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HERA crown jewels
Inclusive cross sections and parton distributions

arXiv.org > hep-ex > arXiv:1506.06042

High Energy Physics – Experiment

Combination of Measurements of Inclusive Deep Inelastic $e^{\pm}p$ Scattering Cross Sections and QCD Analysis of HERA Data

H1, ZEUS Collaborations

(Submitted on 19 Jun 2015)

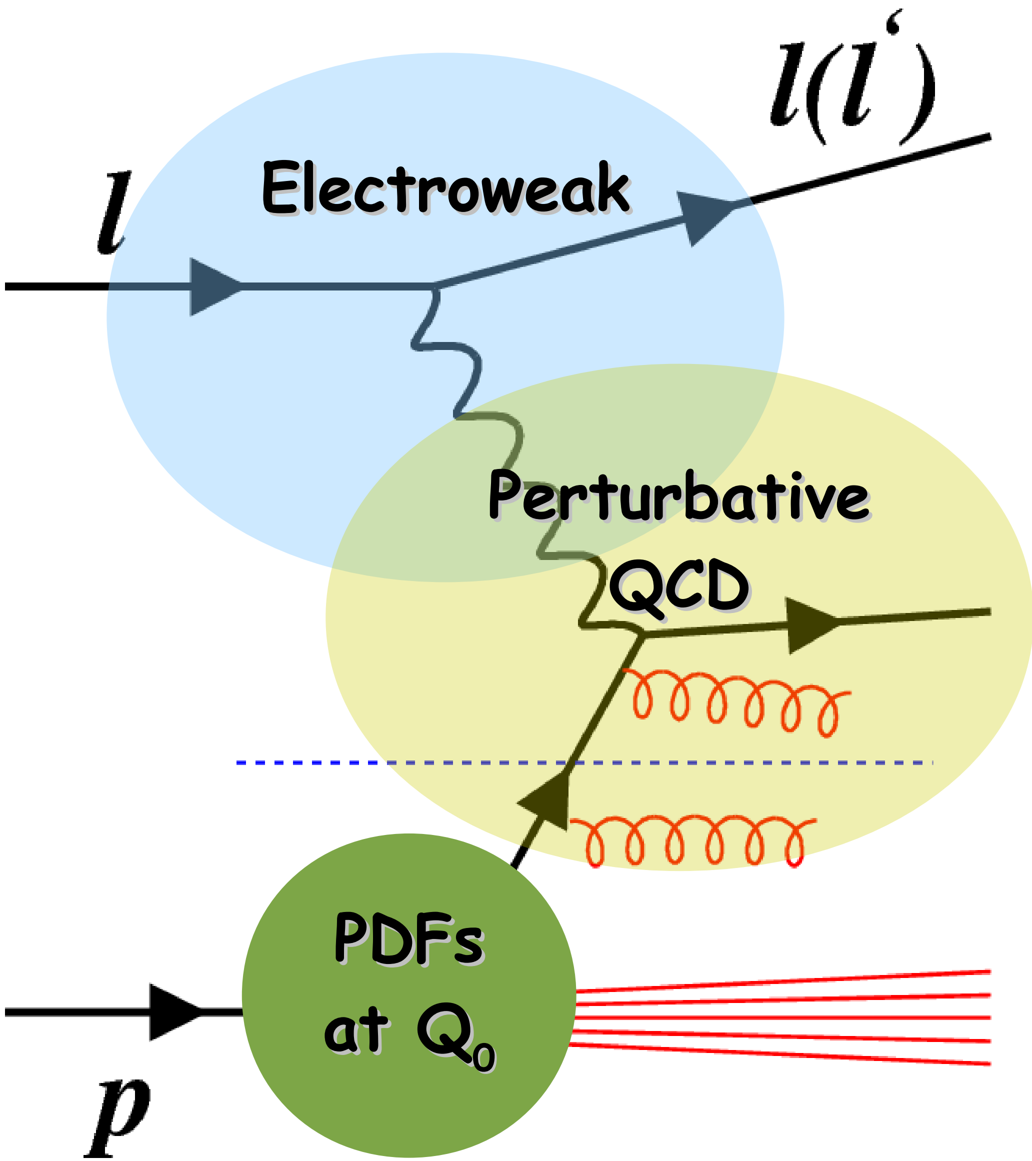
K. Wichmann on behalf of H1 and ZEUS Collaborations

HERA accelerator

ZEUS

Two colliding experiments

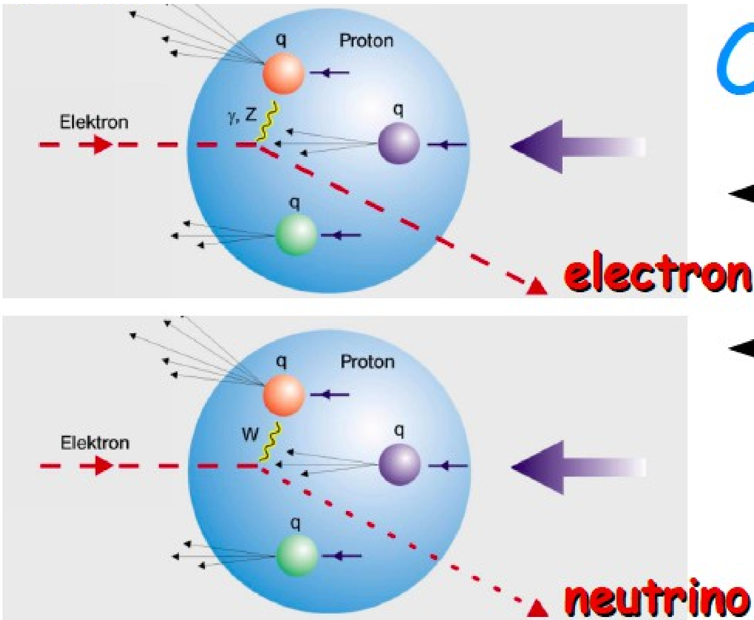
Deep Inelastic Scattering @ HERA



- Fix pQCD & PDFs
  ! Test Electroweak
- Fix Electroweak
  ! Test pQCD & PDFs

- Fix Electroweak & pQCD
  ! Determine PDFs

Combined inclusive DIS



Neutral Current (NC)

γ, Z^0 exchange

Charged Current (CC)

$W^{\pm}$ exchange

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

$$x_{Bj} = \frac{Q^2}{2p \cdot q} \qquad y = \frac{p \cdot q}{p \cdot k}$$

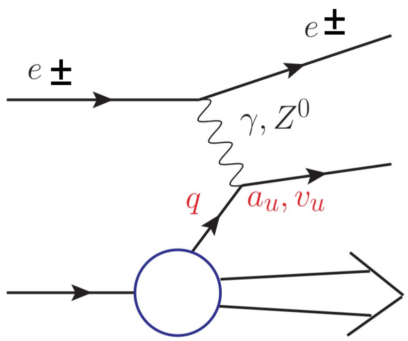
$$s = (p + k)^2 \qquad Q^2 = x_{Bj} \cdot y \cdot s$$

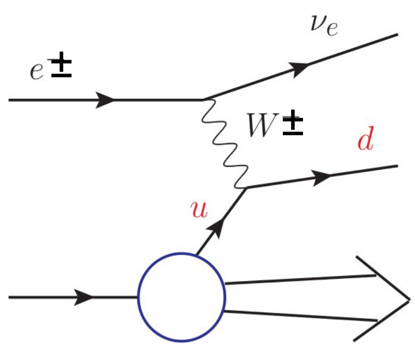
<u>H1 and ZEUS published all HERA inclusive DIS measurements – 1 fb^{-1}</u>

Now we combine these measurements

Inclusive DIS data samples

- 41 final data sets with HERA inclusive measurements
- NCep and CCep
  - 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





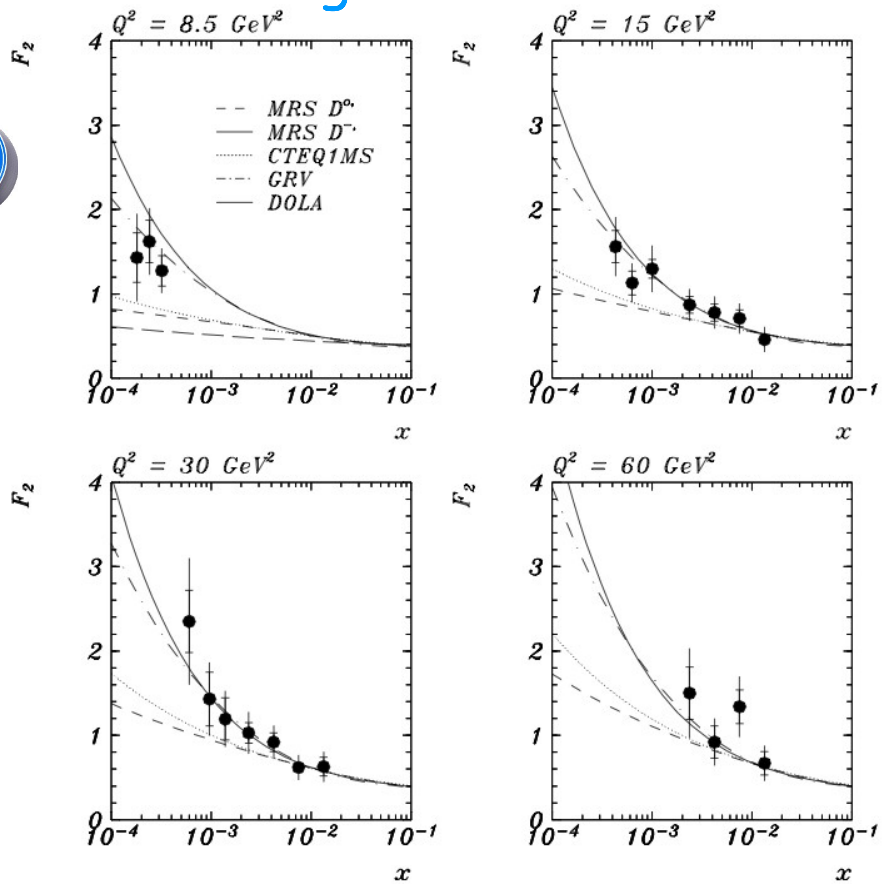
- Data 1994-2007: over 10 years of data taking!
- 22 papers between 1997-2014: almost 20 years of data analysis!

Total of 2927 data points combined to 1307

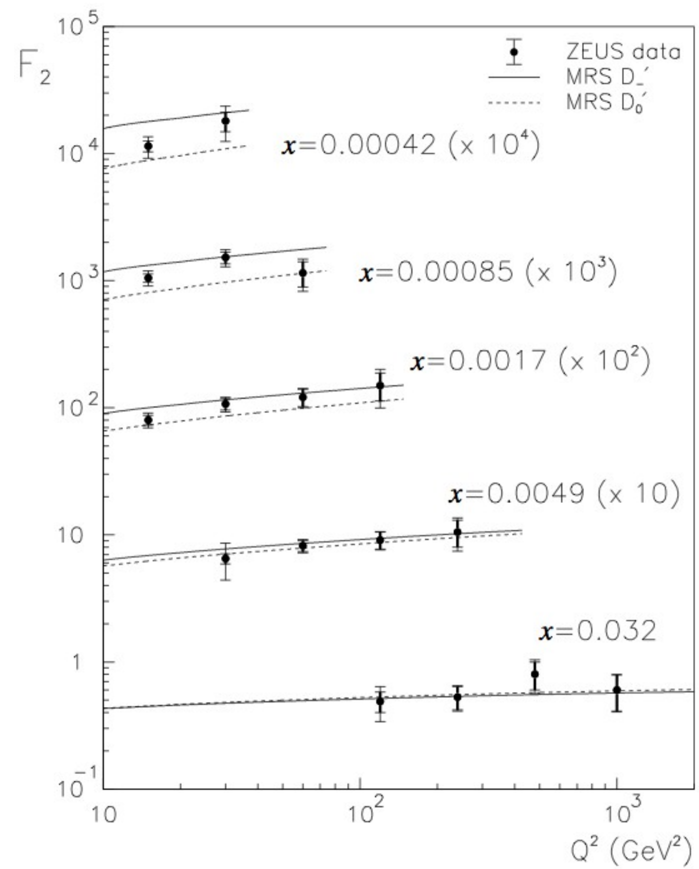
First F_2 measurements @ HERA: 1993

~20 nb^{-1} → 1 fb^{-1}

August 25th



August 13th



The F_2 structure function increases rapidly as x decreases.

it is exciting to see F_2 rise at small x.

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Full publication list

F. Aaron *et al.* [H1 Collaboration], Eur. Phys. J. C **63**, 625 (2009), [arXiv:0904.0929].

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S. Chekanov *et al.* [ZEUS Collaboration], Eur. Phys. J. C **61**, 223 (2009), [arXiv:0812.4620].

H. Abramowicz *et al.* [ZEUS Collaboration], Phys. Rev. D **87**, 052014 (2013), [arXiv:1208.6138].

H. Abramowicz *et al.* [ZEUS Collaboration], Eur. Phys. J. C **70**, 945 (2010), [arXiv:1008.3493].

H. Abramowicz *et al.* [ZEUS Collaboration], Phys. Rev. D **90**, 072002 (2014), [arXiv:1404.6376].

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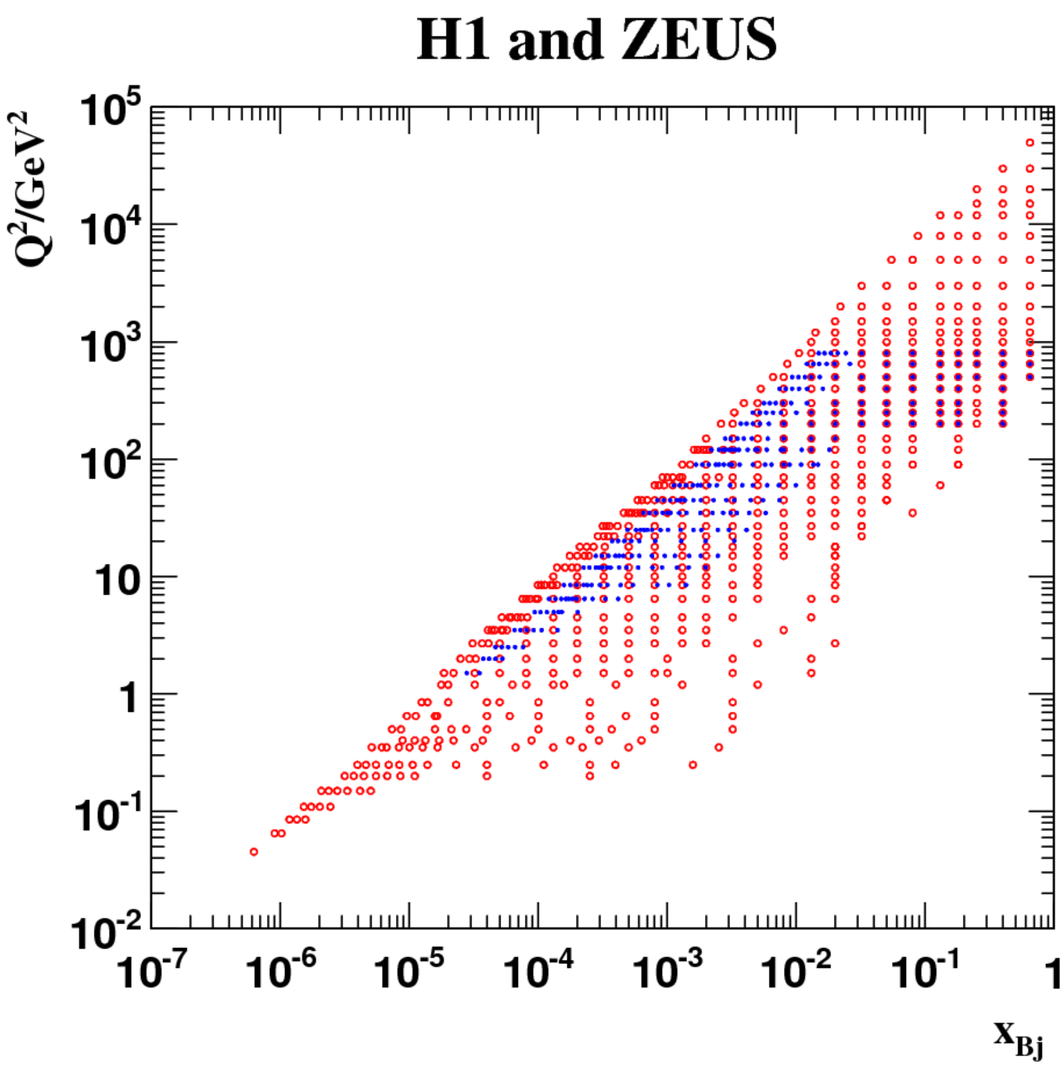
Q^2-x_{Bj} common grids



Two separate grids

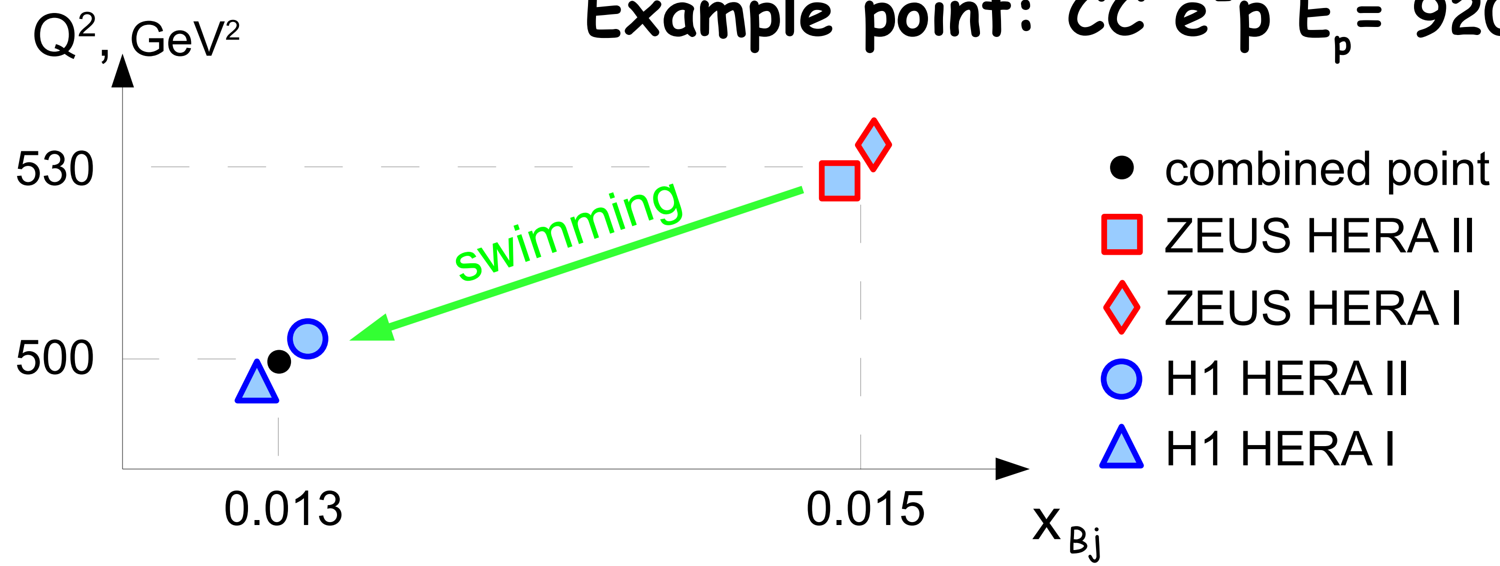
○ inclusive grid, for E_p= 920 GeV and E_p= 820 GeV data sets

● fine-x_{Bj} grid, for E_p= 575 GeV and E_p= 460 GeV data sets

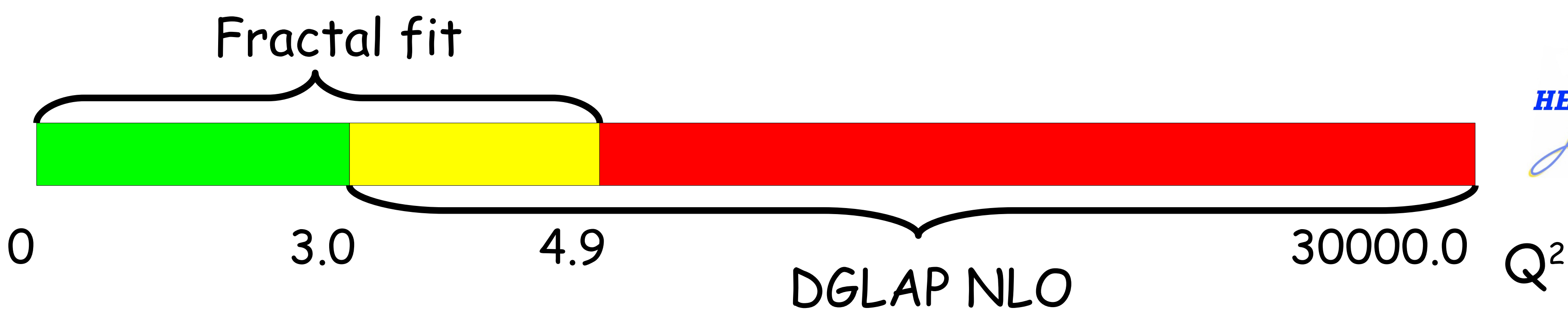
- 1307 grid points
  - $0.045 < Q^2 < 50000$ GeV^2
  - $6\times10^{-07} < x_{Bj} < 0.65$

Swimming procedure

Example point: CC e^-p E_p= 920 GeV



- Swimming done iteratively using our own data
  - 1st iteration uncombined HERAI+II data, later - combined data



- Swimming factors are usually at level of few %

Averaging procedure

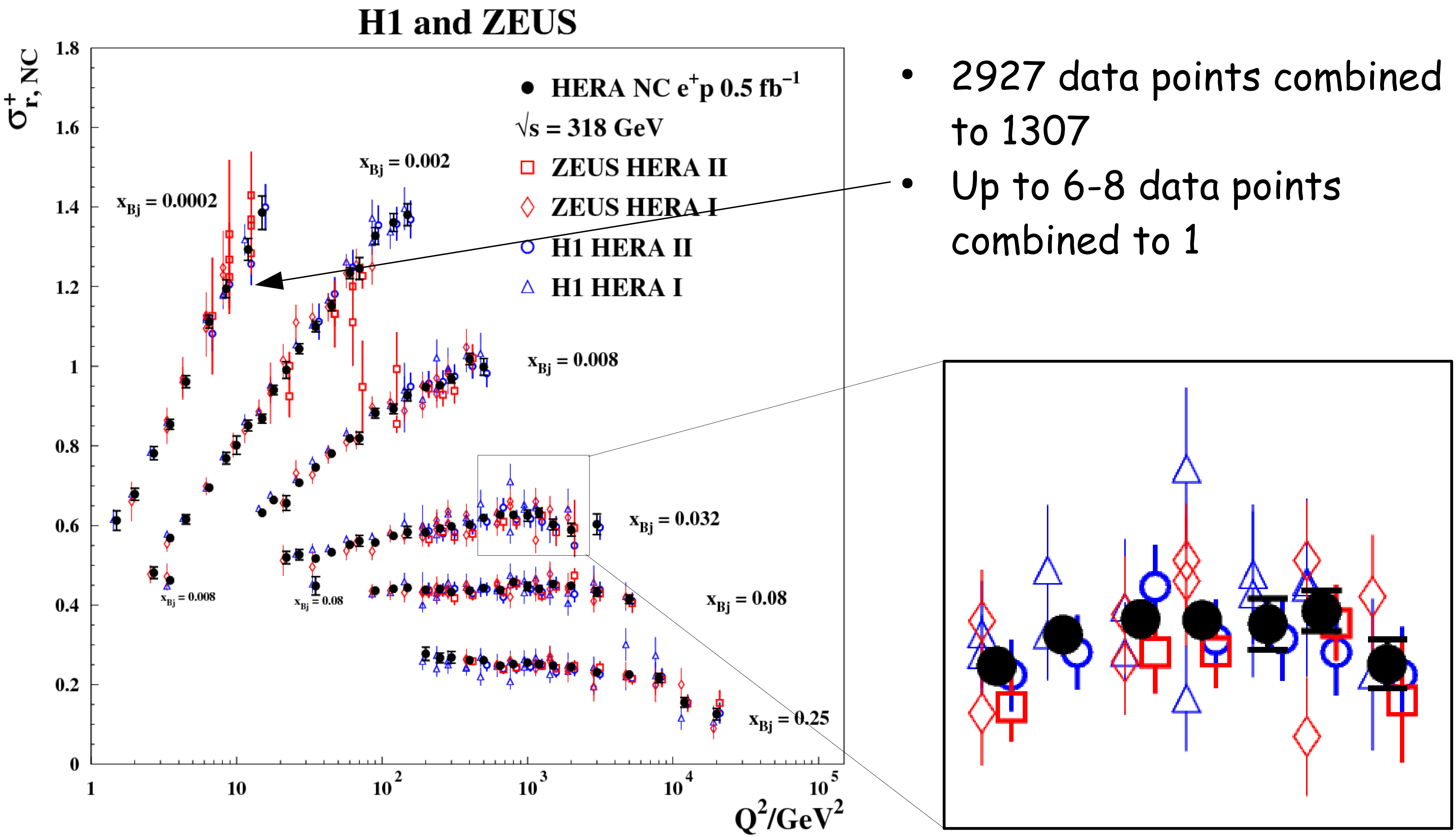
- Combination done using HERAverager: wiki-zeuthen.desy.de/HERAverager

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

- **162** correlated systematic sources taken into account
- Output
  - 7 data samples for $e^{\pm}p$, NC and CC, 3 CMEs
  - Statistical and uncorrelated systematic uncertainties
  - 162 correlated statistical uncertainties
  - 7 procedural uncertainties calculated → see additional material

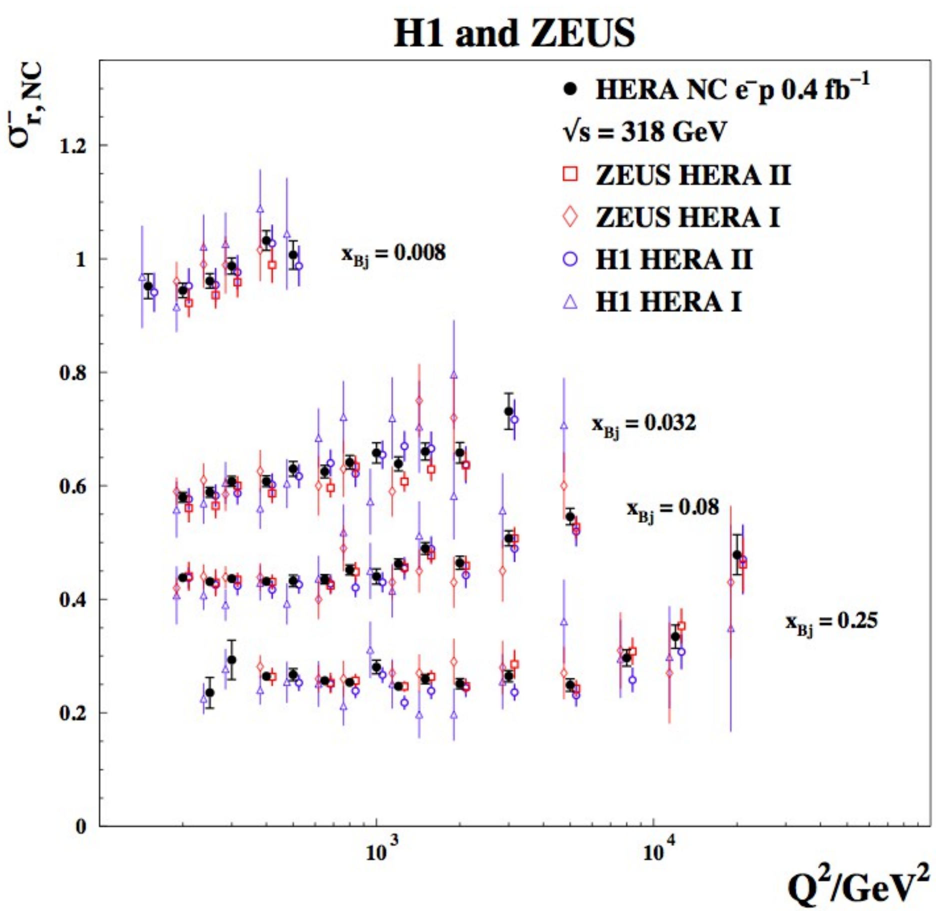
Good data consistency: χ^2/dof = 1687/1620

