LHC data and PDFs

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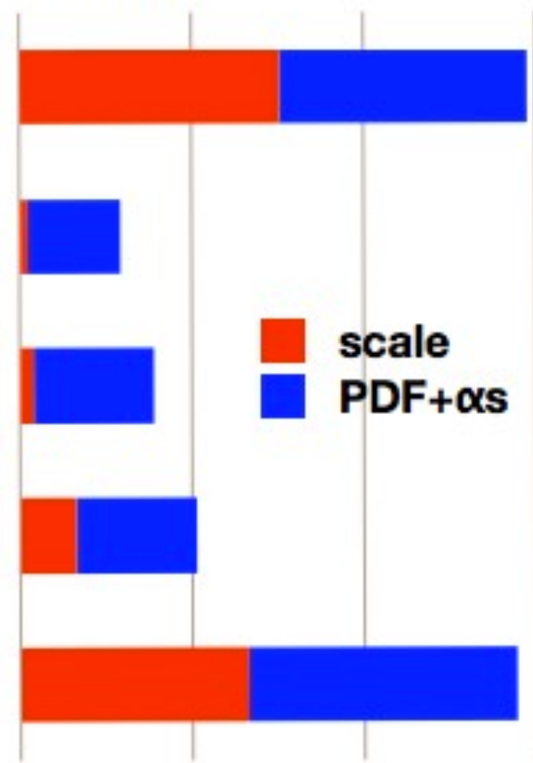
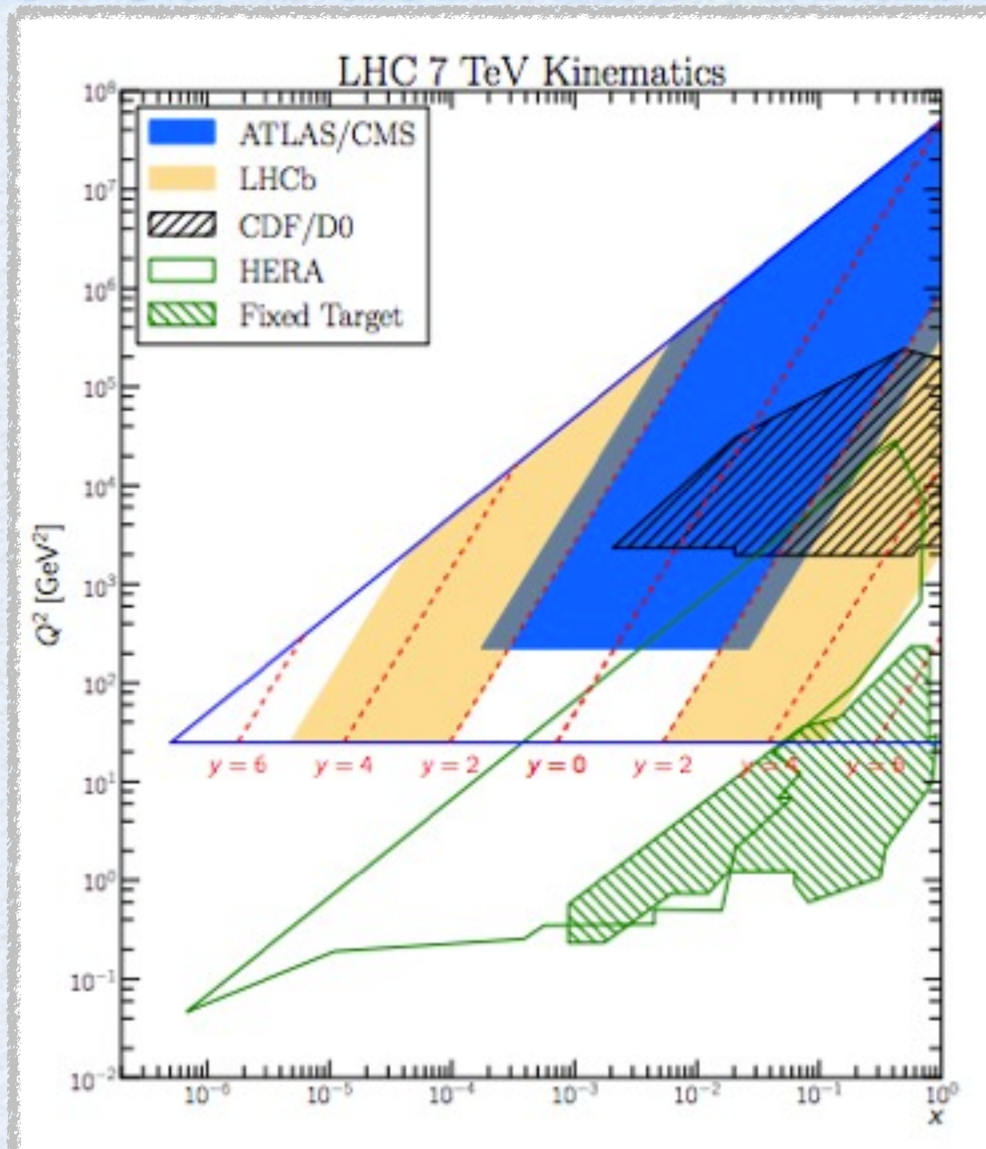
PDFs and LHC interplay

J. Campbell, ICHEP 2012 plenary talk

	σ (8 TeV)	uncertainty
gg→H	19.5 pb	14.7%
VBF	1.56 pb	2.9%
WH	0.70 pb	3.9%
ZH	0.39 pb	5.1%
ttH	0.13 pb	14.4%



S. Farry, QCD@LHC 2013



PDFs

PDFs uncertainties are a crucial input at the LHC, often being the limiting factor in the accuracy of theoretical predictions and parameter determination (W mass)

LHC

Exploit the power of precise LHC data to reduce PDF uncertainties and discriminate among PDF sets

Outline

- Introduction
  - Basic definition
  - PDFs: State of the art
- LHC data and PDF analyses
  - Gluon
  - Light (anti-)quarks
  - Strangeness
  - Photon
- Whishlist and conclusions

Basic definitions

$$\frac{d\sigma_H^{pp\to ab}}{dX} = \sum_{i,j=1}^{N_f} f_i(x_1,\mu_F)\, f_j(x_2,\mu_F)\, \frac{d\sigma_H^{ij\to ab}}{dX}(x_1 x_2 S_{\rm had}, \alpha_s(\mu_R), \mu_F) + \mathcal{O}\left(\frac{\Lambda_{\rm QCD}^{2n}}{S_{\rm had}^n}\right)$$

- PDFs are universal and their evolution with the scale is predicted by perturbative QCD by means of DGLAP equations predictions

- They can be extracted from available experimental data and used as a phenomenological input for theory

$$\frac{d}{dt}\begin{pmatrix} q_i(x,t) \\ g(x,t)\end{pmatrix} = \frac{\alpha_s(t)}{2\pi}\int_x^1 \sum_{j=q,\bar{q}} \frac{d\xi}{\xi}\begin{pmatrix} P_{ij}\left(\frac{x}{\xi},\alpha_s(t)\right) & P_{ig}\left(\frac{x}{\xi},\alpha_s(t)\right) \\ P_{gj}\left(\frac{x}{\xi},\alpha_s(t)\right) & P_{gg}\left(\frac{x}{\xi},\alpha_s(t)\right)\end{pmatrix} \otimes \begin{pmatrix} q_j(\xi,t) \\ g(\xi,t)\end{pmatrix}$$

$$t = \log\frac{Q^2}{\mu^2}$$

DGLAP evolution equations

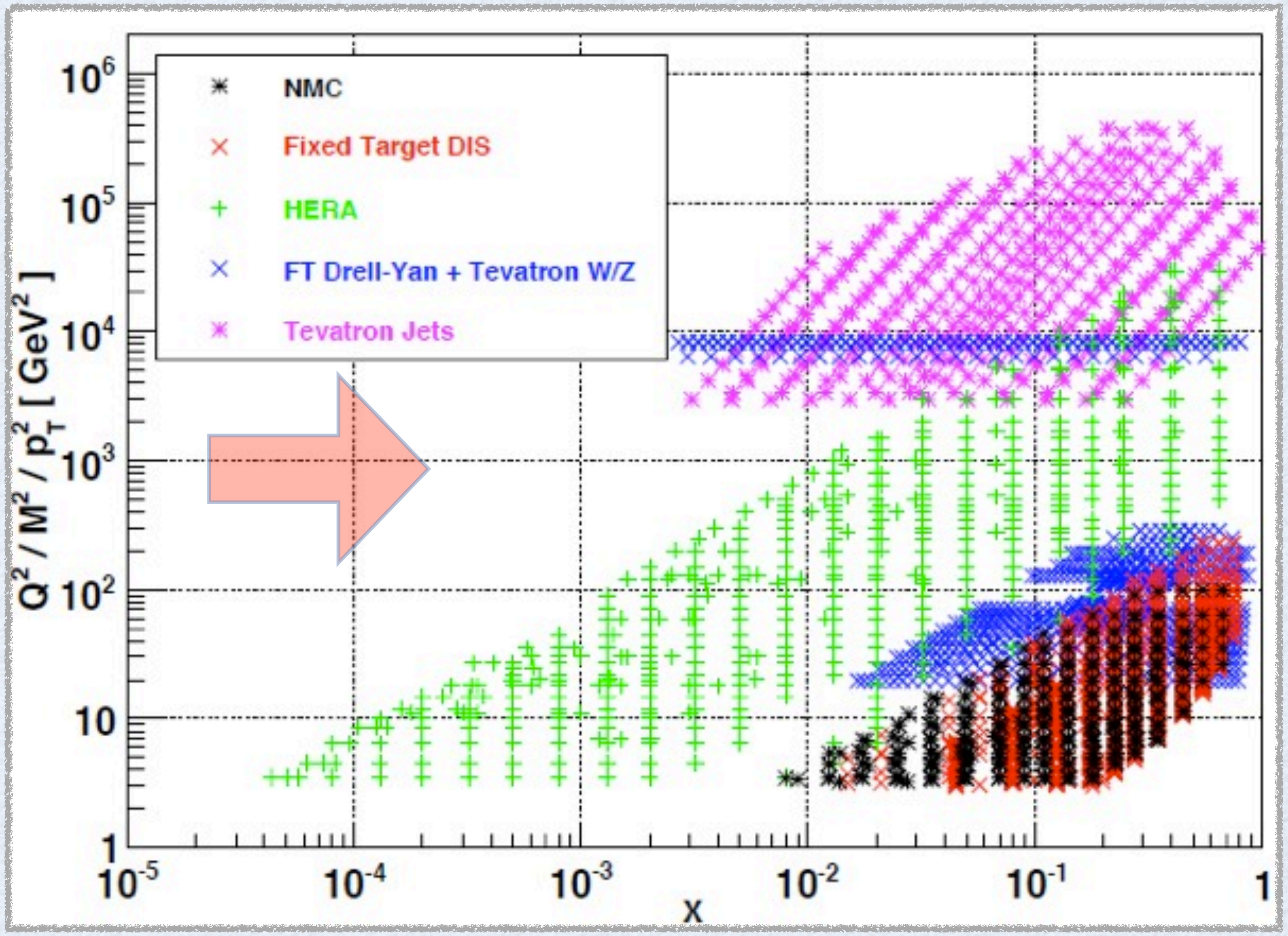
Splitting functions are known up to NNLO [2004: Moch,Vogt, Vermaseren]

Constraints from data

Before the LHC

Different data constrain some partonic combinations at different x.

Global analyses include Deep Inelastic Scattering (DIS), neutrino data, fixed-target Drell-Yan (DY), vector boson production, jets data



DIS data

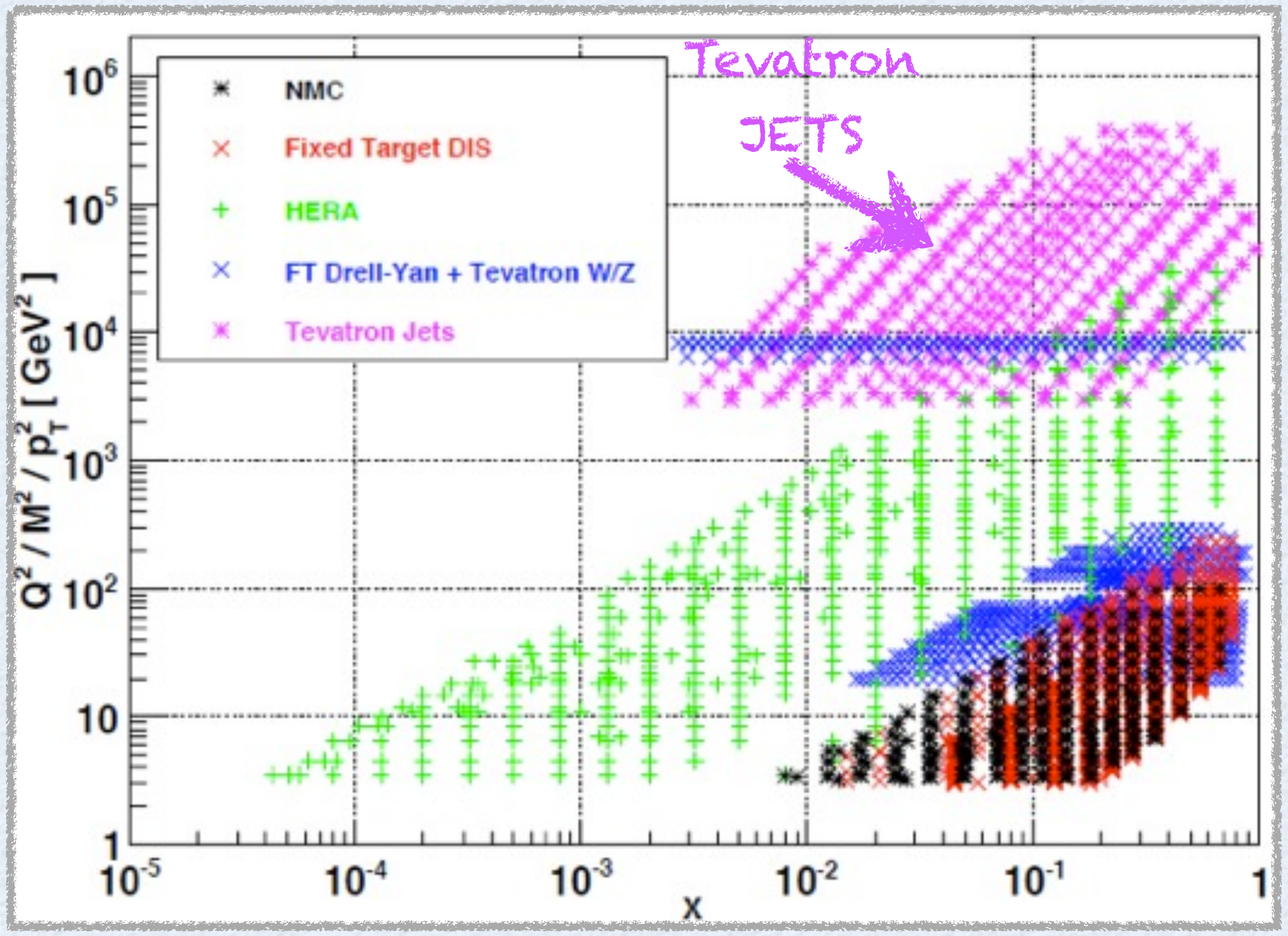
- q,qbar at $x > 10^{-4}$
- g at small and medium x
- deuteron data: disentangle isospin triplet and singlet contributions
- neutrino DIS data: handle on strange

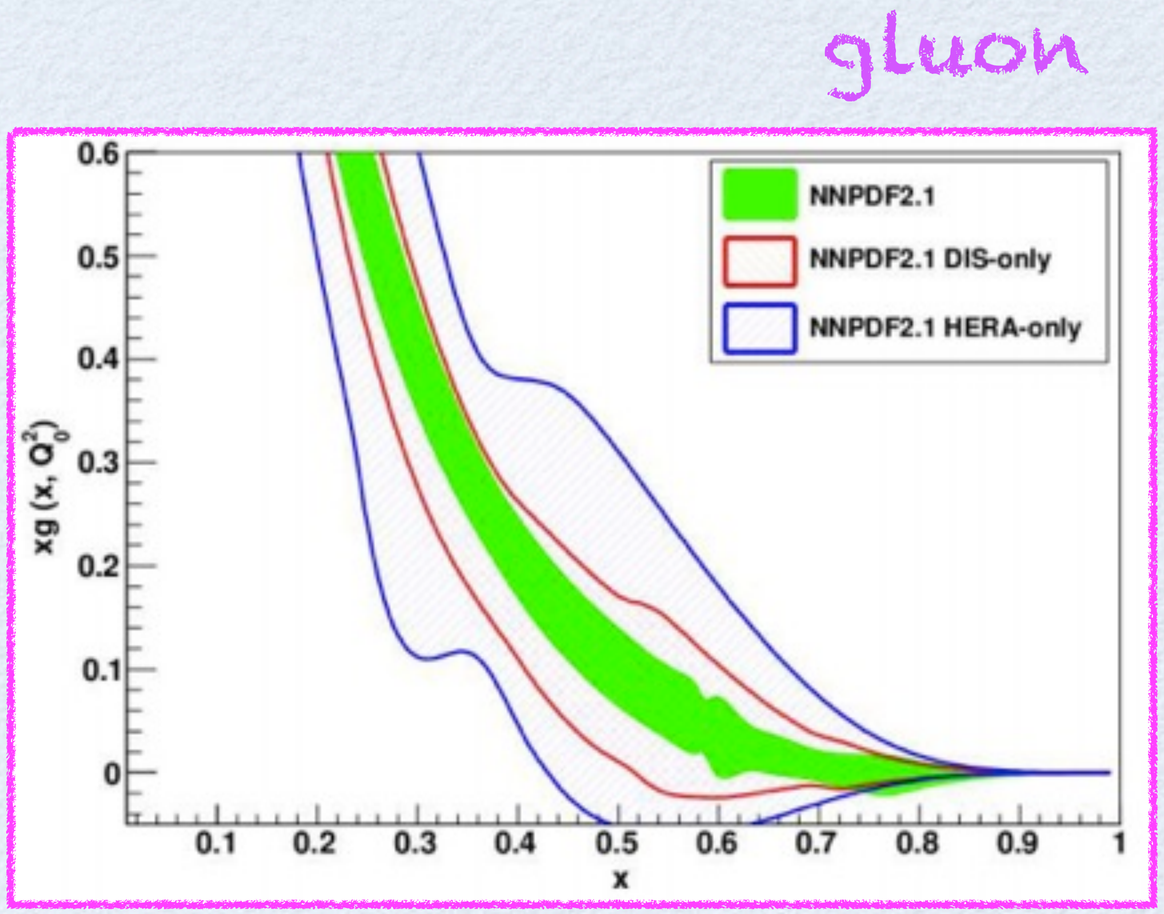
R. Ball, V. Bertone, L. Del Debbio, S. Forte, A. Guffanti, J. Latorre, J Rojo, M.Ubiali

Nucl.Phys. B849 (2011) 296

Constraints from data

Before the LHC





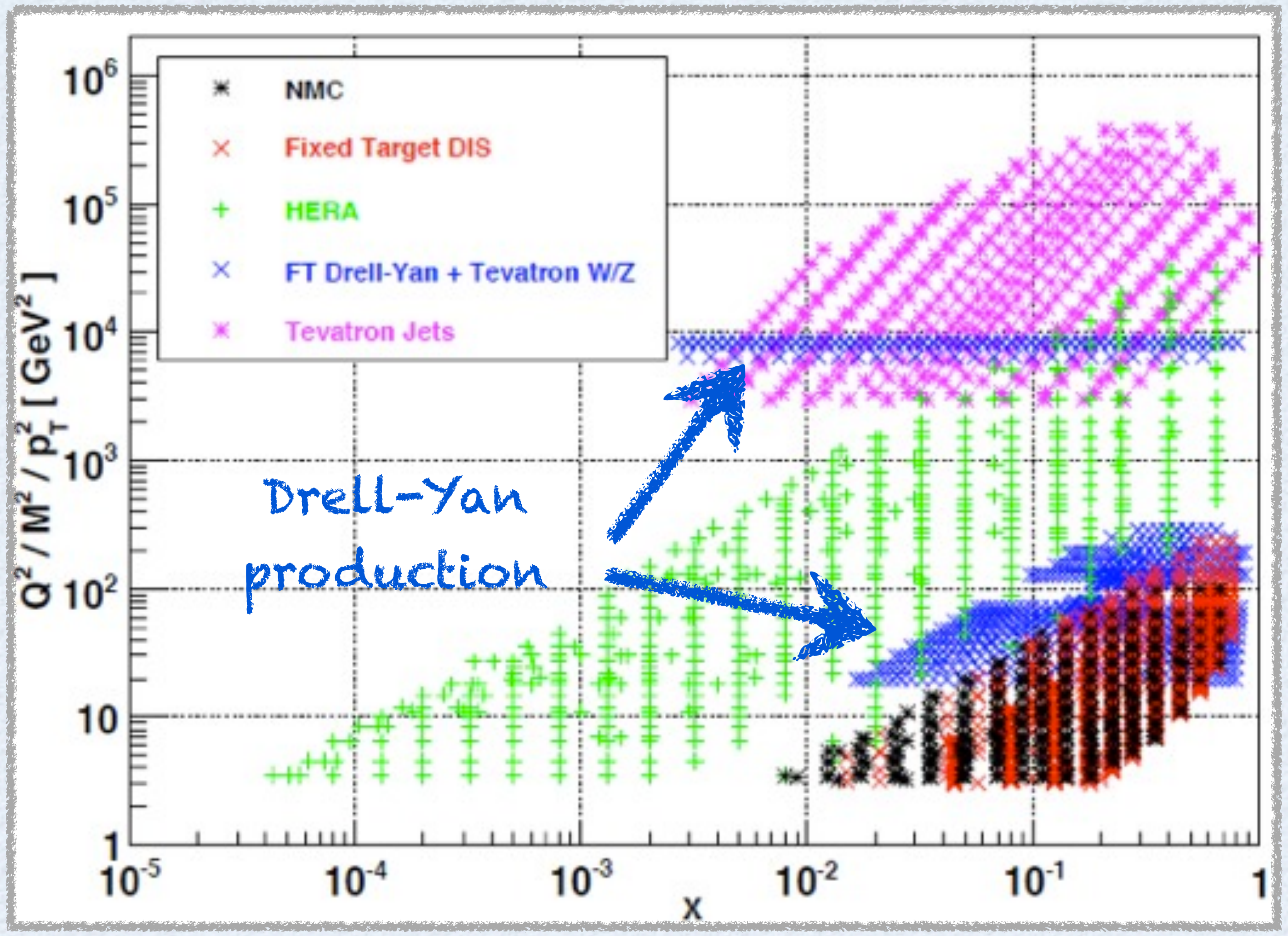
R. Ball, L.Del Debbio, S.Forte, A.Guffanti, J.Latorre, J.Rojo, M. Ubiali, Nucl. Phys. B838 (2010) 136

Tevatron jets

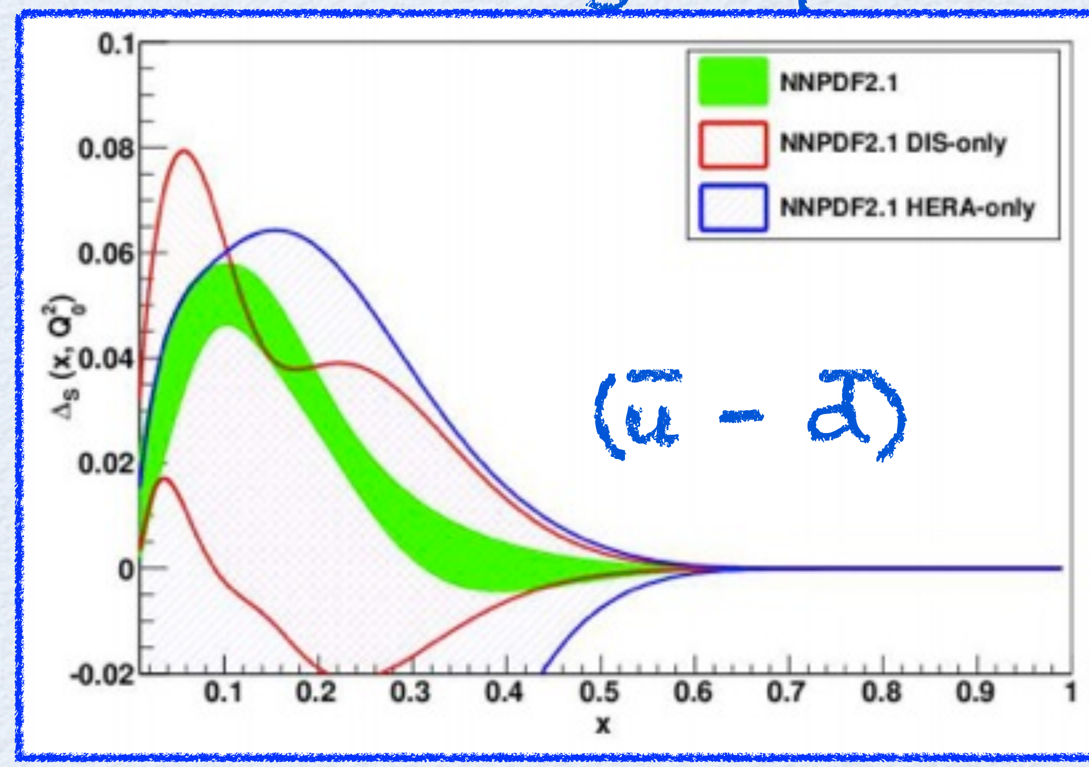
- Good consistency with DIS data, i.e. scaling violation
- Largest impact on large-x gluon
- Significant improvements in accuracy, uncertainty reduced by factor of 2 for $0.1 < x < 0.7$

Constraints from data

Before the LHC



light quarks



R. Ball, L.Del Debbio, S.Forte, A.Guffanti, J.Latorre, J.Rojo, M. Ubiali, Nucl. Phys. B838 (2010) 136

$$\sigma^{\mathrm{DY,p}} \propto u(x_1)\bar{u}(x_2) + d(x_1)\bar{d}(x_2)$$

$$\sigma^{\mathrm{DY,d}} \propto u(x_1)(\bar{u}+\bar{d})(x_2) + d(x_1)(\bar{u}+\bar{d})(x_2)$$

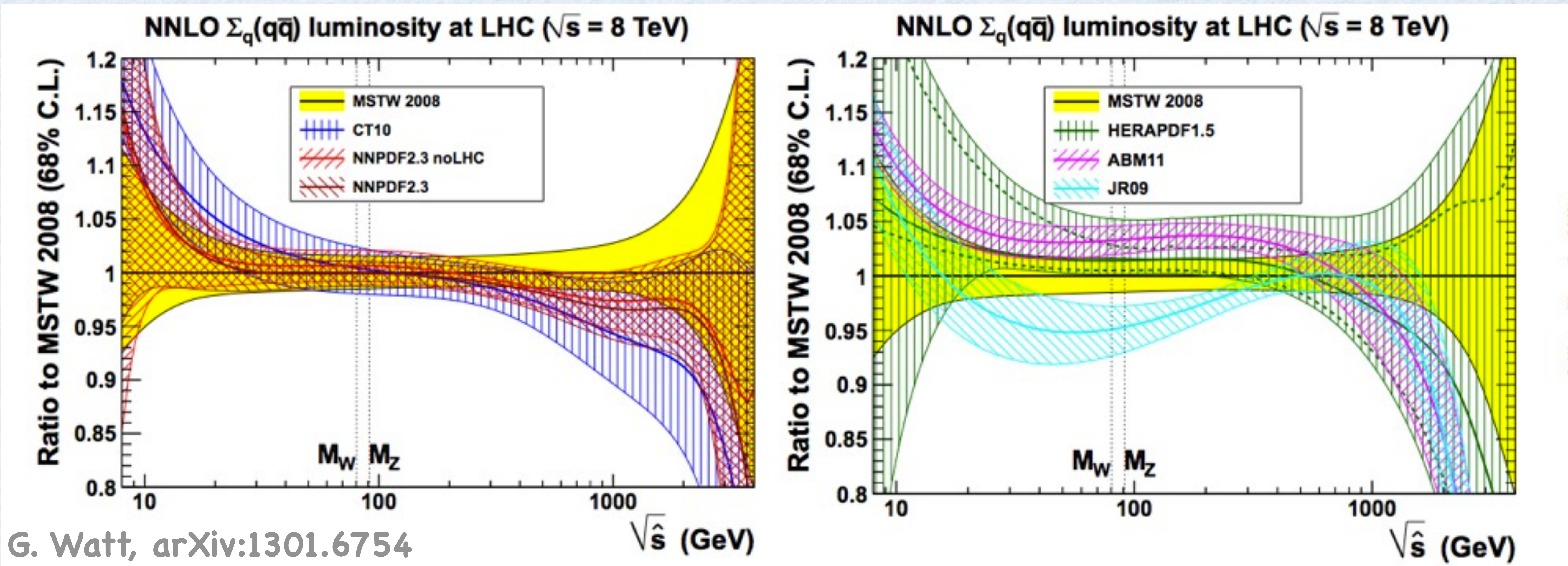
$$A_W = \frac{d\sigma^{W^+}/dy_{W^+} - d\sigma^{W^-}/dy_{W^-}}{d\sigma^{W^+}/dy_{W^+} + d\sigma^{W^-}/dy_{W^-}}$$

Tevatron

$$\frac{u(x_1)d(x_2) - d(x_1)u(x_2)}{u(x_1)d(x_2) + d(x_1)u(x_2)}$$

Old DY fixed-target data **and** Tevatron data constrain light quark separation and disentangle quark-antiquark distributions

State of the art



G. Watt, arXiv:1301.6754

$$\Phi_{ij}(M_X^2) = \frac{1}{s}\int_\tau^1 \frac{dx_1}{x_1} f_i(x_1, M_X^2) f_j(\tau/x_1, M_X^2)$$

MSTW2008: global fit (DIS+DY+EW+Jets)

CT10: global fit (DIS+DY+EW+Jets)

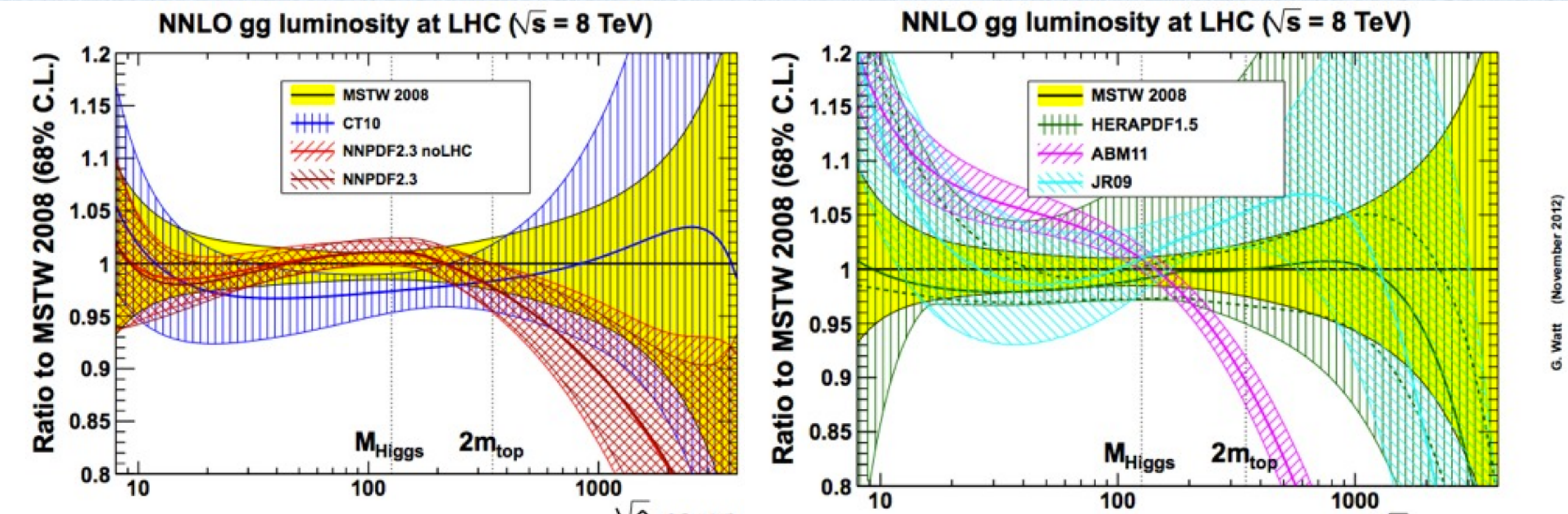
NNPDF23: global fit (DIS+DY+EW+Jets) **+ LHC data**

HERAPDF1.5: reduced dataset (HERA DIS data)

ABM11: reduced dataset (DIS+DY fixed target), much lower values of $\alpha_s(M_Z)$, FFN scheme

JR09: reduced dataset (DIS+DY fixed target + Jets only at NLO)

State of the art



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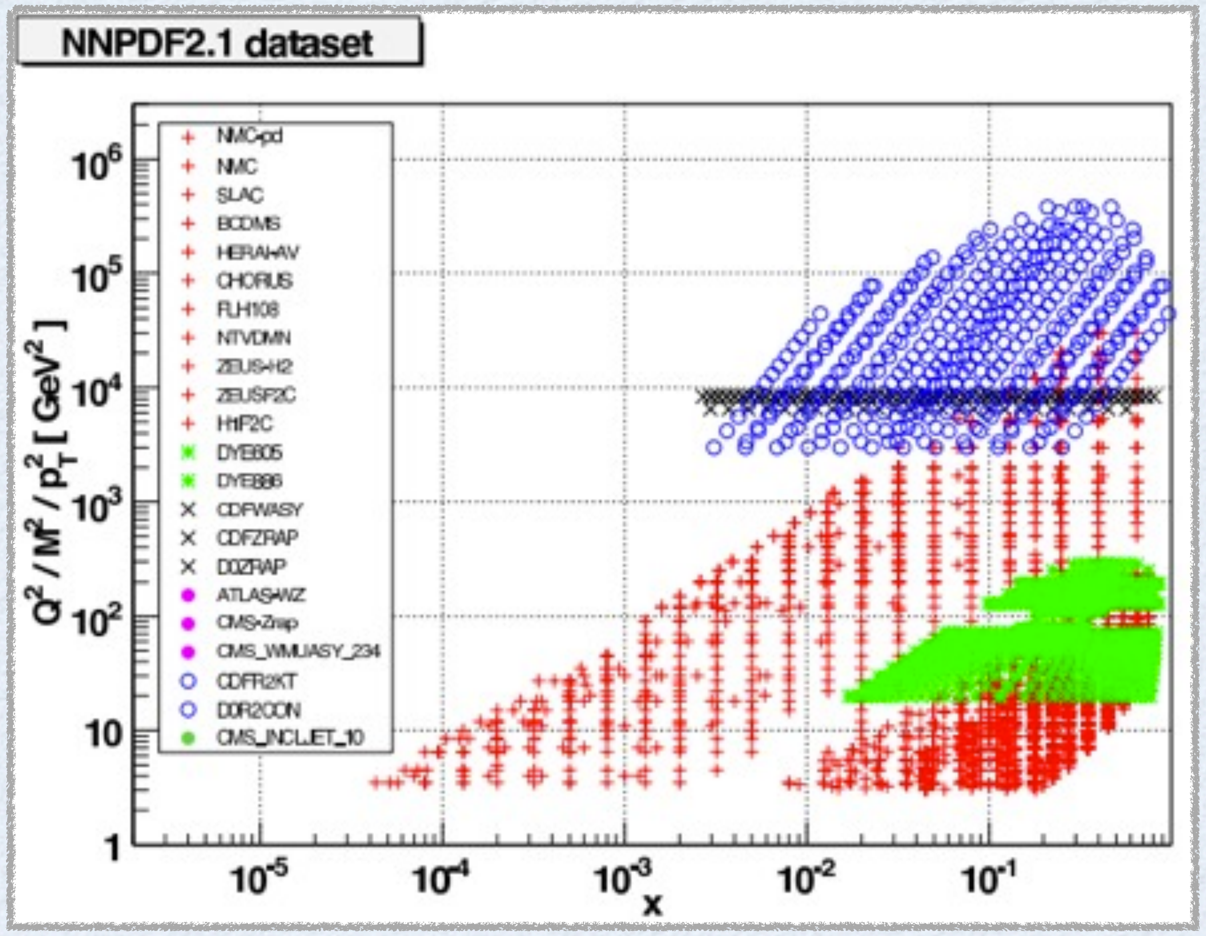
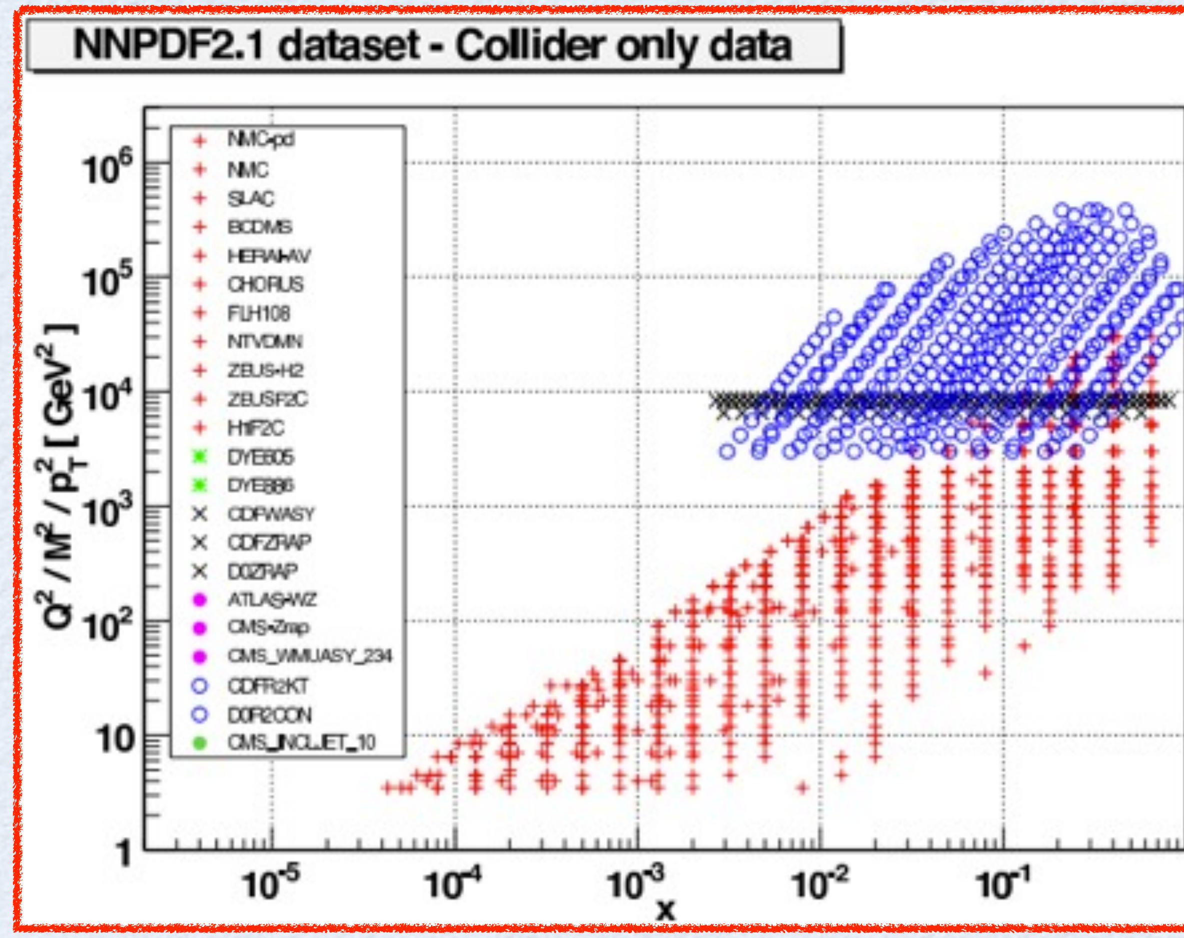
Collider-only fits

