PDFs with the LHeC*

Quarks
Gluon
α_s
eA
Detector
Status

Max Klein
ATLAS and H1

For the LHeC Study Group

LPCC Workshop, CERN, 1.8.11

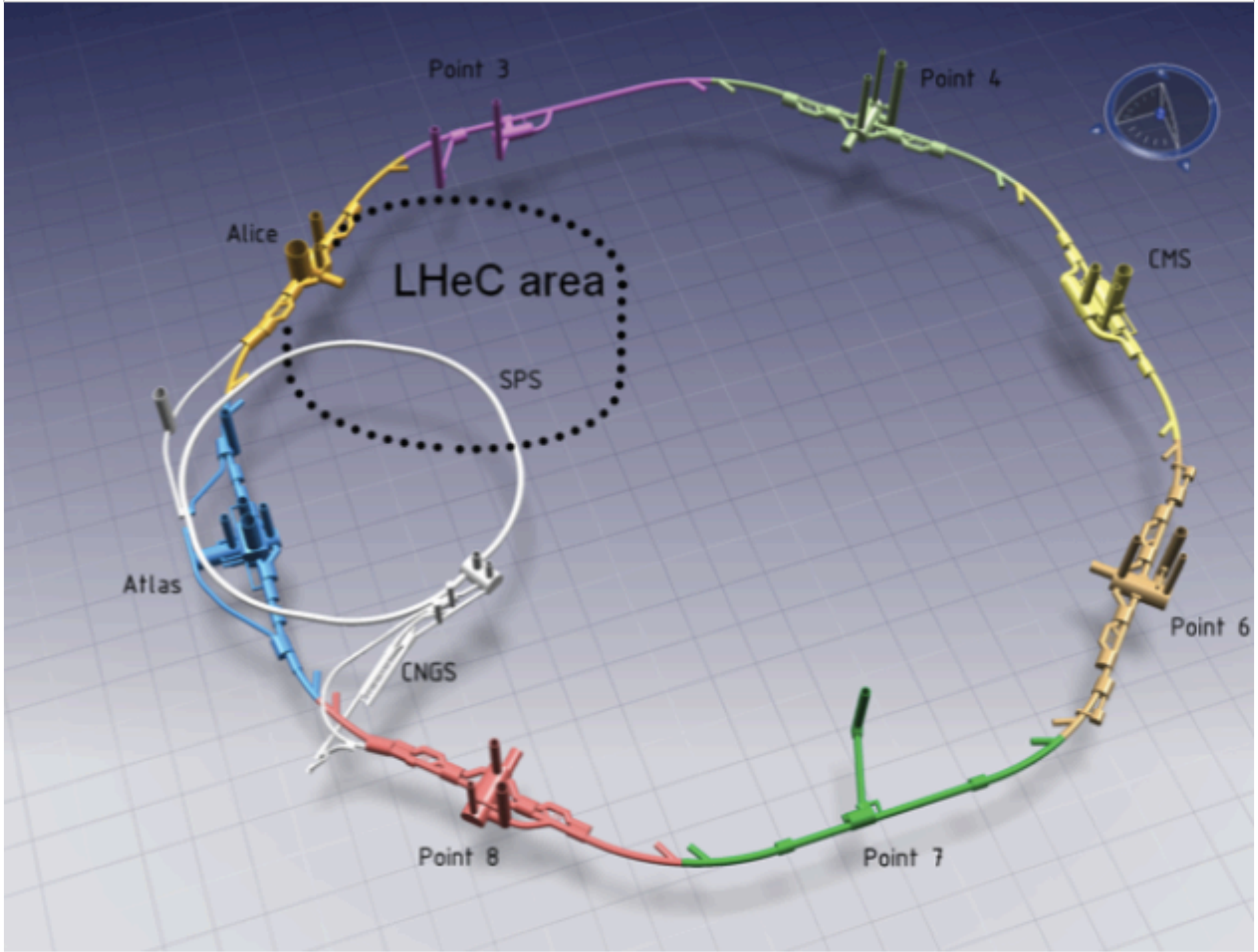
http://cern.ch/lhec

*) work in progress – based on draft CDR

60GeV E_e, 100 x HERA Luminosity, Ring or Linac, $e^{\pm}$(P) off p, N=D, Pb, Ar after LS3

CERN, ECFA, NuPECC (long range plane 2010). CDR this year. 150 authors, 50 institutes

Wide physics programme often complementary to LHC and LC. Here PDFs “only”



Valence quarks

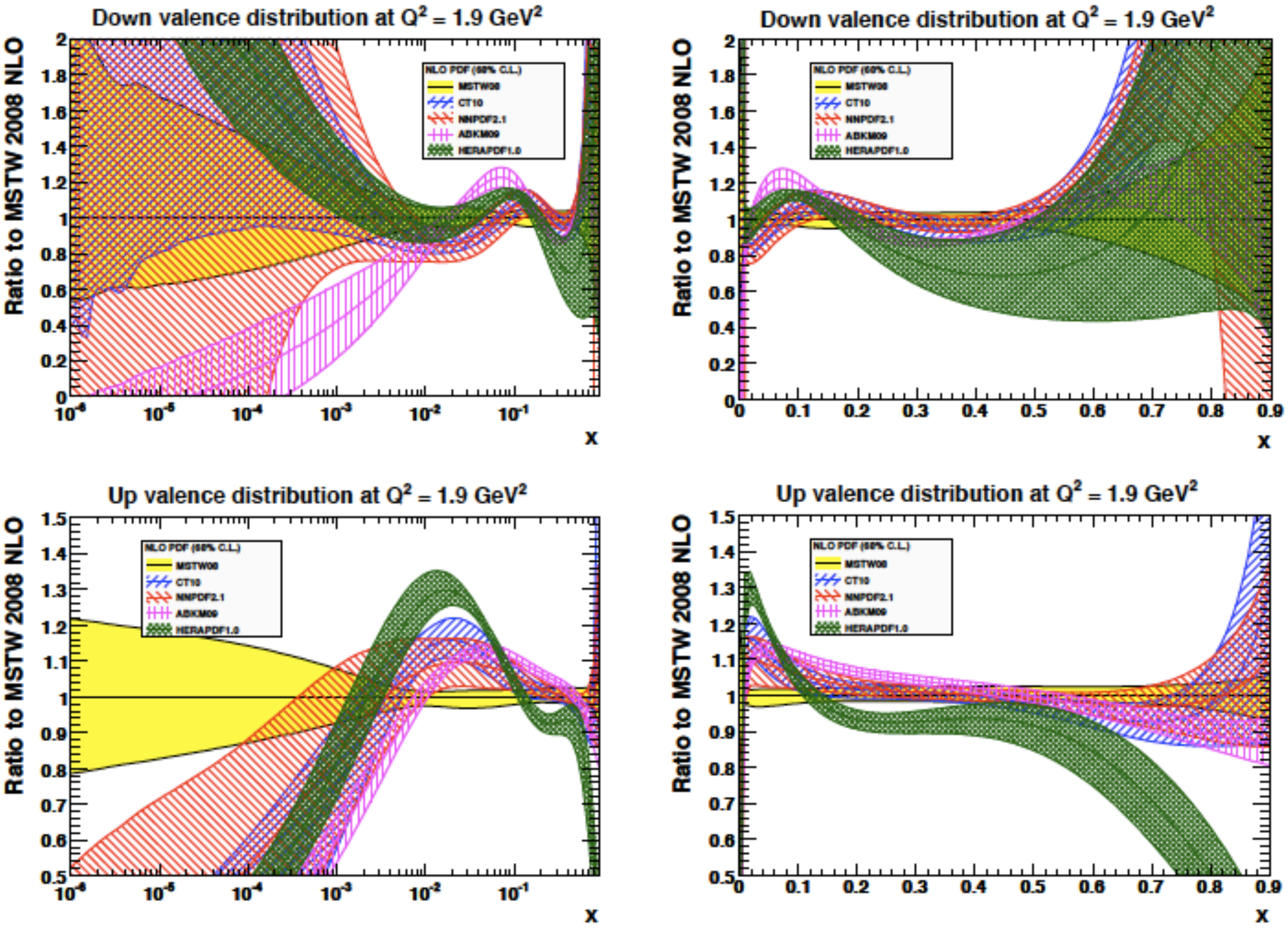
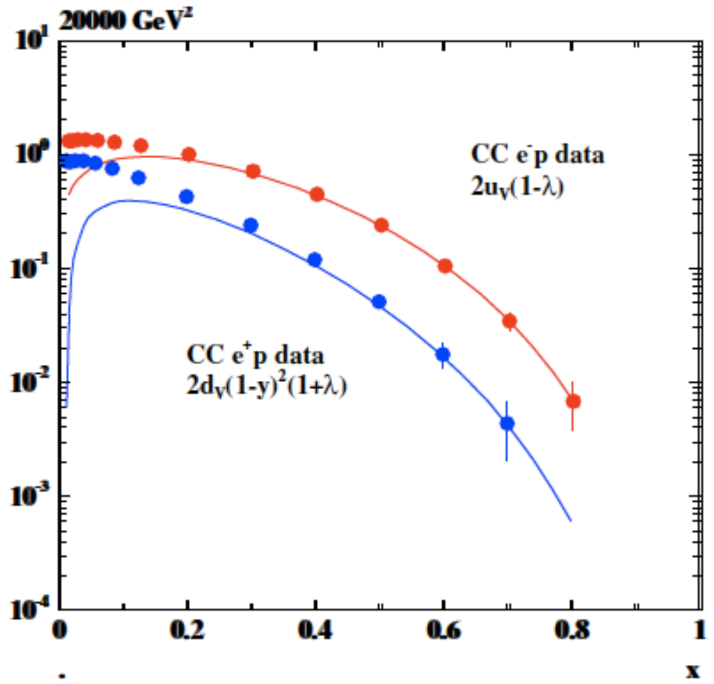
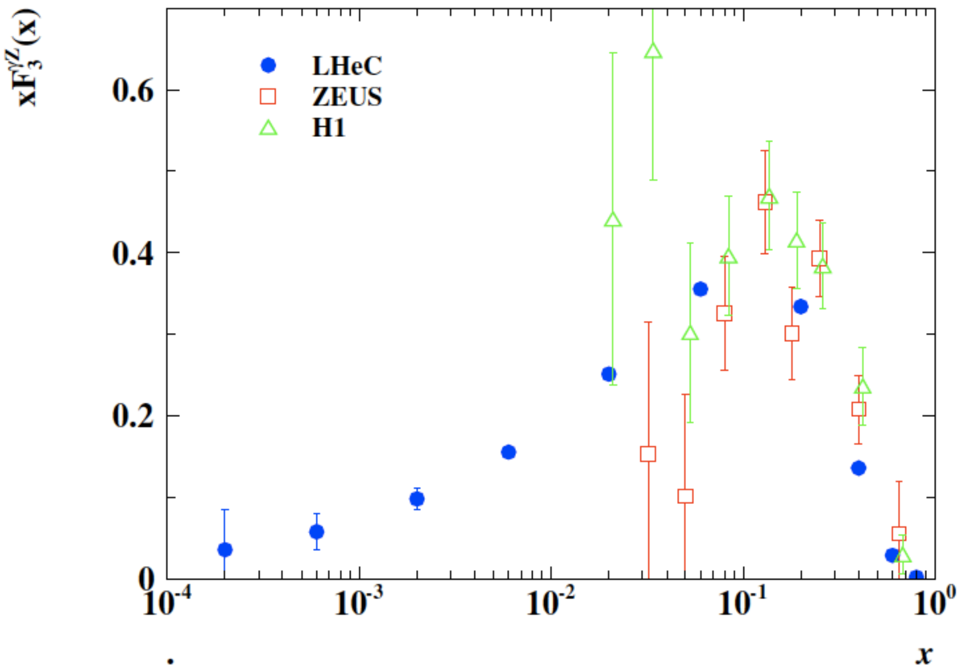


