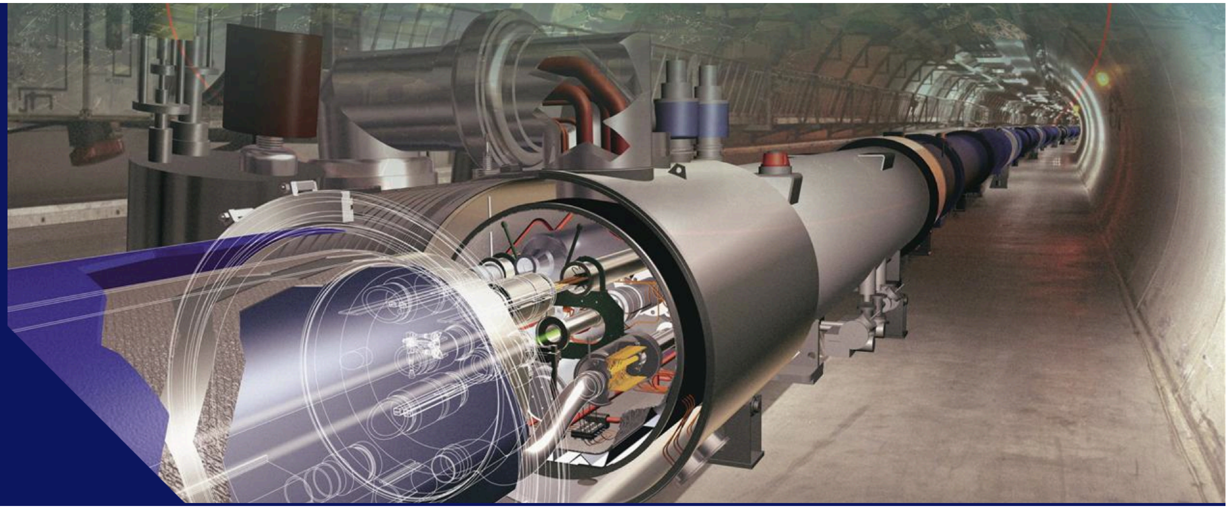
ICHEP 2020 | PRAGUE

28 July – 6 August 2020



Precision QCD at the LHeC and FCC-eh

Claire Gwenlan, Oxford

on behalf of the LHeC and FCC-eh study groups

UNIVERSITY OF OXFORD

focus on results from NEW LHeC white paper

LHeC

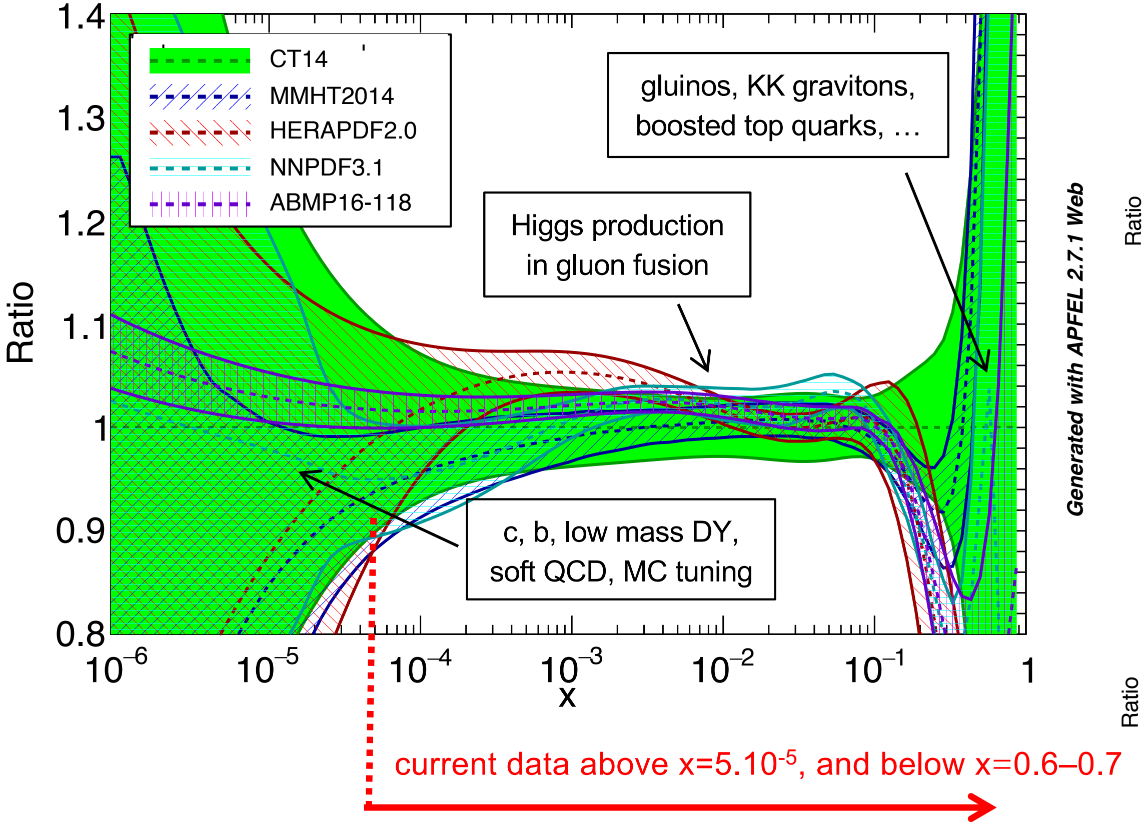
PERLE

FCC hh ee he

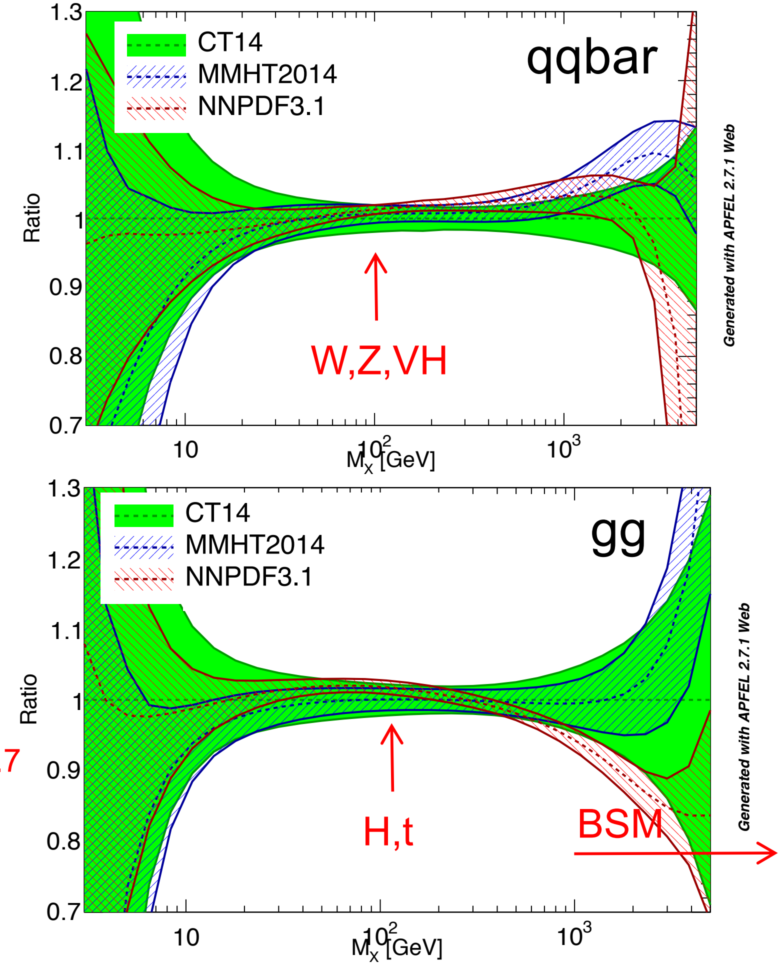
CERN

pdfs: the situation today

xg(x,Q), NNLO, Q^2=100 GeV^2, $\alpha_s(M_Z)$=0.118



pdf luminosities (LHC@14TeV)

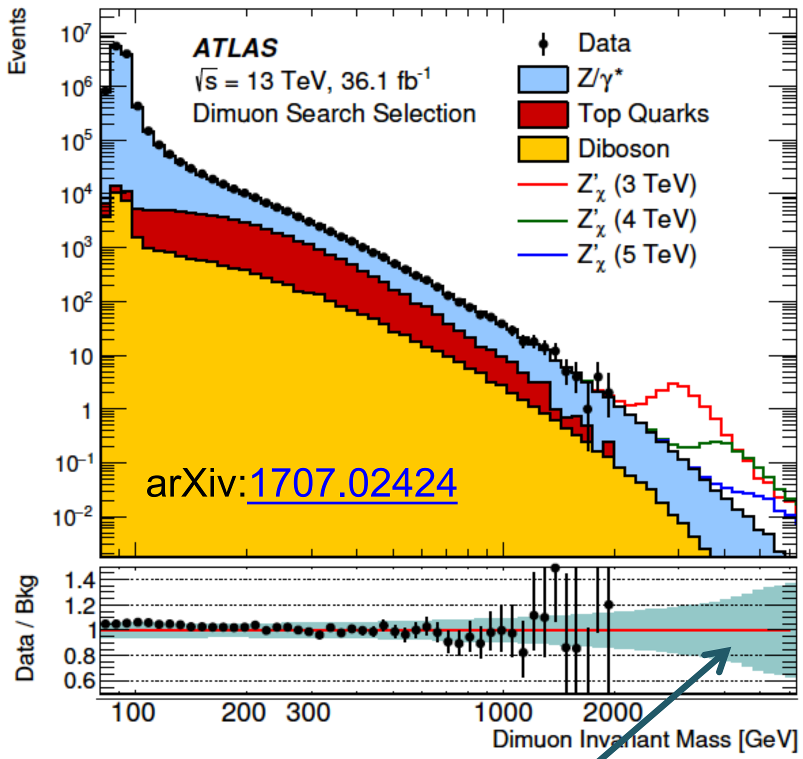


pdfs poorly known at **large** and **small x**

higher precision needed also for H, W, t

why pdfs matter

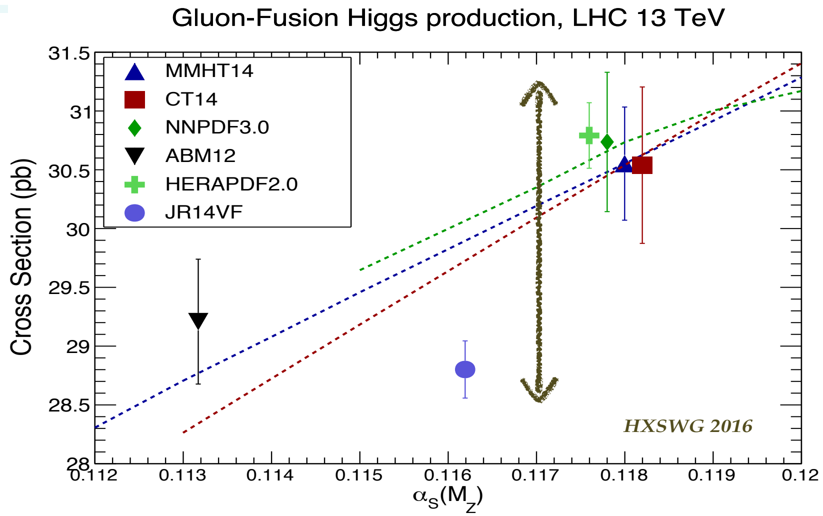
- **BSM searches** and other processes at high scales limited by (lack of) knowledge of **large x gluon** and **quark pdfs** (EG. top, SUSY, LQs, extra heavy bosons, …)
- … plus precision **MW**, **sin²ϑW** (where small discrepancies may indicate BSM physics) and **Higgs**, are also limited by **pdf uncertainties** at medium x, where we know pdfs best!



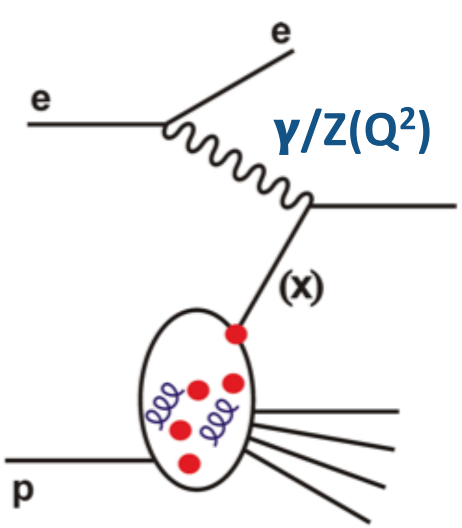
pdf uncertainty dominates

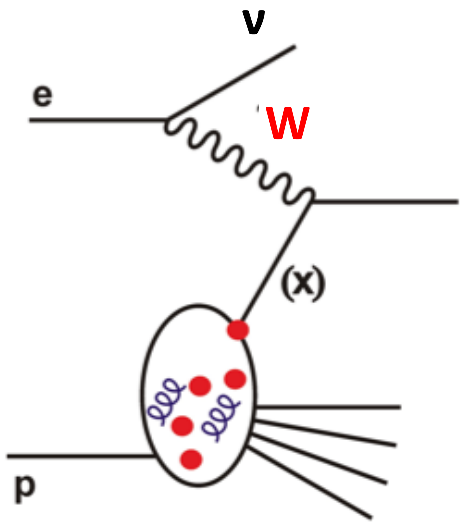
ATLAS Mw, arXiv:1701.07240

Channel	$m_{W^+} - m_{W^-}$ [MeV]	Stat. Unc.	Muon Unc.	Elec. Unc.	Recoil Unc.	Bckg. Unc.	QCD Unc.	EW Unc.	PDF Unc.	Total Unc.
$W \to e\nu$	−29.7	17.5	0.0	4.9	0.9	5.4	0.5	0.0	24.1	30.7
$W \to \mu\nu$	−28.6	16.3	11.7	0.0	1.1	5.0	0.4	0.0	26.0	33.2
Combined	−29.2	12.8	3.3	4.1	1.0	4.5	0.4	0.0	23.9	28.0



ep collider – a precision microscope



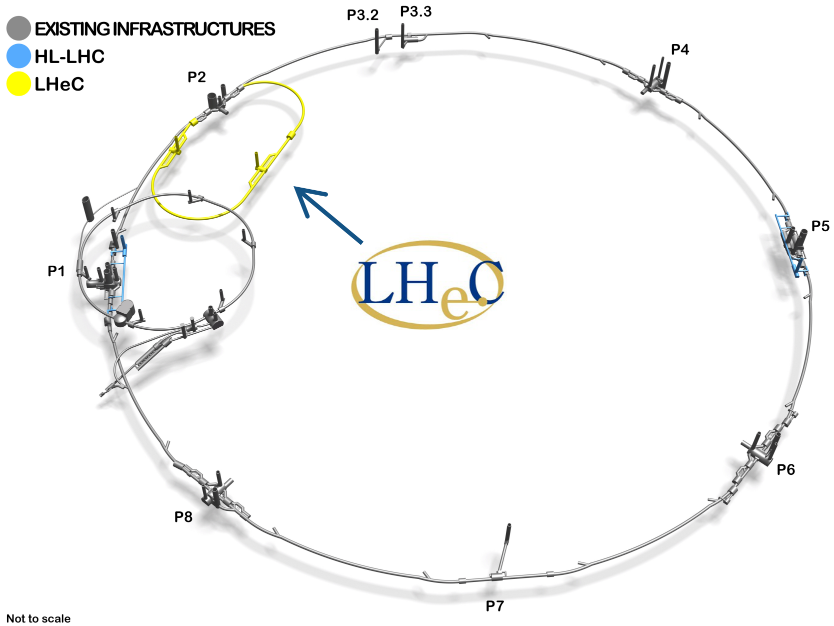


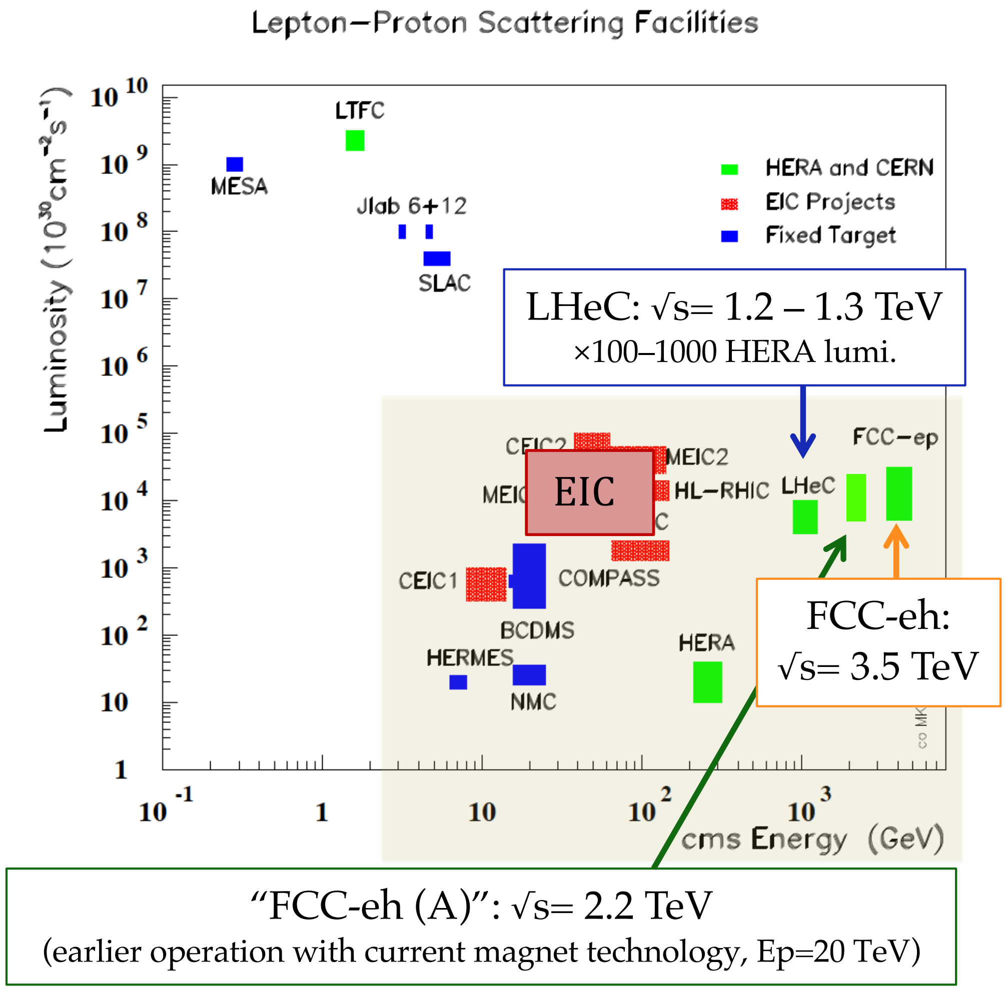
Neutral Current: $ep \rightarrow e'X$ **Charged Current:** $ep \rightarrow \nu_e X$

"*The point-like electron "probes" the interior of the proton via the* ***electroweak force****, while acting as a neutral observer with regard to the* ***strong force***", **R-D Heuer**

cleanest high resolution microscope for probing proton structure and ideal QCD laboratory

LHeC and FCC-eh





energy recovery LINAC (ERL)

attached to HL-LHC (or FCC)

e beam: ⟶ **50 or 60 GeV**

Lint ⟶ **1** ab^{-1} (**1000×** HERA ; per **10** yrs)

ESPPU: ERL is a "high-priority future initiative" for CERN

see also talks:

LHeC and **FCC-eh**, B. Holzer

LHeC detector, Y. Yamazaki

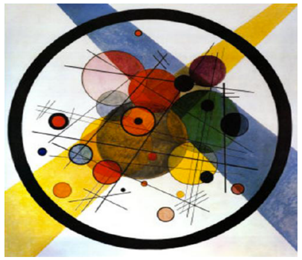
LHeC white paper

CERN-ACC-Note-2020-0002
Version v2.0
Geneva, July 24, 2020

LHeC

The Large Hadron-Electron Collider at the HL-LHC

LHeC Study Group



To be submitted to J.Phys. G

LHeC white paper: **BEING SUBMITTED**

update to LHeC CDR, arXiV:1206.2913

compilation of new and updated studies over the past two years, from > 330 authors

this talk:

QCD and **proton structure** – Ch. 3, 4

see also other talks in this conference:

