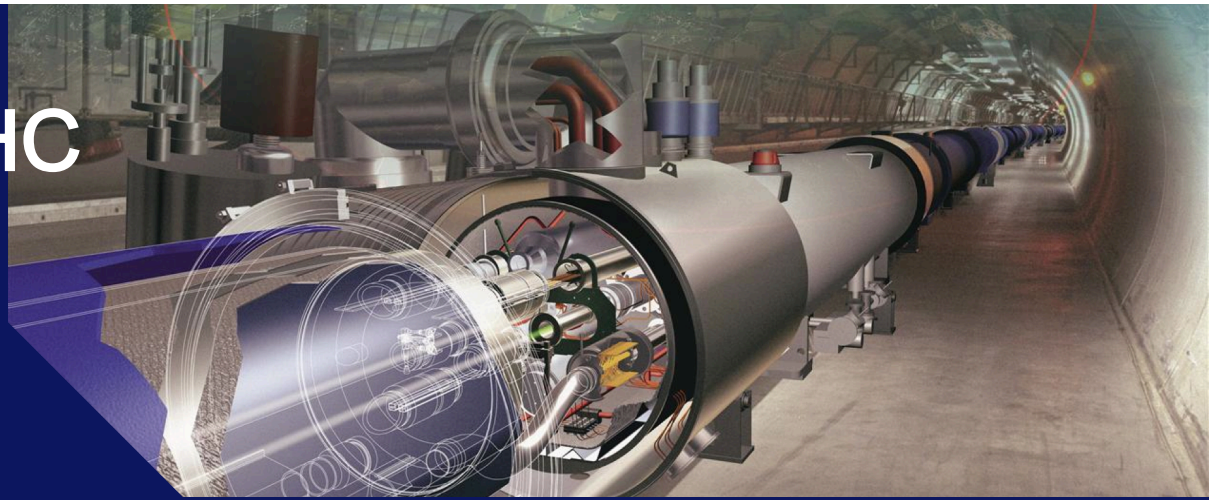
electrons for the LHC

Chavannes de Bogis

24 – 25 October 2019



Proton PDFs and α_s

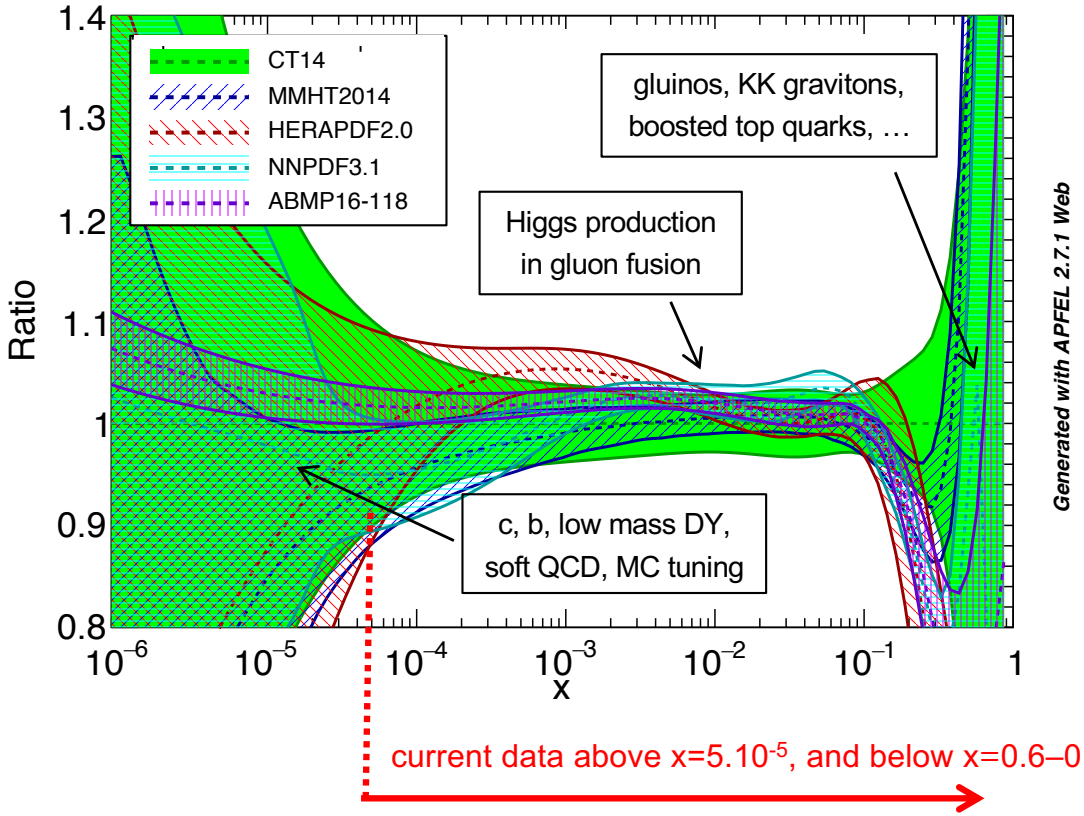
Claire Gwenlan, Oxford

Fred Olness, SMU

with thanks to Max Klein and Daniel Britzger

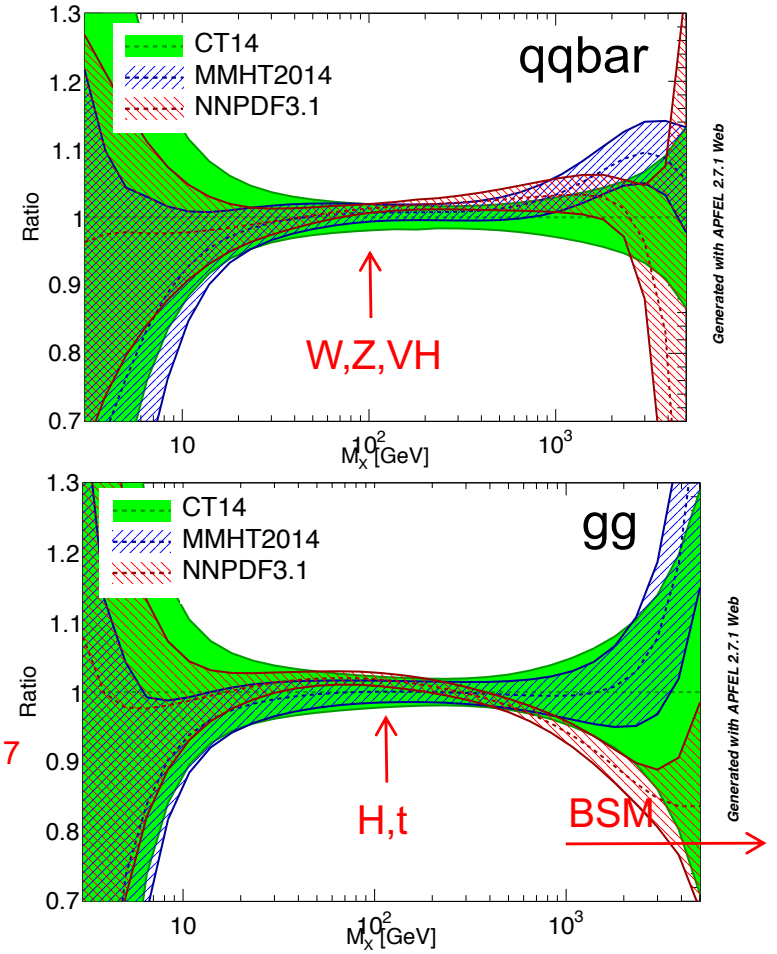
pdfs: the situation today

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



current data above x=5.10^{-5}, and below x=0.6–0.7

pdf luminosities (LHC@14TeV)

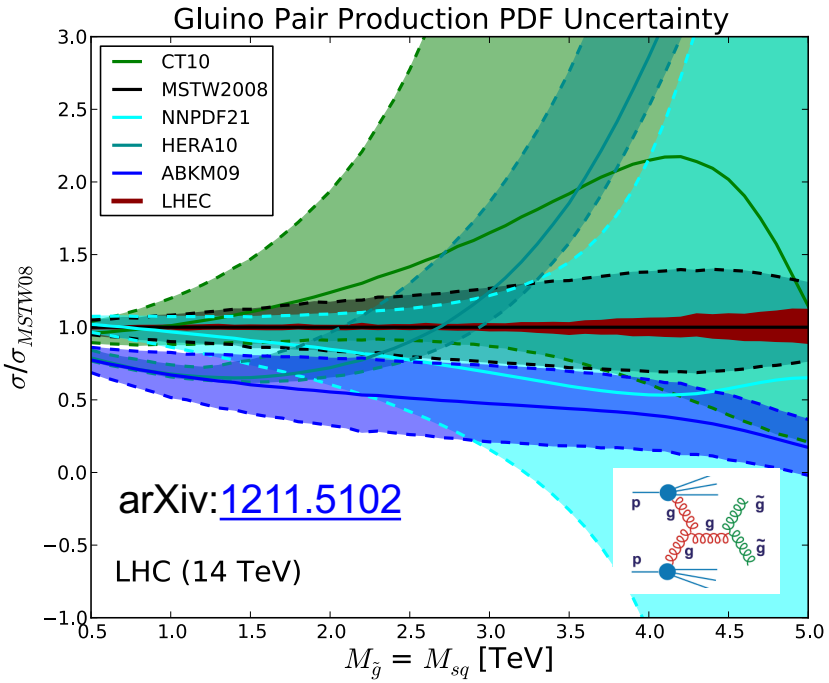


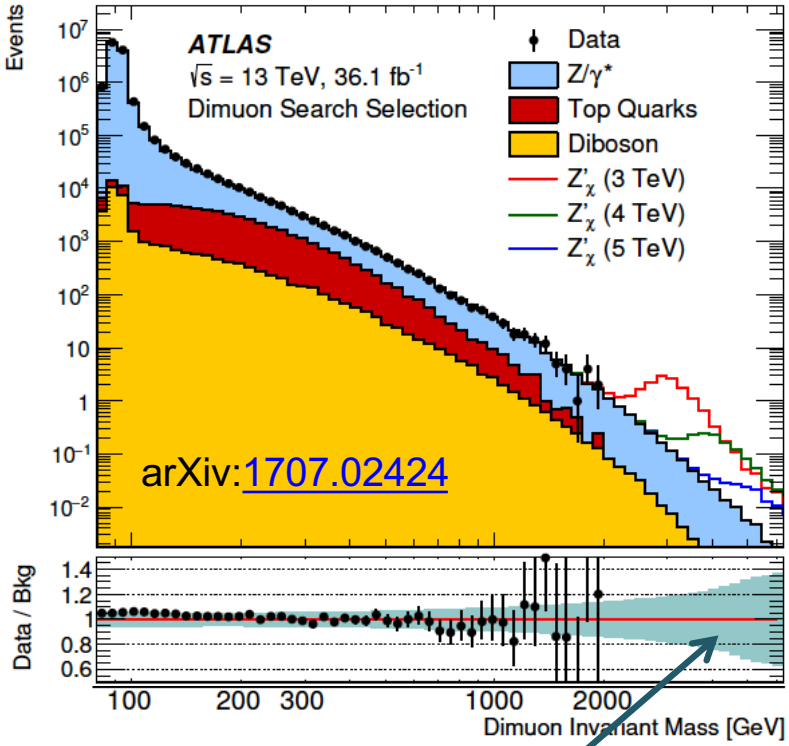
pdfs poorly known at **large** and **small x**

higher precision needed also for H, W, t

why large x pdfs matter at the LHC

BSM searches at high scales limited by (lack of) knowledge of large x pdfs





pdf uncertainty dominates

many interesting processes at LHC are **gg** initiated – top; Higgs; BSM, EG. gluino pair production, LQs etc.; …

current BSM searches at high mass also limited by **large x valence** and **sea quark** uncertainties

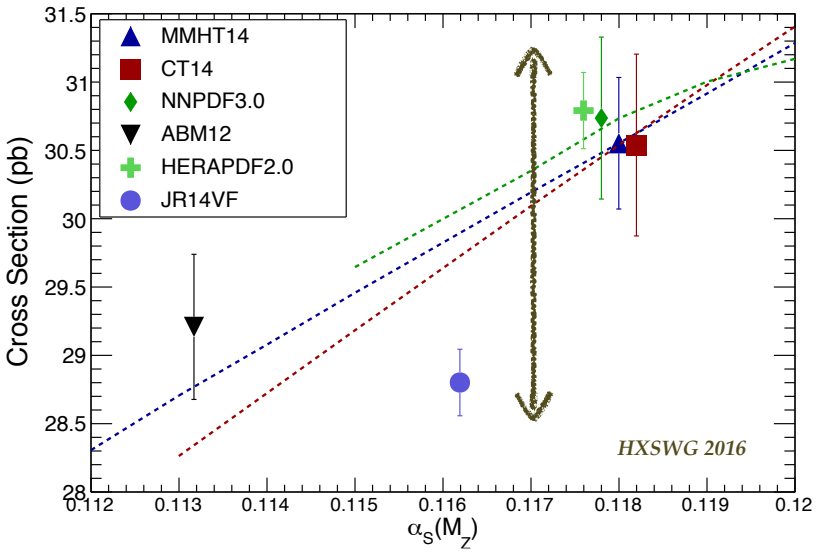
and other LHC measurements…

… such as precision M_W, $\sin^2\theta_W$ (where small discrepancies may indicate BSM physics) and Higgs, are also limited by **pdf uncertainties** at medium x, where we know pdfs best!

