PDFs in the light of the LHC data

Alberto Guffanti

Niels Bohr International Academy & Discovery center
Niels Bohr Institute - Copenhagen

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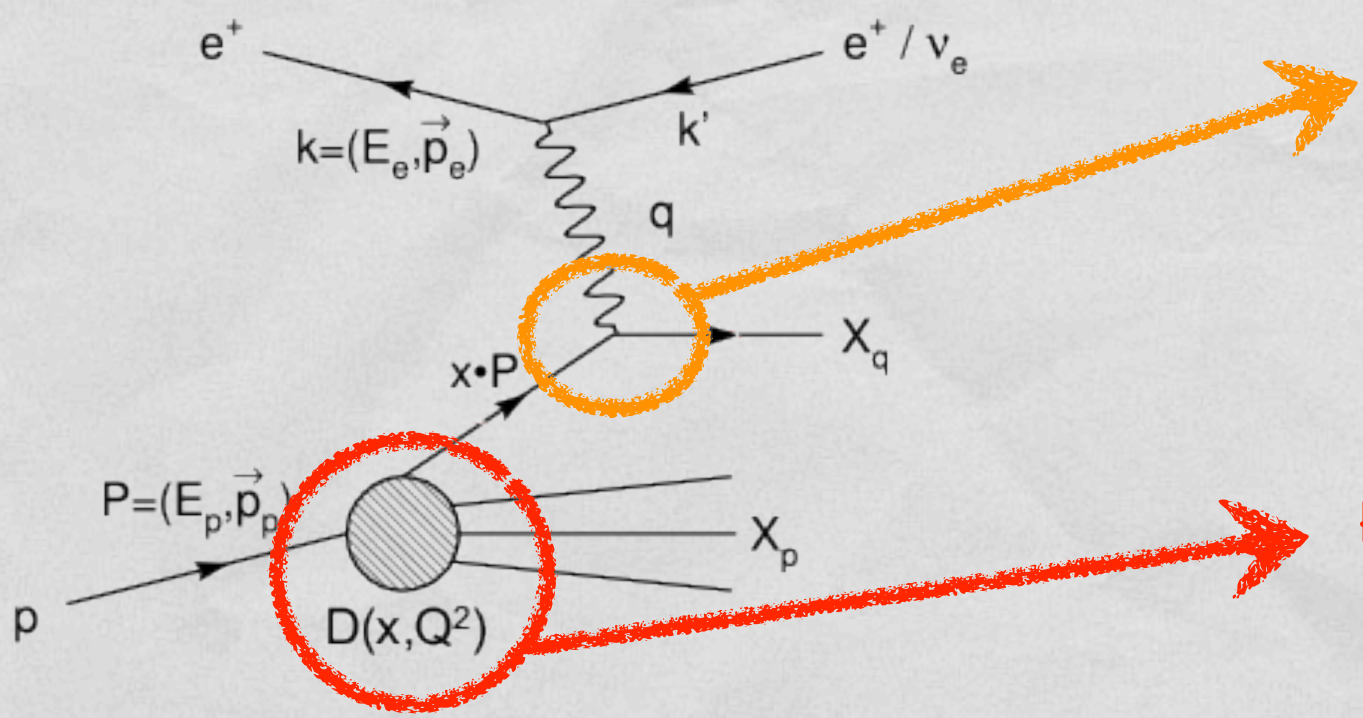
Parton Distribution Functions

What are they? - Definition

Consider a process with a single hadron in the initial state



Partonic Cross Section

Parton Distribution Function

The cross section for such a process can be written (**Factorization Theorem**) as

$$d\sigma = \sum_a \int_0^1 \frac{d\xi}{\xi} D_a(x,\mu^2)\, d\hat{\sigma}_a\left(\frac{x}{\xi}, \frac{\hat{s}}{\mu^2}, \alpha_s(\mu^2)\right) + O\left(\frac{1}{Q^p}\right)$$

Parton Distribution Functions

What are they? - DGLAP evolution

- Parton Distribution Functions are non-perturbative objects and their value at given x and Q^2 cannot be computed in QCD Perturbation Theory (Lattice?)
- ... but the **scale dependence** of PDFs is governed by the **DGLAP** evolution equations

$$\frac{\partial q_i(x,\mu^2)}{\partial \ln \mu^2} = \frac{\alpha_s(\mu^2)}{2\pi}\left[P_{qq}(x)\otimes q_i(x,\mu^2)\right] + \frac{\alpha_s(\mu^2)}{2\pi}\left[P_{qg}\otimes g(x,\mu^2)\right]$$

$$\frac{\partial g(x,\mu^2)}{\partial \ln \mu^2} = \frac{\alpha_s(\mu^2)}{2\pi}\left[P_{gq}(x)\otimes \sum_i \left(q_i(x,\mu^2)+\bar{q}_i(x,\mu^2)\right)\right] + \frac{\alpha_s(\mu^2)}{2\pi}\left[P_{gg}\otimes g(x,\mu^2)\right]$$

- ... where the **splitting functions** (P_{ij}) can be computed in Perturbation Theory and are known up to **NNLO**

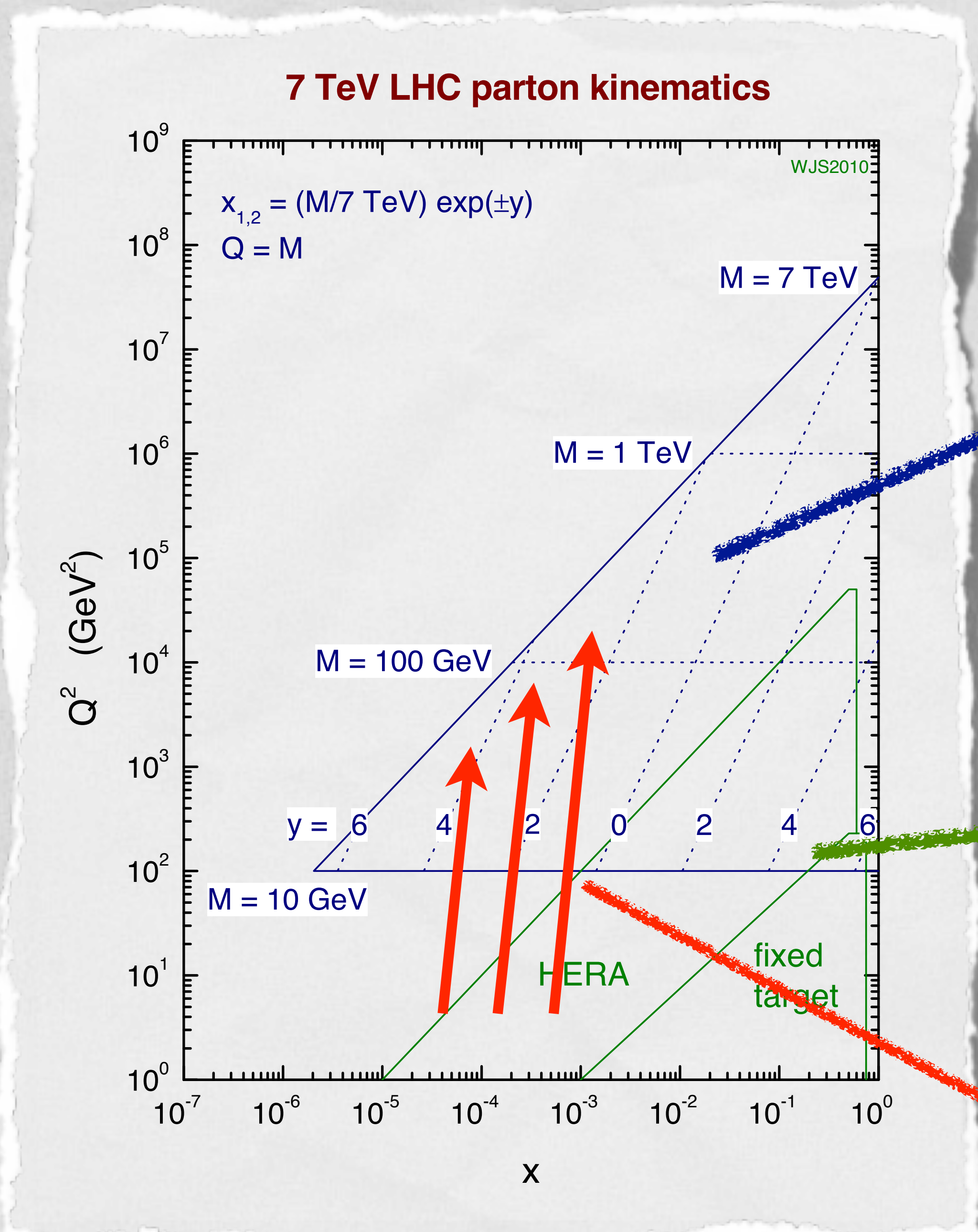
[**LO** - Dokshitzer; Gribov, Lipatov; Altarelli, Parisi (1977)]

[**NLO** - Floratos, Ross, Sachrajda; Gonzalez-Arroyo, Lopez, Yndurain; Curci, Furmanski, Petronzio (1981)]

[**NNLO** - Moch, Vermaseren, Vogt (2004)]

Parton Distribution Functions

Why do we care?



