Parton Distributions in the Higgs Boson Era

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CERN, PH Division, TH Unit

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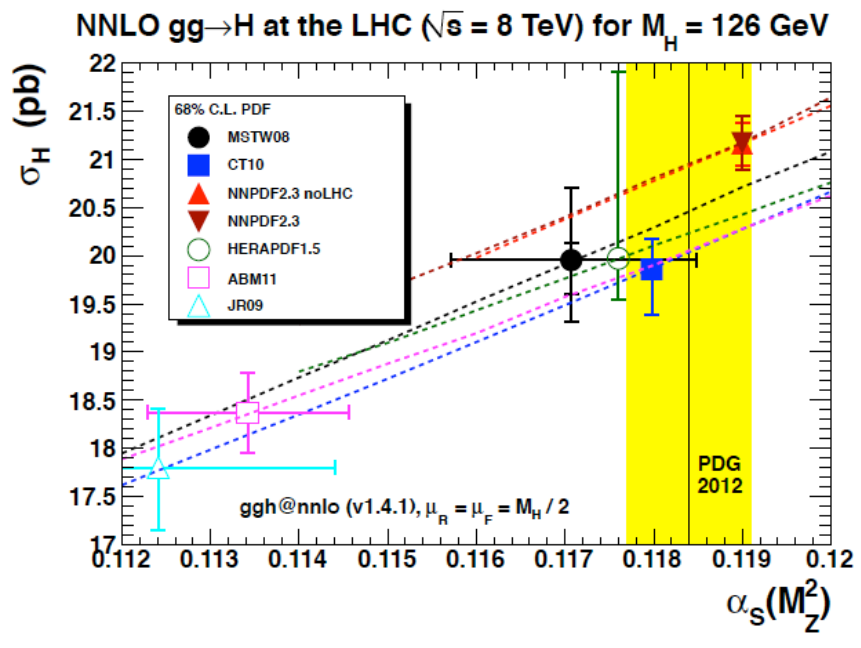
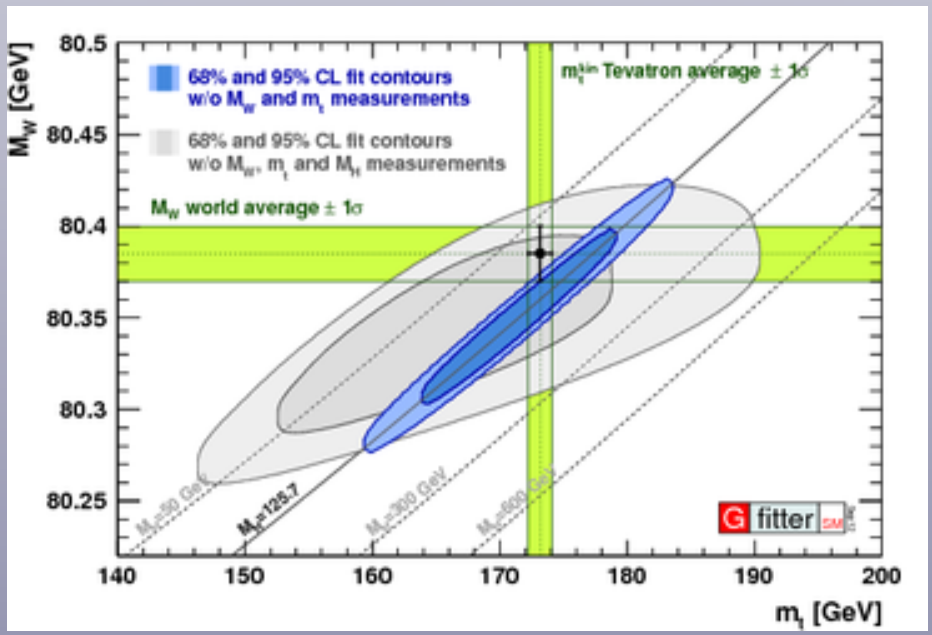
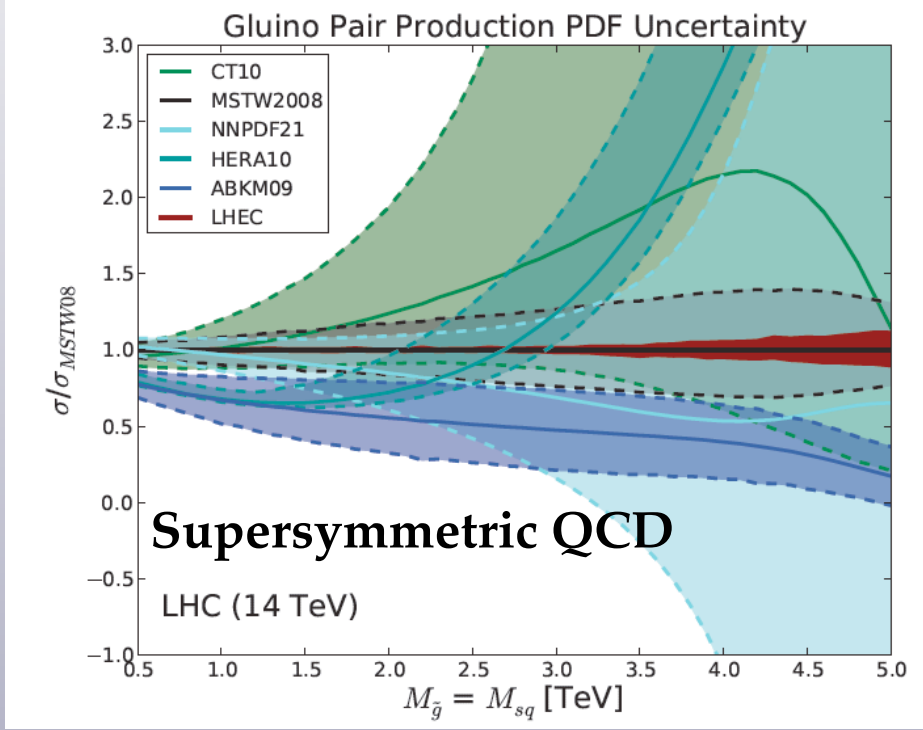
Parton Distributions and LHC phenomenology