BSM, G. Azuelos

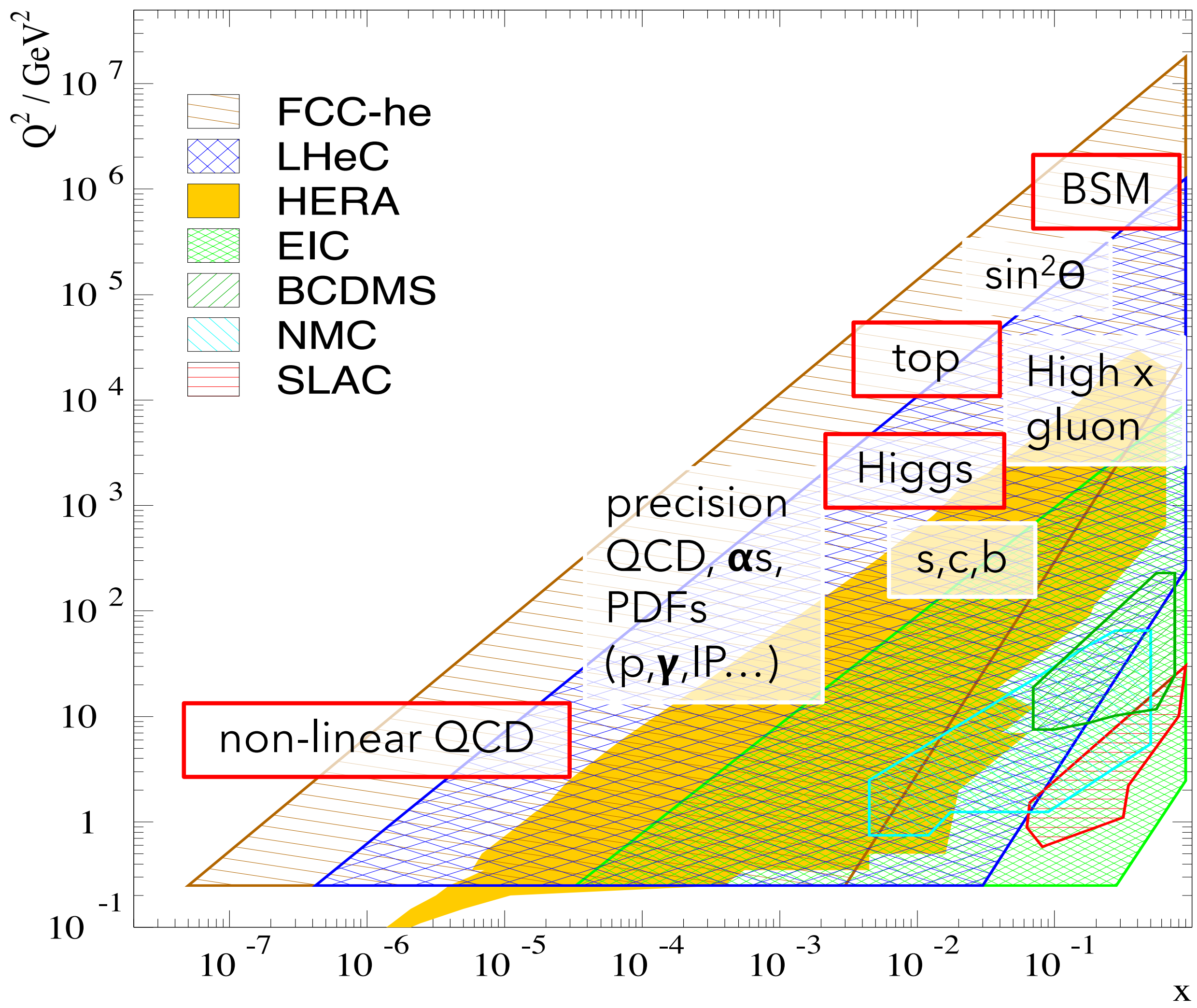
HI, H. Mantysaari

Higgs, U. Klein

top and **EW**, D. Britzger

see also FCC CDR, volume 1, EPJ C79 (2019), no.6, 474

kinematic coverage



opportunity for **unprecedented increase in DIS kinematic reach**;
×1000 increase in lumi. cf. HERA

no higher twist,
no nuclear corrections,
free of symmetry assumptions,
N^3LO theory possible,
…

precision pdfs up to x→1,
and exploration of small x regime;
plus extensive additional physics programme

×**15**/**120** extension in Q^2,1/x reach vs **HERA**

LHeC simulated data and QCD fits

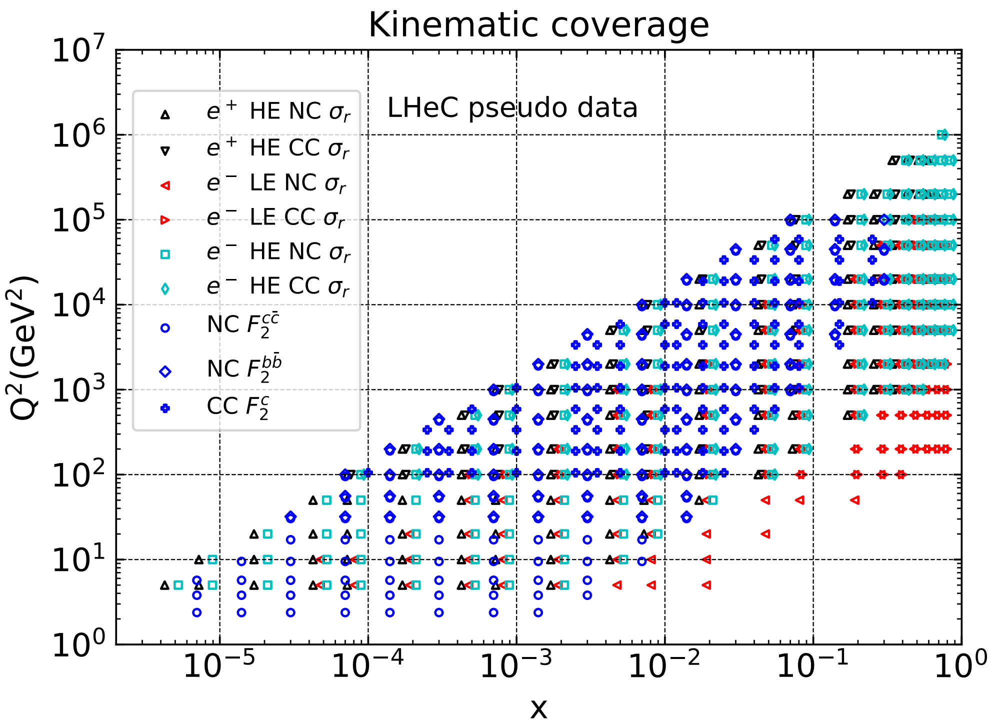
- LHeC projected timeline (several years concurrent operation, plus dedicated run), see arXiv:[1810.13022](1810.13022)

LHeC 1st Run

50 fb^{-1} e– only; 3 yrs;
concurrent with HL-LHC

LHeC full incl.

1000 fb^{-1} e– (P_e=–0.8)
50 fb^{-1} e– (P_e=+0.8)
1 fb^{-1} e+
1 fb^{-1} e– (Ep=1 TeV)

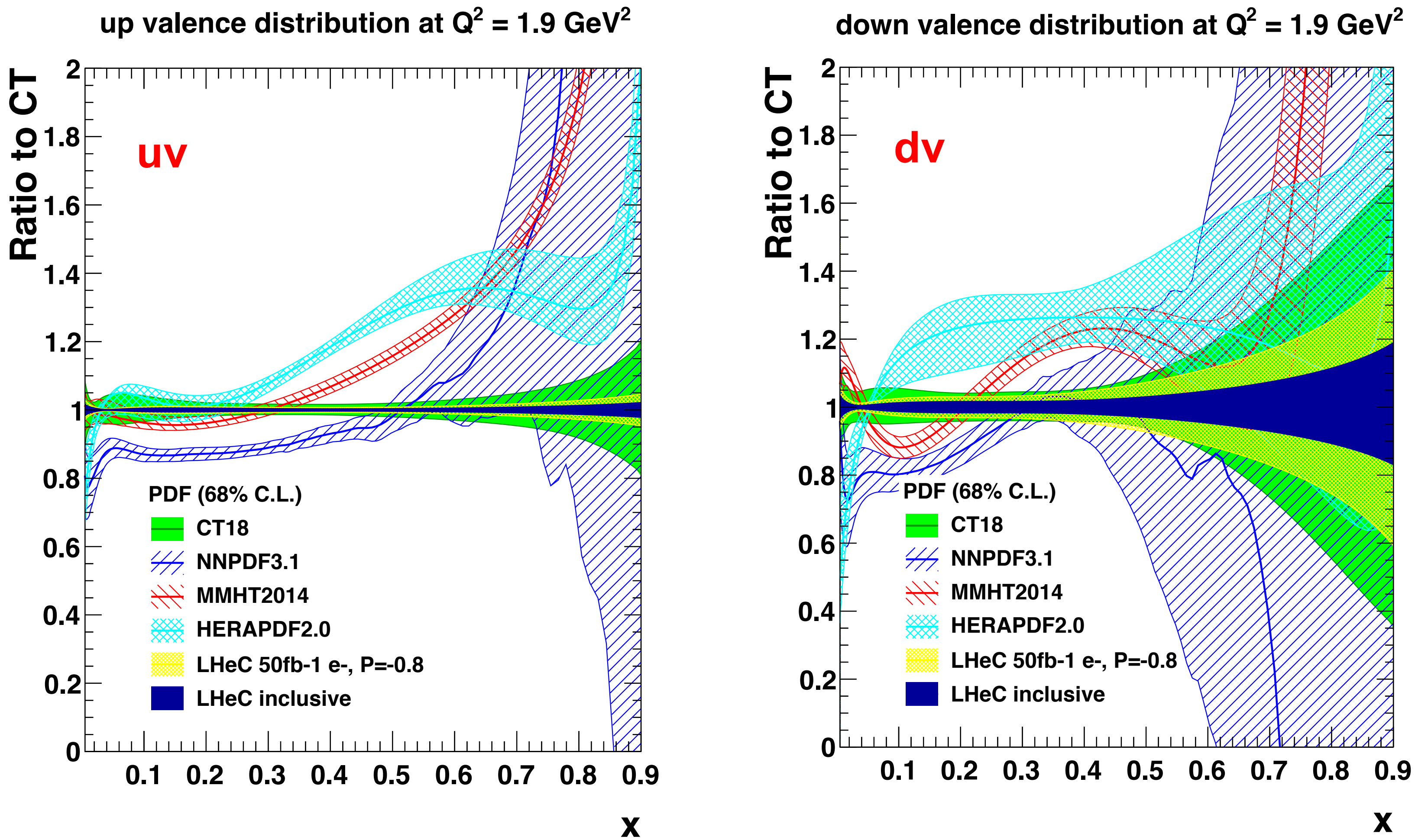


Ee: **50** GeV
HE: Ep=**7** TeV
LE: Ep=**1** TeV

full set of systematic uncertainties considered:
elec. energy scale: 0.1%
hadr. energy scale 0.5%
radiative corrs.: 0.3%
γp at high y: 1%
uncorrelated uncert.: 0.5%
CC syst.: 1.5%
luminosity: 0.5%

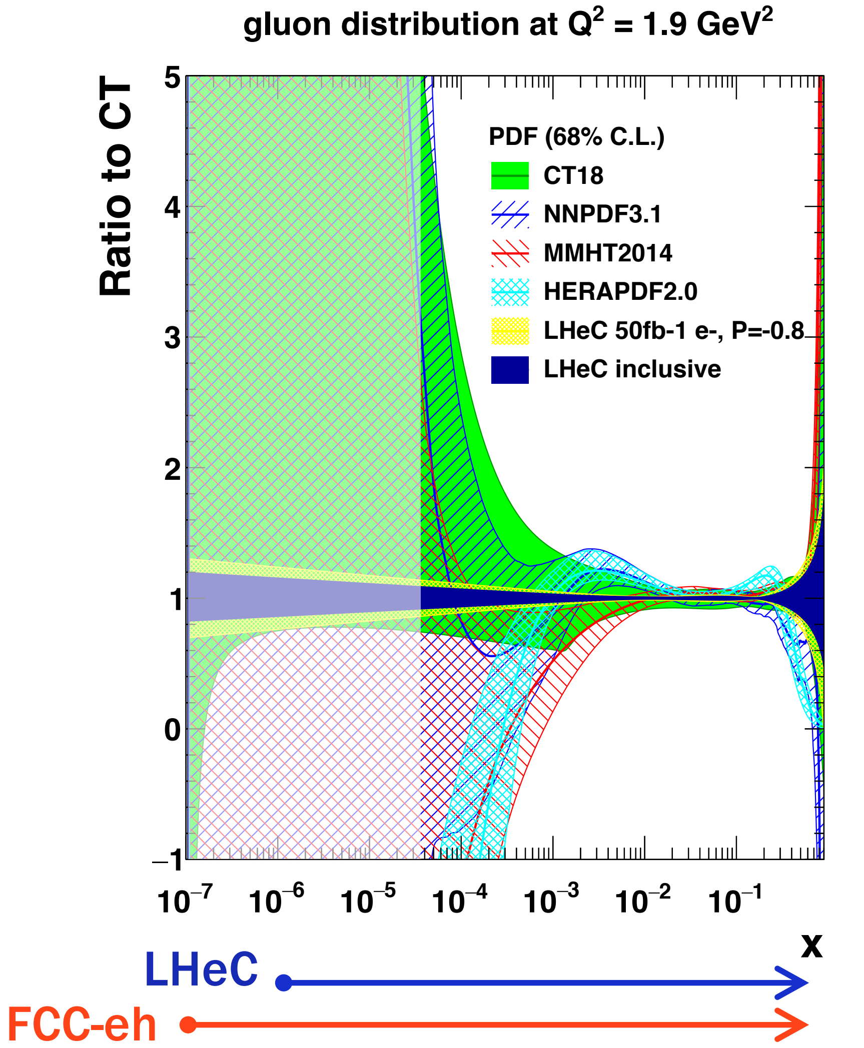
- QCD analysis a la HERAPDF2.0, except more flexible, notably in **NO constraint** requiring dbar=ubar at small x;
- **4+1 xuv, xdv, xUbar, xDbar** and **xg** (**14 free parameters**, cf. 10 by default in CDR)
- **5+1 xuv, xdv, xUbar, xdbar, xsbar** and **xg** (if strange and HQ included; **17 free parameters**)

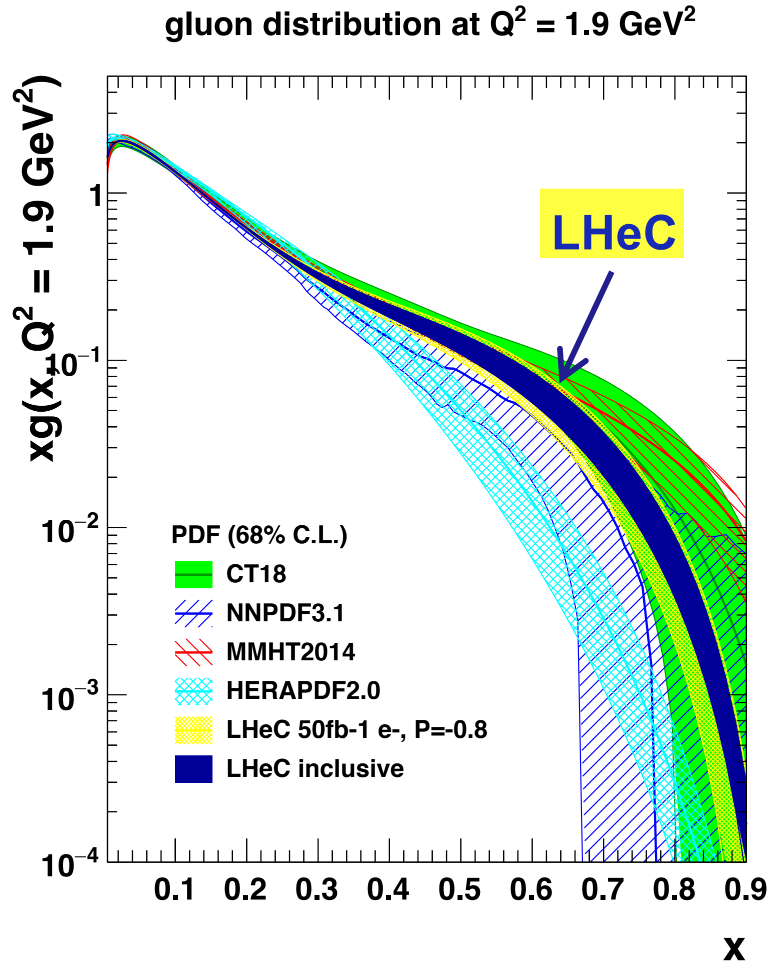
valence quarks



- precision determination, free from higher twist corrections and nuclear uncertainties
- **large x crucial for HL/HE–LHC and FCC searches;** also relevant for DY, MW etc.;
- can also resolve long-standing mystery of d/u ratio at large x

gluon



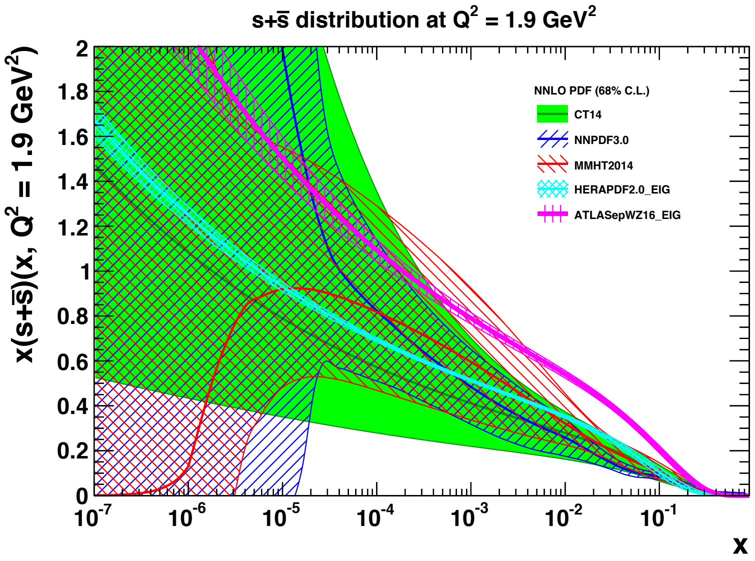


exploration of small x QCD: DGLAP vs BFKL; non-linear evolution; gluon saturation; implications for ultra high energy neutrinos

gluon at large x is small and currently poorly known; **crucial for BSM searches**

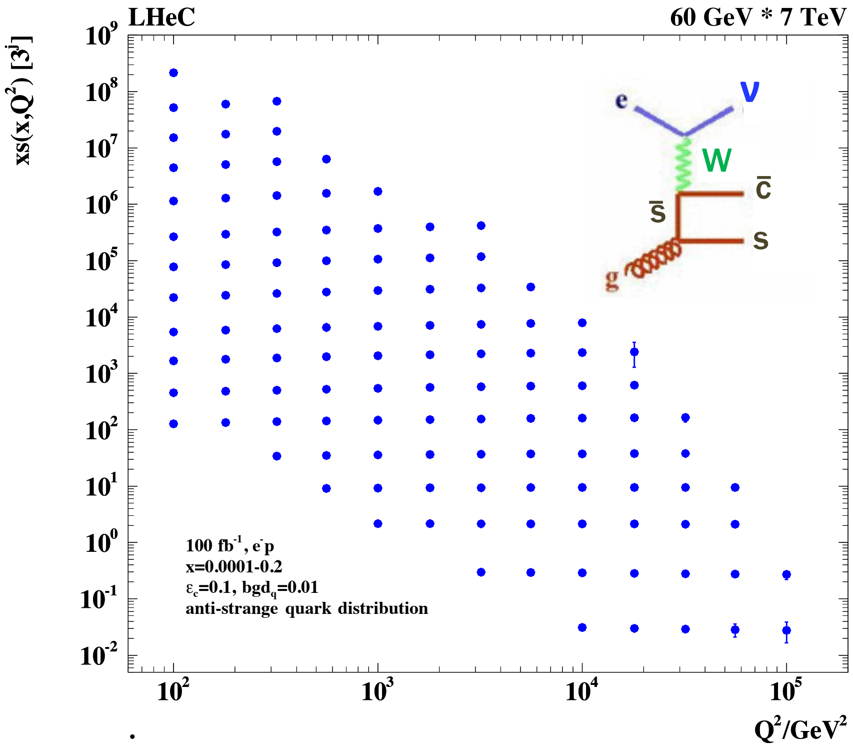
strange, c, b

- **strange pdf** poorly known
- suppressed cf. other light quarks? strange valence?

