Impact of LHC data on PDF analysis

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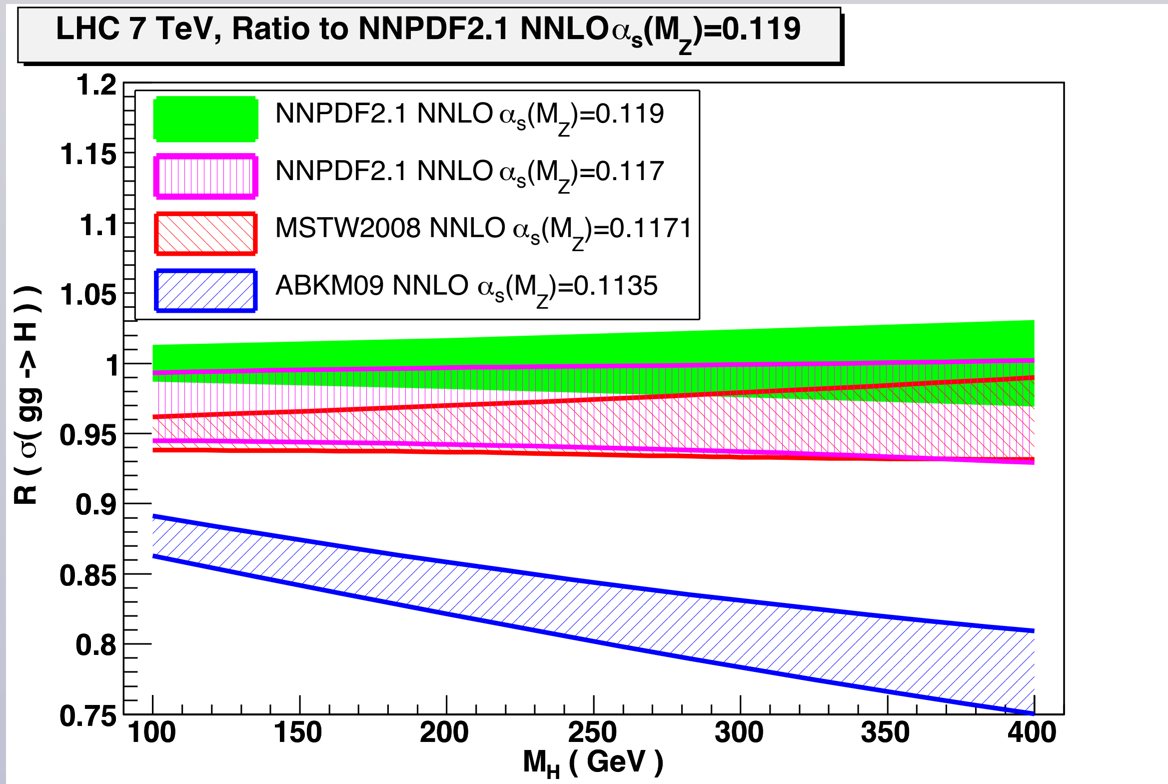
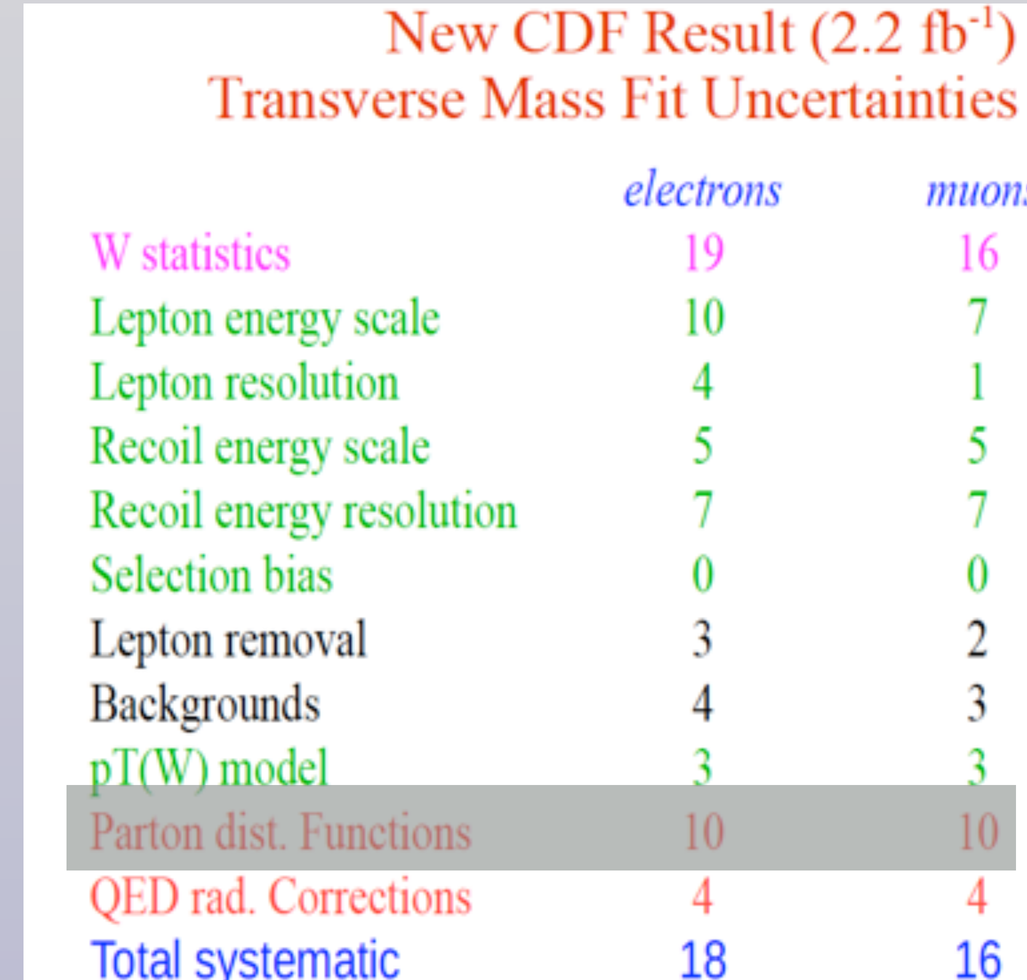
Parton Distributions at the LHC

Parton Distributions, and their associated **theoretical and experimental uncertainties** play a crucial for **hadron collider phenomenology**:



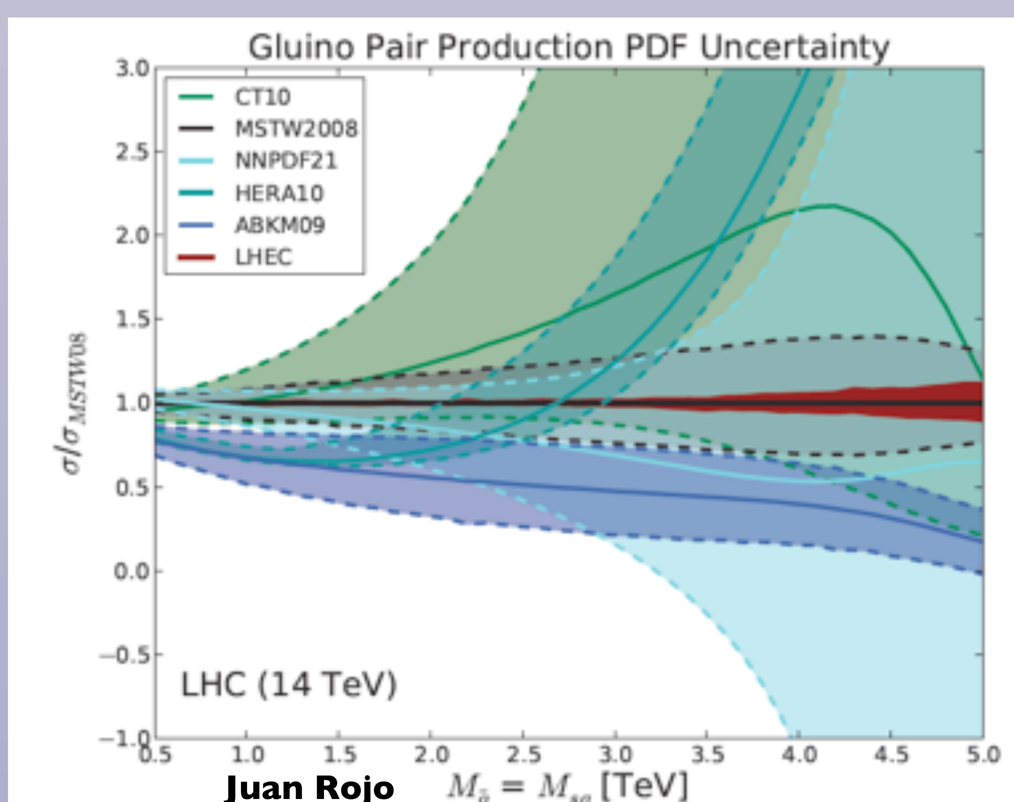
PDFs one of main TH uncertainties in Higgs production: limit coupling extraction, ...



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

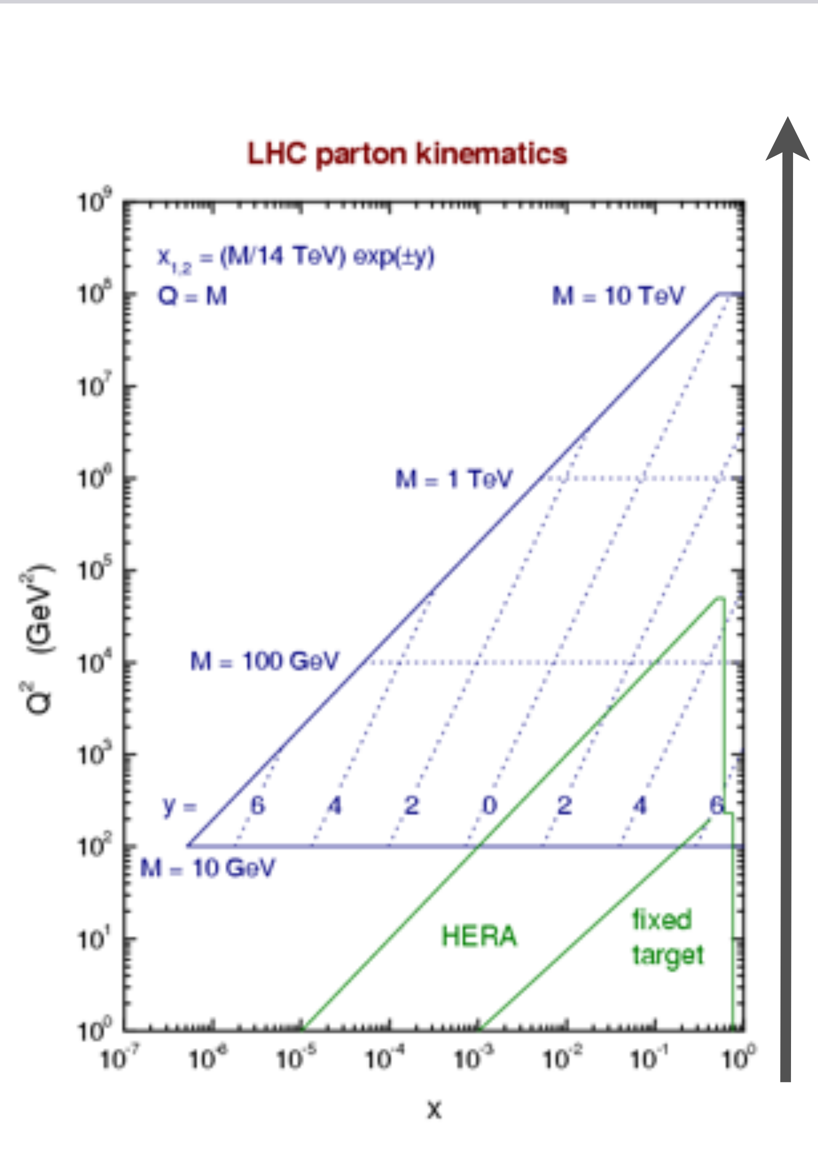


PDF uncertainties affect substantially theory predictions for BSM high mass production (SUSY, Z', KK)

And many other cases: alphas determination, CKM elements, effective lepton mixing angle, cross section rations between CM energies, neutrino astrophysics ....

