Searches for New Physics at H1

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on behalf of the H1 Collaboration

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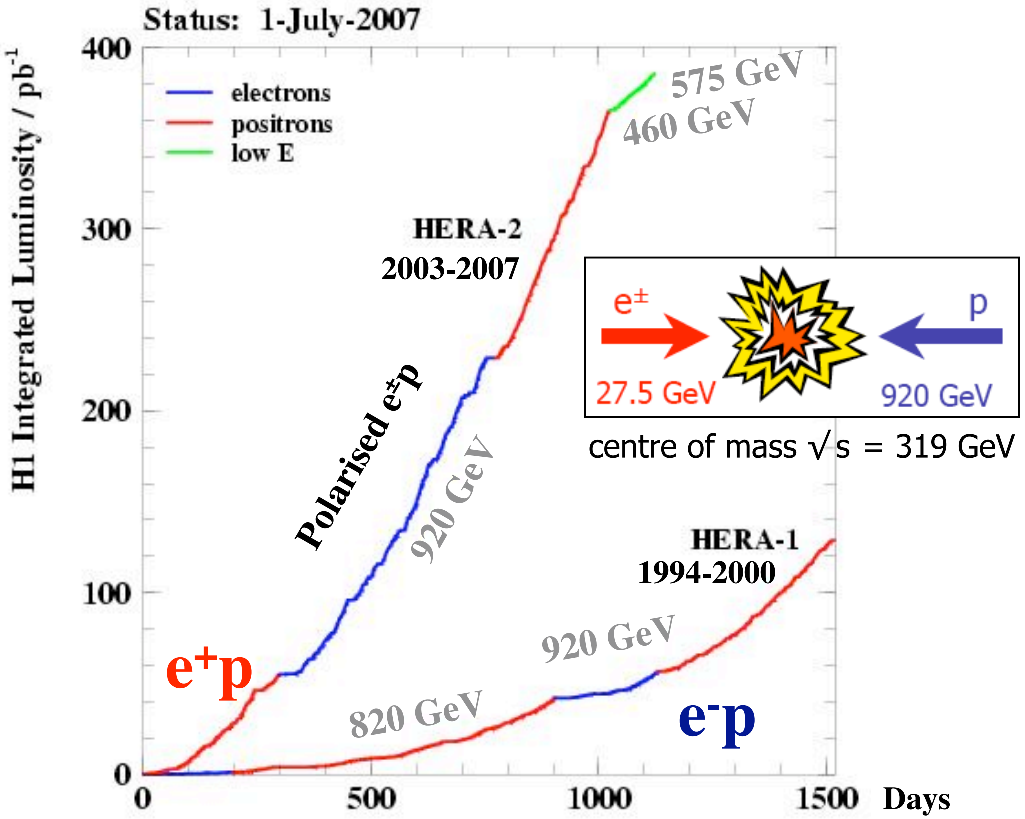
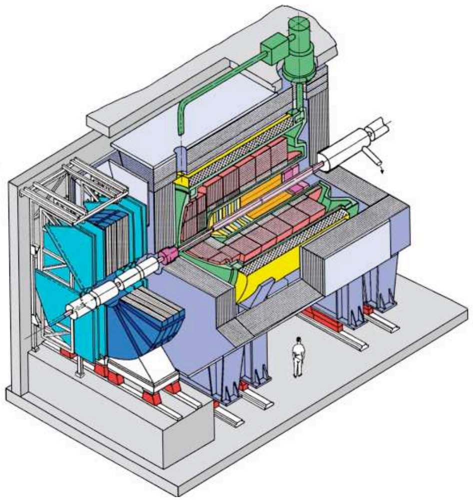
H1 and HERA 1994-2007





- H1 detector at HERA, asymmetric design
- Large increase in data from HERA II and polarised $e^{\pm}p$ data
- Final H1 dataset ~ 0.5 fb^{-1} : **Final Limits on searches**
- Presented here: **Leptoquarks and Excited Fermions**

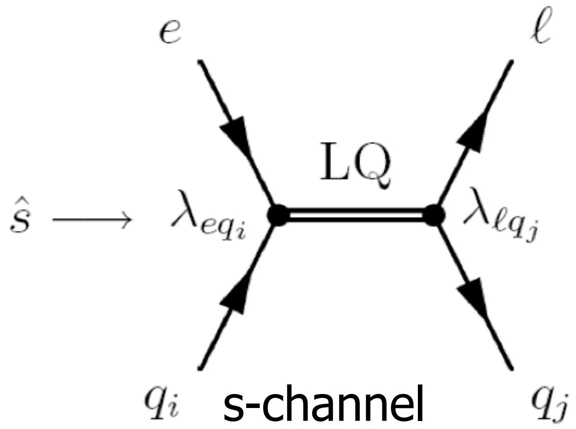
Introduction to the Leptoquark Model

- Leptoquarks are hypothetical bosons that couple to both leptons and quarks
- 7 scalar, 7 vector LQs in the Buchmüller, Rückl, Wyler model
- LQ carry SU(3) colour, electric charge, baryon (B) and lepton (L) numbers
- Fermion Number F = |3B+L| = 0,2
- LQ decays to $l^{\pm}q$ or $\nu_l q'$

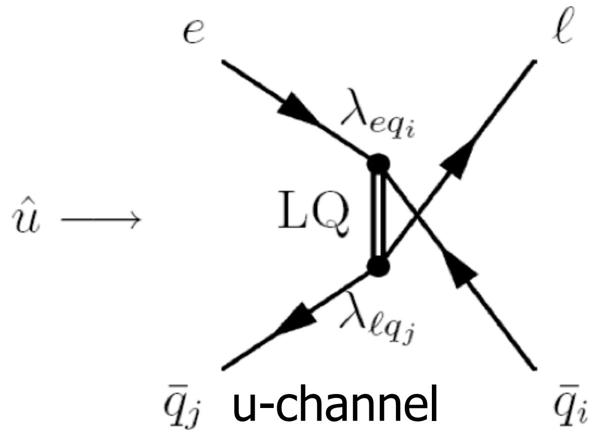
couples to e^-q — couples to e^+q

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

Leptoquarks may be singly produced at HERA



s-channel
(Resonant production)
$M_{LQ} \approx (sx)^{1/2}$

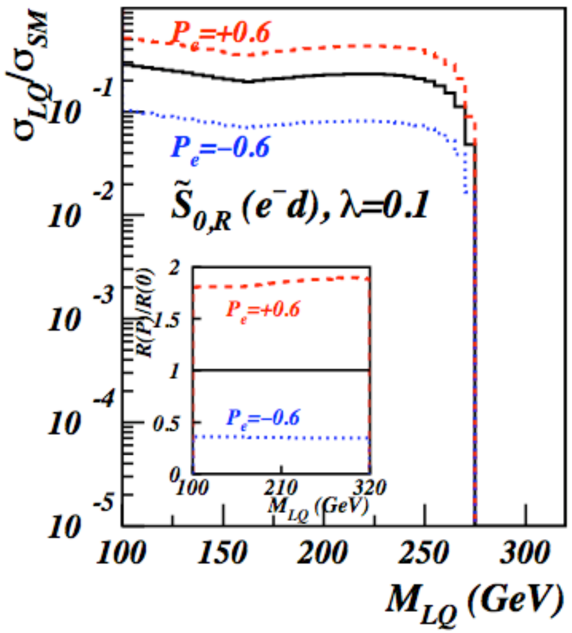


u-channel
(LQ exchange)
$M_{LQ} > s^{1/2}$

M_{LQ} = Leptoquark mass
λ = Yukawa coupling

Resonance width, $\Gamma \sim \lambda^2 M_{LQ}$

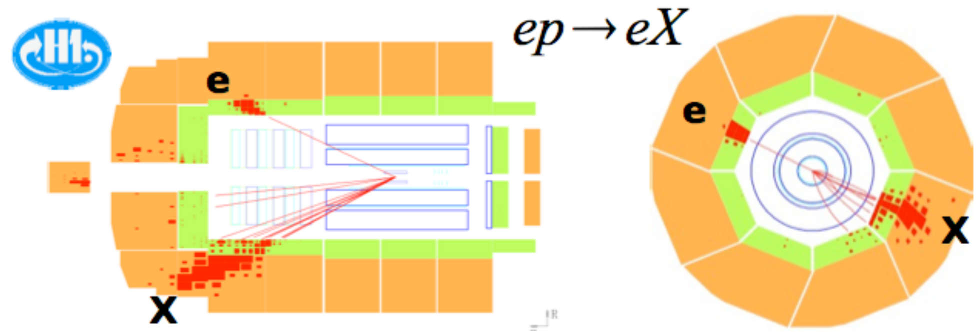
Dependence on polarisation

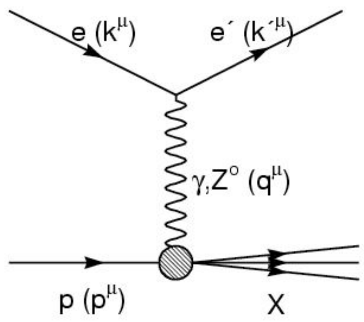


- LQ → eq: 1st generation, *large irreducible SM background from NC and CC DIS*
- LQ → μq, τq: 2nd and 3rd generation, *(lepton flavour violating), essentially no background*
- LQ are chiral particles, can expect gain in sensitivity due to polarised lepton beam

