SEARCH FOR LEPTOQUARKS AND CONTACT INTERACTIONS WITH ZEUS

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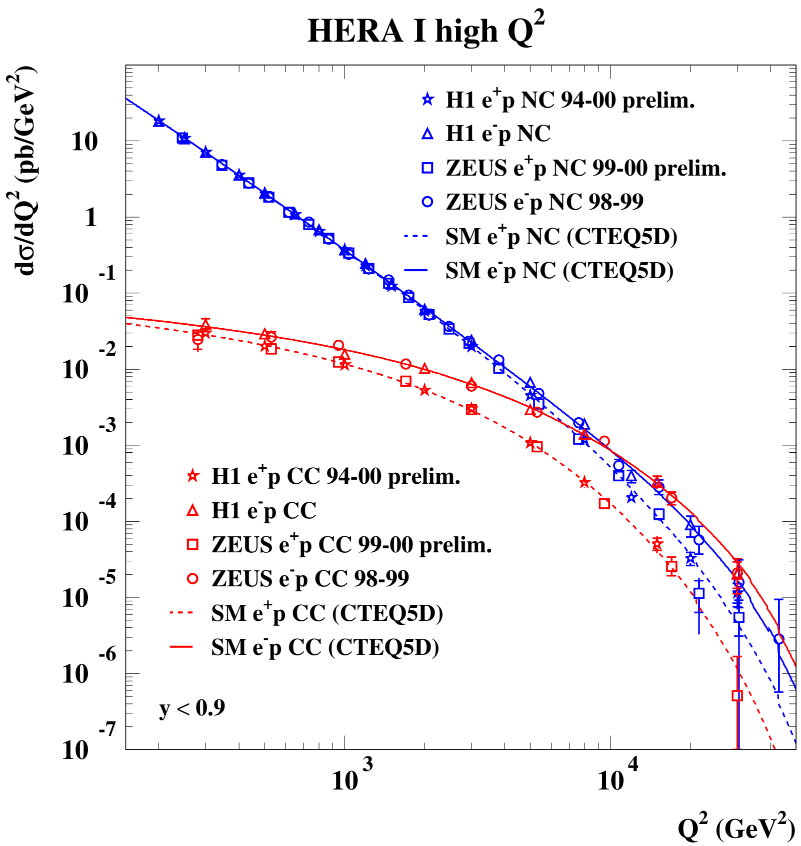
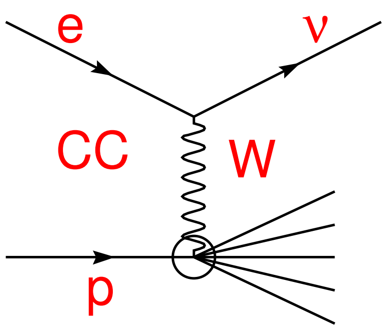
representing the collaboration

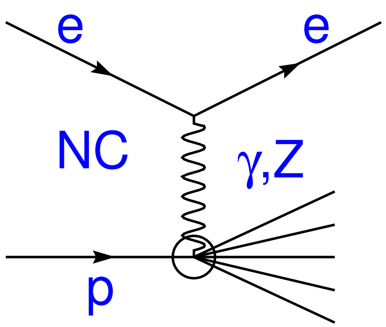
Outline:

- Introduction
- Resonances
- Lepton Flavour Violation
- Contact Interactions
- Conclusions

HERA I







ZEUS gated luminosity

1994-1997 e^+p 300 GeV (CM) 48.3 pb^{-1}

1998-1999 e^-p 318 GeV (CM) 16.7 pb^{-1}

1999-2000 e^+p 318 GeV (CM) 66.3 pb^{-1}

LEPTOQUARKS

Many extensions of the SM predict Bosons with both Lepton and Baryon numbers.

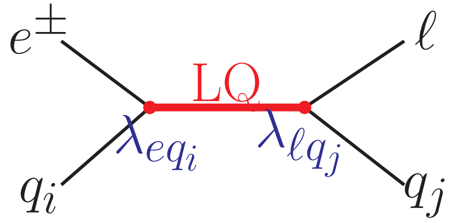
Phenomenological model of Buchmüller-Rückl-Wyler (BRW):

- invariance under $SU(3)_C \times SU(2)_L \times U(1)_Y$, L and B conservation
- 14 LQ species (7 Scalar and 7 Vector) (4 - $S_0^L, V_0^L, S_1^L, V_1^L$ - decaying into both eq and νq)
- fermion number $F = 3B + L = 0, 2$
- family diagonal (if not can mediate LFV)
- coupling to either LH or RH leptons, not both
- fixed branching ratio into $e\nu$ 1, 1/2, νq 0, 1/2

$F = 0$ $e^-\bar{q}$ or $e^+q \Rightarrow$ best sought in e^+p

$F = 2$ e^-q or $e^+\bar{q} \Rightarrow$ best sought in e^-p

LEPTOQUARKS



Different regimes:

$M_{LQ} << \sqrt{s}$: resonant production, dominated by s-channel

$\sigma^{NWA}(s, M_{LQ}) = (J+1)\,\frac{\pi\lambda^2}{4s} q(x_0, M_{LQ}^2)$

$x_0 = \frac{M_{LQ}^2}{s}$, J spin of LQ, q quark density

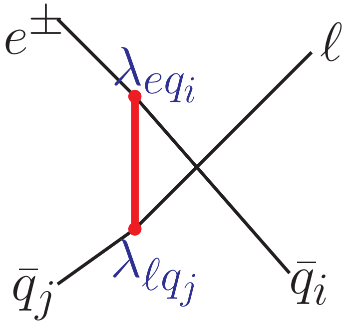
LQs have a different angular distribution:

let θ^* be the e scattering angle in eq (νq) rest frame then $y = \frac{1}{2}(1 - cos\theta^*)$

NC DIS: $\frac{d\sigma}{dy} \propto \frac{1}{y^2}$

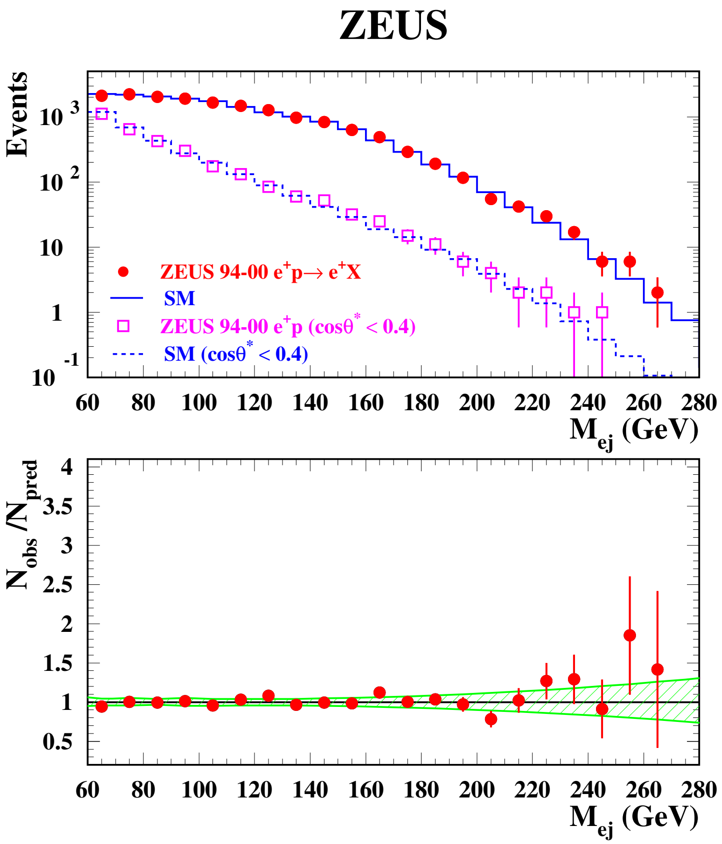
Scalar LQ: $\frac{d\sigma}{dy}$ flat in y

