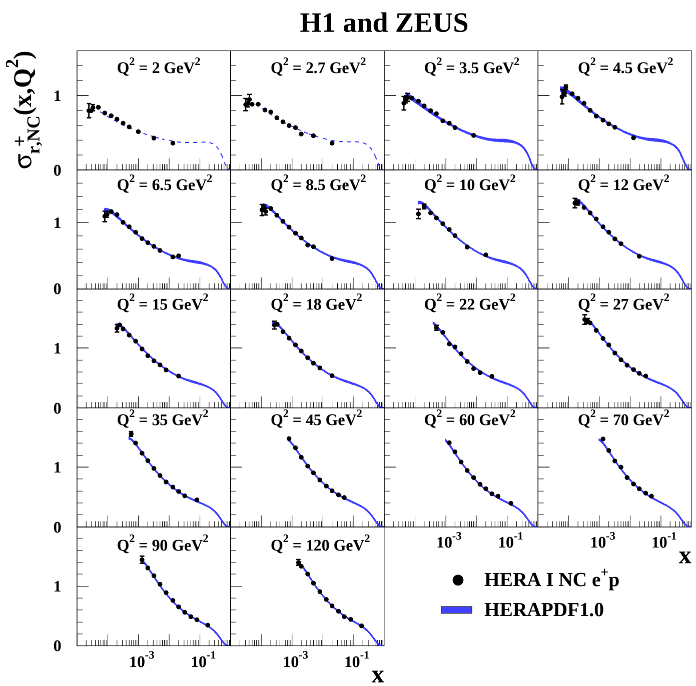
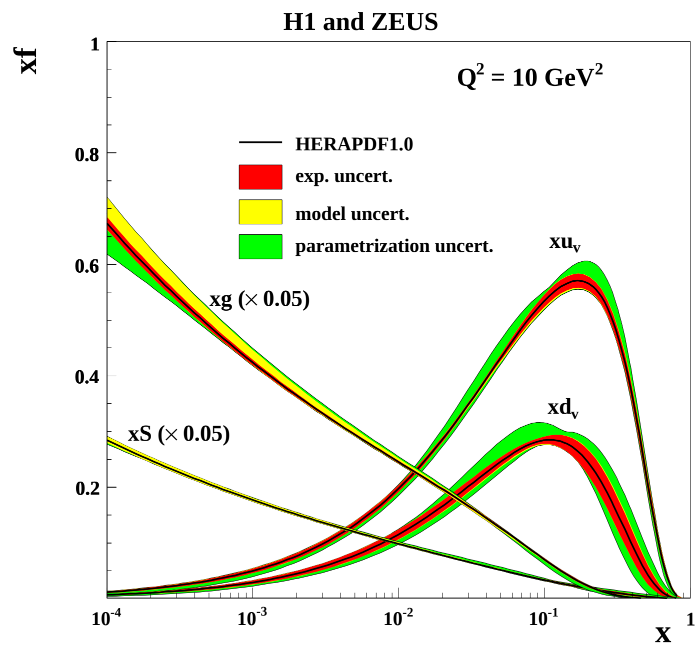
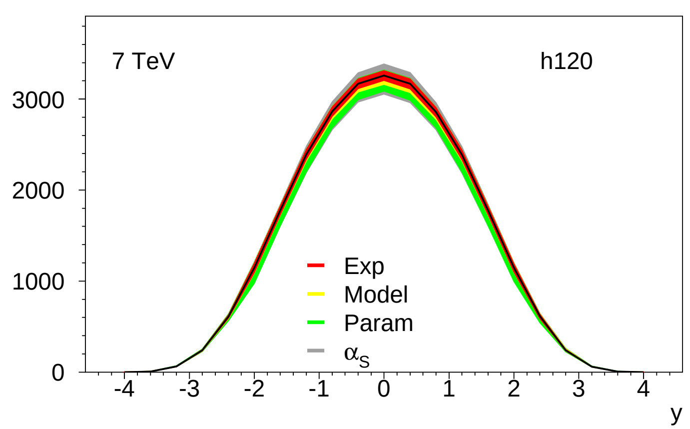
HERA Achievements