SM Background to 1st Generation Leptoquarks

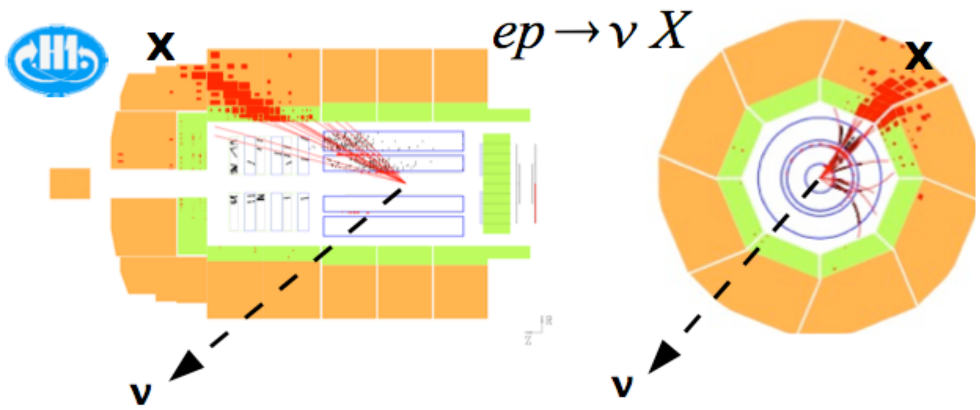
- Final state indistinguishable from SM NC/CC DIS: jet + electron/neutrino
  - Selection based on the inclusive DIS analysis
  - Look for enhancements in mass spectra

