Recent Combined Results of H1 and ZEUS

Katerina Lipka, DESY

69 PRC Open Session 29 April 2010

Aim: best precision for HERA legacy

HERA Combination Working Groups

- **Exotics:** maximize the statistical precision of the H1 and ZEUS observations
- **ElectroWeak:** test EW unification in the t-channel, W-production
- **Proton Structure:** NC and CC cross sections, PDF fits
- **Diffraction:** extraction of the proton diffractive structure function, better understanding of colour neutral exchanges
- **Jets:** extraction of α_s, combined measurement of jet cross sections
- **Heavy Flavours:** combine measurements of charm and beauty production

Official webpage: https://www.desy.de/h1zeus/combined_results

Since last PRC

Publications:

JHEP 0910 (2009) 013

Multi-Leptons with High Transverse Momentum at HERA

JHEP 1003 (2010) 035

Events with an Isolated Lepton and Missing Transverse Momentum and Measurement of W Production at HERA

JHEP 1001 (2010) 109

Combined Measurement and QCD Analysis of the Inclusive ep Scattering Cross Sections at HERA

Preliminary Results:

- Combination of DIS cross sections at low energy and extraction of F_L at HERA
- QCD analysis of NC and CC DIS cross sections including the measurements at low energy
- QCD analysis of HERA charm data

Since last PRC

Publications:

JHEP 0910 (2009) 013

Multi-Leptons with High Transverse Momentum at HERA

JHEP 1003 (2010) 035

Events with an Isolated Lepton and Missing Transverse Momentum and Measurement of W Production at HERA

JHEP 1001 (2010) 109

Combined Measurement and QCD Analysis of the Inclusive ep Scattering Cross Sections at HERA

Combined data in the PDF Fits

Performance of HERAPDF1.0

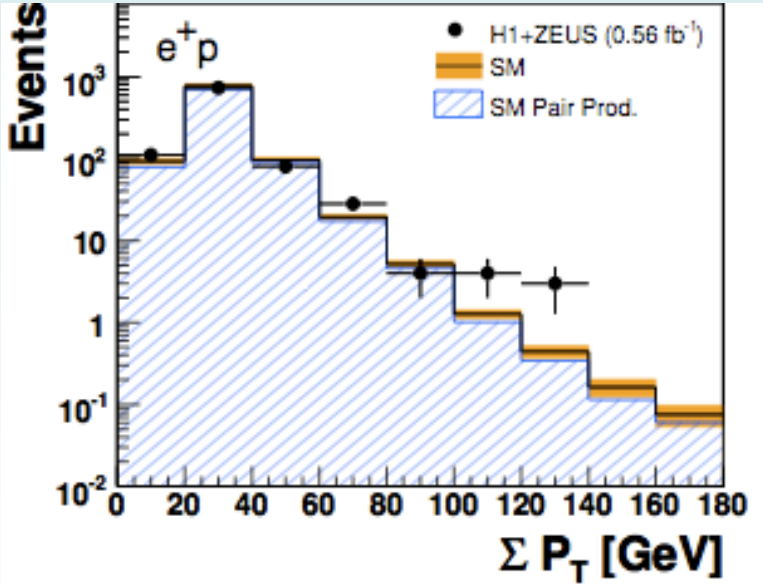
Preliminary Results:

- Combination of DIS cross sections at low energy and extraction of F_L at HERA
- QCD analysis of NC and CC DIS cross sections including the measurements at low energy
- QCD analysis of HERA charm data

Multileptons with high p_T, Isolated Leptons, W production at HERA

JHEP 0910 (2009) 013

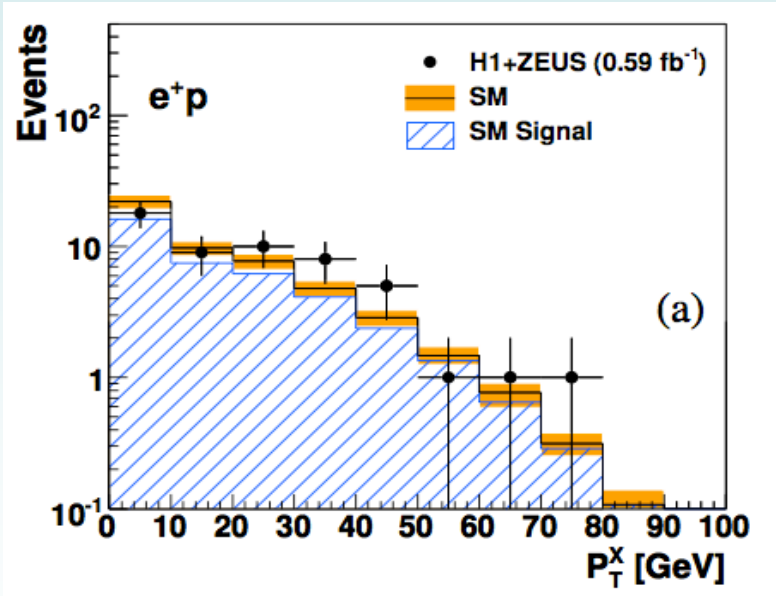
Multi-Leptons with High Transverse Momentum at HERA



good agreement with the SM
small excess at high p_T in the e^+p data

JHEP 1003 (2010) 035

Events with an Isolated Lepton and Missing Transverse Momentum and Measurement of W Production at HERA

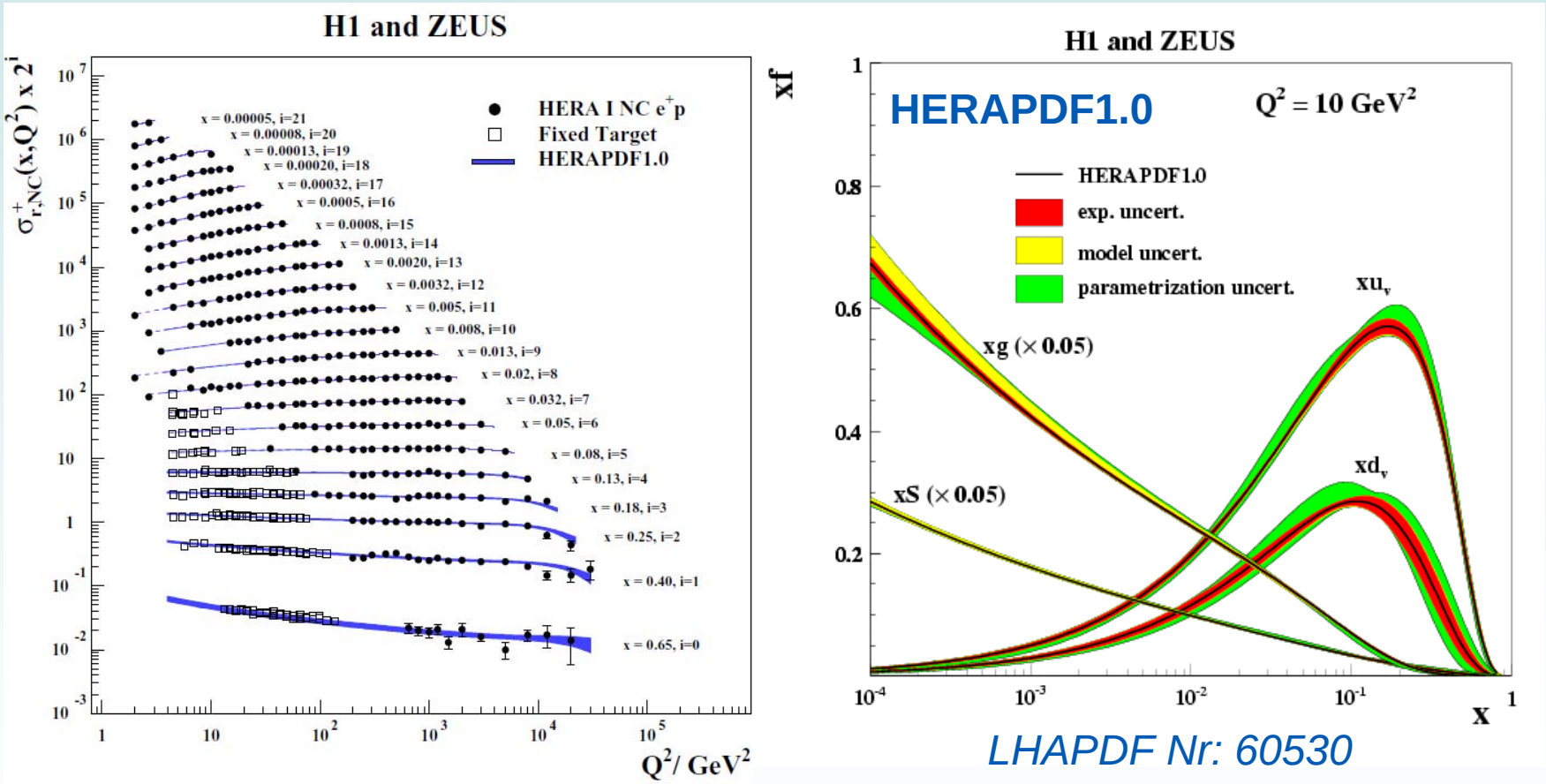


excess in e^+p data at H1 less significant with addition of ZEUS data

good agreement with the SM observed W cross section measurement

Measurement and QCD Analysis of ep Cross Sections at HERA

JHEP 1001 (2010) 109



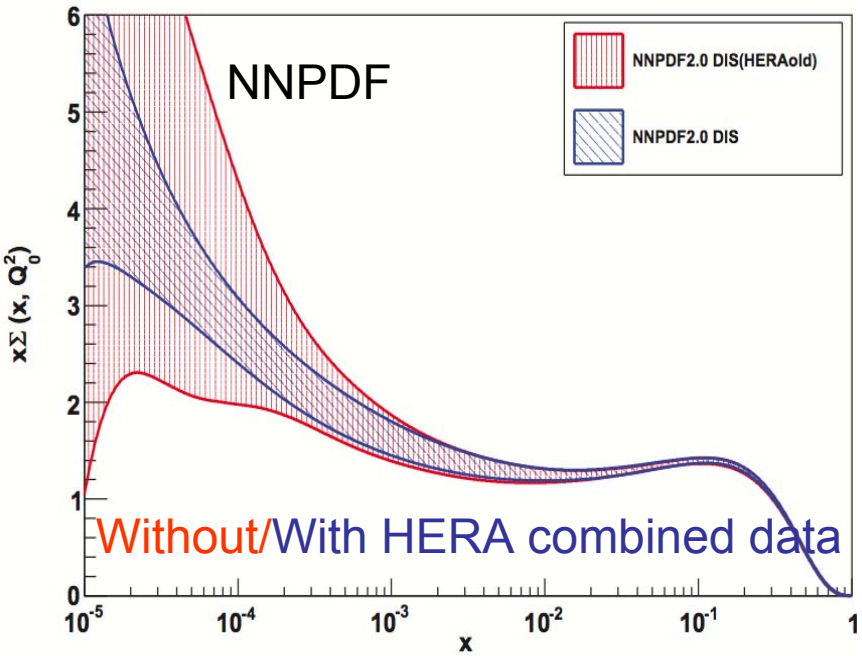
PDFs determined from the QCD fit to the NC and CC cross sections

Gluon density determined from scaling violations $\frac{\partial F_2}{\partial \ln Q^2} \propto \alpha_S(Q^2) xg(x,Q^2)$

