Search for Contact Interactions and Leptoquarks at HERA

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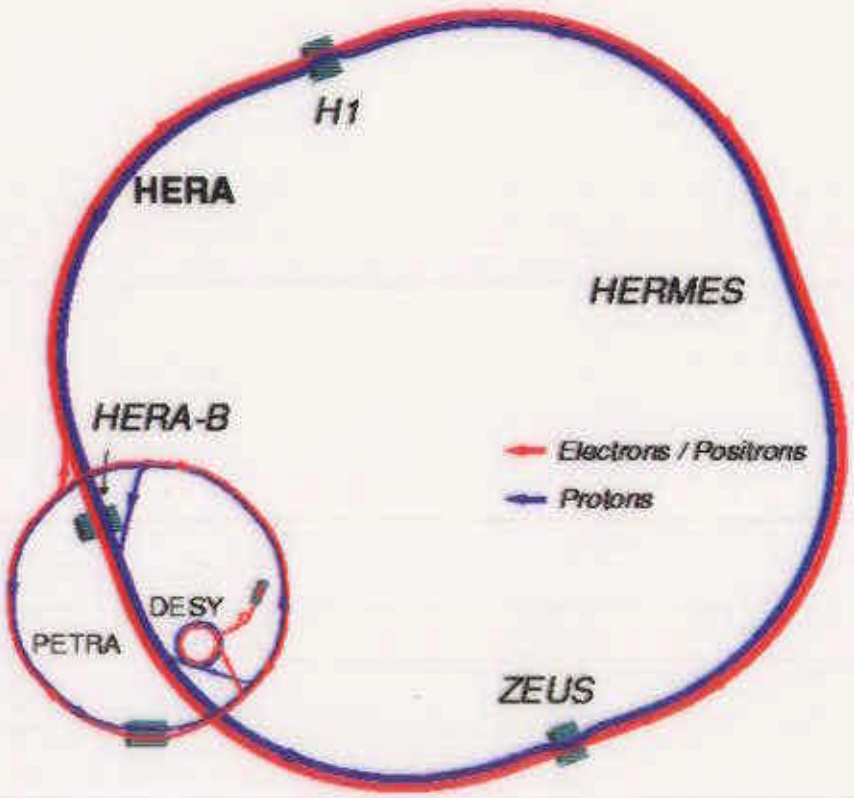
representing the H1 and ZEUS collaborations

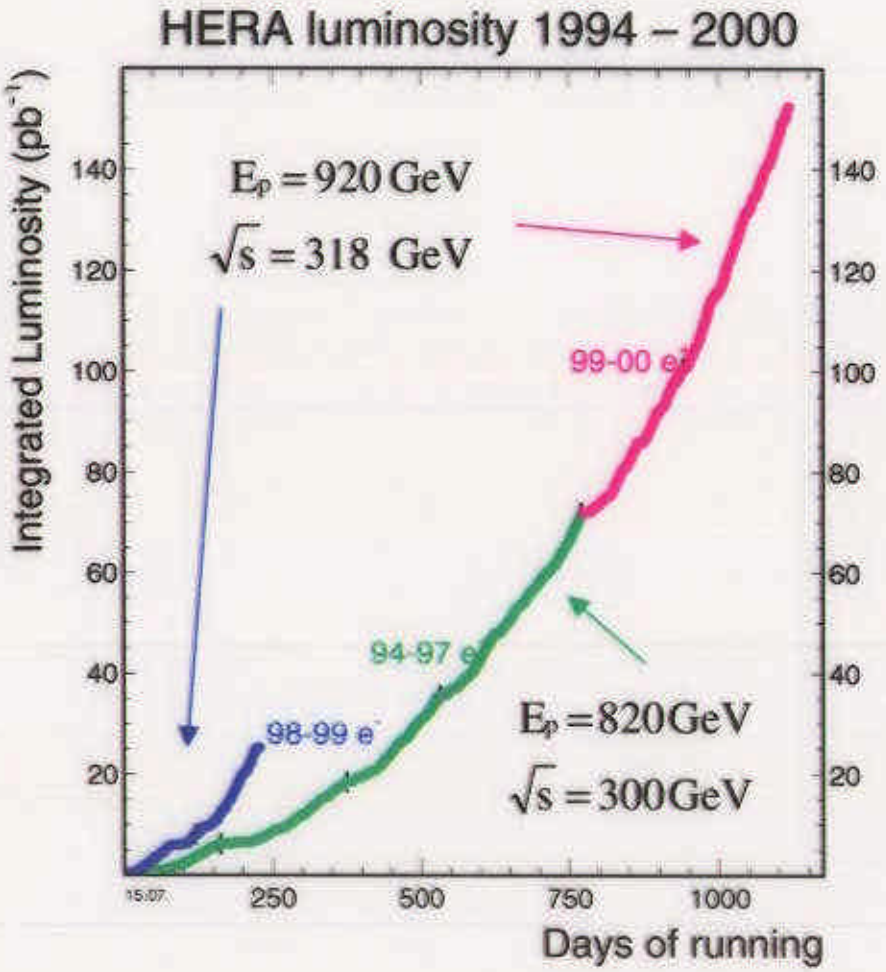
Outline

- Data Sets
- Contact Interactions
- Search for Leptoquarks
- Lepton Flavour Violation
- Summary

Available Datasamples at HERA

HERA - the only e-p Collider





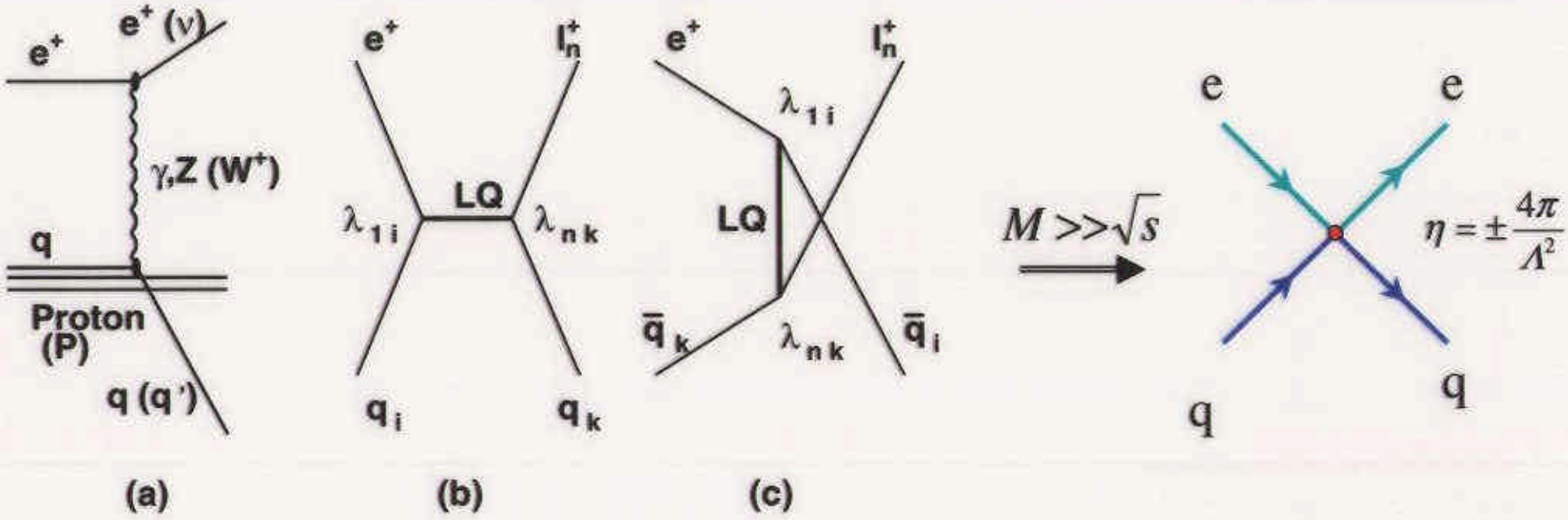
More than 100 pb^{-1} delivered per experiment

eq - Scattering and Kinematics

DIS

"New Physics"