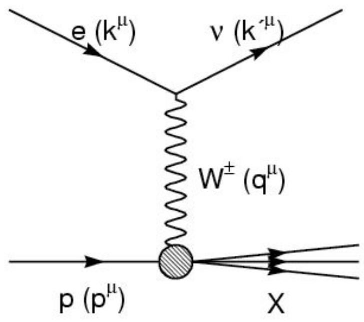




Selection

Isolated electron
E_e > 11 GeV
Q^2 > 1000 GeV^2
0.1 < y_e < 0.9

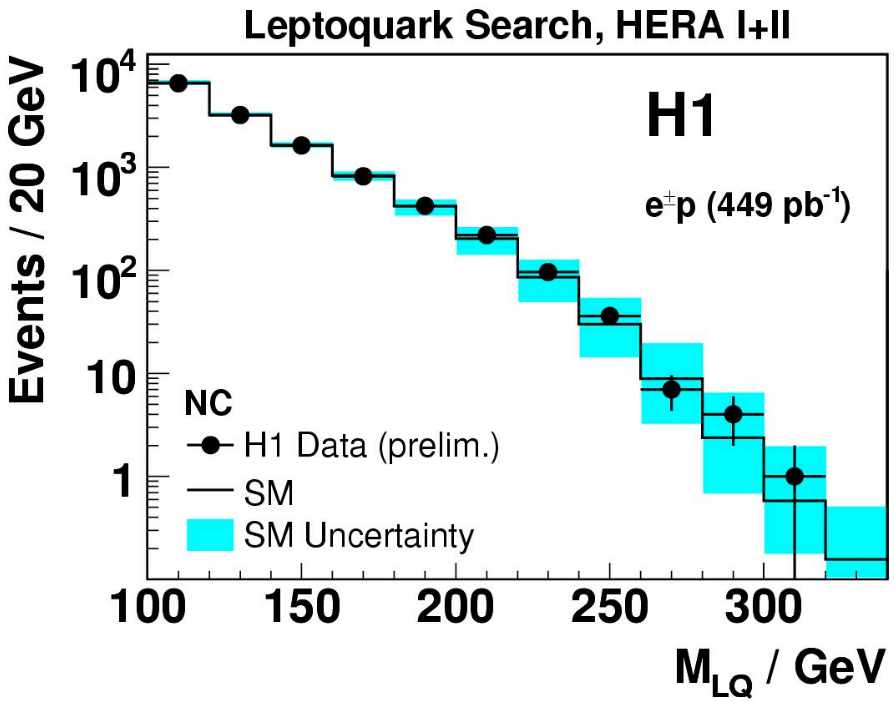


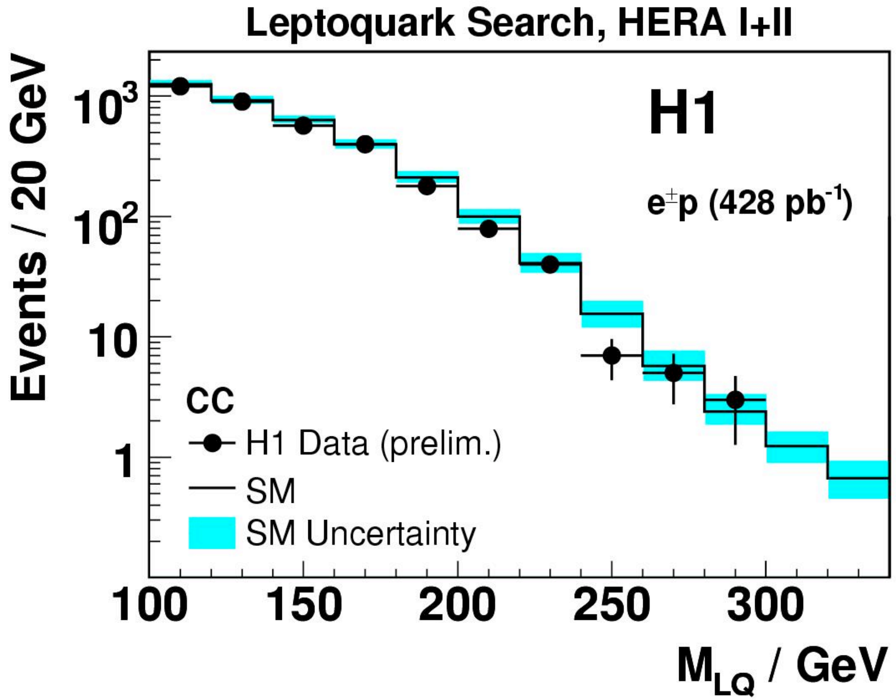


Selection

P_T^{Miss} > 12 GeV
Q^2 > 5000 GeV^2
0.1 < y_h < 0.9

Search for 1st Generation Leptoquarks





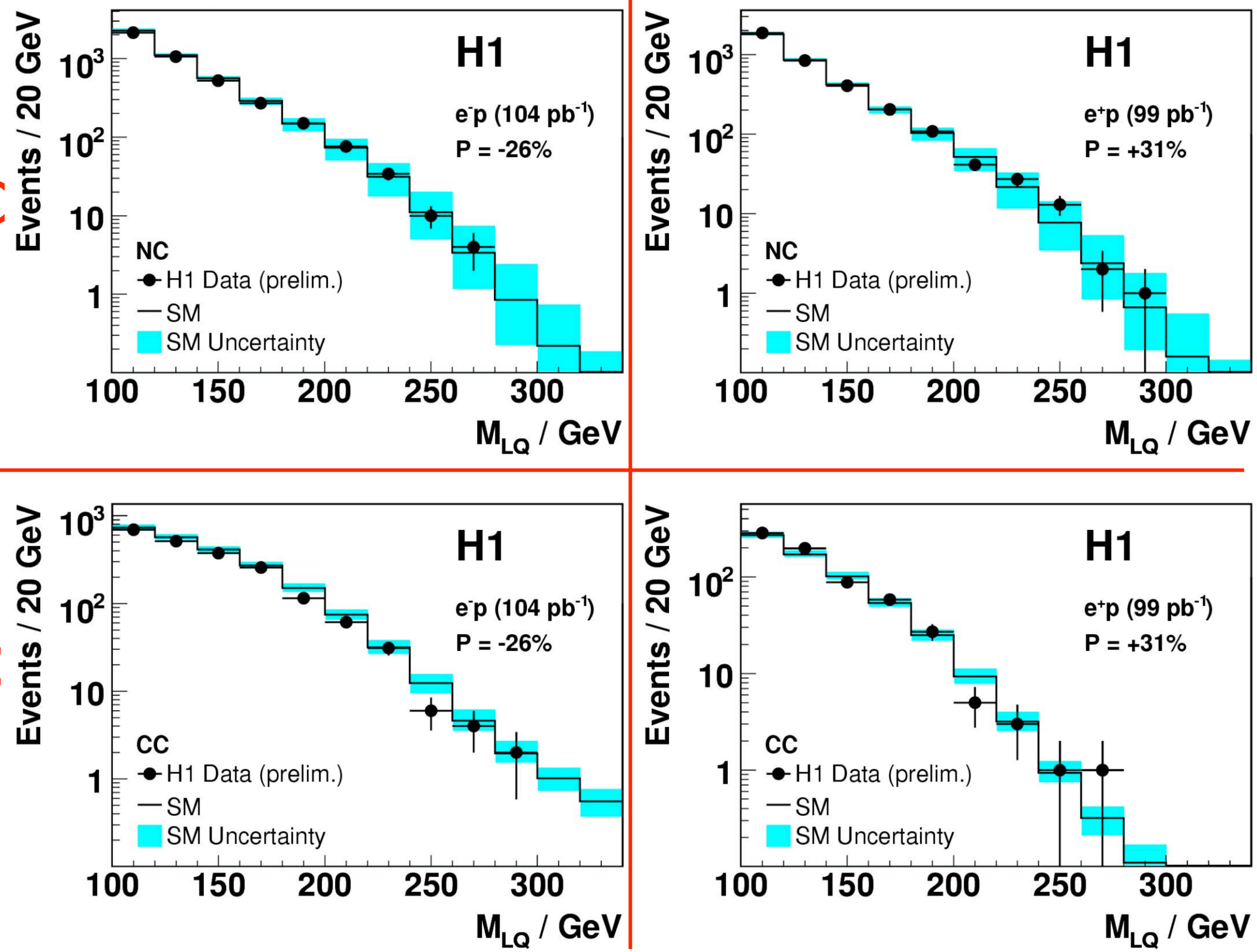
- Complete H1 $e^{\pm}p$ data analysed, luminosity ~ 0.5 fb^{-1}
- Good description of data by SM prediction: no LQ resonance observed
- No evidence for LQ signal: interpret in terms of exclusion limits

