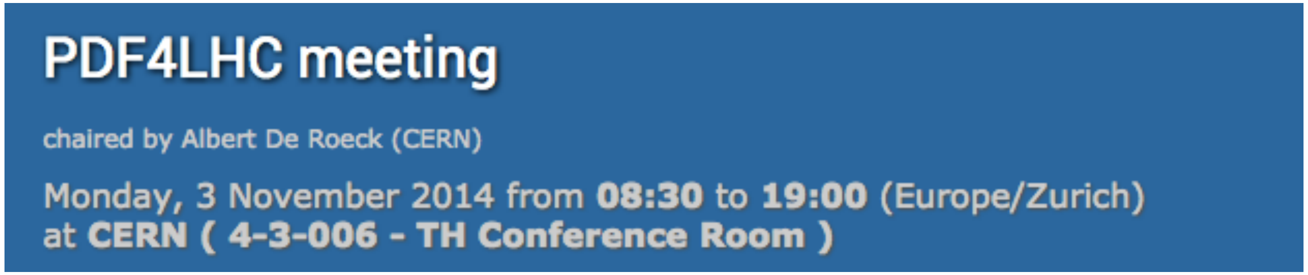
HELMHOLTZ
GEMEINSCHAFT

Update on HERAPDF

Voica Radescu (DESY)
on behalf of the H1 and ZEUS collaborations



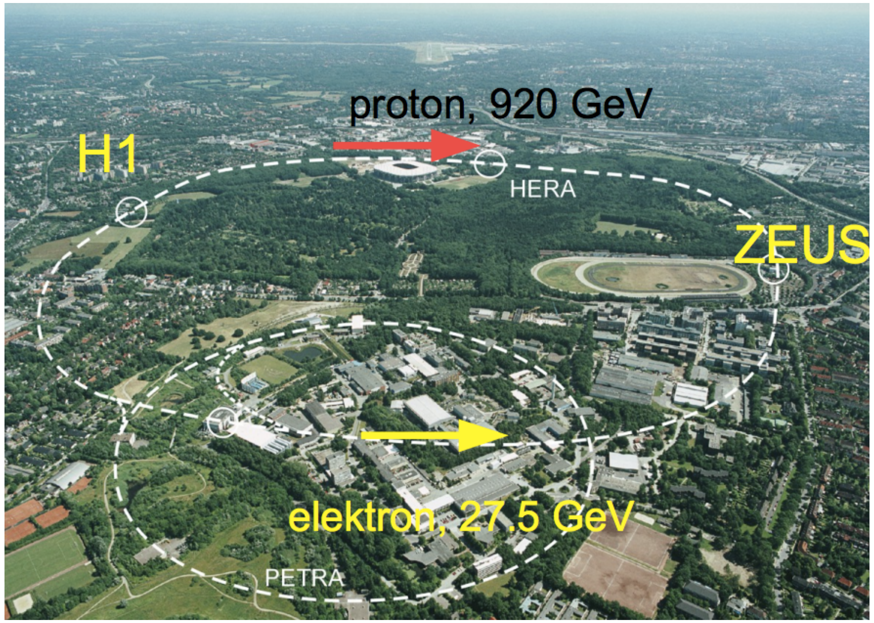
PDF4LHC meeting

chaired by Albert De Roeck (CERN)

Monday, 3 November 2014 from **08:30** to **19:00** (Europe/Zurich)
at **CERN (4-3-006 - TH Conference Room)**

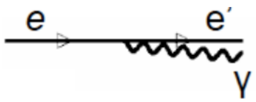
HERA ep collider (1992-2007) @ DESY

- HERA: unique lepton-proton collider
  - **Operational:**
    - **1992-2000 (HERA I)**
    - **2003-2007 (HERA II)**
  - **Ep=460, 575, 820, 920 GeV, Ee = 27.6GeV**
- H1 and ZEUS collected 0.5/fb per experiment
- Rich Physics Programme:
  - **proton structure, EW, QCD, diffraction, BSM searches,…**



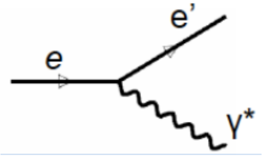
Two kinematic regimes:

- **Photo-production (PHP)**: $Q^2 < 1$ GeV^2



- **Deep Inelastic Scattering (DIS)**: $Q^2 > 1$ GeV^2

4 processes are available at HERA:



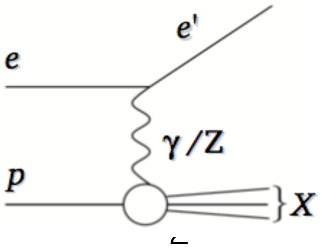
Kinematic variables

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

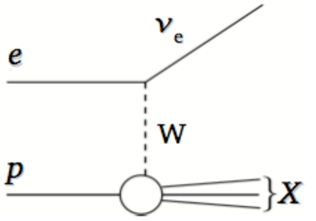
$$x = \frac{Q^2}{2p \cdot q}$$ Bjorken variable

$$y = \frac{p \cdot q}{p \cdot k}$$ Inelasticity

$\text{NC}: \ e\,p \to e'\,X$



$\text{CC}: \ e\,p \to \nu_e\,X$



Structure Functions at HERA

- Differential cross sections as function of x and Q2 can be decomposed as:

$$\frac{d\sigma^{\pm}_{NC}}{dxdQ^2} = \frac{2\pi\alpha^2}{x}\left[\frac{1}{Q^2}\right]^2\left[Y_+\tilde{F}_2 \mp Y_- x\tilde{F}_3 - y^2\tilde{F}_L\right]$$

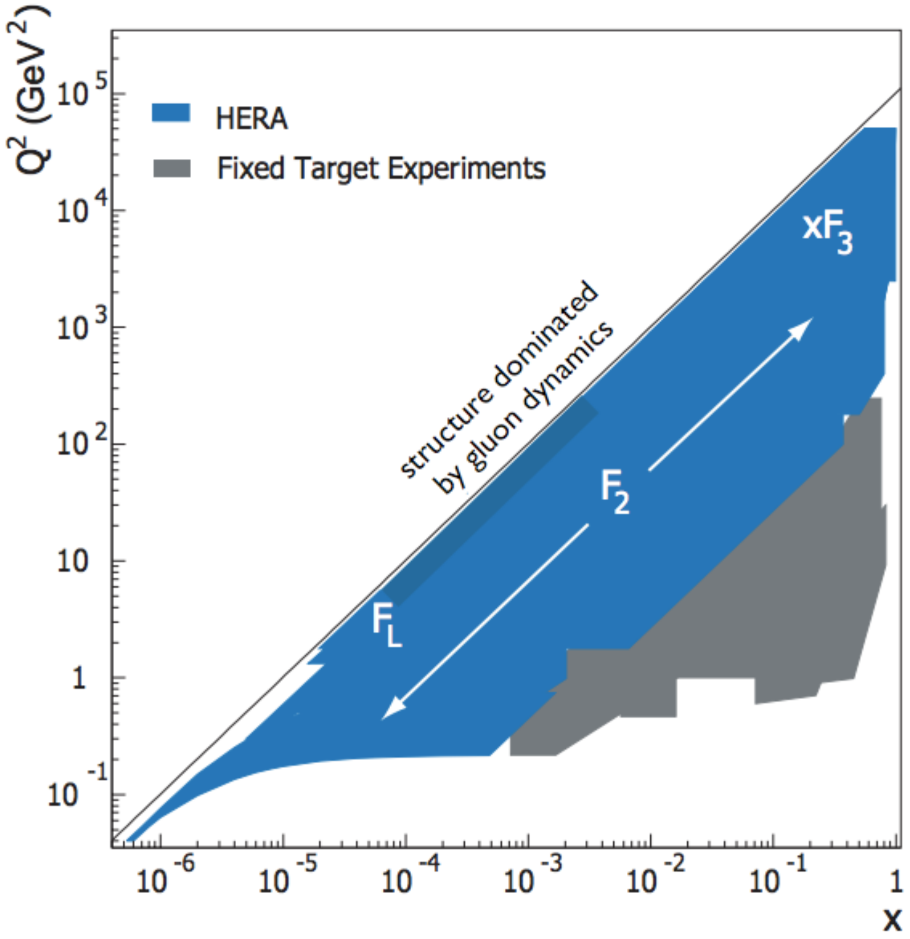
$$\frac{d\sigma^{\pm}_{CC}}{dxdQ^2} = \frac{G_F^2}{4\,\pi\,x}\left[\frac{M_W^2}{M_W^2+Q^2}\right]^2\left[Y_+\,\tilde{W}_2^{\pm} \mp Y_-\,x\tilde{W}_3^{\pm} - y^2\tilde{W}_L^{\pm}\right]$$

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

$$\tilde{F}_2 \propto \sum (xq_i + x\bar{q}_i)$$

$$x\tilde{F}_3 \propto \sum (xq_i - x\bar{q}_i)$$

$$\tilde{F}_L \propto \alpha_s \cdot xg(x,Q^2)$$



NC Measurements

- F2 dominates most of Q2 reach
- xF3 contributes in EW regime
- FL contributes only at highest y

CC Measurements

- W2 and xW3 contribute equally
- WL only at high y

New measurements from HERA

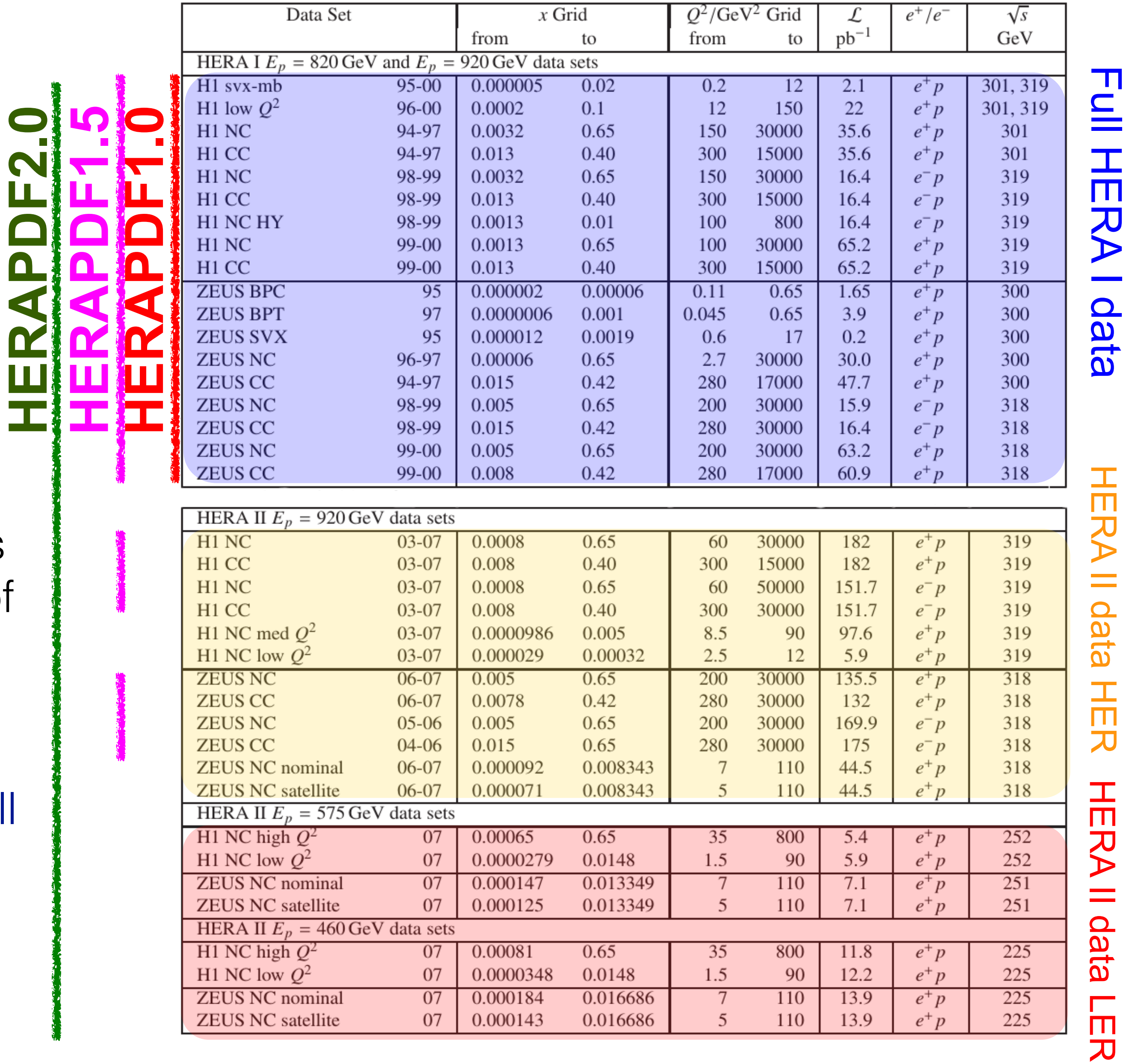
All inclusive individual DIS results from H1 and ZEUS are final and published

Typically several experiments provide their data in a similar kinematic phase space:

$0.045 < Q^2 < 50000$ GeV^2

$6\times10^{-7} < x < 0.65$

- Best precision achieved when data are combined:
  - averaging procedure takes correlations of systematic of uncertainties into account
- Data combination provides a test of data consistency as well



Data Set		x Grid		Q^2/GeV^2 Grid		$\mathcal{L}$	e^+/e^-	$\sqrt{s}$
		from	to	from	to	pb^{-1}		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	03-07	0.0000986	0.005	8.5	90	97.6	e^+p	319
H1 NC low Q^2	03-07	0.000029	0.00032	2.5	12	5.9	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	06-07	0.000092	0.008343	7	110	44.5	e^+p	318
ZEUS NC satellite	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	5.4	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	11.8	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

