News from NNPDF

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On behalf of the NNPDF Collaboration
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Standard Model Benchmarks at High-Energy Hadron Coliders
DESY (Zeuthen), June 15-17, 2011

NNPDF Methodology

Main Ingredients

- **Monte Carlo** determination of errors
  - No need to rely on linear propagation of errors
  - Possibility to test for the impact of non gaussianly distributed errors
  - Possibility to test for non-gaussian behaviour in fitted PDFs ($1 - \sigma$ vs. 68% CL)
- **Neural Networks**
  - Provide an **unbiased** parametrization
- **Stopping based on Cross-Validation**
  - Ensures proper fitting avoiding overlearning

NNPDF Methodology

... in a Nutshell

- Generate N_{rep} **Monte-Carlo replicas** of the experimental data (sampling of the probability density in the space of data)
- Fit a set of Parton Distribution Functions on each replica (sampling of the probability density in the space of PDFs)
- **Expectation values** for observables are **Monte Carlo integrals**

$$\langle \mathcal{F}[f_i(x,Q^2)] \rangle = \frac{1}{N_{rep}} \sum_{k=1}^{N_{rep}} \mathcal{F}\left(f_i^{(net)(k)}(x,Q^2) \right)$$

... the same is true for errors, correlations, etc.

Reweighting PDFs

Assessing the impact of new data on PDF fits

[R. D. Ball et al., arXiv:1012.0836]

- Inspired by Giele and Keller [hep-ph/9803393]
- The $N_{\rm rep}$ **replicas** of a NNPDF fit give the **probability density** in the space of PDFs
- **Expectation values** for observables are **Monte Carlo integrals**

$$\langle \mathcal{F}[f_i(x,Q^2)] \rangle = \frac{1}{N_{rep}} \sum_{k=1}^{N_{rep}} \mathcal{F}\left(f_i^{(net)(k)}(x,Q^2) \right)$$

(... the same is true for errors, correlations, etc.)

- We can **assess the impact** of including **new data** in the fit updating the probability density distribution.

Reweighting PDFs

Assessing the impact of new data on PDF fits

- According to **Bayes Theorem** we have

$$\mathcal{P}_{\rm new}(\{f\}) = \mathcal{N}_\chi \mathcal{P}(\chi^2|\{f\}) P_{\rm init}(\{f\}) \, , \quad \mathcal{P}(\chi^2|\{f\}) = [\chi^2(y,\{f\})]^{\frac{n_{dat}-1}{2}} e^{-\frac{\chi^2(y,\{f\})}{2}}$$

- **Monte Carlo integrals** are now **weighted sums**

$$\langle \mathcal{F}[f_i(x,Q^2)] \rangle = \sum_{k=1}^{N_{rep}} w_k \mathcal{F}\left(f_i^{(net)(k)}(x,Q^2) \right)$$

where the **weights** are

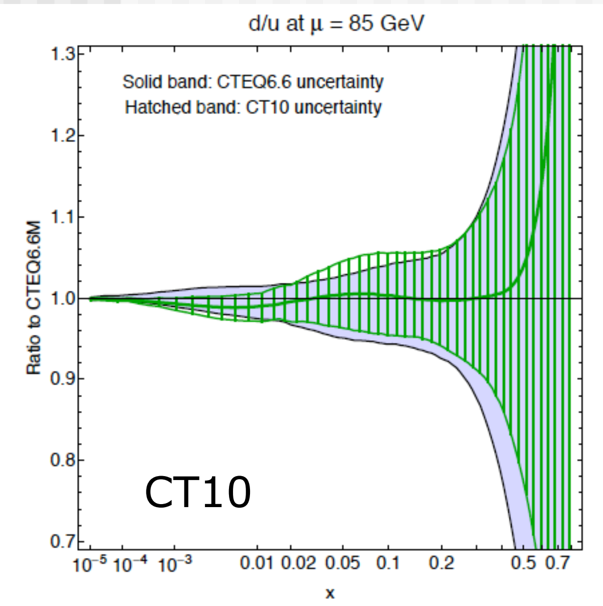
$$w_k = \frac{[\chi^2(y,f_k)]^{\frac{n_{dat}-1}{2}} e^{-\frac{\chi^2(y,f_k)}{2}}}{\sum_{i=1}^{N_{\rm rep}} [\chi^2(y,f_i)]^{\frac{n_{dat}-1}{2}} e^{-\frac{\chi^2(y,f_i)}{2}}}$$

