Results obtained with XFitter

– Overview

– General/Phenomenological studies

– HERA results

– LHC data

Kristin Lohwasser[1]

[1]University of Sheffield

European Research Council
Established by the European Commission

The University Of Sheffield.

Overview: A huge amount of XFitter publications

> 45 publications in total, 13 since the last workshop in dubna [1]

- 2 analyses by the xFitter team
- 10 by researchers using the xFitter code
- All listed from the website [2]

[1] https://indico.cern.ch/event/458944/contributions/1972225/attachments/1230431/1803354/pirumov_dubna_180216.pdf

[2]https://www.xfitter.org/xFitter/xFitter/results

List of analyses by xFitter

The link to the list of analyses using former HERAFitter can be accessed here

44	01.2017	F. Giuli, xFitter Developers' team and M. Lisovyi	arXiv:1701.08553	The photon PDF from high-mass Drell Yan data at the LHC
43	03.2016	xFitter and APFEL teams and A. Geiser	JHEP 1608 (2016) 050, arXiv:1605.01946	A determination of mc(mc) from HERA data using a matched heavy flavor scheme

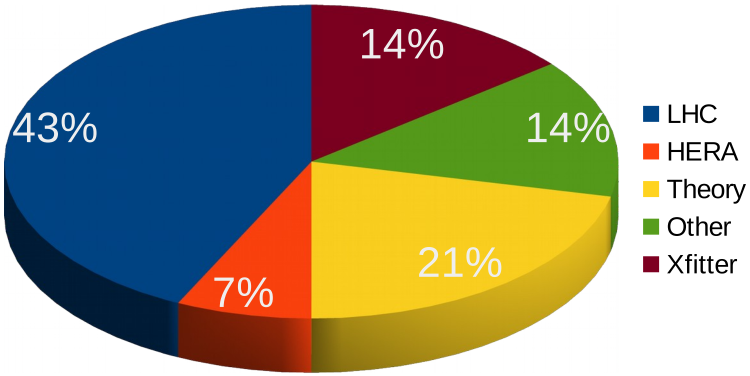
List of analyses using xFitter

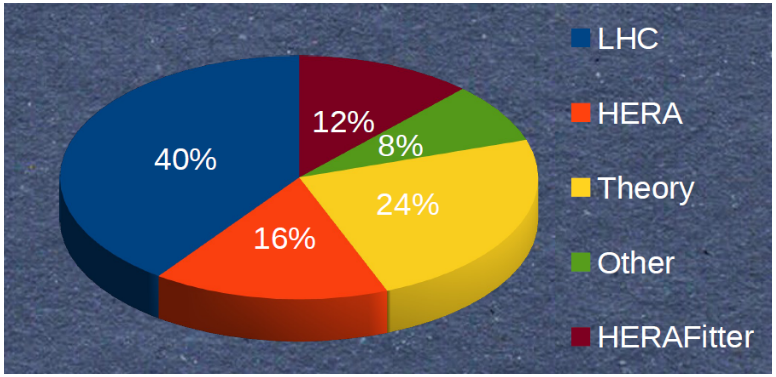
Number	Date	Group	Reference	Title
2016				
42	03.2017	CMS	arXiv:1703.01630, submitted to EPJC (TOP-14-013)	Measurement of double differential cross sections for top quark pair production in pp collisions at 8 TeV and impact on PDFs
41	02.2017	A. Aleedaneshvara, M. Goharipour, S. Rostami	Chin Phys C 41, 2 (2017) 023101	Uncertainty of parton distribution functions due to physical observables in a global analysis
40	01.2017	Y.G. Gbedo, M. Mangin-Brinet	arXiv:1701.07678	Markov Chain Monte Carlo technics applied to PDF determination: proof of concept
39	01.2017	ABMP	arXiv:1701.05838	Parton Distribution Functions, αs and Heavy-Quark Masses for LHC Run II
38	12.2016	ATLAS	arXiv:1612.03636	Measurements of top-quark pair to Z-boson cross-section ratios at s = 13; 8; 7 TeV with the ATLAS detector
37	12.2016	ATLAS	arXiv:1612.03016	Precision measurement and interpretation of inclusive W and Z production with the ATLAS detector
36	12.2016	A. Aleedaneshvara, M. Goharipour, S. Rostami	EPJA (2016) 52: 352	The impact of intrinsic charm on the parton distribution functions
35	11.2016	CMS	CMS PAS SMP-16-011	Measurement of triple-differential dijet cross sections at 8 TeV with the CMS detector and constraints on PDFs
34	11.2016	A. Luszczak and H. Kowalski	arXiv:1611.10100, PRD 95 (2017)014030	Dipole model analysis of highest precision HERA data, including very low Q2's
33	11.2016	PROSA	arXiv:1611.03815	Prompt neutrino fluxes in the atmosphere with PROSA parton distribution functions
32	06.2016	ATLAS	arXiv:1606.01736	Measurement of the double-differential high-mass Drell–Yan cross section in pp collisions at 8 TeV with the ATLAS detector
45:		CMS	arXiv:1609.05331	Double-differential inclusive jet cross-sections at $\sqrt{s}$ = 8 TeV and ratios to 2.76 and 7 TeV

Looking into the details

> Nothing changed to much from Dubna review

- LHC is still the biggest client so far





> 2017: Oxford

> 2016: Dubna

- 2 Xfitter team publications in 2016/2017
- In addition to the papers: 16 conference talks in 2016

What is Xfitter used for?

> **Now this is perhaps the actual key question to ask when thinking about**

- How to develop the package as is now (→ Voica's overview talk)
- For the future (→ Sasha's talk on plans)

LHC: 6 papers	Using mainly full fit, profiling or reweighting to investigate **sensitivity of new measurement**
HERA: 1 papers	More detailed analysis complementary to the main HERA results: **beyond the standard approach / data**
Theory: 3 papers	**Specialized analysis / interpretations**, possibly with additions to the code, but without feedback to main code or **basic methodology / proof-of-principle development**
Other: 2 papers	Very basic Xfitter usage (e.g. plotting) – feedback unclear
Xfitter: 2 papers	Usually a **project with larger developments** within Xfitter needed – extending the scope and the possibilities

- **Wide and exciting range of use cases !!!**

LHC results: W/Z bosons, tops and jets

arXiv:1612.03016

> **High precision differential measurements of W and Z bosons**

- W^+/W^- : $|\eta|$ (ℓ) < 2.5
- Z/γ^* : $|y|$ ($\ell\ell$) < 3.6 for 3 mass ranges 46 < $m_{\ell\ell}$ < 150 GeV

> **Full fletched PDF fit on top of Hera Dat (similar to 2010 "strange sea fit")**

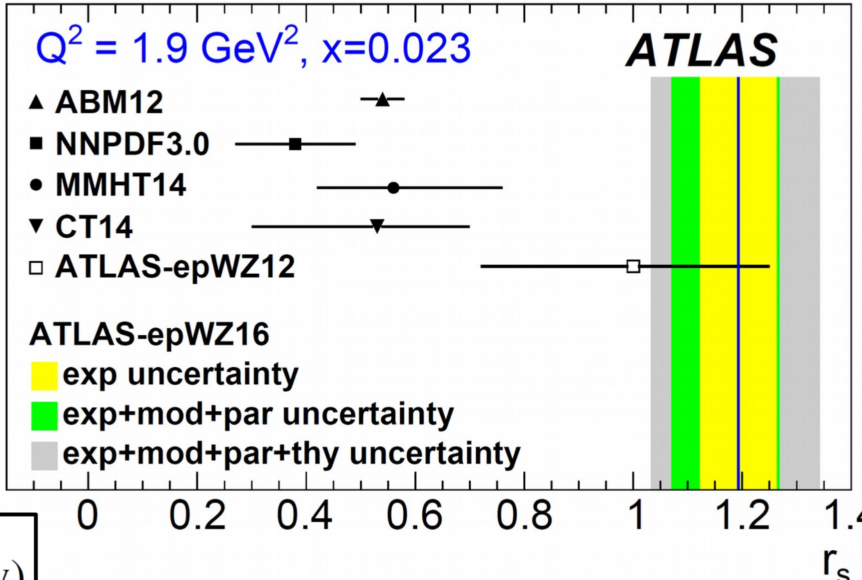
- NNLO QCD + NLO EW fit using k-factors (~1-2%, 5% for $m_{\ell\ell}$)
- 15 free parameters
- VFNS, m_c=1.43 GeV, m_b=4.5 GeV
- Q_0^2 = 1.9 GeV^2
- α_S = 0.118 GeV