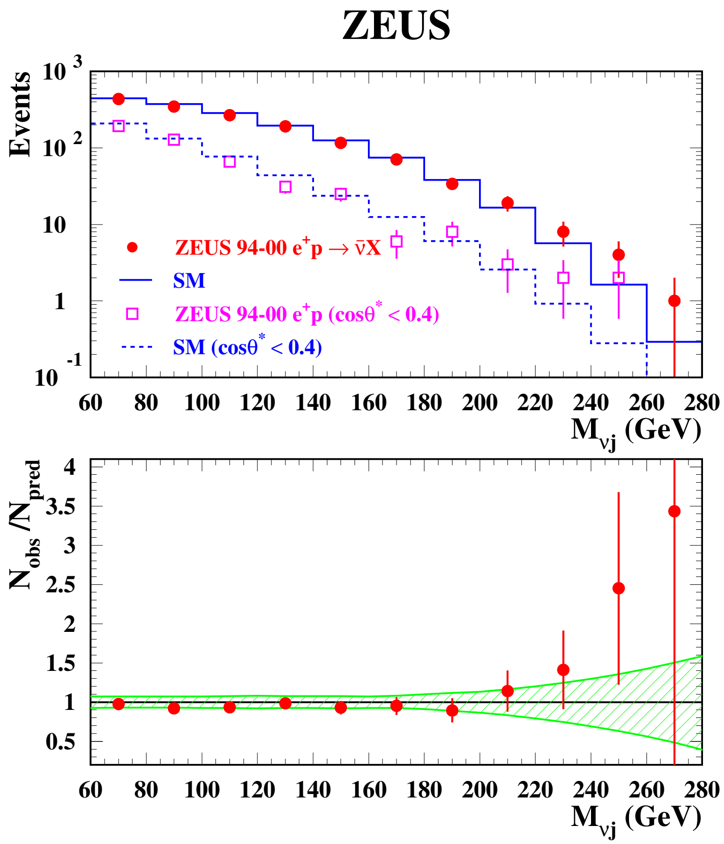
Vector LQ: $\frac{d\sigma}{dy} \propto (1-y)^2$



$M_{LQ} >> \sqrt{s}$: both s- and u-channel contribute,
analysis in terms of contact interactions.

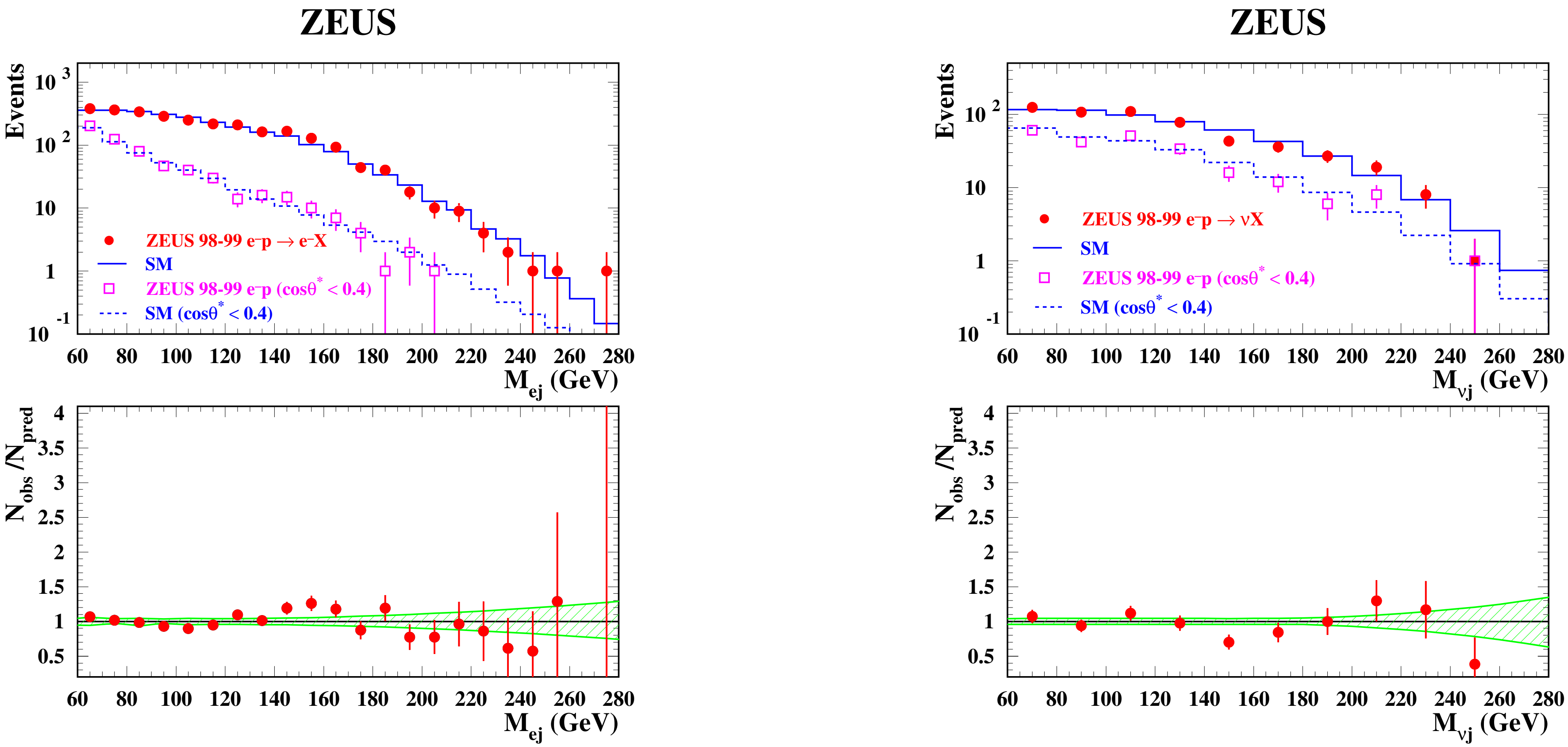
RESONANCES IN e^+p





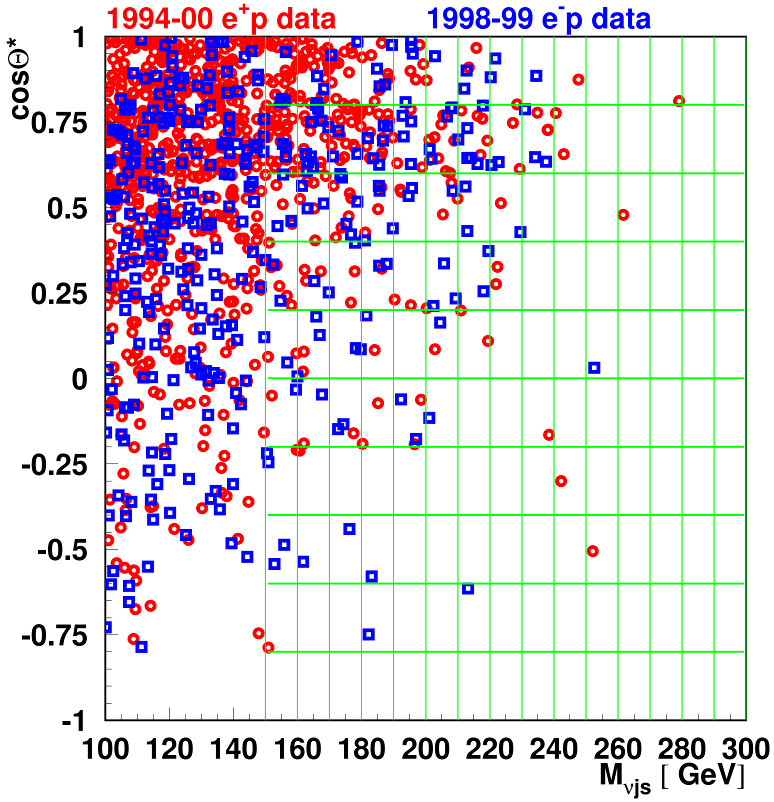
Spectrum of invariant mass for $e - jet$ and $\nu - jet$ No resonance observed

RESONANCES IN $e^{-}p$



Spectrum of invariant mass for $e-jet$ and $\nu-jet$ No resonance observed

SETTING LIMITS



Good agreement with SM: no resonance

Limits from 2-dimensional likelihood fits.

