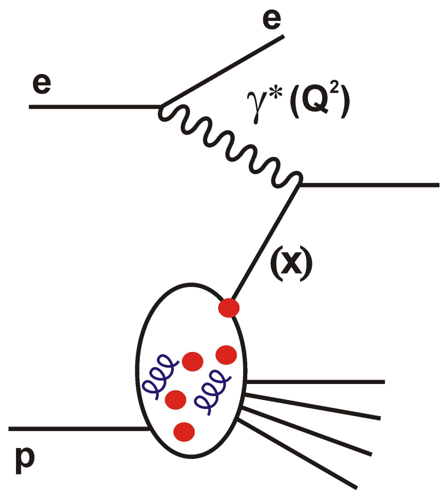
High x Parton Densities: Impact on the LHC

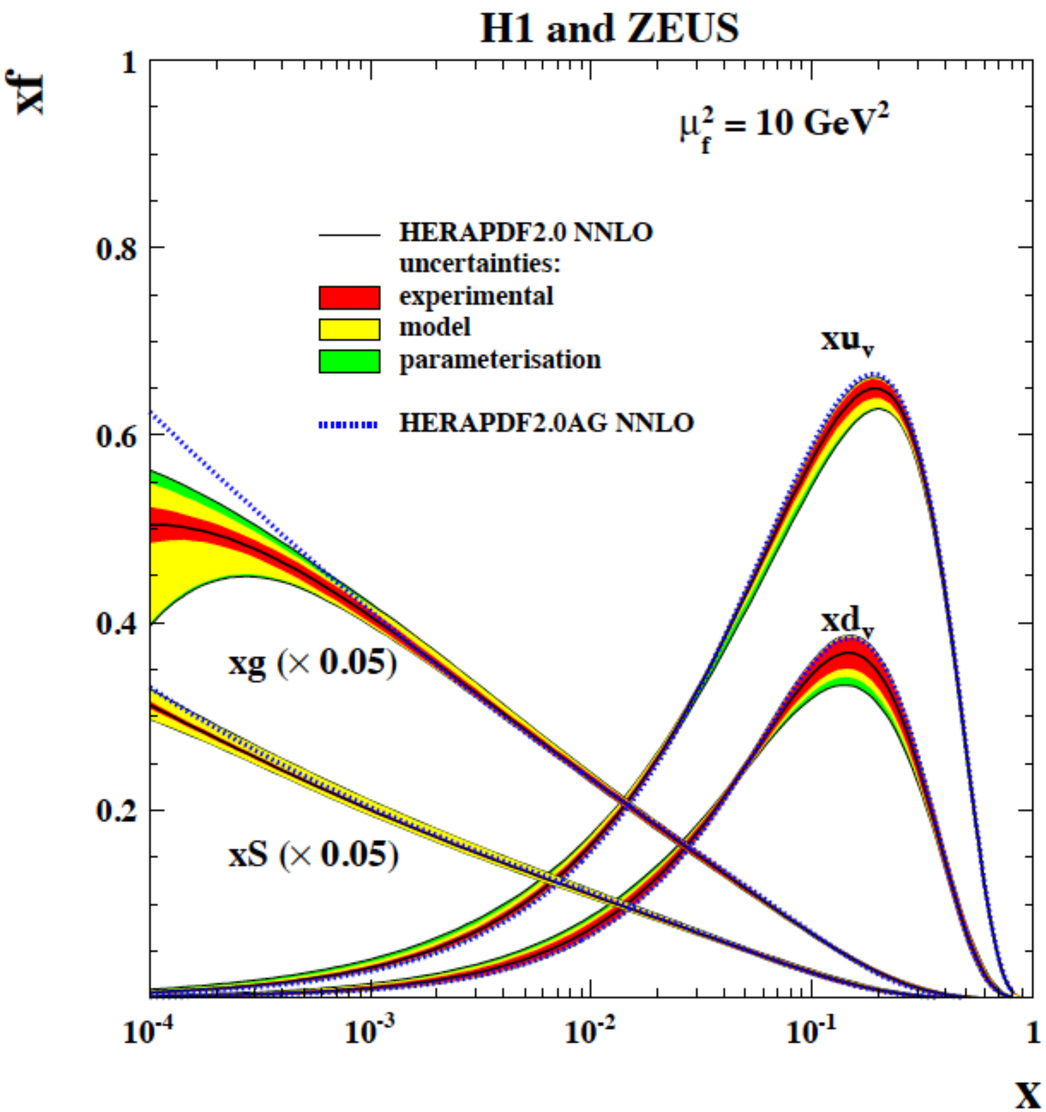


Paul Newman
Birmingham University
Jlab Large x Workshop

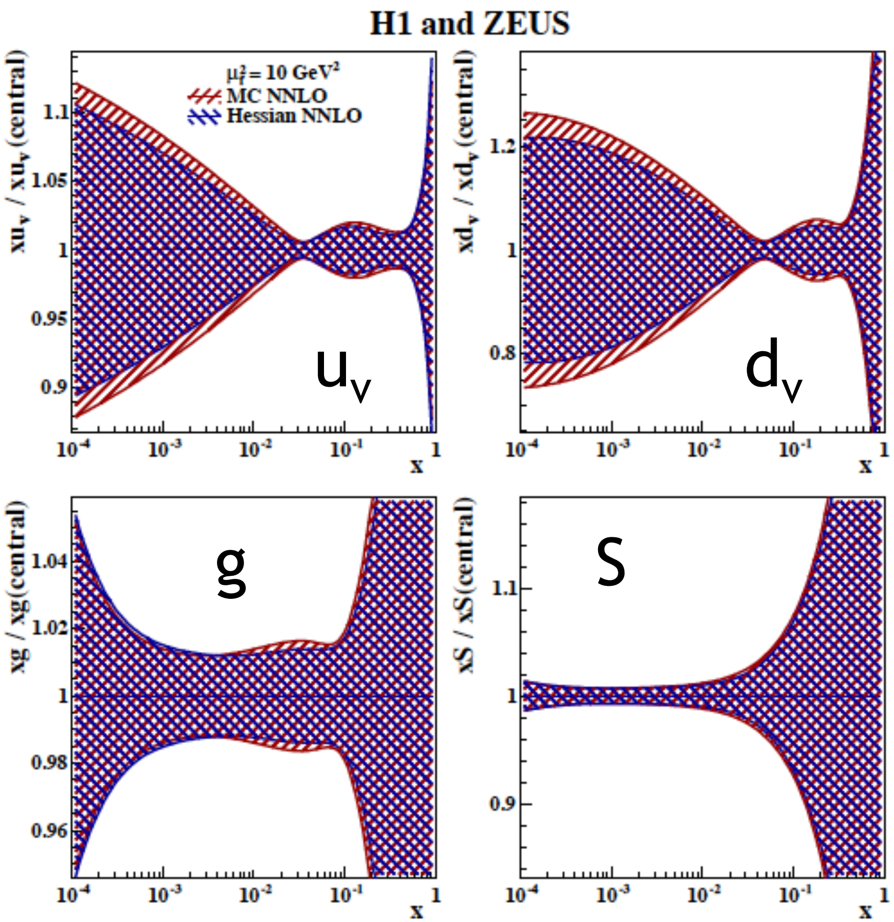
4 Oct 2016

- Current status of (unpolarised) high x PDFs
- Why the LHC needs high x PDFs
- Constraints on high x PDFs from LHC data
- Potential constraints on high x PDFs from ep data

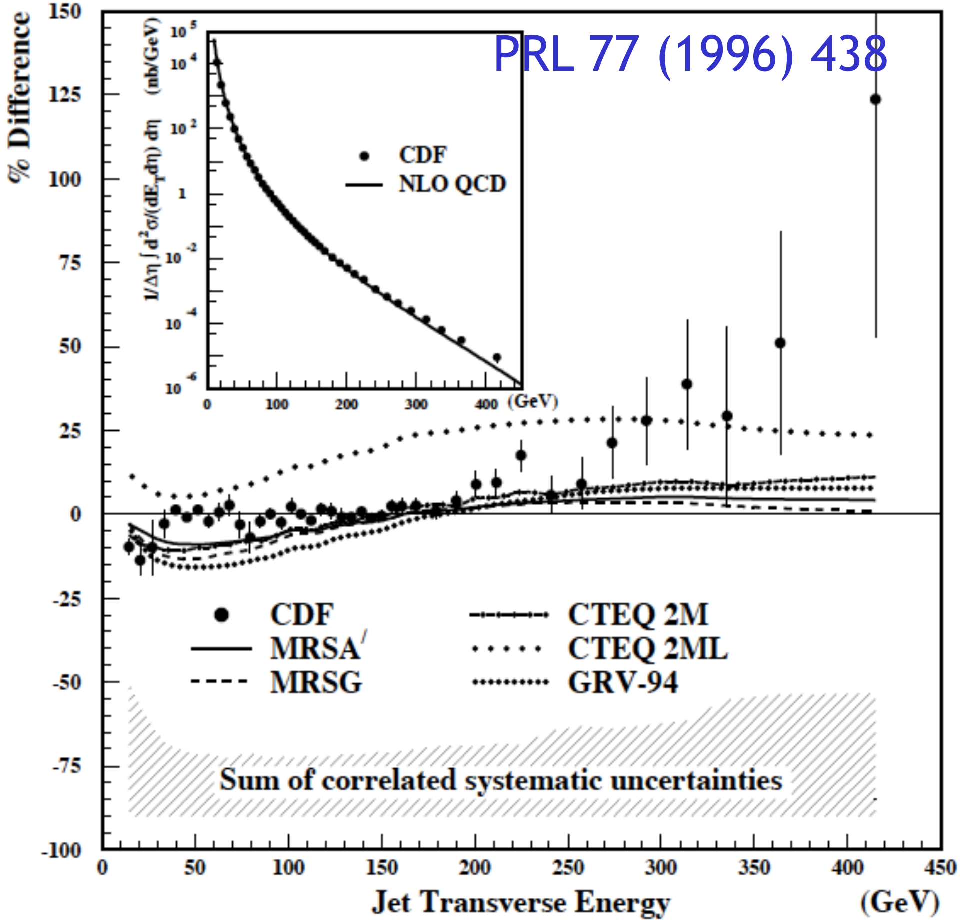
Final Picture of the Proton through the HERA ~~Micro~~Attoscope



… lack of precision at the highest x hidden by fact that PDFs tend to zero.

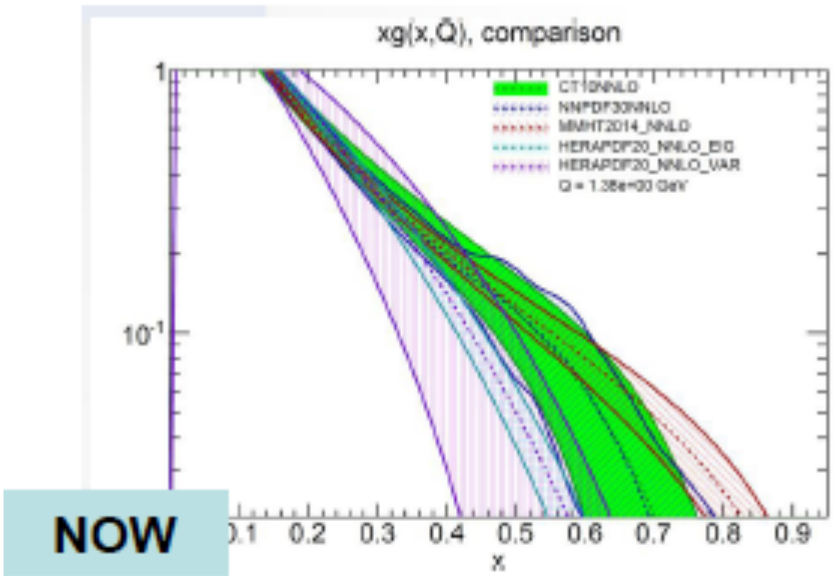


Why Do we need to Care about High x?



