LHeC-Note-2013-002 PHY
Geneva, July 26, 2013

Partons from the LHeC

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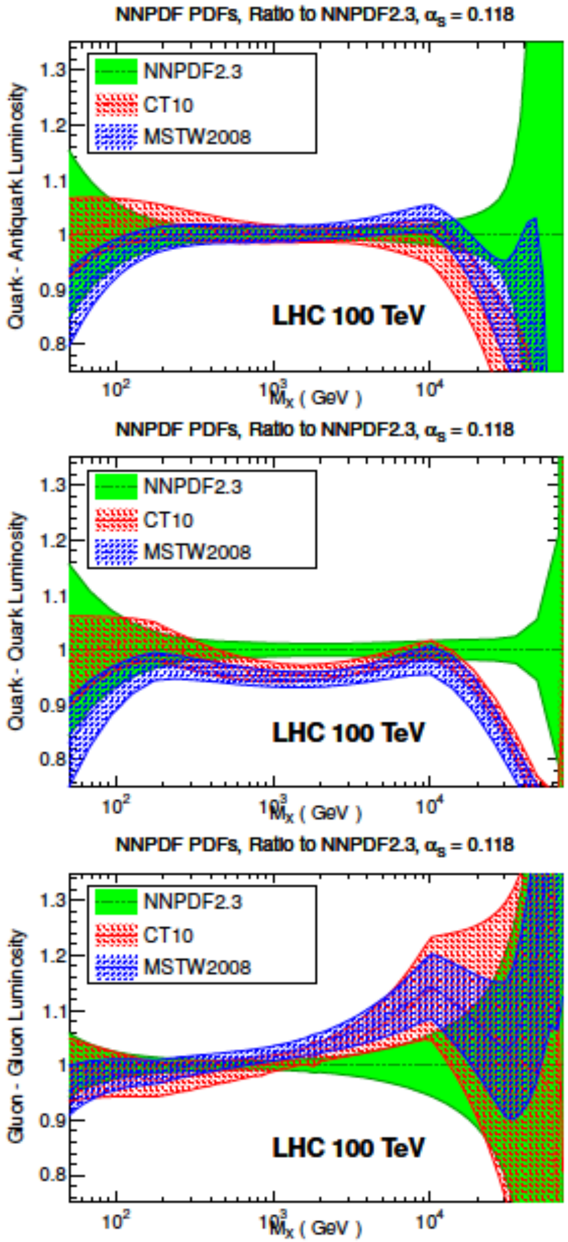
Contribution to the Snowmass 2013 Workshop

Introduction and Updates (work in progress)

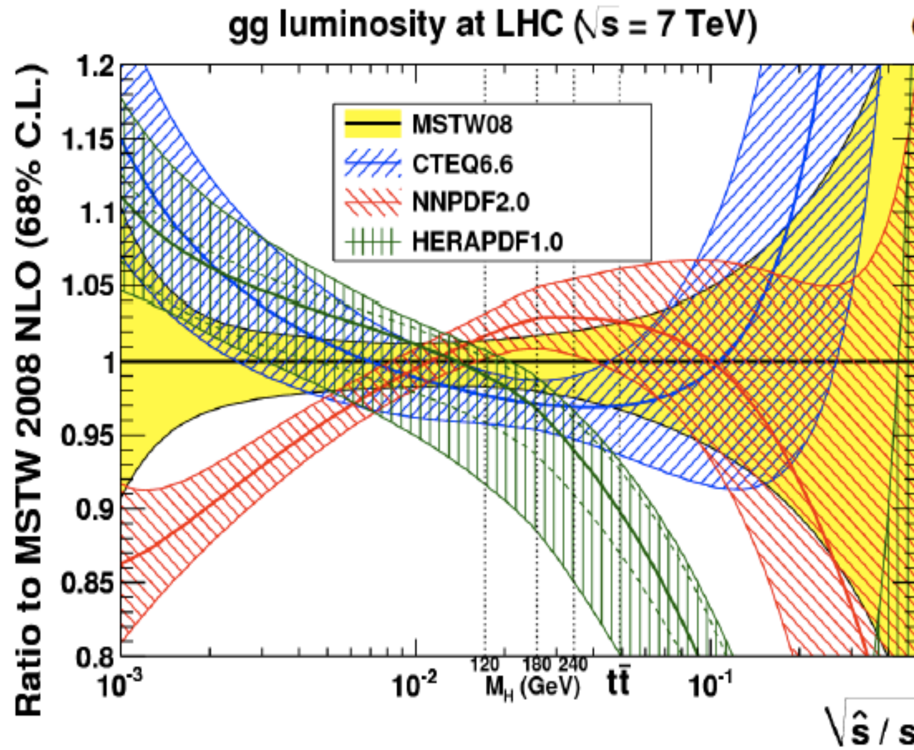
LHeC Workshop, Chavannes-de-Bogis, January 20th, 2014

Parton Distributions

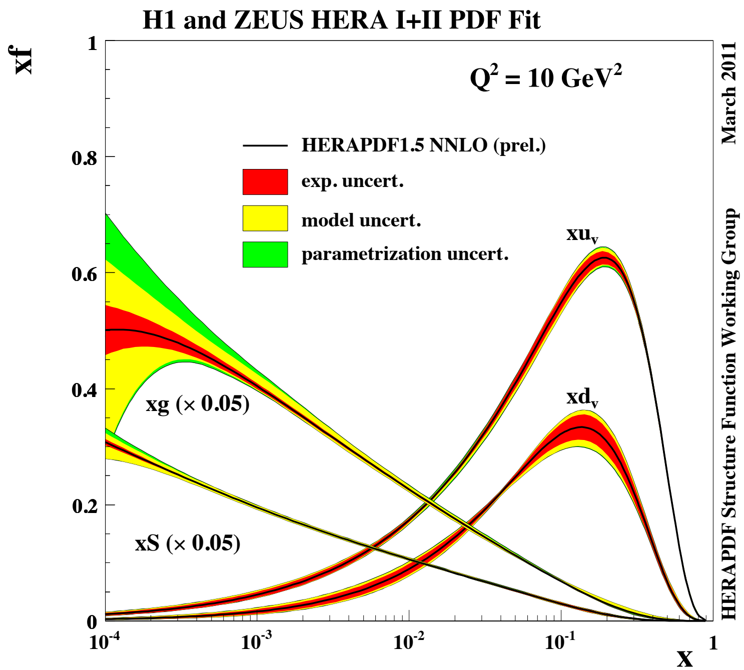


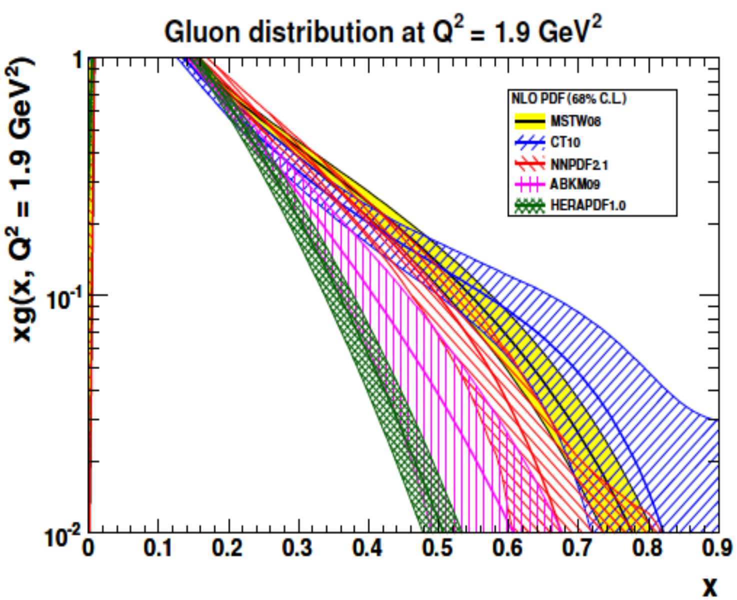
Snowmass13 QCD WG report

G. Watt



Need to know the PDFs much better than so far, for nucleon structure, q-g dynamics, Higgs, searches, future colliders, and for the development of QCD.





(Un)certainty on PDFs

Light Quarks:
valence $x < 0.01$, u_v $x > 0.8$, d_v $x>0.6$
light sea (related to strange) -8% ATLAS/F_2,
light sea quark asymmetry, d/u=?
Isospin relations (en!) ??

Strange: unknown, =dbar? strange valence?

Charm: need high precision to % for α_s
(recent HERA 5%)
Beauty: HERA 10-20%, bb → A?
Top: tPDF at high Q^2 >M_t^2 - unknown

Gluon: low x, saturation?, high x - unknown
medium x: preciser for Higgs!
Recent review: cf E.Perez, E.Rizvi 1208.1178, in RPP

..unintegrated, diffractive, generalised, polarised, photonic, nuclear PDFs ???

