Parton distributions with LHC data

The new generation of PDFs

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Outline

1. Introduction
   - Definition
   - Motivation
2. NNPDF approach
   - Overview on current PDF providers
   - The NNPDF methodology
3. NNPDF with LHC data
   - The new dataset
   - PDF results with LHC data
   - Comparing results between different PDF providers
   - Phenomenology at $\sqrt{s} = 8\,\text{TeV}$
4. Conclusion and outlook

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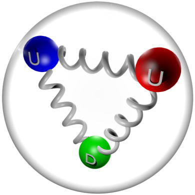
- **What are parton distribution functions?**

PDF definition:

The **probability density** of finding a constituent of the proton, called **parton**, with a momentum fraction x of the proton at momentum transfer Q^2.



- **Partons** are **gluons**, **quarks** and **antiquarks**
  $\Rightarrow g, u, \bar{u}, d, \bar{d}, s, \bar{s}, \ldots$

Introduction - PDF definition

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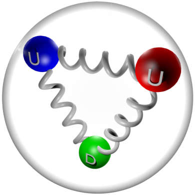

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  $\Rightarrow g, u, \bar{u}, d, \bar{d}, s, \bar{s}, \ldots$
- Facts about PDFs:
  - **Not calculable**: reflect **non-perturbative** physics of confinement
  - Extracted by comparing **theoretical predictions** to **experimental** data:

Deep Inelastic Scattering	Drell-Yan process	Electroweak distributions	Jet distributions

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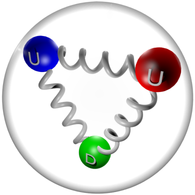

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PDF ≠

Motivation - Computing observables

- **Why do we need parton distribution functions?**

Following the factorization theorem in QCD, the observable of a hard process ($Q \gg \Lambda_{\mathrm{QCD}}$)can be written as

$$\frac{d\sigma}{dxdQ^2} = \sum_{i=1}^{n_f} \frac{d\hat{\sigma}_i}{dQ^2} \otimes f_{i/p}(x, Q^2),$$

the sum over all PDF flavors n_f of the convolution product between:

$$\frac{d\hat{\sigma}_i}{dQ^2}$$

the elementary "hard" cross section which is computed in QCD, depends on the physical process.

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the PDF of parton i inside a proton p, carrying a momentum fraction x at the energy scale Q^2.

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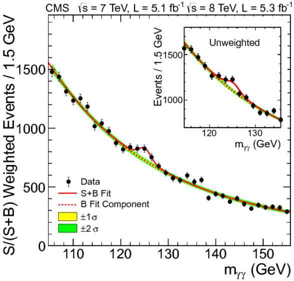
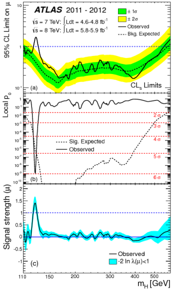
Remark: PDFs are essential for theoretical predictions.

- **Where do we need parton distribution functions?**





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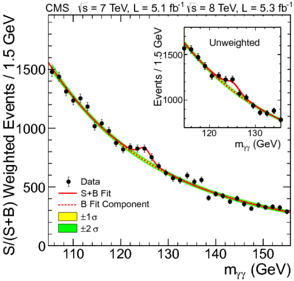

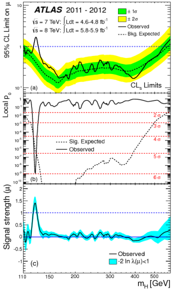

- PDFs are necessary to determine theoretical predictions for signal/background of experimental measurements.

Problem: PDF **uncertainties** on signal range from **4% up to 8%**, accordingly to the channel, of the systematic uncertainties of the measurements.

Solution: Improve PDF extraction **methodology** and add more **data** (LHC data).

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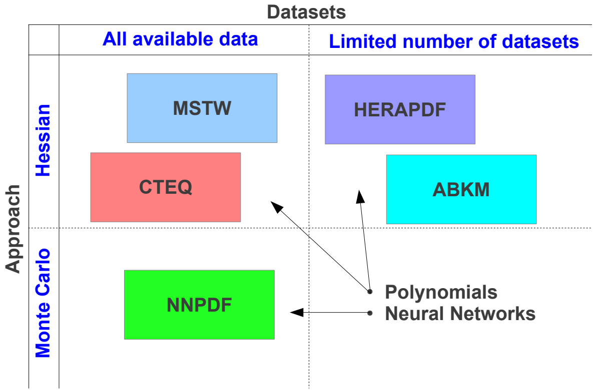
PDFs on the market...



