XXV11 International Workshop on DIS 2019, Torino: Summary of Working Group 1

Mark Sutton, University of Sussex
C.-P. Yuan, Michigan State University
Sasha Zenaiev, Hamburg University

12th April 2019

Preface

- A very full agenda …
  - 50 presentations over 10 sessions - 1 joint session with WG7 Future of DIS
  - Clearly would be impossible to summarise everything in the time available, and unfair on you - the audience - to have to listen to me for that long, but can at least hope to provide a reasonable flavour of the content of the working group presentations
  - This is a decidedly imperfect summary and we are duty bound to offer the usual apologies for any exclusions
    - Such significant, unfortunate exclusions due to lack of time, include how to correctly treat scales, spin, fracture function, fit of fragmentation functions, new W and Z data, presentations from STAR, SHiP….

- Broadly structured as follows …
  - PDF analyses for the proton
  - PDF global analyses for the nucleus
  - Impact of data to PDFs
  - New progress in theoretical calculations, and tools
  - Data Constraints on PDFs and nPDFs

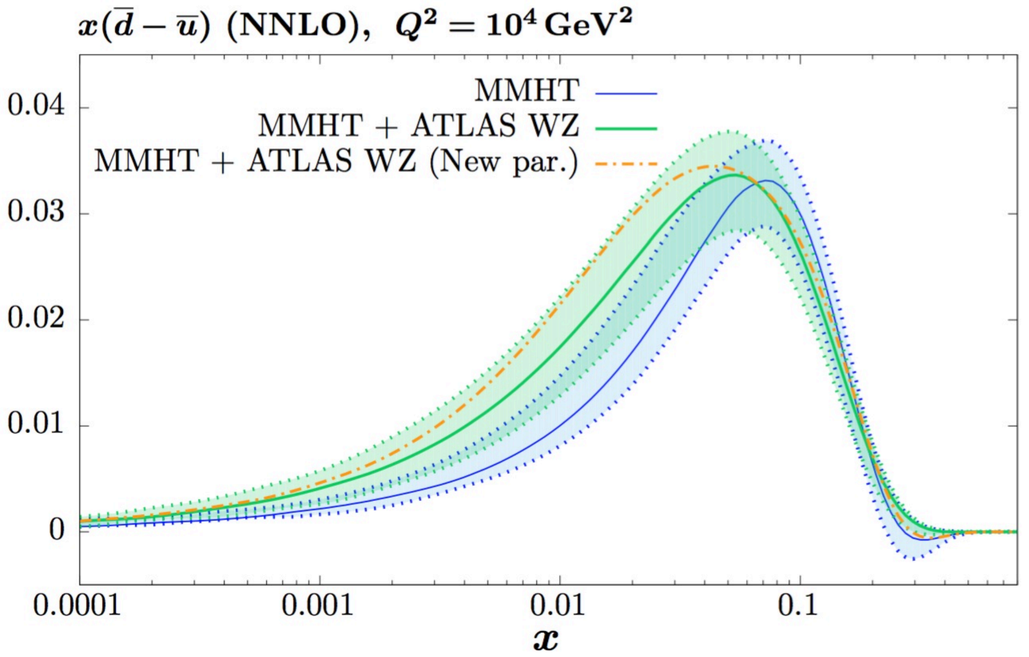
PDF analyses for the proton …

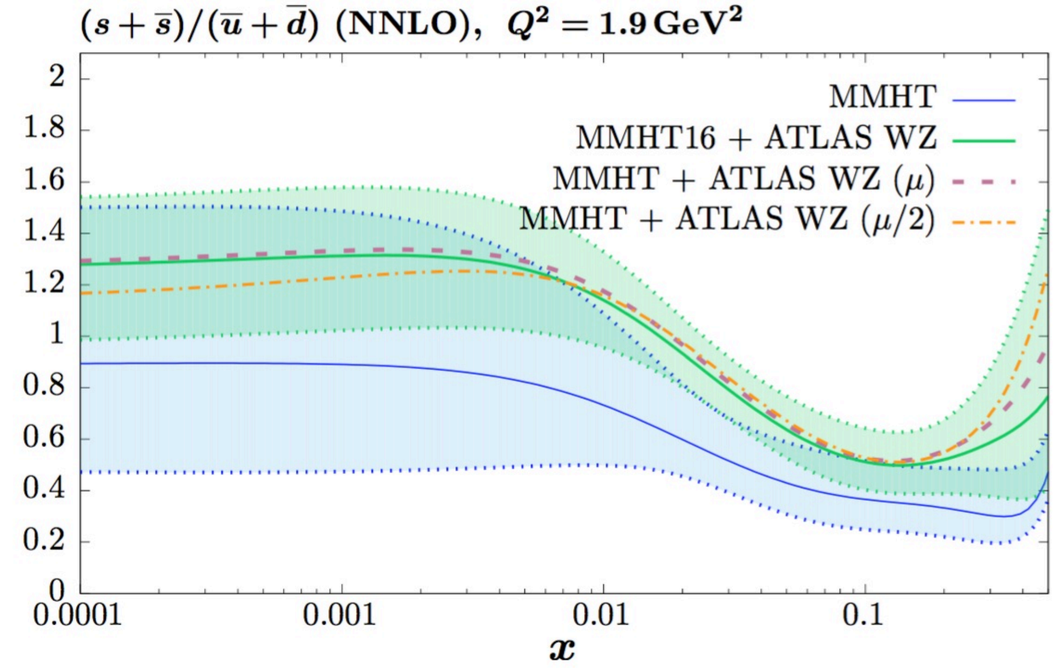
- MMHT
  - To be released soon, with QED corrections completed
- CT18 and CT18Z PDFs
  - CT18Z including ATLAS W, Z data - completed, ready to be released.
- NNPDF
  - Studying impact of missing higher order uncertainties
- ABMP16 – updated
- HERAPDF2.0 NNLOJets
  - Completed, with NNLO calculations
- ATLAS updates
  - ATLASepWZtop18 - fit with top, ATLASepWZ-Wjet19
- CMS updates
  - New fits including top data
- JAM19
  - Combined PDF and (pion and Kaon) FF fit
- Review talks on
  - Polarized PDFs
  - PDFs from the Lattice

Update to the MMHT PDF

Robert Thorne

- Inclusion of new LHC data sets - largely electroweak processes, particularly precise ATLAS W, Z 7 TeV results. Implications for strange with NNLO corrections to dimuon production.
- Extended parameterisation and eigenvectors sets, using Chebyshev polynomials
  Problems with correlated uncertainties - jets and differential top data.
- Completion and imminent release of MMHT PDFs with QED corrections.





Including ATLAS W, Z data in fit goes from $\chi^2/N_{pts} \sim 387/61 \rightarrow \chi^2/N_{pts} \sim 108/61$ (with scales set to $\mu_{R,F} = M_{W,Z}/2$).

Deterioration in fit to other data $\Delta\chi^2 \sim 54$. CMS double differential Z/γ data CCFR/NuTeV dimuon data Drell-Yan asymmetry.

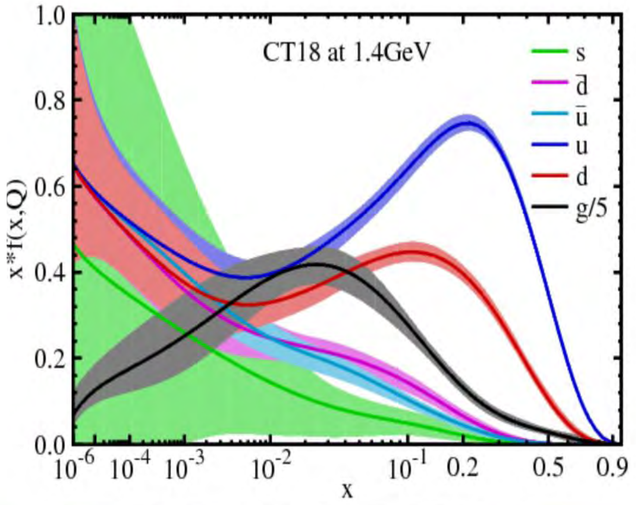
Ratio of $(s+\bar{s})$ to $\bar{u}+\bar{d}$, i.e. R_s at $Q^2 = 1.9\ \mathrm{GeV}^2$.

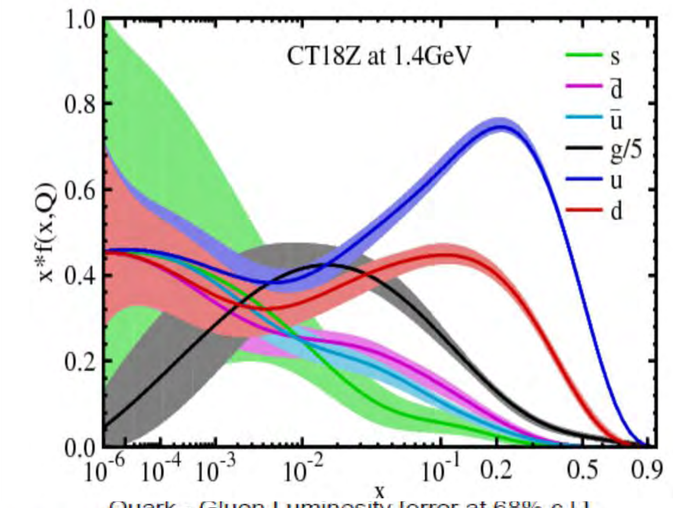
At $x = 0.023$ $R_s \sim 0.83 \pm 0.15$. Compare to ATLAS with $R_s = 1.13^{+0.08}_{-0.13}$

New CTEQ Global Analysis with High Precision Data from the LHC

C.-P. Yuan
Michigan State University
Wu-Ki Tung Endowed Professor

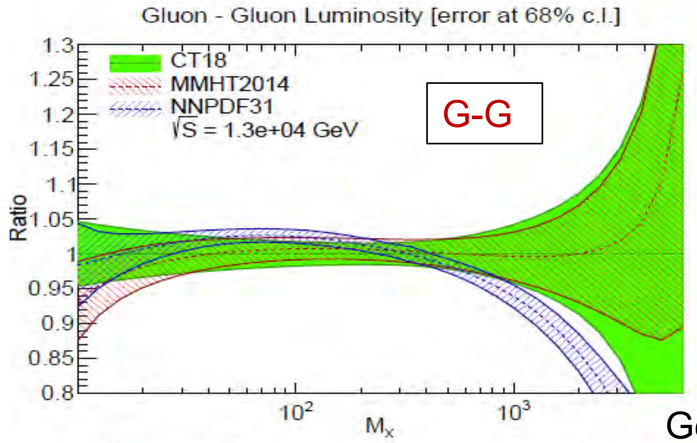
CTEQ – Tung et al. (TEA)
in memory of Prof. Wu-Ki Tung

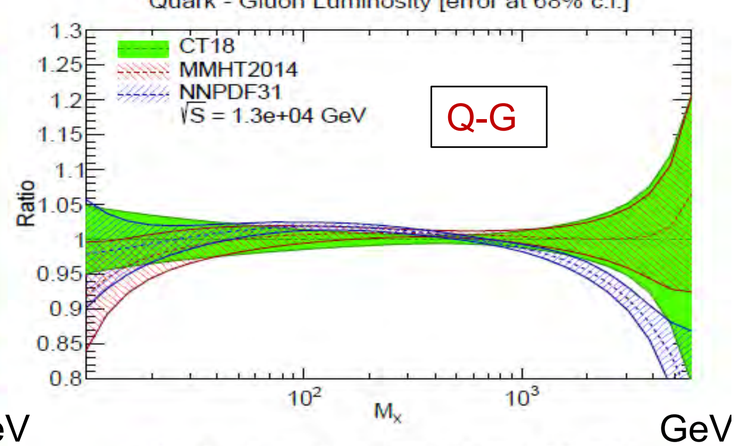


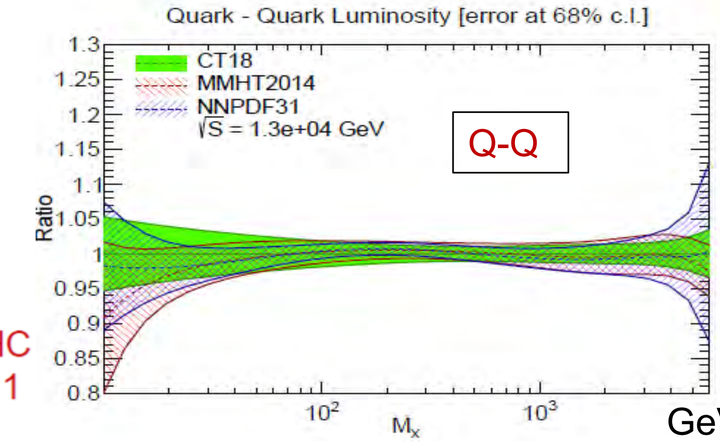


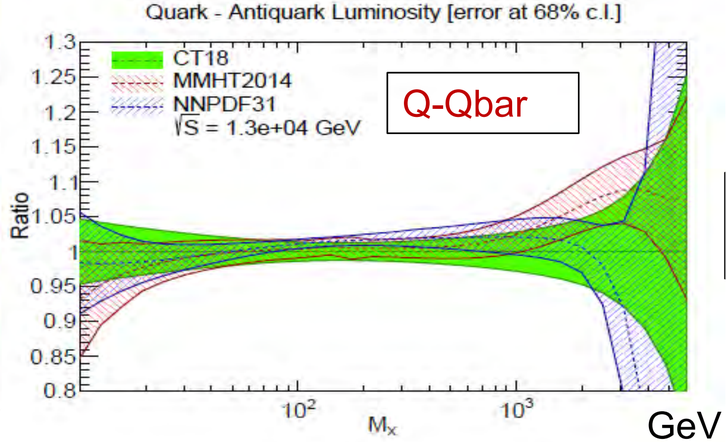
- New CT18 PDF ready for release
- CT18Z including the ATLAS 7, 8 TeV W and Z data
  - CT18Z has enhanced gluon and strange at $x \sim 10^{-4}$, and reduced light-quark PDFs at $x < 10^{-2}$
- Uncertainty mildly reduced at NNLO compared to CT14
- More than 700 data points from 12 new LHC data sets
- HERA DIS and fixed target still deliver key constraints
- Observe some impact from ATLAS and CMS inclusive jets; ATLAS, AMD and LHCb W / Z data and ATLAS 8TeV z PT
- LHC top pair provides similar impact

PDF Luminosities at 13 TeV LHC
CT18, MMHT14 and NNPDF3.1





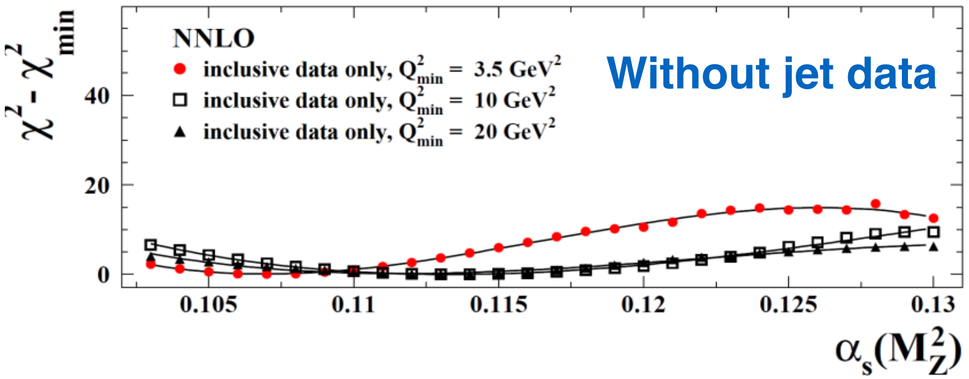




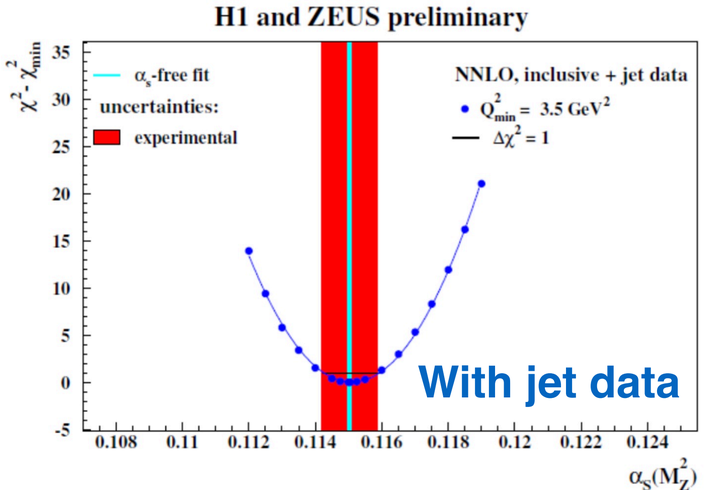
New HERAPDF 2.0 fit

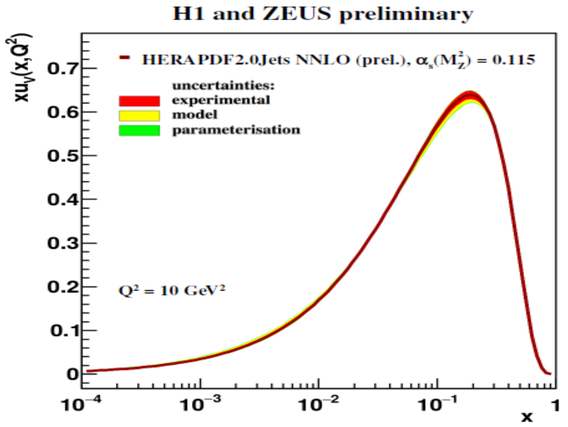
Mandy Cooper-Sarkar
on behalf of H1 and ZEUS

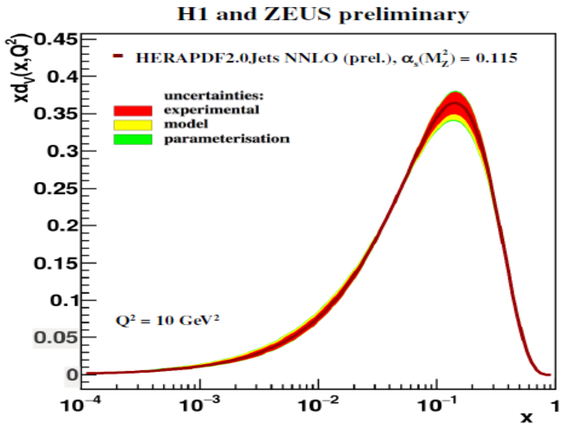
- First inclusion of Inclusive DIS data with DIS Jet data from ZEUS and HI
  - Jet processes calculated **at full NNLO using NNLOJET** interfaced to APPLfast
- New NNLO fit favours lower αs …
  - αs(MZ)=0.1150 ± 0.0008(exp) +0.0002 -0.0005(model/param) ± 0.0006 (had) ± 0.0027 (scale)
  - Compared the NLO result αs(MZ)=0.1183 ± 0.0009(exp)± 0.0005 (model/param) ± 0.0012 (had) +0.0037 -0.0030(scale)
- Two new PDF sets:
  - HERAPDF2.0JetsNNLO αs(MZ) =0.118 – the PDF value
  - HERAPDF2.0JetsNNLO αs(MZ) =0.115 – The value favoured by the new fit

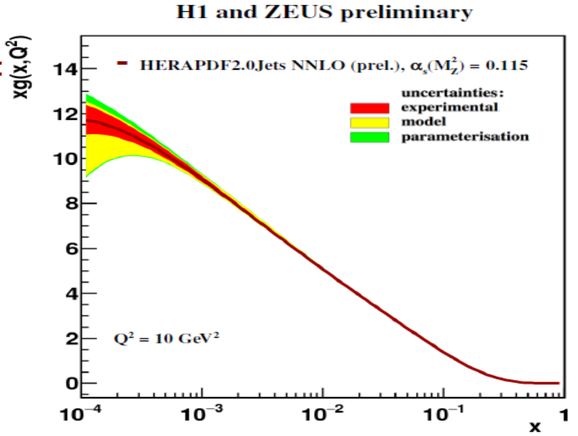


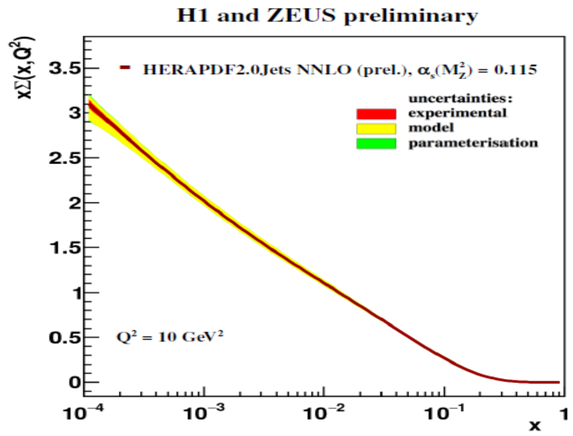
add DIS jet data











Developments with APPLfast

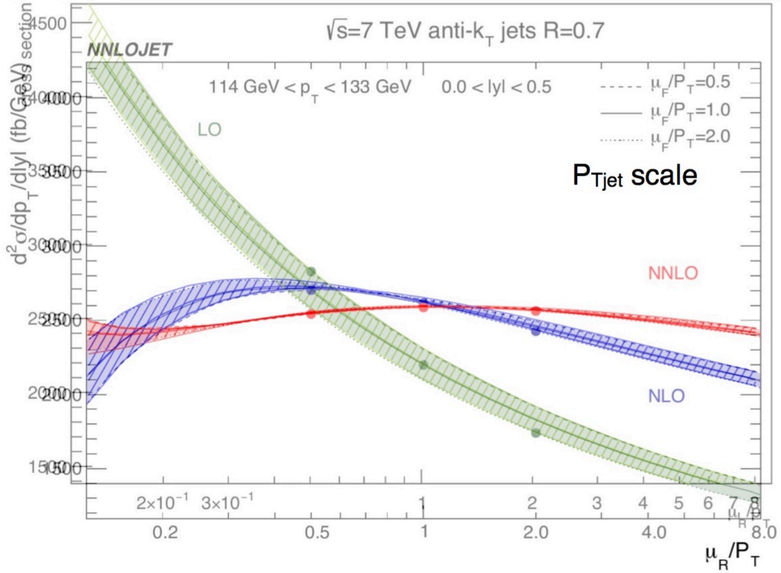
- Presentation from Daniel Britzger on DIS and a complementary fit to αs
- Fit to subsample of inclusive jet data from ZEUS and H1, optimised for αs fit