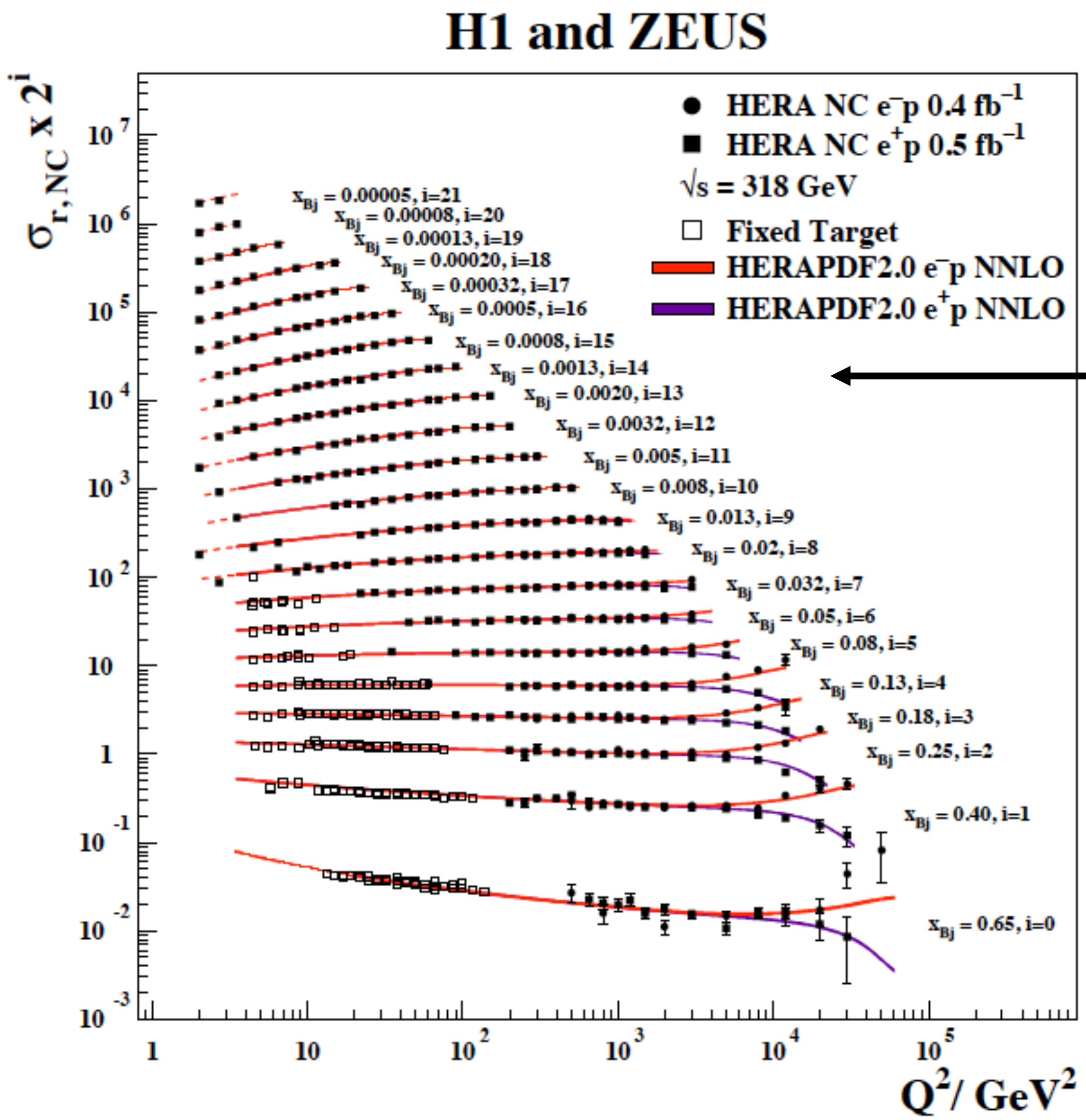
Ancient history (HERA, Tevatron)

- Apparent excess in large E_T jets at Tevatron turned out to be explained by well within uncertainties on high x gluon …

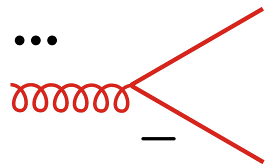


- Confirmation of (non-resonant) new physics near LHC kinematic limit relies on breakdown of factorisation between ep and pp

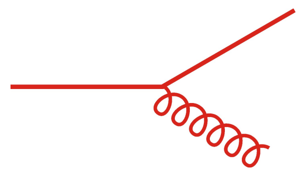
What makes the High x Gluon so Tricky?



NC Q^2 dependence driven by …



$g \rightarrow q\bar{q}$

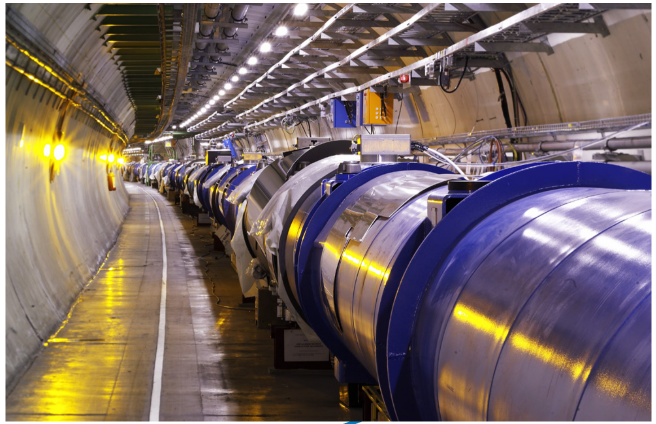


$q \rightarrow qg$

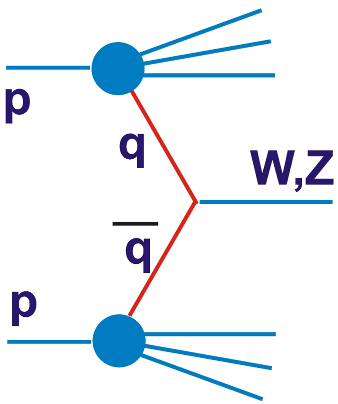
… QCD fit description over vast range

- High x evolution (starting from valence quarks) driven by q→qg splitting → reduced sensitivity … need other observables?...

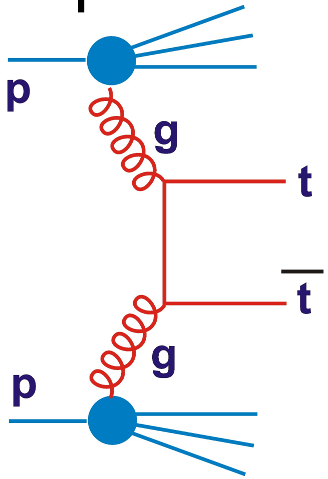
PDFs and the LHC



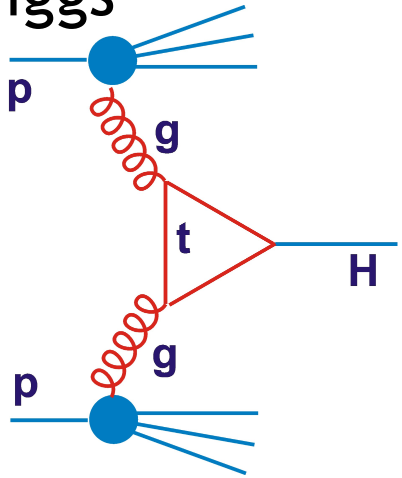
EW SM



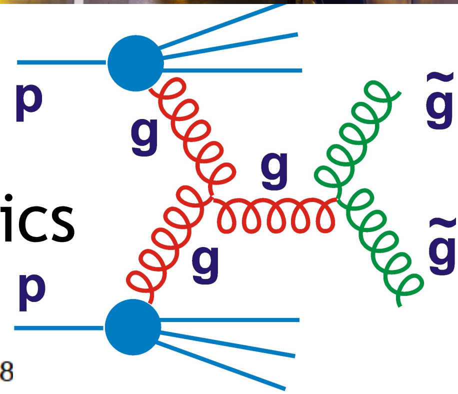
Top

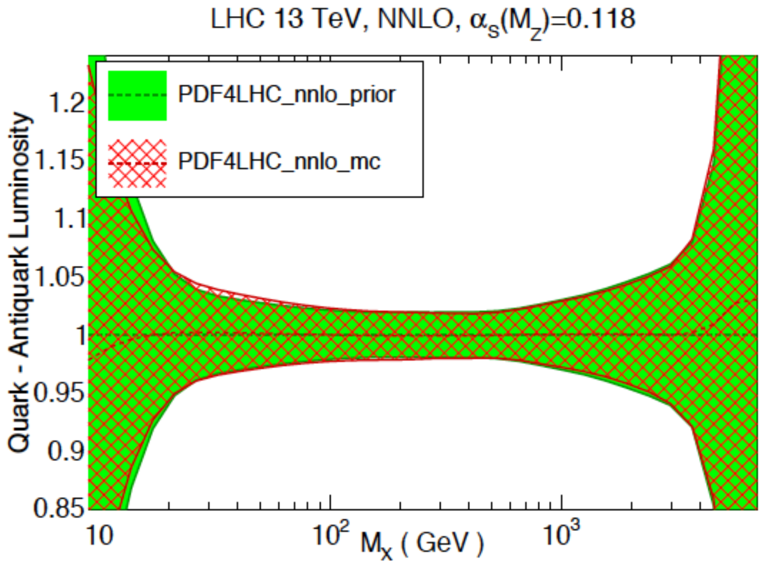


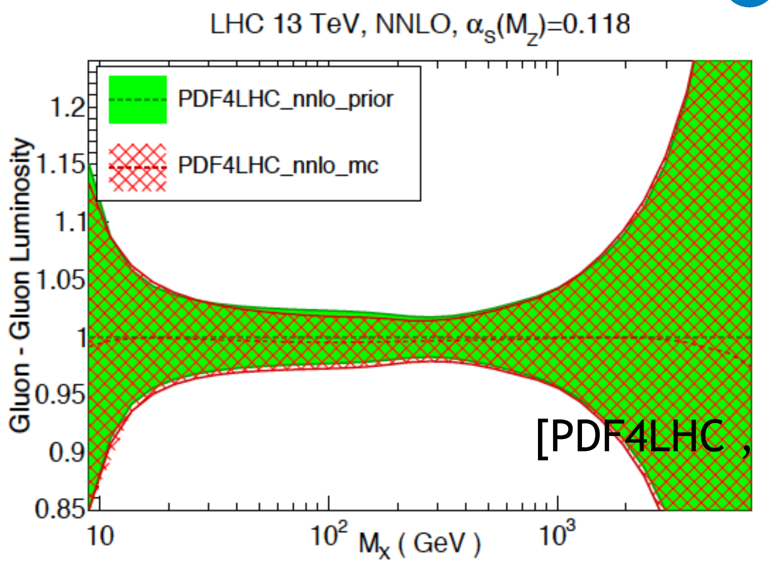
Higgs



Exotics



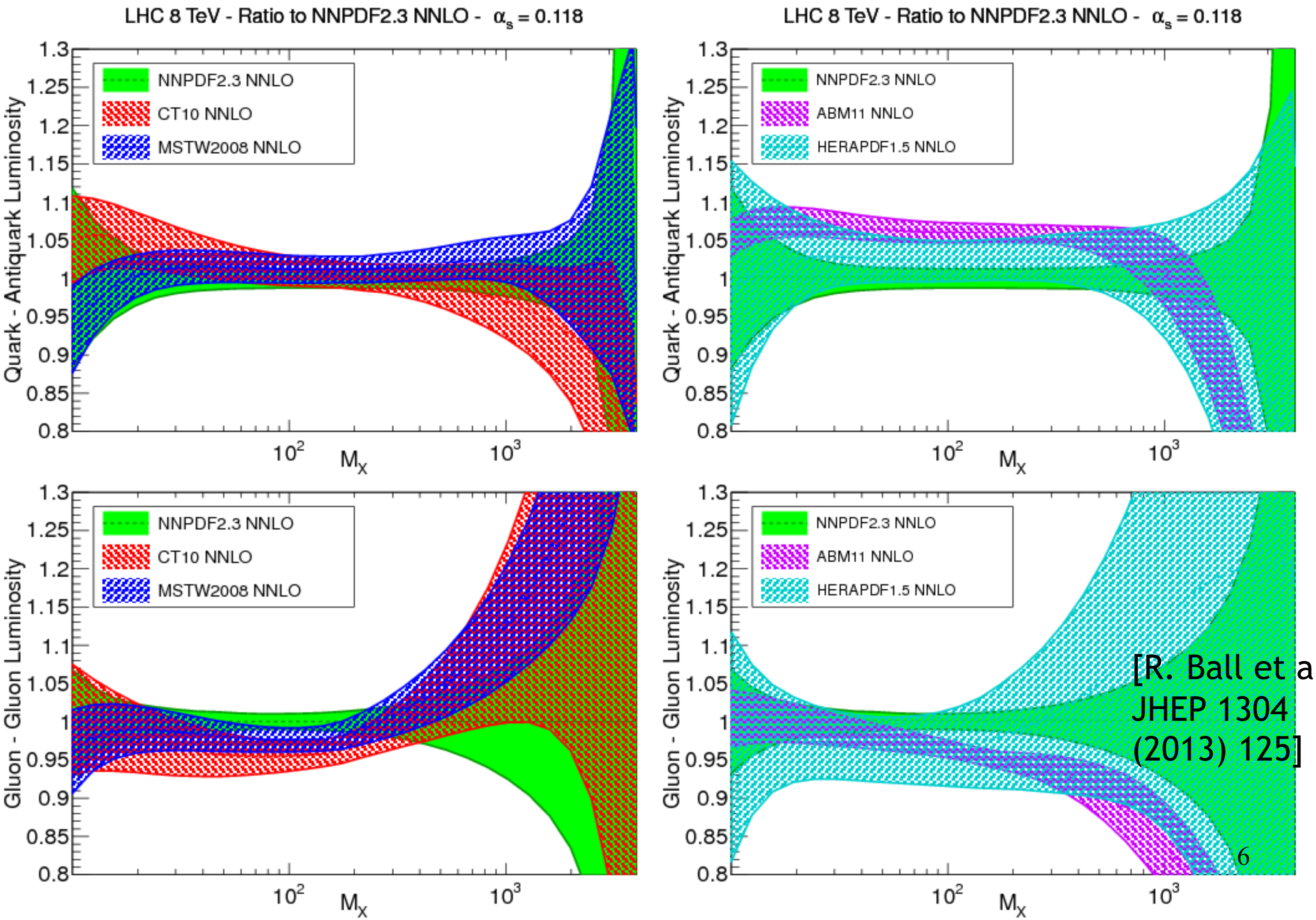




[PDF4LHC , arXiv:1510.03865]

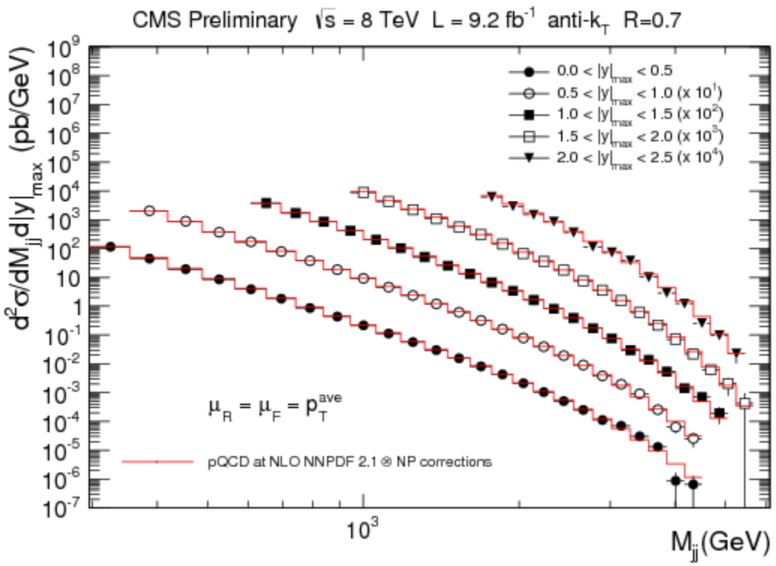
(something close to) current status, as function of mass of new resonances being produced (M_X)

Even more variation than PDF4LHC suggests?