Both M and y information are taken into account.

Divide $\cos\theta^\star$ vs. M 2 dimensional plane into N bins

LQ limits can be evaluated for masses above $\sqrt{s}$ ($\Rightarrow$ Set limit for virtual LQs).

Bayesian approach : limit from solving the equation:

$$\int_0^{\lambda^2_{lim}} d\lambda^2 \; P(\lambda) = 0.95 \int_0^{\infty} d\lambda^2 \; P(\lambda)$$

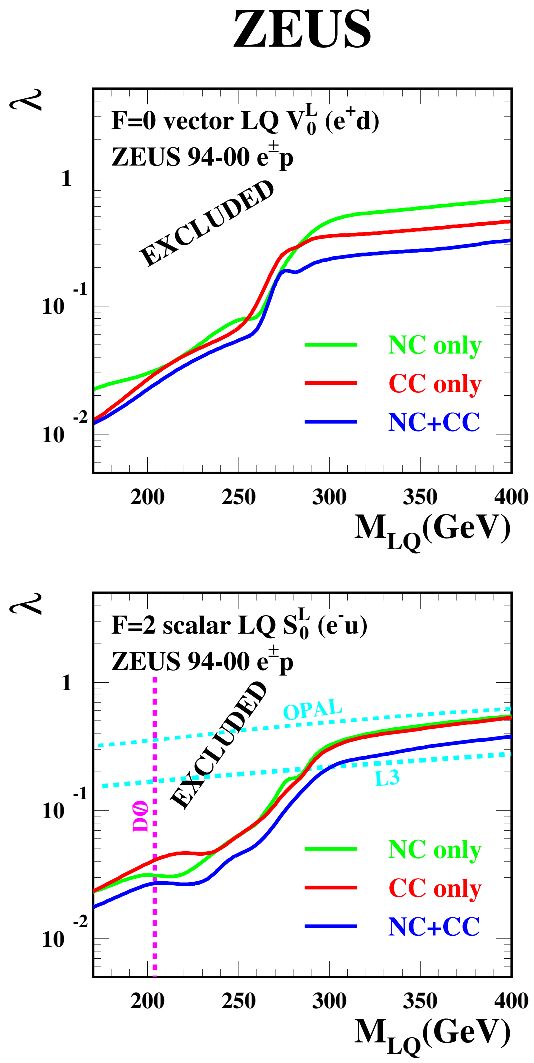
where: $P(\lambda_{LQ}, M_{LQ}) = \prod_i^N \frac{e^{-\mu_i(\lambda)} \mu_i(\lambda)^{N^i_{obs}}}{N^i_{obs}!}$

N^i_{obs} - number of observed in bin i μ_i- number of expected in bin i

$\mu_i(\lambda_{LQ}; M_{LQ}) = \mu_i^{DIS} \star W$

W - weight factor for LQ: $W = (1.0 + \frac{\frac{d^2\sigma^{Int}}{dxdy} + \frac{d^2\sigma^{LQ}}{dxdy}}{\frac{d^2\sigma_{DIS}}{dxdy}})$

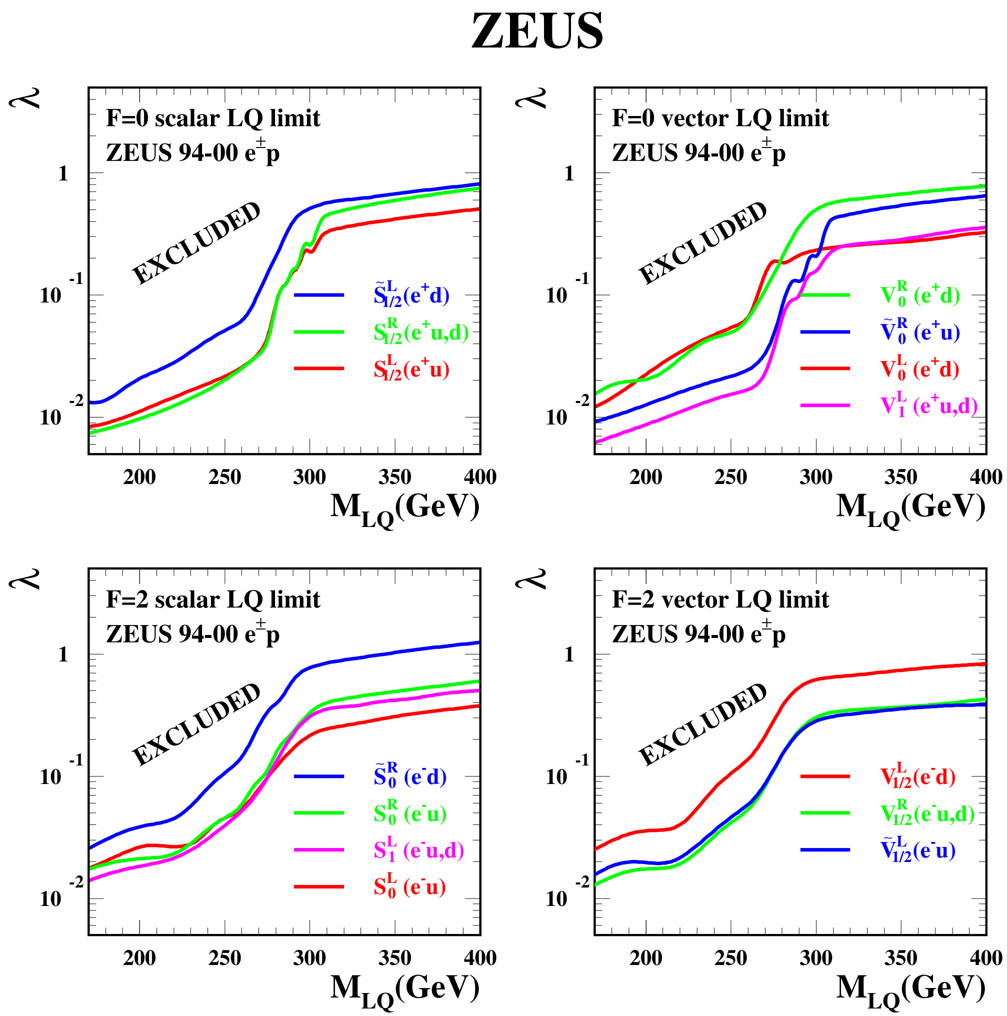
Systematic uncertainties have been included with gaussian distribution in the definition of L and redefining μ_i taking into account the effect of the variations.