Experimental data in global PDF fits

Q² dependence of PDFs: determined by pQCD



x dependence of PDFs: determined from data

- A **global dataset** covering a wide set of hard-scattering observables is required to constrain **all possible PDF combinations** in the **whole range of Bjorken-x**

- For example, **inclusive jets** are sensitive to the **large-x gluon**, while **HERA neutral current** data pins down the **small-x quarks**

- **LHC data** is introducing completely new observables to be used for PDF constraints

pre-LHC dataset

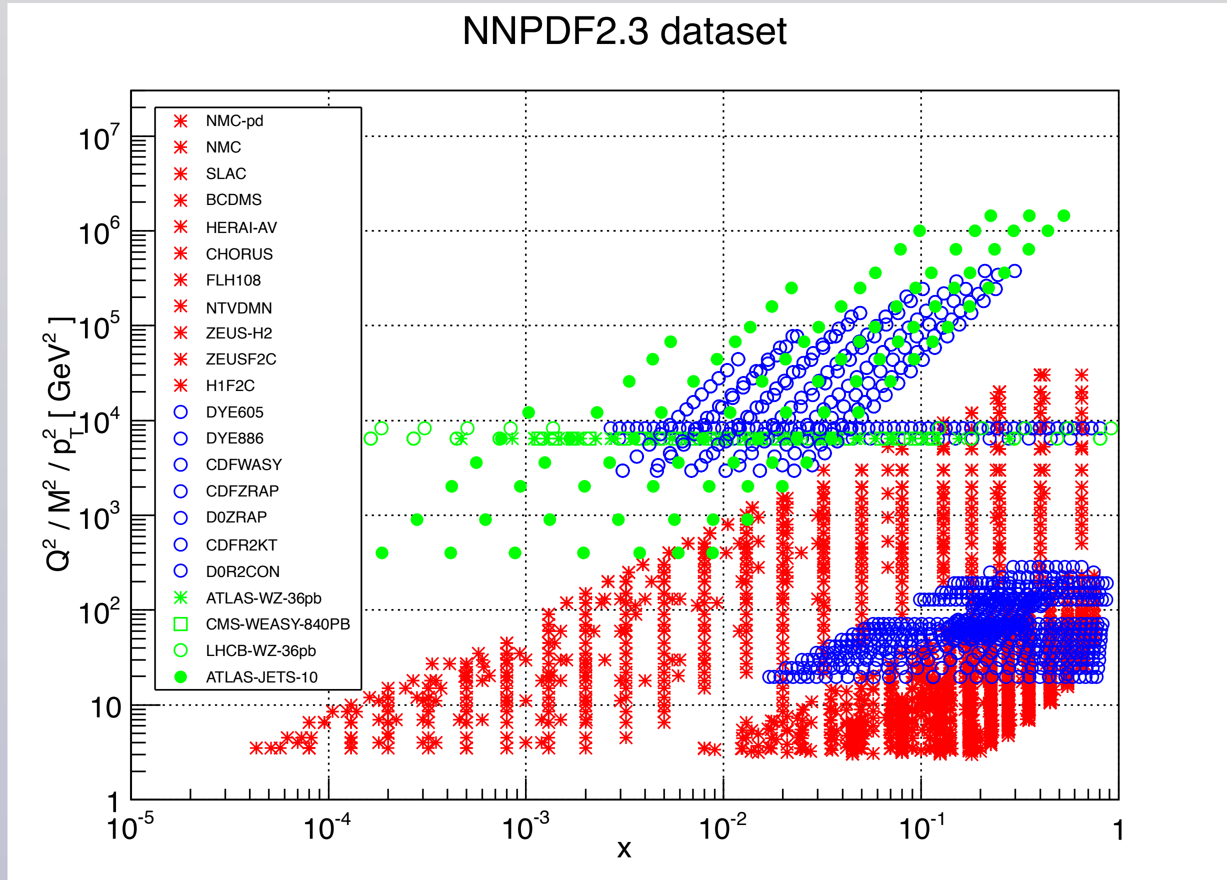
Process	Subprocess	Partons	x range
$\ell^\pm \{p,n\} \to \ell^\pm X$	$\gamma^* q \to q$	$q, \bar{q}, g$	$x \gtrsim 0.01$
$\ell^\pm n/p \to \ell^\pm X$	$\gamma^* d/u \to d/u$	d/u	$x \gtrsim 0.01$
$pp \to \mu^+\mu^- X$	$u\bar{u}, d\bar{d} \to \gamma^*$	$\bar{q}$	$0.015 \lesssim x \lesssim 0.35$
$pn/pp \to \mu^+\mu^- X$	$(u\bar{d})/(u\bar{u}) \to \gamma^*$	$\bar{d}/\bar{u}$	$0.015 \lesssim x \lesssim 0.35$
$\nu(\bar{\nu}) N \to \mu^-(\mu^+) X$	$W^* q \to q'$	$q, \bar{q}$	$0.01 \lesssim x \lesssim 0.5$
$\nu N \to \mu^-\mu^+ X$	$W^* s \to c$	s	$0.01 \lesssim x \lesssim 0.2$
$\bar{\nu} N \to \mu^+\mu^- X$	$W^* \bar{s} \to \bar{c}$	$\bar{s}$	$0.01 \lesssim x \lesssim 0.2$
$e^\pm p \to e^\pm X$	$\gamma^* q \to q$	$g, q, \bar{q}$	$0.0001 \lesssim x \lesssim 0.1$
$e^+ p \to \bar{\nu} X$	$W^+ \{d,s\} \to \{u,c\}$	d, s	$x \gtrsim 0.01$
$e^\pm p \to e^\pm c\bar{c} X$	$\gamma^* c \to c, \gamma^* g \to c\bar{c}$	c, g	$0.0001 \lesssim x \lesssim 0.01$
$e^\pm p \to \text{jet} + X$	$\gamma^* g \to q\bar{q}$	g	$0.01 \lesssim x \lesssim 0.1$
$p\bar{p} \to \text{jet} + X$	$gg, qg, qq \to 2j$	g, q	$0.01 \lesssim x \lesssim 0.5$
$p\bar{p} \to (W^\pm \to \ell^\pm \nu) X$	$ud \to W, \bar{u}\bar{d} \to W$	$u, d, \bar{u}, \bar{d}$	$x \gtrsim 0.05$
$p\bar{p} \to (Z \to \ell^+\ell^-) X$	$uu, dd \to Z$	d	$x \gtrsim 0.05$

MSTW08, arXiv:0901.0002

PDF whishlist at the LHC

- At the LHC, there is a long list of **PDF-related important measurements** to be pursued. Will be the main topic of this talk. Some of these already available, and used in PDF analysis.
- Data **ready to be used** in PDF analysis:
    - Inclusive **jets and dijets**, central and forward: **large-x quarks and gluons**
    - Isolated **photons**: **medium-x gluons**
    - Inclusive **W and Z production** and asymmetries: **quark flavor separation, strangeness**
- **Ongoing/future measurements** for PDF constraints:
    - W production with charm quarks: **direct handle on strangeness**
    - W,Z production with jets: **medium and small-x gluon**
    - Off resonance Drell-Yan and W production at small and high mass: **quarks at very small and very large-x**
    - Top quark differential distributions: **large-x gluon**
    - Z+charm: **intrinsic charm PDF**
    - Single top production: **gluon and bottom PDFs**
    - Charmonium production: **small-x gluon**
- Available data on jets, photons and W,Z based on 2010/2011 run**. Much more stringent** constraints are expected to be larger with the **full 8 TeV dataset** and with **13/14 TeV** data

LHC data and PDF analysis (I)

