Search for First Generation Leptoquarks at HERA.

David South (DESY)
on behalf of the H1 Collaboration

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HELMHOLTZ
ASSOCIATION

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Melbourne

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on High Energy Physics

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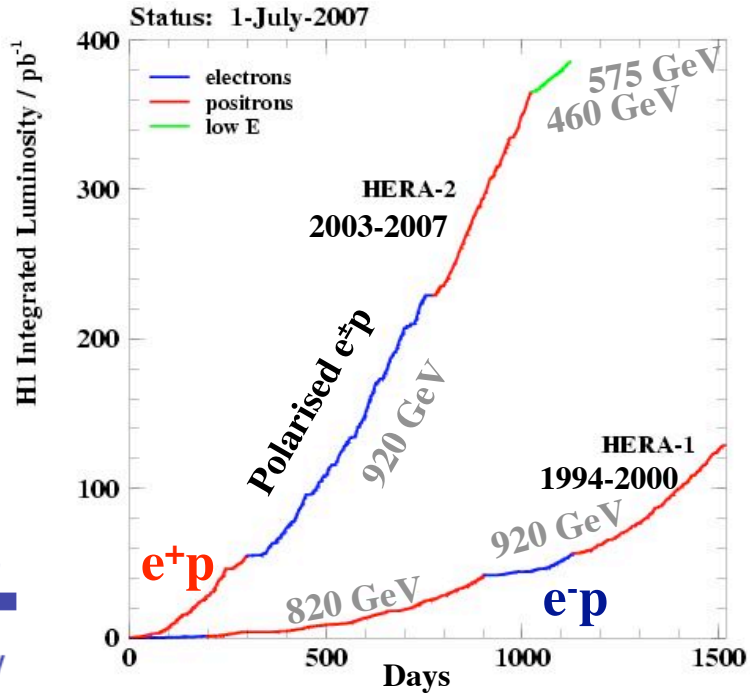
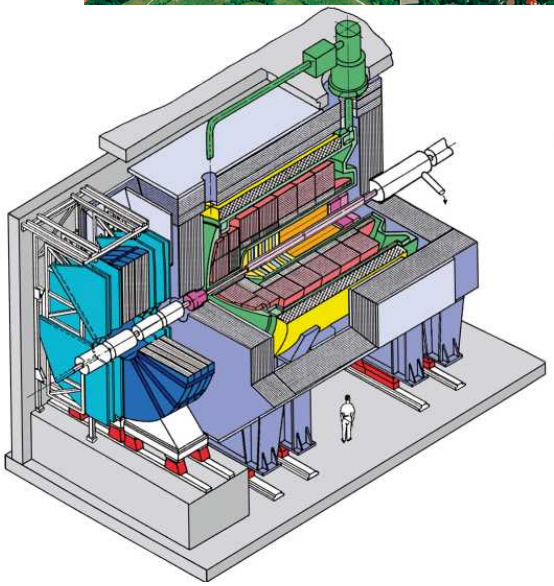
Melbourne Convention and Exhibition Centre

DESY

The H1 experiment at HERA

Centre of mass √s = 319 GeV





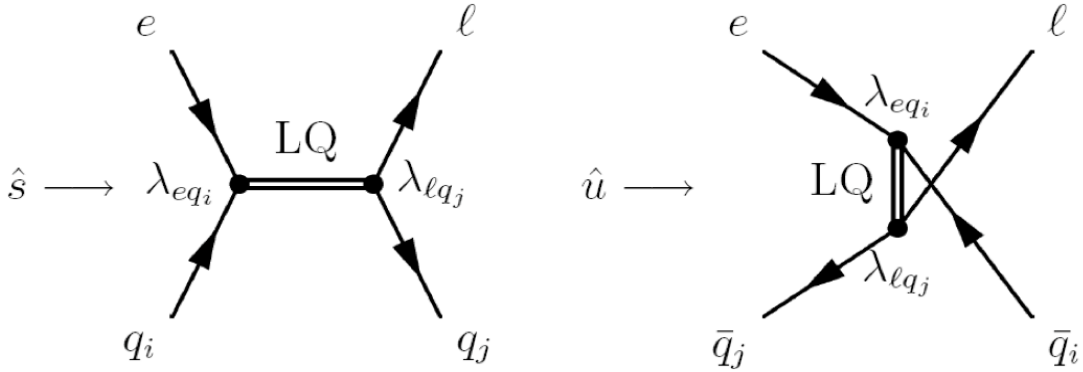
- H1 detector operated 1992-2007, asymmetric design
- HERA II phase with longitudinally polarised $e^{\pm}$ beam
- Luminosity of full H1 high energy data ~ 0.5 fb^{-1}
- Initial $e^{\pm}p$ state: Ideal machine to find Leptoquarks

Leptoquark basics

- Leptoquarks are hypothetical colour triplet bosons, with fractional charge, with both lepton and baryon number ≠ 0
- Couple to both quarks and leptons (as well as gluons)
- Parameterised in terms of mass M_{LQ}, coupling λ and quantum numbers
- The most general model with respect to the SM symmetry groups $SU(3)_c \times SU(2)_L \times U(1)_Y$ results in the 14 different LQ types*
- Classified by weak isospin, charge, spin and chirality, where the fermion number $F = | L + 3B | = 0, 2$
- LQ decays to μq or τq imply lepton flavour violation (LFV)