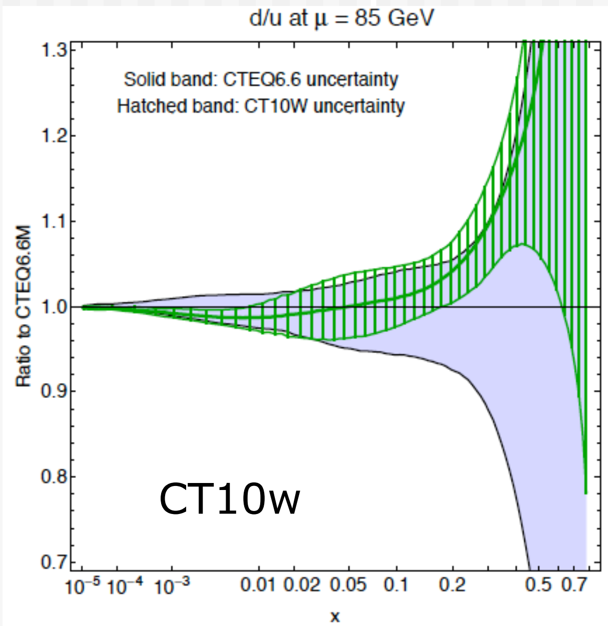
NNPDF2.2

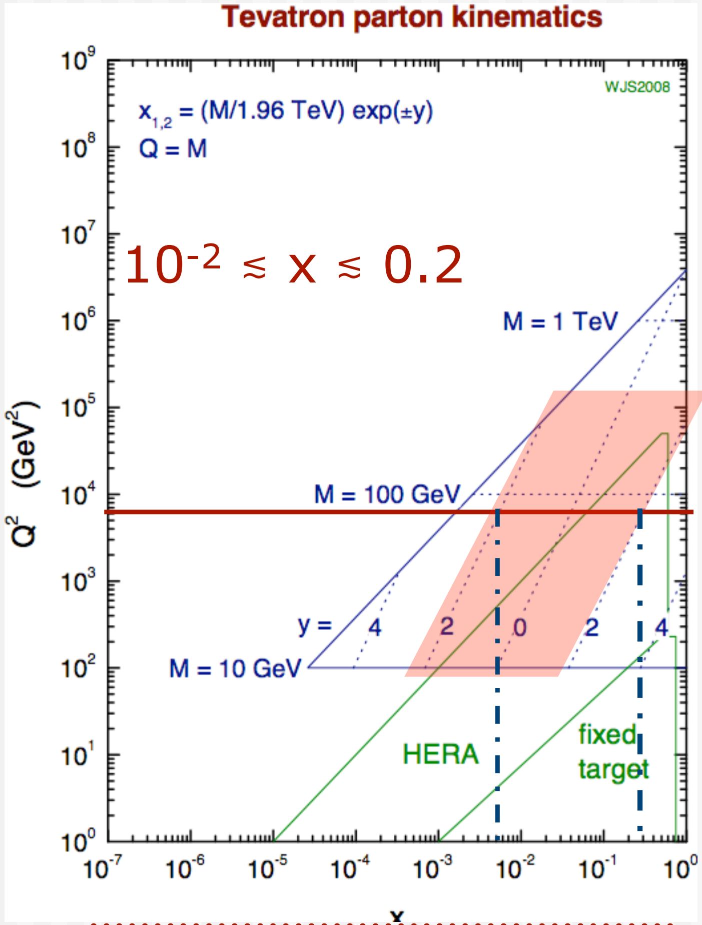
Including Tevatron & LHC W asymmetry data in NNPDF fits

The W lepton asymmetry
Tevatron Run II

- ✓ CDF W charge asymmetry is fitted in NNPDF2.1
  [ArXiv:0901.2169]
- ➔ D0 muon charge asymmetry in single p_T^{μ} bin
  [ArXiv:0709.4254]
- ➔ D0 electron charge asymmetry combined and separated p_T^{e} bins :
  [ArXiv: 0807.3367]







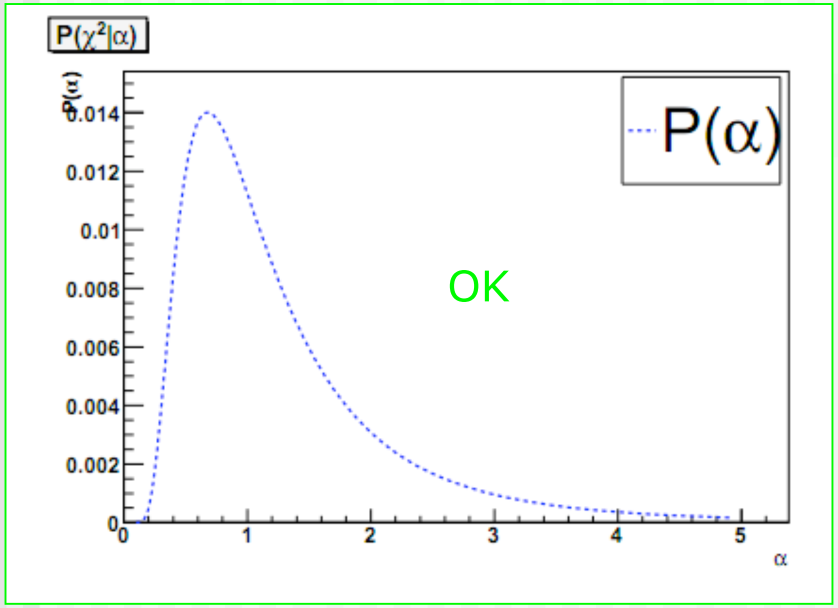
$$\frac{u(x_1)d(x_2) - d(x_1)u(x_2)}{u(x_1)d(x_2) + d(x_1)u(x_2)}$$

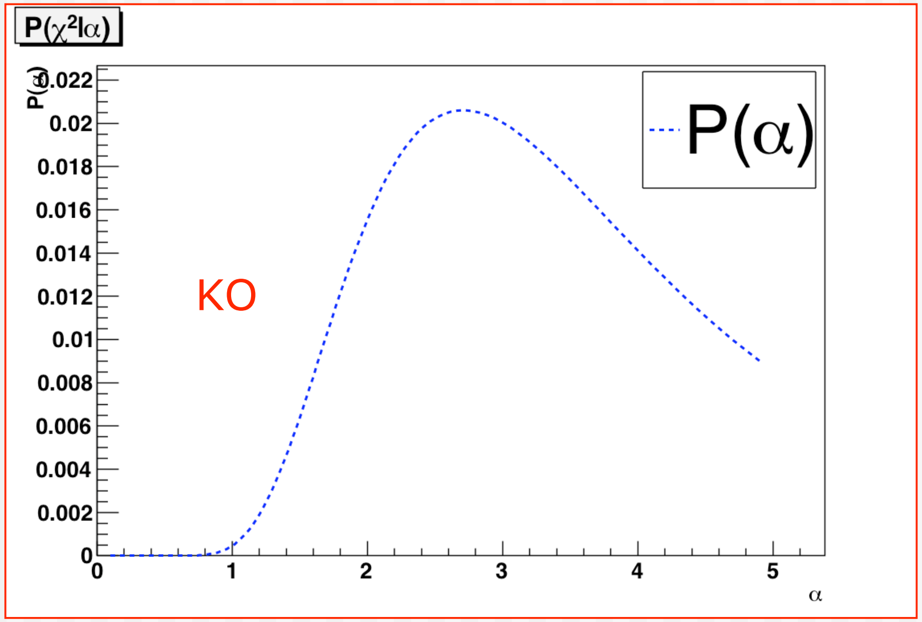
The W lepton asymmetry
Tevatron Run II

H. Schellman, DIS 2011

Reweighting analysis
[NNPDF, ArXiv:1012.0836]
✓ It is possible to include D0 lepton asymmetry inclusive data in global analyses: no need of producing separate sets
✓ Issues with exclusive bins