HERAPDF2.0

HERAPDF1.5

HERAPDF1.0

Full HERA I data

HERA II data HER

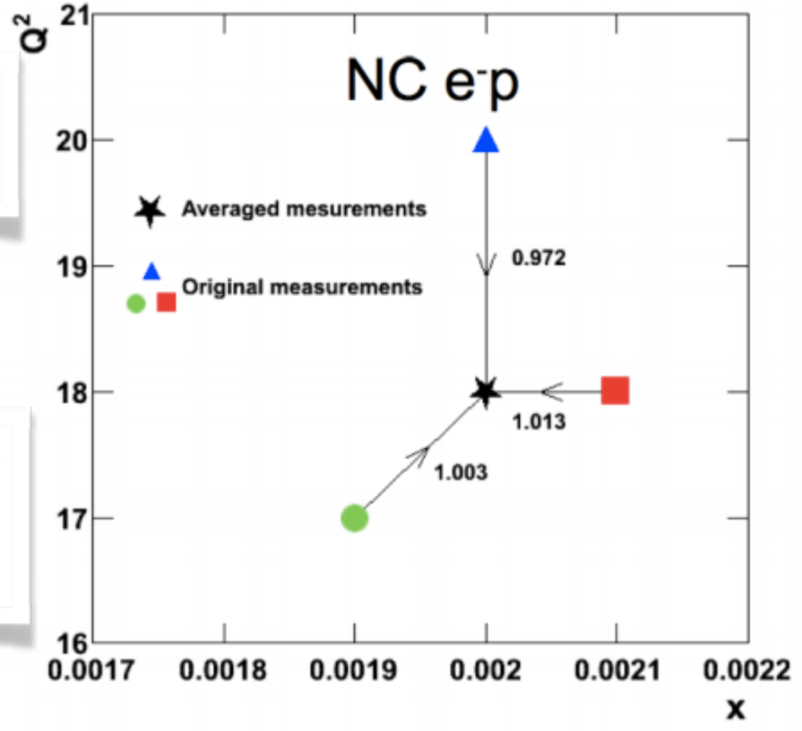
HERA II data LER

HERA data combination

H1prelim-14-041 and ZEUS-prel-14-005

- All individual measurements from H1 and ZEUS are published.
- There are 41 data sets: 2927 data points are combined into 1307 averaged measurements with 162 sources of correlated systematic uncertainties.
  - **Data are combined into a common x, Q2 grid —> original measurements are swum to the nearest grid point via linear interpolation**

$$\sigma(x_{grid}, Q^2_{grid}) = \frac{\sigma_{model}(x_{grid}, Q^2_{grid})}{\sigma_{model}(x_{meas}, Q^2_{meas})} \cdot \sigma_{meas}(x_{meas}, Q^2_{meas})$$



  - **Combination performed using the HERAverager package**

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

  - As a default choice: multiplicative treatment of the systematic
  - **Procedural uncertainties:**
    - multiplicative vs additive
    - correlation of photoproduction background and hadronic energy scale
  - **Consistent data sets: total χ2/ndf = 1685/1620=1.04.**

HERA data combination

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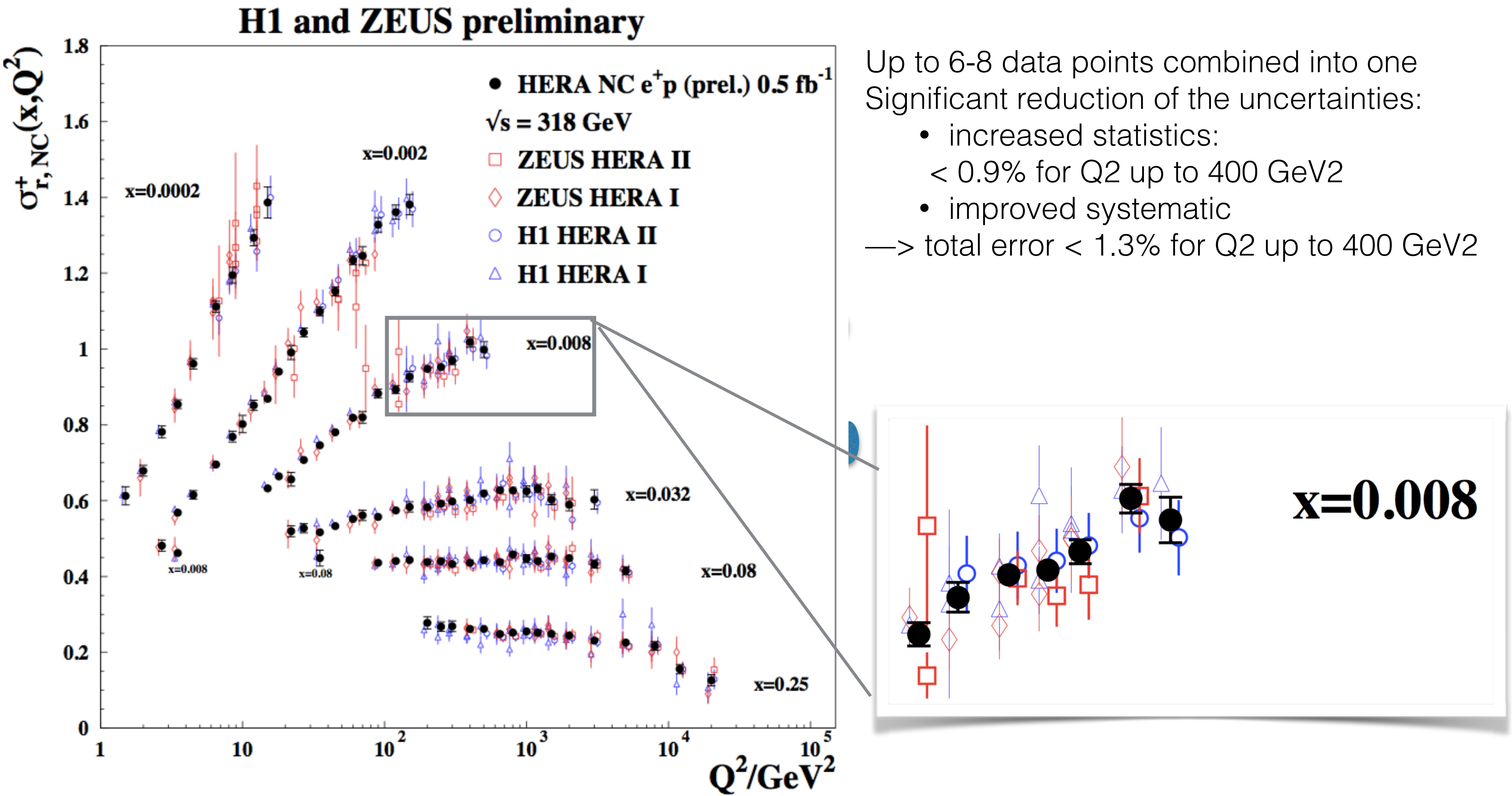
- There are 41 data sets: 2927 data points are combined into 1307 averaged measurements with 162 sources of correlated systematic uncertainties.



Up to 6-8 data points combined into one
Significant reduction of the uncertainties:

- increased statistics:
  < 0.9% for Q2 up to 400 GeV2
- improved systematic

—> total error < 1.3% for Q2 up to 400 GeV2

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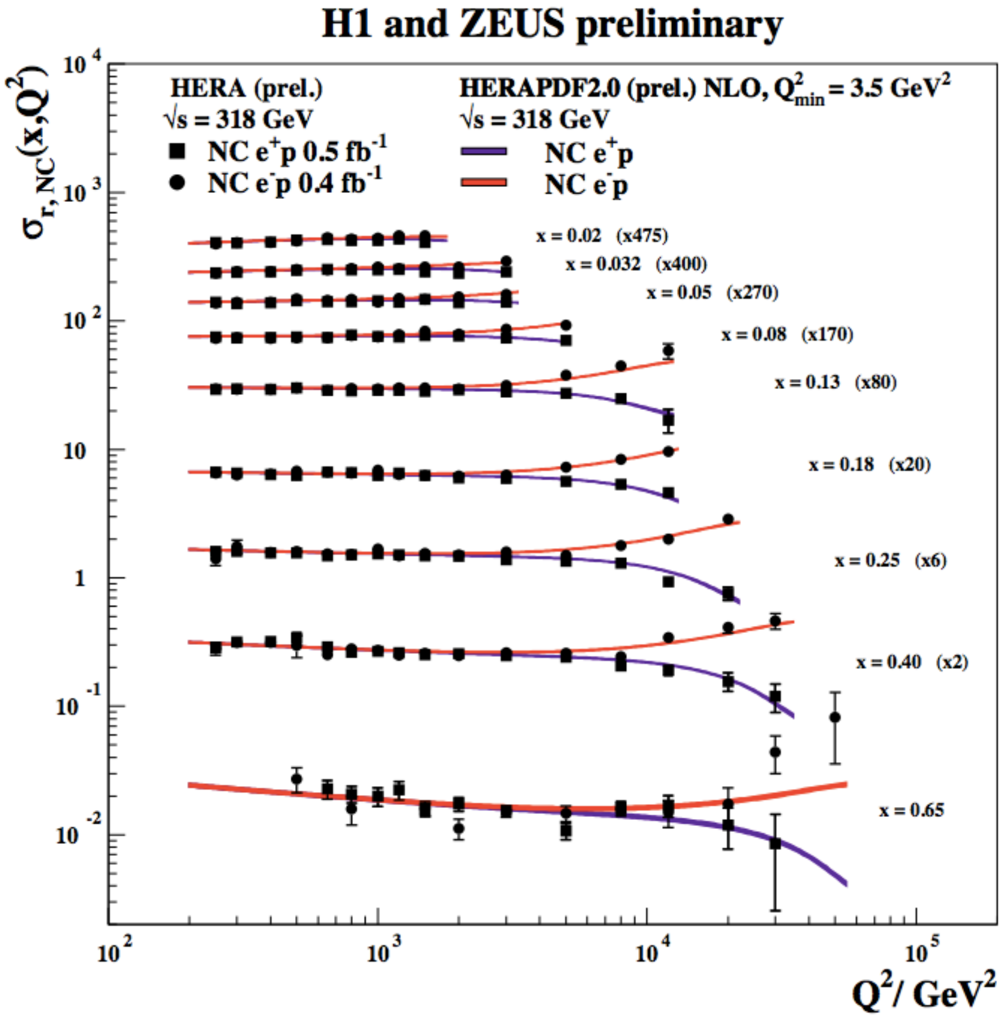
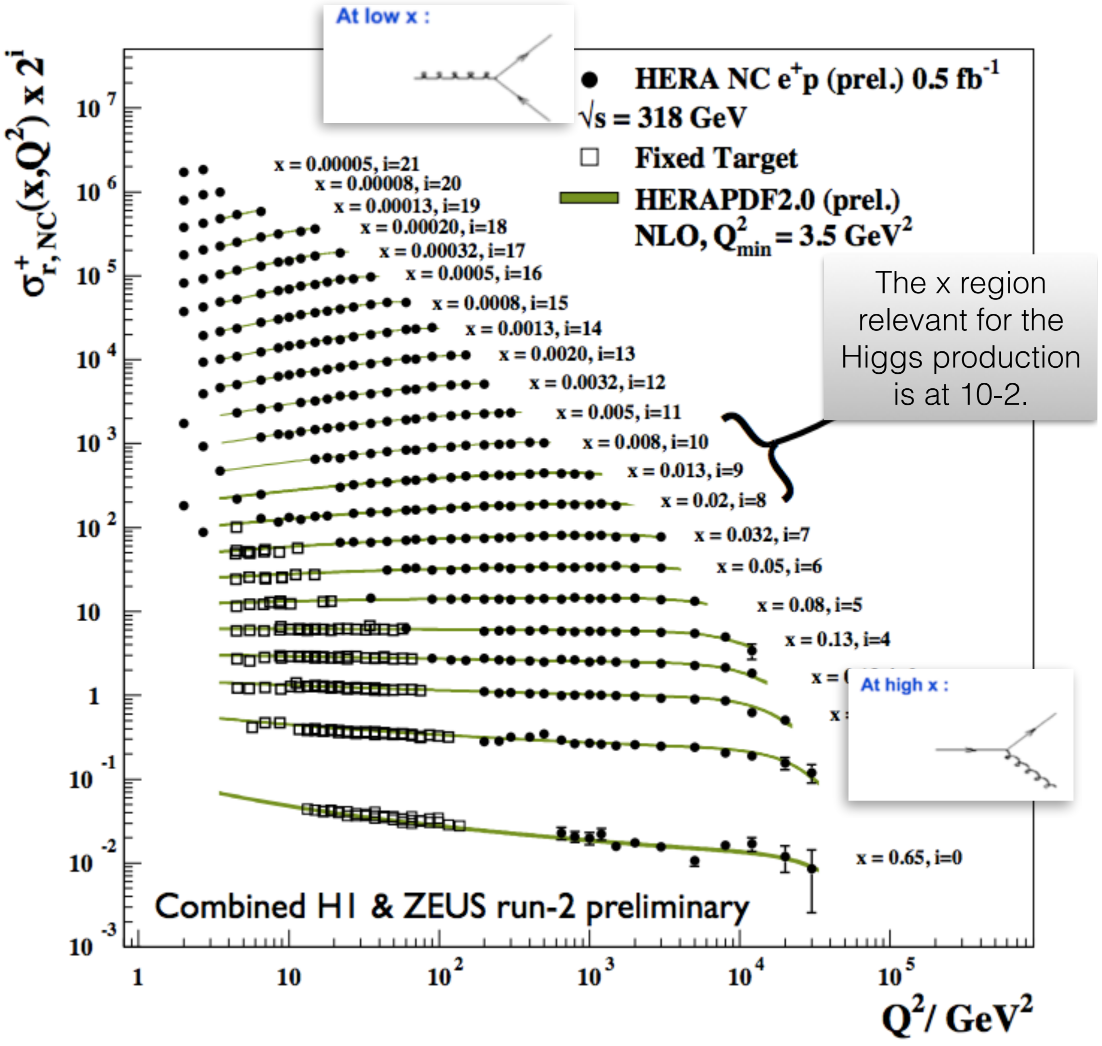
QCD scaling and EW effects

H1prelim-14-041 and ZEUS-prel-14-005

- EW effects clearly seen at high Q2:

QCD scaling violations nicely seen:





The x region relevant for the Higgs production is at 10-2.