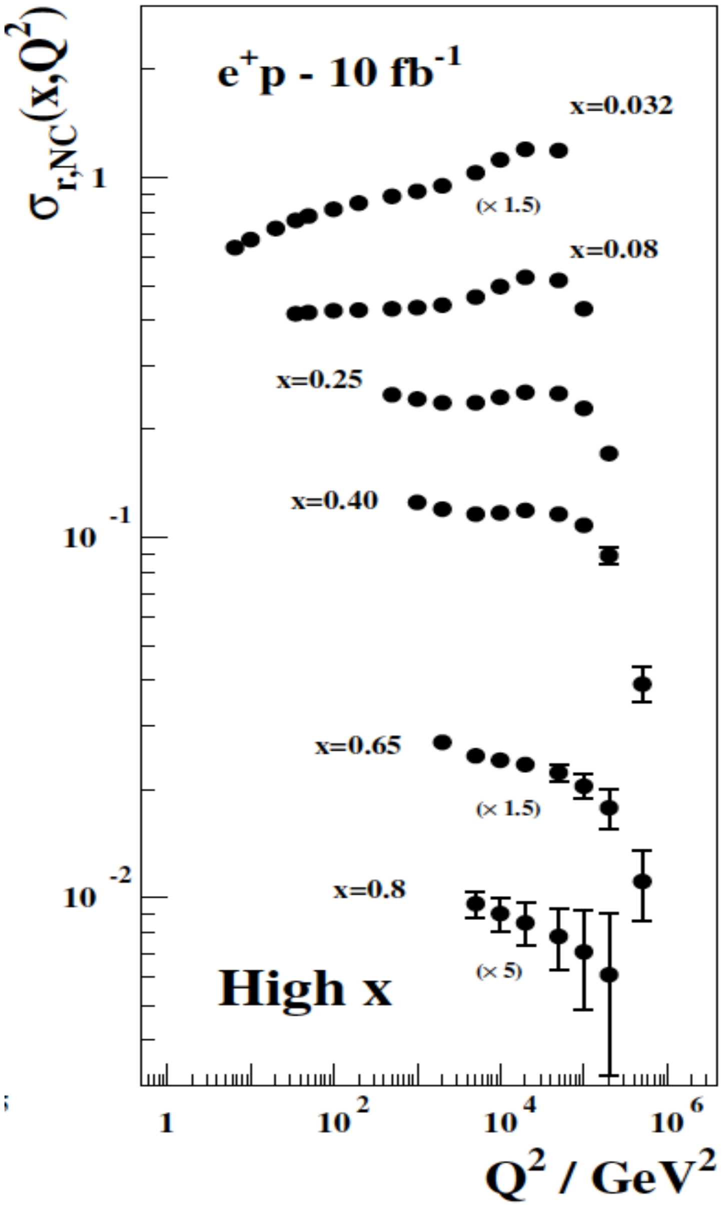
Figure 4.7: Ratios (to MSTW08) and uncertainty bands of valence quark distributions, at $Q^2 = 1.9\,\mathrm{GeV}^2$, for most of the available recent PDF determinations. Top: up valence quark; down: down valence quark; left: logarithmic x, right: linear x.

Valence quark input





CC
NC
yZ



Valence quarks

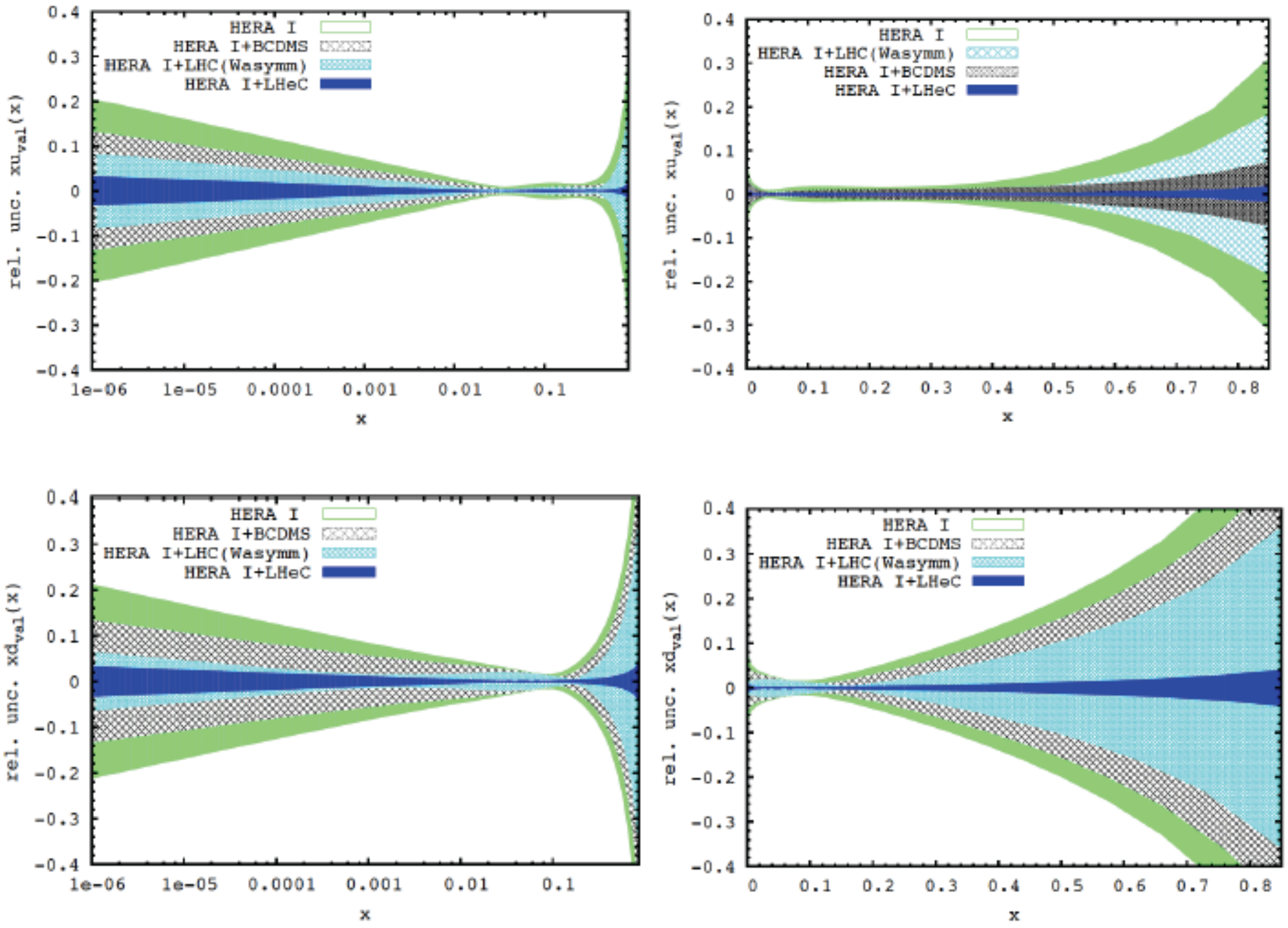


Figure 4.8: Uncertainty of valence quark distributions, at $Q^2 = 1.9\,\mathrm{GeV}^2$, as resulting from an NLO QCD fit to HERA (I) alone (green, outer), HERA and BCDMS (crossed), HERA and LHC (light blue, crossed) and the LHeC added (blue, dark). Top: up valence quark; down: down valence quark; left: logarithmic x, right: linear x.

Strange Quarks

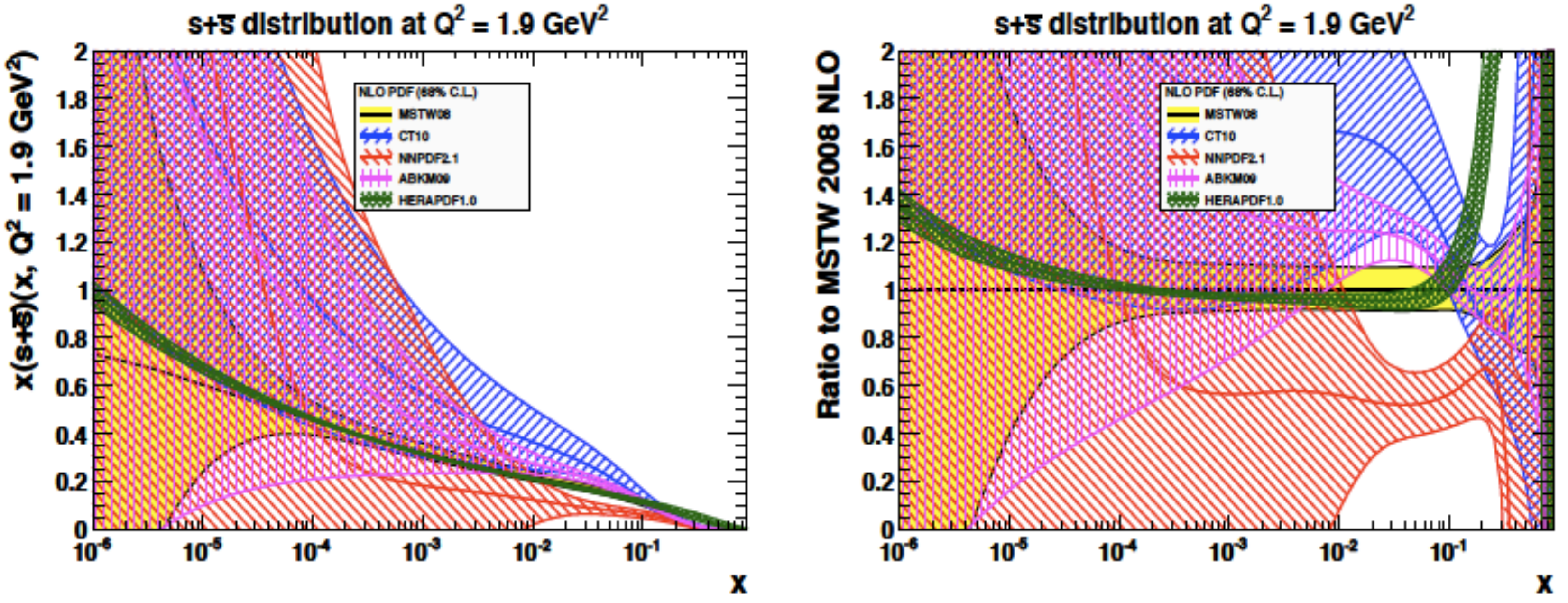
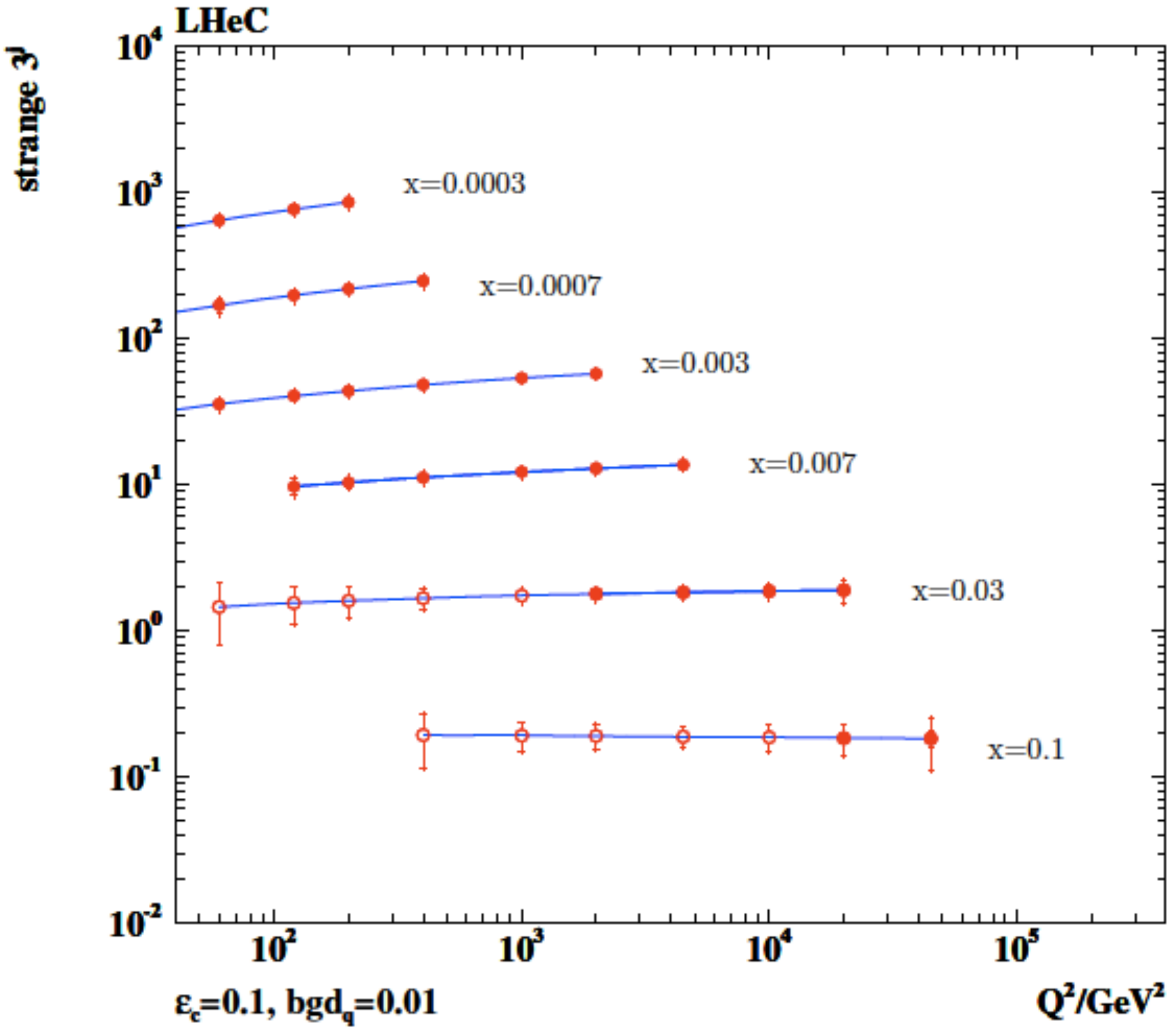


Figure 4.11: Sum of the strange and anti-strange quark distribution as embedded in the NLO QCD fit sets as noted in the legend. Left: $s + \overline{s}$ versus Bjorken x at $Q^2 = 1.9\,\text{GeV}^2$; right: ratio of $s + \overline{s}$ of various PDF determinations to MSTW08. In the HERAPDF1.0 analysis (green) the strange quark distribution is assumed to be a fixed fraction of the down quark distribution which is conventionally assumed to have the same low x behaviour as the up quark distribution, which results in a small uncertainty of $s + \overline{s}$.