HERA II LQ Search for Different Polarisations

left handed e^-p | right handed e^+p

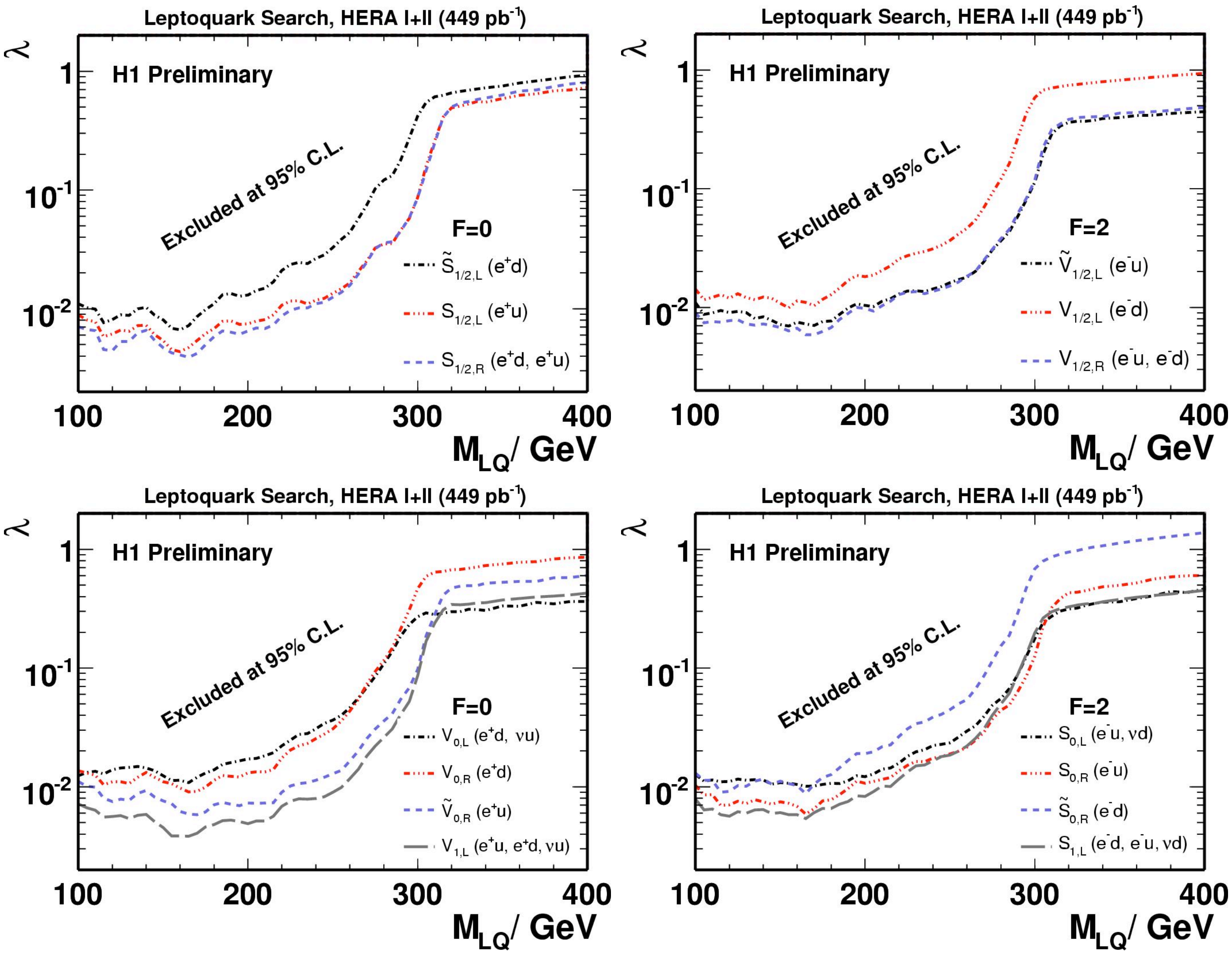
NC

CC



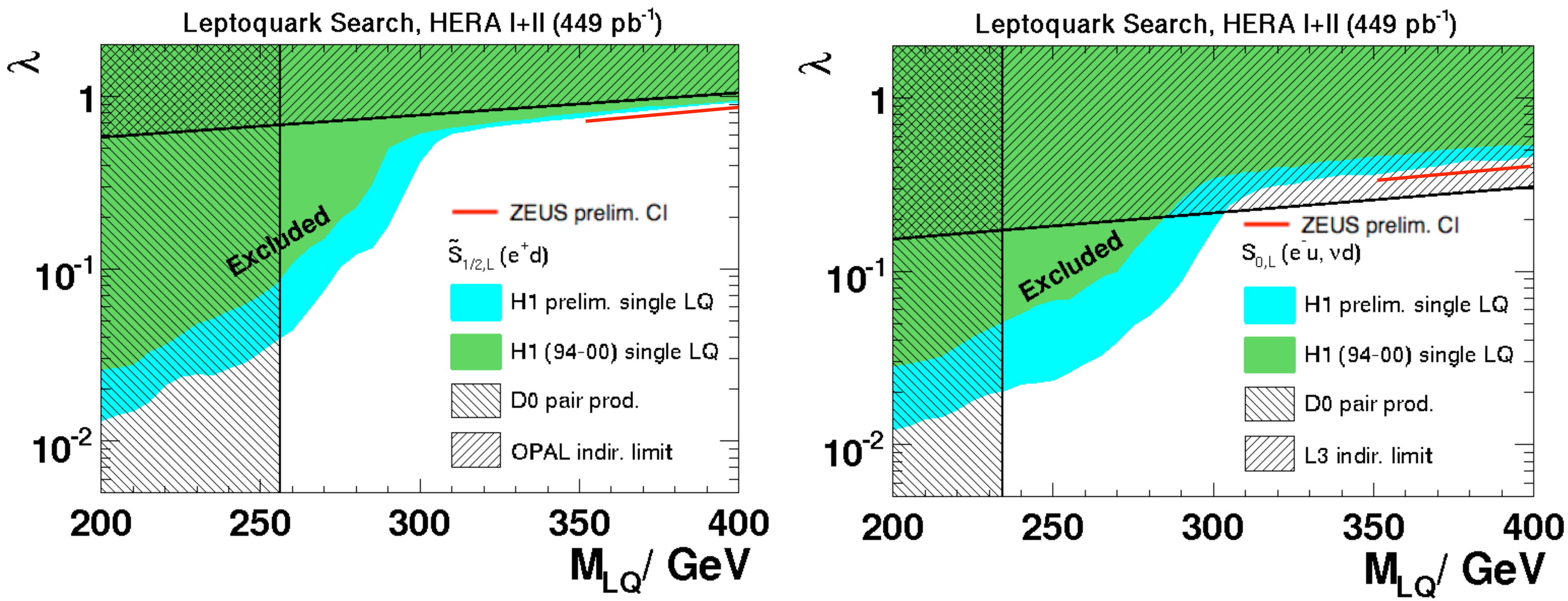
- Data analysed taking into account the different polarisation periods
- Good description of data by SM prediction

Limits on the Yukawa coupling as function of M_{LQ}



- Limits derived for all 14 types of Leptoquark
- *M_{LQ} < 300 GeV:* Resonant LQ production, strongest limits
- *M_{LQ} > 300 GeV:* LQ exchange, CI domain
- For λ=0.3: M_{LQ} < 291-330 GeV are ruled out @ 95% C.L.

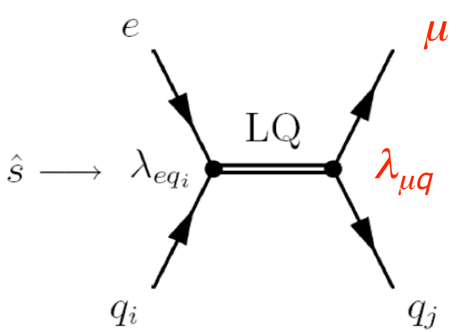
Comparison of Limits to Other Colliders



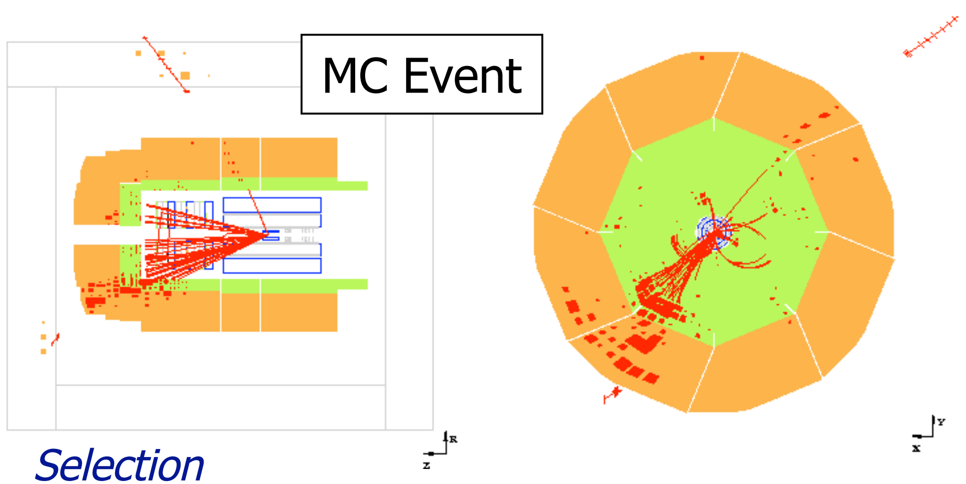
- New H1 limits extend beyond HERA I limits and beyond those from other colliders

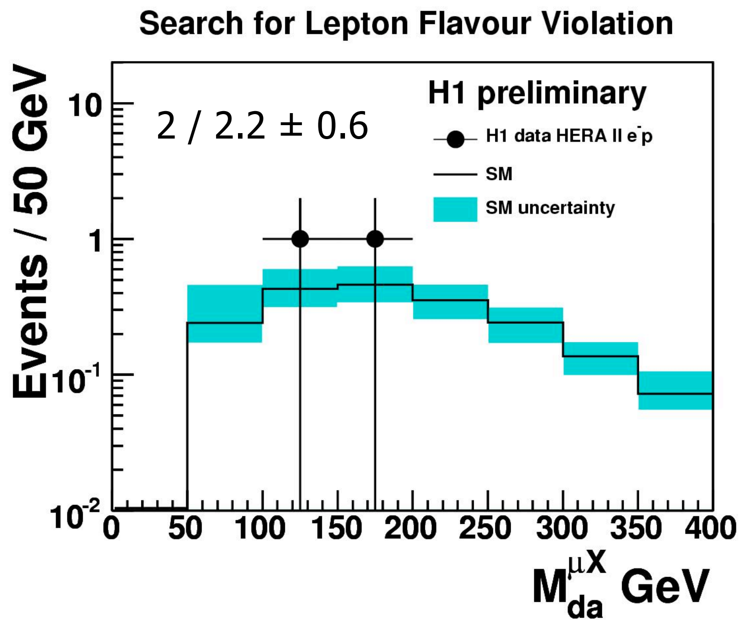
- LEP (OPAL, L3): Indirect limits from: $e^+e^- \rightarrow LQ \rightarrow qq$
- TEVATRON (D0): From LQ pair production: qq (gg) → $LQ\overline{LQ}$, independent of λ

Search for 2nd Generation Leptoquarks



- Lepton Flavour Violation mediated by LQ resonance resulting in μ,τ + jet final state
- This analysis: $e^{\pm}p \rightarrow$ LQ $\rightarrow$ μX , using HERA II $e^{-}p$ data
- Clean experimental signature, background dominated by lepton pair production



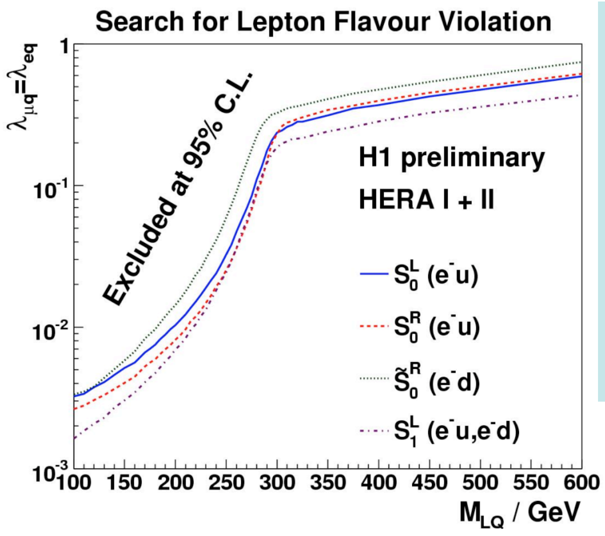


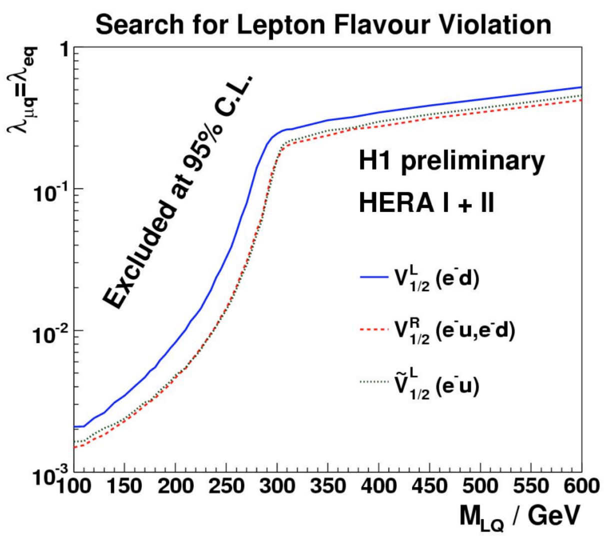
Selection

Isolated, high P_T muon
P_T^{Calo} > 20 GeV (missing energy from muon)
Back-to-back event topology

