Search for contact interactions in inclusive ep scattering at HERA

ICHEP2018 SEOUL

ZEUS DESY

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On behalf of ZEUS Collaboration

- Combined inclusive DIS data from HERA
- Beyond-the-Standard-Model analysis combined with PDFs fit
- Contact interactions and heavy leptoquarks search results

6 July 2017

HERA - world's only $e^{\pm}p$ collider

HERA operated during 1992 - 2007 with:

- ***e***± energy of 27.5 GeV;
- ***p*** energies of 920, 820, 575 and 460 GeV.

H1 and **ZEUS** - two general purpose collider experiments at HERA:

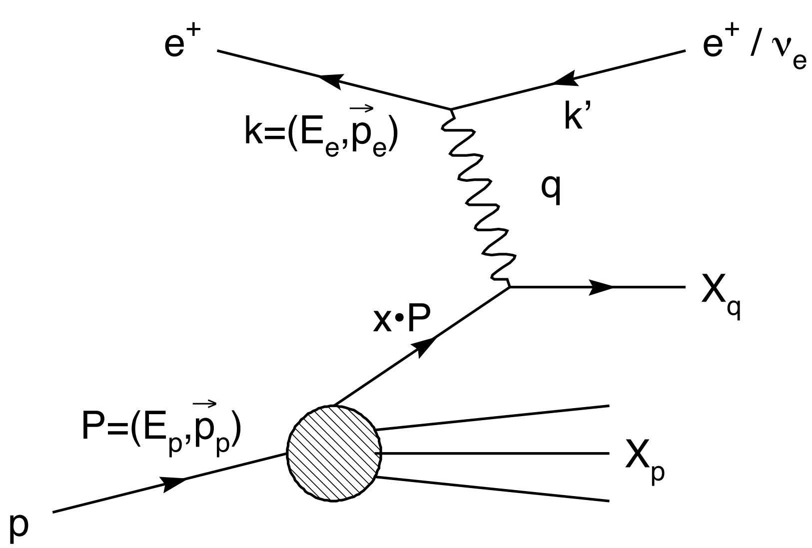
- **~0.5 fb^{-1}** of luminosity were recorded by each experiment.

Kinematics of the $e^{\pm}p$ collisions:

$$Q^2 = -(k - k')^2$$

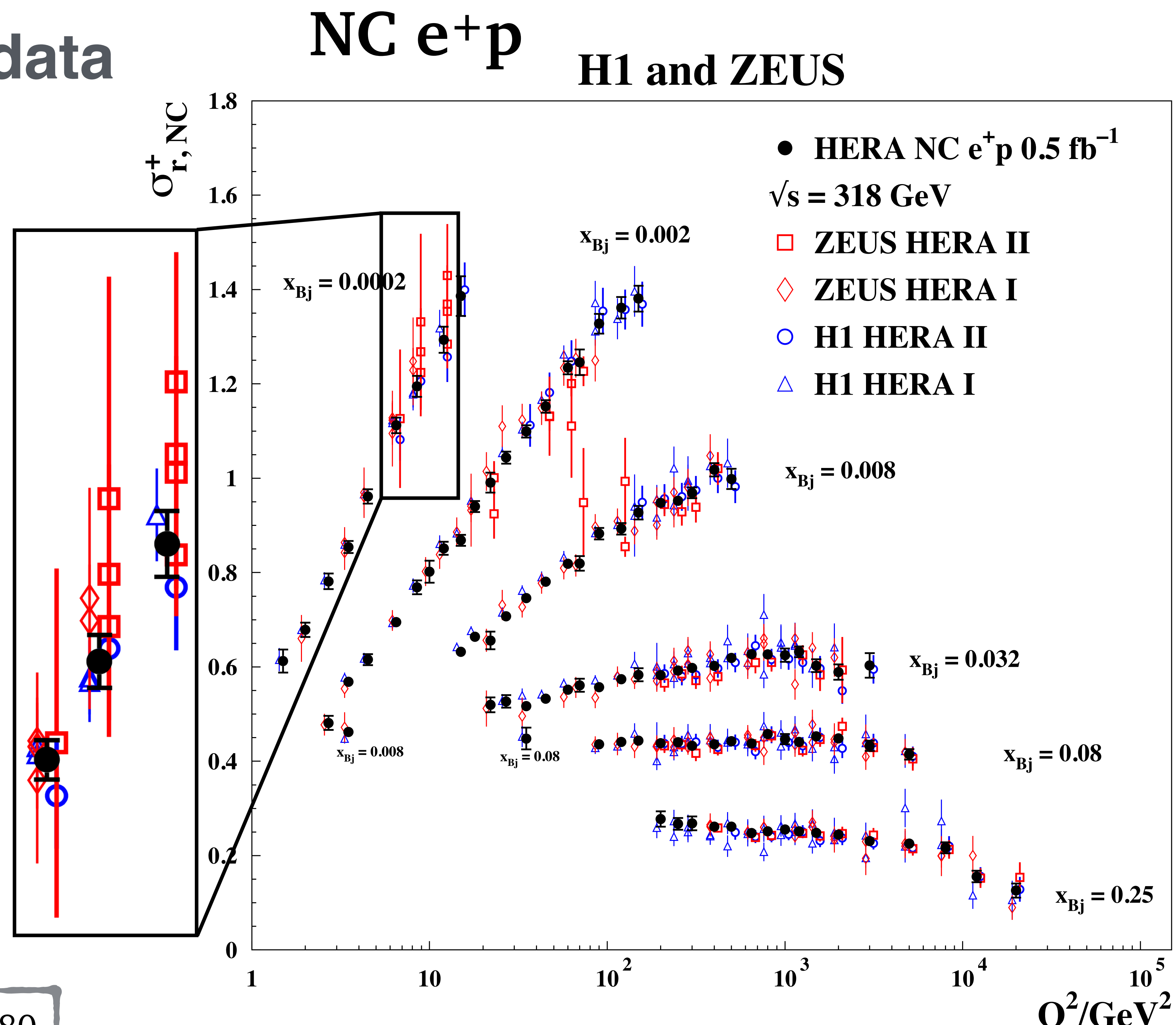
$$x_{Bj} = \frac{Q^2}{2P \cdot q}$$

$$y = \frac{P \cdot q}{P \cdot k}$$



HERA inclusive data combination

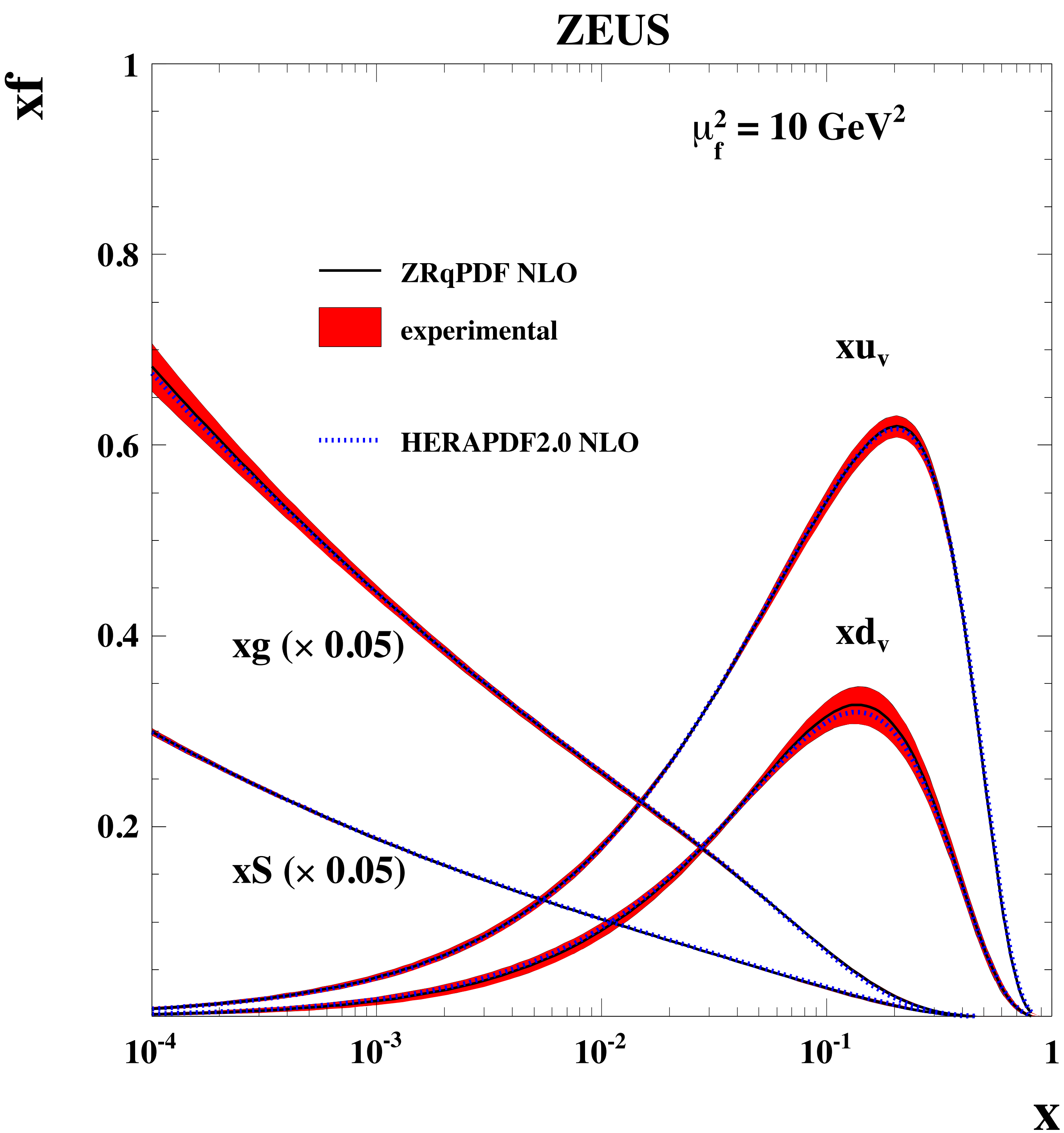
H1 + ZEUS data



- 2927 data point combined to 1307
- up to 8 data points combined to 1
- impressive improvement of precision due to:
  - increased statistics
  - better understanding of systematics
  - cross-calibration of the data from two experiments

Eur. Phys. J. **C75** (2015), No. 12, 580

QCD analysis of the combined DIS data



Parton **D**ensity **F**unctions

Parameterised at the starting scale of $Q^2_0 = 1.9$ GeV^2:

$$xg(x) = A_g x^{B_g} (1-x)^{C_g} - A'_g x^{B'_g} (1-x)^{C'_g}$$

$$xu_v(x) = A_{u_v} x^{B_{u_v}} (1-x)^{C_{u_v}} \left(1 + E_{u_v} x^2\right)$$

$$xd_v(x) = A_{d_v} x^{B_{d_v}} (1-x)^{C_{d_v}}$$

$$x\bar{U}(x) = A_{\bar{U}} x^{B_{\bar{U}}} (1-x)^{C_{\bar{U}}} \left(1 + D_{\bar{U}} x\right)$$

$$x\bar{D}(x) = A_{\bar{D}} x^{B_{\bar{D}}} (1-x)^{C_{\bar{D}}}$$

fixed or calculated by the sum-rules

set equal

Evolve to any $Q^2 > Q^2_0$ with DGLAP at NLO.

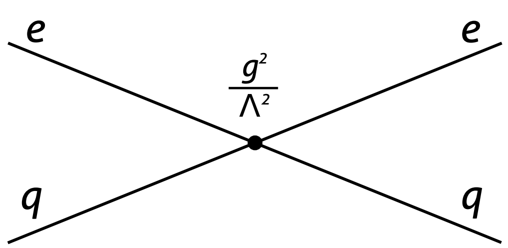
Obtained PDFs are referred to as **ZRqPDFs** and have a good agreement with the HERAPDF 2.0.

Phys. Lett. **B757** (2016), 468-472

General contact interactions

Low-energy effects due to physics at much higher energy scales can be described with the four-fermion contact interactions (CI). Vector contact interactions considered in the analysis provide additional terms to the Standard Model Lagrangian:

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



$$\eta^{eq}_{kj} = \epsilon^{eq}_{kj} \frac{g^2}{\Lambda^2}$$

$$\epsilon^{eq}_{kj} = \pm 1; 0$$

All up- or down-type quarks were assumed to have the same contact-interaction couplings:

$$\eta^{eu}_{kj} = \eta^{ec}_{kj} = \eta^{et}_{kt}$$

$$\eta^{ed}_{kj} = \eta^{es}_{kj} = \eta^{eb}_{kt}$$

Considered CI models:

Model	ϵ_{LL}	ϵ_{LR}	ϵ_{RL}	ϵ_{RR}
LL	+1			
RR				+1
LR		+1		
RL			+1	
VV	+1	+1	+1	+1
AA	+1	-1	-1	+1
VA	+1	-1	+1	-1
X1	+1	-1		
X2	+1		+1	
X3	+1			+1
X4		+1	+1	
X5		+1		+1
X6			+1	-1

Reason for the simultaneous fit procedure

➢ BSM signal in the data could affect the PDF fit and result in **biased PDFs**.

➢ Use of the **biased PDFs** in the BSM analysis would result in **overestimated limits**.

➢ This cannot be avoided for the analysis of HERA data by using another available PDF set, since all high-precision PDF fits include the DIS data from HERA (MMHT2014, NNPDF 3.0, etc.).