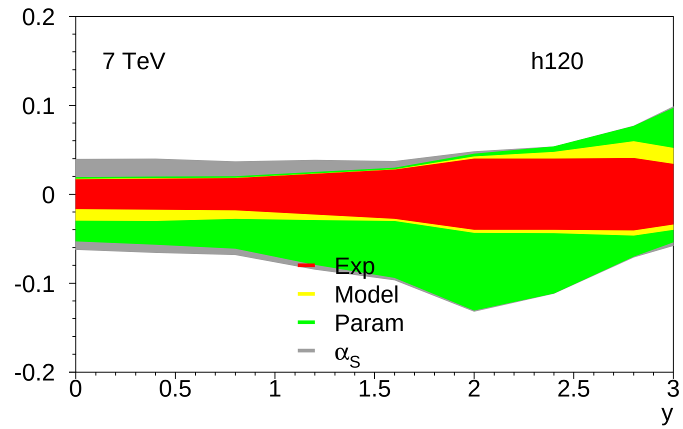
- Accurate measurement of the inclusive structure function F_2 gives access to the proton structure at low $x > 0.0001$.
- Checks of conventional QCD evolution + accurate predictions for the LHC.
- Indications that at lowest x and lowest Q^2 we may start entering high density regime.
- Total luminosity of $\sim 1\ \mathrm{fb}^{-1}$ allowed to measure with statistically limited accuracy
  - CC processes: flavor decomposition at higher x
  - DVCS: proton structure in 3D.
- Reduced proton beam energy runs at the end of HERA operation allowed to determine structure function F_L: direct measure of the gluon.

HERA PDFs

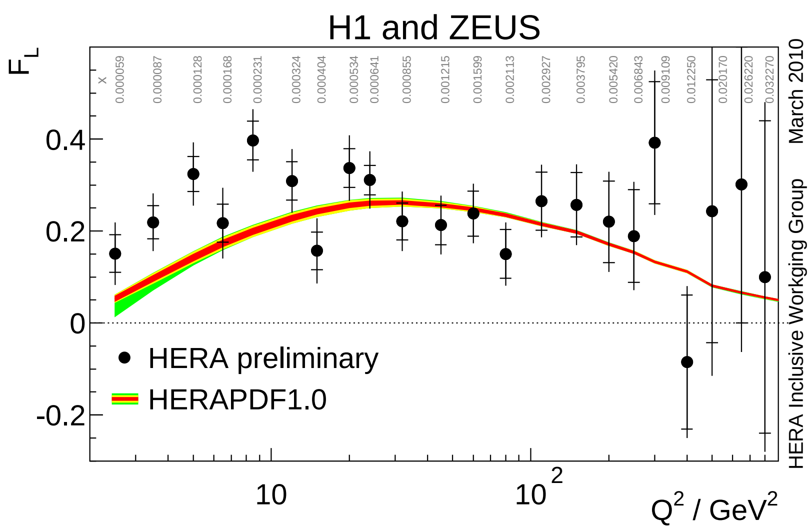

H1 and ZEUS
$\sigma^{+}_{r,NC}(x,Q^2)$
Q^2 = 2 GeV^2
Q^2 = 2.7 GeV^2
Q^2 = 3.5 GeV^2
Q^2 = 4.5 GeV^2
Q^2 = 6.5 GeV^2
Q^2 = 8.5 GeV^2
Q^2 = 10 GeV^2
Q^2 = 12 GeV^2
Q^2 = 15 GeV^2
Q^2 = 18 GeV^2
Q^2 = 22 GeV^2
Q^2 = 27 GeV^2
Q^2 = 35 GeV^2
Q^2 = 45 GeV^2
Q^2 = 60 GeV^2
Q^2 = 70 GeV^2
Q^2 = 90 GeV^2
Q^2 = 120 GeV^2
HERA I NC e^+p
HERAPDF1.0
x

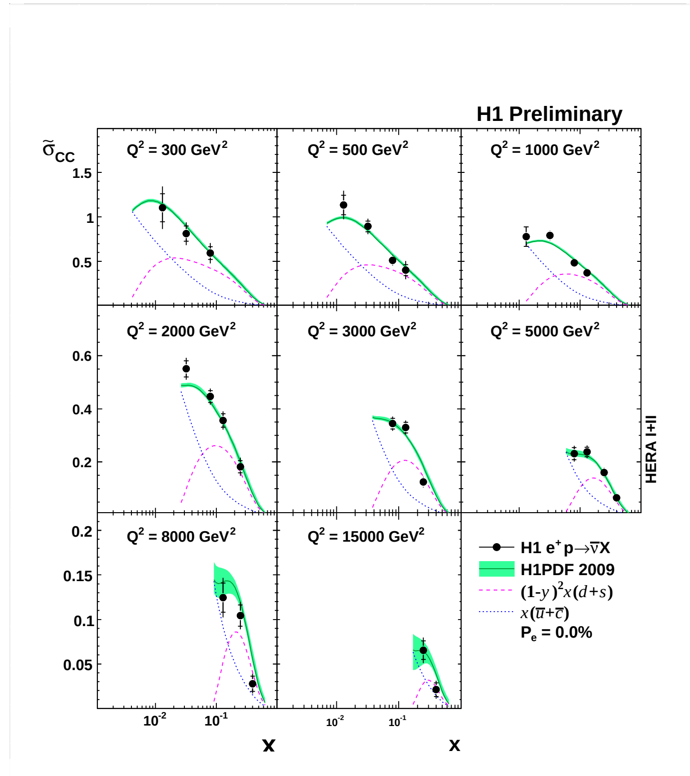

H1 and ZEUS
xf
Q^2 = 10 GeV^2
HERAPDF1.0
exp. uncert.
model uncert.
parametrization uncert.
xu_v
xd_v
xg (× 0.05)
xS (× 0.05)
x