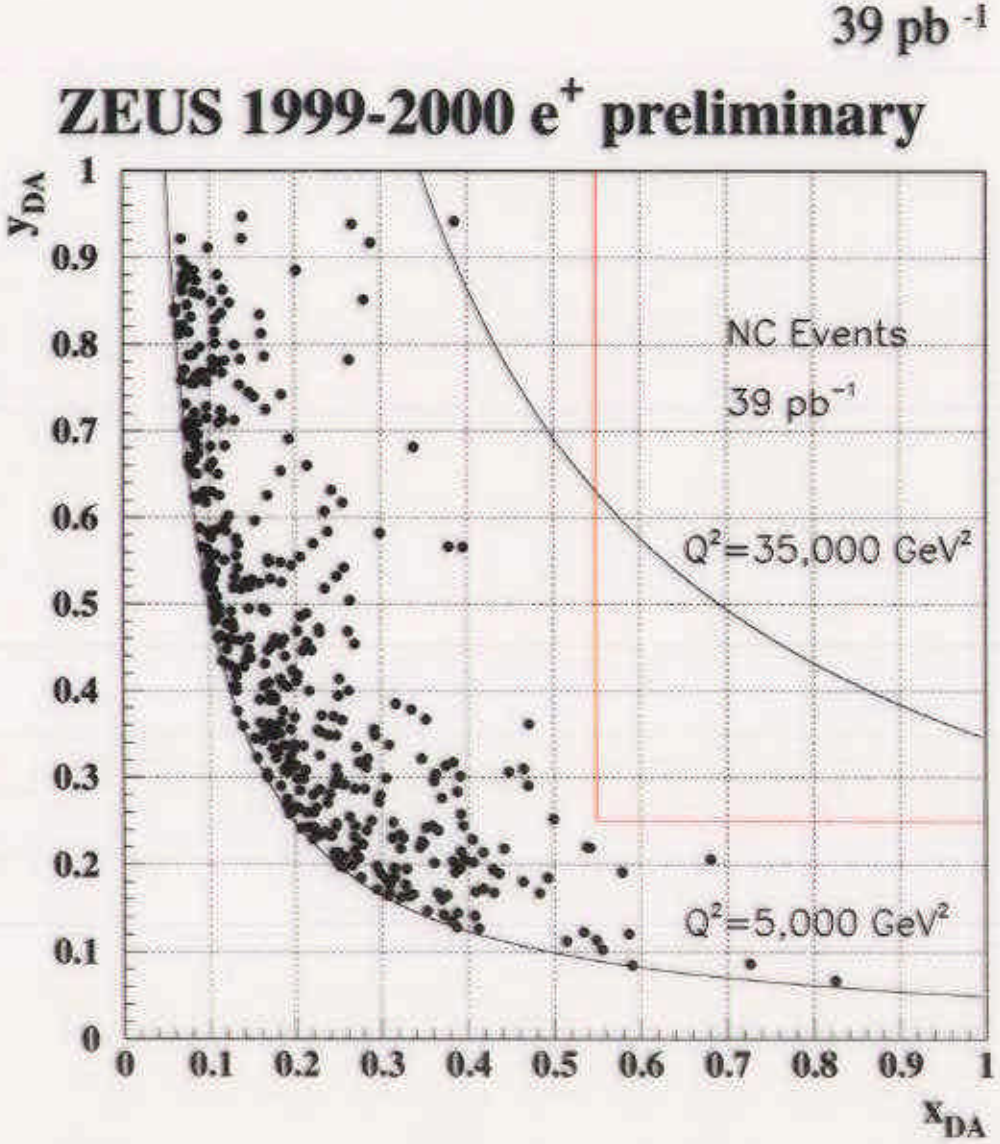
Low energy limit



$Q^2 = -(k - k') = -q^2$	four momentum transfer squared
$x = -q^2/(2 \cdot P \cdot q)$	Bjorken scaling variable
$y = (q \cdot P)/(k \cdot P) = (1 - \cos\theta^*)/2$	inelasticity
$s = 2 \cdot k \cdot P = Q^2/(x \cdot y)$	ep CM energy squared

High Q^2 Event Distributions for e^+p at 318 GeV

39 pb $^{-1}$



$Q^2_{DA} > 35,000\ GeV^2$

Year	Luminosity	data	SM
94-97 e^+	47.7 pb^{-1}	2	0.34
98-99 e^-	16.2 pb^{-1}	2	1.02
99-00(part) e^+	39.2 pb^{-1}	1	0.53

$x_{DA} > 0.55\ and\ y_{DA} > 0.25$

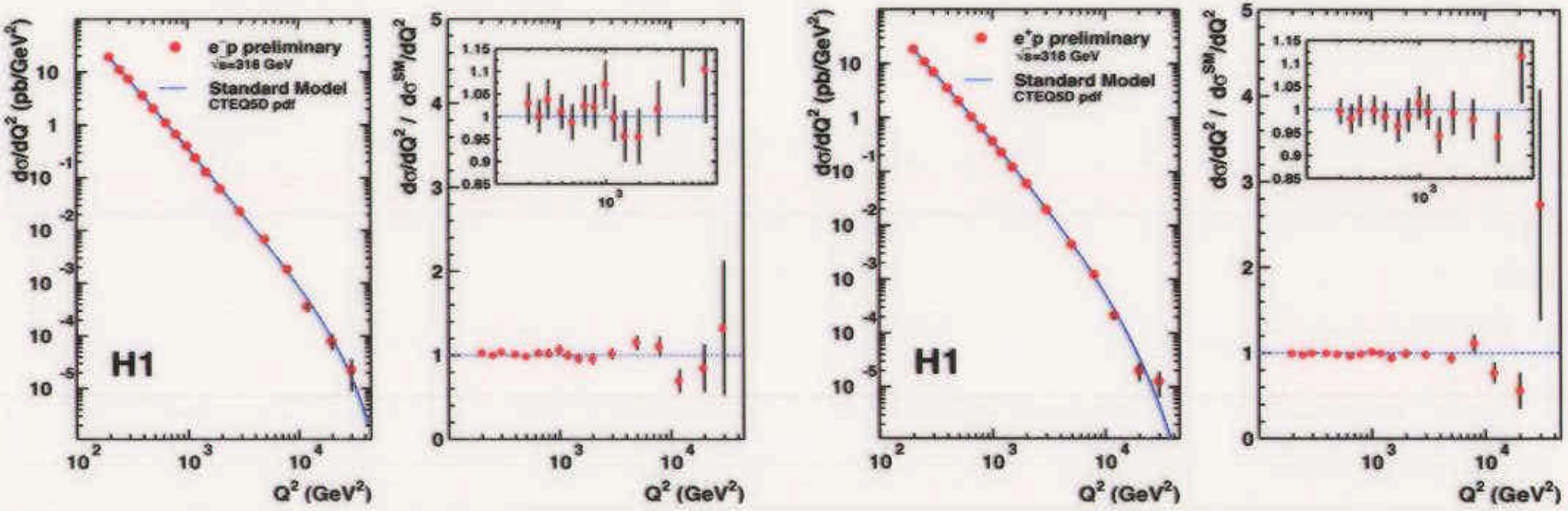
Year	Luminosity	data	SM
94-97 e^+	47.7 pb^{-1}	4	1.9
98-99 e^-	16.2 pb^{-1}	1	1.3
99-00(part) e^+	39.2 pb^{-1}	0	1.6