Strange Quarks



c tag in CC

$W^+s \to c$

$1\,fb^{-1}$

$\varepsilon_c = 0.1$

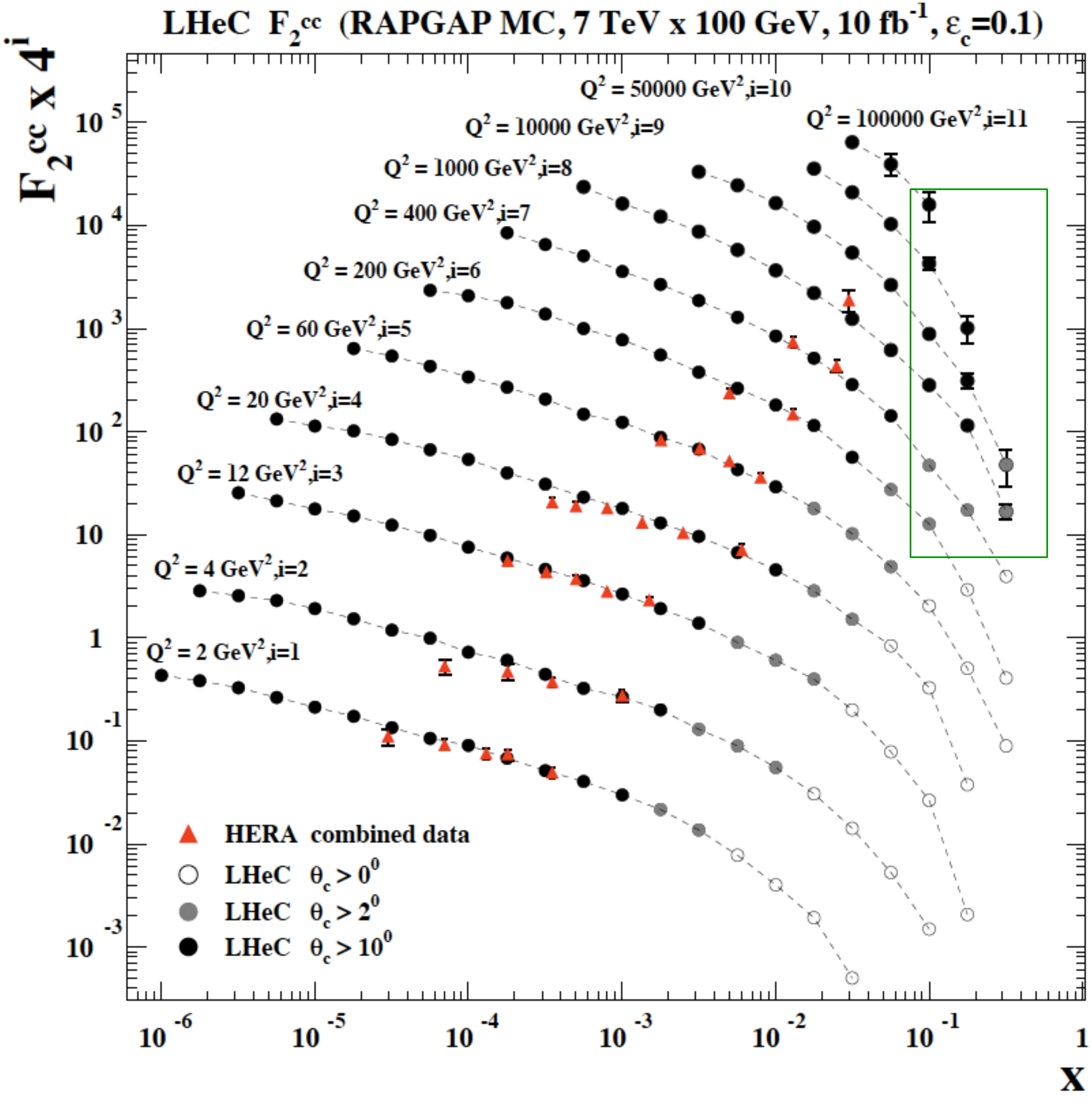
$\varepsilon_q = 0.01$

$\delta_{syst} = 0.1$

$\circ - \vartheta_h \geq 1^o$

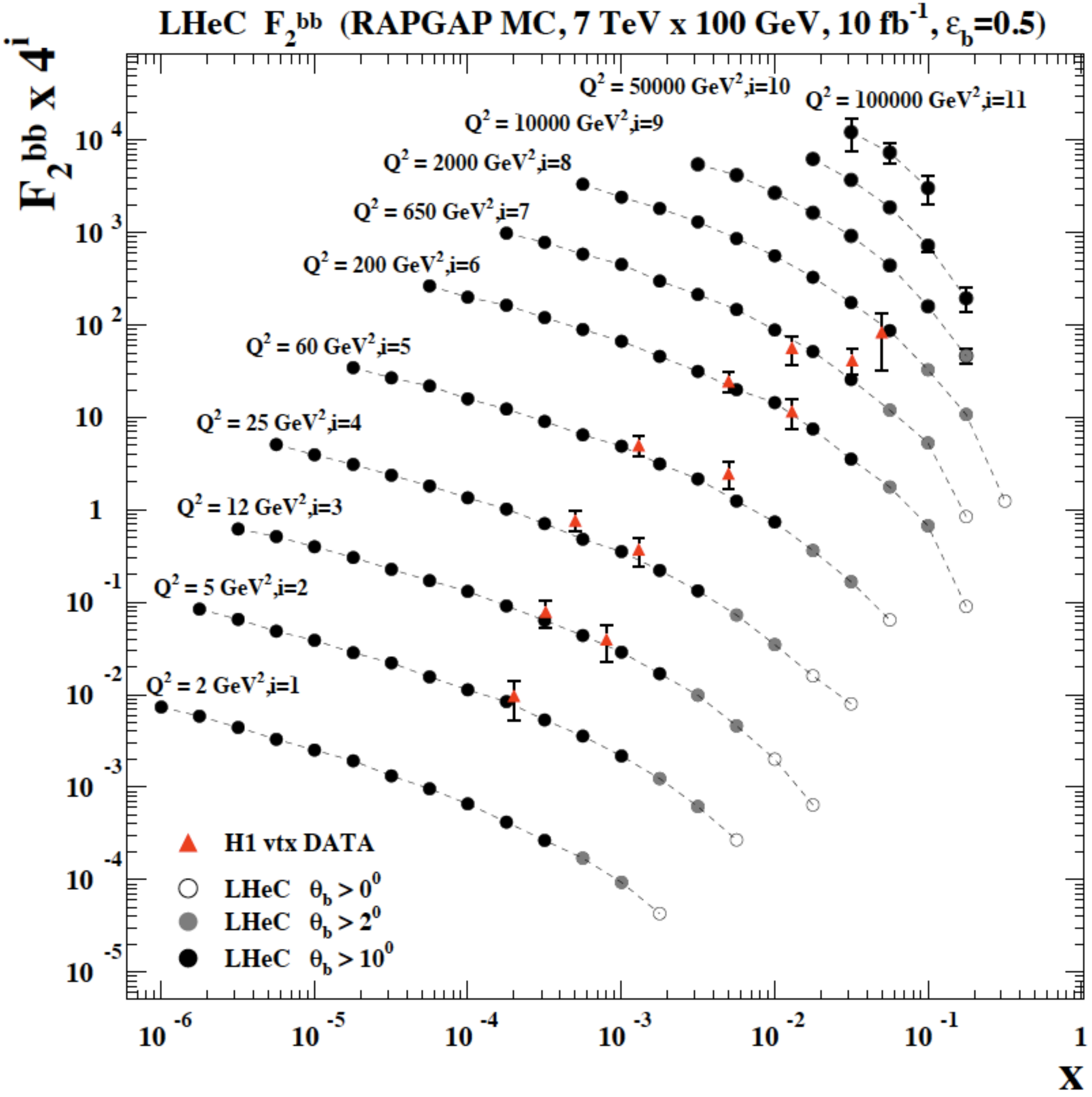
$\bullet - \vartheta_h \geq 10^o$

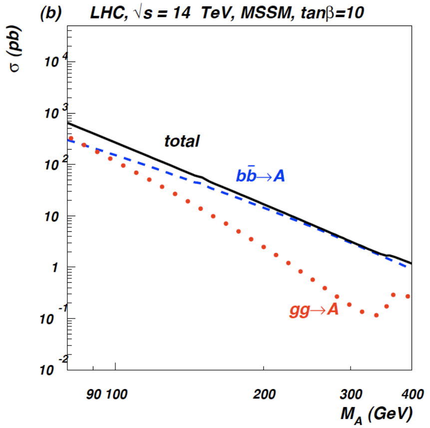
Charm

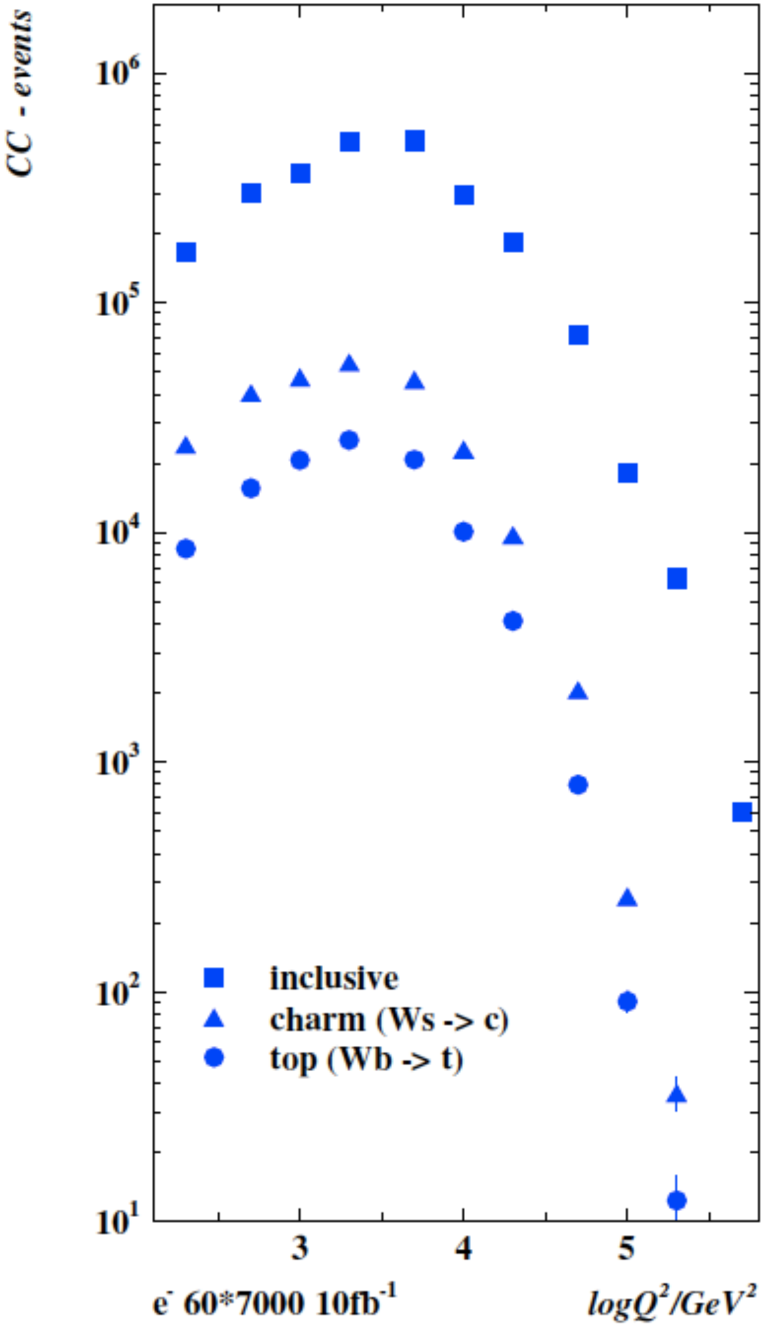


← intrinsic ?