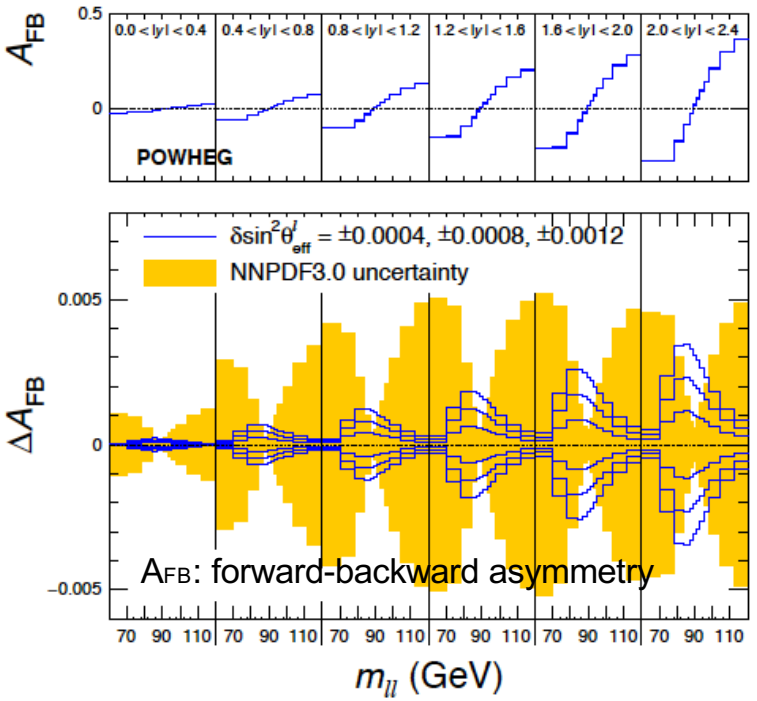
ATLAS M_W, arXiv:1701.07240

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

Gluon-Fusion Higgs production, LHC 13 TeV



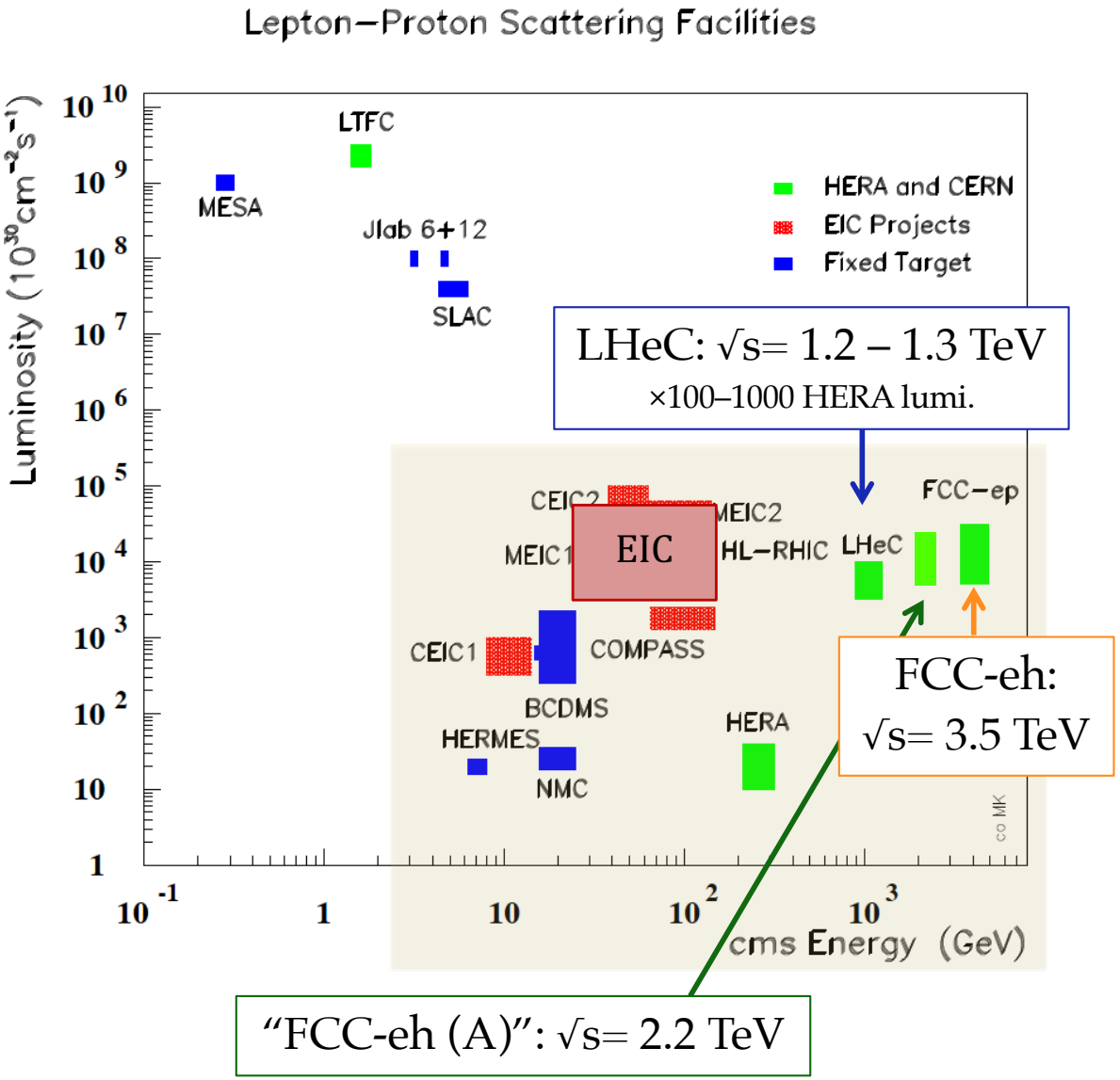
CMS $\sin^2\theta_W$, arXiv:1806.00863



BLUE: vary $\sin^2\theta_{eff}$ for fixed pdf

ORANGE: NNPDF3.0 pdf uncertainty for fixed $\sin^2\theta_{eff}$

ep collider configurations



LHeC and FCC-eh

ERL, Ee: ⟶ 60 GeV

LHeC

Ep: 7 TeV (or more, with a HE-LHC)