HERA + TEVATRON





No fixed-target data ⟷ No low-energy troubles

i.e. higher twists, nuclear corrections, poorer perturbative convergence

No older data without correlation information

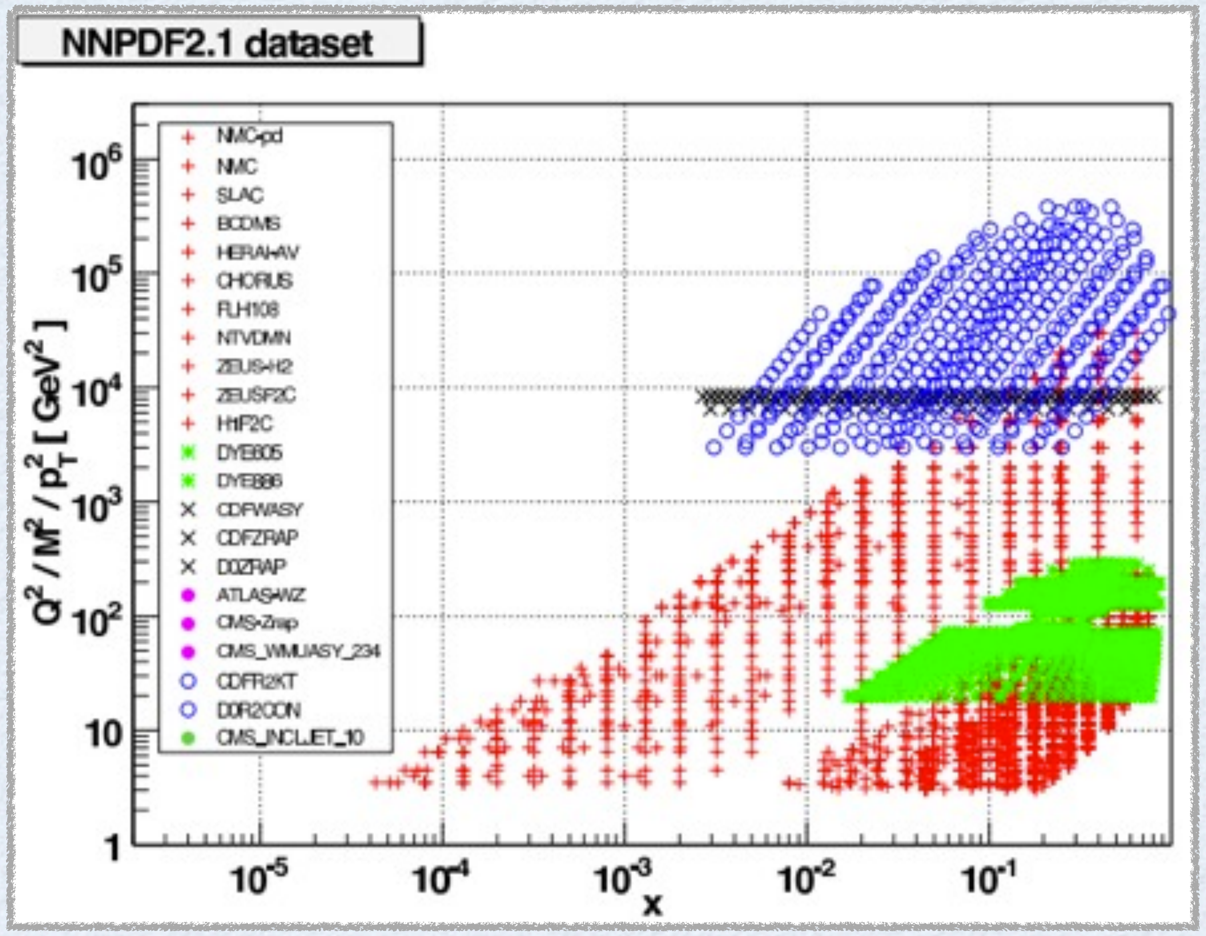
HERA + TEVATRON

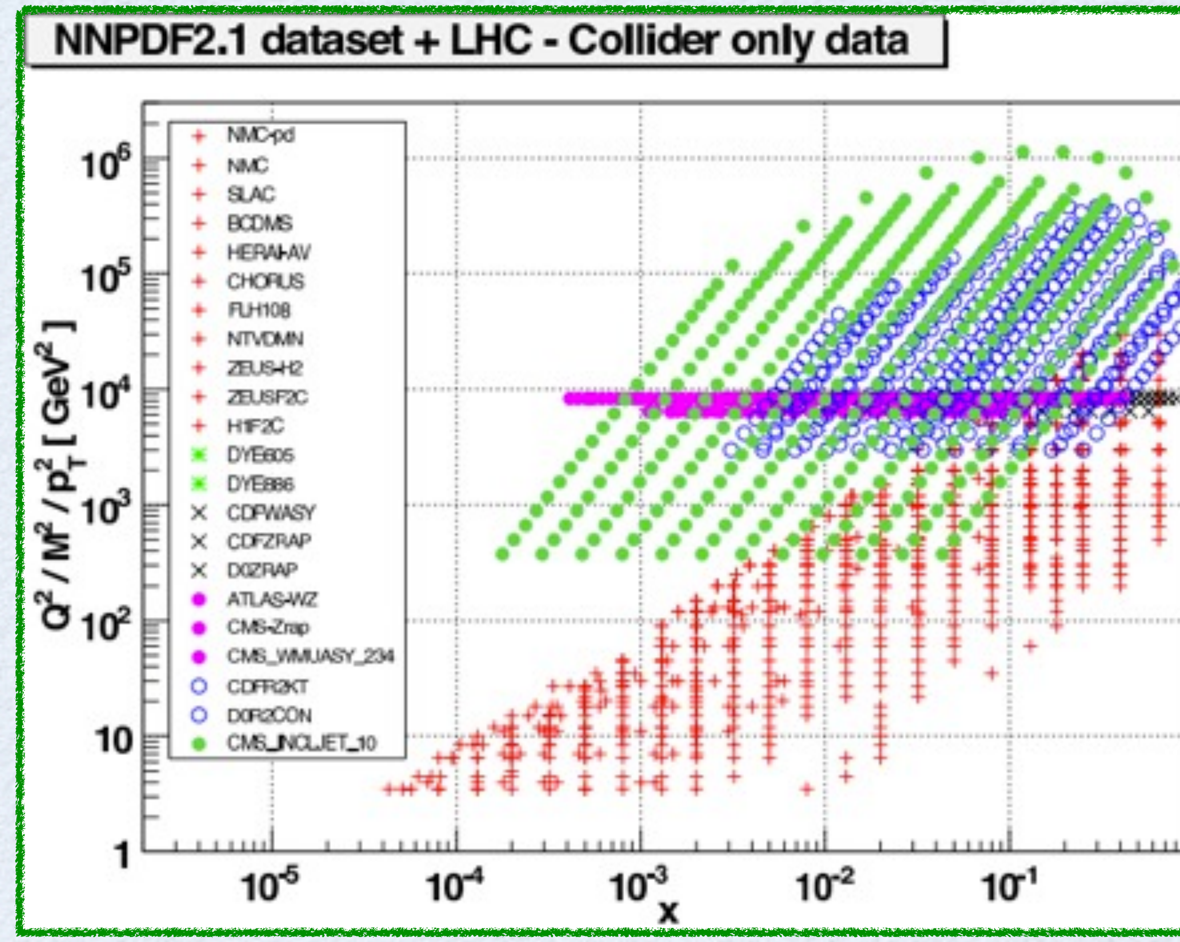
- Good accuracy for gluon
- Loss of accuracy for strange and flavor separation

Experiment	Data
Fixed Target DIS	1952
Fixed Target DY	318
HERA DIS	834
Tevatron W/Z	70
Tevatron Jets	186

Collider-only fits

HERA + TEVATRON + early LHC data





HERA + TEVATRON + LHC ?

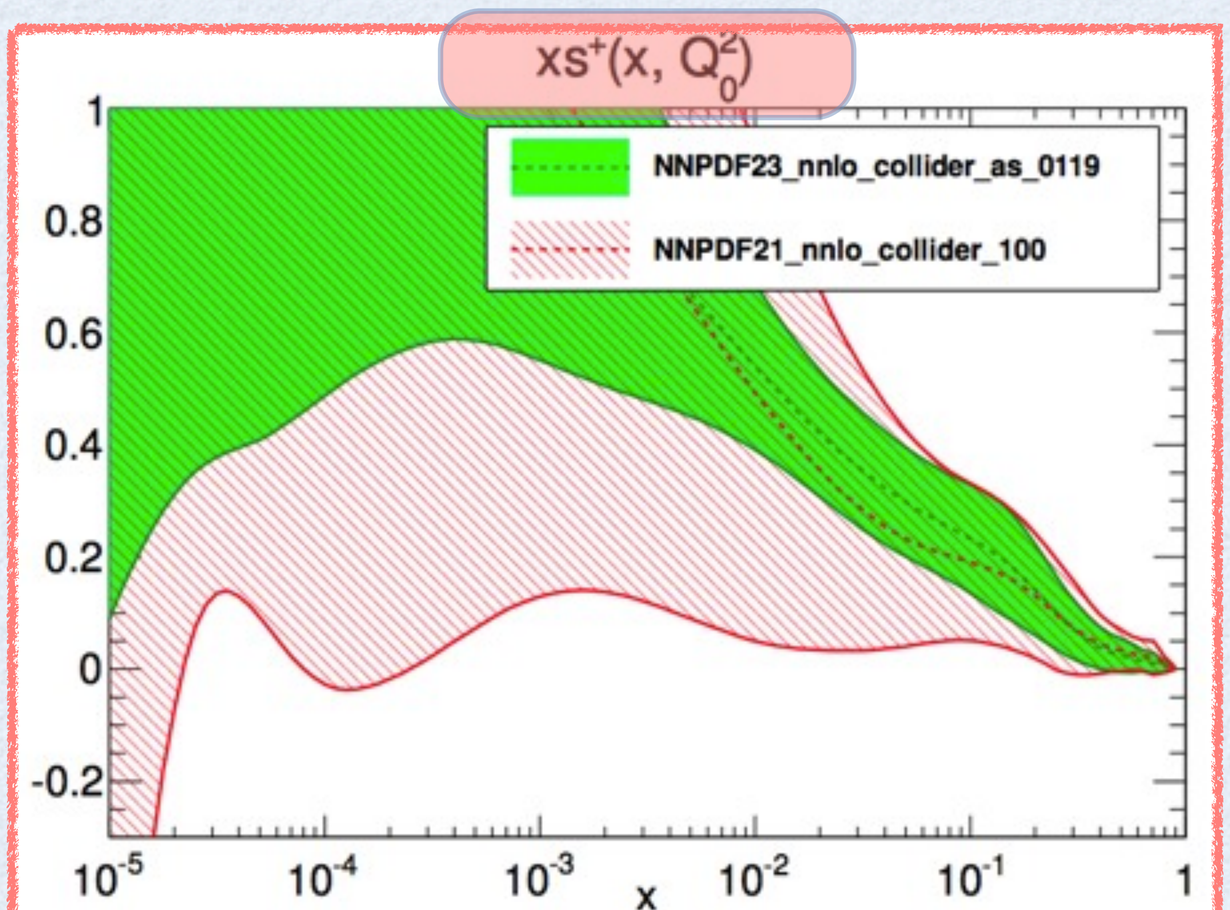
Experiment	Data
Fixed Target DIS	1952
Fixed Target DY	318
HERA DIS	834
Tevatron W/Z	70
Tevatron Jets	186
ATLAS incl. Jets	**90**
ATLAS W/Z lept. rap.	**30**
CMS W letp. asym.	**11**
LHCb W rap.	**10**

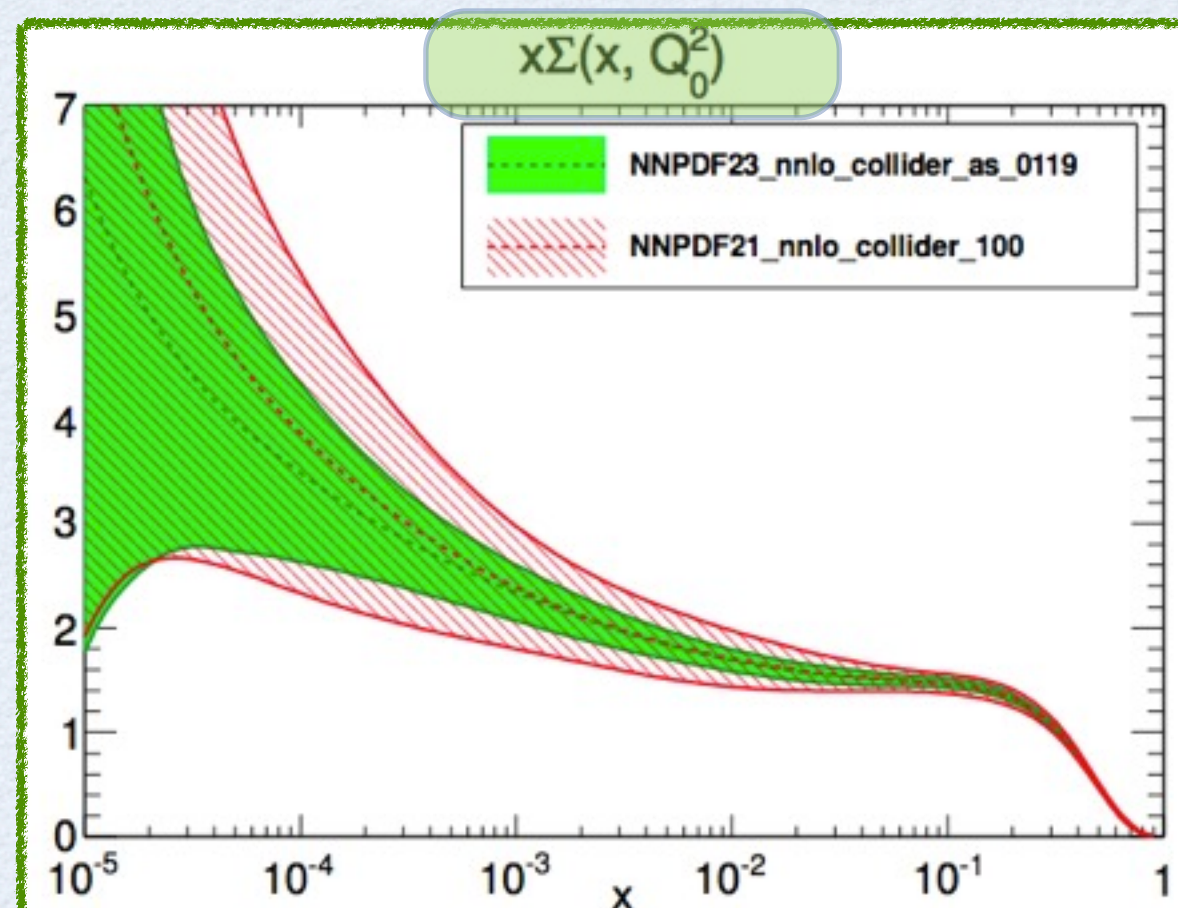
All and **only** data with full covariance matrix (as on Oct. 2012) are included

Collider-only fits

HERA + TEVATRON + early LHC data

- First LHC data included in the NNPDF2.3 fit already show that the LHC data have the potential to provide missing information
- Light quark uncertainty is reduced
- Still not enough to substitute fixed target data
- Need more constraints on strange and light flavor decomposition!





R. Ball et al, Nucl. Phys. B867 (2013) 244

The LHC data

Cross section ratios at different CME

Mangano, Rojo ArXiv:1206.3557

- The staged increase of LHC energy beams provides a new class of observables: cross section ratios for different beam energies

$$R_{E_2/E_1}(X) = \frac{\sigma(X, E_2)}{\sigma(X, E_1)}$$

$$R_{E_2/E_1}(X, Y) = \frac{\sigma(X, E_2)/\sigma(Y, E_2)}{\sigma(X, E_1)/\sigma(Y, E_1)}$$

- These ratios can be computed at very high precision due to the correlations of theoretical uncertainties at different energies and cancellation of most of theory systematics

- For some ratios, PDFs are left as the dominant remainder, especially at large mass

- Experimentally these ratios can also be measured accurately since many systematics partially cancel

- They can be pursued as a novel way to constrain PDFs

8 TeV / 7 TeV

Cross Section	$R^{\rm th,nnpdf}$	$\delta_{\rm PDF}$(%)	δ_{α_s} (%)	$\delta_{\rm scales}$ (%)
$t\bar{t}/Z$	1.23	± 0.4	−0.2 – 0.2	−0.2 – 0.3
$t\bar{t}$	1.43	± 0.3	−0.2 – 0.2	−0.1 – 0.3
Z	1.16	± 0.1	−0.0 – 0.1	−0.1 – 0.1
W^+	1.15	± 0.1	−0.0 – 0.1	−0.1 – 0.1
W^-	1.17	± 0.1	−0.0 – 0.1	−0.1 – 0.1
W^+/W^-	0.98	± 0.1	−0.0 – 0.0	−0.0 – 0.0
W/Z	0.99	± 0.0	−0.0 – 0.0	−0.0 – 0.0
ggH	1.27	± 0.2	−0.0 – 0.1	−0.2 – 0.2
$t\bar{t}(M_{tt} \geq 1$ TeV)	1.81	± 0.8	−0.0 – 0.3	−0.6 – 0.5
$t\bar{t}(M_{\rm tt} \geq 2$ TeV)	2.80	± 3.2	−0.6 – 0.3	−0.0 – 1.4
$\sigma_{\rm jet}(p_T \geq 1$ TeV)	2.30	± 1.0	−0.0 – 0.5	−0.4 – 1.0
$\sigma_{\rm jet}(p_T \geq 2$ TeV)	7.38	± 5.2	−0.4 – 1.0	−2.5 – 2.3

14 TeV / 7 TeV

Cross Section	$R^{\rm th,nnpdf}$	$\delta_{\rm PDF}$(%)	δ_{α_s} (%)	$\delta_{\rm scales}$ (%)
$t\bar{t}/Z$	2.61	± 1.6	−1.1 – 1.0	−0.6 – 1.4
$t\bar{t}$	5.58	± 1.4	−0.7 – 0.9	−0.5 – 1.4
Z	2.14	± 0.8	−0.1 – 0.4	−0.3 – 0.3
W^+	2.01	± 0.8	−0.0 – 0.3	−0.4 – 0.3
W^-	2.17	± 0.8	−0.1 – 0.3	−0.4 – 0.2
W^+/W^-	0.93	± 0.4	−0.0 – 0.1	−0.0 – 0.1
W/Z	0.97	± 0.2	−0.1 – 0.1	−0.0 – 0.0
ggH	3.26	± 0.8	−0.1 – 0.2	−1.1 – 1.1
$t\bar{t}(M_{tt} \geq 1$ TeV)	14.8	± 3.3	−1.0 – 1.2	−2.2 – 2.6
$t\bar{t}(M_{\rm tt} \geq 2$ TeV)	69.7	± 9.6	−0.6 – 0.6	−2.8 – 2.0
$\sigma_{\rm jet}(p_T \geq 1$ TeV)	34.9	± 2.9	−0.0 – 0.3	−2.0 – 2.8
$\sigma_{\rm jet}(p_T \geq 2$ TeV)	1340	± 12	−0.7 – 1.1	−8.0 – 6.4

The LHC data

Data and constraints on PDFs

Gluons ←

- ★ Inclusive jets and dijets (medium/large x)
- ★ Isolated photon and γ +jets (medium/large x)
- ★ Top pair production (large x)
- ★ High p_T Z(+jets) distribution (small/medium x)

Light flavors and strangeness ←

- ★ High p_T W(+jets) ratios (medium/large x)
- ★ W and Z production (medium x)
- ★ Low and high mass Drell-Yan (small and large x)
- ★ Wc (strangeness at medium x)

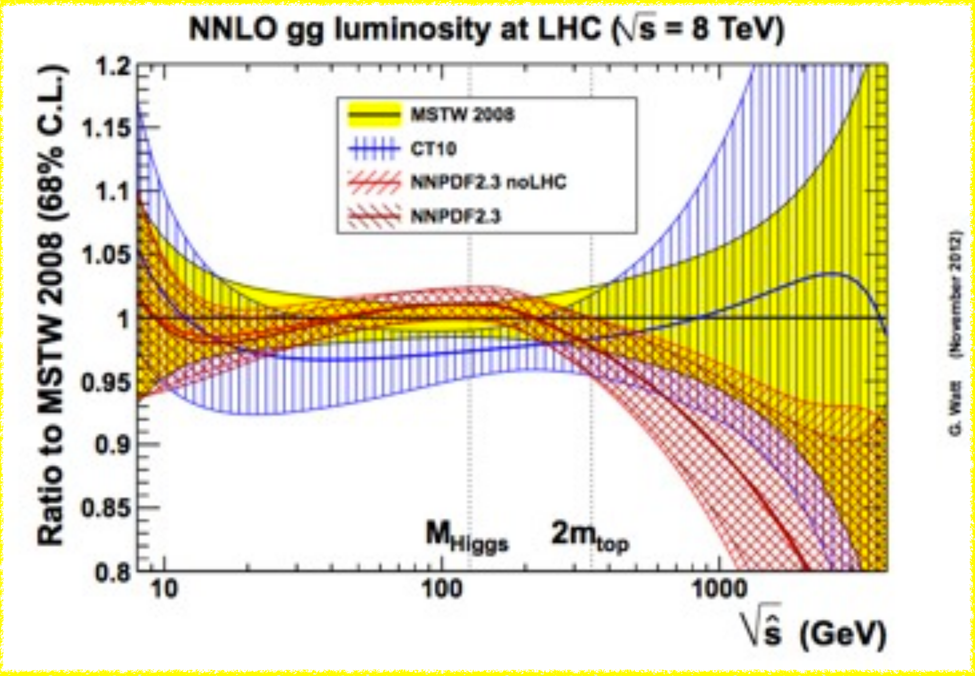
Photon ←

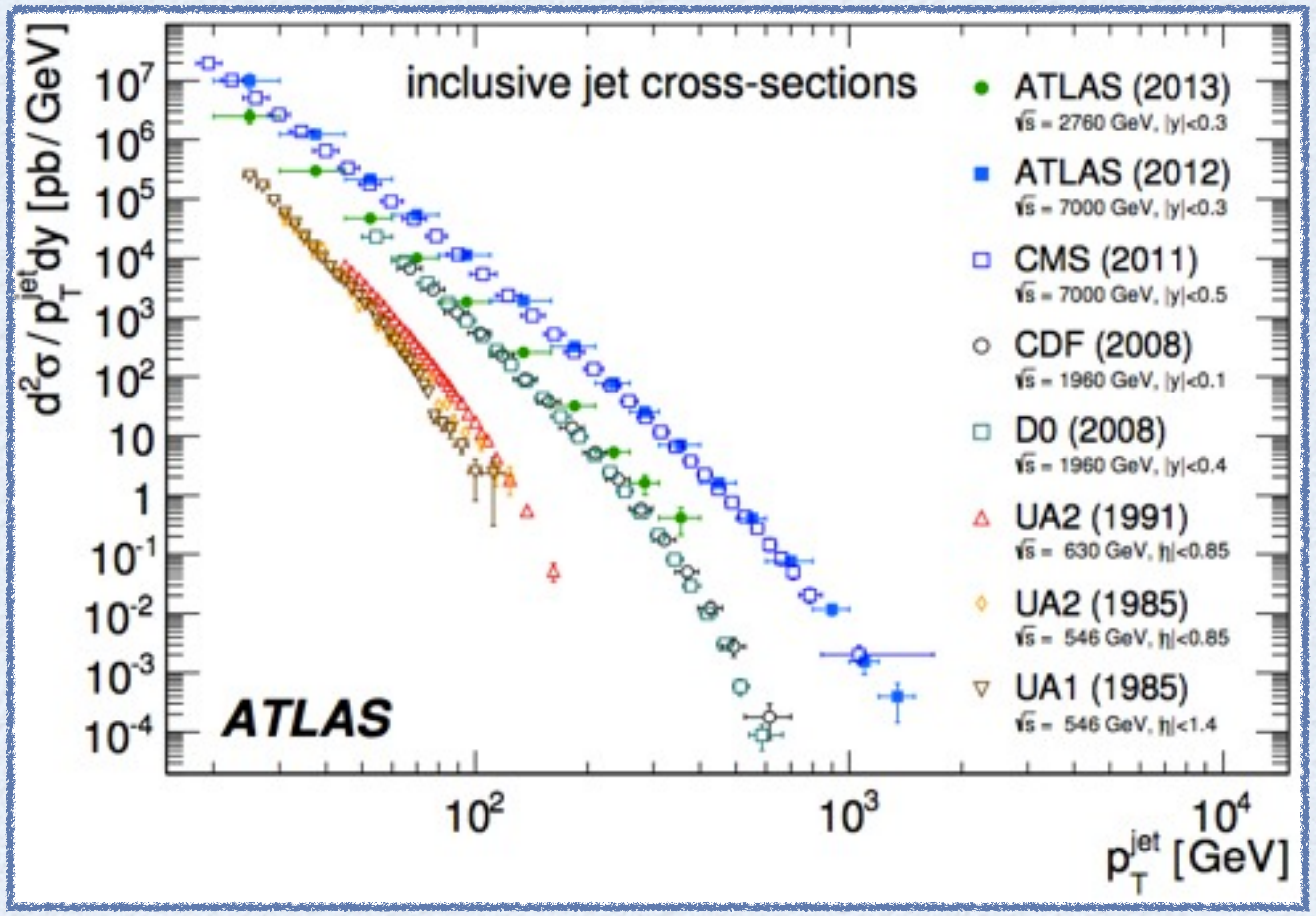
- ★ Low and high mass Drell-Yan
- ★ WW production

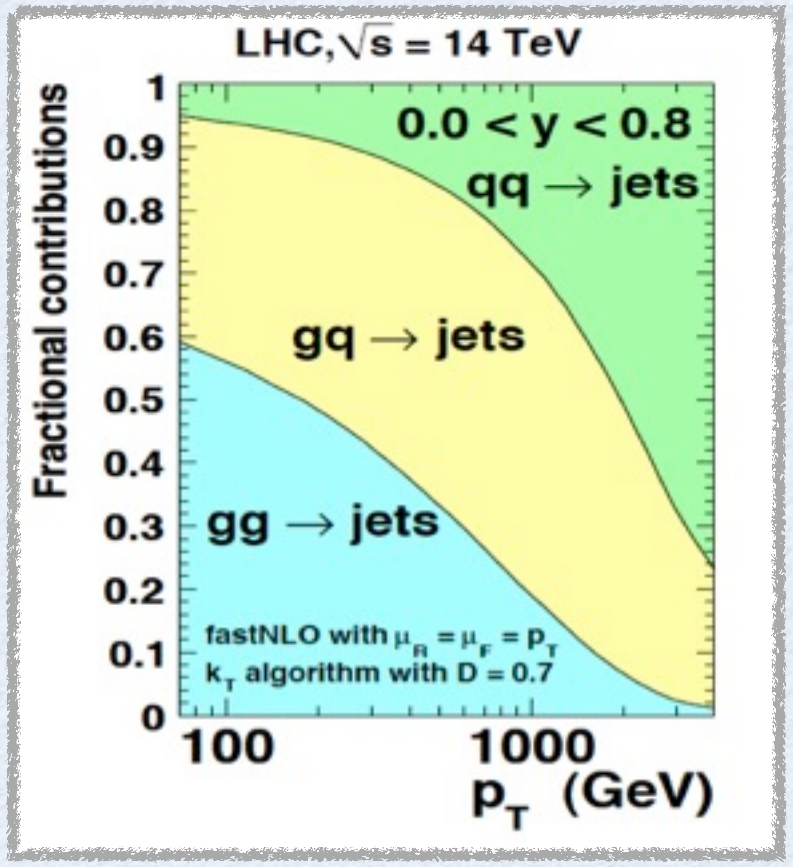
Gluons

Inclusive jet data at the LHC

- Jets are traditional source of information on gluon and α_S
- The higher the p_T the higher is the x probed
- Large-x is the region where gluons and quarks are mostly unconstrained
- Wealth of precise experimental measurements
- Theoretical calculation: NLO and partially also NNLO gg initiated contribution has now been calculated. Soon full NNLO [Gehrmann et al]







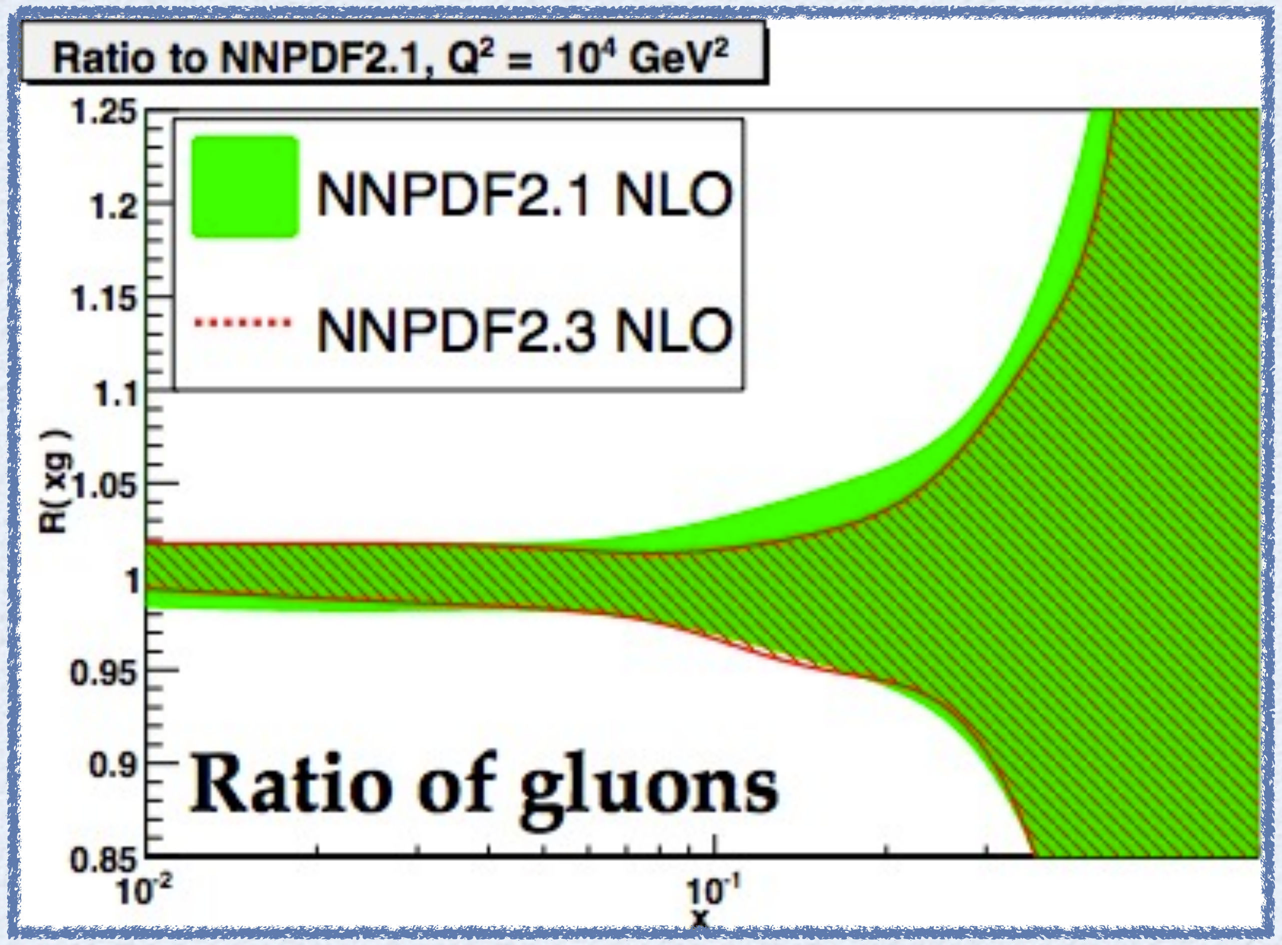
ATLAS, EPJC (2013) 73 2509

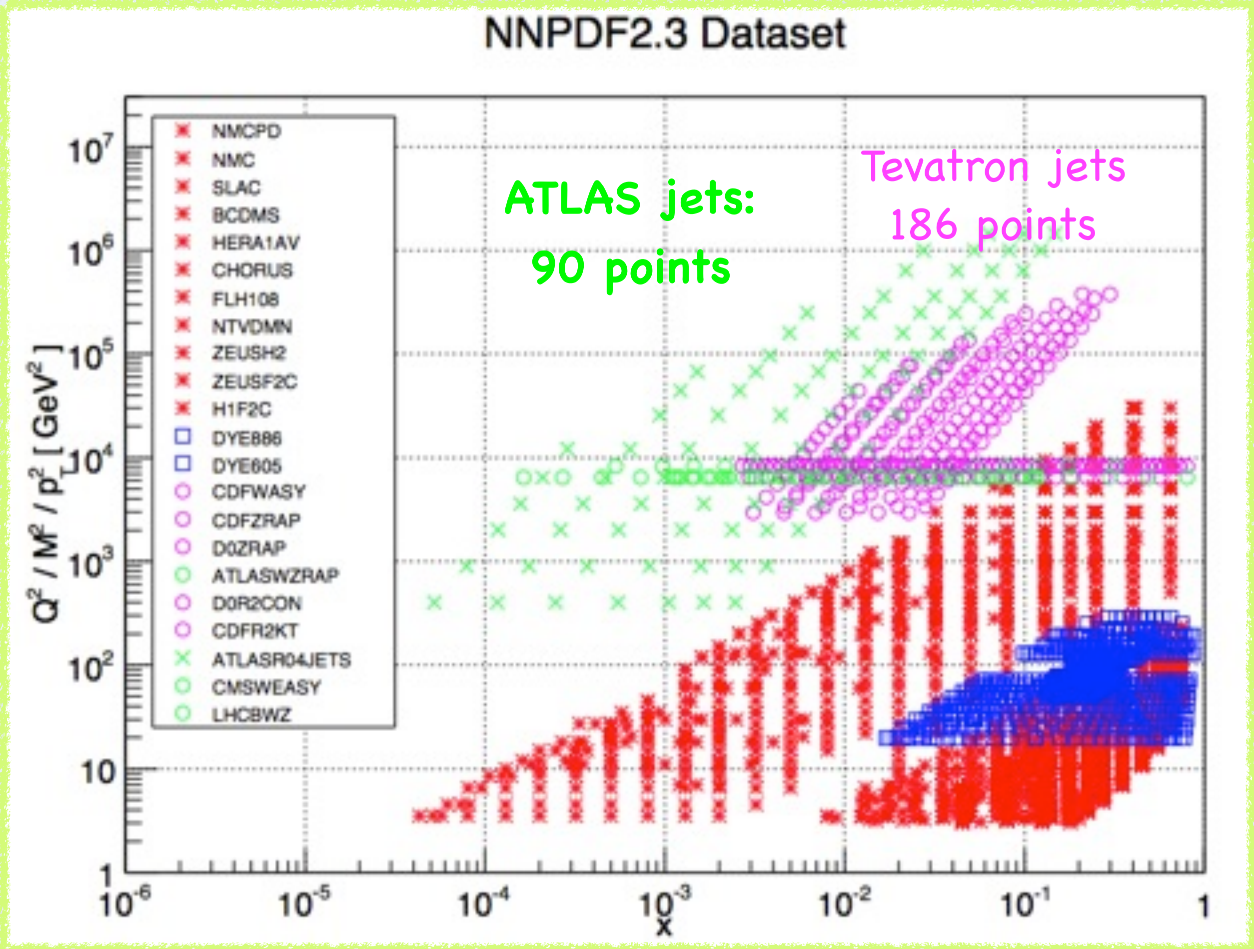
Martin et al, Eur.Phys.J. C63 (2009) 189-285

Gluons

Inclusive jet data at the LHC

ATLAS	2.76 TeV	0.2 pb^{-1}	20 - 430 GeV	EPJC (2013) 73 2509
ATLAS	7 TeV	35 pb^{-1}	20 - 1500 GeV	Phys.Rev. D86 (2012) 014022
CMS	7 TeV	5 fb^{-1}	100 - 2000 GeV	Phys.Rev. D87 (2013) 112002
CMS	8 TeV	11 fb^{-1}	74 - 2500 GeV	CMS-PAS-SMP-12-012





R. Ball et al, Nucl. Phys. B867 (2013) 244

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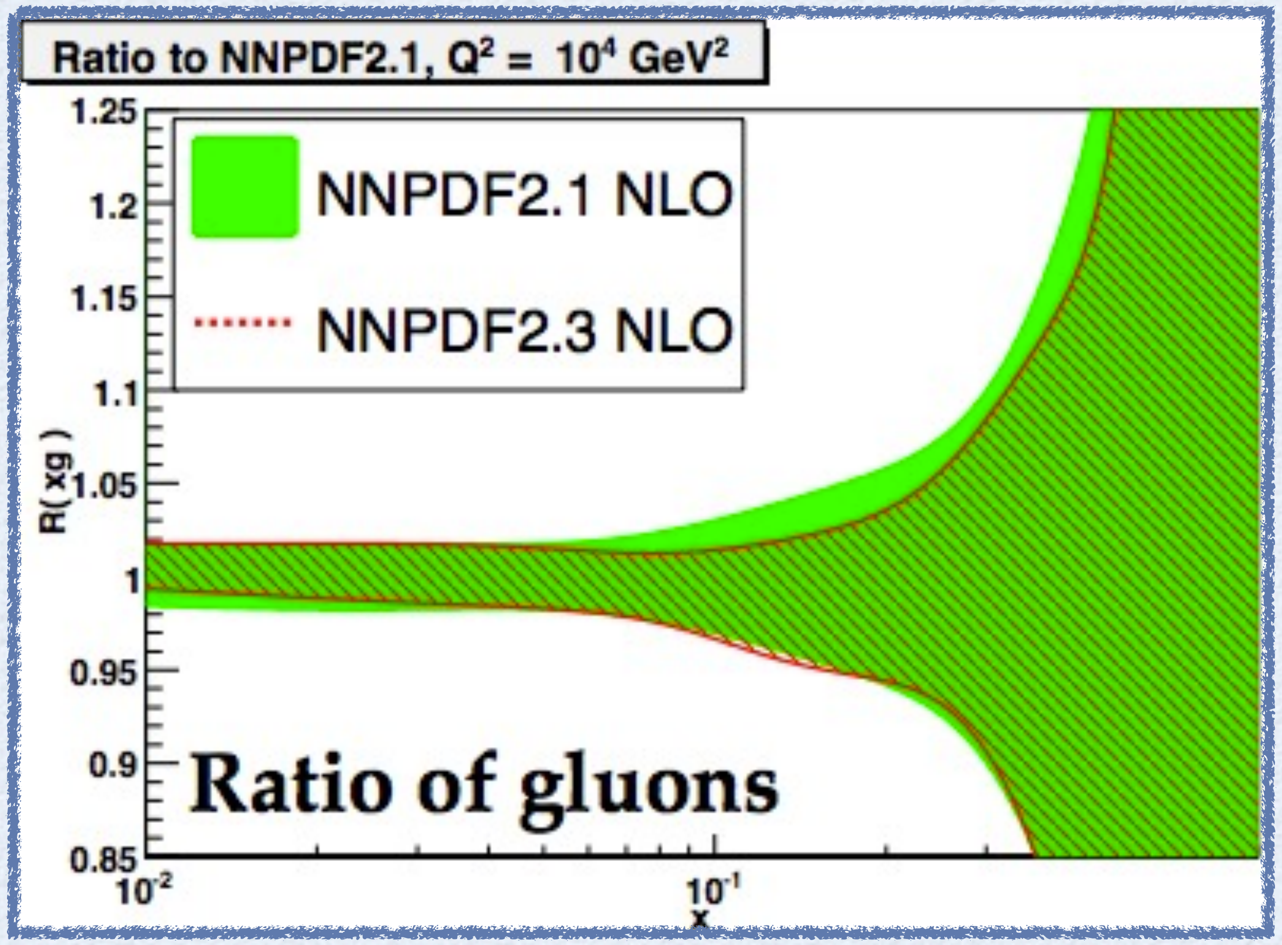
largest constraint comes from ratio at different CME



