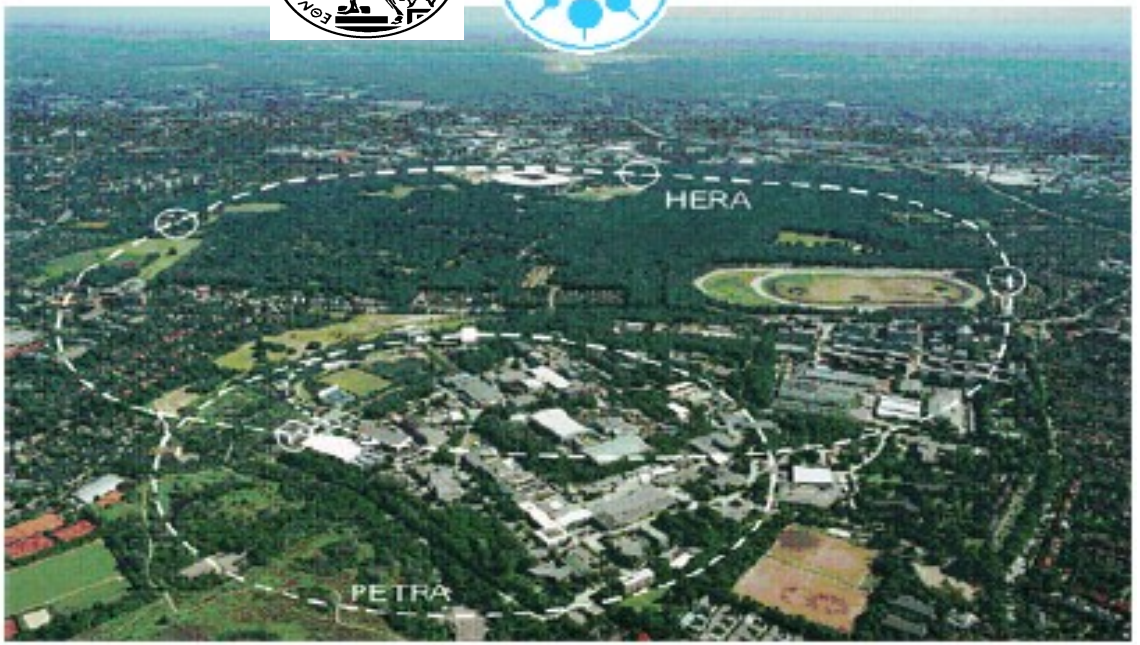
Search for Leptoquarks and Contact Interactions at HERA

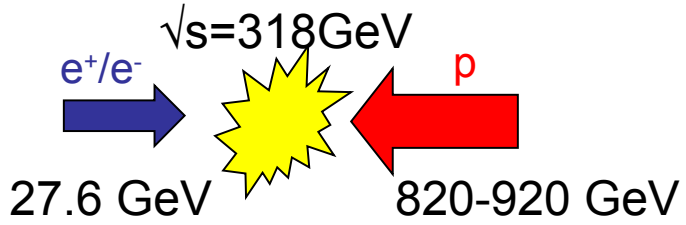
Ilias Panagoulias
NTU Athens/DESY



18th International Workshop On Deep Inelastic Scattering And Related Subjects (DIS 10)

19-23 Apr 2010 Florence, Italy

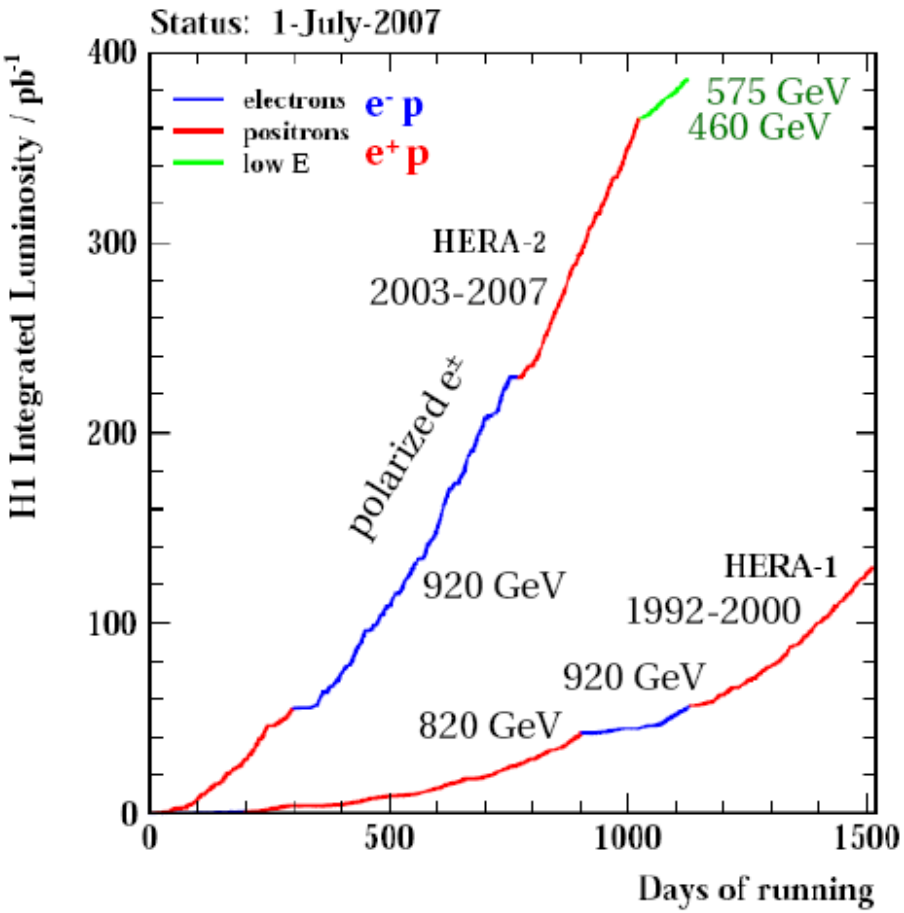
HERA Operation



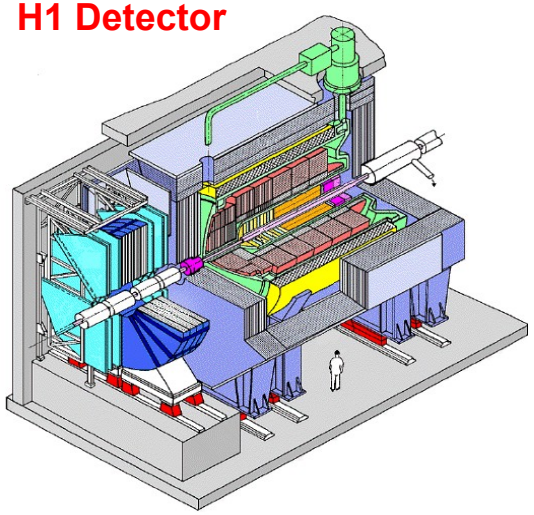
HERA

An unique $e^{\pm}p$ collider (1992-2007)

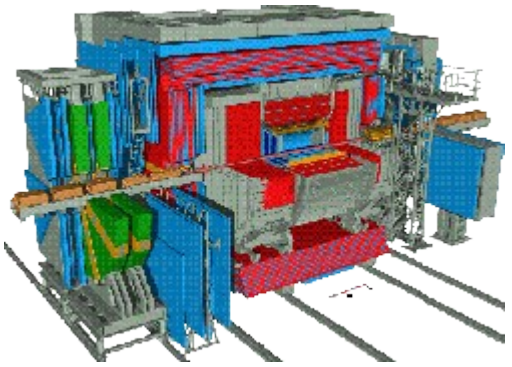
Two large colliding general purpose detectors H1 and ZEUS with asymmetric design



H1 Detector



Zeus Detector

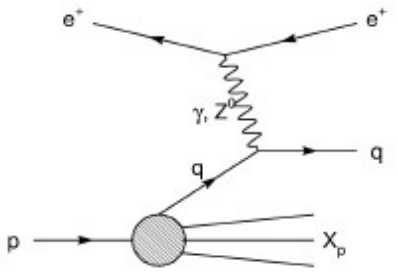


HERA I (1994-2000), L=~120pb^{-1}

HERA II (2002-2007), L=~360pb^{-1}
Longitudinal polarisation of lepton beam (P=30-40%)

