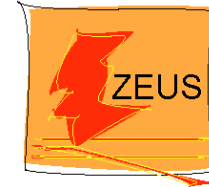


Combination and QCD Analysis of the HERA Inclusive Cross Sections



Voica A. Radescu
(Physikalisches Institut Heidelberg)



on behalf of the HI and ZEUS Collaborations
ICHEP 2010, Paris



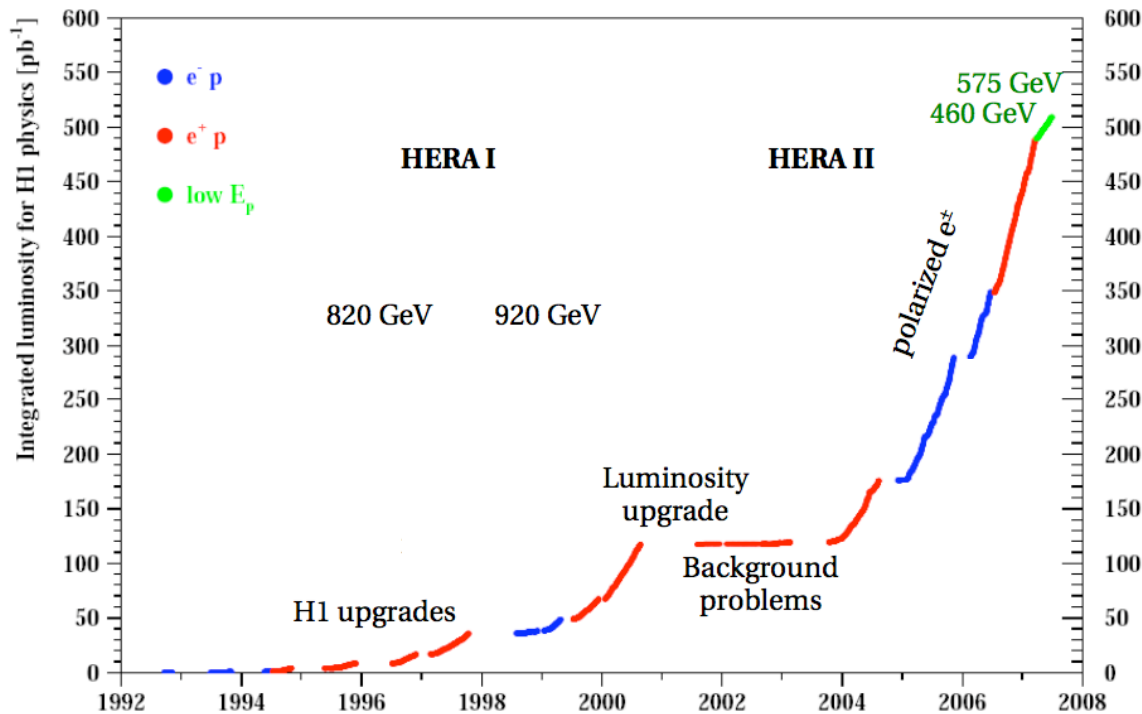
Outline:

- HI and ZEUS at the HERA collider
- Data Combination
- QCD Analysis
- Results and Comparisons
- Summary



HERA at DESY

- HERA is world's only e^+p collider
 - located at DESY, Hamburg - Germany
 - In operation for 15 years (1992-2007)
 - H1 and ZEUS collider experiments
 - ▽ General purpose detectors



HERA-I	1992-2000	$E_p=820,920$ GeV
HERA-II	2003-2007	$E_p=920,$ $460,575$ GeV

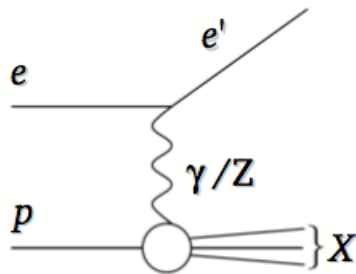
Registered $\sim 1\text{fb}^{-1}$ of integrated luminosity of physics data.



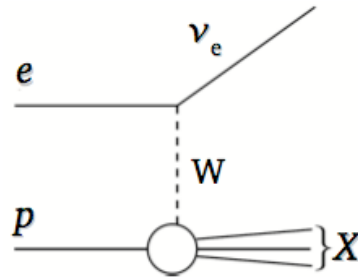
HI and ZEUS kinematics

- HERA provides unique opportunity to study the structure of proton:

NC: $ep \rightarrow e'X$



CC: $ep \rightarrow \nu_e X$



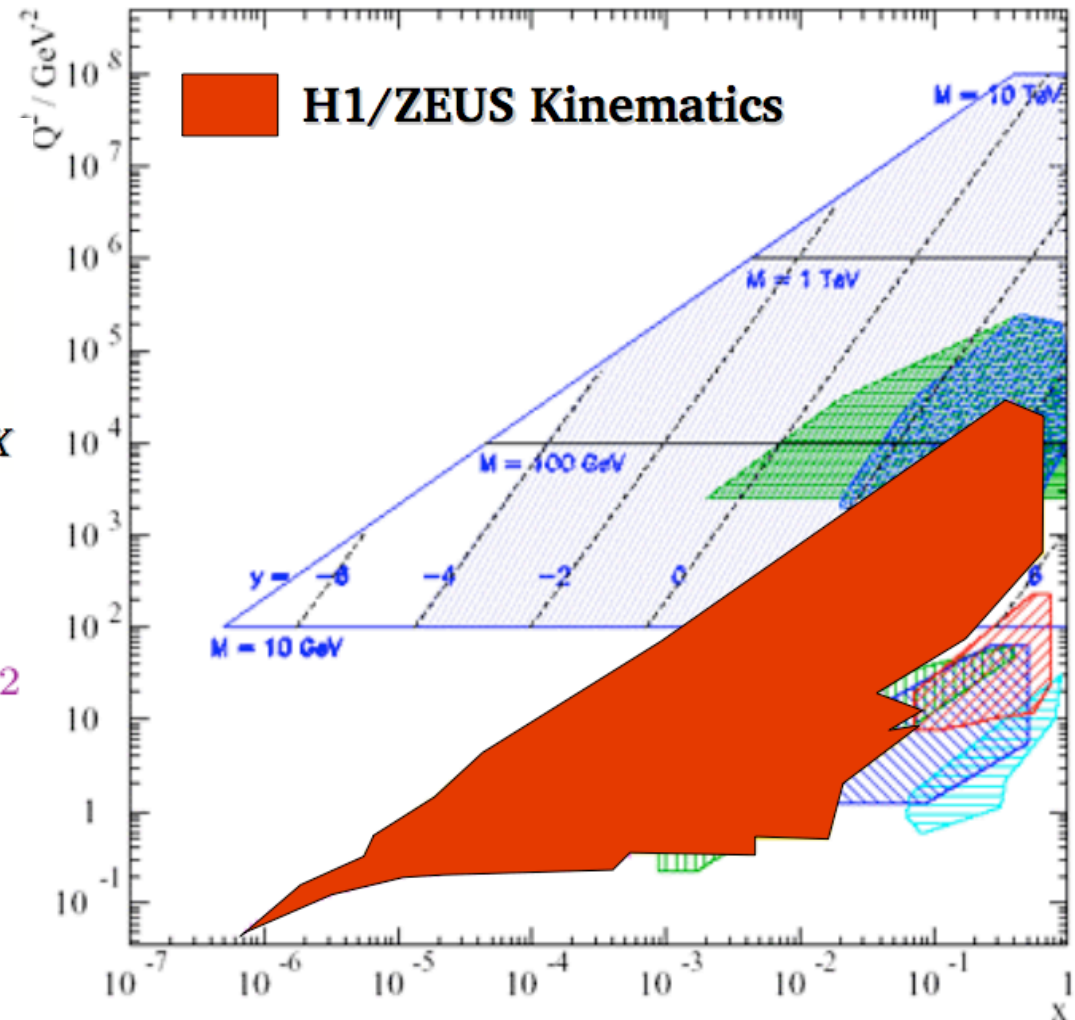
- Kinematic variables:

- Virtuality of exchanged boson:

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

- Bjorken scaling variable:

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



HI and ZEUS kinematics span over 6 orders of magnitude in x and Q^2 !