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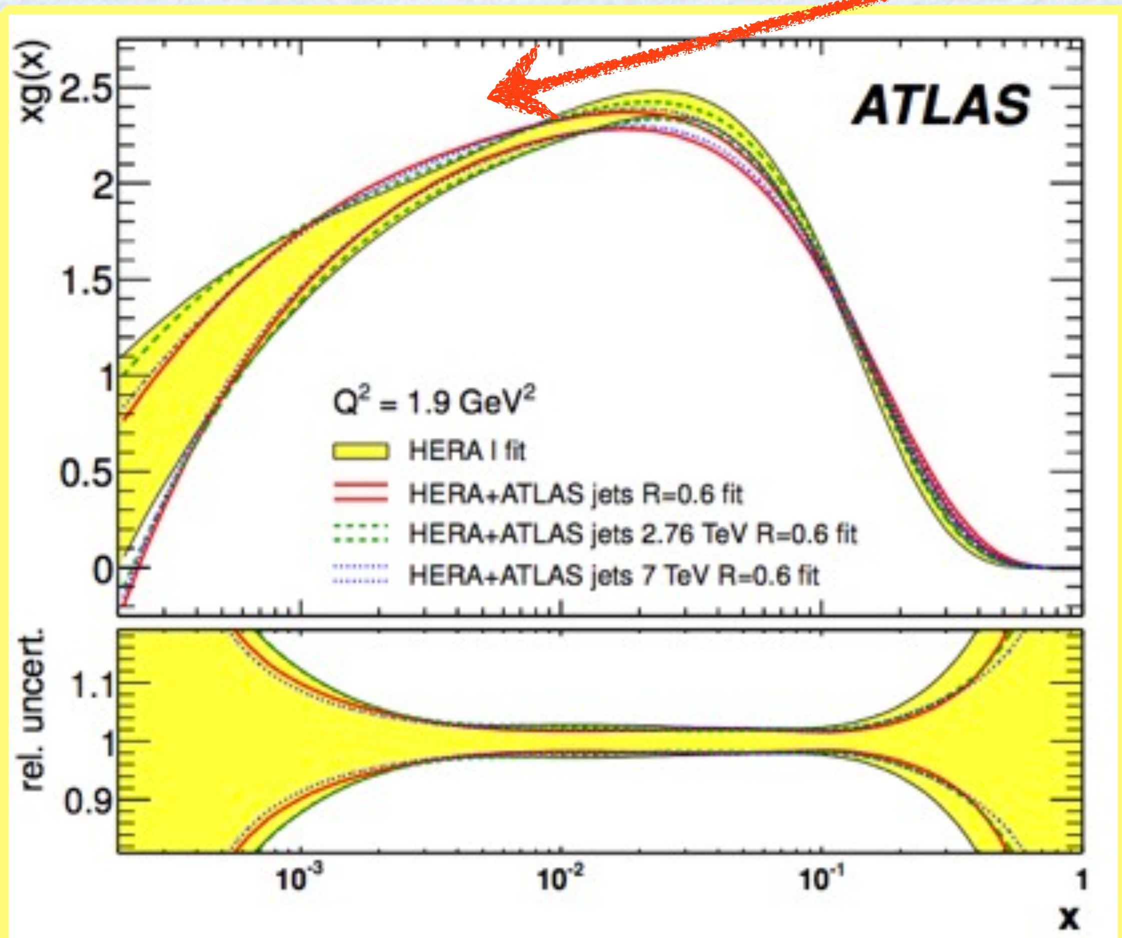

ATLAS, EPJC (2013) 73 2509

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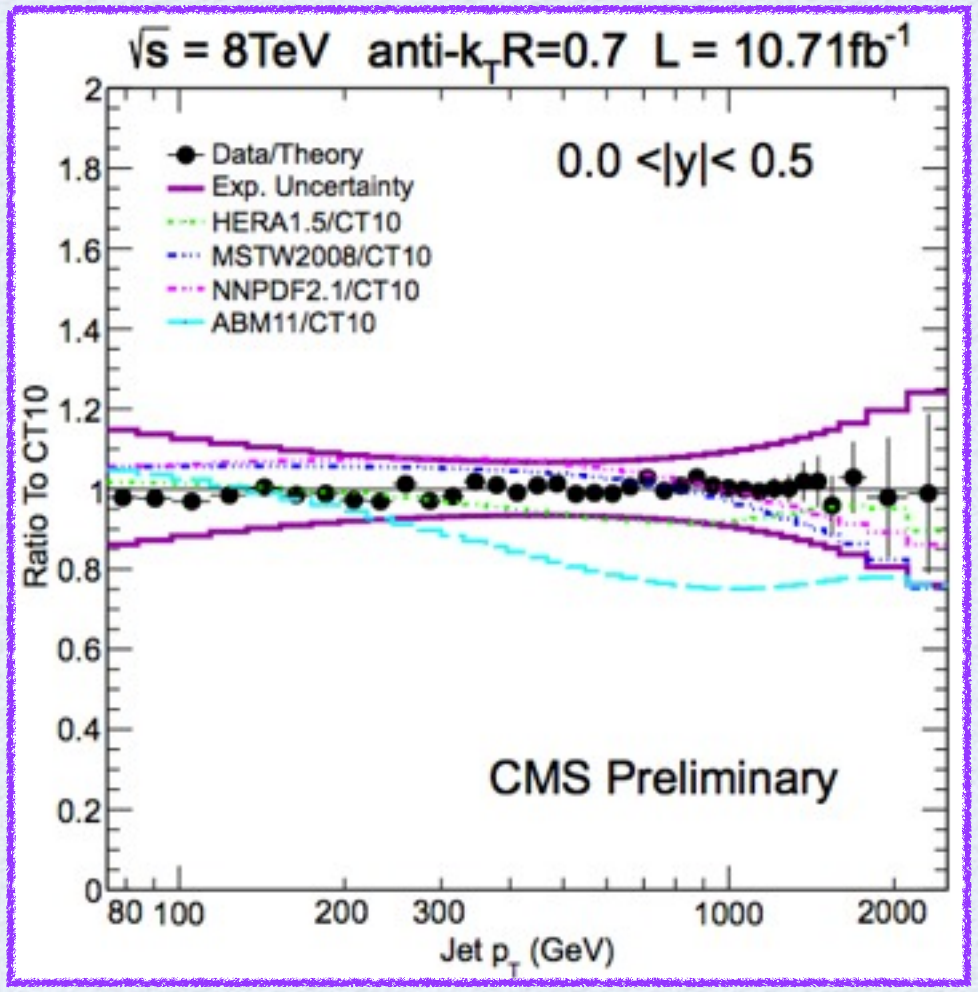
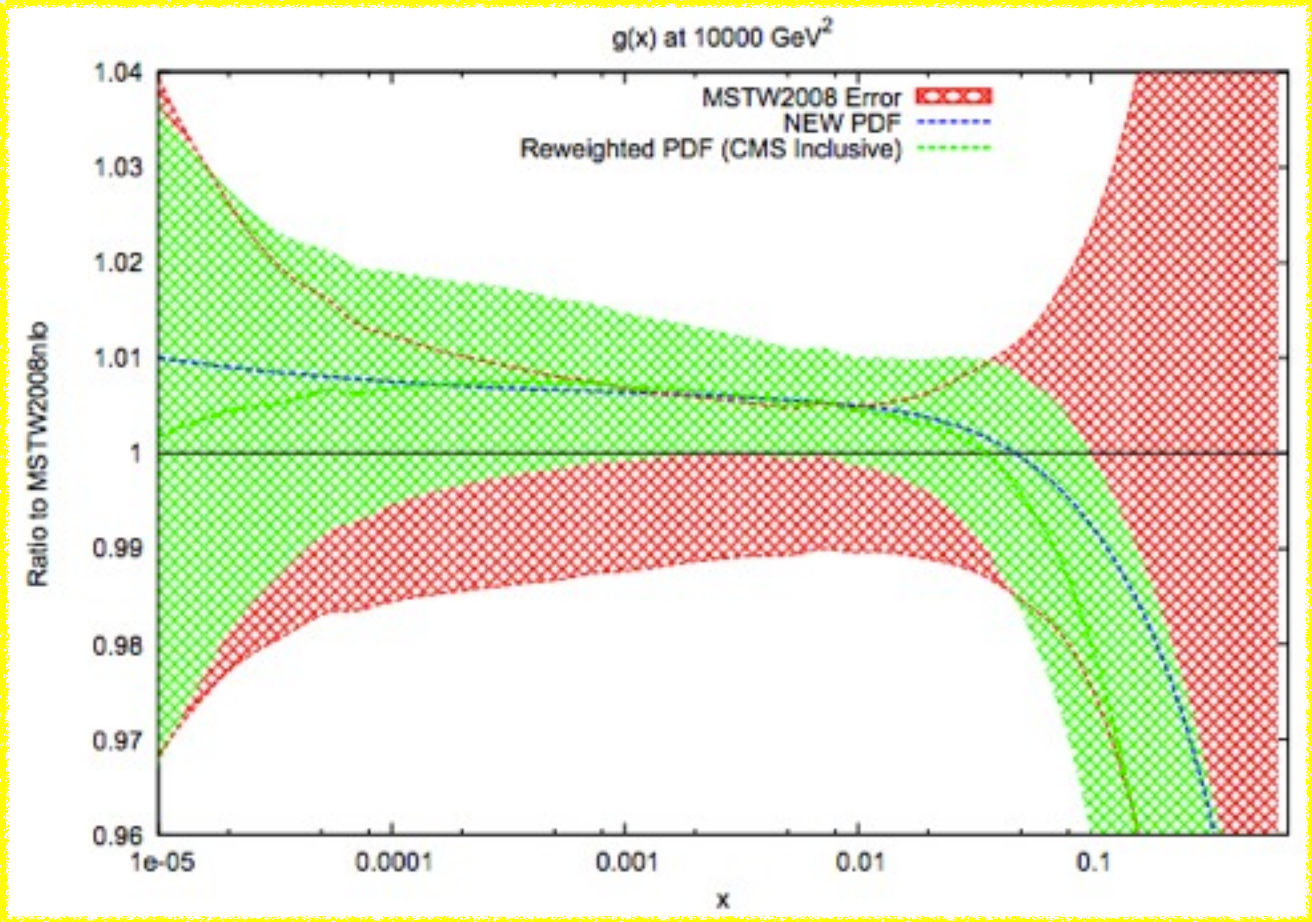
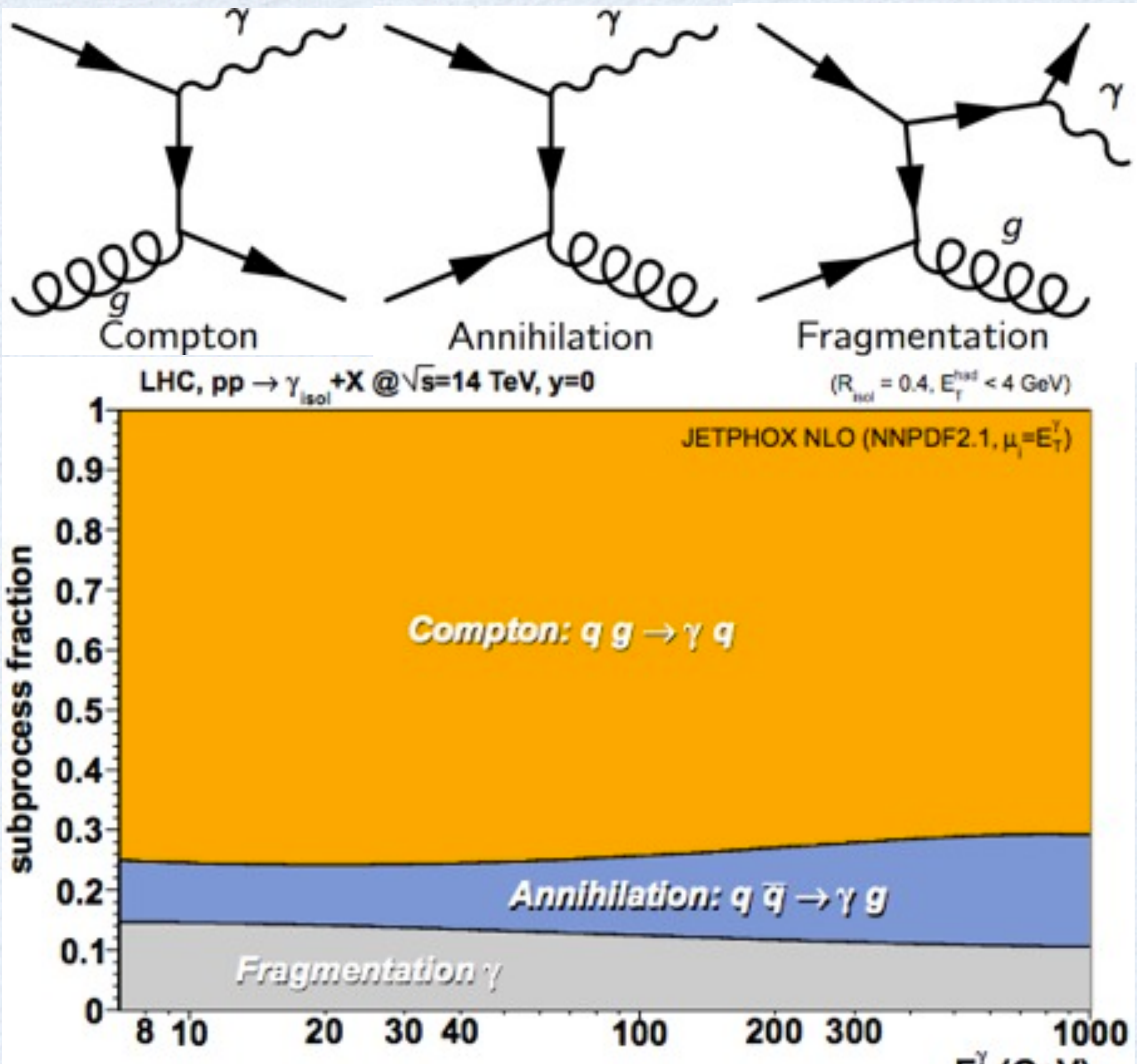




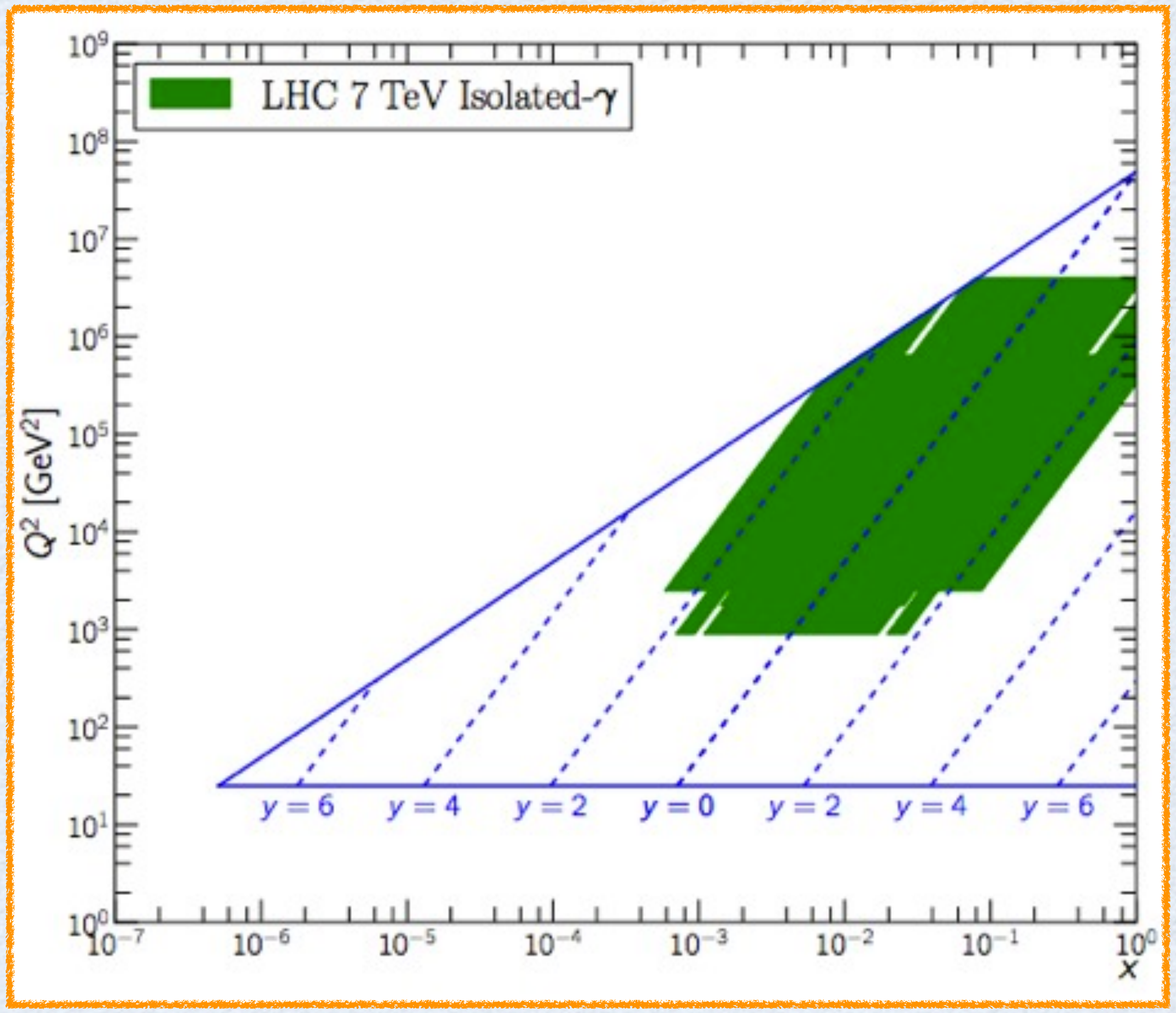
CMS-PAS-SMP-12-012

Prompt photon production



D'Enterria, Rojo, Nucl. Phys. B860 (2012), 311

- Prompt photon production at hadron colliders is directly sensitive to the gluon-quark luminosity via Compton scattering
- Isolated prompt photon data well described by NLO QCD theory
- ATLAS and CMS measurements at 7 TeV constrain medium-x region



ATLAS, 7TeV, 880 nb^{-1}, 15<E_T<100, **Phys. Rev. D 83, 052005 (2011)**

ATLAS, 7TeV, 35 pb^{-1}, 45<E_T<400, **Phys. Lett. B706, 150-167 (2011)**

ATLAS, 7TeV, 4.5 fb^{-1}, 100<E_T<1000, **ATLAS-CONF-2013-022**

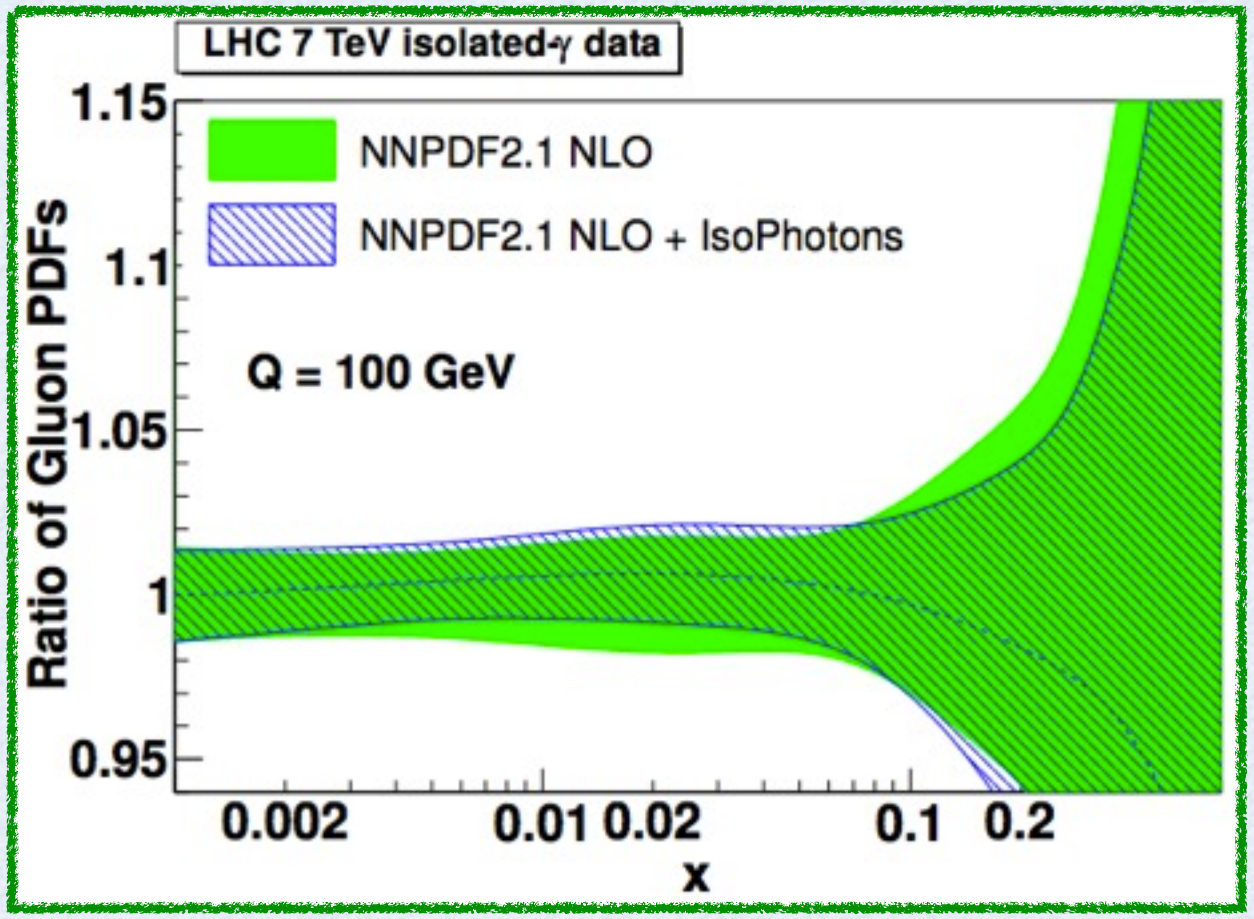
ATLAS, photon + jet, 7TeV, 35 pb^{-1}, **Phys. Rev. D 85, 092014 (2012)**

CMS, 7 TeV, 1.9 pb^{-1}, 21<E_T<300, **Phys. Rev. Lett. 106 (2011) 082001**

CMS, 7 TeV, 36 pb^{-1}, 25<E_T<400, **Phys. Rev. D 84, 052011 (2011)**

Gluons

Prompt photon production



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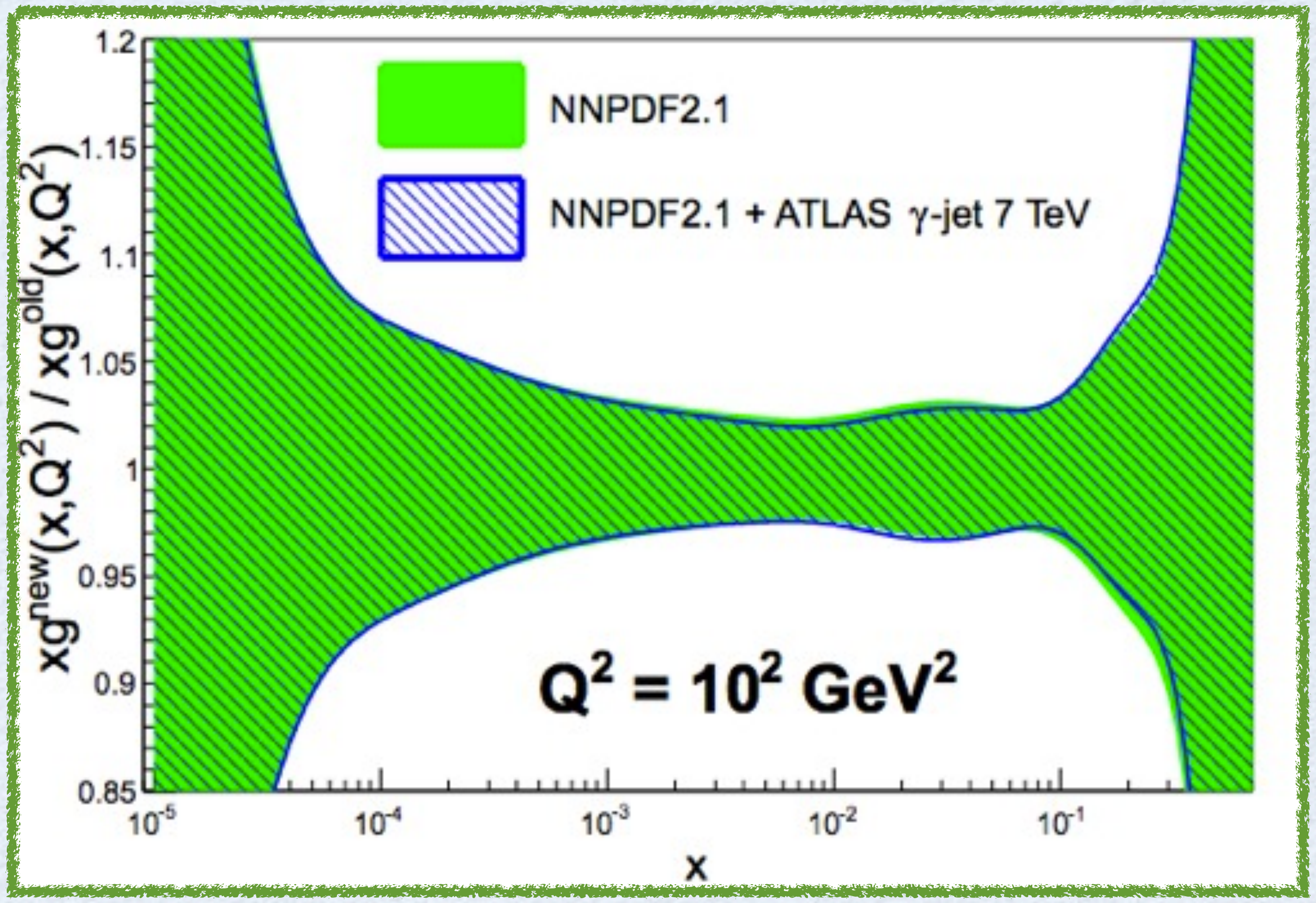


Carminati et al, EPL 101 (2013) 61002

- Included ATLAS 880 nb $^{-1}$, and 35 pb $^{-1}$, CMS 1.9 $^{-1}$ and 36 pb $^{-1}$

- Moderate uncertainty reduction in the region which affects and reduce uncertainties for Higgs gluon fusion predictions by 20%

- Issue: there is not yet a fast interface available for JETPHOX [P. Aurenche et al] in PDF fits

- Isolated photon+jet at central rapidities probe mostly gluon at x=0.01 (low E^{γ}_T) and x=0.1 (high E^{γ}_T).

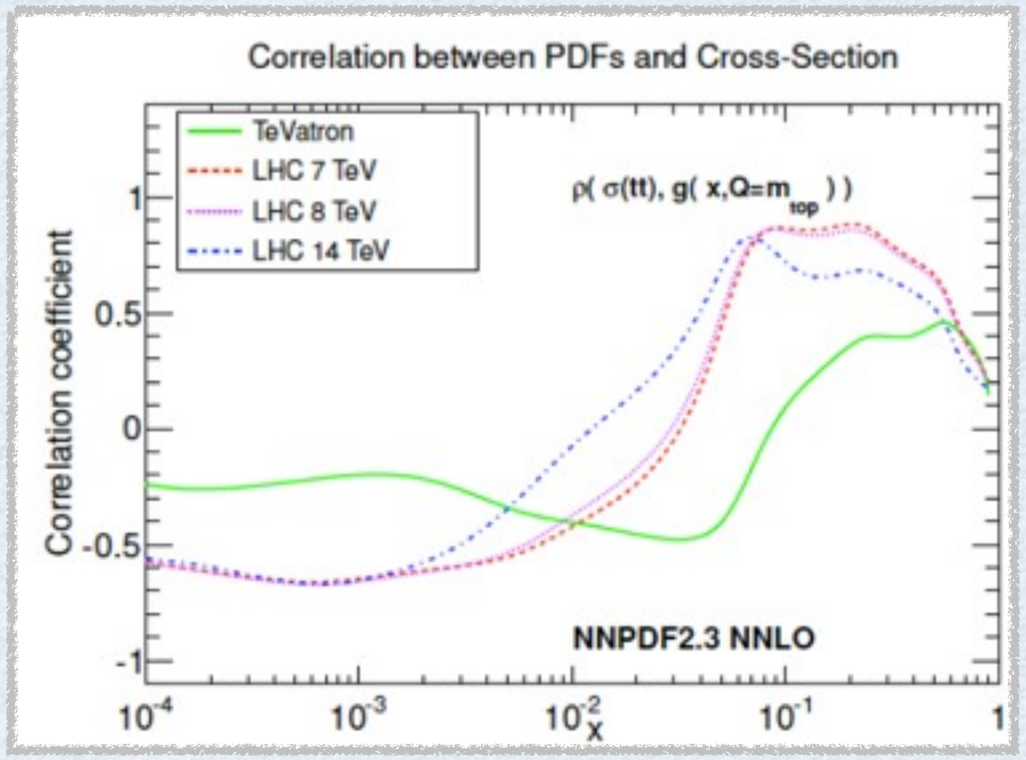
- At forward jet rapidities probe the gluon and light-quark densities at medium and small-x (low E^{γ}_T), or quarks at very large-x (v. high E^{γ}_T))

- Systematic uncertainties of early LHC data [Phys. Rev. D 85, 092014 (2012)] still too large to provide significant constraints.

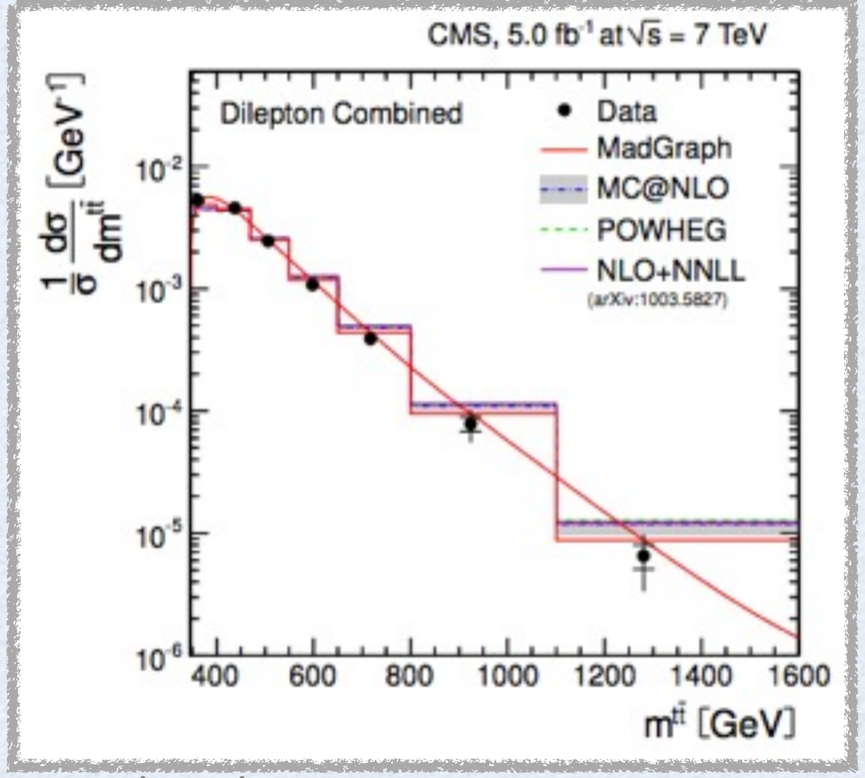
Top pair production

- At the LHC, the dominant channel for top pair production is gluon-gluon fusion
- Exp: precise measurements of total xsec by ATLAS and CMS + differential distributions with full info on covariance matrix
- Theory: full NNLO available for total cross sections **[Czakon et al, Phys.Rev.Lett. 110 (2013) 252004]**, and NLO + NNLL code for distributions public soon **[Guzzi, Lipka, Moch 1308.1635]**
- Reduced sensitivity to non perturbative parameters wrt jets

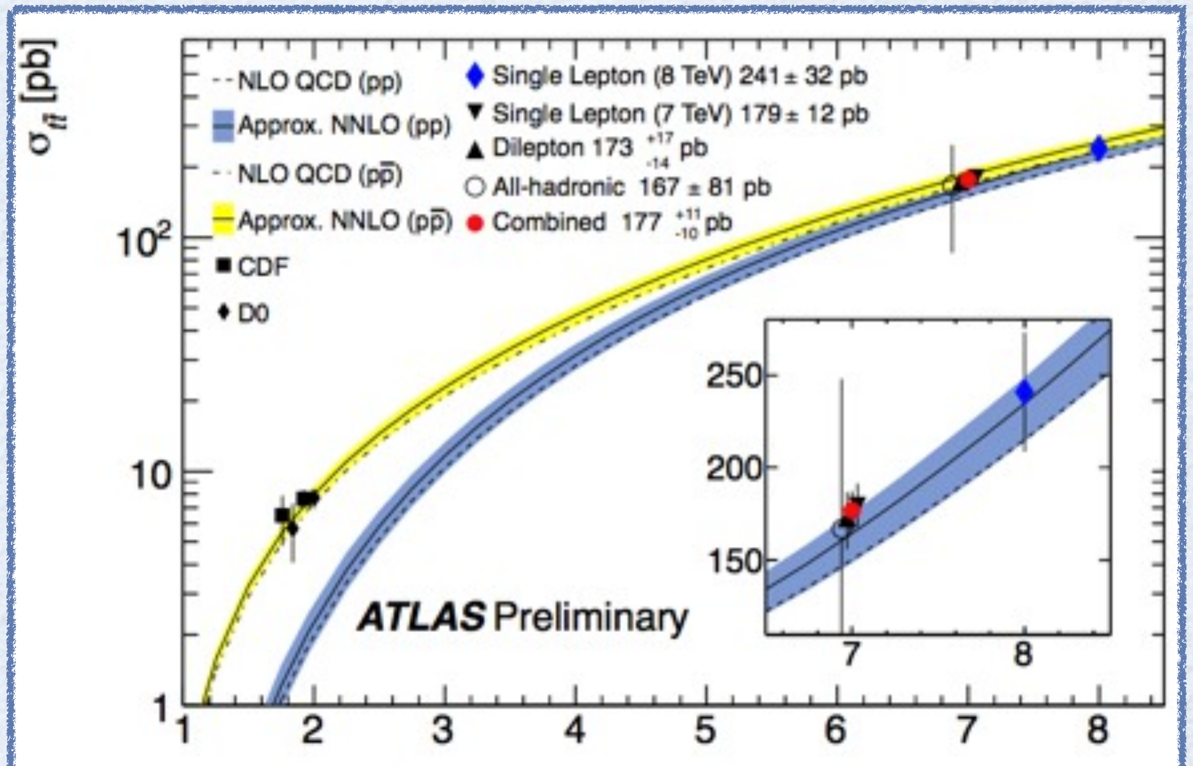
	TeVatron	LHC 7 TeV	LHC 8 TeV	LHC 14 TeV
gg	15.4%	84.8%	86.2%	90.2%
$qg+\bar{q}g$	-1.7%	-1.6%	-1.1%	0.5%
qq	86.3%	16.8%	14.9%	9.3%



Czakon et al, ArXiv:1303.7215



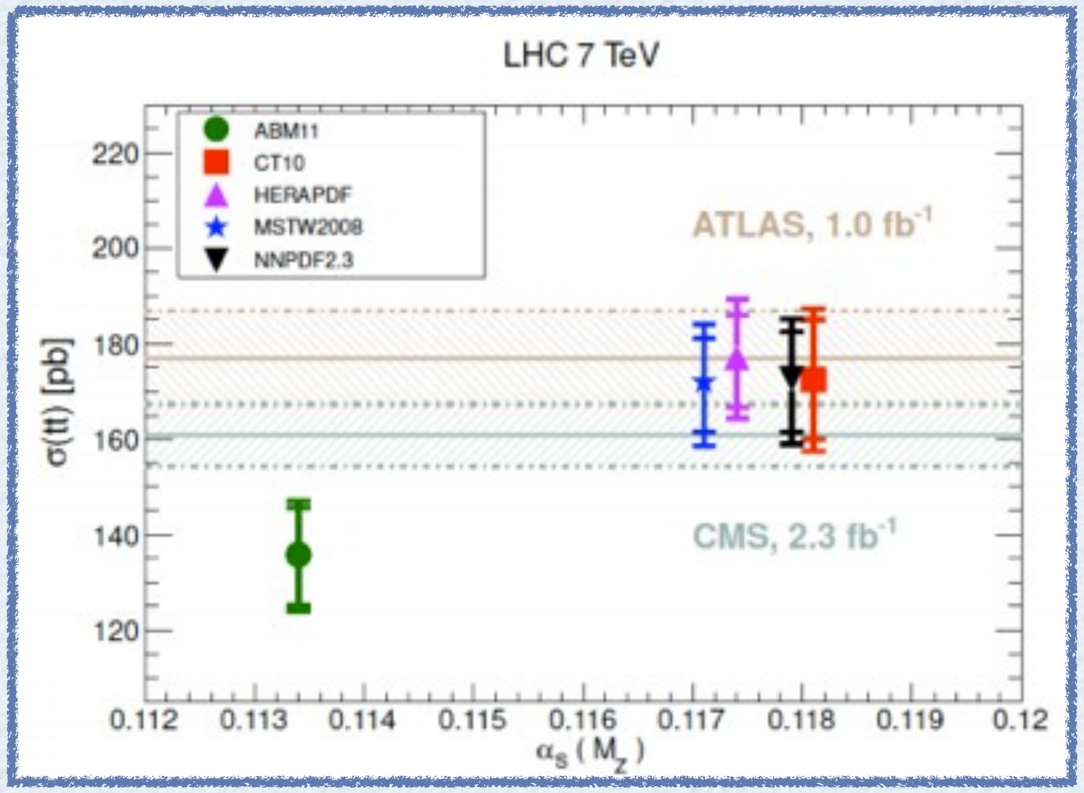
CMS, EPJC 73 (2013) 2339

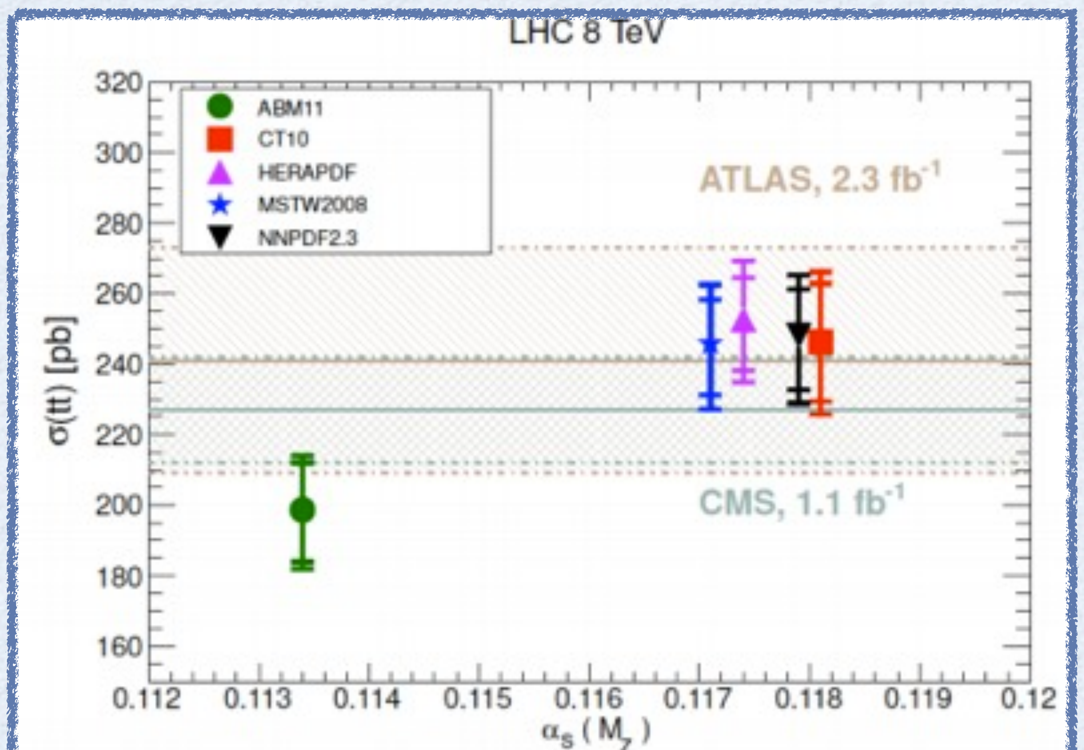


ATLAS-CONF-2012-024

Gluons

Top pair production

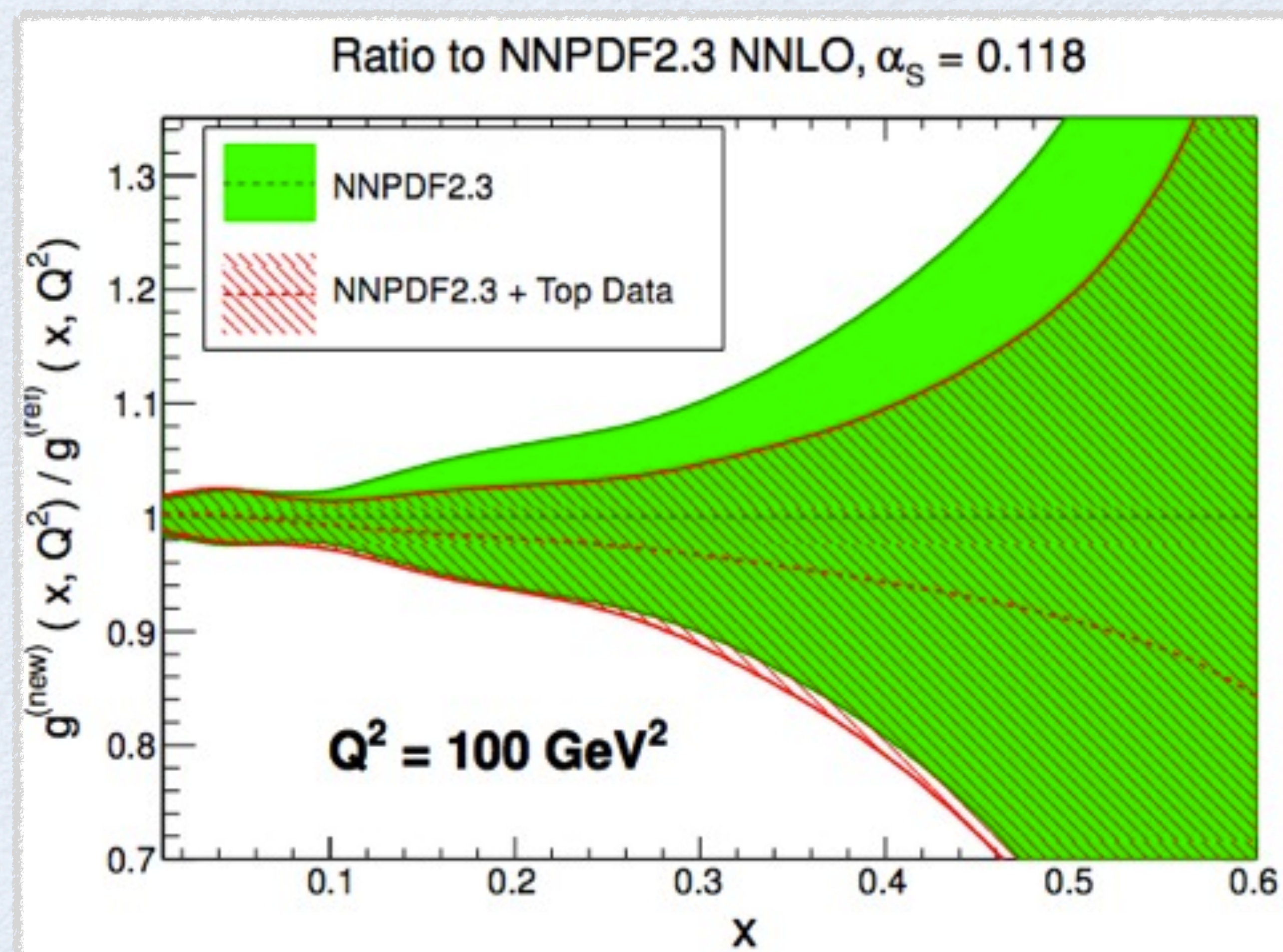




Czakon et al, JHEP 1307 (2013) 167

- Several studies on effect of top pair inclusive cross section on the gluon **[Czakon et al, Beneke et al]**
- Predictions computed at NNLO+NNLL accuracy
- Inclusion in the recent NNPDF23 PDF analysis shows that top-quark inclusive cross section data (N_{data} = 4) reduces uncertainty of large x gluon up to 20%
- Effect of HERA+top data on gluon similar to HERA+jets
- Ultimate constraint power expected from distributions
- Fast interface available in MCFM