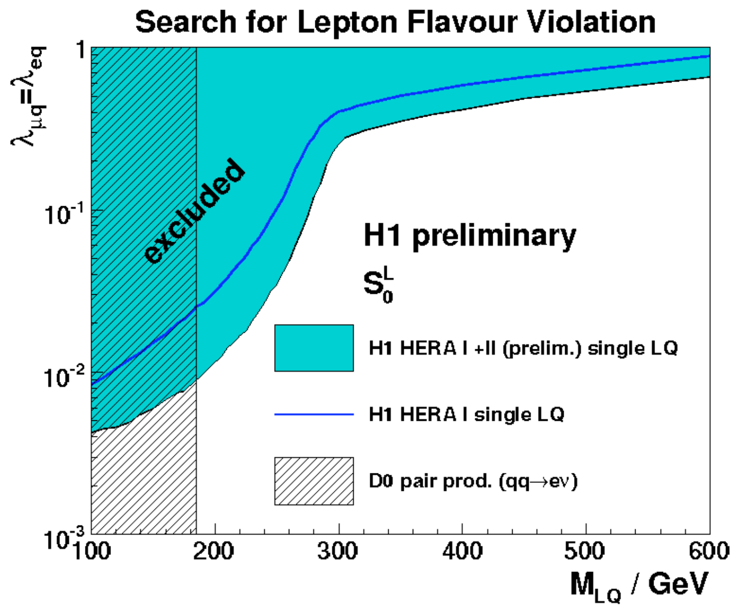
- No evidence for 2nd gen LQ signal in mass spectra: interpret results in terms of exclusion limits

2nd Generation Leptoquarks Limits





- Limits derived @ 95% CL for the 7 F=2 Leptoquarks, under the assumption $\lambda_{eq} = \lambda_{\mu q}$ and $\lambda_{\tau q} = 0$
- H1 Limits improved with respect to HERA I analysis (more than tenfold increase in e^-p luminosity)
- TEVATRON (D0) Limit: Again from LQ pair production: qq (gg) → LQLQ → eνqq



For λ=0.3:
M_{LQ} < 291-433 GeV are ruled out @ 95% C.L.

The GM Model of Excited Fermions

- Theories of quark and lepton compositeness, which is at a *characteristic scale* Λ
  - Composite models can explain the three-family structure of the SM
  - Excited Fermions would show up as signal of this substructure

- The main† model for the coupling of fermions and excited fermions considered by H1 is via Gauge Mediated (GM) interactions
  - Assume f* have spin, isospin 1/2 and exist in weak doublets $F_{L,R}^* = (\nu_e^*, e^*)_{L,R}$
  - Only right handed component of F^* involved in the exchange
  - Lagrangian describing the $f \leftrightarrow f^*$ transitions described by:

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

g, g′, g_s : electroweak and strong gauge couplings

SU(2) (em)

U(1) (weak)

SU(3) (strong)

f, f′, f_s : unknown coupling parameters

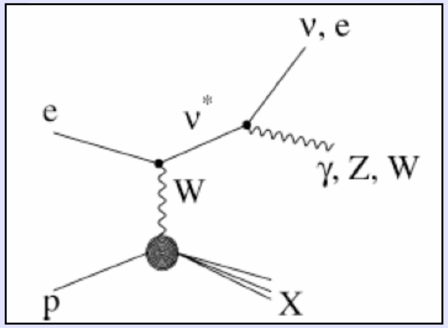
H1 searches for f^* by looking for f* de-excitation by emission of γ,Z or W

†Contact Interactions are also considered for excited electrons: see later

Excited Fermions: Production and Decay at HERA

ν^*

Phys. Lett. B663, 382, 2008.



- produced via t-channel W boson exchange

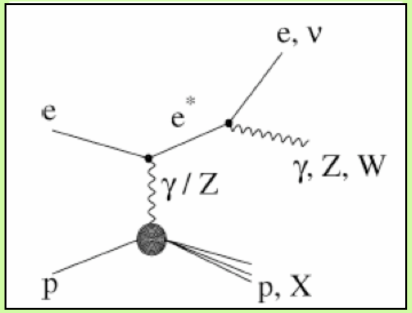
$\sigma(e^-p)/\sigma(e^+p) \sim 100$

("charged current" like production)

H1 analysis : use all e^-p data (184 pb^{-1})

e^*

Accepted by Phys. Lett. B, hep-ex/0805.4530



- produced via t-channel γ/Z bosons exchange

H1 analysis : use all $e^{\pm}p$ data (475 pb^{-1})

q^*

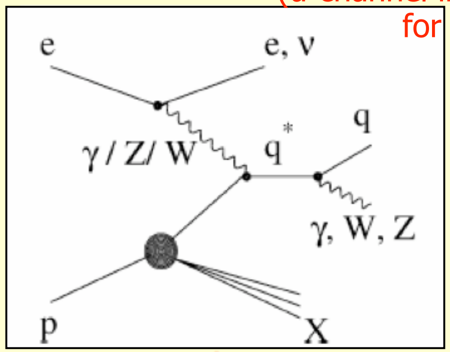
New Preliminary this Conference!

Under the assumption $f_s = 0$ (assumed for all f^* here)

(q^* prod. via qg = 0)
(q^* decay into qg = 0)

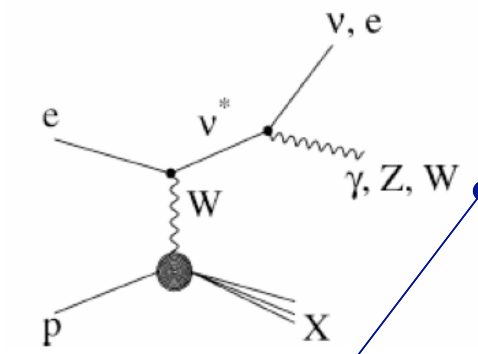
- q^* produced via t-channel γ/Z/W bosons exchange

(u-channel included for $q^* \to q\gamma$)



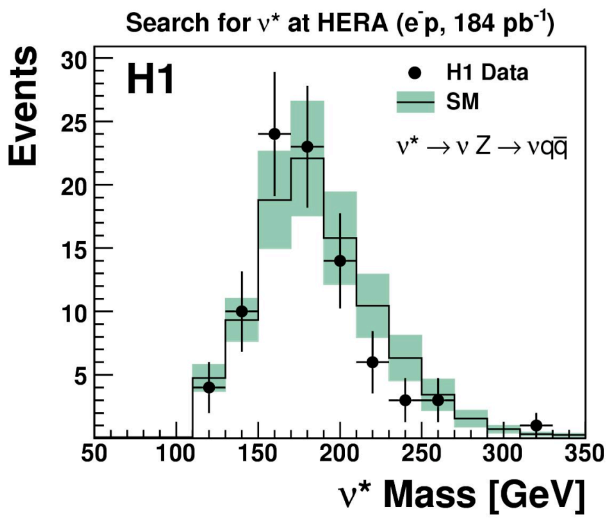
H1 analysis on all $e^{\pm}p$ data (475 pb^{-1})

