Ultimi risultati di HERA e il loro impatto su LHC

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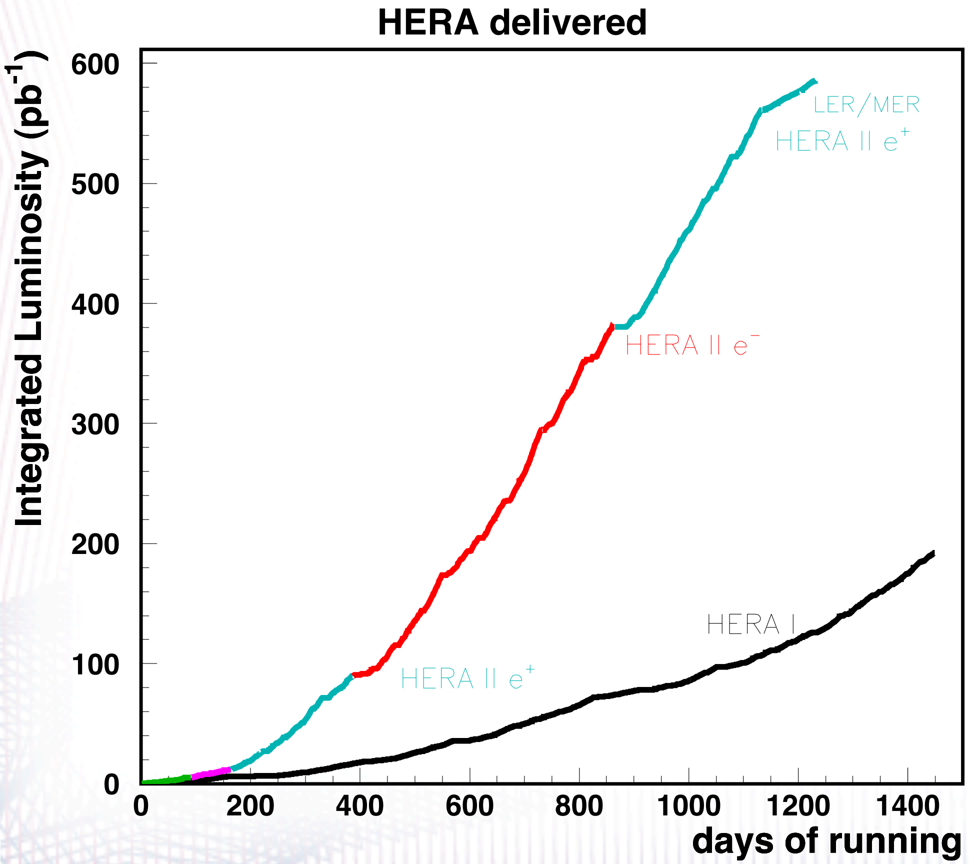
Questa e' per forza di cose una selezione limitata di risultati di HERA, che riflette il tempo limitato a disposizione e le preferenze personalissime dell'autore...

The HERA collider

HERA was an ep collider operating at a center of mass energy of 318 GeV.

Two collider experiments: H1 and ZEUS.



$e^{\pm}$ 27.5 GeV

p 920 GeV

Data taking ended in June 07.

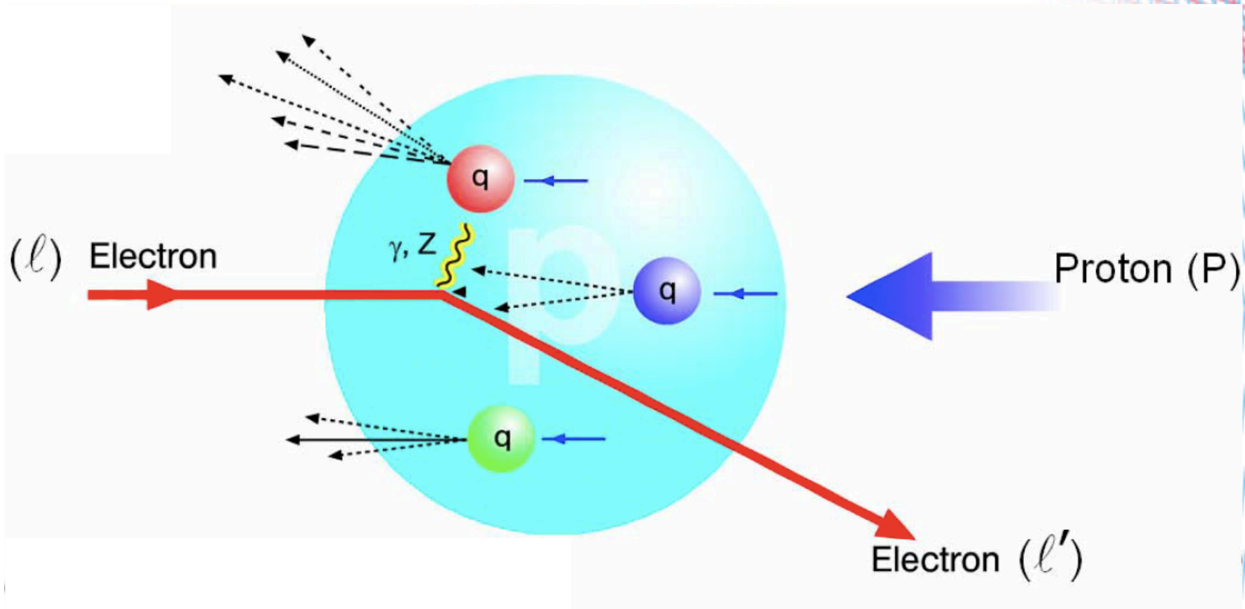
Collected luminosity :

~0.5 fb^{-1} per experiment

DIS at HERA

DIS kinematic:

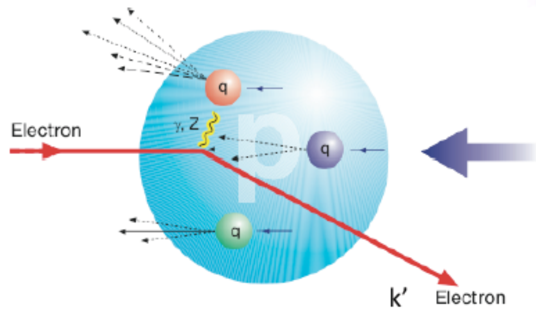
$$
\begin{aligned}
s &= (P+k)^2 \\
Q^2 &= -q^2 = -(k-k')^2 \\
x &= \frac{Q^2}{2P\cdot q} \\
y &= \frac{P\cdot q}{P\cdot k} \simeq \frac{Q^2}{sx} \\
W^2 &= (P+q)^2 \simeq Q^2\frac{1-x}{x} \\
Y_\pm &= 1 \pm (1-y)^2
\end{aligned}
$$



The structure of the proton

The proton structure is a fundamental input for cross sections predictions at the LHC. Best determination from different inputs:

- inclusive NC and CC cross sections
- jet production
- heavy flavour production



Focus on the combination of the data of the H1 and ZEUS experiments.

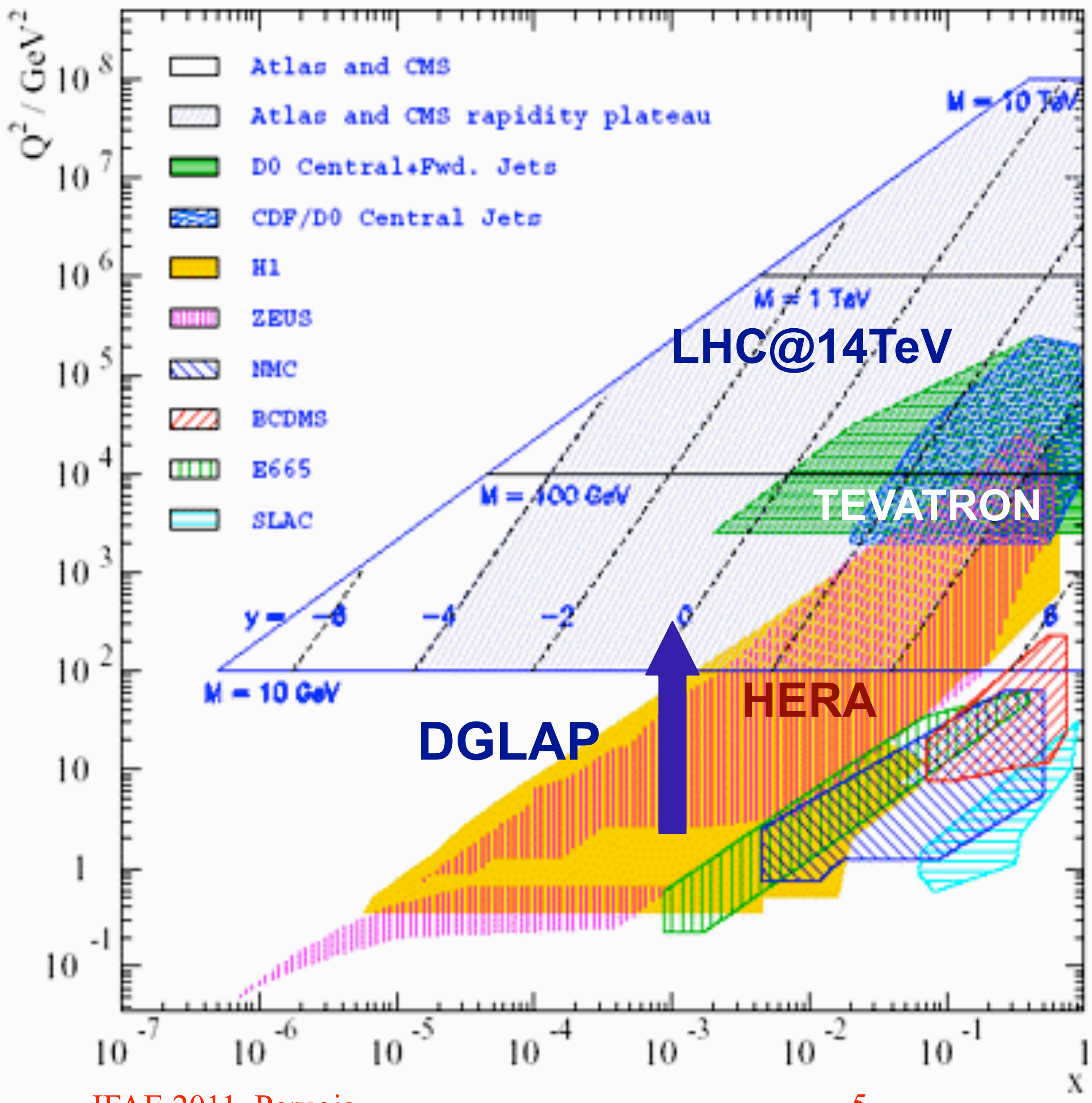
HERA, Tevatron and the LHC

- Q^2: 'hardness' of the interaction
- x: momentum fraction of the parton

At LHC:

$$M \widehat{=} Q$$

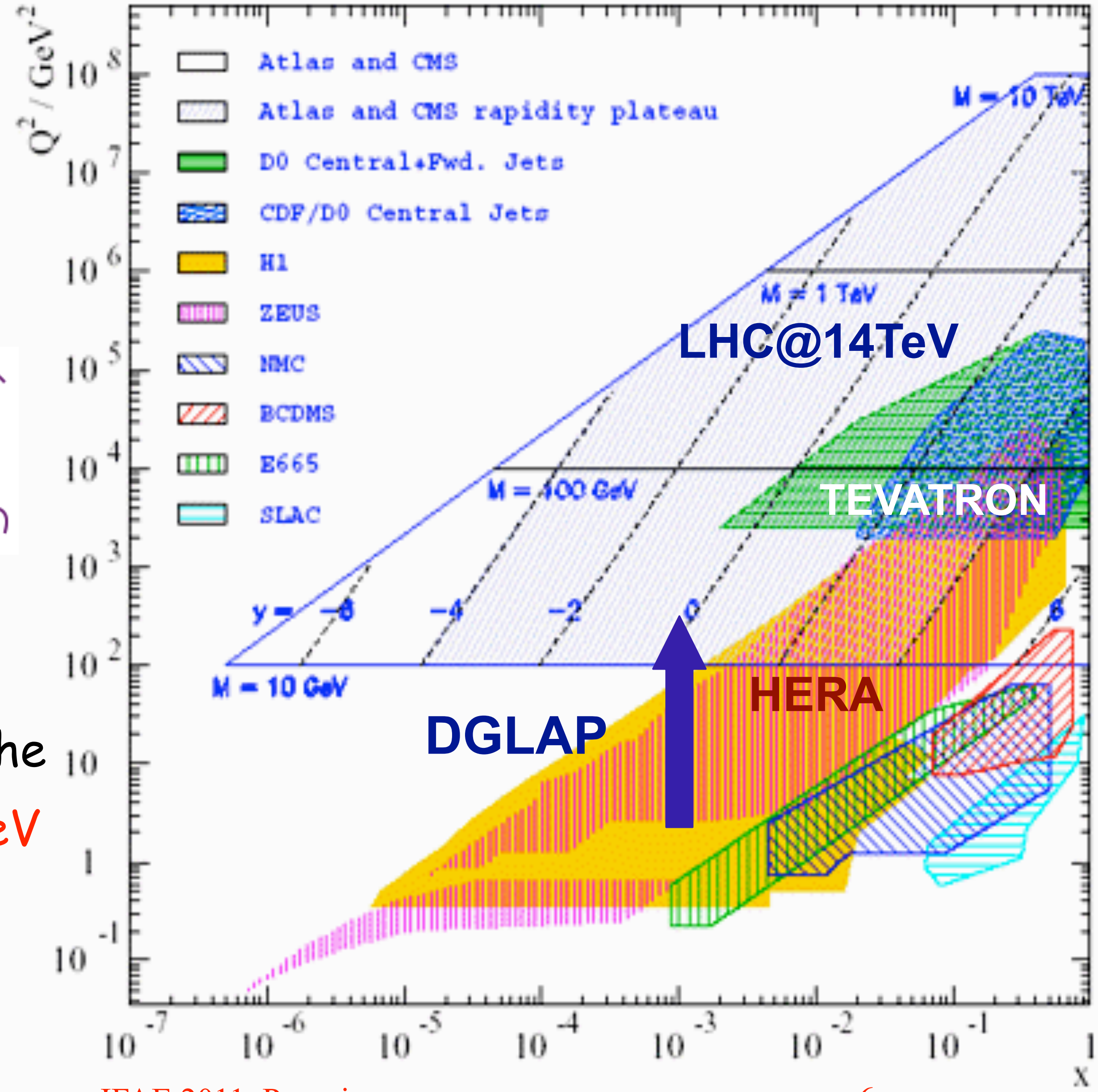
$$x_{1,2} \widehat{=} \frac{M}{14\ \text{TeV}}\, e^{\pm y}$$



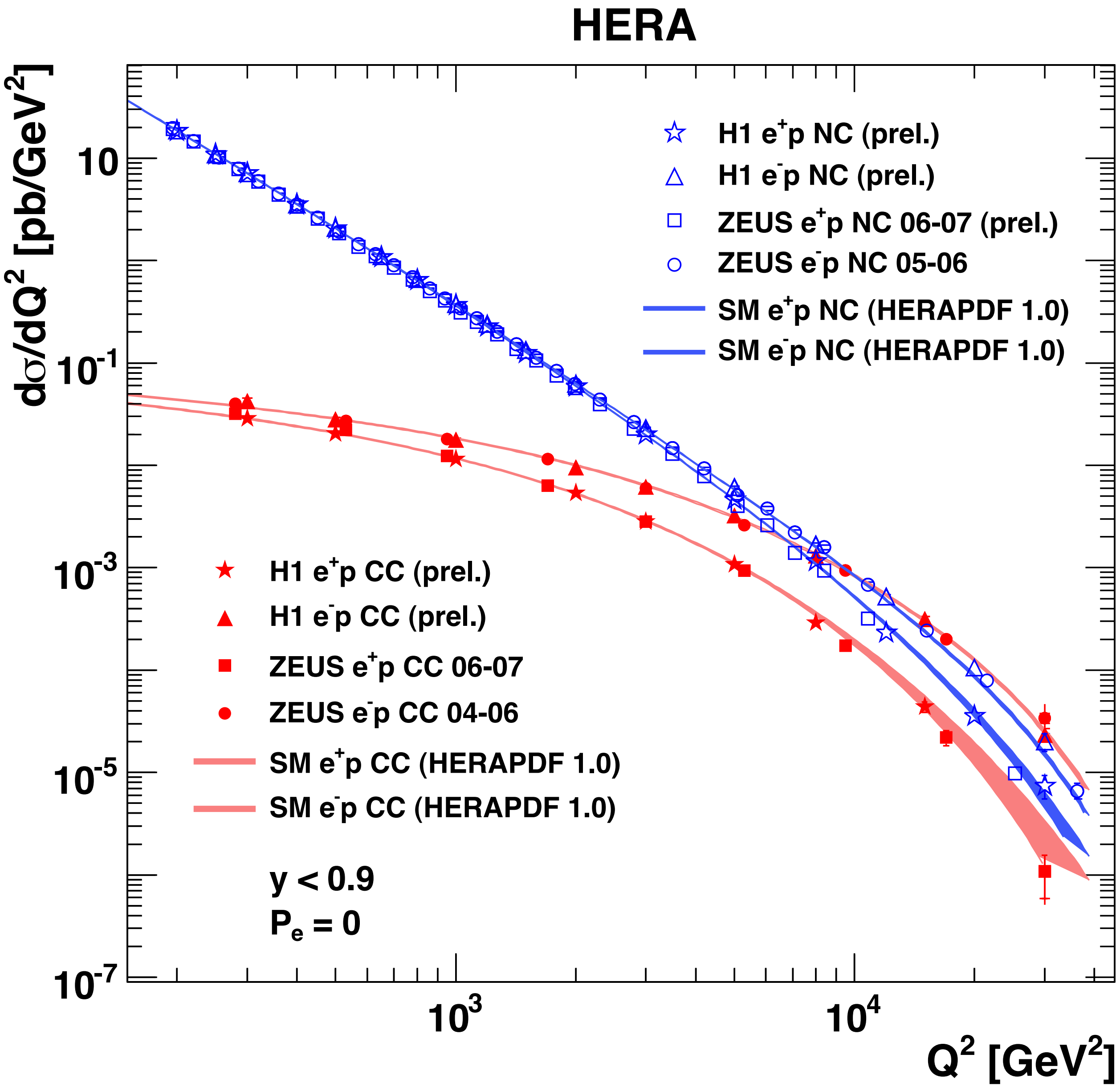
HERA, Tevatron and the LHC

Evolution in Q^2 driven by the DGLAP equation, determines the PDFs for each Q^2 at a given x.

Using the HERA data and DGLAP evolution precise predictions can be made at the LHC for masses of M~100 GeV in the central rapidity region (M=Q)



H1 and ZEUS NC and CC cross sections



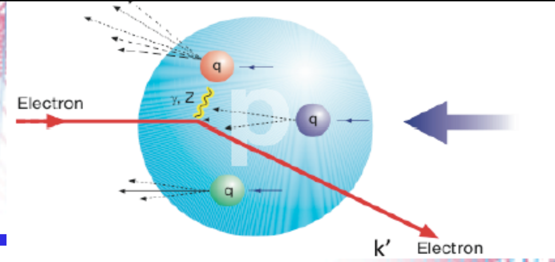
Tools to investigate QCD at HERA

NC, low Q^2 dominated by γ exchange. High-Q^2, Z/γ interference becomes important.

CC: smaller at low Q^2 (W exchange)

Unification at $Q^2 \sim M_W^2 \sim 10.000$ GeV^2

The structure of the proton



- The ep NC cross section can be expressed in terms of the structure functions F_2, F_3, F_L.

$$\frac{d^2\sigma^{e^\pm p}}{dx\,dQ^2} = \frac{2\pi\alpha^2}{xQ^4}\boxed{\left[Y_+F_2(x,Q^2) \mp Y_-xF_3(x,Q^2) - y^2F_L(x,Q^2)\right]} \quad \text{where } Y_\pm = 1 \pm (1-y)^2$$

point-like

structure functions

- These structure functions are related to the proton parton distribution functions:

$$F_2 \sim x(q+\bar{q}) \qquad xF_3 \sim x(q-\bar{q}) \qquad F_L \sim x\alpha_s g$$

- Charged current is sensitive to the quark charges:

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

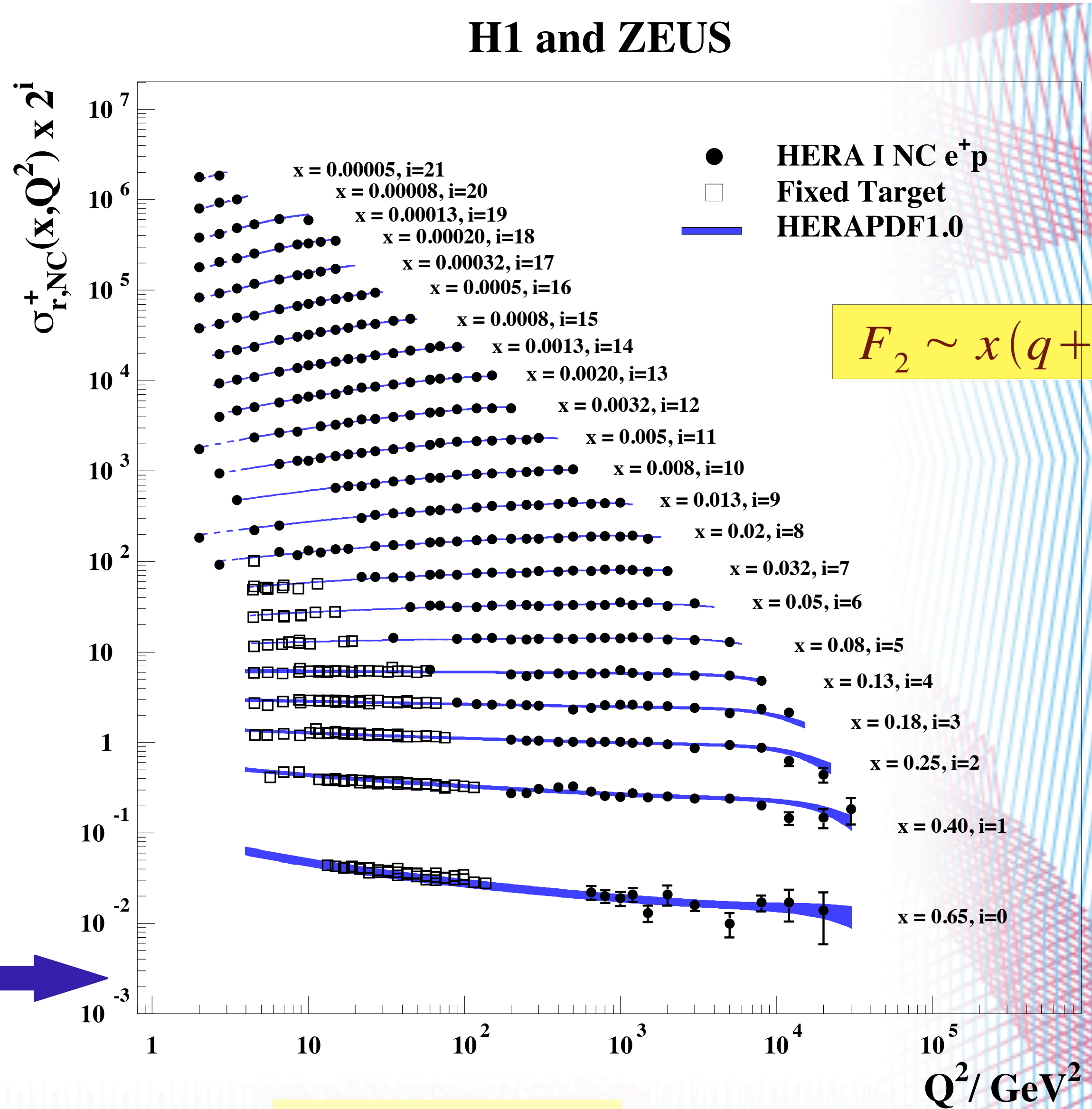
The F_2 structure function

- NC and CC cross sections from H1 and ZEUS combined
- Precision of 1-2% also due to different systematic uncertainties in the two experiments
- Gluon density from scaling violations

$$\frac{\partial F_2}{\partial \ln Q^2} \propto \alpha_s(Q^2)xg(x,Q^2)$$

- DGLAP drives the evolution in Q^2 at fixed x

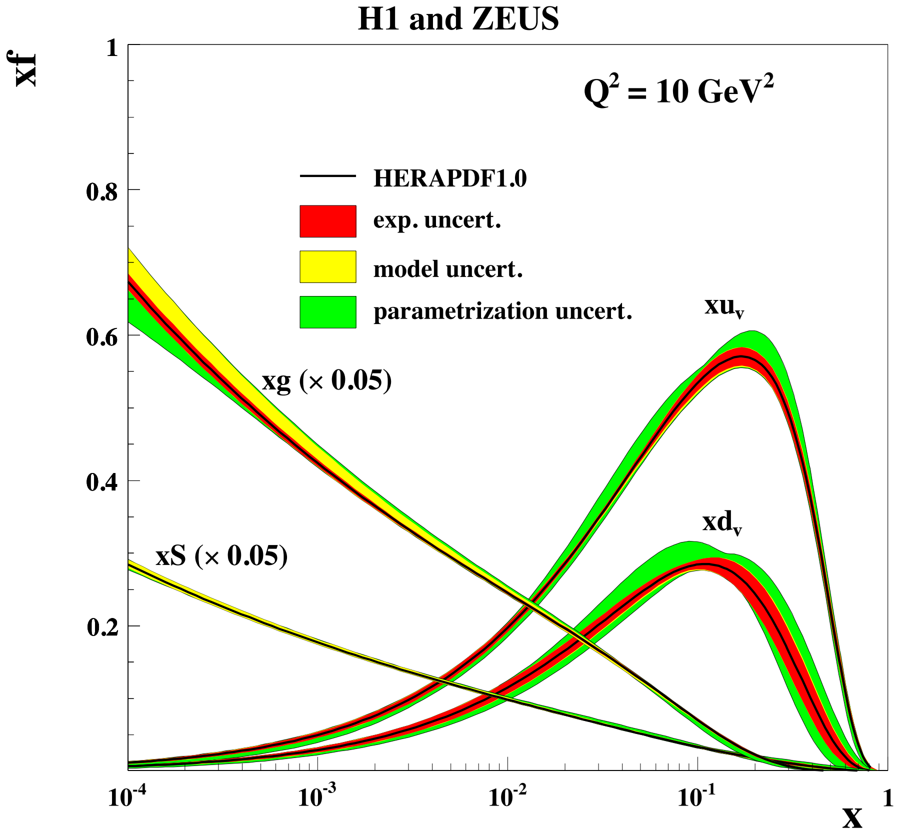
$F_2 \sim x(q+\bar{q})$

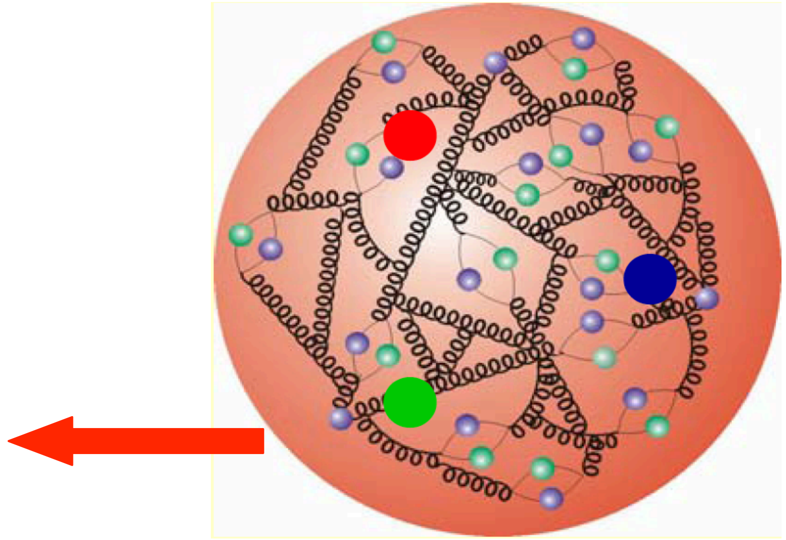


JHEP01(2010)109

HERAPDF1.0

The combined HERA data have been used as the sole input for the extraction of the HERAPDF1.0.