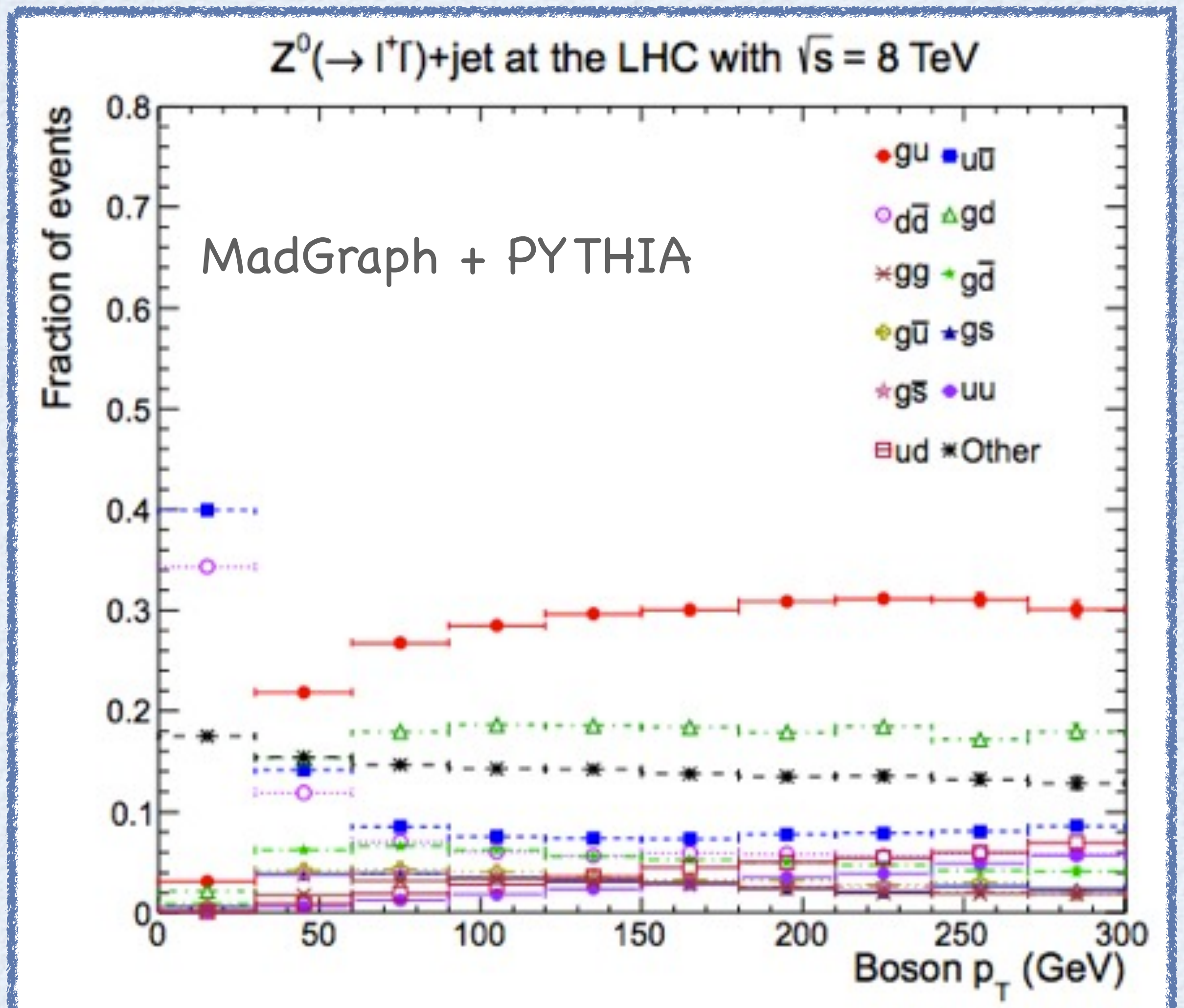
Czakon et al, JHEP 1307 (2013) 167

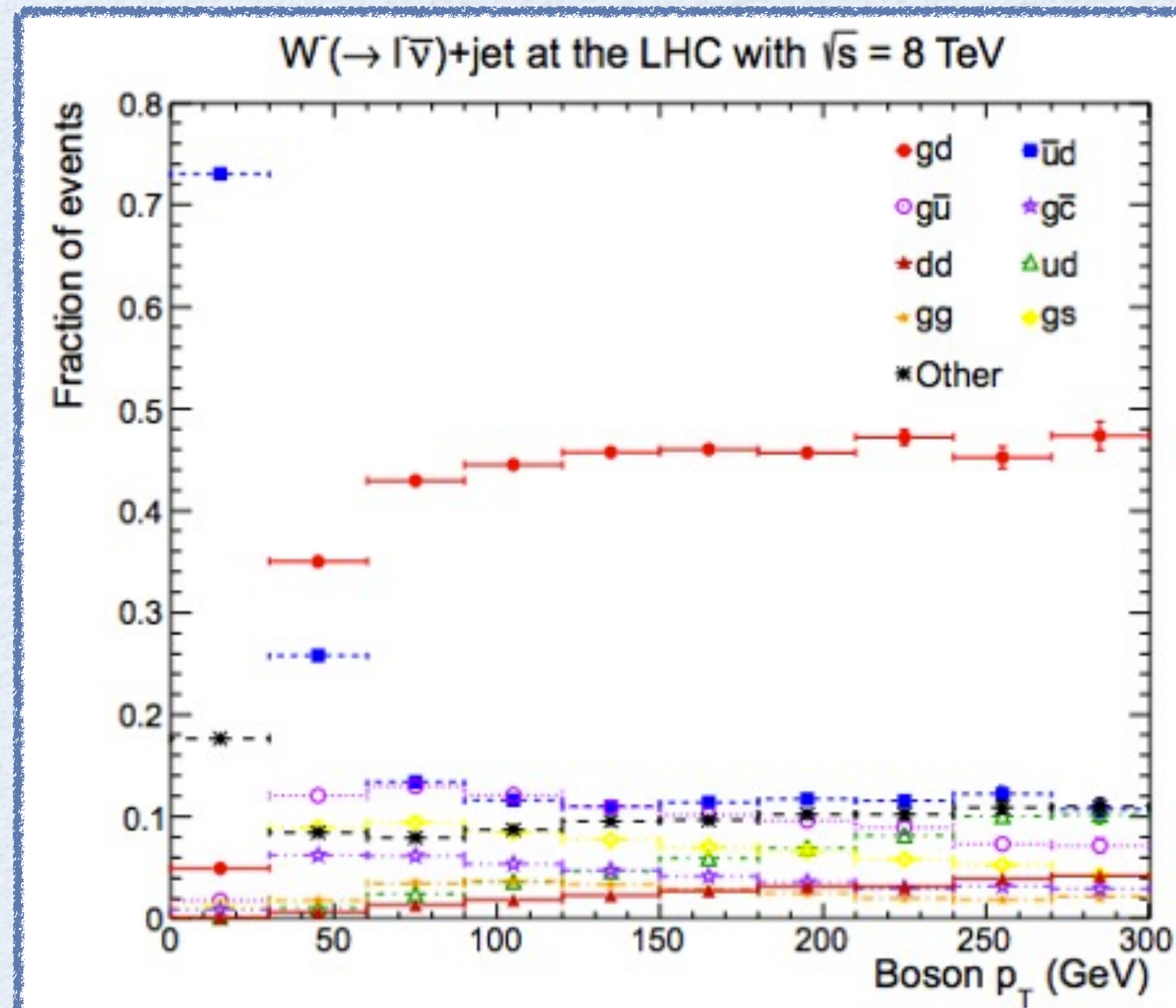


Gluons

High p_T Z/W production

- In global fits, medium/large x gluon is mainly constrained by jet data.
- W/Z boson at large p_T (associated with jets) would provide a complementary constraint in x region which enters gg>H production
- At large pT, gluon up (for Z and W^+) or gluon down (for W^-) scattering dominate: can exploit these observables to constrain gluon and u/d ratio





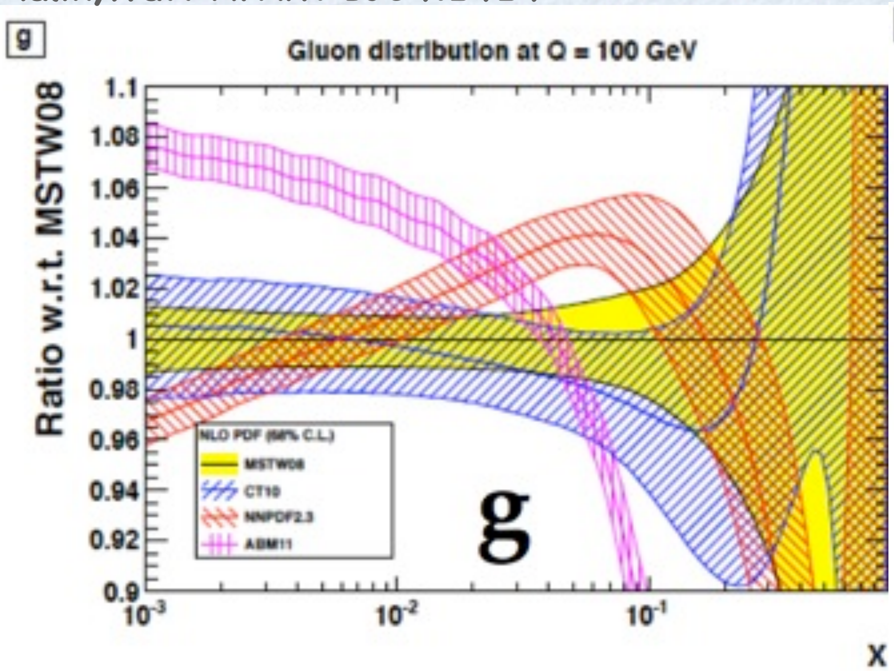
Malik,Watt ArXiv: 1304.2424

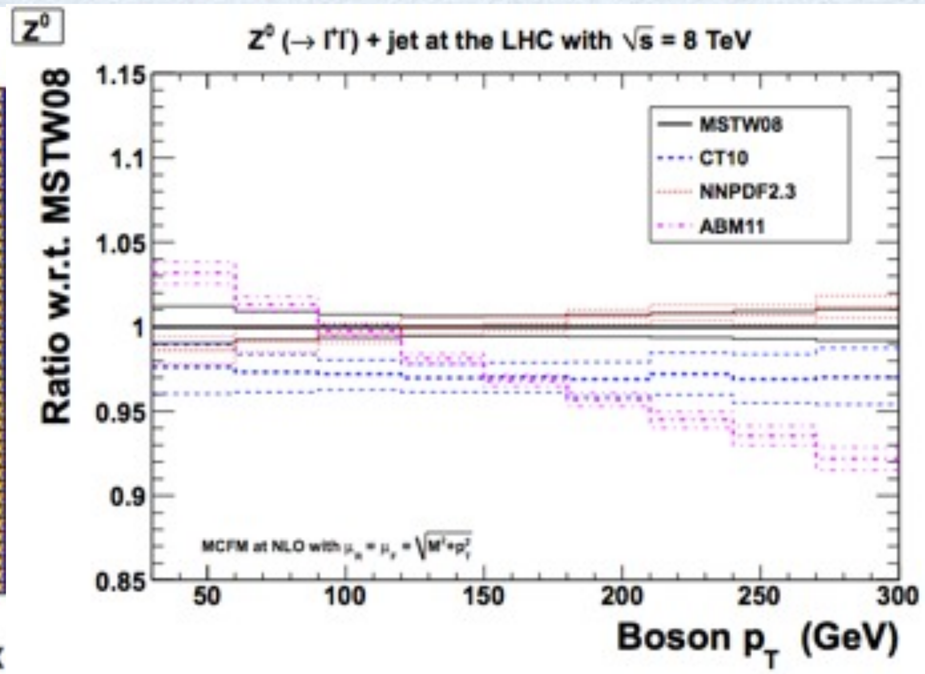
Gluons

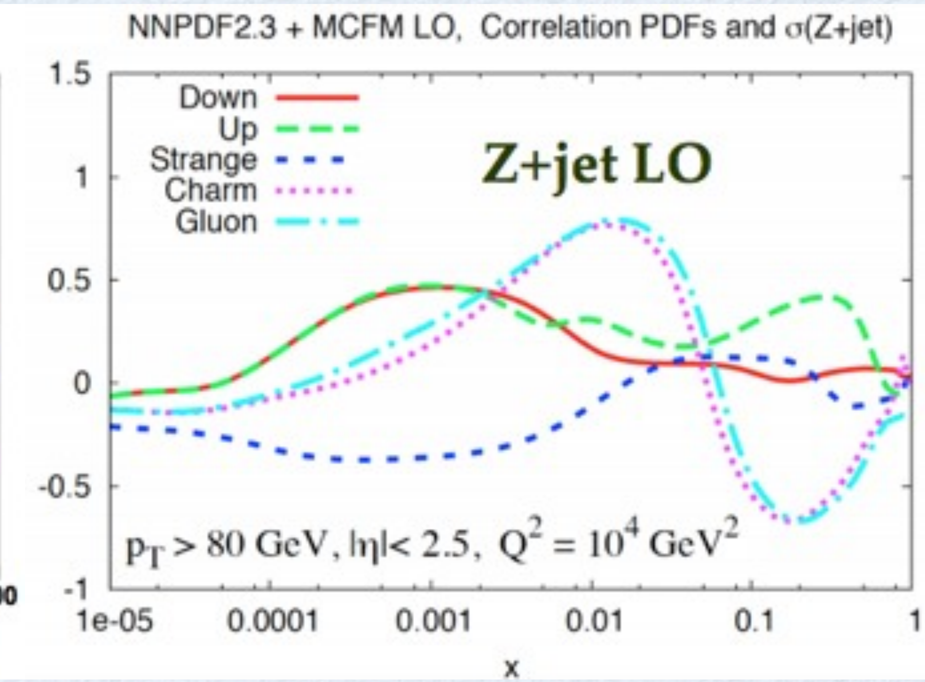
High p_T Z production

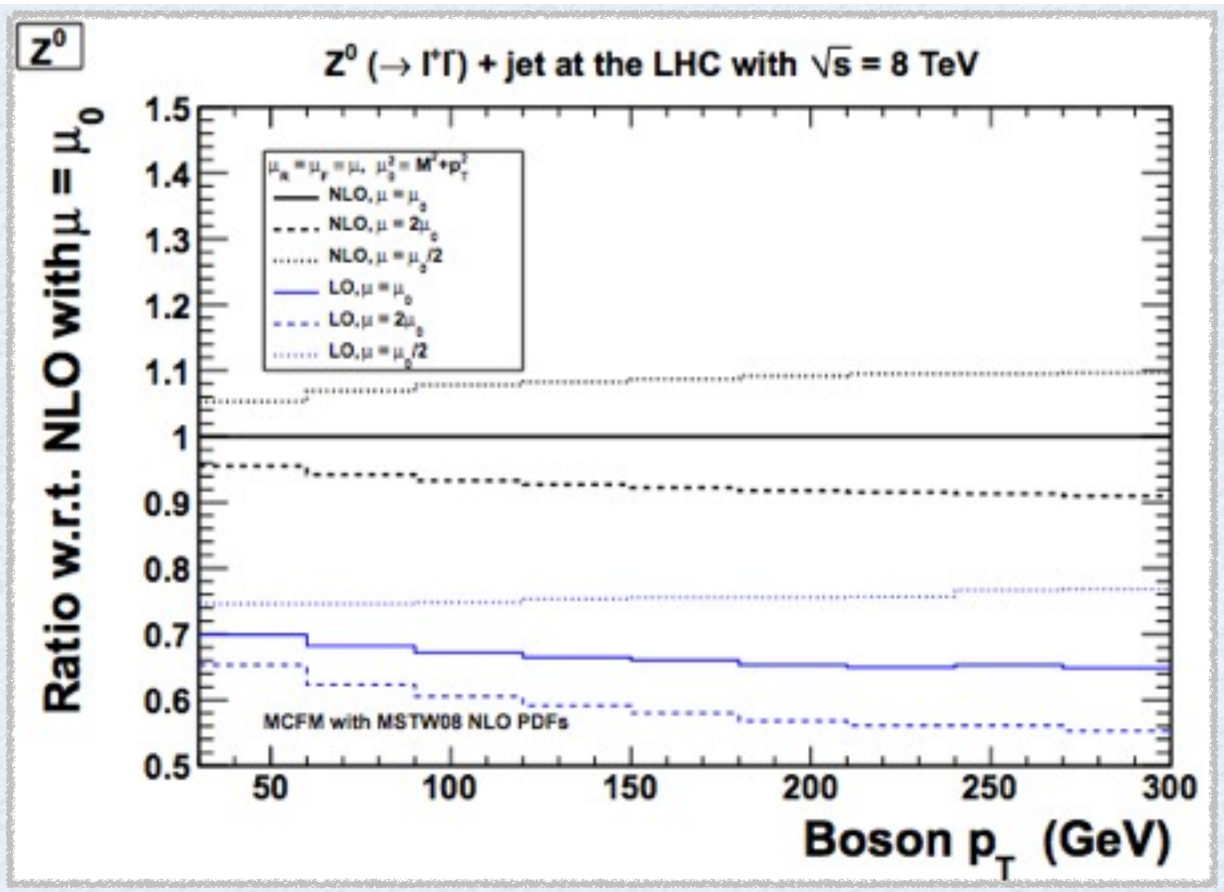
Malik,Watt ArXiv: 1304.2424

J. Rojo, PDF4LHC







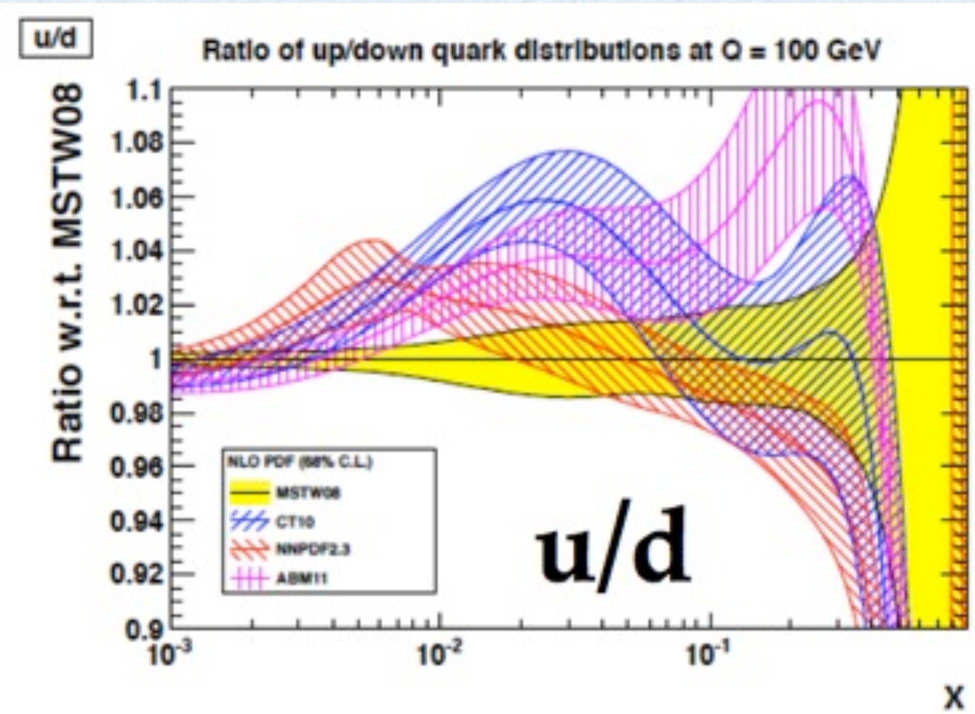


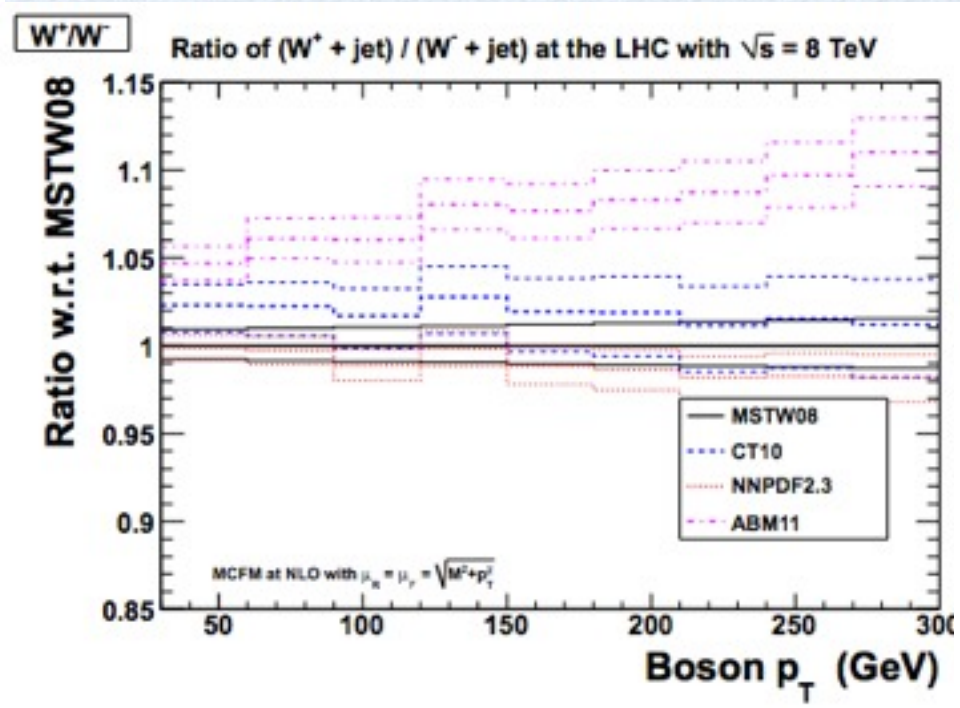
- Z boson at large p_T (associated with jets) is mostly correlated to gluon at medium x and light quarks. Similar to direct photon
- x dependence on gluon -> p_T dependence on $d\sigma/dp_T$
- p_T spectrum is affected by possibly large theoretical uncertainties
- For p_T > 30 GeV, the need of resumming soft logs of M_V/p_T is minimized. Still scale uncertainty and NLO/LO ratio grows with p_T. Need NNLO!
- NNLO Z+jets not much different from H+jets, therefore NNLO calculation is expected soon [Boughezal et al]
- EW NLO effects, large EW logs can be significant at large lepton pT [Denner et al, 1103.0914] Local K-factor?

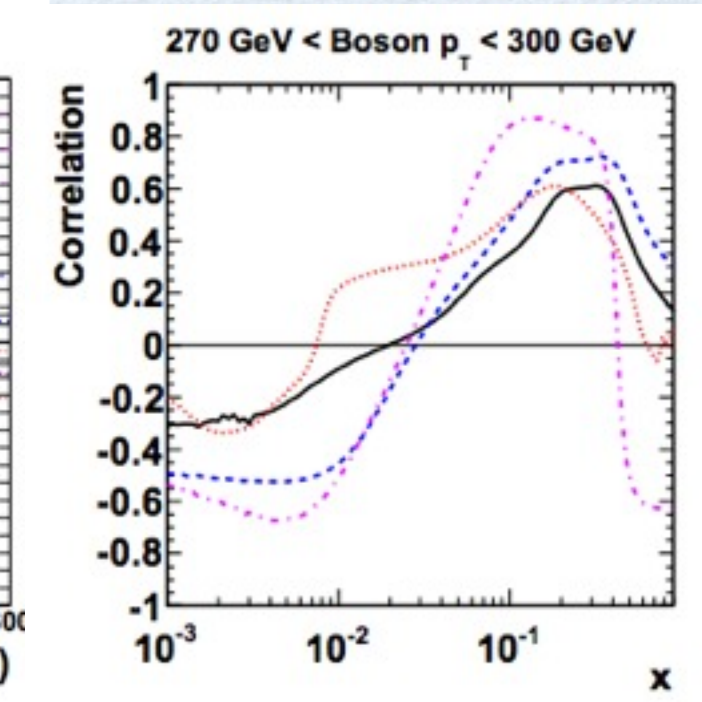
Malik,Watt ArXiv: 1304.2424

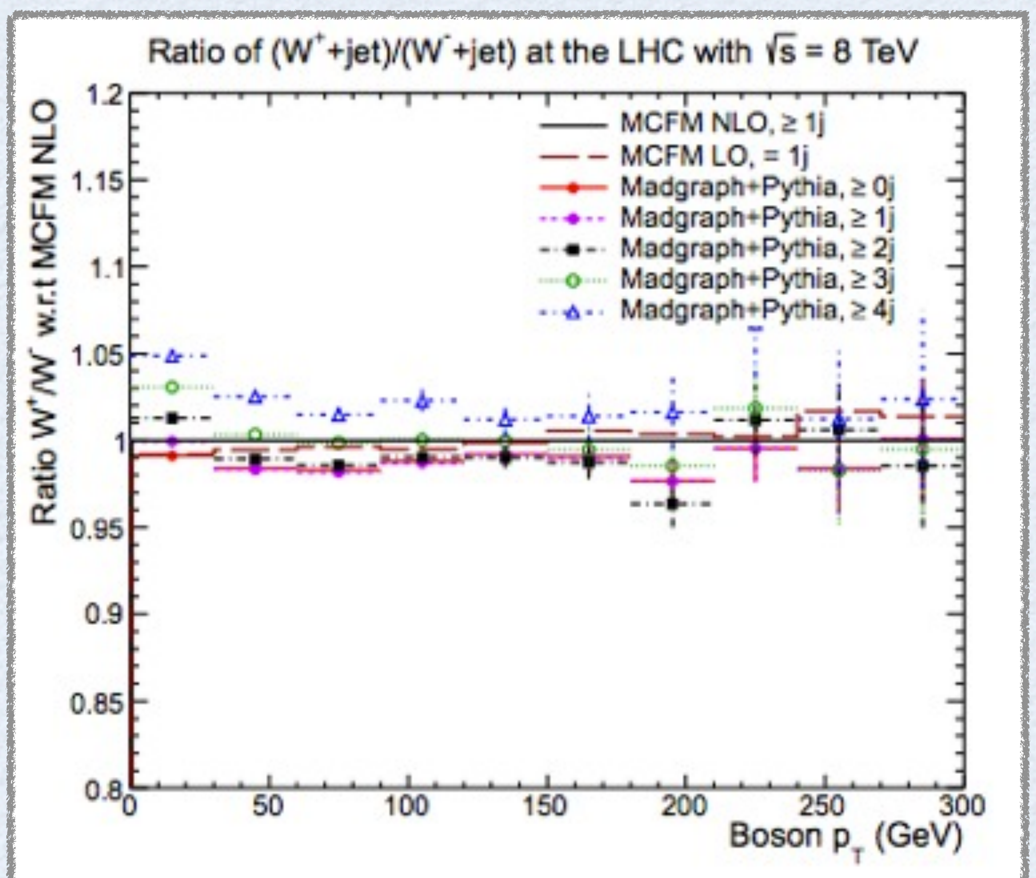
Light (anti-)quarks

High p_T W^+/W^- ratio









- In ratios theoretical uncertainties for higher order QCD corrections cancel below 1%.
- Impact of PS almost negligible in W^+/W^- ratio as well as EW high-p_T log corrections
- x dependence on (u/d) -> p_T dependence on ratio $d(W^+/W^-)/dp_T$ in the region where differences are larger
- Very promising observable giving complementary information as W asymmetry measured as a function of rapidity
- Work in progress to make V+jets NLO theoretical predictions available in APPLGRID format

Malik,Watt ArXiv: 1304.2424

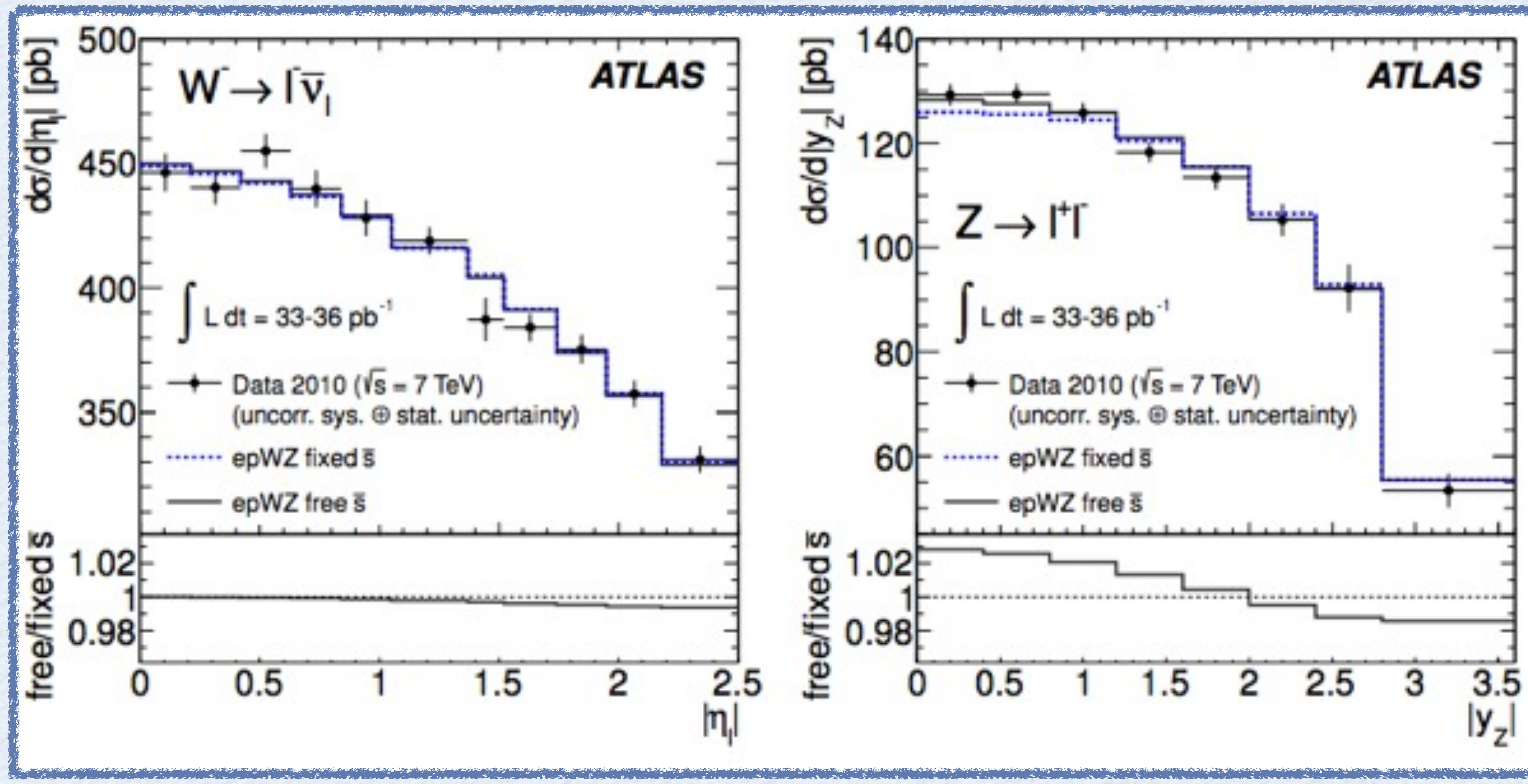
Light (anti-)quarks

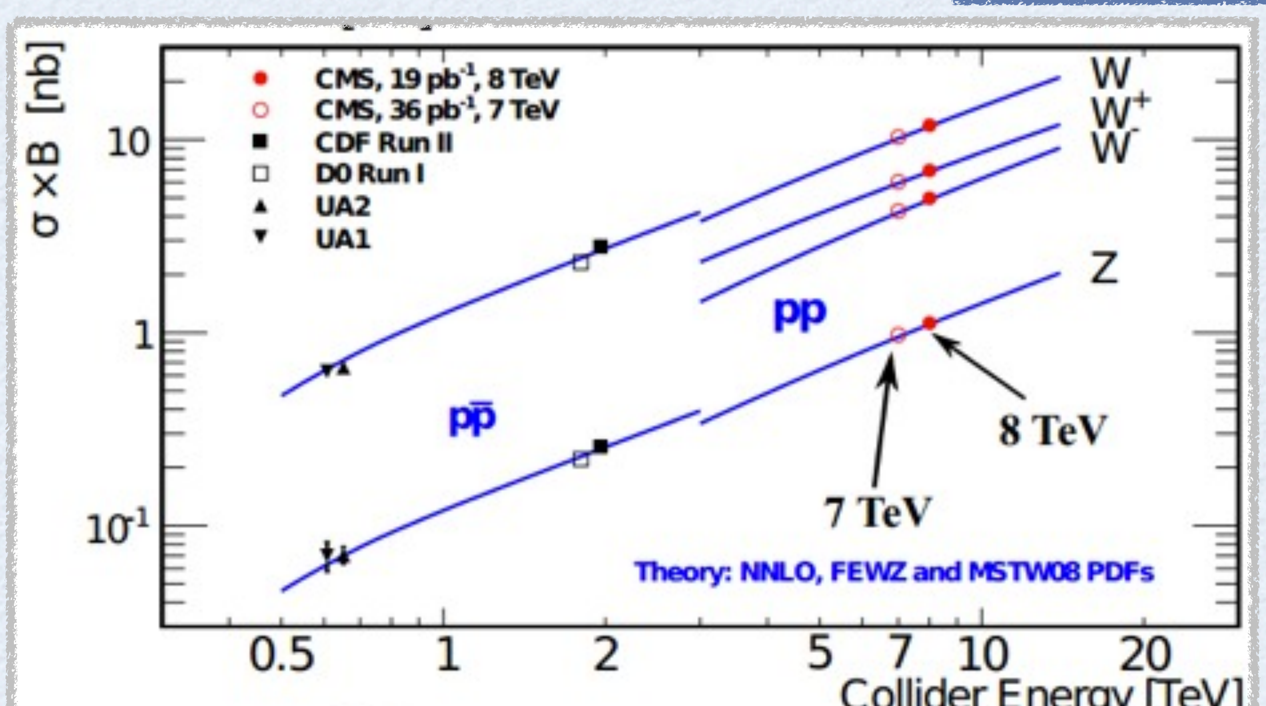
Vector boson production

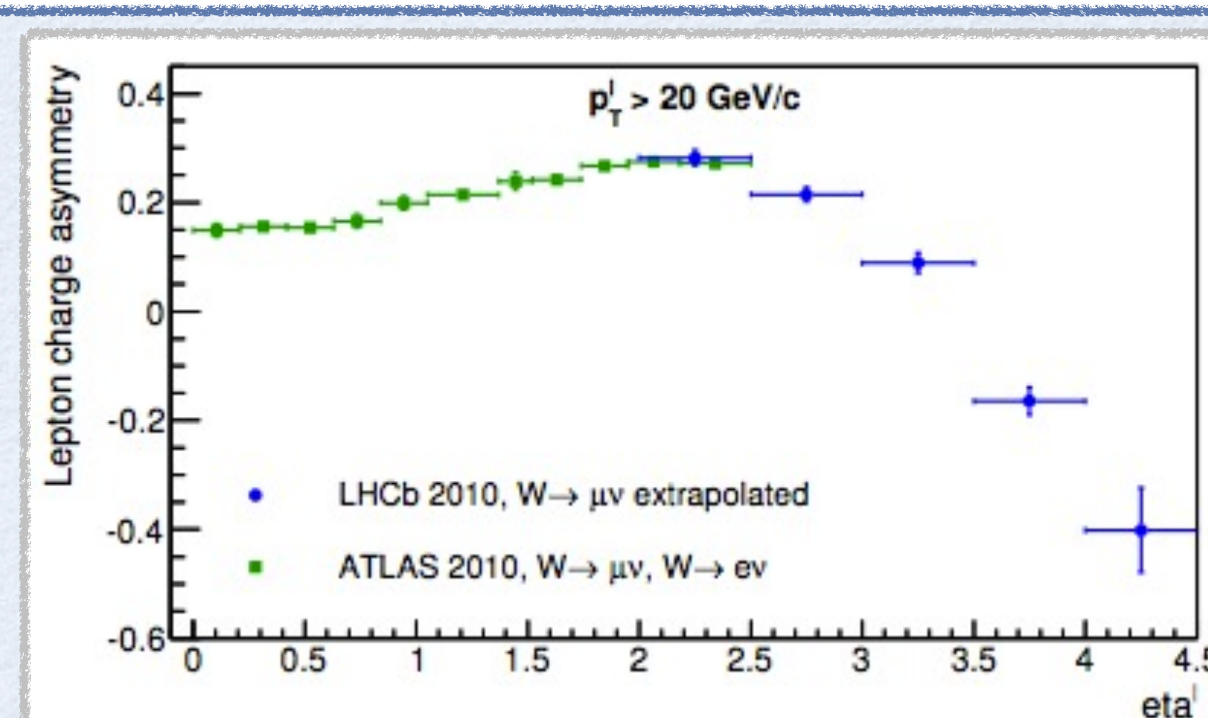
ATLAS, Phys. Rev. D85, 072004

- Inclusive W and Z production probes quark flavor separation in a wide range of x

- Wealth of experimental measurements: inclusive cross sections, ratios, rapidity and pseudo-rapidity distributions







