MSHT20: Updates

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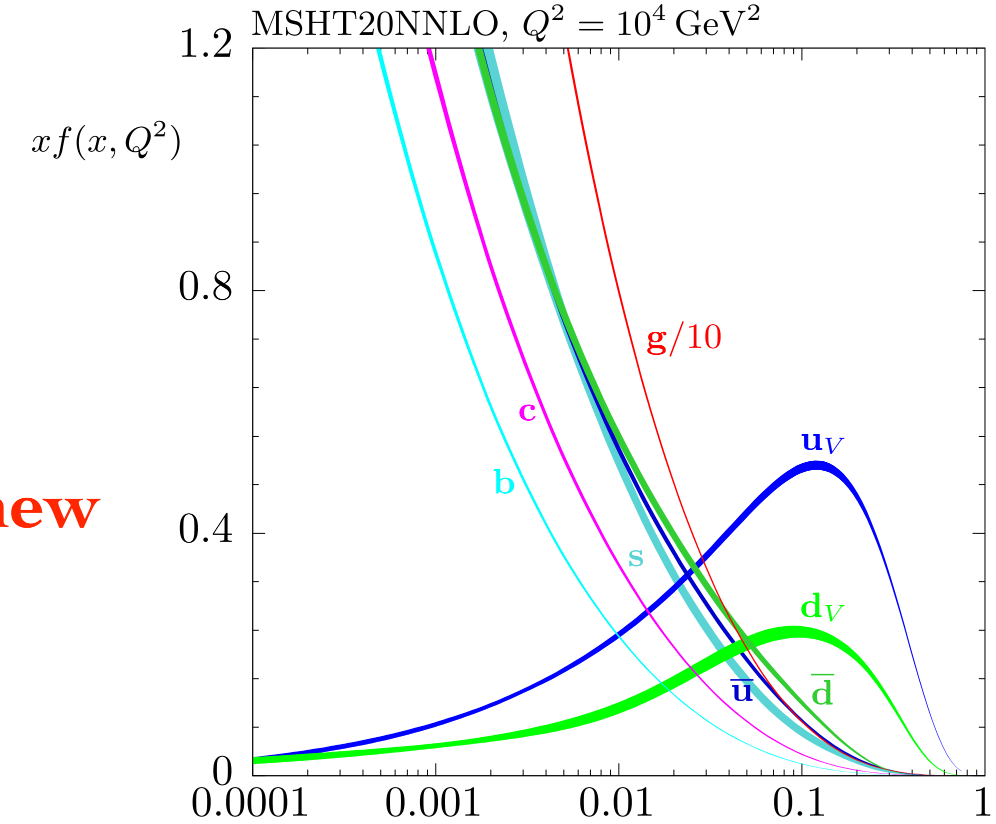
PDF4LHC Meeting, November 17, CERN

In collaboration with Tom Cridge, Jamie McGowan and Robert Thorne

Outline

- The 'Post-Run I' set from the MSTW, MMHT… group: **MSHT20.**



- Focus on including significant amount of **new data**, higher **precision theory** and on **methodological improvements**.

- More recent major update: extended to (approximate) N3LO order.
- Will discuss here on two follow up studies that build on this:

  ★ First QED and aN3LO PDF analysis.

  ★ First study of jet vs. dijet production at aN3LO.

MSHTaN3LO_QED:
including QED + aN3LO in a global fit

Motivation

- In the high precision LHC era: much focus on providing PDFs that are as accurate and precise as possible.
- Two key recent avenues for improvement have been pursued:

★ Increasing QCD order: moving to **aN3LO** and including MHOUs.

★ Including **QED** in PDF evolution and photon PDF.

Need to combine these to achieve highest possible precision!

- First such combination achieved here: **MSHT20 aN3LO+QED** PDFs.

MSHT20 aN3LO+QED PDFs

- Basic idea very simple. DGLAP evolution in previous MSHT studies:

★ MSHT20aN3LO:

QED $P_{ij} =$

NNLO QCD $+\frac{\alpha_S}{2\pi}P_{ij}^{(1,0)} + \left(\frac{\alpha_S}{2\pi}\right)^2 P_{ij}^{(2,0)} + \left(\frac{\alpha_S}{2\pi}\right)^3 P_{ij}^{(3,0)}$

aN3LO QCD $+\left(\frac{\alpha_S}{2\pi}\right)^4 P_{ij}^{(4,0)}\ .$

★ (MMHT15/MSHT20)qed:

$$P_{ij} = \frac{\alpha}{2\pi}P_{ij}^{(0,1)} + \frac{\alpha\alpha_S}{(2\pi)^2}P_{ij}^{(1,1)} + \left(\frac{\alpha}{2\pi}\right)^2 P_{ij}^{(0,2)}$$

$$+\frac{\alpha_S}{2\pi}P_{ij}^{(1,0)} + \left(\frac{\alpha_S}{2\pi}\right)^2 P_{ij}^{(2,0)} + \left(\frac{\alpha_S}{2\pi}\right)^3 P_{ij}^{(3,0)}$$

- To combine the two, simply combine linearly (i.e. no cross talk):

QED $P_{ij} = \frac{\alpha}{2\pi}P_{ij}^{(0,1)} + \frac{\alpha\alpha_S}{(2\pi)^2}P_{ij}^{(1,1)} + \left(\frac{\alpha}{2\pi}\right)^2 P_{ij}^{(0,2)}$

NNLO QCD $+\frac{\alpha_S}{2\pi}P_{ij}^{(1,0)} + \left(\frac{\alpha_S}{2\pi}\right)^2 P_{ij}^{(2,0)} + \left(\frac{\alpha_S}{2\pi}\right)^3 P_{ij}^{(3,0)}$

aN3LO QCD $+\left(\frac{\alpha_S}{2\pi}\right)^4 P_{ij}^{(4,0)}\ .$

- In a little more detail, in fact requires as usual we move to QED basis:

$$q_i^{\pm} = q_i \pm \overline{q_i}\ , \qquad g\ , \qquad \gamma$$

but nothing in principle new here at aN3LO (same QCD splitting functions as in QCD only fit).

- **Photon PDF** calculated as in earlier studies, i.e. following modification to LUXqed framework. Recap:

A. Manohar et al., JHEP 1712 (2017) 046

$$x\gamma(x,Q_0^2) = \frac{1}{2\pi\alpha(Q_0^2)}\int_x^1 \frac{dz}{z}\left\{\int_{\frac{x^2 m_p^2}{1-z}}^{Q_0^2}\frac{dQ^2}{Q^2}\alpha^2(Q^2)\left[\left(zP_{\gamma,q}(z)+\frac{2x^2m_p^2}{Q^2}\right)F_2(x/z,Q^2)\right.\right.$$
$$\left.\left.-z^2F_L(x/z,Q^2)\right] - \alpha^2(Q_0^2)\left(z^2+\ln(1-z)zP_{\gamma,q}(z)-\frac{2x^2m_p^2z}{Q_0^2}\right)F_2(x/z,Q_0^2)\right\}\ ,$$

  - ⋆ Set $\mu_F = Q_0 = 1\,\mathrm{GeV}$ in order to determine photon at input scale and then coupled QED DGLAP above that. Upper limit of Q^2 integral suitably modified/matched to achieve this.
  - ⋆ Precise determination of structure function input $\Rightarrow$ precise photon PDF.
  - ⋆ Depends on QCD parton via inelastic $q \to q\gamma$ evolution.

$$x\gamma(x,Q_0^2) = \frac{1}{2\pi\alpha(Q_0^2)}\int_x^1 \frac{dz}{z}\left\{\int_{\frac{x^2 m_p^2}{1-z}}^{Q_0^2} \frac{dQ^2}{Q^2}\alpha^2(Q^2)\left[\left(zP_{\gamma,q}(z)+\frac{2x^2m_p^2}{Q^2}\right)F_2(x/z,Q^2)\right.\right.$$
$$\left.\left.-z^2F_L(x/z,Q^2)\right] - \alpha^2(Q_0^2)\left(z^2+\ln(1-z)zP_{\gamma,q}(z)-\frac{2x^2m_p^2 z}{Q_0^2}\right)F_2(x/z,Q_0^2)\right\},$$

- In more detail, our inputs for the SFs closely follow LUXqed:
  - ★ **Elastic** form factors from A1 collaboration data.
  - ★ **Inelastic** SF divided into low scale resonant (CLAS data), low scale continuum (HERMES parameterisation) and high scale continuum (NNLO pQCD) contributions.

A1 Collaboration, Phys. Rev. C90, 015206 (2014)

CLAS, M. Osipenko et al., Phys. Rev. D67, 092001 (2003)

HERMES, A. Airapetian et al., JHEP 05, 126 (2011)

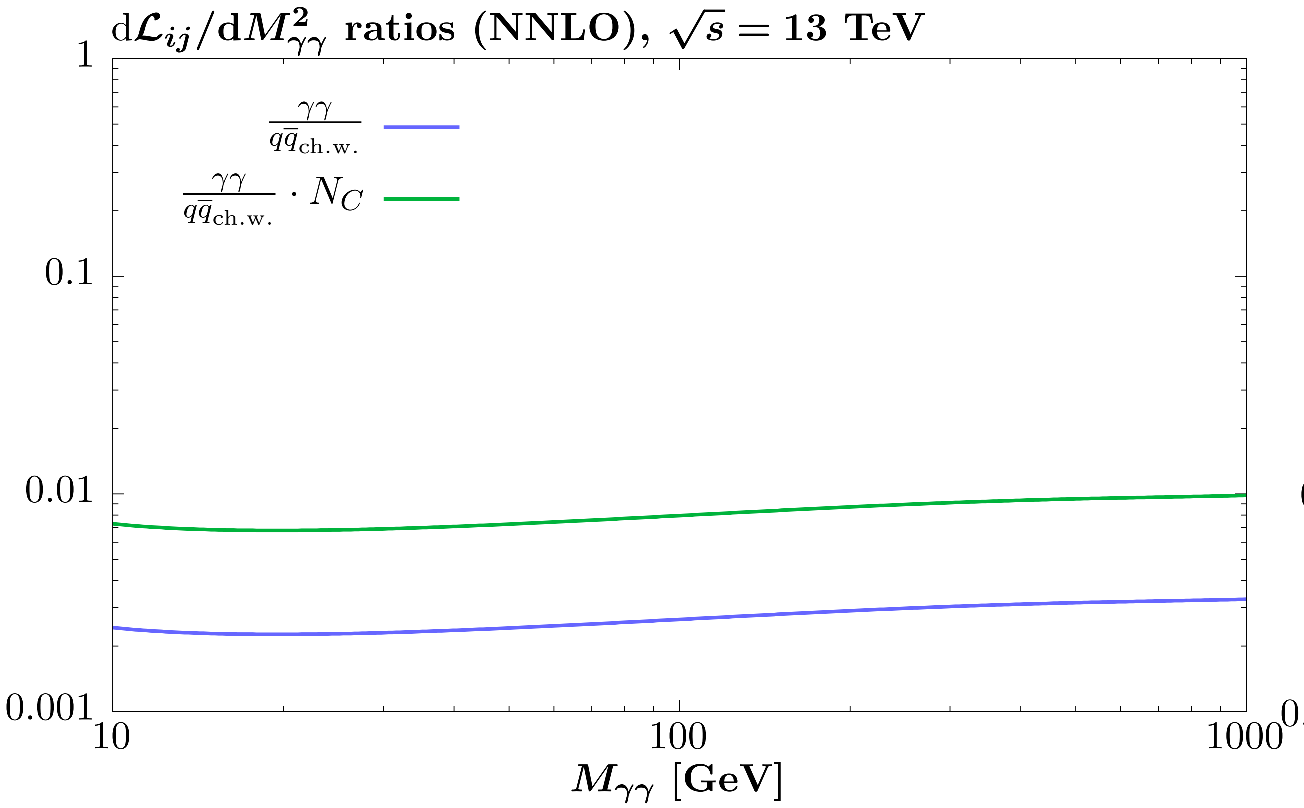
- We in addition include **renormalon** corrections, relevant in low scale region.
- **Uncertainties** due to the above experimental inputs, renormalon corrections + usual eigenvector uncertainties from global fit also included.
- **32** PDF + **6** photon eigenvectors = **38** in total.

EW corrections/PI contributions

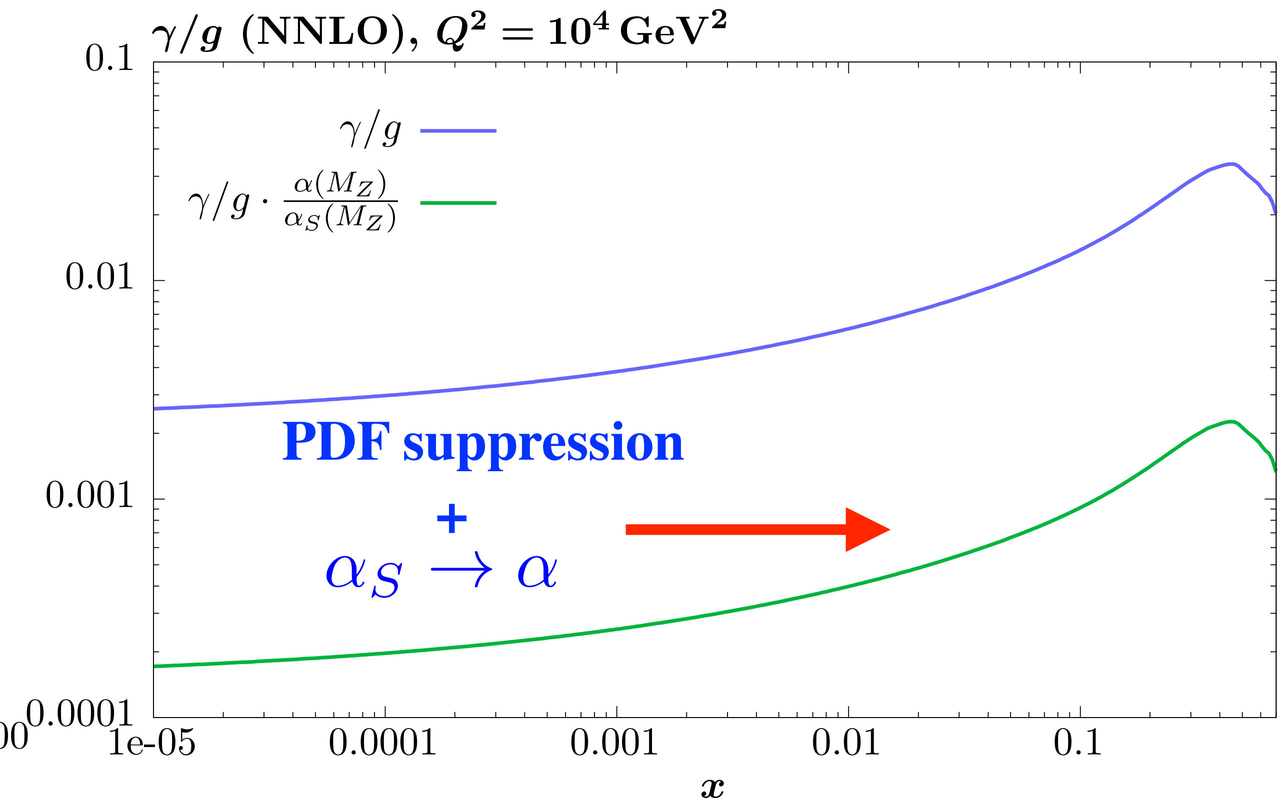
- As usual include photon-initiated (PI) production in QED fit where possible.
- EW corrections included by default (dominantly not QED).
- In terms of PI, worth recalling these are ~ sub permille for many processes.

T. Cridge et al., *Eur.Phys.J.C* 82 (2022) 1, 90

$\gamma\gamma \to l^+ l^-$



$gg \to t\bar{t} \longrightarrow \gamma g \to t\bar{t}$



- Off peak DY the exception (1% level), but here at least NLO/SF calculation needed for precision. **LHL, *JHEP* 03 (2020) 128**

Results: Fit Quality

- Dataset/theory settings v. similar to MSHT20.
- Global fit quality:

	$\chi^2/N_{\rm pt}$ aN^{3}LO (QED)	$\Delta\chi^2_{\rm aN^3LO}$ QED-QCD	$\Delta\chi^2_{\rm NNLO}$ QED-QCD	$\Delta\chi^2_{\rm QCD,QED}$ aN^{3}LO-NNLO
Total	5323.6/4534	(+3.6)	(+17.3)	(-209.3, -223.1)

- ⋆ NNLO: mild deterioration (~ 0.004 per point) upon inclusion of QED.
- ⋆ aN3LO: deterioration is less (sub ~ 0.001 per point) - difference now fairly marginal - though still not improvement. Similar if NNLO K-factors used.
- ⋆ Similar to MSHTaN3LO QCD fit, significant improvement in going from NNLO to aN3LO. Remains true in QED fit.

	$\chi^2/N_{\rm pt}$ aN^{3}LO (QED)	$\Delta\chi^2_{\rm aN^3LO}$ QED-QCD	$\Delta\chi^2_{\rm NNLO}$ QED-QCD	$\Delta\chi^2_{\rm QCD,QED}$ aN^{3}LO-NNLO
Total	5323.6/4534	(+3.6)	(+17.3)	(-209.3, -223.1)

- Much of QED-QCD difference spread across datasets. But some trends clear.

★ Gluon sensitive LHC data (photon PDF $\longrightarrow$ momentum sum rule):

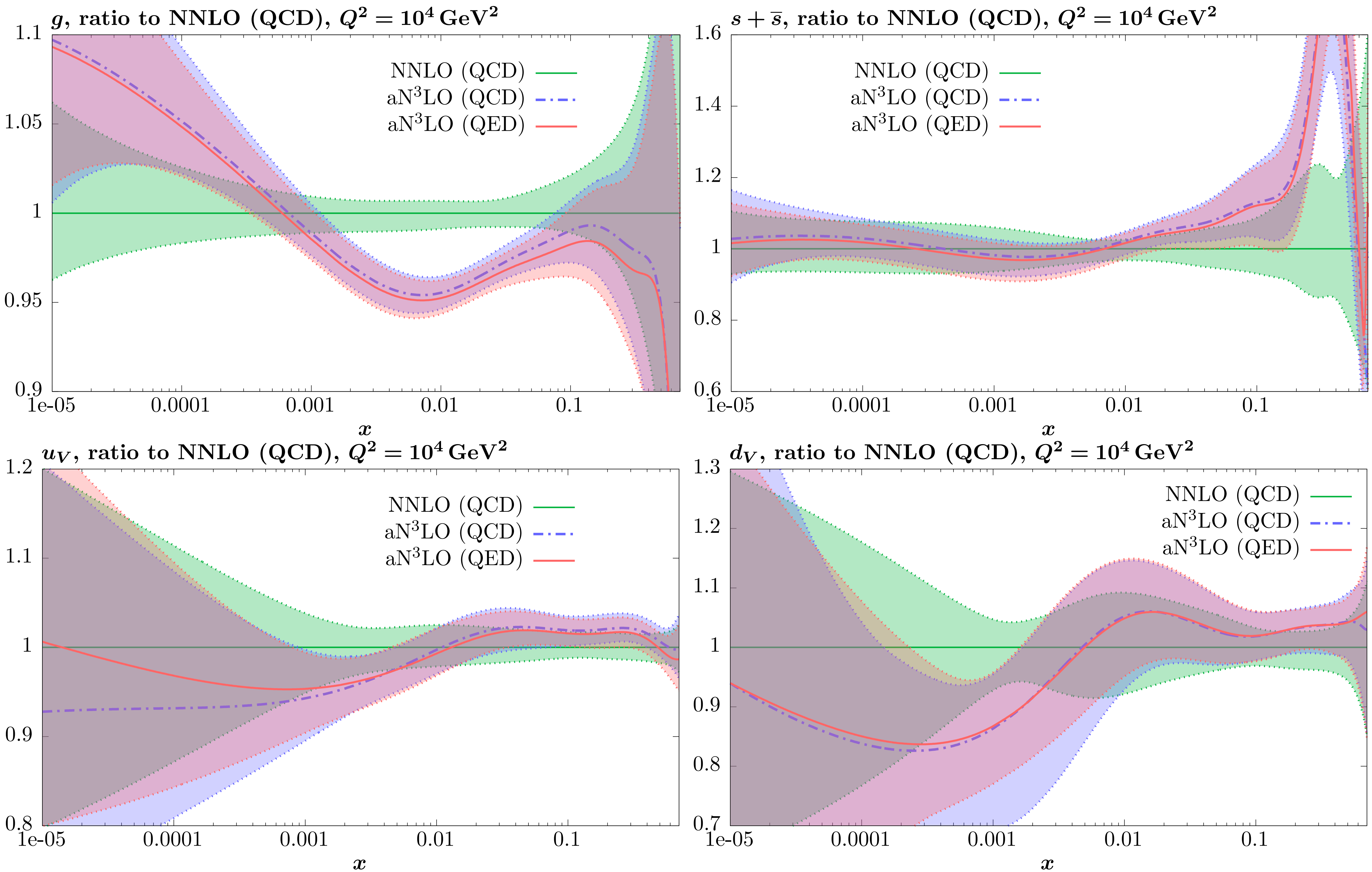
ATLAS 7 TeV jets	201.7/140	(-2.6)	(-4.2)	(-10.8, -9.1)
ATLAS 8 TeV jets	318.6/171	(-6.2)	(-8.4)	(-11.9, -9.7)
CMS 8 TeV jets	316.8/174	(+5.1)	(+6.3)	(-7.0, -8.2)
ATLAS 8 TeV Z p_T	112.1/104	(+4.0)	(+12.0)	(-87.7, -95.7)

Improvement and deterioration: difference largely maps onto known tensions between datasets (CMS vs. ATLAS jets, Z p_T vs, other sets…).

