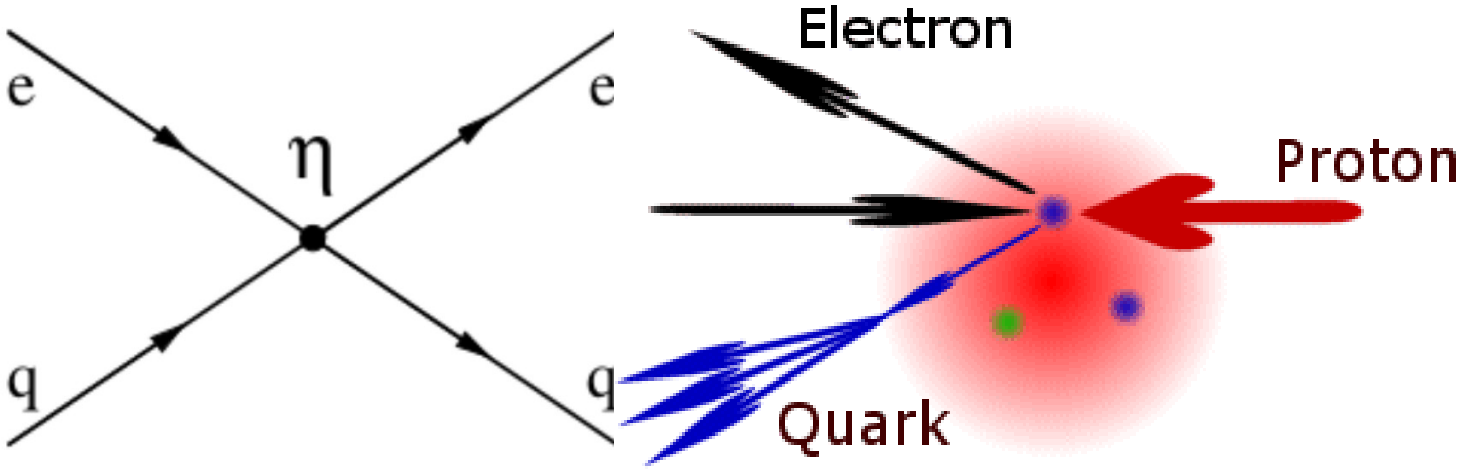
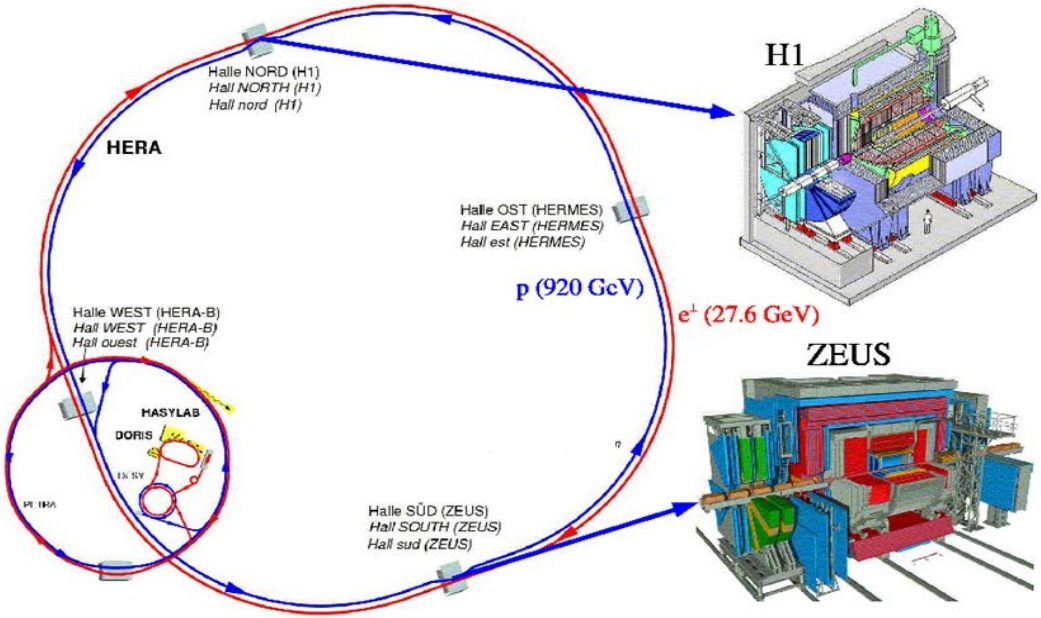
Contact Interaction Search @ HERA

K. Wichmann for the ZEUS Collaboration

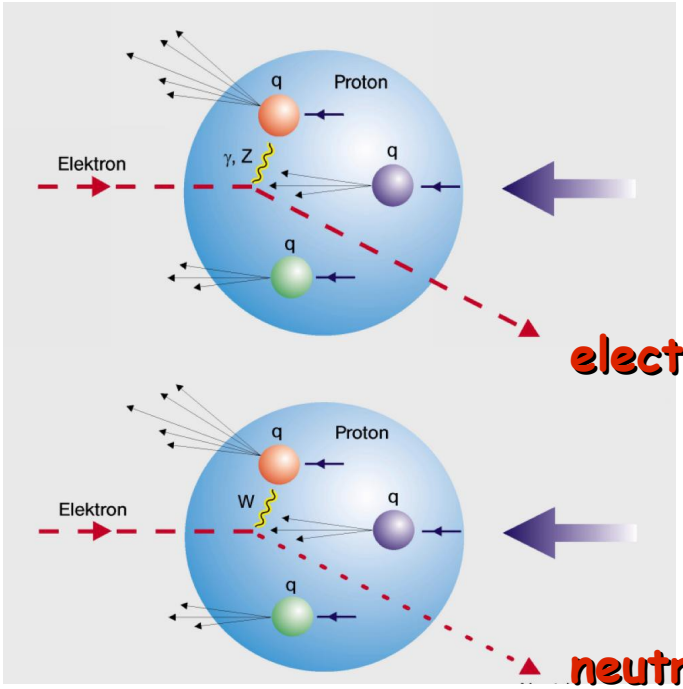


Thanks to A. Zarnecki I O. Turkot for help with the slides

HERA and DIS



- HERA: ep collider in Hamburg
- Operation: 1992-2007
- Colliding experiments: H1 and ZEUS