Combination of the H1 and ZEUS Measurements

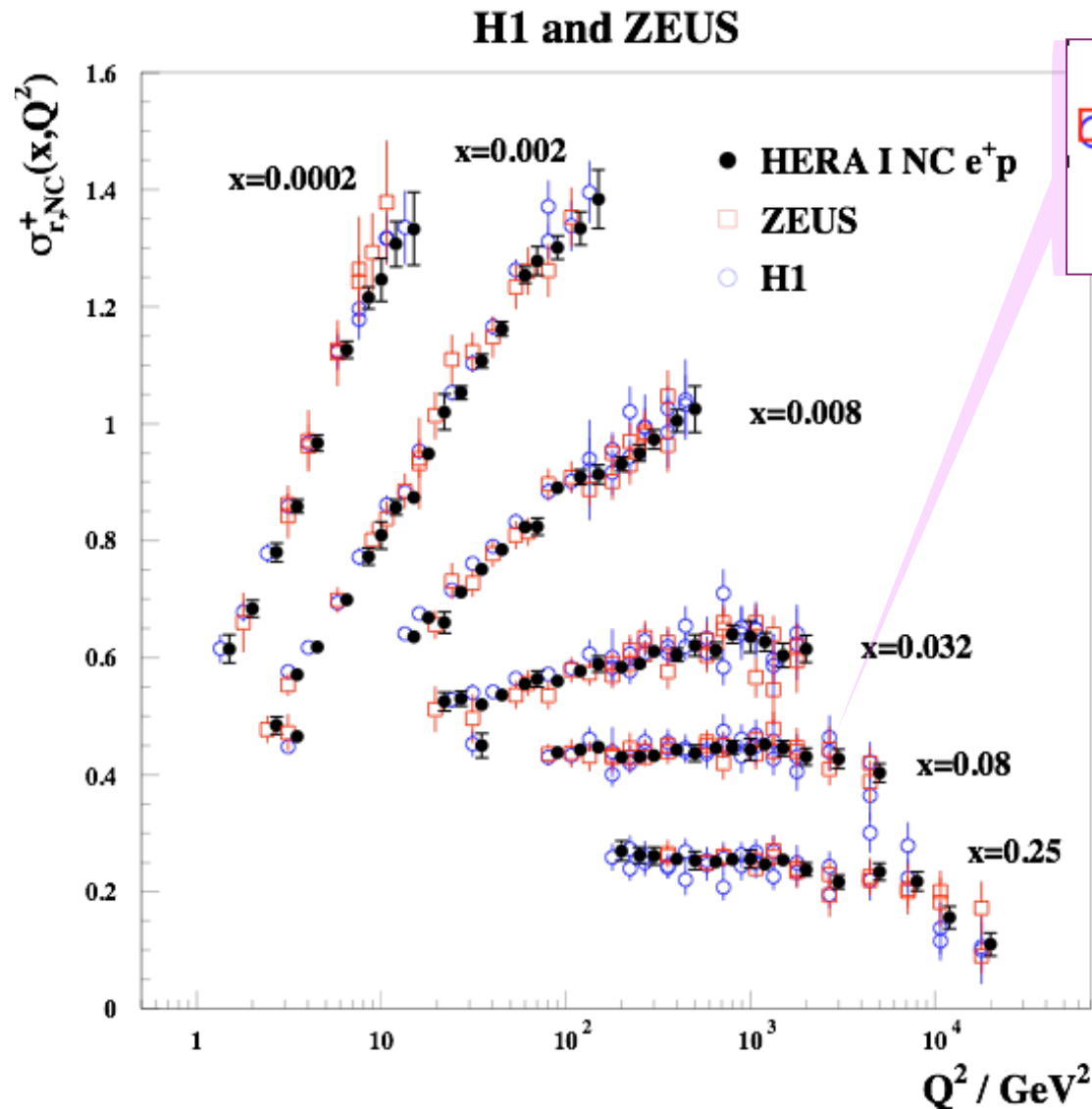
[JHEP01 (2010) 109]

- Ultimate precision is obtained by combining the H1 and ZEUS measurements
- The combination procedure is performed before QCD analysis:
 - The combination of data is performed using the χ^2 minimisation procedure
 - 1402 of HERA I H1 and ZEUS measurements were combined into 741 unique cross section points with 113 correlated systematic sources.
 - Improvement on Statistical precision:
 - H1 and ZEUS collected similar amounts of physics data.
 - Improvement of Systematic precision:
 - H1 and ZEUS are different detectors and use different analysis techniques;
 - The H1 and ZEUS cross sections have different sensitivities to similar sources of correlated systematic uncertainty.



Results of Combining H1 and ZEUS Data

[JHEP01 (2010) 109]



The combination procedure yields a consistent data set:

- $\chi^2/\text{dof}=637/656$
- Before combination, the systematic errors are ~ 3 times larger than statistical for $Q^2 < 100 \text{ GeV}^2$
- After combination, the systematic errors are of same precision as the statistical errors, reaching 1% total precision!



QCD Analysis Framework

- Data Sets:

- HERA I combined data [JHEP01 (2010) 109]
 - ▽ NC e⁻, CC e⁻, CC e⁺ (Q²>100 GeV²)
 - ▽ NC e⁺ (Q²>0.045 GeV²)
- Combined HERA II Low Energy Data Set of E_p=460, 575 GeV [prelim.]
 - ▽ Q²>2.5 GeV²
- Combined HERA I+high Q² HERA II data [prelim.]

- QCD Fit settings:

- NLO (and NNLO) DGLAP evolution equations
- RT-VFNS (as for MSTW08)
 - ▽ Other schemes were investigated as well:
RT (optimal), ACOT (full and χ), FFNS
- PDF parametrised at the starting scale Q₀²:

$$\mathbf{G}, \mathbf{u}_{\text{val}}, \mathbf{d}_{\text{val}}, \bar{\mathbf{U}} = \bar{\mathbf{u}}(+\bar{\mathbf{c}}), \bar{\mathbf{D}} = \bar{\mathbf{d}} + \bar{\mathbf{s}}(+\bar{\mathbf{b}})$$

$$xf(x, Q_0^2) = Ax^B(1-x)^C(1+Dx+Ex^2)$$

- Apply quark number and momentum sum rules
- The optimum number of parameters chosen by saturation of the χ^2
 - central fit with 10 free parameters
 - $\chi^2/\text{dof}=574/582$

Scheme	TRVFNS
Evolution	QCDNUM17.02
Order	NLO
Q ₀ ²	1.9 GeV ²
f _s = s/D	0.31
Renorm. scale	Q ²
Factor. scale	Q ²
Q _{min} ²	3.5 GeV ²
$\alpha_S(M_Z)$	0.1176
M _c	1.4 GeV
M _b	4.75 GeV



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Sources of PDF uncertainties at HERA

- **Experimental Uncertainties:**

- Consistent data sets → use $\Delta\chi^2 = 1$

- **Model Uncertainties:**

- following variations have been considered

Variation	Standard Value	Lower Limit	Upper Limit
f_s	0.31	0.23	0.38
m_c [GeV]	1.4	1.35	1.65
m_b [GeV]	4.75	4.3	5.0
Q_{min}^2 [GeV ²]	3.5	2.5	5.0