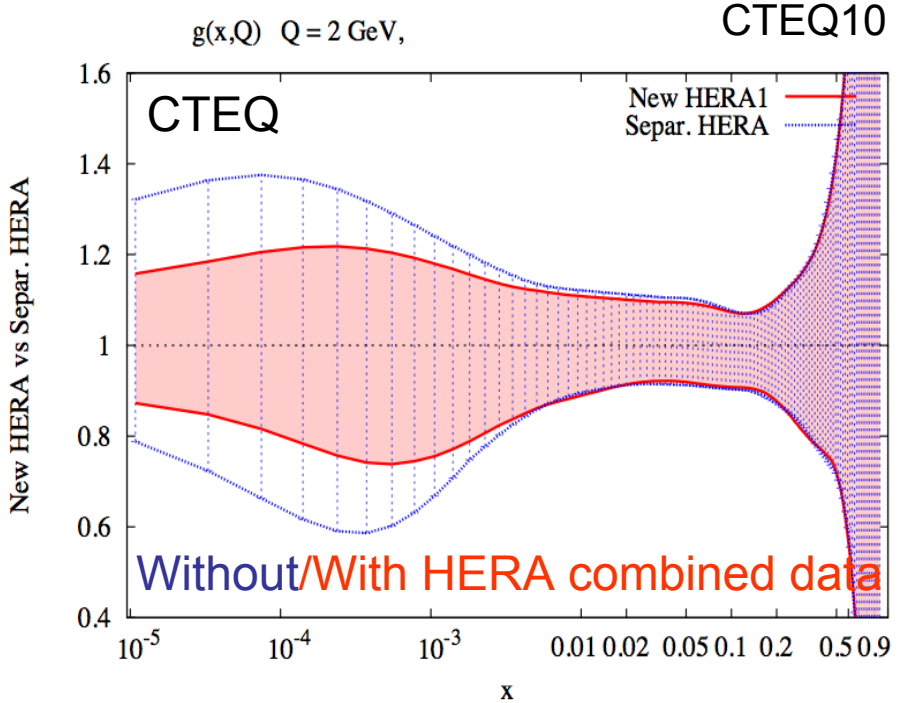
Combined HERA data in PDF fits

HERA data *(JHEP 1001 (2010) 109)* included in the global PDF analyses

NNPDF2.0



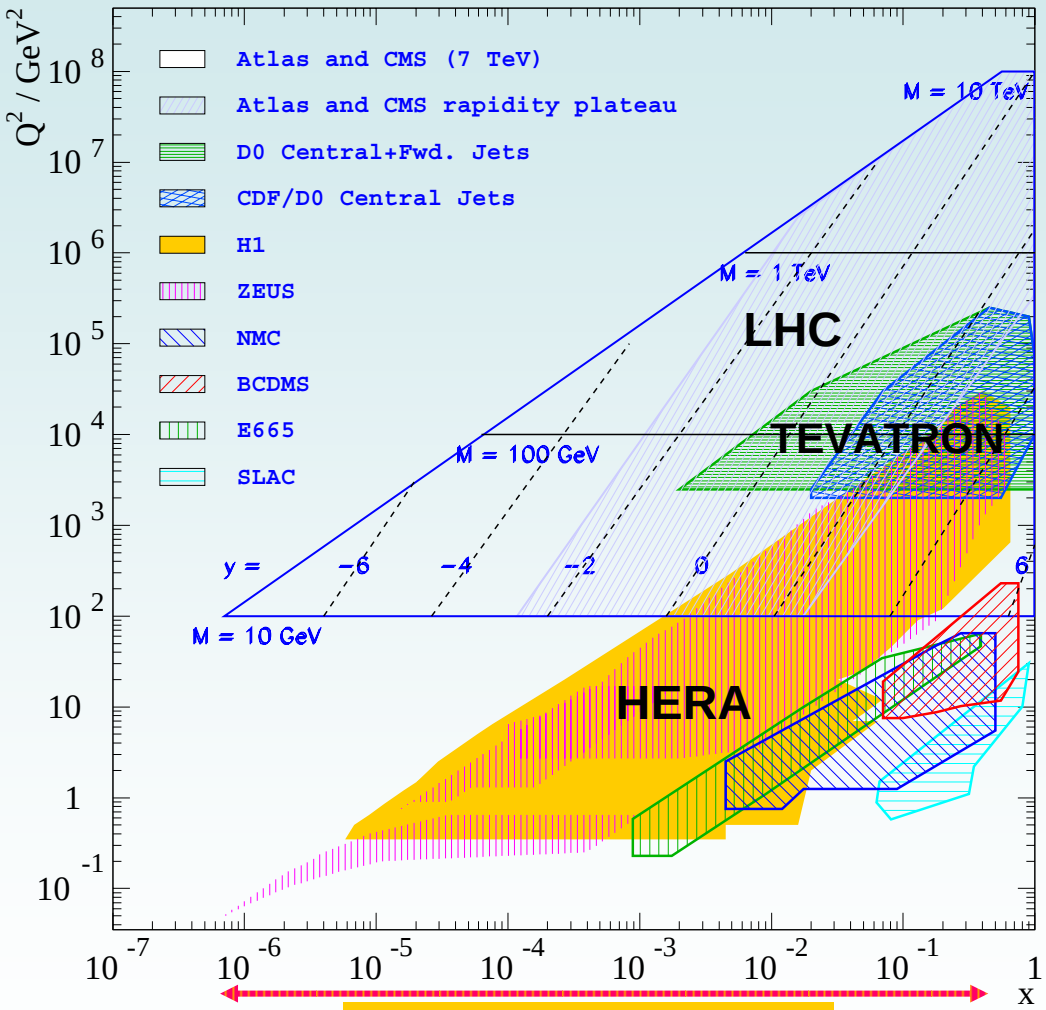
CTEQ10



Combined HERA data are now used by global PDF Fit groups

Experimental uncertainty improves significantly at low x

PDFs from HERA to other experiments



HERA coverage in x

HERA DIS Measurements:

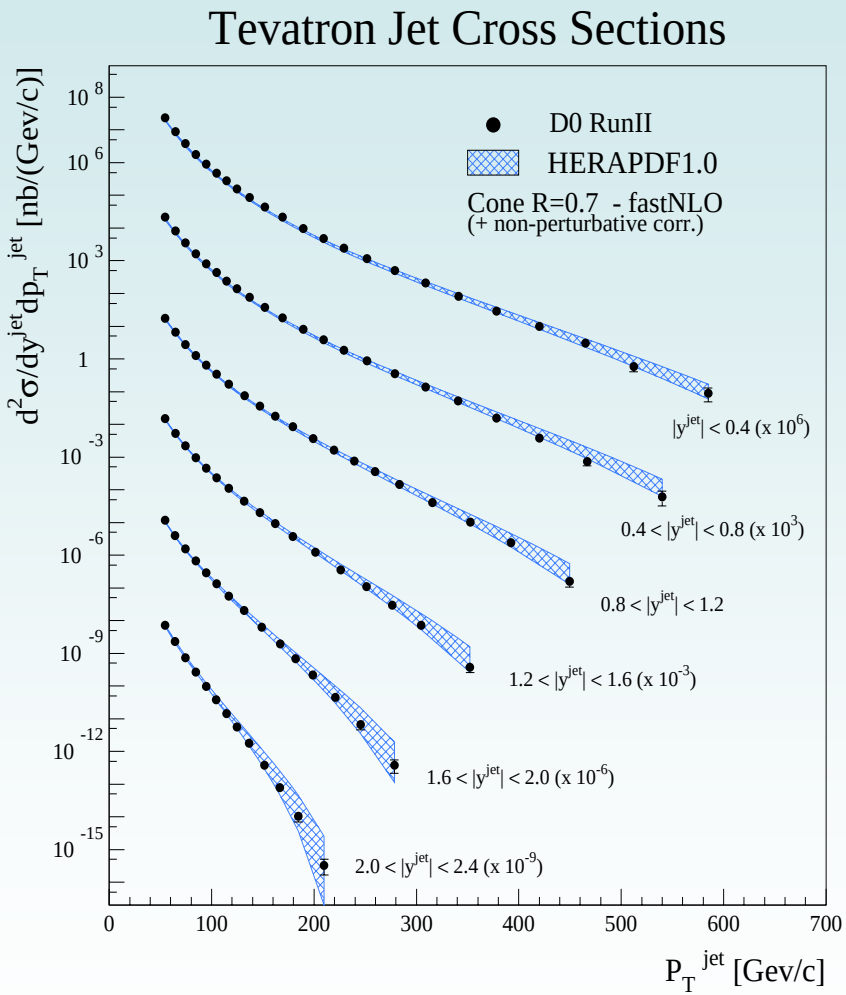
covers most of the (x,Q^2) plane,

best constrain at low, medium x

From HERA to kinematics of Tevatron, LHC:

Evolution via DGLAP

HERAPDF1.0 vs Jets at TEVATRON



Data: D0 Run II

Band: NLO calculation

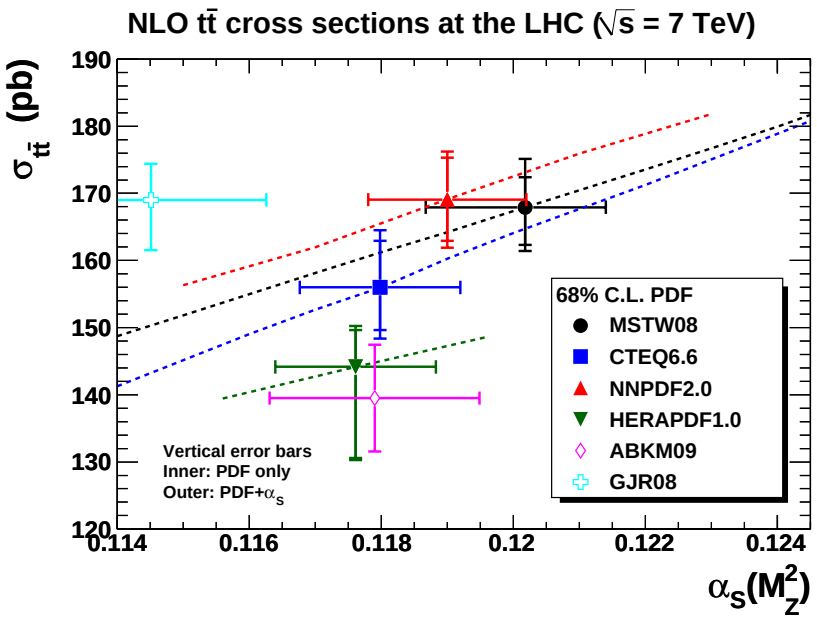
+ hadronization

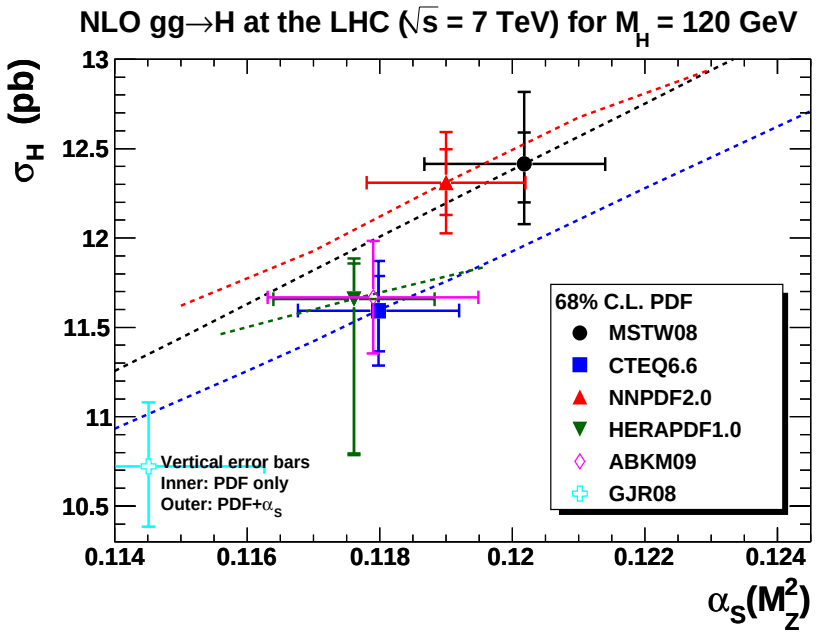
+ underlying event

PDF HERAPDF1.0

Prediction based on HERAPDF1.0 is in agreement with Tevatron data

Benchmarking PDFs: LHC cross sections





HERAPDF one of the major players in benchmarking activity

HERAPDF1.0 provides realistic uncertainty for LHC cross sections

dominant uncertainty (parameterization) not accounted for in most global Fit groups

