Search for Contact Interactions

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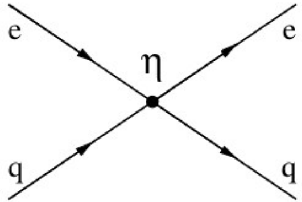
Contact Interactions

Search for "new physics" has always been one of the most important subjects in field of particle physics. But since it is still "new", it wasn't yet observed with direct searches, and alternative approach should be considered. If masses of those new species are such that $M_{\mathcal{X}} \gg \sqrt{s}$, their footprints can still be investigated as evidences of virtual exchange.

Four-fermion *eeqq* vector contact interactions provide a convenient method for such search and can be represented by additional terms in the Standard Model Lagrangian:



$$\mathcal{L}_{LO}^{CI} = \sum_{\text{chilarity},\textit{quarks}} \eta_{kj}^{eq} (\bar{e}_k \gamma^\mu e_k)(\bar{q}_j \gamma_\mu q_j)$$

Contact Interactions

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							$+\eta$	$-\eta$

Structure of the effective couplings for general CI models.

Model	α^{ed}_{LL}	α^{ed}_{LR}	α^{ed}_{RL}	α^{ed}_{RR}	α^{eu}_{LL}	α^{eu}_{LR}	α^{eu}_{RL}	α^{eu}_{RR}
S_o					1/2			1/2
S^L_o					1/2			
S^R_o								1/2
$\tilde{S}^R_o$				1/2				
$S_{1/2}$			−1/2			−1/2	−1/2	
$S^L_{1/2}$						−1/2		
$S^R_{1/2}$			−1/2				−1/2	
$\tilde{S}^L_{1/2}$		−1/2						
S^L_1	1				1/2			
V_o	-1			-1				
V^L_o	-1							
V^R_o				-1				
$\tilde{V}^R_o$								-1
$V_{1/2}$		1	1				1	
$V^L_{1/2}$		1						
$V^R_{1/2}$			1				1	
$\tilde{V}^R_{1/2}$						1		
V^L_1	-1				-2			

Structure of the effective couplings for LQ models.

Limits extractions

- CI+PDFs fit: take into account possible absorbtion of CI by common PDFs resulting in overestimated limits.

NC cross section:

$$M_{ij}^{sg}(t) = -\frac{4\pi\alpha_{em}e_q}{t} + \frac{4\pi\alpha_{em}}{\sin^2\Theta_W \cdot \cos^2\Theta_W} \cdot \frac{g_l^e g_j^q}{t - M_Z^2} + \eta_{ij}^{eq}$$

CC cross section:

$$\frac{d^2\sigma_{CC}^{e,p}}{dxdQ^2} = (1-P)\frac{1}{\pi}\sum_{i=1}^{2}[u_i(x,Q^2) + (1-y)^2\bar{d}_i(x,Q^2)] \times [\frac{G_F}{\sqrt{2}}\frac{M_W^2}{M_W^2+Q^2}]^2 \cdot \frac{\eta_L^{evud}}{4}$$

$$\left.\begin{aligned}
xg(x) &= A_g x^{B_g}(1-x)^{C_g} - A'_g x^{B'_g}(1-x)^{C'_g}, \\
xu_v(x) &= A_{u_v} x^{B_{u_v}}(1-x)^{C_{u_v}}\left(1 + E_{u_v}x^2\right), \\
xd_v(x) &= A_{d_v} x^{B_{d_v}}(1-x)^{C_{d_v}}, \\
x\bar{U}(x) &= A_{\bar{U}} x^{B_{\bar{U}}}(1-x)^{C_{\bar{U}}}(1 + D_{\bar{U}}x), \\
x\bar{D}(x) &= A_{\bar{D}} x^{B_{\bar{D}}}(1-x)^{C_{\bar{D}}}.
\end{aligned}\right\} \sigma^{SM+CI} = \sigma_{NLO}^{SM} \cdot \frac{\sigma_{LO,EW}^{SM+CI}}{\sigma_{LO,EW}^{SM}} \rightarrow \chi^2_{MC} = \frac{\sum_i \left[m^i + \sum_j \gamma_j^i m^i s_j - \mu^i\right]^2}{\left(\delta^2_{i,stat} + \delta^2_{i,uncor}\right)(\mu^i)^2} + \sum_j s_j^2$$

Limits extractions

- Monte Carlo replicas: express data uncertainties.