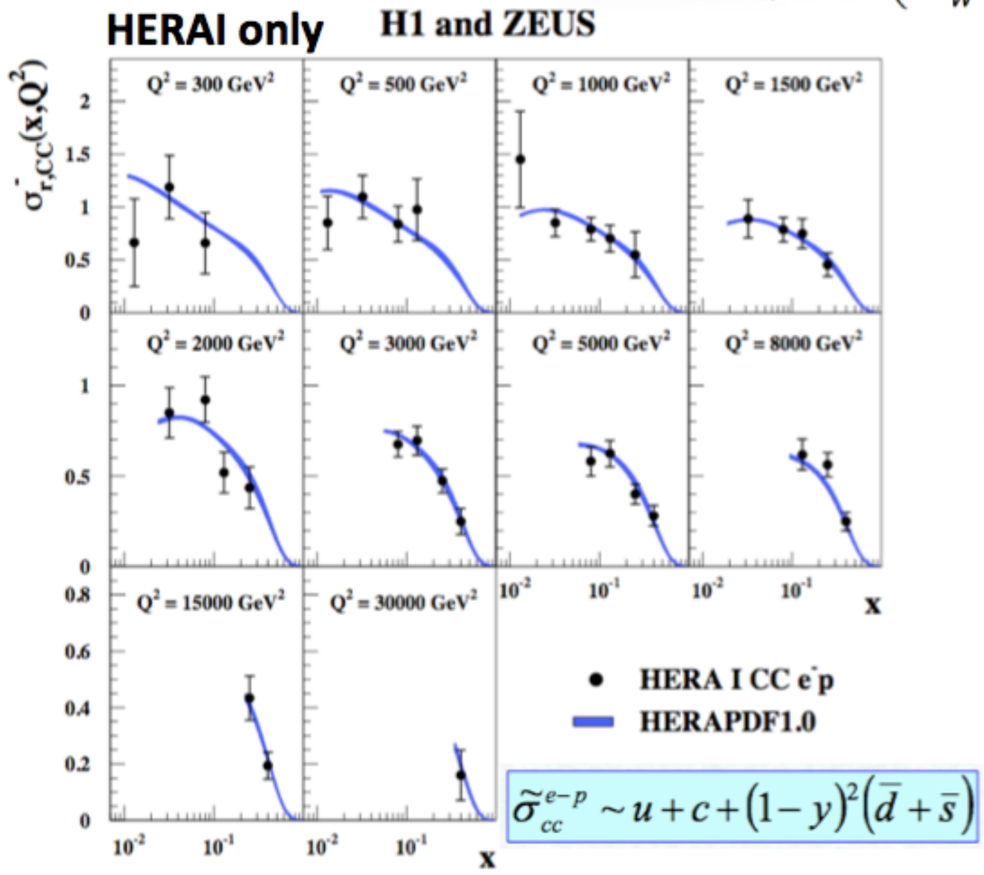
Charged Current Cross Section Measurements

H1prelim-14-041 and ZEUS-prel-14-005

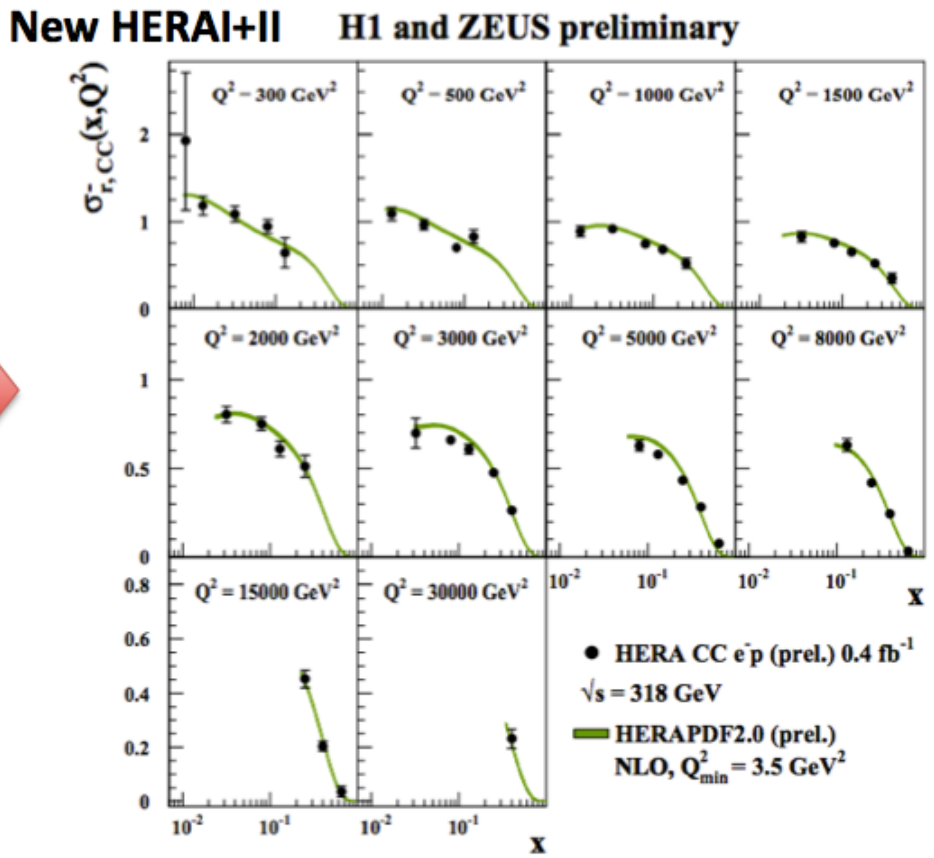
Charged Current: provides important flavour decomposition

e-p: $$\frac{d^2\sigma^-_{CC}}{dxdQ^2} = \frac{G_F^2}{2\pi}\left(\frac{M_W^2}{M_W^2+Q^2}\right)\left[u + c + (1-y)^2(\bar{d} + \bar{s})\right]$$

e+p: $$\frac{d^2\sigma^+_{CC}}{dxdQ^2} = \frac{G_F^2}{2\pi}\left(\frac{M_W^2}{M_W^2+Q^2}\right)\left[\bar{u} + \bar{c} + (1-y)^2(d + s)\right]$$



$$\tilde{\sigma}^{e-p}_{cc} \sim u + c + (1-y)^2(\bar{d} + \bar{s})$$



Much more precise CC measurements after including new high Q^2 HERA II set!

Review of HERAPDF sets:

PDFs at HERA are determined from QCD Fits to solely HERA data:

- no need for heavy target corrections nor strong isospin assumptions

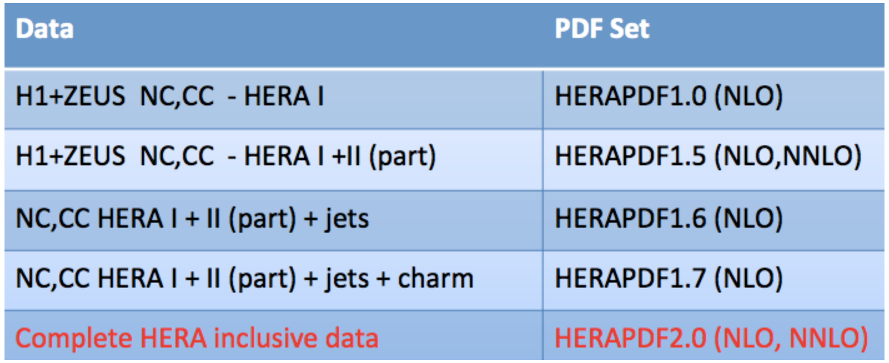
HERAPDF1.0:
- Combined NC and CC HERA-I data (public)
- NLO set, RT scheme —> available in LHAPDF

HERAPDF1.5(prel.) -> recommended so far:
- Include additional NC and CC HERA-II data (not public)
- LO, NLO, NNLO sets —> available in LHAPDF

HERAPDF1.6 (prel., not public)
- Include additional NC inclusive jet data 5 < Q2 < 15000
- αs = 0.1202 ± 0.0013 (exp) ± 0.004 (scales) free in fit
- NLO

HERAPDF1.7 (prel. not public)
- Include F2cc data 4 < Q2 < 1000
- Include combined cross section points Ep=575/460 GeV
- NLO

HERAPDF2.0(prel) —> NEW



Data	PDF Set
H1+ZEUS NC,CC - HERA I	HERAPDF1.0 (NLO)
H1+ZEUS NC,CC - HERA I +II (part)	HERAPDF1.5 (NLO,NNLO)
NC,CC HERA I + II (part) + jets	HERAPDF1.6 (NLO)
NC,CC HERA I + II (part) + jets + charm	HERAPDF1.7 (NLO)
Complete HERA inclusive data	HERAPDF2.0 (NLO, NNLO)

QCD Settings for HERAPDF2.0

The QCD settings are optimised for HERA measurements of proton structure functions:

PDFs are parametrised at the starting scale Q_0^2=1.9 GeV^2 as follows:

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

▨ fixed or constrained by sum-rules

🟦 parameters set equal but free

NC structure functions

$$F_2 = \frac{4}{9}\left(xU + x\bar{U}\right) + \frac{1}{9}\left(xD + x\bar{D}\right)$$

$$xF_3 \sim xu_v + xd_v$$

CC structure functions

$$W_2^- = x(U + \overline{D}), \qquad W_2^+ = x(\overline{U} + D)$$

$$xW_3^- = x(U - \overline{D}), \qquad xW_3^+ = x(D - \overline{U})$$

Due to increased precision of data, more flexibility in functional form is allowed —> 15 free parameters

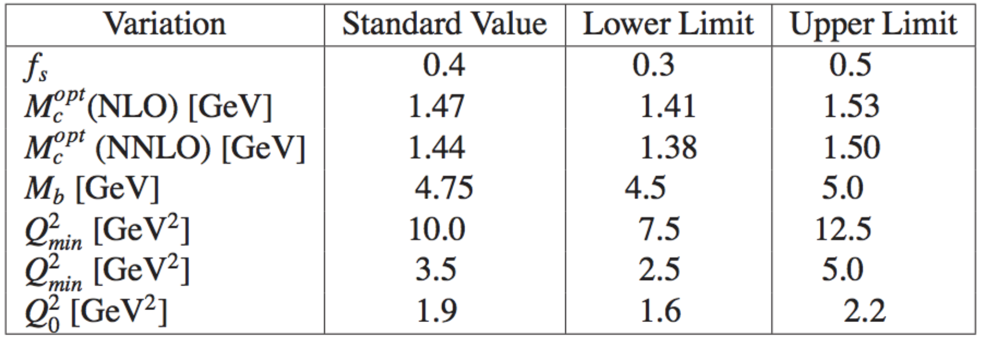
- PDFs are evolved via evolution equations (DGLAP) to NLO and NNLO (as(MZ)=0.118)
- Thorne-Roberts GM-VFNS for heavy quark coefficient functions – as used in MSTW
- Chi2 definition used in the minimisation [MINUIT] accounts for correlated uncertainties:

$$\chi^2_{tot}(\mathbf{m},\mathbf{b}) = \sum_i \frac{[\mu^i - m^i(1 - \sum_j \gamma^i_j b_j)]^2}{\delta^2_{i,stat}\mu^i m^i(1 - \sum_j \gamma^i_j b_j) + (\delta_{i,unc} m^i)^2} + \sum_j b_j^2 + \sum_i \ln \frac{\delta^2_{i,unc} m_i^2 + \delta^2_{i,stat}\mu^i m^i}{\delta^2_{i,unc}\mu_i^2 + \delta^2_{i,stat}\mu_i^2}$$

Modern understanding of PDFs

Uncertainties of three types considered:

- Experimental:
  - Hessian method used
  - Consistent data sets → use $\Delta\chi^2=1$
- Model:
  - variations of all assumed input parameters in the fit

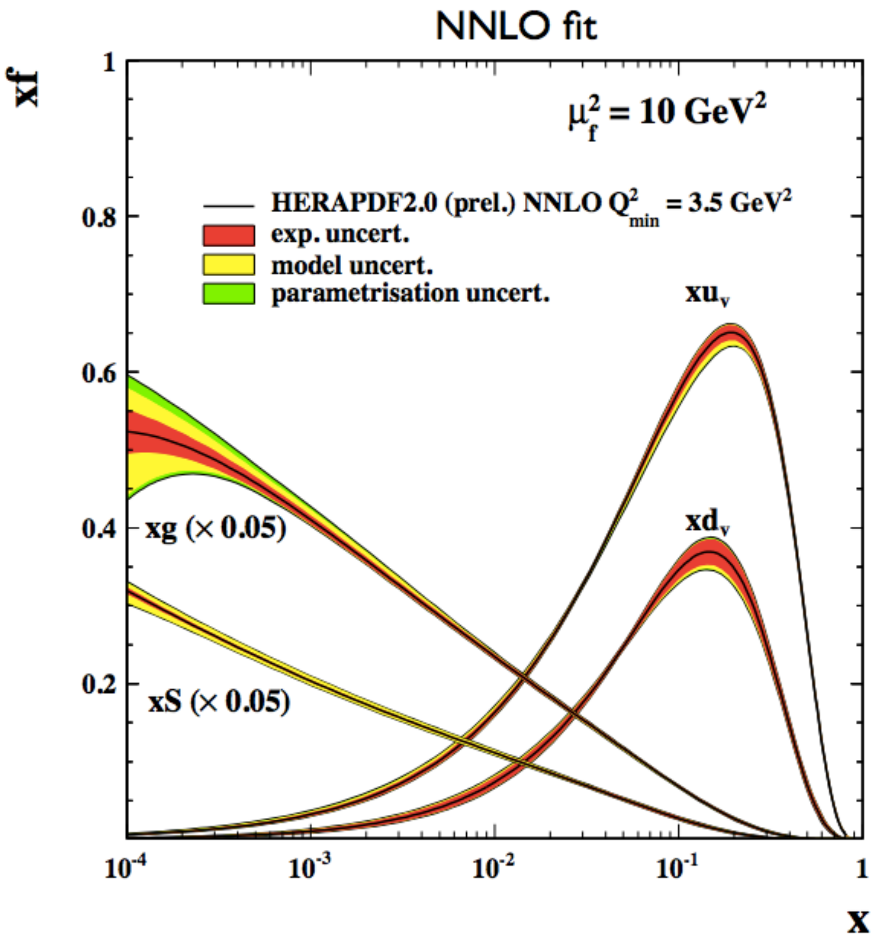


Variation	Standard Value	Lower Limit	Upper Limit
f_s	0.4	0.3	0.5
M_c^{opt}(NLO) [GeV]	1.47	1.41	1.53
M_c^{opt} (NNLO) [GeV]	1.44	1.38	1.50
M_b [GeV]	4.75	4.5	5.0
Q^2_{min} [GeV^2]	10.0	7.5	12.5
Q^2_{min} [GeV^2]	3.5	2.5	5.0
Q^2_0 [GeV^2]	1.9	1.6	2.2