➢ The proper procedure for a BSM analysis of the HERA data - global **QCD analysis which includes a possible contribution from BSM** processes.

…and HERA data allows such analysis to be performed.

Limits setting with Monte Carlo replicas

Limits are derived in a classical (frequentist) approach using the technique of Monte Carlo replicas:

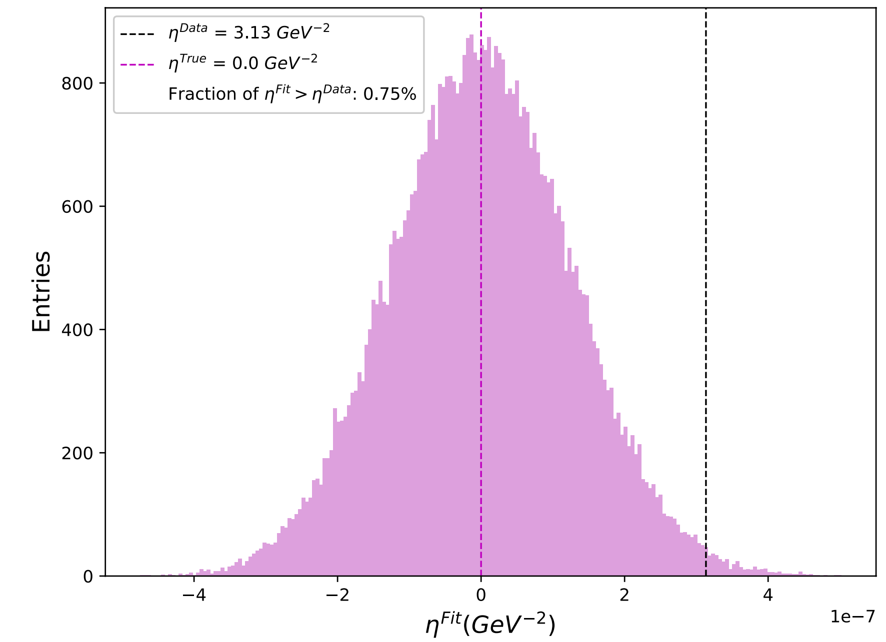
First, Monte Carlo replicas of the cross-section measurements for some value of η^{True} were calculated as:

$$\mu^i = \left[m_0^i + \sqrt{\delta_{i,stat}^2 + \delta_{i,uncor}^2} \cdot \mu_0^i \cdot r_i\right] \cdot \left(1 + \sum_j \gamma_j^i \cdot r_j\right)$$

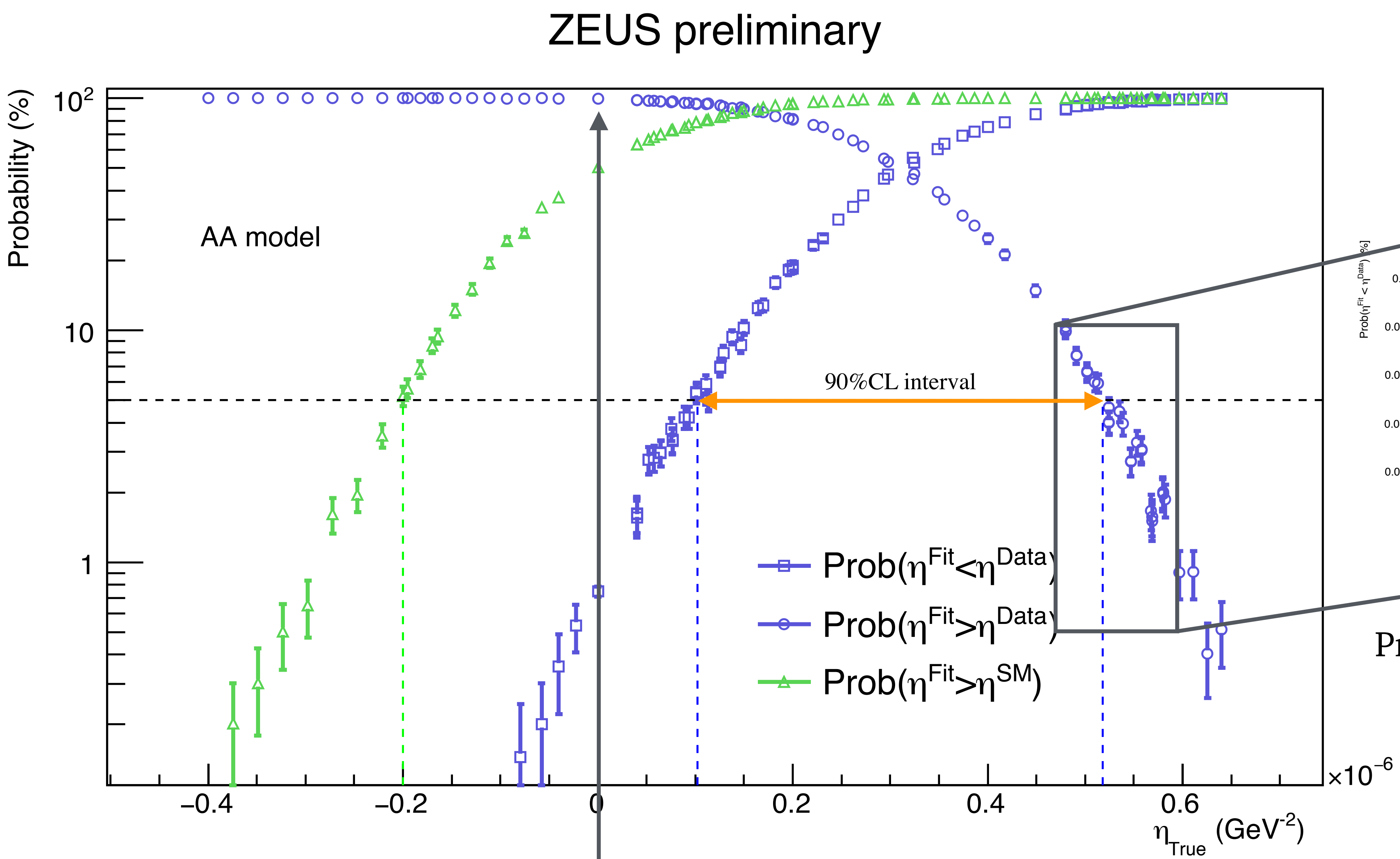
- m_0^i: Cross-section prediction from the ZRqPDF modified with η^{True}
- μ_0^i: Measured cross-section value
- γ_j^i: Correlated systematic uncertainties
- $\delta_{i,stat}$, $\delta_{i,uncor}$: Relative statistical and uncorrelated systematic uncertainties
- r_i, r_j: Random numbers from a normal distribution