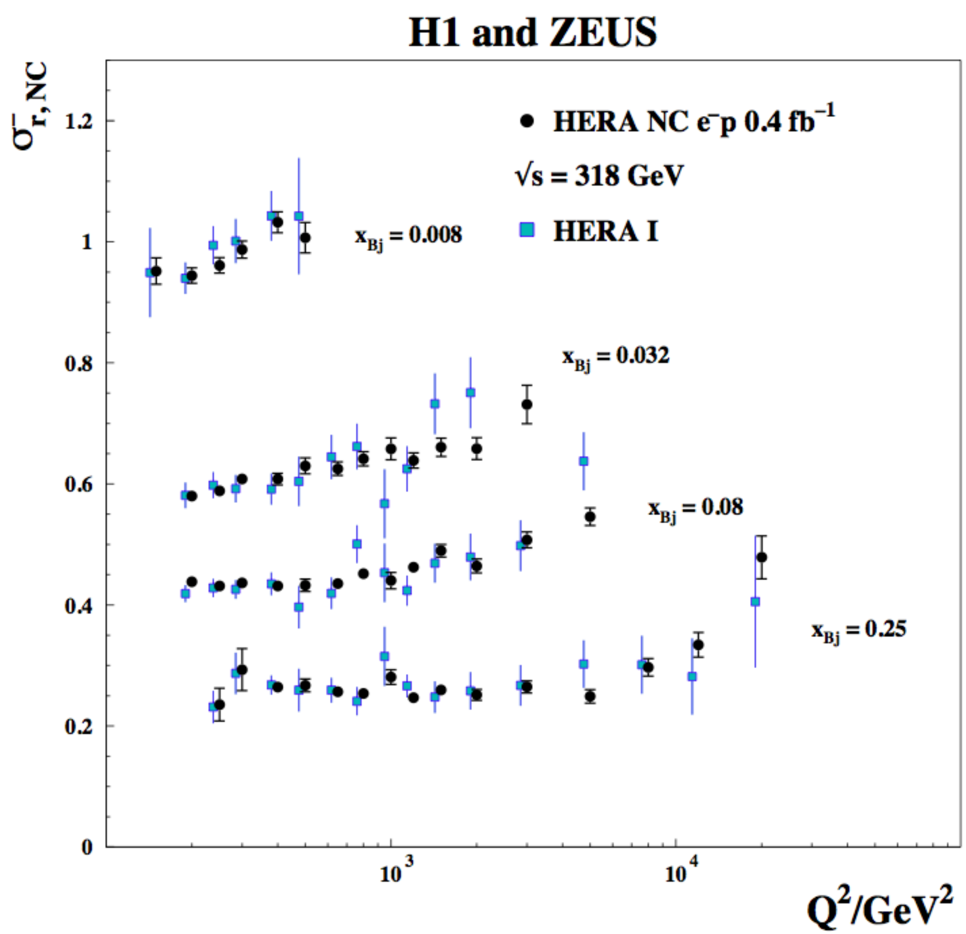
Impressive amount of data points combined



- 2927 data points combined to 1307
- Up to 6-8 data points combined to 1

Improved precision

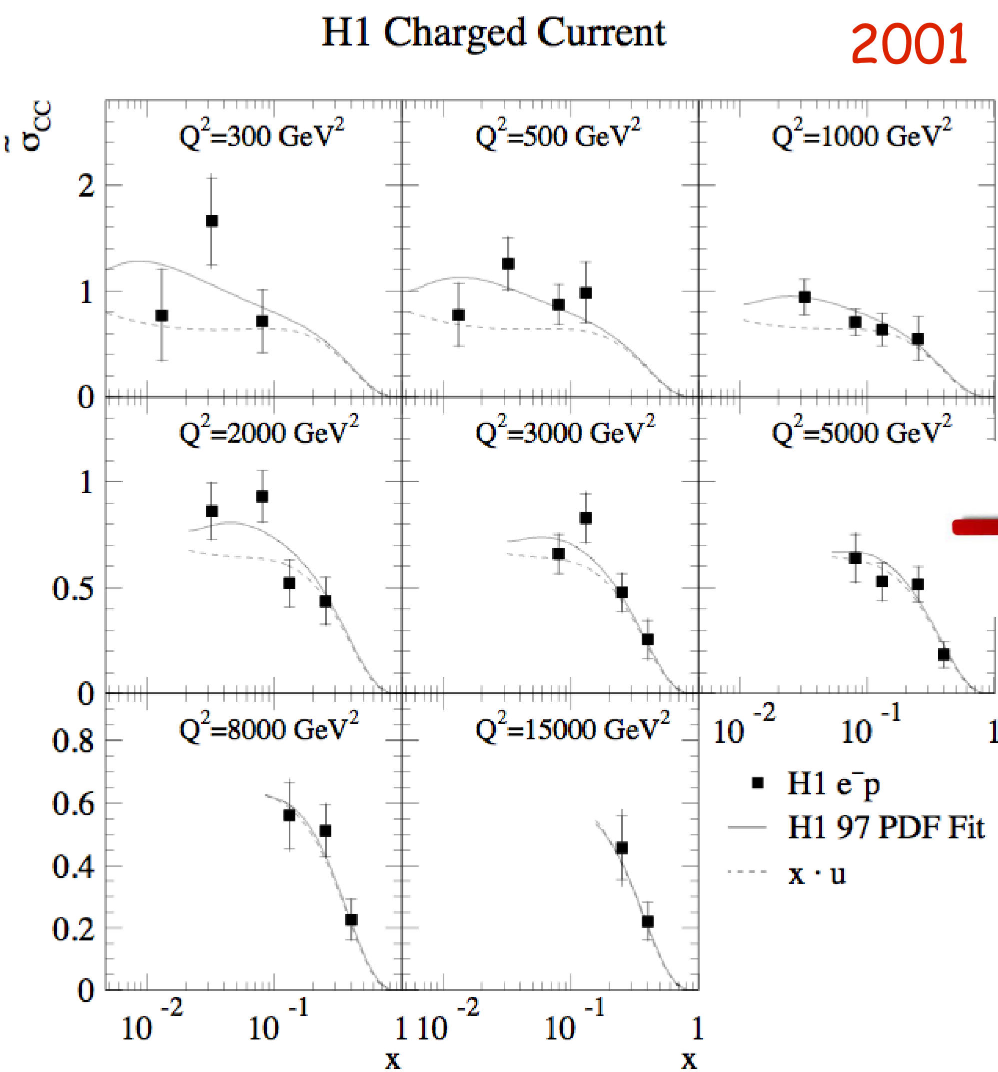


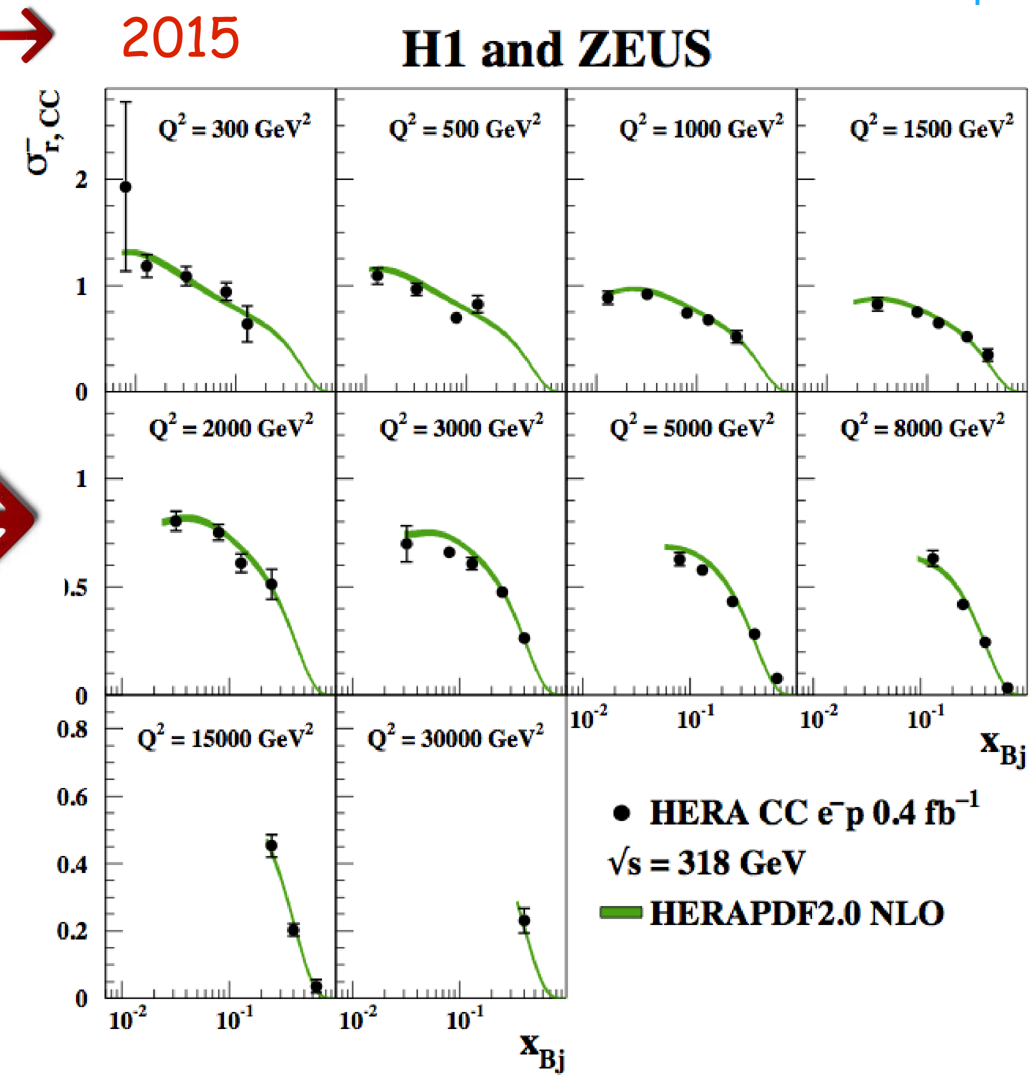


- Largest and most accurate data sample is for the NC e^+p process
- The combined data accuracy reaches ~ 1%
- Largest improvement for NC e^-p – 10 times more luminosity
- Consistent with HERA-I + improved uncertainties

Improving previous results

2001 → 2015



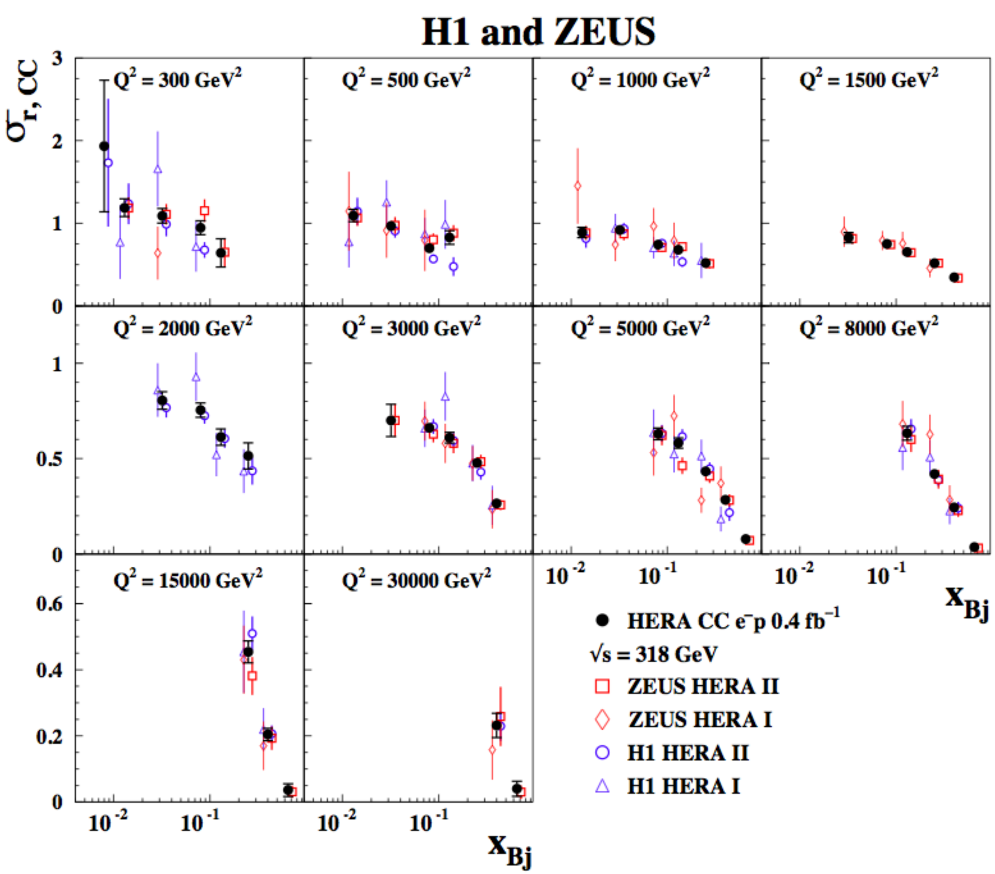


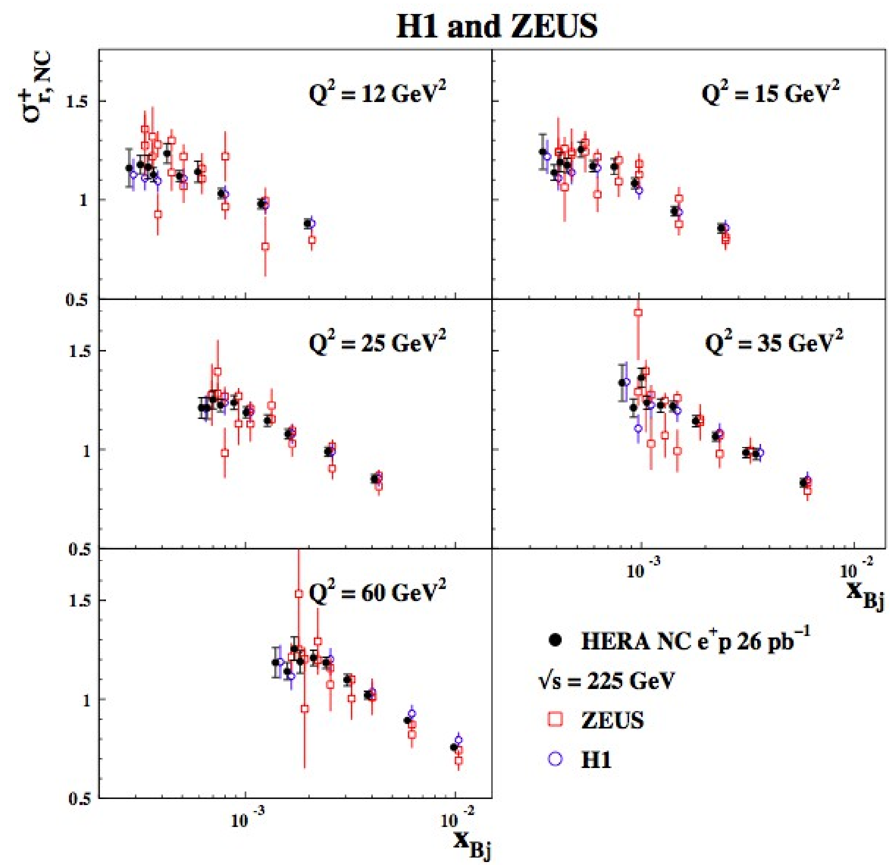
- increases statistical significance
- reduces systematic uncertainties via cross calibration techniques

Great gain in precision

New kinematic ranges explored

- Kinematic range extended for existing data samples
- Low energies added: CME = 225 GeV and 251 GeV





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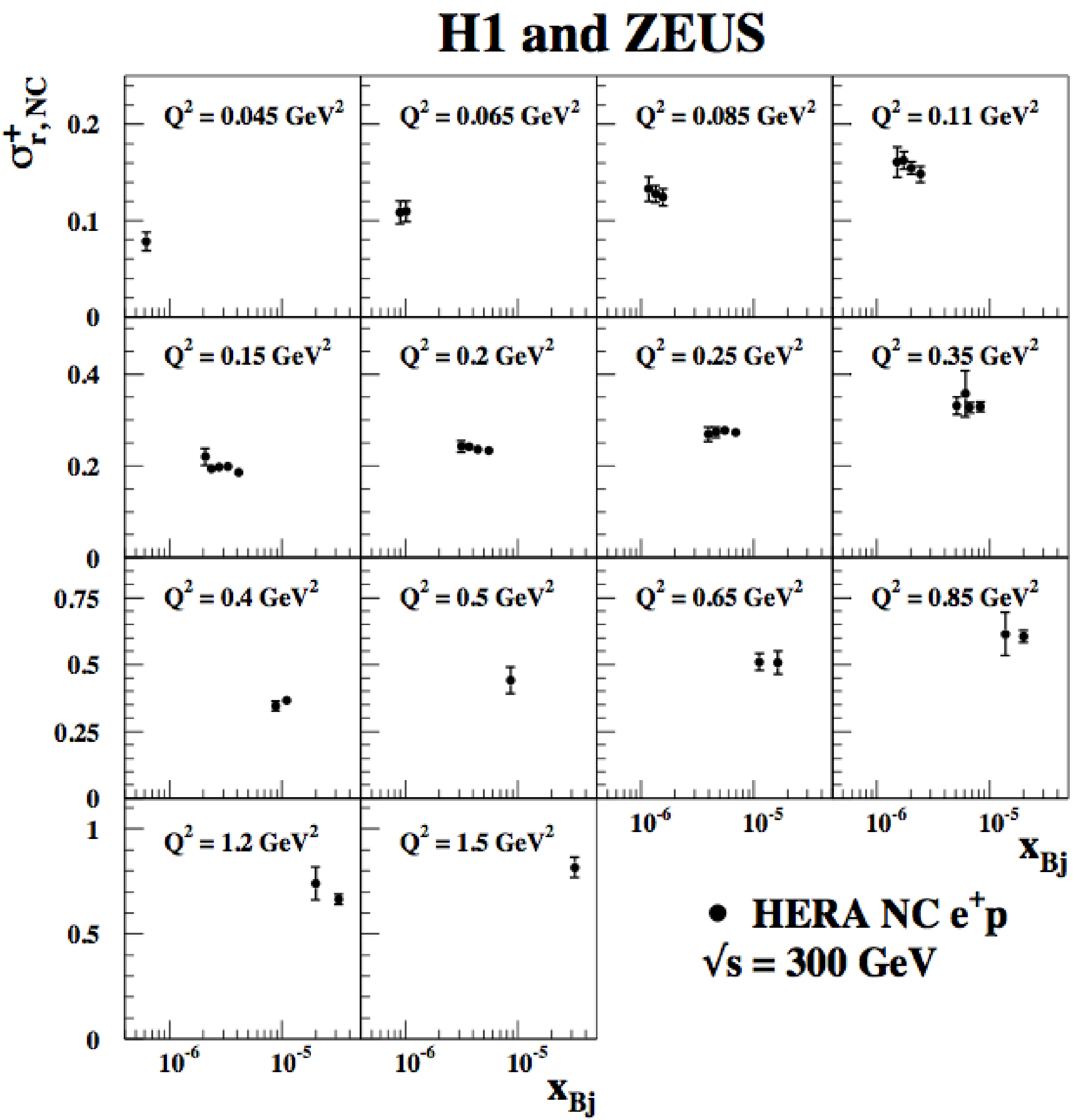
Low Q^2 combined data

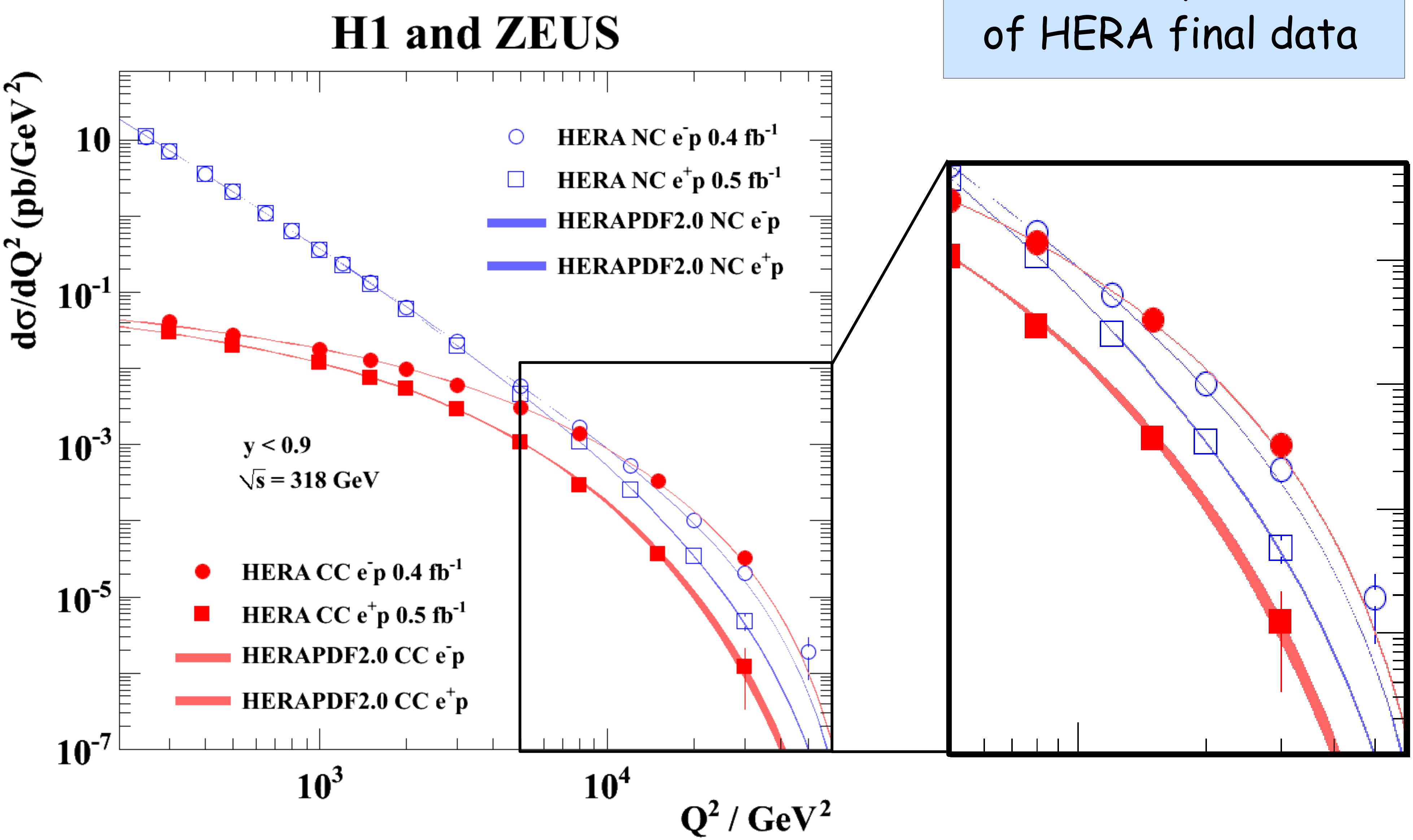


- Combined inclusive cross sections for low Q^2
- Available for two CMEs
  - 300 GeV
  - 318 GeV
- Interesting for
  - dipole/saturation models
  - studying higher twists