- **Parametrisation Uncertainties:**

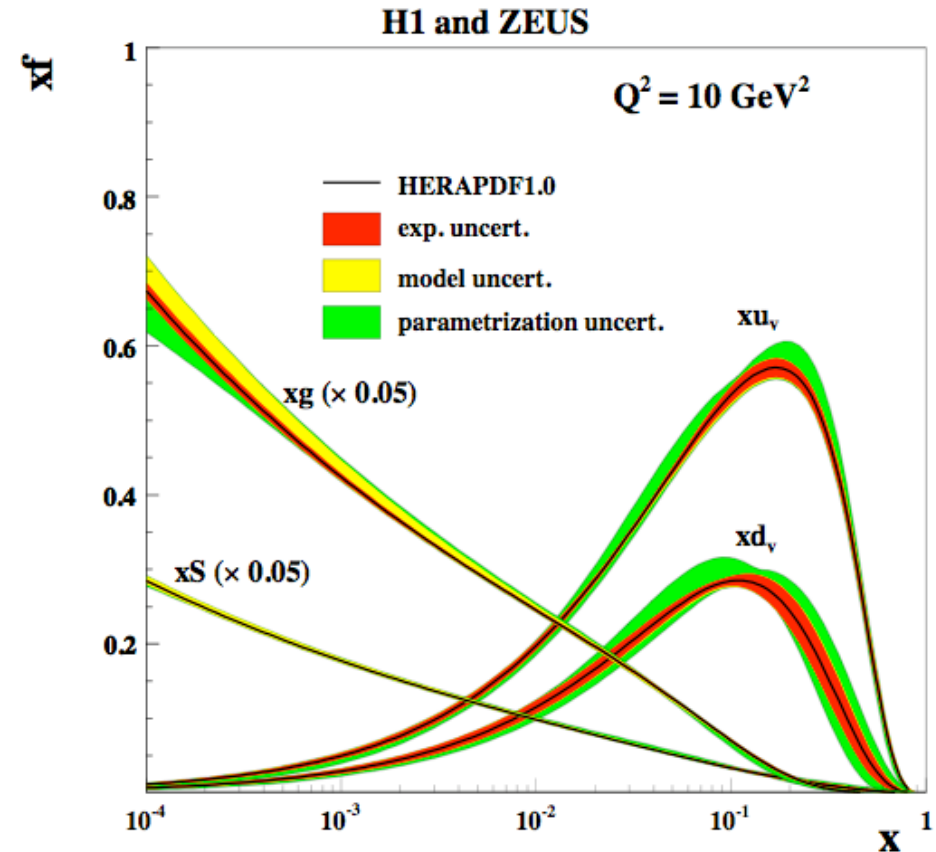
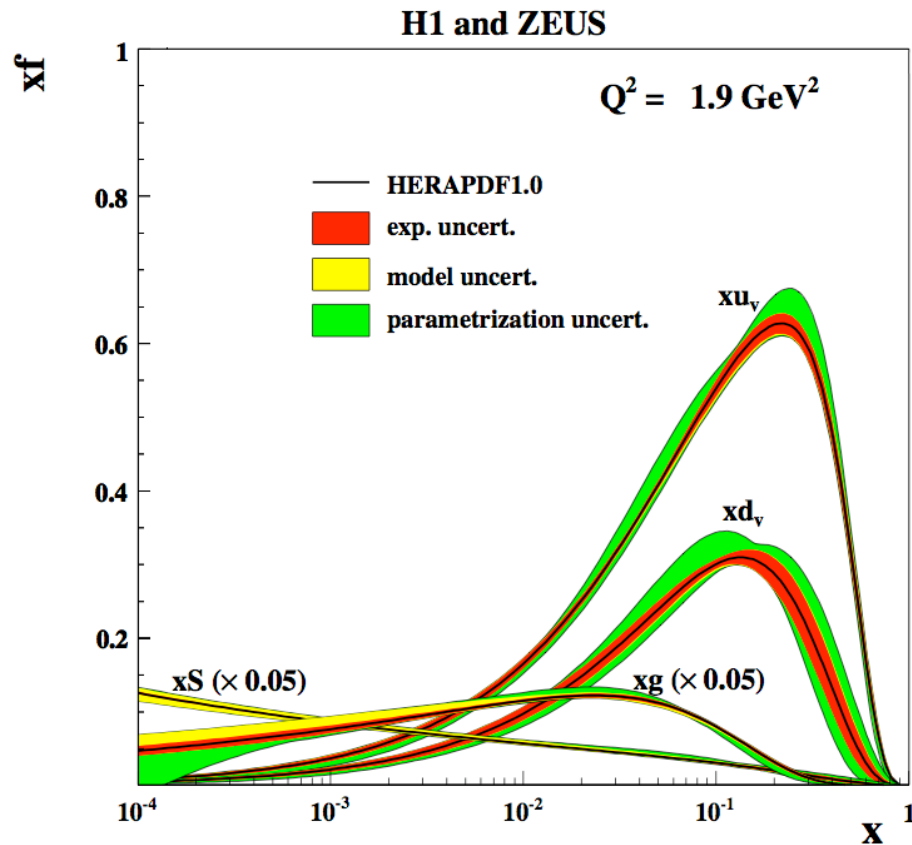
- An envelope formed from PDF fits using other variants of parametrisation form at the starting scale:
 - ▽ Scanning of $||$ parameter space
 - ▽ Q_0^2 variation and negative gluon parametrisation
 - ▽ Relaxing assumptions used for central fit



HERAPDF1.0 at NLO

- Starting Scale

10 GeV²



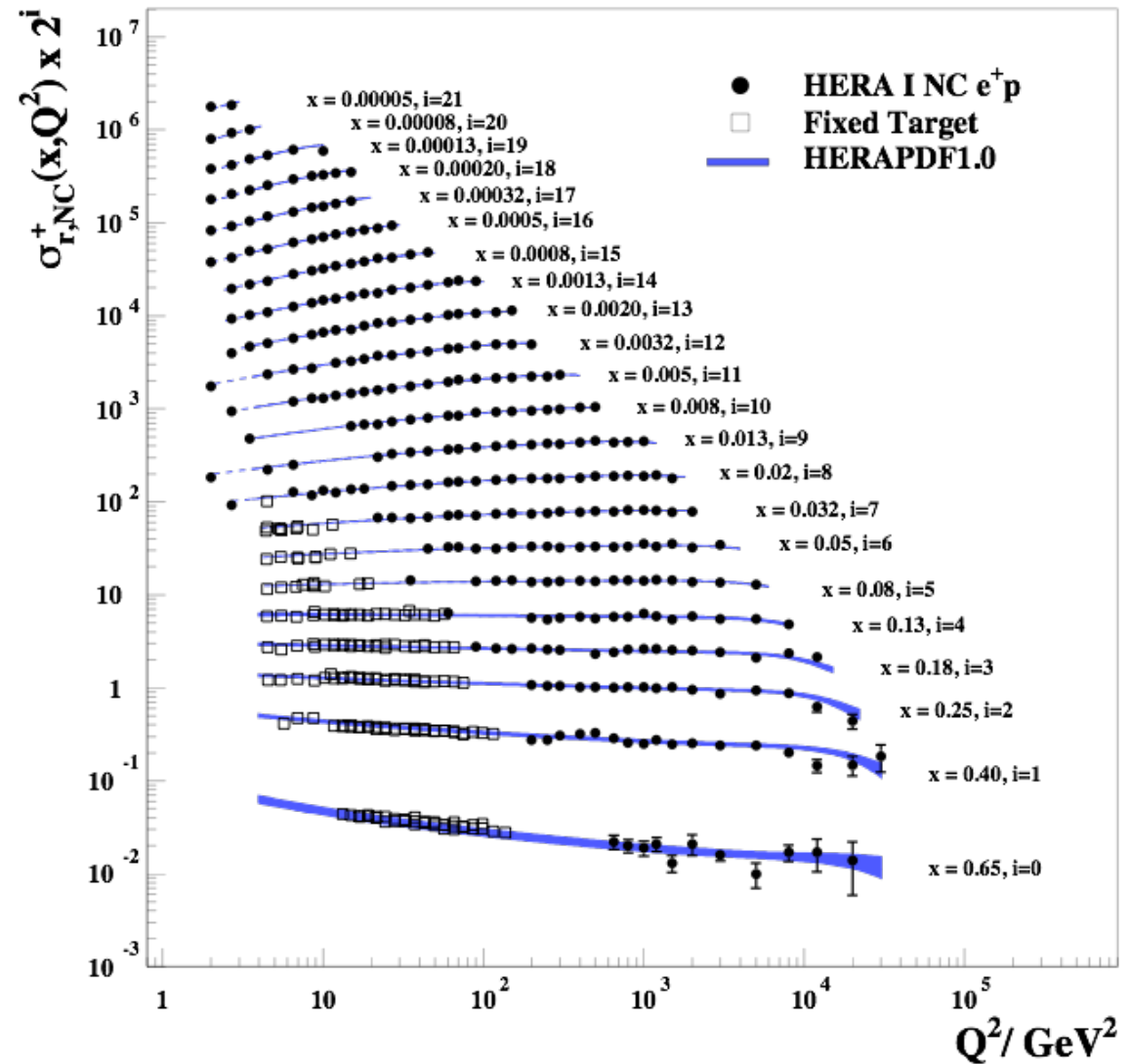
- Observe valence like shape of the gluon at the starting scale.
- Parametrisation uncertainty dominates.
- HERAPDF1.0 set available in LHAPDF since v5.8.1 (Dec 2009)