Simulated LHeC Data (Note=CDR=OLD)

Scenario "B": (Lumi $e^{+/-}p$ = 50 fb^{-1}) Ep=7 TeV, Ee=50 GeV, Pol=±0.4

– Kinematic region: 2 < Q^2 < 500 000 GeV^2 and 0.000002 < x < 0.8

Scenario "H": (Lumi $e^{-}p$ = 1 fb^{-1}) Ep=1TeV, Ee=50 GeV, Pol=0

– Kinematic region: 2 < Q^2 < 100 000 GeV^2 and 0.000002 < x < 0.8

Typical uncertainties:

Full simulation of NC and CC inclusive cross section measurements including statistics, uncorrelated and correlated uncertainties – based on typical best values achieved by H1

– Statistical it ranges from 0.1% (low Q^2) to ~10% for x=0.7 in CC

– Uncorrelated systematic: 0.7 %

– Correlated systematic: typically 1-3% (for CC high x up to 9%)

source of uncertainty	error on the source or cross section
scattered electron energy scale $\Delta E'_e/E'_e$	0.1 %
scattered electron polar angle	0.1 mrad
hadronic energy scale $\Delta E_h/E_h$	0.5 %
calorimeter noise (only $y < 0.01$)	1-3 %
radiative corrections	0.5%
photoproduction background (only $y > 0.5$)	1 %
global efficiency error	0.7 %

This set is available on LHAPDF

Settings for the PDF determination

[HERAFitter framework]

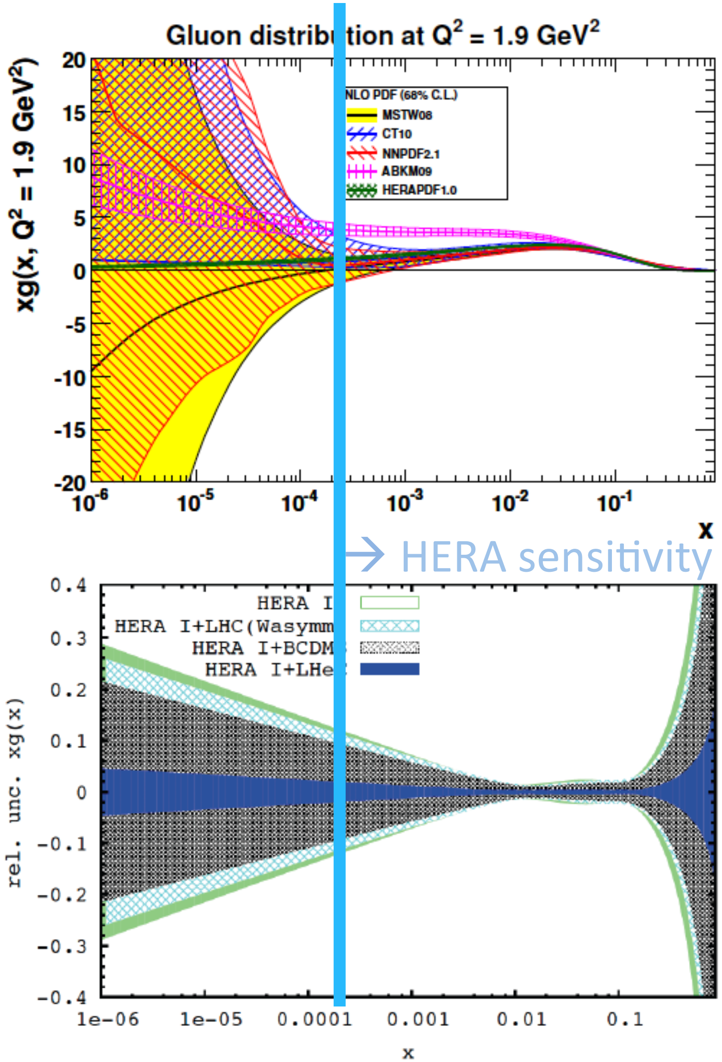
– Data:
  - **LHeC simulated data:**
    - **NC e^+p, NC, e^-p, CC e^+p, CC e^-p postive and negative polarisations P=±0.4**
  - Published HERA I (NC, CC $e^{\pm}p$ data, P=0)
    - Kinematics of HERA data: $0.65>x>10^{-4}$, 30 000 $>Q^2>3.5$ GeV^2
  - Full experimental Uncertainties

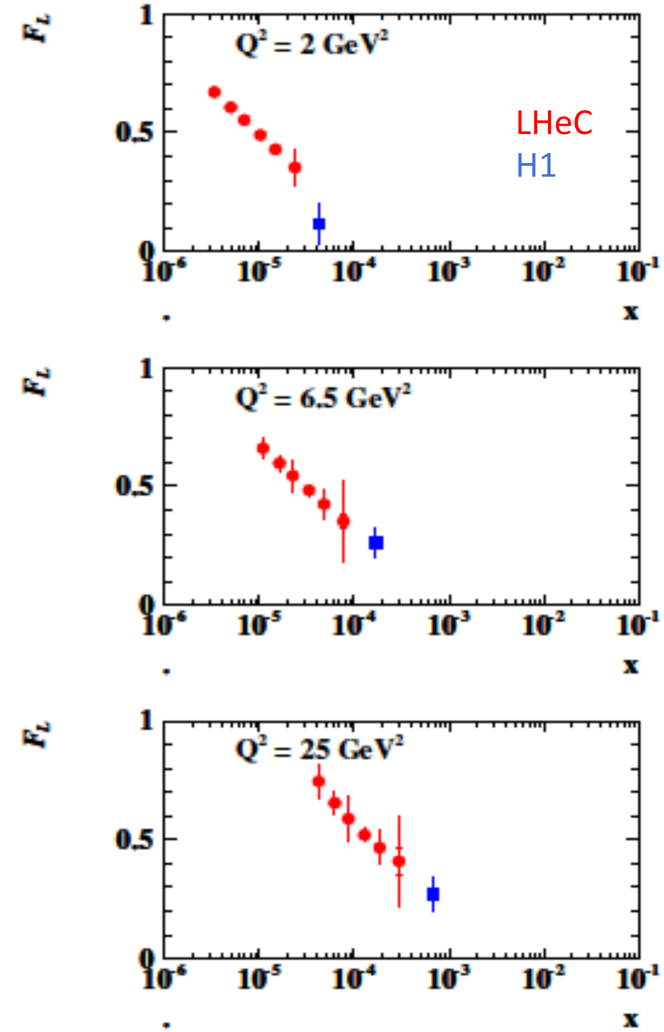
– Initial Theory settings:
  - NLO DGLAP [QCDNUM package], RT scheme
  - Fitted PDFs:
    - uval, dval, g, Ubar=ubar+cbar, Dbar=dbar+sbar
      - » Sea=Ubar+Dbar
      - » sbar=s=fsDbar=dbar fs/(1-fs)
        with fs=0.31 at starting scale

$$
\begin{aligned}
xg(x) &= A_g x^{B_g}(1-x)^{C_g}(1+D_g x)\,, \\
xu_v(x) &= A_{u_v} x^{B_{u_v}}(1-x)^{C_{u_v}}(1+E_{u_v}x^2)\,, \\
xd_v(x) &= A_{d_v} x^{B_{d_v}}(1-x)^{C_{d_v}}\,, \\
x\bar{U}(x) &= A_{\bar{U}} x^{B_{\bar{U}}}(1-x)^{C_{\bar{U}}}\,, \\
x\bar{D}(x) &= A_{\bar{D}} x^{B_{\bar{D}}}(1-x)^{C_{\bar{D}}}\,.
\end{aligned}
$$

- Impose the fermion and momentum sum rules
- One B parameter for sea and one for valence

Gluon Saturation at Low x?



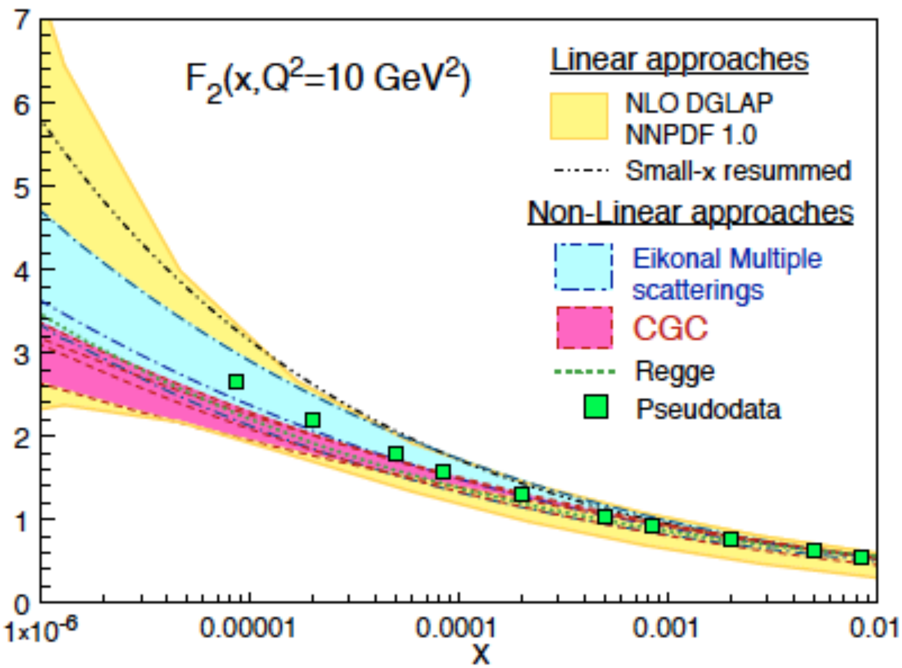


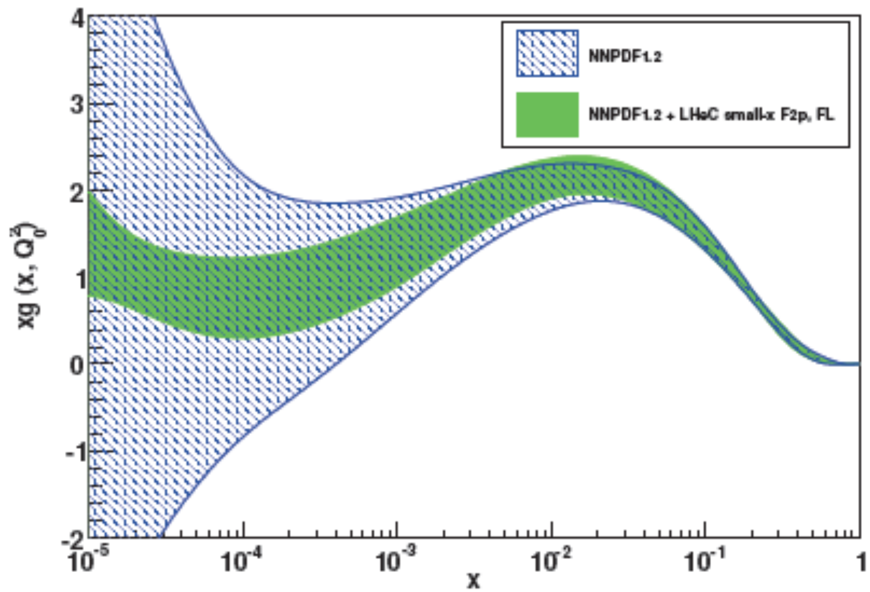
Gluon measurement down to $x=10^{-5}$, **Saturation or no saturation** (F_2 and precise F_L)
Non-linear evolution equations? Relations to string theory, and **SUSY at ~10 TeV**?