This is the region where we want to use PDFs for predictions at the LHC

This is the region where we measure PDFs, from DIS and Tevatron experiments

DGLAP evolution

The PDF fitting game

The players

Collaboration	Authors	arXiv
ABM	S. Alekhin, J. Blümlein, S. Moch	1105.5349, 1101.5261, 1107.3657, 0908.3128, 0908.2766, ...
CTEQ/TEA	M. Guzzi J. Huston, H.-L. Lai, P. Nadolsky, J. Pumplin, D. Stump, C.-P. Yuan	1108.5112, 1101.0561, 1007.2241, 1004.4624, 0910.4183, 0904.2424, 0802.0007, ...
GJR	M. Glück, P. Jimenez-Delgado, E. Reya	1003.3168, 0909.1711, 0810.4274, ...
HERAPDF	H1 and ZEUS Collaborations	1107.4193, 1006.4471, 0906.1108, ...
MSTW	A. Martin, J. Stirling, R. Thorne, G. Watt	1107.2624, 1006.2753, 0905.3531, 0901.0002, ...
NNPDF	R. D. Ball, V. Bertone, F. Cerutti, L. Del Debbio, S. Forte, AG, N. P. Hartland, J. I. Latorre, J. Rojo, M. Ubiali	1110.2483, 1108.2758, 1107.2652, 1103.2369, 1102.3182, 1101.1300, 1005.0397, 1002.4407, 0912.2276, 0906.1958, ...

The PDF fitting game

Present status of PDF fits

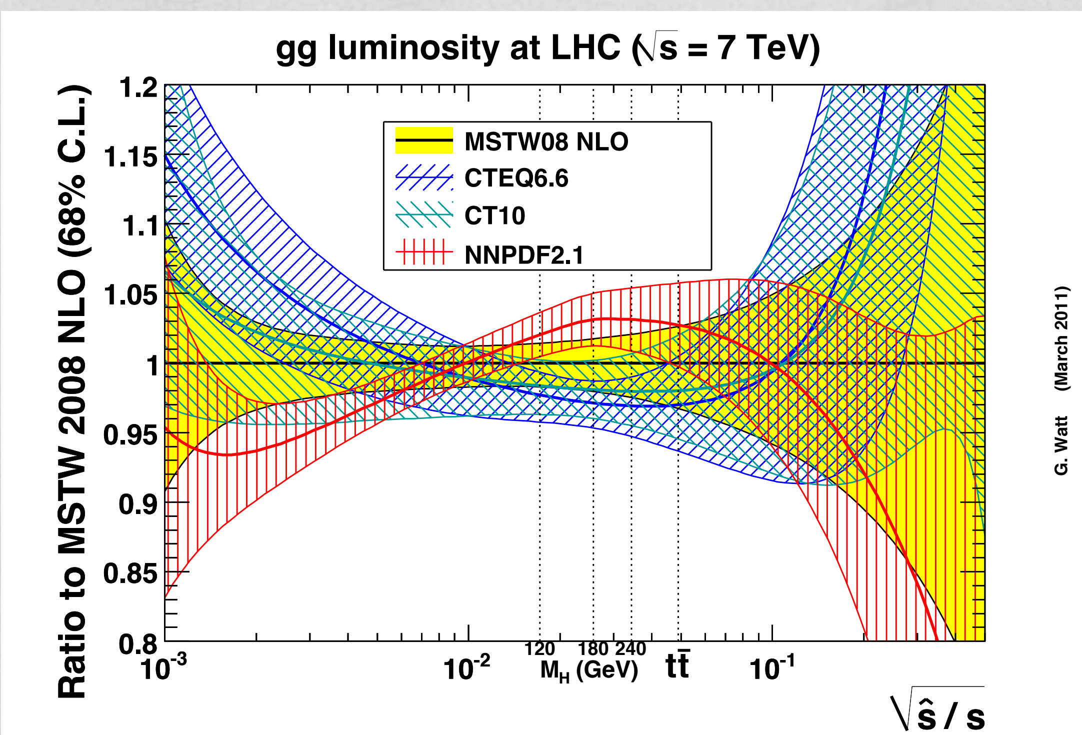
	DATASET	PERT. ORDER	HQ TREATMENT	α_s	PARAM.	UNCERT.
ABM11	DIS Drell-Yan	NLO NNLO	FFN (BMSN)	Fit (multiple values available)	6 indep. PDFs Polynomial (25 param.)	Hessian ($\Delta\chi^2$=1)
CT10	**Global**	LO NLO NNLO	GM-VFNS (S-ACOT)	External (multiple values available)	6 indep. PDFs Polynomial (26 param.)	Hessian ($\Delta\chi^2$=100)
JR09	DIS Drell-Yan Jets	NLO NNLO	FFN VFN	Fit	5 indep. PDFs Polynomial (15 param.)	Hessian ($\Delta\chi^2$=1)
HERAPDF1.5	DIS (HERA)	NLO NNLO	GM-VFNS (TR)	External (multiple values available)	5 indep. PDFs Polynomial (14 param.)	Hessian ($\Delta\chi^2$=1)
MSTW08	**Global**	LO NLO NNLO	GM-VFNS (TR)	Fit (multiple values available)	7 indep. PDFs Polynomial (20 param.)	Hessian ($\Delta\chi^2$~25)
NNPDF2.1/2.3	**Global**	LO NLO NNLO	GM-VFNS (FONLL)	External (multiple values available)	7 indep. PDFs Neural Nets (259 param.)	Monte Carlo

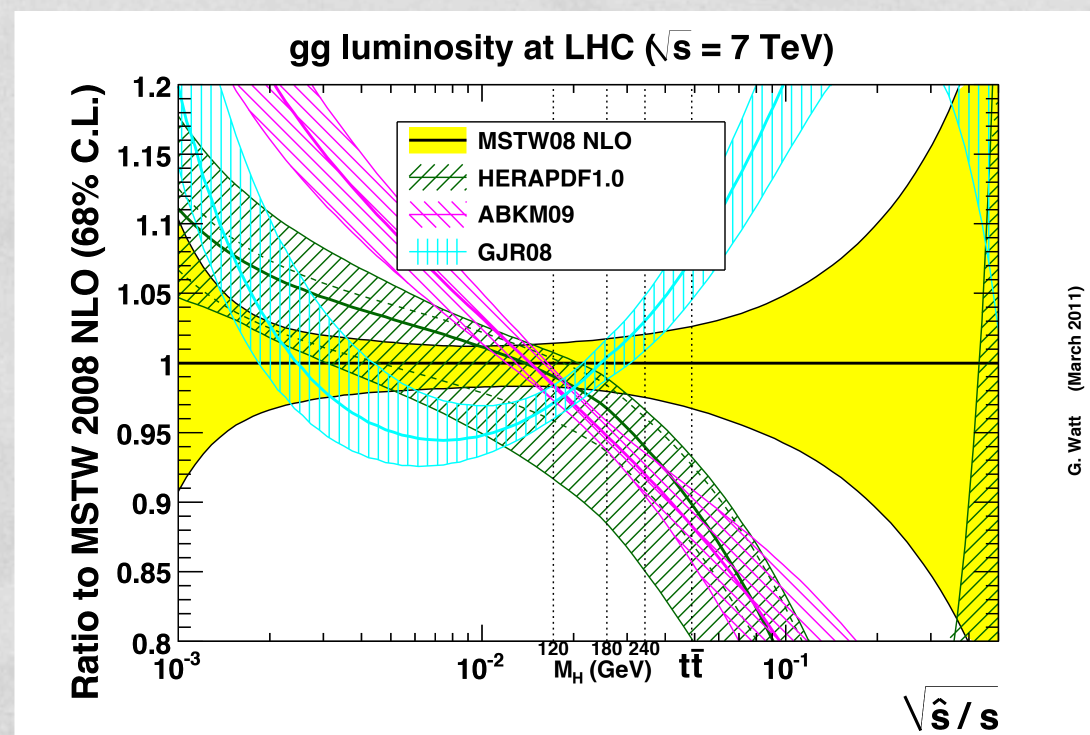
PDFs for the LHC

Comparing Parton Luminosities

Let us first compare **parton luminosities** at the LHC (7 TeV)

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





Plots by G.Watt (arXiv:1106.5788)

