Combination and QCD Analysis of the HERA Inclusive Cross Sections

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on behalf of the H1 and ZEUS Collaborations

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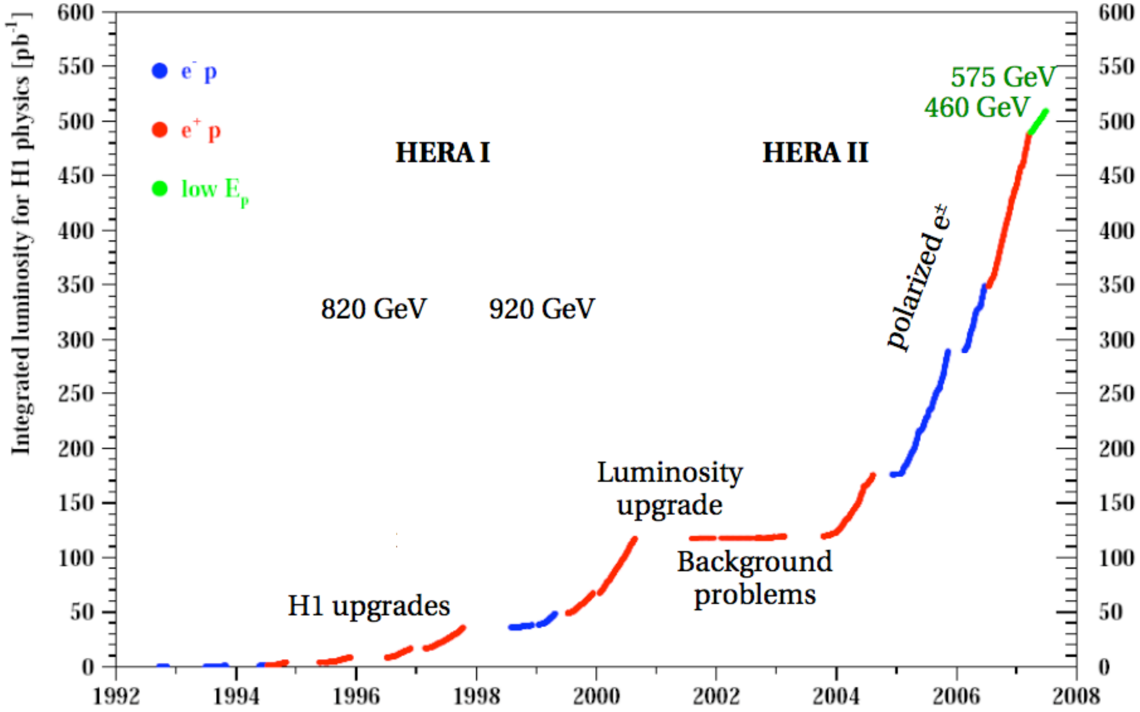
Outline:

- H1 and ZEUS at the HERA collider
- Data Combination
- QCD Analysis
- Results and Comparisons
- Summary

HERA at DESY

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

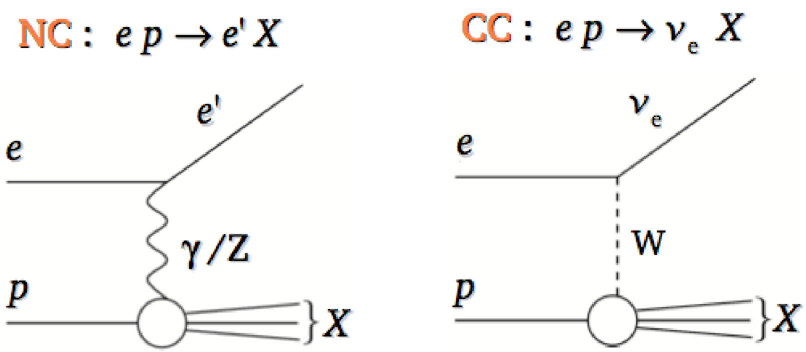


HERA-I	1992-2000	Ep=820,920 GeV
HERA-II	2003-2007	Ep=920, 460,575 GeV

Registered ~1fb^{-1} of integrated luminosity of physics data.

H1 and ZEUS kinematics

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

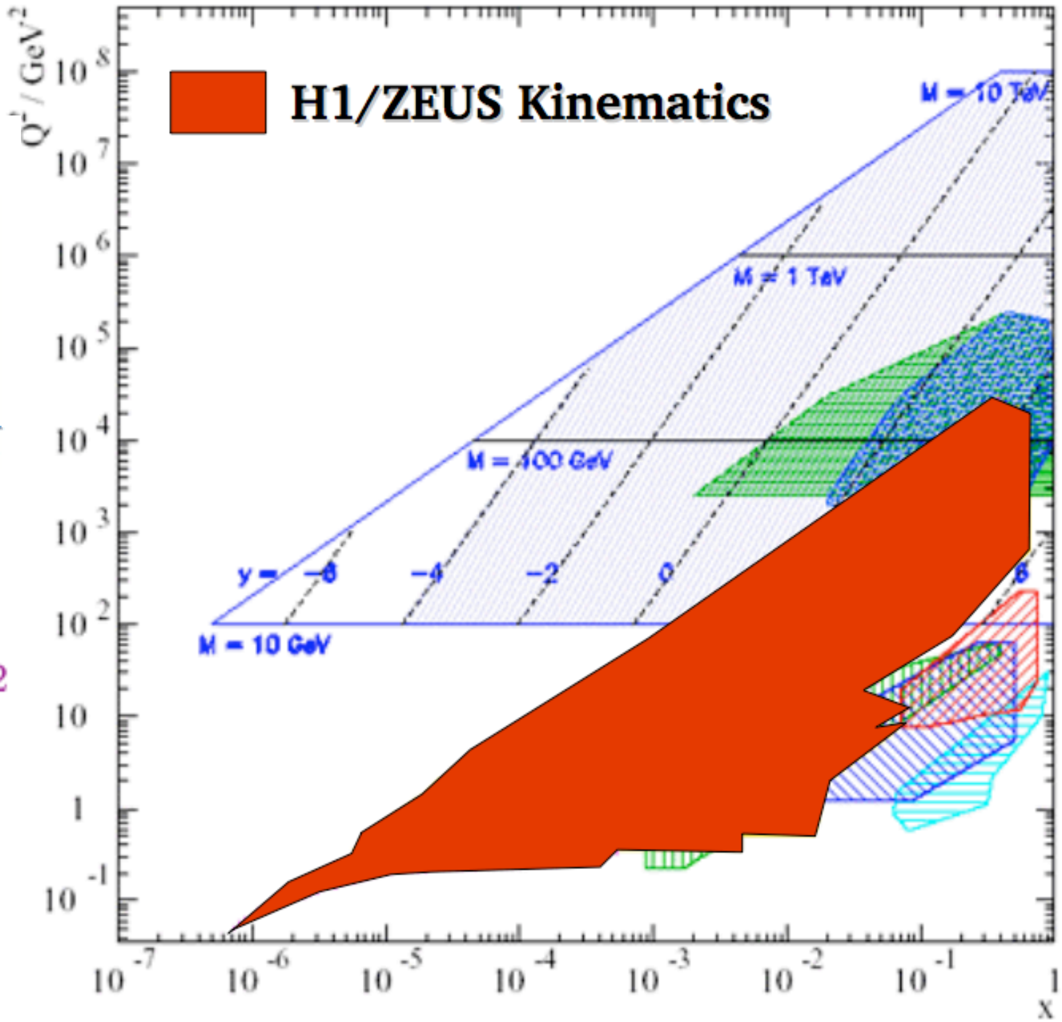


- Kinematic variables:
  - Virtuality of exchanged boson:

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

  - Bjorken scaling variable:

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



H1 and ZEUS kinematics span over 6 orders of magnitude in x and Q^2!