★ QED-QCD deterioration in Z p_T less at aN3LO. Possibly linked to dramatic improvement seen at this order vs. NNLO.

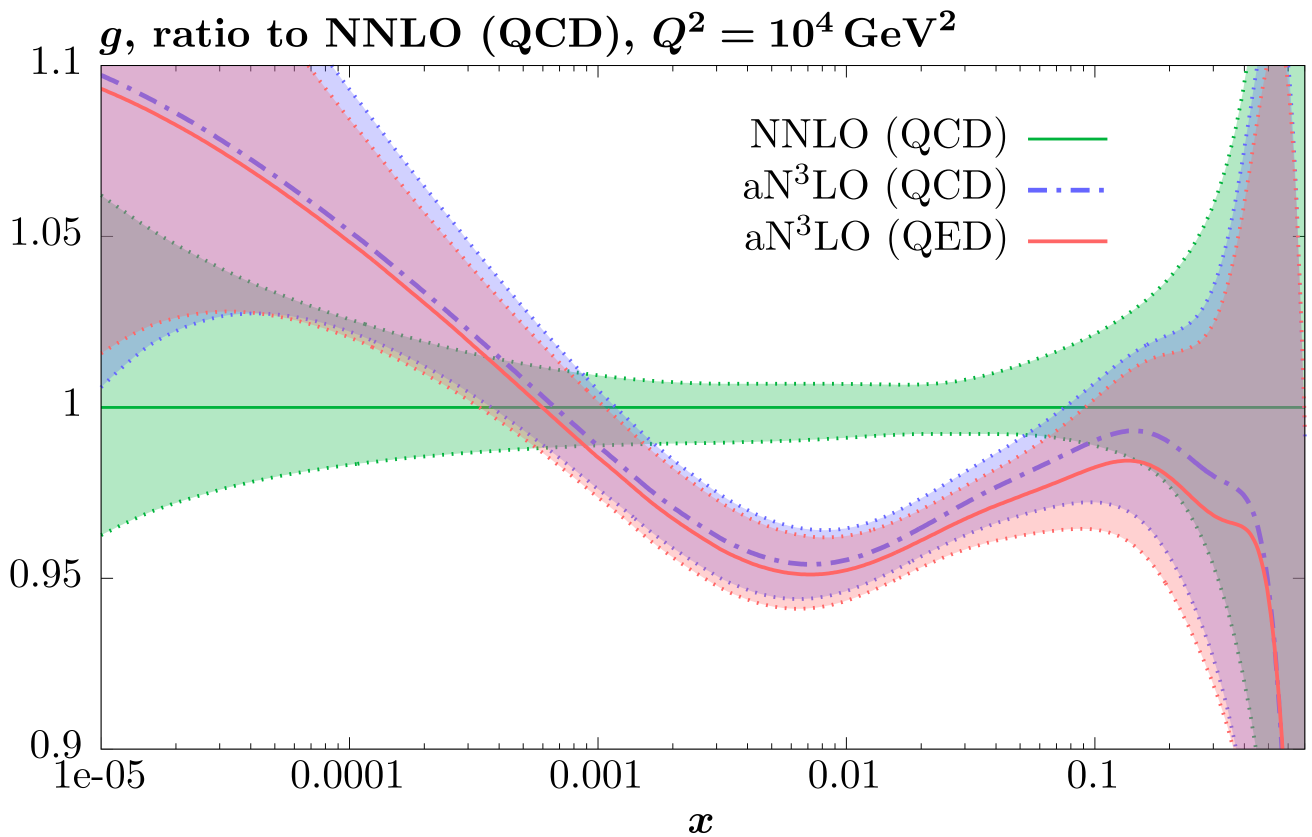
★ Broad trend in QED-QCD is however very similar between NNLO and aN3LO cases.

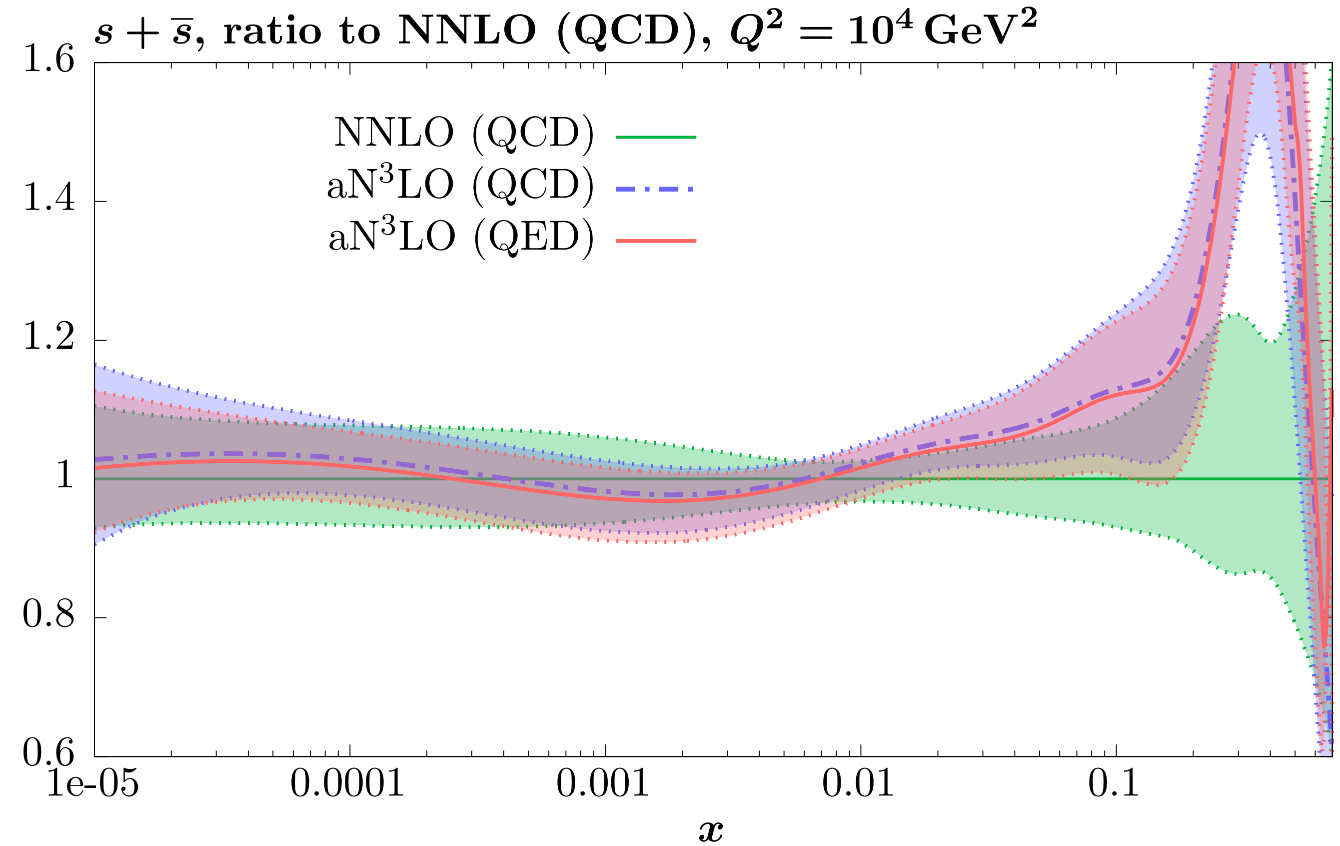
Results: PDFs



- Consider ratio to NNLO. aN3LO/NNLO trend in both QCD and QED fits similar, and similar to MSHT20aN3LO.

See Robert's talk





- aN3LO - NNLO difference $\gg$ QED - QCD difference

  $\Longrightarrow$ Impact of aN3LO QCD $\gg$ impact of QED.

- Also clear from χ^2comparison

$\chi^2/N_{\rm pt}$ aN^{3}LO (QED)	$\Delta\chi^2_{\rm aN^3LO}$ QED-QCD	$\Delta\chi^2_{\rm NNLO}$ QED-QCD	$\Delta\chi^2_{\rm QCD,QED}$ aN^{3}LO-NNLO
5323.6/4534	(+3.6)	(+17.3)	(-209.3, -223.1)

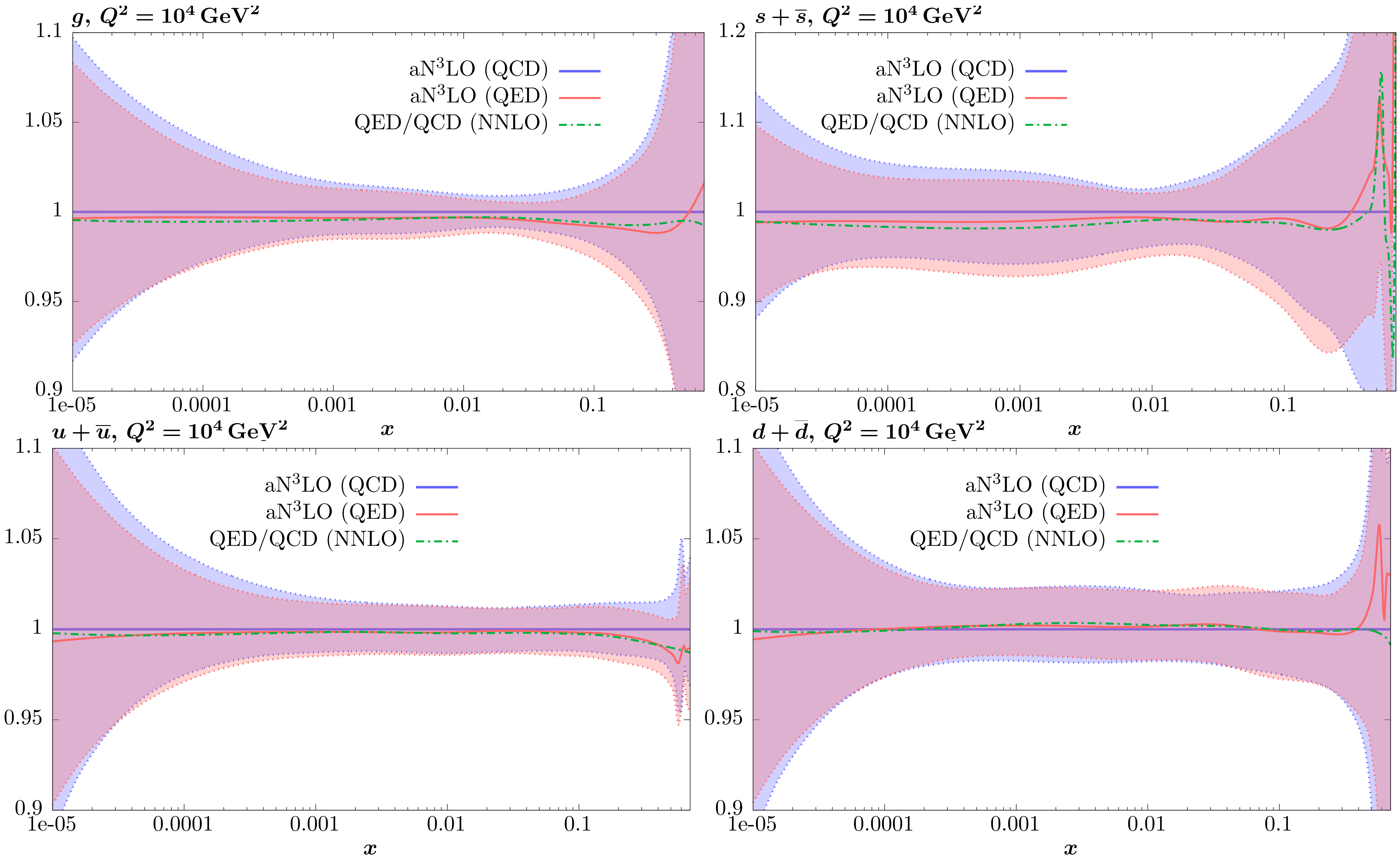
- Naive $\alpha \sim \alpha_S^2$ analysis does not apply at all here. Why?

  ★ $\alpha \sim \alpha_S^2$ only holds for $Q^2 \sim M_Z^2$. Much data has lower Q^2 .

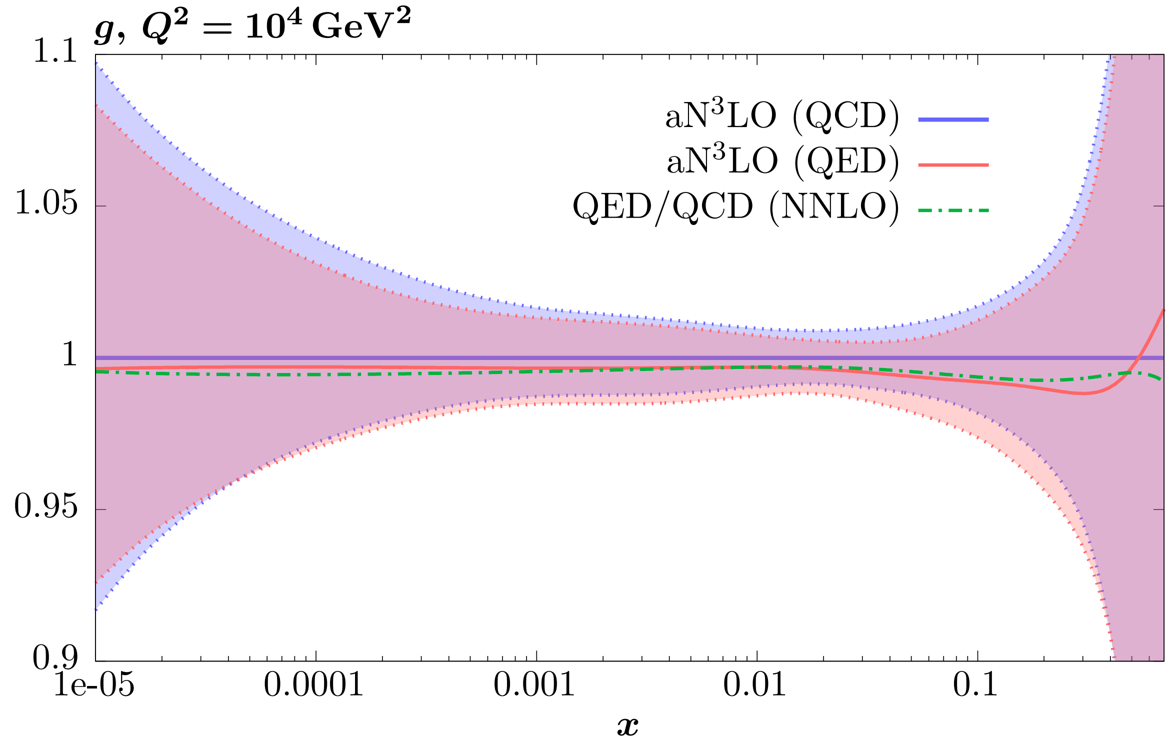
  ★ Higher order QCD receives $\ln 1/x$...enhancements (c.f. P_{ij}).

  ★ QCD K-factors often larger than naive scaling. PI production additionally suppressed by photon PDF…

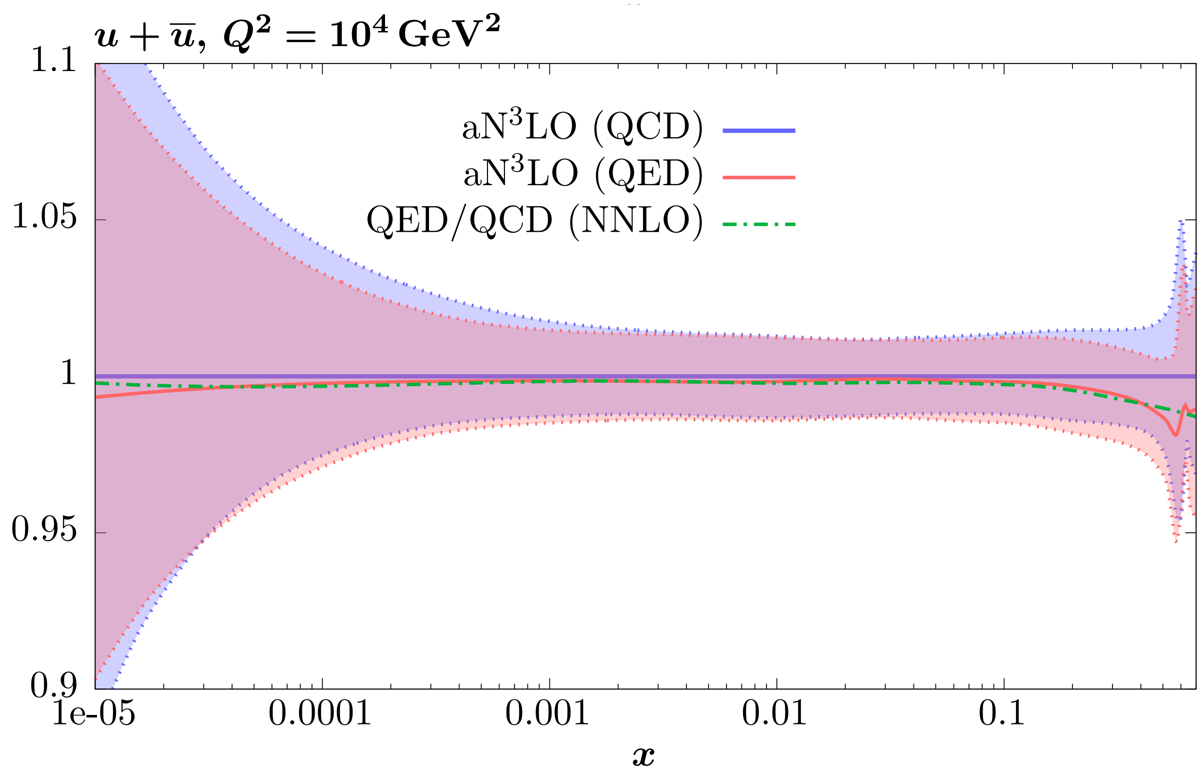
- Still, QED does have some effect (!) …



- Consider QED/QCD ratio at both orders. Impact small (% level) but not negligible, in line with previous studies….