Gluon (and sea) scaled down by a factor 20, dominate at low x.

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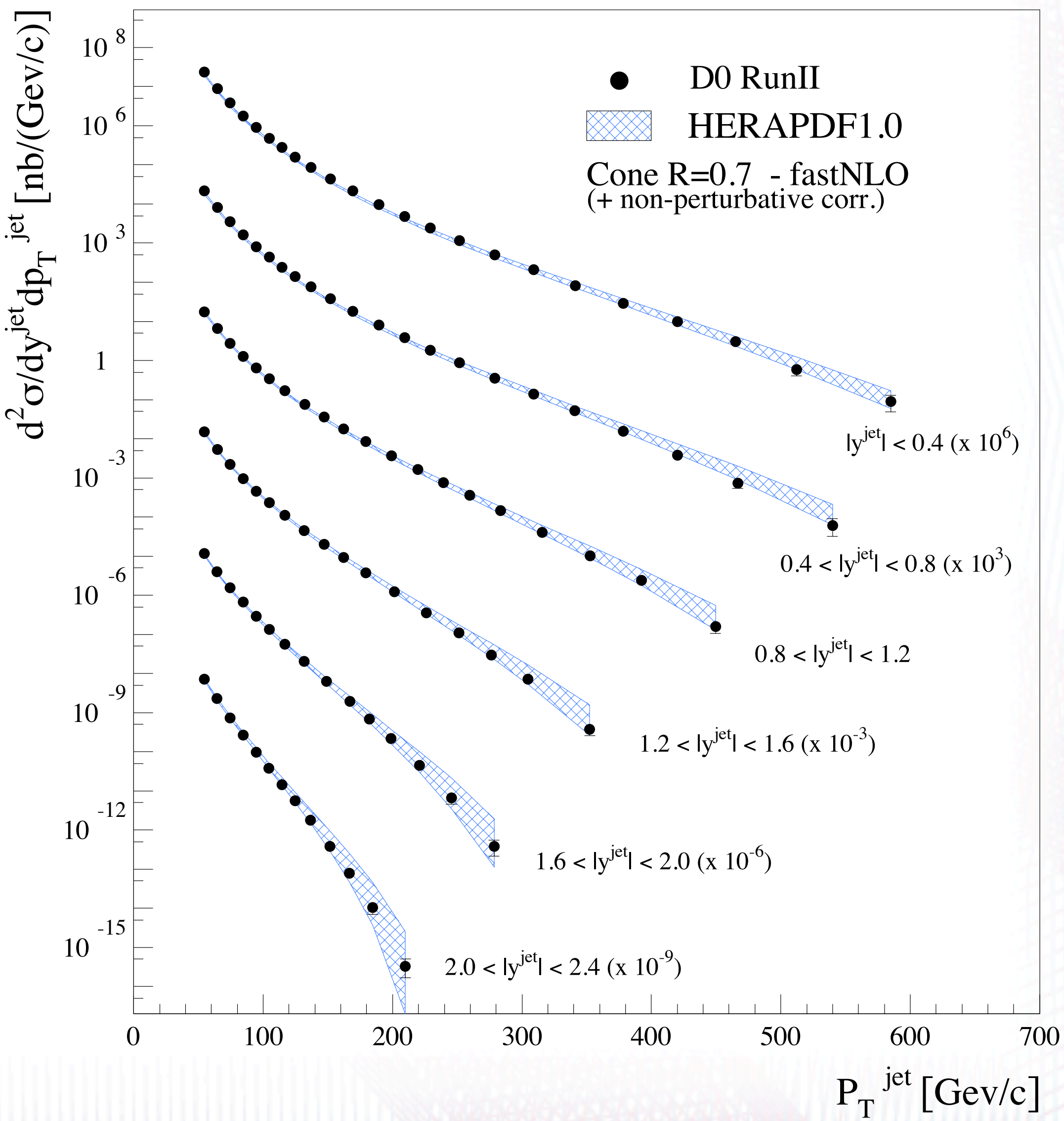
Precise picture of the proton

HERAPDF1.0 and the Tevatron jets

Test of the PDFs in the high p_T kinematic region at the Tevatron.

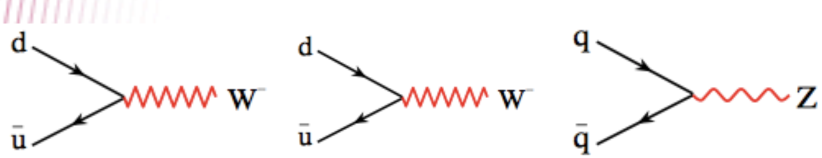
HERAPDF1.0 able to describe Tevatron jets also at high p_T (different kinematic region)

Consistent picture of QCD: extrapolation from HERA (Q^2 ~ 1-10000 GeV^2) to Tevatron (1TeV) works

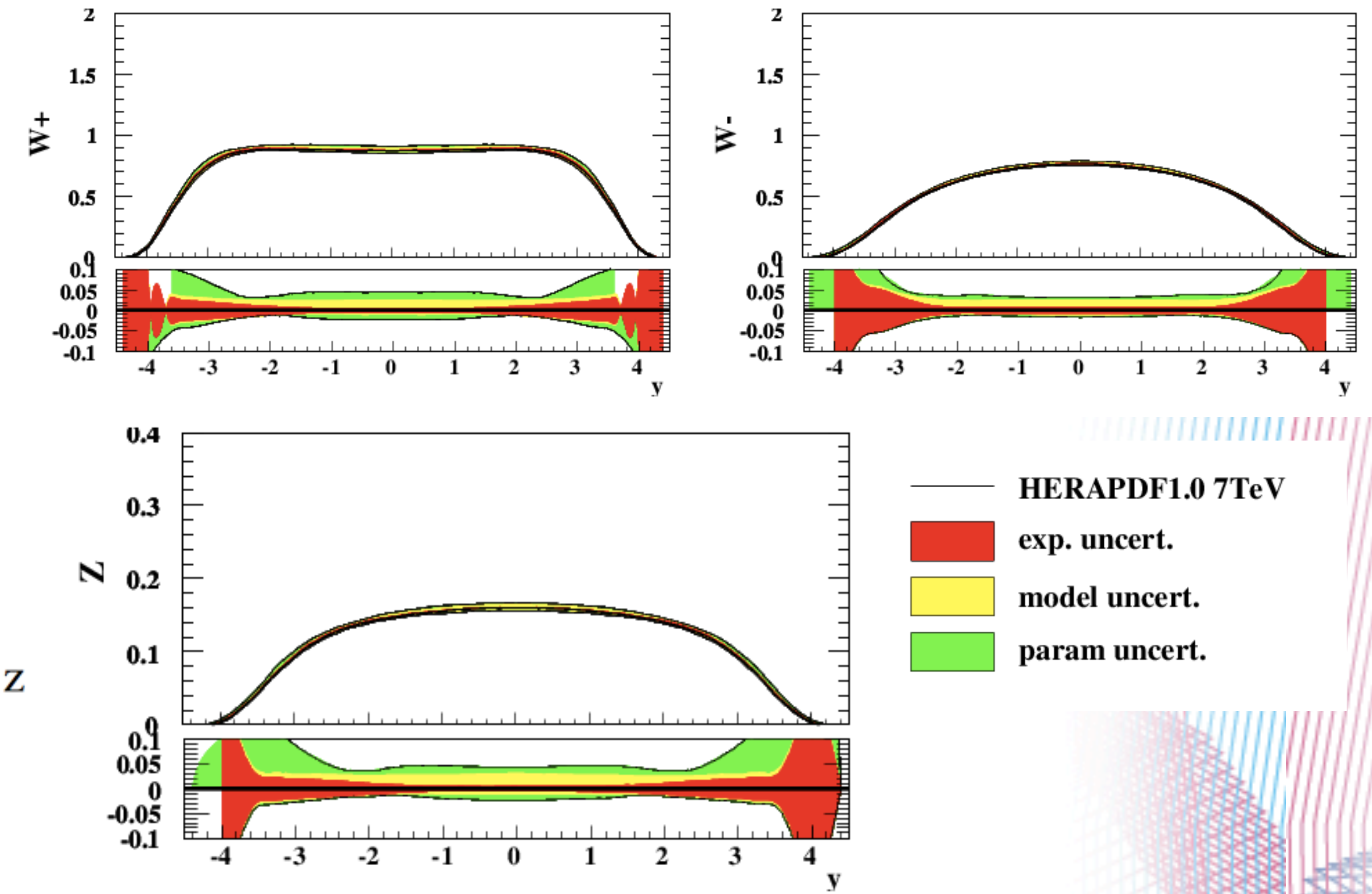


HERAPDF1.0 at the LHC: W and Z

- Parton distribution functions are universal
- Standard 'candles' of the SM can be predicted using the HERAPDF1.0
- Here: W and Z at LHC



- Sensitivity to the $x \sim 10^{-3}$ region

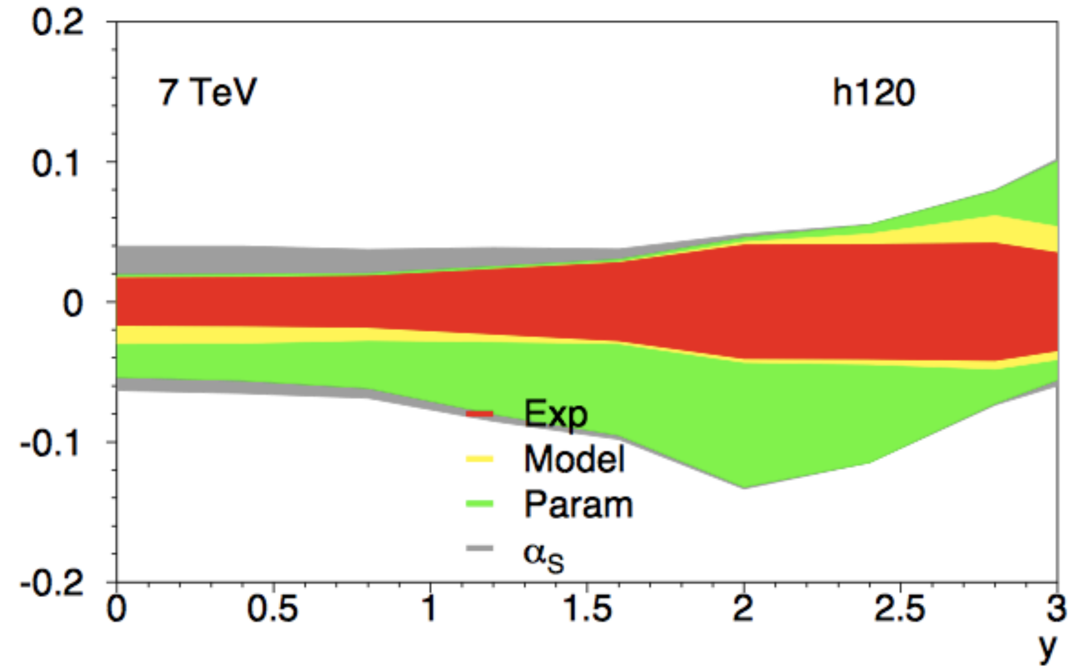


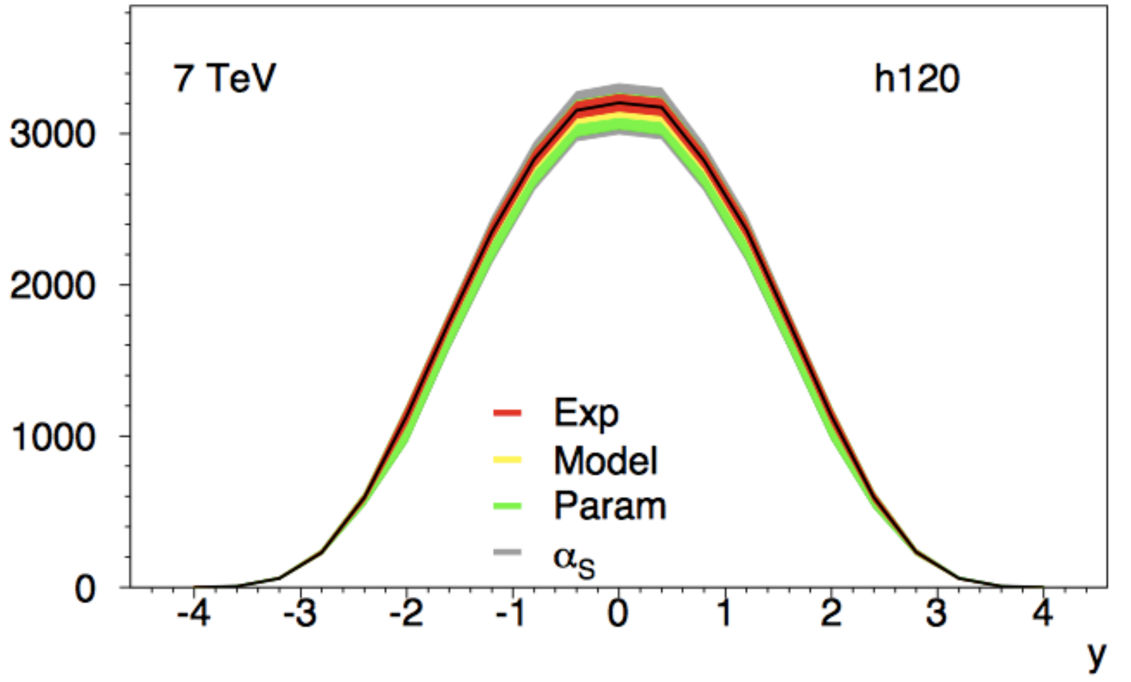
Very good precision in the central rapidity region

Precise prediction of SM cross sections for LHC

… and the Higgs

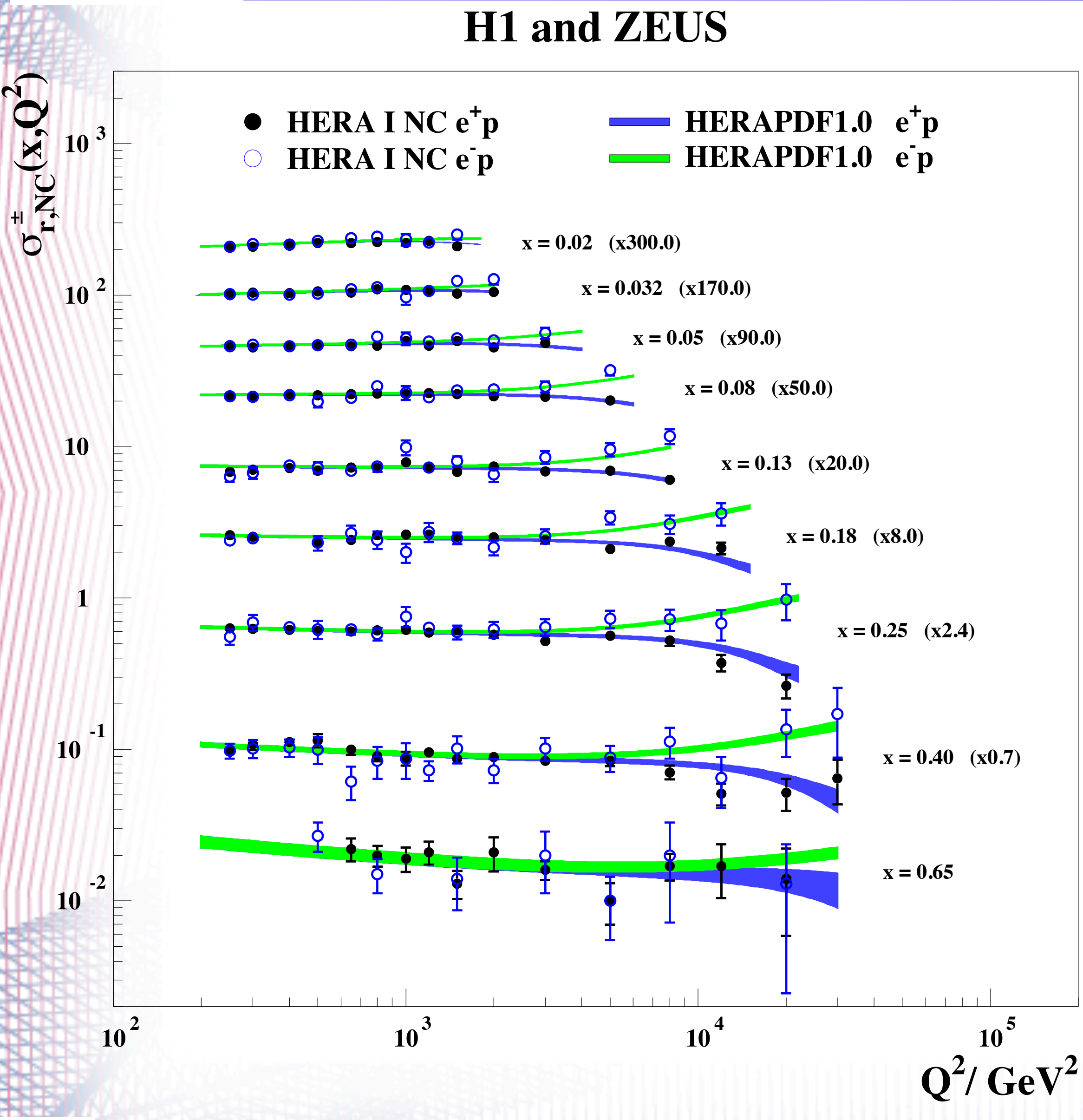
Here for an Higgs mass of 120 GeV





https://www.desy.de/h1zeus/combined_results/benchmark/lhc.html

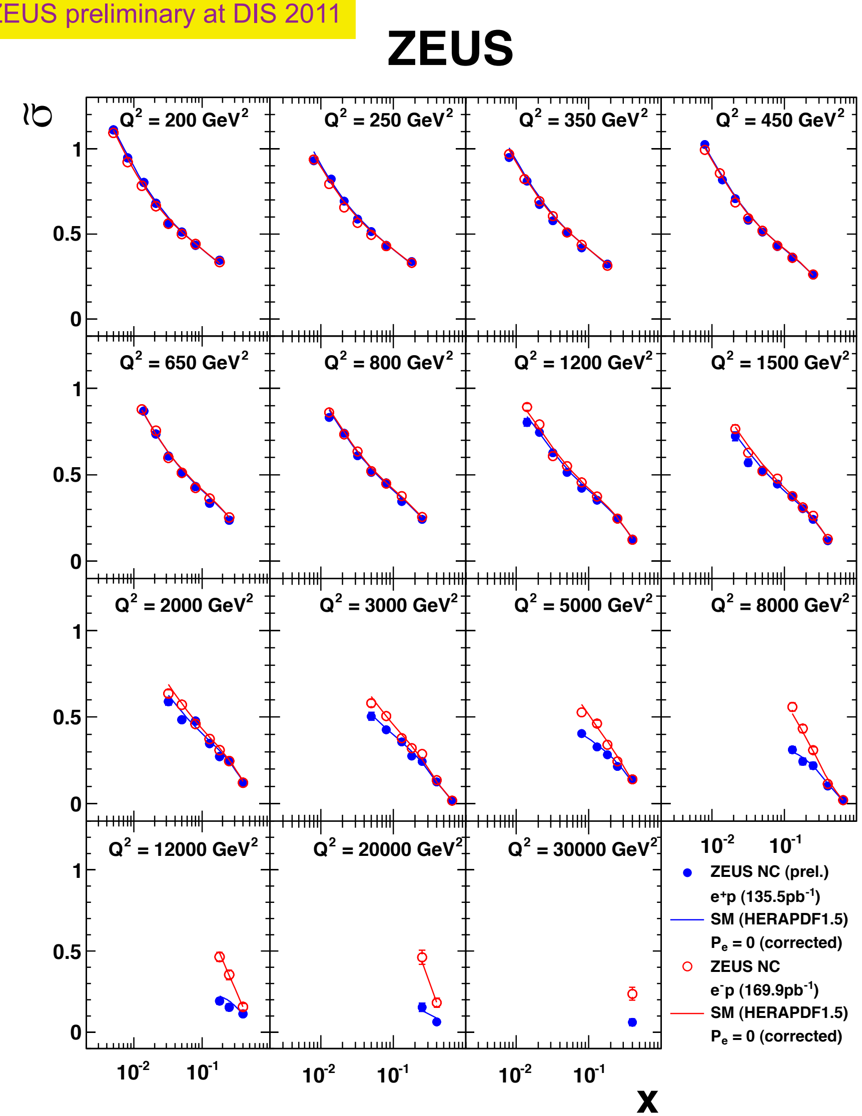
…is that it?



- Precision is 2% for 3 < Q^2 < 500 GeV^2 and reaches 1% for 20 < Q^2 < 100 GeV^2
- At higher Q^2 the precision is lower
- HERAII data (~3 times the HERAI statistics, 10 times for e$^-$p collisions) can significantly improve the picture