Combination of the H1 and ZEUS Measurements

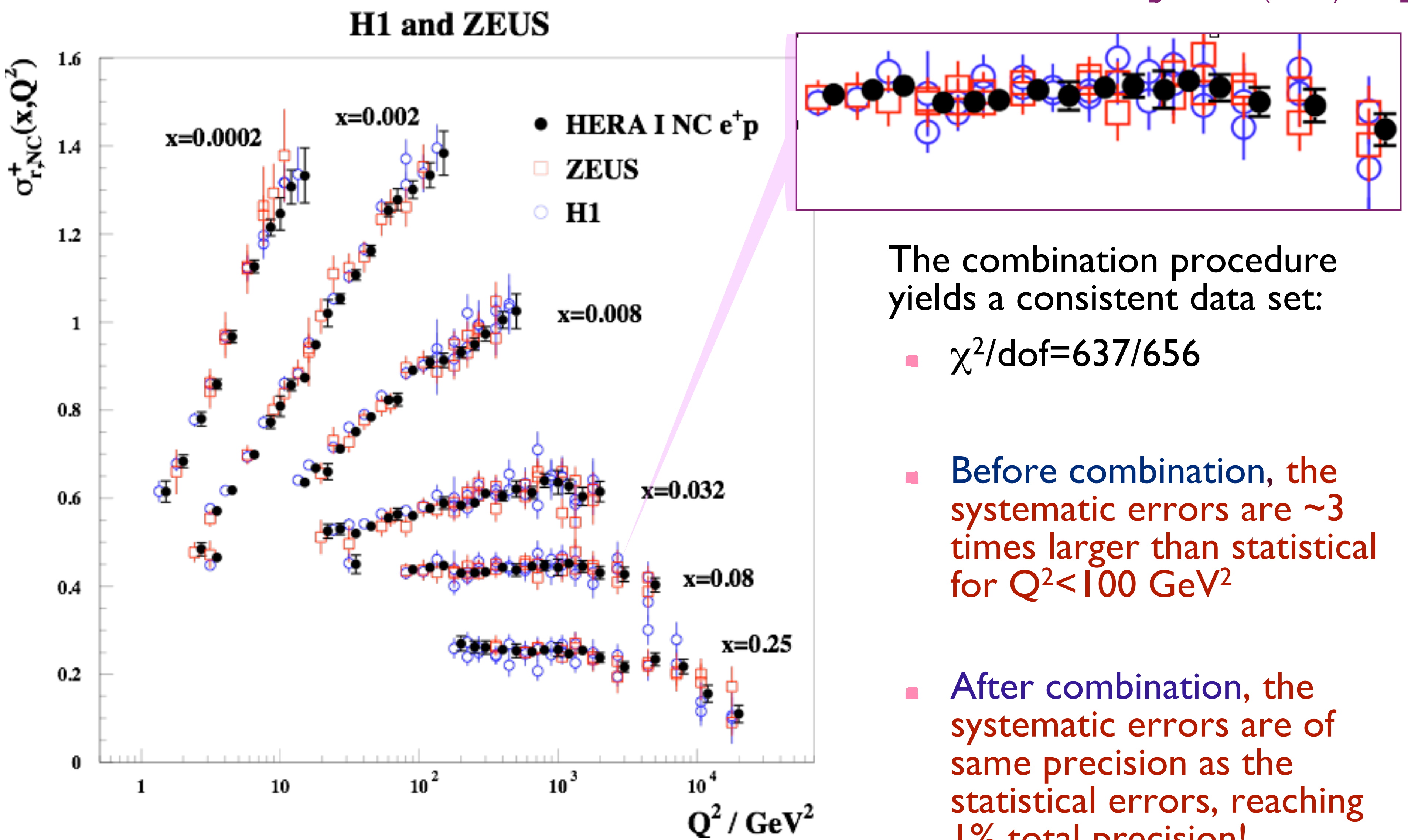
[JHEP01 (2010) 109]

- 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:

- χ^2/dof=637/656
- Before combination, the systematic errors are ~3 times larger than statistical for Q^2<100 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^+ (Q^2>100 GeV^2)
    - NC e^+ (Q^2>0.045 GeV^2)
  - Combined HERA II Low Energy Data Set of Ep=460, 575 GeV [prelim.]
    - Q^2>2.5 GeV^2
  - Combined HERA I+high Q^2 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 Q_0^2:

$$\mathbf{G}, \mathbf{u_{val}}, \mathbf{d_{val}}, \overline{\mathbf{U}} = \overline{\mathbf{u}}(+\overline{\mathbf{c}}), \overline{\mathbf{D}} = \overline{\mathbf{d}} + \overline{\mathbf{s}}(+\overline{\mathbf{b}})$$

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

- 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
  - χ^2/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^2_{min}	3.5 GeV^2
$\alpha_S(M_Z)$	0.1176
M_c	1.4 GeV
M_b	4.75 GeV

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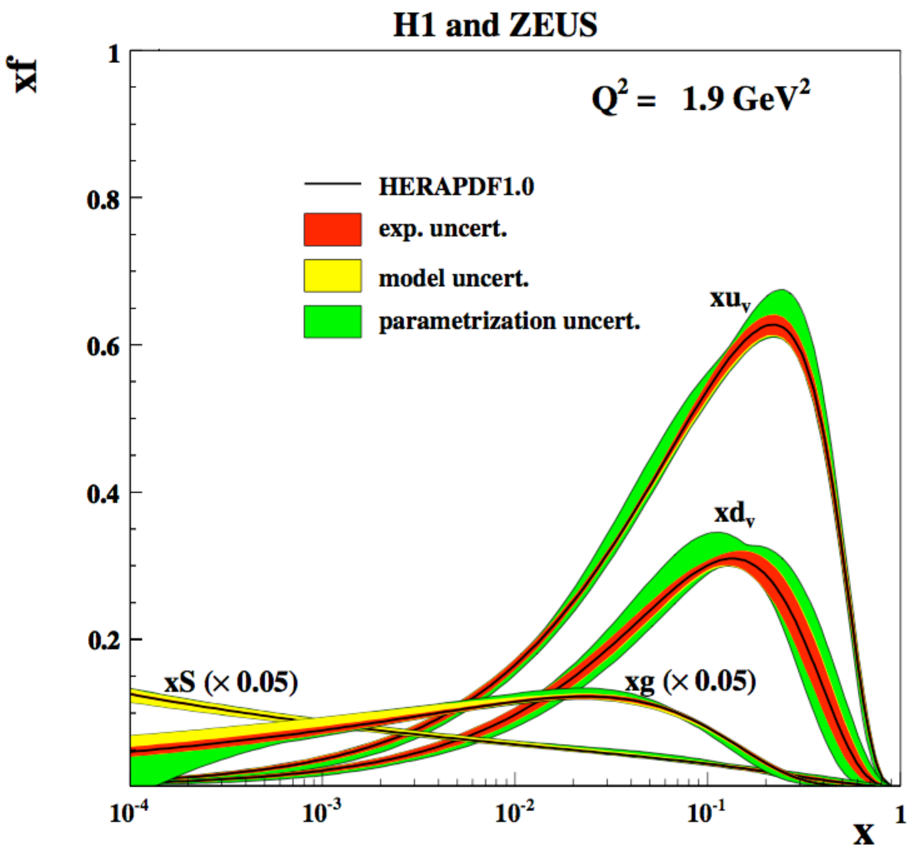
Sources of PDF uncertainties at HERA