□ Need to encourage use of least sensitive observable – either a very inclusive lepton asymmetry or the W asymmetry itself





Inclusive bins in p^T_{muon}

Exclusive bins in p^T_{el}

The W lepton asymmetry
Tevatron Run II

Reweighting analysis
[NNPDF, ArXiv:1012.0836]
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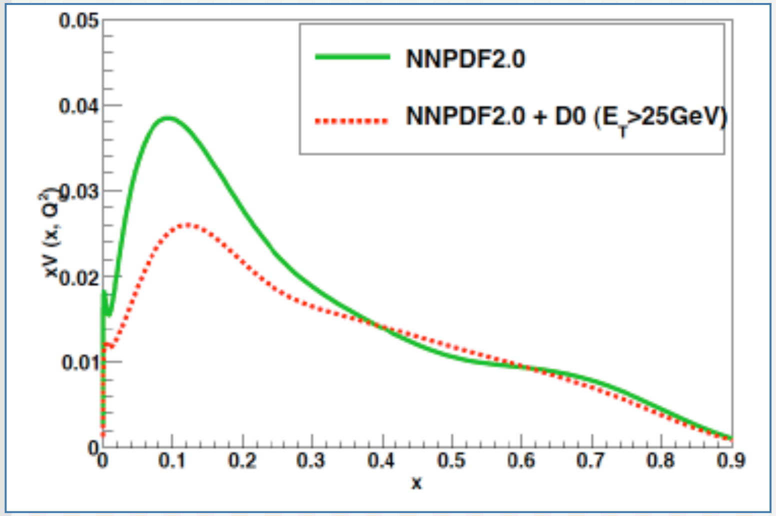
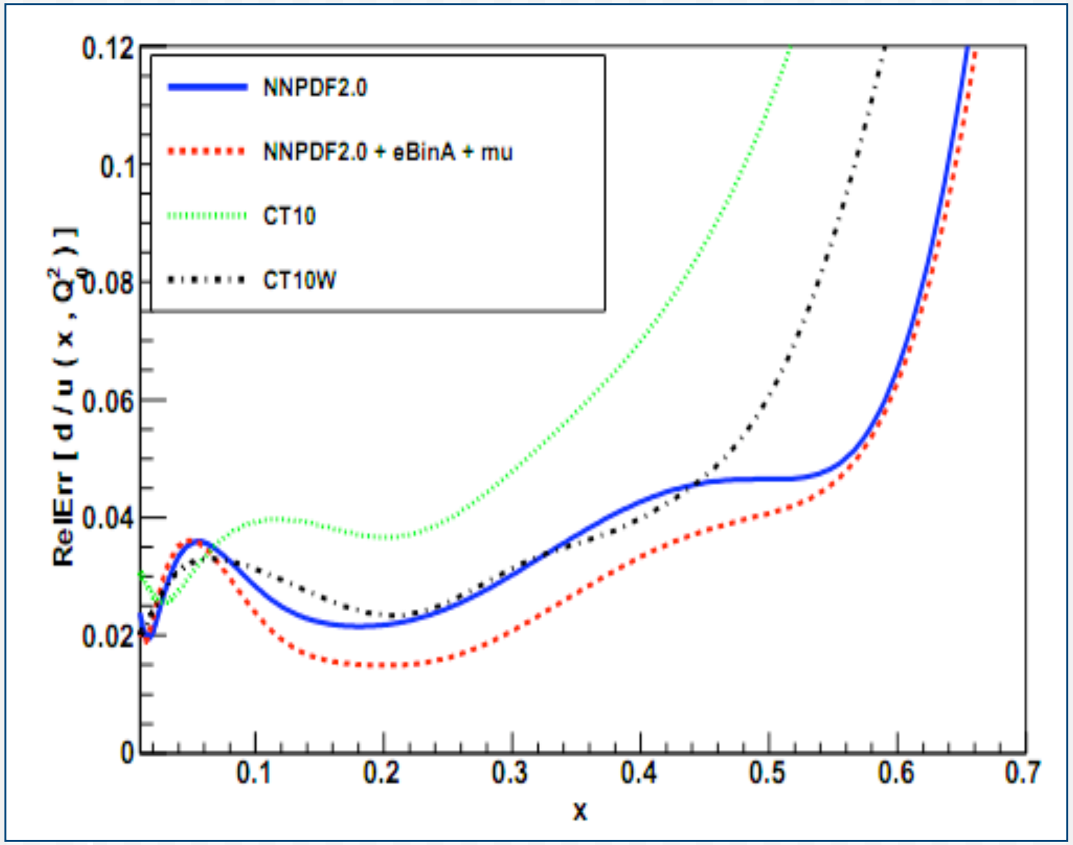




Reduction of the valence PDFs uncertainty and on the d/u ratio!