New data at 318 GeV consistent with SM expectation

NC cross section for $e^- p$ / $e^+ p$ at 318 GeV

98-99: 15 pb^{-1} $e^- p$

99-00: 46 pb^{-1} $e^+ p$



- data are well described by SM over more than 6 orders of magnitude
- possible deviations from SM would show up at large Q2

Contact Interaction Phenomenology

Possible sources:

- **Compositeness**
  - limits on scale parameter $\Lambda^{+/-}$ ($g^2=4\pi$)
- **new heavy particles like Leptoquarks**
  - limits on ratio M/λ
- **low scale Quantum Gravity**
  - limits on scale M_S

Analysis methods:

Obtain sensitivity to new physics via observation of distortion of cross section especially at high Q^2:

- **ZEUS:** shape analysis using 2 dim unbinned log likelihood : $\frac{dN}{dxdy}\cdot\frac{1}{N}$
- **H1:** 1 dimensional χ^2 method: $\frac{d\sigma}{dQ^2}$

Formalism:

Effective Lagrange Density (vector terms only) modifies scattering amplitude:

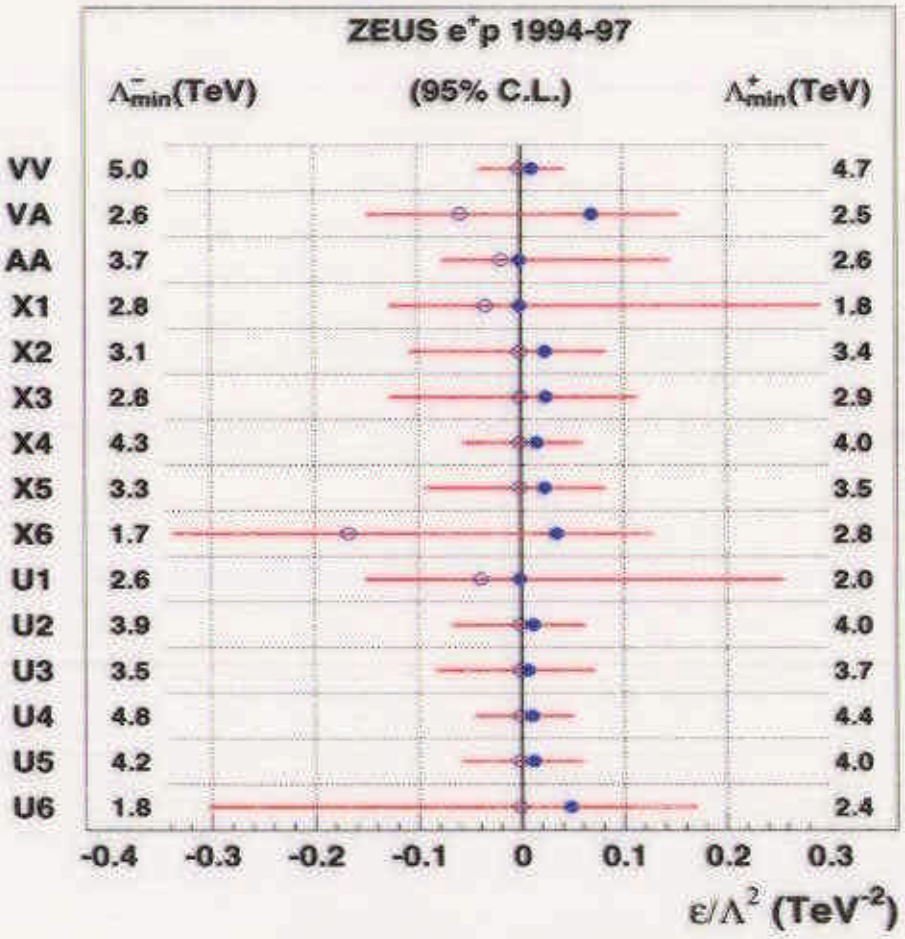
$$L_{CI} = \sum_{q=u,d} \sum_{a,b=L,R} \eta^q_{ab} (\bar{e}_a \gamma^\mu e_a)(\bar{q}_b \gamma_\mu q_b)$$

$$\eta^q_{ab} \equiv \pm (g / \Lambda^q_{ab})^2$$

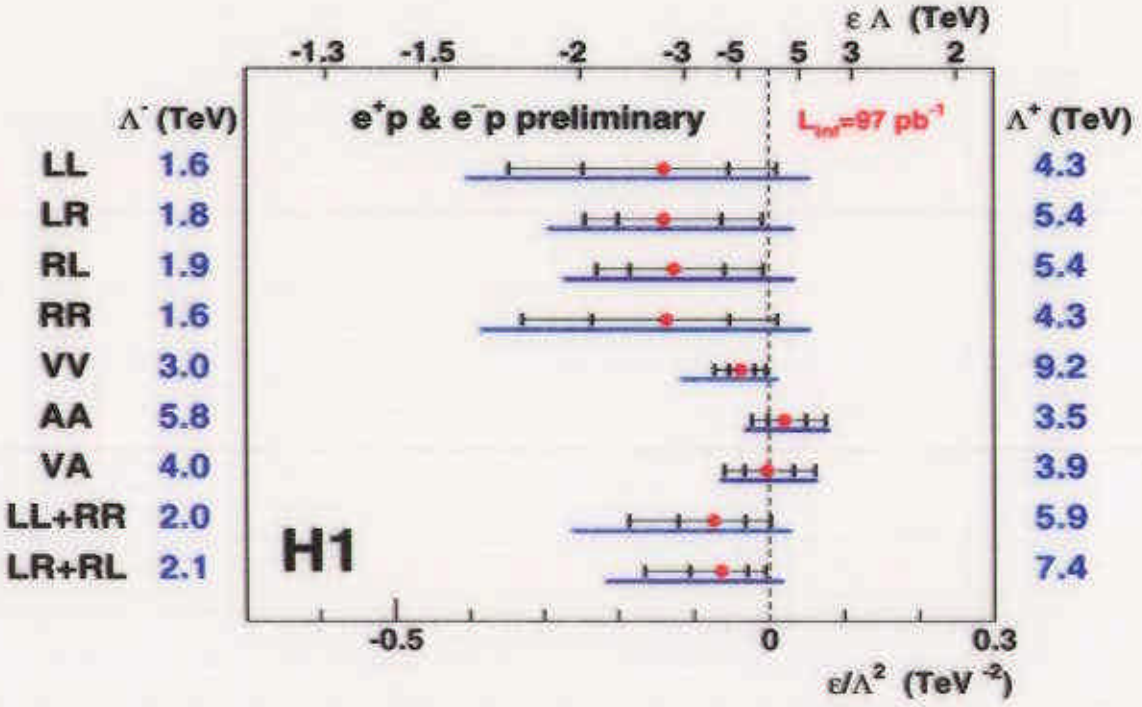
$g^2 = 4\pi$; Λ = effective mass scale

CI Limits on Compositeness Models

48 pb^{-1}



Combination of all H1 data sets: ~100 pb^{-1}
e$^+$p and e$^-$p often complementary in sensitivity



No evidence for CI signal => resulting limits on Λ are in the range **1.6 - 9.2 TeV**
depending on the chiral structure of the model
Comparable limits are obtained at LEP and at the TeVatron

Limits on Low Scale Gravitational Effects

- string theory implies existence of **extra spatial dimensions**, which must be **compactified**.
  conventionally:
  $M_{PL} \sim 10^{19}$ GeV implies $R < 1/M_{PL} \sim 10^{-32}$ cm
  => unobservable