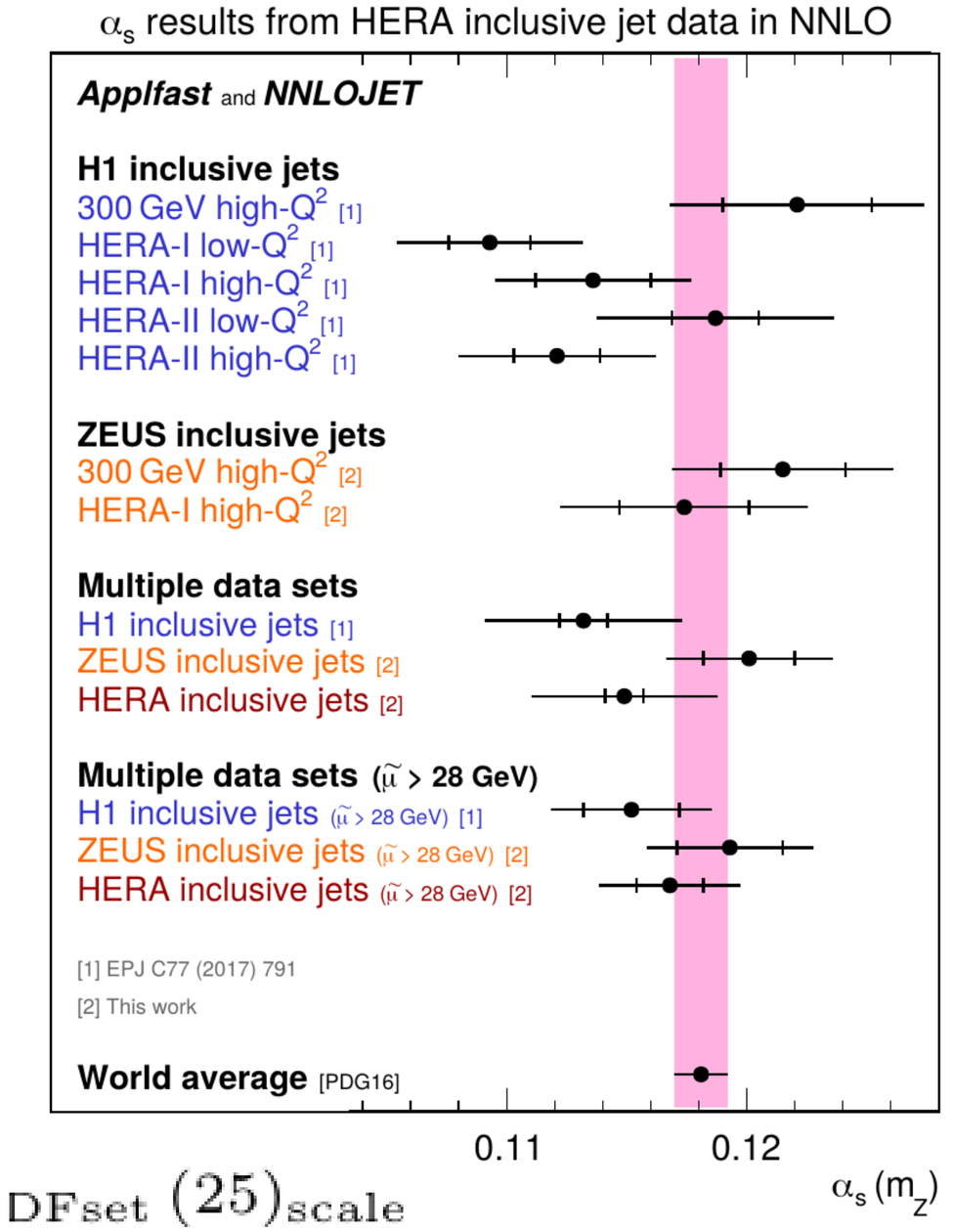
$$0.1148\,(9)_{\mathrm{exp}}\,(5)_{\mathrm{had}}\,(4)_{\mathrm{PDF}}\,(3)_{\mathrm{PDF}\alpha_s}\,(2)_{\mathrm{PDFset}}\,(38)_{\mathrm{scale}}$$

- Fitting both ZEUS and H1 inclusive DIS jet data

$$0.1169\,(14)_{\mathrm{exp}}\,(7)_{\mathrm{had}}\,(3)_{\mathrm{PDF}}\,(2)_{\mathrm{PDF}\alpha_s}\,(3)_{\mathrm{PDFset}}\,(25)_{\mathrm{scale}}$$

- Good description of data, X2 per degree of freedom 191.3 / 193
- Additional fitm, just to high ET data (> 28 GeV)
- Full NNLO grids for the DIS jets will be made available on ploughshare soon
- Presentation from MS on LHC cross sections and grid distribution





$$\mathrm{DFset}\,(25)_{\mathrm{scale}}$$

NNPDF - including theory uncertainties

Cameron Voisey

- Attempting to better quantify theoretical uncertainties due to missing higher orders
- Theory uncertainties induced correlations between experiments

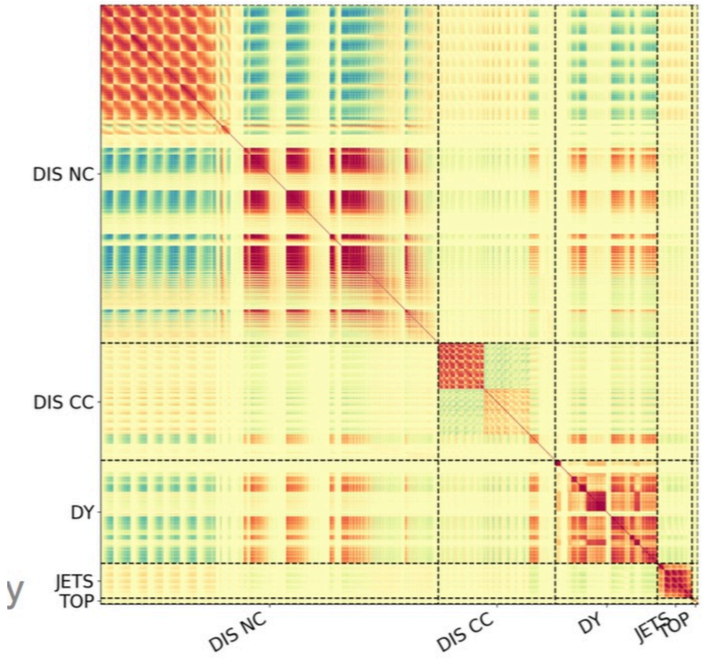
Construct cov_{th} from **scale variations** to estimate:

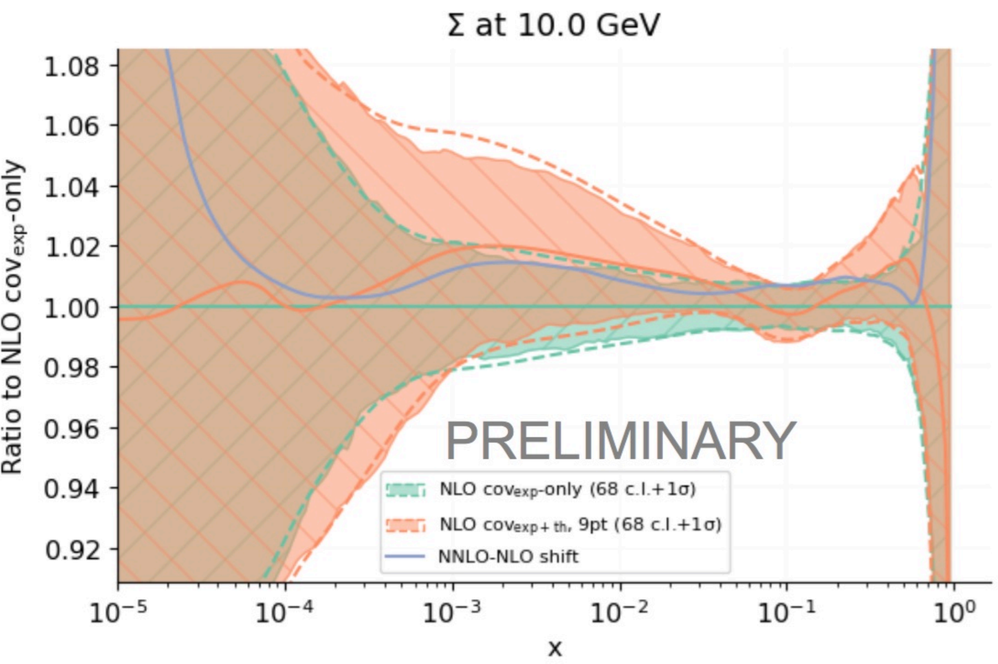
1. MHOU on each point
2. Correlations between points

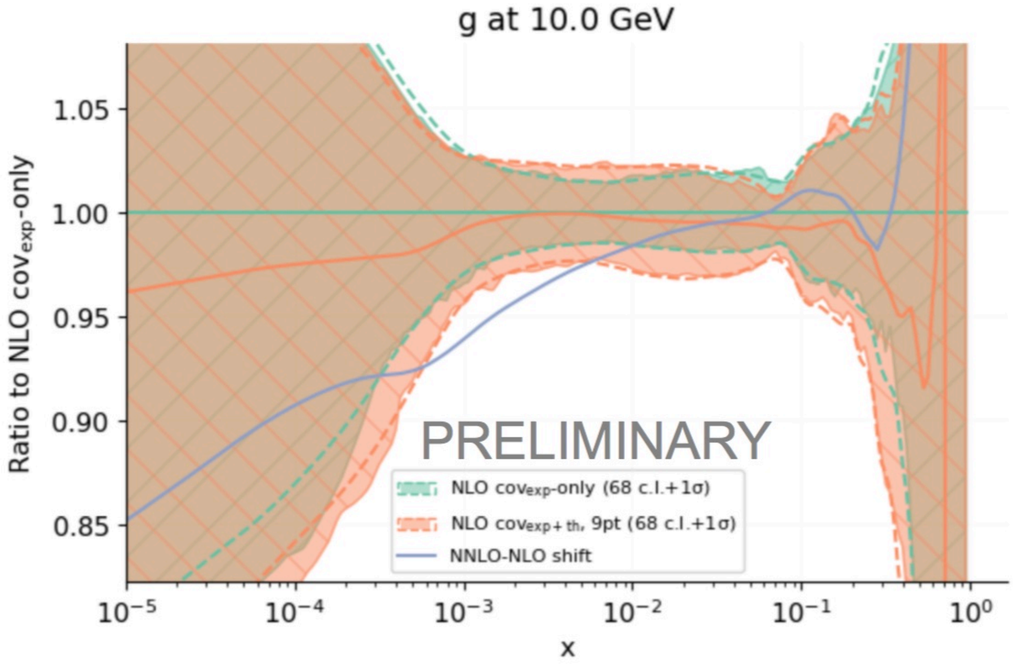
i,j: data points

k: scale combinations

$$\text{cov}_{\text{th,ij}} = \frac{1}{N}\sum_{k} \Delta_i^{(k)}\Delta_j^{(k)} \qquad \Delta_i^{(k)} = t_i(\mu_R,\mu_F) - t_i(\mu_{R,0},\mu_{F,0})$$



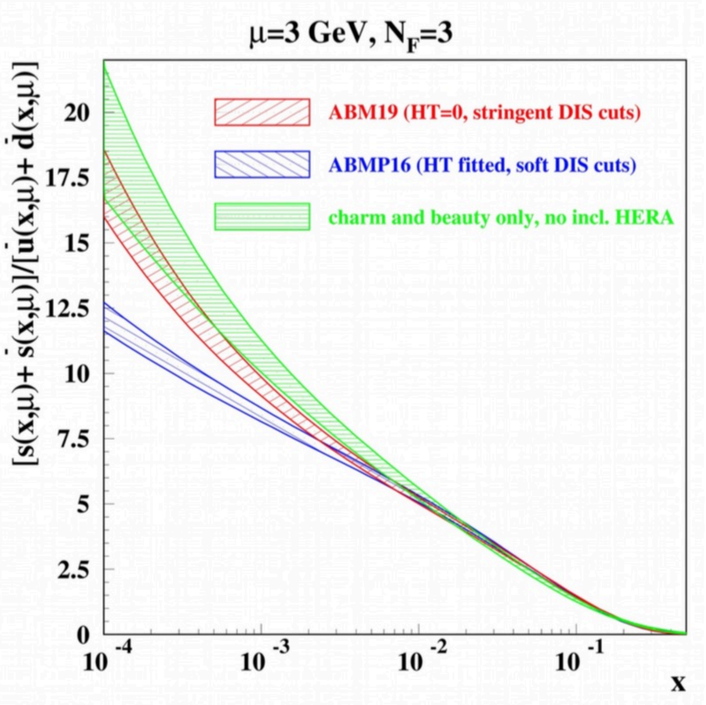


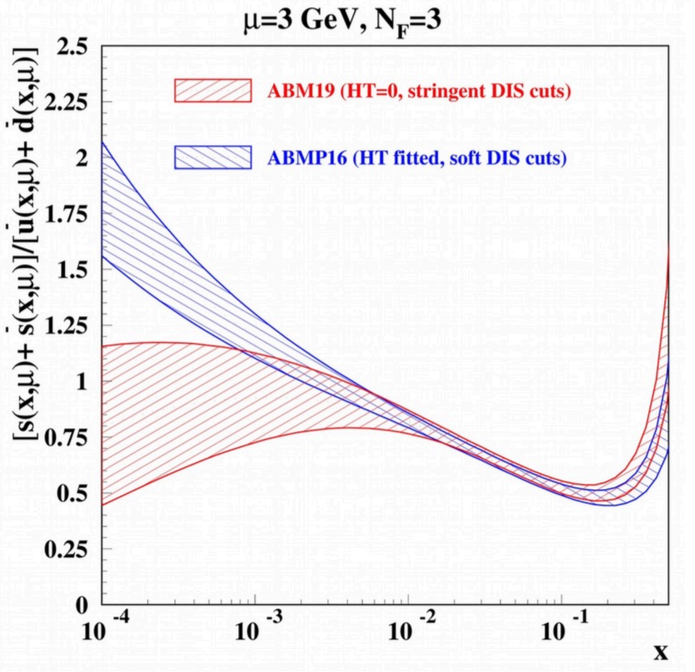


ABM Sergey Alekhin

- Update to the ABM PDF including higher twist effects, top pair production
- Stringent cuts, lower strange at low x, higher gluon
- Impact of the higher-twist terms is minimized
  - Small-x gluon goes higher, consistent with the constraint from charm/ beauty; small-x strange sea goes lower at small x, consistent with 1 within errors; valence quarks stable
  - Reasonable description of the recent charm/beauty HERA data with mc(mc)=1.245±0.019(exp.) GeV
    - mb(mb)=3.96±0.10(exp.) GeV

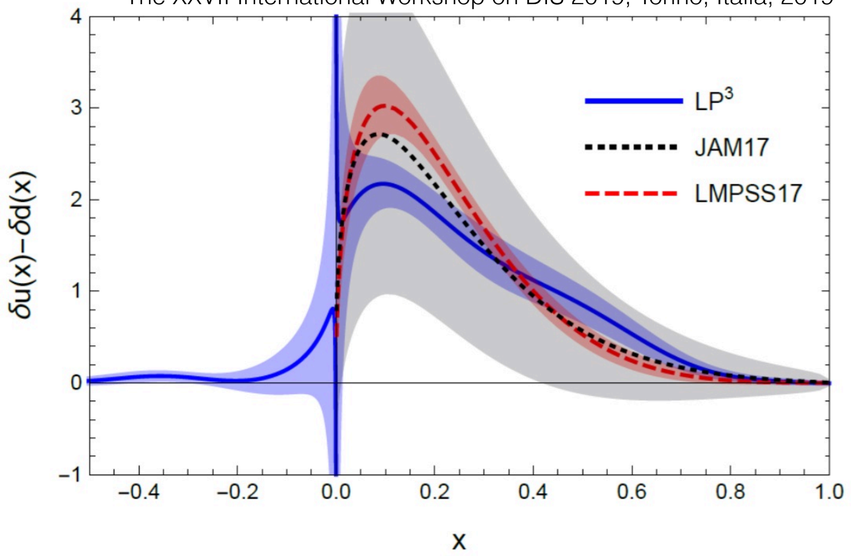
- Update of the pair- and single-top production with
  - mt(mt)== 160.8±1.1 GeV
  - mt(mt)= 161.1± 3.8GeV (single-top only)
  - potential impact on the d/u ratio form t/tbar, however validation of MC tools is still needed
- Steady progress with accommodating more DY data into the fit
  - Recent ATLAS data at 5 and 7 Tev
  - Double differential data on Z-boson production from CMS and ATLAS





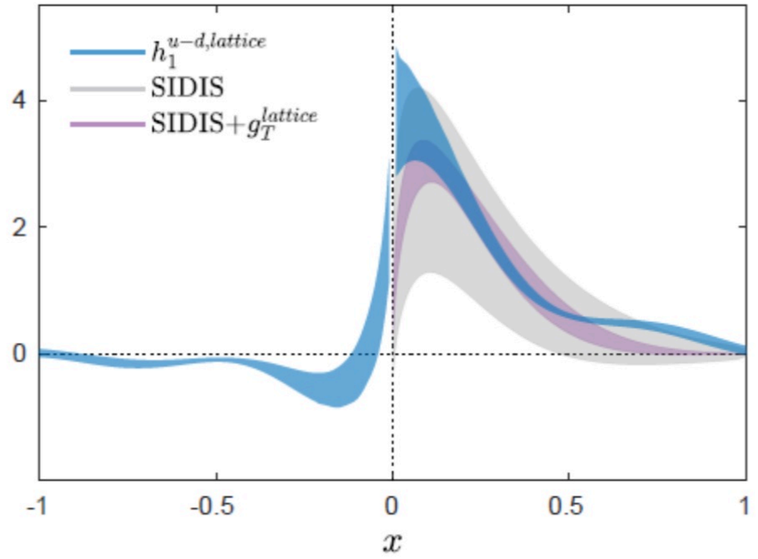
Parton distributions from the lattice

Review from Jianhui Zhang



LP3, $m_\pi \approx 135\ MeV, a = 0.09\ fm, L \approx 5.8 fm$

- Recent years have witnessed rapid progress on direct computations of x-dependence of hadron structure from lattice QCD …
- Large momentum effective theory and related proposals
- Applications to nucleon PDFs (isovector quark), as well as meson PDFs & DAs have yielded encouraging results
- Flavour-singlet quark PDF and Gluon PDF
  - Renormalization and factorisation



Alexandrou et al, 1807.00232, $m_\pi \approx 130\ MeV,\ a = 0.094\ fm, L \approx 4.5 fm$

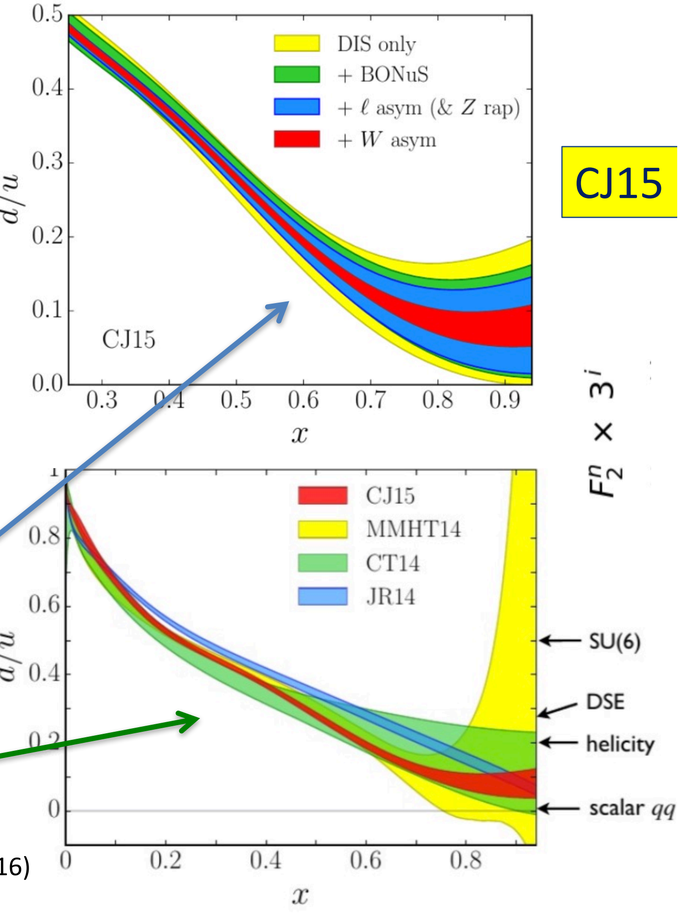
PDF analyses for the nucleus

- CTEQ-Jefferson Lab (CJ)
  - F2 neutron extraction
- TuJu19
  - A new nuclear PDF at NNLO
- nNNPDF 1.0
  - Completed, NLO and NNLO
- EPPS 16
  - Constraints from LHCb D mesons
- nCTEQ++
  - Starting to add LHC data (pPb -> W / Z)