- Parametrisation:
  - An envelope formed from PDF fits using variants of parametrisation form (extra parameter added)

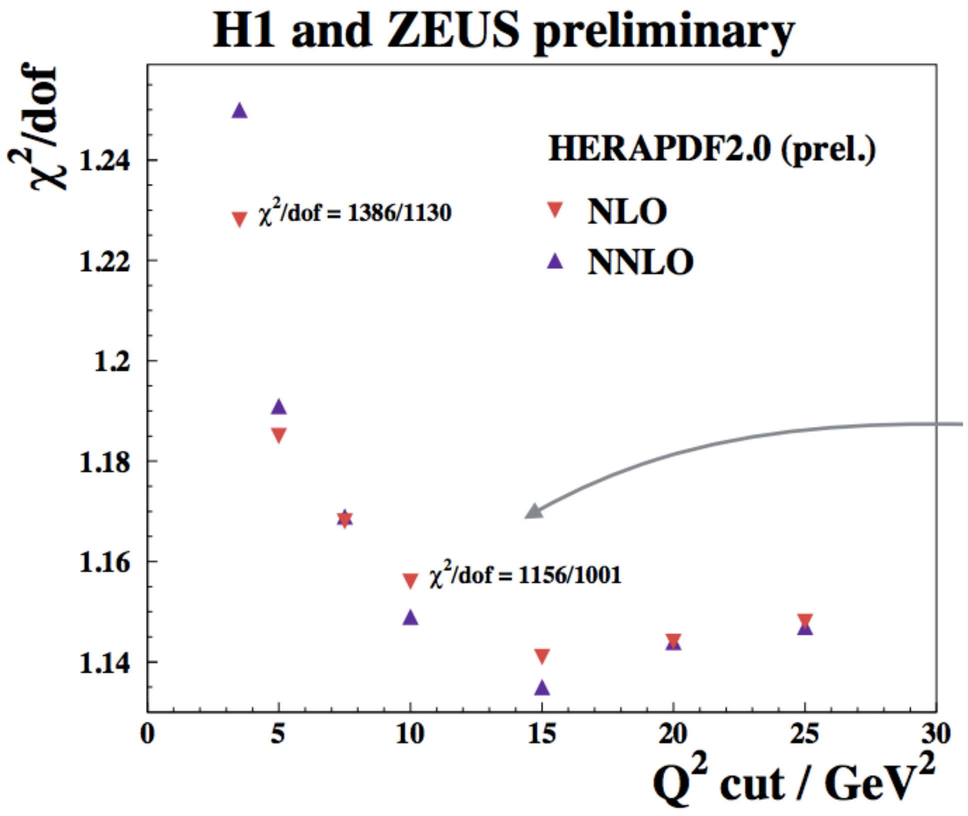
$$xf(x) = Ax^B(1-x)^C(1+Dx+Ex^2)$$

  - Q_0^2 variation dominant parametrisation uncertainty



HERAPDF2.0 and Q2 cut dependence

The Q^2 cut dependence on the fit is already included in the model variation for the HERAPDF sets, however usually we look at small range in cuts when assessing an uncertainty to Q^2_{min} choice.



- Look at larger range and effect on χ2/ndf
- For Q2min = 3.5 GeV2
  - **χ2/ndf = 1385 / 1130 at NLO**
  - **χ2/ndf = 1414 / 1130 at NNLO**
- For Q2min = 10 GeV2
  - **χ2/ndf = 1156 / 1001 at NLO**
  - **χ2/ndf = 1150 / 1001 at NNLO**
- χ2 appears to saturate for Q2min = 10 GeV2
- Similar behaviour observed for HERA-I data
  - **however, less precise data**
  - **χ2/ndf = 637 / 656 at NLO**

HERAPDF2.0 and Q2 cut dependence

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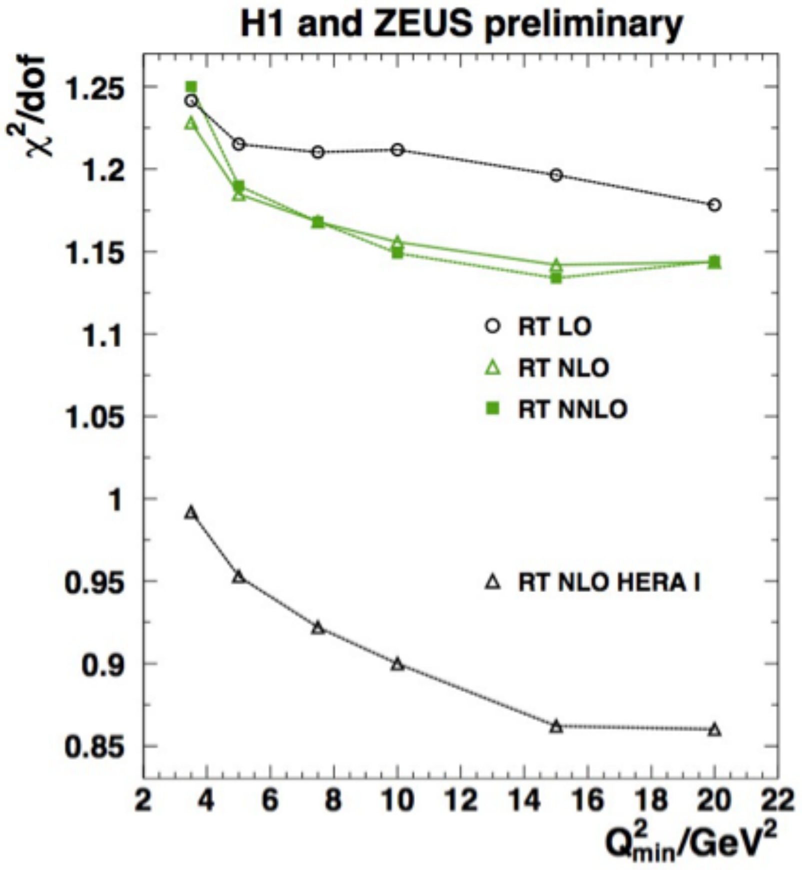
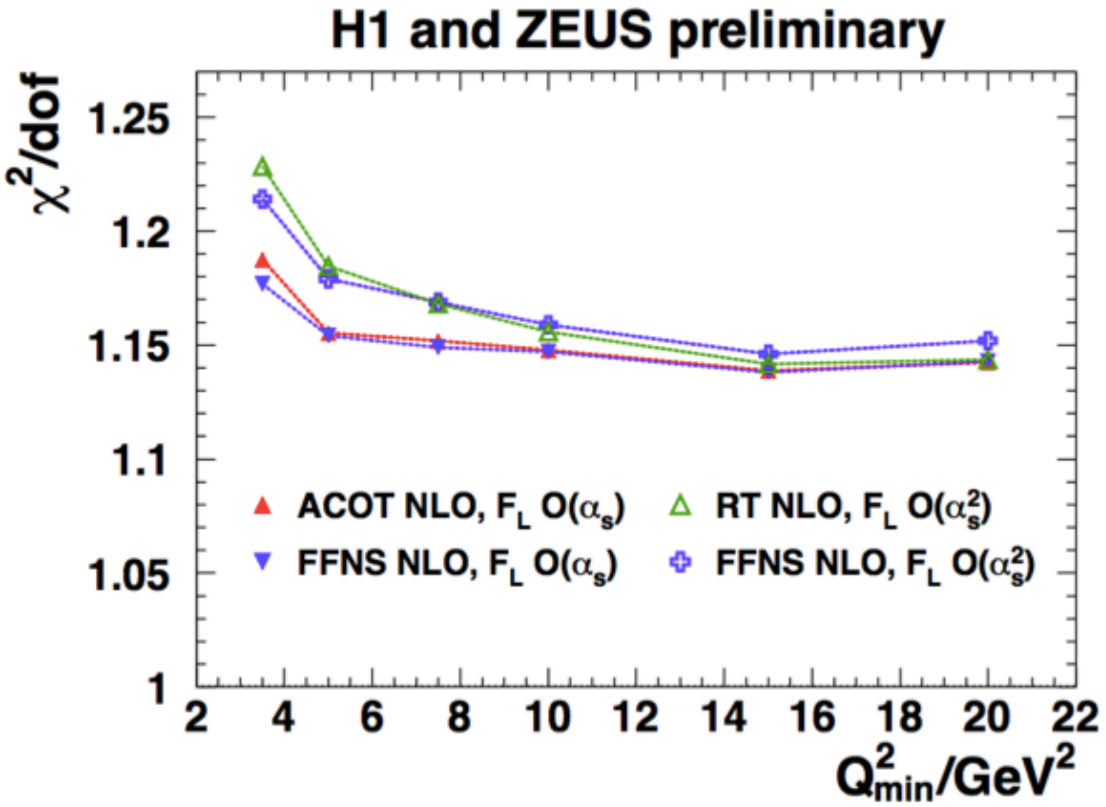




Investigation carried on:

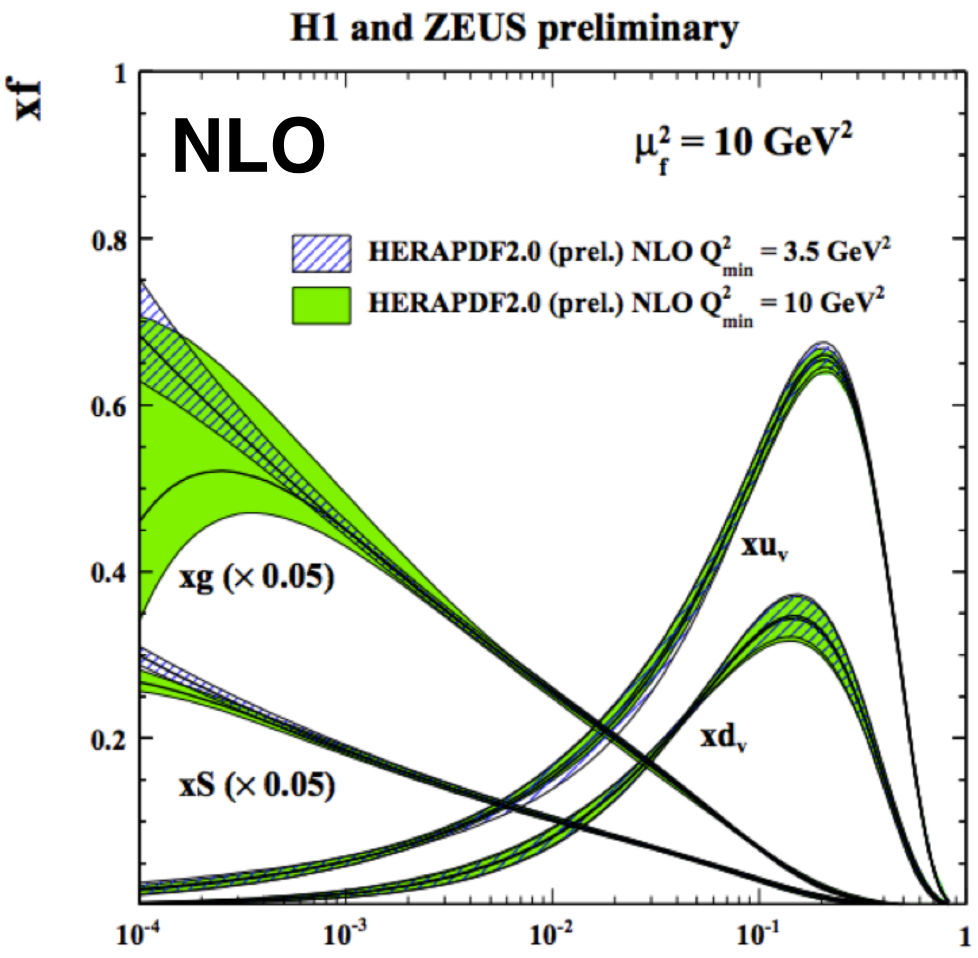
- pQCD order dependence
- heavy flavour scheme dependence

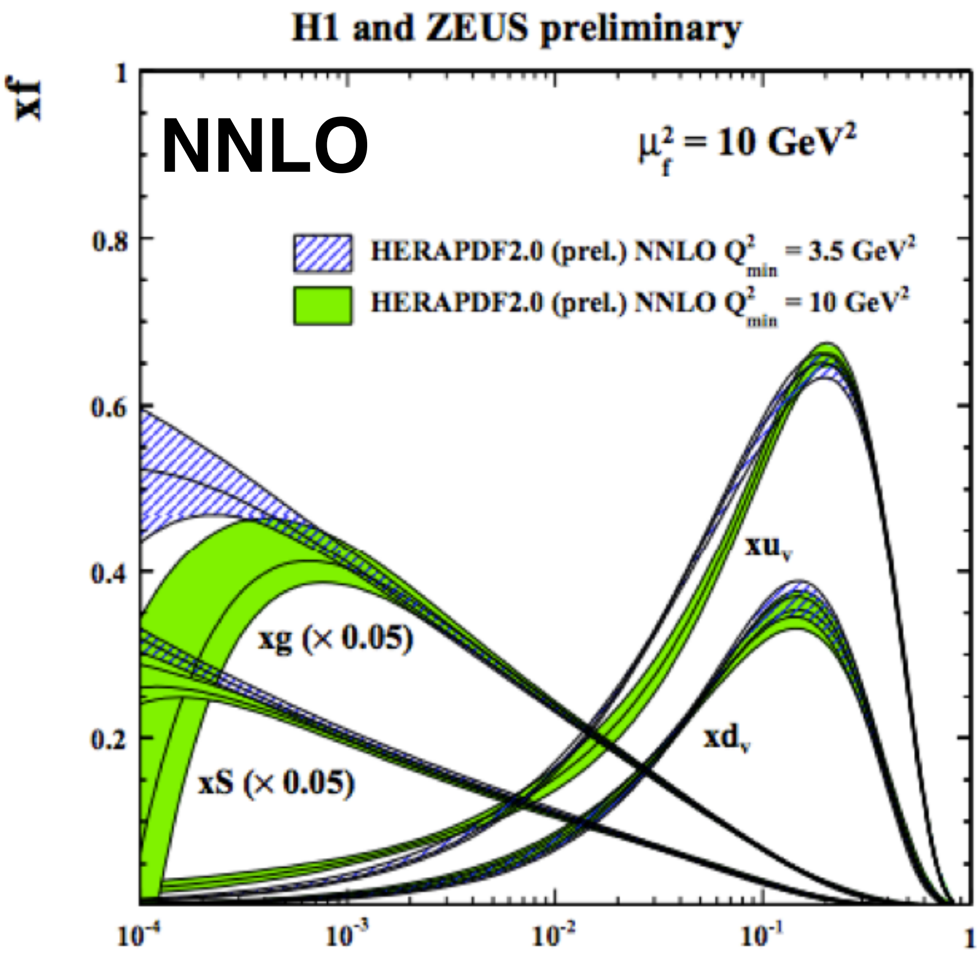
low Q2/low x remains an interesting region!

