Leptoquarks and Contact Interactions at HERA

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DESY

H1 ref:
DESY-03-052
DESY-05-087
DESY-07-009
H1 prelim-06-061

ZEUS ref:
DESY-03-218
DESY-03-041
DESY-05-016
ZEUS prelim-06-018

→ Introduction

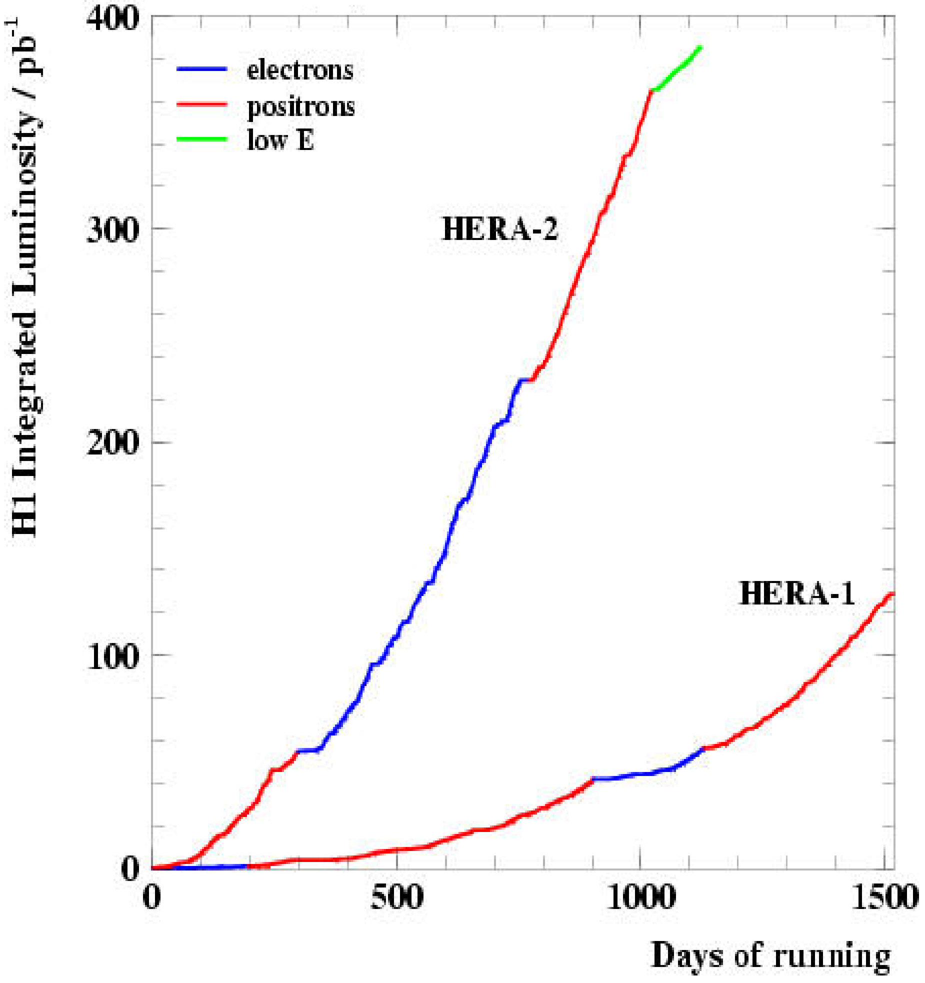
→ Search for leptoquarks and lepton flavour violation

→ Search for new physics in contact interactions

→ Summary

HERA

- $e^{\pm}p$ collider (27.6 GeV e, 920 GeV p), $\sqrt{s}$ = 318 GeV
- Two large colliding detectors: H1 and ZEUS (asymmetric design)
- 30^{th} of June: end of collisions
- 1994-2000: HERA I data
  2003-07 HERA II data (longitudinal $e^{\pm}$ polarisation)
- ~0.5 fb^{-1} luminosity per experiment



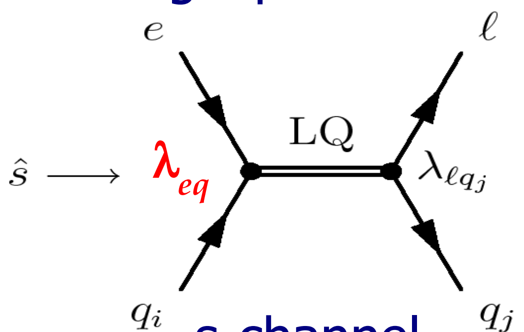
Leptoquarks (LQ) at HERA

Leptoquarks (bosons with baryonic and leptonic quantum numbers),

Fermion number F=L+3B F = 2 (e^-p) F = 0 (e^+p)

Buchmüller-Rückl-Wyler model: LQ are classified into 14 types (7 scalar, 7 vector) by: spin, Isospin, chirality

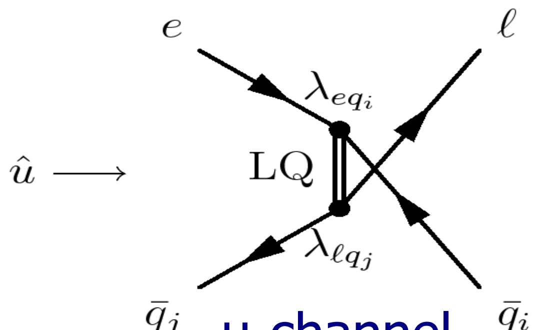
LQ at HERA: single production:



s-channel

(resonant production)

$M_{LQ} \approx (sx)^{1/2}$



u-channel

(LQ exchange)

