Towards the ultimate precision from HERA data: HERAPDF2.0

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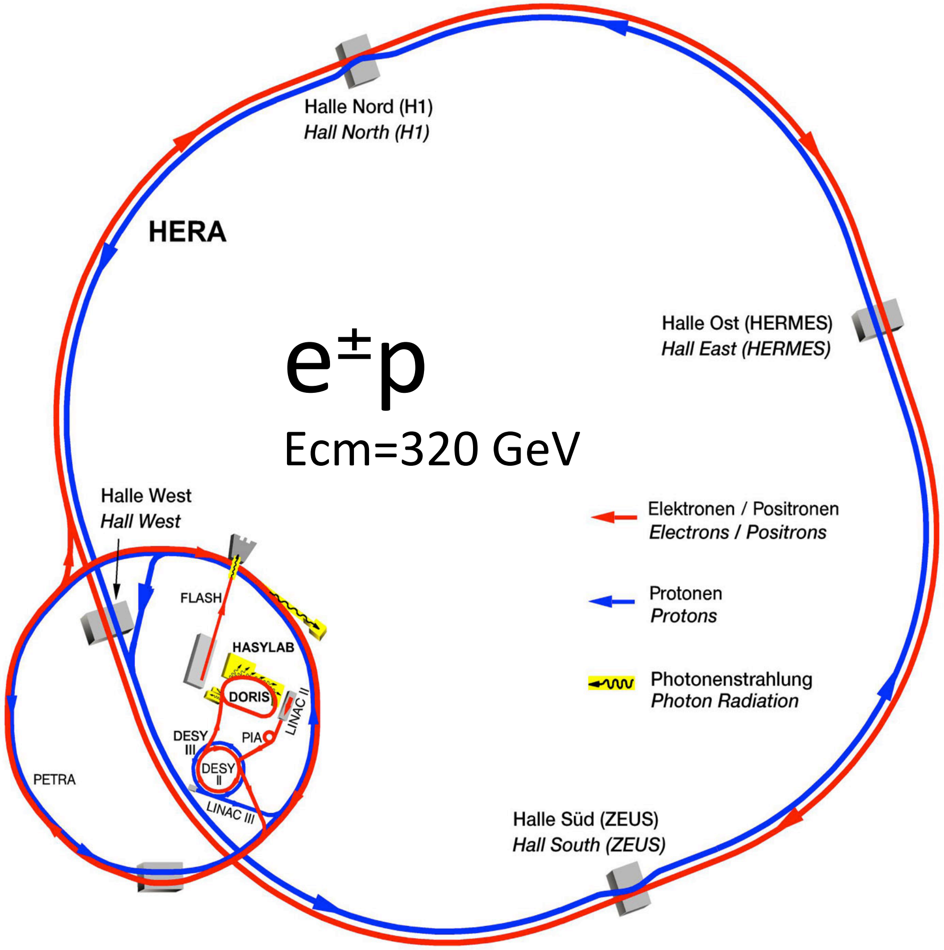
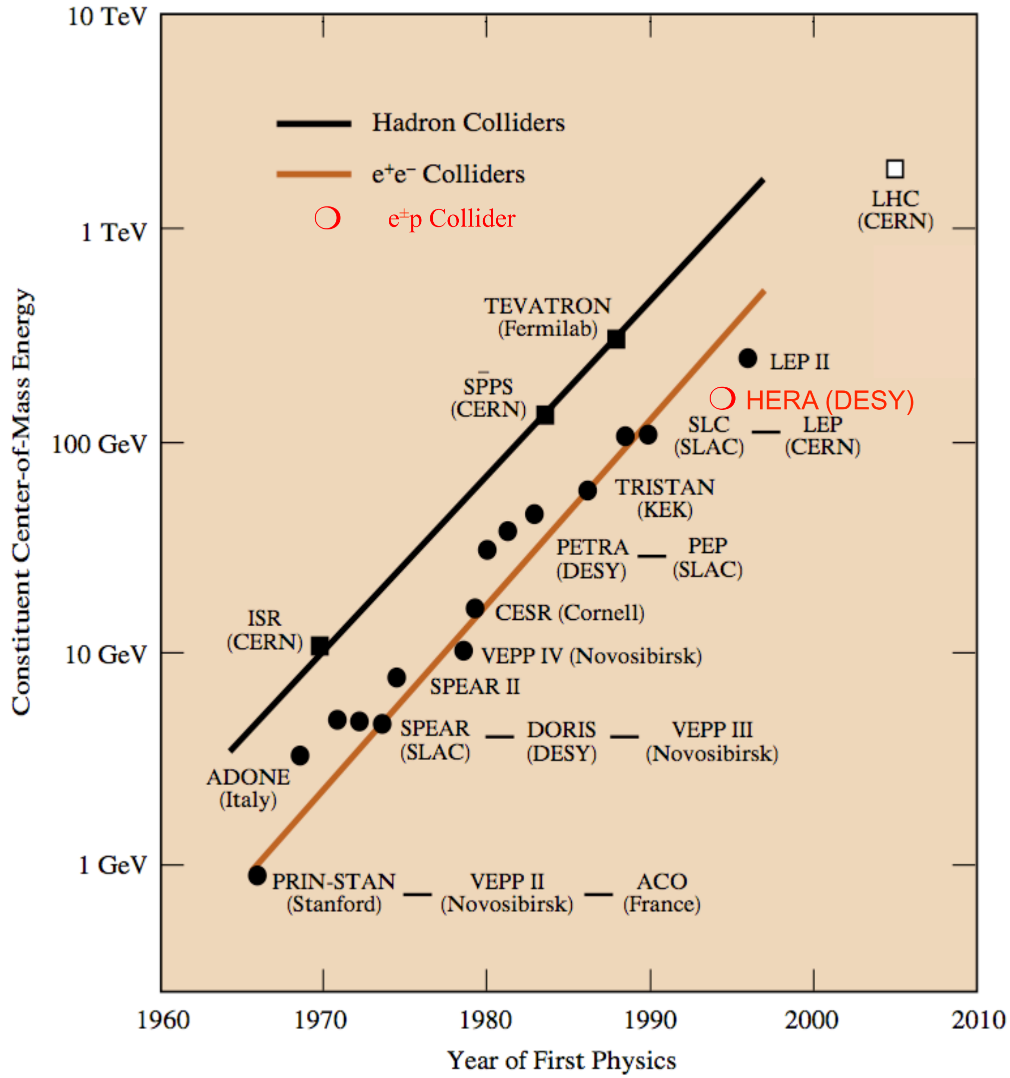
HERA: the unique ep collider



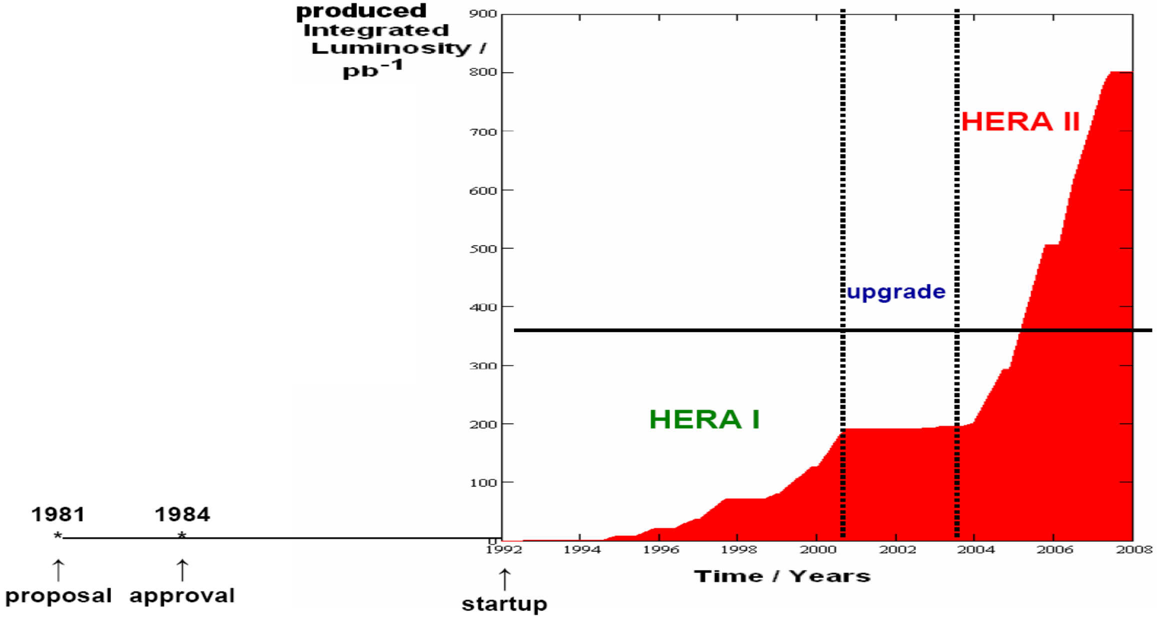


HERA Milestones

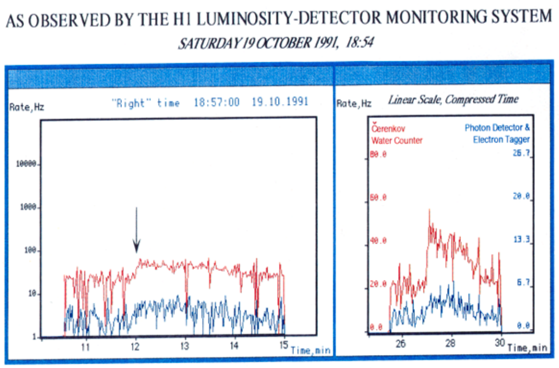
1981: proposal

1984: decision

Volker Soergel and the Minister of Science of Germany, Heinz Riesenhuber, at DESY (Hamburg) announcing on 6th of April 1984 that HERA will be built.

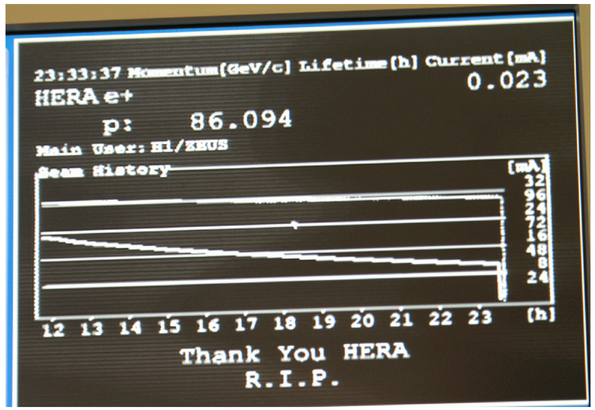


1991: first collisions



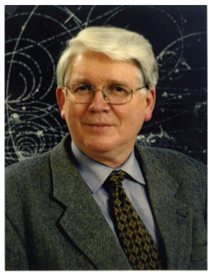
Electron Energy	12 GeV
Proton Energy	480 GeV
Expected Luminosity	$0.95 \times 10^{26} \pm 30\%\ cm^{-2}s^{-1}$
Measured Luminosity	$1.03 \times 10^{26} \pm 13\%\ cm^{-2}s^{-1}$

2007: end of collisions



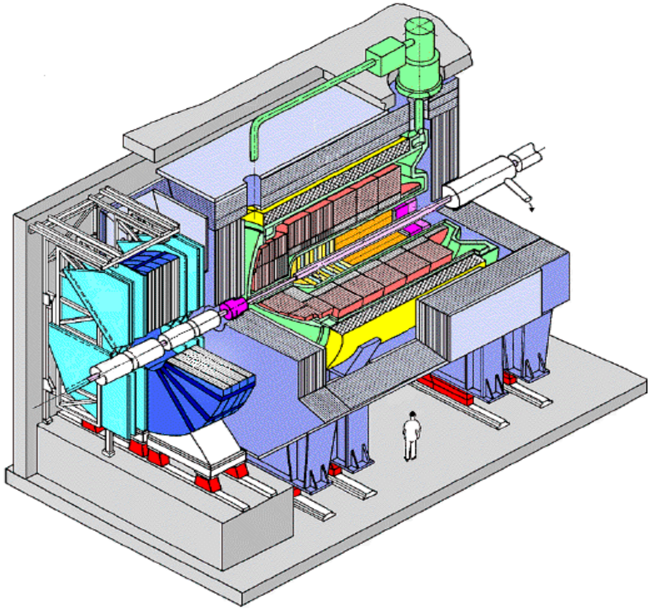
G.A.Voss, B. Wiik, F. Willeke

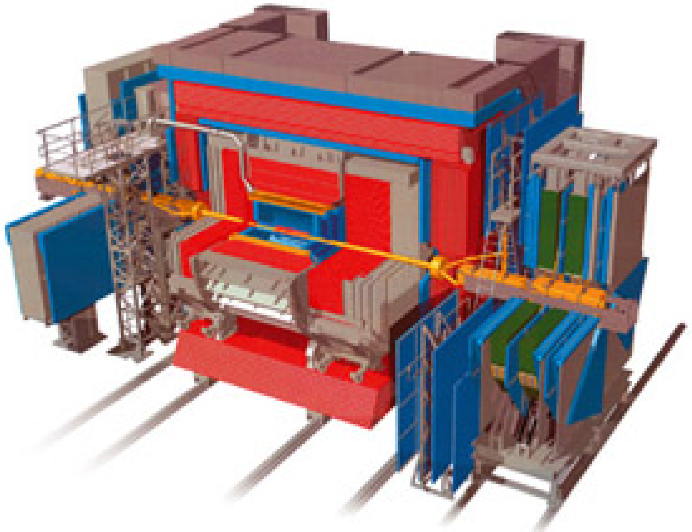
G. A. Voss



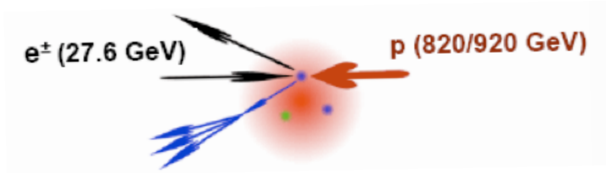
B. H. Wiik

Collider-mode detectors: H1 and ZEUS

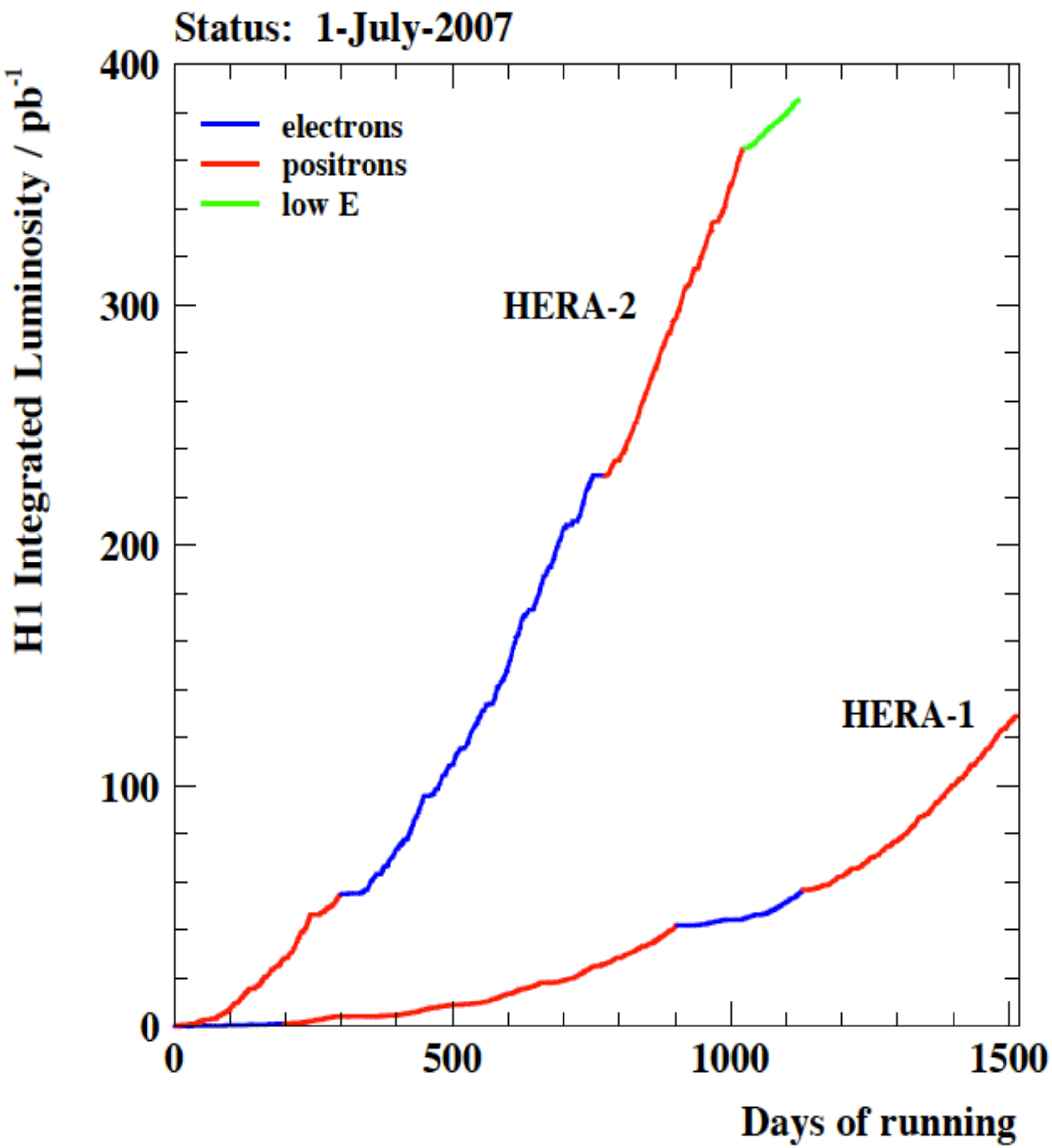




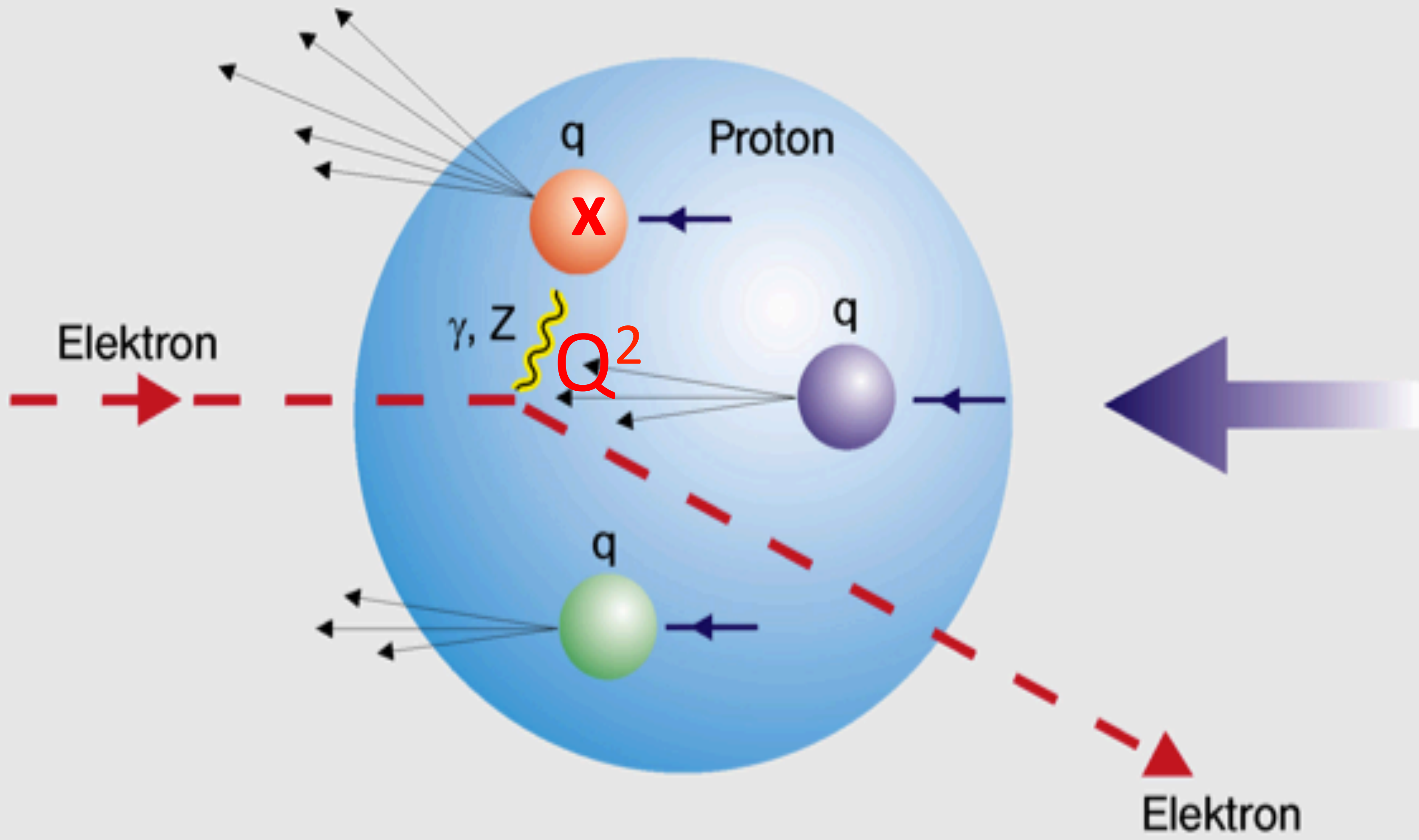
Data sets



- HERA I : 115 pb^{-1}
  - e+/e- 27.6 GeV
  - Protons 820/920 GeV
- HERA II: 330 pb^{-1}
  - Polarised e+/e- 27.6 GeV
  - Protons 920 GeV
    - L_{e+} x 3
    - L_{e-} x 10
- Low energy runs
  - Protons 460/575 GeV