Deep Inelastic Scattering

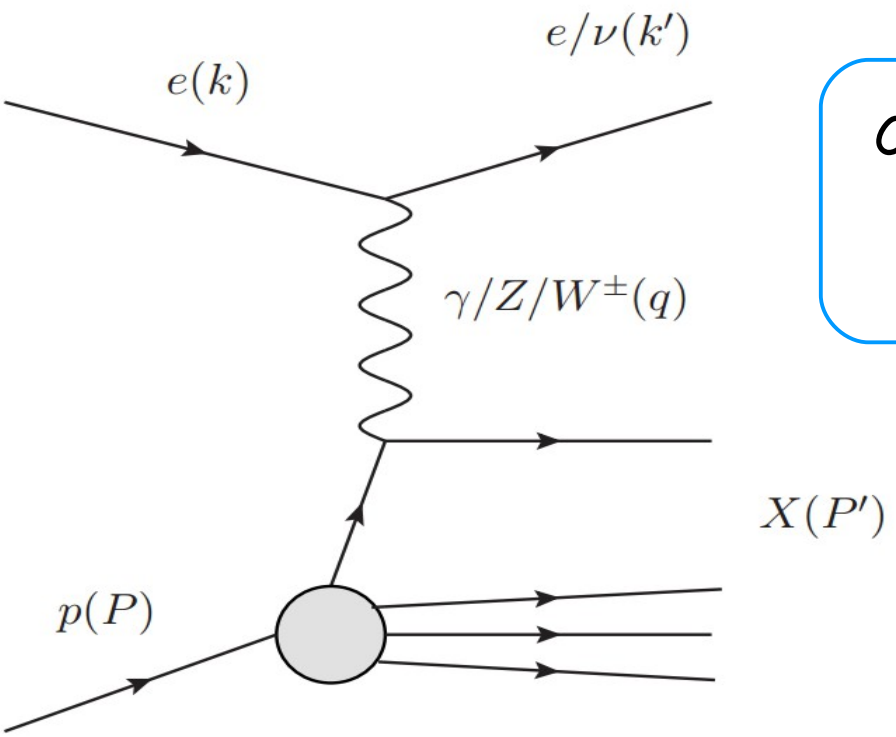
Neutral Current (NC)

γ, Z^0 exchange

Charged Current (CC)

$W^{\pm}$ exchange

Deep Inelastic Scattering at HERA



Combined H1/ZEUS inclusive DIS cross sections → final word from HERA → HERA legacy

$$\sqrt{s} = 318\,(300, 225, 252)\,GeV$$

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

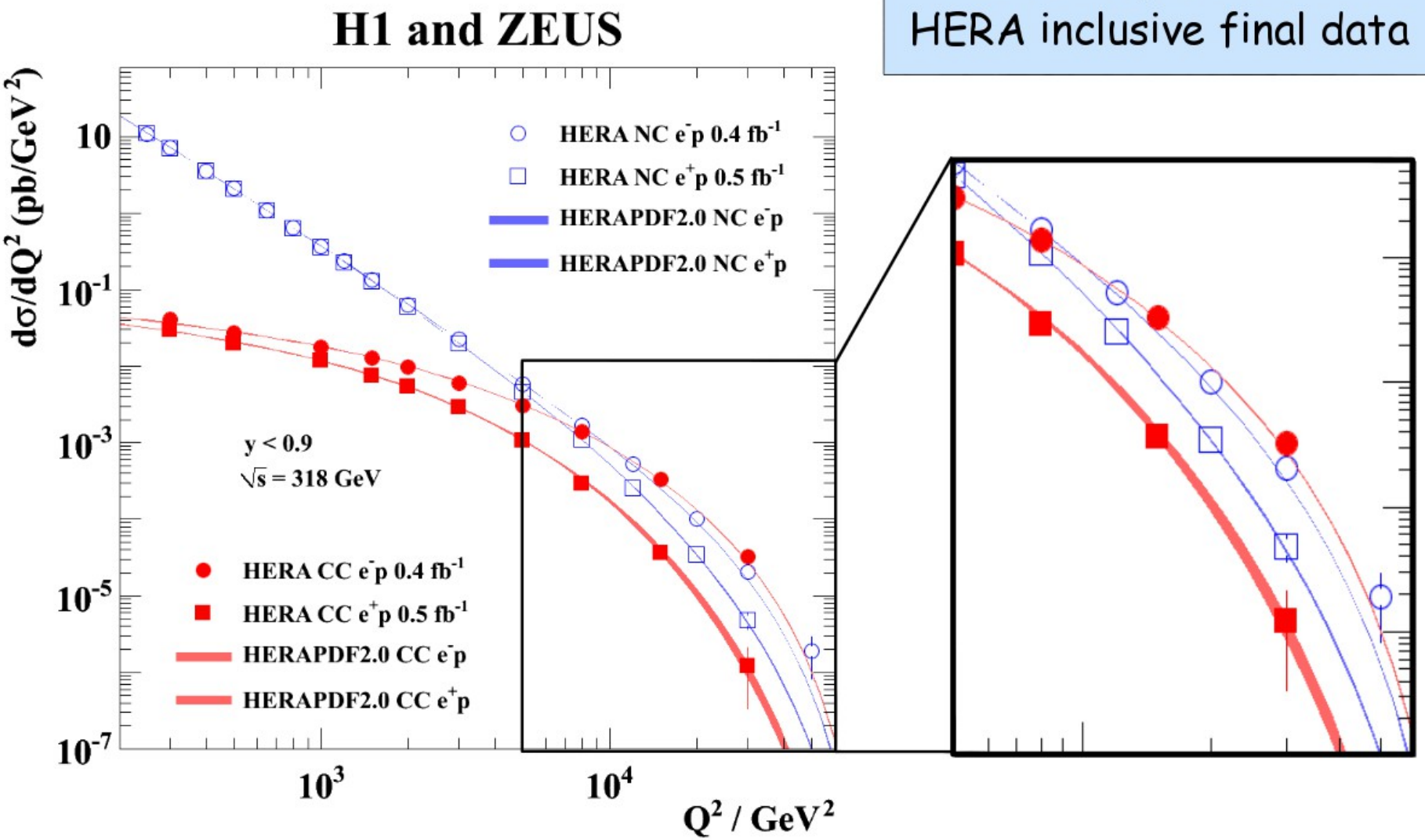
$$x_{Bj} = \frac{Q^2}{2\,pq} \qquad y = \frac{pq}{pk}$$

$$s = (p + k)^2 \qquad Q^2 = xys$$

Experimental luminosity (H1 & ZEUS):