HERAPDF1.0 vs NC DIS Data

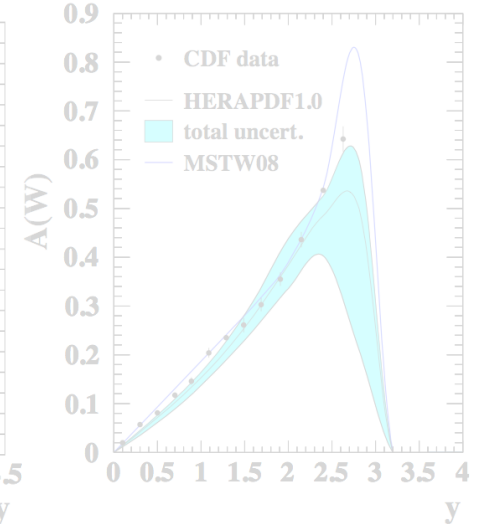
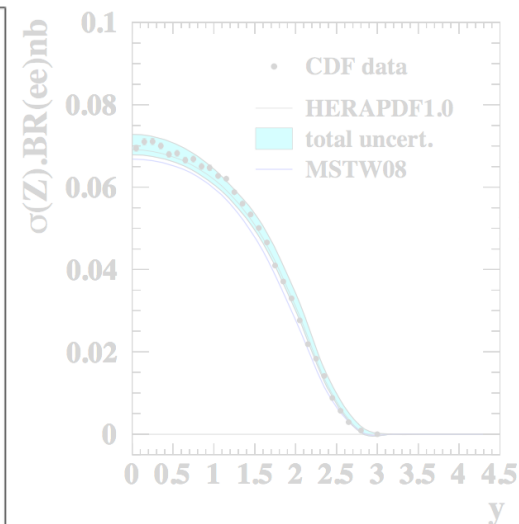
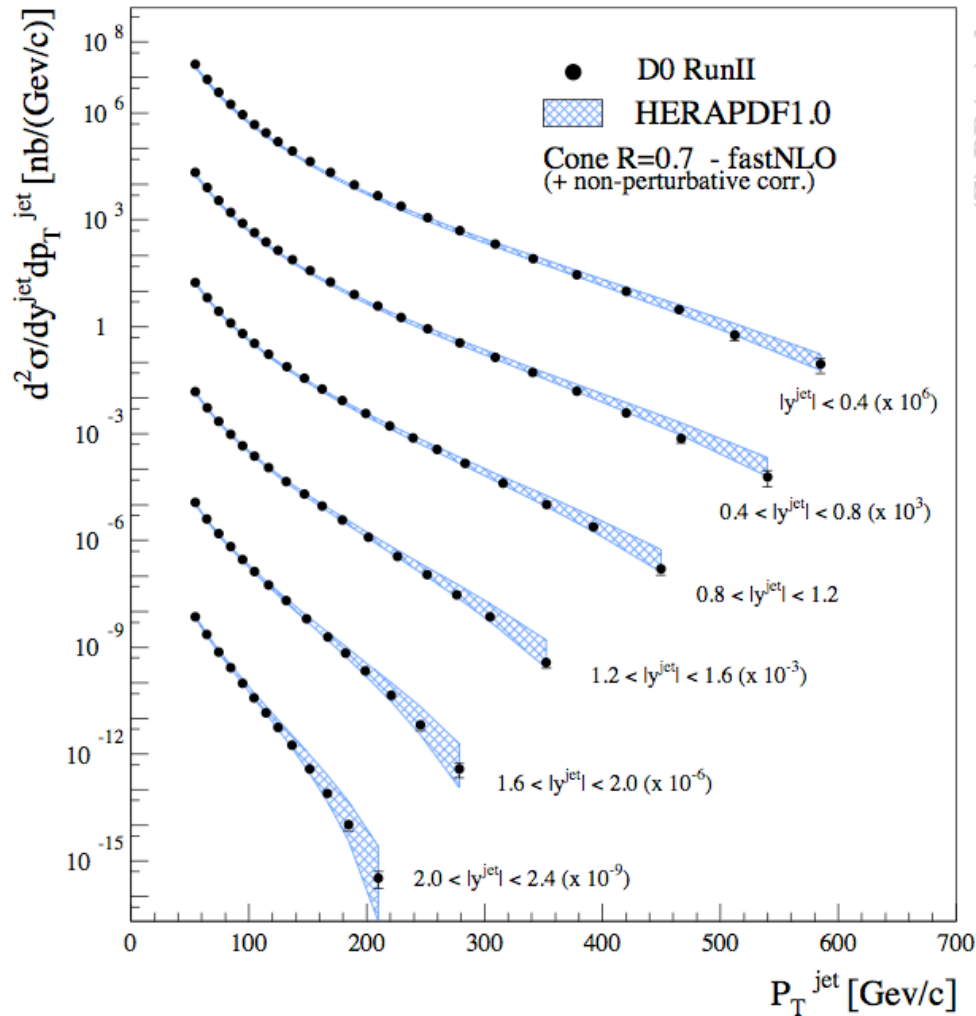
H1 and ZEUS

- Plots show the extended kinematic range of the HERA I data as compared to the fixed target measurements:
 - Data points include experimental errors
 - Fit line includes total error
- HERAPDF1.0 fit describes our data well!
- Extrapolation of the HERAPDF1.0 fit agrees well with fixed target data (SLAC and BCDMS)!



HERAPDF1.0 vs Tevatron Data

Tevatron Jet Cross Sections

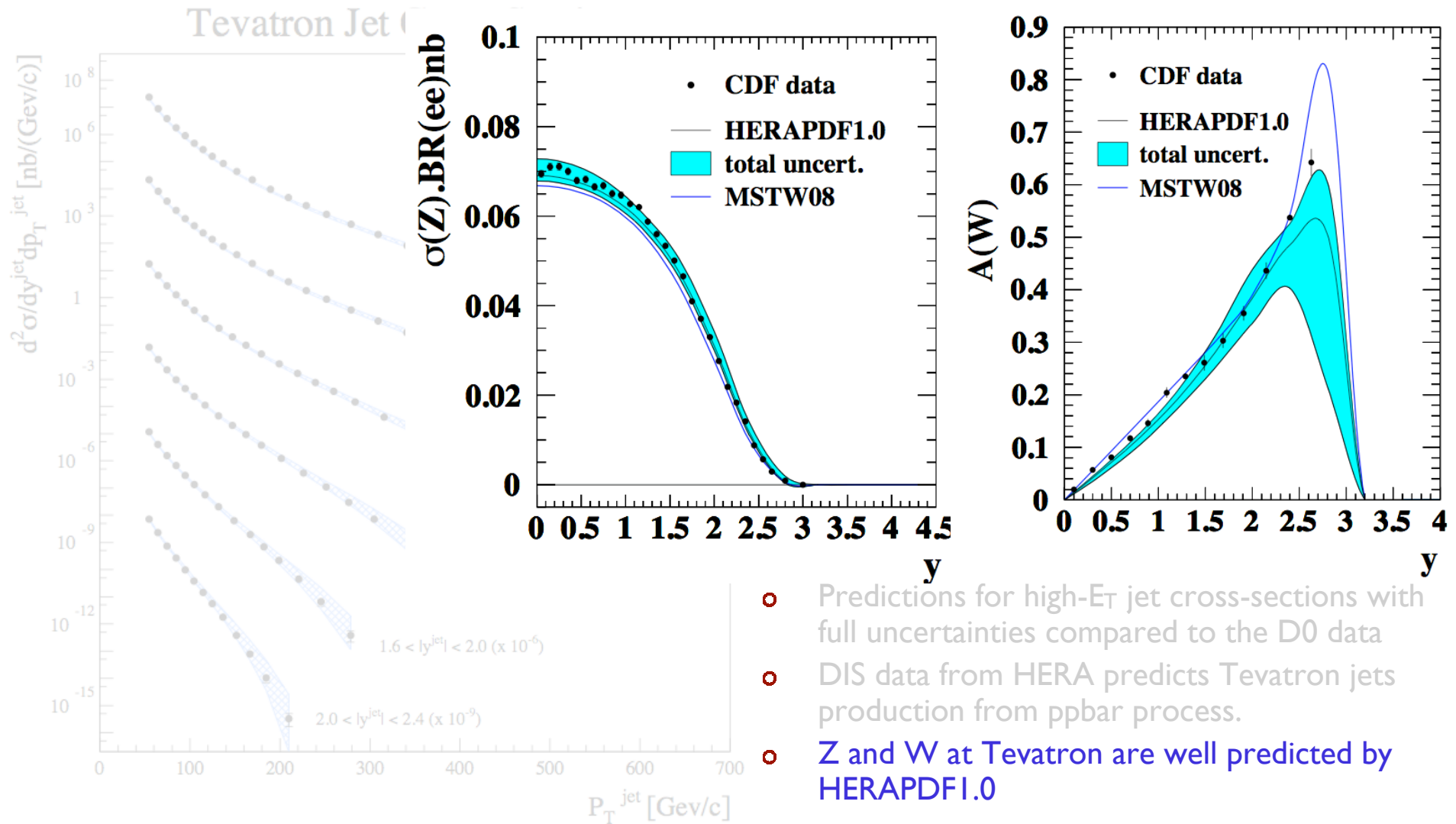


- Predictions for high- E_T jet cross-sections with full uncertainties compared to the D0 data
- DIS data from HERA predicts Tevatron jets production from $p\bar{p}$ process.
- Z and W at Tevatron are well predicted by HERAPDF1.0

- Hence, there is a universal description of partonic processes and all can be described with: HERA input, SM couplings and pQCD evolution!



HERAPDF1.0 vs Tevatron Data

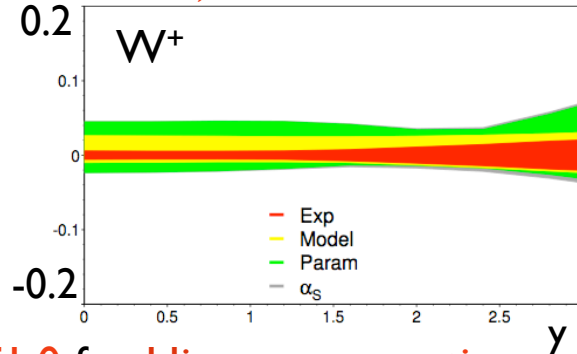
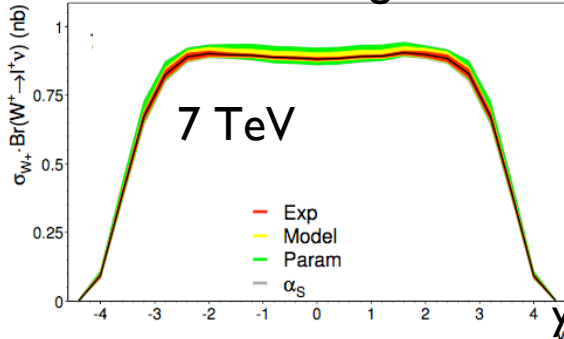