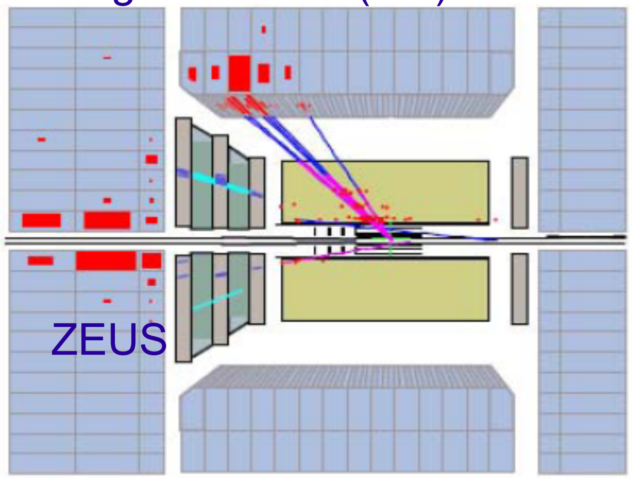
Deep-Inelastic Scattering



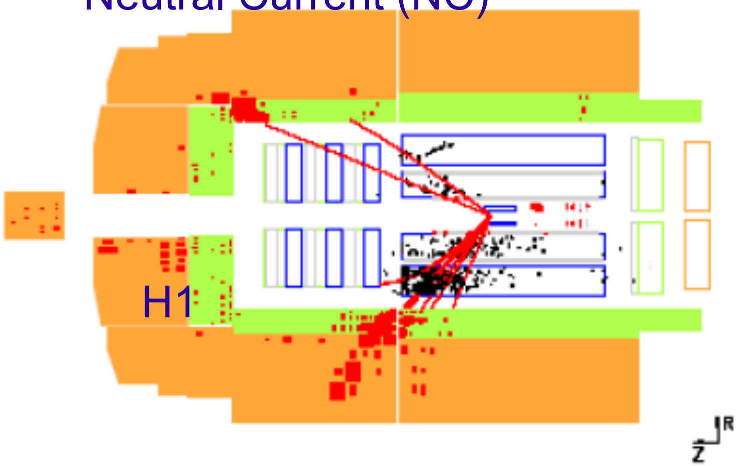
Kinematics x, Q2 can be measured from the detected particles
Charged current interactions also accessible (neutrino in the final state)

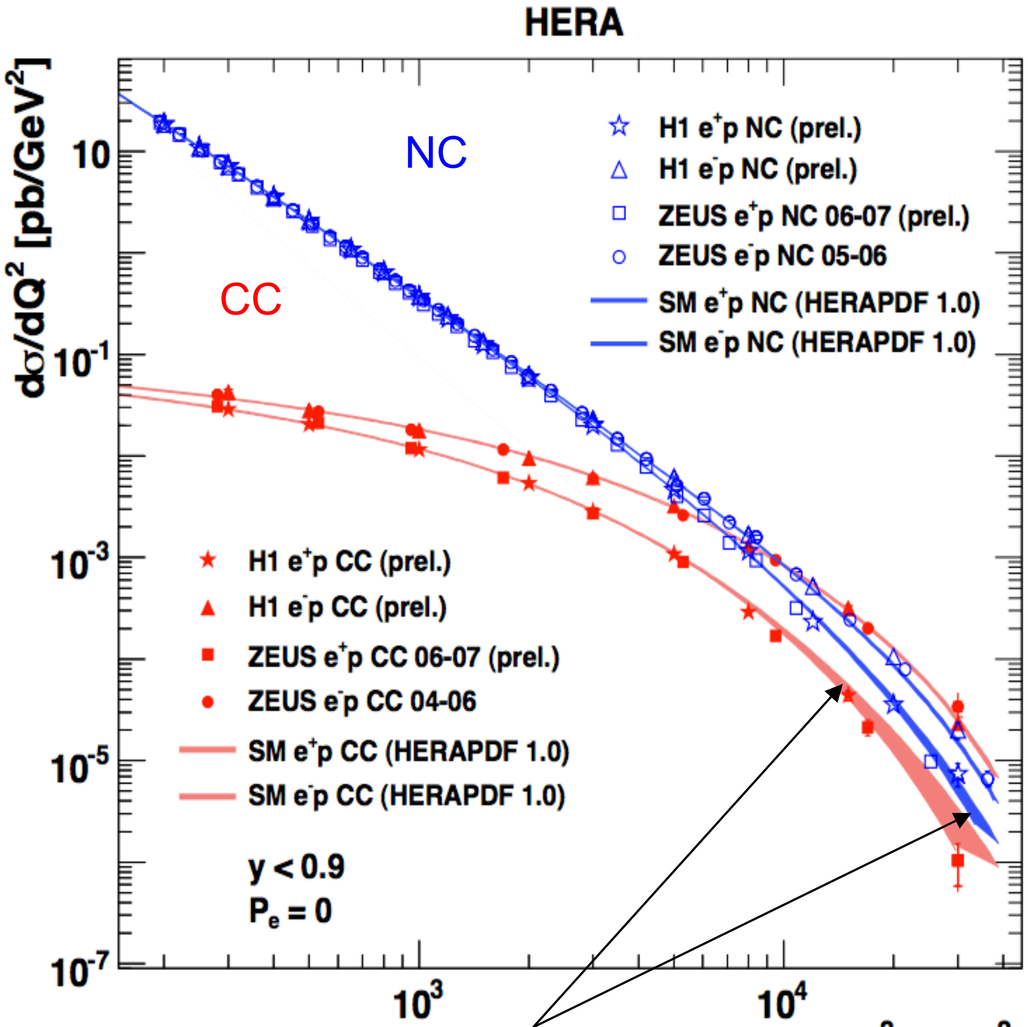
DIS at HERA

Charged Current (CC)



Neutral Current (NC)

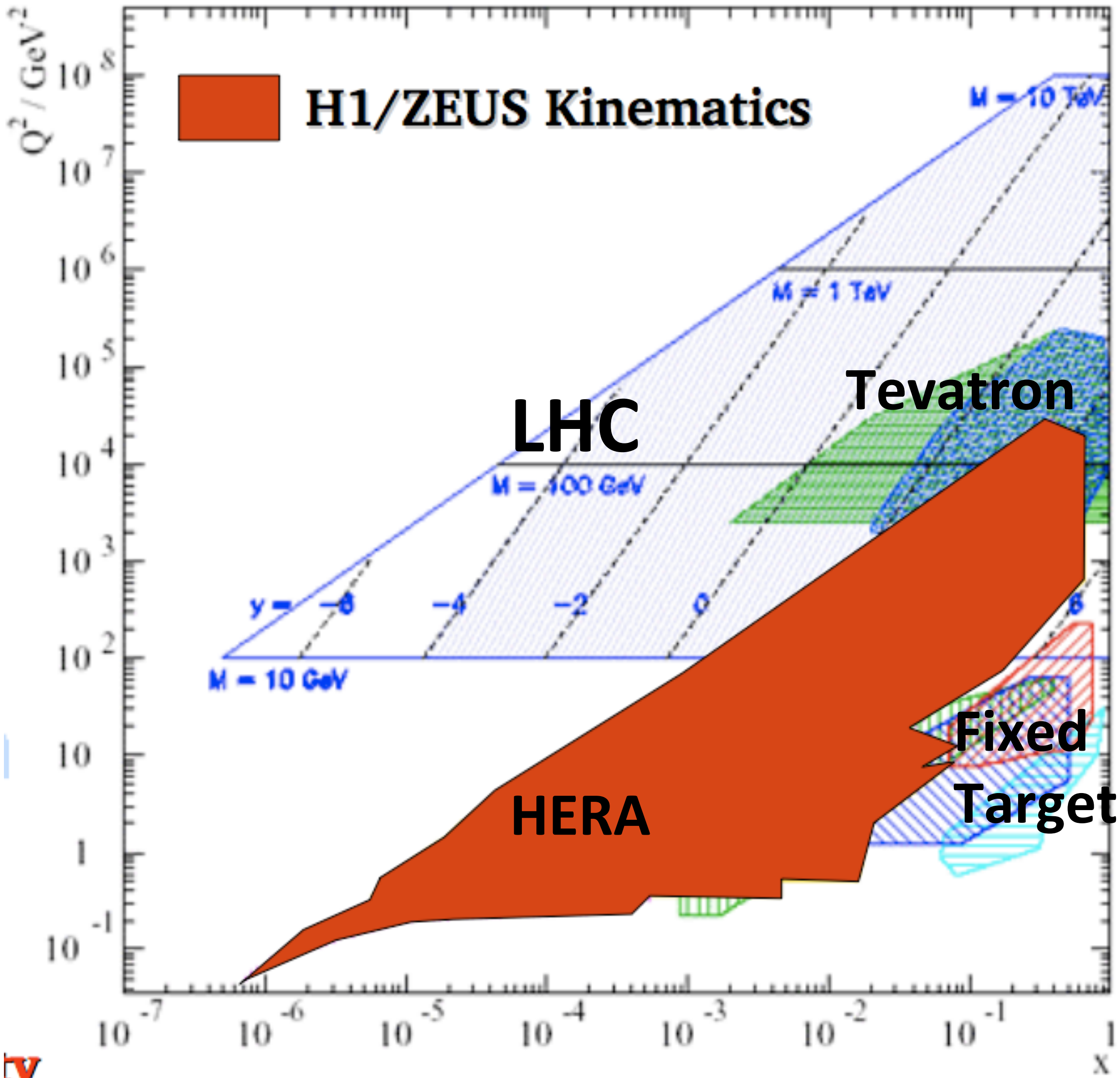




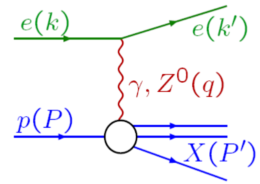
$Q^2 \sim M^2_{W,Z}$ (EW regime)

$r_{quark} < 10^{-18}$m
"p"/1000

Proton map x/Q^2



DIS: Cross sections, structure functions, partons



$$\tilde{\sigma}^{\pm}_{NC} = \frac{\mathrm{d}^2\sigma^{e^{\pm}p}_{NC}}{\mathrm{d}x\mathrm{d}Q^2}\frac{xQ^4}{2\pi\alpha^2 Y_+} = \tilde{F}_2 - \frac{y^2}{Y_+}\tilde{F}_L \mp \frac{Y_-}{Y_+}x\tilde{F}_3, \quad Y_{\pm} = 1 \pm (1-y)^2$$

Leading Order picture of the proton

Parton Distribution Functions

F_2 $$\left[F_2, F_2^{\gamma Z}, F_2^Z\right] = x\sum_q \left[e_q^2, 2e_q v_q, v_q^2 + a_q^2\right](q+\bar{q})$$ **quarks**

gluons from scaling violations

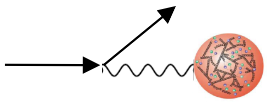
F_3 $$\left[xF_3^{\gamma Z}, xF_3^Z\right] = 2x\sum_q \left[e_q a_q, v_q a_q\right](q-\bar{q})$$ **(valence) quarks**

F_L $$F_L \sim x\alpha_s g$$ **gluons**

CC: similar decomposition, but different quarks combinations accessed
flavour sensitive (separate in e+p/e-p)

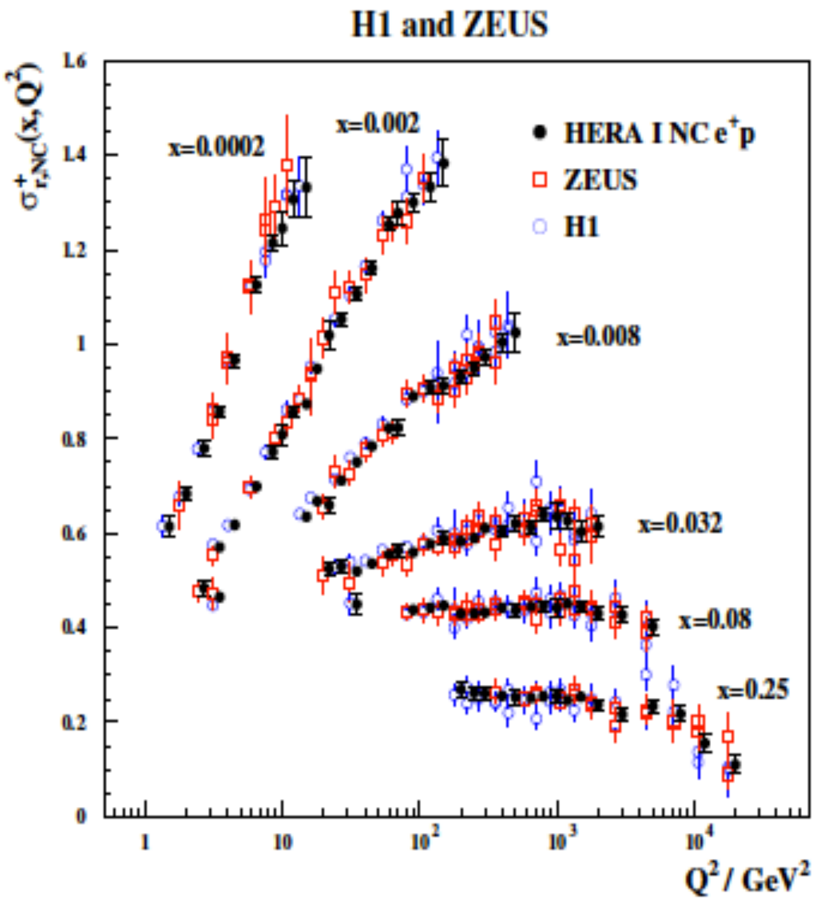
Proton structure from HERA data

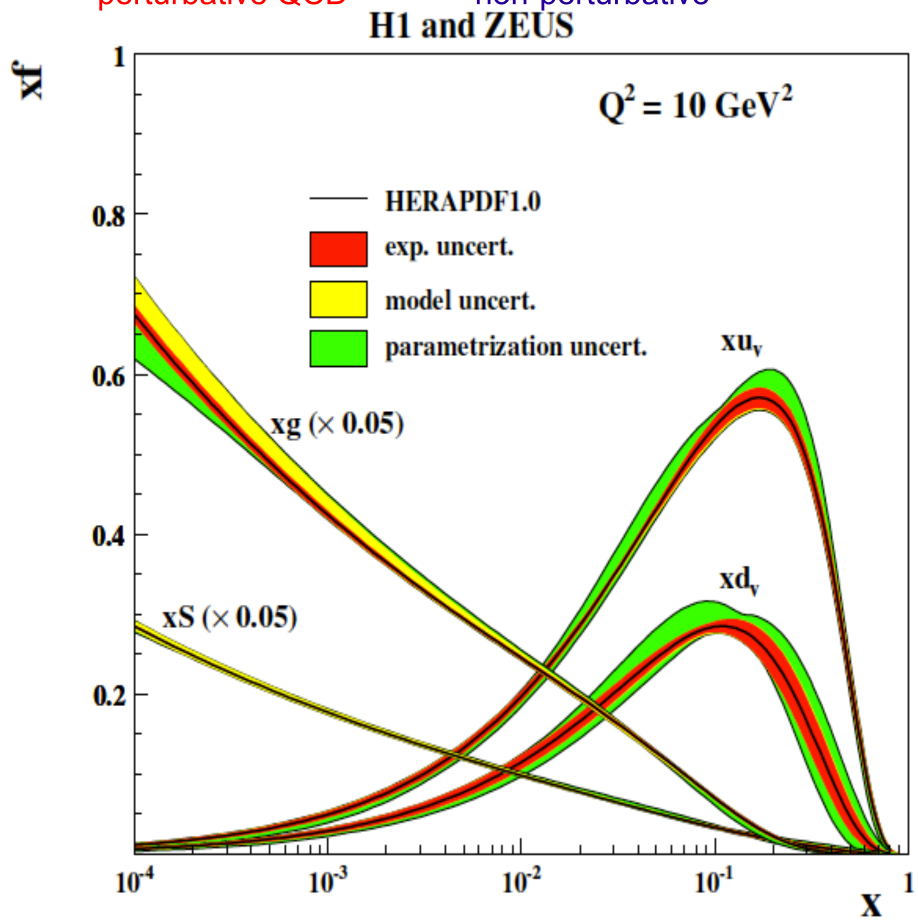
- Combination of data with consistent treatment of systematics
- Extraction of parton distribution functions (PDFs) using HERA data only
  - A milestone of HERA physics program: HERAPDF 1.0 (2009)



$$\sigma_{DIS} \equiv c_{\text{lepton}-\text{parton}} \otimes f(x, Q^2)$$

perturbative QCD — non-perturbative



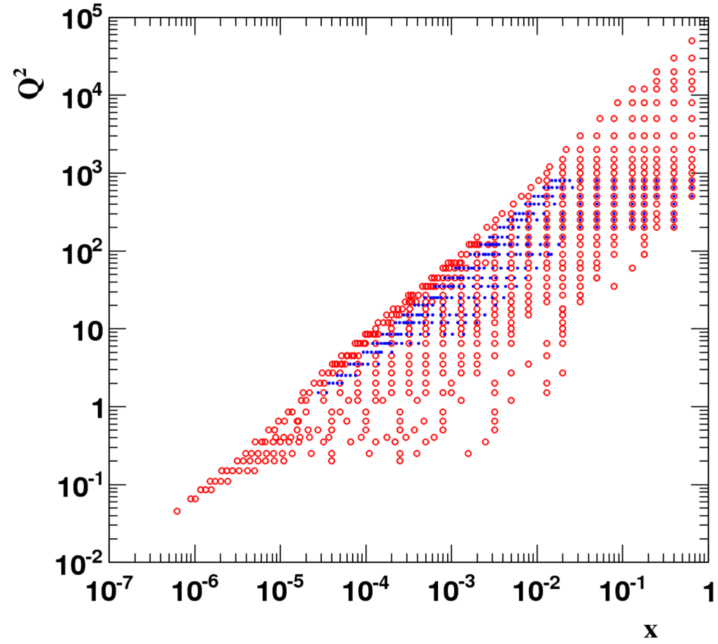


Full HERA Data Combination

- 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 Ep = 920 GeV
    - 4 high y data Ep = 920 GeV
    - 4 high y data Ep = 575 GeV
    - 4 high y data Ep = 460 GeV
- Procedure:
  - « Swim » data to a common x,Q2 grid
  - Average taking into account systematics
  - Include procedural errors
- Total of 2927 data points combined to 1307.