- The providers use different **approaches** and **datasets.**
- **NNPDF** uses a high technological approach.

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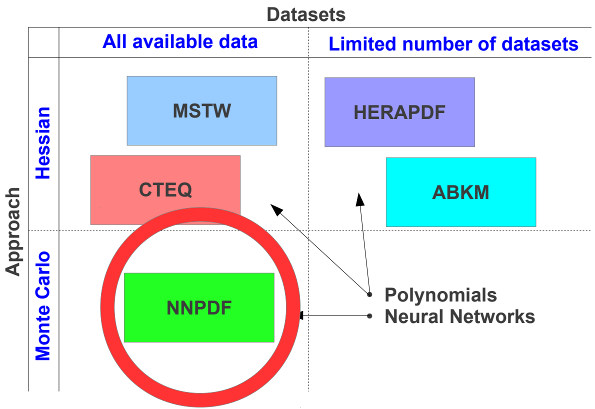

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The NNPDF methodology (shortly)

- NNPDF has introduced a new methodology:
  - implementation started in 2002, based on **Neural Networks**,
  - reduction of all sources of theoretical **bias**, e.g. the functional form.

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  - Minimization driven by a **genetic algorithm**,
  - Optimization controlled by **training/validation method**,
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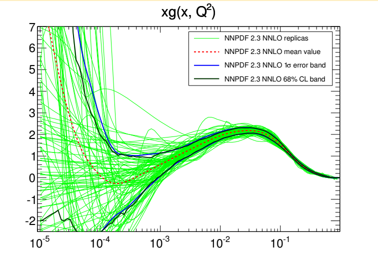
  - **Monte Carlo** representation of results.
- Expectation values for **observables are Monte Carlo integrals:**



MC approach:

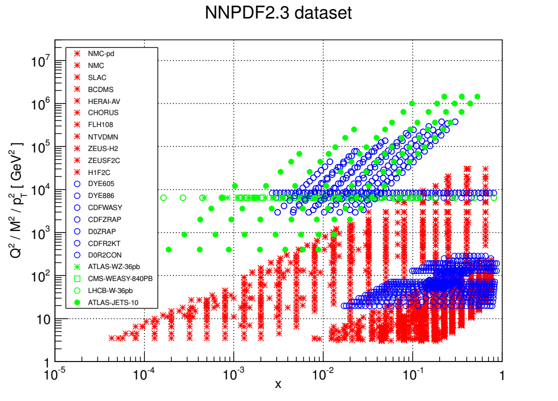
$$\langle \mathcal{O}[f] \rangle = \frac{1}{N} \sum_{k=1}^{N} \mathcal{O}[f_k]$$

- for **observables**, **errors**, **correlations**, etc.

Outline

NNPDF2.3 - The new dataset

- **NNPDF2.3** is the first PDF set which includes **all the LHC data** for which the complete experimental information is available (●).



ATLAS:

- inclusive jets
- W/Z lepton rapidity distributions

CMS:

- W lepton asymmetry

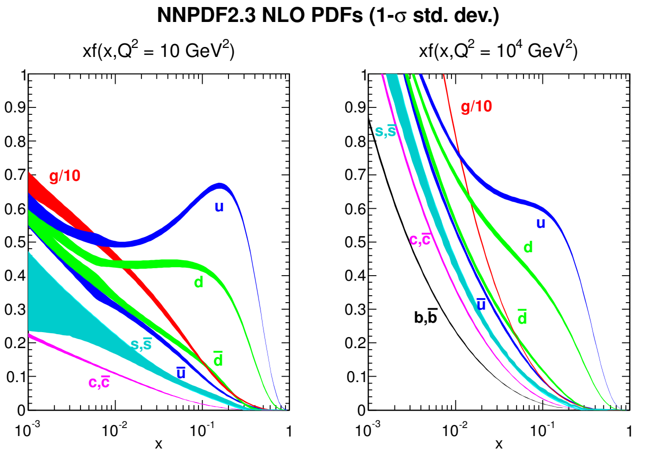
LHCb:

- W rapidity distributions

- **3501 data points**: **51** LHC W/Z, **90** LHC Jets

(ATLAS jets arXiv:1112.6297, ATLAS W/Z arXiv:1109.5141, CMS Weasy arXiv:1206.2598, LHCb W arXiv:1204.1620)

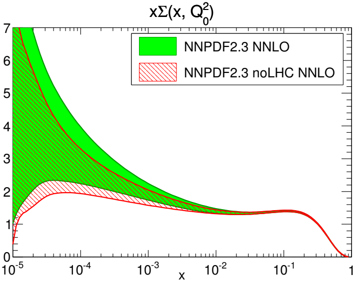
NNPDF2.3 - The new PDF set

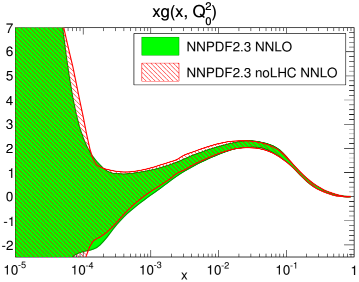


- **NNPDF2.3** sets are also available:
  - varying datasets,
  - varying QCD parameters, e.g. α_s,
  - with different theoretical frameworks, e.g. perturbative order (NLO/NNLO).

Example of NNPDF2.3 PDF

- Example of PDFs at $Q_0^2 = 2.0\,\text{GeV}^2$, with and without LHC data.



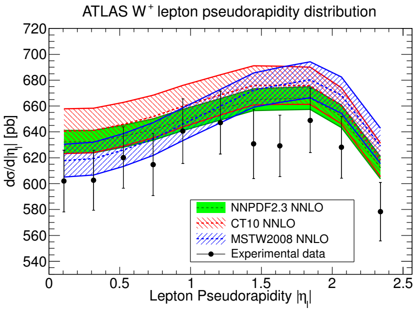


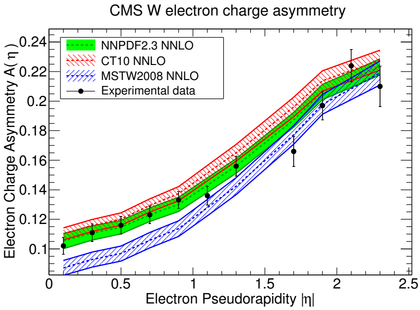
- LHC data reduces **PDF uncertainties** and **improves the χ^2/d.o.f** between data and theoretical predictions produced by the PDFs:

	NNPDF2.3 noLHC	NNPDF2.3
Total χ^2/d.o.f.	1.142	1.139

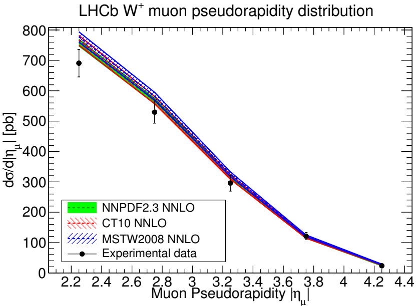
- Improvement about 10 units of χ^2.

Example of LHC observables

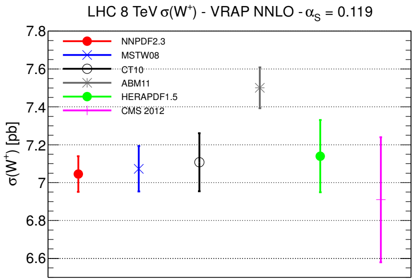


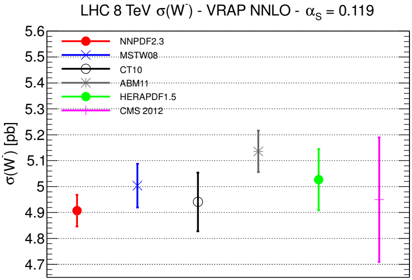


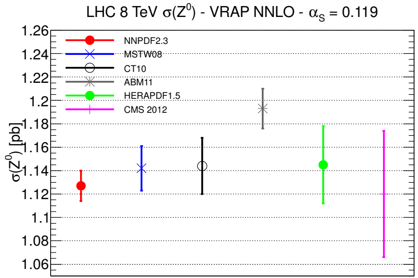
NNLO, $\alpha_s = 0.119$			
PDF Set	**NNPDF2.3**	**MSTW08**	**CT10**
ATLAS W, Z	**1.435**	**3.201**	**1.160**
CMS Weasy	**0.813**	**3.862**	**1.772**
LHCb W	**0.831**	**1.050**	**0.966**
ATLAS jets	**0.937**	**0.935**	**1.016**