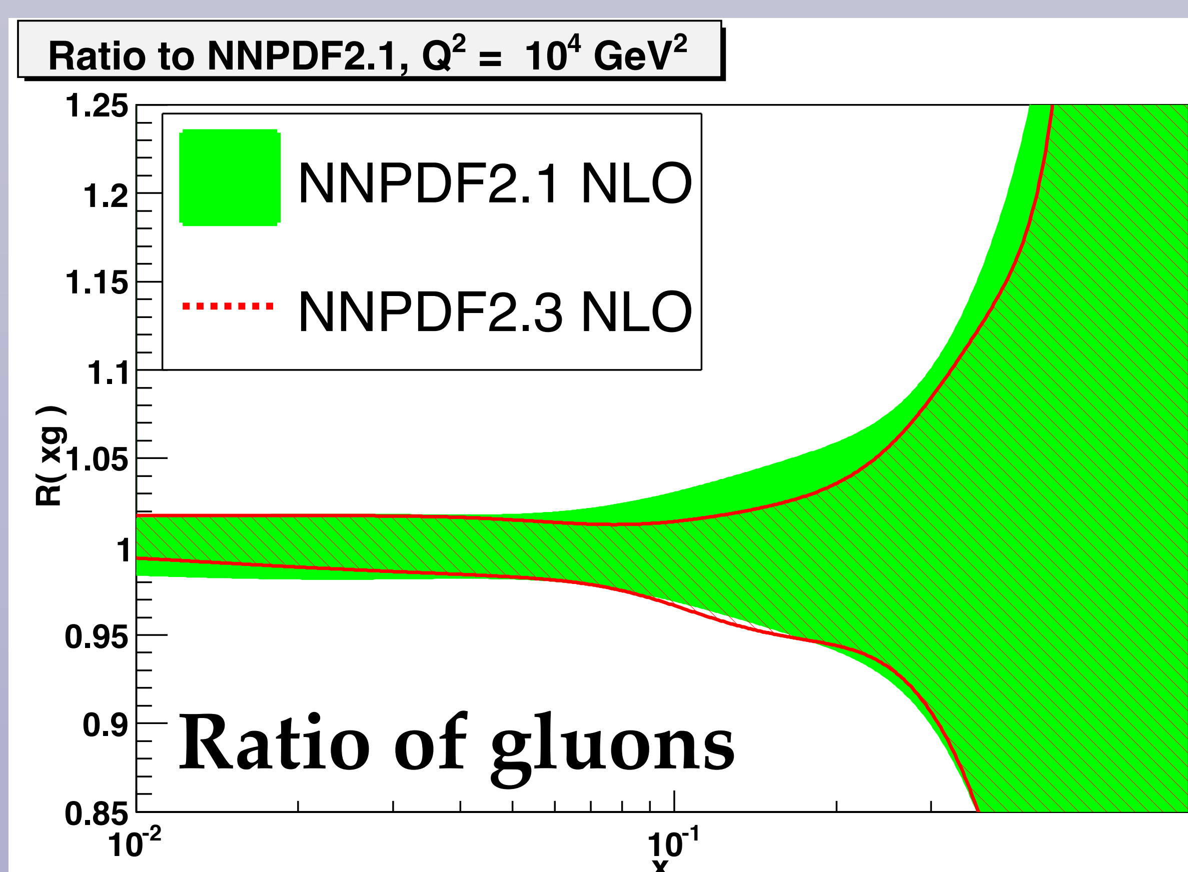


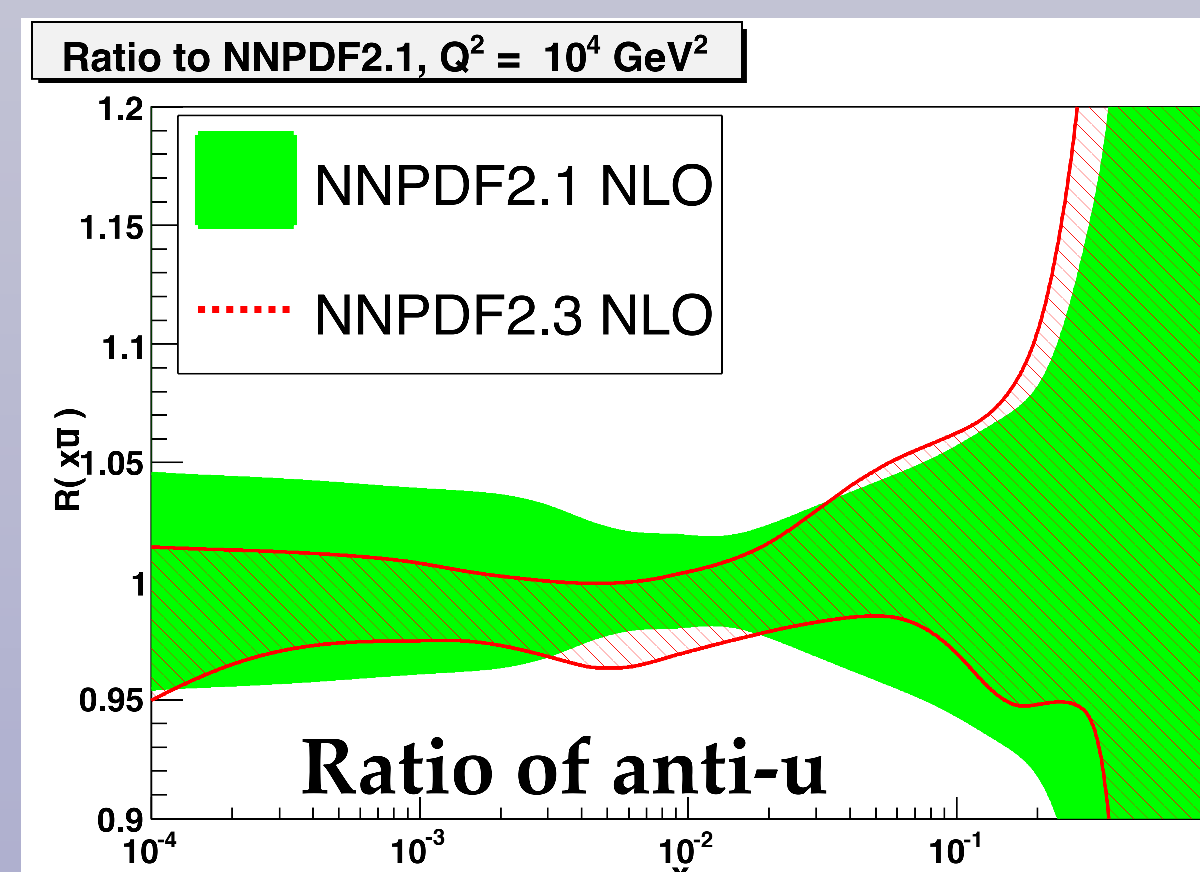
LHC data already part of global PDF analysis, *ie*. the recent **NNPDF2.3** sets.

The **inclusive jet data** help to constrain the large-x gluon

The **W and Z production** data from CMS, ATLAS and LHCb constrain **medium-x antiquarks**

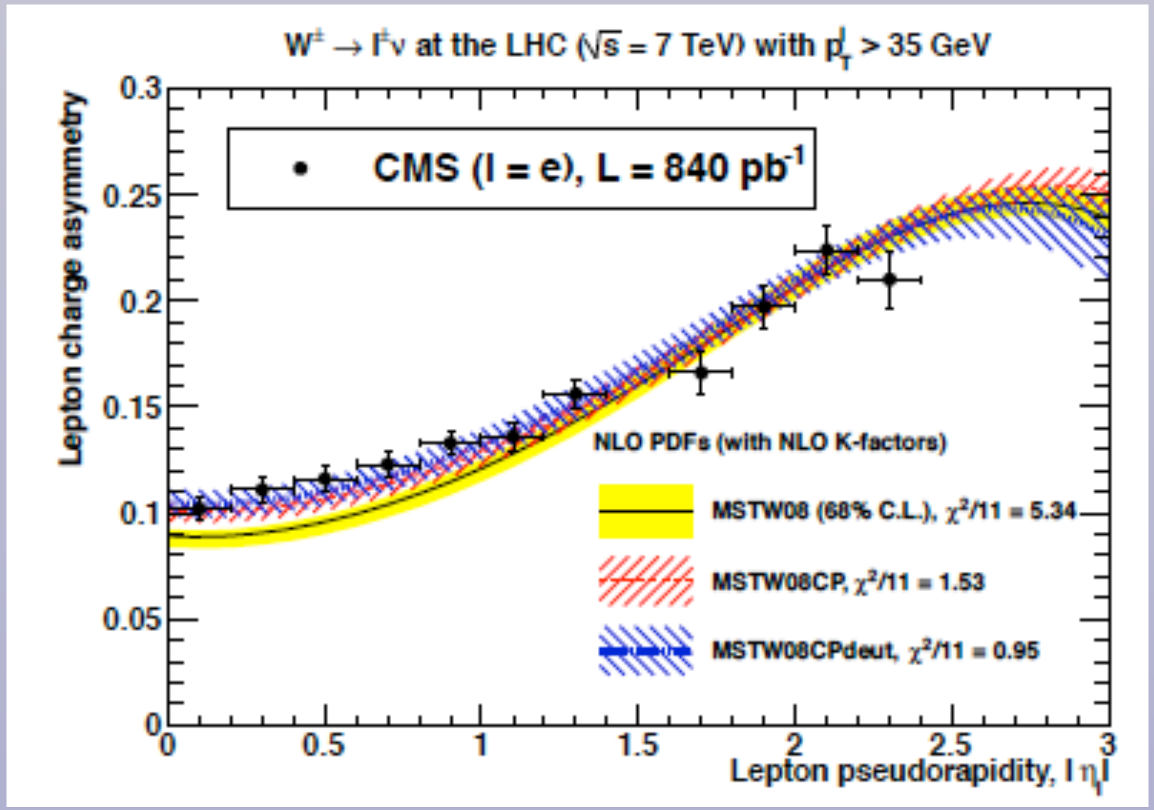
We are already working in adding **more LHC data**, like the **2011 CMS jets** and the ATLAS and CMS Drell-Yan distributions

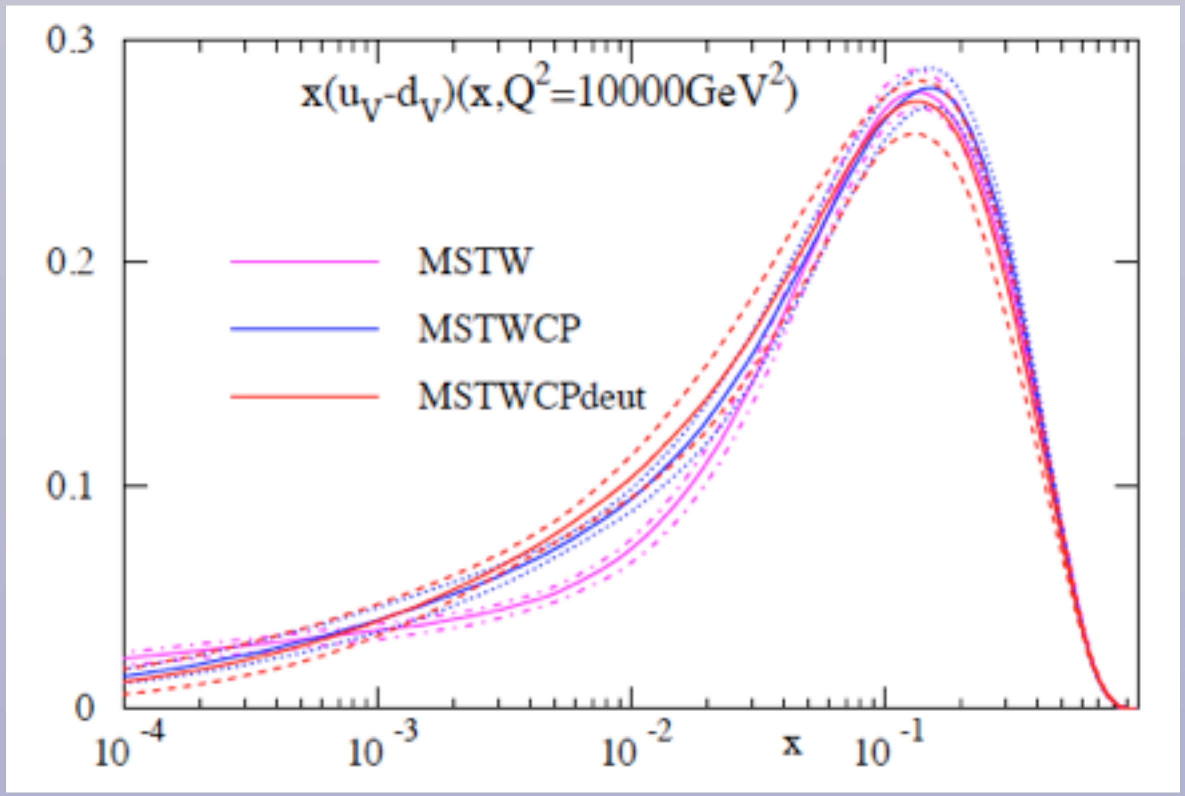




LHC data and PDF analysis (II)

- **LHC data** already studied in the context of the MSTW analysis
- MSTW2008 leads to the **poor description of the ATLAS and CMS asymmetry** data (undershooting data at central rapidities)
- By including the LHC data with PDF reweighting, a good fit quality is achieved by a **larger uv-dv PDF at medium x**
- Similar effects can be achieved starting from the MSTW08 dataset but with a **more flexible parametrization with Chebyshev polynomials,** as well as with an improved treatment of deuteron corrections