NC and CC in HERAII

New ZEUS preliminary at DIS 2011



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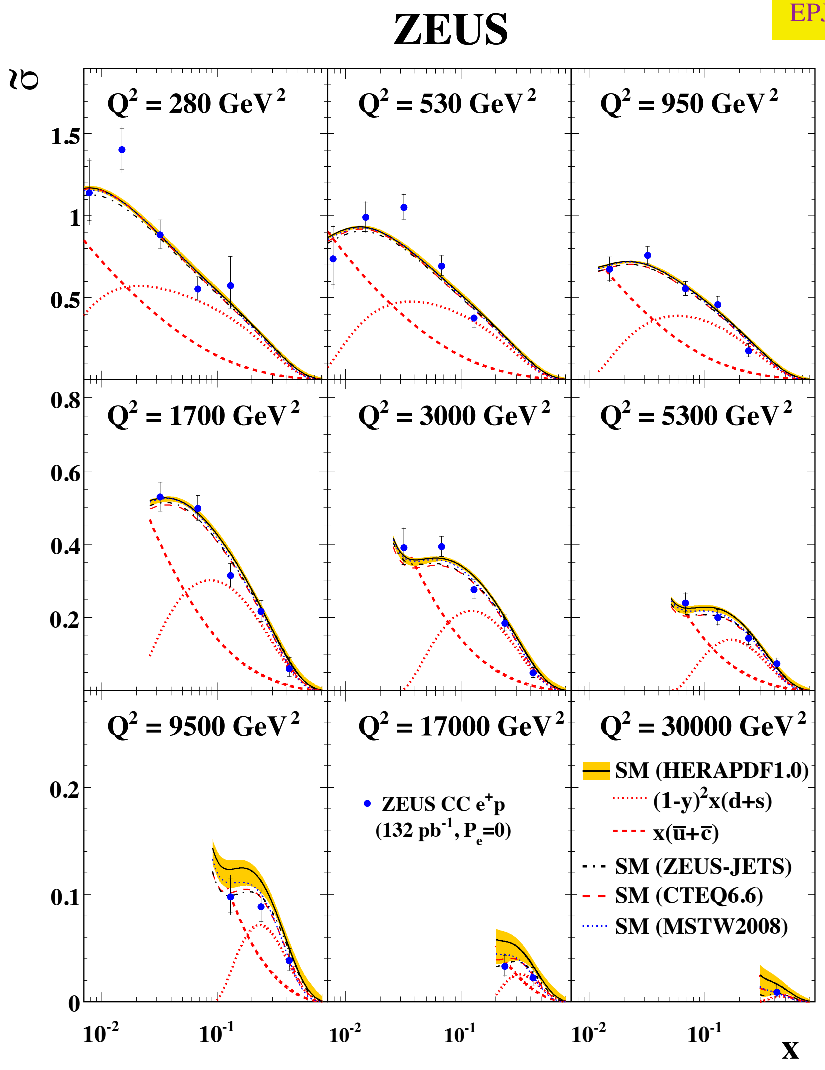
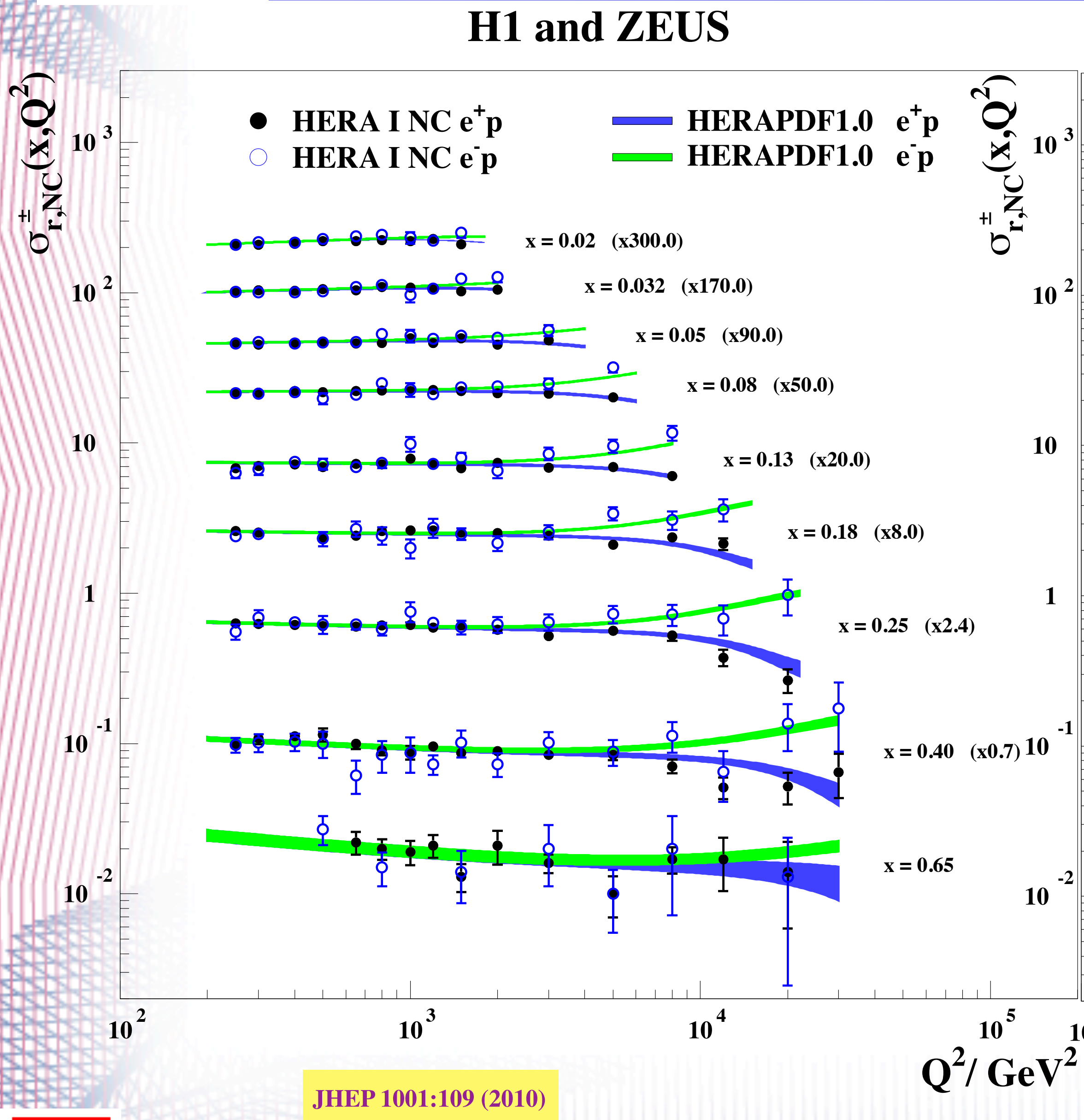
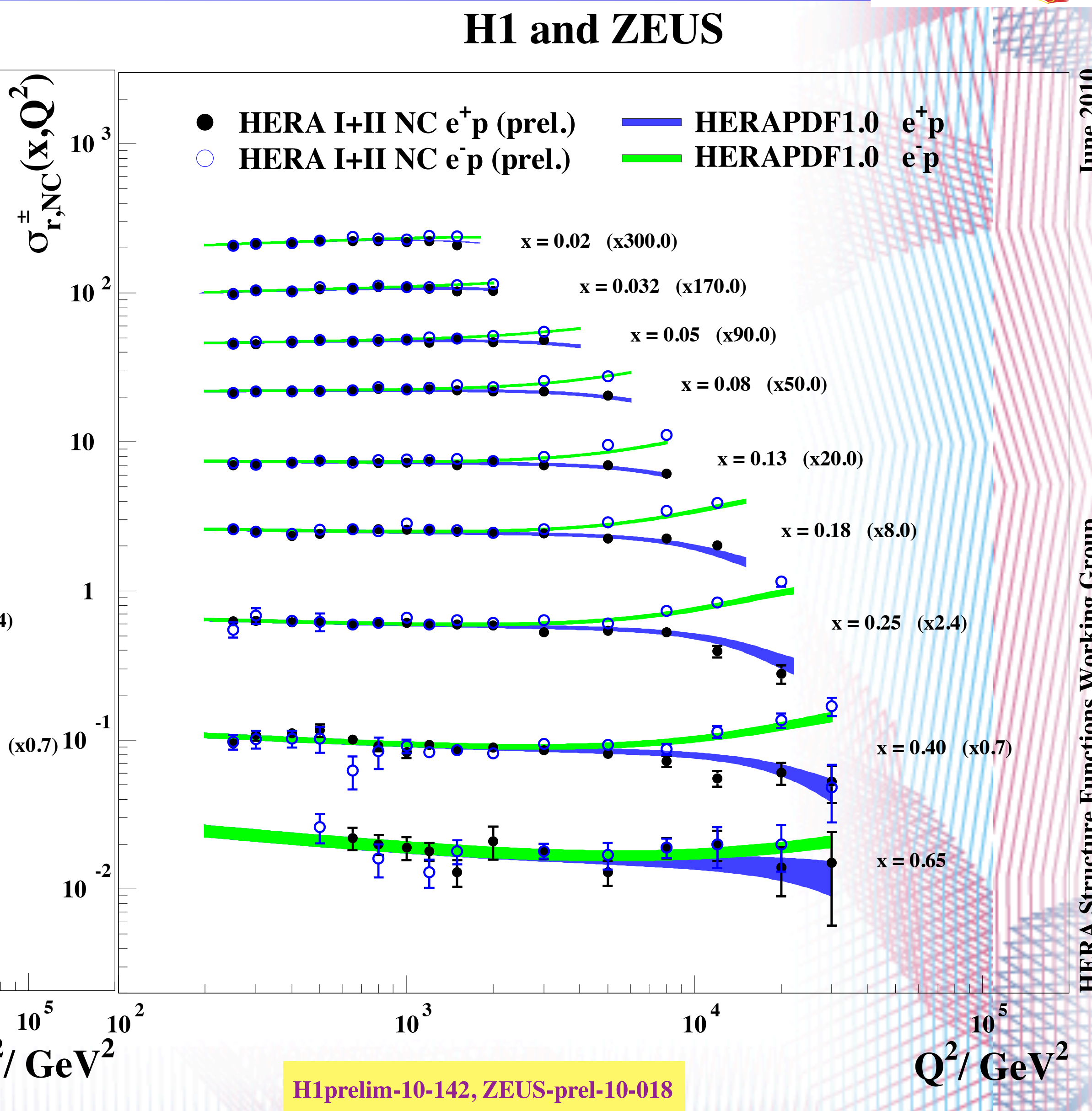


ZEUS and H1 are finishing their analyses of NC and CC processes

Combination including the HERAII data

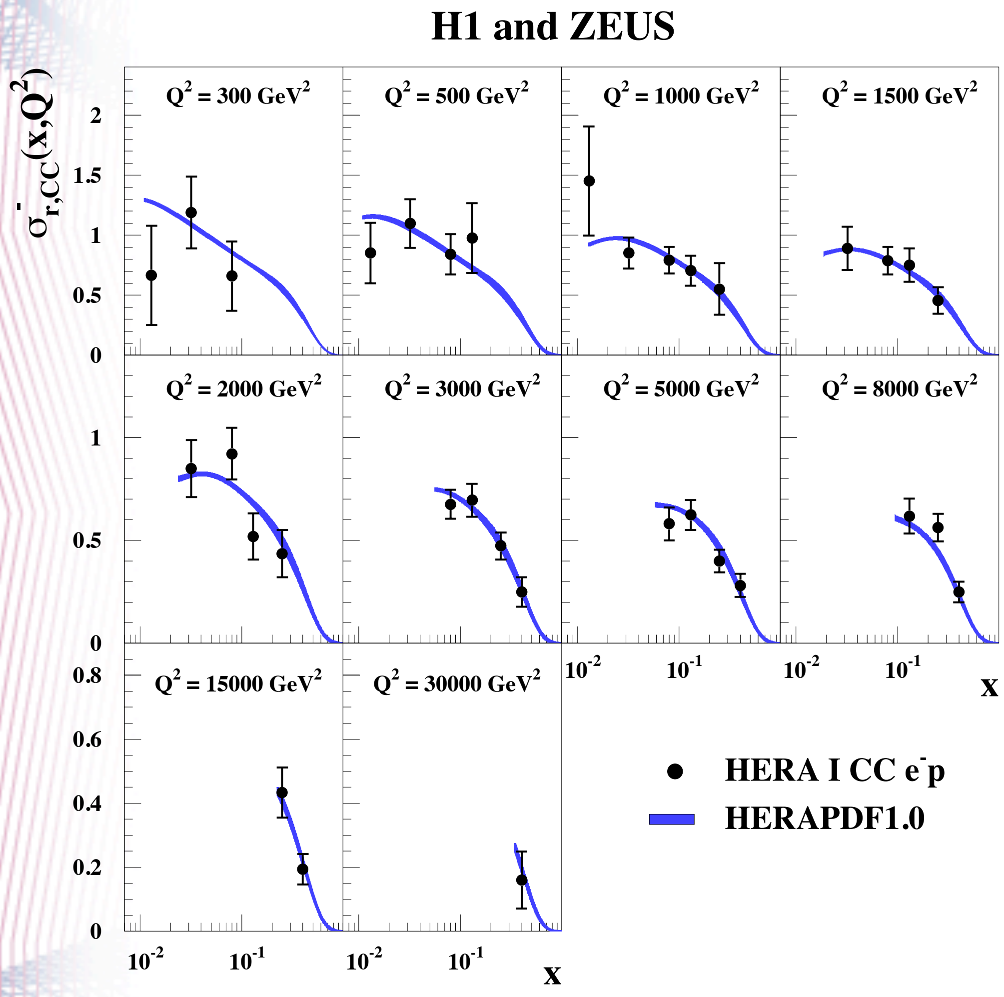


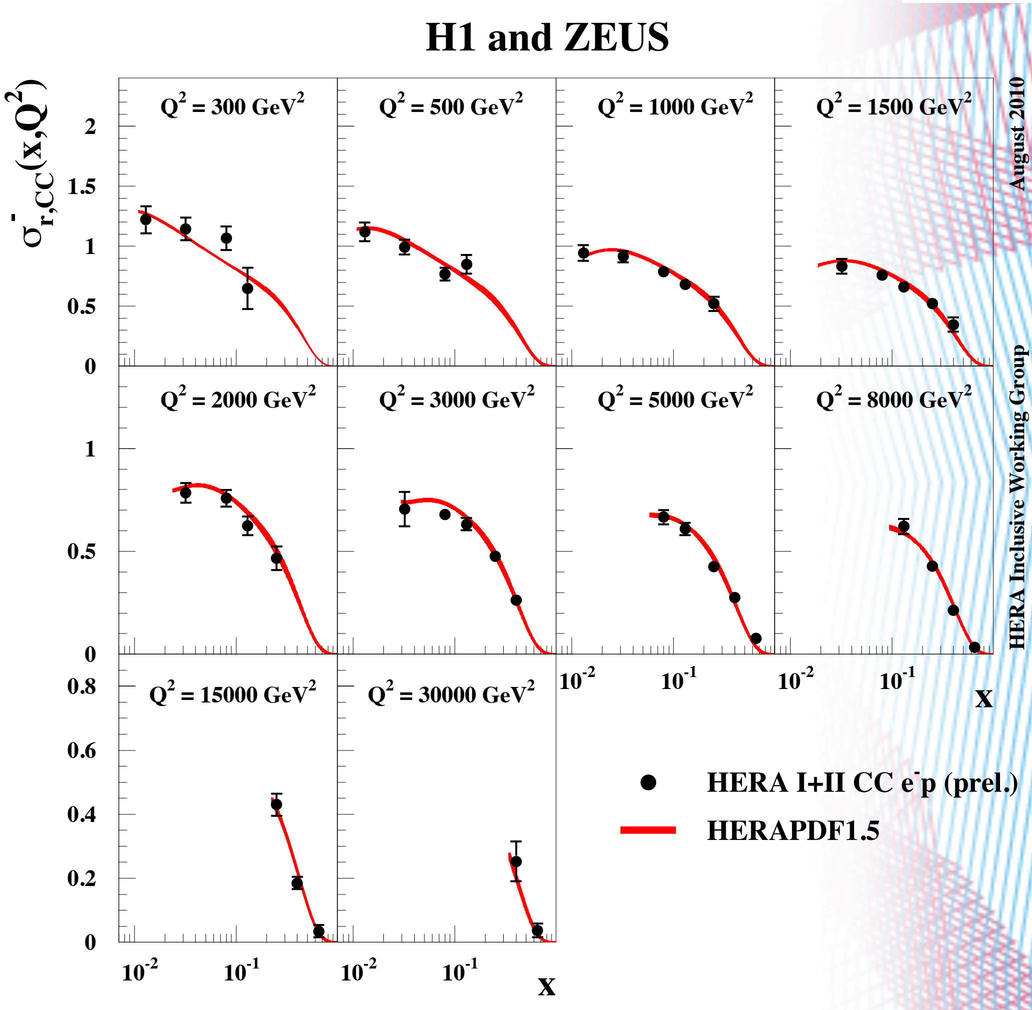
JHEP 1001:109 (2010)



H1prelim-10-142, ZEUS-prel-10-018

CC e^-p and HERAPDF1.5



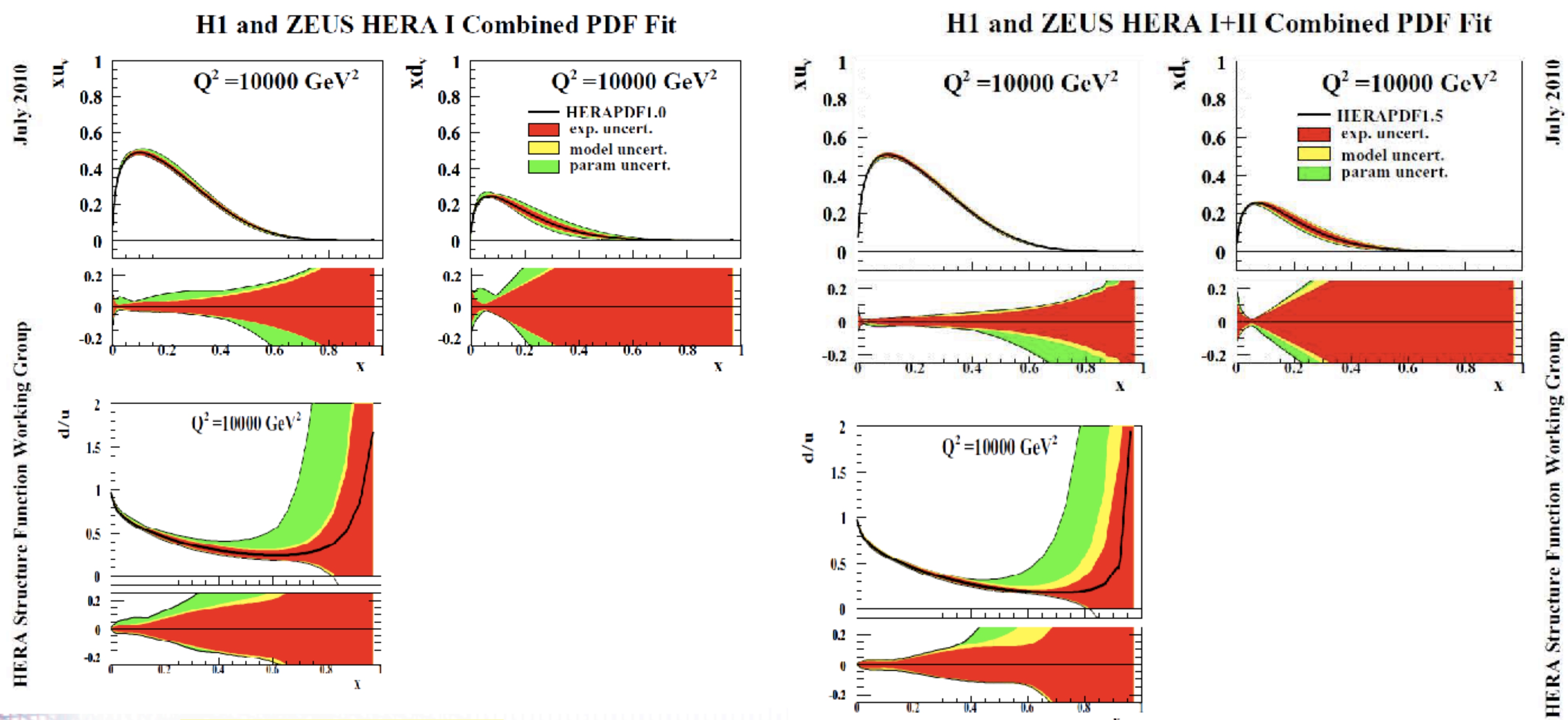


Significant improvement on the precision, impact on the valence quark distributions

H1prelim-10-142, ZEUS-prel-10-018

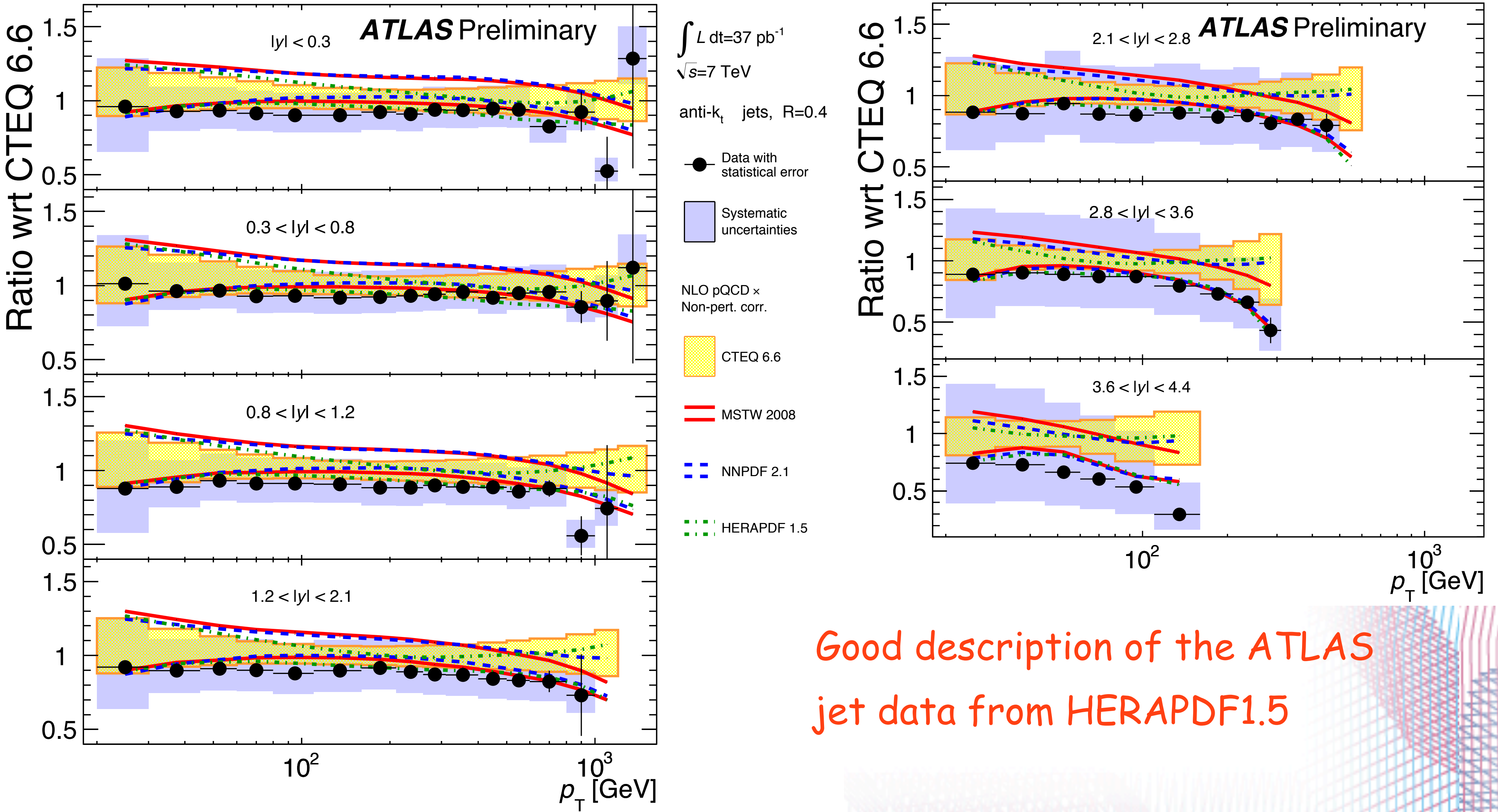
Valence quark distributions

u-valence significantly improved in HERAPDF1.5



H1prelim-10-142, ZEUS-prel-10-018

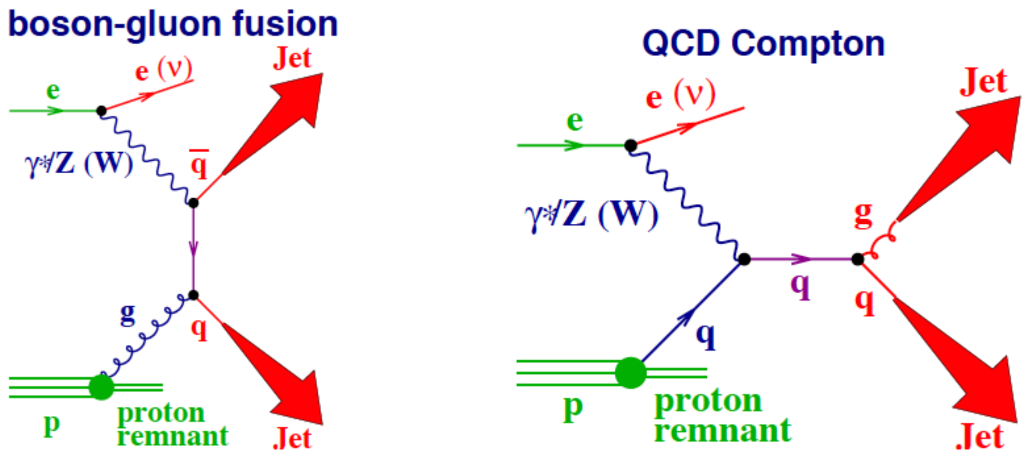
HERAPDF1.5 and ATLAS jets



Good description of the ATLAS jet data from HERAPDF1.5

Jet cross sections

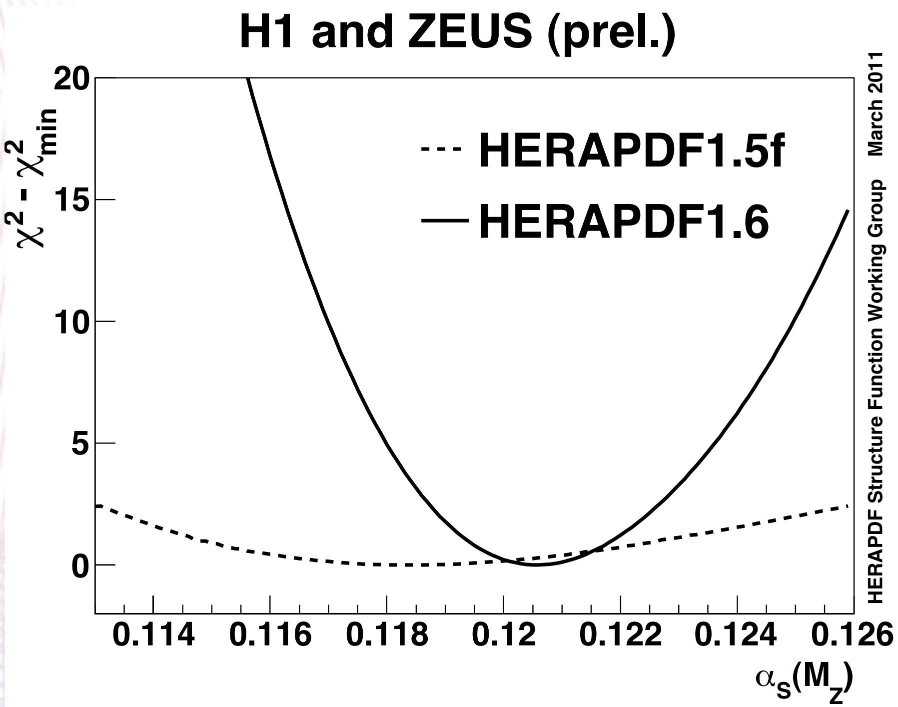
- Stringent test of perturbative QCD
- Sensitivity to the gluon in the proton, precise input to QCD fits.



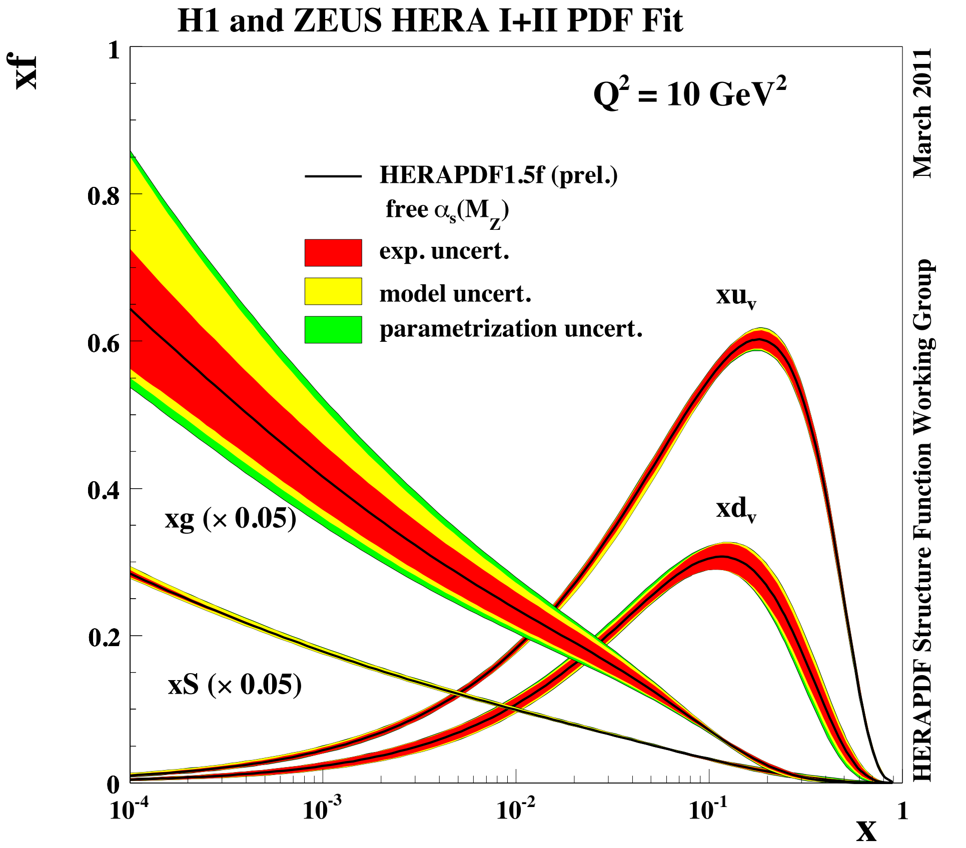
- Extract α_s with high precision, check the scale dependence within a single experiment and in different regimes.

HERAPDF1.6: HERA jets included

The PDF fit done with inclusive NC and CC cross sections is not sensitive to α_s: α_s is fixed in the fit for HERAPDF1.0 and 1.5.