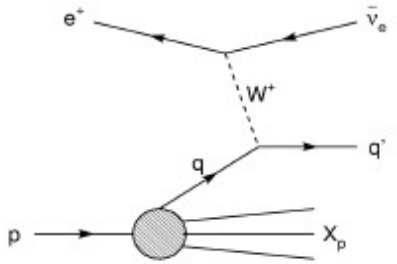
High Q^2 NC and CC processes

Main processes studied at HERA

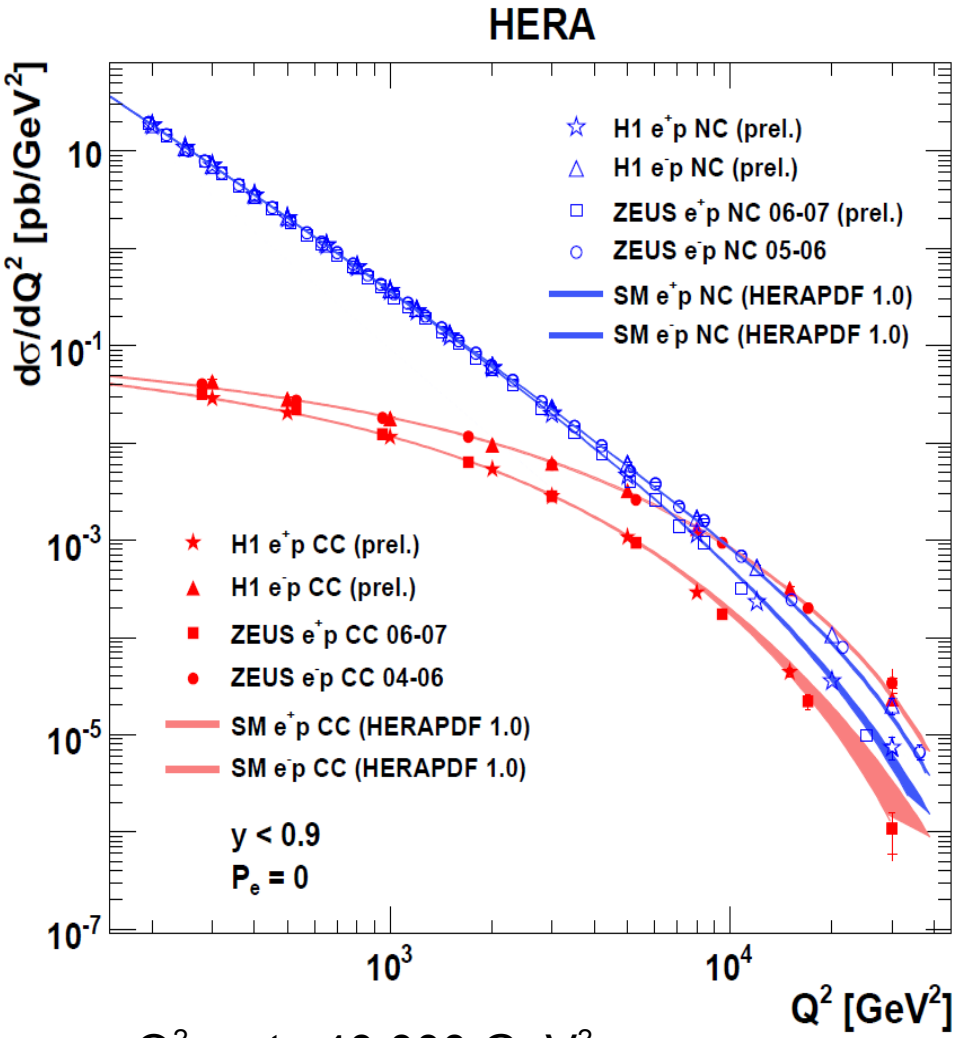


Neutral Current DIS

ep → eX



Charged Current DIS
ep → νX



Excellent agreement between data and SM
Precise tests of QCD and EW Physics

Possible deviation at high Q^2 should indicate
Beyond SM physics
-Leptoquark production
-Contact Interactions

Q^2 up to 40.000 GeV^2
Spatial resolution ~ 1/Q = 10^{-3} fm
Probe small distances

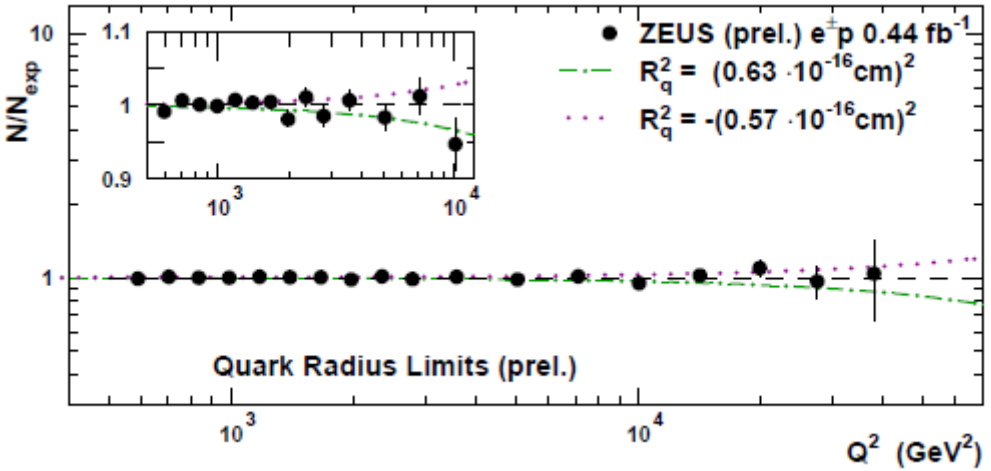
Search for quark substructure

Form factor analysis to search for quark substructure.
If a quark has a finite size, the SM prediction for the cross sections are modified to

$$\frac{d\sigma}{dQ^2} = \frac{d\sigma^{SM}}{dQ^2}\left[1 - \frac{R_q^2}{6}Q^2\right]^2$$

- Electron assumed to be point -like
- R_q is a root mean square radius of the EW charge of the quark
- Cross section expected to decease as higher Q^2
- Same dependence for e^-p, e^+p

ZEUS



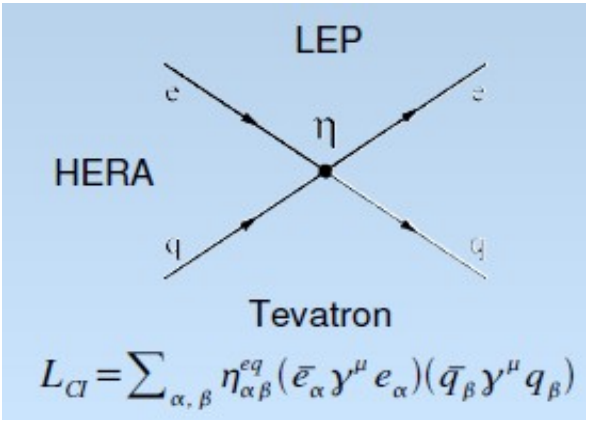
Effect of quark radius limit in SM cross section

ZEUS (94-07 data): Rq<0.63 x 10^{-3} fm
H1 (94-07 data): Rq<0.74 x 10^{-3} fm
(preliminary results)

Excellent agreement with SM up to highest Q^2

Contact Interactions (CI)

New interactions at higher scale (Λ>>√s) can be effectively described at lower energies as 4-fermion eeqq Contact Interaction.



$$L_{CI} = \sum_{\alpha,\beta} \eta^{eq}_{\alpha\beta} (\bar{e}_\alpha \gamma^\mu e_\alpha)(\bar{q}_\beta \gamma^\mu q_\beta)$$

where α,β are the electrons and quark helicities (L,R)

Coupling η, is related to the mass scale Λ

$$\eta^{eq}_{\alpha\beta} = \frac{\epsilon\, g^2_{CI}}{\Lambda^2}$$

ε=±1

$g^2_{CI}=4\pi$

Models conserving parity:

Model	η^{ed}_{LL}	η^{ed}_{LR}	η^{ed}_{RL}	η^{ed}_{RR}	η^{eu}_{LL}	η^{eu}_{LR}	η^{eu}_{RL}	η^{eu}_{RR}
VV	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$
AA	$+\eta$	$-\eta$	$-\eta$	$+\eta$	$+\eta$	$-\eta$	$-\eta$	$+\eta$
VA	$+\eta$	$-\eta$	$+\eta$	$-\eta$	$+\eta$	$-\eta$	$+\eta$	$-\eta$
X1	$+\eta$	$-\eta$			$+\eta$	$-\eta$		
X2	$+\eta$		$+\eta$		$+\eta$		$+\eta$	
X3	$+\eta$			$+\eta$	$+\eta$			$+\eta$
X4		$+\eta$	$+\eta$			$+\eta$	$+\eta$	
X5		$+\eta$		$+\eta$		$+\eta$		$+\eta$
X6			$+\eta$	$-\eta$			$+\eta$	$-\eta$
U1					$+\eta$	$-\eta$		
U2					$+\eta$		$+\eta$	
U3					$+\eta$			$+\eta$
U4						$+\eta$	$+\eta$	
U5						$+\eta$		$+\eta$
U6							$+\eta$	$-\eta$

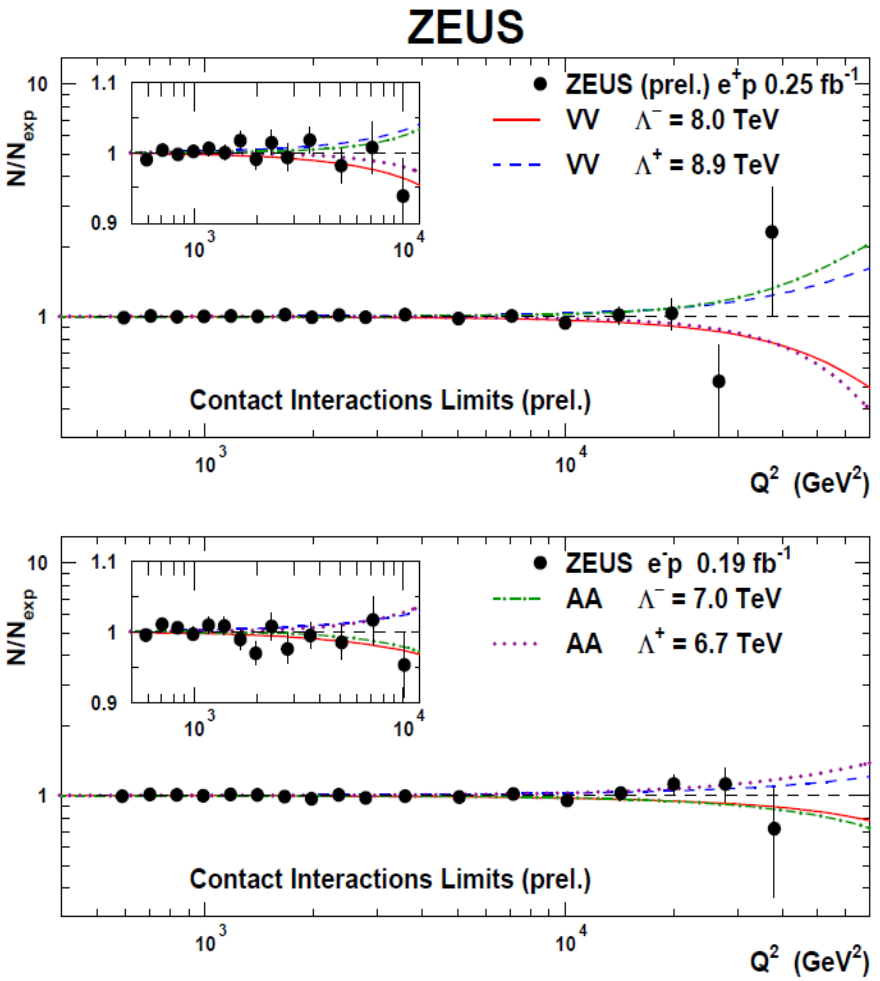
Models violating parity:

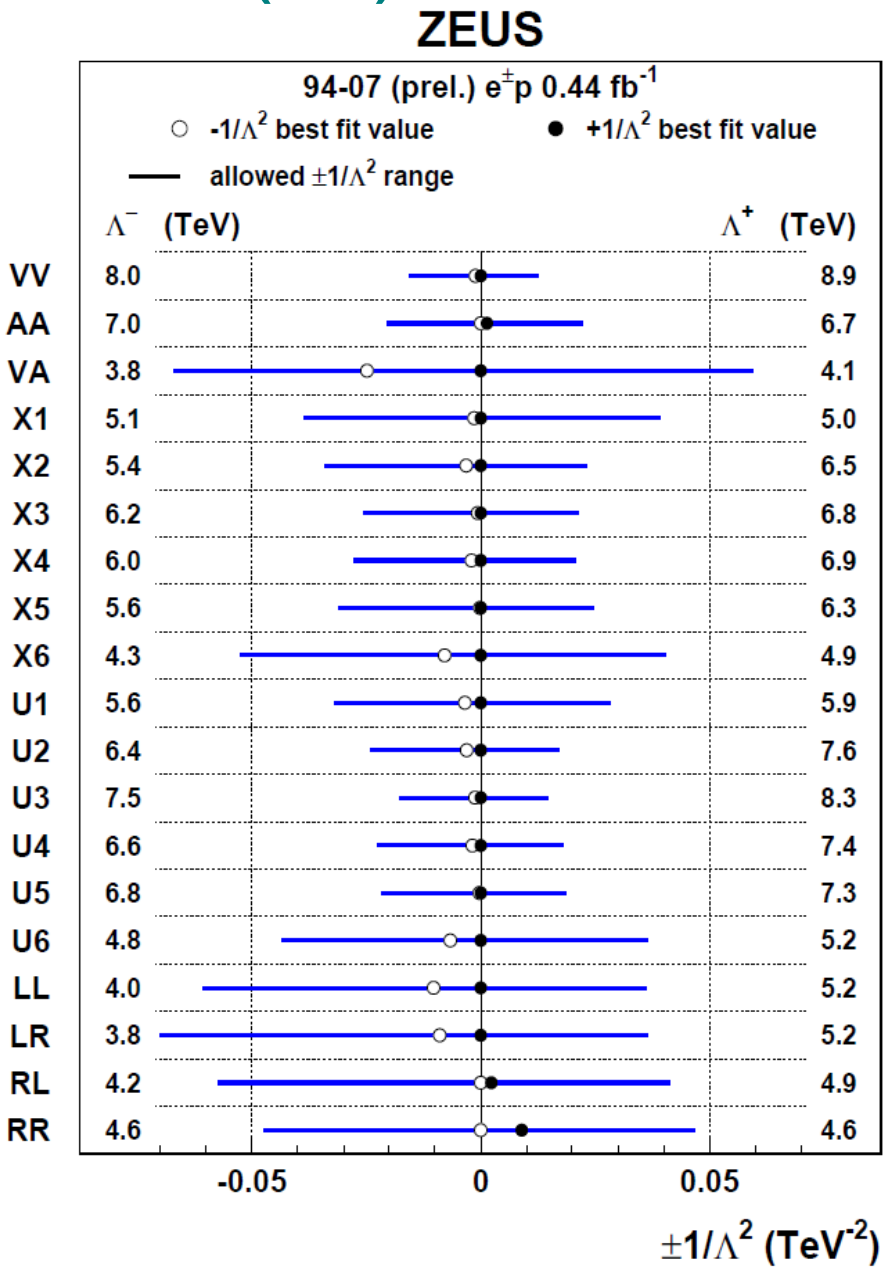
LL	$+\eta$				$+\eta$			
LR		$+\eta$				$+\eta$		
RL			$+\eta$				$+\eta$	
RR				$+\eta$				$+\eta$

Different models assume different helicity structure of new interactions, given by set of couplings $\eta^{eq}_{\alpha\beta}$

Contact Interactions (CI)