Candle Cross Sections - $W^{\pm}$ and Z

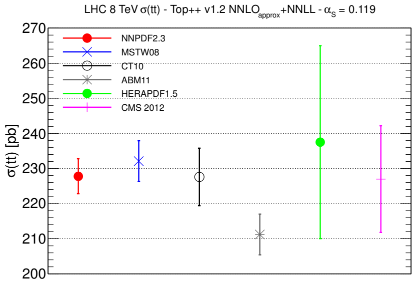




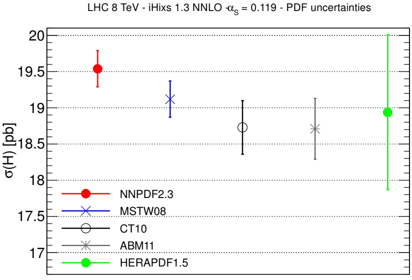


Sets extracted from all datasets produce similar and more precise results (**NNPDF**/**CT10**/**MSTW**)

Sets extracted from partial datasets have large uncertainties and less precision (**ABM**/**HERAPDF**).



(a) Top inclusive cross section.



(b) Higgs inclusive cross section.

- Waiting for **Higgs** cross section measurements!

Outline

Conclusion and outlook

1. NNPDF2.3 is the **first PDF set** including **all the LHC data**
2. The impact of LHC data is small but **non-negligible**
3. The paper will be impressed by Nuclear Physics B.

Outlook:

- Improvements of the code and the general structure.
- Near future: Electroweak corrections to PDFs, **photon** PDF.

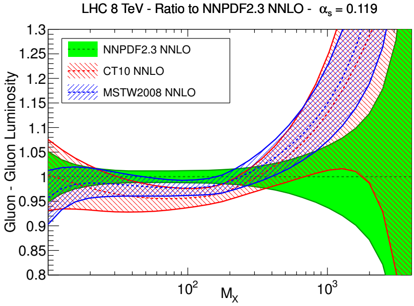
BACKUP SLIDES

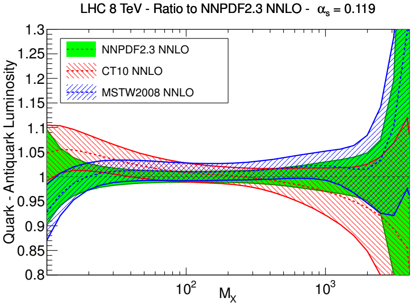
Luminosities at $\sqrt{s} = 8$ TeV

Luminosity is defined as

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

- Preliminary results: gg and $q\bar{q}$ luminosities at **8 TeV** (2012 runs)

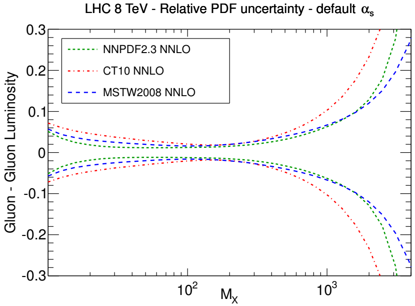


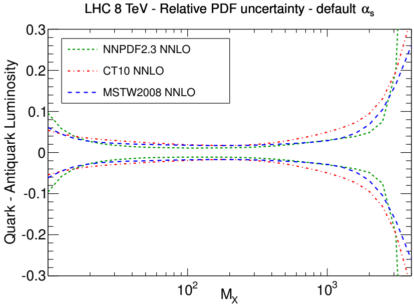


- All luminosities **are reasonably compatible** between **global PDF sets.**

PDF relative uncertainty

- Results: gg and $q\bar{q}$ luminosities PDF relative uncertainty at **8 TeV**.





- NNPDF2.3 with LHC data has **small relative uncertainties**
  $\Longrightarrow$ Improvement of **quality** in **theoretical predictions**.