*** W. Buchmüller, R. Rückl, D. Wyler, "*Leptoquarks in lepton-quark collisions*", Phys. Lett. B191 (1987) 442**

Leptoquarks at HERA: Production

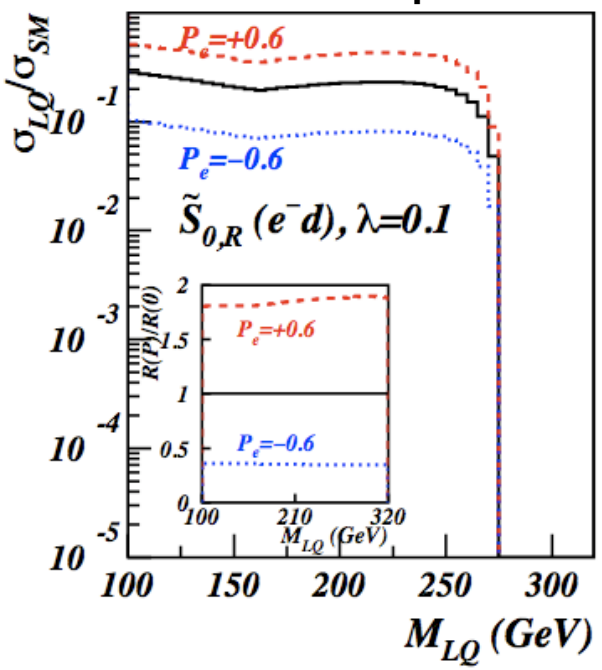


1st gen: eq → LQ → e(ν)q
2nd gen: eq → LQ → μ(ν)q
3rd gen: eq → LQ → τ(ν)q
} LFV

s-channel: resonant production
For $M_{LQ} \leq (sx)^{1/2}$
Cross section $\sigma \sim \lambda^2$

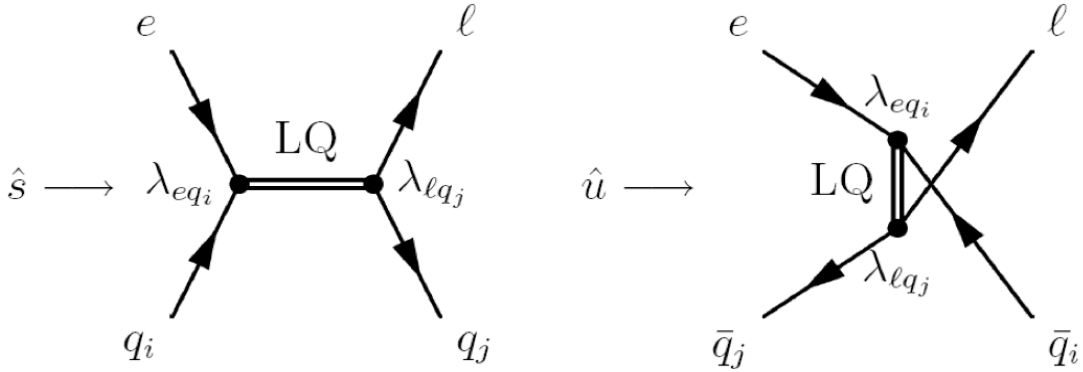
u-channel: LQ exchange
For $M_{LQ} > s^{1/2}$
Cross section $\sigma \sim \lambda^4$

Polarisation dependence



- For LQ masses up to the centre of mass at HERA, resonant production in the s-channel dominates
  - Electron-proton collisions, mainly $F = |L + 3B| = 2$ LQs produced
  - Positron-proton collisions, mainly $F = |L + 3B| = 0$ LQs produced
- For LQ masses well above 319 GeV, the u-channel also contributes: e^-p and e^+p similar sensitivity to $F = 0, 2$ LQs
- LQ are chiral particles, gain in sensitivity at HERA II due to polarised lepton beam

Leptoquarks at HERA: Decay



1st gen: eq → LQ → e(ν)q
2nd gen: eq → LQ → μ(ν)q
3rd gen: eq → LQ → τ(ν)q
} LFV

- First generation search: LQ → e(ν)q
  - Some LQs decay to neutrino-quark as well as electron-quark: search in NC/CC DIS
  - Gauge invariance leads to a branching fraction $\beta_\ell = \Gamma_{\ell q}/(\Gamma_{\ell q} + \Gamma_{\nu_\ell q}) = 0.5$
  - Interference with SM NC/CC (identical final state) included in the model

- Second and third generation searches: LQ → μq, τq
  - No CC contributions considered in the analysis, neutrino flavours indistinguishable
  - Branching ratio $\beta = \beta_\ell \times \beta_{LFV}$ with $\beta_{LFV} = \dfrac{\Gamma_{\mu(\tau)q}}{\Gamma_{\mu(\tau)q} + \Gamma_{eq}}$ and $\Gamma_{\ell q} = m_{\mathrm{LQ}} \lambda_{\ell q}^2 \times \begin{cases} \frac{1}{16\pi} & \text{scalar} \\ \frac{1}{24\pi} & \text{vector} \end{cases}$
  - Assuming lepton universality, and that only one LFV transition is possible, $\beta_{LFV} = 0.5$
  - No LFV transition: first generation only