CMS-PAS-SMP-12-011

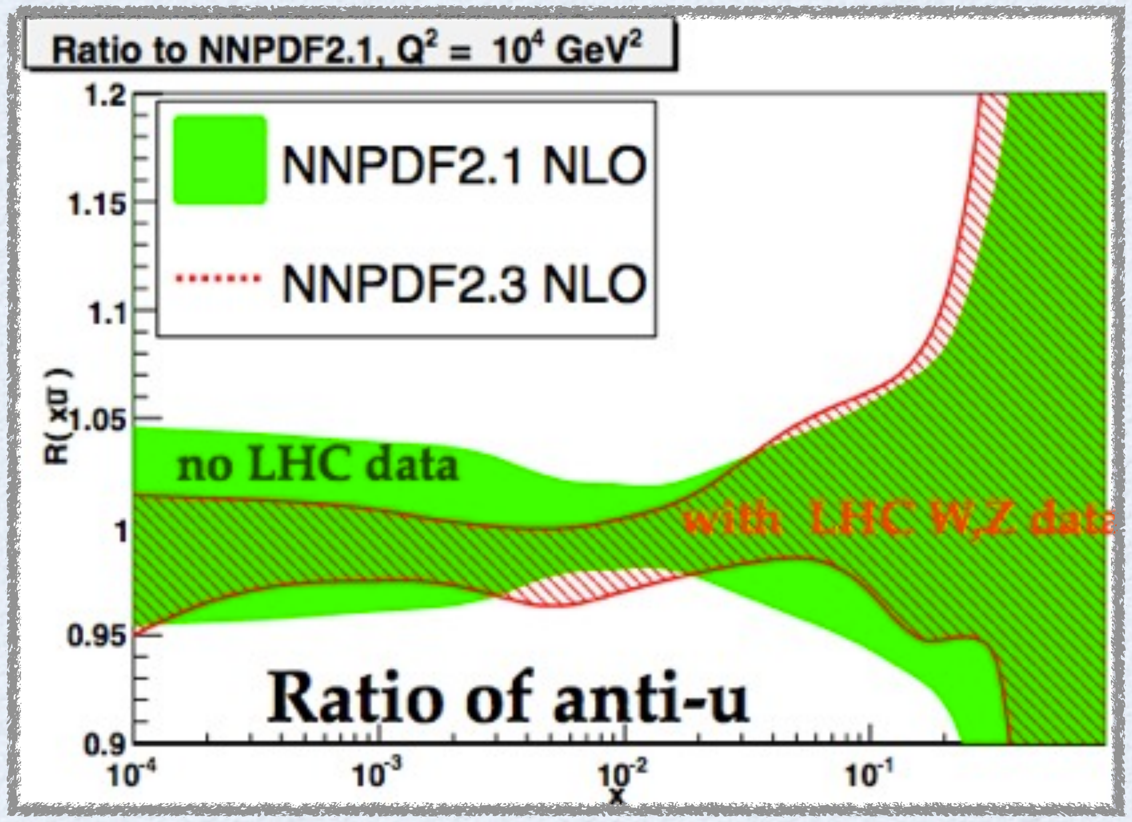
LHCb-CONF-2013-005

Light (anti-)quarks

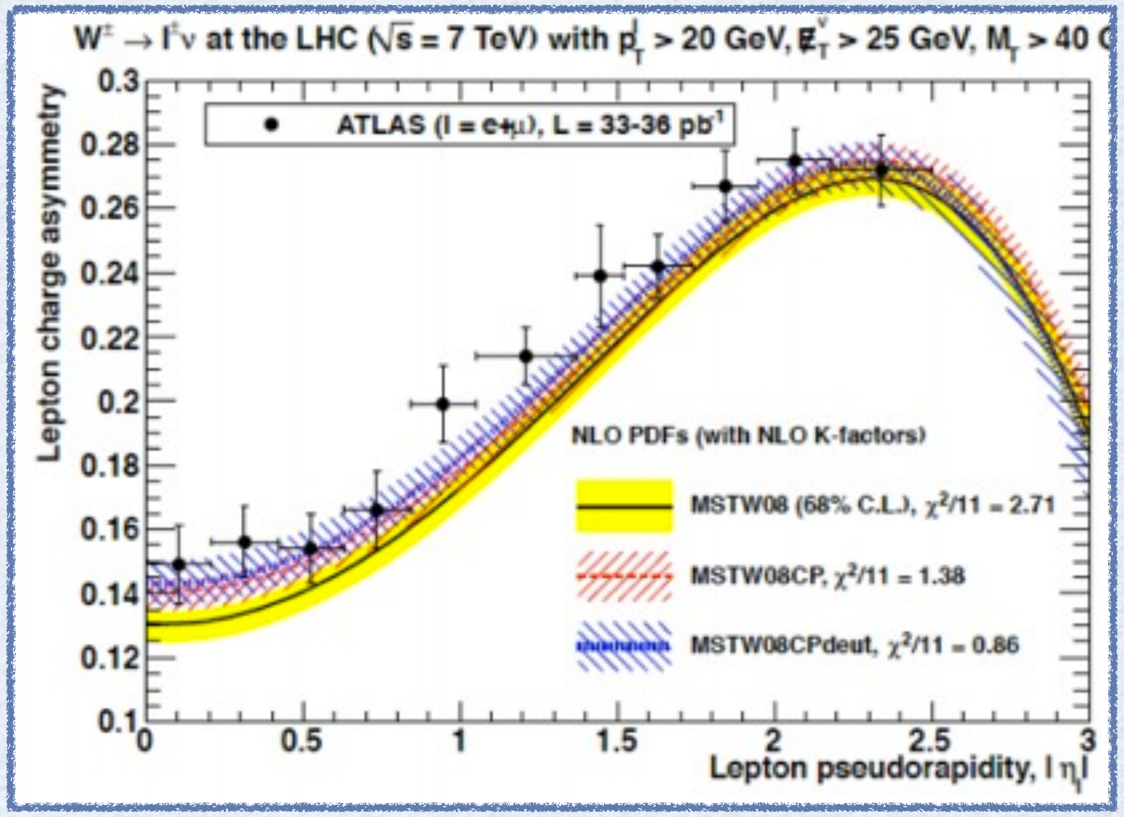
Vector boson production

NNPDF2.3

- ATLAS W/Z lepton rapidity distributions, 36 pb^{-1} Phys. Rev. D85(2012) 072004
- CMS W lepton asymmetry, 840 pb^{-1} Phys. Rev. Lett. 109(2012) 111806
- LHCb W rapidity distributions, 36 pb^{-1} JHEP 1206(2012) 058



R. Ball et al, Nucl. Phys. B867 (2013) 244

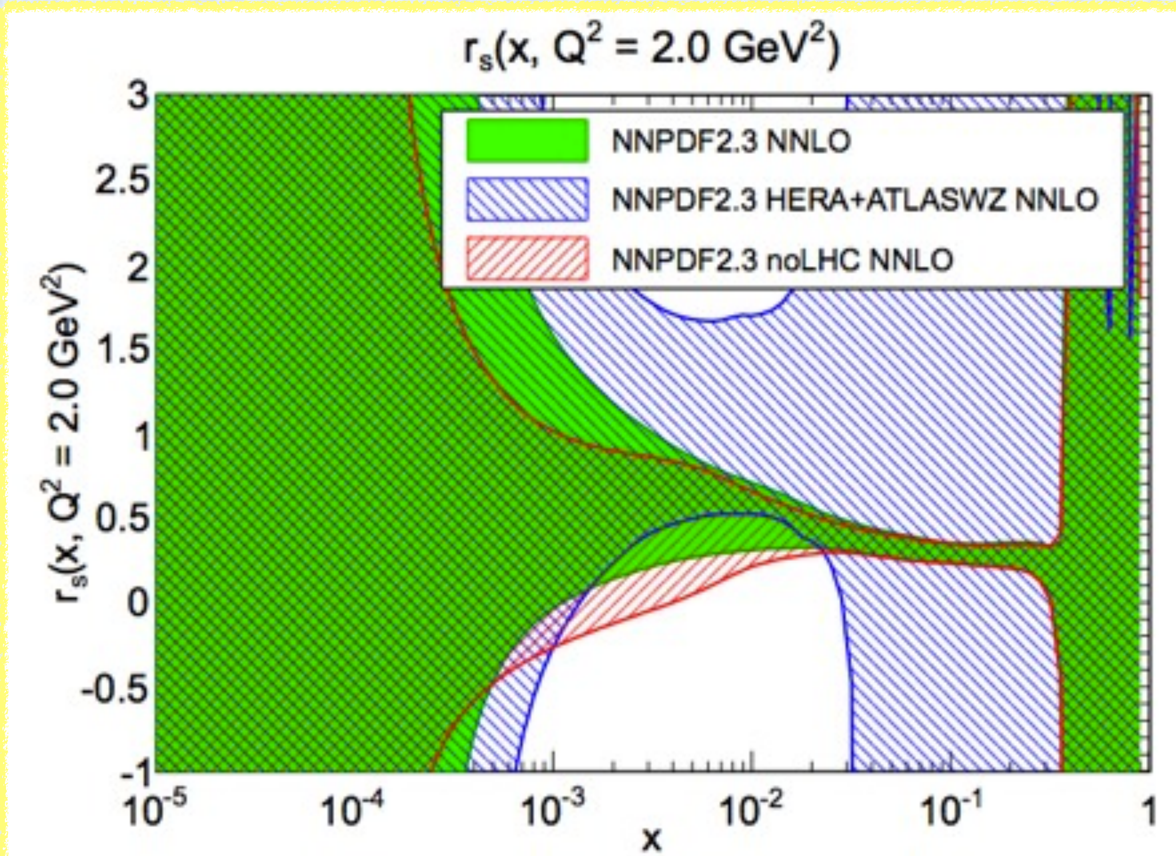


R. Thorne, QCD@LHC 2013

- Inclusive electroweak production decreases antiquark uncertainty (NNPDF2.3)
- W asymmetry data enabled MSTW to spot a restrictive u_v-d_v parametrization
- Upcoming PDF sets will include higher statistics measurements -> stronger constraints
- Most useful: separate differential distribution of W and Z together with the corresponding covariance matrix. Individual distributions can be combined a posteriori in a global analysis!

Strangeness

Vector boson production



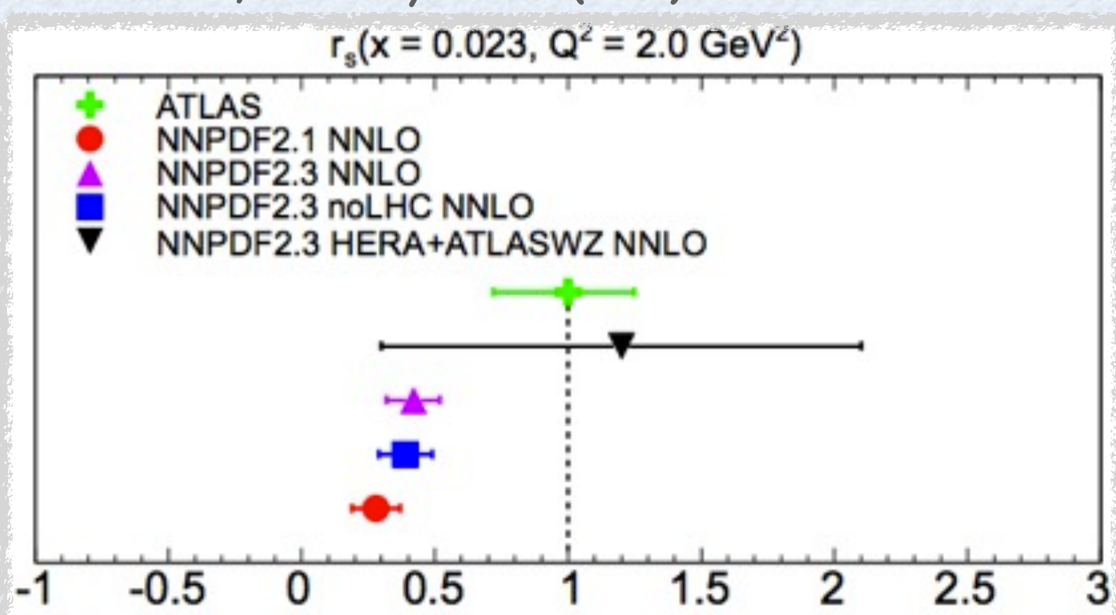
R. Ball et al, Nucl. Phys. B867 (2013) 244

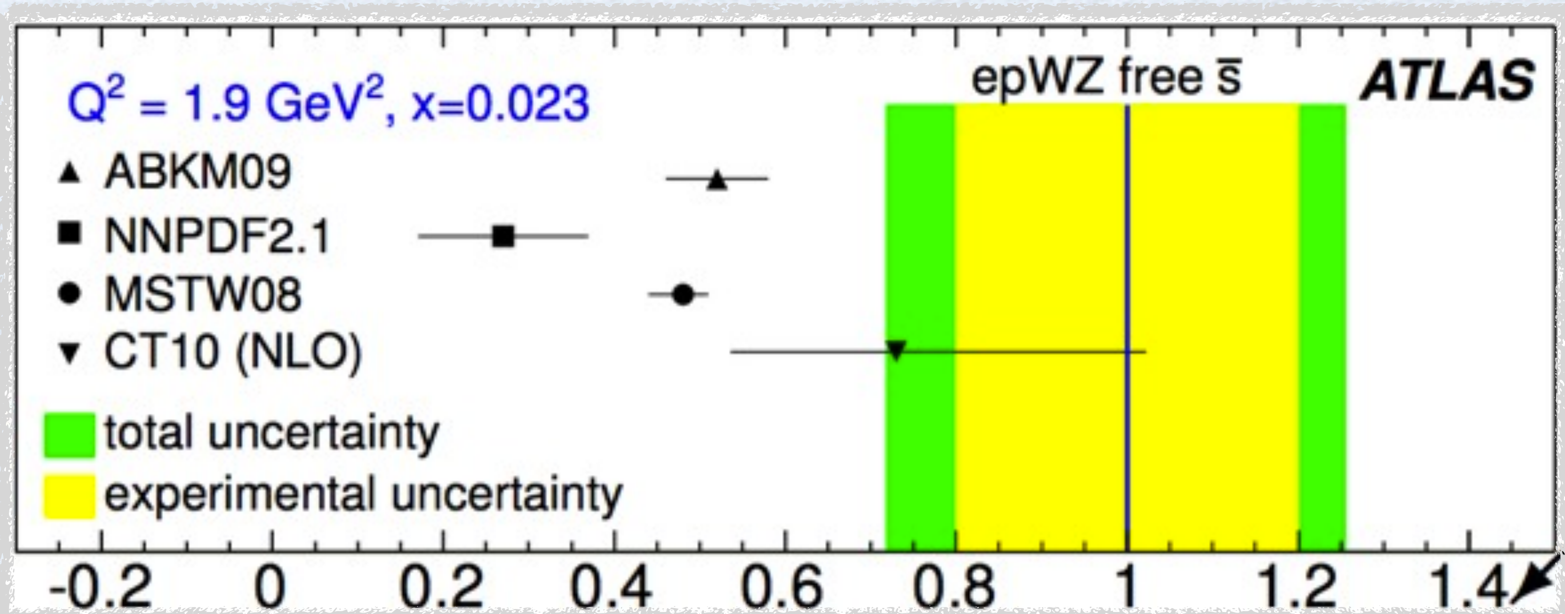
- ATLAS (2012) claims large value of $r_s \sim 1$

$$r_s(x,Q^2) = \frac{s(x,Q^2) + \bar{s}(x,Q^2)}{2d(x,Q^2)}$$

- Results based on the HERAPDF + HERAFITTER approach
- NNPDF2.3 analysis confirms the central value of the ATLAS analysis but finds larger uncertainties.
- Strangeness in NNPDF2.3 is still mostly determined by NuTeV data, LHC data have minor impact
- In the upcoming analyses more input from 8 TeV data

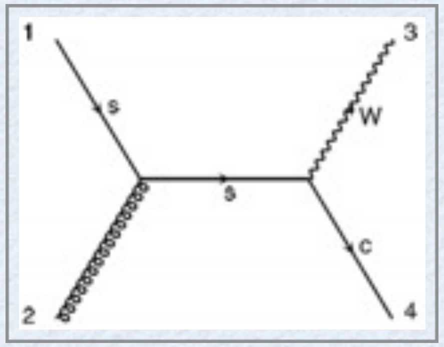
ATLAS, Phys. Rev. Lett. 109 (2012) 012001

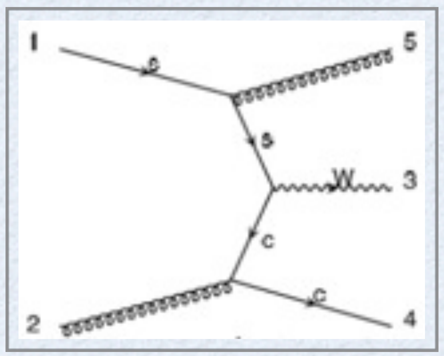


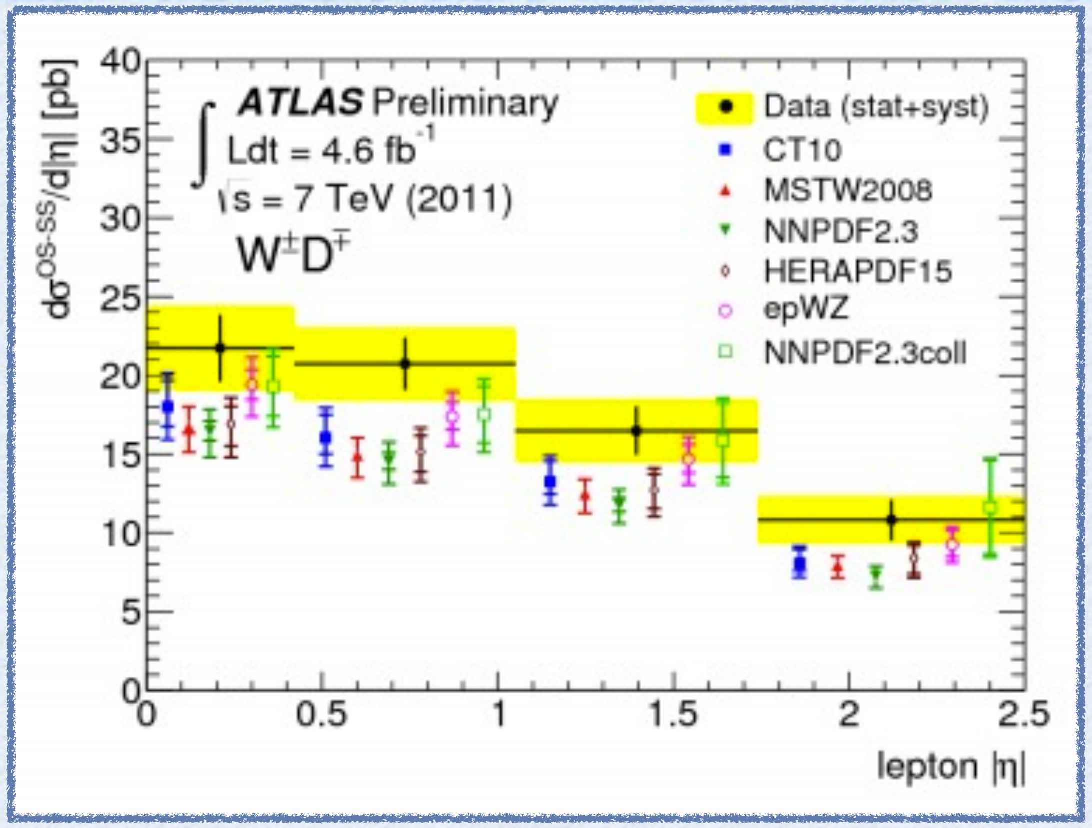


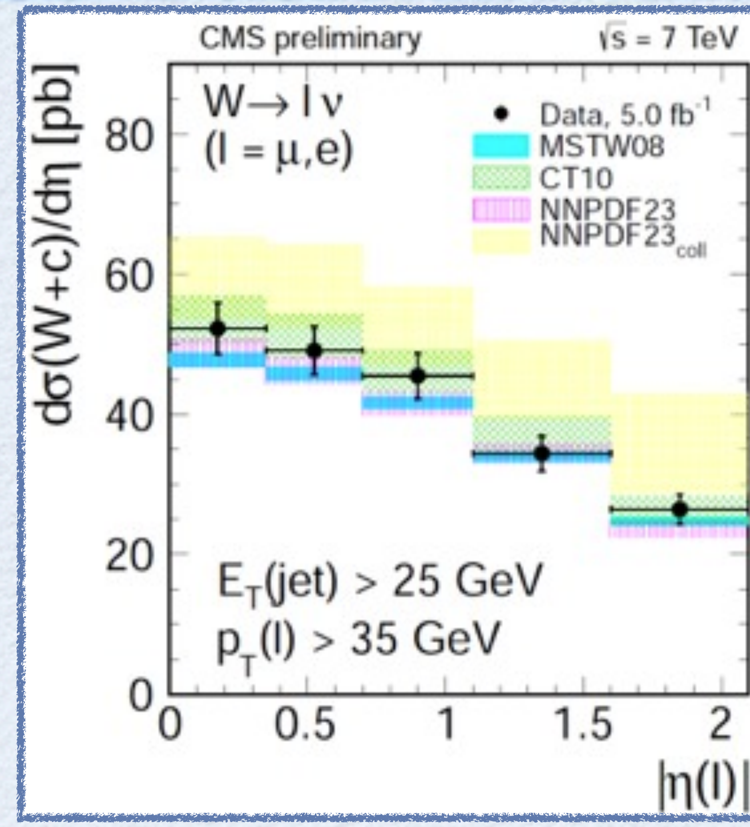
Strangeness

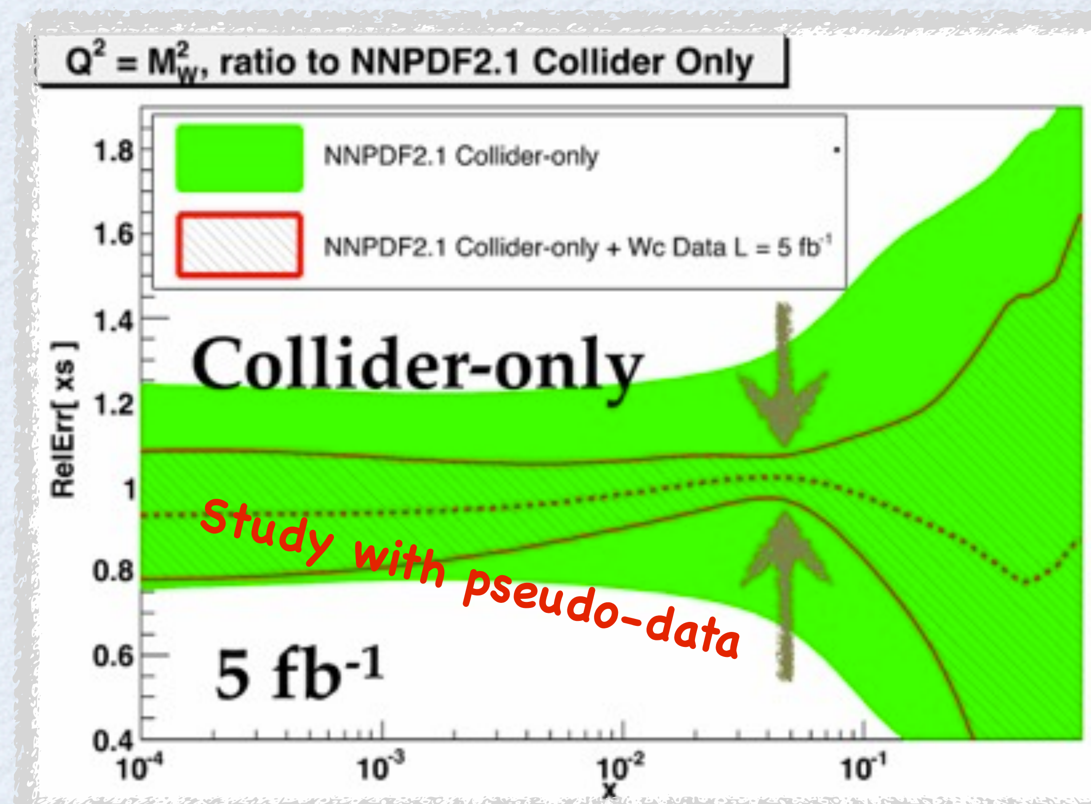
W + charm









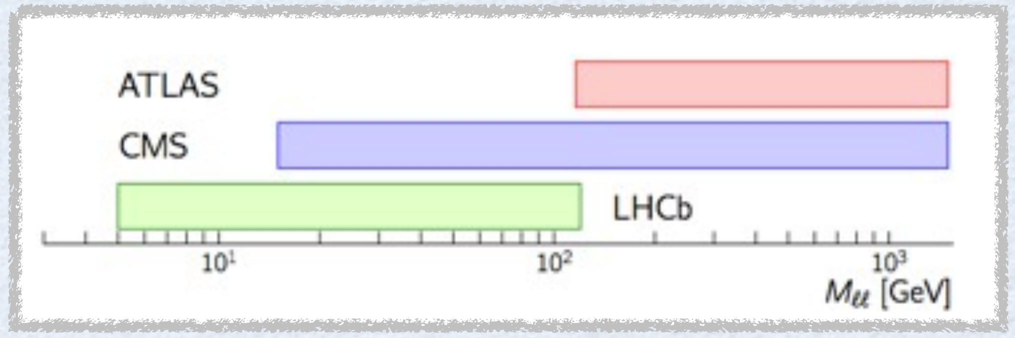


- Strange PDF is the most poorly constrained, mostly determined by neutrino charm production data on nuclear target (NuTeV and CHORUS)
- W+charm data from ATLAS and CMS (both inclusive and distributions) provide a cleaner set of data to constrain strangeness from collider **[J. Rojo, study with pseudodata]**
- ATLAS data consistent with large strangeness, as opposite to CMS data consistent with suppressed strangeness
- Recent from NOMAD: charm dimuon production in neutrino-iron scattering consistent with NuTeV **[ArXiv:1308.4750]**
- Ultimate answer comes from inclusion of W+c data in PDF fits **(ongoing effort by NNPDF, HERAFITTER)**

Light (anti-)quark

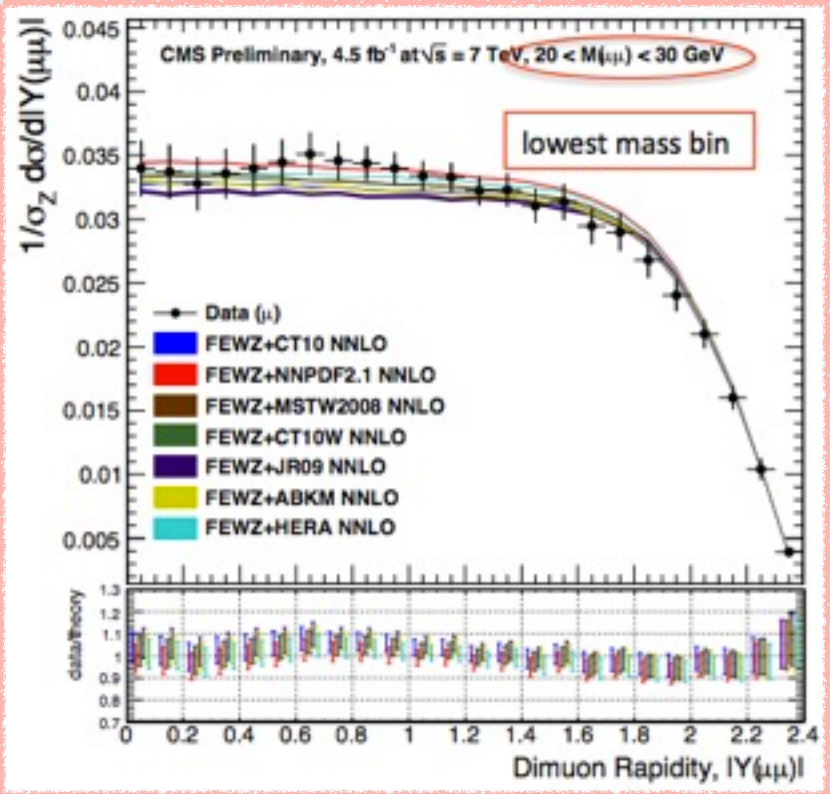
High and low mass Drell-Yan

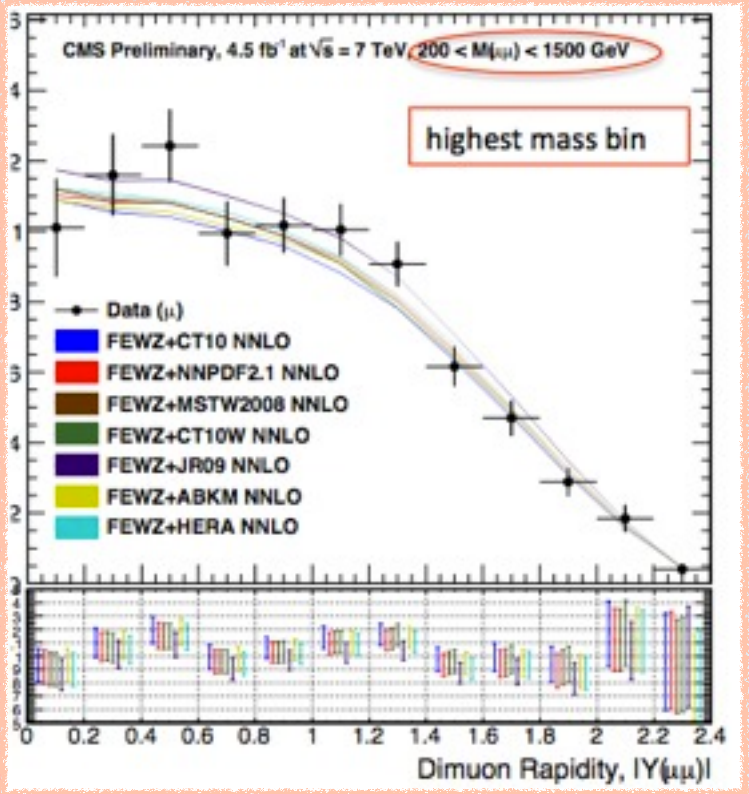
- In global fits, quark flavor separation mostly comes from fixed-target DY data
- Large and low mass DY measurements at the LHC can be used to constrain small and large x quark and anti-quark distributions.
- NNLO theory predictions available **[FEWZ, DYNNLO]**
- Very precise data available both from CMS (preliminary double differential in M_{ll} and Y_{ll}), from ATLAS and LHCb (single differential as a function of M_{ll} and Y_{ll})

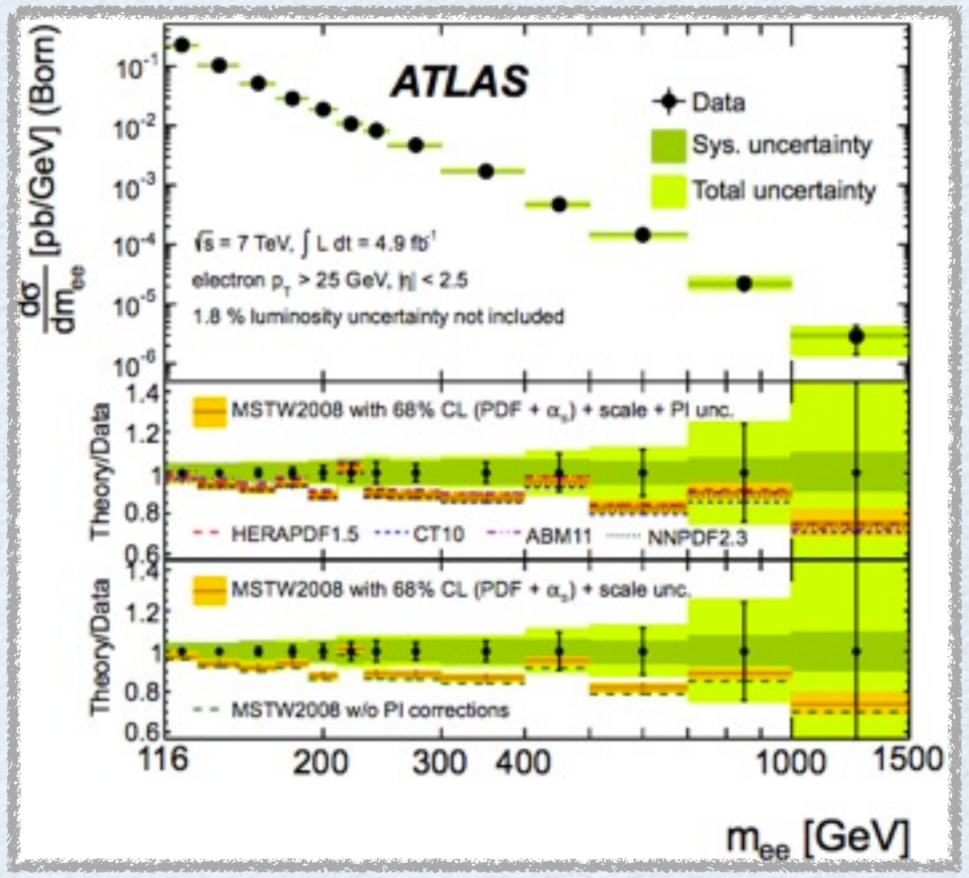


$$x^0_{1,2} = \frac{M}{\sqrt{s}} e^{\pm Y}$$

S. Farry, QCD@LHC2013







E. Gallo, QCD@LHC2013

CMS PAS SMP-13-003

ATLAS, Phys. Let. B 725 (2013) 223-242

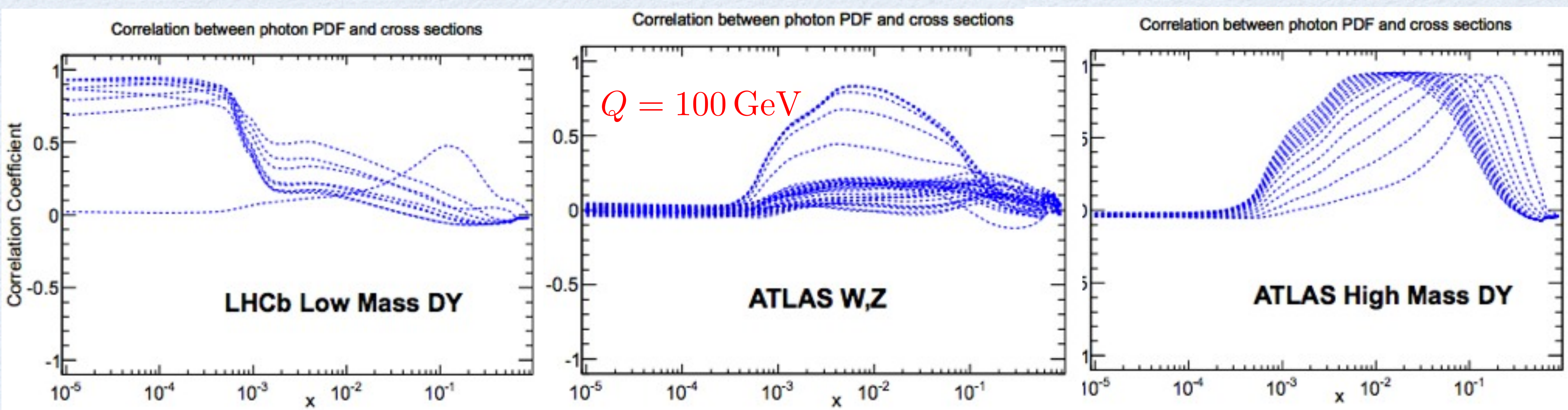
Photon PDF

High and low mass Drell-Yan

Ball et al, 1308.0598

- EW corrections have become relevant at the current phenomenological precision level
- A consistent inclusion of EW corrections requires PDF with QED effects
- NNPDF23QED is new PDF set with uncertainties which incorporates (N)NLO QCD + LO QED effects
- Photon PDF fitted from DIS and DY data (on-shell W,Z production and low/high mass DY)
- DIS data fitted and DY data included via Bayesian reweighting **[Ball et al., Nucl.Phys. B855 (2012) 608-638]**
- Photon PDF is poorly determined from DIS data. Need hadron collider processes where photon contributes at LO!

