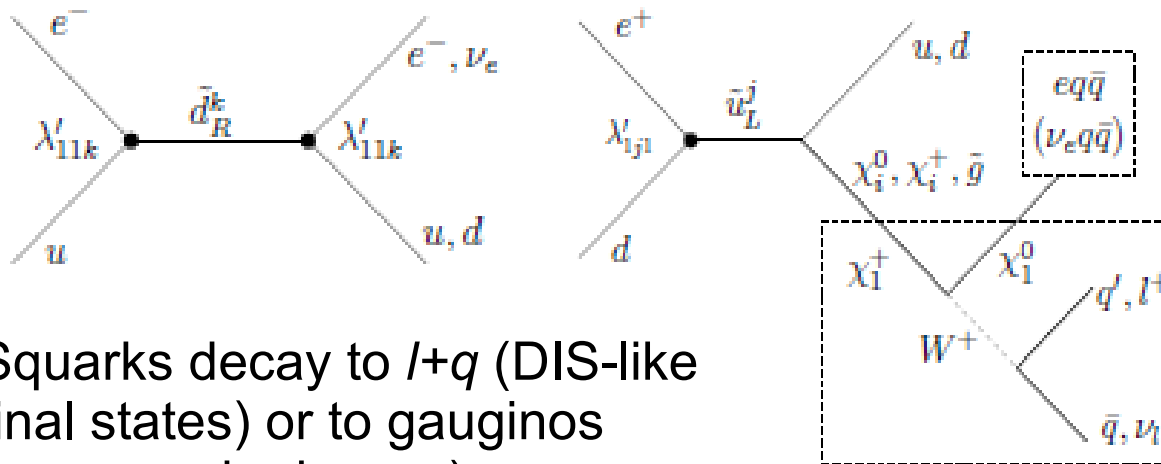


- Full H1 data analyzed for NC/CC-like final states
- No deviations from SM seen
- Limits set on Yukawa coupling  $\lambda$  as a function of the LQ mass (95% CL)
- For  $\lambda = \sqrt{4\pi\alpha} = 0.3$  :  
 $M_{LQ} < 291\text{-}330 \text{ GeV}$  excluded, depending on LQ type
- ZEUS CI limit (94-07 prel.):  
 $M_{LQ}/\lambda > 0.41\text{-}1.88 \text{ TeV}$ , depending on LQ type (95% CL)



# Squark Production in RPV SUSY

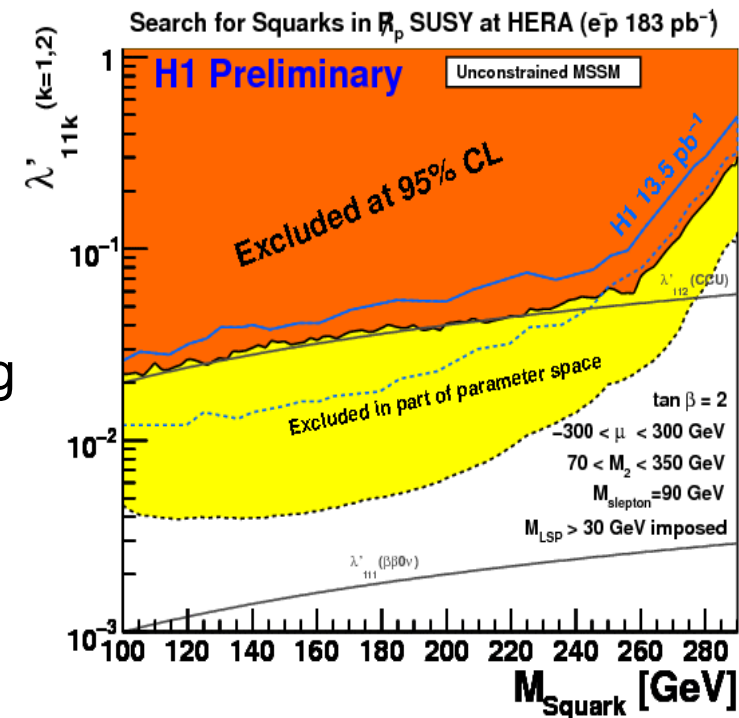
- **R-parity:**  $R_p = (-1)^{L+3B+2S}$
- $R_p = +1$  for SM particles,  $-1$  for SUSY particles
- If RPV: **single resonant squark production** possible in  $ep$  collisions



