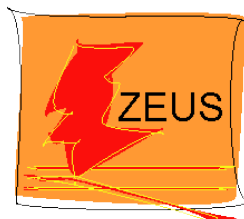




24 July 2015
Vienna, Austria

Combined Measurement of Inclusive $e^\pm p$ Scattering Cross Sections at HERA

[arXiv:1506.06042]



Oleksii Turkot
DESY

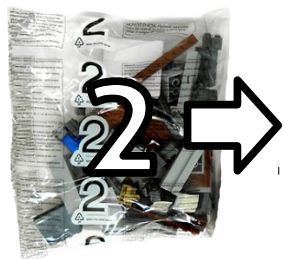


On behalf of H1 and ZEUS Collaborations



Combined Measurement of Inclusive $e\pm p$ Scattering Cross Sections at HERA

being presented now.



QCD Analysis HERAPDF2.0 of the combined HERA structure function data

Voica Radescu today at 12:15.



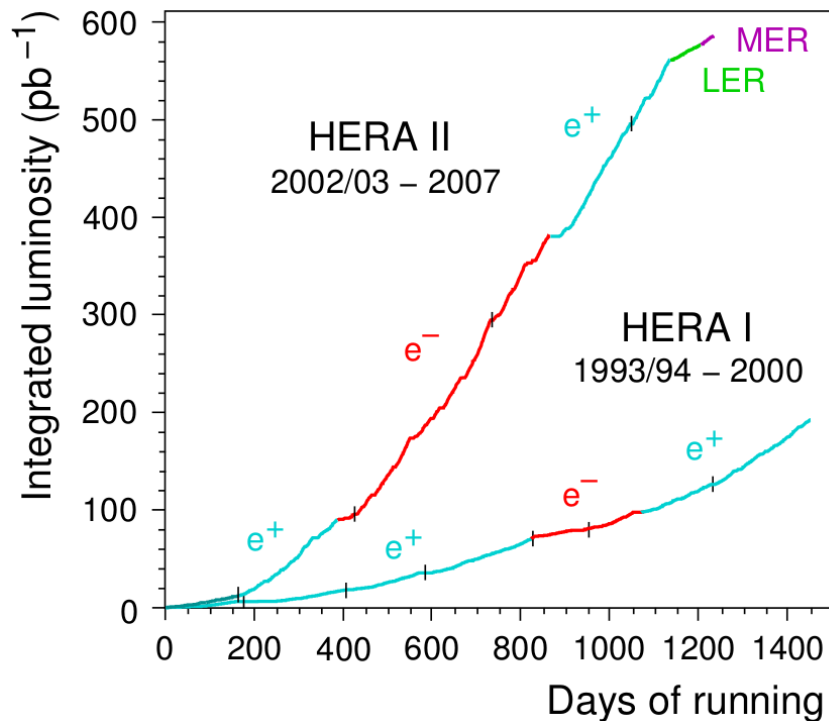
QCD Analysis of the combined HERA inclusive data together with HERA jet and charm data

Katarzyna Wichmann today at 12:30.

ZEUS and H1 experiments

HERA is worlds only $e^{\pm}p$ collider :

operated during 1992 — 2007;
 e^{\pm} energy 27.5 GeV;
 p energies 920, 820, 575 and 460 GeV.

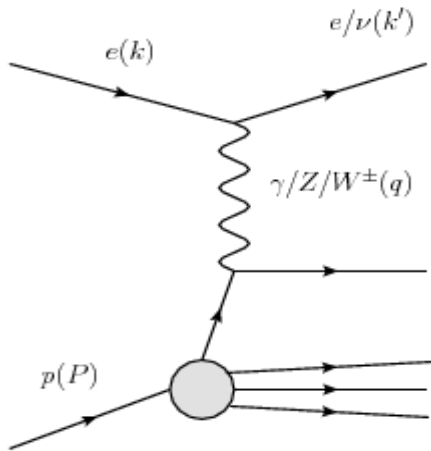


H1 and ZEUS — two collider experiments at HERA :

$\sim 0.5 \text{ fb}^{-1}$ of luminosity recorded by each experiment.

HERA data provides unique opportunity to study the structure of the proton.

HERA data and the LHC



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

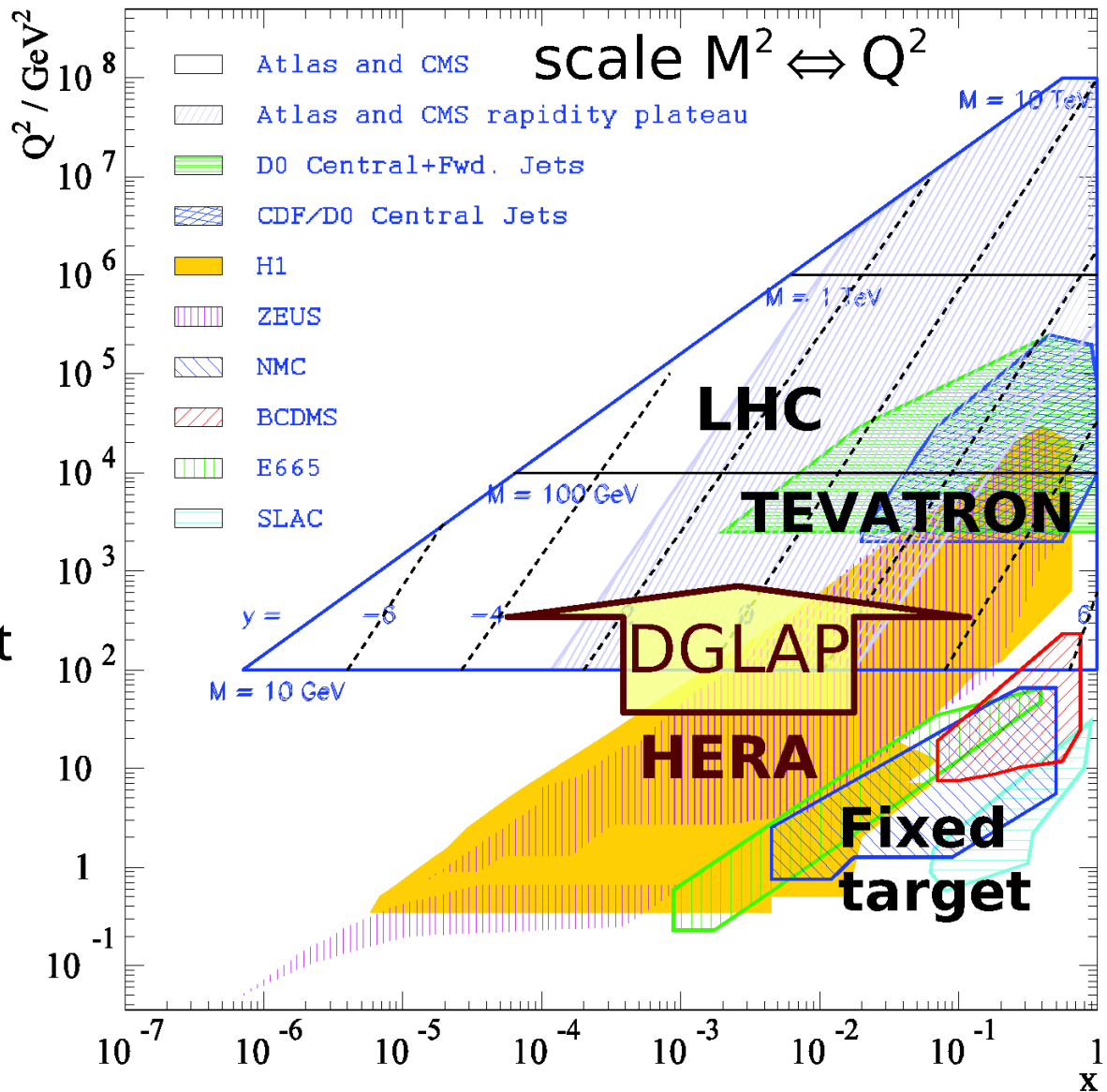
$$x = Q^2 / 2P \cdot q$$

$$y = P \cdot q / P \cdot k$$

$X(P')$

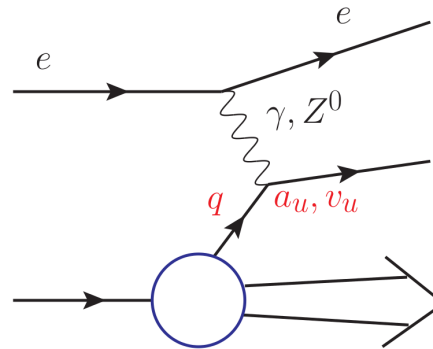
HERA data covers a large part of the LHC x range.

Evolution in Q^2 via DGLAP allows to extrapolate HERA PDFs into LHC region.



