

Search for Contact Interactions in ep Collisions at ZEUS



Stefan Schlenstedt
for the ZEUS collaboration



DIS meeting, München, Apr 2007

A Look beyond the Standard Model

- measurements of neutral cross section reactions at HERA over a wide range of Q^2 – well described by the Standard Model (SM)
 - is there more? 🖱️ look for deviations from SM description and compare/ parametrize as additional terms to Neutral Current Standard Model Lagrangian
 - general ansatz: effective four-fermion contact interactions
 - more specific models
 - heavy leptoquarks
 - large extra dimensions
 - “offer a rich alternative to the phenomenology of supersymmetry” (J Ellis)
 - and connect to cosmology
 - quark form factor using form-factor approximation
- ⊙ e^+p and e^-p data are sensitive to different coupling combinations

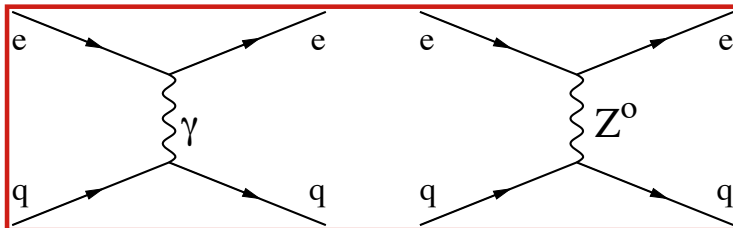
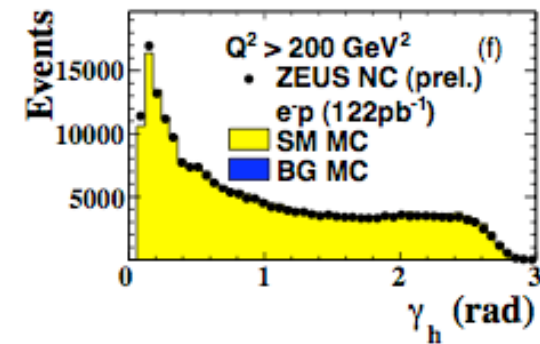
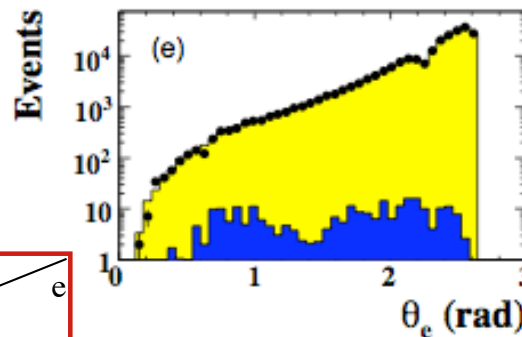
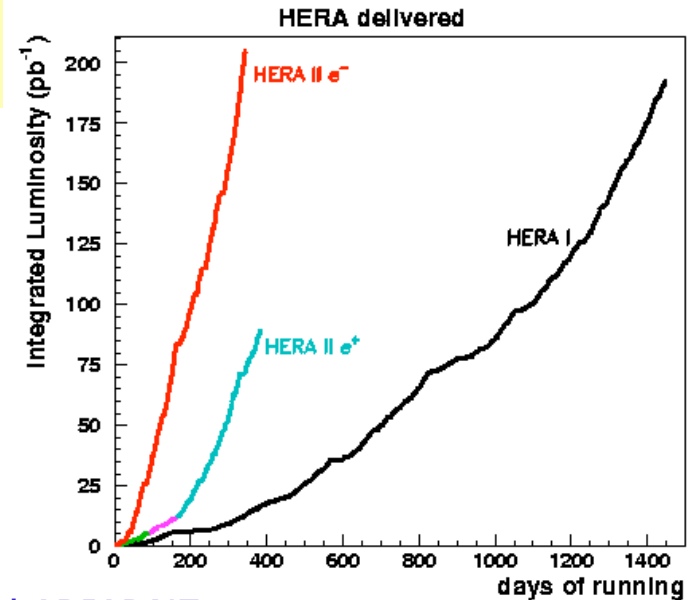
Neutral Current Data

- ZEUS ep data

- HERA I $\sqrt{s} = 300 \text{ GeV}$ 1994-2000 128 pb⁻¹
 - unpolarized e⁺ (112 pb⁻¹) and e⁻ data sets
- HERA II $\sqrt{s} = 318 \text{ GeV}$ 2003-2005 146 pb⁻¹
 - polarization e⁻ -0.27, +0.33, e⁺ -0.41, +0.32