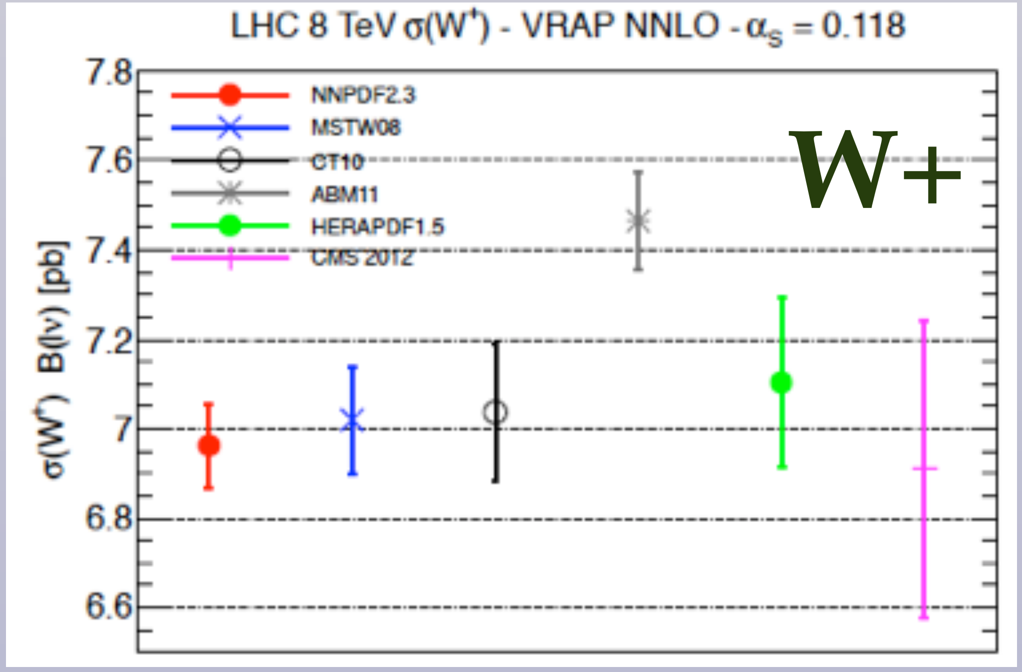


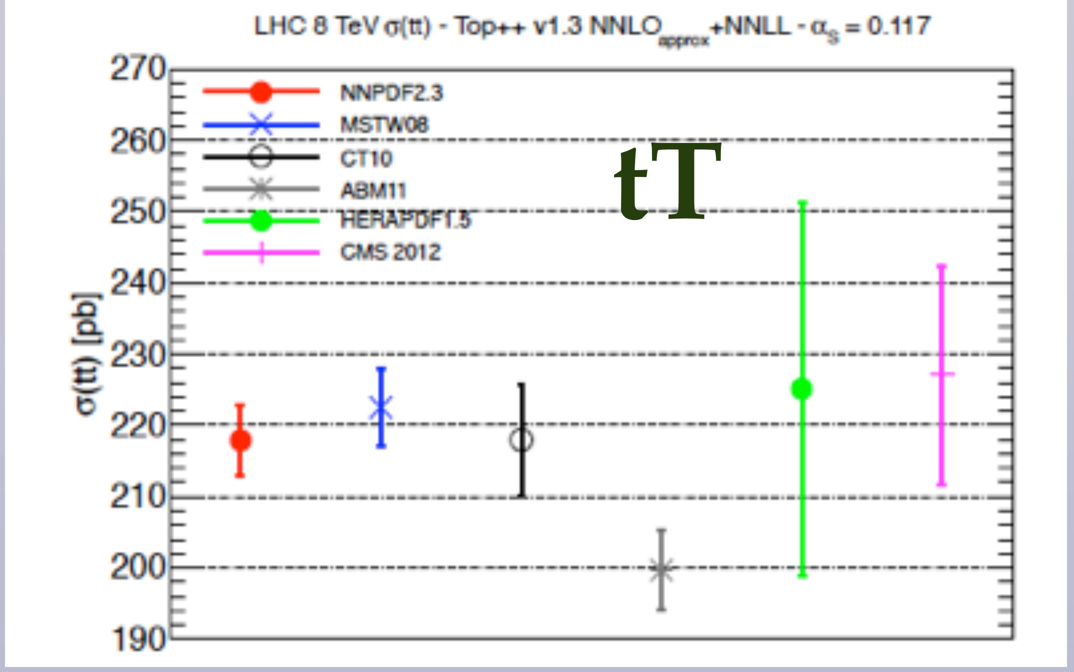
arXiv:1211.1215

Juan Rojo

LHC data and PDF analysis (III)

- A **systematic comparison of all modern NNLO PDFs with LHC data** on inclusive cross sections and differential distributions performed in **arXiv:1211.5142**: "Parton Distribution benchmarking with LHC data"
- Reasonable agreement between **NNPDF2.3, CT10 and MSTW08** found, both for central values and errors, with larger differences with **HERAPDF1.5 and ABM**
- Quantitative comparisons with χ^2 estimator, **NNPDF2.3 best overall description** (as expected since it is the only set that already includes all the data)



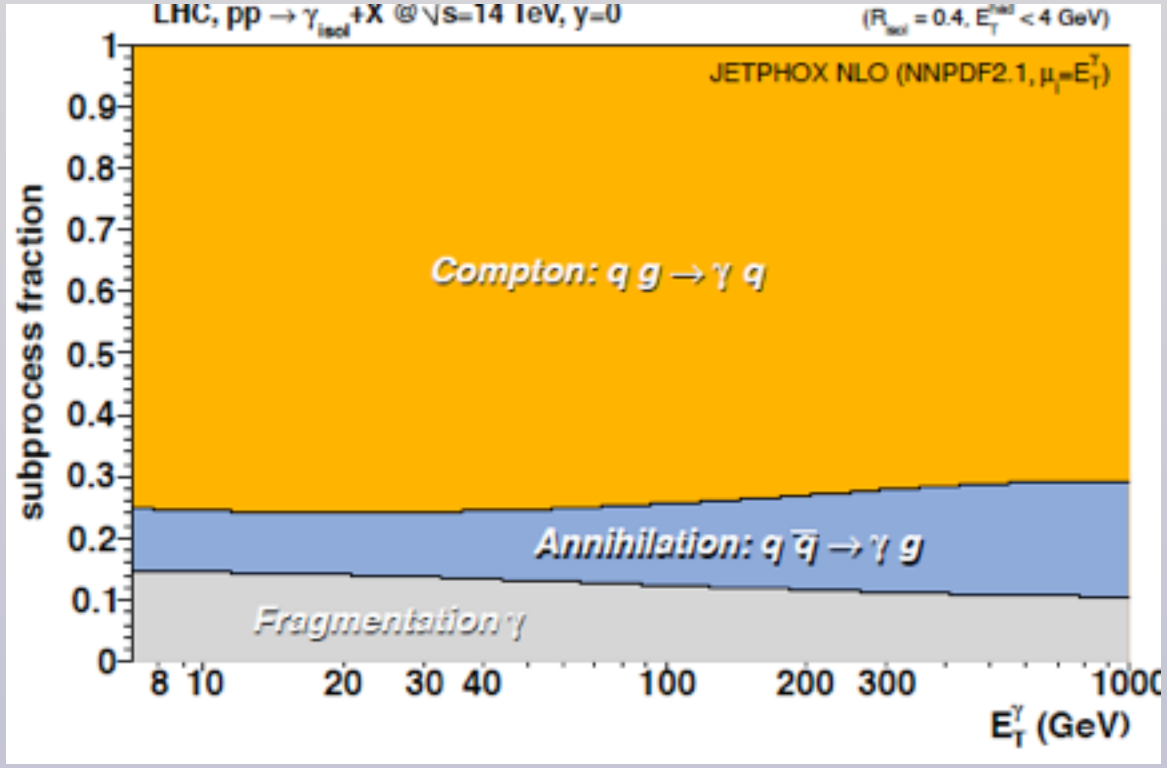


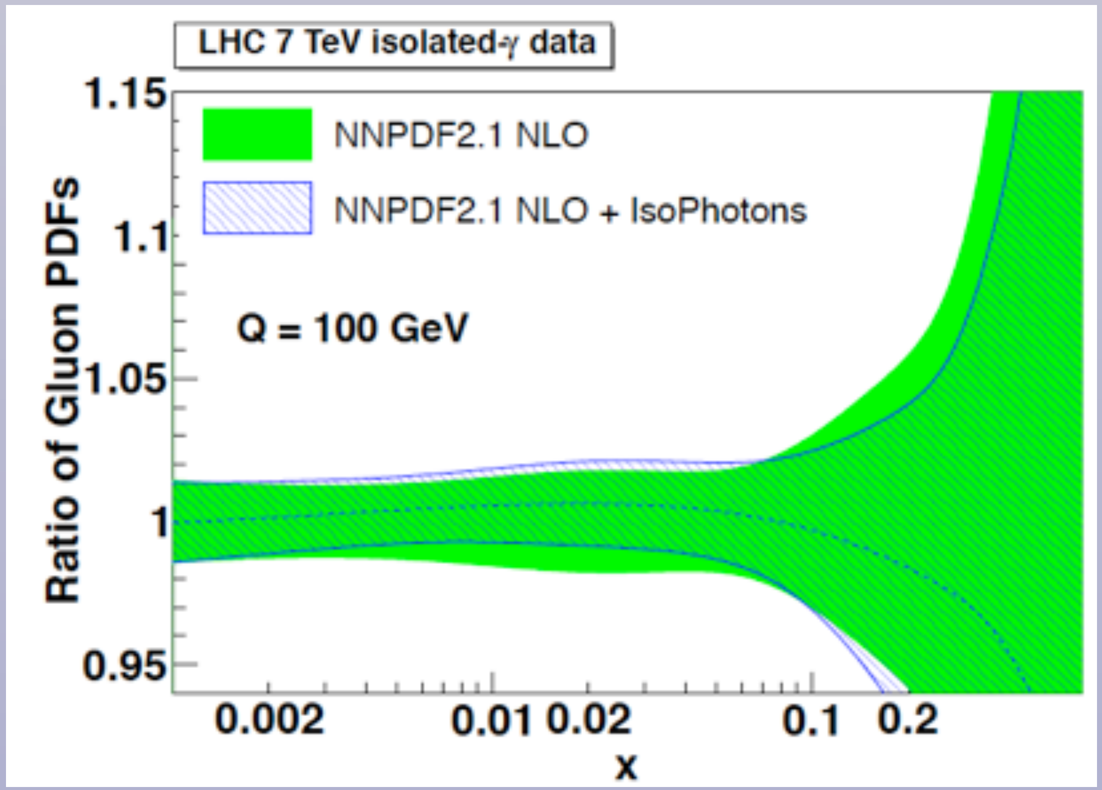
χ^2

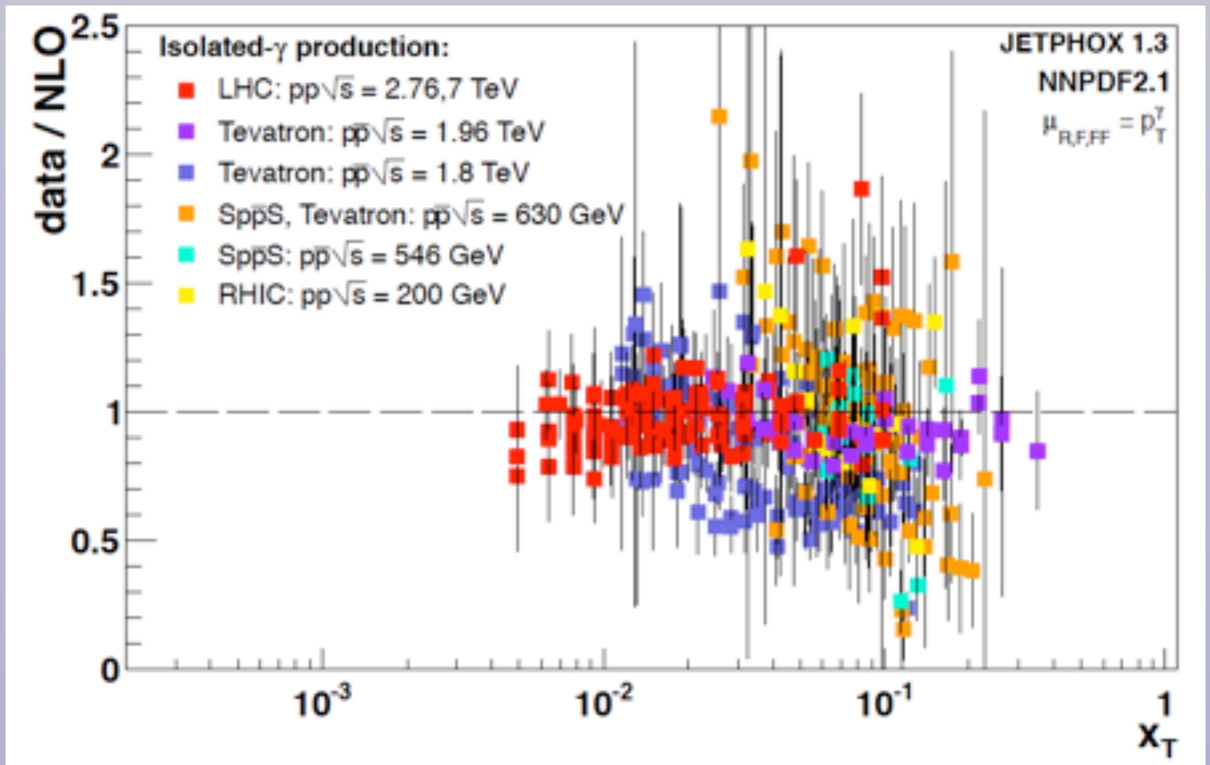
	NLO $\alpha_s = 0.119$				
Dataset	NNPDF2.3	MSTW08	CT10	ABM11	HERAPDF1.5
ATLAS W, Z	1.271	2.003	1.061	1.561	1.757
CMS W el asy	0.822	4.698	1.421	1.929	0.693
LHCb W	0.673	0.919	1.063	2.332	4.124
ATLAS jets	1.004	0.972	1.352	1.345	1.111