The W lepton asymmetry
LHC @ 7TeV measurements

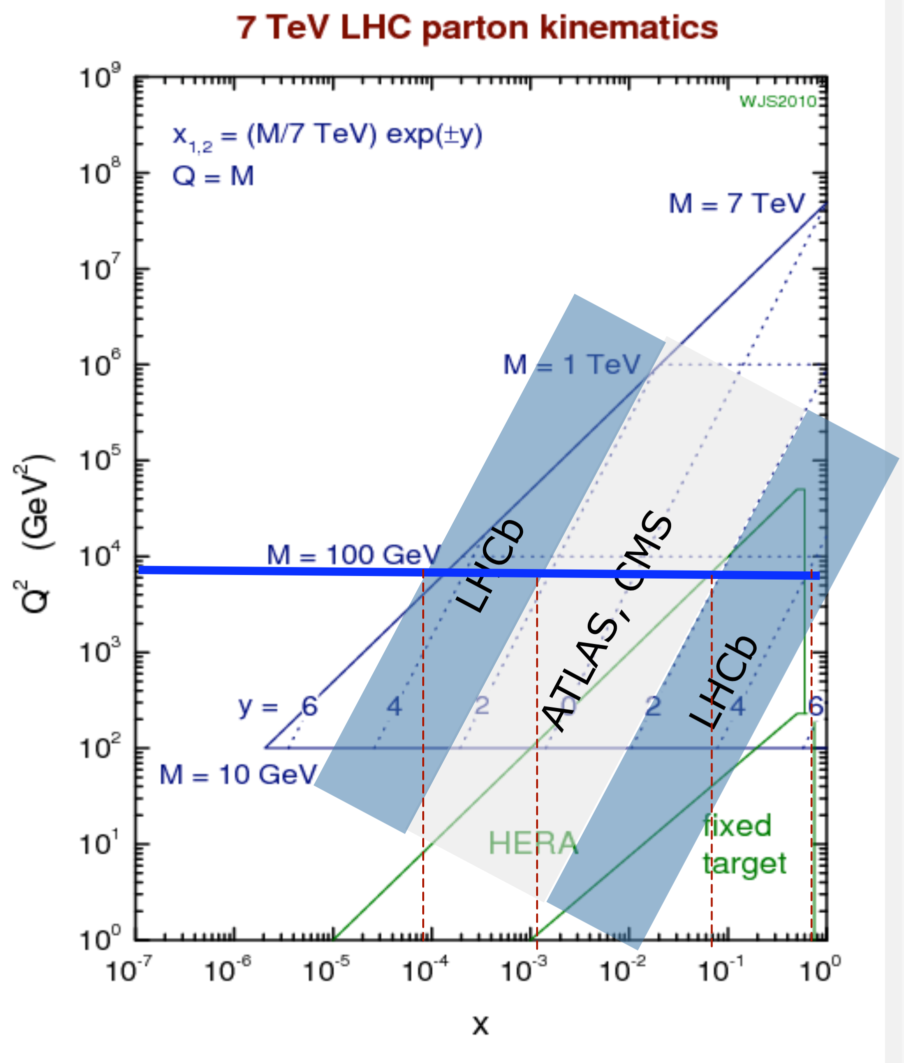
$$A_l = \frac{d\sigma(l^+)/dy(l^+) - d\sigma(l^-)/dy(l^-)}{d\sigma(l^+)/dy(l^+) + d\sigma(l^-)/dy(l^-)}$$

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

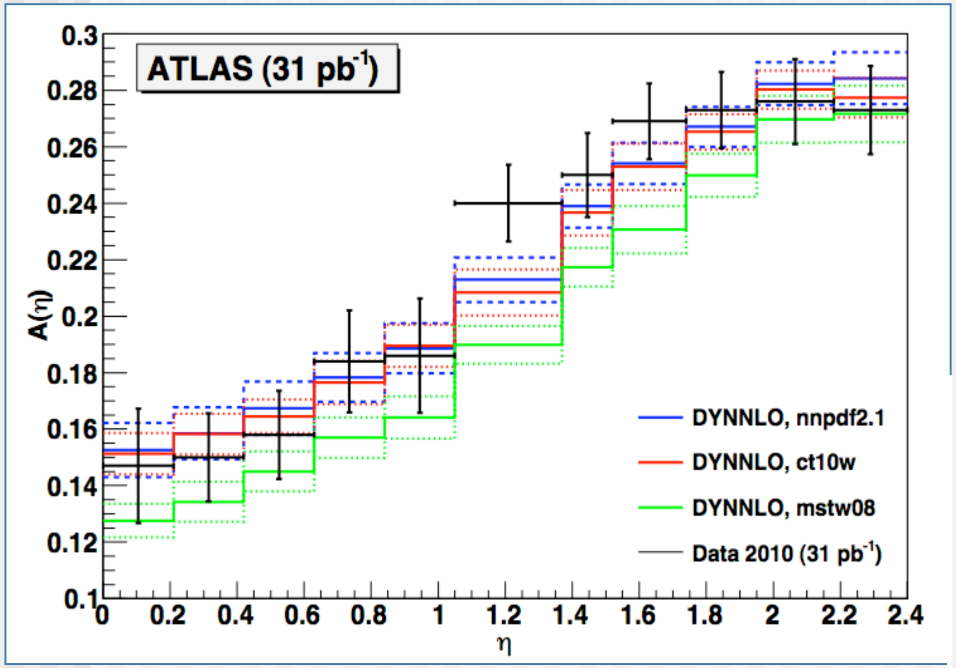
✓ **ATLAS:**
W muon charge asymmetry ($31pb^{-1}$)
ArXiv: 1103.2929

