MMHT updates, LHC data and α_S

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April 17th, 2018

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With contributions from Lucian Harland-Lang, Alan Martin and Ricky Nathvani

I will briefly summarise final results on studies for new LHC jet collider data at NLO and NNLO.

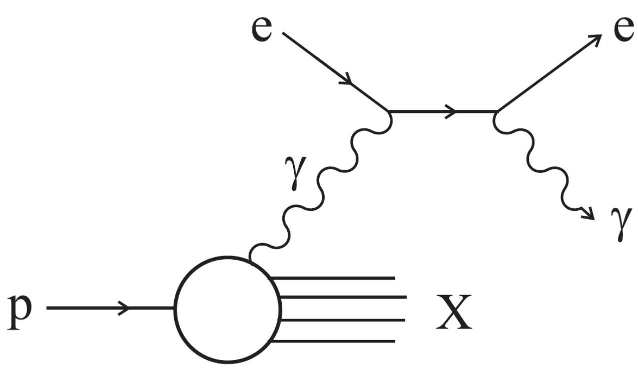
I will also discuss recent preliminary results on the best-fit $\alpha_S(M_Z^2)$ values.

I also consider the consistency of all the most recent added LHC data.

PDFs with QED corrections - advert

At the level of accuracy we are now approaching it is important to account for electroweak corrections. At the LHC this can be important for many processes ($W, Z, WH, ZH, WW, jets \ldots$).

For a consistent treatment need PDFS which incorporate QED into the evolution, i.e. the inclusion of the photon PDF $\gamma(x, Q^2)$. (A. De Rujula *et. al.* NPB154 (1979) 394, J. Kripfganz and H. Perlt, ZPC41 (1988) 319, J. Blümlein, ZPC47 (1990) 89.)



$$\frac{\partial\gamma(x,Q^2)}{\partial \log Q^2} = \frac{\alpha}{2\pi}\int_x^1 \frac{dy}{y}\left(P_{\gamma\gamma}\otimes\gamma + \sum_1 e_i^2 P_{\gamma q}\otimes q_i\right)$$

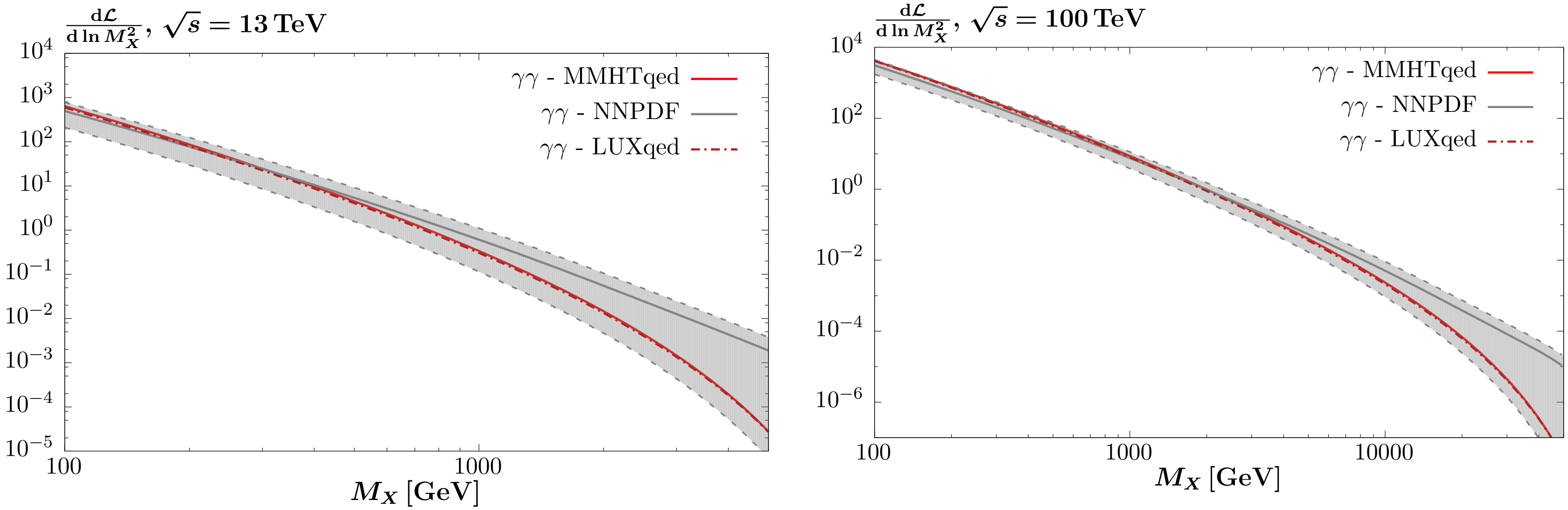
MRST2004 assumed $\gamma(x, Q^2)$ generated by photon emission off model for valence quarks with QED evolution from $m_q \rightarrow Q_0^2$.

Breakdown into well-known elastic (coherent) contribution and moderately model dependent inelastic part Harland-Lang *et al.* PRD94 (2016) 074008. Much better constraint on input.

MMHT PDFs with QED corrections.

Full quantitative relationship between photon PDF and structure function made by LUXqed (A. Manohar et al., PRL 117, 242002 (2016), arXiv:1708.01256).

We now base photon input for PDFs at low Q^2 on the LUXqed prescription, MMHT photon (Nathvani) very similar to LUXqed.



Effect of photon evolution fully incorporated to couple with that of quarks and gluon for both proton and neutron.

Evolution now included at $\mathcal{O}(\alpha + \alpha_S\alpha + \alpha^2)$.

Many more details on Thursday – Nathvani.