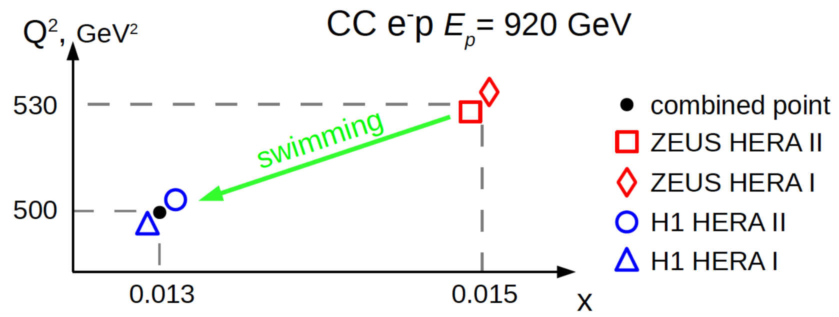
Data Combination

- Grid
  - Inclusive grid for Ep:820 and 920 GeV
  - Fine grid in x for low energy data
- Data is swimmed using a model



$$\sigma^{e\mp p}_{\rm meas}(x_{\rm grid},Q^2_{\rm grid}) = \frac{\sigma^{e\mp p}_{\rm model}(x_{\rm grid},Q^2_{\rm grid})}{\sigma^{e\mp p}_{\rm model}(x_{\rm meas},Q^2_{\rm meas})}\cdot\sigma^{e\mp p}_{\rm meas}(x_{\rm meas},Q^2_{\rm meas})$$

- Data is combined taking into account systematics



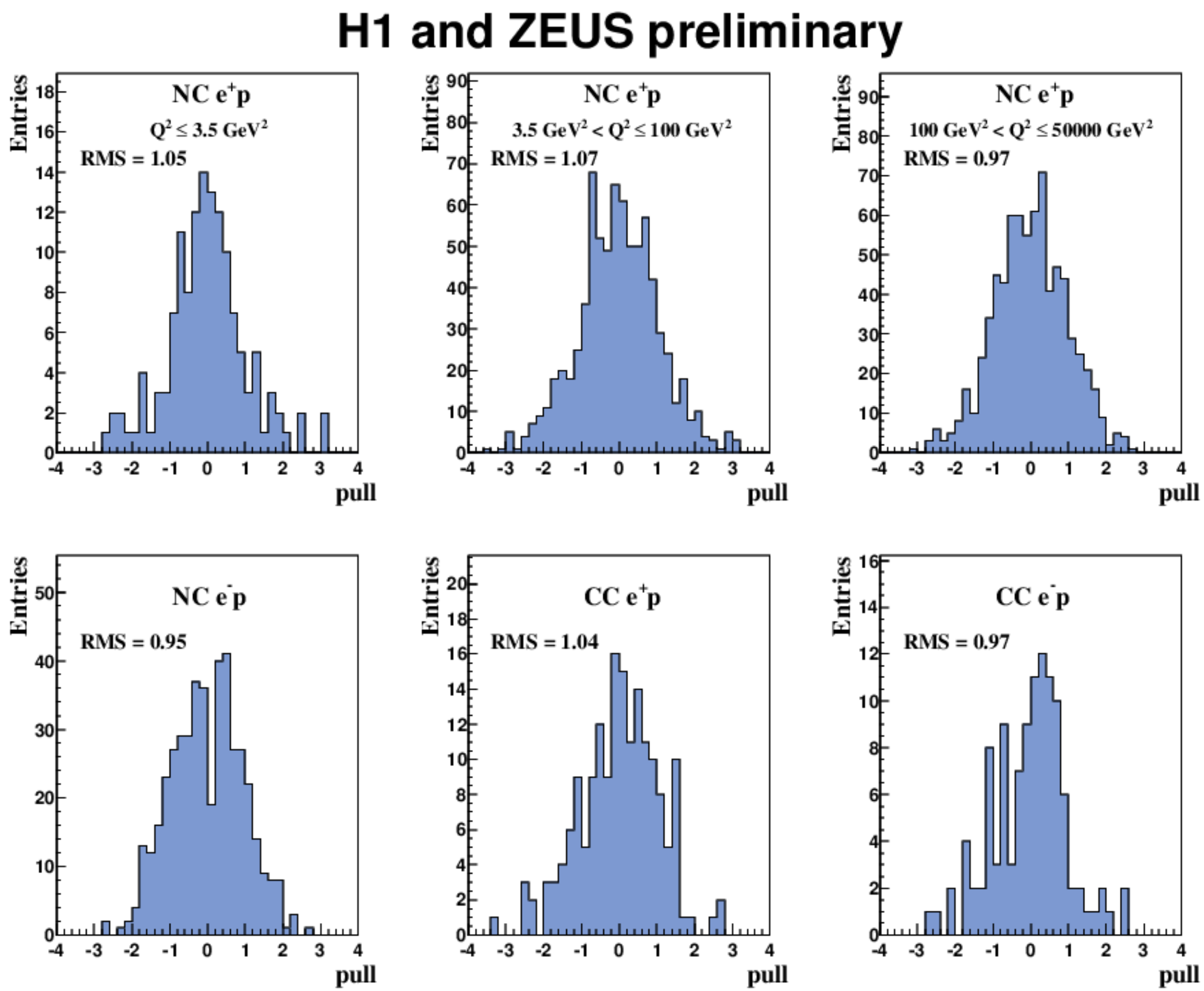
$$\chi^2_{\exp,ds}(\boldsymbol{m},\boldsymbol{b}) = \sum_{i,ds} + \sum_{j,b} = \sum_i \frac{\left[m^i - \sum_j \gamma^i_j m^i b_j - \mu^i\right]^2}{\delta^2_{i,\rm stat}\,\mu^i\left(m^i - \sum_j \gamma^i_j m^i b_j\right) + \left(\delta_{i,\rm uncor}\, m^i\right)^2} + \sum_j b_j^2 ,$$

Data combination

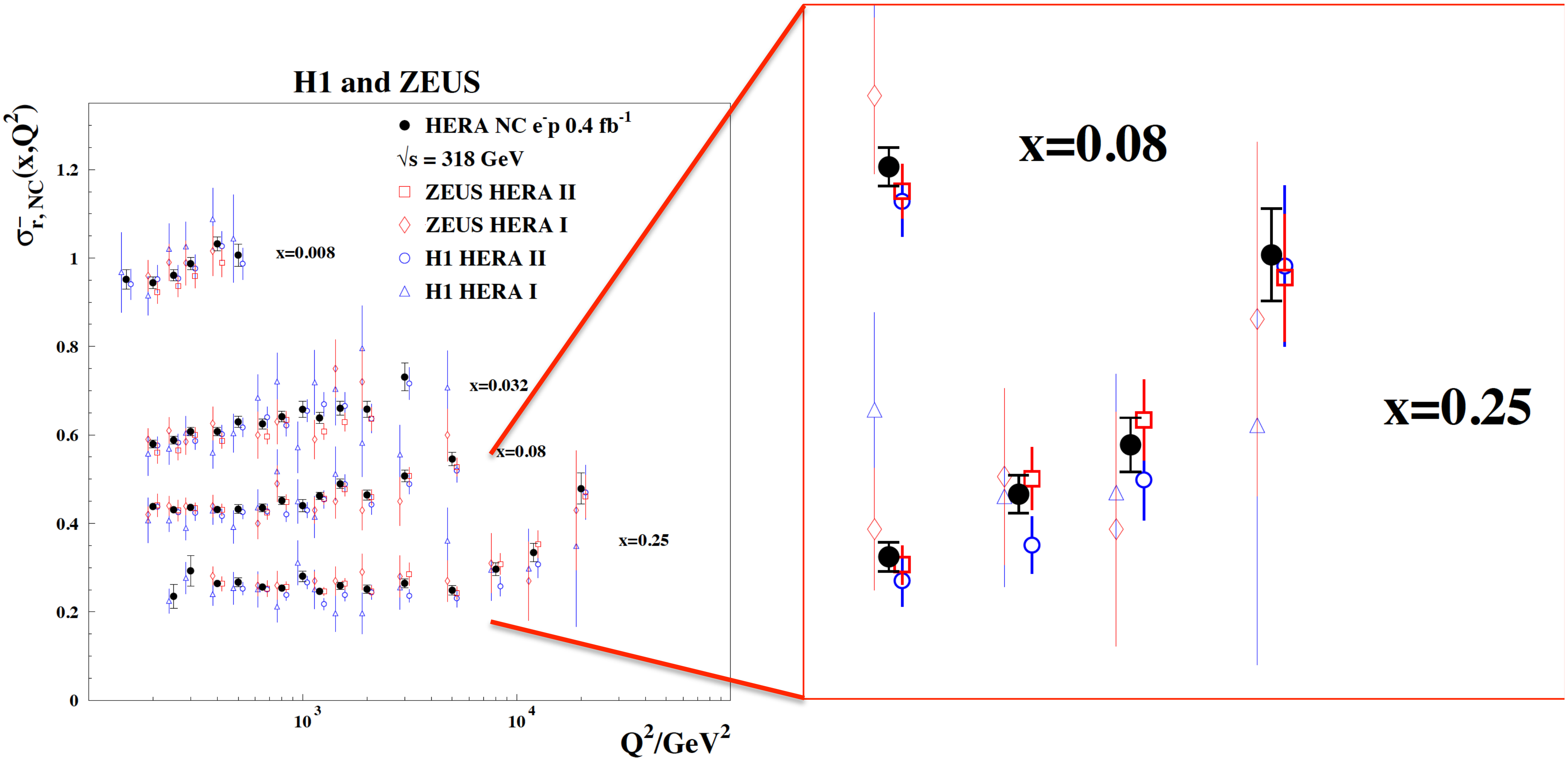
- Good consistency between the combined data sets

$$p^{i,k} = \frac{\mu^{i,k} - \mu^{i,\mathrm{ave}}\left(1 - \sum_j \gamma_j^{i,k} b_{j,\mathrm{ave}}\right)}{\sqrt{\Delta_{i,k}^2 - \Delta_{i,\mathrm{ave}}^2}}$$