$M_{LQ} > s^{1/2}$

i,j – quark generation indices

if LQ → eq, νq (l=e,ν) → Lepton Flavour Conserving (LFC) decays

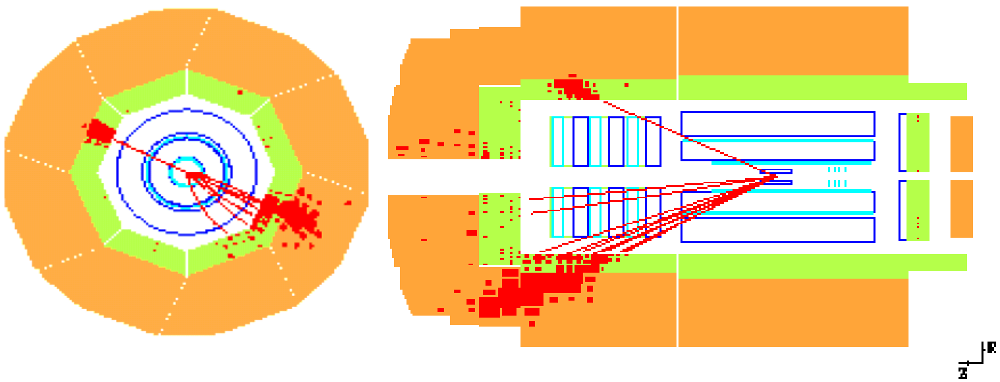
if LQ → μq, τq (l=μ,τ) → Lepton Flavour Violating (LFV) decays

$M_{LQ} < 300$ GeV - resonant production, $M_{LQ} > 300$ GeV - contact interaction region

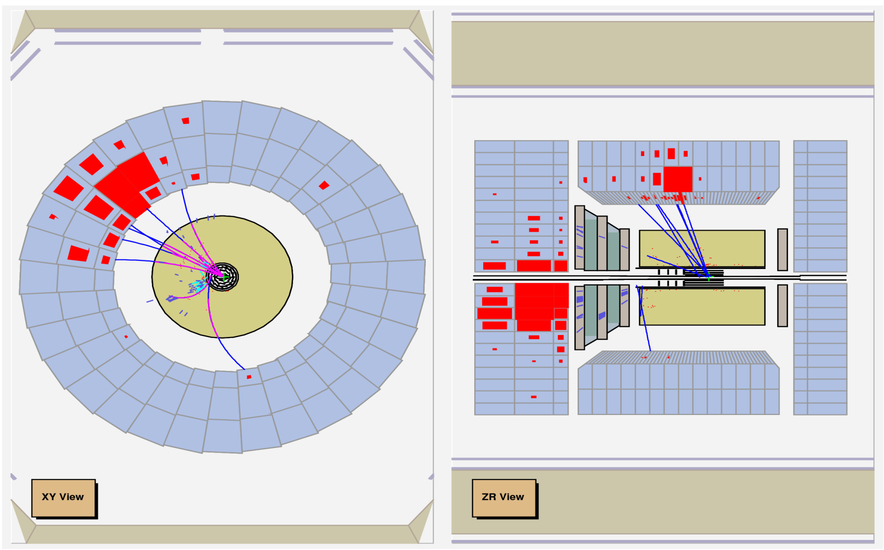
H1/ZEUS → search for scalar and vector LQ

Search for first generation (LFC) LQ at HERA

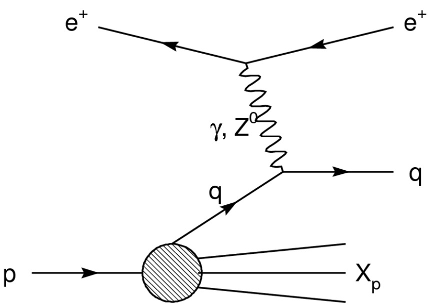
ep $\rightarrow$ eX signature



ep $\rightarrow$ νX signature

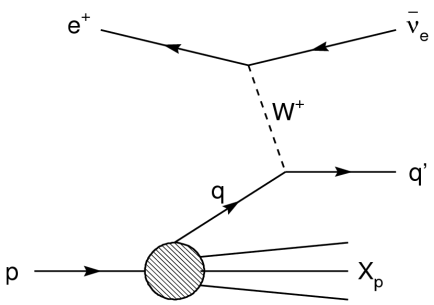


SM background



Neutral Current DIS

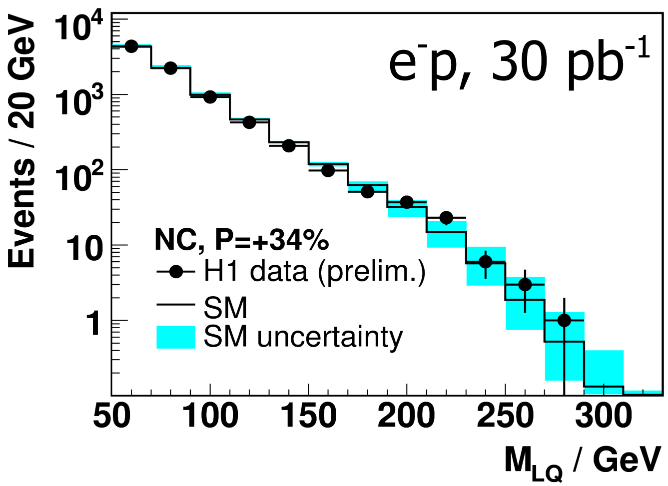
typical selection cuts:
E_e>11 GeV,
Q^2> 1000 GeV^2