Inclusion of full $7\ \mathrm{TeV}$ ATLAS, CMS jet data.

Initial fit to high luminosity ATLAS $7\ \mathrm{TeV}$ inclusive jet data (JHEP 02 (2015) 153) taking as default $R = 0.4$ and $\mu = p_{T,1}$ and work at NLO.

Prediction at NLO gives $\chi^2/N_{pts} = 413.1/140$.

Refit gives improvement only to $\chi^2/N_{pts} = 400.4/140$.

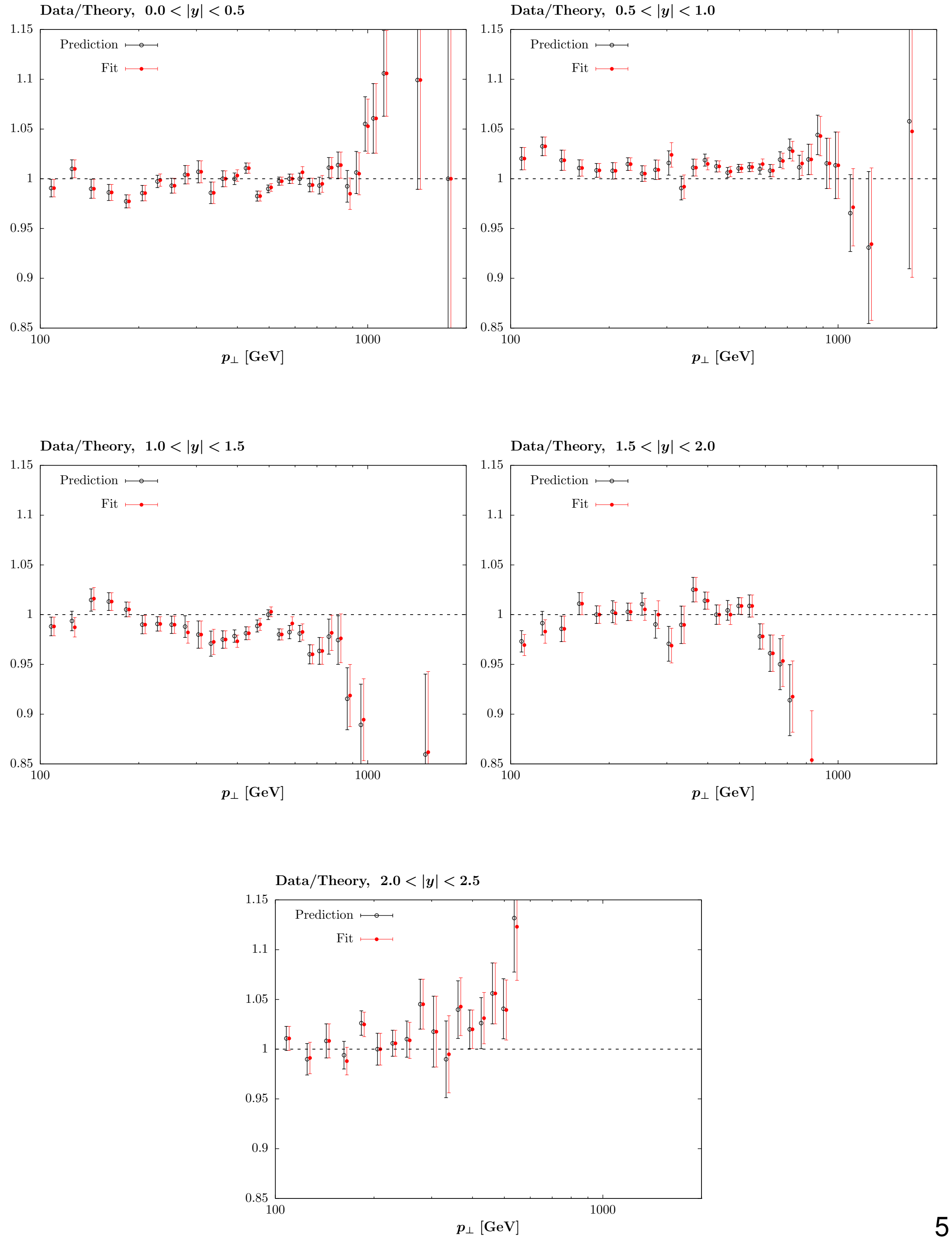
Deterioration in other data $\Delta\chi^2 \sim 3$, so no strong tensions.

Cannot simultaneously fit data in all rapidity bins. Mismatch in one bin different in form to neighbouring bin constraining PDFs of similar x, Q^2.

Similar results also seen by other groups.

Qualitative conclusion shown to be independent of jet radius R, choice of scale or inclusion of NNLO corrections, though χ^2 often a bit better.

Cannot simultaneously fit well data in all bins. Mismatch in one rapidity bin different to others probing PDFs of similar flavour, x and Q^2.



Exercise on decorrelating uncertainties

We consider the effect on the χ^2 of the simultaneous fit to all data of decorrelating two uncertainty sources, i.e. making them independent between the 6 rapidity bins.

Compared to the original $\chi^2/N_{pts} = 2.85$ we get instead

	Full	21	62	21,62
$\chi^2/N_{\mathrm{pts.}}$	2.85	1.58	2.36	1.27

Table 1: χ^2 per number of data points ($N_{\mathrm{pts}} = 140$) for fit to ATLAS jets data [23], with the default systematic error treatment ('full') and with certain errors, defined in the text, decorrelated between jet rapidity bins.

Very significant improvement, particularly from decorrelating jes21.

With correlations between rapidity bins relaxed for just two sources of systematics $\chi^2/N_{pts} = 178/140 = 1.27$.