χ2 / ndf = 1685 / 1620

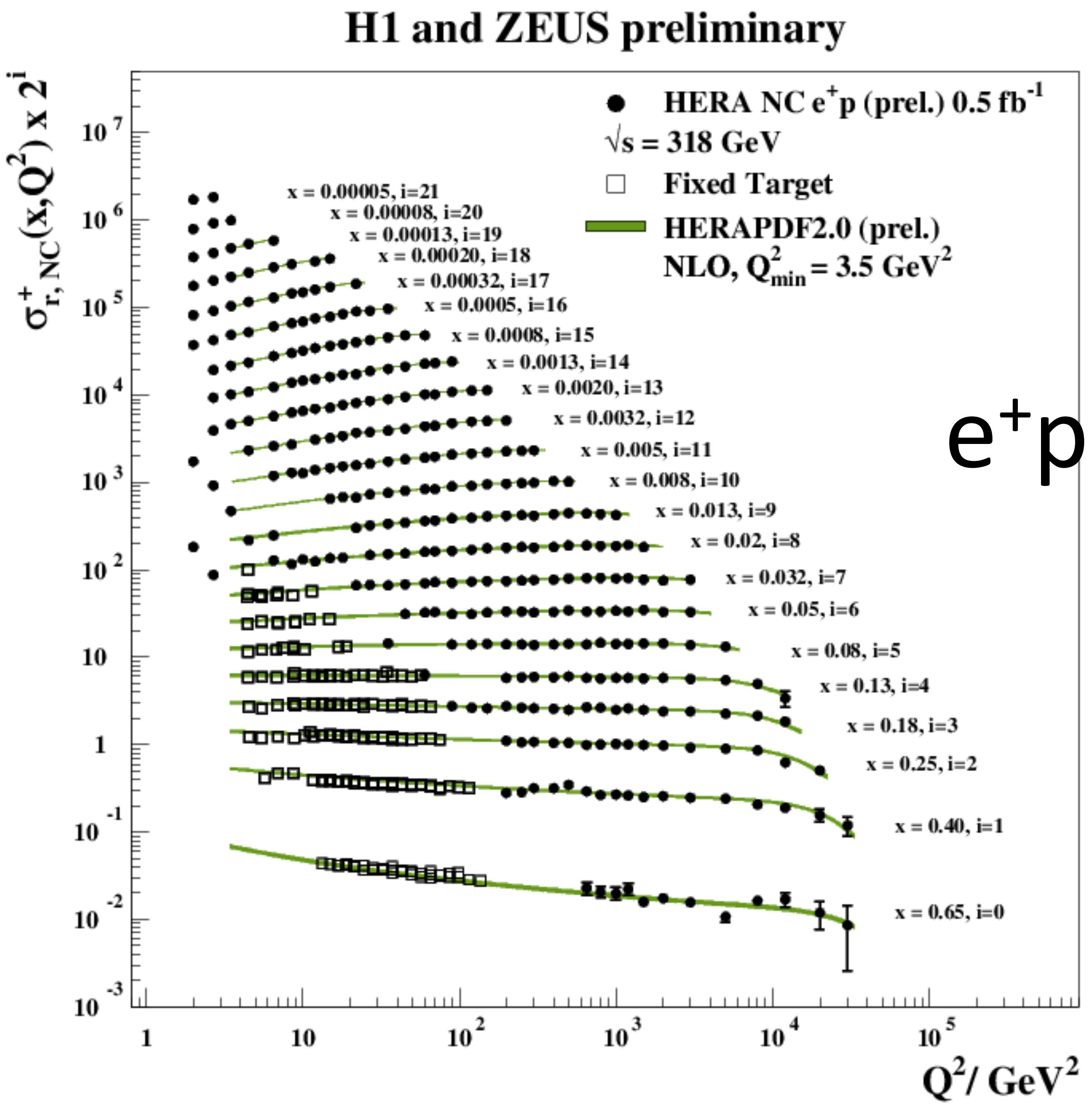


NC data combination



Tremendous gain in precision from data combination

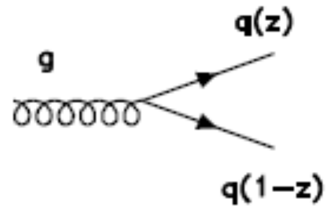
Proton map with full precision



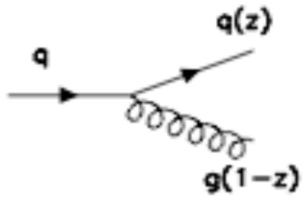
e^+p

Low x

$$\frac{\partial F_2}{\partial \log Q^2} \simeq \alpha_S g(x,Q^2)$$

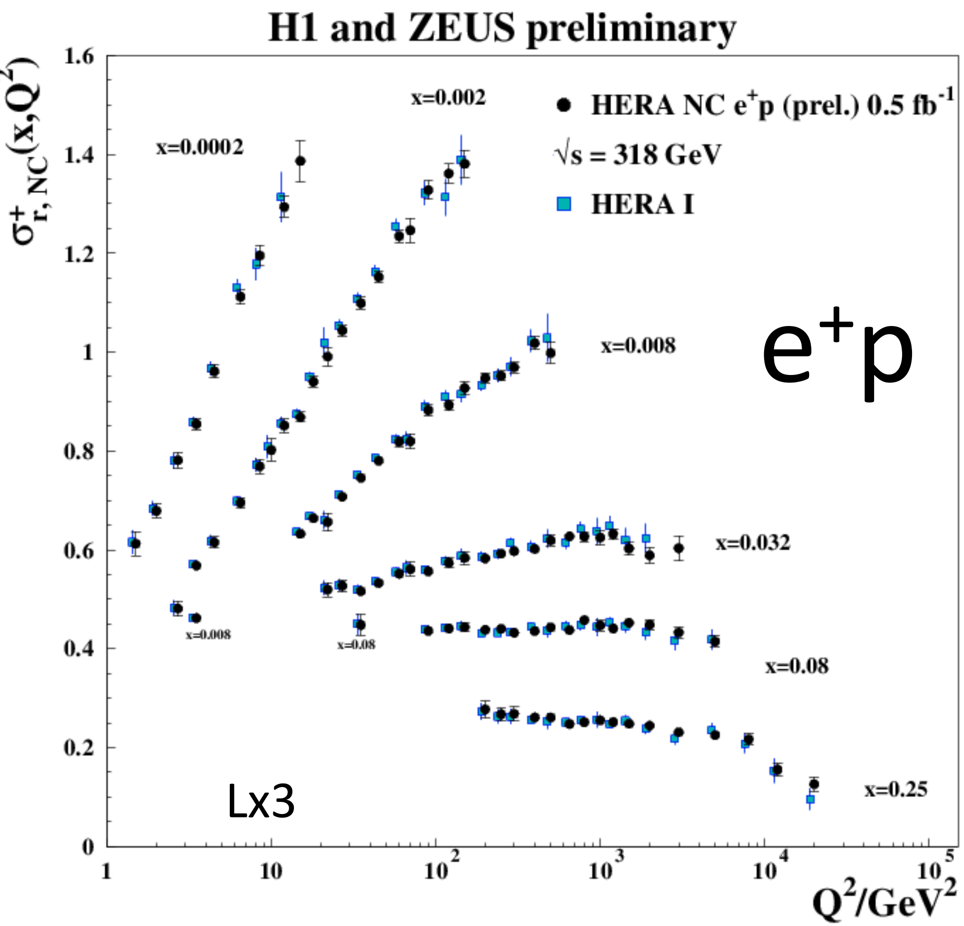


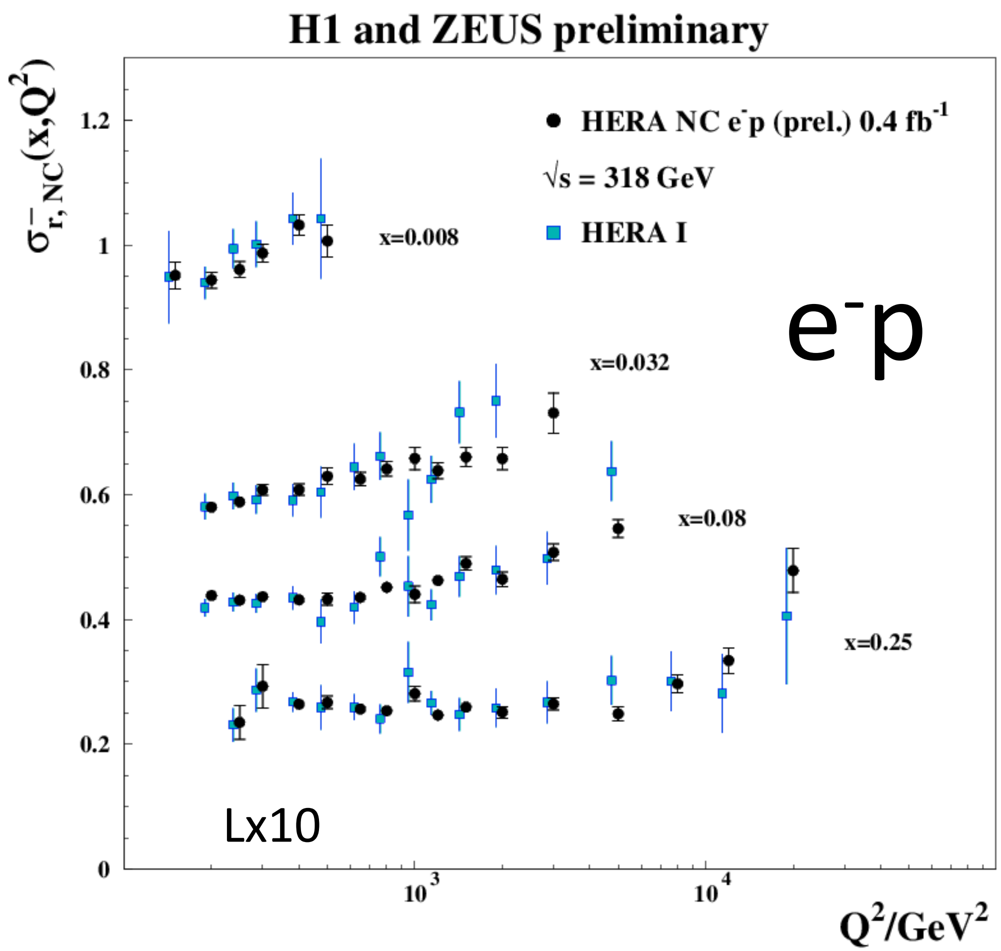
High x



$$\frac{\partial F_2}{\partial \log Q^2} \simeq \alpha_S q(x,Q^2)$$

NC data sets: compared to HERA I

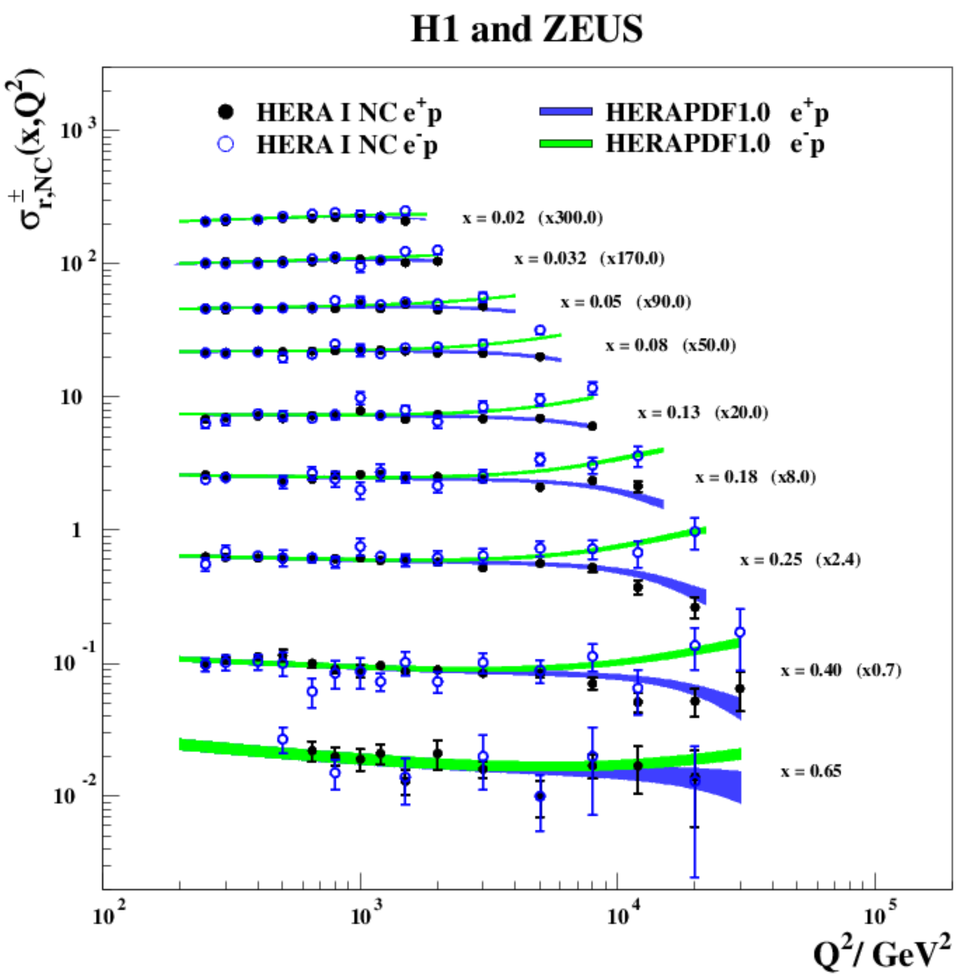


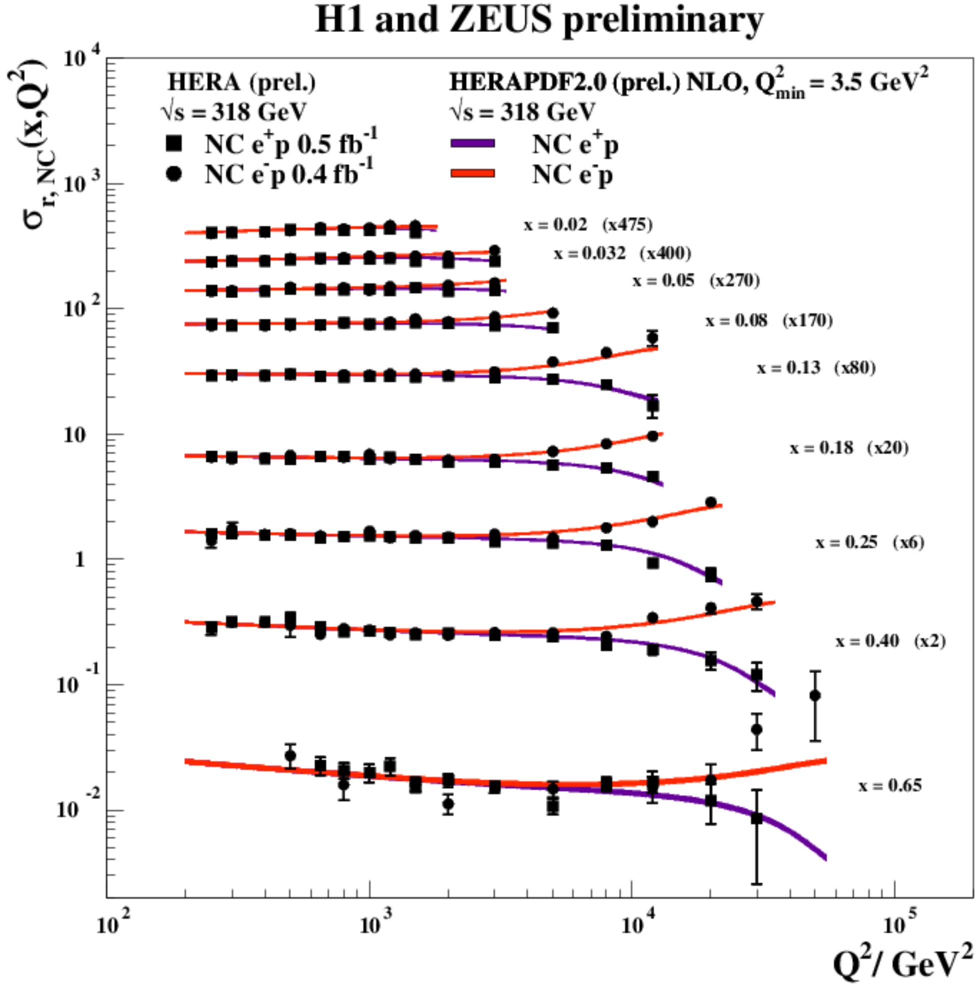


Impressive precision achieved at high Q2 as well

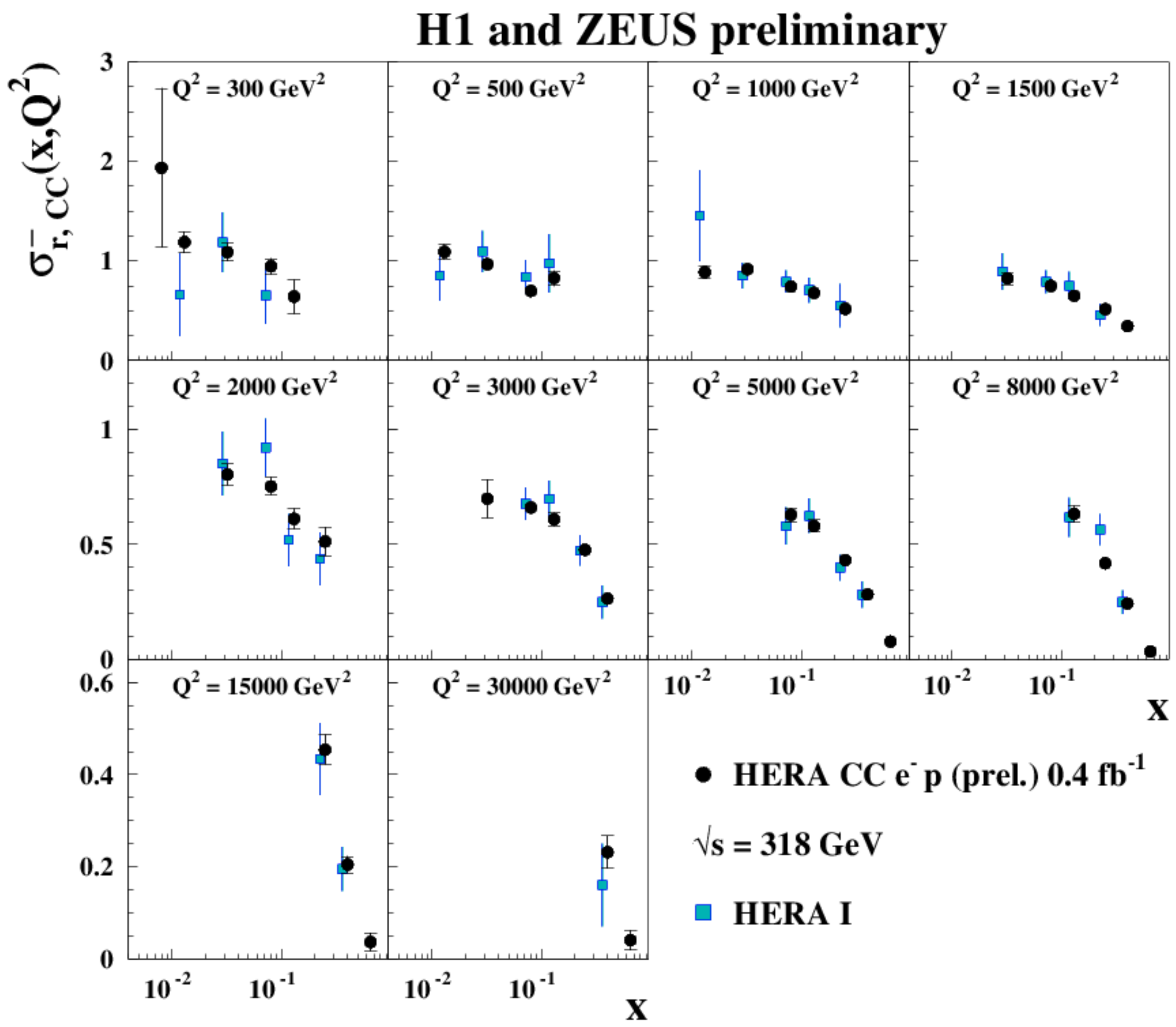
HERA I → II

$$\sigma_r(x,Q^2) = \frac{d^2\sigma(e^{\pm}p)}{dxdQ^2}\frac{Q^4x}{2\pi\alpha^2Y_+} = F_2(x,Q^2) - \frac{y^2}{Y_+}F_L(x,Q^2) \mp \frac{Y_-}{Y_+}xF_3(x,Q^2)$$





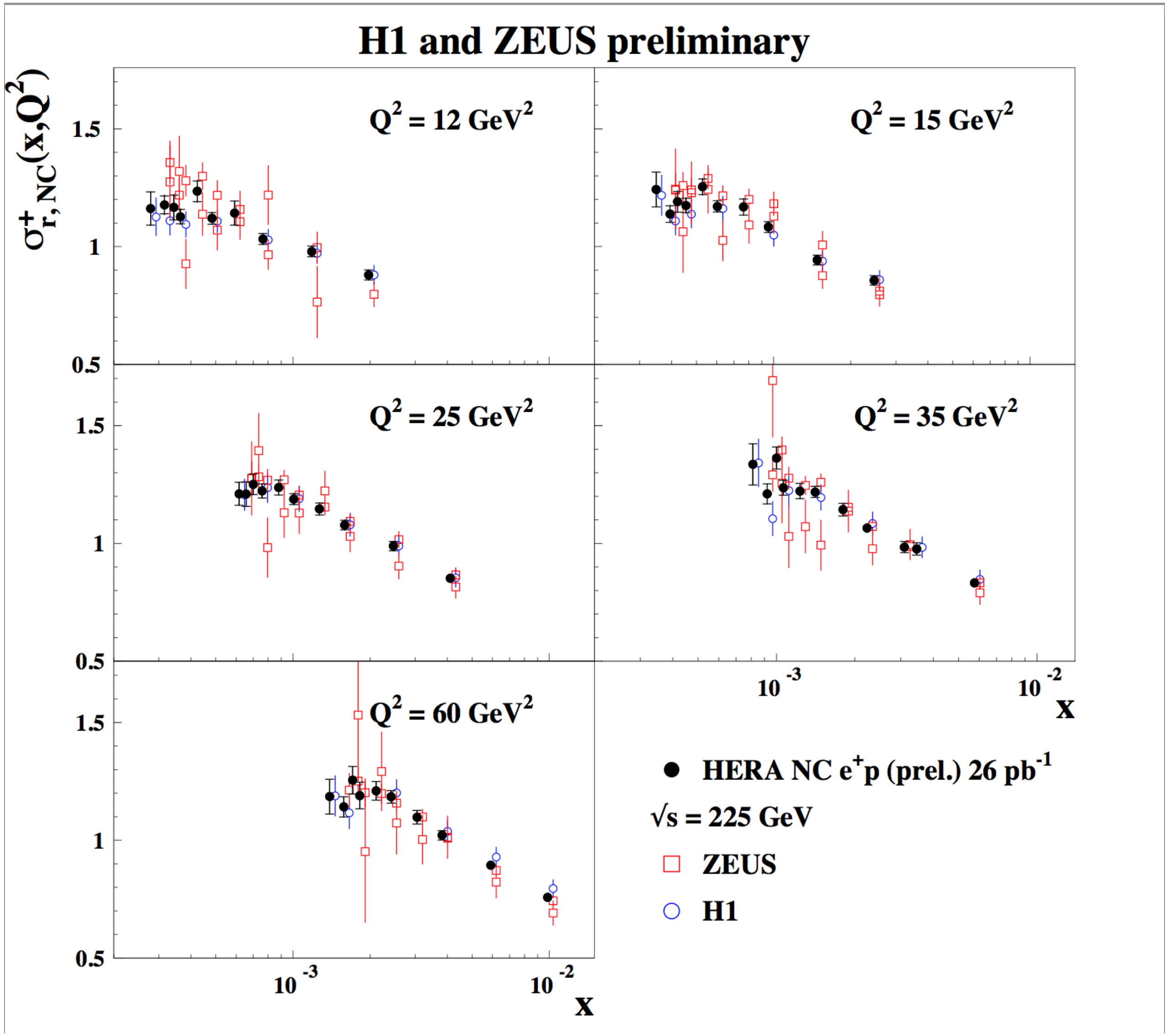
CC: large precision gain with HERA II data



Lx10

Low Energy Data

- HERA ran at low energy: data is combined as well
  - Significant gain in precision
- Sensitivity to FL



HERAPDF 2.0

HERAPDF 1.5

HERAPDF 1.0

HERA Data and HERAPDF saga

Data Set		x Grid from	x Grid to	Q^2/GeV^2 Grid from	Q^2/GeV^2 Grid to	$\mathcal{L}$ 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	0.000005	0.02	0.2	12	2.1	e^+p	301, 319
H1 low Q^2	96-00	0.0002	0.1	12	150	22	e^+p	301, 319
H1 NC	94-97	0.0032	0.65	150	30000	35.6	e^+p	301
H1 CC	94-97	0.013	0.40	300	15000	35.6	e^+p	301
H1 NC	98-99	0.0032	0.65	150	30000	16.4	e^-p	319
H1 CC	98-99	0.013	0.40	300	15000	16.4	e^-p	319
H1 NC HY	98-99	0.0013	0.01	100	800	16.4	e^-p	319
H1 NC	99-00	0.0013	0.65	100	30000	65.2	e^+p	319
H1 CC	99-00	0.013	0.40	300	15000	65.2	e^+p	319
ZEUS BPC	95	0.000002	0.00006	0.11	0.65	1.65	e^+p	300
ZEUS BPT	97	0.0000006	0.001	0.045	0.65	3.9	e^+p	300
ZEUS SVX	95	0.000012	0.0019	0.6	17	0.2	e^+p	300
ZEUS NC	96-97	0.00006	0.65	2.7	30000	30.0	e^+p	300
ZEUS CC	94-97	0.015	0.42	280	17000	47.7	e^+p	300
ZEUS NC	98-99	0.005	0.65	200	30000	15.9	e^-p	318
ZEUS CC	98-99	0.015	0.42	280	30000	16.4	e^-p	318
ZEUS NC	99-00	0.005	0.65	200	30000	63.2	e^+p	318
ZEUS CC	99-00	0.008	0.42	280	17000	60.9	e^+p	318
HERA II E_p = 920 GeV data sets								
H1 NC	03-07	0.0008	0.65	60	30000	182	e^+p	319
H1 CC	03-07	0.008	0.40	300	15000	182	e^+p	319
H1 NC	03-07	0.0008	0.65	60	50000	151.7	e^-p	319
H1 CC	03-07	0.008	0.40	300	30000	151.7	e^-p	319
H1 NC med Q^2 *y.5	03-07	0.0000986	0.005	8.5	90	182	e^+p	319
H1 NC low Q^2 *y.5	03-07	0.000029	0.00032	2.5	12	182	e^+p	319
ZEUS NC	06-07	0.005	0.65	200	30000	135.5	e^+p	318
ZEUS CC	06-07	0.0078	0.42	280	30000	132	e^+p	318
ZEUS NC	05-06	0.005	0.65	200	30000	169.9	e^-p	318
ZEUS CC	04-06	0.015	0.65	280	30000	175	e^-p	318
ZEUS NC nominal *y	06-07	0.000092	0.008343	7	110	44.5	e^+p	318
ZEUS NC satellite *y	06-07	0.000071	0.008343	5	110	44.5	e^+p	318
HERA II E_p = 575 GeV data sets								
H1 NC high Q^2	07	0.00065	0.65	35	800	17.2	e^+p	252
H1 NC low Q^2	07	0.0000279	0.0148	1.5	90	5.9	e^+p	252
ZEUS NC nominal	07	0.000147	0.013349	7	110	7.1	e^+p	251
ZEUS NC satellite	07	0.000125	0.013349	5	110	7.1	e^+p	251
HERA II E_p = 460 GeV data sets								
H1 NC high Q^2	07	0.00081	0.65	35	800	17.2	e^+p	225
H1 NC low Q^2	07	0.0000348	0.0148	1.5	90	12.2	e^+p	225
ZEUS NC nominal	07	0.000184	0.016686	7	110	13.9	e^+p	225
ZEUS NC satellite	07	0.000143	0.016686	5	110	13.9	e^+p	225