- following an idea of Arkani-Hamed, Dimopoulos, Dvali one can circumvent the hierarchy problem: fundamental Planck scale, where gravity becomes comparable in strength to other interactions is taken to be near the weak scale :
  => n Large Extra Dimensions get compactified to size $R \sim 1 / M_S$ with $M_S = O(1\ \text{TeV})$

- huge $1/M_{PL}$ suppression of the graviton coupling to SM particles gets compensated by summation over large multiplicity of Kaluza-Klein modes
  => effective contact interaction coupling

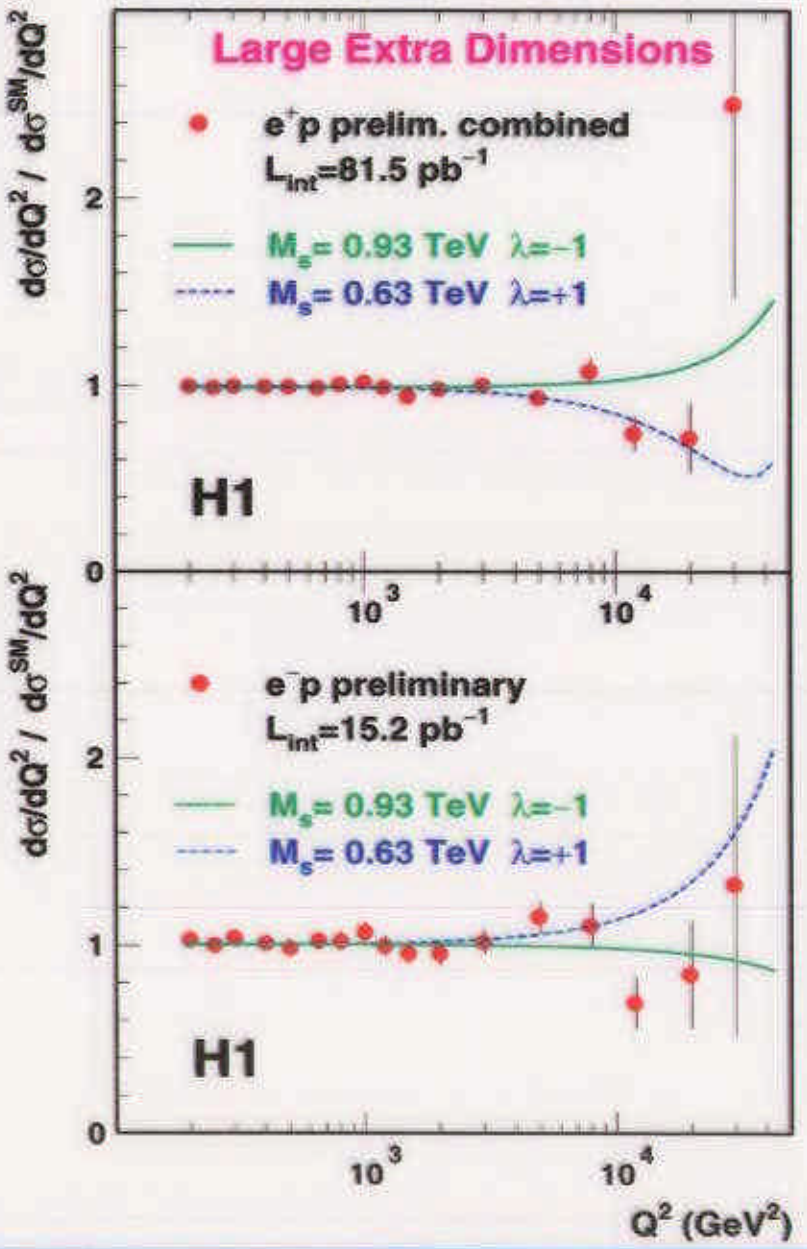
$$\eta_G = \frac{\lambda}{M_S^4}$$

- resulting lower limits from combination of all data sets (H1: 97 pb^{-1}):

$$M_S > 0.63\ \text{TeV} \quad \text{for } \lambda = +1$$
$$M_S > 0.93\ \text{TeV} \quad \text{for } \lambda = -1$$

at 95% CL

See also mini review by G.Landsberg !

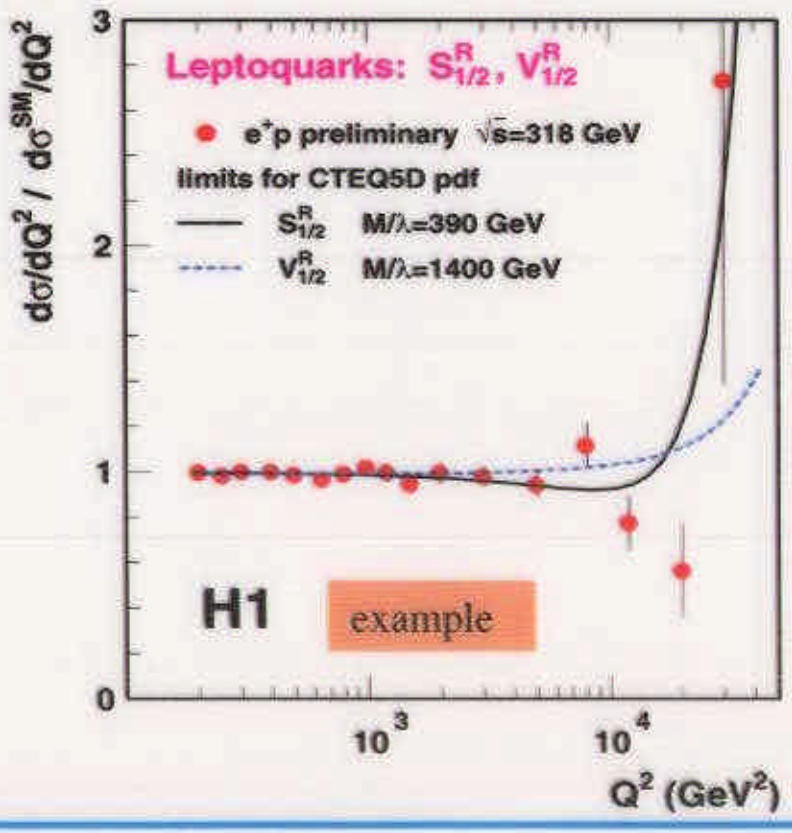


Search for Leptoquarks in Contact Interactions: $M_{LQ} > \sqrt{s}$

Leptoquarks are scalar or vector bosons which couple to quarks & leptons.
Buchmueller- Rueckl-Wyler Model: 14 types of LQs

which are classified by their quantum numbers:

$S^J_{L,R}$ or $V^J_{L,R}$, $\quad F = L + 3B = 0, \pm 2$



Combination of all H1 data sets: ~100 pb^{-1}

H1 preliminary

LQ	η^u $(\lambda/M_{LQ})^2$	η^d $(\lambda/M_{LQ})^2$	F	M_{LQ}/λ [GeV]
S_0^L	$+\frac{1}{2}$		2	1070
S_0^R	$+\frac{1}{2}$		2	960
$\tilde{S}_0^R$		$+\frac{1}{2}$	2	290
$S_{1/2}^L$	$-\frac{1}{2}$		0	380
$S_{1/2}^R$	$-\frac{1}{2}$	$-\frac{1}{2}$	0	380
$\tilde{S}_{1/2}^L$		$-\frac{1}{2}$	0	650
S_1^L	$+\frac{1}{2}$	$+1$	2	690
V_0^L		-1	0	1030
V_0^R		-1	0	810
$\tilde{V}_0^R$	-1		0	530
$V_{1/2}^L$		$+1$	2	480
$V_{1/2}^R$	$+1$	$+1$	2	1510
$\tilde{V}_{1/2}^L$	$+1$		2	1690
V_1^L	-2	-1	0	680