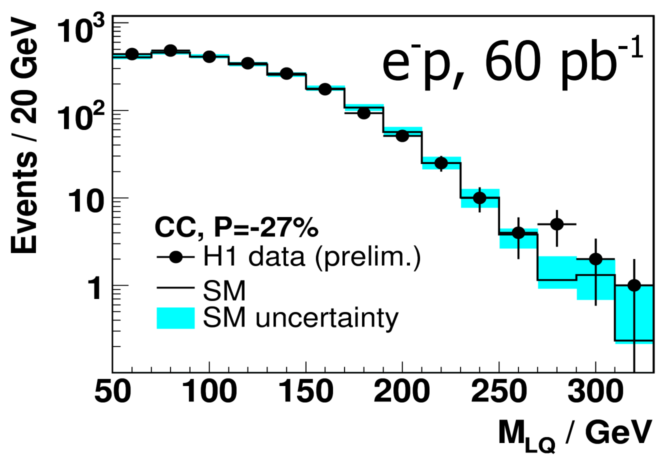


Charged Current DIS

typical selection cuts:
P_T^{miss}>12 GeV,
Q^2> 500 GeV^2

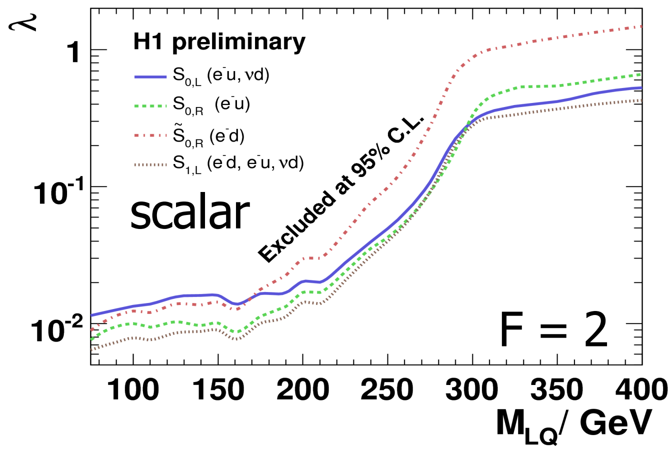
Search for first generation (LFC) LQ at HERA

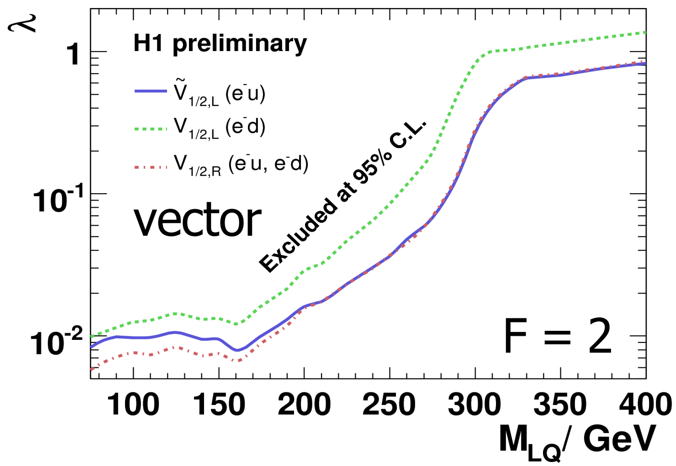




no evidence for signal
(enhancement in LQ mass spectra)

Limits on Yukawa coupling λ as a function of M_{LQ}

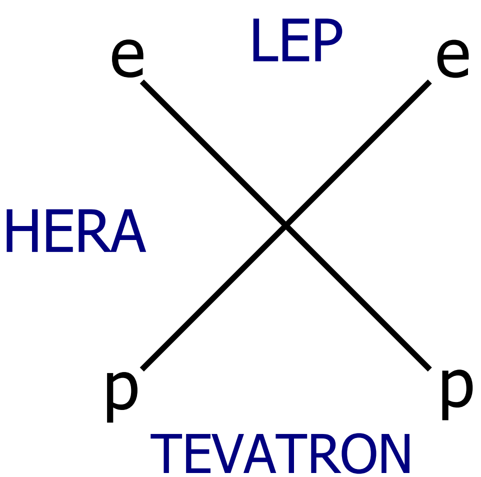




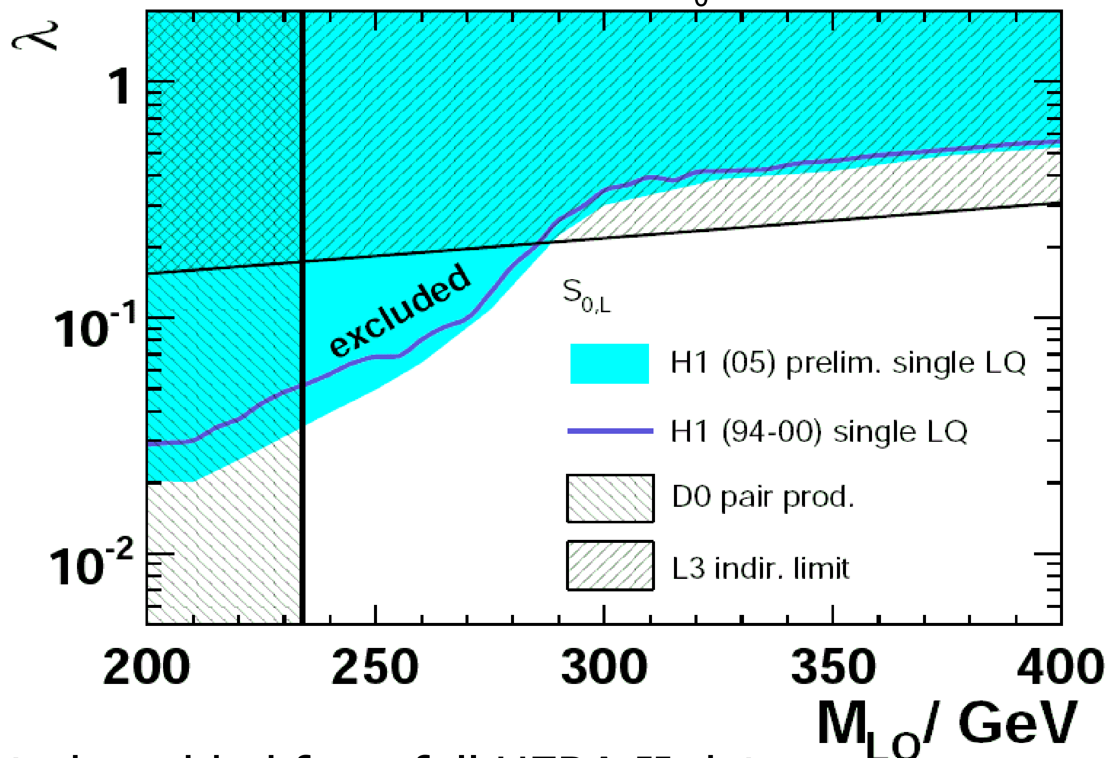
$\lambda \approx 0.3$ (corresponds EM coupling strength) exclude $M_{LQ} > 276$-304 GeV