- Squarks decay to  $l+q$  (DIS-like final states) or to gauginos ( $\rightarrow$  cascade decays)
- **No deviations from SM** observed ( $>90\%$  of branching ratio analyzed)  $\rightarrow$  limits set using full H1 data
- For **1<sup>st</sup> and 2<sup>nd</sup> generation** and  $\lambda' = \sqrt{4\pi\alpha} = 0.3$ :

$$M_{\text{Squark}} < 275 \text{ GeV } (\lambda'_{1j1})$$

$$M_{\text{Squark}} < 290 \text{ GeV } (\lambda'_{11k})$$



# Excited Fermions (I)

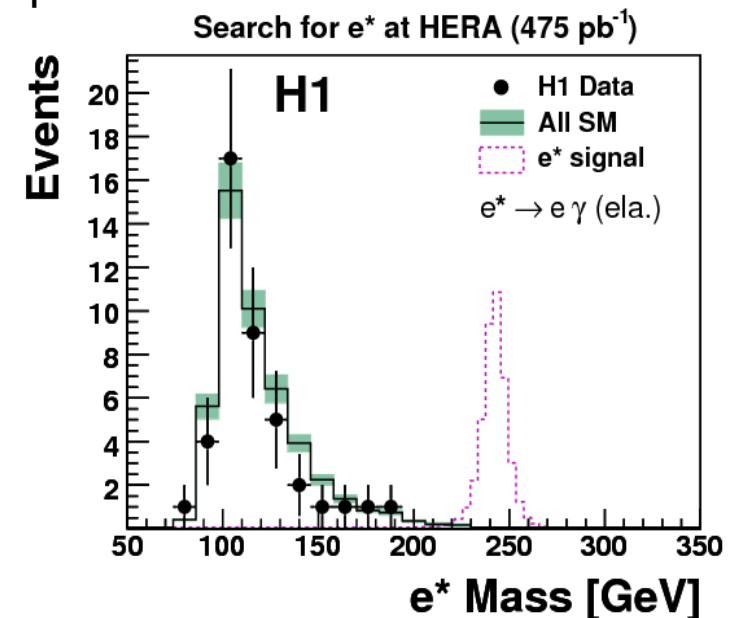
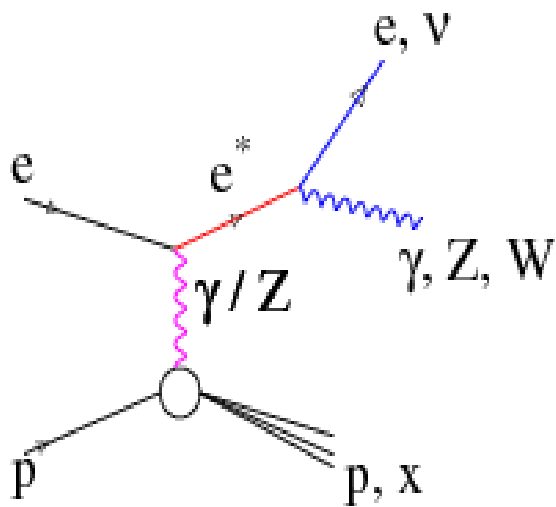
- Observation would be direct **evidence for compositeness**
- Compositeness could explain the three lepton/quark families and their mass hierarchy
- Excitation/de-excitation described by **effective Lagrangian**:

$$\mathcal{L}_{GM} = \frac{1}{2\Lambda} \bar{F}_R^* \sigma^{\mu\nu} \left[ g f \frac{\tau^a}{2} W_{\mu\nu}^a + g' f' \frac{Y}{2} B_{\mu\nu} + g_s f_s \frac{\lambda^a}{2} G_{\mu\nu}^a \right] F_L$$