After combination:
7 data sets
165 sources of systematics

```
HERA CC e+p 101 (920)
HERA CC e-p 102 (920)
HERA NC e-p 103 (920)
HERA NC e+p 104 (820)
HERA NC e+p 105 (920)
HERA NC e+p 106 (460)
HERA NC e+p 107 (575)
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The preliminary HERA I +II combination is used as a sole input in QCD fit platform to determine HERAPDF2.0 (prel)

HERAPDF 2.0 : Ingredients

- QCD settings adapted to HERA sensitivities with

$$F_2(x,Q^2) = \frac{4}{9}(xU + x\overline{U}) + \frac{1}{9}(xD + x\overline{D})$$

- Parametrisation at the starting scale Q_0^2=1.9 GeV^2

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

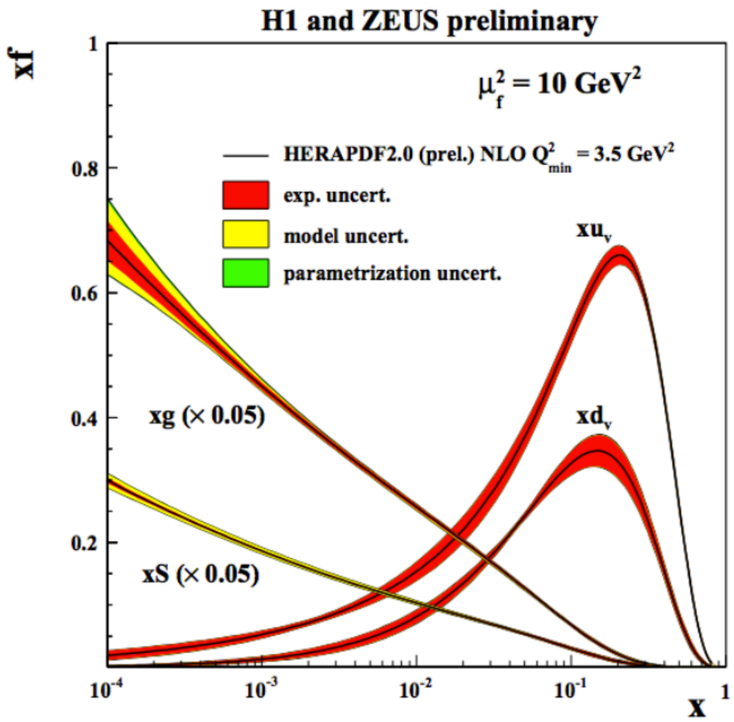
Assumptions:

- QCD Sum rules contrain the normalisation parameters A
- Xubar -> xdbar as x -> 0
- PDF are evolved using DGLAP equations at NLO and NNLO (QCDNUM) with α_S=0.118 (M_Z)
- Thorne-Roberts GM-VFNS for heavy quarks coefficients
- Chi2 minimisation (Minuit)

Fit platform: **HERAFitter** (multiexperiment+theory collaboration)
http://herafitter.org

Uncertainties

- **Experimental:**
  - Hessian method is used to evaluate experimental uncertainties
  - Consistent data sets → use $\Delta\chi^2=1$



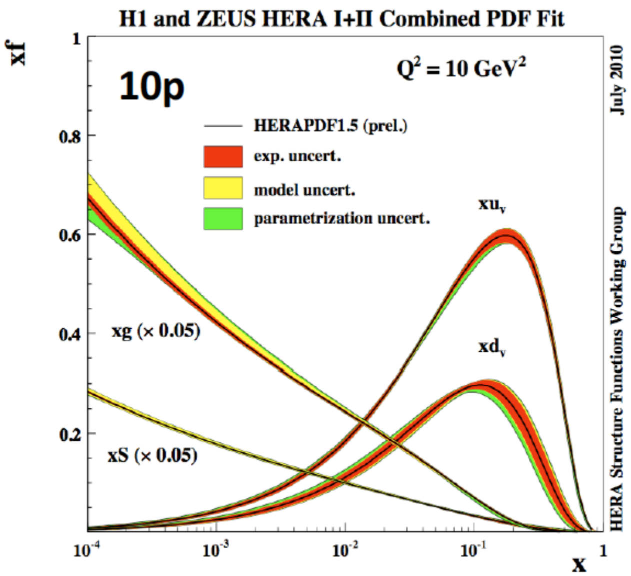
- **Model:**
  - Following variations have been considered

Variation	Standard Value	Lower Limit	Upper Limit
f_s	0.4	0.3	0.5
M_c^{opt}(NLO) [GeV]	1.47	1.41	1.53
M_c^{opt} (NNLO) [GeV]	1.44	1.38	1.50
M_b [GeV]	4.75	4.5	5.0
Q^2_{min} [GeV^2]	10.0	7.5	12.5
Q^2_{min} [GeV^2]	3.5	2.5	5.0
Q^2_0 [GeV^2]	1.9	1.6	2.2

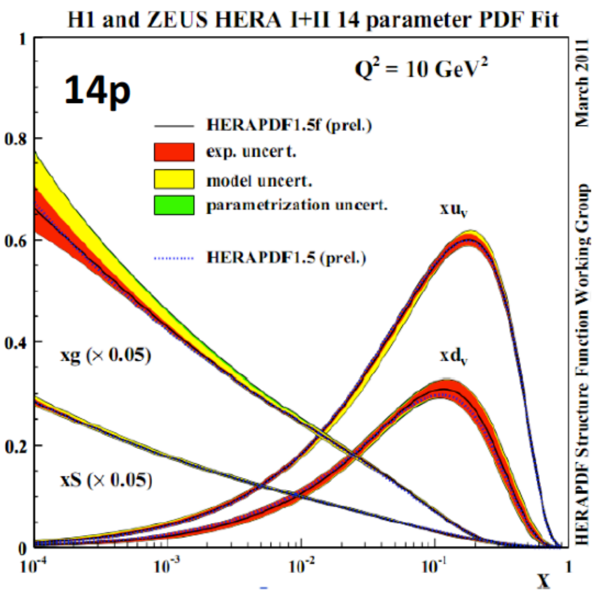
- **Parametrisation:**
  - An envelope is formed from PDF fits using variants of parametrisation form
    - Scanning of 16 parameter space with D or E as extra parameters of $(1 + Dx + Ex^2)$
    - Q_0^2 variation → dominant parametrisation uncertainty

HERAPDF1.5 vs HERAPDF2.0 with Q2min=3.5 GeV2

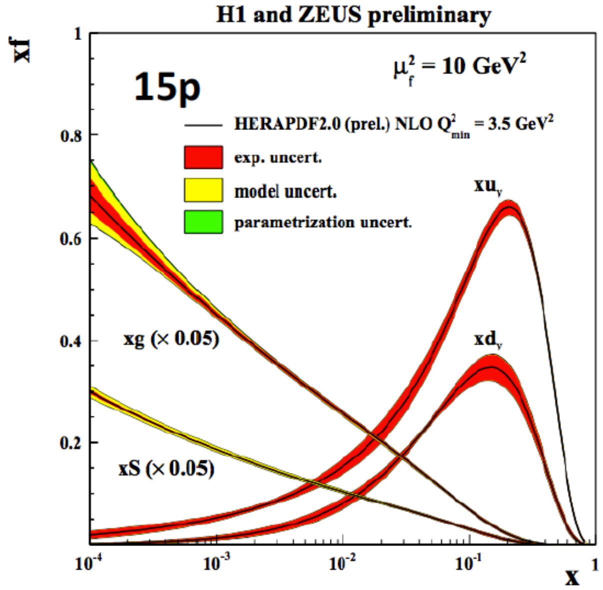
HERAPDF1.5-NLO(10p) → HERAPDF1.5-NLOf(14p) → HERAPDF2.0-NLO (15p)



We started with similar settings as used for HERAPDF1.0 (10 free parameters)



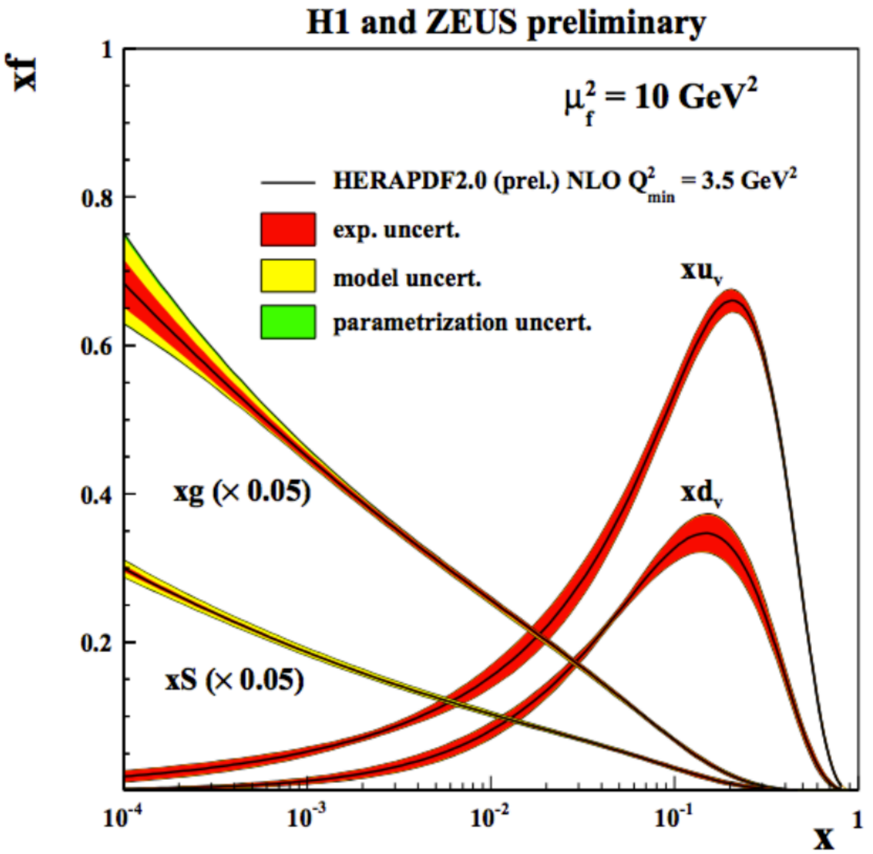
preliminary HERA II data Required additional flexibility (14 free parameters)



New HERAI+II combiation (15 free parameters)

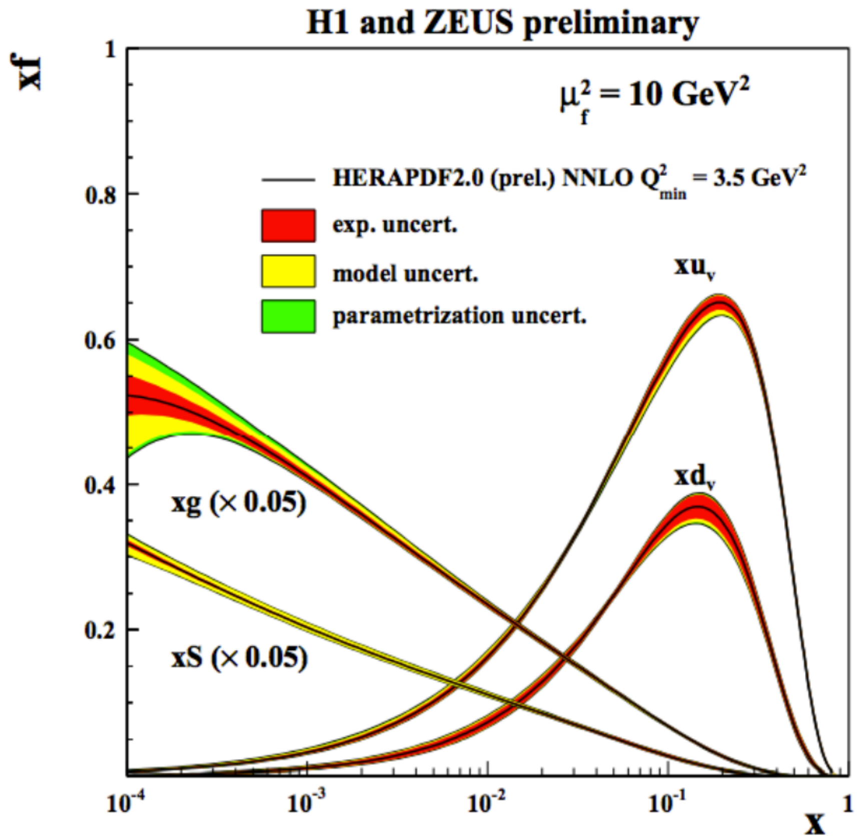
NLO/NNLO

At NLO



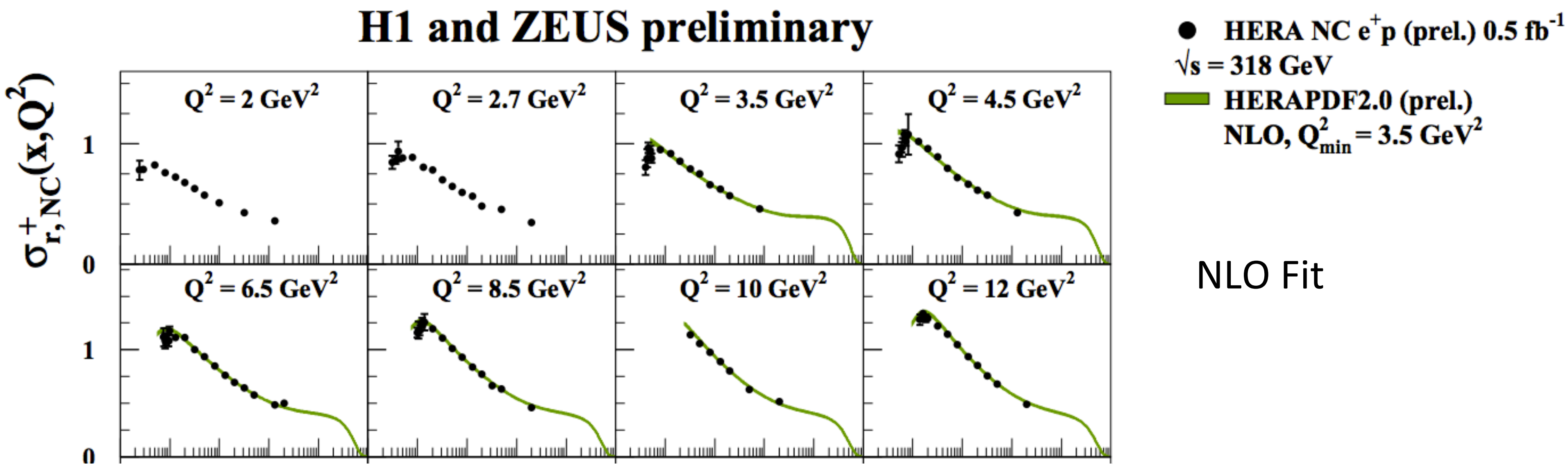
Chi2/dof = 1386/1130

At NNLO

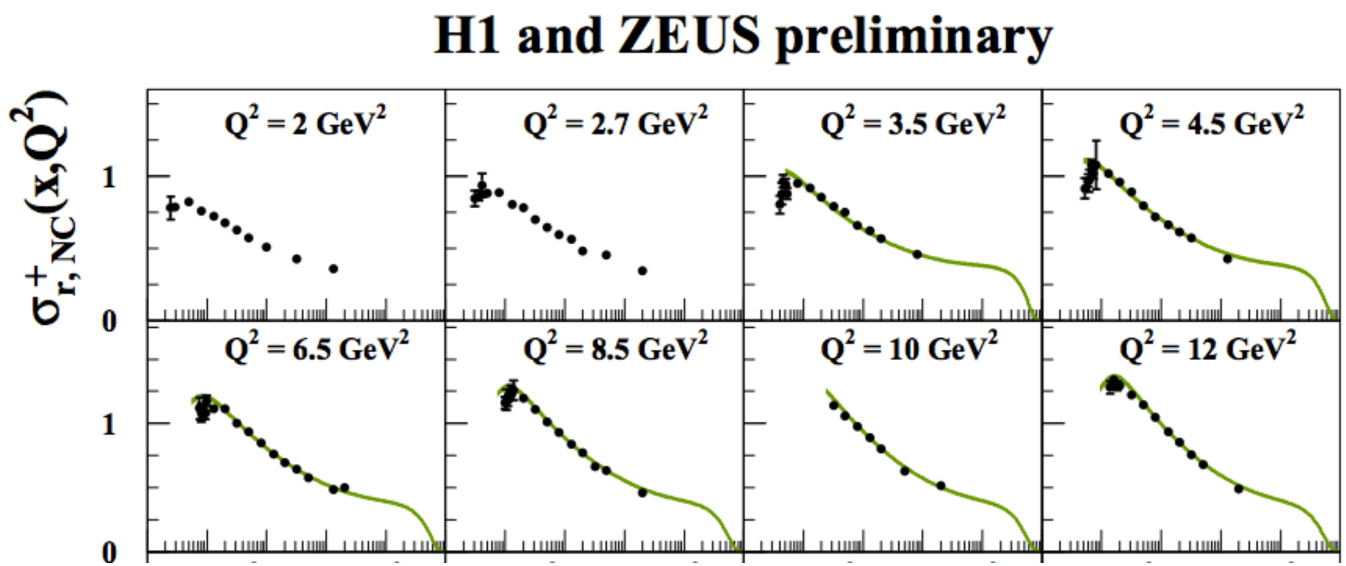


Chi2/dof = 1414/1130

Fit quality at low Q2 (fit with Q2 cut 3.5 GeV^2)



NLO Fit

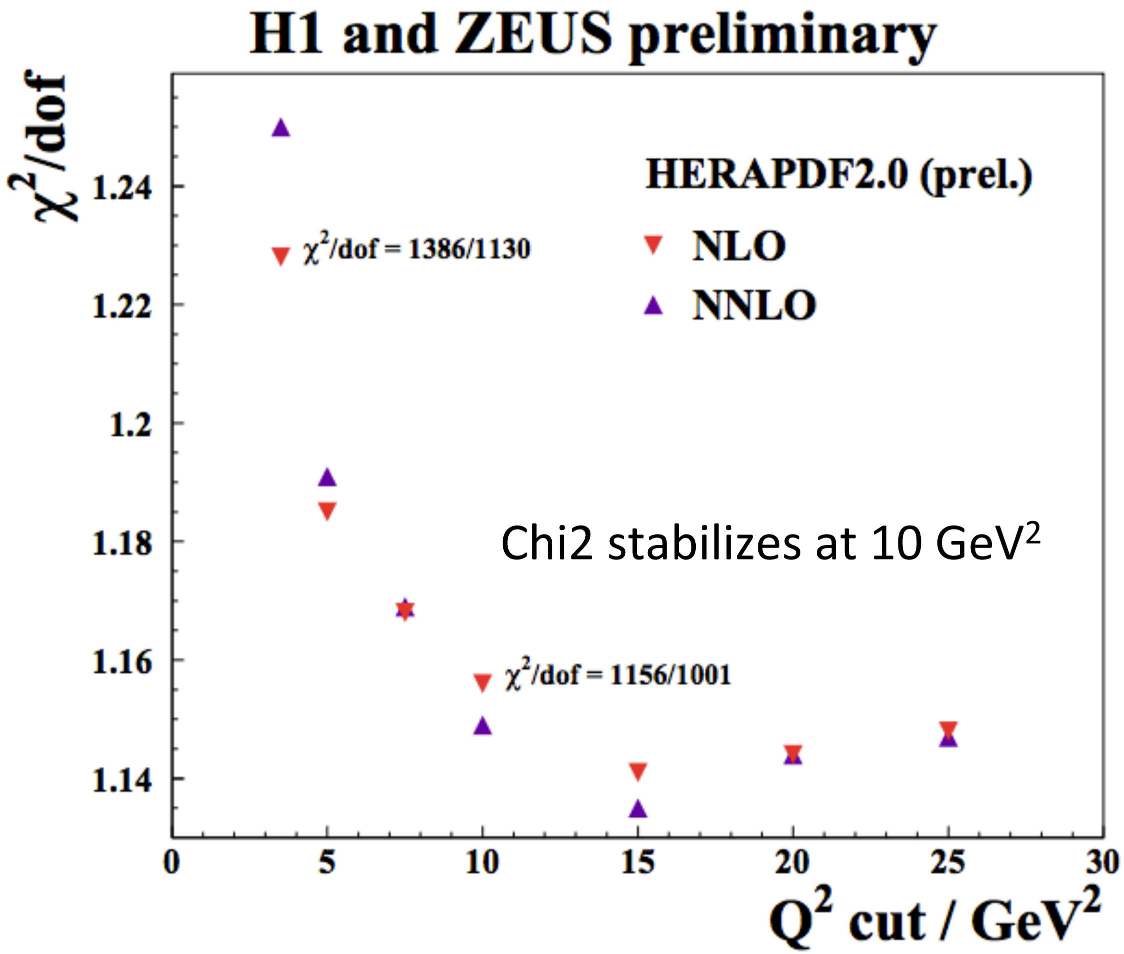


NNLO Fit

Better (higher orders)
Theory does not improve
The fit at low Q2

Q^2 cut variation

- Q2 Cut variation is usually a parameterisation error
- Here the compatibility between data and NLO/NNLO DGLAP based fits is tested



For Q^2_{min}= 3.5 GeV^2

Chi2/dof (NLO) = 1386/1130

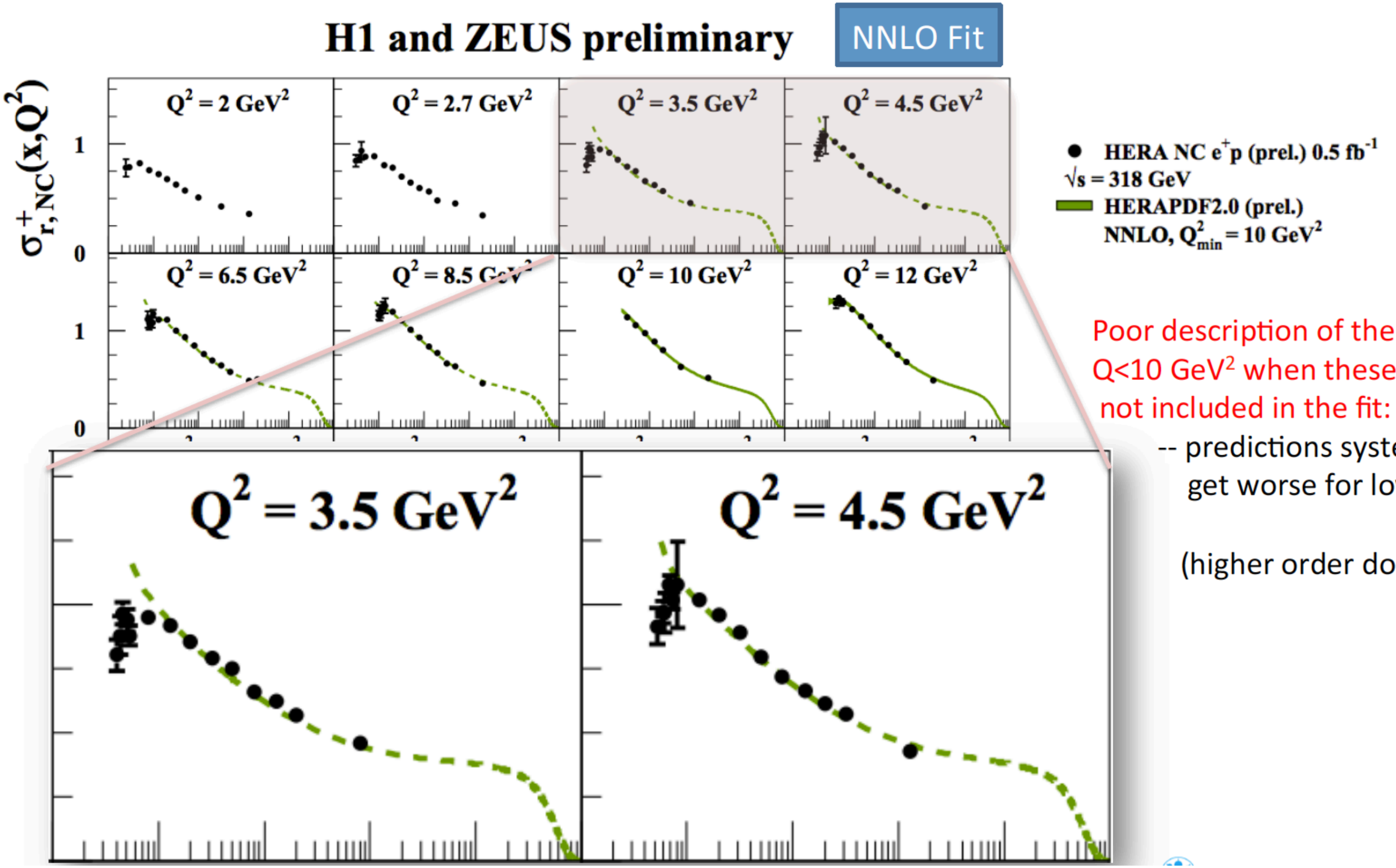