- Predictions for high- E_T jet cross-sections with full uncertainties compared to the D0 data
- DIS data from HERA predicts Tevatron jets production from ppbar process.
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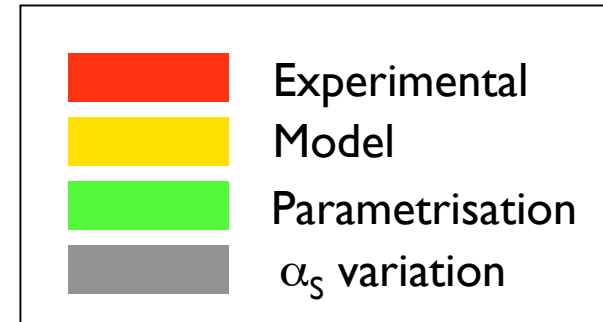


LHC predictions based on HERAPDF1.0

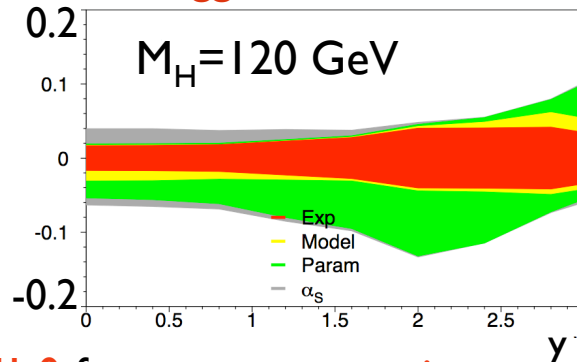
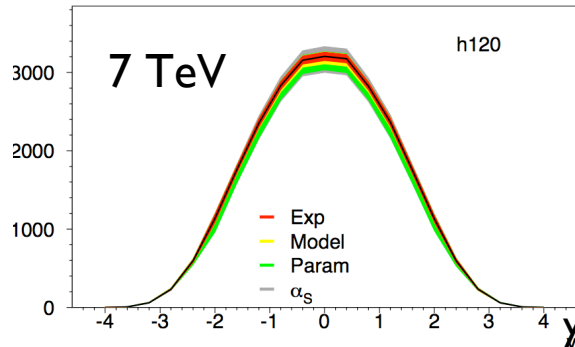
o Predictions using HERAPDF1.0 for W, Z cross sections.



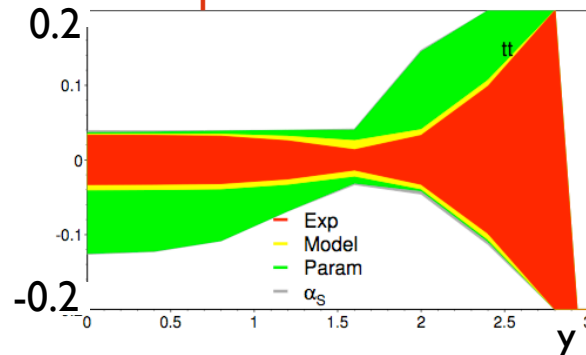
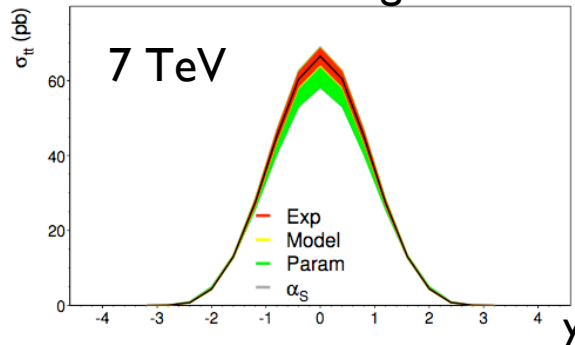
Uncertainties:



o Predictions using HERAPDF1.0 for Higgs cross sections.



o Predictions using HERAPDF1.0 for top cross sections.



Exciting new times ahead to actually compare the predictions to real measurements from the LHC!



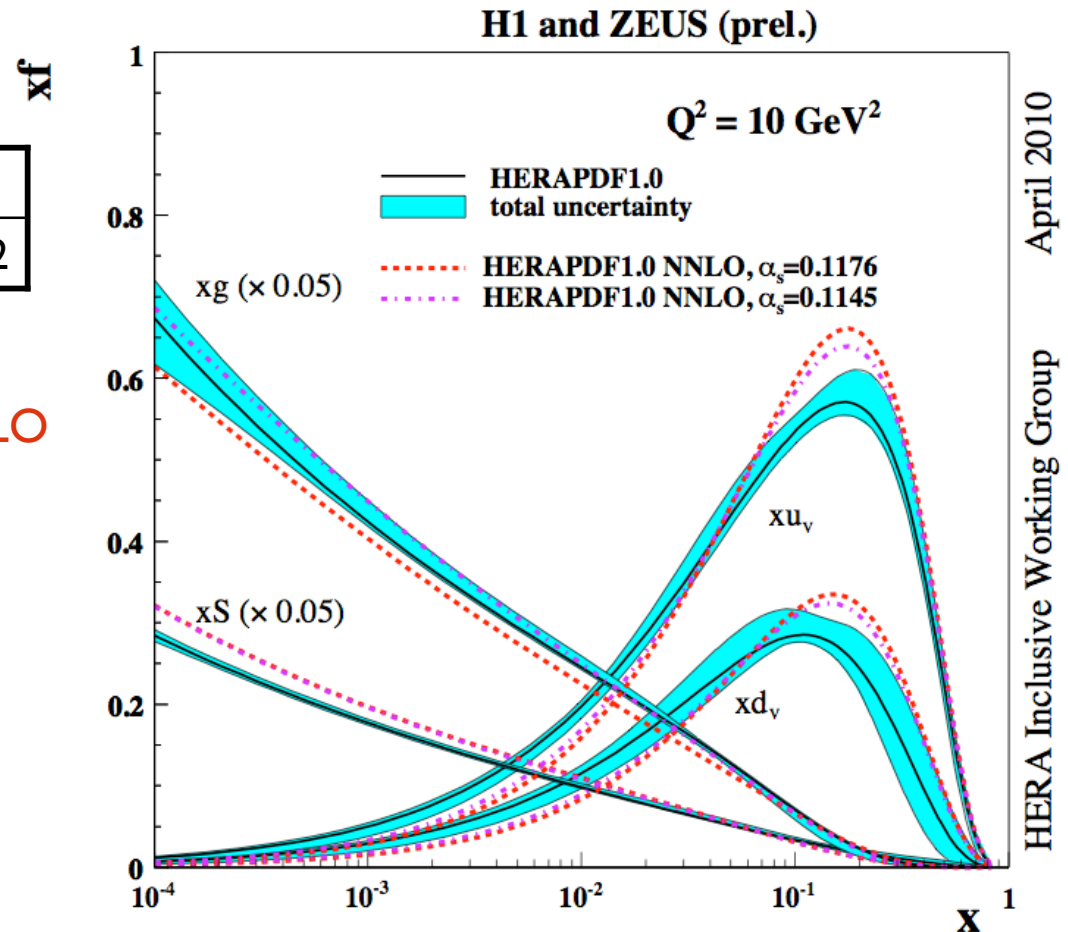
HERAPDF fits at NNLO

- Fits performed to HERA I data (as used for HERAPDF1.0) at NNLO using RT-VFNS:
 - $\alpha_s(M_z)$ at NLO = 0.1176
 - $\alpha_s(M_z)$ at NNLO = 0.1145

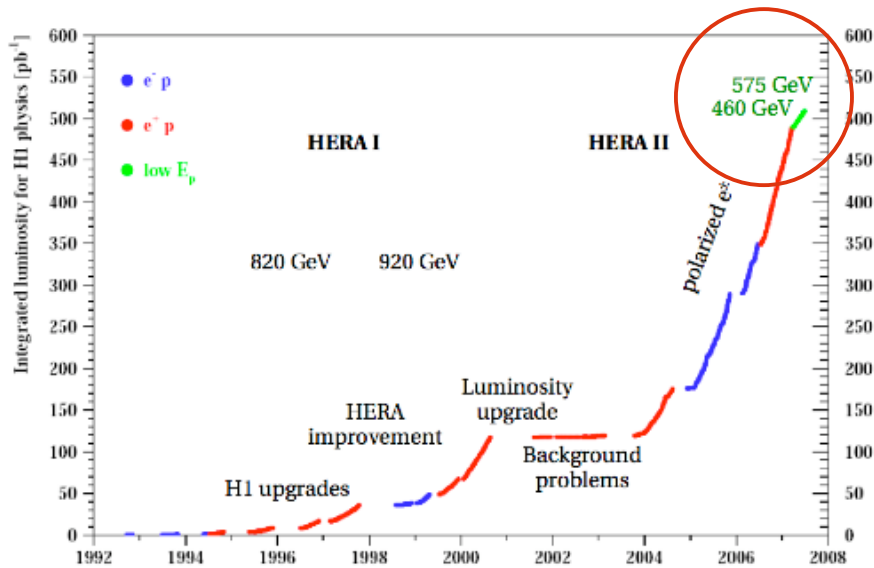
scheme	NNLO	NNLO	NLO
All χ^2/dof	623.7/582	638.3/582	574.4/582

- NNLO fits are slightly worse than NLO

Note: Plots at NNLO are compared to HERAPDF1.0 (NLO) only illustratively \rightarrow expect to be different!