14 LQ types in the BRW model

Type	J	F	Q	ep dominant process	Coupling	Branching ratio β_ℓ
S_0^L	0	2	$-1/3$	$e_L^- u_L \to \ell^- u$	λ_L	1/2
				$e_L^- u_L \to \nu_\ell d$	$-\lambda_L$	1/2
S_0^R	0	2	$-1/3$	$e_R^- u_R \to \ell^- u$	λ_R	1
$\tilde{S}_0^R$	0	2	$-4/3$	$e_R^- d_R \to \ell^- d$	λ_R	1
S_1^L	0	2	$-1/3$	$e_L^- u_L \to \ell^- u$	$-\lambda_L$	1/2
				$e_L^- u_L \to \nu_\ell d$	$-\lambda_L$	1/2
			$-4/3$	$e_L^- d_L \to \ell^- d$	$-\sqrt{2}\lambda_L$	1
$V_{1/2}^L$	1	2	$-4/3$	$e_L^- d_R \to \ell^- d$	λ_L	1
$V_{1/2}^R$	1	2	$-1/3$	$e_R^- u_L \to \ell^- u$	λ_R	1
			$-4/3$	$e_R^- d_L \to \ell^- d$	λ_R	1
$\tilde{V}_{1/2}^L$	1	2	$-1/3$	$e_L^- u_R \to \ell^- u$	λ_L	1

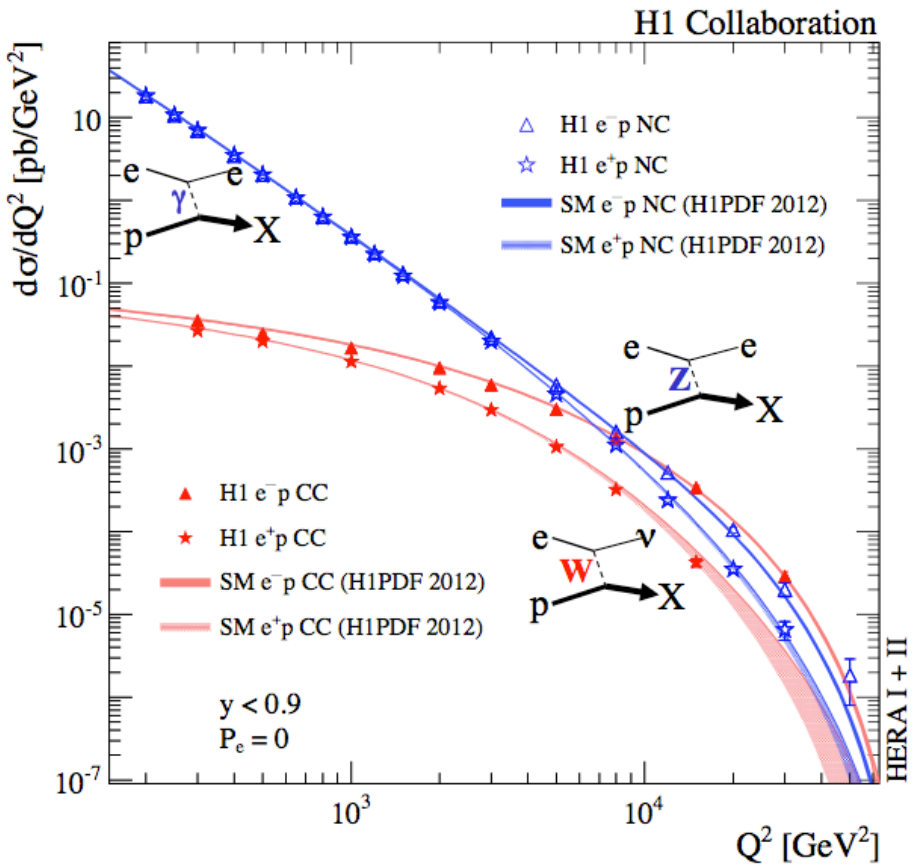
Type	J	F	Q	ep dominant process	Coupling	Branching ratio β_ℓ
V_0^L	1	0	$+2/3$	$e_R^+ d_L \to \ell^+ d$	λ_L	1/2
				$e_R^+ d_L \to \bar{\nu}_\ell u$	λ_L	1/2
V_0^R	1	0	$+2/3$	$e_L^+ d_R \to \ell^+ d$	λ_R	1
$\tilde{V}_0^R$	1	0	$+5/3$	$e_L^+ u_R \to \ell^+ u$	λ_R	1
V_1^L	1	0	$+2/3$	$e_R^+ d_L \to \ell^+ d$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