ZEUS CI analysis based on full NC sample





ZEUS (94-07 data): Λ>3.8-8.9 TeV, 95% CL

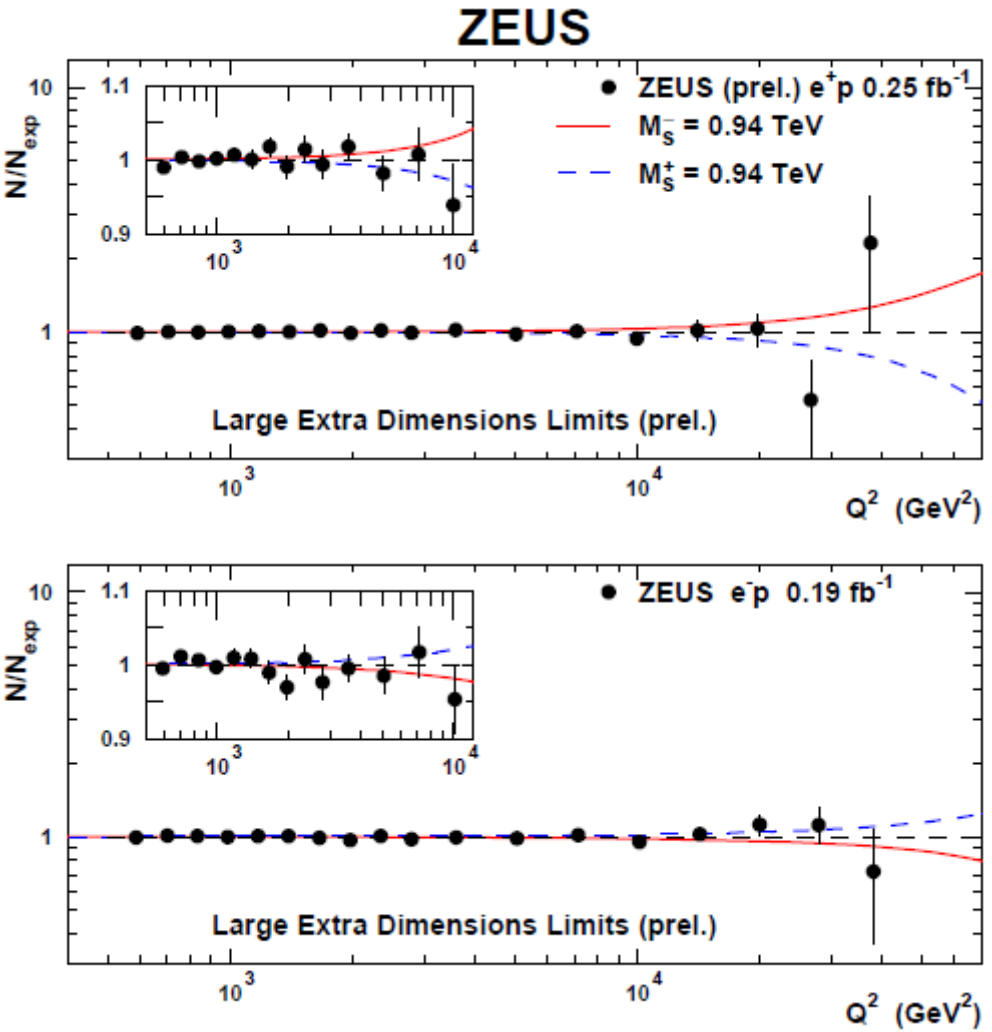
Search for Large Extra Dimensions

Arkani-Hamed, Dimopoulos, Dvali model (proposed solution to the hierarchy problem)

- Gravity can propagate to 4+n dimensions
- effective Plank scale M_D can be ~1TeV
- At high energies, the strengths of gravitational and electroweak interactions can be comparable.

Graviton exchange contribution to eq→eq interactions can be described as a contact interaction with an effective coupling of

$\eta \sim 1/M^4$



ZEUS (94-07 data): Ms>0.94 TeV, 95% CL

The Leptoquark Model

LEPTOQUARKS

Hypothetical bosons which appear in many SM extensions to explain symmetry between leptons and quarks

LQs are coupled to both leptons and quarks and carry SU(3) colour, fractional electrical charge, baryon (*B*) and lepton (*L*) numbers

→ Fermion number F = 3B + L = 0 , 2

Buchmuller-Ruckl-Wyler Model

$SU(3)_C \times SU(2)_L \times U(1)_Y$ invariance

Lepton and baryon number conservation

Chiral particles: either left- or right-handed couplings

7 scalar and 7 vector LQs

$F=2$	Prod./Decay	β_e	$F=0$	Prod./Decay	β_e
	e^-p Scalar Leptoquarks			e^+p	
$S_{0,L}$	$e_L^- u_L \to e^- u$	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
$\tilde{V}_{1/2,L}$	$e_L^- d_R \to e^- d$	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

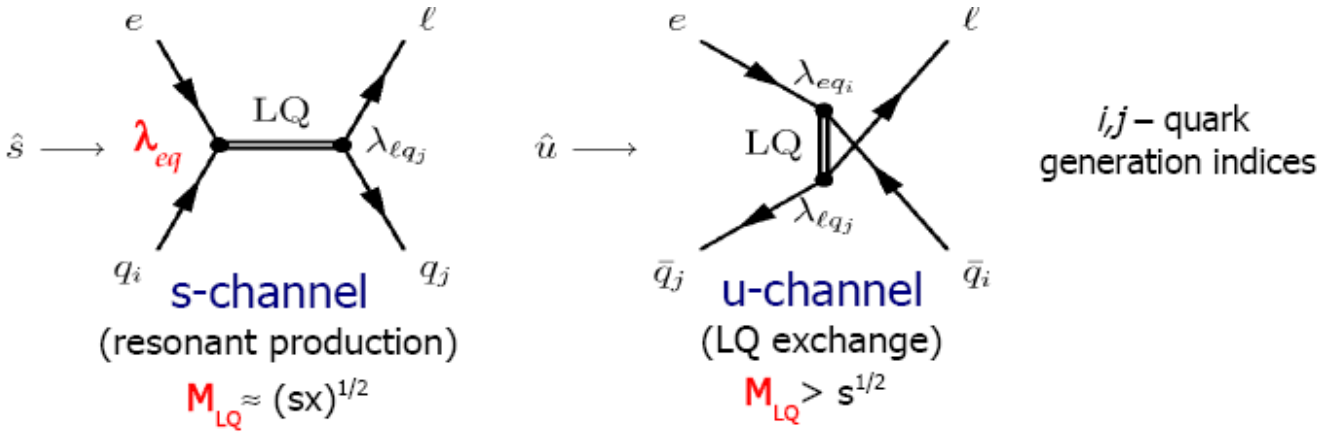
Resonance width $\Gamma \sim \lambda^2 \cdot M_{LQ}$

Each LQ characterized by two free parameters:

LQ mass, M_{LQ}

LQ-l-q Yukava coupling, λ

LQ production at HERA



If LQ→eq, Lepton Flavor Conserving (LFC) decays, (1st generation LQ's)

If LQ→μq/τq, Lepton Flavor Violating (LFV) decays, (2nd/3rd generation LQ's)