Inclusive DIS

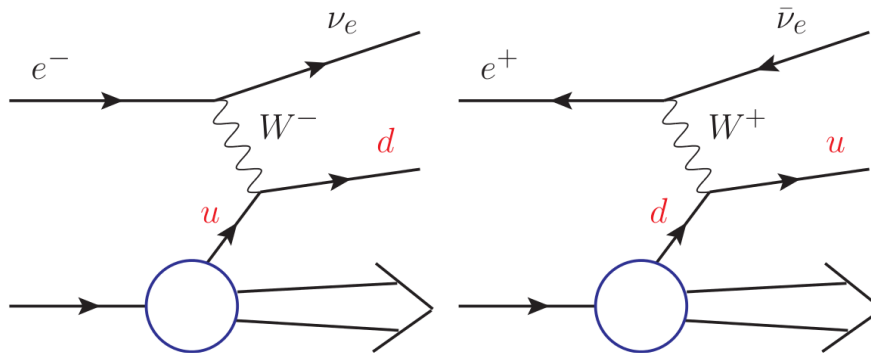
Neutral Current :



$$\frac{d^2 \sigma_{NC}^{e\bar{\nu}p}}{dx dQ^2} = \frac{2\pi\alpha^2 \cdot Y_{\pm}}{xQ^4} \cdot \left(F_2(x, Q^2) \pm \frac{Y_{-}}{Y_{\pm}} \cdot x \cdot F_3(x, Q^2) - \frac{y^2}{Y_{\pm}} \cdot F_L(x, Q^2) \right)$$

$$Y_{\pm} = 1 \pm (1-y)^2$$

Charged Current :



$$\frac{d^2 \sigma_{CC}^{e\bar{\nu}p}}{dx dQ^2} = \frac{G_F^2}{4\pi x} \cdot \kappa^2 \cdot \left(Y_{\pm} \cdot W_2^{\mp} \pm Y_{-} \cdot x \cdot W_3^{\mp} - y^2 \cdot W_L^{\mp} \right)$$

$$\kappa = \frac{M_W^2}{M_W^2 + Q^2}$$

Inclusive DIS Data Samples

Input data — 41 final data sets with HERA inclusive measurements:

- ◆ 21 HERA I data samples
- ◆ 20 HERA II data samples, including:
 - ◆ 8 inclusive HERA II $E_p = 920$ GeV
 - ◆ 4 high y data $E_p = 920$ GeV
 - ◆ 4 high y data $E_p = 575$ GeV
 - ◆ 4 high y data $E_p = 460$ GeV

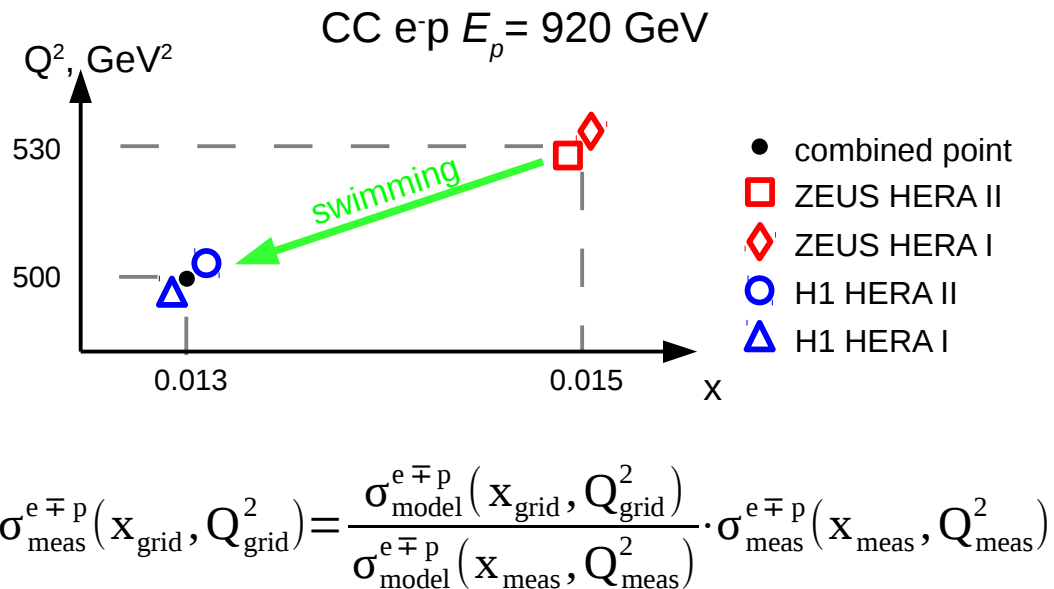
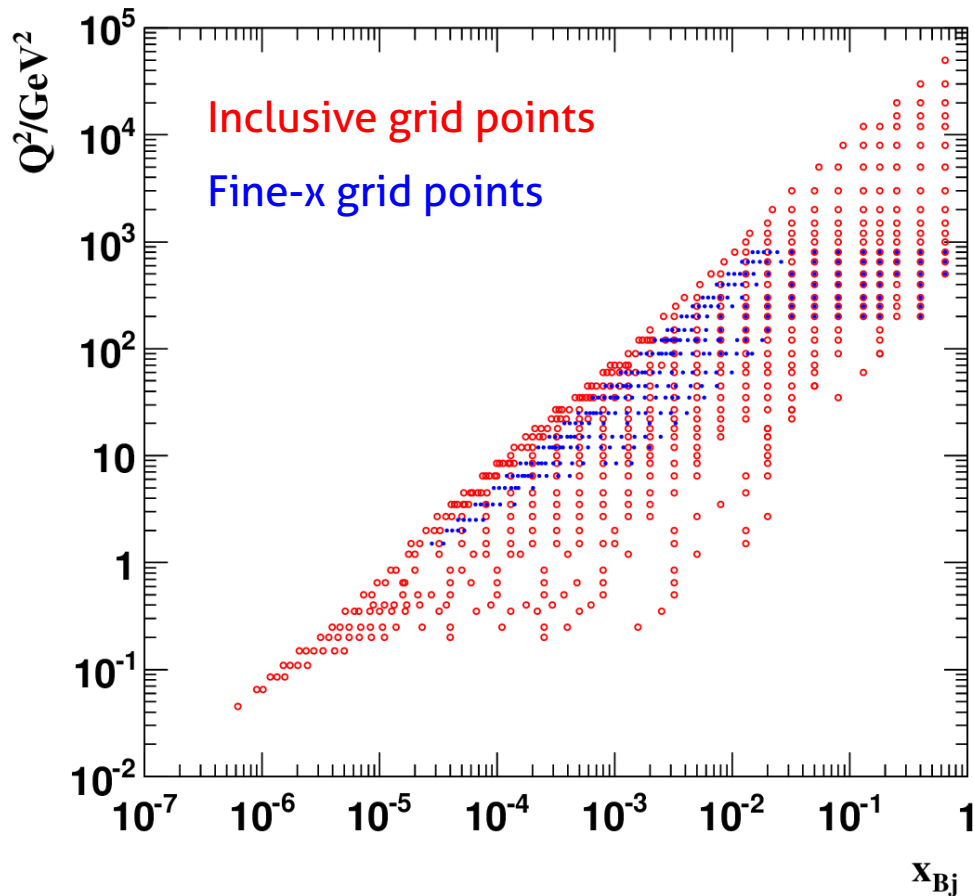
More than **10** years of data taking: 1994 — 2007.

Total of **2927** data points combined to **1307**.

$Q^2 - x$ common grids

All data points are swum to common $Q^2 - x$ grids:

H1 and ZEUS



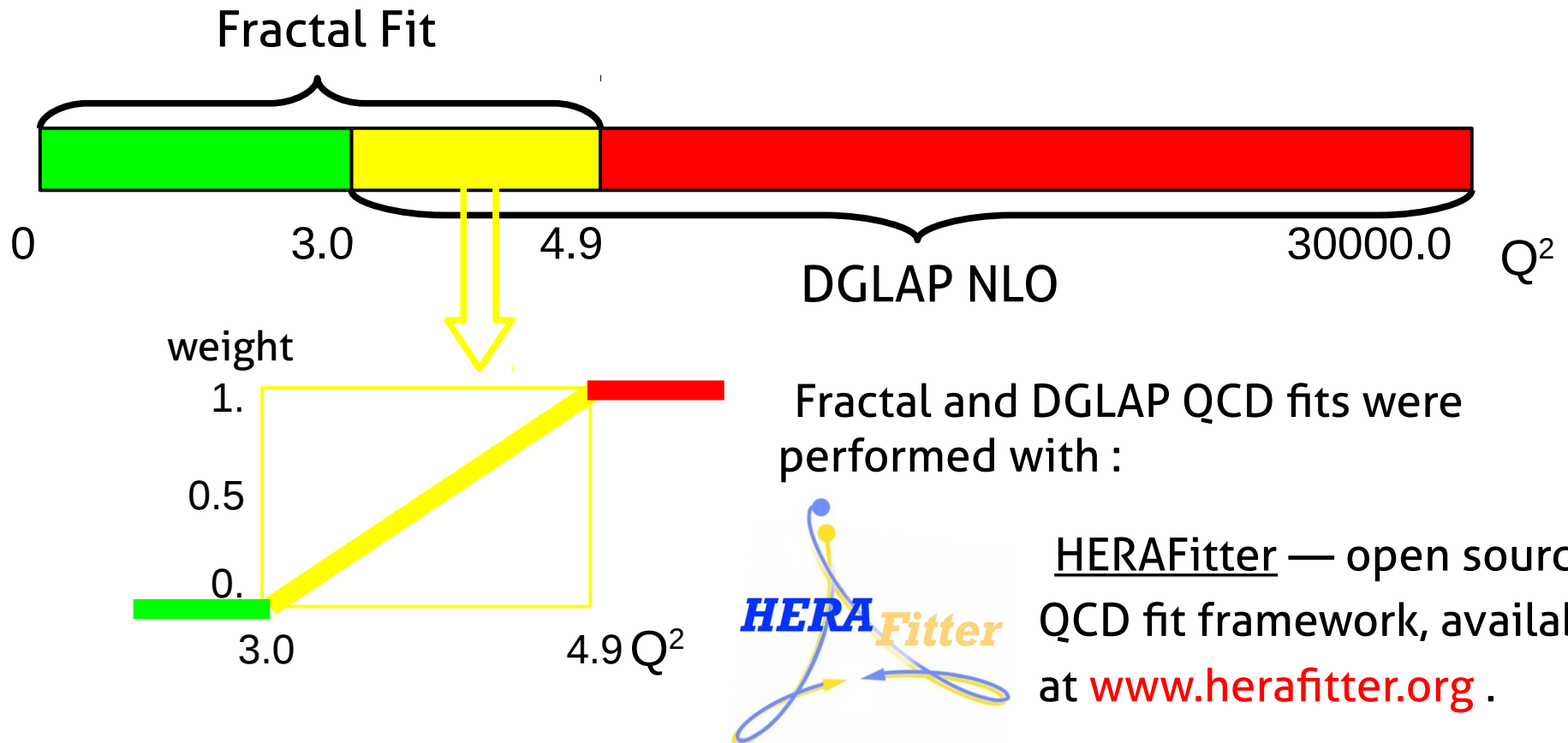
1307 grid points cover wide range:

$$0.045 < Q^2 < 50000 \text{ GeV}^2$$

$$6 \cdot 10^{-7} < x_{\text{Bj}} < 0.65$$

Swimming procedure

The swimming done iteratively using our own data.



Averaging of scale factors is performed in dependence on Q^2 .

Averaging procedure

The combination of the data done with HERAverager.

(available at wiki-zeuthen.desy.de/HERAverager).

All **162** correlated systematic sources are treated as multiplicative and the χ^2 definition:

$$\chi^2(\mathbf{m}, \mathbf{b}) = \sum_i \frac{[\mathbf{m}^i - \sum_j \gamma_j^i \mathbf{m}^i \mathbf{b}_j - \mu^i]^2}{\delta_{i,\text{stat}}^2 \mu^i (\mathbf{m}^i - \sum_j \gamma_j^i \mathbf{m}^i \mathbf{b}_j) + (\delta_{i,\text{uncorr}} \mathbf{m}^i)^2} + \sum_j \mathbf{b}_j^2$$

Output:

- ◆ 7 data sets for NC and CC $e^\pm p$ with 3 CMEs, available at:
<https://www.desy.de/h1zeus/herapdf20/>
- ◆ Statistical, uncorrelated and 162 correlated systematic uncertainties;
- ◆ 7 procedural uncertainties \Rightarrow see additional material.

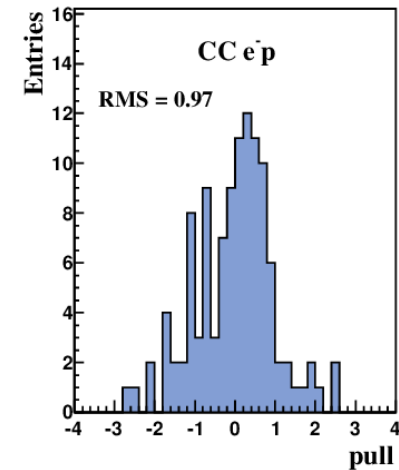
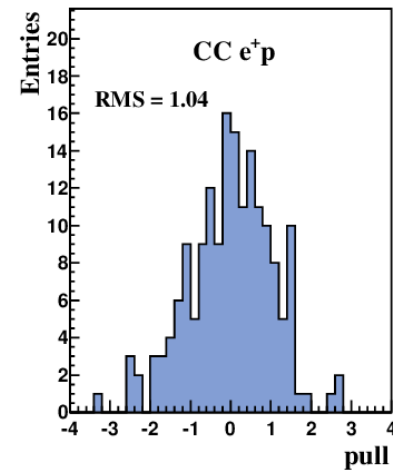
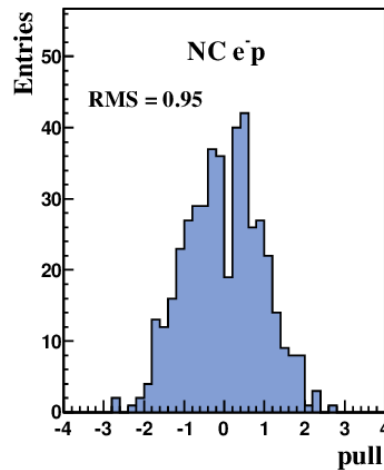
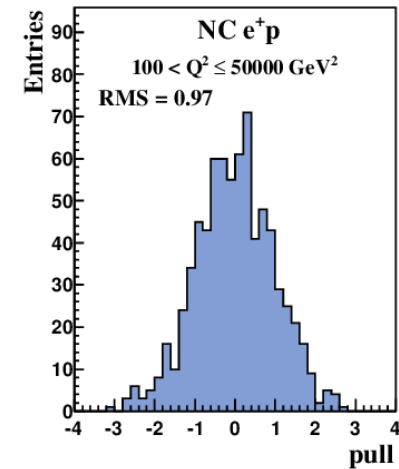
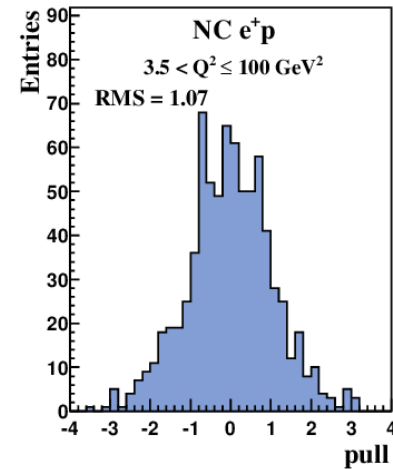
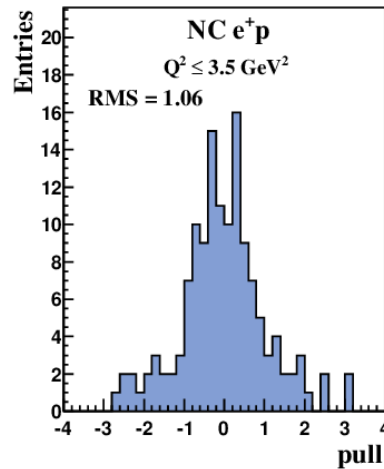
Averaging results

Good consistency of data:
 $\chi^2 / \text{ndf} = 1685 / 1620$

The pulls are defined as:

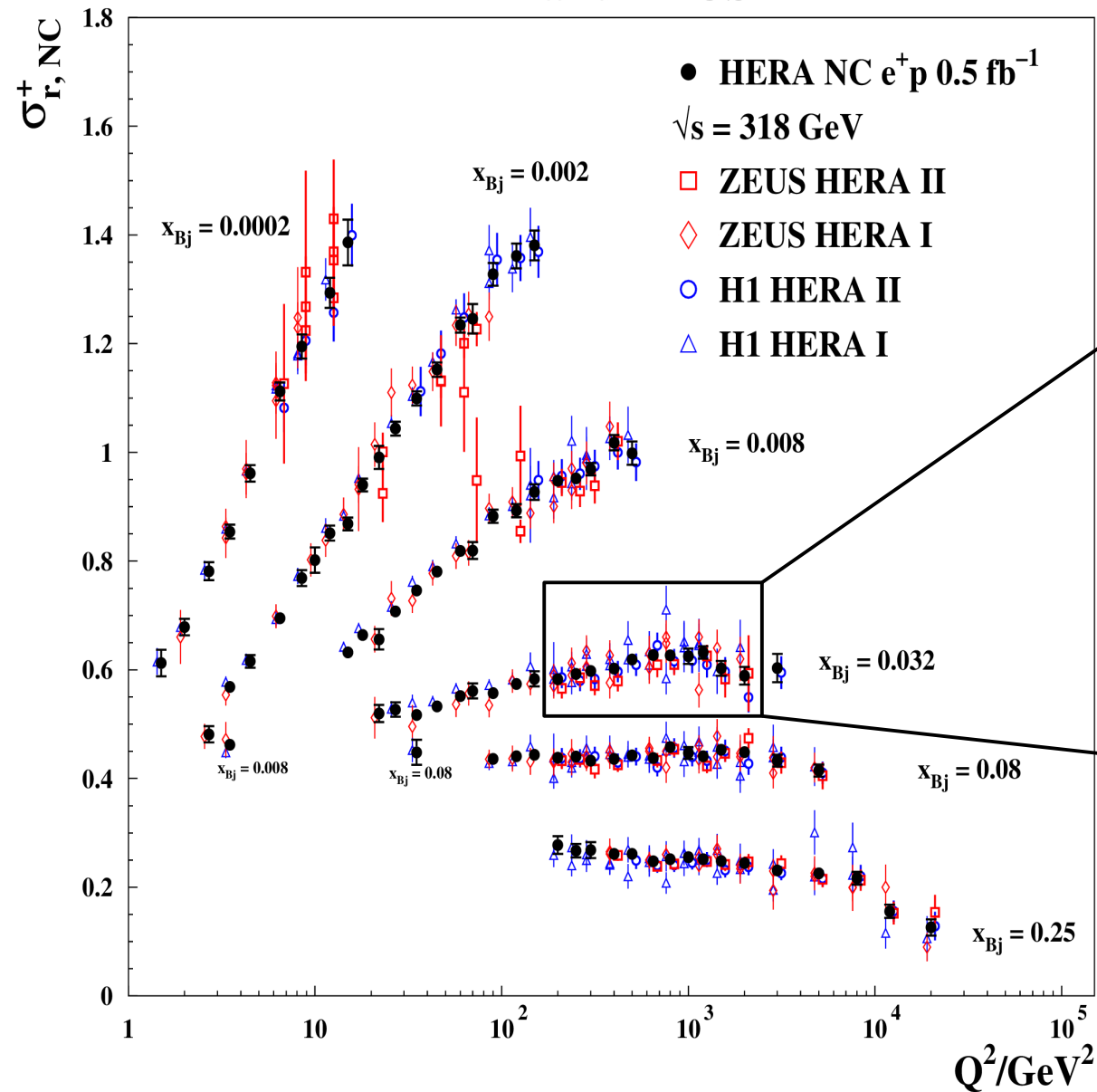
$$\text{pull}^{i,k} = \frac{\mu^{i,k} - m^i}{\sqrt{\Delta_{i,k}^2 - \Delta_{i,\text{ave}}^2}}$$

