Search for Contact Interactions (Status report)

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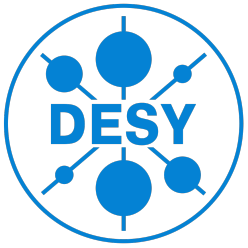
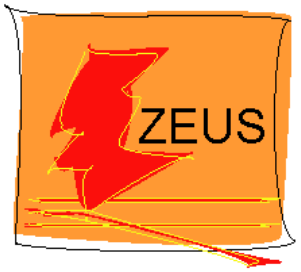


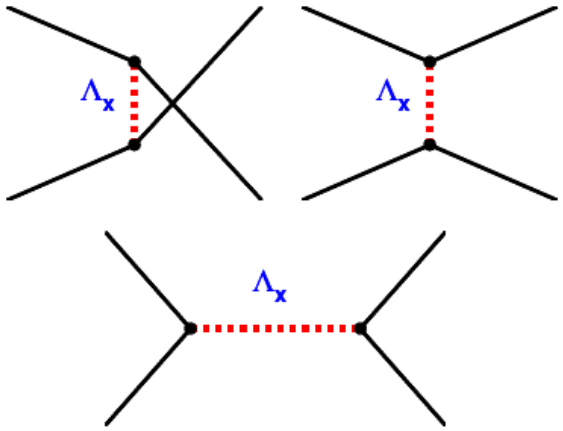


Content:

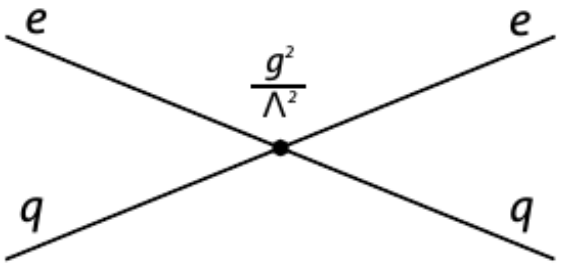
- Contact Interactions
- Migration from HERAfitter to xFitter
- Results for General CI models
- Comparison of results
- Cls approach
- Further steps

Contact Interaction

An investigation of possible effects due to the virtual exchange allows to search for evidence of new particles with mass much higher than the center of mass energy.



$\Lambda_x \gg \sqrt{s}$



$$\mathcal{L}_{\mathrm{CI}} = \sum_{\substack{k,j=L,R \\ q=u,d,s,c,b}} \eta_{kj}^{eq} (\bar{e}_k \gamma^\mu e_k)(\bar{q}_j \gamma_\mu q_j)$$

NC cross section:

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

CC cross section:

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

Contact Interaction

Combined QCD + CI Fit (PDF fit together with CI parameters fit):

In HERAPDF2.0 appoach:

$$xg(x) = A_g x^{B_g}(1-x)^{C_g} - A'_g x^{B'_g}(1-x)^{C'_g}$$
$$xu_v(x) = A_{u_v} x^{u_v}(1-x)^{C_{u_v}}(1+E_{u_v}x^2)$$
$$xd_v(x) = A_{d_v} x^{B_{d_v}}(1-x)^{C_{d_v}}$$
$$x\bar{U}(x) = A_{\bar{U}} x^{B_{\bar{U}}}(1-x)^{C_{\bar{U}}}(1+D_{\bar{U}}x)$$
$$x\bar{D}(x) = A_{\bar{D}} x^{B_{\bar{D}}}(1-x)^{C_{\bar{D}}}$$

$$\sigma_{NLO}^{SM+CI} = \sigma_{NLO}^{SM} \frac{\sigma_{LOEW}^{SM+CI}}{\sigma_{LOEW}^{SM}}$$

Reason for the simultaneous fit procedure:

- BSM signal in the data could affect the PDF fit and result in biased PDFs
- This cannot be avoided for the analysis of HERA data by using another available PDF set
- Use of the biased PDFs in the BSM analysis would result in overestimated limits.

