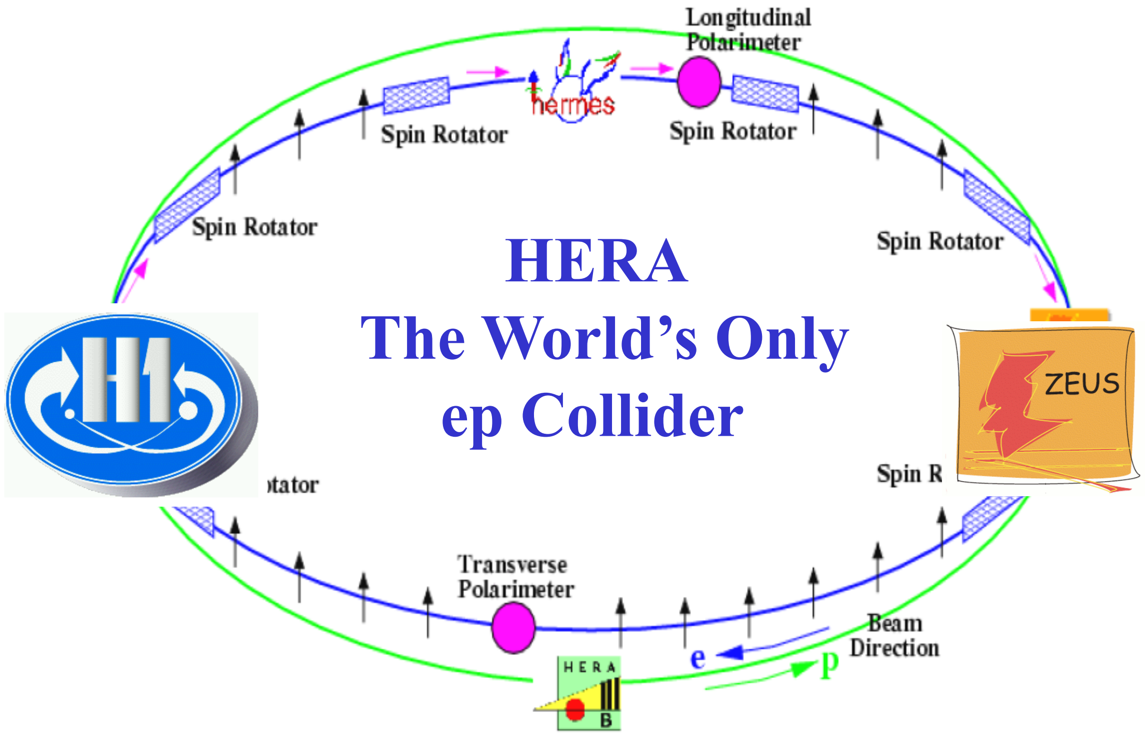
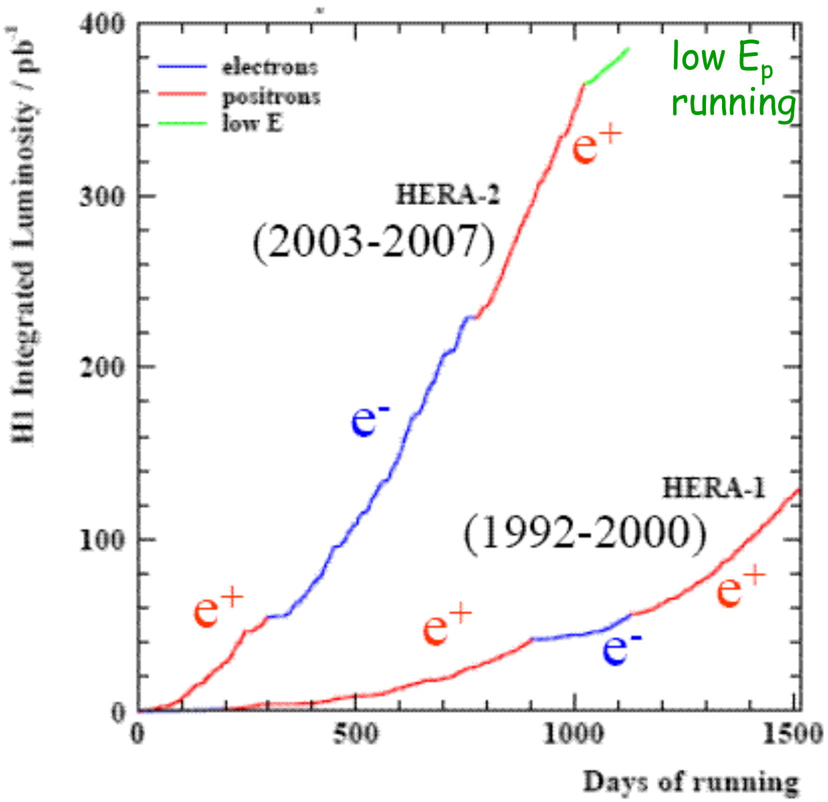
H1 & ZEUS Review 2011

Vladimir Chekelian (MPI for Physics, Munich)

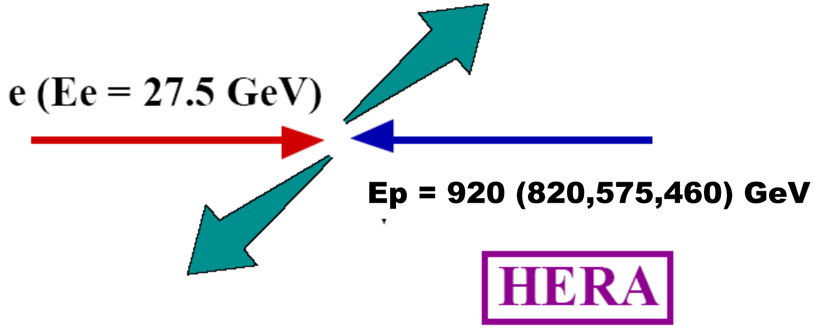


- HERA
- MPI group members
- Inclusive DIS / NC / CC
- H1 & ZEUS Combination
- $F_L(x,Q^2)$
- HERAPDF
- Hadronic energy
- Multijets & $\alpha_s(M_Z)$
- Single top production
- Summary

HERA: 15 years of operation (1992–2007)



HERA I 1992-2000 ~120 pb-1
HERA II 2003-2007 ~380 pb-1



DESY, Hamburg
peak luminosity 5 10^{31} cm^{-2} sec^{-1}
$Q^2_{max} = 10^5$ GeV^2
$\lambda_{min} \sim 1/1000\ r_{proton}$
longitudinal e-beam polarisation

$$P_e=(N_R-N_L)/(N_R+N_L)$$

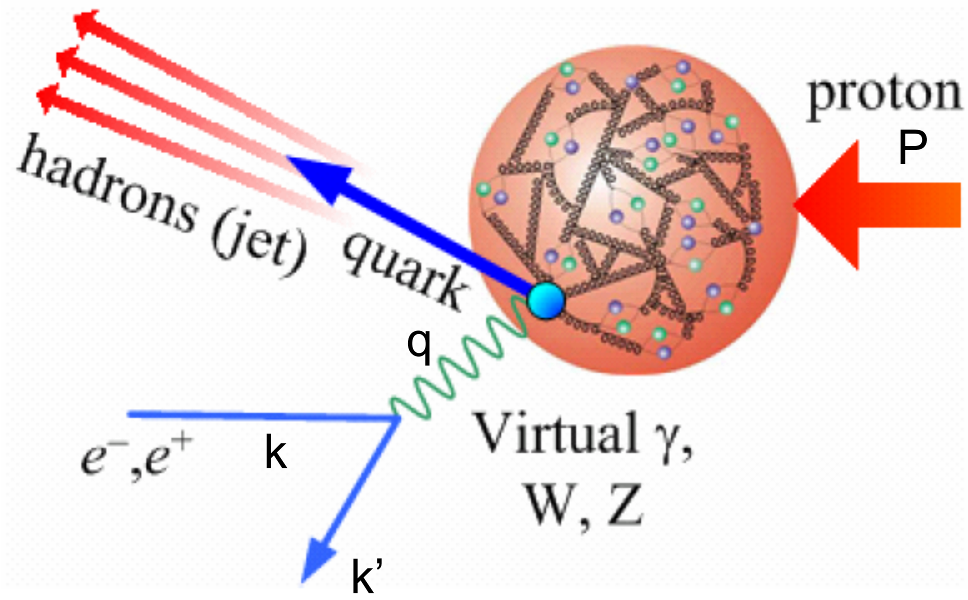
H1+ZEUS in total ~ 1 fb^{-1}
about equally shared between
- experiments (H1, ZEUS)
- e^+ and e^-,
- positive and negative P_e