Neutron structure function

Cynthia Keppel

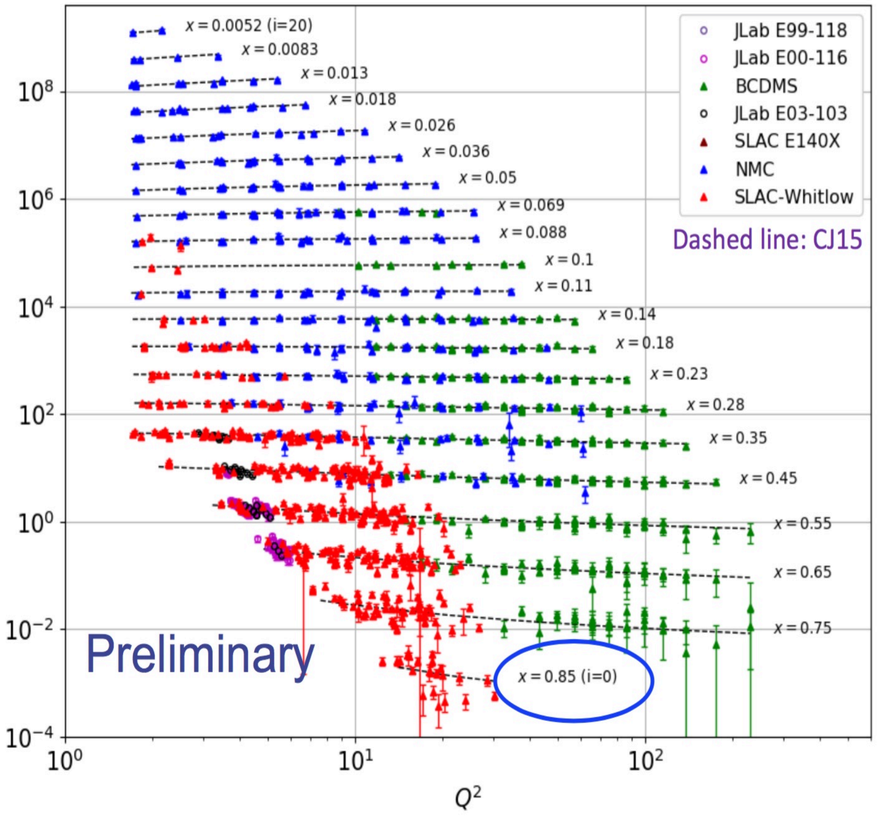
- CJ fit based on CTEQ fit
- Optimised for higher x, lower Q2
- Includes higher twist and target mass correction
- Allow light quark ratio (d/u) to be constant

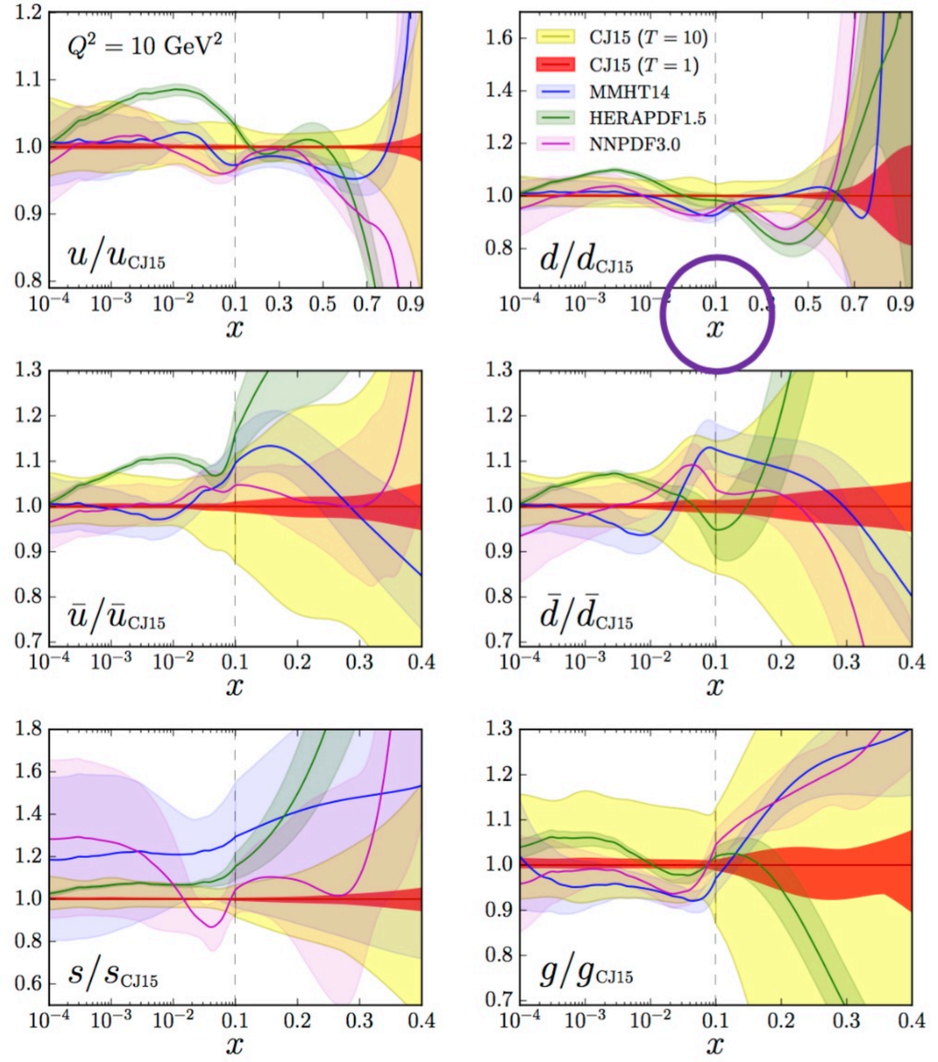


16)

CJ15

F_2 *Neutron* Results!





- Extraction of F2 neutron

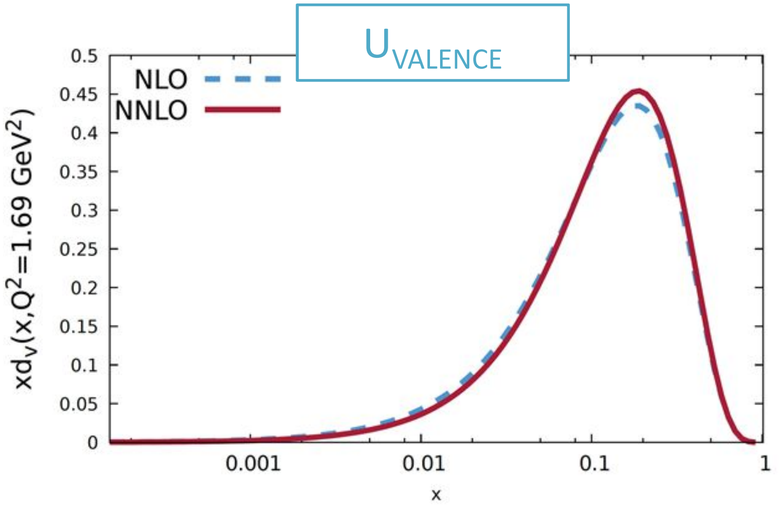
$$n_{data} = (p+n)^*_{data} - p^*_{data}$$

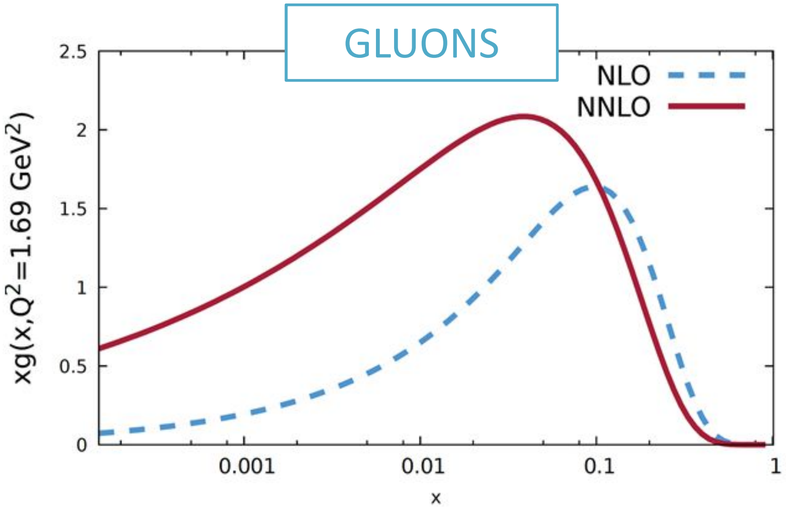
$$= d^*_{data} * (p+n)_{cj}/d_{cj} - p^*_{data}$$

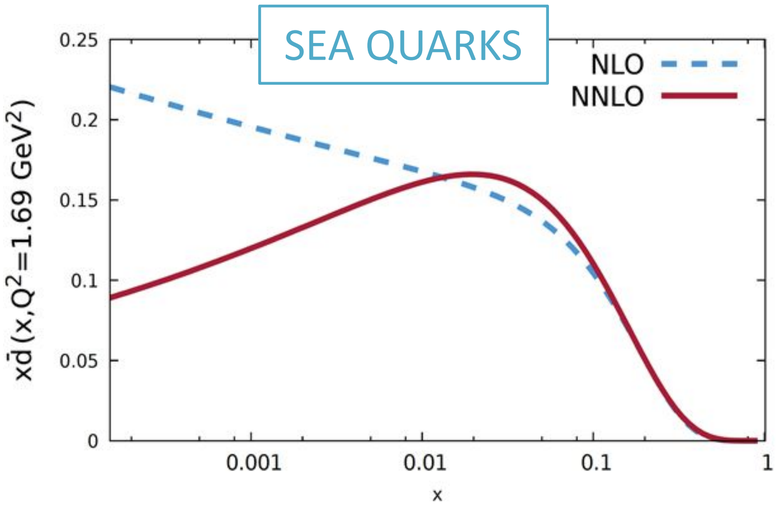
A QCD Analysis for nuclear PDF as NNLO

Marina Walt

- A new open source nPDF set using xFitter - called **TuJu19**
- Currently adding full uncertainties







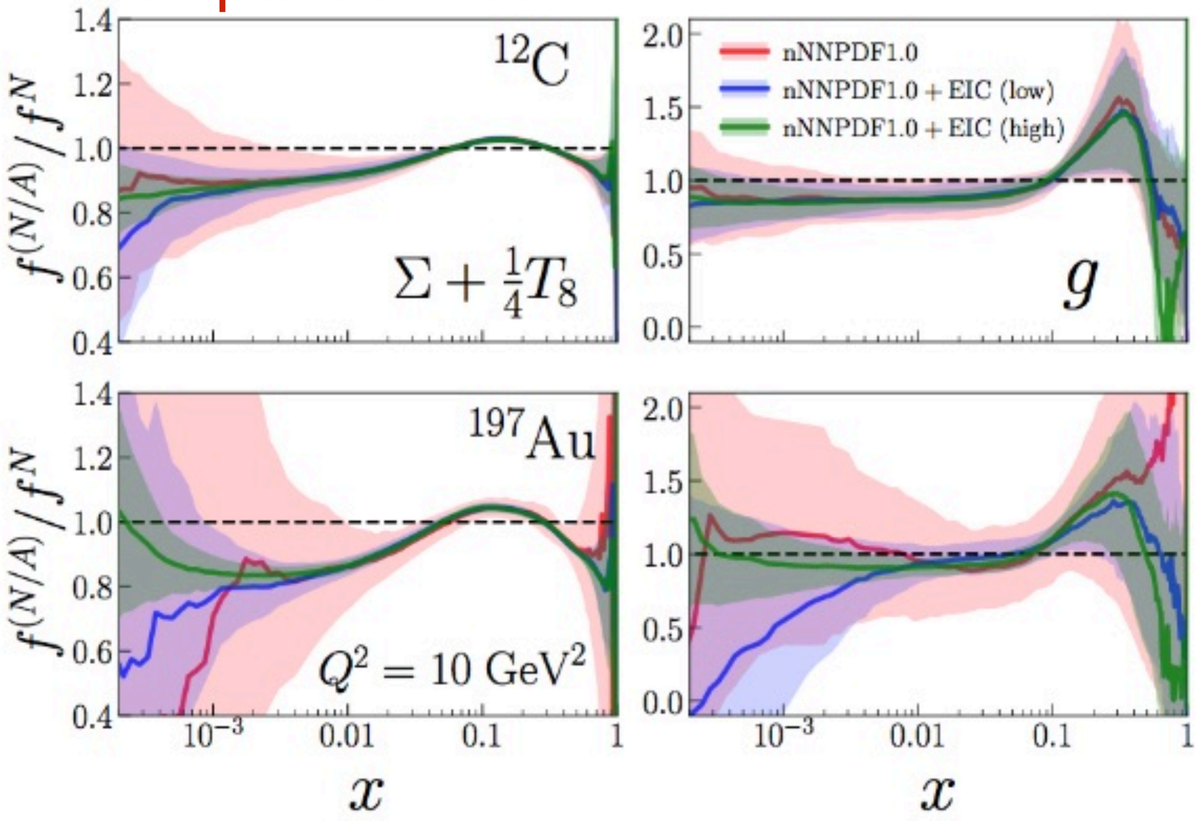
DSSZ	nCTEQ15	EPPS16	nNNPDF1.0	TuJu19
Neutral current DIS				
Neutrino nucleus DIS		Neutrino nucleus DIS		Neutrino nucleus DIS
Drell-Yan data				
		LHC data		
MSTW2008	CTEQ6	CTEQ14	NNPDF3.1	own proton fit
NLO			NLO, NNLO	NLO, NNLO
$R_{A/p}$	f(x)	$R_{A/p}$	f'(x)	f*(x)
				^{2}D fitted as nucleus
				Open Source Toolset

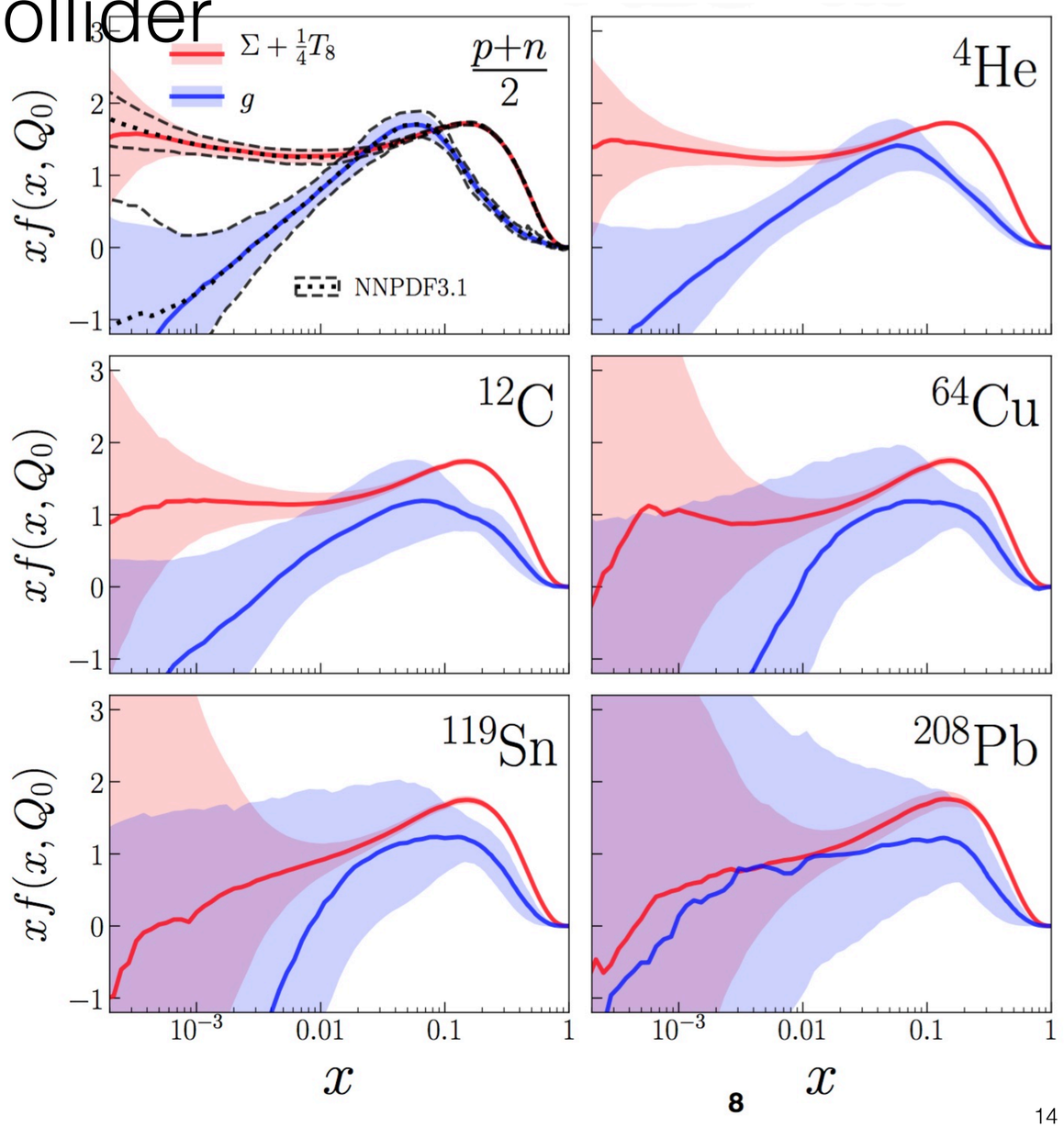
nNNPDF nPDF from Lepton-Nucleus Scattering and the Impact of an Electron-Ion Collider