cf H.Kowalski, L.Lipatov, D.Ross, arXiv:1205.6713

Partons at low x

Studies within NNPDF (CDR 8/12)





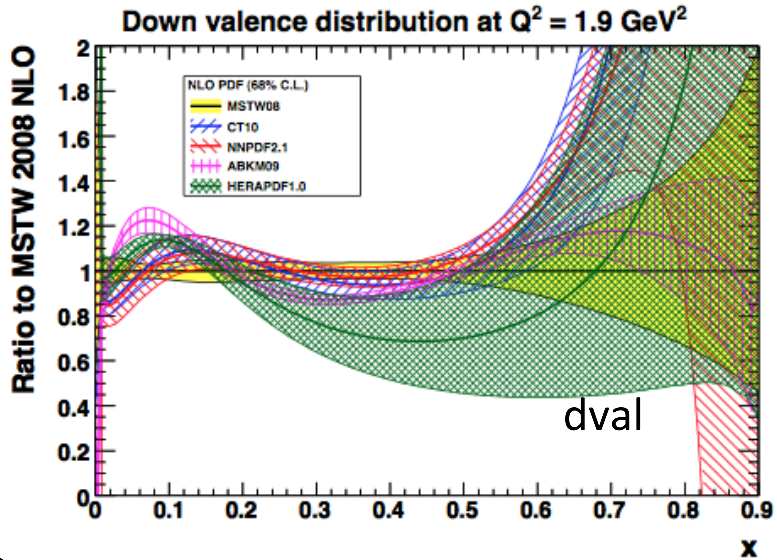
High precision F_2 and F_L pin down low x phenomenology and determine the gluon distribution down to $x \sim 10^{-5}$

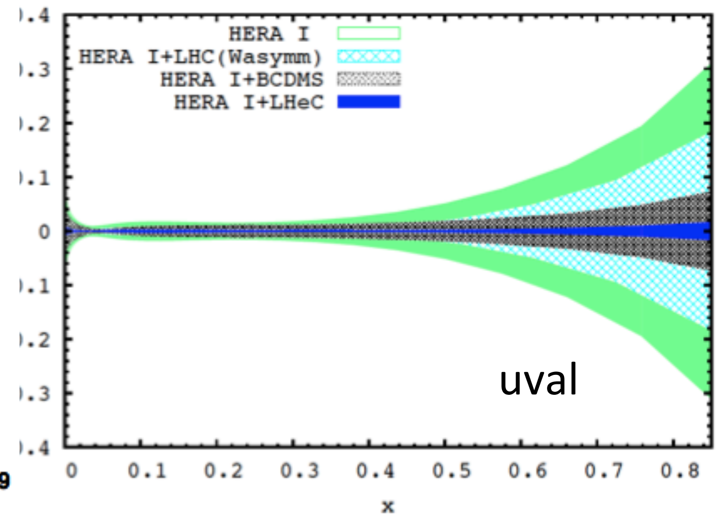
Valence quark distributions

Now…

…Then

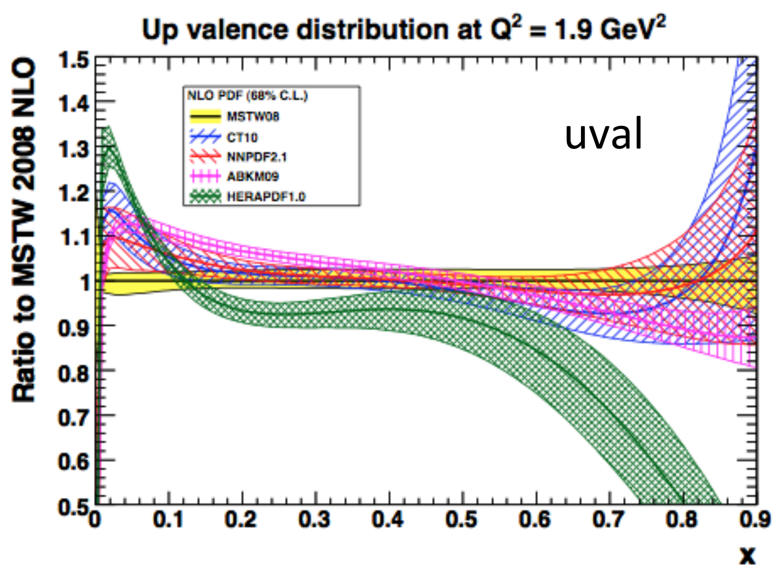
Current knowledge is limited at high x:
- Lumi barrier
- challenging systematic
- nuclear effects
- Effects of higher twists

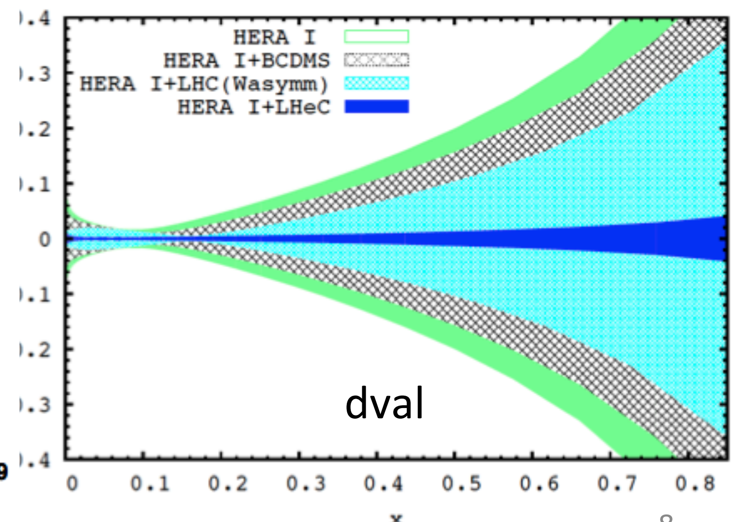




LHeC could improve the knowledge of the valence at high x to a precision of:
- 2% (uval) x=0.8
- 4% (dval) x=0.8

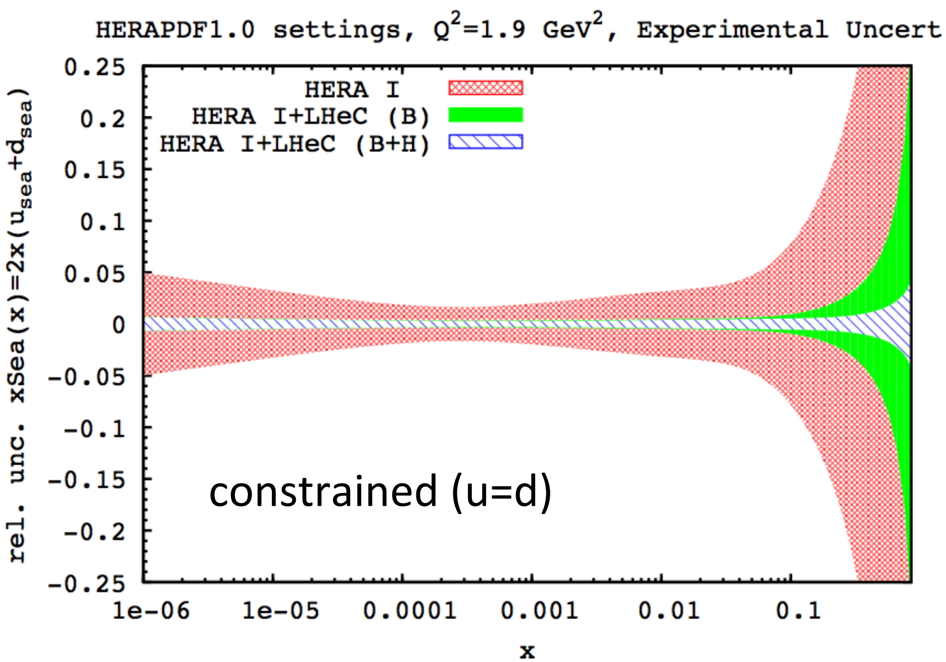
Important for d/u limit clarification

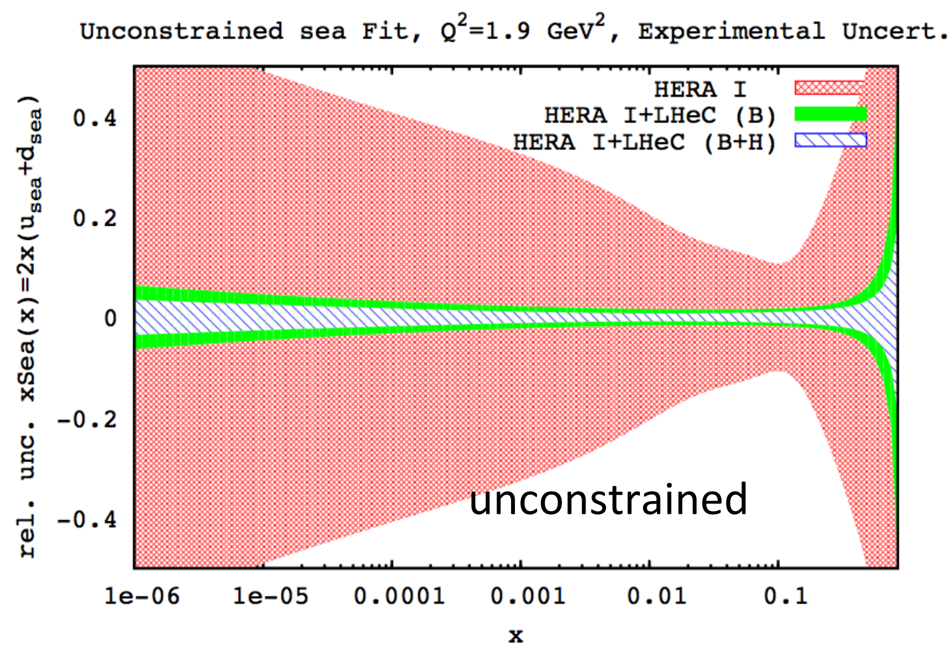




Unconstrained setting at low x

- Usual assumptions for light quark decomposition at low x may not necessary hold.
- Relaxing the assumption at low x that **u=d** , we observe that uncertainties escalate:

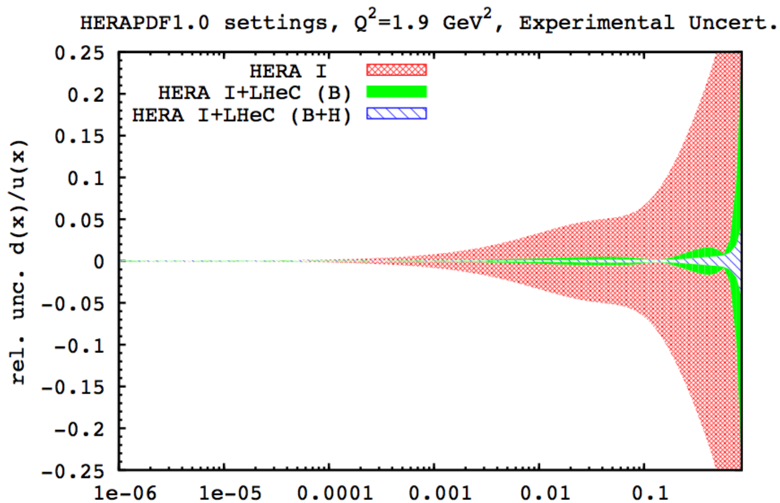


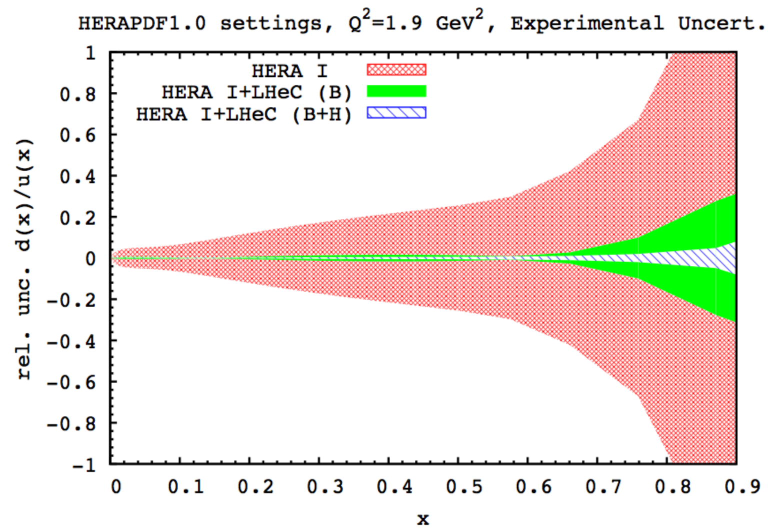


- One can see that for HERA data, if we relax the low x constraint on u and d,the errors are increased tremendously!
- However, when adding the LHeC simulated data, we observe that uncertainties are visibly improved even without this assumption.
- Further important cross check comes from the deuteron measurements, with tagged spectator and controlling shadowing with diffraction [see tomorrow LHeC talks]

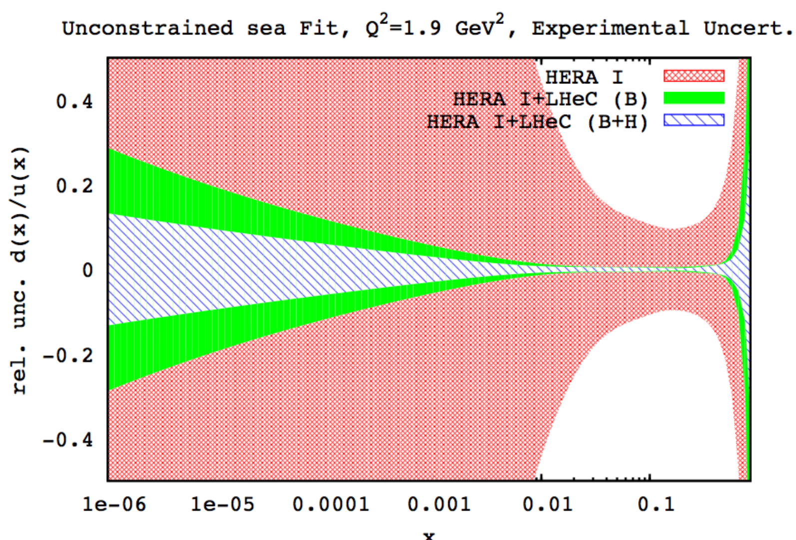
Impact on d/u ratios

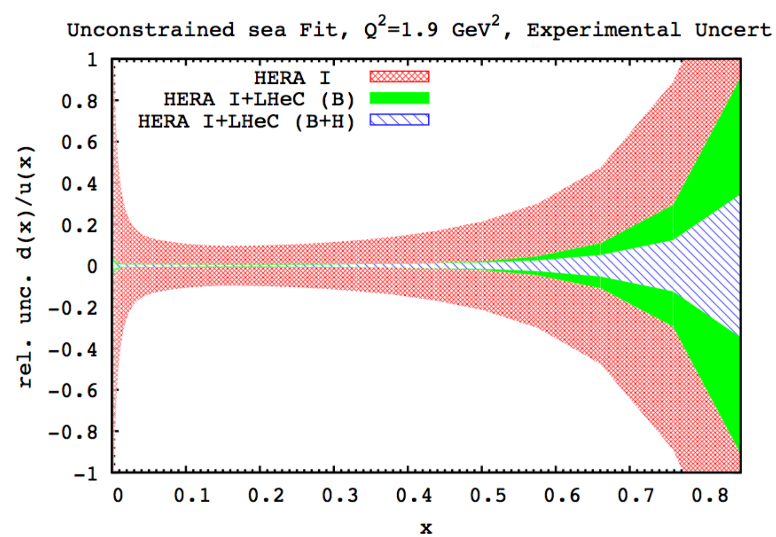
- Constrained decomposition:





- Unconstrained sea decomposition:





Releasing further PDF constraints

- Releasing further the assumptions:

$$
\begin{aligned}
xg(x) &= A_g x^{B_g}(1-x)^{C_g}(1+D_g x), \\
xu_v(x) &= A_{u_v} x^{B_{u_v}}(1-x)^{C_{u_v}}(1+E_{u_v}x^2), \\
xd_v(x) &= A_{d_v} x^{B_{d_v}}(1-x)^{C_{d_v}}, \\
x\bar{U}(x) &= A_{\bar{U}} x^{B_{\bar{U}}}(1-x)^{C_{\bar{U}}}, \\
x\bar{D}(x) &= A_{\bar{D}} x^{B_{\bar{D}}}(1-x)^{C_{\bar{D}}}.
\end{aligned}
$$