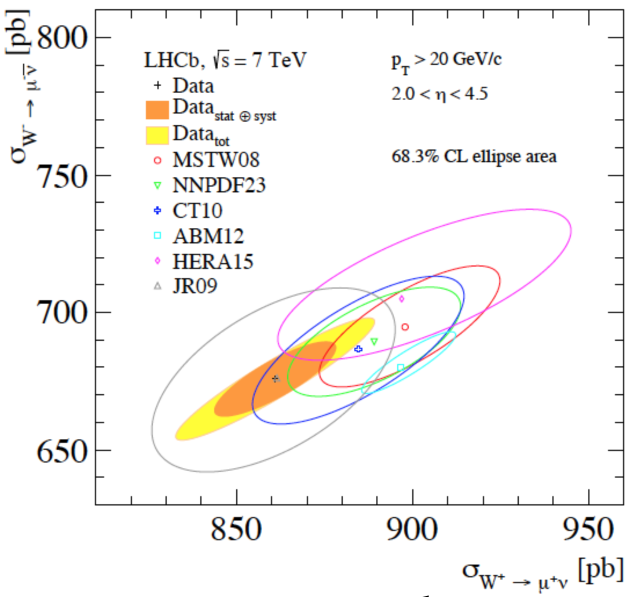
[R. Ball et al., JHEP 1304 (2013) 125]

PDFs working in extreme cases at the LHC …

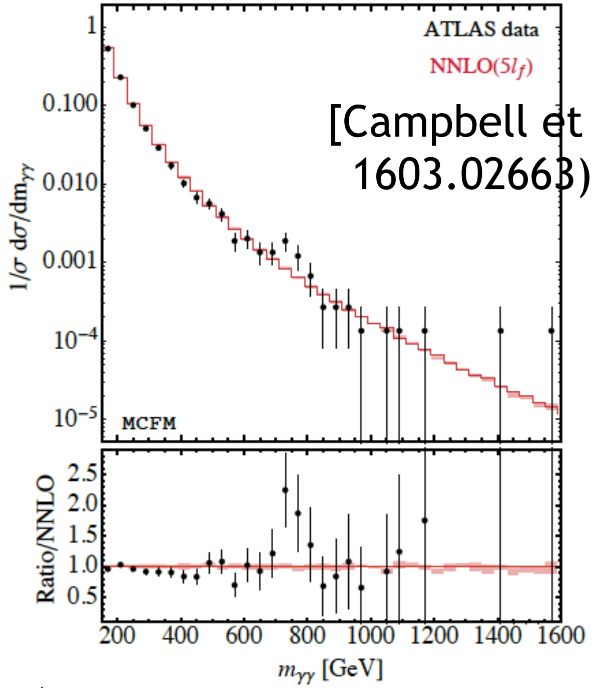


- Jets with cross sections varying over many orders of magnitude, extending to eg M_{jj} ~ 5 TeV

- LHCb Electroweak gauge bosons, extending well into forward region



- (NNLO) shape comparison of γγ background v "X(750)", for perfect rec'n and no backgrd



[Campbell et al, 1603.02663)]

… but LHC has a VERY long programme
what are the limiting factors in 15 years time?...

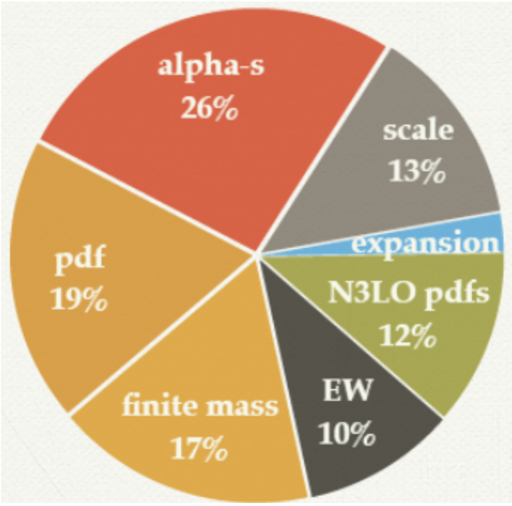
Higgs X-Section / Coupling PDF Uncertainties

Theoretical Uncertainties

After N^3LO calculation of gluon-fusion Higgs cross section at 13 TeV → much reduced scale uncertainty

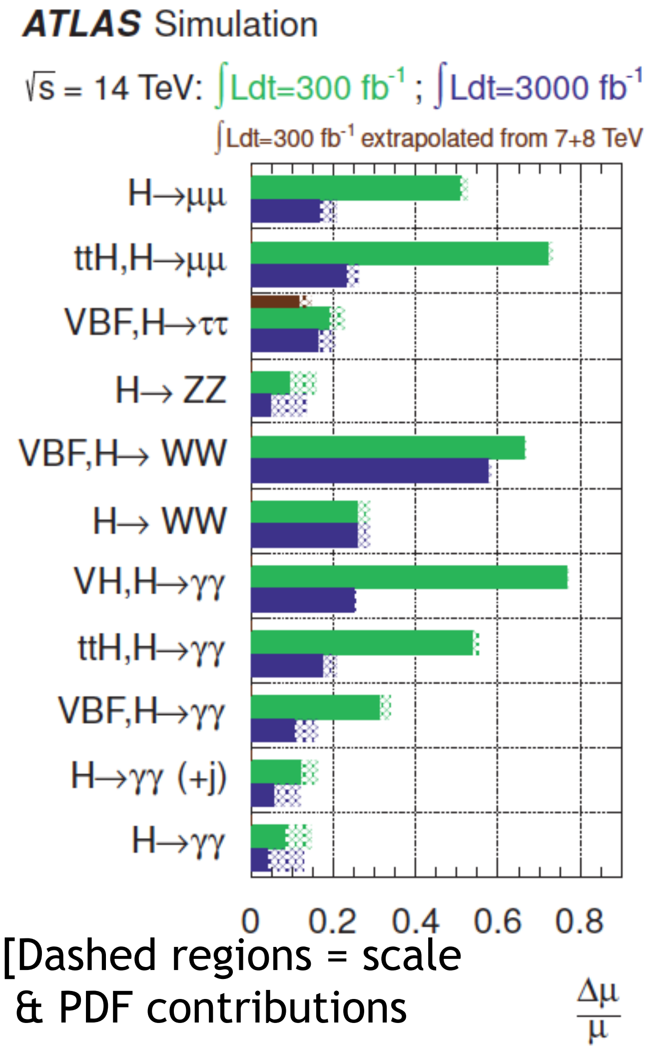
… largest sources of uncertainty:
- PDFs [1.9%]
- α_s [2.6%]

with additional 1.2% uncertainty on non-availability of N^3LO PDFs



[Anastasiou et al [1503.06056], Dulat, CERN Dec '15]

Projected Experimental Uncertainties

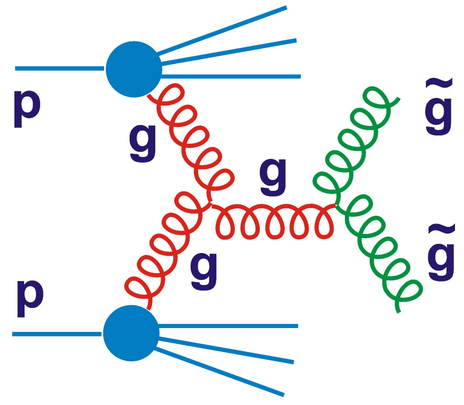


[Dashed regions = scale & PDF contributions

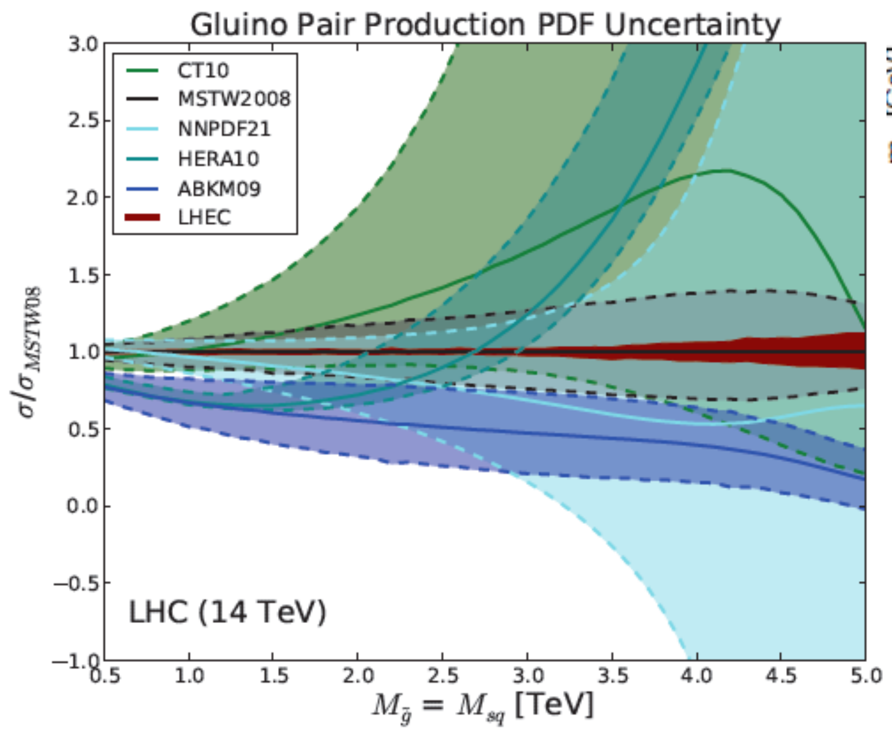
… much of Higgs sector becomes PDF limited in HL-LHC era …
(though it's $x \sim 10^{-2}$, so not really today's topic)

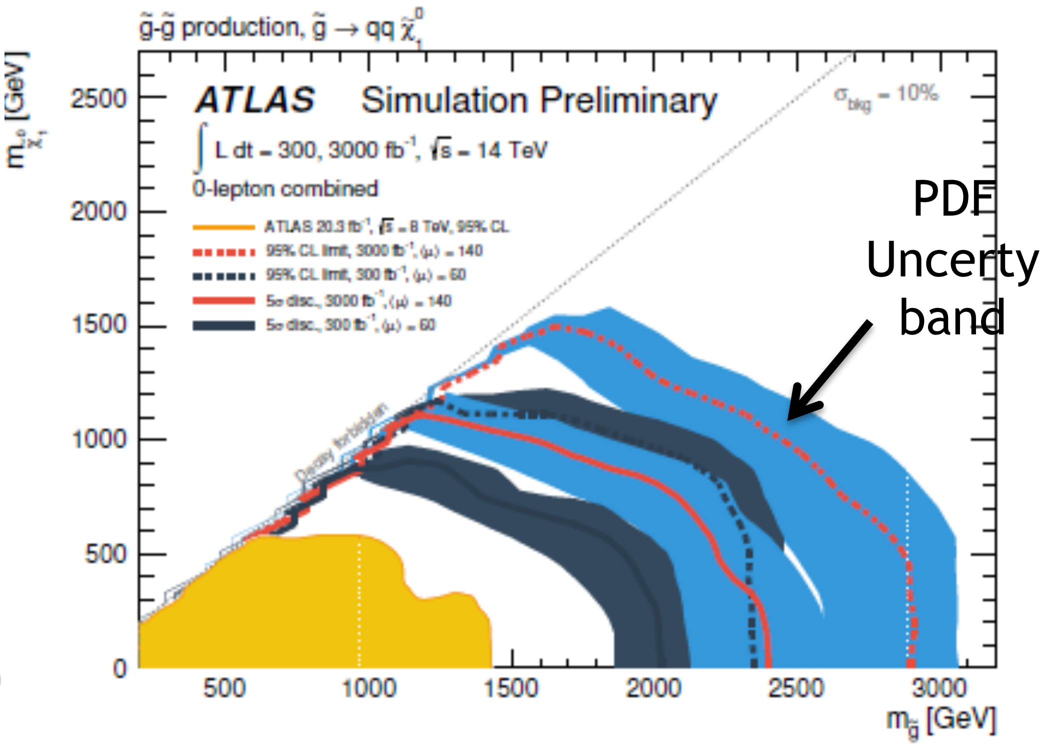
e.g. High Mass 2 Gluino Production

- Signature is excess @ large invariant mass
- Expected SM background (e.g. gg → gg) poorly known for s-hat > 1 TeV.