$$\mu^i_{MC} = \left[m^i + \sqrt{\delta^2_{i,stat} + \delta^2_{i,uncor}} \cdot \mu^i \cdot r_i \right] \cdot \left(1 + \sum_j \gamma^i_j \cdot r_j \right)$$

$$\chi^2_{MC} = \frac{\sum_i \left[m^i + \sum_j \gamma^i_j m^i s_j - \mu^i_{\mathrm{MC}} \right]^2}{\left(\delta^2_{i,stat} + \delta^2_{i,uncor} \right) (\mu^i)^2} + \sum_j s^2_j$$

r random numbers from a normal distribution

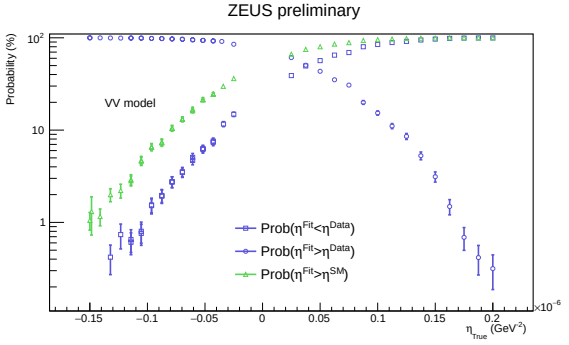
m predicted SM+BSM cross sections

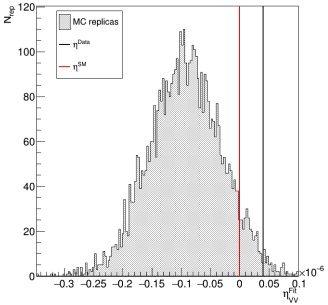
μ HERAPDF2.0 cross sections

γ, δ_{stat}, δ_{uncor} relative correlated systematic, statistical and uncorelated systematic uncertainties

Limits extraction

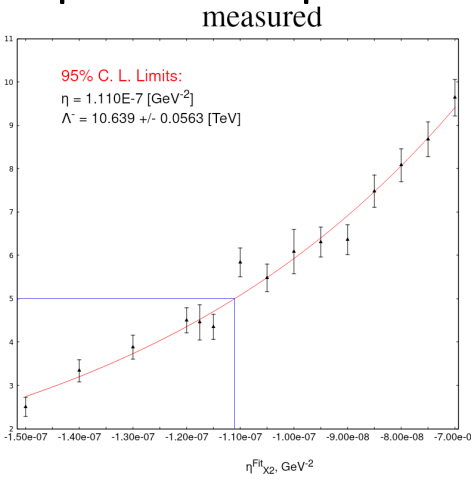
- Measured limits: 95% C.L. interval is set around the η^{Data}, obtained from the fit on data
  $\Rightarrow$ predictions on BSM physics.
- Expected limits: η^{Data} is taken as zero (SM expectation)
  $\Rightarrow$ sensitivity of the data.

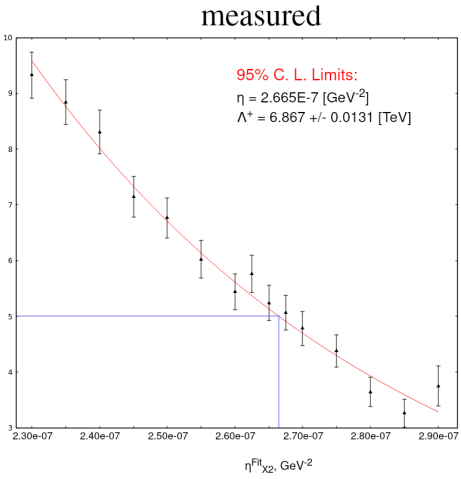




Limits extraction

Replicas scan example:



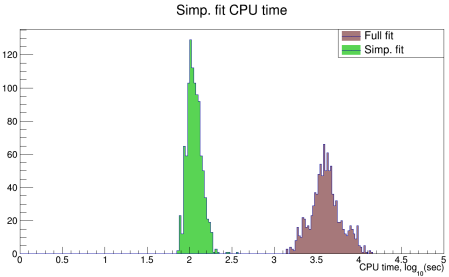


Measured limits for X2 model.

Simplified fit

On avarage, single fit takes about 50 minuites of CPU time. Even if we are able to run ≈ 1000 simultanious fits, it would take about $\frac{50[\text{min}]\cdot 50000[\text{fits per limit}]}{1000[\text{processes}]} \approx 40$ hours for one limit.

