

# *Searches from ep energy frontier at HERA*

*Hayk Pirumov (PI Heidelberg)  
On behalf of the H1 and Zeus Collaborations*

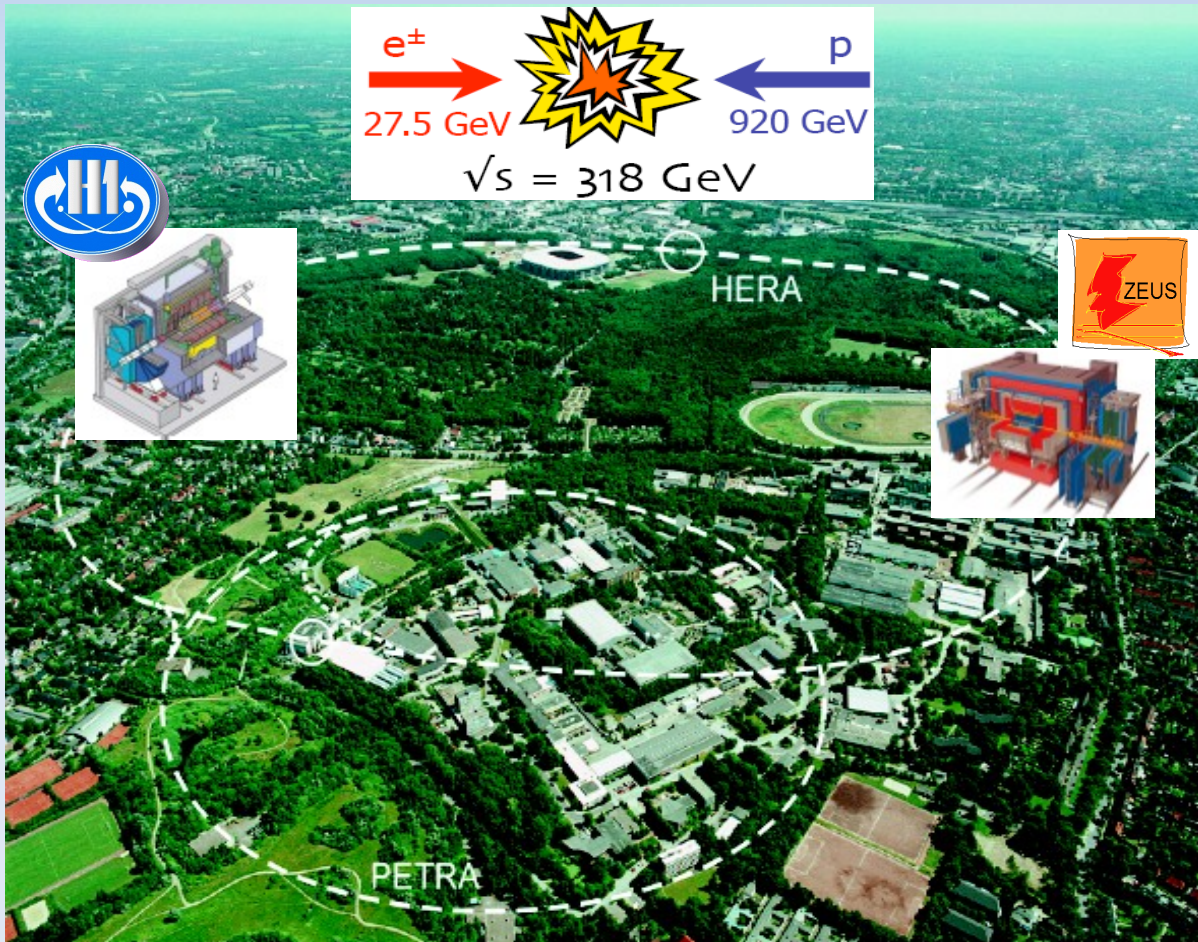


Outline:

- HERA Collider and Experiments
- Search for Contact Interactions (CI)
- First Generation Leptoquarks(LQ)
- Lepton Flavor Violation (LFV)
- Single-top production
- Summary

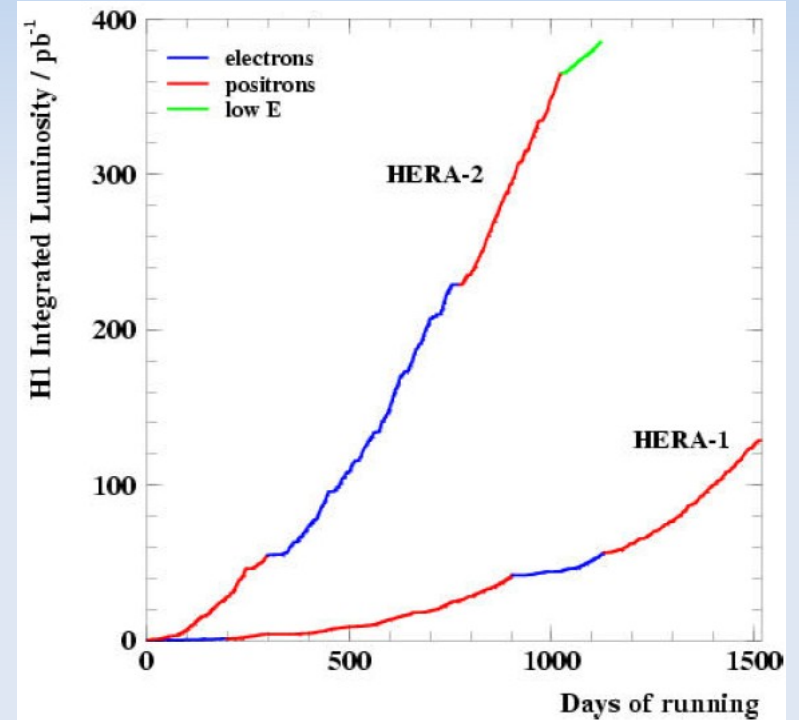
# The HERA Collider

- World's only electron proton collider, at DESY, Hamburg.
- HERA I (1992 – 2000):  $\sim 130 \text{ pb}^{-1}$  / exp, mainly  $e^+p$ .
- HERA II (2003 – 2007): lumi upgrade, longitudinally polarised lepton.