LHeC CDR, arXiV:1206.2913

FCC-eh

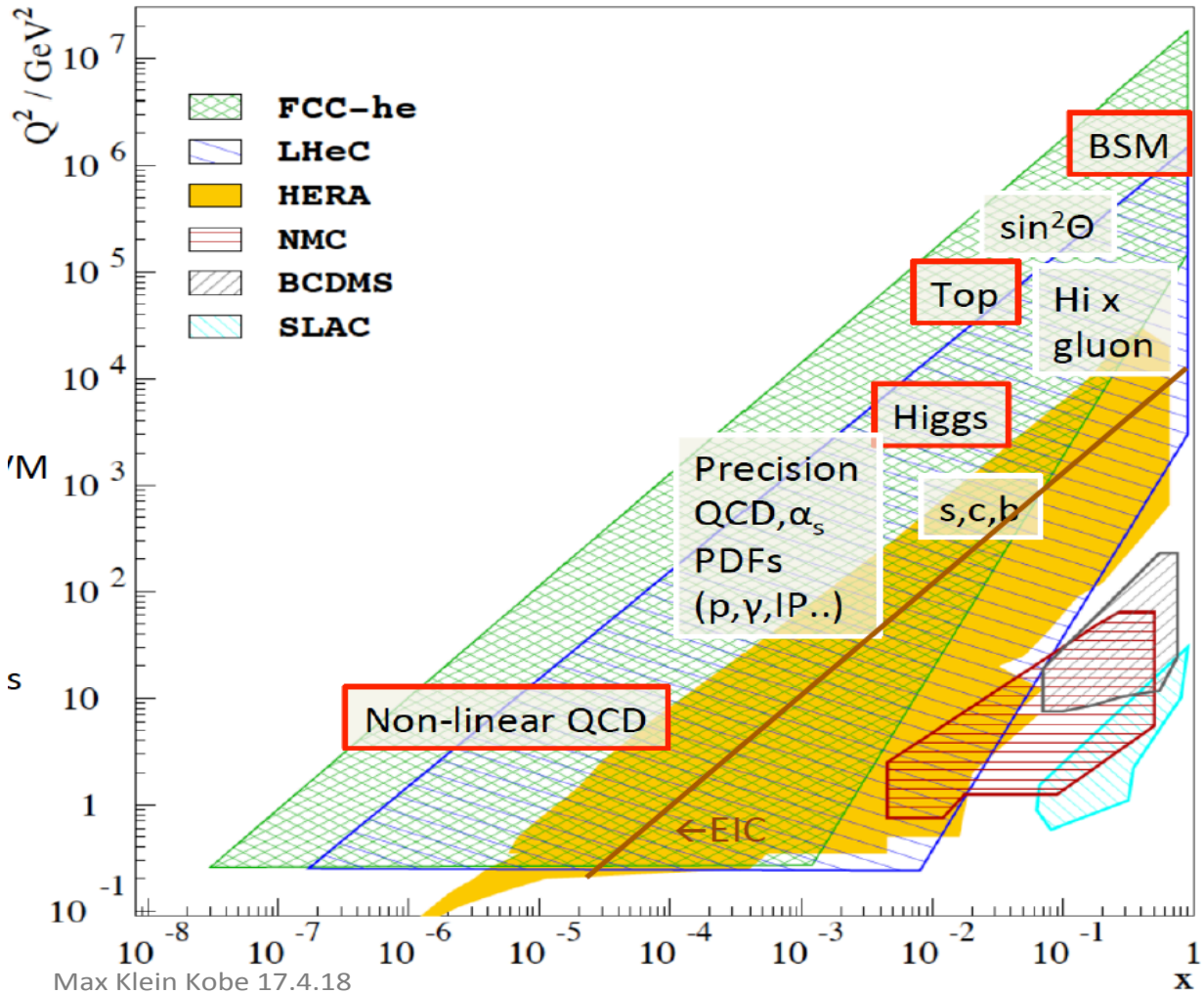
Ep: 50 TeV

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

or possible earlier FCC configuration,

Ep: 20 TeV

kinematic coverage



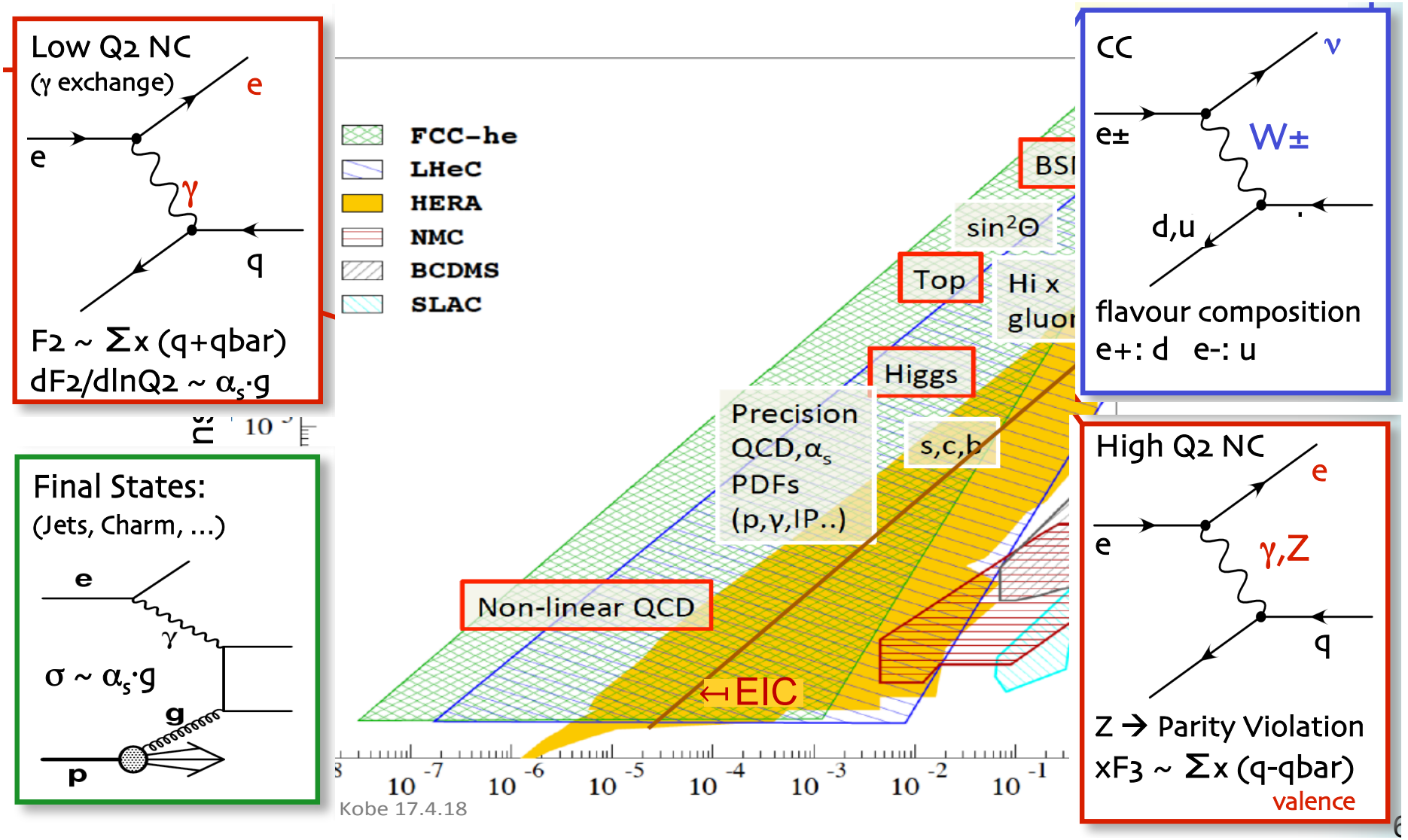
opportunity for **unprecedented increase in DIS kinematic reach**; ×1000 increase in lumi. cf. HERA

no higher twist, no nuclear corrections, free of symmetry assumptions, N³LO 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**

pdfs from LHeC or FCC-eh



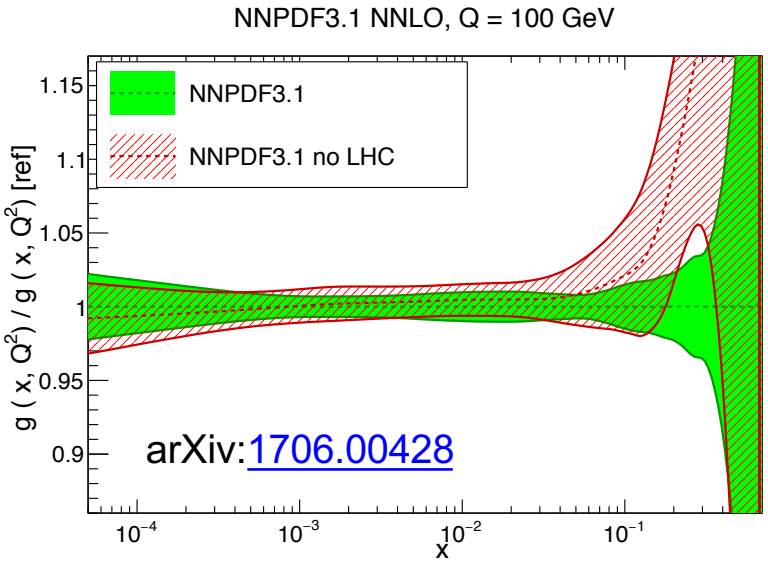
completely resolve all proton **pdfs** and **αs** → **ubar, uv, dbar, dv, s, c, b, t, xg** and **αs**

pp vs ep ?

(slide based on one from M. Klein)

LHC data **constrain pdfs**;

BUT **don't** precisely **determine** them



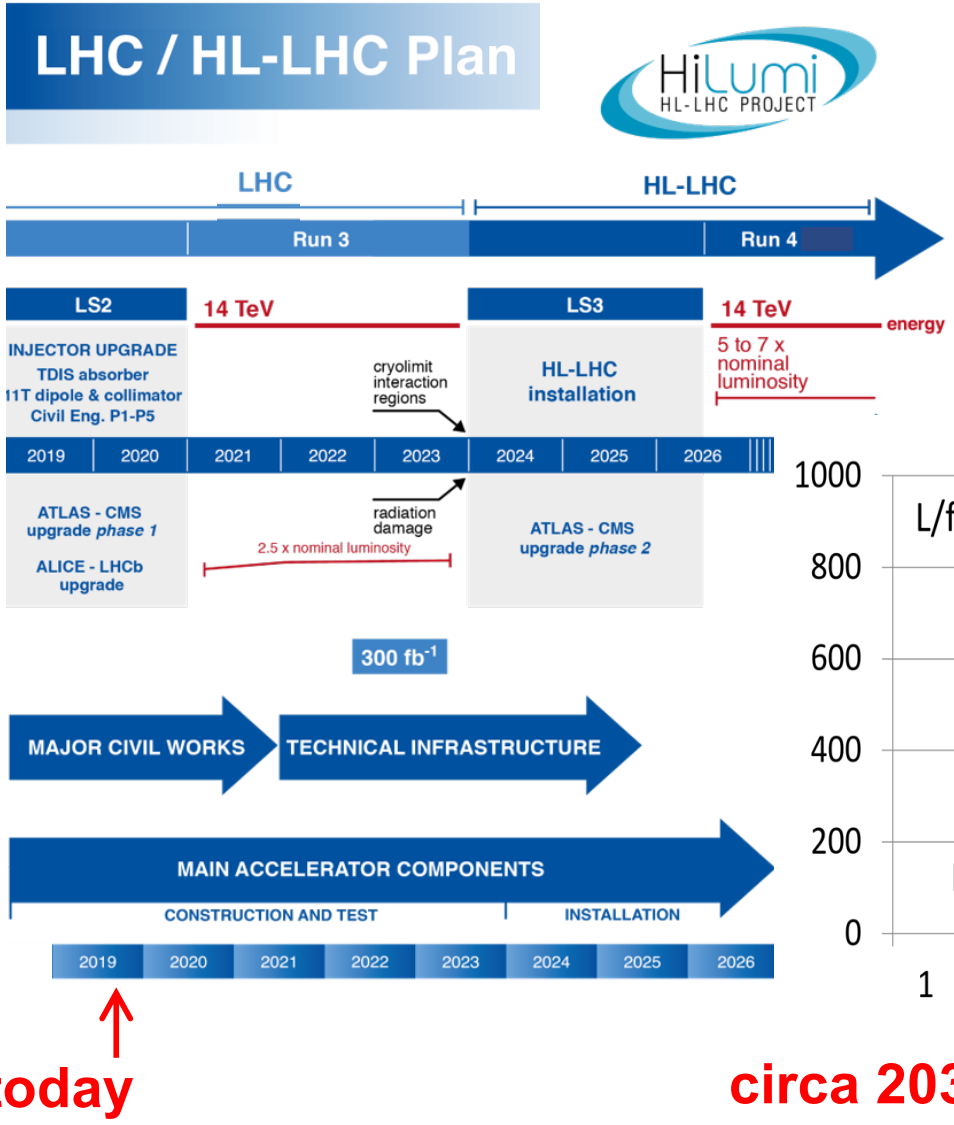
pp: we can and should try; currently we have nothing else; also interesting results (EG. non-suppressed strange at x ~ 0.01 from ATLAS); future prospects studied; must nevertheless be aware of limitations …

see also talk by L. Harland-Lang

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 ($\Delta\chi^2=1$; cf. current LHC measurements; issues understanding systematics, correlations, data inconsistencies, …)

… plus, issues of timing?

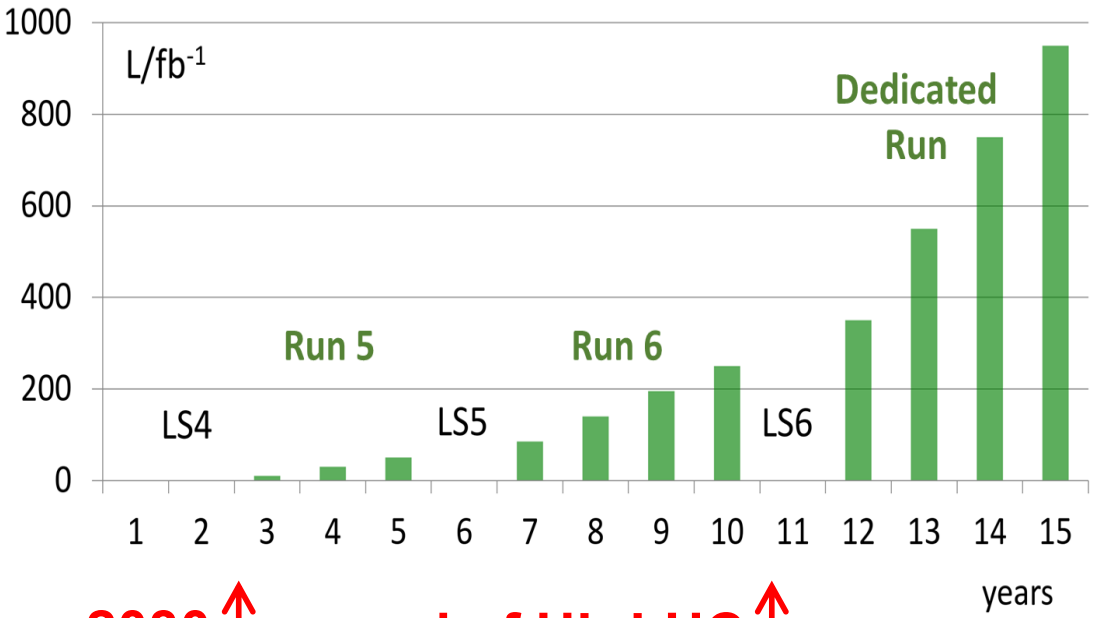


LHeC: first 3 yrs: Lint ~ 50 fb^{-1}

total: Lint ⟶ 1 ab^{-1}

F. Bordry arXiv:1810.13022

LHeC projected Integrated Luminosity:



circa 2030 ↑ end of HL-LHC ↑

50 fb^{-1} (×50 HERA) achievable by LHeC in 3 years, **long before end** of **HL-LHC** running

LHeC and FCC-eh pdfs WG

lhec.web.cern.ch
fcc.web.cern.ch

PDFs and Low x Working Groups

LHeC and FCC-eh

Conveners:

- Nestor Armesto Perez (Universidade de Santiago de Compostela (ES))
- Paul Newman (University of Birmingham (UK))
- Anna Stasto (Penn State (US))
- Claire Gwenlan (University of Oxford (GB))
- Fred Olness (Southern Methodist University (US))

Working Group Meetings

A list of all LHeC+FCC-eh related Indico meetings is here https://indico.cern.ch/category/1874/

everyone is welcome!

contributions:
(partial list)
L. Bella
M. Bonvini
D. Britzger
S. Camarda
A. Cooper-Sarkar
F. Giuli
A. Guffanti
C. Gwenlan
T. Hobbs
M. Klein
U. Klein
P. Nadolsky
F. Olness
R. Placakyte
G. Pownall
V. Radescu
J. Rojo
W. Slominski

see talks in this WS by:
Anna Stasto
Lucian Harland-Lang
Oleksandr Zenaiev
Nestor Armesto Perez
Paul Newman
Daniel Britzger