Isolated photons

- **Photon** production in hadronic collisions is **directly sensitive to the gluon** via QCD Compton scattering
- Photon production was used in **early PDF fits** for gluon constraints, then replaced by jets due to poor data/theory agreement of **some fixed-target data**
- Recently we revisited the data/theory comparison of all **isolated collider** photon data with the most updated theory, **JetPhox +NNPDF2.1,** and found an **excellent overall agreement**
- **Moderate reduction of gluon PDF errors** from LHC photon data, in the region relevant for ggF Higgs
- Need a **fast interface** to include photon data in PDF fits



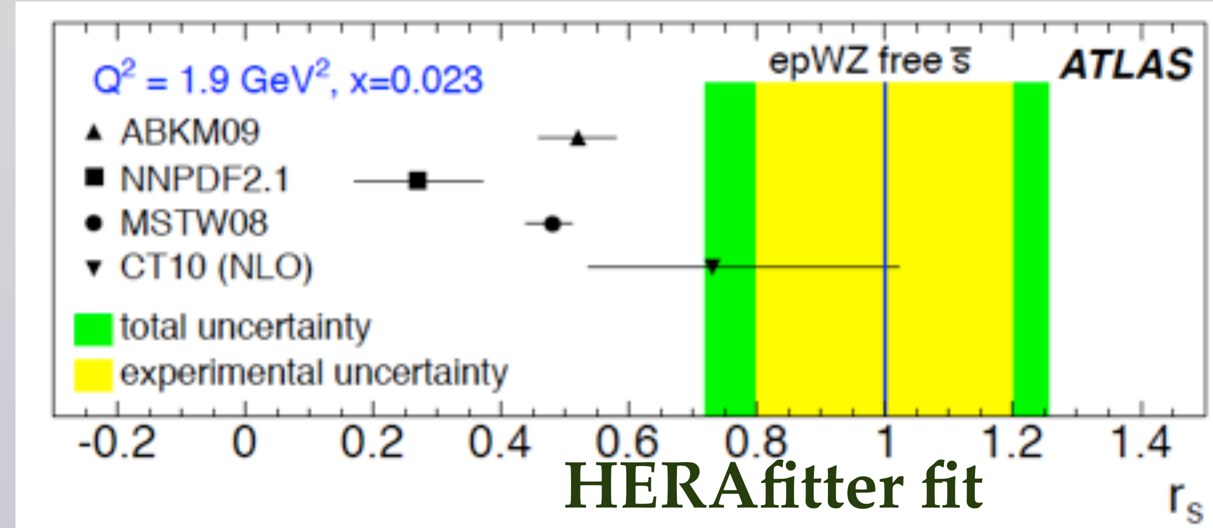


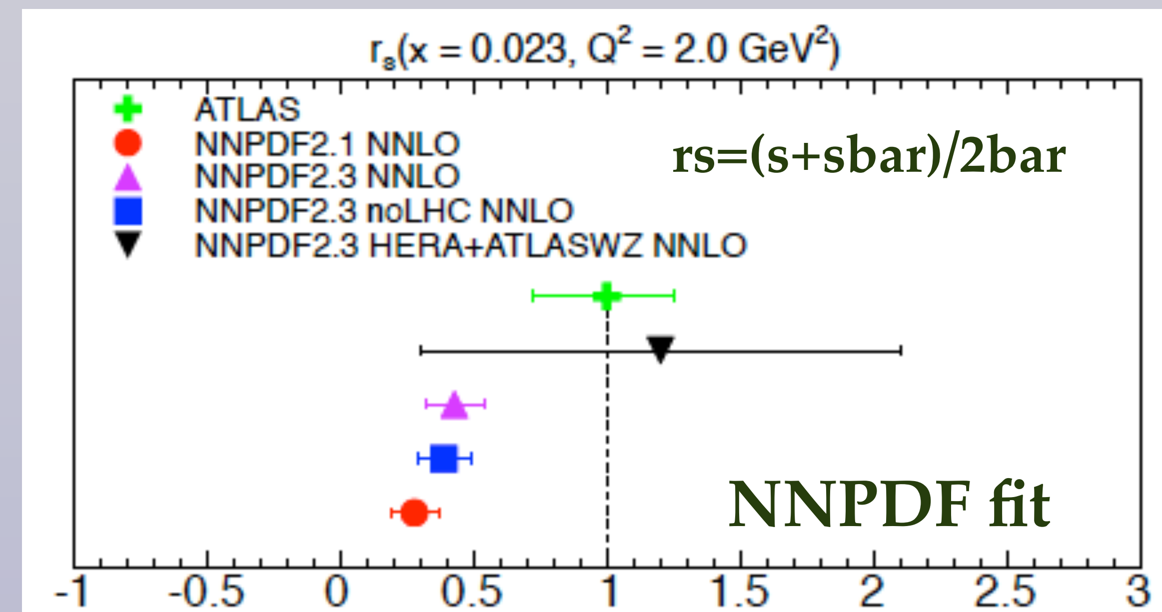


D'Enterria and J. R, arXiv:1202.1762

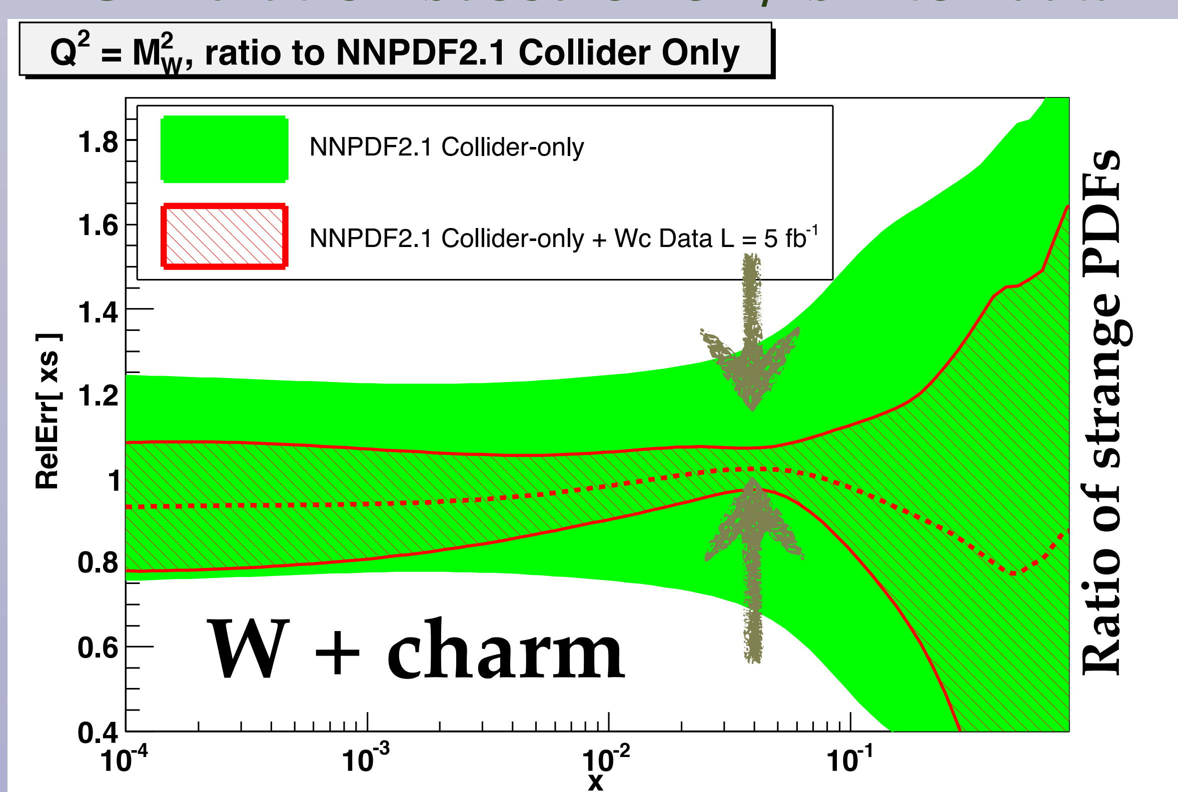
Pinning down strangeness

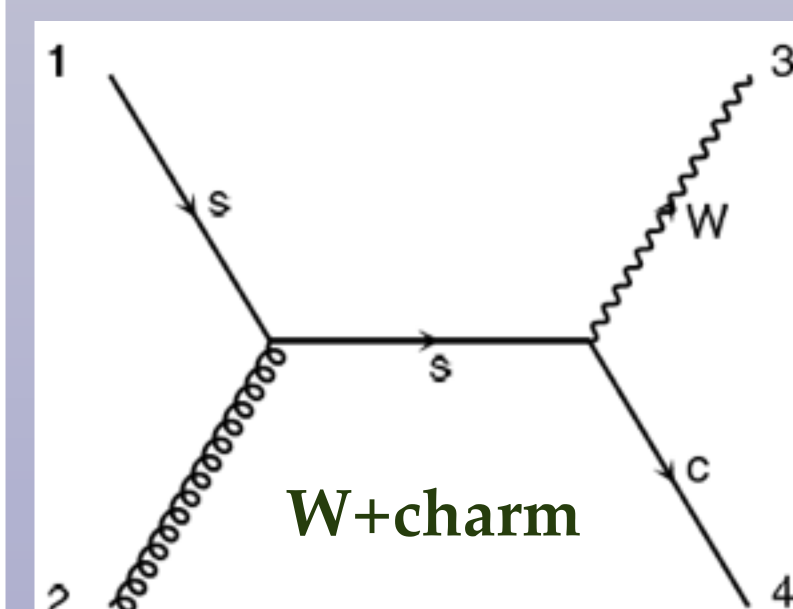
- **Strangeness** is the worst known of all light quark PDFs
- In global PDF fits determined by **neutrino charm production** data (NuTeV+CHORUS)
- A **HERAfitter analysis** of **ATLAS inclusive W and Z** data points to a **larger strangeness** than usually assumed (difficult to reconcile with neutrino DIS data)
- A **NNPDF2.3 analysis** based on the same data as above confirms the larger central value of strangeness, but with **much larger uncertainties (factor 3)**: no tension between LHC and neutrino data
- **W+c data from ATLAS and CMS** (total xsecs and differential distributions) will be instrumental to conclusively determine **strangeness from collider-only data**