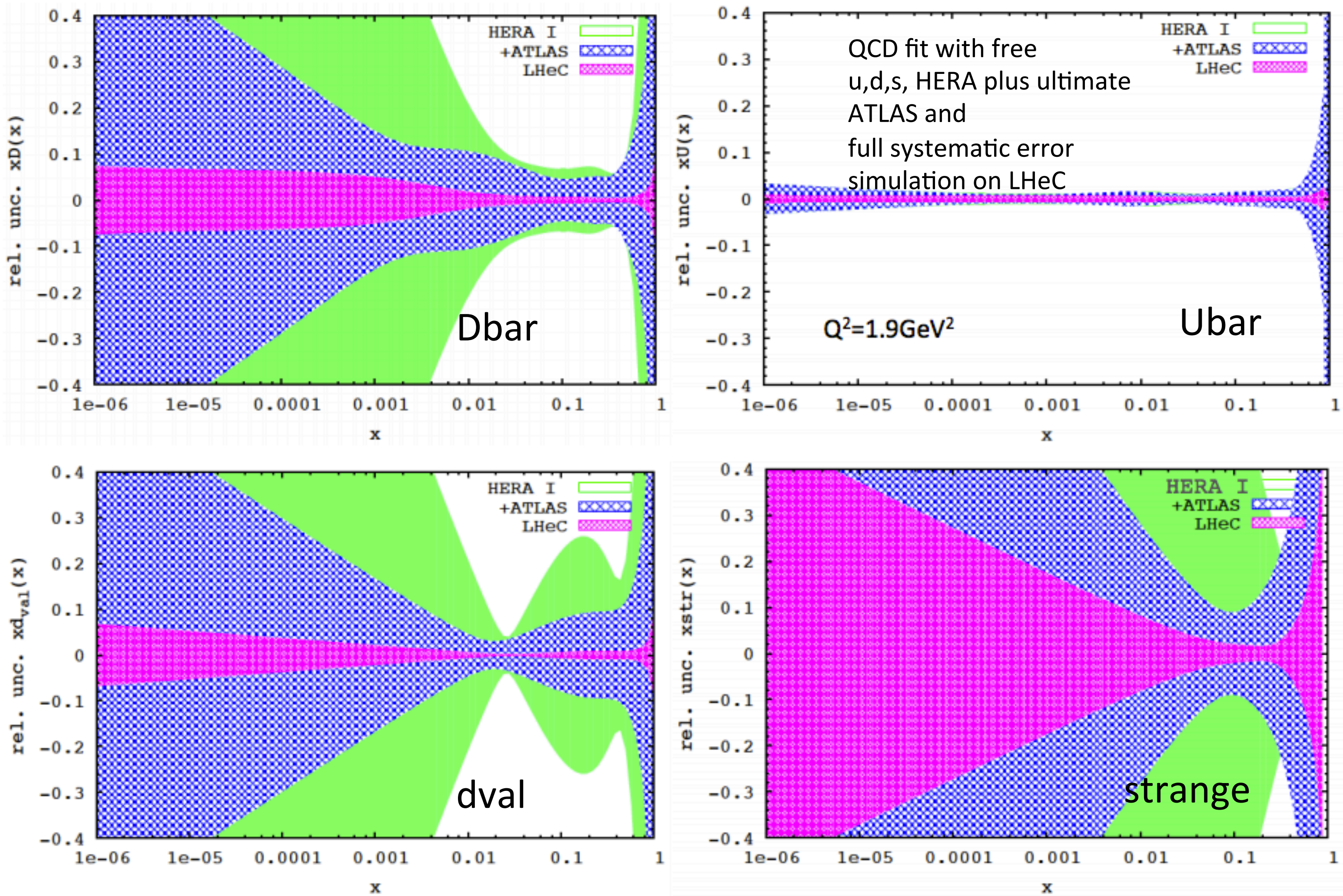
→

$$
\begin{aligned}
xg(x) &= A_g x^{B_g}(1-x)^{C_g}(1+D_g x), \\
xu_v(x) &= A_{u_v} x^{B_{u_v}}(1-x)^{C_{u_v}}(1+E_{u_v}x^2), \\
xd_v(x) &= A_{d_v} x^{B_{d_v}}(1-x)^{C_{d_v}}, \\
x\bar{u}(x) &= A_{\bar{u}} x^{B_{\bar{u}}}(1-x)^{C_{\bar{u}}}, \\
x\bar{d}(x) &= A_{\bar{d}} x^{B_{\bar{d}}}(1-x)^{C_{\bar{d}}}, \\
xs(x) &= r_s A_s x^{B_s}(1-x)^{C_s}
\end{aligned}
$$

  - Removing the correlation that ubar=dbar at low x
  - Free parameters for the strange quark are introduced

  - This study was driven by the recent ATLAS results on strange determination, hence we have repeated the impact of LHeC study under the new conditions.

Releasing assumptions

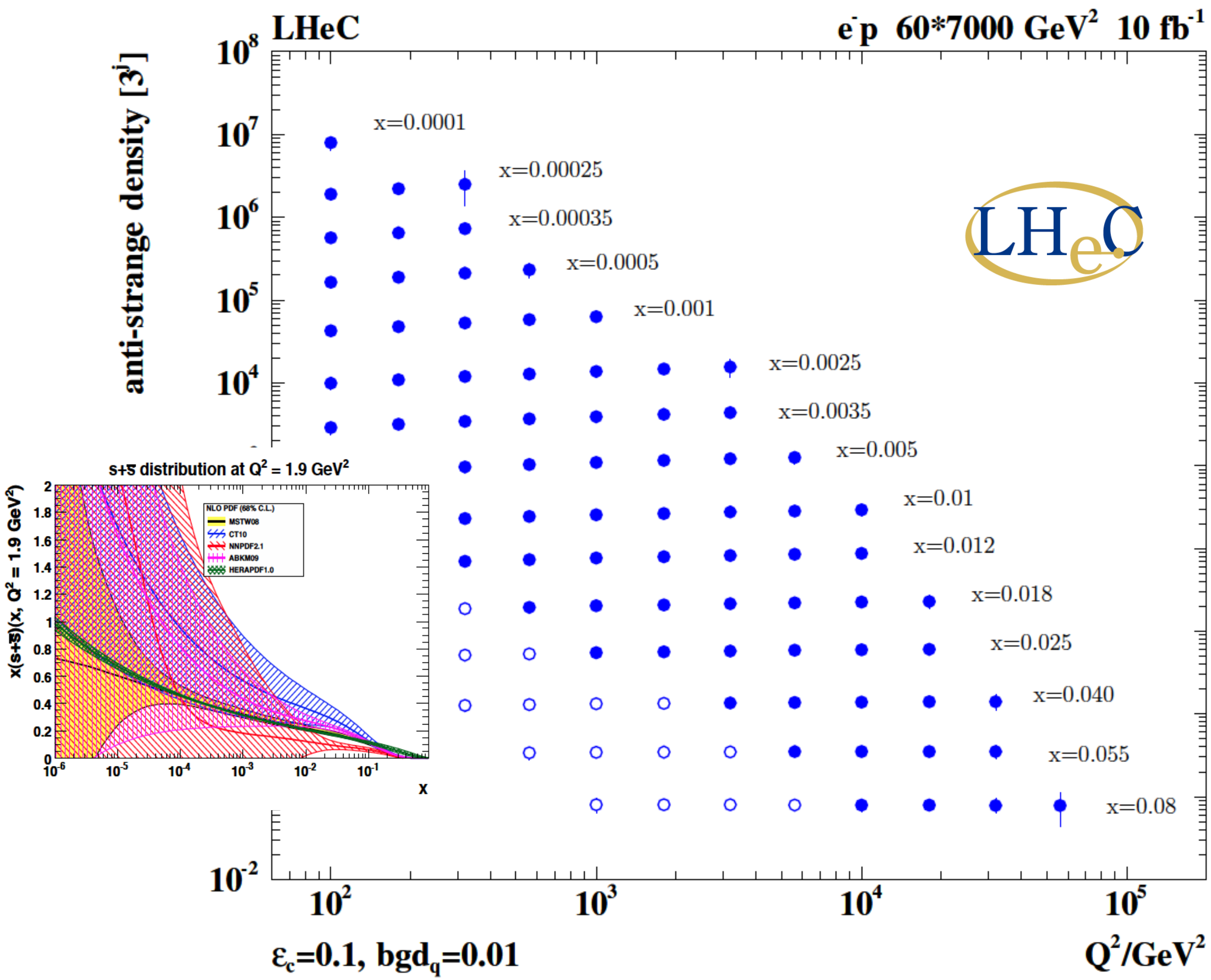


Inclusive LHeC data leads to very precise determination of all PDFs even after removing large bulk of assumptions:

LHeC ep data constrain better U than D distributions, however deuteron data would symmetrise our understanding.

Determination of the strange can complement the strange determination from the charm data

Strange Quark Distribution



High luminosity

High Q^2

Small beam spot

Modern Silicon

NO pile-up..

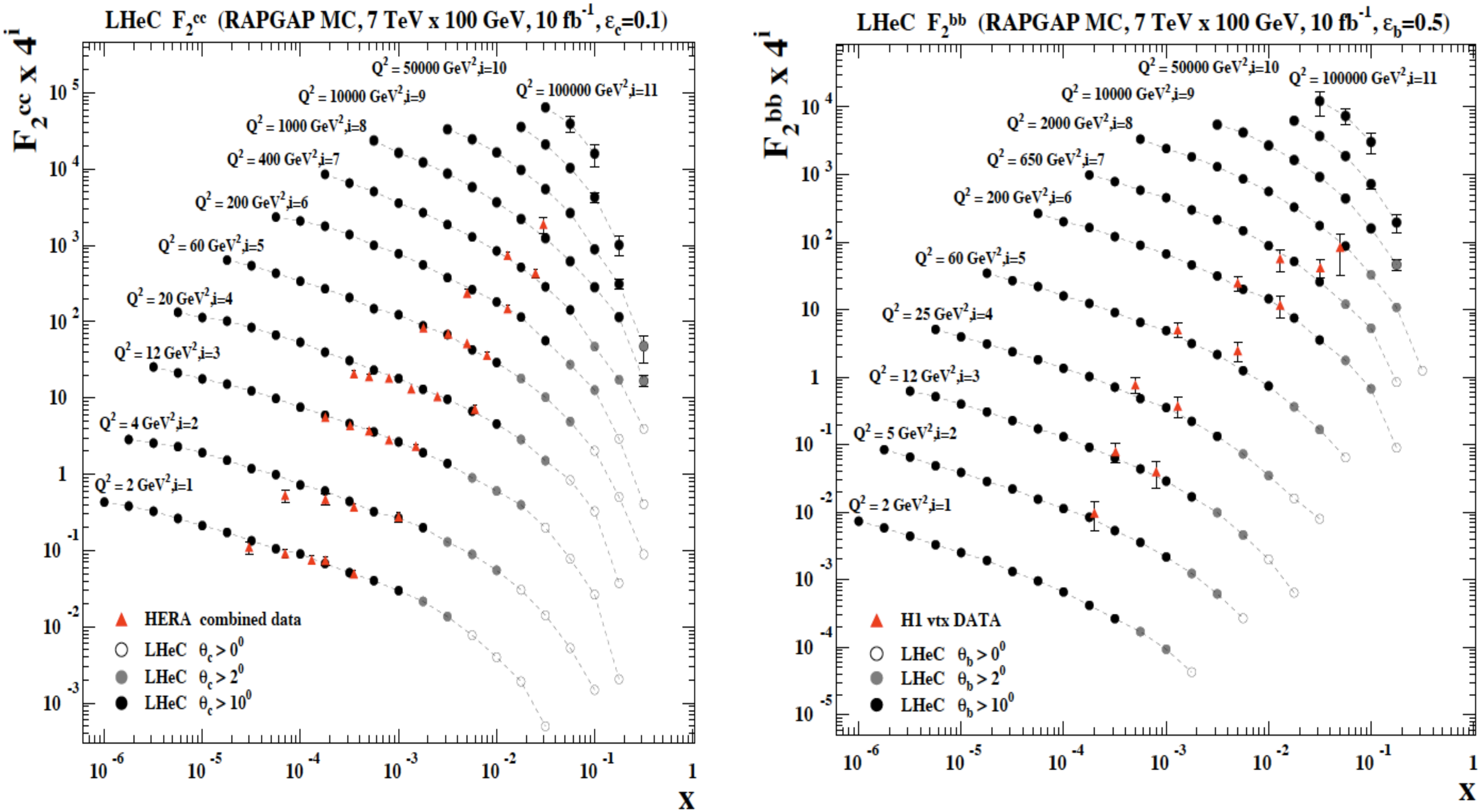
→ First (x,Q^2) measurement of the (anti-)strange density, HQ valence?