Rabah Abdul Khalek

- Use the NNPDF approach to fit the nuclear PDF
- PDF available with LHAPDF

Impact of EIC





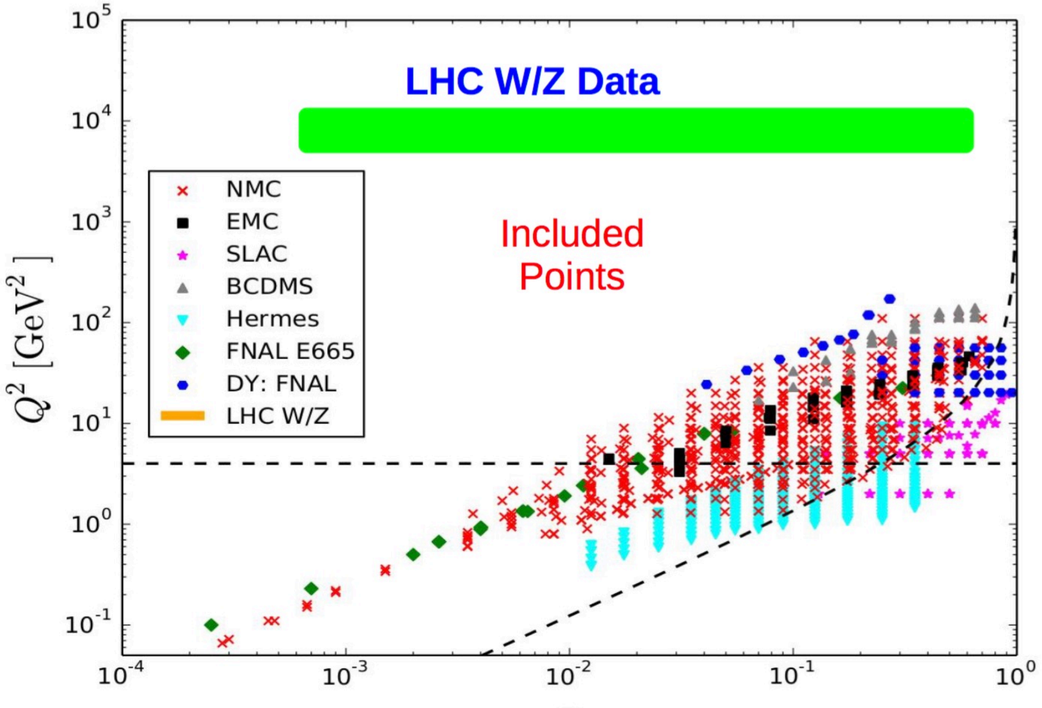
nCTEQ and PDFs at the LHC

Fred Olness

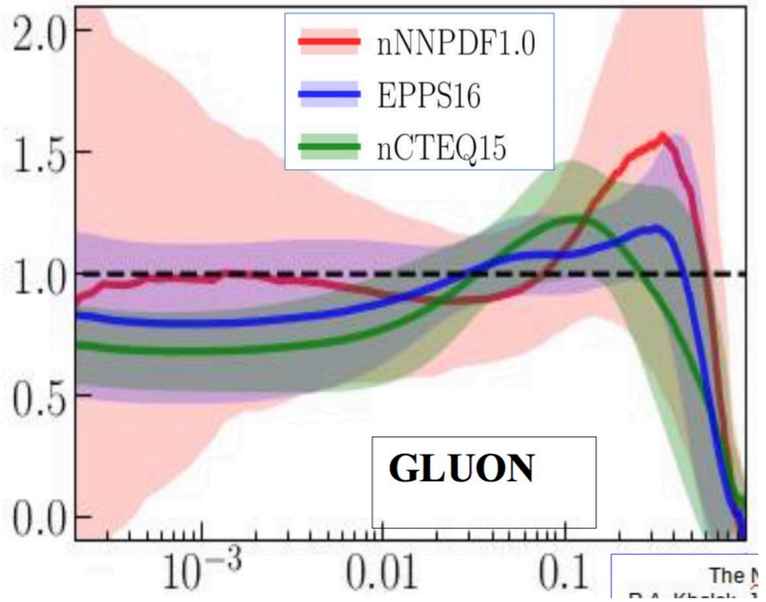
pPb Data for nCTEQ+LHC

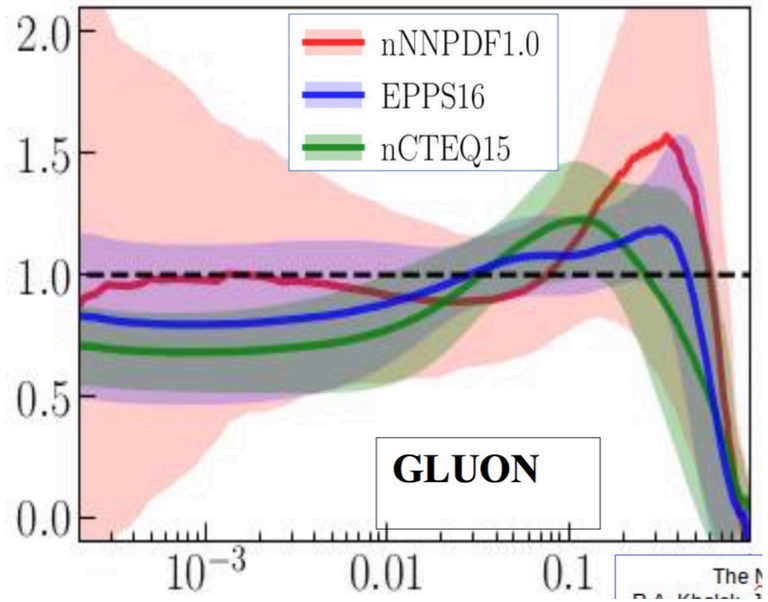
No LHC data in any previous nCTEQ fit

- New nCTEQ++ code using ApplGrid predictions make this possible



CMS	W+
CMS	W-
CMS	Z
ATLAS	W+
ATLAS	W-
ATLAS	Z
ALICE	W+
ALICE	W-
LHCb	Z
CMS_II	W+
CMS_II	W-

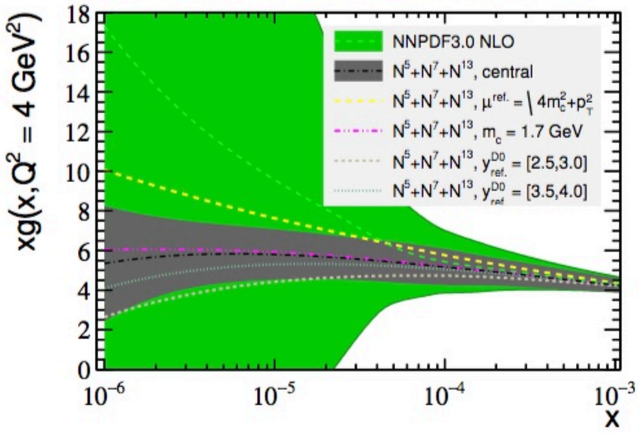




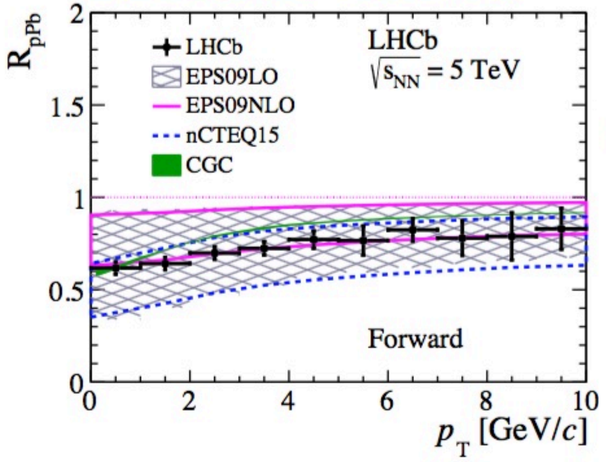
Constraints on the nPDF from LHCb D meson data

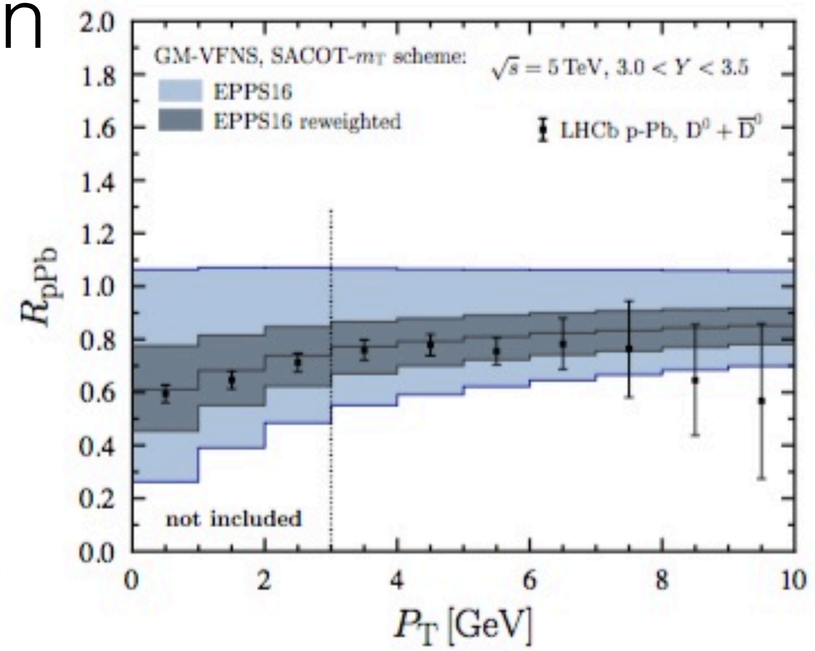
Hannu Paukkunen

reduction of NNPD3.0 gluon uncertainty upon including LHCb D-meson data

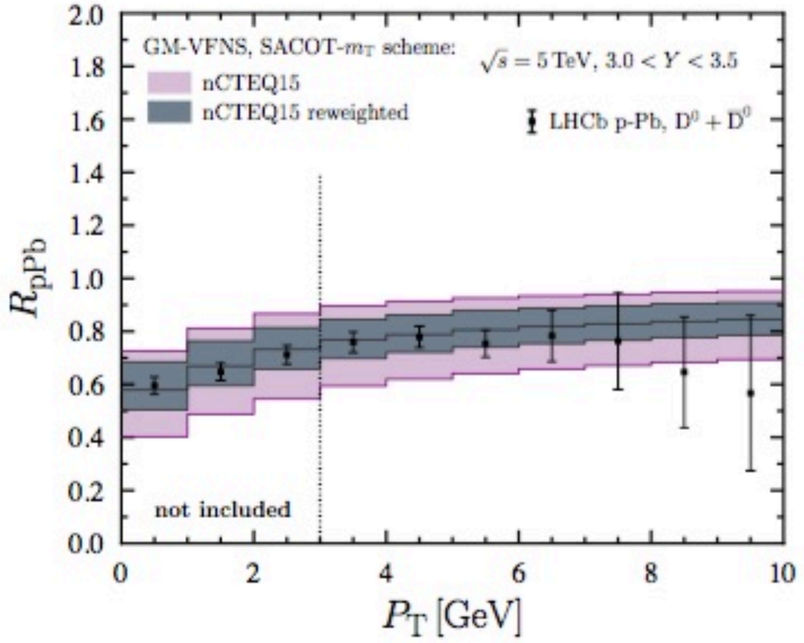


large y nuclear modification in p-Pb from LHCb [JHEP 10 (2017) 090]





- Studied the compatibility and impact of LHCb D-meson data on nuclear PDFs within a realistic GM-VFNS scheme (SACOT-mT)
- Theoretical uncertainties quickly grow below PT~ 3 GeV
- EPPS16 and nCTEQ15 nPDFs can be brought to an excellent agreement with the LHCb data by Hessian PDF reweighting
- Only mild changes (very little for EPPS16, more for nCTEQ15) in the original central values
  - D-meson data compatible with other data in the the global analysis
  - Significant decrease in uncertainties
- The agreement with the data remains very good down to PT = 0
  - No obvious need for invoking BFKL, non-linear evolution, intrinsic kt kicks, etc.



Impact of data on the PDF

- Top quark data
- W+jets data
- W+c
- Forward-backward Drell-Yan
- LHCb D-meson data

The impact of top data

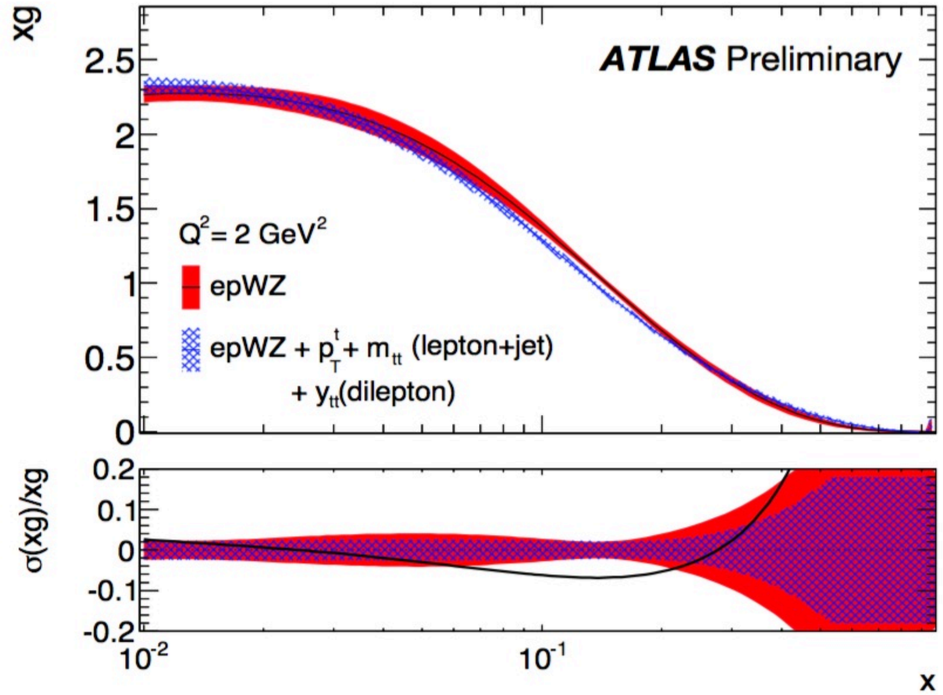
- If jet data is included in the global fit, top quark pair data has little noticeable effect on further constraining the gluon PDFs.

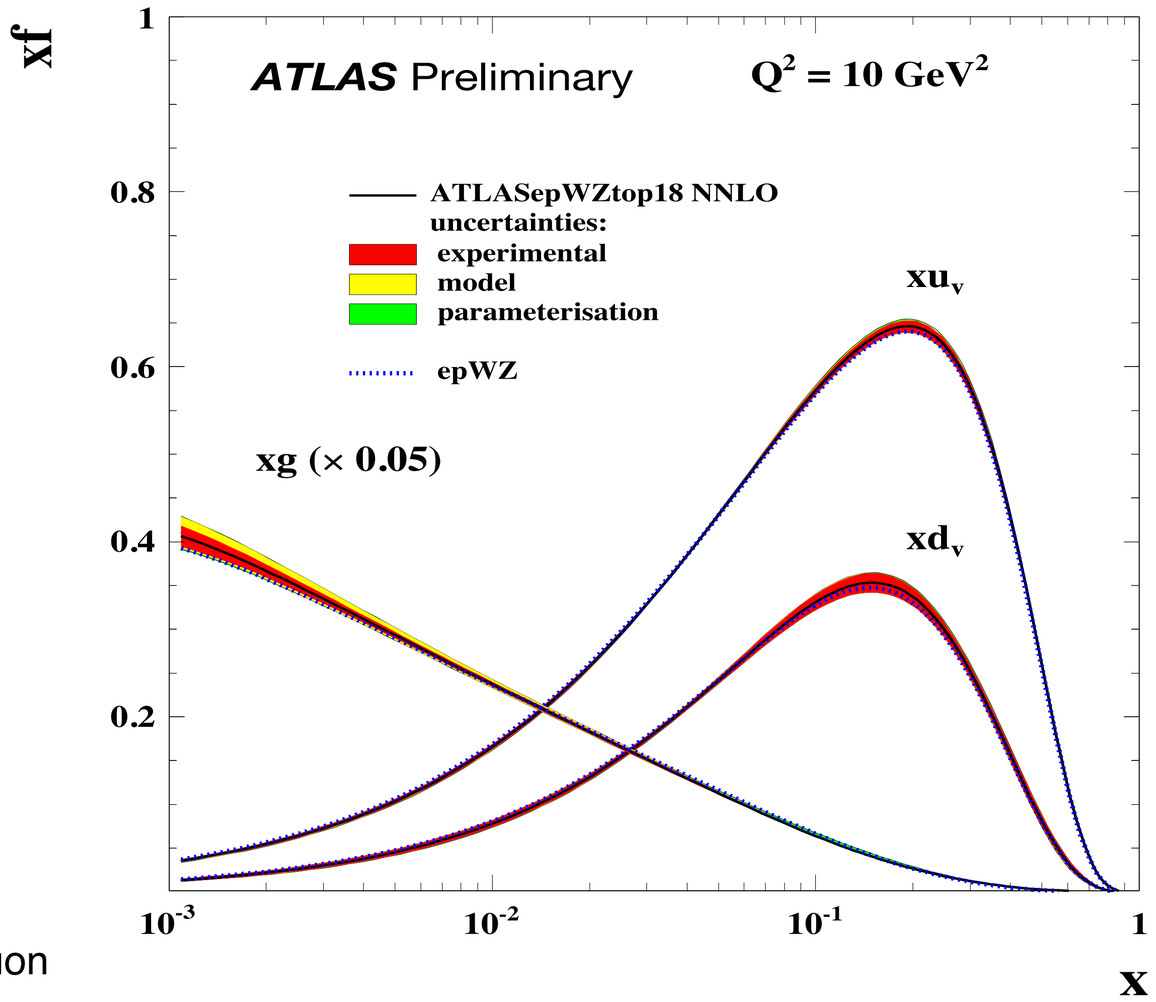
- If jet data is **not** included, then the top data provides similar constraint as the jet data on the central gluon, but with a larger error band since there are fewer top data points

- At the HL-LHC, top quark pair data should provide useful constraints on the gluon at large-x values …

ATLAS ep WZ top 18 fit

Francesco La Ruffa on behalf of ATLAS



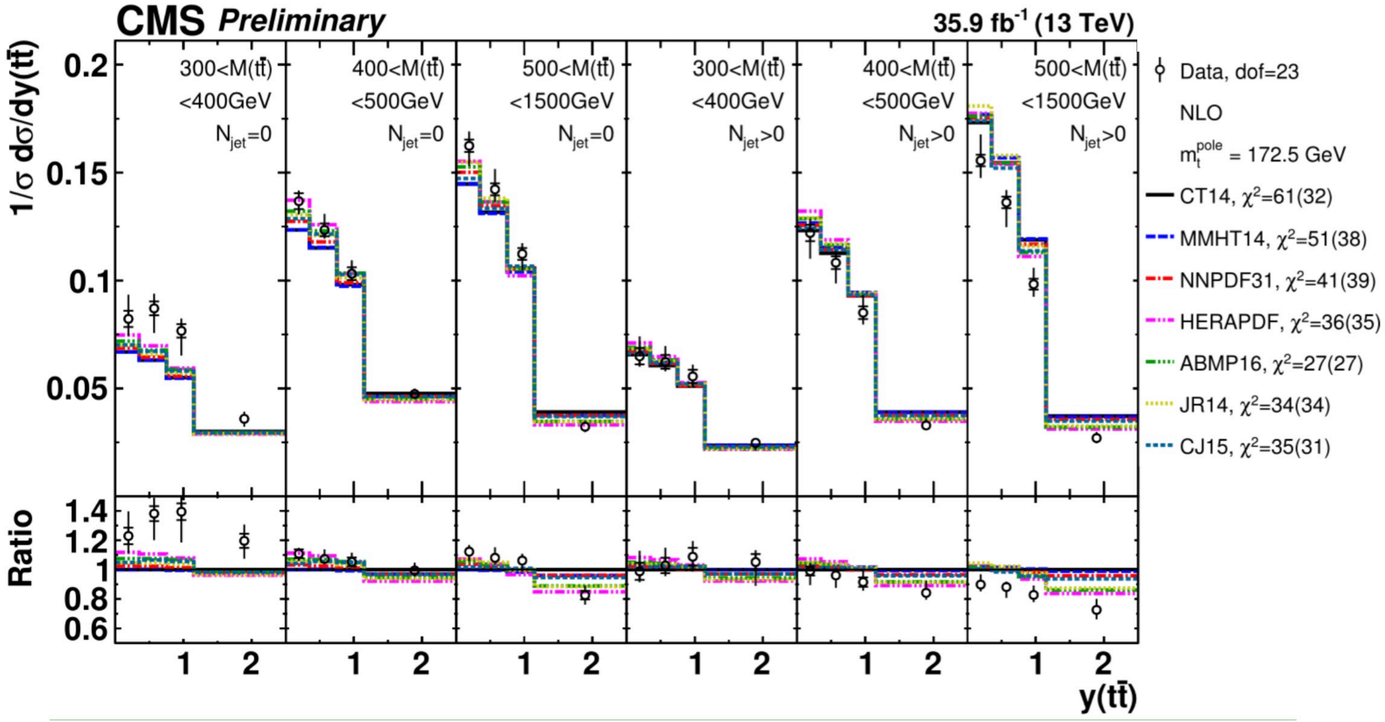


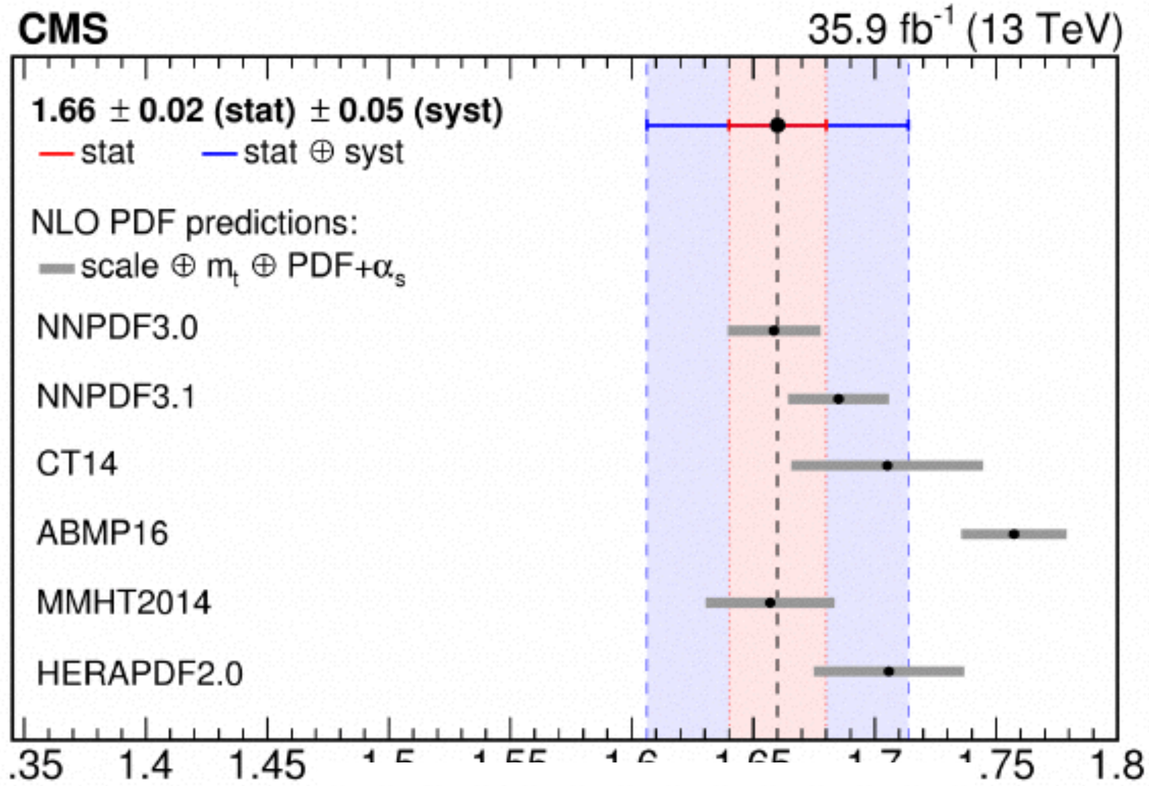
- New fit at NNLO (NLO with NNLO K-factors) using top to stabilise the gluon
  - Lepton plus jets channel: top pair mass, and top pt …
  - Dilepton channel: top pair rapidity
  - Full statistical and systematic correlated uncertainties between cross
- Results in slightly harder gluon, smaller uncertainties at larger x
- Available on LHAPDF (ATLASepWZtop18)