H1 and ZEUS

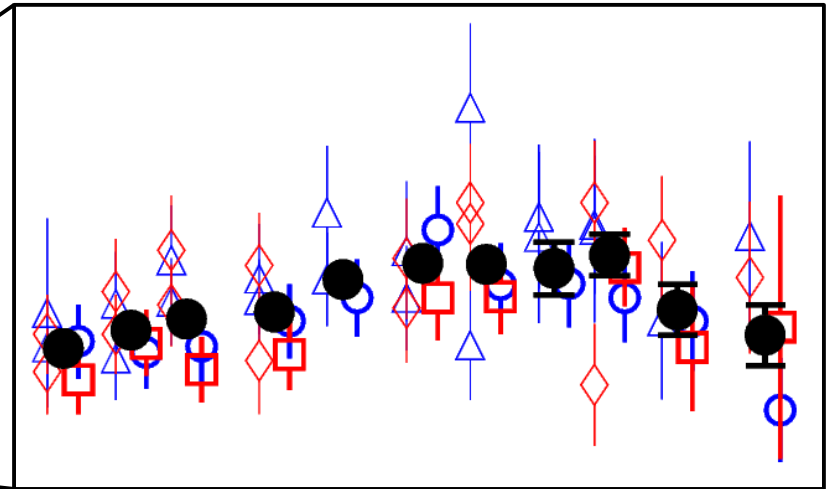


Averaged cross sections: NC e^+p

H1 and ZEUS



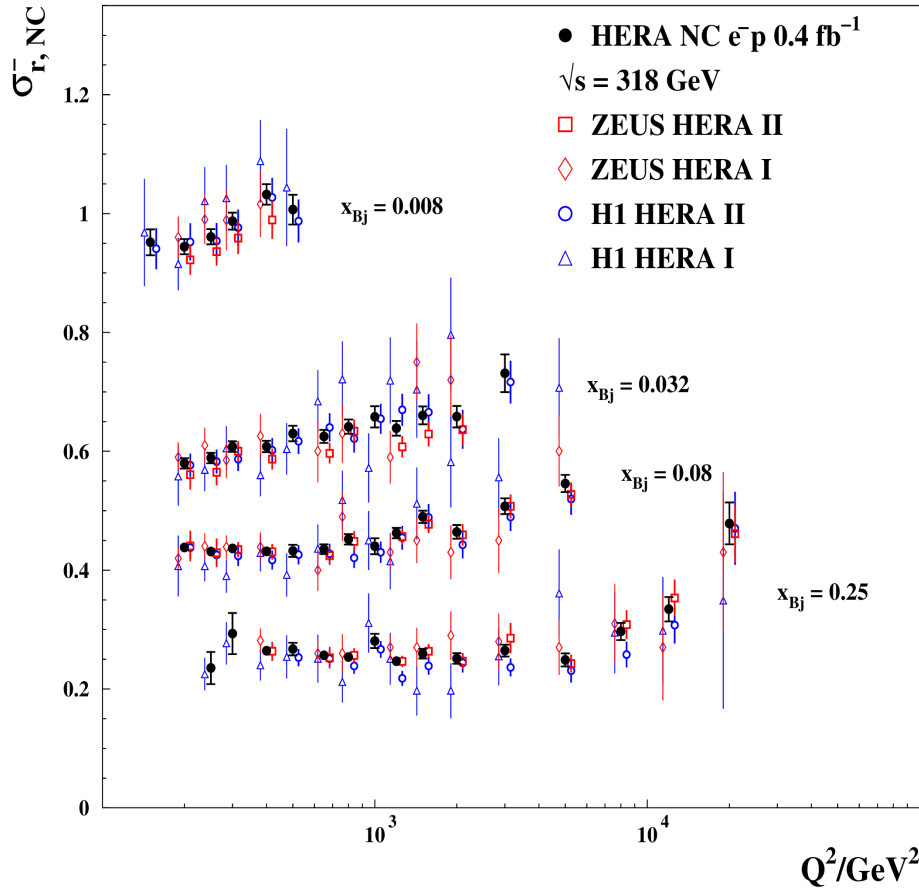
• 2927 data points
combined to 1307



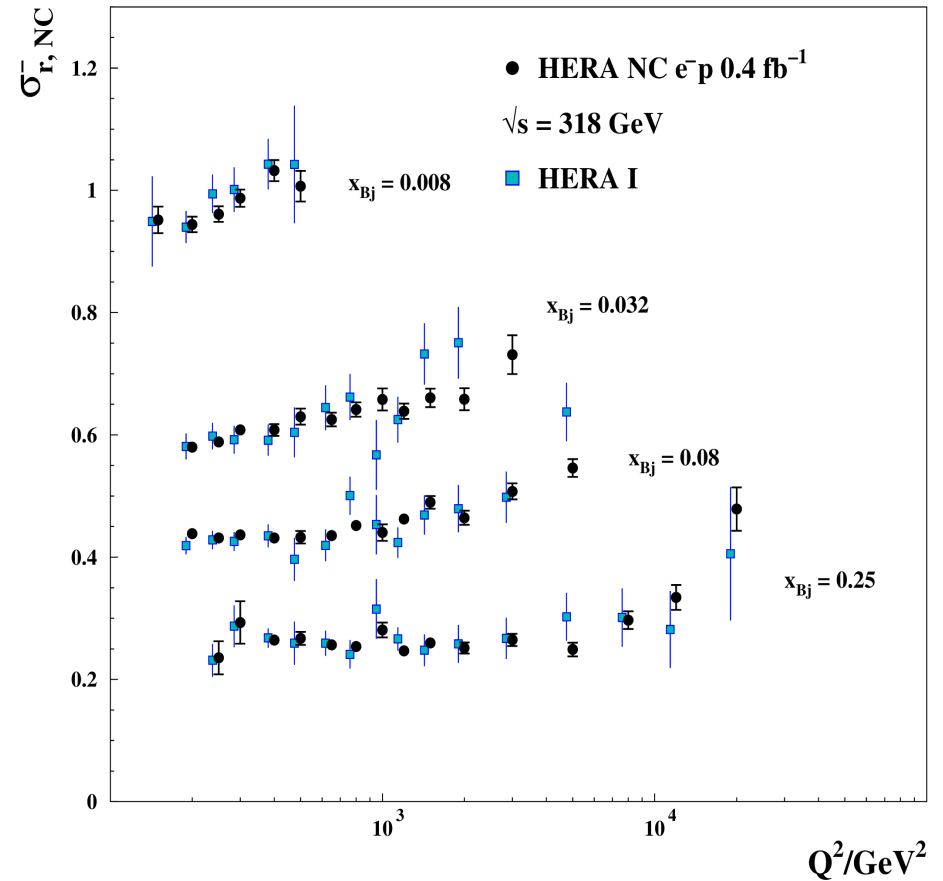
• up to 8 data points
combined to 1

Averaged cross sections: NC e-p

H1 and ZEUS



H1 and ZEUS

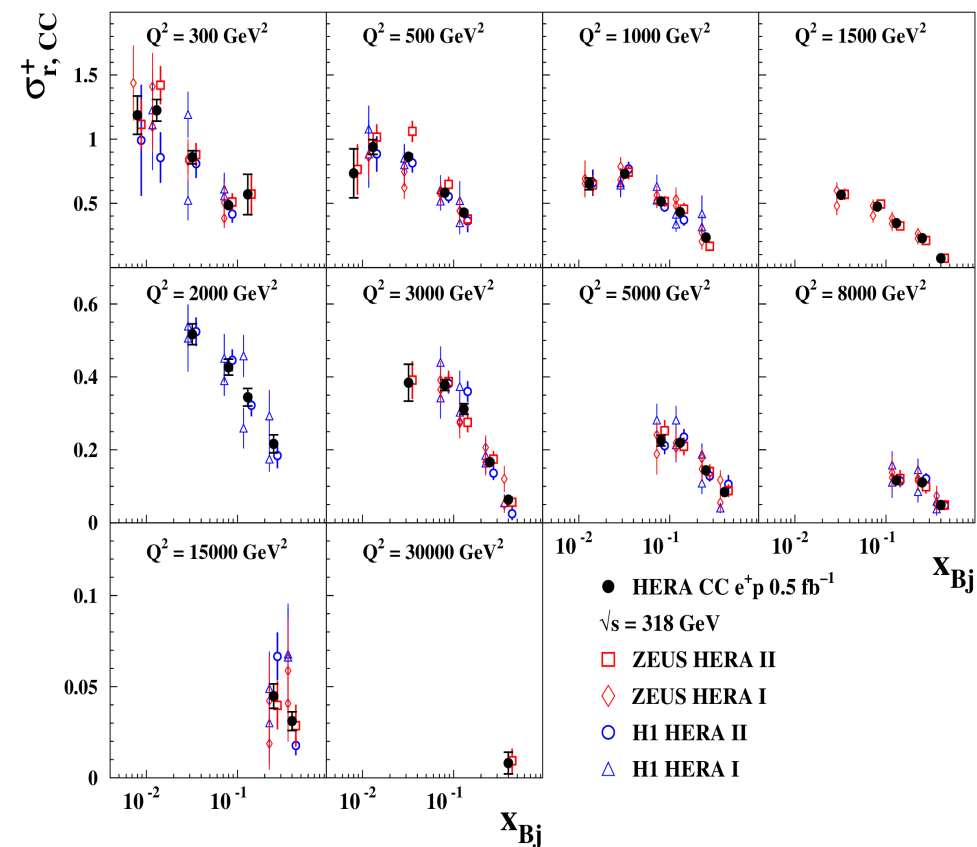


- ~3 times larger luminosity for NC e+p compare to HERA I, and for NC e-p — 10 times !