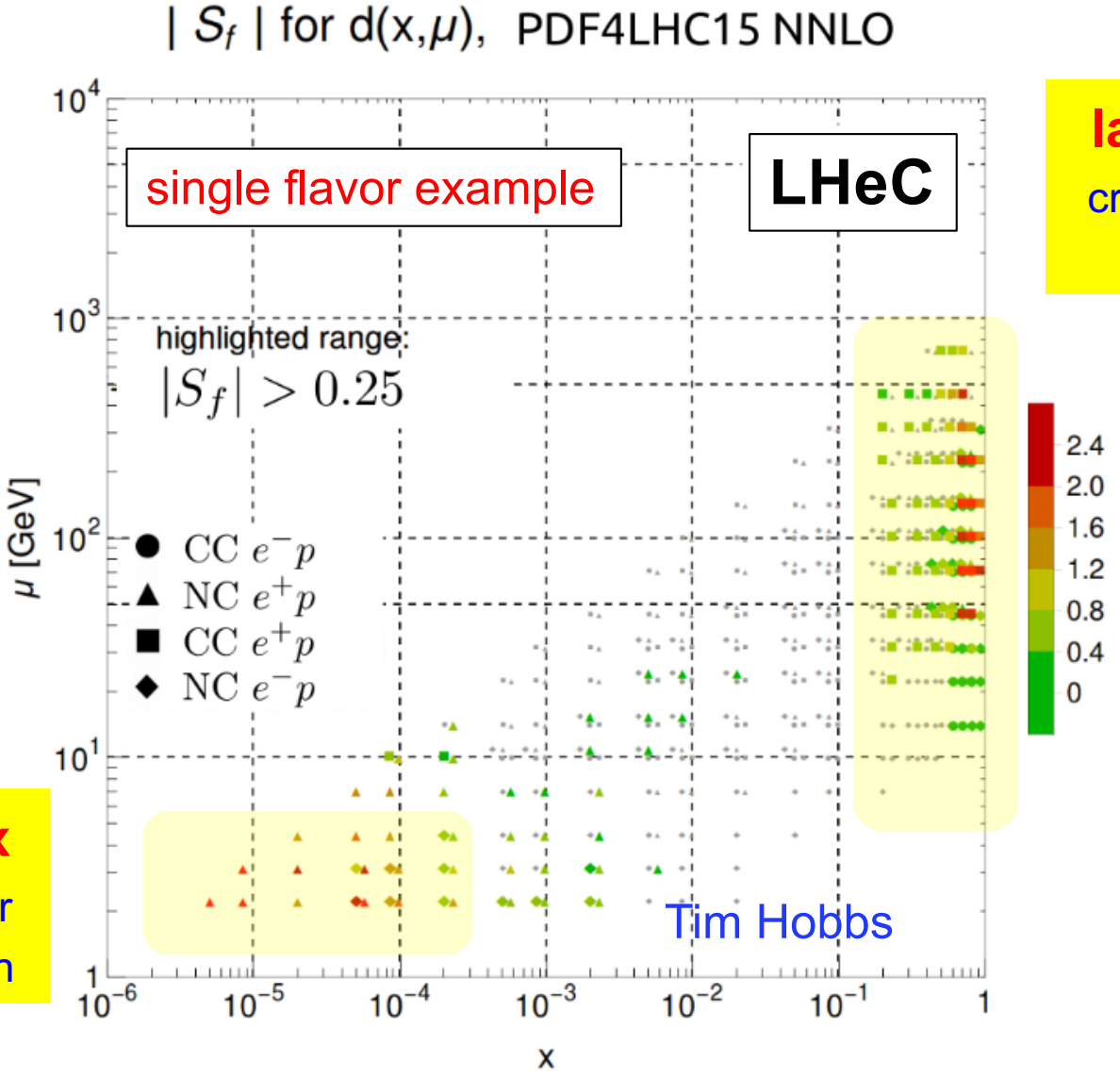
since the LHeC (arXiV:1206.2913) and FCC (vol1, EPJ C79 (2019), no.6, 474) CDRs,
many additional studies, with updated running scenarios etc.

LHeC sensitivity to pdfs

B.-T. Wang et al.
arXiv:1803.02777

"sensitivity" Sf
= **C**orrelation ×
scaled **r**esidual

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



large-(x,Q^2)
crucial for BSM searches

small-x
crucial for saturation

enormous sensitivity in regions currently poorly constrained

PDFSENSE: tool for quickly quantifying potential impact of experimental (pseduo)data

LHeC simulated data and QCD fits

NEW: LHeC simulations (e: **50 GeV***, p: 7 TeV)

simulation: M. Klein

dataset	e charge	e pol.	lumi (fb-1)	
NC/CC	–	–0.8	5,50,1000	**luminosity**
NC/CC	+	0	1,10	**positron**
NC/CC	–	0	50	**polarisation** (important for EW physics)
NC/CC	–	+0.8	10,50	

uncert. assumptions:
elec. scale: 0.1%
hadr. scale 0.5%
radcor: 0.3%
γp at high y: 1%
uncorrelated uncert.: 0.5%
CC syst.: 1.5%
luminosity: 0.5%

*corresponds to possibility of smaller ERL cf. previous 60 GeV simulations

various combinations studied;
shown frequently in next slides:

LHeC 1st Run (50 fb^{-1} e– only; 3 yrs)

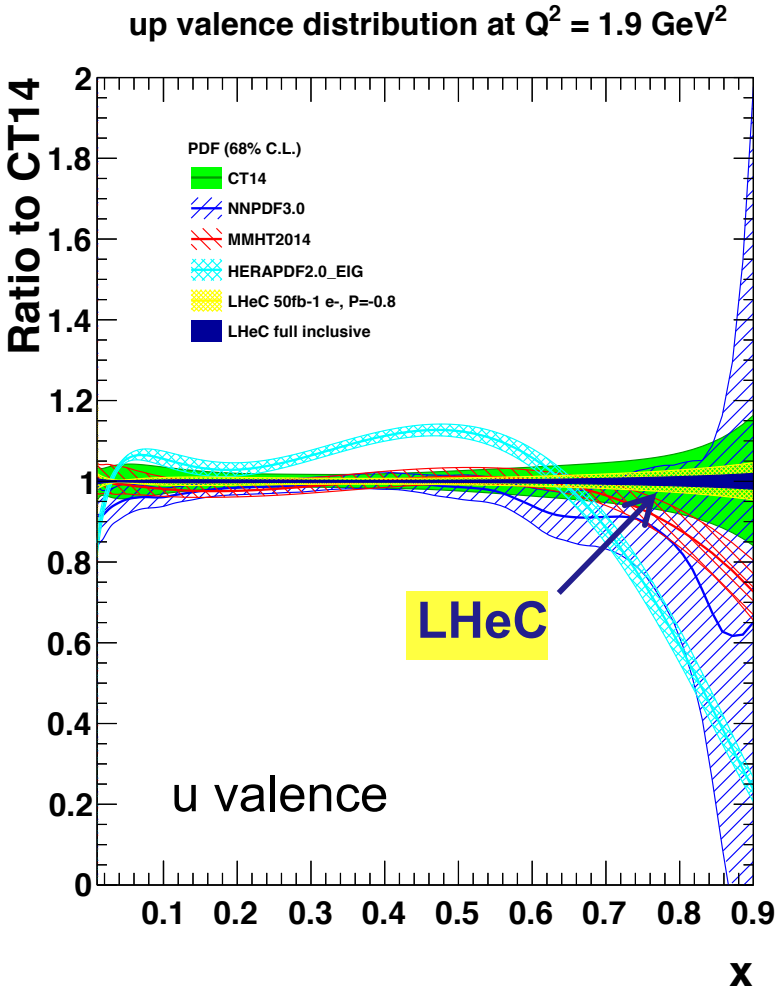
LHeC full inclusive

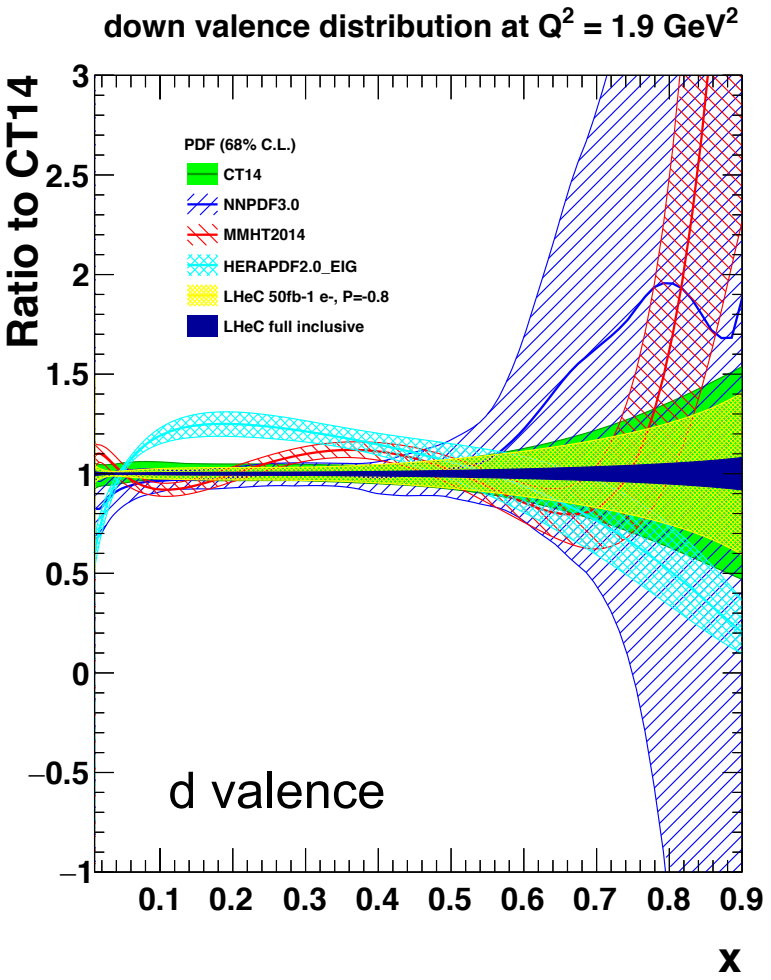
QCD analysis a la HERAPDF2.0, except **more flexible**, most notably in that **NO constraint** requiring dbar=ubar at small x;

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 HQ included; **17 free parameters**)

valence quarks from LHeC

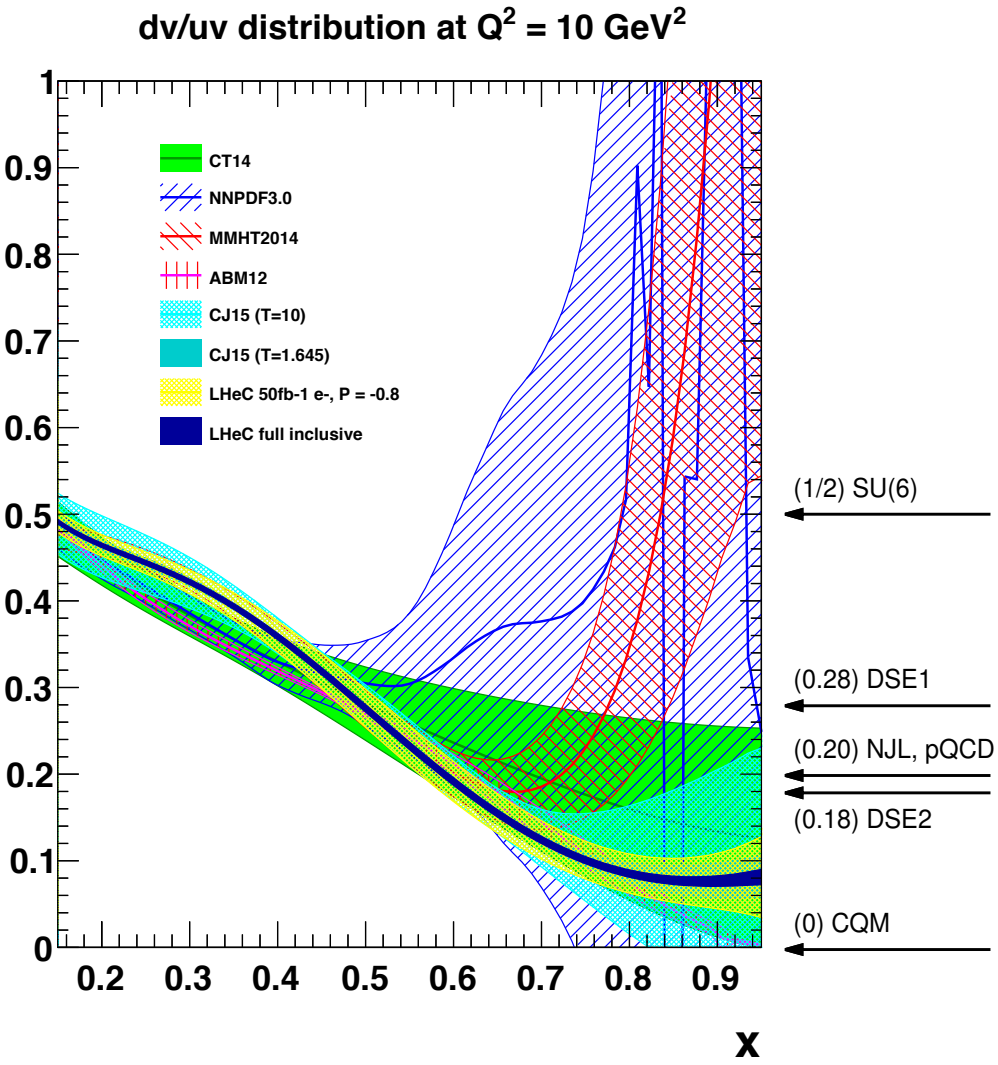




precision determination, free from higher twist corrections and nuclear uncertainties

large x crucial for HL/HE–LHC and FCC searches; also relevant for DY, MW etc.