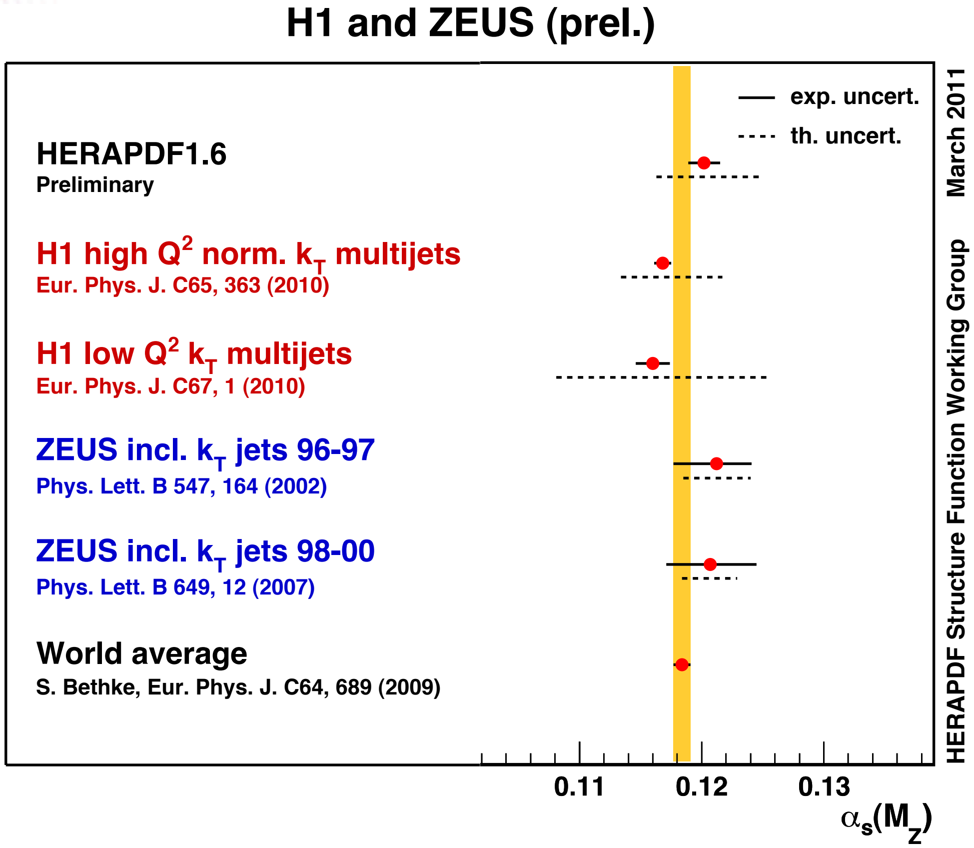
Data included: H1 HERAI+II and ZEUS HERAI high-Q2 jets, H1 HERAI low-Q2 jets.

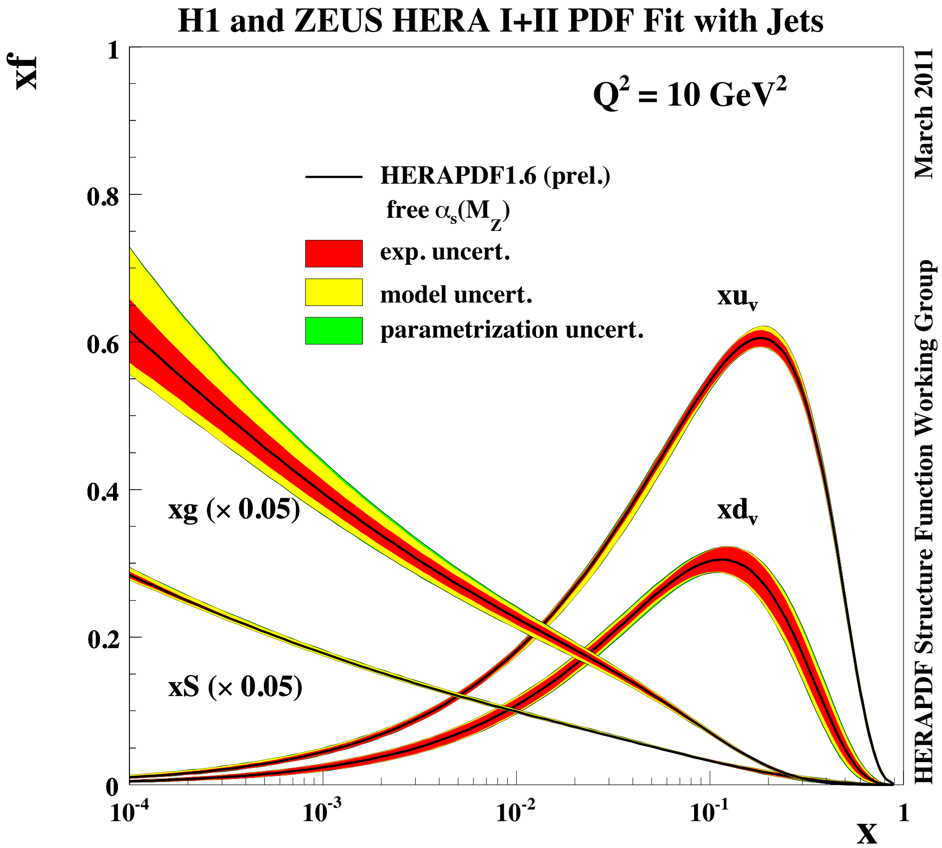


If α_s is set free, the uncertainty on the gluon becomes much bigger...

HERAPDF1.6: HERA jets included

Inclusion of the jets allows a precise α_s determination in the PDF fit!

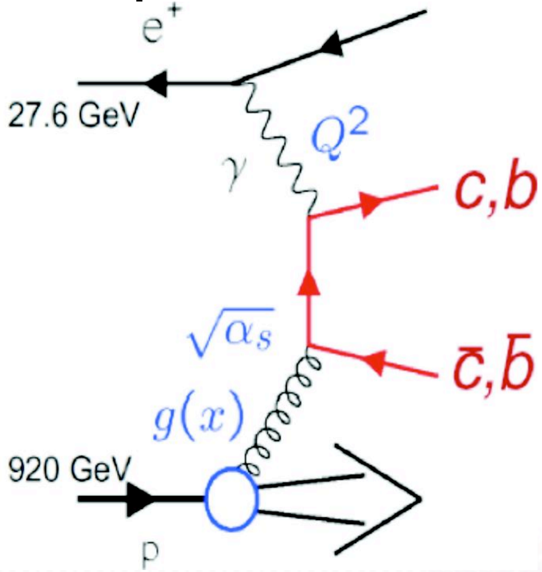




The uncertainty on the gluon is similar to that of HERAPDF1.5

Charm and beauty production

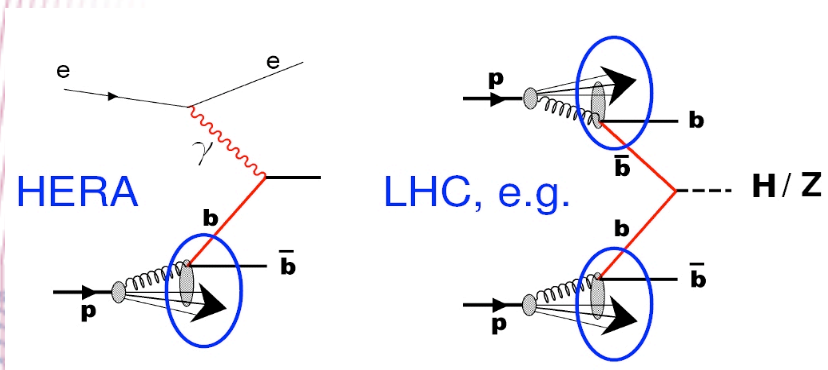
- Stringent test of perturbative QCD, sensitivity to the gluon in the proton.
- Multi-scale problem (mass, p_T, Q^2)
- Check of the QCD fits depencence on the heavy flavour treatment

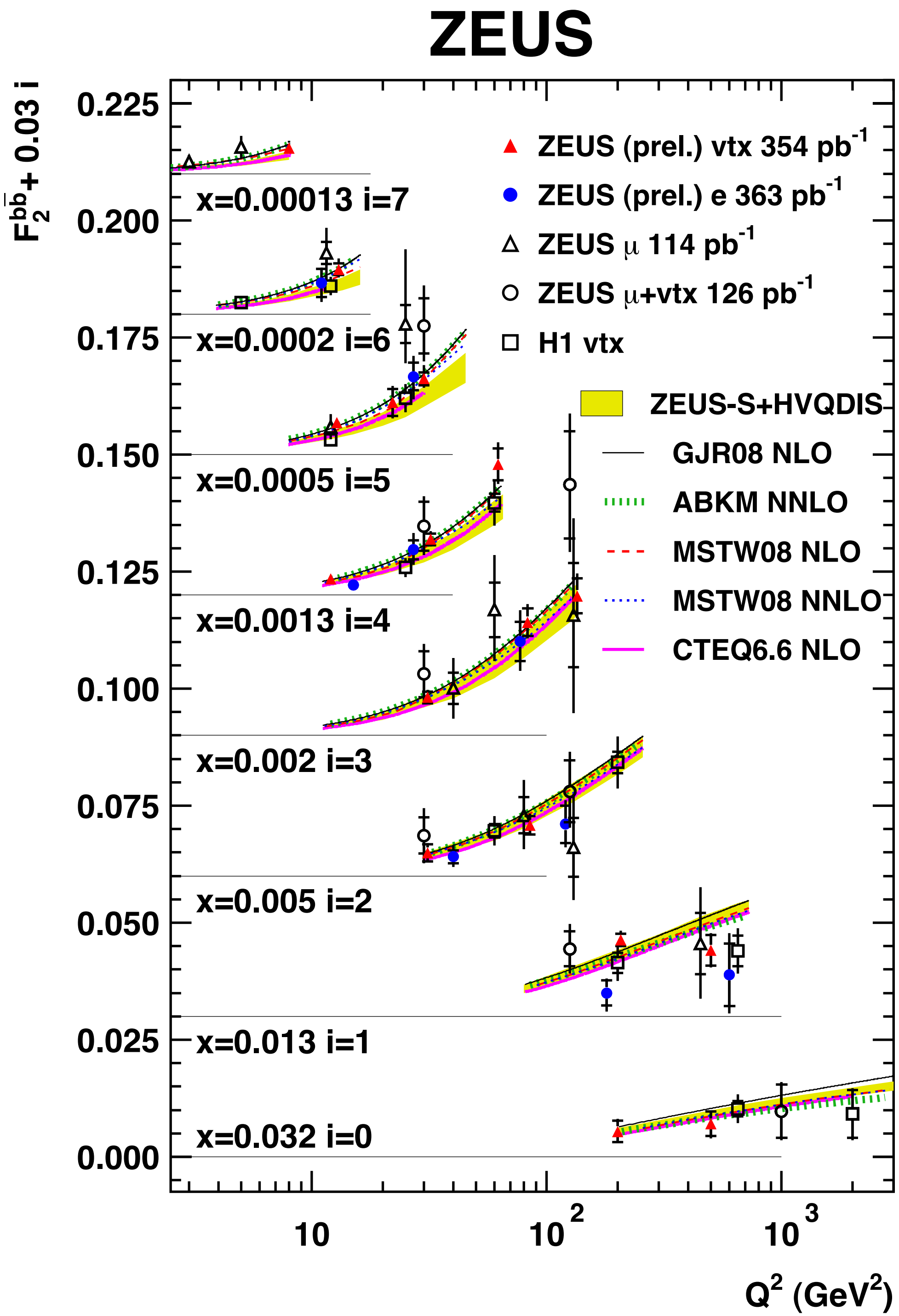


F_2^b

Consistent picture among various analyses using different methods.

The secondary vertices analysis significantly improves the precision.





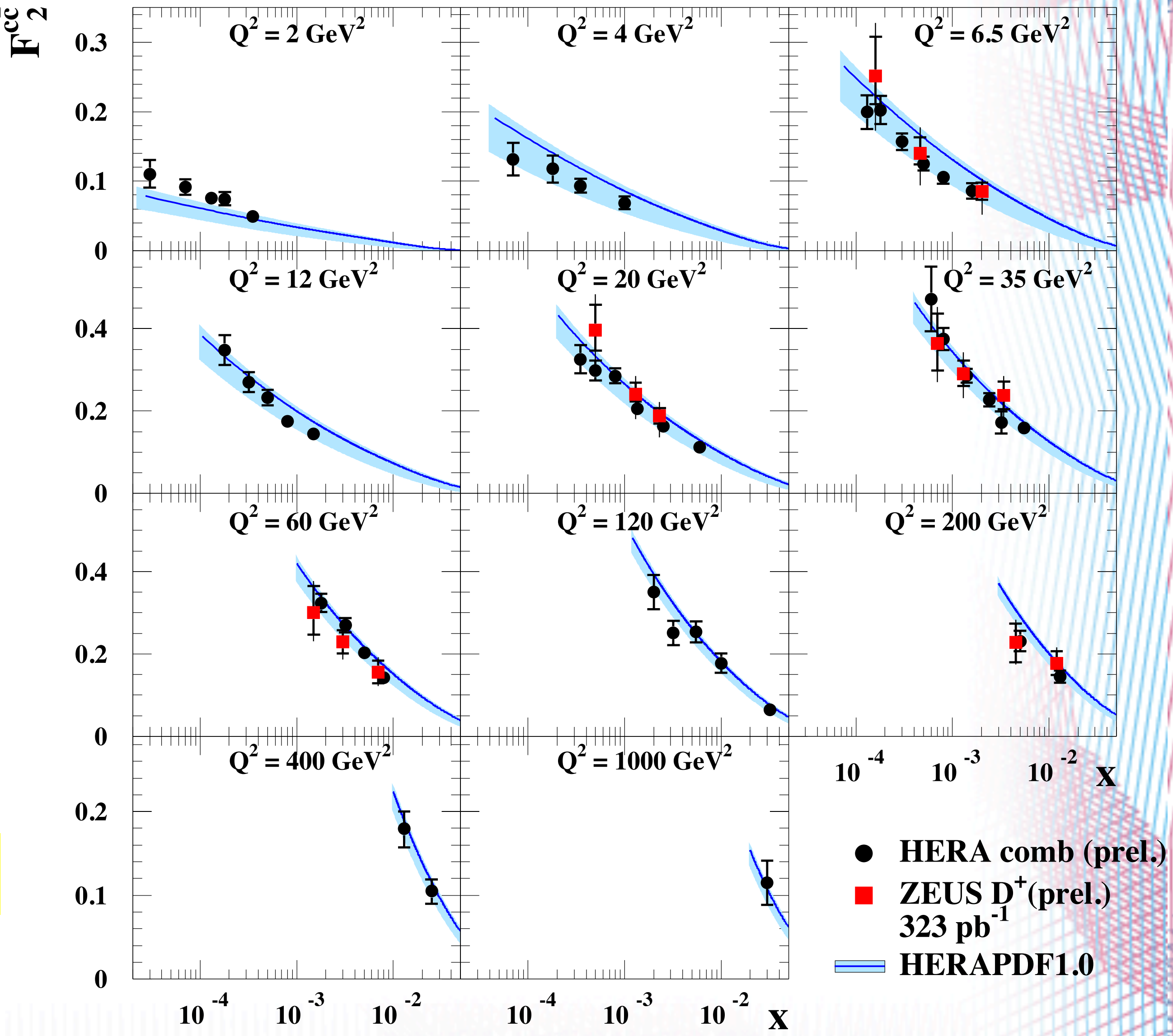
$F_2^{c\bar{c}}$: charm content of the proton

Test of the PDFs on a different final state at HERA (data are not in the HERAPDF1.0 fit).

Combination of ZEUS and H1 data brings the precision to 5-10% (to be improved)

Good description of the charm data.

Consistent picture of QCD



H1prelim-09-171,ZEUS-prel-09-015

ZEUS-prel-10-005

$F_2^{c\bar{c}}$: charm content of the proton

- Test of the PDFs on a different final state at HERA (data are not in the HERAPDF1.0 fit).
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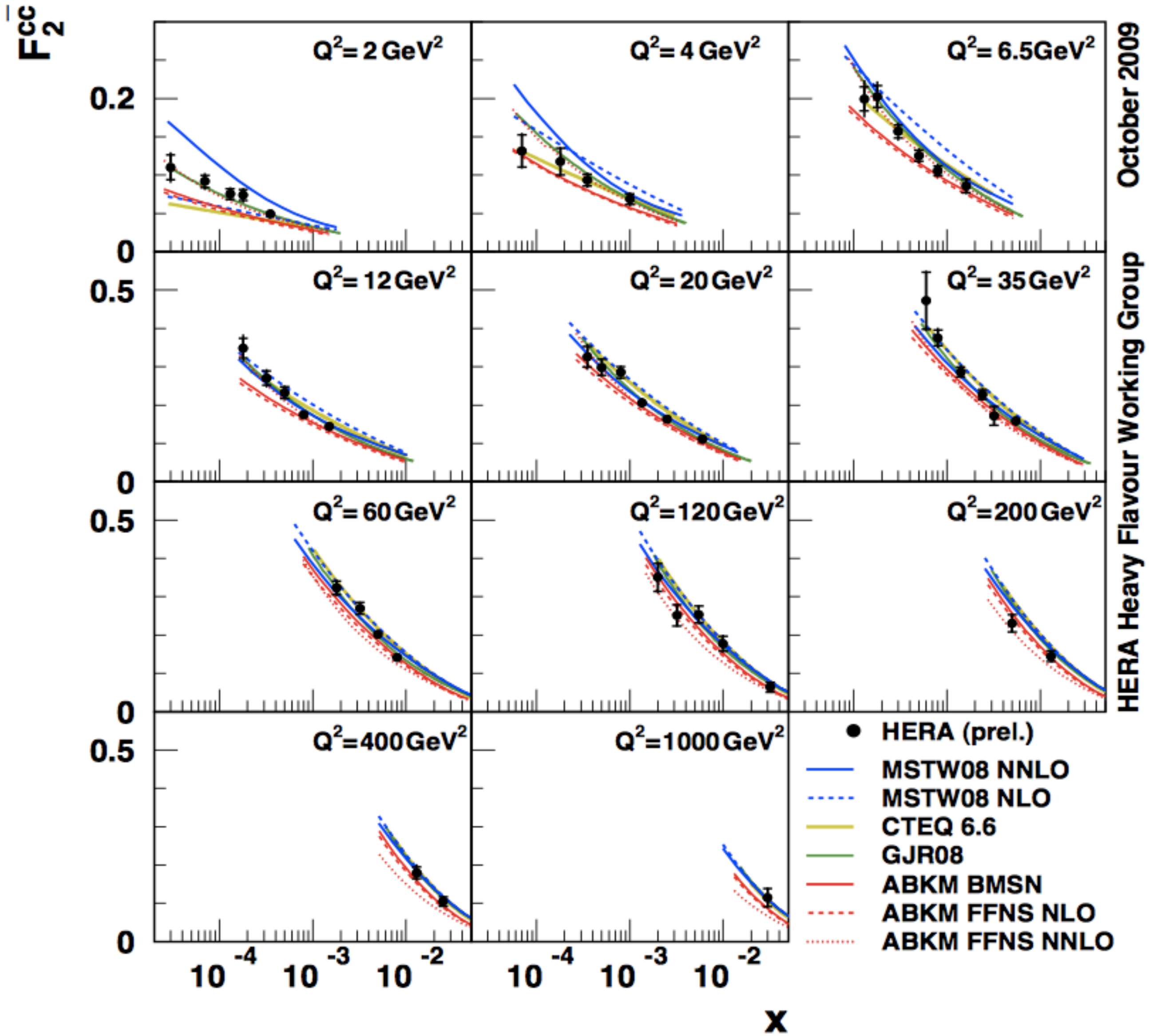
Consistent picture of QCD

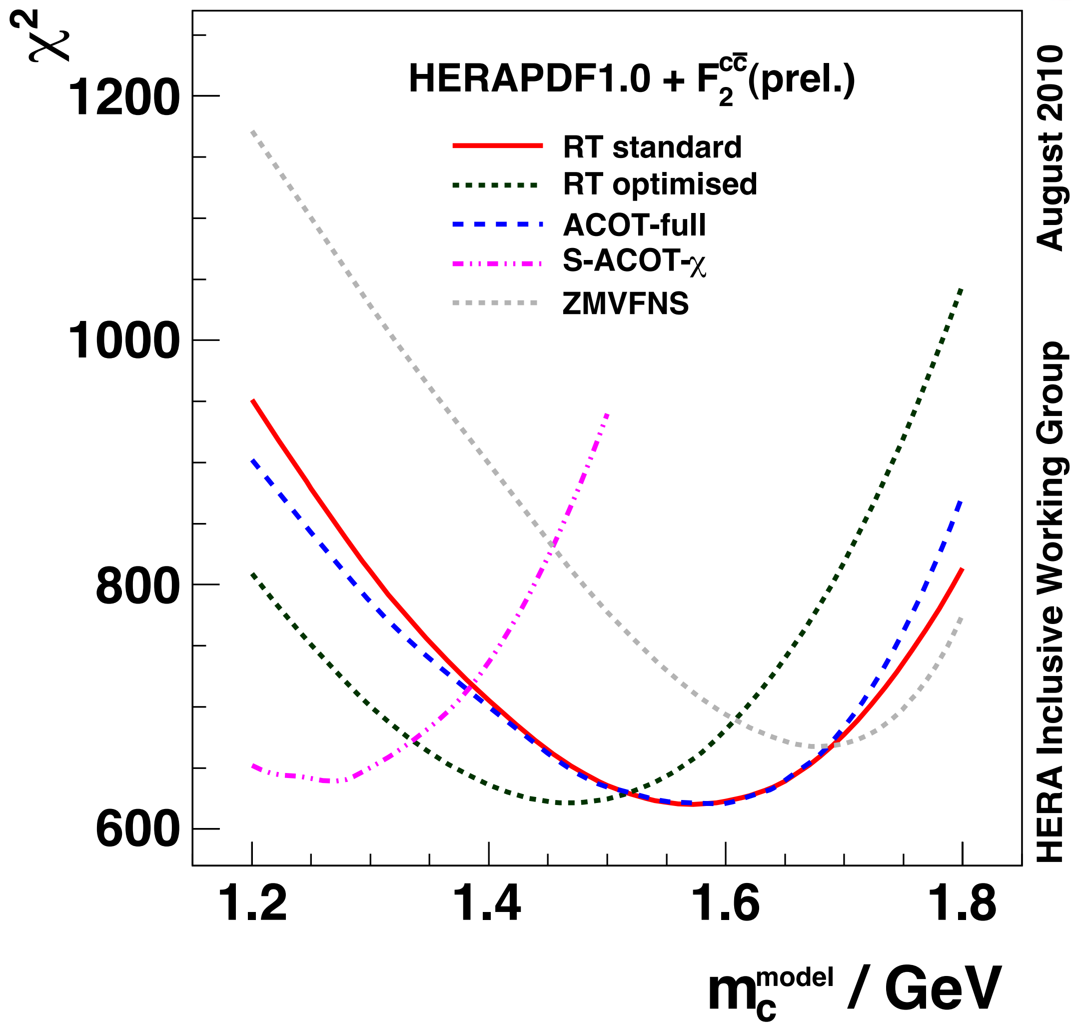
H1prelim-09-171,ZEUS-prel-09-015



Impact of the charm data on the PDFs

Values of the W and Z cross sections at the LHC depend significantly on the heavy quark treatment used and on the charm mass

- But if the charm data are considered, an 'optimal' charm mass can be extracted for each scheme
- W and Z cross section at this point do not depend on scheme or mass



H1prelim-10-143, ZEUS-prel-10-019

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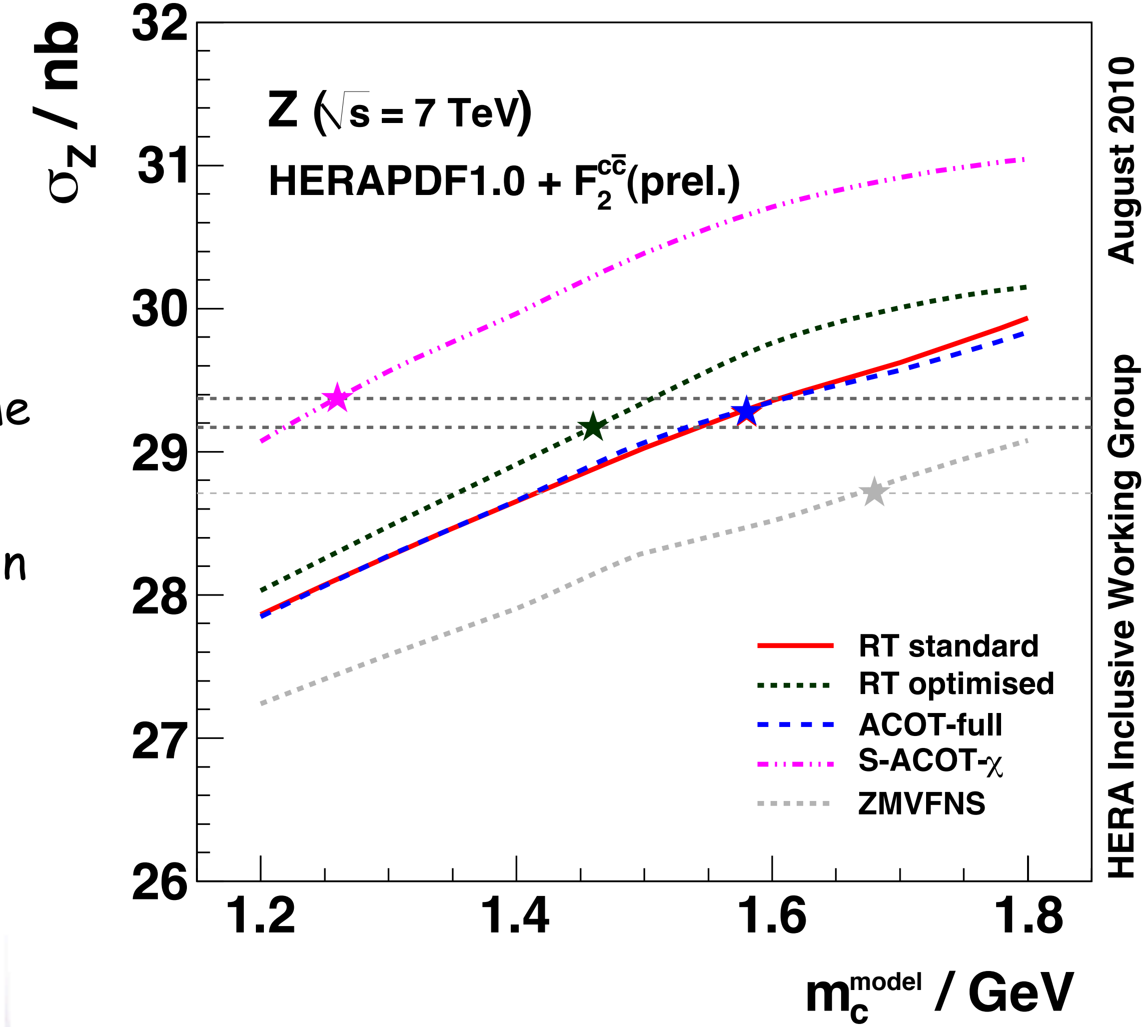


H1prelim-10-143, ZEUS-prel-10-019

Conclusions

The HERA experiments H1 and ZEUS are completing their analyses.

The focus is now on the combination of the data.

Precise inclusive cross section measurements have already provided important input for the determination of the proton structure.