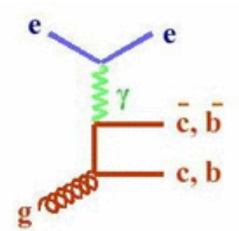


→ **LHeC:** direct sensitivity via charm tagging in Ws→c

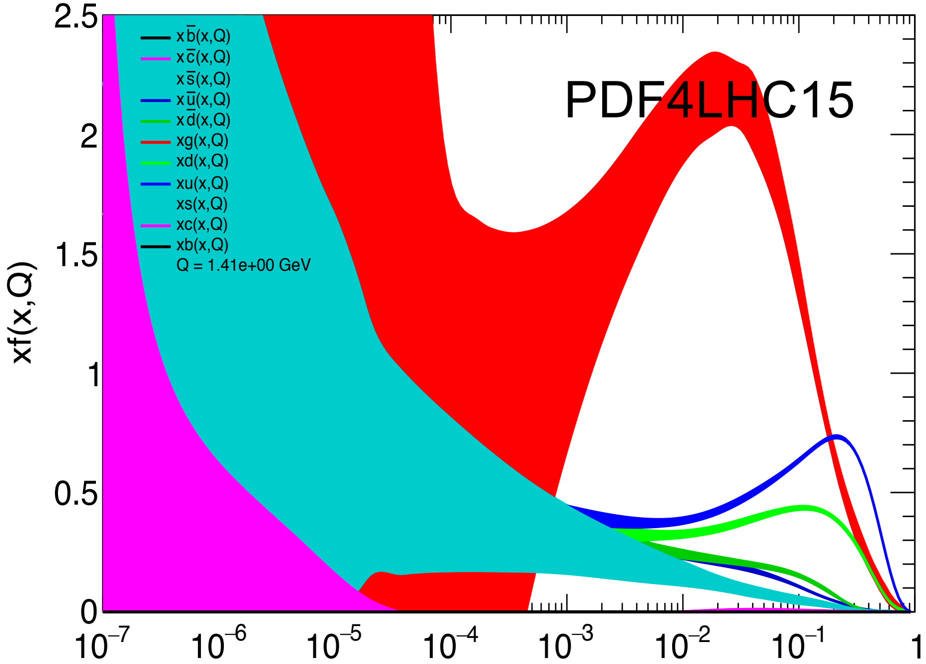
(x,Q^2) mapping of strange density for first time

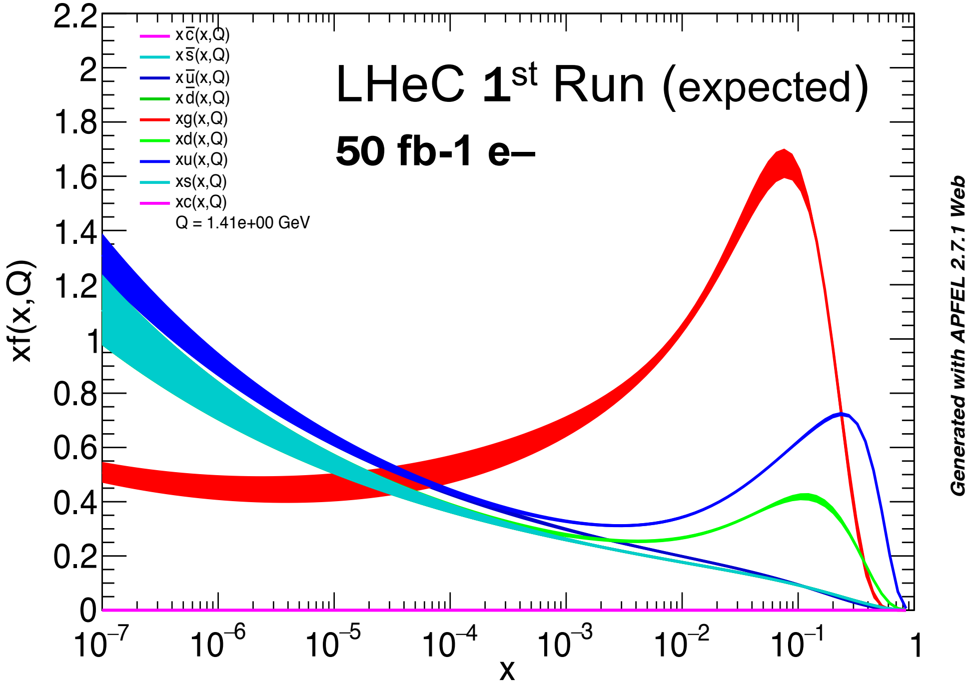


- **c, b:** enormously extended range and much improved precision c.f. HERA
- **δMc = 50 (HERA)** to **3 MeV**: impacts on **α**s, regulates ratio of charm to light, crucial for precision t, H
- **δMb** to **10 MeV**; MSSM: Higgs produced dominantly via $b\bar{b}$ → A



summary of LHeC pdfs

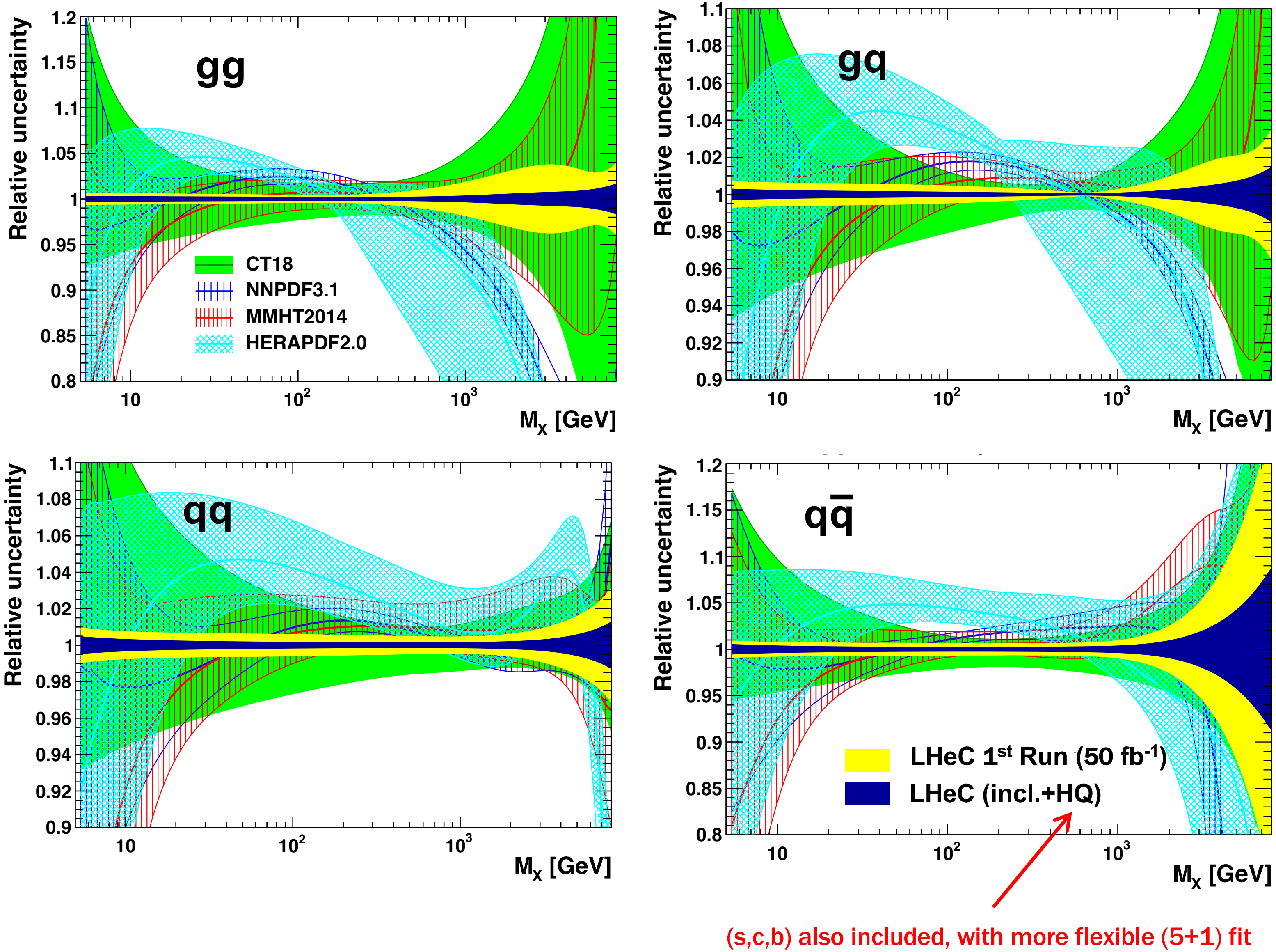




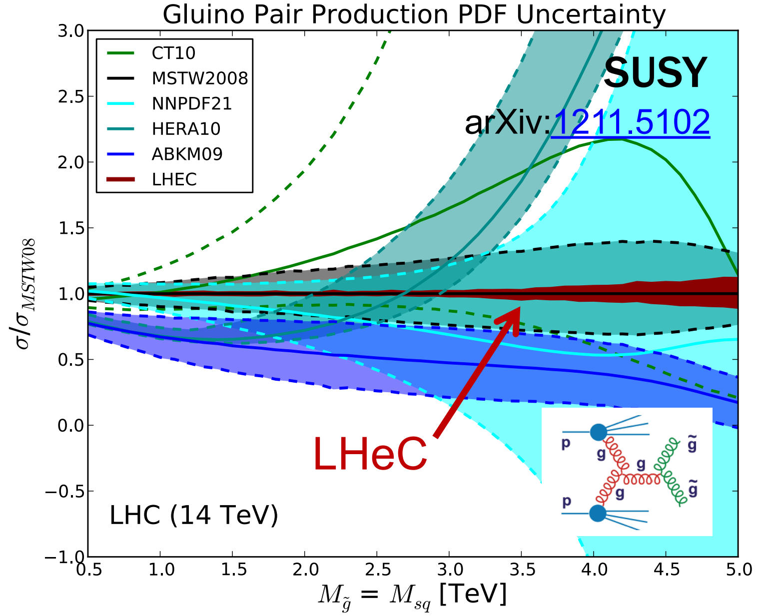
situation today → after 1st LHeC Run

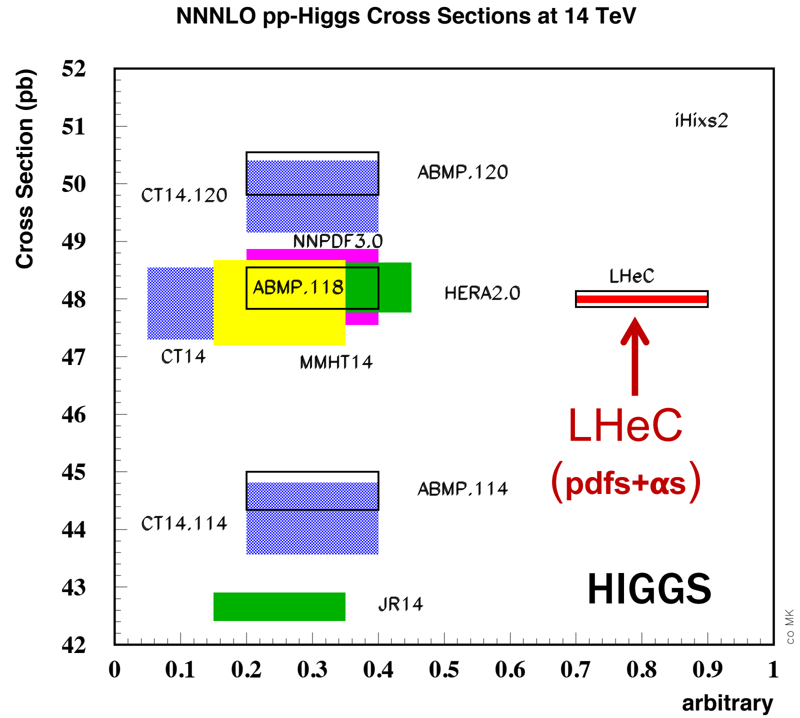
with further improvements after full running period, plus HQs, (DIS jets, …)

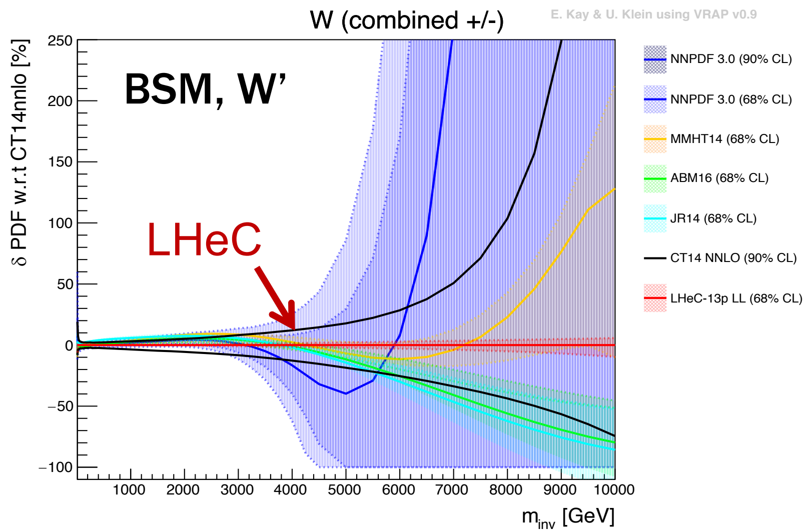
pdf luminosities @ 14TeV



empowering the LHC

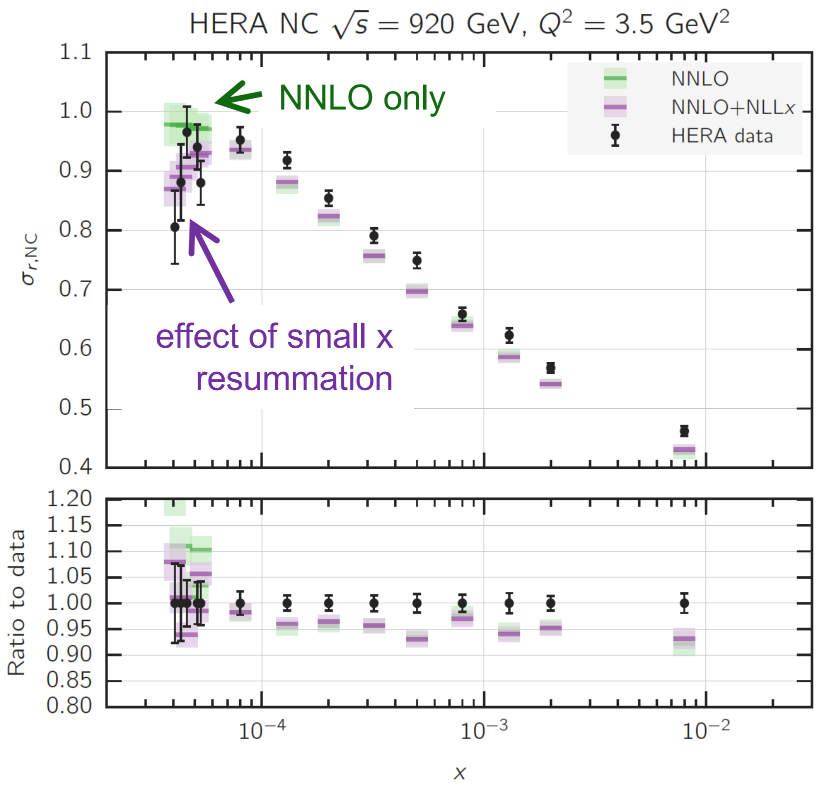


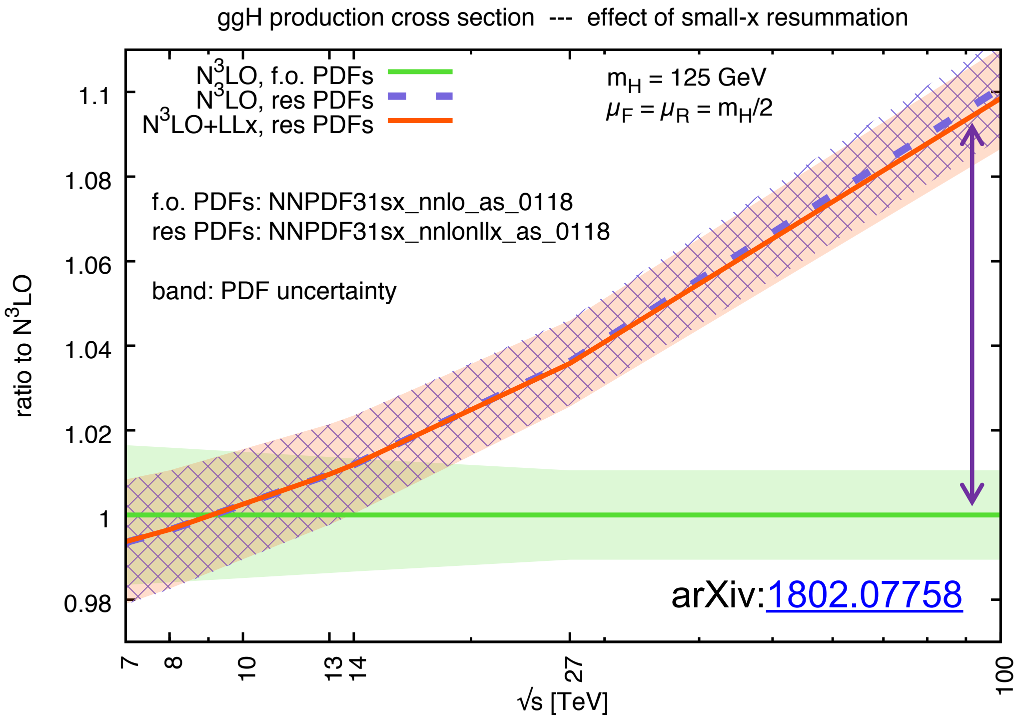




- external, reliable, precise pdfs needed for range extension and interpretation
- **BSM**, gluons and quarks at large x (SUSY, LQs, additional high mass bosons, …)
- **Higgs**, theory uncert. dominated by **pdfs+αs**
- SM parameters, EG. **MW**, **sin²θW** (see white paper)

more on small x QCD



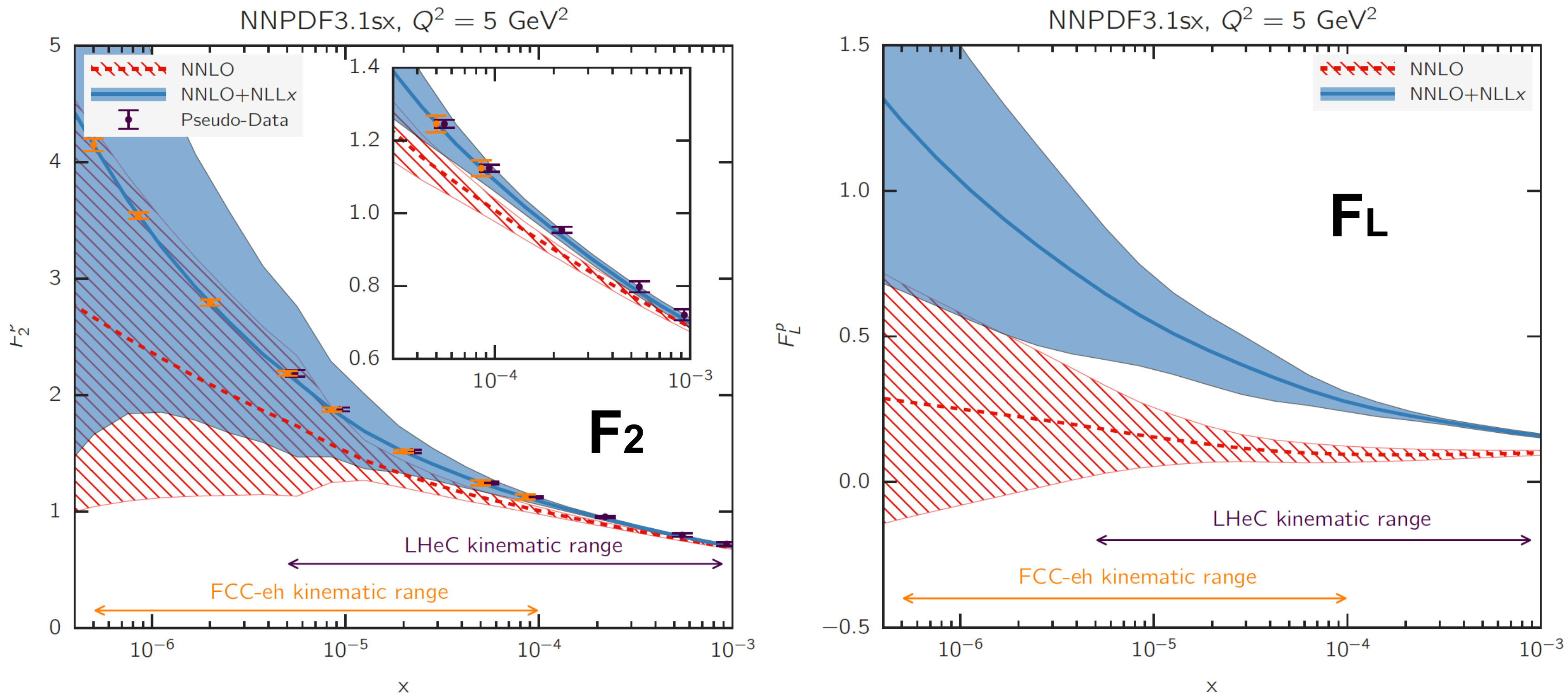


- recent evidence for onset of BFKL dynamics in HERA inclusive data,
- arXiv:1710.05935; confirmed in xFitter study, arXiv:1802.00064

- effect of small x resummation on ggH cross section for LHC, HE-LHC, FCC
- impact for LHC, and most certainly at ultra low x values probed at FCC

- LHeC and FCC-eh have unprecedented kinematic reach to **explore small x** phenomena