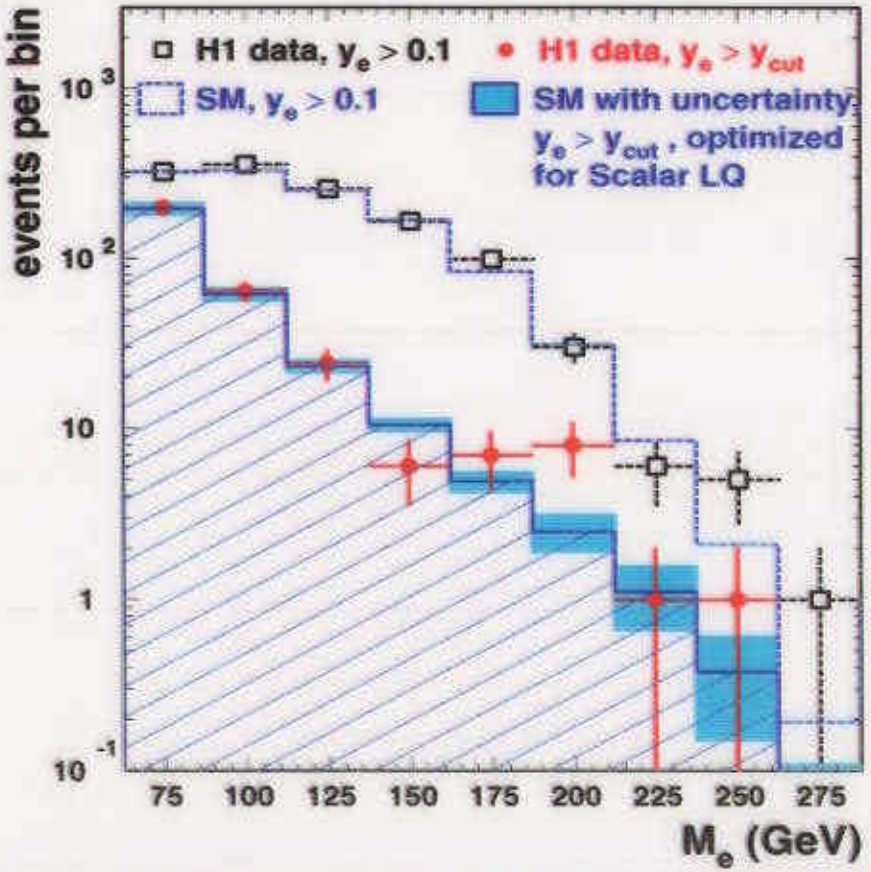
=> Limits for M_{LQ}/λ are in the range 0.3-1.7 TeV

LQ Search : Resonance Decays $\rightarrow e + jet + X$

94-97 e^+ data 37 pb^{-1}

H1: Eur.Phys.J.C11:447-471,1999

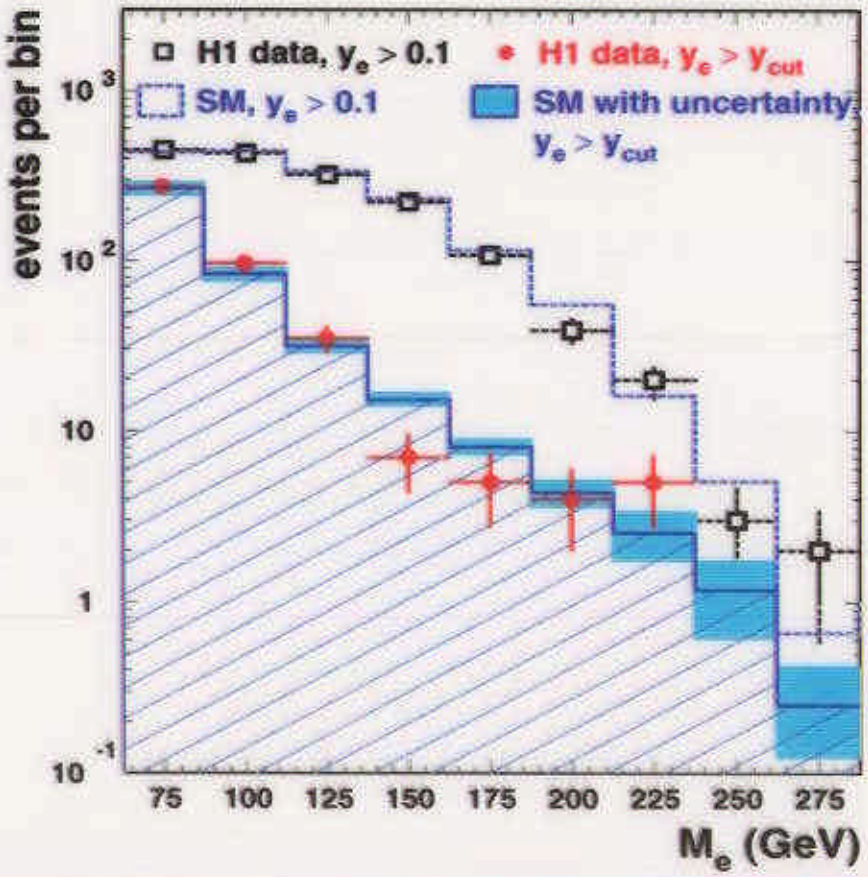
- optimised angular (y) cut for improved signal/bkg
- slight excess around 200 GeV at high y



99-00 e^+ data 48 pb^{-1}

- new data with same analysis cuts
- mass effect suggested from 94-97 data is **not confirmed**

H1 preliminary

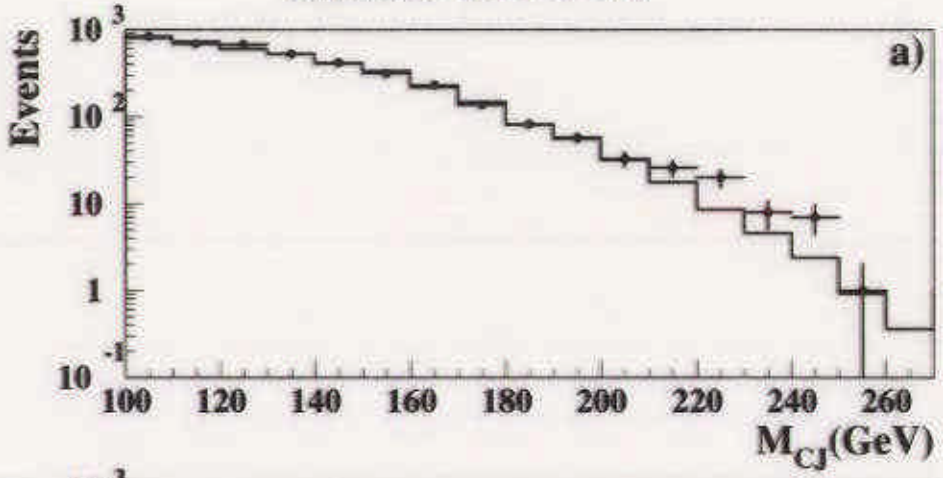


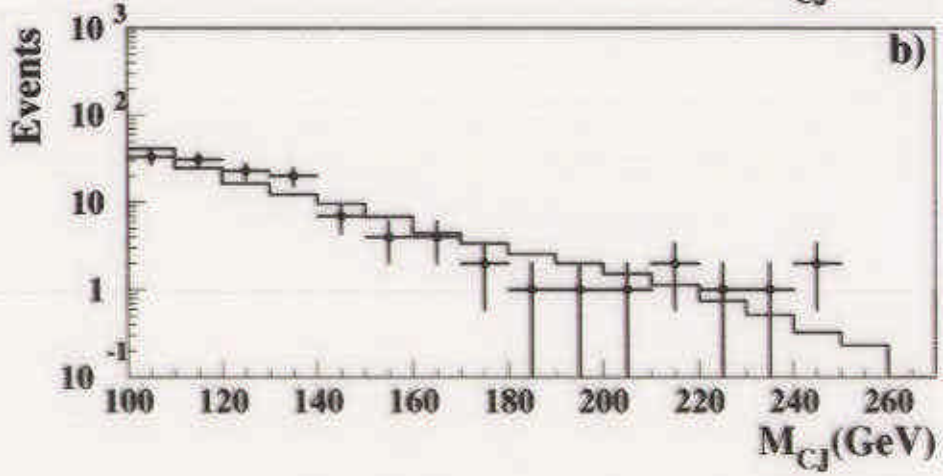
LQ Search in Resonance Decays $\rightarrow e + jet + X$ & $\bar{\nu} + jet + X$