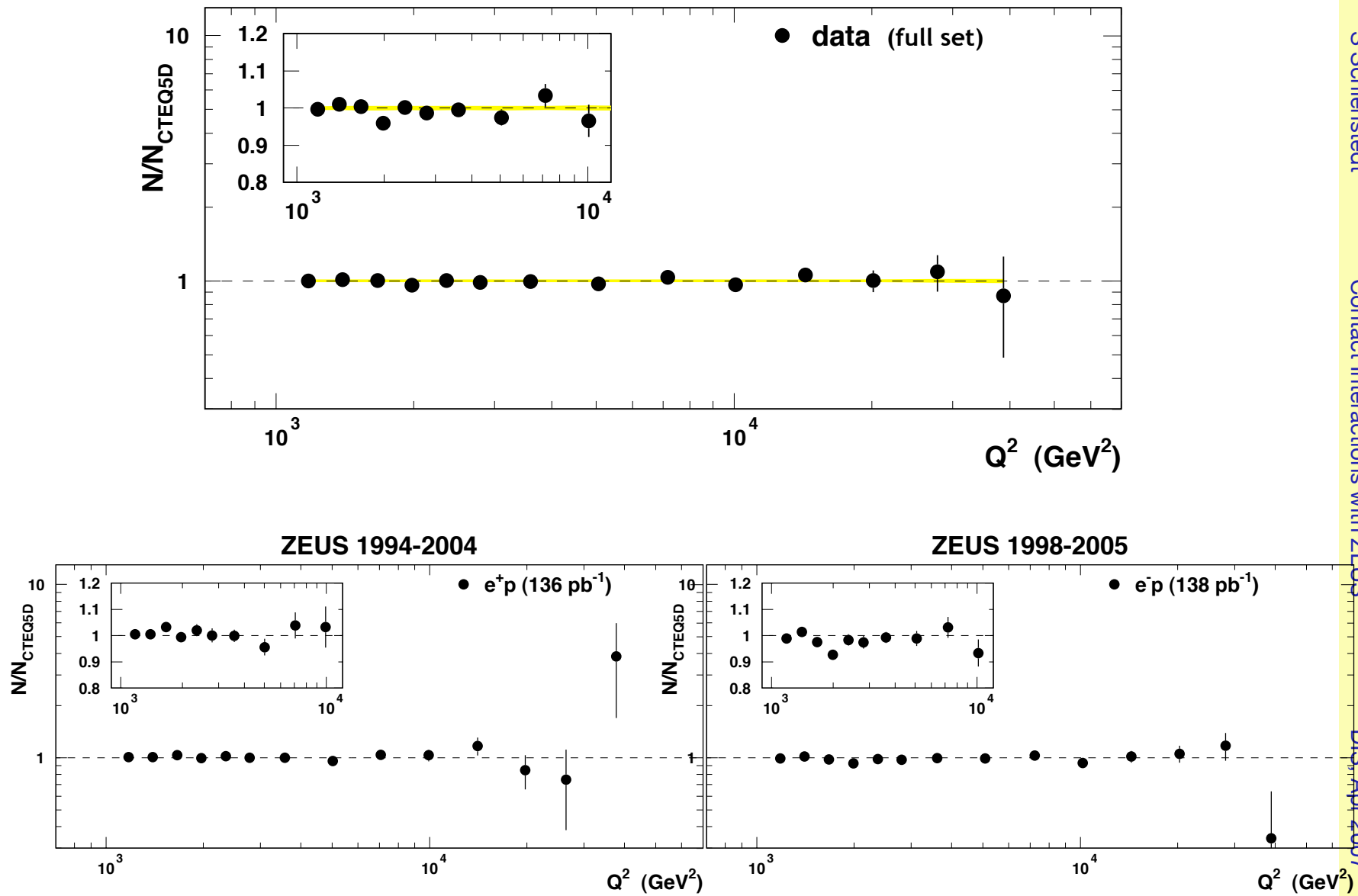
- Use high Q² NC data

- reconstructed with the double-angle method
- MC data generated with HERACLES/ DJANGO and ARIADNE
- detector response simulated with GEANT 3.13



$$\frac{d^2\sigma(e^\pm p)}{dx dQ^2}(x, Q^2) = \frac{2\pi\alpha^2}{xQ^2} [(1 + (1-y)^2) F_2 \mp ((1 - (1-y)^2)) x F_3]$$

The High Q^2 Neutral Current Data in ZEUS



Look beyond the Standard Model

- general ansatz for contact interactions (CI) with a large "new" scale Λ – effective Lagrangian for vector $eeqq$ CI

$$\mathcal{L}_{CI} = \sum_{i,j=L,R; q=u\dots b} \eta_{ij}^{eq} (\bar{e}_i \gamma^\mu e_i) (\bar{q}_j \gamma_\mu q_j)$$