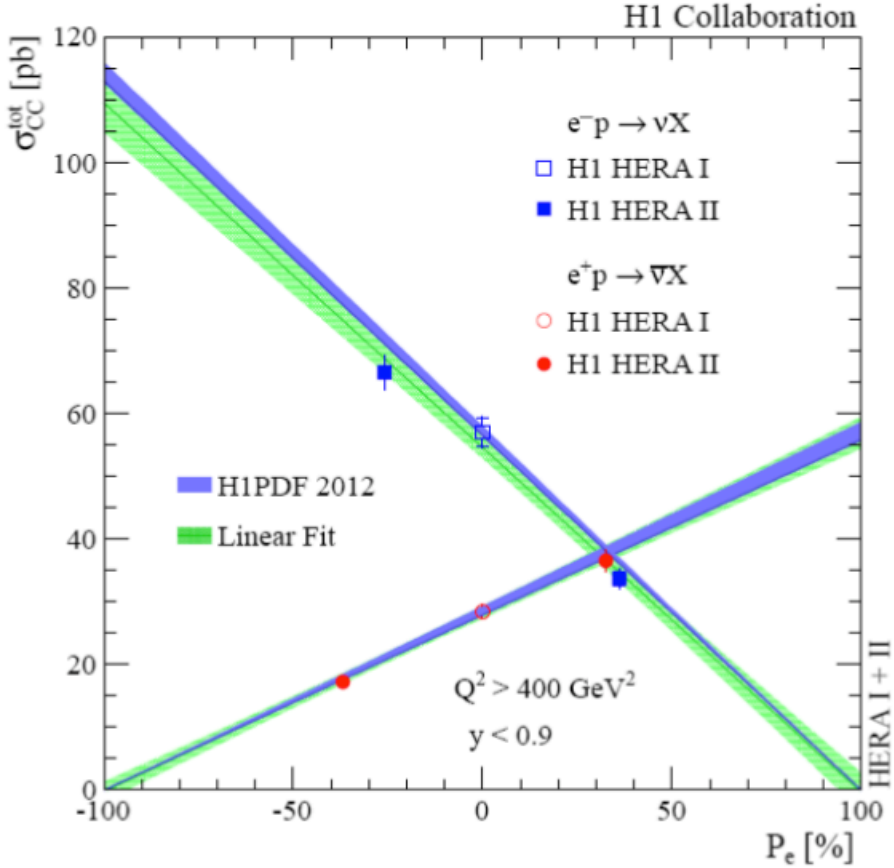
For ease of comparison to hadron collider limits:

$$\beta_\ell = 1.0\,\text{LQs}: \; S_0^R \;\; \tilde{S}_0^R \;\; V_{1/2}^L \;\; V_{1/2}^R \;\; \tilde{V}_{1/2}^L \;\; V_0^R \;\; \tilde{V}_0^R \;\; S_{1/2}^L \;\; S_{1/2}^R \;\; \tilde{S}_{1/2}^L$$

$$\beta_\ell = 0.5\,\text{LQs}: \; S_0^L \quad V_0^L$$

High Q^2 measurements from H1

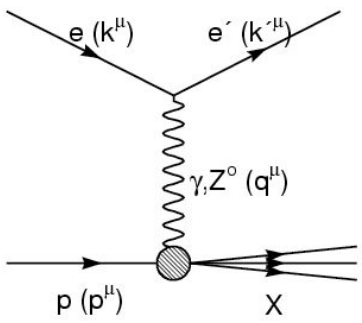




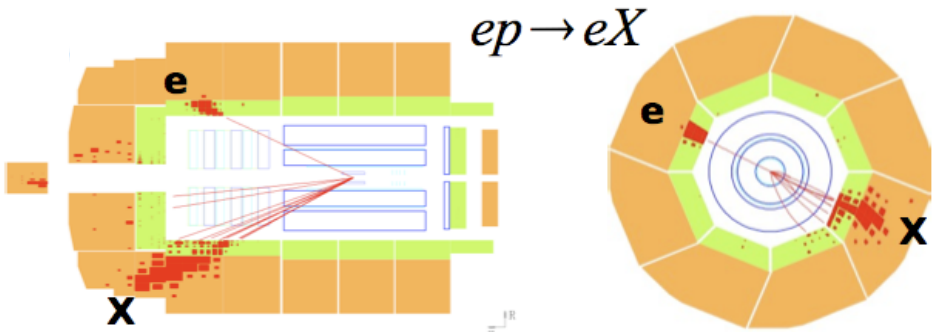
- H1 recently completed the high Q^2 programme of measurements
- Much information contained in the complete NC and CC analysis
  - *See ICHEP talk by Z. Zhang, as well as the publication:* ***arXiv:1206.7007***

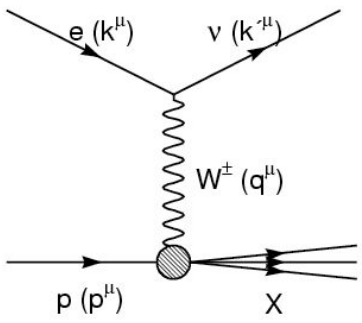
First Generation Search Background: High Q^2 NC and CC

- Final state indistinguishable from SM NC/CC DIS: jet + electron/neutrino
  - Selection based on the inclusive DIS analyses
  - Look for enhancements in mass spectra

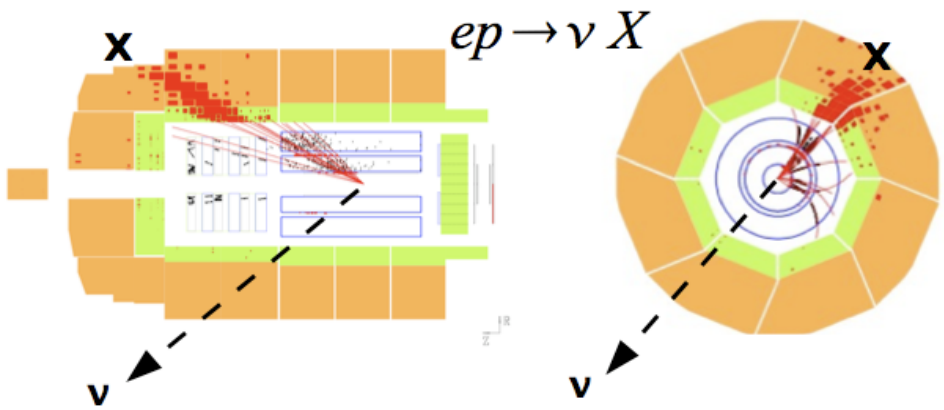


- Main NC Selection Criteria
  - Isolated electron
  - $E_e > 11$ GeV
  - $Q_e^2 > 500$ GeV^2
  - $0.1 < y_e < 0.9$