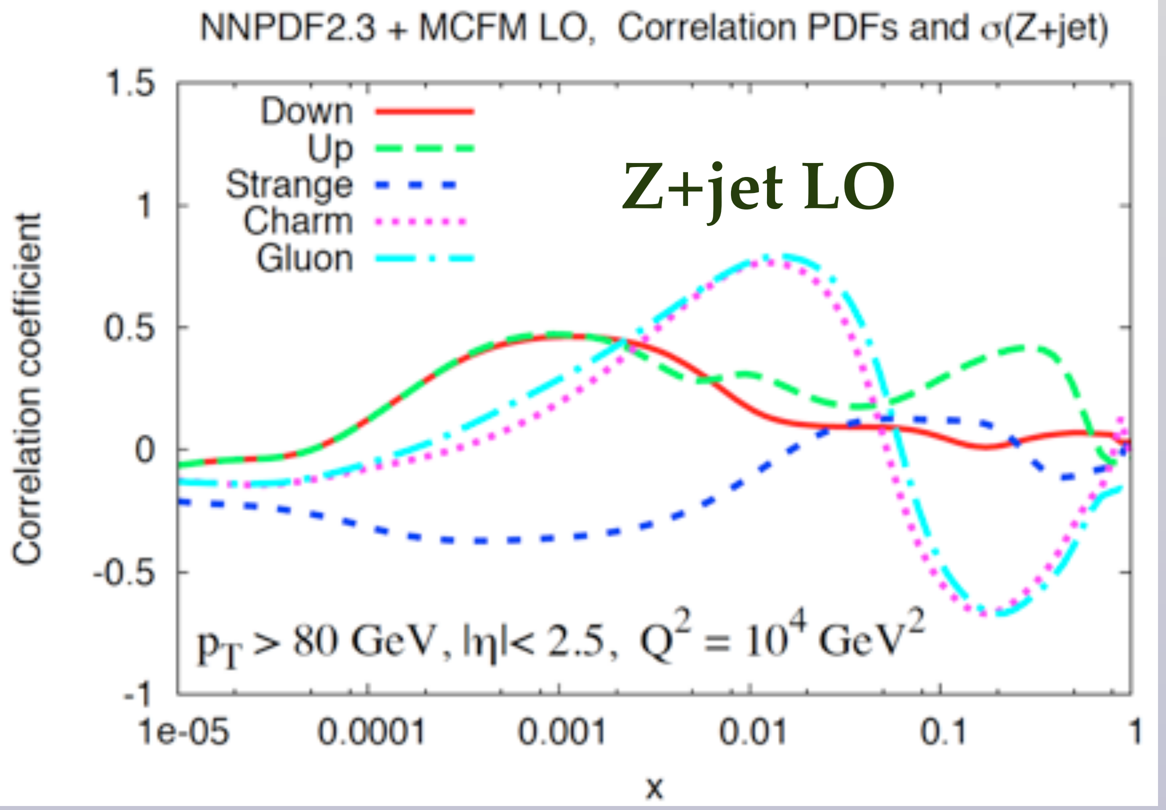
Simulation based on 5 1/fb 7 tev data

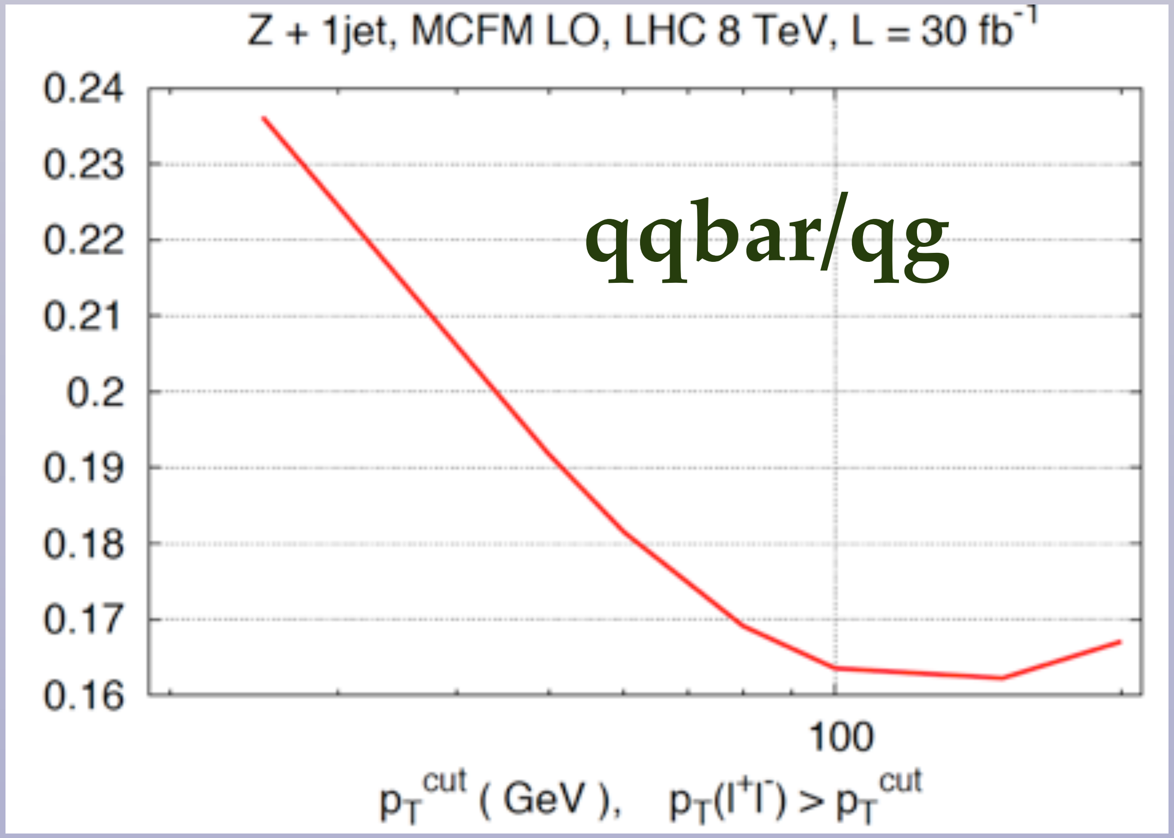




New avenues to the gluon (I)

- In global PDF fits, the **gluon** is directly constrained by **jet data** only (and HERA at small-x)
- Jets are NLO with **large scale uncertainties** (though NNLO close, **arxiv:1301.7310**), and experimental errors substantial because of the **JES**
- Given the crucial role of the gluon for LHC physics, **complementary LHC observables directly sensitive the gluon** would be beneficial
- One possibility is **Z/W boson production at large pT** (in association with jets). Cross section > 80% **dominated by gluon-quark scattering** (ISR of extra jets gluon dominated)
- The measurement can be only with leptons (double differential in pT and rapidity), thus with **very small systematic errors**
- Statistical errors will be negligible
- This measurement will be equivalent to **measuring the partonic luminosity relevant for gg > H**





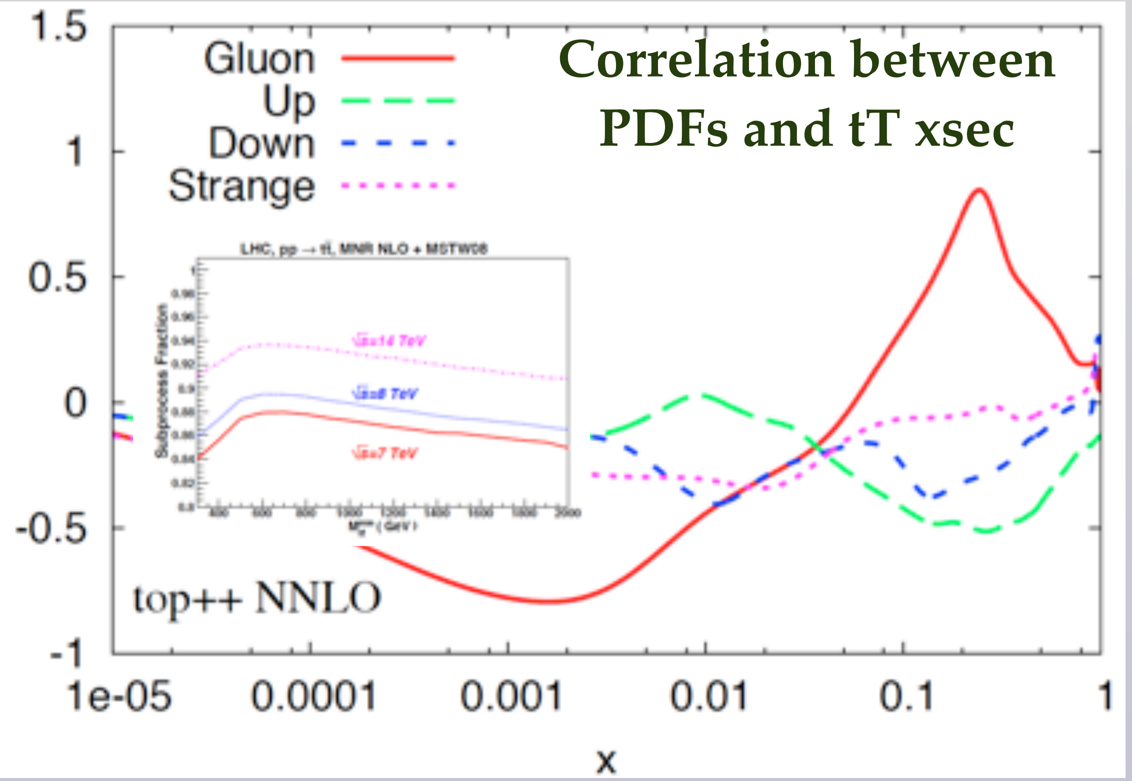
New avenues to the gluon (II)

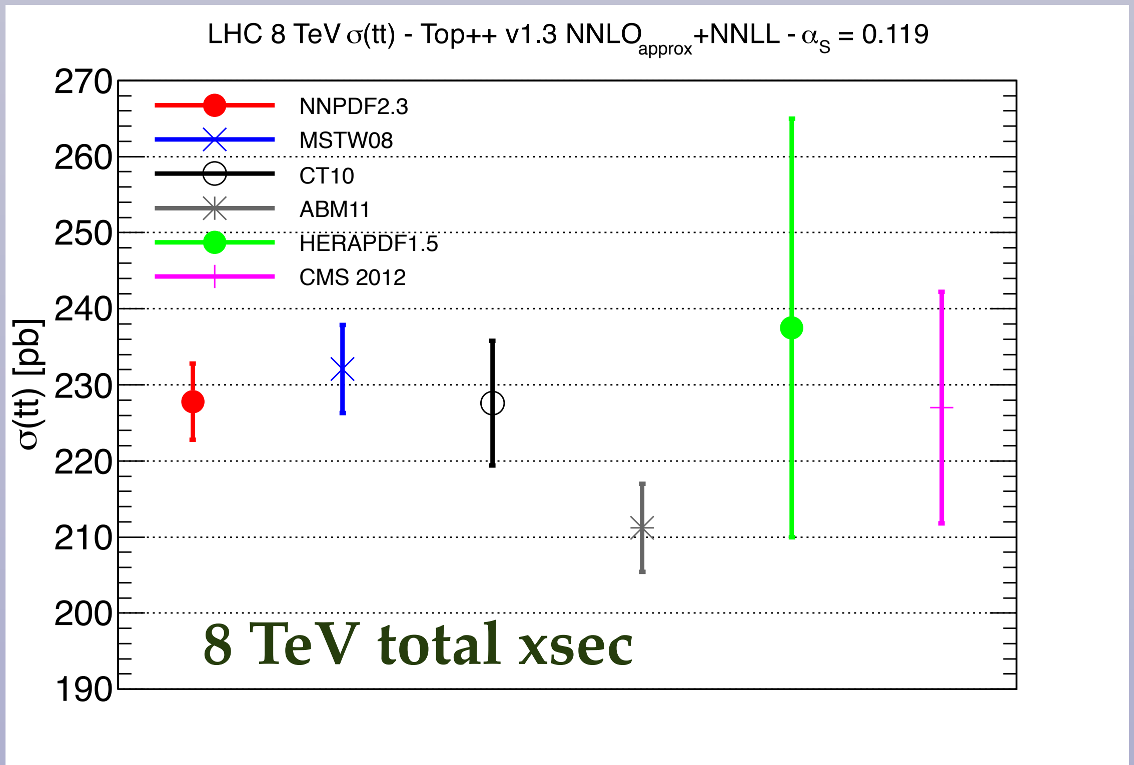
- Another interesting possibility would be to use top quark data to constrain the gluon PDF: at the **LHC tT is gg dominated**