~~Mortal Kombat~~

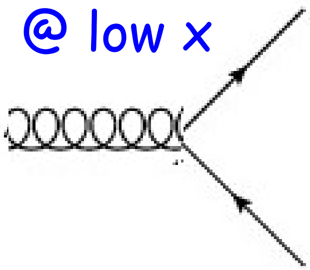
HERA Legacy

Electroweak unification

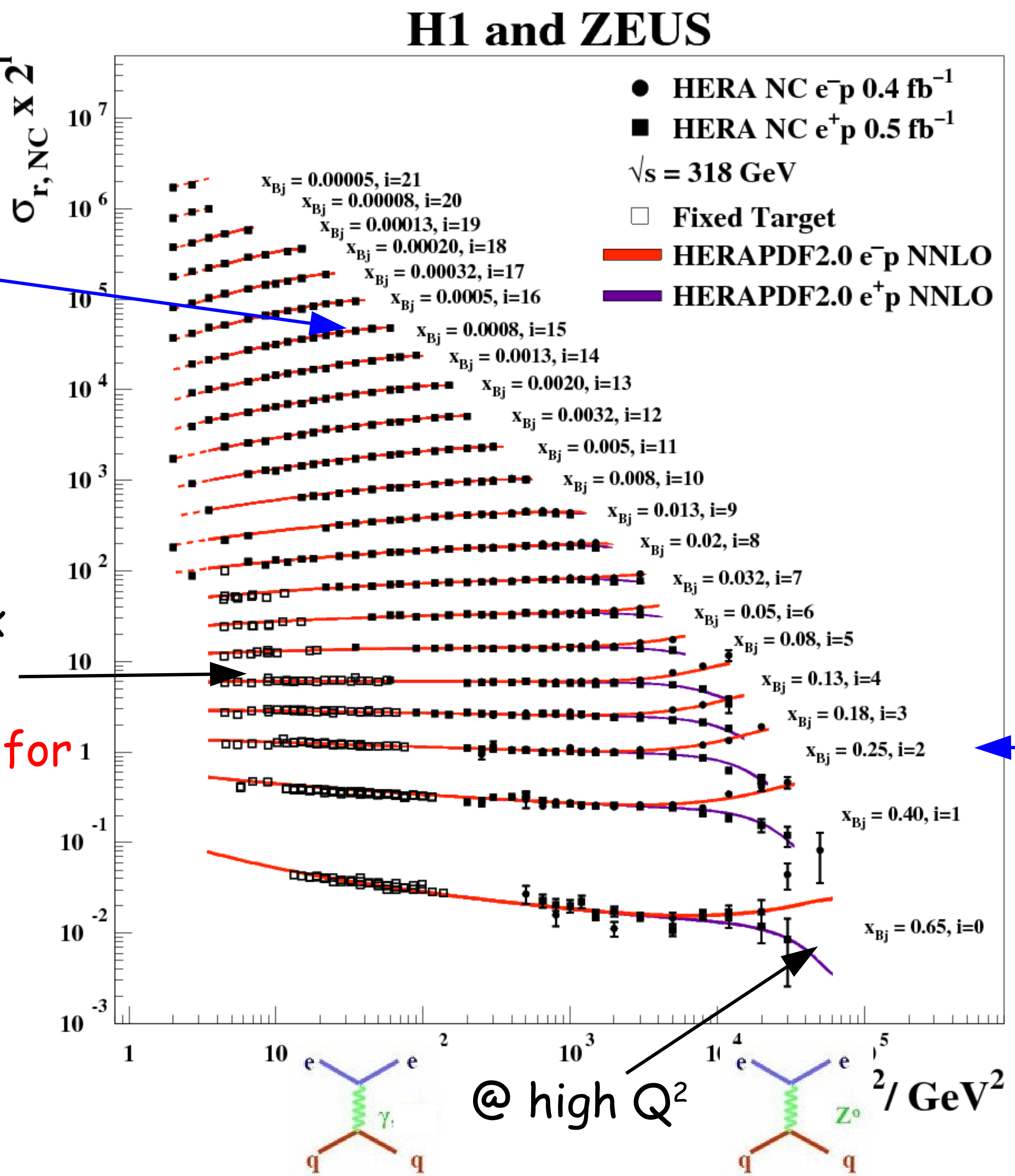


Fantastic precision of HERA final data

@ low x



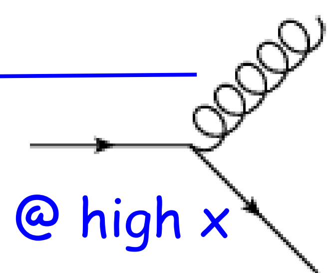
electron-proton
positron-proton



@ moderate x

QCD scaling

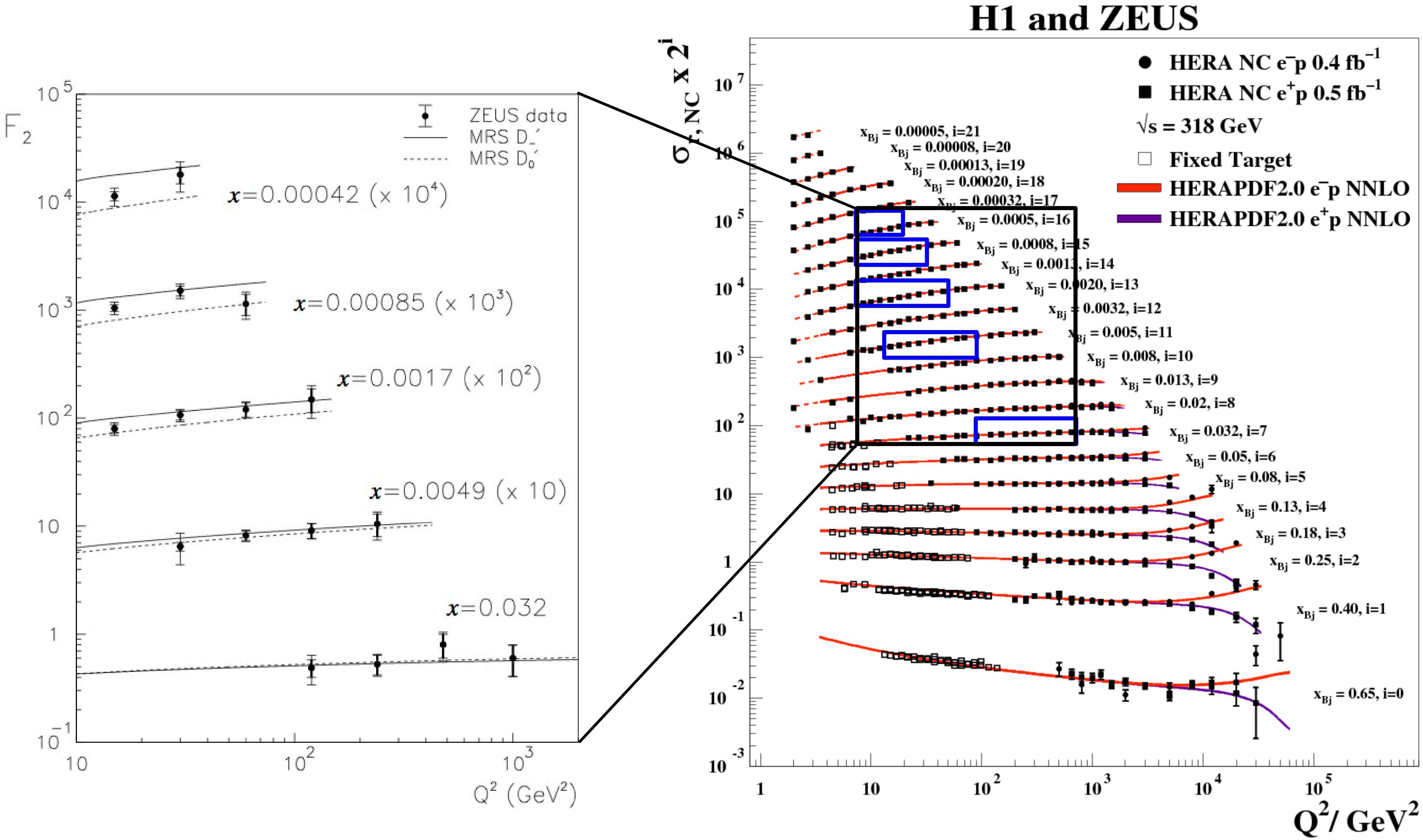
2015 Wolf prize for
J. Bjorken!



@ high x

Text book plots of fundamental properties of particle interactions

First → Final


ZEUS data
MRS D_′
MRS D0′
F2
x=0.00042 (× 10⁴)
x=0.00085 (× 10³)
x=0.0017 (× 10²)
x=0.0049 (× 10)
x=0.032
Q² (GeV²)
H1 and ZEUS
σr,NC x 2^i
HERA NC e⁻p 0.4 fb⁻¹
HERA NC e⁺p 0.5 fb⁻¹
√s = 318 GeV
Fixed Target
HERAPDF2.0 e⁻p NNLO
HERAPDF2.0 e⁺p NNLO
xBj = 0.00005, i=21
xBj = 0.00008, i=20
xBj = 0.00013, i=19
xBj = 0.00020, i=18
xBj = 0.00032, i=17
xBj = 0.0005, i=16
xBj = 0.0008, i=15
xBj = 0.0013, i=14
xBj = 0.0020, i=13
xBj = 0.0032, i=12
xBj = 0.005, i=11
xBj = 0.008, i=10
xBj = 0.013, i=9
xBj = 0.02, i=8
xBj = 0.032, i=7
xBj = 0.05, i=6
xBj = 0.08, i=5
xBj = 0.13, i=4
xBj = 0.18, i=3
xBj = 0.25, i=2
xBj = 0.40, i=1
xBj = 0.65, i=0
Q²/ GeV²

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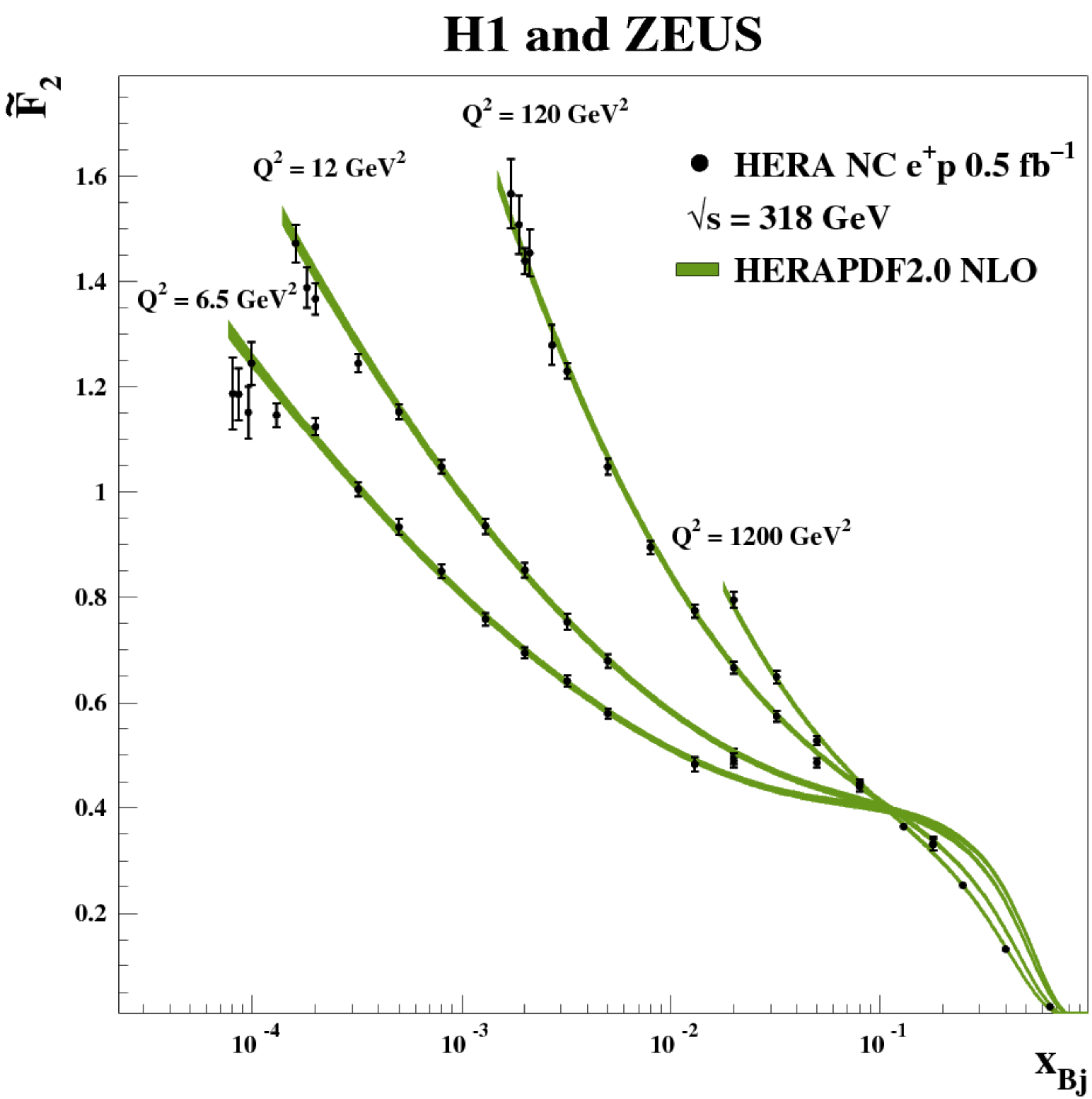
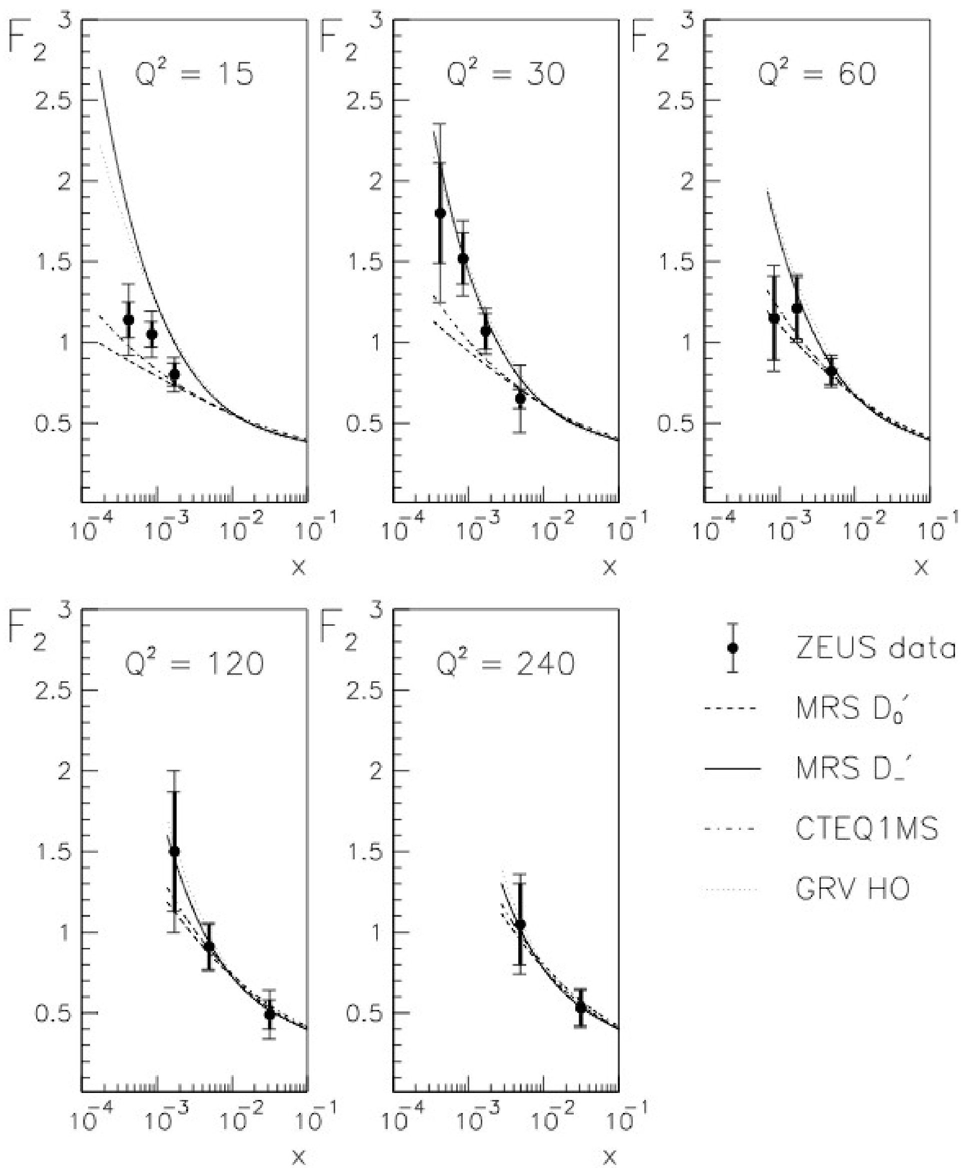
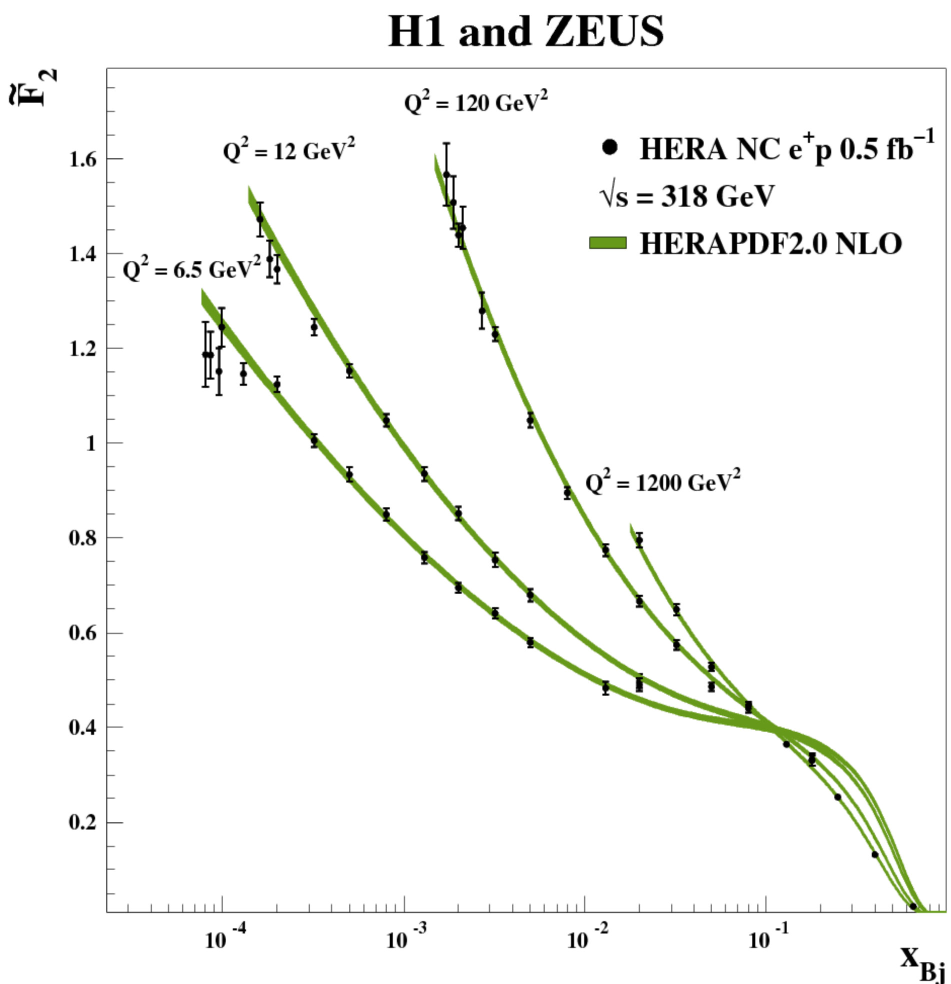
As expected: low-x rise of F_2



1993 → 2015



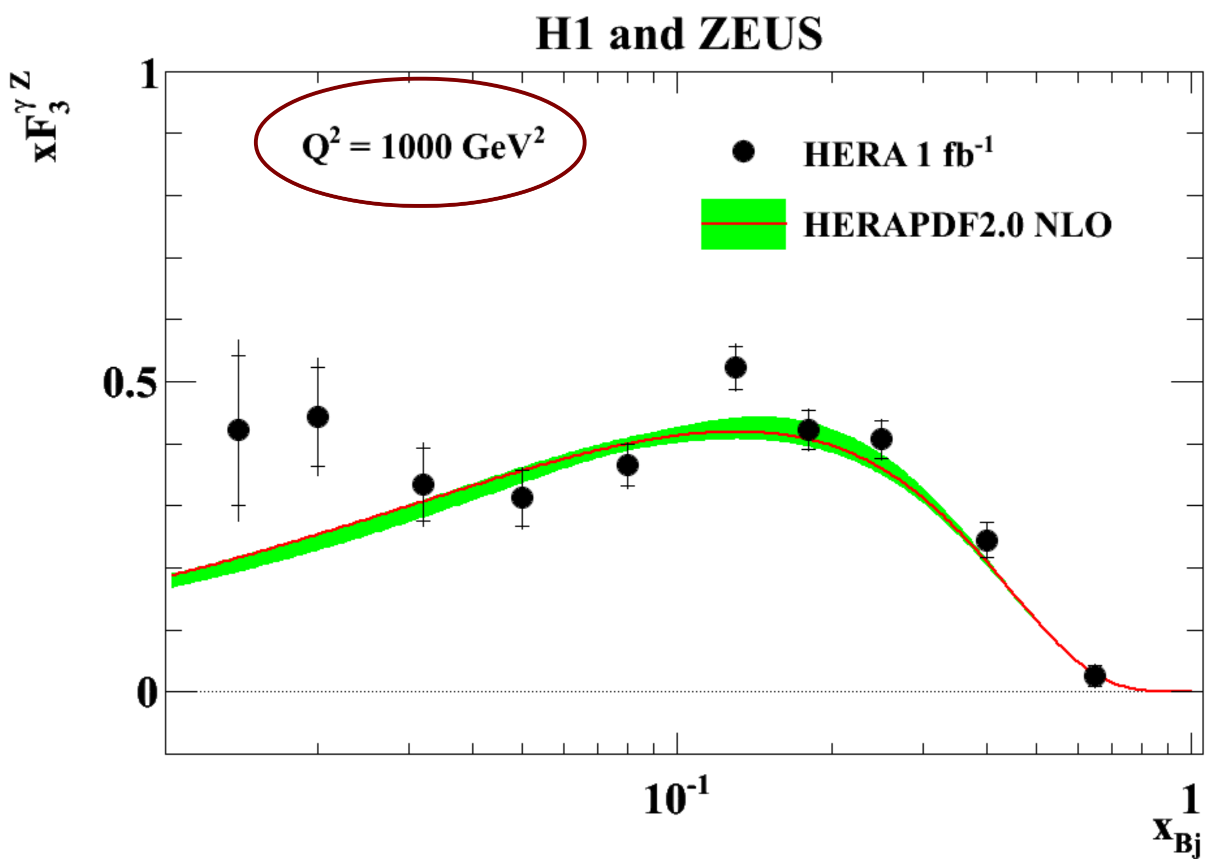
Q² = 15
Q² = 30
Q² = 60
Q² = 120
Q² = 240
F2
x
ZEUS data
MRS D0′
MRS D-′
CTEQ1MS
GRV HO



H1 and ZEUS
F̃2
xBj
Q² = 6.5 GeV²
Q² = 12 GeV²
Q² = 120 GeV²
Q² = 1200 GeV²
HERA NC e⁺p 0.5 fb⁻¹
√s = 318 GeV
HERAPDF2.0 NLO

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

- xF_3^{gZ} from subtracting the NC e^+p from the NC e^-p cross sections
- Weak Q^2 dependence → translated to Q^2 = 1000 GeV^2 and averaged
- Good agreements with predictions



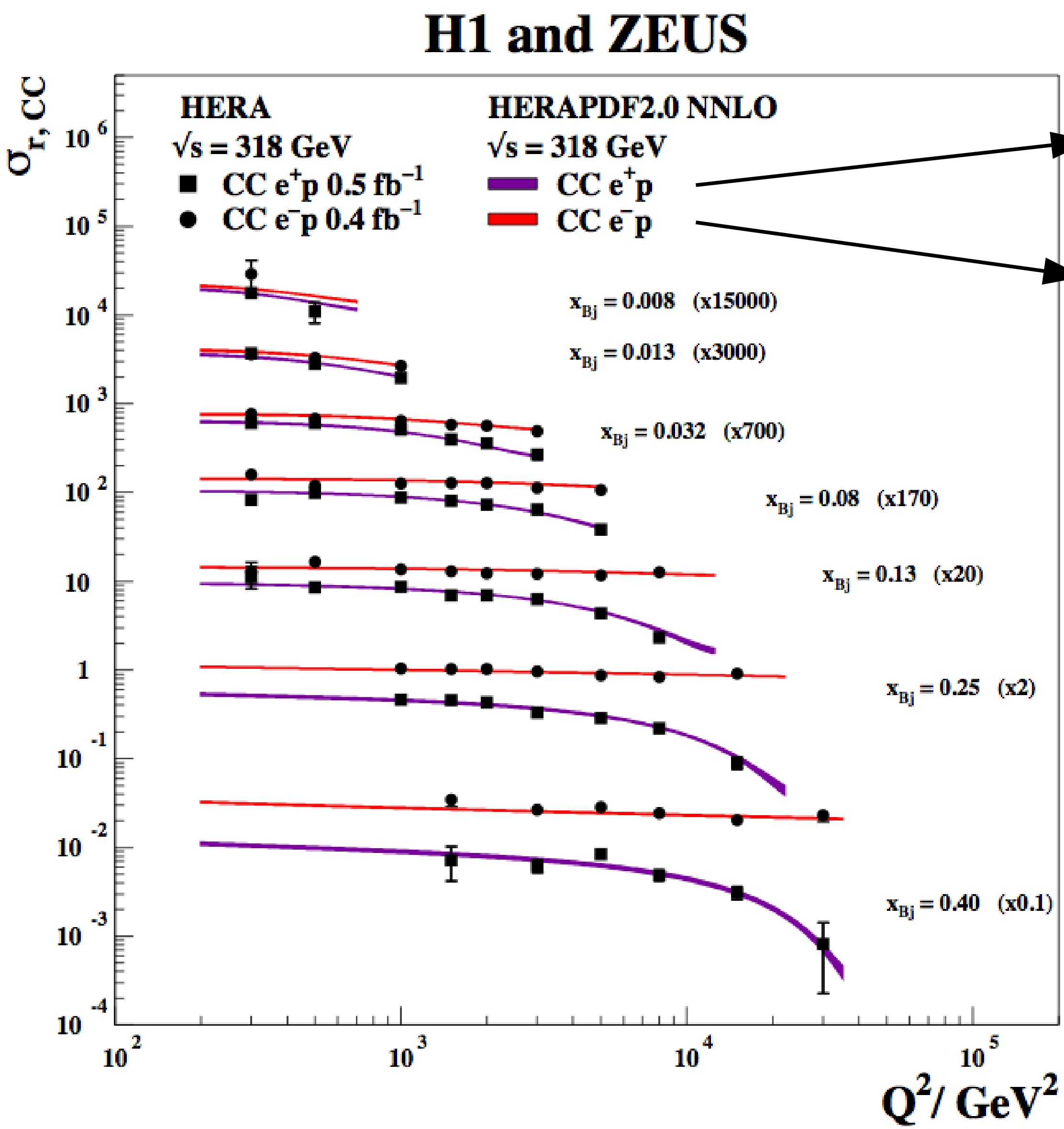
- Integrated over x:

$0.016 < x_{Bj} < 0.725$ HERAPDF2.0 : $1.165^{+0.042}_{-0.053}$ Data : $1.314 \pm 0.057(\text{stat}) \pm 0.057(\text{syst})$

$0 < x_{Bj} < 1$ { HERAPDF2.0 : $1.588^{+0.078}_{-0.100}$ Data : $1.790 \pm 0.078(\text{stat}) \pm 0.078(\text{syst})$

QPM: 5/3

CC: helicity effects



$$\sigma^{+}_{CC} \sim x[\bar{u} + \bar{c}] + x(1-y)^2[d + s]$$

$$\sigma^{-}_{CC} \sim x[u + c] + x(1-y)^2[\bar{d} + \bar{s}]$$

- e^+p: d_v quarks are suppressed at high Q^2
- e^-p: helicity factor applies to sea quarks only