- Reduction in gluon from momentum sum rule (photon PDF).

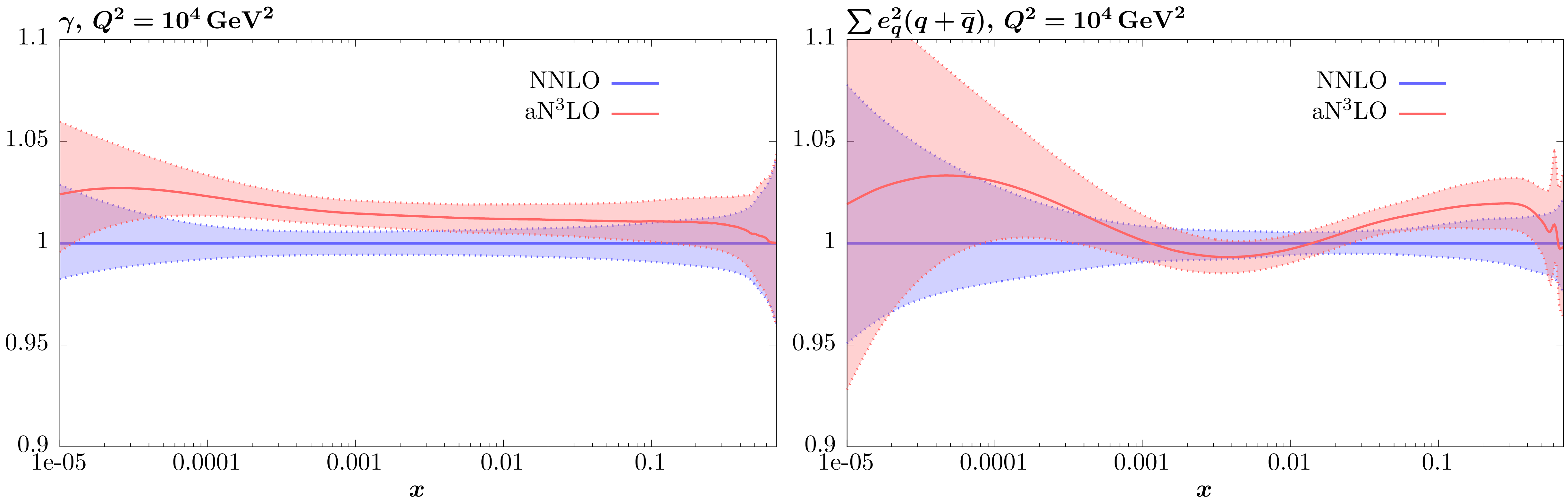


- Reduction in high x up quark singlet from $q \to q\gamma$

- QED - QCD difference is v. similar at NNLO and aN3LO.

  $\Longrightarrow$ To good approximation, factorisation of QED and QCD corrections at level of PDFs.

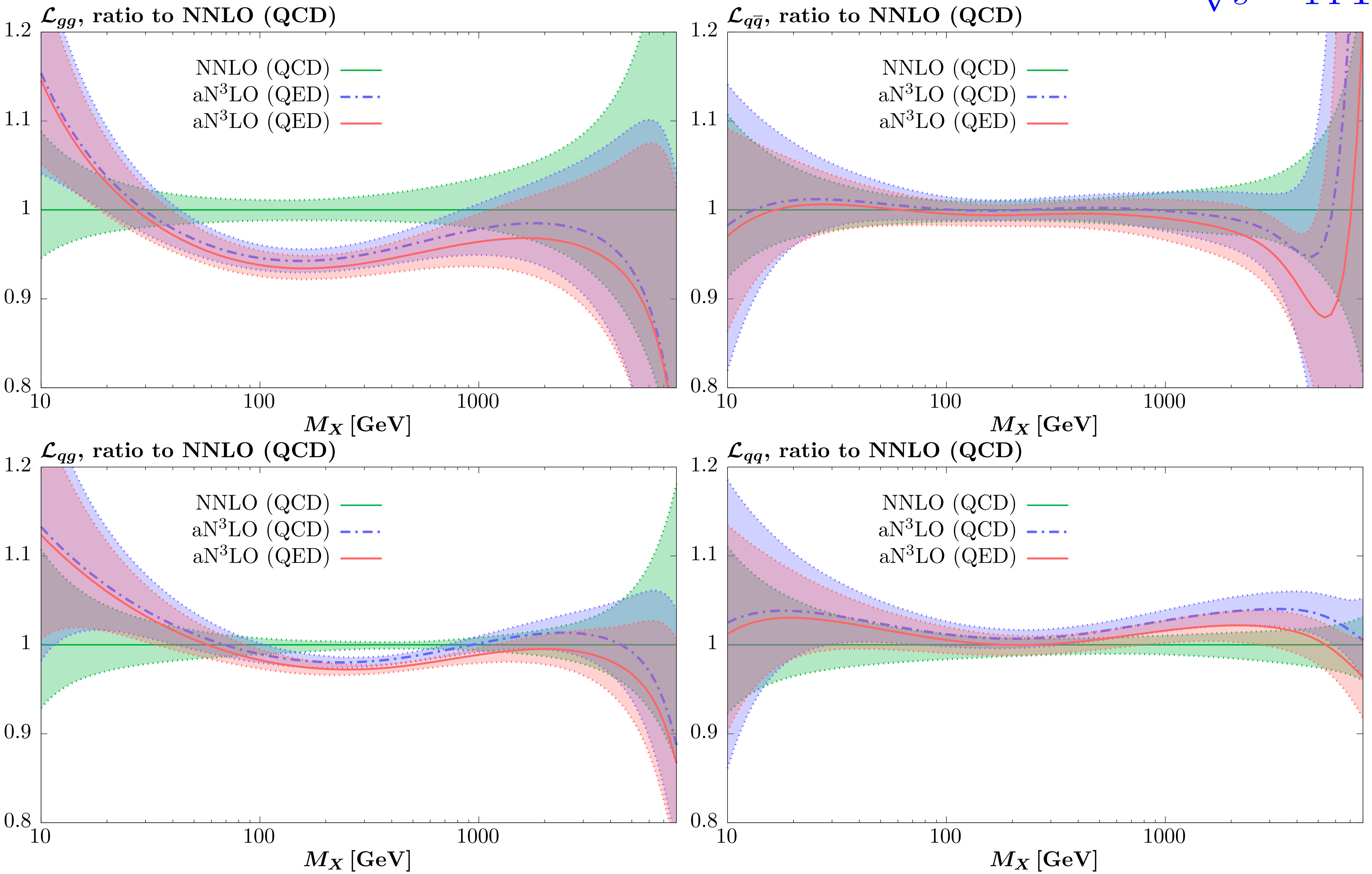
Photon PDF



- Some difference in photon PDF at NNLO vs. aN3LO. Largely follows charge weighted quark singlet, i.e. due to evolution.

Luminosities

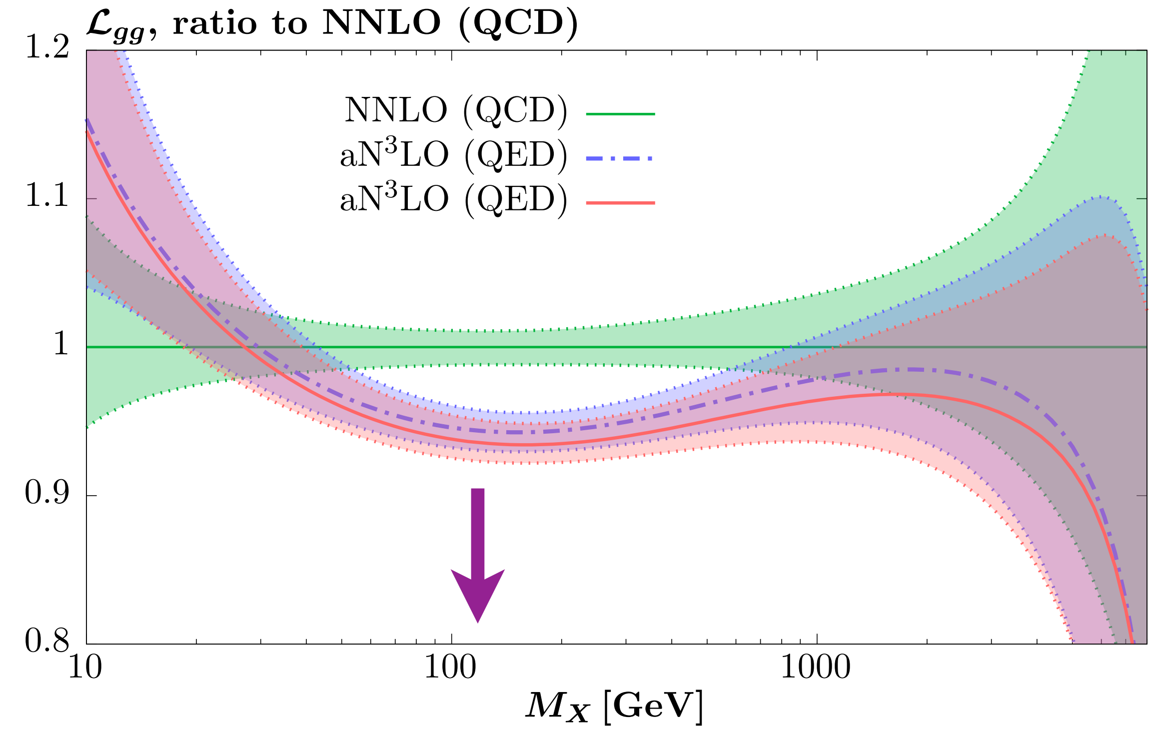
$\sqrt{s} = 14\,\text{TeV}$

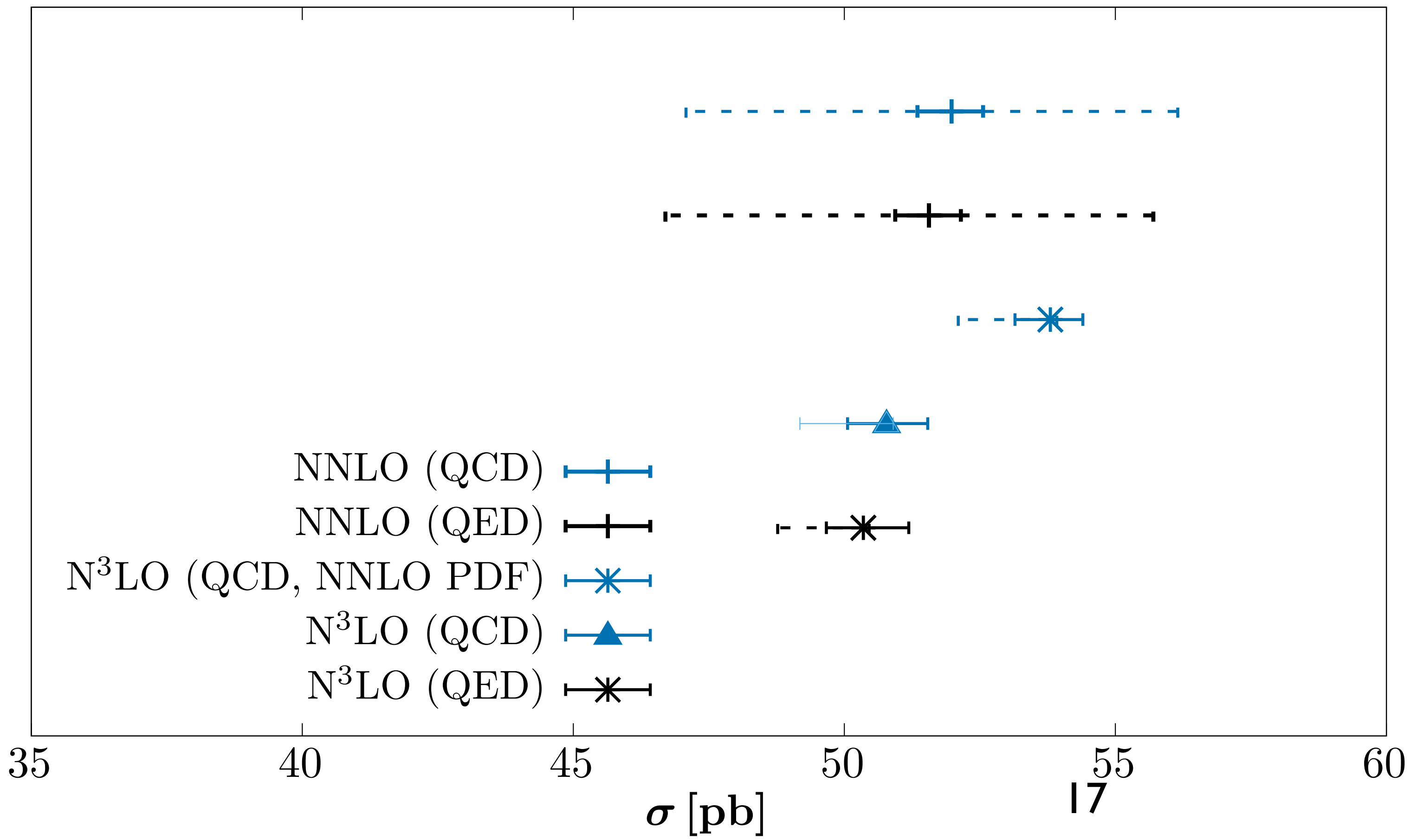


- Phenomenological impact of QED clearer by looking at luminosities. Moderate, and less than aN3LO QCD. But not negligible.

Cross Sections

- Both QED and aN3LO QCD lead to reduction in gluon in Higgs mass region.
- QED further reduces N3LO ggH cross section by ~ 1%, though aN3LO more significant (~ 5%).





N3LO QCD + NNLO PDFS

N3LO QCD + aN3LO PDFS

N3LO QCD + aN3LO/QED PDFS

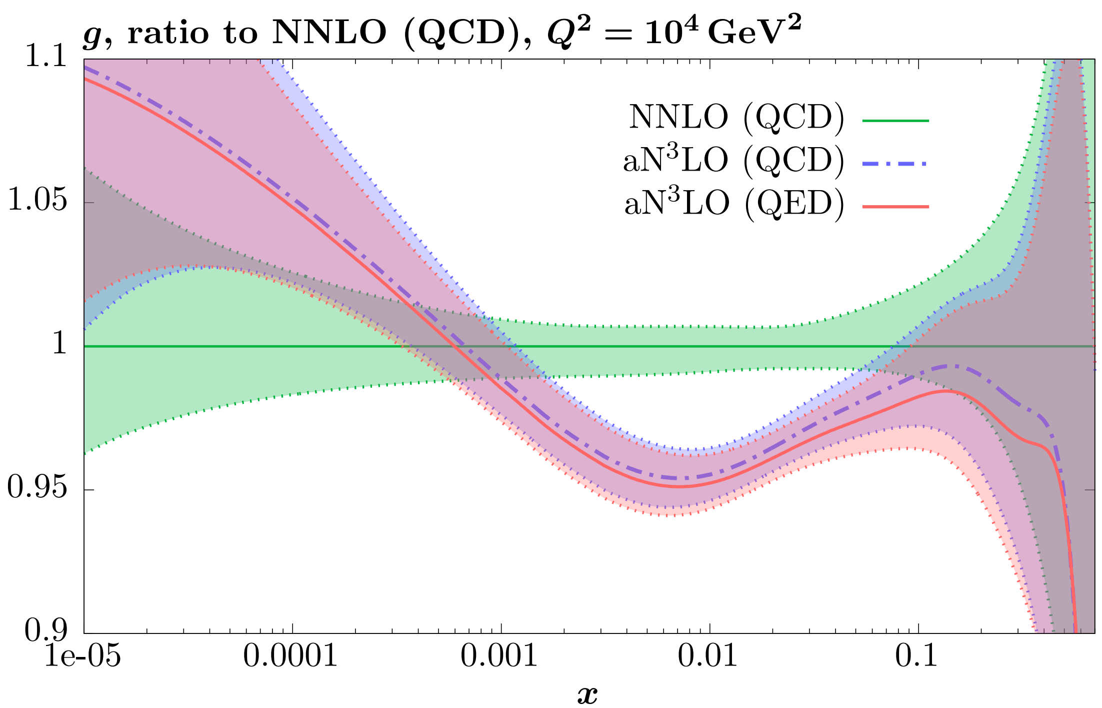
Summary

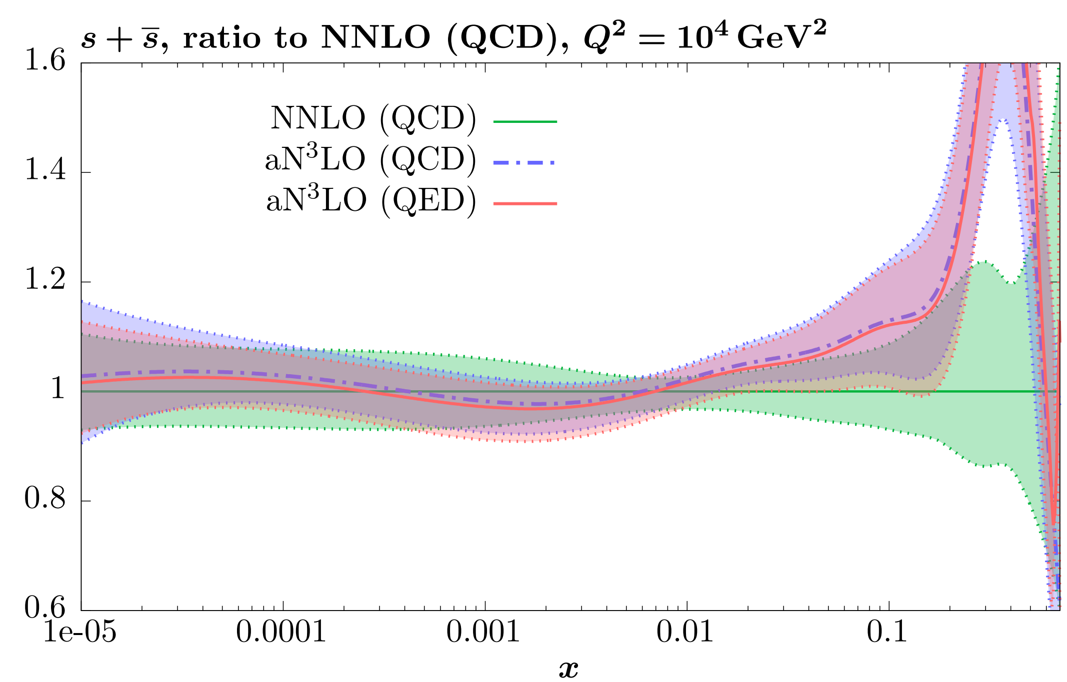
★ Impact of QED corrections to aN3LO QCD fit considered for first time.

★ These largely factorise, i.e. QED-QCD difference at level of fit quality and PDFs is similar at NNLO and aN3LO orders.

★ Impact of QED corrections generally a lot smaller than aN3LO.