PDFs for the LHC

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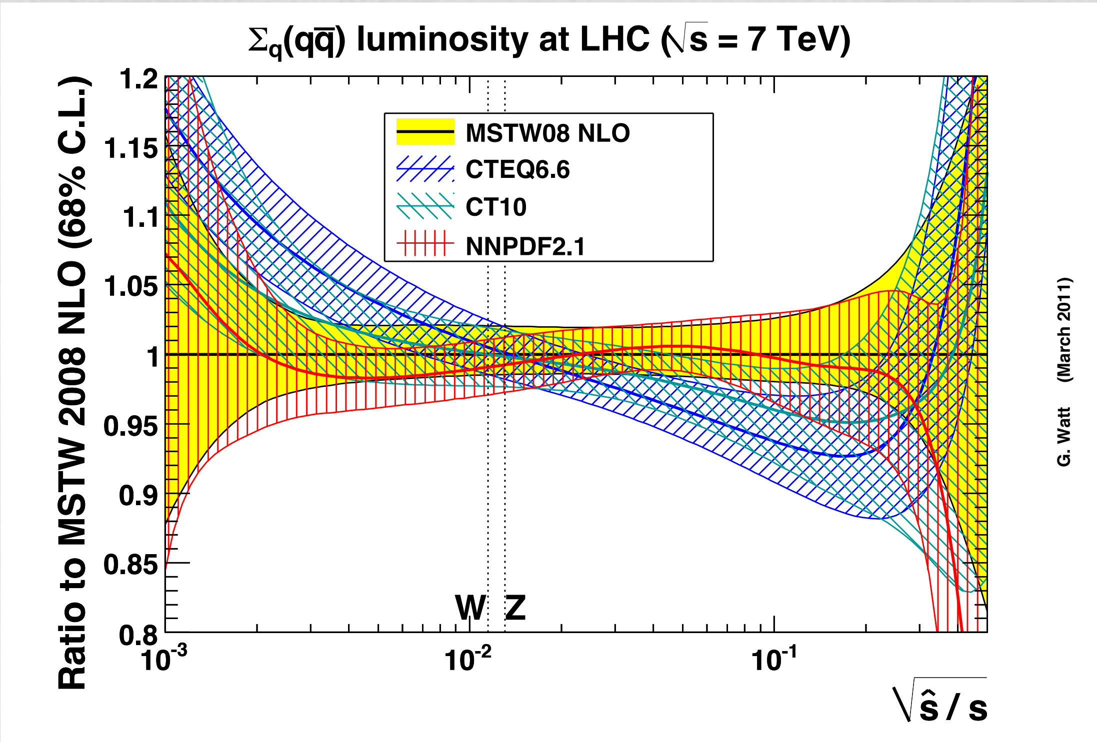

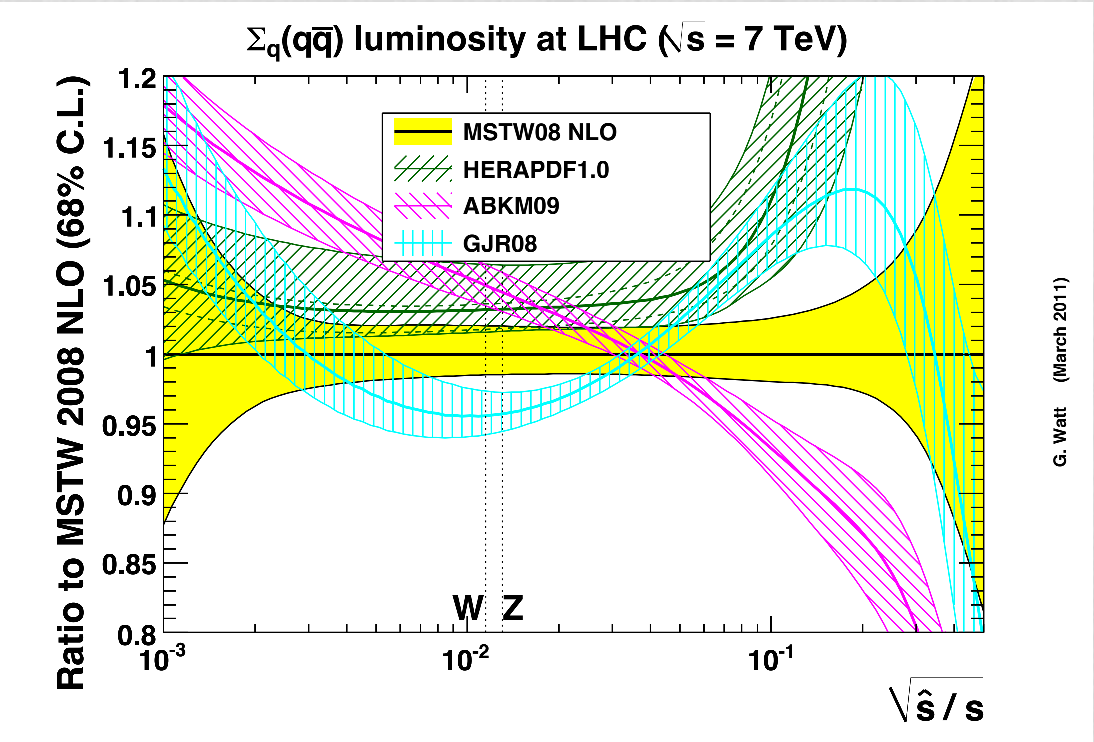

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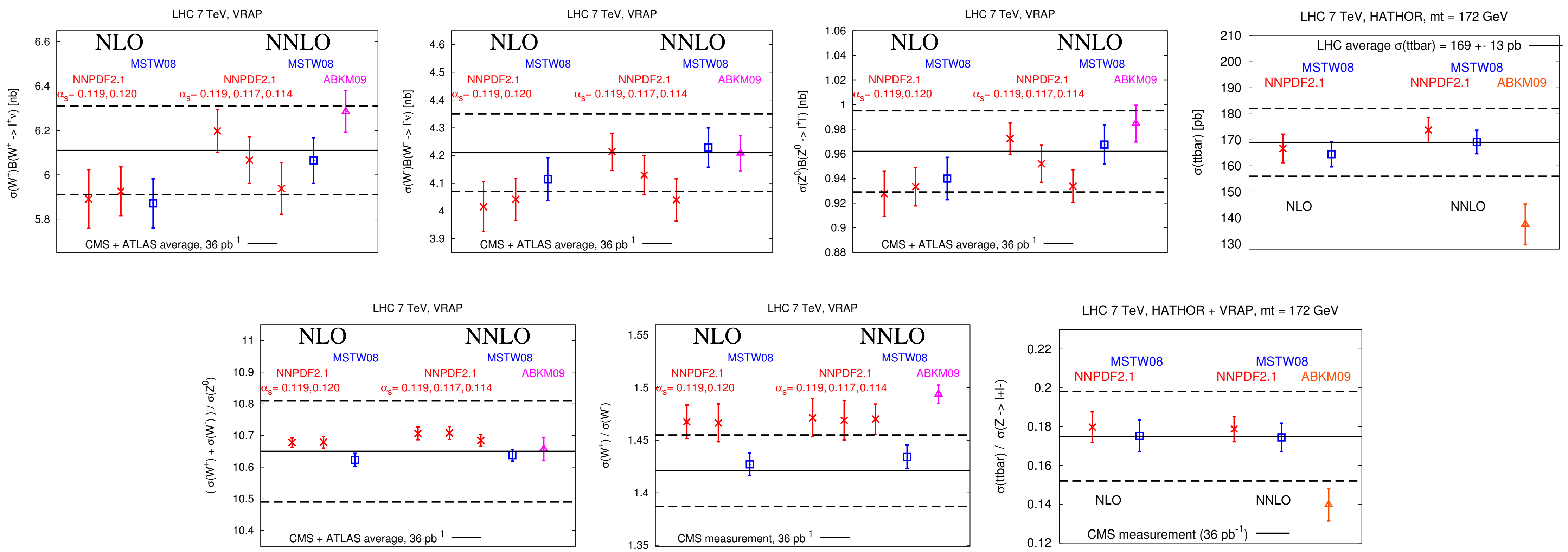
PDFs for the LHC