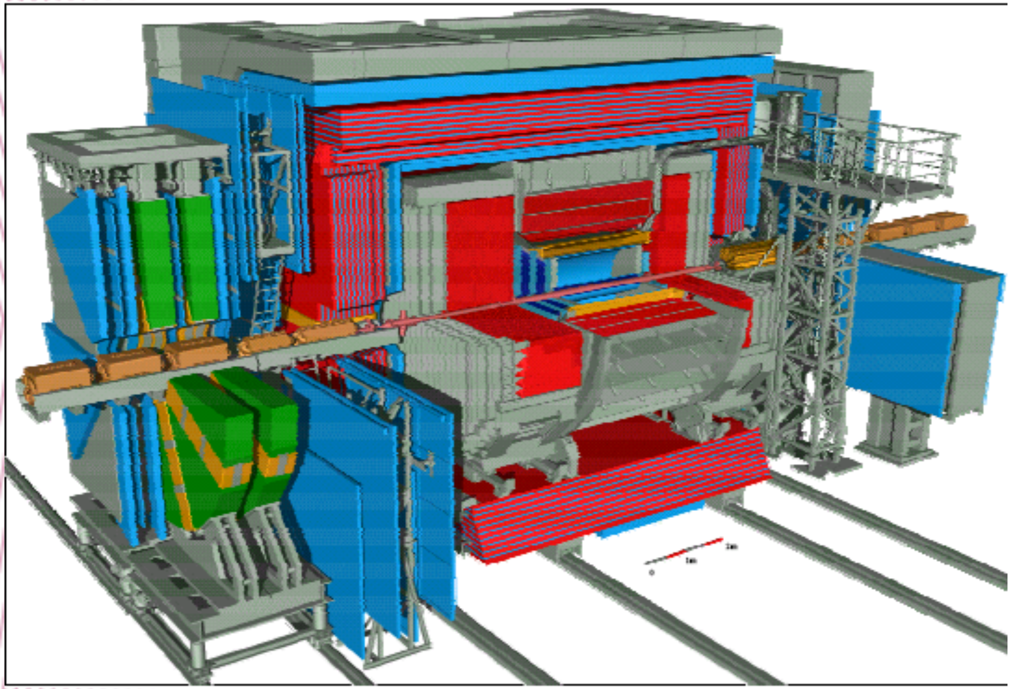
Improvements on the precision and the understanding of the proton structure can come from jets and heavy flavour measurements.

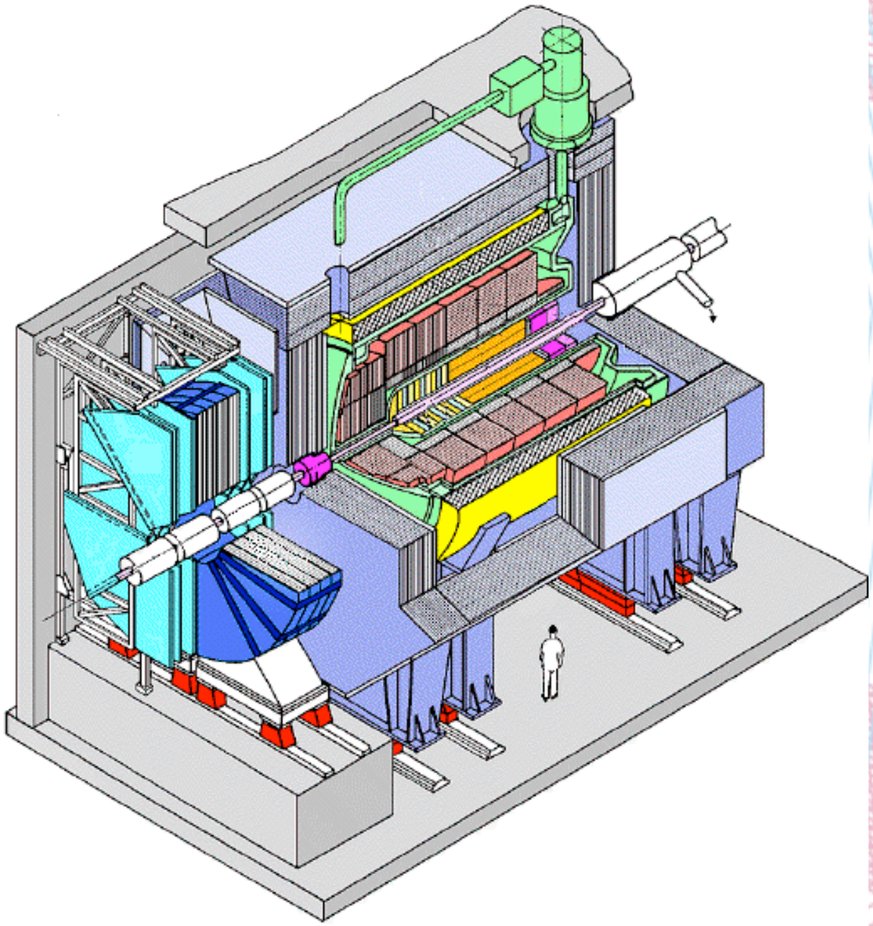
The HERA legacy is an important input for the present LHC experiments!

Backup

The ZEUS and H1 detectors

Multi-purpose detectors, asymmetric in the proton beam (forward) direction due to the two different beam energies.





Upgraded for the HERAII running (2003-2007) with a silicon vertex detector.

Combination of the data: motivation

- Basic assumption: the two experiments are measuring the same cross sections in the same kinematic points
- In the combination procedure the consistency of the data is studied. Different systematic uncertainties are reduced in the procedure.
- Combined cross sections are used as input to QCD fits to determine the proton PDF.
- The combination method uses an iterative χ^2 minimization which include full error correlations.
- Code available, S. Glazov, DIS05 and HERA-LHC WS

χ^2 Definition

$$\chi^2_{exp}(M^{i,true}, \Delta\alpha_j) = \sum_i \frac{[M^{i,true} - (M^i + \sum_j \frac{\partial M^i}{\partial \alpha_j} \frac{M^{i,true}}{M^i} \Delta\alpha_j)]^2}{(\sigma_i \frac{M^{i,true}}{M^i})^2} + \sum_j \frac{(\Delta\alpha_j)^2}{\sigma^2_{\alpha_j}}$$

for a single data set

Minimization is non-linear and use an iterative procedure

Convergence is usually after two iterations

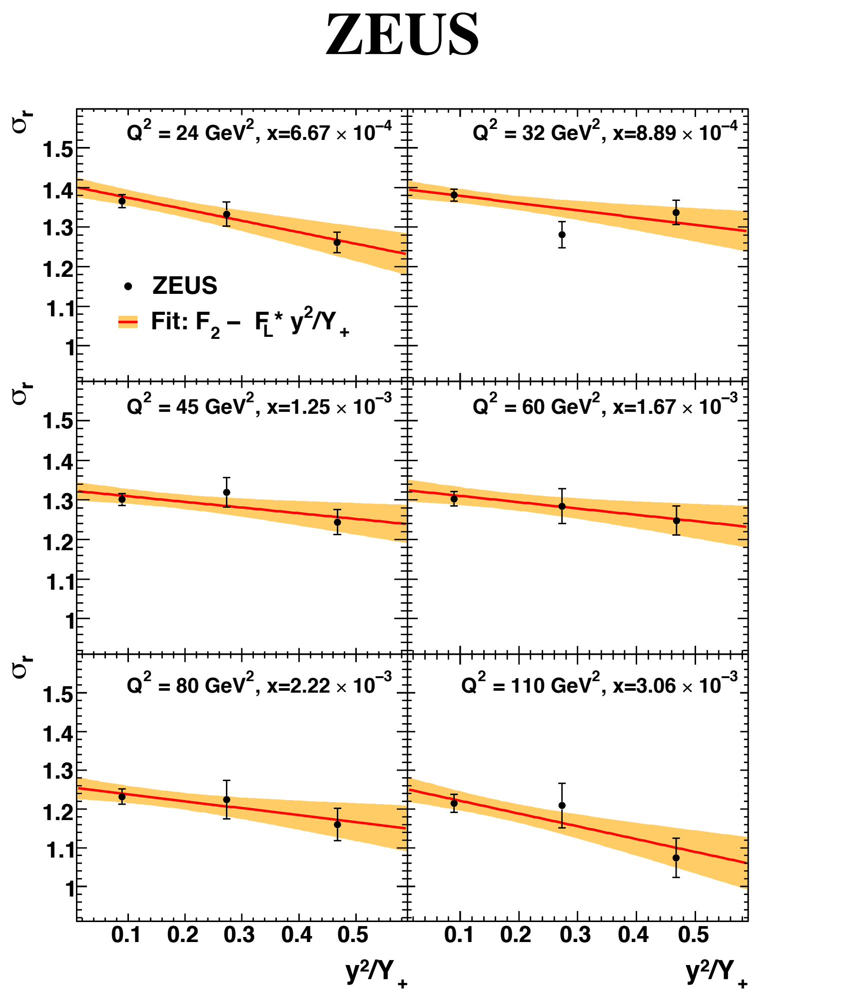
⇨ Full χ^2 is the sum over all χ^2_{exp}

M^i	measured central values
$M^{i,true}$	fitted combined H1 – ZEUS values
σ_i	statistical and uncorrelated systematic uncertainties
σ_{α_j}	correlated systematic uncertainties
$\frac{\partial M^i}{\partial \alpha_j}$	sensitivity of datum i to systematic j
$\Delta\alpha_j$	fitted shift of correlated uncertainties

The F_L structure function

$$F_L \sim x\alpha_s g$$

- Vanishes at LO in QCD, direct sensitivity to the gluon.
- Can be measured as the slope of the reduced cross section vs y straight line, when the reduced cross section is measured at the same Q^2 and x but different y.
- Need to measure the reduced cross section at different centre of mass energies ($Q^2 = sxy$)

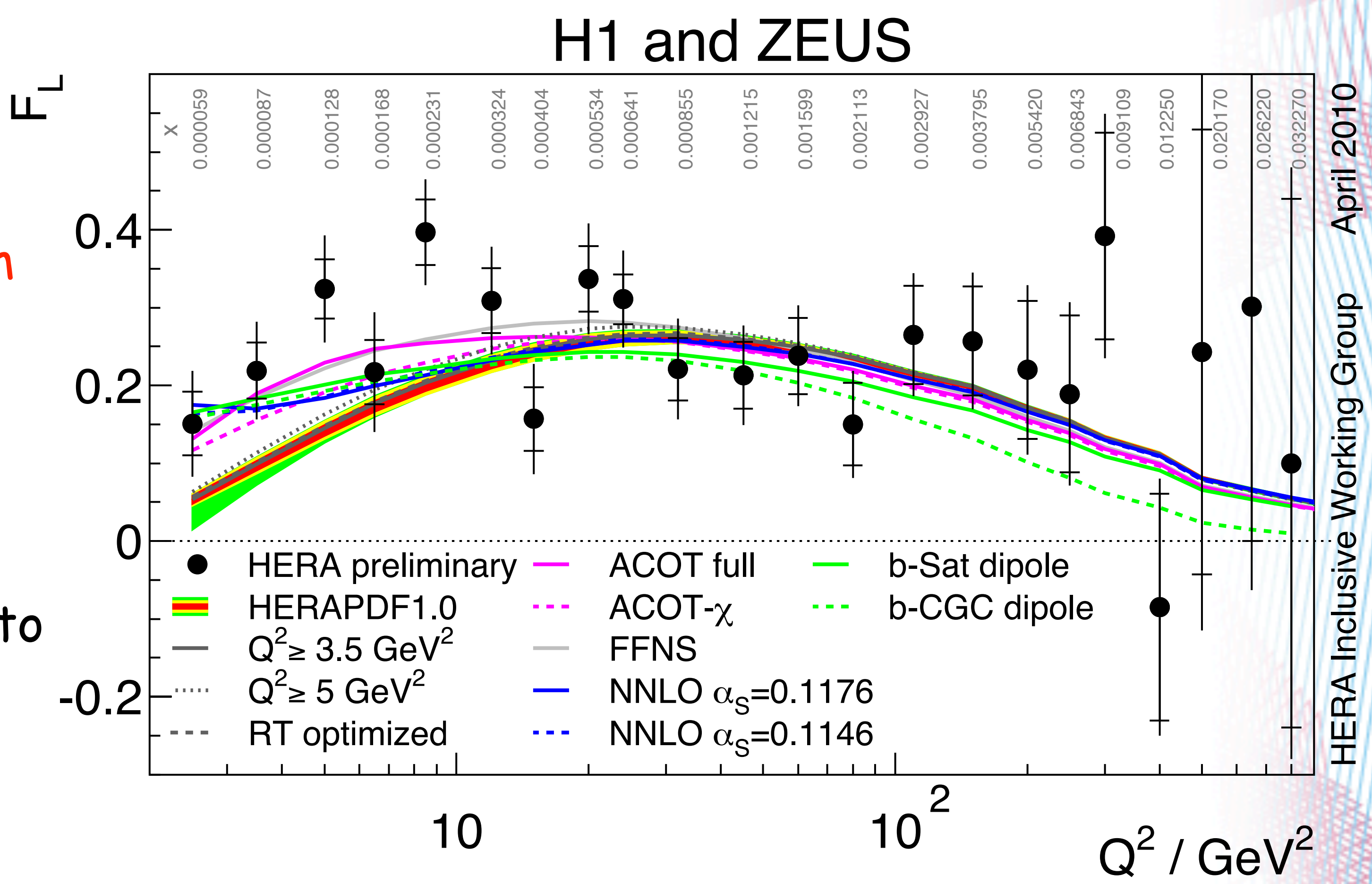


The F_L structure function

Direct F_L measurement from three different centre of mass energies.

Directly sensitive to the gluon,

$F_L \sim \alpha_s \, xg(x,Q^2)$



Good understanding of the gluon content of the proton

H1prelim-10-043, ZEUS-prel-10-001

The F_L structure function

Direct F_L measurement from three different centre of mass energies.

Directly sensitive to the gluon,

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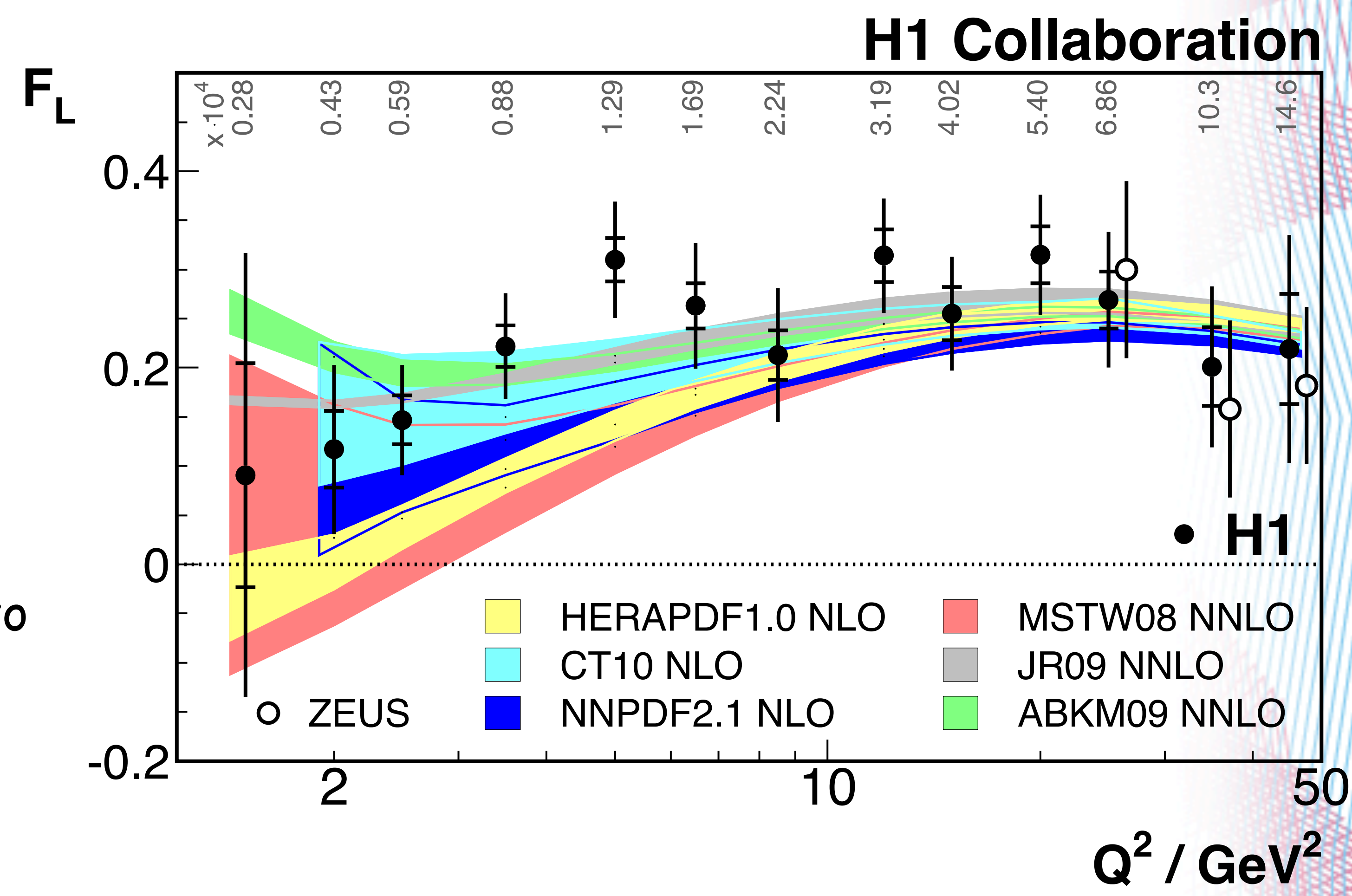
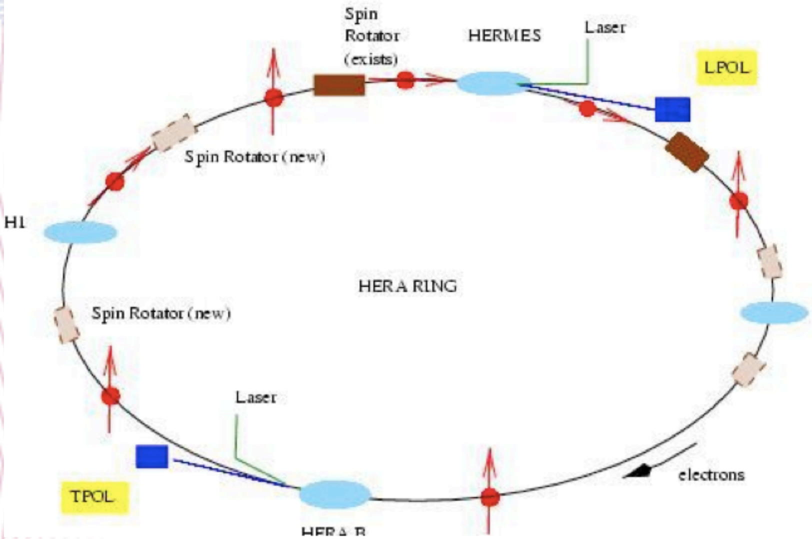


Good understanding of the gluon content of the proton

Eur.Phys.J.C71 (2011) 1579

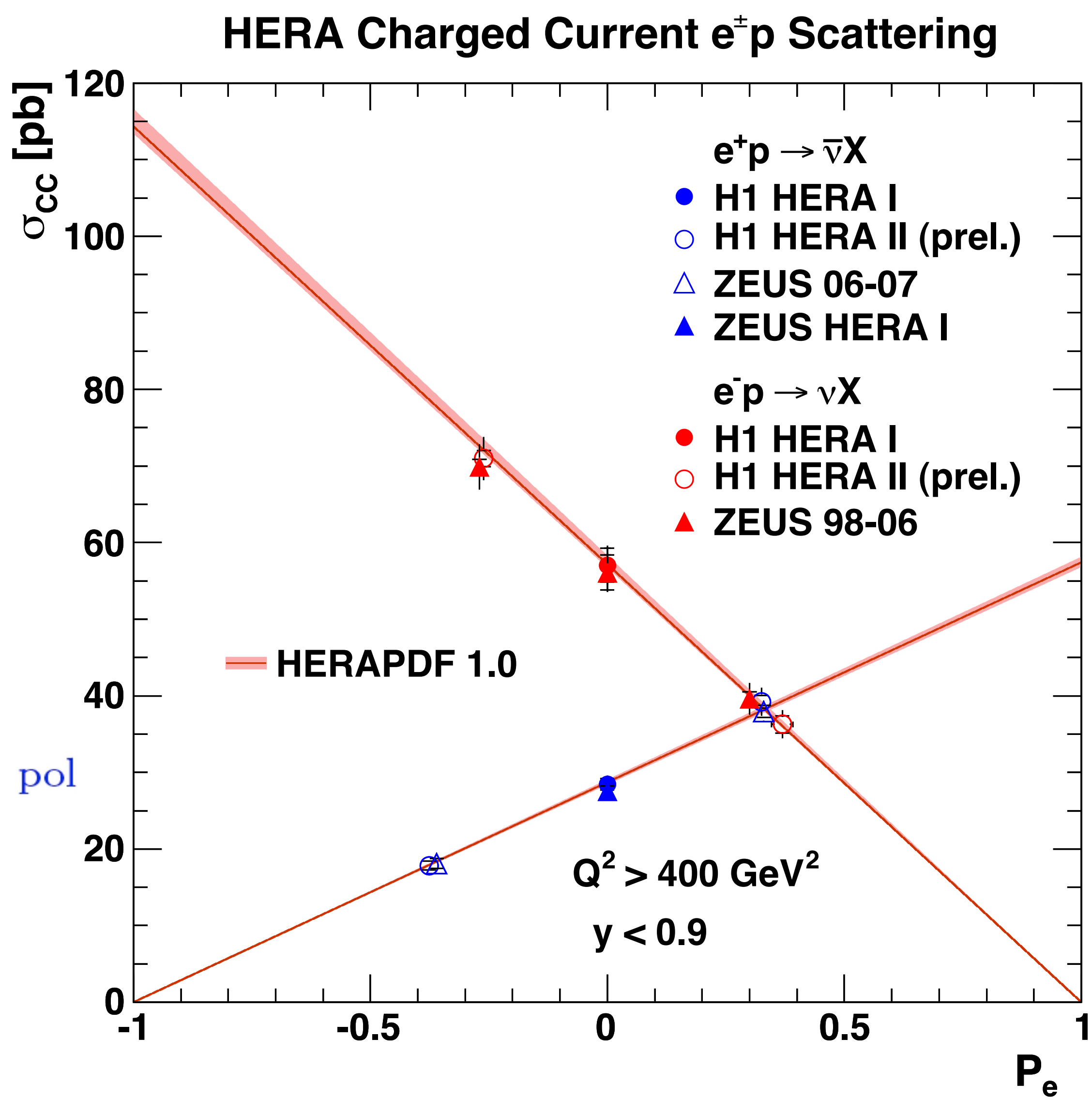
CC cross sections vs polarization



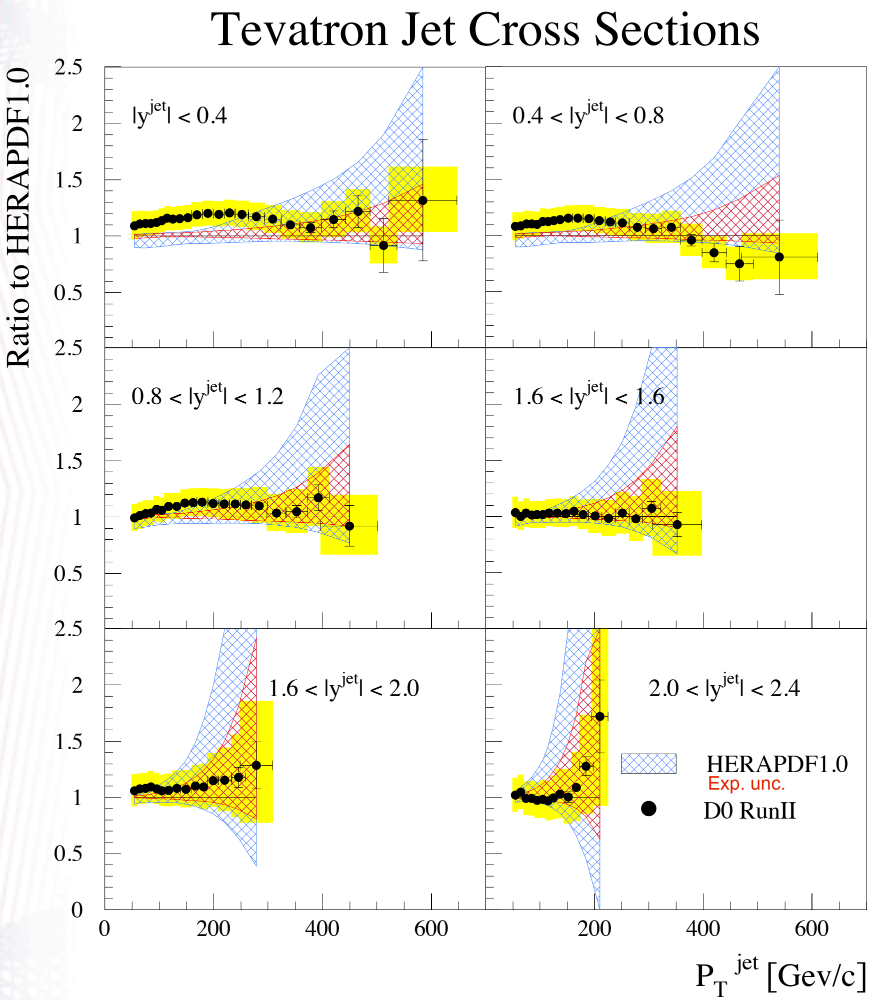
$$P_e = \frac{N_R - N_L}{N_R + N_L}$$

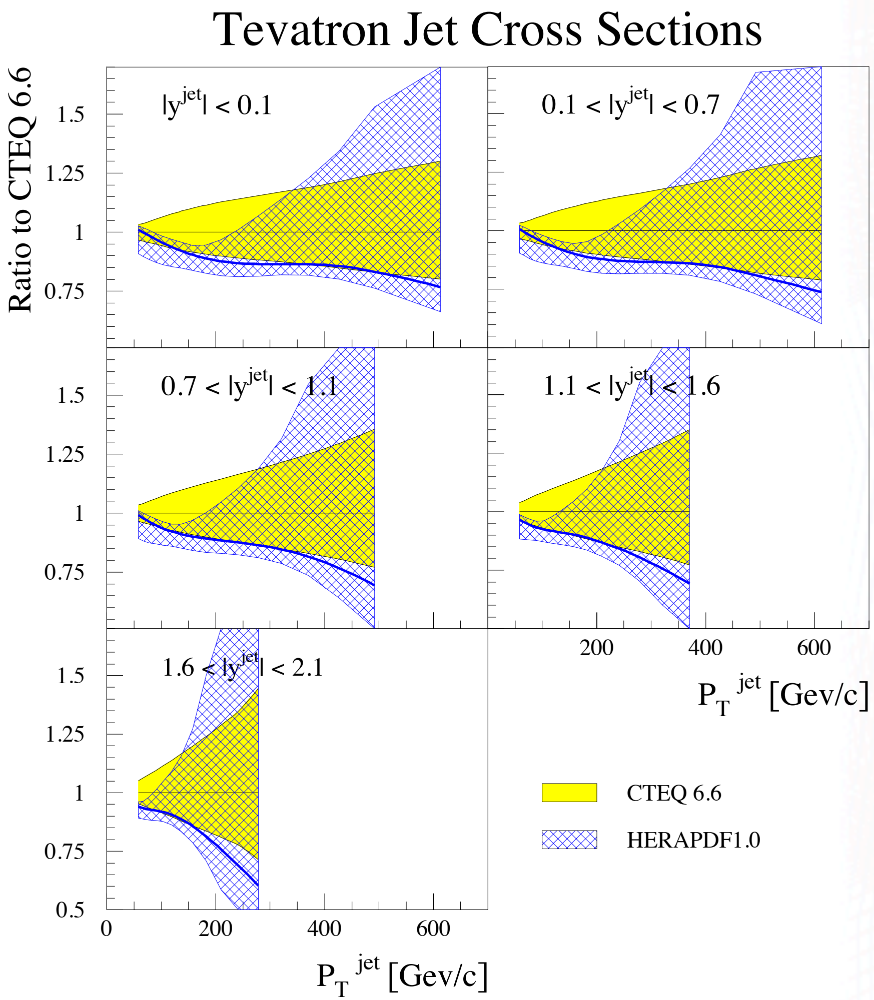
$$\sigma^{NC}_{e^\pm p} = \sigma^{NC,\ \mathrm{unpol}}_{e^\pm p} + P_e\, \sigma^{NC,\ \mathrm{pol}}_{e^\pm p}$$

$$\sigma^{CC}_{e^\pm p} = (1 \pm P_e)\, \sigma^{CC}_{e^\pm p,\ \mathrm{unpol}}$$



Going in more detail...