1) PDFs fundamental limit for Higgs boson characterization in terms of couplings



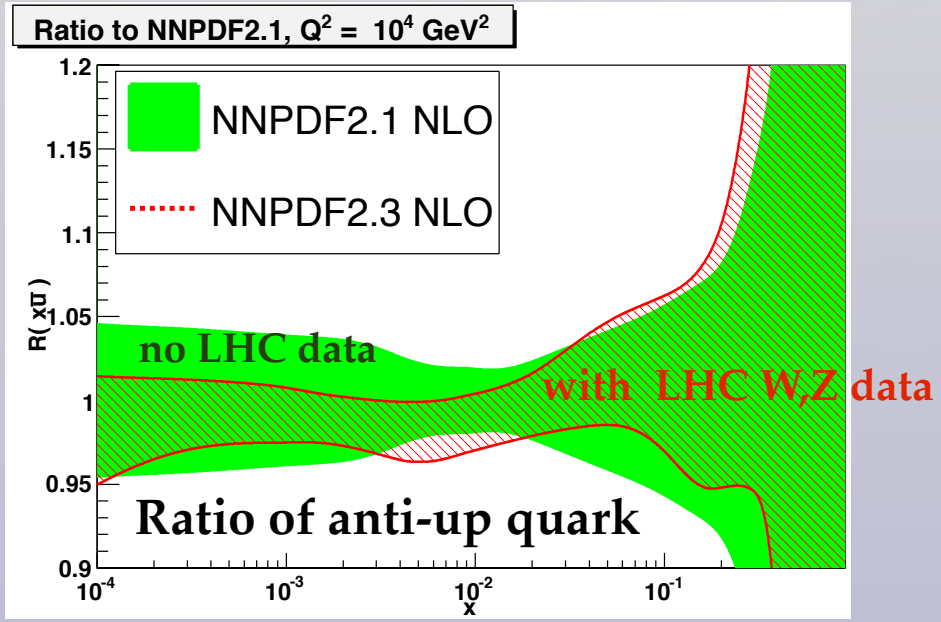
2) Very large PDF uncertainties (>100%) for new heavy particle production

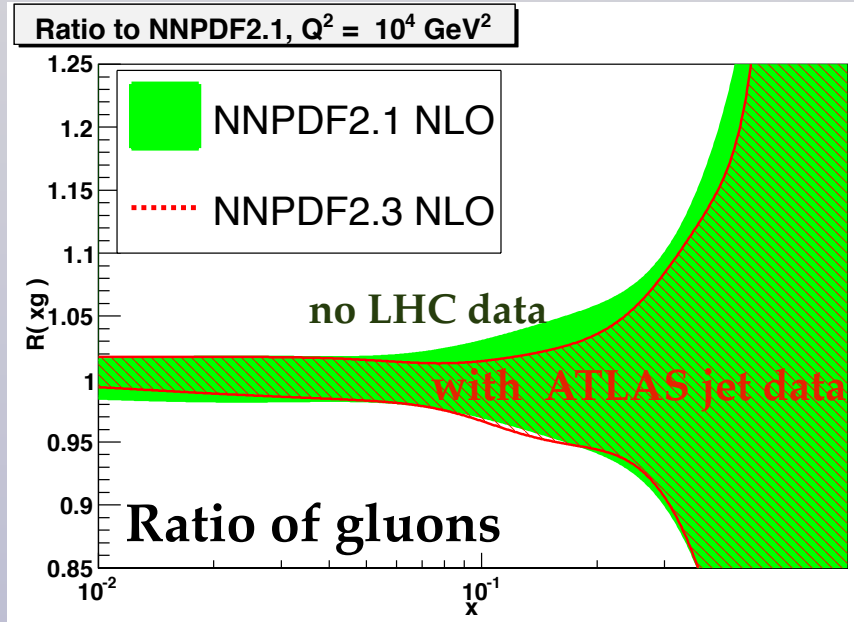


3) PDFs dominant systematic for precision measurements, like W boson mass, that test internal consistency of the Standard Model

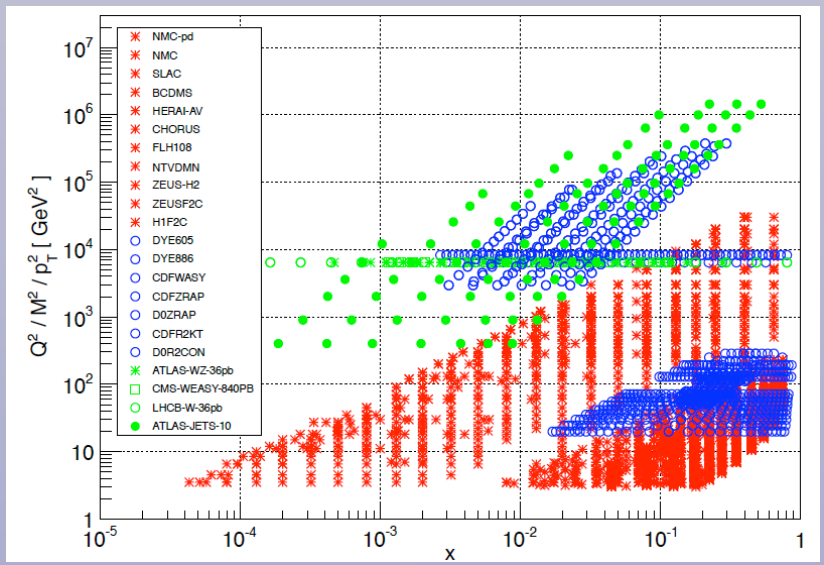
PDFs with LHC data

- A major improvement in PDF sets is **use of LHC data** to constrain quark and gluon PDFs
- **NNPDF2.3** is only publicly available PDF set that includes constrains from **LHC jet and W,Z data**
- Near future goal: PDFs sets based only on **collider data**





NNPDF Collaboration, arxiv:1207.1303



LHC data included in NNPDF2.3

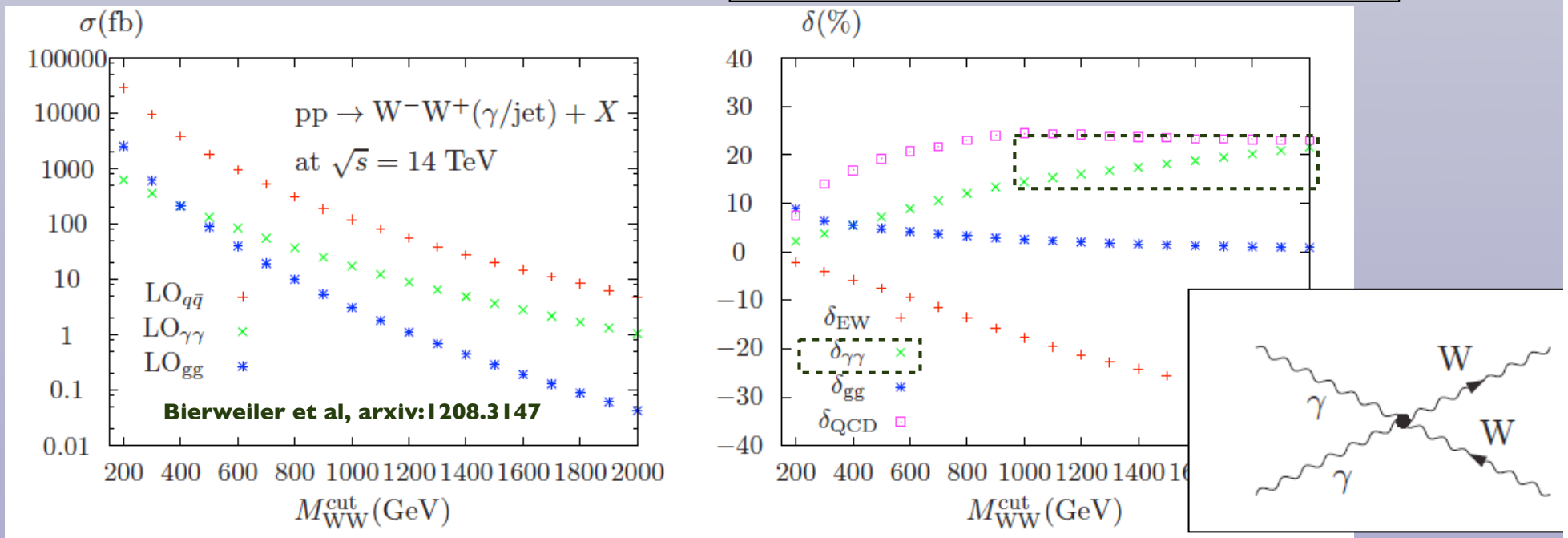
Data Set	Ref.	N_{dat}	$[\eta_{min}, \eta_{max}]$
CMS W electron asy 840 pb^{-1}	[58]	11	[0, 2.4]
ATLAS W$^+$ 36 pb^{-1}	[56]	11	[0, 2.4]
ATLAS W$^-$ 36 pb^{-1}	[56]	11	[0, 2.4]
ATLAS Z 36 pb^{-1}	[56]	8	[0, 3.2]
LHCb W$^+$ 36 pb^{-1}	[61]	5	[2, 4.5]
LHCb W$^-$ 36 pb^{-1}	[61]	5	[2, 4.5]
ATLAS Inclusive Jets 36 pb^{-1}	[55]	90	[0, 4.5]

