

Search for Leptoquarks at HERA-I

Christian Helebrant

H1

DIS2006, Tsukuba, April 20-24, 2006



Leptoquarks

- couple directly to a lepton and a quark
- carry both color and electric charge
- appear in many theories beyond SM (RPV SUSY, GUT)
- **experimentalist approach**: derive properties of LQs from experimentally observed limitations only

Limitations from Observations

- assume no LFV, no FCNC
⇒ each LQ couples only to *one* generation
- don't favour $\pi \rightarrow e\nu$
⇒ chiral couplings (either left- or right-handed)
- no p -decay
⇒ LQ only couples to lepton and quark, never to two quarks

Introduction

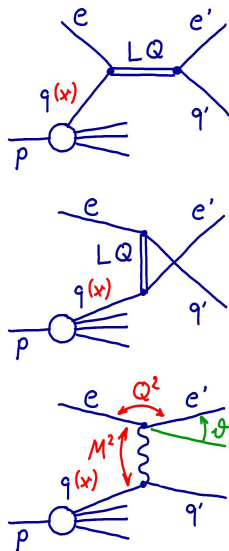
Buchmüller-Rückl-Wyler-Model

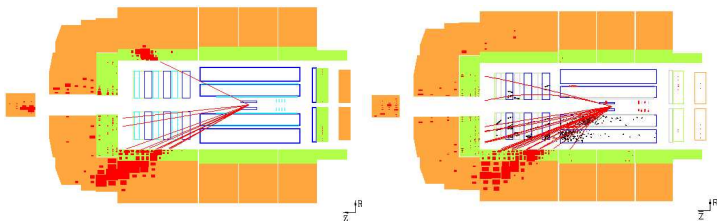
- 14 first generation LQs
- classified by Spin, Weak Isospin, e^- chirality
- Fermion number $F = 2$ ($e^- q$) or $F = 0$ ($e^+ q$)
- all can decay into $e^\pm q$
- **only 4** of them can also decay into $\nu q'$
- **branching ratio fixed to $\beta_e = 1$ or 0.5**
- two free parameters: LQ mass M
Yukawa coupling λ

$F = 2$	Prod./Decay	β_e	$F = 0$	Prod./Decay	β_e
Scalar Leptoquarks					
$S_{0,L}$	$e_L^- u_L \rightarrow e^- u$	1/2	$S_{1/2,L}$	$e_R^+ u_R \rightarrow e^+ u$	1
	$\rightarrow \nu d$	1/2			
$S_{0,R}$	$e_R^- u_R \rightarrow e^- u$	1	$S_{1/2,R}$	$e_L^+ u_L \rightarrow e^+ u$	1
$\tilde{S}_{0,R}$	$e_R^- d_R \rightarrow e^- d$	1		$e_L^+ d_L \rightarrow e^+ d$	1
$S_{1,L}$	$e_L^- d_L \rightarrow e^- d$	1	$\tilde{S}_{1/2,L}$	$e_R^+ d_R \rightarrow e^+ d$	1
	$e_L^- u_L \rightarrow e^- u$	1/2			
	$\rightarrow \nu d$	1/2			
Vector Leptoquarks					
$V_{1/2,R}$	$e_R^- d_L \rightarrow e^- d$	1	$V_{0,R}$	$e_L^+ d_R \rightarrow e^+ d$	1
	$e_R^- u_L \rightarrow e^- u$	1	$V_{0,L}$	$e_R^+ d_L \rightarrow e^+ d$	1/2
				$\rightarrow \bar{\nu} u$	1/2
$V_{1/2,L}$	$e_L^- d_R \rightarrow e^- d$	1	$\tilde{V}_{0,R}$	$e_L^+ u_R \rightarrow e^+ u$	1
$\tilde{V}_{1/2,L}$	$e_L^- u_R \rightarrow e^- u$	1	$V_{1,L}$	$e_R^+ u_L \rightarrow e^+ u$	1
				$e_R^+ d_L \rightarrow e^+ d$	1/2
				$\rightarrow \bar{\nu} u$	1/2

Leptoquarks at HERA

- resonant production in s-channel at $M = \sqrt{x \cdot s_{ep}}$
- exchange in u-channel
- signature: one jet, one e/ν
- single events indistinguishable from SM NC/CC-DIS
- detection only statistical
- sensitive quantities:
 - mass $M = \sqrt{Q^2/y}$
 - y-spectrum $d\sigma/dy$
- scalar LQ in s-channel: $d\sigma/dy$ flat
- vector LQ in s-channel: $d\sigma/dy \propto (1-y)^2$
- DIS: $d\sigma/dy \propto y^{-2}$