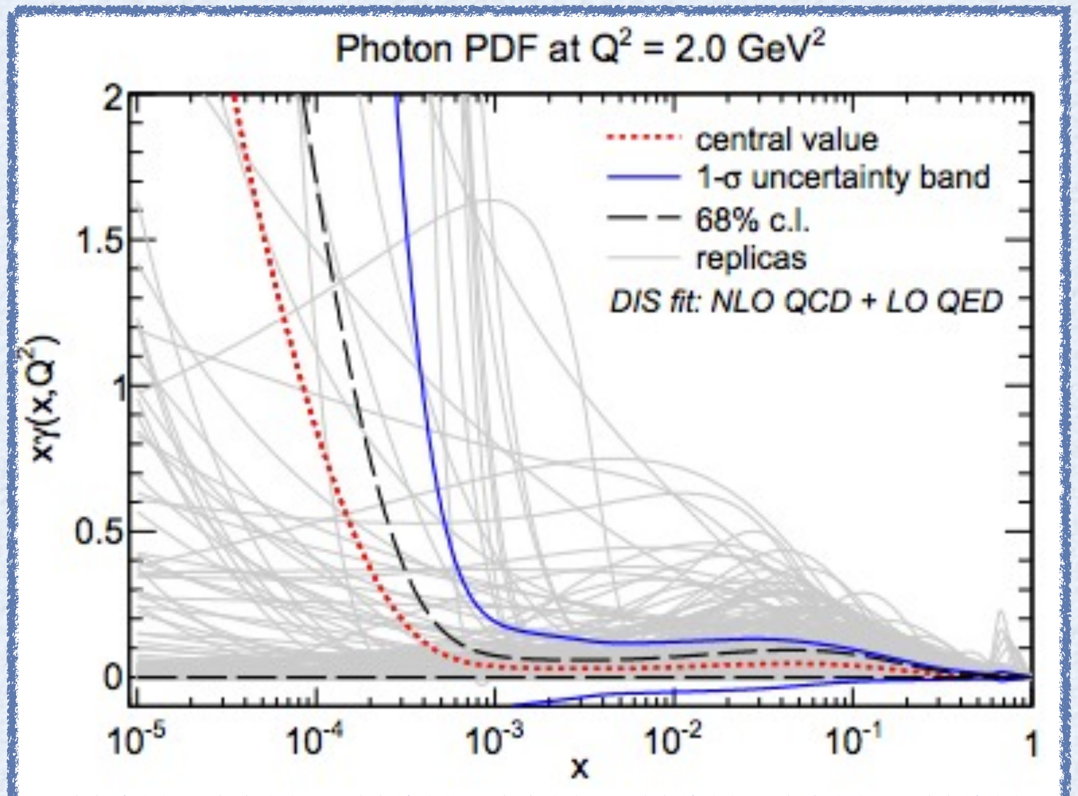
Dataset	Observable	$N_{\rm dat}$	$[\eta_{\rm min}, \eta_{\rm max}]$	$\left[M_{ll}^{\rm min}, M_{ll}^{\rm max}\right]$	
LHCb γ^*/Z Low Mass	$d\sigma(Z)/dM_{ll}$	9	[2,4.5]	[5,120] GeV	no cov. matrix
ATLAS W, Z	$d\sigma(W^{\pm}, Z)/d\eta$	30	[-2.5,2.5]	[60,120] GeV	full cov. matrix
ATLAS γ^*/Z High Mass	$d\sigma(Z)/dM_{ll}$	13	[-2.5,2.5]	[116,1500] GeV	full cov. matrix



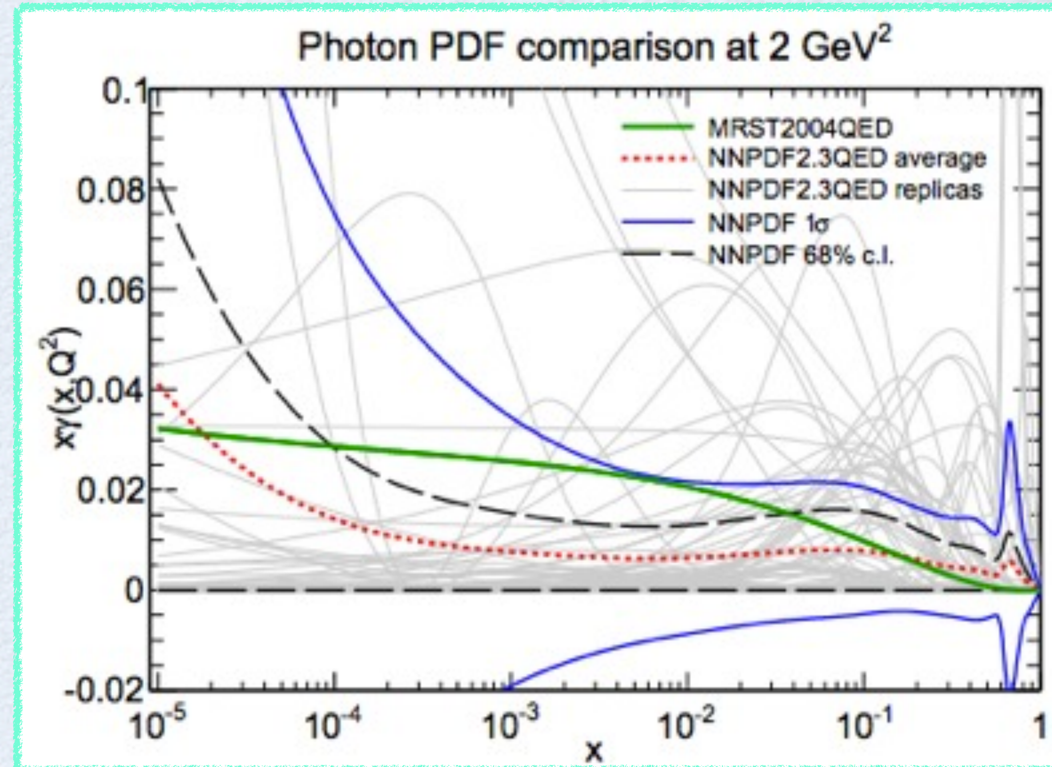
Photon PDF

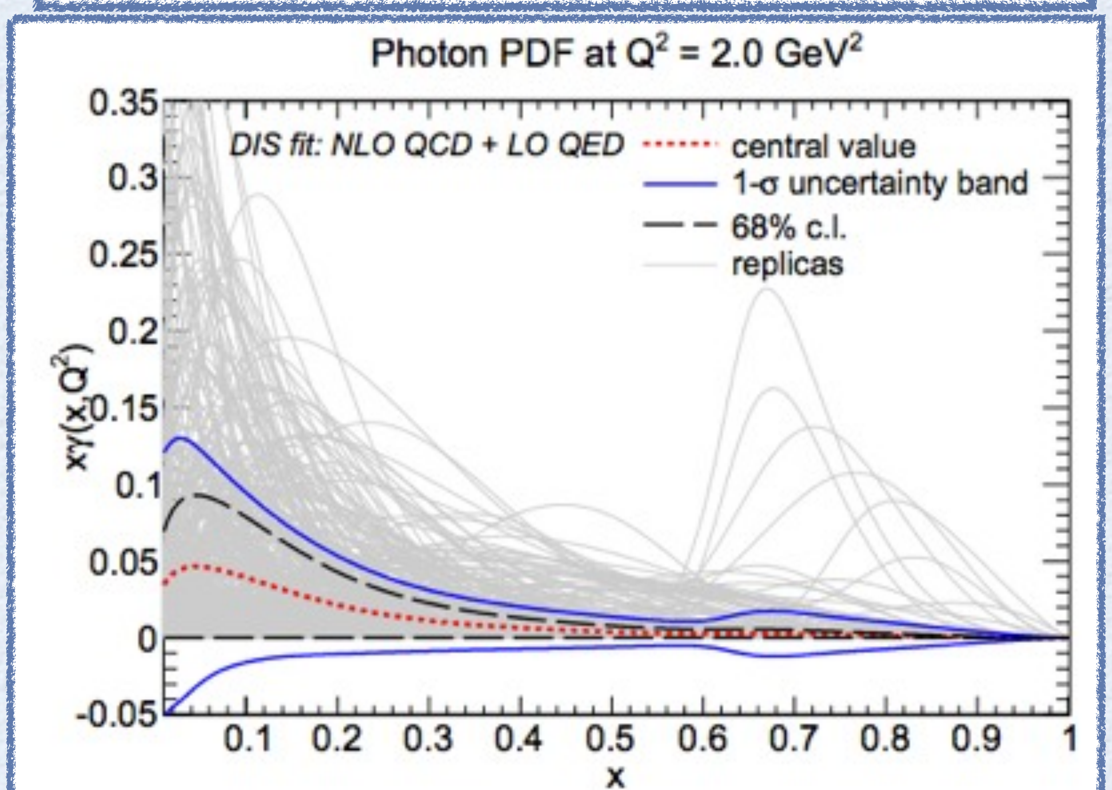
High and low mass Drell-Yan

Ball et al, 1308.0598

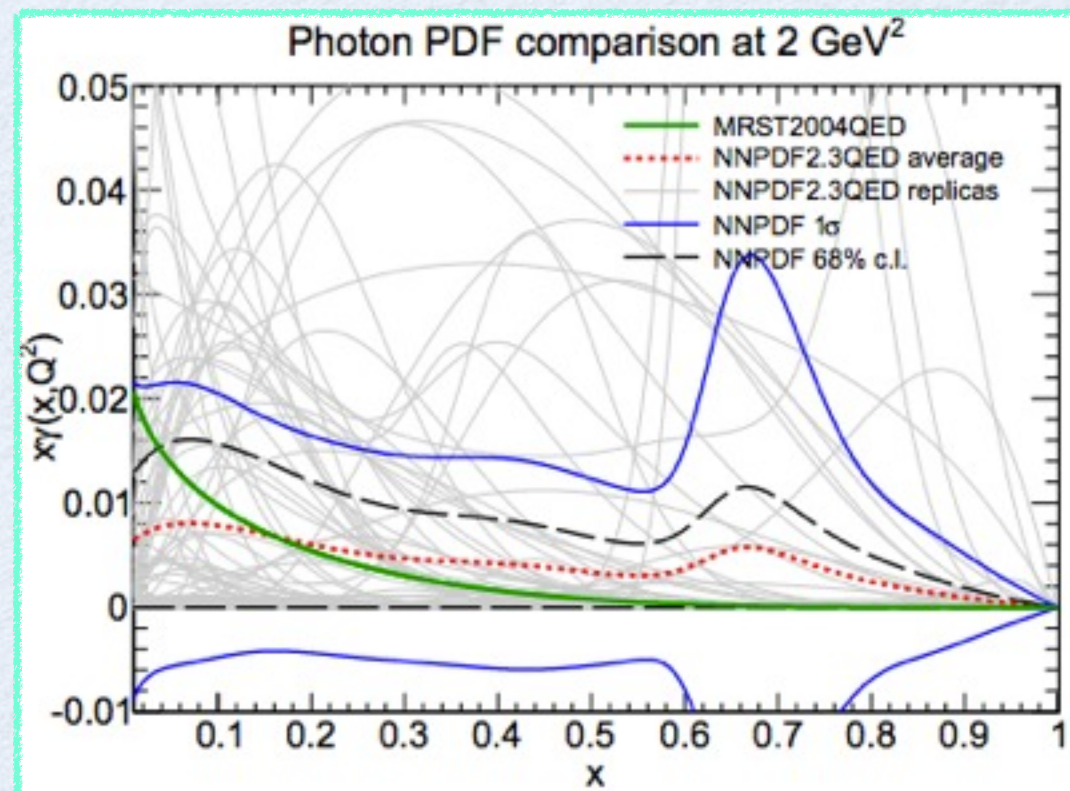


small x





large x

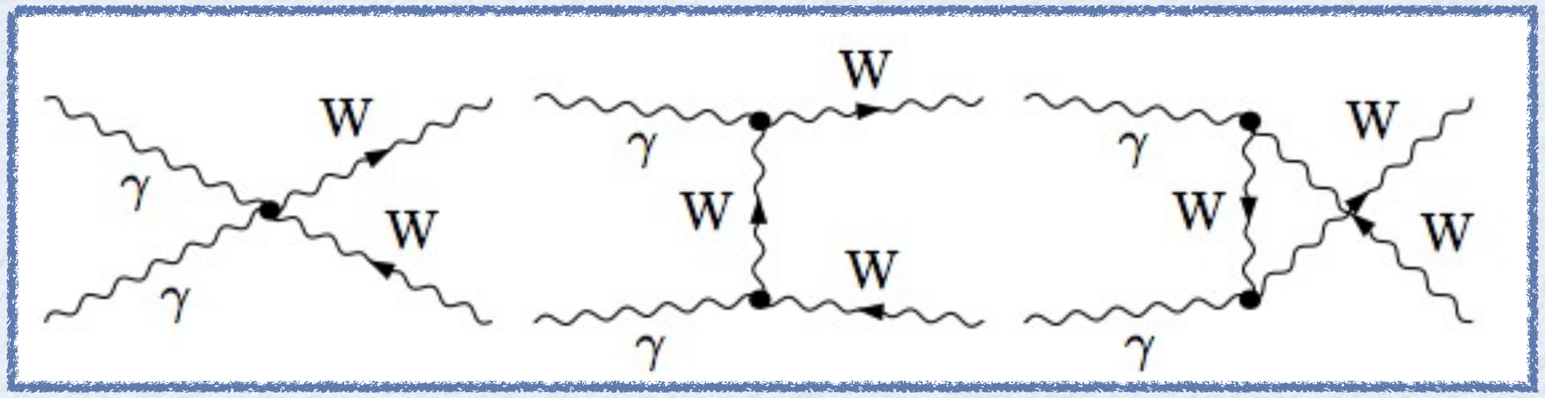


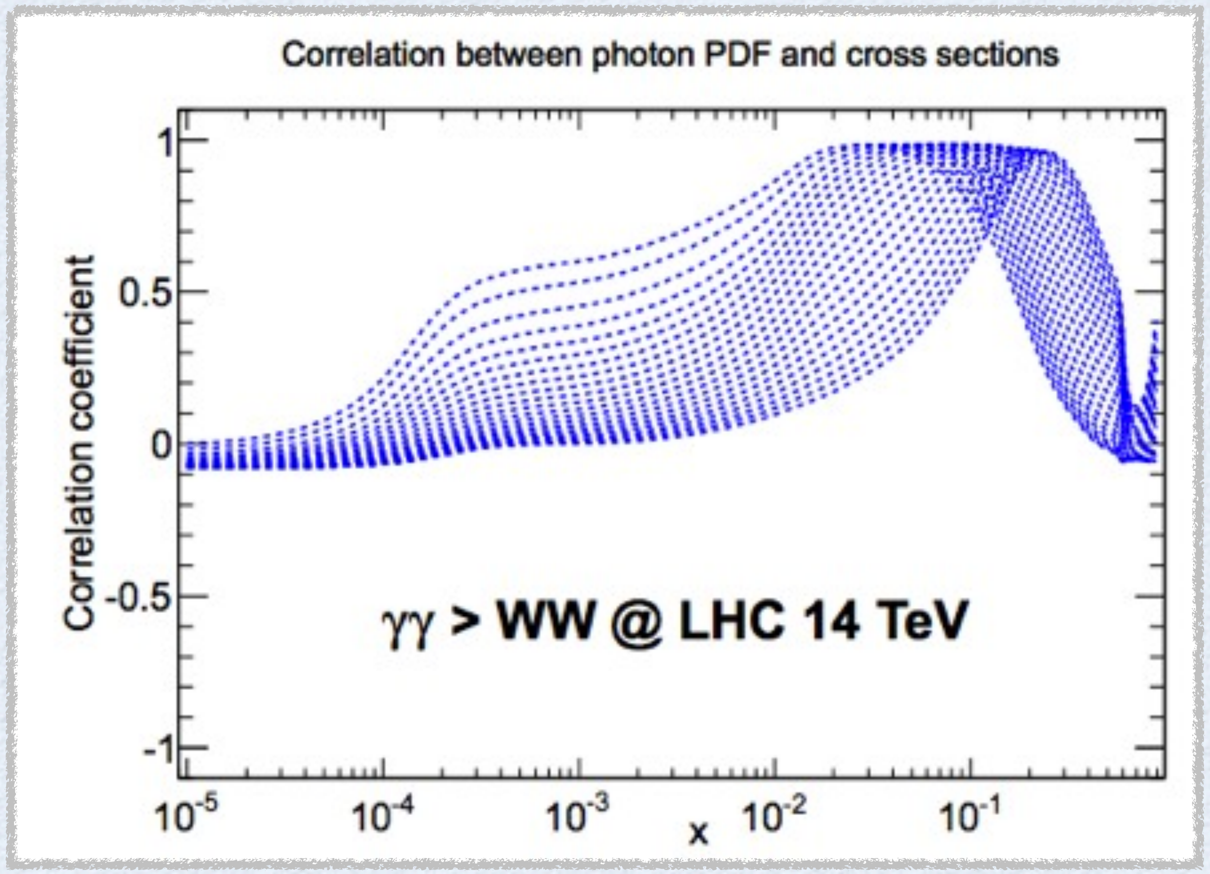
Photon PDF

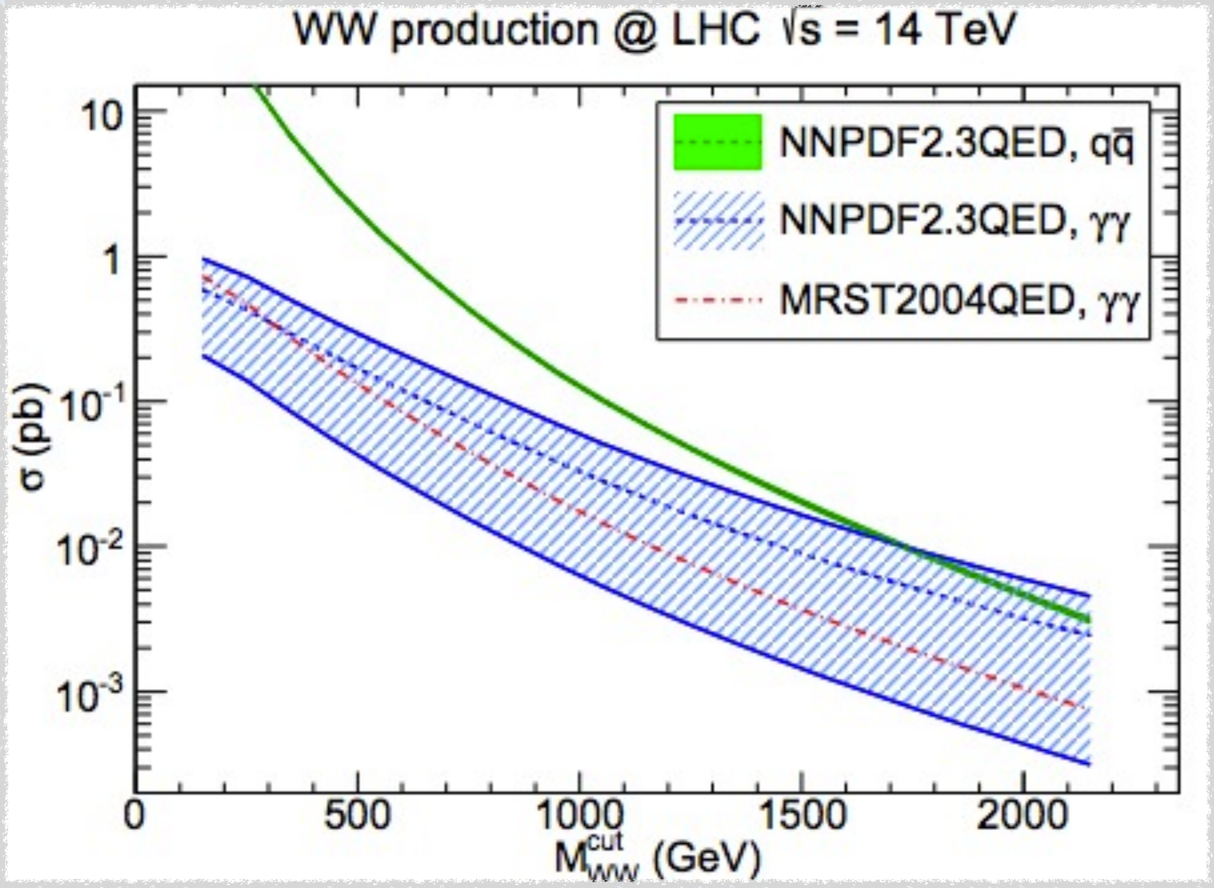
WW production

Ball et al, 1308.0598

- WW production is phenomenologically relevant as a background for BSM searches
- At high M_{WW}, photon-induced contribution become relevant
- The large uncertainty at large M_{WW} comes from the large uncertainty of photon PDF for x > 0.1
- New LHC data give unique opportunity of constraining the photon in that region







PDF Wishlist at the LHC

In this talk only a portion of PDF-related measurements to be pursued at the LHC has been covered. Notice that, in order to use measurements in PDF fits we need full information on correlations!

✓ Already used in PDF fits

- Inclusive jets and dijets both central and forward: large-x quarks and gluons
- Inclusive W and Z productions and asymmetries: quark-flavor separation, strangeness, photon

✓ (Almost) Ready to be used in PDF fits

- Isolated photon: medium-x gluon
- High-pT Z transverse momentum distribution
- W+charm: direct handle on strangeness
- W,Z + jets: gluon at medium-x and u/d ratio
- Off-resonance Drell-Yan at small and large mass: quarks & photon at small and large x
- WW production: photon and light quarks
- Top quark inclusive and differential distribution: large-x gluon
- Ratios at different CME

✓ Some speculation

- Z+c: intrinsic charm PDF
- Z+b: gluon and bottom PDF
- Single top production: gluon and bottom PDFs

BACK - UP

Bayesian Reweighting

In a nutshell

- Nrep of a Monte Carlo fit give the probability density in the space of PDFs
- Expectation values are MC integrals. Same for errors, correlations
- One can assess the impact of including new data in the fit by updating the probability density distribution

$$w_k \propto (\chi^2_k)^{\frac{1}{2}(n-1)} e^{-\frac{1}{2}\chi^2_k}$$

$$\langle \mathcal{O} \rangle = \int \mathcal{O}[f]\,\mathcal{P}(f)\,Df = \frac{1}{N}\sum_{k=1}^{N} \mathcal{O}[f^{(k)}]$$

$$\langle \mathcal{O} \rangle_{\rm new} = \int \mathcal{O}[f]\mathcal{P}_{\rm new}(f)\mathcal{D}f = \frac{1}{N}\sum_{k=1}^{N} w_k \mathcal{O}[f^{(k)}]$$

Refitting:

- × Whenever add new data, need to do full refitting, tune parametrization and statistic treatment
- × Can be done only by PDF fitting collaborations themselves.

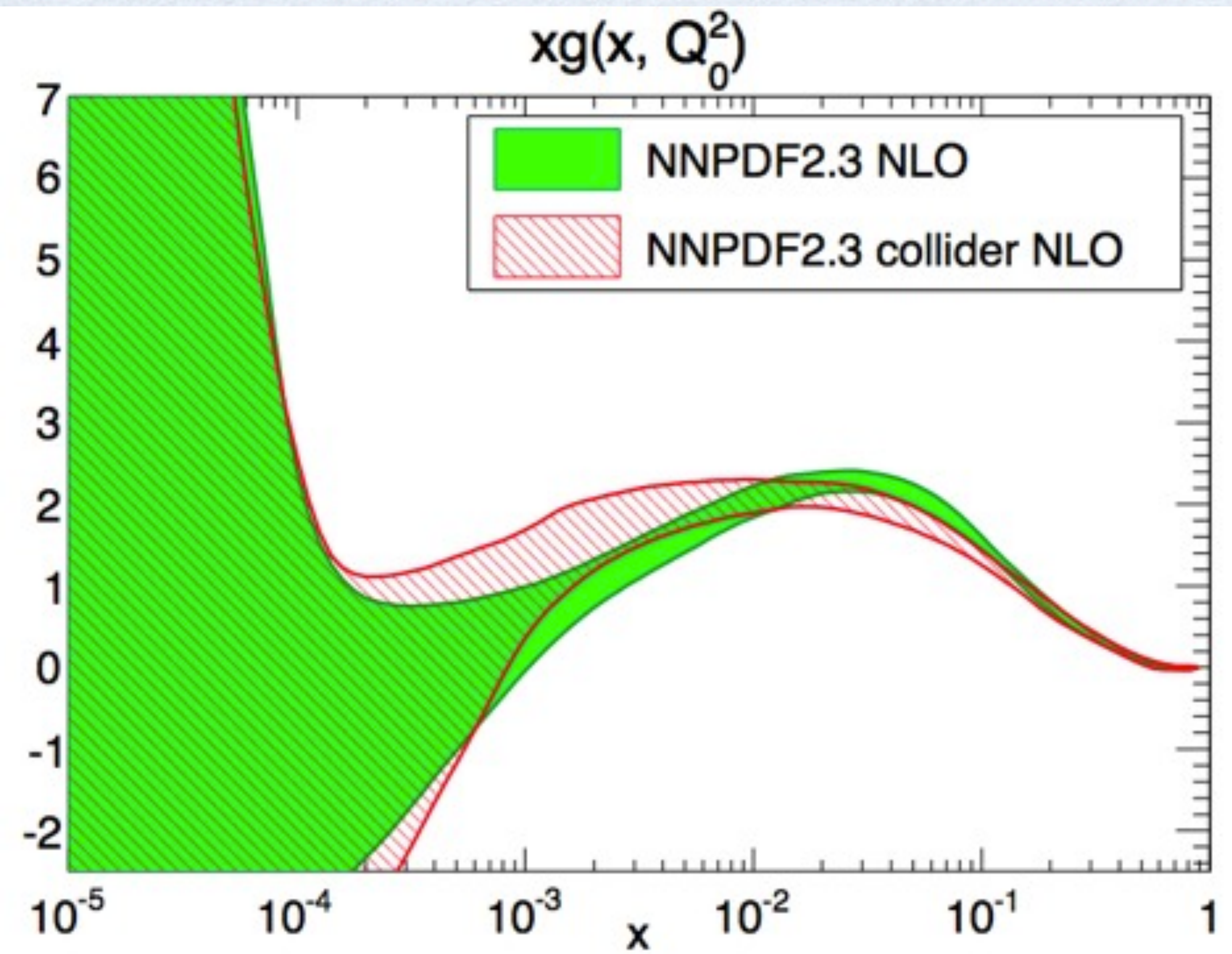
Reweighting:

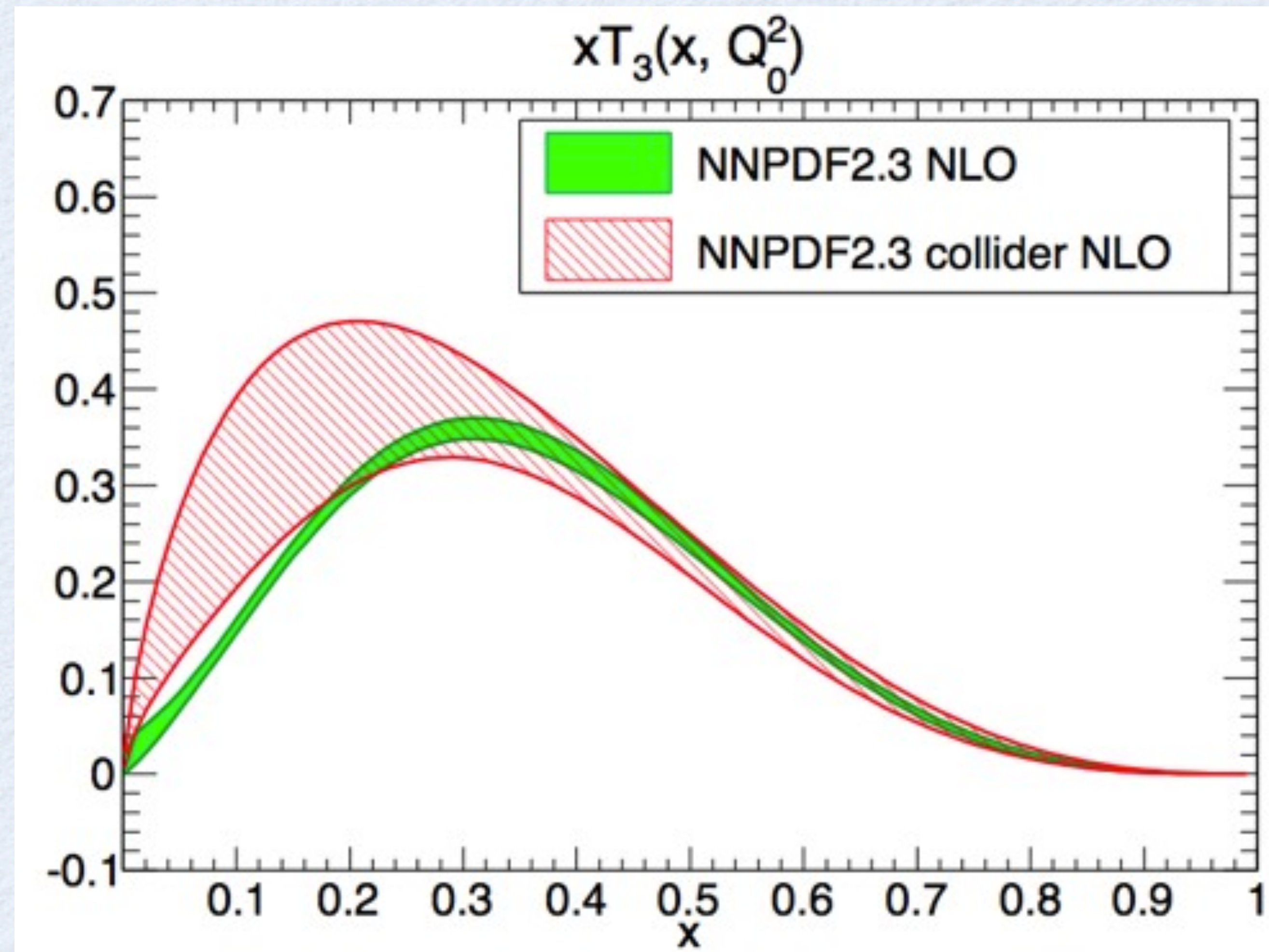
- ✓ Immediate: no need to refit
- ✓ Anybody can do it just evaluating weights with each replica of a PDF set and producing a new PDF set through unweighting

Ball et al, ArXiv: 1012.0836

Collider only

NNPDF23

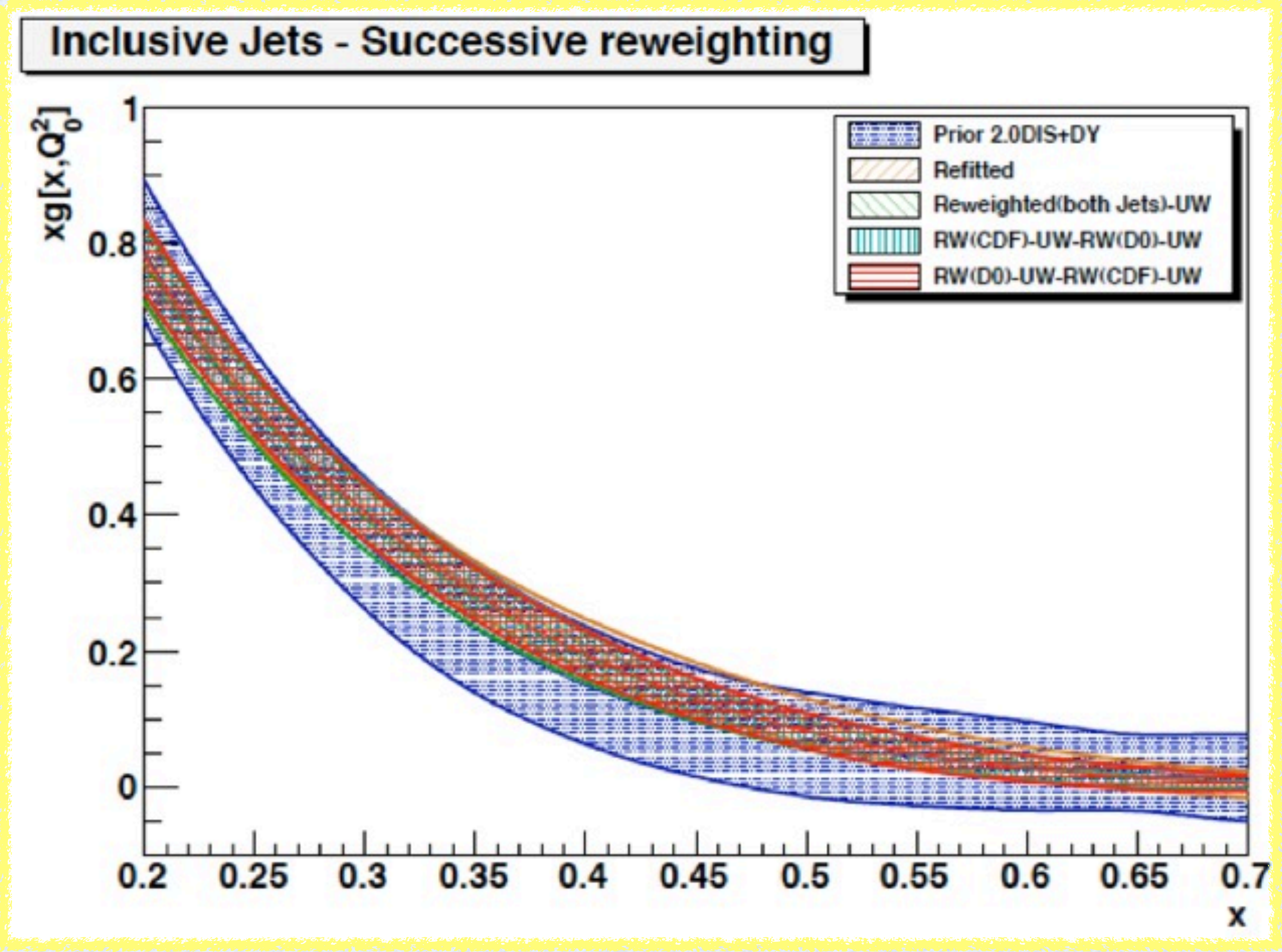




Bayesian Reweighting

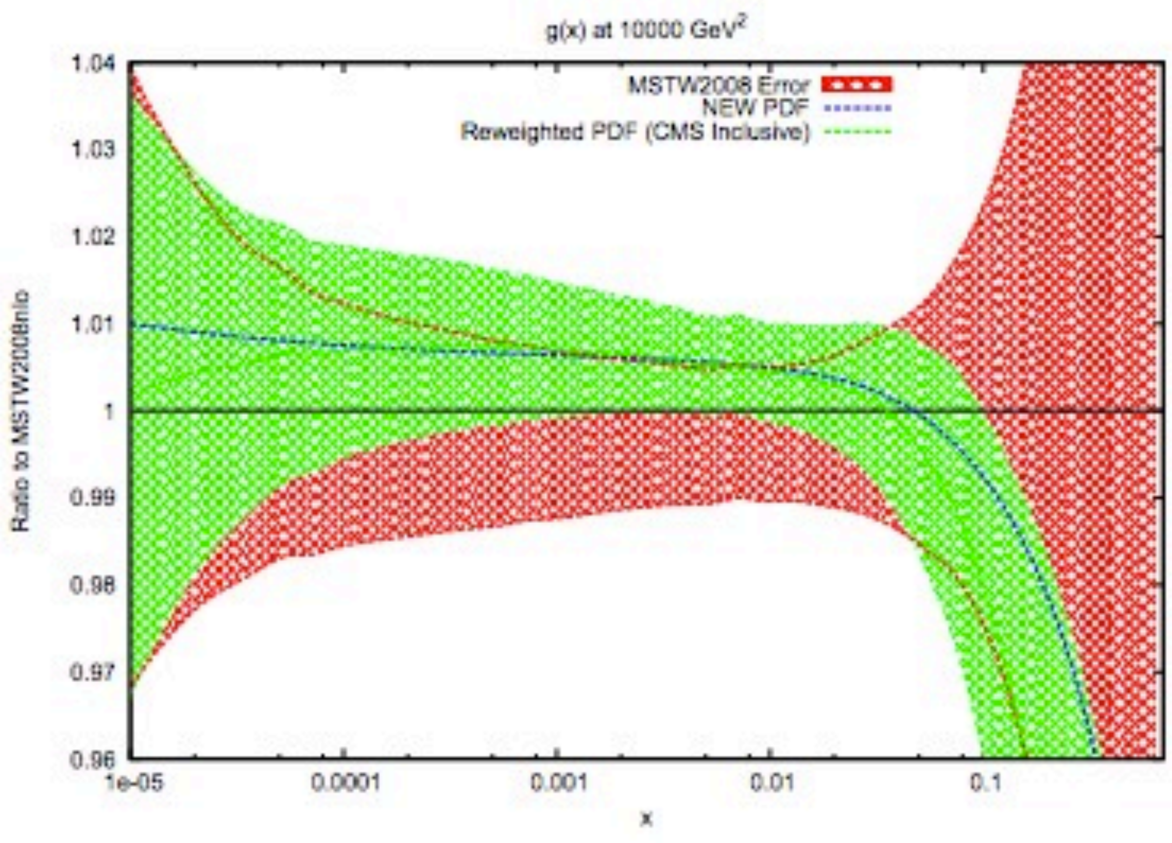
Test-case

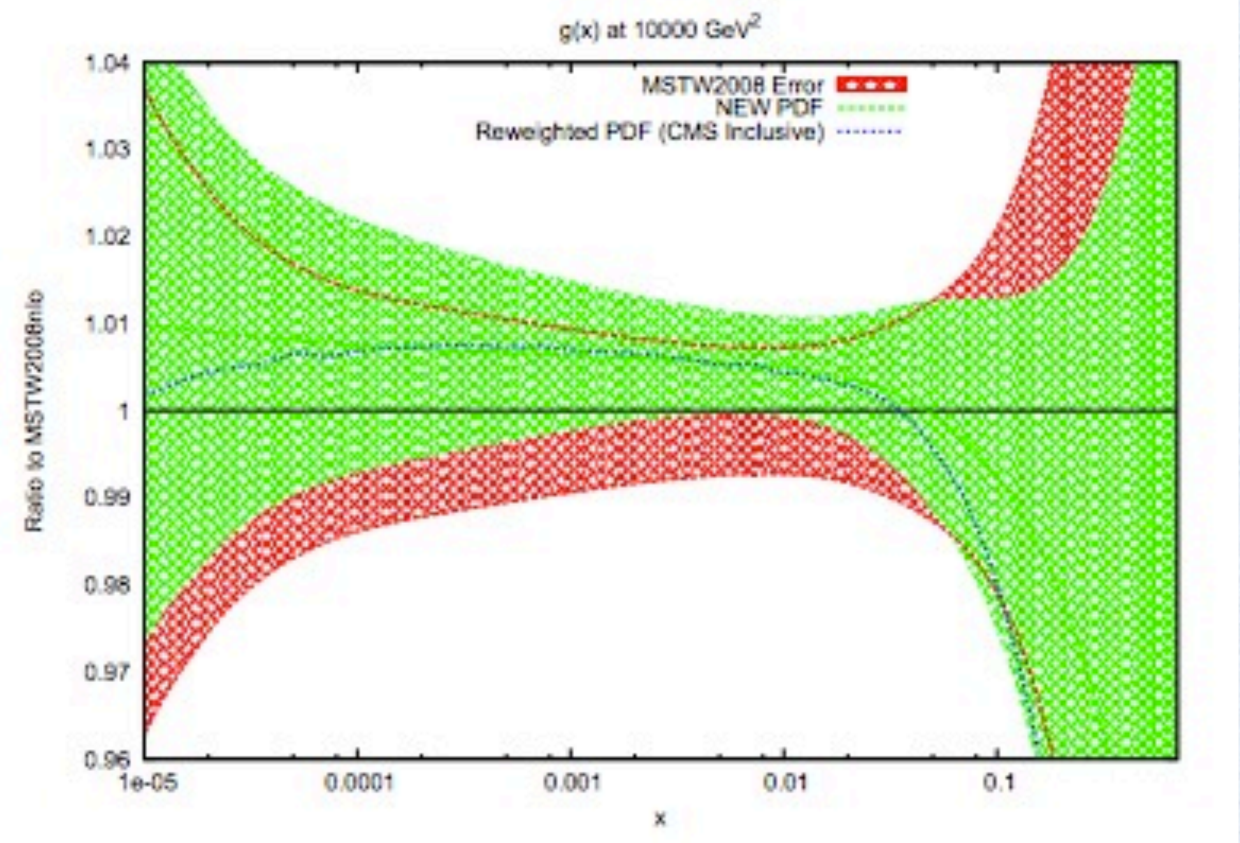
- Start from DIS+DY only fit (blue)
- Add CDF and D0 data by refitting (as benchmark)
- Add first CDF data by reweighting, unweight, then reweight D0 data on unweighted set
- Add first D0 data by reweighting, unweight, then reweight CDF data on unweighted set
- Add CDF+D0 data by reweighting at the same time
- Same results!!