HERAPDF2.0 and Q2 cut dependence

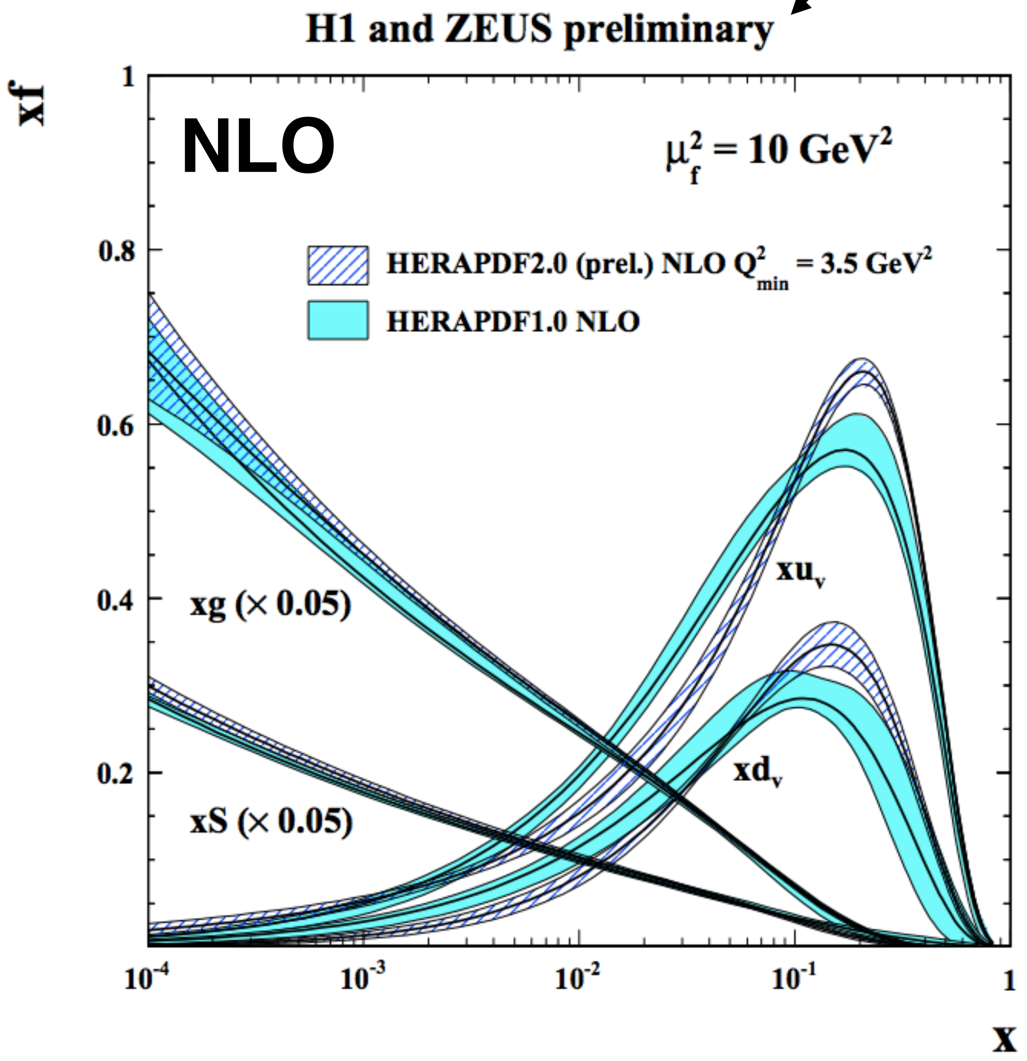
The Q^2 cut dependence on the fit is already included in the model variation for the HERAPDF sets, however usually we look at small range in cuts when assessing an uncertainty to Q^2_{min} choice.

- PDFs with Q^2 cut min @ 3.5 GeV^2 and @10 GeV^2 are shown
- uncertainties are larger for Q^2cut=10 GeV^2 (more data is cut away) and impact mostly gluon PDF