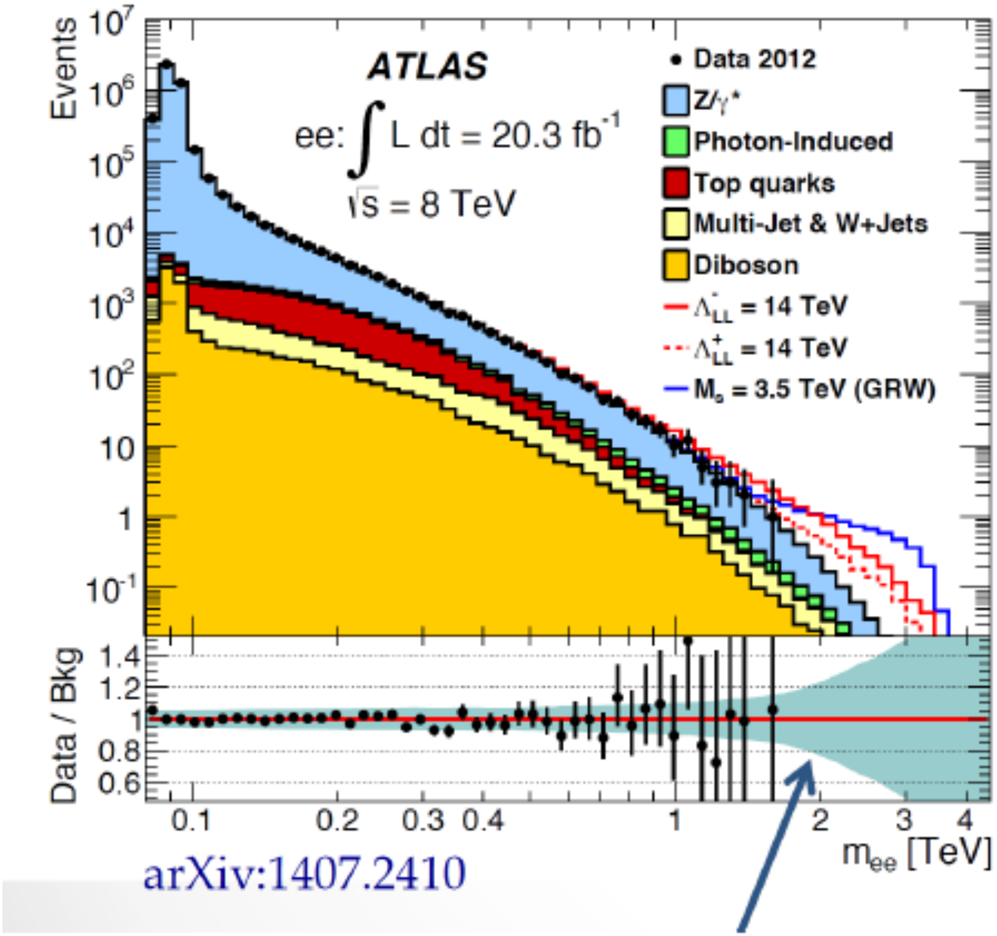


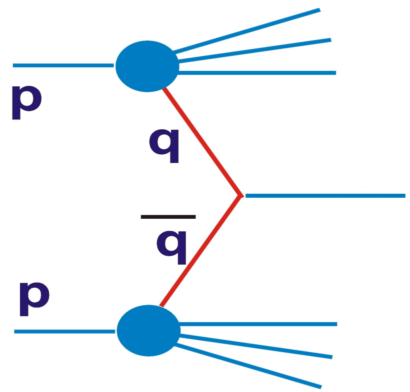
- Both signal & background uncertainties driven by error on gluon density … essentially unknown for masses much beyond 2 TeV





High x (Anti)-Quarks Matter Too …



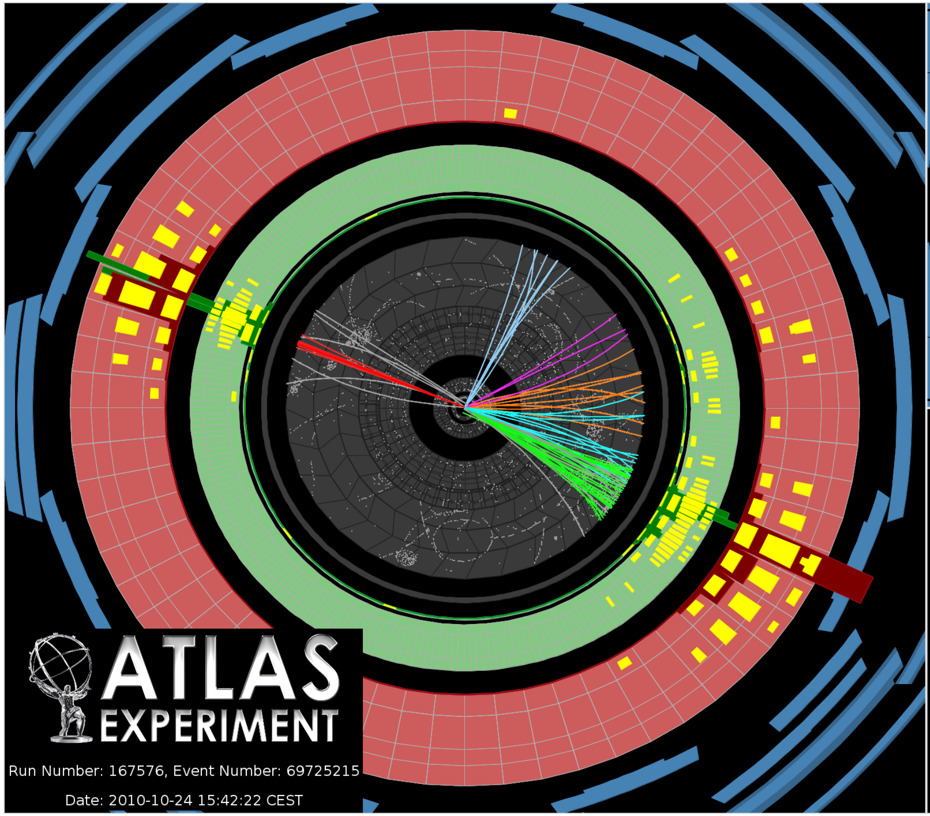


- BSM sensitivity through excess in high mass Drell-Yan limited by high x antiquark uncertainties as well as valence

… bottom line is that much of the LHC search programme will become limited by the high x parton density uncertainties as we head towards the ultimate lumi of the LHC unless there is a transformation in precision in the meantime …

Constraining PDFs with LHC Data

- Many claims that the LHC will be able to measure PDFs sufficiently accurately on its own



-Electroweak gauge bosons

- High pT jet production

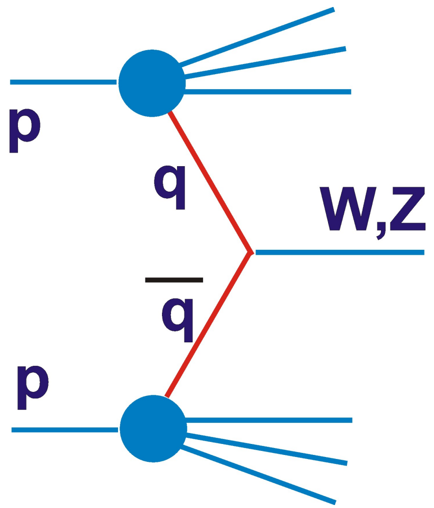
- Drell Yan

- Top Quarks

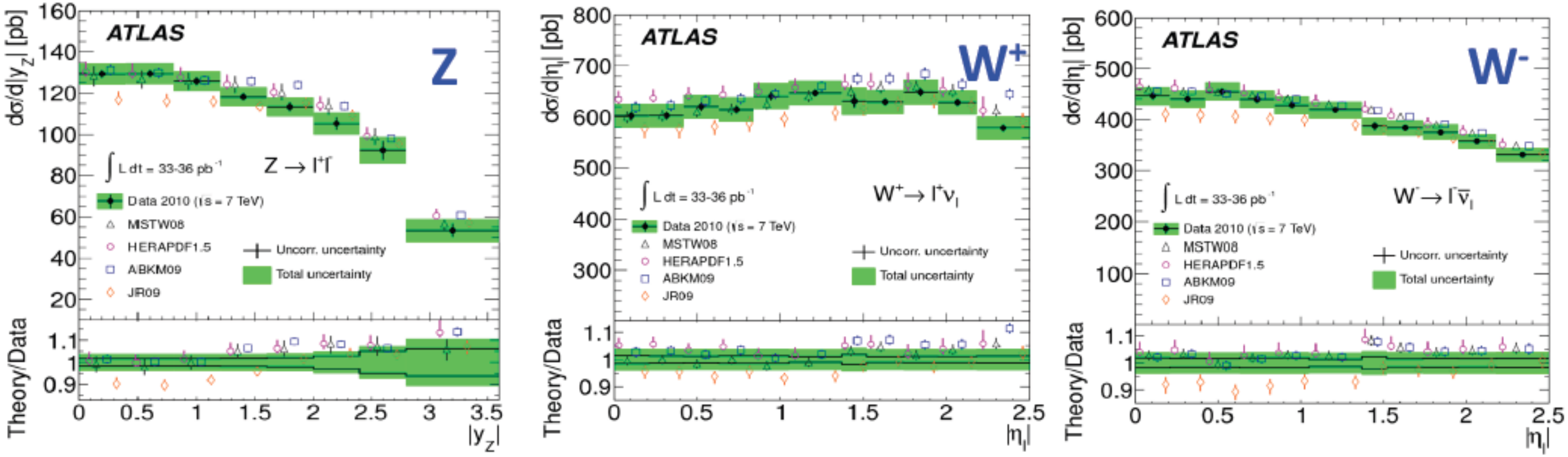
- Direct Photons

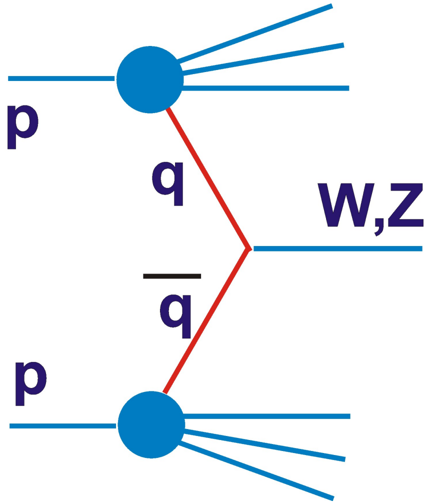
… a few examples (a bit out of date) …

Electroweak Gauge Bosons

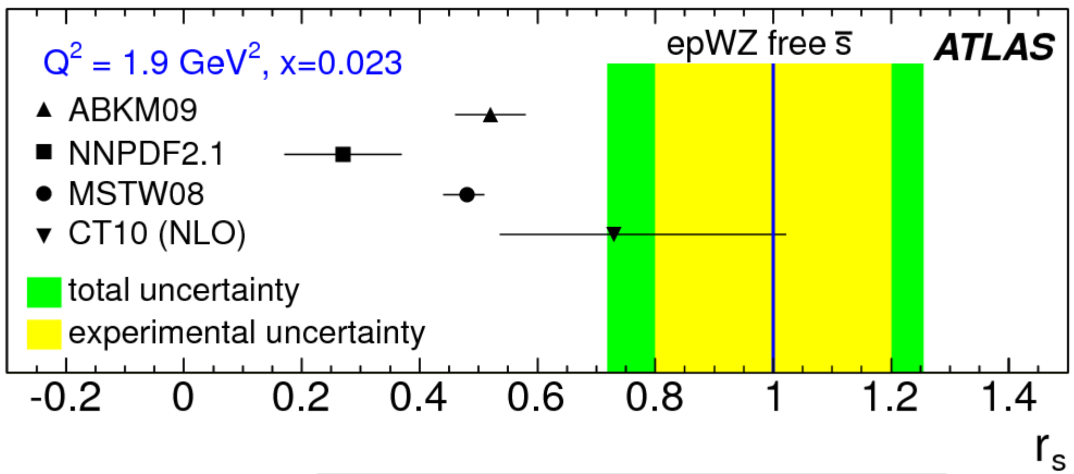


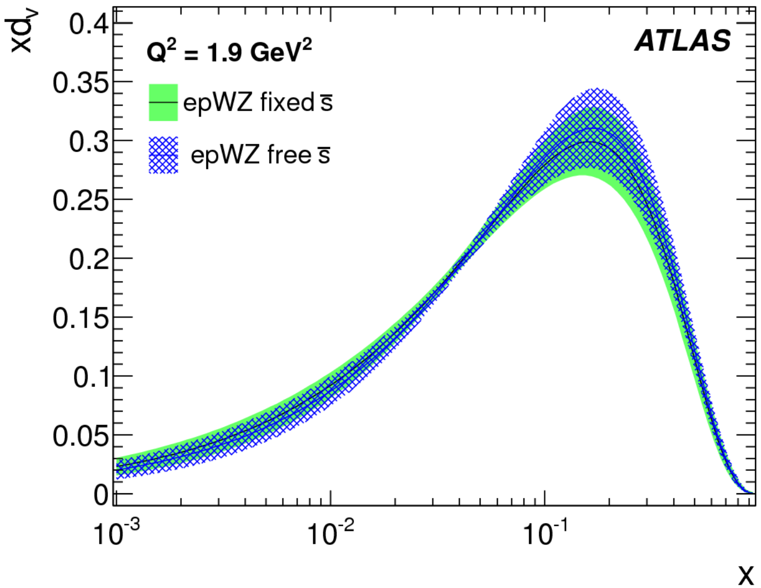
- Rates high in LHC terms
- Known to NNLO (QCD) and NLO (EW)
- Flavour sensitive through shapes … has shown that strange sea is too small in most PDF sets
- In principle sensitive to valence (q-qbar)
- LHCb have been extended studies to forward region (i.e. lower / higher x)