~ 0.5fb^{-1} data from each experiment

Fantastic precision of HERA inclusive final data



High-Q^2 NC and CC HERA data used to search for BSM

Simultaneous QCD and BSM global fit

- HERA combined only data used to obtained HERAPDF2.0
- HERA combined data are CORE of any modern PDF set

Unrecognised BSM contributions in HERA inclusive cross sections may have been partially or totally absorbed into any PDF set

→ biased PDFs

→ too strong limits, **more details in O.Turkot's talk at 12:30**

- New approach to new physics searches used

Simultaneous fit to parton distribution functions and BSM contributions

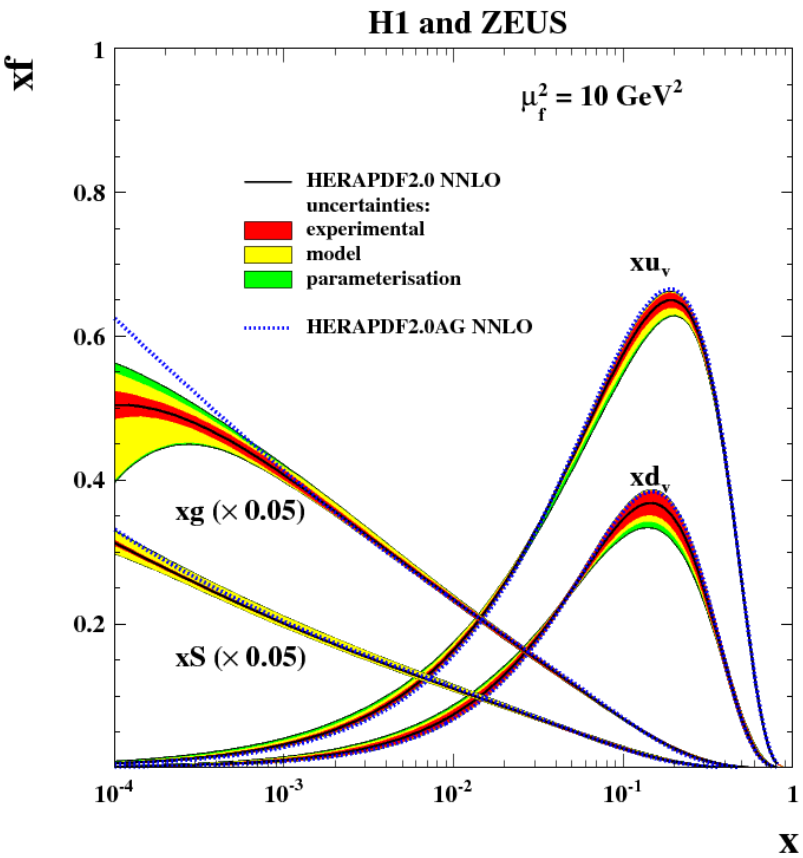
→ only proper way, **more details in O.Turkot's talk at 12:30**

- HERAPDF2.0-like QCD fits used

HERAPDF2.0-like QCD fits

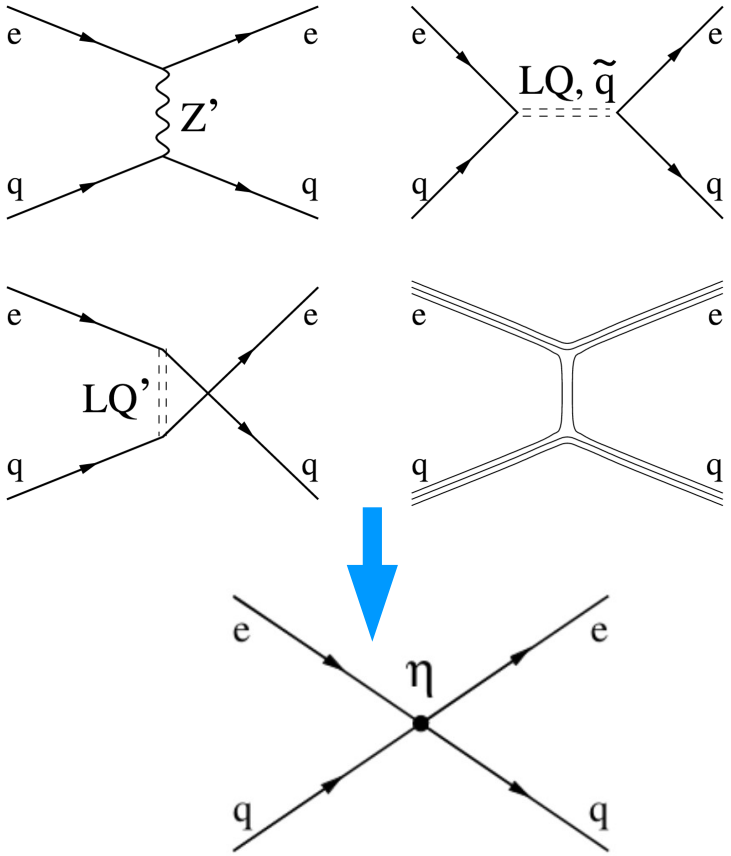
- QCD fits are performed using xFitter package
- PDFs (14p) are parametrised at $Q_0^2 = 1.9\ \mathrm{GeV}^2$

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



- PDF evolution using DGLAP equations
- Heavy flavor coefficients: GM VFNS

Contact Interactions



- For many BMS scenarios at large scales interactions approximated as eeqq Contact Interactions (CI)

Considered models:

Model	η^{eq}_{LL}	η^{eq}_{LR}	η^{eq}_{RL}	η^{eq}_{RR}
LL	$+\eta$			
RR				$+\eta$
VV	$+\eta$	$+\eta$	$+\eta$	$+\eta$
AA	$+\eta$	$-\eta$	$-\eta$	$+\eta$
VA	$+\eta$	$-\eta$	$+\eta$	$-\eta$
X1	$+\eta$	$-\eta$		
X2	$+\eta$		$+\eta$	
X4		$+\eta$	$+\eta$	

$$\mathscr{L}_{CI} = \sum_{\substack{i,j=L,R \\ q=u,d}} \eta^{eq}_{ij} (\bar{e}_i \gamma^\mu e_i)(\bar{q}_j \gamma_\mu q_j)$$