$M_{CJ} = e + jet$ - mass

$M_{\nu js} = \bar{\nu} + jet$ - mass

ZEUS 1994-97



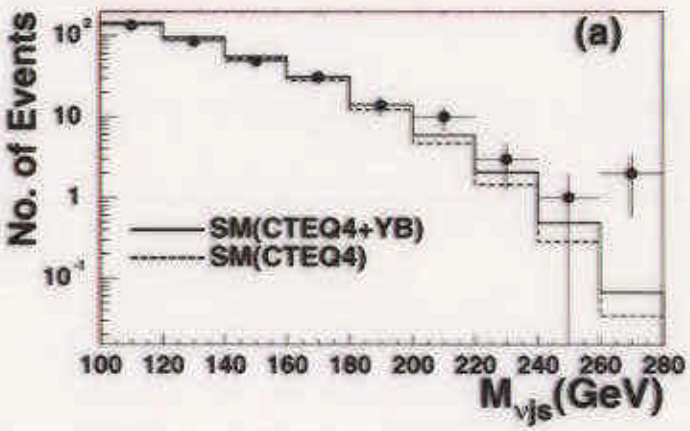


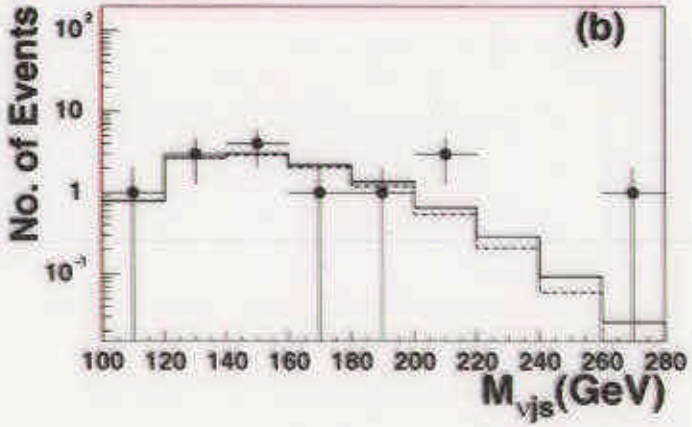
without

with

cut on cos θ*

ZEUS 1994-97

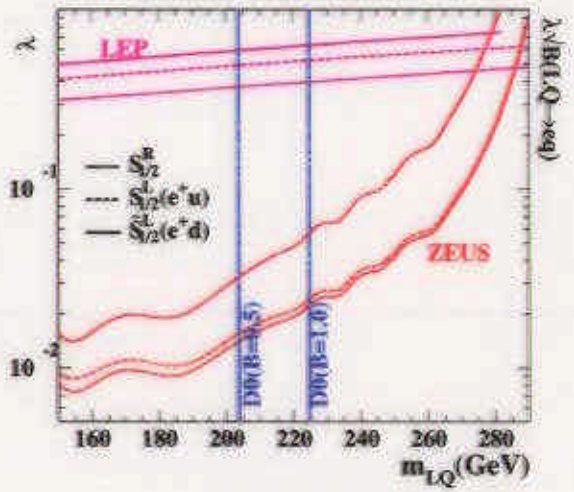




LQ Limits for Resonance Decays → e + jet + X & $\bar{\nu}$ + jet + X

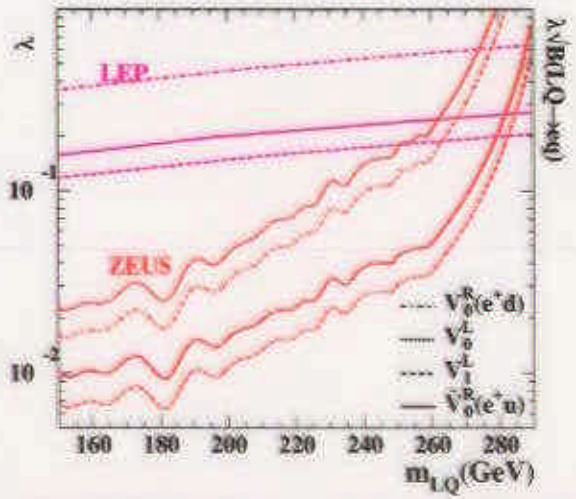
e + jet - limits on λ

ZEUS 1994-97



F=0

ZEUS 1994-97



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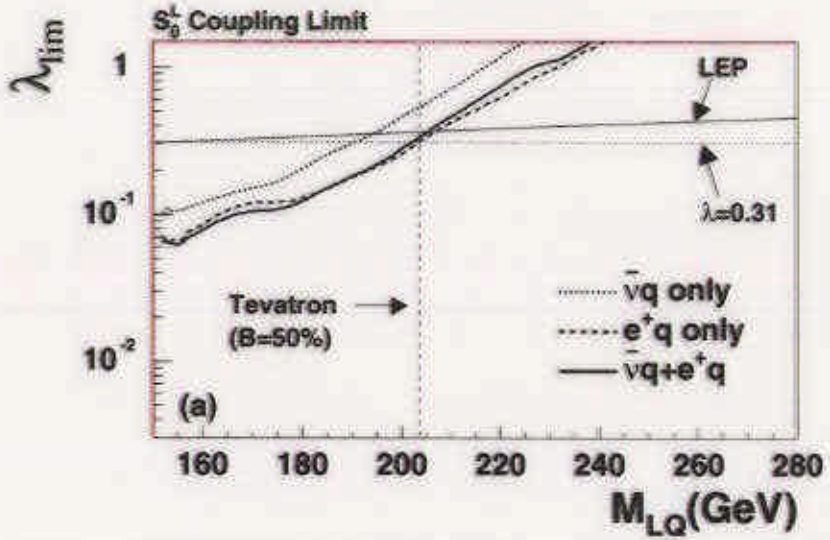
Scalar LQs