New Combination: low energy data

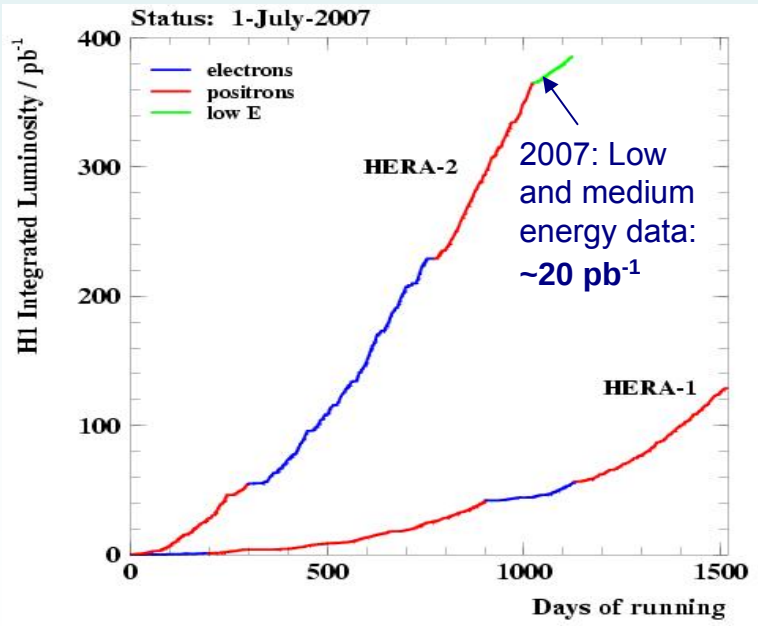
Combination of HERA II NC cross sections: Lower Energy Data

Measurements performed at 3 different energies: sensitive to F_L

$$\sigma_r = F_2(x,Q^2) - \frac{y^2}{1+(1-y)} F_L(x,Q^2), \quad y = 1 - \frac{E_{e'}}{E_e}$$

direct access to gluon density

HERA II running:

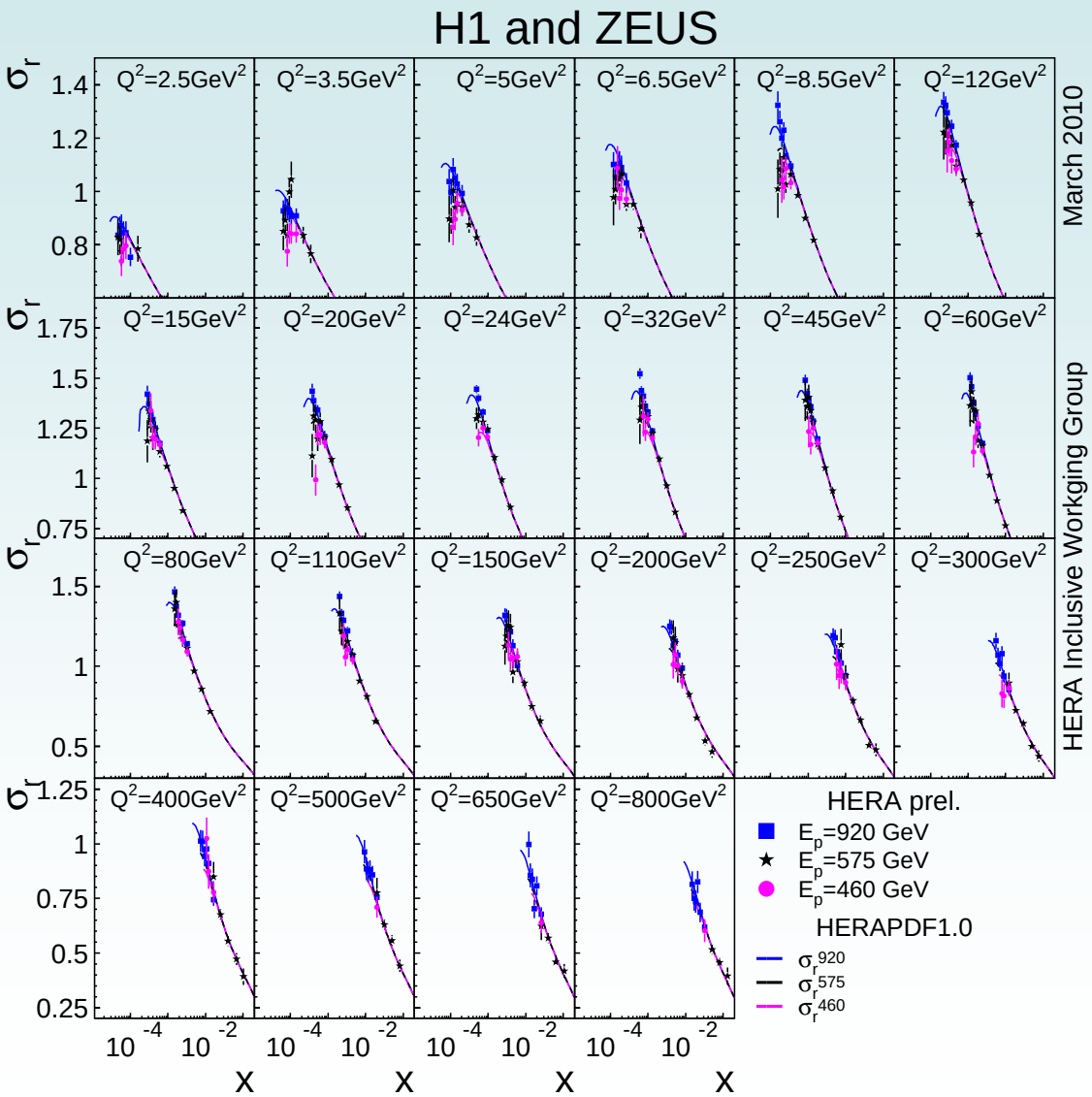


Combined data:

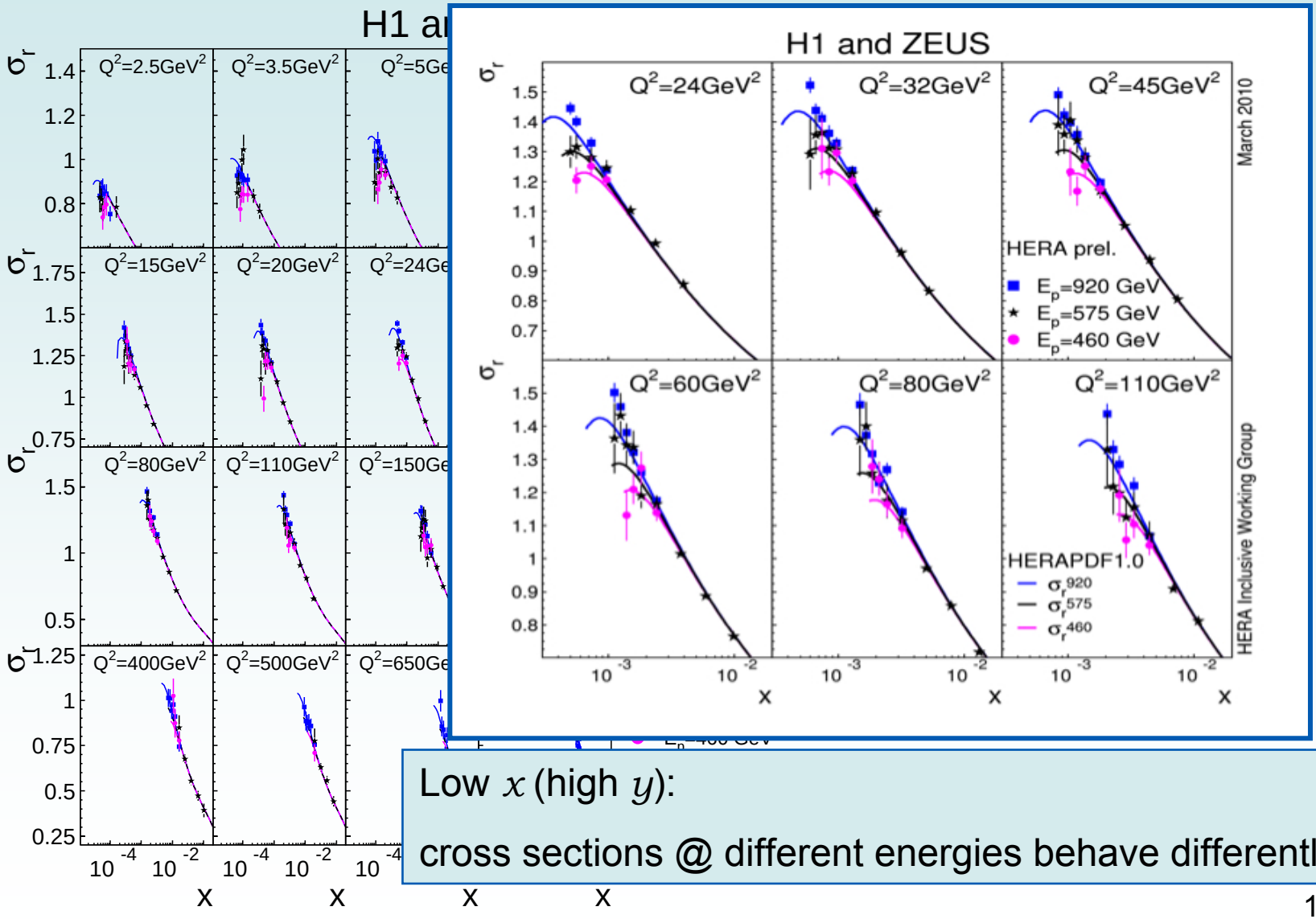
H1	ZEUS
$2.5<Q^2<800$ GeV^2	$24<Q^2<110$ GeV^2
EPJ C63,625(2009)	Phys. Lett B682,8 (2009)
EPJ C64,561(2009)	
H1-prel-09-044	
H1-prel-08-042	

Systematic correlations are taken into account

Combination of low energy data



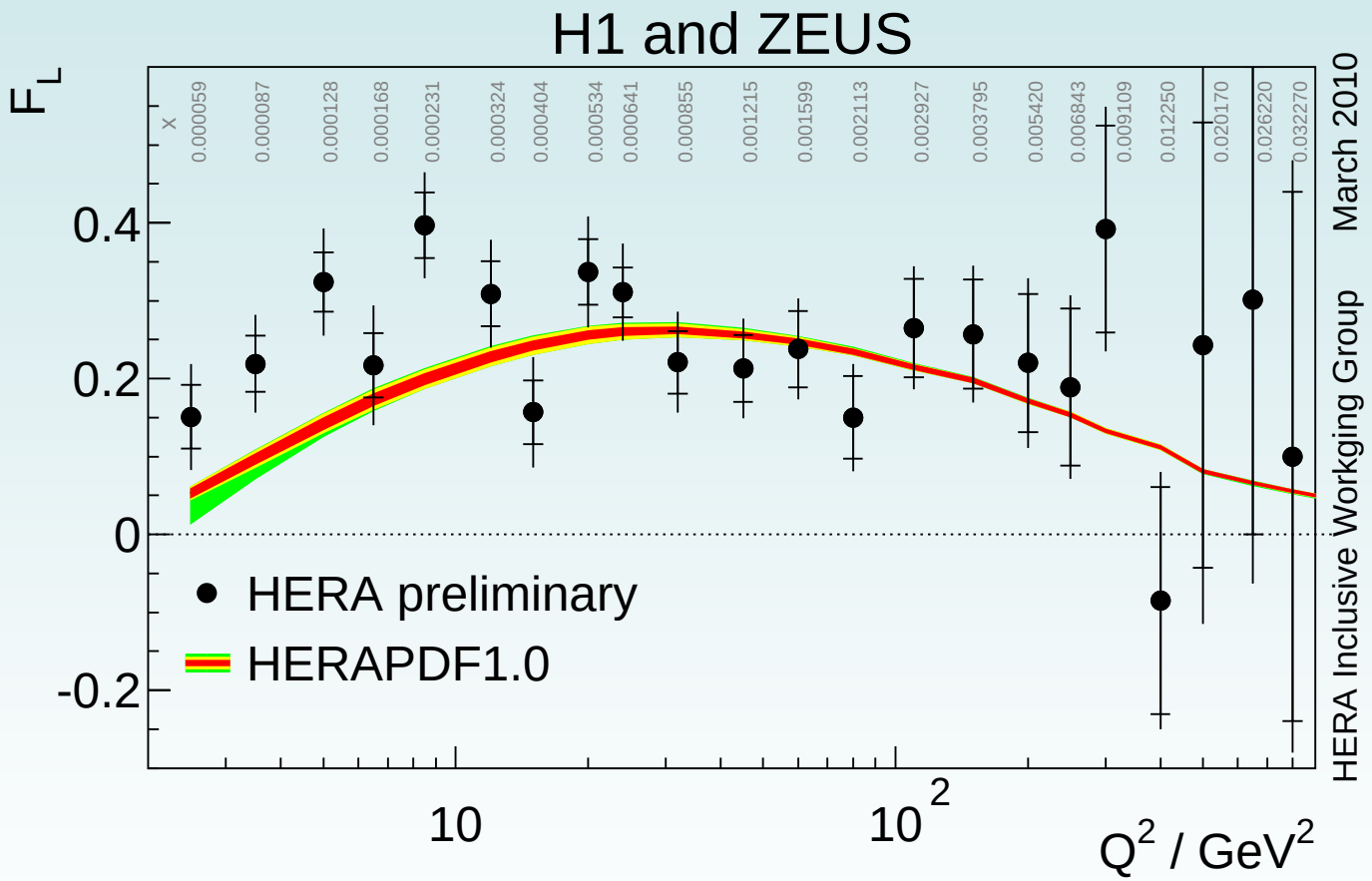
Combination of low energy data



Low x (high y):