$$\eta \sim 1/\Lambda^2$$

- heavy leptoquarks

$$\eta \sim (\lambda/M_{LQ})^2$$

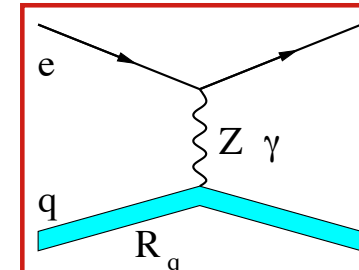
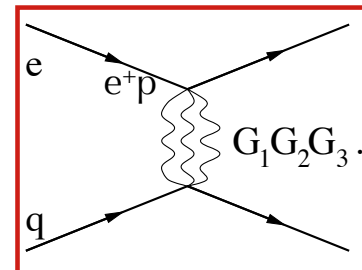
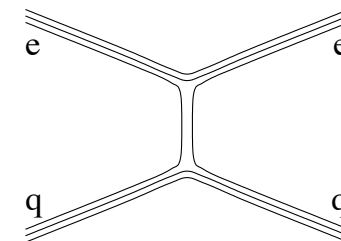
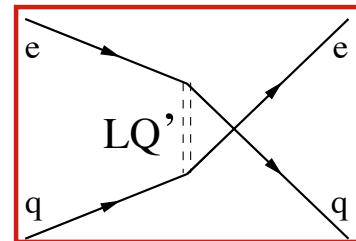
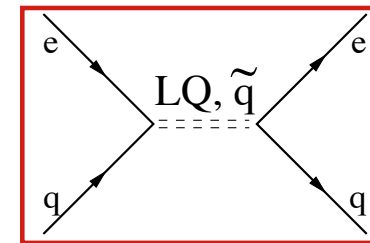
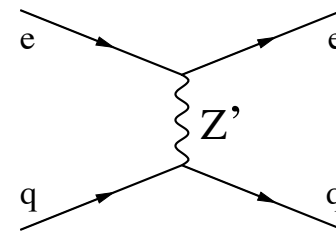
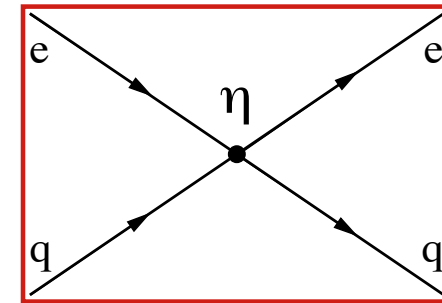
- large extra dimensions

$$\eta_G \sim 1/M_S^4$$

- quark form factor using approximation

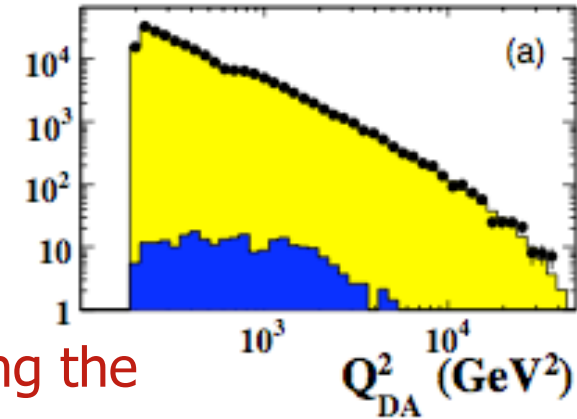
$$\left(1 - \frac{R_q^2}{6} Q^2\right)$$

- $e p$ constraints mostly LL and RR, mostly RL and LR couplings



Extraction of Limits from Event Ratios

- use neutral current data $Q^2 > 1000 \text{ GeV}^2$ in bins of Q^2 and compare with model predictions from Monte Carlo data
- use Poisson statistics

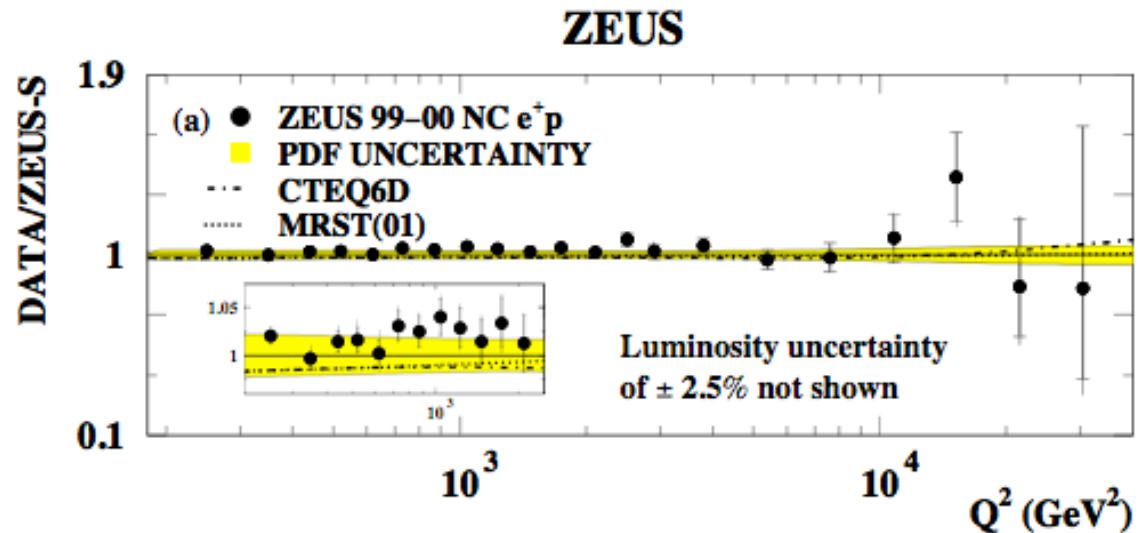


- likelihood for the complete data set by multiplying the likelihoods of each data sample
- search for best agreement between data and prediction
- set limits based on large number of equivalent MC experiments
 - effects on BSM scenarios by reweighting the SM MC data
 - excluded at the 95% CL are models which, in more than 95% of the MC experiments, result in the most likely coupling strength greater than determined for the data