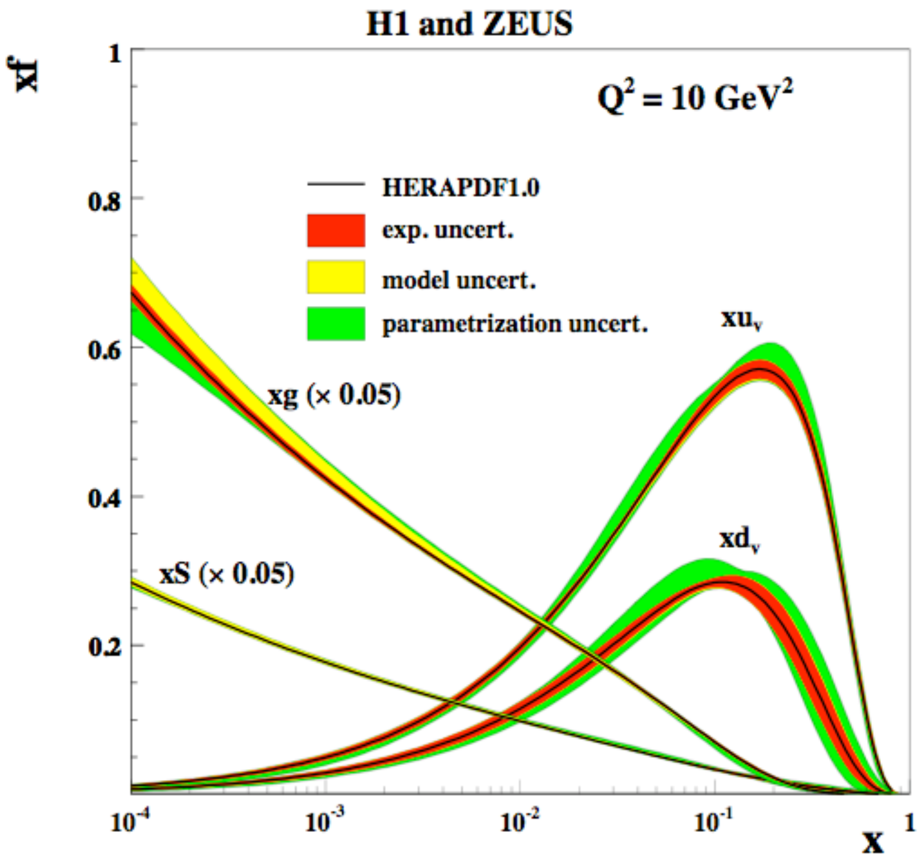
- **Experimental Uncertainties:**
  - Consistent data sets → use $\Delta\chi^2 = 1$
- **Model Uncertainties:**
  - following variations have been considered

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^2_{min} [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 11 parameter space
    - Q_0^2 variation and negative gluon parametrisation
    - Relaxing assumptions used for central fit

- Starting Scale 10 GeV^2

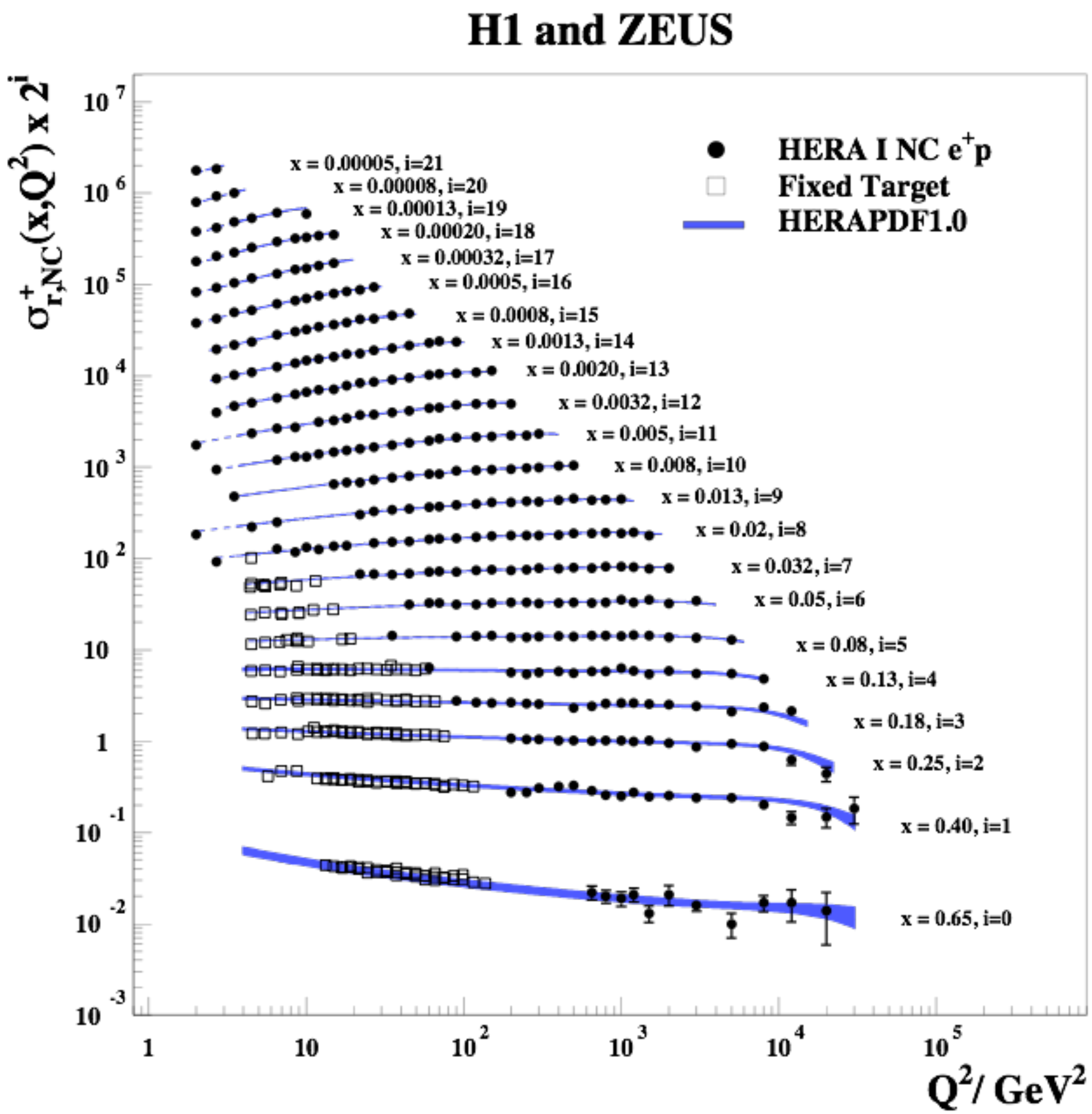




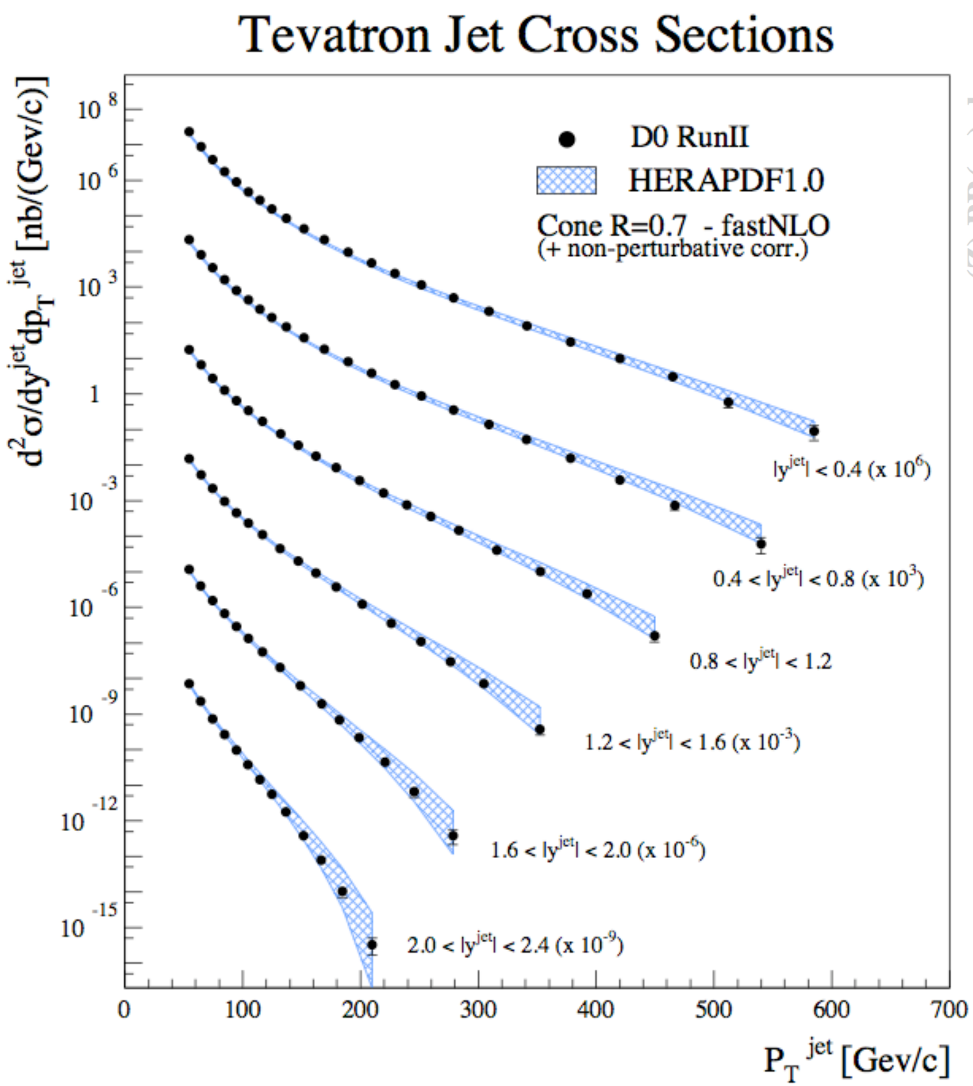
  - Observe valence like shape of the gluon at the starting scale.
  - Parametrisation uncertainty dominates.
- HERAPDF1.0 set available in LHAPDF since v5.8.1 (Dec 2009)