Moriond 2012, La Thuile, March 12

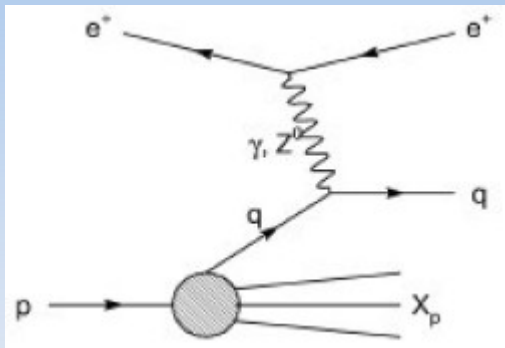
Hayk Pirumov



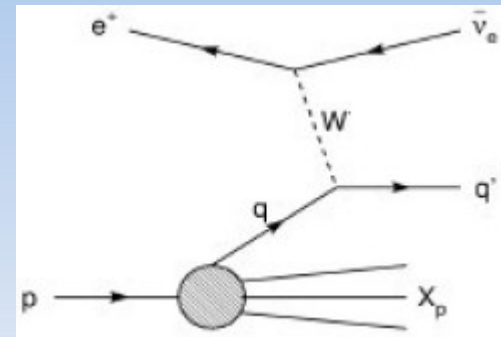
- Two multipurpose detectors: H1 and ZEUS
- About  $0.5 \text{ fb}^{-1}$  of data collected by each of the experiments.

# Deep Inelastic ep Scattering

## Neutral Current (NC)



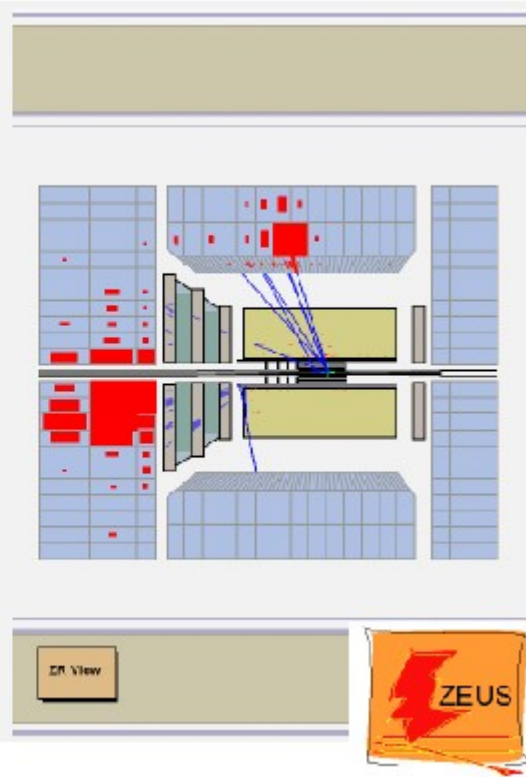
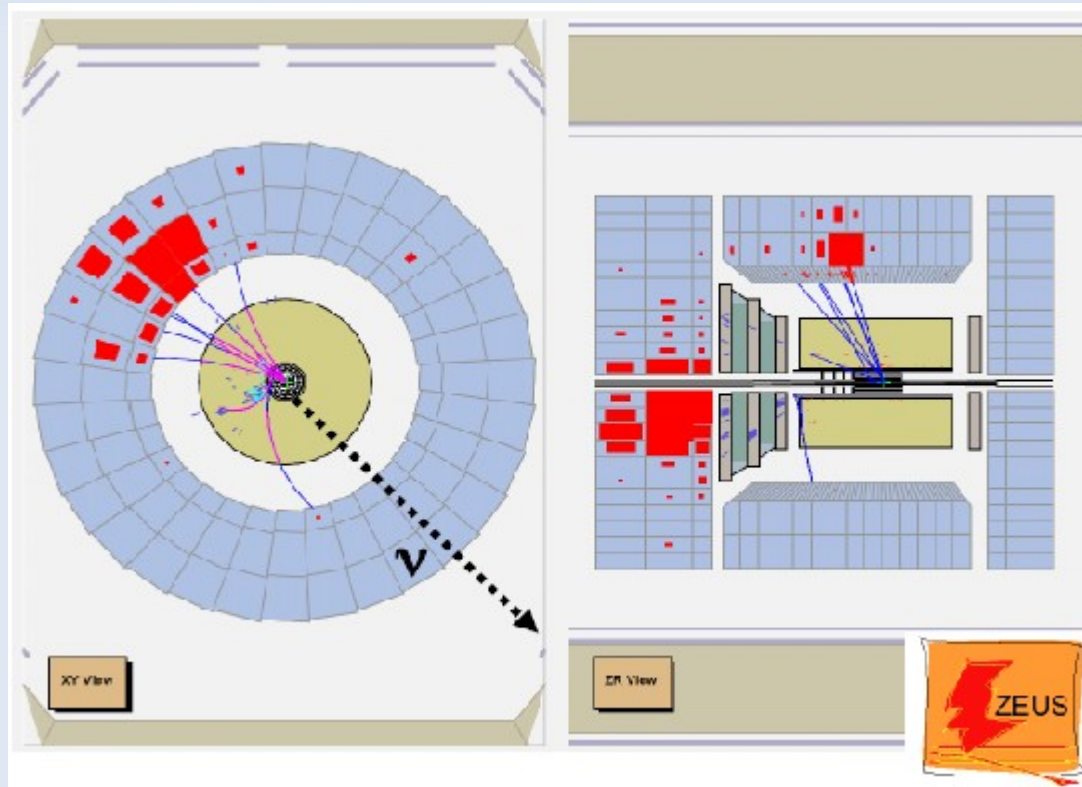
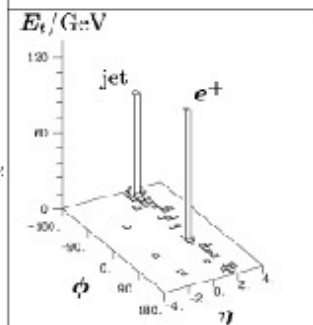
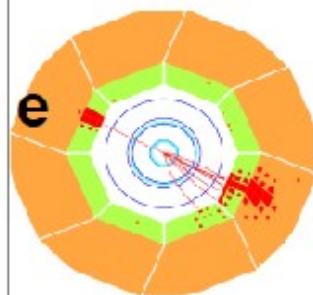
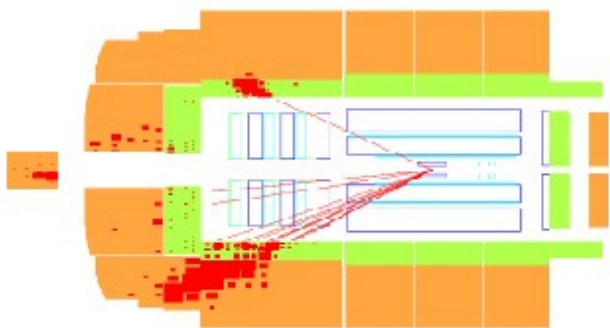
## Charged Current (CC)