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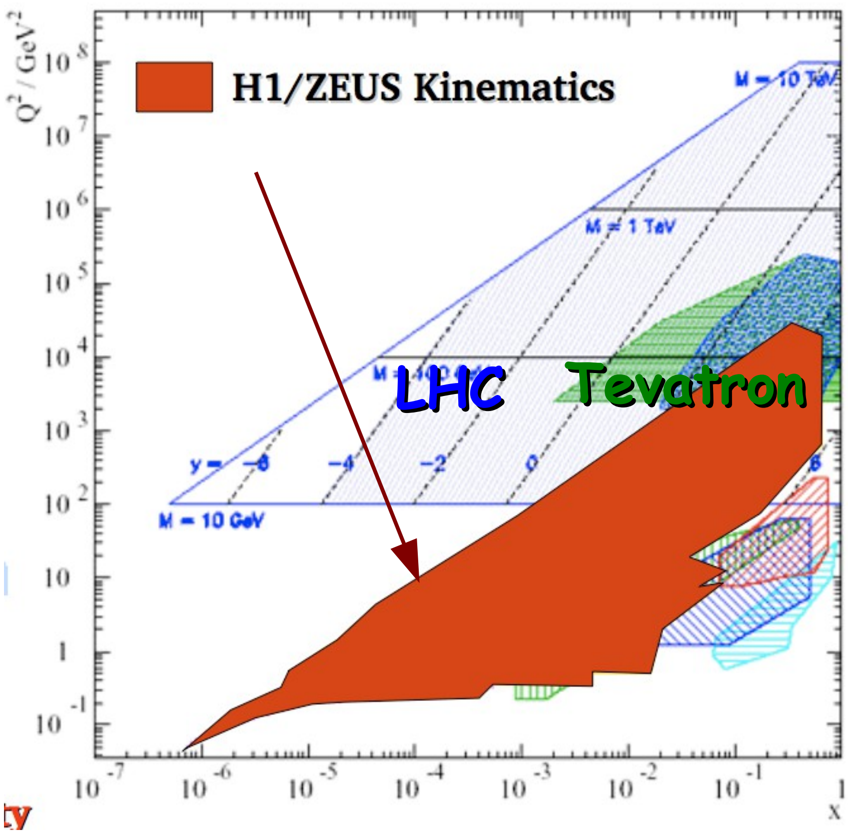
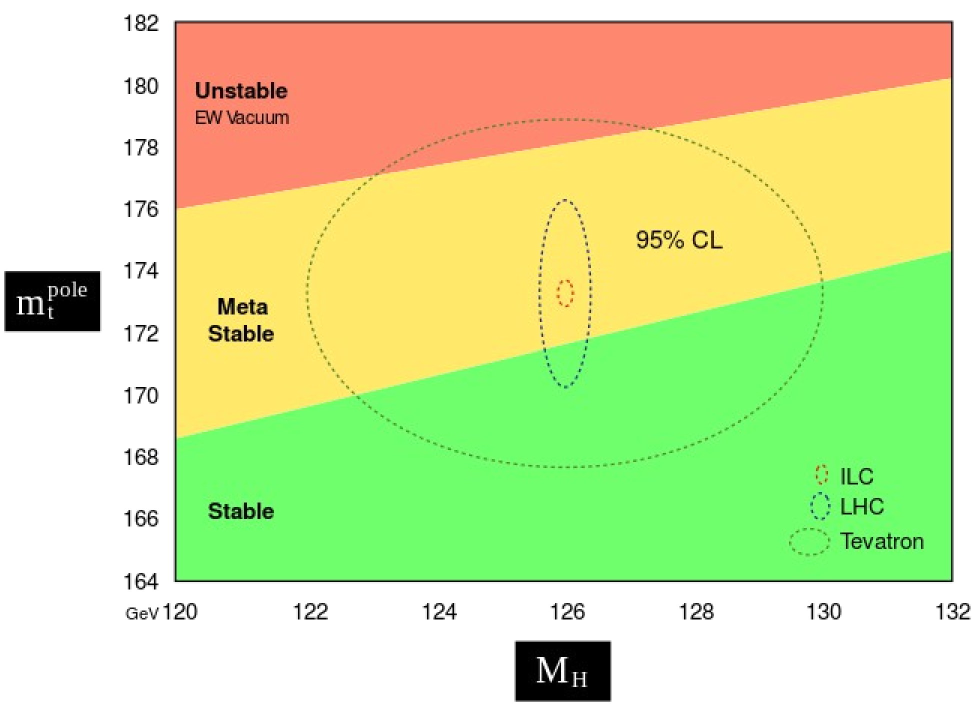
Proton structure

Inclusive measurements from HERA are core of every parton density extraction

- PDFs used in interactions with proton: LHC, Tevatron, HERA
- Precision of many measurements often limited by PDF uncertainty
  - Higgs/top properties

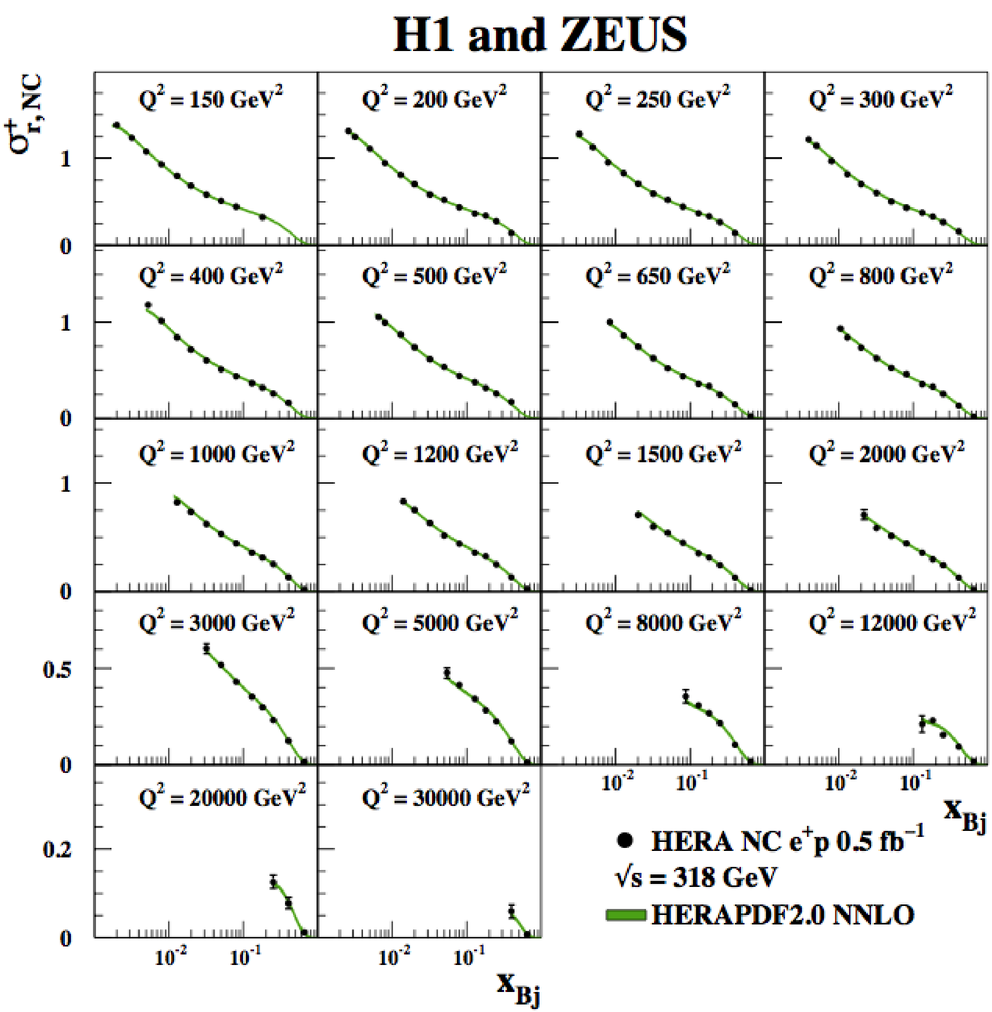
Will we tunnel?...





Neutral Current

$$\frac{d^2\sigma^{\pm}_{NC}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+F_2 \mp Y_-xF_3 - y^2F_L\right]$$



Proton structure functions

$$F_2 = x\sum e_q^2[q(x) + \bar{q}(x)]$$

- Sensitive to quarks

$$xF_3 = x\sum 2e_q a_q[q(x) - \bar{q}(x)]$$

- Sensitive to valence distributions

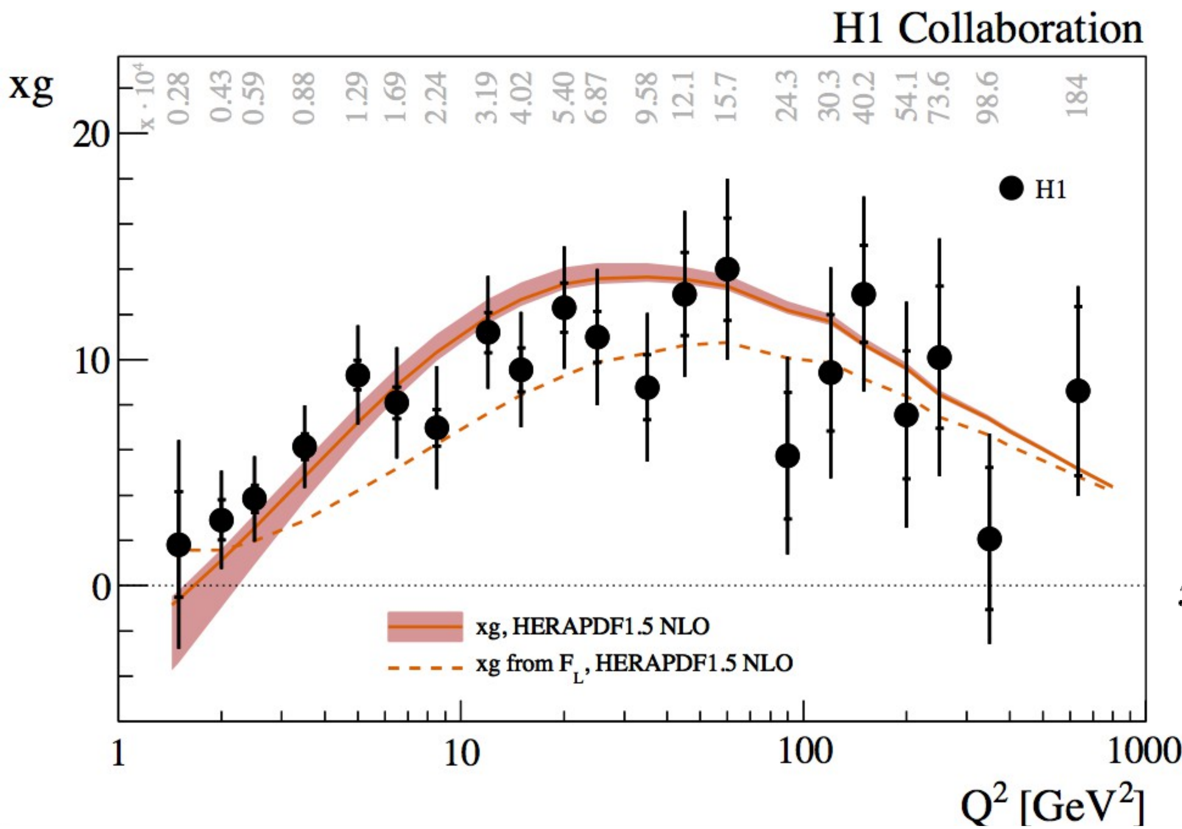
$$F_L \sim \alpha_S \, x \, g$$

- Sensitive to gluon

- Gluon also from scaling violation and charm+jet data

Gluon meets F_L

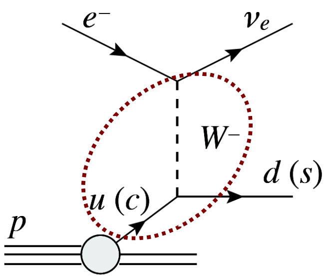
- H1 performed direct extraction of gluon density from F_L measurement @NLO



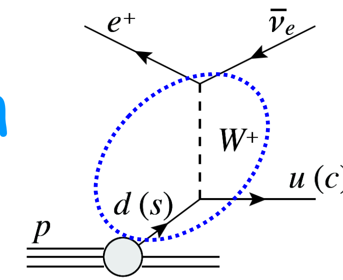
- Direct extraction of gluon density from F_L using approximation

$$xg(x, Q^2) \approx 1.77 \frac{3\pi}{2\alpha_S(Q^2)} F_L(ax, Q^2)$$

Gluon approximated from F_L agrees with gluon determined from scaling violations

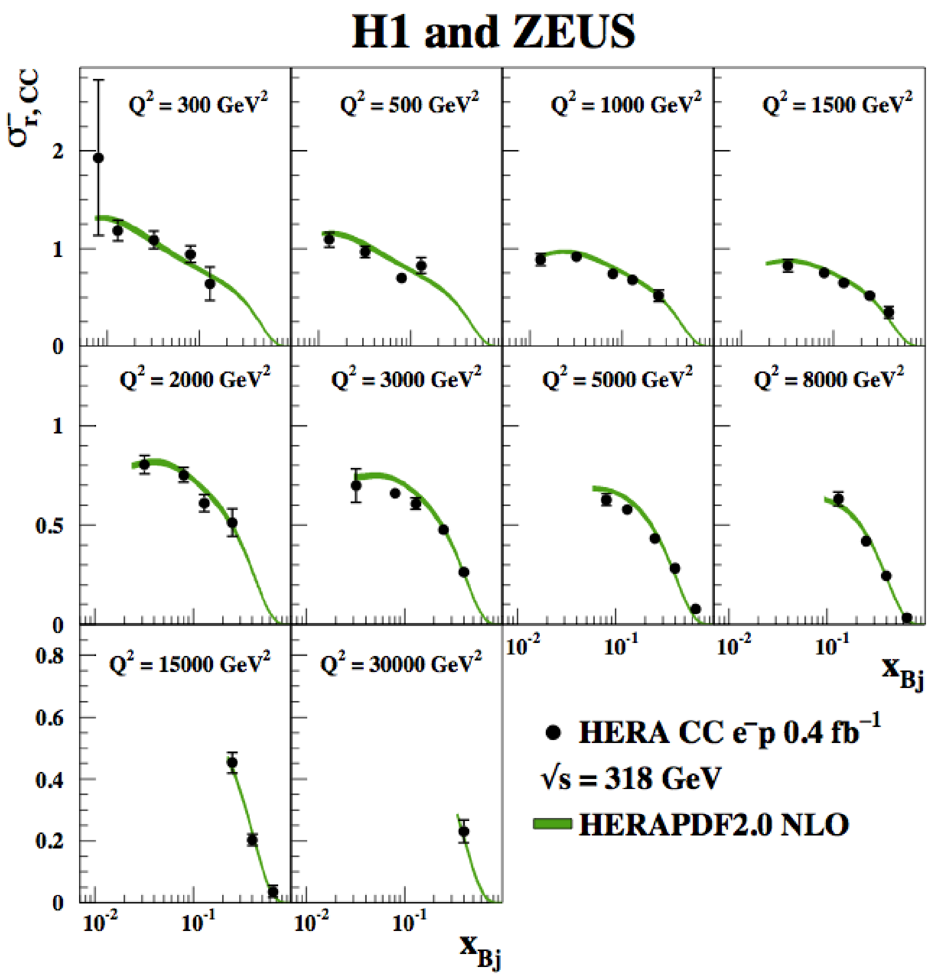


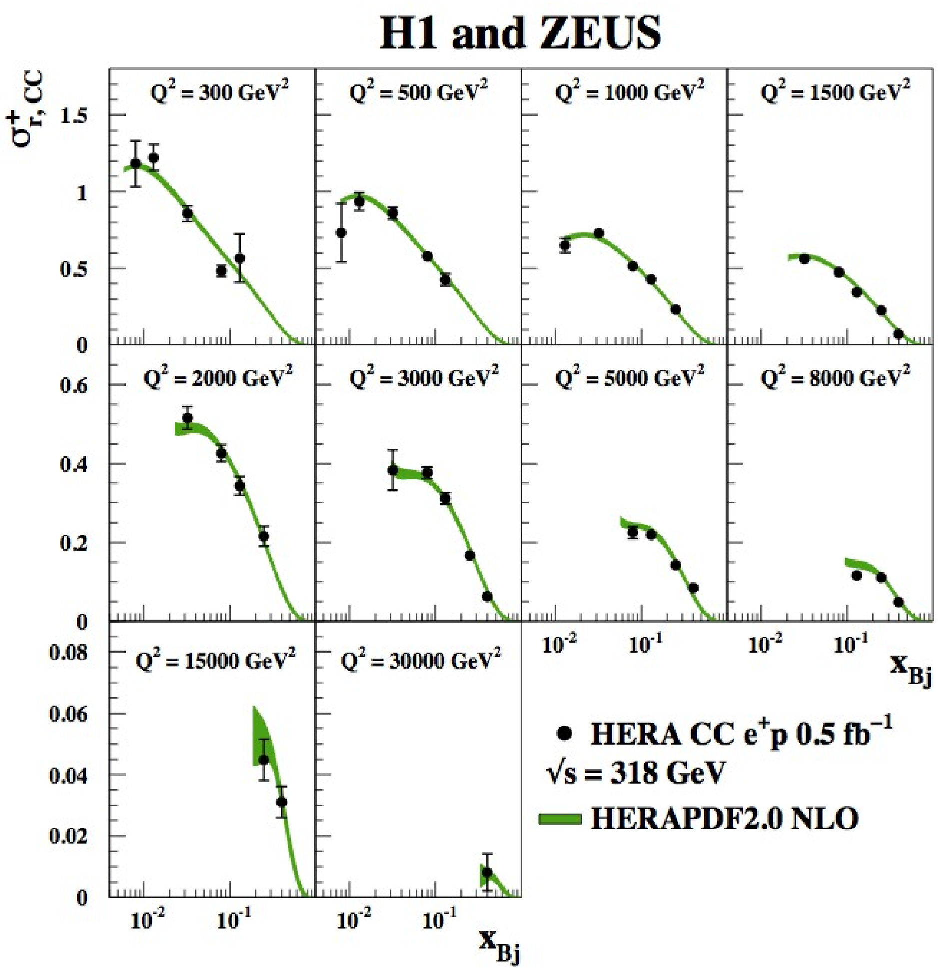
Charge Current: flavor decomposition



$$\sigma_{CC}^{-} \sim x[u+c] + x(1-y)^2[\bar{d}+\bar{s}]$$

$$\sigma_{CC}^{+} \sim x[\bar{u}+\bar{c}] + x(1-y)^2[d+s]$$





Global analysis of parton distributions

Goal: determination of the ***input distributions*** (for light quarks and gluons):

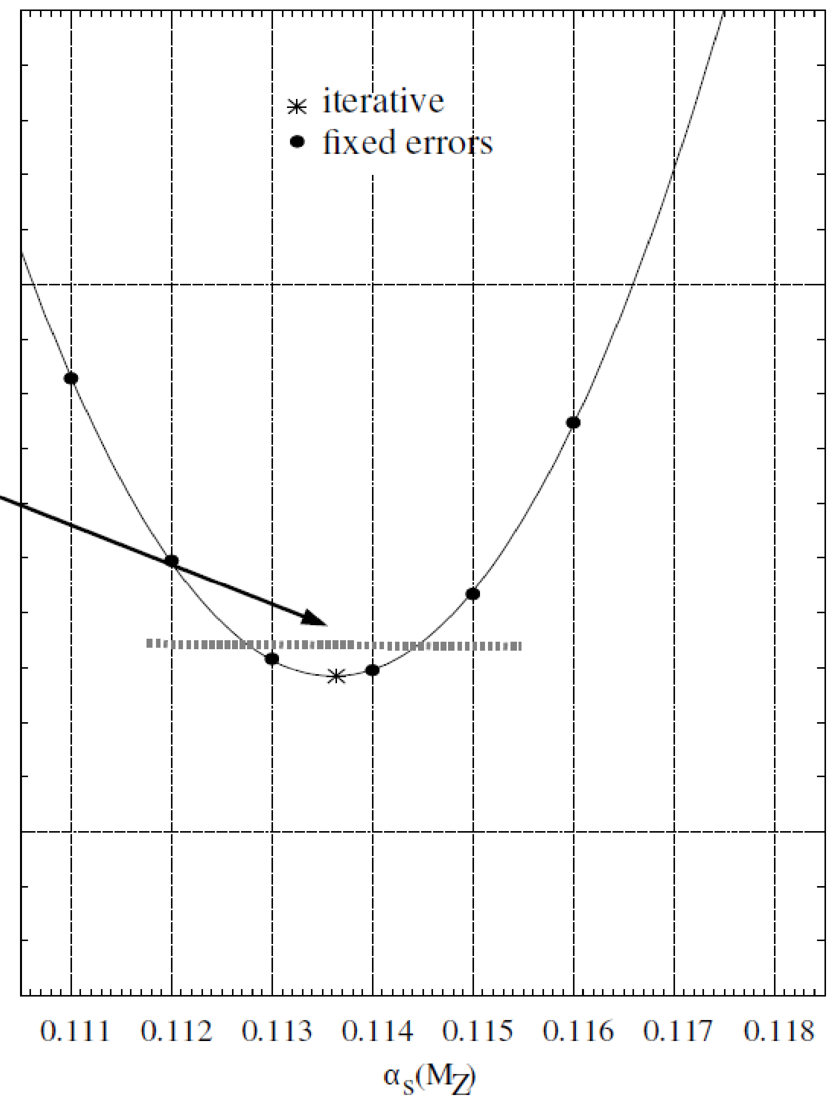
Method: Parametrizations $xf(x, Q_0^2) = N x^a (1-x)^b \, \text{function}(x)$
and usual *statistical estimation* (fits):

$$\chi^2(p) = \sum_{i=1}^{N} \left(\frac{\text{data}(i) - \text{theory}(i,p)}{\text{error}(i)} \right)^2$$

Position of minimum gives the value and curvature gives the error (region within a certain “tolerance” $\Delta\chi^2 = 1$)

(Monte Carlo methods can also be used)

Usually the chi-square definition is more sophisticated, experimental correlations are also treated, etc.



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1 fb^{-1} HERA data – exclusively! - used as input to global QCD fit HERAPDF2.0

• Parton densities parametrised @ Q^2 = 1.9 GeV^2

$$xf(x) = Ax^B(1-x)^C(1+Dx+Ex^2)$$

$$xg(x),\, xu_v(x),\, xd_v(x),\, x\bar{U}(x),\, x\bar{D}(x)$$

• Evolution using DGLAP equations

•14 parameters determined in paramerisation scan

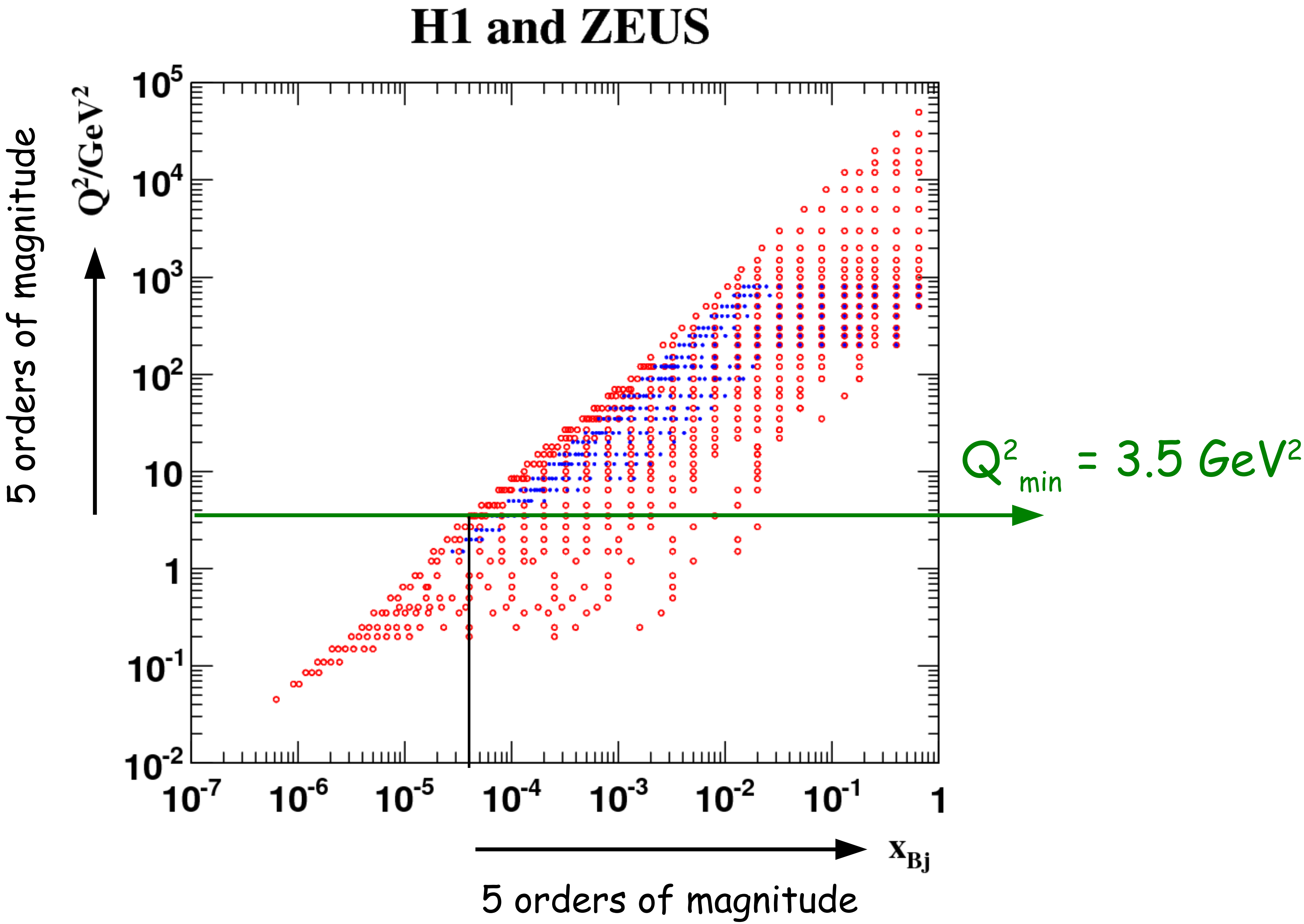
• Heavy quarks from Roberts-Thorne Variable Flavor Number Scheme