resonant production in s-channel

exchange in u-channel

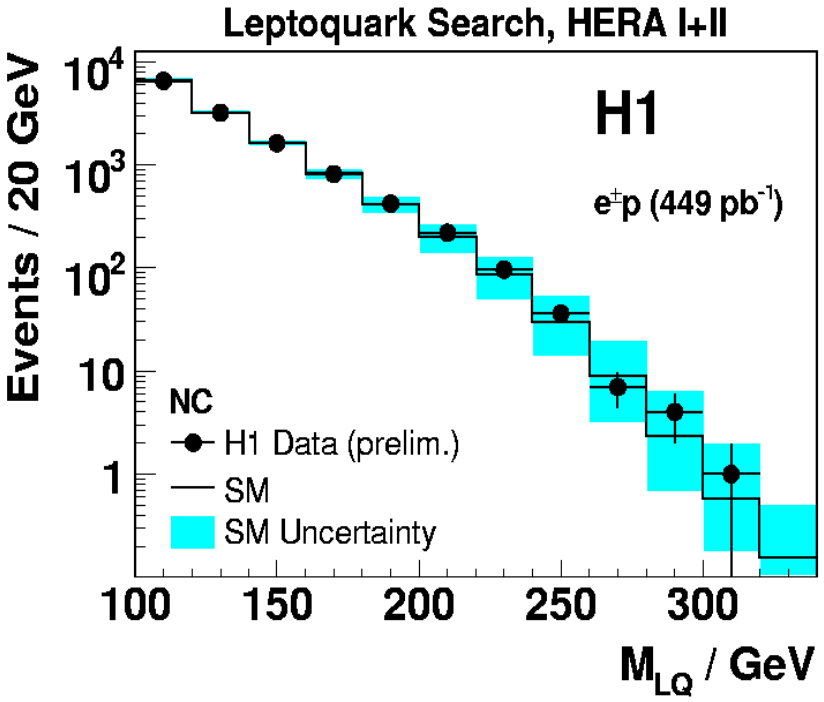
signature one jet & one l/ν

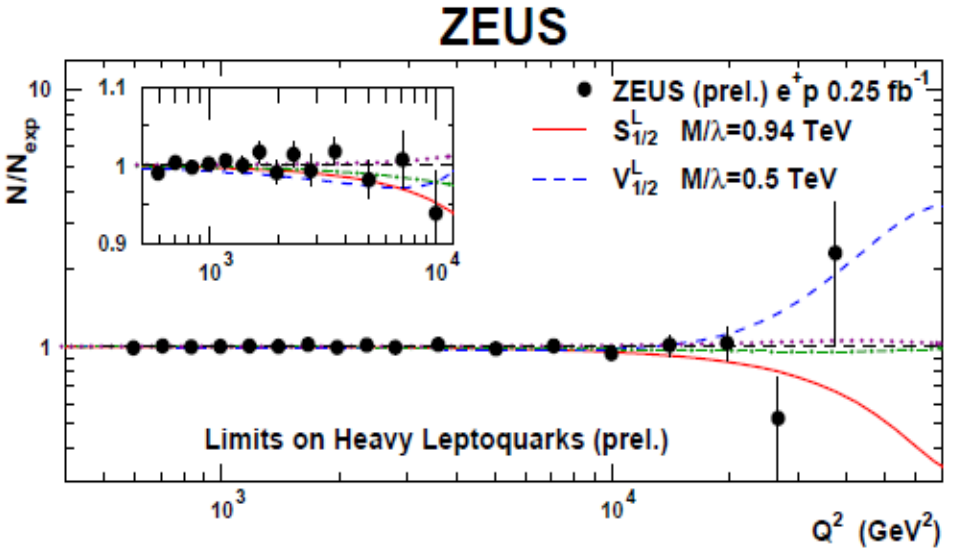
final state indistinguishable from SM NC/CC DIS for 1st generation LQs

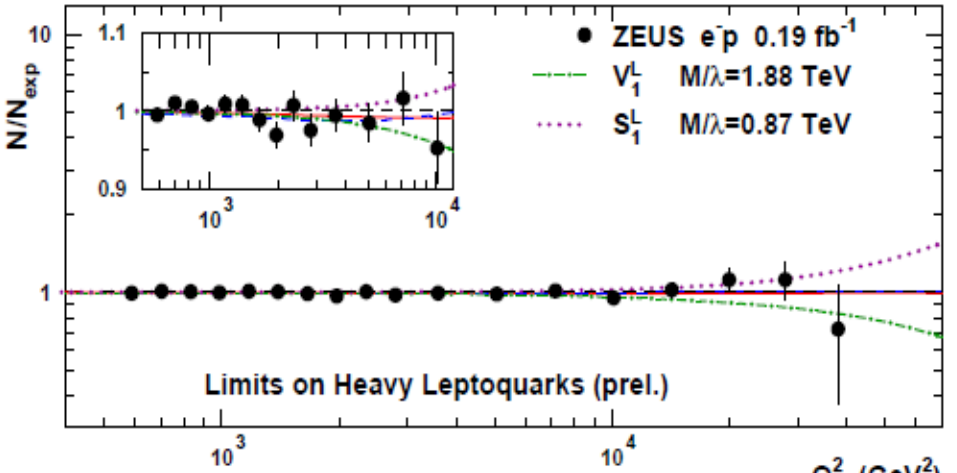
clear signal if we assume LFV

Search for 1st generations Leptoquarks

Complete HERA e^+p/e^-p data analysed, L~0.45 fb^{-1}







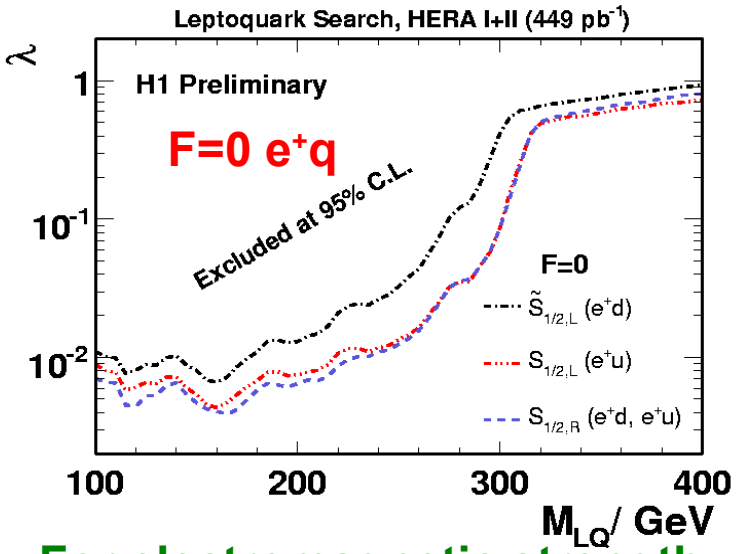
Good description of data by SM prediction in both NC and CC processes

Data analysed taking into account the different polarization periods

No evidence for signal → interpretation in terms of exclusion limits

Analysis similar to CI, limits on heavy LQ's

Search for 1st generation Leptoquarks



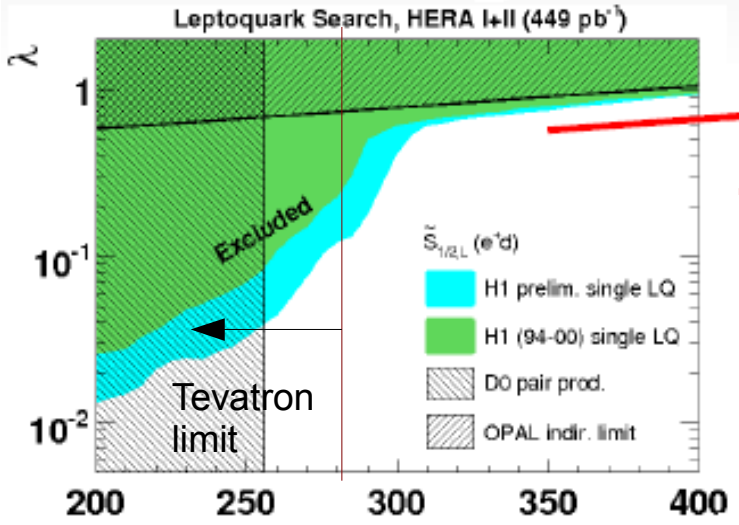
For electromagnetic strength λ=0.3

M_{LQ}<291-330 GeV can be ruled out

ZEUS Preliminary 1994-2007 $e^{\pm}p$		
Model	Coupling Structure	95% C.L. (TeV) M_{LQ}/λ_{LQ}
S_0^L	$a_{LL}^{eu} = +\frac{1}{2}$	1.24
S_0^R	$a_{RR}^{eu} = +\frac{1}{2}$	1.02
$\tilde{S}_0^R$	$a_{RR}^{ed} = +\frac{1}{2}$	0.41
$S_{1/2}^L$	$a_{LR}^{eu} = -\frac{1}{2}$	0.94
$S_{1/2}^R$	$a_{RL}^{ed} = a_{RL}^{eu} = -\frac{1}{2}$	0.81
$\tilde{S}_{1/2}^L$	$a_{LR}^{ed} = -\frac{1}{2}$	0.60
S_1^L	$a_{LL}^{ed} = +1,\ a_{LL}^{eu} = +\frac{1}{2}$	0.87
V_0^L	$a_{LL}^{ed} = -1$	1.05
V_0^R	$a_{RR}^{ed} = -1$	0.77
$\tilde{V}_0^R$	$a_{RR}^{eu} = -1$	1.50
$V_{1/2}^L$	$a_{LR}^{ed} = +1$	0.50
$V_{1/2}^R$	$a_{RL}^{ed} = a_{RL}^{eu} = +1$	1.36
$\tilde{V}_{1/2}^L$	$a_{LR}^{eu} = +1$	1.60
V_1^L	$a_{LL}^{ed} = -1,\ a_{LL}^{eu} = -2$	1.88