More extensive decorrelation study in ATLAS – JHEP 09 020 (2017).

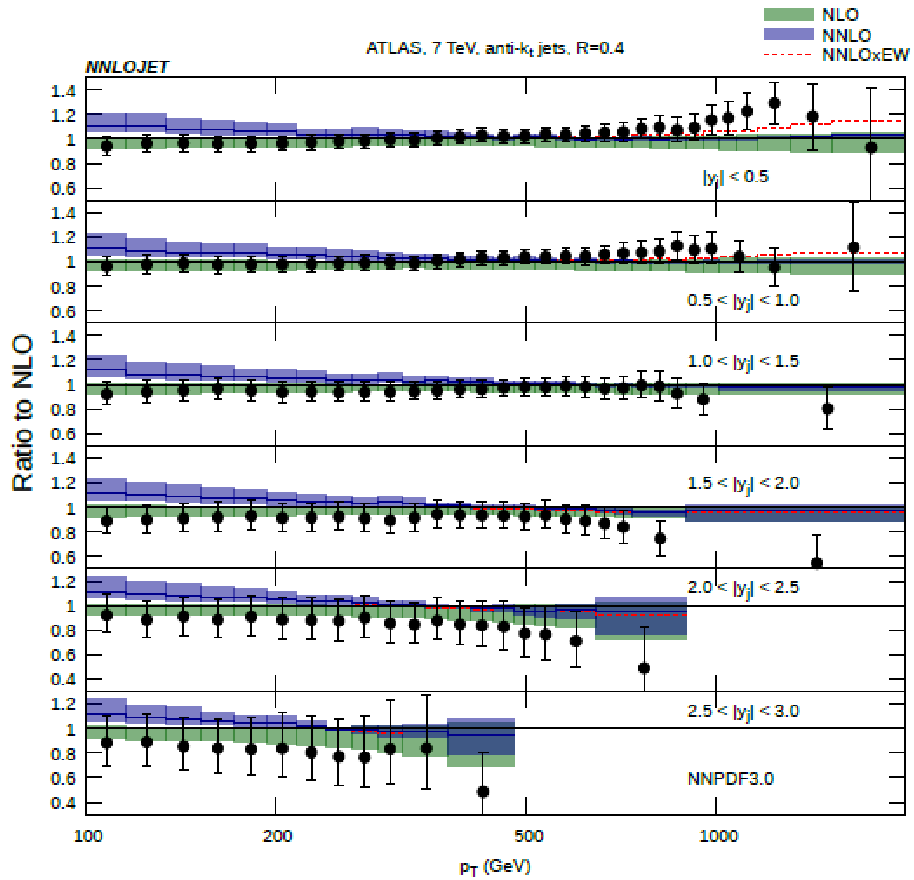
NNLO corrections

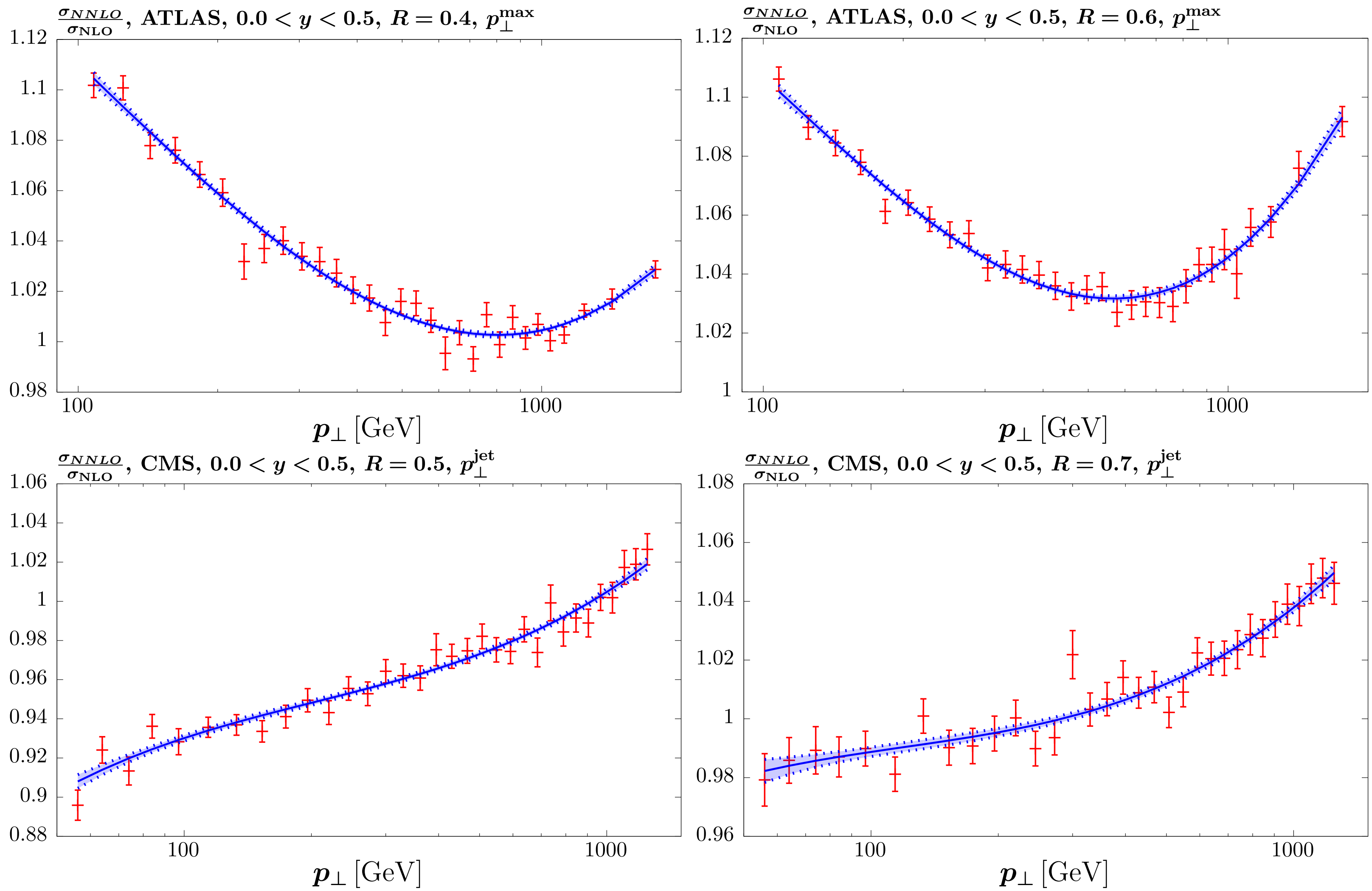
Currie *et al* Phys.Rev.Lett. 118 (2017) 072002.