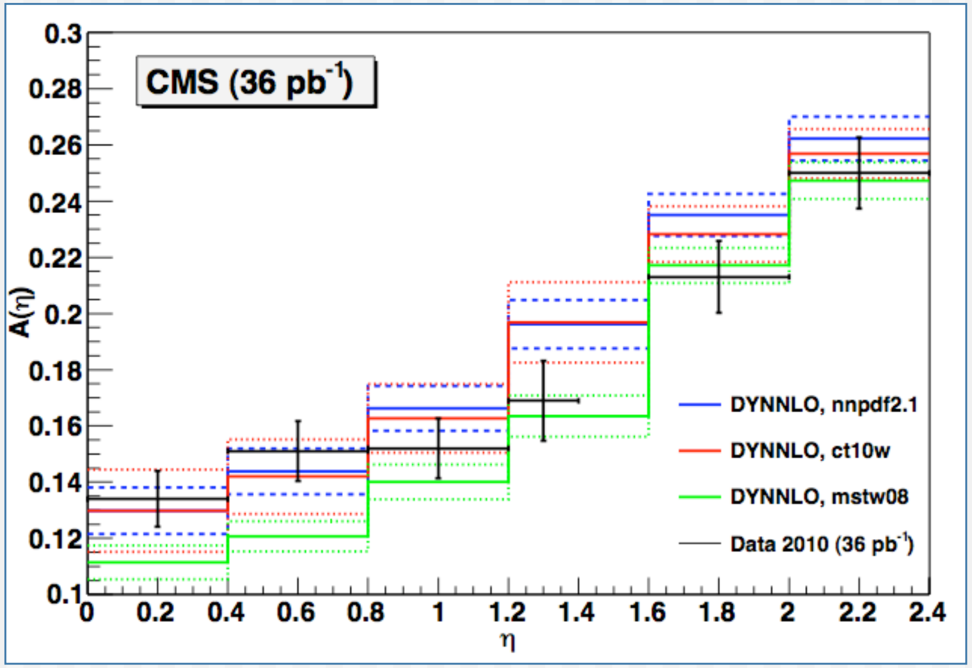
✓ **CMS:**
W muon and electron charge asymmetry ($36pb^{-1}$)
ArXiv: 1103.3470

× **LHCb:**
Preliminary forward W muon charge asymmetry ($16.5pb^{-1}$)
Not corrected for FSR radiation



The W lepton asymmetry
LHC @ 7TeV predictions

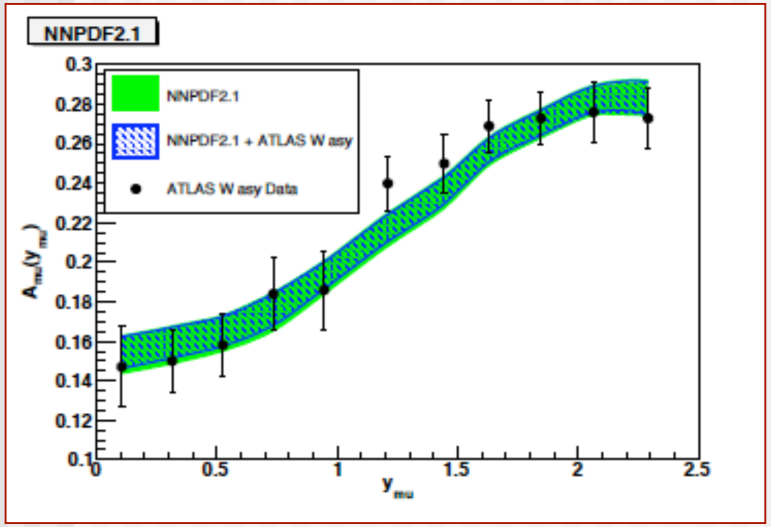




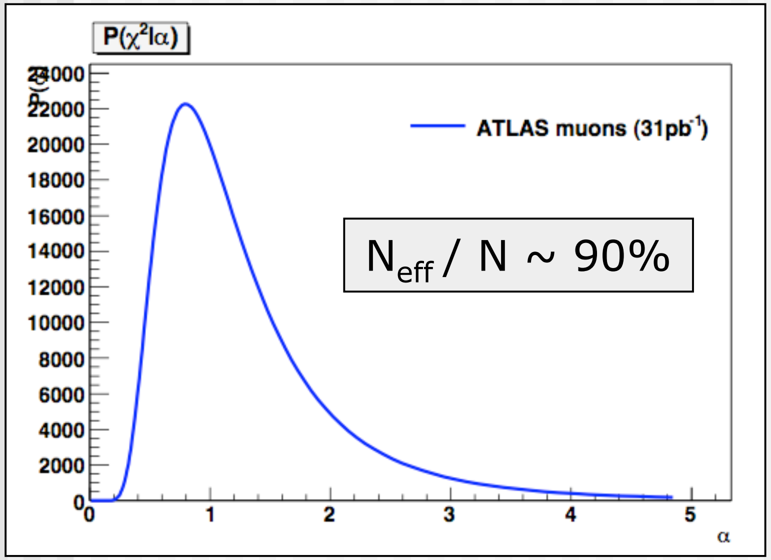
NLO theoretical predictions obtained with DYNNLO
[ArXiv: 0903.2120]

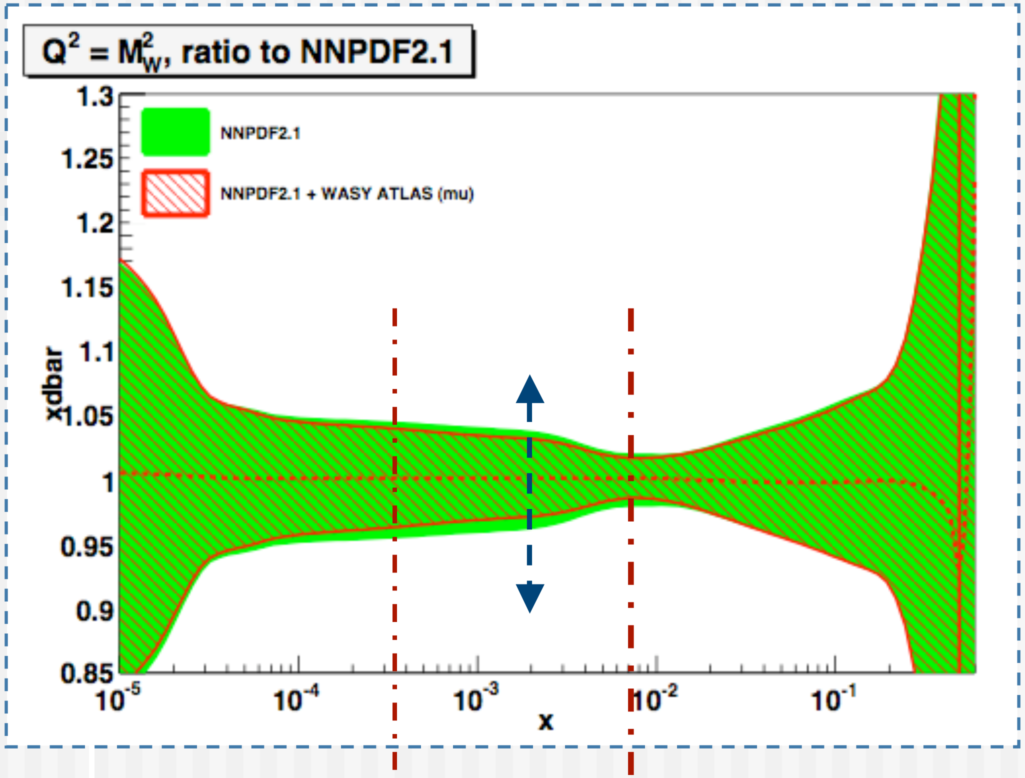
χ^2/d.o.f.	NNPDF2.1	CT10w	MSTW08
ATLAS(31pb^{-1}) muon $p_T > 20$ GeV	0.7	0.8	3.2
CMS(36pb^{-1}) electron $p_T > 25$ GeV	1.9	0.8	2.4
CMS(36pb^{-1}) electron $p_T > 30$ GeV	1.7	1.2	2.5
CMS(36pb^{-1}) muon $p_T > 25$ GeV	1.3	0.5	1.1
CMS(36pb^{-1}) muon $p_T > 30$ GeV	0.8	0.6	1.3