LHeC sensitivity to small x phenomena



F2 and FL predictions for simulated kinematics of **LHeC** and **FCC-eh**

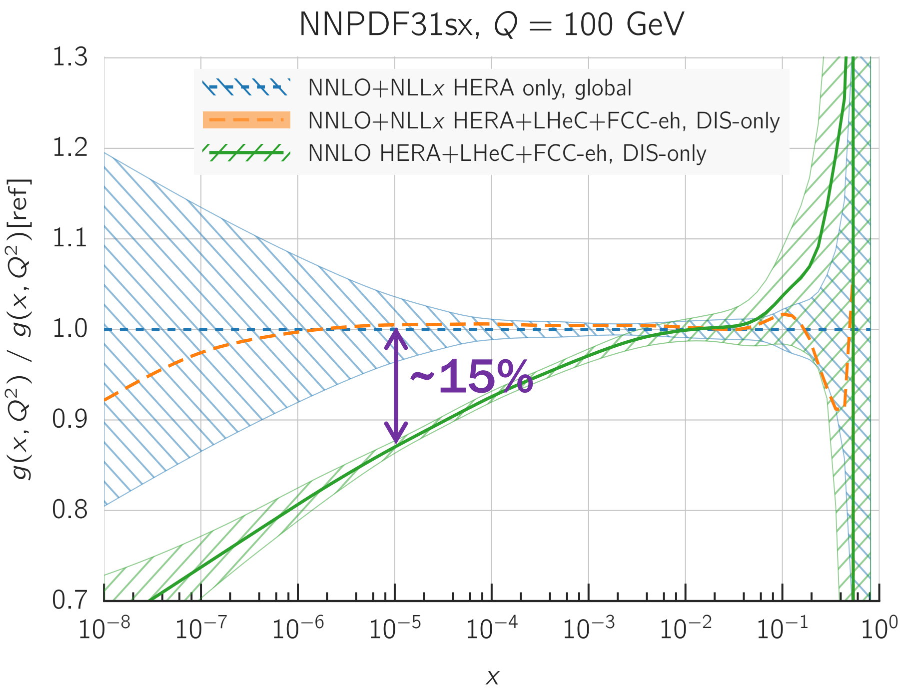
- **ep simulated data very precise** – significant constraining power to discriminate between theoretical scenarios of small x dynamics, arXiv:1710.05935
- **measurement of FL has a critical role to play**
  see, EG. arXiv:1802.04317

small x resummation

- NNLO+NLLx resummed calculation used to produce **LHeC** and **FCC-eh** simulated inclusive NC and CC pseudo-data
- then, fitted using **NNLO (DGLAP only)** vs. **NNLO+NLLx**

X^2 per DOF	LHeC / FCC-eh
NNLO:	**1.71 / 2.72**
NNLO+NLLx	**1.22 / 1.34**

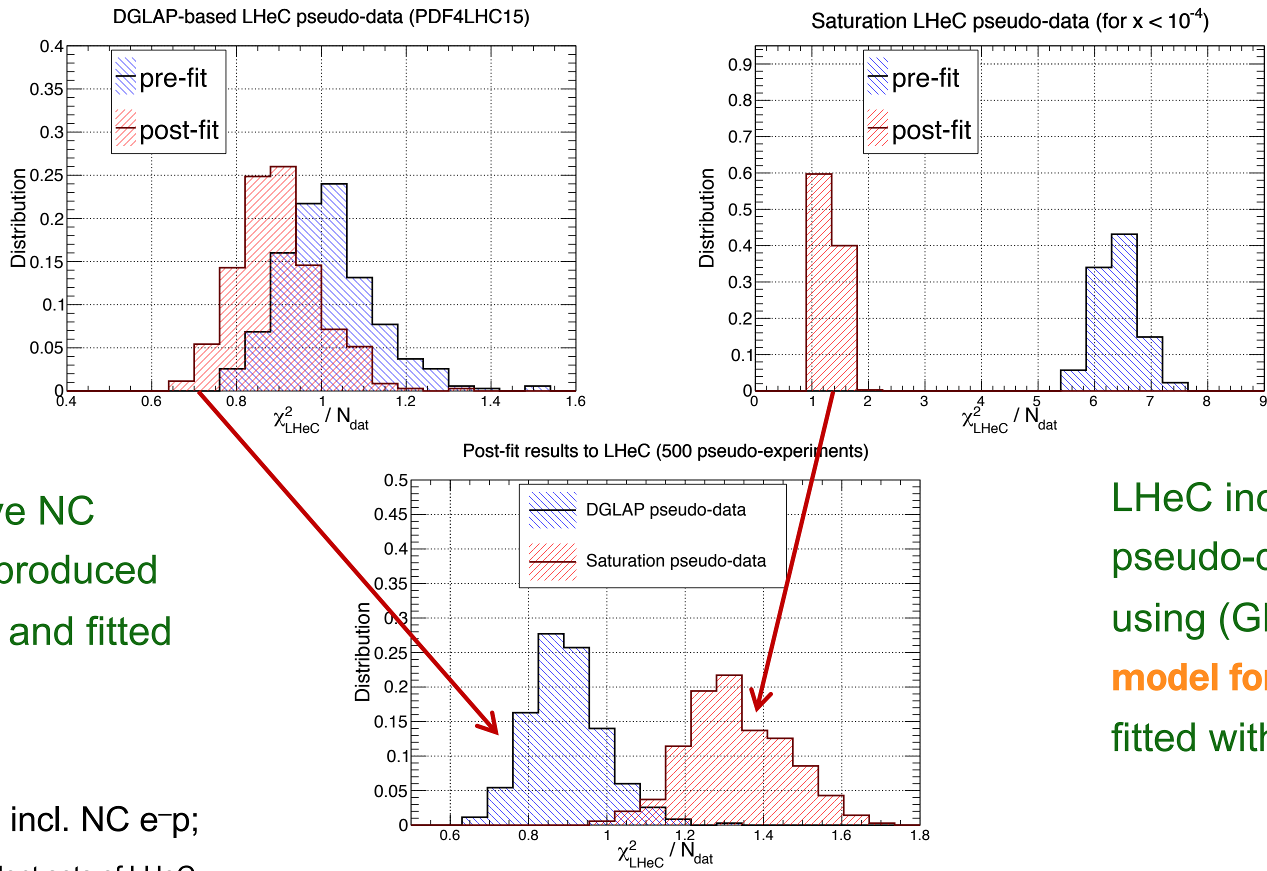
- substantial difference in extracted gluon (**10** (**15**)% at x=**10^{-4}** (**10^{-5}**))
- much larger than precision with which gluon can be determined using LHeC or FCC-eh DIS data



- large sensitivity and discriminatory power to pin down details of **small x QCD dynamics**

non-linear QCD dynamics

- with the unprecedented small-x reach, **gluon recombination / parton saturation may also be expected**, manifesting as deviation from linear DGLAP



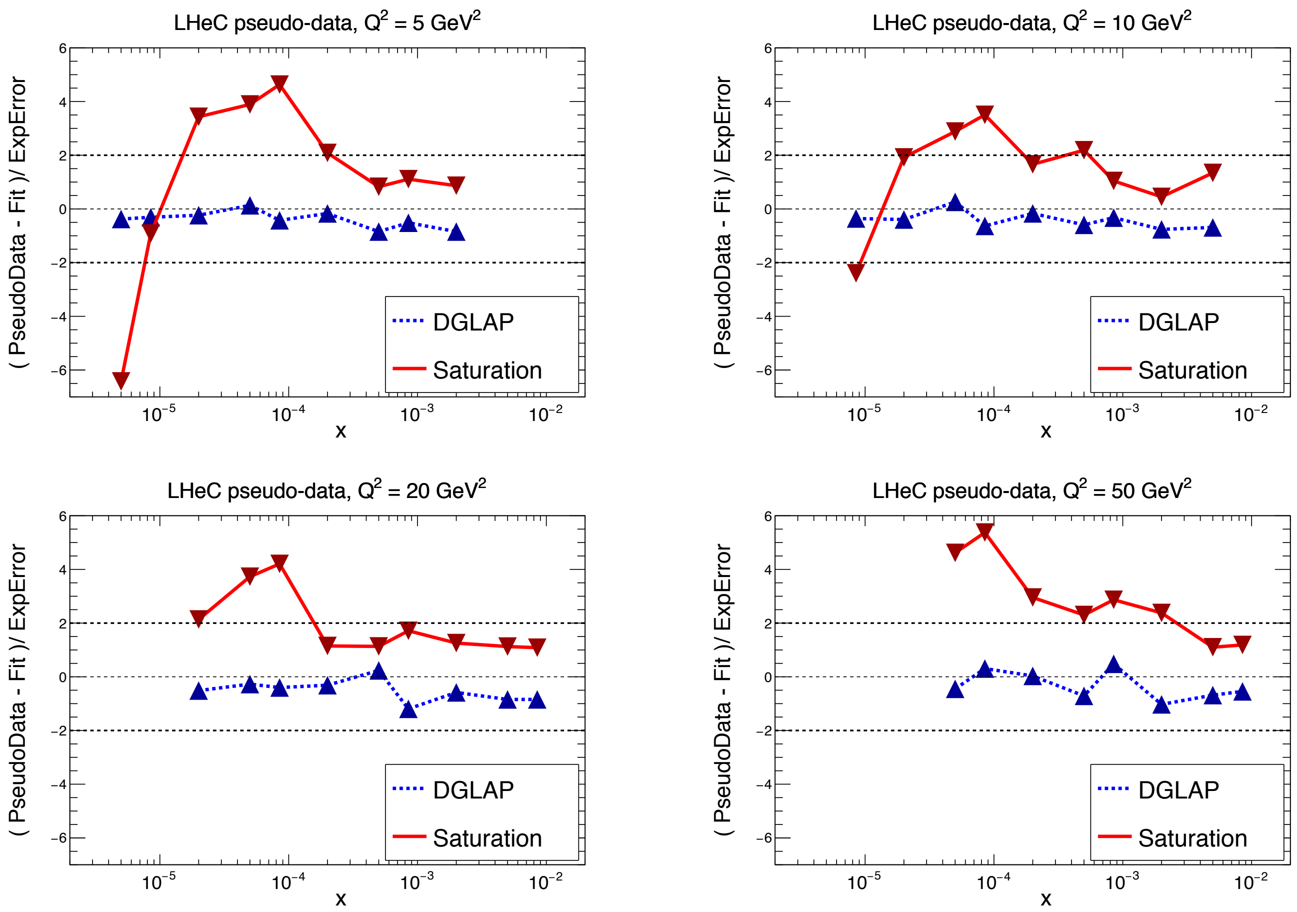
LHeC inclusive NC pseudo-data produced using **DGLAP**, and fitted with **DGLAP**

LHeC inclusive NC pseudo-data produced using (GBW) **saturation model for x ≤ 10^{-4}**, and fitted with **DGLAP**

LHeC HE and LE incl. NC e⁻p;

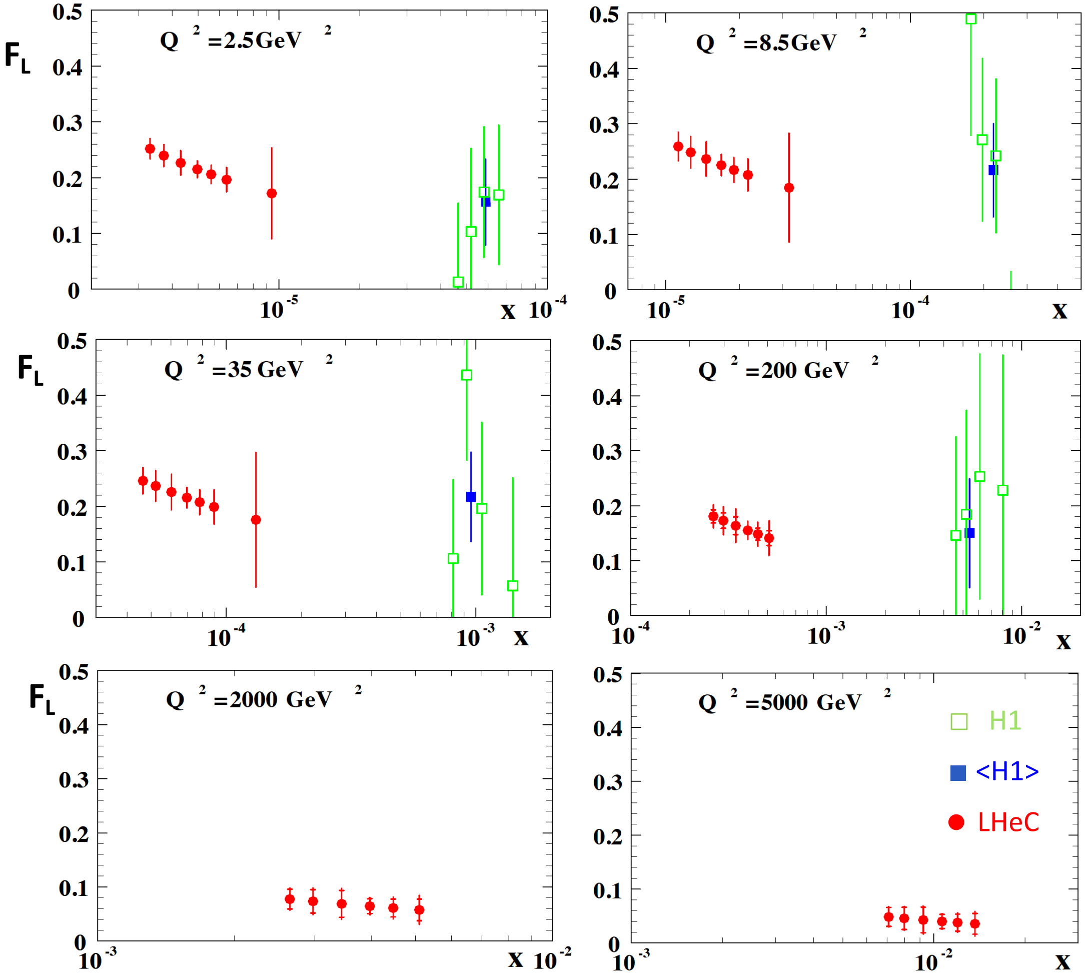
(Nexp=500 independent sets of LHeC pseudodata, each characterised by different random fluctuations)

non-linear QCD dynamics



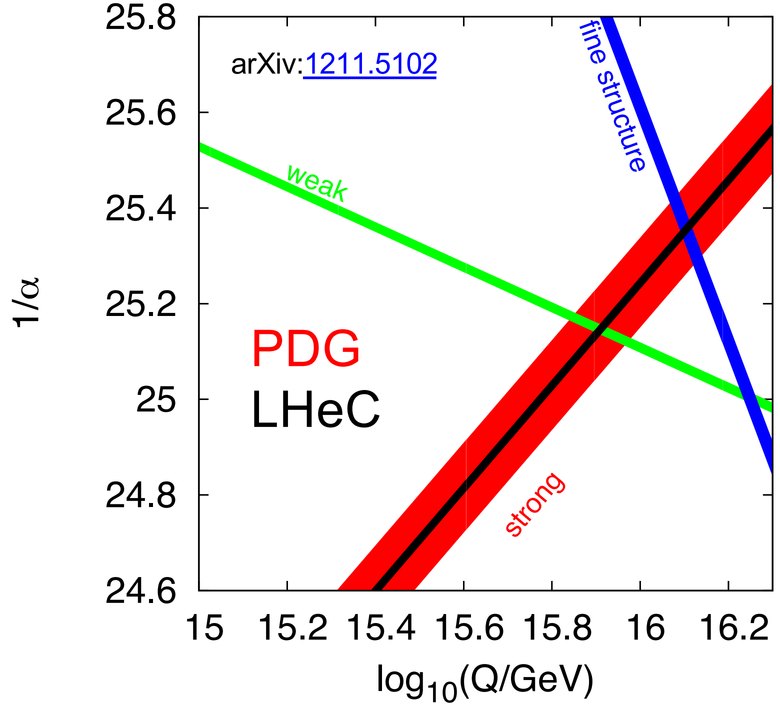
- inspect **PULLS** to highlight origin of worse agreement: in **saturation case (fitted with DGLAP)**, theory wants to overshoot data at smallest x, and undershoot at higher x
- while a different x dependence might be absorbed into PDFs at scale Q_0, this is not possible with a Q^2 dependence – **large Q^2 lever arm crucial**

FL from the LHeC

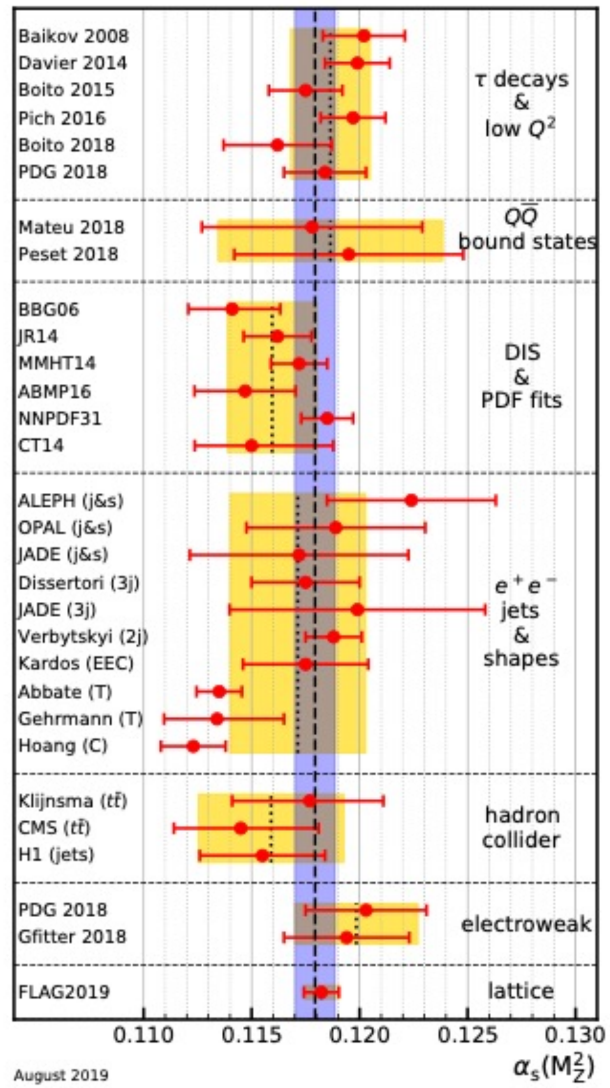


- **expect significant additional discrimination from dedicated precision measurement of FL** (not yet included in shown studies); incorrect **small x** treatment unlikely to accommodate both F2 **and** FL

strong coupling, αs



PDG19



- **αs is the least known coupling**
- needed: for cross section predictions, including Higgs; to constrain GUT scenarios, etc.
- measurements not all consistent:– what is true central value, uncertainty? is αs(DIS) lower than world average? role of lattice QCD?

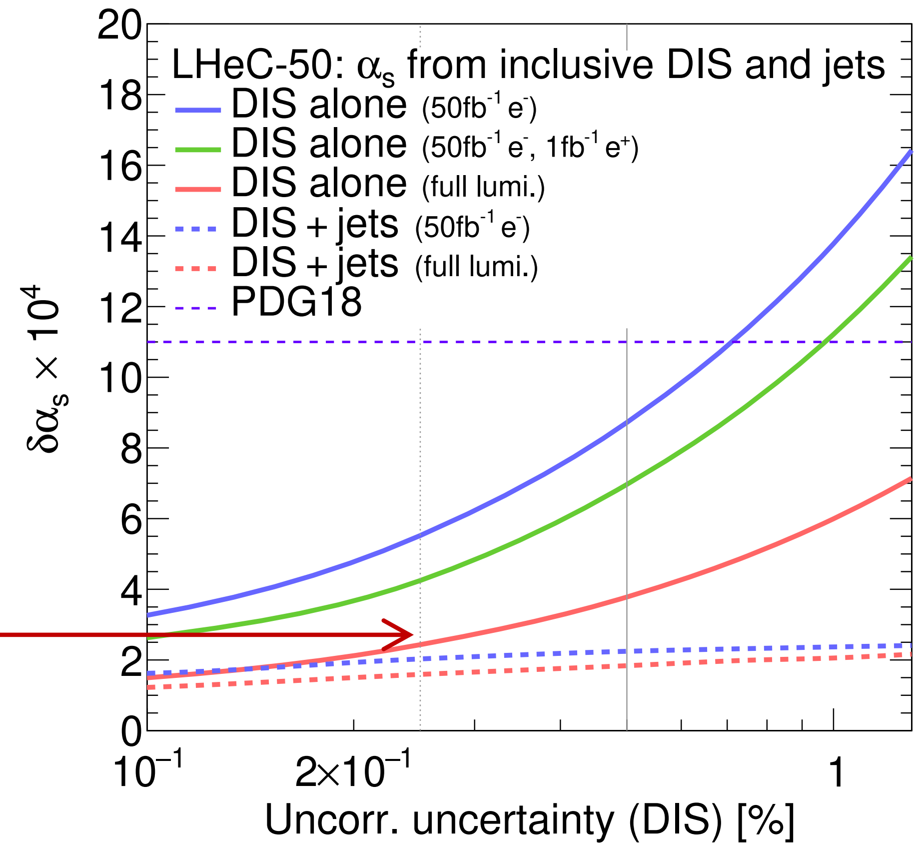
world ave. $\alpha_s(M_Z^2) = 0.1179 \pm 0.0010$

αs from LHeC inclusive NC/CC DIS

- **αs** from inclusive NC/CC DIS:
- simultaneous determination of **pdfs** and **αs** in **NNLO QCD** fit

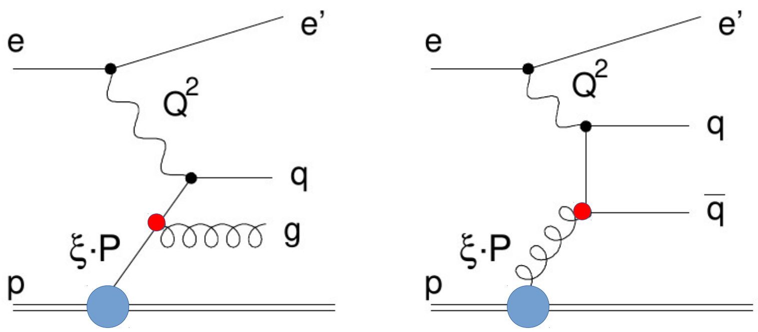
- **3** LHeC scenarios:
- LHeC **1**st Run (**50** fb^{-1} e-p)
- plus **1** fb^{-1} positron data
- full inclusive LHeC dataset (**1** ab^{-1})

