Proton Structure Measurements from HERA to LHC

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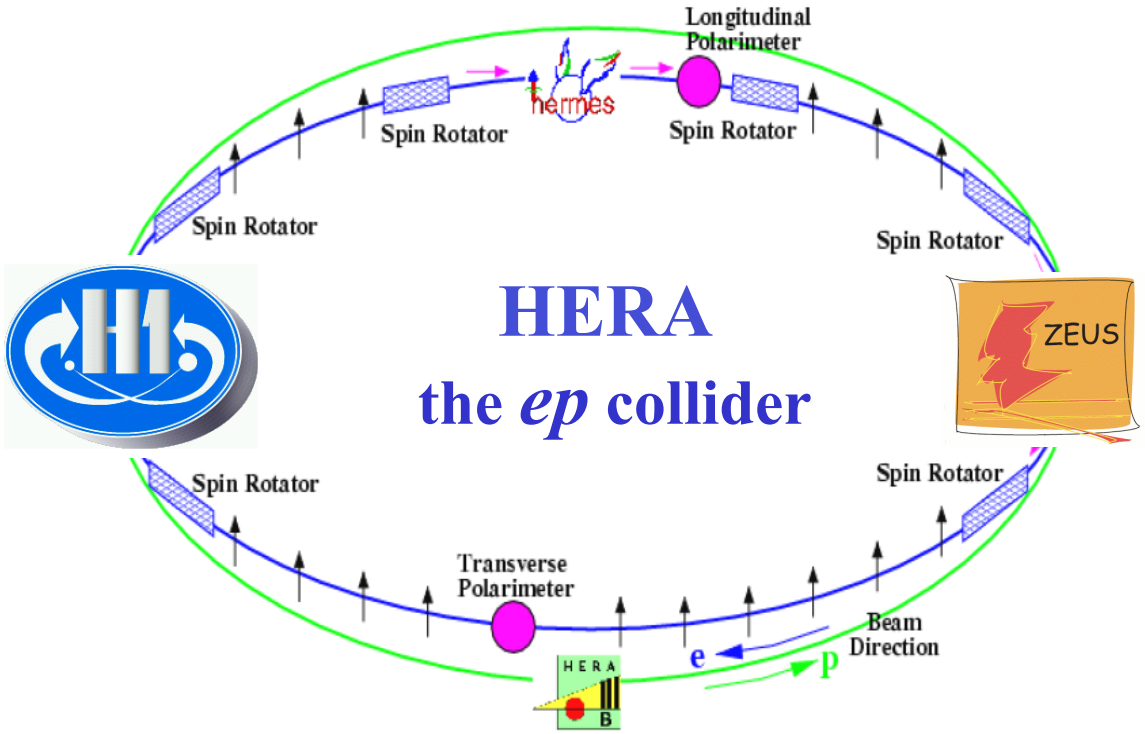
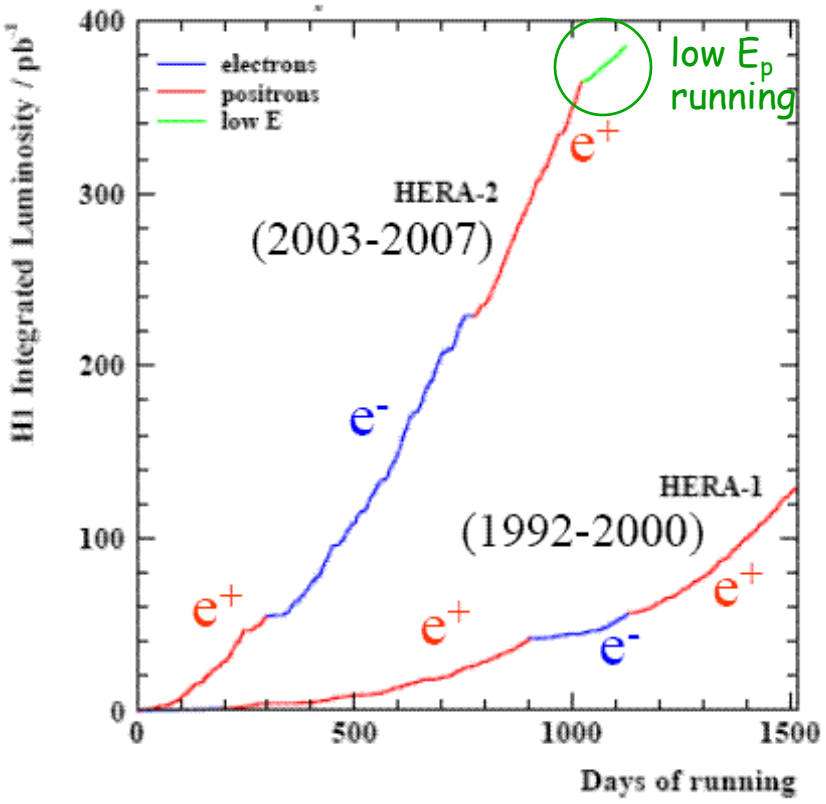
on behalf of the H1 and ZEUS Collaborations

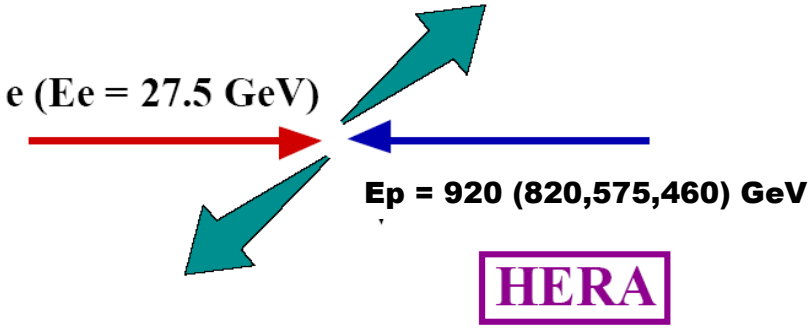


- **HERA / DIS / NC / CC**
- **Inclusive ep Cross Sections**
- **Proton Structure Functions**
- **HERAPDF**
- **HERAFitter**
- **Summary**

20 Years of HERA (data taking 1992–2007)



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

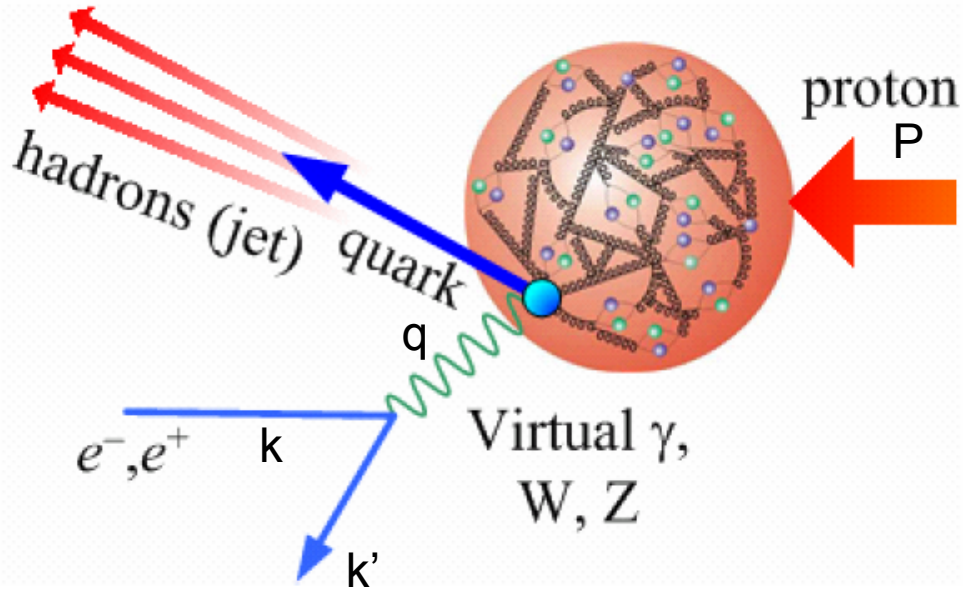


located at DESY, Hamburg
peak luminosity 5 10^{31} cm^{-2} sec^{-1}
$Q^2_{max} = 10^5$ GeV^2
λ_{min} ~ 1/1000 r_{proton}
longitudinal polarisation of e-beam