The W lepton asymmetry
LHC @ 7TeV, ATLAS data

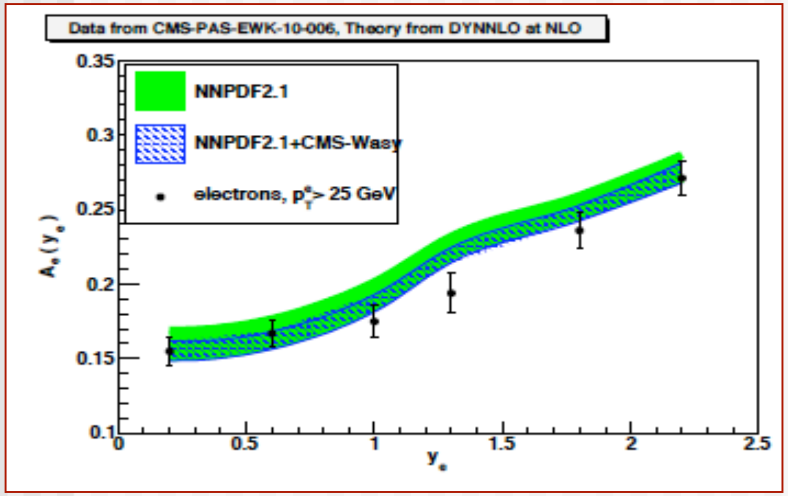


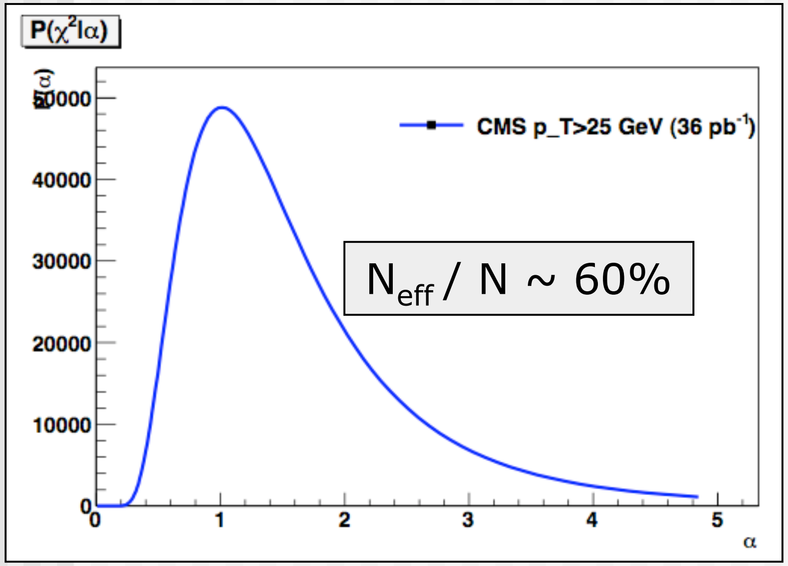
- Data compatible with data included in global PDF analysis
- Slight reduction of uncertainty at medium-small x for light (anti)quark