$$\eta_{ij} = \epsilon_{ij} \cdot \frac{4\pi}{\Lambda^2}$$

$$\epsilon_{ij} = \pm 1; 0$$

Fitted simultounsly with PDFs to data to get η^{Data}

MC replicas & limit setting procedure

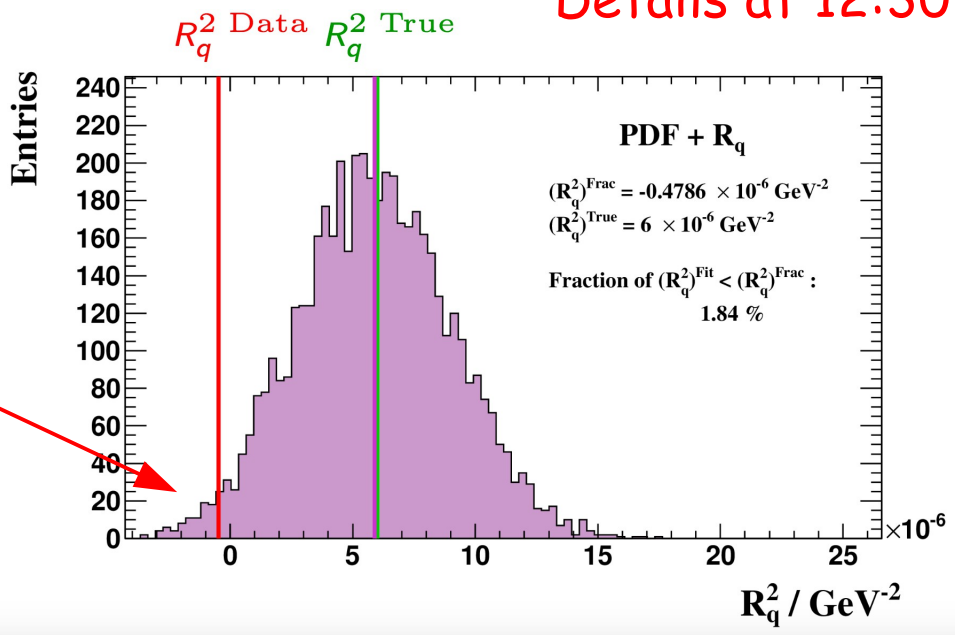
- Limits derived using MC replicas - frequentist approach
- Replicas are generated sets of cross-section values

→ calculated for given coupling η^{True} and varied randomly according to statistical and systematic uncertainties (including correlations) of input data

- Each replica is then used as an input to QCD+BSM fit ⇒ η^{Fit}
- Number of replicas for each η^{True} ⇒ distribution of η^{Fit}
- η^{True} is tested by comparing η^{Fit} distribution with η^{Data}

Details at 12:30

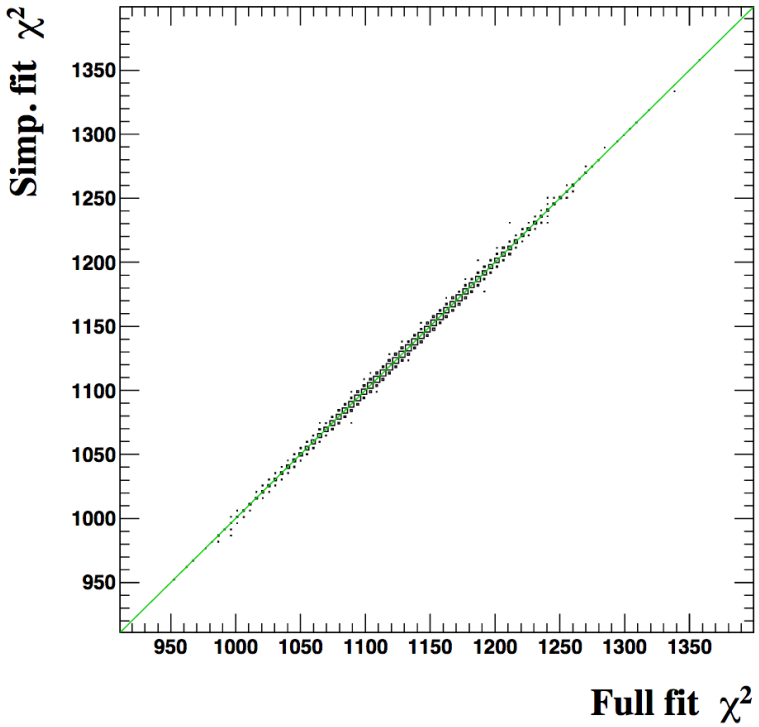
- Prob($\eta^{Fit} < \eta^{Data}$) studied as a function of η^{True}
- η^{True} values corresponding to probability < 5% are excluded at 95% C. L.

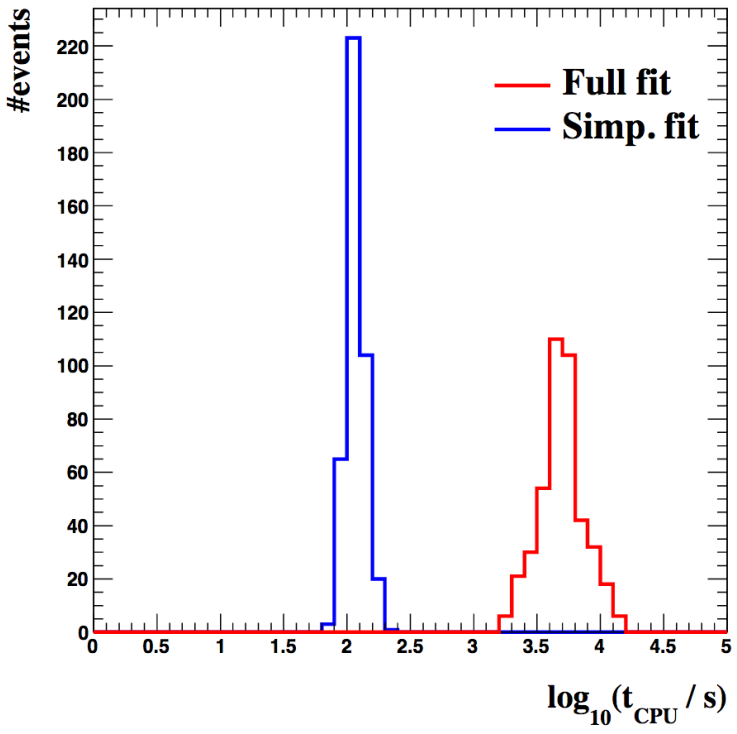


Simplified fit procedure

arXiv:1606.06670

- On average every CI+PDF fit takes ~1.5 hours of CPU time
- For R_q analysis 215000 replicas fitted → ~36.8 years of CPU time
- For other BSM models simplified fit procedure developed
  - based on the approximation of cross-section predictions with Taylor expansion
  - reduces the average fit duration to ~2 minutes of CPU time