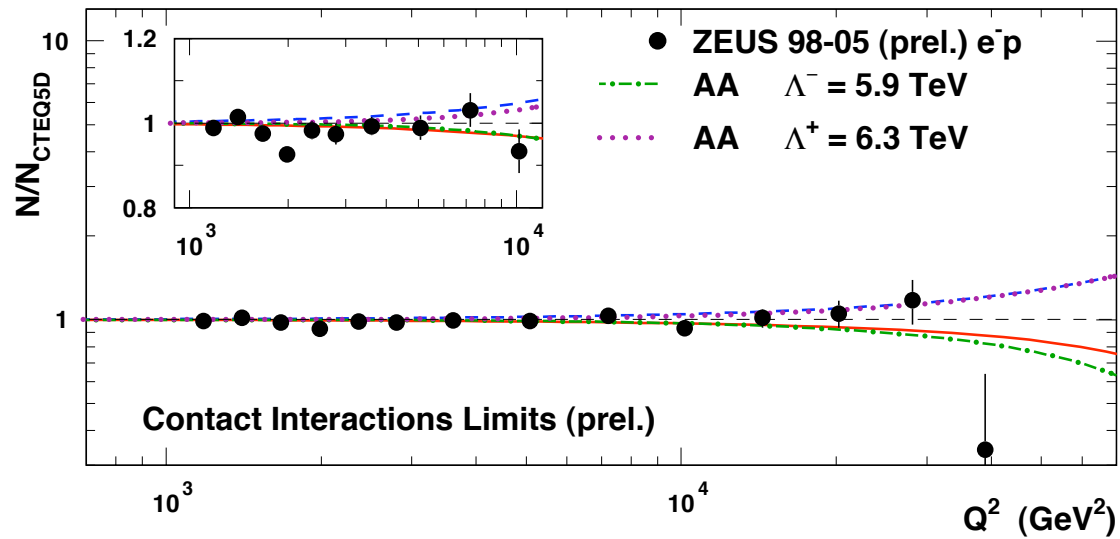
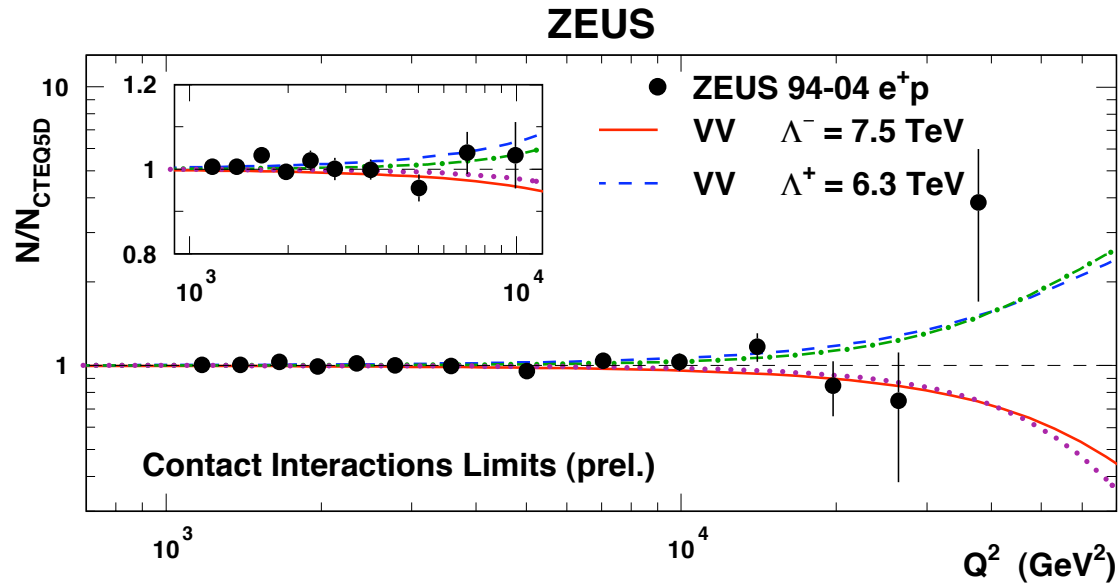
Systematic Uncertainties

- vary PDF CTEQ – ZEUS-S
 - α_s uncertainty 0.002
 - energy scale electrons 3%
 - energy scale hadrons 3%
 - polarization uncertainty per period 3...5%
 - luminosity uncertainty per year 1.6...3.5%
- ⊙ take (un)correlation between data sets into account