Limits on heavy LQ's

ZEUS (94-07 data): M_{LQ}/λ > 0.41-1,88 TeV, 95% CL



ZEUS CI limit

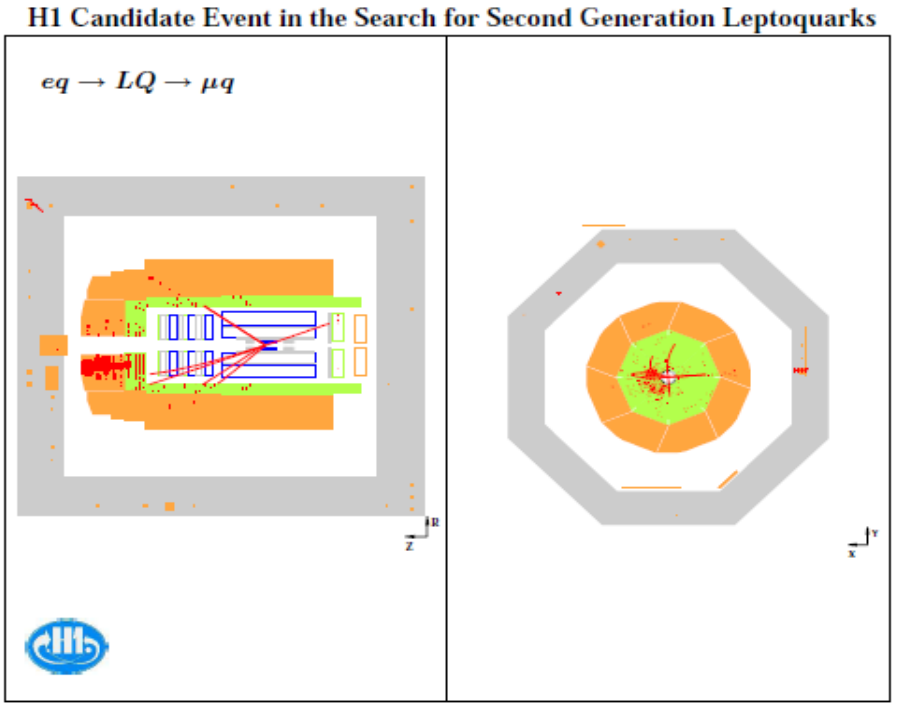
LEP (OPAL, L3) : indirect constraints from $e^+e^- \rightarrow qq$

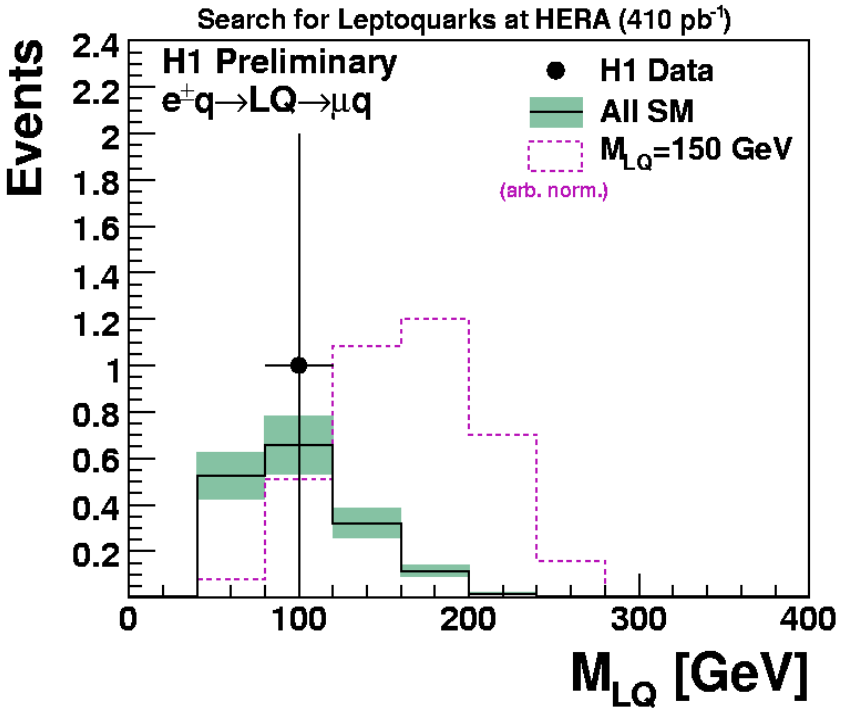
TEVATRON (D0) : qq annihilation or gg fusion (pair production), limit independent of λ

HERA extends the excluded domain

Search for 2nd generation Leptoquarks

LQ could decay to a muon





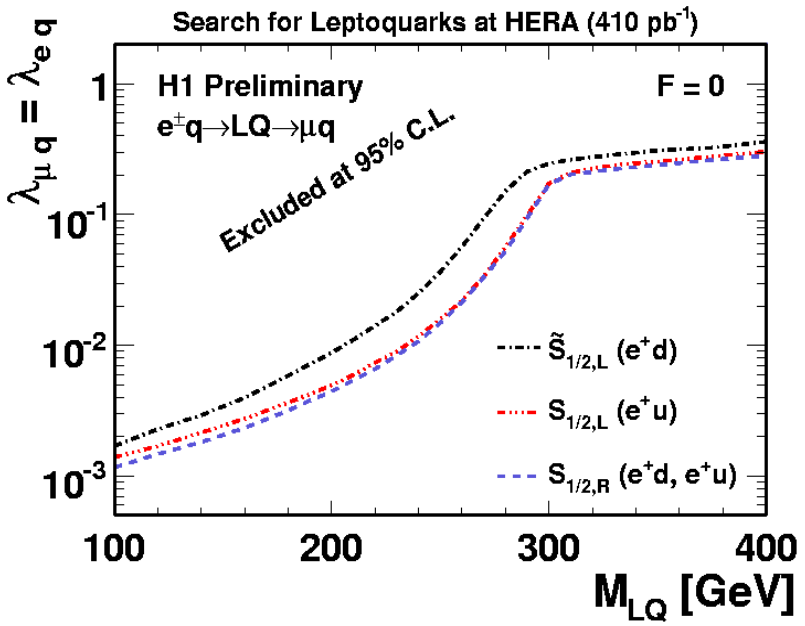
No evidence for signal
Limits set for all 14 LQ types, under assumption

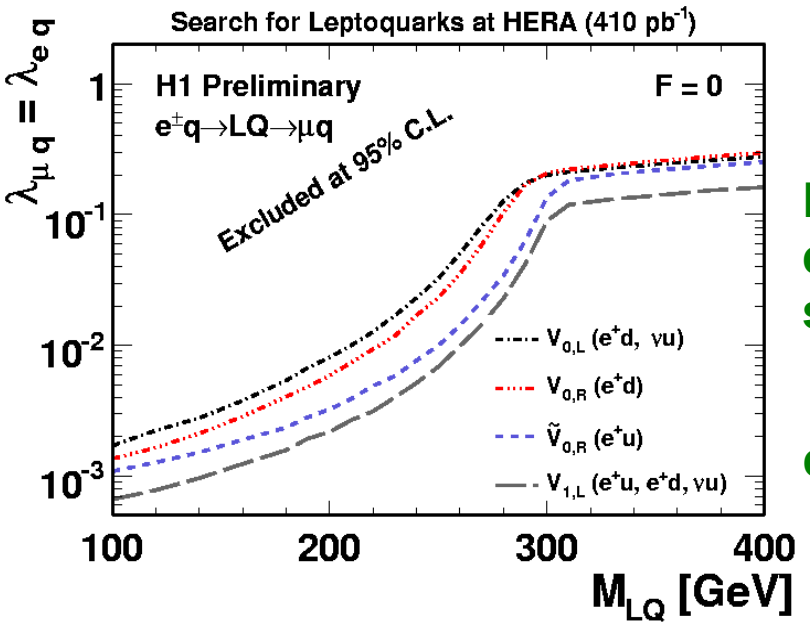
$\lambda_{\mu q} = \lambda_{eq}, \lambda_{\tau q} = 0$