VV model: highest sensitivity

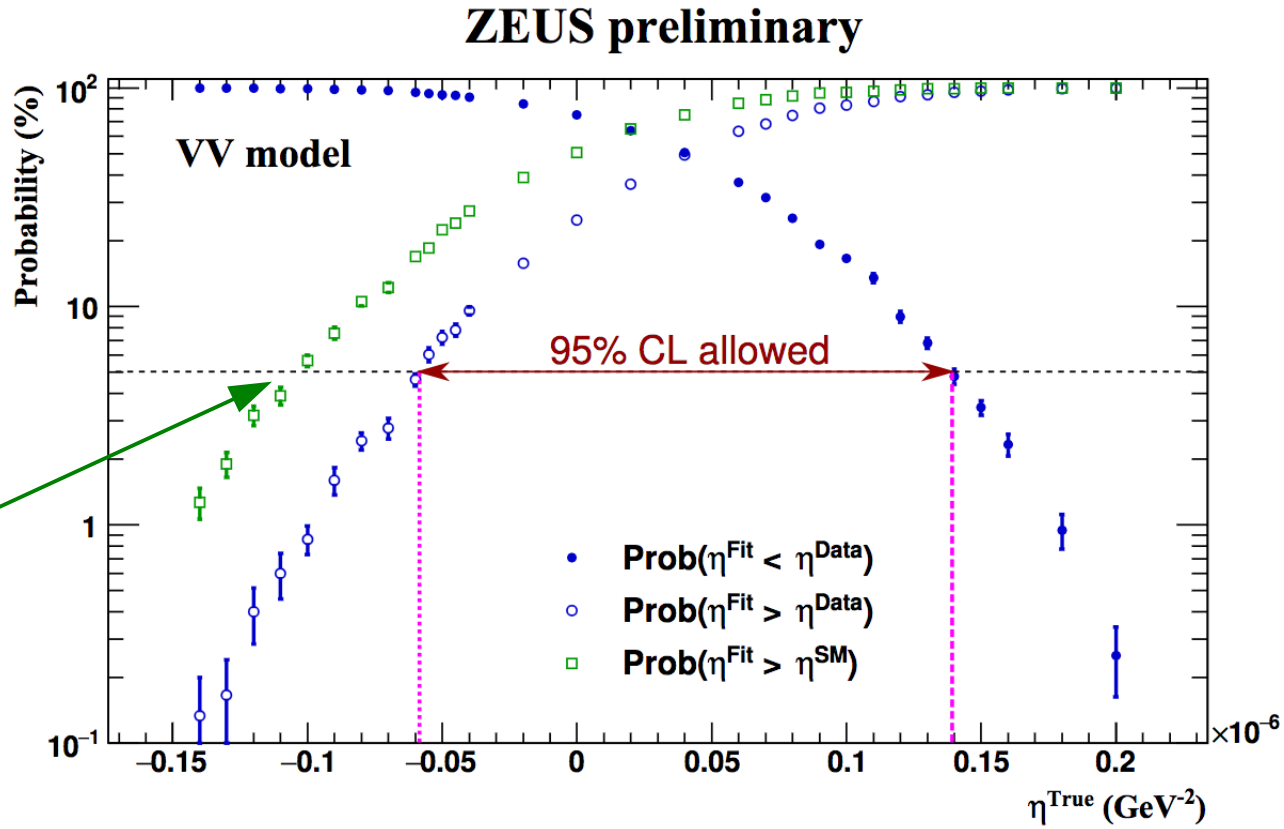
- MC replicas used to calculate

$$\mathrm{Prob}(\eta^{\mathrm{Fit}} < \eta^{\mathrm{Data}}) \quad \text{for} \quad \eta > \eta^{\mathrm{Data}}$$

$$\mathrm{Prob}(\eta^{\mathrm{Fit}} > \eta^{\mathrm{Data}}) \quad \text{for} \quad \eta < \eta^{\mathrm{Data}}$$

for different η^{True}

SM expectations



Excluded @ 95% CL → $\Lambda^- > 14.7$ TeV $\Lambda^+ > 9.5$ TeV

AA model: deviation of 2.5σ from SM

- For AA scenario → QCD+CI fit gives improved description of data

Fitted coupling

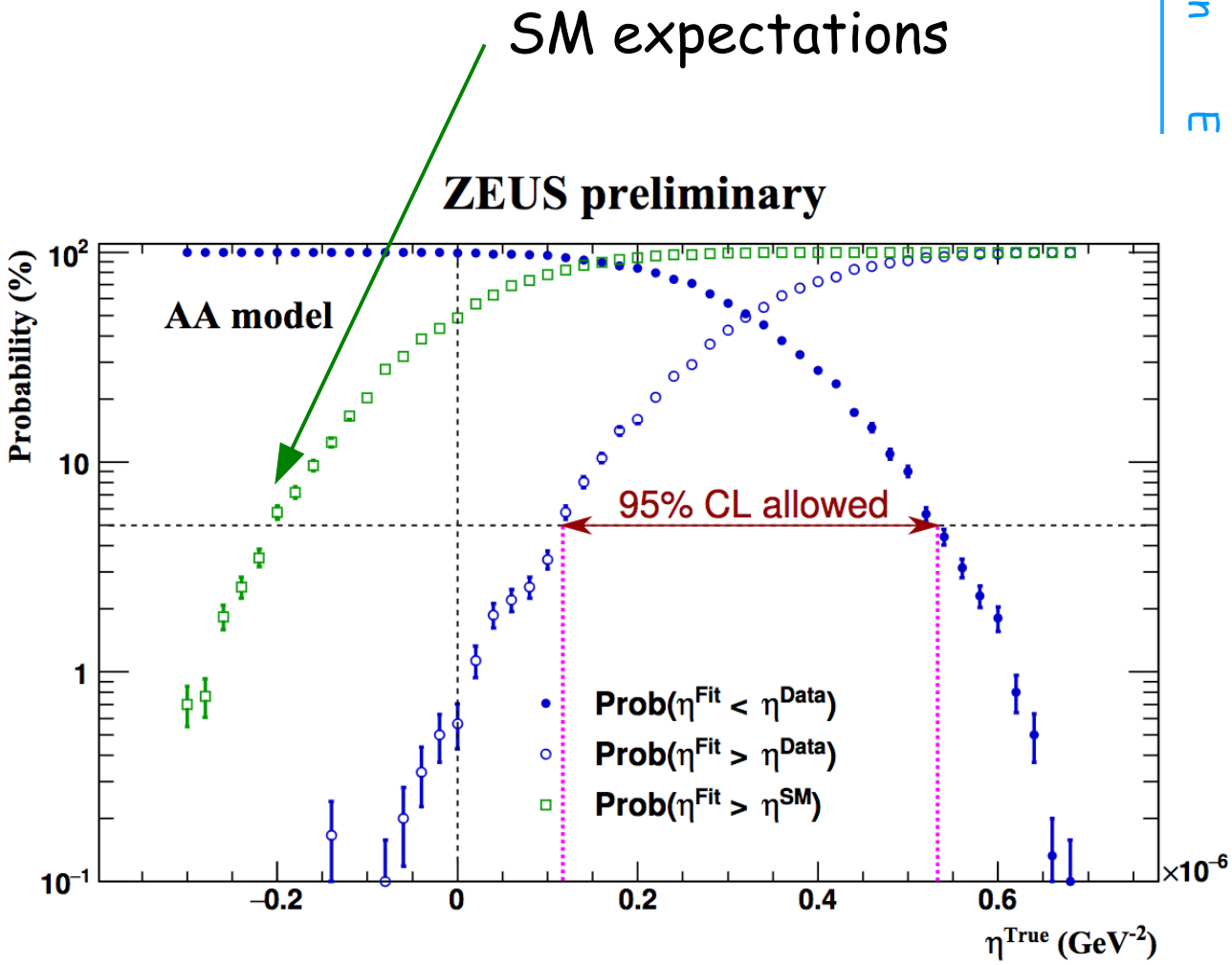
$$\eta^{Data} = 0.32\ \mathrm{TeV}^{-2}$$