$$
\begin{aligned}
xu_v(x) &= A_{u_v} x^{B_{u_v}} (1-x)^{C_{u_v}} (1 + E_{u_v} x^2), \\
xd_v(x) &= A_{d_v} x^{B_{d_v}} (1-x)^{C_{d_v}}, \\
x\bar{u}(x) &= A_{\bar{u}} x^{B_{\bar{u}}} (1-x)^{C_{\bar{u}}}, \\
x\bar{d}(x) &= A_{\bar{d}} x^{B_{\bar{d}}} (1-x)^{C_{\bar{d}}}, \\
xg(x) &= A_g x^{B_g} (1-x)^{C_g} - A'_g x^{B'_g} (1-x)^{C'_g} \\
x\bar{s}(x) &= A_{\bar{s}} x^{B_{\bar{s}}} (1-x)^{C_{\bar{s}}}
\end{aligned}
$$

Data set	ATLAS-epWZ16 χ^2/n.d.f.
ATLAS $W^+ \to \ell^+\nu$	8.4 / 11
ATLAS $W^- \to \ell^-\bar{\nu}$	12.3 / 11
ATLAS $Z/\gamma^* \to \ell\ell$ ($m_{\ell\ell}$ = 46–66GeV)	25.9 / 6
ATLAS $Z/\gamma^* \to \ell\ell$ ($m_{\ell\ell}$ = 66–116GeV)	15.8 / 12
ATLAS forward $Z/\gamma^* \to \ell\ell$ ($m_{\ell\ell}$ = 66–116GeV)	7.4 / 9
ATLAS $Z/\gamma^* \to \ell\ell$ ($m_{\ell\ell}$ = 116–150GeV)	7.1 / 6
ATLAS forward $Z/\gamma^* \to \ell\ell$ ($m_{\ell\ell}$ = 116–150GeV)	4.0 / 6
ATLAS Correlated + Log penalty	27.2
ATLAS Total	108 / 61
HERA I+II CC e^+p	44.3 / 39
HERA I+II CC e^-p	62.7 / 42
HERA I+II NC e^-p	222 / 159
HERA I+II NC e^+p	838 / 816
HERA Correlated + Log penalty	45.5
HERA Total	1213 / 1056
Total	1321 / 1102

LHC results: Strange quarks

- **Result consistent with 2010 W/Z data QCD analysis – yielding ATLAS-epWZ15**
  - Strange sea even more enhanced than before
  - Multiple checks done yielding still an enhance strange – with no difference to r_s
    - Removing constrain $\bar{u} = \bar{d} \rightarrow 0$
    - Adding E866 data (that predicts positive $x\bar{d} - x\bar{u}$ ~0.04)
    - Separate analyses of electron and muon data, discarding of low mass Z
  - Forcing suppressed strange yields significant worse fit
- **Consistent and robust results with independent ATLAS data**



arXiv:1612.03016

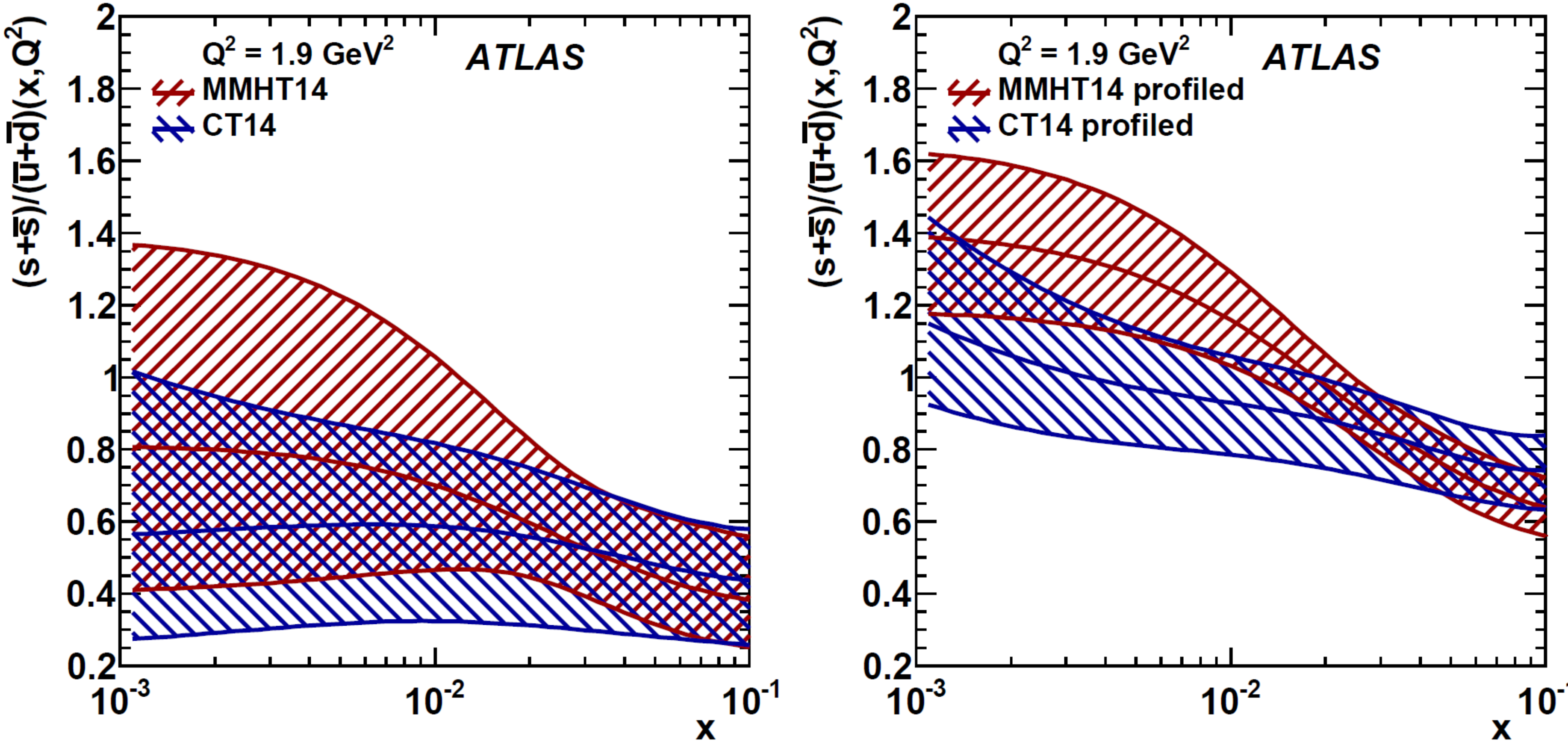
$$r_s = \frac{s+\bar{s}}{2\bar{d}} = 1.19 \pm 0.07\,(\text{exp})\,^{+0.13}_{-0.14}\,(\text{mod}+\text{par}+\text{thy})$$