Combined search for both
eq, νq topologies
(when available) give
tight limits on LQ

Limits for V_0^L (up)
and S_0^L (down)

If $\lambda = 0.3$ excluded m(V_0^L) is
284 GeV (NC), 286 GeV (CC), 386 GeV (both)
If $\lambda = 0.3$ excluded m(S_0^L) is
298 GeV (NC), 301 GeV (CC),351 GeV (both)



Coupling limits on scalar (left) and vector (right) LQ

Results much better than LEP below 300 GeV comparable above

λ limits at M_{LQ} = 400 GeV: 0.3-1.0

Excluded mass region:

$\lambda = 0.3$ 273-386 GeV

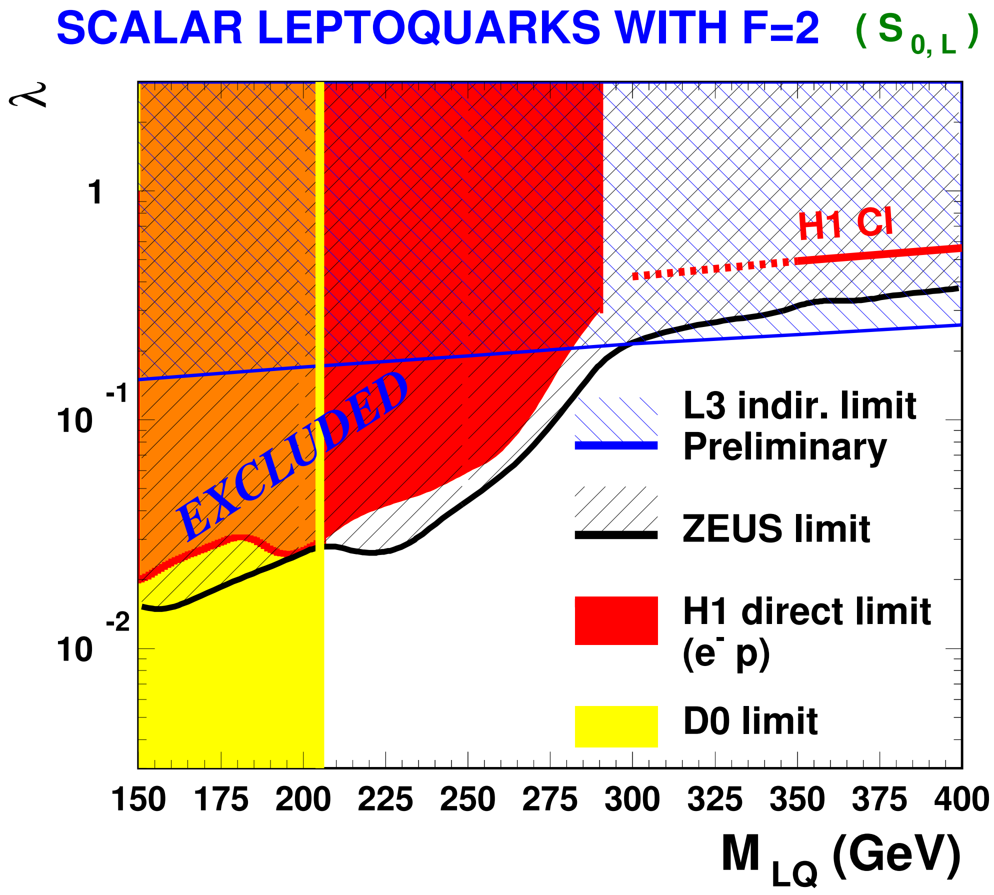
$\lambda = 0.1$ 248-290 GeV

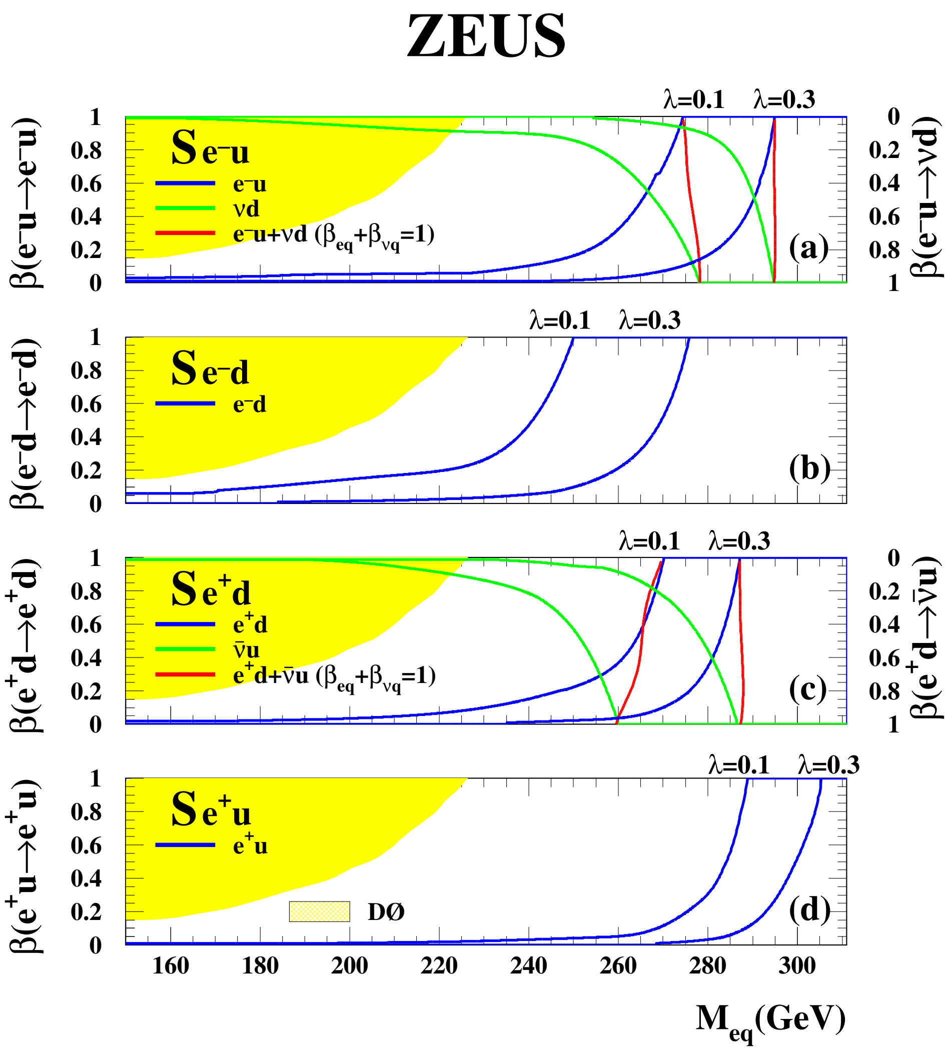
(most stringent limits available..)

LEP limits are obtained through indirect (virtual) t-channel effects $e^+e^- \rightarrow q\bar{q}$ and depend on λ

Tevatron limits come from the gauge contribution to $q\bar{q} \rightarrow e^+e^- q\bar{q}$ and are independent of λ

ZEUS direct searches improve by a factor 1-10 the λ limit for 200 Gev $< M_{LQ} <$ 300 GeV.