corresponding to

$$\Lambda^{Data} = 6.2\ \mathrm{TeV}$$

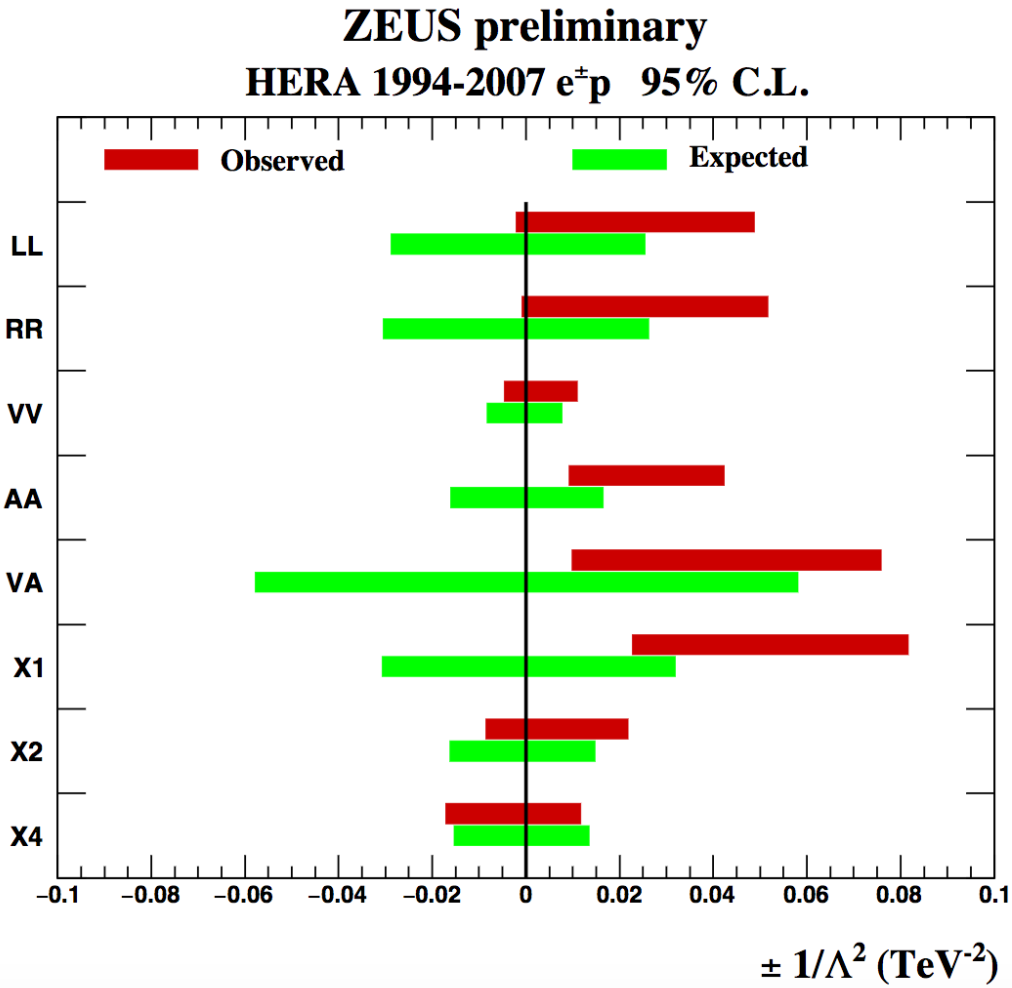
The probability of obtaining larger best-fit coupling for $\eta^{\mathrm{True}} = 0$