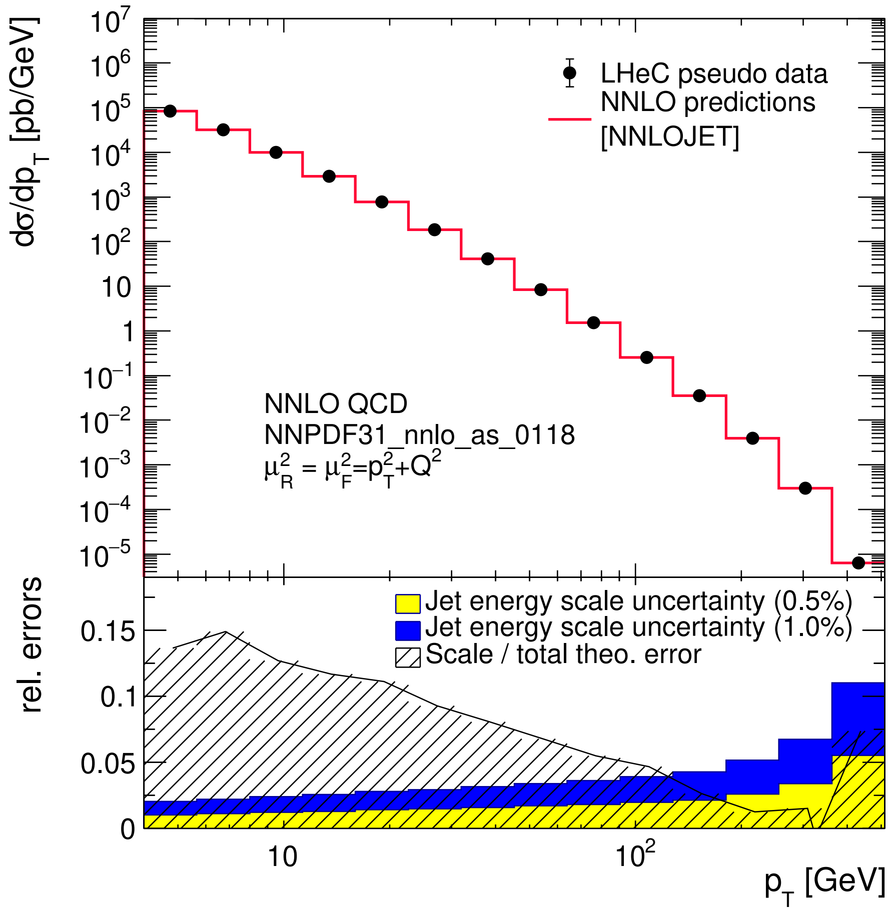
$$\Delta\alpha_s(M_Z)(\text{incl. DIS}) = \pm 0.00022_{(\text{exp+PDF})}$$



- **αs** to better than **2** permille experimental uncertainty!
- inclusion of jet cross sections yields further improvement, and stabilises against uncorrelated uncertainty scenario →

NC DIS jet production at the LHeC





- **sensitive to αs at lowest order**
- different dependencies on **xg(x)** and **αs** c.f. inclusive DIS; improved constraints on both, when used in simultaneous **pdf+αs** fit

- NNLO QCD calculations for DIS jets available in NNLOJet (arXiv:1606.03991, 1703.05977), and implemented in APPLfast (arXiv:1906.05303)

- full set of systematic uncertainties considered; benchmarked with H1, ZEUS, ATLAS, CMS

Exp. uncertainty	Shift	Size on σ [%]
Statistics with 1 ab^{-1}	min. 0.15 %	0.15 – 5
Electron energy	0.1 %	0.02 – 0.62
Polar angle	2 mrad	0.02 – 0.48
Calorimeter noise	±20 MeV	0.01 – 0.74
Jet energy scale (JES)	0.5 %	0.2 – 4.4
Uncorrelated uncert.	0.6 %	0.6
Normalisation uncert.	1.0 %	1.0

αs from LHeC NC DIS jet production

- **αs** extracted in **NNLO QCD** fit to LHeC simulated jet data only
- methodology as for arXiv:1709.07251, 1906.05303

$$\Delta\alpha_s(M_Z)(\text{jets}) = \pm 0.00013_{(\text{exp})} \pm 0.00010_{(\text{PDF})}$$

- extraordinary experimental precision
- scale uncertainty dominates $\Delta\alpha_s(M_Z) = 0.0035\,(\text{NNLO})$

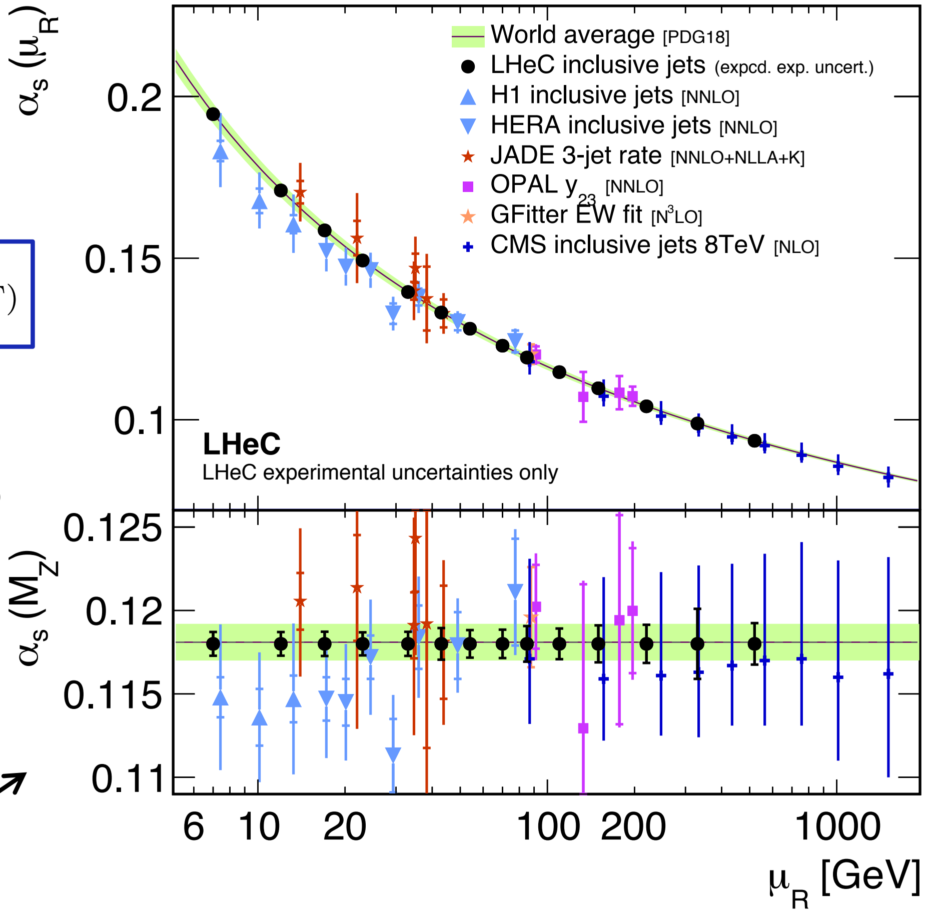
  restricting to higher pt or Q^2 can reduce to

  $\Delta\alpha_s(M_Z) \approx 0.0010$

  trade off with increased experimental uncertainties

  (N^3LO by **2030**s ?)

- **αs** running tested over two orders of magnitude in μR



$= \sqrt{(Q^2 + p_T^2)}$

- enormous improvement over other jet-based measurements
- LHeC uniquely connects low $\mathcal{O}$(GeV) scales with high $\mathcal{O}$(MZ) scales

LHeC αs summary

- LHeC is an ideal QCD laboratory
- connects low-scale to **Z**-pole and beyond with high experimental precision

- **inclusive NC/CC DIS only:**

$$\Delta\alpha_s(M_Z)(\text{incl. DIS}) = \pm 0.00022_{(\text{exp+PDF})}$$

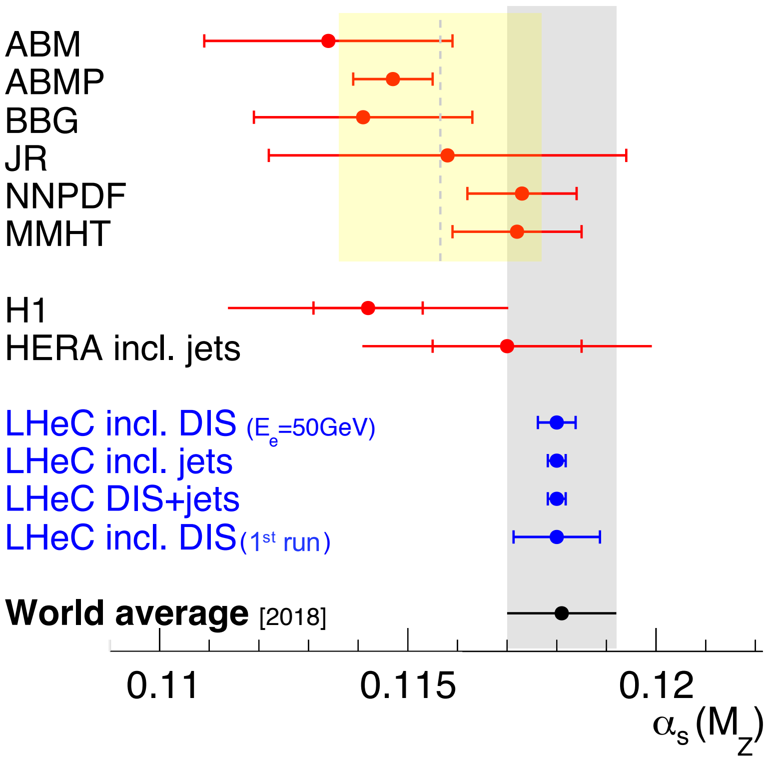
- **inclusive jet cross sections only:**

$$\Delta\alpha_s(M_Z)(\text{jets}) = \pm 0.00013_{(\text{exp})} \pm 0.00010_{(\text{PDF})}$$

- **inclusive DIS <u>and</u> jet cross sections:**

$$\Delta\alpha_s(M_Z)(\text{incl. DIS \& jets}) = \pm 0.00018_{(\text{exp+PDF})}$$

αs determinations at NNLO:



- achievable precision on same level as αs determination from FCC-ee
- QCD theory uncertainties will be limiting factor for ultimate precision

- other sensitive processes/measurements: dijets, multijets, HQs, jets in γp, event shapes, …

summary

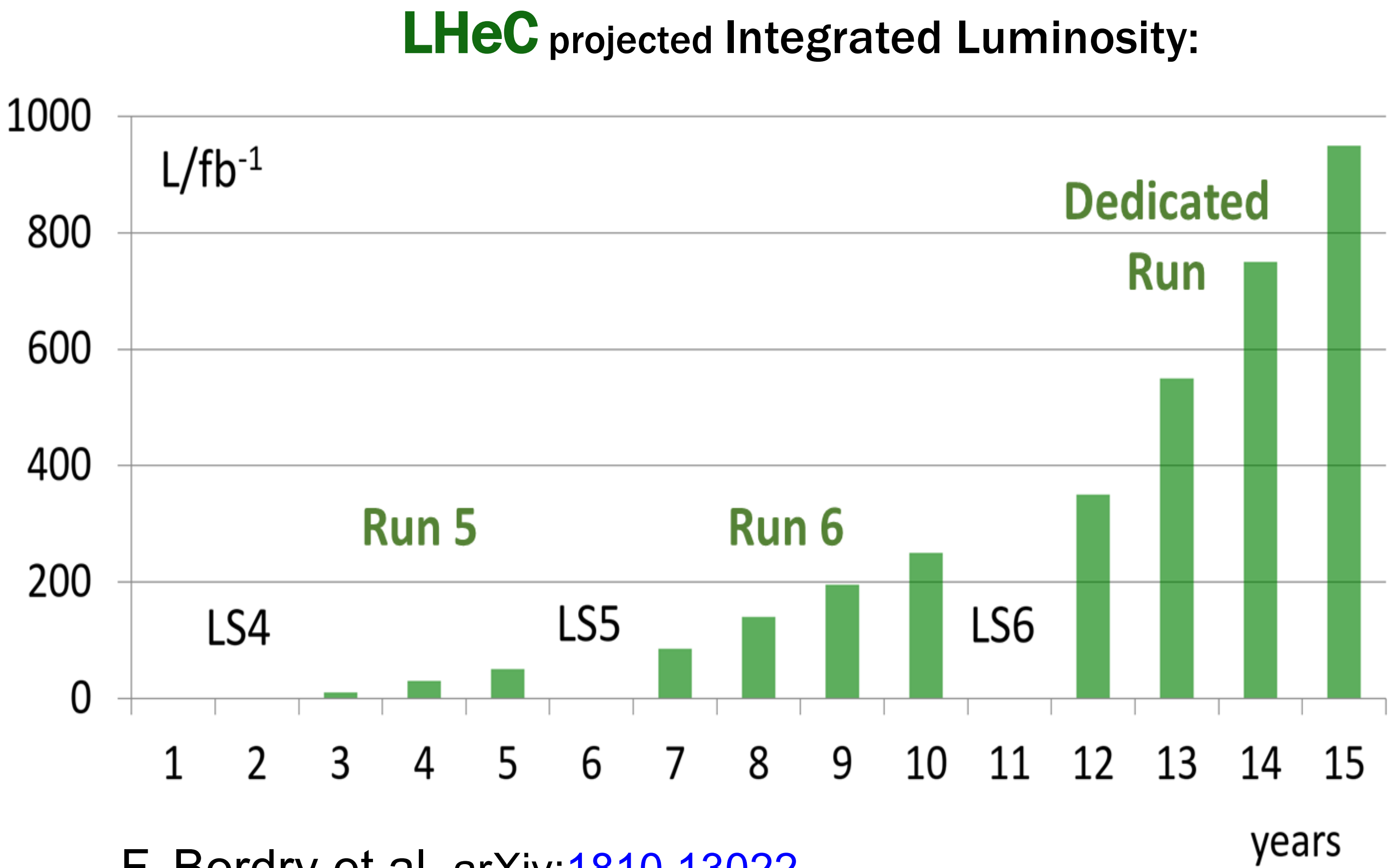
- energy frontier **electron-proton colliders** essential for full exploitation of current and future hadron colliders (Higgs, BSM, electroweak, …)
- **external precision pdf input**; complete q,g unfolding, high luminosity $x \longrightarrow 1$, s, c, b, (t); N3LO; small x; strong coupling to permille precision; …

- NEW LHeC white paper summarises wealth of new and updated studies
- enormously rich physics programme both in **own right**, and for **transformation of proton-proton machines** into precision facilities

- **all critical pdf information can be obtained early** (~ **50** fb^{-1} ≡ **×50** HERA), in parallel with HL-LHC operation
- **α_s** to permille exp. precision also achievable early, with use of NC DIS jets
- unprecedented access to novel kinematic regime, with **unique potential to explore novel small x phenomena**

extras

LHeC timescale



F. Bordry et al. arXiv:1810.13022

LHeC simulated data

Source of uncertainty	Uncertainty
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 %
Radiative corrections	0.3 %
Photoproduction background (for $y > 0.5$)	1 %
Global efficiency error	0.5 %

Table 3.1: Assumptions used in the simulation of the NC cross sections on the size of uncertainties from various sources. The top three are uncertainties on the calibrations which are transported to provide correlated systematic cross section errors. The lower three values are uncertainties of the cross section caused by various sources.

Parameter	Unit	Data set								
		D1	D2	D3	D4	D5	D6	D7	D8	D9
Proton beam energy	TeV	7	7	7	7	1	7	7	7	7
Lepton charge		−1	−1	−1	−1	−1	+1	+1	−1	−1
Longitudinal lepton polarisation		−0.8	−0.8	0	−0.8	0	0	0	+0.8	+0.8
Integrated luminosity	fb^{-1}	5	50	50	1000	1	1	10	10	50

Table 3.2: Summary of characteristic parameters of data sets used to simulate neutral and charged current $e^{\pm}$ cross section data, for a lepton beam energy of $E_e = 50\,\text{GeV}$. Sets D1-D4 are for $E_p = 7\,\text{TeV}$ and e^-p scattering, with varying assumptions on the integrated luminosity and the electron beam polarisation. The data set D1 corresponds to possibly the first year of LHeC data taking with the tenfold of luminosity which H1/ZEUS collected in their lifetime. Set D5 is a low Ep energy run, essential to extend the acceptance at large x and medium Q^2. D6 and D7 are sets for smaller amounts of positron data. Finally, D8 and D9 are for high energy e^-p scattering with positive helicity as is important for electroweak NC physics. These variations of data taking are subsequently studied for their effect on PDF determinations.

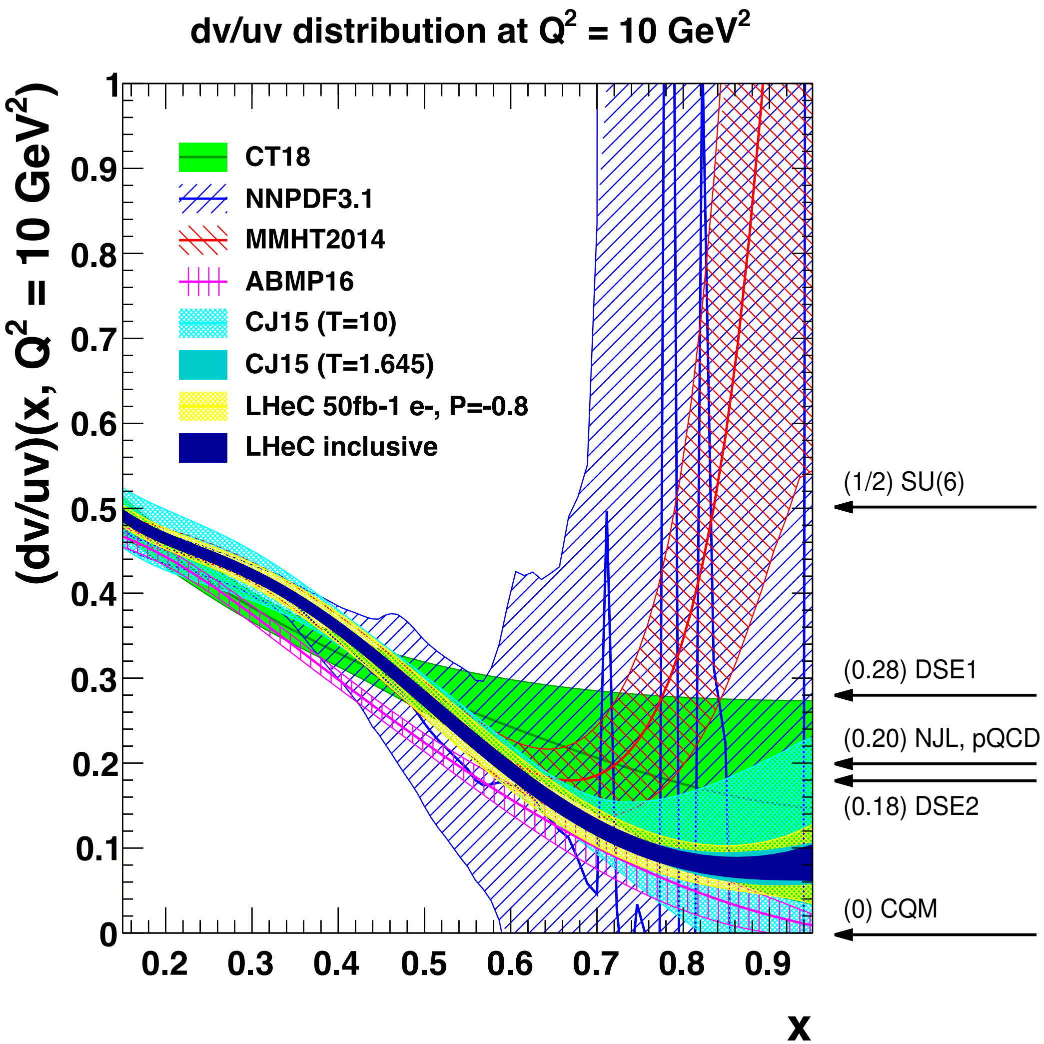
LHeC pdf parameterisation

- QCD fit ansatz based on HERAPDF2.0, with following differences:
- no requirement that ubar=dbar at small x
- no negative gluon term (only for the aesthetics of ratio plots – it has been checked that this does not impact size of projected uncertainties)