Further strange sea investigations

arXiv:1612.03016

> **Profiling used to investigate impact on other PDF sets**

- **It's in the data!**

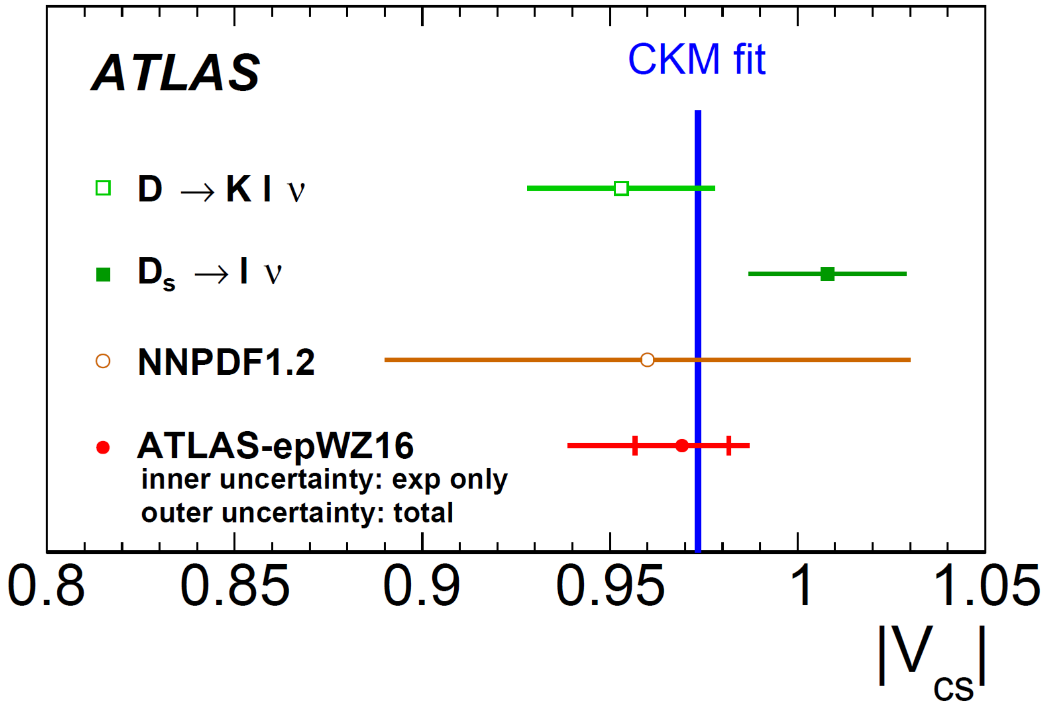


W/Z bosons and electroweak parameters

arXiv:1612.03016

> Xfitter allows to leave also other parameters free

- Determination of $|V_{cs}|$ matrix element competitive to other measurements

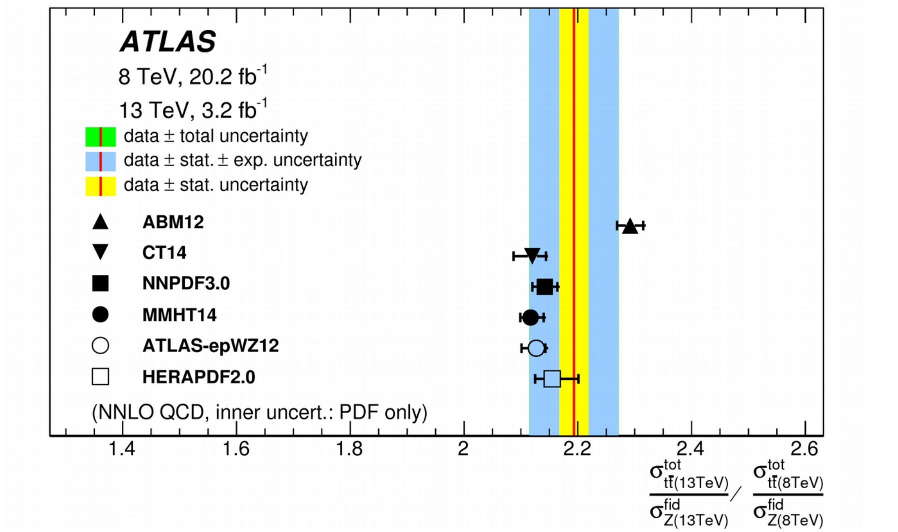


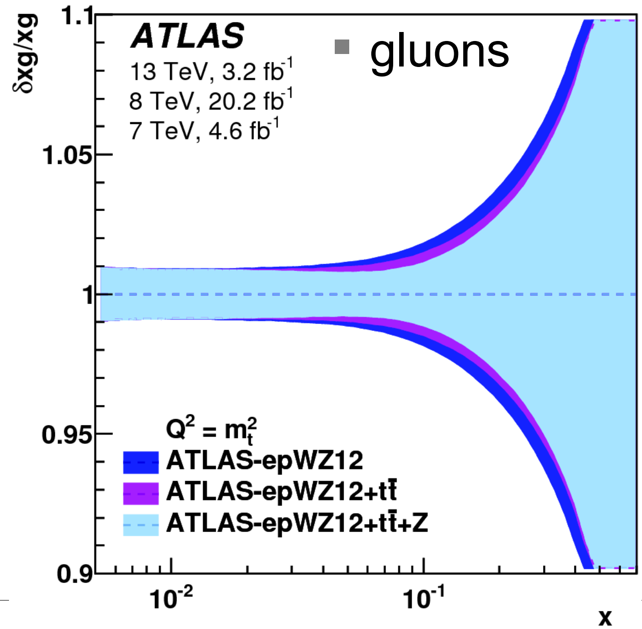
$$|V_{cs}| = 0.969 \pm 0.013\,(\text{exp})\ ^{+0.006}_{-0.003}\,(\text{mod})\ ^{+0.003}_{-0.027}\,(\text{par})\ ^{+0.011}_{-0.005}\,(\text{thy})$$

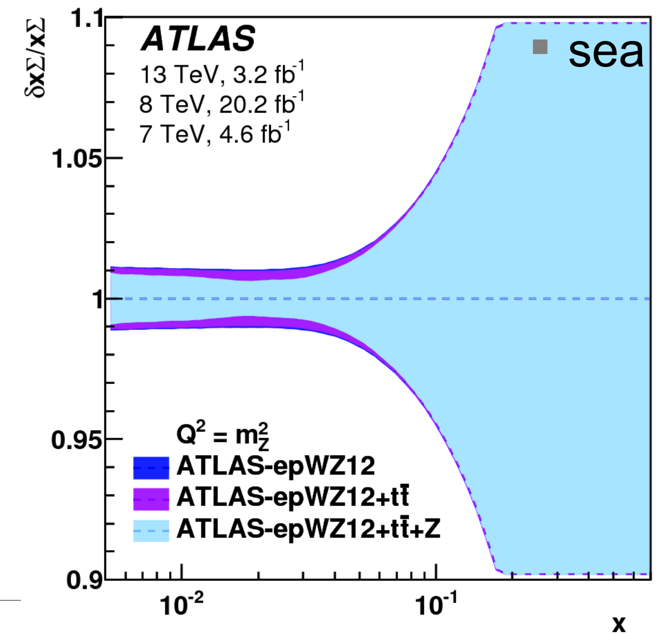
Z/top double ratios: Reducing luminosity uncertainty

> Measurements of fiducial cross sections of Z boson and top quarks

- Correlated over 7,8,13 TeV
- Profiling indicates some gain with respect to ATLAS-epWZ12
- **Gluons and Sea quarks** particularly sensitive