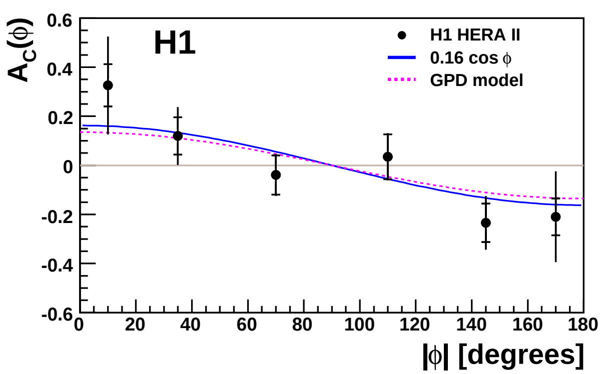

7 TeV
h120
Exp
Model
Param
α_S
y


7 TeV
h120
Exp
Model
Param
α_S
y

Stat. limited processes at HERA

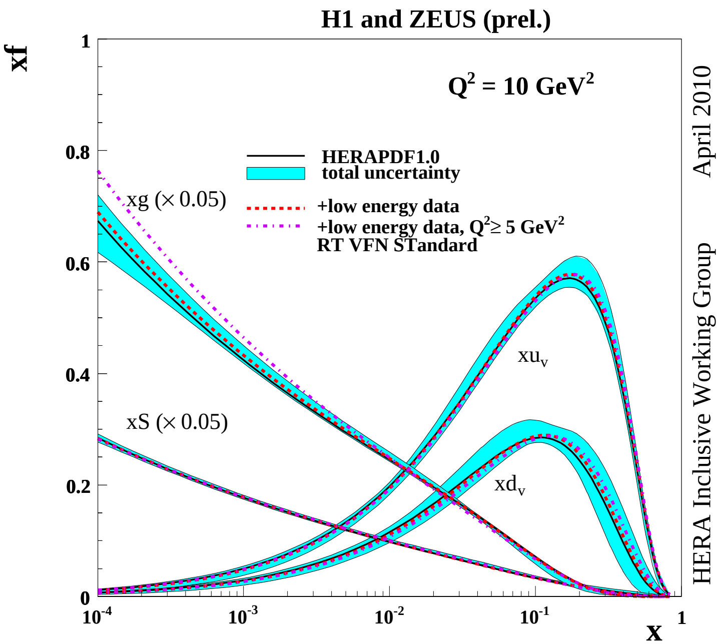






Measurements of F_L, CC cross section, DVCS would benefit greatly from higher luminosity.

High density regime at HERA?



Significant change in solution when excluding data at $Q^2 < 5\ \mathrm{GeV}^2$, most pronounced when using combined HERA-I and low E_p data.

Results from the combined HERA-I dataset

Evidence for deviations from NLO DGLAP

- at low $Q^2 \lesssim 10\ \mathrm{GeV}^2$: deviations from NLO DGLAP
- deviations compatible with resummation / saturation, but not with NNLO

(F. Caola, DIS2010)

What was not done at HERA

- Beyond ep scattering:
  - Structure function F_2 does not provide flavor decomposition information at low x: $F_2 \sim 4/9(U + \bar{U}) + 1/9(D + \bar{D})$, $\rightarrow$ run in ed mode.
  - High density QCD regime is achieved with eA scattering. Measurements of F_2^A/F_2^p, F_L^a/F_L^p and exclusive processes provide new dimension for accurate QCD studies.
- Higher luminosities:
  - Accurate measurement of CC, CC + tagged c (strangeness at medium x, NuTeV anomaly.)
  - Proton structure in 3D with DVCS.
- Higher e energy:
  - Extend range to low x.
  - More symmetric beams: easier to study forward flows.
- Detector optimization: Better instrumentation for low x physics. Measurements in high-background environment (F_L) benefits from modern highly segmented calorimetry/light tracking.

HERA ++ vs other projects

Project	$E_p \times E_p$, GeV^2	Luminosity, cm^{-2}s^{-1}	Year
ELIC	$30 \times 10 \rightarrow 250 \times 10$	$0.5 - 4.5 \times 10^{33}$	202?
eRICH	$250 \times 10 \rightarrow 250 \times 30$	3×10^{33}	202?
LHeC	7000×70	5×10^{33}	2025+
HERA ++	$920 \times 30 \rightarrow 920 \times 50$	???	202?

- *ep* colliders are under active discussion in USA and Europe.
- "High intensity polarized" but at lower energy in USA (eRICH and ELIC) and "High energy frontier" at CERN (LHeC). Projects are supported by both high energy and nuclear physics communities.
- HERA ++ project fills the gap between the other projects, has unique advantages.