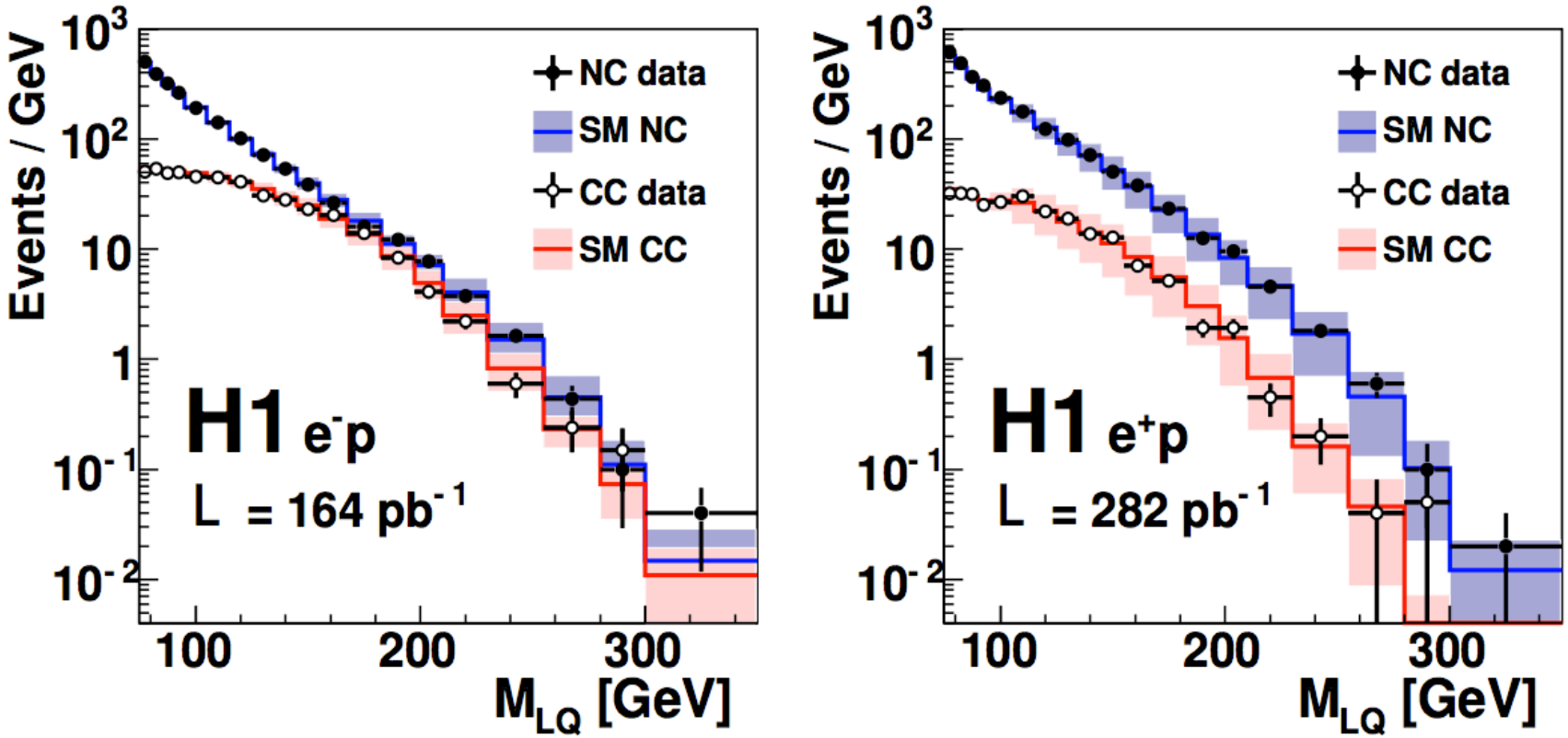




- Main CC Selection Criteria
  - $P_T^{miss} > 12$ GeV
  - $Q_h^2 > 1000$ GeV^2
  - $0.1 < y_h < 0.9$