- Reduced systematic uncertainties due to cross calibration of data from two experiment.
- Combined data accuracy reaches ~1%.

Averaged cross sections: CC $e^\pm p$

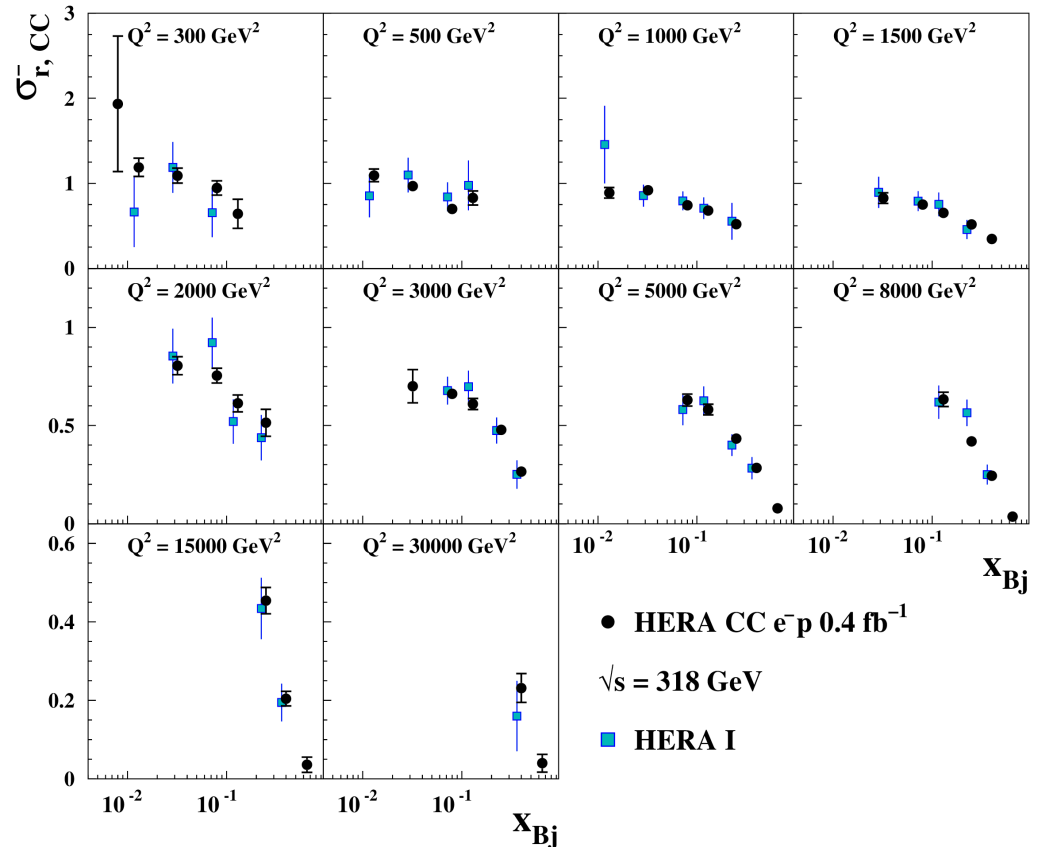
CC e^+p

H1 and ZEUS



CC e^-p

H1 and ZEUS

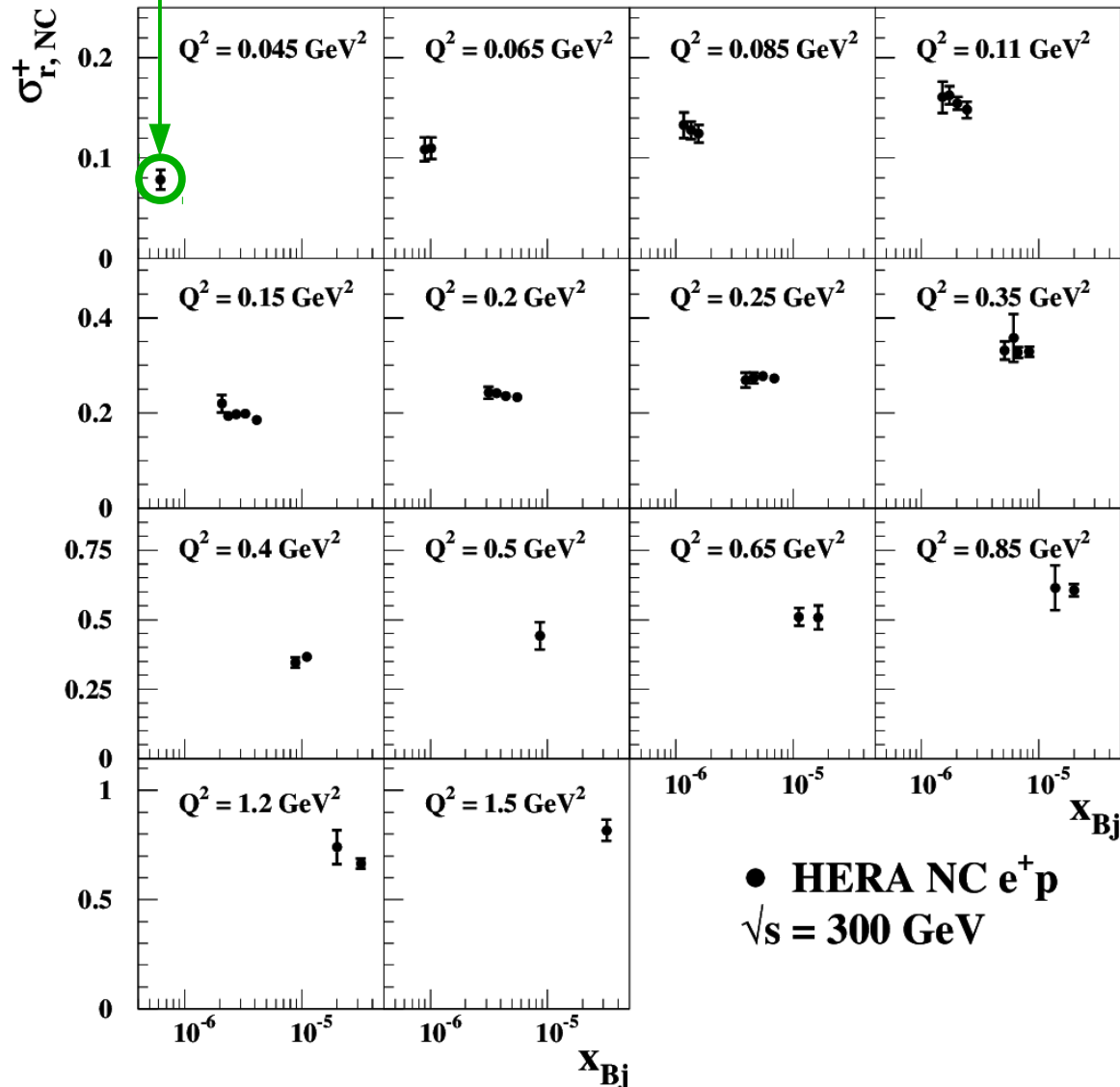


- Many data points are combined into one averaged point
- Kinematic range extended