LQ: comparison with LEP & TEVATRON

- LEP: contact interaction (indirect constraints from $e^-e^+ \rightarrow q\bar{q}$)
- TEVATRON: pair production (λ independent)
- HERA: single production ($M_{LQ} < 300$ GeV) and contact interaction ($M_{LQ} > 300$ GeV)



Scalar leptoquarks (S_0^L) with F=2

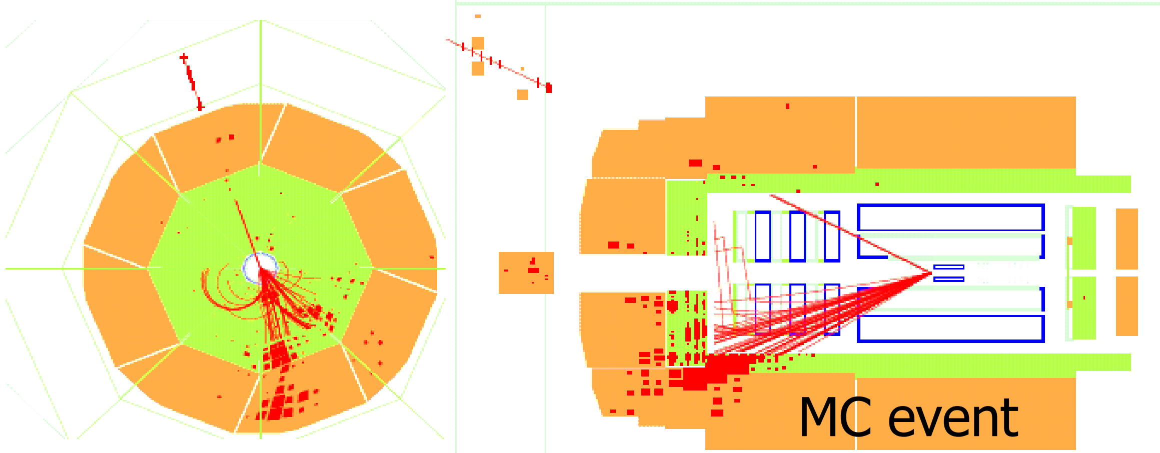


~ factor of 2 more luminosity to be added from full HERA II data

Search for LFV at HERA

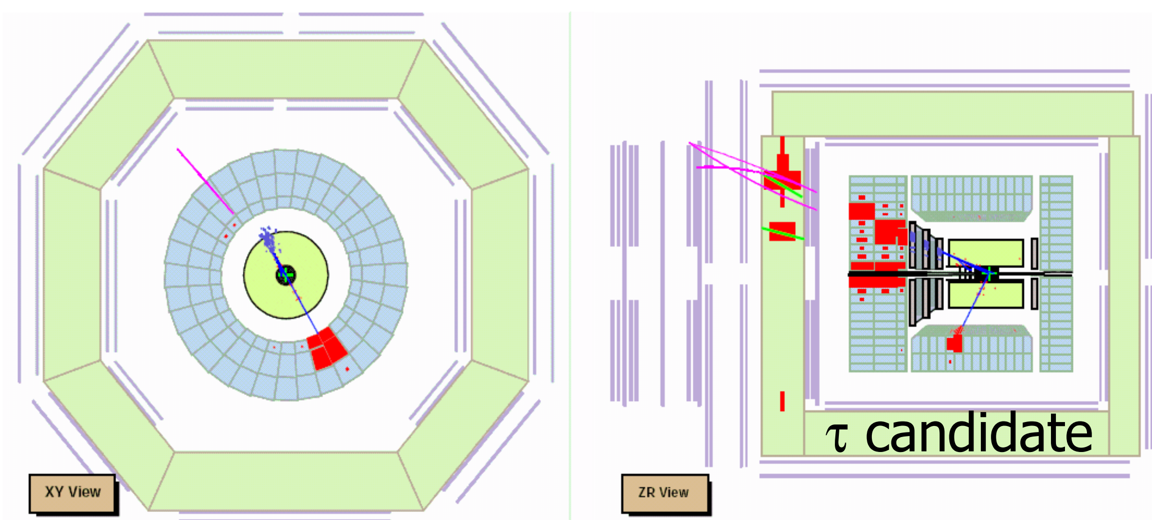
ep $\rightarrow \mu X$ signature

$\rightarrow$ low background, good sensitivity



typical selection cuts:
$P_t^{calo} > 20$ GeV,
back to back topology

ep $\rightarrow \tau X$ signature



<u>Leptonic τ decay</u>:

muonic: as for ep $\rightarrow \mu X$
electronic: $P_T^{jet} > 25$ GeV
back to back topology with e

<u>hadronic τ decay:</u>

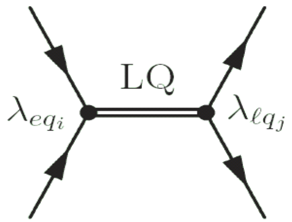
τ identifier (low track multiplicity and limited transverse spread)

Search for LFV at HERA

no evidence for signal found,

limits on λ_{eq} with assumption:

$\lambda_{eq}=\lambda_{\eta q'}$ or $\lambda_{eq}=\lambda_{\tau q}$

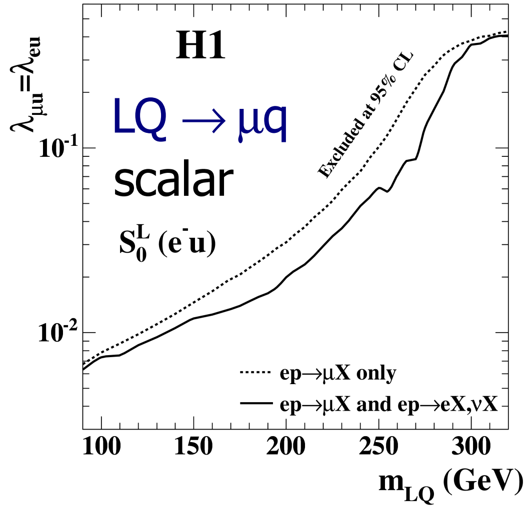


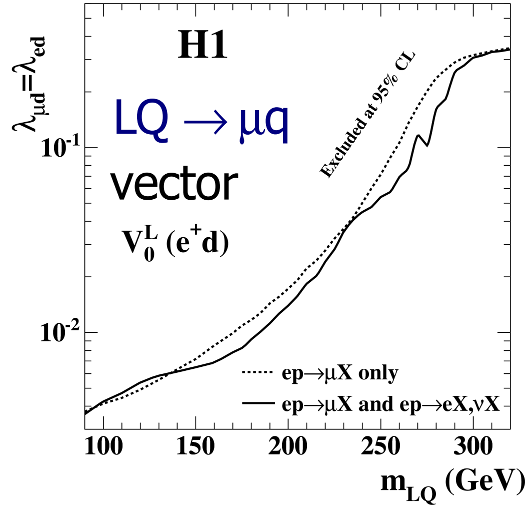
for:

$\rightarrow$ LFV channels alone

$\rightarrow$ in combination with LFC channels

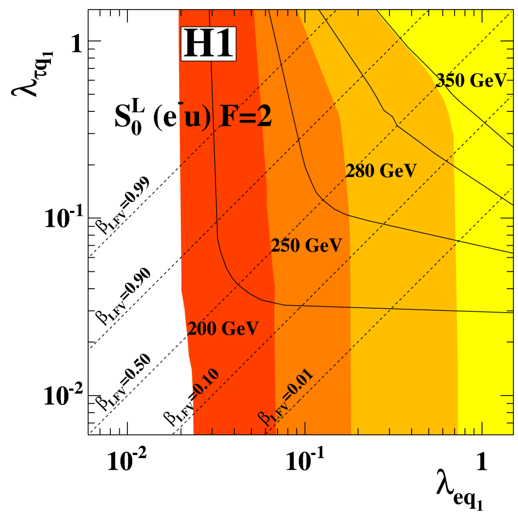
$\lambda \approx 0.3$ exclude $M_{LQ} \gtrsim 300$ GeV

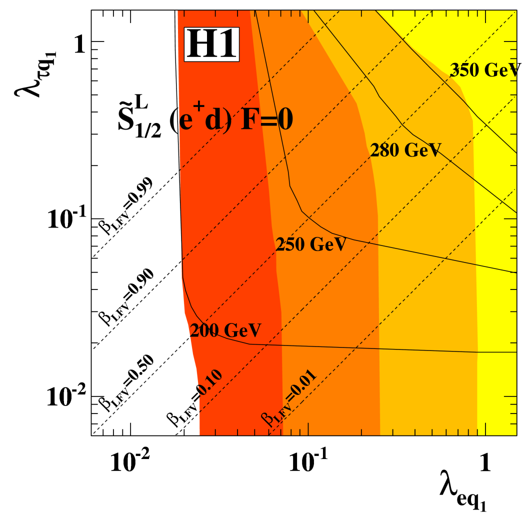




First limits with free β_{LFV} (arbitrary decay rate between LFC and LFV)

for large β_{LFV} limits are significantly extended to lower λ_{eq} values





Contact interactions (CI)

- Possible new interactions between e and q can modify DIS cross section at high Q^2 via virtual effects
- Four fermion eeqq contact interactions → convenient method to investigate these interferences
- Effective Lagrangian for neutral current vector like contact interactions:
  (scalar and tensor CI are constrained beyond HERA sensitivity)

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

↑ 4 possible couplings for every flavour q

- Certain models can be constructed by appropriate choice of the couplings η_{ij}^{eq}
- General models considered:

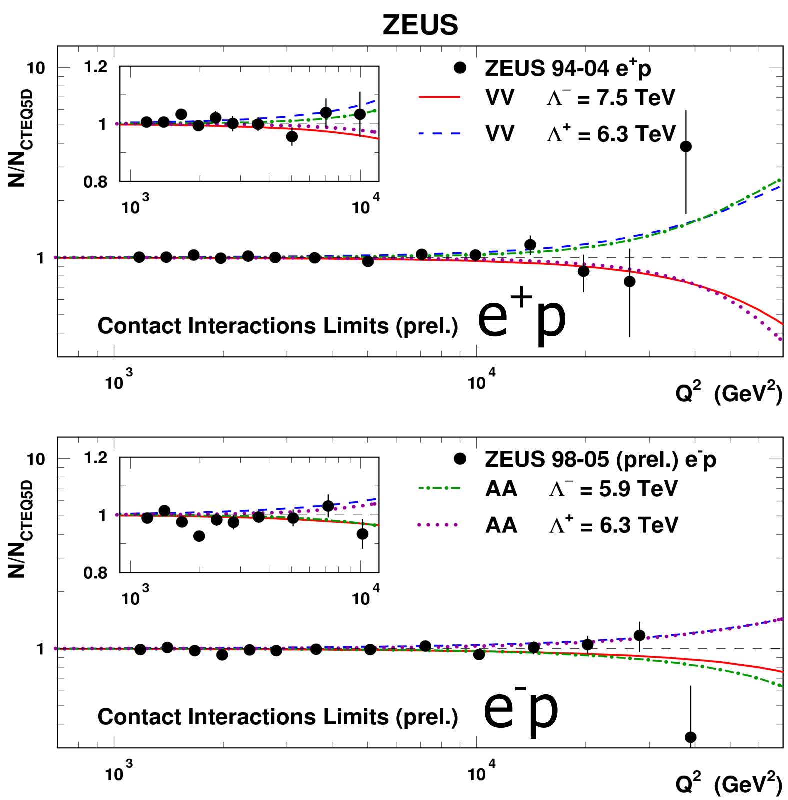
  - compositeness
  - large extra dimnensions (LED)
  - quark form factor