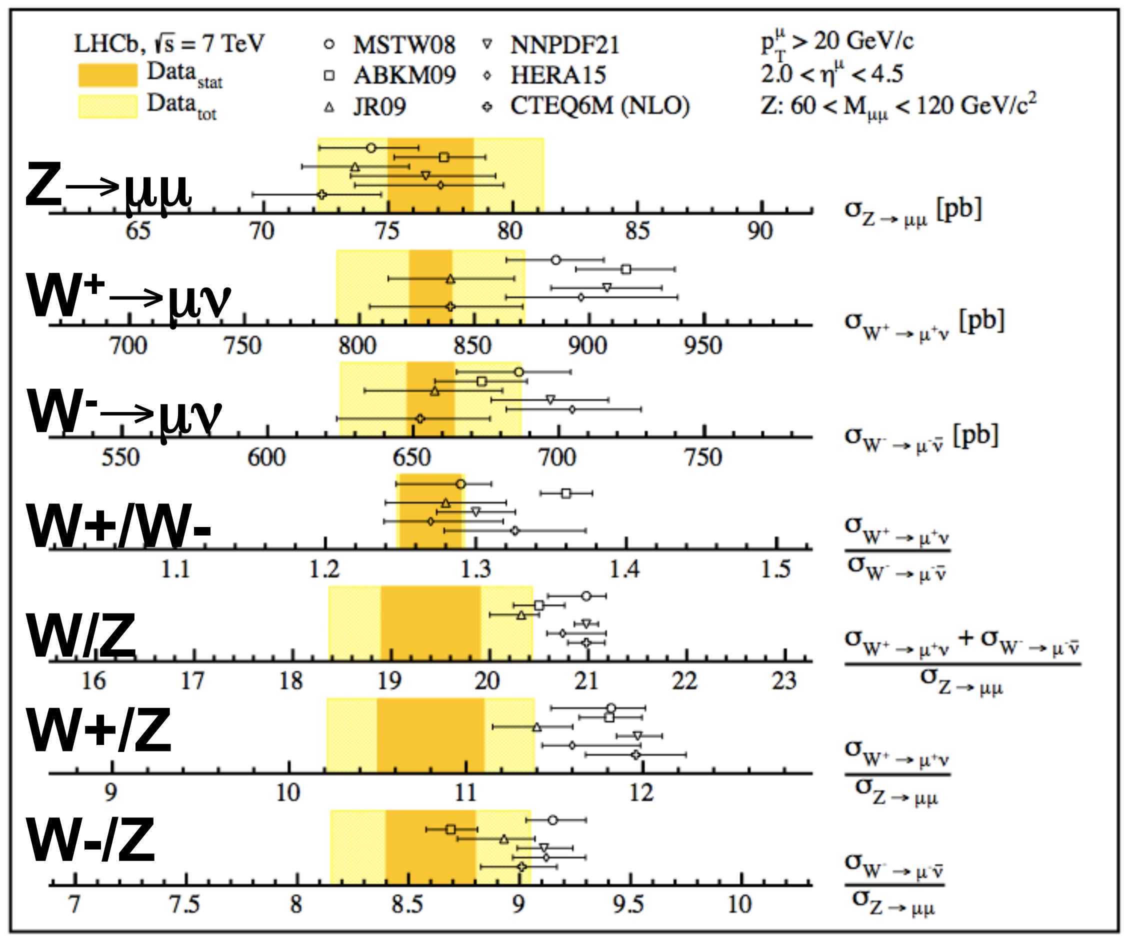
Comparing predictions for LHC Benchmark processes



LHC data will soon be accurate enough to **distinguish** between predictions from **different PDF sets**

PDFs for the LHC

Comparing predictions for LHC Benchmark processes

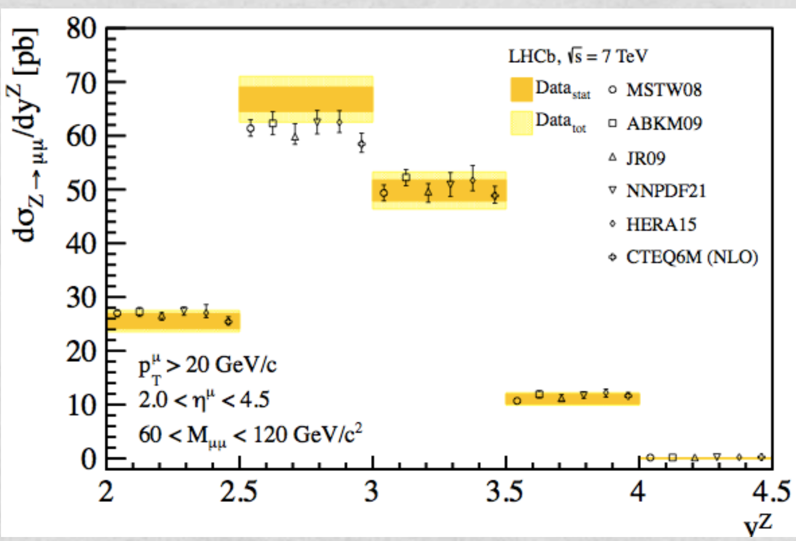


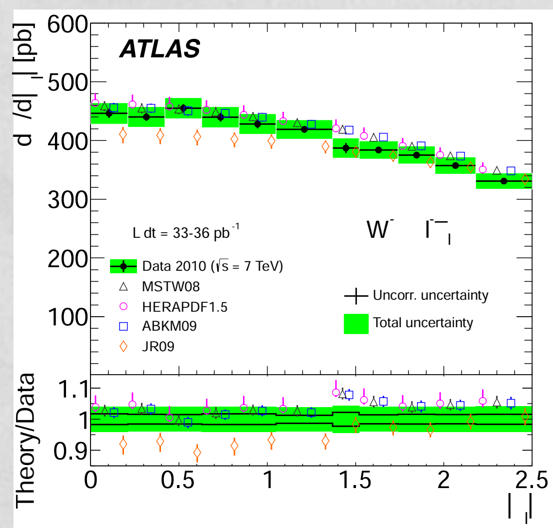
LHC data will soon be accurate enough to **distinguish** between predictions from **different PDF sets**

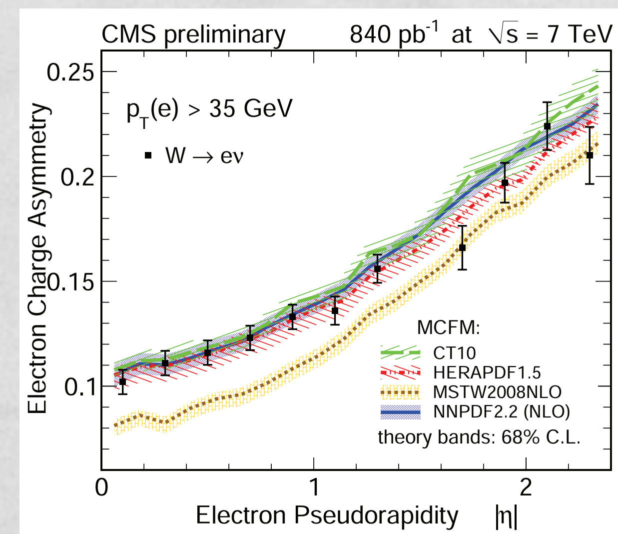
PDFs for the LHC

Comparing predictions for LHC Benchmark processes

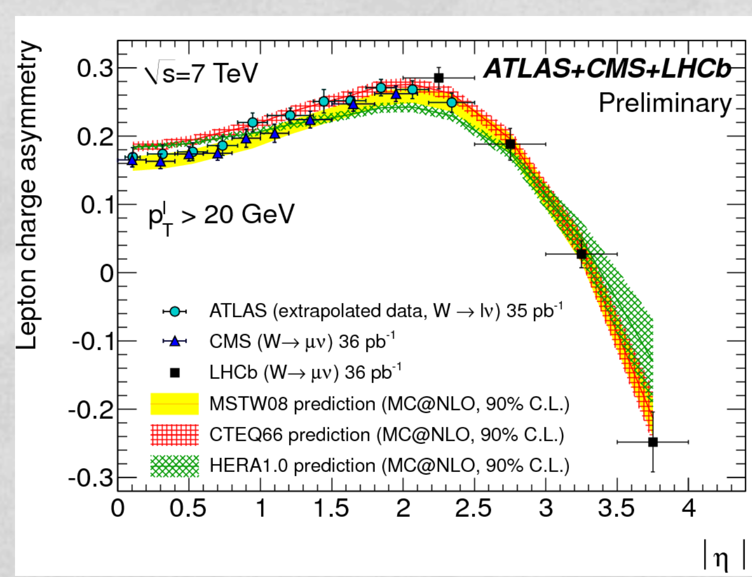
Going beyond inclusive quantities and looking at **differential distributions** adds even **more information**







LHC data are testing previously untested assumptions and fine details of PDF fits