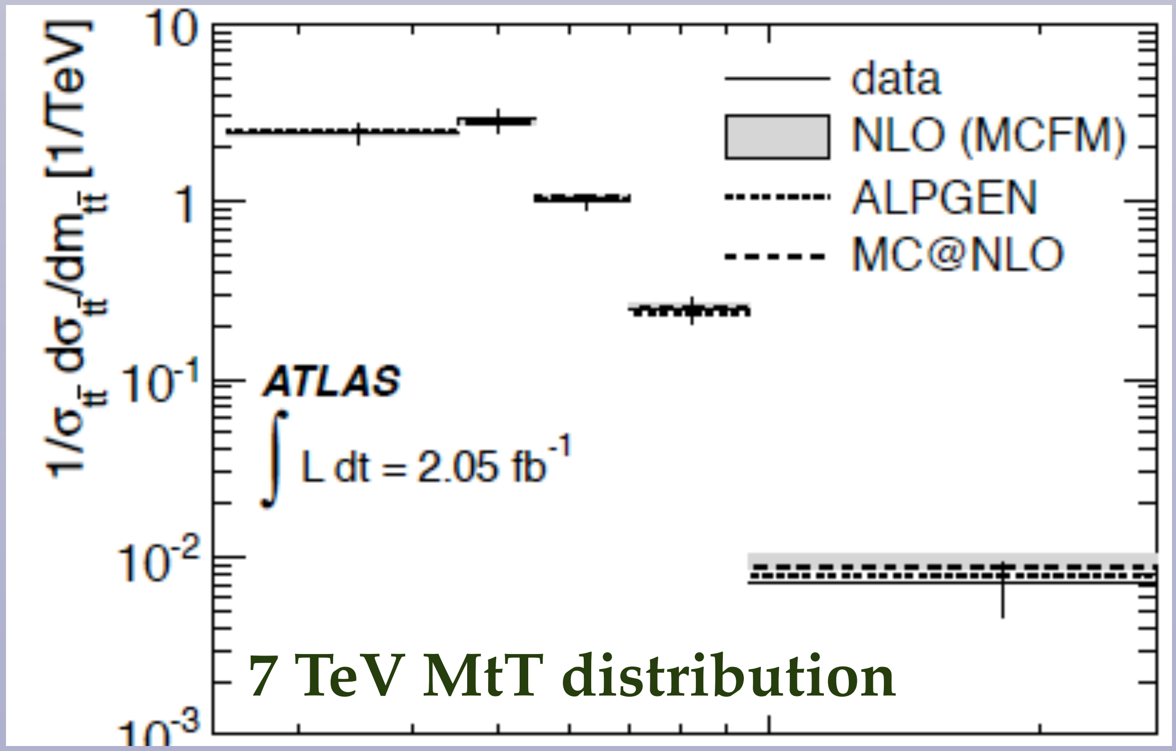
- **Full NNLO available for total cross sections**, in the near future also for distributions

- Total cross sections already help to **discriminate between different PDF sets**. Also a **direct handle on the strong coupling** (CMS determination: CMS-PAS-TOP-12-022)

- Ultimate constraining power from **ATLAS and CMS differential distributions**







Low and high mass Drell-Yan

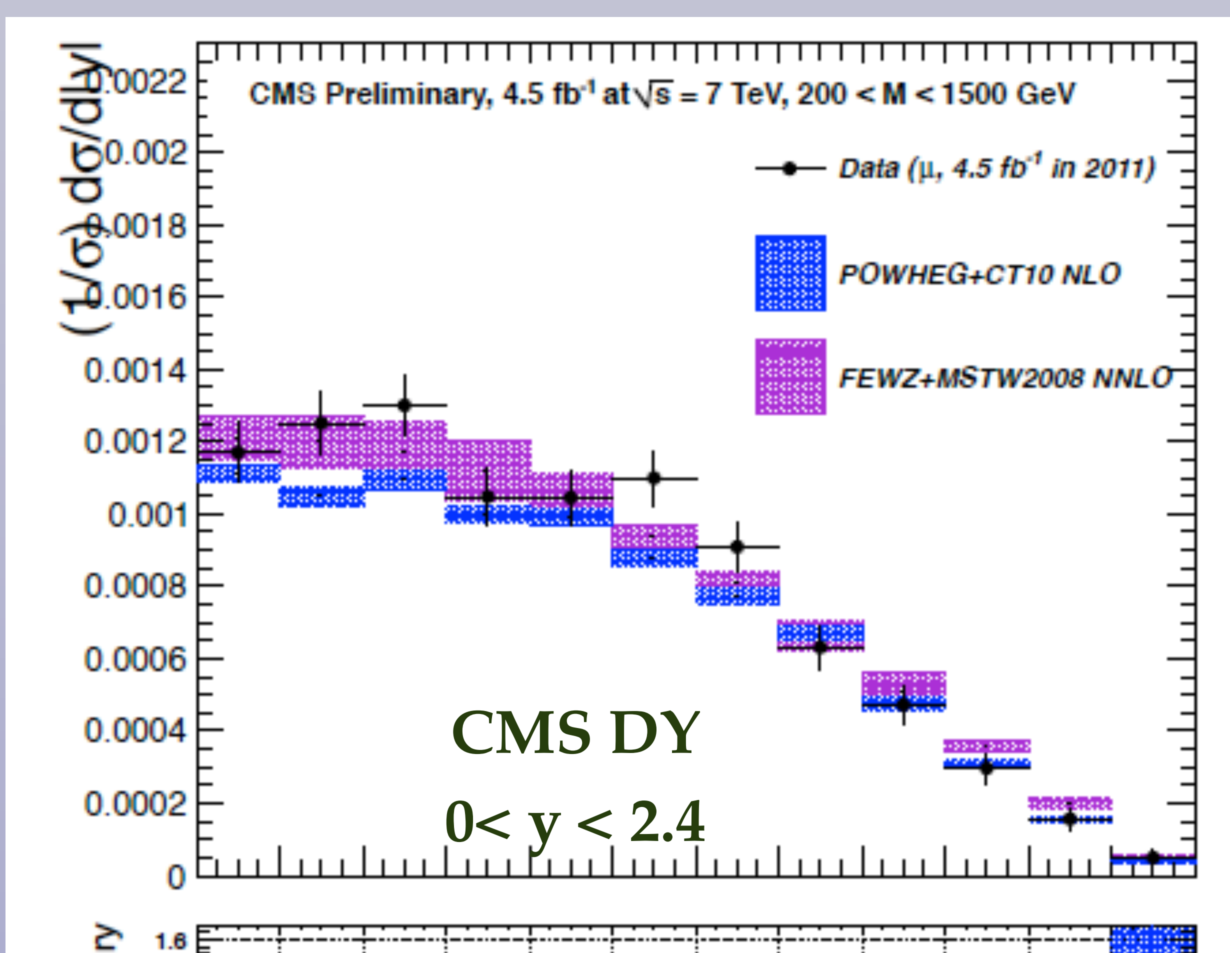
- In global PDF fits, **fixed target Drell-Yan data** are **instrumental for quark flavor separation**, but several issues: **low energies** (thus larger scale errors), **nuclear corrections**, **no covariance matrix**: we would like to replace them with collider data

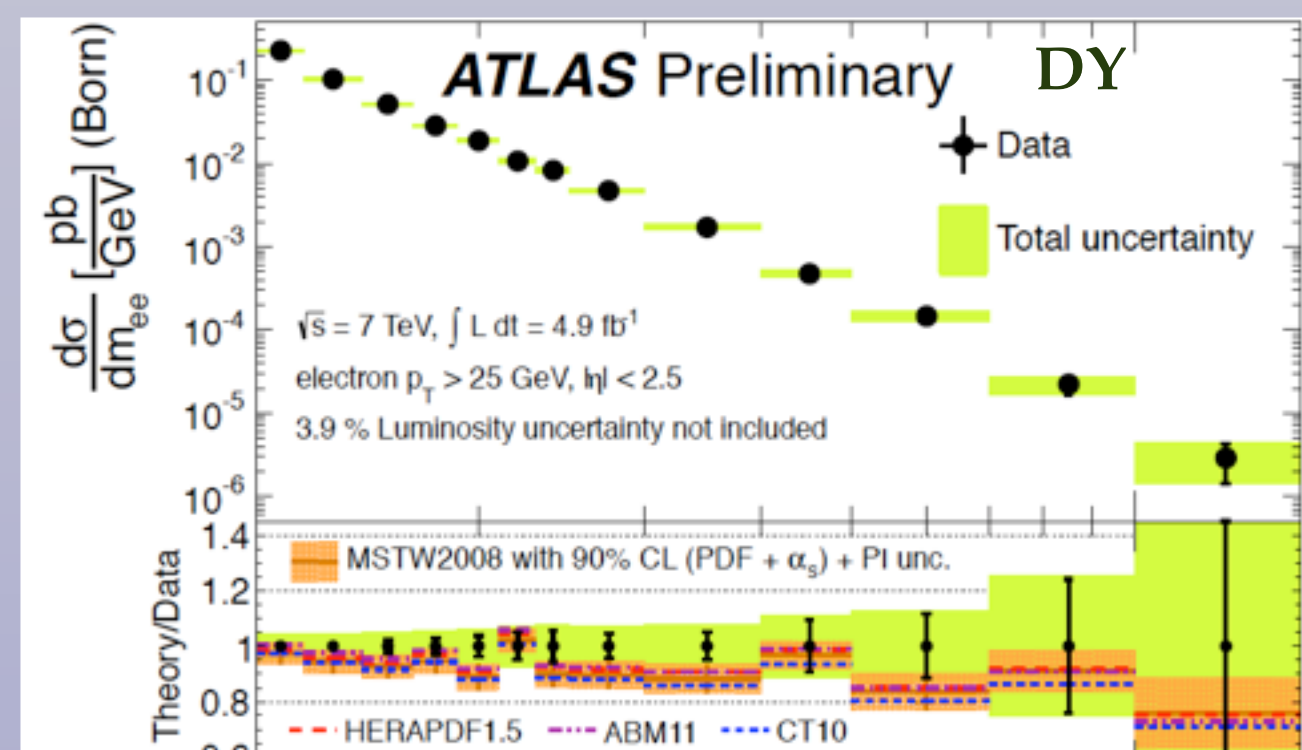
$$x_1^0 = \sqrt{\tau} e^y = \frac{M}{\sqrt{s}} e^y \,, \qquad x_2^0 = \sqrt{\tau} e^{-y} = \frac{M}{\sqrt{s}} e^{-y}$$

- At the LHC, **low mass DY** constraints small-x quarks, with **large mass DY** determines large-x quarks and antiquarks: **essential for high mass BSM searches.**

- **Binning in rapidity** improves the constraining power

- At large masses, it is crucial to properly account **for electroweak corrections**