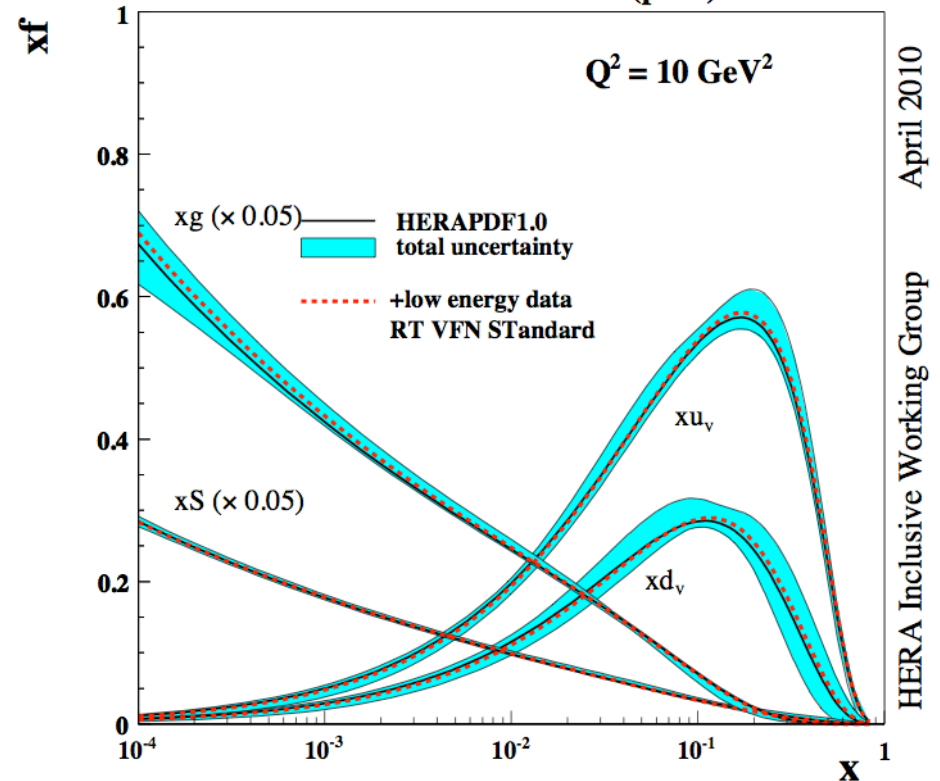


HERAPDF including Low Energy data



- Preliminary HERA Combined Low Energy data available!
- New accurate measurement in $Q^2 > 2.5 \text{ GeV}^2$ range, sensitive to structure function F_L are included in the QCD analysis on top of the HERA I data →

H1 and ZEUS (prel.)

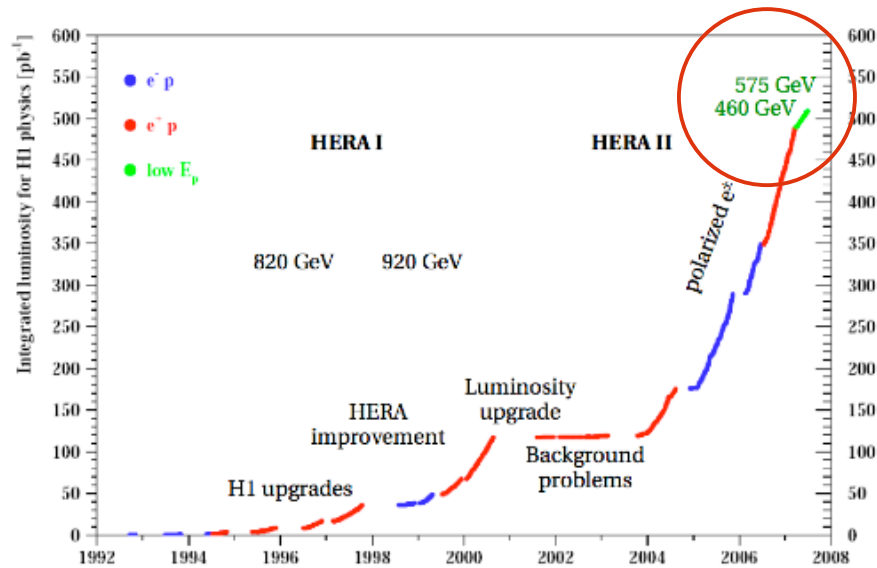


- PDFs from the new fit agree very well with HERAPDF1.0

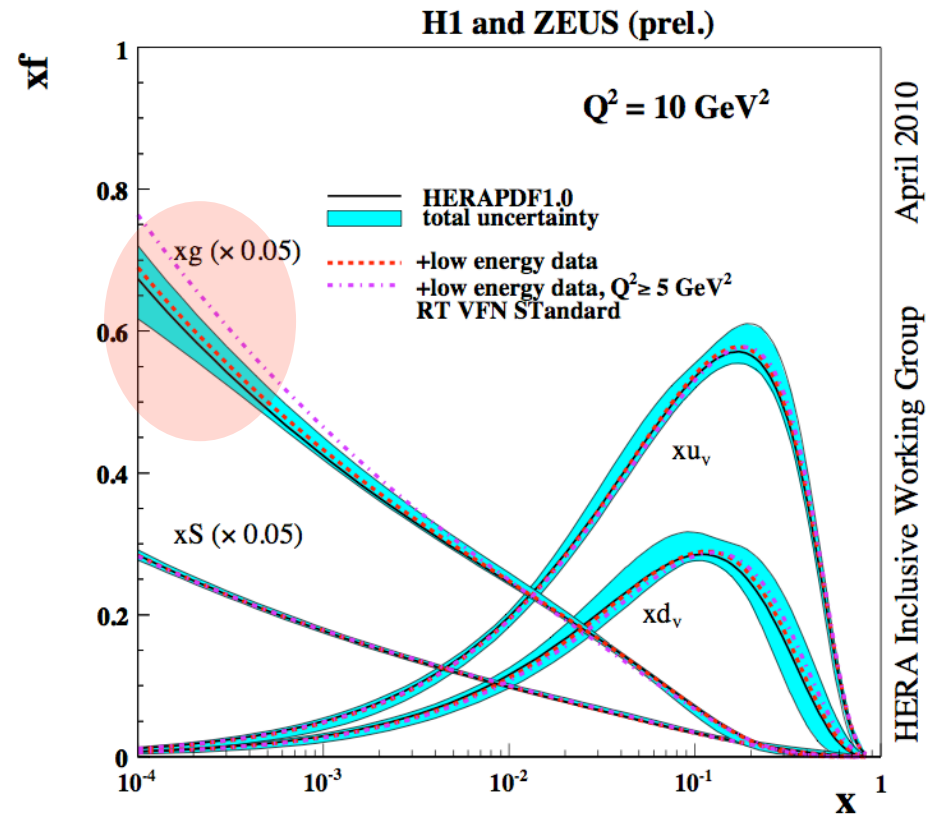
Data sets	HERAPDF1.0	+ Low Energy data
Total χ^2/dof	574/582	818/806