$\Lambda$ : compositeness scale

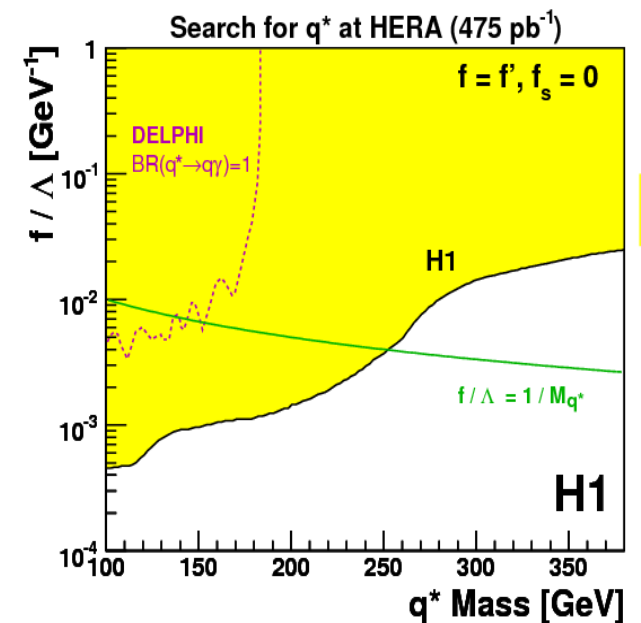
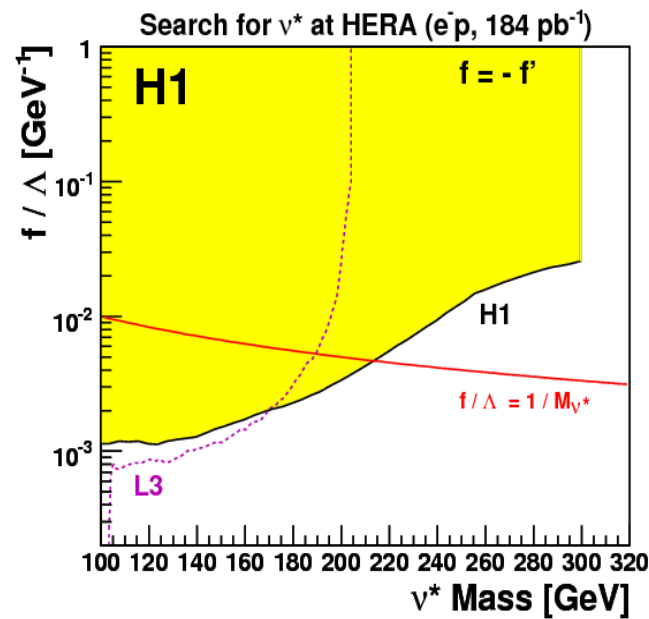
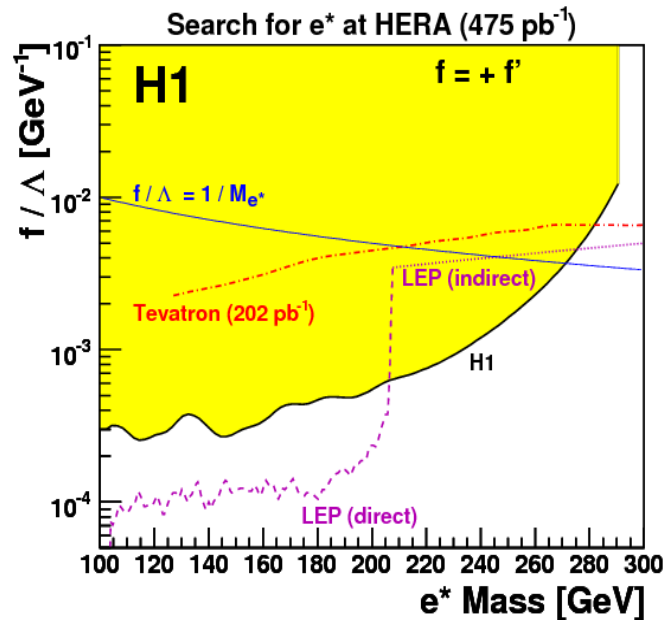
$f, f', f_s$ : coupling parameters associated to SM gauge groups