- QCD fits performed using HERAFitter package

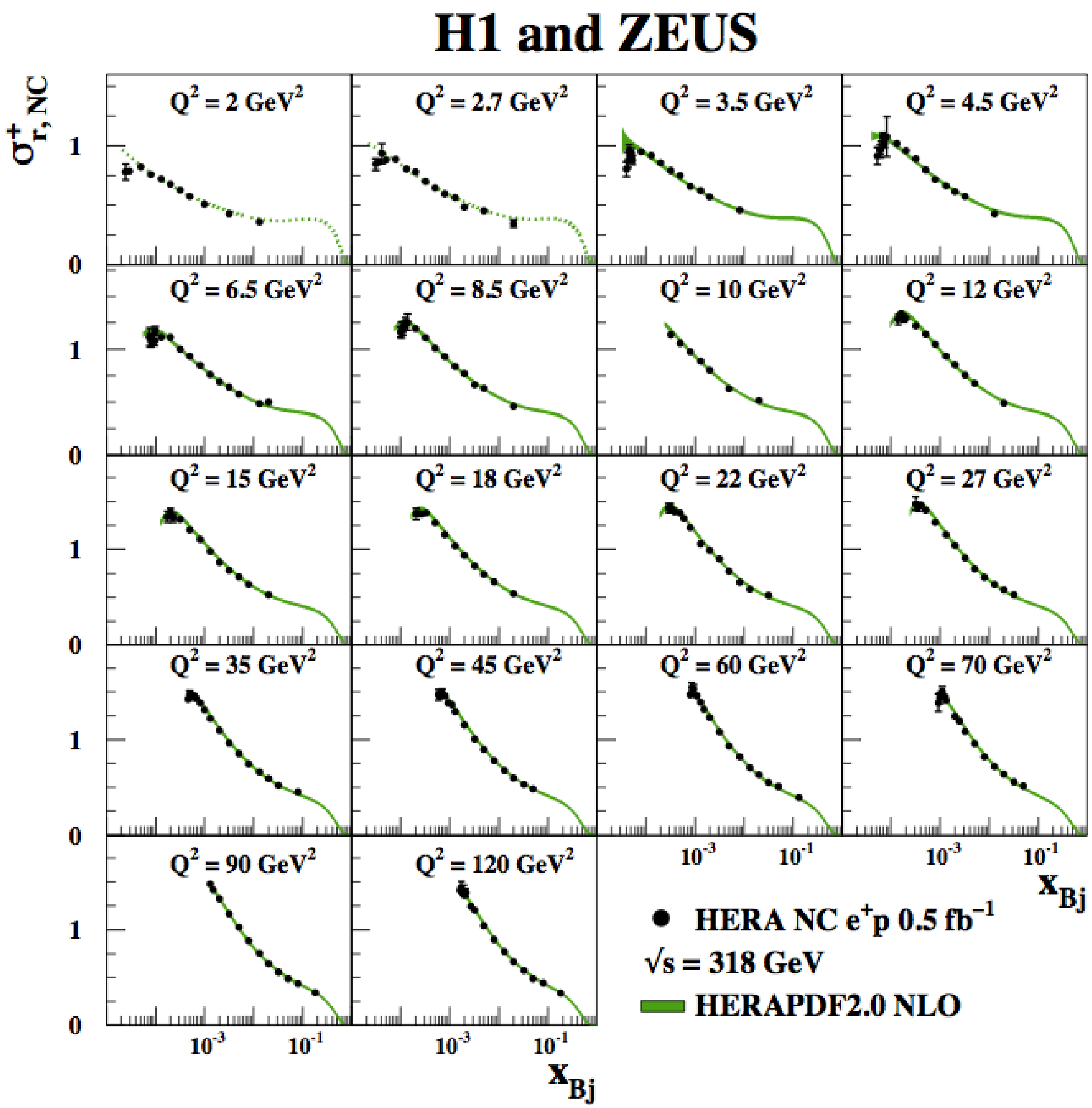
www.herafitter.org

HERAFitter

Data in PDF fit



HERAPDF2.0



- NLO fit for Q^2_{min} = 3.5 GeV^2

  χ^2/dof = 1357/1131

- Additional fit performed with Q^2_{min} = 10 GeV^2

  χ^2/dof = 1156/1002

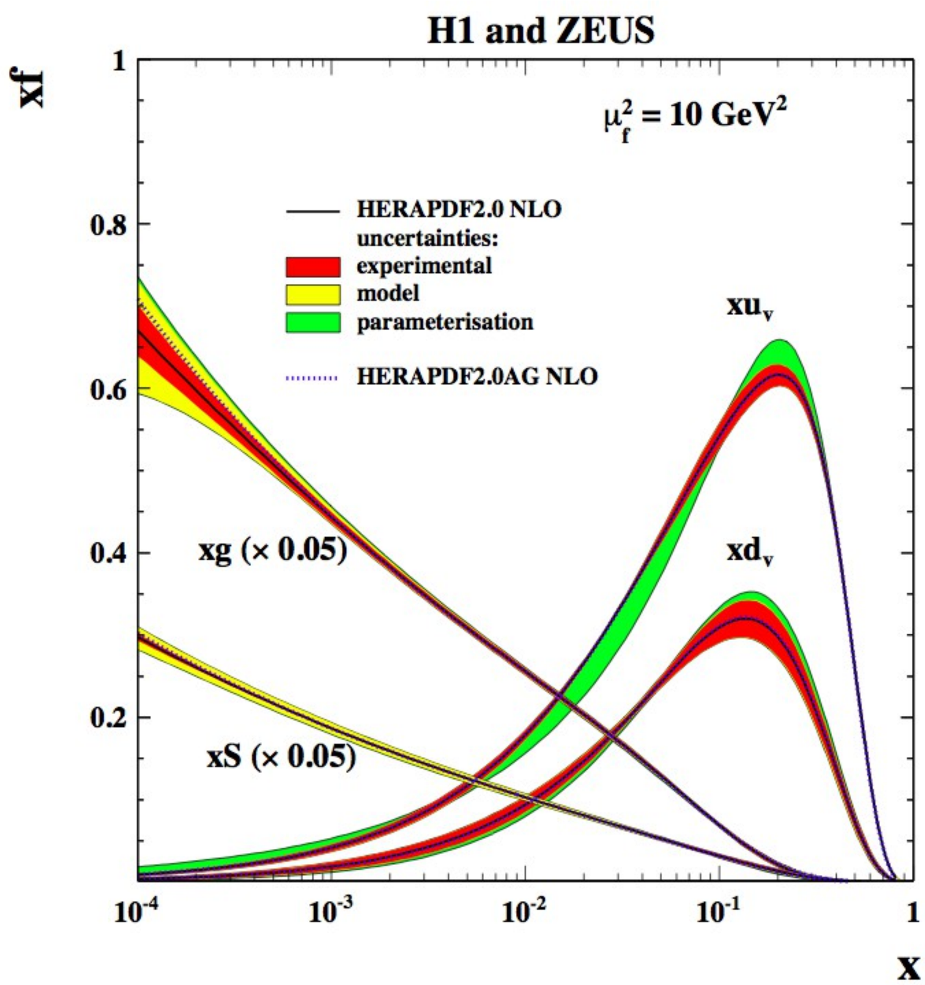
Situation somewhat improved

- **Similar results for NNLO**

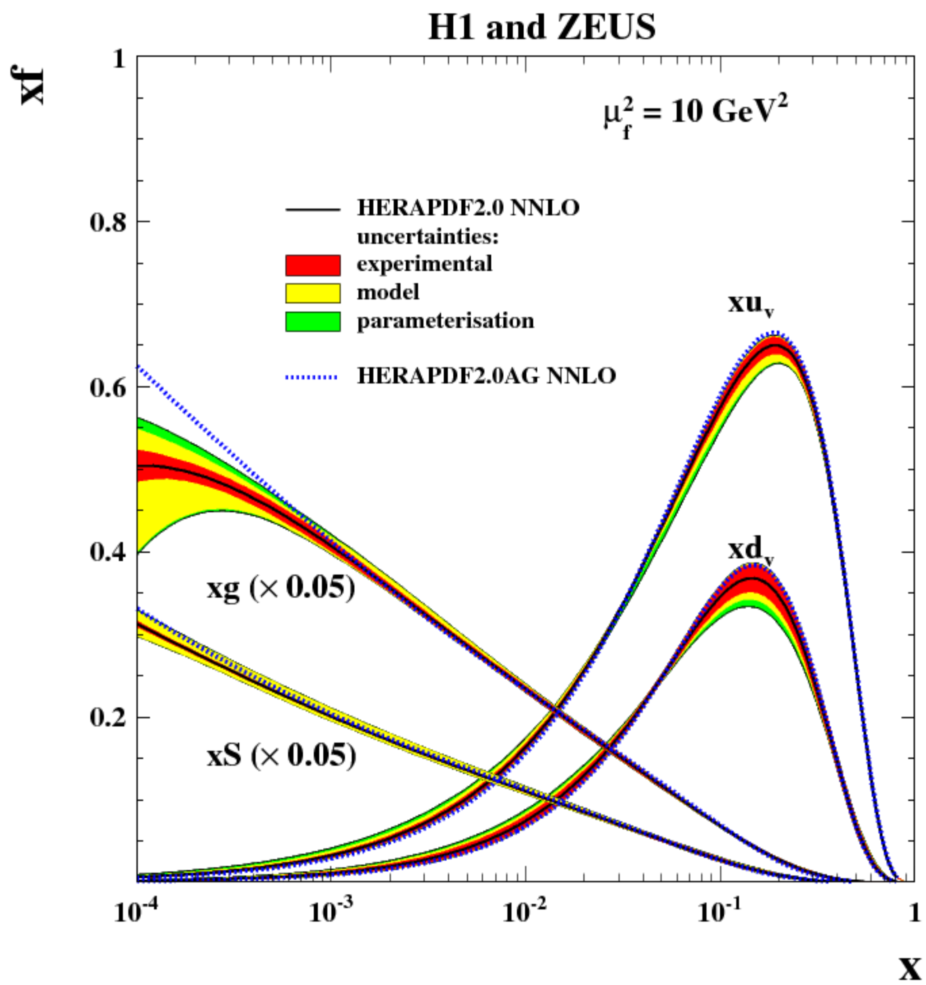
Reasonable description of NC, CC and low energy data for NLO and NNLO

NLO & NNLO parton densities

NLO



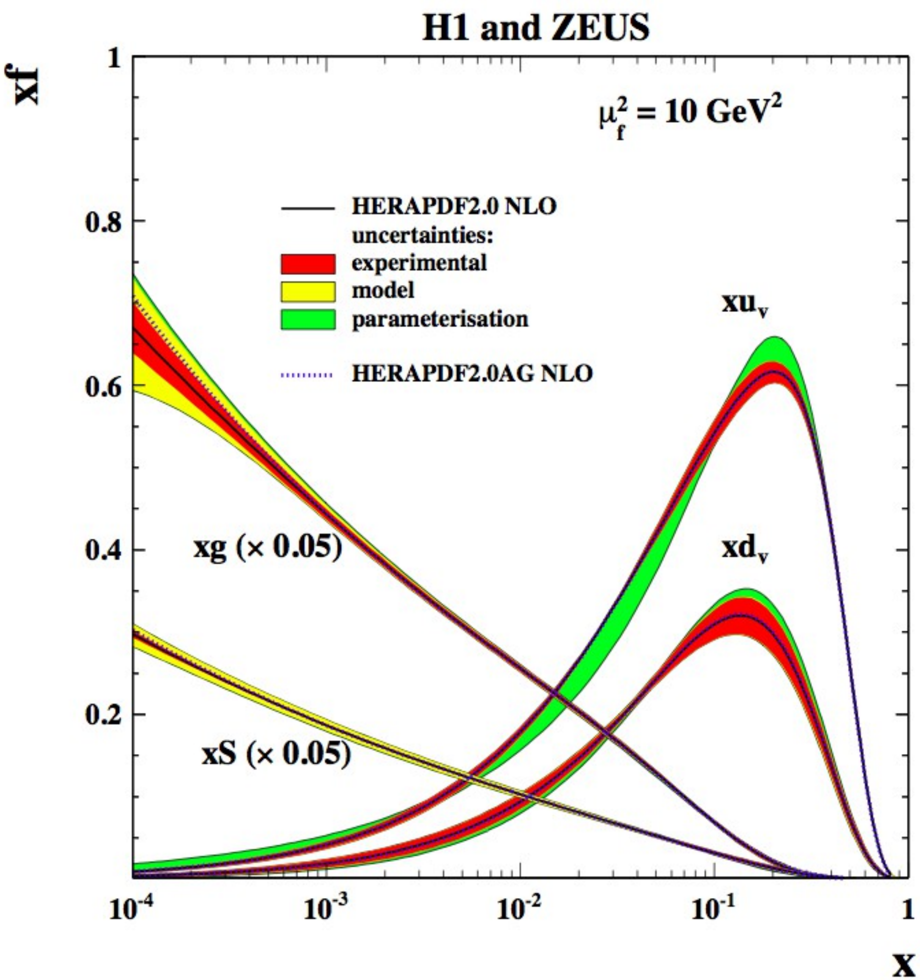
NNLO



HERAPDF2.0 extracted

with experimental, model and parametrization uncertainties

Color decomposition of uncertainties



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

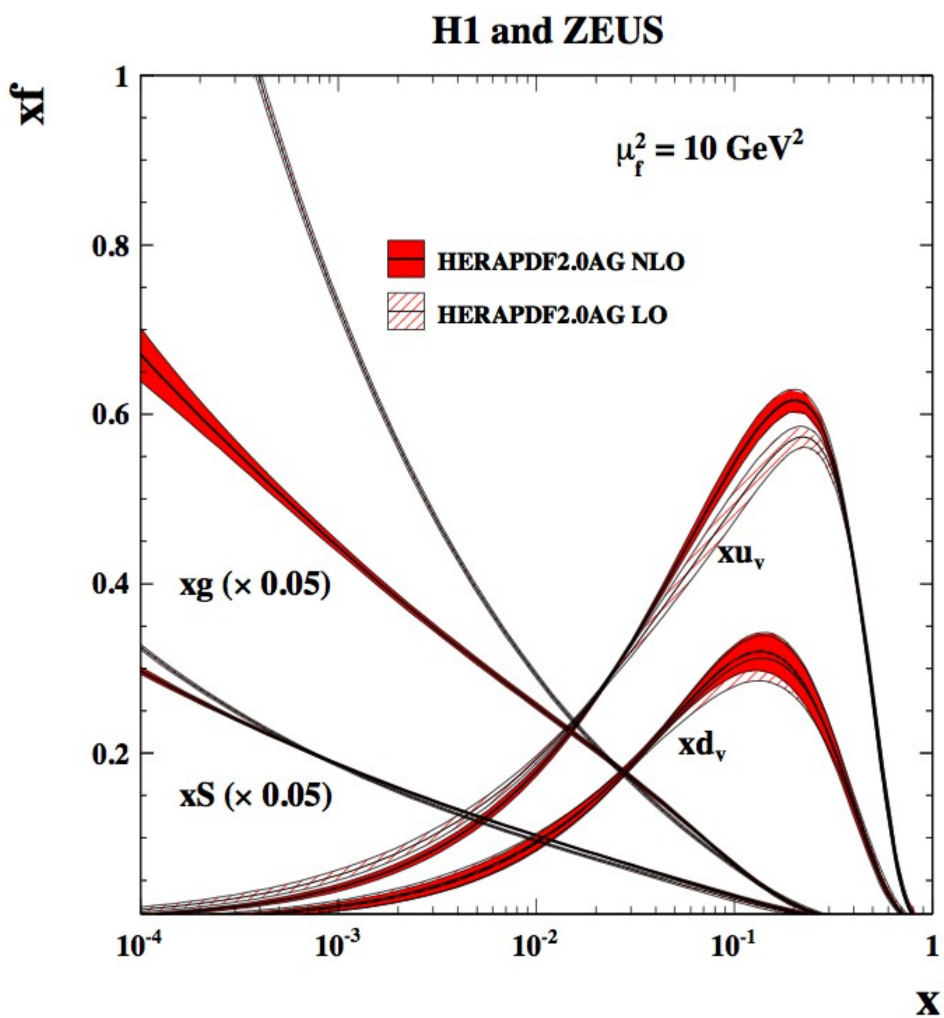
Variation	Standard Value	Lower Limit	Upper Limit
$Q^2_{\rm min}$ [GeV^2]	3.5	2.5	5.0
$Q^2_{\rm min}$ [GeV^2] HiQ2	10.0	7.5	12.5
M_c(NLO) [GeV]	1.47	1.41	1.53
M_c (NNLO) [GeV]	1.43	1.37	1.49
M_b [GeV]	4.5	4.25	4.75
f_s	0.4	0.3	0.5
μ_{f_0} [GeV]	1.9	1.6	2.2

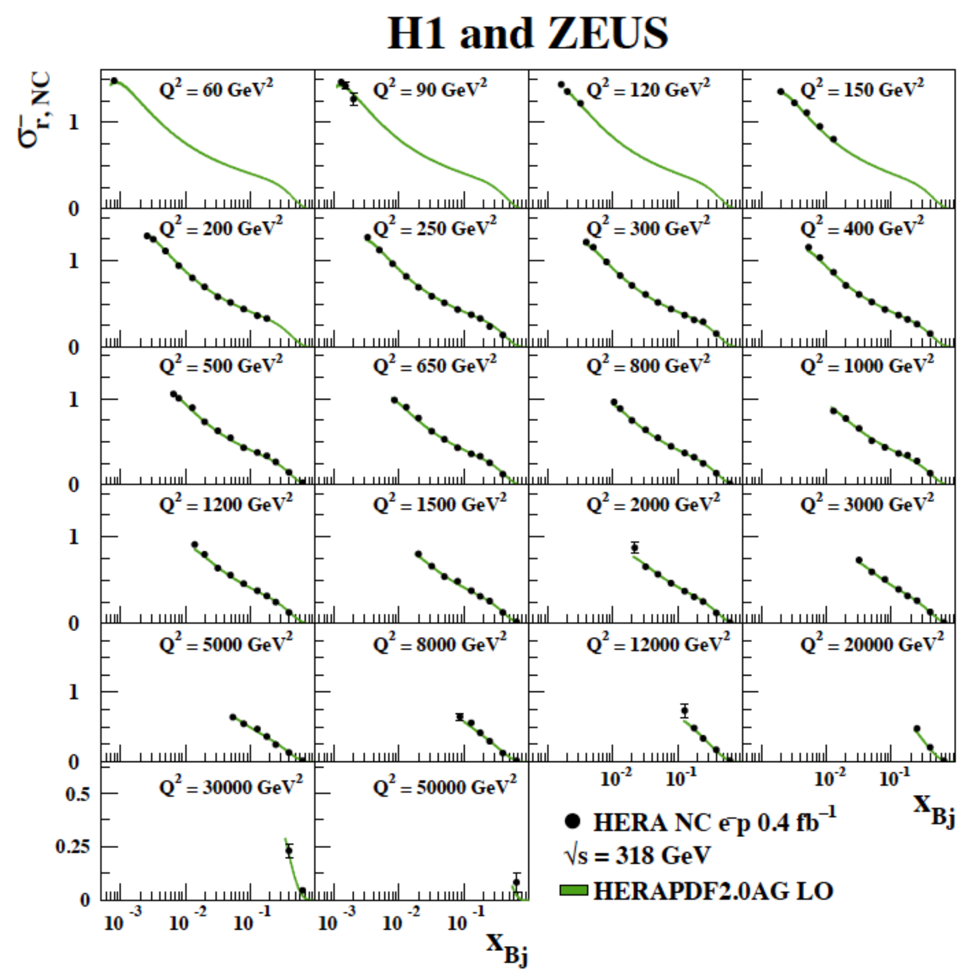
Adding D and E parameters to each PDF

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

HERAPDF2.0AG LO

- Parton densities @LO are essential for proper simulation of parton showers and underlying event properties in LO+PS Monte Carlo event generators
- Includes experimental uncertainties



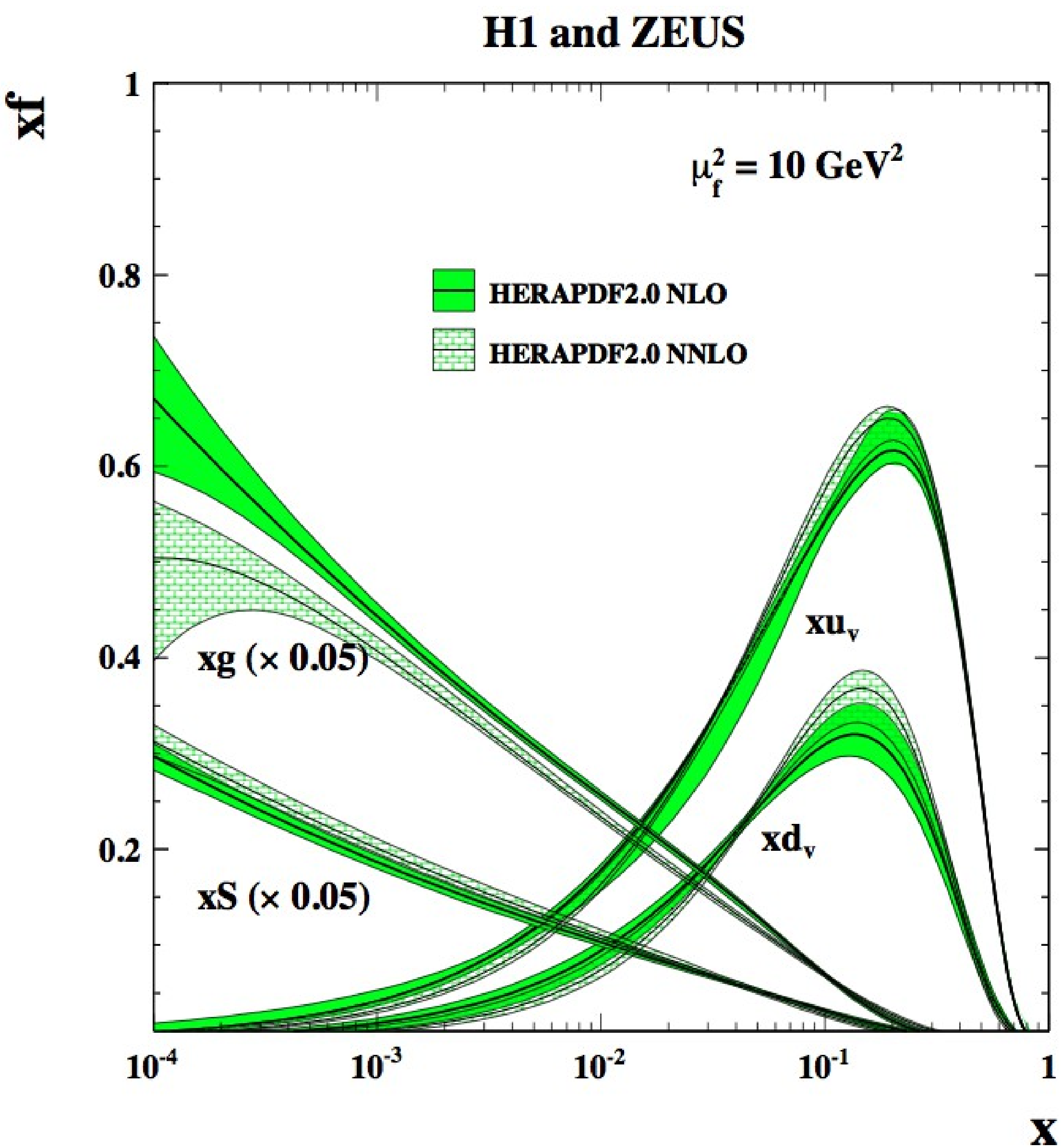


Comparisons are odious

Miguel de Cervantes, “Don Quixote”

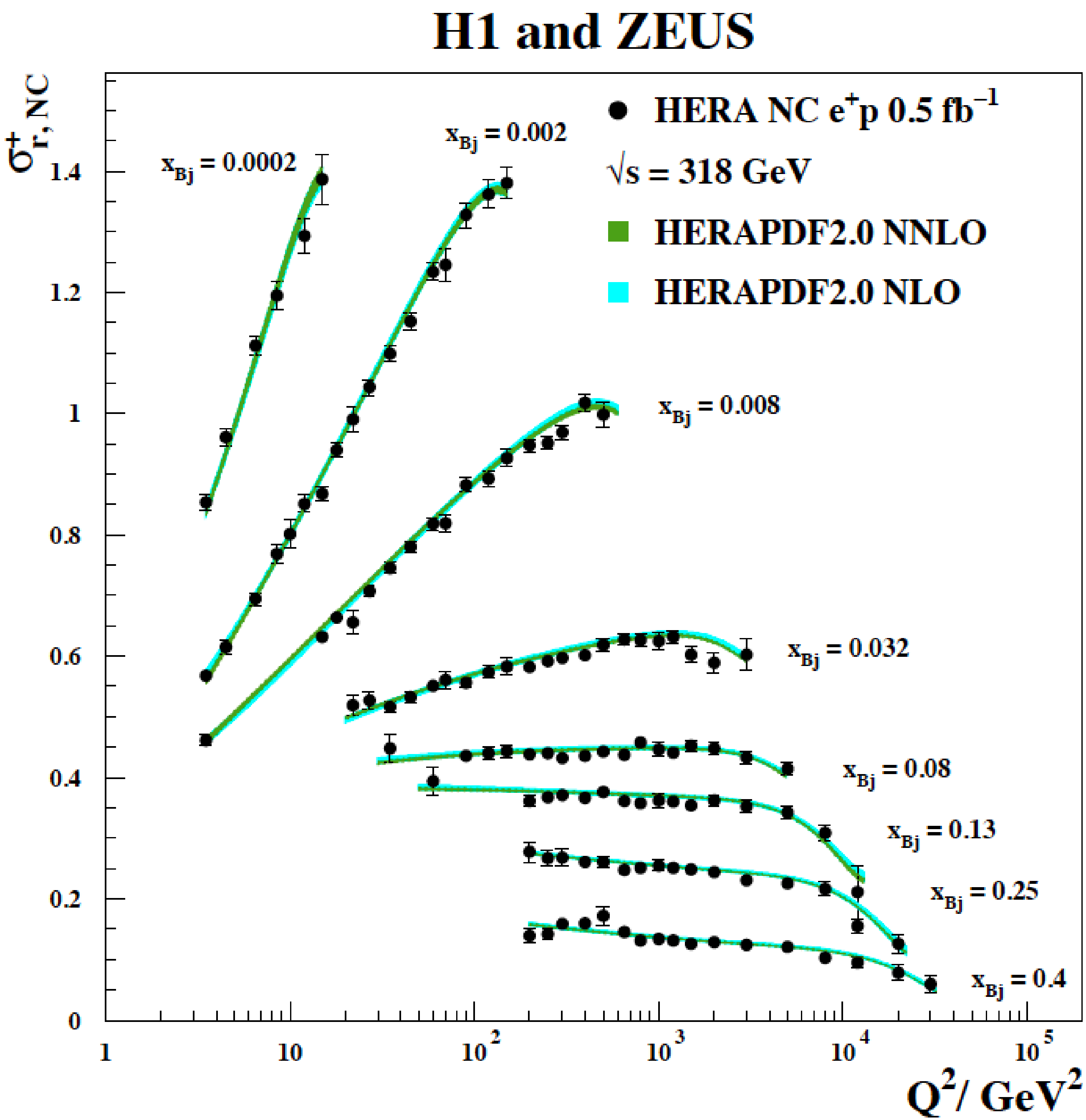
Alexander von Humboldt Stiftung/Foundation