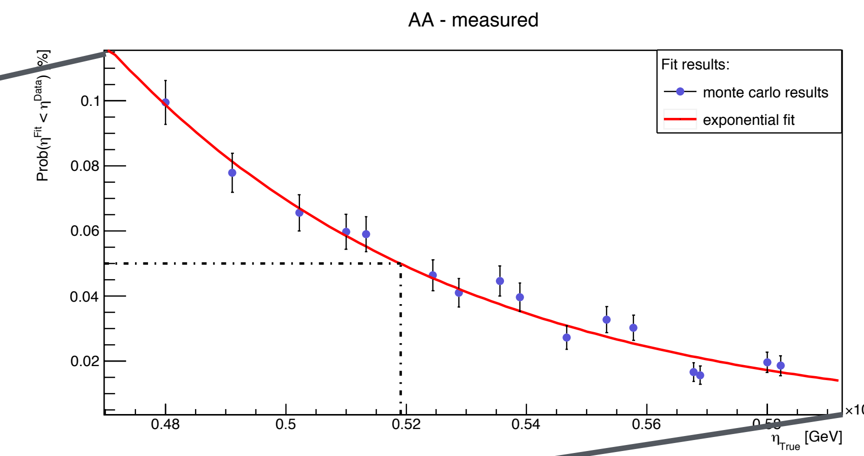
Next each Monte Carlo replica is fitted for the η^{Fit} parameter **simultaneously** with PDFs.

Lastly the fraction of η^{Fit} values less than η^{Data} obtained from the fit of data is evaluated and used further as $\mathrm{Prob}(\eta^{\mathrm{Fit}} < \eta^{\mathrm{Data}})$.



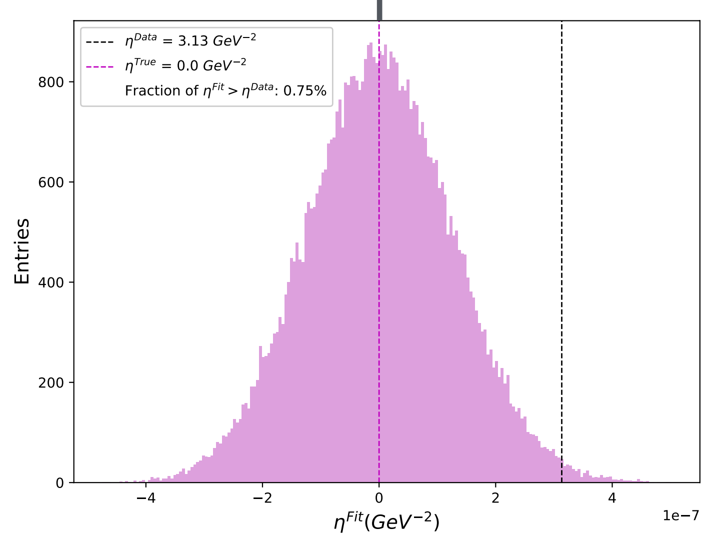
Limits setting with Monte Carlo replicas





Probabilities close to 5% fitted with:

$$f(x) = 5 \cdot e^{(x-A)\cdot B}$$



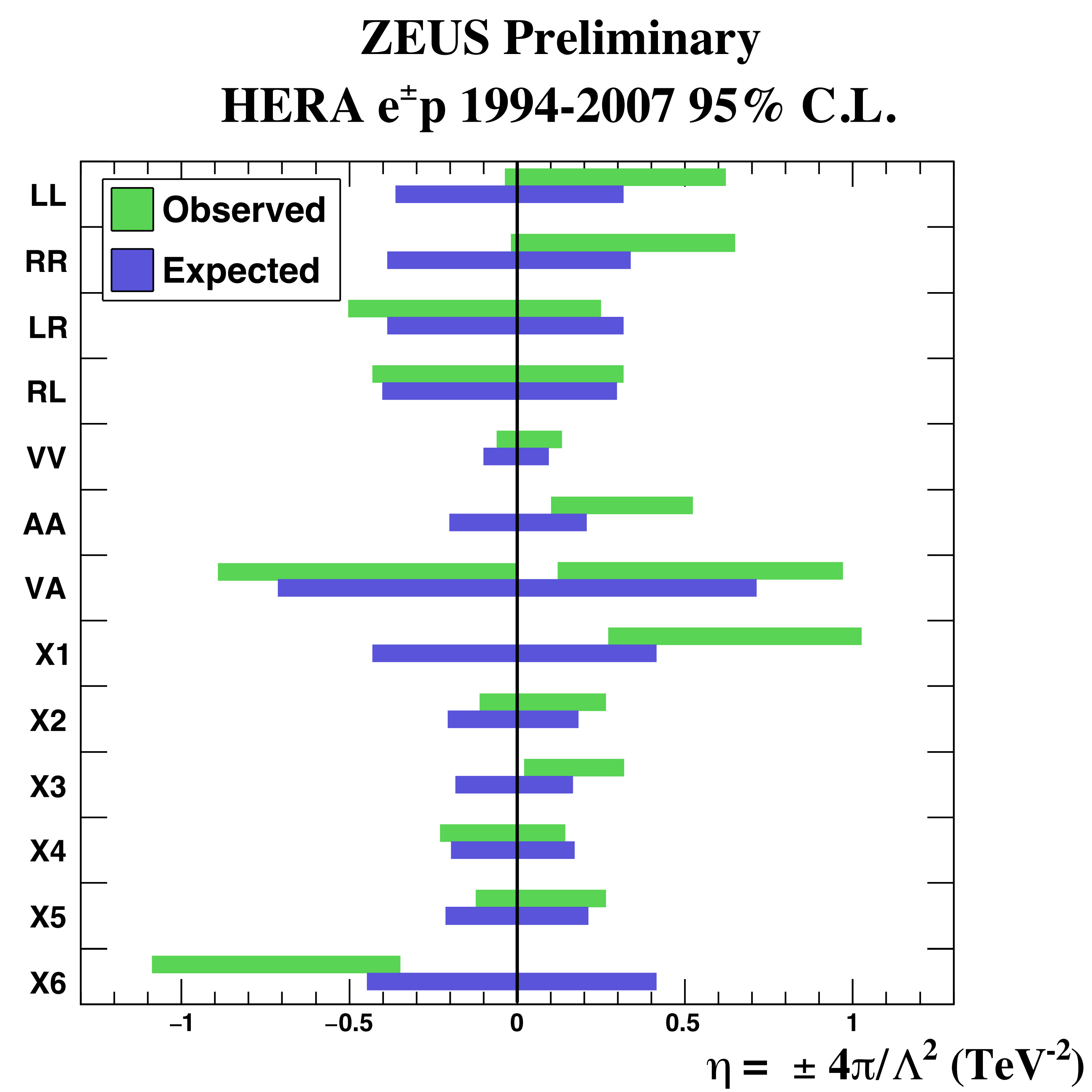
Procedure is repeated for different η^{True} and central 90% CL coupling interval is evaluated:

$0.10 \cdot 10^{-6}$ GeV^{-2} < η < $0.52 \cdot 10^{-6}$ GeV^{-2}

$\Lambda^+ < 11.1$ TeV $\Lambda^+ > 5.0$ TeV

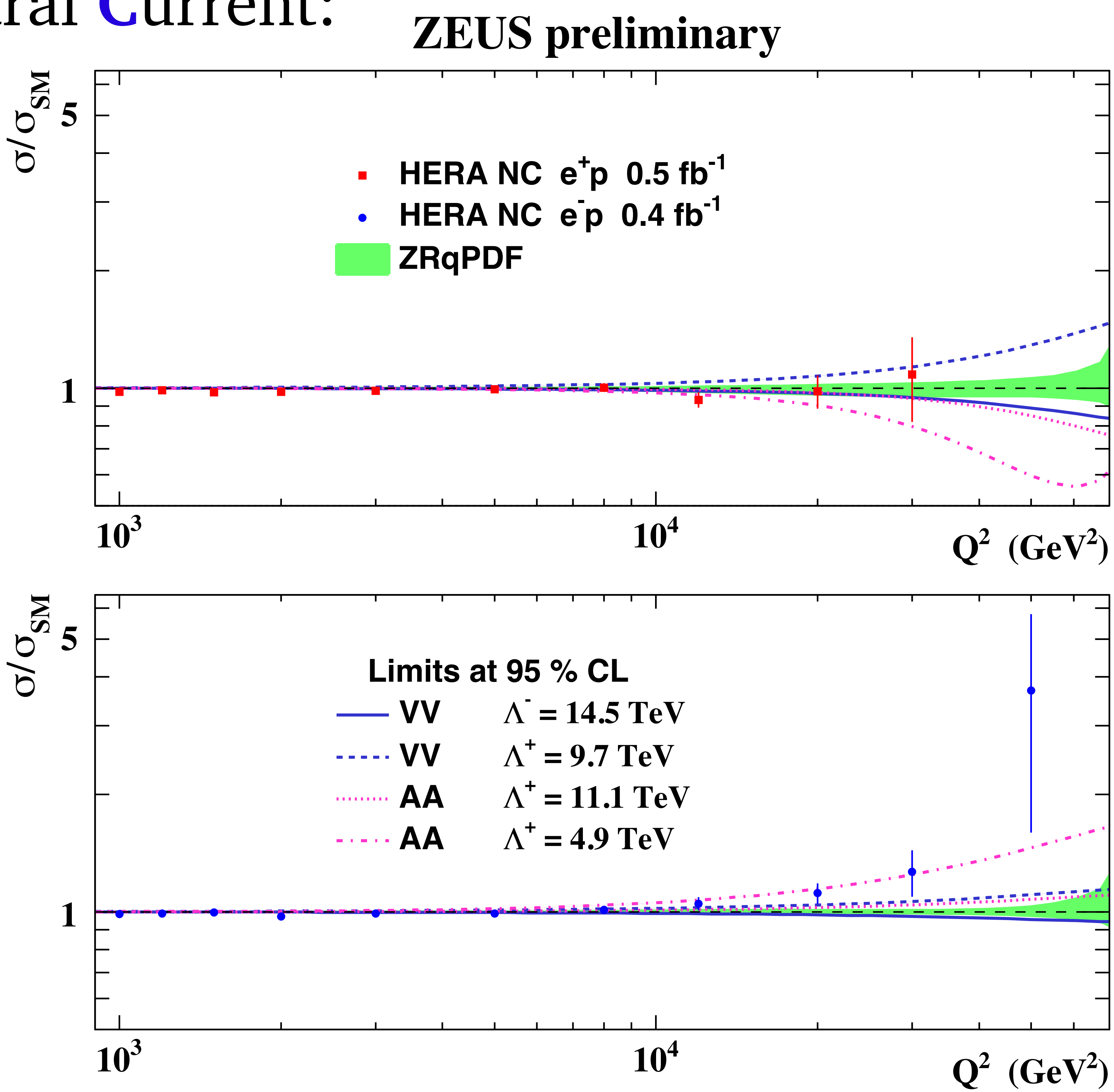
General contact interactions limits

	95% C.L. limits (TeV)				
	Measured		Expected		p_{SM} [%]
	Λ^-	Λ^+	Λ^-	Λ^+	
LL	18.9	4.5	5.9	6.3	7.0
RR	27.2	4.4	5.7	6.1	5.9
LR	5.0	7.1	5.7	6.3	34
RL	5.4	6.3	5.6	6.5	42
VV	14.7	9.7	11.2	11.4	25
AA	-	5.0 - 11.1	7.9	7.8	0.8
VA	3.76	3.6 - 10.2	4.2	4.2	5.8 2.8
X1	-	3.5 - 6.8	5.4	5.5	0.4
X2	10.1	6.9	7.8	8.3	23
X3	24.4	6.3	8.3	8.7	7.3
X4	7.4	9.4	8.0	8.6	39
X5	10.1	6.9	7.7	7.7	26
X6	3.4 - 6.0	-	5.3	5.5	0.3



Comparison to Data

Neutral Current:

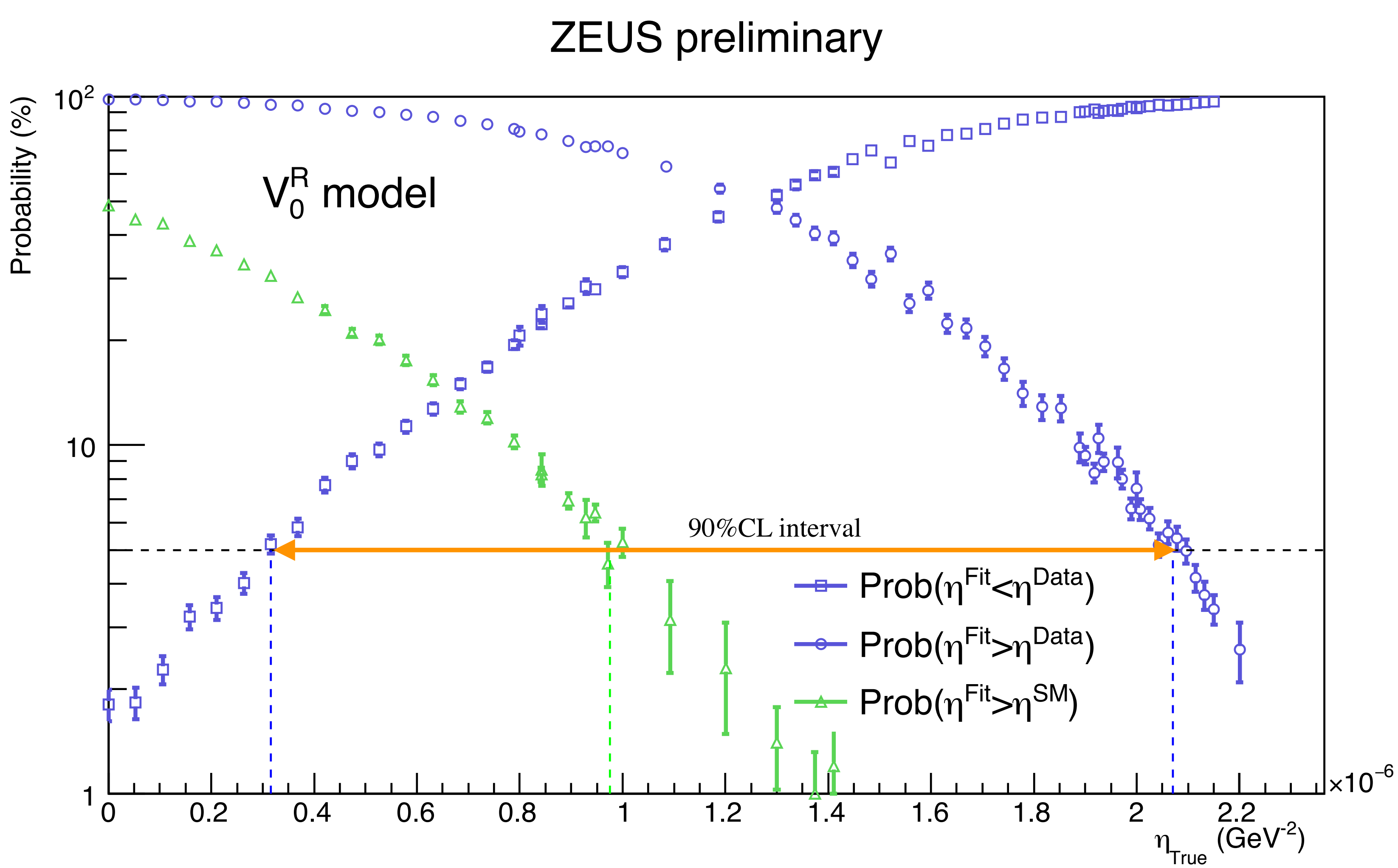


Heavy leptoquarks

In the limit of heavy leptoquarks ($M_{LQ} \gg \sqrt{s}$), the effect of *s*- and *t*-channel LQ exchange is equivalent to a vector-type *eeqq* contact interaction with the coupling of:

$$\eta_{kj}^{eq} = a_{kj}^{eq} \left(\frac{\lambda_{LQ}}{M_{LQ}} \right)^2$$

Analysis performed similarly to the general CI:



LQ species:

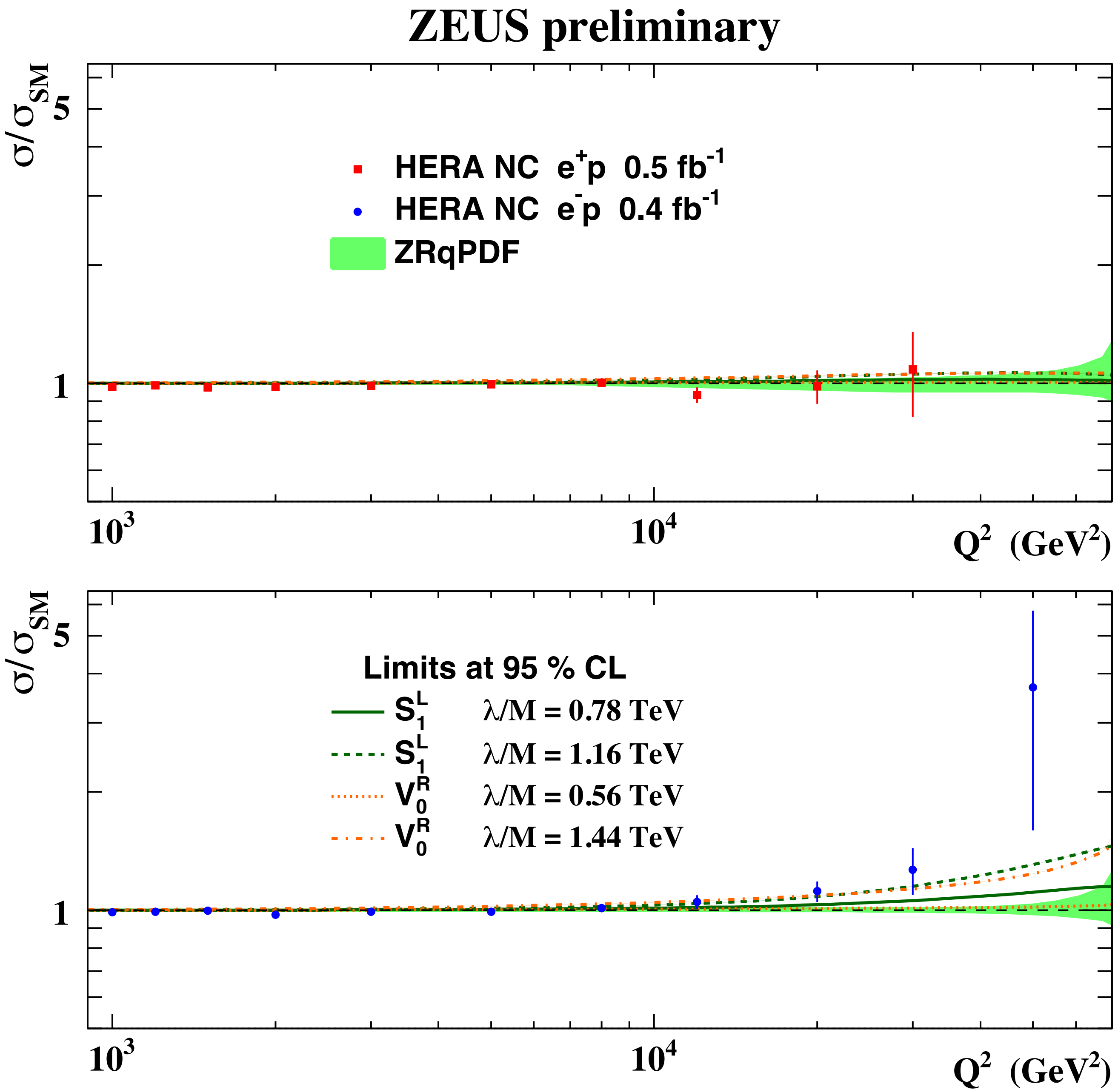
Model	Coupling Structure
S_o^L	$a_{LL}^{eu} = +\frac{1}{2}$
S_o^R	$a_{RR}^{eu} = +\frac{1}{2}$
$\widetilde{S}_o^R$	$a_{RR}^{ed} = +\frac{1}{2}$
$S_{\frac{1}{2}}^L$	$a_{LR}^{eu} = -\frac{1}{2}$
$S_{\frac{1}{2}}^R$	$a_{RL}^{ed} = a_{RL}^{eu} = -\frac{1}{2}$
$\widetilde{S}_{\frac{1}{2}}^L$	$a_{LR}^{ed} = -\frac{1}{2}$
S_1^L	$a_{LL}^{ed} = +1, a_{LL}^{eu} = +\frac{1}{2}$
V_o^L	$a_{LL}^{ed} = -1$
V_o^R	$a_{RR}^{ed} = -1$
$\widetilde{V}_o^R$	$a_{RR}^{eu} = -1$
$V_{\frac{1}{2}}^L$	$a_{LR}^{ed} = +1$
$V_{\frac{1}{2}}^R$	$a_{RL}^{ed} = a_{RL}^{eu} = +1$
$\widetilde{V}_{\frac{1}{2}}^L$	$a_{LR}^{eu} = +1$
V_1^L	$a_{LL}^{ed} = -1, a_{LL}^{eu} = -2$