Bayesian Reweighting

Inclusion of CMS jet data





R. Thorne, QCD@LHC 2013

Covariance matrix

Consistent treatment of experimental uncertainties

without covariance matrix
add statistic and systematic
errors in quadrature

Dataset	χ^2	χ^2_{rw}	N_{eff}
ATLAS	2.7	1.2	16
ATLAS W^+ 36 pb^{-1}	5.7	1.5	17
ATLAS W^- 36 pb^{-1}	2.5	1.0	205
ATLAS Z 36 pb^{-1}	1.8	1.1	581
CMS	2.0	1.2	56
CMS Z rapidity 36 pb^{-1}	1.9	1.4	223
CMS muon asymmetry 234 pb^{-1}	2.0	0.4	200
LHCb	0.8	0.8	972
LHCb Z rapidity 36 pb^{-1}	1.1	1.0	962
LHCb W lepton asymmetry 36 pb^{-1}	0.8	0.5	961
All data combined	2.1	1.2	4

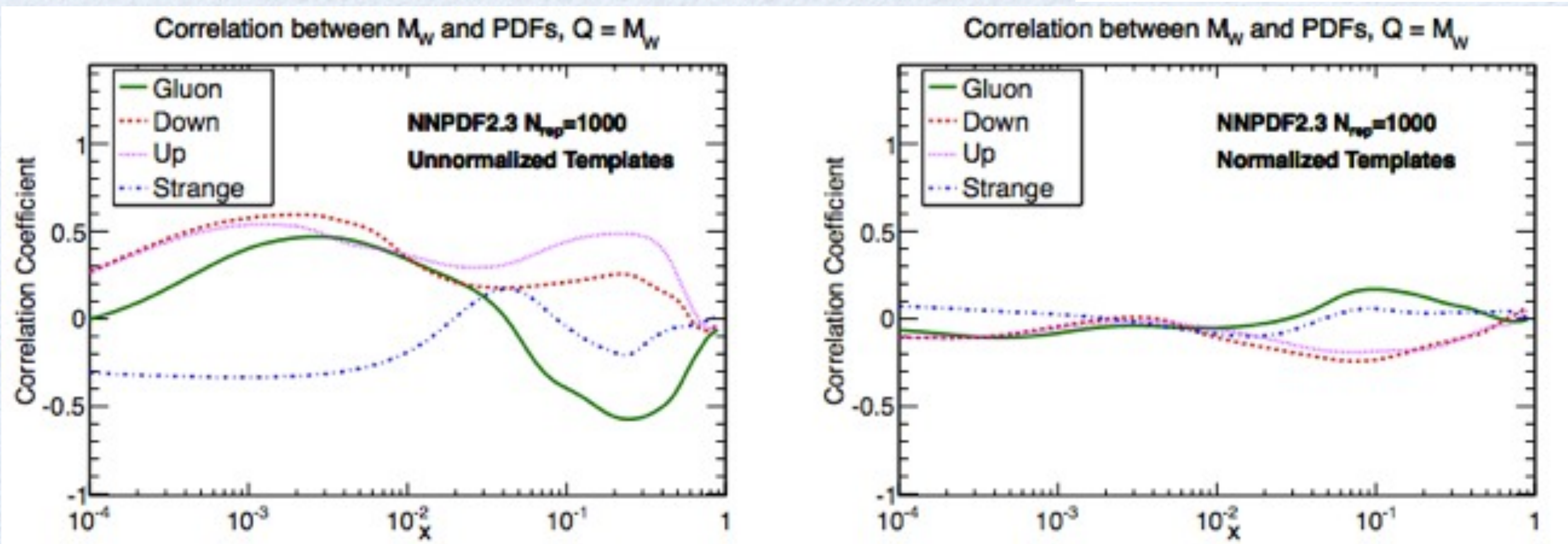
NNPDF2.3 noLHC reweighted with LHC data	NLO		NNLO	
	N_{eff}	$\langle\alpha\rangle$	N_{eff}	$\langle\alpha\rangle$
ATLAS W/Z	285	1.4	134	1.6
CMS W e asy	284	1.6	290	1.6
LHCb W	492	1.1	483	1.2
ATLAS inclusive jets	476	1.0	456	0.9
All LHC data	338	1.1	271	1.2

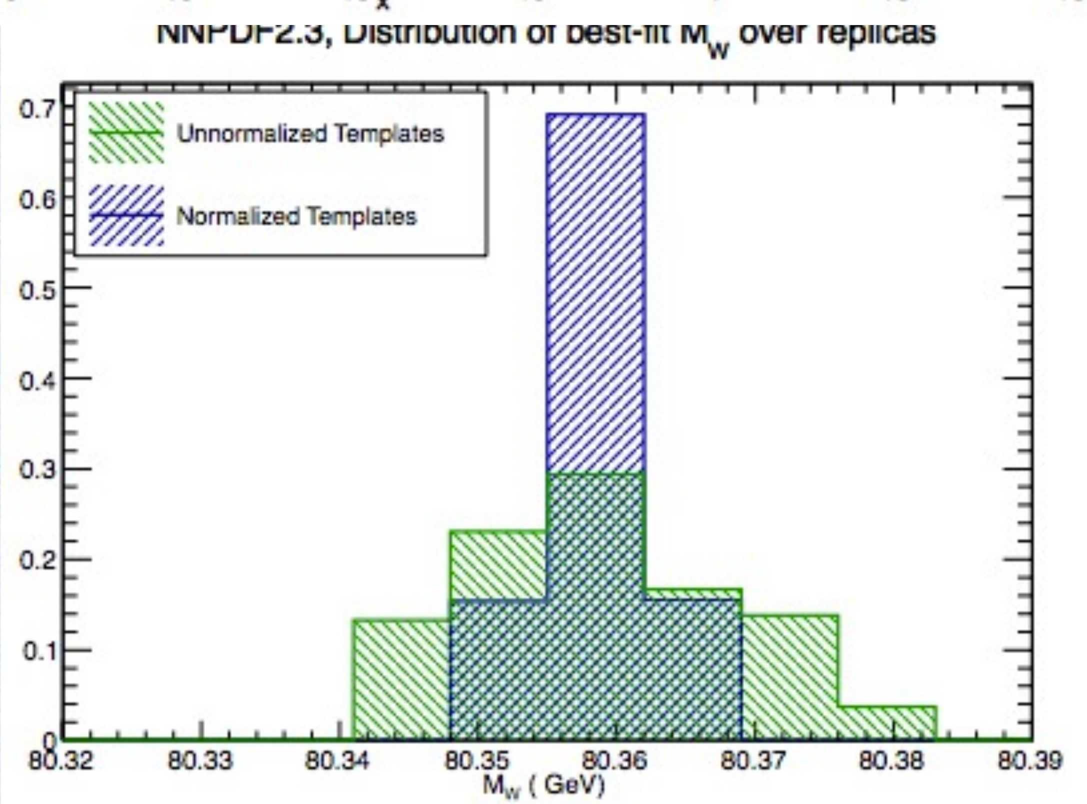
with covariance matrix:
include all bin correlations

W mass determination

	Absolute Templates	Normalized Templates
$M_W \pm \delta_{\rm pdf} M_W$	80.359 ± 0.010	80.359 ± 0.004

Rojo, Vicini, ArXiv: 1309.1311





New CDF Result (2.2 fb^{-1})
Transverse Mass Fit Uncertainties

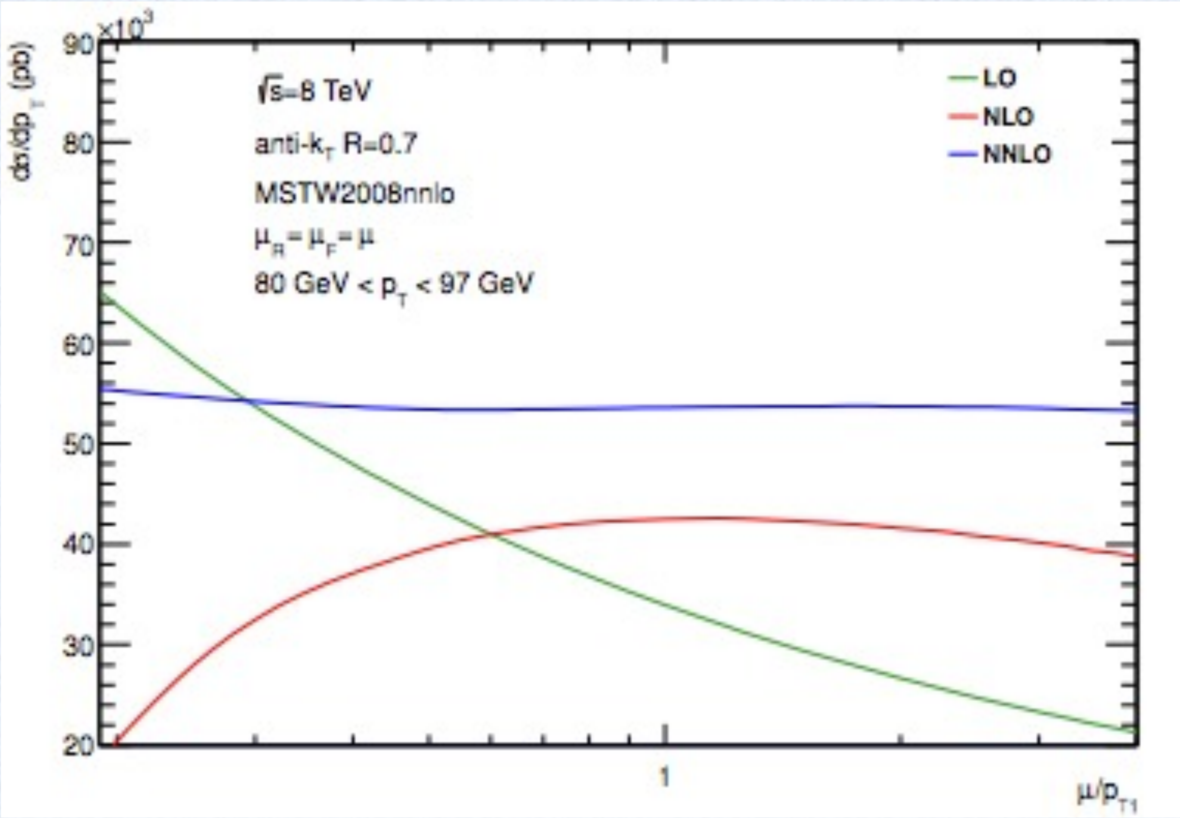
	electrons	muons
W statistics	19	16
Lepton energy scale	10	7
Lepton resolution	4	1
Recoil energy scale	5	5
Recoil energy resolution	7	7
Selection bias	0	0
Lepton removal	3	2
Backgrounds	4	3
pT(W) model	3	3
Parton dist. Functions	10	10
QED rad. Corrections	4	4
Total systematic	18	16

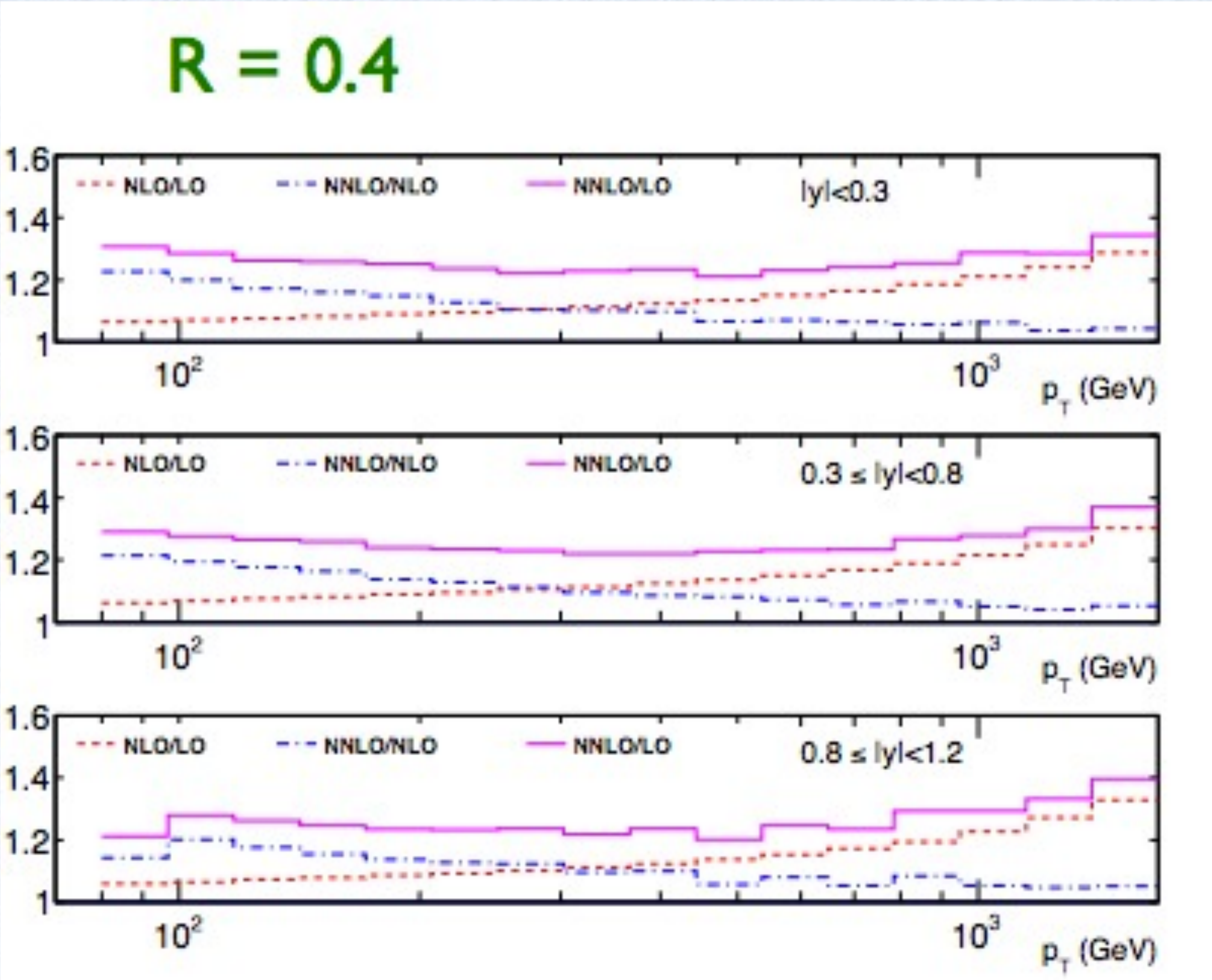
PDFs are dominant systematic in the very precise W mass @ Tevatron (even more at LHC), which indirectly constraints Higgs mass and checks for SM consistency

Gluons

Jet cross section at NNLO

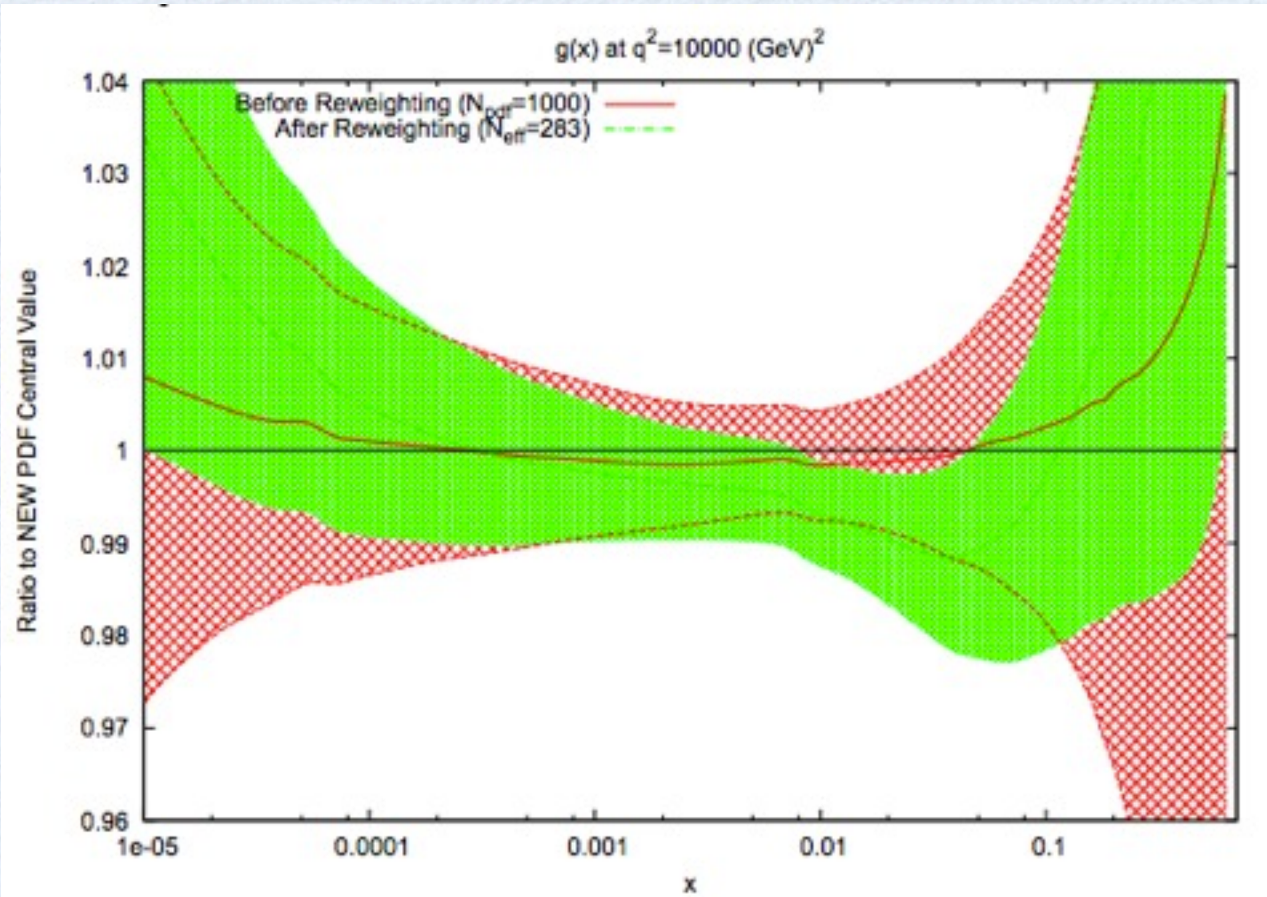
A. De Ridder Gehrmann, SM@LHC 2013



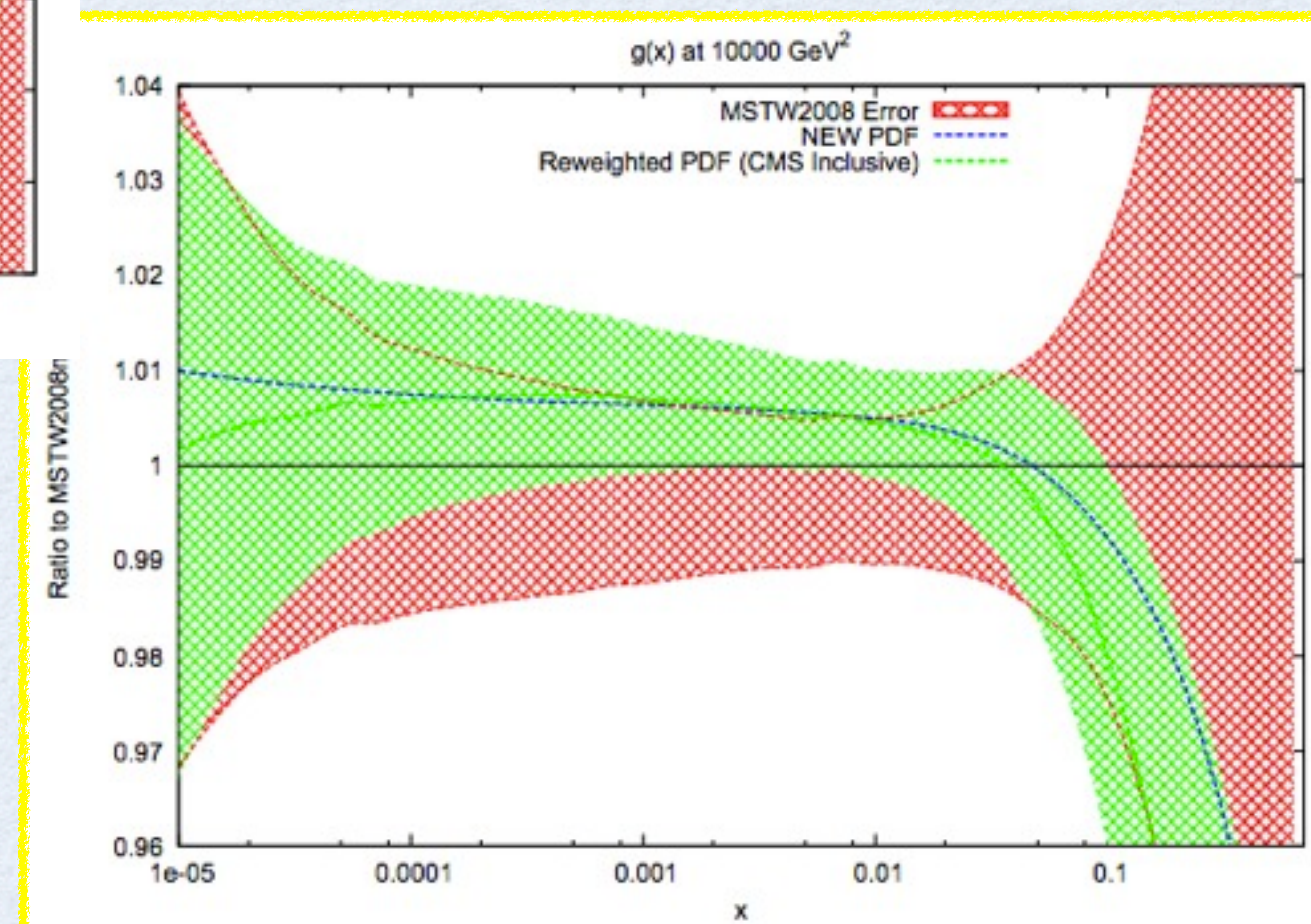


Gluons

Dijets versus jets

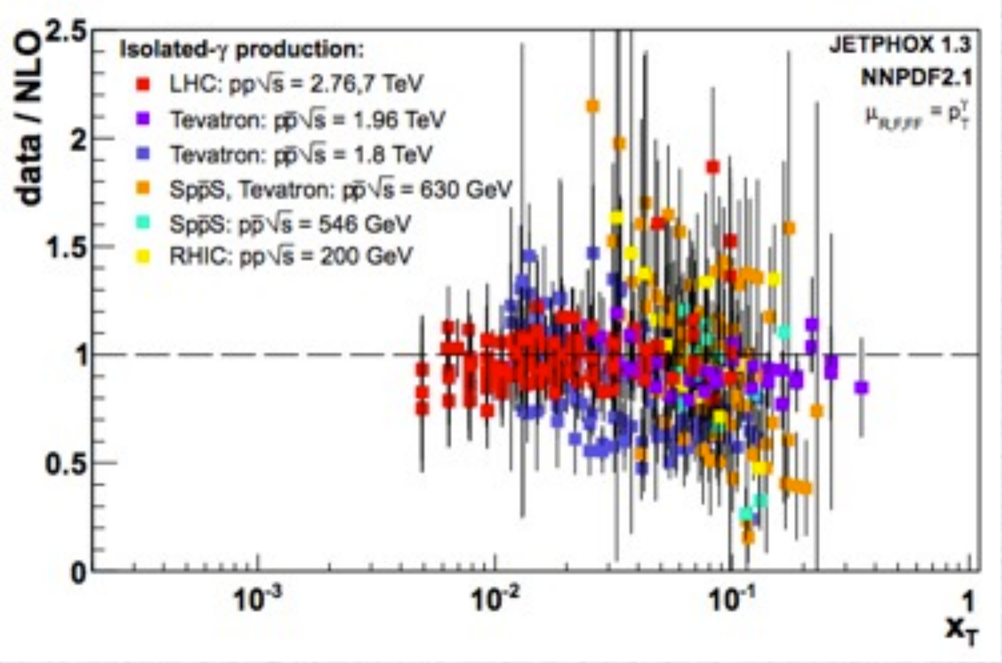


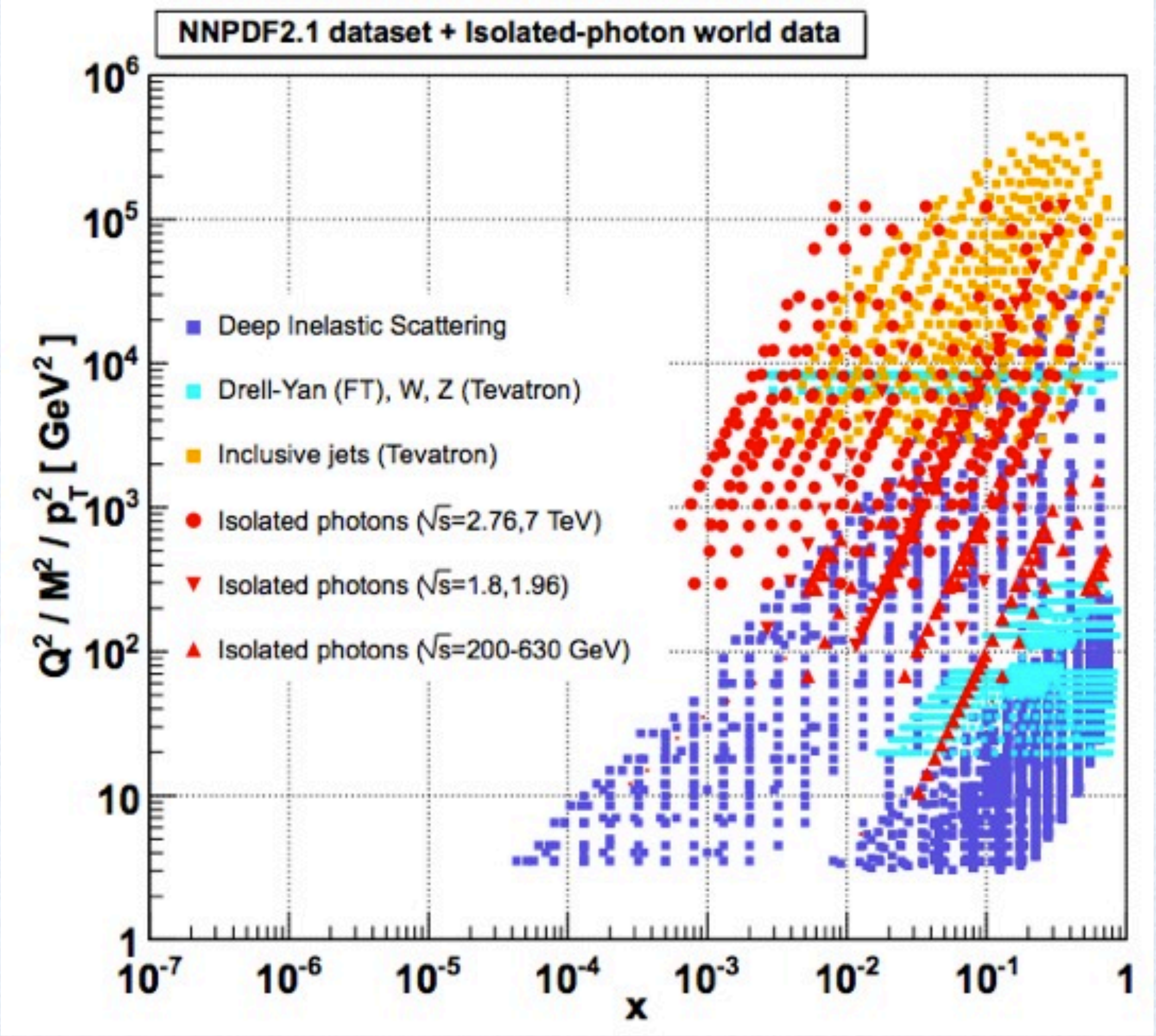
R. Thorne, QCD@LHC 2013



Gluons

Prompt photon production

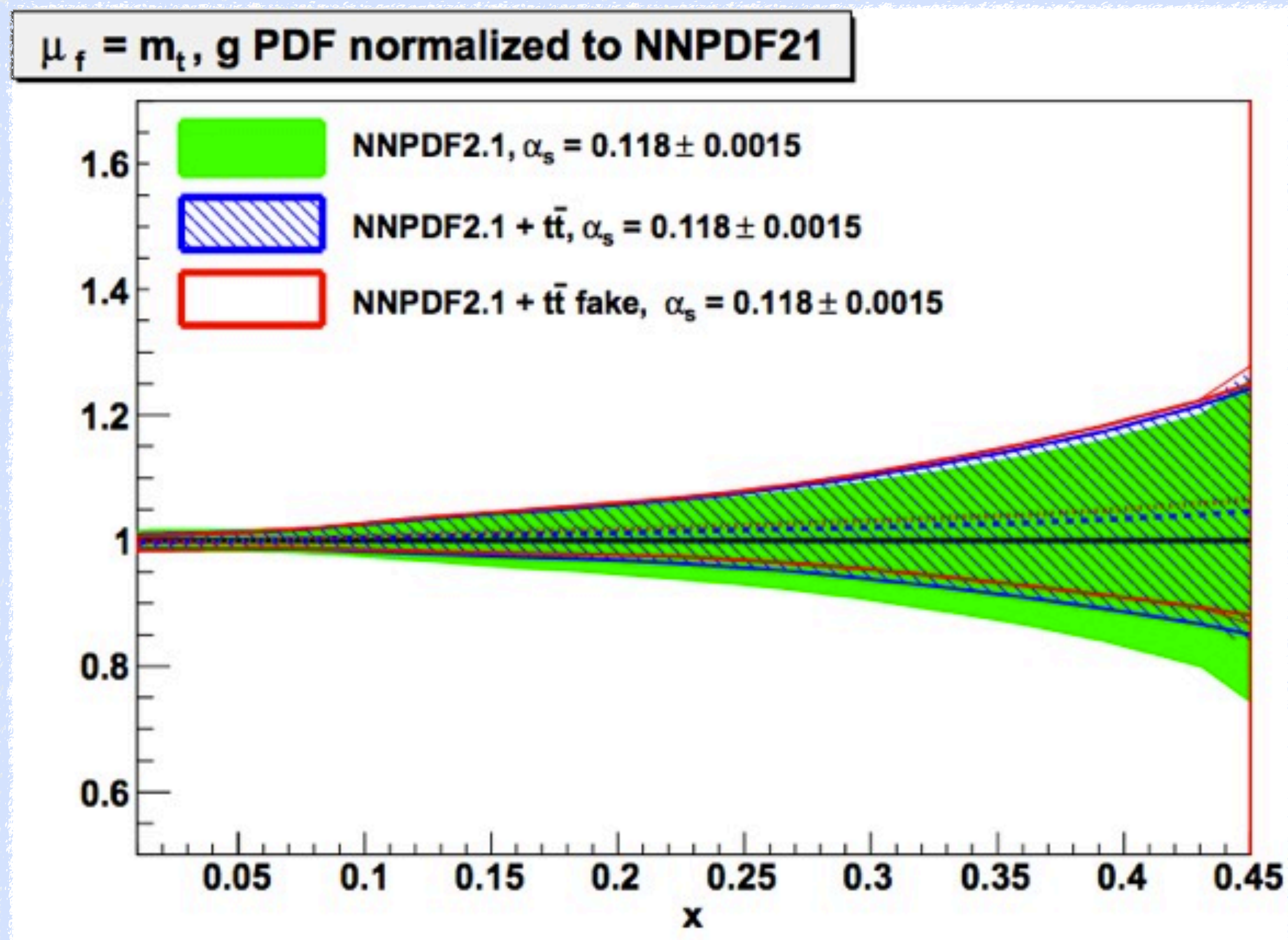




Gluons

Top pair production

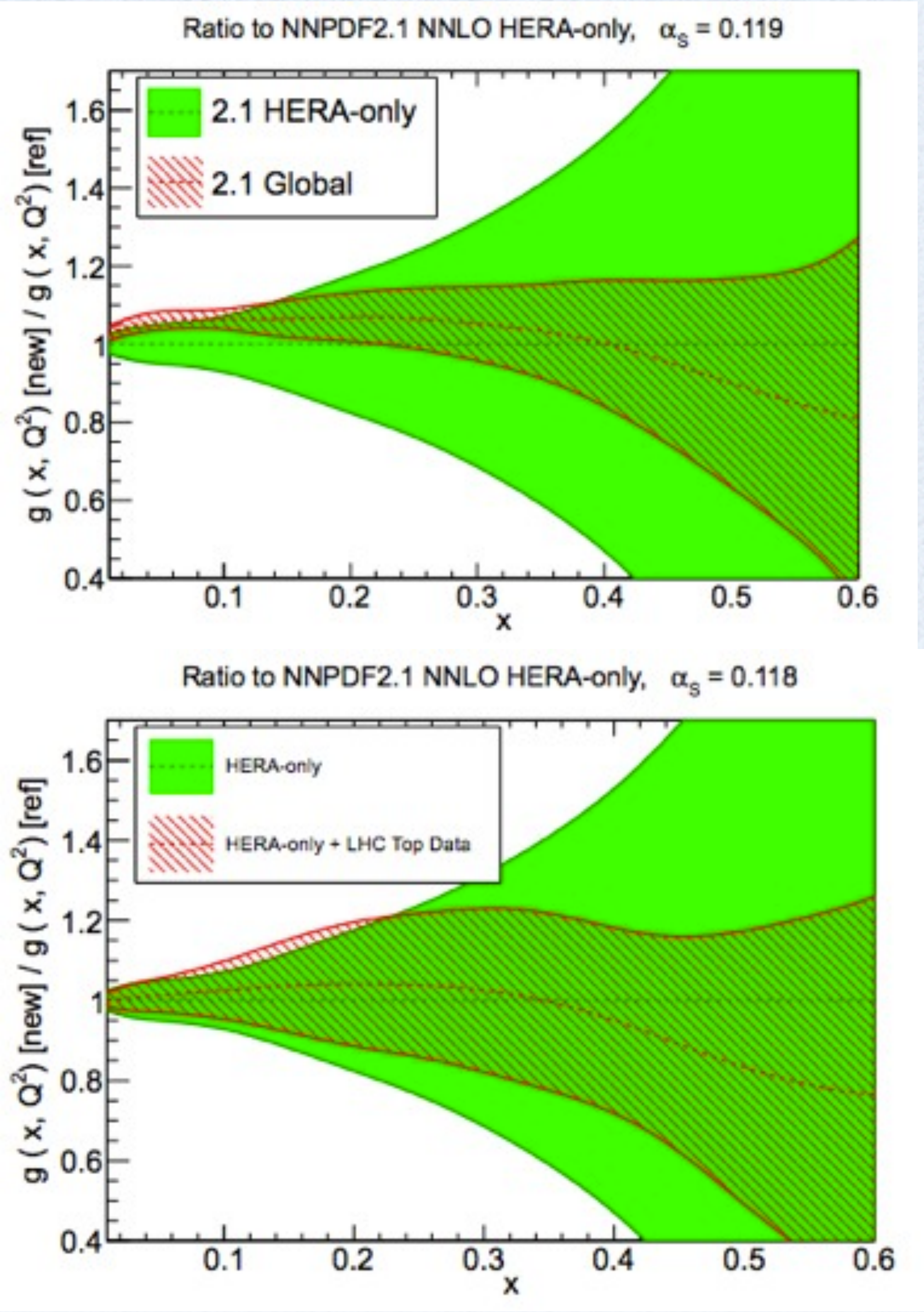
- PDF fits including the jet data from the Tevatron agree in their predicted top cross section at the LHC
- PDF uncertainty is the dominant theoretical uncertainty
- Top pair production cross section data not included in any fit
- Reweighting study suggests that they would already have significant impact on the gluon

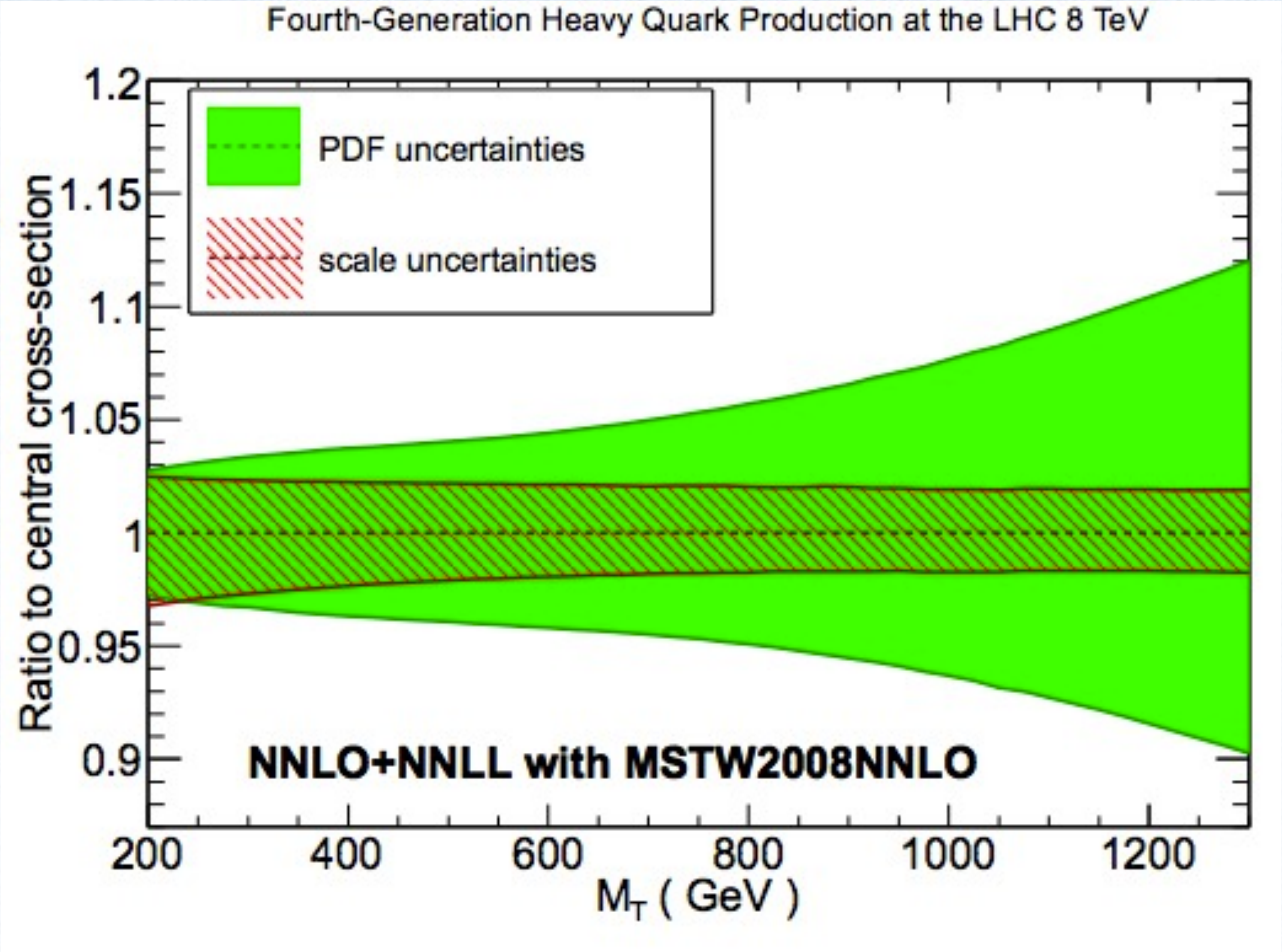


Beneke et al, ArXiv: 1212.5511

Gluons

Top pair production



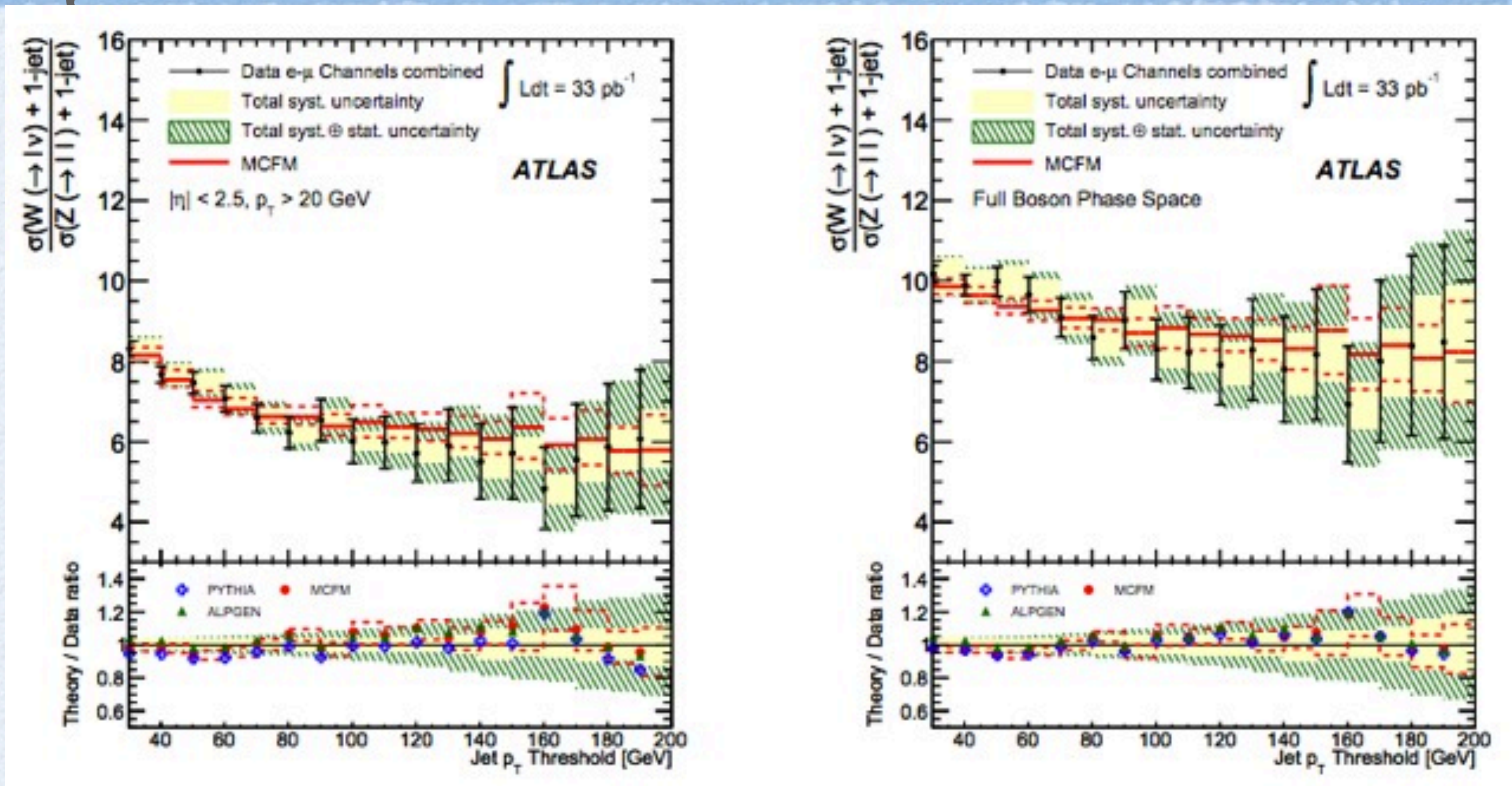


Czakon et al, JHEP 1307 (2013) 167

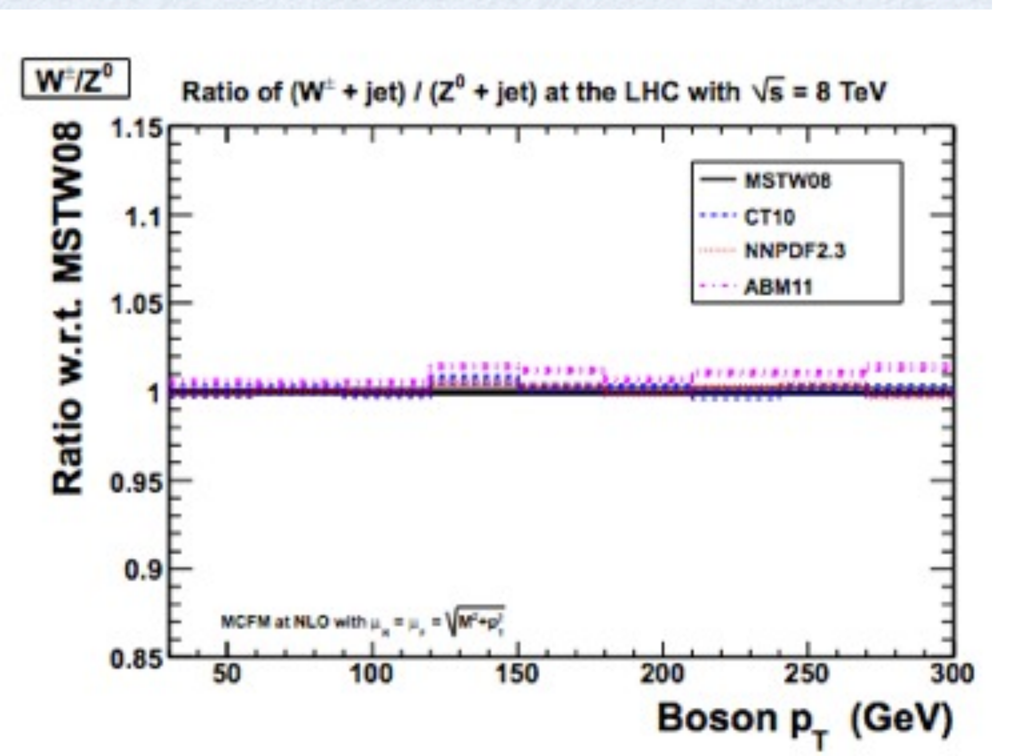
Gluons

W+jets/Z+jets at hight pT

W+j/Z+j ratio is insensitive to PDFs



ATLAS, arXiv:1108.4908]



$$\frac{\sigma(W^+ + \text{jet}) + \sigma(W^- + \text{jet})}{\sigma(Z^0 + \text{jet})} \sim \frac{u+d}{0.29\,u + 0.37\,d}$$

Malik,Watt ArXiv: 1304.2424

Photon PDF

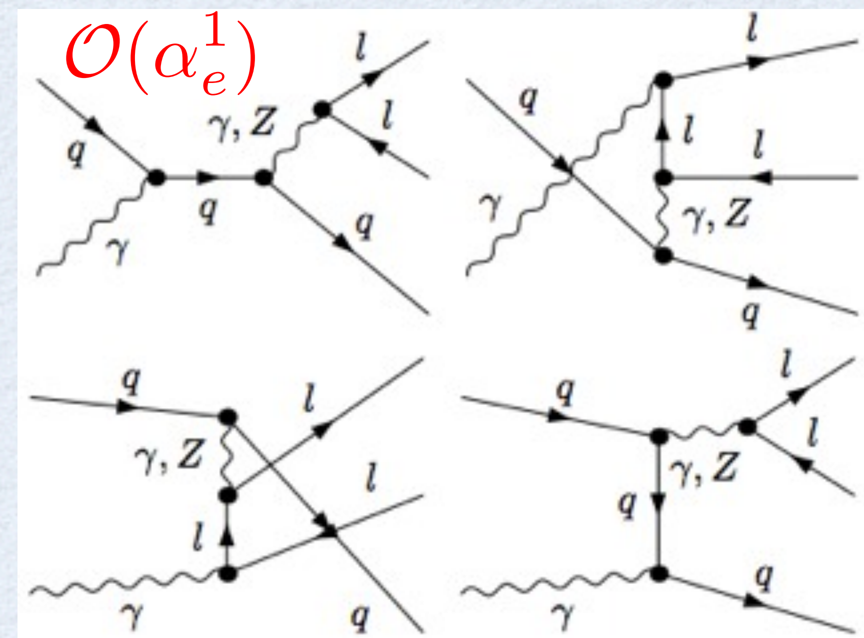
High and low mass Drell-Yan

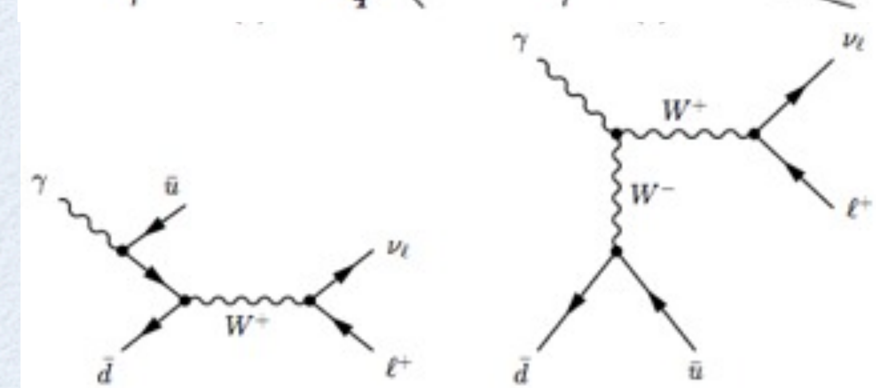
Ball et al, 1308.0598

- EW corrections have become relevant at the current phenomenological precision level
- A consistent inclusion of EW corrections requires PDF with QED effects
- NNPDF23QED is the first PDF set with uncertainties which incorporates (N)NLO QCD + LO QED effects
- Photon PDF fitted from DIS and DY data (on-shell W,Z production and low/high mass DY)
- DIS data fitted and DY data included via Bayesian reweighting **[Ball et al., Nucl.Phys. B855 (2012) 608-638]**
- Photon PDF is poorly determined from DIS data. Need hadron collider processes where photon contributes at LO!