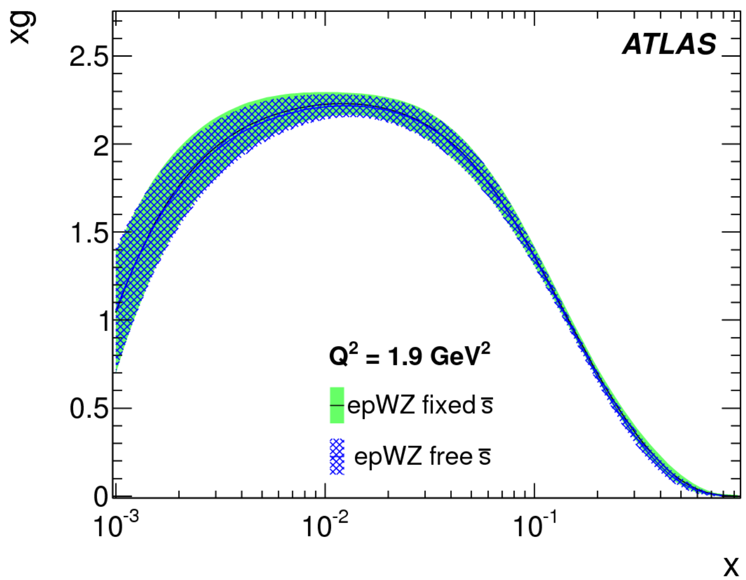




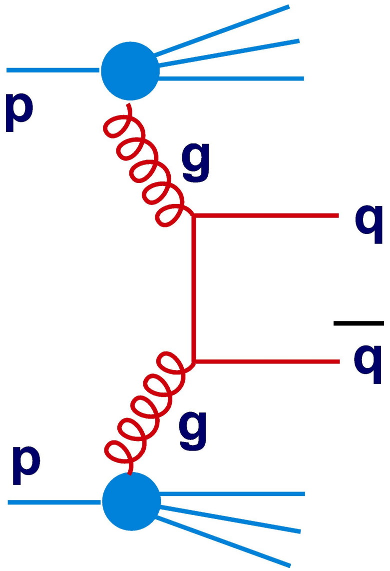
Impact of W/Z (ATLAS)





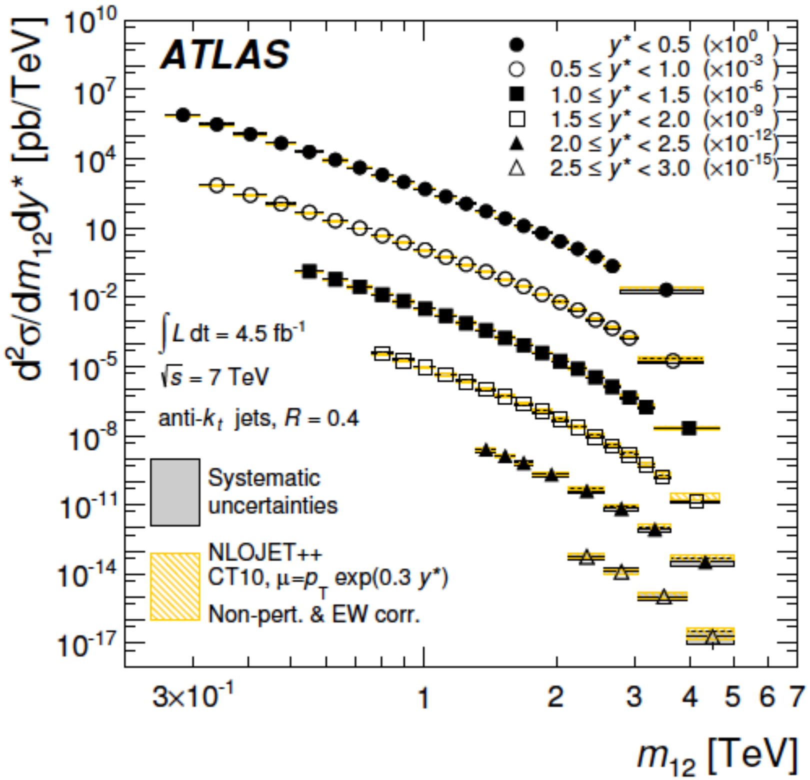


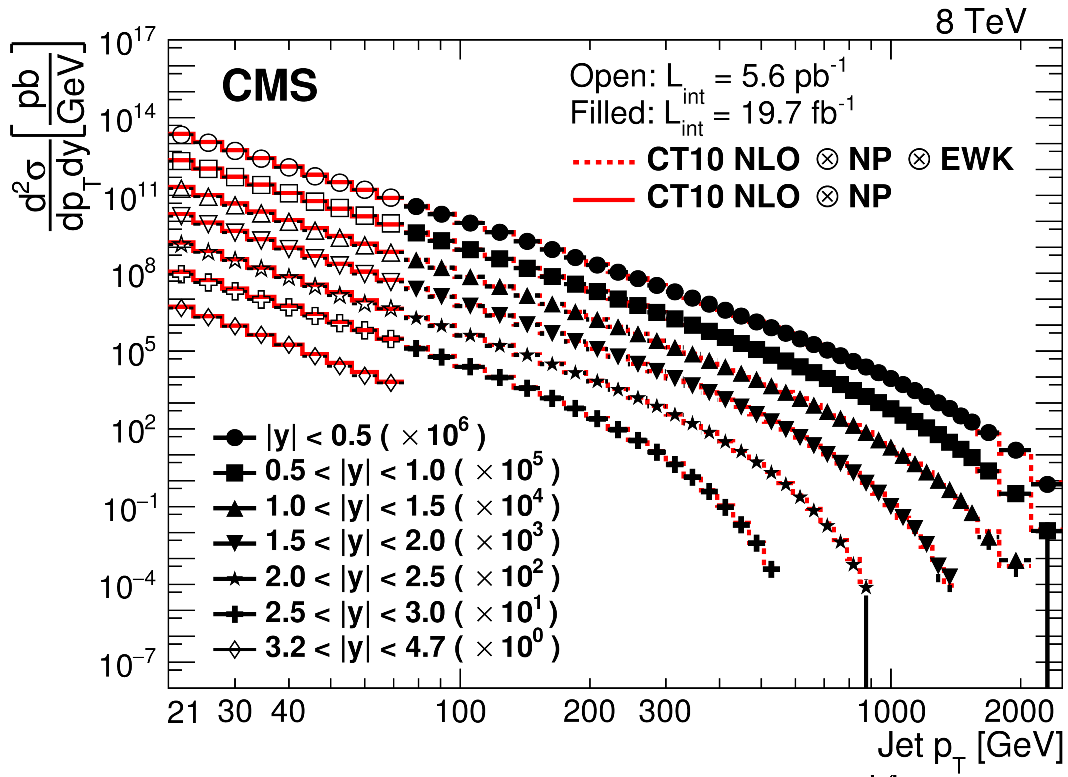
- Not (yet) transformational
- Much more data to come → may impact q and qbar at high x
- Will never have a major impact on high x gluon



Jet Production

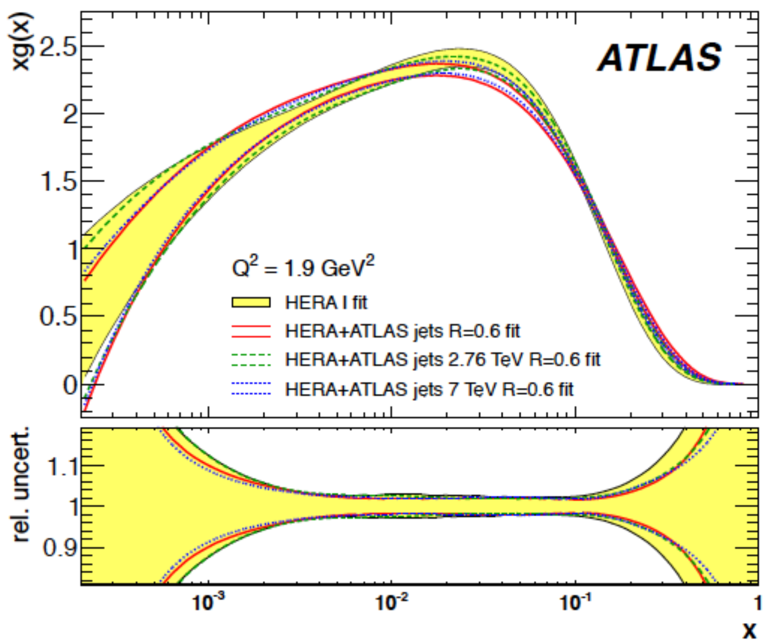
- Gluon density
- Rates v high & in principle sensitive to highest x
- Limited experimentally by jet Energy Scale Uncty
- Limited theoretically by no NNLO corrections, underlying event …





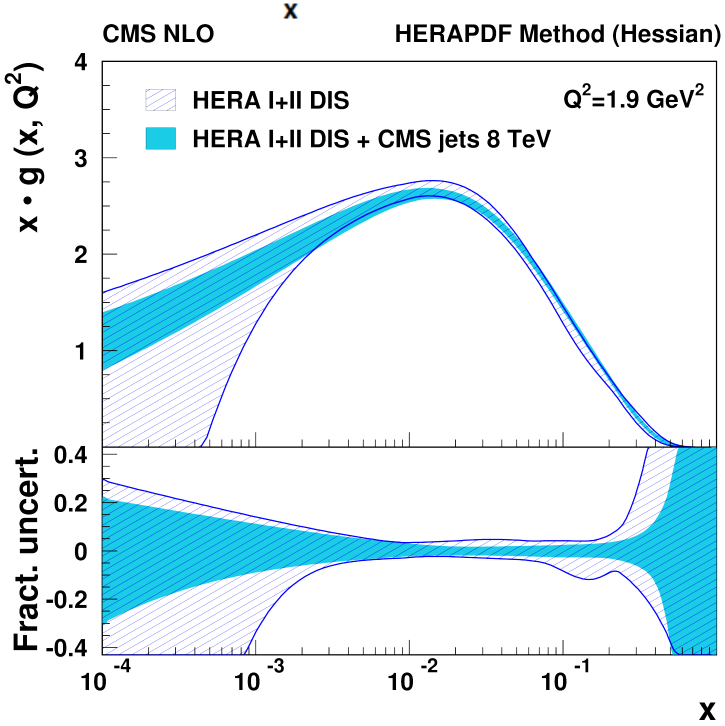
… plentiful (amazing!) data

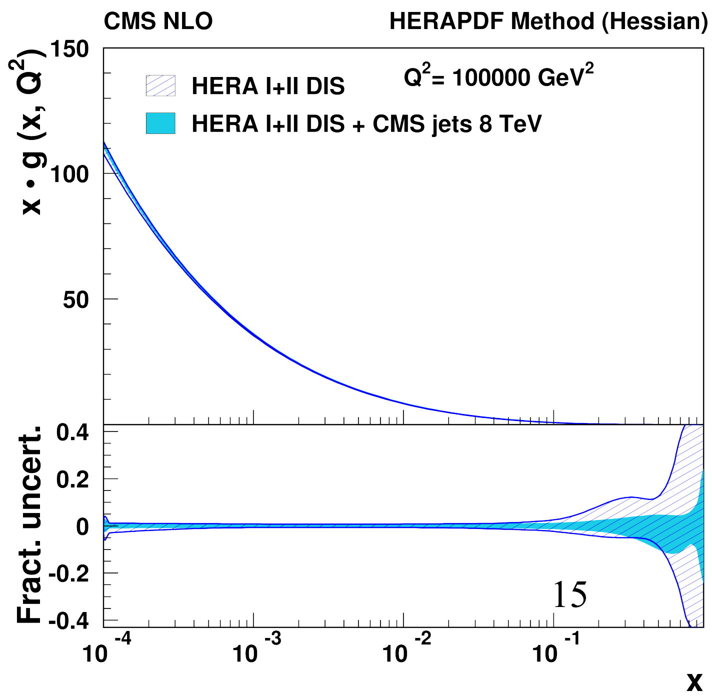
Including Jet Data in PDF Fits



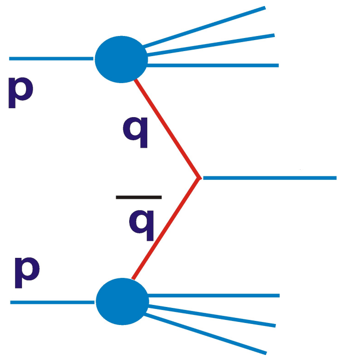
Influence of LHC jets relative to HERA-only is to make gluon slightly harder and to slightly reduce its Uncertainty

… large uncertainties remain on the high x gluon, particularly at modest scales





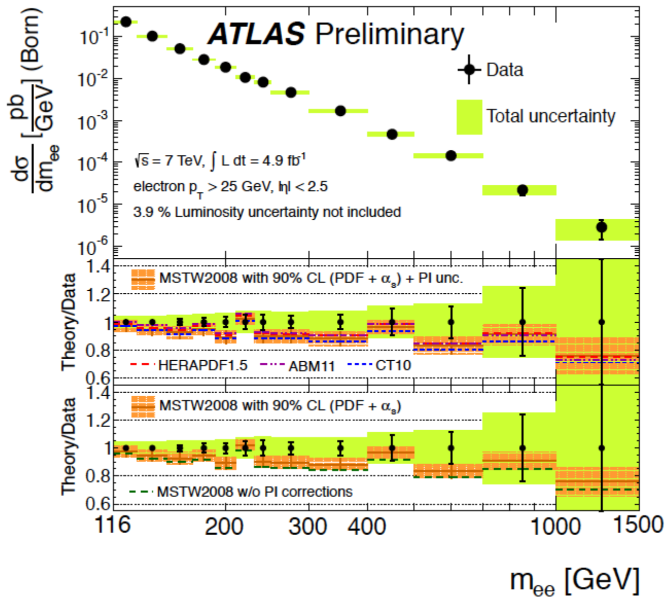
Other Possible Processes

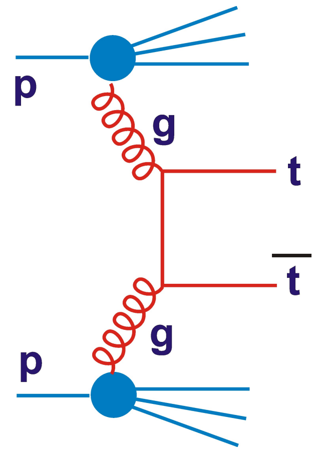


<u>Drell-Yan away from Z pole</u>

- Sea Quarks at high x?