Chi2/dof(NNLO)= 1414/1130

For Q^2_{min}= 10 GeV^2

Chi2/dof (NLO) = 1156/1001

Chi2/dof(NNLO)= 1150/1001

Data Description at low Q2



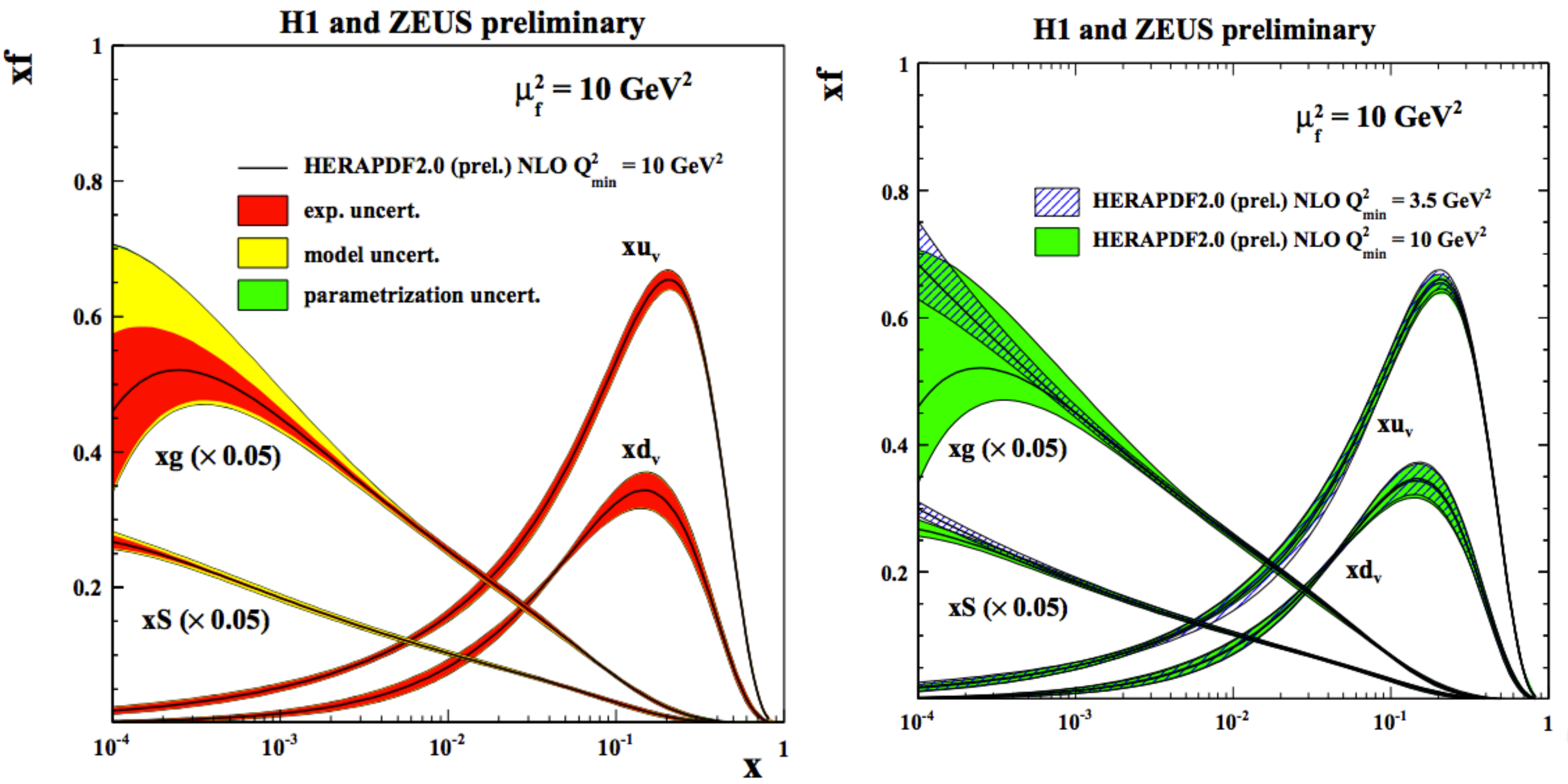
Poor description of the data for $Q<10\ GeV^2$ when these data are not included in the fit:

-- predictions systematically get worse for low x, Q^2

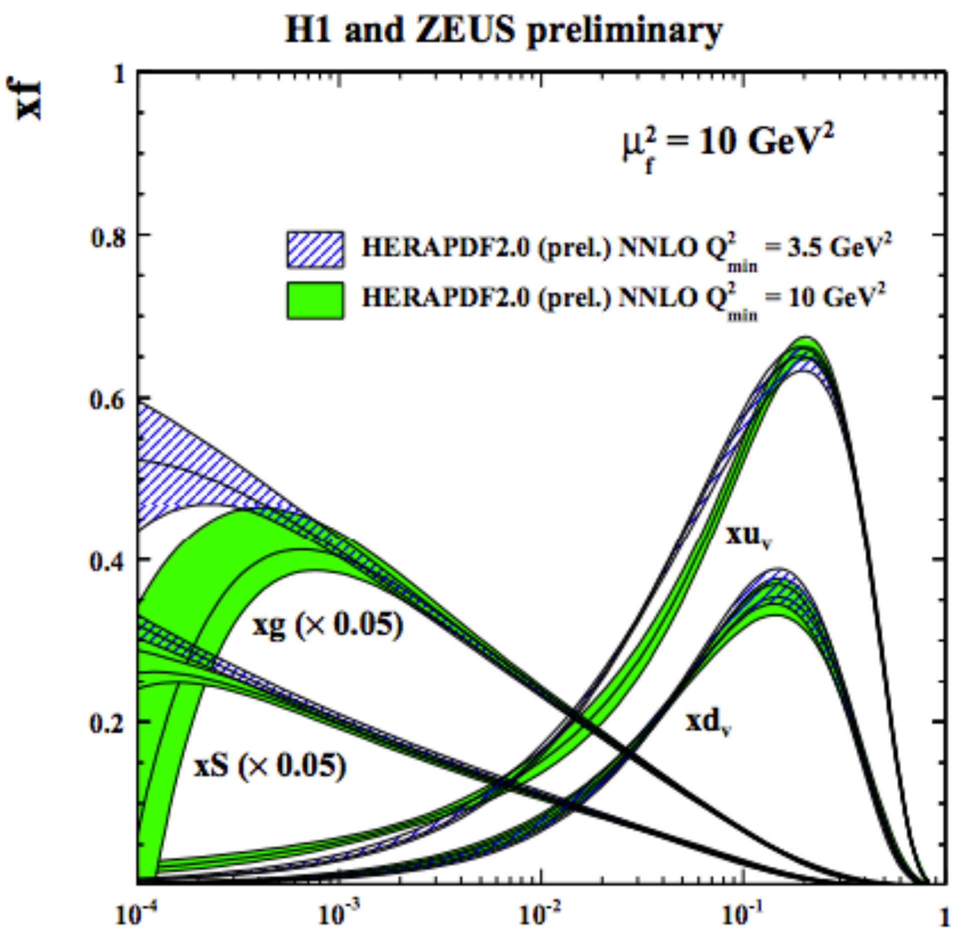
(higher order do not help)

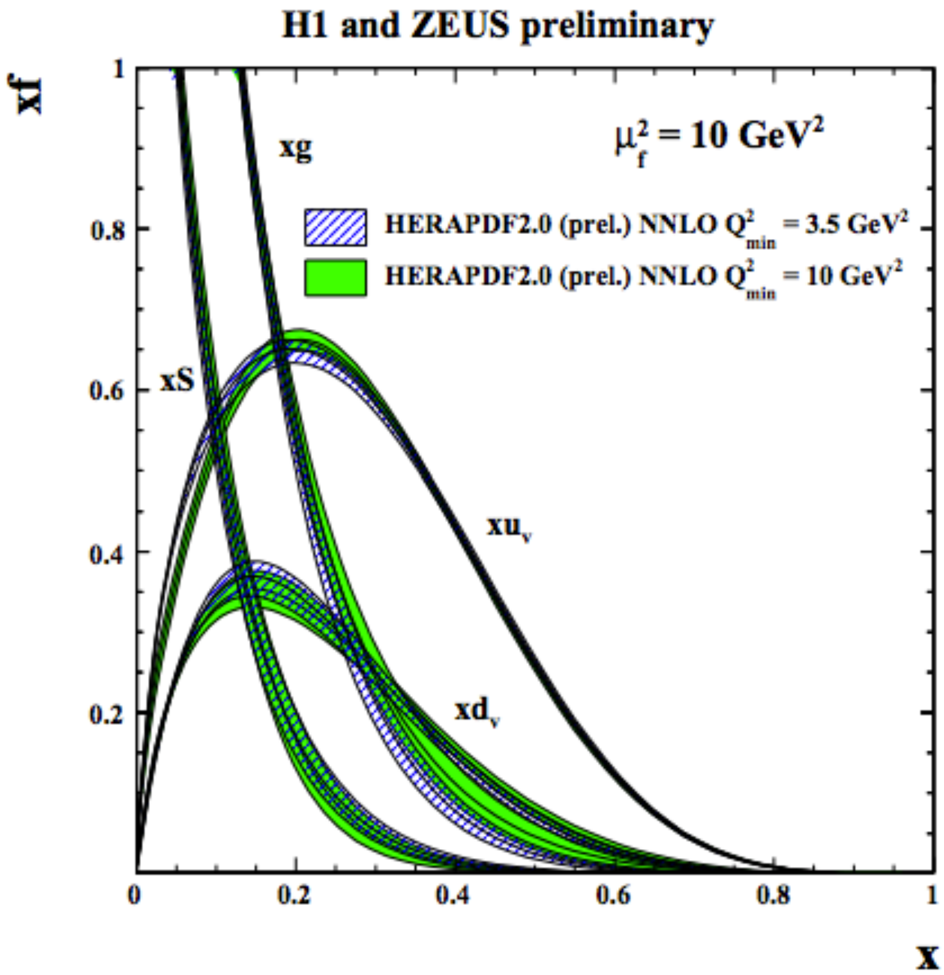
PDF determinations with the two options

- Parametrization error is dominated by Q2 cut variation
- Gluon determination is affected by Q2min>10



HERAPDF2.0 with different Q2cut





PDFs compatible at high x
Gluon mostly affected by the data removal at low Q2

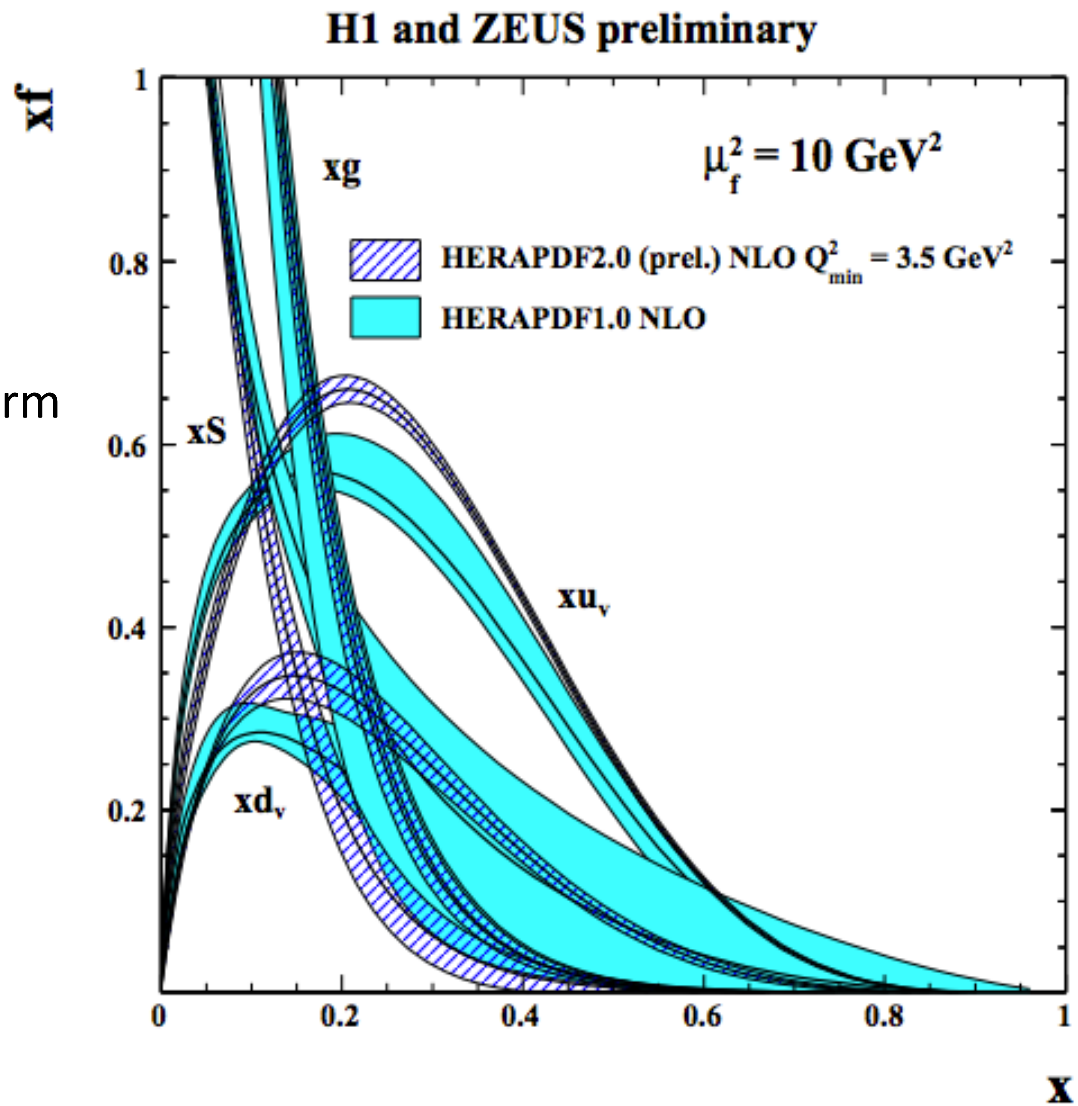
Comparison with HERA I fit (HERAPDF1.0)

HERAPDF1.0 [JHEP01 (2010) 109]

- It used a rigid parametrisation form (10p)

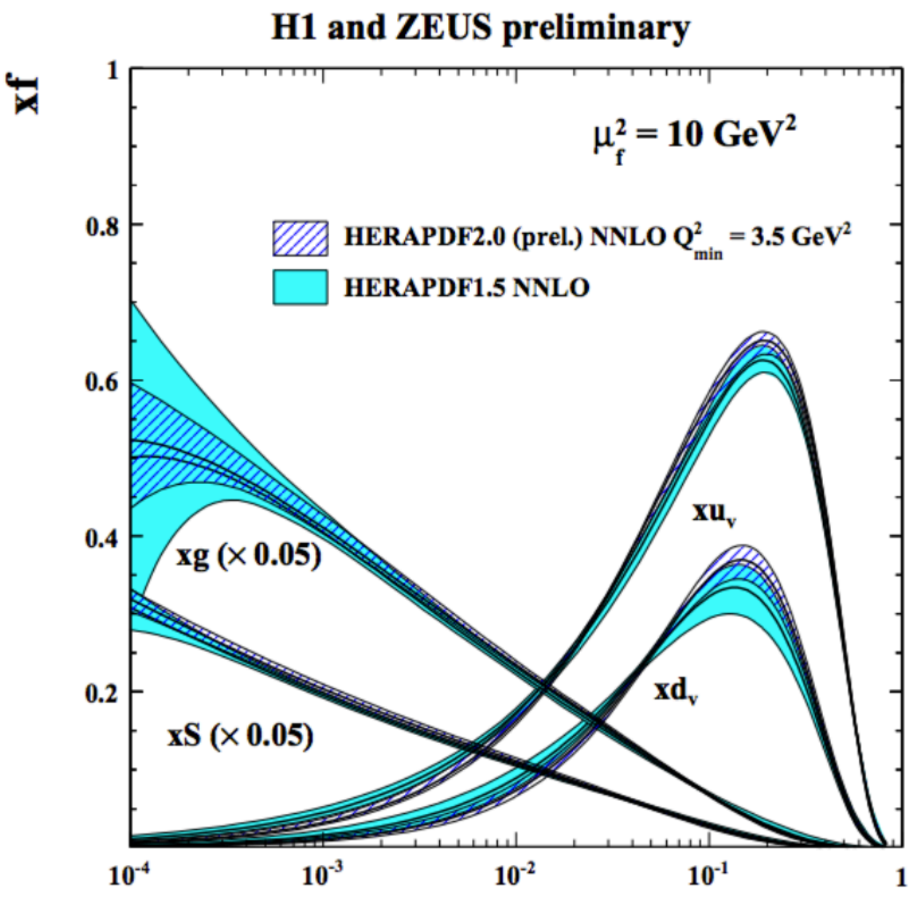
Comparison with HERAPDF2.0:

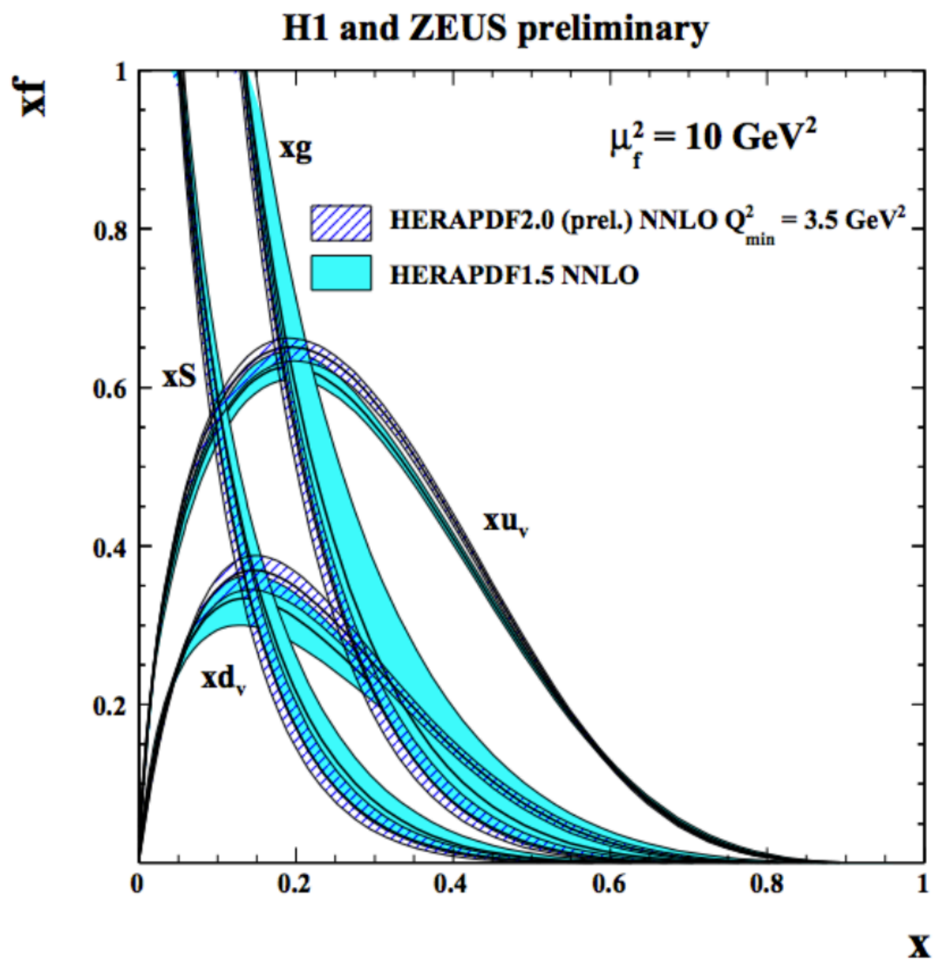
- Improved Distributions
- Sea is softer at high x
- Gluon is harder at high x



Comparison HERAPDF2.0 to HERAPDF1.5

- Most used HERAPDF set is HERAPDF1.5NNLO, how does it compare to it?





Shapes are similar:

- Gluon and sea at low and high x has improved and they become slightly softer
- Valence at high x has also improved

Conclusions

- The full inclusive data set from HERA is being combined

- Precision at high Q2 improve a lot
  - Electroweak effects
  - Flavour disentanglement

- HERAPDF2.0 (prelim)
  - precision at high x,
  - tensions with data at low Q2
  - two versions provided
    - Q2>3.5 and 10 GeV^2
- More studies ongoing
  - Impact for LHC physics
  - Polarised data/EW fits

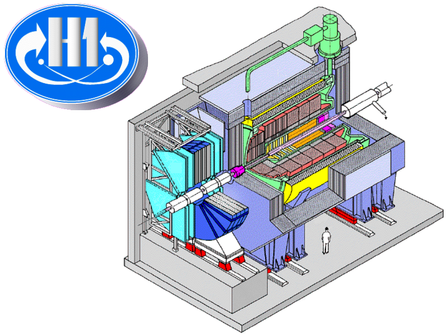
BACKUP

Data Set		x Grid		Q^2/GeV^2 Grid		$\mathcal{L}$	e^+/e^-	$\sqrt{s}$	x,Q^2 from	Ref.
		from	to	from	to	pb^{-1}		GeV	equations	
HERA I $E_p = 820$ GeV and $E_p = 920$ GeV data sets										
H1 svx-mb	95-00	0.000005	0.02	0.2	12	2.1	e^+p	301 , 319	11,15,16	[26]
H1 low Q^2	96-00	0.0002	0.1	12	150	22	e^+p	301 , 319	11,15,16	[27]
H1 NC	94-97	0.0032	0.65	150	30000	35.6	e^+p	301	17	[28]
H1 CC	94-97	0.013	0.40	300	15000	35.6	e^+p	301	12	[28]
H1 NC	98-99	0.0032	0.65	150	30000	16.4	e^-p	319	17	[45]
H1 CC	98-99	0.013	0.40	300	15000	16.4	e^-p	319	12	[45]
H1 NC HY	98-99	0.0013	0.01	100	800	16.4	e^-p	319	11	[46]
H1 NC	99-00	0.0013	0.65	100	30000	65.2	e^+p	319	17	[46]
H1 CC	99-00	0.013	0.40	300	15000	65.2	e^+p	319	12	[46]
ZEUS BPC	95	0.000002	0.00006	0.11	0.65	1.65	e^+p	300	11	[16]
ZEUS BPT	97	0.0000006	0.001	0.045	0.65	3.9	e^+p	300	11, 17	[17]
ZEUS SVX	95	0.000012	0.0019	0.6	17	0.2	e^+p	300	11	[33]
ZEUS NC	96-97	0.00006	0.65	2.7	30000	30.0	e^+p	300	19	[47]
ZEUS CC	94-97	0.015	0.42	280	17000	47.7	e^+p	300	12	[48]
ZEUS NC	98-99	0.005	0.65	200	30000	15.9	e^-p	318	18	[49]
ZEUS CC	98-99	0.015	0.42	280	30000	16.4	e^-p	318	12	[50]