Parton densities @ NLO and NNLO

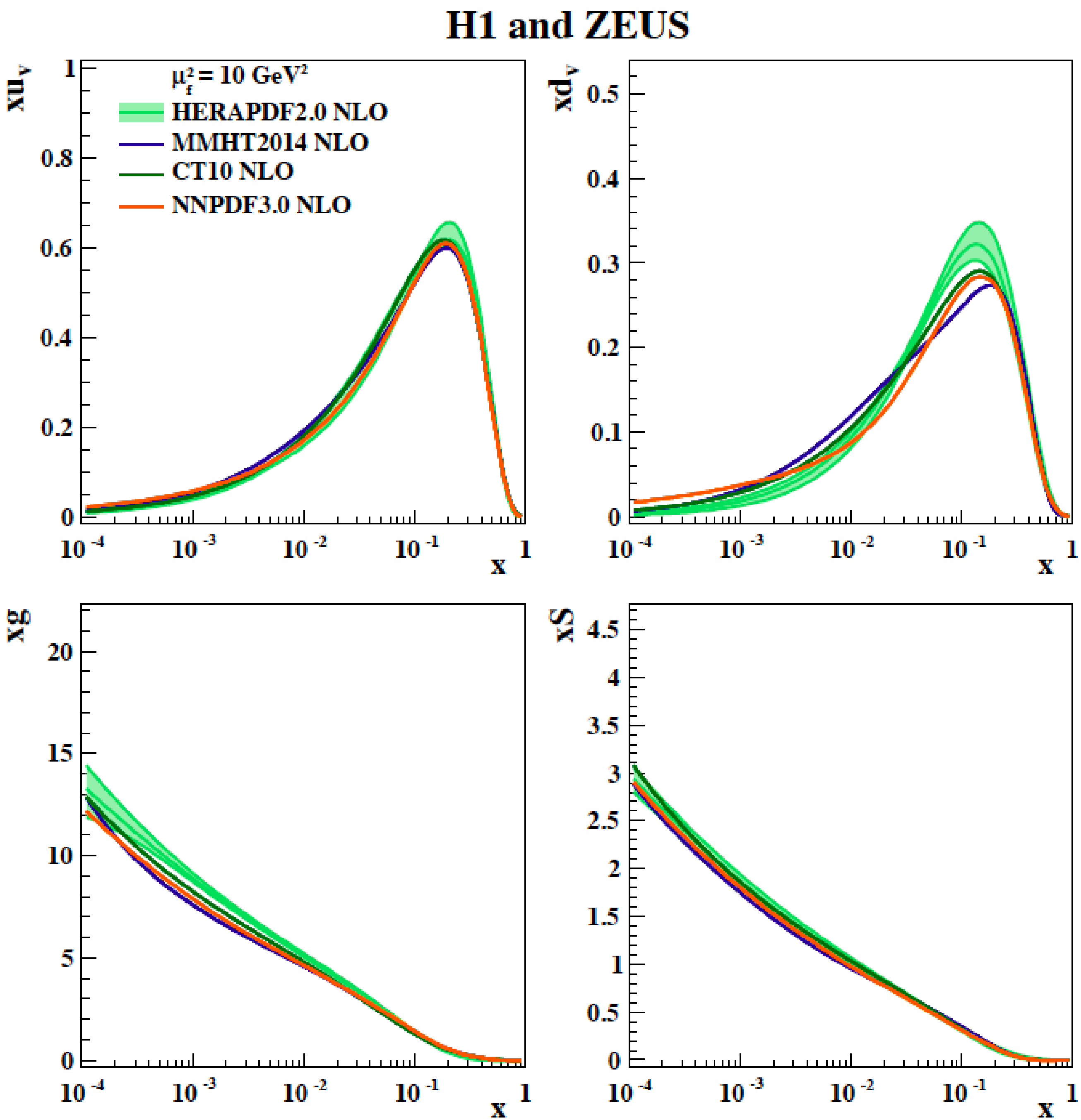


- Valence distributions similar
- Gluons and sea differ

Theory predictions @ NLO and NNLO



World of PDFs

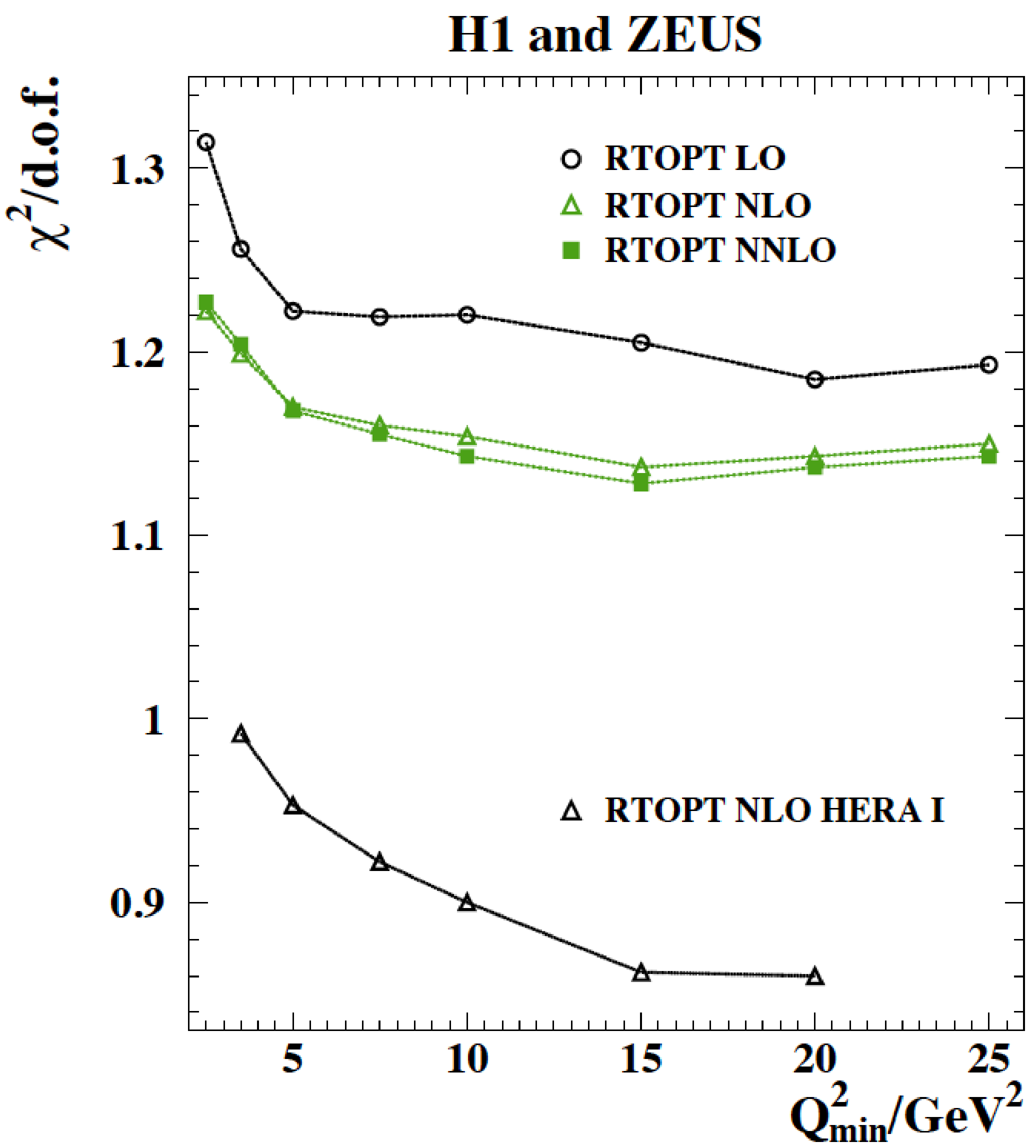


- Difference for valence quarks

HERAPDF - the only group to get d valence from proton in CCe+p and not from neutron by assuming that u in neutron = d in proton

- Various gluon behaviours at low x

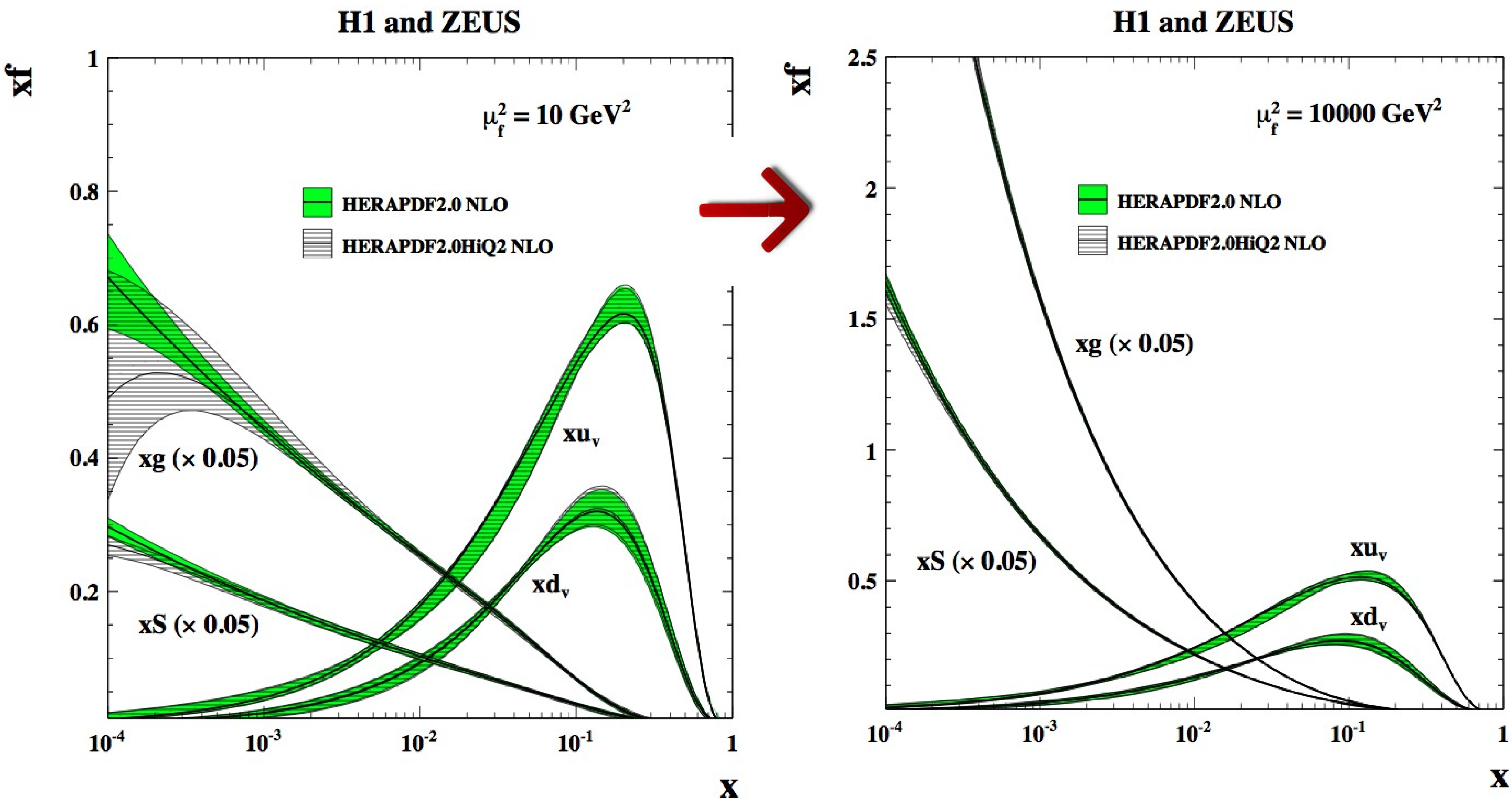
Q^2_{min}-cut studies



- Dependence of chi2/dof on Q^2_{min} cut
  - Drop of chi2 with Q^2_{min} cut
  - Saturation around 10 GeV²
- Significant improvement of NLO compared to LO
- Marginal to no improvement of NNLO compared to NLO
- NLO behavior similar in HERAI and HERAI+II

HERAPDF2.0HiQ2 variant issued

HERAPDF2.0HiQ2



- Larger uncertainty for HERAPDF2.0HiQ2 gluon at low x.
- PDFs become very alike at higher scales.

Alexander von Humboldt Stiftung/Foundation

Adding more HERA data

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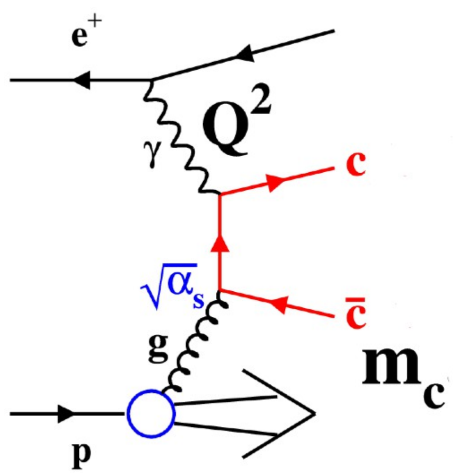
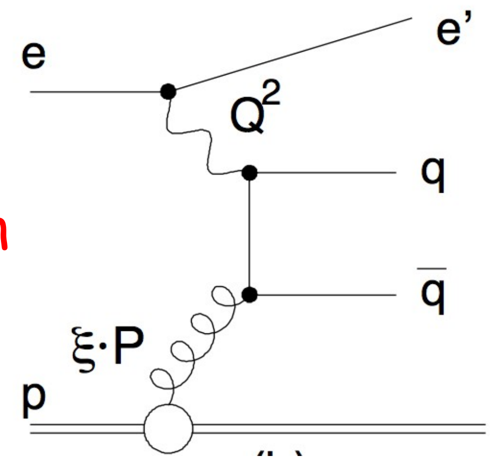
Charm and jet data from HERA

Charm production

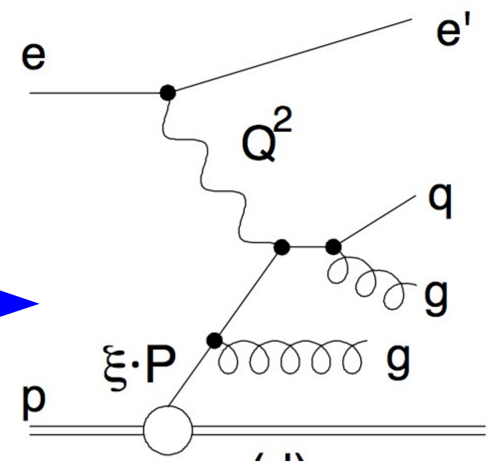


Jet production

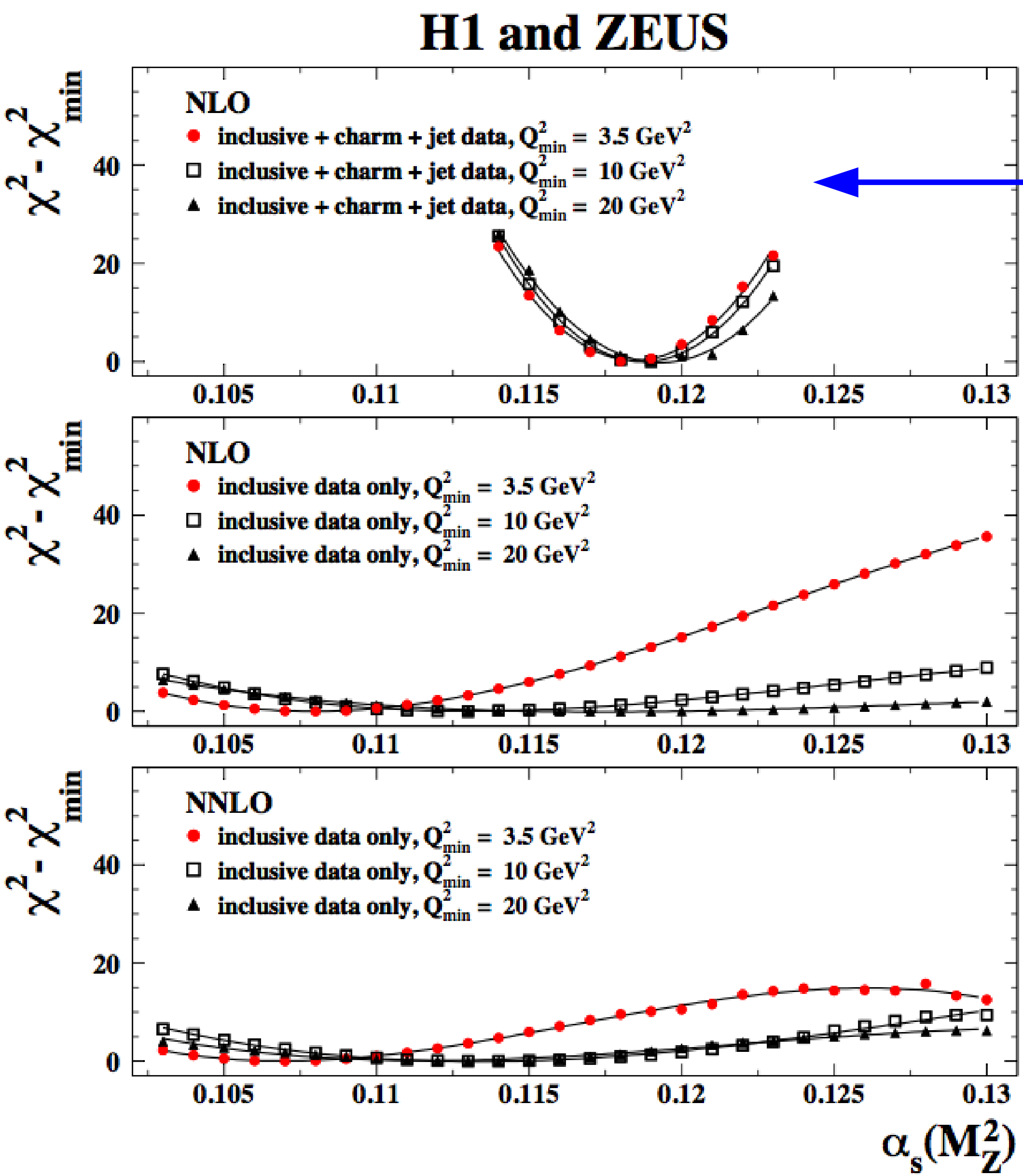


Boson-Gluon Fusion

- Charm and jet data sensitive to gluon/α_s
  - At high Q^2 up to 30% of charm
- Trijets most sensitive to α_s

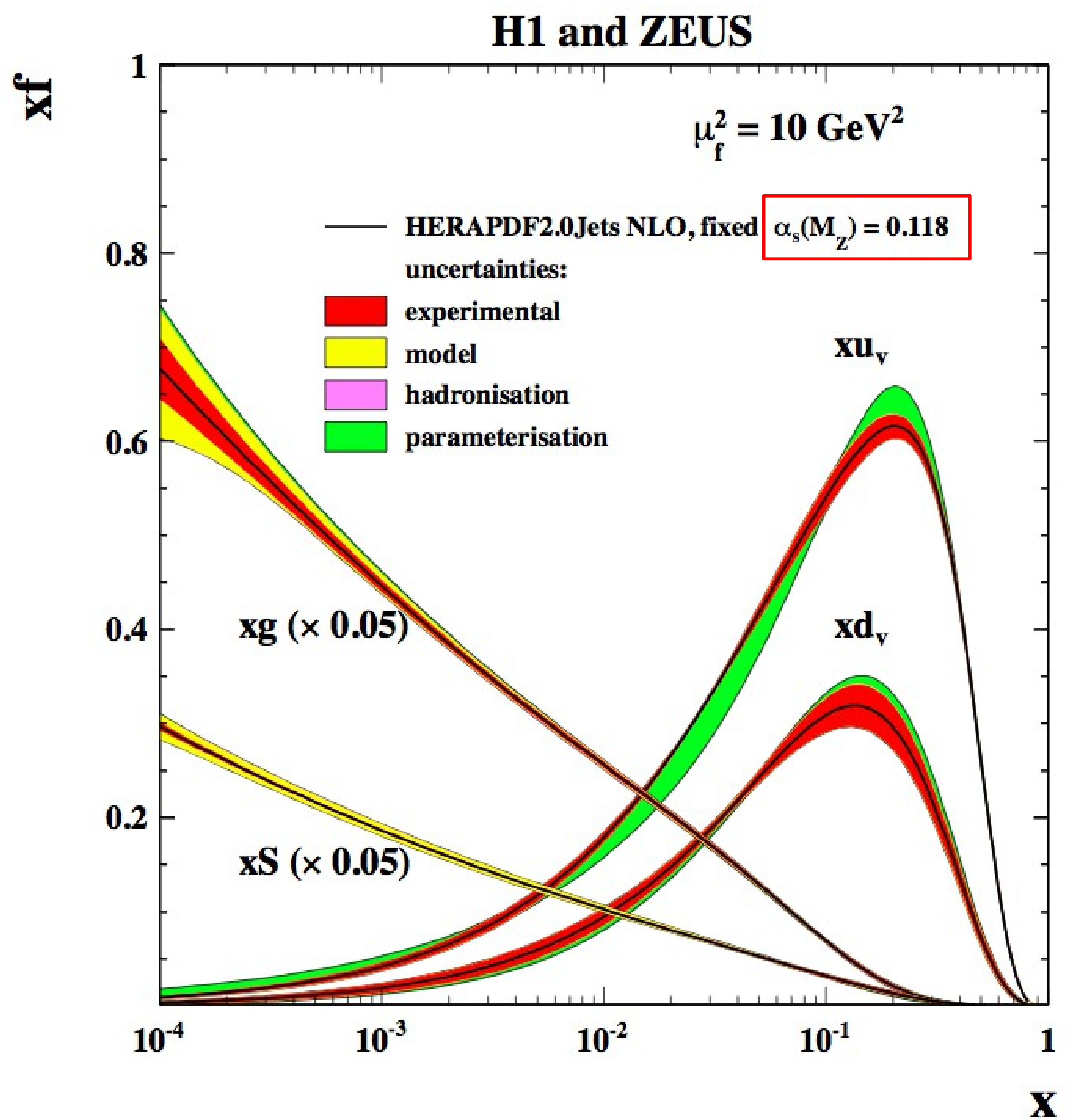


Including HERA jets in QCD global fits

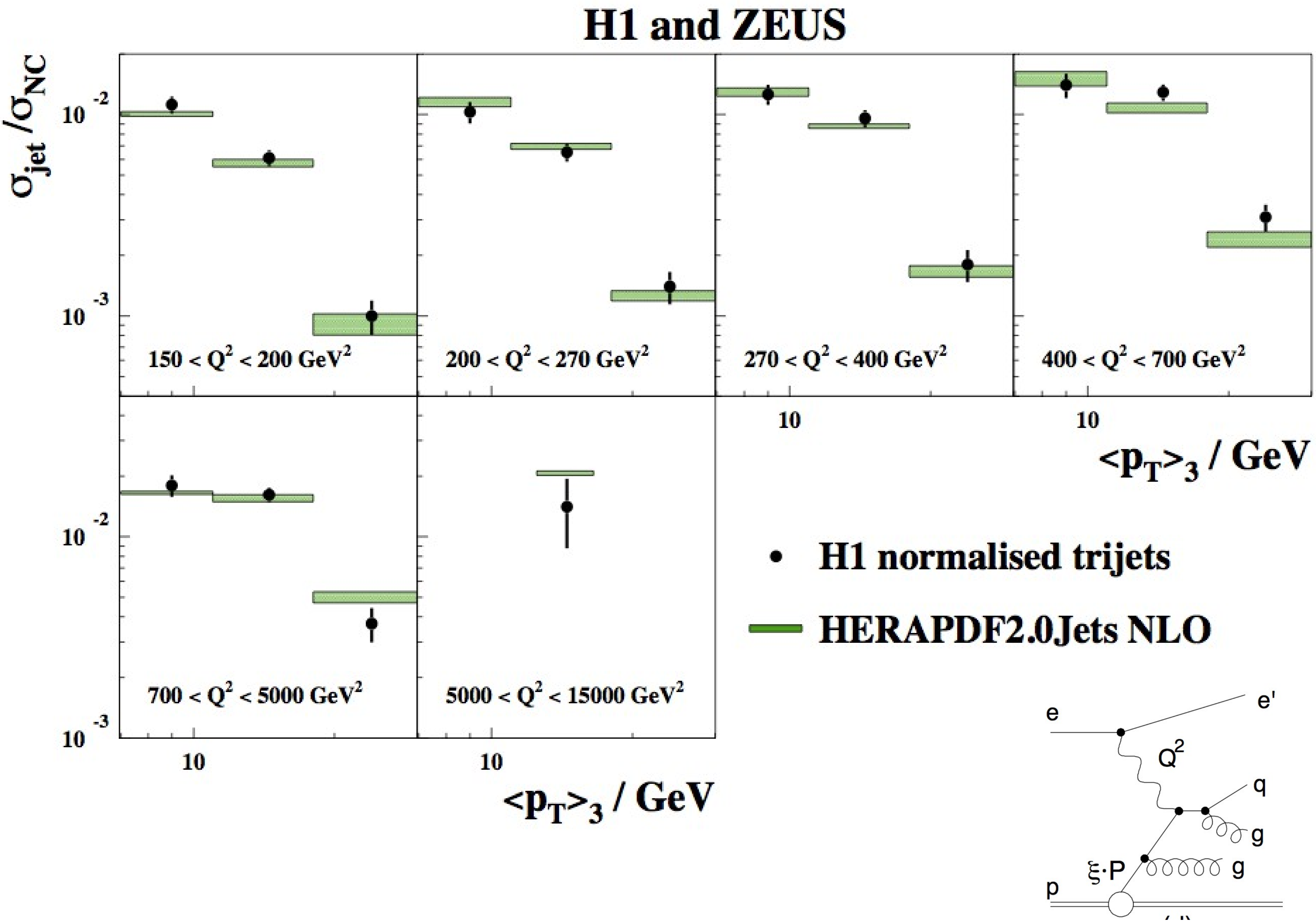


- HERA combined charm data
- 7 H1 and ZEUS jet samples
  - Inclusive jets
  - Dijets
  - Trijets
  - Some are normalised cross sections → best α_s sensitivity
- Validated choice of α_s = 0.118