PDFs with QED corrections

- **QED** and **electroweak corrections** are essential for **precision LHC phenomenology**: precision predictions for **W and Z production**, **W mass determination**, **vector boson pair** production, **TeV scale** jet and top quark pair production, searches for new **W′, Z′ bosons**
- The consistent inclusion of electroweak effects require PDFs with **QED corrections** and a **photon PDF**
- Only available set with QED corrections is **MRST2004QED**, where the photon PDF is derived from model assumptions
- The upcoming **NNPDF2.3 QED set** is based on a photon PDF **derived from DIS and LHC data,** parametrized with an **artificial neural network without any ad-hoc model bias**
- **Much larger uncertainties for photon-induced processes** are obtained once an unbiased photon PDF is derived from data, **important phenomenological consequences**

WW production at high mass

Based on MRST
Larger corrections expected with NNPDF2.3QED



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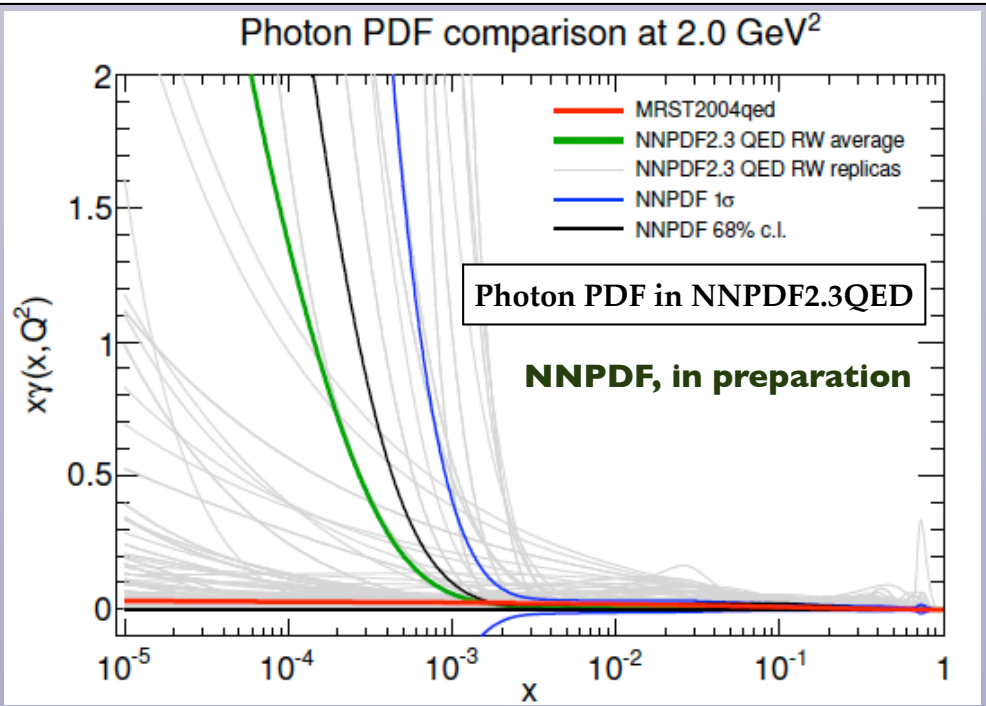
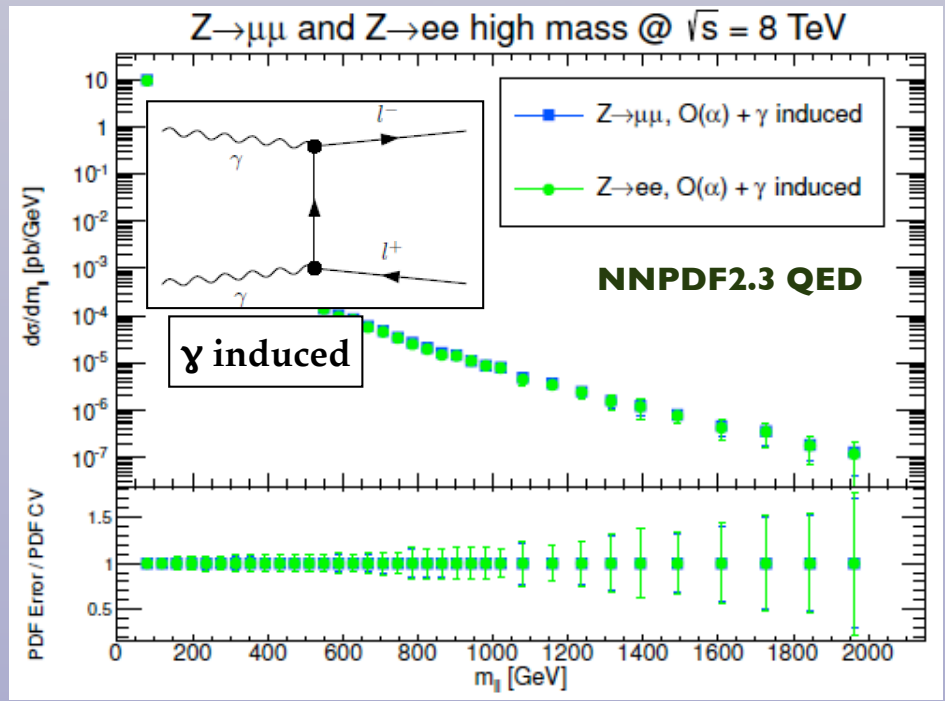
Similar to MRST at large-x, large PDF errors at small-x