$\Rightarrow$ 37 CI models $\approx$ 4160 hours $\approx$ 6 months of incessant computations. In reality you can tenfold this time.

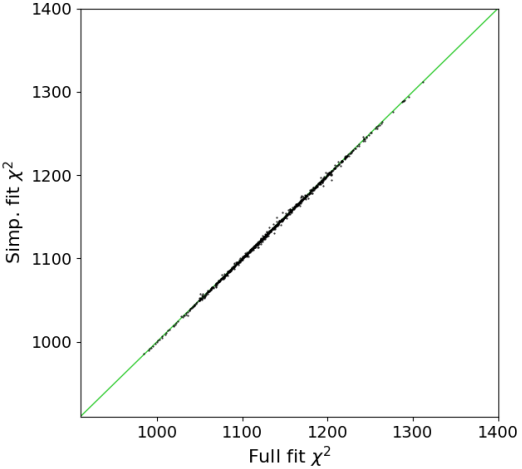


Solution:

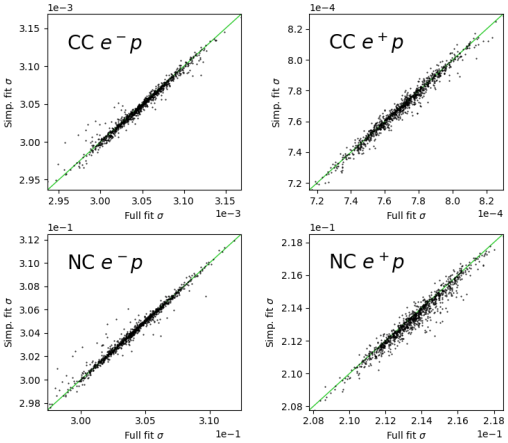
$$\left\| m_1^i = \frac{\partial m_0^i}{\partial \eta}, m_2^2 = \frac{\partial^2 m_0^i}{\partial \eta^2} \right\|$$

$$m^i = m_0^i + \sum_k \frac{\partial m_0^i}{\partial p^k}\,|_{p_0}\,(p^k - p_0^k) + \left(m_1^i + \sum_k \frac{\partial m_1^i}{\partial p^k}\,|_{p_0}\,(p^k - p_0^k)\right)\cdot\eta + \left(m_2^i + \sum_k \frac{\partial m_2^i}{\partial p^k}\,|_{p_0}\,(p^k - p_0^k)\right)\cdot\eta^2$$

Simplified fit



χ^2 after simplified fit approach and after default fit.



Fitted cross sections at $Q^2 = 8000 GeV, x_{Bj} = 0.25$ after simplified and default fits

Results

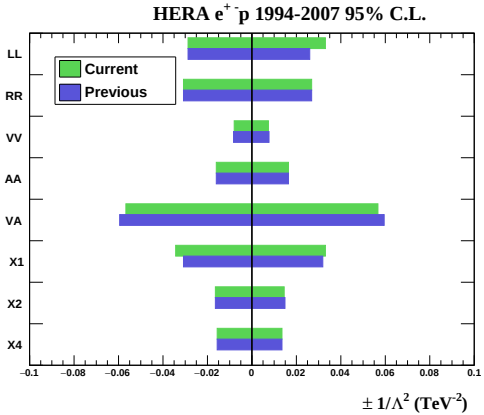
Expected limits comparison

95% C.L. limits (TeV)			$\eta^{Data}_{CI_{PDF}}$ (TeV^{-2})
Model	Λ^-	Λ^+	
LL	5.9	5.5	0.302
RR	5.7	6.1	0.334
VV	11.2	11.6	0.040
AA	7.9	7.8	0.213
VA	4.2	4.2	0.664
X1	5.4	5.5	0.493
X2	7.8	8.3	0.086
X4	8.0	8.6	-0.023

Current research.

95% C.L. limits (TeV)			$\eta^{Data}_{CI_{PDF}}$ (TeV^{-2})
Model	Λ^-	Λ^+	
LL	5.9	6.2	0.308
RR	5.7	6.1	0.341
VV	11.0	11.4	0.043
AA	7.9	7.8	0.324
VA	4.1	4.1	0.679
X1	5.7	5.6	0.680
X2	7.8	8.2	0.091
X4	8.0	8.6	-0.026

Previous research.