Constant λ limits for scalar LQ as functions of branching ratios (β) into eq (left) and νq (right)

Solid line:

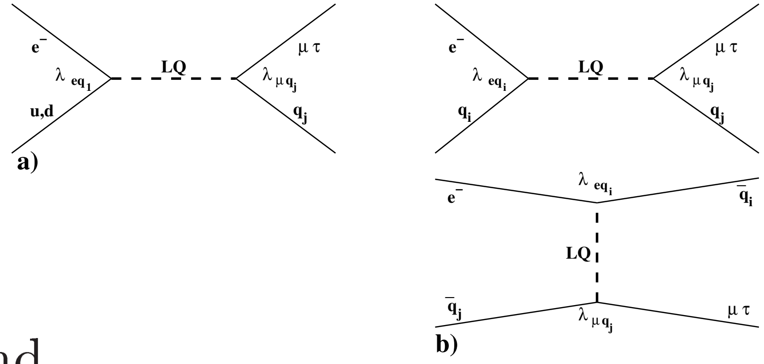
$$\beta_{eq} + \beta_{\nu q} = 1$$

Significant improvement over D0

weak dependence on β

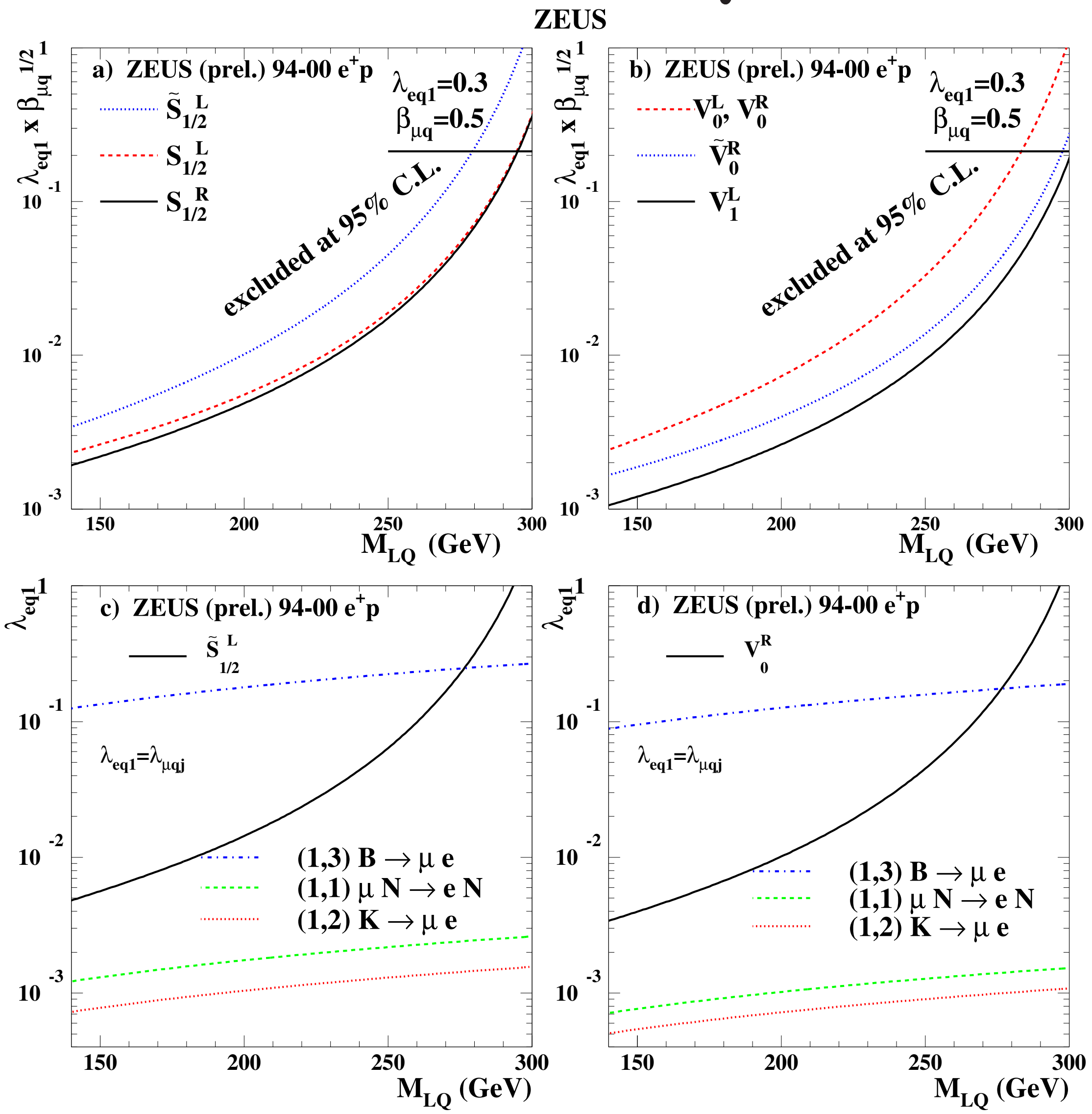
Lepton Flavour Violation

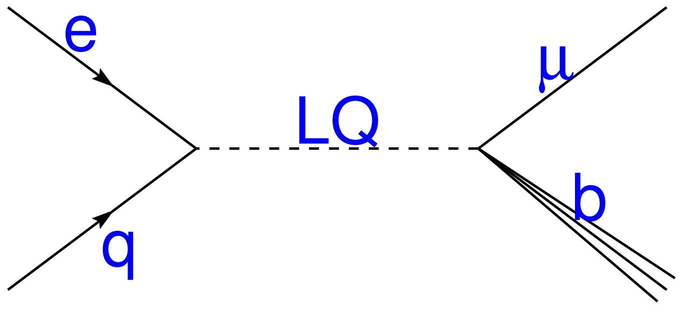
LFV: Flavour changing NC processes, Scattered e^- (or e^+) replaced by a μ (or τ) in the final state, with high p_t balancing the jet in the transverse plane.



Signature : high missing p_t
accompanied by an aligned μ (or τ).
Striking signal, with small SM background.
ZEUS found no evidence for LFV $e^-p \to \mu^- X$ in the whole integrated luminosity (130 pb^{-1}). LFV can be mediated by LQs (or s-quarks). Limits set on coupling versus mass provided for resonantly produced leptoquarks. Limits also set on the 4-fermion contact-interaction term $\frac{\lambda_{eq_i}\lambda_{\mu q_j}}{M^2_{LQ}}$ for high mass leptoquarks coupling to different quark generations.

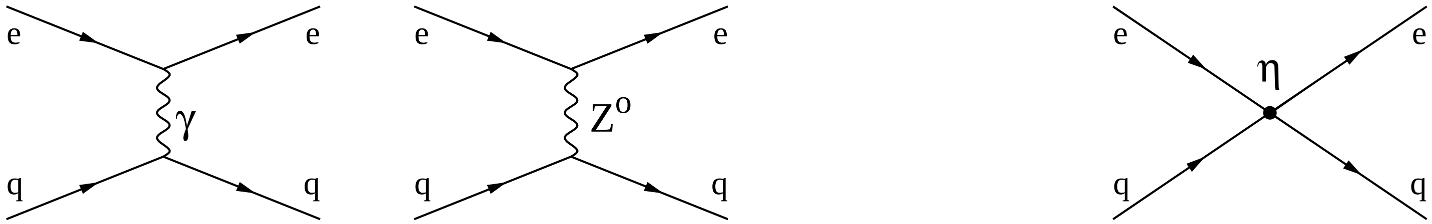
Results for low mass LQs.