low proton energy running for F_L

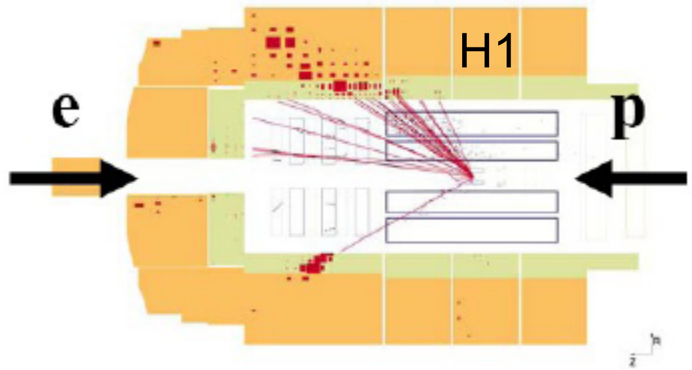
H1 & ZEUS MPI Group Members

Director	Allen Caldwell
External scientific member	Halina Abramowicz (ZEUS)
Guest	Aharon Levy (Tel Aviv U., ZEUS spokesperson)
Staff	Iris Abt (ZEUS, project leader, Physics Chair since 4/2011) Vladimir Chekelian (H1, project leader) Guenter Grindhammer (H1, QCD convener)
PhD students	Stas Shushkevich (H1, untill 8/2011) Aziz Dossanov (H1) Danial Britzger (H1, Hamburg U., DESY) Inderphal Singh (ZEUS, Panjab U.) Ritu Aggarwal (ZEUS, Panjab U.) Prabdhip Kaur (ZEUS, Panjab U.)
Postdocs	Burkard Reisert (ZEUS, Physics Chair untill 4/2011; left 8/2011) Roman Kogler (DESY)
Support	Ina Wacker Marlene Schaber (untill 5/2011)

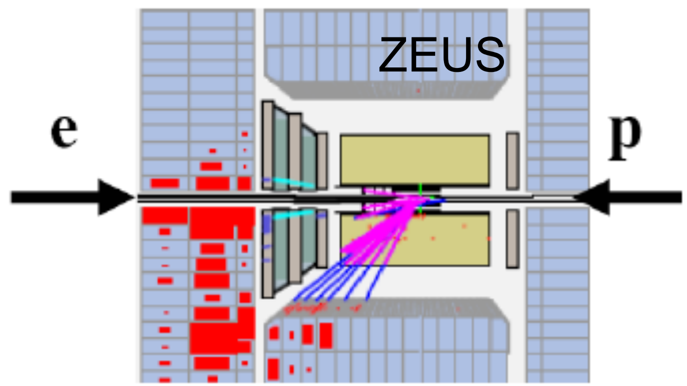
Deep Inelastic Scattering (DIS)



Neutral Current (NC): $e^{\pm}p \rightarrow e^{\pm}X$



Charged Current (CC): $e^{\pm}p \rightarrow \nu X$



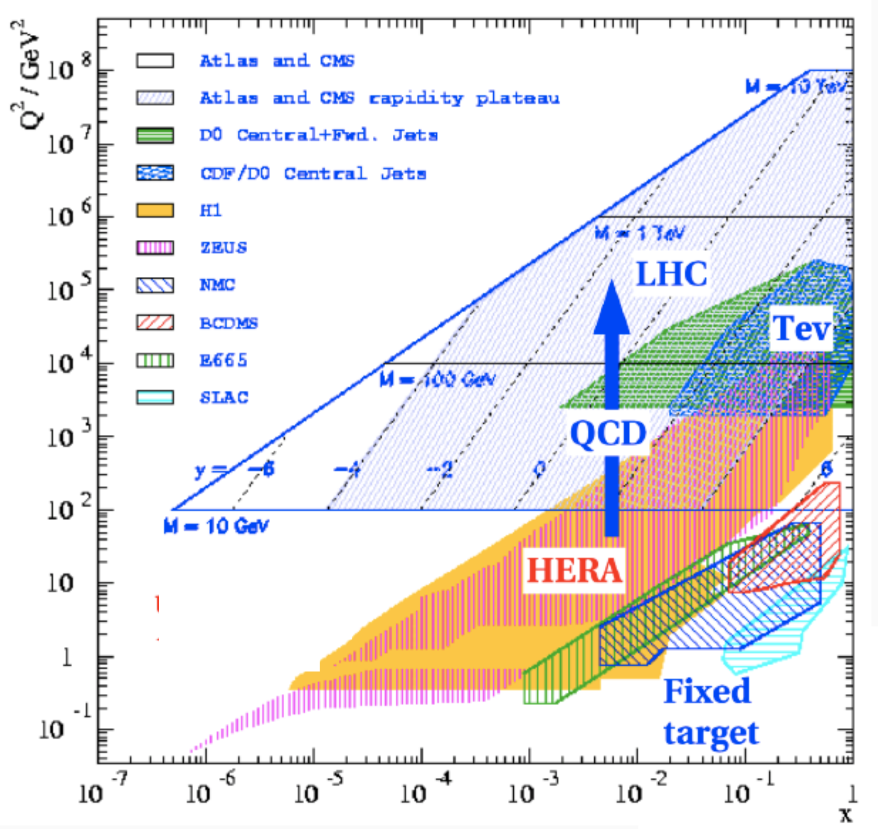
$Q^2 = -q^2 = -(k-k')^2$	virtuality of γ^*, Z^0, W
$x = Q^2/2(Pq)$	Bjorken x
$y = (Pq)/(Pk)$	inelastisity
$Q^2 = sxy$	$s=(k+P)^2$

Factorisation: $\sigma_{DIS} \sim \hat{\sigma} \otimes pdf(x)$

$\hat{\sigma}$ – perturbative QCD cross section
pdf – universal parton distribution functions

Inclusive NC and CC at HERA

HERA: span 6 orders of magnitude in x and Q^2



$$\tilde{\sigma}^{\pm}_{NC} \equiv \frac{d^2\sigma^{e^\pm p}_{NC}}{dxdQ^2}\frac{xQ^4}{2\pi\alpha^2}\frac{1}{Y_+} \equiv \tilde{F}_2 - \frac{y^2}{Y_+}\tilde{F}_L \mp \frac{Y_-}{Y_+}x\tilde{F}_3$$

$$F_2(x,Q^2) = x\sum A_i(q_i + \bar{q}_i) \qquad xF_3(x,Q^2) = x\sum B_i(q_i - \bar{q}_i)$$

$$F_L = F_2 - 2xF_1 = 0 \quad \text{(QPM)} \qquad Y_\pm = 1 \pm (1-y)^2$$

$$\tilde{\sigma}_{CC} = \frac{2\pi x}{G_F^2}\left[\frac{M_W^2 + Q^2}{M_W^2}\right]^2 \frac{d^2\sigma_{CC}}{dxdQ^2}$$

$$\tilde{\sigma}^{+}_{CC} \sim (x\bar{u} + x\bar{c}) + (1-y)^2(xd + xs)$$

$$\tilde{\sigma}^{-}_{CC} \sim (xu + xc) + (1-y)^2(x\bar{d} + x\bar{s})$$

Full HERA x range is of importance for LHC

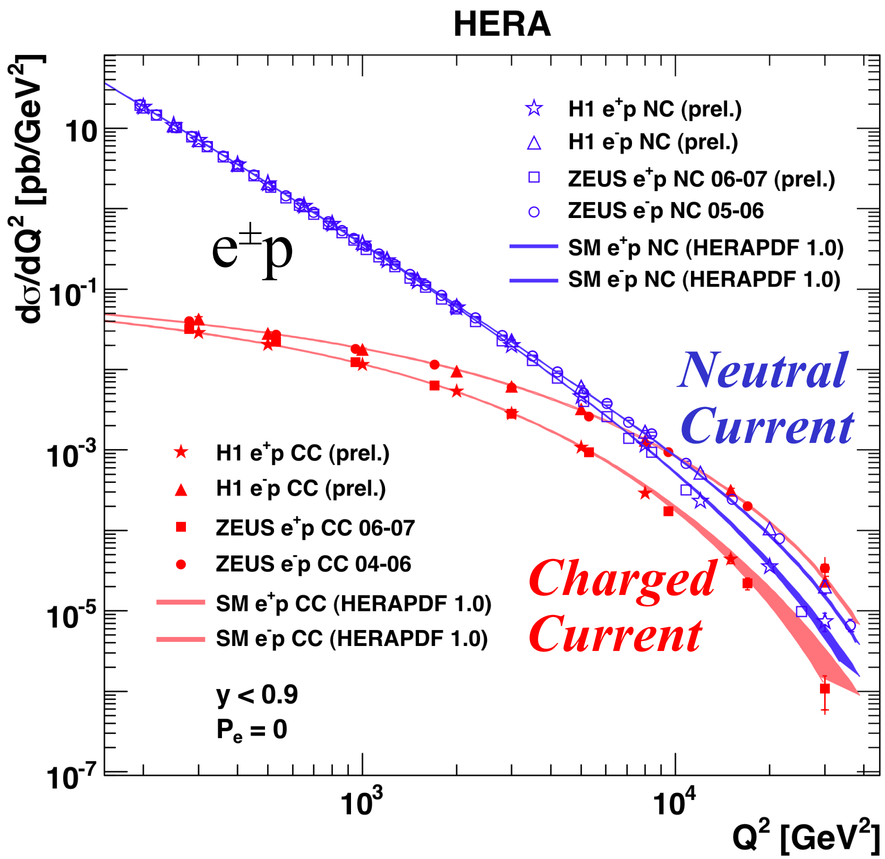
Inclusive data from H1 and ZEUS
- cover different parts of the phase space
- are obtained in different periods
- using different detector components,
- different beam energies and polarisation.