General models

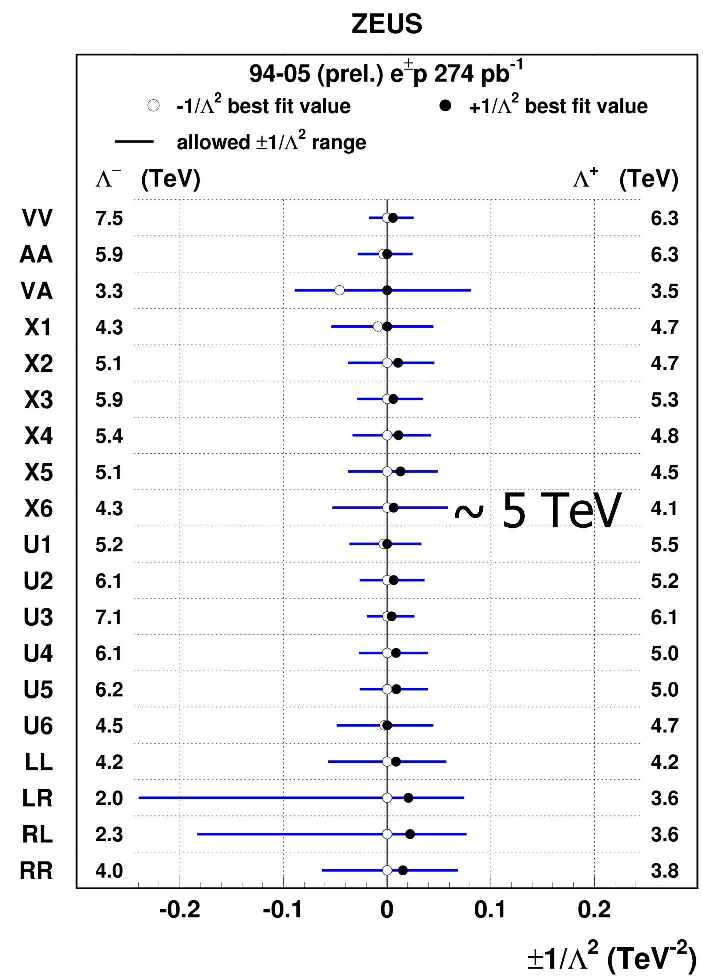
contact interaction coupling related to the mass scale Λ via:

$$\eta_{ij}^{eq} = \pm 1/\Lambda^2$$

Λ – compositeness scale



H1 ref: DESY-03-052



Limits comparable with those derived at LEP and TEVATRON

Large Extra Dimensions

Gravitation scale M_s in 4+n dimensional string theory may be as low as 1 TeV
→ comparable to electroweak strength

Contribution of graviton exchange to the neutral current DIS cross section can be described by an effective contact interaction type coupling:

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

λ - the coupling strength
set limits on M_s

H1 ref:
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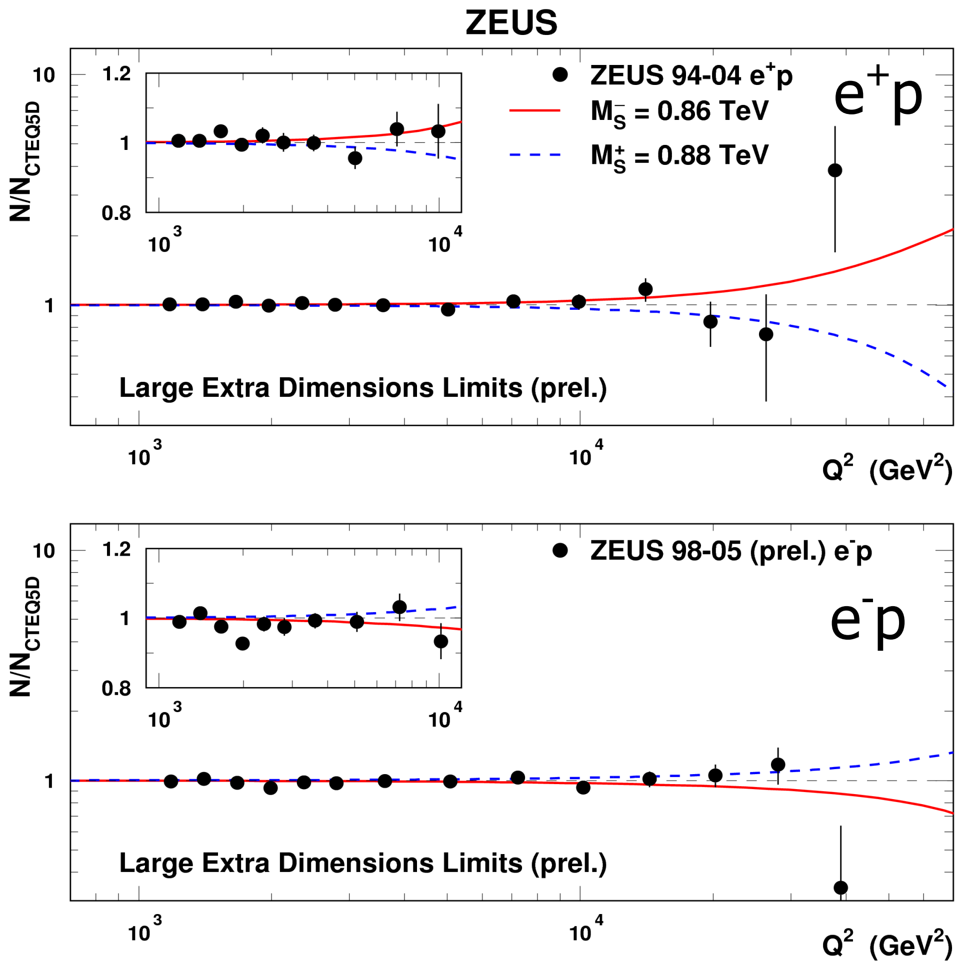