Exact form dependent on R (smaller for $R \sim 0.6$) and on scale choice, e.g $\mu = p_{T,1}$ or p_T. Up to 20% at low p_T.

Fit quality can slightly improve or decrease compared to NLO depending on choices.

Electroweak corrections to jets different in different bins, but much smaller than systematic effect.





We fit K-factors (with uncertainties) to calculated corrections.

Depend significantly on scale, less on R.

Similar results on improvement with decorrelation using new NNLO results. (p(f)d = partial(full) decorrelation.)

	ATLAS	ATLAS, σ_{pd}	ATLAS, σ_{fd}		CMS
$R = 0.4$	350.8 (333.7)	183.1 (170.7)	128.4 (122.2)	$R = 0.5$	191.7 (163.4)
$R = 0.6$	304.0 (264.0)	178.8 (148.9)	128.9 (115.7)	$R = 0.7$	200.1 (175.2)

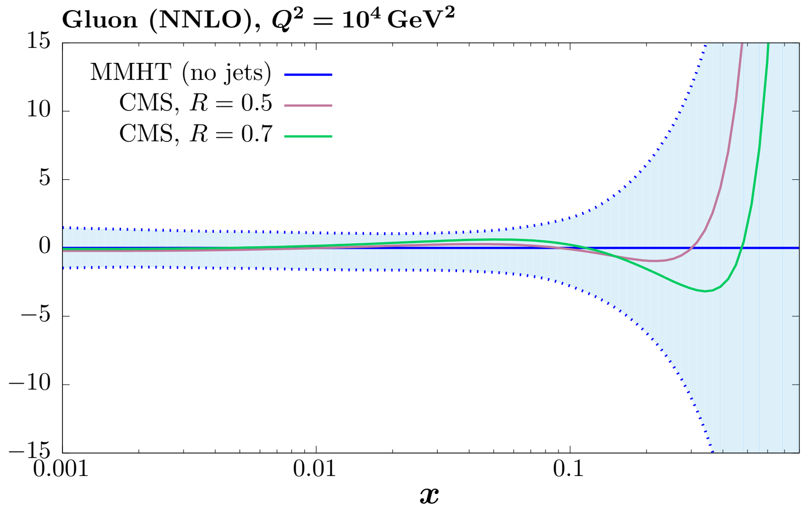
Table 2: The χ^2 for the ATLAS ($N_{\rm pts} = 140$) and CMS 7 TeV jet data ($N_{\rm pts} = 158$) at NNLO. The quality of the description using the baseline set is shown, while the result of re–fitting to the single jet data set is given in brackets. Results with the different treatments of the ATLAS systematic uncertainties, described in the text, are also shown.

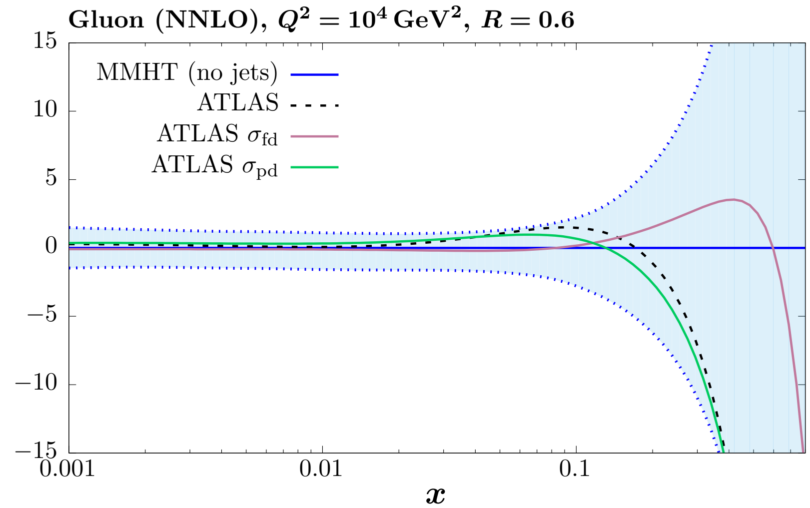
Clear that generally fit better at NNLO.

Also very dependent on scale and jet radius.

Fit to final CMS jet data (Phys.Rev. D90 (2014) 072006) generally quite good quality.