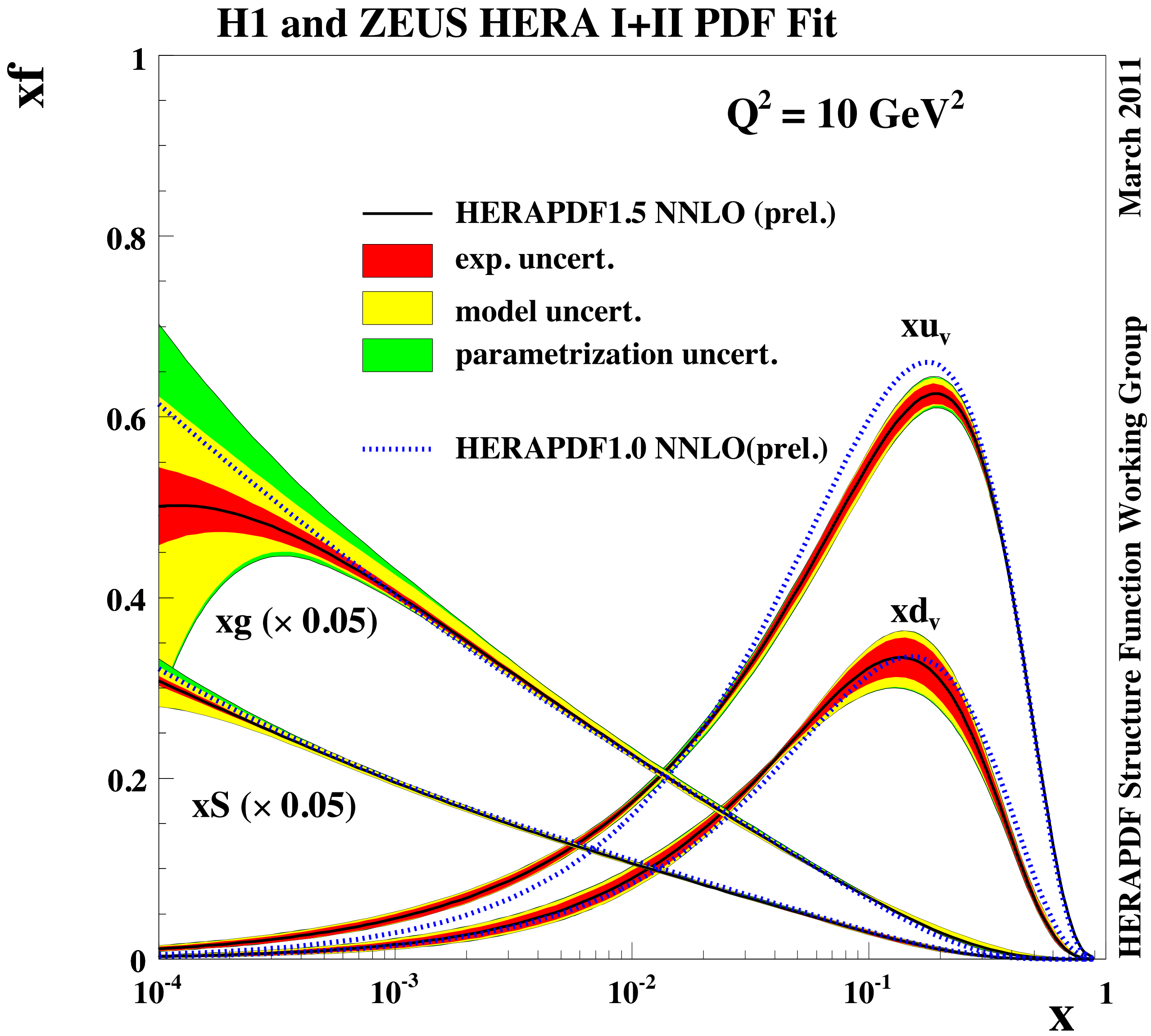
https://www.desy.de/h1zeus/combined_results/benchmark/tev.html

PDF fit at NNLO

Gluon parameterisation is more flexible.

Quality of the fit is similar at NLO and NNLO.

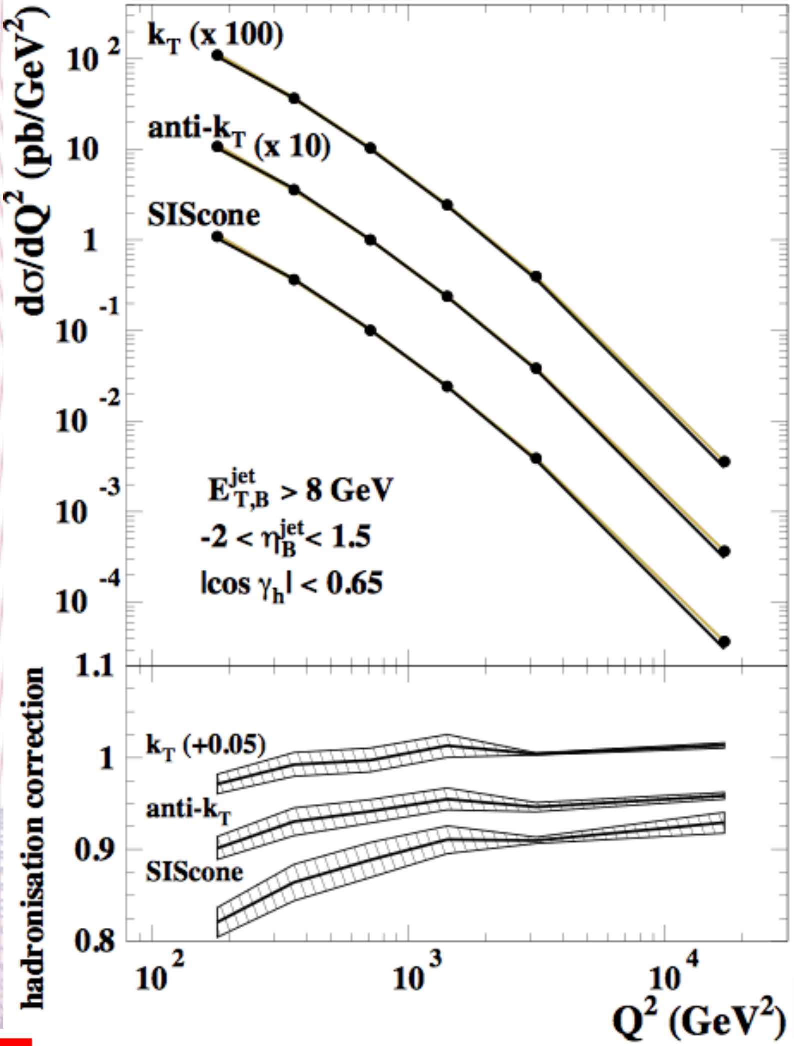
Gluon distribution changes a bit.

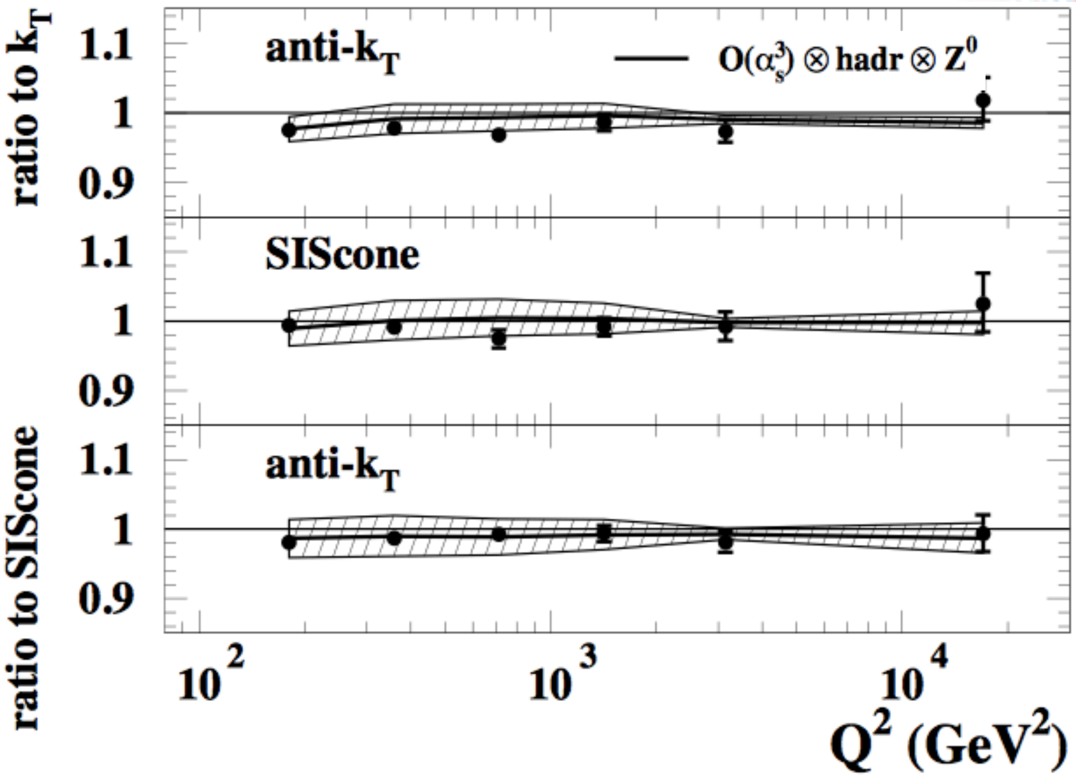


Anti-k_T and SIScone jet algorithms

Reanalysis of inclusive jets in DIS

(k_T used originally)





Data very well described by NLO and all the algorithms.

Similar precision (slightly worse for SIScone)

Ratios evaluated up to order α_s^3

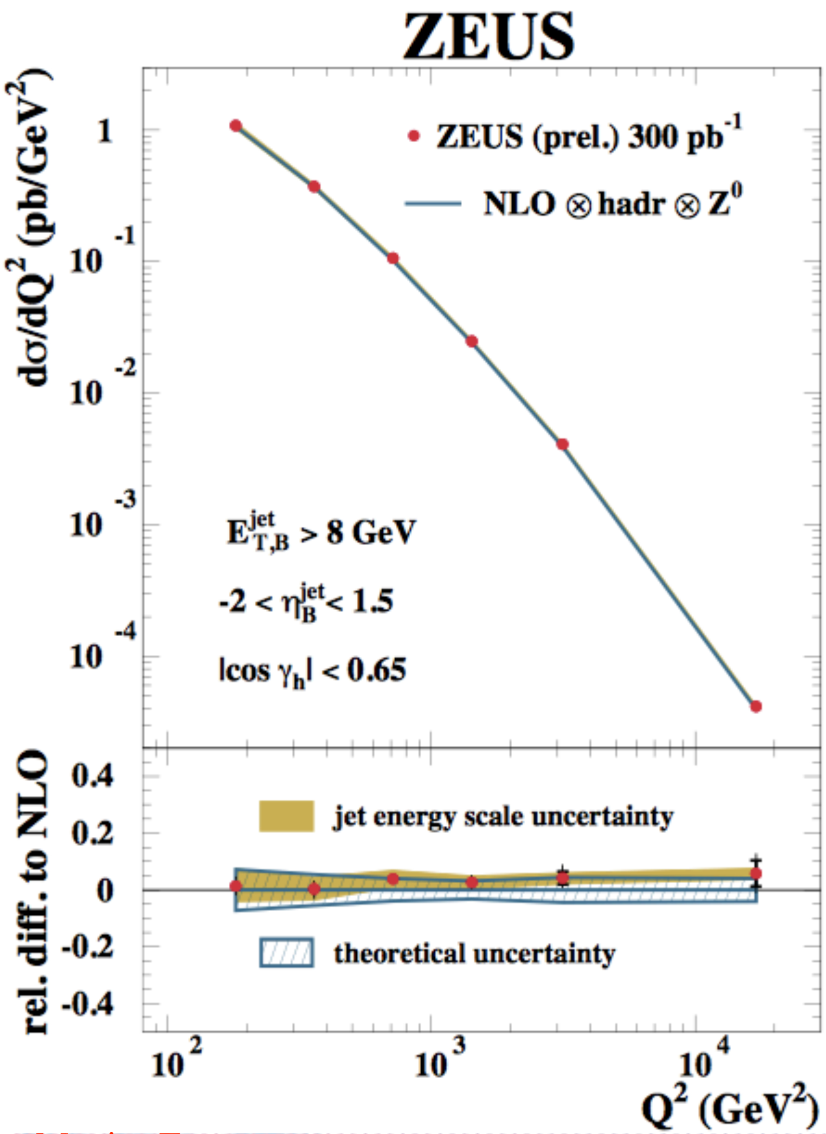
First publication on data, now prel. also for PHP

DESY-10-034

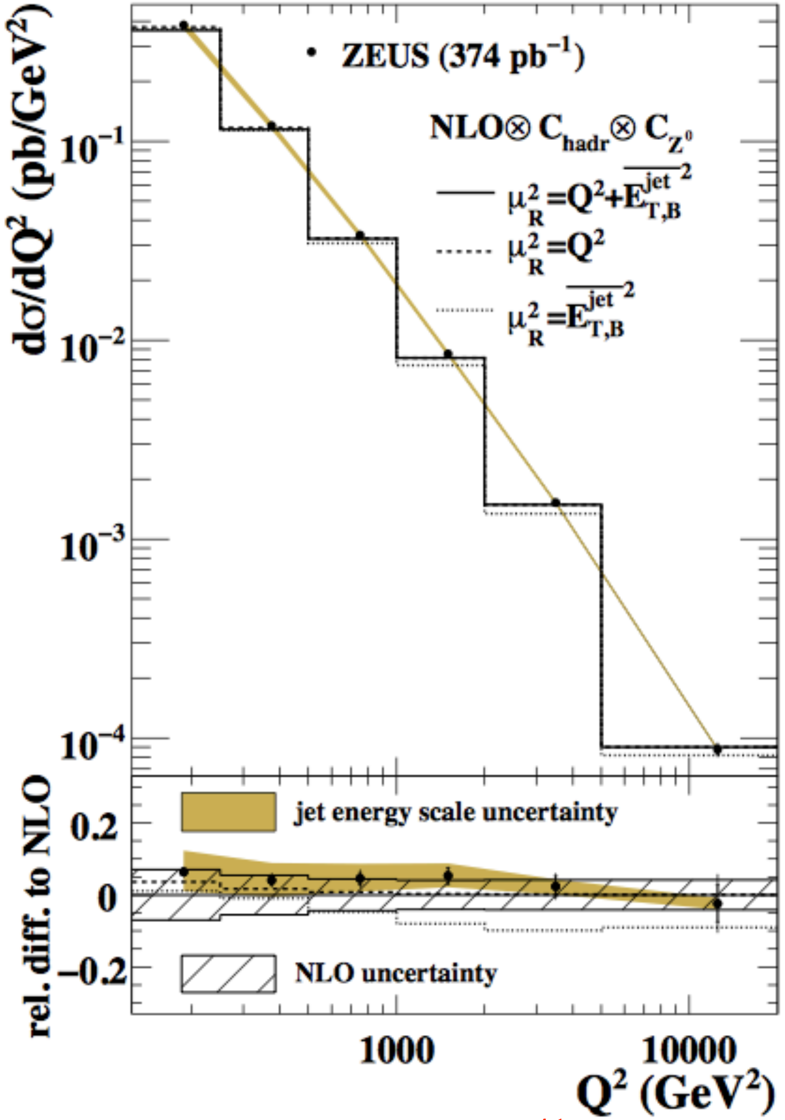
Inclusive jets and dijets in NC DIS

Kinematic range $Q^2 > 125\ GeV^2$. Good agreement with QCD at NLO.

Inclusive jets, $L=300\ pb^{-1}$



Inclusive dijets, $L=374\ pb^{-1}$



ZEUS-prel-10-002

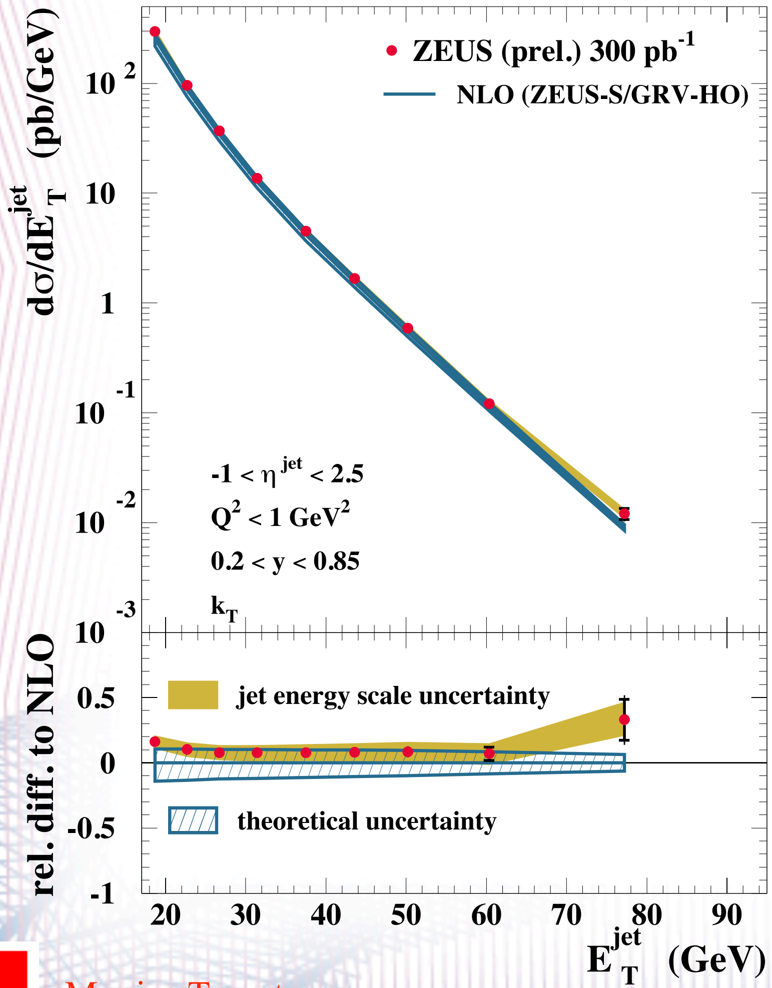
ZEUS-pub-10-005

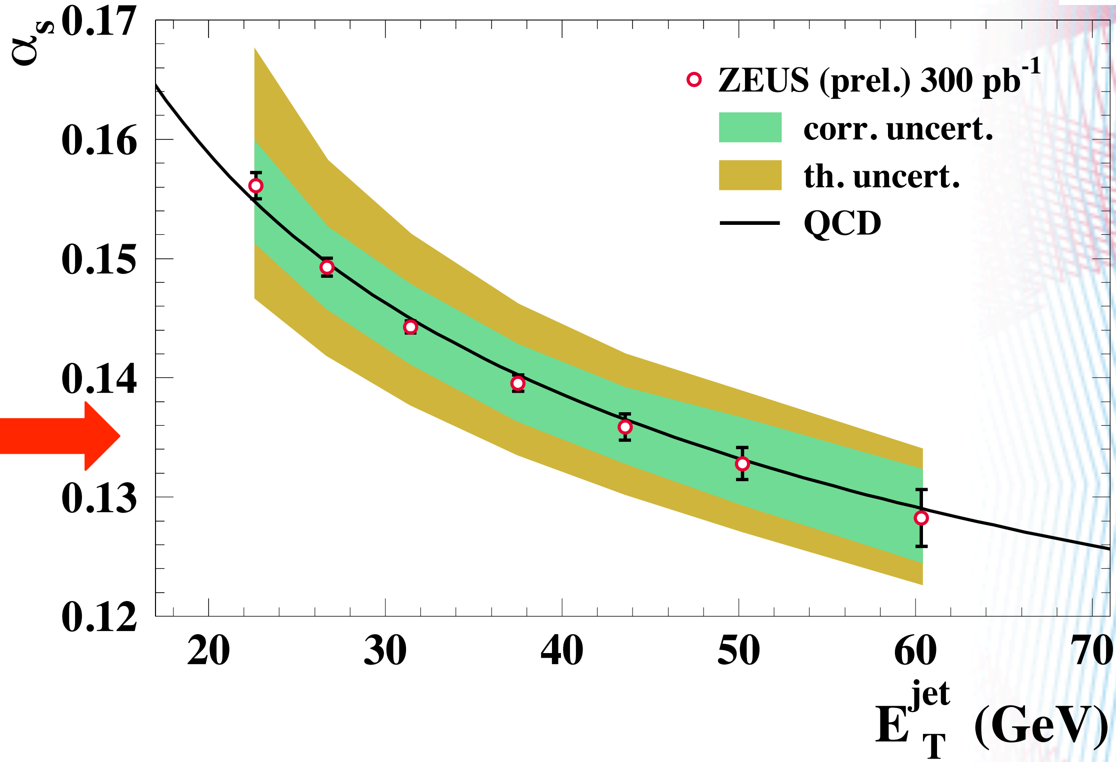
Inclusive jets in PHP

$Q^2 < 1\ GeV^2$, $0.2 < y < 0.85$

At least one jet with

$E_T^{jet} > 17$ GeV, $-1 < \eta jet < 2.5$





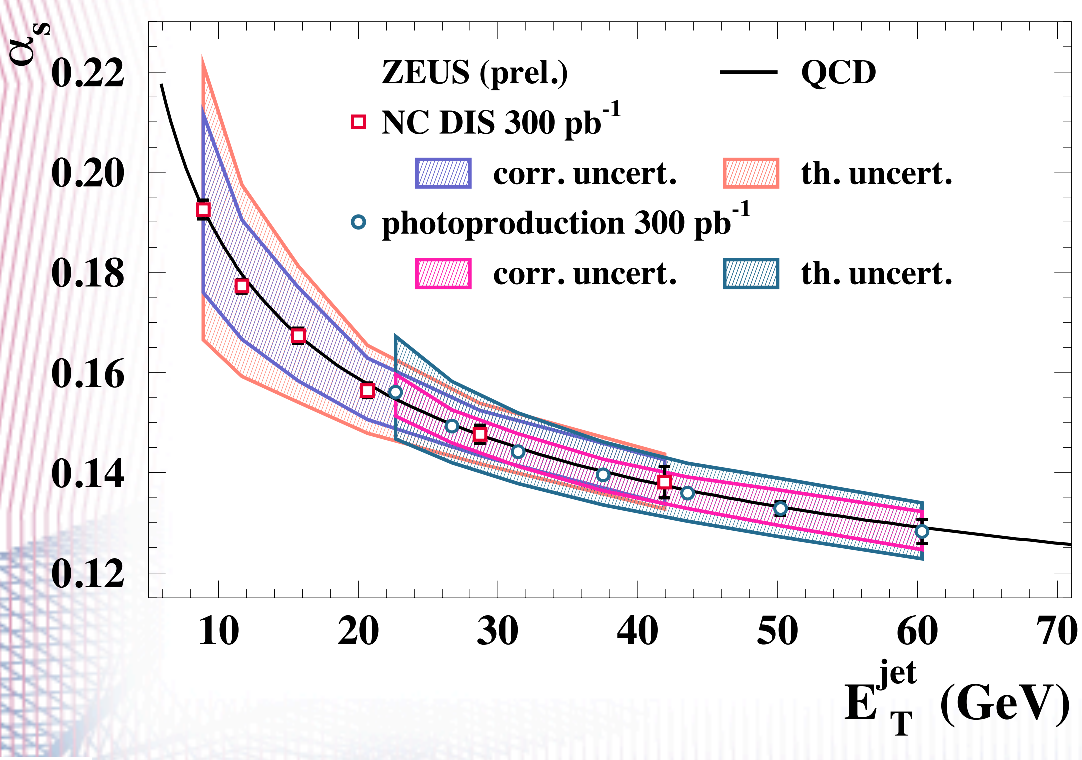
α_s extracted from the dependence of the cross section on E_T. Jets in PHP gave the most precise α_s measurement at ZEUS, now extended to HERAII

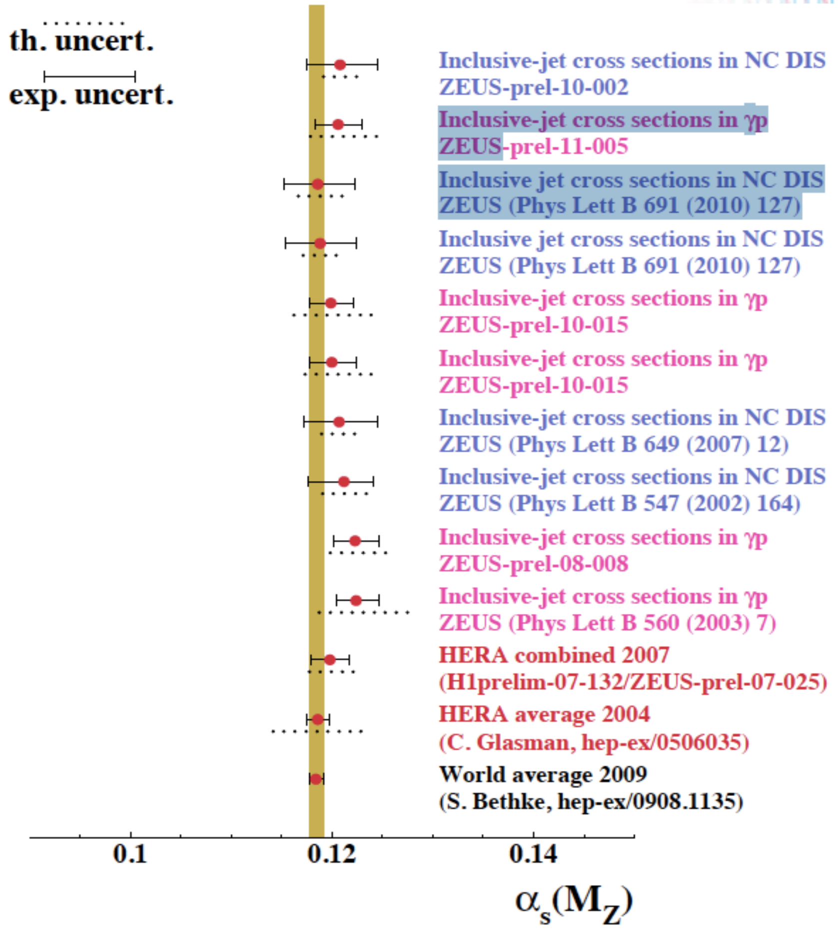
Test of the running of α_s.