Low Q^2 data

Lowest achieved Q^2 point

H1 and ZEUS



Combined inclusive cross sections for low Q^2 available for two CMEs:

- 300 GeV
- 318 GeV

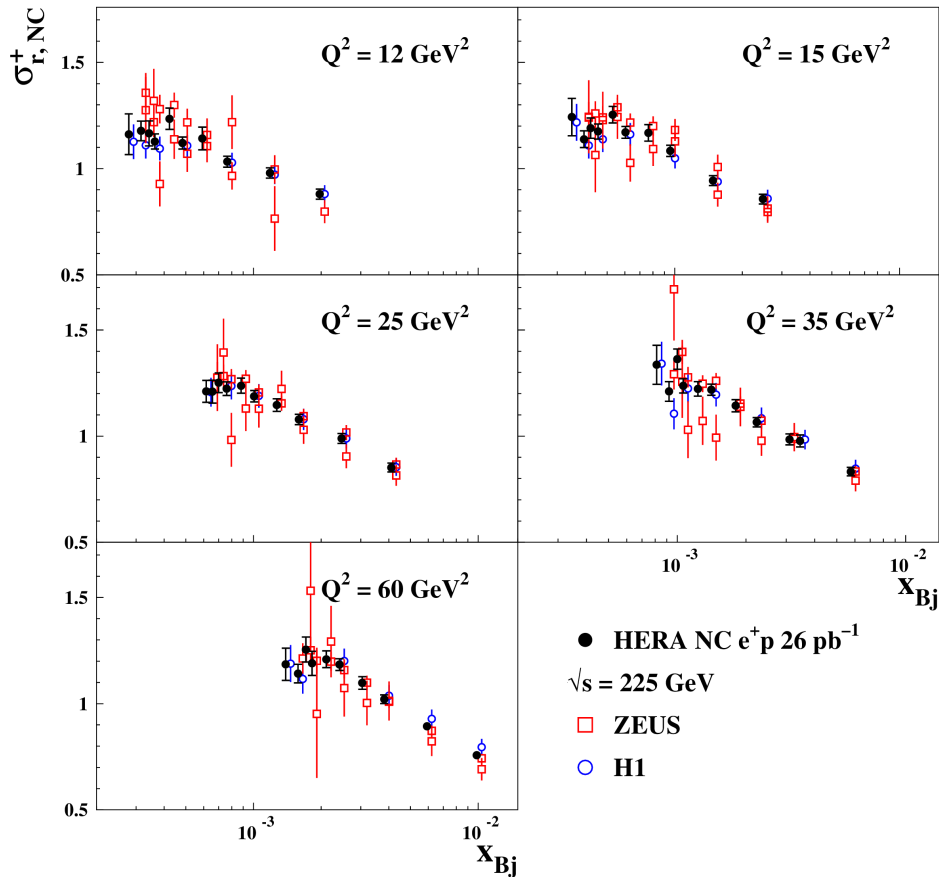
Interesting for:

- dipole / saturation models;
- study of higher twists.