New data – results of fits





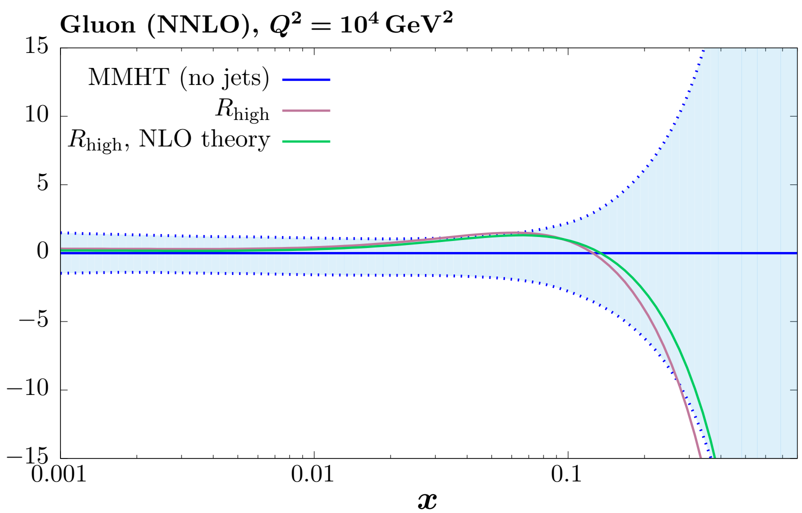
ATLAS and CMS pull in opposite direction for gluon – both within or comparable to uncertainties.

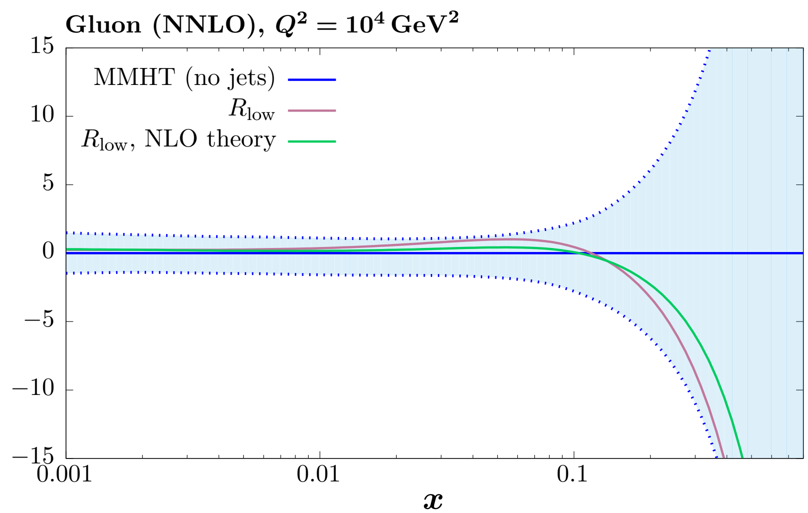
No or partial decorrelation have almost identical results for ATLAS (full decorrelation does not).

Inclusion of both data sets.

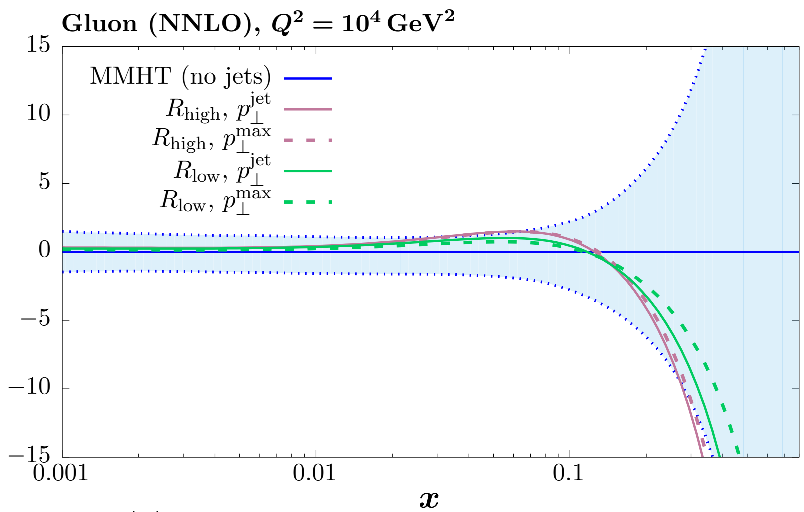
	$R_{\text{low}},\, p_\perp^{\text{jet}}$	$R_{\text{low}},\, p_\perp^{\text{max}}$	$R_{\text{high}},\, p_\perp^{\text{jet}}$	$R_{\text{high}},\, p_\perp^{\text{max}}$
ATLAS (NLO)	213.8	190.5	171.5	161.2
ATLAS (NNLO)	172.3	199.3	149.8	152.5
CMS (NLO)	190.3	185.3	195.6	193.3
CMS (NNLO)	177.8	187.0	182.3	185.4

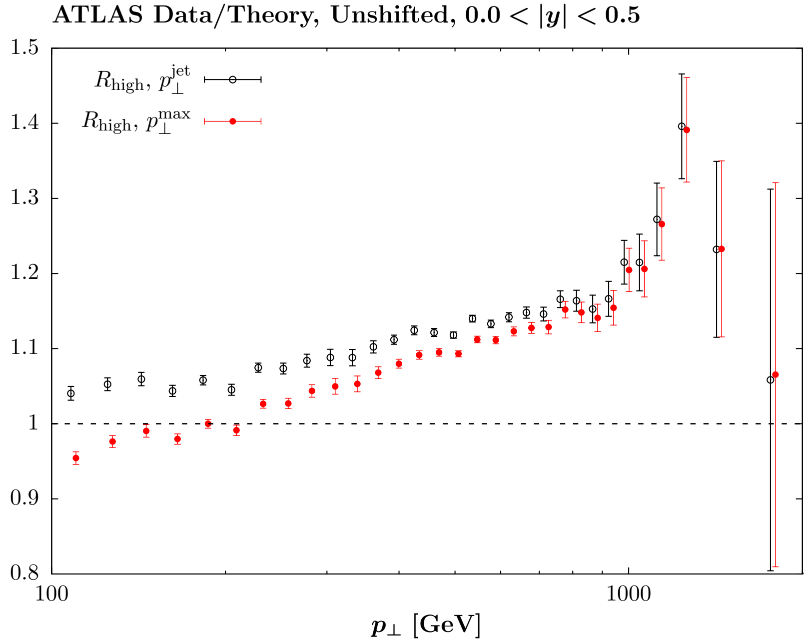
Table 3: The χ^2 for the combined fit to the ATLAS ($N_{\text{pts}} = 140$) and CMS ($N_{\text{pts}} = 158$) 7 TeV jet data. The values for the ATLAS and CMS contributions are given, for different choices of jet radius and scale, at NLO and NNLO.