cross sections @ different energies behave differently

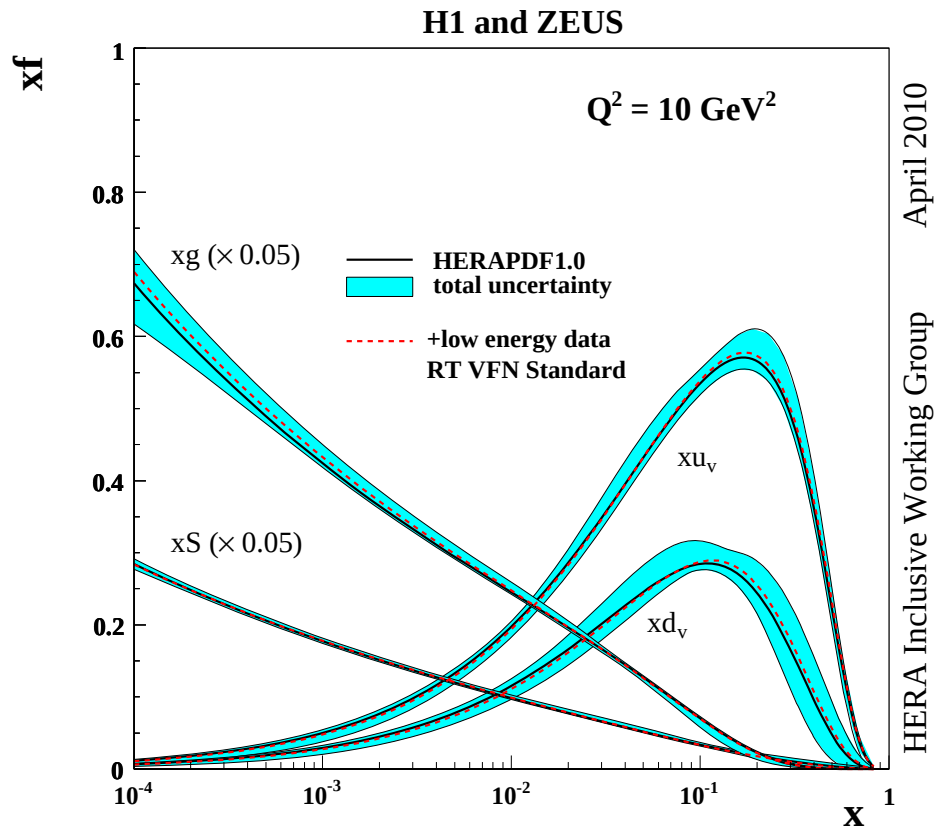
Measured F_L vs QCD⊗HERAPDF1.0



Combined F_L in general consistent with QCD prediction (HERAPDF1.0)

Low Q^2: QCD prediction tend to underestimate the measurement

PDF Fits using low energy data



Combined cross sections at lower energies used in PDF fit

Settings as in HERAPDF1.0

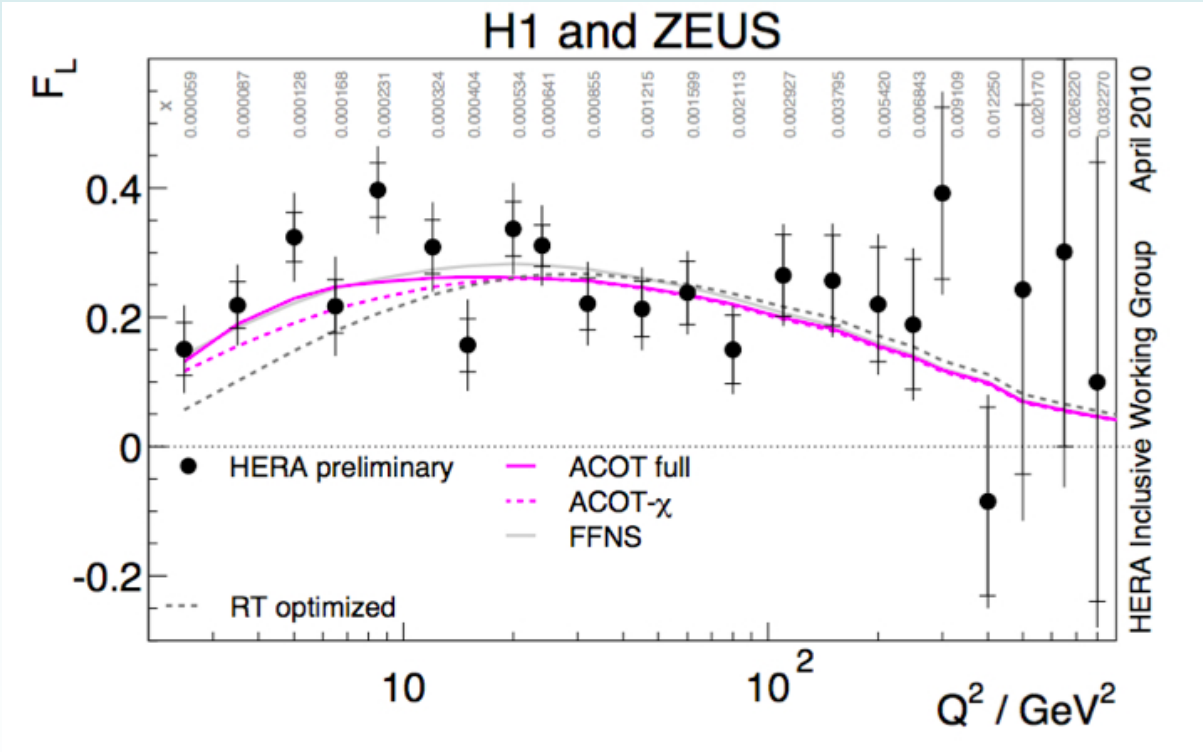
PDF using LER cross sections agree well with HERAPDF1.0

Does not explain the low Q^2 problem in F_L

F_L and heavy quark treatment in PDFs

Different prescriptions how to treat Heavy Quarks in PDF Fits available:

c, b - massless partons in the proton / massive c, b from boson-gluon fusion



Combined F_L

vs

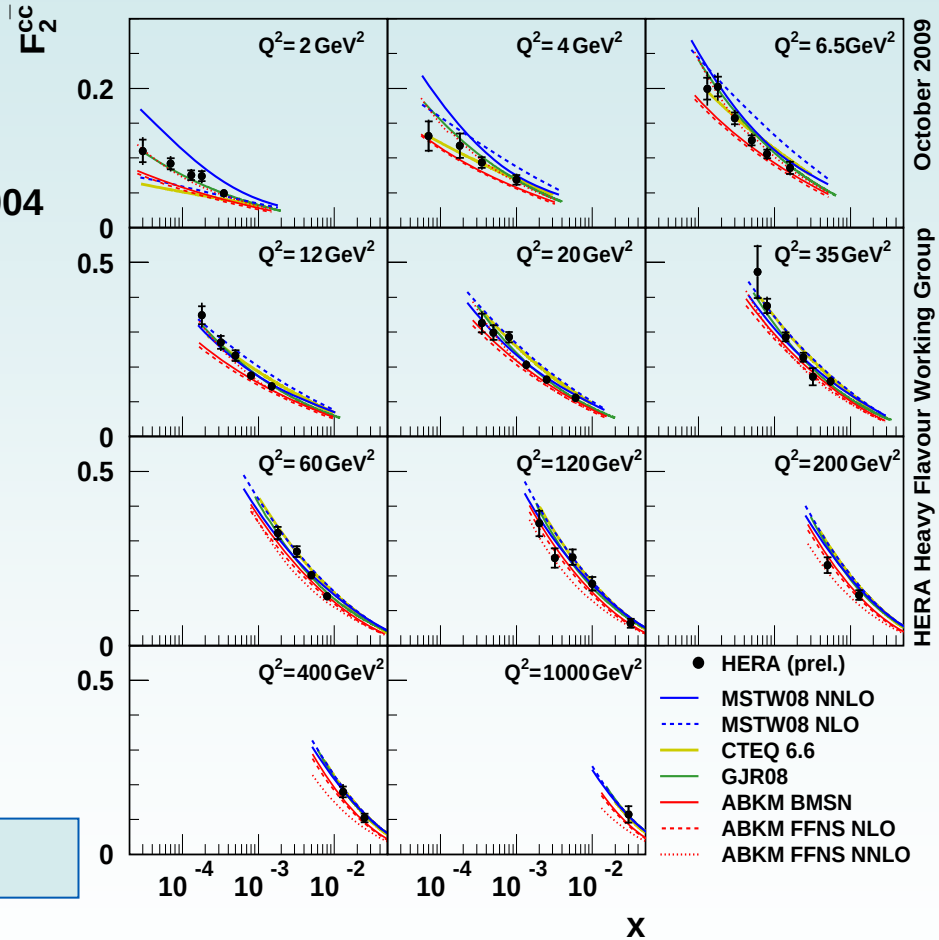
HERAPDF fits with different heavy flavour treatment

F_L data have sensitivity to treatment of heavy quarks in the PDF fit

Combined charm vs global fit predictions

Data in the combination

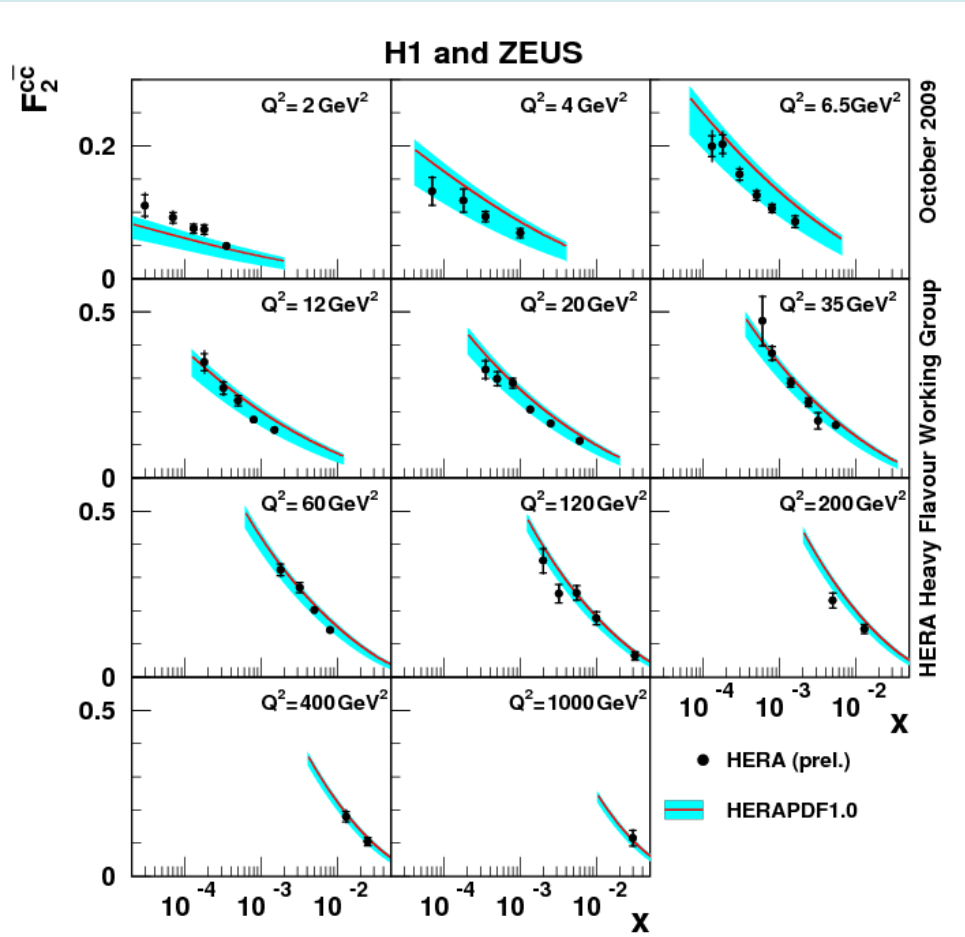
H1	ZEUS
EPJC 51 (2007) 271	PRD69 (2004) 012004
EPJC 45(2006) 23	EPJC 12 (2000) 35
EPJ C65 (2010) 89	EPJC63(2009) 171
H1-prel-08 -074	EPJC 65(2010) 65
H1-prel-08 -172	
H1-prel-08 -173	