★ To be provocative: does this call into question the benefit of QED PDFs without also considering (a)N3LO QCD?*





***Of course in the end QED correction/photon PDF needed for consistency with PI production. And this is important for e.g. off-peak DY.**

Jets and Dijets in MSHT20

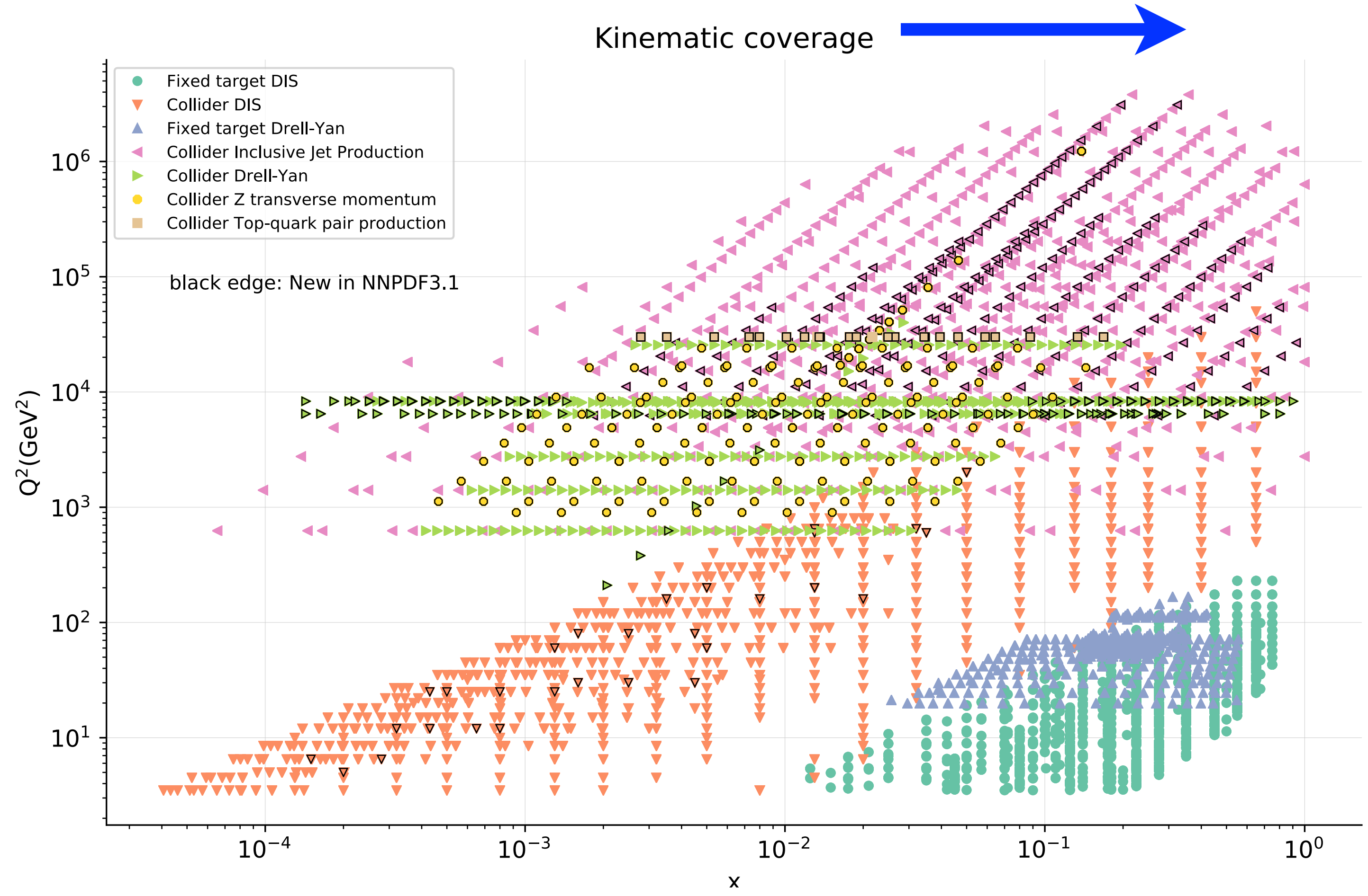
Jets for PDF fits

- Jet production a key ingredient in modern PDF fits.
- By pushing to larger jet $p_\perp$ (dijet m_{jj}) go to larger x.
- Quark-initiated contribution tends to be better constrained $\longrightarrow$ particularly relevant for gluon at high x.

High $p_\perp$, m_{jj}

- NNLO QCD (and NLO EW) theory available for both inclusive and dijet data.

- In addition, high precision LHC data available, spanning large range of kinematic space.



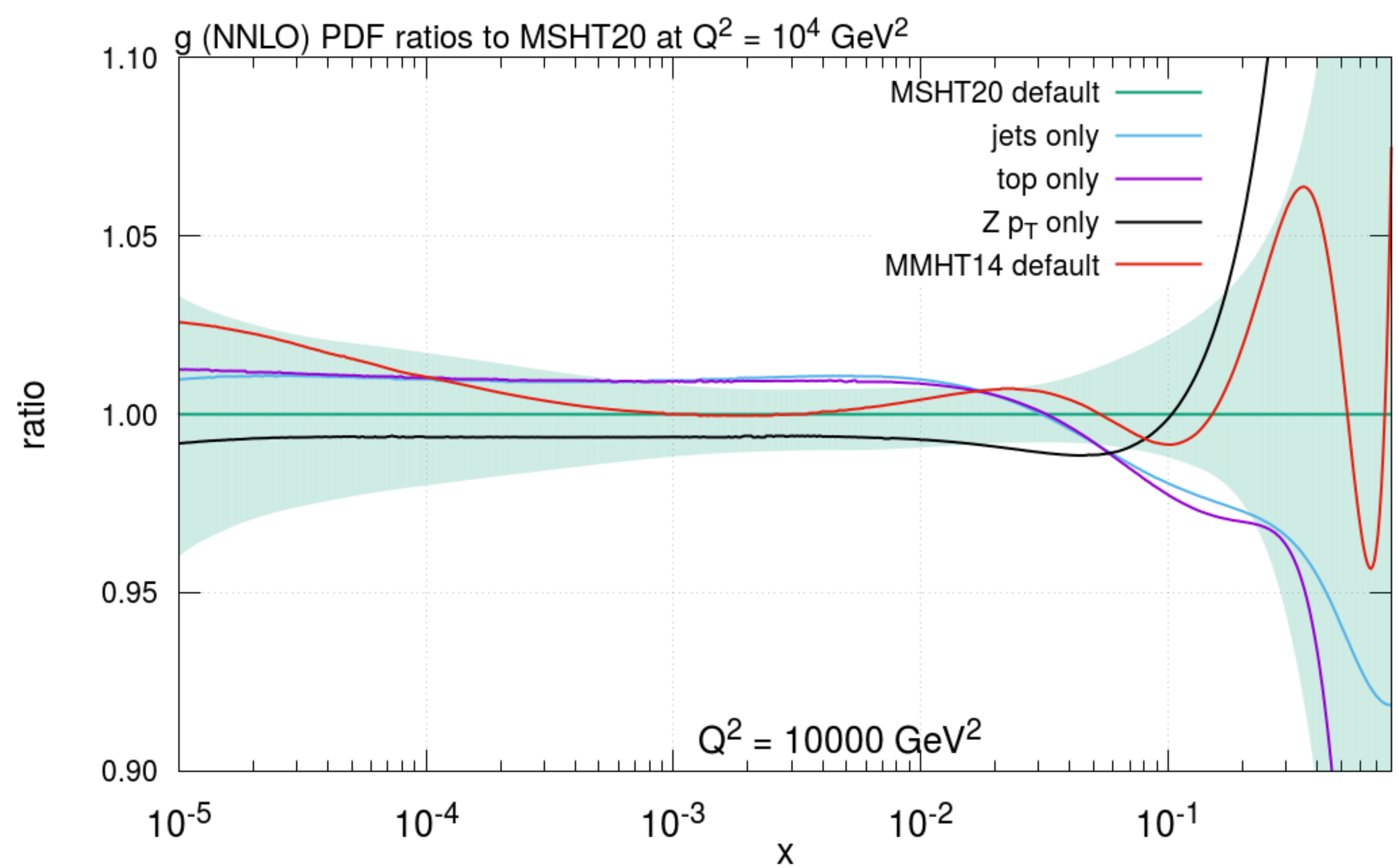
Jets in MSHT20

	NNLO, χ^2/N_{pt}
ATLAS 7 TeV jets [18]	221.6/140
CMS 2.76 TeV jet [107]	102.9/81
CMS 7 TeV jets [100]	175.8/158
CMS 8 TeV jets [101]	261.3/174

- Range of **inclusive** LHC jet data fit:

- Fit quality acceptable. N.B. For ATLAS data smooth decorrelation of systematic errors applied.

- PDF impact tied up with other high x gluon sensitive data….



MSHT20 updates: Jet data

- Focussing on Run-I data (i.e. current PDF fits): $\mathrm{d}^2\sigma/\mathrm{d}p_\perp \mathrm{d}y$
  - Inclusive jets: $0.0 < |y| < 2.5 - 3.0$

★ CMS 2.76 TeV: 81 points – 5.43 pb^{-1} – $74 < p_\perp < 592\,\mathrm{GeV}$

★ CMS 7 TeV: 158 points – 5.0 fb^{-1} – $74 < p_\perp < 2500\,\mathrm{GeV}$

★ CMS 8 TeV: 174 points – 19.7 fb^{-1} – $60 < p_\perp < 1300\,\mathrm{GeV}$

★ ATLAS 7 TeV: 140 points – 4.5 fb^{-1} – $100 < p_\perp < 2000\,\mathrm{GeV}$

★ **ATLAS 8 TeV**: 171 points – 20.2 fb^{-1} – $70 < p_\perp < 2500\,\mathrm{GeV}$

$\longrightarrow$ ***724*** points in total, v.s. ~ 4500 in global MSHT fit (inc.).

- We take the larger of the jet radii available in both cases, i.e. R=0.6/0.7.

- Dijets:

  - ⋆ ATLAS 7 TeV: 90 points – 4.5 fb^{-1} – $\mathrm{d}^2\sigma/\mathrm{d}m_{jj}\mathrm{d}|y_{\max}|$ $0.26 < m_{jj} < 5.04$ TeV

  - ⋆ CMS 7 TeV: 54 points – 5.0 fb^{-1} – $\mathrm{d}^2\sigma/\mathrm{d}m_{jj}\mathrm{d}|y^*|$ $0.25 < m_{jj} < 4.48$ TeV

  - ⋆ CMS 8 TeV: 122 points – 19.7 fb^{-1} – $\mathrm{d}^3\sigma/\mathrm{d}p_{\perp,avg}\mathrm{d}y_b\mathrm{d}y^*$ $143 < p_{\perp,avg} < 1638$ GeV

$\longrightarrow$ **266** points in total, v.s. ~ 4000 in global MSHT fit (inc.).

- Again take the larger of the jet radii available in both cases, i.e. R=0.6/0.7.

- **CMS 8 TeV** data the only cases where this is **triple differential**. Only case where LO kinematics fully specified $\Rightarrow$ higher impact (backup).

Fit Quality

All results preliminary

- Consider impact of both inclusive or dijet data at NNLO and aN3LO in the MSHT20 fit.

Jet fit:

	N_{pts}	NNLO	aN^{3}LO
ATLAS 7 TeV jets	140	1.54	1.46
CMS 7 TeV jets	158	1.29	1.32
ATLAS 8 TeV jets	171	1.96	1.90
CMS 8 TeV jets *	174	1.83	1.80
Total Jets	643	1.67	1.63

NB: smooth decorrelation of systematics applied for ATLAS inclusive jet data.

χ^2/N_{pts}

Dijet fit:

	N_{pts}	NNLO	aN^{3}LO
ATLAS 7 TeV dijets	90	1.06	1.12
CMS 7 TeV dijets	54	1.43	1.39
CMS 8 TeV dijets	122	1.05	0.82
Total Dijets	266	1.13	1.04

★ NNLO: Fit quality to dijet data very good (1.13), clearly worse for jets (1.67).

★ aN3LO: Some improvement in both cases (1.04, 1.63 for jets, dijets) but inclusive jet remains a rather bad fit!

Dijets ✓ **Jets** ✗

*NB we use stat. correlations here. Not included by other groups, and leads to deterioration in fit quality.

- What about interplay with other gluon sensitive data?

Jet fit:

	$N_{\rm pts}$	NNLO	aN^{3}LO
ATLAS Z $p_\perp$	104	1.89	1.03
Diff. top	54	1.10	1.06
7 + 8 TeV dijets	266	[1.30]	[1.10]
7 + 8 TeV jets	643	1.67	1.63

Dijet fit:

	$N_{\rm pts}$	NNLO	aN^{3}LO
ATLAS Z $p_\perp$	104	1.66	1.05
Diff. top	54	1.26	1.09
7 + 8 TeV jets	643	[1.75]	[1.65]
7 + 8 TeV dijets	266	1.13	1.04

★ Jet data: no signs of significant inconsistency in fit vs. prediction though some difference in pull implied.

★ NNLO: Fit quality to top (Z $p_\perp$) data better in jet (dijet) fit. Latter particularly notable $\Rightarrow$ overall tension less in dijet fit.

★ aN3LO: tensions reduced in all cases. No clear difference between jet/dijets.

★ (Not shown) - fit quality to other data in global fit v. similar.

Dijets ✔ **Jets** ✘

With some preference for aN3LO

Impact of EW corrections

Jet fit:

NNLO: χ^2 (no EW) $\rightarrow \chi^2$ (EW) : $1.57 \rightarrow 1.67$

aN3LO: χ^2 (no EW) $\rightarrow \chi^2$ (EW): $1.59 \rightarrow 1.63$

Dijet fit:

NNLO: χ^2 (no EW) $\rightarrow \chi^2$ (EW) : $1.37 \rightarrow 1.13$

aN3LO: χ^2 (no EW) $\rightarrow \chi^2$ (EW) : $1.27 \rightarrow 1.04$

- ⋆ Significant improvement in dijet fit upon including EW corrections. However trend is opposite for inclusive jets (!). Given these are there:

  Dijets ✓ **Jets** ✗

  indeed even absent EW correction dijet fit quality is better.

- ⋆ Remains true at aN3LO. Deterioration in fit quality for no EW fit somewhat improved but not entirely $\Longrightarrow$ not true that freedom in aN3LO K-factors can (fully) absorb other theoretical deficiencies.

Impact on PDFs small: Backup

Inclusive Jets: scale choice

J. Currie et al., *JHEP* 10 (2018) 155

- Default inclusive fits taken with $\mu = p_\perp^j$ scale choice. However some indication that $\mu = \hat{H}_\perp$ may be preferable.

$$\hat{H}_\perp = \sum_i p_{i\perp}$$

- What does global fit say?

NLO: $\chi^2(p_\perp^j) \to \chi^2(\hat{H}_\perp) : 1.68 \to 1.60$

NNLO: $\chi^2(p_\perp^j) \to \chi^2(\hat{H}_\perp) : 1.64 \to 1.65$

aN3LO: $\chi^2(p_\perp^j) \to \chi^2(\hat{H}_\perp) : 1.58 \to 1.60$

★ NLO fit quality better with $\mu = \hat{H}_\perp$ but difference marginal at NNLO/aN3LO.

★ Trend for improved description with order not present with $\mu = \hat{H}_\perp$.

$\longrightarrow$ Scale choice does not appear to play significant role at NNLO and beyond.

Impact on PDFs small: Backup

NB. Cuts for CMS 7 jet data slightly different here

Taking step back: pQCD working?

- Worth taking a look at **NLO** fit quality…

Jets fit:

	$N_{\rm pts}$	NLO	NNLO	aN^{3}LO
ATLAS 7 TeV jets	140	1.61	1.54	1.46
CMS 7 TeV jets	158	1.37	1.29	1.32
ATLAS 8 TeV jets	171	2.24	1.96	1.90
CMS 8 TeV jets	174	1.66	1.83	1.80
Total Jets	643	1.73	1.67	1.63

Dijets fit:

	$N_{\rm pts}$	NLO	NNLO	aN^{3}LO
ATLAS 7 TeV dijets	90	1.12	1.06	1.12
CMS 7 TeV dijets	54	1.70	1.43	1.39
CMS 8 TeV dijets	122	5.27	1.05	0.82
Total Dijets	266	3.14	1.13	1.04

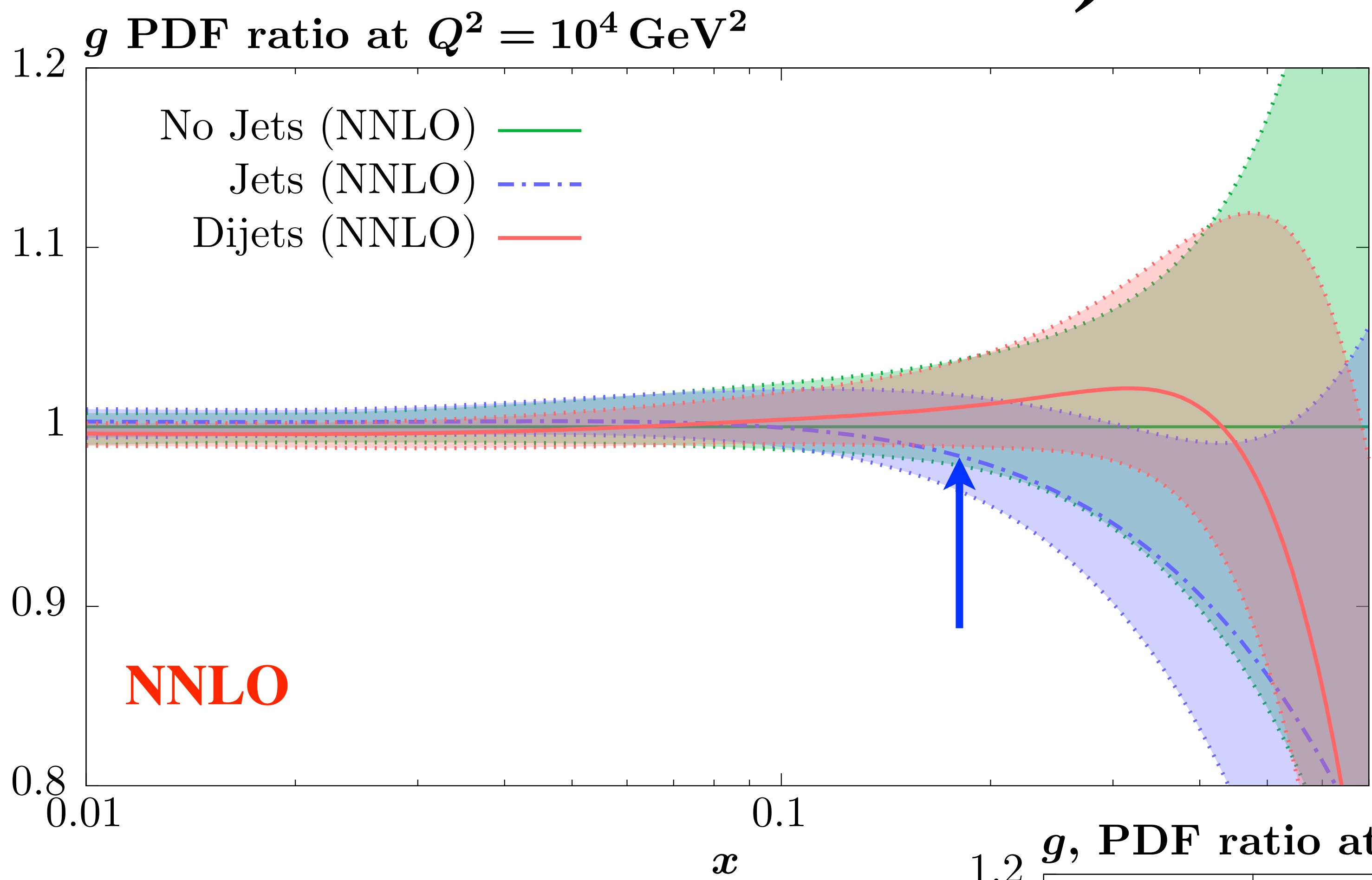
Not a typo!