$$p_{SM} = 0.7\% \qquad (2.5\ \sigma)$$



Excluded @ 95% CL → $4.9\ \mathrm{TeV} < \Lambda^{+} < 10.4\ \mathrm{TeV}$

Contact Interaction Limits



ZEUS preliminary

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

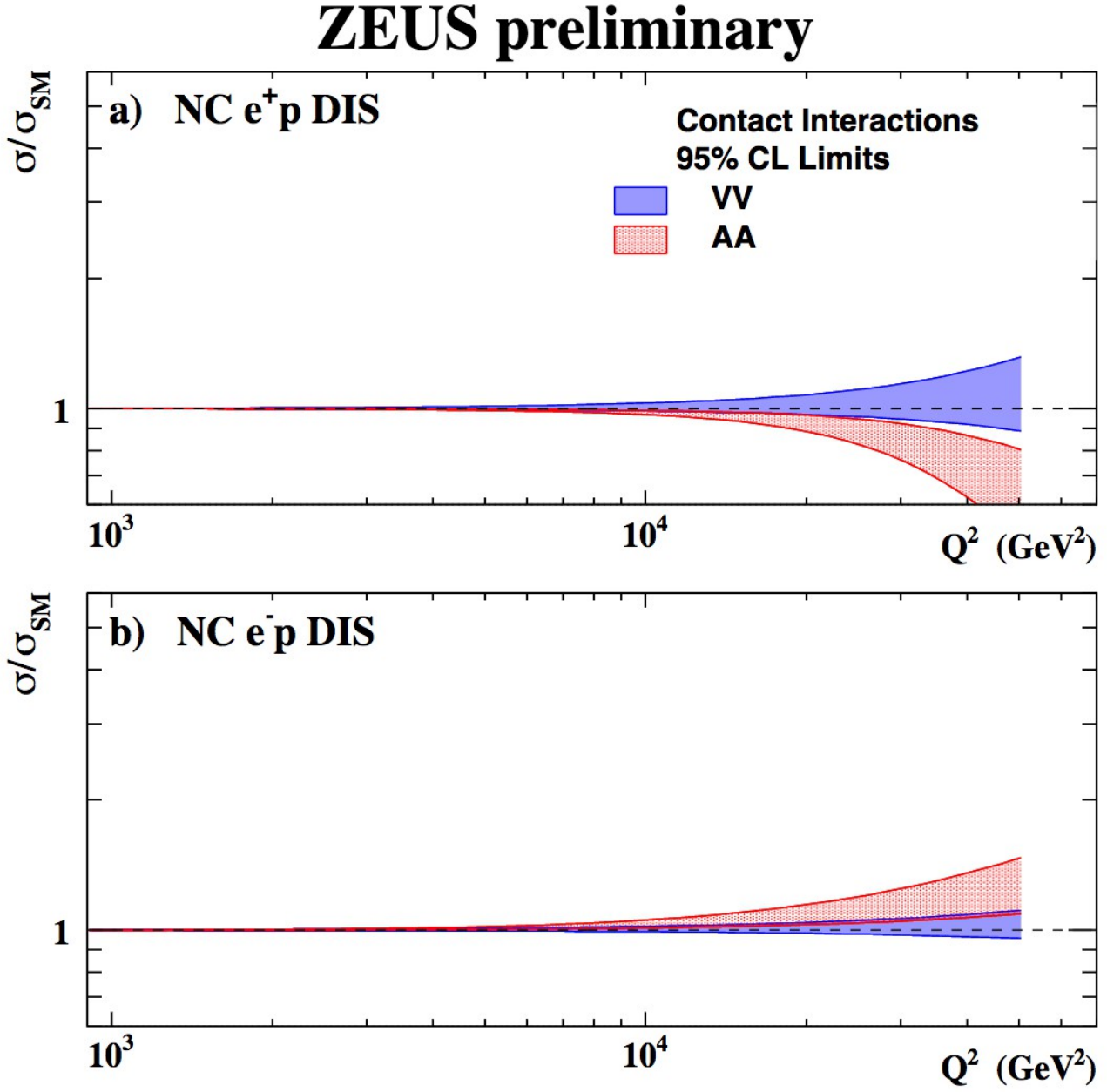
Model	95%C.L. limits (TeV) Observed Λ^-	Observed Λ^+	Expected Λ^-	Expected Λ^+	p_{SM} (%)
LL	22.0	4.5	5.9	6.2	6.5
RR	32.9	4.4	5.7	6.1	5.6
VV	14.7	9.5	11.0	11.4	24.8
AA	-	4.8 - 10.4	7.9	7.8	0.7
VA	-	3.6 - 10.1	4.1	4.1	2.1
X1	-	3.5 - 6.6	5.7	5.6	0.3
X2	10.8	6.8	7.8	8.2	23.1
X4	7.6	9.2	8.0	8.6	60.3

- Improved description of data for 3 models

- Possible explanations within SM
  - missing higher-order EW corrections
  - limitations of the assumed PDF parametrisation/evolution scheme

Cross section deviations corresponding to allowed coupling range for VV and AA models

No PDF variation included!



Comparison to other experiments

	Measured 95% C.L. limits (TeV)											
	HERA combined		Atlas		CMS		ALEPH		ZEUS 2004		H1 2011	
	Λ^-	Λ^+	Λ^-	Λ^+	Λ^-	Λ^+	Λ^-	Λ^+	Λ^-	Λ^+	Λ^-	Λ^+
LL	22.0	4.5	20.7	16.4	18.3	13.5	7.2	12.9	1.7	2.7	4.0	4.2
RR	32.9	4.4	20.2	16.6			5.3	10.2	1.8	2.7	3.9	4.4
VV	14.7	9.5					8.3	16.9	6.2	5.4	7.2	5.6
AA	—	4.8 - 10.4					9.6	15.9	4.7	4.4	5.1	4.4
VA	—	3.6 - 10.1							3.3	3.2	3.6	3.8
X1	—	3.5 - 6.6							3.6	2.6		
X2	10.8	6.8							3.9	4.0		
X4	7.6	9.2	25.2	19.2			6.8	3.7	5.1	4.8	4.8	5.4