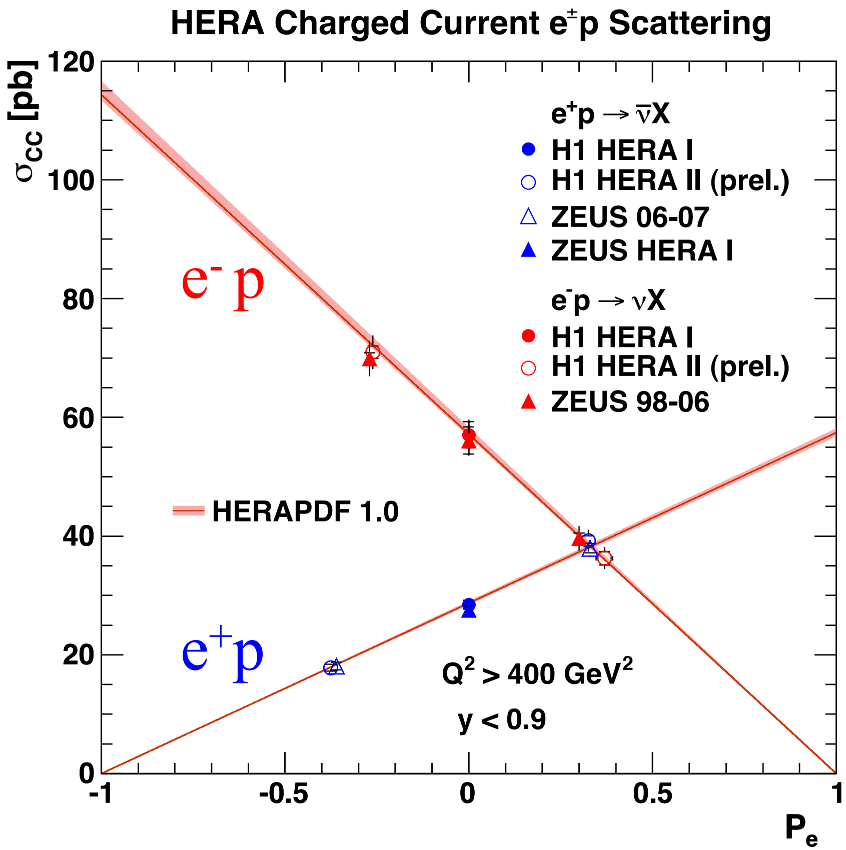
They are an indispensable input to modern QCD PDF fits

NC & CC at HERA

Unpolarised $e^{\pm}p$ cross sections

$$\sigma_{CC}^{e^{\pm}p} = (1 \pm P_e)\sigma_{CC}^{e^{\pm}p}(P_e = 0)$$

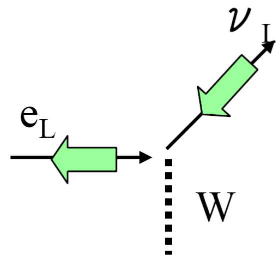




electro-weak unification:

$\sigma_{NC} \approx \sigma_{CC}$ at $Q^2 \geq M_Z^2, M_W^2$

Weak CC is pure left-handed (V-A)
→ linear dependence on the longitudinal polarization of e beam both for e^+ and e^-



Combination of H1 and ZEUS

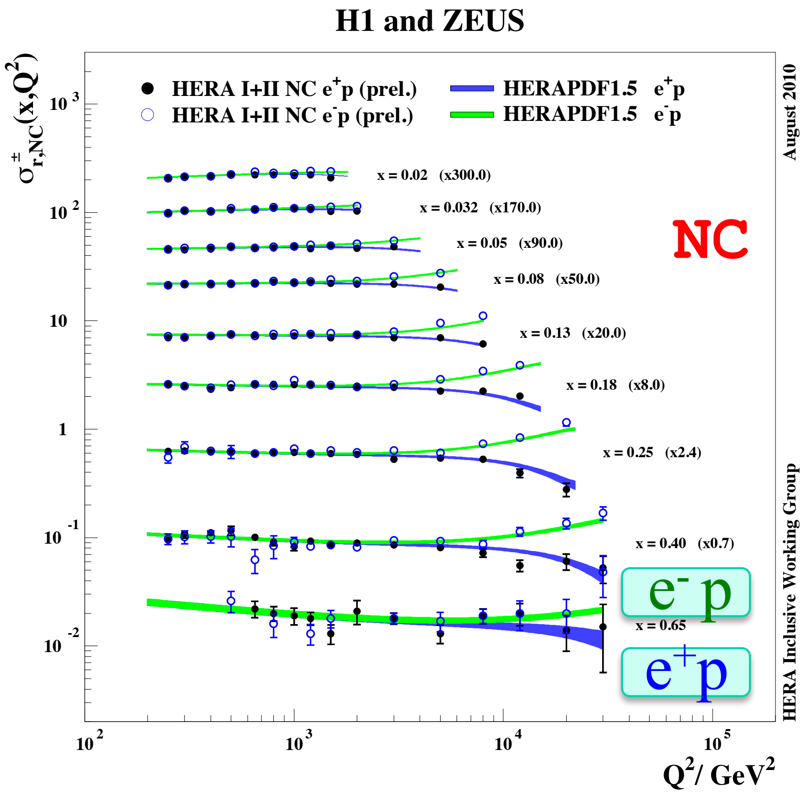
The ultimate goal is to get combined HERA data set which includes expert knowledge in the treatment of the correlations between many individual data sets from H1 and ZEUS

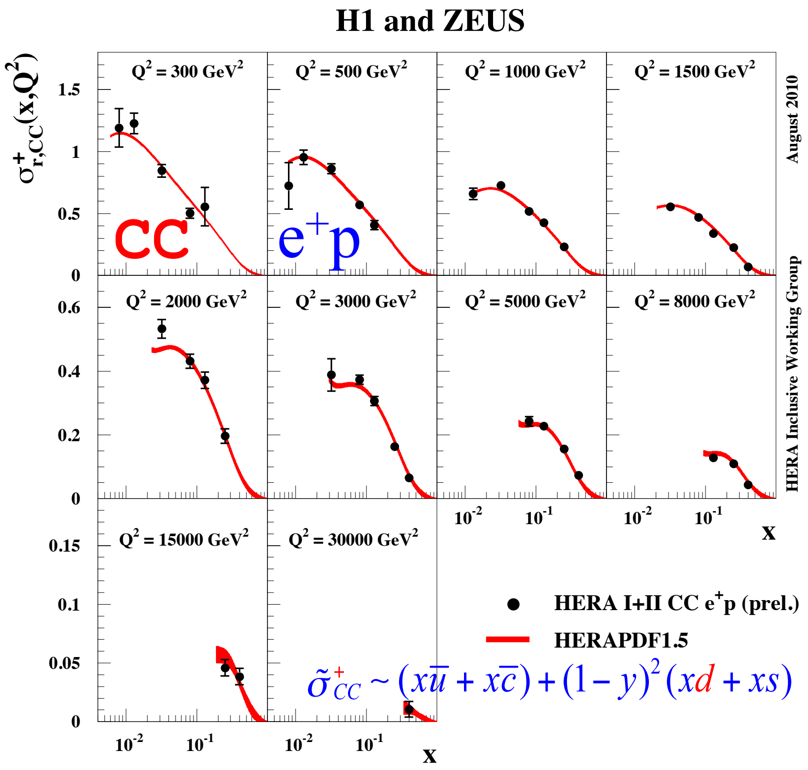
→ precise, complete and easy in use

Published: combination of inclusive unpolarized NC & CC cross sections from H1 & ZEUS at HERA I (1994-2000)
Preliminary: combination of H1 & ZEUS (unpolarised) at HERA I and HERA II :