d/u at large x

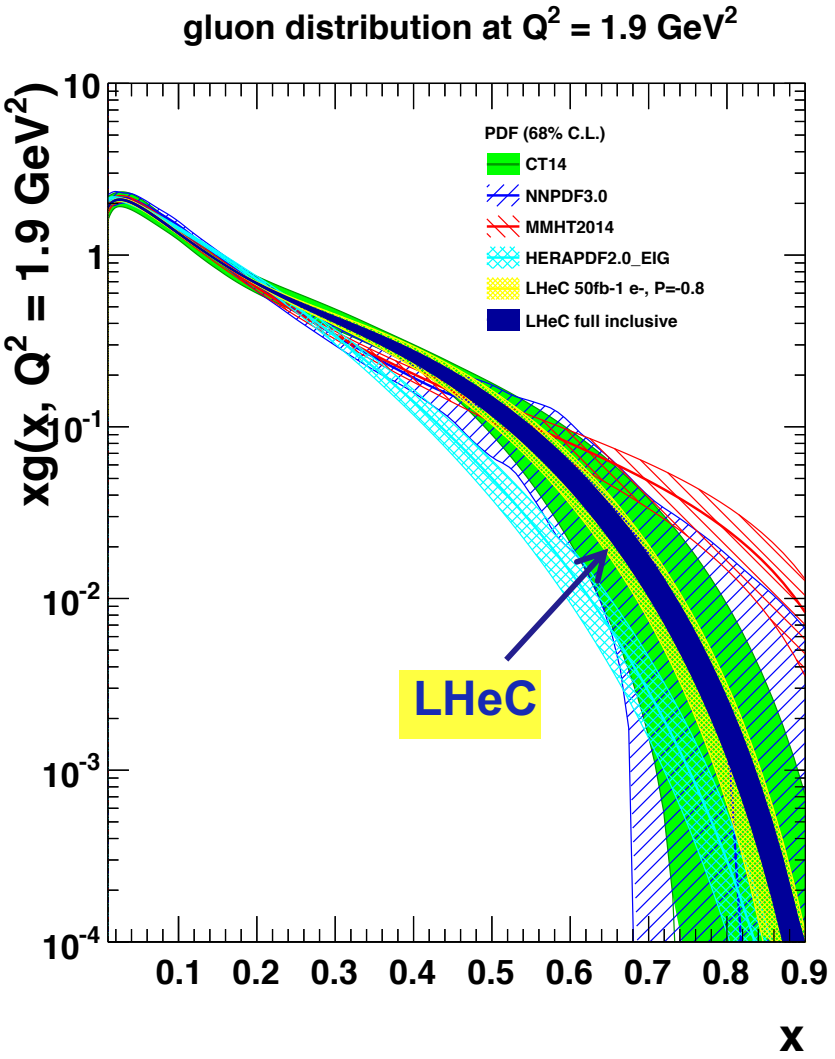


d/u essentially unknown at large x

no predictive power from current pdfs;
conflicting theory pictures;
data inconclusive, large nuclear uncertainties

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

gluon at large x



gluon at large x is small and currently very poorly known;
crucial for new physics searches

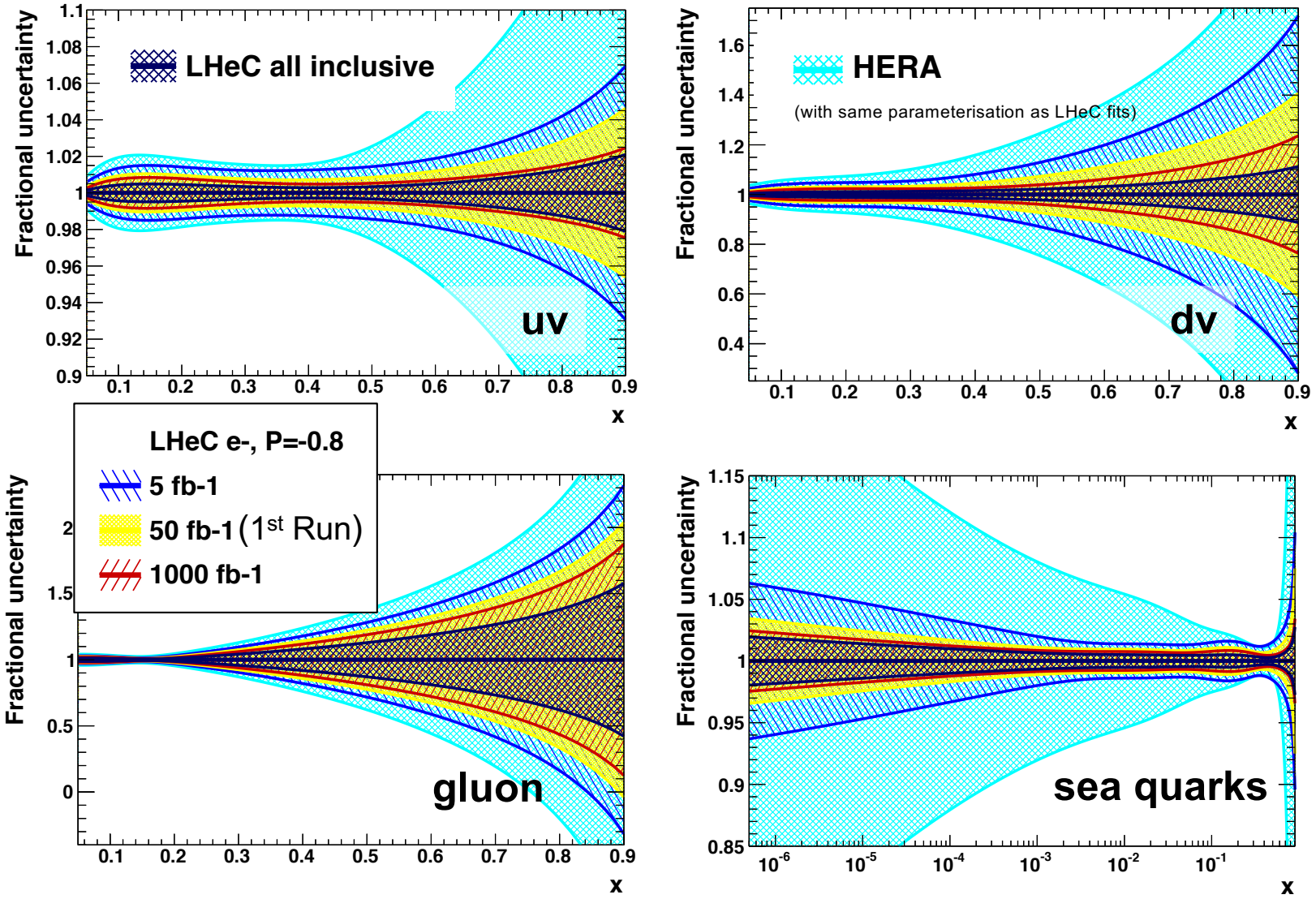
LHeC sensitivity at large x comes as part of overall package

high luminosity (×50–1000 HERA); fully constrained quark pdfs; small x; momentum sum rule

gluon and sea intimately related

LHeC can disentangle sea from valence quarks at large x, with precision measurements of **CC** and **NC** $F2^{\gamma Z}$, $xF3^{\gamma Z}$

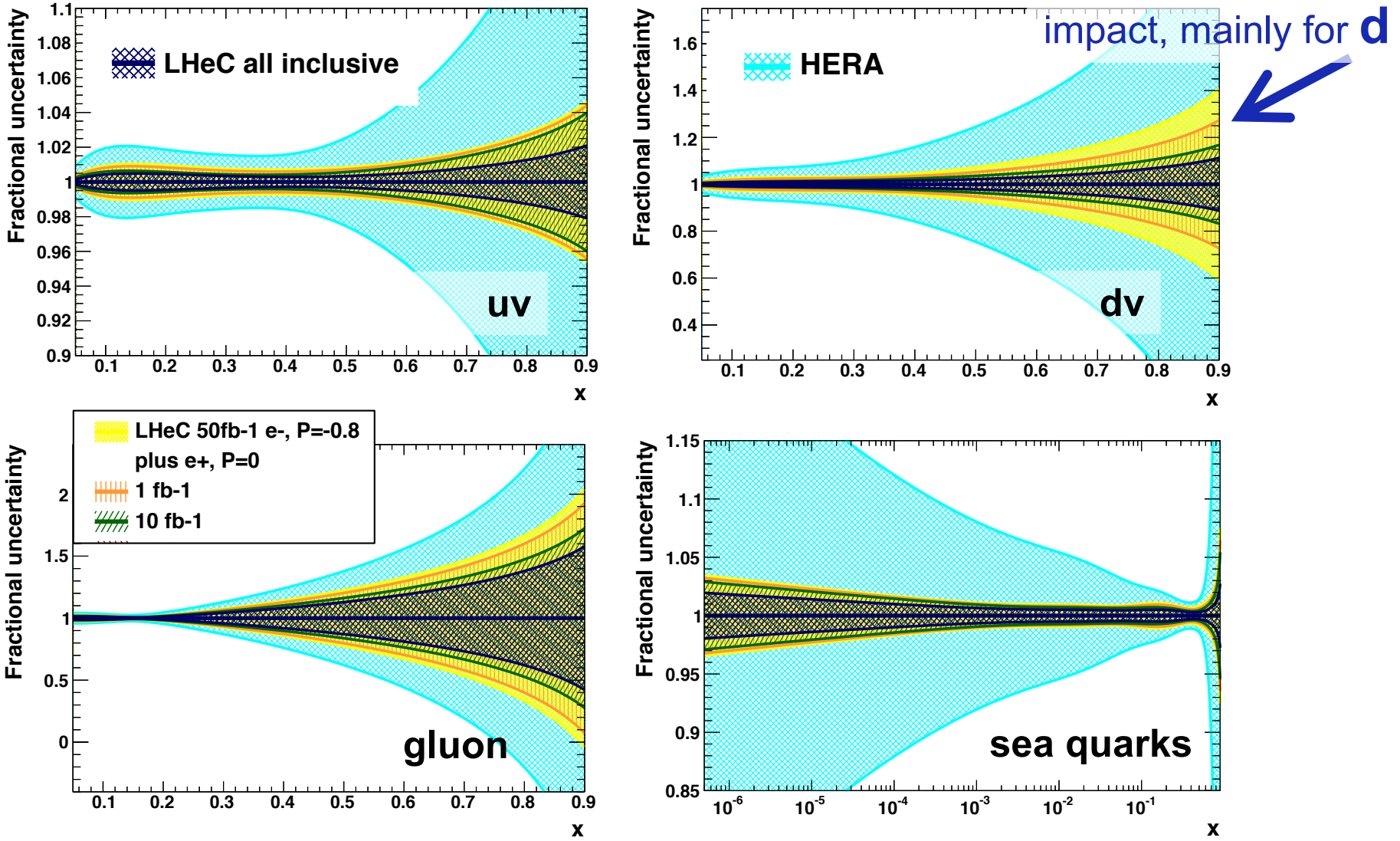
impact of luminosity on LHeC pdfs



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

large x (≡ large Q2), gain from increased Lint; still, early massive improvement cf. today