Results

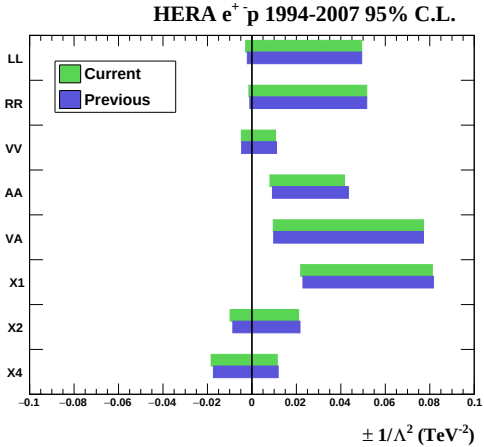
Measured limits comparison

95% C.L. limits (TeV)			$\eta^{Data}_{CI_{PDF}}$ (TeV^{-2})
Model	Λ^-	Λ^+	
LL	18.9	4.5	0.304
RR	27.2	4.4	0.337
VV	14.5	9.7	0.040
AA	-	4.9-11.1	0.314
VA	-	3.6-10.2	0.664
X1	-	3.51-6.75	0.667
X2	10.1	6.9	0.086
X4	7.38	9.36	-0.029

Current research.

95% C.L. limits (TeV)			$\eta^{Data}_{CI_{PDF}}$ (TeV^{-2})
Model	Λ^-	Λ^+	
LL	22.0	4.5	0.308
RR	32.9	4.4	0.341
VV	14.7	9.5	0.043
AA	-	4.8-10.4	0.324
VA	-	3.6-10.1	0.679
X1	-	3.5-6.6	0.680
X2	10.8	6.8	0.091
X4	7.6	9.2	-0.026

Previous research.

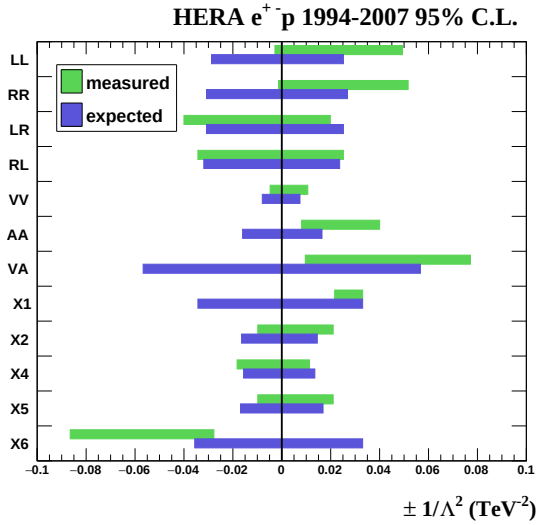


Results

HERA $e^{\pm}p$ 1994-2007 data

Coupling structure		95% C.L. limits (TeV)				$\eta^{\text{Data}}_{\text{CI+PDF}}$
		Measured		Expected		
Model	$[\epsilon_{LL},\epsilon_{LR},\epsilon_{RL},\epsilon_{RR}]$	Λ^-	Λ^+	Λ^-	Λ^+	(TeV^{-2})
LL	[+1 , 0, 0, 0]	18.9	4.5	5.9	6.3	0.304
RR	[0 , 0, 0, +1]	27.2	4.4	5.7	6.1	0.337
LR	[0 , +1, 0, 0]	5.0	7.1	5.7	6.3	-0.086
RL	[0 , 0, +1, 0]	5.4	6.3	5.6	6.5	-0.027
VV	[+1 , +1, +1, +1]	14.5	9.7	11.2	11.6	0.040
AA	[+1 , −1, −1, +1]	-	5.0 - 11.1	7.9	7.8	0.314
VA	[+1 , −1, +1, −1]	-	3.6 - 10.2	4.2	4.2	0.678
X1	[+1 , −1, 0, 0]	-	5.5 - 6.8	5.4	5.5	0.666
X2	[+1 , 0, +1, 0]	10.1	6.9	7.8	8.3	0.086
X3	[+1 , 0, 0, +1]	24.4	6.3	-	-	0.160
X4	[0 , +1, +1, 0]	7.4	9.36	8.0	8.6	-0.030
X5	[0 , +1, 0, +1]	10.1	6.9	7.7	7.7	0.080
X6	[0 , 0, +1, −1]	3.4 - 6.0	-	5.3	5.5	-0.765

Results



Measured and expected limits for genereal contact interactions.