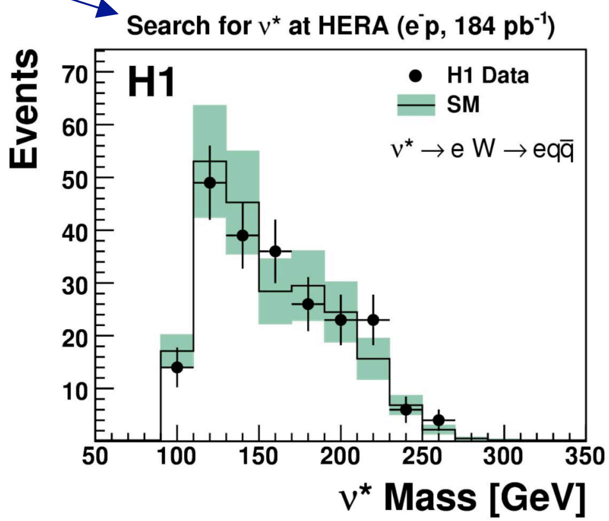
Search for ν^* at HERA (e^-p, 184 pb^{-1})



Channel	Data	SM	Signal Efficiency [%]
$\nu^* \to \nu\gamma$	7	12.3 ± 3.0	50–55
$\nu^* \to eW \to eq\bar{q}$	220	223 ± 47	40–65
$\nu^* \to eW \to e\nu\mu$	0	0.40 ± 0.05	35
$\nu^* \to eW \to e\nu e$	0	0.7 ± 0.1	45
$\nu^* \to \nu Z \to \nu q\bar{q}$	89	95 ± 21	25–55
$\nu^* \to \nu Z \to \nu ee$	0	0.19 ± 0.05	45

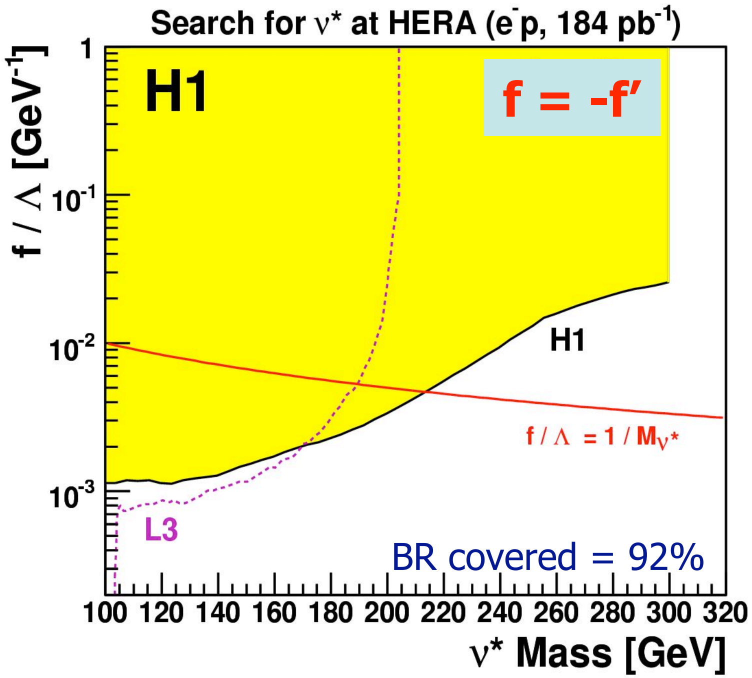
Almost all ν^* decay topologies investigated

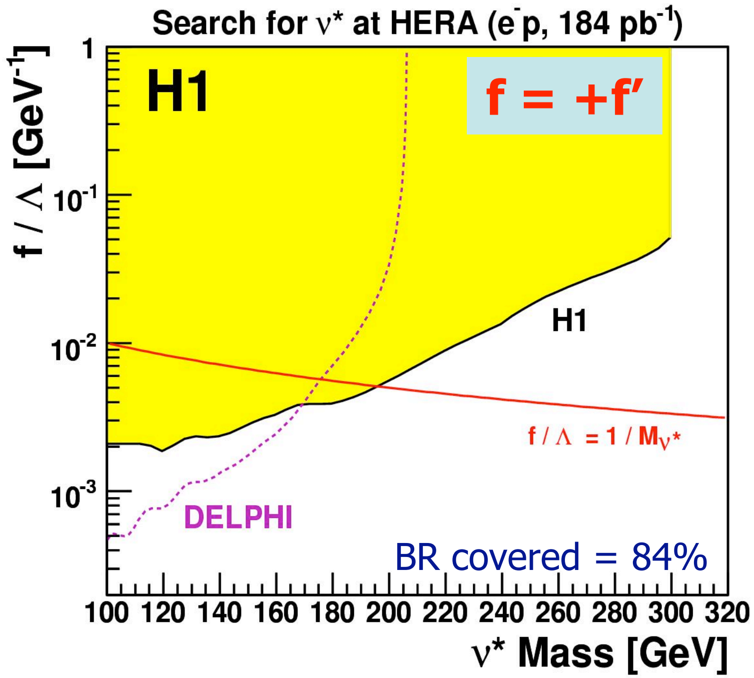




- Good agreement with the SM and no resonance observed in mass spectra
- Derive limits @ 95% C.L. on f/λ as a function of M_{ν^*} for channels combined
- *Conventional assumptions*:
  - ν^* is insensitive to f_s (=0)
  - f,f′ comparable; examine f = -f′ or f = +f′

Limits on f/λ from ν^* Production





$M_{\nu*}$ < 213 GeV excluded for f/λ = $1/M_{\nu*}$

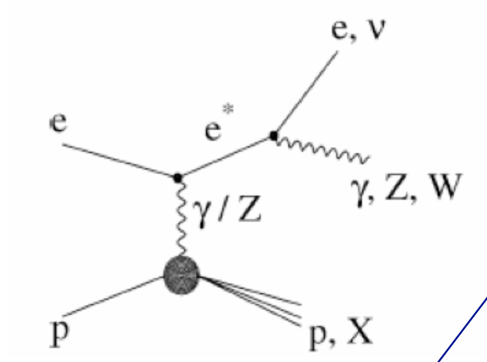
Limit driven by $\nu^* \rightarrow \nu\gamma$ at low mass,
$\nu^* \rightarrow eW$ contributes for M > 200 GeV

$M_{\nu*}$ < 196 GeV excluded for f/λ = $1/M_{\nu*}$

Limit mainly driven by $\nu^* \rightarrow eW$
($\nu^* \rightarrow \nu\gamma$ forbidden for f = +f′)

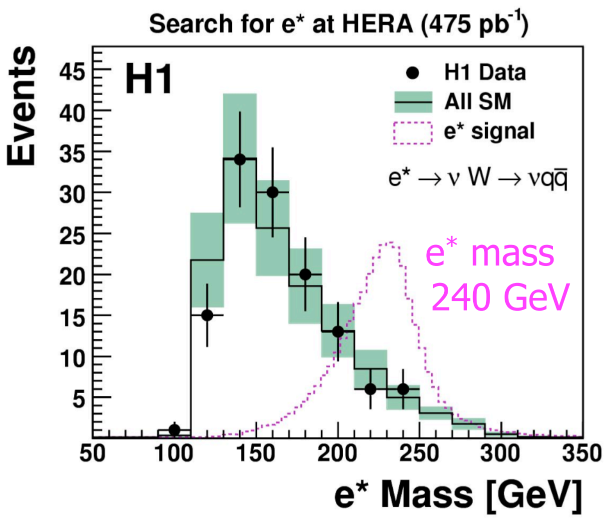
HERA: Best sensitivity for masses beyond the LEP reach

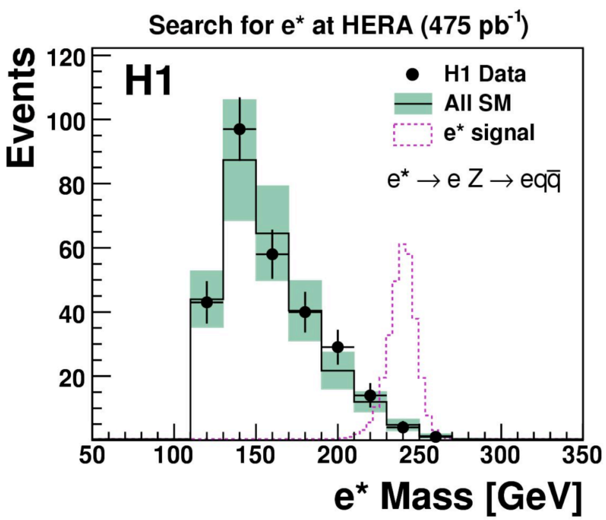
Search for e* at HERA (e±p, 475 pb^{-1})