Features

- Heavy quark mass effects included using the FONLL method up to NNLO,
  S. Forte et al., arXiv:1001.2312.
- FastKernel method for the inclusion of the higher order corrections
  The NNPDF Collaboration, arXiv:1002.4407
  - DIS up to NNLO
  - DY and JET up to NLO
- NNLO corrections to DY included by means of K-factors (DYNNLO)
- NNLO corrections to inclusive JET implement using FastNLO (hep-ph/0609285)
  - approximated NNLO corrections based on threshold resummation.

Data sets

- NLO/NNLO cuts
  - $W^2 = Q^2(1-x)/x > 12.5\,\text{GeV}^2$
  - $Q^2 > 3\,\text{GeV}^2$ + further cuts on F_2^c
- ATLAS W, Z lepton rapidity distributions cuts

$$p_T^l \geq 20\,\text{GeV}, \quad p_T^\nu \geq 25\,\text{GeV}, \quad m_T < 40\,\text{GeV}, \quad |\eta_l| \leq 2.5$$

$$p_T^l \geq 20\,\text{GeV}, \quad 66\,\text{GeV} \leq m_{l^+l^-} \leq 116\,\text{GeV}, \quad \eta_{l^+,l^-} \leq 4.9$$

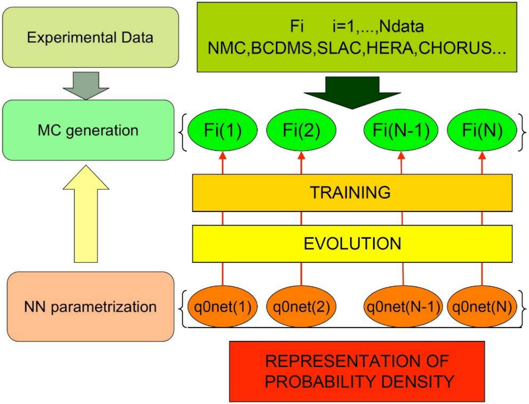
- CMS W electron asymmetry

$$p_T^e \geq 35\,\text{GeV}$$

- LHCb W, Z rapidity distribution

$$p_T^\mu \geq 20\,\text{GeV}, \quad 60\,\text{GeV} \leq m_{l^+l^-} \leq 120\,\text{GeV}, \quad 2.0 \leq \eta_{1,2}^\mu \leq 4.5$$

NNPDF mechanism



Neural Networks

- Neural Networks are defined as

$$\xi_i^{(l)} = g\left(\sum_{j=1}^{n_l - 1} \omega_{ij}^{(l-1)} \xi_j^{(l-1)} - \theta_i^{(l)}\right)$$

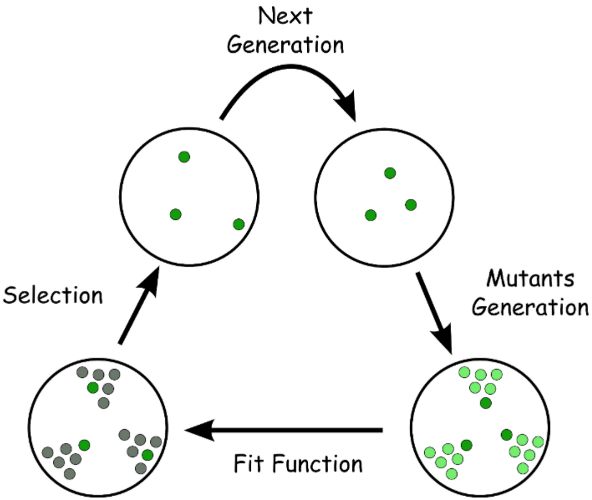
- $\omega_{ij}^{(l-1)}$ weights, $\theta_i^{(l)}$ thresholds, i^{th} neuron, l^{th} layer, where g is the sigmoid activation function:

$$g(x) \equiv \frac{1}{1 + e^{-x}}$$

- Example: Neural network 1-2-1

$$\xi_1^{(3)} = \left\{ 1 + \exp\left[\theta_1^{(3)} - \frac{\omega_{11}^{(2)}}{1 + e^{\theta_1^{(2)} - x\omega_{11}^{(1)}}} - \frac{\omega_{12}^{(2)}}{1 + e^{\theta_2^{(2)} - x\omega_{21}^{(1)}}} \right] \right\}^{-1}$$

Genetic algorithm



Training/validation method