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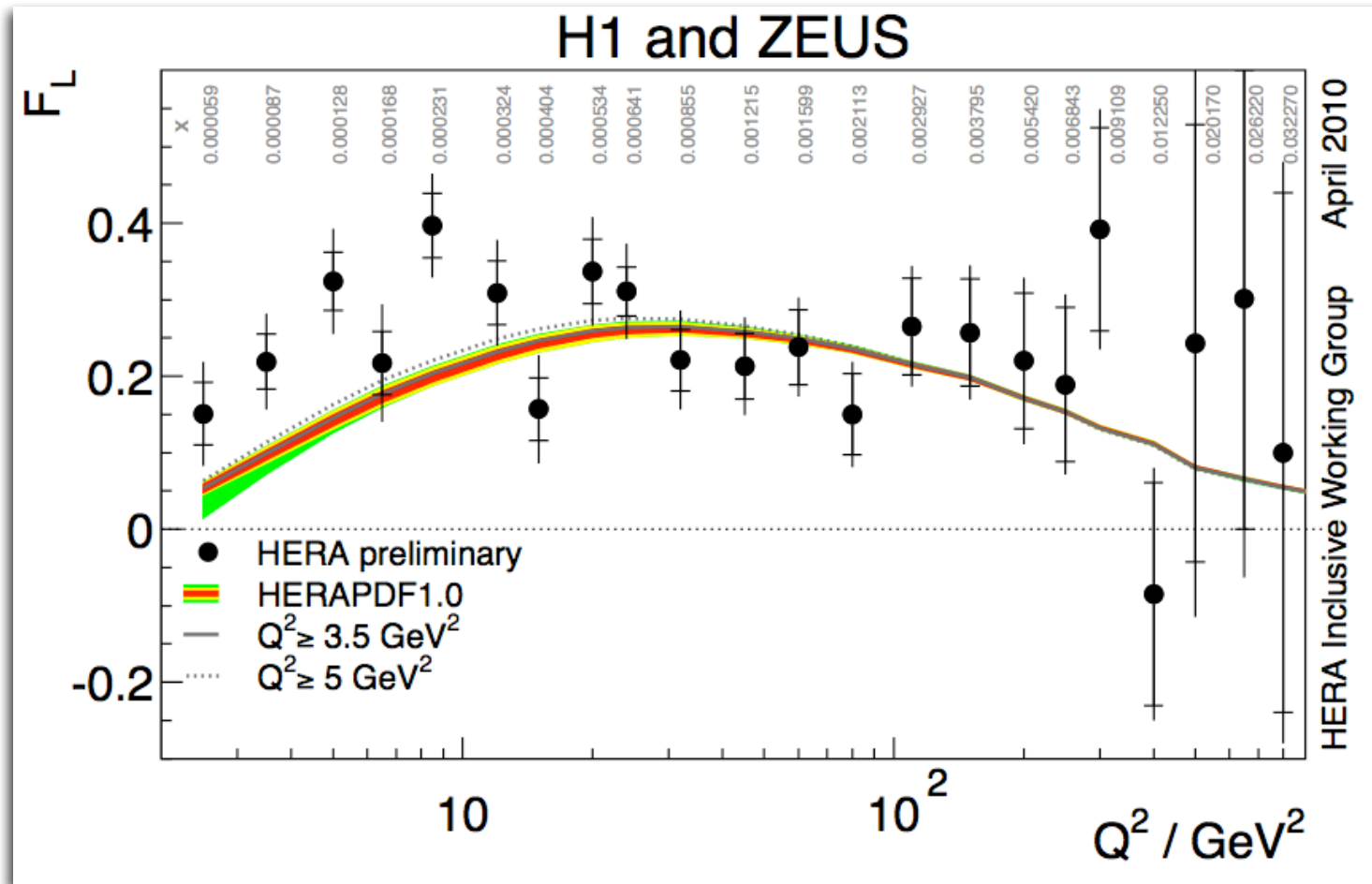


- However, The $Q^2 \geq 5 \text{ GeV}^2$ cut brings large improvement in χ^2 [818/806 → 698/771] and it yields different shapes for gluon and sea PDFs.
 - for HERAPDF1.0, Q^2 cut variation is included in the model uncertainty, but it had smaller effect.



HERA F_L data vs F_L predictions

The lines are F_L predictions using combined HERA I and low energy data.



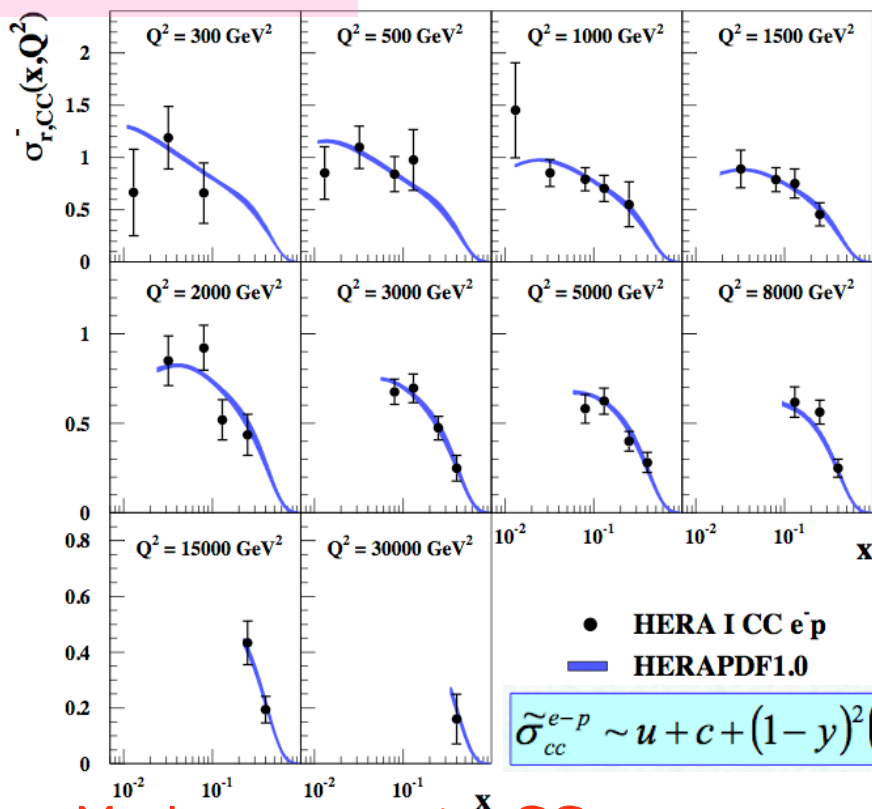
Low Q^2 region remains very interesting for further QCD tests!



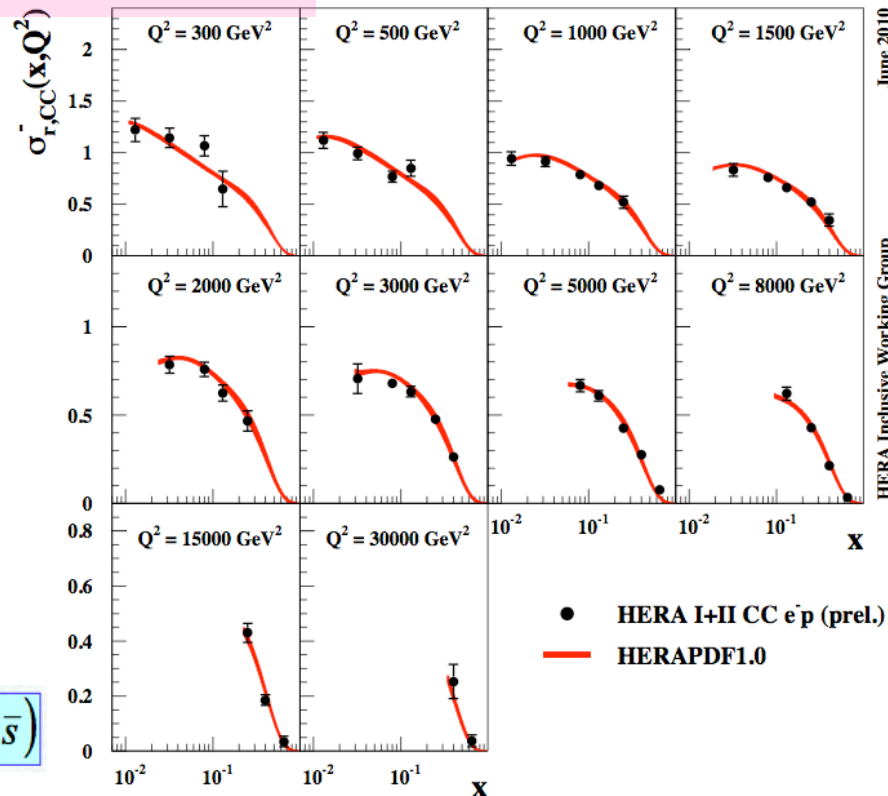
Combining HERA I and II Inclusive data

- **New HERA II preliminary data available!**
 - More precise measurements in the high Q^2 and high x regions (especially NC e^-p and CC $e^\pm p$)
 - ➔ could constrain better PDFs at high x
- HERA I and HERA II are combined using same averaging procedure as described before:
 - 674 unique cross sections points with 134 sources of systematic uncertainties