impact of positrons on LHeC pdfs



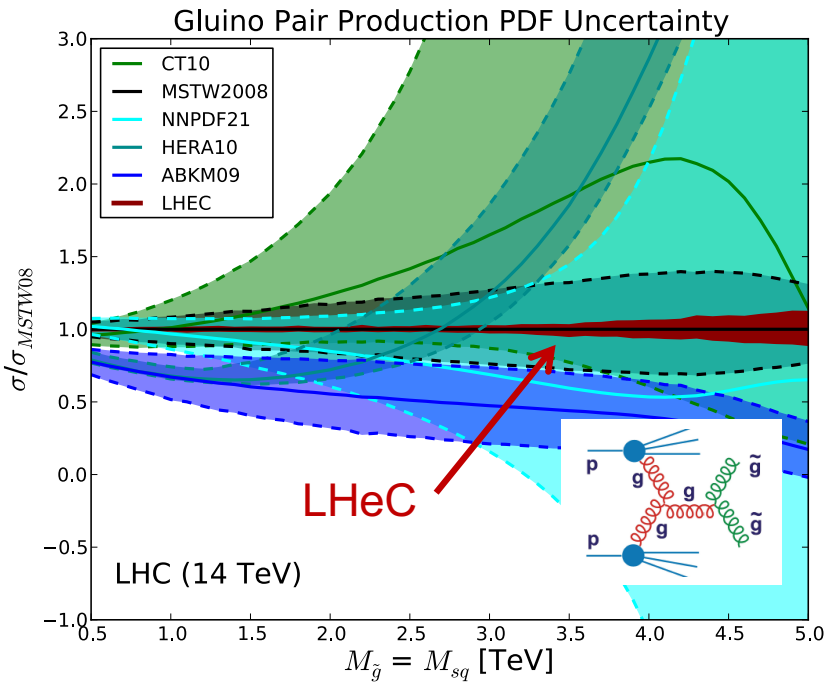
CC: e+ sensitive to d; **NC**: e± asymmetry gives $xF3^{\gamma Z}$, sensitive to valence

empowering LHC searches

external, reliable, precise **pdfs** needed for range extension and interpretation

gluons at large x

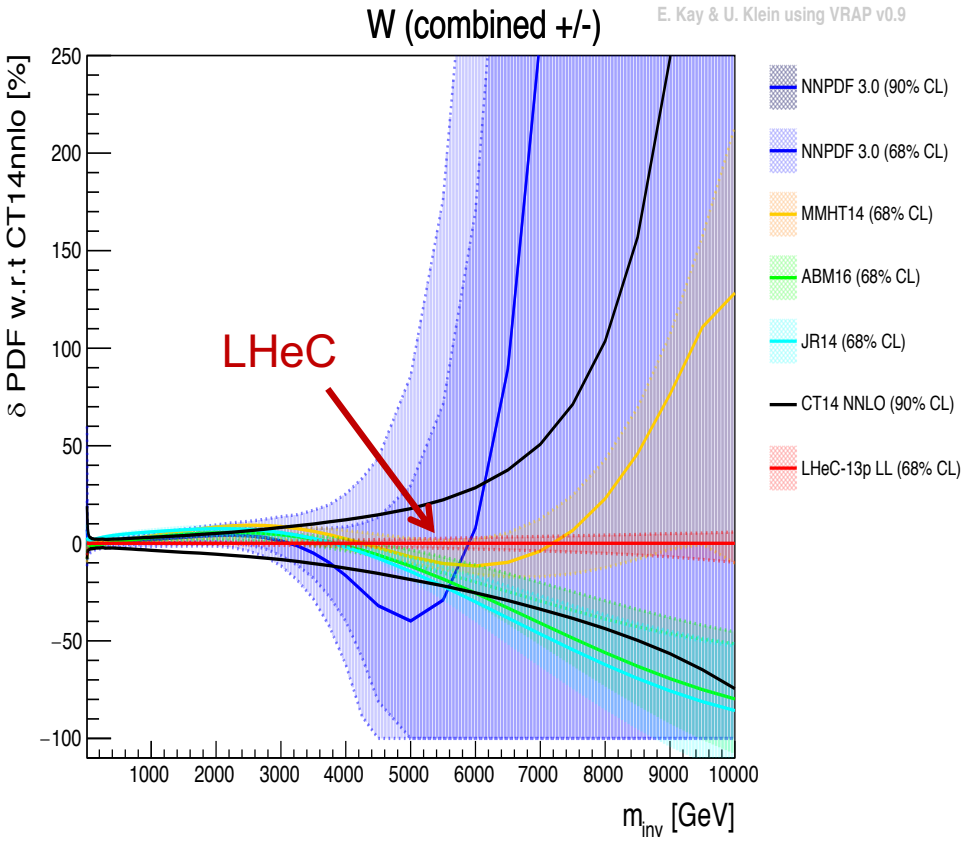
SUSY (RPC, RPV), LQs, …



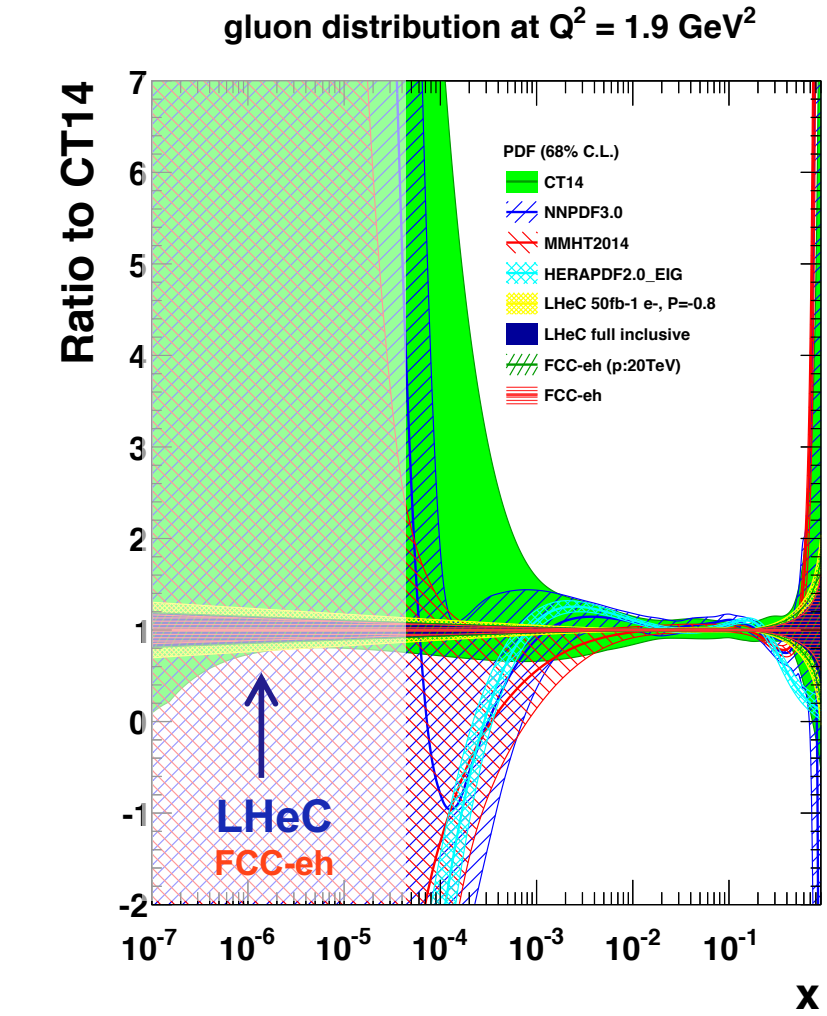
arXiv:1211.5102

quarks at large x

exotic and extra boson searches at high mass



gluon at small x



no current data much below $x=5\times10^{-5}$

LHeC provides single, precise and unambiguous dataset down to $x=10^{-6}$

FCC-eh probes to even smaller $x=10^{-7}$

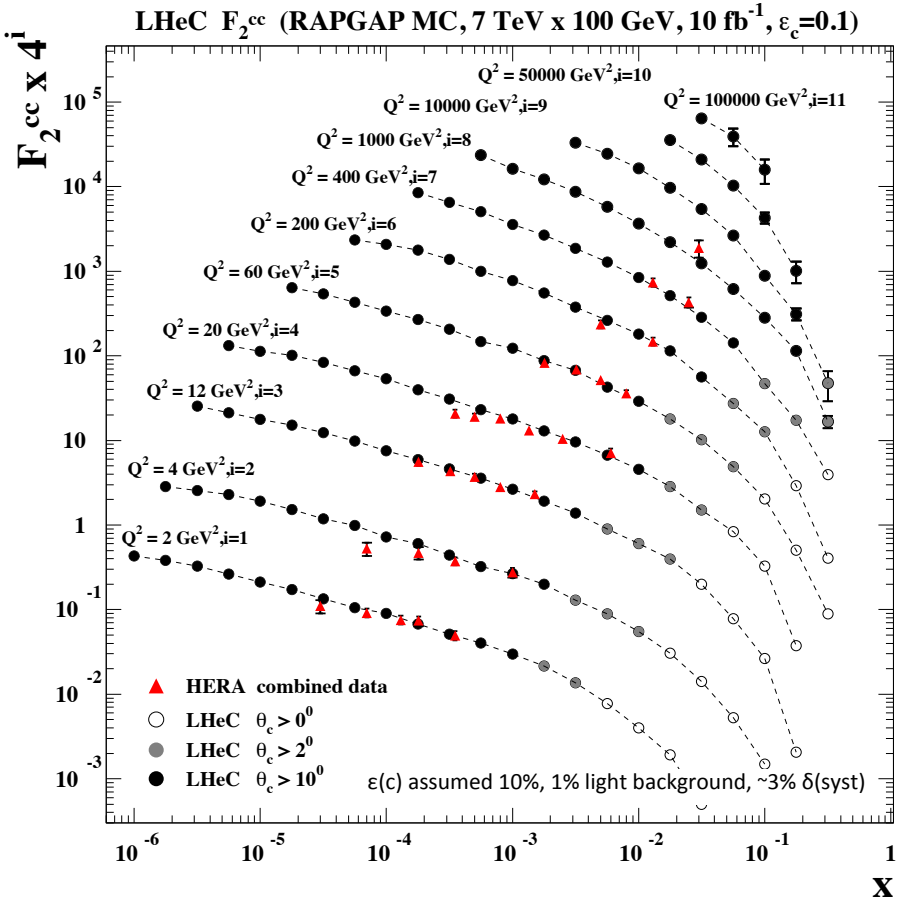
explore small x QCD:

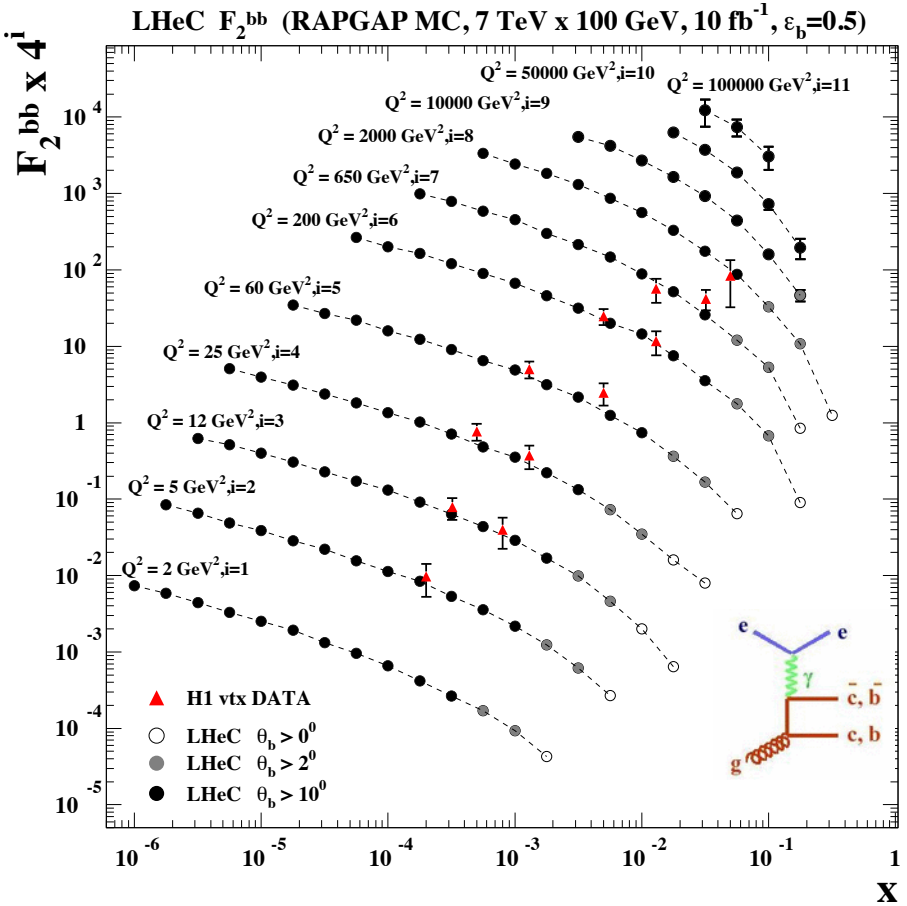
DGLAP vs BFKL; non-linear evolution;
gluon saturation; implications
for ultra high energy neutrino cross sections