HERAPDF1.0 vs NC DIS Data

- 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



- 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.
- 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!

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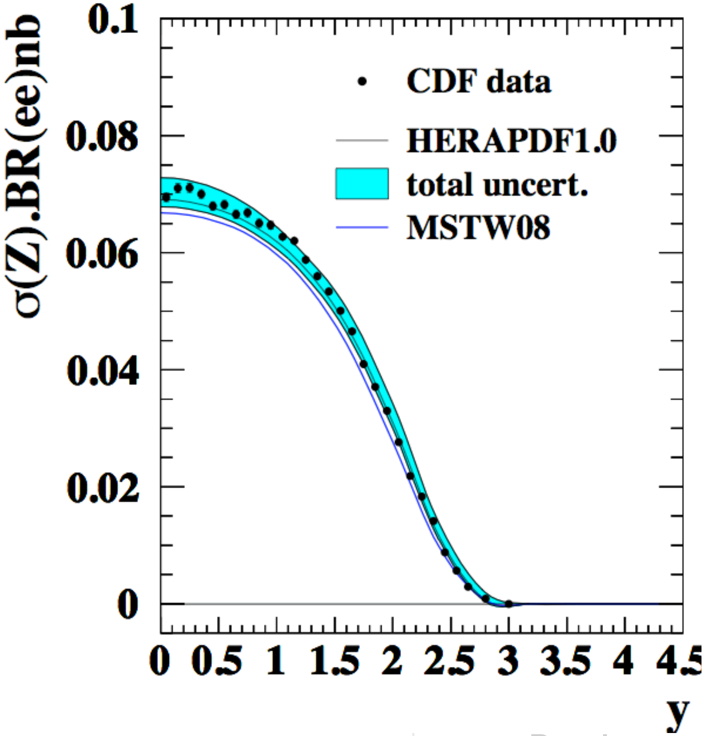

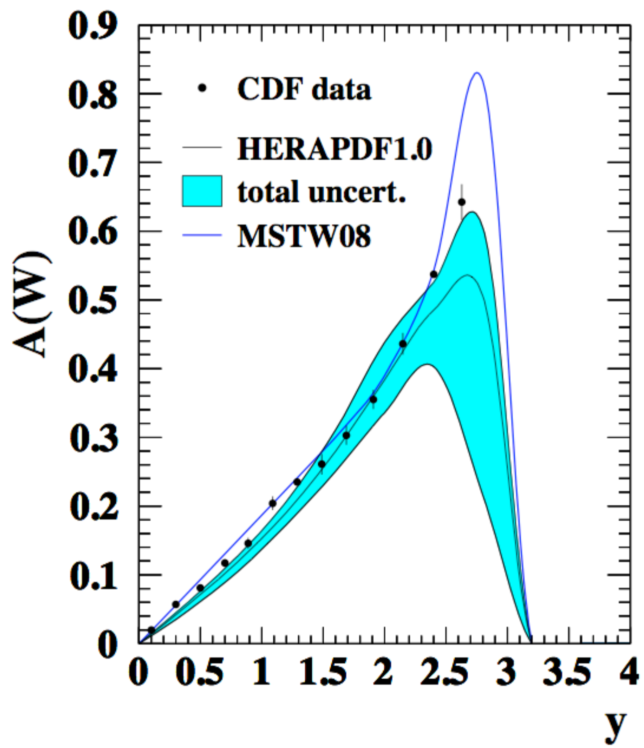

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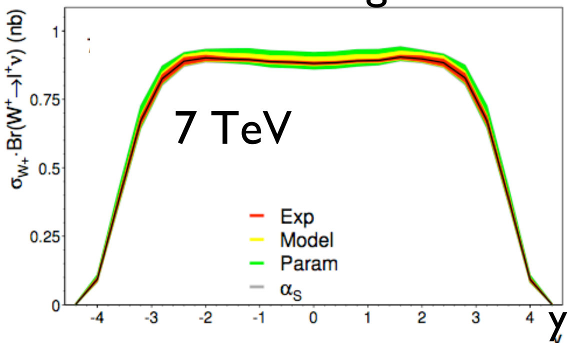
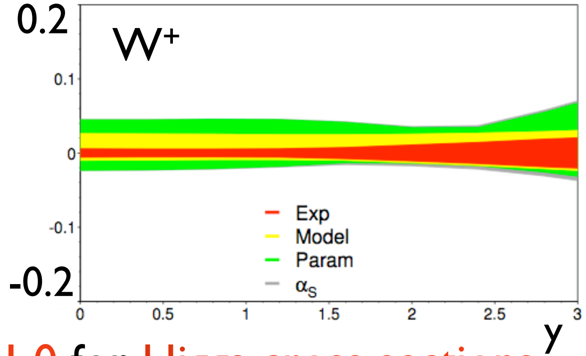
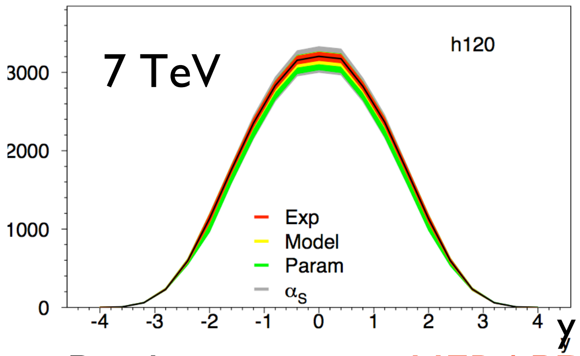
LHC predictions based on HERAPDF1.0

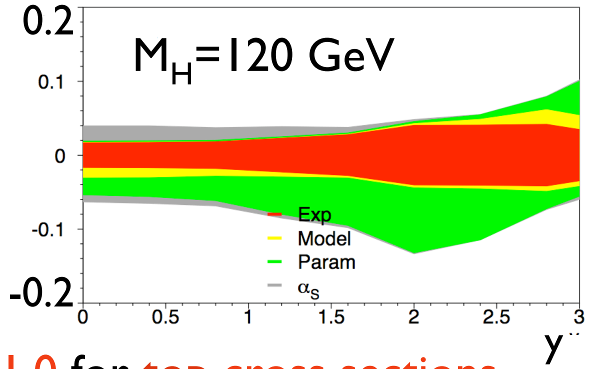
- Predictions using HERAPDF1.0 for W, Z cross sections.