NLO QCD fits of the combined HERA data: HERAPDF1.0 (HERA I); HERAPDF1.5 (HERA I+II)

HERA I+II & HERAPDF1.5

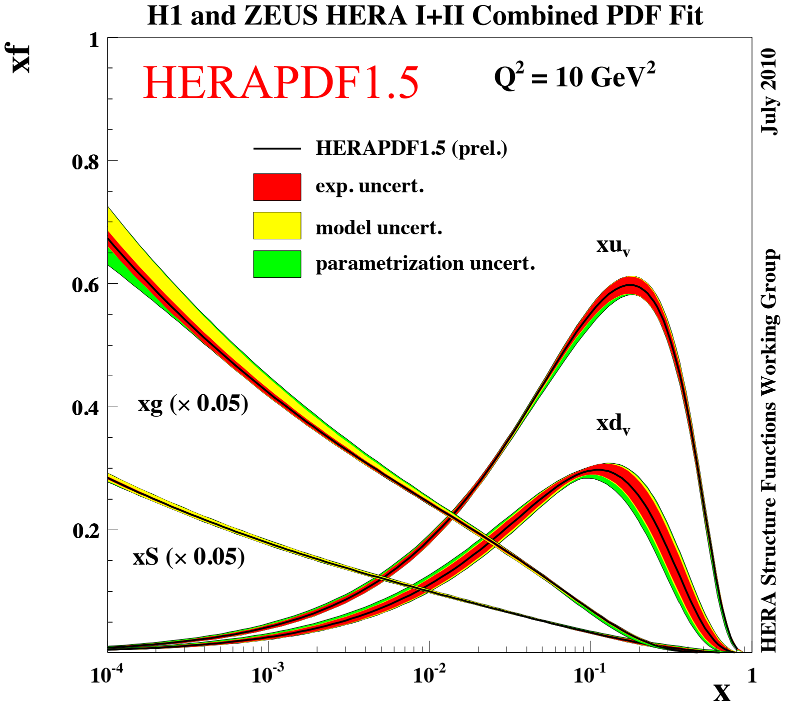




$$\tilde{\sigma}^{+}_{CC} \sim (x\bar{u} + x\bar{c}) + (1-y)^2 (xd + xs)$$

HERAPDF: QCD Fits using HERA data

PDFs : xg, xuv, xdv, xS (xS=xUbar+xDbar) at the scale $Q^2 = 10\ GeV^2$



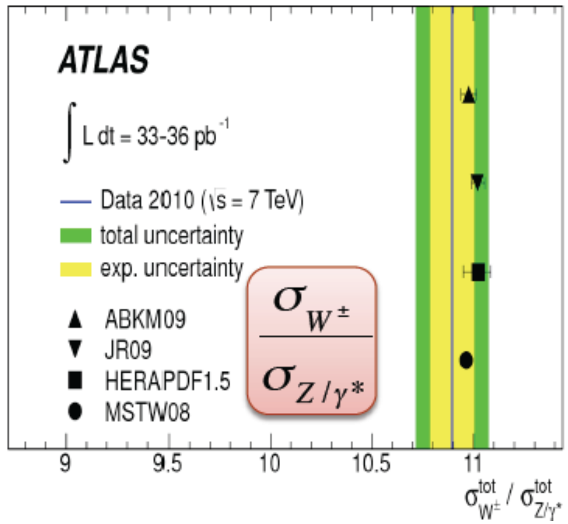
HERA I+II data only

experimental (red):
tolerance $D\chi^2 = 1$
134 sorces of syst.

model (yellow):
variations of input assumptions
(m_c, m_b, f_s, Q^2_o, Q^2_{min}, α_s)

parameterisation (green):
make envelope from
other 10, 11 parameter fits

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



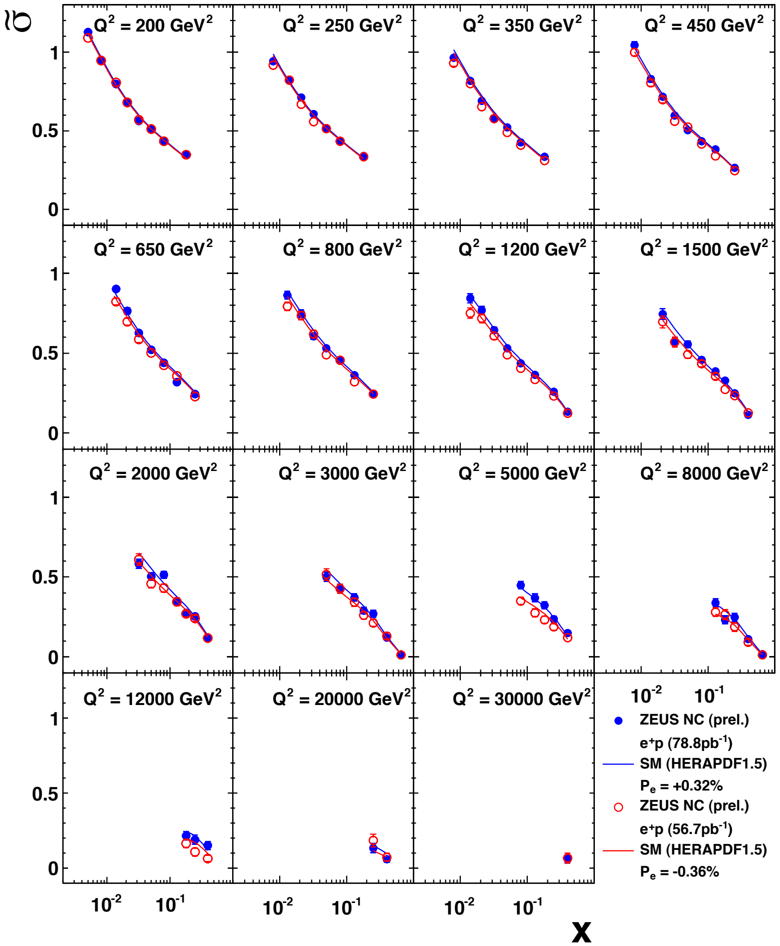
HERAPDF : NLO/NNLO QCD fits to HERA inclusive NC/CC (HERAPDF1.5)
& jets (HERAPDF1.6) & F_2^{cc} (HERAPDF1.7)

There is an initiative to form a collaboration around HERAPDF/H1Fitter
with an open access code and with non-HERA contributions
→ interests from the theory side and the LHC experiments