H1 HERA (98-07) sample

1 event seen/1.6±0.5 expected

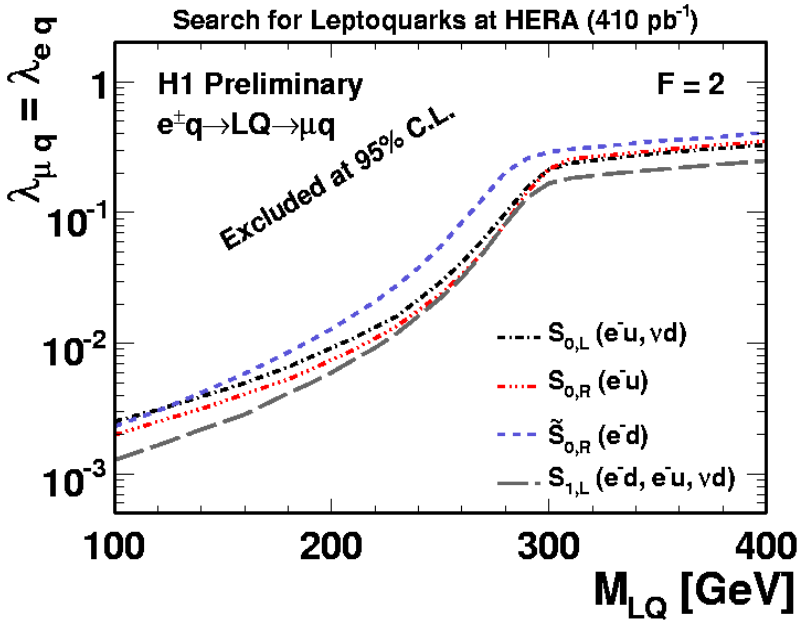
Search for 2st generation Leptoquarks

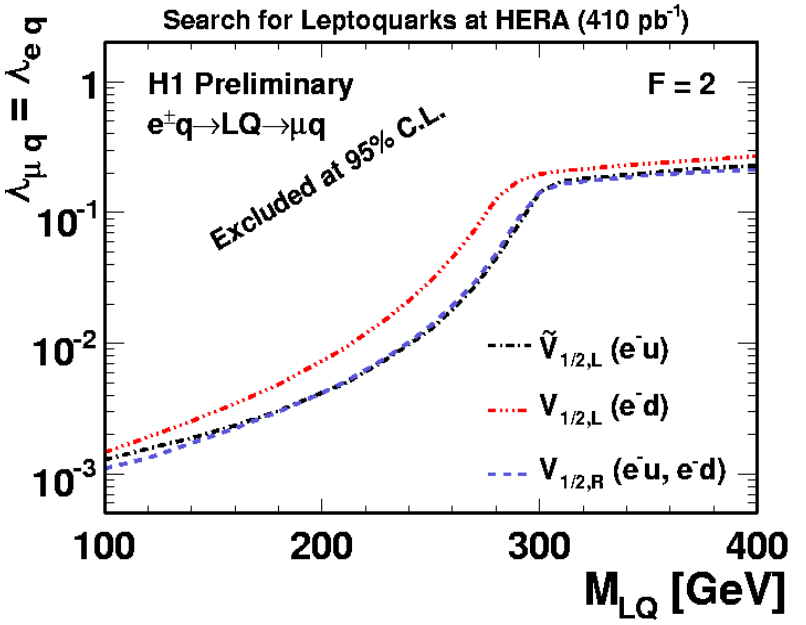




For electromagnetic strength λ=0.3

M_{LQ}<304-530 GeV can be ruled out



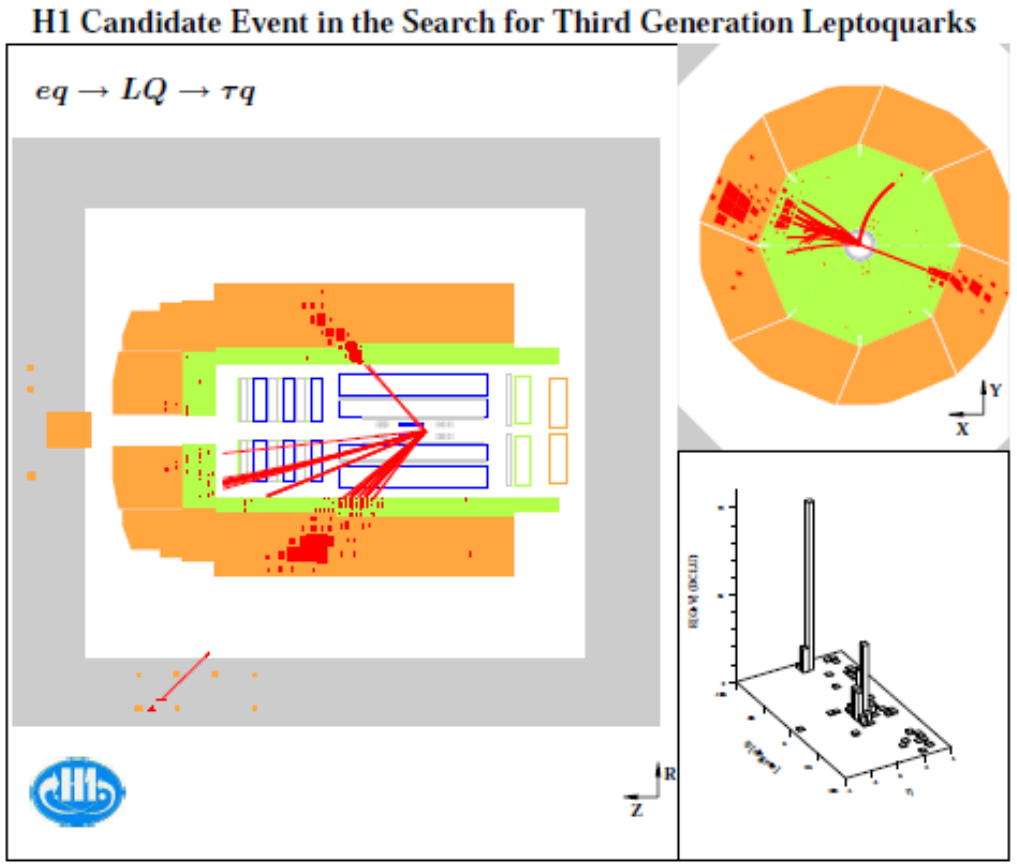


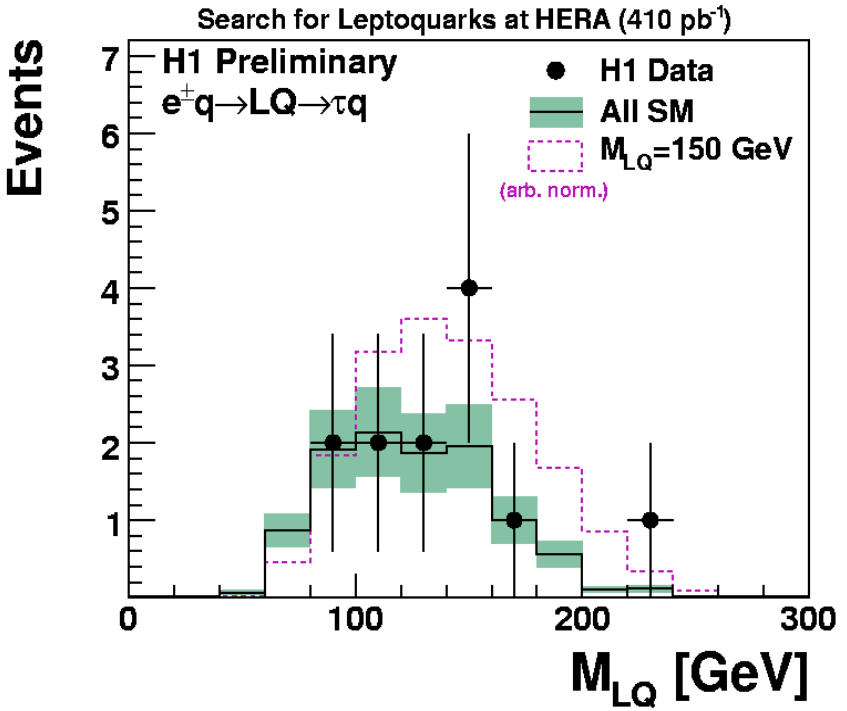
For scalar LQ, β=0.5
Tevatron limit
M_{LQ}>259 GeV