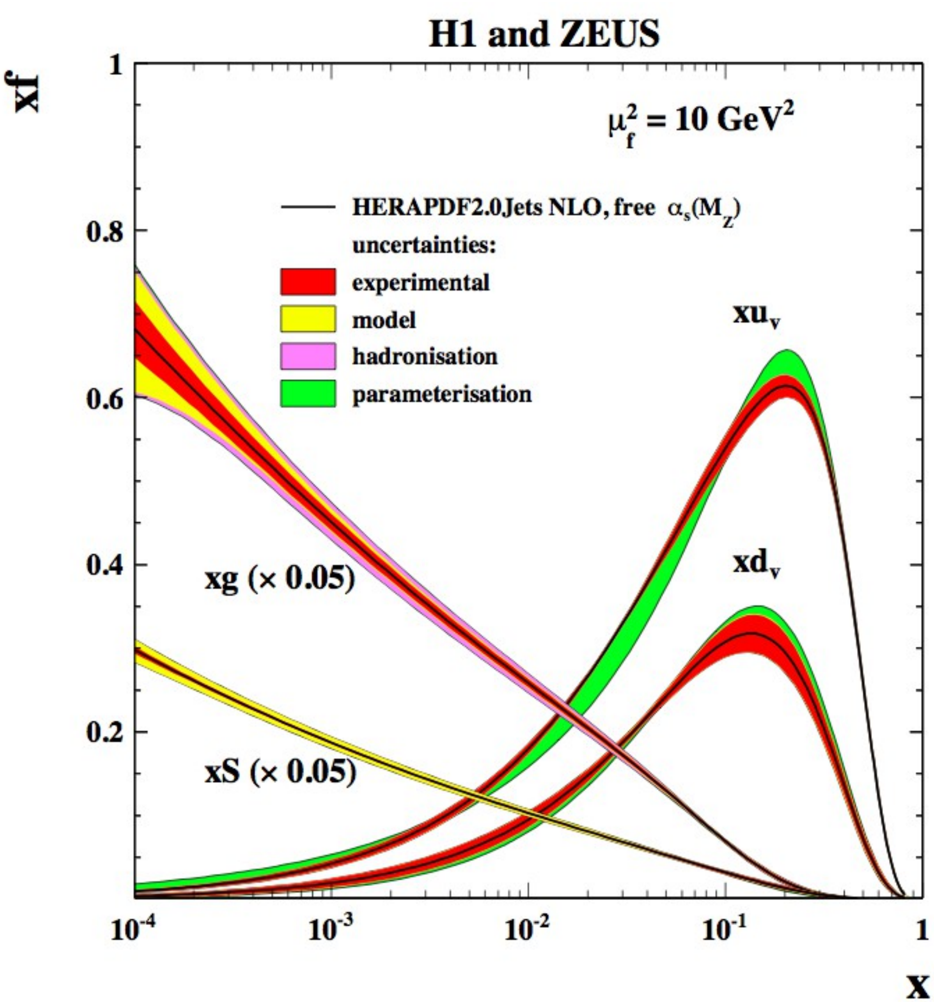
HERAPDF2.0Jets α_s = 0.118



HERAPDF2.0Jets α_s = 0.118



HERAPDF2.0Jets α_s free



<u>α_s determined from QCD fit</u>

$$\alpha_s(M_Z^2) = 0.1183 \pm 0.0009(\mathrm{exp})$$

Experimental uncertainty below 1%

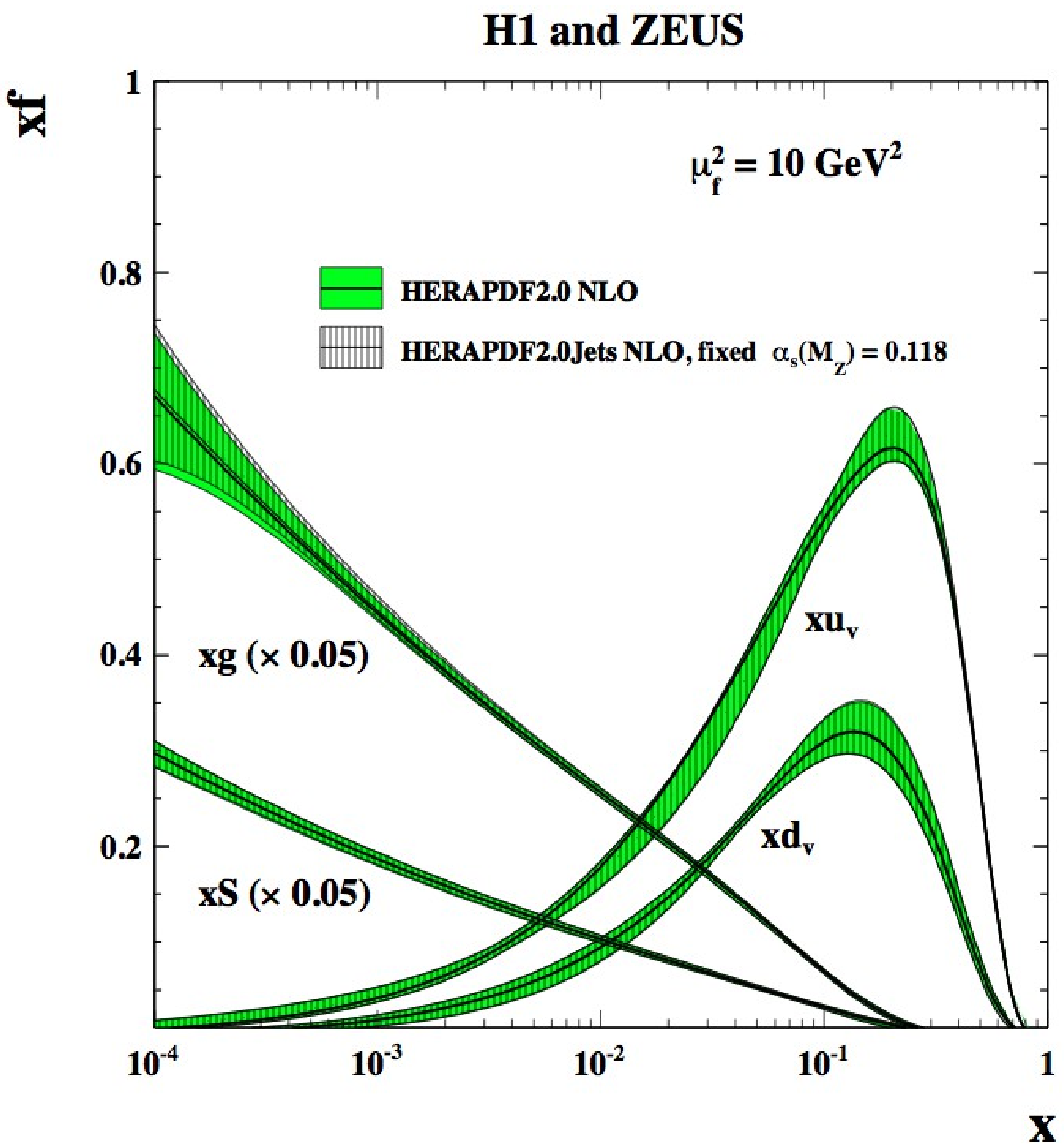
$$\pm\, 0.0005(\mathrm{model/parameterisation})$$

$$\pm\, 0.0012(\mathrm{hadronisation})$$

$$^{+0.0037}_{-0.0030}(\mathrm{scale})$$

Uncertainty dominated by theory
NNLO ep jet calculations needed

HERAPDF2.0Jets

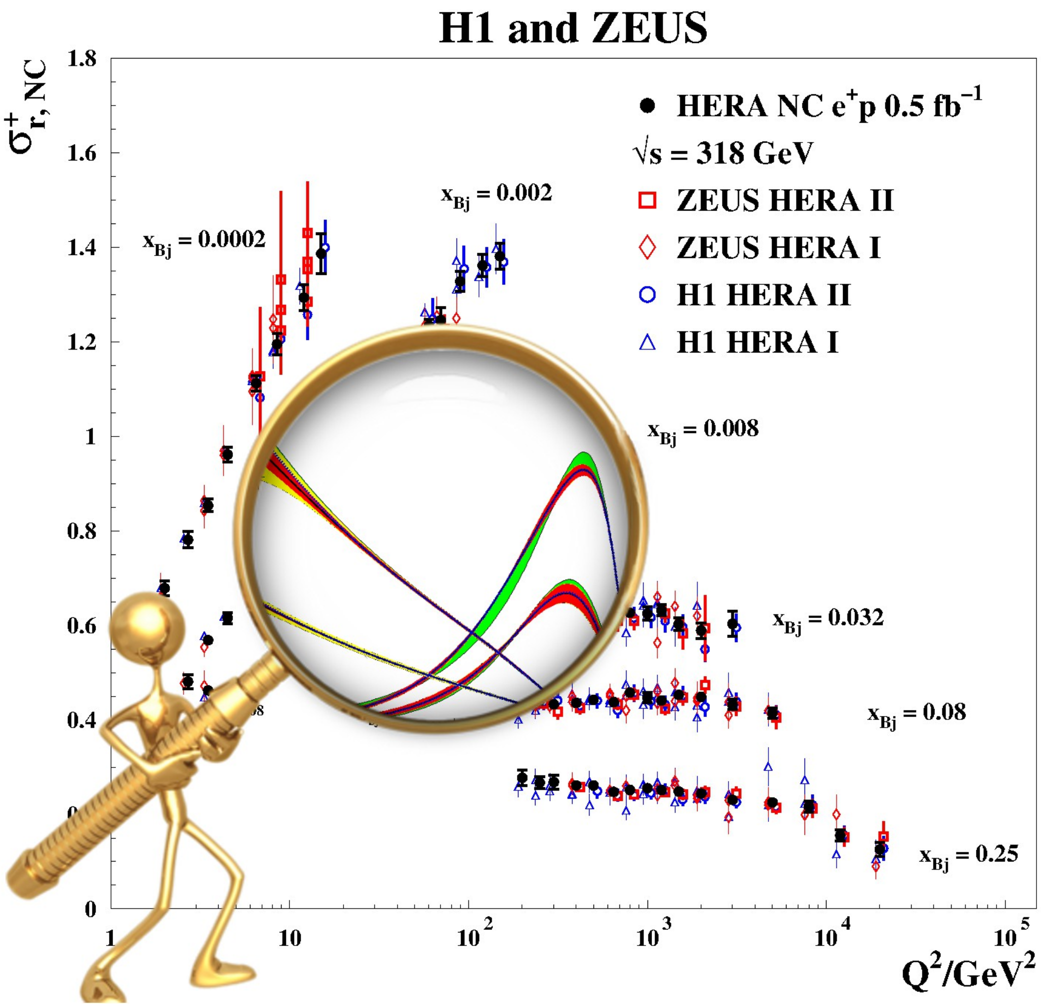


HERA Summary

- Combined HERA data set provides ultimate sample for inclusive neutral and charged current cross section studies in wide kinematic rang.
  - Low Q^2 data -> additional checks of QCD calculations
- Plethora of beautiful physics seen in inclusive DIS measurements

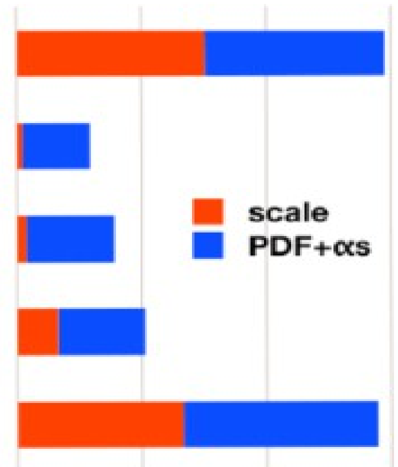
HERA legacy of almost 25 years of activity

- HERAPDF2.0 extracted solely from HERA final data



PDF uncertainties important

		σ (8 TeV)	uncertainty
NNLL QCD +NLO EW	gg→H	19.5 pb	14.7%
NNLO QCD +NLO EW	VBF	1.56 pb	2.9%
	WH	0.70 pb	3.9%
	ZH	0.39 pb	5.1%
NLO QCD	ttH	0.13 pb	14.4%



J. Campbell, ICHEP12

1) PDFs fundamental limit for Higgs boson characterization in terms of couplings

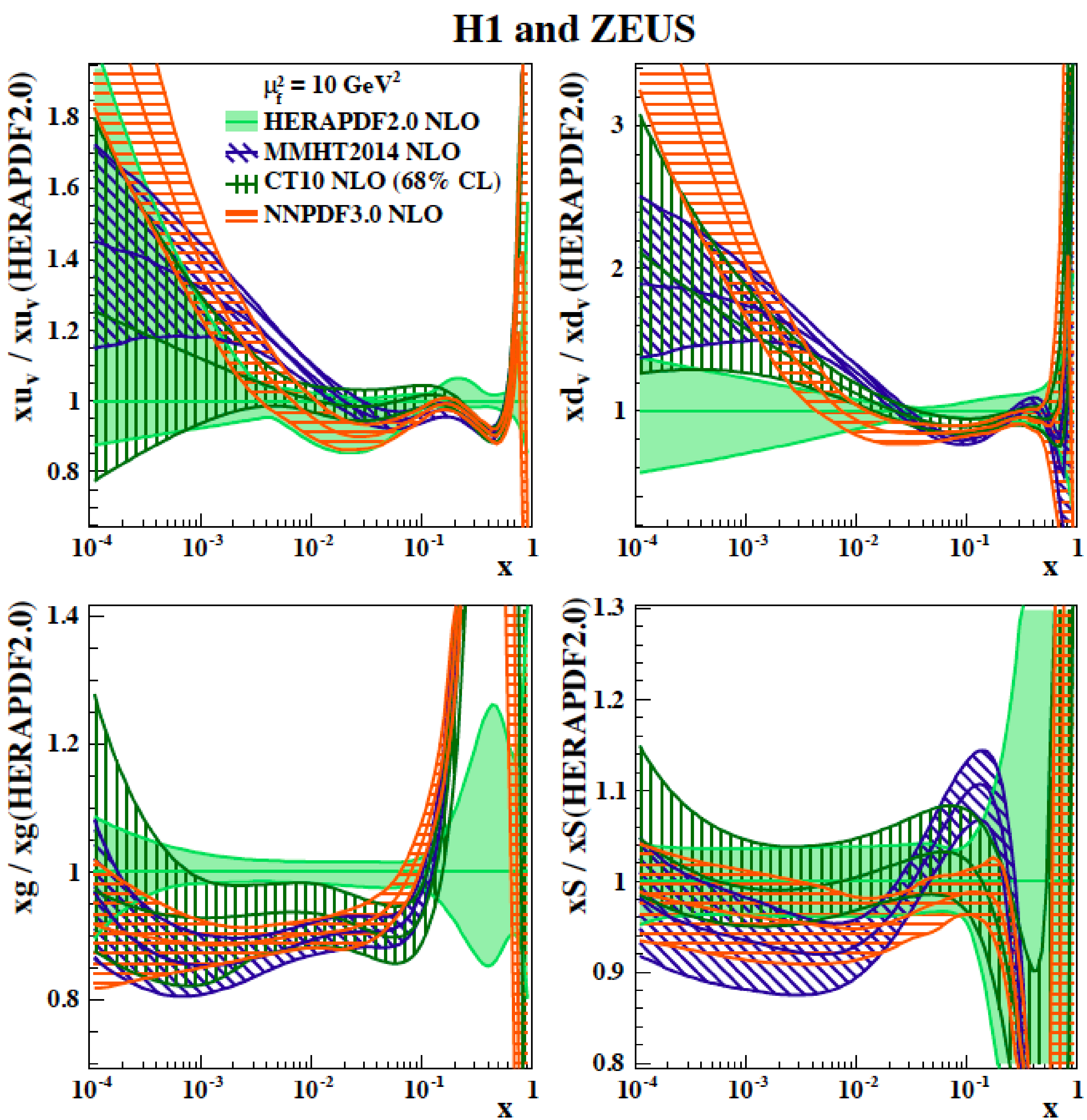
Uncertainties of many variables often dominated by PDF uncertainties

- 2014 CMS combined best-fit signal strength relative to SM

  $1.00 \pm 0.09\ (\text{stat})\ ^{+0.08}_{-0.07}\ (\text{theo}) \pm 0.07\ (\text{syst})$

- PDFs necessary for background estimate BSM searches and SM tests
- Important for global electroweak fit parameters like m_W

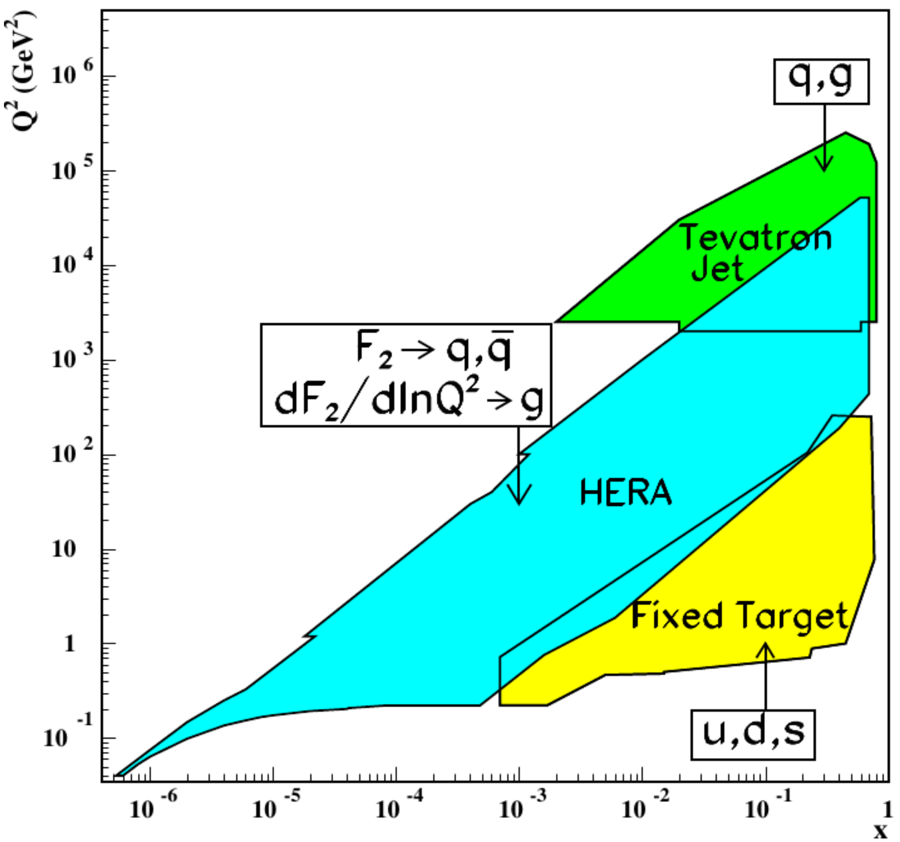
Global Situation in global QCD fits



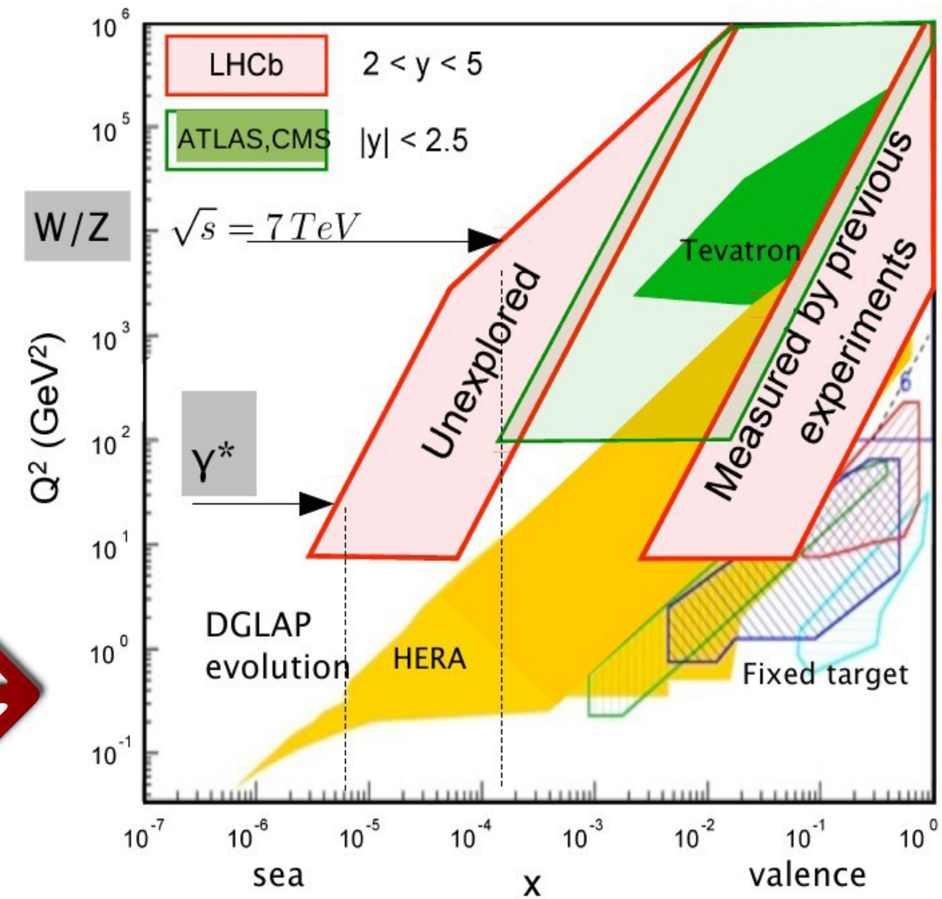
- PDF uncertainties still large
- Especially at low and high x
- New data needed → LHC data used

Outlook

Data for parton distributions: preLHC



Now:from predicting LHC measurements to using them to constraining parton distributions

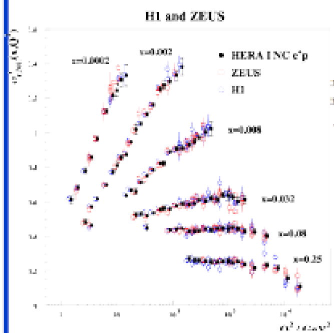


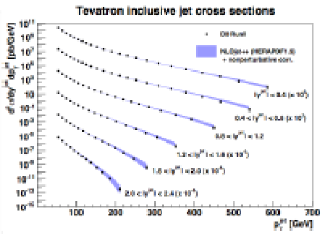
Additional slides

Data Set		x_{Bj} Grid from	x_{Bj} Grid to	Q^2[GeV^2] Grid from	Q^2[GeV^2] Grid to	$\mathcal{L}$ pb^{-1}	e^+/e^-	$\sqrt{s}$ GeV	x_{Bj}, Q^2 from 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	13,17,18
H1 low Q^2	96-00	0.0002	0.1	12	150	22	e^+p	301, 319	13,17,18
H1 NC	94-97	0.0032	0.65	150	30000	35.6	e^+p	301	19
H1 CC	94-97	0.013	0.40	300	15000	35.6	e^+p	301	14
H1 NC	98-99	0.0032	0.65	150	30000	16.4	e^-p	319	19
H1 CC	98-99	0.013	0.40	300	15000	16.4	e^-p	319	14
H1 NC HY	98-99	0.0013	0.01	100	800	16.4	e^-p	319	13
H1 NC	99-00	0.0013	0.65	100	30000	65.2	e^+p	319	19
H1 CC	99-00	0.013	0.40	300	15000	65.2	e^+p	319	14
ZEUS BPC	95	0.000002	0.00006	0.11	0.65	1.65	e^+p	300	13
ZEUS BPT	97	0.0000006	0.001	0.045	0.65	3.9	e^+p	300	13, 19
ZEUS SVX	95	0.000012	0.0019	0.6	17	0.2	e^+p	300	13
ZEUS NC	96-97	0.00006	0.65	2.7	30000	30.0	e^+p	300	21
ZEUS CC	94-97	0.015	0.42	280	17000	47.7	e^+p	300	14
ZEUS NC	98-99	0.005	0.65	200	30000	15.9	e^-p	318	20
ZEUS CC	98-99	0.015	0.42	280	30000	16.4	e^-p	318	14
ZEUS NC	99-00	0.005	0.65	200	30000	63.2	e^+p	318	20
ZEUS CC	99-00	0.008	0.42	280	17000	60.9	e^+p	318	14
HERA II $E_p = 920$ GeV data sets									
H1 NC $^{1.5p}$	03-07	0.0008	0.65	60	30000	182	e^+p	319	13, 19
H1 CC $^{1.5p}$	03-07	0.008	0.40	300	15000	182	e^+p	319	14
H1 NC $^{1.5p}$	03-07	0.0008	0.65	60	50000	151.7	e^-p	319	13, 19
H1 CC $^{1.5p}$	03-07	0.008	0.40	300	30000	151.7	e^-p	319	14
H1 NC med Q^2 $^{*y.5}$	03-07	0.0000986	0.005	8.5	90	97.6	e^+p	319	13
H1 NC low Q^2 $^{*y.5}$	03-07	0.000029	0.00032	2.5	12	5.9	e^+p	319	13
ZEUS NC	06-07	0.005	0.65	200	30000	135.5	e^+p	318	13,14,20
ZEUS CC $^{1.5p}$	06-07	0.0078	0.42	280	30000	132	e^+p	318	14
ZEUS NC $^{1.5}$	05-06	0.005	0.65	200	30000	169.9	e^-p	318	20
ZEUS CC $^{1.5}$	04-06	0.015	0.65	280	30000	175	e^-p	318	14
ZEUS NC nominal ^{*y}	06-07	0.000092	0.008343	7	110	44.5	e^+p	318	13
ZEUS NC satellite ^{*y}	06-07	0.000071	0.008343	5	110	44.5	e^+p	318	13
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	13, 19
H1 NC low Q^2	07	0.0000279	0.0148	1.5	90	5.9	e^+p	252	13
ZEUS NC nominal	07	0.000147	0.013349	7	110	7.1	e^+p	251	13
ZEUS NC satellite	07	0.000125	0.013349	5	110	7.1	e^+p	251	13
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	13, 19
H1 NC low Q^2	07	0.0000348	0.0148	1.5	90	12.2	e^+p	225	13
ZEUS NC nominal	07	0.000184	0.016686	7	110	13.9	e^+p	225	13
ZEUS NC satellite	07	0.000143	0.016686	5	110	13.9	e^+p	225	13

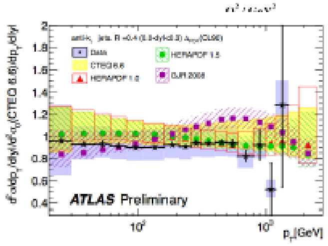
https://www.herafitter.org

experimental input





experiments:
HERA, Tevatron, LHC, fixed target



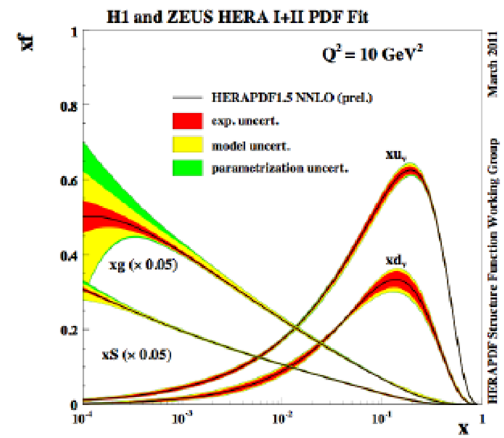
processes:
NC, CC DIS, jets, diffraction, heavy quarks (c,b,t)
Drell-Yan, W production

theoretical calculations/tools

Heavy quark schemes:	MSTW, CTEQ, ABM
Jets, W, Z production:	fastNLO, Applgrid
Top production	NNLO (Hathor)
QCD Evolution	DGLAP (QCDNUM)
	k_T factorisation
Alternative tools	NNPDF reweighting
Other models	Dipole model

+ Different error treatment models
+ Tools for data combination (HERAaverager)

HERAFitter



PDF or uPDF or DPDF

$\alpha_s(M_Z), m_c, m_b, m_t, f_s, ..$

Theory predictions

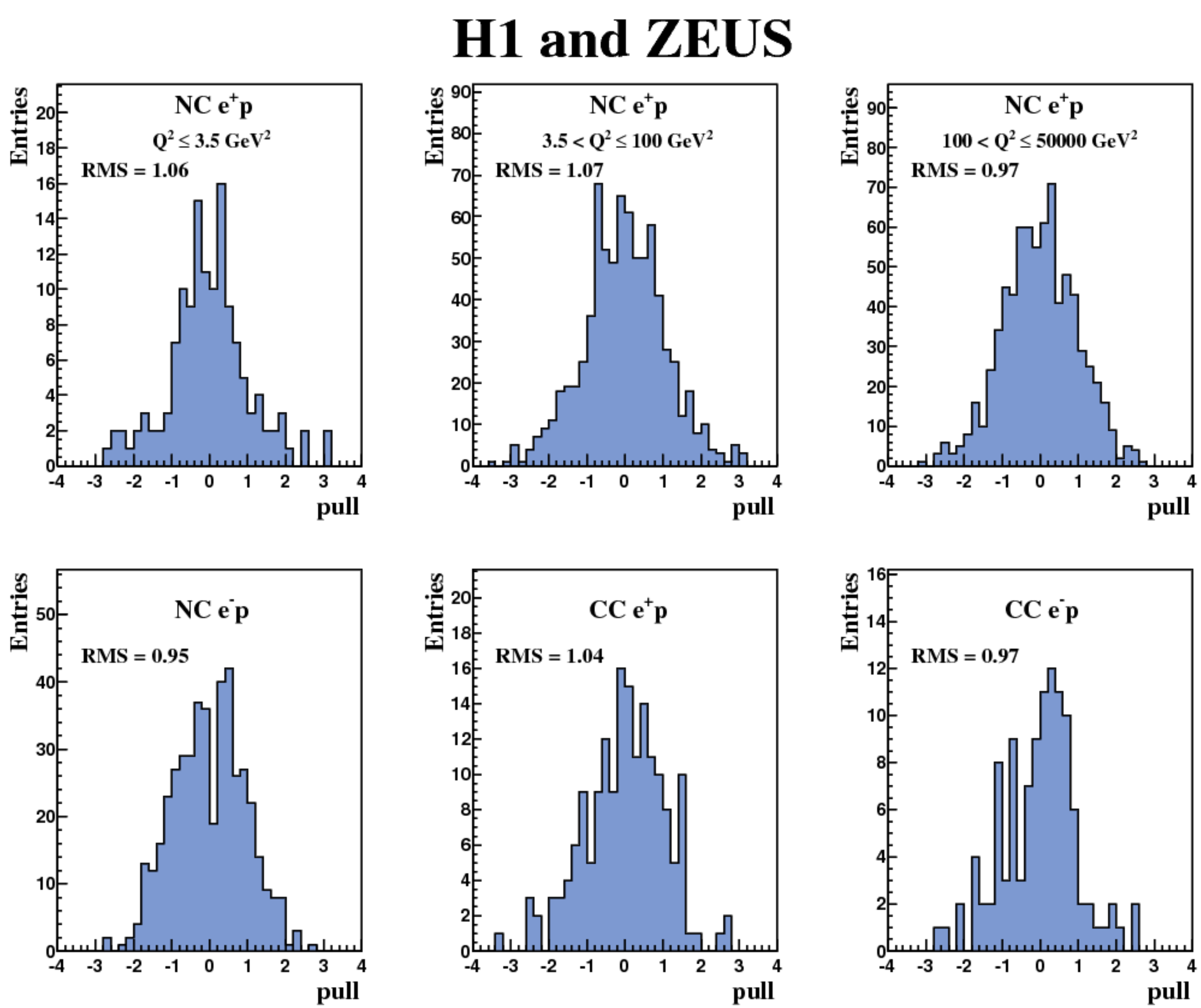
Benchmarking

Comparison of schemes

Averaging results

- Good data consistency: χ^2/dof = 1687/1620

$$p^{i,k} = \frac{\mu^{i,k} - \mu^i \left(1 - \sum_j \gamma_j^{i,k} b'_j\right)}{\sqrt{\Delta_{i,k}^2 - \Delta_i^2}}$$