Quark form factor

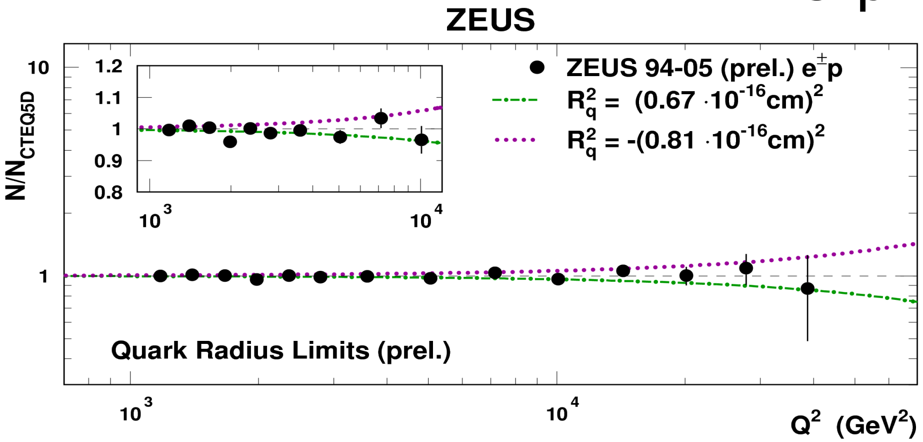
- Fermion substructure can be detected measuring spatial distribution of charge radius:

$$\frac{d\sigma}{dQ^2} = \frac{d\sigma^{SM}}{dQ^2} f_e^2(Q^2)\, f_q^2(Q^2)$$

where $f(Q^2) = 1 - \frac{\langle r^2 \rangle}{6} Q^2$

- R is the root-mean-square radius of the electroweak charge of the e/q
- reduces SM cross section at high momentum transfer
- assuming:
  $f_e = 1$, R_q can be constrained
  $f_e = f_q$, common limit on fermion sizes

e^+p



ZEUS
(combined 94-05):
$R_q < 0.67 \cdot 10^{-18}$ m

H1 ref:
DESY-03-052

Summary

→ LQ and CI results are updated by H1 and ZEUS experiments with partial HERA II data (higher sensitivity)

→ LQ: no evidence for new physics, limits improved with HERA II (polarised) data

→ CI: explore DIS cross sections at high Q^2, no evidence for new physics

→ further improvements are expected:

→ combining HERA I+II (factor of 2 of luminosity for HERA II to be added)

→ combining H1 and ZEUS data

Backup slides

Buchmüller-Rückl-Wyler (BRW) Model

- LQ are classified into 14 types (7 scalar and 7 vector) by: spin, Isospin and chirality

- Fermion number F=L+3B
  F = 2 (e^-p)
  F = 0 (e^+p)

- Two free parameters:
  - LQ mass (M_{LQ})
  - Yukawa coupling (λ)

- Branching ratio β_l (decay into charged leptons) is 1 for 10 and ½ for 4 LQ (decaying to νq pair)

Type	J	F	Q	ep dominant process	Coupling	Branching ratio β_ℓ
S_0^L	0	2	$-1/3$	$e_L^- u_L \rightarrow \begin{cases} \ell^- u \\ \nu_\ell d \end{cases}$	λ_L $-\lambda_L$	1/2 1/2
S_0^R	0	2	$-1/3$	$e_R^- u_R \rightarrow \ell^- u$	λ_R	1
$\tilde{S}_0^R$	0	2	$-4/3$	$e_R^- d_R \rightarrow \ell^- d$	λ_R	1
S_1^L	0	2	$-1/3$ $-4/3$	$e_L^- u_L \rightarrow \begin{cases} \ell^- u \\ \nu_\ell d \end{cases}$ $e_L^- d_L \rightarrow \ell^- d$	$-\lambda_L$ $-\lambda_L$ $-\sqrt{2}\lambda_L$	1/2 1/2 1
$V_{1/2}^L$	1	2	$-4/3$	$e_L^- d_R \rightarrow \ell^- d$	λ_L	1
$V_{1/2}^R$	1	2	$-1/3$ $-4/3$	$e_R^- u_L \rightarrow \ell^- u$ $e_R^- d_L \rightarrow \ell^- d$	λ_R λ_R	1 1
$\tilde{V}_{1/2}^L$	1	2	$-1/3$	$e_L^- u_R \rightarrow \ell^- u$	λ_L	1
V_0^L	1	0	$+2/3$	$e_R^+ d_L \rightarrow \begin{cases} \ell^+ d \\ \bar{\nu}_\ell u \end{cases}$	λ_L λ_L	1/2 1/2
V_0^R	1	0	$+2/3$	$e_L^+ d_R \rightarrow \ell^+ d$	λ_R	1
$\tilde{V}_0^R$	1	0	$+5/3$	$e_L^+ u_R \rightarrow \ell^+ u$	λ_R	1
V_1^L	1	0	$+2/3$ $+5/3$	$e_R^+ d_L \rightarrow \begin{cases} \ell^+ d \\ \bar{\nu}_\ell u \end{cases}$ $e_R^+ u_L \rightarrow \ell^+ u$	$-\lambda_L$ λ_L $\sqrt{2}\lambda_L$	1/2 1/2 1
$S_{1/2}^L$	0	0	$+5/3$	$e_R^+ u_R \rightarrow \ell^+ u$	λ_L	1
$S_{1/2}^R$	0	0	$+2/3$ $+5/3$	$e_L^+ d_L \rightarrow \ell^+ d$ $e_L^+ u_L \rightarrow \ell^+ u$	$-\lambda_R$ λ_R	1 1
$\tilde{S}_{1/2}^L$	0	0	$+2/3$	$e_R^+ d_R \rightarrow \ell^+ d$	λ_L	1