Channel	Data	SM	Signal Efficiency [%]
$e^* \to e\gamma$ (ela.)	42	48 ± 4	60–70
$e^* \to e\gamma$ (inel.)	65	65 ± 8	60–70
$e^* \to \nu W \to \nu q\bar{q}$	129	133 ± 32	20–55
$e^* \to \nu W \to \nu e \nu$	4	4.5 ± 0.7	60
$e^* \to eZ \to e\nu\nu$			35
$e^* \to eZ \to eq\bar{q}$	286	277 ± 62	20–55
$e^* \to eZ \to eee$	0	0.72 ± 0.06	60
$e^* \to eZ \to e\mu\mu$	0	0.52 ± 0.05	40–15

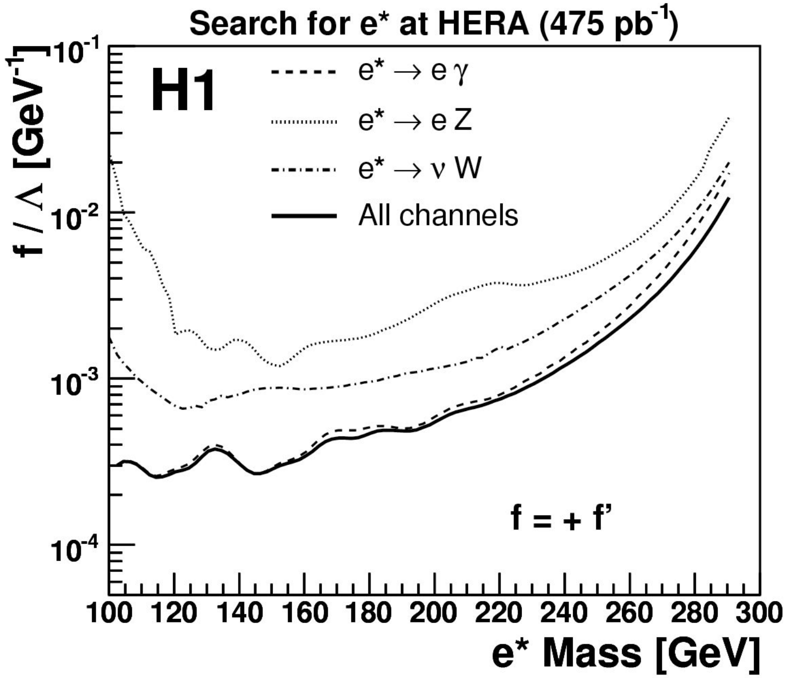
Almost all e* decay topologies investigated

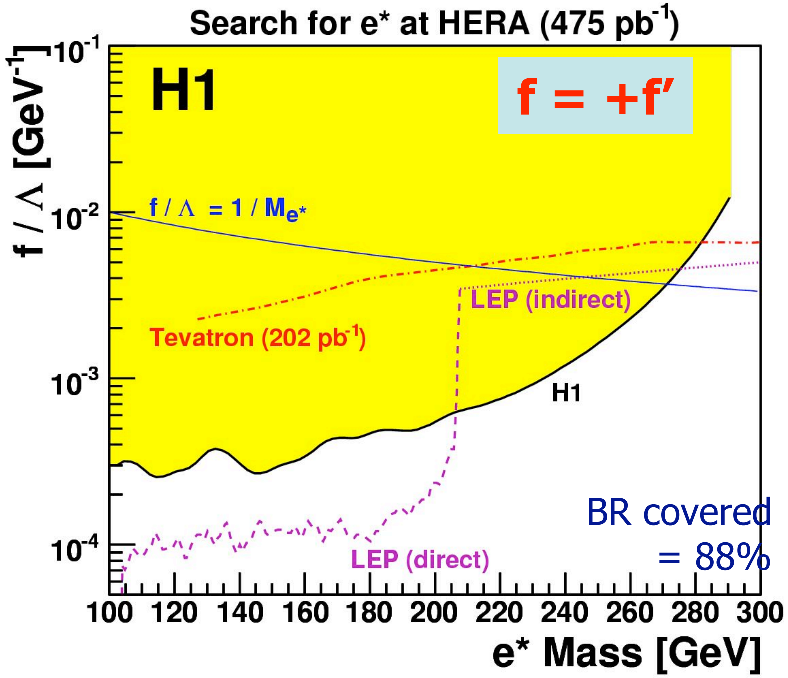




- Good agreement with the SM and no resonance observed in mass spectra
- Derive limits @ 95% C.L. on f/λ as a function of M_{e*} for channels combined
- *Conventional assumptions*:
  - e* is insensitive to f_s (=0)
  - f = +f′ only (ν*→νγ, high BR, forbidden for f = -f′)

Limits on f/λ from e* Production





M_{e*} < 272 GeV excluded for $f/\lambda = 1/M_{e*}$

Limit driven by e* → eγ at low mass, e* → νW contributes at higher masses

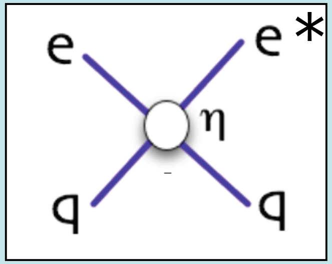
Results from LEP (OPAL, DELPHI) and from CDF (e* within GM model) also shown

HERA: Best sensitivity in the intermediate e* mass range

e^* Limits including the CI Production Model

- In addition to the GM interactions, a CI model can be used to describe the $f \leftrightarrow f^*$ transitions, described by:

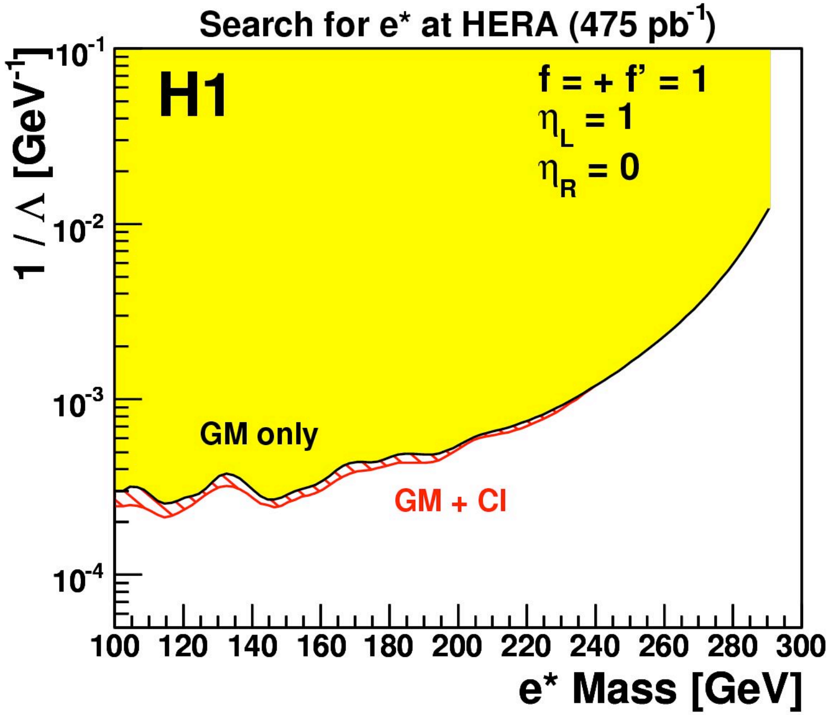
$$\mathcal{L}_{CI} = \frac{4\pi}{2\Lambda^2} j^\mu j_\mu$$



with left-handed fermion currents

- Total e^* *production* cross section is the sum of the cross sections σ_{GM+CI}

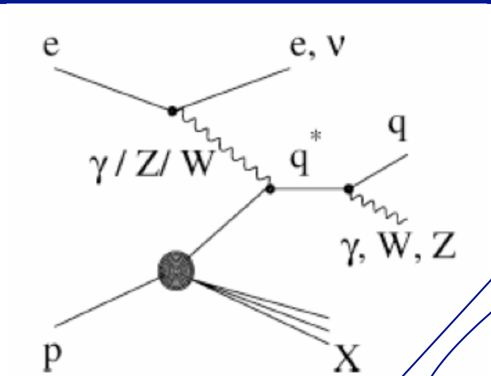
- For simplicity, set f = +f′ = 1, fixing the relative strength of the GM and CI components and use only GM e^* *decays* (> 95% of total here)