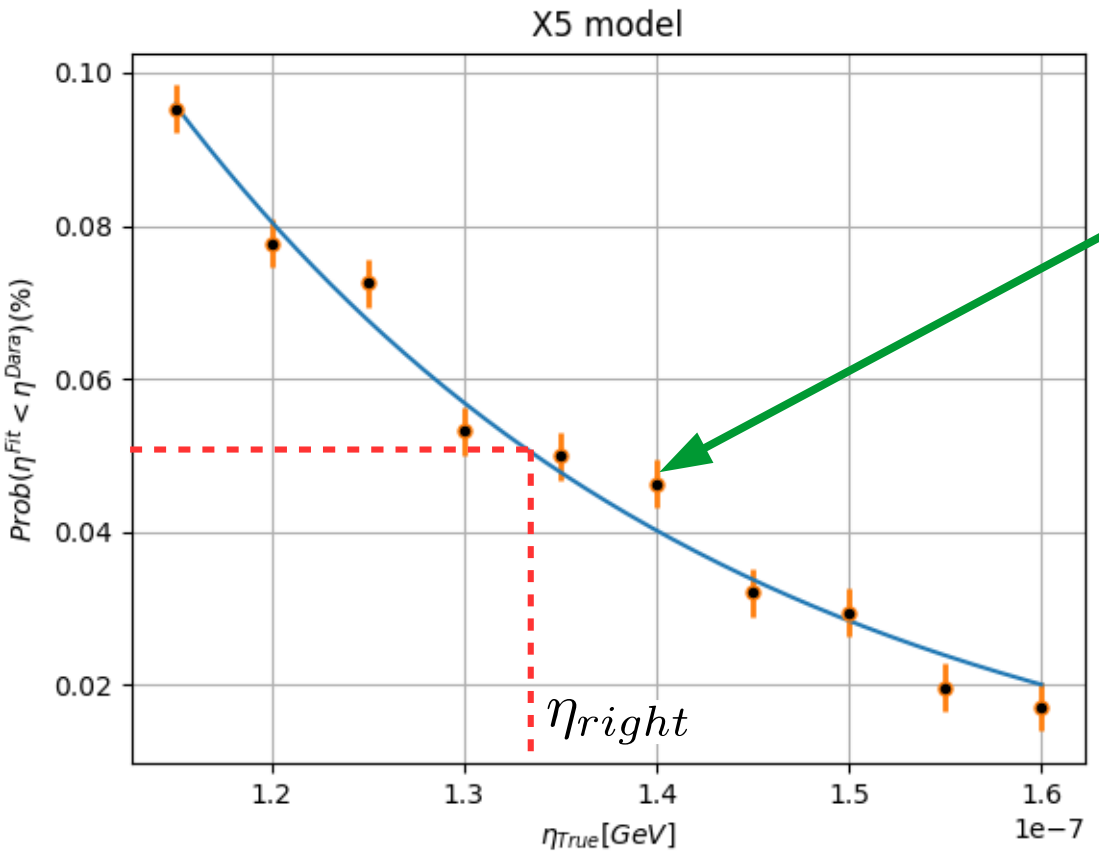
QCD + CI fit → $\eta = \pm \frac{g_{CI}^2}{\Lambda^2}$

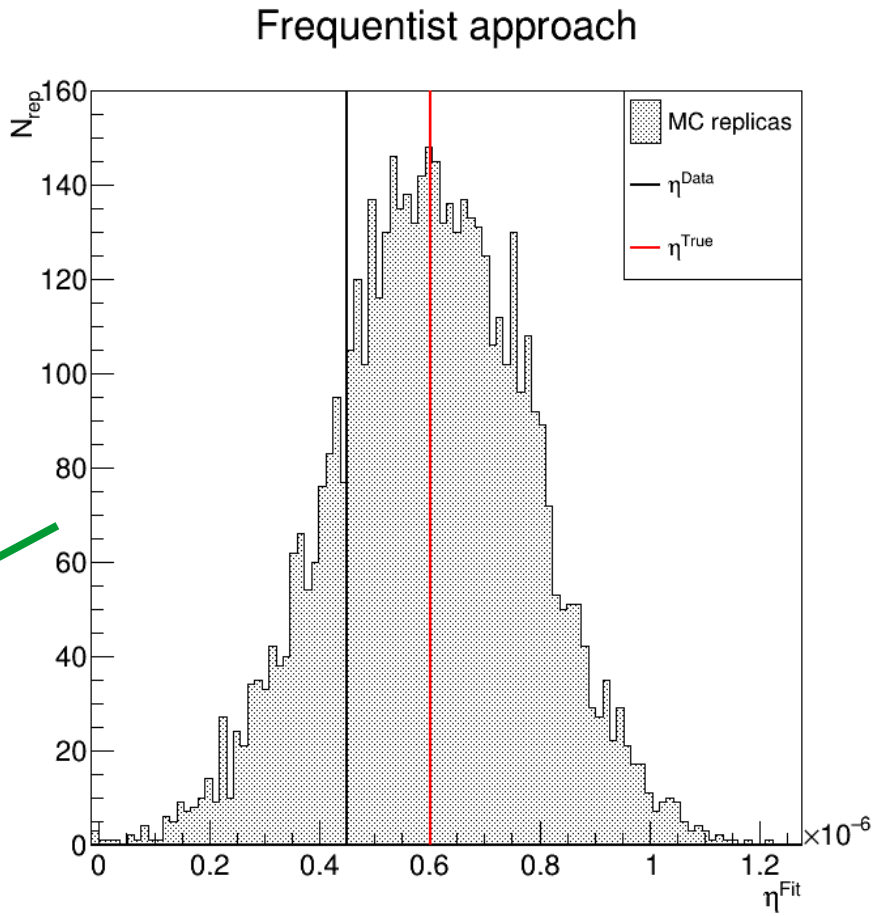
Fitting procedure

Data → Fit (free η + PDFs) → η^{Data}

Replicas ($\eta = \eta^{true}$):

Replica → Fit (free η + PDFs) → η^{Fit}





$$\eta = \pm \frac{g_{CI}^2}{\Lambda^2}$$

Migration from HERAfitter to xFitter

To migrate to xFitter framework:

- Simplified fit algorithm were implemented
- C.I. models were implemented
- MC replicas was fixed
- Errors treatment in χ^2 for MC replicas was corrected

$$\chi^2_{MC} = \frac{\sum_i \left[m^i + \sum_j \gamma^i_j m^i s_j - \mu^i_{0,MC} \right]^2}{\left(\delta^2_{i,stat} + \delta^2_{i,uncor}\right)\left(\mu^i_{0,data}\right)^2} + \sum_j s^2_j$$

m^i - theory predictions,

μ^i - cross section from data or MC replicas

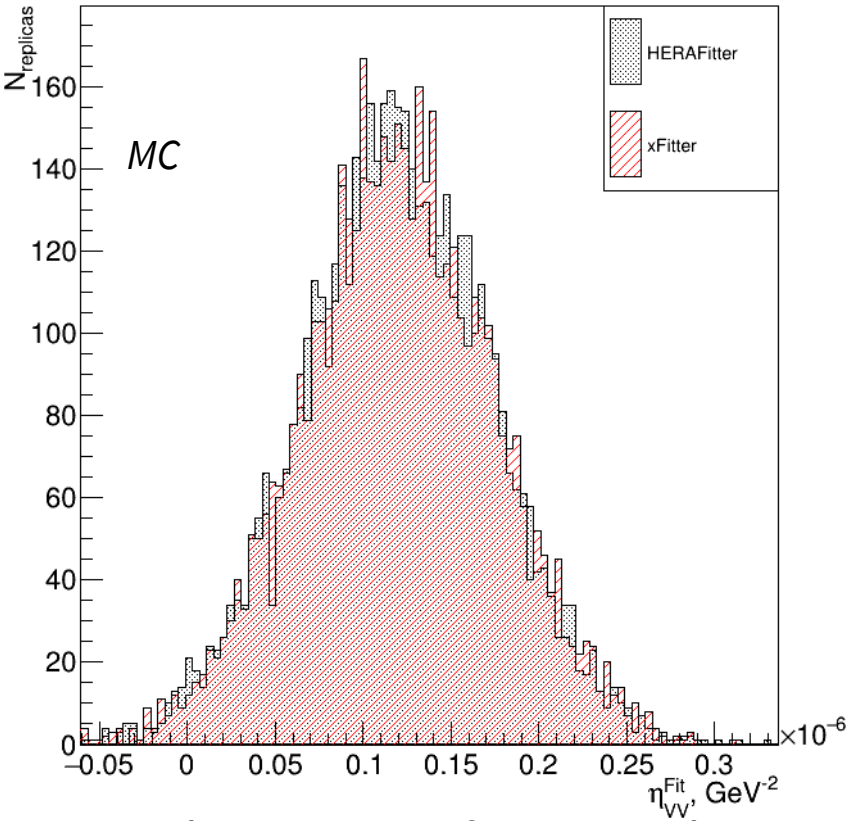
Default xFitter:

$$\mu^i = m^i_0 + \sqrt{\delta^2_{i,stat} + \delta^2_{i,uncor}} \cdot \mu^i_0 \cdot r_i + \sum_j \gamma^i_j \cdot \mu^i_0 \cdot b_j$$

Our analysis:

$$\mu^i = \left[m^i_0 + \sqrt{\delta^2_{i,stat} + \delta^2_{i,uncor}} \cdot \mu^i_0 \cdot r_i \right] \cdot \left(1 + \sum_j \gamma^i_j \cdot r_j \right)$$