Beauty


LHeC F_2^{bb} (RAPGAP MC, 7 TeV x 100 GeV, 10 fb^{-1}, ε_b=0.5)
F_2^{bb} x 4^i
Q^2 = 100000 GeV^2,i=11
Q^2 = 50000 GeV^2,i=10
Q^2 = 10000 GeV^2,i=9
Q^2 = 2000 GeV^2,i=8
Q^2 = 650 GeV^2,i=7
Q^2 = 200 GeV^2,i=6
Q^2 = 60 GeV^2,i=5
Q^2 = 25 GeV^2,i=4
Q^2 = 12 GeV^2,i=3
Q^2 = 5 GeV^2,i=2
Q^2 = 2 GeV^2,i=1
H1 vtx DATA
LHeC $\theta_b > 0^0$
LHeC $\theta_b > 2^0$
LHeC $\theta_b > 10^0$
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
x


(b) LHC, $\sqrt{s}$ = 14 TeV, MSSM, tanβ=10
σ (pb)
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
total
$b\bar{b}\rightarrow A$
$gg\rightarrow A$
90 100
200
300
400
M_A (GeV)

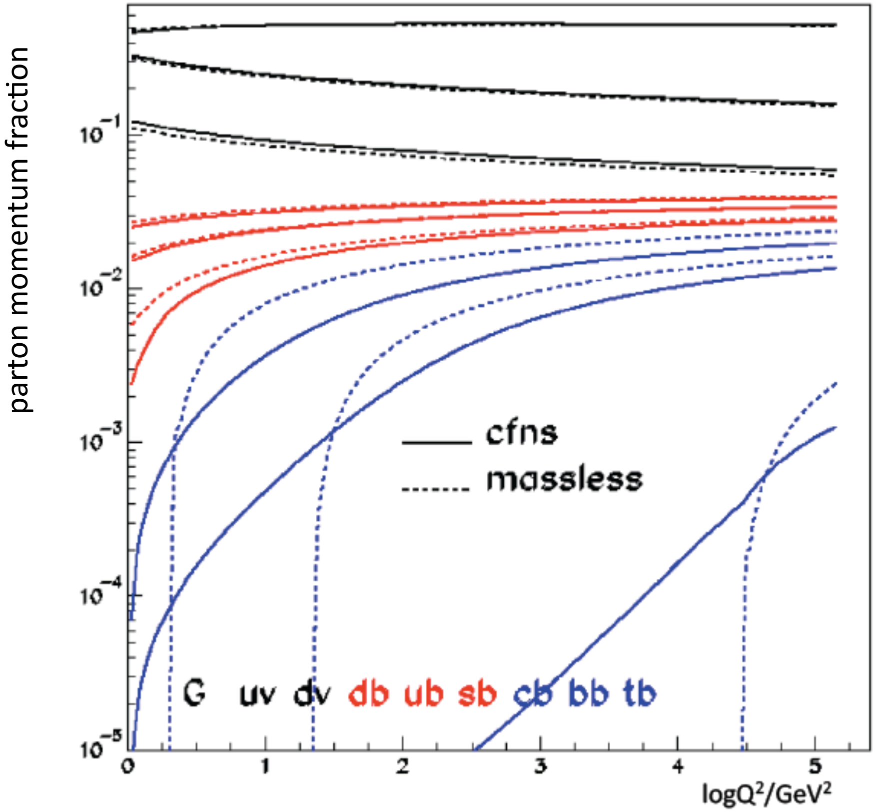


Top (t,ŧ)

Cross section in CC O(5)pb

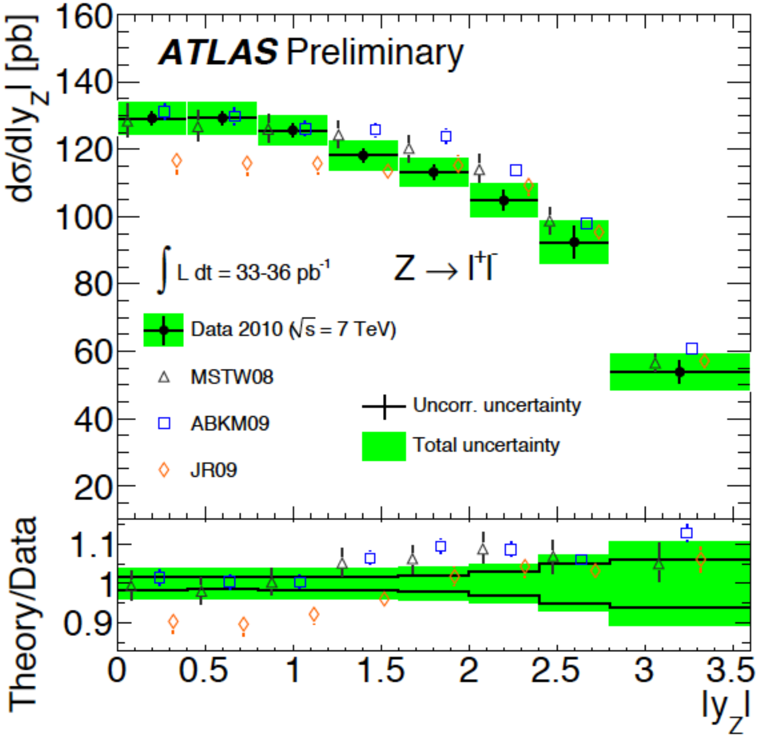
Single top and anti-top

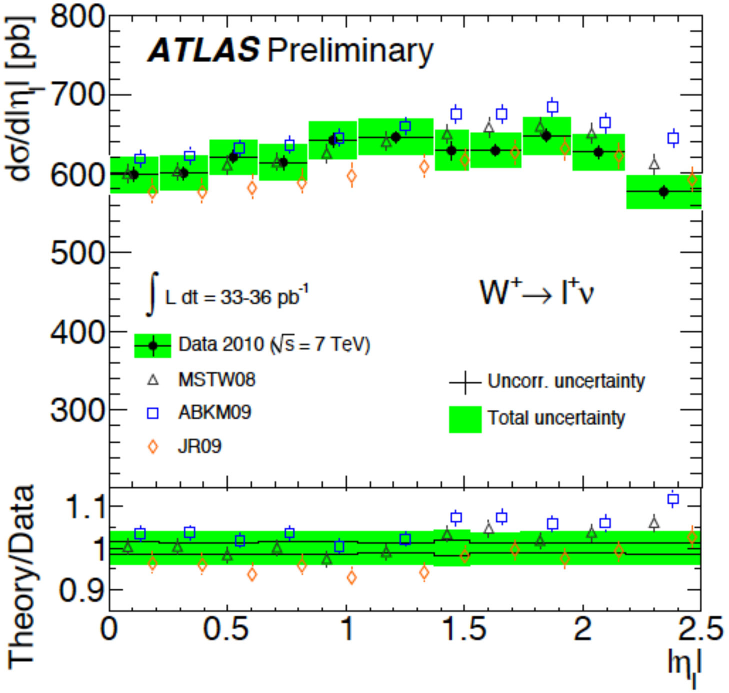
6 flavour variable scheme:

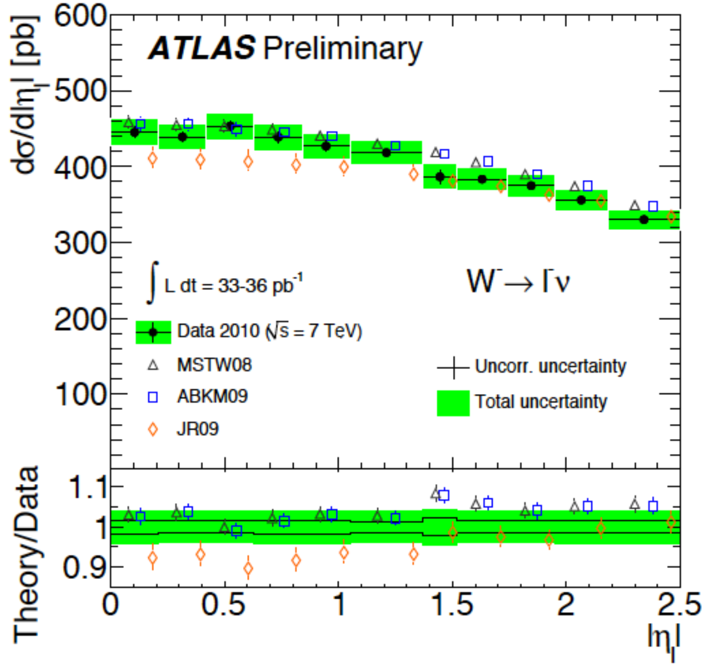


ATLAS: inclusive W,Z at EPS Grenoble

Talk by M.Bellomo on Friday in QCD session



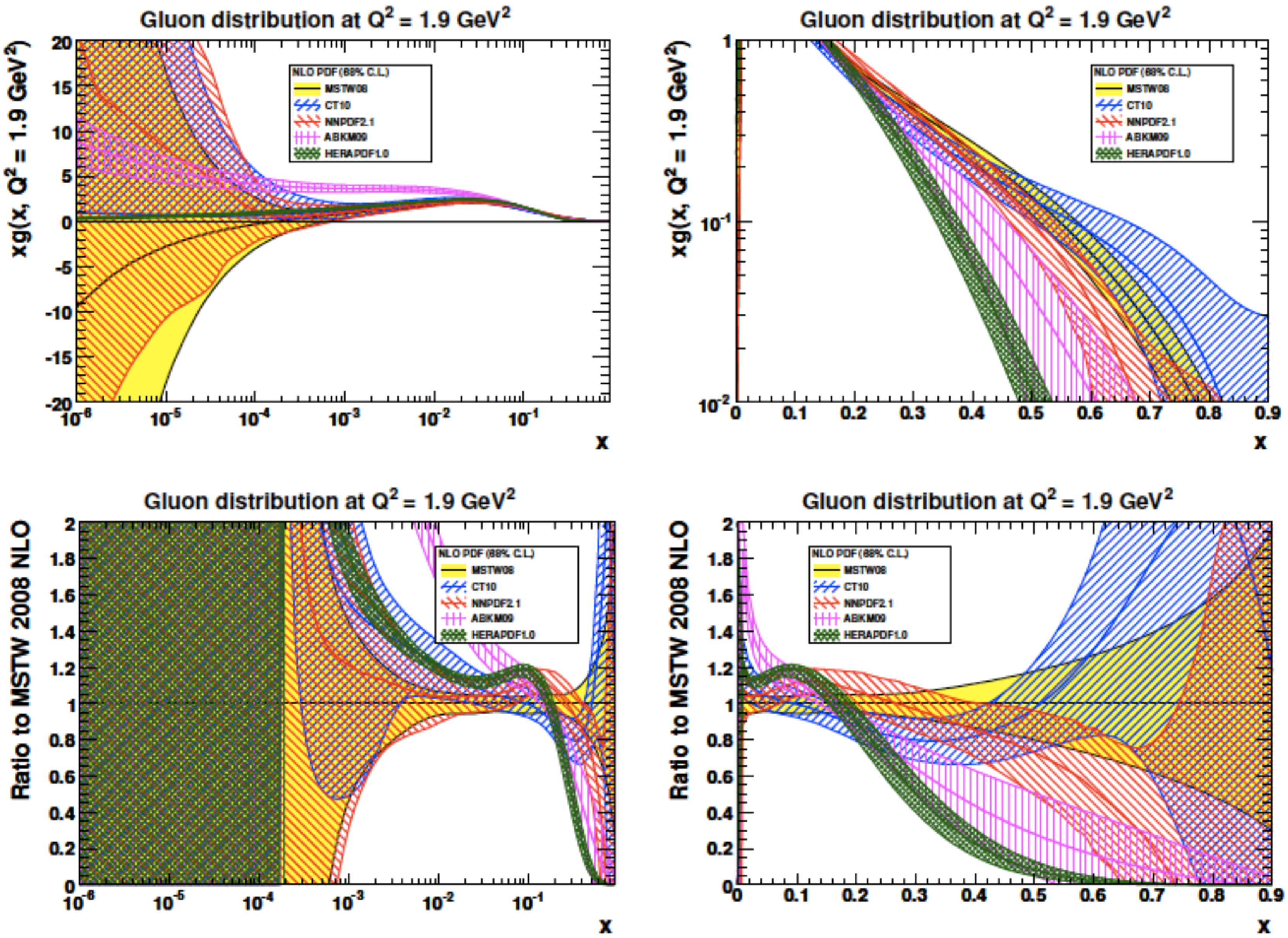




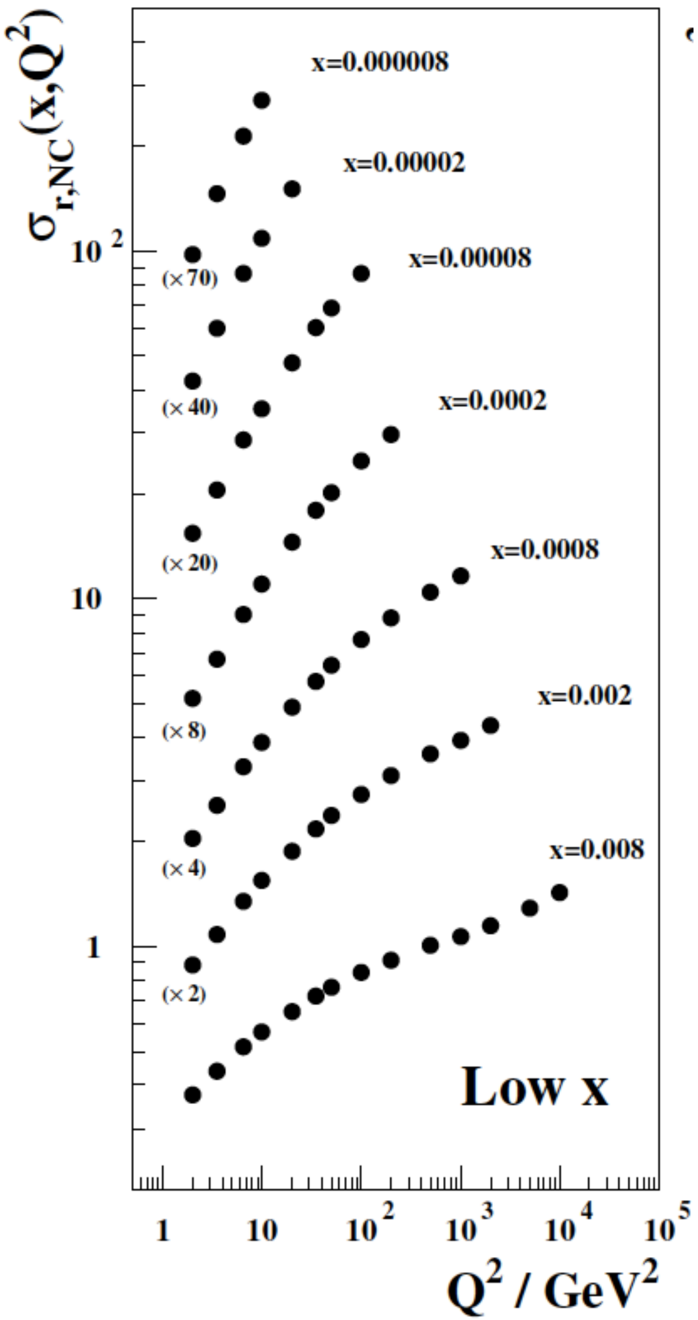
High precision (integrated 1%, bin wise ~2%, δL= 3.7%)
Comparison with NNLO in fiducial region, more certain.
Differential cross sections + correlations: superior over A_l

WZ: Test of PDFs at very high scales where evolution
has "washed out" differences. Limited range in
Bjorken x (cf ABKM vs MSTW08 'agree' at x ~ .01)
The LHeC spans 6 orders of magnitude in Q^2,x .

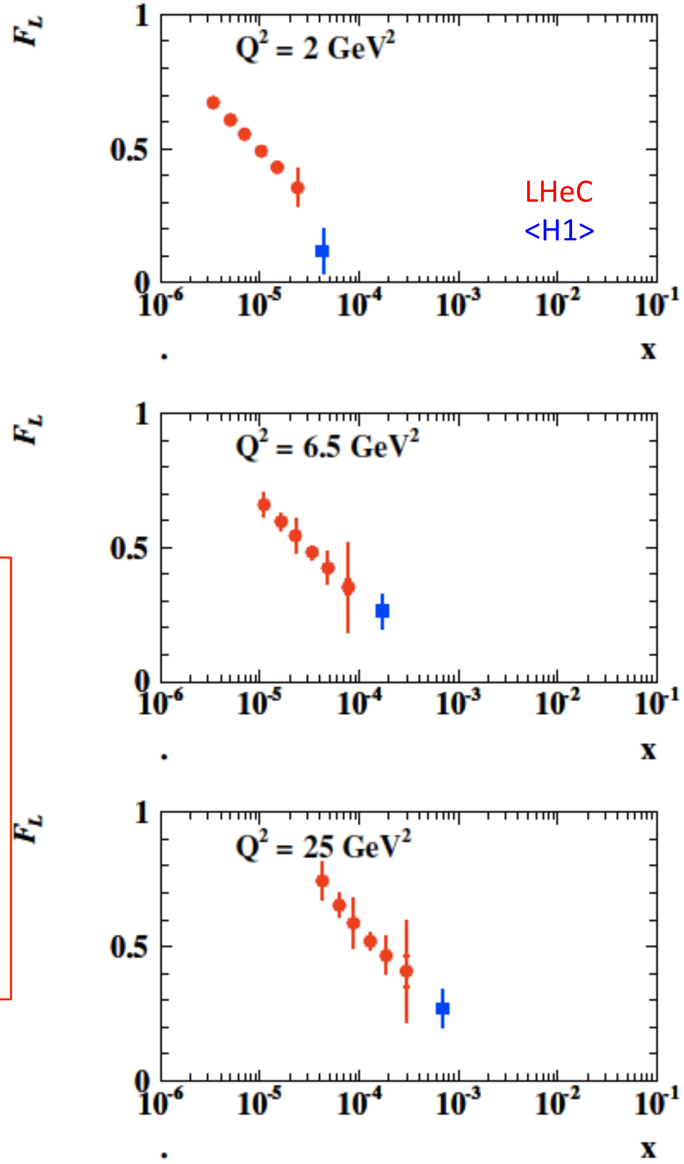
Gluon


Gluon distribution at $Q^2 = 1.9$ GeV^2
$xg(x, Q^2 = 1.9$ GeV$^2)$
Ratio to MSTW 2008 NLO
x
NLO PDF (68% C.L.)
MSTW08
CT10
NNPDF2.1
ABKM09
HERAPDF1.0
20
15
10
5
0
-5
-10
-15
-20
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10^{-1}
10^{-2}
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0

Gluon input



F_2 and F_L crucial to discover gluon saturation in ep in DIS region



Gluon

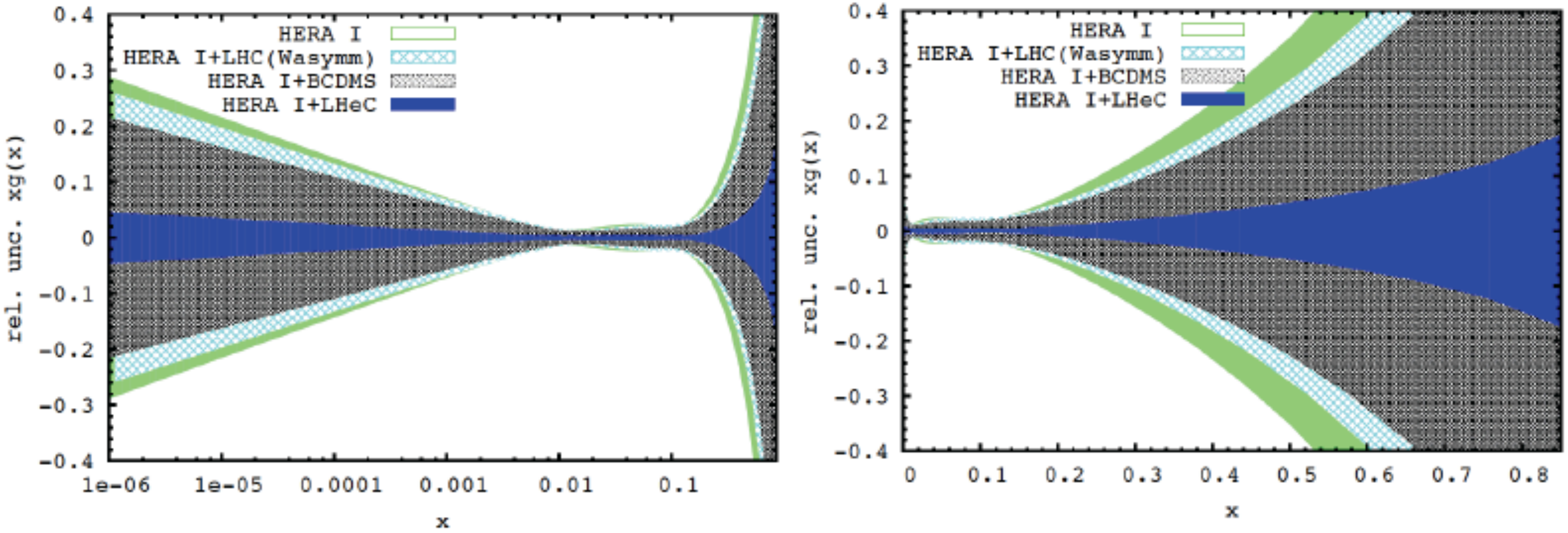
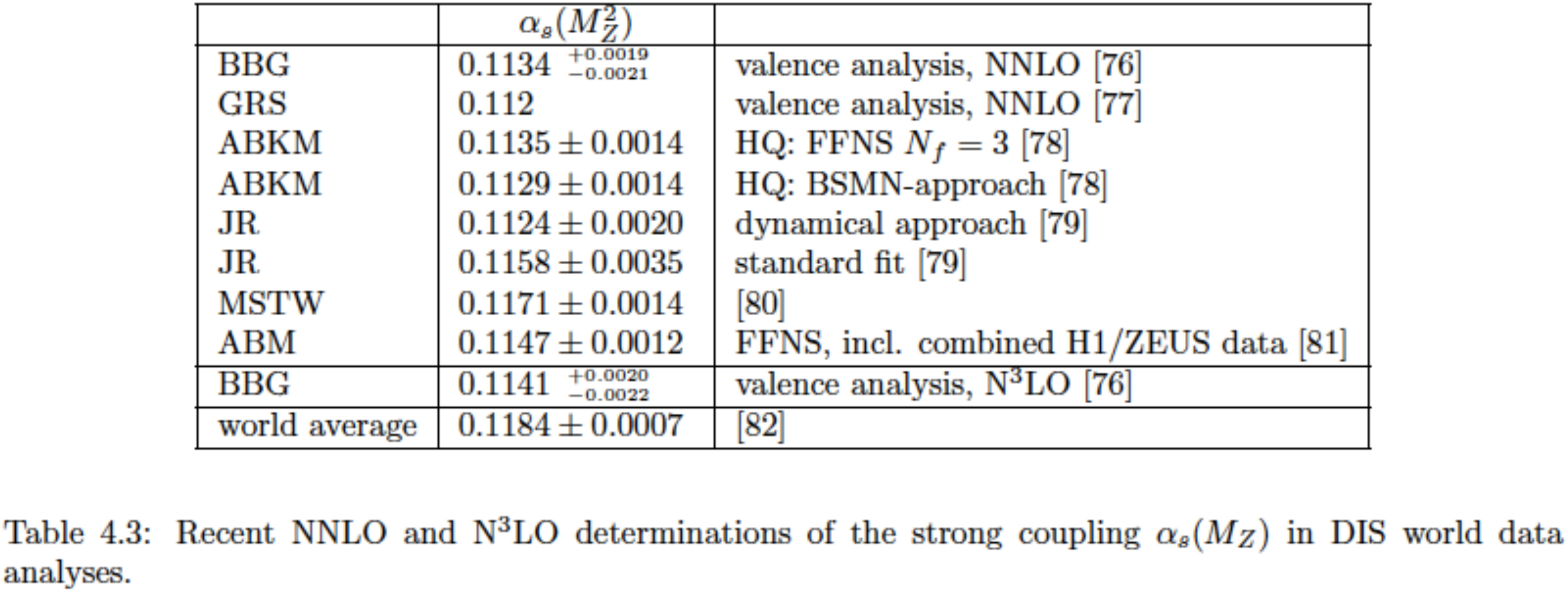


Figure 4.17: Relative uncertainty of the gluon distribution at $Q^2 = 1.9\,\mathrm{GeV}^2$, as resulting from an NLO QCD fit to HERA (I) alone (green, outer), HERA and BCDMS (crossed), HERA and LHC (light blue, crossed) and the LHeC added (blue, dark). Left: logarithmic x, right: linear x.