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

- **4+1** pdf fit (above) has **14 free parameters**
- **5+1** pdf fit for HQ studies parameterises dbar and sbar separately, **17 free parameters**

d/u at large x



d/u essentially unknown at large x

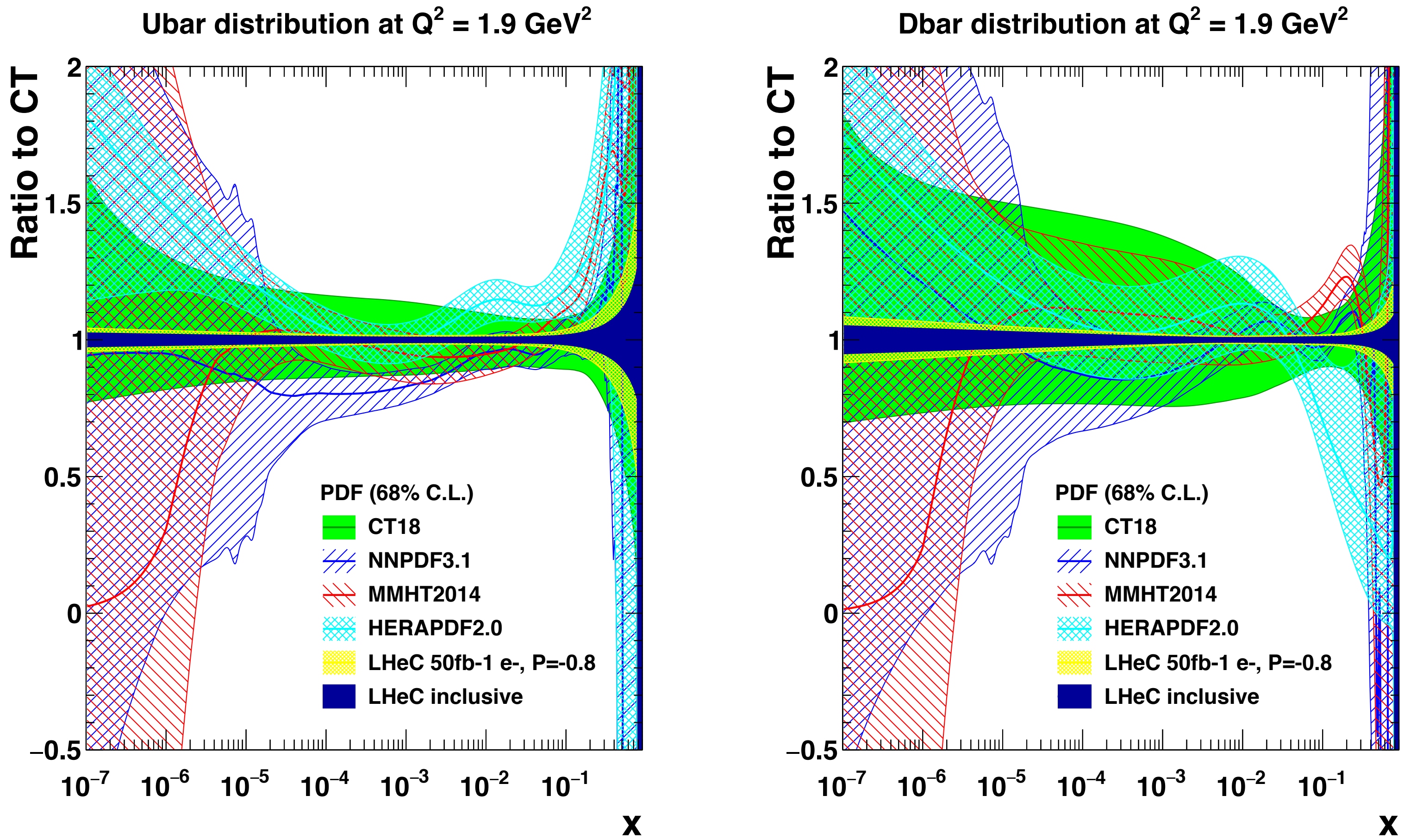
no predictive power from current pdfs;

conflicting theory pictures;

data inconclusive, large nuclear uncertainties

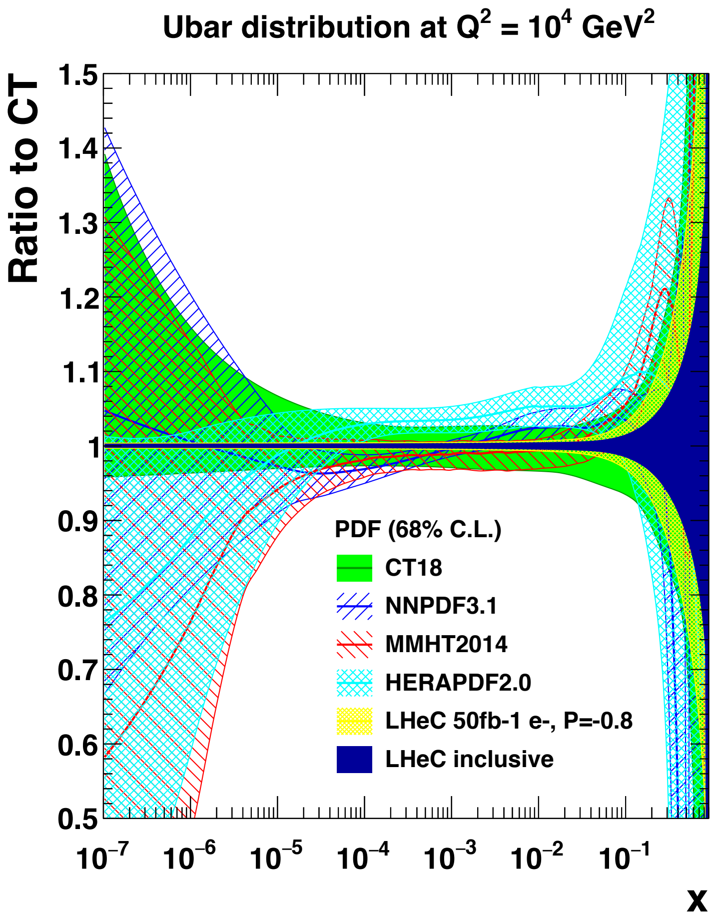
can resolve long-standing mystery of d/u ratio at large x

sea quarks

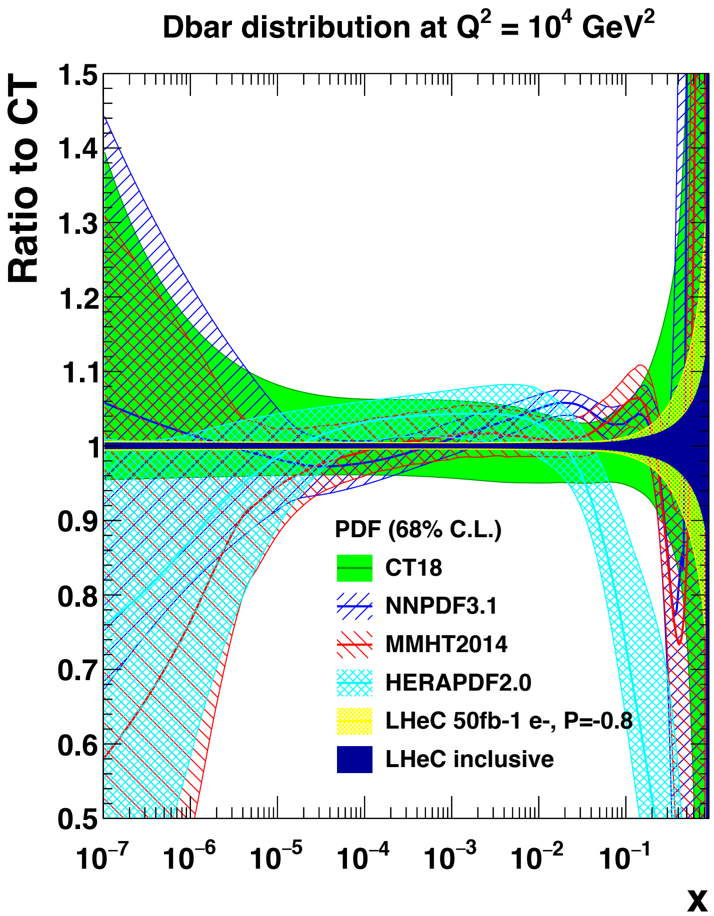


Ubar distribution at Q^2 = 1.9 GeV^2
Dbar distribution at Q^2 = 1.9 GeV^2
Ratio to CT
x
PDF (68% C.L.)
CT18
NNPDF3.1
MMHT2014
HERAPDF2.0
LHeC 50fb-1 e-, P=-0.8
LHeC inclusive

sea quarks

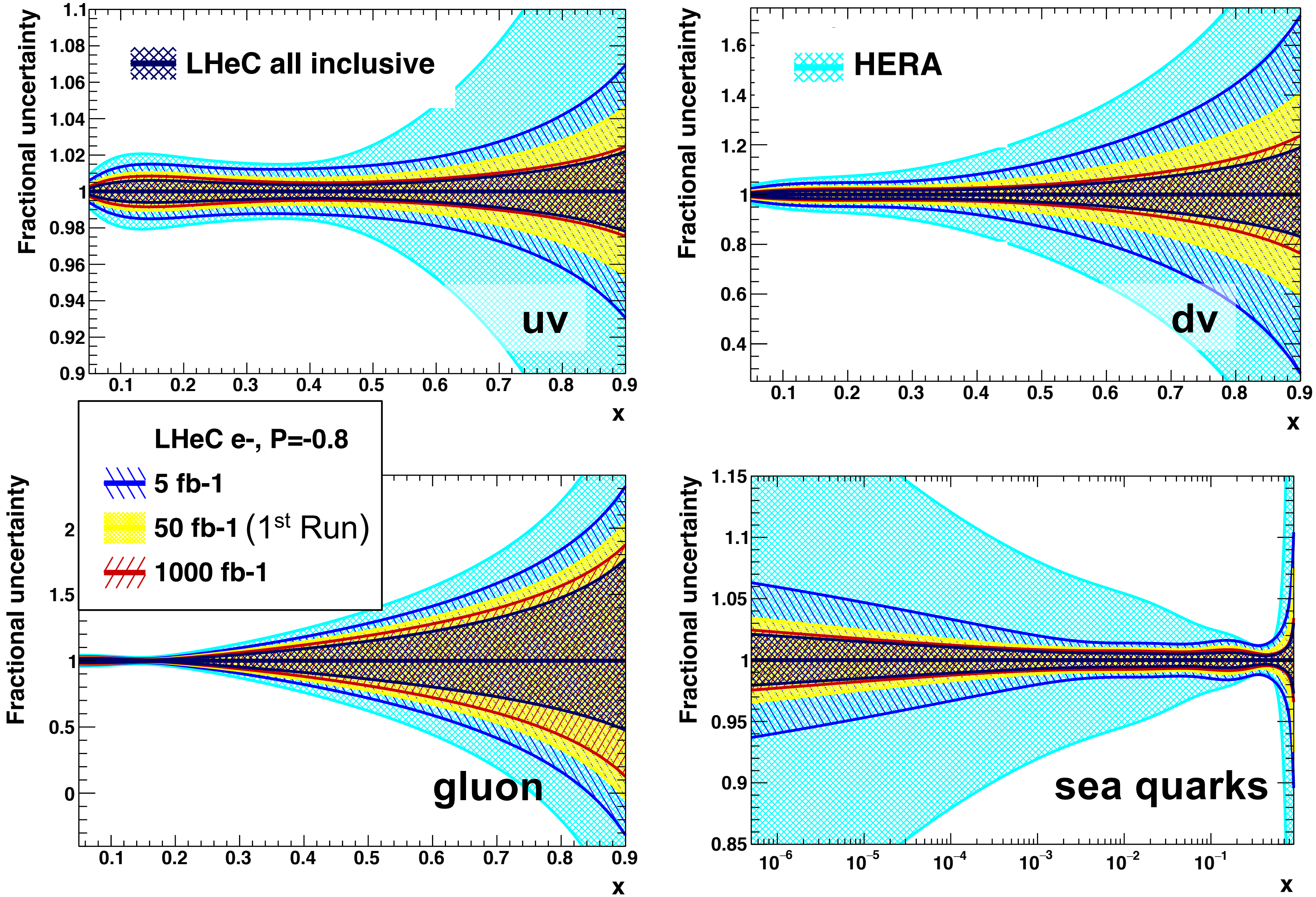


Ubar distribution at Q2 = 10^4 GeV2
Ratio to CT
x
PDF (68% C.L.)
CT18
NNPDF3.1
MMHT2014
HERAPDF2.0
LHeC 50fb-1 e-, P=-0.8
LHeC inclusive



Dbar distribution at Q2 = 10^4 GeV2
Ratio to CT
x
PDF (68% C.L.)
CT18
NNPDF3.1
MMHT2014
HERAPDF2.0
LHeC 50fb-1 e-, P=-0.8
LHeC inclusive

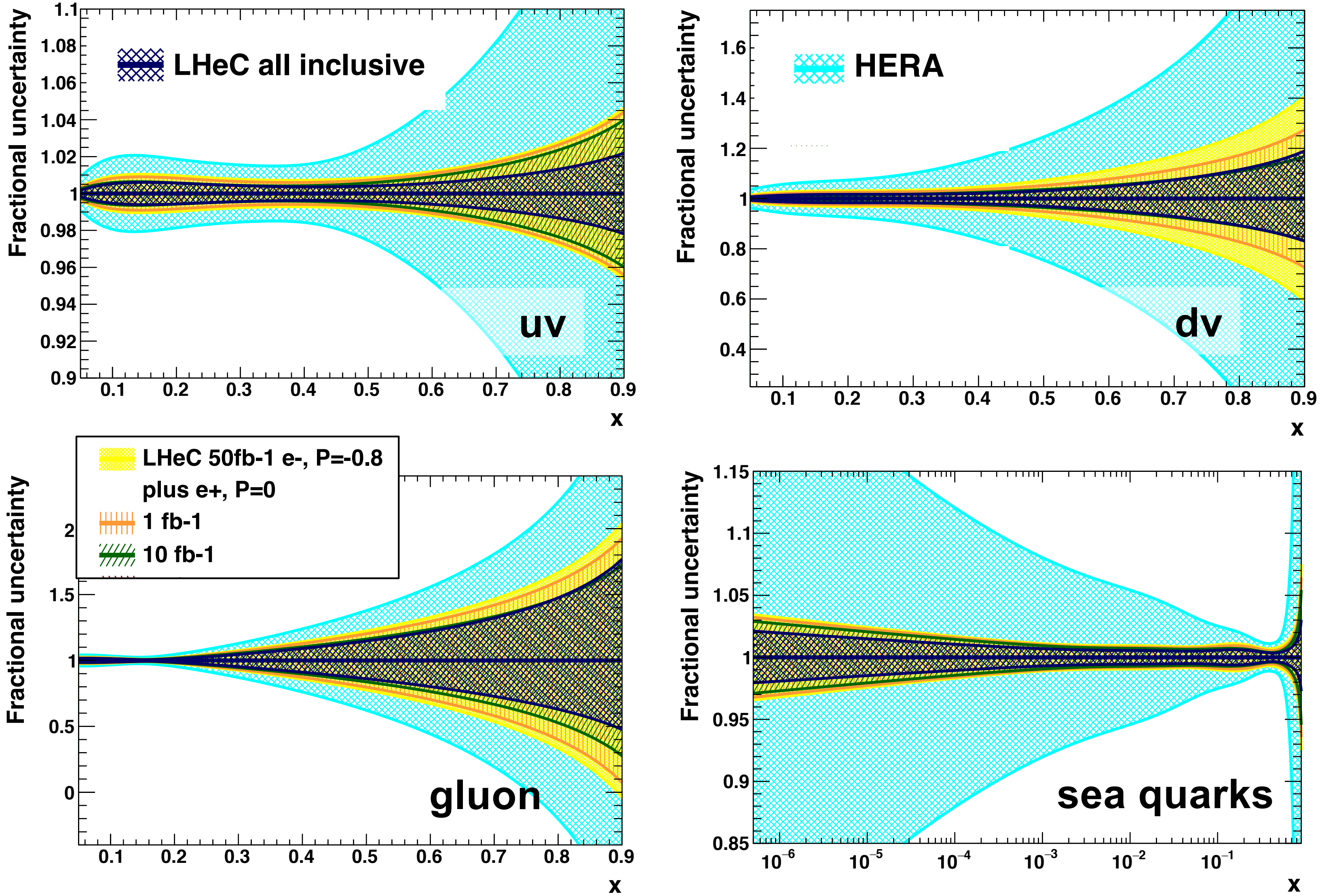
impact of luminosity



small and **medium x** quickly constrained (**5** fb-1 ≡ ×**5** HERA ≡ **1**st year LHeC)

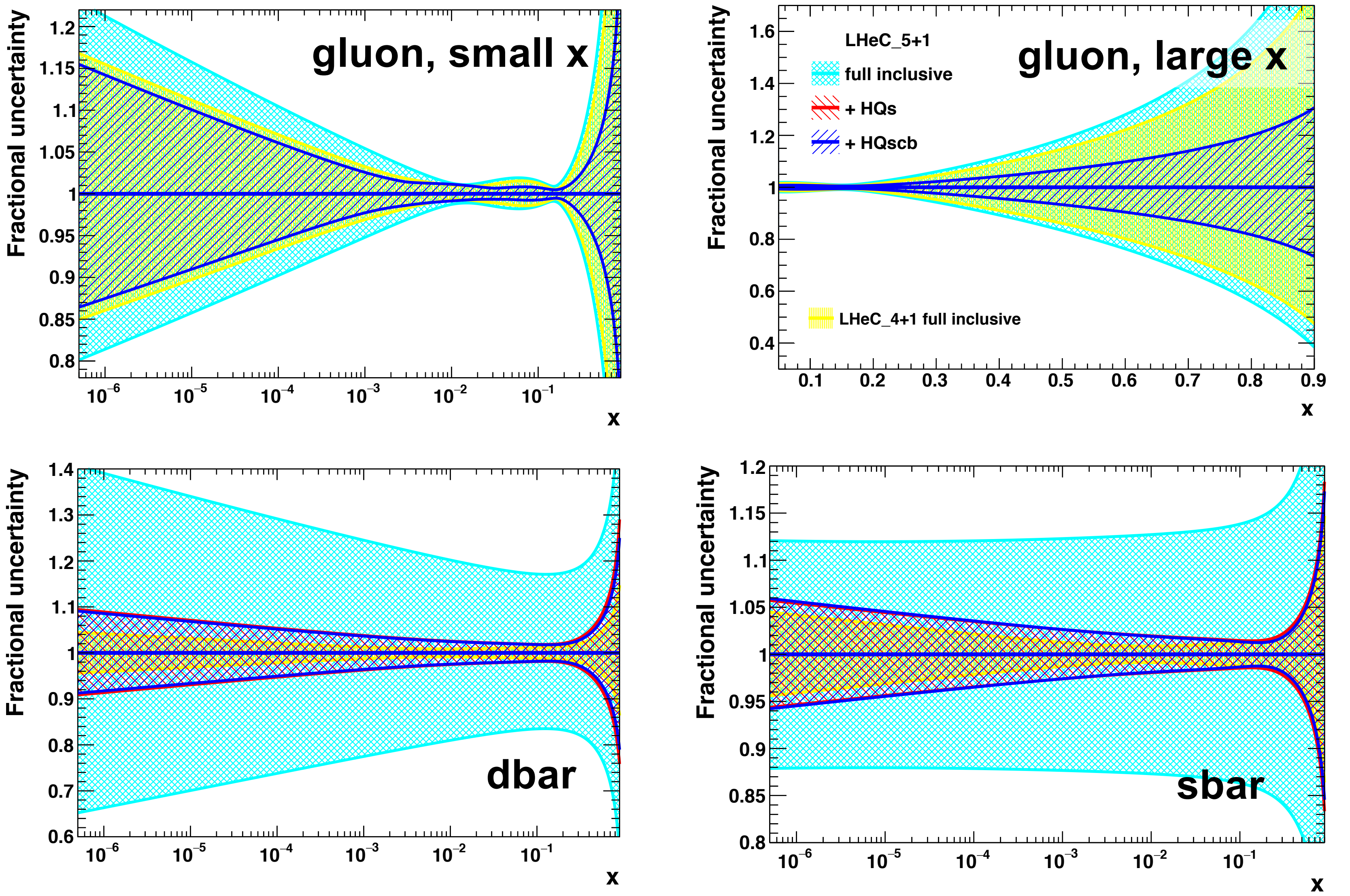
large x (≡ large Q^2), gain from increased Lint

impact of positrons



CC: e+ sensitive to d; **NC**: e± asymmetry gives $xF3^{\gamma Z}$, sensitive to valence

impact of s, c, b



- **4+1 xuv, xdv, xUbar, xDbar + xg (14)**
- **5+1 xuv, xdv, xUbar, xdbar, xsbar + xg (17)**