For both low and high mass LQs
ZEUS limits are competitive
in cases involving heavy quarks

CONTACT INTERACTIONS



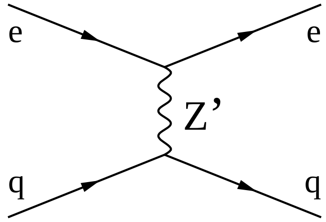
4-fermion contact interactions (CI) describe effects from processes at much higher scales. Such effects could alter the distributions predicted by the SM at high Q^2 and interfere with the prediction at intermediate Q^2.
Vector terms (scalar and tensor are already costrained):

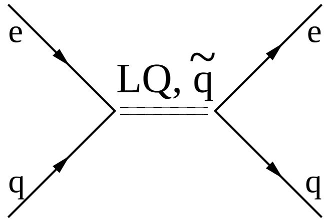
$$L_{CI} = \sum_{\alpha,\beta=L,R}^{q=u,d} \eta^q_{\alpha\beta}(\bar{e}_\alpha\gamma^\mu e_\alpha)(\bar{q}_\beta\gamma_\mu q_\beta)$$

$\eta_{\alpha\beta} = \epsilon\frac{g^2_{CI}}{\Lambda^2}$ define the structure of the model. $g_{CI} = 4\pi$ $\epsilon = \pm 1$