50% uncertainties from γγ for m_{ll}=2 TeV

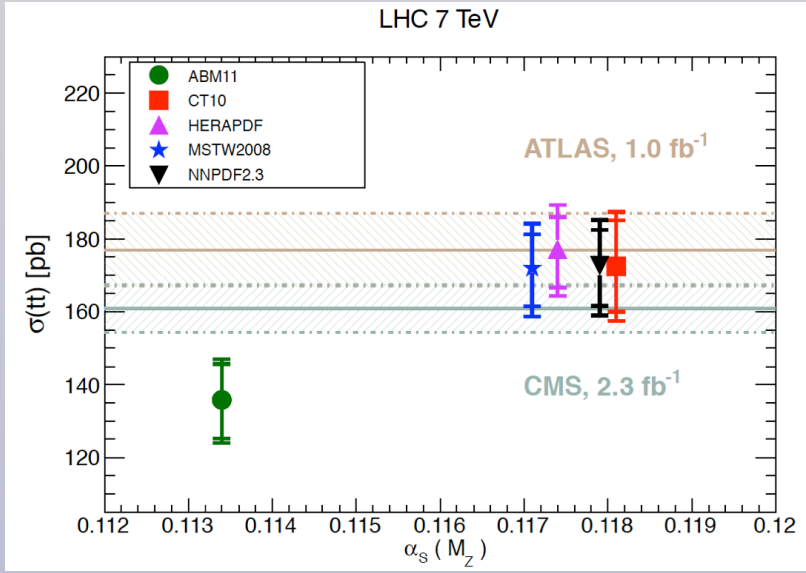


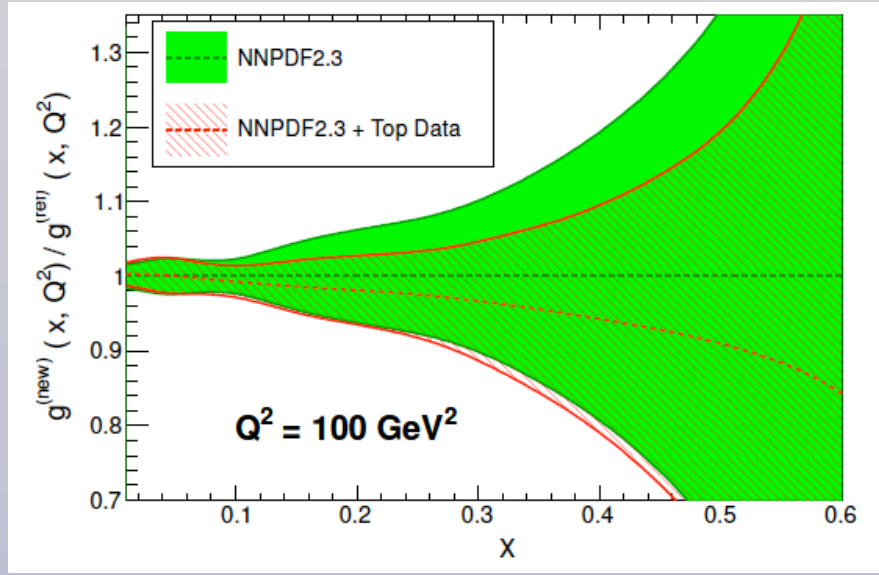
Top quarks as gluon luminometers

- The recent **NNLO top quark cross section** make top data the **only LHC observable** that is both **directly sensitive to the gluon PDF** and can be included consistently in a **NNLO global analysis**

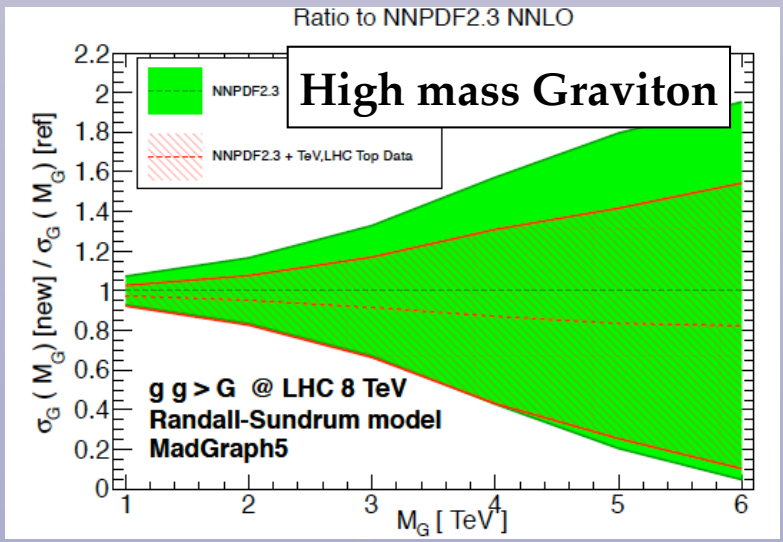
- The precise 7 and 8 TeV LHC data can be used to **discriminate between PDF sets** and **to reduce the PDF uncertainties on the poorly known large-x gluon**

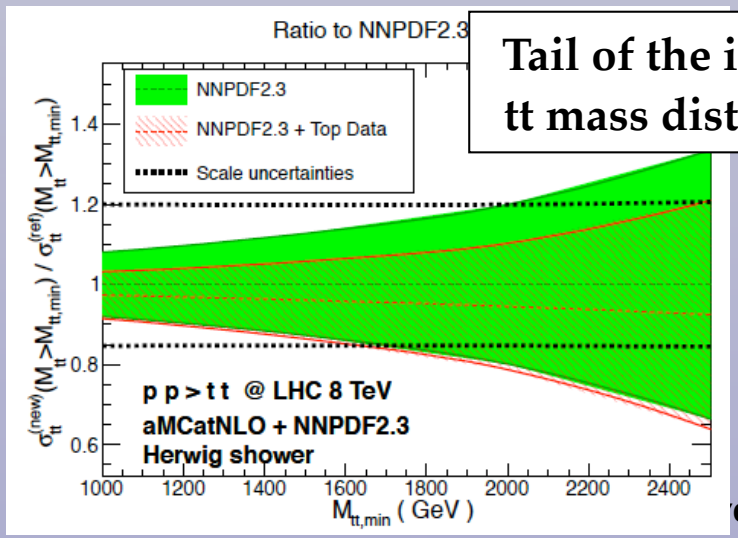
Czakon, Mangano, Mitov, Rojo, arxiv:1303.7215





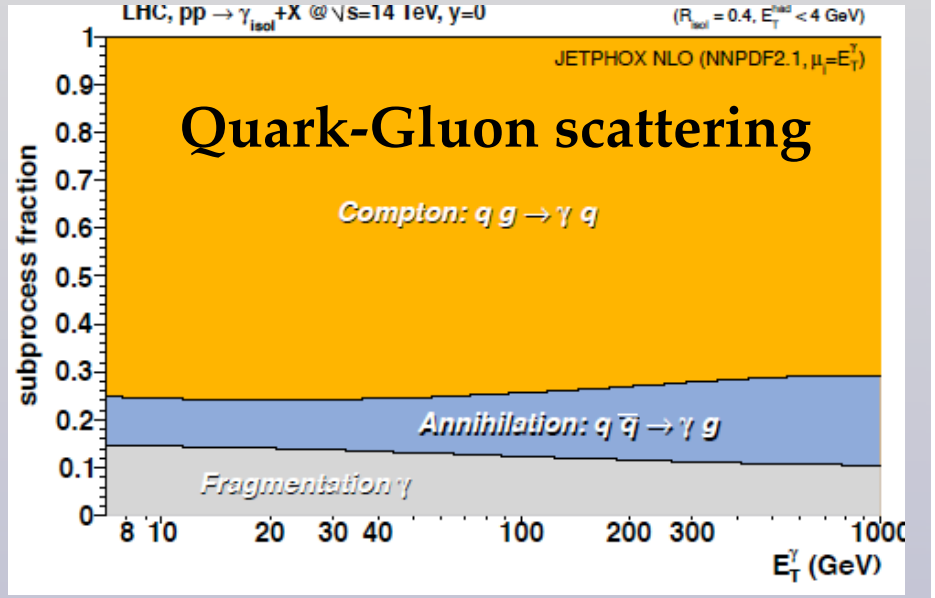
- The **improved large-x gluon** leads to more accurate theory predictions for **BSM searches**