More on xg: local hot or cold spots? Charm, beauty. DVCS. Diffraction

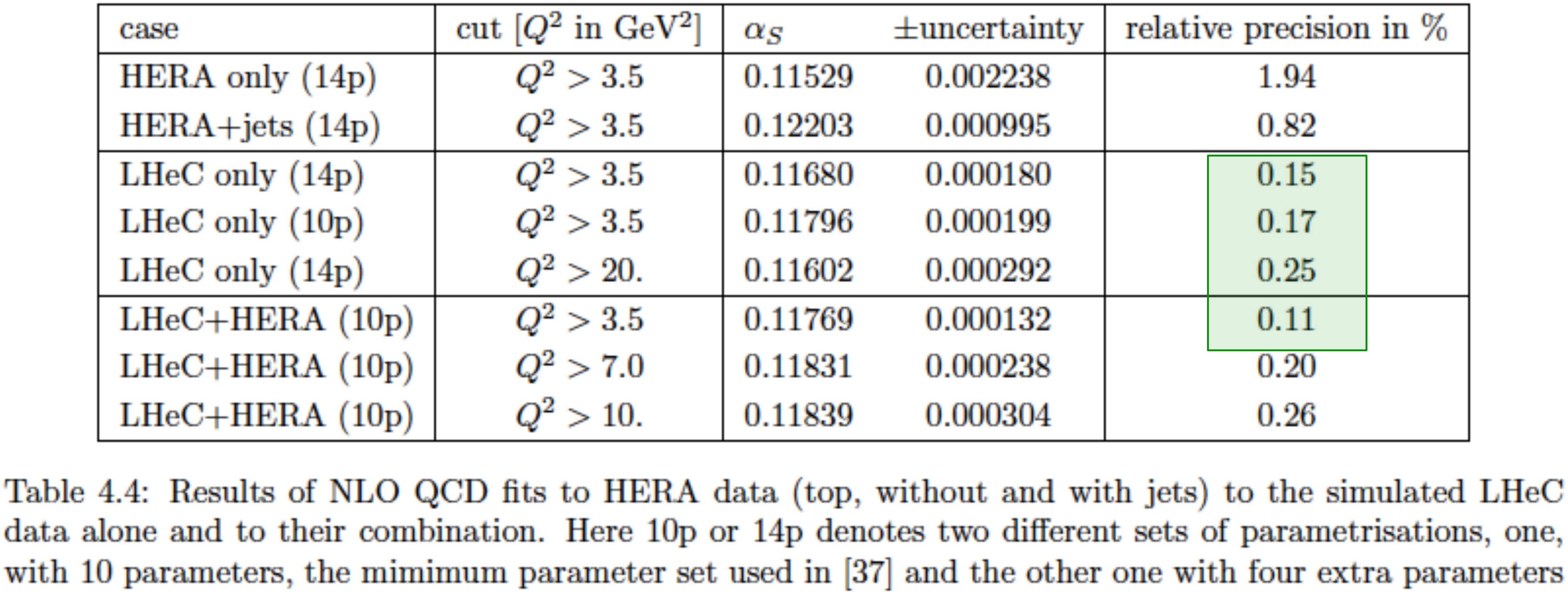
α_s



	$\alpha_s(M_Z^2)$	
BBG	$0.1134\ ^{+0.0019}_{-0.0021}$	valence analysis, NNLO [76]
GRS	0.112	valence analysis, NNLO [77]
ABKM	0.1135 ± 0.0014	HQ: FFNS $N_f = 3$ [78]
ABKM	0.1129 ± 0.0014	HQ: BSMN-approach [78]
JR	0.1124 ± 0.0020	dynamical approach [79]
JR	0.1158 ± 0.0035	standard fit [79]
MSTW	0.1171 ± 0.0014	[80]
ABM	0.1147 ± 0.0012	FFNS, incl. combined H1/ZEUS data [81]
BBG	$0.1141\ ^{+0.0020}_{-0.0022}$	valence analysis, N^3LO [76]
world average	0.1184 ± 0.0007	[82]

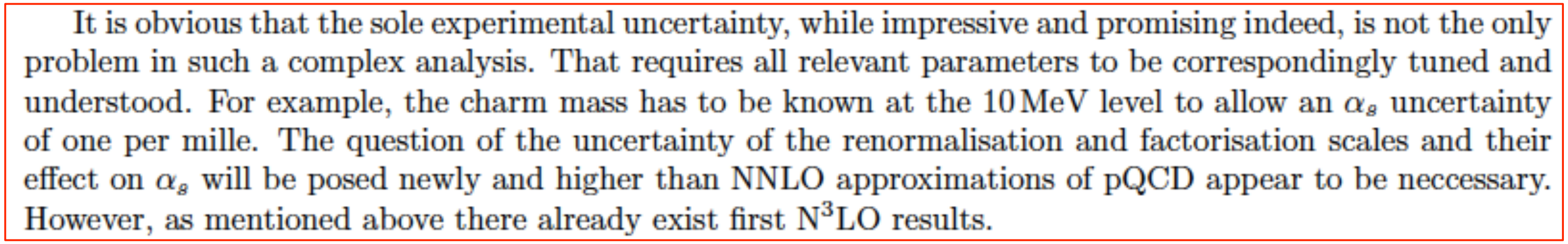
Table 4.3: Recent NNLO and N^3LO determinations of the strong coupling $\alpha_s(M_Z)$ in DIS world data analyses.

α_s



case	cut [Q^2 in GeV^2]	α_S	±uncertainty	relative precision in %
HERA only (14p)	$Q^2 > 3.5$	0.11529	0.002238	1.94
HERA+jets (14p)	$Q^2 > 3.5$	0.12203	0.000995	0.82
LHeC only (14p)	$Q^2 > 3.5$	0.11680	0.000180	0.15
LHeC only (10p)	$Q^2 > 3.5$	0.11796	0.000199	0.17
LHeC only (14p)	$Q^2 > 20.$	0.11602	0.000292	0.25
LHeC+HERA (10p)	$Q^2 > 3.5$	0.11769	0.000132	0.11
LHeC+HERA (10p)	$Q^2 > 7.0$	0.11831	0.000238	0.20
LHeC+HERA (10p)	$Q^2 > 10.$	0.11839	0.000304	0.26

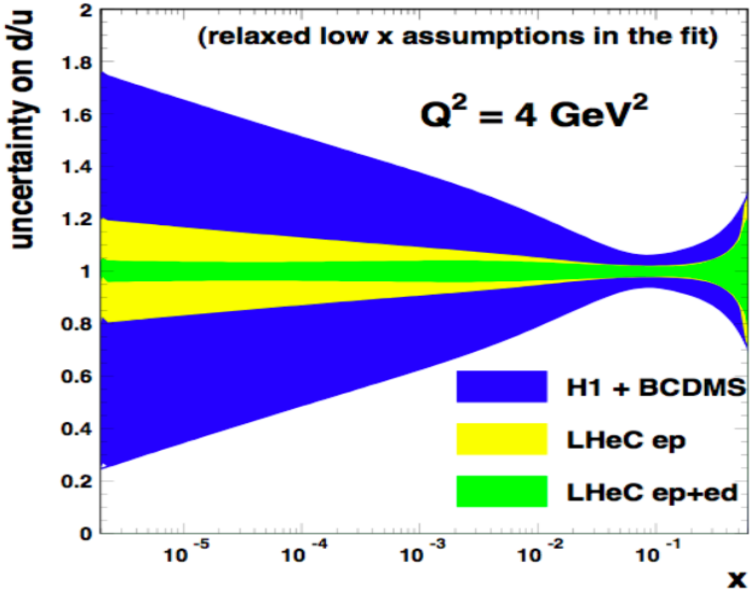
Table 4.4: Results of NLO QCD fits to HERA data (top, without and with jets) to the simulated LHeC data alone and to their combination. Here 10p or 14p denotes two different sets of parametrisations, one, with 10 parameters, the mimimum parameter set used in [37] and the other one with four extra parameters

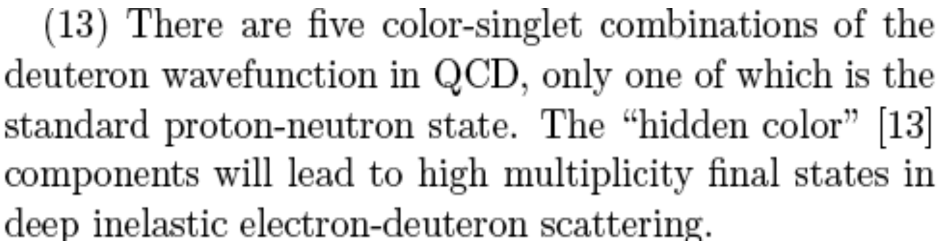


It is obvious that the sole experimental uncertainty, while impressive and promising indeed, is not the only problem in such a complex analysis. That requires all relevant parameters to be correspondingly tuned and understood. For example, the charm mass has to be known at the 10 MeV level to allow an α_s uncertainty of one per mille. The question of the uncertainty of the renormalisation and factorisation scales and their effect on α_s will be posed newly and higher than NNLO approximations of pQCD appear to be neccessary. However, as mentioned above there already exist first N^{3}LO results.

Neutron Structure (ed → eX)

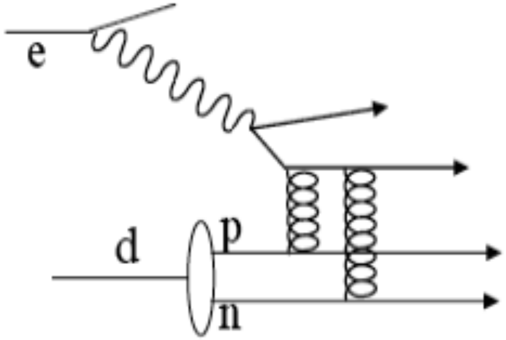
d/u at low x from deuterons

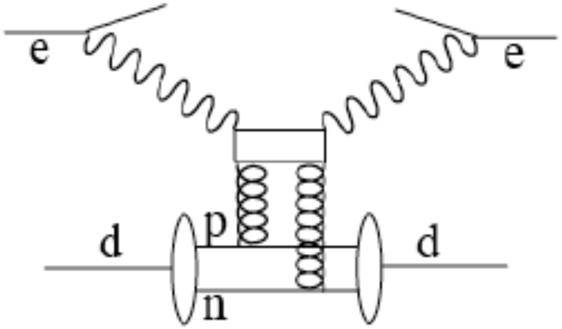




(13) There are five color-singlet combinations of the deuteron wavefunction in QCD, only one of which is the standard proton-neutron state. The "hidden color" [13] components will lead to high multiplicity final states in deep inelastic electron-deuteron scattering.