Contact Interaction sources

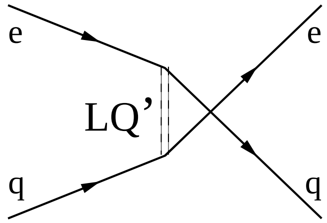
Exchange of extra gauge bosons

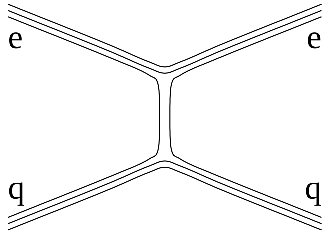




Production of LQ, squark

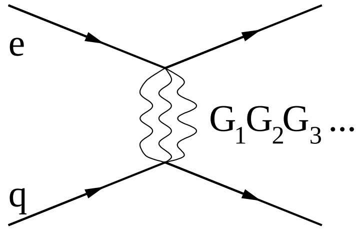
Exchange of LQ

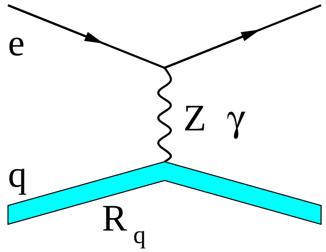




Compositeness

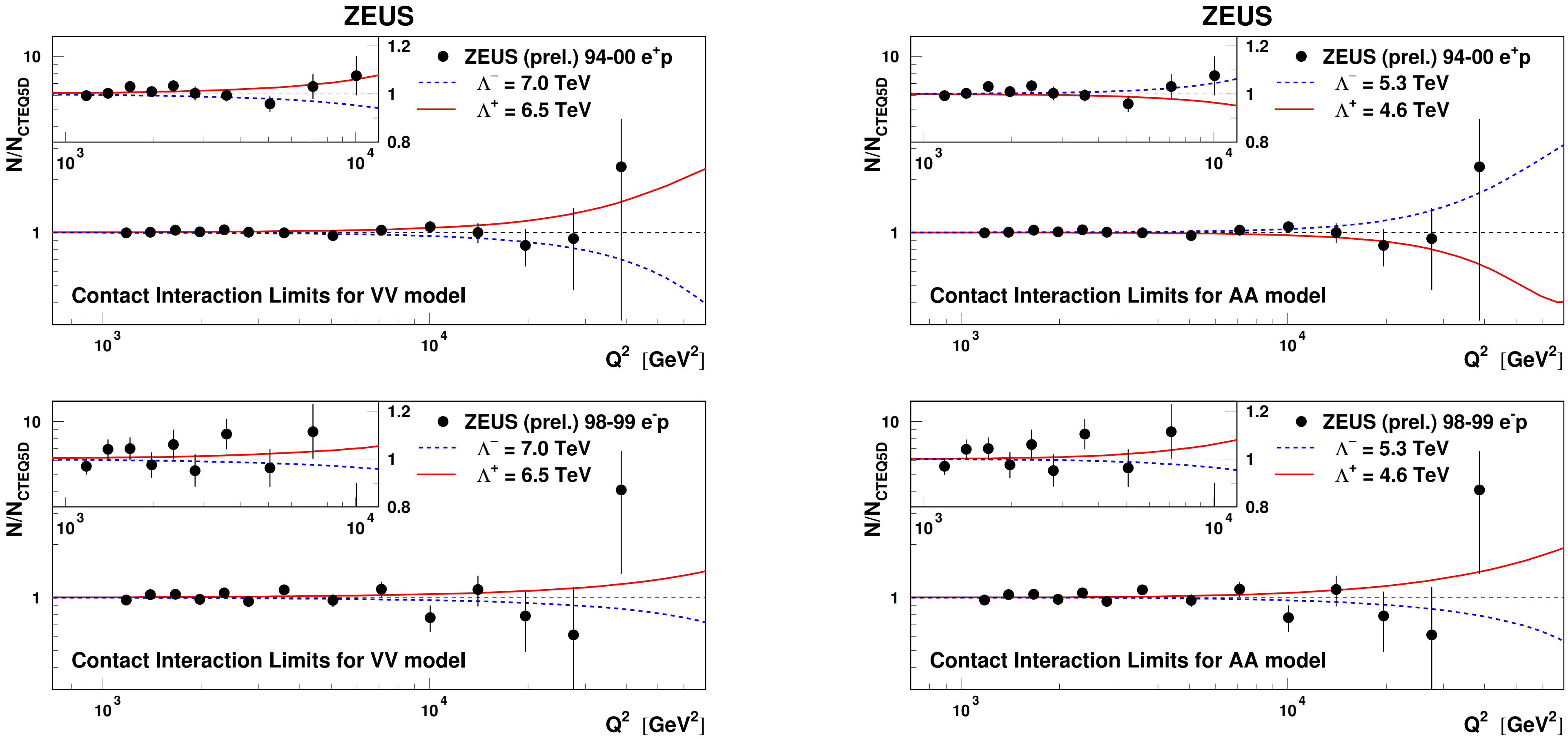
Gravitational effects



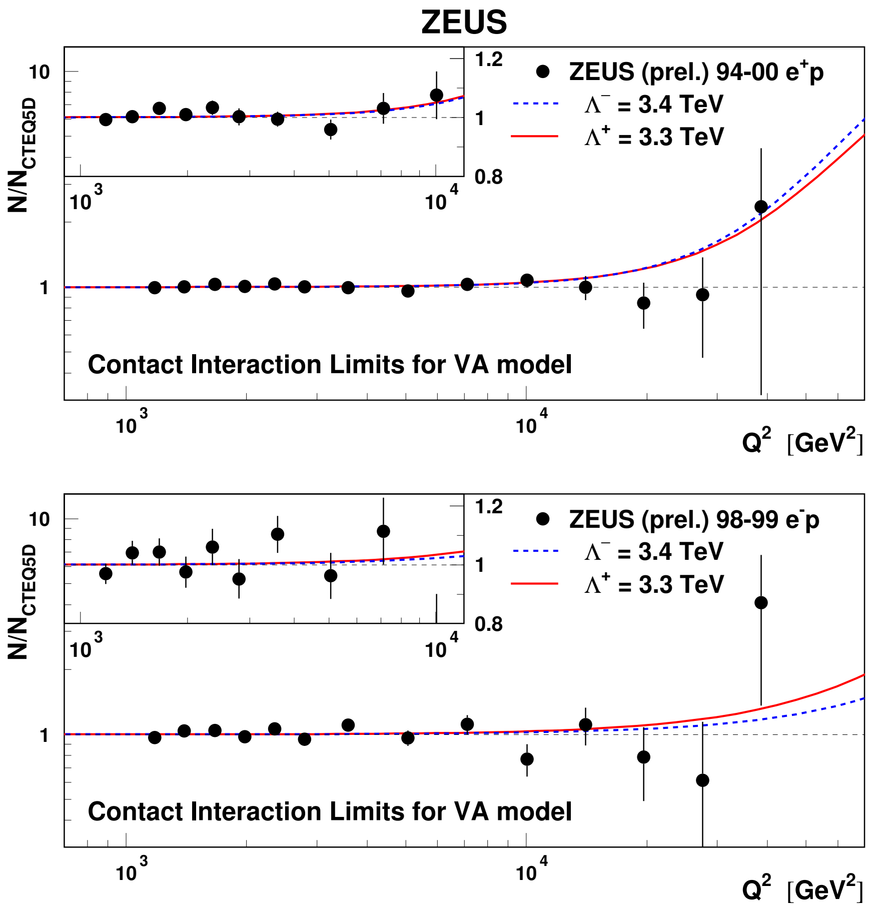


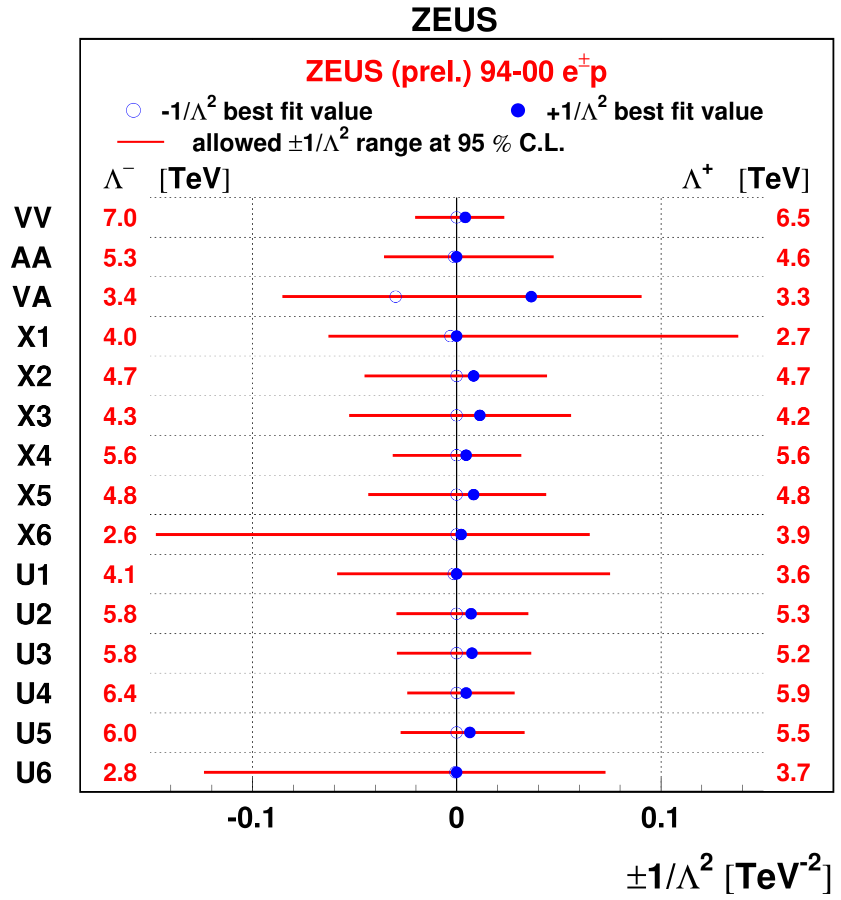
Quark radius

Contact Interaction scale



Limits for effective mass scale : Λ_{eeqq} 2.7-7.0 TeV



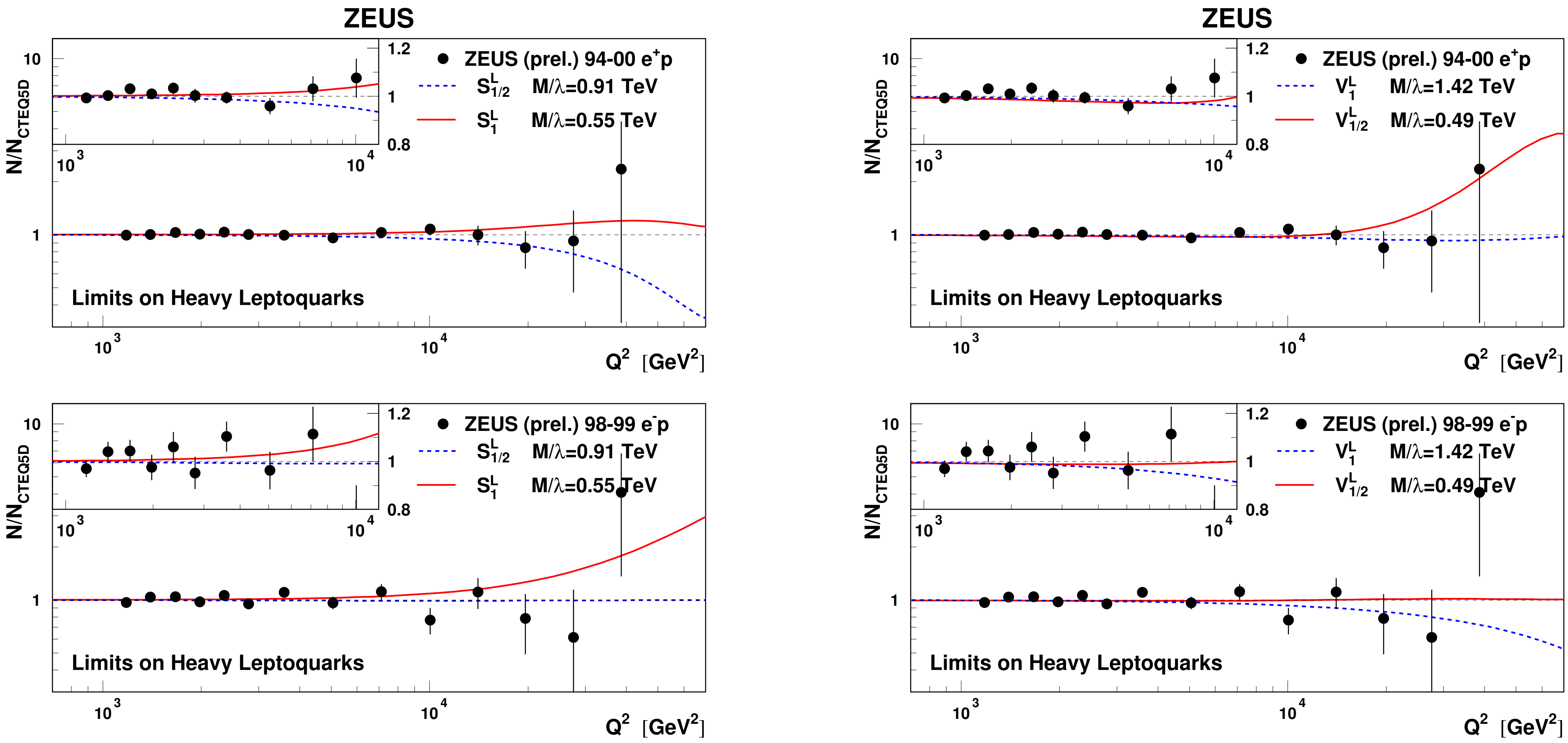


Limits for all chiral combinations

ZEUS (prel.) 1994-2000 $e^{\pm}p$										
	Coupling structure								95% CL [TeV]	
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}	Λ^-	Λ^+
VV	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	$+\eta$	7.0	6.5
AA	$+\eta$	$-\eta$	$-\eta$	$+\eta$	$+\eta$	$-\eta$	$-\eta$	$+\eta$	5.3	4.6
VA	$+\eta$	$-\eta$	$+\eta$	$-\eta$	$+\eta$	$-\eta$	$+\eta$	$-\eta$	3.4	3.3
X1	$+\eta$	$-\eta$			$+\eta$	$-\eta$			4.0	2.7
X2	$+\eta$		$+\eta$		$+\eta$		$+\eta$		4.7	4.7
X3	$+\eta$			$+\eta$	$+\eta$			$+\eta$	4.3	4.2
X4		$+\eta$	$+\eta$			$+\eta$	$+\eta$		5.6	5.6
X5		$+\eta$		$+\eta$		$+\eta$		$+\eta$	4.8	4.8
X6			$+\eta$	$-\eta$			$+\eta$	$-\eta$	2.6	3.9
U1					$+\eta$	$-\eta$			4.1	3.6
U2					$+\eta$		$+\eta$		5.8	5.3
U3					$+\eta$			$+\eta$	5.8	5.2
U4						$+\eta$	$+\eta$		6.4	5.9
U5						$+\eta$		$+\eta$	6.0	5.5
U6							$+\eta$	$-\eta$	2.8	3.7