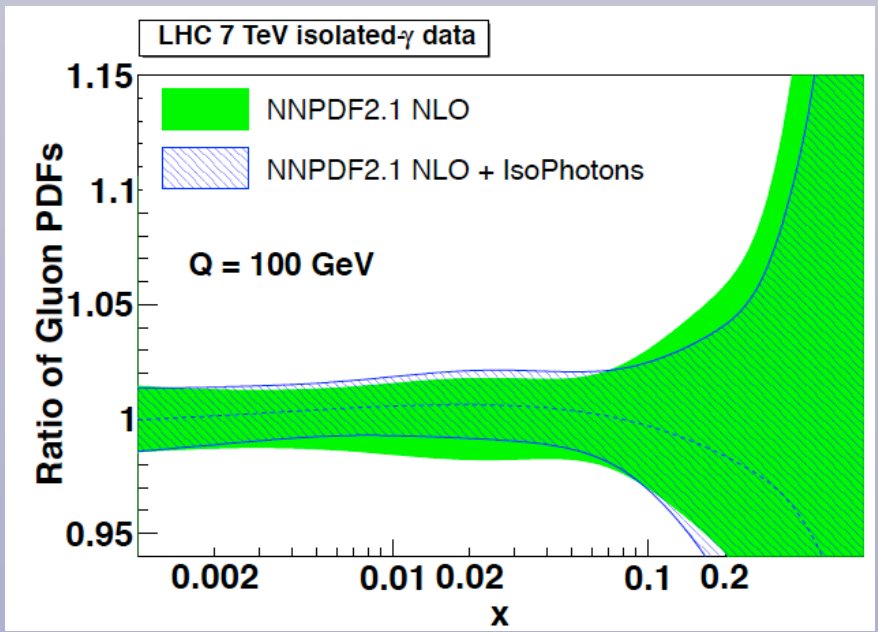


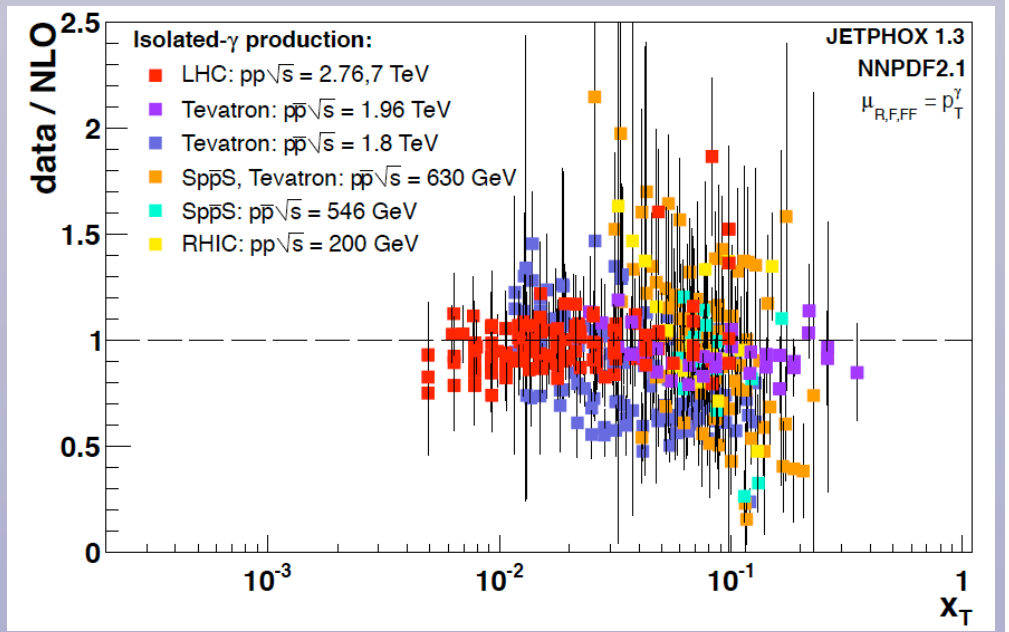


Isolated photons and the gluon PDF

- **Photon** production **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 reanalysis of all **isolated collider** photon data with the most updated theory, **JetPhox+NNPDF2.1,** and found **overall agreement** **(D'Enterria and Rojo, arXiv:1202.1762)**
- **Moderate reduction of gluon PDF errors** from LHC photon data, in the region relevant for **Higgs production in gluon fusion**
- **Photon+jet data also studied,** but need more precise data to impact on PDF uncertainties **(Carminati et al, arXiv:1212.5511)**