- Excited fermions decay to standard fermions and **gauge bosons**
- leptonic and hadronic decay channels of gauge bosons investigated



# Excited Fermions (II)

H1 analyzed the full HERA data, **no deviations from SM observed in any channel**  
 → **limits set on  $f/\Lambda$**  as a function of the excited fermion mass (95% CL)



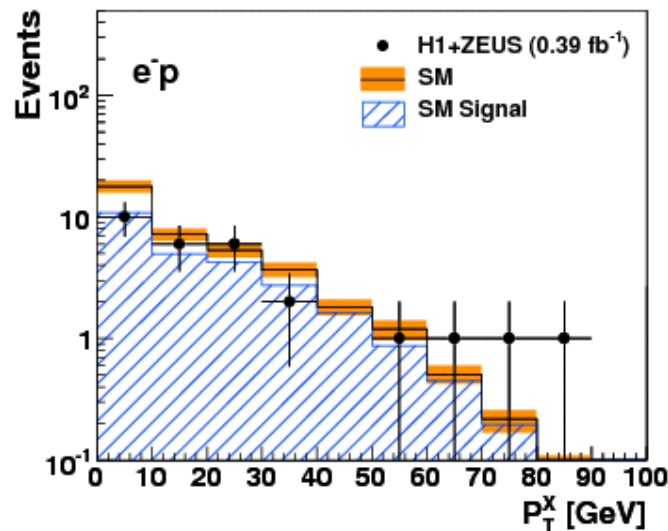
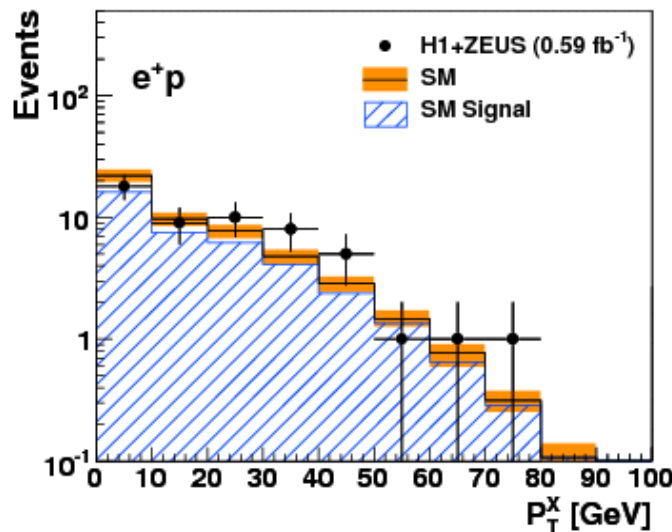
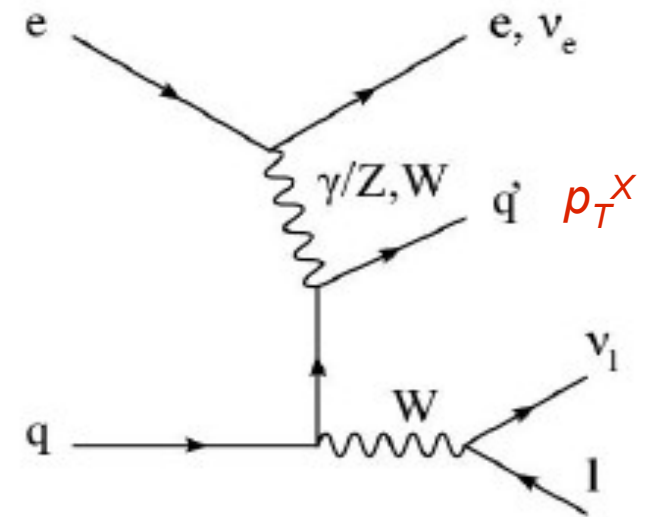
Mass limits **assuming  $f/\Lambda = 1/M_{f^*}$**