HERA-I

- ① $e^+ p$ $\sqrt{s_{ep}} \approx 300$ GeV 37 pb^{-1}
- ② $e^- p$ $\sqrt{s_{ep}} \approx 320$ GeV 15 pb^{-1}
- ③ $e^+ p$ $\sqrt{s_{ep}} \approx 320$ GeV 65 pb^{-1}

⇒ full statistics accumulated by H1 (1994-2000): 117 pb^{-1}

- analysis published in 2005: [hep-ex/0506044](https://arxiv.org/abs/hep-ex/0506044)

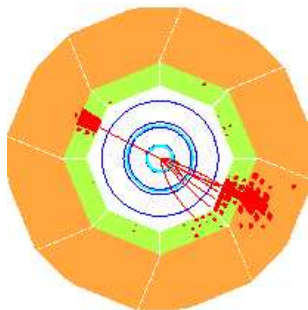
Selection Cuts - Neutral Current Sample

General

- kinematic reconstruction from scattered electron
- $Q_e^2 > 2500 \text{ GeV}^2$
- $0.1 < y_e < 0.9$

NC-specific

- identified e^\pm with $P_T > 15 \text{ GeV}$
- one jet with $E_{T,jet} > 7 \text{ GeV}$
- $P_T^{miss} / \sqrt{E_{T,e}} < 4 \sqrt{\text{GeV}}$
- $40 \text{ GeV} < E - p_z < 70 \text{ GeV}$



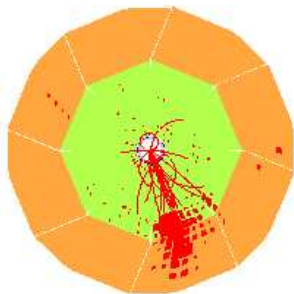
Selection Cuts - Charged Current Sample

General

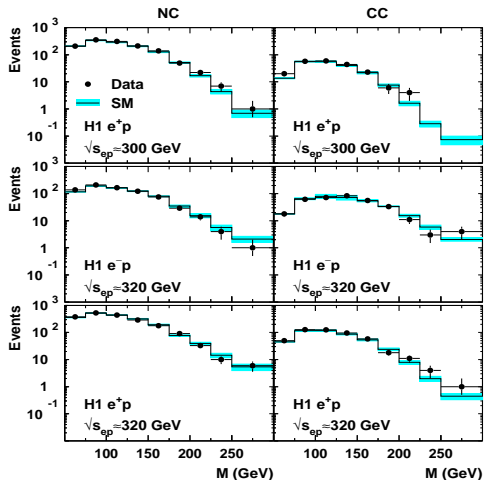
- kinematic reconstruction from hadronic final state
- $Q_h^2 > 2500 \text{ GeV}^2$
- $0.1 < y_h < 0.9$

CC-specific

- no e^\pm candidate with $E_T > 5 \text{ GeV}$
- $P_T^{miss} > 25 \text{ GeV}$
- $V_{ap}/V_p < 0.2$



Mass Distributions after all Cuts

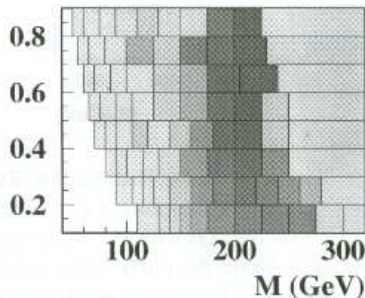


- good agreement with SM prediction
- no sign of LQs \implies interpretation in terms of exclusion limits

Setting Constraints on Leptoquarks

Fractional Event Counting

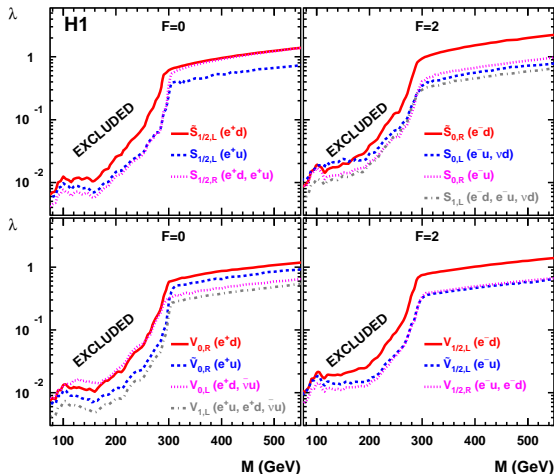
- BRW model: two free parameters M , λ
- analysis in binned M - y -plane (sensitive quantities)
- apply weight w_i to each bin according to its signal-to-background ratio ($w_i = \frac{s_i}{s_i+2b_i}$)