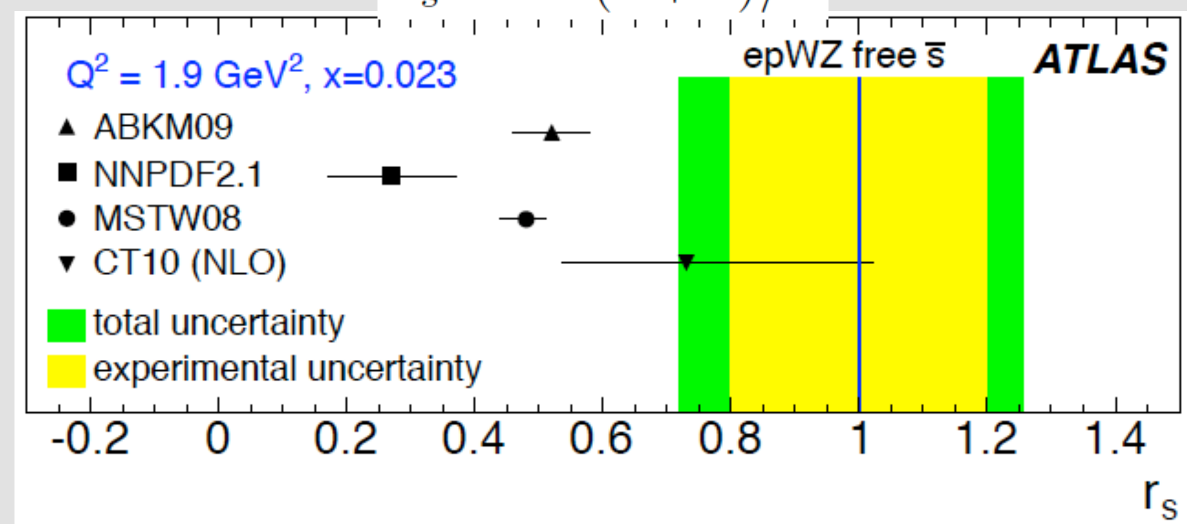


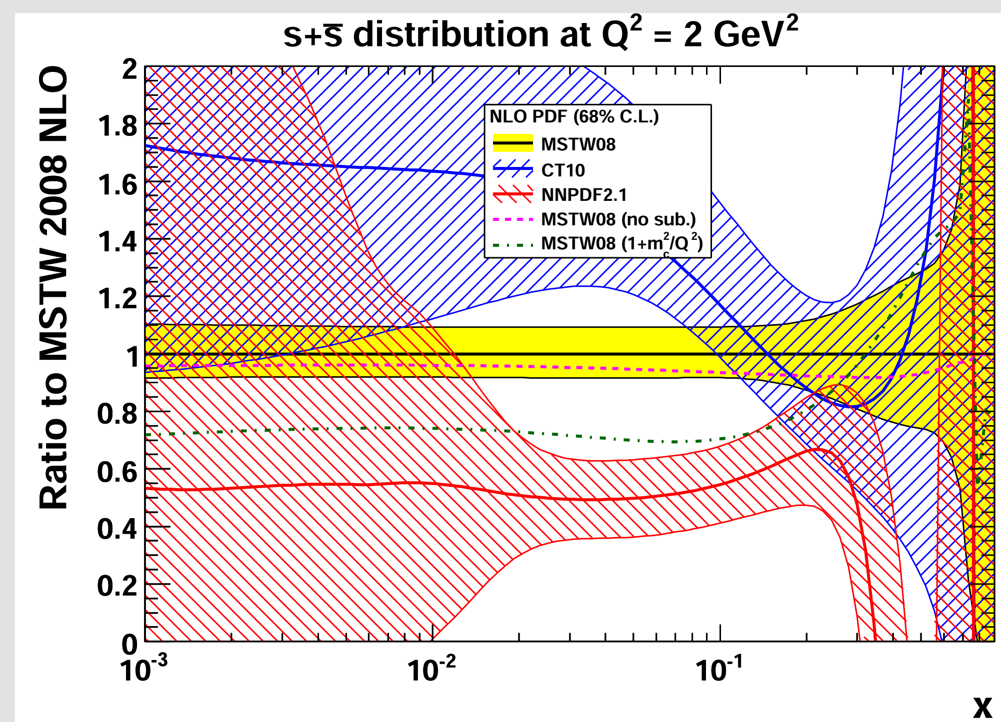
PDFs for the LHC

A "strange" story ...

- In a recent publication (arXiv:1203.4051) ATLAS performed a QCD analysis of **HERA-I** and **ATLAS W/Z** data
- **Strange sea PDF roughly equal** to the u and d quark sea PDFs, at odds with predictions from most PDF sets
- Strangeness is one place where different sets differ most
- Strange PDFs parametrized with only **two free parameters**
- We repeated the analysis within the **NNPDF framework** (using a substantially more flexible strange parametrization)

$$r_s = 0.5(s+\bar{s})/\bar{d}$$



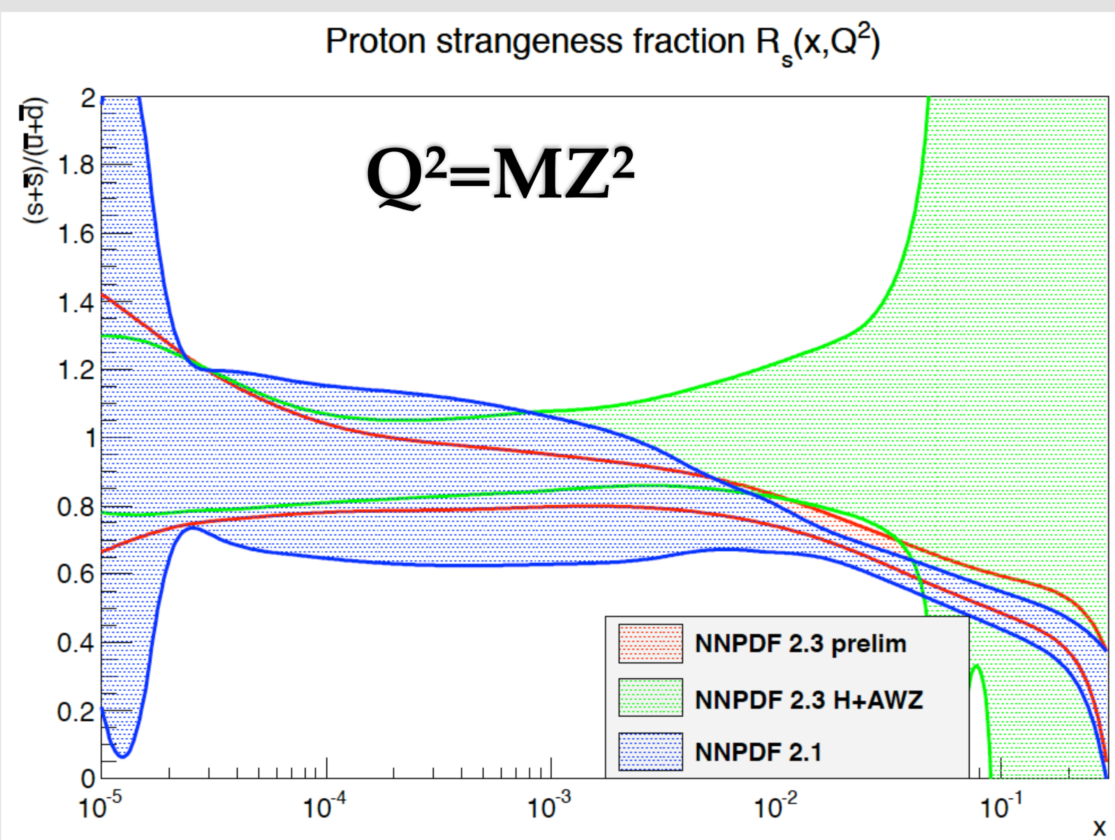


Plot by R. Thorne, PDF4LHC

PDFs for the LHC

A “strange” story ...

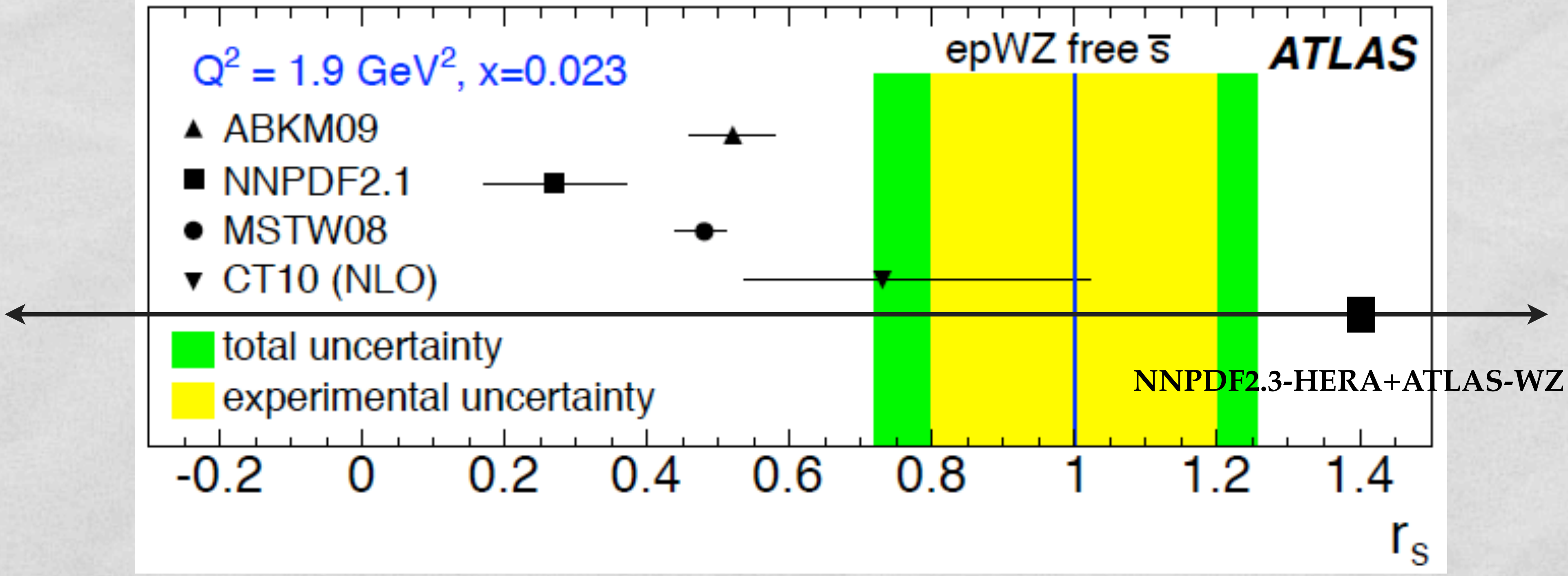
- Compare **NNPDF2.1**, **NNPDF2.3-noLHC**, and **NNPDF2.3** sets with various datasets: **global, HERA+ATLAS-WZ**, **collider-only**
- **HERA+ATLAS-WZ** (and **collider-only**) **fit:** central value consistent with ATLAS analysis, but substantially larger **PDF uncertainties**
- Possible signs of “tension” between fixed target (NuTeV/CCFR) and collider data