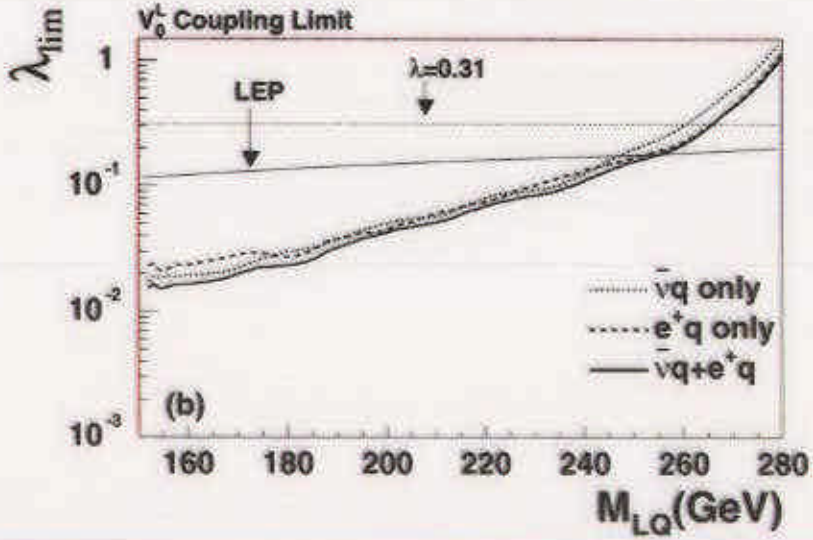
Vector LQs

$\bar{\nu}$ + jet - limits on λ

ZEUS 1994-97



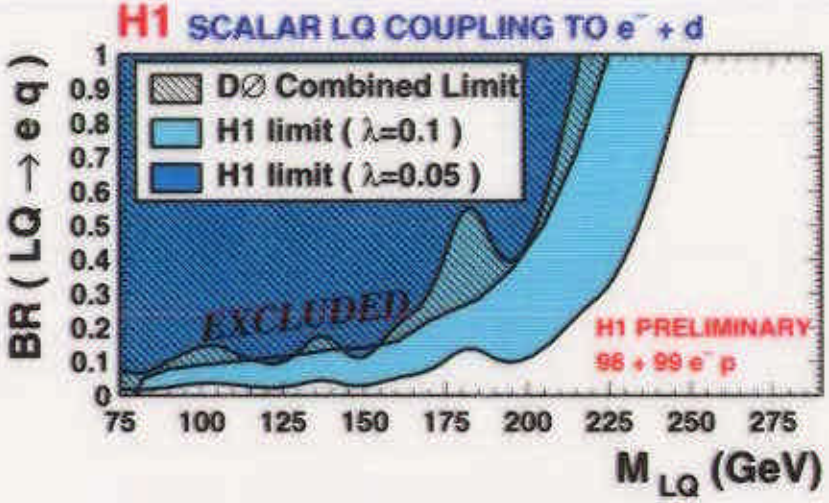
F=2

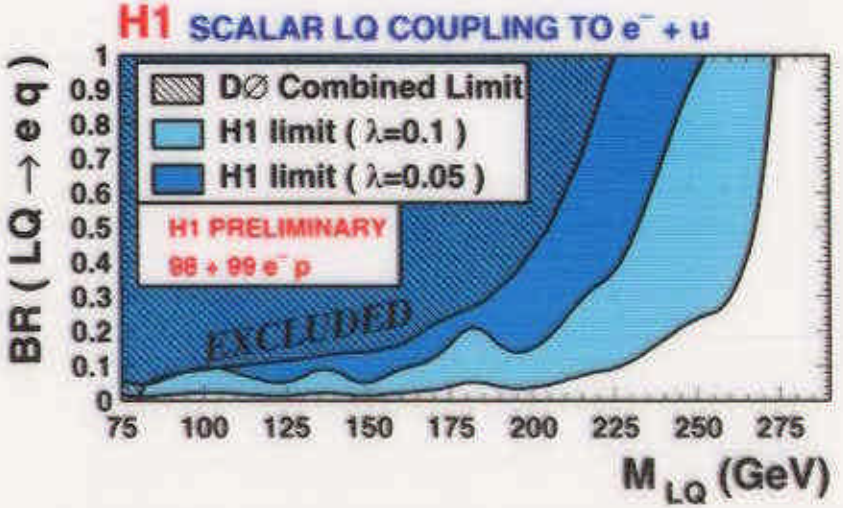


F=0

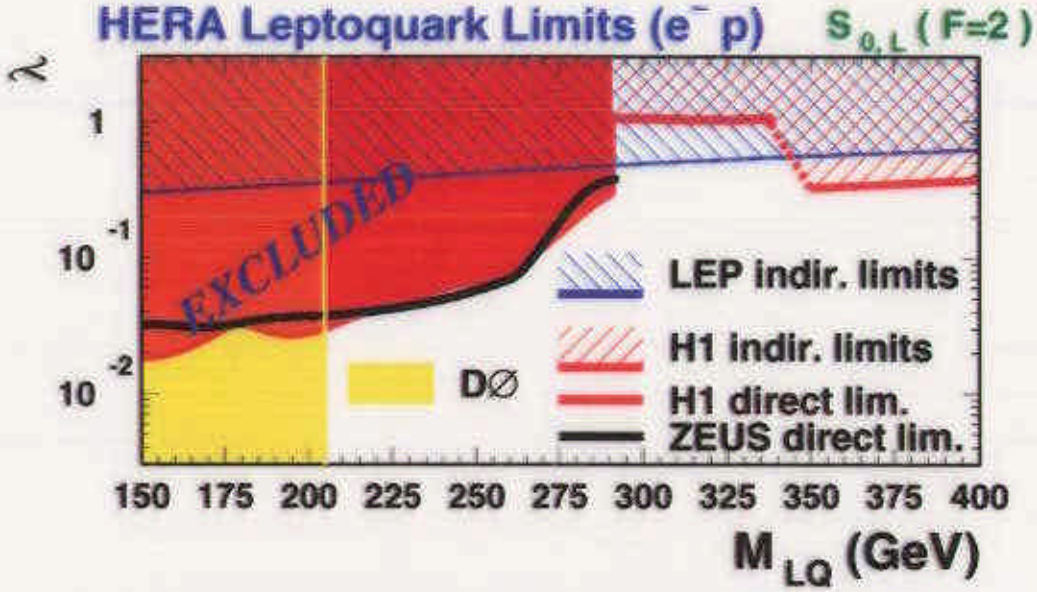
Summary of present LQ Limits

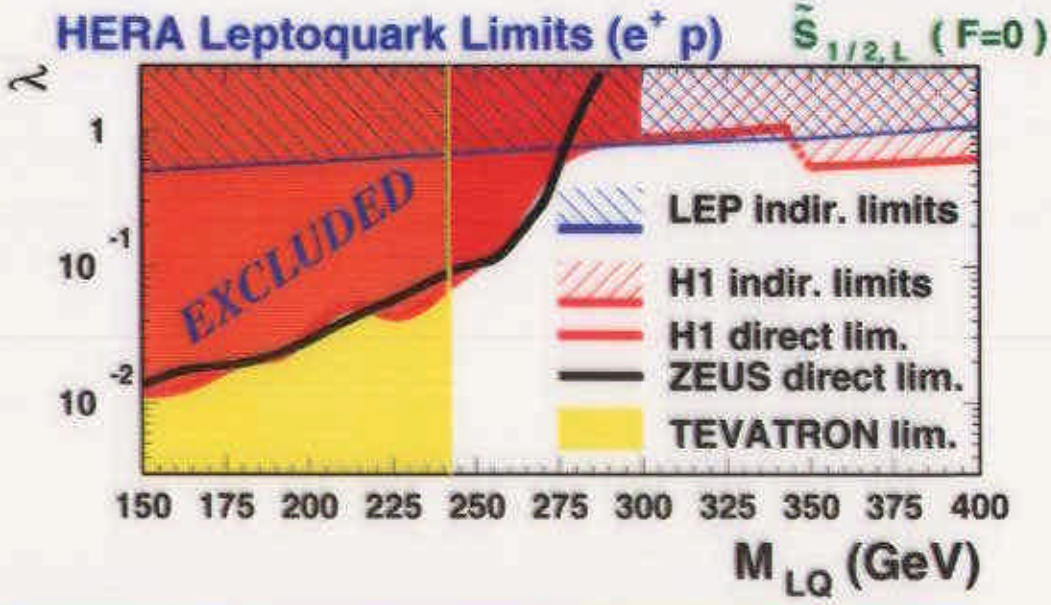
Mass dependent limits on BR(LQ->eq) in a "generic" model (non BRW)





Significant improvements, especially for small BR !