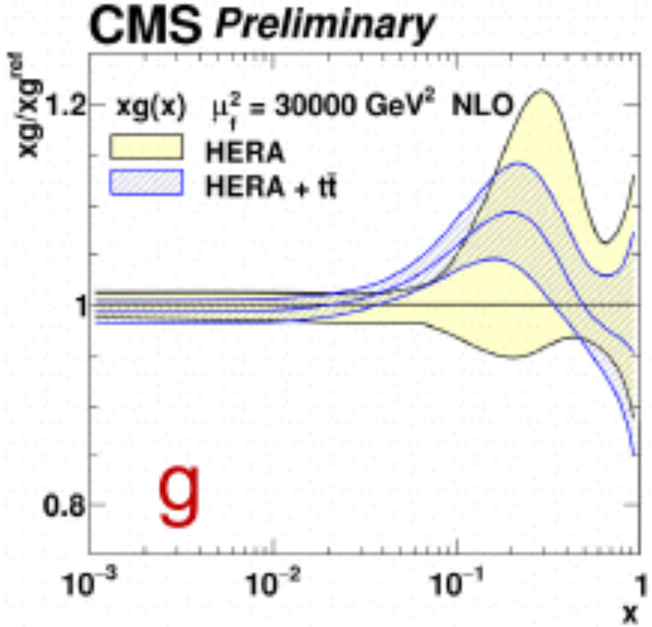
		lepton+jets p_T^t, m_{tt} and dilepton y_{tt} spectra
total χ^2/NDF		1253.8 / 1061
Partial χ^2/NDP	HERA	1149 / 1016
Partial χ^2/NDP	ATLAS $W, Z/\gamma^*$	78.9 / 55
Partial χ^2/NDP	ATLAS lepton+jets p_T^t, m_{tt}	16.0 / 15
Partial χ^2/NDP	ATLAS dilepton y_{tt}	5.4 / 5

CMS PDF results on top quark pair and single top production

O.Behnke on behalf of CMS Collaboration







→ Reduced g uncertainty at high x

$$\alpha_s(m_Z) = 0.1135 \pm 0.0016(\text{fit})^{+0.0002}_{-0.0004}(\text{model})^{+0.0008}_{-0.0001}(\text{param})^{+0.0011}_{-0.0005}(\text{scale}) = 0.1135^{+0.0021}_{-0.0017}(\text{total}),$$

$$m_t^{\text{pole}} = 170.5 \pm 0.7(\text{fit}) \pm 0.1(\text{model})^{+0.0}_{-0.1}(\text{param}) \pm 0.3(\text{scale})\ \text{GeV} = 170.5 \pm 0.8(\text{total})\ \text{GeV}$$

→ Two SM parameters determined precisely, weak correl. (ρ=0.3)

- Top data beginning to play an increasing important role in PDF fits

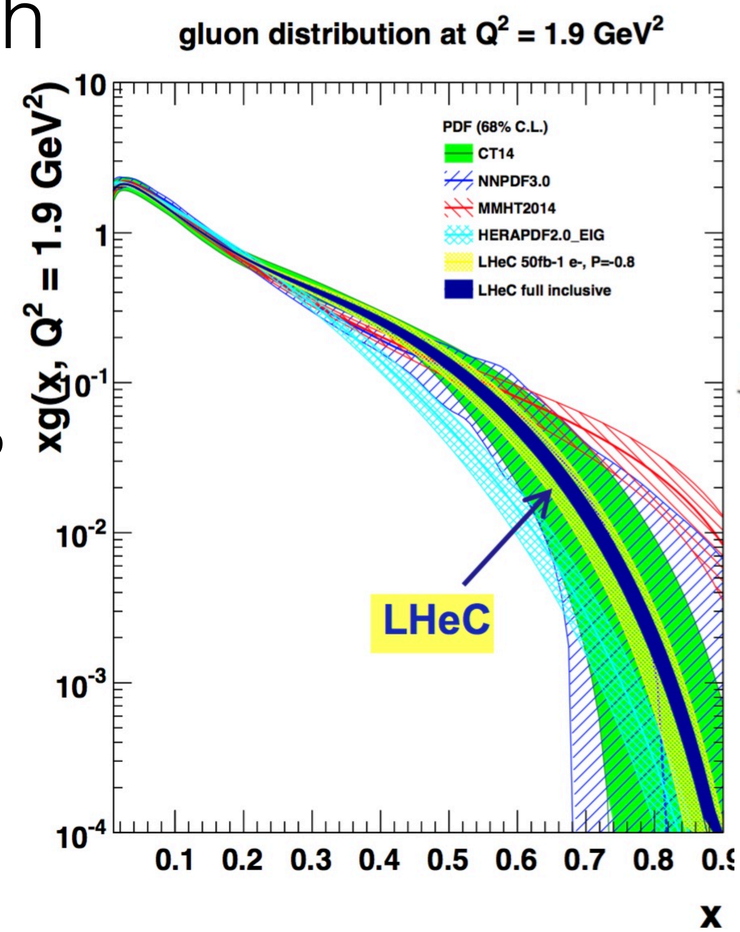
Towards Ultimate Parton Distributions at the HL-LHC

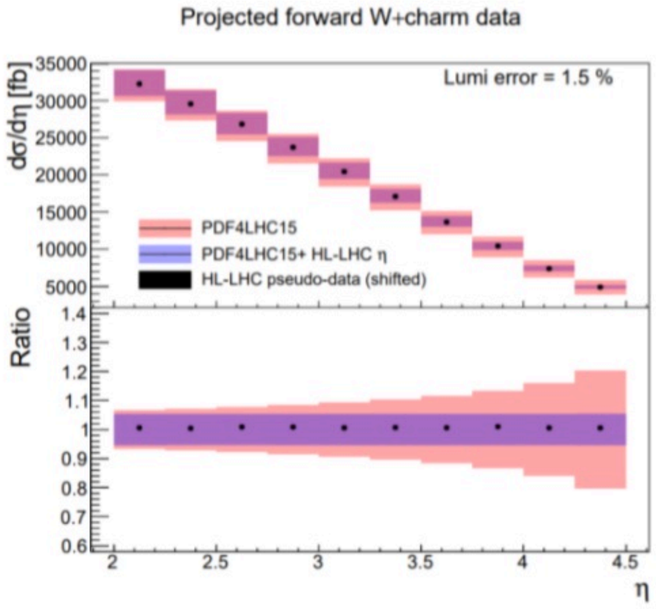
Shaun Bailey

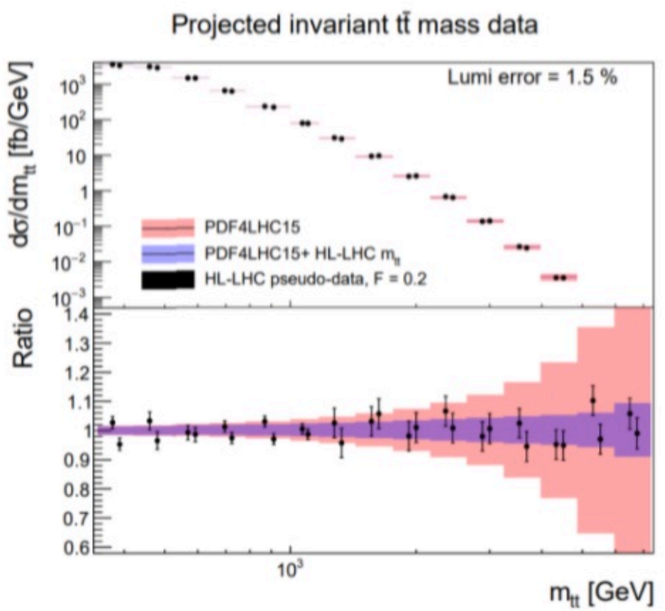
Precision QCD with the LHeC and FCC-eh

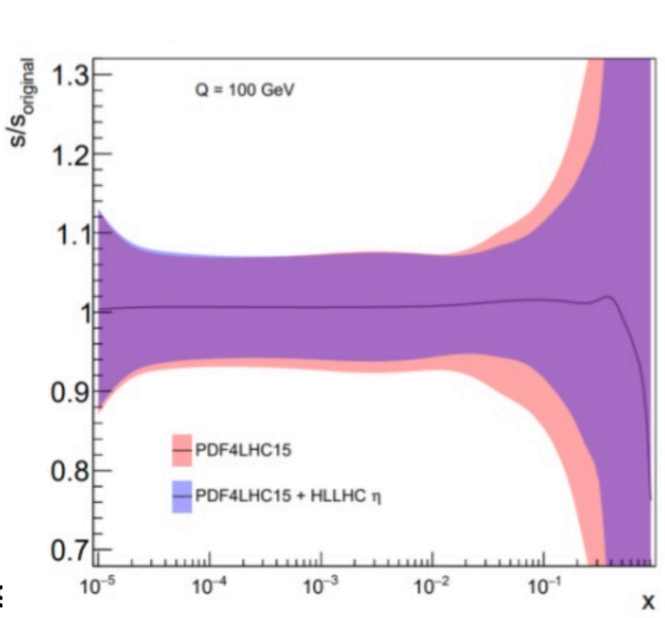
Claire Gwenlan

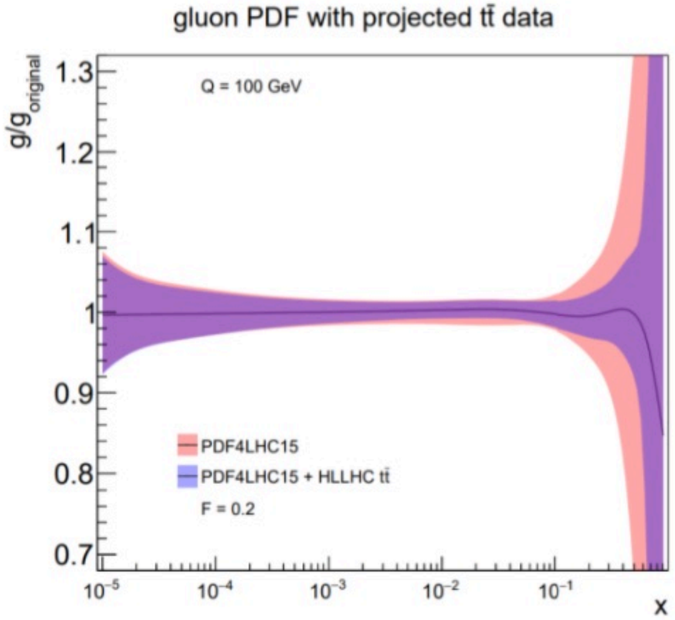
- tt provides a good constraint on high-x gluon
- LHeC will also help to constrain the gluon at high x
- Forward W + charm data constrains the strange PDF



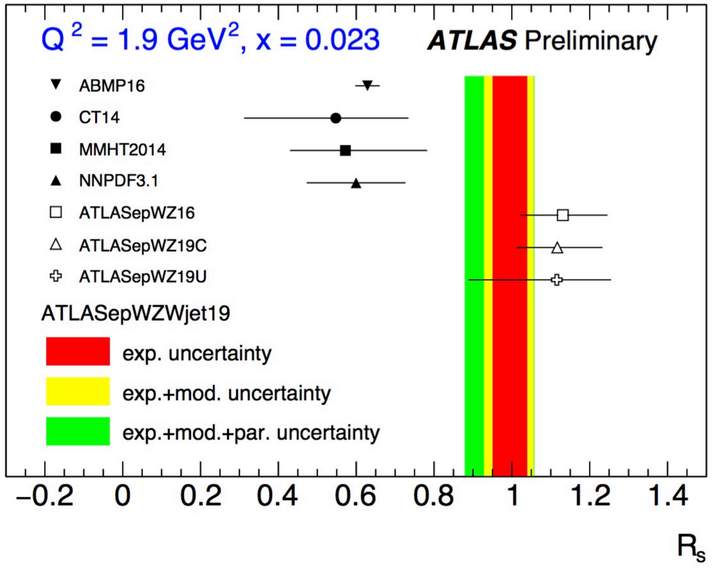


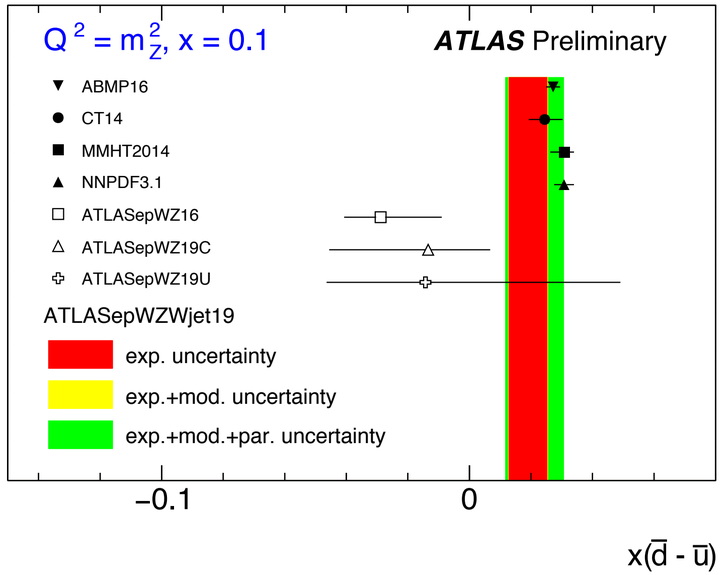


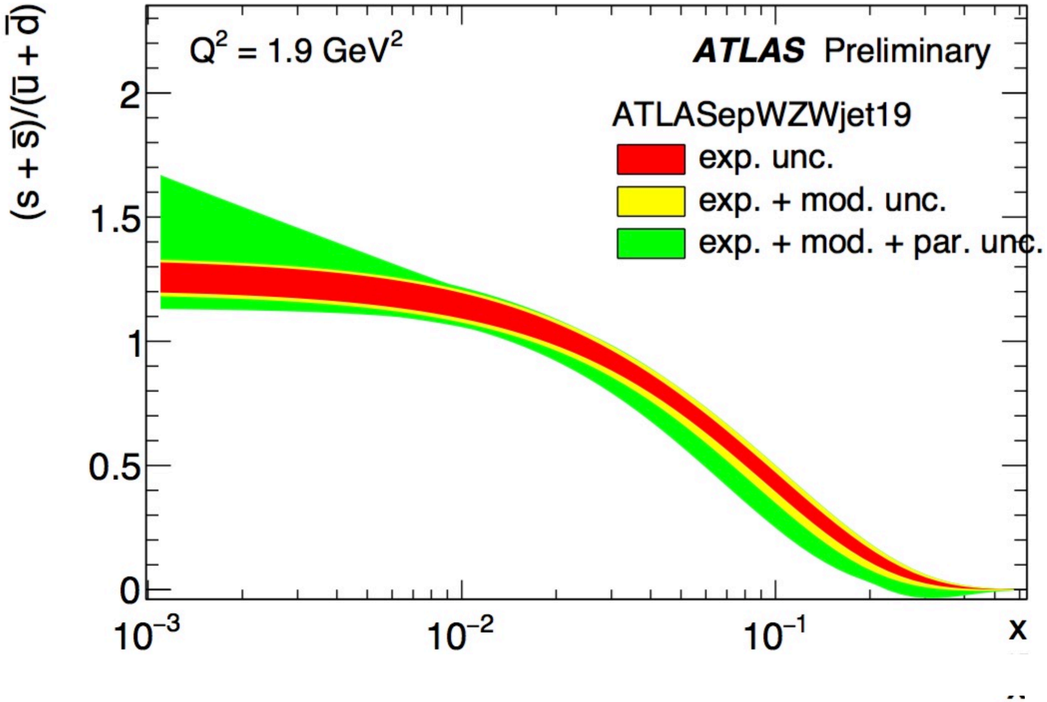


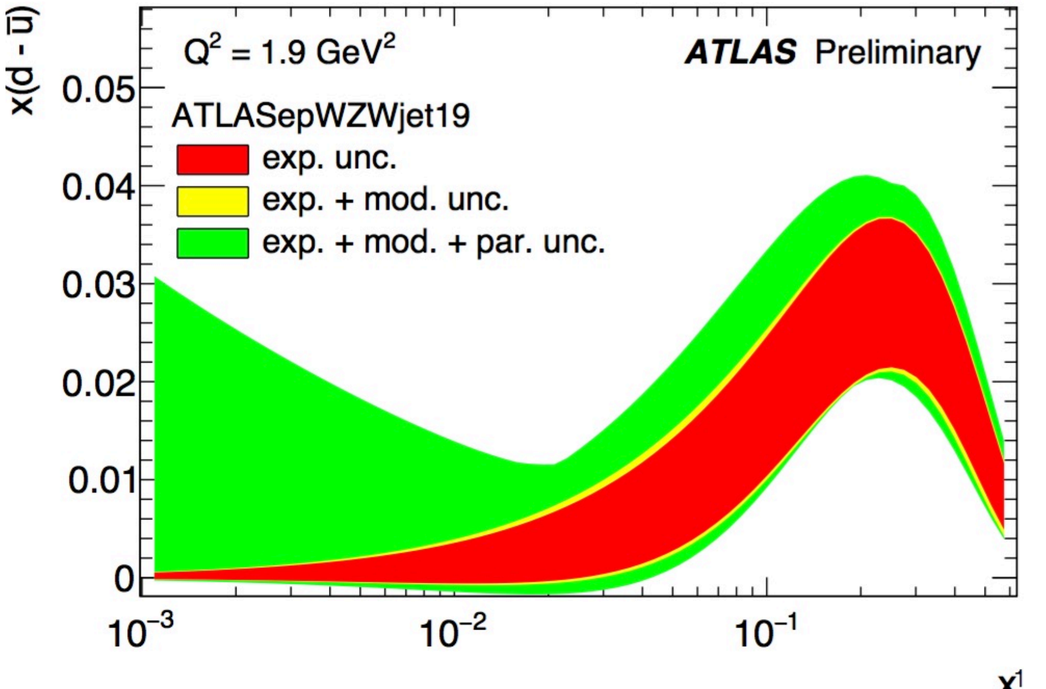


ATLAS Fit: inclusive W, Z and W + jets: how strange is the proton ?







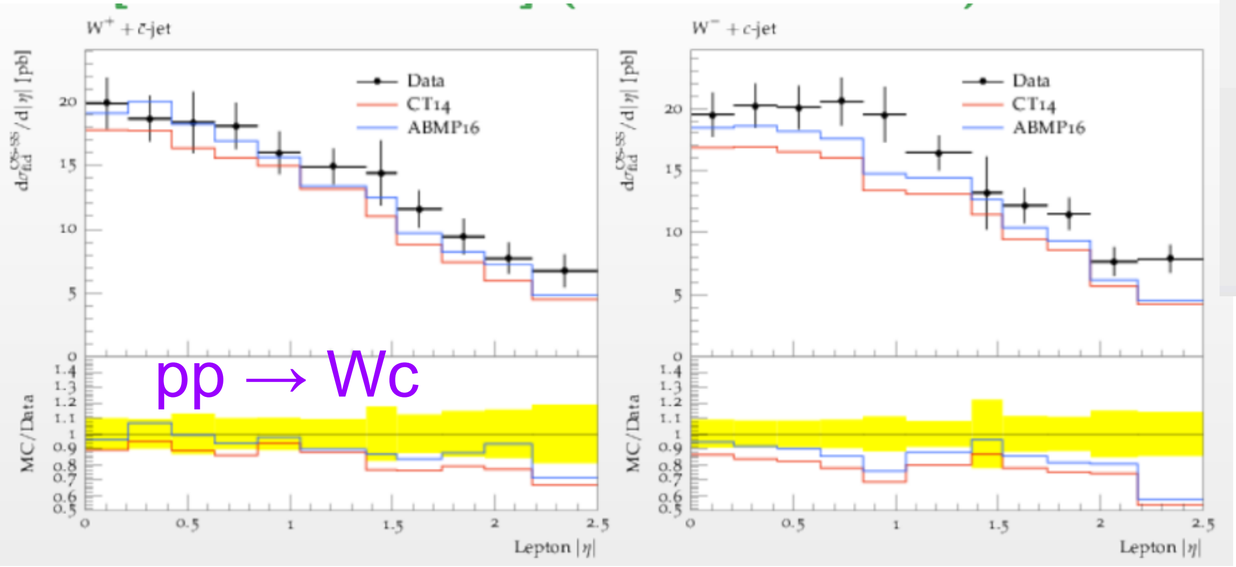


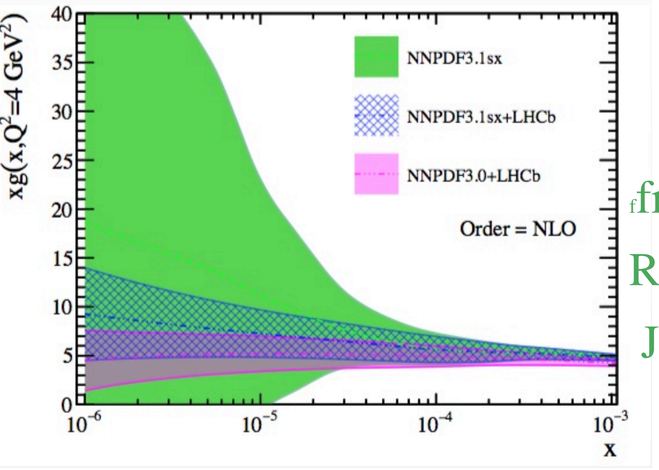
- New ATLAS fit extends epWZ16 fit including W + jets data at 8 TeV to constrain quark distributions at slightly higher x
  - Better constraint on dbar - ubar, which is now positive
  - Strange enhancement at higher x is reduced
  - Still see enhanced strange at low x even with positive dbar - bar