Average precision 10%

Data precise enough to distinguish between various HF schemes

Charm data vs HERAPDF1.0



sensitivity to charm quark mass

m_c=1.4 GeV

m_c=1.35 *vs* 1.65 GeV

Impact on W/Z @ LHC (7 TeV):

choice of m_c=1.65 GeV

raises σ_W ,σ_Z by ~3%

(significant wrt other errors)

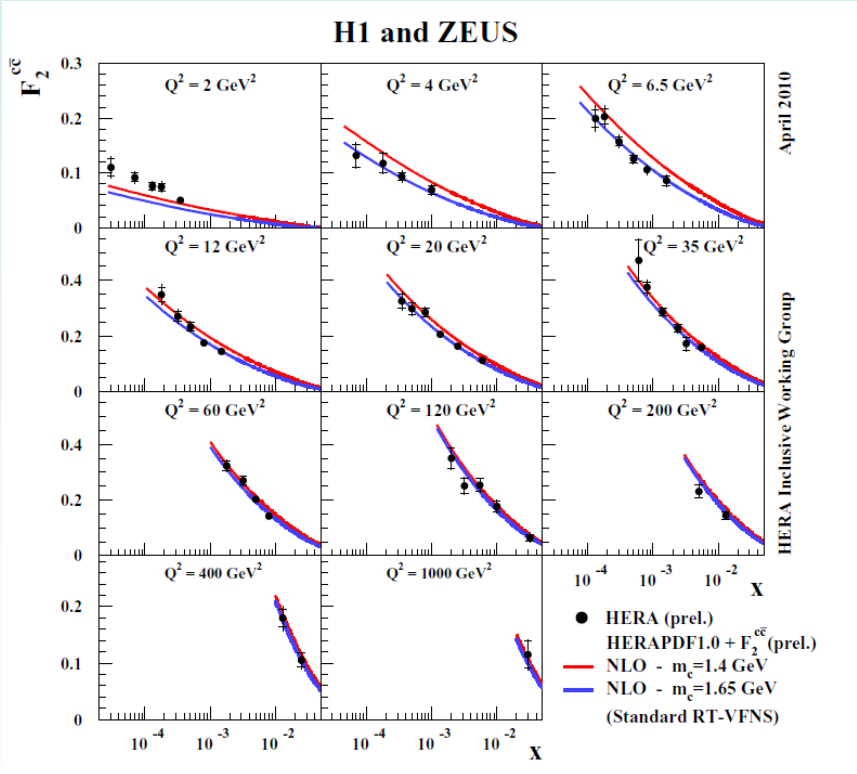
F_2^{cc} data not included in HERAPDF1.0

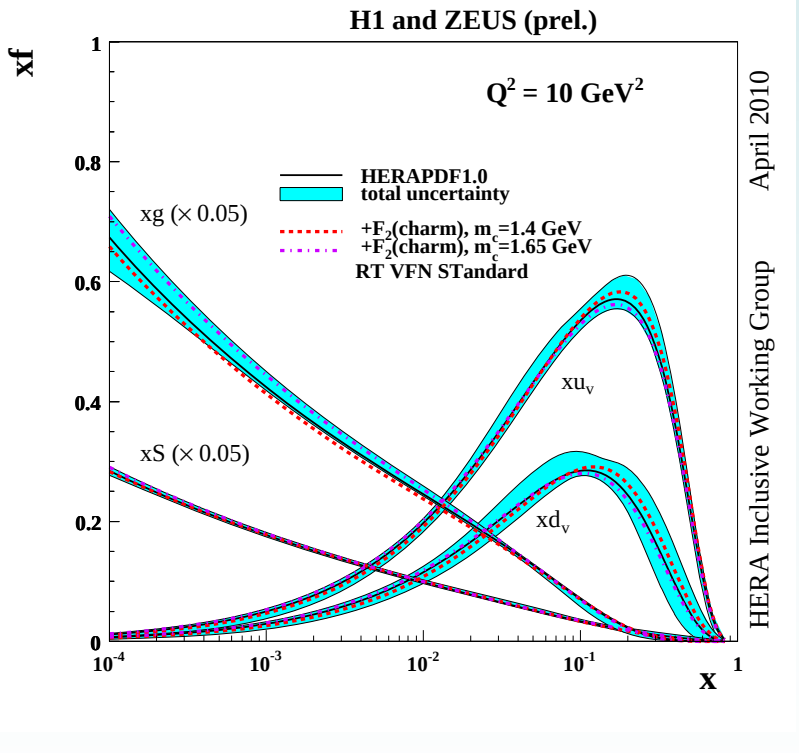
F_2^{cc} consistent with HERAPDF1.0 prediction

New: PDF Fits using HERA F_2^c data

formalism as for HERAPDF1.0, $Q^2 > 3.5\ GeV^2$,

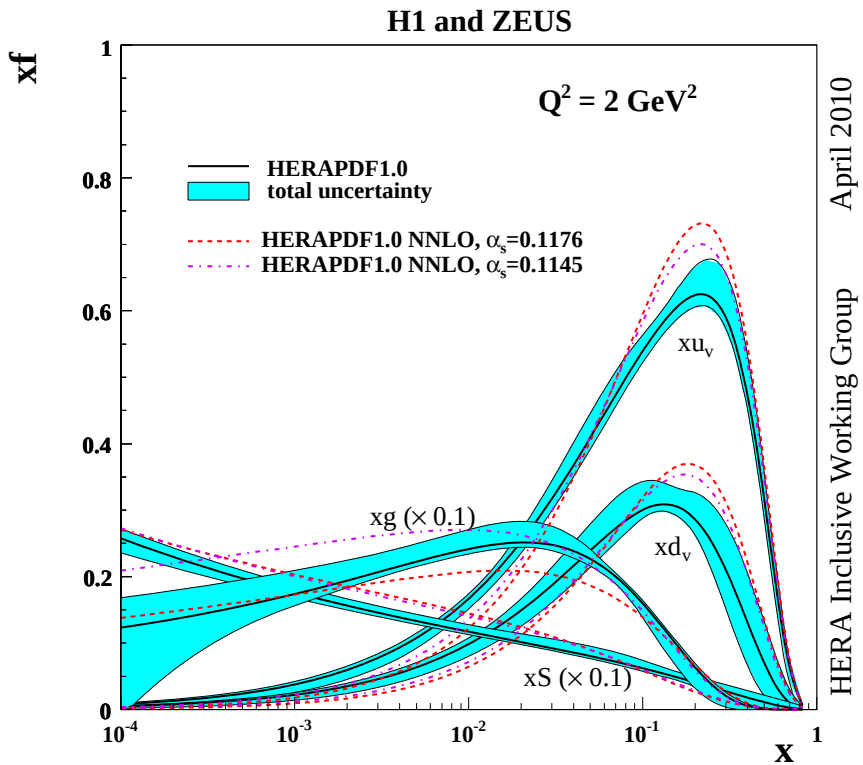
two values of charm mass $m_c = 1.4\ GeV$ and $m_c = 1.65\ GeV$ compared



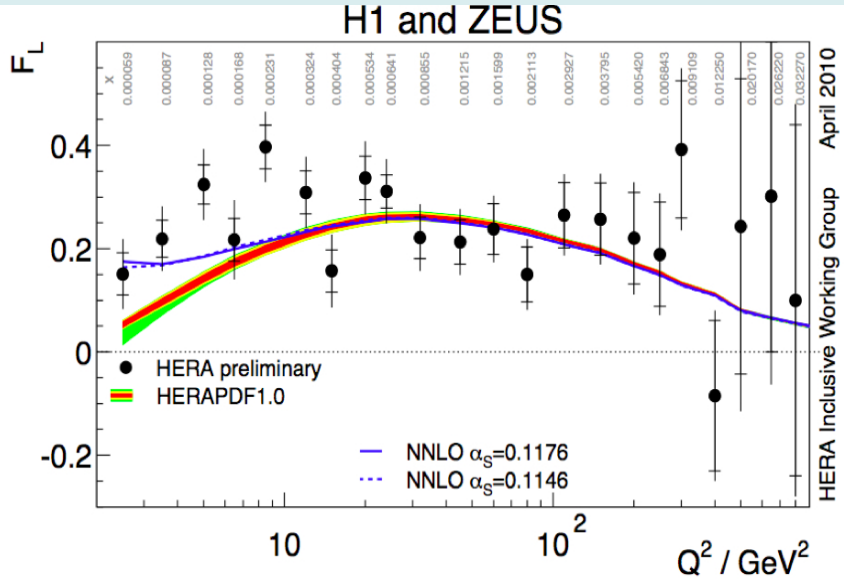


Best fit using $m_c = 1.65\ GeV$, preference for steeper gluon

HERA PDF Fits at NNLO



NNLO fit predicts different F_L shape



First PDF Fits in NNLO

NNLO has impact on F_L at low Q^2

Summary

- **Combination of H1 and ZEUS provides increasing precision**
  - HERAPDF1.0 best PDF measurements at medium and low x
  - HERA combined data decreases experimental uncertainty on PDFs
- **HERAPDF has a visible impact on LHC physics**

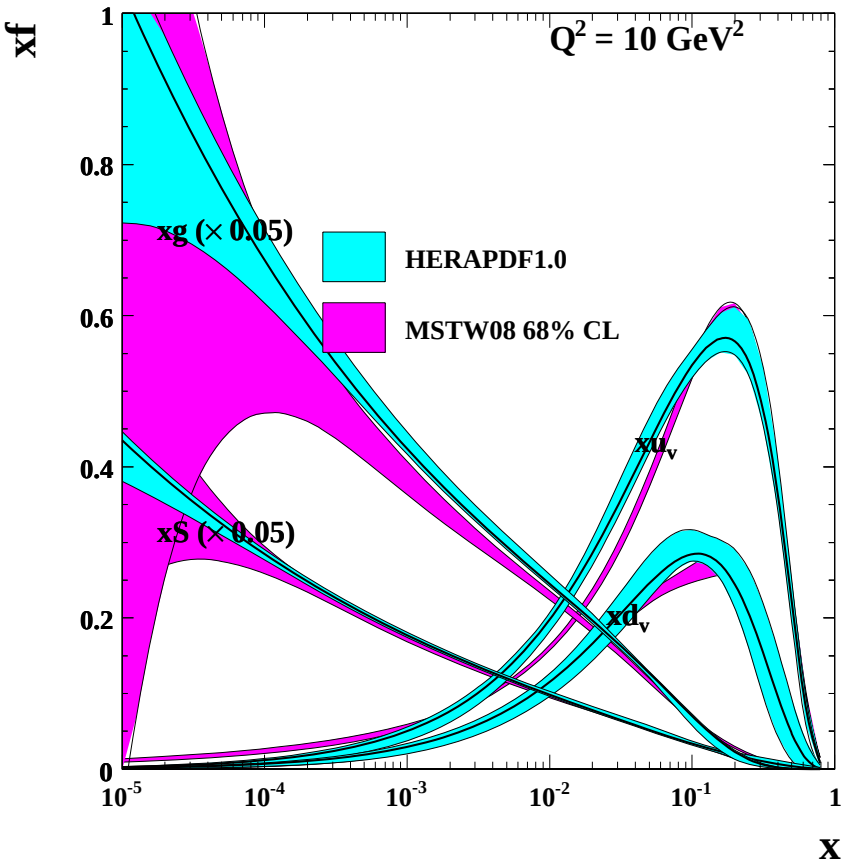
- **Combination of Low Energy cross sections and F_L released**
- **HERA performs PDF fits using Low Energy and charm data**
- **HERA NNLO PDF fits available**