Recent ZEUS measurements

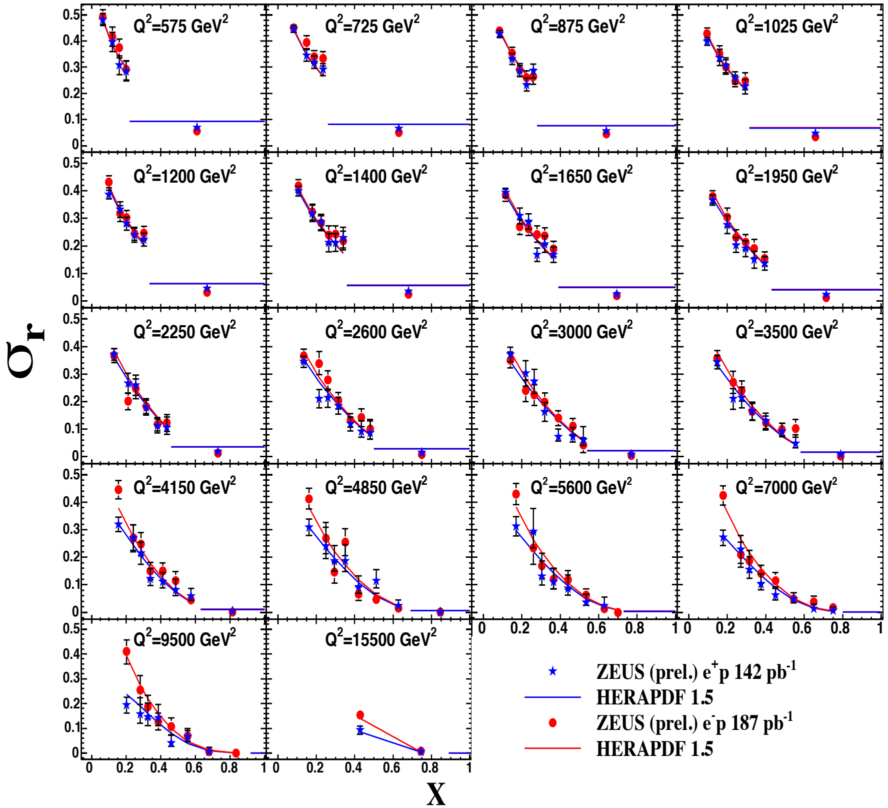
ZEUS-prel-11-003

NC e+p at high Q2 inclusive



ZEUS-prel-11-004

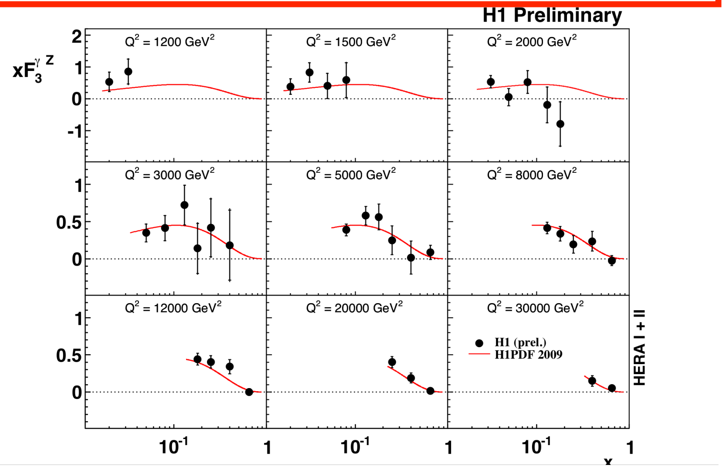
NC e+p at high x

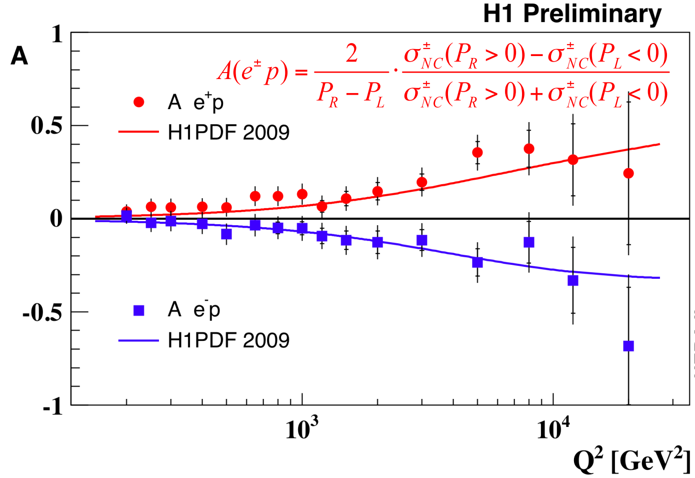


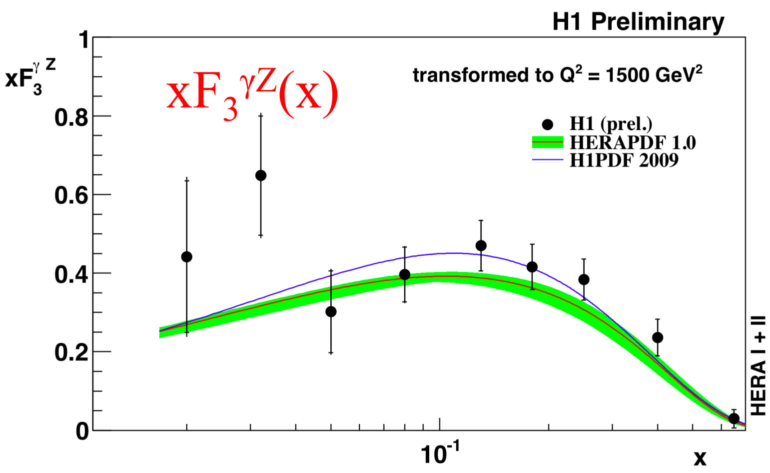
Polarity and polarisation effects in NC

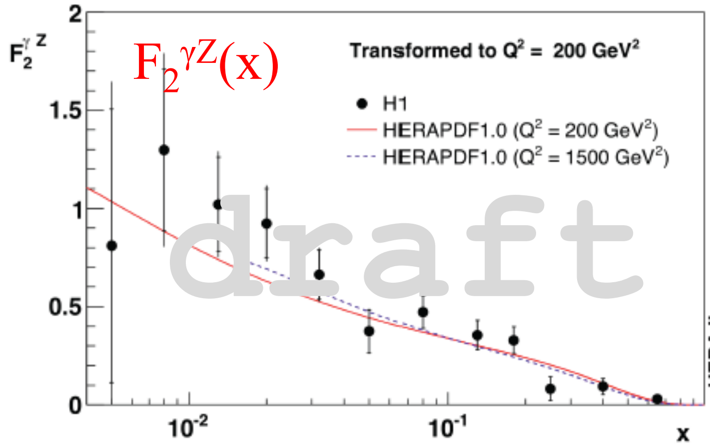
$$xF_3^{\gamma Z} = -x\frac{Y_+}{2Y_-}\left(\tilde{\sigma}^-_{NC} - \tilde{\sigma}^+_{NC}\right)/\, a_e\kappa \sim 2u_v + d_v$$

$$F_2^{\gamma Z(\pm)}(x,Q^2) = \frac{\sigma^{\pm}_{r,NC}(P_L) - \sigma^{\pm}_{r,NC}(P_R)}{P_L - P_R} \;/\,(\mp\kappa_Z a_e)$$