… no strong discimination at present precision

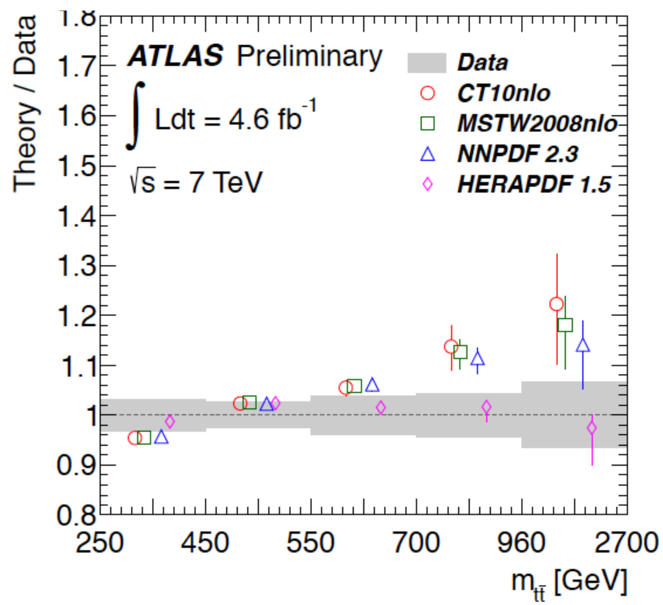


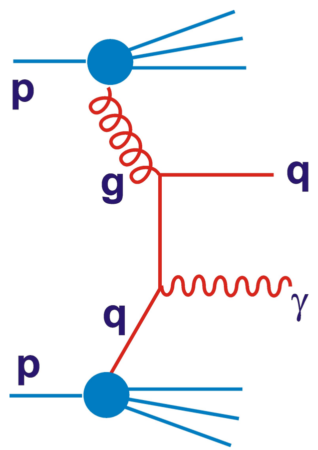


<u>Single Top and t-tbar</u>

- Gluon, u/d

… some apparent sensitivity (HERAPDF favoured), but large NLO corrections and correlations with m_t and α_s





<u>Direct Photons</u>

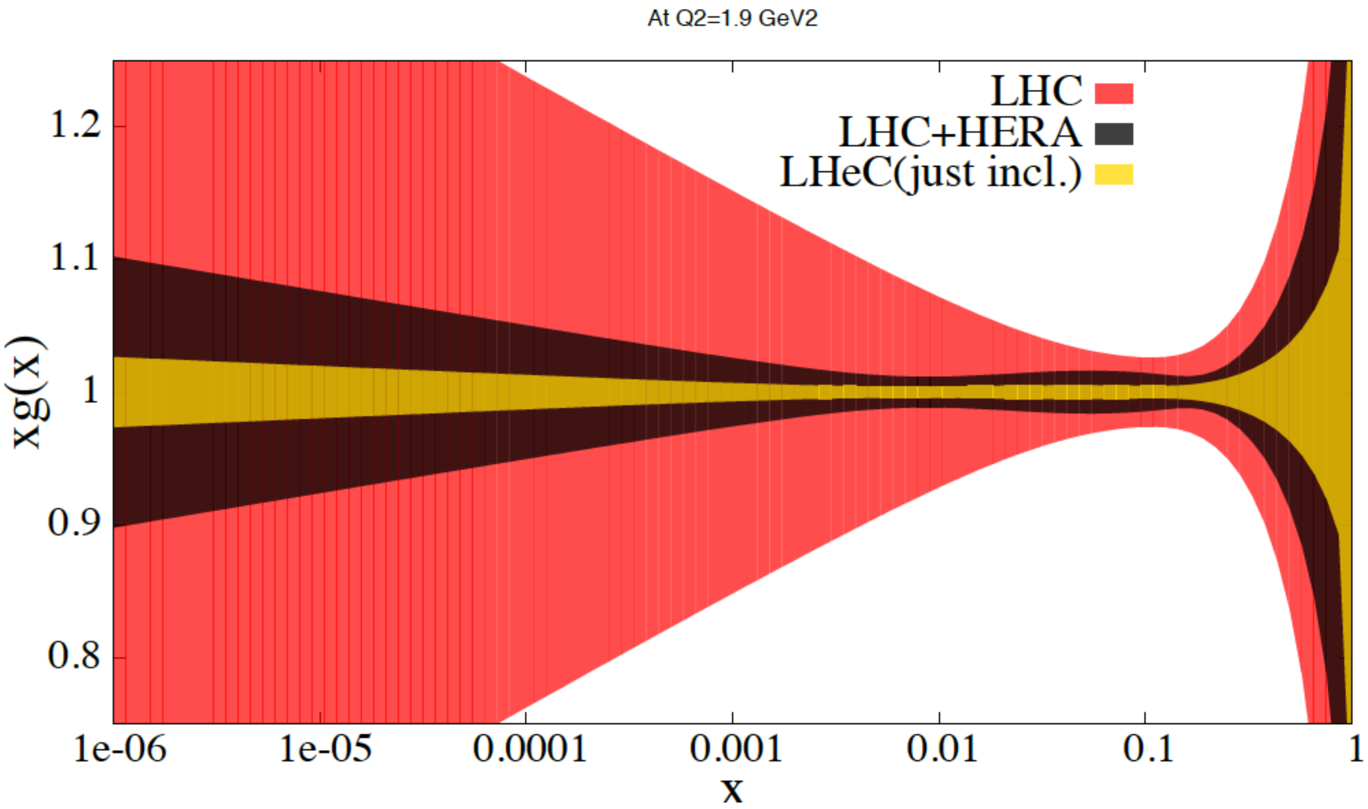
-Gluon at high and low x

… Agreement with NLO thy not established (NNLO?)

Asking the Question the Other Way Around

- LHC = current LHC W, Z and jet Data

… some Constraints, but poor compared with ep



Theoretical Limitations:
- Hadronisation and Underlying Event
- Missing higher orders (QCD & EW)
- Large logs needing resummations

Experimental Limitations:
- Systematics (energy scale …)
- Correlations between measurements

Summary of LHC Constraints

- LHC is providing some constraints on parton densities
- More to come, particularly from W/Z
- As lumi (and pile-up) increase, we cannot expect precision of Standard Model measurements to keep improving

→ LHC unlikely to have a transformational impact on high x

What about Future ep Facilities

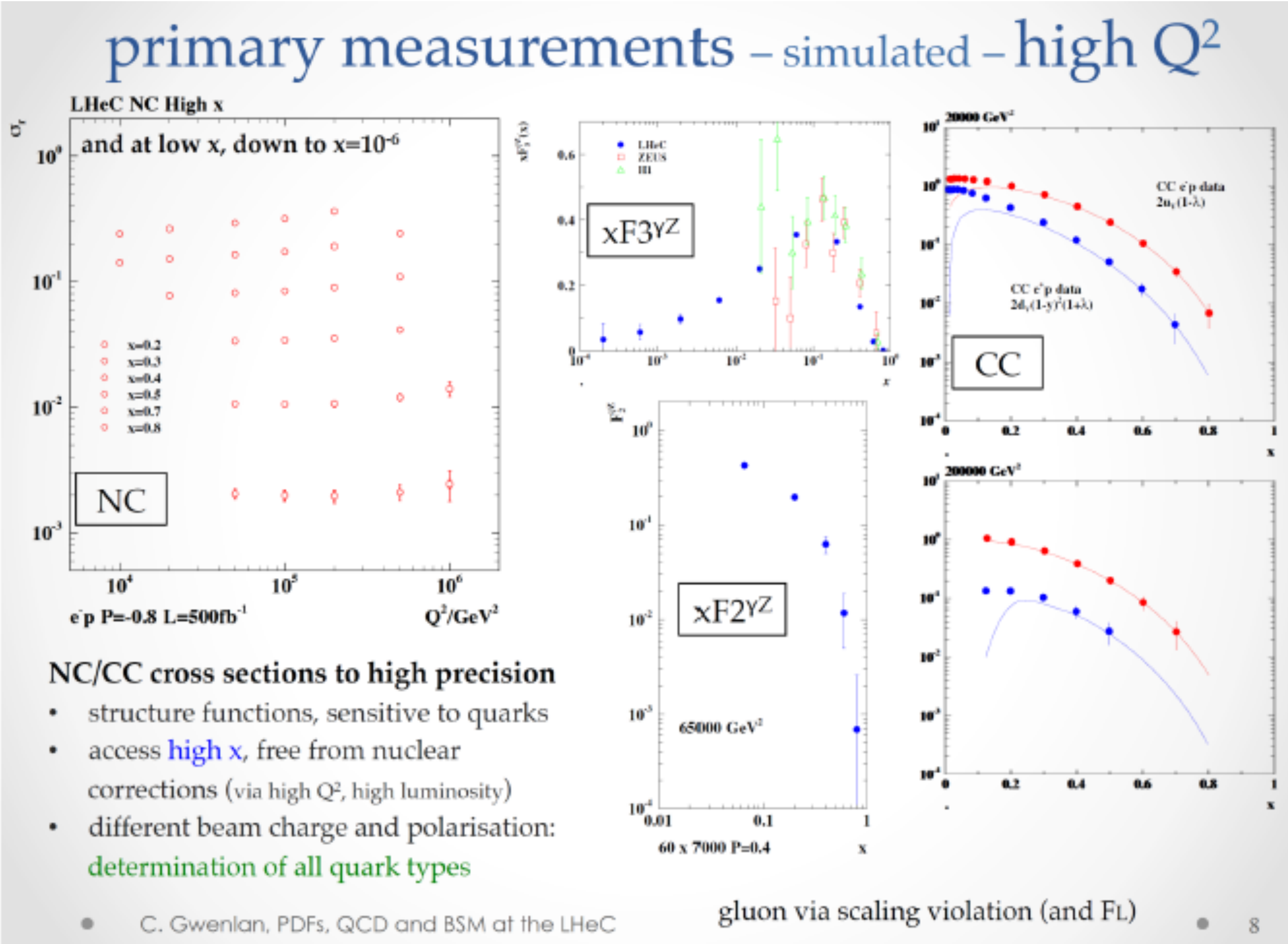
→ Summary of LHeC studies …

Simulated LHeC Data used as Input to PDF fits

- Simulated `pseudo-data': E_e=50GeV, E_p=7TeV, 50fb^{-1} with each of ±40% beam lepton polarisation (unpolarised target)
- Reasonable assumptions on systematics: typically 2x better than H1 and ZEUS at HERA.