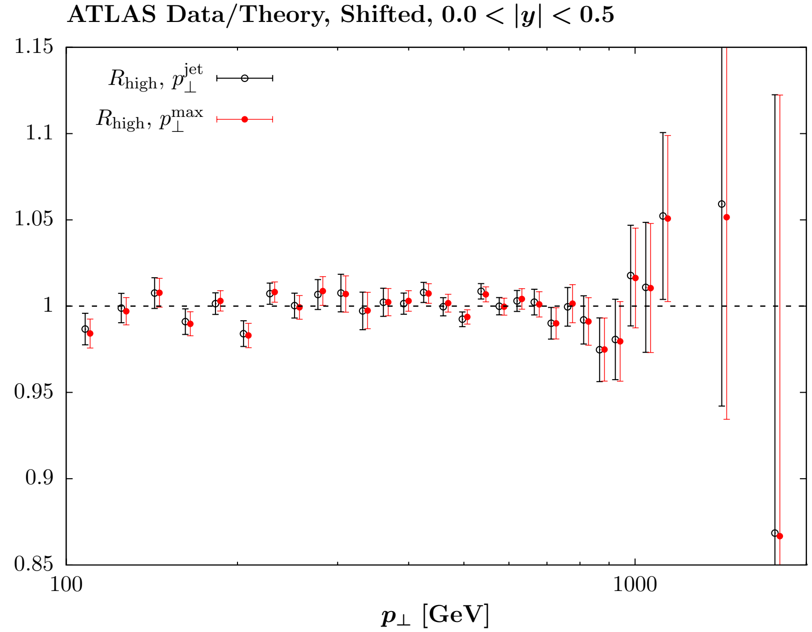




ATLAS data seems to present bigger pull.



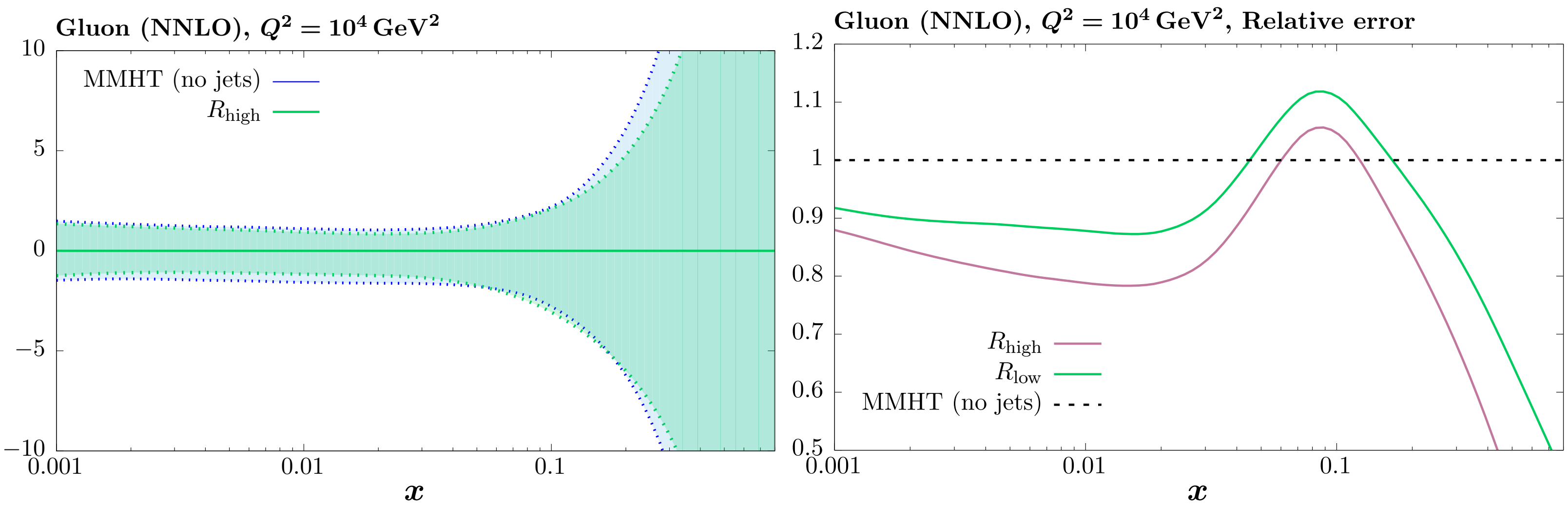




PDFs currently insensitive to choice of scale and jet radius at NNLO.

Different shifts of data relative to theory required.

Uncertainties



LHC jet data reduces uncertainties at level of up to 20% (more at very high x.