- two hypotheses (Monte Carlo):
 - background only
 - signal + background
- no generic LQ-MC but reweighted SM-MC because of interferences between signal and background (negative signal)
- in weighted bins compare data to both hypotheses

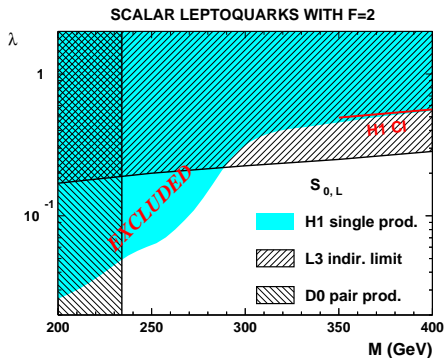
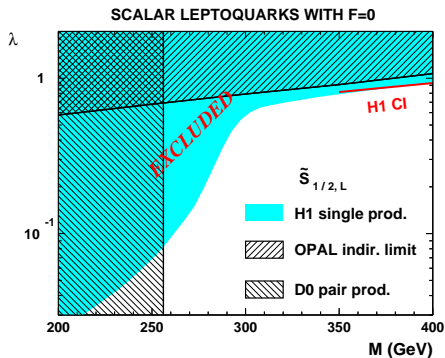
⇒ calculate minimal $\lambda(M)$ to be excluded

Exclusion Limits within the BRW Model



- $F = 2$ LQs with weaker limits ($\mathcal{L}_{e-p} = 15 \text{ pb}^{-1}$)
- $M < 300 \text{ GeV}$: resonant production, strong limits
- $M \approx 300 \text{ GeV}$: CM energy of HERA
- $M > 300 \text{ GeV}$: u-channel
- $\lambda = \sqrt{4\pi\alpha_{em}} = 0.3$: $M < 275 - 325 \text{ GeV}$ ruled out

Results Compared to Other Experiments

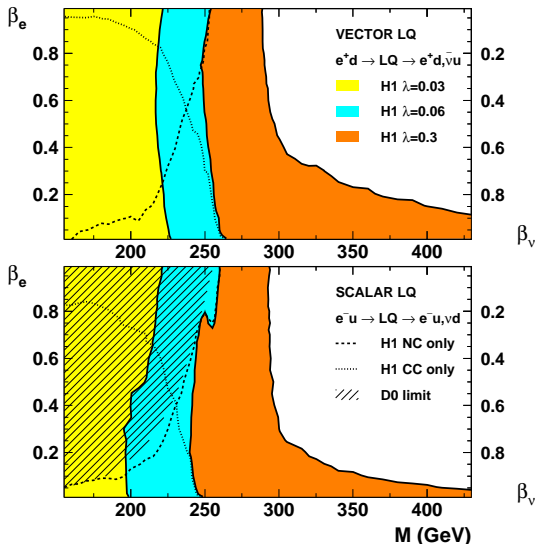


- D0: $q\bar{q}$ annihilation, gg fusion \Rightarrow limit is independent of λ
- LEP: u/t -channel exchange \Rightarrow limits similar to H1 at $M > 300$ GeV
- results of H1 Contact Interaction analysis reproduced
- in s -channel region: H1 limits extend those set by other experiments

Beyond the BRW Model

Generic LQ Models

- β_e is now a free parameter
 \implies M -dependent limits on β for a given λ
- for small λ : limits largely independent of β
- high sensitivity for LQs with mostly CC-like decays (small β_e , high β_ν)



Summary

- search for LQs using all data collected by H1 between 1994 and 2000
- no signal observed
- constraints on LQs have been set
- limits extend beyond results by other analyses
- $M < 275 - 325$ GeV can be ruled out for $\lambda = \sqrt{4\pi\alpha_{em}} = 0.3$

Summary and Outlook

Outlook

- analysis of HERA-II data from H1 is ongoing
- higher luminosity than for HERA-I
- large e^-p data set
⇒ improve limits for LQs with $F = 2$
- polarised electron beams
⇒ enhance sgn-to-bgr ratio since LQs have chiral couplings