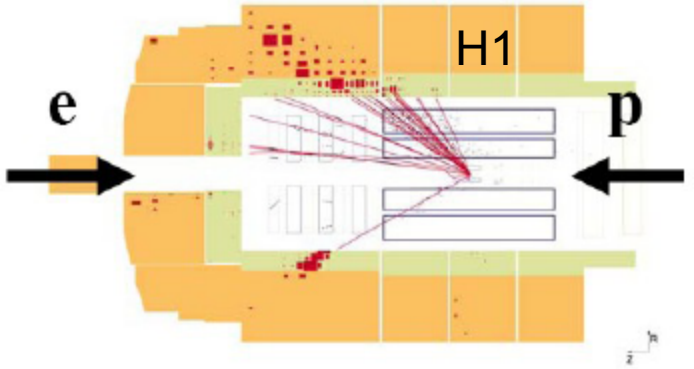
H1+ZEUS in total ~ 1 fb^{-1}
about equally shared between
- **experiments (H1, ZEUS)**
- **e^+ and e^-,**
- **positive and negative P_e**

low proton energy running for F_L

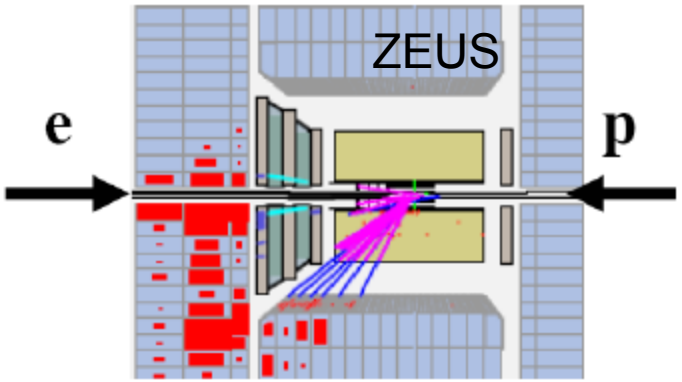
Deep Inelastic Scattering (DIS)



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
$y = (Pq)/(Pk)$ inelasticity

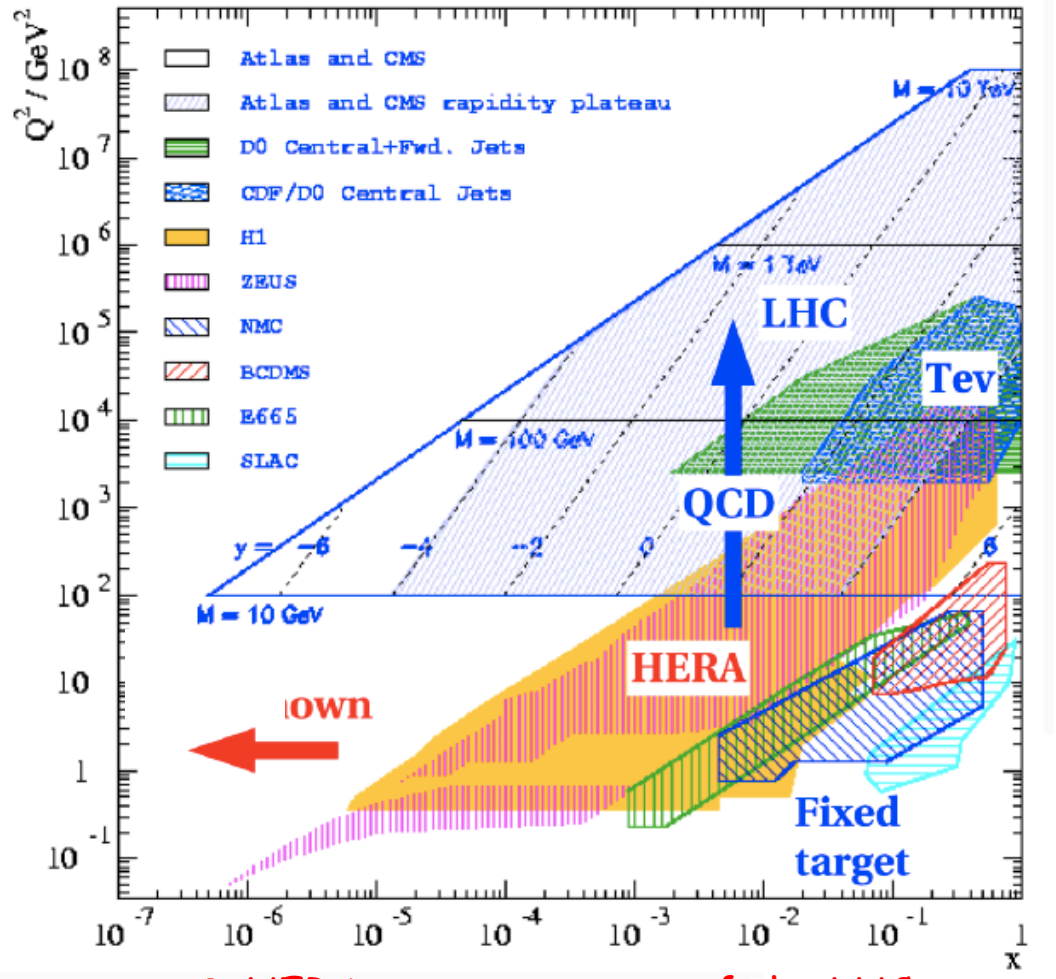
$Q^2 = sxy$ $s=(k+P)^2$

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

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

from HERA to LHC

HERA: span 5 orders of magnitude in x and Q^2



→ HERA covers x range of the LHC

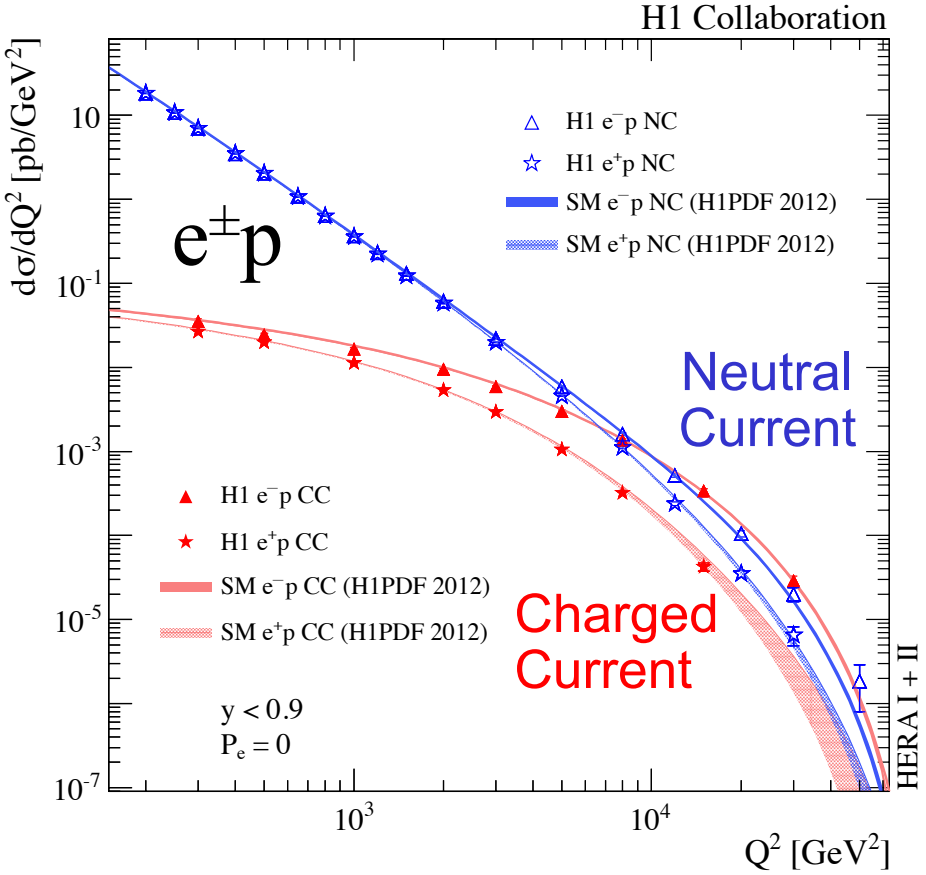
HERA: large number of individual data sets from H1 and ZEUS, covering different parts of the phase space, obtained in different periods, using different detector components, different beam energies, …

HERA I (1994-2000) inclusive NC & CC analyses are completed and published both by H1 and ZEUS, and combined.