Fit Quality

	NLO theory	NNLO	NNLO (no errors)
ATLAS, $R_{\rm low}$	215.3	172.3	179.1
ATLAS, $R_{\rm high}$	159.2	149.8	153.5
CMS, $R_{\rm low}$	194.2	177.8	182.8
CMS, $R_{\rm high}$	198.5	182.3	188.8

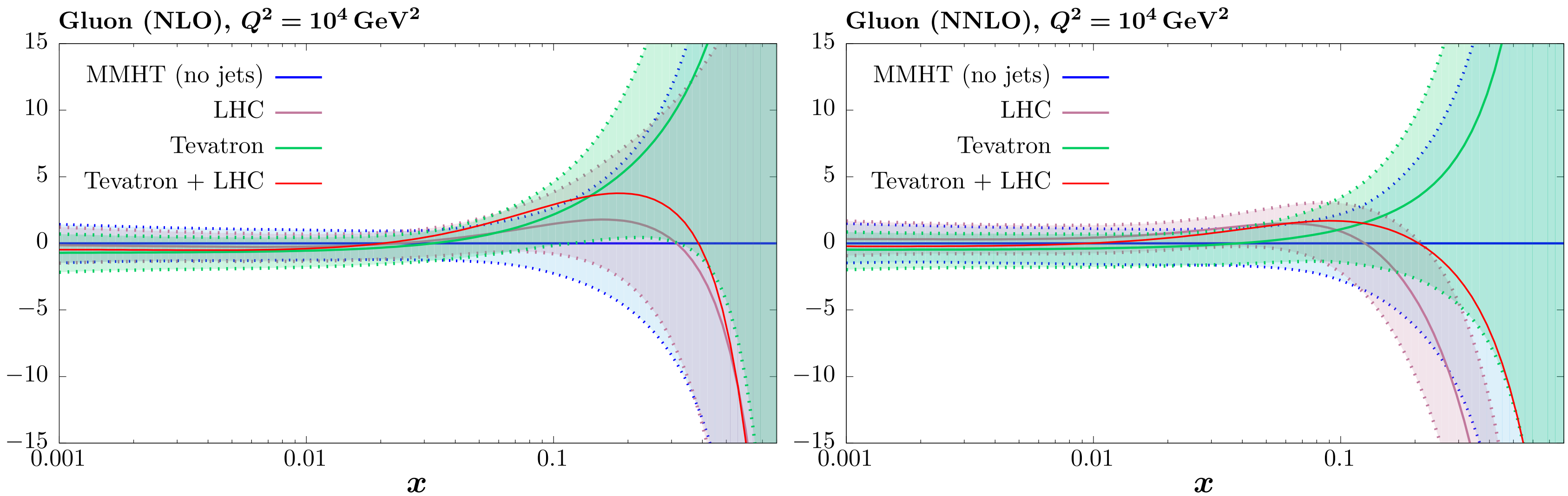
Table 4: The χ^2 for the combined NNLO fit to the ATLAS and CMS 7 TeV jet data, excluding and including the calculated NNLO K–factors, and excluding the errors associated with the polynomial fit to the K–factors. The $p_\perp^{\rm jet}$ factorization/renormalization scale is taken.

ATLAS 140 pts, CMS 158pts.

Much of the improvement in χ^2 at NNLO due to cross section, rather than PDFs.

However, change in PDFs currently relatively insensitive to this.

Addition of Tevatron jet data with NNLO threshold corrections.

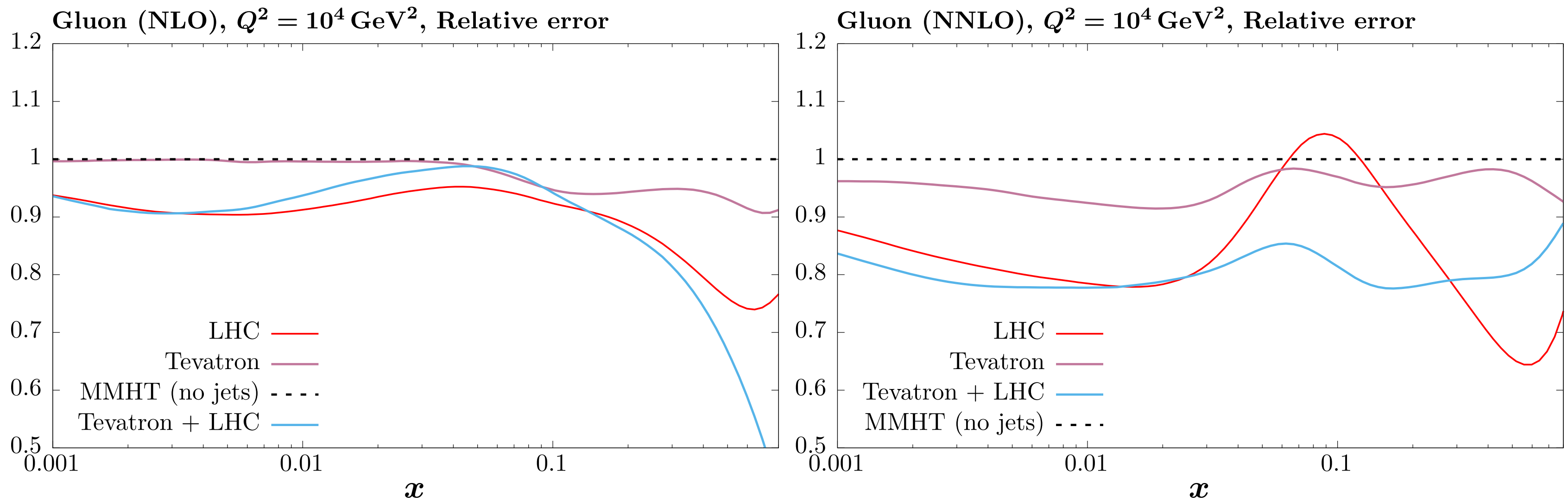


Makes high-x gluon harder at NNLO.