arXiv:1612.03636

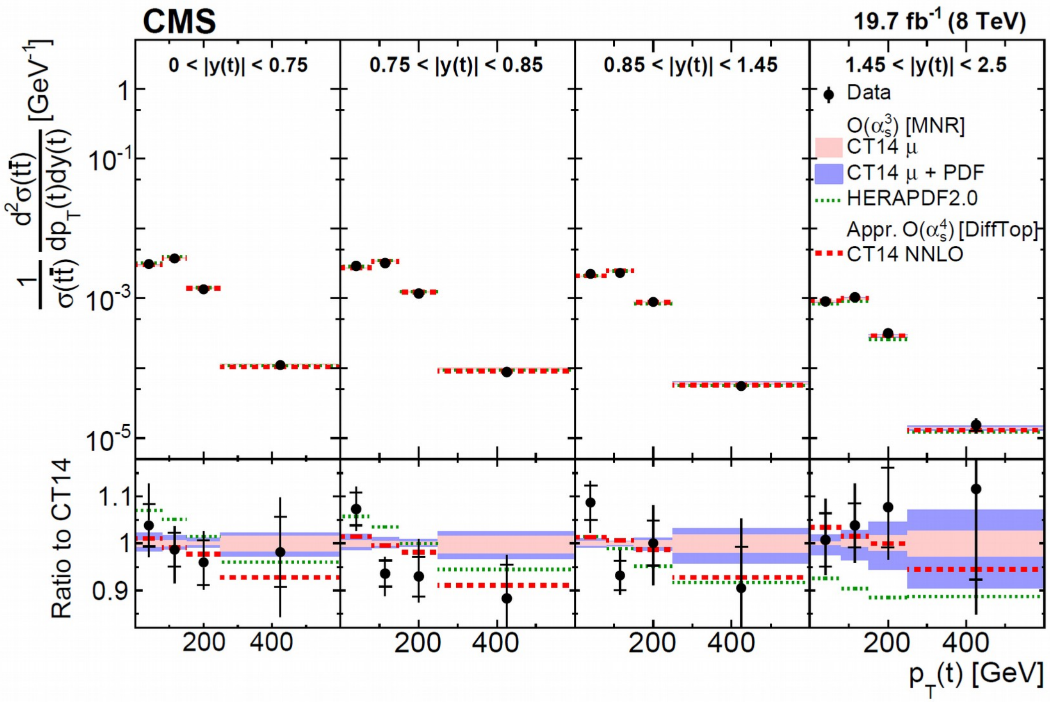
LHC results: Double-differential $t\bar{t}$ measurements

arXiv:1703.01630

> Double-differential top production cross-sections at CMS

$\sqrt{s}$ = 8 TeV, L=19.7 fb^{-1}, eμ channel, any of the following variables are measured differentially in bins of invariant mass of the top system $M(t\bar{t})$

- Transverse momentum top quark pT(t)
- Rapidity of top quark y(t)
- Transverse momentum of top quark pair system $pT(t\bar{t})$
- Rapidity of top quark pair system $pT(t\bar{t})$
- Pseudo-Rapidity between top and anti-top quark $\Delta\eta(t\bar{t})$
- Angle between top and anti-top quark in transverse plane $\Delta\varphi(t\bar{t})$



> Compared to NLO predictions

- MCFM
- Approximate NNLO for pT / y (t) using DiffTop

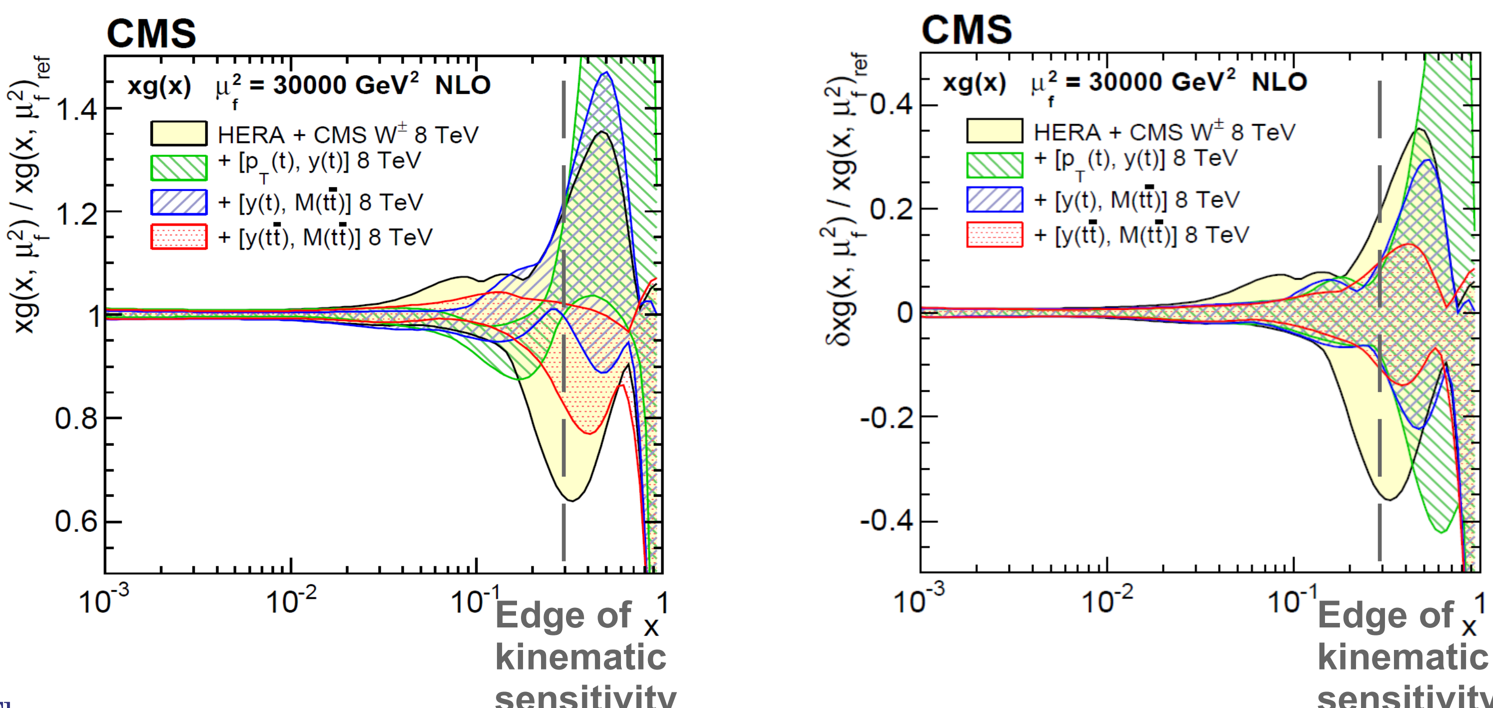
The University Of Sheffield.

LHC results: Top results constraining the gluon

arXiv:1703.01630

> NLO PDF fit carried out including HERA and CMS W asymmetry with top added

- Expected sensitivity $0.01 < x < 0.25$
- 18 parameter fit after optimization
- TR-VFNS used with 5 flavours, m_c=1.47 GeV, m_b = 4.5 GeV
- Angle between top and anti-top quark in transverse plane $\Delta\varphi(t\bar{t})$
- Fixed strange of f_s = 0.4 (r_s = 0.66) consistent with CMS W+c measurement



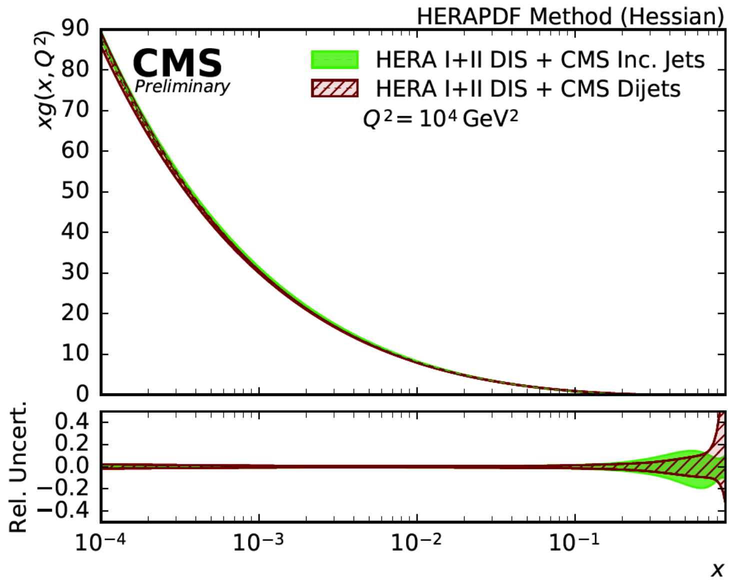
LHC results: Results on Jet data

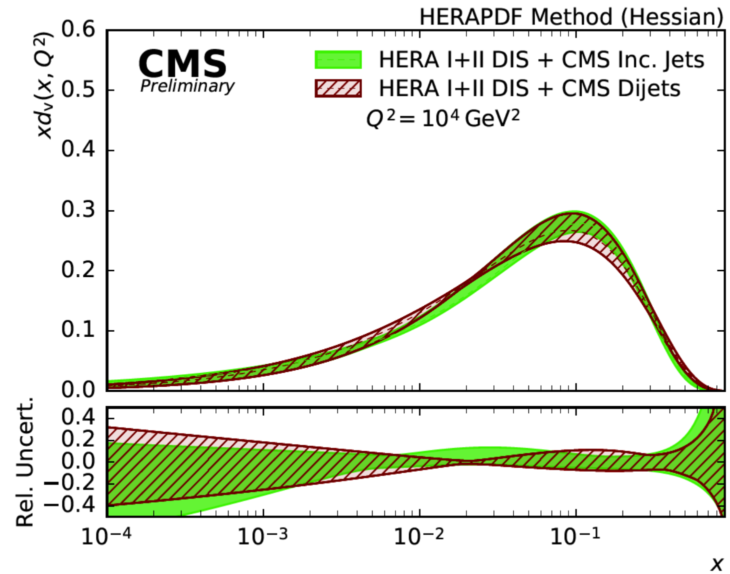
11:40 **xFitter performance: CMS report and wishes**
Speakers: Oleksandr Zenaiev (DESY), Oleksandr Zenaiev

After coffee break!!