New CME data: NC e^+p

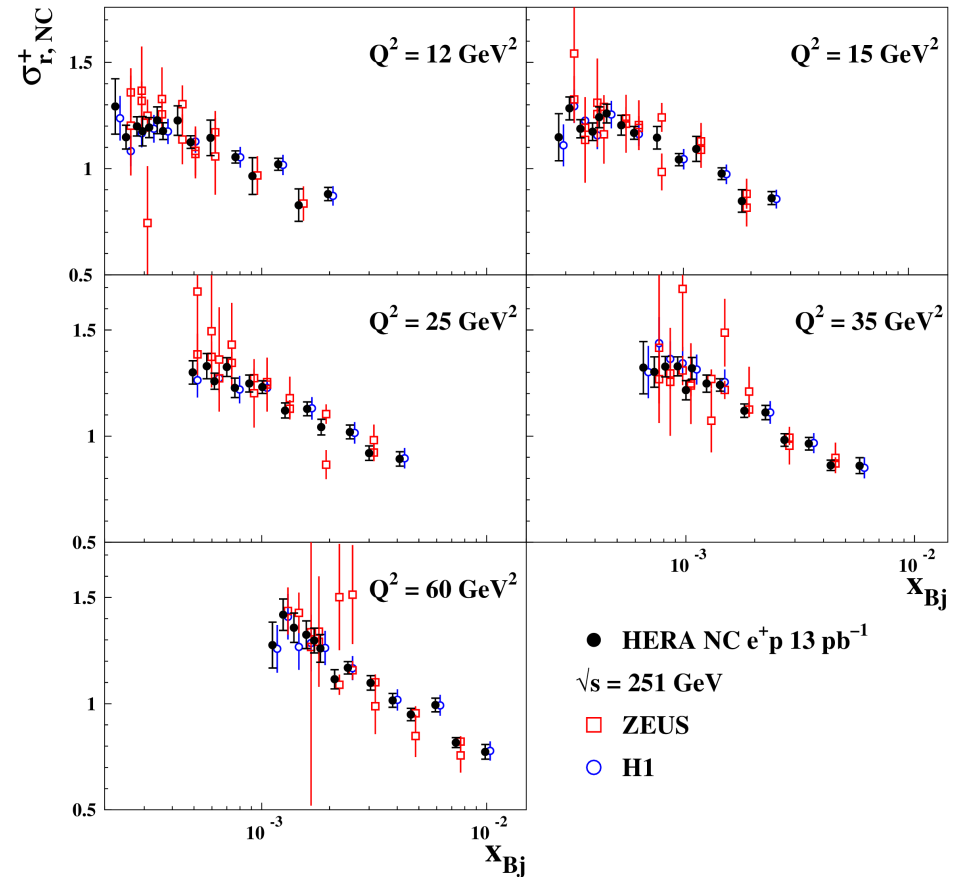
$E_p = 460 \text{ GeV}$

H1 and ZEUS



$E_p = 575 \text{ GeV}$

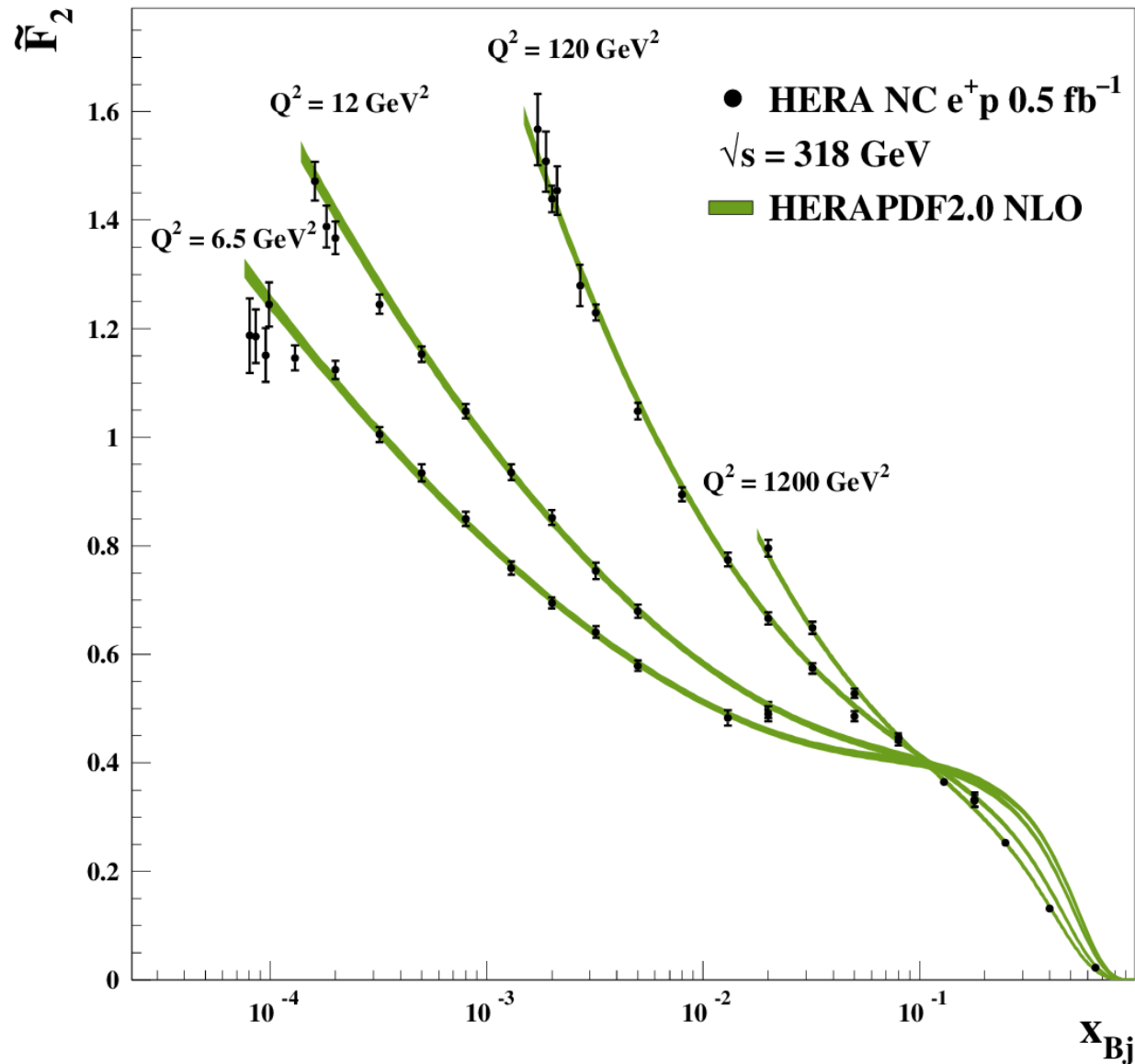
H1 and ZEUS



- Lowered proton beam energies data included

Scaling violations

H1 and ZEUS

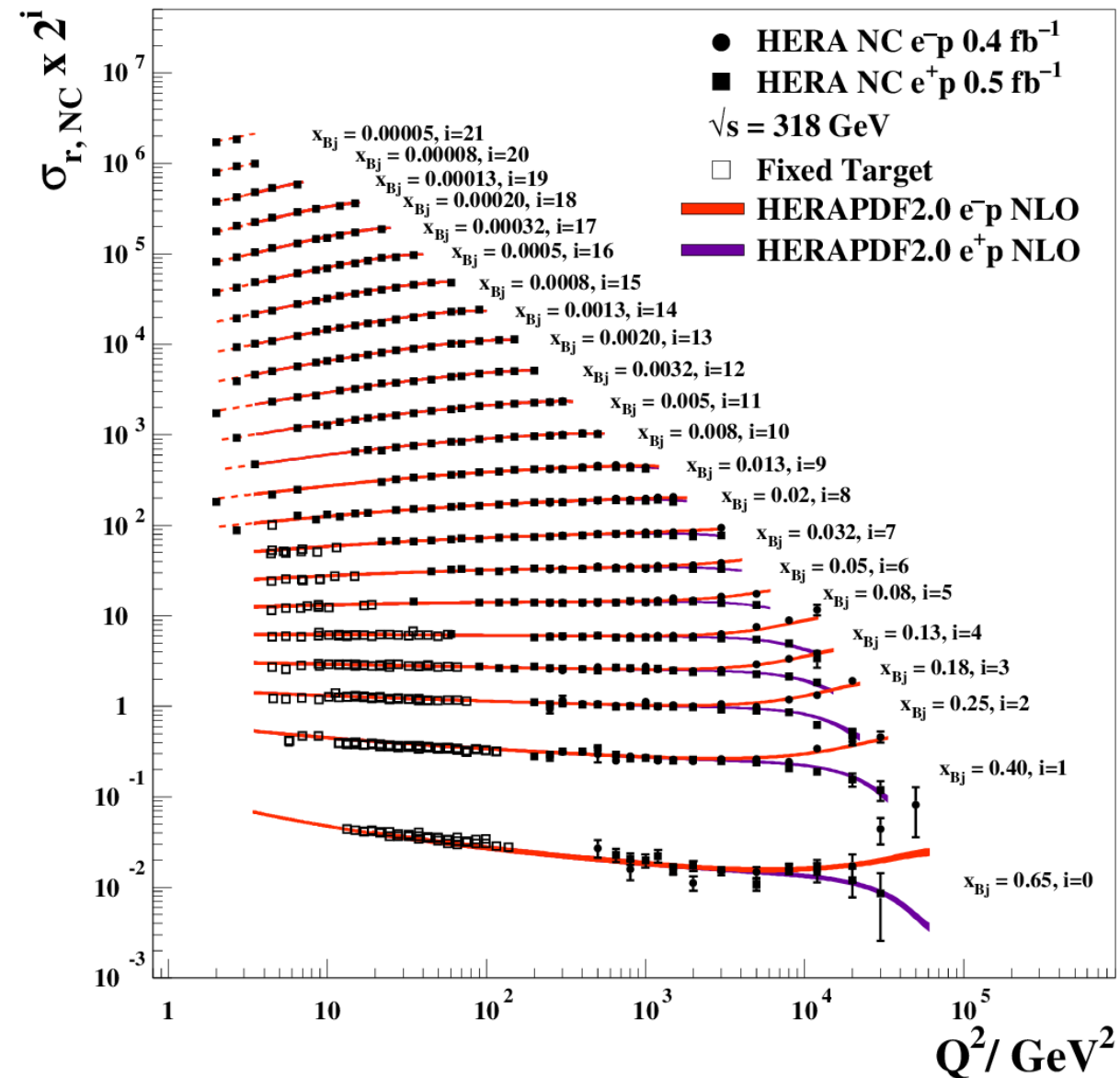


Scaling violations introduce a step rise of \tilde{F}_2 at low x_{Bj} :

◆ Steeper rise for higher Q^2 .

γZ^0 interference

H1 and ZEUS



Difference in NC e^+p and e^-p at high Q^2 :

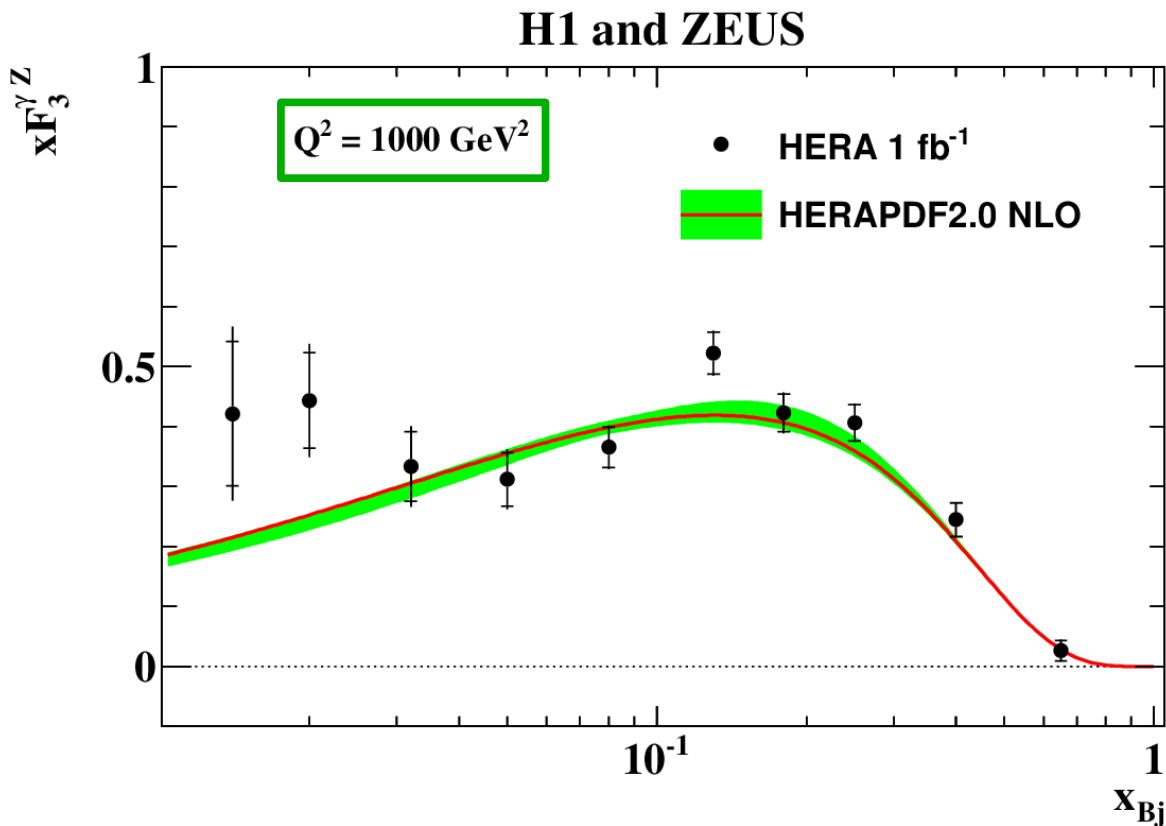
◆ $Q^2 \sim M_Z^2 \Rightarrow \gamma Z^0$ interference clearly seen :

◆ In NC e^+p negative γZ^0 interference

◆ In NC e^-p positive γZ^0 interference

$xF_3^{\gamma Z}$ from combined data

- $xF_3^{\gamma Z}$ estimated by subtracting NC e^+p and e^-p cross sections
- Due to weak dependance in Q^2 — translated to $Q^2 = 1000 \text{ GeV}^2$ and averaged.