ZEUS NC	99-00	0.005	0.65	200	30000	63.2	e^+p	318	18	[51]
ZEUS CC	99-00	0.008	0.42	280	17000	60.9	e^+p	318	12	[52]
HERA II $E_p = 920$ GeV data sets										
H1 NC	03-07	0.0008	0.65	60	30000	182	e^+p	319	11, 17	[22][1]
H1 CC	03-07	0.008	0.40	300	15000	182	e^+p	319	12	[22][1]
H1 NC	03-07	0.0008	0.65	60	50000	151.7	e^-p	319	11, 17	[22][1]
H1 CC	03-07	0.008	0.40	300	30000	151.7	e^-p	319	12	[22][1]
H1 NC med Q^2 *y.5	03-07	0.0000986	0.005	8.5	90	97.6	e^+p	319	11	[36]
H1 NC low Q^2 *y.5	03-07	0.000029	0.00032	2.5	12	5.9	e^+p	319	11	[36]
ZEUS NC	06-07	0.005	0.65	200	30000	135.5	e^+p	318	11,12,18	[53]
ZEUS CC	06-07	0.0078	0.42	280	30000	132	e^+p	318	12	[54]
ZEUS NC	05-06	0.005	0.65	200	30000	169.9	e^-p	318	18	[55]
ZEUS CC	04-06	0.015	0.65	280	30000	175	e^-p	318	12	[56]
ZEUS NC nominal *y	06-07	0.000092	0.008343	7	110	44.5	e^+p	318	11	[37]
ZEUS NC satellite *y	06-07	0.000071	0.008343	5	110	44.5	e^+p	318	11	[37]
HERA II $E_p = 575$ GeV data sets										
H1 NC high Q^2	07	0.00065	0.65	35	800	5.4	e^+p	252	11, 17	[35]
H1 NC low Q^2	07	0.0000279	0.0148	1.5	90	5.9	e^+p	252	11	[36]
ZEUS NC nominal	07	0.000147	0.013349	7	110	7.1	e^+p	251	11	[37]
ZEUS NC satellite	07	0.000125	0.013349	5	110	7.1	e^+p	251	11	[37]
HERA II $E_p = 460$ GeV data sets										
H1 NC high Q^2	07	0.00081	0.65	35	800	11.8	e^+p	225	11, 17	[35]
H1 NC low Q^2	07	0.0000348	0.0148	1.5	90	12.2	e^+p	225	11	[36]
ZEUS NC nominal	07	0.000184	0.016686	7	110	13.9	e^+p	225	11	[37]
ZEUS NC satellite	07	0.000143	0.016686	5	110	13.9	e^+p	225	11	[37]

Data Samples

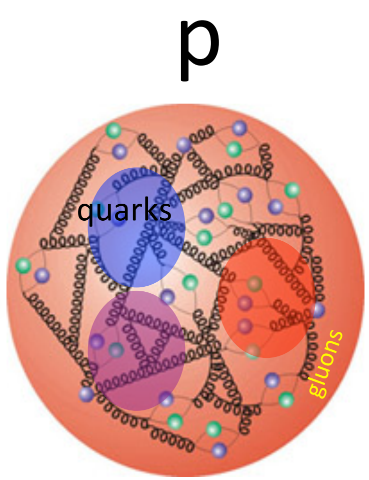
H1					ZEUS				
Data set		$\mathcal{L}$ [pb^{-1}]	e^+ / e^-	$\sqrt{s}$ [GeV]	Data set		$\mathcal{L}$ [pb^{-1}]	e^+ / e^-	$\sqrt{s}$ [GeV]
HERA I E_p = 820 GeV and E_p = 920 GeV data sets									
H1 svx-mb	95-00	2.1	$e^+ p$	301, 319	ZEUS BPC	95	1.65	$e^+ p$	300
H1 low Q^2	96-00	22	$e^+ p$	301,319	ZEUS 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

The physics at HERA



The proton structure
with unprecedented precision

Parton distribution functions for the future

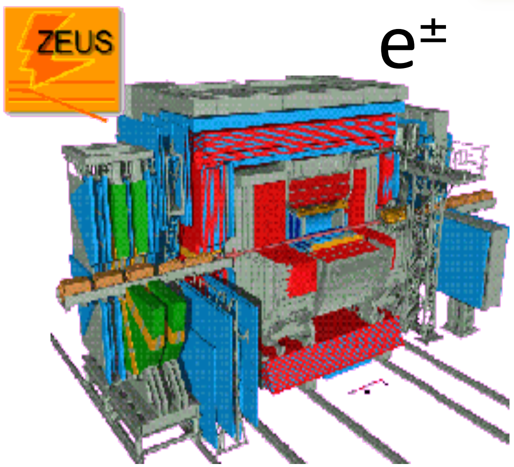


The strong force
in a clean “laboratory”

Jets, Diffraction, Low x

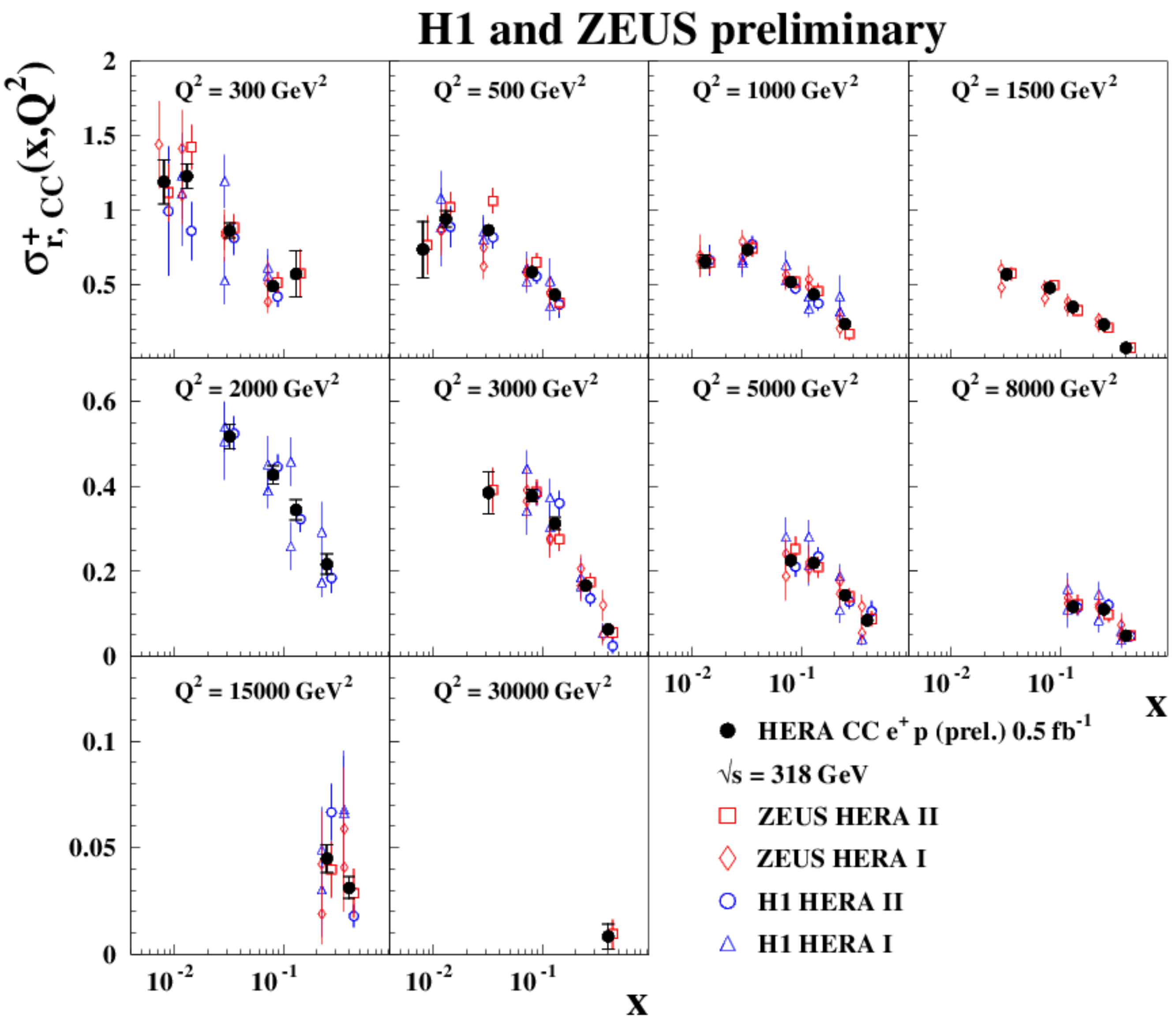
The proton spin surgery

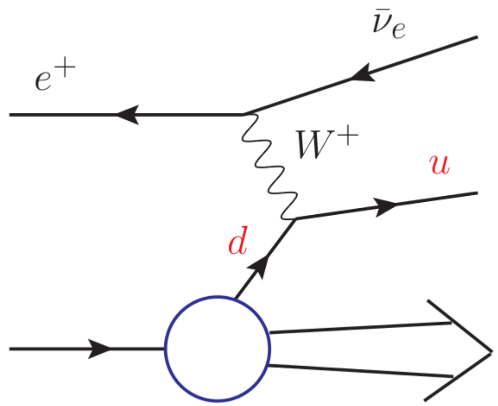
$e^{\pm}$



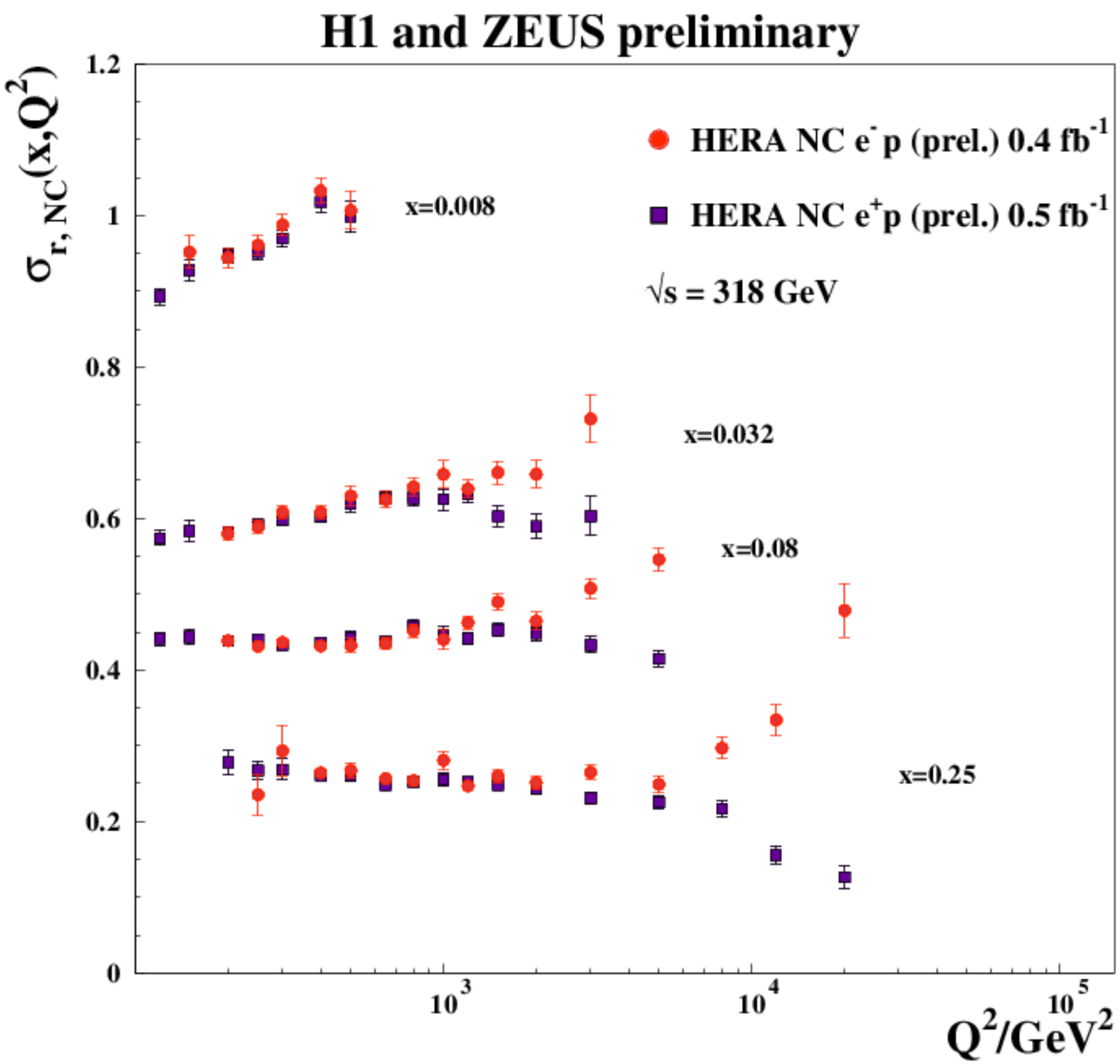
Searches for new physics
at the ep energy frontier

CC Data sets


H1 and ZEUS preliminary
$\sigma^{+}_{r,\,CC}(x,Q^2)$
Q² = 300 GeV²
Q² = 500 GeV²
Q² = 1000 GeV²
Q² = 1500 GeV²
Q² = 2000 GeV²
Q² = 3000 GeV²
Q² = 5000 GeV²
Q² = 8000 GeV²
Q² = 15000 GeV²
Q² = 30000 GeV²
x
HERA CC e⁺p (prel.) 0.5 fb⁻¹
√s = 318 GeV
ZEUS HERA II
ZEUS HERA I
H1 HERA II
H1 HERA I


e^+
$\bar{\nu}_e$
W^+
u
d

Electroweak effects

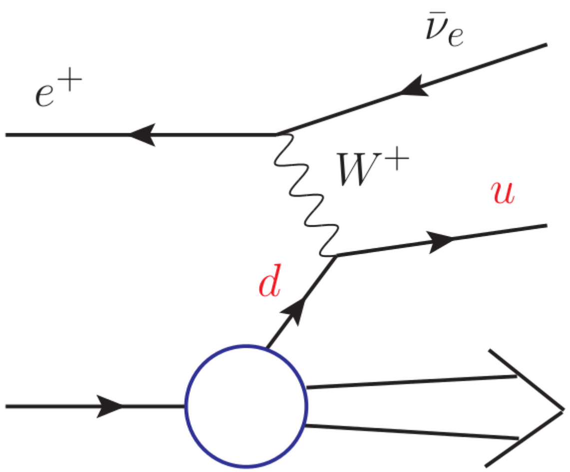


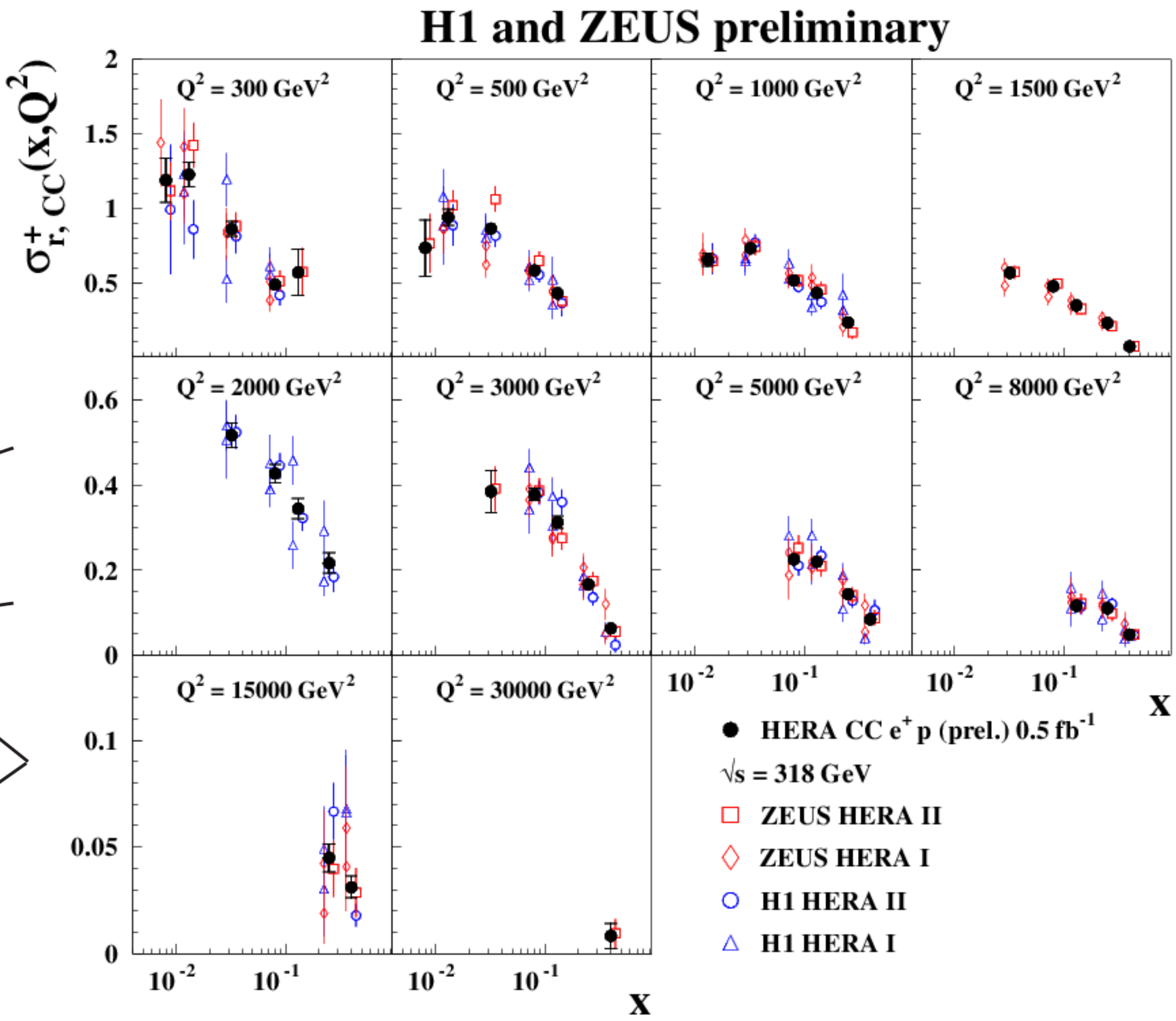
$$\tilde{F}_2 - \frac{y^2}{Y_+}\tilde{F}_L \mp \frac{Y_-}{Y_+} x\tilde{F}_3$$