NNPDF2.3	Rs ($x=0.023, Q^2=2GeV^2$)
noLHC	0.32 ± 0.10
Global	0.35 ± 0.10
HERA+ ATLAS-WZ	1.4 ± 2.2
Collider-only	0.95 ± 0.60

PDFs for the LHC

A "strange" story ...



- **PDF uncertainties** in ATLAS determination of strangeness probably **seriously underestimated**
- ... but LHC data begin to provide constraints on strangeness and hint at a possible "tension" with fixed-target data
- Upcoming **W+charm** measurement will shed more light on the issue

LHC for PDFs

NNPDF2.3 - Inclusion of LHC data in global fits

NLO	NNPDF2.3 noLHC	NNPDF2.3
NMCpd	0.93	0.94
NMC	1.62	1.65
SLAC	1.27	1.26
BCDMS	1.24	1.25
HERA-I	1.03	1.02
CHORUS	1.15	1.14
NuTeV	0.42	0.42
DYE605	0.78	0.81
DYE866	1.20	1.21
CDFWASY	1.60	1.60
CDFZRAP	1.71	1.65
D0ZRAP	0.61	0.61
ATLAS-WZ	1.41	1.30
CMS-WEASY	1.60	1.05
LHCb-WZ	1.13	1.07
CDFR2KT	0.76	0.79
D0R2CON	0.78	0.79
ATLAS-JETS-2010	1.31	1.25

- Compare the quality of the fit to LHC data before and after inclusion in the global fit
- Including LHC data in the fit improves the quality of their description, w/o deteriorating quality of the fit to other datasets
- Moderate impact of the LHC data, supporting consistency of the global fit framework
- Fit quality is comparable at NLO and NNLO, thought the former marginally better

LHC for PDFs

NNPDF2.3 - Inclusion of LHC data in global fits

NNLO	NNPDF2.3 noLHC	NNPDF2.3
NMCpd	0.93	0.95
NMC	1.58	1.62
SLAC	1.02	1.01
BCDMS	1.31	1.32
HERA-I	1.07	1.04
CHORUS	1.12	1.12
NuTeV	0.49	0.57
DYE605	0.82	0.82
DYE866	1.33	1.33
CDFWASY	1.67	1.69
CDFZRAP	1.87	1.90
D0ZRAP	0.64	0.64
ATLAS-WZ	1.80	1.41
CMS-WEASY	1.19	0.95
LHCb-WZ	1.20	1.11
CDFR2KT	0.75	0.73
D0R2CON	0.83	0.81
ATLAS-JETS-2010	1.26	1.21

- Compare the quality of the fit to LHC data before and after inclusion in the global fit
- Including LHC data in the fit improves the quality of their description, w/o deteriorating quality of the fit to other datasets
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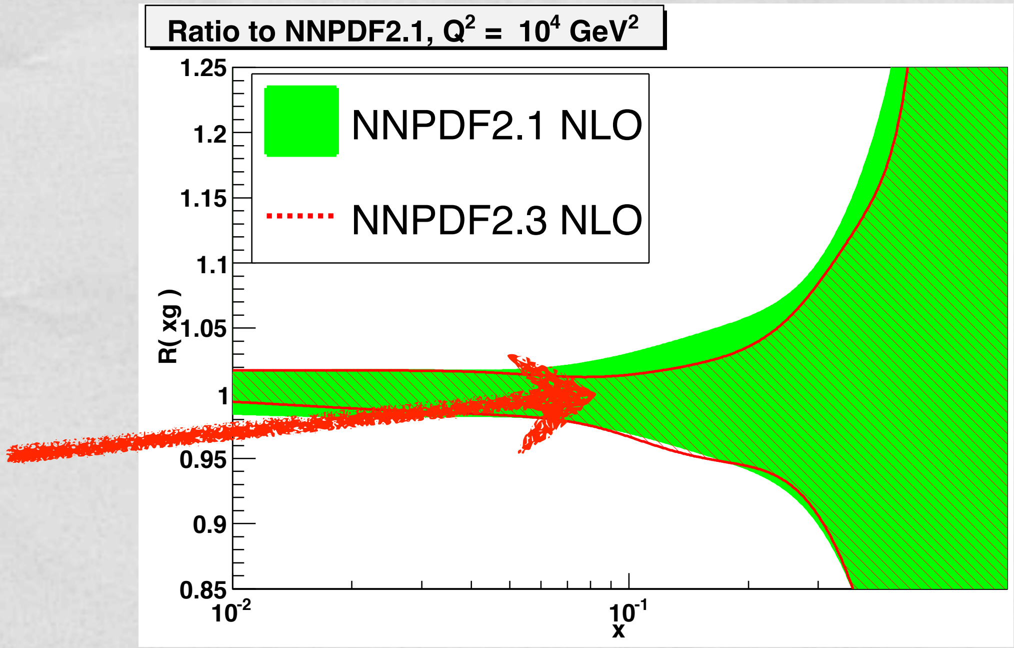
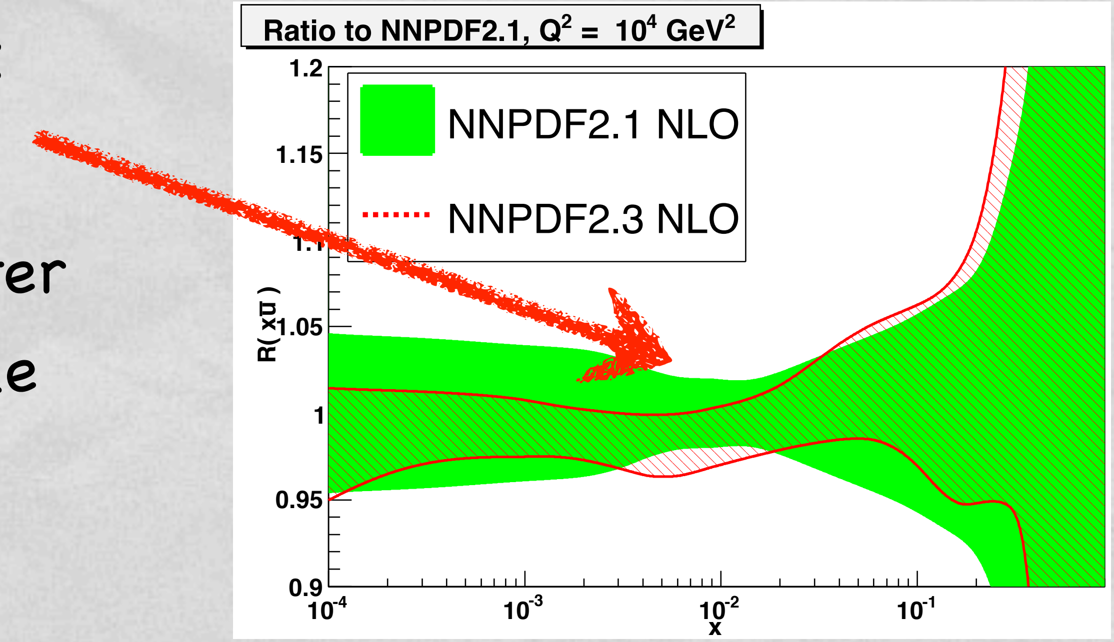
LHC for PDFs

NNPDF2.3 - Inclusion of LHC data in global fits

- **NNPDF2.3** is the first **global fit including LHC data**
  - ✳ ATLAS, CMS & LHC-b W/Z data
  - ✳ ATLAS inclusive jet data
- Reduction on uncertainty in **large-x gluon** (ATLAS jet data)
- Reduction on uncertainties on **light quark** distributions both at **small- and large-x** (W/Z data)
- Changes in **light flavour PDFs shape** after due to inclusion of **LHC W/Z data**: handle on **flavour separation**