Heavy flavour: W+charm

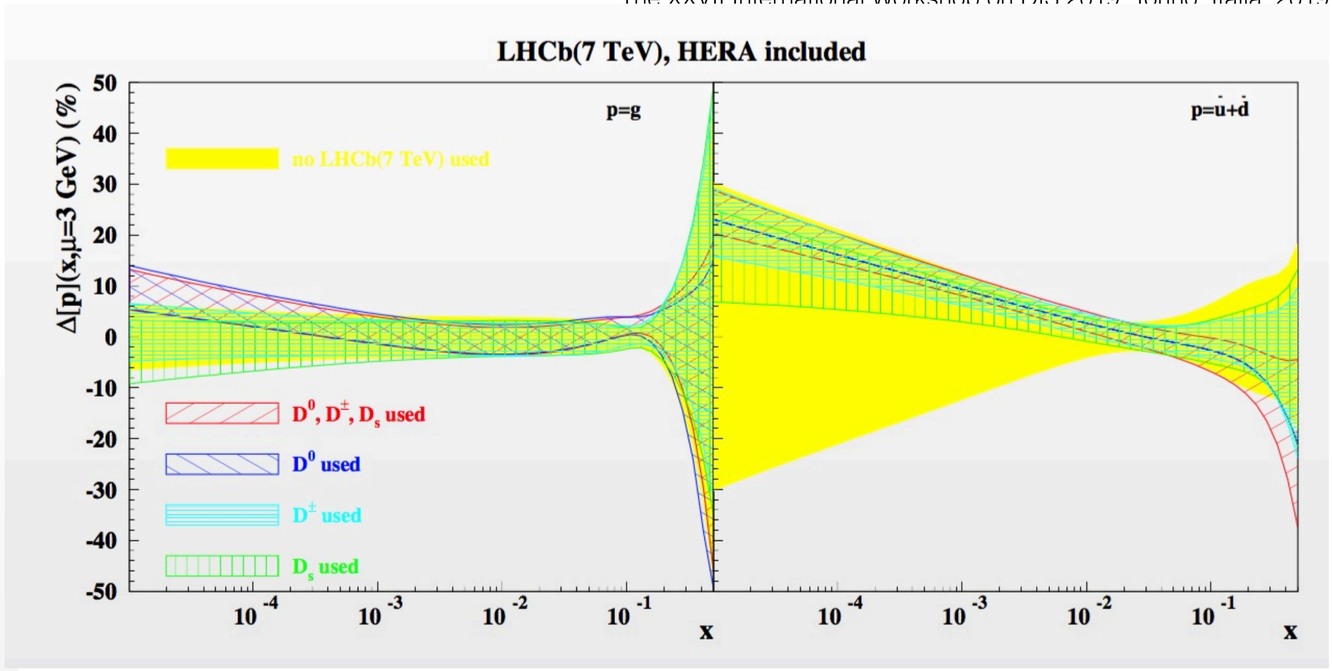
Maria Vittoria Garzelli

- W + charm hadron production - sensitive to the s and star densities in the proton
- Open charm and bottom constraint Gluon and sea quarks





from V. Bertone, R. Gauld and J. Rojo,



- LHCb open charm and bottom data have the potentiality to constrain gluon and sea quark PDF at low and large x's.
- Incorporation in PDF fits so far limited to very few cases (PROSA, recent NNPDF variants, ABMP preliminary, nCTEQ15).
- Compatibility with other open charm and bottom data under investigation.
- Theory predictions (and PDF fits) plagued by large scale uncertainty. Similar uncertainties when using MSbar scheme for charm mass renormalization,
- Still under investigation: how to reconcile shapes of absolute distributions with experimental data ?

Using Forward-Backward Drell-Yan Asymmetry in PDF determination

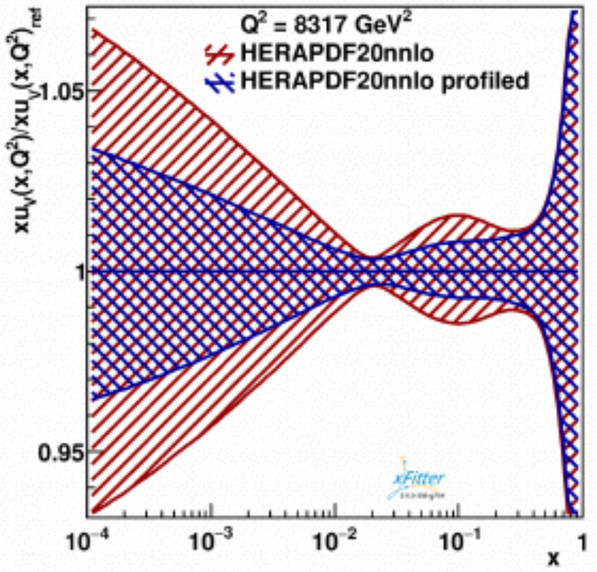
J. Fiaschi, E. Accomando, F. Hautmann, S. Moretti
& xFitter developers

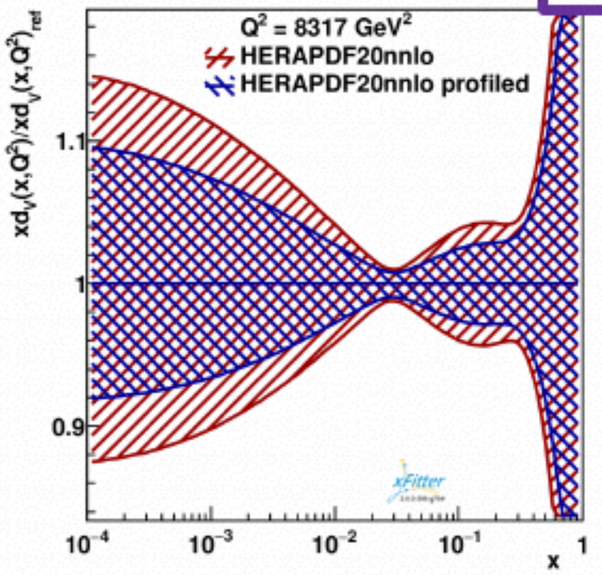
xFitter

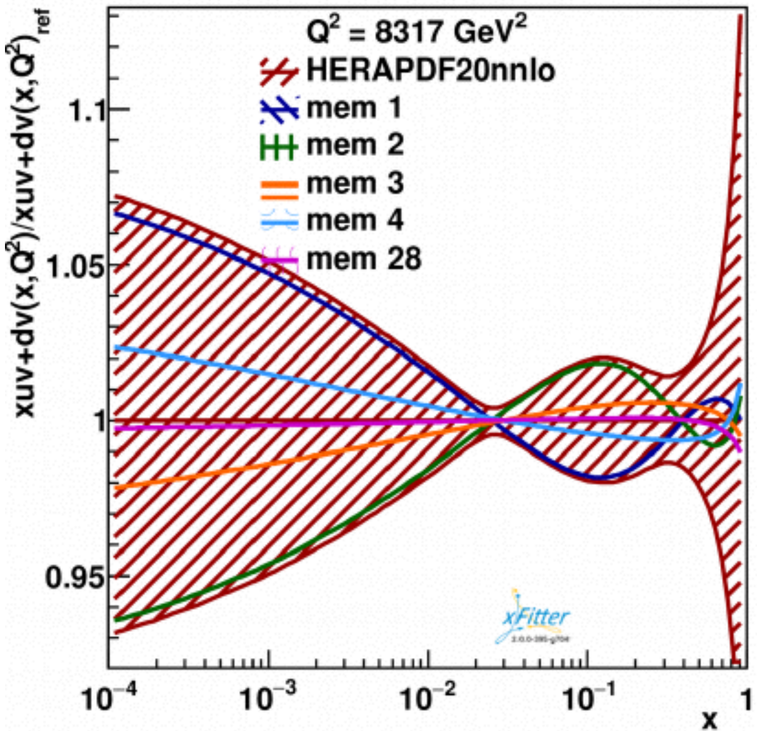
Westfälische Wilhelms-Universität Münster

University of Southampton
School of Physics and Astronomy

HERA2.0 nnlo ($Q^2 = M_Z^2$ GeV^2) (L = 3000 fb^{-1}) |Y| > 0



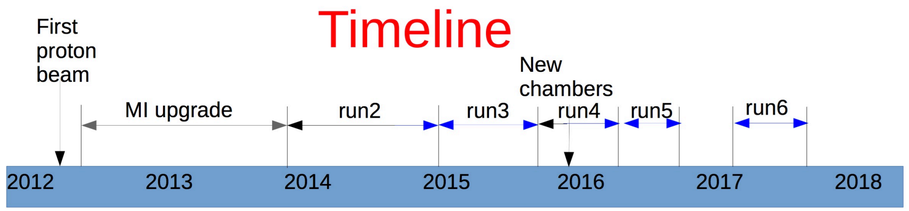




- Forward-Backward Asymmetry (AFB) asymmetry can be used to constrain PDFs
- Compared to 2D DY cross sections, AFB carries extra information on angular distributions and features reduction of systematic theoretical and experimental uncertainties
- Detailed study of several scenarios carried out using xFitter

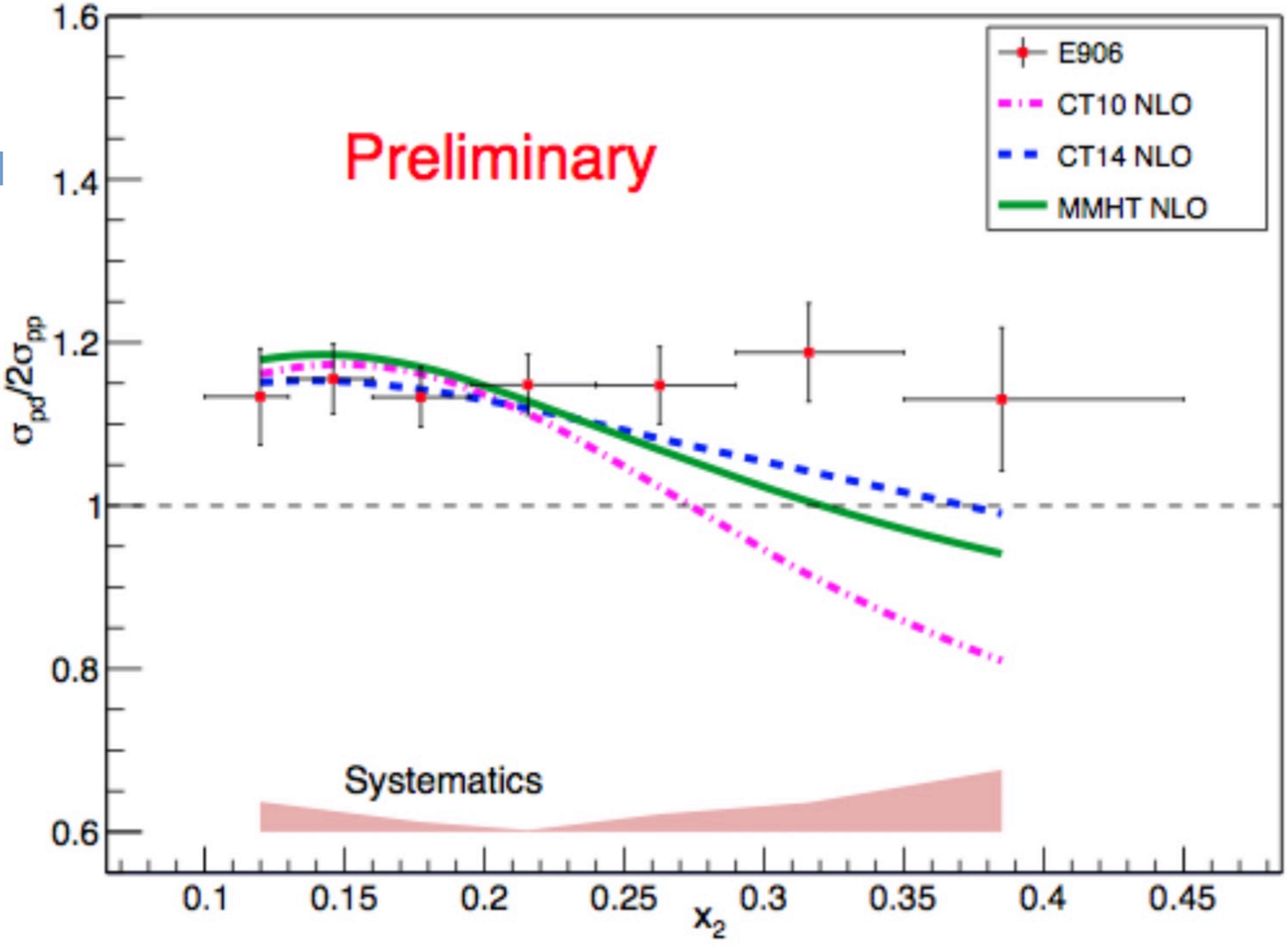
Measuring the light quark sea in SeaQuest

Jason Dove



- SeaQuest data collection completed July 2017
- So far have analyses around 50 % of their data
- New extraction of Drell-Yan D2/H2 as a function of x from 0.1 to 0.45

- Independent mass-fit method shows consistent D2/H2 ratio
- Extraction of dbar/ubar ratio from D2/H2 ratio is underway
- Inclusion of data from after 2016 is underway



New progress in theoretical calculations

- Large log resummations
- Estimating missing higher order uncertainties
- Understanding nuclear corrections

Progress in theoretical calculations - Part I

- Large-log resumption
  - Large-log resummation in the VFN scheme of the DIS heavy-quark production; Sergey Alekhin
  - Soft correction to inclusive DIS cross-section at four-loops; Goutam Das

- Estimating missing higher order contributions
  - On the Consistent Use of Scale Variations in PDF Fits and Prediction; Lucian Harland-Lang
  - A statistical description of theory uncertainty from missing higher orders; Marco Bonvin

- Effect of nuclear uncertainties
  - Nuclear Uncertainties in the Determination of Proton PDFs; Rosalyn Pearson

- No time to discuss individual contributions (even if if I was qualified to do them justice)

Progress in theoretical calculations - Part II

- Parton Branching method for generating TMD (transverse momentum dependent) PDFs
  - PB TMD distributions from fits to DIS precision data; Sara Taheri Monfared
  - Parton Branching TMDs with angular ordering condition and their application to Z boson pt spectrum; Aleksandra Anna Lelek

- Fracture functions and their factorizations -- particles produced at forward rapidity
  - Fracture Functions in different kinematic regions and their factorizations; Kai-bao Chen

- Hadron mass correction in DIS and SIDIS processes
  - Testing collinear factorization in a spectator model with mass corrections; Juan Guerrero

- Photon PDFs -- Photon-photon scattering
  - Production of $W^+ W^-$ and $t \bar t$ pairs via photon-photon processes in proton-proton scattering; Antoni Szczurek

Tools

A new parameterisation ?

Francesco Giuli

- Replace this …

$$xf(x,\mu_0^2) = Ax^B(1-x)^C[1+Dx+Ex^2] - A'x^{B'}(1-x)^{C'}$$

Negative term
(only for gluon)

- with this …

$$xf(x,\mu_0^2) = Ax^B(1-x)^C[1+Dx+Ex^2+F\log(x)+G\log^2(x)+H\log^3(x)]$$

- ie

$$xg(x,\mu_0^2) = A_g\,x^{B_g}(1-x)^{C_g}\left[1+F_g\log x+G_g\log^2 x\right]$$

$$xu_v(x,\mu_0^2) = A_{u_v}\,x^{B_{u_v}}(1-x)^{C_{u_v}}\left[1+E_{u_v}x^2+F_{u_v}\log x+G_{u_v}\log^2 x\right]$$

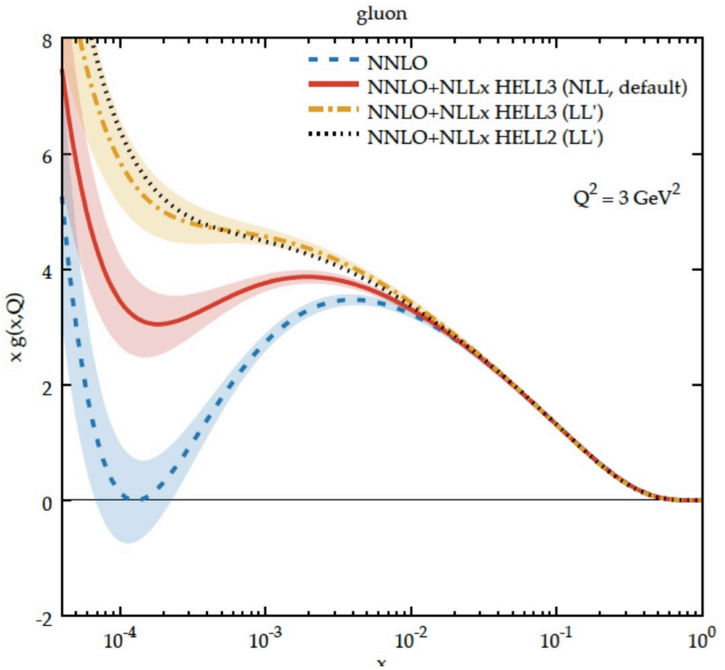
$$xd_v(x,\mu_0^2) = A_{d_v}\,x^{B_{d_v}}(1-x)^{C_{d_v}}$$

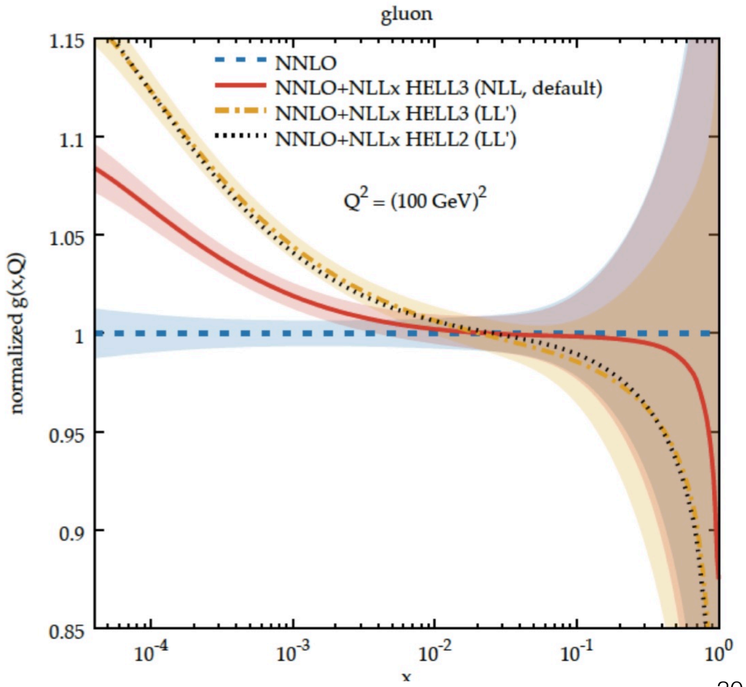
$$x\bar{u}(x,\mu_0^2) = A_{\bar{u}}\,x^{B_{\bar{u}}}(1-x)^{C_{\bar{u}}}\left[1+D_{\bar{u}}x+F_{\bar{u}}\log x\right]$$

$$x\bar{d}(x,\mu_0^2) = A_{\bar{d}}\,x^{B_{\bar{d}}}(1-x)^{C_{\bar{d}}}\left[1+D_{\bar{d}}x+F_{\bar{d}}\log x\right],$$

$$xs(x,\mu_0^2) = x\bar{s}(x,\mu_0^2) = r_s\,x\bar{d}(x,\mu_0^2) \qquad r_s = \frac{f_s}{1-f_s} \quad \text{with } f_s = 0.4 \text{ fixed}$$