Heavy leptoquarks limits

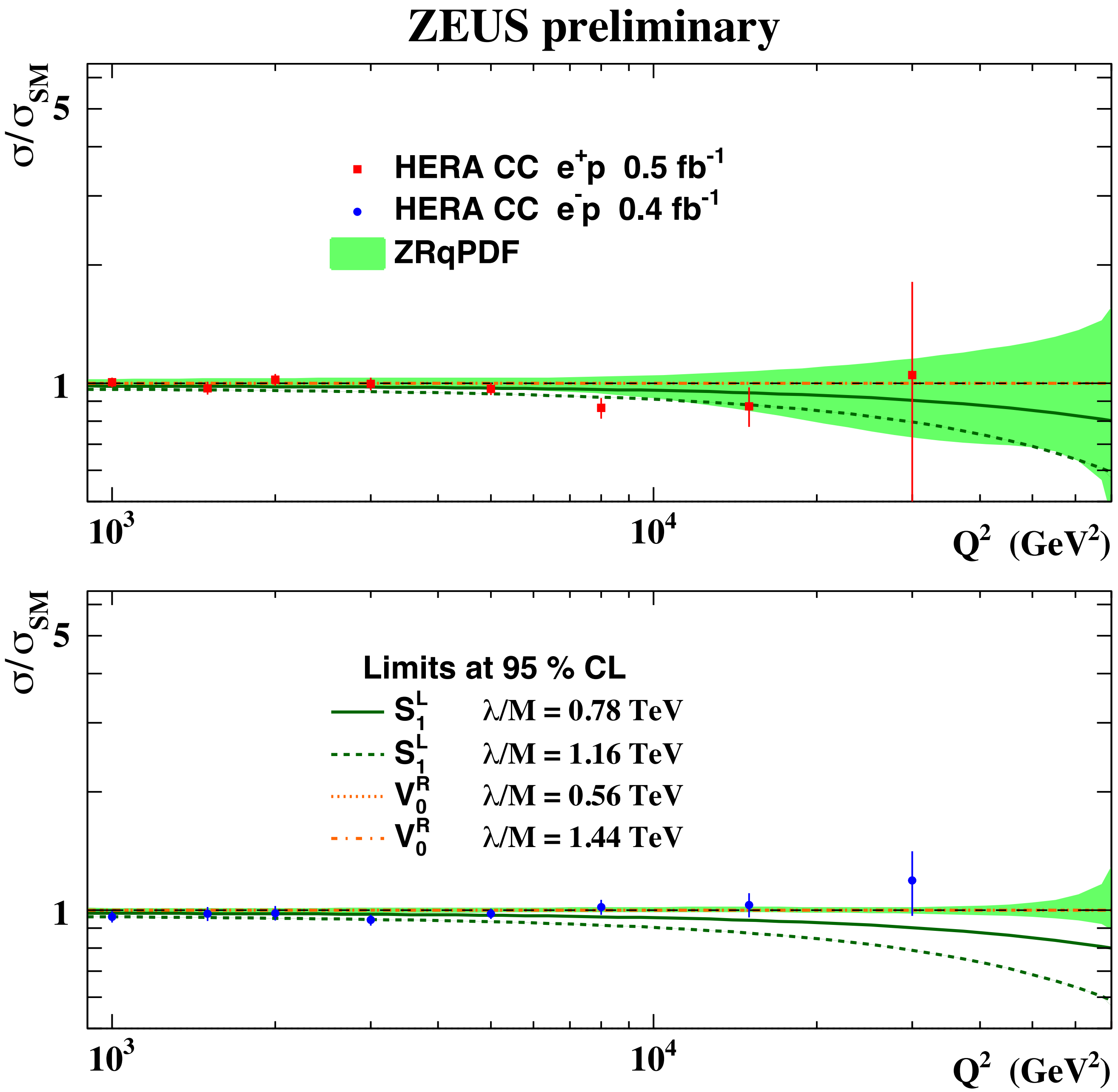
	95% C.L. limits		
	λ_{LQ} / M_{LQ} (TeV^{-1})		p_{SM} [%]
Model	Measured	Expected	
S_o^L	0.27	0.56	8.4
S_o^R	1.02	0.72	5.9
$\widetilde{S}_o^R$	-	1.71	1.8
$S_{\frac{1}{2}}^L$	0.8	0.76	42
$S_{\frac{1}{2}}^R$	0.99	0.92	37
$\widetilde{S}_{\frac{1}{2}}^L$	1.51	1.39	41
S_1^L	0.78 - 1.16	0.62	<0.01
V_o^L	-	0.44	0.4
V_o^R	0.56 - 1.44	0.99	1.8
$\widetilde{V}_o^R$	0.16	0.53	6.3
$V_{\frac{1}{2}}^L$	1.11	1.29	38
$V_{\frac{1}{2}}^R$	0.53	0.57	39
$\widetilde{V}_{\frac{1}{2}}^L$	0.47	0.49	42
V_1^L	0.39	0.35	31