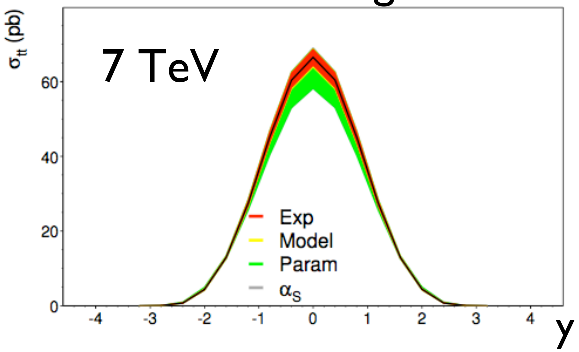


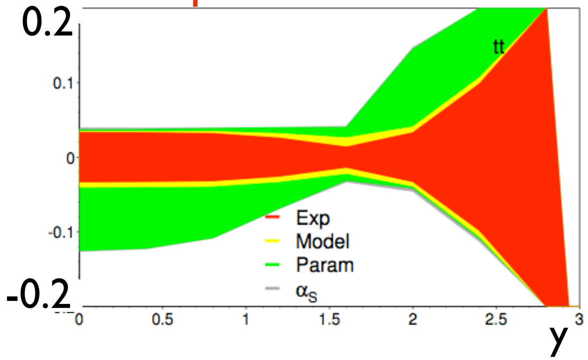
- Predictions using HERAPDF1.0 for Higgs cross sections.





- Predictions using HERAPDF1.0 for top cross sections.





Uncertainties:

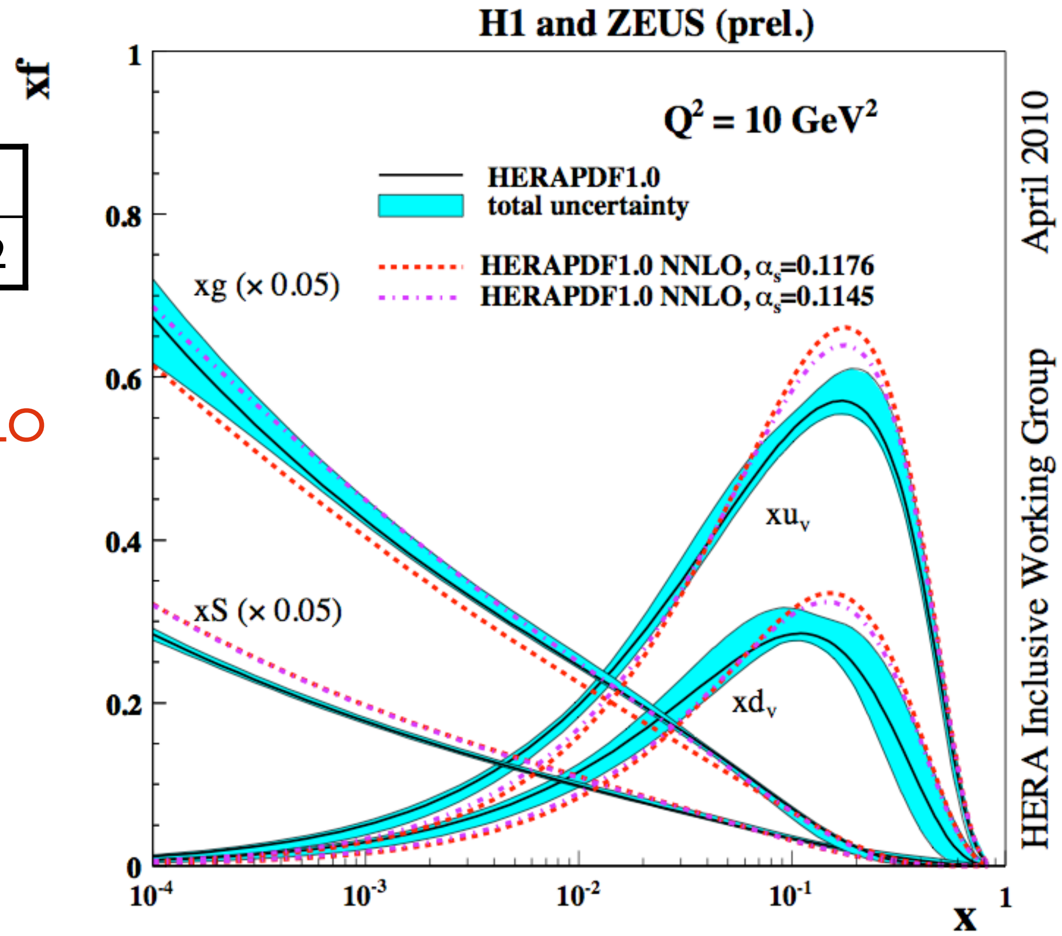
- Experimental
- Model
- Parametrisation
- α_S variation

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:
  - α_S(Mz) at NLO = 0.1176
  - α_S(Mz) at NNLO = 0.1145

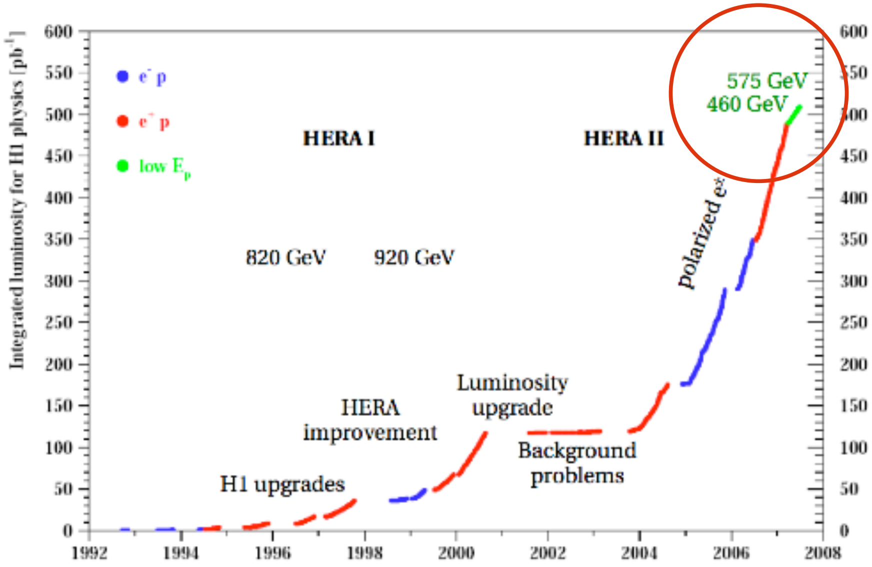
scheme	NNLO	NNLO	NLO
All χ^2/dof	623.7/582	638.3/582	574.4/582



- NNLO fits are slightly worse than NLO

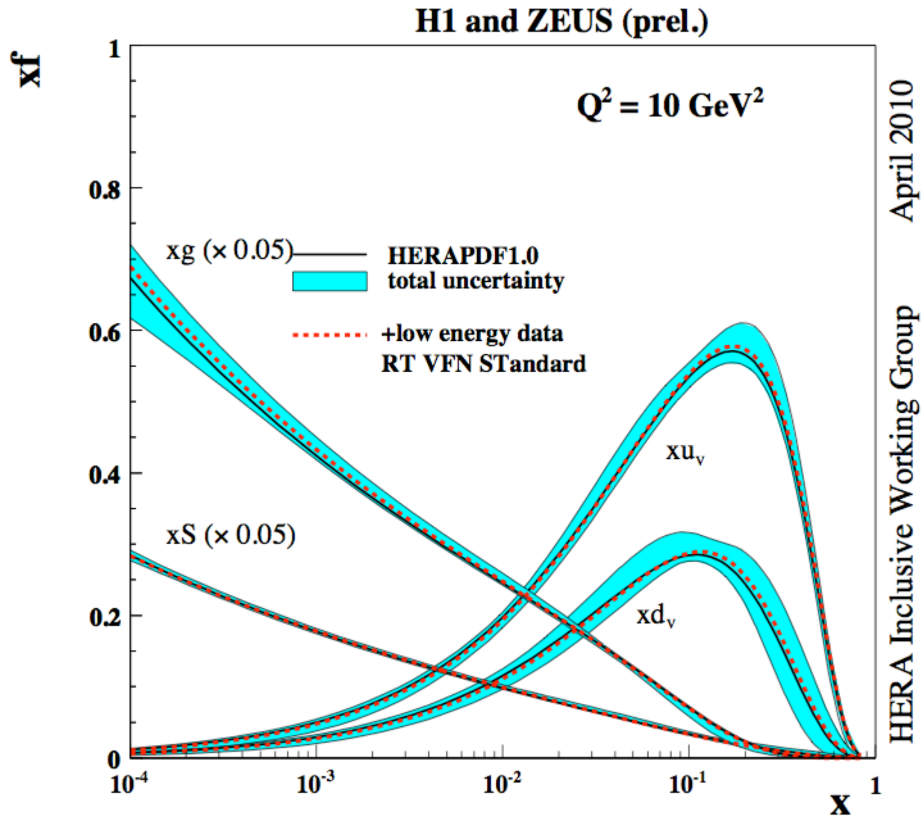
Note: Plots at NNLO are compared to HERAPDF1.0 (NLO) only illustratively ➔ expect to be different!