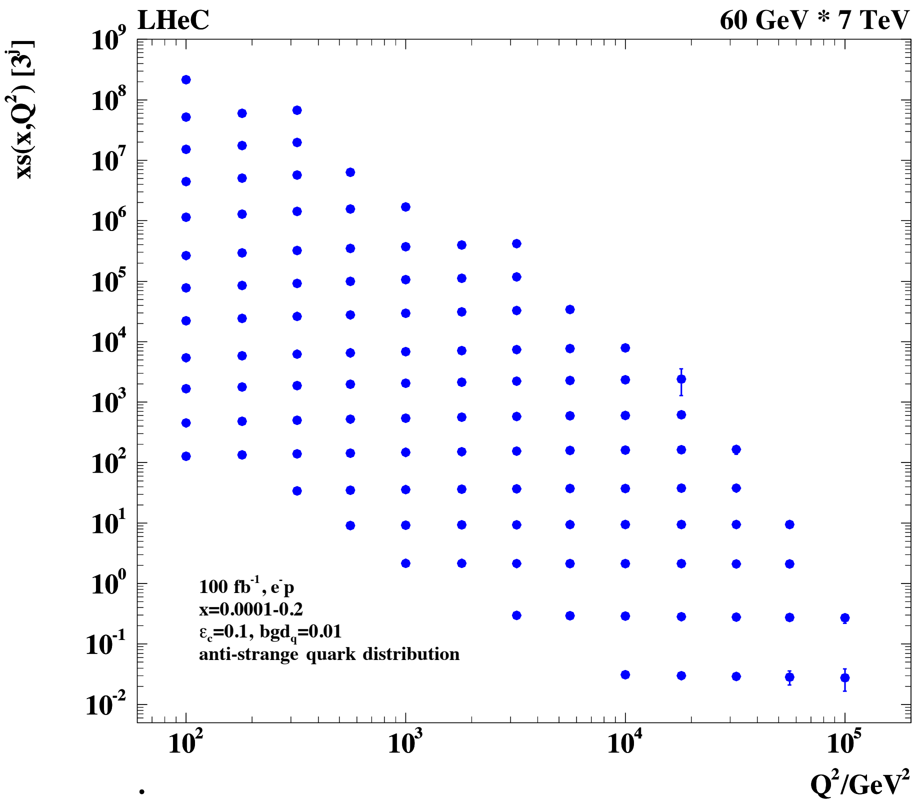
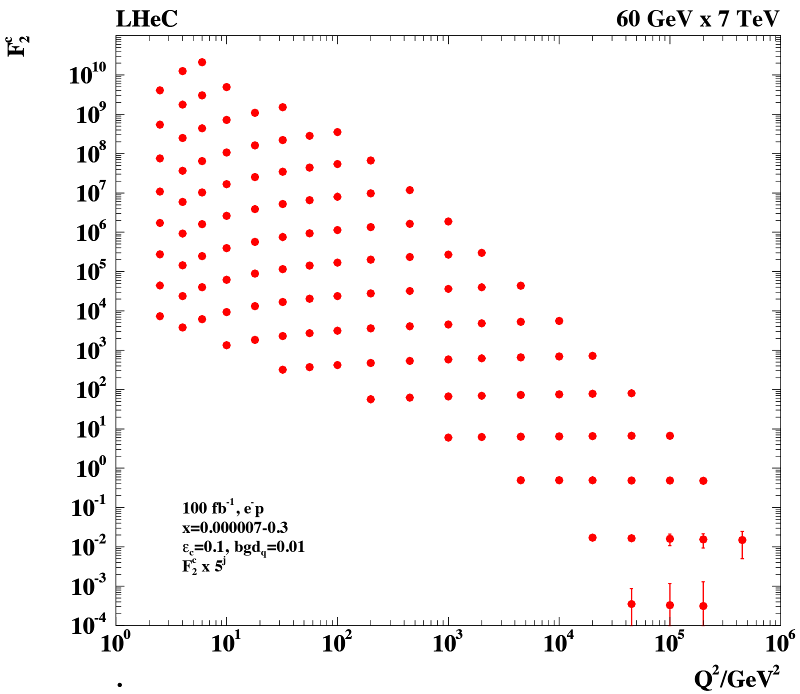
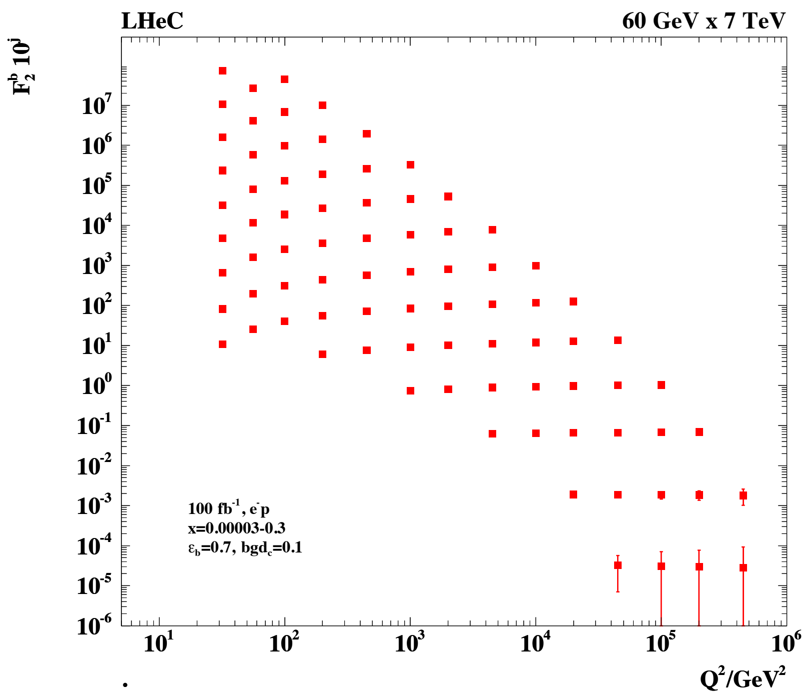


Figure 3.5: Simulation of the measurement of the (anti)-strange quark distribution, $x\bar{s}(x,Q^2)$, in charged current e^-p scattering through the t-channel reaction $W^-\bar{s} \to c$. The data are plotted with full systematic and statistical errors added in quadrature, mostly non-visible. The covered x range extends from 10^{-4} (top left bin), determined by the CC trigger threshold conservatively assumed to be at $Q^2 = 100\,\mathrm{GeV}^2$, to $x \simeq 0.2$ (bottom right) determined by the forward tagging acceptance limits, which could be further extended by lowering E_p.

c, b quarks





LHeC: enormously extended range and much improved precision c.f. HERA

- **δMc = 50 (HERA)** to **3 MeV**: impacts on αs, regulates ratio of charm to light, crucial for precision t, H
- **δMb** to **10 MeV**; MSSM: Higgs produced dominantly via $b\bar{b} \rightarrow A$

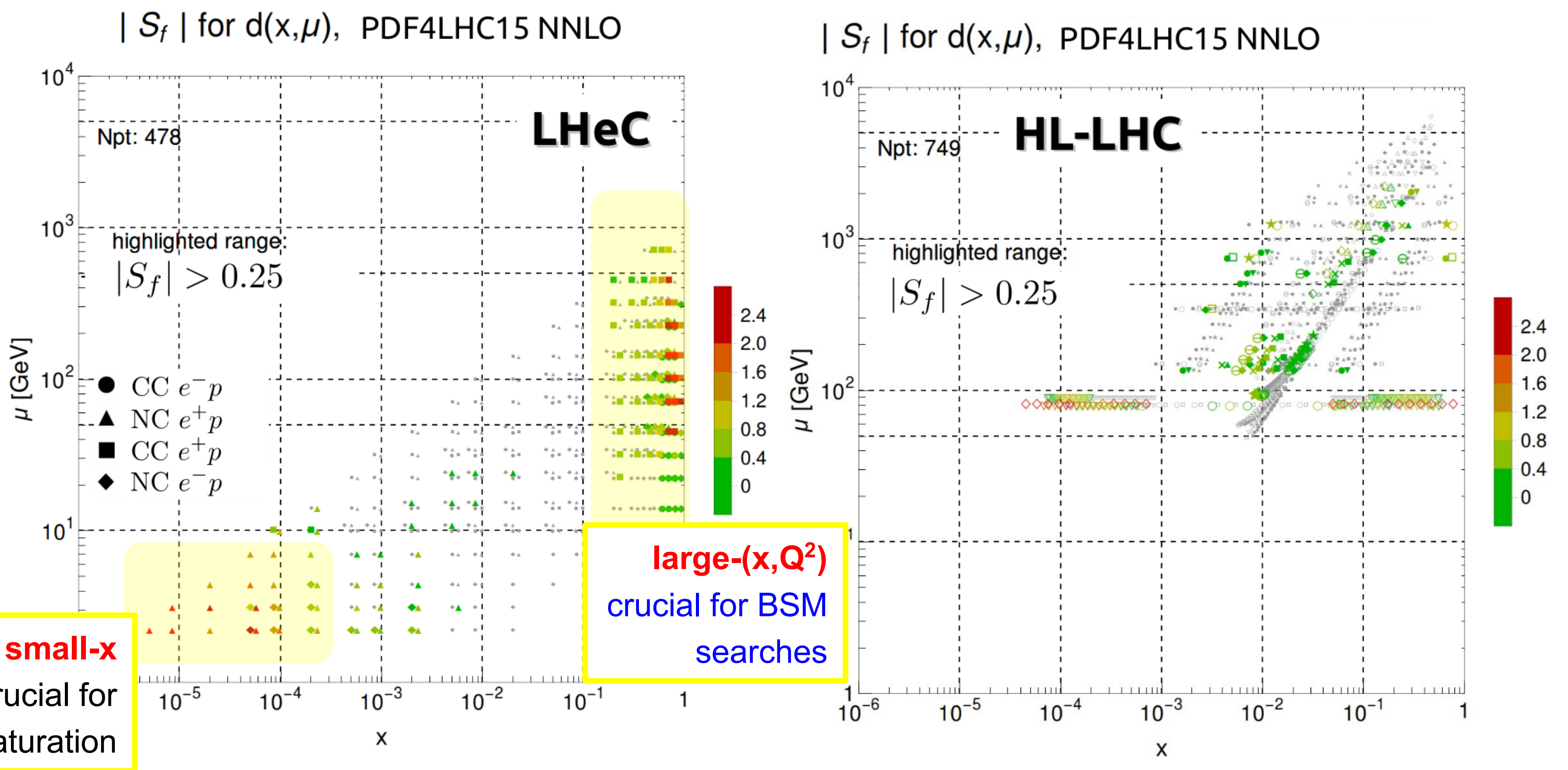
pdf sensitivity

"sensitivity" Sf

= **C**orrelation ×

scaled **r**esidual

$$S_f(x_i,\mu_i) \equiv \frac{\delta^{(\mathrm{PDF})} r_i}{\sqrt{\frac{1}{N}\sum_{i=1}^{N} r_i^2}} C_f(x_i,\mu_i).$$



enormous sensitivity in regions currently poorly constrained

PDFSENSE: tool for quickly quantifying potential impact of experimental pseduodata

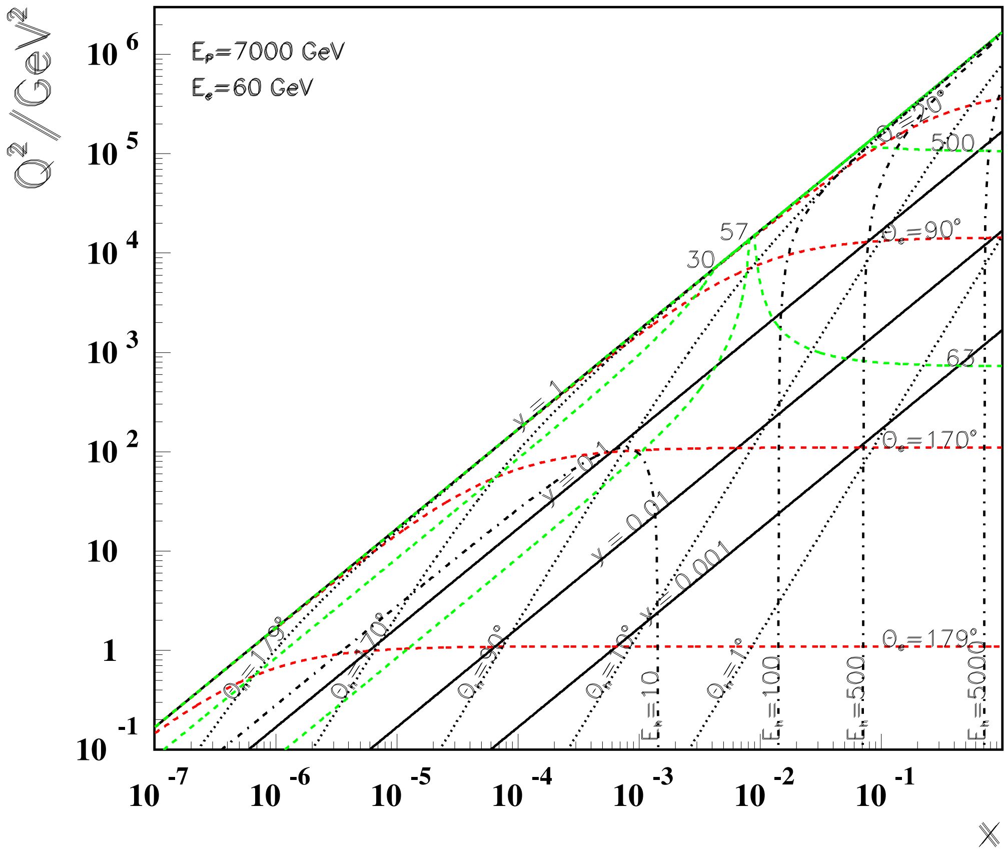


Figure 3.2: Kinematic plane covered with the maximum beam energies at the LHeC. Red dashed: Lines of constant scattered electron polar angle. Note that low Q^2 is measured with electrons scattered into the backward region, highest Q^2 is reached with Rutherford backscattering; Black dotted: lines of constant angle of the hadronic final state; Black solid: Lines of constant inelasticity $y = Q^2/sx$; Green dashed: Lines of constant scattered electron energy E'_e. Most of the central region is covered by what is termed the kinematic peak, where $E'_e \simeq E_e$. The small x region is accessed with small energies E'_e below E_e while the very forward, high Q^2 electrons carry TeV energies; Black dashed-dotted: lines of constant hadronic final state energy E_h. Note that the very forward, large x region sees very high hadronic energy deposits too.

αs from LHeC NC DIS jets

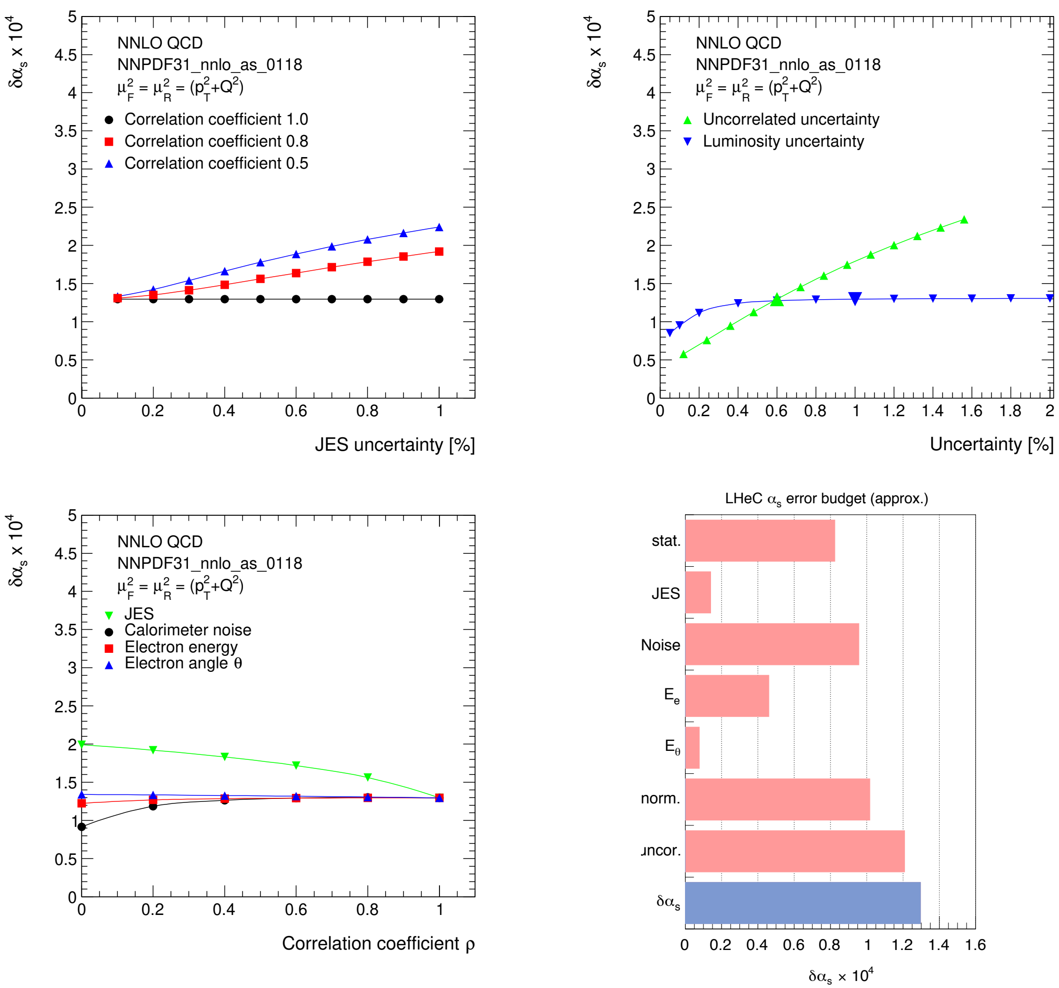
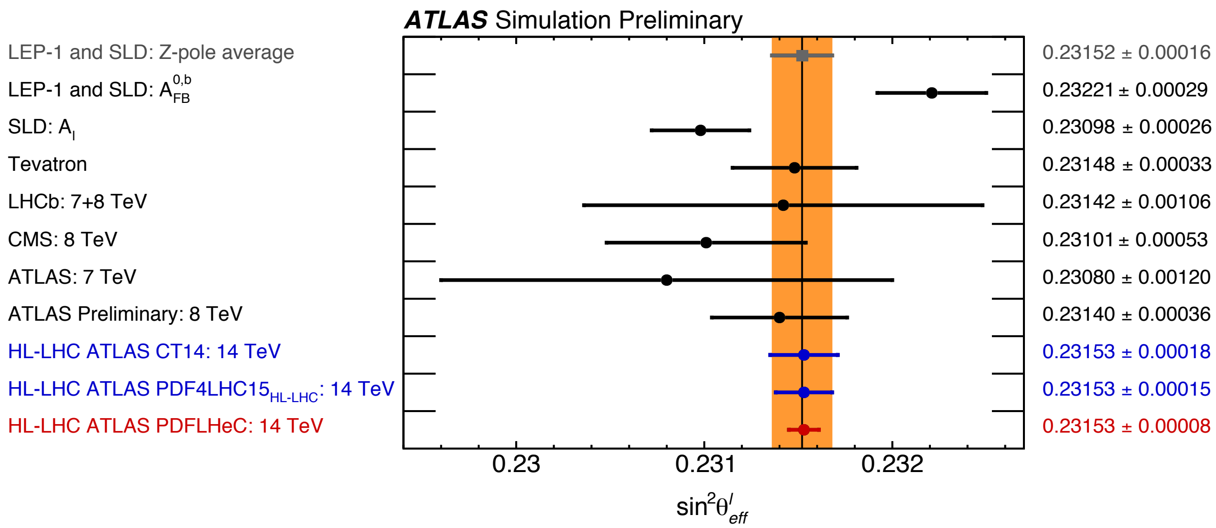


Figure 4.3: Studies of the size and correlations of experimental uncertainties impacting the uncertainty of $\alpha_s(M_Z)$. Top left: Study of the value of the correlation coefficient ρ for different systematic uncertainties. Common systematic uncertainties are considered as fully correlated, $\rho = 1$. Top right: Size of the JES uncertainty for three different values of $\rho_{\rm JES}$. Bottom left: Impact of the uncorrelated and normalisation uncertainties on $\Delta\alpha_{\rm s}(M_{\rm Z})$. Bottom right: Contribution of individual sources of experimental uncertainty to the total experimental uncertainty of $\alpha_{\rm s}(M_{\rm Z})$.