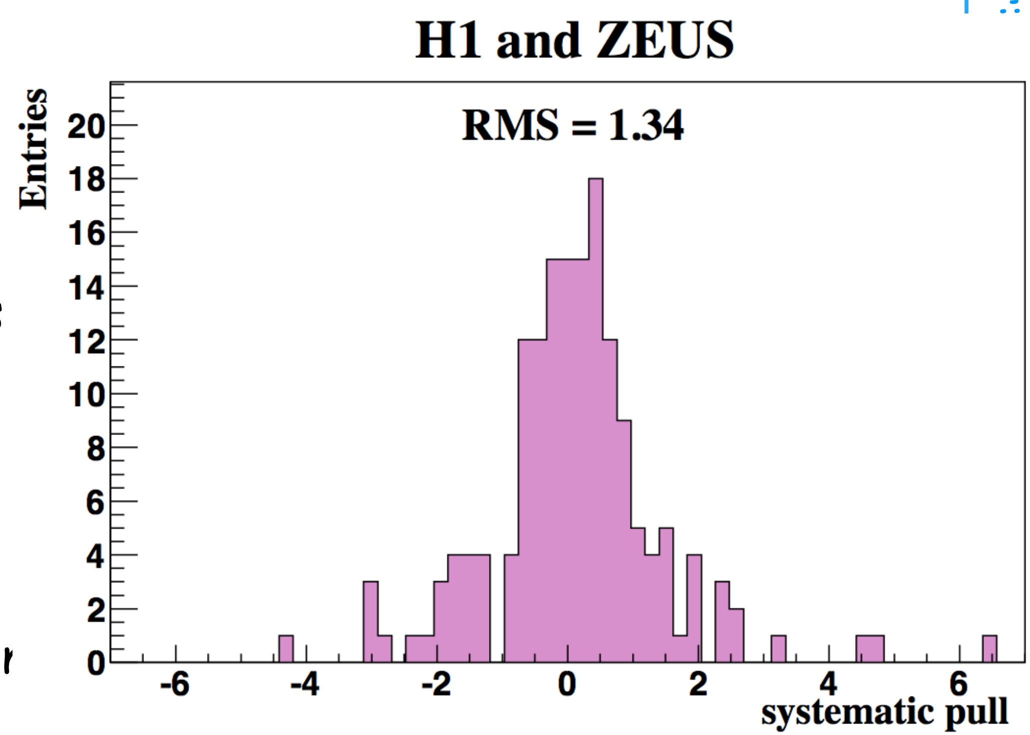
Procedural uncertainties

- Combination done using HERAverager: wiki-zeuthen.desy.de/HERAverager

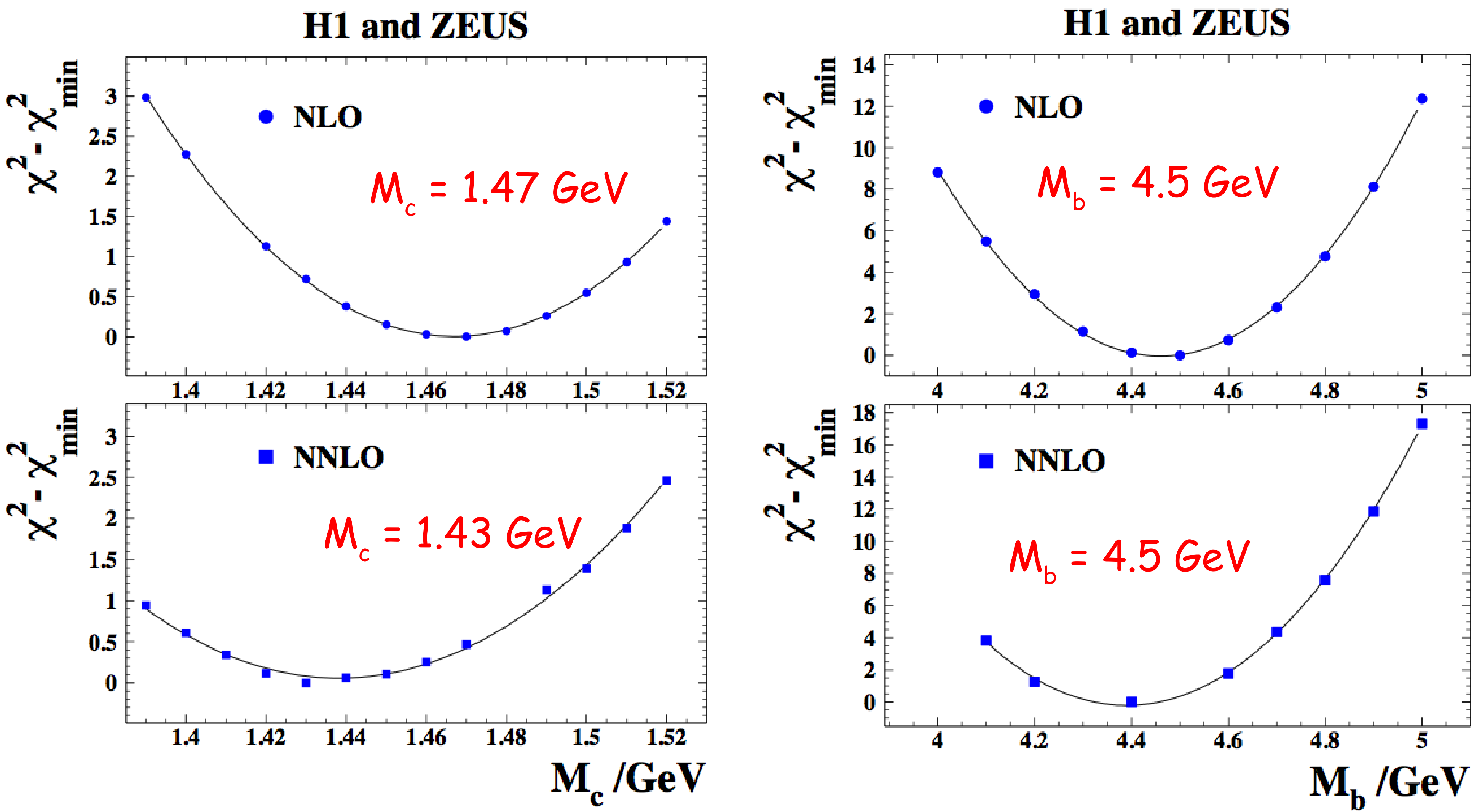
$$\chi^2_{\exp,ds}(\boldsymbol{m},\boldsymbol{b}) = \sum_i \frac{\left[m^i - \sum_j \gamma_j^{i,ds} m^i b_j - \mu^{i,ds}\right]^2}{\delta^2_{i,ds,\text{stat}}\,\mu^{i,ds}\left(m^i - \sum_j \gamma_j^{i,ds} m^i b_j\right) + \left(\delta_{i,ds,\text{uncor}}\, m^i\right)^2} + \sum_j b_j^2$$

- **162** correlated systematic sources taken into account
  - treated as multiplicative

- Procedural errors calculated
  - multiplicative vs additive
  - possible correlations between data sets (H1/ZEUS, HERAI/HERAII)
    - photoproduction background
    - hadronic energy scale
  - connected with large pulls in combination



Estimation of beauty and charm mass parameters

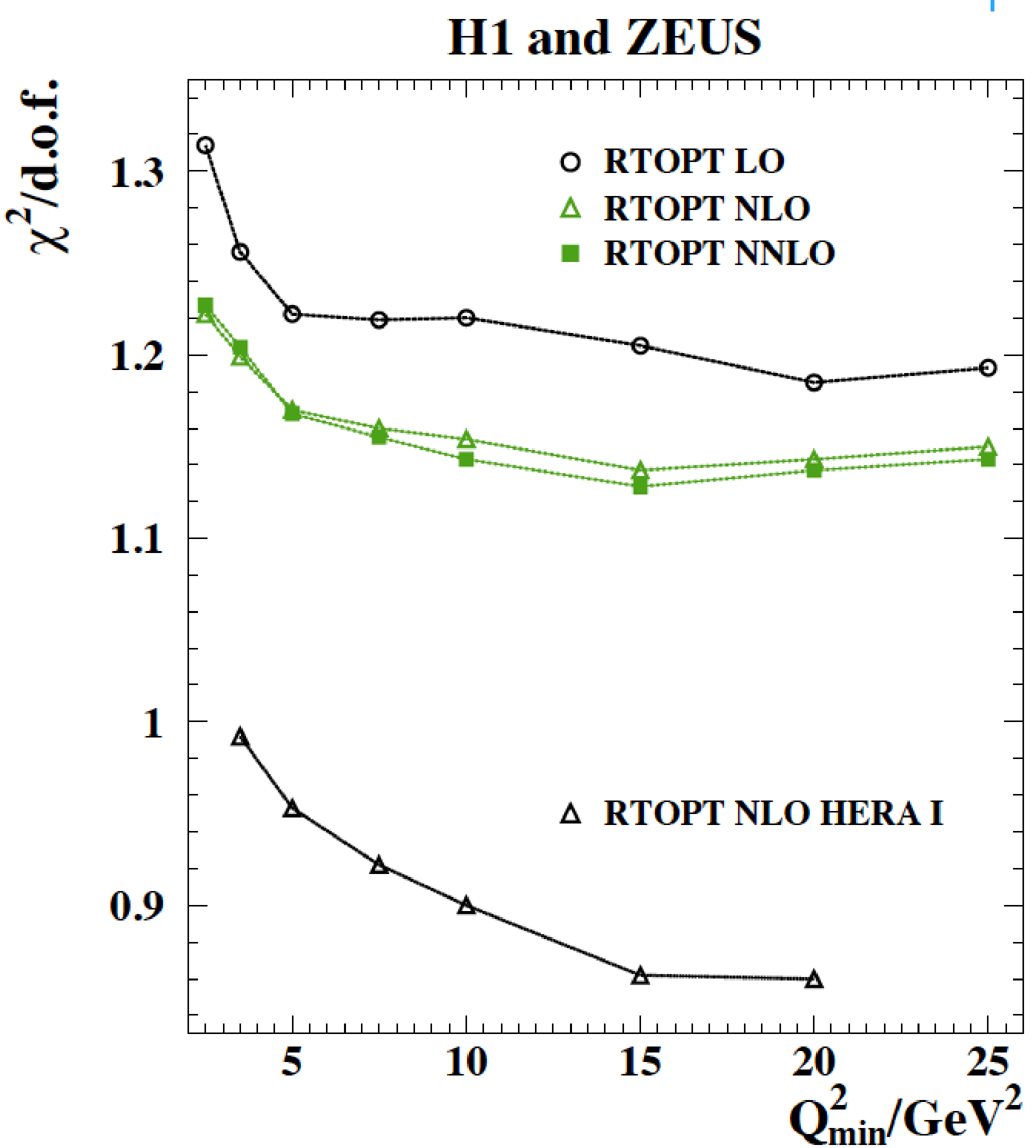


→ M_c/M_b determined from inclusive data + charm/beauty data

Method comes from the HERA charm combination (Eur. Phys. J. C73 (2013) 2311)

Q^2_{min} studies

- Q^2_{min} = 3.5 GeV² HERAPDF2.0
  - NLO $\frac{\chi^2}{ndf} = \frac{1357}{1131}$
  - NNLO $\frac{\chi^2}{ndf} = \frac{1363}{1131}$
- Q^2_{min} = 10 GeV² HERAPDF2.0HiQ2
  - NLO $\frac{\chi^2}{ndf} = \frac{1156}{1002}$
  - NNLO $\frac{\chi^2}{ndf} = \frac{1146}{1002}$



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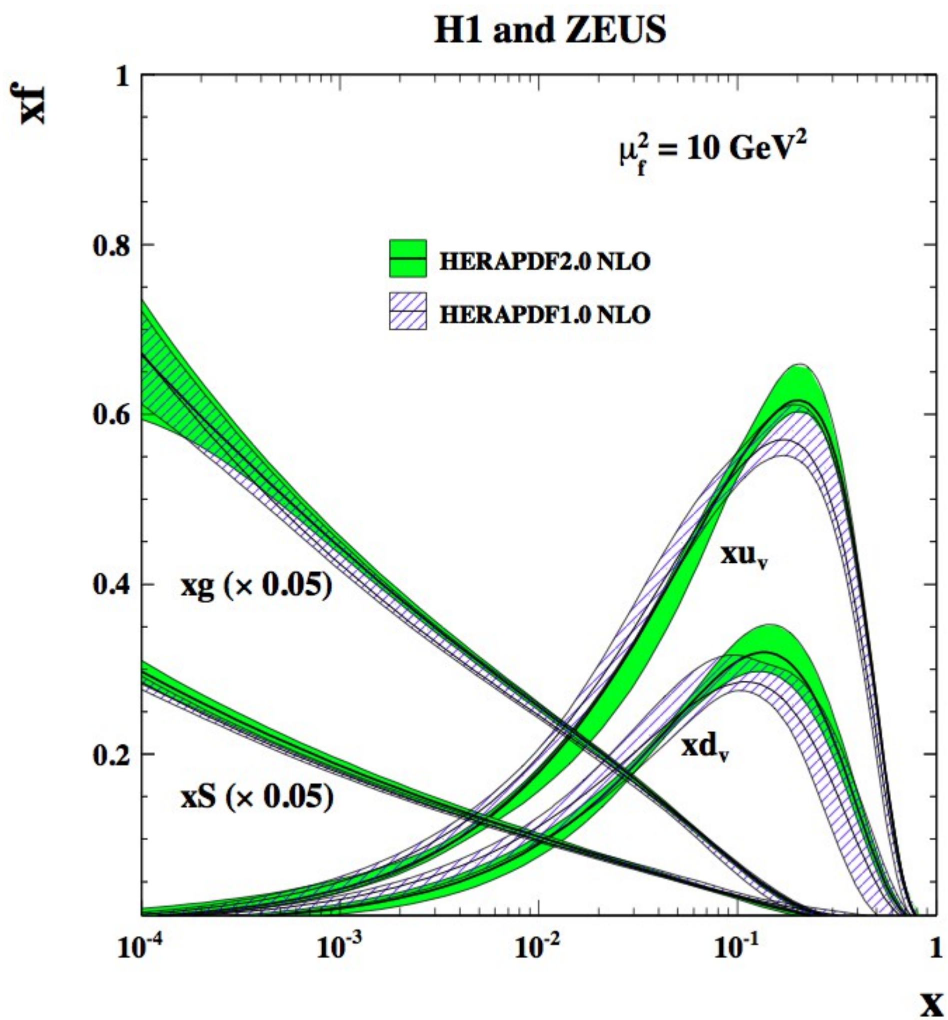
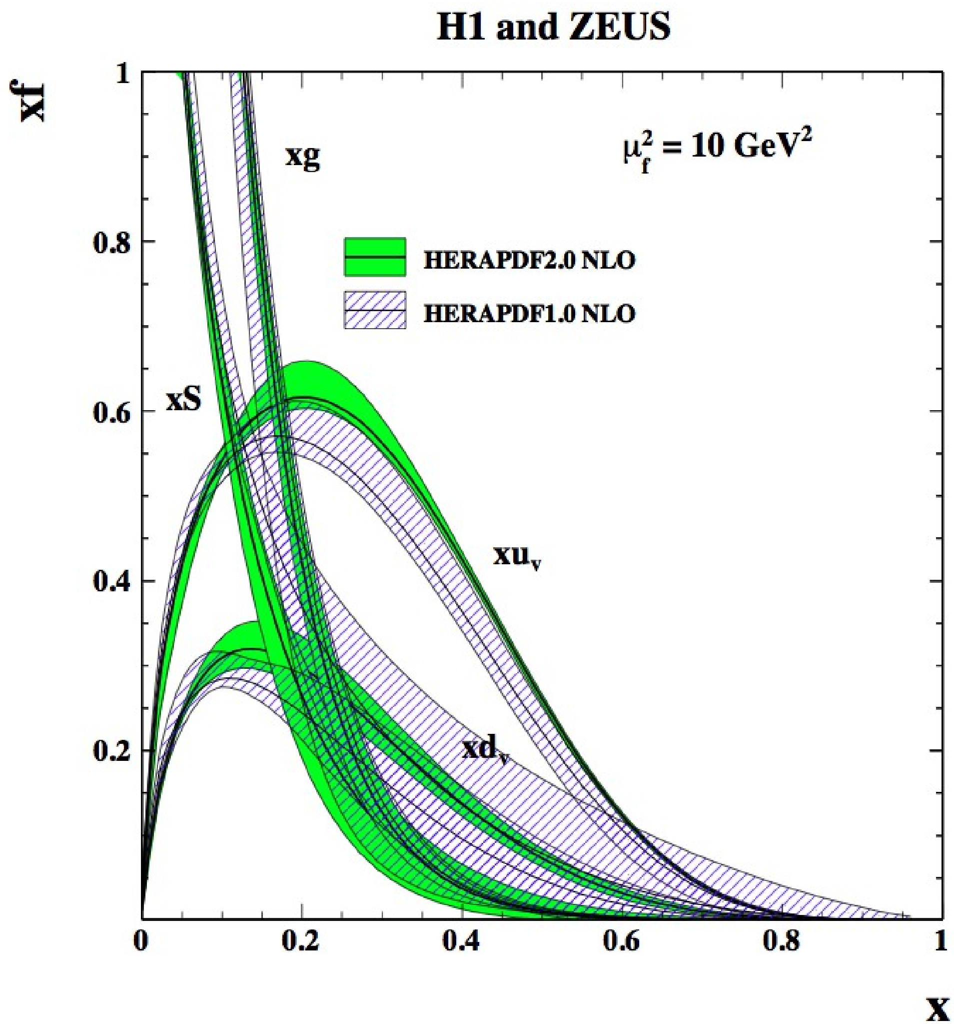
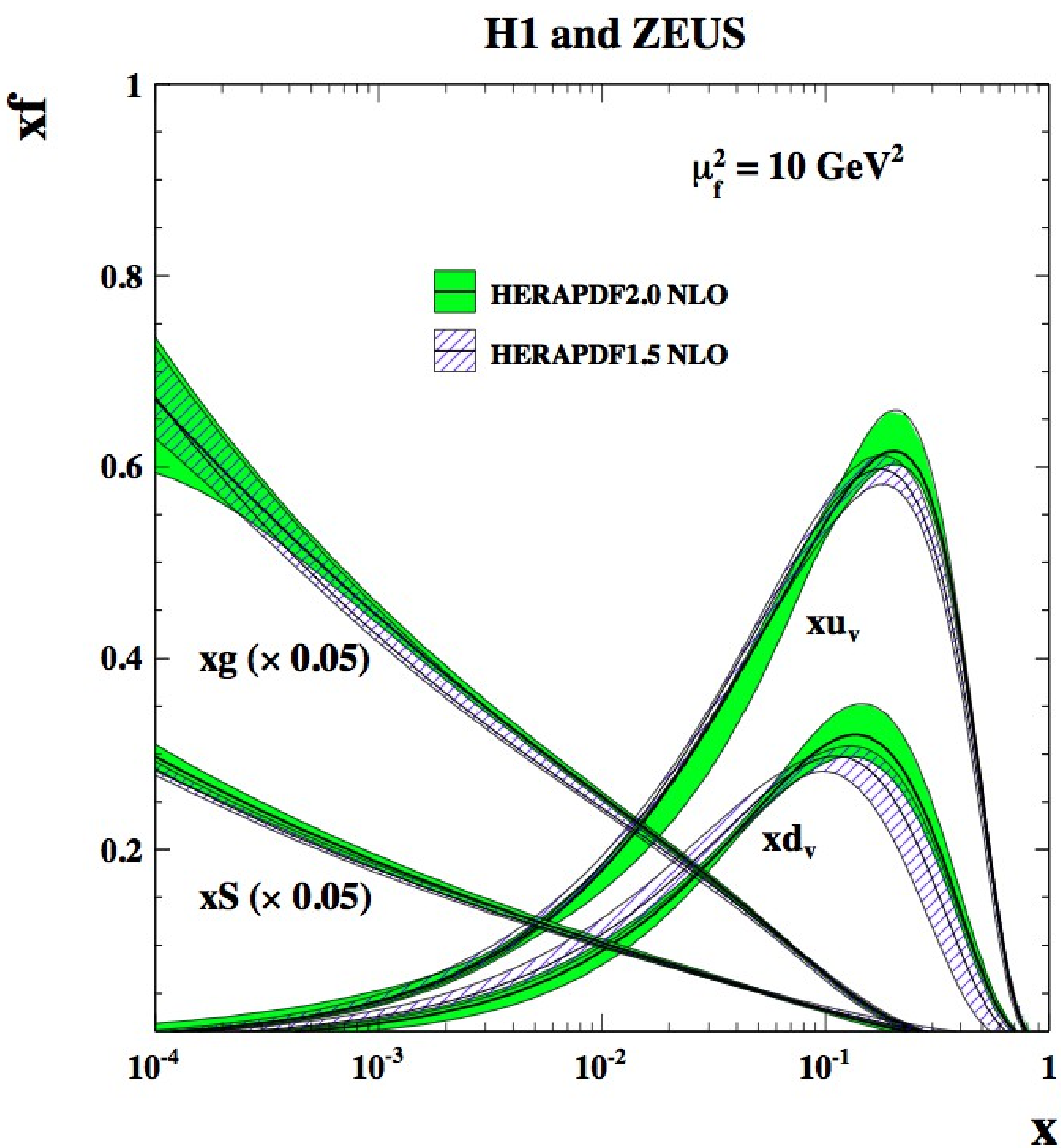
HERAPDF1.0 vs HERAPDF2.0





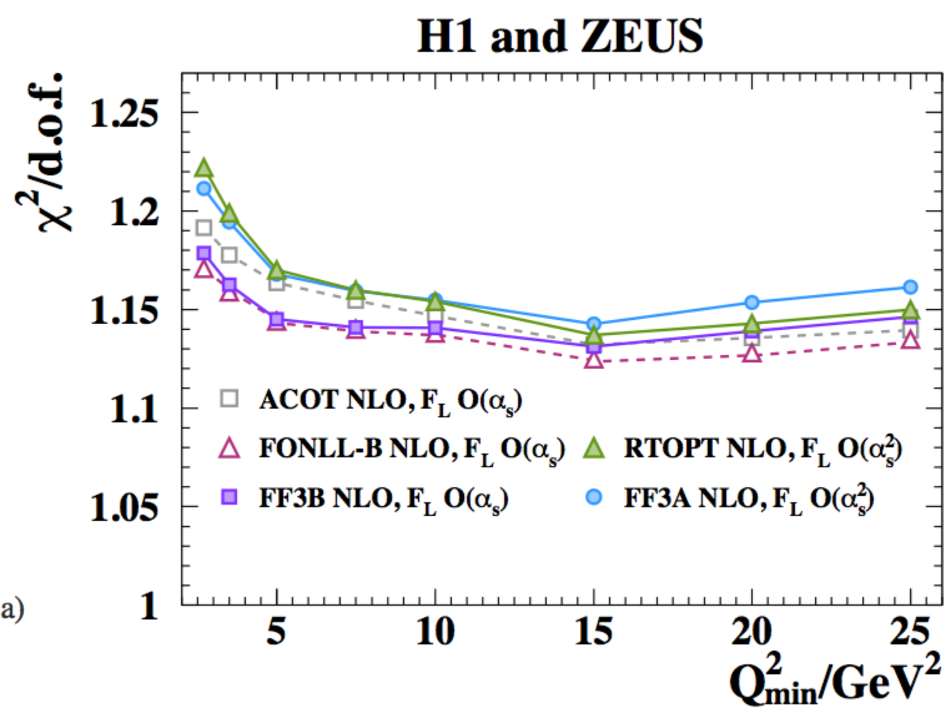
- Valence distributions are more peaked at HERAPDF2.0 ← new data
- High x sea is softer whereas gluon is harder at HERAPDF2.0
- Smaller uncertainties at high x.

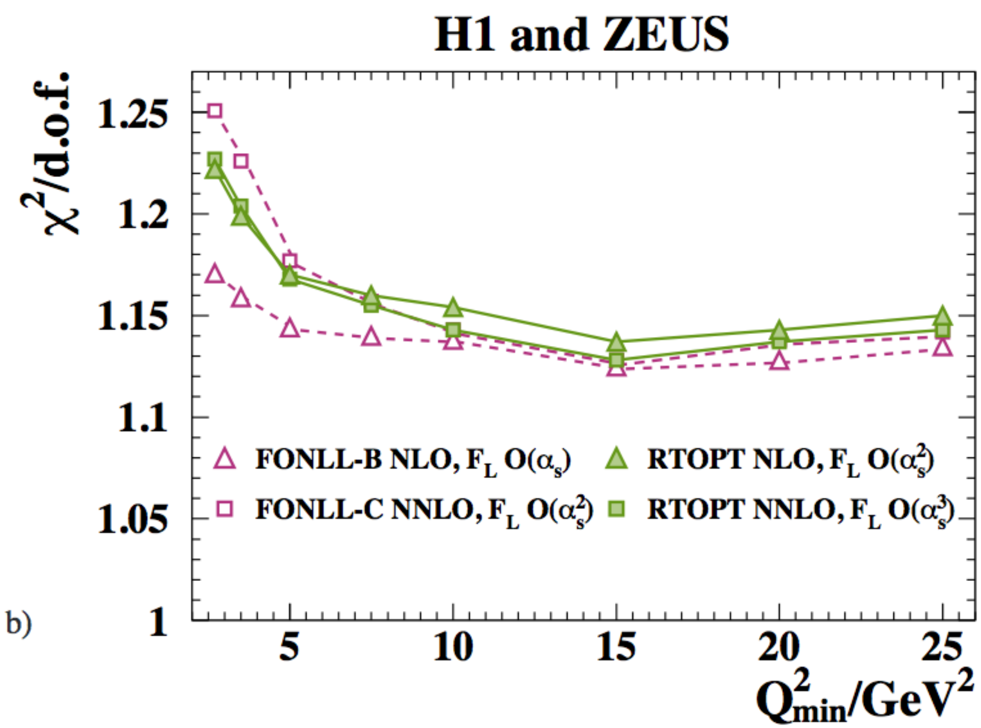
HERAPDF1.5 vs HERAPDF2.0



- Distributions similar
- 10 param → 14 param
- Low x gluon uncertainty smaller for HERAPDF2.0

Looking at F_L order





- RTOPT ~ MMHT
- ACOT ~ CT
- FF3A ~ ABM

- Treating of F_L to the same order in α_s as F_2 gives better results at NLO but not at NNLO
- Almost independent of HF scheme

HERAPDF2.0FF3A/3B variant issued