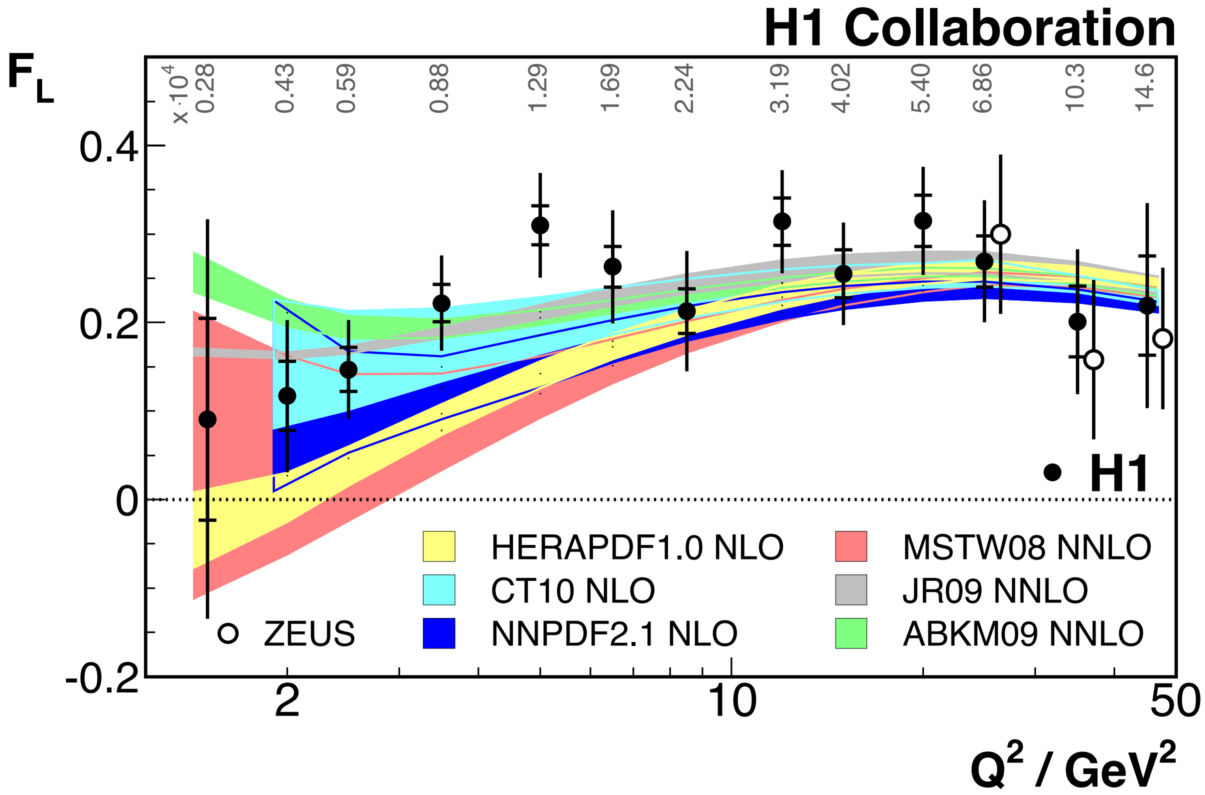








F_L measurements at HERA and QCD predictions

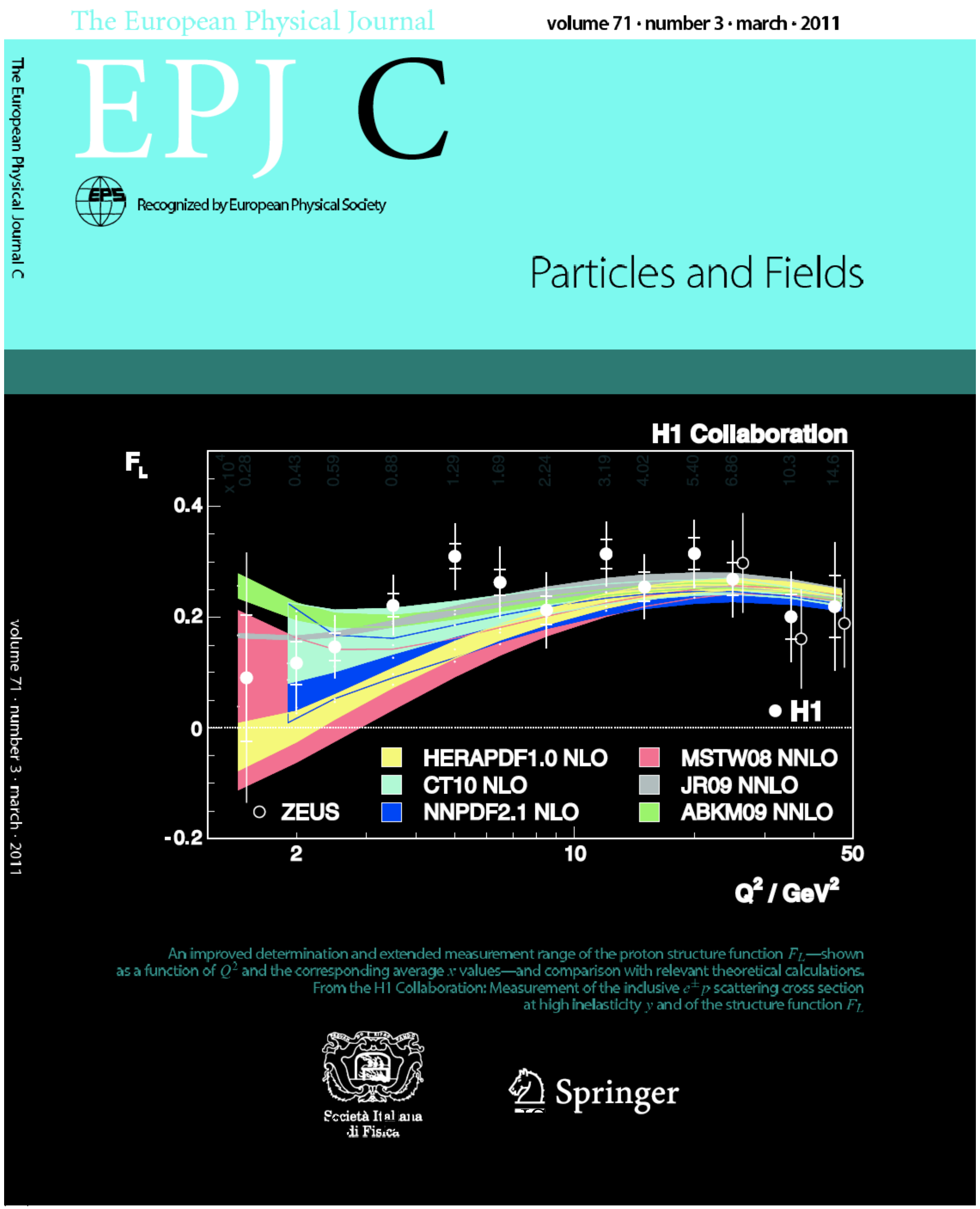


EPJ C71(2011)1579

- F_L is measured using data with Ep = 920, 575, 460 GeV
- perfect description of the F_L data by QCD at $Q^2 \geq 10$ GeV^2
- large spread/uncertainty of the QCD predictions at low Q^2

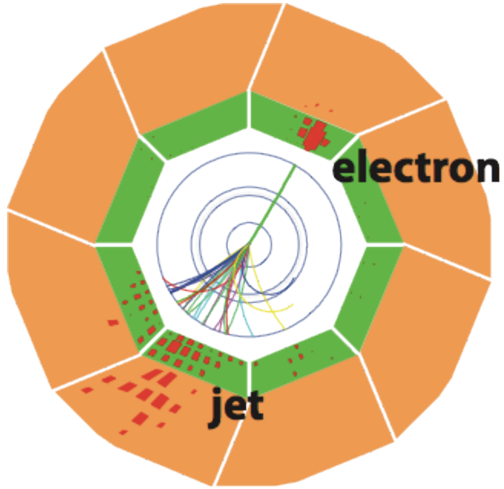
→ *F_L data are a valuable input to the QCD fits*

HERA F_L data are consistent with constant value of $R = F_L/(F_2-F_L) = 0.26 \pm 0.05$


The European Physical Journal
volume 71 · number 3 · march · 2011
EPJ C
Recognized by European Physical Society
Particles and Fields
The European Physical Journal C
volume 71 · number 3 · march · 2011
H1 Collaboration
F_L
0.4
0.2
0
-0.2
2
10
50
Q² / GeV²
H1
ZEUS
HERAPDF1.0 NLO
CT10 NLO
NNPDF2.1 NLO
MSTW08 NNLO
JR09 NNLO
ABKM09 NNLO
An improved determination and extended measurement range of the proton structure function F_L—shown as a function of Q² and the corresponding average x values—and comparison with relevant theoretical calculations.
From the H1 Collaboration: Measurement of the inclusive e±p scattering cross section at high inelasticity y and of the structure function F_L
Società Italiana di Fisica
Springer

Improvement of hadronic energy measurement (H1)

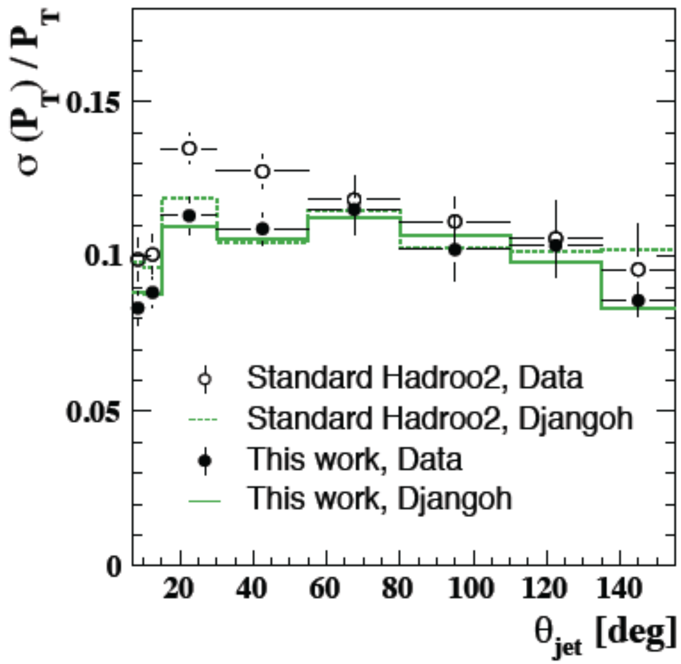
Hadronic/jet energy scale uncertainty is the dominant exp. uncertainty in measurements of jet cross sections and extractions of α_S, and affects all other analyses.



improve em/had shower separation (complex neural network with many cluster shapes/estimators as input, pre- and postprocessing of input variables)