H1 Run 122145 Event 69506

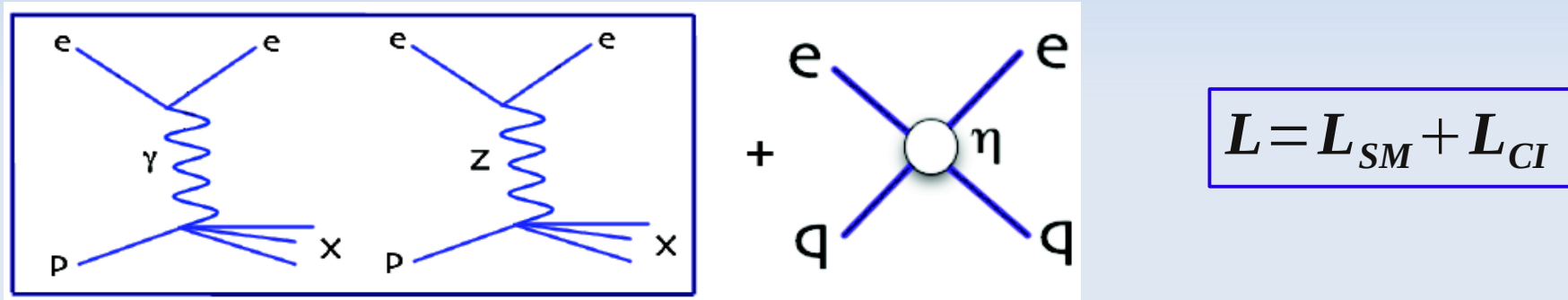
Date 19/09/1995

$Q^2 = 25030 \text{ GeV}^2$ ,  $y = 0.56$ ,  $M = 211 \text{ GeV}$



# Contact Interactions

- Possible new interactions between  $e$  and  $q$  could modify the DIS cross section at high  $Q^2$  via virtual effects.
- **Four-fermion  $eeqq$  contact interactions (CI)** → convenient method to investigate the interference of new fields.



- Effective Lagrangian for neutral current vector-like contact interactions:

$$L_{CI} = \sum_{i,j=L,R} \eta_{ij}^{eq} (\bar{e}_i \gamma_\mu e_i) (\bar{q}_j \gamma^\mu q_j)$$

4 possible couplings for each  $q$  flavor

- Various models can be constructed by appropriate choice of the coupling  $\eta$

# Search for Contact Interactions at HERA

*Phys. Lett. B 705 (2011) 52-58, ZEUS-prel-09-013*

Full HERA neutral current data ( $0.44 \text{ fb}^{-1}$  per experiment) are used to set constraints at 95% CL on various CI models.