see talk by A. Stasto

c, b quarks

arXiV:1206.2913

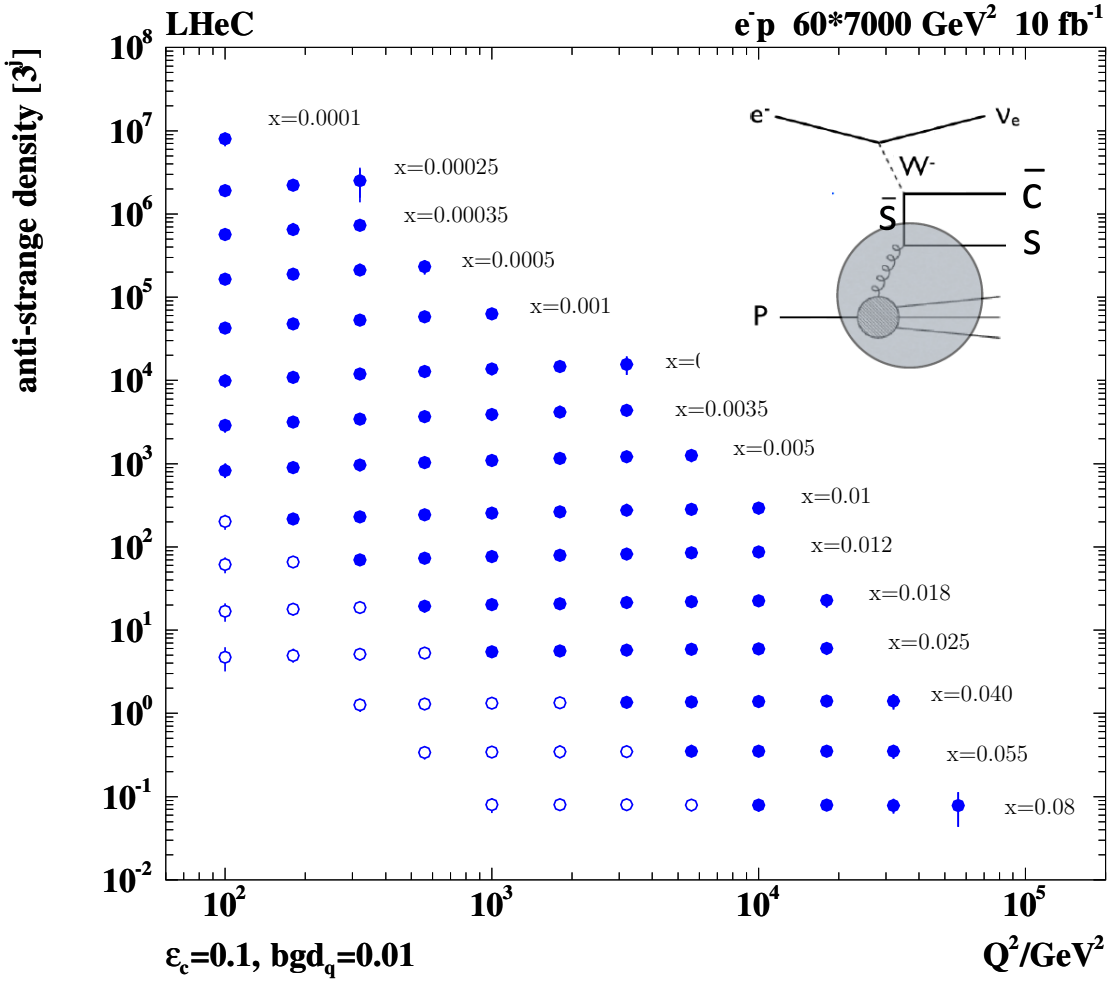




LHeC: enormously extended range and much improved precision c.f. HERA

- **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 $b\bar{b} \rightarrow A$

strange

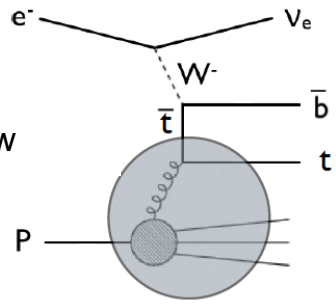


strange pdf poorly known;
suppressed cf. other light quarks?
strange valence?

LHeC: direct sensitivity to **strange** via W+s → c
(x,Q^2) mapping of (anti) strange for first time

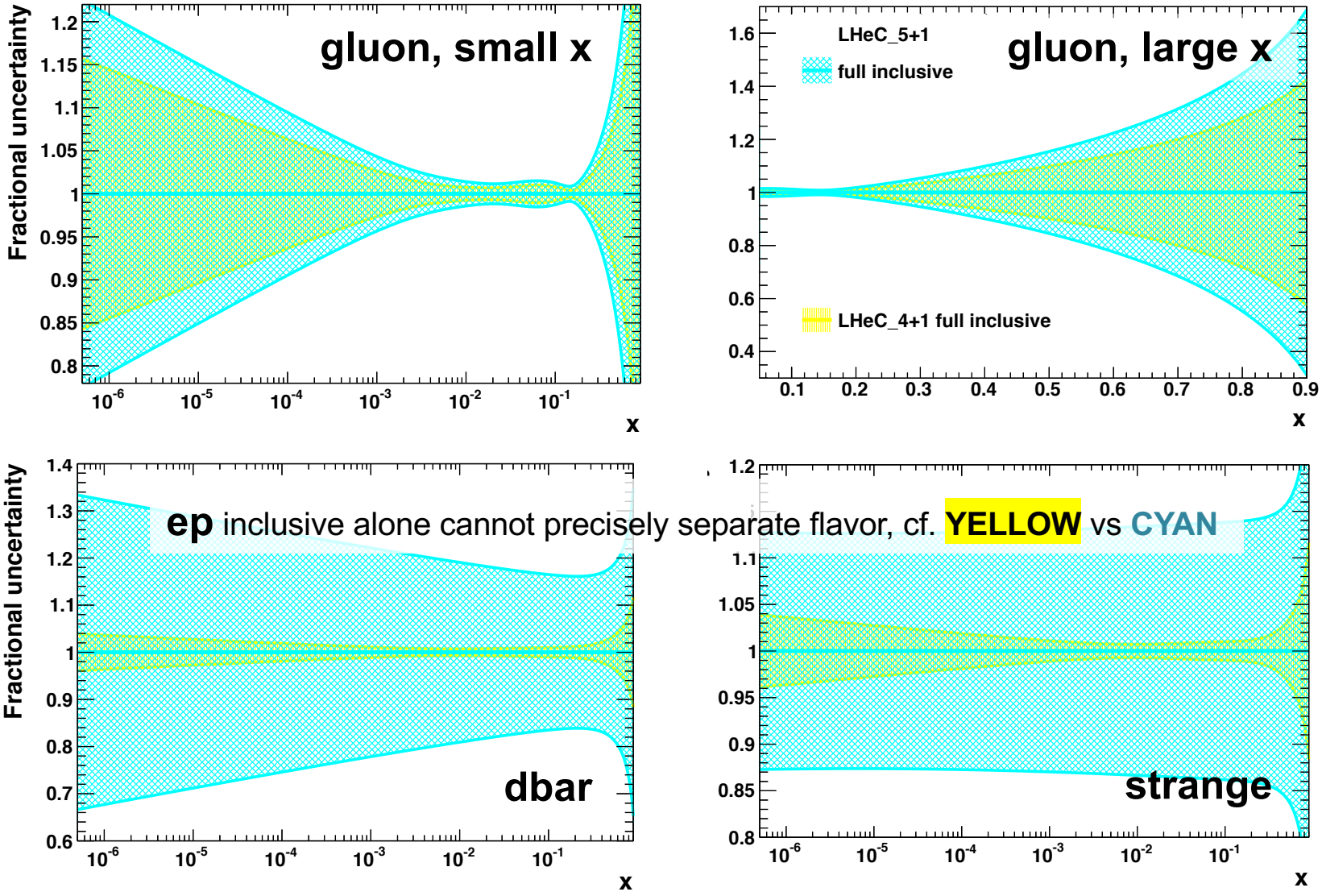
also top PDF

top quark becomes light at large Q^2: new field of research opens for top PDFs!



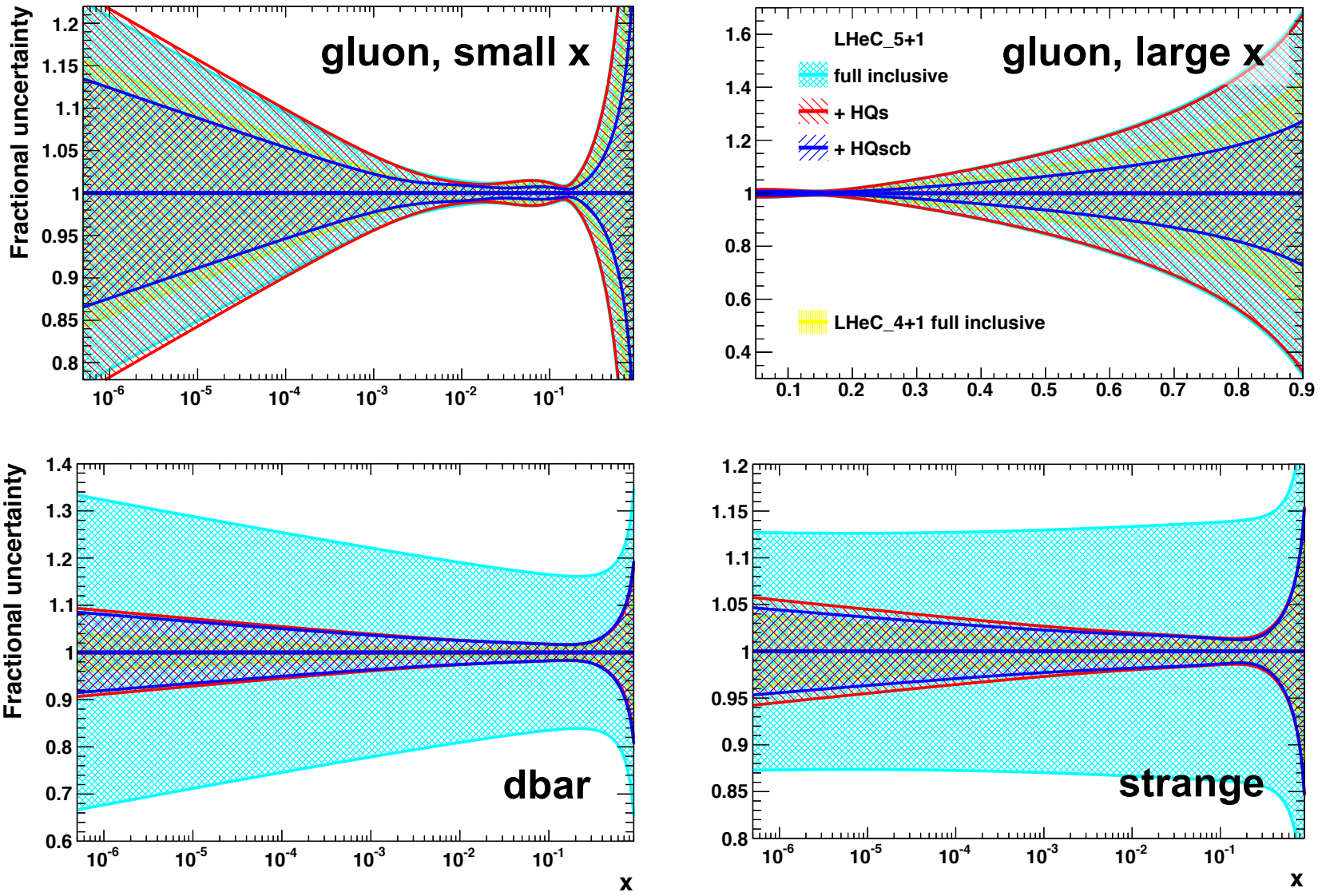
G.R. Boroun, PLB 744 (2015) 142
G.R. Boroun, PLB 741 (2015) 197

pdf flavour separation



more flexible parameterisation (5+1): **xuv, xdv, $x\overline{U}$, $x\overline{d}$, $x\overline{s}$** and **xg**