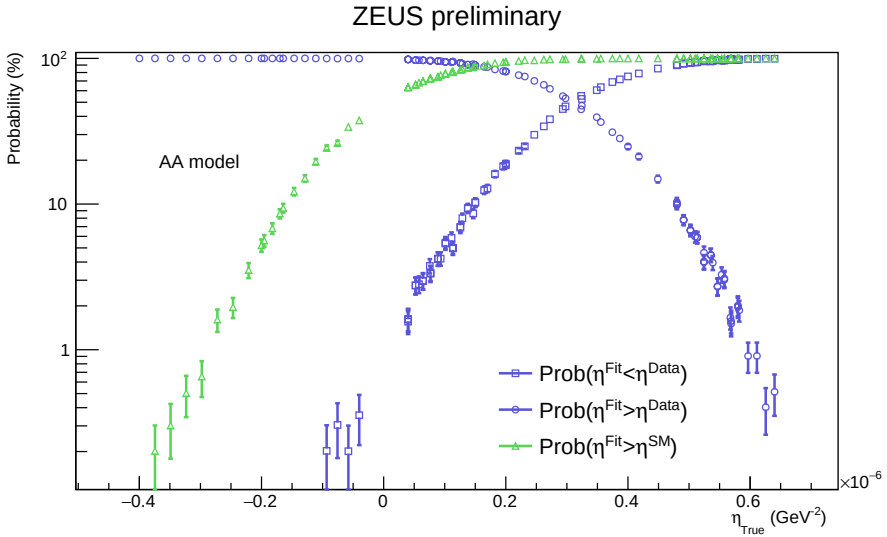
ZEUS preliminary

HERA $e^{\pm}p$ 1994-2007 data

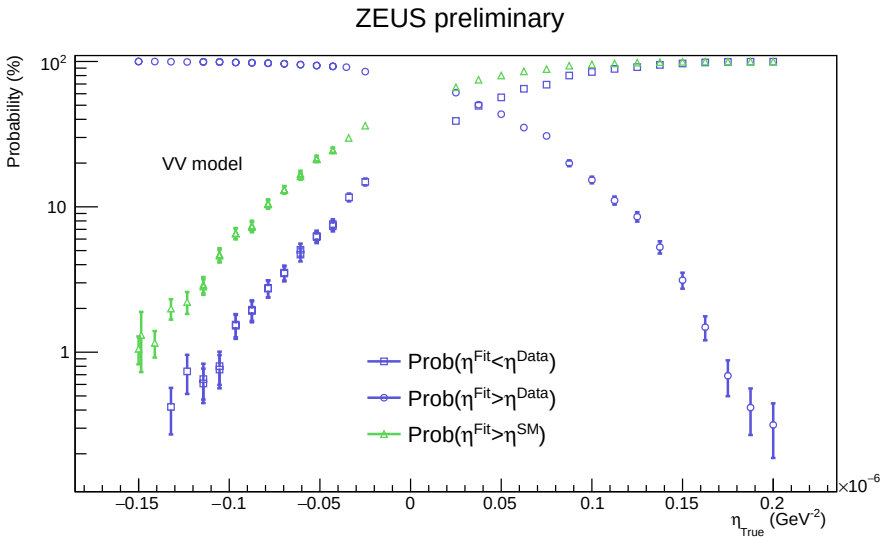
Model	Coupling Structure	M_{LQ}/λ_{LQ} (TeV) 95% C.L. limit	
		Measured	Expected
S_0^L	$a_{LL}^{eu} = +\frac{1}{2}$	0.95	1.26
S_0^R	$a_{RR}^{eu} = +\frac{1}{2}$	4.68	0.96
$\tilde{S}_0^R$	$a_{RR}^{ed} = +\frac{1}{2}$	0.39	1.83
$S_{1/2}^L$	$a_{LR}^{eu} = -\frac{1}{2}$	1.02	0.99
$S_{1/2}^R$	$a_{RL}^{ed} = a_{RL}^{eu} = -\frac{1}{2}$	0.94	0.87
$\tilde{S}_{1/2}^L$	$a_{LR}^{ed} = -\frac{1}{2}$	-	-
S_1^L	$a_{LL}^{ed} = +1,\ a_{LL}^{eu} = +\frac{1}{2}$	-	1.75
V_0	$a_{LL}^{ed} = a_{RR}^{ed} = -1$	1.67	2.41
V_0^L	$a_{LL}^{ed} = -1$	1.50	2.22
V_0^R	$a_{RR}^{ed} = -1$	-	-
$\tilde{V}_0^R$	$a_{RR}^{eu} = -1$	-	-
$V_{1/2}^L$	$a_{LR}^{ed} = +1$	-	-
$V_{1/2}^R$	$a_{RL}^{ed} = a_{RL}^{eu} = +1$	-	-
$\tilde{V}_{1/2}^L$	$a_{LR}^{eu} = +1$	-	-
V_1^L	$a_{LL}^{ed} = -1,\ a_{LL}^{eu} = -2$	-	-