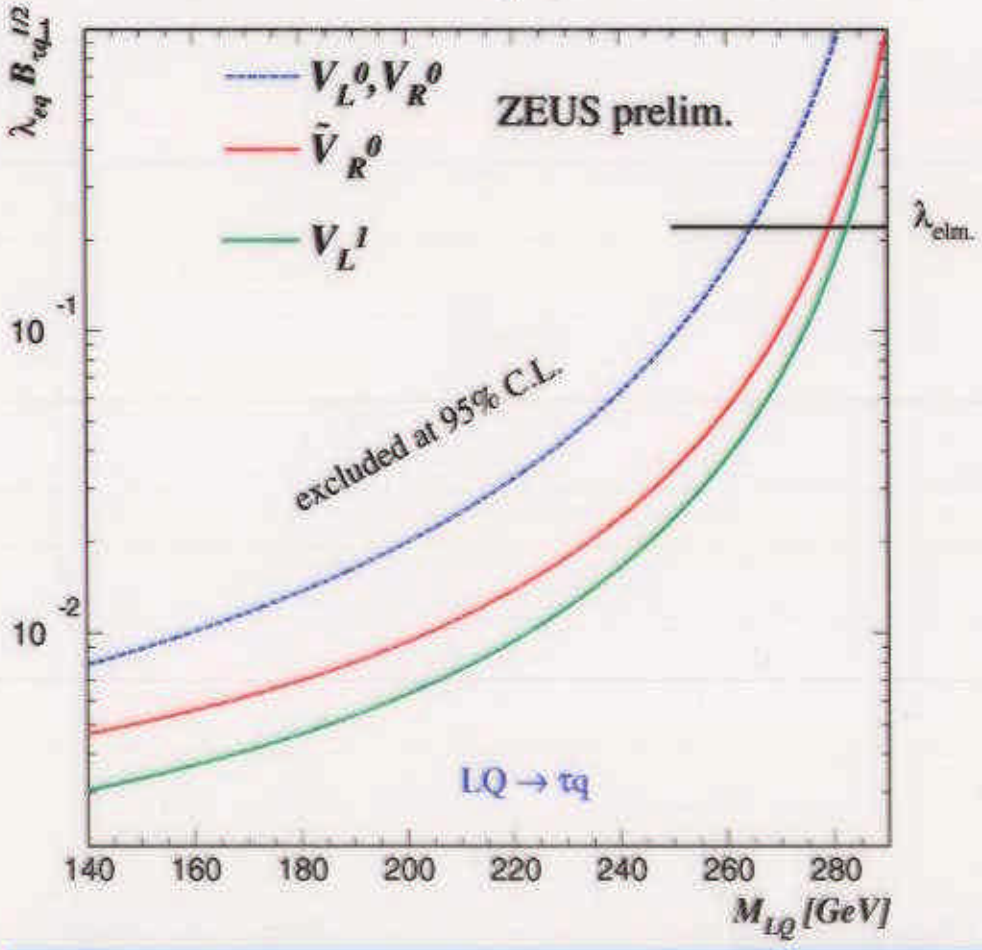




Search for Lepton-Flavour violating LQs $e \leftrightarrow \tau$

LFV can be mediated by LQs which couple to different generations ($e \leftrightarrow \mu$ usually better constrained by low energy experiments)

Example for limit on $\lambda_{eq_1} \cdot \sqrt{BR(LQ \to \tau q)}$



Limits on $\lambda_{ei}\lambda_{\tau j} / M_{LQ}^2$ in 10^{-4} GeV^{-2} (F = 0)

e	τ	eq_j	$S_{1/2}^L$	$S_{1/2}^R$	$\tilde{S}_{1/2}$	V_0^L	V_0^R	$\tilde{V}_0^R$	V_1^L
1	1	1 1	$\tau \to \pi e$ 0.0032 0.030 0.045	$\tau \to \pi e$ 0.0016 0.025 0.037	$\tau \to \pi e$ 0.0032 0.046 0.062	G_F 0.002 0.033 0.049	$\tau \to \pi e$ 0.0016 0.033 0.049	$\tau \to \pi e$ 0.0016 0.024 0.041	G_F 0.002 0.012 0.019
1	2	1 2	0.030 0.047	$\tau \to K e$ 0.05 0.025 0.038	$\tau \to K e$ 0.05 0.046 0.063	$\tau \to K e$ 0.03 0.036 0.053	$\tau \to K e$ 0.03 0.036 0.053	0.026 0.045	$K \to \pi \nu \bar{\nu}$ $2.5 \cdot 10^{-6}$ 0.012 0.021
1	3	1 3	—	$B \to \tau e X$ 0.08 0.049 0.065	$B \to \tau e X$ 0.08 0.048 0.065	$B \to l \nu X$ 0.02 0.044 0.062	$B \to \tau e X$ 0.04 0.044 0.062	—	$B \to l \nu X$ 0.02 0.044 0.062
2	1	2 1	0.153 0.15	$\tau \to K e$ 0.05 0.092 0.095	$\tau \to K e$ 0.05 0.105 0.12	$\tau \to K e$ 0.03 0.049 0.064	$\tau \to K e$ 0.03 0.049 0.064	0.081 0.073	$K \to \pi \nu \bar{\nu}$ $2.5 \cdot 10^{-6}$ 0.026 0.032
2	2	2 2	$\tau \to e \gamma$ 0.03 0.187 0.18	$\tau \to e \gamma$ 0.02 0.101 0.10	0.120 0.13	0.061 0.076	0.061 0.076	0.102 0.107	0.041 0.044
2	3	2 3	—	$B \to \tau e X$ 0.08 0.153 0.14	$B \to \tau e X$ 0.08 0.153 0.14	$B \to l \nu X$ 0.02 0.102 0.112	$B \to \tau e X$ 0.04 0.102 0.112	—	$B \to l \nu X$ 0.02 0.102 0.112
3	1	3 1	—	$B \to \tau e X$ 0.08 0.162 0.16	$B \to \tau e X$ 0.08 0.162 0.16	V_{ub} 0.002 0.062 0.068	$B \to \tau e X$ 0.04 0.062 0.068	—	V_{ub} 0.002 0.062 0.068
3	2	3 2	—	$B \to \tau e X$ 0.08 0.202 0.19	$B \to \tau e X$ 0.08 0.202 0.19	$B \to l \nu X$ 0.02 0.073 0.083	$B \to \tau e X$ 0.04 0.073 0.083	—	$B \to l \nu X$ 0.02 0.073 0.083
3	3	3 3	—	0.275 0.25	0.275 0.25	$\tau \to e \gamma$ 0.51 0.144 0.14	$\tau \to e \gamma$ 0.51 0.144 0.14	—	0.144 0.14

Most stringent limit from: indirect ZEUS H1

Summary and Conclusions

- no evidence for Contact Interactions in **O(50-100 pb^{-1})** ep data
  => strong limits from HERA for
  - compositeness scales up to **$\Lambda > 1.6 - 9$ TeV**
  - leptoquarks masses **$M_{LQ}/\lambda > 0.3 - 1.7$ TeV**
  - low scale gravitational effects **$M_S = 0.5 - 1$ TeV**
- direct searches for resonances in e+jet and ν+jet yield lower mass limits
  which are typically in the range: **M > 150 - 290 GeV for λ=0.3**
- limits are set on LFV LQs: **M > ~280 GeV**
- significant enhancements of sensitivity can be expected after year 2001:
  - HERA luminosity upgrade => **1 fb^{-1} until 2006**
  - lepton polarisation for H1 & ZEUS