$$\eta^{True}_{VV} = 0.120 \times 10^{-6} [GeV^{-2}]$$

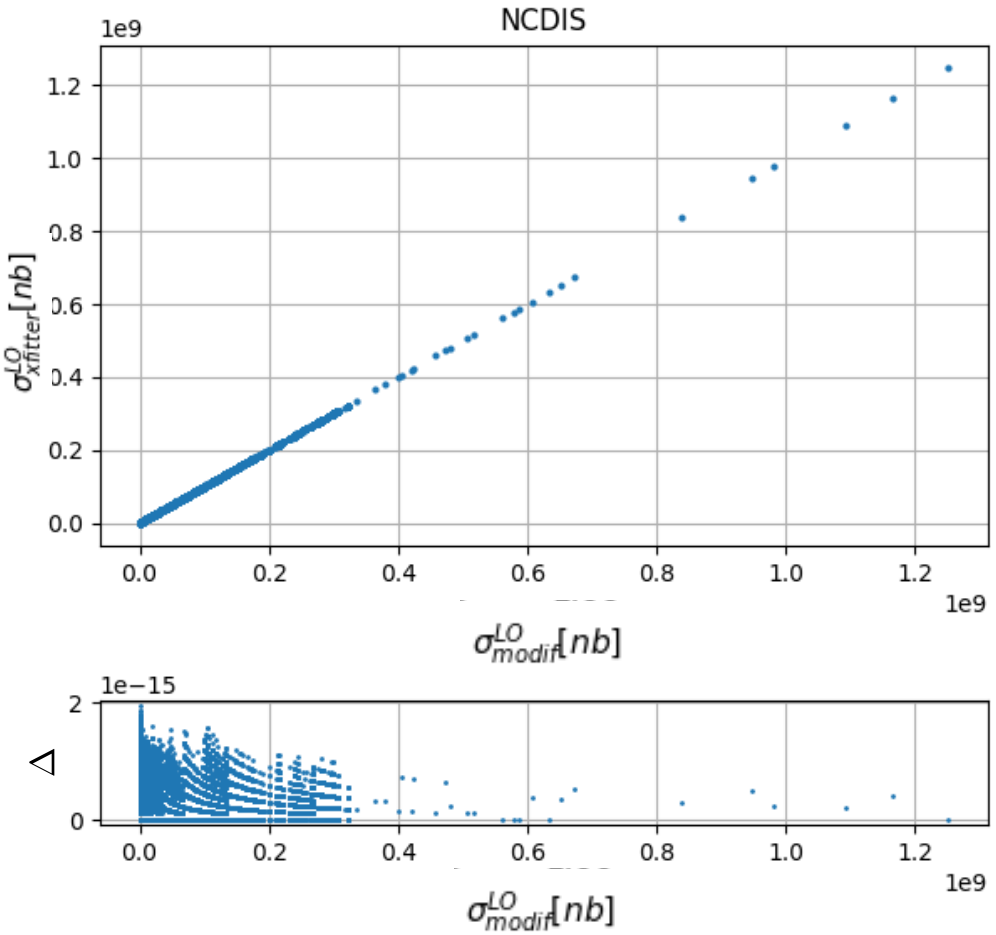


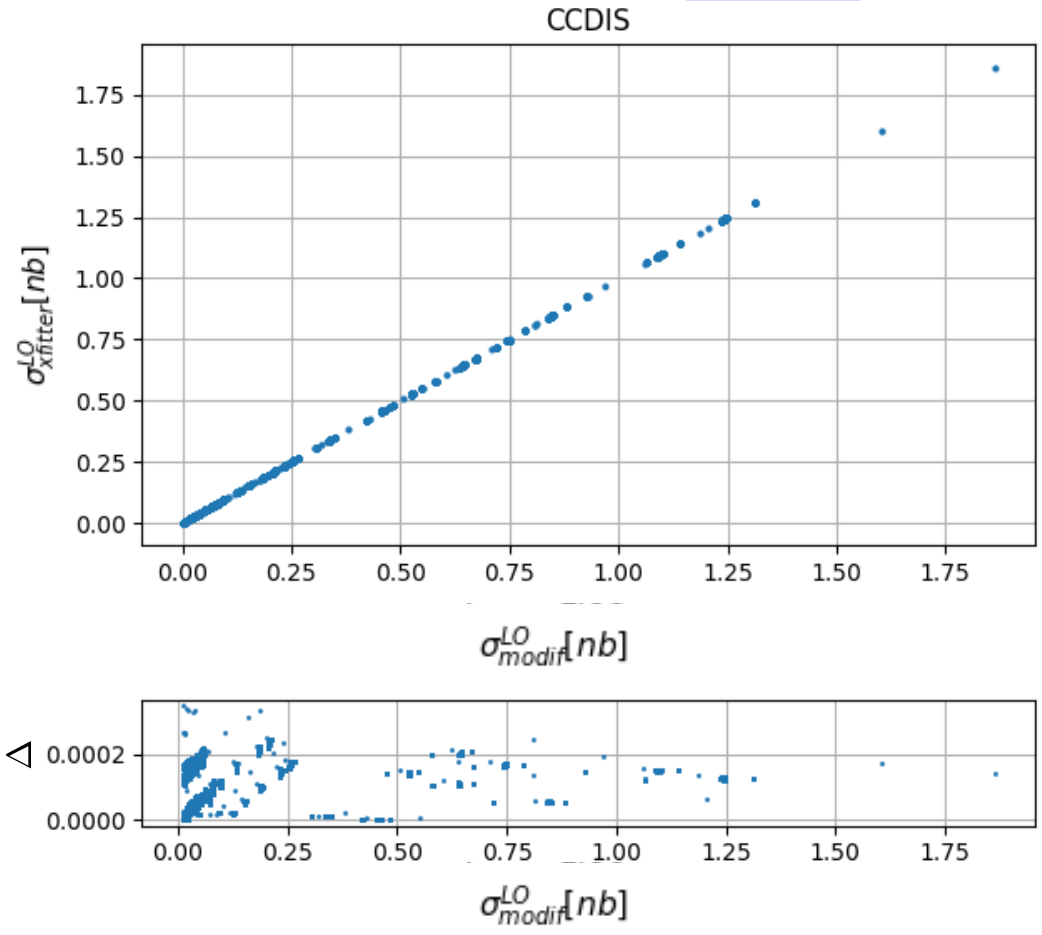
Good agreement of Monte Carlo replicas for HERAfitter and xFitter

Migration from HERAfitter to xFitter

To test our CI implementation we compared xFitter default σ^{LO} and our subroutine σ^{LO}

$$\sigma_{NLO}^{SM+CI} = \sigma_{NLO}^{SM} \frac{\sigma_{LOEW}^{SM+CI}}{\sigma_{LOEW}^{SM}}$$





- NC Δ < 1e-13 %
- CC Δ < 3e-2 %

Good agreement for NC and CC

$$\Delta = (\sigma^{LO}_{xfitter} - \sigma^{LO}_{modify})/\sigma^{LO}_{modify}$$

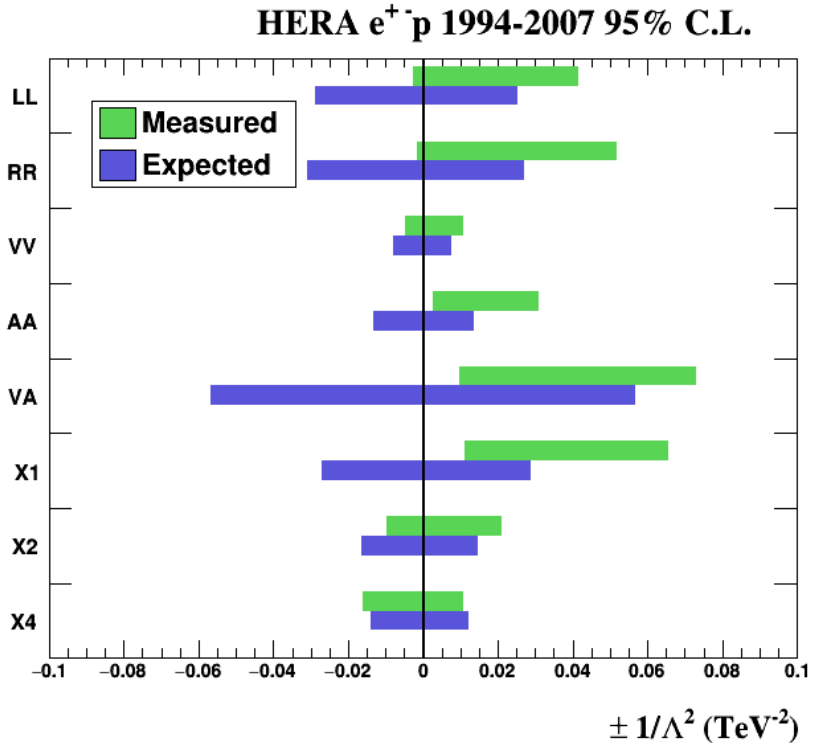
Results for General CI models (after the migration to the xFitter)