$x = 10^{-4}$ .. 0.05
$Q^2 = 100 - 10^5$ GeV^2

JPhysG 39(2012)7

Initial study (CDR): Charm tagging efficiency of 10% and 1% light quark background in impact parameter

F_2^{charm} and F_2^{beauty} from LHeC



Hugely extended range and much improved precision (δM_c=60 HERA → 3 MeV)
will pin down heavy quark behaviour at and far away from thresholds, crucial for precision t,H..
In MSSM, Higgs is produced dominantly via bb → H , but where is the MSSM..

Further studies ("New")

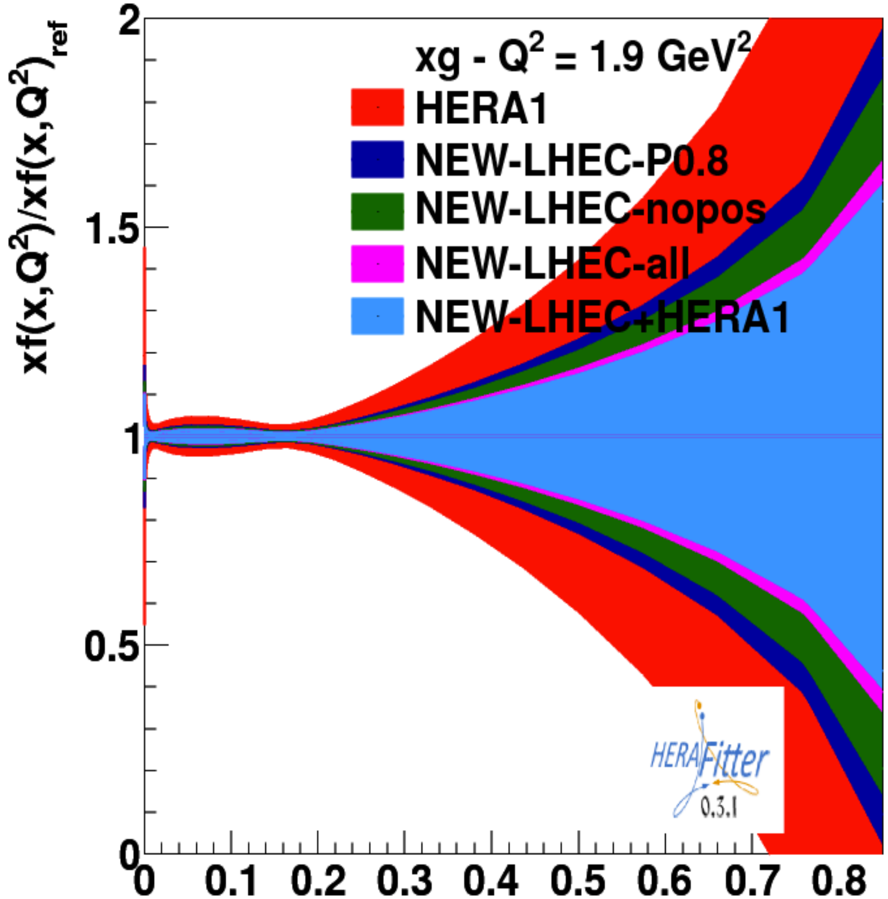
The ERL configuration does not provide polarised positrons at comparable L
The interest in the Higgs prefers electrons with negative, high polarisation:

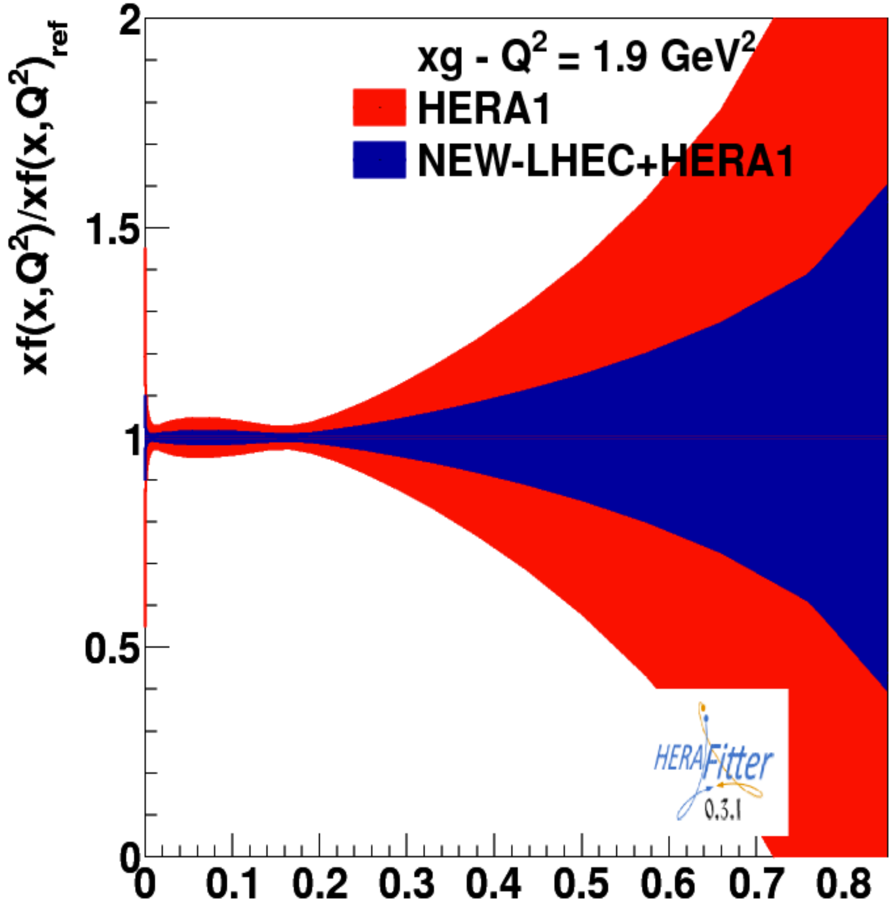
all for ep: Ee=60 GeV, Ep=7000GeV, MSTWLO

acronym	charge	polarisation	luminosity (fb-1)
mimi	-	-0.8	500
mipl	-	+0.8	50
plnu	+	0	5

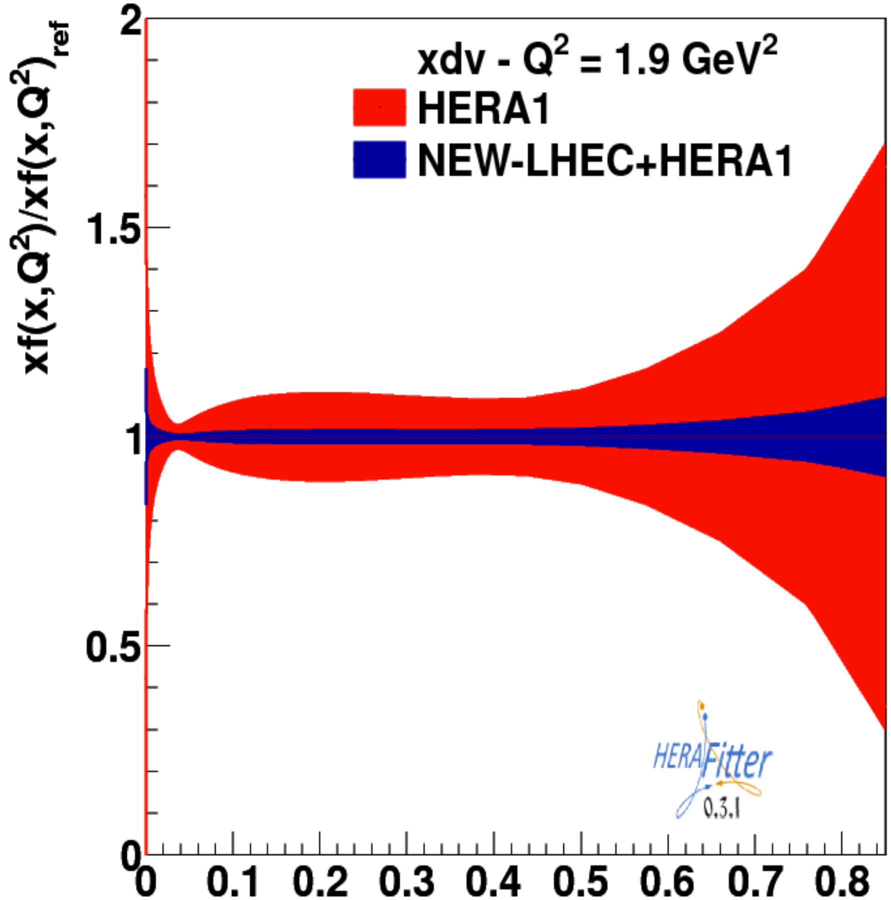
Not (yet) included low E_p data (important for high x) nor low E_e (F_L)