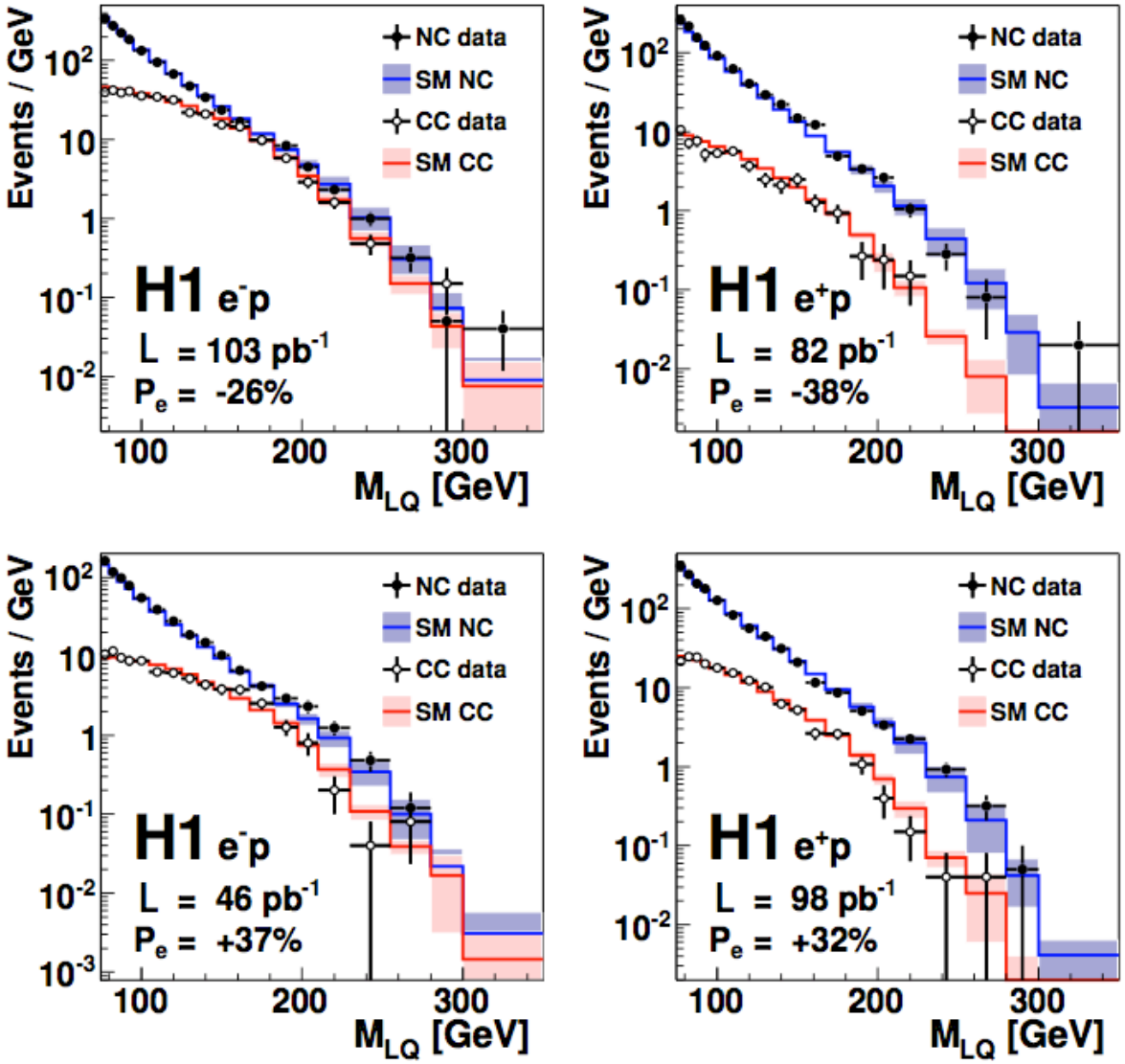


First Generation Leptoquark Search



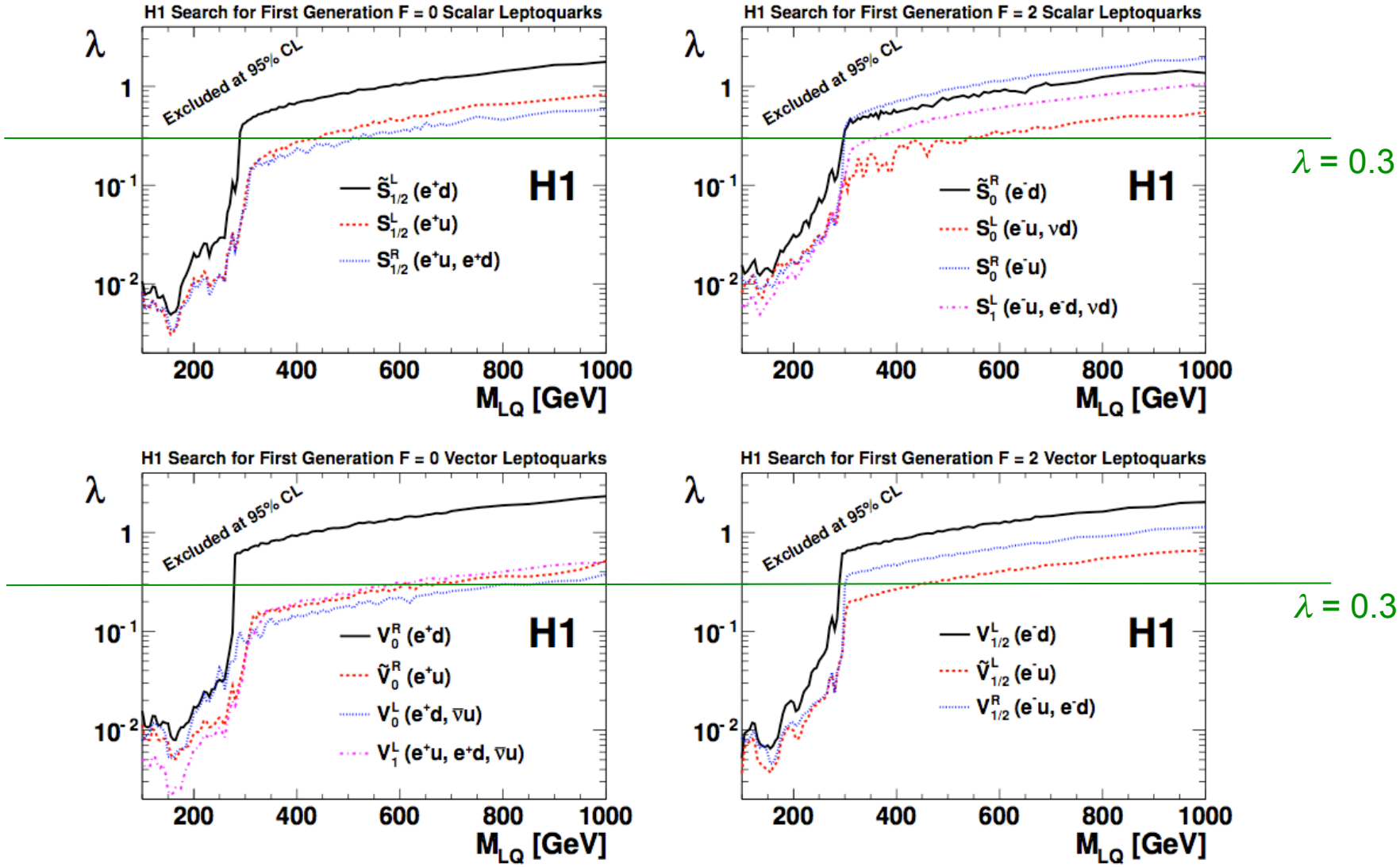
> Good description of the full HERA I+II H1 data set by the MC prediction, with no significant deviation from SM