- For a given mass, CI contribution decreases for increasing Λ
- For e^* masses below 250 GeV, the additional contribution of CI to e* production changes the limit by a factor 1.15 → 1.2

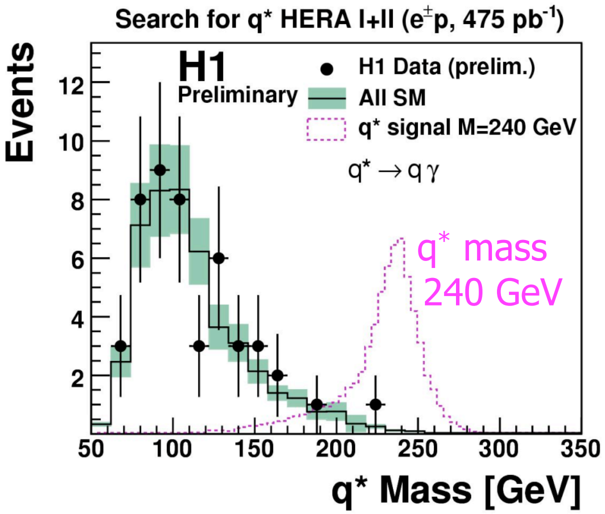
Search for q^* at HERA ($e^{\pm}p$, 475 pb^{-1})

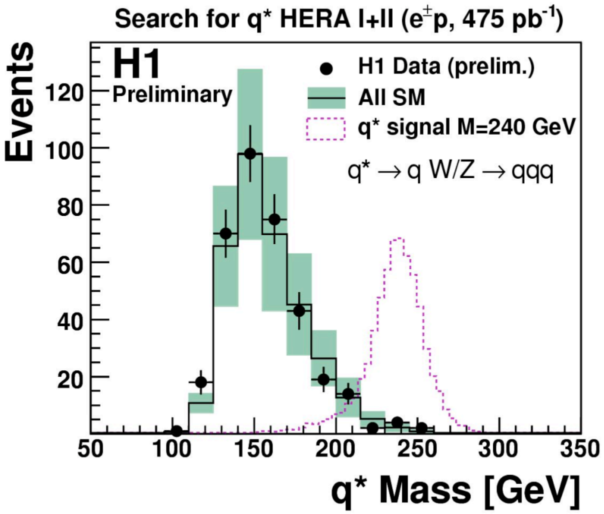
New Preliminary this Conference



Almost all q^* decay topologies investigated

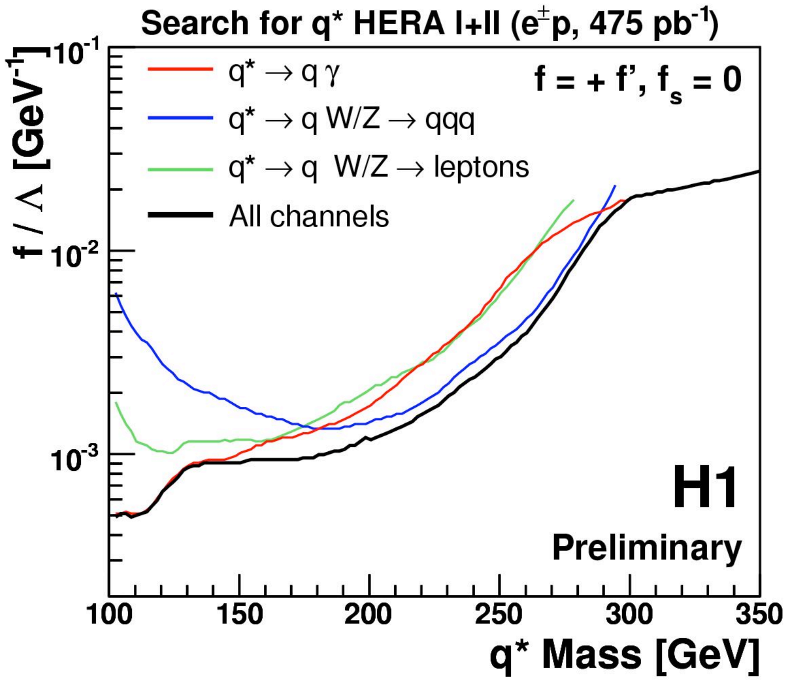
Channel	Data	SM	Signal Efficiency [%]
$q^* \to q\gamma$	47	47 ± 7	35–45
$q^* \to qW/Z \to qq\bar{q}$	346	338 ± 137	5–60
$q^* \to qW \to qe\nu$	6	6.0 ± 0.8	25–40
$q^* \to qW \to q\mu\nu$	5	4.4 ± 0.7	25–50
$q^* \to qZ \to qee$	0	0.44 ± 0.08	35
$q^* \to qZ \to q\mu\mu$	0	0.87 ± 0.08	35

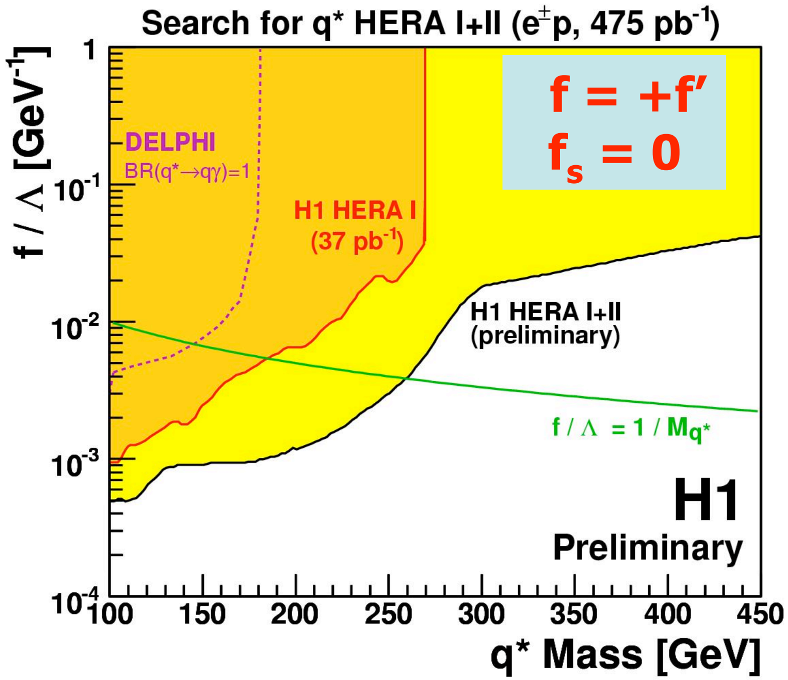




- Good agreement with the SM and no resonance observed in mass spectra
- Derive limits @ 95% C.L. on f/λ as a function of M_{q*} for channels combined
- *Conventional assumptions*:
  - $f_s = 0$ (no s interactions)
  - f,f′ comparable; only examine f = +f′ so far

Limits on f/λ from q^* Production





$M_{q*} < 259$ GeV excluded for $f/\lambda = 1/M_{q*}$

Limit driven by $q^* \rightarrow q\gamma$ at low mass, W/Z decays contribute at higher masses

Limits *greatly improved* with respect to HERA I limit

Inclusion of u-channel in $q^* \rightarrow q\gamma$ calculation: limits extended to higher masses

HERA: Best sensitivity for masses beyond the LEP reach

Summary

- HERA provides a unique opportunity to search for new physics
- H1 has performed searches for resonant production of LQs as well as excited fermions, using the complete HERA dataset
  - Analysis of LFV LQs with full HERA data is underway
- No significant deviation from the SM observed and limits, often the world's most stringent, are set on the production of such particles
  - (LFV) Leptoquark masses up to 433 GeV excluded @ 95% CL for λ=0.3
  - Excited fermion masses up to 272 GeV excluded @ 95% CL for $f/\lambda = 1/M_{f*}$
- Plan to use the full 1 fb^{-1} of HERA data including ZEUS