> More on the gluon: two results on jet production from CMS

- Double-differential inclusive jet cross-sections at $\sqrt{s}$ = 8 TeV and ratios to 2.76 and 7 TeV [arXiv:1609.05331]
- Triple-differential dijet cross-sections at $\sqrt{s}$ = 8 TeV [CMS-PAS-SMP-16-011]
- Both yield constraints on gluon distributions at medium-x (with some increase at high-*x*), dijets with larger sensitivity to light quark and impact on valence quarks

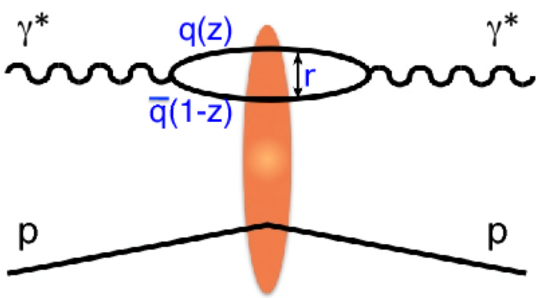




HERA results

16:50 Dipole Models in xFitter
Speaker: Agnieszka Luszczak
- Tuesday

> Investigation of the low-x part of the HERA data and its description



- Dipole models developed for the low-x regime (x<0.01)
- Describe inclusive and diffractive simultaneously: Photon modeled as fluctuating into $q\bar{q}$ (or $q\bar{q}g$…) system *before* interacting with the proton
- **Final precision HERA data allows to probe models much more deeply than ever before**

- Investigation of the BGK (Golec-Biernat, Kowalski) that combines dipole model with the DGLAP evolution for the gluon density

> Key questions:

- Is the gluon best described as **soft or are there also hard components?**
- Is there any sign of **saturation of the gluon density?**

arXiv:1611.10100

HERA results

16:50 Dipole Models in xFitter
Speaker: Agnieszka Luszczak
▪ Tuesday

> Two-staged analysis approach

- **Fit of the high-Q^2 regime: 3.5 – O(250) GeV^2**

  → Test of the validity of the dipole model in the regime still well described by DGLAP evolution

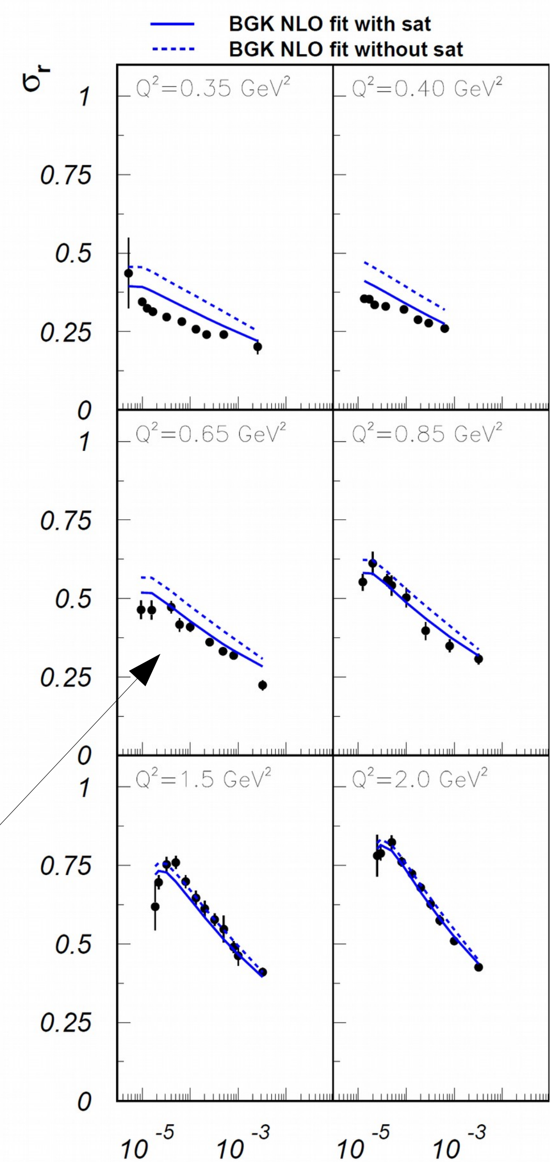
  → Test soft and hard gluon models

  → Test impact of valence quarks on the fits (previous data not sensitive enough)

- **Extend the fit to lower Q^2: 0.35 - 3.5 GeV^2**

  → Test whether dipole models can extend the perturbative regime also when confronted with much more precise data

  → Are there signs of saturation? **Yes!**



arXiv:1611.10100 **For more results → see Agnieszka's talk!!**

The University Of Sheffield.

Theory results: Intrinsic charm strikes back

> First proposed by Brodsky et el. (BHPS model) – but so far unclear evidence

- “extrinsic” charm generated by gluon splitting **(particularly at low-*x*)**
- Intrinsic charm however described as non-perturbative fluctuations of the proton into a |uudqq> Fock state → these other kind of sea quarks exist independent of the time or the momentum with which the proton is probed **(it’s a high-*x* thing!)**
- A new investigation with old data:
  Inclusion of EMC data in a global Xfitter analysis
- European Muon Collaboration (EMC) measured charm production in muon deep inelastic scattering using various target (1980’s)

  → data are however rarely used in global fits: issues with DIS structure function

  → large inconsistencies with other data sets confirmed by different global fitter groups

A. Aleedaneshvara, M. Goharipour, S. Rostami
EPJA (2016) 52: 352
The impact of intrinsic charm on the parton distri bution functions

Intrinsic charm: Setup of the global fit

> Strategy of the fit: Include as many data as possible using Xfitter

- Fairly standard setup: HERAPDF parametrization at a starting scale Q^2_0 =1 GeV^2
- Using parameter optimization and constraints from sum rules as well as:

$x\bar{s} = f_s x\bar{D}$ with f_s=0.31
$x\bar{u} \sim x\bar{d} \rightarrow 0$

$\rightarrow$ 14 free parameters

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

- Fixing α_s = 0.118, using aMCfast, Applgrid, MadGraph and MCFM for predictions
- Kinematic cuts on data: Q^2>4 GeV^2, W^2 > 15 GeV^2 (for xF_3, W^2 > 15 GeV^2)
- Thorne-Roberts general-mass variable-number scheme for heavy quarks