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]	19.0	4.9	5.9	6.3	0.302
RR	[0, 0, 0, 0]	26.1	4.4	5.7	6.1	0.334
VV	[+1, +1, +1, +1]	14.5	9.7	11.2	11.6	0.040
AA	[+1, −1, −1, +1]	-	5.7 - 19.1	8.7	8.6	0.213
VA	[+1, −1, +1, −1]	-	3.7 - 10.2	4.2	4.2	0.664
X1	[+1, −1, 0, 0]	-	3.9 - 9.5	6.1	5.9	0.493
X2	[+1, 0, +1, 0]	10.1	6.9	7.8	8.3	0.086
X4	[0, +1, +1, 0]	7.9	9.6	8.5	9.0	-0.023
X5	[0, +1, 0, +1]	10.1	7.0	-	-	0.077
X6	[0, 0, +1, −1]	3.7 - 8.2	-	-	-	-0.565

$$\eta = \pm\frac{g^2_{CI}}{\Lambda^2}$$

95% C.L. measured and expected limits on the compositeness scale, Λ for the considered general contact-interactions models.



Comparison of the expected limits

Frequentist approach previous 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

Frequentist approach (current research):

95% C.L. limits (TeV)			$\eta^{Data}_{CI_{PDF}}$ (TeV^{-2})
Model	Λ^-	Λ^+	
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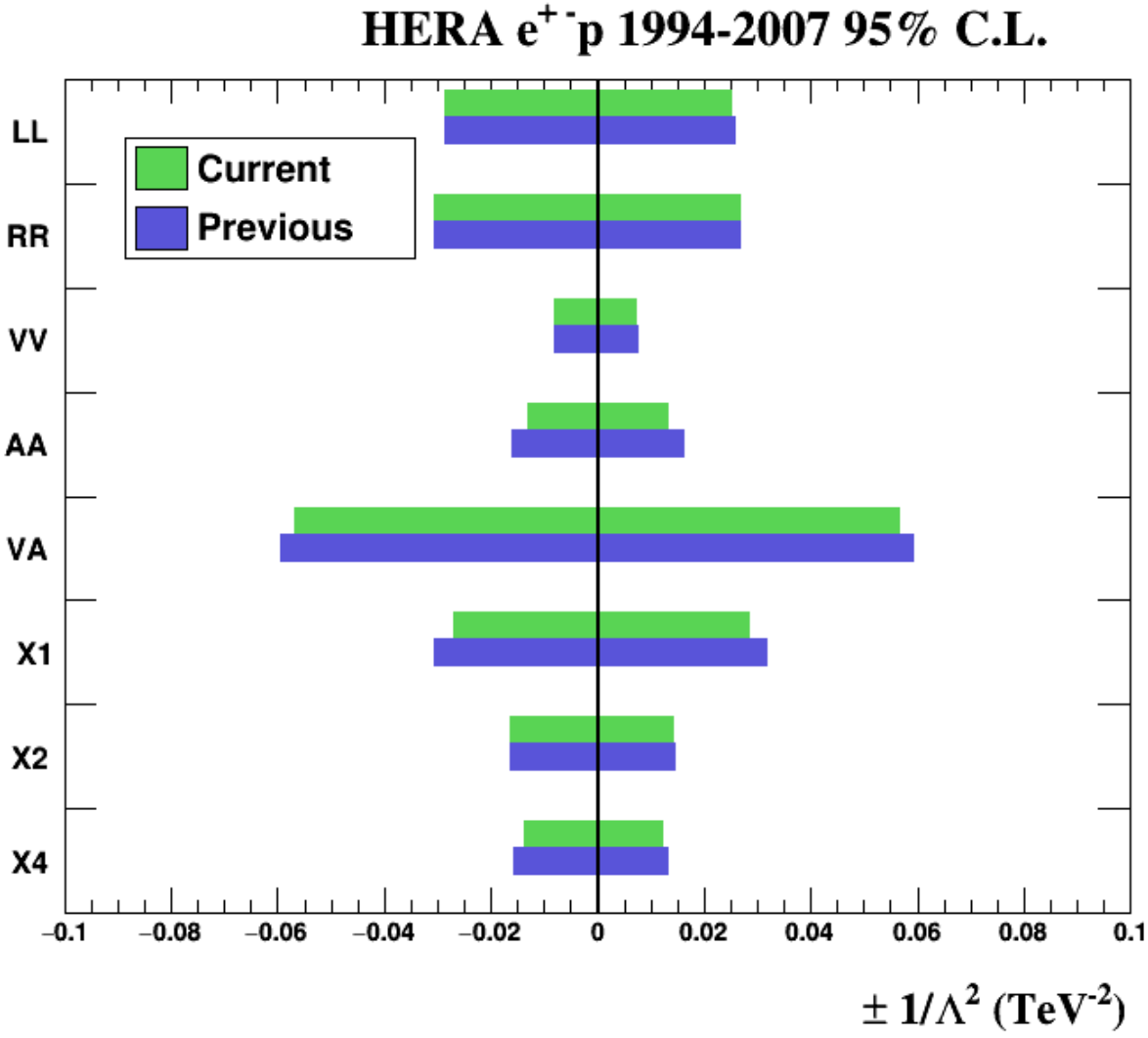