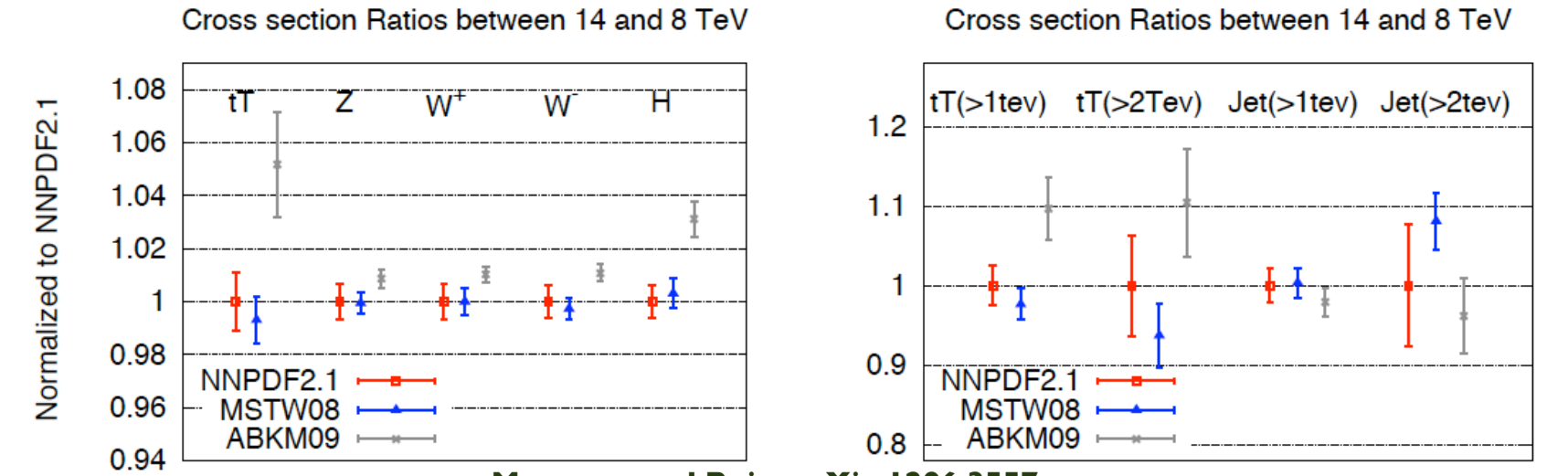




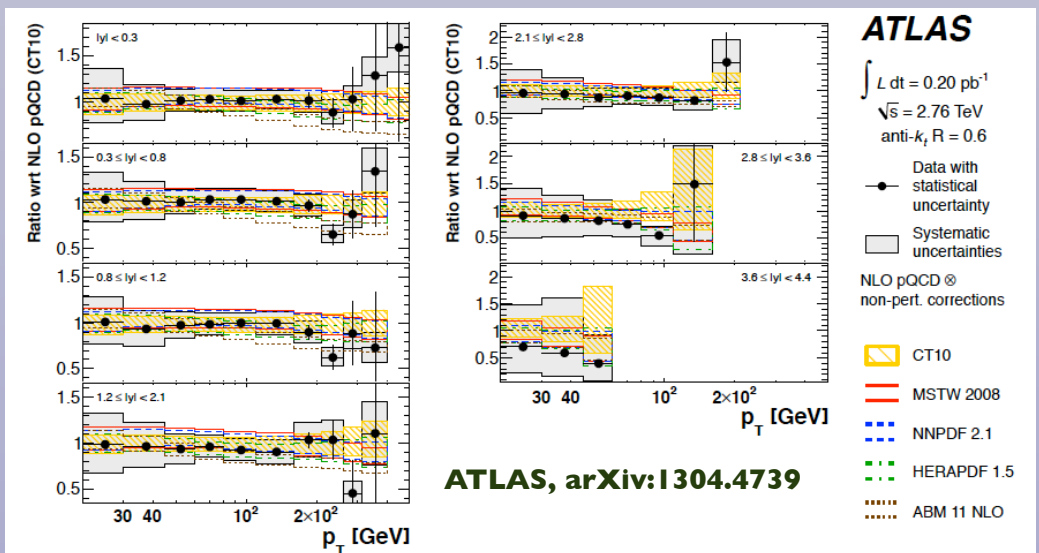


Cross section ratios between LHC beam energies

- The **staged increase of the LHC beam energy** provides a new class of interesting precision observables: **cross section ratios** for different beam energies
- Can be computed with **high precision** due to **correlation of theoretical errors** at different energies
- **Experimentally** these ratios can also be measured accurately since many systematics, like luminosity or jet energy scale, **cancel partially in the ratio**s
- These ratios allow **stringent precision tests of the SM**, in particular **PDF discrimination**



Mangano and Rojo, arXiv:1206.3557

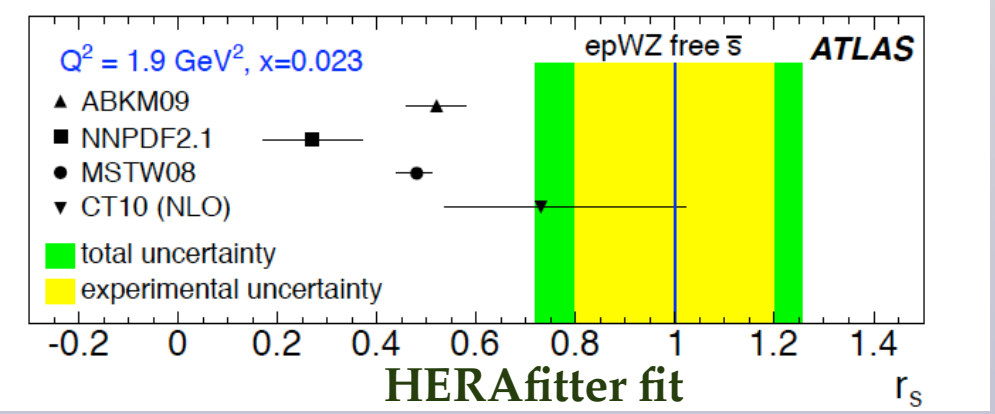


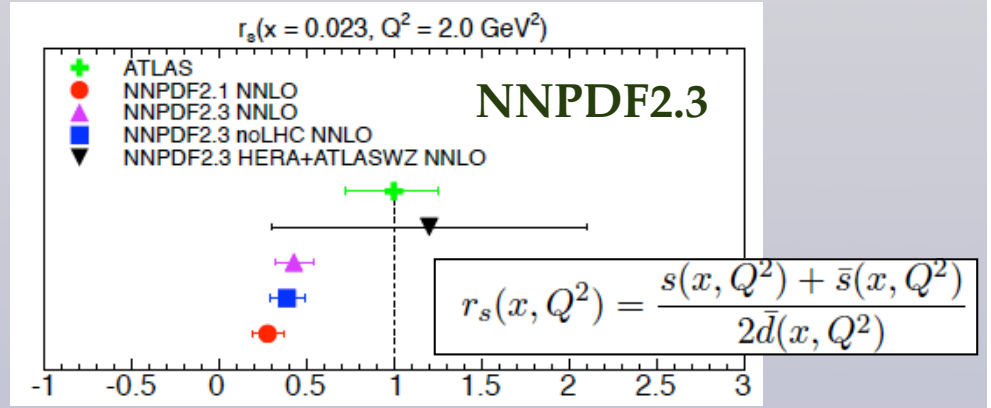
ATLAS, arXiv:1304.4739

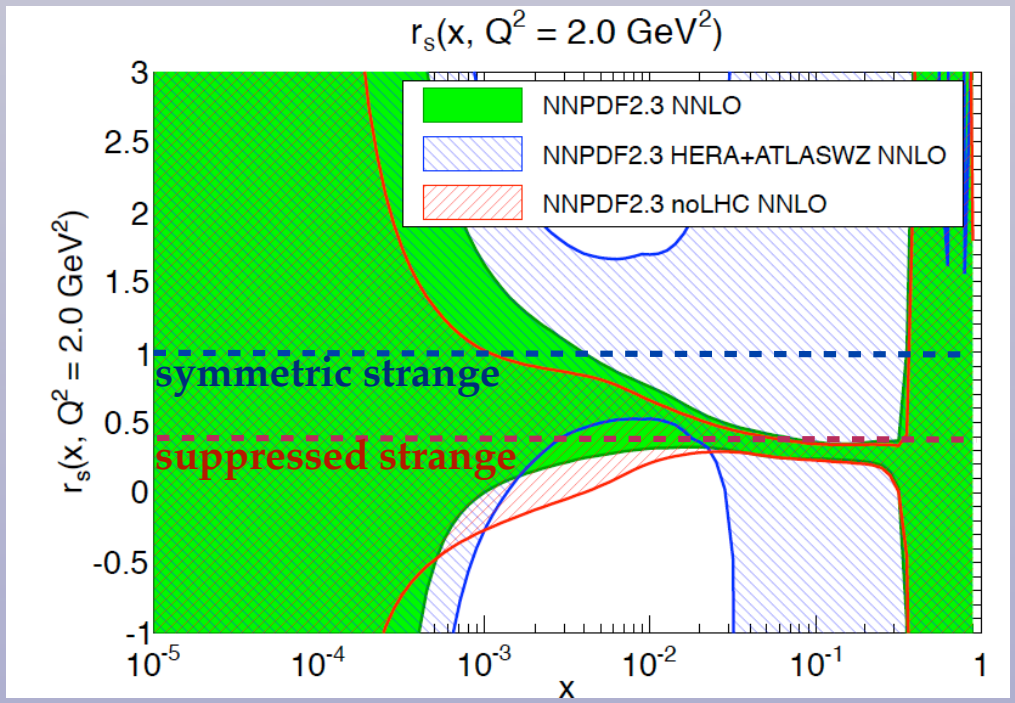
- Cross section ratios should thus be pursued as a **novel approach to constrain PDF**
- First implementation: measurement of jet cross section ratios by **ATLAS between 7 and 2.76 TeV**
- Reduced experimental and theory (scale) uncertainties, potentially can **improve the sensitivity to PDFs of 7 TeV ATLAS jet data alone**