Without HERA II H1 and ZEUS



With HERA II H1 and ZEUS

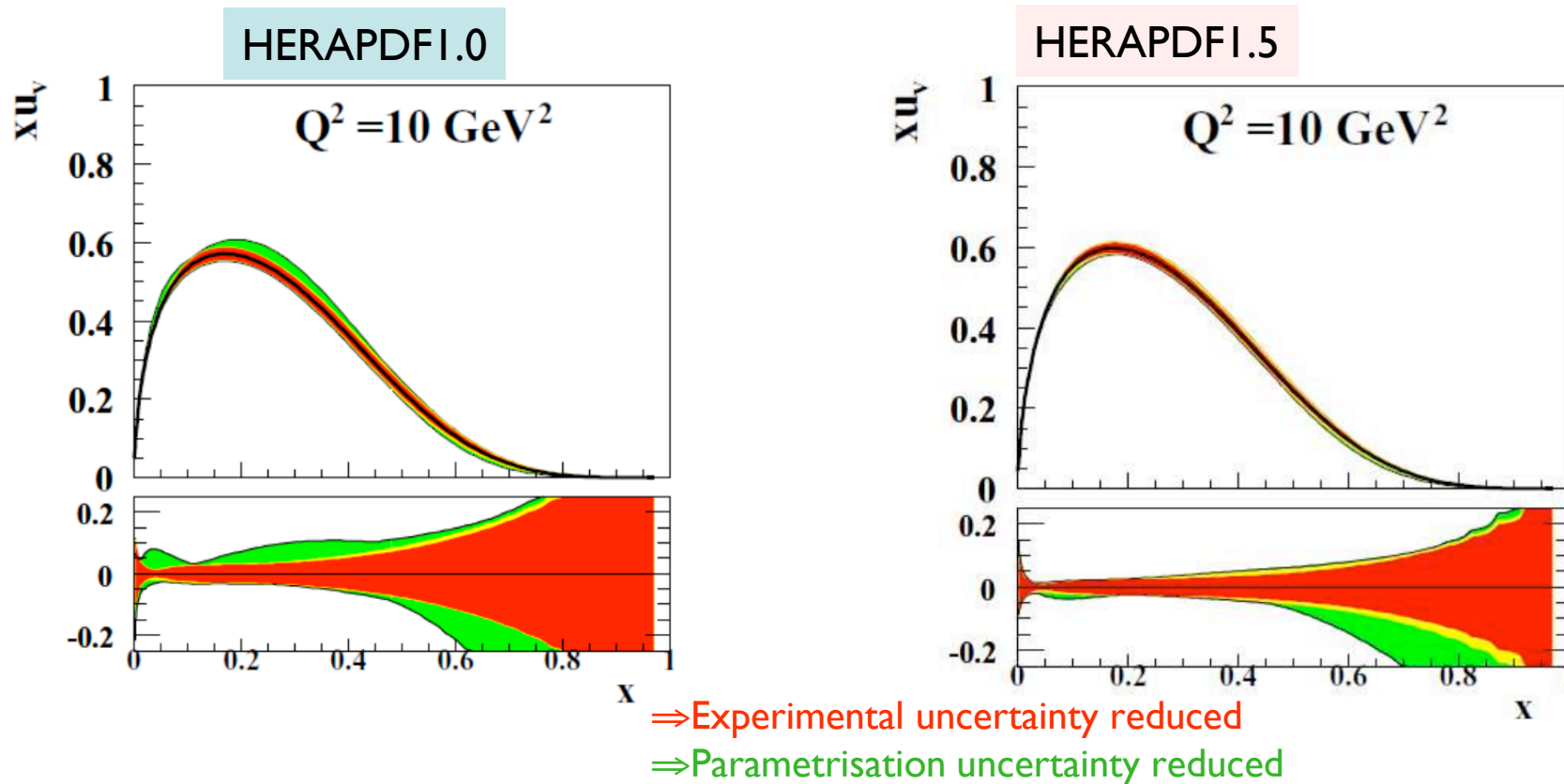


Much more precise CC measurements after including new high Q^2 HERA II set!



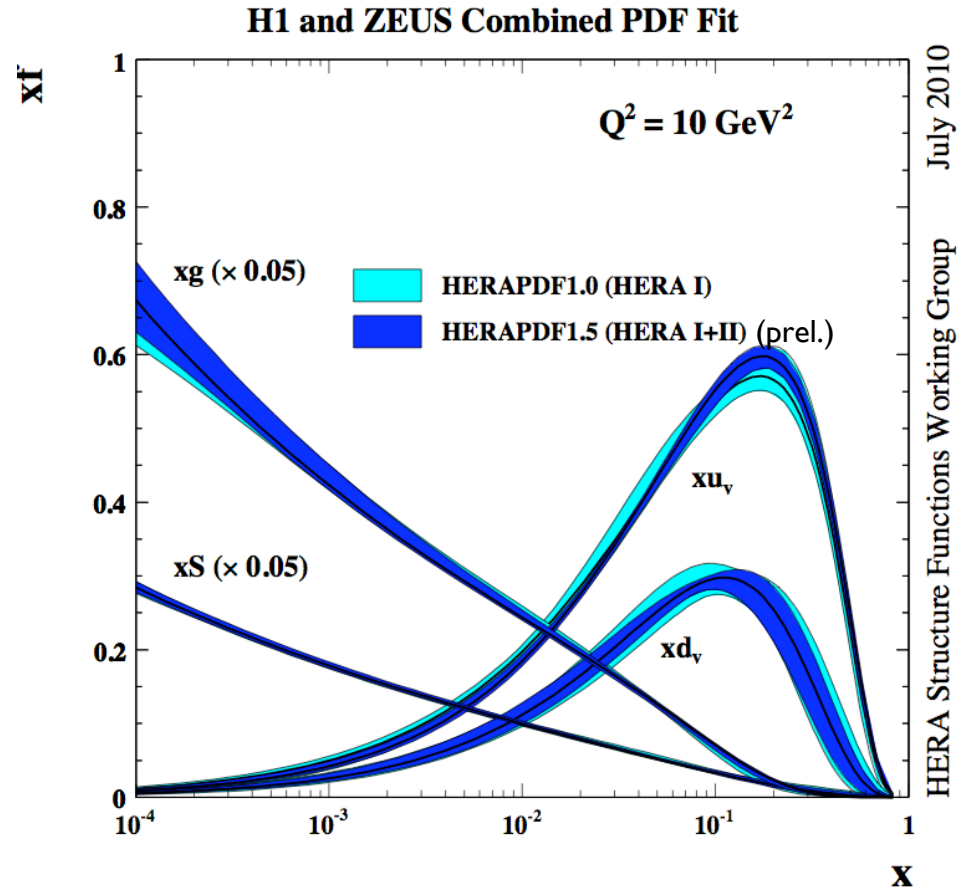
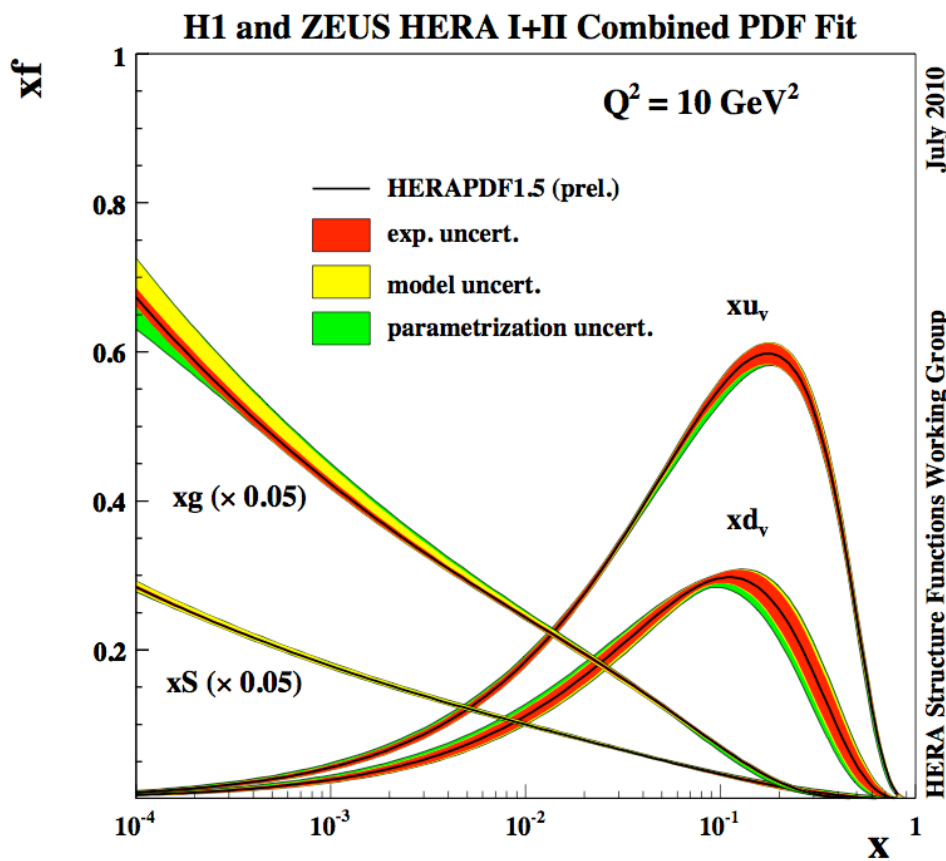
Fits to New Combined HERA data: HERAPDF1.5

- Propagate new data through QCD fit analysis to produce a new set of HERAPDFs: HERAPDF1.5
 - For preliminary studies use same settings as for HERAPDF1.0
 - Parametrisation uncertainty will be further investigated for final release.



HERAPDF1.5 vs HERAPDF1.0

- xg , xu_v , xd_v , $xSea$ ($xSea=x\bar{U}+x\bar{D}$) at the scale $Q_0^2=10 \text{ GeV}^2$



- Inclusion of the HERA II data reduces the uncertainties on PDFs in the high x region especially visible on the valence distributions!

▪ See [HERAPDF1.5\(prel\)](#) vs [HERAPDF1.0](#)



Summary

- HERA provides accurate determinations of the proton structure and can predict related Standard Model processes!
- New preliminary measurements from HERA II time period are available in the HERA QCD analyses!
- Using HERA information, we have precise predictions for the LHC and the time has come to confront them with the data!