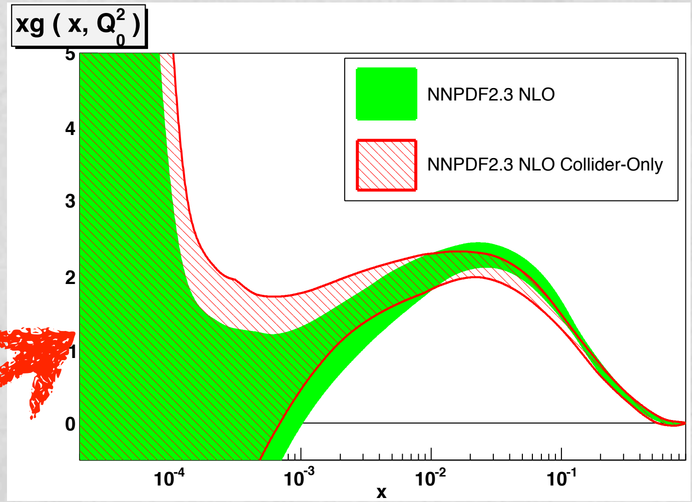
LHC for PDFs

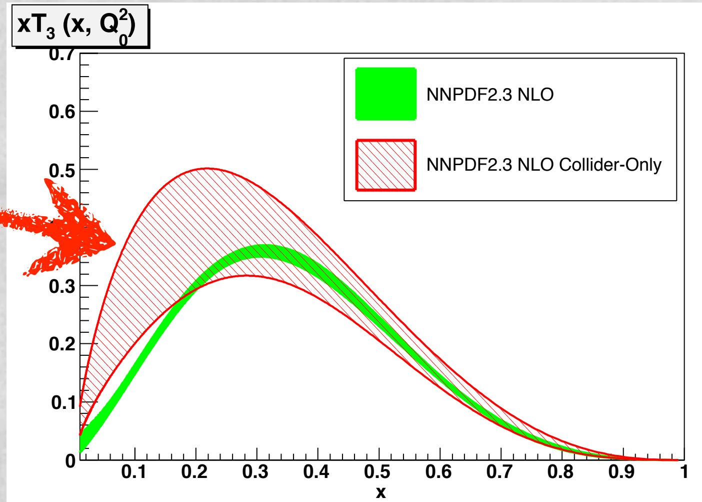
Collider-only fits, are we there yet?

It is the fit we would love to have

- Only **high energy data**: minimize the effects of higher-twist contributions
- Only **proton data**: no assumptions based on models for nuclear corrections

- How does a fit including only HERA DIS, Tevatron W/Z and inclusove jet and LHC data compares to global fits?
- **Gluon distribution** is very well constrained both at small-x (HERA) and large-x (Tevatron/LHC jets)
- PDF combinations sensitive to **light flavour separation** have much larger uncertainties in the collider-only fit (missing constraints from fixed target DIS/DY data)

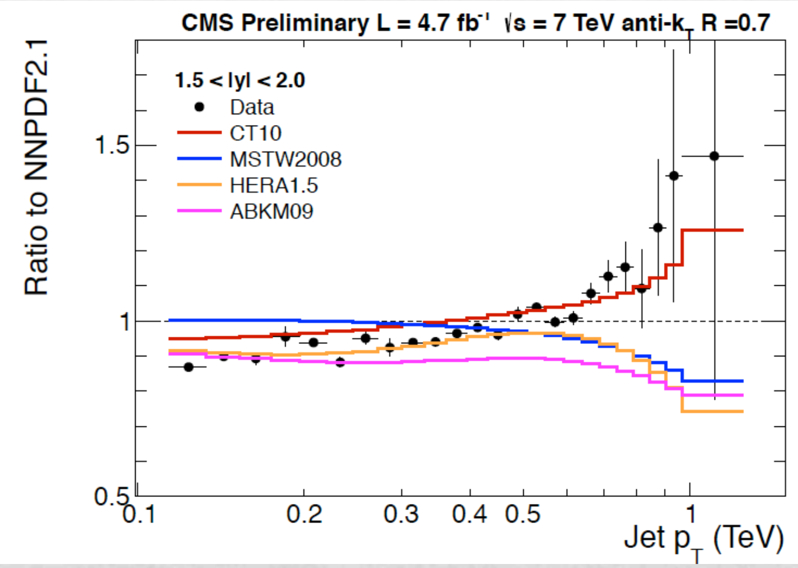




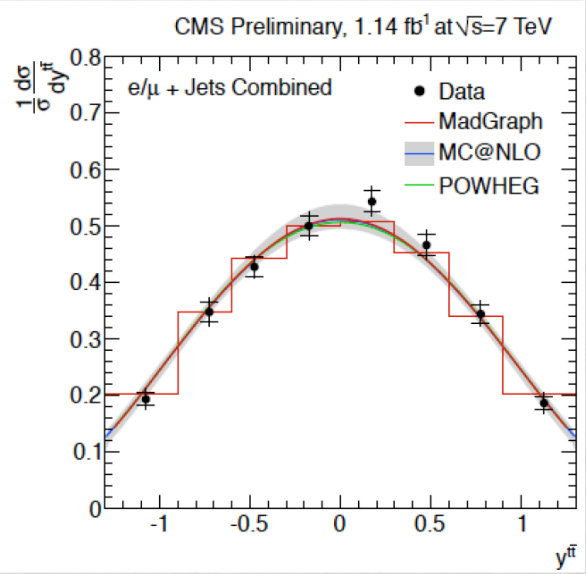
LHC for PDFs

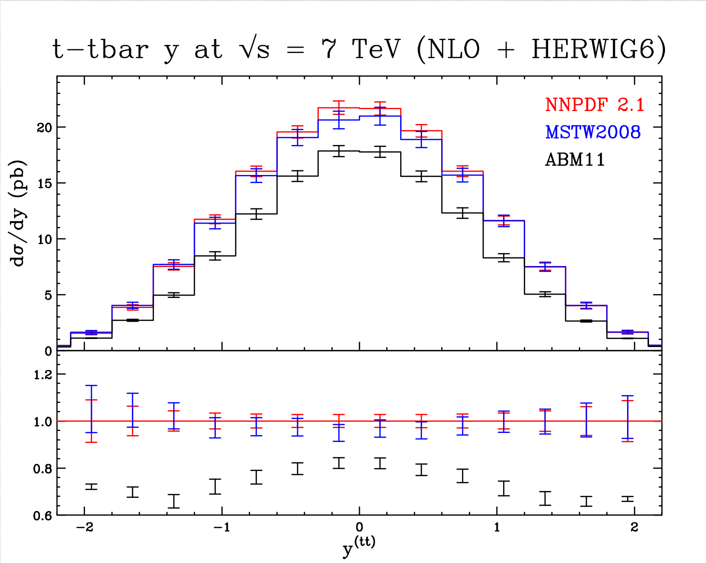
Collider-only fit? More data are coming!

More inclusive jet (and dijet) data



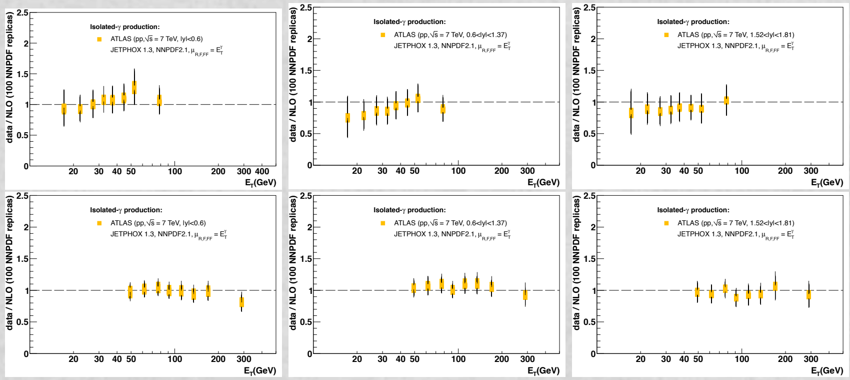
top-pair differential distributions





V. Bertone, PDF4LHC Workshop

Prompt photons



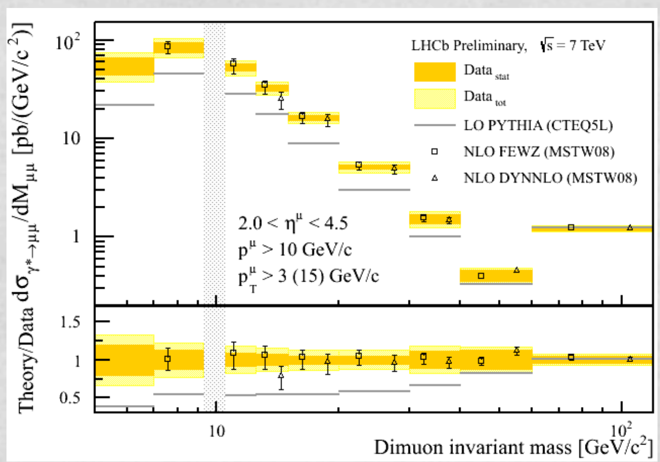
D. d'Enterria & J. Rojo, arXiv:1202.1762