	LHeC	HERA
Lumi [$cm^{-2}s^{-1}$]	10^{33}	$1\text{-}5 \cdot 10^{31}$
Acceptance [º]	1-179	7-177
Tracking to	0.1 mrad	0.2-1 mrad
EM calorimetry to	0.1%	0.2-0.5%
Hadronic calorimetry	0.5%	1-2%
Luminosity	0.5%	1%

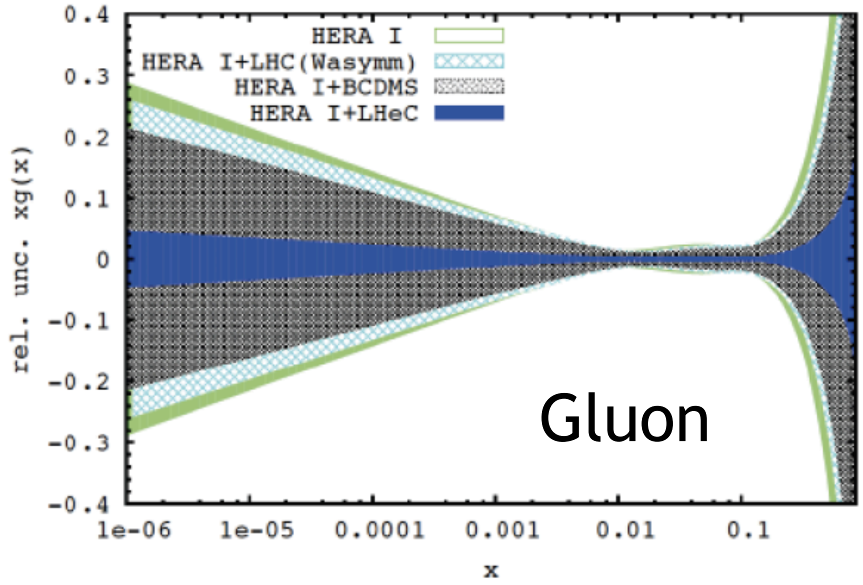
- Forward (outgoing hadron) direction of detector is vital for kinematic reconstruction … needed for CC and also for precision in NC (resolution of electron method diverges and radiative corrections become large as $y \to 0$ and $x \to 1$)

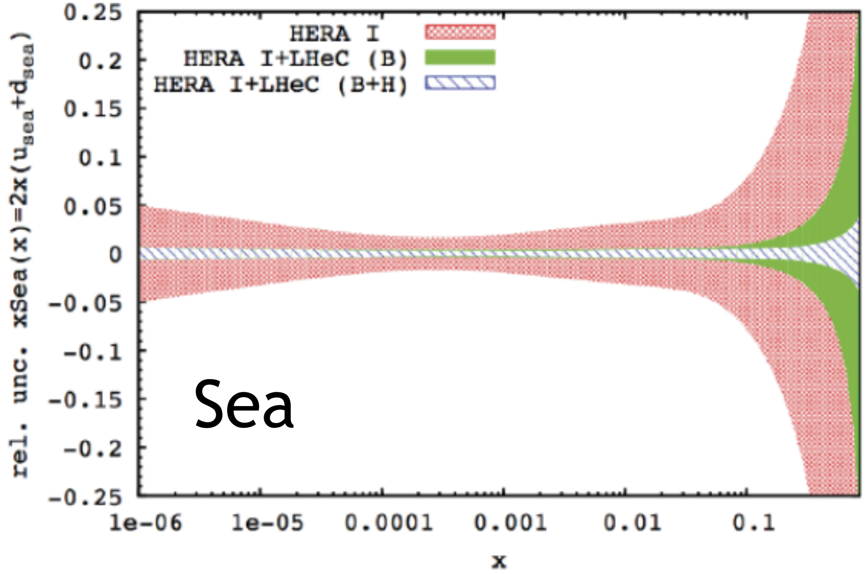


- NC and CC data: $2 < Q^2 < 100{,}000\ \mathrm{GeV}^2$, $2\times10^{-6} < x < 0.8$

PDF Constraints at LHeC

LHeC Pseudo-data subjected to NLO DGLAP fit using standard HERA-Fitter technology (as also standard at LHC)

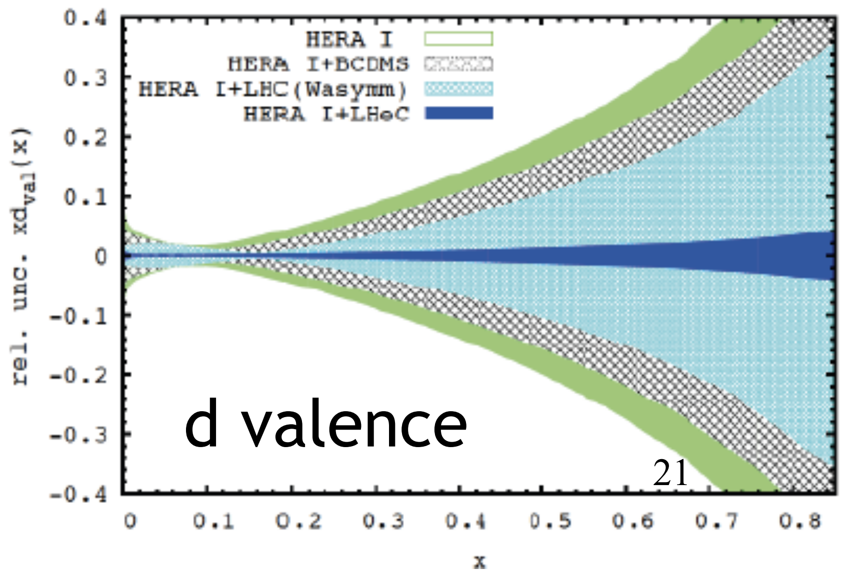




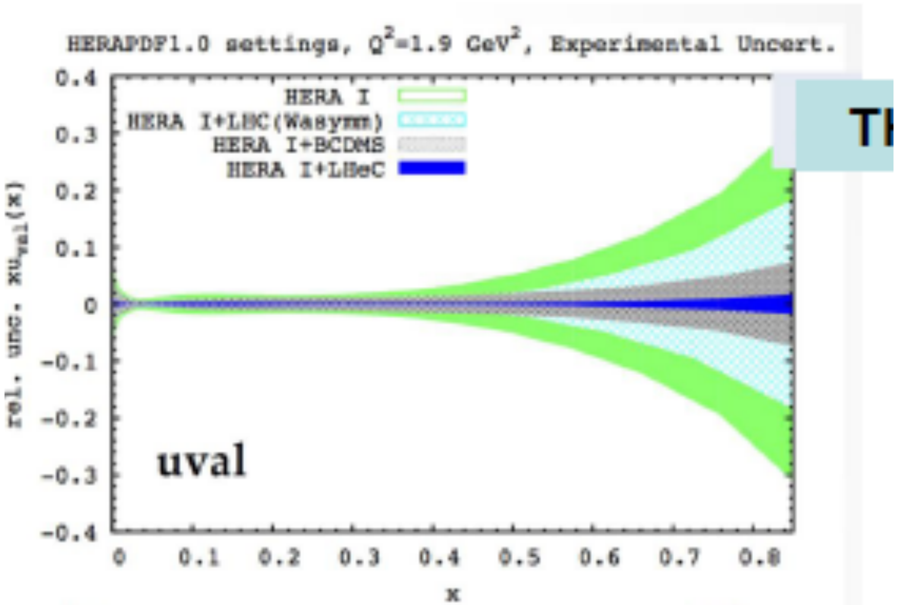
... impact at low x (kinematic range) and high x (luminosity)

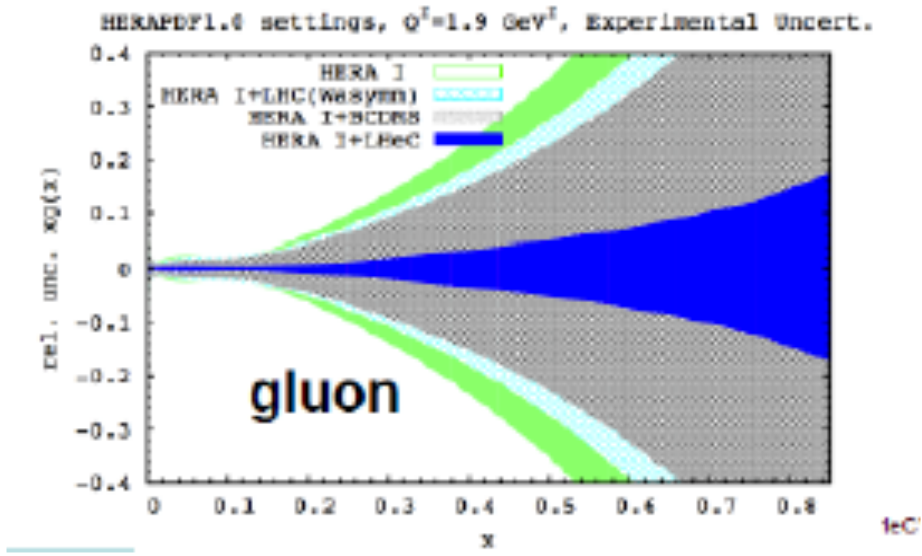
... precise light quark vector, axial couplings, weak mixing angle

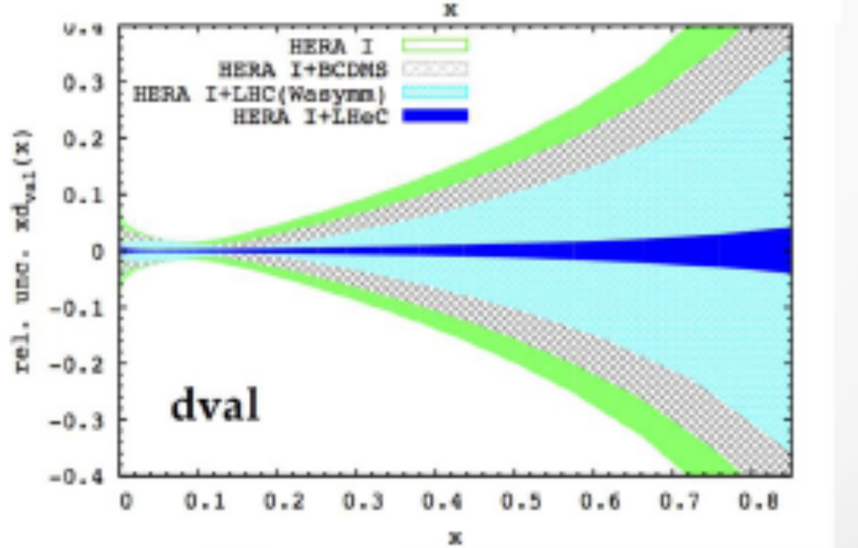
... full flavour decomposition

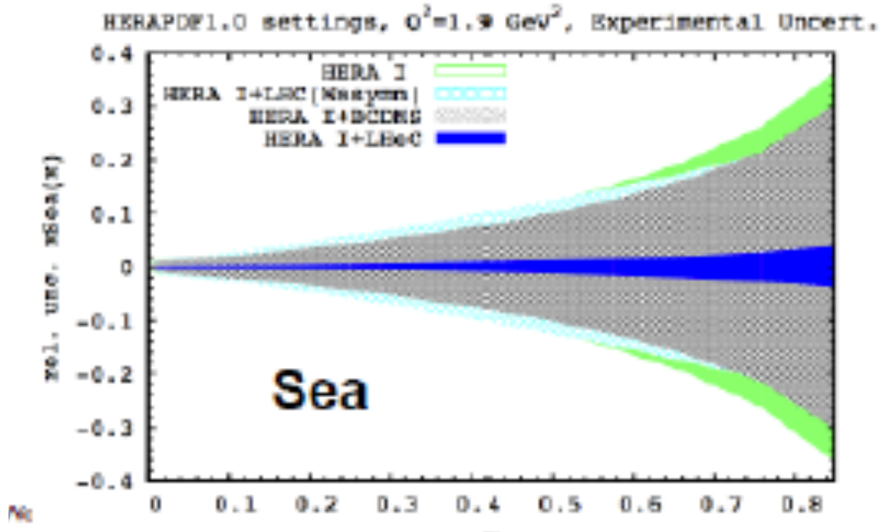


Focus on Impact at High x









Impact comes as part of overall package which derives from high lumi but also flavour-decomp, low x, momentum sum rule …

Summary

- LHC search physics will become increasingly limited by knowledge of high x partons (particularly the gluon) in the HL-LHC era (50x more data than now)

- LHC constraints will be useful but are unlikely to transform the picture

- LHeC studies indicate that transformation is possible with ep at sufficient lumi, polarised beams etc

- Given $\sigma \sim 1/Q^4$, this may be easier to achieve (e.g. in terms of lumi) with high x and not-quite-so-high Q^2, not clear whether loss of low x constraints has an impact e.g. via mom sum rule

- Detector has to be well matched to resolution at high x (in particular, precise and hermetic for hadronic final state, including very forward particles)

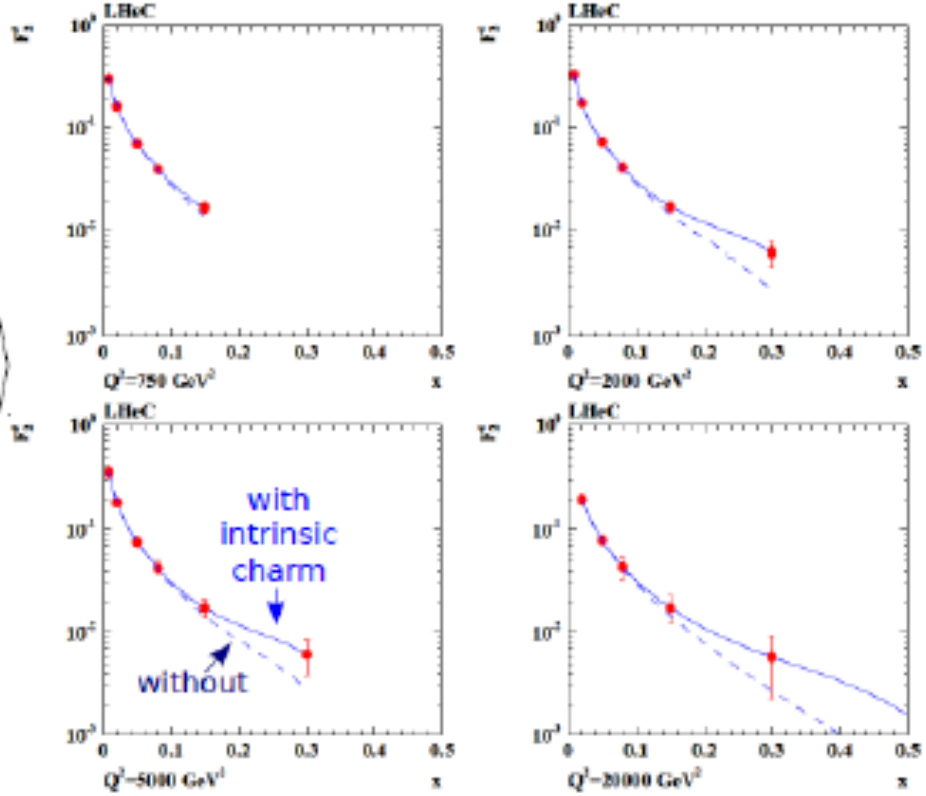
Intrinsic Charm

Intrinsic charm: existence of $c\bar{c}$ pair as non-perturbative component in the bound state nucleon (Fock state components such as $|uudc\bar{c}>$)