HERAPDF including Low Energy data



- Preliminary HERA Combined Low Energy data available!

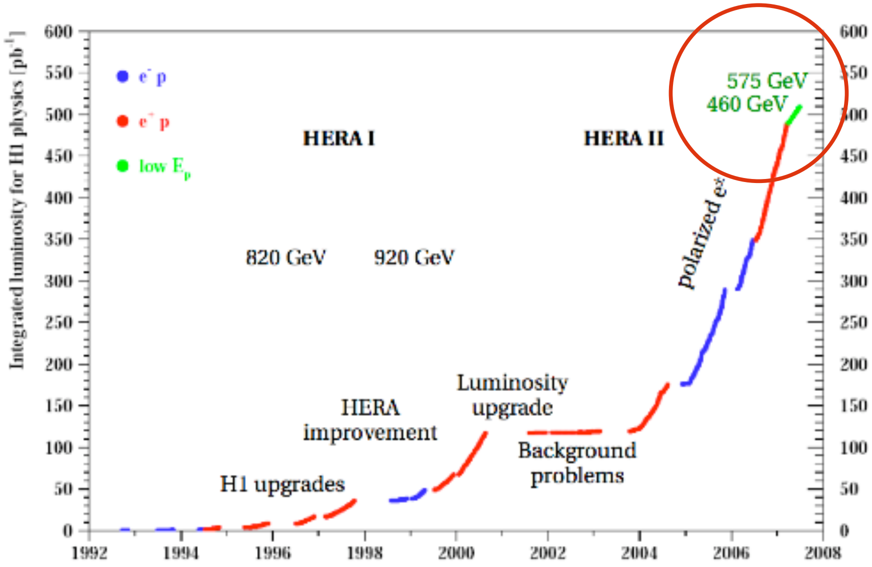
- New accurate measurement in Q^2>2.5 GeV^2 range, sensitive to structure function F_L are included in the QCD analysis on top of the HERA I data➔



- 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

HERAPDF including Low Energy data



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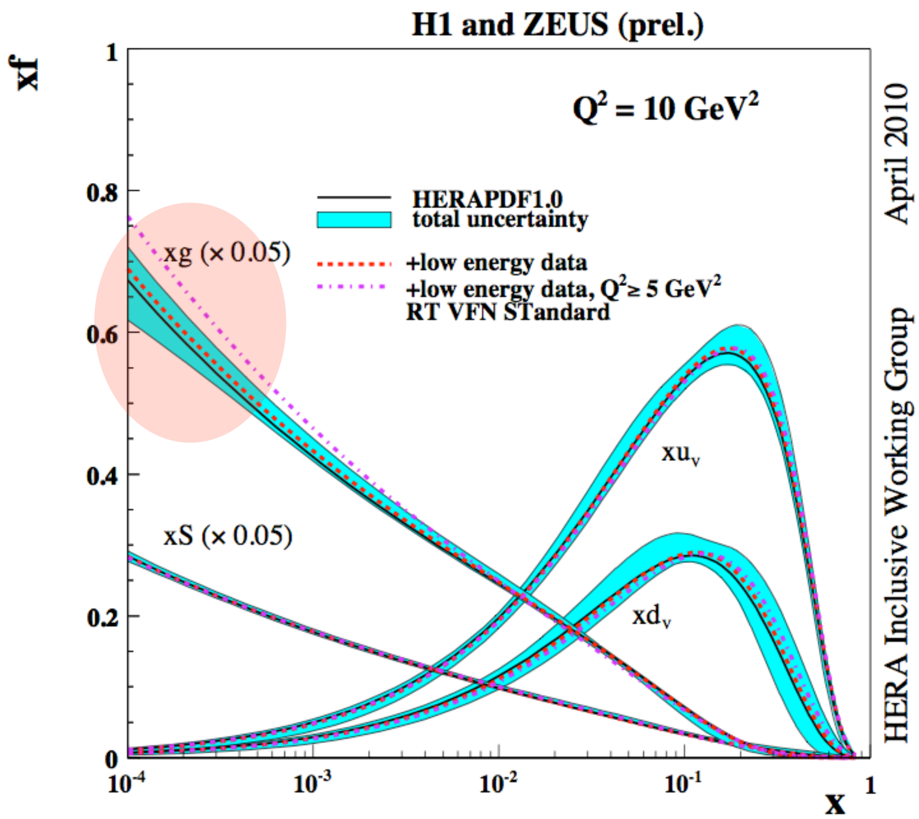
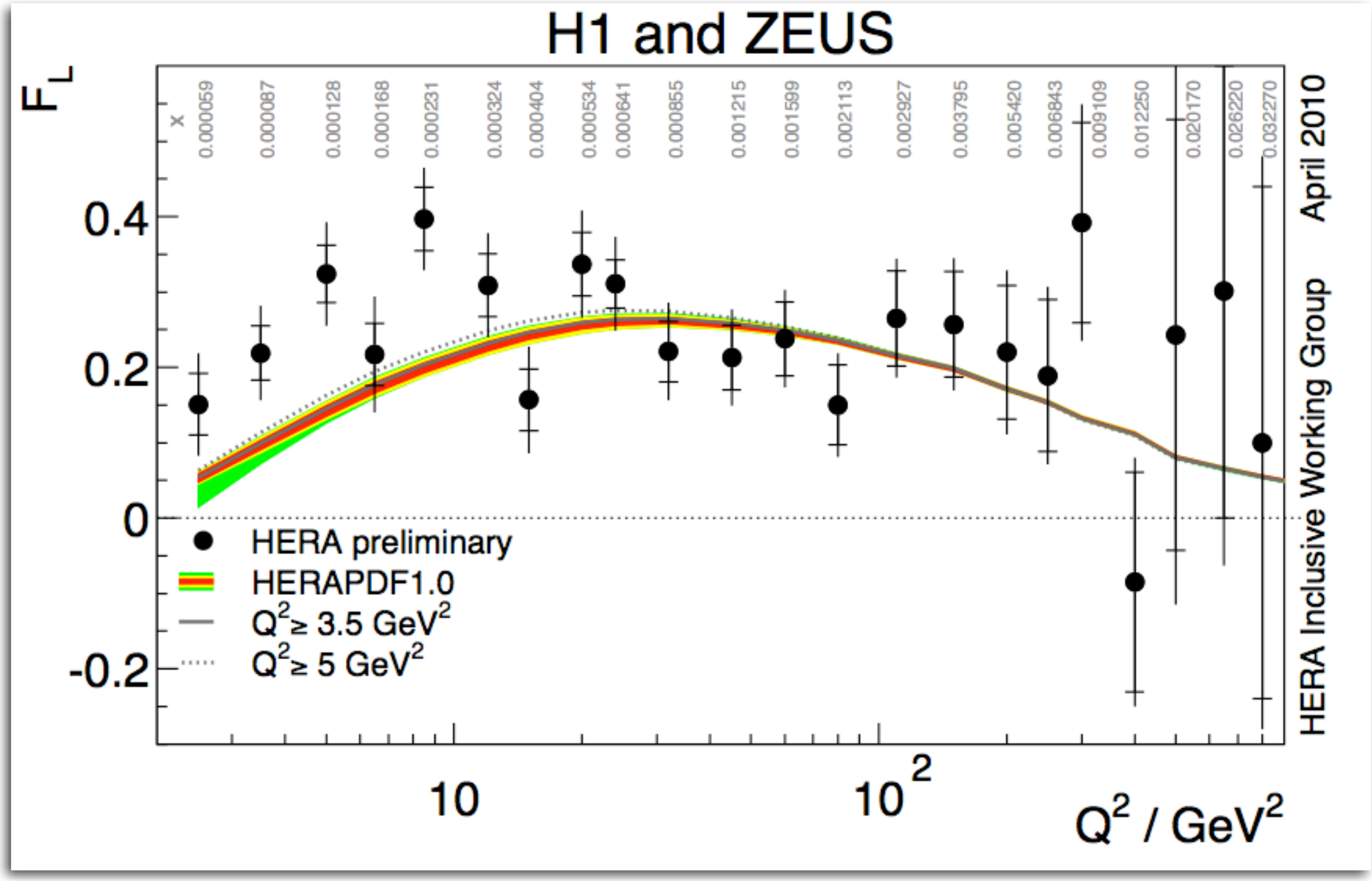