HERA II (2003-2007)
- ZEUS e^-p NC/CC, e^+p CC: published
- low Ep data at low Q^2: published
- H1 high y & low Q^2: published

recent:
→ ZEUS e^+p NC: preliminary
→ H1 NC & CC at high Q^2: published

Inclusive NC & CC at HERA



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

→ remaining differences are due to u/d flavor asymmetry and helicity factors

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

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

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

→ all three SF are measured at HERA

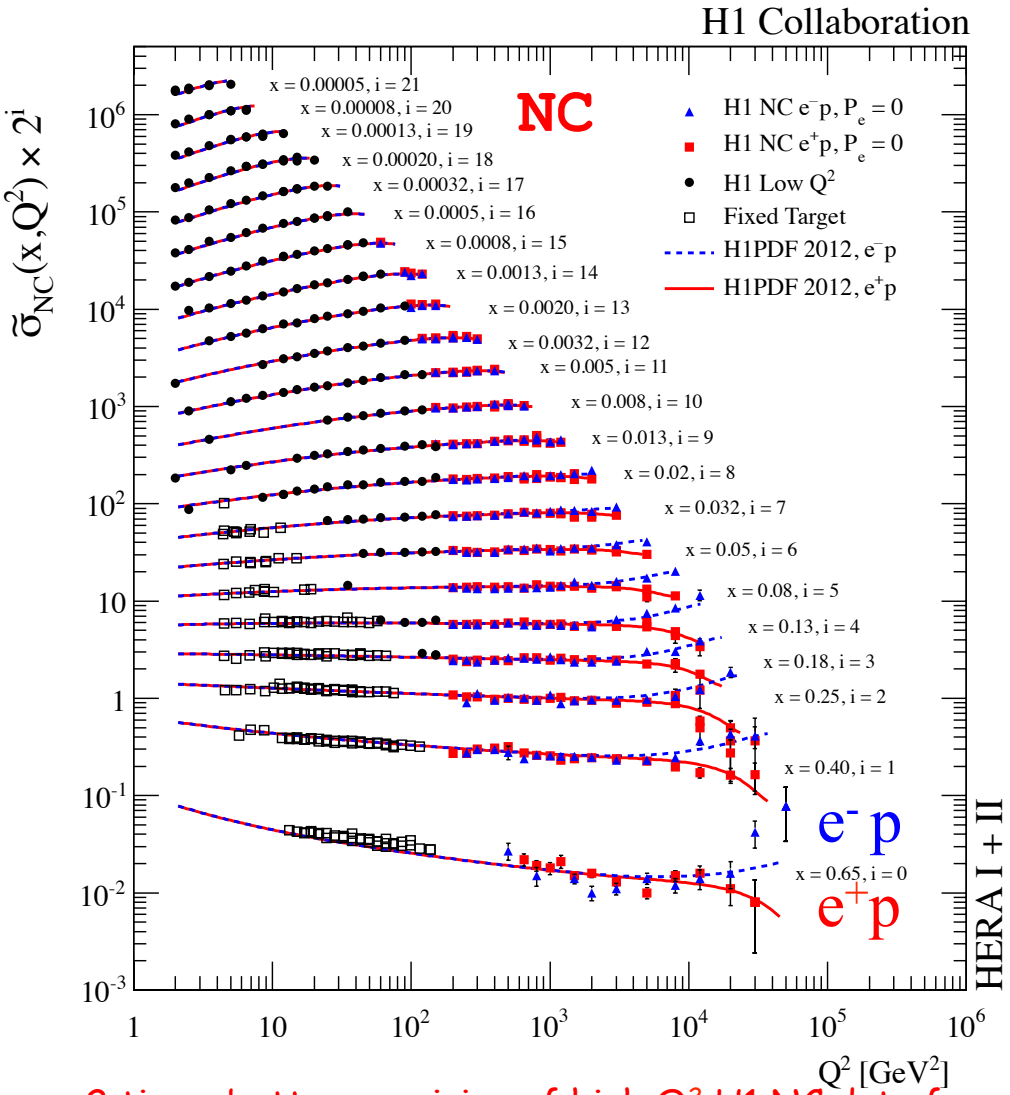
$$\tilde{\sigma}_{CC} = \frac{2\pi x}{G_F^2}\left[\frac{M_W^2 + Q^2}{M_W^2}\right]^2 \frac{d^2\sigma_{CC}}{dxdQ^2}$$

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

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

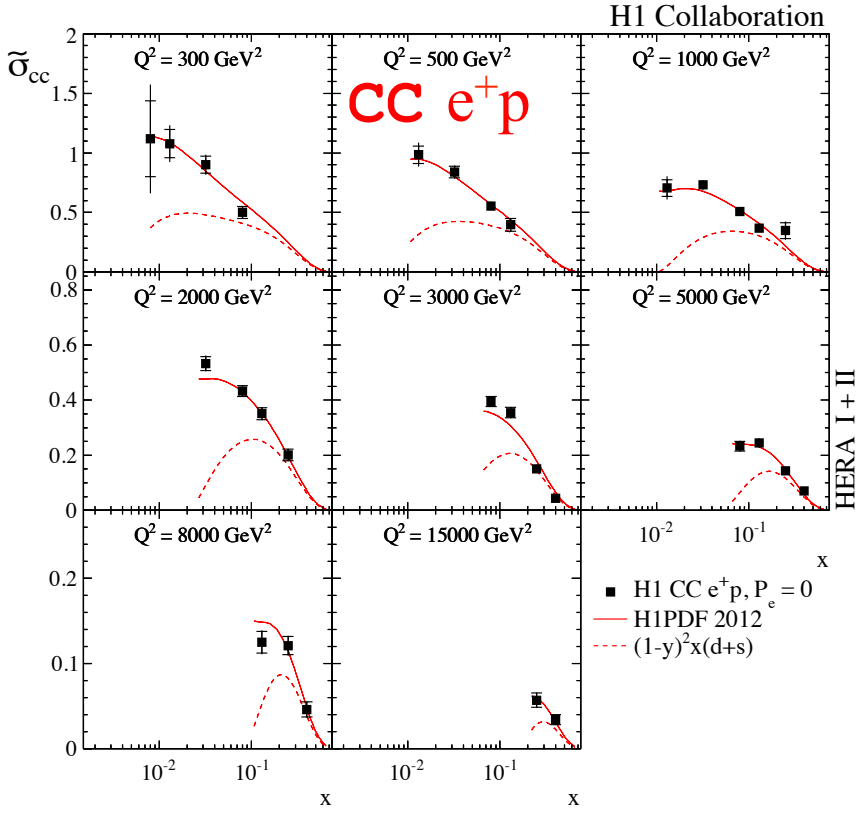
→ CC data allow flavor separation in QCD fits

NC and CC Cross Sections $\sigma_{NC,CC}(x,Q^2)$



H1 HERA II NC&CC: DESY 12-107 (June 2012)

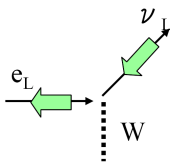
→ H1 luminosity at HERA II is measured using QED Compton process with overall uncertainty of 2.3% DESY 12-062