example of PDF uncertainty for one data-set



Derive Contact Interaction Limits

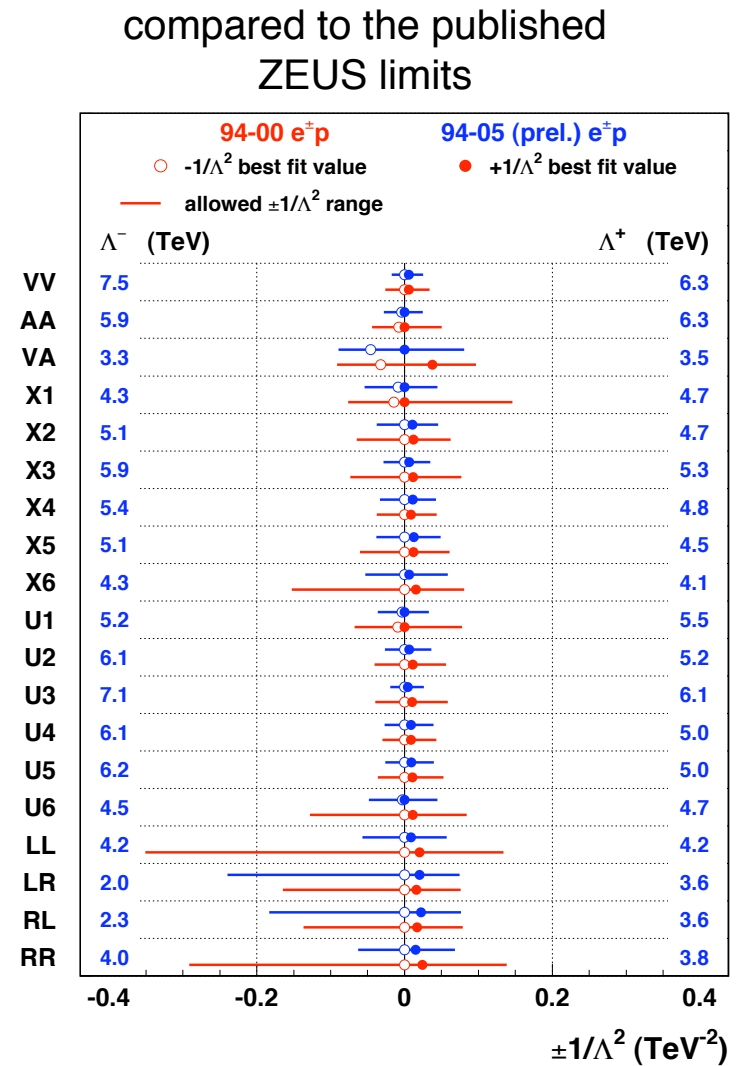
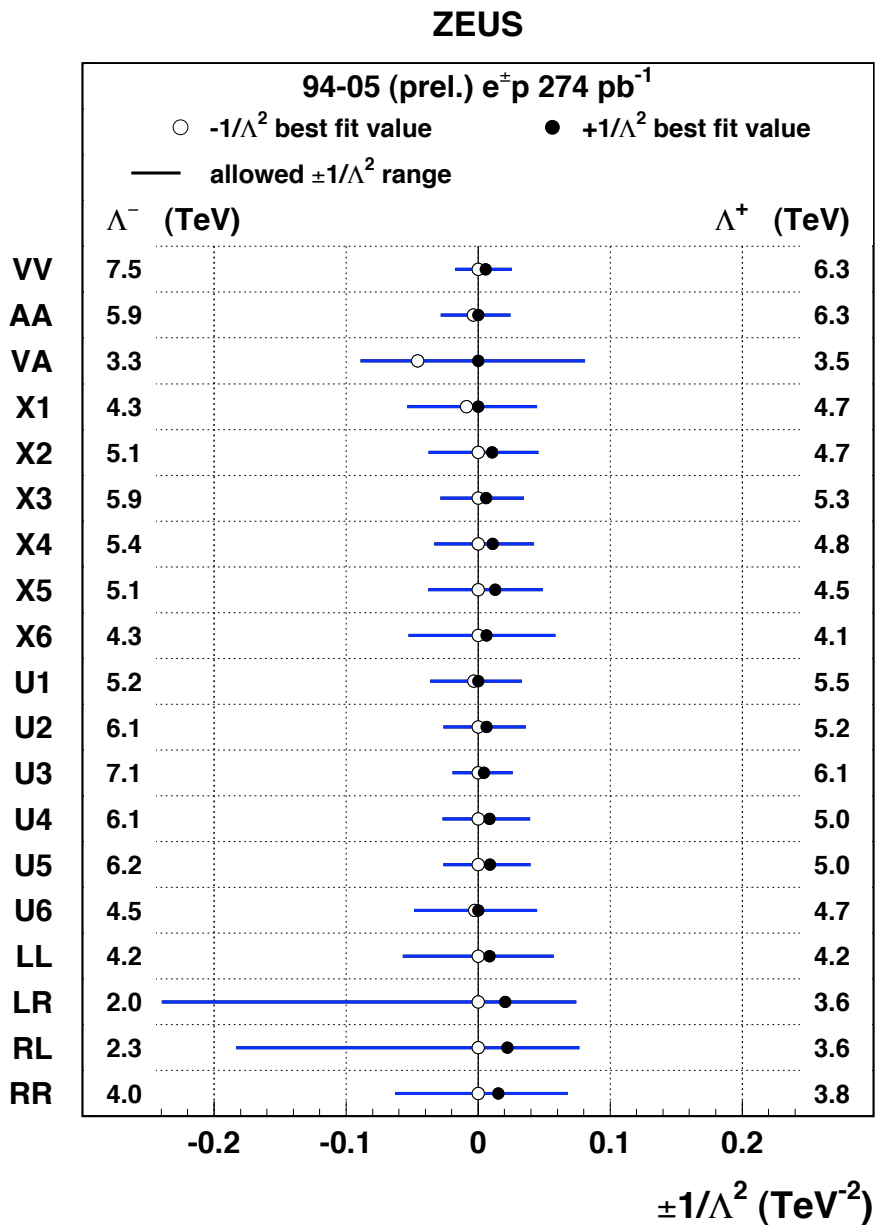