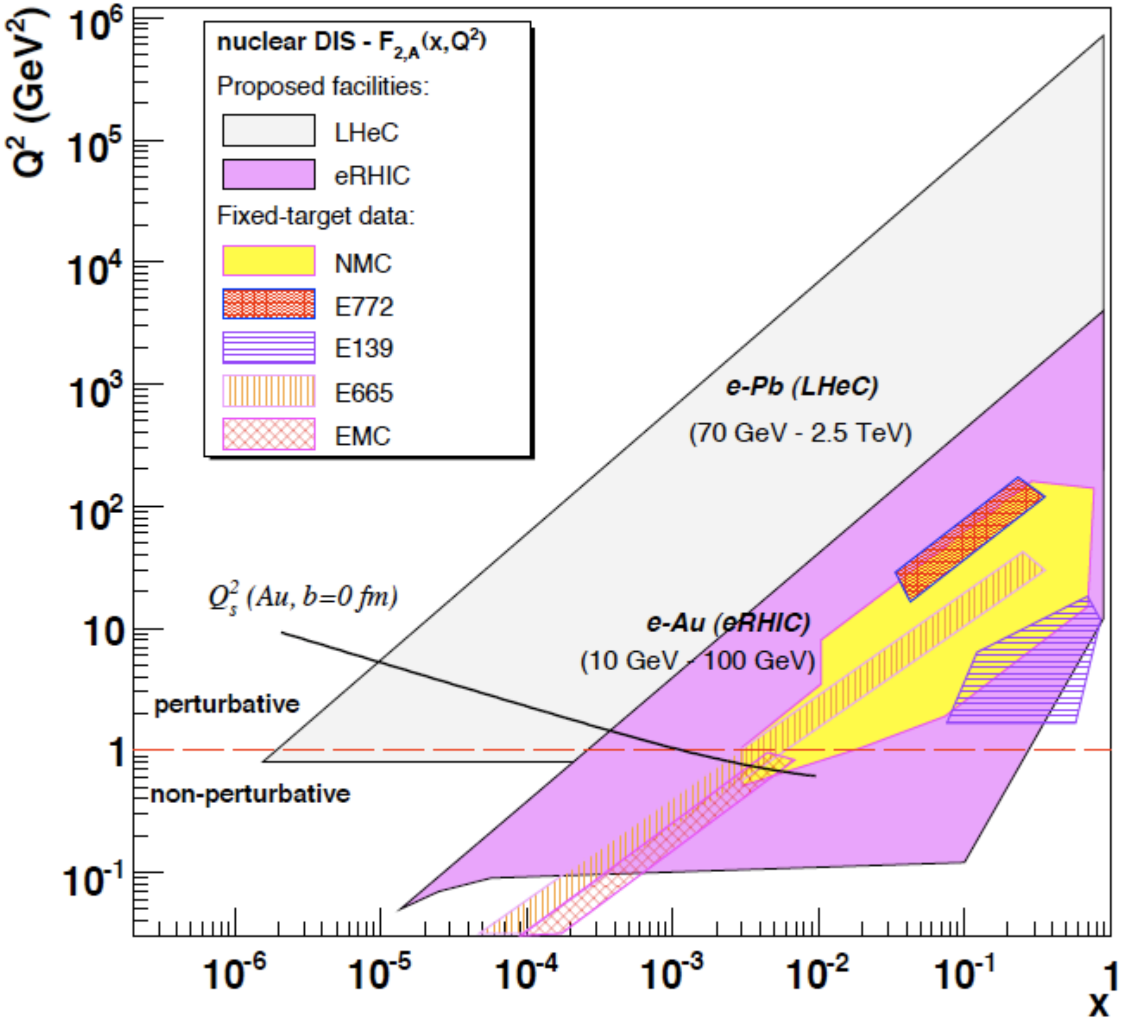
crucial constraint on evolution (S-NS), improved α_s





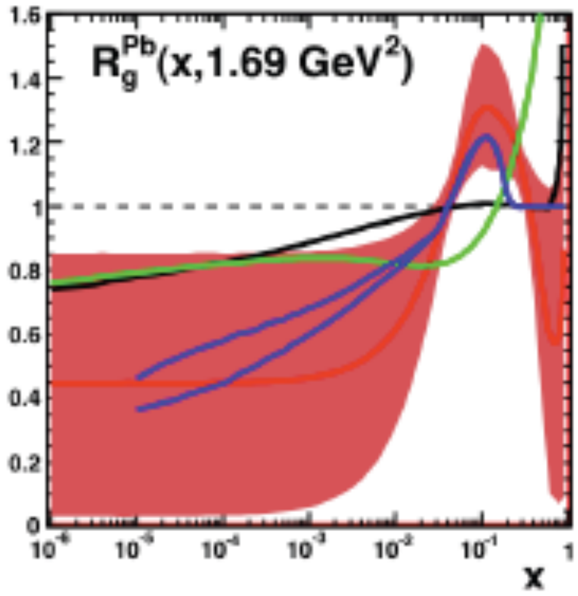
In eA at the collider, test Gribovs relation between shadowing and diffraction, control nuclear effects at low Bjorken x to high accuracy

Electron-Ion Scattering: eA → eX



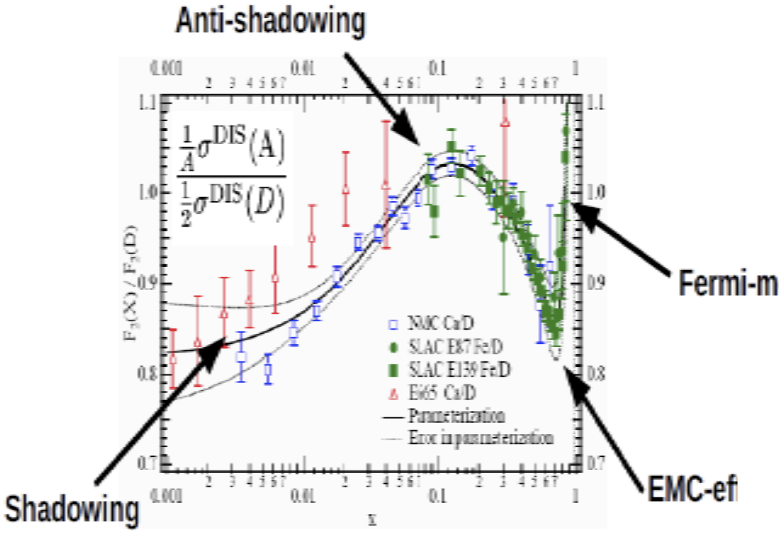
Qualitative change of behaviour

- **Bb limit of F_2**
- **Saturation of cross sections amplified with $A^{1/3}$ (A wider than p)**
- **Rise of diffraction to 50%**
- **hot spots of gluons ?**



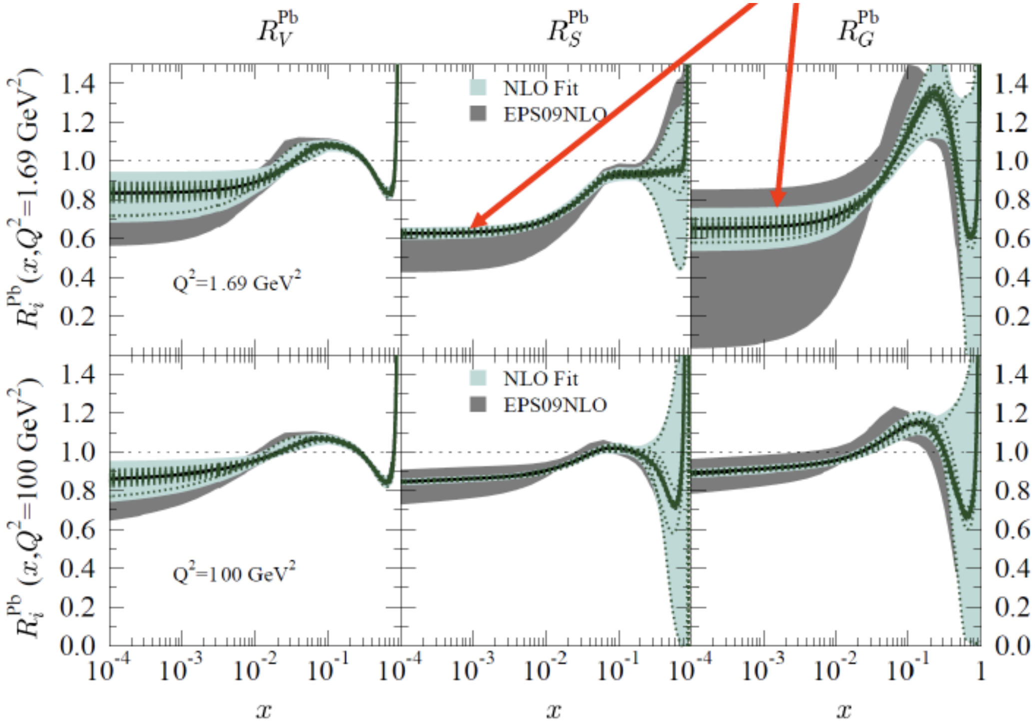
Extension of kinematic range by 3-4 orders of magnitude into saturation region **(with p and A)**
Like LHeC ep without HERA.. (e.g. heavy quarks in A)

Nuclear Parton Distributions



Predictions of NPDFs
at x < 0.01 rely on HERA
convoluted with
shadowing theory.
Not sure that is right.

Effects of eA LHeC pseudodata



$R=q^{Pb}/q^{p}$

→A complete determination of nPDFs in grossly extended range, into nonlinear regime
certainly more diverse than in V,S,G terms

IV Detector

Requirements

High Precision
(resolution,
calibration,
low noise at low y
tagging of b,c)

Modular for 'fast'
installation

State of the art
for 'no' R+D

1-179° acceptance
for low Q^2, high x

Affordable

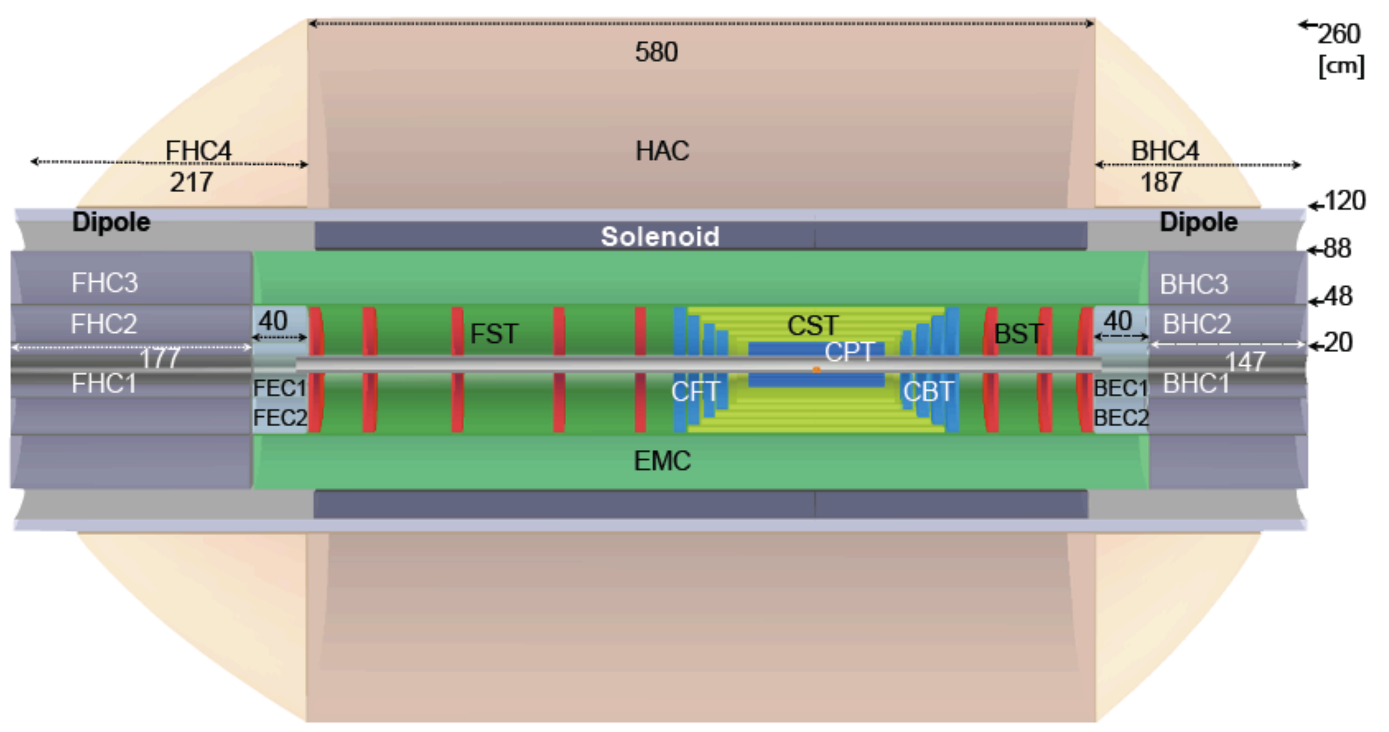
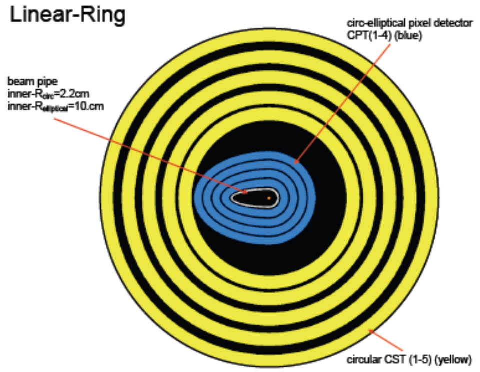
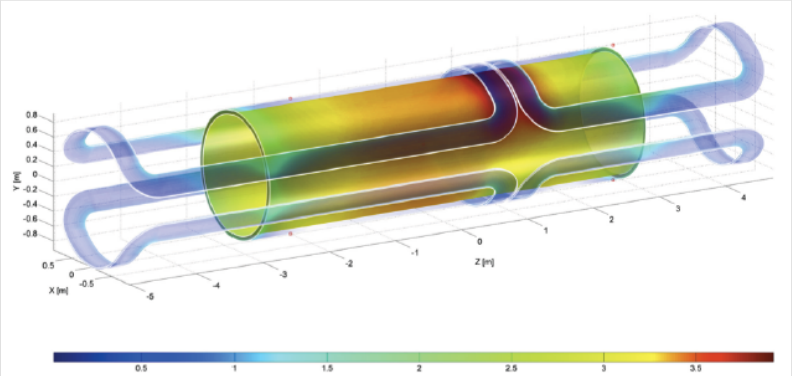