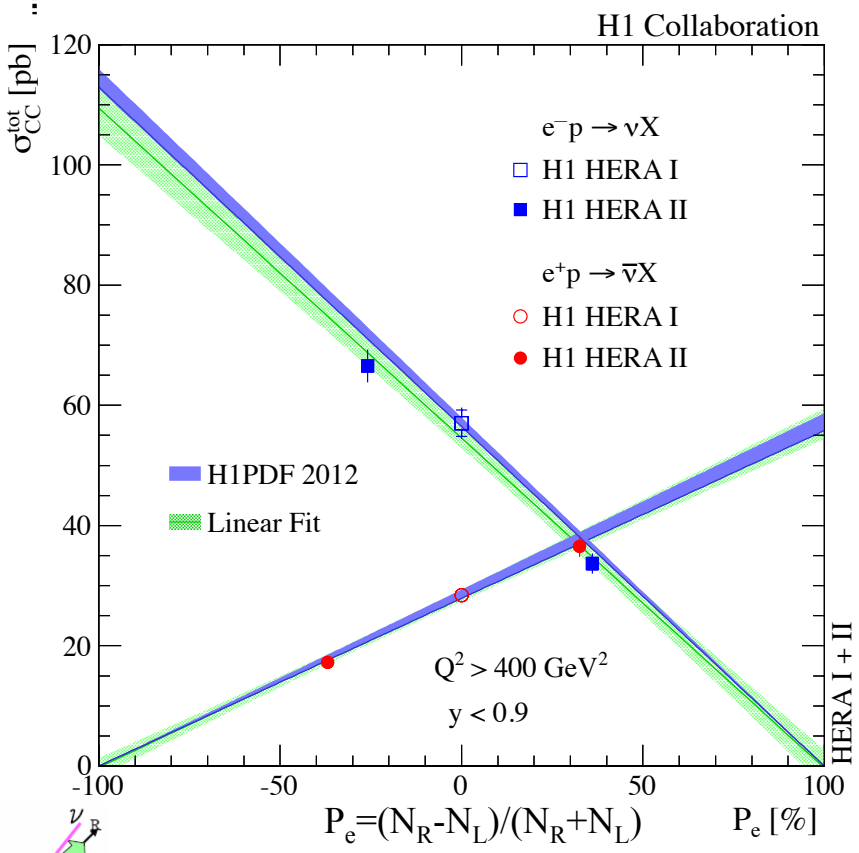
→ 2 times better precision of high Q^2 H1 NC data from HERA II compared to HERA I & prel. HERA II

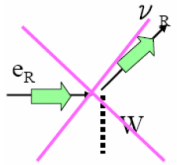
Polarisation effects in CC and NC

Polarisation dependence of the total CC cross section



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



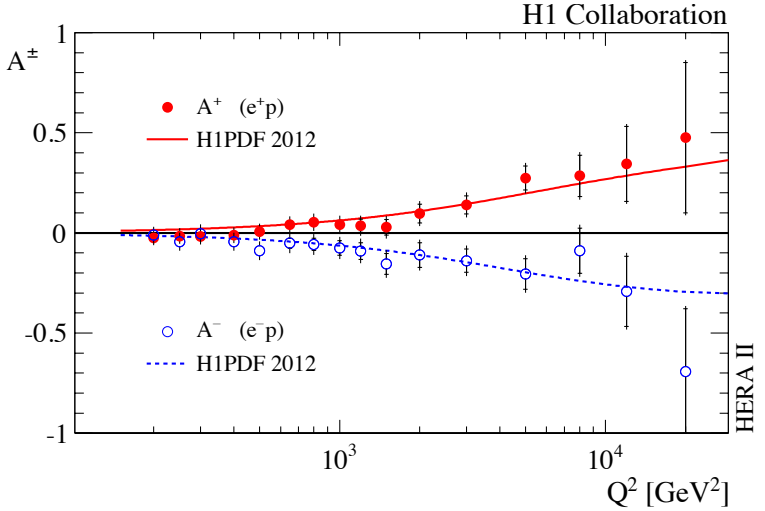


→ absence of right-handed weak current

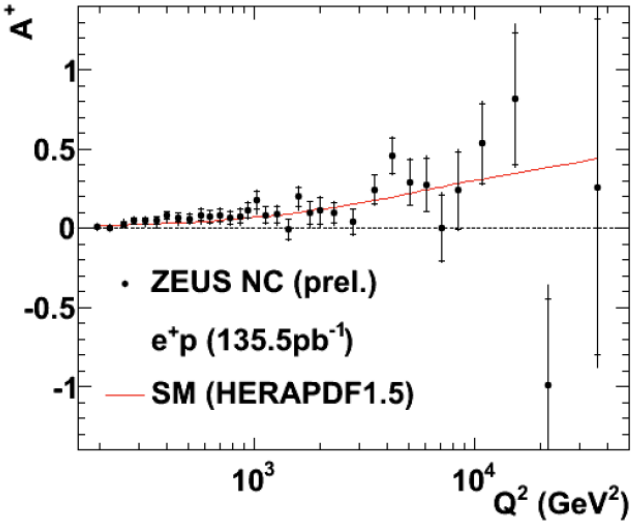
e^-p (e^+p): $M_{WR} > 214$ (194) GeV at 95% CL

Polarisation asymmetry in NC:

$$A^\pm = \frac{2}{P_L^\pm - P_R^\pm} \cdot \frac{\sigma^\pm(P_L^\pm) - \sigma^\pm(P_R^\pm)}{\sigma^\pm(P_L^\pm) + \sigma^\pm(P_R^\pm)}$$