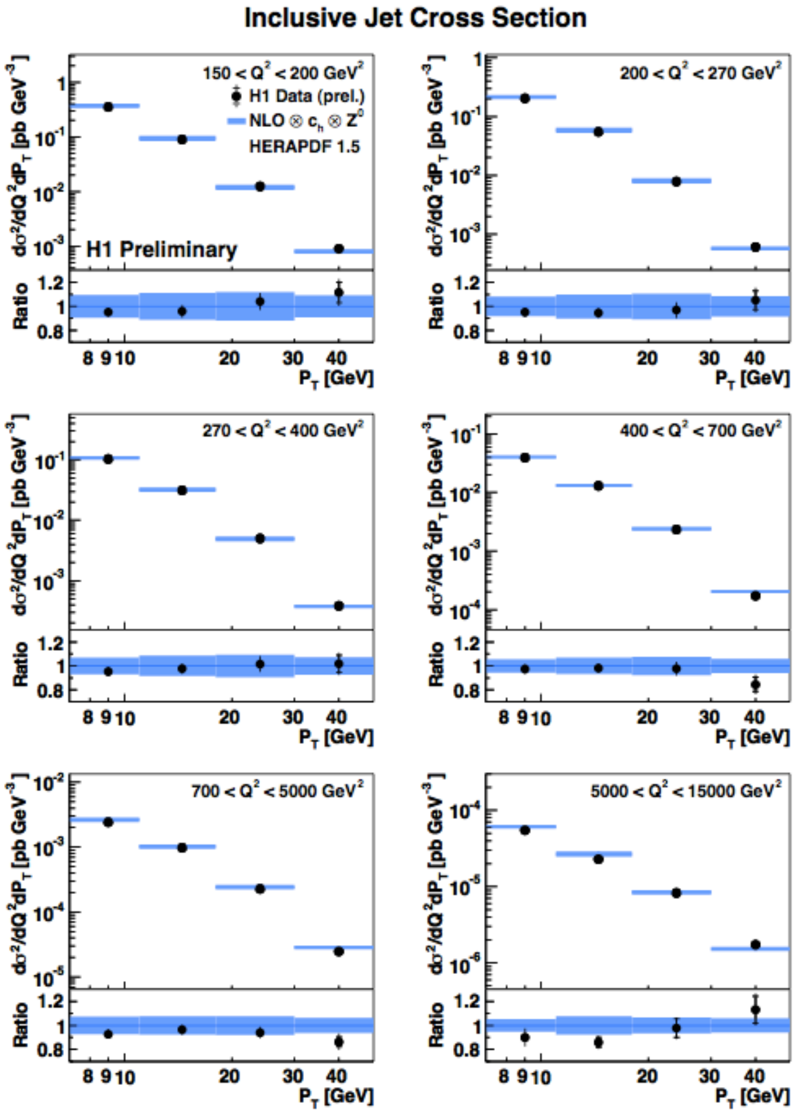
improve energy flow algorithm (compare measurements from tracks and clusters and prefer those with better expected resolution; remove tracks/clusters to avoid double-counting of energy)

introduce new calibration method (for single clusters, making use of the probability for a single cluster to originate from an em or had shower by obtaining 47 parameters from a global minimisation procedure)

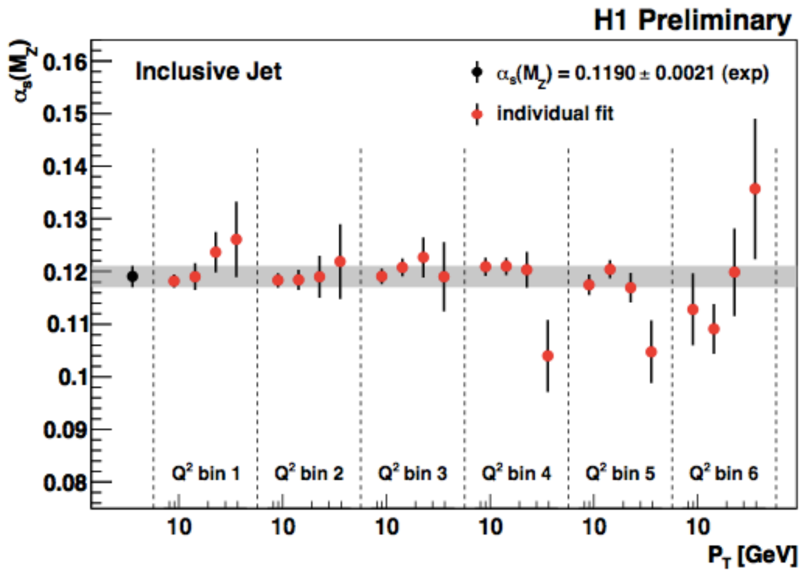


→ 1% hadronic energy scale uncertainty
→ the new H1 standard

Multijets & $\alpha_s(M_Z)$ extraction (H1)



H1prelim-11-032



incl. jets:

$$\alpha_s(M_Z) = 0.1190 \pm 0.0021(\text{exp}) \pm 0.0020(\text{pdfs})\ ^{+0.0050}_{-0.0056}(\text{theory})$$

dijets:

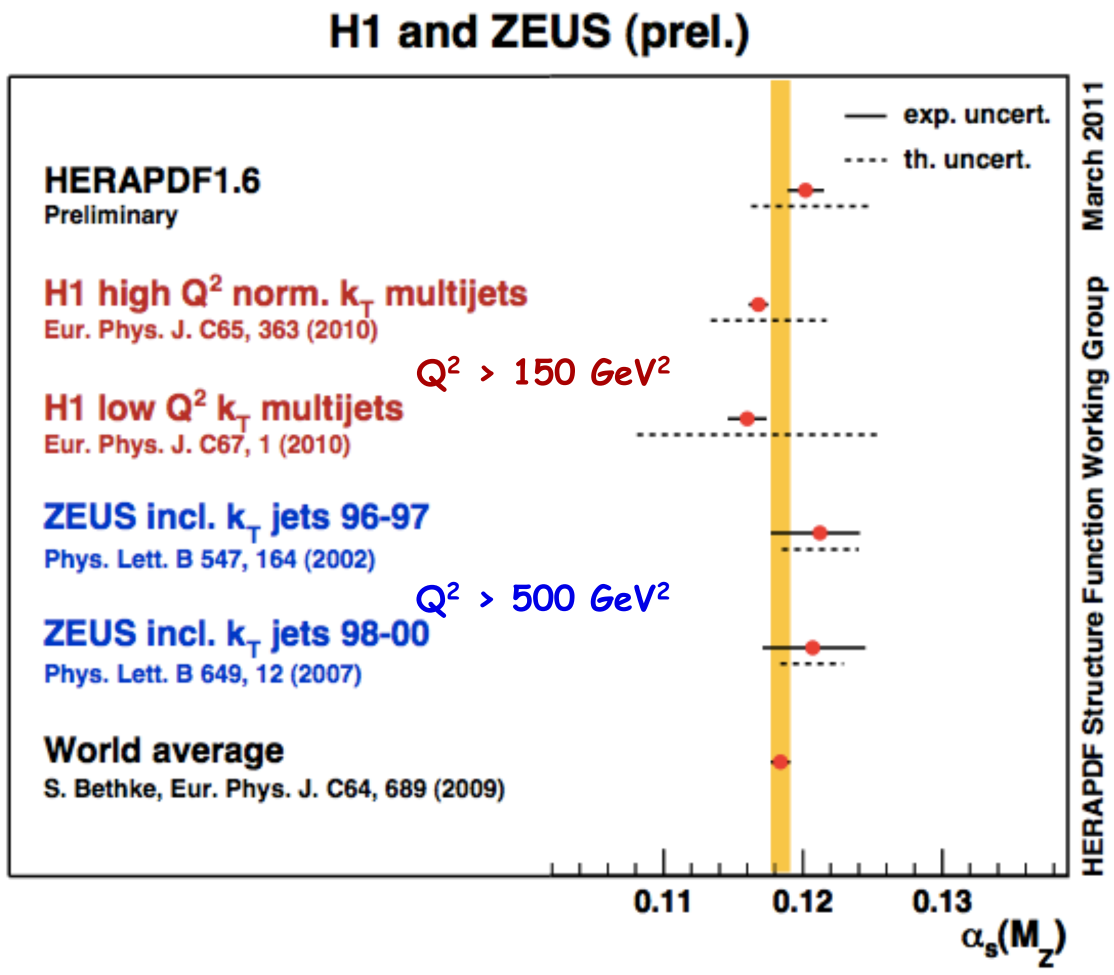
$$\alpha_s(M_Z) = 0.1146 \pm 0.0022(\text{exp}) \pm 0.0021(\text{pdfs})\ ^{+0.0044}_{-0.0045}(\text{theory})$$

trijets $O(\alpha_s^2)$:

$$\alpha_s(M_Z) = 0.1196 \pm 0.0016(\text{exp}) \pm 0.0010(\text{pdfs})\ ^{+0.0055}_{-0.0039}(\text{theory})$$