The strangeness conundrum

- **Strangeness** worst known of all light quarks. In global fits determined by **neutrino charm production** data
- A **QCD analysis of the ATLAS W, Z data** allows to determine **the strange PDF**. ATLAS analysis based on **HERAfitter** indicates **strange ≈ down**. **NNPDF2.3** analysis confirms central value, **but much larger uncertainties**







- **NNPDF2.3 coll** is a PDF set based only and HERA and LHC data, including ATLAS W,Z
- Suggests **strange ≈ down** but with large uncertainties, **consistent with strange suppression** from neutrino DIS data

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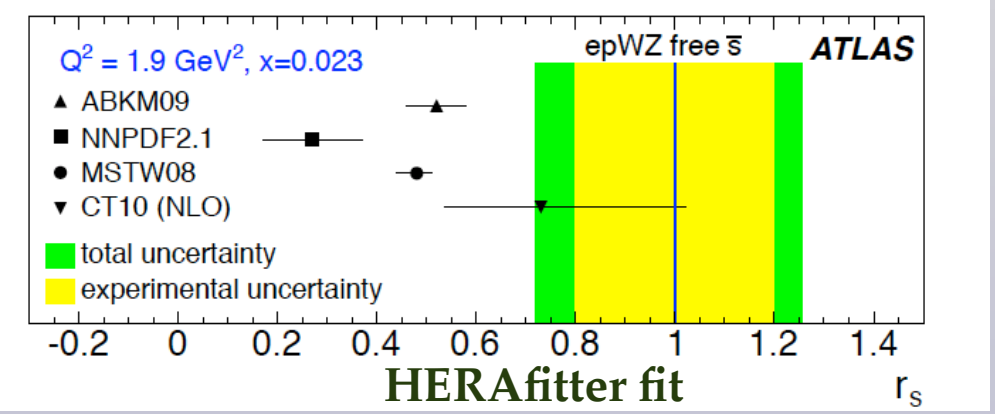
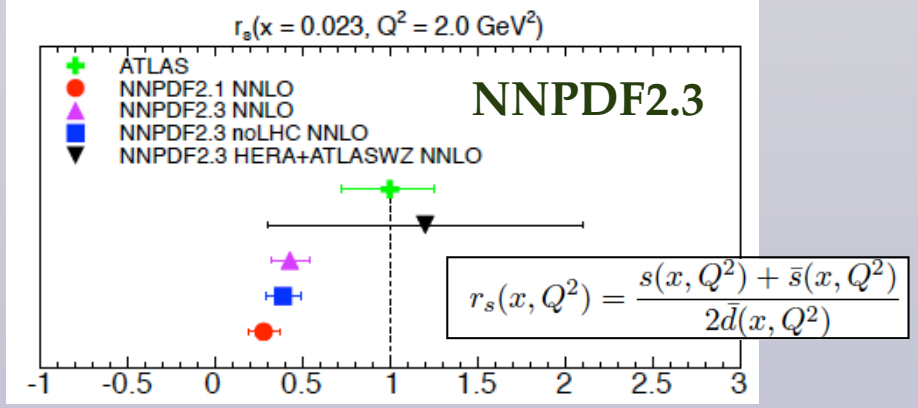
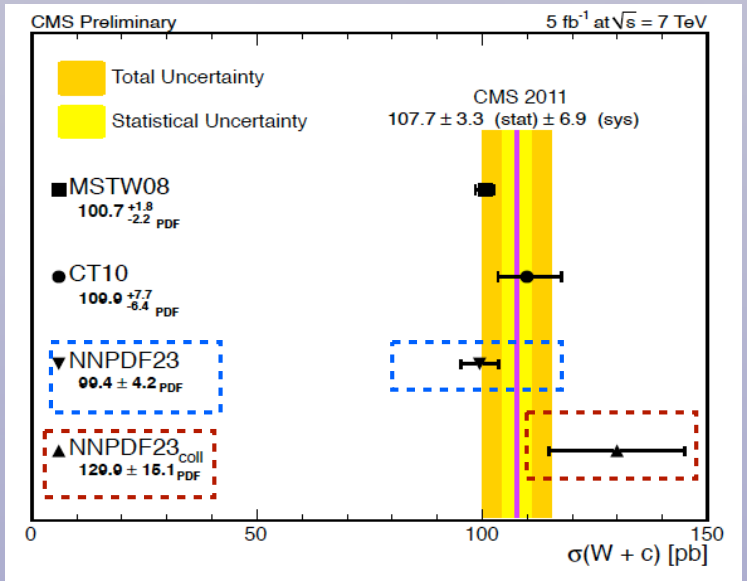
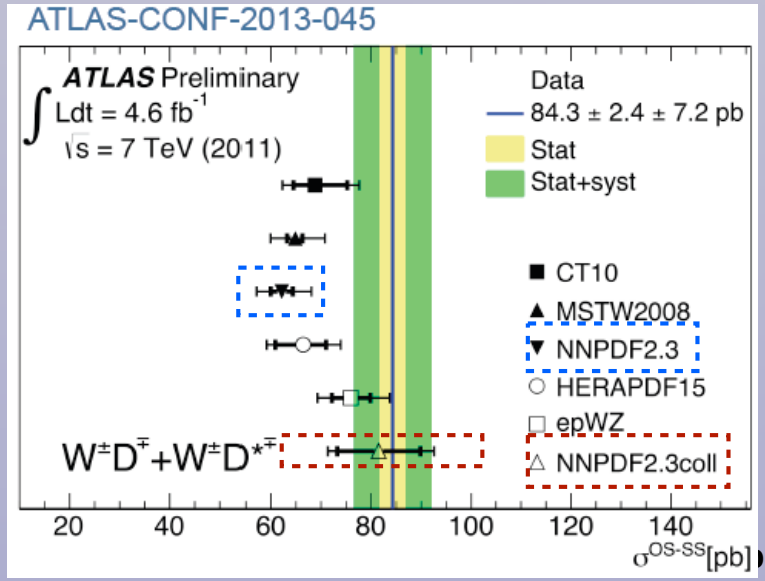