Limits on M_{LQ}/λ_{LQ} relation for leptoquarks.

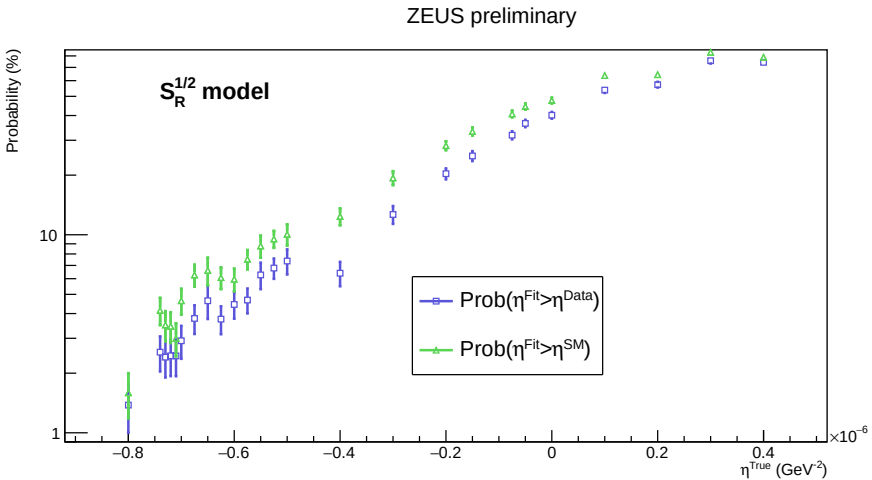
Preliminary plots



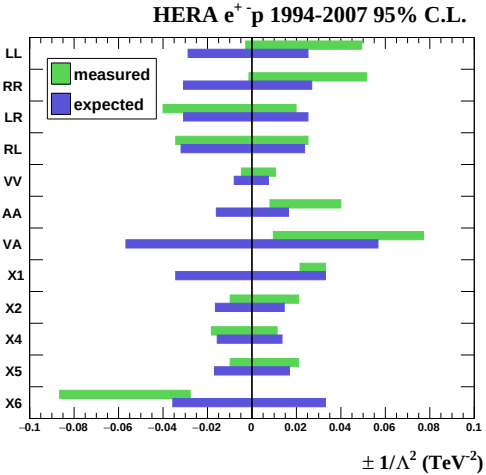
Preliminary plots



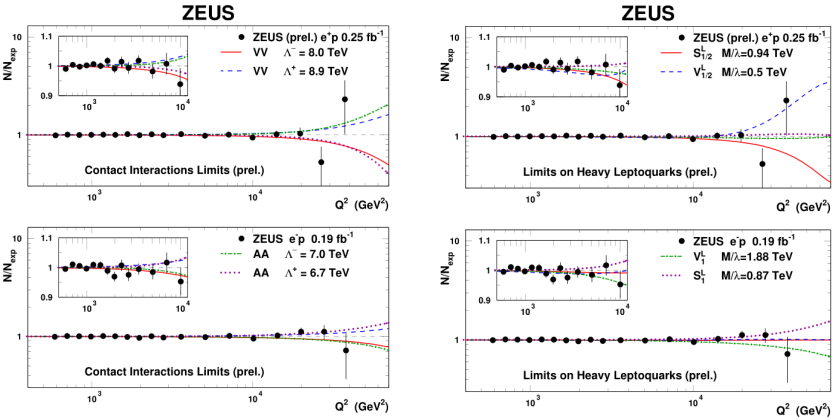
Preliminary plots



Preliminary plots



Preliminary plots



Combined HERA $e^{\pm}p$ and e$-p$ NC DIS data compared to the 95% C.L. exclusion limits. **example**!