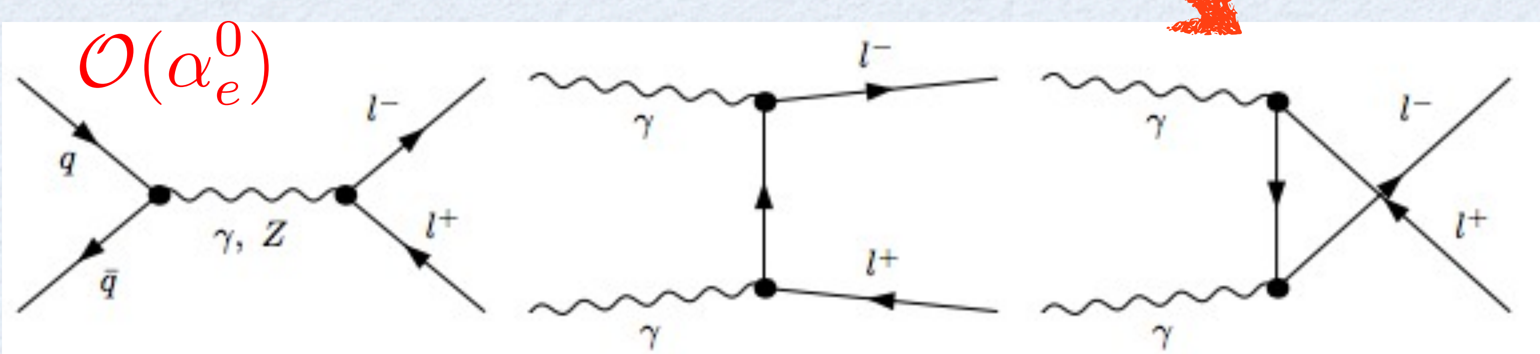
	NLO	NNLO .
$\gamma;\ Q^2 = 2\ \mathrm{GeV}^2$	(0.42 ± 0.42) %	(0.34 ± 0.34)%
$\gamma;\ Q^2 = 10^4\ \mathrm{GeV}^2$	(0.68 ± 0.42) %	(0.61 ± 0.34)%
total; $Q^2 = 2\ \mathrm{GeV}^2$	(100.43 ± 0.44)%	(100.32 ± 0.34)%
total; $Q^2 = 10^4\ \mathrm{GeV}^2$	(100.38 ± 0.43)%	(100.29 ± 0.36) %

approximate inclusion





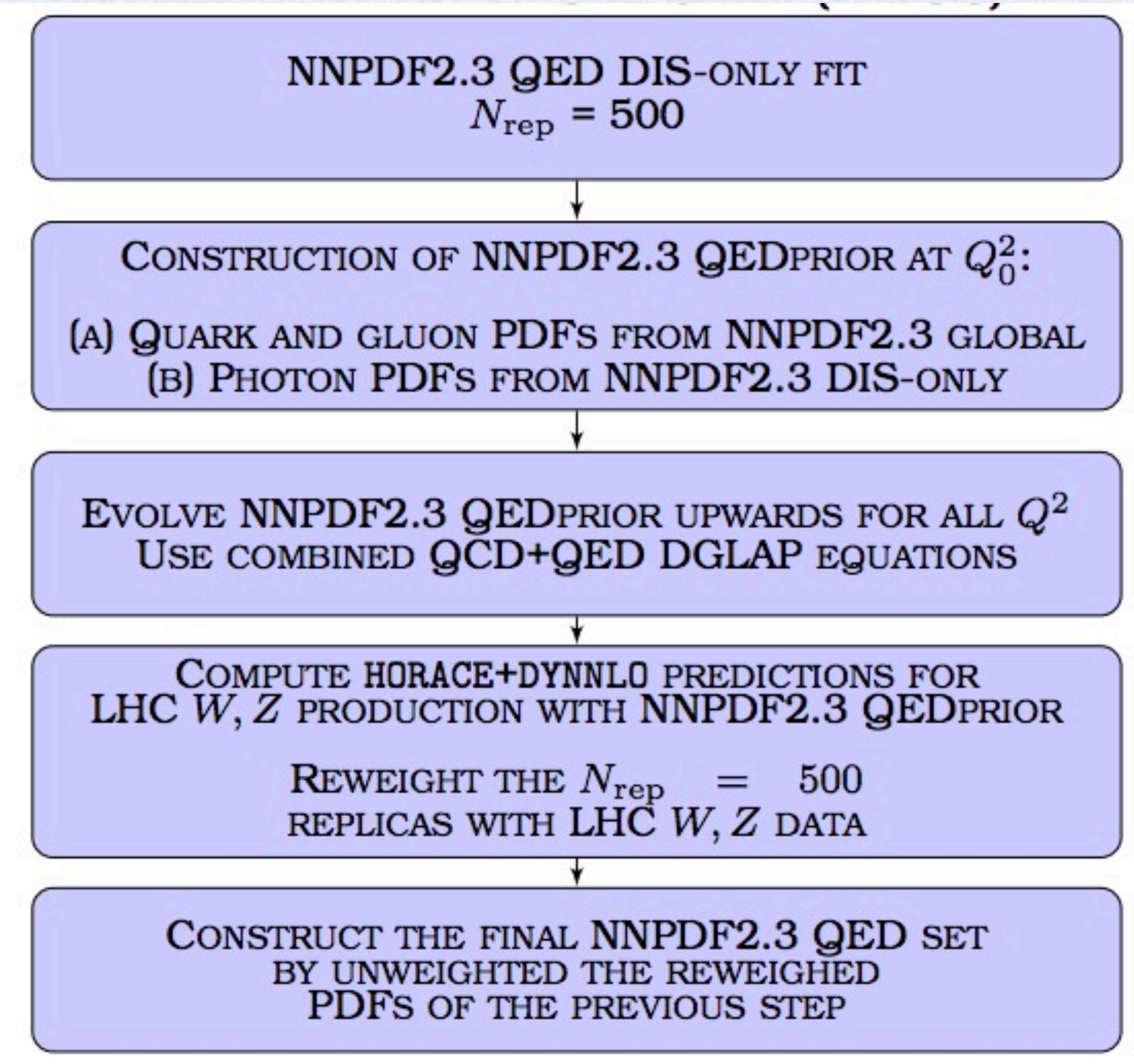
photon-initiated contribution to dilepton production

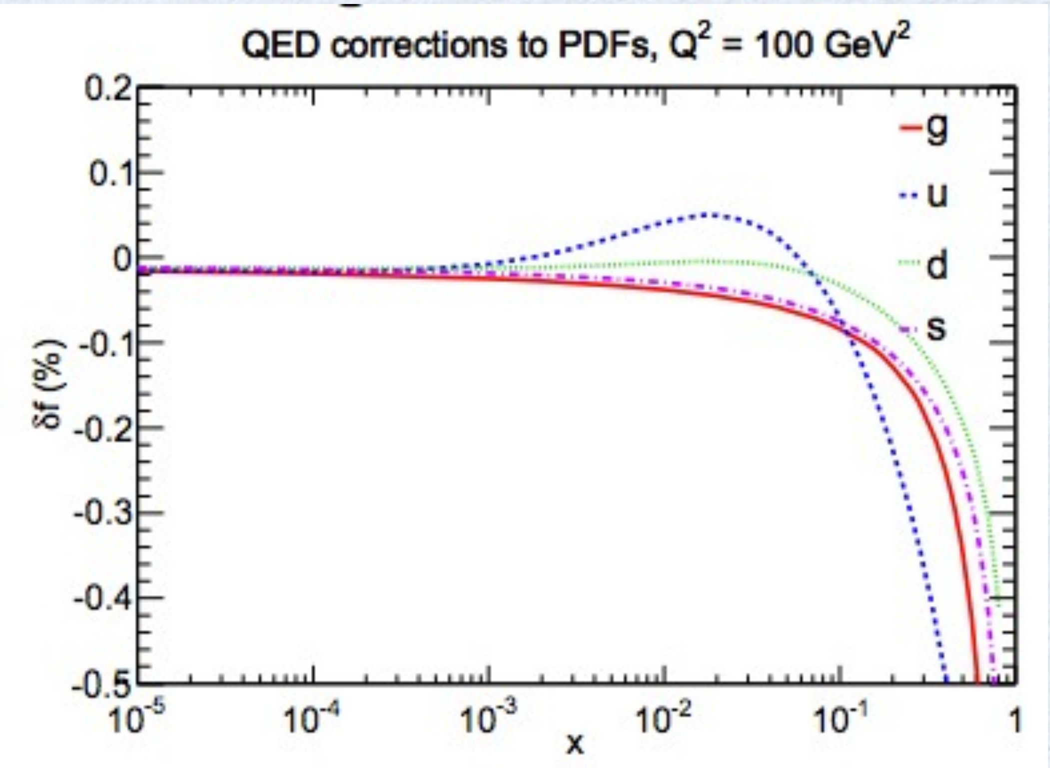


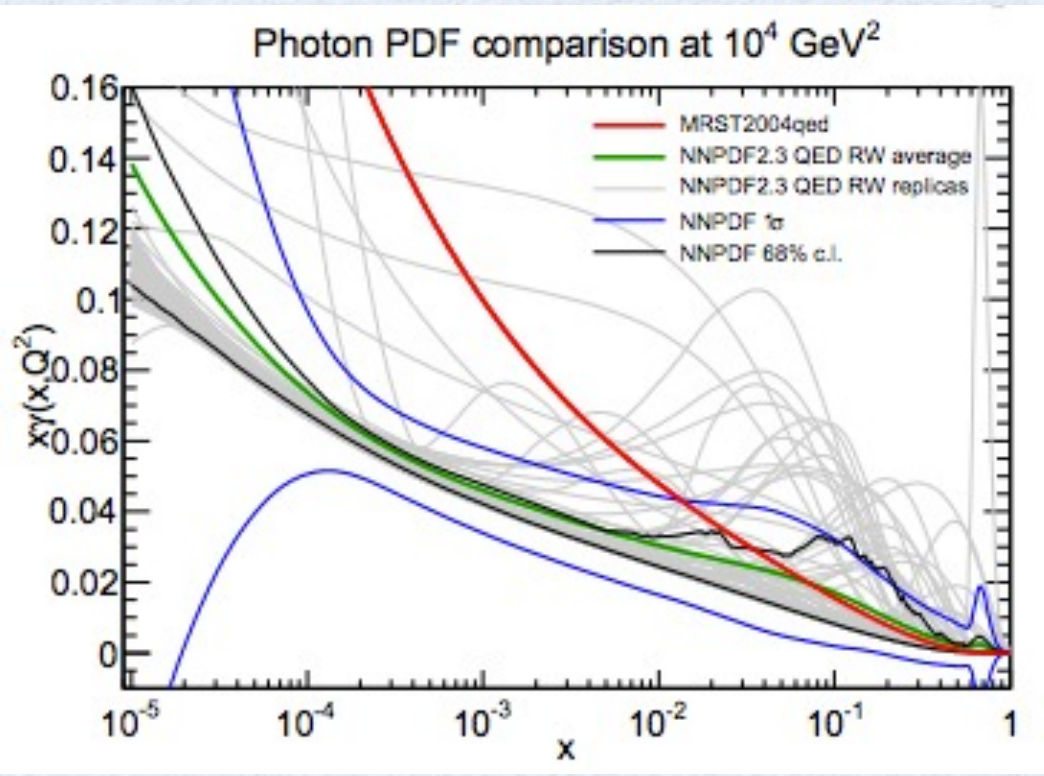
Photon PDF

The NNPDF23QED analysis

Ball et al, 1308.0598



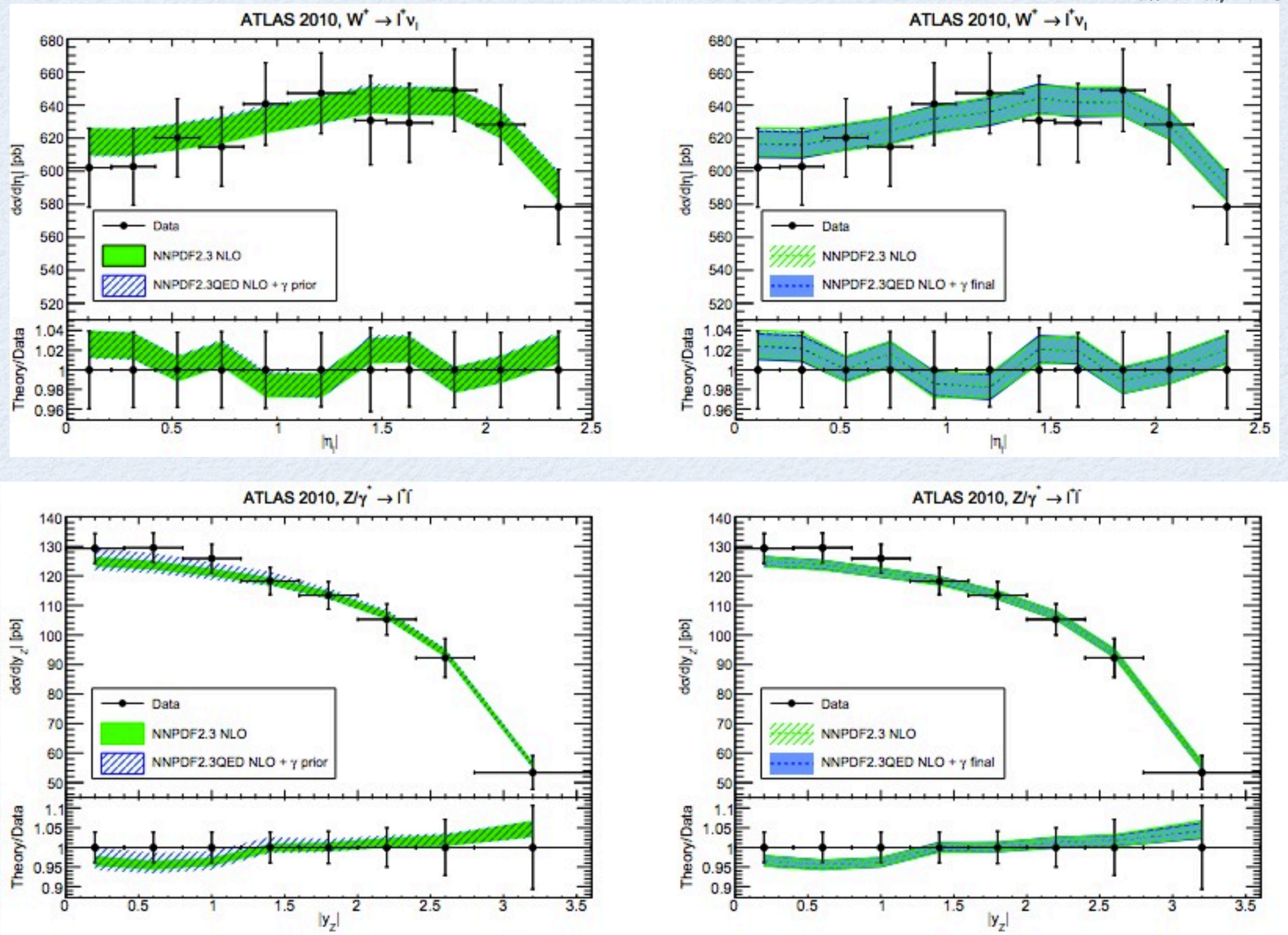




Photon PDF

Inclusive W and Z production

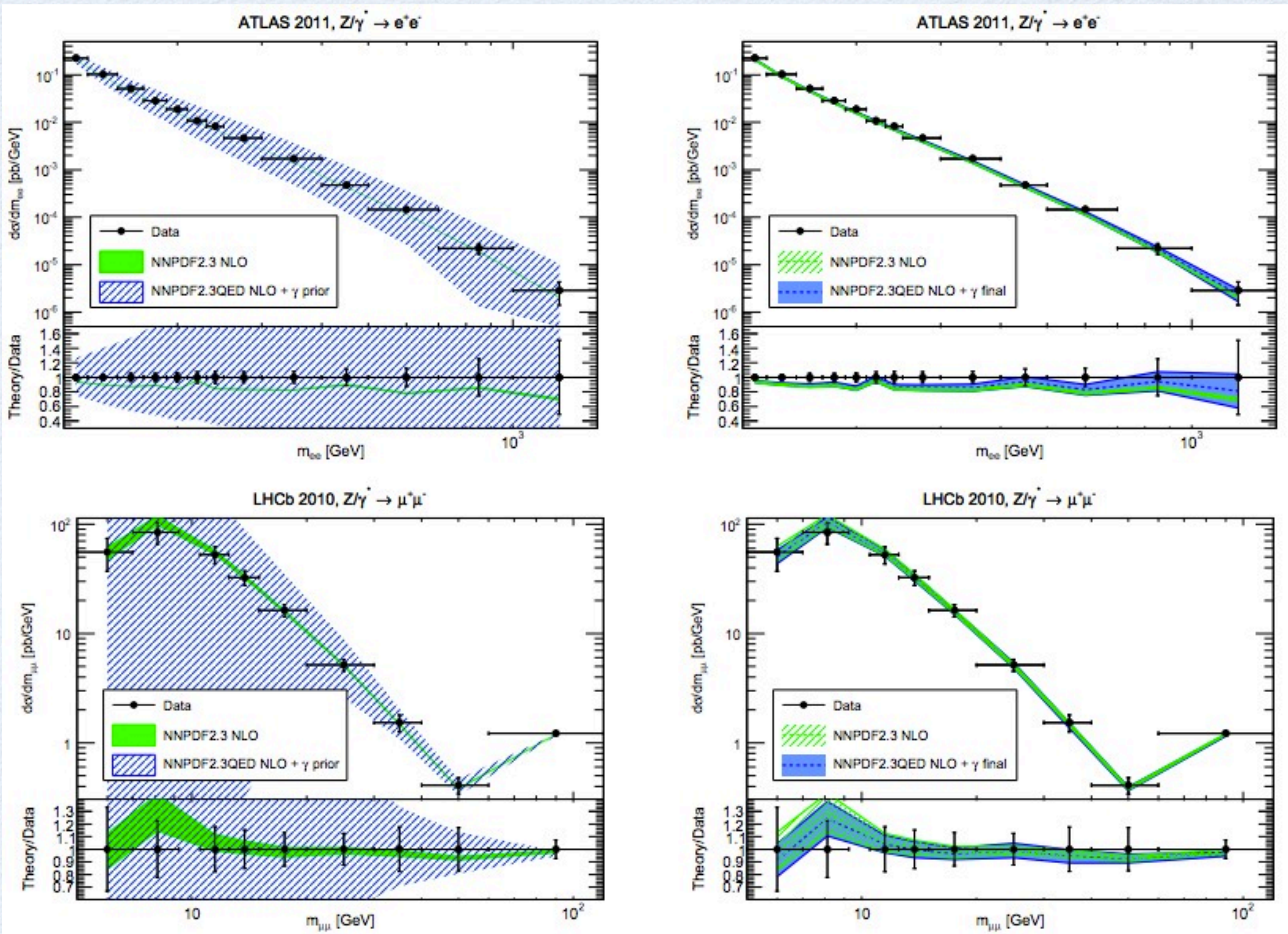
Ball et al, 1308.0598



Photon PDF

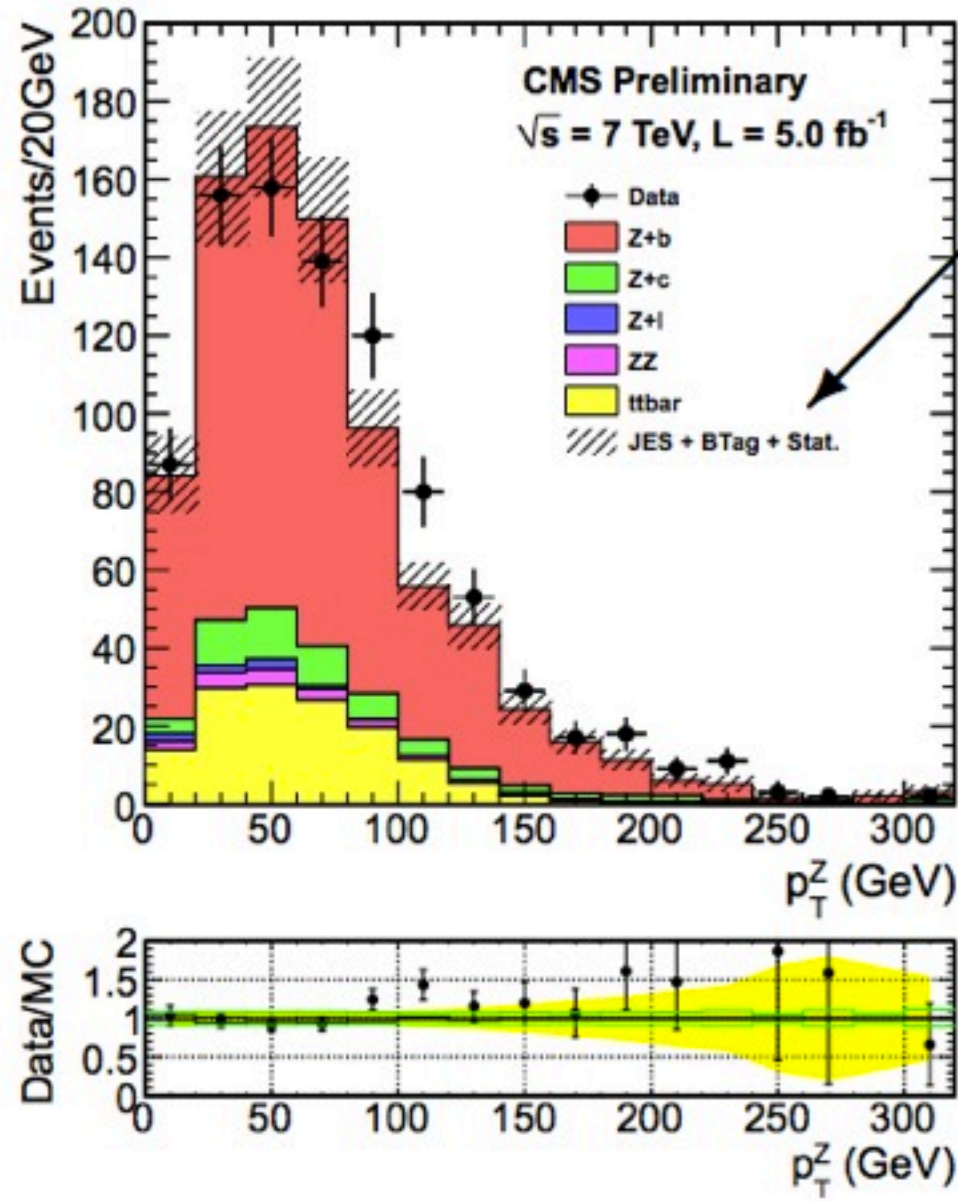
High and low mass Drell-Yan

Ball et al, 1308.0598

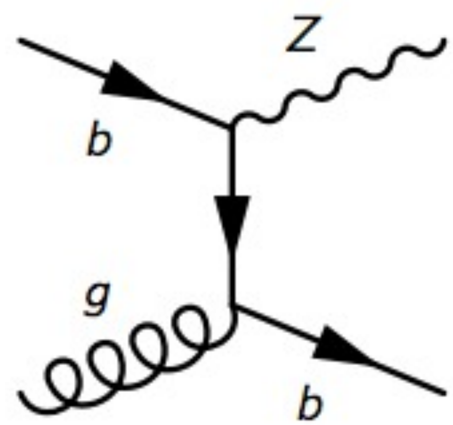


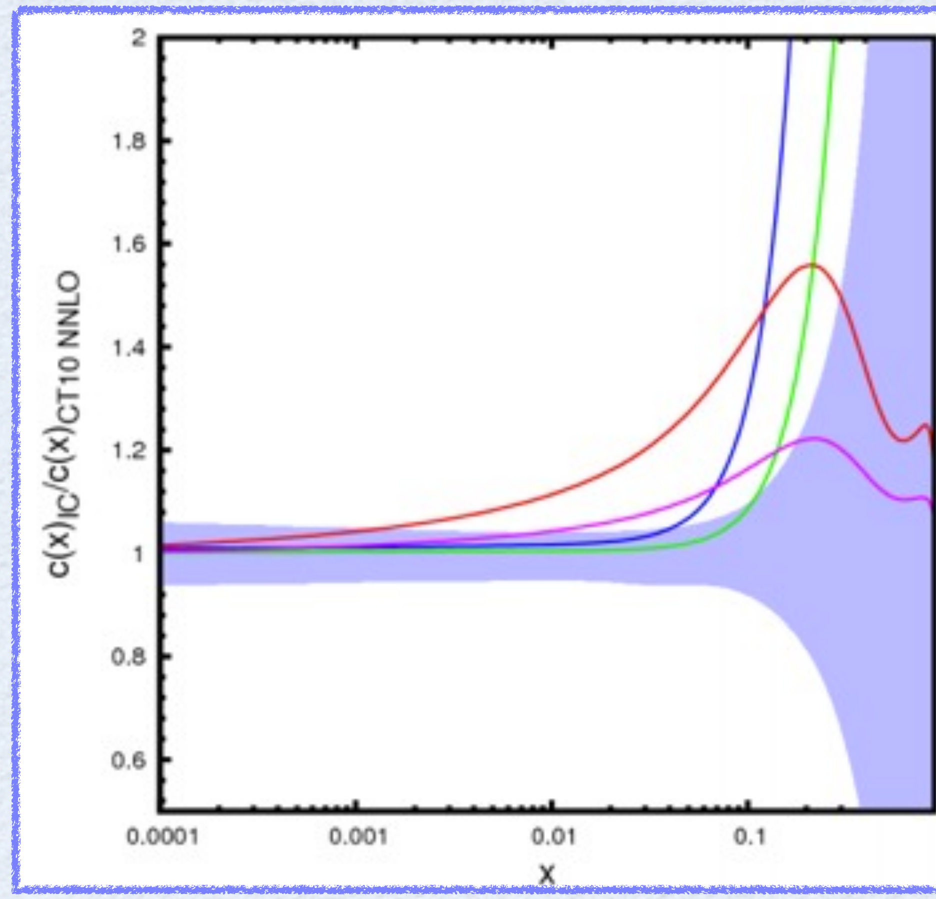
Heavy quarks

Z + b and Z + c



$Z + b$ - CMS



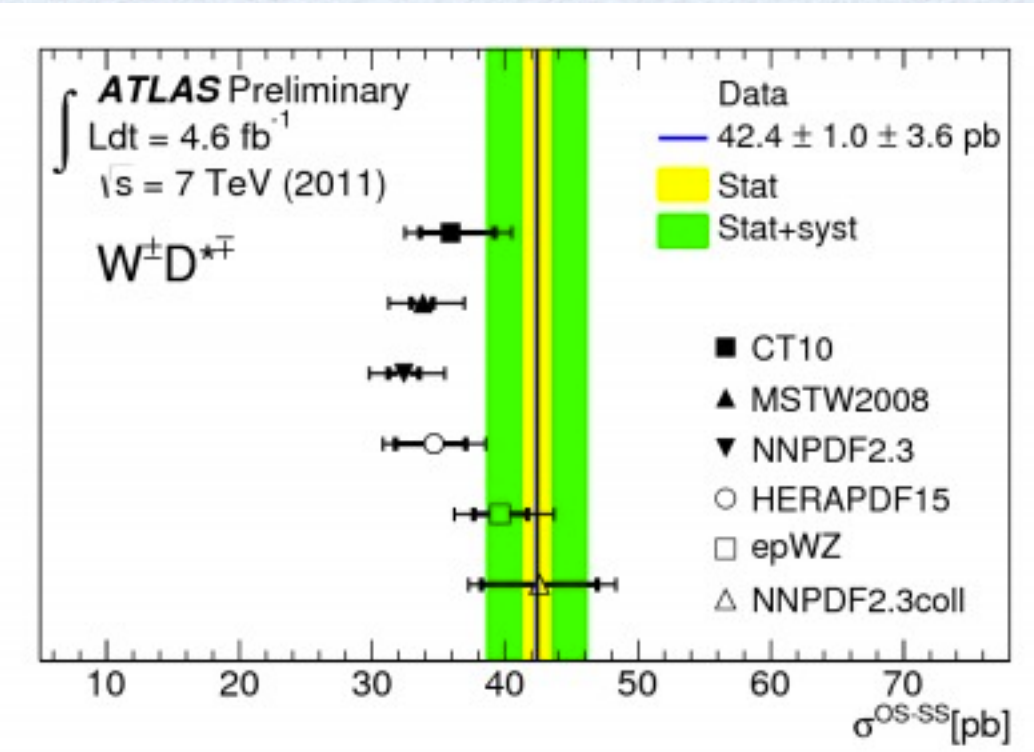


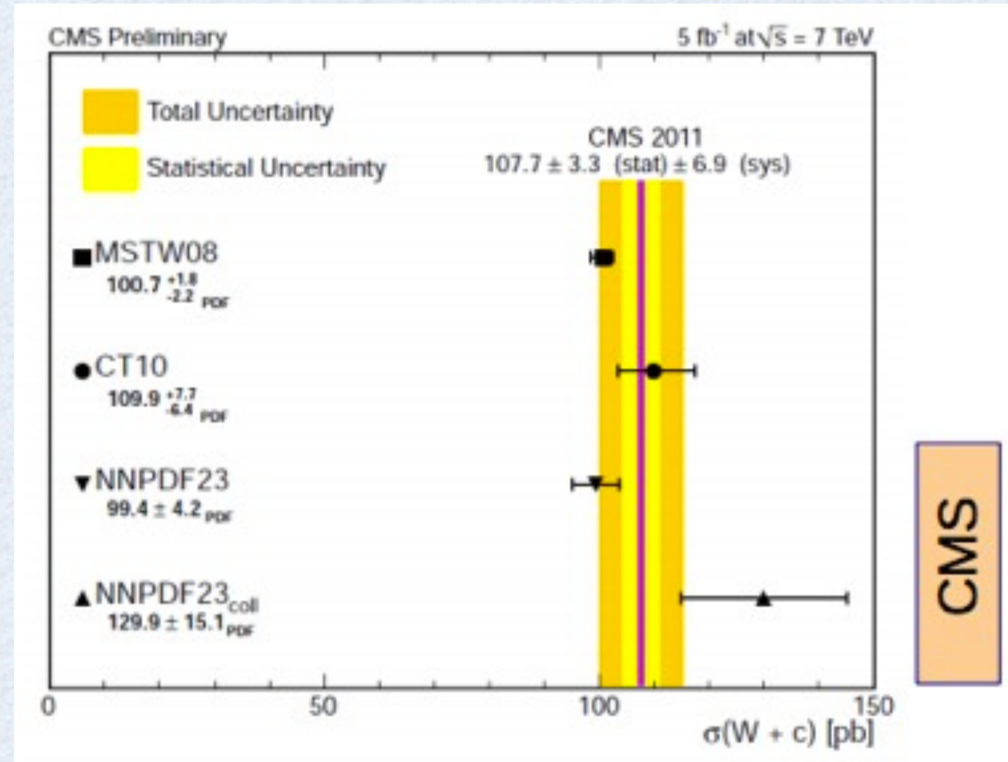
D. Stump, QCD@LHC 2013

Intrinsic charm: it is not ruled out in global fits

Strangeness

Ks in ATLAS, CMS and NOMAD analyses

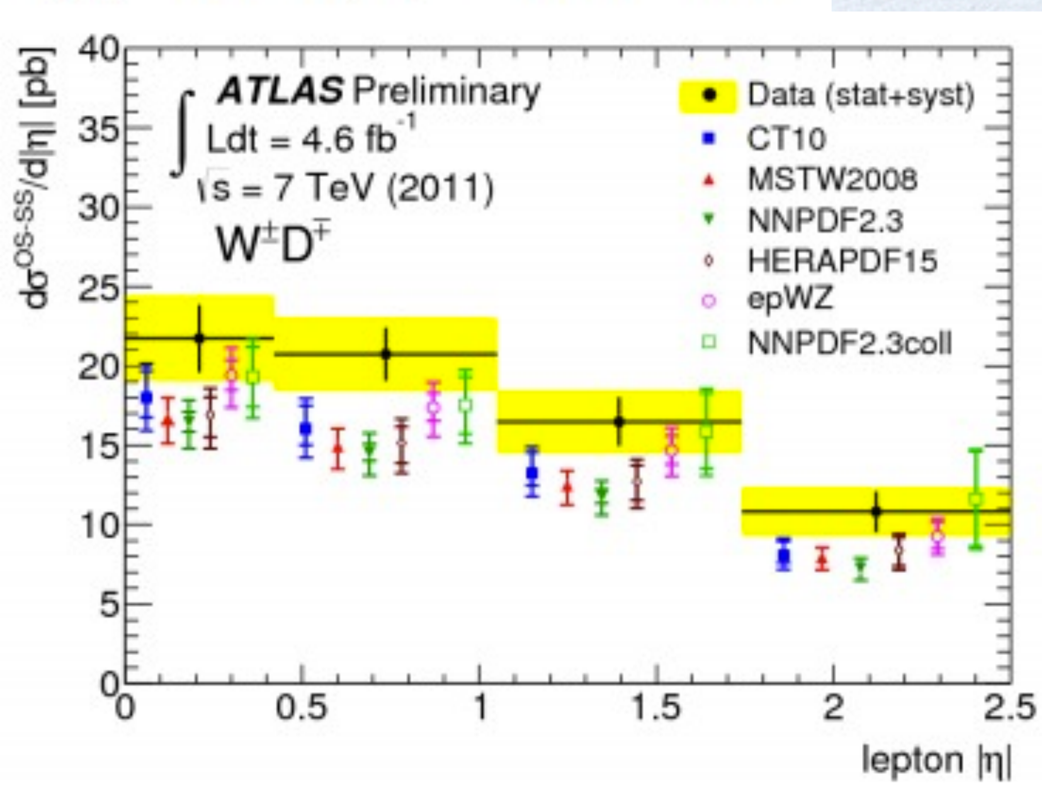


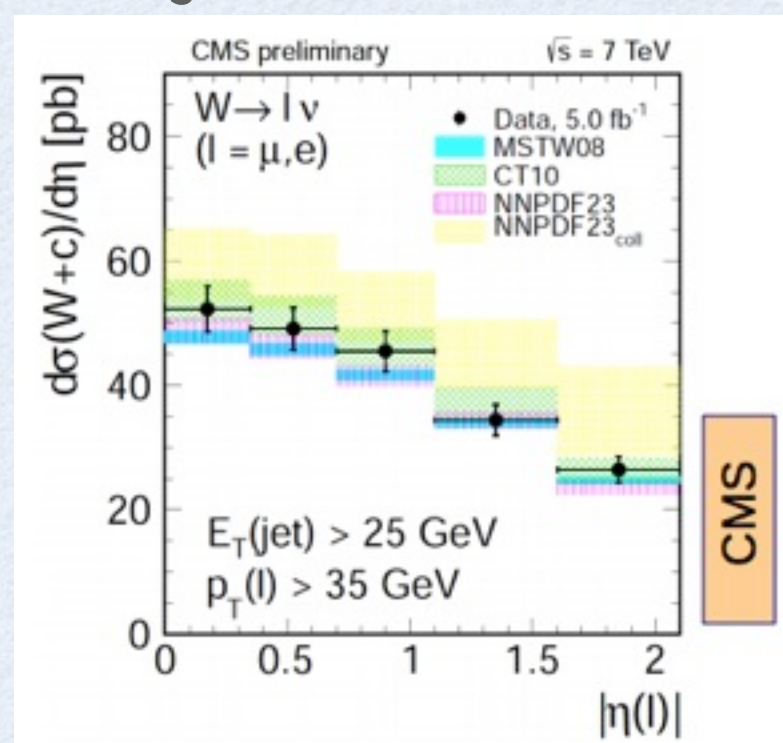


$$\kappa_s(Q^2 = 20\ \mathrm{GeV}^2/\mathrm{c}^2) \quad = \quad 0.591 \pm 0.019$$

Nomad

A. Vargas Trevinos, QCD@LHC 2013





Strangeness

Global versus collider only