Search for 3rd generation Leptoquarks

LQ could decay to a tau lepton

Signature ep → τX
(τ decays to 1 pronge hadrons)





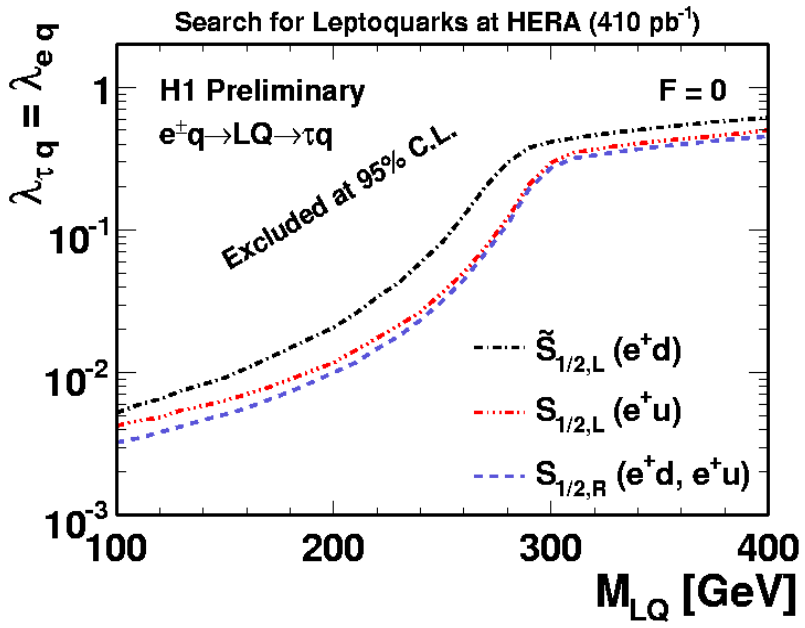
H1 HERA (98-07) sample

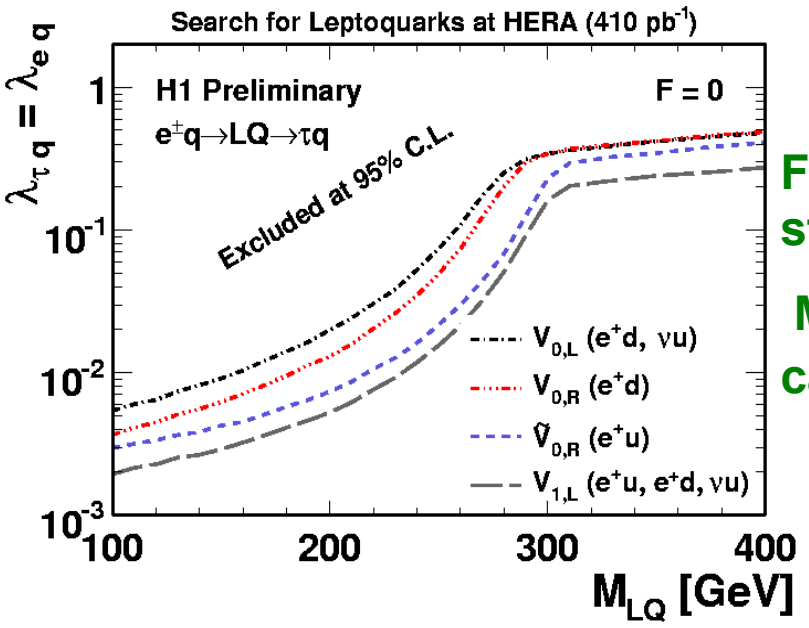
12 events seen/10.6 expected

No evidence for signal
Limits set for all 14 LQ types
(for hadronic and muonic tau decays)

$\lambda_{\tau q} = \lambda_{eq}, \ \lambda_{\mu q} = 0$

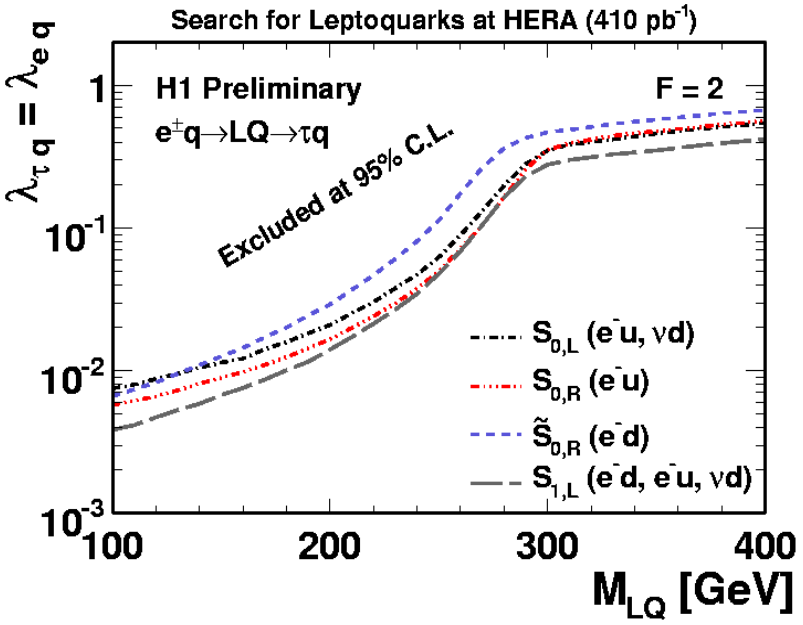
Search for 3rd generation Leptoquarks

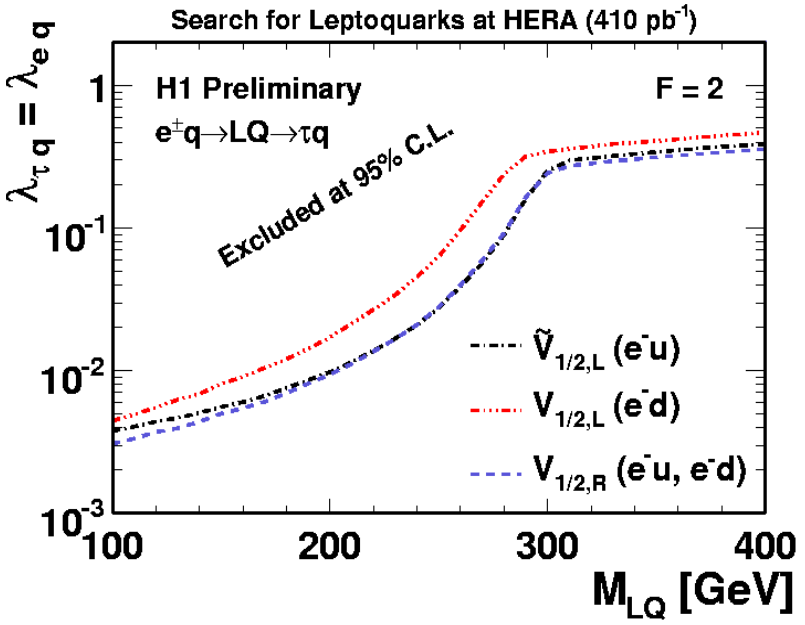




For electromagnetic strength λ=0.3

M_{LQ}<272-450 GeV can be ruled out





For scalar LQ, β=0.5
Tevatron limit
M_{LQ}>207 GeV

Conclusions

- Searches for deviations from SM in high Q^2 e^+p and e^-p DIS data has been performed by H1 and ZEUS based on full HERA datasets (~0.45 fb^{-1} per experiment)
- No data excess or deviations from SM cross sections have been found.
- ZEUS (NC DIS): 95% CL limits have been set for different CI mondels
- H1(NC, CC DIS): 95% CL limits have been set for resonant and non-resonant 1^{st} generation LQ production
- New limits from H1 on LFV LQ's with the complete HERA dataset
- HERA limits complementary to Tevatron and LEP limits