Good agreement of the expected limits.

Comparison of the measured limits

Frequentist approach (previous 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

Frequentist approach (current research):

95% C.L. limits (TeV)			$\eta^{Data}_{CI_{PDF}}$ (TeV^{-2})
Model	Λ^-	Λ^+	
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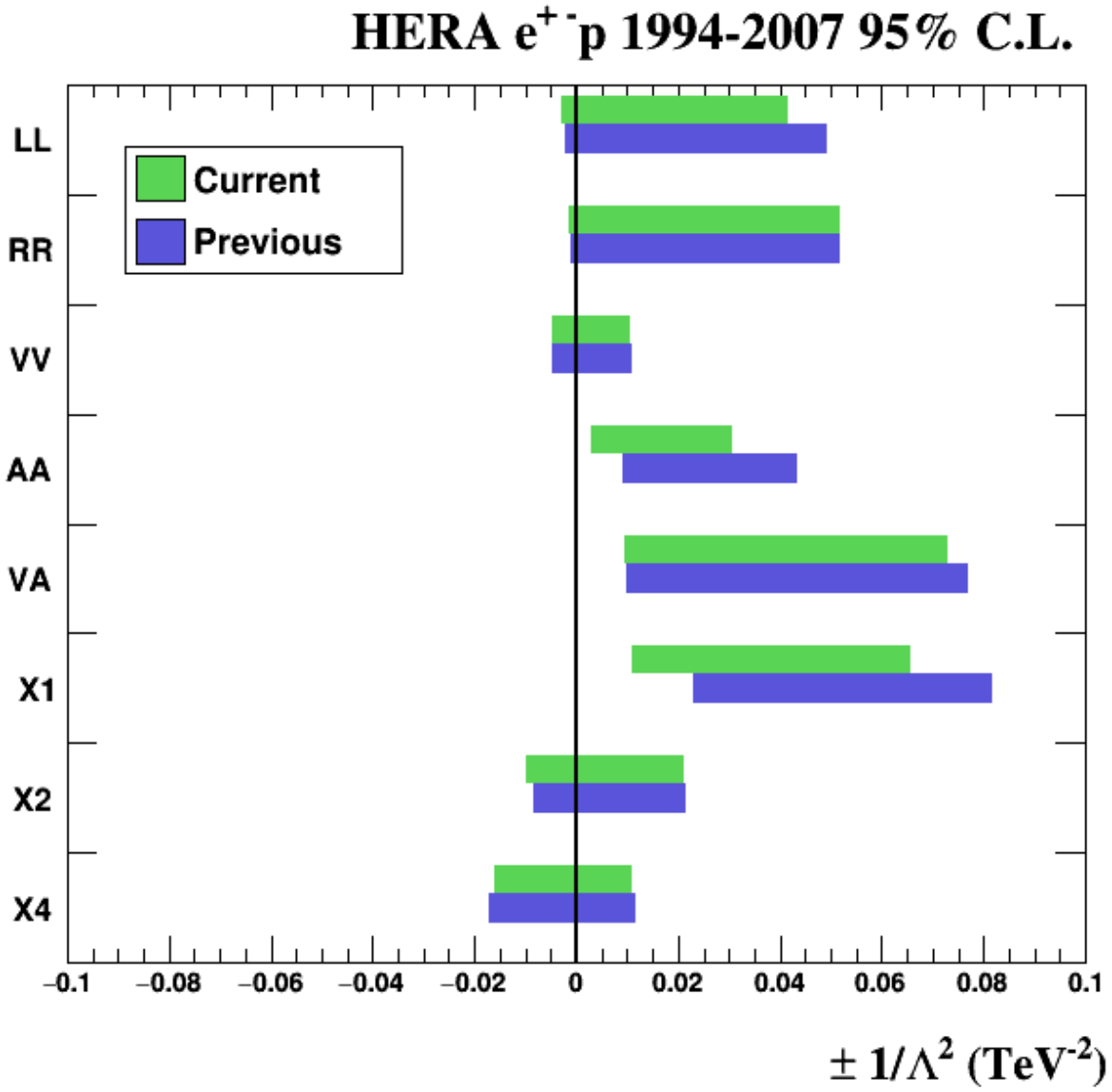


Difference between new and previous measured limits are mostly due to the difference in η^{data}