ZEUS-prel-10-003

α_s running from PHP to DIS

Running of the coupling constant with the scale tested from the low to the high Q^2 regime.



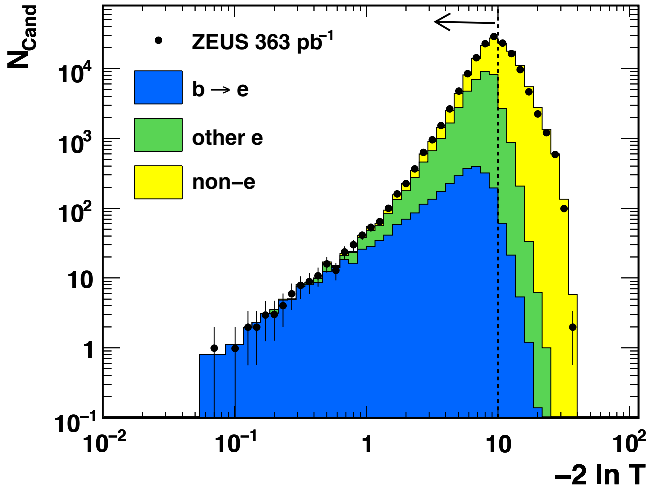


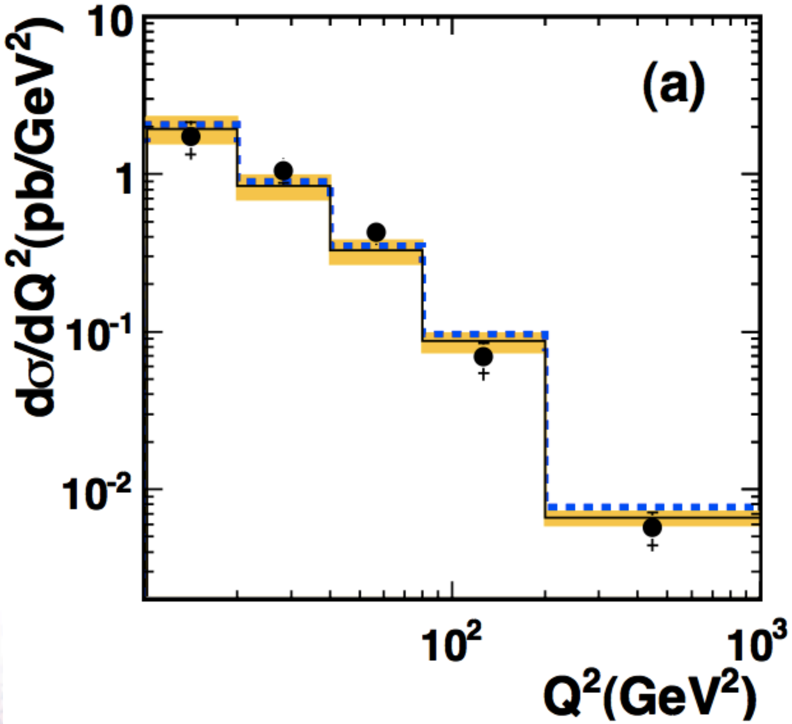
New precise α_s measurements from DIS and PHP in agreement with the world average.

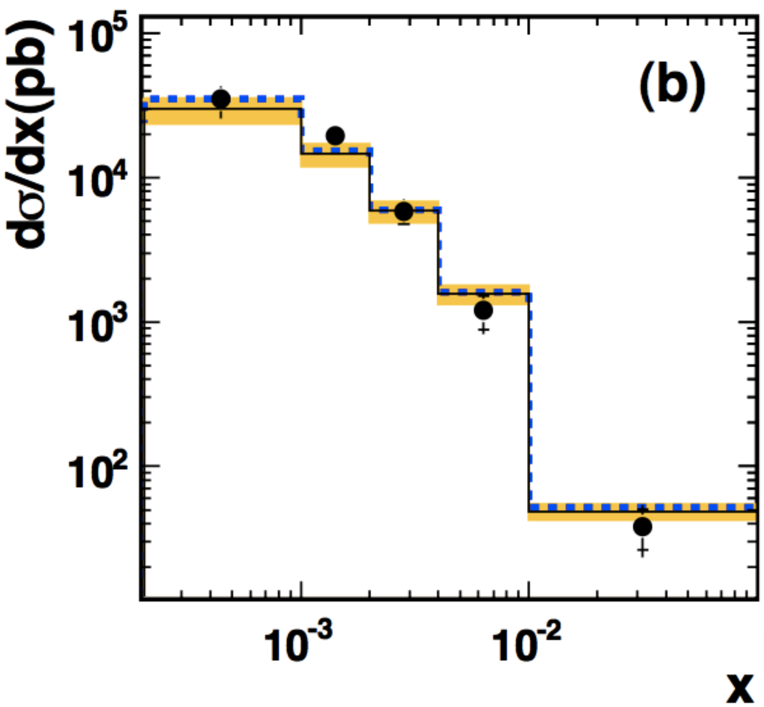
Beauty in DIS with electrons

L=363 pb^{-1}

Signal determined from a likelihood function involving electron and beauty variables.



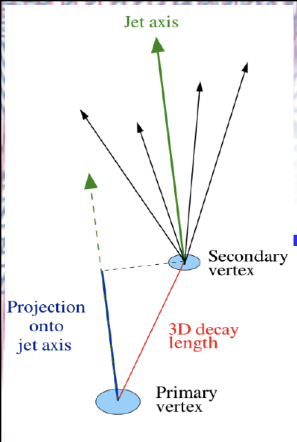




arXiv:1101.3692

Beauty in DIS

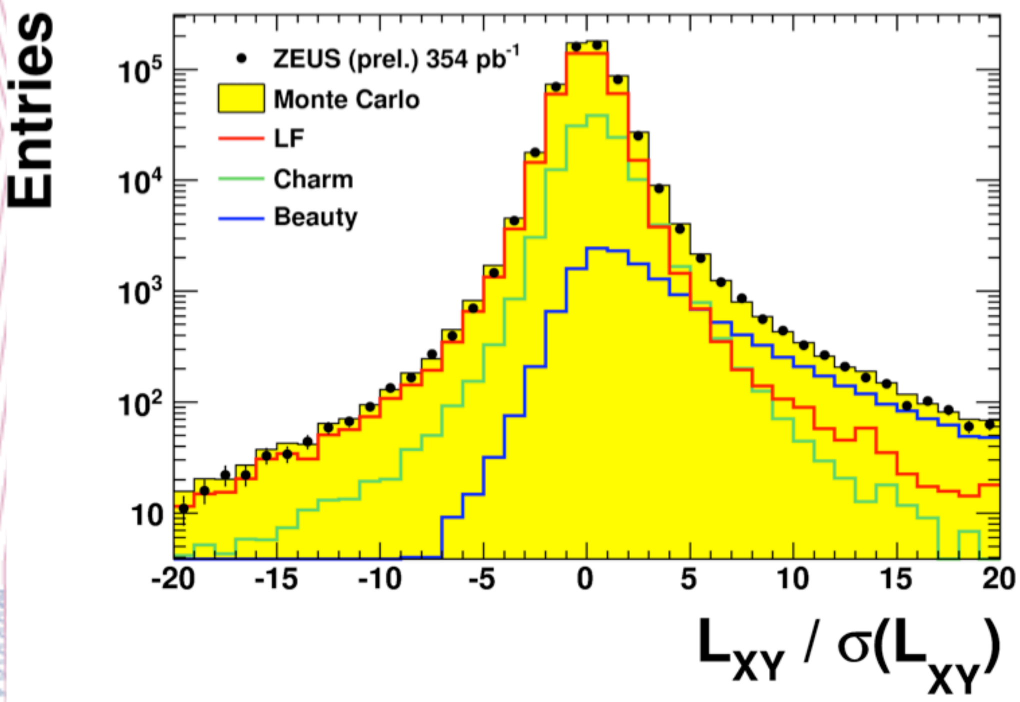
L=354 pb^{-1}

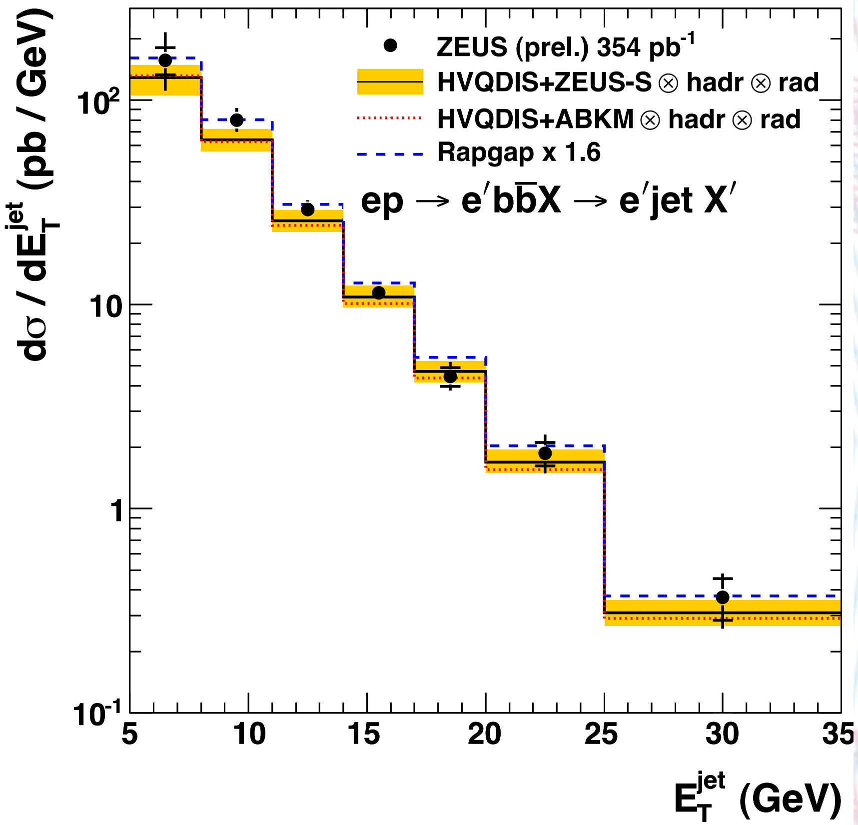


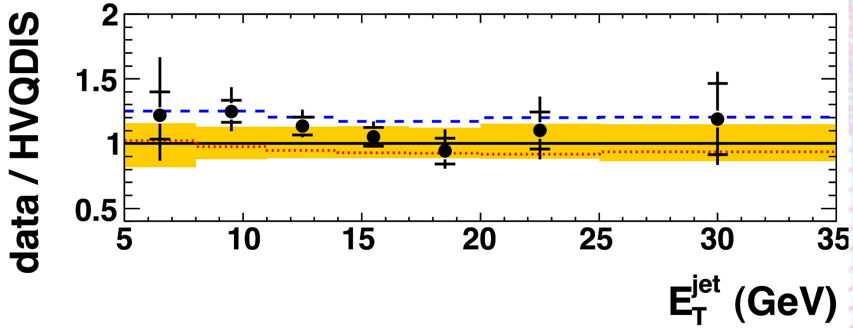
Beauty reconstructed from jets with secondary vertices.

$5.0\ GeV^2 < Q^2 < 1000.0\ GeV^2, 0.02 < y < 0.7$

$E_T(Jet) > 5.0$ GeV, $-1.6 < \eta(Jet) < 2.2$





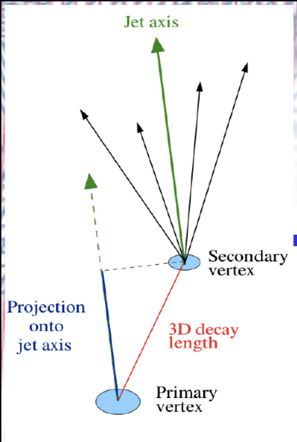


90000 beauty events available

ZEUS-prel-10-006

Beauty in DIS

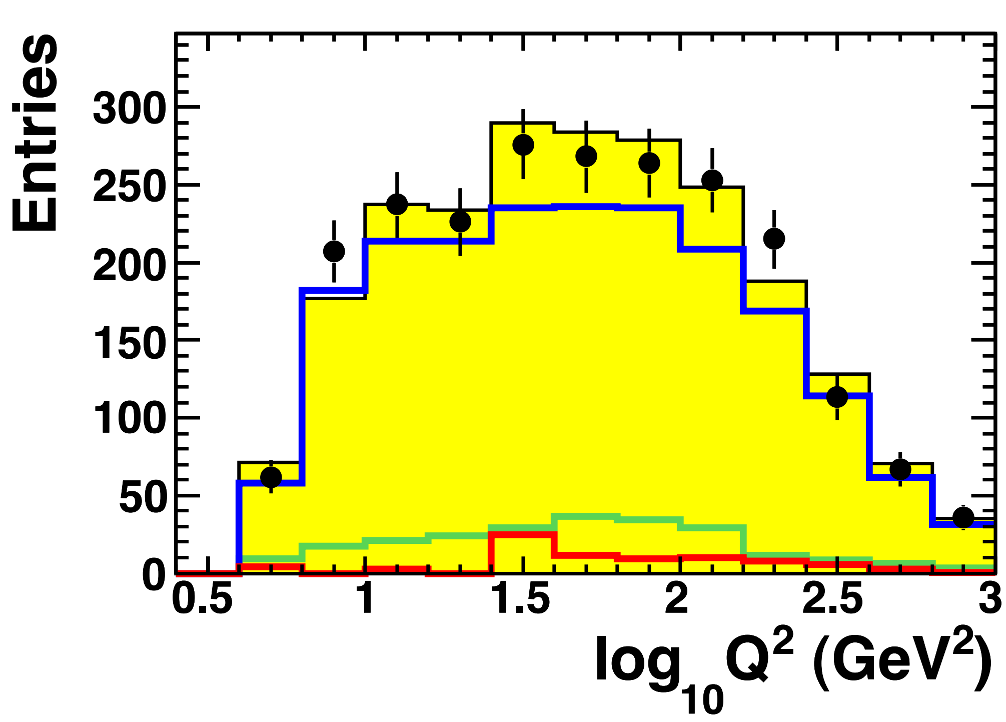
L=354 pb^{-1}

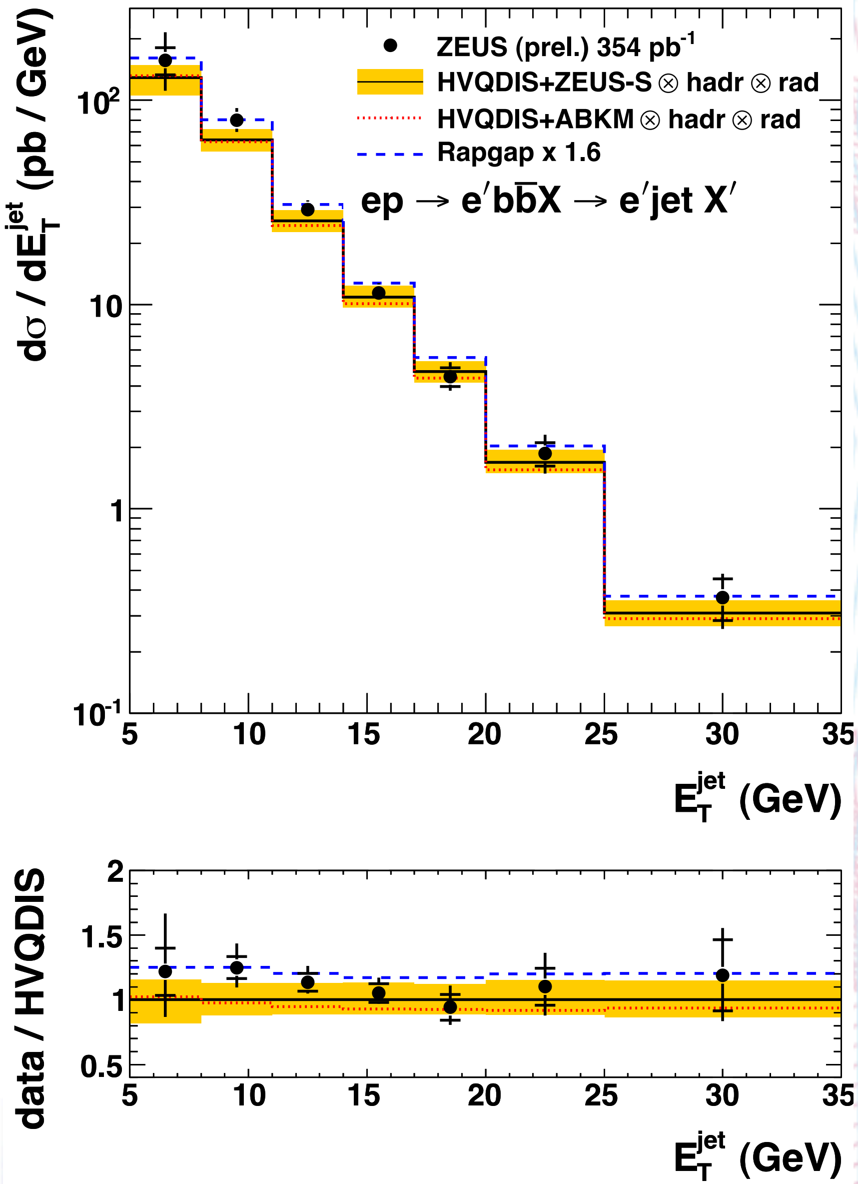


Beauty reconstructed from jets with secondary vertices.

$5.0\ GeV^2 < Q^2 < 1000.0\ GeV^2, 0.02 < y < 0.7$

$E_T(Jet) > 5.0\ GeV, -1.6 < \eta(Jet) < 2.2$





90000 beauty events available

ZEUS-prel-10-006

D^+ in DIS

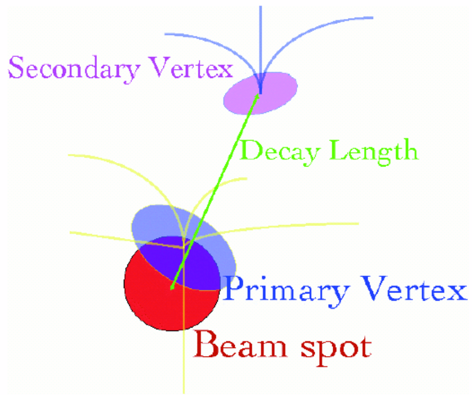
D+ reconstructed using lifetime information. $L = 323\ pb^{-1}$.

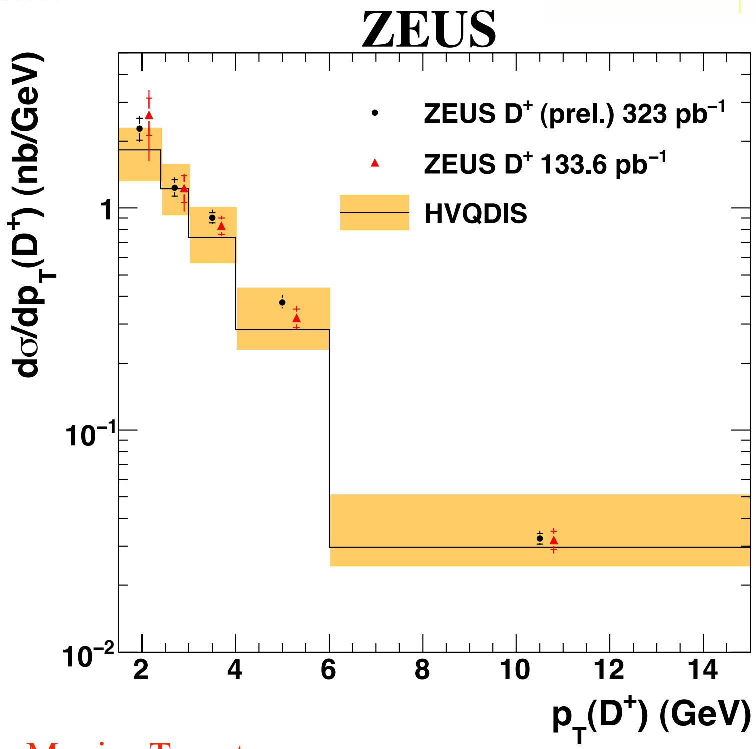
$5 < Q^2_{DA} < 1000\ GeV^2$

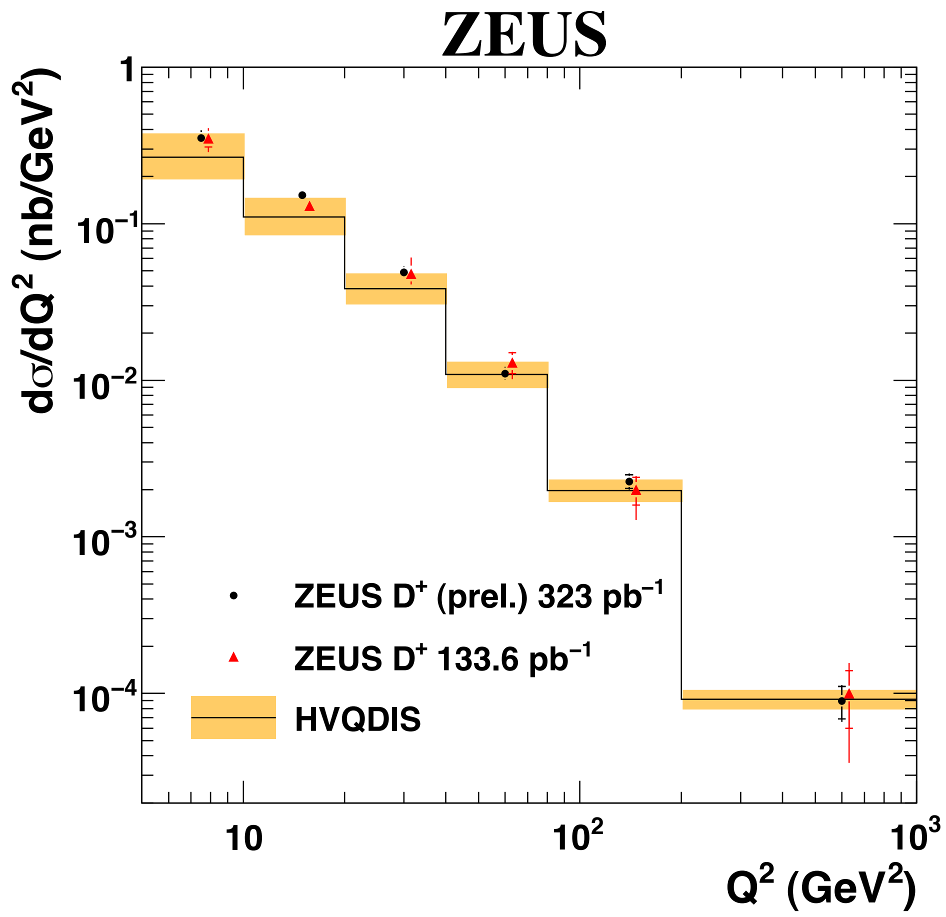
$0.02 < y_{DA} < 0.7$

$1.5 < p_T(D^+) < 15\ GeV$

$|\eta(D^+)| < 1.6$







~ 7200 D^+ events available

Precision comparable to D* in HERAI

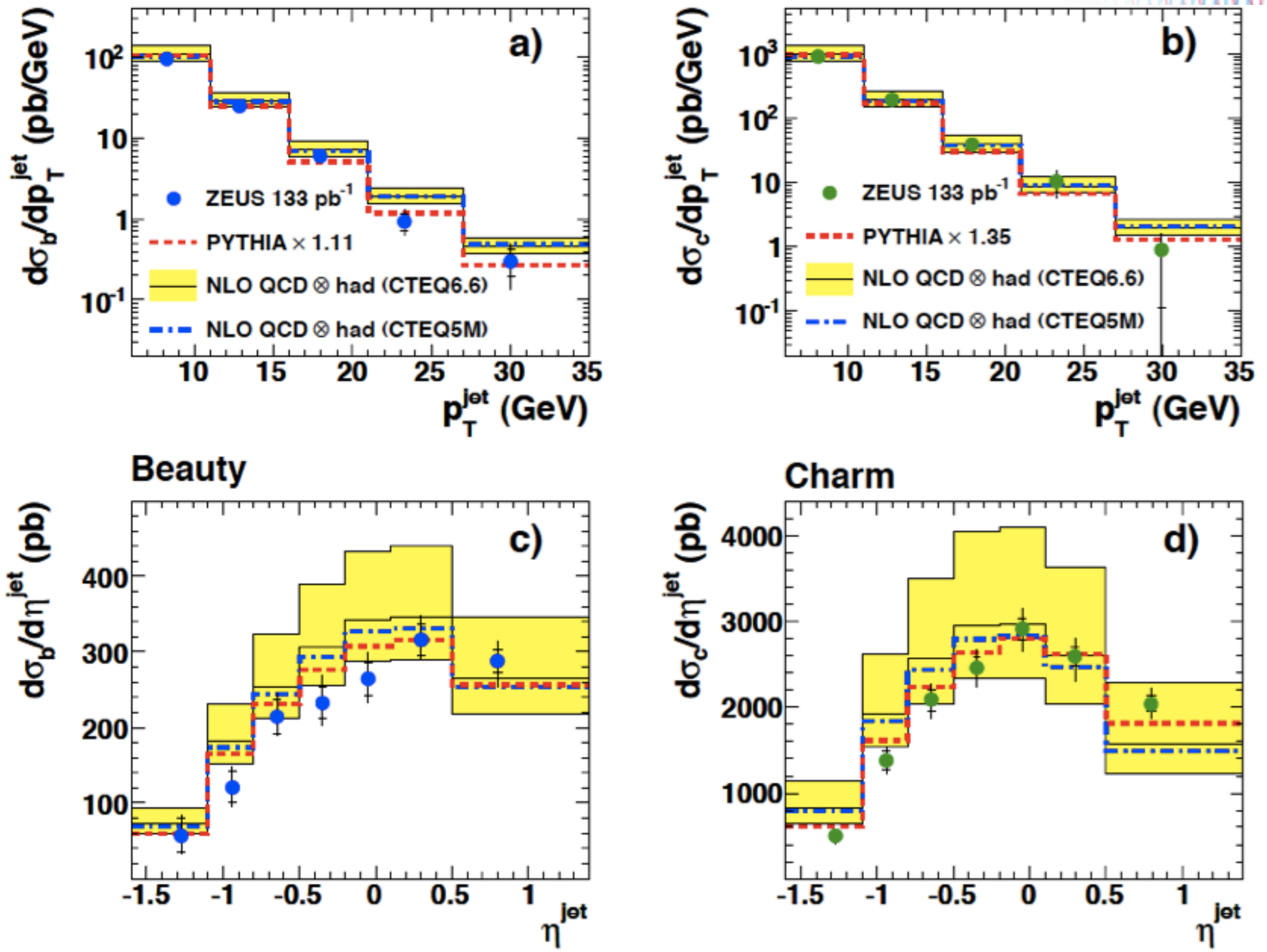
ZEUS-prel-10-005

Beauty and charm in photoproduction

Latest measurement based on inclusive secondary vertices.