- Tests performed using small x resumption using HELL



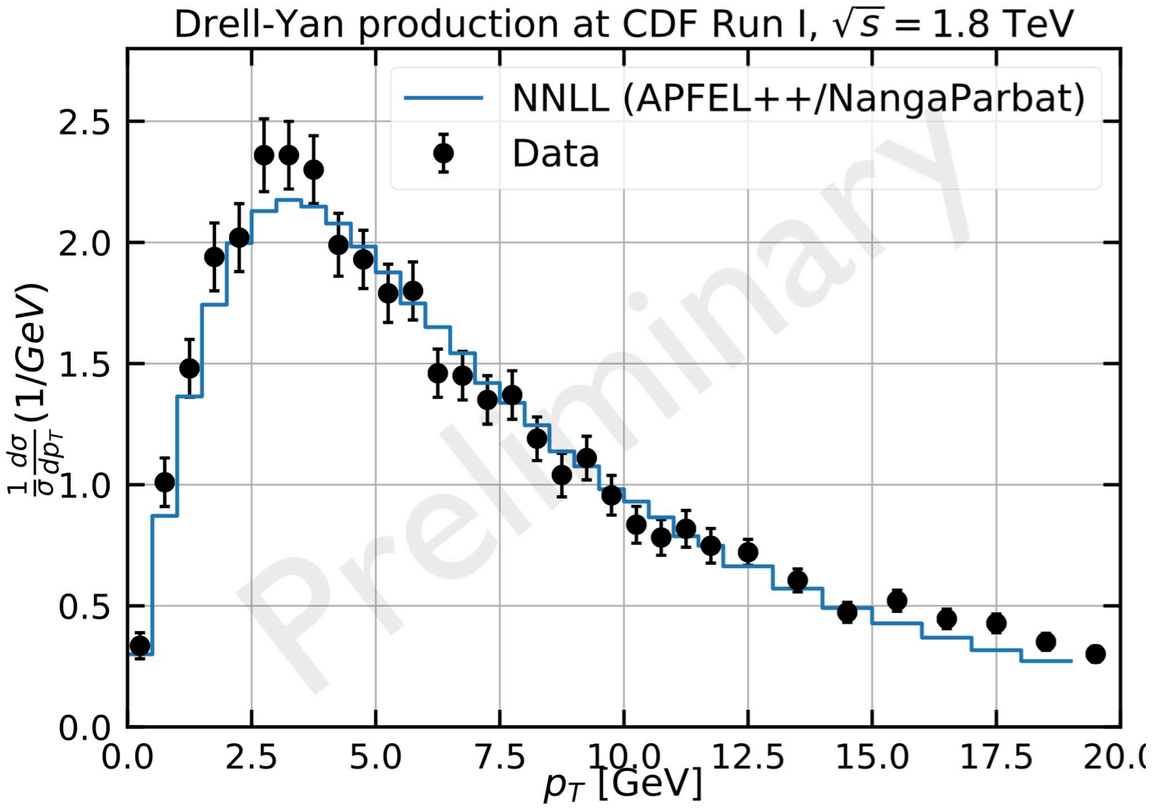


The evolution of APFEL: APFEL++

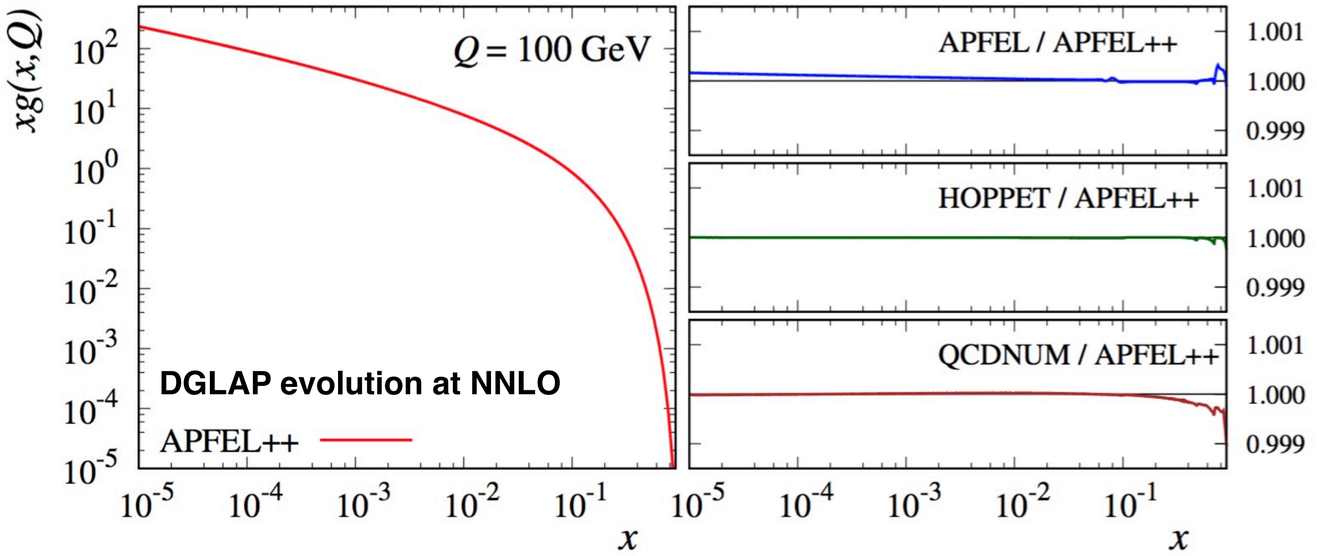
Valerio Bertone

INFN and Università di Pavia

- Ground up redesign of the fortran APFEL: APFEL++
- Newer very efficient C++ library for PDF evolution and DIS cross section calculation
  - Some minor features of the fortran version still being implemented
- Code is stable and version 4.0.0 is released
  - https://github.com/vbertone/apfelxx



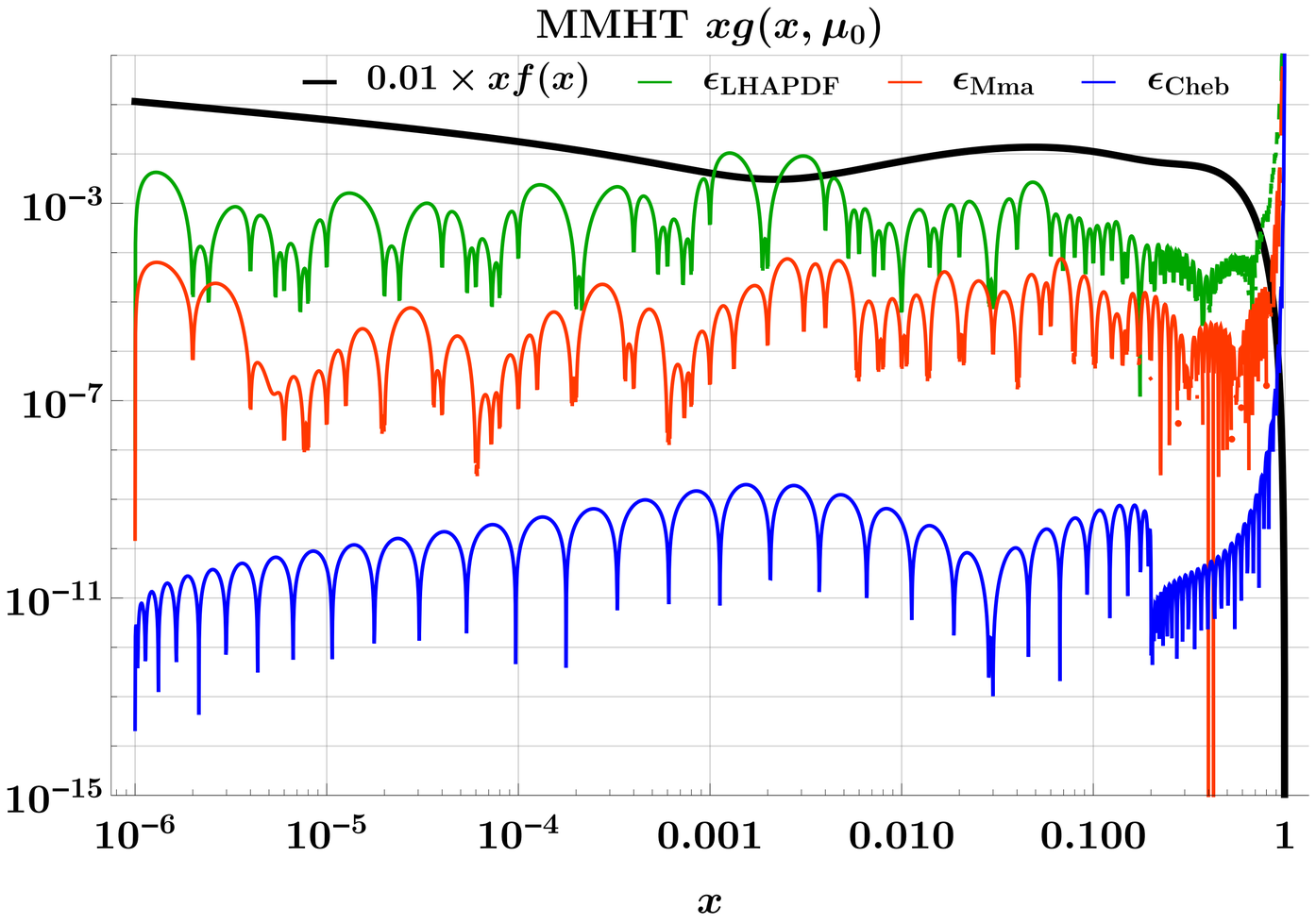
- Extensive code documentation (Doxygen)
- New applications
  - Semi-inclusive DIS at NLO
  - qT distribution for Drell-Yan in TMD factorisation - will be used to extract non-perturbative transverse TMD componen



More efficient interpolation of parton distributions: ChiliPDF

Riccardo Nagar

- Size of the interpolation errors is becoming increasingly important
  - Limits accuracy of calculations, or creates large memory footprints for storing coefficients
- C++ Chebyshev-based Interpolation Library for PDFs
- Higher numerical accuracy for a considerably smaller number nodes than interpolation used in LHAPDF
  - Up to NNLO DGLAP evolution with O(αs2) flavour matching for PDFs and DPDs
- Will become more important as current interpolation becomes inadequate for high precision N^{3}LO without smaller grids
  - Initial use case for double parton scattering
- May have potential benefits for fast interpolation grids such as APPLgrid and fastNLO



- LHAPDF: 64 pts
- Mathematica: 64 pts
- Chebyshev: 63 pts

Recent QCD results from the xFitter project

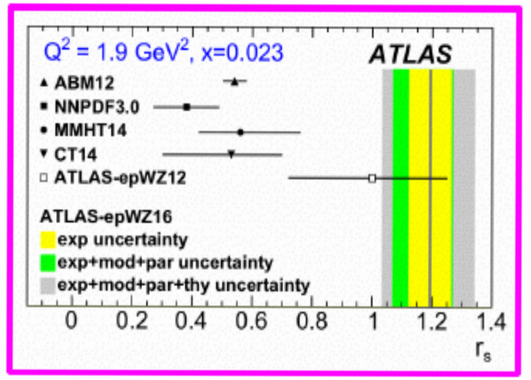
Demonstration of xFitter with FFNS/VFNS and multi-scale predictions

Fred Olness
SMU
on behalf of the xFitter team

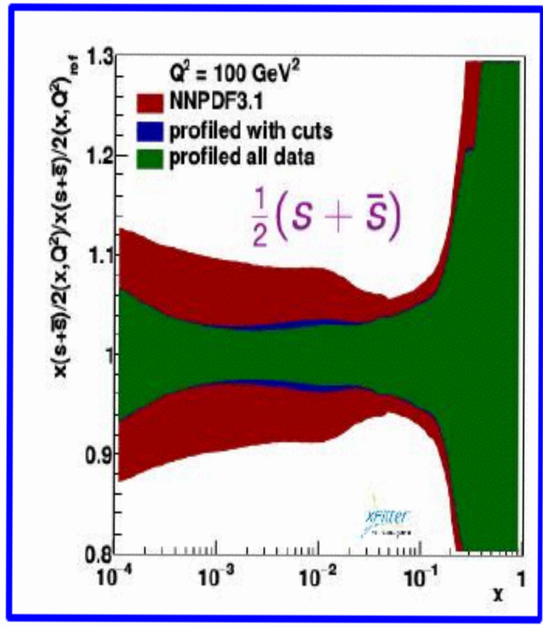
xFitter Meeting: Minsk March 2019

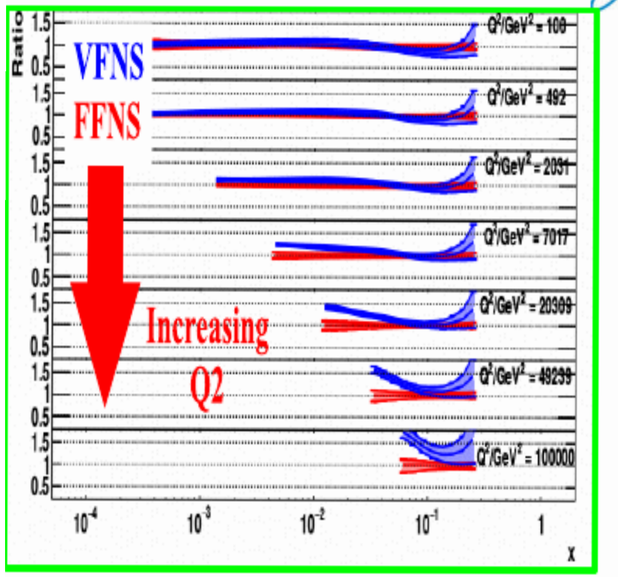
- xFitter is open-source framework for PDF determination [xfitter.org]
- Used extensively by theorists and experimentalists for phenomenolgical analyses
- Several recent studies by xFitter team: e.g. determination of strange PDFs at LHeC

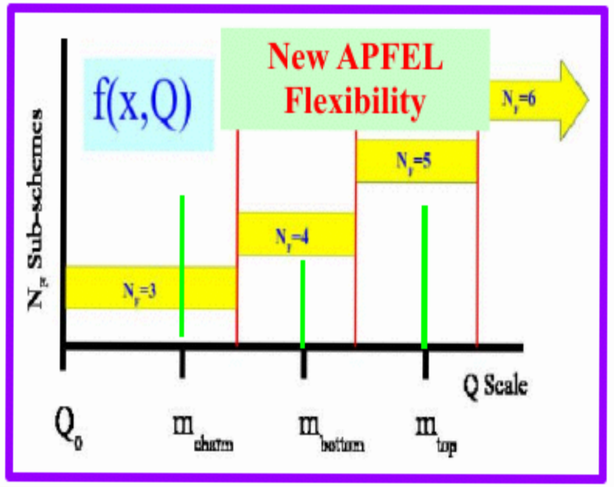
Summary: Versatility of xFitter



xFitter.org







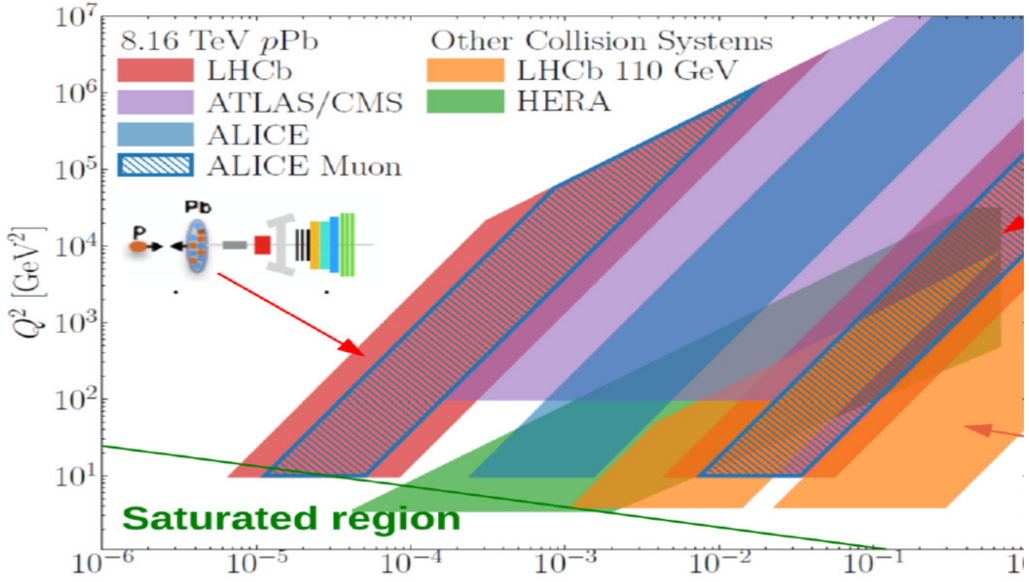
PDF Uncertainty, heavy quarks, FFNS & VFNS, C & G initiated, s(x) extraction, resummation...

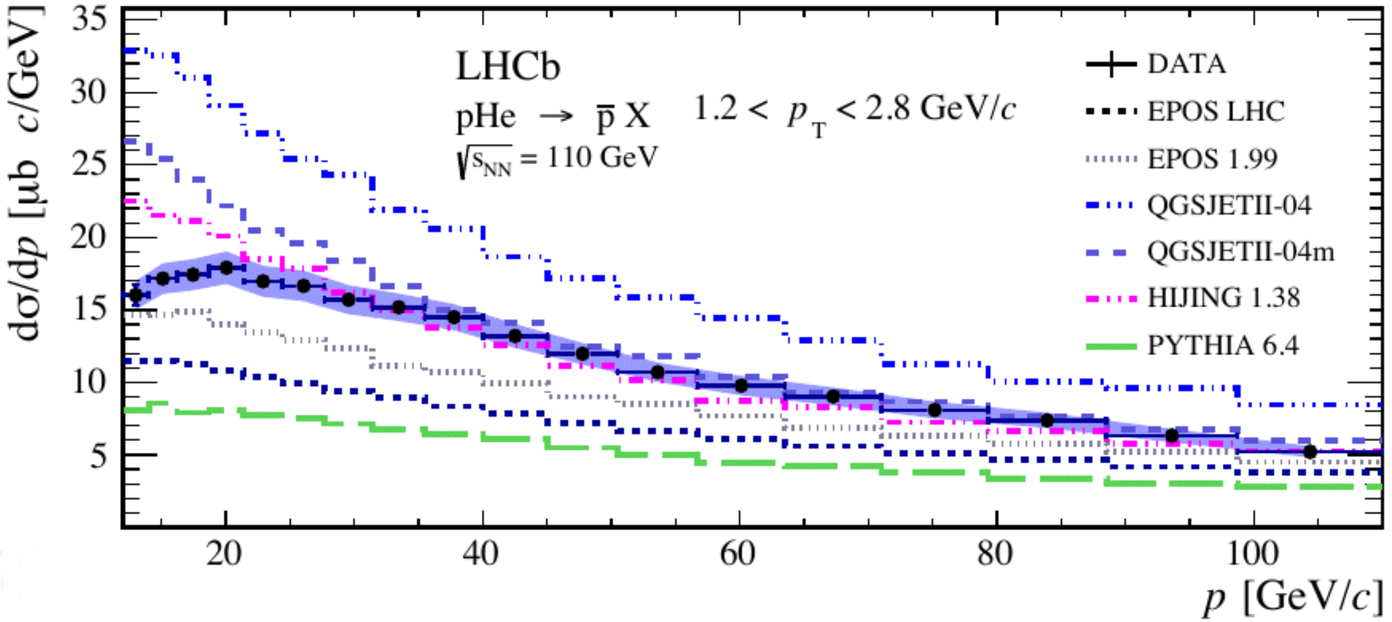
Data constraints on the proton and nuclear PDFs

pPb and fixed target results from LHCb

Óscar Boente García
on behalf of LHCb Collaboration

- p production in pHe - dark matter searches in cosmic rays
- p production in pHe never directly measured at these energies
- Uncertainty smaller than spread of predictions
  - Decisive contribution to reduce background uncertainties in dark matter searches



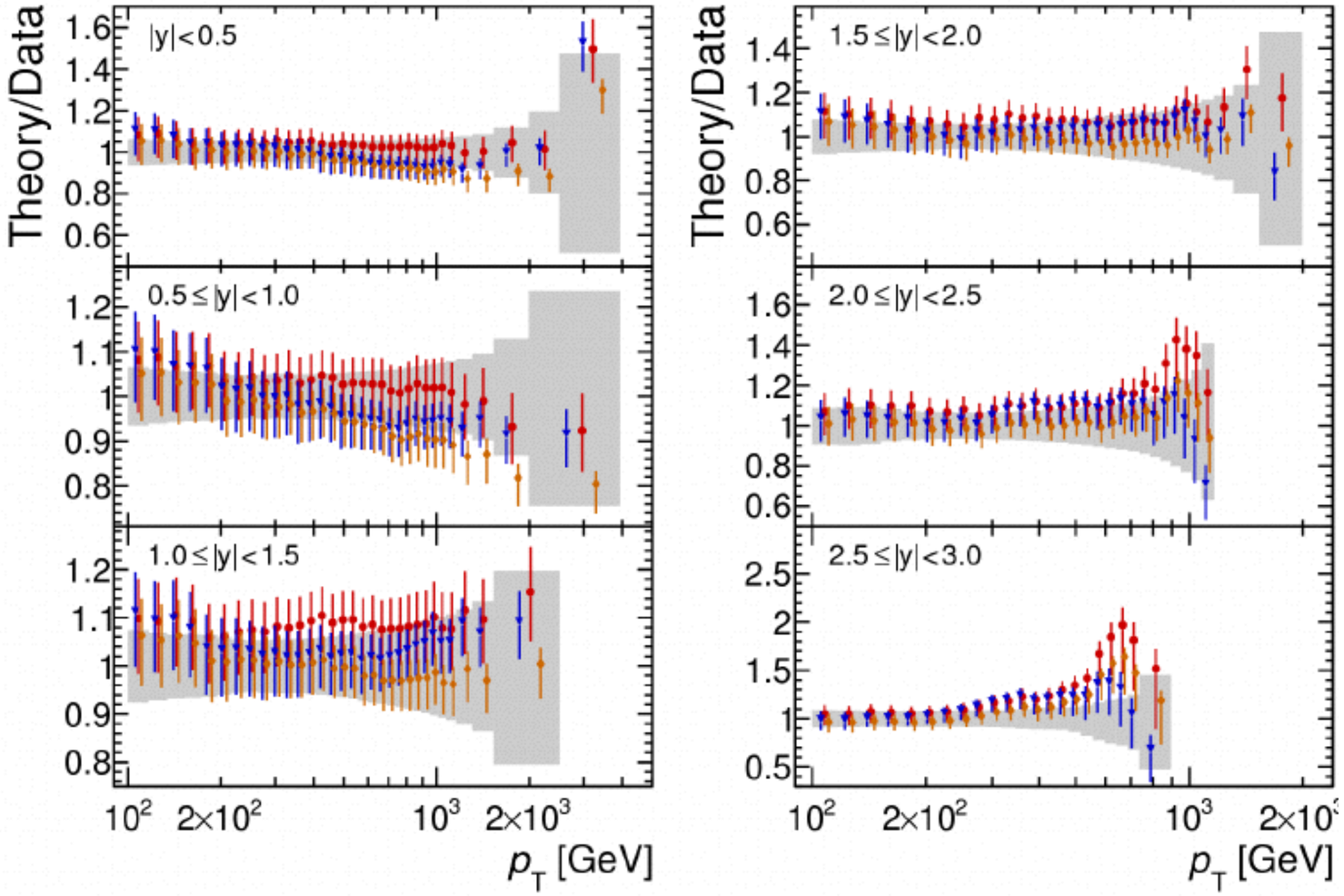


- Latest measurements with heavy ions at LHCb have been reported:
  - Fixed-target mode: $\bar{p}$ production in pHe; Charm production
  - pPb and PbPb: Coherent J/ψ production in UPC PbPb collisions; Heavy flavour production in pPb (Λ_c^+, B hadron, $\Upsilon(nS)$

Jet Measurements for PDFs + Uncertainties

Chris Young on behalf of ATLAS Collaboration

- The results are compared at NLO to a variety of PDFs.