Contact Interaction Limits

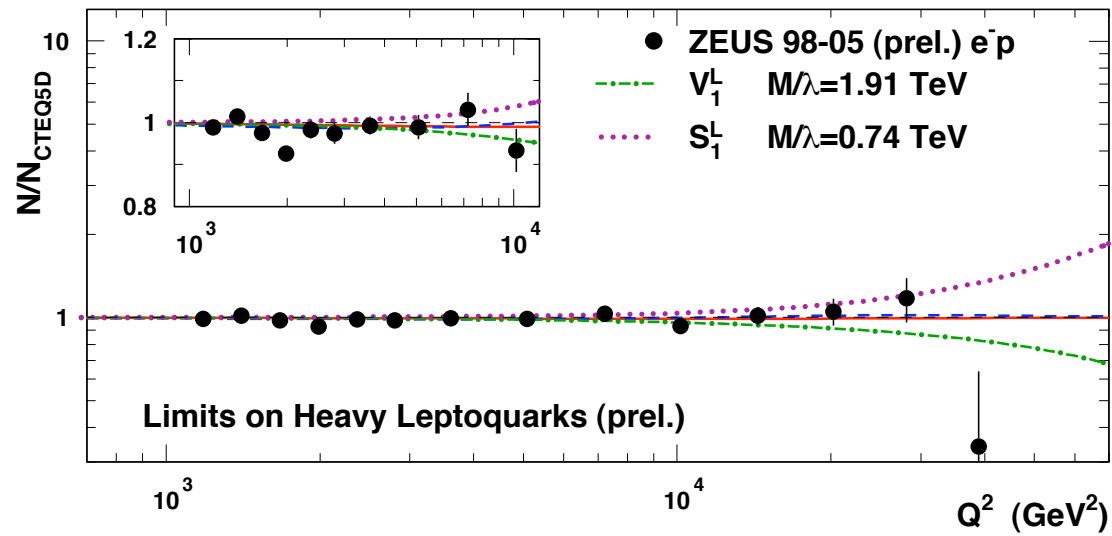
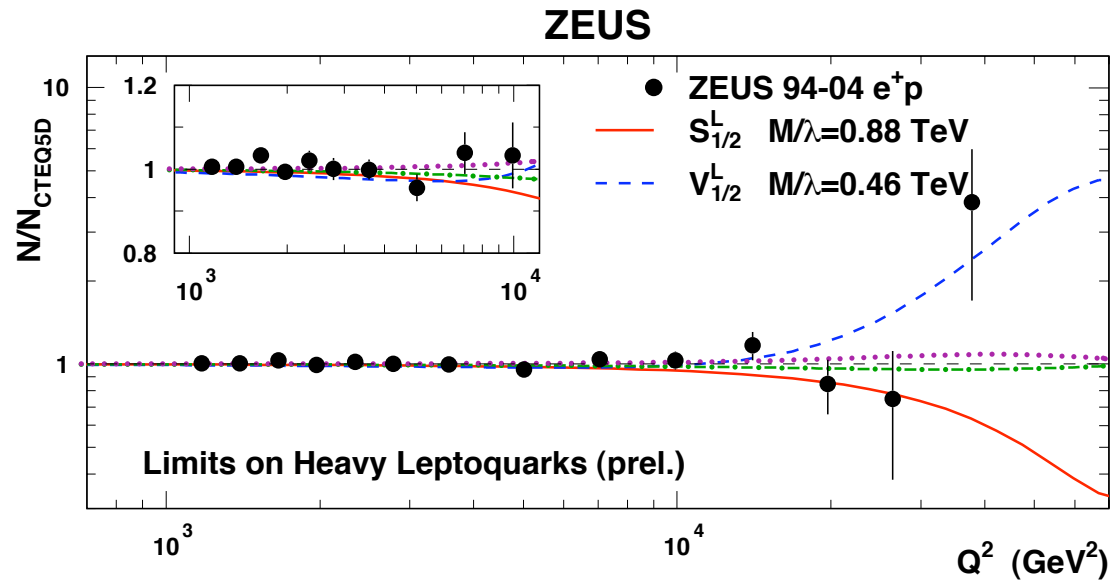
ZEUS 1994-2005 (prel.) $e^\pm p$			
Model	Coupling structure [$\epsilon_{LL}, \epsilon_{LR}, \epsilon_{RL}, \epsilon_{RR}$]	95% C.L. (TeV)	
		Λ^-	Λ^+
LL	[+1, 0, 0, 0]	4.2	4.2
LR	[0, +1, 0, 0]	2.0	3.6
RL	[0, 0, +1, 0]	2.3	3.6
RR	[0, 0, 0, +1]	4.0	3.8
VV	[+1, +1, +1, +1]	7.5	6.3
AA	[+1, -1, -1, +1]	5.9	6.3
VA	[+1, -1, +1, -1]	3.3	3.5
X1	[+1, -1, 0, 0]	4.3	4.7
X2	[+1, 0, +1, 0]	5.1	4.7
X3	[+1, 0, 0, +1]	5.9	5.3
X4	[0, +1, +1, 0]	5.4	4.8
X5	[0, +1, 0, +1]	5.1	4.5
X6	[0, 0, +1, -1]	4.3	4.1
U1	[+1, -1, 0, 0] ^{eu}	5.2	5.5
U2	[+1, 0, +1, 0] ^{eu}	6.1	5.2
U3	[+1, 0, 0, +1] ^{eu}	7.1	6.1
U4	[0, +1, +1, 0] ^{eu}	6.1	5.0
U5	[0, +1, 0, +1] ^{eu}	6.2	5.0
U6	[0, 0, +1, -1] ^{eu}	4.5	4.7