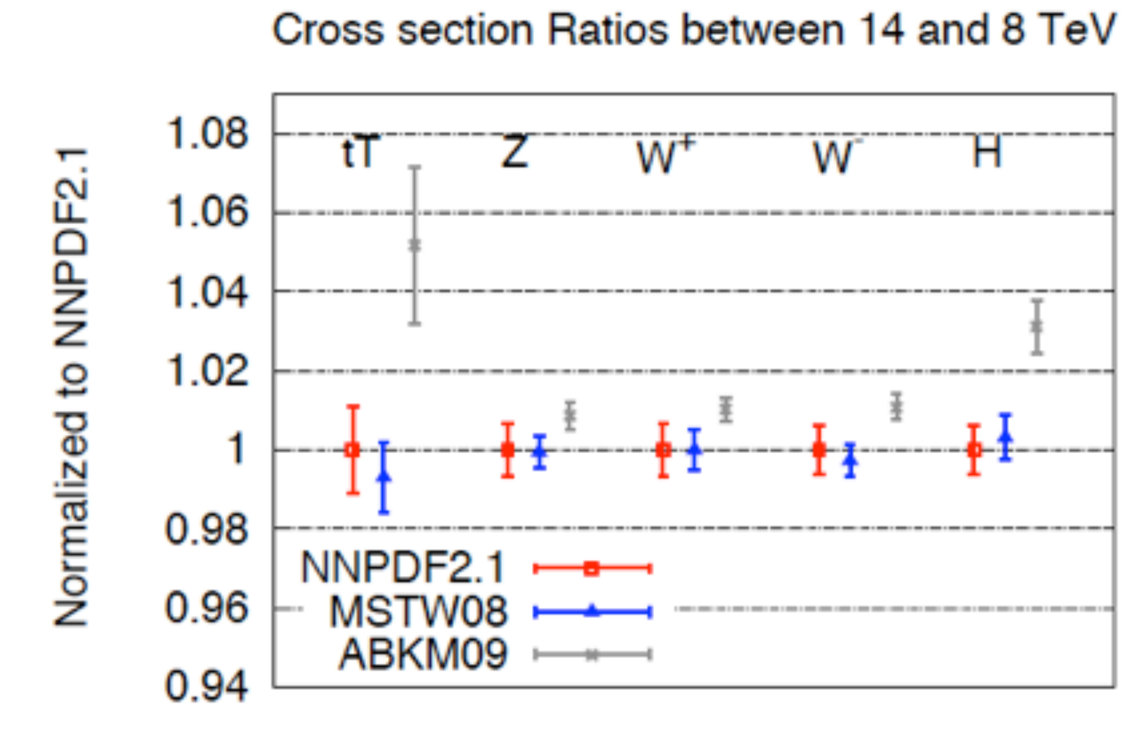
116 GeV < M < 1500 GeV

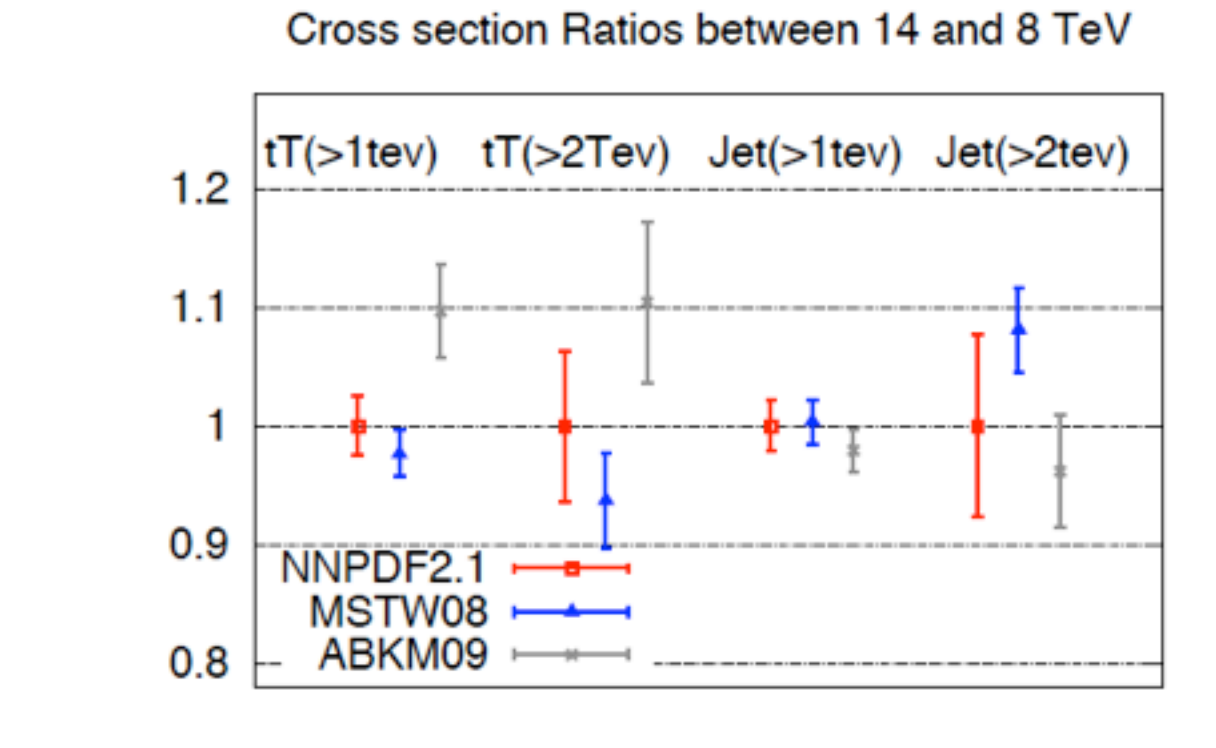
Cross section Ratios between 7, 8 and 14 TeV

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

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

- These ratios can be computed with **very high precision** due to the large degree of **correlation of theoretical uncertainties** at different energies
- **Experimentally** these ratios can also be measured accurately since many systematics, like luminosity or jet energy scale, **cancel partially in the ratios**
- These ratios allow **stringent precision tests of the SM**, in particular **PDF discrimination**



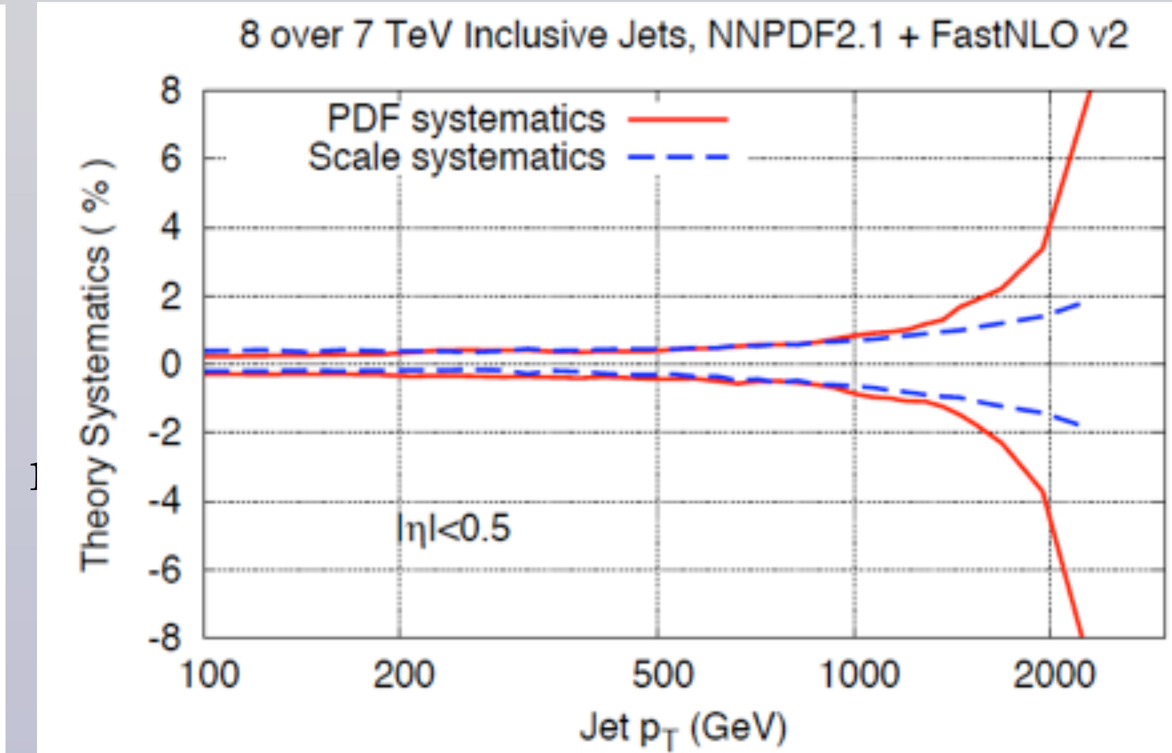


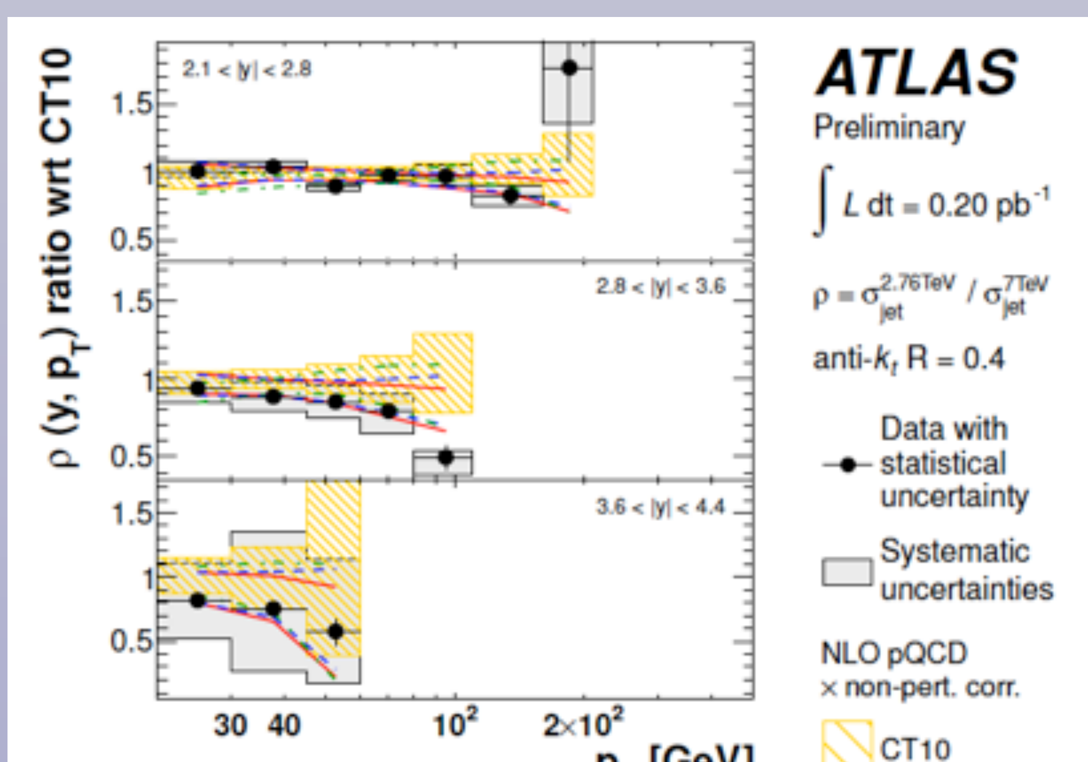
M. Mangano, J. Rojo, arXiv:1206.3557

Cross section Ratios between 7, 8 and 14 TeV

- Cross section ratios **cancel most of theory systematics**, **PDFs dominant** remainder, specially at large masses

Cross Section	$R^{\rm th,nnpdf}$	$\delta_{\rm PDF}(\%)$	δ_{α_s} (%)	$\delta_{\rm scales}$ (%)
$t\bar{t}/Z$	2.12	$\pm$ 1.3	-0.8 – 0.8	-0.4 – 1.1
$t\bar{t}$	3.90	$\pm$ 1.1	-0.5 – 0.7	-0.4 – 1.1
Z	1.84	$\pm$ 0.7	-0.1 – 0.3	-0.3 – 0.2
W^+	1.75	$\pm$ 0.7	-0.0 – 0.3	-0.3 – 0.2
W^-	1.86	$\pm$ 0.6	-0.1 – 0.3	-0.3 – 0.1
W^+/W^-	0.94	$\pm$ 0.3	-0.0 – 0.0	-0.0 – 0.0
W/Z	0.98	$\pm$ 0.1	-0.1 – 0.0	-0.0 – 0.0
ggH	2.56	$\pm$ 0.6	-0.1 – 0.1	-0.9 – 1.0
$t\bar{t}(M_{tt} \geq 1$ TeV)	8.18	$\pm$ 2.5	-1.3 – 1.1	-1.6 – 2.1
$t\bar{t}(M_{tt} \geq 2$ TeV)	24.9	$\pm$ 6.3	-0.0 – 0.3	-3.0 – 1.1
$\sigma_{\rm jet}(p_T \geq 1$ TeV)	15.1	$\pm$ 2.1	-0.4 – 0.0	-1.9 – 2.4
$\sigma_{\rm jet}(p_T \geq 2$ TeV)	182	$\pm$ 7.7	-0.3 – 0.2	-5.7 – 4.0





- Therefore, cross section ratios should be pursued as a **novel approach to constrain PDF**
- First measurement of cross section ratios by **ATLAS: jet cross sections between 7 and 2.76 TeV**
- Reduced experimental and scale uncertainties, potentially can **improve the sensitivity to PDFs of 7 TeV ATLAS jet data alone**
- Improved discrimination power from **14 to 8 TeV ratios**

Summary

- **Parton Distributions** are an essential ingredient for LHC phenomenology
- Accurate PDFs are required for **precision SM measurements, Higgs characterization** and many **New Physics searches**
- The determination of **fundamental SM parameters** like the **W mass** or α_S **from LHC data** also greatly benefit from improved PDFs
- LHC data is already providing **direct constraints on the proton PDFs**: 7 TeV measurements of jets, electroweak bosons and photons
- Many more **ongoing/future measurements** at 7 and 8 TeV will provide stringent constraints on PDFs in the next years: W, Z, dijets, top distributions, photons, W +charm, W,Z+jets, high mass off resonance W, ...
- Combining data at **different LHC center of mass energies** also provides useful handles on PDF, in particular the poorly-constrained large-x PDFs.