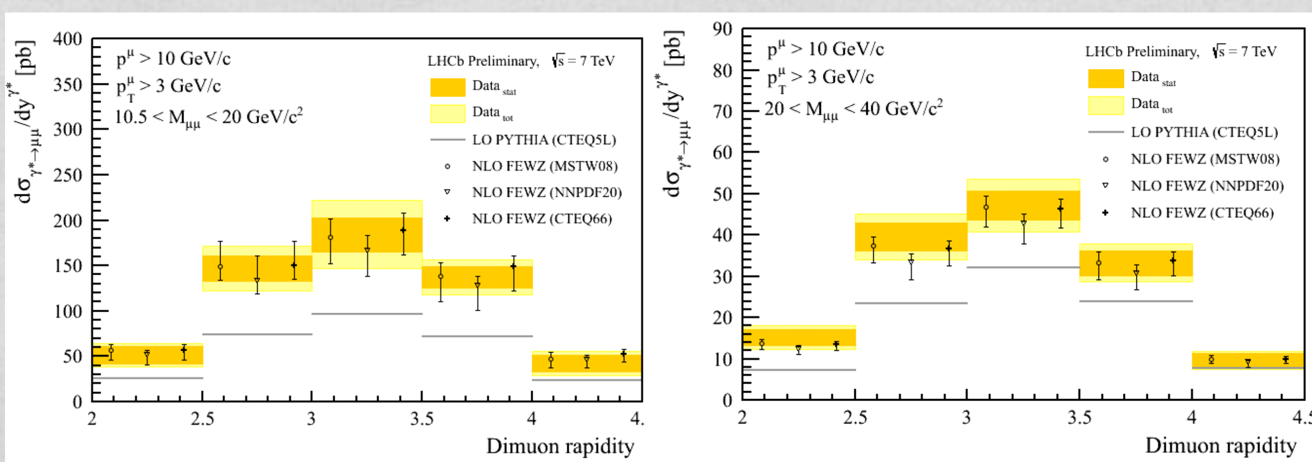
Constraining the **medium/large-x gluon**

LHC for PDFs

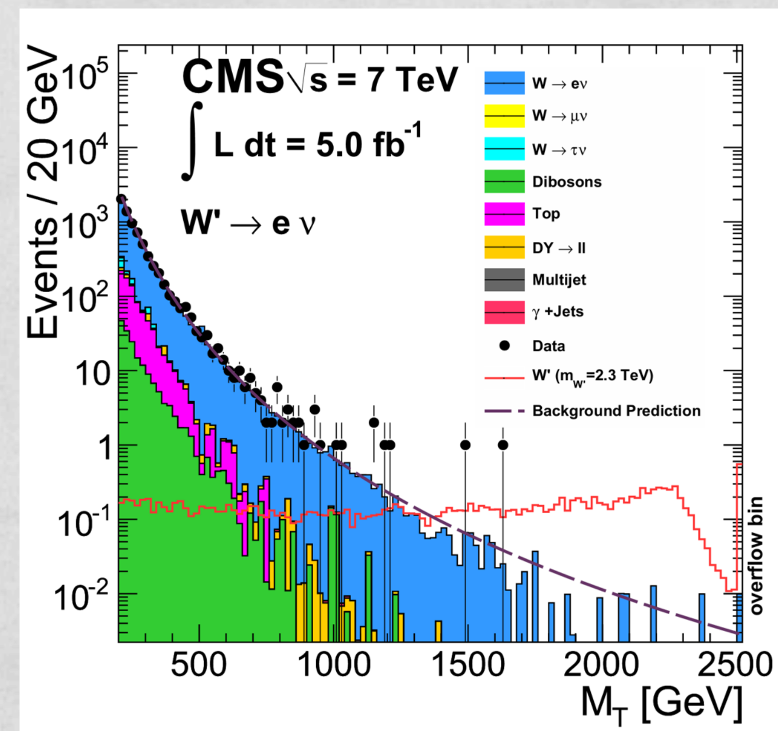
Collider-only fit? More data are coming!

Low-mass Drell-Yan





High mass W production



(**CAVEAT:** needs to be turned from a search into a measurement)

Constraining **light quark flavour separation**

LHC for PDFs

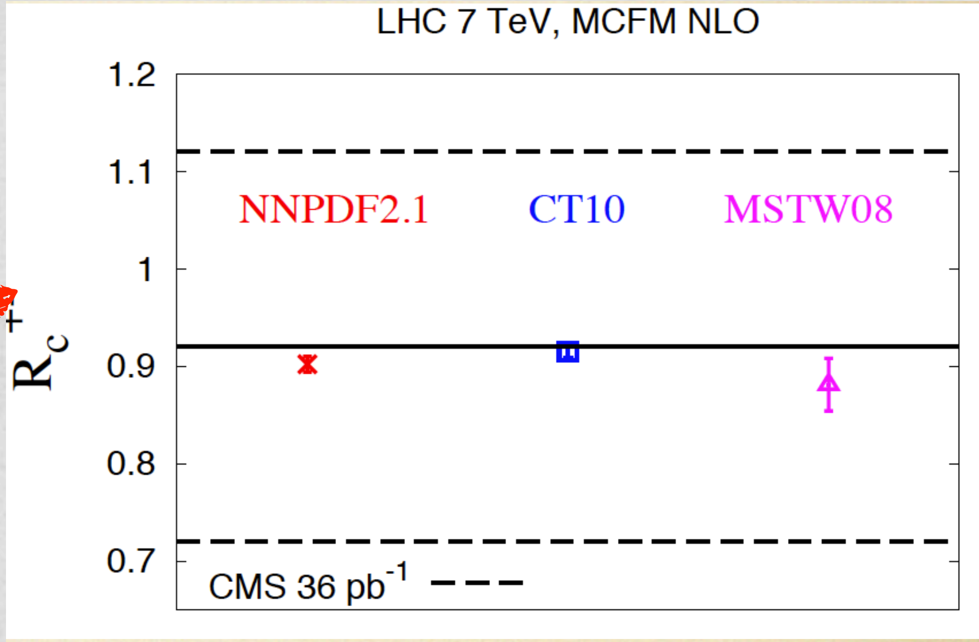
Collider-only fit? More data are coming!

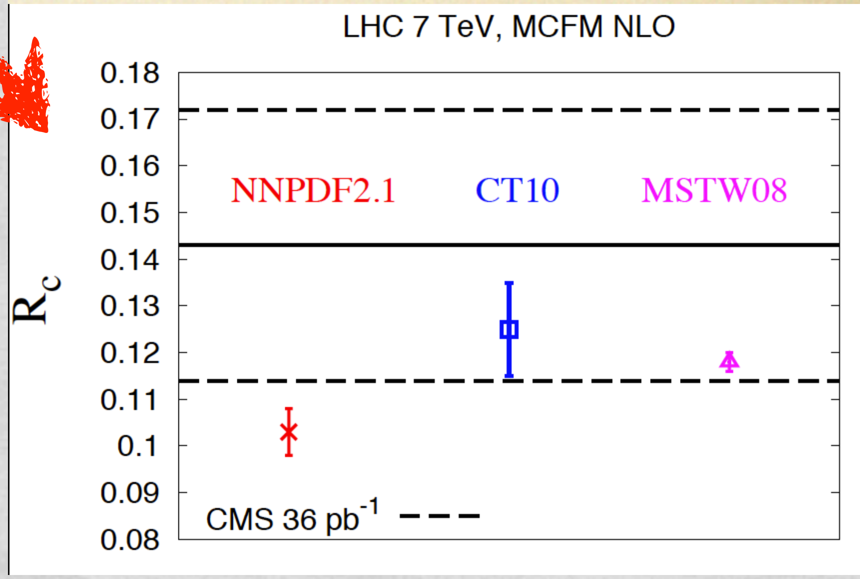
W+charm production

CMS Preliminary results (CMS-PAS-EWK-11-013)

$R_c^{\pm} = \sigma(W^+\bar{c})/\sigma(W^-c)$ $R_c = \sigma(W+c)/\sigma(W+jets)$

$$R_c^{\pm} = 0.92 \pm 0.19\,(stat.) \pm 0.04\,(syst.)$$
$$R_c = 0.143 \pm 0.015\,(stat.) \pm 0.024\,(syst.)$$





Z+bottom
Z+charm
γ+charm
single-top
....

Constraining **strangeness** & **heavy flavour PDFs**

Conclusions & Outlook

- **Parton distribution Functions** are an **essential ingredient** in **predictions** of observables **at the LHC** experiments
- The use of **different methods** and **techniques** in the extraction of PDFs guarantees the **solidity of predictions** and a thorough understanding of the differences and assumptions
- **LHC data** will soon (and indeed already do) **discriminate** between predictions from **different PDF sets**
- **Measurements** at the **LHC** will soon (and indeed already do) provide valuable information to **further constrain PDFs**