- Sum of perturbative and non-perturbative F_2^c contributions fitted:

$$F^c_{2,tot}(x,Q^2,m_c^2) = F_2^c(x,Q^2,m_c^2) + F^c_{2,IC}(x,Q^2,m_c^2).$$

EPJA (2016) 52: 352

- With instrinsic charm PDF

$$c(x) = 6x^2\left[(1-x)\left(1+10x+x^2\right) + 6x(1+x)\ln(x)\right],$$

Dataset	No EMC	+EMC	+EMC+IC
HERA1+2 NCep 820 [5]	78/68	85/68	80/68
HERA1+2 NCep 920 [5]	470/363	517/363	481/363
HERA1+2 NCep 460 [5]	214/200	214/200	214/200
HERA1+2 NCep 575 [5]	220/249	215/249	219/249
HERA1+2 CCep [5]	41/39	42/39	43/39
HERA1+2 CCem [5]	66/42	68/42	65/42
HERA1+2 NCem [5]	233/159	229/159	232/159
HERA ep F_2^c [41]	40/47	45/47	43/47
H1 99-00 ep incl. jets [55]	12/24	13/24	12/24
ZEUS incl. jets [56, 57]	53/60	61/60	53/60
BCDMS F_2 [58]	308/328	326/328	311/328
NMC F_2^d/F_2^p [59]	99/79	81/79	86/79
CCFR xF_3 [60]	85/78	82/78	87/78
SLAC F_2 [39]	147/59	104/59	141/59
EMC F_2^c [22]	–	190/16	200/16
DØ Z rap. [61]	22/28	22/28	22/28
DØ W asym. [62]	44/14	39/14	51/14
CDF Z rap. [63]	29/28	30/28	30/28
CDF W asymm. [64]	38/13	29/13	39/13
ATLAS jets [65, 66]	41/90	42/90	41/90
ATLAS W^+, W^-, Z [67]	29/30	32/30	31/30
CMS electron asymm. [68]	8/11	9/11	8/11
CMS boson rap. [69]	58/35	61/35	60/35
CMS W muon asymm. [70]	20/11	36/11	25/11
TOTAL χ^2/dof	1.25	1.37	1.35

Intrinsic charm: Fit results

Inclusion of a huge number of data set

Comparison of three fit settings

- Nominal global data
- + EMC data
- + EMC data + intrisic charm (IC)

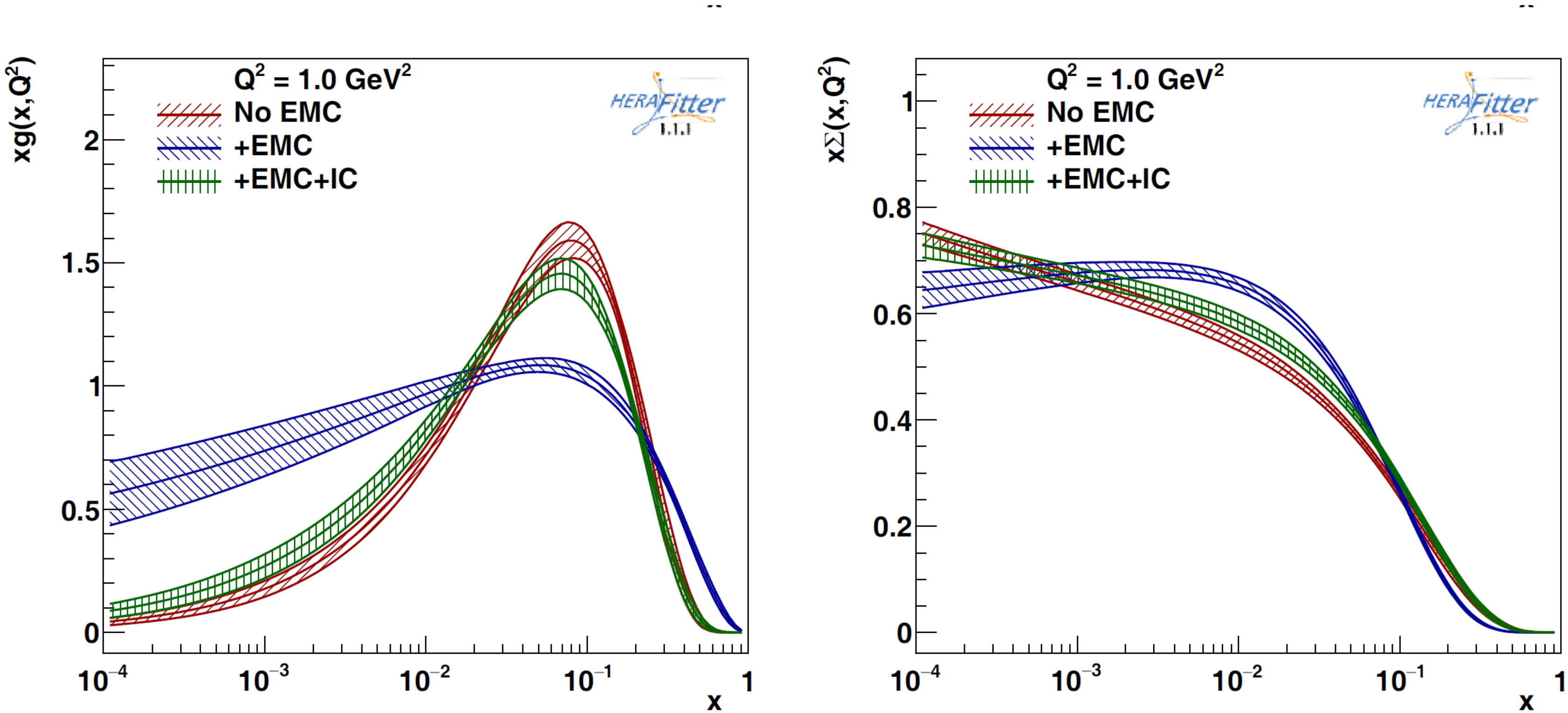
Striking findings

- Increase in χ^2 for HERA and BCDMS data sets mitigated if IC is allowed when including EMC data
- Decrease in SLAC data χ^2 when including EMC data → good competability / SLAC data sensitive to intrinsic charm

EPJA (2016) 52: 352

Intrinsic charm: The gluon and sea quark distributions

> **EMC data has pronounced affect on actual gluon and sea distributions**



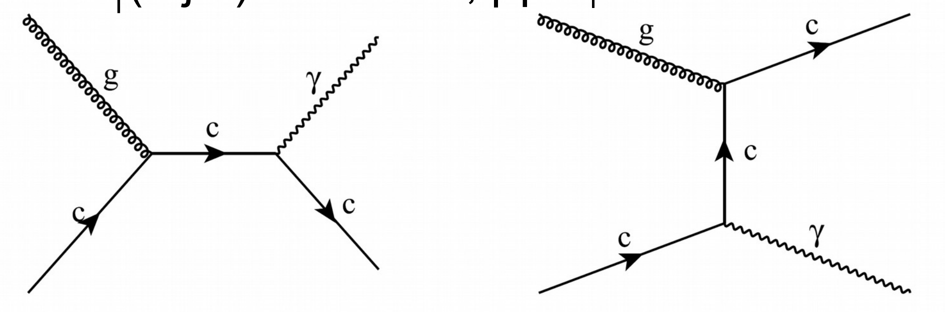
- This is not unexpected: momentum sum rules lead to an increase of gluon at high-*x* if it is decreased as *x* ~ 0.05 and the sea (charm) quark are very correlated with gluons. Intrinsic charm adds towards the high-*x* quarks (or gluons) and allows them to keep their value at *x* ~ 0.05

EPJA (2016) 52: 352

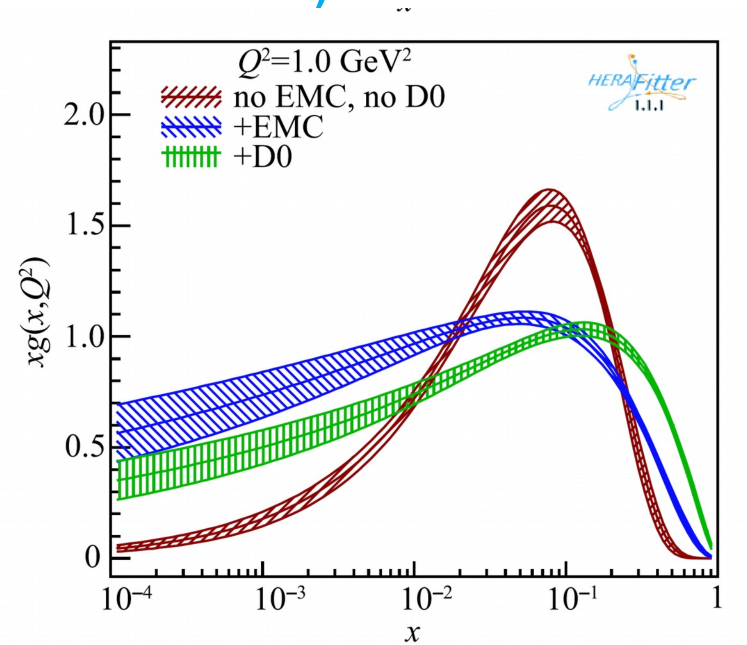
Follow-up on intrinsic charm with new data