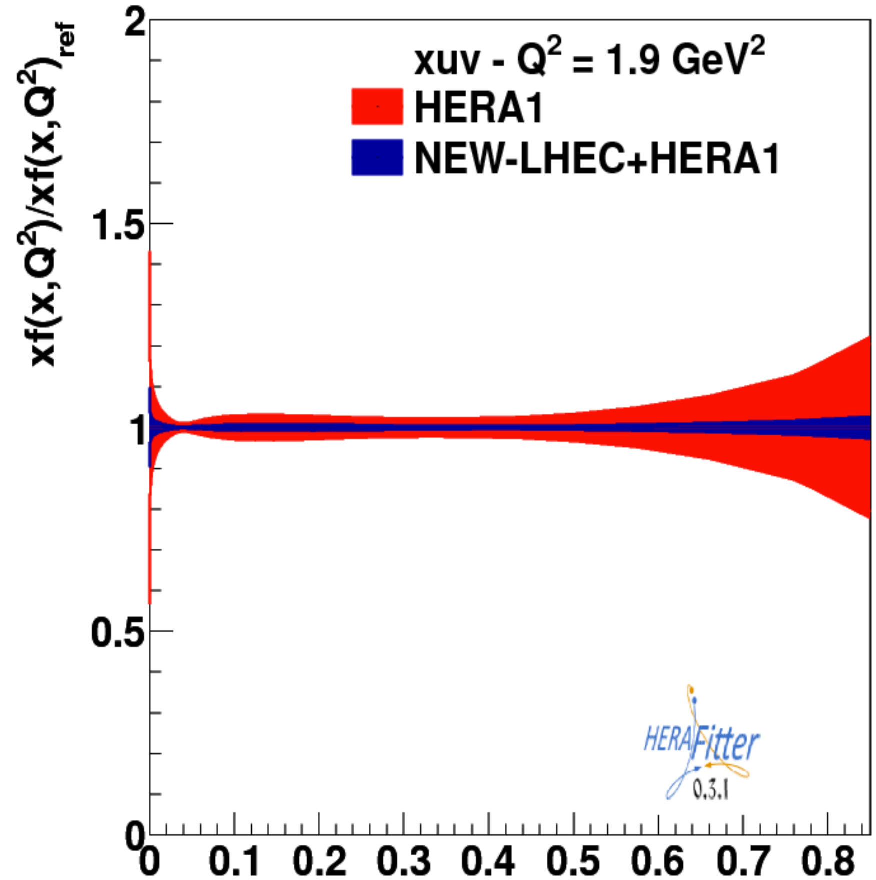
PDF Uncertainties high x - Gluon



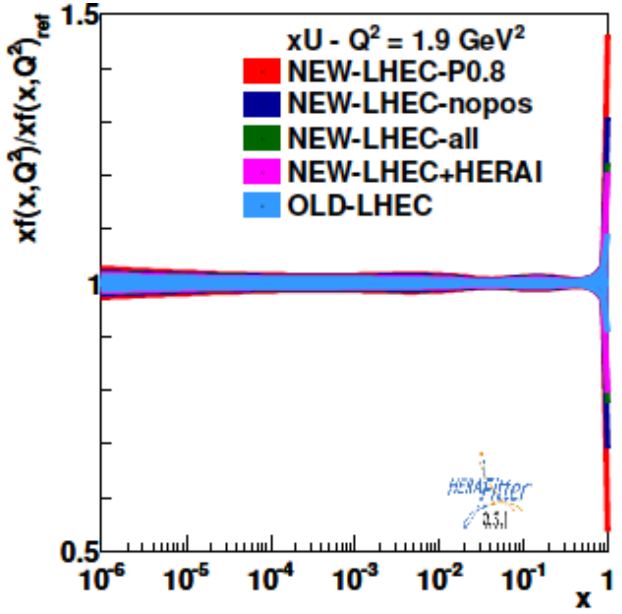


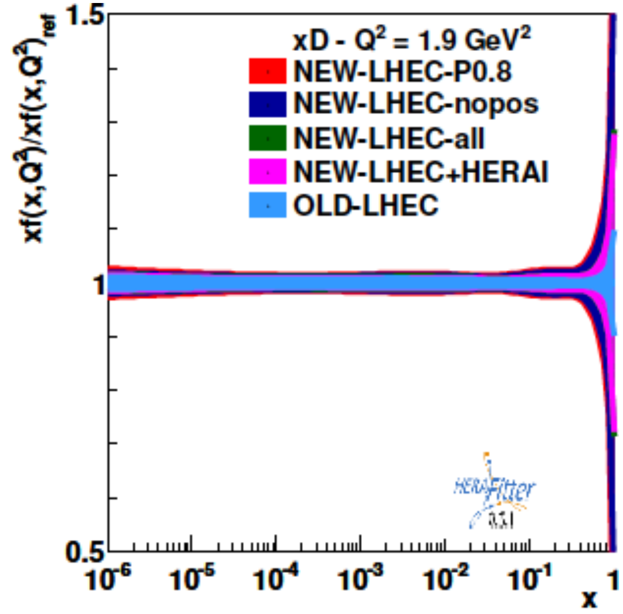
PDF Uncertainties high x - Valence

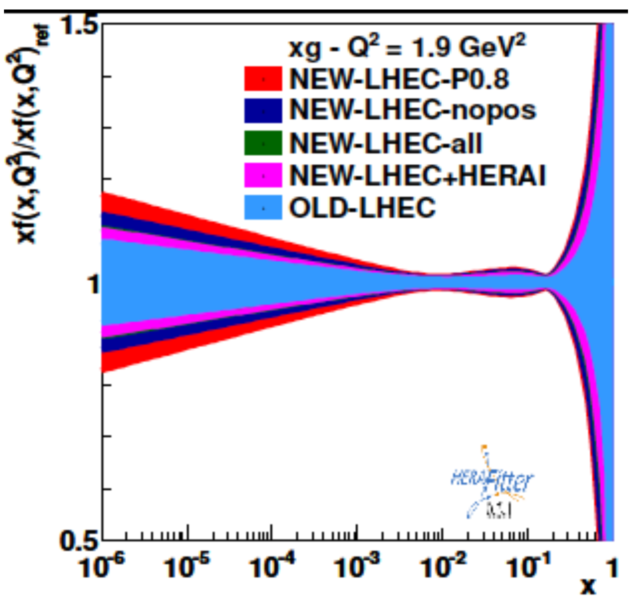


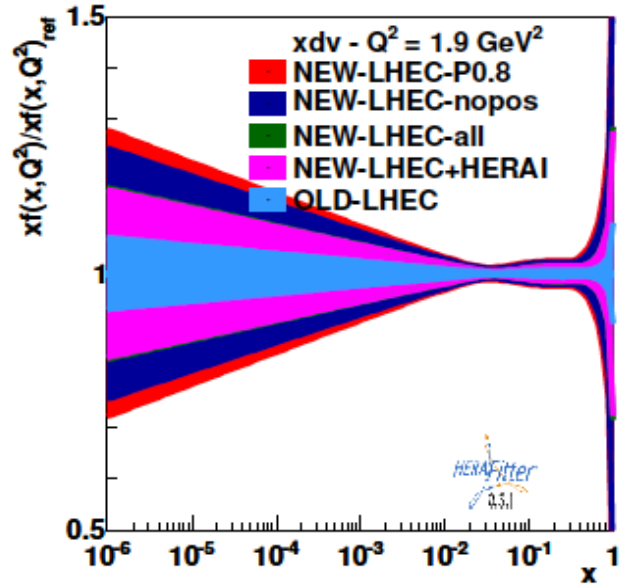


Further initial results









Next steps:

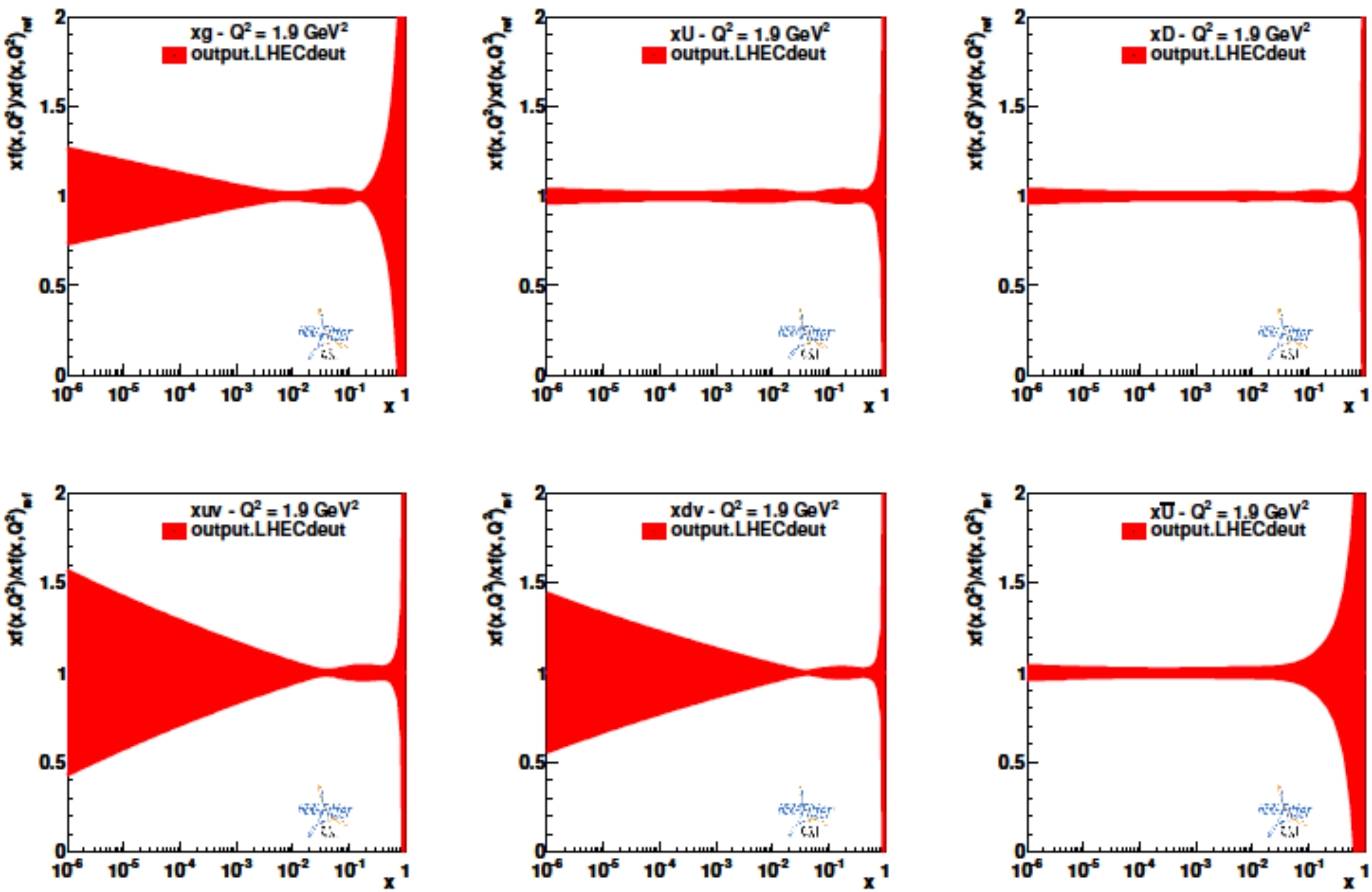
include low Ep

also consider FL

and eD + ep

First, standalone eD data fits

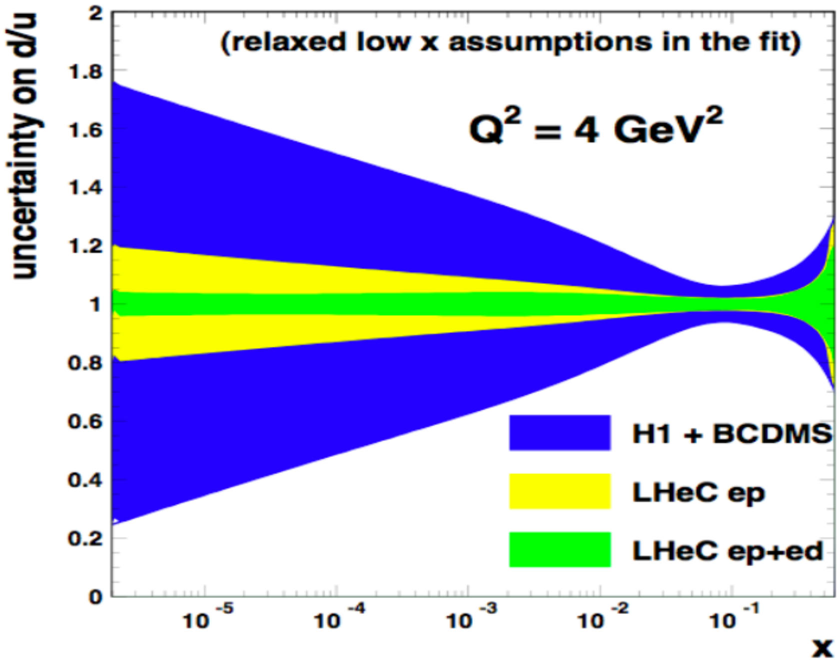
3.5 TeV x 60 GeV, e-, P=-0.8, 1fb-1 Neutral and Charged Current, exp uncertainties



Future fit of jointly ep and eD data will lead to precise unfolding of u-d

Deuterons and Light Sea Quark Asymmetry

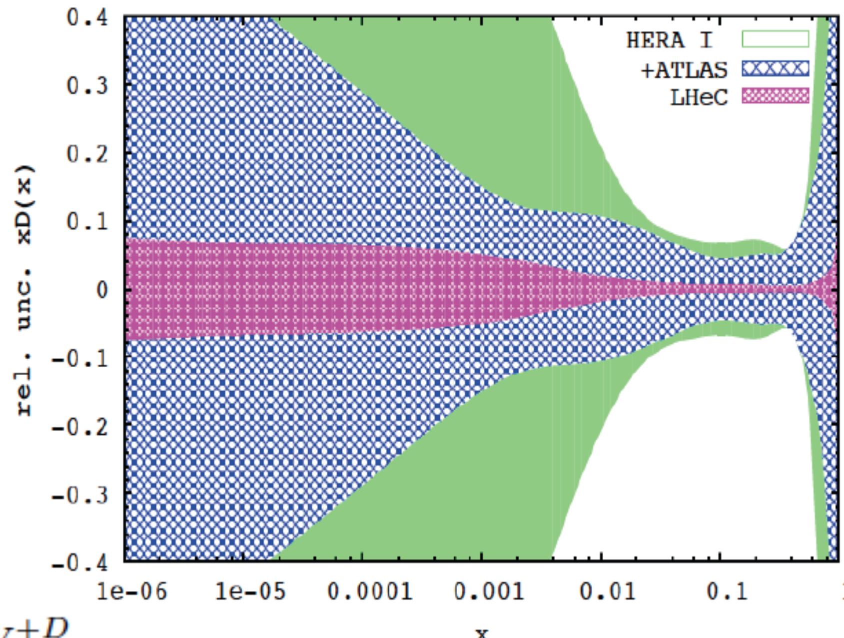
d/u at low x from deuterons



From 2007 LHeC paper: E.Perez et al.

D="total down" from LHeC (ep) fit with FREE d-u difference, including simulated high precision LHC W,Z

CDR



Deuterons: Crucial for

- NS-S decomposition
- Neutron structure
- Flavour separation

$$R^- = 2\frac{W_2^{-D} - W_2^{+D}}{W_2^{-p} + W_2^{+p}}$$

Nice: Gribov relation and spectator tagging to get rid off shadowing and Fermi motion!!

Summary

With the LHeC the determination of the PDFs, quarks and gluons, will be put on a completely new base:

- Determination of all quark PDFs, including d/u, s, c, b
- Mapping of the gluon distribution from nearly 10^{-5} to x=1
- Determination of the strong coupling to permille level (CDR)

This puts severe requirements to detector design, precision of tracking and calorimetry in large acceptance and to QCD.

Besides the classic PDFs, the LHeC provides much further insight to photon, neutron, nuclear, Pomeron structure and to the extension of the collinear approximation to generalised PDs.

Further studies are envisaged (data optimisation, role of e+, d..)

backup

The strong coupling "constant"

Method	Current relative precision		Future relative precision
e^+e^- evt shapes	expt $\sim 1\%$ (LEP) thry $\sim 3\%$ (NNLO+NLL, n.p. signif.)	[24]	$< 1\%$ possible (ILC/TLEP) $\sim 1.5\%$ (control n.p. via Q^2-dep.)
e^+e^- jet rates	expt $\sim 2\%$ (LEP) thry $\sim 1\%$ (NNLO, n.p. moderate)	[25]	$< 1\%$ possible (ILC/TLEP) $\sim 0.5\%$ (NLL missing)
precision EW	expt $\sim 3\%$ (R_Z, LEP) thry $\sim 0.5\%$ (N^{3}LO, n.p. small)	[26, 7]	0.1% (TLEP [8]), 0.5% (ILC [9]) $\sim 0.3\%$ (N^{4}LO feasible, $\sim$ 10 yrs)
τ decays	expt $\sim 0.5\%$ (LEP, B-factories) thry $\sim 2\%$ (N^{3}LO, n.p. small)	[6]	$< 0.2\%$ possible (ILC/TLEP) $\sim 1\%$ (N^{4}LO feasible, $\sim$ 10 yrs)
ep colliders	$\sim$ 1–2% (pdf fit dependent) (mostly theory, NNLO)	[27, 28, 29, 30]	0.1% (LHeC + HERA [21]) $\sim 0.5\%$ (at least N^{3}LO required)
hadron colliders	$\sim 4\%$ (Tev. jets), $\sim 3\%$ (LHC $t\bar{t}$) (NLO jets, NNLO $t\bar{t}$, gluon uncert.)	[15, 19, 31]	$< 1\%$ challenging (NNLO jets imminent [20])
lattice	$\sim 0.5\%$ (Wilson loops, correlators, ...) (limited by accuracy of pert. th.)	[32, 33, 34]	$\sim 0.3\%$ ($\sim$ 5 yrs [35])

Table 1-1. *Summary of current uncertainties in extractions of $\alpha_s(M_Z)$ and targets for future (5 − 25 years) determinations. For the cases where theory uncertainties are considered separately, the theory uncertainties for future targets reflect a reduction by a factor of about two.*

Snowmass QCD WG report 9/2013

Prospects to measure $\alpha_s(M_Z^2)$ to per mille precision with future ep and ee colliders
Important for gauge unification, precision Higgs at LHC, and to overcome the past..

The strong coupling constant

	$\alpha_s(M_Z)$	
BBG	$0.1134\ ^{+0.0019}_{-0.0021}$	valence analysis, NNLO [235, 236]
BB	0.1132 ± 0.0022	valence analysis, NNLO [237]
GRS	0.112	valence analysis, NNLO [238]
ABKM	0.1135 ± 0.0014	HQ: FFNS $n_f = 3$ [228]
ABKM	0.1129 ± 0.0014	HQ: BSMN-approach [228]
JR	0.1124 ± 0.0020	dynamical approach [231]
JR	0.1158 ± 0.0035	standard fit [231]
ABM11	0.1134 ± 0.0011	[229]
MSTW	0.1171 ± 0.0014	[239]
NN21	0.1173 ± 0.0007	[233]
CT10	0.118 ± 0.005	[240]
Gehrmann et al.	$0.1153 \pm 0.0017 \pm 0.0023$	e^+e^- thrust [241]
Abbate et al.	$0.1135 \pm 0.0011 \pm 0.0006$	e^+e^- thrust [242]
3 jet rate	0.1175 ± 0.0025	Dissertori et al. 2009 [243]
Z-decay	0.1189 ± 0.0026	BCK 2008/12 (N^3LO) [121, 244]
τ decay	0.1212 ± 0.0019	BCK 2008 [244]
τ decay	0.1204 ± 0.0016	Pich 2011 [20]
τ decay	0.1180 ± 0.0008	Beneke, Jamin 2008 [245]
lattice	0.1205 ± 0.0010	PACS-CS 2009 (2+1 fl.) [246]
lattice	0.1184 ± 0.0006	HPQCD 2010 [247]
lattice	0.1200 ± 0.0014	ETM 2012 (2+1+1 fl.) [248]
BBG	$0.1141\ ^{+0.0020}_{-0.0022}$	valence analysis, $N^3LO(^*)$ [235]
BB	0.1137 ± 0.0022	valence analysis, $N^3LO(^*)$ [237]
world average	0.1184 ± 0.0007	[249] (2009)
	0.1183 ± 0.0010	[20] (2011)

α_s is the worst measured fundamental coupling constant.
Is there grand unification?

In DIS, values (NNLO) range from 0.113 to 0.118.

τ leads to about 0.120

Lattice predictions seem to determine the world average.

The LHeC has the potential to measure αs to permille accuracy (0.0002) from a consistent data set. This leads to high precision understanding of all related effects (low x, δM_c=3MeV) and pQCD at N^3LO

J.Bluemlein, Why Precision, arXiv:1205.4991