## General Compositeness

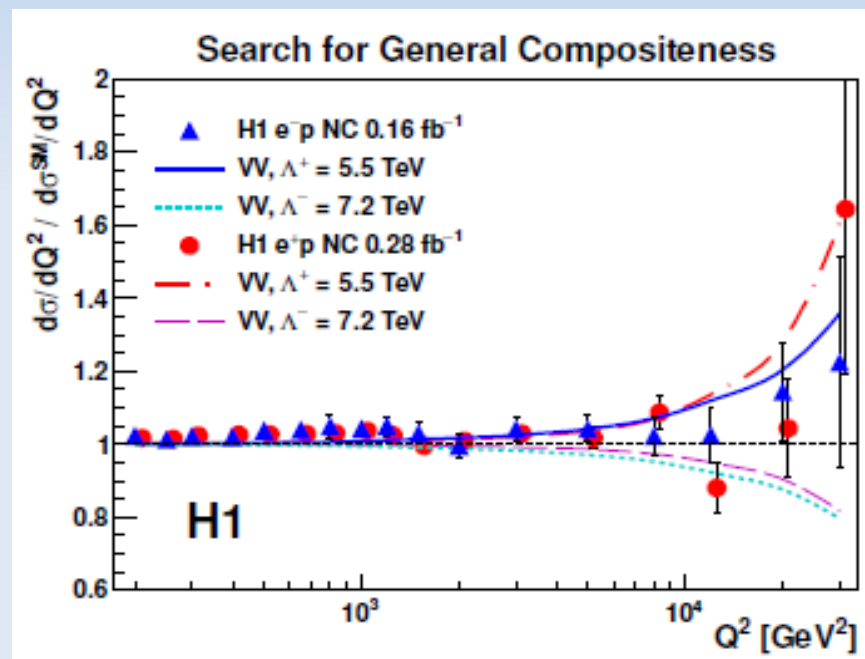
- CI couplings related to the mass scale:

$$\eta_{ab}^{eq} = \frac{\pm 4\pi}{\Lambda^2}$$

- Limit on effective mass scale:

$$\text{H1: } \Lambda > 3.2 - 7.2 \text{ TeV}$$

$$\text{ZEUS: } \Lambda > 3.8 - 8.9 \text{ TeV}$$



# Search for Contact Interactions at HERA

*Phys. Lett. B 705 (2011) 52-58, ZEUS-prel-09-013*

## Quark Radius

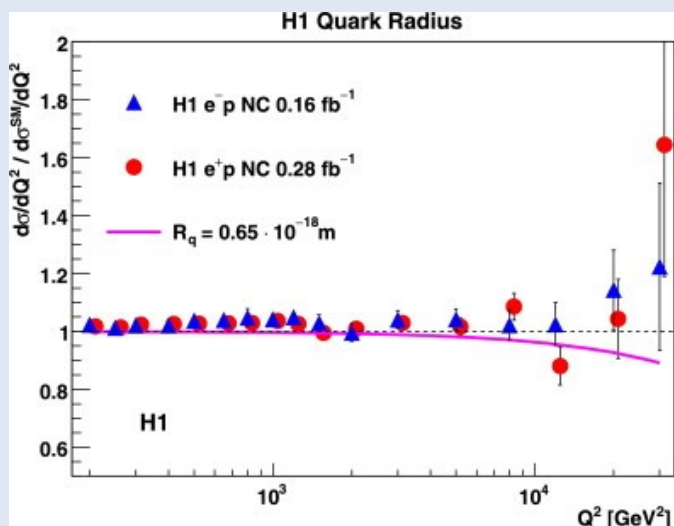
- Assuming spatial distribution of the electroweak charge of quark:

$$\frac{d\sigma}{dQ^2} = \frac{d\sigma_{SM}}{dQ^2} \cdot \left(1 - \frac{R^2}{6} \cdot Q^2\right)^2$$

- Upper limit on quark radius:

**H1:**  $R < 0.65 \cdot 10^{-18} \text{ m}$

**ZEUS:**  $R < 0.63 \cdot 10^{-18} \text{ m}$



Moriond 2012, La Thuile, March 12

## Large Extra Dimensions

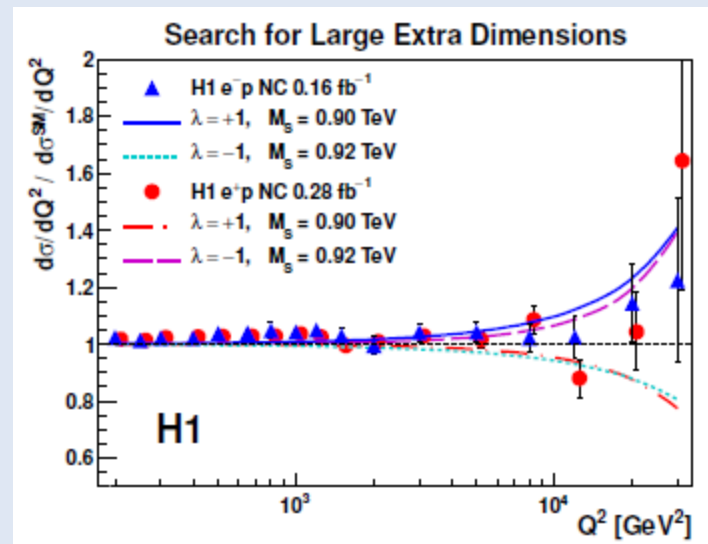
- ADD model:  $4+n$  dimensions.
- Effective CI type coupling with scale  $M_s$ :

$$\eta_G \sim \lambda / M_s^4$$

- Lower limit on gravitational scale:

**H1:**  $M_s > 0.90 - 0.91 \text{ TeV}$

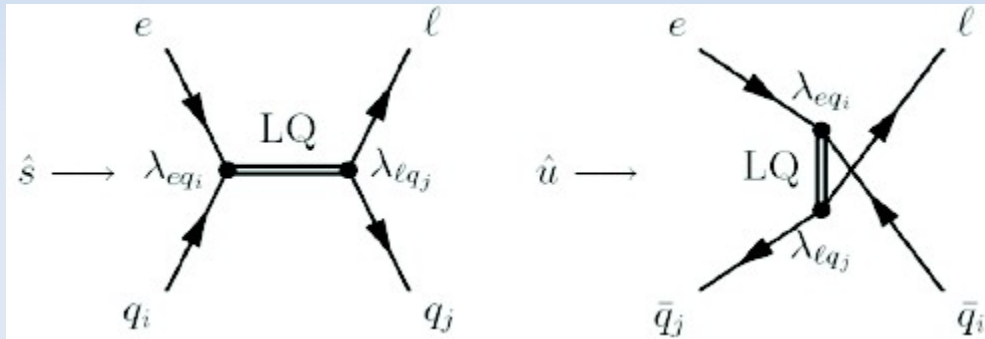
**ZEUS:**  $M_s > 0.94 \text{ TeV}$



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# Leptoquarks at HERA

- Leptoquarks (**LQ**), compound states of leptons and quarks  
 Fermion number  $F = L+3B$        $F = 2 (e^+p)$        $F = 0 (e^+p)$
- Buchmüller-Rückl-Wyler** framework: 14 different types (7 scalar, 7 vector)
- LQ at HERA:



- 1st gen:  $eq \rightarrow LQ \rightarrow e(\nu)q$  (**LQ**)
- 2nd gen:  $eq \rightarrow LQ \rightarrow \mu(\nu)q$  (**LFV**)
- 3rd gen:  $eq \rightarrow LQ \rightarrow \tau(\nu)q$  (**LFV**)

s-channel:  
(resonant production)

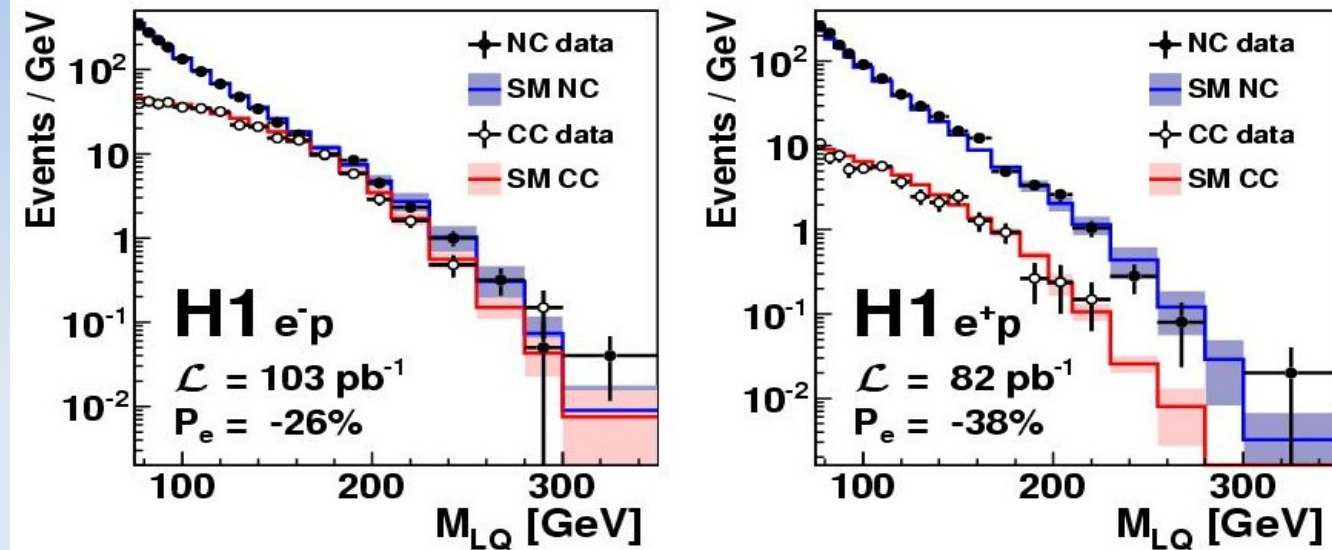
u-channel:  
(LQ exchange)

- Signature is similar to NC or CC DIS.
- Leptoquarks are chiral particles → additional sensitivity at HERA due to polarised lepton beam