- $M_{e^*} > 272 \text{ GeV}$
- $M_{\nu^*} > 213 \text{ GeV}$
- $M_{q^*} > 252 \text{ GeV}$

Tevatron:  
 $q^*$  analyzed  
 assuming  $f_s = 1$

# Isolated Leptons and Missing $p_T$

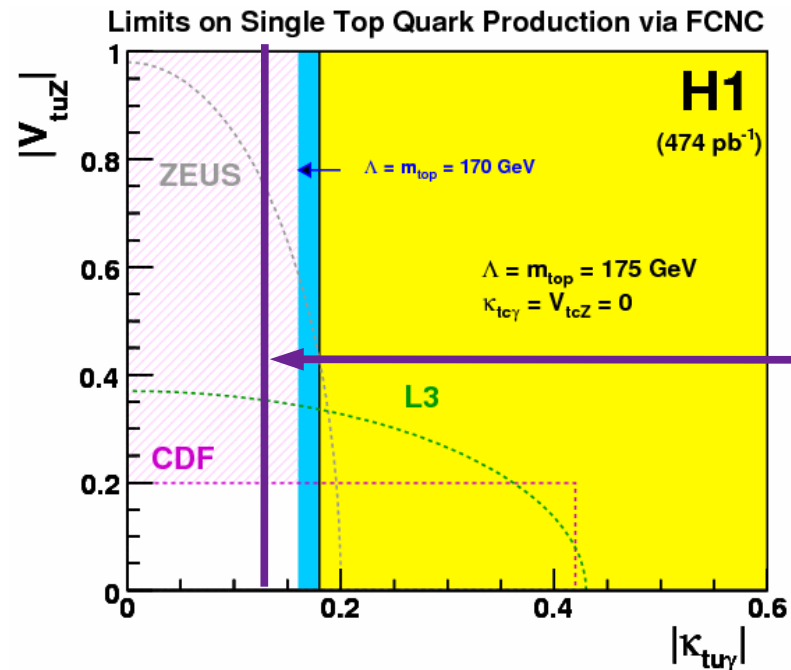
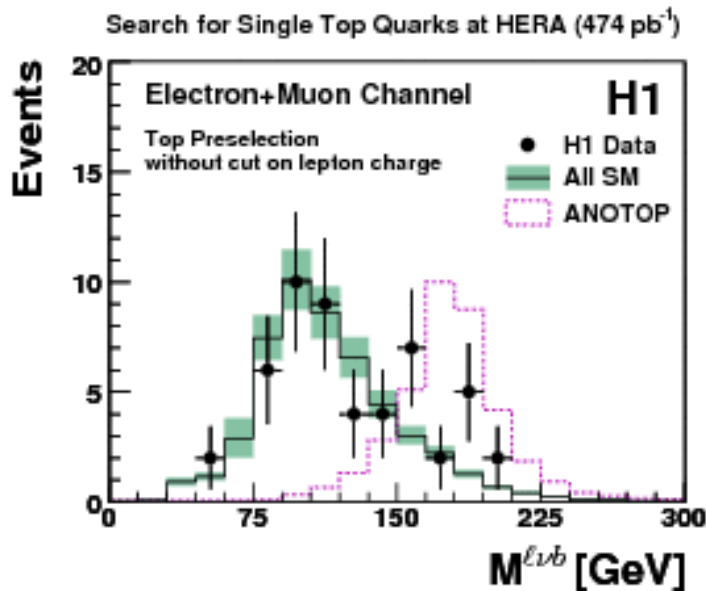
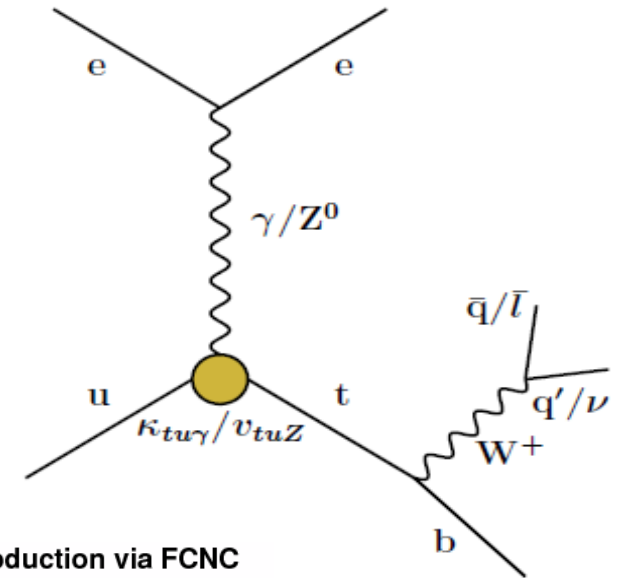
- Look for events with isolated leptons and missing  $p_T$
- Main corresponding **SM process: single  $W$  production**
- **Search for new phenomena:** anomalous single top production, stop decay,...
- H1 and ZEUS results combined,  $L = 0.98 \text{ fb}^{-1}$