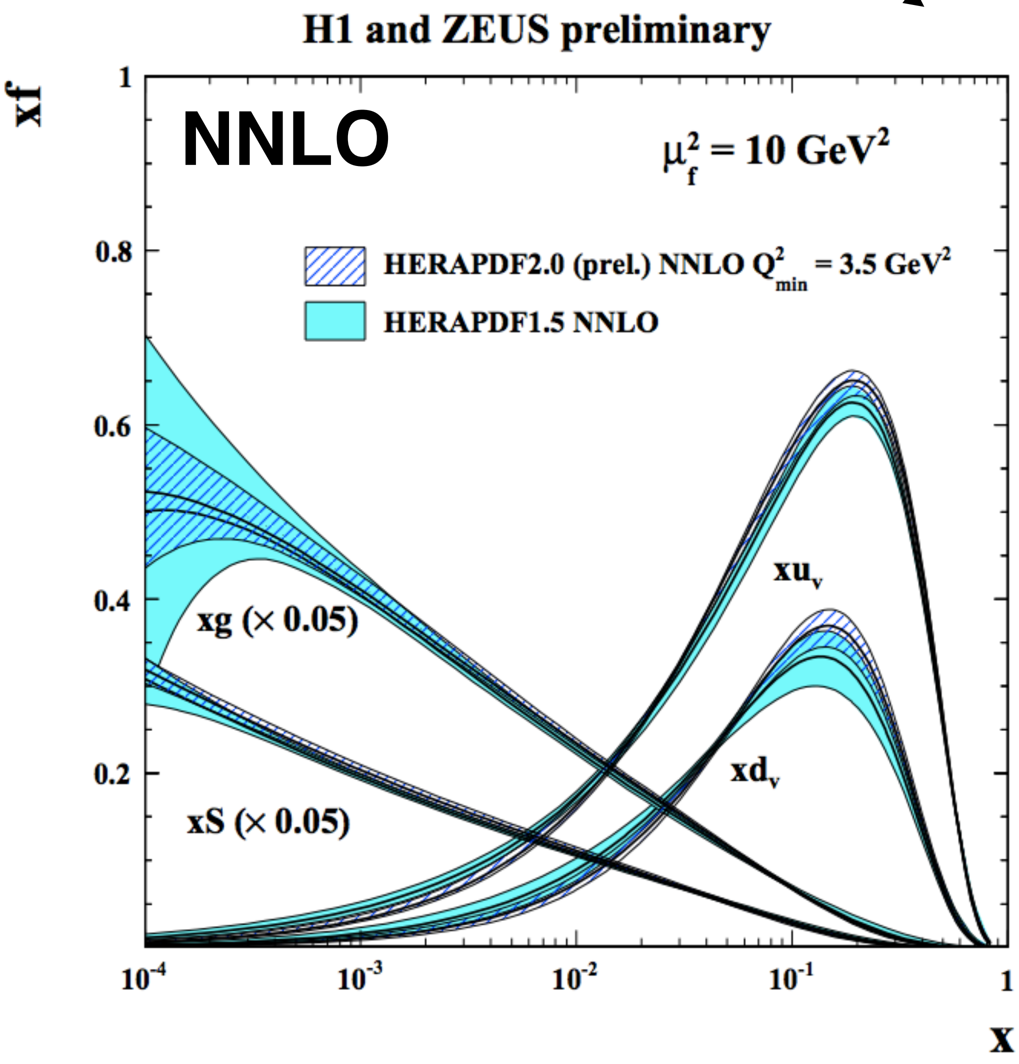




HERAPDF2.0 vs **HERAPDF1.0** and **HERAPDF1.5**



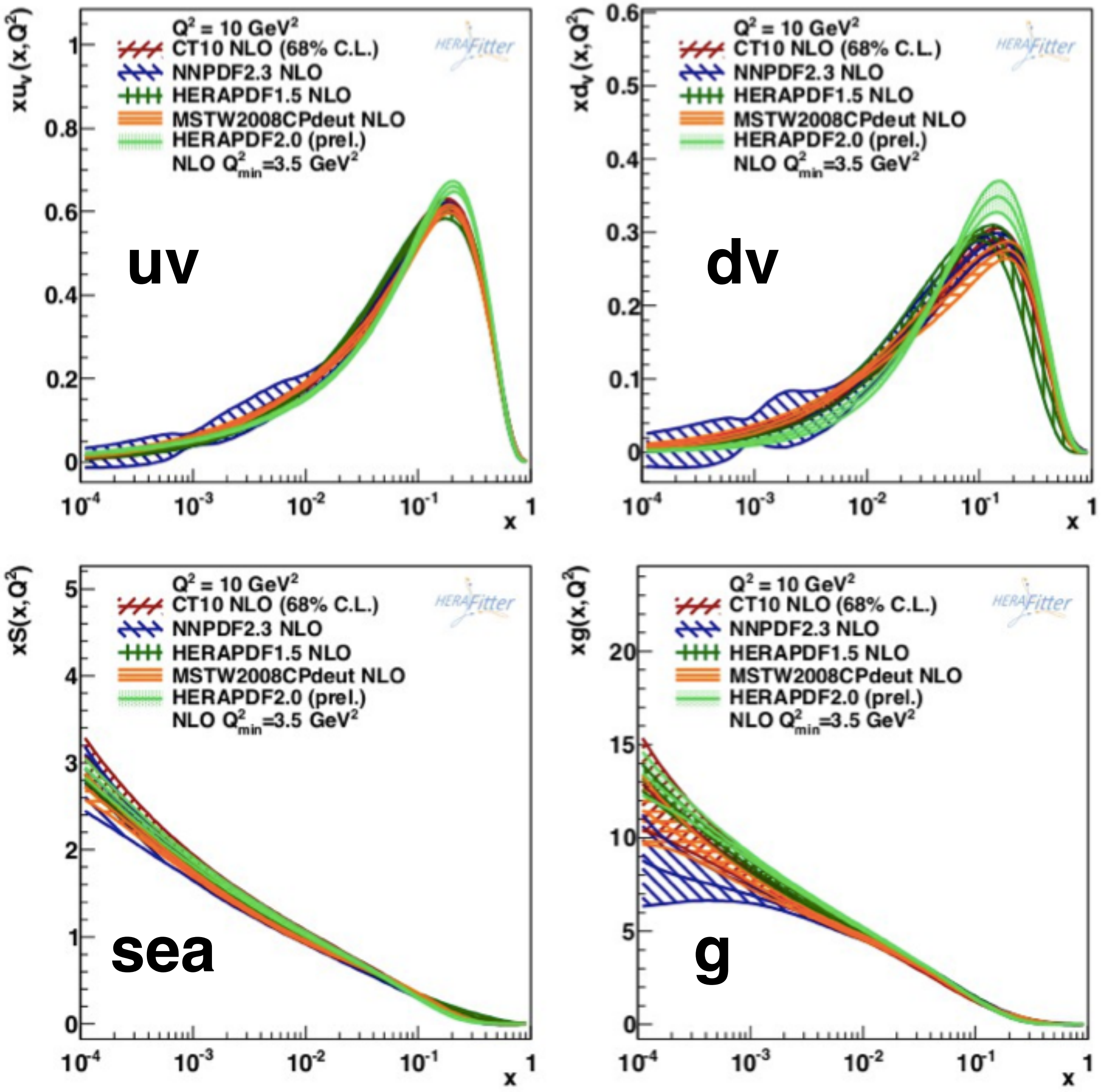
Valence PDFs most affected



Reduced gluon uncertainty

HERAPDF2.0 vs world PDFs

H1 and ZEUS preliminary NLO



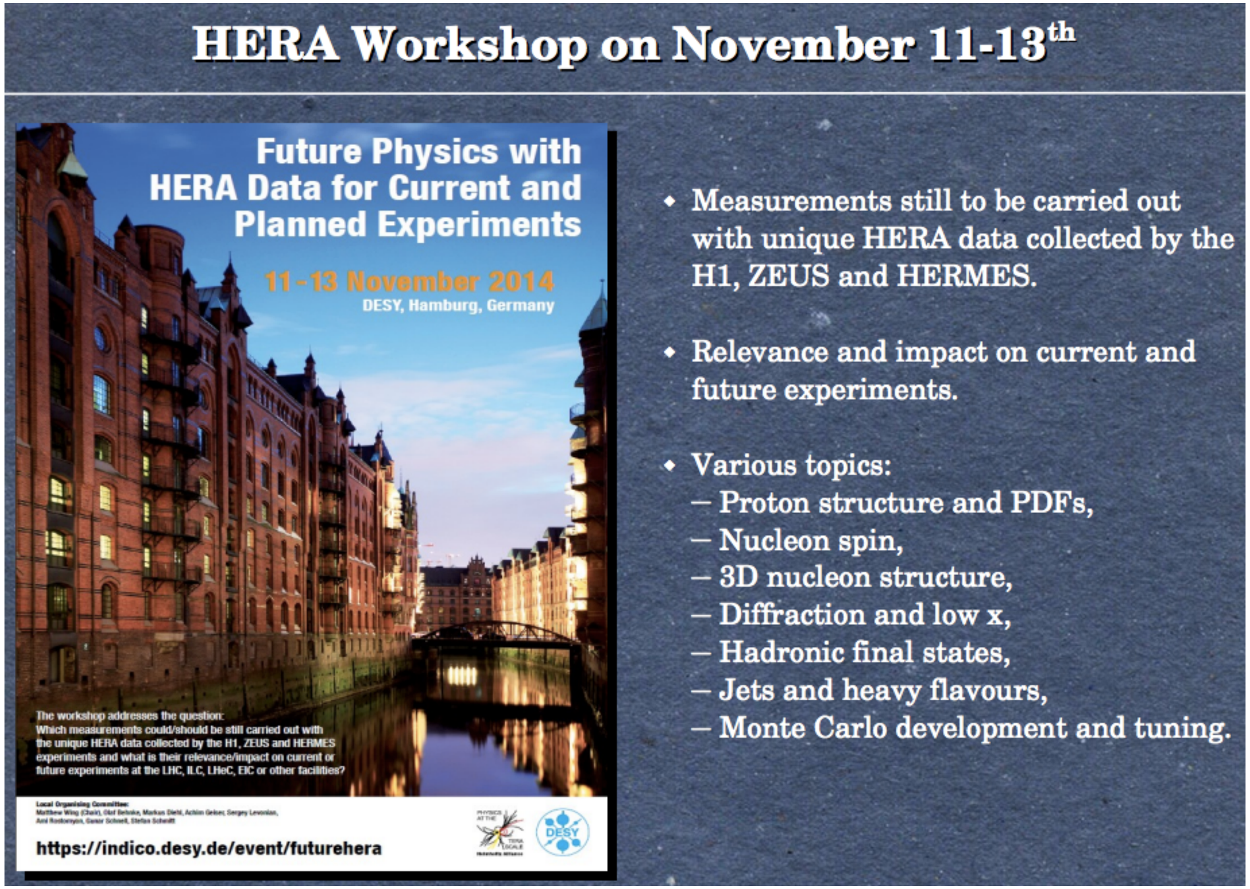
Summary

- HERA has finalised its separate measurements relevant to PDFs
- Currently in process of providing final HERA combination together with HERAPDFs, mc, mb, alphas …

Where we are now:

- data combination is finalised:
  - new sources of procedural uncertainties (minor)

- All physics discussed in the HERAPDF1.x studies are considered, especially the simultaneous extraction of alphas and PDFs from inclusive, jets and charm.



HERA Workshop on November 11-13th

Future Physics with HERA Data for Current and Planned Experiments

11 - 13 November 2014

DESY, Hamburg, Germany

The workshop addresses the question:
Which measurements could/should be still carried out with the unique HERA data collected by the H1, ZEUS and HERMES experiments and what is their relevance/impact on current or future experiments at the LHC, ILC, LHeC, EIC or other facilities?

Local Organising Committee:
Matthew Wing (Chair), Olaf Behnke, Markus Diehl, Achim Geiser, Sergey Levonian, Ami Rostomyan, Gunar Schnell, Stefan Schmitt

https://indico.desy.de/event/futurehera

- Measurements still to be carried out with unique HERA data collected by the H1, ZEUS and HERMES.
- Relevance and impact on current and future experiments.
- Various topics:
  - Proton structure and PDFs,
  - Nucleon spin,
  - 3D nucleon structure,
  - Diffraction and low x,
  - Hadronic final states,
  - Jets and heavy flavours,
  - Monte Carlo development and tuning.

Final results coming soon, stay tuned …

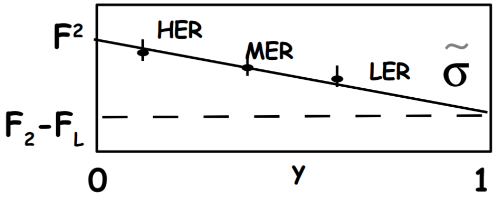
Longitudinal Structure Function

Longitudinal structure function FL is a pure QCD effect:

—> an independent way to probe sensitivity to gluon

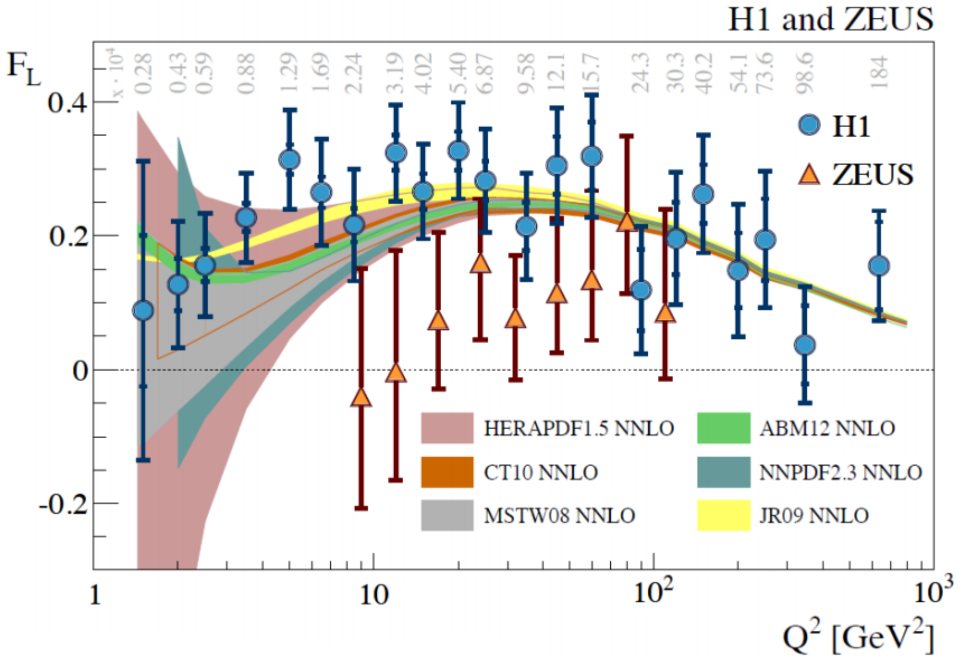
$$F_L = \frac{\alpha_s}{4\pi} x^2 \int_x^1 \frac{dz}{z^3}\left[\frac{16}{3}\underbrace{F_2}_{\text{quarks radiating a gluon}} + 8\sum_q \underbrace{e_q^2\left(1-\frac{x}{z}\right)zg(z)}_{\text{gluons splitting into quarks}}\right]$$

Direct measurement of FL at HERA required differential cross sections at same x and Q^2 but different y —> different beam energies: Ep= 460, 575, 920 GeV

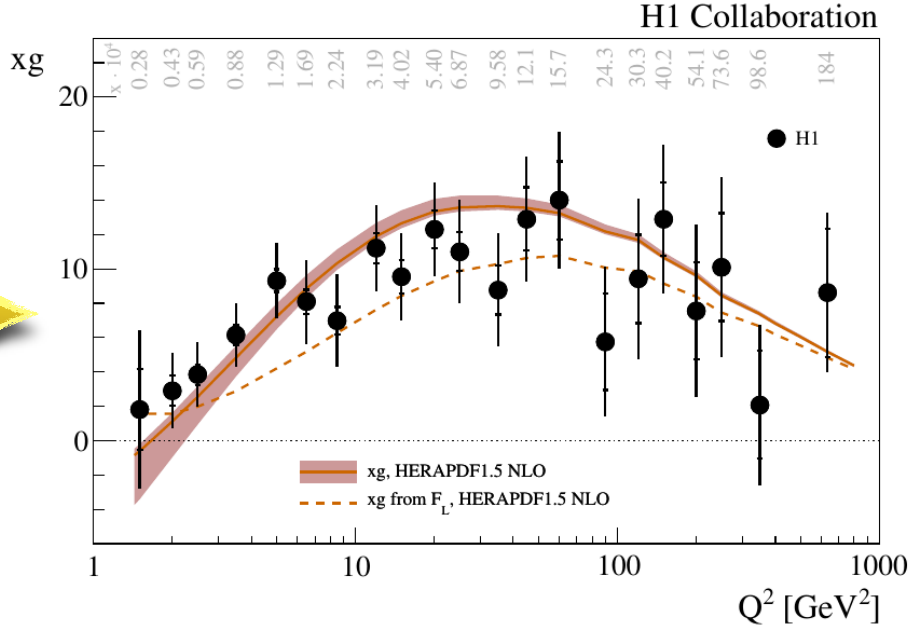


$$\sigma_{NC}(x,Q^2,y) \propto F_2(x,Q^2) - \frac{y^2}{1+(1-y)^2}F_L(x,Q^2)$$

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



Consistency of H1 and ZEUS FL was checked accounting for corr. unc: χ2/ndf = 11/8 (p-value = 20%)



Eur. Phys. J. C 74 (2014) 2814 [arXiv:1312.4821]

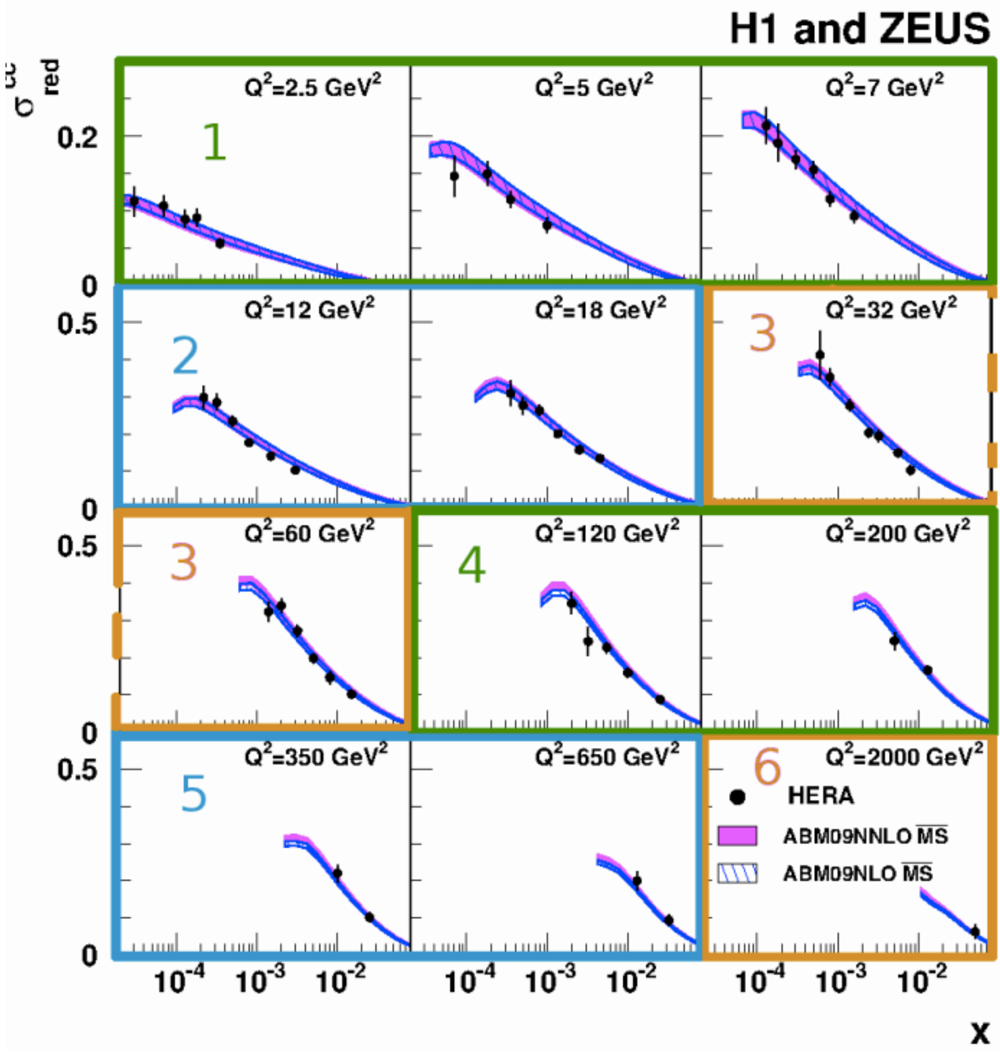
DESY-14-053, submitted to Phys. Lett. B [arXiv:1404.6376]

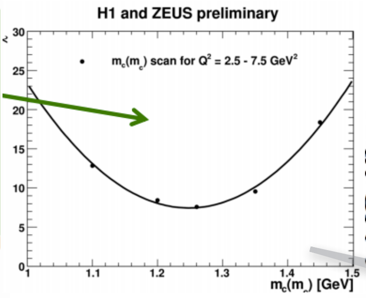
New Measurement of Charm Mass Running

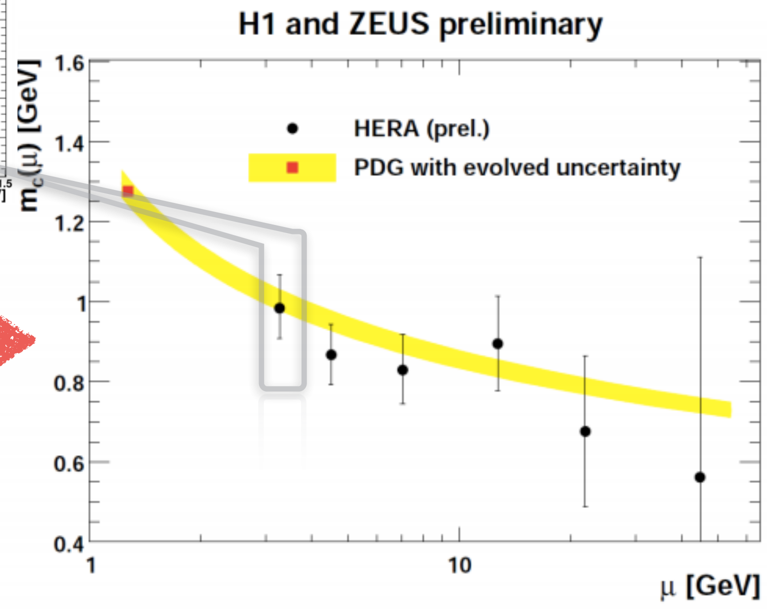
H1-prelim-14-071 ZEUS-prel-14-006 and S. Moch

The running of the charm mass in the $\overline{\text{MS}}$ scheme is measured for the first time from the same HERA combined charm data:

- Extract $m_c(m_c)$ in 6 separate kinematic regions
- Translate back to $m_c(\mu)$ [with $\mu=\sqrt{Q^2+4m_c^2}$] using OpenQCDrad [S.Alekhin's code].