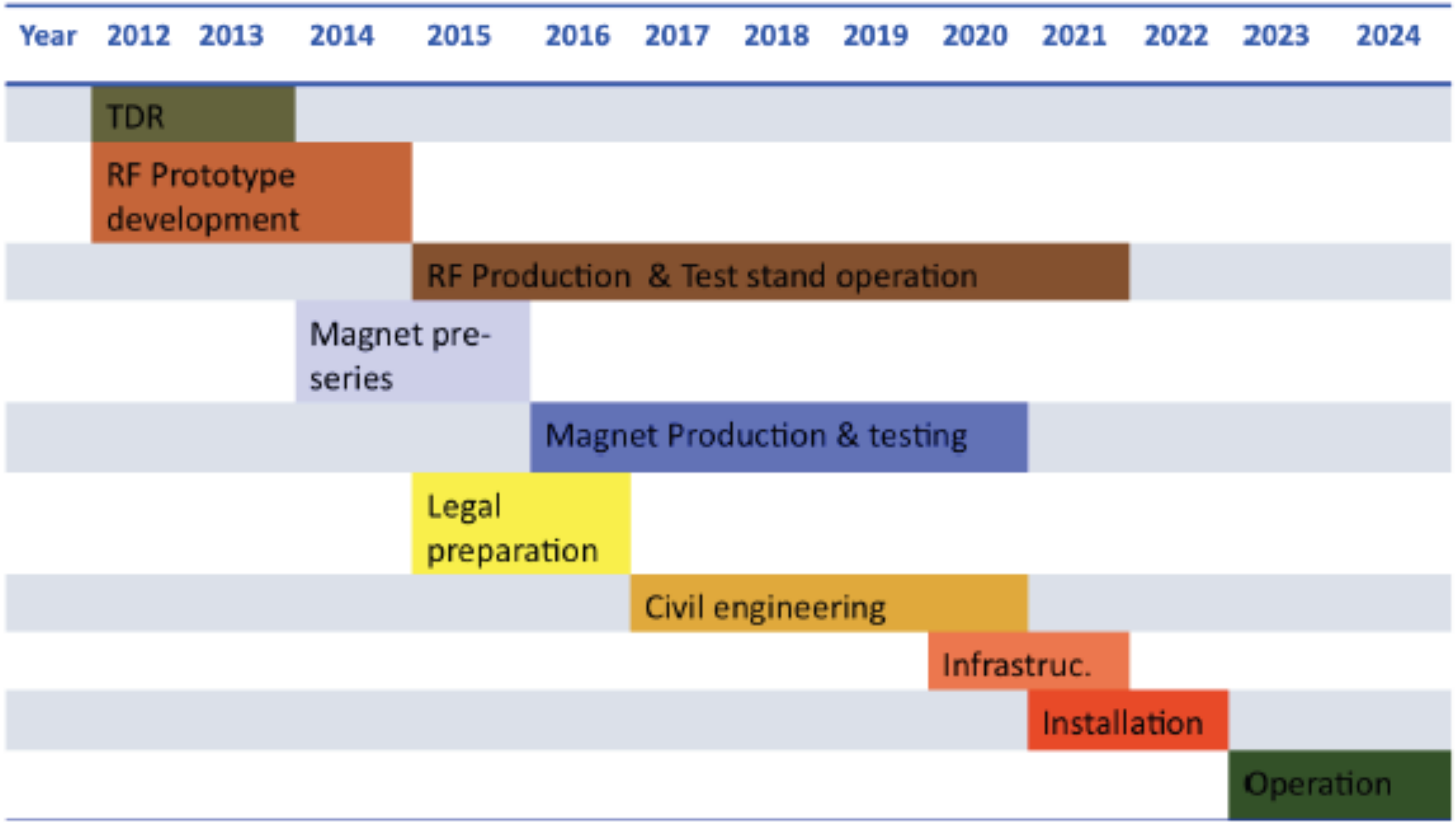
Figure 13.9: An rz cross section of the LHeC detector, in its baseline configuration (A). In





Present dimensions: LxD =14x9m² [CMS 21 x 15m², ATLAS 45 x 25 m²]
Taggers at -62m (e),100m (γ,LR), -22.4m (γ,RR), +100m (n), +420m (p)

11 Project Planning

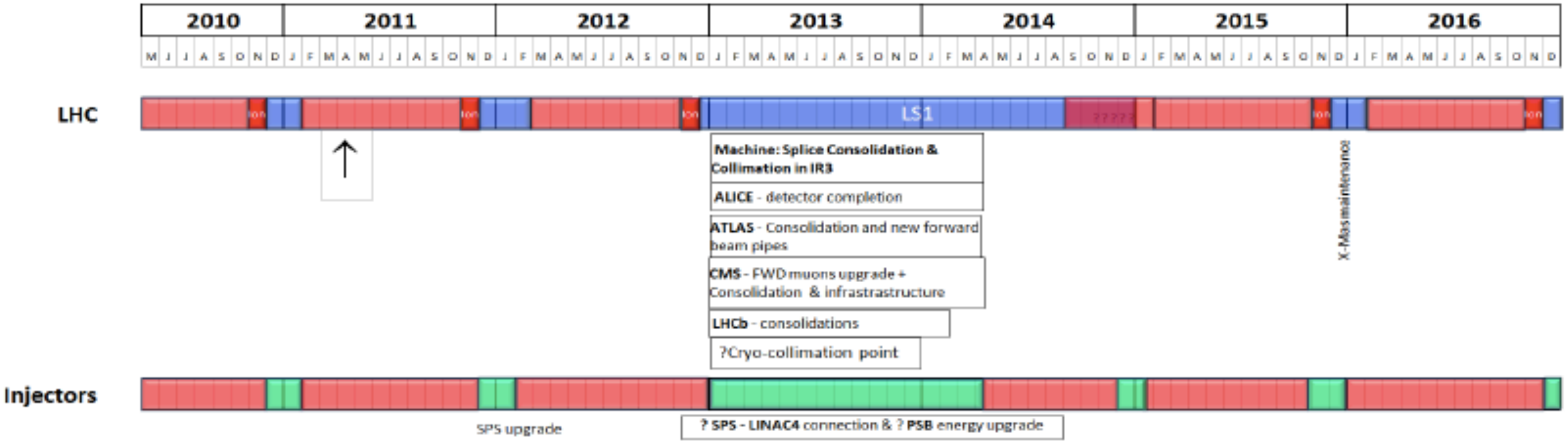


LS3 --- HE LHC

We base our estimates for the project time line on the experience of other projects, such as (LEP, LHC and LINAC4 at CERN and the European XFEL at DESY and the PSI XFEL). In

New rough draft 10 year plan

Not yet approved!



Machine: Splice Consolidation & Collimation in IR3

ALICE - detector completion

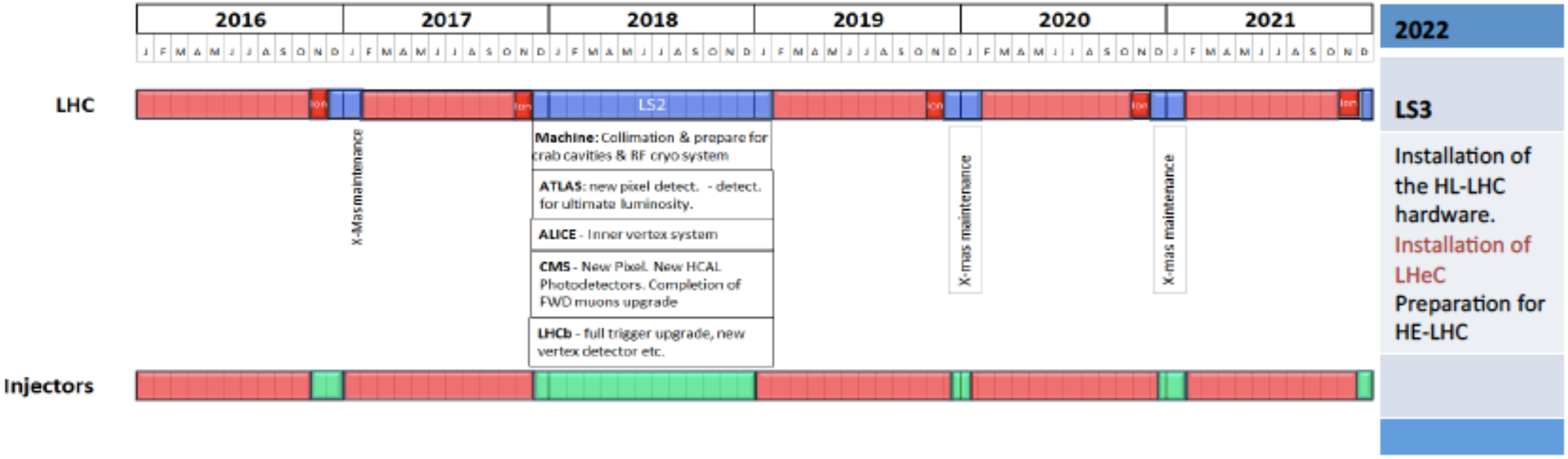
ATLAS - Consolidation and new forward beam pipes

CMS - FWD muons upgrade + Consolidation & infrastrastructure

LHCb - consolidations

?Cryo-collimation point

? SPS - LINAC4 connection & ? **PSB** energy upgrade



Machine: Collimation & prepare for crab cavities & RF cryo system

ATLAS: new pixel detect. - detect. for ultimate luminosity.

ALICE - Inner vertex system

CMS - New Pixel, New HCAL Photodetectors. Completion of FWD muons upgrade

LHCb - full trigger upgrade, new vertex detector etc.

2022

LS3

Installation of the HL-LHC hardware.

Installation of LHeC

Preparation for HE-LHC

The LHeC determines all! quark and the gluon distributions [valence, strange, top?, …] with extreme precision and range: This provides a new experimental basis for understanding proton structure and will lead to a qualitatively new level of QCD analyses [heavy flavour, local x spots? etc.]

The LHeC will map the gluon [$x=10^{-6}$-1] and measure α_s to per mille

At low x saturation is bound to be discovered in the DIS region where α_s is small enough for a perturbative interpretation.

Deuteron data (tagged proton spectator) resolve the the neutron structure (shadowing-diffraction) and ‘stabilize’ QCD evolution. eD is one example for many novel QCD effects.

Parton distributions in nuclei can be measured over 4 extra orders of magnitude in Q^2 and 1/x which will clarify a plethora of speculations as on colour transparency, the black body limit, flavour dependent shadowing etc..

The LHeC may be built and can run simultaneously with pp in 10 years, as its technology is at hand. This will enrich the physics of the LHC (QCD, eweak and BSM) substantially.