→ a direct measure of parity violation in NC

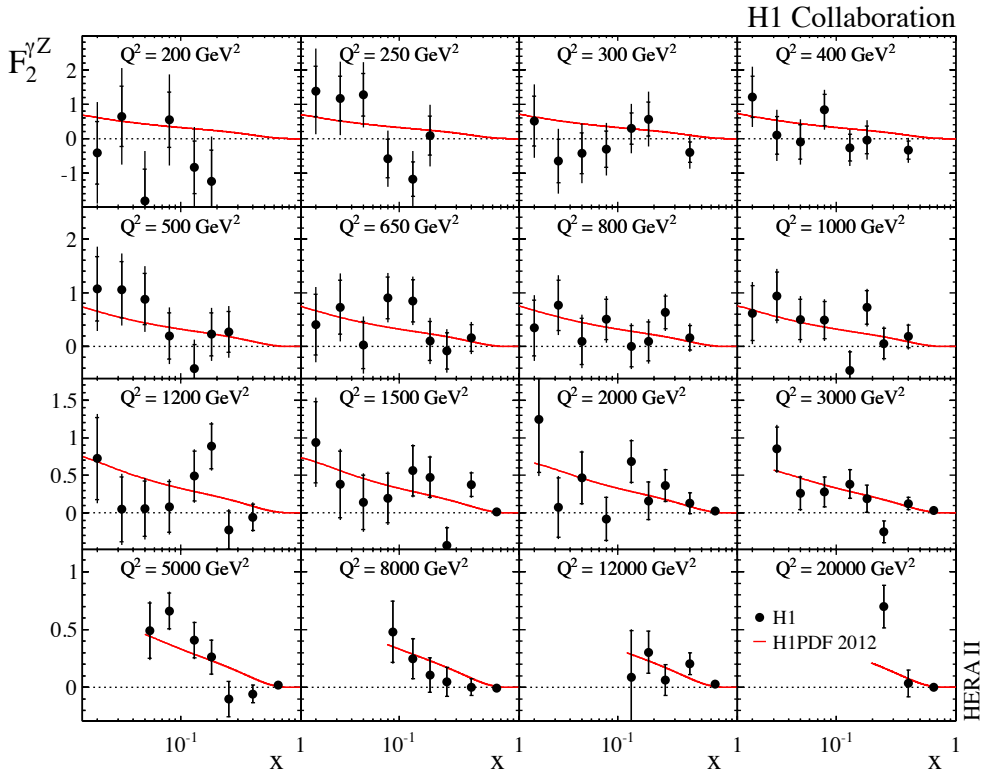


The First Measurement of Parity Violating SF $F_2^{\gamma Z}(x,Q^2)$

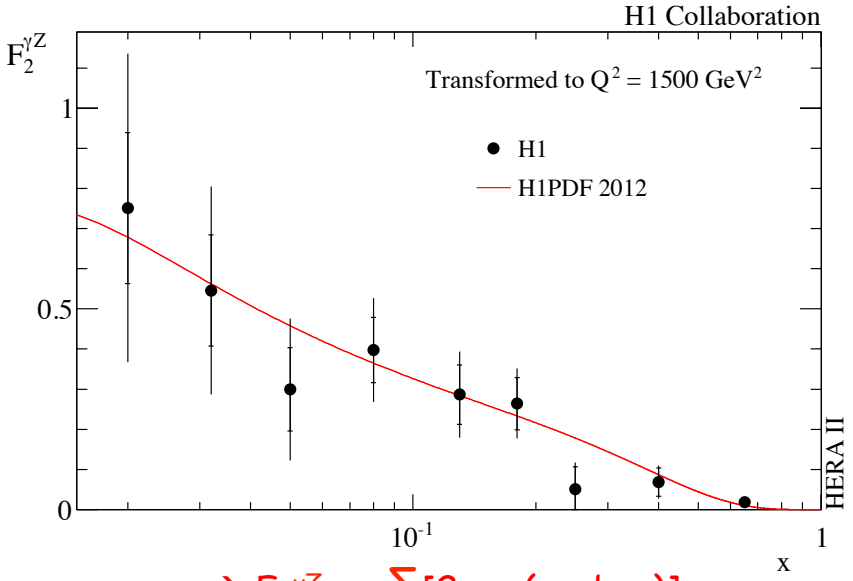
$$\frac{\sigma^{\pm}(P_L^{\pm}) - \sigma^{\pm}(P_R^{\pm})}{P_L^{\pm} - P_R^{\pm}} = \frac{\kappa Q^2}{Q^2 + M_Z^2}\left[\mp a_e F_2^{\gamma Z} + \frac{Y_-}{Y_+} v_e x F_3^{\gamma Z} - \frac{Y_-}{Y_+}\frac{\kappa Q^2}{Q^2 + M_Z^2}(v_e^2 + a_e^2) x F_3^Z\right]$$

taking the difference for e^+p and e^-p, the terms with $xF_3^{\gamma Z}$ and xF_3^Z cancel and $F_2^{\gamma Z}$ can be directly extracted from measured polarised cross sections

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



transform the $F_2^{\gamma Z}(x,Q^2)$ measurements to Q^2 = 1500 GeV^2 and average them to get $F_2^{\gamma Z}(x)$ at Q^2 = 1500 GeV^2



→ $F_2^{\gamma Z} = x\Sigma[2e_q v_q(q+\bar{q})]$

Structure Function $xF_3(x,Q^2)$

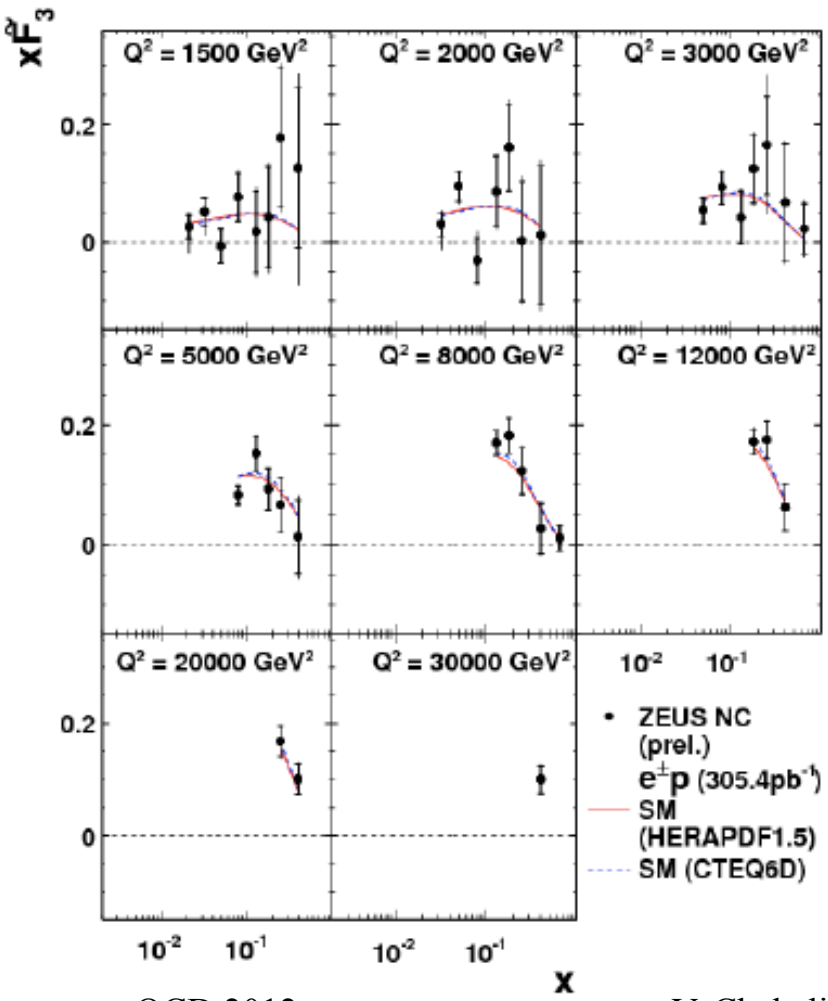
$$x\tilde{F}_3 = \frac{Y_+}{2Y_-}\left(\tilde{\sigma}^-_{NC} - \tilde{\sigma}^+_{NC}\right)$$

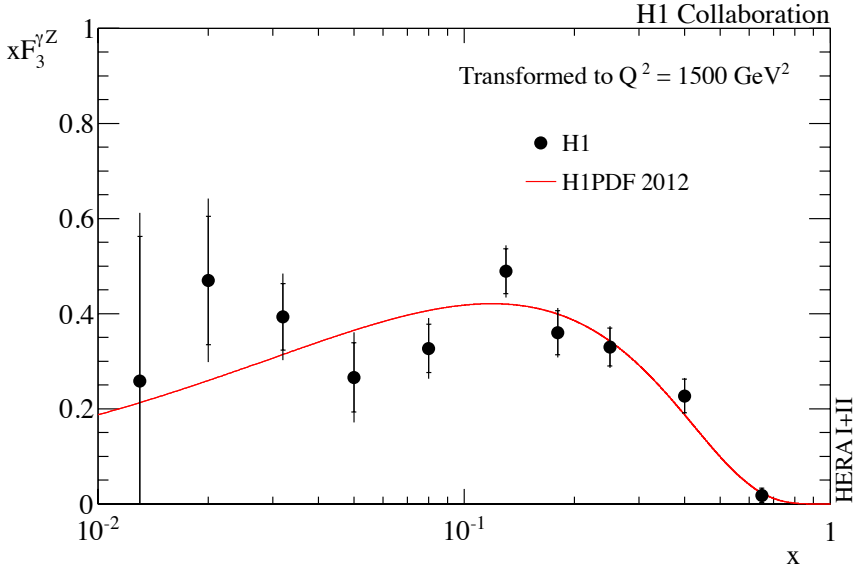
- charge asymmetry of unpolarised $e^{\pm}p$ NC cross sections

→ *mostly due to γZ interference*

$$xF_3^{\gamma Z} = -x\tilde{F}_3 \cdot (Q^2+M_Z^2)/(a_e \kappa Q^2)$$

transform the $xF_3^{\gamma Z}(x,Q^2)$ measurements to Q^2 = 1500 GeV^2 and average them to get $xF_3^{\gamma Z}(x)$ at Q^2 = 1500 GeV^2





→ sensitive to valence quark: $F_3^{\gamma Z} \approx (2u_v+d_v)/3$

$$\int_{0.016}^{0.725} dx\, F_3^{\gamma Z}(x, Q^2 = 1\,500\,\mathrm{GeV}^2) = 1.22 \pm 0.09(\mathrm{stat}) \pm 0.07(\mathrm{syst})$$