★ Clear trend in both cases for QCD corrections to improve fit quality. pQCD working as it should!

★ Improvement in CMS 8 TeV dijets particularly **remarkable**. Clear need for NNLO QCD at high precision + multi-differential LHC.

See also: ATLAS high precision W,Z

PDFs: dijets vs. Jets

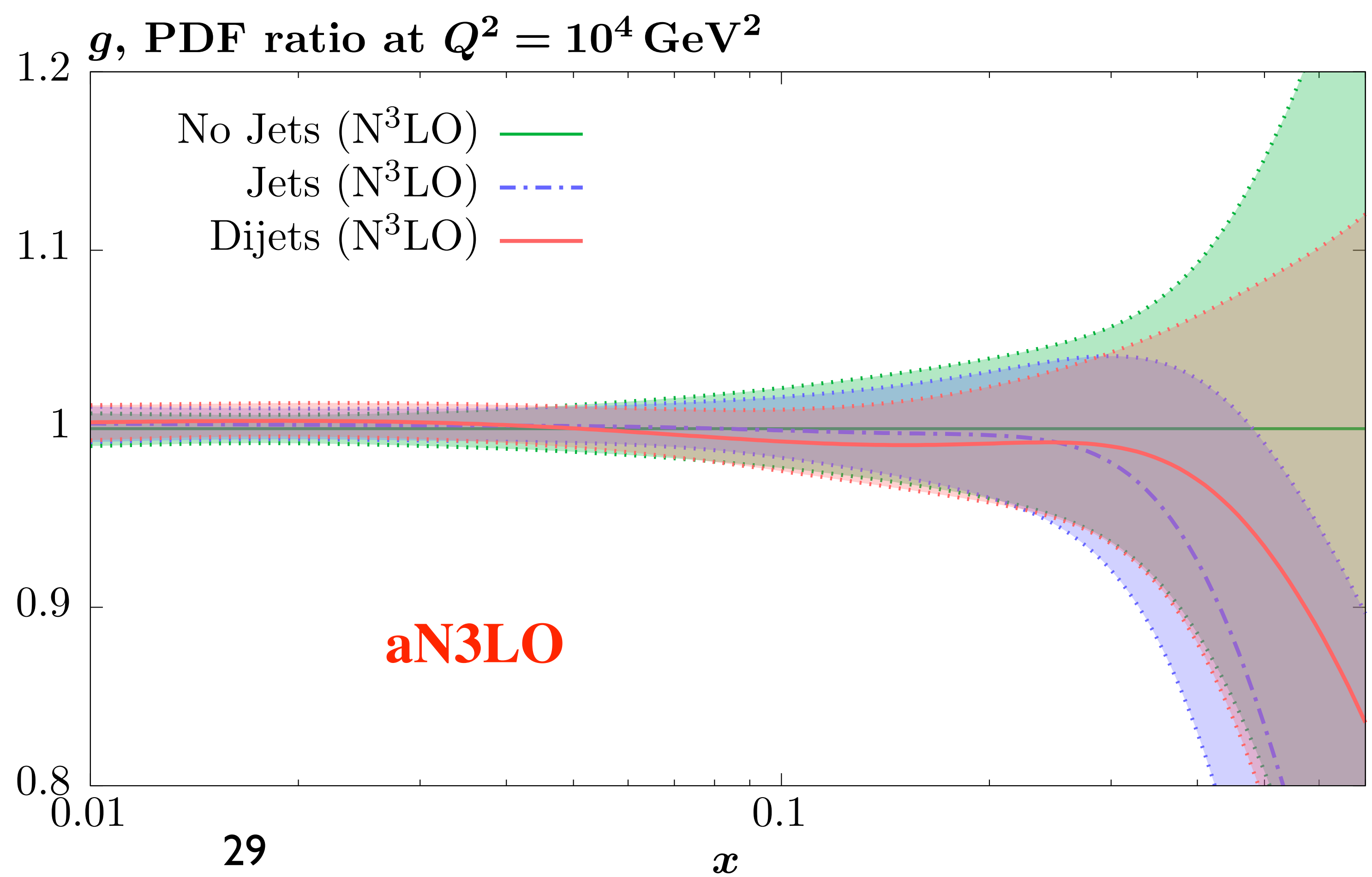


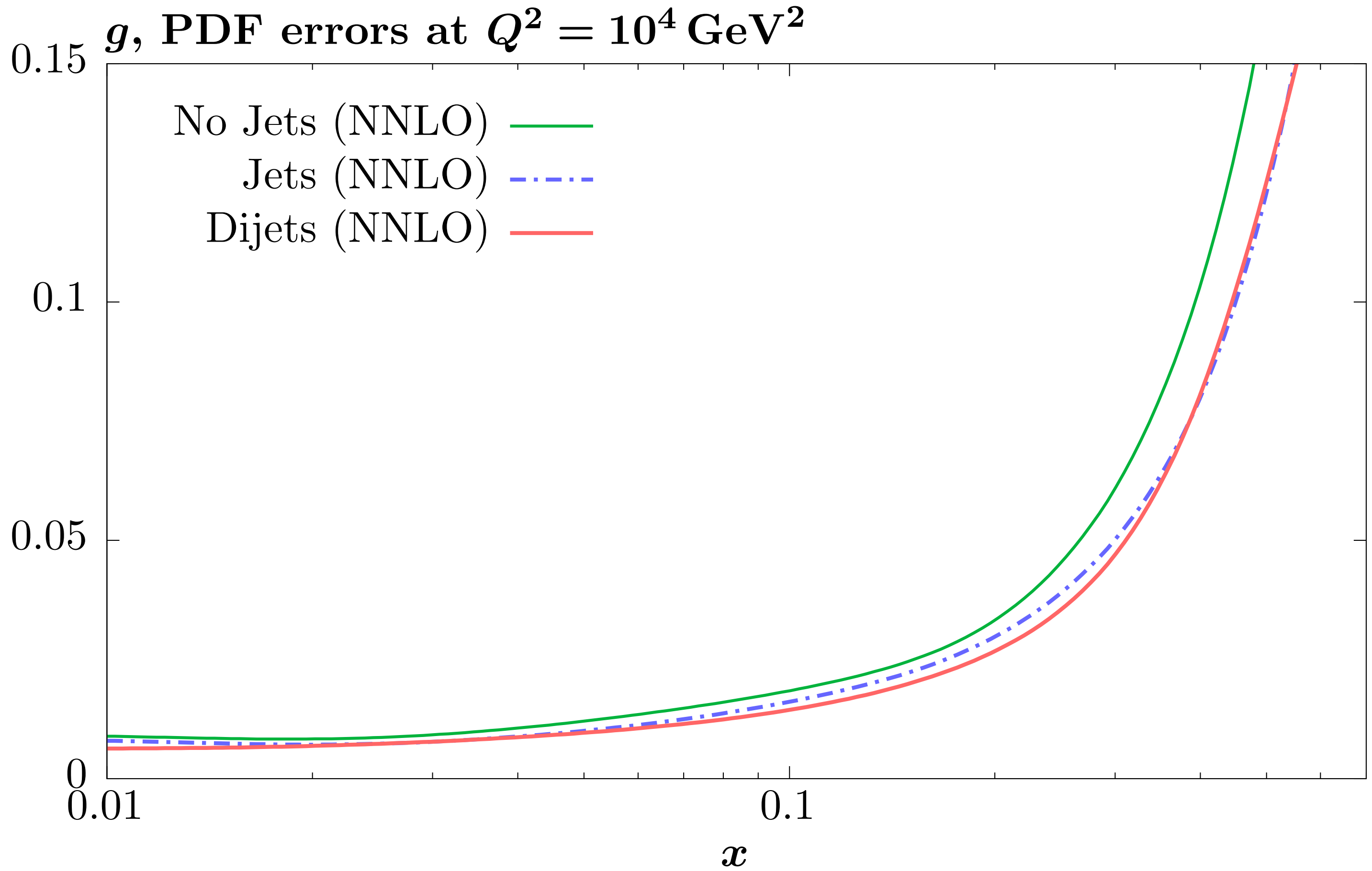
★ Focus on gluon: largest expected impact.

★ Overall consistency between two cases…

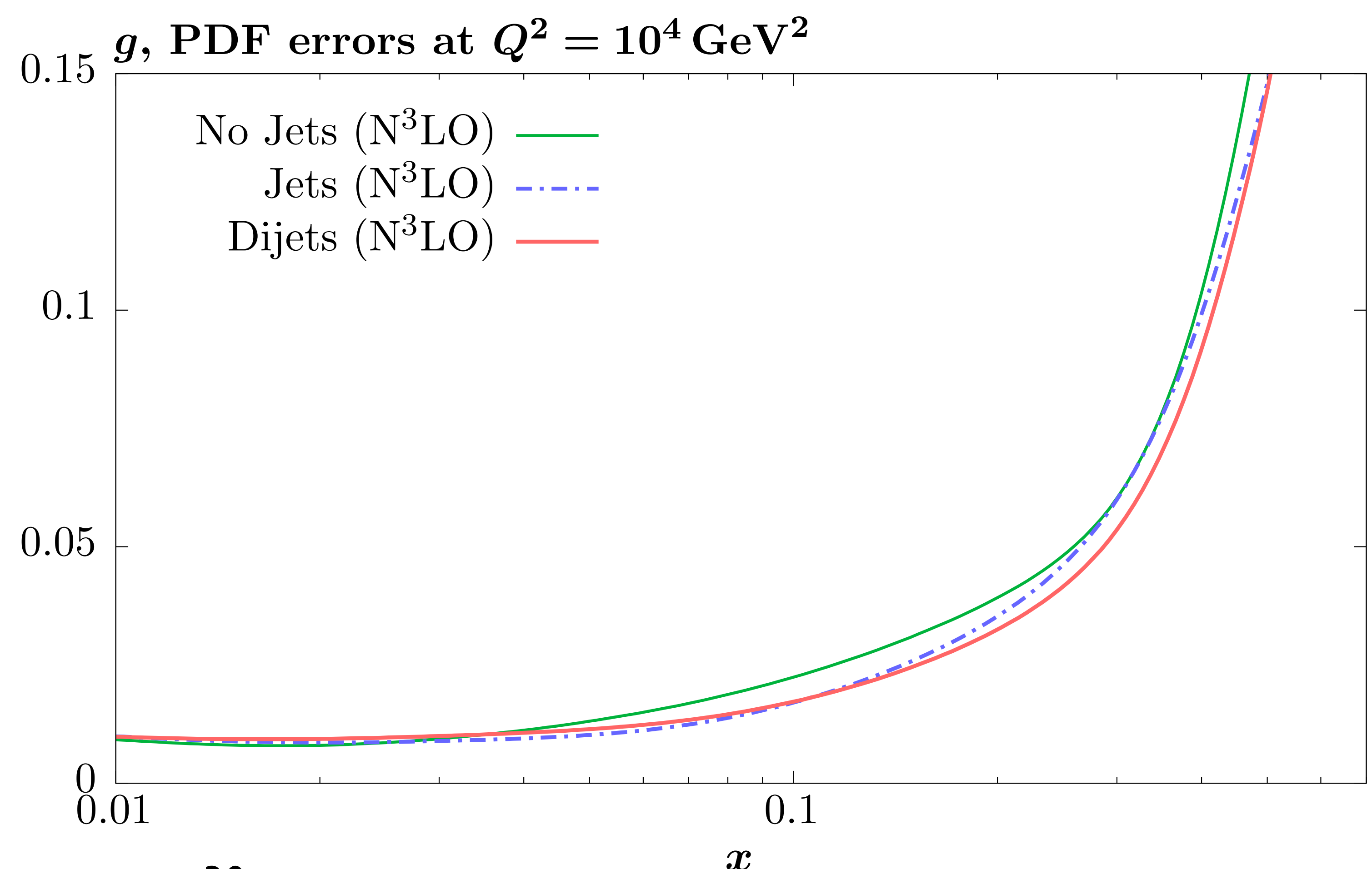
★ But some difference in pull observed between jets/dijets at NNLO.

★ At aN3LO pulls rather similar.





★ Clear reduction in uncertainty in both cases and at both orders.



★ Marginally more significant for dijets.

★ Slightly less significant at aN3LO.

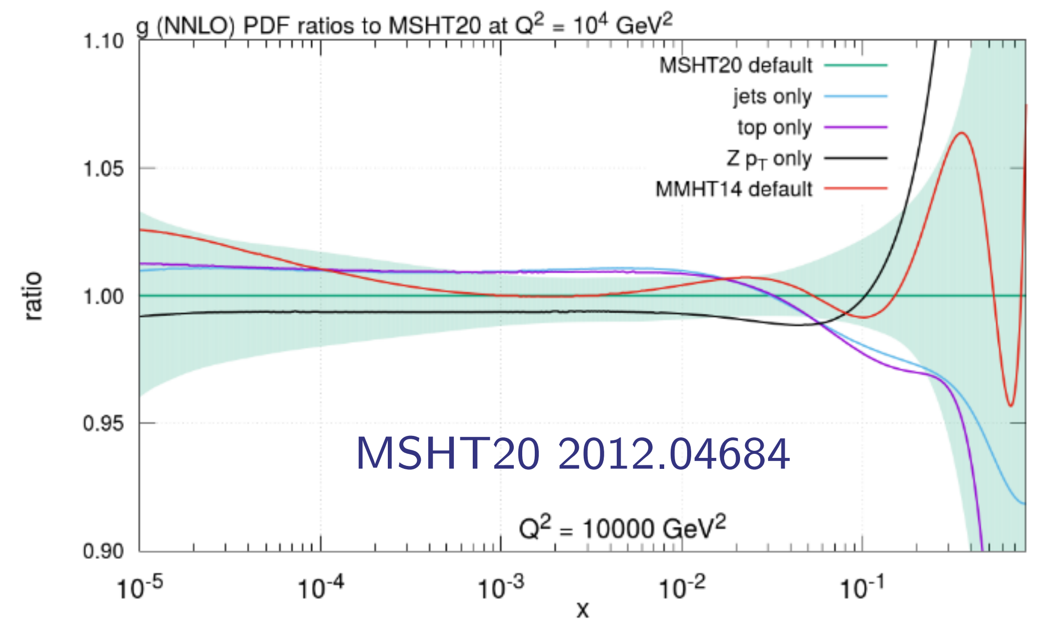
ATLAS $Z\ p_\perp$ data: a closer look

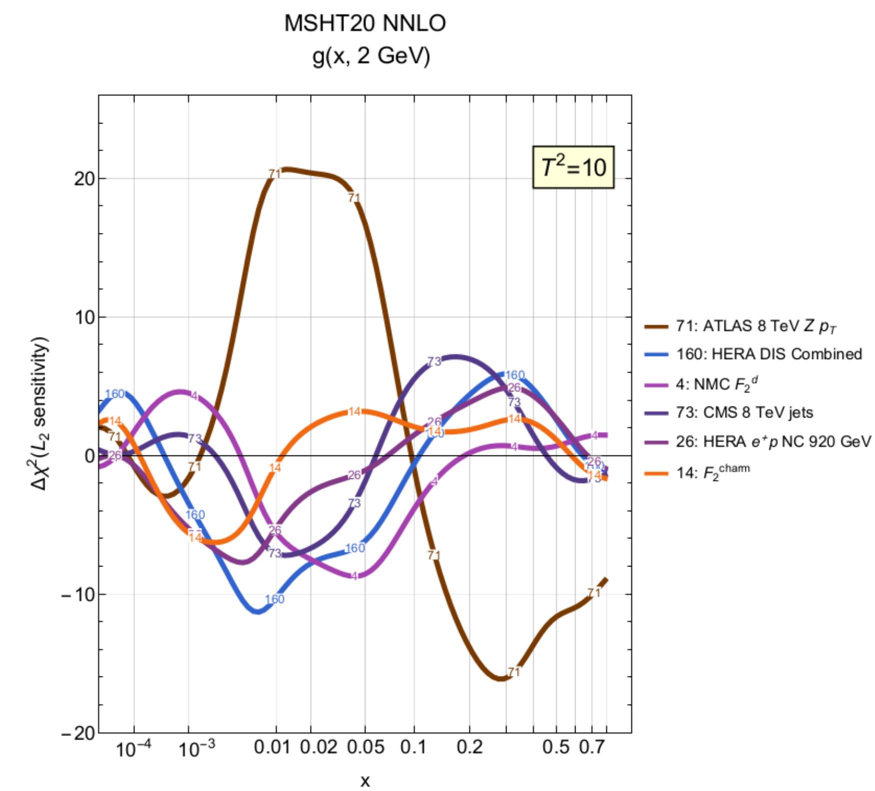
ATLAS 8 TeV Zp_T at NNLO and aN3LO

Preliminary!

- Precise ATLAS 8 TeV Zp_T data constrains high x gluon PDF.
- Tensions with other datasets, certainly at NNLO.
- Different groups treat it differently - differing numbers of datapoints and uncertainties assigned. 104 datapoints in MSHT $\rightarrow$ most of any group.
- Fit quality at NNLO is poor, but at aN3LO is good:

Order	NNLO	aN3LO
ATLAS 8 TeV Zp_T	1.87	1.05
Total	1.22	1.17





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- **Question:** What's responsible for this? $\Rightarrow$ Next slides...

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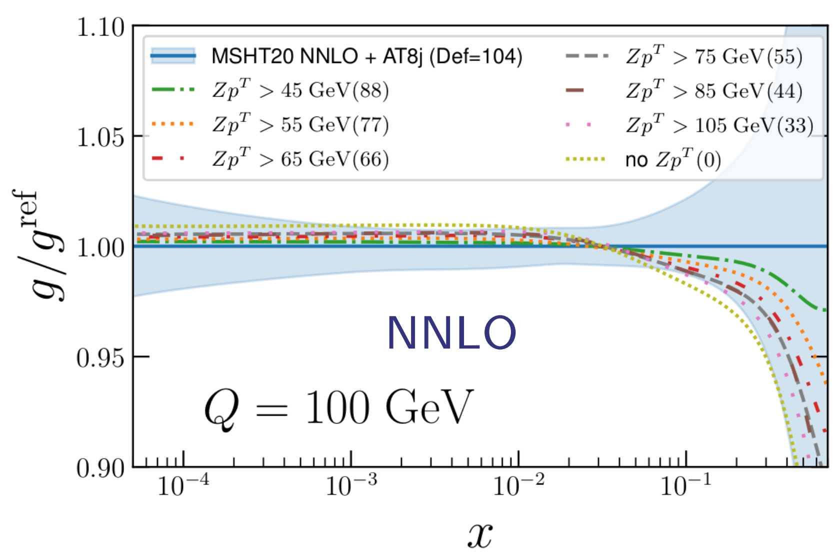
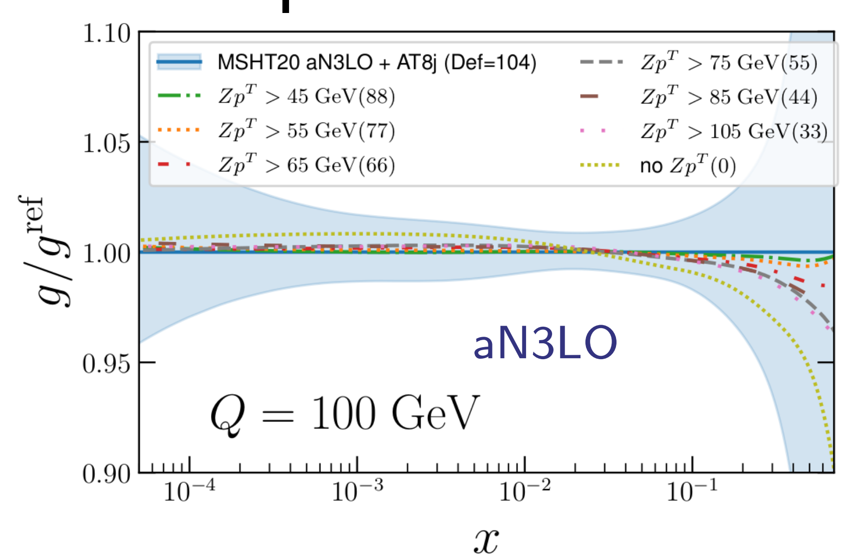
- Any evidence of resummation/EW corrections at low/high p_T^{ll} causing poor fit?
- Alter p_T^{ll} min/max cut and examine fit quality and PDFs.

	p_T^{ll} minimum cut (GeV)							p_T^{ll} maximum cut (GeV)
Fit Order	Default (30)	45	55	65	75	85	105	150
NNLO	1.87	1.73	1.72	1.47	1.45	1.47	1.24	1.91
aN^{3}LO	1.05	0.97	1.03	0.86	0.88	0.71	0.83	1.08
$N_{\rm pts}$	104	88	77	66	55	44	33	82

- Fit quality smoothly improves at each order as more data cut, aN3LO always much better fit than NNLO, regardless of cut/data treatment.
- Same observed in PDFs - effect of cut less pronounced at aN3LO.