$\alpha_s(M_Z)$ summary from H1 and ZEUS

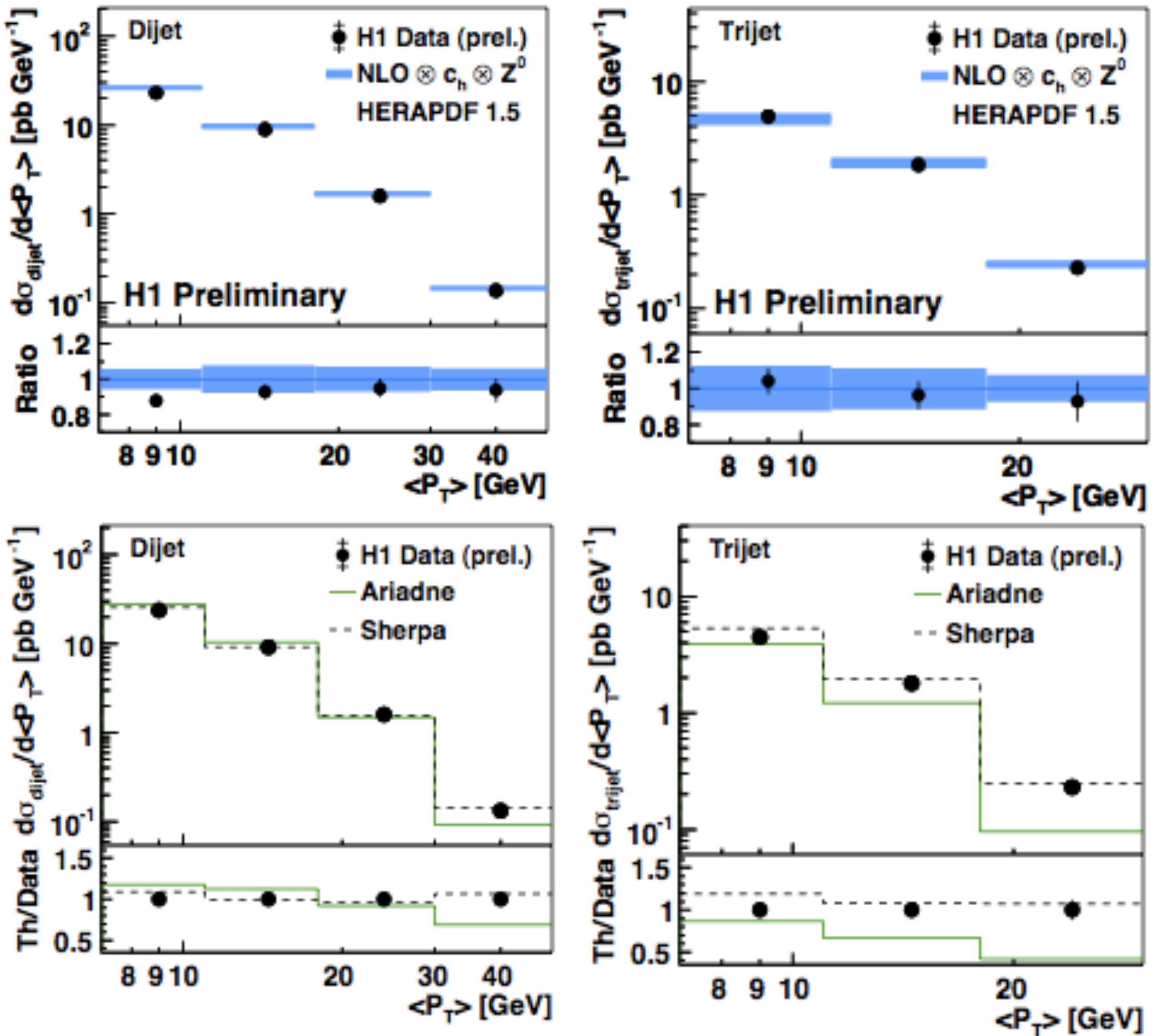
- for HERAPDF1.6 the PDF uncertainty is part of the exp. uncertainty
- for the H1 and ZEUS results from jets only, it is part of the theory uncertainty



Comparison of dijet and trijet data to NLO & Sherpa

Data are always corrected to hadron level

NLO calculations are corrected to hadron level



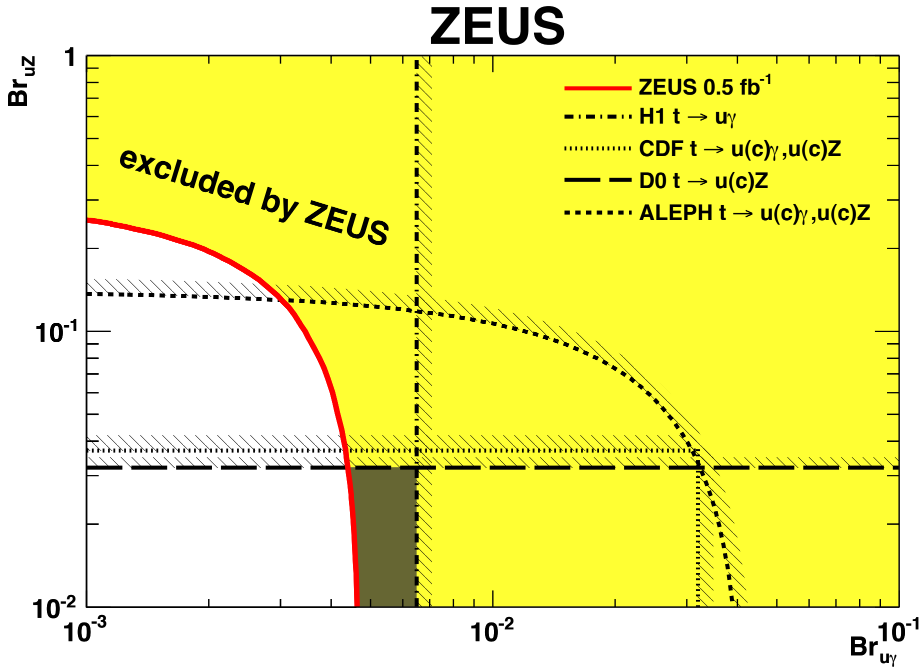
Sherpa & Ariadne (CDM)
- predictions at hadron level

Sherpa :
- tree level processes with up to 6 partons in the final state
- tree levels are matched to parton showers
- partons are fragmented according to the cluster model or Lund model

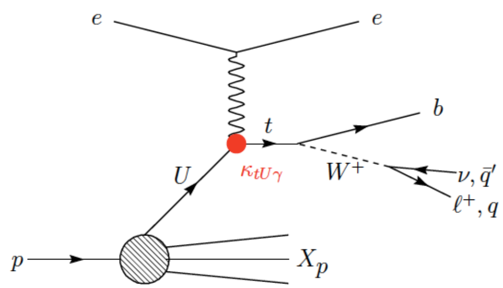
→ *good description of the H1 jet data out of the box*

ZEUS publications with strong involvement of I. Abt as Physics Chair

arXiv:1101.3692 **Measurement of beauty production in deep inelastic scattering at HERA using decays into electrons**
arXiv:1104.5444 **Measurement of heavy-quark jet photoproduction at HERA**
arXiv:1111.2133 **Measurement of the t dependence in exclusive photoproduction of Upsilon(1S) mesons at HERA**
arXiv:1111.3526 **Scaled momentum distributions for K0s and Lambda/bar Lambda in DIS at HERA**
arXiv:1111.4905 **Exclusive electroproduction of two pions at HERA**
arXiv:1111.3901 **Search for single-top production in ep collisions at HERA**



FCNC coupling $\kappa_{tu\gamma}$



→ limits on *Br(t→uγ), Br(t→uZ)*

Summary

H1 and ZEUS are in the process of finalizing and publishing final precision results which are the HERA legacy

- inclusive NC/CC from HERA II (H1)
- e+p NC HERA II (ZEUS)
- combination of the final H1 & ZEUS HERA I + II (H1 & ZEUS)
- HERAPDF fit of the combined final data (H1 & ZEUS)
- NC at highest x (ZEUS)
- extension of F_L measurements to low Q^2 (ZEUS) and high Q^2 (H1)
- multijets and strong coupling α_s (H1)

Both MPI groups in H1 and ZEUS have high visibility in the HERA community

12-14 September 2012 MPP will host the H1 External Collaboration meeting

Polarised NC Structure Functions

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

$$x\tilde{F}_3^{\pm} = -(a_e \pm P_e v_e)\frac{\kappa Q^2}{Q^2 + M_Z^2} xF_3^{\gamma Z} + (2 v_e a_e \pm P_e (v_e^2 + a_e^2))\left(\frac{\kappa Q^2}{Q^2 + M_Z^2}\right)^2 xF_3^Z$$

$P_e = \frac{N_R - N_L}{N_R + N_L}$, $N_R(N_L)$- number of right (left) handed leptons in the beam

$$\kappa^{-1} = 4\frac{M_W^2}{M_Z^2}\left(1 - \frac{M_W^2}{M_Z^2}\right)$$

in QPM:

$$\left[F_2, F_2^{\gamma Z}, F_2^Z\right] = x\sum_q \left[e_q^2, 2e_q v_q, v_q^2 + a_q^2\right](q + \bar{q})$$

$$\left[xF_3^{\gamma Z}, xF_3^Z\right] = 2x\sum_q \left[e_q a_q, v_q a_q\right](q - \bar{q})$$