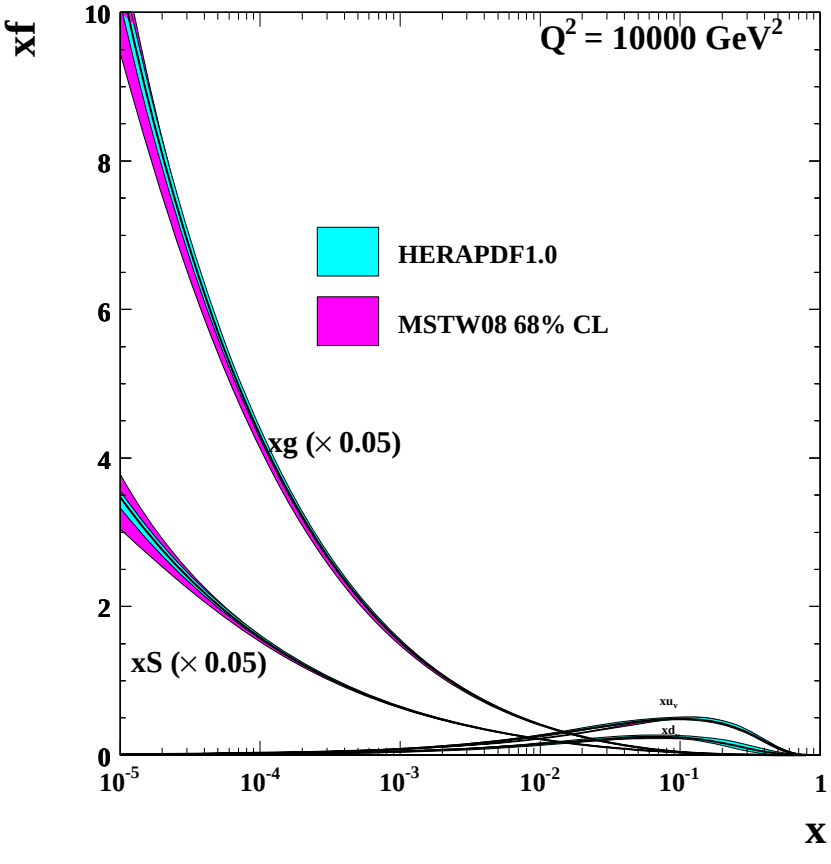
Plans and further Strategy

- Inclusive: combine high Q^2 data, win in precision at high Q^2 and x
  - HERA PDF + α_s fit using inclusive DIS cross sections, F_L, F_2^c, jets
- Diffraction: use HERA II data → HERA DPDFs
- Combination of Jet measurements → best determination of α_s
- Searches: extract best limits for high Q^2 data *(contact interactions, leptoquark)*
- HERA data preservation activities started for long term analysis
  - DESY-wide group formed, initial plans submitted to PRC

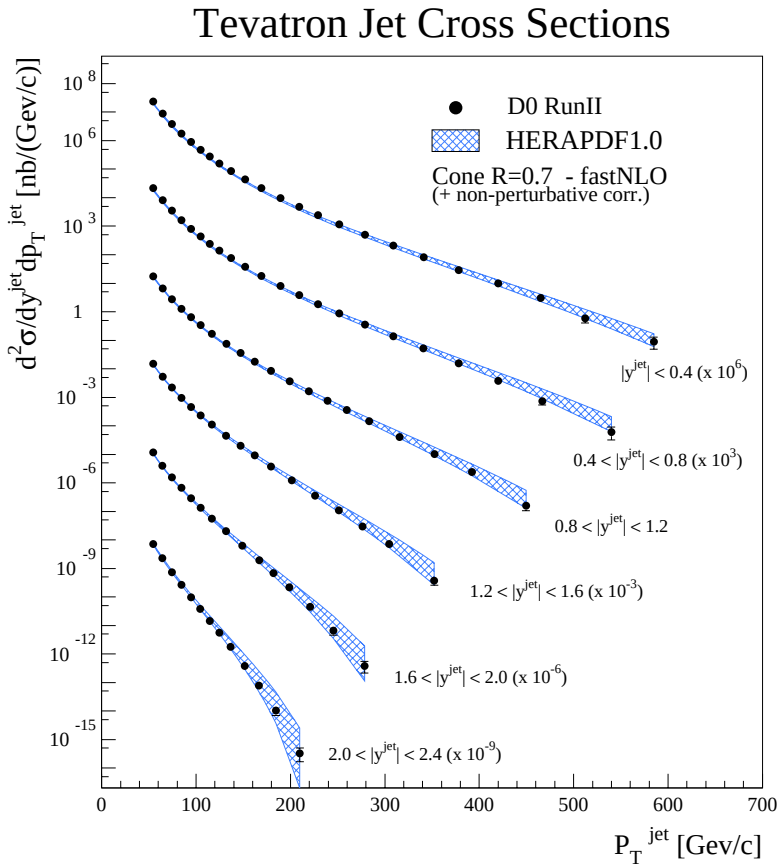
Back up

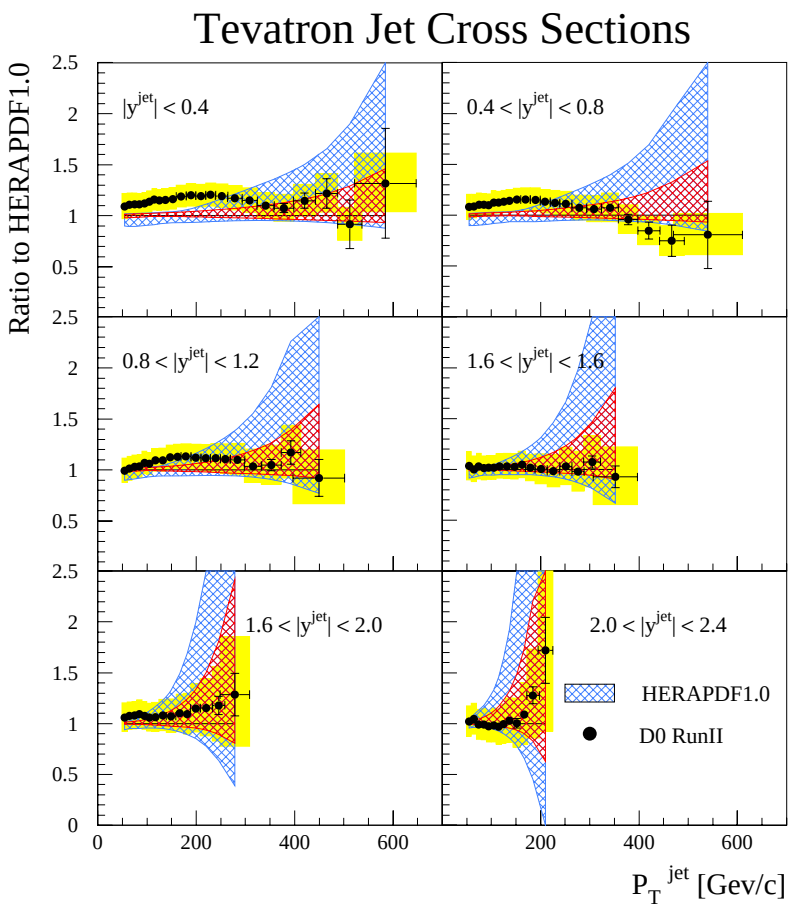
HERAPDF1.0 vs other PDF set





HERAPDF1.0 prediction for TEVATRON

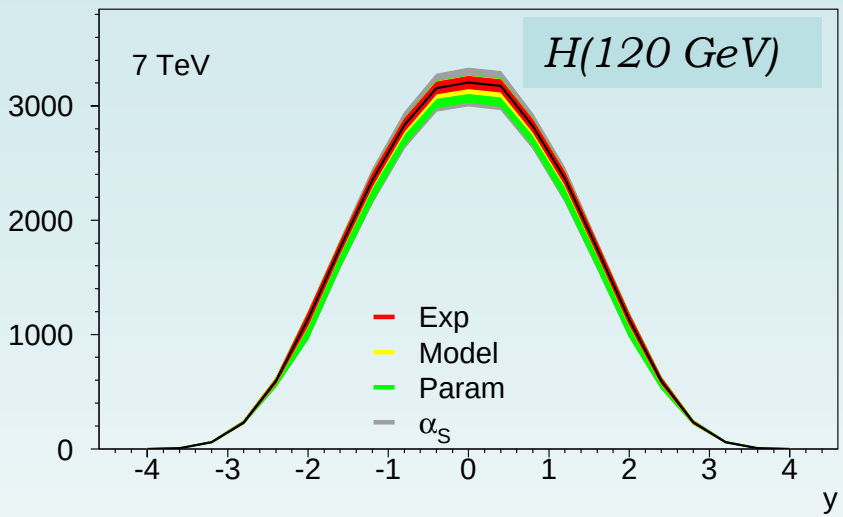


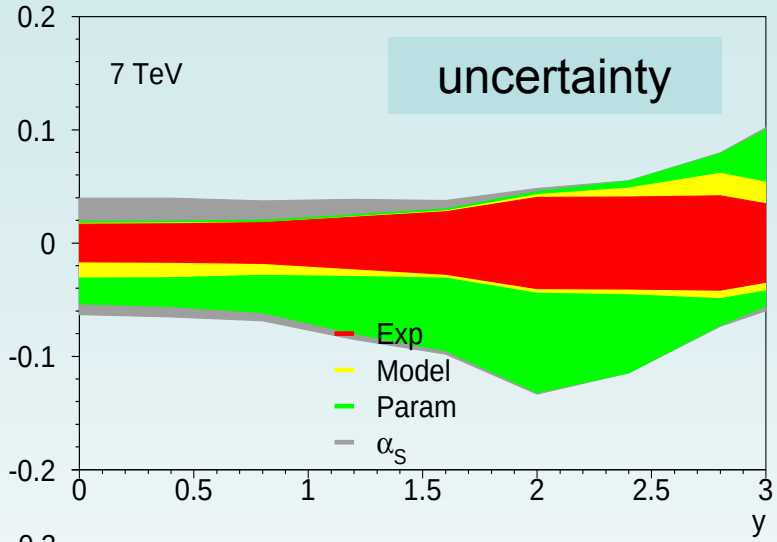


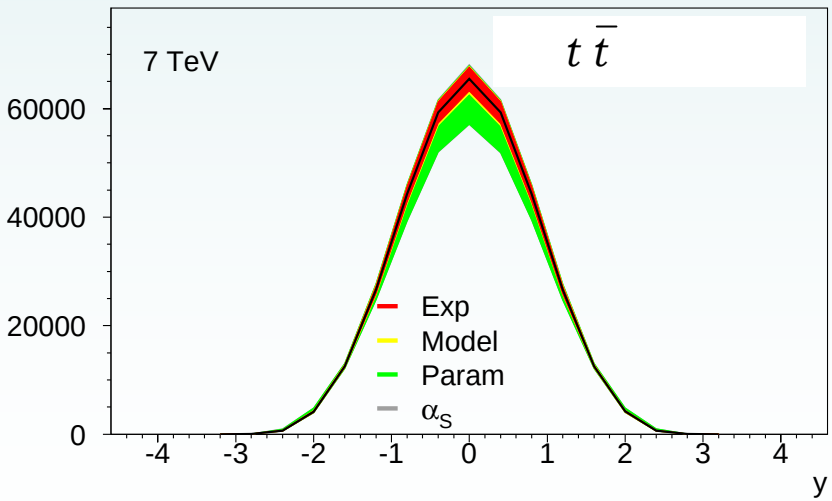
Band: NLO + hadronization + UE, proton described by HERAPDF1.0

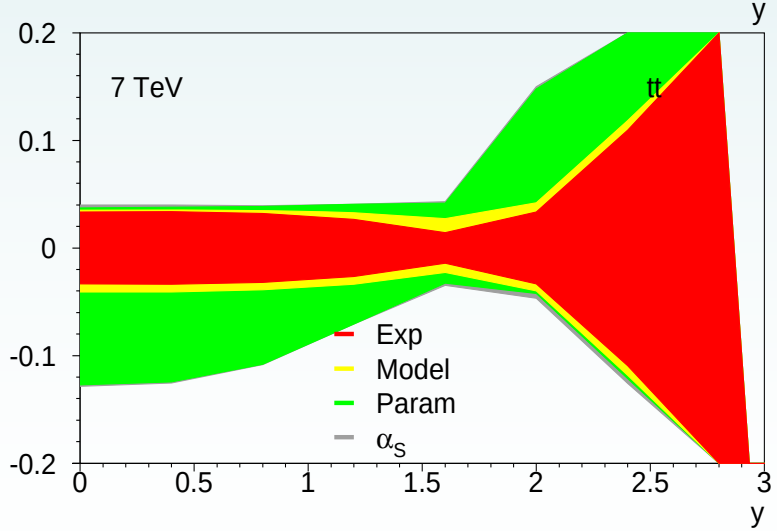
Uncertainties: total, experimental, correlated systematics of measurements