$$\eta_{ij} = \epsilon_{i,j} \frac{4\pi}{\Lambda^2}$$

Contact Interaction Limits



Limits on Leptoquarks

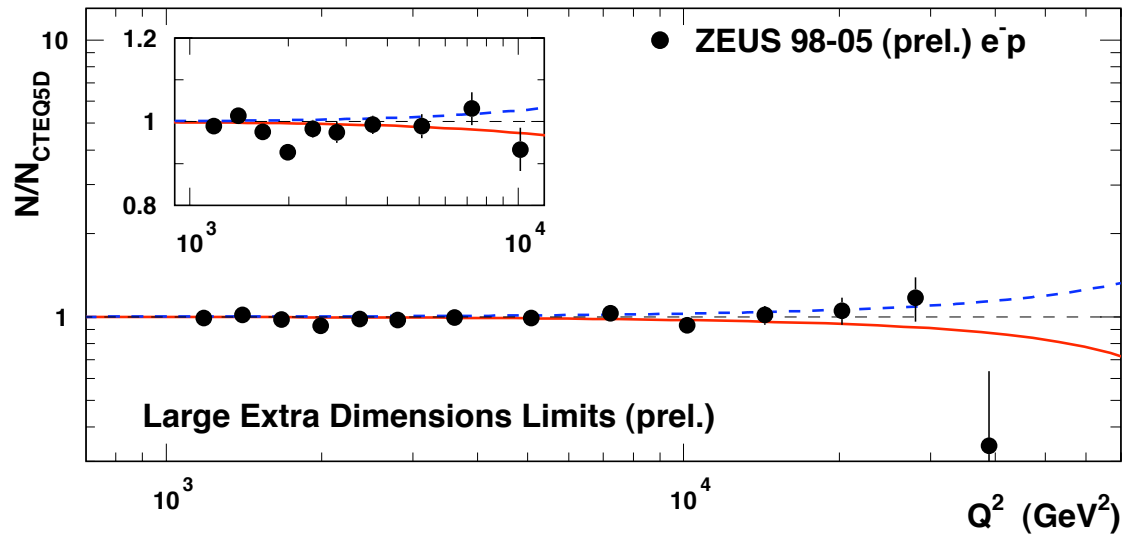
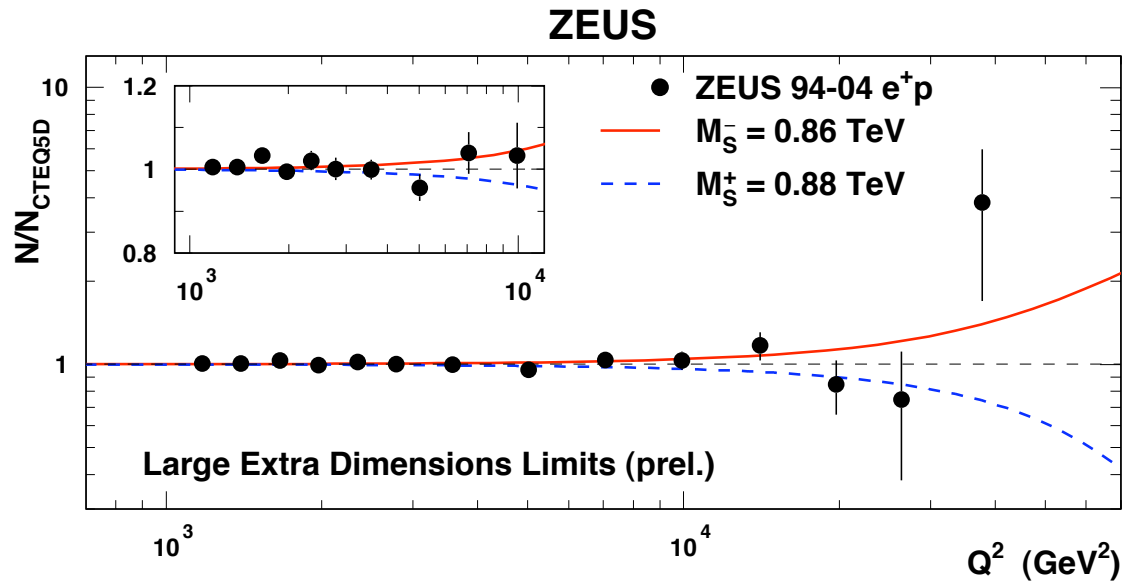