- **$e^+p$  data,  $p_T^X > 25 \text{ GeV}$ :**  
23 events observed,  
 $14.0 \pm 1.9$  expected
- No excess in  $e^-p$  data

# Anomalous Single Top Production

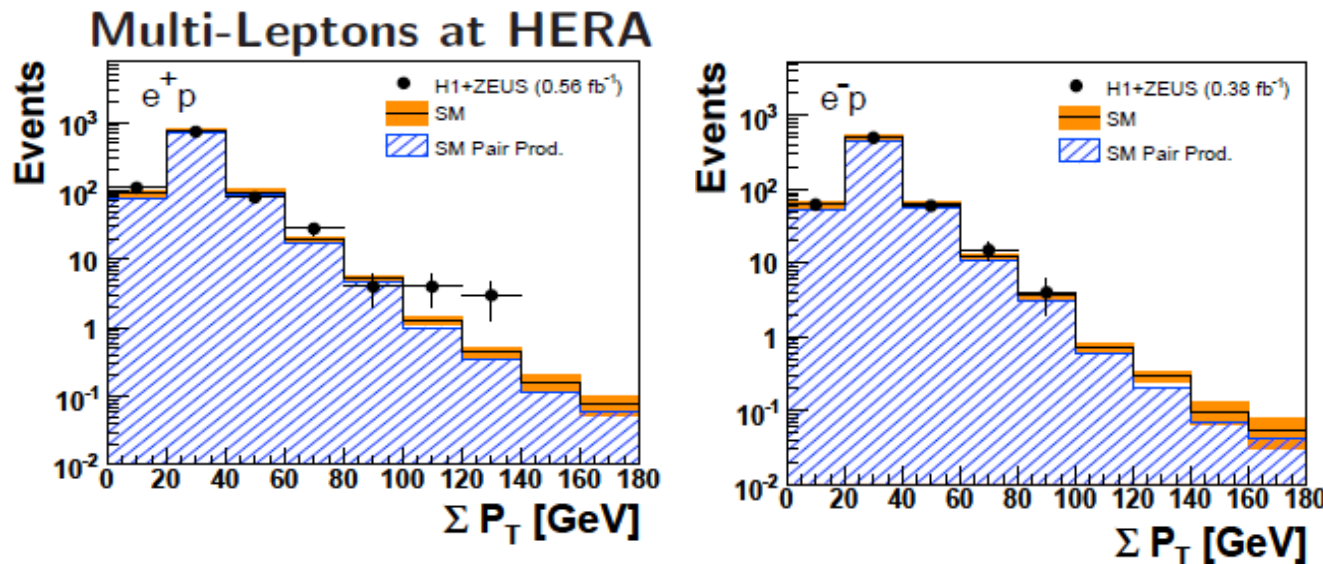
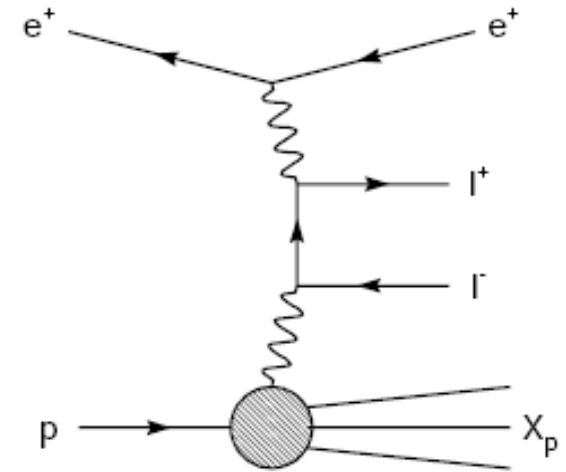
- Top quarks at HERA can only be singly produced
- SM cross section negligible ( $\sigma < 1\text{fb}^{-1}$ ), but production predicted by several BSM theories → **observation would be clear indication of new physics**
- Full HERA data analyzed by both H1 and ZEUS
- No deviations from SM seen → **limits set** on couplings  $\kappa_{tu\gamma}$ ,  $v_{tuZ}$  (95% CL)