Benchmarking HERAPDF1.0









Low energy measurements and F_L

Longitudinal structure function directly sensitive to the gluon density:

$$F_L \sim \sigma_L$$
$$F_2 \sim (\sigma_T + \sigma_L)$$

QCD: $$F_L = \frac{\alpha_s}{4\pi} x^2 \int_x^1 \frac{dz}{z^3} \left[\frac{16}{3} F_2 + 8 \sum_q e_q^2 (1 - \frac{x}{z}) z g(z) \right]$$

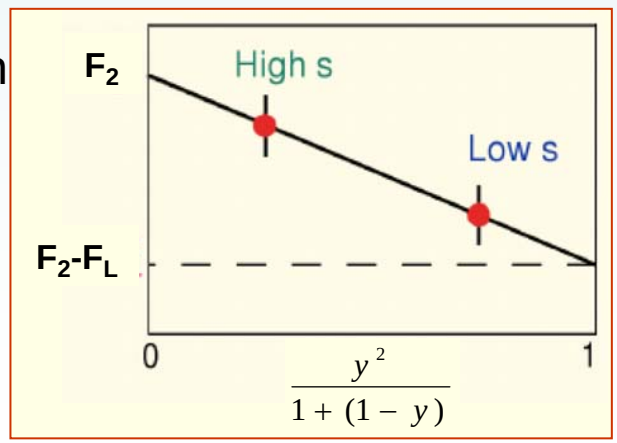
Reduced cross section:

$$\sigma_r = F_2(x, Q^2) - \frac{y^2}{1 + (1 - y)} F_L(x, Q^2), y = 1 - \frac{E_{e'}}{E_e}$$

Method: measurement of σ_r for same (Q^2, x) at different y (different $\sqrt{s}$)

Rosenbluth plot:

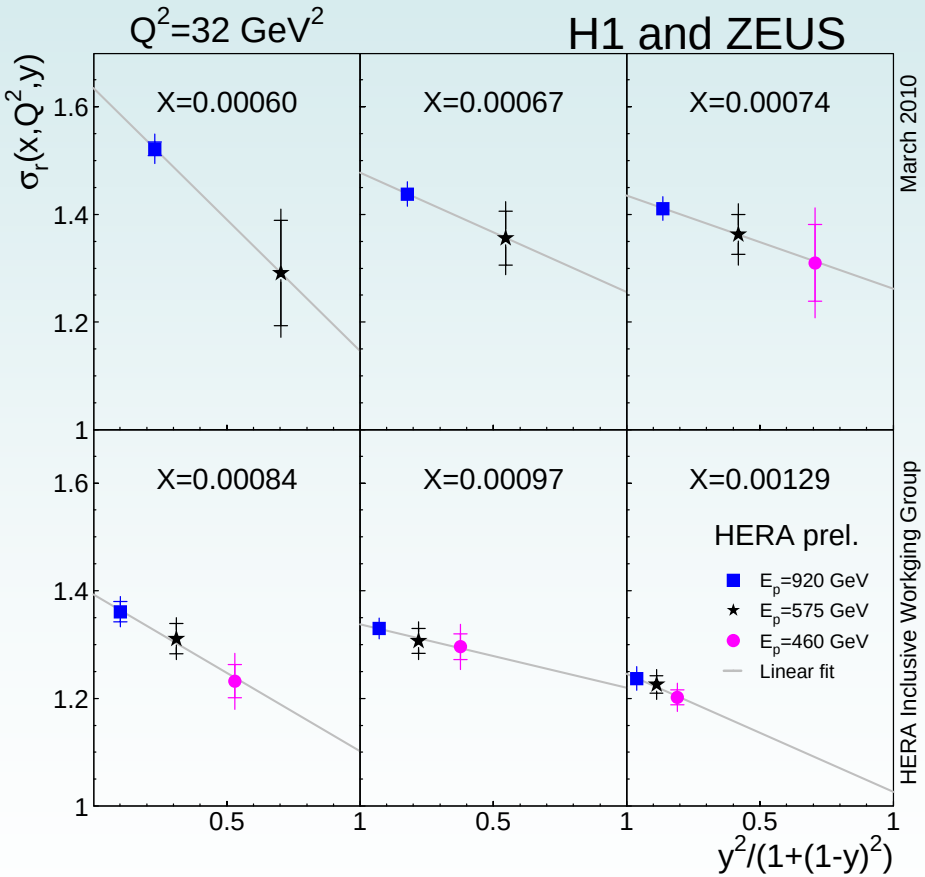
at same (x, Q^2)



slope: F_L
intercept at $y=0$: F_2

Extraction of F_L from combined data

Combined cross sections used to extract HERA F_L: example $Q^2 = 32\ GeV^2$



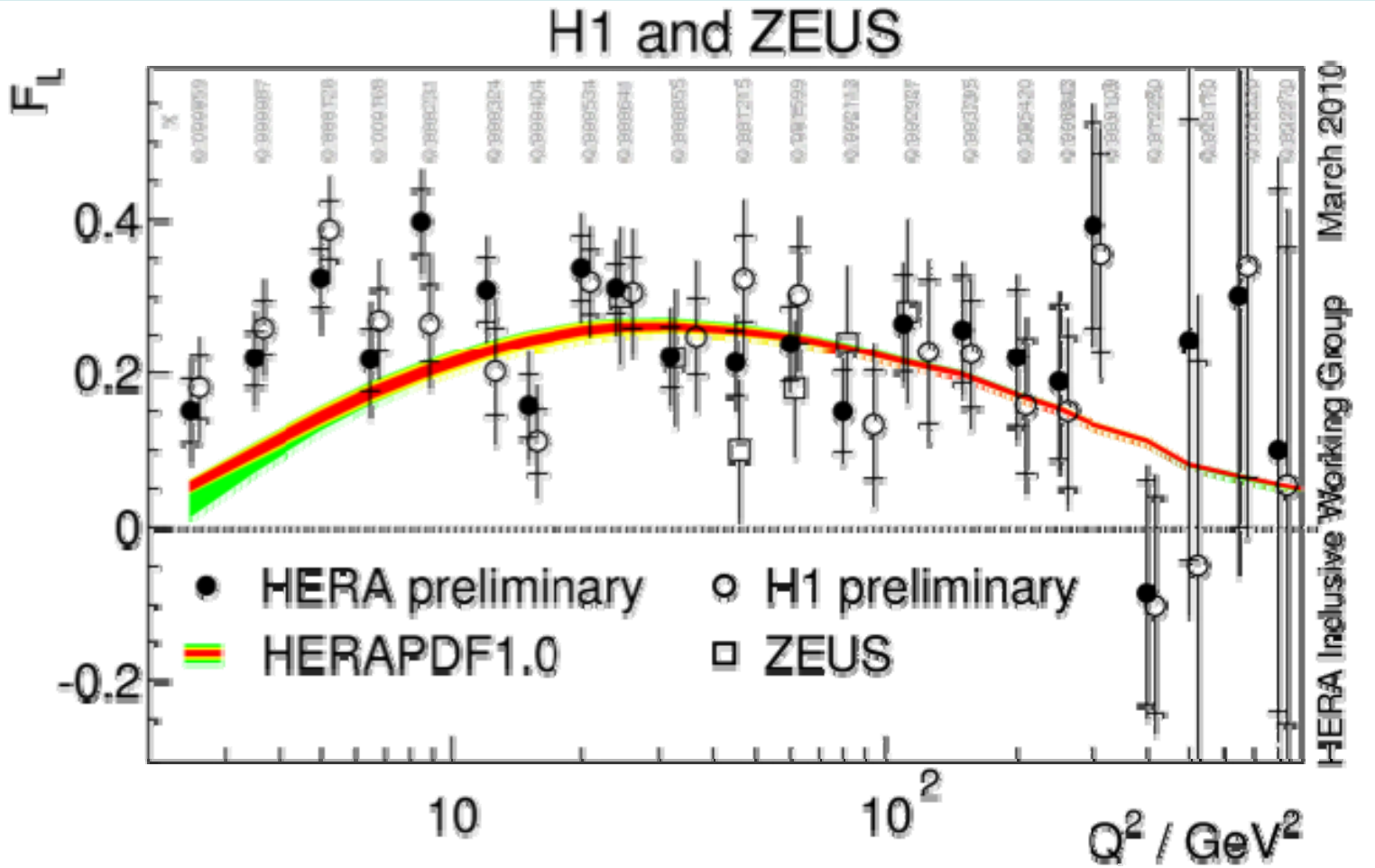
Linear fit to σ_r at different $\sqrt{s}$:

$$\sigma_r = F_2(x,Q^2) - \frac{y^2}{1+(1-y)} F_L(x,Q^2)$$

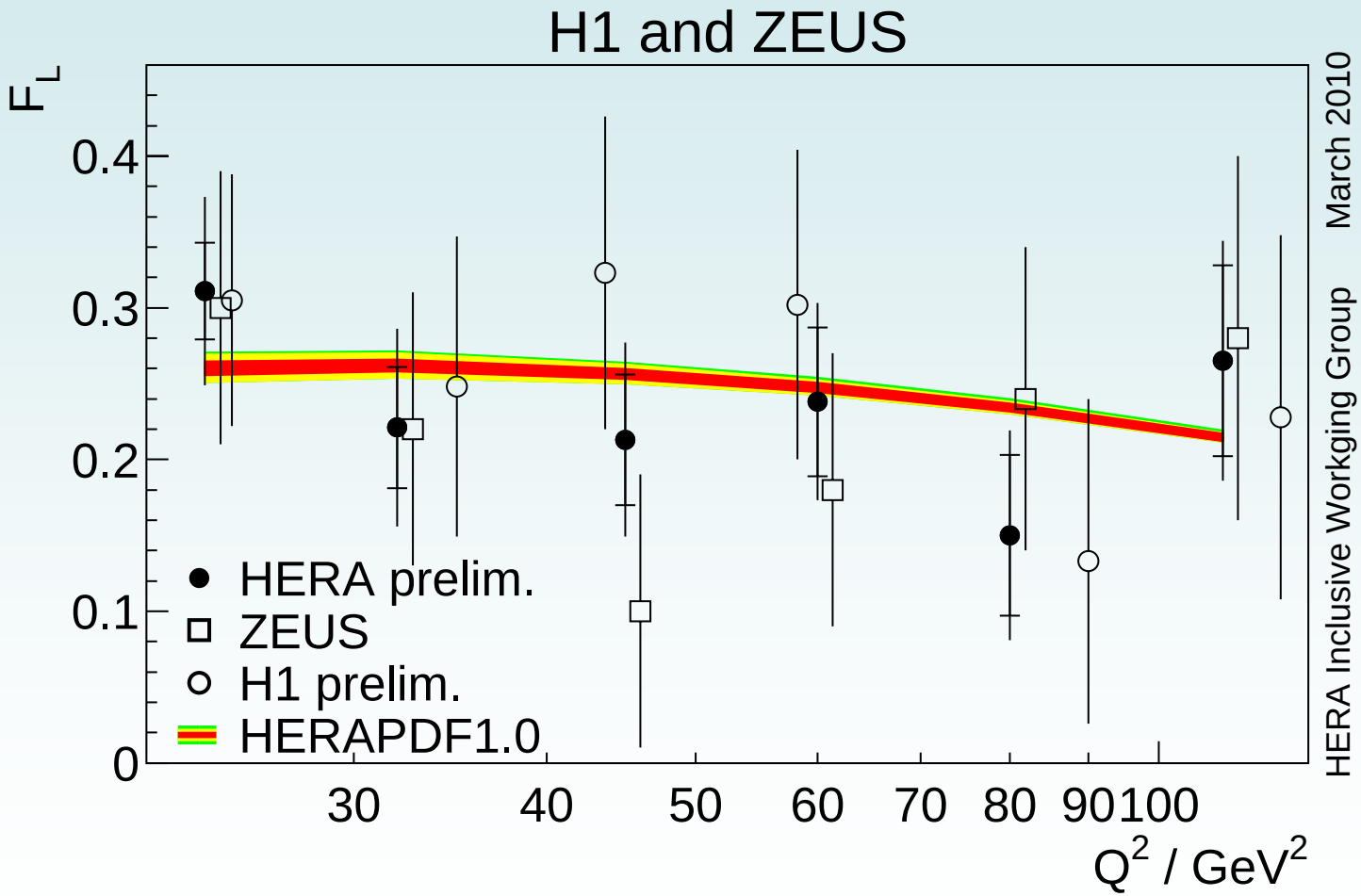
slope: F_L
intercept at $y=0$: F_2

Combined cross sections (NOT F_L) : input to PDF fits

F_L extracted from combined data



F_L extracted from combined data



Heavy Quarks Schemes in PDF Fits

QCD analysis of the proton structure: treatment of heavy quarks essential !