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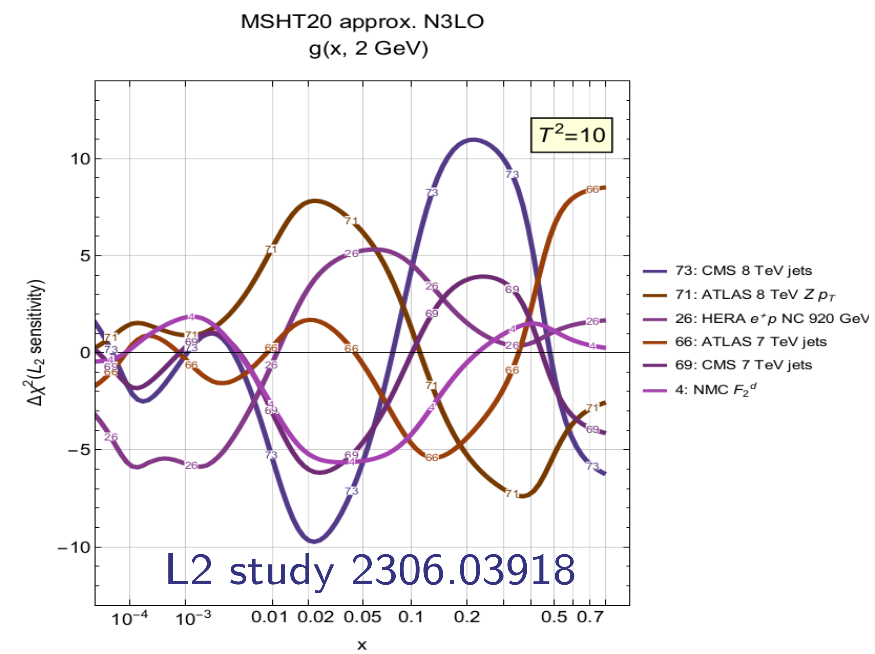
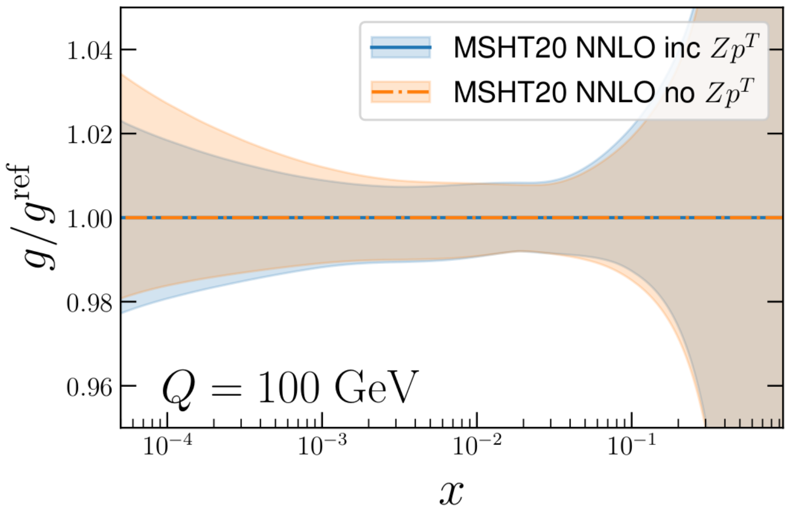
Preliminary!

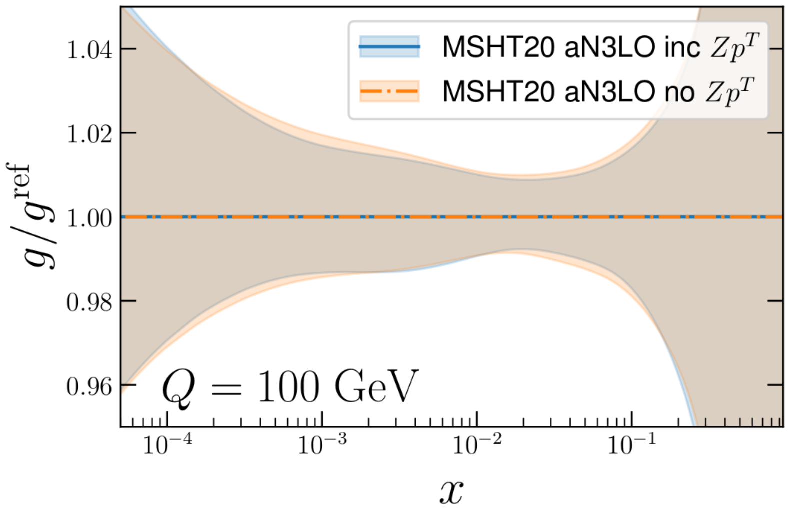
- Tensions between ATLAS 8 TeV Zp_T and other datasets also reduced at aN3LO, e.g. below is $\Delta\chi^2$ upon removal of ATLAS 8 TeV Zp_T:

Dataset	$N_{\rm pts}$	$\Delta\chi^2$ relative to baseline	
		NNLO	aN^{3}LO
NMC μd F_2	123	−4.2	−1.3
CCFR $\nu N \rightarrow \mu\mu X$	86	−2.3	+0.4
HERA e^+p NC 920 GeV	402	−4.1	+2.2
ATLAS 7 TeV jets	140	−3.4	−0.6
ATLAS 7 TeV high prec. W, Z	61	−8.4	−3.9
ATLAS 8 TeV W	22	−4.1	−1.3
ATLAS 8 TeV double diff. Z	59	−5.5	−4.3
ATLAS 8 TeV jets	171	−6.4	−4.3
Total	4430	−35.9	−22.0



- Reduced tensions enable Zp_T to have notable impact on high x gluon PDF uncertainty, unlike at NNLO.





- Fit strongly prefers aN3LO over NNLO.
- High precision data requires high precision theory.

Summary/Outlook

★ First QED + aN3LO PDF analysis presented here. Publicly available PDF sets + accompanying paper to appear soon. Stay tuned!

★ Study of jet vs. dijet production at up to aN3LO

- Jet fit quality relatively poor, remains so in aN3LO fit.
- Dijet fit quality good, and with improvement at aN3LO in line with expectations.
- Scale choice does not play big role in inclusive, EW corrections make fit quality worse (!).

★ All indicates that dijet data may be preferable. However remains preliminary: impact of full colour and more precise K-factors under investigation.

★ Study of ATLAS ZpT data: no sign of issues in any particular region. Dramatic improvement at aN3LO.

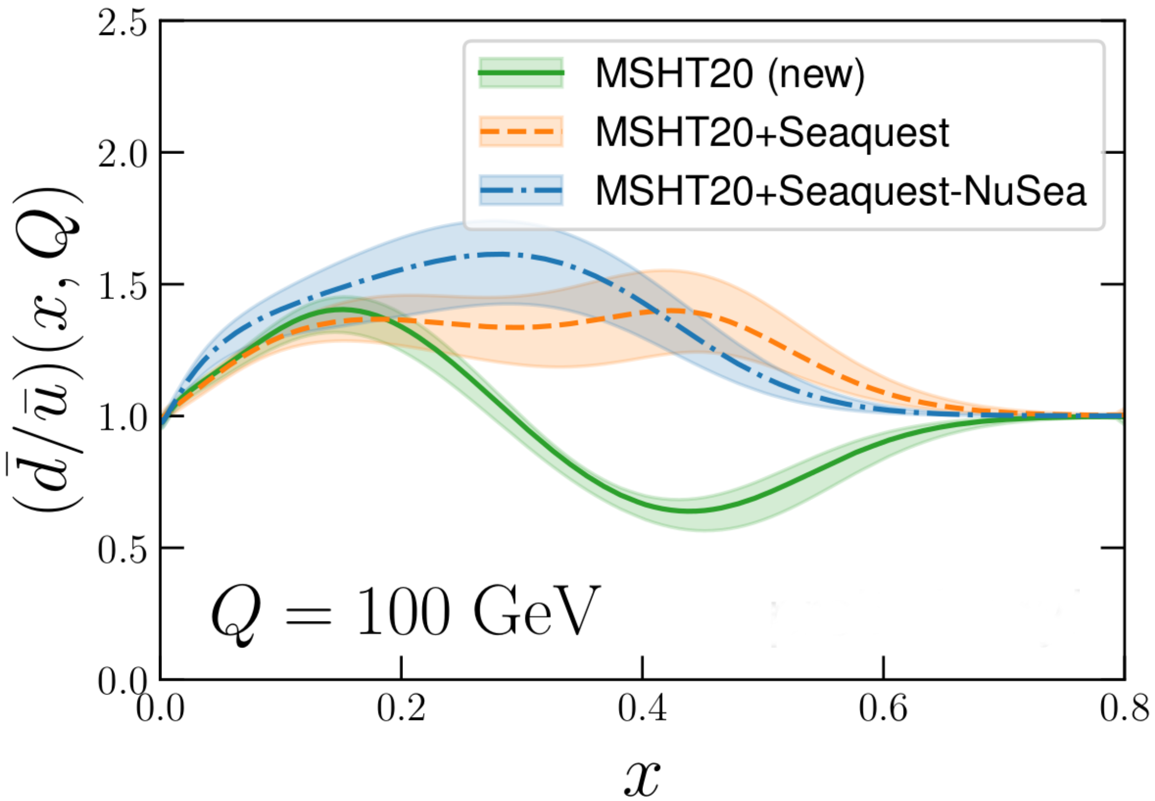
Thank you for listening!

Backup

New data - Seaquest (NNLO)

Preliminary!

- Seaquest (E906) fixed target DY data - sensitivity to high x q, $\bar{q}$:
  $\Rightarrow \sigma_D/\sigma_H \sim 1 + \bar{d}/\bar{u}$. Direct measurement of $\bar{d}/\bar{u}$ at high x.
- Various models for $\bar{d}/\bar{u}$ at high x: Pauli blocking, pion cloud, etc.
- Previous questions of NuSea (E866) data preferring $\bar{d} < \bar{u}$ at $x \approx 0.4$.
- Clearly raises high x $\bar{d}/\bar{u}$. Tension with NuSea which pulls it down.



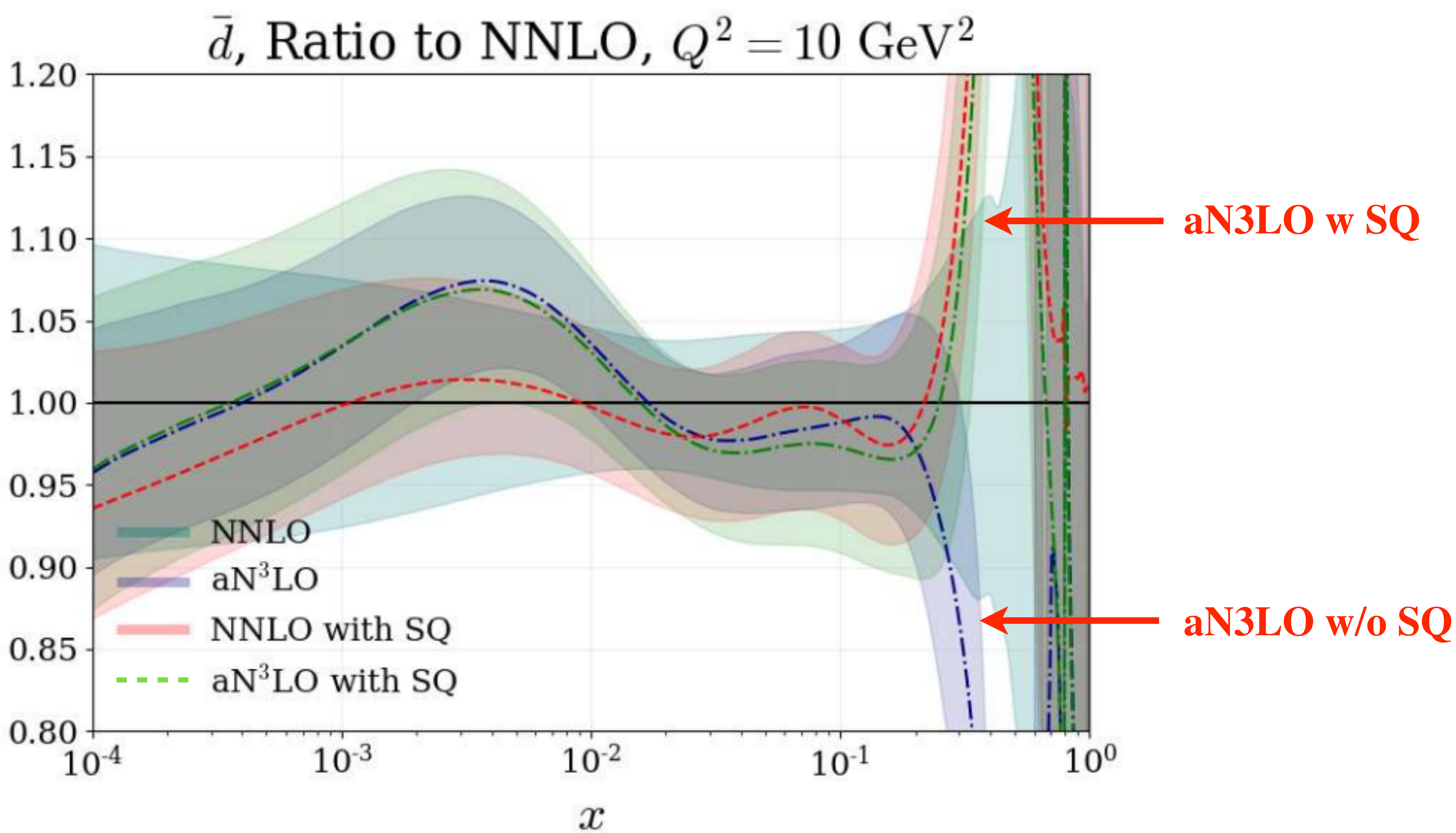
Dataset	$N_{\rm pts}$	MSHT20	New
Seaquest	6	-	8.2
NuSea	15	9.8	19.0
Total (without Seaquest or NuSea)	4348	5102.3	5112.1

- NuSea $\chi^2/N_{\rm pts}$: $0.65 \rightarrow 1.27$, when Seaquest added.

- Rest of data also worsens in χ^2 by 9 points, with 4.5 in E866 absolute DY (rather than ratio), 4.4 in NMC n/p, 4.3 in DØ W asymmetry.

Slide credit: T. Cridge

- At aN3LO, the $\bar{d}$ become negative above $x \sim 0.5$ with a minimum at $x \sim 0.6$. Nonetheless remains positive within uncertainties.
- Like at NNLO, adding the Seaquest data raises the $\bar{d}/\bar{u}$.
- Adding Seaquest $\Rightarrow$ NNLO and aN3LO $\bar{d}$, $\bar{u}$ again very similar.
- Effect on fit quality of adding Seaquest similar to NNLO, $\Delta\chi^2 = +6$ in rest of data, NuSea χ^2/N doubles from ~ 0.6 to ~ 1.3.