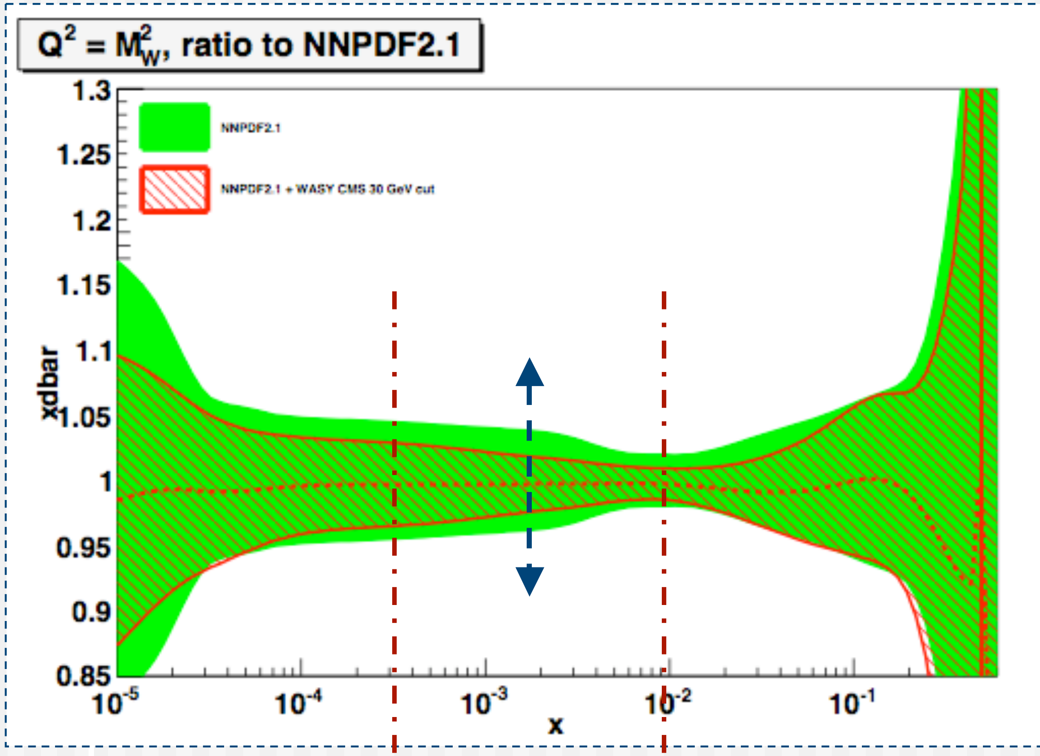


The W lepton asymmetry
LHC @ 7TeV, CMS data



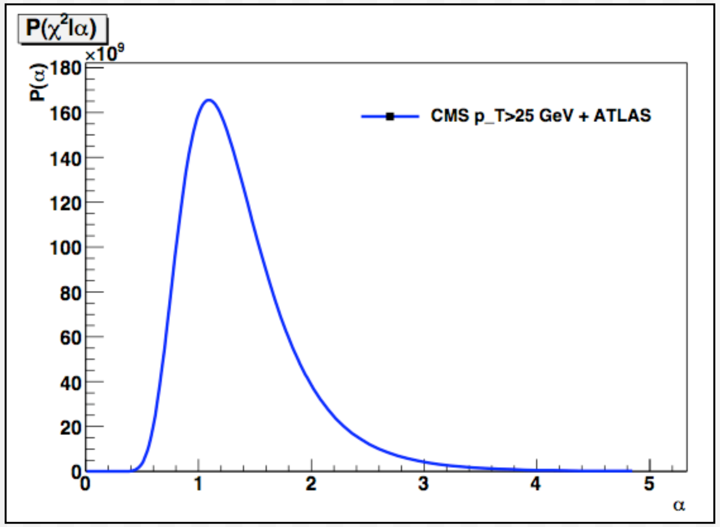


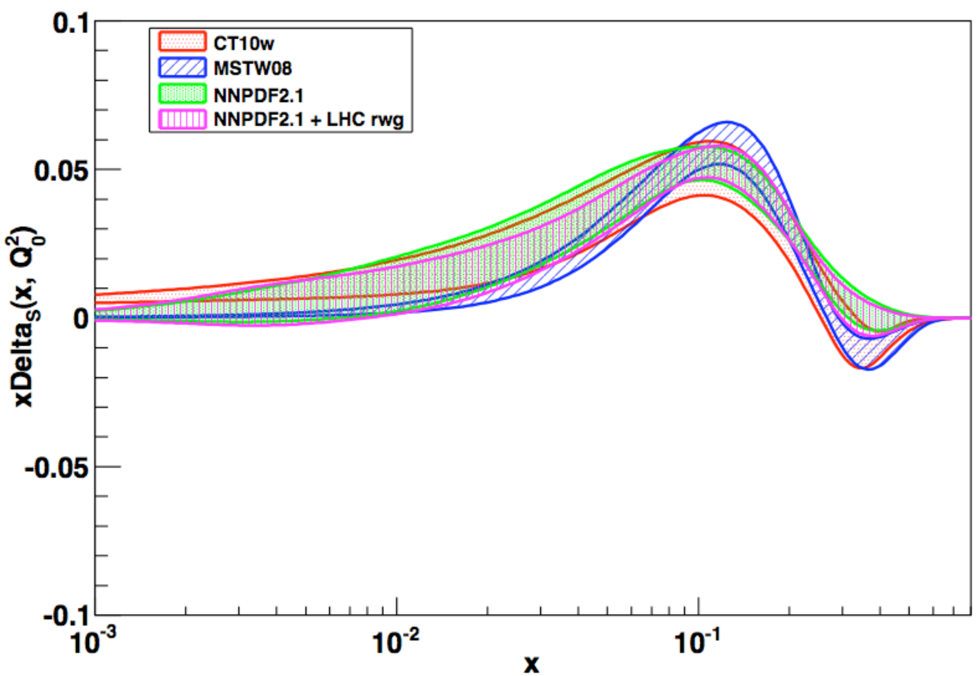
- Data compatible with data included in global PDF analysis
- Significant reduction of uncertainty at medium-small x for light (anti)quark



The W lepton asymmetry
LHC @ 7TeV, ATLAS & CMS data

Data/χ^2	NNPDF2.1	NNPDF2.1 + rwt SET
ATLAS + CMS $p_T^l > 25$ GeV	1.0	0.9
ATLAS + CMS $p_T^l > 30$ GeV	1.2	1.0





- ATLAS and CMS data can be added at the same time, no clear signs of tension
- CMS data are more constraining than ATLAS data.
- Inclusion of data in PDFs fits reduces uncertainty of more than 40% in the small-medium x region for light (anti)quark PDFs