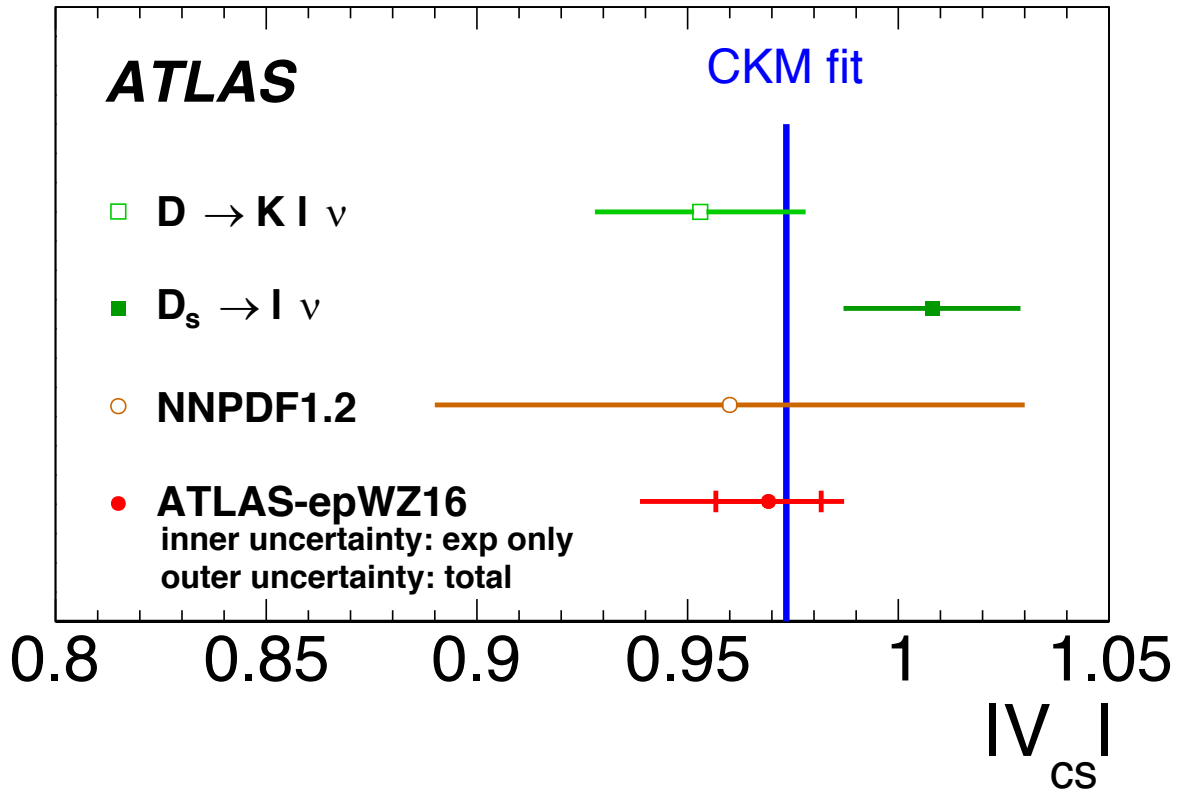
impact of HQ data on LHeC pdfs



addition of **s** and **b,c** data gives flavour separation!

Vcs

ATLAS coll., arXiv:1612.03016



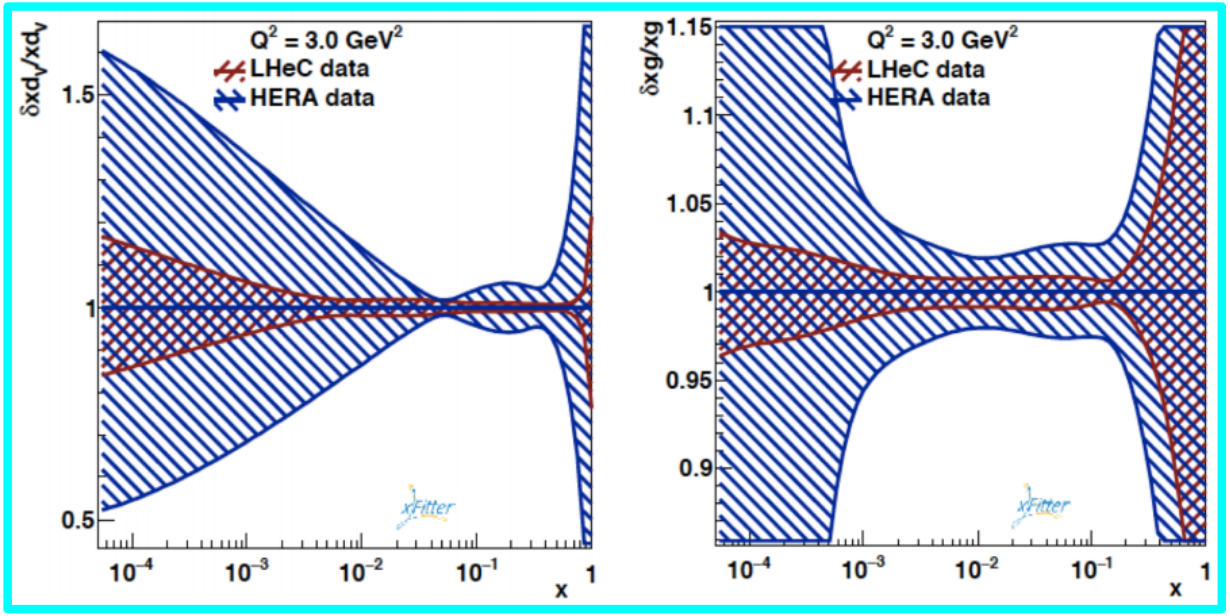
HERA+ATLAS ⟶ Vcs

expect much better precision from **LHeC** or **FCC-eh** (×10 or more)

Updates on LHeC impact to PDFs with xFitter

M. Bonvini, F. Giuli

Comparison to PDFs from HERA data



… ongoing study to understand PDF uncertainty dependence on:

- tolerance criteria
- parametrization bias
- pseudo-data set choice

- We have created a new dataset staring from a different input PDF:
- We have introduced a new, more flexible, parametrization for the PDFs
- The obtained χ^2/dof ~ 1.22 is good

- To-do list:
  - Studies with small-x resummation
  - Estimate model uncertainties
  - Inclusion of heavy flavour data

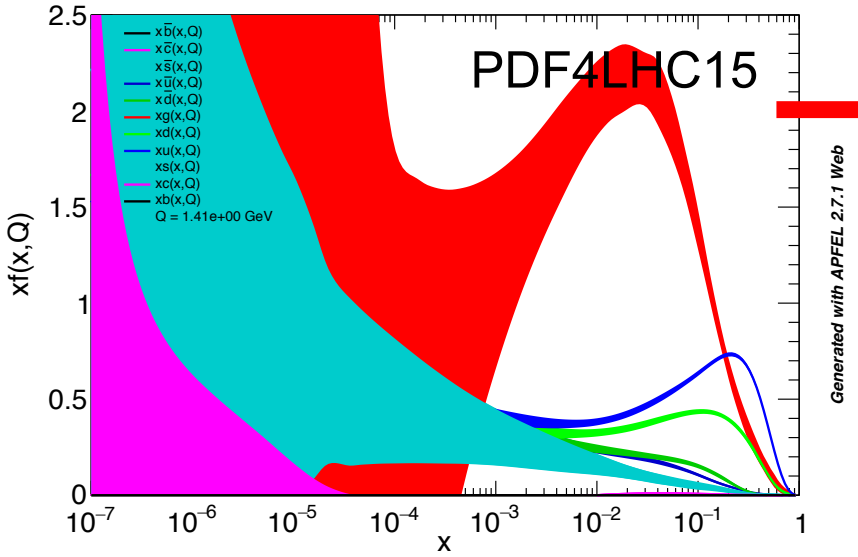
CG: this is slide Fred gave me to summarise other work – will probably revamp, or summarise in the summary instead?

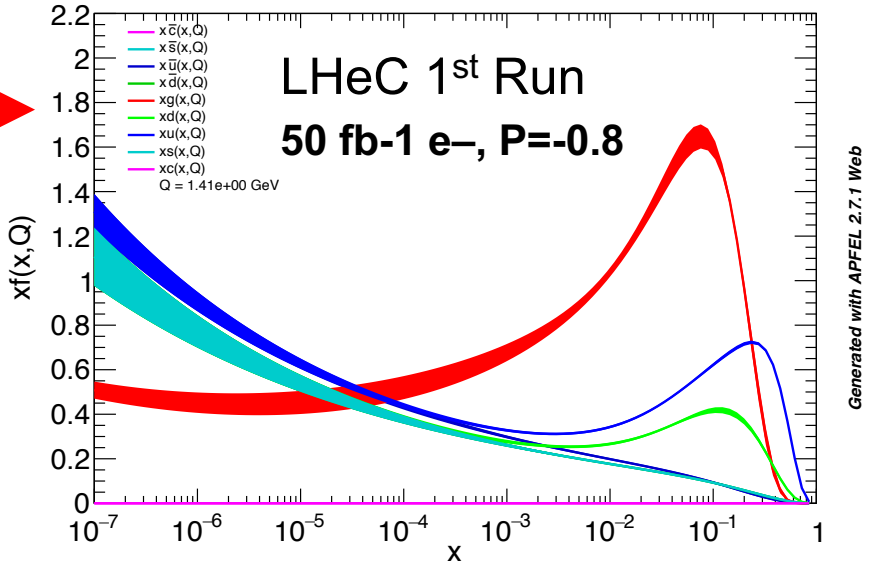
Compare with:
CT14nnlo
HERA Data
NNPDF31sx

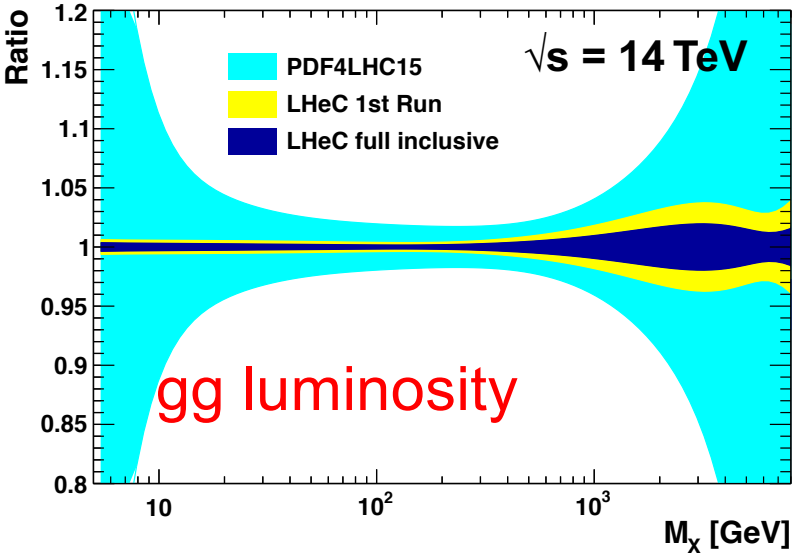
, a remarkable reduction of PDF uncertainties is obtained

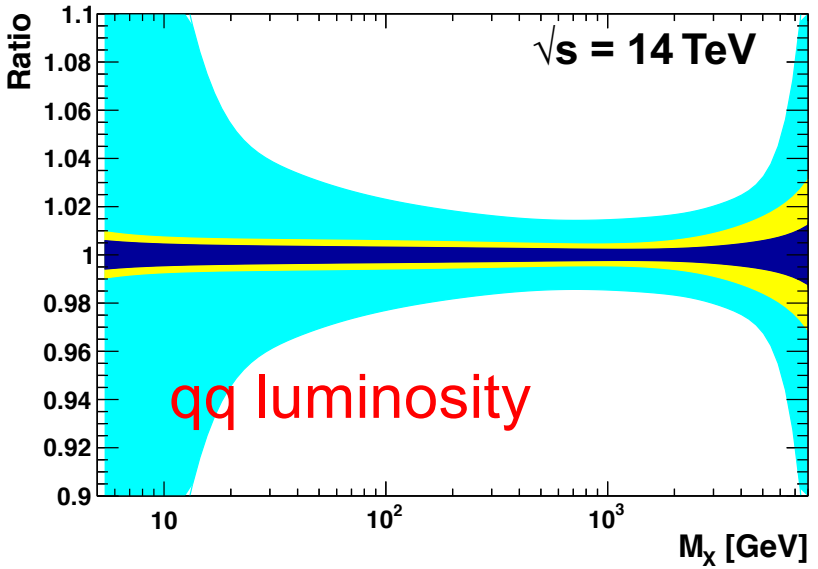
placeholder for Daniel's α_s stuff

summary of pdfs from ep









summary

precision determination of quark and gluon structure of proton and αs

of fundamental importance for future hadron collider physics programme (Higgs, BSM, …)

BLAH BLAH, need to finish this…