→ may explain certain aspects of the charm data and dominate in some regions of the phase space

for large x very good forward tag acceptance needed (possible with reduced E_p)

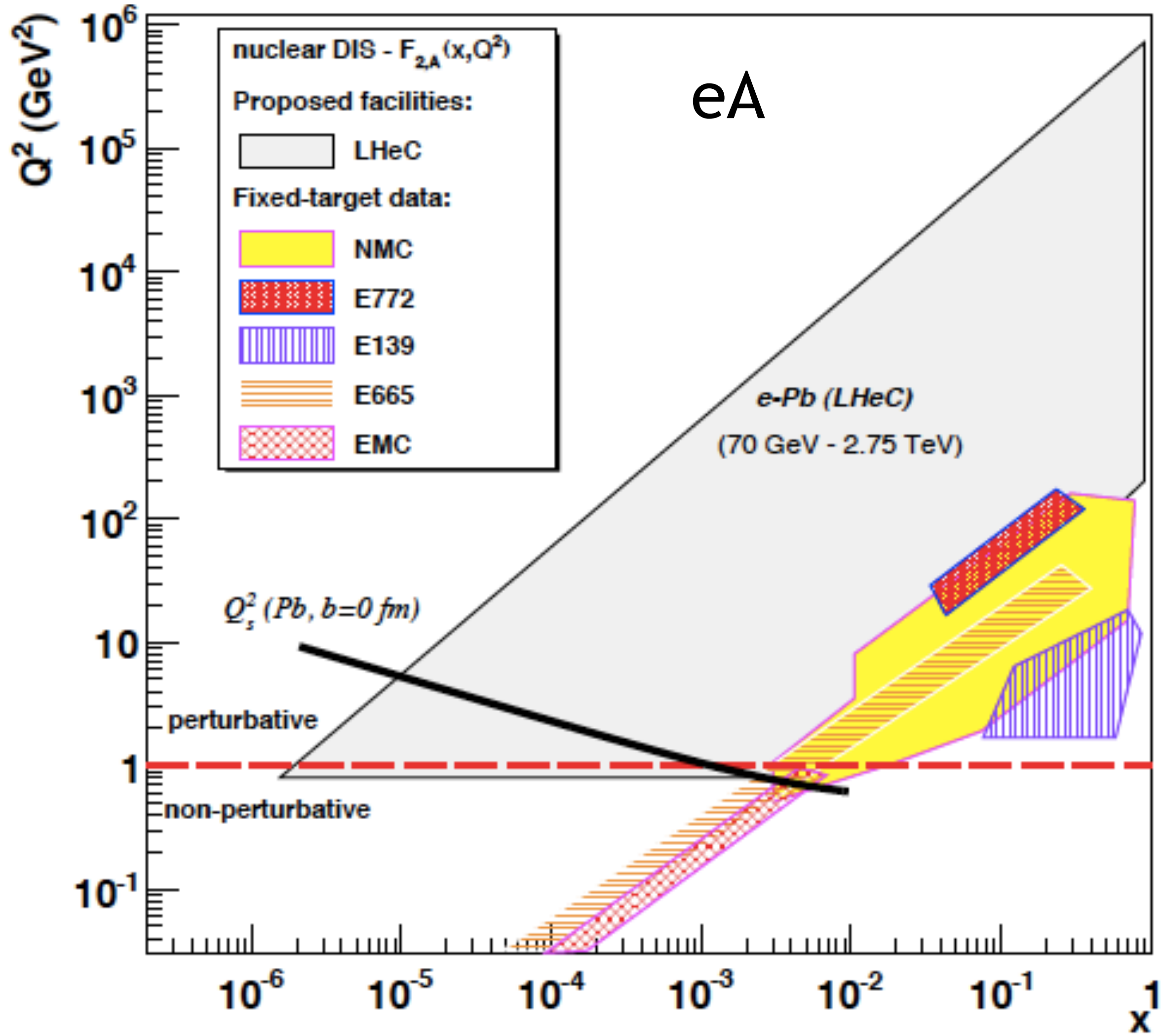
simulated measurement of the charm structure function (E_p=1 TeV, L=1 fb^{-1}, CTEQ66)



→ reliable detection of an intrinsic heavy charm component challenging but possible

LHeC as an Electron-ion Collider

Four orders of magnitude increase in kinematic range over previous DIS experiments.



Current knowledge for $x <\sim 10^{-2}$ almost zero.

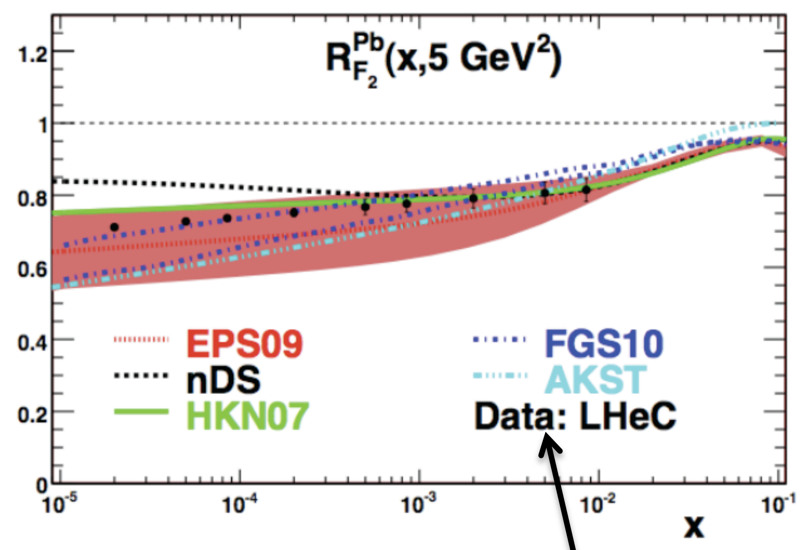
→LHeC revolutionises our view of partonic structure of nuclei.

→ Study interactions of densely packed, but weakly coupled, partons

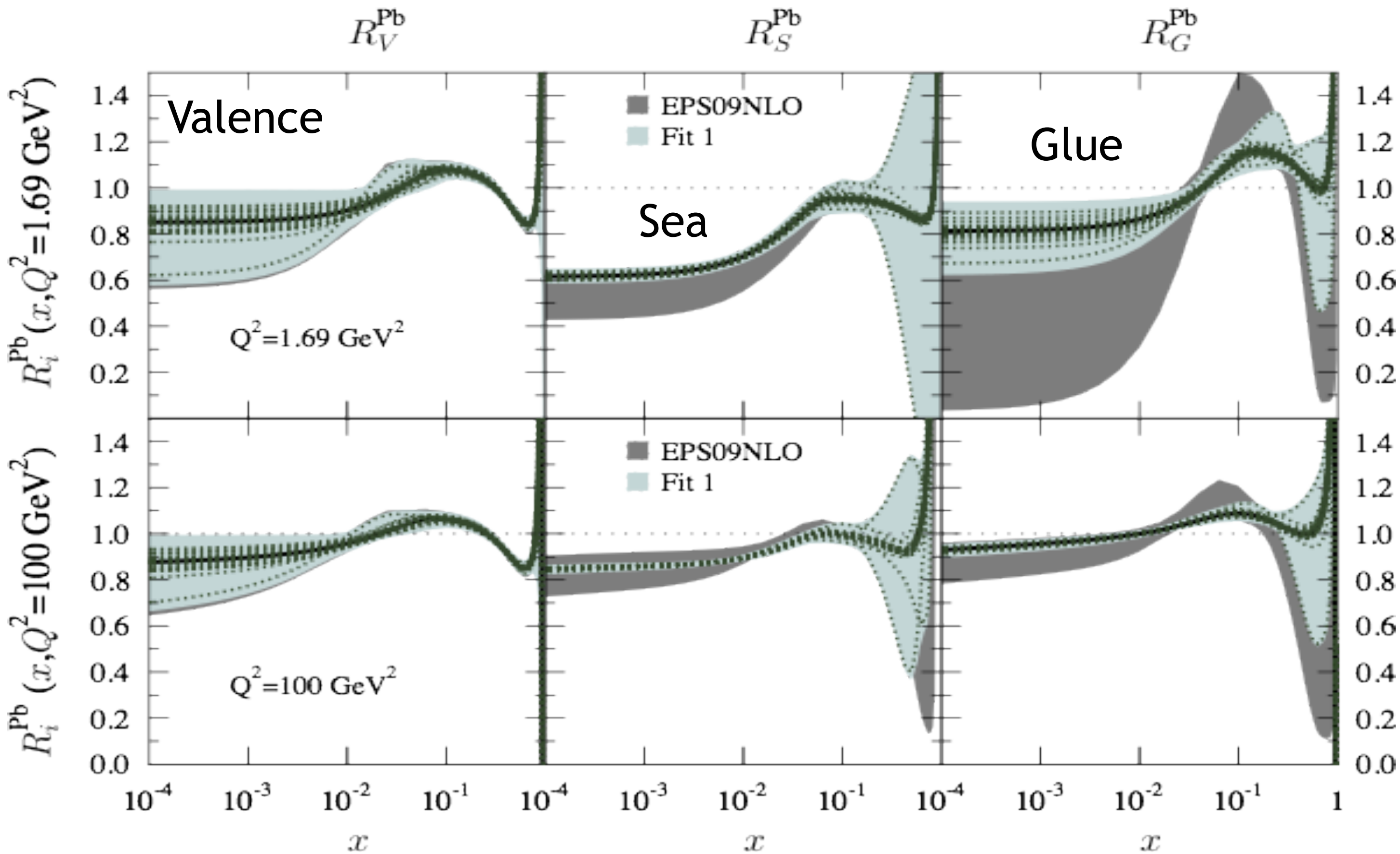
→Ultra-clean probe of passage of `struck' partons through cold nuclear matter

Impact of eA F_2 LHeC data

- Simulated LHeC ePb F_2 measurement has huge impact on uncertainties
- Most striking effect for sea & gluons
- High x gluon uncertainty still large



[Example pseudo-data from single Q^2 Value]



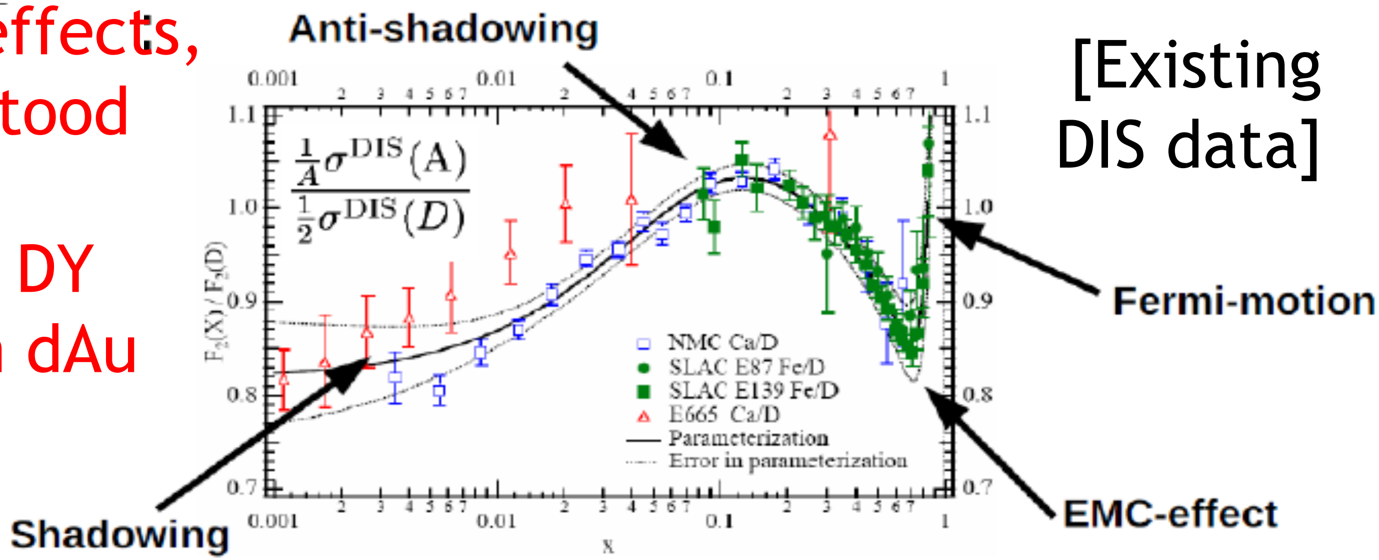
[Effects on EPS09 nPDF fit]

Current Status of Nuclear Parton Densities

- Complex nuclear effects, not yet fully understood

- Quarks from DIS & DY
- Gluon mainly from dAu single π^0 rates

- All partons poorly constrained for $x < 10^{-2}$



[Existing DIS data]

R_i = Nuclear PDF i / (A * proton PDF i)