Comparison to Data

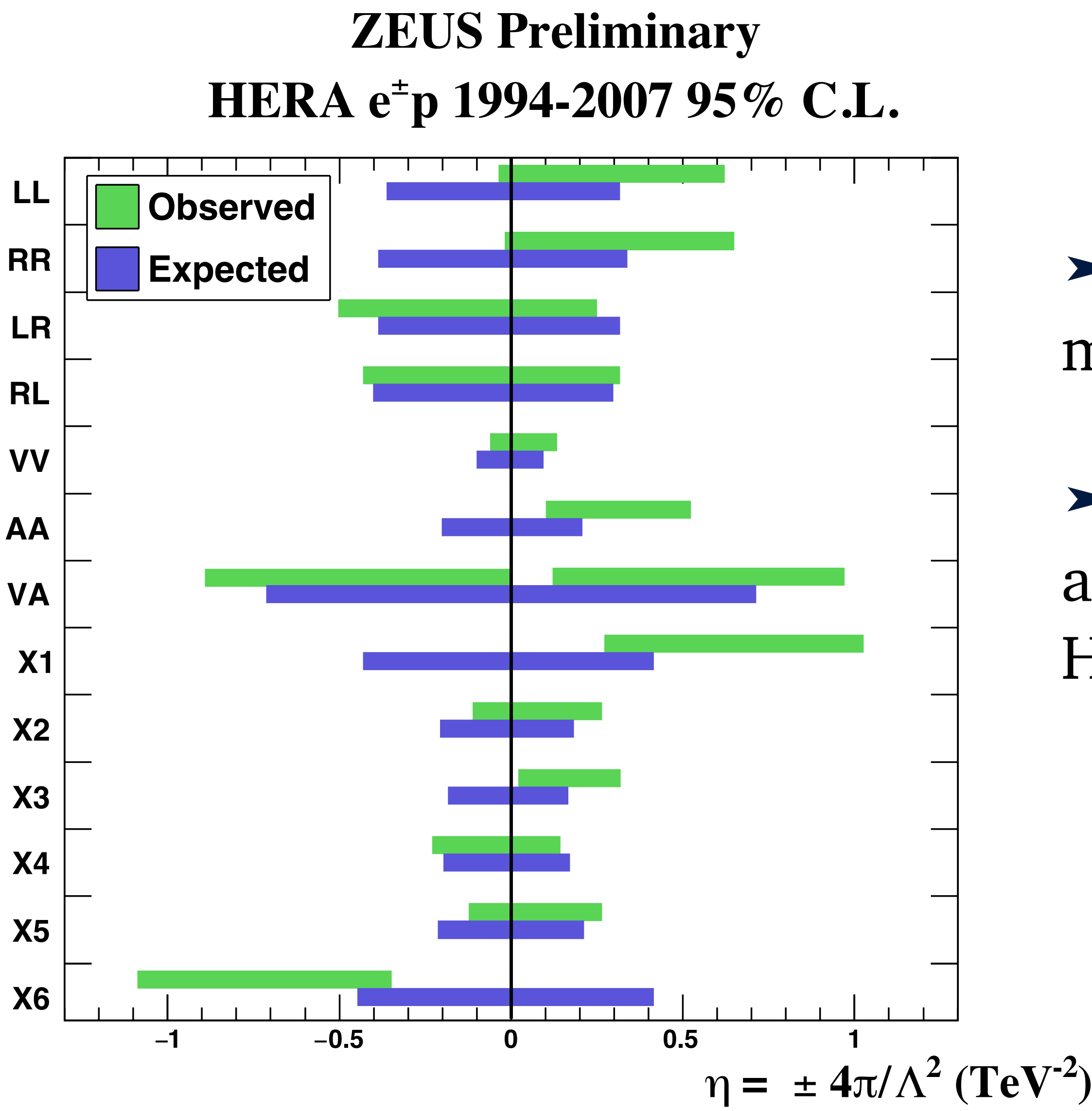
Neutral Current:



Charged Current:

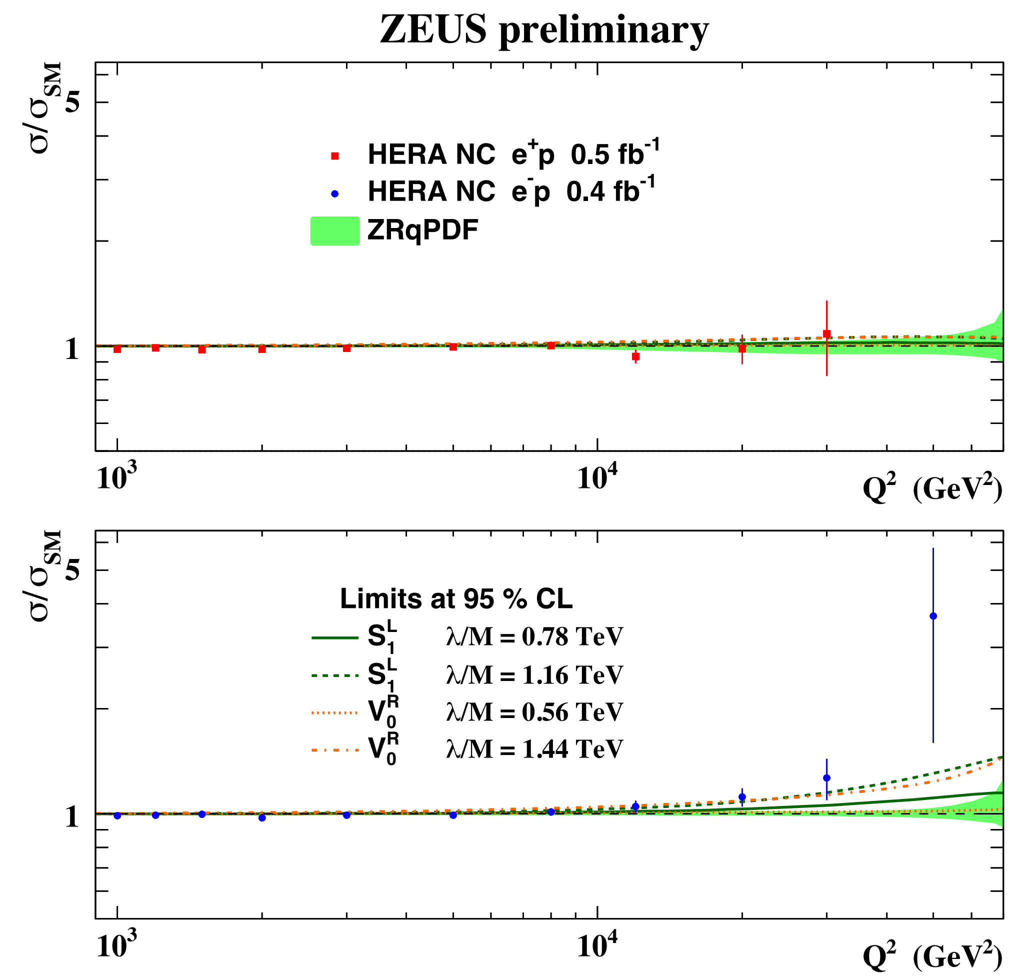


Summary



➢ Combined HERA inclusive DIS cross-section measurements allow BSM searches up to TeV scales.

➢ New method - simultaneous fit of PDF parameters and BSM contribution deployed for BSM analysis of HERA data



➢ Some of the general contact interactions and heavy leptoquarks models provide significantly improved description of the data.

➢ Analysis is ongoing to understand the nature of the effect.