Cls approach for cross check

Data → Fit (η=0, $\Delta\eta$=0) → L_b^{data}

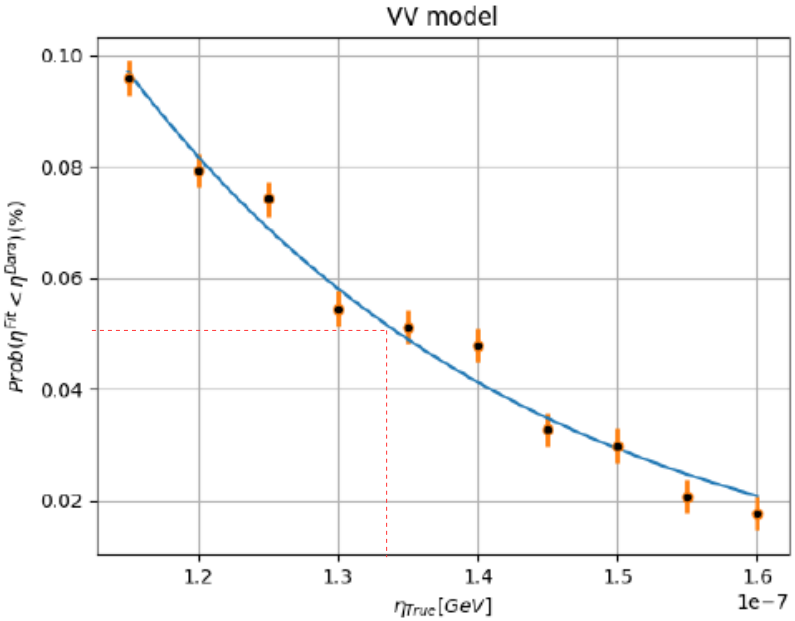
Replicas ($\eta = \eta^{true}$):

Data → Fit ($\eta = \eta^{true}$, $\Delta\eta$=0) → L_{s+b}^{data}

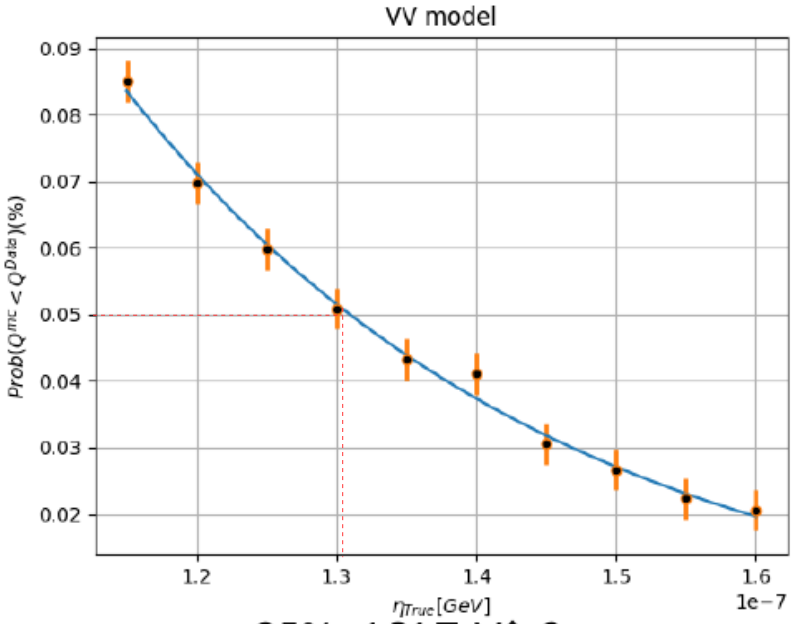
Replica ($\eta = \eta^{true}$) → Fit (η= 0 ,$\Delta\eta$=0) → L_b

Replica ($\eta = \eta^{true}$) → Fit ($\eta = \eta^{true}$, $\Delta\eta$=0) → L_{s+b}