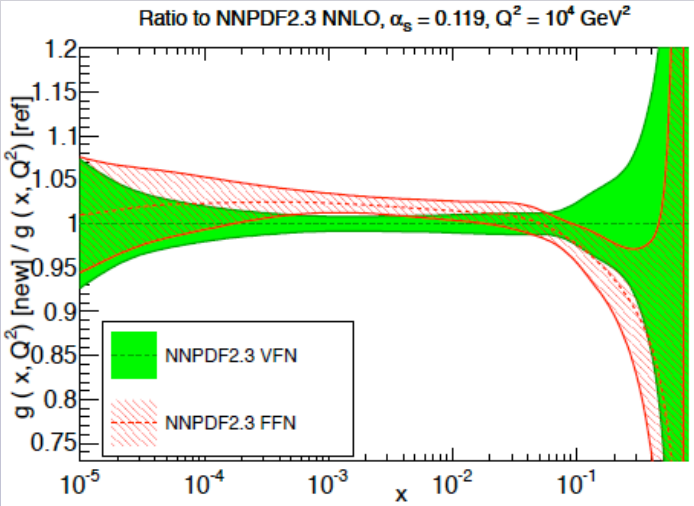
- **W+c data from ATLAS and CMS** instrumental to determine **strangeness from collider-only data**
- **Recent results from CMS** are consistent with the strange PDF determined in global fits from neutrino data, while **ATLAS** prefers symmetric strange sea: perform **global PDF fit** to derive **optimal strange PDF**

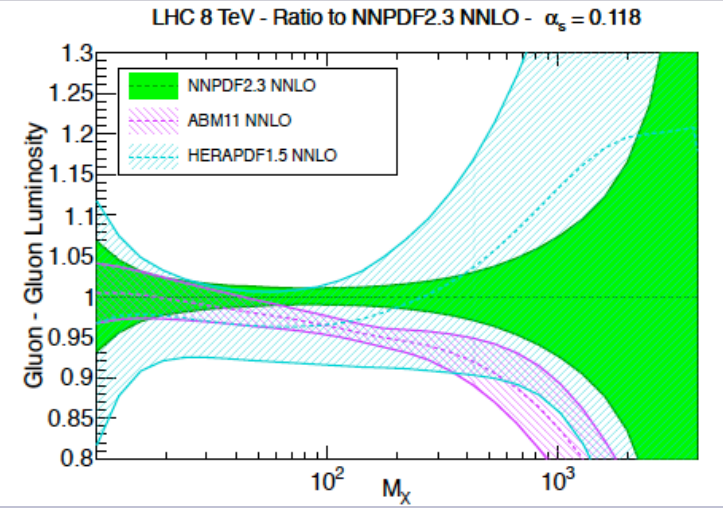


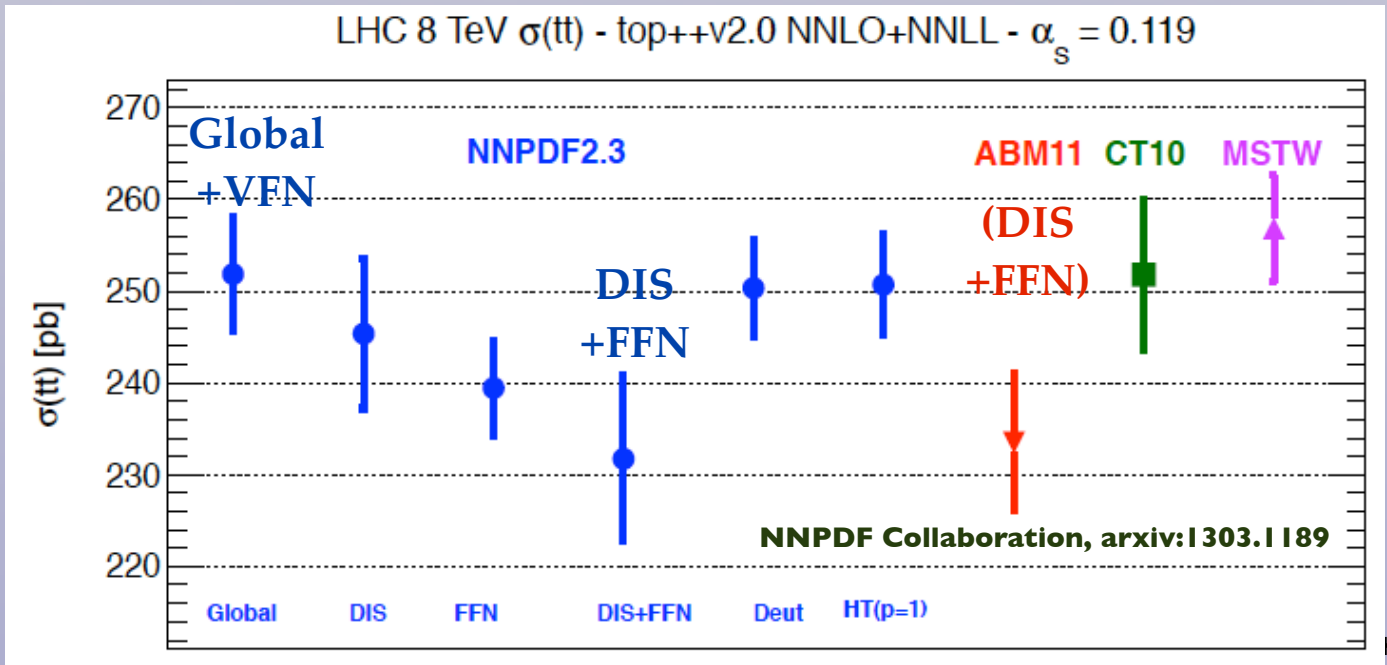


Theoretical uncertainties in PDFs

- The differences between PDF sets can be partly understood in terms of **different theoretical settings**
- A major source of difference is the use of a **fixed-flavor number** (FFN) renormalization scheme (**ABM11, JR09**), as opposed to the general-mass variable-flavor number (GM-VFN) schemes (**CT, MSTW, NNPDF**)







- The use of a FFN scheme leads to **softer large-x gluons** and **harder quarks**
- Together with the use of DIS only data, explains partially **differences between ABM11 and other sets**, both for PDFs and for cross-sections
- A worse description of **high-Q^2 HERA** data obtained in the FFN (missing DGLAP logs)
- **Higher twist** (nuclear corrections) have a negligible (moderate and restricted) impact on PDFs

Summary

- **Parton Distributions** are an **essential ingredient** of the LHC physics program
- **Precision PDFs** are required for most LHC analysis, from **Higgs boson characterization**, **searches for new massive particles** to **self-consistency tests of the Standard Model**
- **PDF analysis** are now entering the **LHC era**: constraints from LHC data, PDFs with QED and electroweak corrections, PDFs for NLO event generators, ...
- Many upcoming developments in the near future, **stay tuned!**

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Thanks for your attention!