Significant improvement in precision for beauty.

Good agreement with NLO.



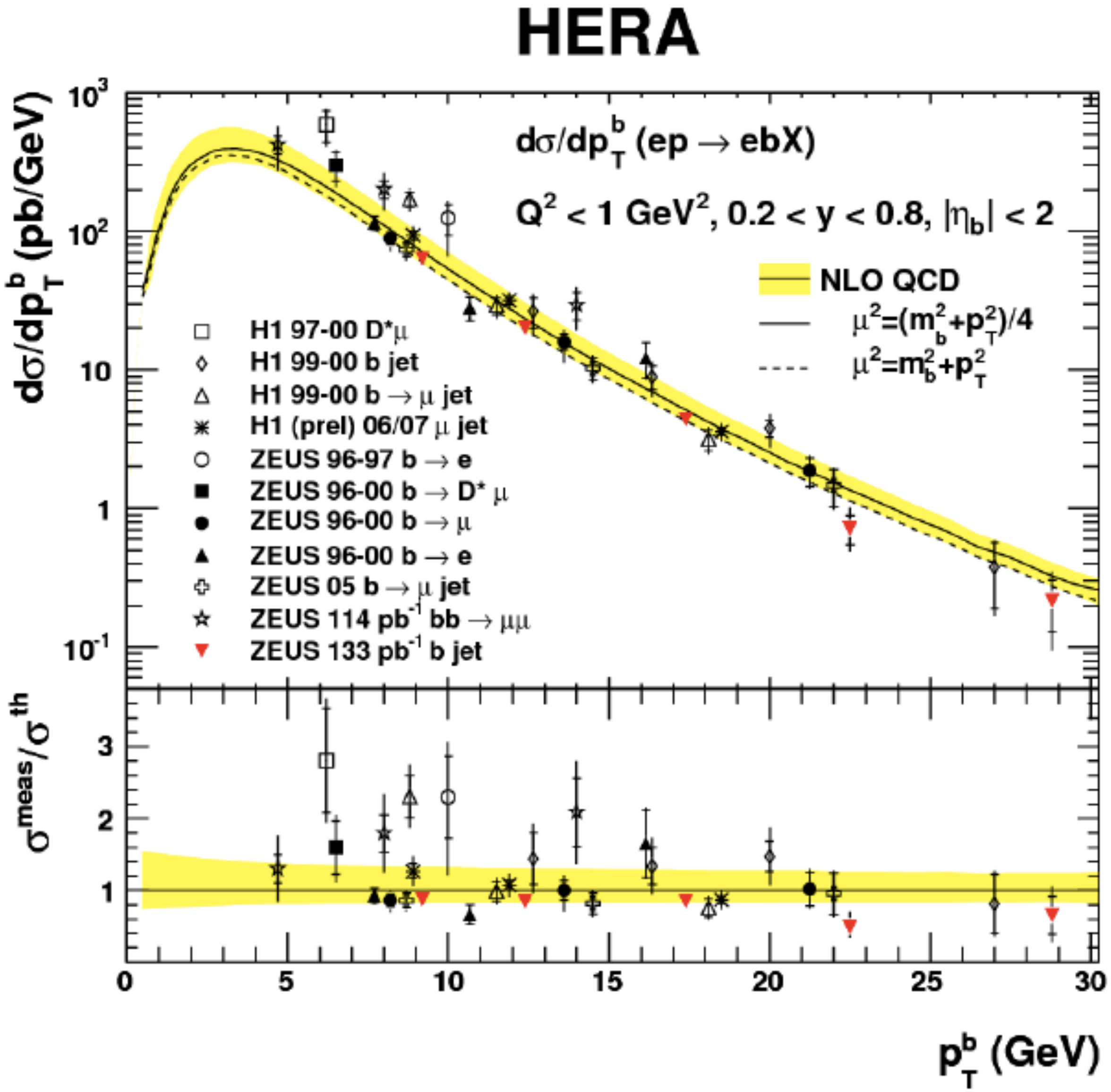
ZEUS-pub-11-002

Beauty and charm in photoproduction

Latest measurement based on inclusive secondary vertices.

Significant improvement in precision for beauty.

Good agreement with NLO.



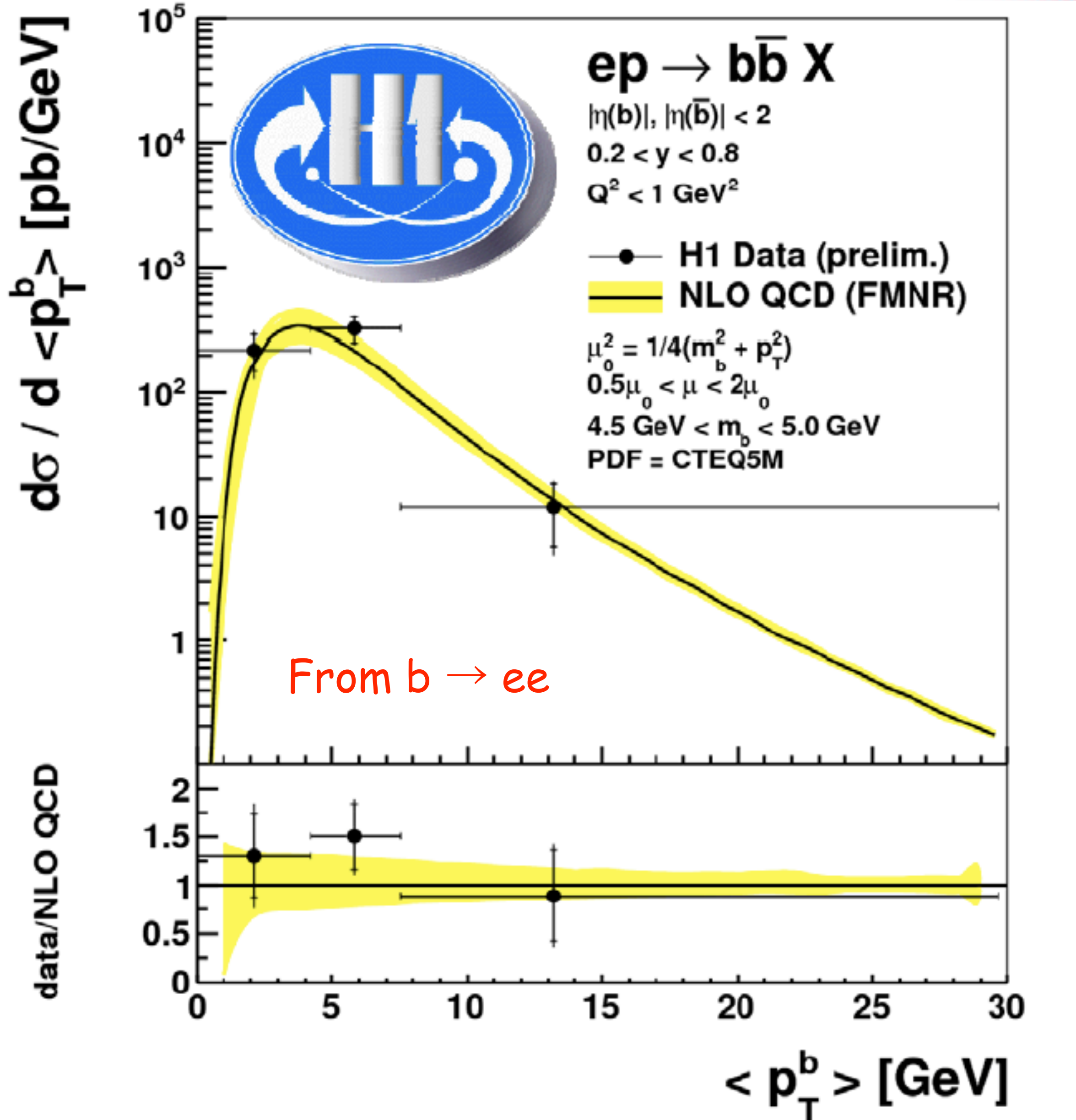
ZEUS-pub-11-002

Beauty and charm in photoproduction

Latest measurement based on inclusive secondary vertices.

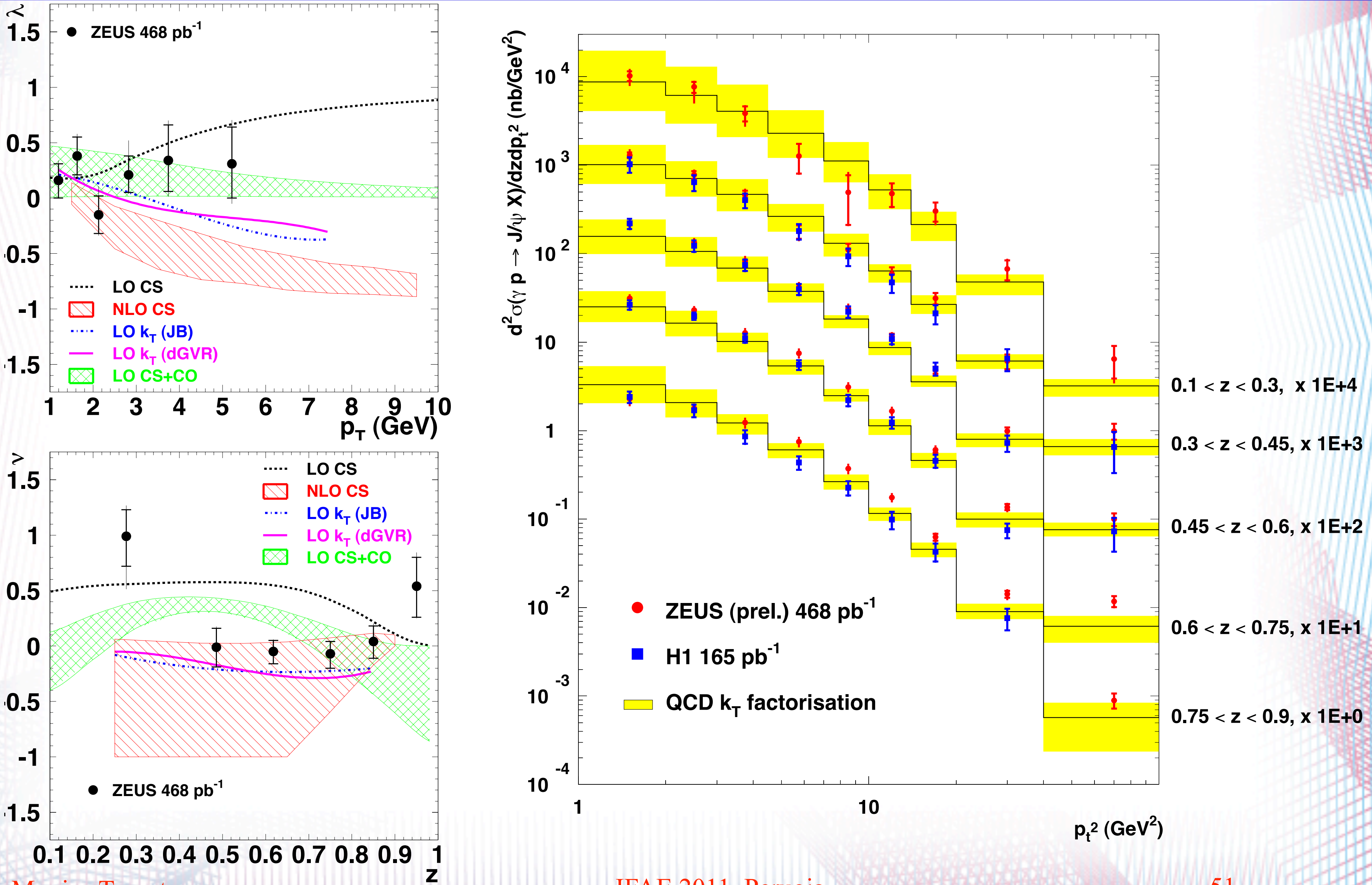
Significant improvement in precision for beauty.

Good agreement with NLO, also at threshold.

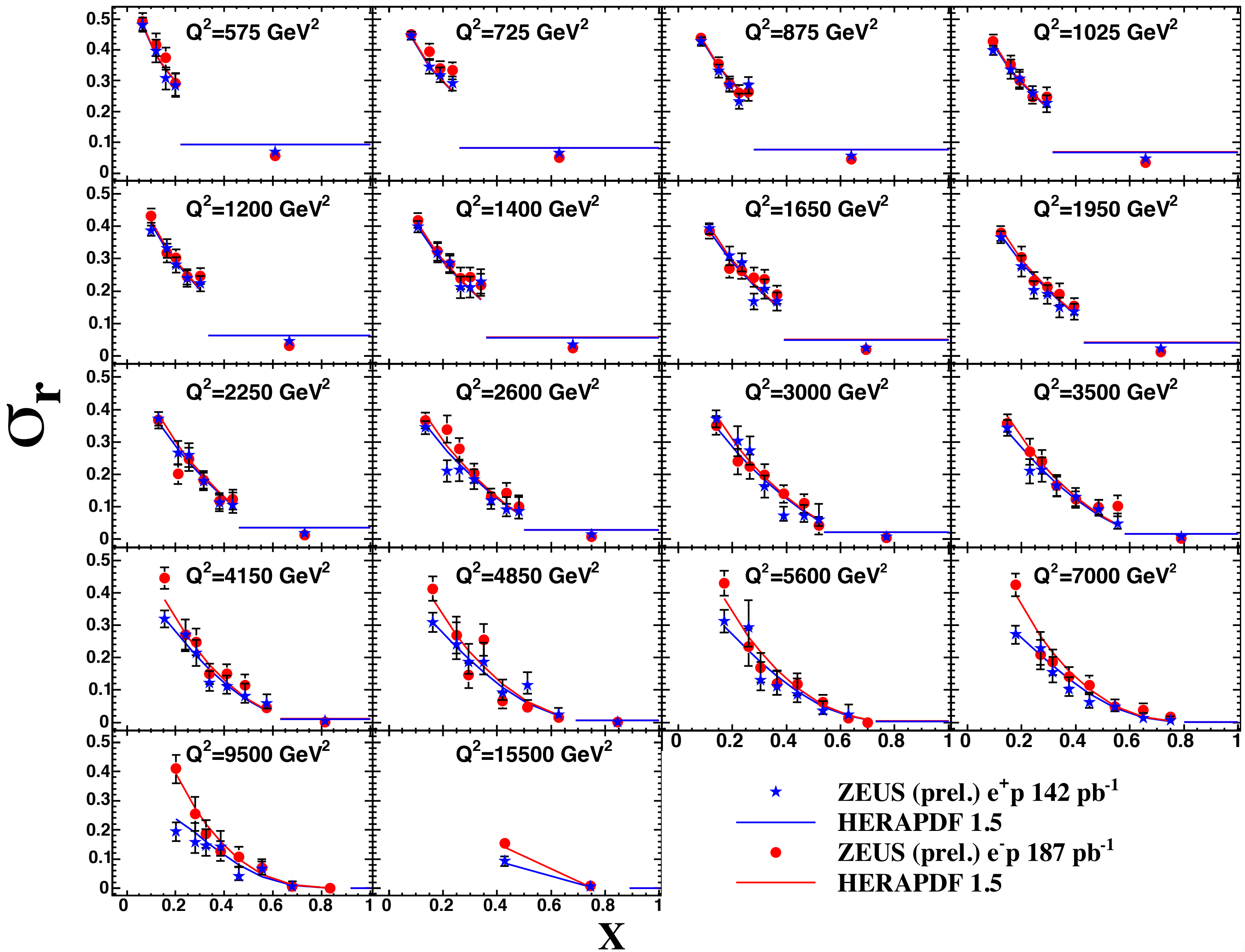


H1prelim-11-xxx

Inelastic J/ψ production



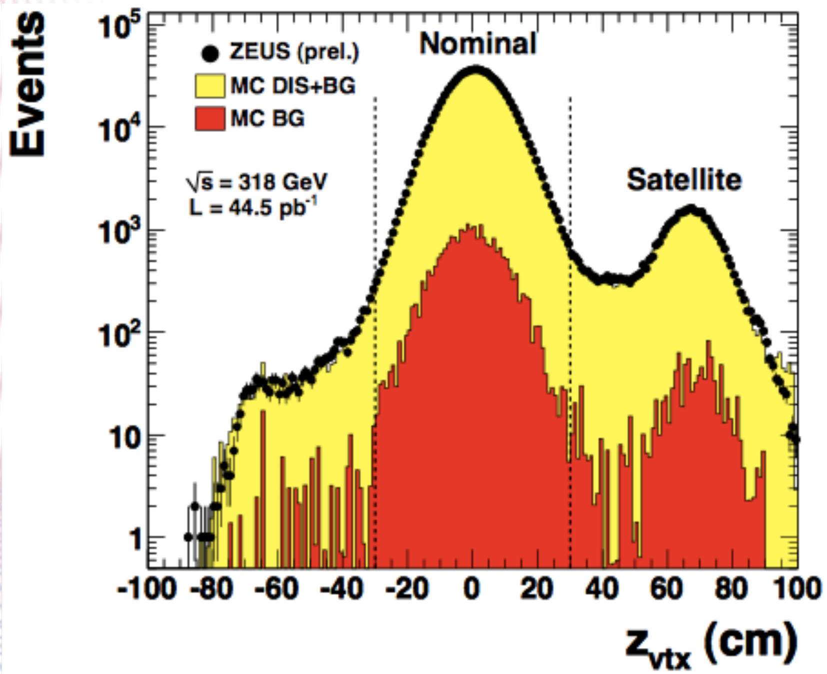
NC cross sections at high x

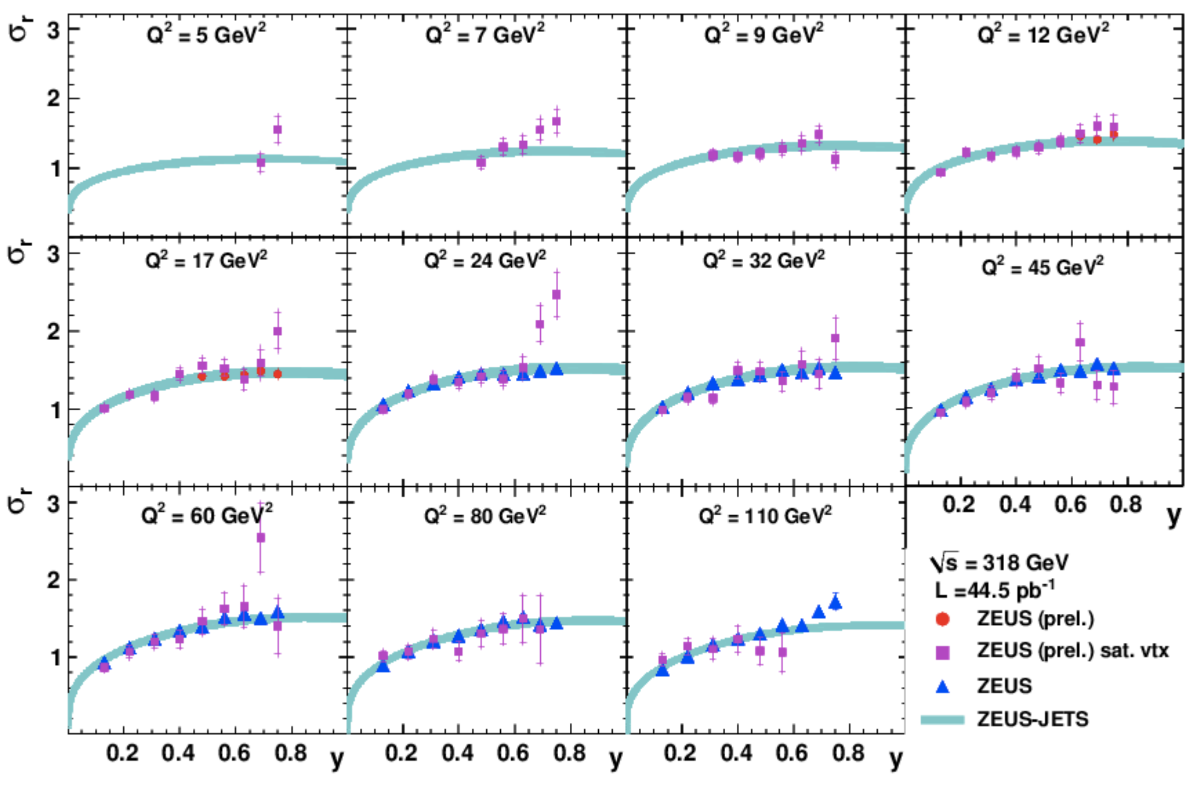


High, medium and low energy cross section at high y

HERA NC cross sections from data collected at E_p=920, 460 and 575 GeV for the F_L determination used in PDF fits.

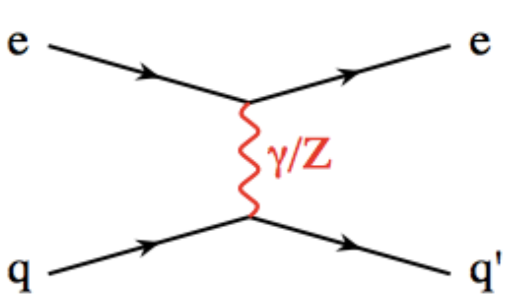
ZEUS extends its Q^2 region for all energies, down to 5 GeV^2 for HER also using shifted vertex data.



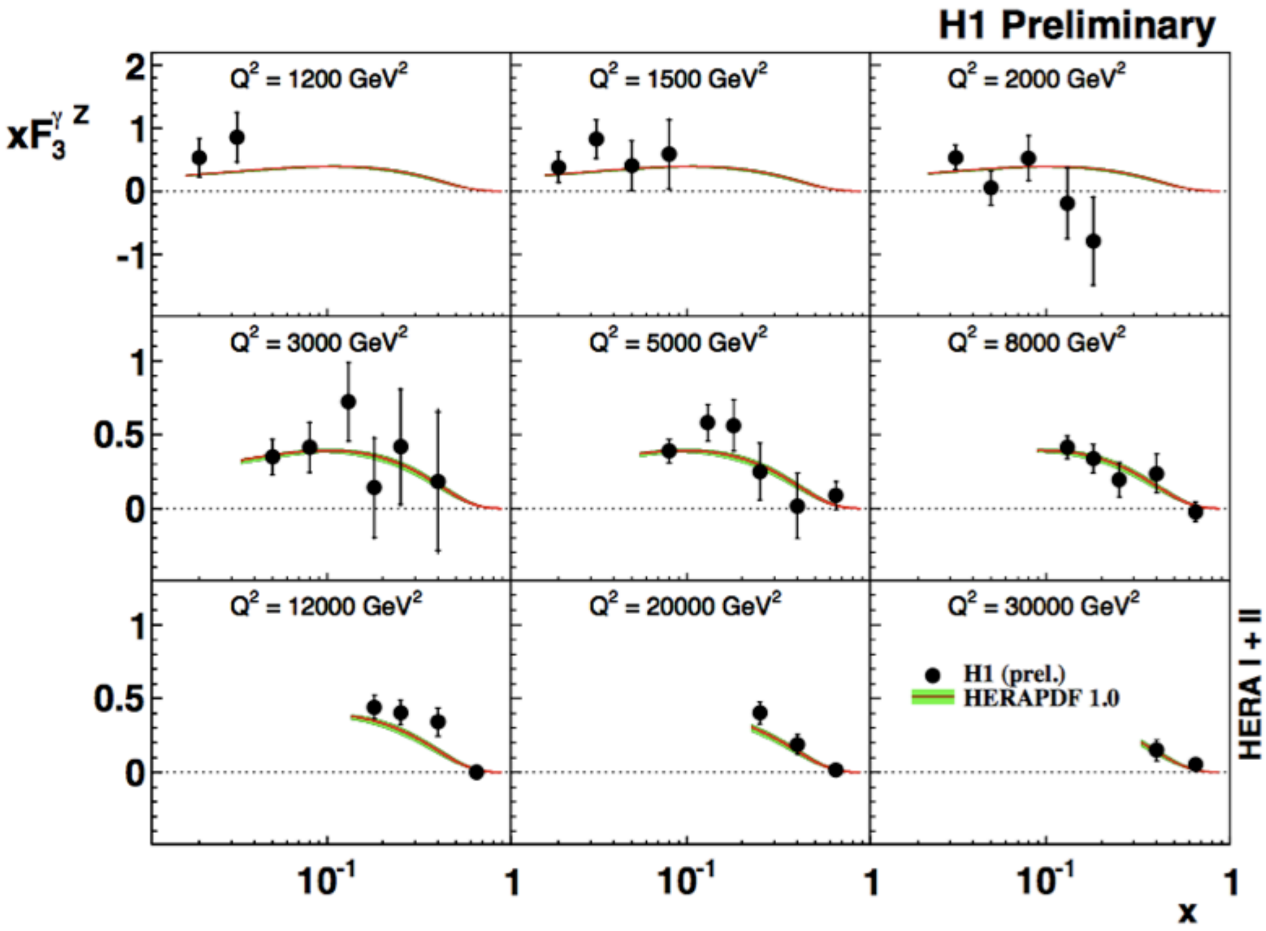


ZEUS-prel-10-006

The F_3 structure function



$$xF_3 \sim x(2u_v + d_v)$$



Good understanding of the quark content of the proton

χ^2 Definition

$$\chi^2_{exp}(M^{i,true}, \Delta\alpha_j) = \sum_i \frac{[M^{i,true} - (M^i + \sum_j \frac{\partial M^i}{\partial \alpha_j} \Delta\alpha_j)]^2}{\sigma_i^2} + \sum_j \frac{(\Delta\alpha_j)^2}{\sigma_{\alpha_j}^2}$$

for a single data set

i = measured data point
j = correlated systematic error source

M^i measured central values

$M^{i,true}$ fitted combined H1 – ZEUS values

σ_i statistical and uncorrelated systematic uncertainties

σ_{α_j} correlated systematic uncertainties

$\frac{\partial M^i}{\partial \alpha_j}$ sensitivity of datum i to systematic j

$\Delta\alpha_j$ fitted shift of correlated uncertainties

Cross calibration of the correlated systematics between different data sets

If all $\Delta\alpha_j = 0 \rightarrow$ standard weighted average

⇨ Full χ^2 is the sum over all χ^2_{exp}