First Generation Leptoquark Search: Polarisation Periods



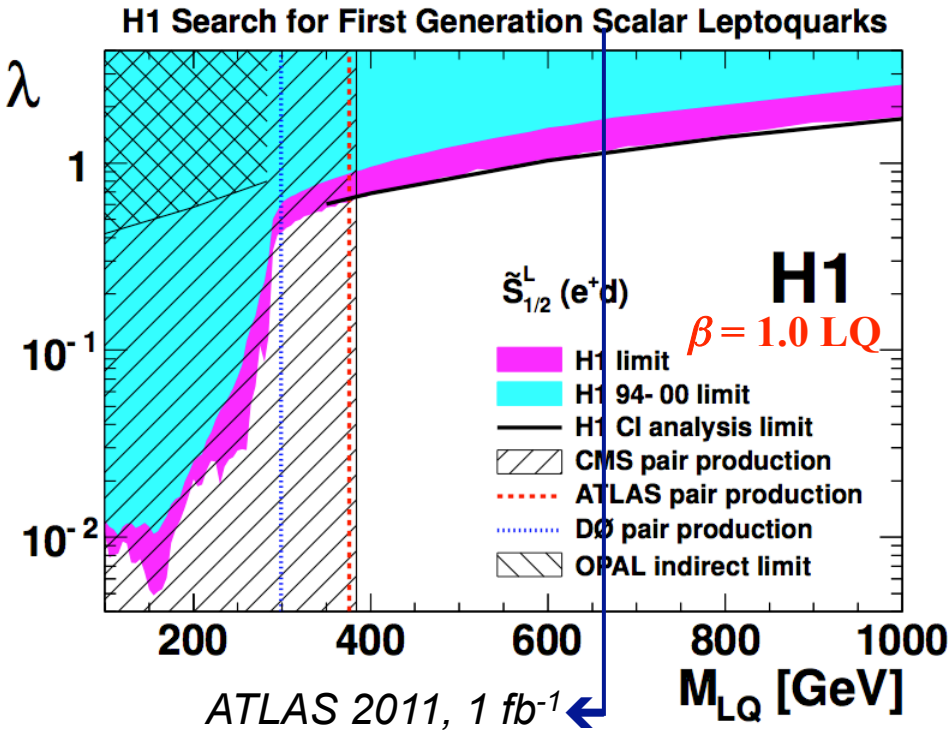
- Analysis of different polarisation periods in HERA II data
- Good description of the H1 data by the SM prediction
- No evidence for LQ signal: interpret in terms of exclusion limits

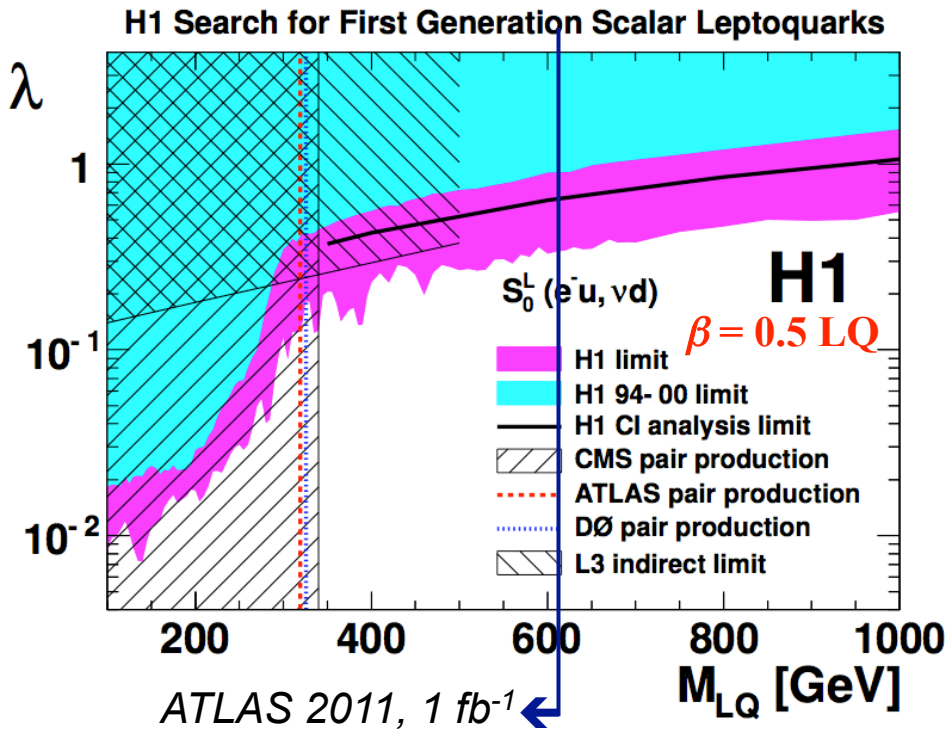
First Generation Leptoquark Limits for all 14 LQ types