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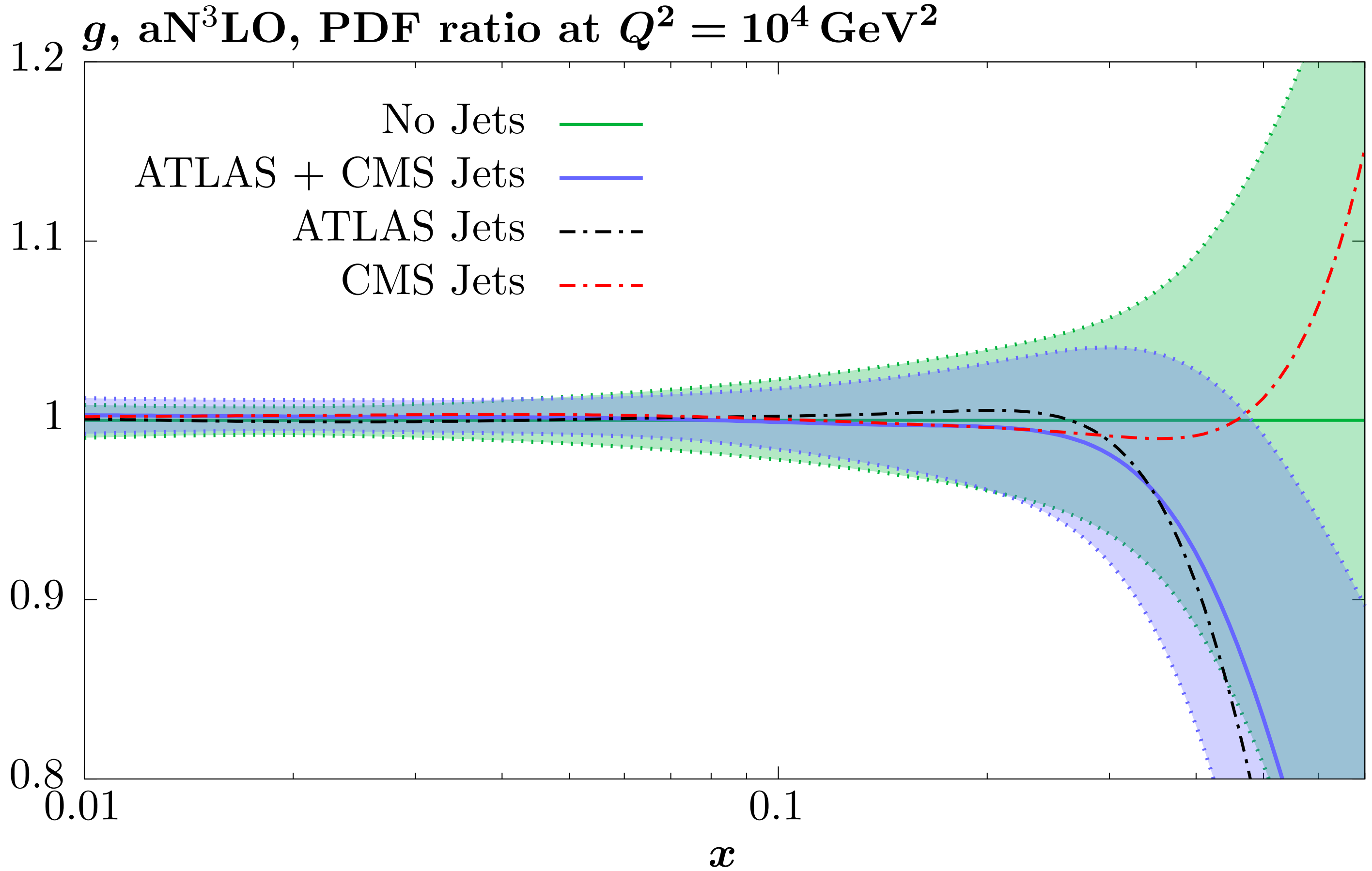
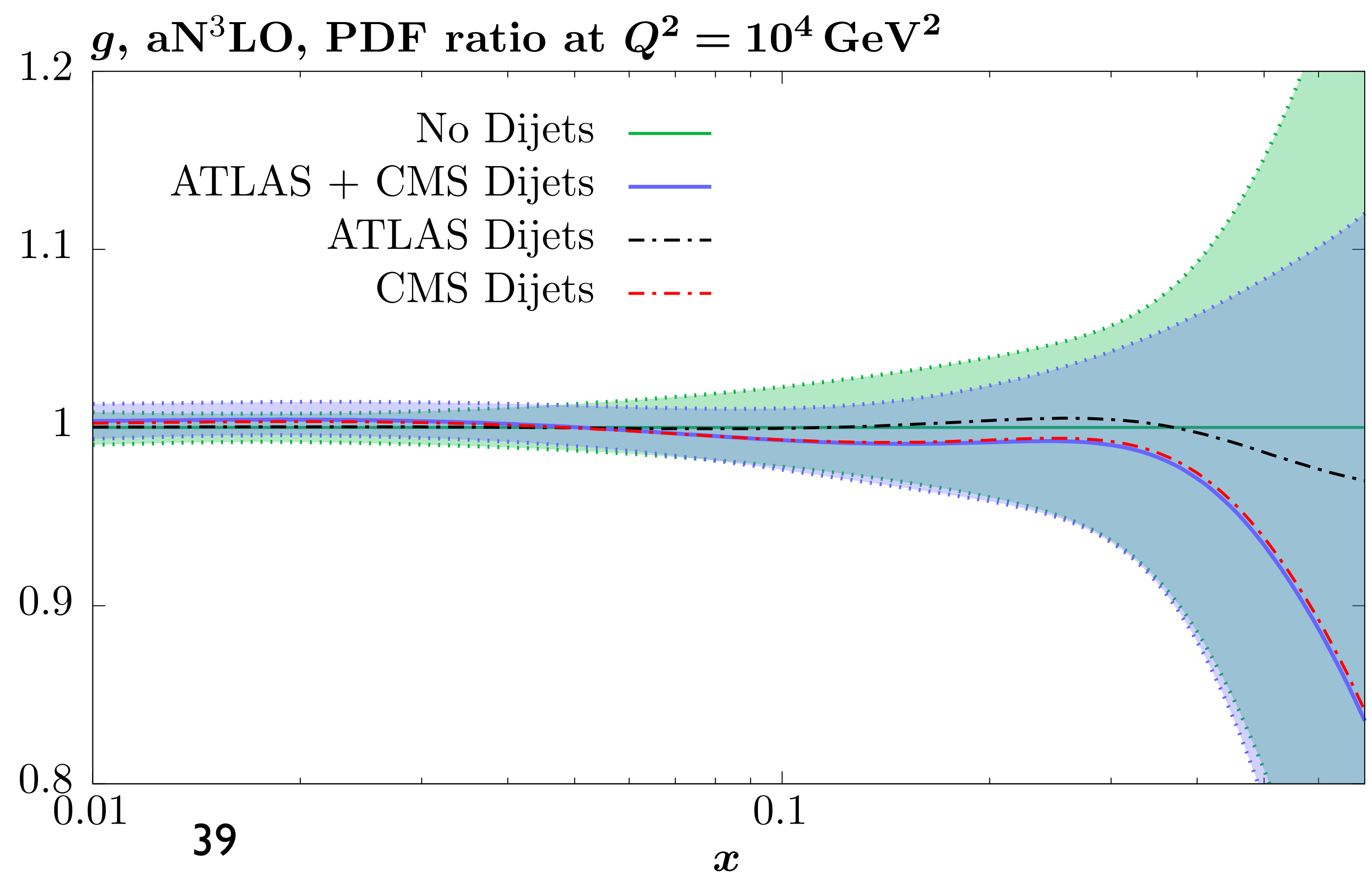
Consistency within datasets

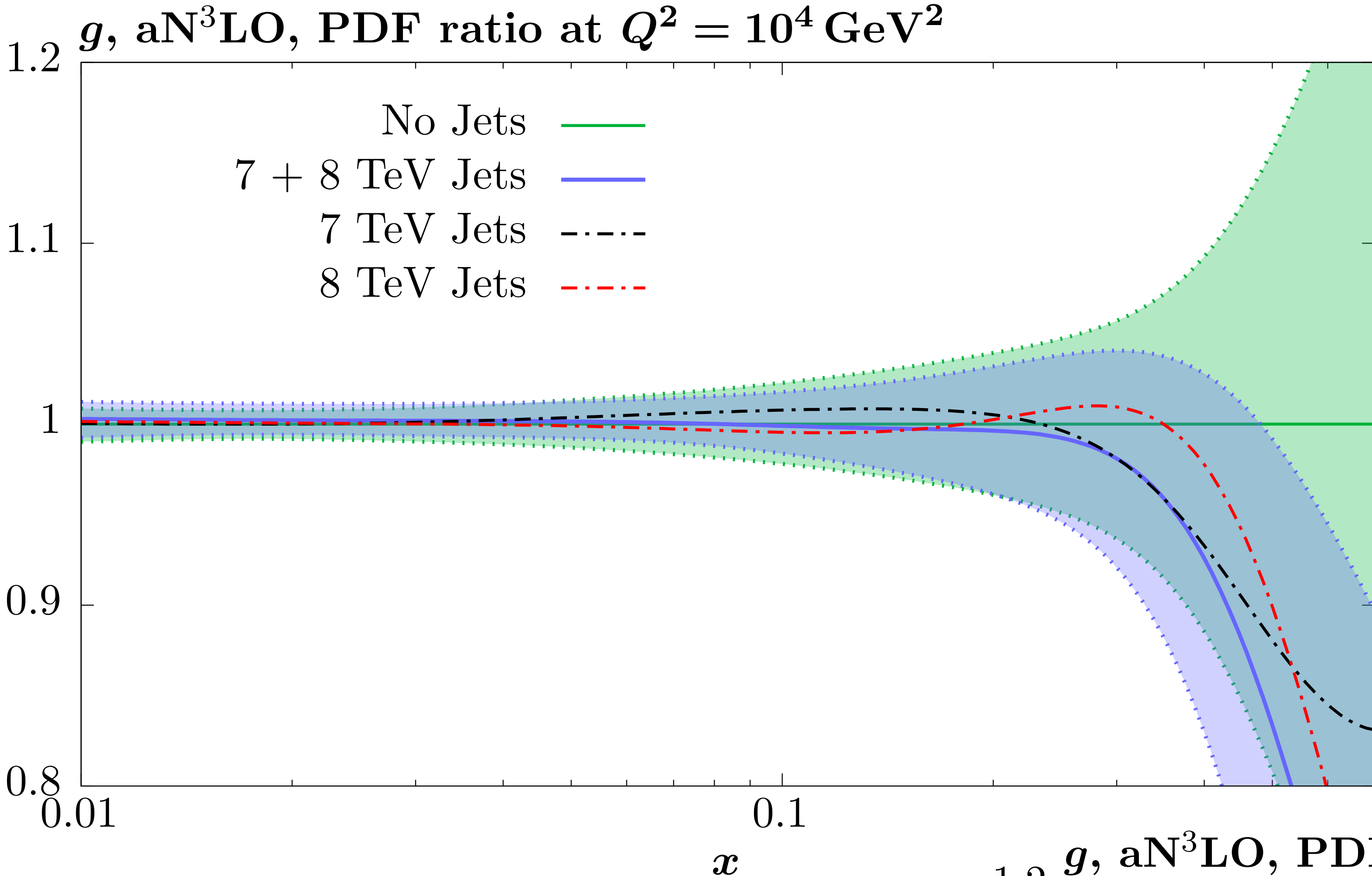


- Jets: At higher x clear difference between pulls of ATLAS and CMS (also seen in MSHT20).
- Final result compromise between these.

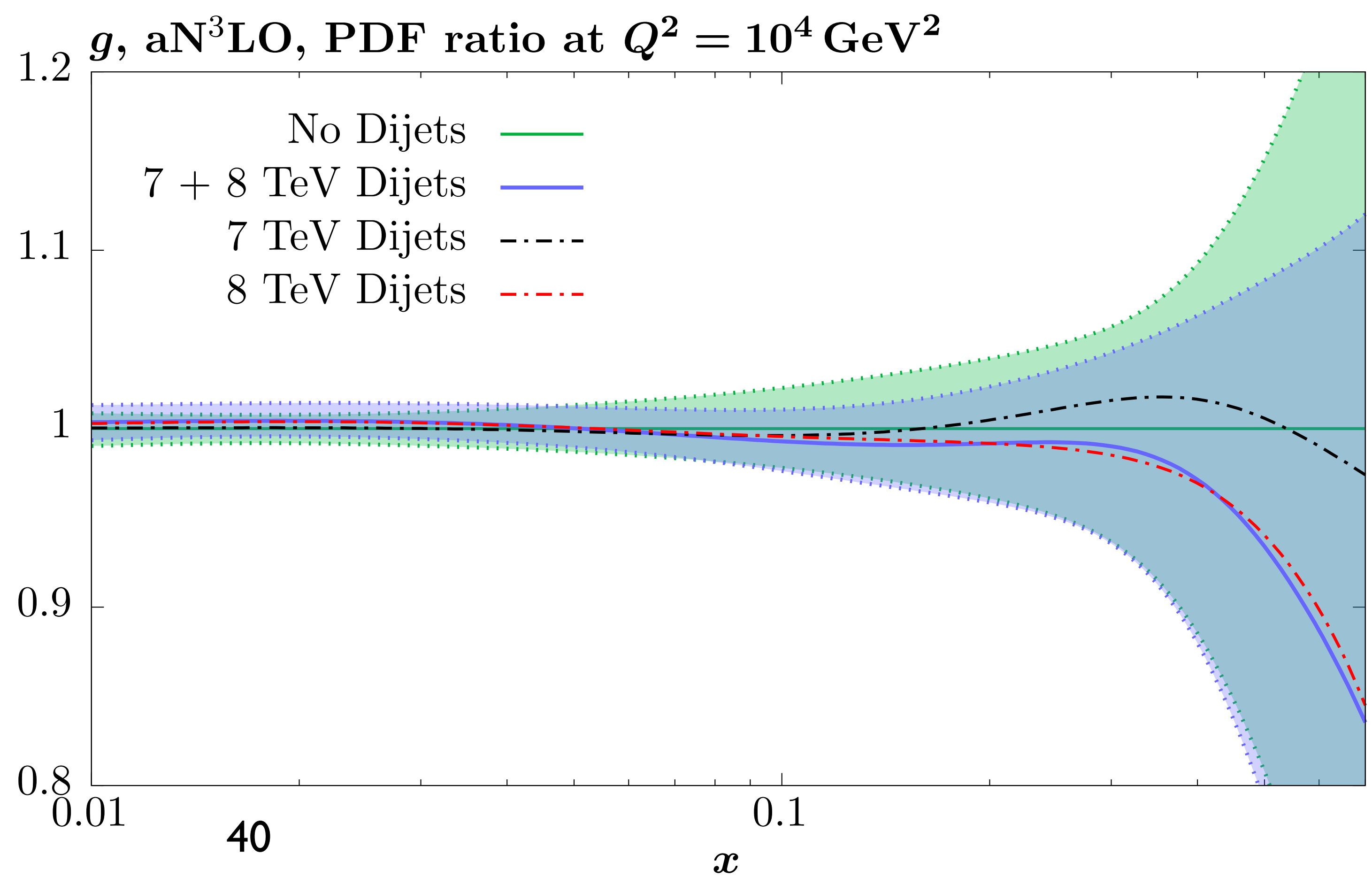


- Dijets: consistency between CMS and ATLAS, but latter has very little impact alone.
- Again CMS 8 TeV driving fit.
- Similar story at NNLO (not shown).

Consistency within datasets

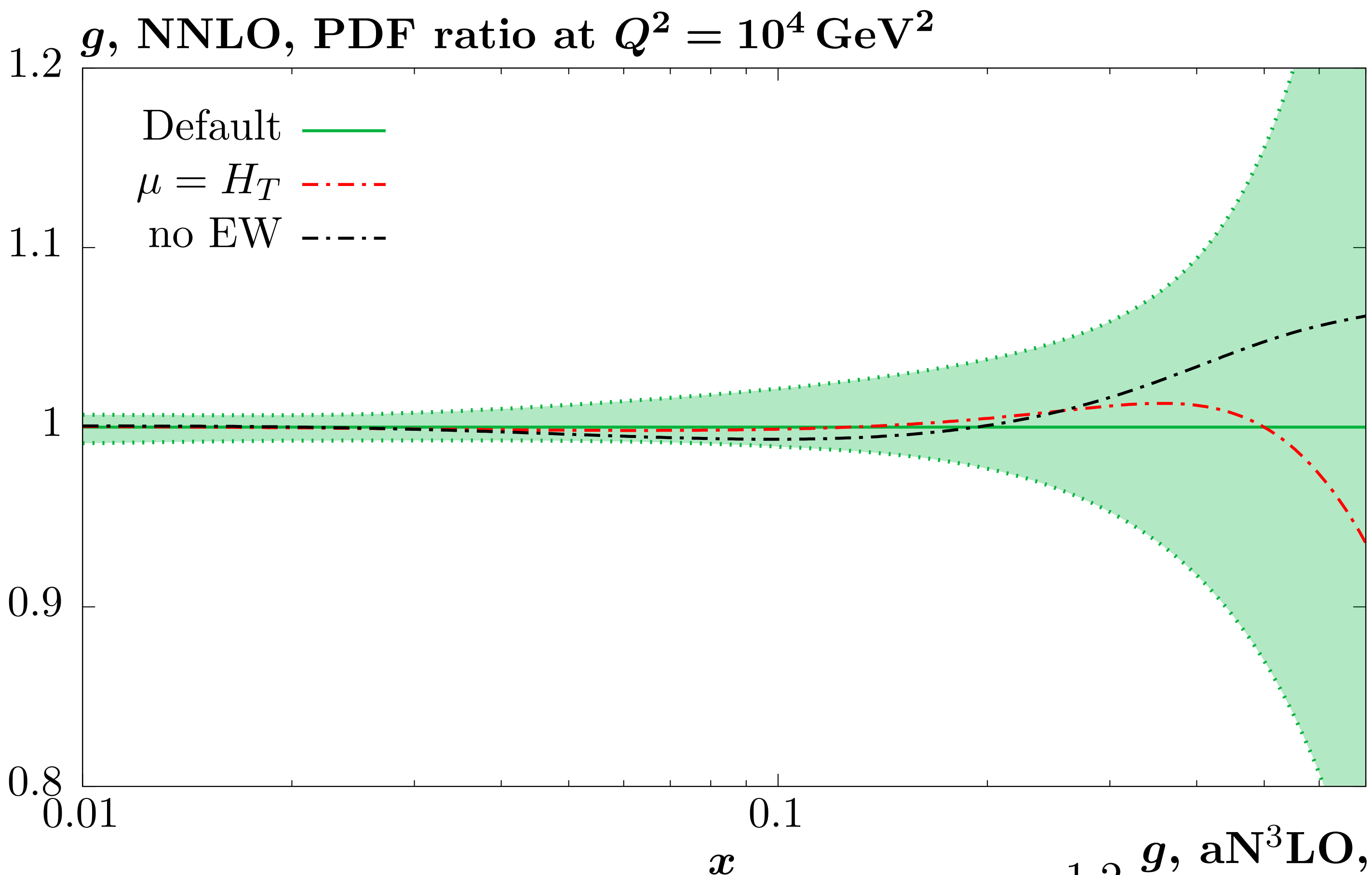


- *7* & 8 TeV data ~ consistent pulls inclusive jets.
- Similar for NNLO (not shown).

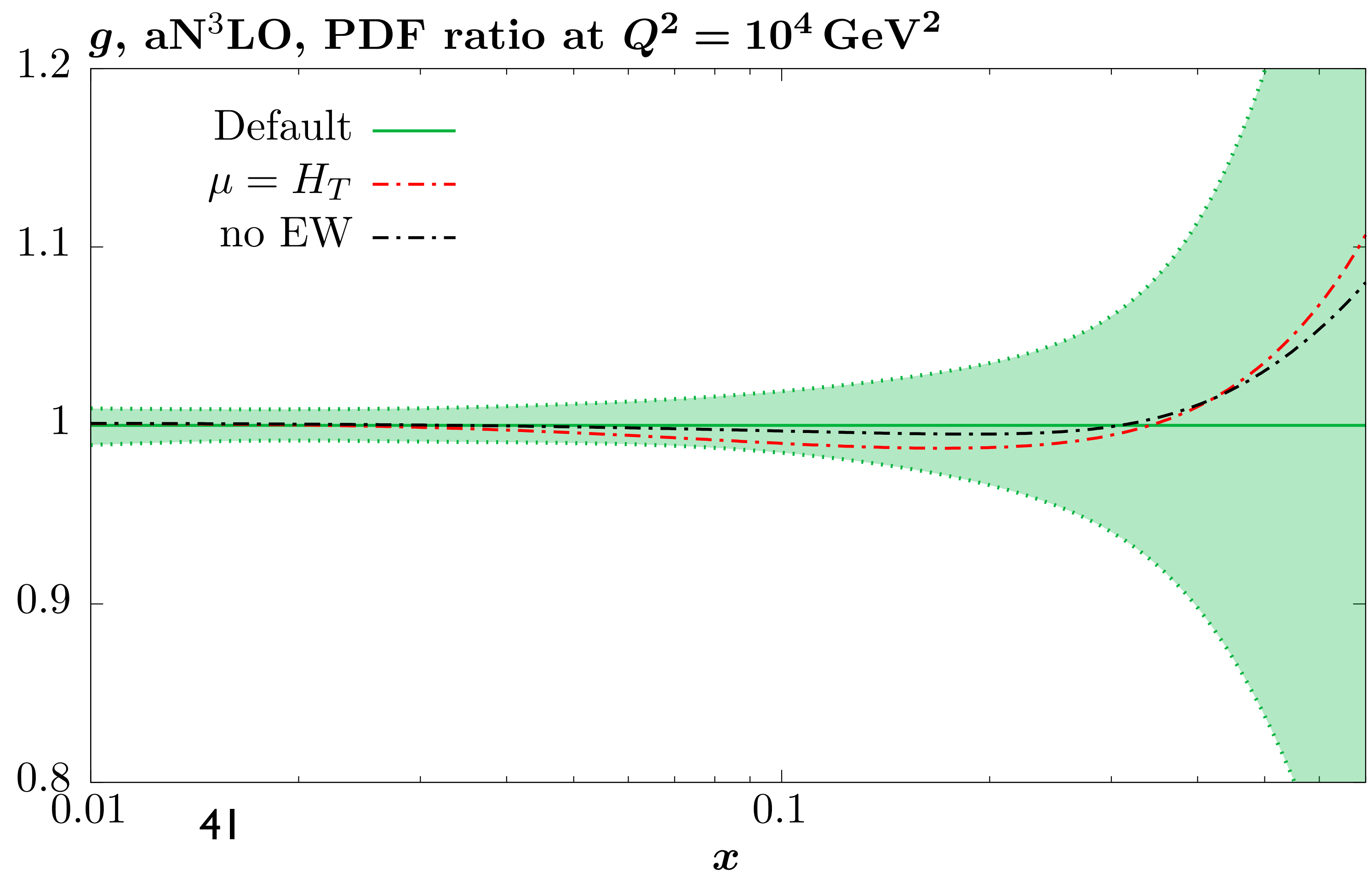


- *7* & 8 TeV data consistent for dijets, but this is due to broader result.
- All dijet fits completely driven by CMS 8 TeV data
- Similar for NNLO (not shown).