> New Tevatron data on γ+c-jet production (D0 collaboration)

- $30 < P_T^\gamma < 300$ GeV, $|\eta^\gamma| < 1.0$
- P_T(c-jet) > 15 GeV, $|\eta^{c\text{-jet}}| < 1.5$



- Same fitting setup as before – studying impa
of D0 data vs. impact of EMS data



BCDMS F_2[37]	308/328	326/328	330/328
NMC F_2^d/F_2^p [40]	99/79	81/79	90/79
CCFR xF_3 [38]	85/78	82/78	81/78
SLAC F_2 [39]	147/59	104/59	90/59
EMC F_2^c [21]	-	186/16	-
DØ γ+c-jet [18]	-	-	217/9
DØ Z rap.[45]	22/28	22/28	22/28
total χ^2/ dof	1.25	1.37	1.43

- D0 data increases χ^2 as EMC
- SLAC data consistent with both
- No fit of intrinsic charm tested (but should be similar)

A. Aleedaneshvara, M. Goharipour, S. Rostami
Chin Phys C 41, 2 (2017) 023101
Uncertainty of parton distribution functions due to physical observables in a global analysis

Theory: Methodology – Markov Chains

arXiv:1701.07678

> Drawback of the conventional Hessian method of PDF fitting

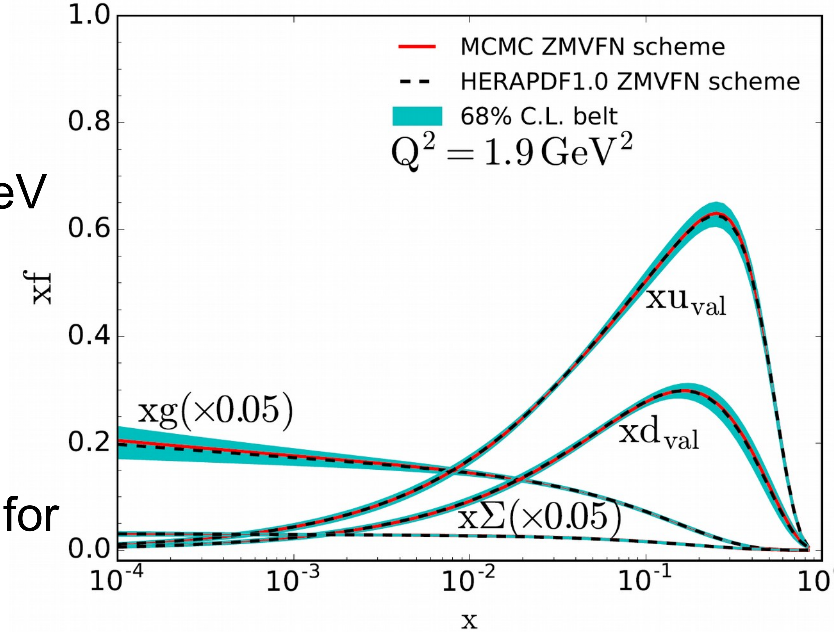
- Assumption of what is an "acceptable" χ^2: Choice of tolerance parameter

> Application of Markov Chain Monte Carlo (MCMC) techniques

- Use an alternative way to determine uncertainties using robust statistical tools
- Mean value and uncertainty are a by-product of the PDF determination
- Confidence intervals can be extracted in controlled way

> Proof-of-principle

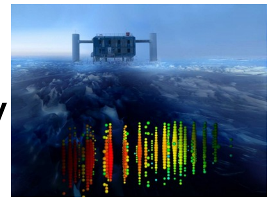
- Using a 10-parameter PDF fit,
  4 HERA-1 default data sets and Q^2>10 GeV
- Results of MCMC scheme and standard determination very close
  $\rightarrow$ **MCMC PDFs are possible**
- For a few parameters: Probability function for parameters is not Gaussian… (indeed proves points why alternative methods are interesting)



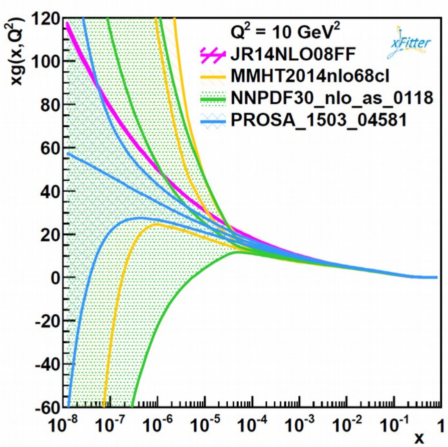
Others: Neutrino flux and PDF review

arXiv:1611.03815

> Flux of neutrinos stemming from atmospheric interactions



- Collisions: E_{lab}~13.8 TeV → close to LHC
- Flux estimated based on calculations interfaced with PROSA PDF
- Important as backgrounds for neutrino telescopes
- PDF uncertainty smaller than scale (+42%, -13.5% vs. +52%, -13.5%) .

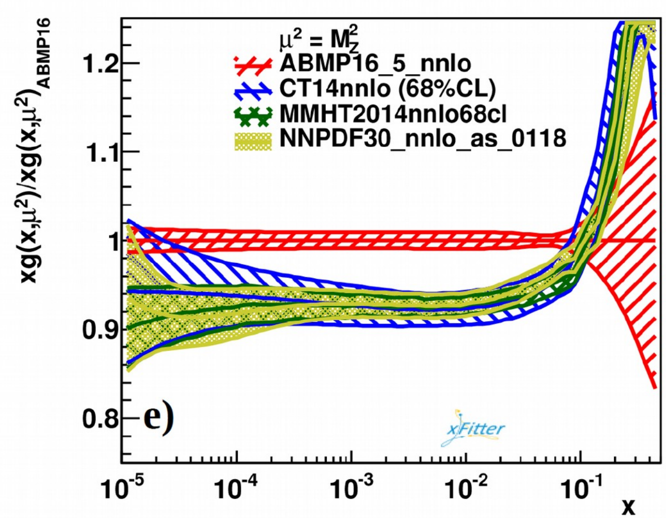


- Xfitter used to compare gluon densities at low-*x* to other PDF sets

arXiv:1701.05838

> ABMP16 PDF Fit: Parton distribution functions, α_s and heavy quark masses

- New PDF determination using new combined HERA data, NOMAD and CHORUS, DY and top from Tevatron and LHC
- Xfitter used for comparison plots of the new sets with other PDFs