Limits on Leptoquarks

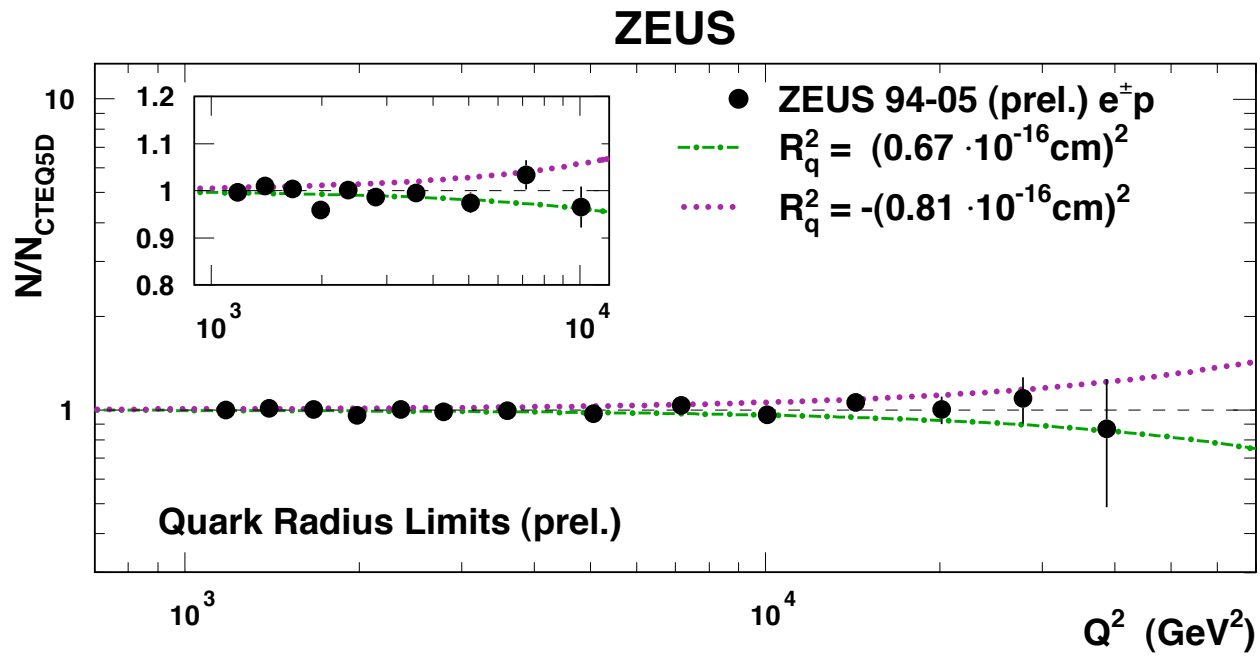
ZEUS 1994-2005 (prel.) $e^\pm p$			
	Model	Coupling Structure	95% C.L. (TeV) M_{LQ}/λ_{LQ}
scalar	S_\circ^L	$a_{LL}^{eu} = +\frac{1}{2}$	0.96
	S_\circ^R	$a_{RR}^{eu} = +\frac{1}{2}$	0.82
	\tilde{S}_\circ^R	$a_{RR}^{ed} = +\frac{1}{2}$	0.32
	$S_{1/2}^L$	$a_{LR}^{eu} = -\frac{1}{2}$	0.88
	$S_{1/2}^R$	$a_{RL}^{ed} = a_{RL}^{eu} = -\frac{1}{2}$	0.46
	$\tilde{S}_{1/2}^L$	$a_{LR}^{ed} = -\frac{1}{2}$	0.44
	S_1^L	$a_{LL}^{ed} = +1, a_{LL}^{eu} = +\frac{1}{2}$	0.74
vector	V_\circ^L	$a_{LL}^{ed} = -1$	0.80
	V_\circ^R	$a_{RR}^{ed} = -1$	0.62
	\tilde{V}_\circ^R	$a_{RR}^{eu} = -1$	1.33
	$V_{1/2}^L$	$a_{LR}^{ed} = +1$	0.46
	$V_{1/2}^R$	$a_{RL}^{ed} = a_{RL}^{eu} = +1$	1.00
	$\tilde{V}_{1/2}^L$	$a_{LR}^{eu} = +1$	1.10
	V_1^L	$a_{LL}^{ed} = -1, a_{LL}^{eu} = -2$	1.91

classification proposed by Buchmüller, Rückl and Wyler

Limits on Extra Dimensions



Limit on Quark radius



Summary

- Search for deviations from the SM of e^+p and e^-p data recorded with the ZEUS detector between 1994 and 2005 in 274 pb^{-1} , approximately same data set for e^+ and e^-
- Published analyses extended to HERA II data, polarization effects taken into account
- Major improvements of the limits, in particular if sensitive to LL and RR couplings:
 - contact interaction limits from $\Lambda = 2.0$ to 7.5 TeV
 - heavy leptoquark limits from $M/\lambda = 0.32$ to 1.9 TeV
 - limits on large extra dimensions $M_S = 0.86/ 0.88 \text{ TeV}$
 - quark radius limit $0.67 \cdot 10^{-16} \text{ cm}$