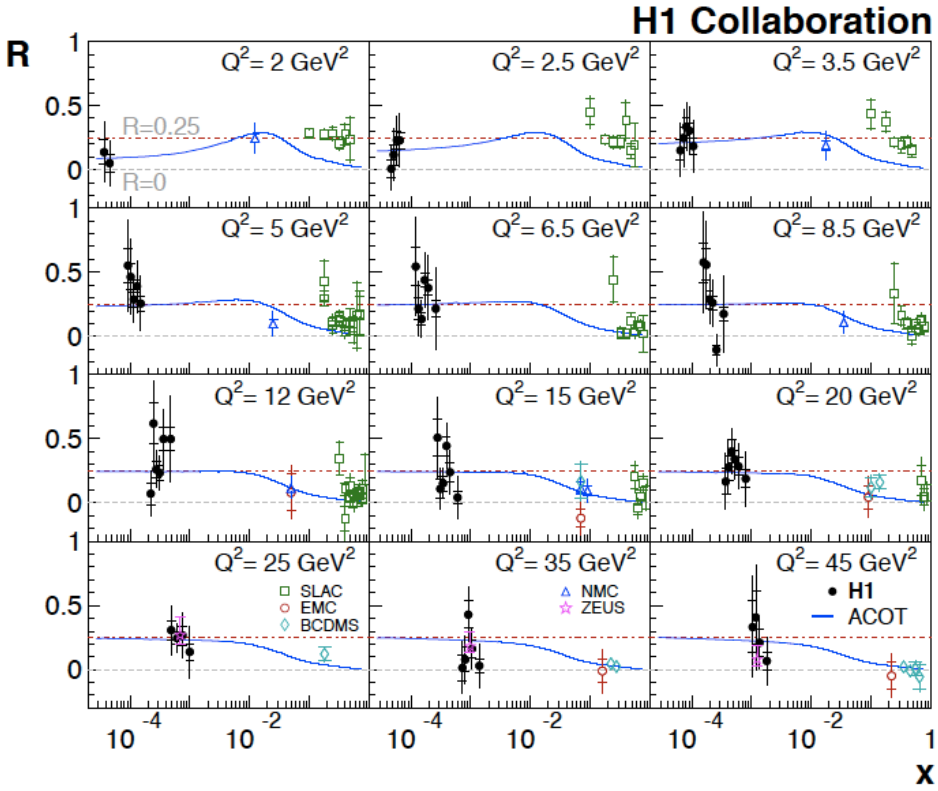
(H1PDF2012: 1.16+0.02-0.03)

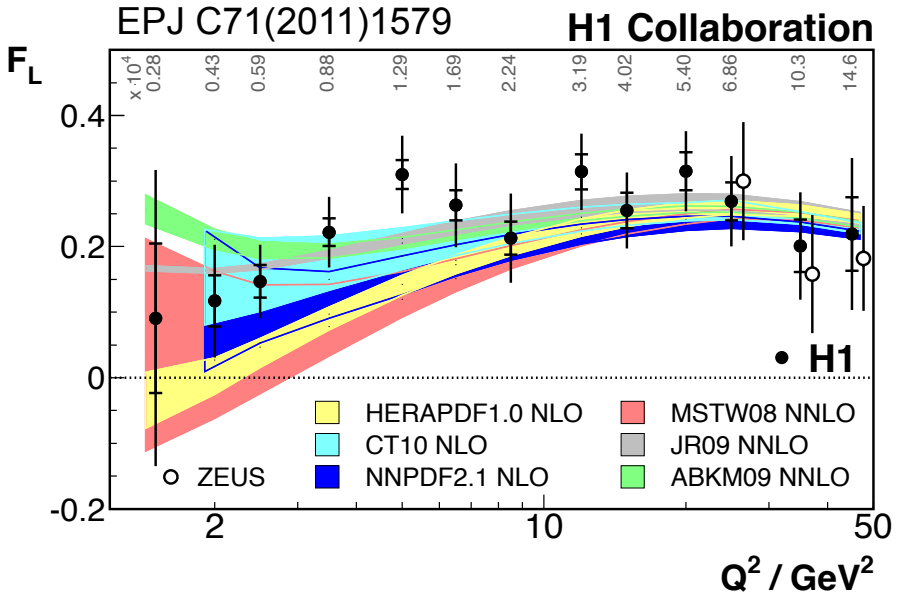
The longitudinal structure function $F_L(x,Q^2)$

- F_L is a pure QCD effect sensitive to gluon density $F_L(x,Q^2) = \frac{\alpha_s}{4\pi} x^2 \int_x^1 \frac{dz}{z^3} \left[\frac{16}{3} F_2 + 8 \sum_q e_q^2 (1 - \frac{x}{z}) \cdot xg \right]$

- F_L is measured at HERA using cross sections at the same x, Q^2 and different y (different proton beam energies Ep = 460, 575, 920 GeV)

$\sigma_{NC}(x,Q^2,y) = F_2(x,Q^2) - f(y)\, F_L(x,Q^2)$, $f(y)=y^2/(1+(1-y)^2)$





→ HERA F_L data are consistent with constant value of $R=F_L/(F_2-F_L)=0.26\pm0.05$

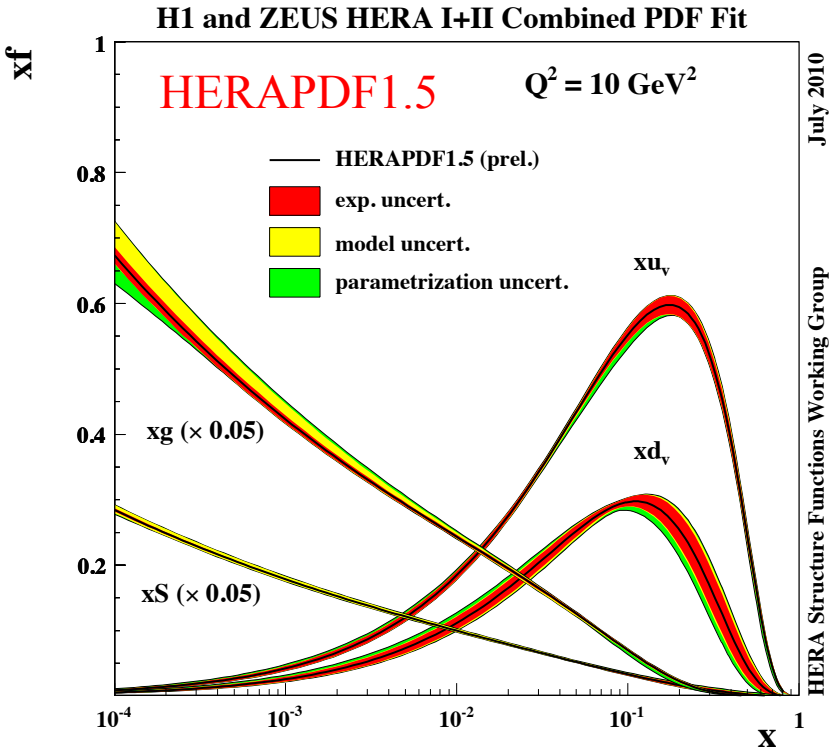
HERAPDF: QCD Fits using HERA data only

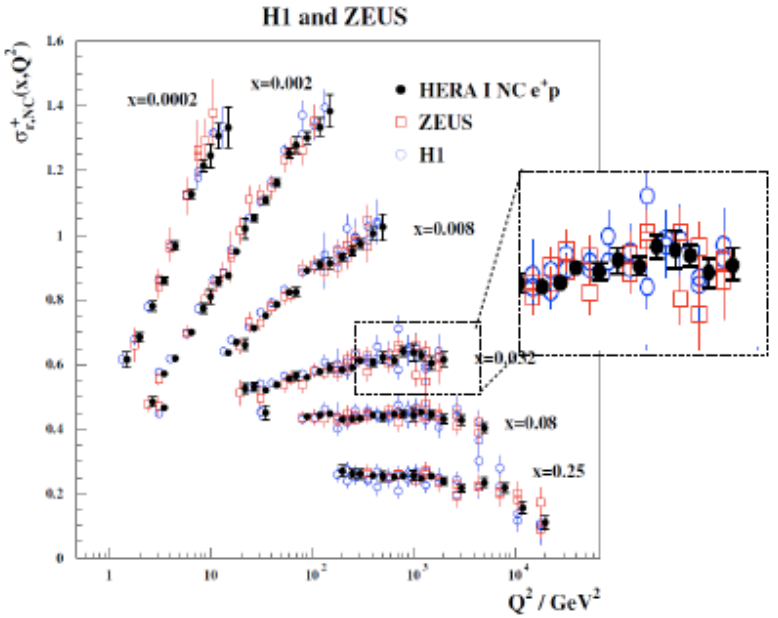
Input: combined H1 & ZEUS incl. ep NC and CC data which include expert knowledge in the treatment of the correlations between many individual data sets.