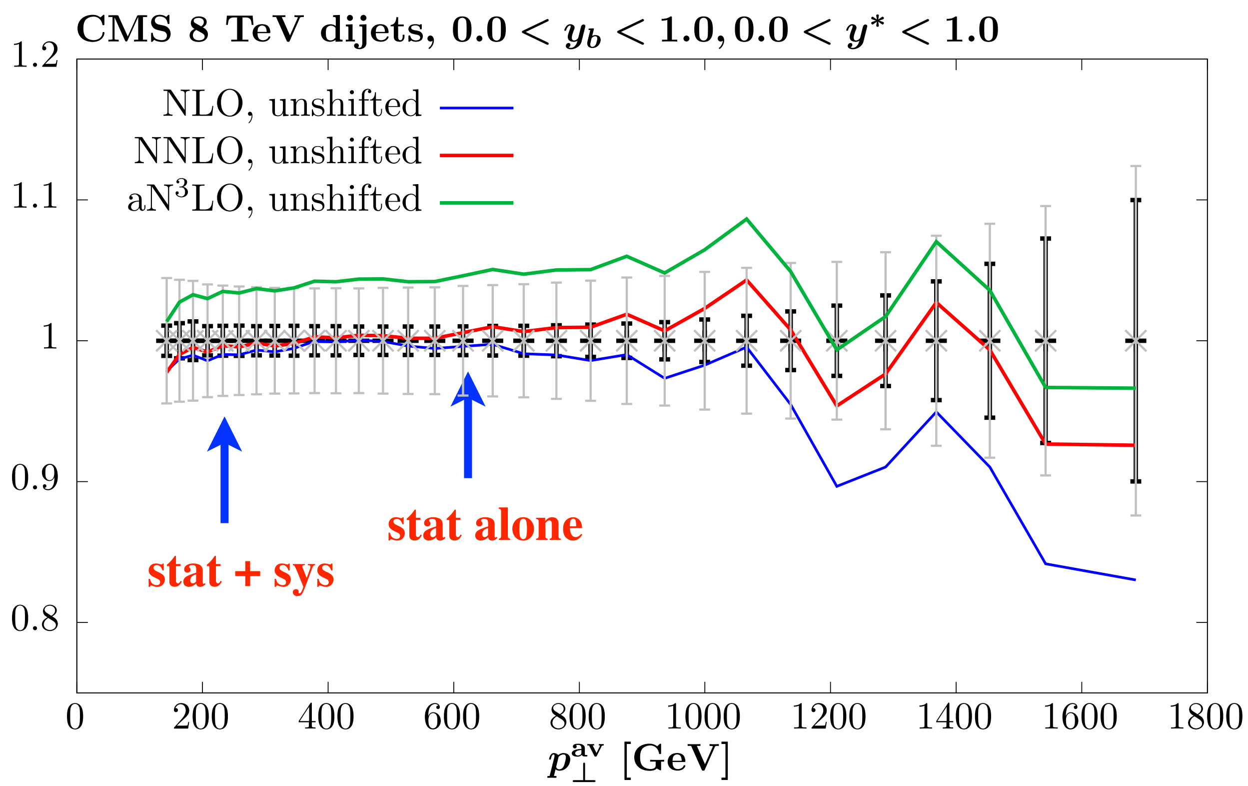
PDFs: EW corrections/scale choice

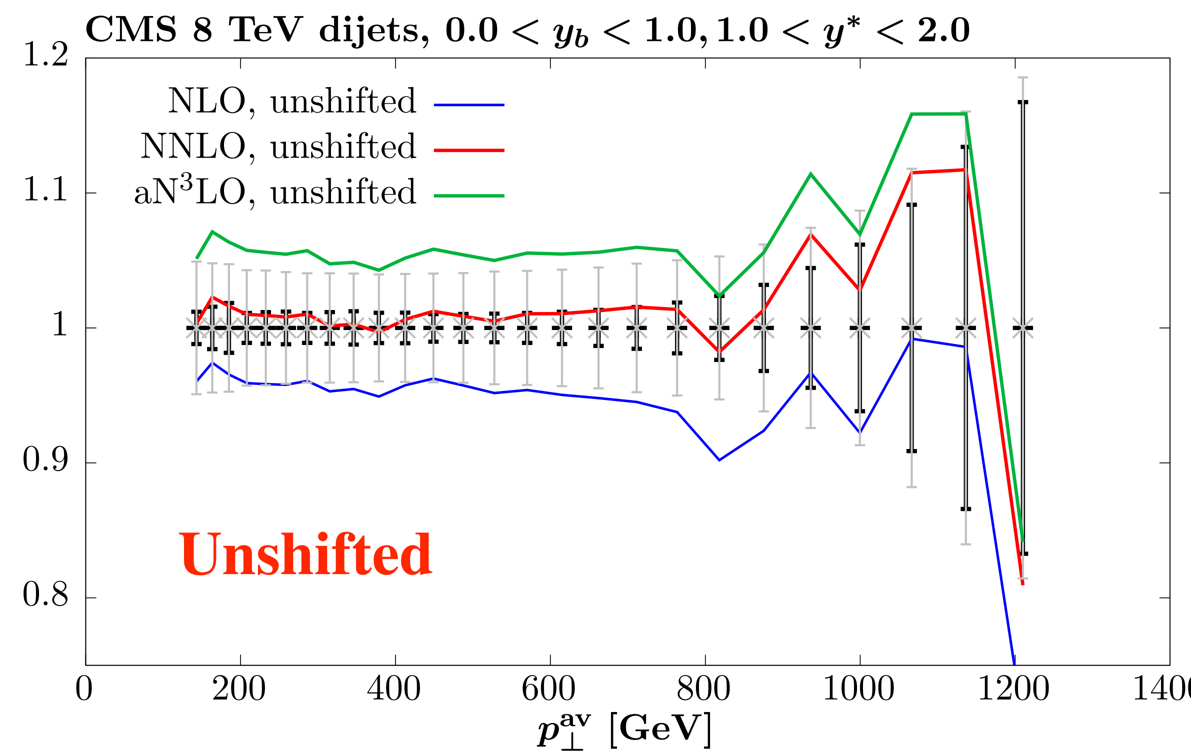


★Impact of these on gluon small, though not completely negligible.

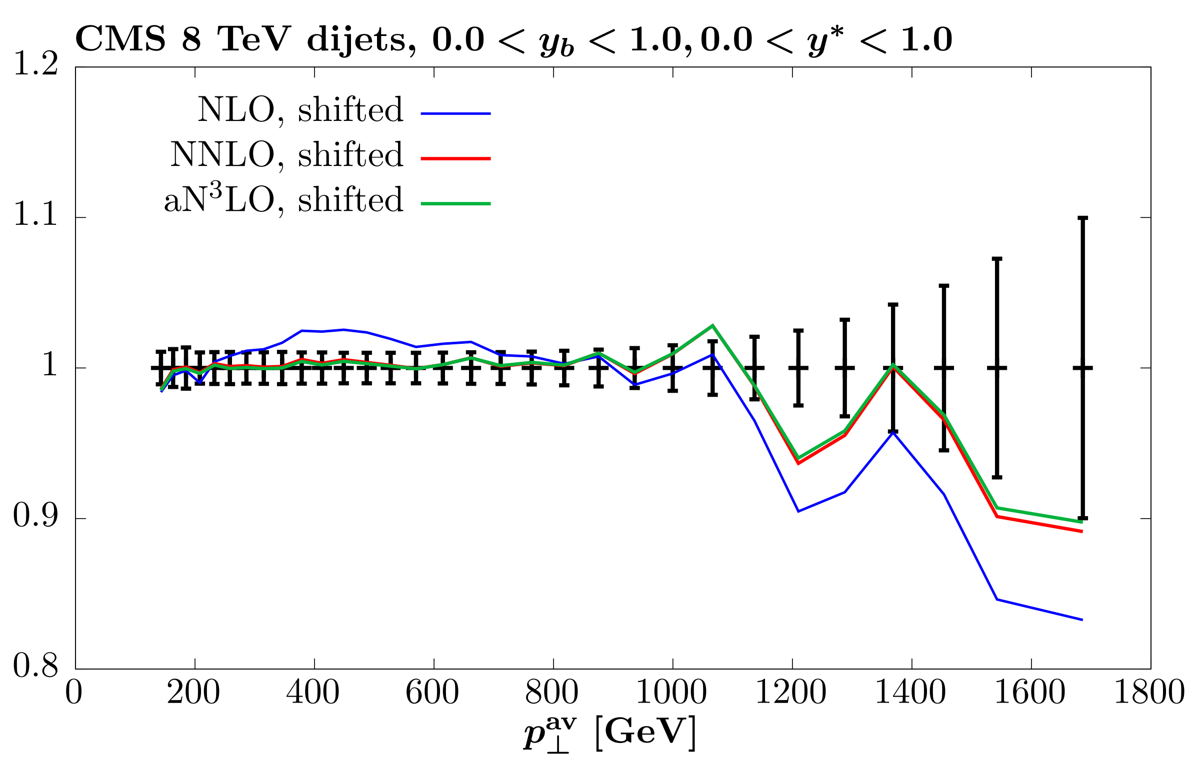


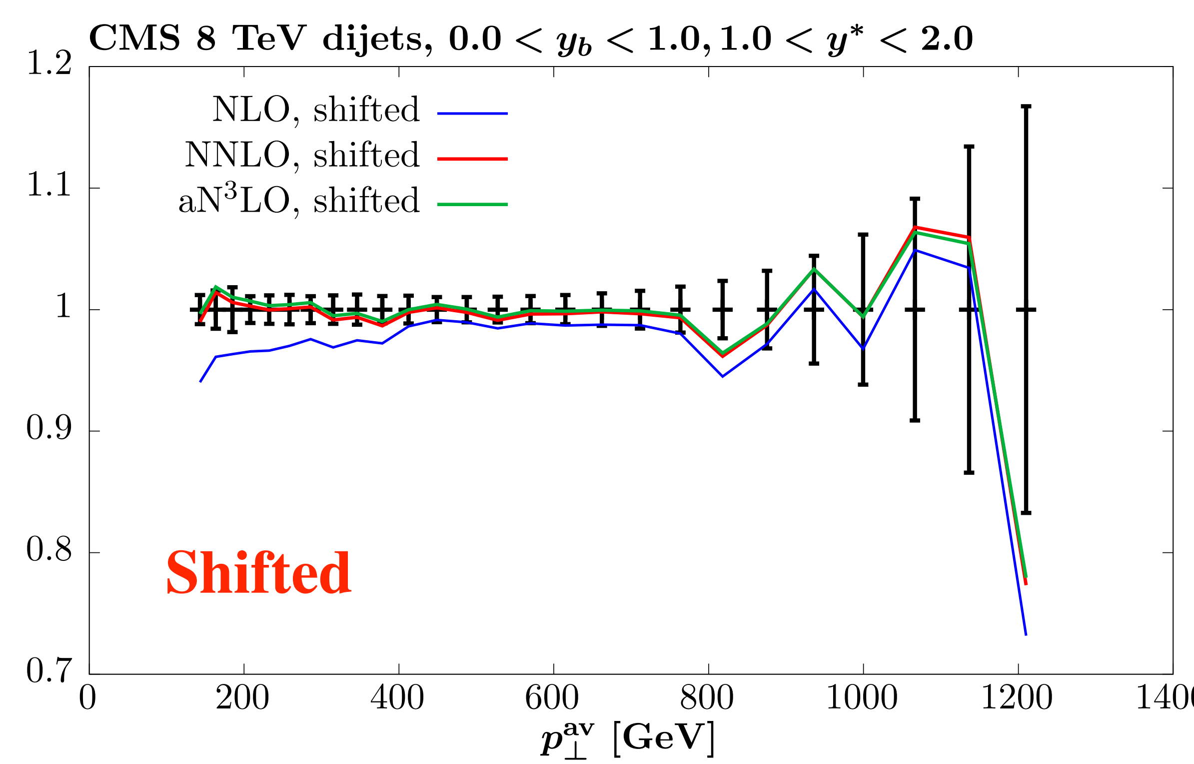
- No clear, by eye, trend for better description at NNLO, aN3LO.





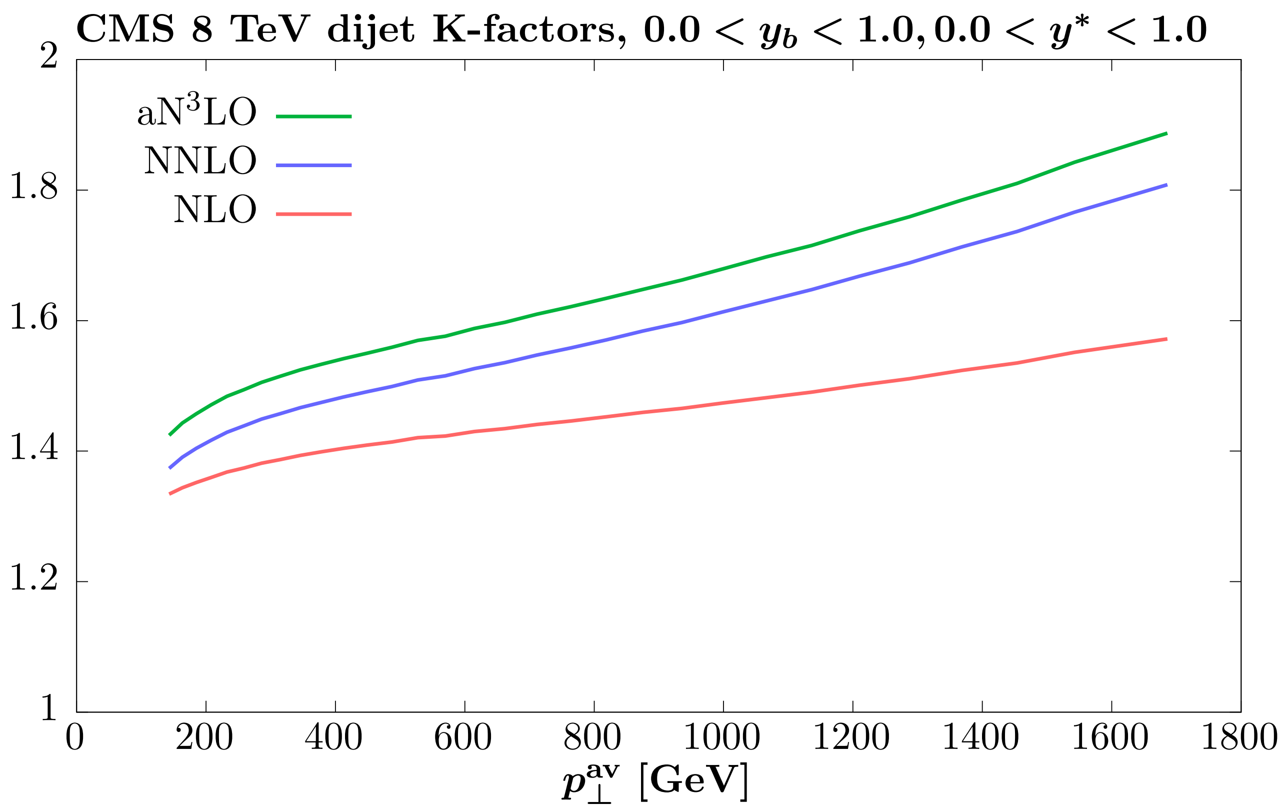
- However this is **before** shifting by correlated systematics.

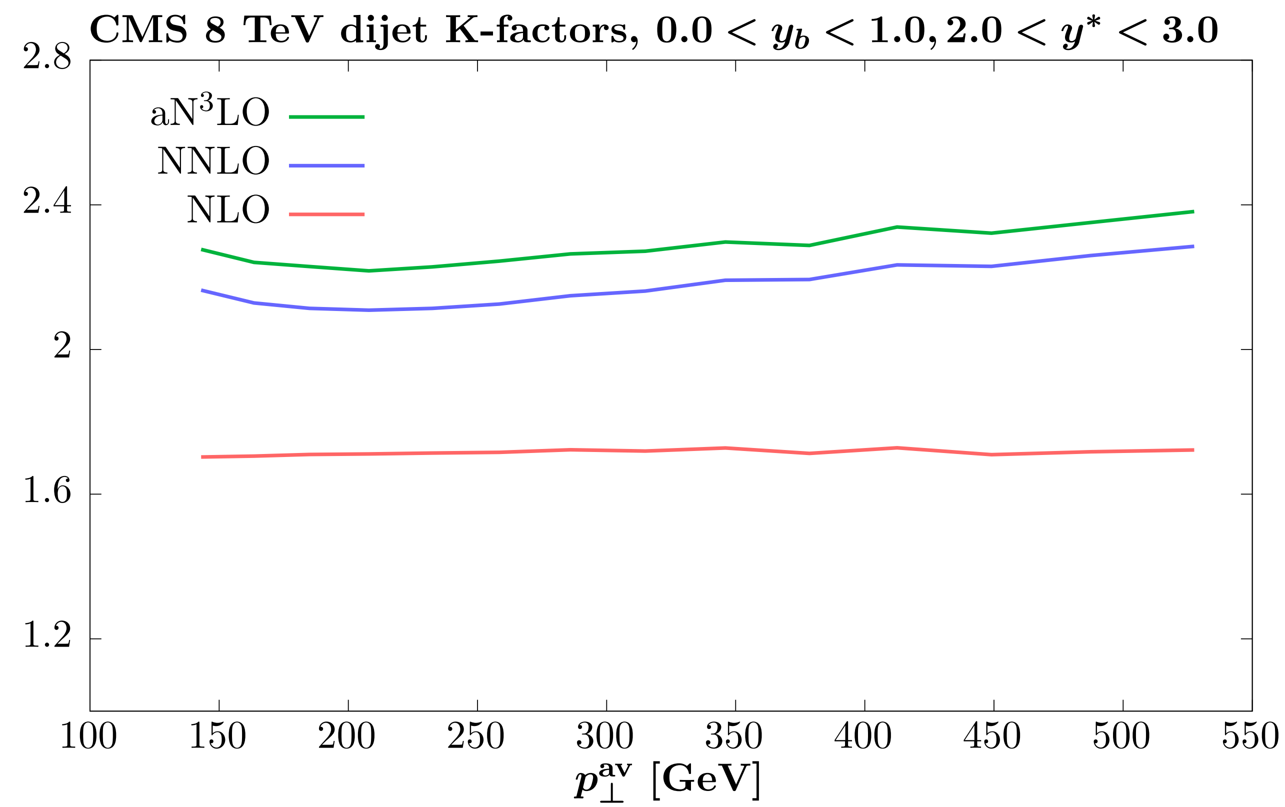




• Impact on shape of distributions in 3D kinematic space and interplay with correlated systematics drives this.

• However some clue from looking at K-factors:





★ NNLO corrections reasonable large, in particular in some regions of phase space.

★ Also shown are the aN3LO K-factors preferred by the fit: nice trend for perturbative stability, in line with lower orders.

★ Similar stability in inclusive jet case, but overall smaller K-factors.