ZEUS  
preliminary,  
 $L \approx 0.36\text{ fb}^{-1}$

# Multi-Leptons

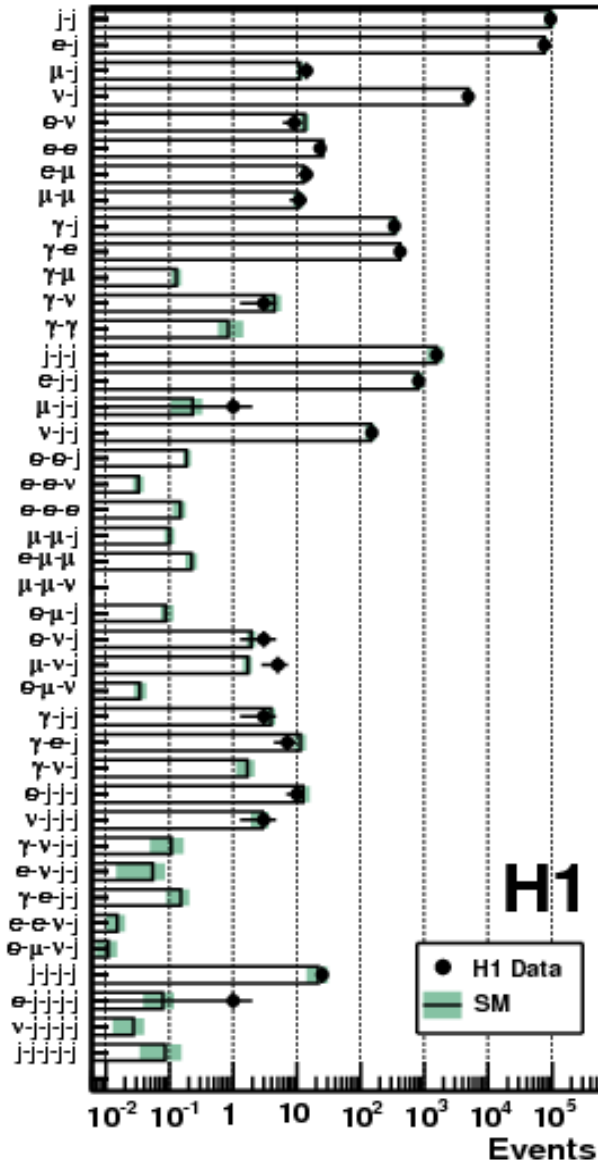
- Look for events with **at least 2 isolated high- $p_T$  electrons or muons** (topologies:  $ee$ ,  $\mu\mu$ ,  $e\mu$ ,  $eee$ ,  $e\mu\mu$ )
- Main production process in **SM:  $\gamma\text{-}\gamma$  interactions**
- SM expectation **small at high invariant mass, high  $p_T$  of the leptons** → look for deviations from SM, would be indication of new phenomena (e.g. exotic resonances such as  $H^{\pm\pm}$ )
- H1 and ZEUS combined their results ( $L=0.94 \text{ fb}^{-1}$ )



- $e^+p$  data,  $\Sigma p_T > 100 \text{ GeV}$ :**  
7 events observed,  
 $1.94 \pm 0.17$  expected
- No excess in  $e^-p$  data