→ precise, complete and easy in use

→ significant reduction of systematic uncertainties

1. HERA I data: JHEP 1001:109,2010 HERAPDF 1.0
2. HERA I and preliminary HERA II data HERAPDF 1.5



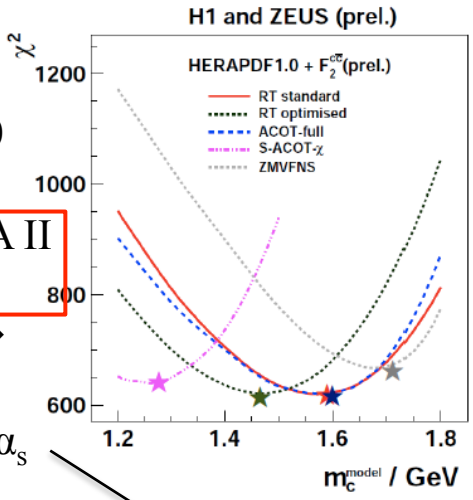


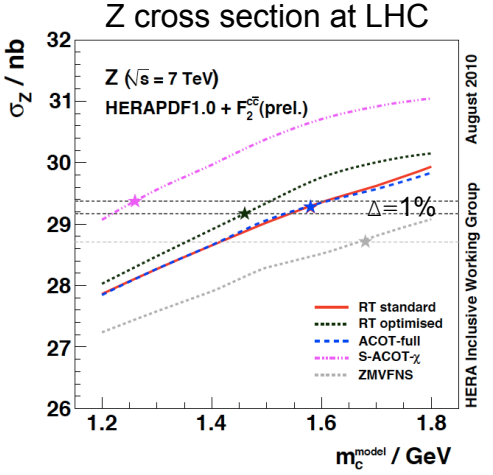
HERAPDF

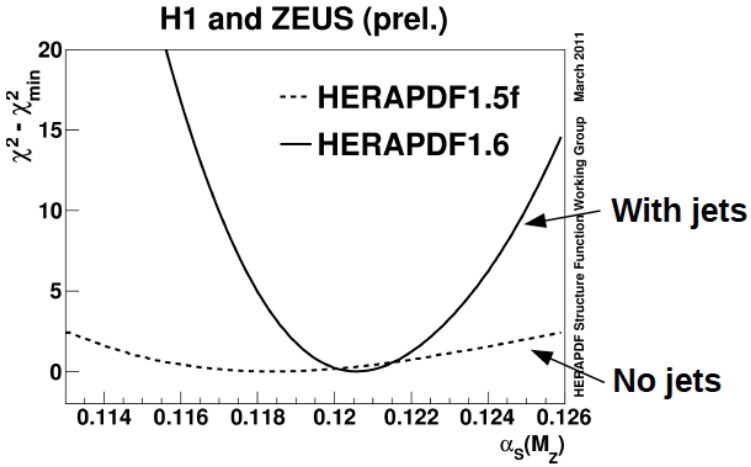
- no nuclear corrections
- no heavy target correction
- $\Delta\chi^2$ = 1 criterion for exp. errors
- parametrise xg(x), xu_v, xd_v, xUbar, Dbar at starting scale Q_o^2
- apply quark number and momentum sum rules
- NLO/NNLO DGLAP evolution
- different schemes for heavy flavor treatment
- uncertainty bands:
  - experimental
  - model (variations of Q^2_{min}, f_s, m_c, m_b)
  - parameterisation (variation of param. assumptions)

HERAPDF Sets

Nov 2009	**HERAPDF 1.0** NC,CC	JHEP 1001:109,2010 HERA I
July 2010	**HERAPDF 1.5** NC,CC	HERA I+ prel HERA II → recommended
Aug 2010	**HERAPDF 1.0** **charm** (+F2c)	optimum m_c →
Mar 2011	**HERAPDF 1.6** NC,CC,jets	fit strong coupling α_s
Jun 2011	**HERAPDF 1.7** NC,CC,F2c,jets, low Ep data	
aim:	**HERAPDF 2.0**	using published and combined complete incl. NC/CC data from HERA I and HERA II

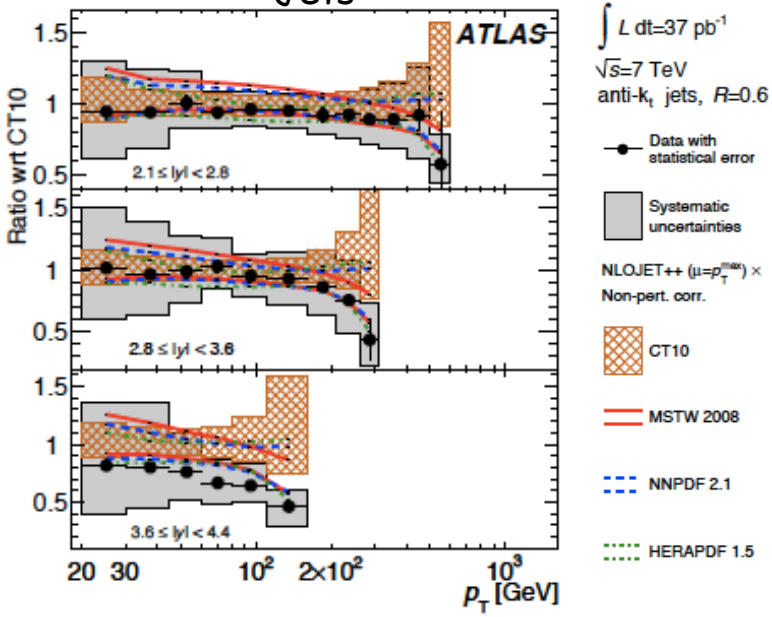




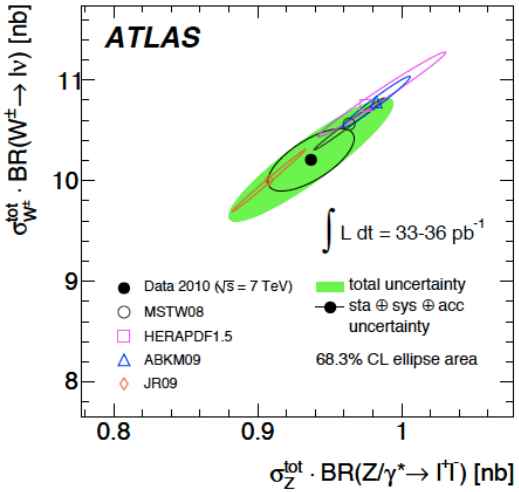


HERAPDF for LHC (few examples)

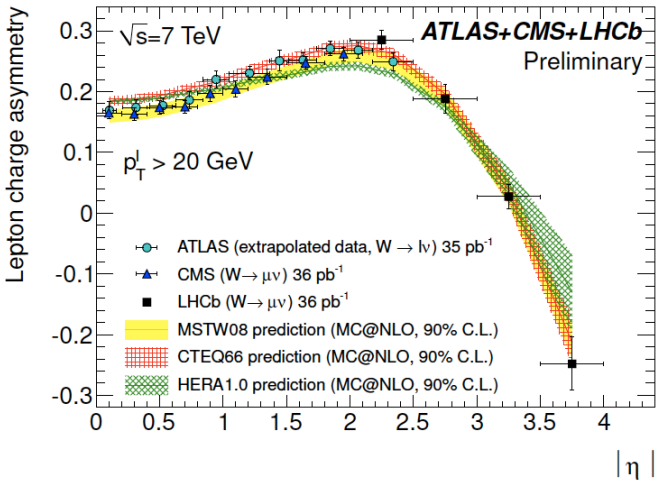
Jets



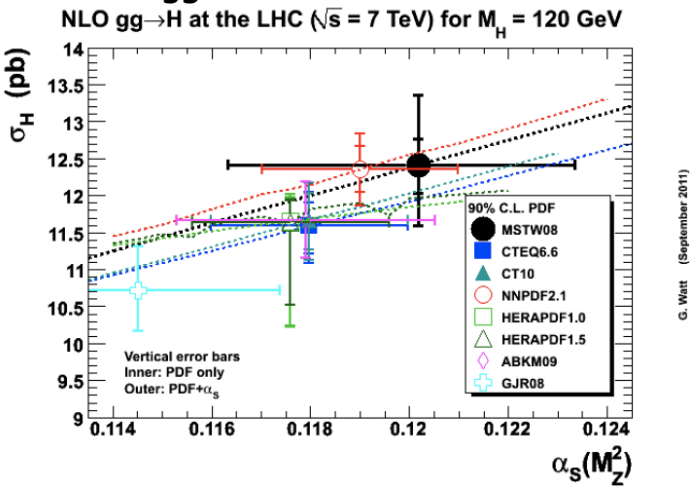
W,Z cross sections



Lepton charge asymmetry



gg → H cross section



→ all modern PDF fits include HERA data

HERAFitter: Open source QCD Fit Framework

HERAFitter is a set of PDF fitting tools initially developed by the H1 and ZEUS collaborations for determination of the parton density functions. The HERAFitter codes were used to obtain the HERAPDF sets.