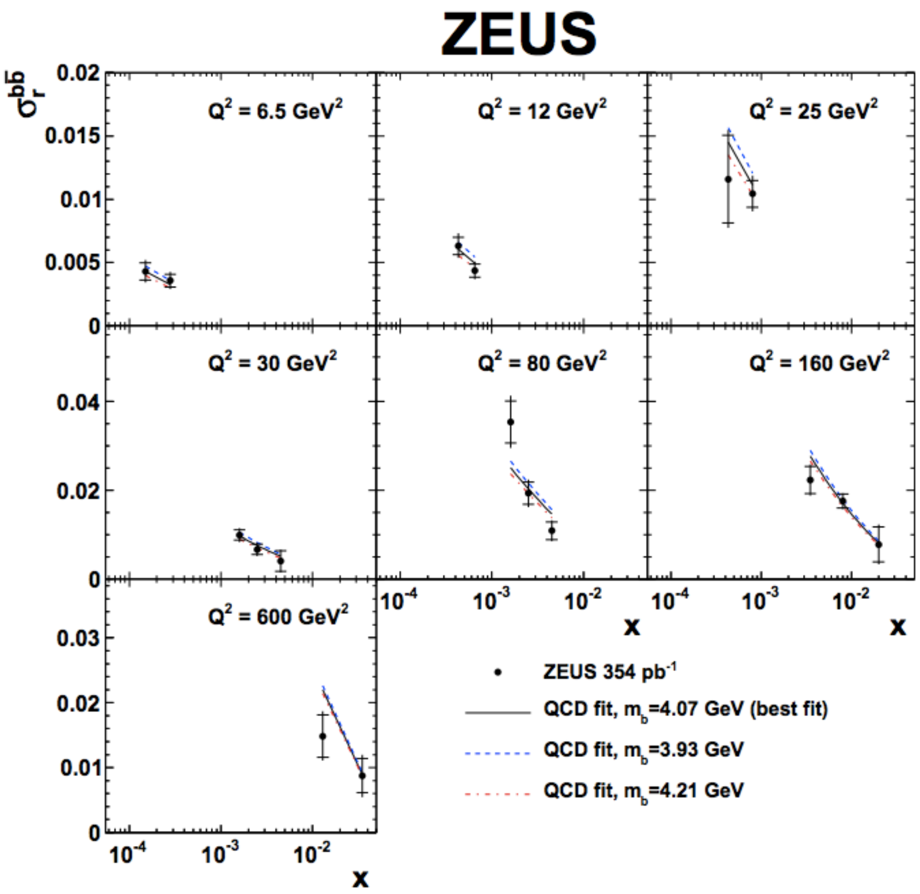


The scale dependence of the mass is consistent with QCD expectations

Running beauty mass $m_b(m_b)$ from F2 beauty

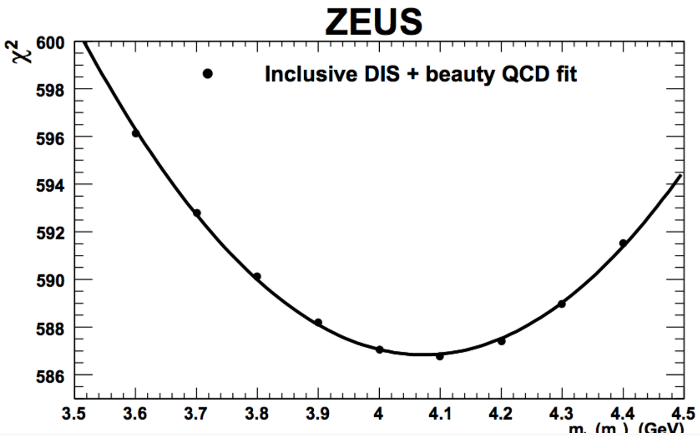
DESY-14-083 arXiv:1405.6915

- The value of the running beauty mass is obtained in a similar manner as for $m_c(m_c)$:
  - chi2 scan method from QCD fits in FFN scheme to the combined HERA I inclusive data + beauty measurements, beauty-quark mass is defined in the $\overline{\text{MS}}$ scheme.



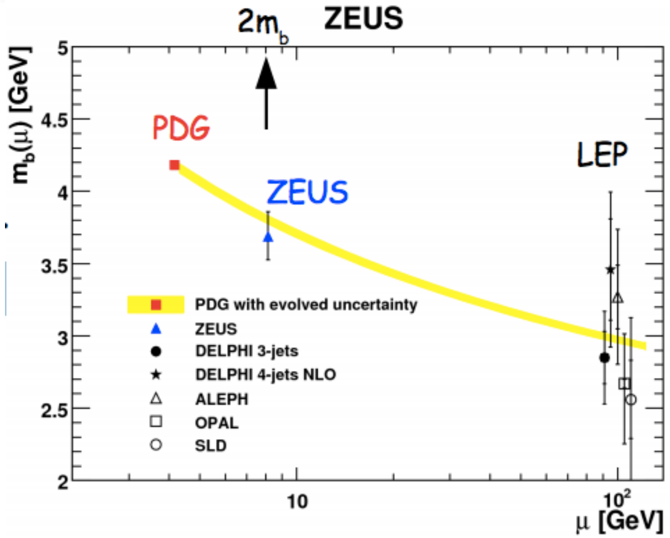
QCD Fits

HERA I+beauty



$$m_b(m_b) = 4.07 \pm 0.14\,(\text{fit})^{+0.01}_{-0.07}\,(\text{mod.})^{+0.05}_{-0.00}\,(\text{param.})^{+0.08}_{-0.05}\,(\text{theo.})\,\text{GeV}$$

$$m_b(m_b) \ = \ (4.18 \pm 0.03)\,\text{GeV}$$ —>PDG2012



The extracted $\overline{\text{MS}}$ beauty-quark mass is in agreement with PDG average and LEP results.

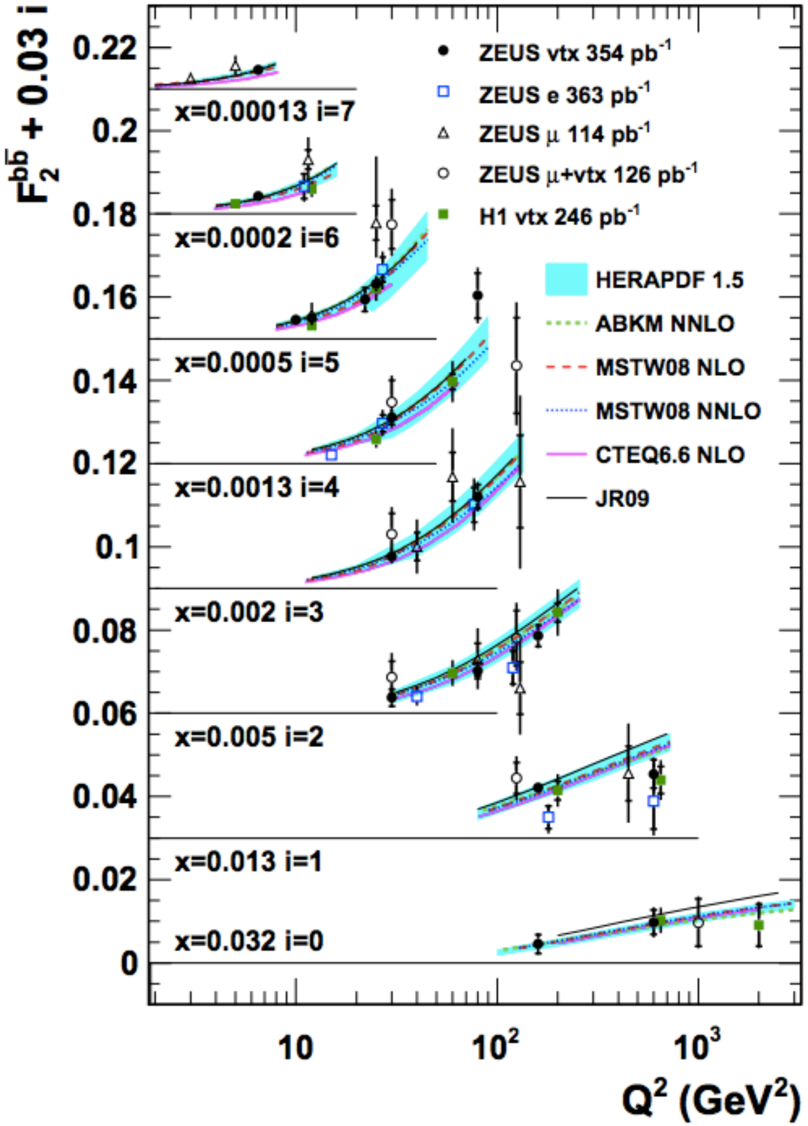
Extra Material

not necessarily useful

New Beauty in DIS from LifeTime-Tagging

DESY-14-083 arXiv:1405.6915

- Inclusive jet cross sections in beauty and charm events are used to:
  - **The good agreement of the data and NLO calculations in the visible phase (given by the heavy quark tagging) allow to extrapolate to the full phase space and to measure F2bb (and identical F2cc) :**



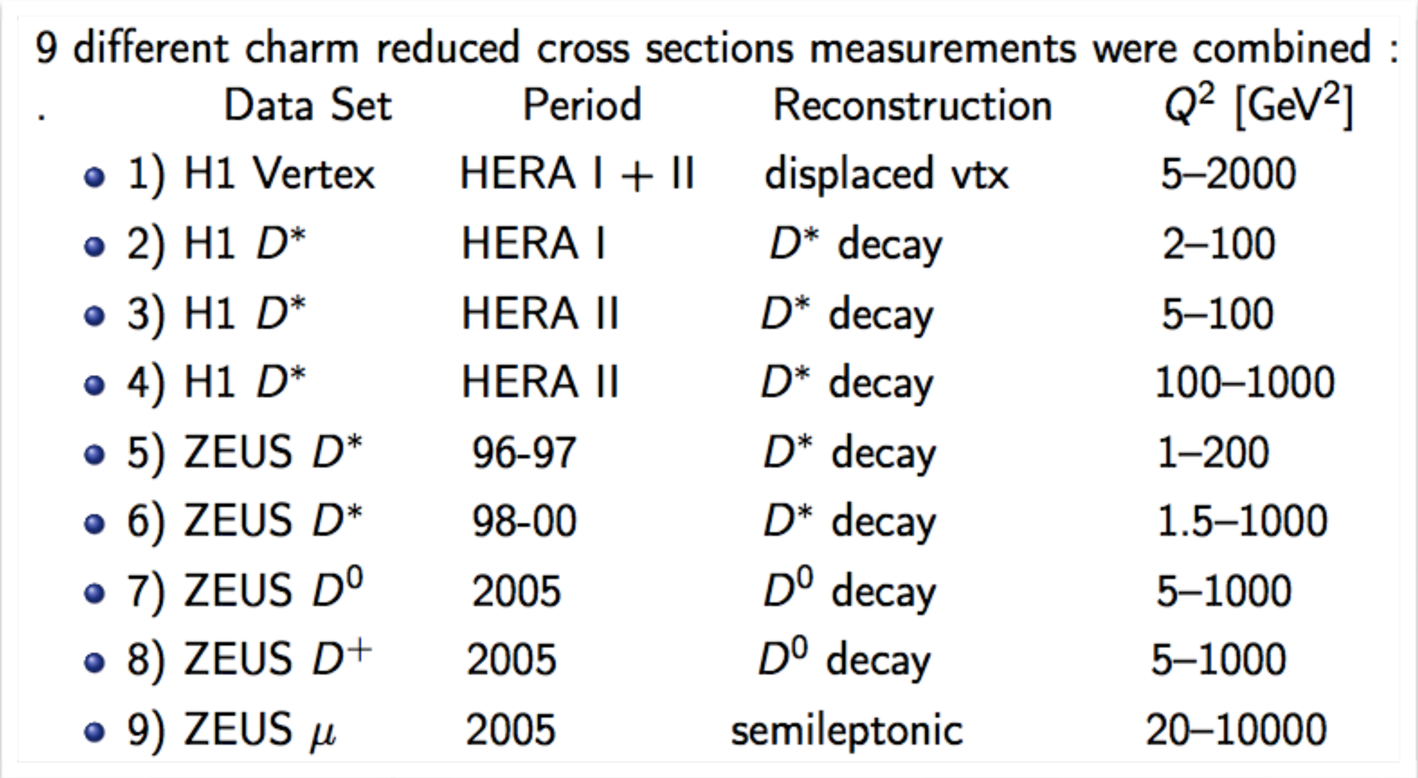
$$\frac{d\sigma^{b\bar{b}}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\cdot[(1+(1-y)^2)\cdot F_2^{b\bar{b}} - y^2\cdot F_L^{b\bar{b}}]$$

- The new measurement is the most precise determination of F_2b from ZEUS
- Data are in good agreement and well described by fixed-order (massive) and variable-flavour (mixed) NLO and NNLO QCD calculations

HERA Charm Data Combination

EPJC 73 (2013) 2311

- Best precision achieved when measurements are combined:
  - **Charm Data Combination: chi2/ndof = 62/103**
    - **155 data points from 9 different measurements of H1 and ZEUS were combined into 52 points**
    - **efforts in accounting for correlations of systematic uncertainties between data sets**



9 different charm reduced cross sections measurements were combined :