# General Searches

H1 General Search at HERA ( $e^+p$ , 285  $\text{pb}^{-1}$ )



- **Model independent** generic search for final states with  $\geq 2$  **high- $p_T$  objects** ( $e$ ,  $\mu$ , jet,  $\gamma$ ,  $\nu$ ), separately for  $e^+p$  and  $e^-p$  collisions
- Complete H1 data analyzed ( $L=0.46 \text{ fb}^{-1}$ )
- At least one event in 27 topologies
- Events found e.g. in multi-lepton analysis are found again
- **Look for possible deviations from SM** in total event number and in  $\Sigma p_T$  and  $M_{all}$  distributions
- **Statistical analysis** used to quantify the significance of the deviations
- **Good agreement with SM**, all deviations consistent with statistical fluctuations
- Number of fluctuations given the large number of search channels is consistent

# Summary

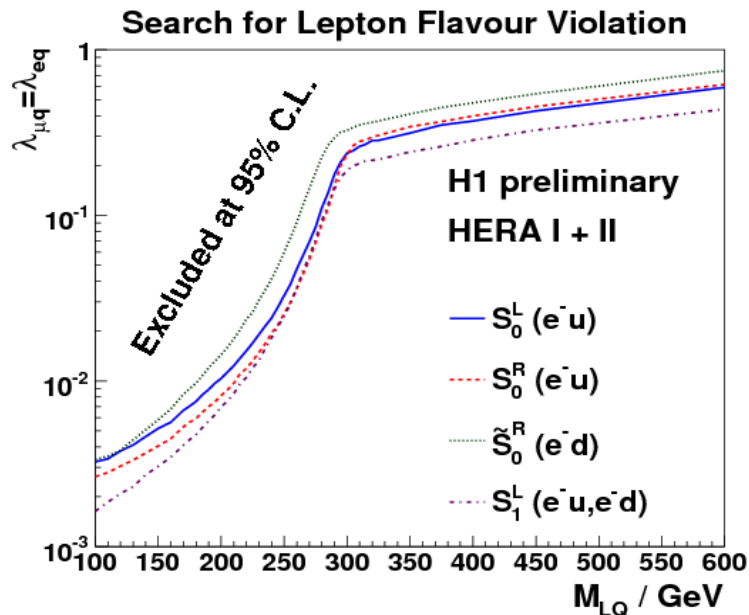
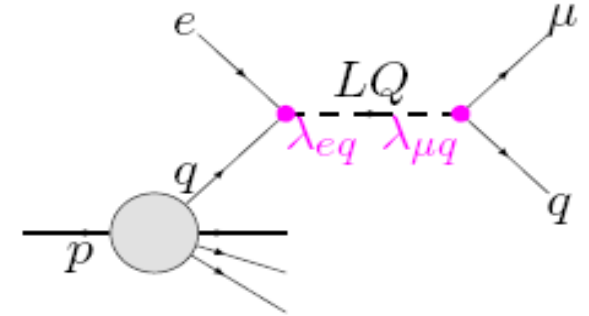
- Searches for new physics have been performed by ZEUS and H1 with the full data sets of  $0.5 \text{ fb}^{-1}$  per experiment
- No deviations from SM observed
- Limits set on various BSM scenarios
- H1 and ZEUS combine their data



# *Backup*

# Lepton Flavor Violation

- If **LQ couplings are not assumed as flavor diagonal**, LQs could couple to more than one fermion generation and **mediate LFV**
- H1 used HERA-I data and HERA-II e- data ( $L=240 \text{ fb}^{-1}$ ) to look for events with a **large transverse momentum final state muon** and at least one jet
- No deviations from SM  $\rightarrow$  limits set on LQs with fermion number  $|F| = |L+3B| = 2$



- Assuming

$$\lambda_{eq} = \lambda_{\mu q} = \sqrt{4\pi\alpha} = 0.3 \quad \text{and} \quad \lambda_{\tau q} = 0 :$$

**$M_{LQ} < 291 - 433 \text{ GeV}$  excluded,**  
depending on LQ type (95% CL)