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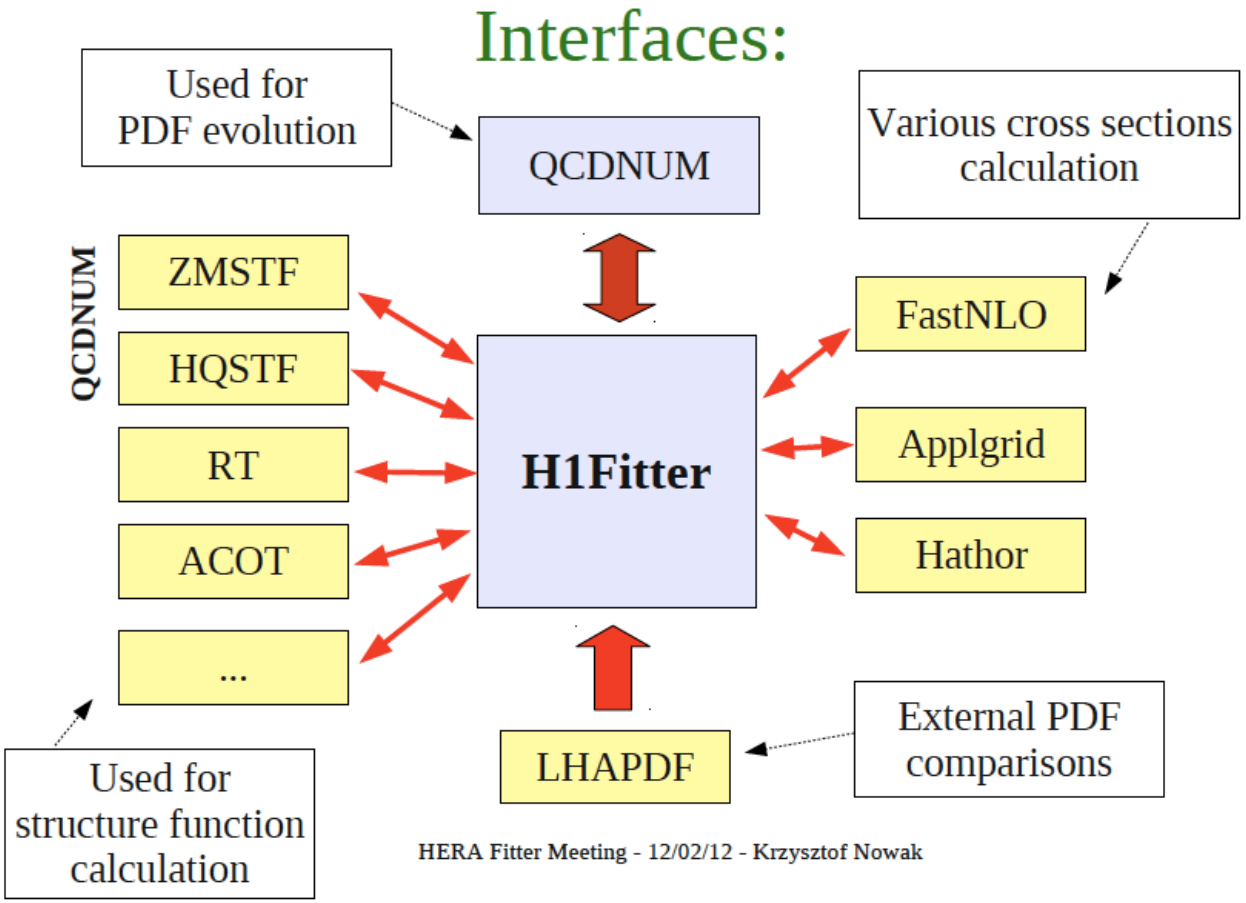
The beta release can be accessed through the HEPFORGE site: http://projects.hepforge.org/herafitter



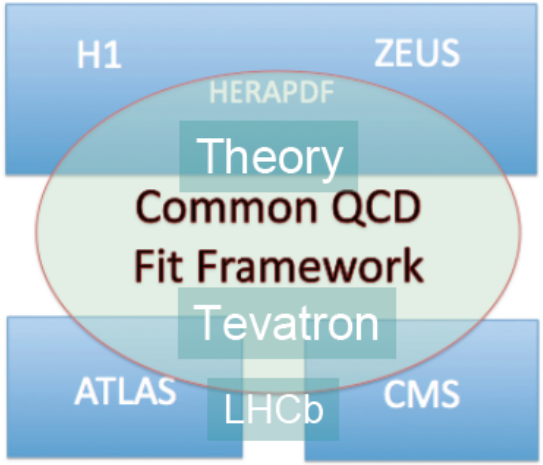
modular structure
flexible, expandable

- evolution by QCDNUM package (M. Botje)
- different HV schemes, error treatments, …

DIS ep
- *inclusive*
- *jets*

pp and ppbar
- *W,Z cross sections*
- *rapidity*
- *charge asymmetries*
- *jets*

HERAFitter for LHC

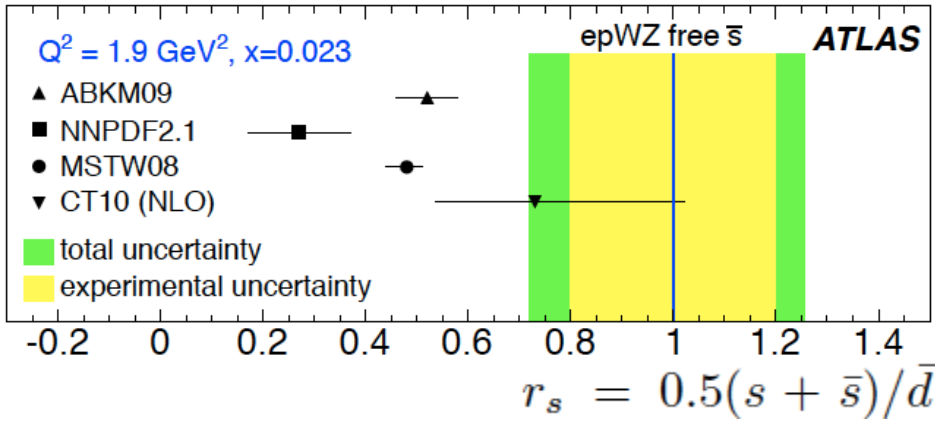


HERAFitter is a ready QCD platform to analyse new data in context of PDFs

Development by
- H1 and ZEUS
- ATLAS and CMS
- Theory groups

The First LHC publication using HERAFitter arXiv:1203.4051

Determination of the strange quark density of the proton using differential W, Z cross section data of ATLAS fitted together with the ep cross sections from HERA



Summary

- Completion of the HERA inclusive NC and CC cross section measurements
  - *H1: HERA II data are published (DESY 12-107)*
    2 times better precision compared to HERA I and prelim. HERA II
  - *ZEUS: preliminary NC e^+p 2006-2007,* publication to come soon

- Combination of the H1 and ZEUS inclusive NC and CC $e^\pm p$ data
  - *HERA I: all inclusive results are published and combined using a model independent approach leading to significant reduction of systematic uncertainties*
  - *HERA I+II: extension of the combination to include prelim. HERA II*
  - *to come: Combination of the complete final HERA I+II H1&ZEUS data*

- HERA, H1 and ZEUS NLO/NNLO QCD analyses are performed
  - *HERAPDF parton densities are extensively used at LHC*
  - *HERAPDF 1.5 is recommended*
  - *to come: HERAPDF 2.0 using final combined data from HERA*

- HERAFitter *is a ready & open QCD platform to analyse new (LHC) data in context of PDFs*