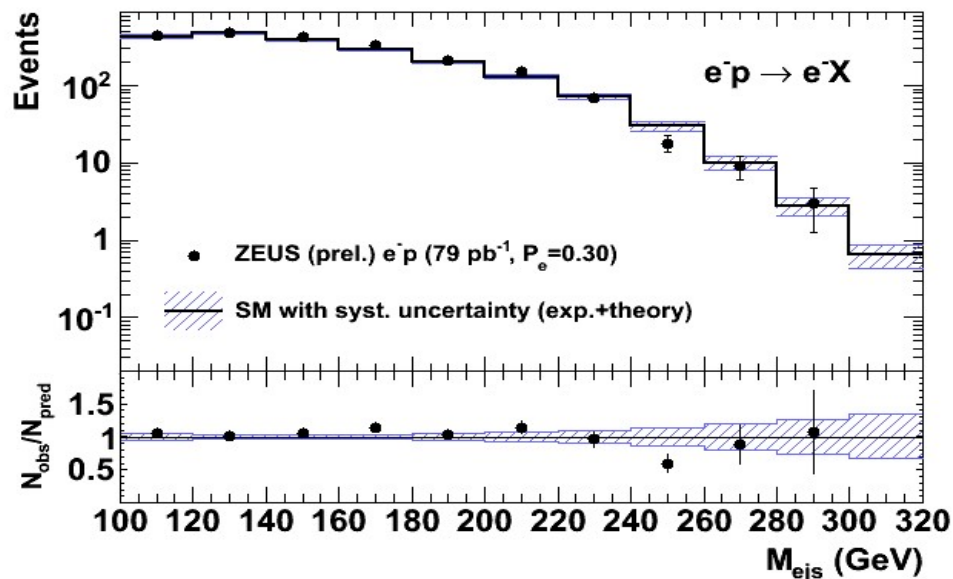
# Search for First Generation LQs

*Phys. Lett. B 704 (2011) 388-396, ZEUS-prel-11-008*

## H1 Search for First Generation Leptoquarks



ZEUS



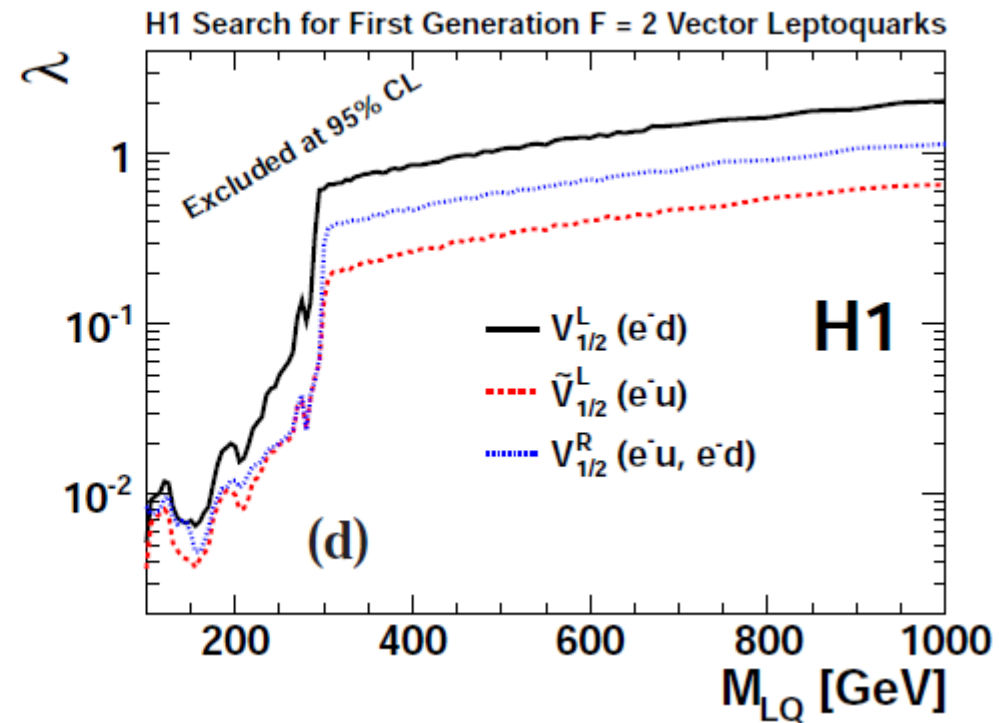
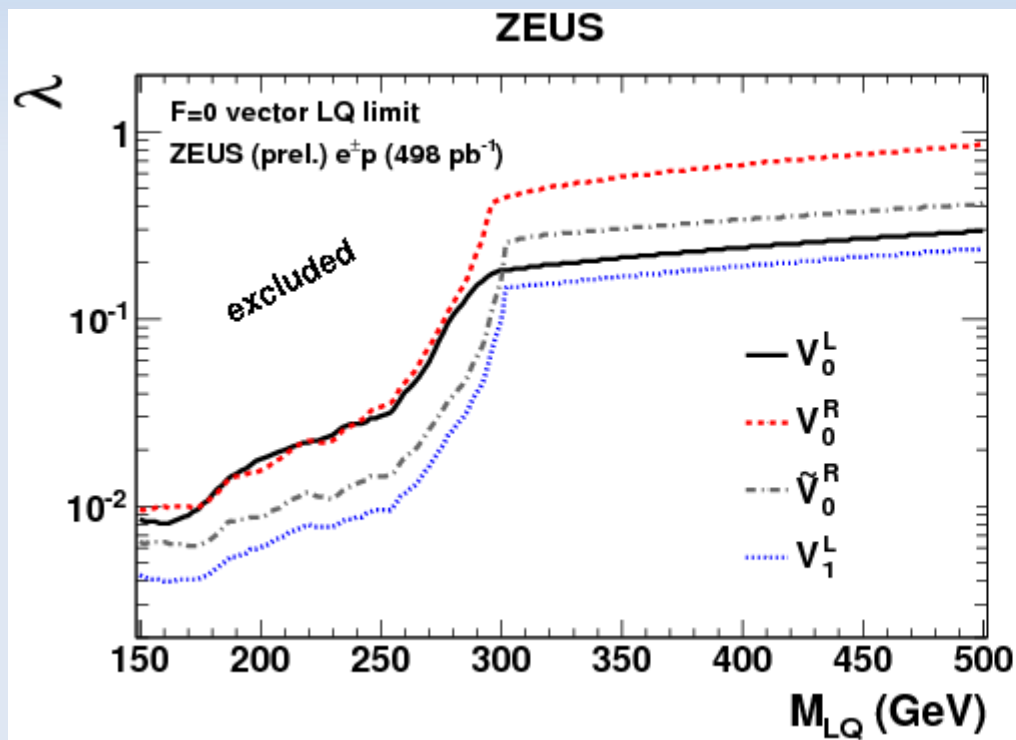
- Full HERA NC and CC data were analysed by H1 and ZEUS
- No evidence for LQ signal found → results are interpreted in terms of exclusion limits.