For some CI scenarios HERA provides only existing limits to date

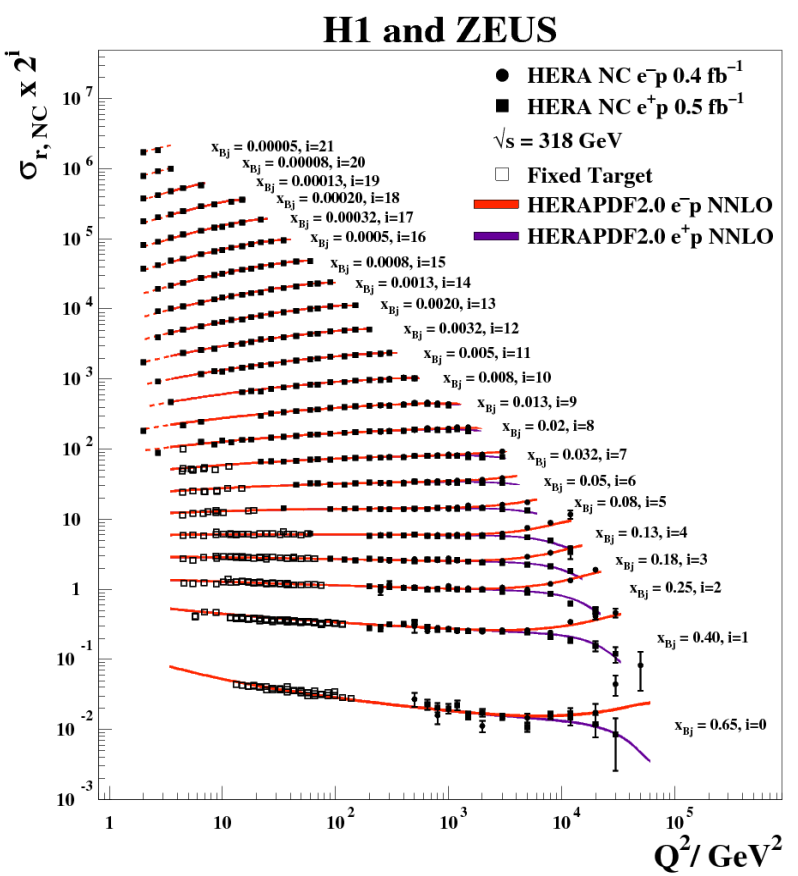
Summary

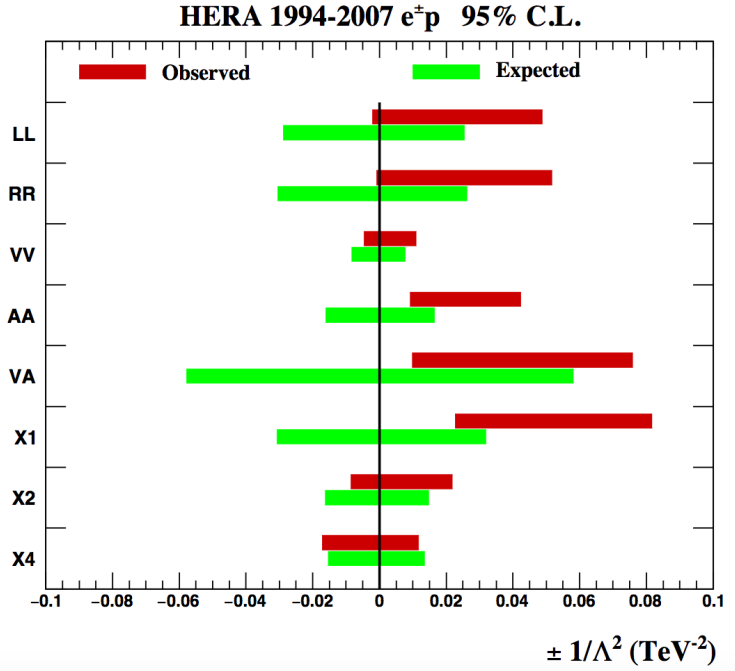
- Combined HERA inclusive DIS cross sections allow BSM searches up to TeV scales

- Simultaneous fit procedure necessary
  → limits obtained with fixed PDFs are too strong
  → dedicated talk on quark radius searches: O. Turkot, today @ 12:30am

- Limits on some CI models set

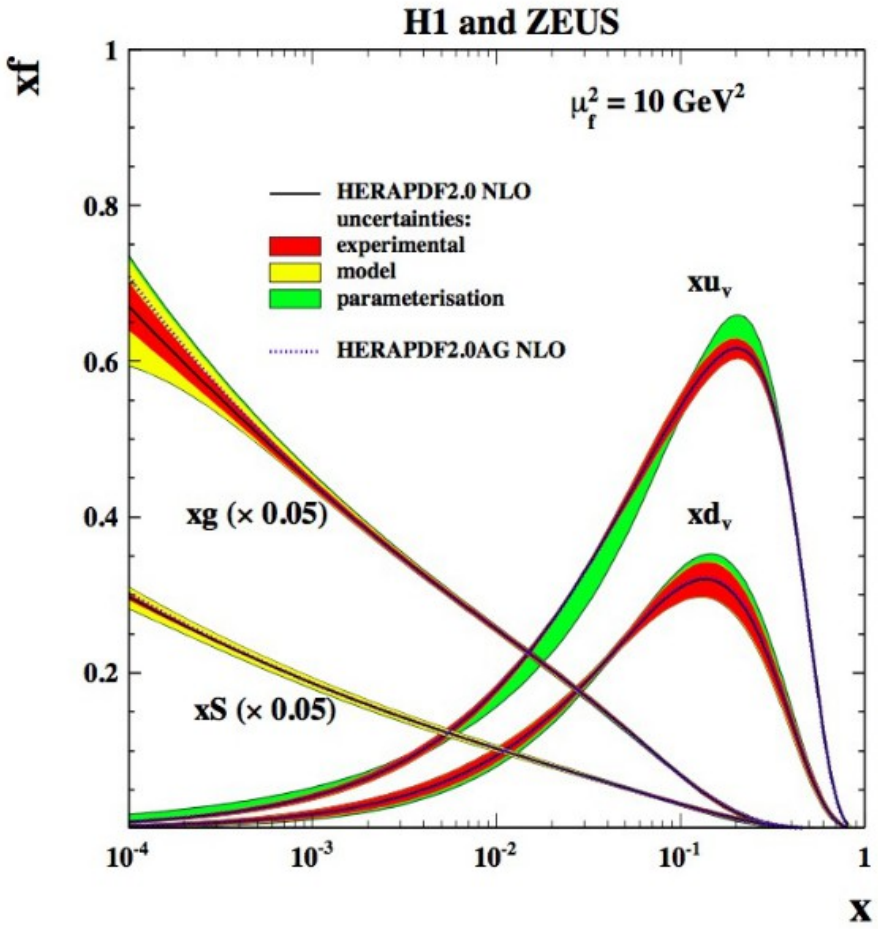
- Some of contact interaction models provide improved description of data





Additional slides

Color decomposition of uncertainties



- Experimental uncertainties:
  - Hessian method
  - Conventional $\Delta\chi^2 = 1$ => 68% CL

Variation	Standard Value	Lower Limit	Upper Limit
Q^2_{min} [GeV^2]	3.5	2.5	5.0
Q^2_{min} [GeV^2] HiQ2	10.0	7.5	12.5
M_c(NLO) [GeV]	1.47	1.41	1.53
M_c (NNLO) [GeV]	1.43	1.37	1.49
M_b [GeV]	4.5	4.25	4.75
f_s	0.4	0.3	0.5
μ_{f_0} [GeV]	1.9	1.6	2.2

Adding D and E parameters to each PDF

- Parametrisation uncertainties
  - largest deviation
- Model uncertainties
  - all variations added in quadrature