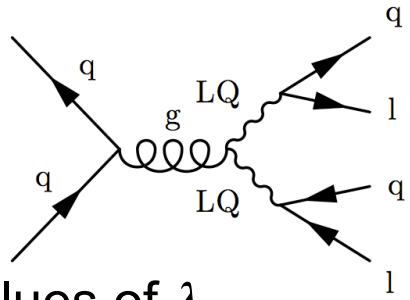
> For λ=0.3 LQ masses up to 800 GeV are ruled out @ 95% CL

First Generation Leptoquark Search: Example Limits





- H1 limits in the resonant LQ production region now superseded by those from the Tevatron and LHC (pair production, independent of λ)



- Still some H1 sensitivity in the CI region, for large values of λ

Summary and conclusions

- The ep collisions at the HERA collider are the ideal environment to search for leptoquarks
  - Searches for LQs of all generations have been performed by the H1 experiment using the complete high energy data taken at $\sqrt{s}$ = 319 GeV
- No significant deviation from the SM observed and limits are set on the production of such particles
  - For large values of the coupling λ, HERA limits in CI region are still beyond current limits from hadron colliders
  - LQ masses up to 800 GeV are ruled out @ 95% CL for λ = 0.3

Final H1 search papers:

"Search for Lepton Flavour Violation at HERA", Phys. Lett. B701 (2011) 20 [arXiv:1103.4938].
"Search for First Generation Leptoquarks at HERA", Phys. Lett B704 (2011) 388 [arXiv:1107.3716].
"Search for Contact Interactions in ep Collisions at HERA", Phys. Lett. B705 (2011) 52 [arXiv:1107.2478].

Extra Slides

Table of Scalar LQ mass limits from hadron colliders

Scalar LQs	1st Gen		2nd Gen		3rd Gen	
β	1.0	0.5	1.0	0.5	1.0	0.5
ATLAS	660[1]	607[1]	685[2]	594[2]	-	-
CMS	384[3]	340[4]	632[5]	523[5]	350[6]	-
DØ	299[7]	326[8]	316[9]	270[9]	247[10]	-
CDF	236[11]	205[11]	226[12]	208[12]	-	-

1. “Search for first generation scalar leptoquarks in pp collisions at sqrt{s}=7 TeV with the ATLAS detector”, Phys. Lett. B709 (2012) 158-176, Erratum-ibid. 711 (2012) 442, [arXiv:1112.4828].

2. “Search for second generation scalar leptoquarks in pp collisions at sqrt(s) = 7 TeV with the ATLAS detector”, arXiv:1203.3172.

3. “Search for pair production of first-generation scalar leptoquarks in pp collisions at sqrt(s) = 7 TeV”, Phys. Rev. Lett. 106 (2011) 201802 [arXiv: 1012.4031].

4. “Search for first generation scalar leptoquarks in the evjj channel in pp collisions at sqrt(s) = 7 TeV”, Phys. Lett. B703 (2011) 246 [arXiv:1105.5237].

5. “Search for second generation scalar leptoquarks”, CMS PAS EXO-11-028.

6. “Search for pair production of third-generation scalar leptoquarks using events produced in pp collisions at sqrt(s) = 7 TeV containing b-jets and missing transverse energy”, CMS PAS EXO-11-030.

7. “Search for pair production of first-generation leptoquarks in p anti-p collisions at s**(1/2) = 1.96-TeV”, Phys. Lett. B681 (2009) 224 [arXiv:0907.1048].

8. “Search for first generation leptoquark pair production in the electron + missing energy + jets final state,’’ Phys. Rev. D84 (2011) 071104 [arXiv: 1107.1849].

9. “Search for pair production of second generation scalar leptoquarks,’’ Phys. Lett. B671 (2009) 224 [arXiv:0808.4023].

10. “Search for scalar bottom quarks and third-generation leptoquarks in p p-bar collisions at sqrt(s) = 1.96 TeV”, Phys. Lett. B693 (2010) 95 [arXiv: 1005.2222].

11. “Search for first-generation scalar leptoquarks in p-pbar collisions at sqrt(s)=1.96 TeV”, Phys. Rev. D72 (2005) 051107 [hep-ex/0506074].

12. “Search for second-generation scalar leptoquarks in p-pbar collisions at sqrt(s)=1.96 TeV”, Phys. Rev. D73 (2006) 051102 [hep-ex/0512055].