Fixed Flavour Number Scheme:

charm (beauty) quarks massive, produced in BGF

only light flavours in the proton: $N_f = 3\ (4)$

Problem: expected to break down at $Q^2 \gg m_{HQ}^2$

Variable Flavour Number Scheme:

- *Zero Mass:* all flavours massless, N_f variable. Breaks down at $Q^2 \sim m_{HQ}^2$

- *Generalized Mass:* matched scheme, expect appropriate description at all Q^2, different implementations available

HQ measurements can decide on the appropriate treatment

HQ Contribution to the Proton Structure

Can be determined experimentally: e.g. “charm structure function”:

$$F_2^{cc} \propto \frac{Q^2 \cdot \alpha_s}{m_c^2} \int \frac{dx}{x} e_c^2 g(x_g, Q^2) \cdot C(...)$$

- use and combine different charm tagging methods

  measure cross sections of charm and beauty production in DIS:

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

- Direct test of different schemes of HQ treatment in PDF fits

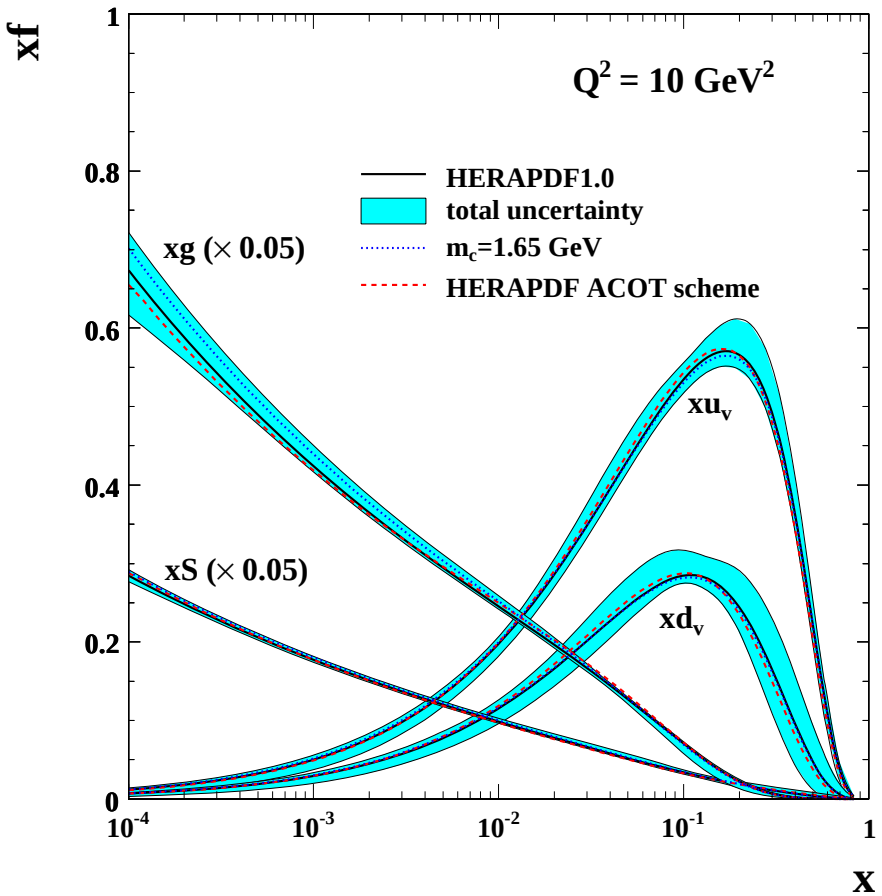
- Can be included in the full QCD analysis of DIS cross sections

  additional constrain on the gluon density in the proton

  reduce parameterization uncertainty

What does value of m_c mean for PDFs

HERA PDF: additional uncertainty due to variation of $1.4 < m_c < 1.65\ GeV$



The choice of the m_c influences

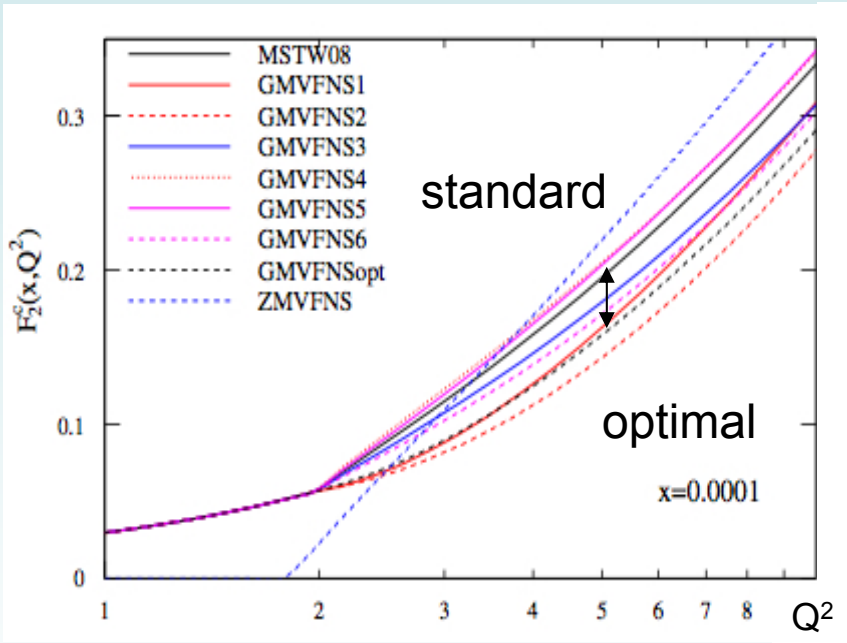
-the gluon PDF,

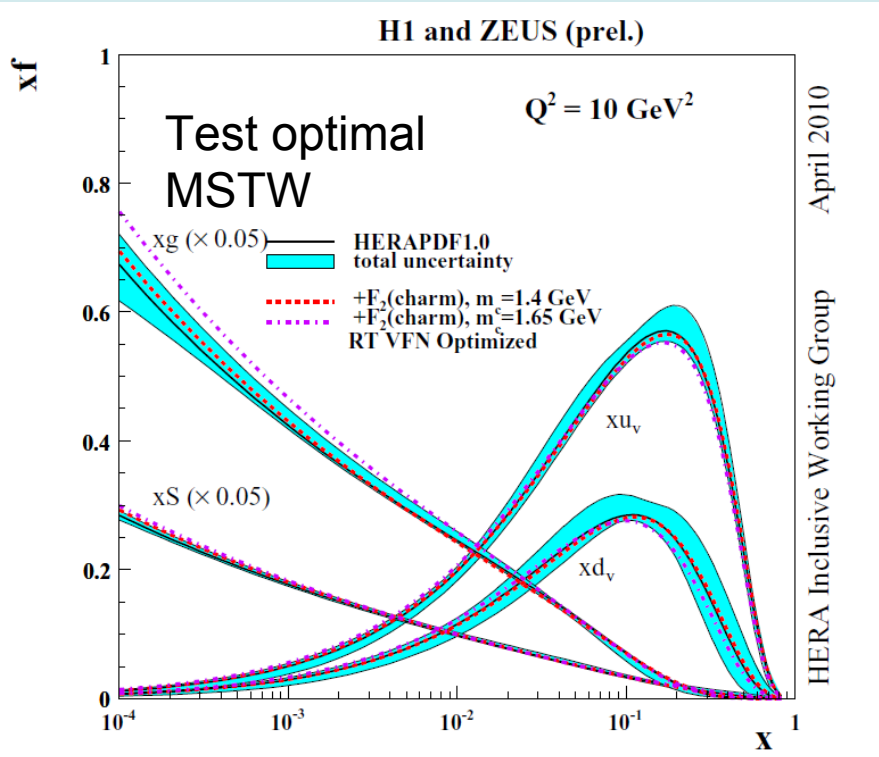
-most visible in charm PDF,

-has consequences for light quarks

PDF Fits using HERA F_2^c data: test scheme

MSTW prescription for HF treatment





Smoother gluon: smaller $F_2^c \Rightarrow$ compensate by smaller m_c, BUT worse fit

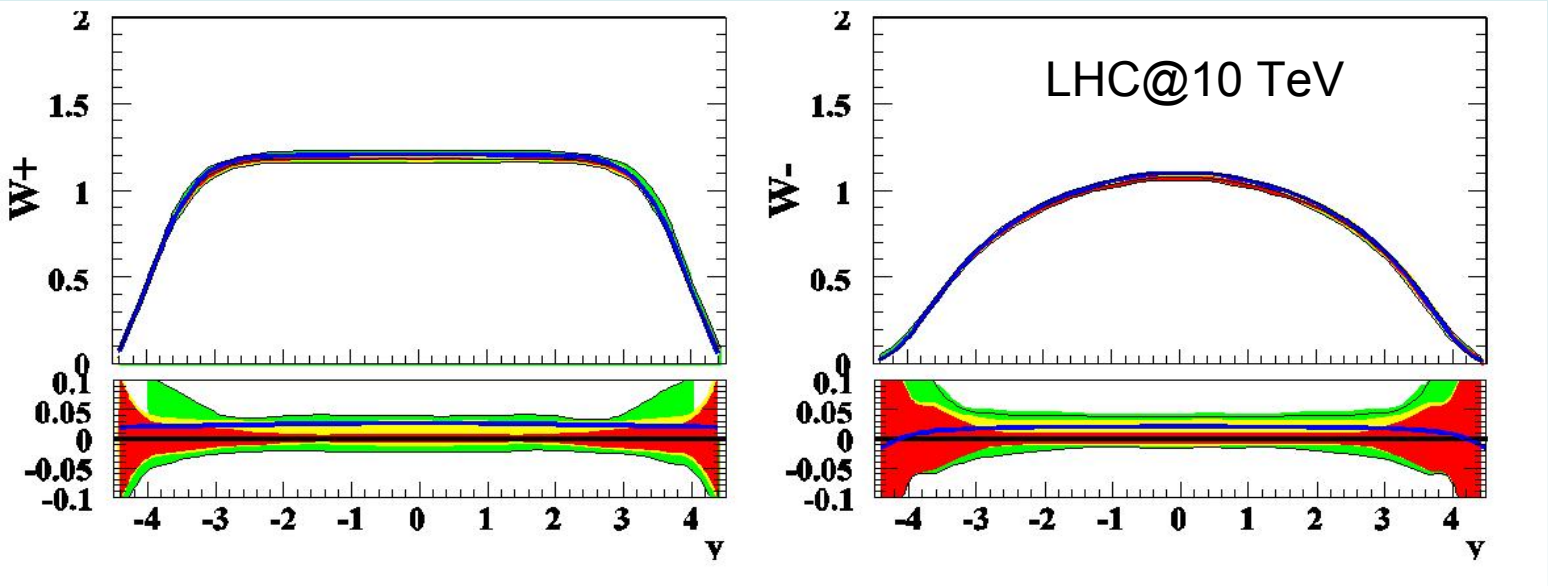
Test MSTW scheme : "Optimal" solution **disfavored** by HERA charm data

HQ treatment is crucial for PDF fits

QCD analysis at HERA: use charm data to test HQ schemes

What would value of m_c mean for LHC

choice of $m_c = 1.65$ raises W/Z cross-section predictions at the LHC by $\sim 3\%$



More significant than other PDF uncertainties (exp. model, param.)

Larger m_c → more gluons, less **charm** → more light quarks → larger σ_W

Does matter for the Luminosity measurement @ LHC !