Heavy Leptoquarks

Limits on M_{LQ}/λ: 0.31-1.42 TeV



Review of limits on Heavy Leptoquarks

ZEUS (prel.) 1994-2000 $e^{\pm}p$

Model	Coupling structure a^{ed}_{LL}	a^{ed}_{LR}	a^{ed}_{RL}	a^{ed}_{RR}	a^{eu}_{LL}	a^{eu}_{LR}	a^{eu}_{RL}	a^{eu}_{RR}	95% CL [TeV] M_{LQ}/λ_{LQ}
S^L_0					$+\frac{1}{2}$				0.75
S^R_0								$+\frac{1}{2}$	0.69
$\tilde{S}^R_0$				$+\frac{1}{2}$					0.31
$S^L_{1/2}$						$-\frac{1}{2}$			0.91
$S^R_{1/2}$			$-\frac{1}{2}$				$-\frac{1}{2}$		0.69
$\tilde{S}^L_{1/2}$		$-\frac{1}{2}$							0.50
S^L_1	$+1$				$+\frac{1}{2}$				0.55
V^L_0	-1								0.69
V^R_0				-1					0.58
$\tilde{V}^R_0$								-1	1.03
$V^L_{1/2}$		$+1$							0.49
$V^R_{1/2}$			$+1$				$+1$		1.15
$\tilde{V}^L_{1/2}$						$+1$			1.26
V^L_1	-1				-2				1.42

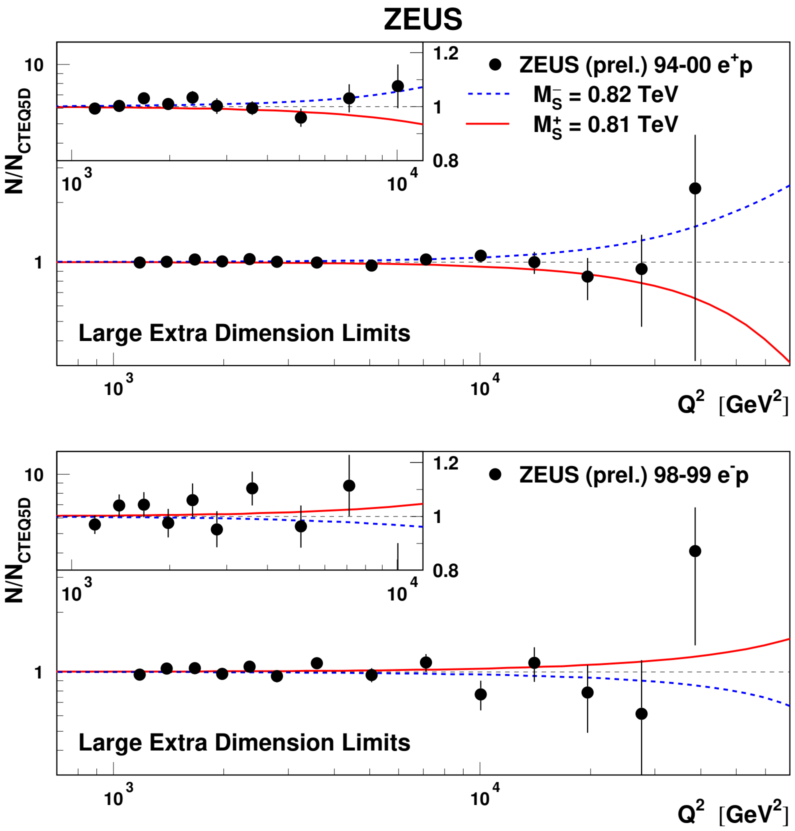
Large Extra Dimensions

In some $4+n$ dimensional string theories (Arkani-Hamed-Dimopoulos-Dvali model) the compactified extra dimensions have size $R \simeq 1$ mm. The effective Planck scale M_S is related to $M_P \simeq 10^{19}$ GeV by the equation:

$$M_P^2 = M_S^{2+n} R^n$$

The graviton can propagate into the extra dimension, visible in the ordinary 4 dimensions as a Kaluza-Klein tower of excited states with spacing $\Delta m = \frac{1}{R}$. These states can be summed up to M_S and give sizeable effects, equivalent to a contact interaction term $\eta^G = \frac{\lambda}{M_S^4}$ where $\lambda \simeq 1$ (Giudice, Rattazzi, Wells).

Limits on Mass Scale of Extra Dimensions



Limits on M_S

λ =-1	$M_S > 0.82$ TeV
λ =+1	$M_S > 0.81$ TeV

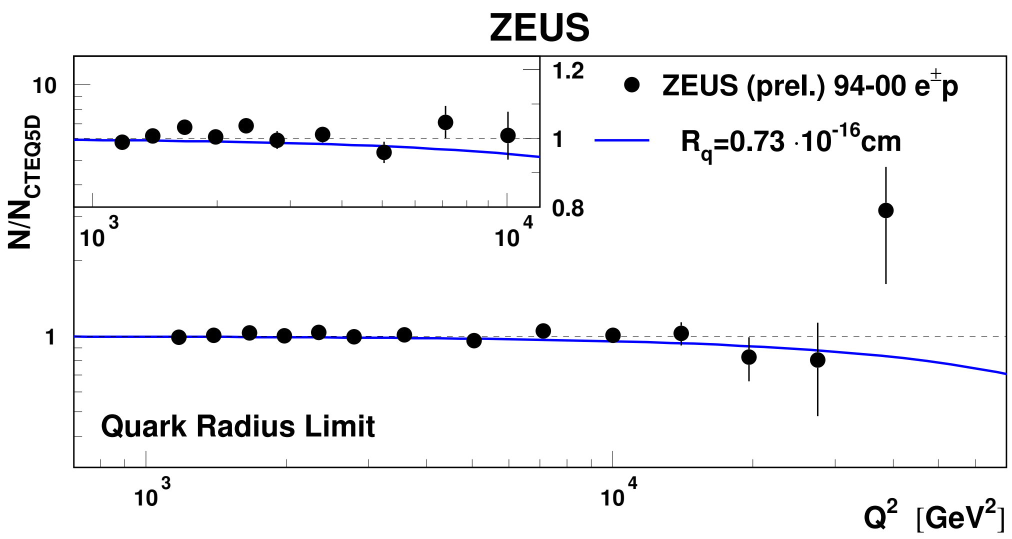
LEP, Tevatron

limits $\simeq 1$ TeV

Quark Radius

Classical approach to the search for quark substructure.
Given a charge distribution of radius R_q in the quark:

$$\frac{d\sigma}{dQ^2} = \frac{d\sigma^{SM}}{dQ^2} \cdot (1 - \frac{R_q^2}{6} \cdot Q^2)^2)$$



$R_q < 0.73 \cdot 10^{-16}$ cm

Conclusions

- HERA offers a unique environment to look for new particles and phenomena
- No evidence for new physics has been found at HERA I with ZEUS so far
- Limits have been set for Leptoquarks, Contact Interactions (including Large Extra Dimensions and Quark Radius), Lepton Flavour Violation.
- These limits show comparable or competitive or complementary sensitivity with respect to LEP or Tevatron.
- HERA II should increase the sensitivity to new physics, especially with the possibility of using polarized $e^{\pm}$ beams