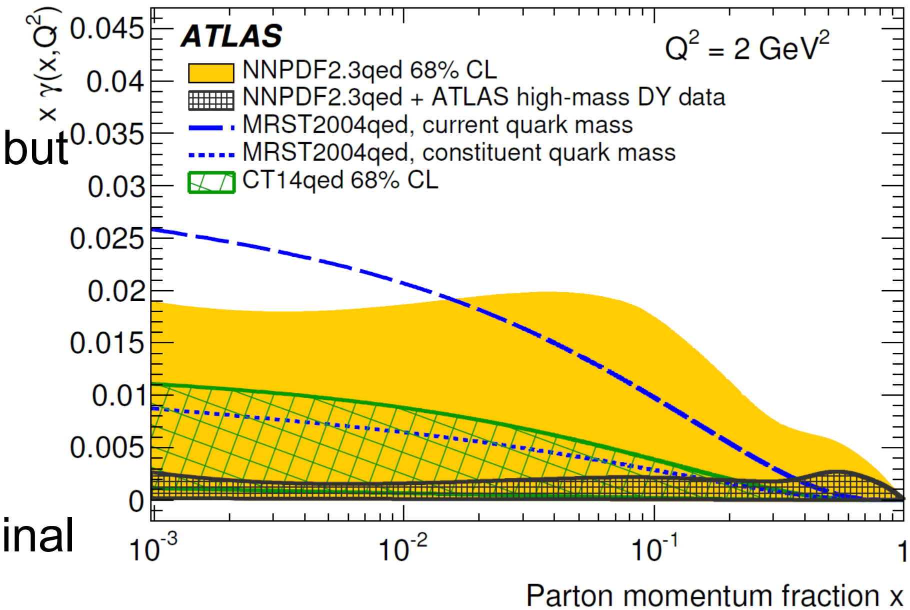


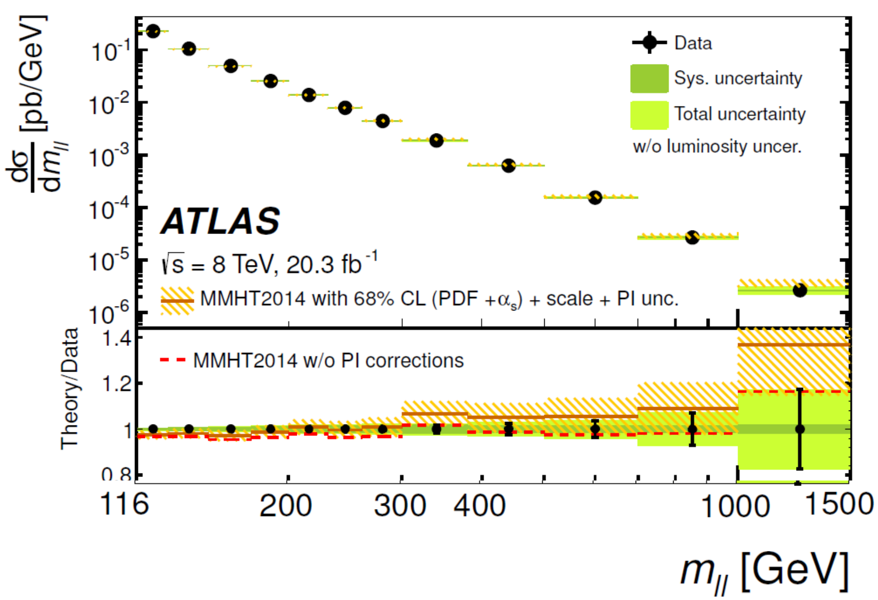
XFitter results: HMDY

16:30 **The photon PDF from high-mass Drell Yan data at the LHC** ▪ Tuesday
Speaker: Mr. Francesco Giuli (University of Oxford (GB))

> High Mass Drell Yan (HMDY) production

- HMDY produced via quark and gluons, but for high masses photon-induced production reaches up to 15%
- Measurement errors as low as 1% (~lower masses)
- Sensitivity to photon PDF shown in original ATLAS paper using Xfitter Reweighting





> Full fit carried you by Xfitter team

- Connected with further technical developments: NLO QCD+QED corrections in APFEL
- Francesco will present details on the fit on Tuesday

arXiv:1606.01736
arXiv:1701.08553

Xfitter: Determination of charm mass

arXiv:1605.01946

> **First usage of Hera1+2 H1 and Zeus inclusive DIS and charm data for extraction of charm mass**

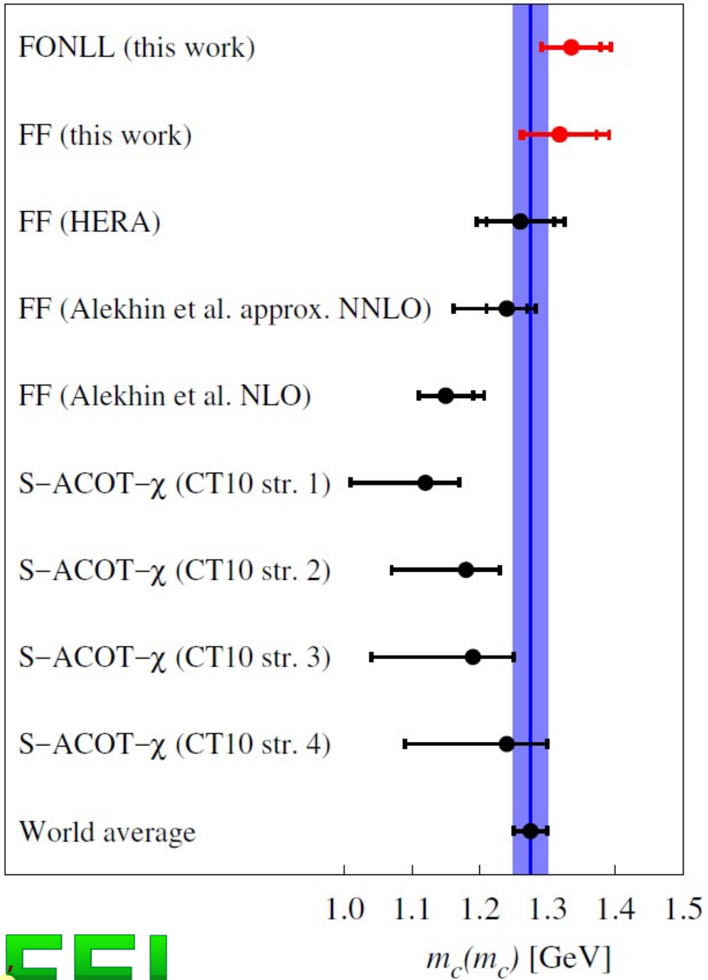
- Determination based on FONLL general-mass variable-flavour-number scheme

  → required generalization of the FONLL structure functions in terms of $\overline{\text{MS}}$ heavy quark mass

- implemented in the general APFEL code and described in the paper

- Alternatively determination using fixed-flavour number scheme (FFN)

- Good agreement with other results



Xfitter: Determination of charm mass

arXiv:1605.01946

> Excellent agreement between the two schemes

scheme	$m_c(m_c)$ [GeV]
FONLL (this work)	$1.335 \pm 0.043(\text{exp})^{+0.019}_{-0.000}(\text{param})^{+0.011}_{-0.008}(\text{mod})^{+0.033}_{-0.008}(\text{th})$
FFN (this work)	$1.318 \pm 0.054(\text{exp})^{+0.011}_{-0.010}(\text{param})^{+0.015}_{-0.019}(\text{mod})^{+0.045}_{-0.004}(\text{th})$
FFN (HERA) [9]	$1.26 \pm 0.05(\text{exp}) \pm 0.03(\text{mod}) \pm 0.02(\text{param}) \pm 0.02(\alpha_s)$
FFN (Alekhin *et al.*) [24]	$1.24 \pm 0.03(\text{exp})^{+0.03}_{-0.02}(\text{scale})^{+0.00}_{-0.07}(\text{th})$ (approx. NNLO)
	$1.15 \pm 0.04(\text{exp})^{+0.04}_{-0.00}(\text{scale})$ (NLO)
S-ACOT-χ (CT10) [29]	$1.12^{+0.05}_{-0.11}$ (strategy 1)
	$1.18^{+0.05}_{-0.11}$ (strategy 2)
	$1.19^{+0.06}_{-0.15}$ (strategy 3)
	$1.24^{+0.06}_{-0.15}$ (strategy 4)
World average [53]	1.275 ± 0.025

- Generally higher values seem to stem from final HERA 1+2 combined inclusive data set

  → **Investigation within a global fit including more charm sensitive data sets would be a very interesting endeavour!**

The University Of Sheffield.

Conclusions

> **Bunch of exciting and diverse results obtained using Xfitter**

- Fits to vector bosons, top, jets
- Determination of charm mass
- Investigation of intrinsic charm
- Investigation of low-x dipole model
- Development of models complementory to χ^2 approach
- Extraction of Photon PDF

> **Xfitter project is going ahead with full steam**

- Providing a useful tool kit and basis for explorations to the HEP community
- Developments from the team further extend the scope and the abilities of Xfitter

Thanks to the team!!