ATLAS

$L = 81\,\text{nb}^{-1}$ - $3.2\,\text{fb}^{-1}$

$\sqrt{s} = 13$ TeV

anti-k_t R=0.4

Data

NLO QCD

$\otimes\, k_{EW} \otimes k_{NP}$

$\mu_R = \mu_F = p_T^{max}$

CT14

HERAPDF 2.0

ABMP16

χ^2/dof all $\lvert y\rvert$ bins	CT14	MMHT 2014	NNPDF 3.0	HERAPDF 2.0	ABMP16
p_T^{max}	419/177	431/177	404/177	432/177	475/177
p_T^{jet}	399/177	405/177	384/177	428/177	455/177

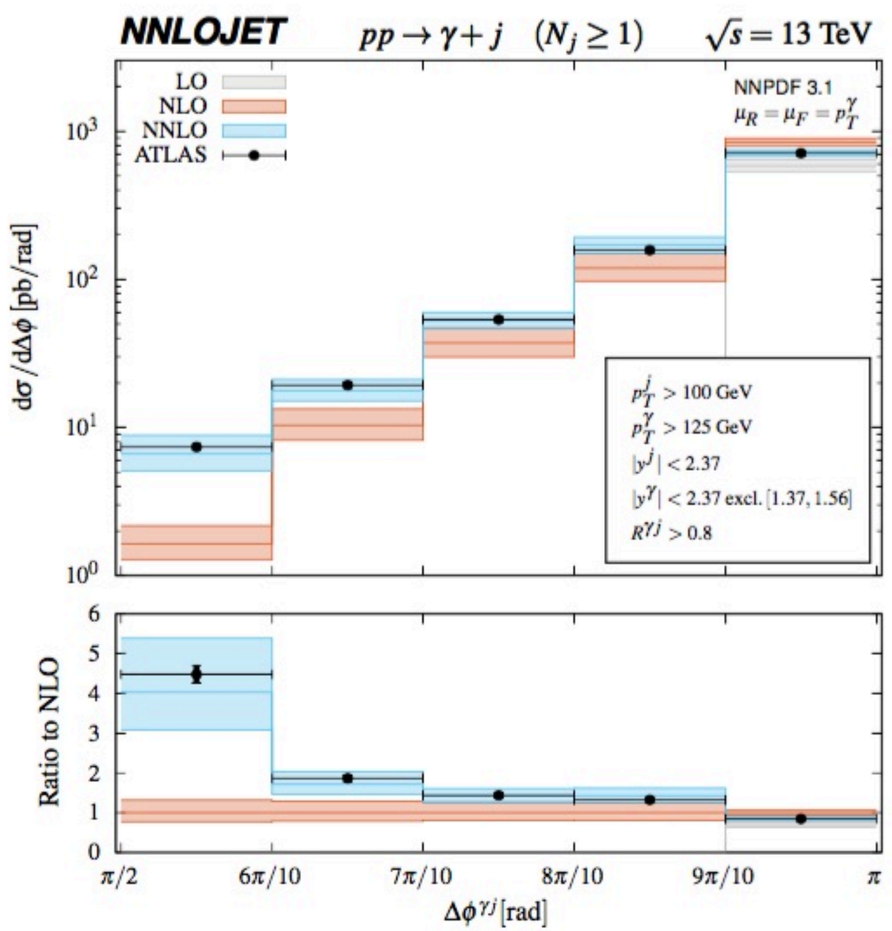
- **As these correlations are clearly extremely important the second part of the talk will detail how we measure the Jet Energy Scale and the correlations across p_T, η on the experimental side.**

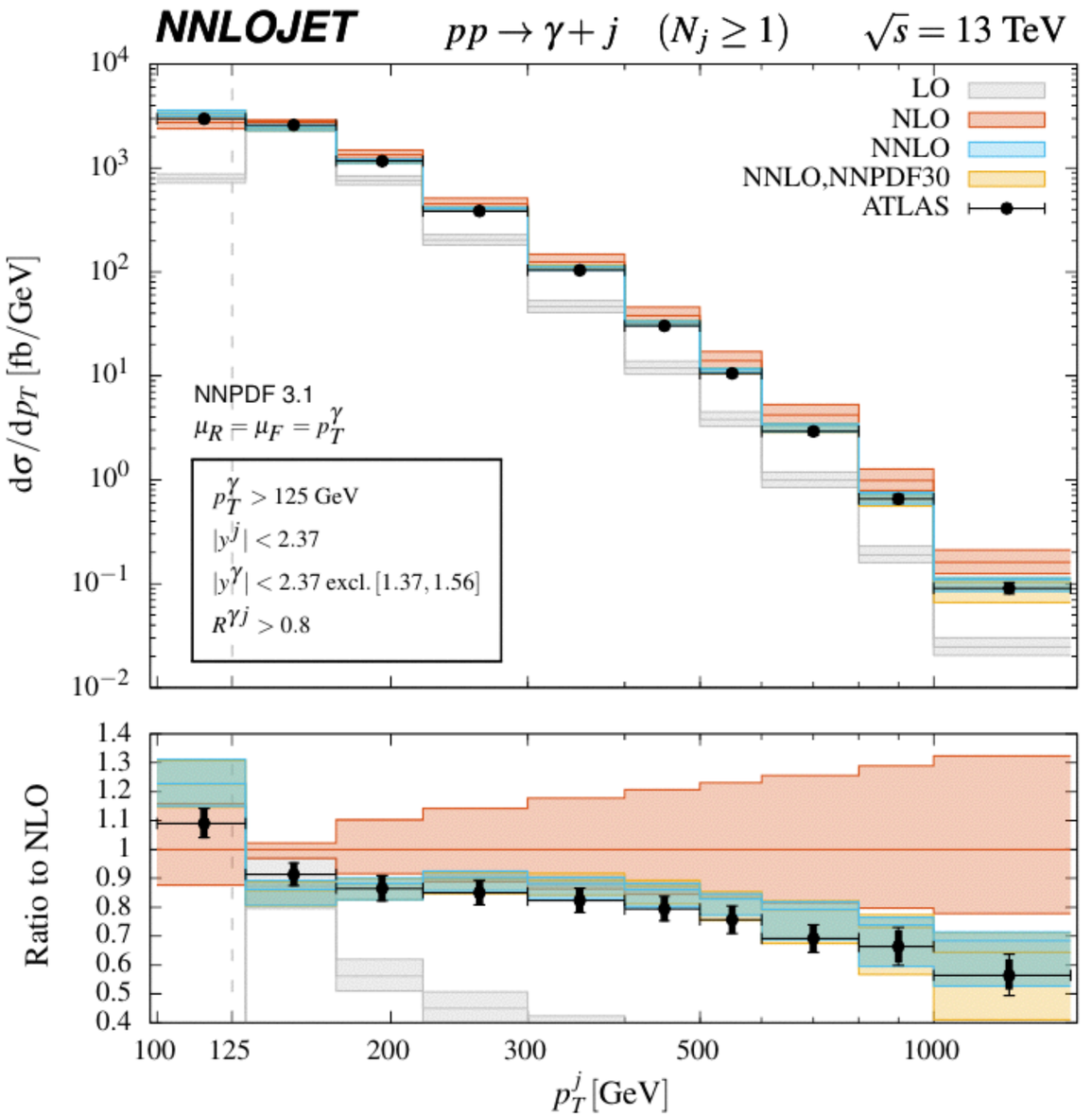
- An impressive array of correlated systematic uncertainties have been studies
- Useful information on how these uncertainties should be included in a fit to these data

Photon production at ATLAS

Ana Cueto on behalf of ATLAS Collaboration

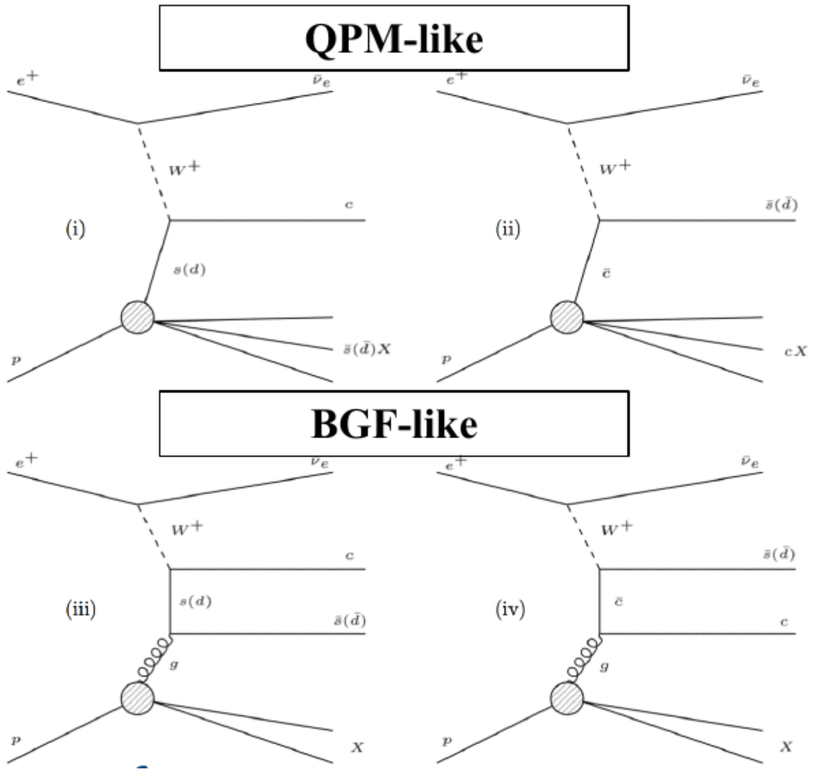
- Cross section and ratios from 8 and 13 TeV
  - Stringent test of QCD, many experimental and theoretical uncertainties will cancel
- Comparisons at NNLO using NNLOJET

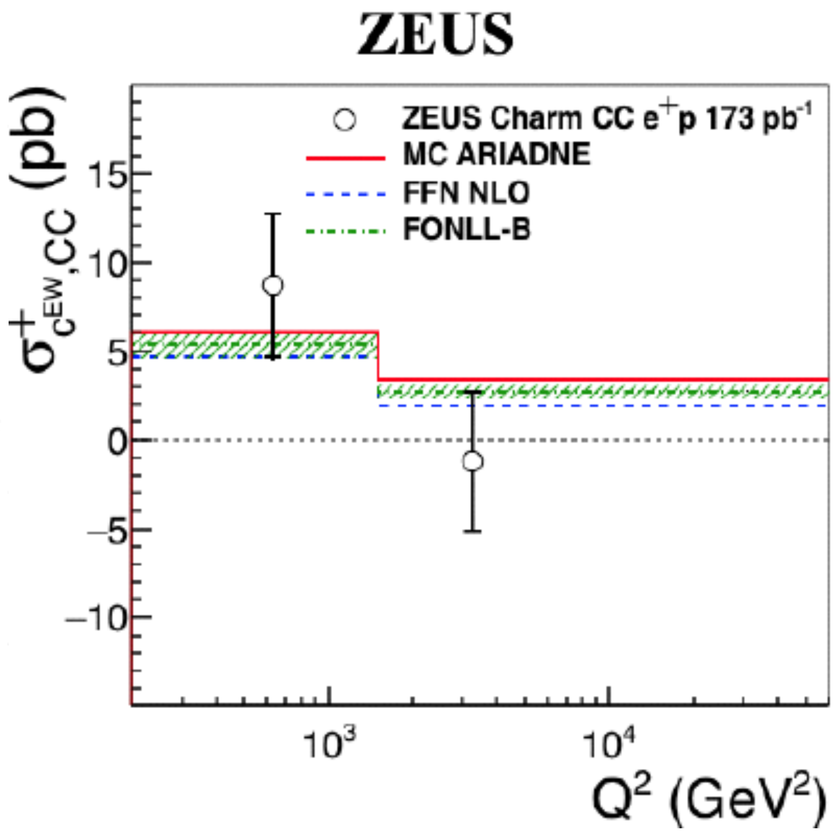


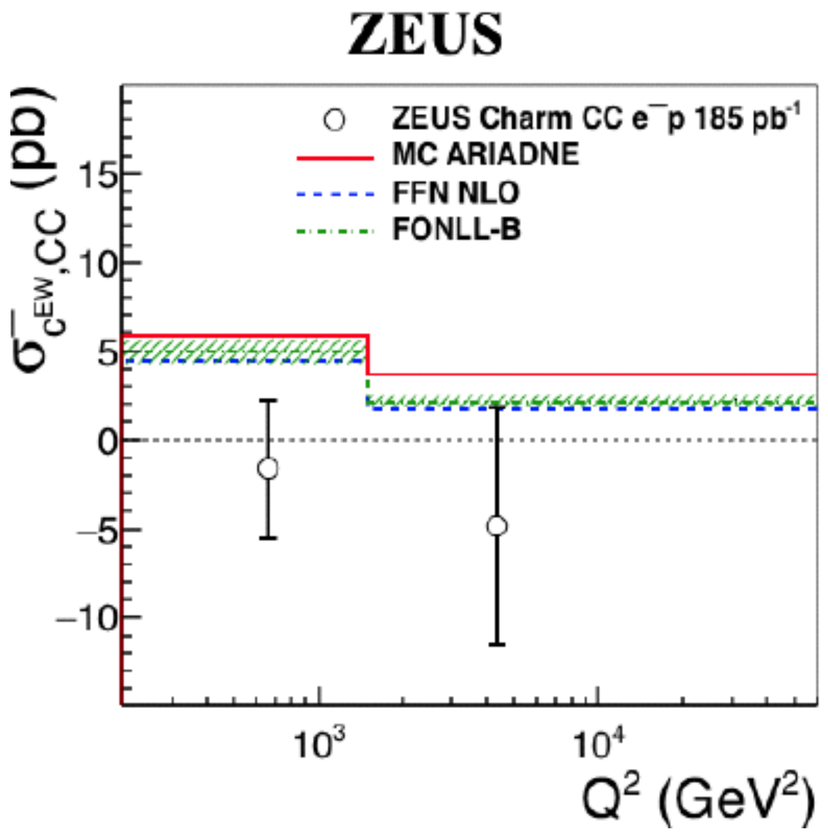


Charm production in CC DIS at HERA

J. Nam on behalf of ZEUS Collaboration







- Charm in DIS directly probes the strange quark density
- ZEUS measurement is limited by statistics
- Much more statistics will be available at EIC, LHeC, EicC
  - Potential of such measurements has been tested

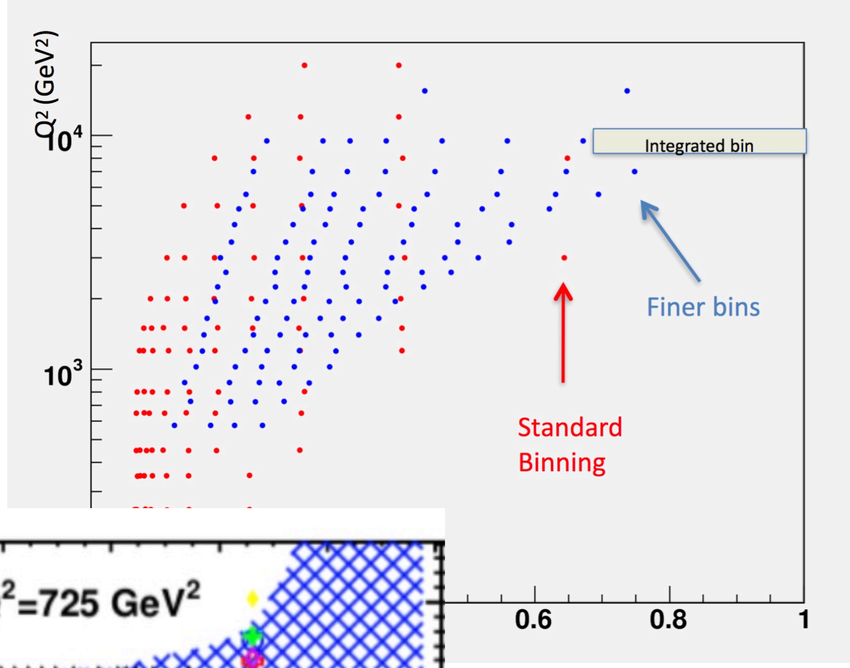
Parton densities at Very High x

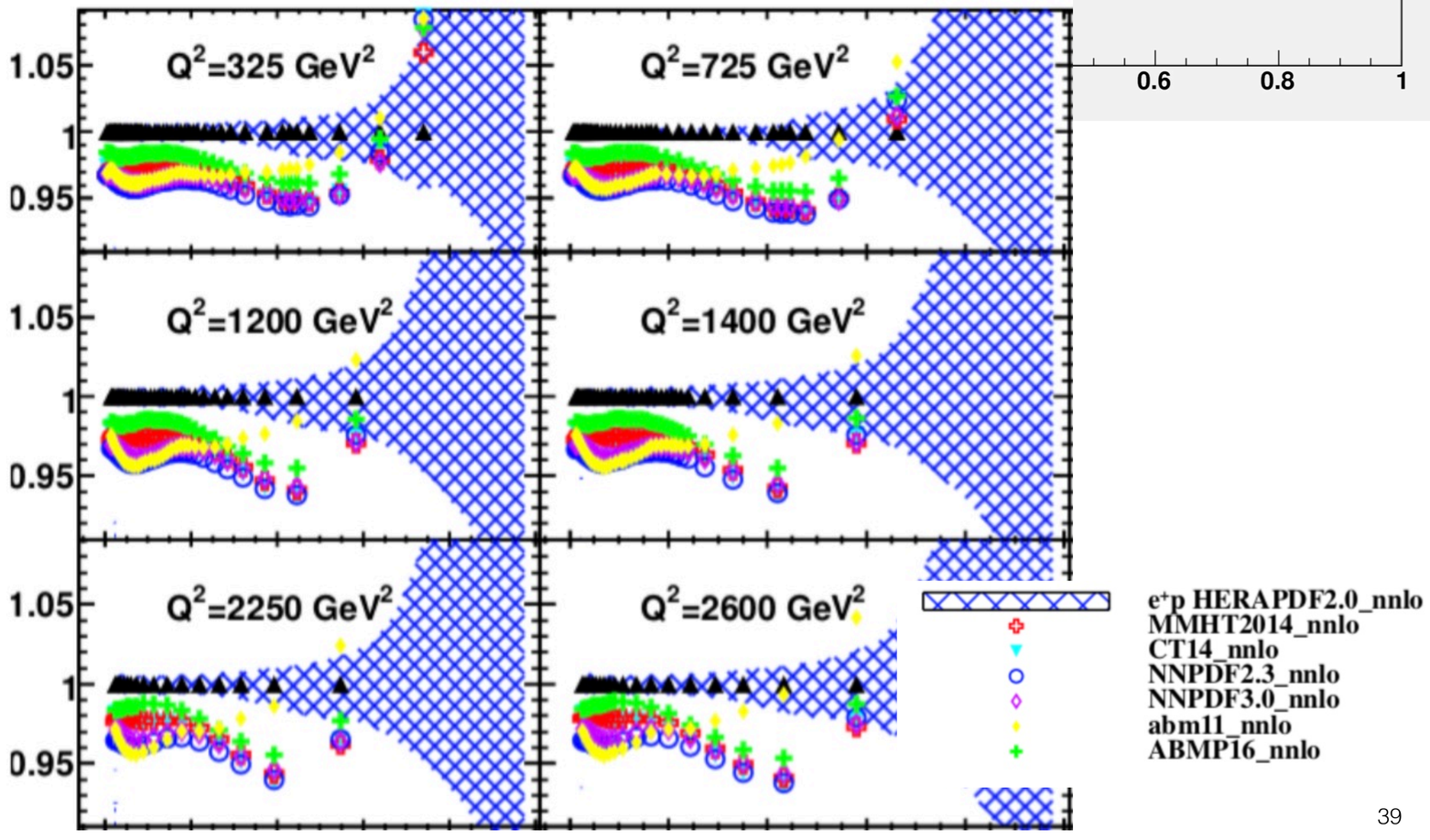
Allen Caldwell on behalf of ZEUS

- Investigations of PDFs at very high x using transfer matrix
- ZEUS high-x (x→1) data unique, but not used in PDF fits
  - Low numbers of events mean error analysis is more complicated but not prohibitively so
  - Overlap with some combined ZEUS+H1 data so need to be be careful about which data to include
  - Effect on PDF uncertainties to be evaluated

	e^-p		e^+p	
PDF	$x < 0.6$	$x \geq 0.6$	$x < 0.6$	$x \geq 0.6$
HERAPDF2.0	0.06	0.2	0.6	0.1
CT14	0.0008	0.2	0.7	0.6
MMHT2014	0.00003	0.1	0.6	0.6
NNPDF2.3	0.00007	0.2	0.6	0.6
NNPDF3.0	0.00003	0.2	0.6	0.6
ABMP16	0.01	0.2	0.8	0.5
ABM11	0.03	0.3	0.7	0.4

p-value for e-p and e+p data sets are shown on comparison to different PDFs for two different x ranges.





in memory of
James Stirling CBE FRS
4 February 1953 – 9 November 2018