$$2x \sum_q \left[e_q a_q, v_q a_q\right](q - \bar{q})$$

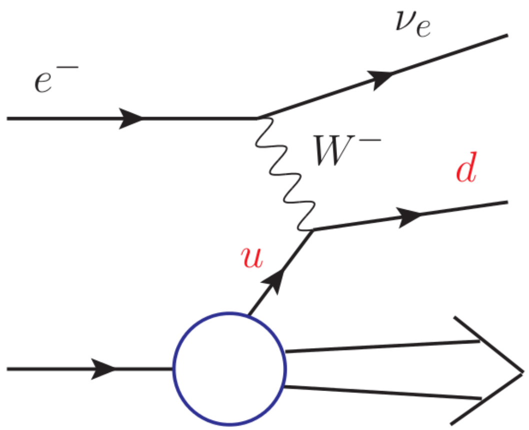
CC Cross sections

e+ p

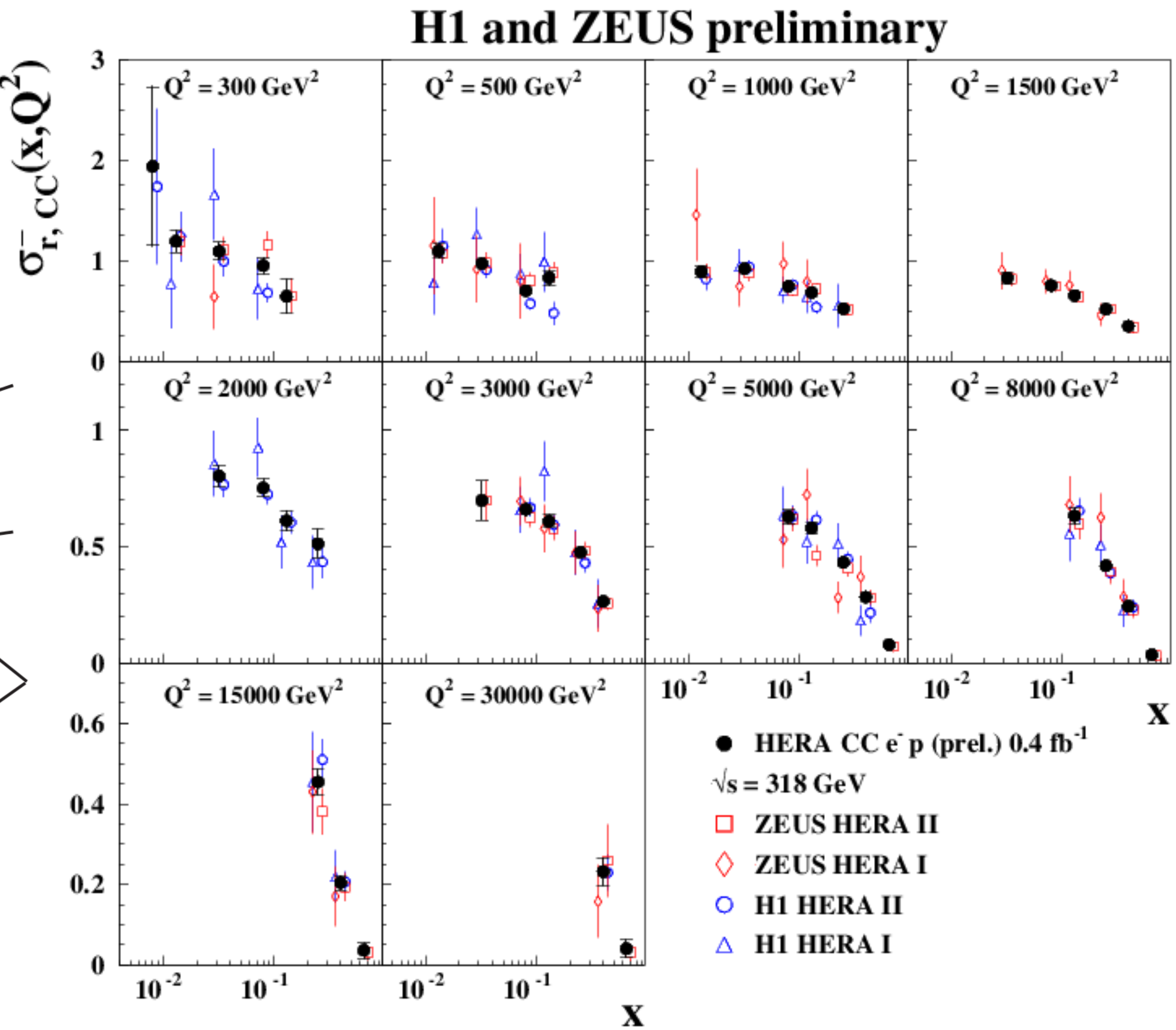




CC Data sets

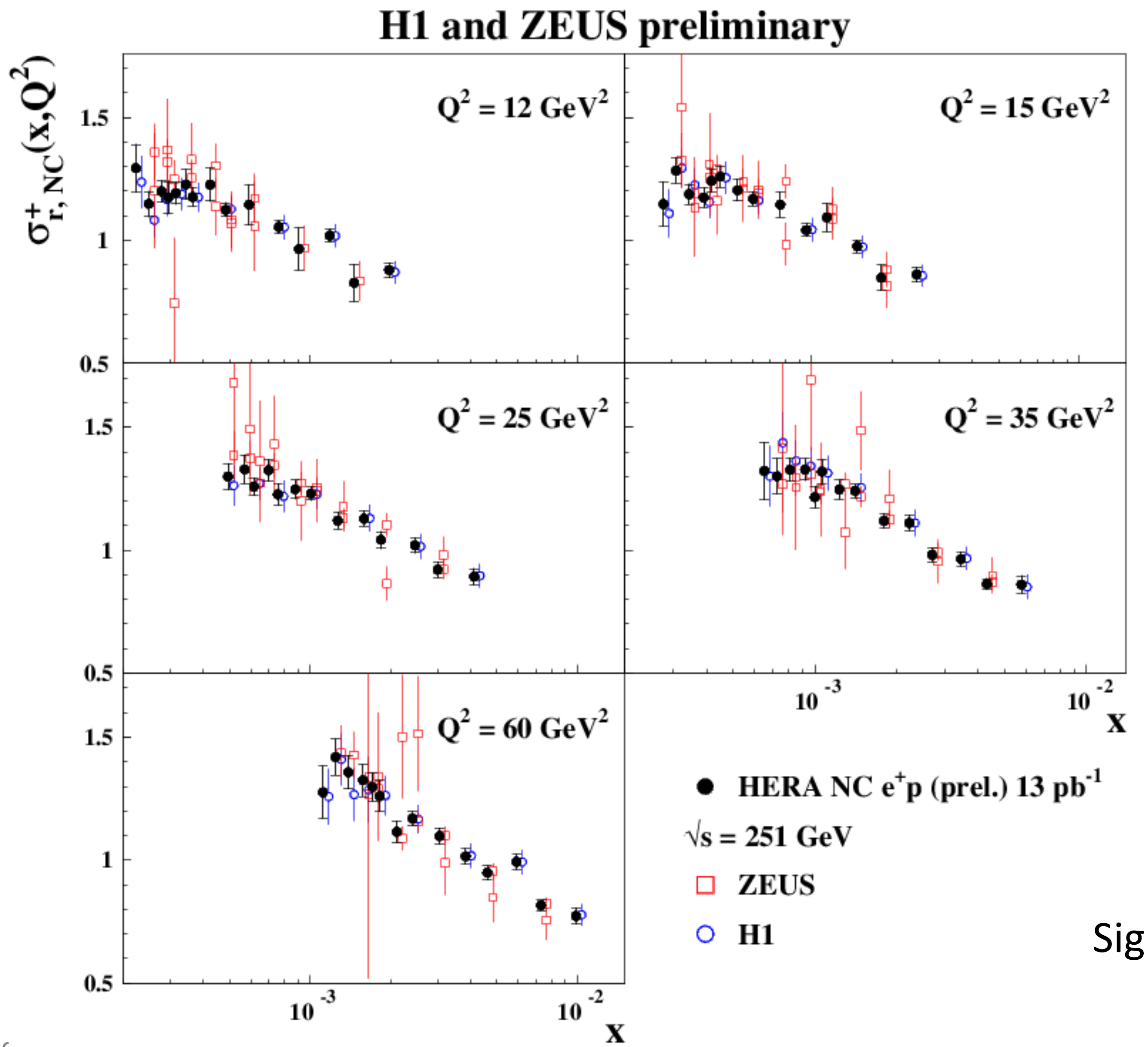


e^-
ν_e
W^-
d
u



H1 and ZEUS preliminary
$\sigma^-_{r,CC}(x,Q^2)$
$Q^2 = 300\ GeV^2$
$Q^2 = 500\ GeV^2$
$Q^2 = 1000\ GeV^2$
$Q^2 = 1500\ GeV^2$
$Q^2 = 2000\ GeV^2$
$Q^2 = 3000\ GeV^2$
$Q^2 = 5000\ GeV^2$
$Q^2 = 8000\ GeV^2$
$Q^2 = 15000\ GeV^2$
$Q^2 = 30000\ GeV^2$
x
HERA CC e^-p (prel.) 0.4 fb^{-1}
$\sqrt{s}$ = 318 GeV
ZEUS HERA II
ZEUS HERA I
H1 HERA II
H1 HERA I

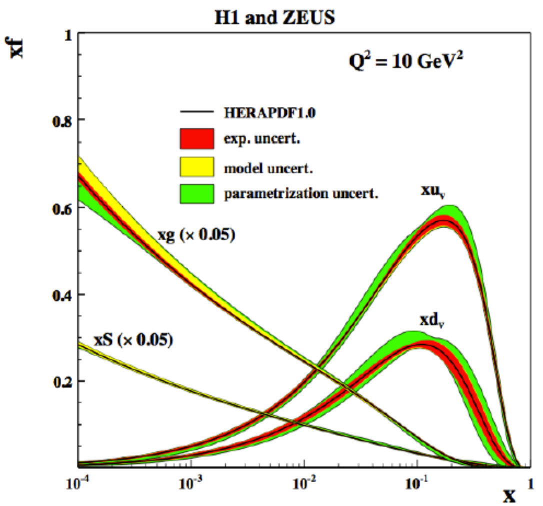
Low Energy Data: NC

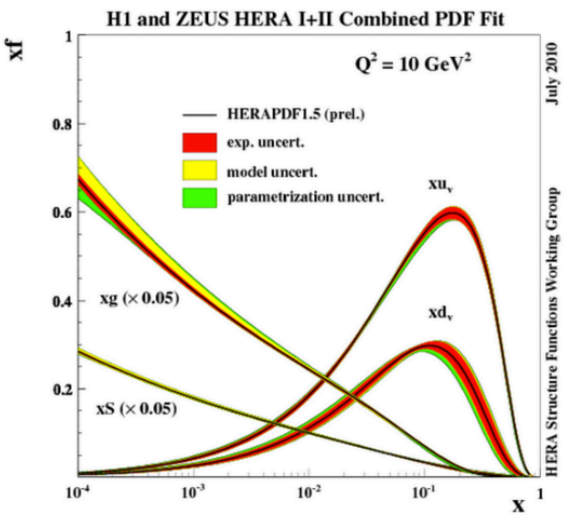


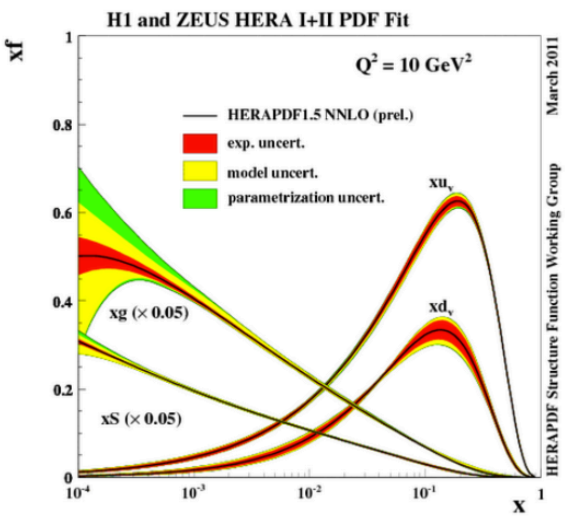
Significant gain in precision

Reminder of PDF sets from HERA

- **Released to LHAPDF:**
  - HERAPDF1.0 NLO: based on published HERA I data (with All Uncertainties) [JHEP01 (2010) 109]
  - HERAPDF1.5 NLO: based on preliminary HERA I+II data (with All Uncertainties) RECOMMENDED
  - HERAPDF1.5 NNLO: based on preliminary HERA I+II data (with All Uncertainties) RECOMMENDED







- **Not released to LHAPDF:**
  - HERAPDF1.0 NNLO: based on published HERA I data (2 central lines with different alphas)
  - HERAPDF1.6 NLO: based on preliminary HERA I+II and inclusive jets
  - HERAPDF1.7 NLO: : based on preliminary HERA I+II, inclusive jets, charm, low energy runs

Fits

- Chi2 minimisation (Minuit)

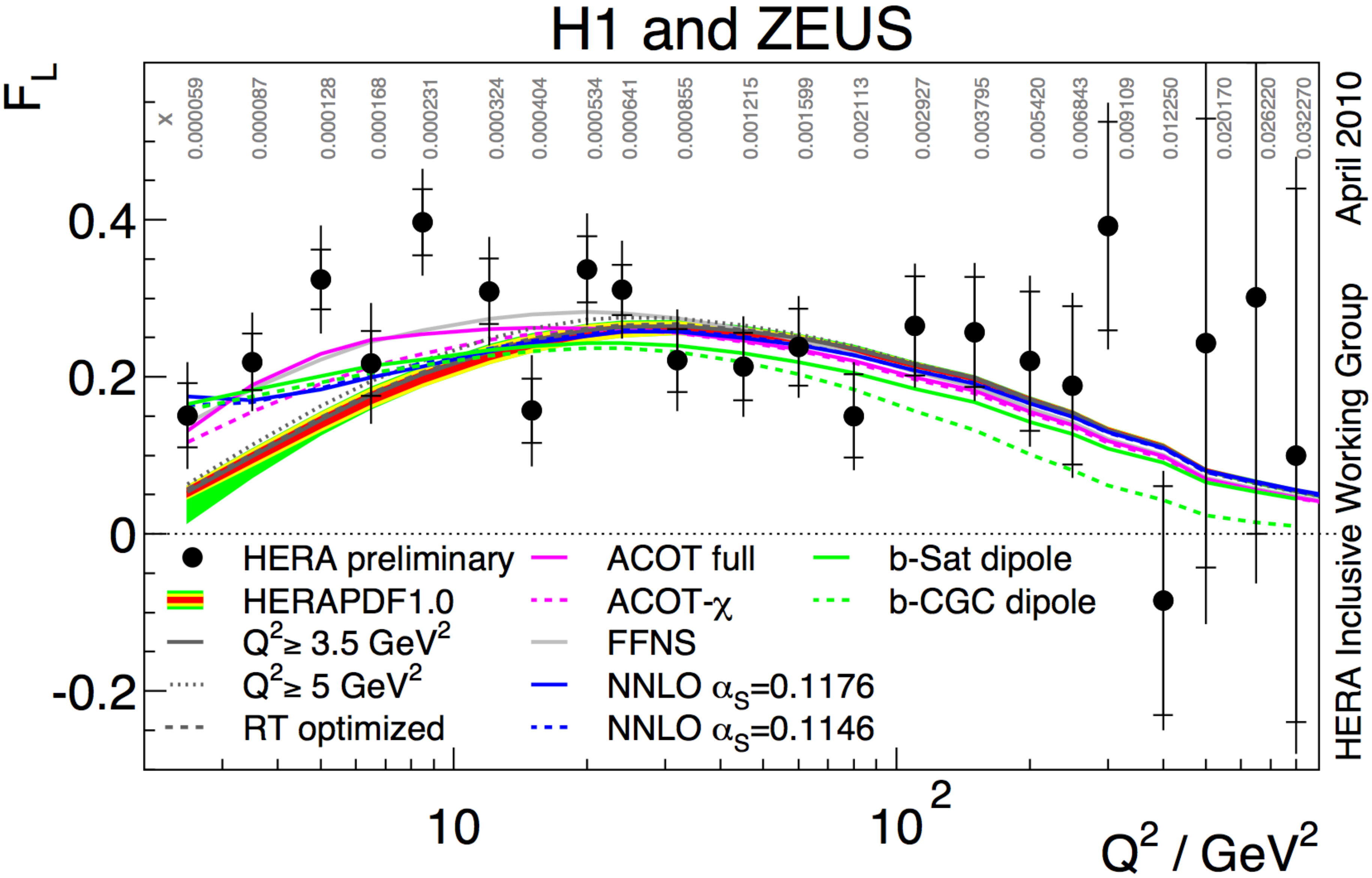
$$\chi^2 = \sum_i \frac{\left[\mu_i - m_i\left(1 - \sum_j \gamma_j^i b_j\right)\right]^2}{\delta_{i,\mathrm{unc}}^2 m_i^2 + \delta_{i,\mathrm{stat}}^2 \mu_i m_i \left(1 - \sum_j \gamma_j^i b_j\right)} + \sum_j b_j^2 + \sum_i \ln \frac{\delta_{i,\mathrm{unc}}^2 m_i^2 + \delta_{i,\mathrm{stat}}^2 \mu_i m_i}{\delta_{i,\mathrm{unc}}^2 \mu_i^2 + \delta_{i,\mathrm{stat}}^2 \mu_i^2}$$

m_i is the theoretical prediction
μ_i is the measured cross section

$\delta_{i\ \mathrm{stat}}$, $\delta_{i,\mathrm{unc}}$ statistical and uncorrelated systematic uncertainty
γ_j^i correlated systematic uncertainties
b_j shifts

Fit platform: **HERAFitter** (multiexperiment+theory collaboration)
http://herafitter.org

FL



H1 and ZEUS
F_L
x
0.000059
0.000087
0.000128
0.000168
0.000231
0.000324
0.000404
0.000534
0.000641
0.000855
0.001215
0.001599
0.002113
0.002927
0.003795
0.005420
0.006843
0.009109
0.012250
0.020170
0.026220
0.032270
0.4
0.2
0
-0.2
HERA preliminary
HERAPDF1.0
$Q^2 \geq 3.5$ GeV^2
$Q^2 \geq 5$ GeV^2
RT optimized
ACOT full
ACOT-χ
FFNS
NNLO α_S=0.1176
NNLO α_S=0.1146
b-Sat dipole
b-CGC dipole
10
10^2
Q^2 / GeV^2
HERA Inclusive Working Group April 2010

HERAPDF 2.0

H1prelim-14-042
ZEUS-prel-14-007

- New data sets and cominations available
- The preliminary HERA I+II combination is used as a sole input in QCD fit platform to determine HERAPDF2.0 (prel)