Leads to $\Delta\chi^2 = 9$ for LHC jet data, mostly for CMS - $\Delta\chi^2 = 7$.

Some tension in high-x gluon.

Comparisons in relative uncertainties.



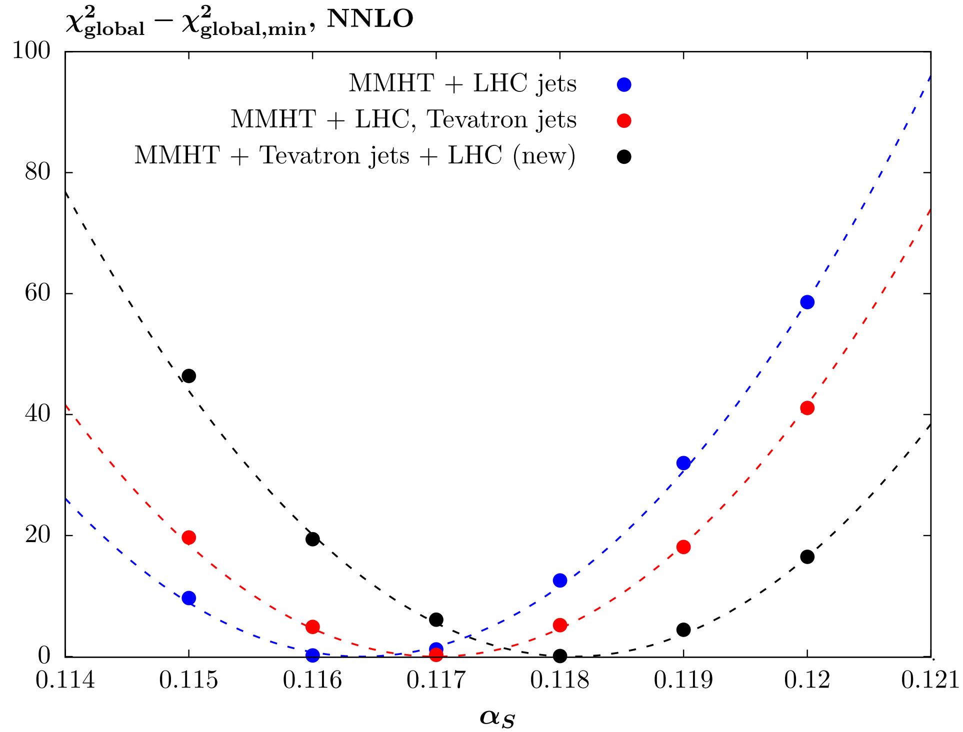
Addition of Tevatron data leads to an uncertainty reduction due to jets over a wider range of x.

Studies on best-fit $\alpha_S(M_Z^2)$

Reminder that for MMHT2014 $\alpha_S(M_Z^2) = 0.1172 \pm 0.0013$ ($\alpha_S(M_Z^2) = 0.1178$ when world average added as data point), and with addition of 8 TeV data on $\sigma_{\bar{t}t}$ and final HERA data went to $\alpha_S(M_Z^2) = 0.118$.

For further addition of LHC jets best-fit and removal of Tevatron jet data, $\alpha_S(M_Z^2) = 0.1164$. Different high and medium -x gluon leads to larger coupling.

When Tevatron jets also added back $\alpha_S(M_Z^2) = 0.1173$



Also look at inclusion of newer W, Z data from ATLAS, CMS, LHCb included previously in preliminary MMHT fits.

Without newer LHC jet data $\alpha_S(M_Z^2) = 0.1179$

Including newer LHC jet data $\alpha_S(M_Z^2) = 0.1176$ (0.1178 for ATLAS jet full decorrelation)

Therefore, recent Drell-Yan type data stabilises $\alpha_S(M_Z^2)$ value slightly.

Include all our recent LHC data updates in the fit at NNLO (for default $\alpha_S(M_Z^2) = 0.118$).

	no. points	NNLO χ^2	NNLO $\chi^2_{\rm LHCjets}$
$\sigma_{t\bar{t}}$ Tevatron +CMS+ATLAS	18	14.3	14.2
LHCb 7 TeV $W+Z$	33	40.0	40.2
LHCb 8 TeV $W+Z$	34	56.4	54.2
LHCb 8TeV e	17	27.9	27.3
CMS 8 TeV W	22	17.7	17.4
CMS 7 TeV $W+c$	10	9.0	9.9
D0 e asymmetry	13	24.2	26.9
ATLAS 7 TeV W, Z	61	108.3	110.5
total	3466	3868	3881

For LHC jet data $\Delta\chi^2 = 2$ with the inclusion of the other recent LHC data.

No tension between LHC jet data and recent LHC W, Z , inclusive top-pair data.

Slight deterioration in global fit partially due to some tension with Tevatron jet data.

Conclusions

MMHT PDFs with QED corrections very near completion (talk by Nathvani on Thursday).

Fit ATLAS and CMS jet data. Pull of each relatively small, but in opposite direction. Overall slightly softer high-x gluon.

For ATLAS data partial decorrelation of systematics improved χ^2 but does not affect results on central values or uncertainties.

Largely the same for NNLO cross section corrections. These (mainly) improve fit quality.

LHC jet data reduces $\alpha_S(M_Z^2)$ by less than 0.001. Due to different gluon shape preferred at high/medium x gluon. Best current value with all new data is $\alpha_S(M_Z^2) = 0.1176$.

No tension between LHC jet data and other recent LHC data.

Back-Up