# Search for First Generation LQs

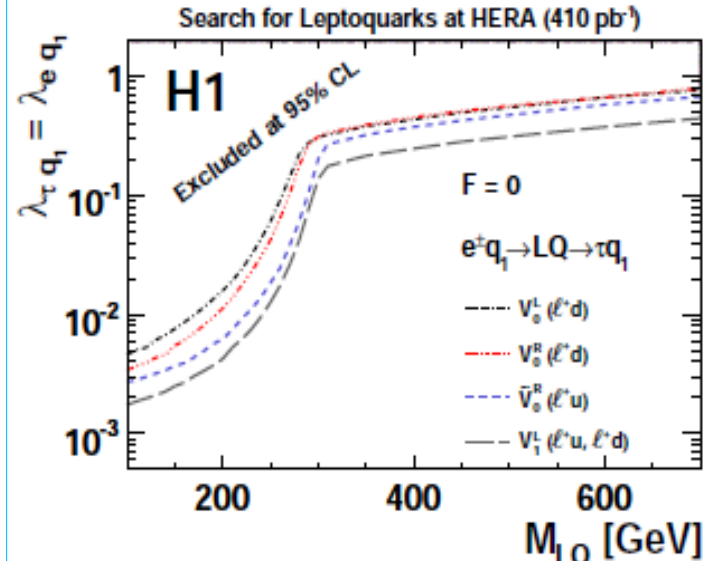
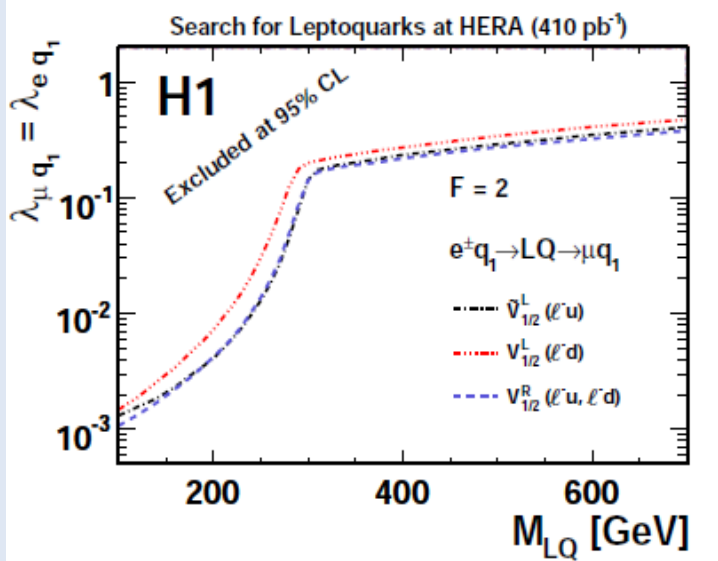
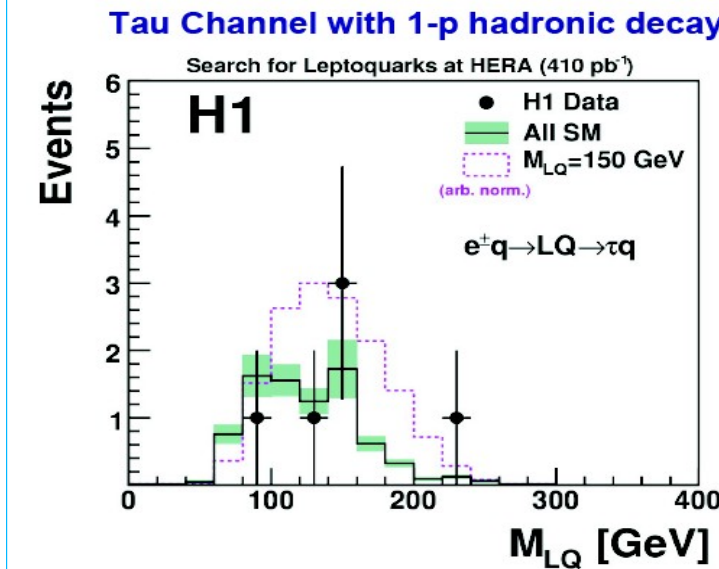
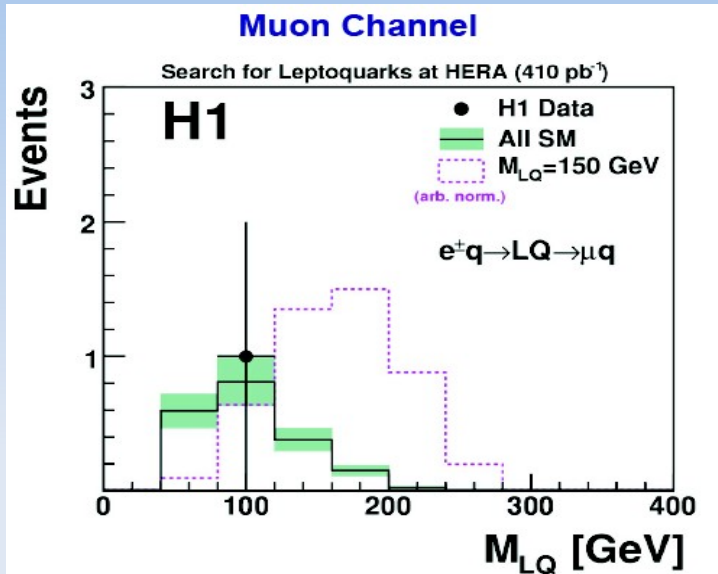
*Phys. Lett. B 704 (2011) 388-396, ZEUS-prel-11-008*

- The exclusion ranges for vector type leptoquarks from ZEUS and H1.
- $e q \rightarrow LQ \rightarrow e(\nu)q$  excluded by ZEUS up to 630 GeV for  $\lambda = 0.3$  (EM coupling strength) and by H1 up to 800 GeV.