- However, The $Q^2 \geq 5\ GeV^2$ cut brings large improvement in χ^2 [818/806 → 698/771] and it yields different shapes for gluon and sea PDFs.
  - for HERAPDF1.0, Q^2 cut variation is included in the model uncertainty, but it had smaller effect.

HERA F_L data vs F_L predictions

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

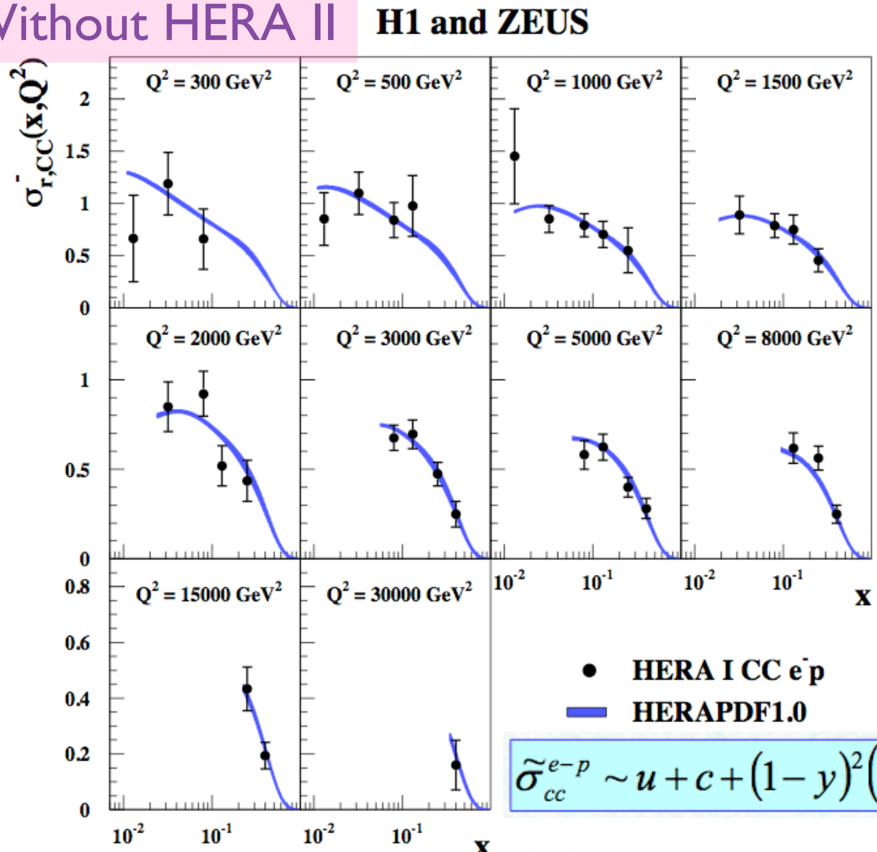


Low Q^2 region remains very interesting for further QCD tests!

Combining HERA I and II Inclusive data

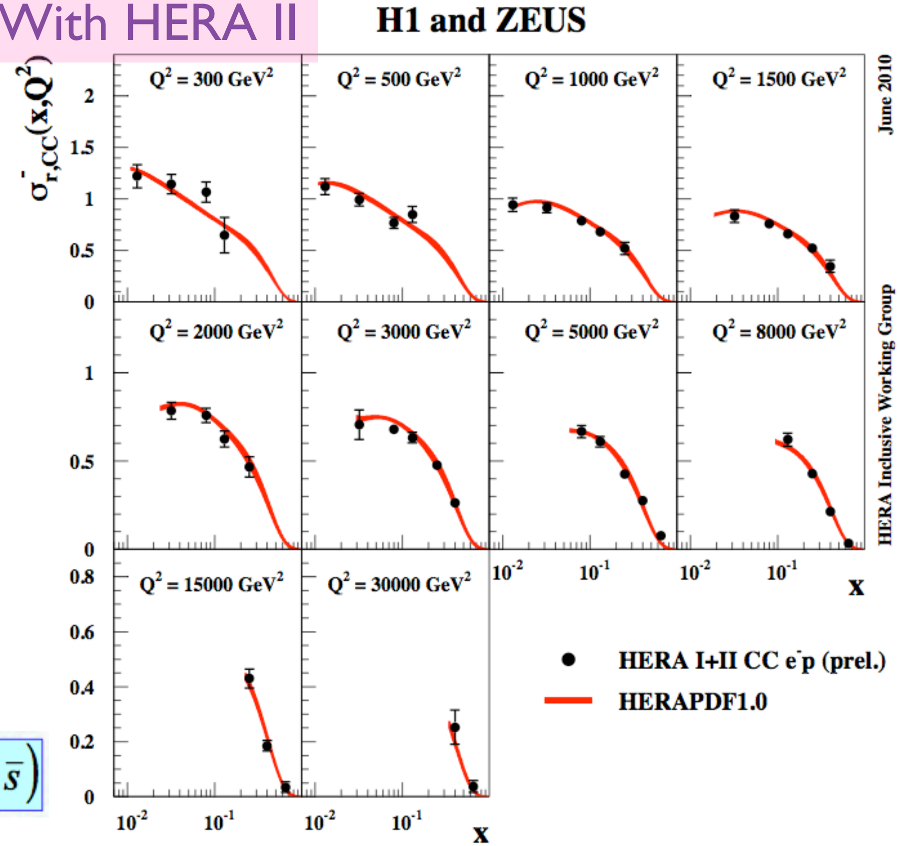
- New HERA II preliminary data available!
  - More precise measurements in the high Q^2 and high x regions (especially NC e^-p and CC $e^\pm p$)
  - ➔ could constrain better PDFs at high x
- HERA I and HERA II are combined using same averaging procedure as described before:
  - 674 unique cross sections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

Without HERA II



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

With HERA II

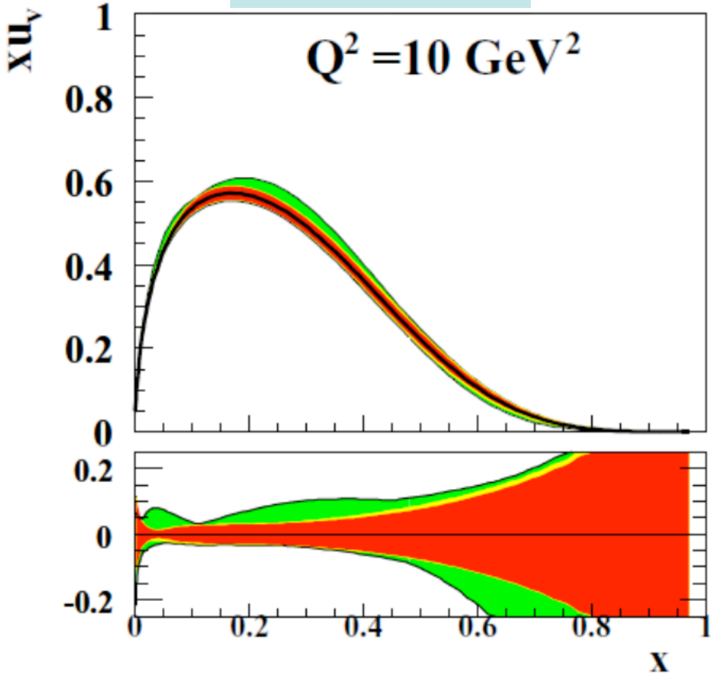


Much more precise CC measurements after including new high Q^2 HERA II set!