- Integrated over x_{Bj} :

$$0.016 < x_{Bj} < 0.725 :$$

$$\text{Data: } 1.314 \pm 0.081$$

$$\text{HERAPDF2.0: } 1.165^{+0.042}_{-0.053}$$

$$0 < x_{Bj} < 1 :$$

$$\text{Data: } 1.790 \pm 0.110$$

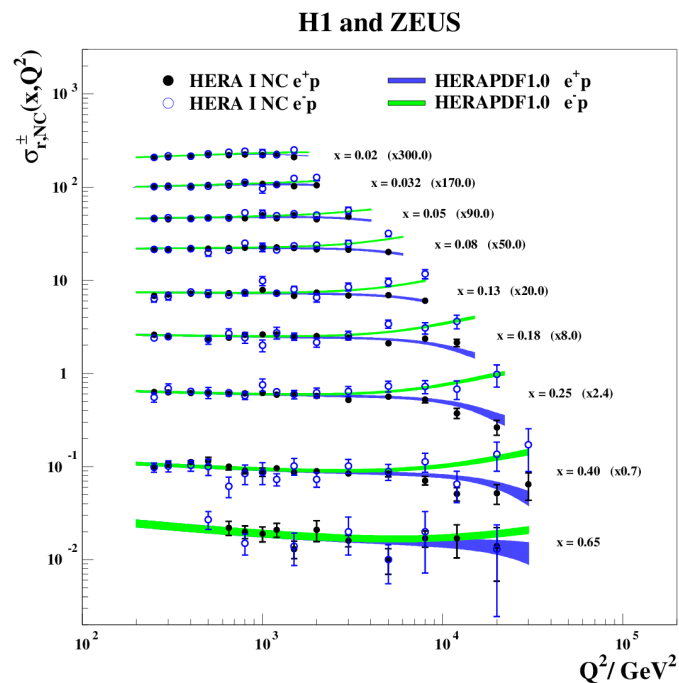
$$\text{HERAPDF2.0: } 1.588^{+0.078}_{-0.100}$$

$$\text{Theory: } \frac{5}{3}$$

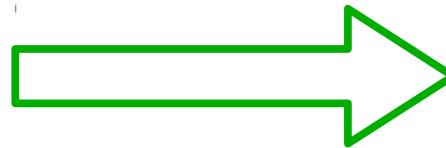
- Good agreement with theory predictions

Summary

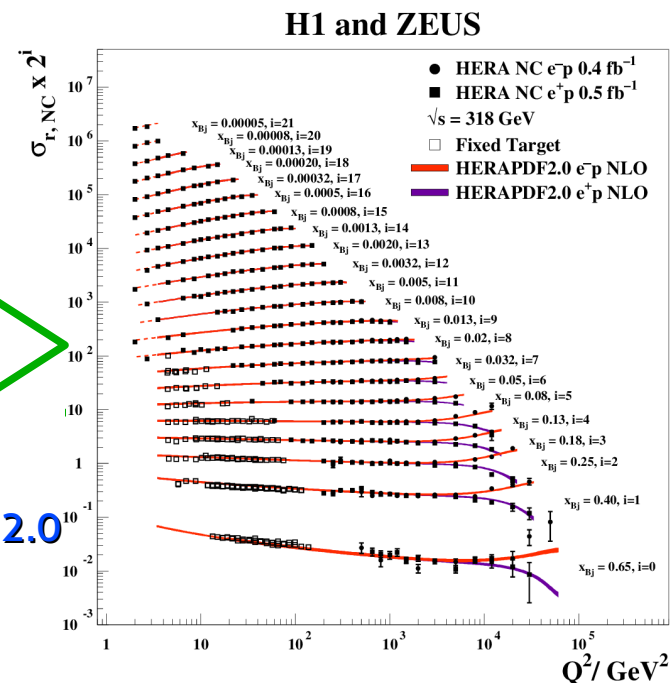
- Combination of all final inclusive deep inelastic cross sections measured by the H1 and ZEUS collaborations has been finalized: [[arXiv:1506.06042](https://arxiv.org/abs/1506.06042)], <https://www.desy.de/h1zeus/herapdf20/>
- The total luminosity of about 1 fb^{-1} collected by two separate experiments provides us with cross sections of very high precision.
- Combined HERA I+II data used as an input in QCD analysis.



HERAPDF 1.0



HERAPDF 2.0



Additional material

Procedural uncertainties

The combination of the data done with HERAverager.

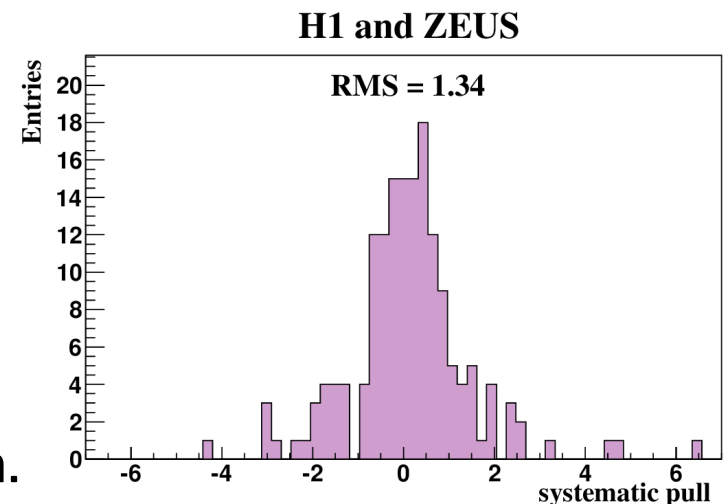
(available at wiki-zeuthen.desy.de/HERAverager).

All **162** correlated systematic sources are treated as multiplicative and the χ^2 definition:

$$\chi^2(\mathbf{m}, \mathbf{b}) = \sum_i \frac{[m^i - \sum_j \gamma_j^i m^i b_j - \mu^i]^2}{\delta_{i, \text{stat}}^2 \mu^i (m^i - \sum_j \gamma_j^i m^i b_j) + (\delta_{i, \text{uncorr}} m^i)^2} + \sum_j b_j^2$$

Procedural uncertainties estimated for:

- ◆ multiplicative vs additive;
- ◆ possible correlations between data sets:
 - ◆ photoproduction background;
 - ◆ hadronic energy scale;
- ◆ investigation of large pulls in combination.



Data samples

H1

ZEUS

Data set	\mathcal{L} [pb ⁻¹]	e ⁺ / e ⁻	\sqrt{s} [GeV]	Data set	\mathcal{L} [pb ⁻¹]	e ⁺ / e ⁻	\sqrt{s} [GeV]		
HERA I $E_p = 820$ GeV and $E_p = 920$ GeV data sets									
H1 svx-mb	95-00	2.1	e ⁺ p	301, 319	ZEUS BPC	95	1.65	e ⁺ p	300
H1 low Q ²	96-00	22	e ⁺ p	301,319	ZEUS BPT	97	3.9	e ⁺ p	300
H1 NC	94-97	35.6	e ⁺ p	301	ZEUS SVX	95	0.2	e ⁺ p	300
H1 CC	94-97	35.6	e ⁺ p	301	ZEUS NC	96-97	30.0	e ⁺ p	300
H1 NC	98-99	16.4	e ⁻ p	319	ZEUS CC	94-97	47.7	e ⁺ p	300
H1 CC	98-99	16.4	e ⁻ p	319	ZEUS NC	98-99	15.9	e ⁻ p	318
H1 NC HY	98-99	16.4	e ⁻ p	319	ZEUS CC	98-99	16.4	e ⁻ p	318
H1 NC	99-00	65.2	e ⁺ p	319	ZEUS NC	99-00	63.2	e ⁺ p	318
H1 CC	99-00	65.2	e ⁺ p	319	ZEUS CC	99-00	60.9	e ⁺ p	318
HERA II $E_p = 920$ GeV data sets									
H1 NC	03-07	182.0	e ⁺ p	319	ZEUS NC	06-07	135.5	e ⁺ p	318
H1 CC	03-07	182.0	e ⁺ p	319	ZEUS CC	06-07	132.0	e ⁺ p	318
H1 NC	03-07	151.7	e ⁻ p	319	ZEUS NC	05-06	169.9	e ⁻ p	318
H1 CC	03-07	151.7	e ⁻ p	319	ZEUS CC	04-06	175.0	e ⁻ p	318
H1 NC med Q ²	03-07	97.6	e ⁺ p	319	ZEUS NC nominal	06-07	44.5	e ⁺ p	318
H1 NC low Q ²	03-07	5.9	e ⁺ p	319	ZEUS NC satellite	06-07	44.5	e ⁺ p	318
HERA II $E_p = 575$ GeV data sets									
H1 NC high Q ²	07	5.4	e ⁺ p	252	ZEUS NC nominal	07	7.1	e ⁺ p	251
H1 NC low Q ²	07	5.9	e ⁺ p	252	ZEUS NC satellite	07	7.1	e ⁺ p	251
HERA II $E_p = 460$ GeV data sets									
H1 NC high Q ²	07	11.8	e ⁺ p	225	ZEUS NC nominal	07	13.9	e ⁺ p	225
H1 NC low Q ²	07	12.2	e ⁺ p	225	ZEUS NC satellite	07	13.9	e ⁺ p	225