General contact interactions

unpolarised NC DIS cross section:

$$\frac{d^2\sigma^{\rm NC}(e^{\pm}p)}{dx\,dQ^2}(x,Q^2) = \frac{2\pi\alpha^2}{xQ^4}\left[\left(1+(1-y)^2\right)\, F_2^{\rm NC} \mp \left(1-(1-y)^2\right)\, xF_3^{\rm NC}\right]$$

structure functions F_2 and xF_3 are given:

$$F_2^{\rm NC}(x,Q^2) = \sum_{q=u,d,s,c,b} A_q(Q^2)\,\left[xq(x,Q^2)+x\bar{q}(x,Q^2)\right]$$

$$xF_3^{\rm NC}(x,Q^2) = \sum_{q=u,d,s,c,b} B_q(Q^2)\,\left[xq(x,Q^2)-x\bar{q}(x,Q^2)\right]$$

$$A_q(Q^2) = \frac{1}{2}\left[(V_q^L)^2+(V_q^R)^2+(A_q^L)^2+(A_q^R)^2\right]$$

$$B_q(Q^2) = (V_q^L)(A_q^L)-(V_q^R)(A_q^R)\,,$$

the coefficient functions are expressed as:

$$V_q^i = Q_q - (v_e \pm a_e)\, v_q\, \chi_Z\,,$$

$$A_q^i = \quad - (v_e \pm a_e)\, a_q\, \chi_Z\,,$$

CI Lagrangian modifies these functions:

$$V_q^i = Q_q - (v_e \pm a_e)\, v_q\, \chi_Z + \frac{Q^2}{2\alpha}(\eta_{iL}^{eq}+\eta_{iR}^{eq})$$

$$A_q^i = \quad - (v_e \pm a_e)\, a_q\, \chi_Z + \frac{Q^2}{2\alpha}(\eta_{iL}^{eq}-\eta_{iR}^{eq})$$

Heavy leptoquarks

$M_{LQ} >> s^{1/2}$

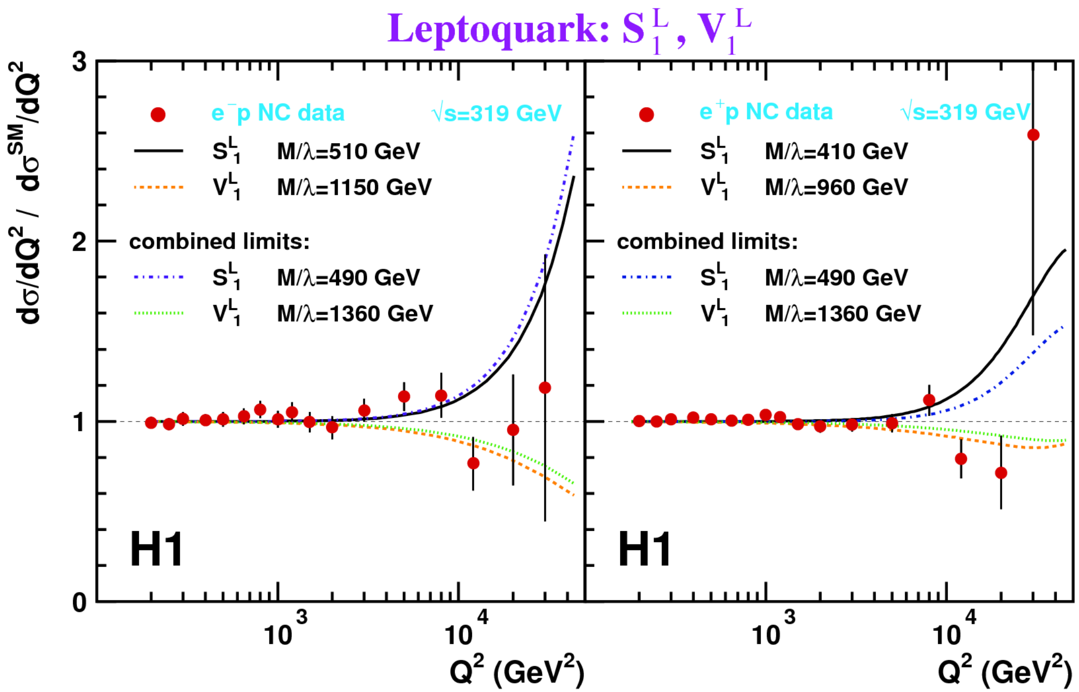
s- and u-channel are equally contributing (equivalent to eeqq CI)
(different sensitivity to leptoquark types from e^+ and e^-)

CI couplings related to M_{LQ} and Yukawa coupling λ via: $\eta_{ij}^{eq} \sim (\lambda/M_{LQ})^2$

95% confidence limits on M_{LQ} to the Yukawa coupling λ ratio (M_{LQ}/λ)

e^- gives more restrictive bounds than e^+

ZEUS ref:
DESY-03-218
ZEUS prelim-06-018



Angular distribution on LQ

→ the y spectra (specific angular distribution of decay products) is different for scalar and vector LQ from DIS (NC) events where $d\sigma/dy \sim 1/y^2$

	Scalar	Vector
s-channel	flat	$(1-y)^2$
u-channel	$(1-y)^2$	flat

→ LQ signal most prominent at high y