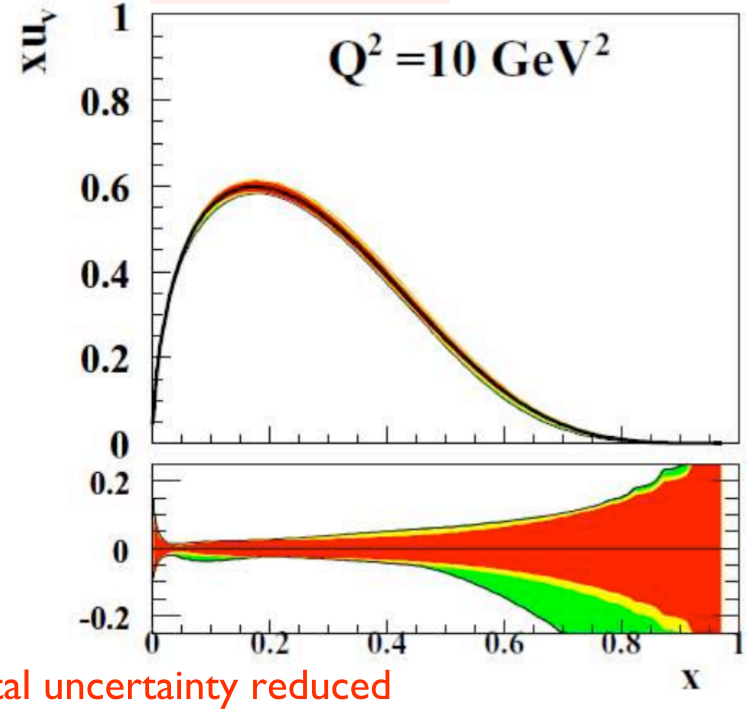
Fits to New Combined HERA data: HERAPDF1.5

- 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.

HERAPDF1.0



HERAPDF1.5

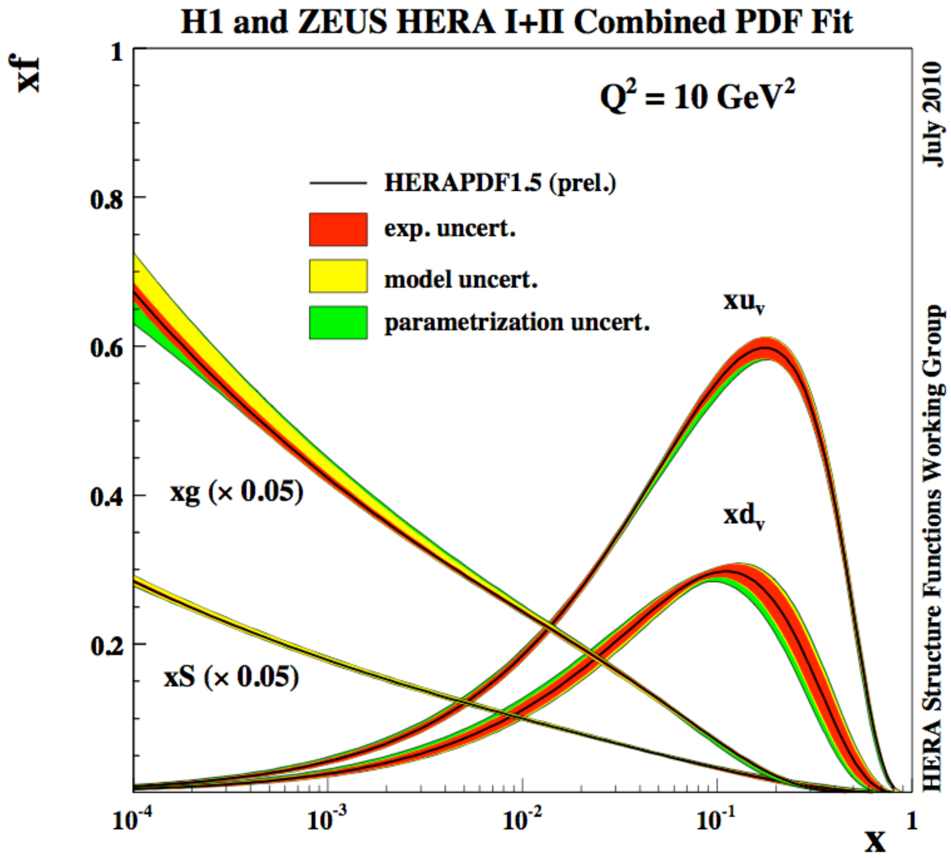


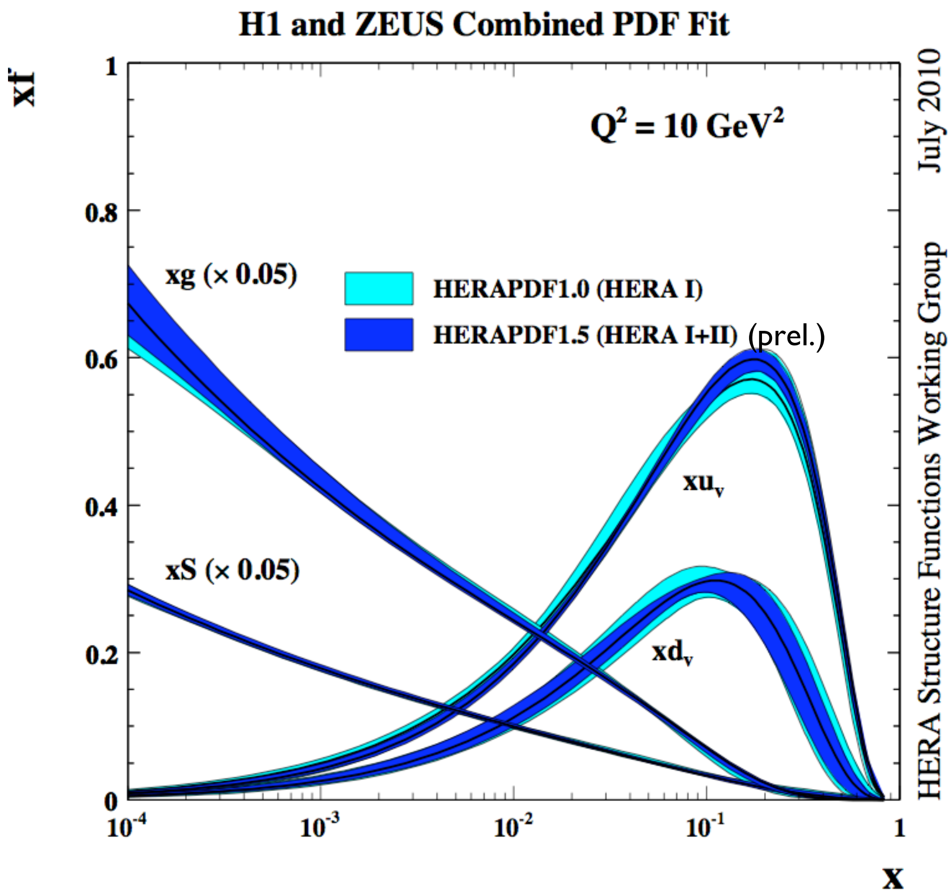
⇒Experimental uncertainty reduced

⇒Parametrisation uncertainty reduced

HERAPDF1.5 vs HERAPDF1.0

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





- 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!