Data Set	Period	Reconstruction	Q^2 [GeV^2]
1) H1 Vertex	HERA I + II	displaced vtx	5–2000
2) H1 D^*	HERA I	D^* decay	2–100
3) H1 D^*	HERA II	D^* decay	5–100
4) H1 D^*	HERA II	D^* decay	100–1000
5) ZEUS D^*	96-97	D^* decay	1–200
6) ZEUS D^*	98-00	D^* decay	1.5–1000
7) ZEUS D^0	2005	D^0 decay	5–1000
8) ZEUS D^+	2005	D^0 decay	5–1000
9) ZEUS μ	2005	semileptonic	20–10000

- Data combination is performed at the reduced charm cross sections level (as in DIS):
  - **they are obtained from xsec in visible phase space and extrapolated to full space**

$$\frac{d^2\sigma^{c\bar{c}}}{dx\,dQ^2} = \frac{2\pi\alpha_{em}^2}{xQ^4} Y_+ \sigma_{red}^{c\bar{c}}(x,Q^2,s)$$

$$\sigma_{red}^{c\bar{c}}(x,Q^2,s) = F_2^{c\bar{c}}(x,Q^2) - \frac{y^2}{Y_+} F_L^{c\bar{c}}(x,Q^2)$$

$$\sigma_{red}^{c\bar{c}}(x,Q^2) = \left(\sigma_{vis} - \sigma_{vis}^{beauty}\right)\left(\frac{\sigma_{red,HVQDIS}^{c\bar{c}}}{\sigma_{vis,HVQDIS}}\right)$$

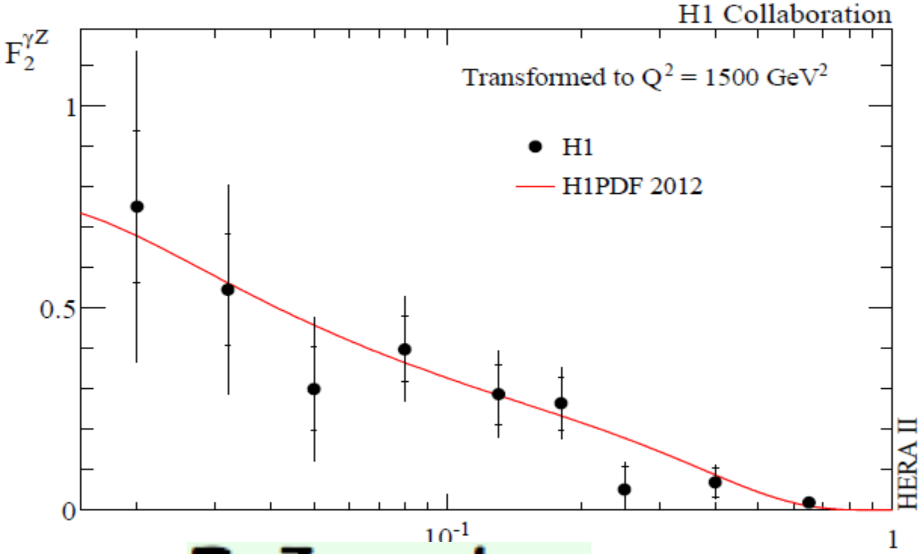
Measurements of Asymmetries from HERA

- Explore polarisation asymmetry to extract $F_2^{\gamma Z}$
- Explore charge asymmetry to extract $xF_3^{\gamma Z}$ (improved measurement from HERA I+II)

$$\tilde{F}_2^{\pm} \approx F_2 - (v_e \pm P_e a_e)\kappa \frac{Q^2}{Q^2 + M_Z^2} F_2^{\gamma Z}$$

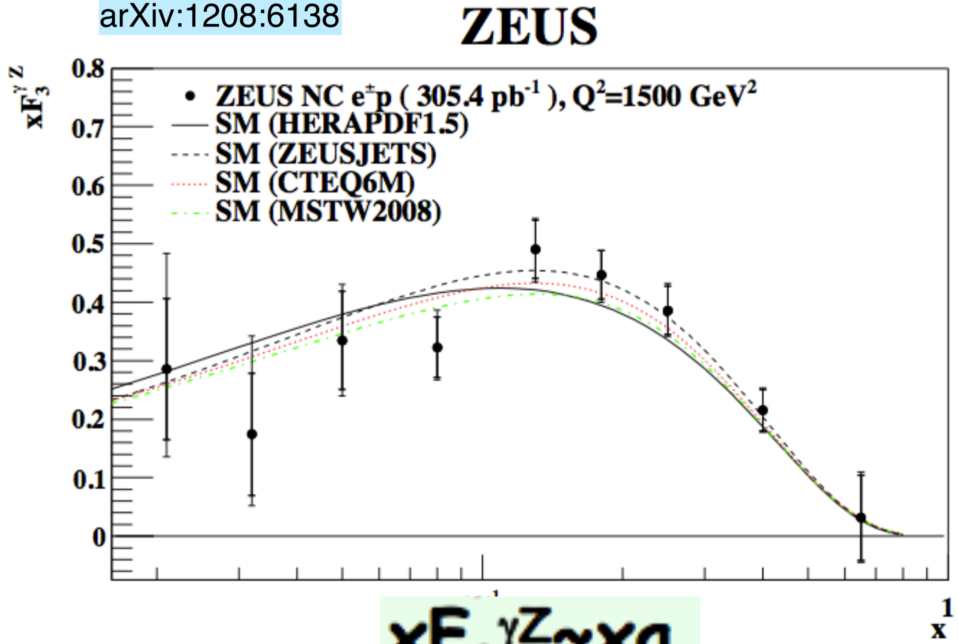
$$\sigma_r^{\pm} = \tilde{F}_2^{\pm} \mp \frac{1-(1-y)^2}{1+(1+y)^2} x\tilde{F}_3 - \frac{y^2}{1+(1-y)^2} \tilde{F}_L$$

JHEP 1209:061 (2012)



$F_2^{\gamma Z}$~q+qbar

arXiv:1208:6138



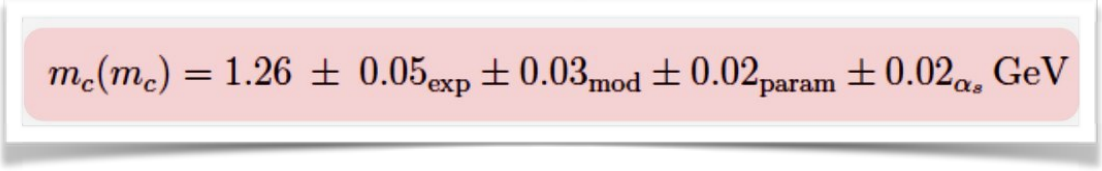
$xF_3^{\gamma Z}$~xq_v

The shape of the distribution reflects their parton sensitivity

Running charm mass $m_c(m_c)$

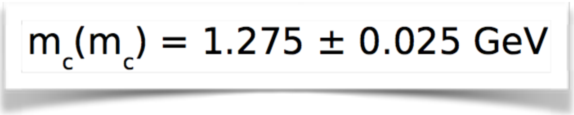
EPJC 73 (2013) 2311

- Charm combination can also be used in a NLO QCD analysis in FFN scheme to determine the running of charm-quark mass mc(mc) in MS:

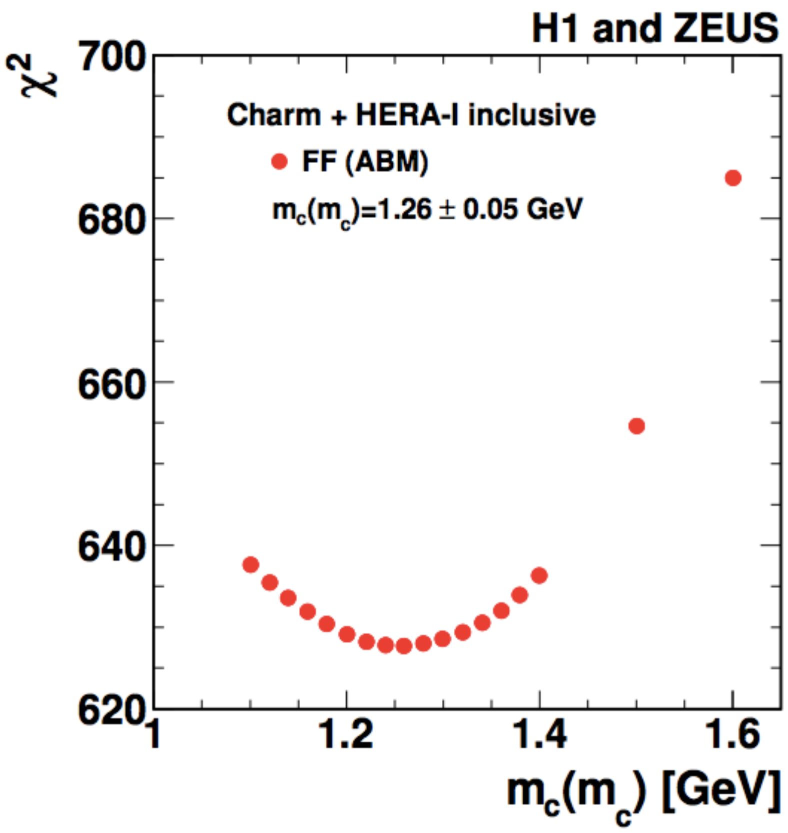


$$m_c(m_c) = 1.26 \pm 0.05_{\mathrm{exp}} \pm 0.03_{\mathrm{mod}} \pm 0.02_{\mathrm{param}} \pm 0.02_{\alpha_s}\ \mathrm{GeV}$$

  - **which is in agreement with the world average extraction:**



$$m_c(m_c) = 1.275 \pm 0.025\ \mathrm{GeV}$$



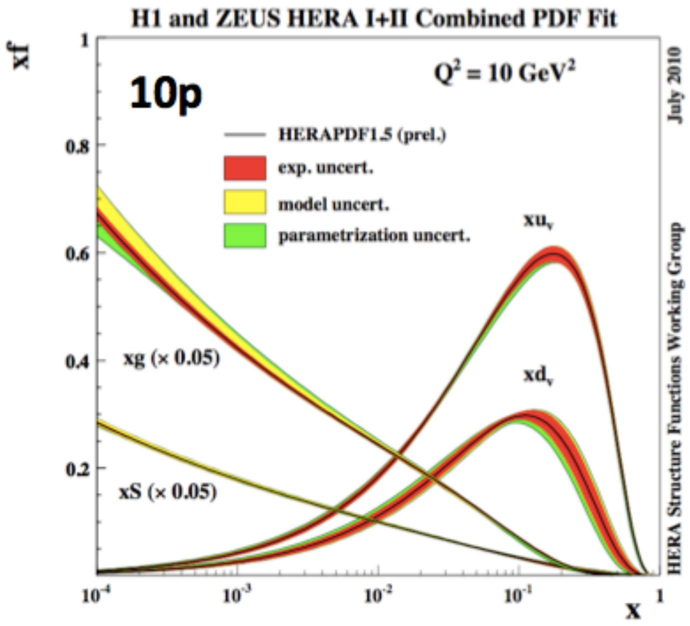
- This has triggered the question:

—> how about measuring the running of m_c?

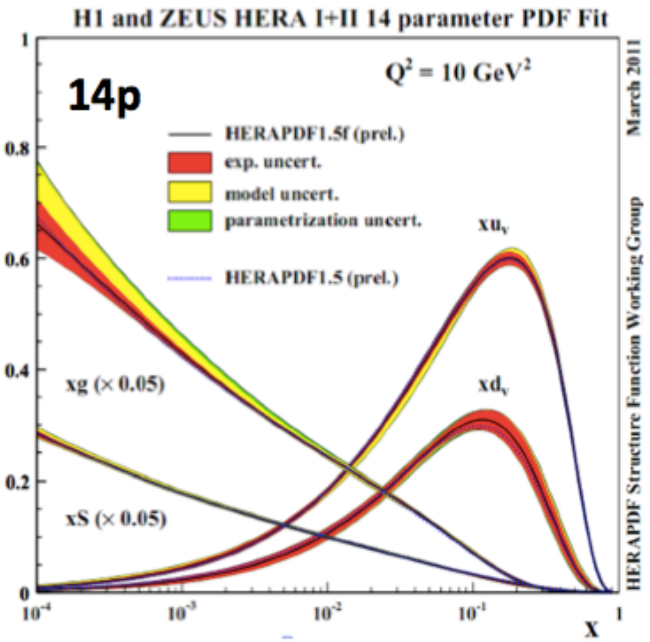
Extraction of PDFs through QCD fits

Review of HERAPDF sets:

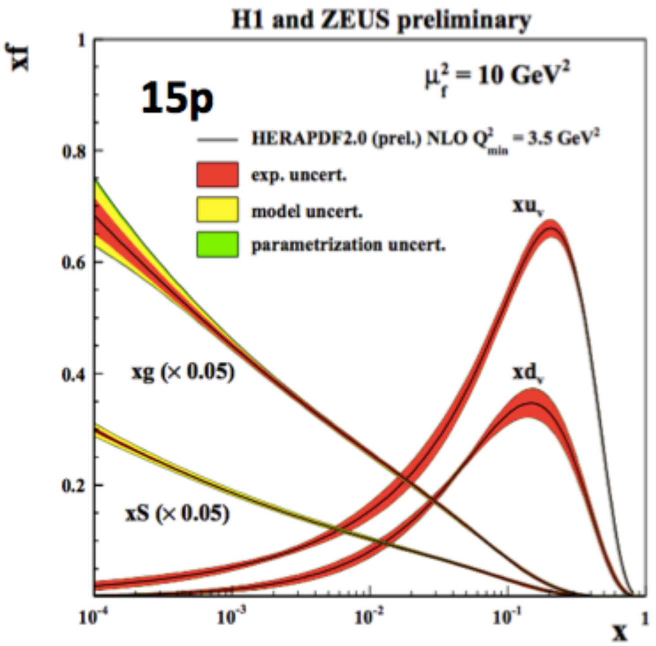
HERAPDF1.5-NLO(10p) → HERAPDF1.5-NLOf(14p) → HERAPDF2.0-NLO (15p)



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)