# Search for LFV: Second and Third Generation LQs

DESY 11-044, arXiv:1103.4938

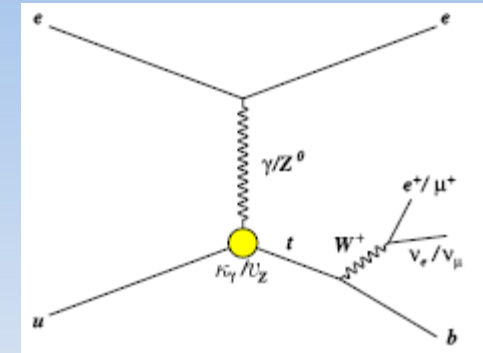


- No evidence for LQ signal found → results are interpreted in terms of exclusion limits.
- $e q \rightarrow LQ \rightarrow \mu(\nu)q$  excluded up to 712 GeV for  $\lambda = 0.3$ .
- $e q \rightarrow LQ \rightarrow \tau(\nu)q$  excluded up to 479 GeV for  $\lambda = 0.3$ .

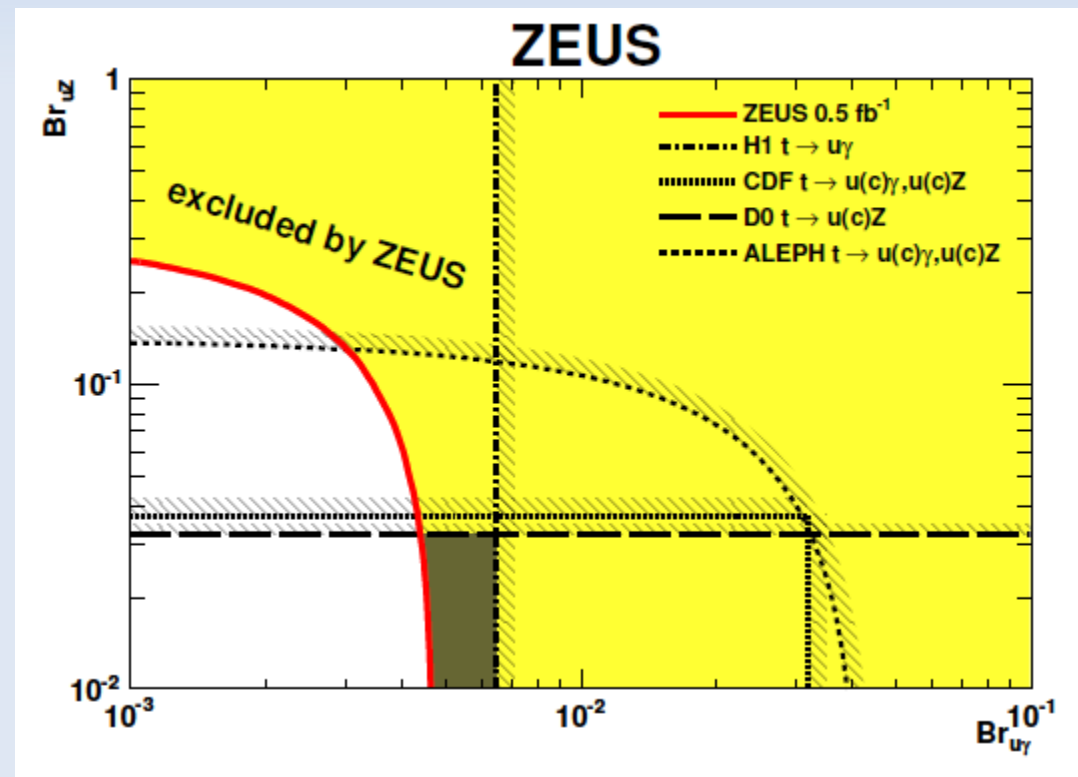
# Search for Single-top production in ep Collisions at HERA

Phys.Lett. B708 (2012) 27-36

- SM cross section for single top quarks at HERA is very small  $\sim 1fb$ .
- However flavor changing neutral current (FCNC) processes could enhance single-top production.



- A search for deviations from the SM due to FCNC top production was performed by ZEUS using full HERA data.
- No deviations from the SM were observed, the results were used to set limits on anomalous top production.



# Summary

- Searches based on the full HERA data performed by the H1 and ZEUS collaborations.
- Data show **good agreement** with the Standard Model predictions.
- Exclusion limits at *95% CL* are determined for
  - **Compositeness (3.8 - 8.9 TeV)**
  - **Large Extra dimensions (0.94 TeV)**
  - **Quark Radius ( $0.63 \cdot 10^{-18}$  m)**
  - **First Generation LQs (up to 800 GeV)**
  - **LFV LQs (up to 712 GeV)**
  - **Single top ( $Br_{uz}$  up to 0.3,  $Br_{u\gamma}$  up to 0.04)**
- HERA provides limits **competitive** with the rest of the world.