$$Q = L_{s+b}/L_b$$
$$P(Q < Q_{data})$$
$$\eta = \eta_{true}$$



95% : 1.34 TeV^-2
\Lambda+ : 9.7 TeV
Old approach



95% : 1.31 TeV^-2
\Lambda+ : 9.8 TeV
Cls approach

- Good agreement
- Can be used for cross check of measured limits

Futher steps

- Calculate all general contact interaction models

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

- Calculate LQ models

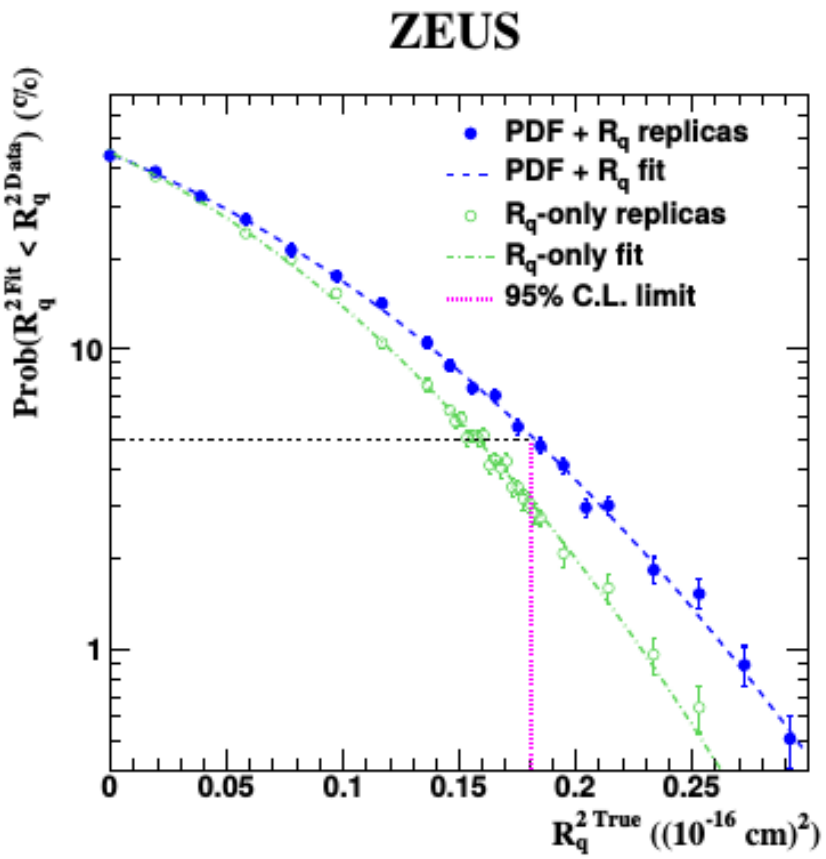
Model	a^{ed}_{LL}	a^{ed}_{LR}	a^{ed}_{RL}	a^{ed}_{RR}	a^{eu}_{LL}	a^{eu}_{LR}	a^{eu}_{RL}	a^{eu}_{RR}
$S^L_\circ$					$+\frac{1}{2}$			
$S^R_\circ$								$+\frac{1}{2}$
$\tilde{S}_\circ$				$+\frac{1}{2}$				
$S^L_{1/2}$						$-\frac{1}{2}$		
$S^R_{1/2}$			$-\frac{1}{2}$				$-\frac{1}{2}$	
$\tilde{S}_{1/2}$		$-\frac{1}{2}$						
S_1	$+1$				$+\frac{1}{2}$			
$V^L_\circ$	-1							
$V^R_\circ$				-1				
$\tilde{V}_\circ$								-1
$V^L_{1/2}$		$+1$						
$V^R_{1/2}$			$+1$				$+1$	
$\tilde{V}_{1/2}$						$+1$		
V_1	-1				-2			

- limits already evaluated
- work in progress

Time constraints ~ 4 weeks

Possible set of preliminary plots

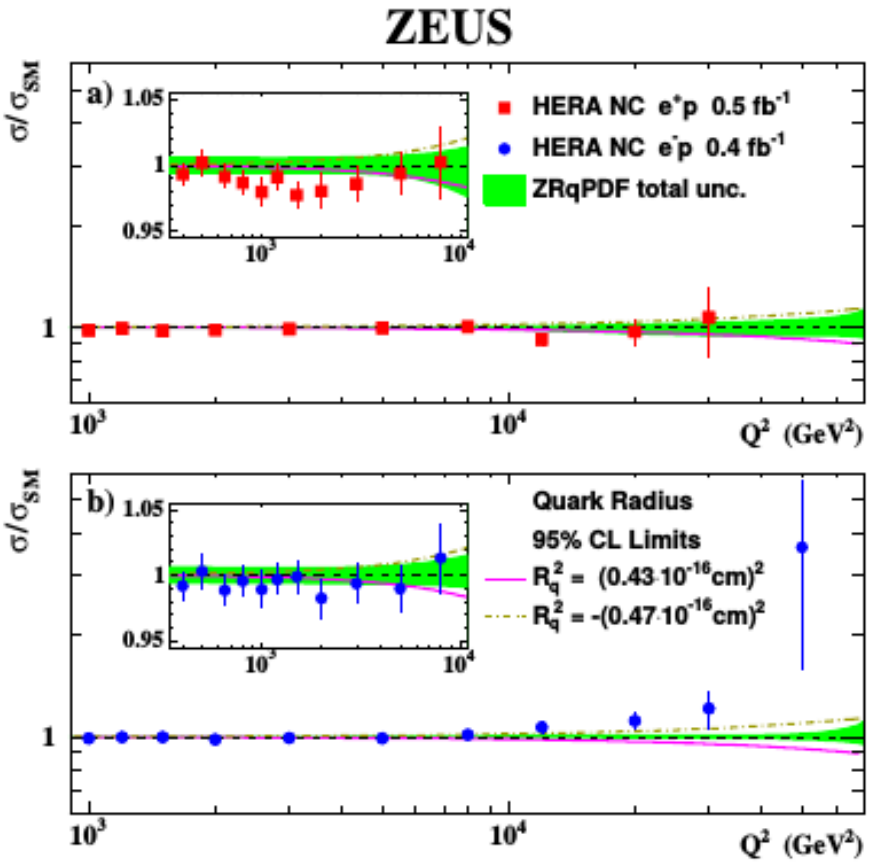
(Plots from ICHEP 2016)



The probability of obtaining η^{Fit} values smaller than that obtained for the actual data, η^{DATA} calculated from Monte Carlo replicas, as a function of the assumed value for the eta parameter $\eta^{True.}$

Possible set of preliminary plots

(Plots from ICHEP 2016)



Cross section deviations from the SM perditions allowed at 95% C.L. for electron-proton and positron NC DIS, as resulting from the analysis of HERA combined data in the Quark Radius Formfactor scenario

Summary

Already done:

- Comparison with old results (presented at ICHEP 2016) is completed
- Implemented all modifications to xFitter framework
  1) Simplified fit algorithm was implemented
  2) C.I. models was implemented
  3) CLs approach modifications
- Tested CLs approach (through the calculation of likelihood)

Futher steps:

- Switch calculations to the HTCondor
- Find 95% C.L. for 6 U-models
- Find 95% C.L. for 14 Leptoquarks models