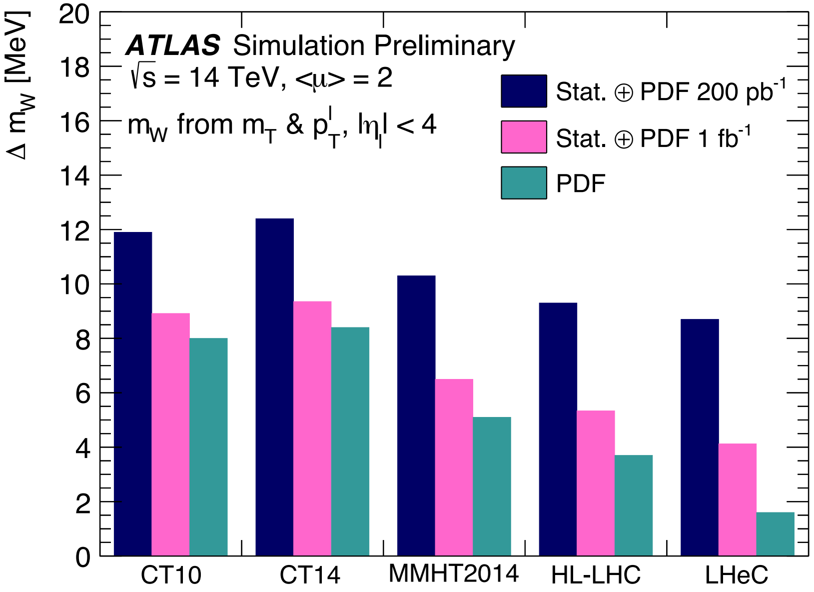
empowering the LHC: $\sin^2\vartheta W$

Parameter	Unit	ATLAS (Ref. [433])	HL-LHC projection		
		MMHT2014	CT14	HL-LHC PDF	LHeC PDF
Centre-of-mass energy, $\sqrt{s}$	TeV	8	14	14	14
Int. luminosity, $\mathcal{L}$	fb^{-1}	20	3000	3000	3000
Experimental uncert.	10^{-5}	± 23	± 9	± 7	± 7
PDF uncert.	10^{-5}	± 24	± 16	± 13	± 3
Other syst. uncert.	10^{-5}	± 13	–	–	–
Total uncert., $\Delta \sin^2\theta_W$	10^{-5}	± 36	± 18	± 15	± 8



empowering the LHC: MW

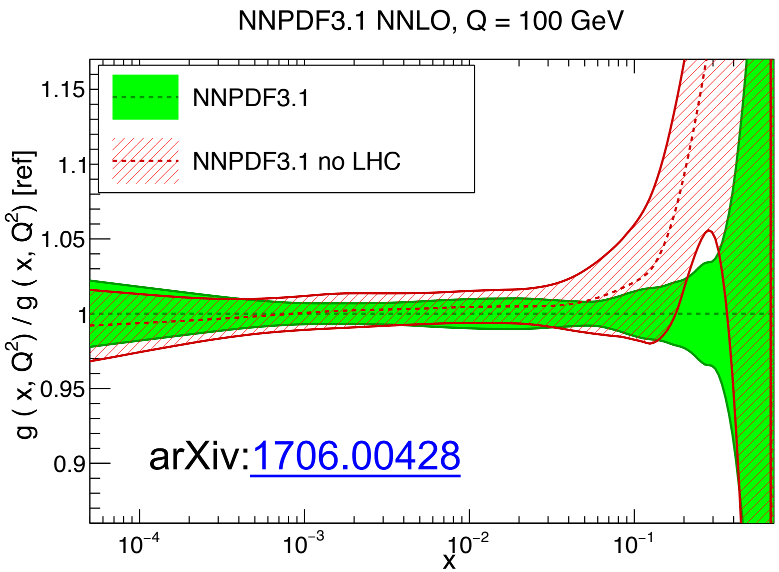
Parameter	Unit	ATLAS (Ref. [424])	HL-LHC projection			
		CT10	CT14	HL-LHC	LHeC	LHeC
Centre-of-mass energy, $\sqrt{s}$	TeV	7	14	14	14	14
Int. luminosity, $\mathcal{L}$	fb^{-1}	5	1	1	1	1
Acceptance		$\|\eta\| < 2.4$	$\|\eta\| < 2.4$	$\|\eta\| < 2.4$	$\|\eta\| < 2.4$	$\|\eta\| < 4$
Statistical uncert.	MeV	± 7	± 5	± 4.5	± 4.5	± 3.7
PDF uncert.	MeV	± 9	± 12	± 5.8	± 2.2	± 1.6
Other syst. uncert.	MeV	± 13	-	-	-	
Total uncert. Δm_W	MeV	± 19	13	7.3	5.0	4.1



pp vs ep ?

(slide based on one from M. Klein)

LHC data constrain **pdfs**, BUT do not precisely **determine** them



pp: providing useful constraints in global fits and also interesting results (EG. non-suppressed strange at x ~ 0.01 from ATLAS); must nevertheless be aware that it is not **ep** …

cf. ep

- complete q,g unfolding at all x
- **α**s to order permille precision (not in pp)
- clear theory (EG. N3LO, scale choice, hadronisation)
- strong effects from Q^2 variation (which cannot come from EG. W, Z at $Q^2=10^4$ GeV^2)
- HQ separation: s,c,b,(t)
- understanding of small x dynamics, EG. BFKL, saturation, … (comes from F2 and FL)
- gives external precision input for QCD subtleties (EG. factorisation, resummation), and for subtle discoveries
- single DIS dataset a tried and tested reliable way to achieve precision (**ΔX^2**=1; cf. current LHC measurements; issues understanding systematics, correlations, data inconsistencies, …)

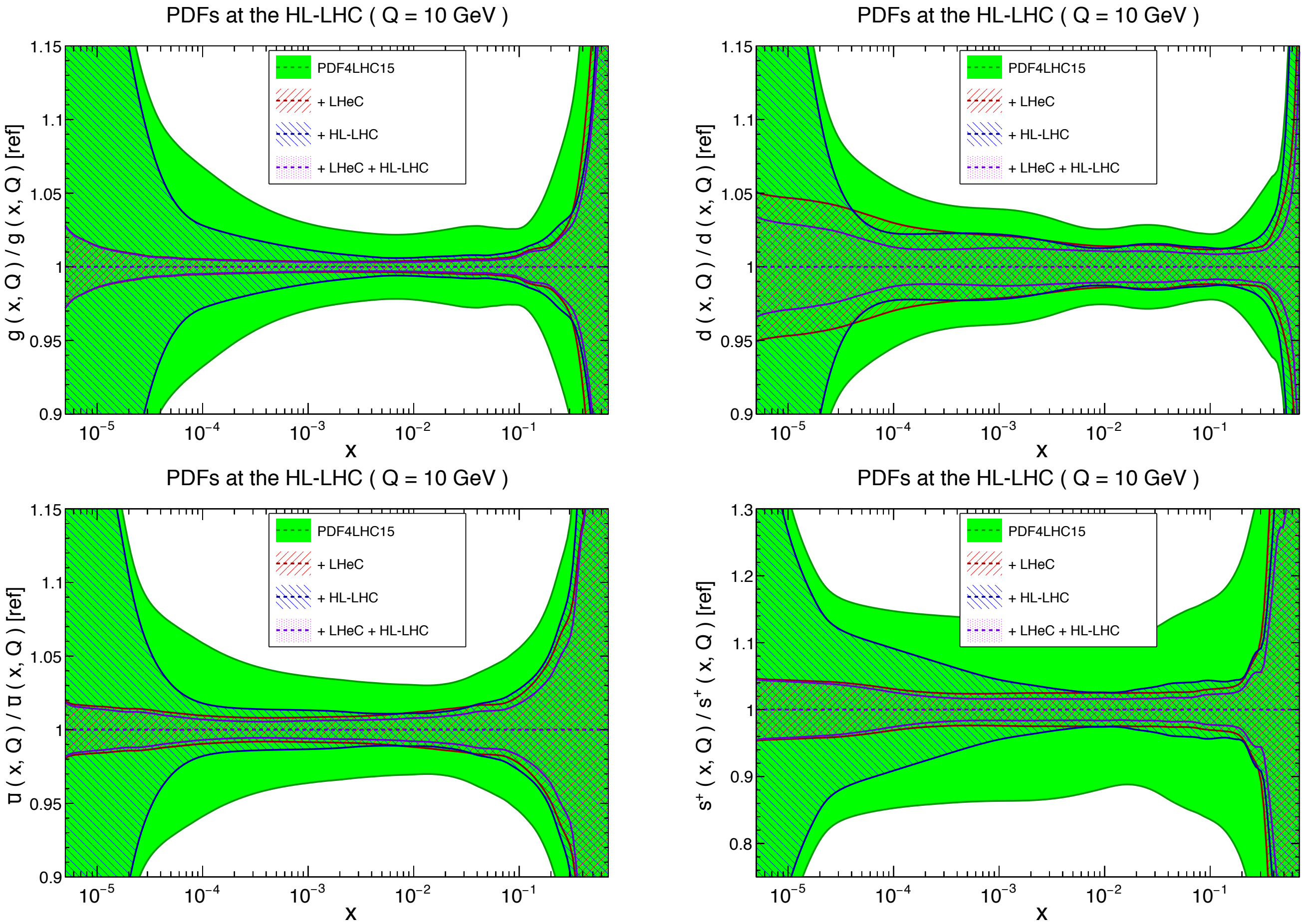


Figure 9.9: Impact of LHeC on the 1-σ relative PDF uncertainties of the gluon, down quark, anti–up quark and strangeness distributions, with respect to the PDF4LHC15 baseline set (green band). Results for the LHeC (red), the HL-LHC (blue) and their combination (violet) are shown.

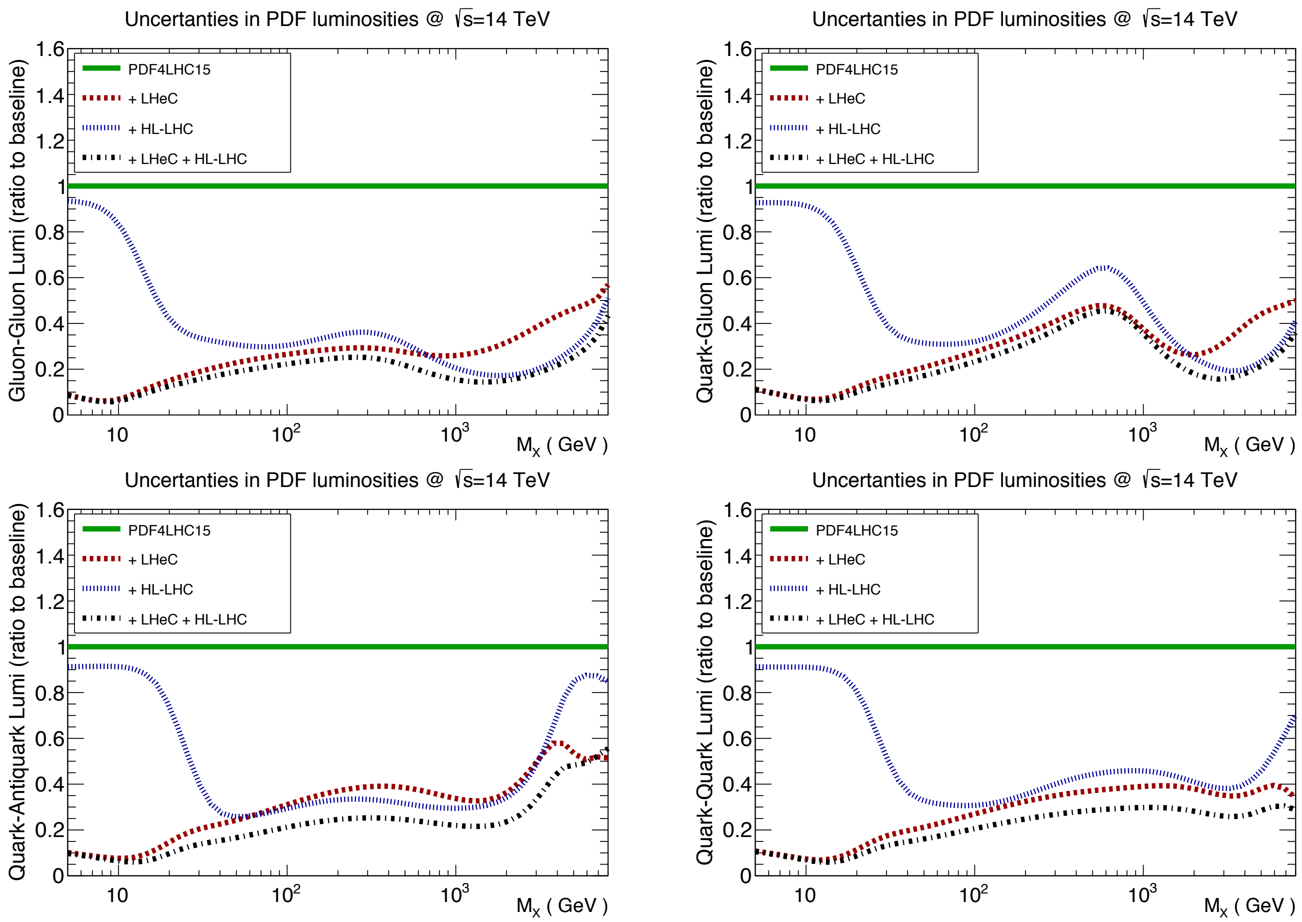
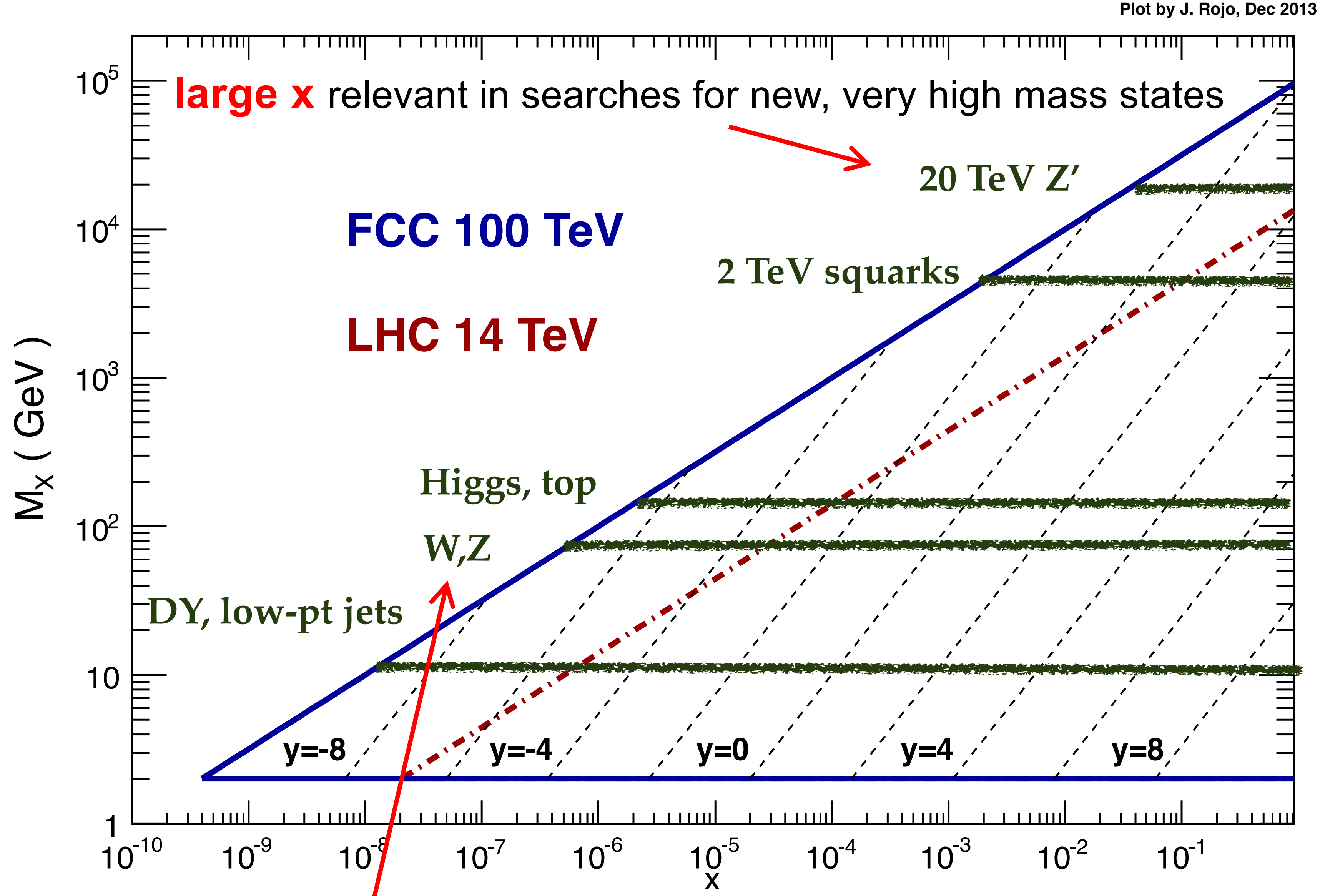


Figure 9.10: Impact of LHeC, HL-LHC and combined LHeC + HL-LHC pseudodata on the uncertainties of the gluon-gluon, quark-gluon, quark-antiquark and quark-quark luminosities, with respect to the PDF4LHC15 baseline set. In this comparison we display the relative reduction of the PDF uncertainty in the luminosities compared to the baseline.

Kinematics of a 100 TeV FCC



small x becomes relevant even for “common” physics (EG. W, Z, H, t)

non-linear QCD dynamics

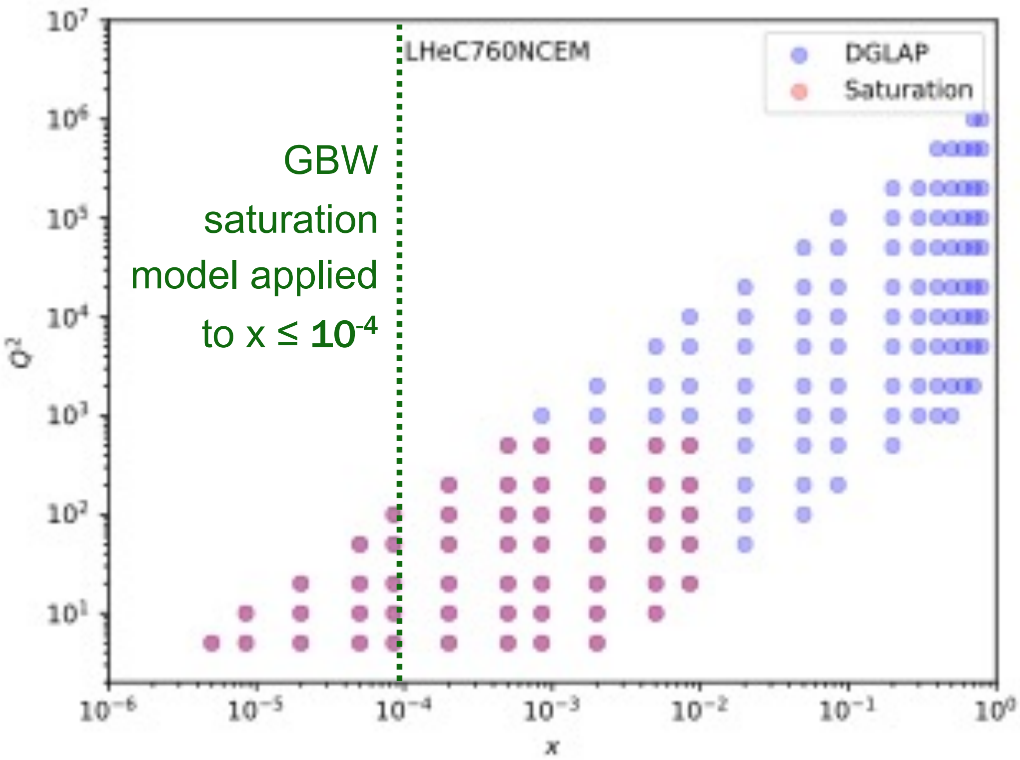


Figure 4.9: The kinematic coverage of the NC e^-p scattering pseudodata at the LHeC, where the blue (red) points indicate those bins for which DGLAP (saturation) predictions are available.

non-linear QCD dynamics

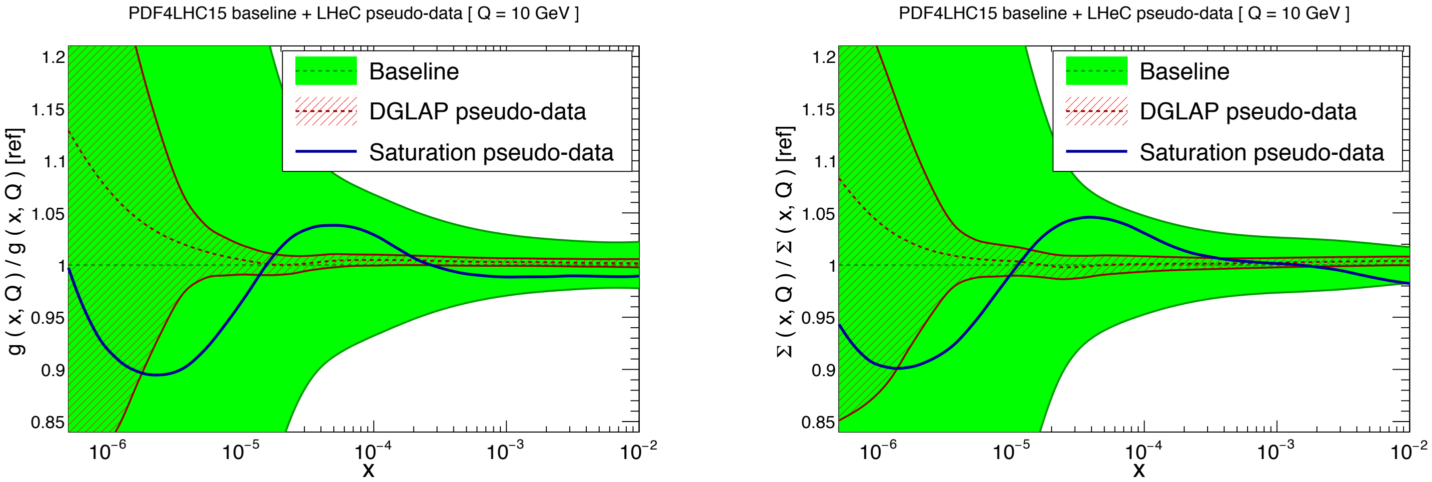


Figure 4.12: Comparison between the PDF4LHC15 baseline (green band) with the results of the profiling of the LHeC pseudodata for the gluon (left) and quark singlet (right) for $Q = 10\,\text{GeV}$. We show the cases where the pseudodata is generated using DGLAP calculations (red hatched band) and where it is partially based on the GBW saturation model (blue curve).