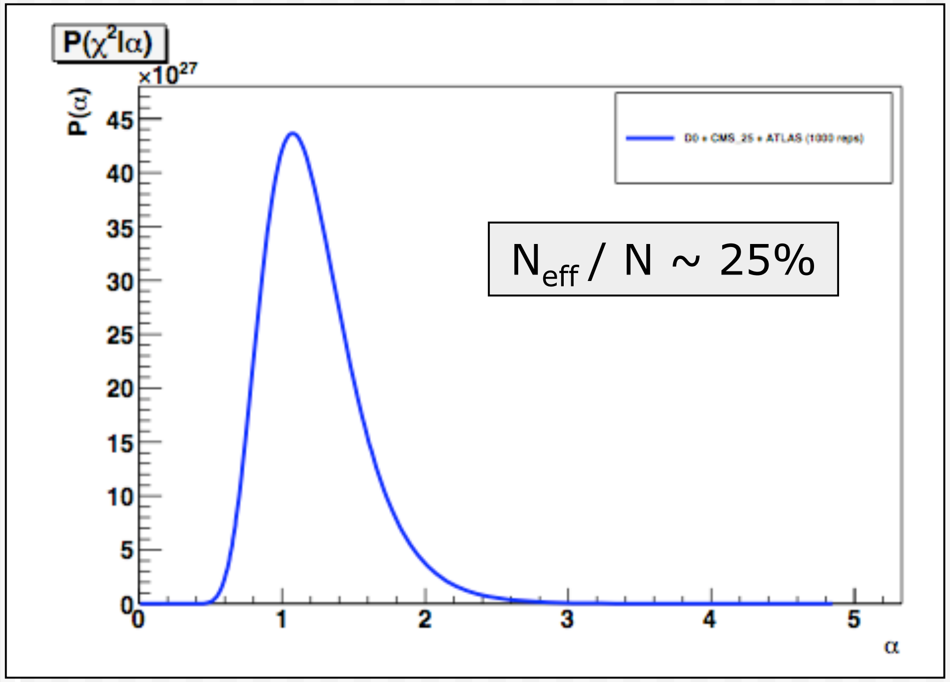
The W lepton asymmetry
Can we combine Tevatron and LHC data?

	NNPDF2.1	NNPDF2.1 + TeV + LHC
χ^2	2.0	0.7

✓ YES data are very constraining on PDFs but compatible with data included in the global analyses

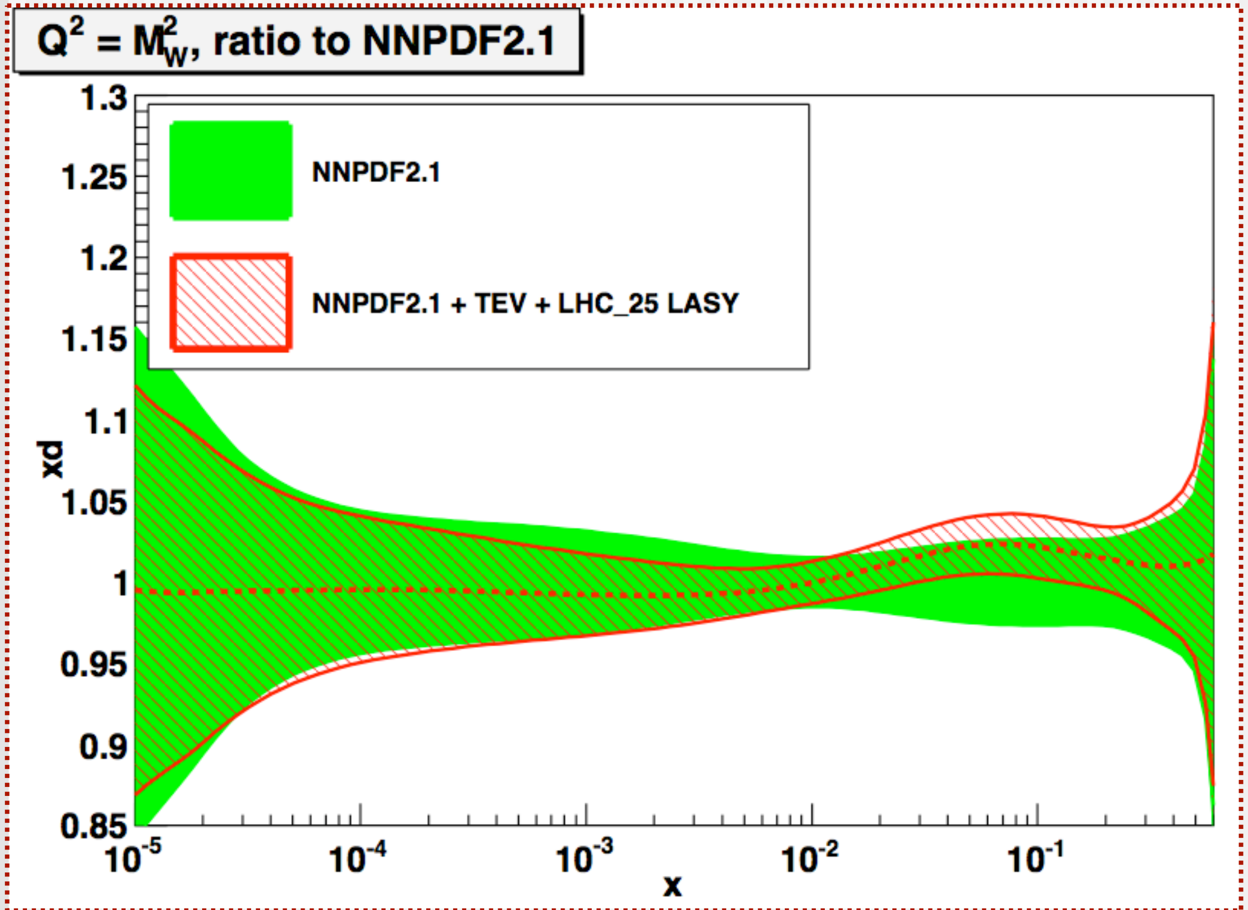
✓ After reweighting the reweighted set fits very well both Tevatron (D0 muon and D0 electron inclusive) and LHC (ATLAS and CMS) W lepton asymmetry data

✓ The description of W asymmetry from CDF does not deteriorate



What about the PDFs central values and PDFs uncertainty?

The W lepton asymmetry
Can we combine Tevatron and LHC data?

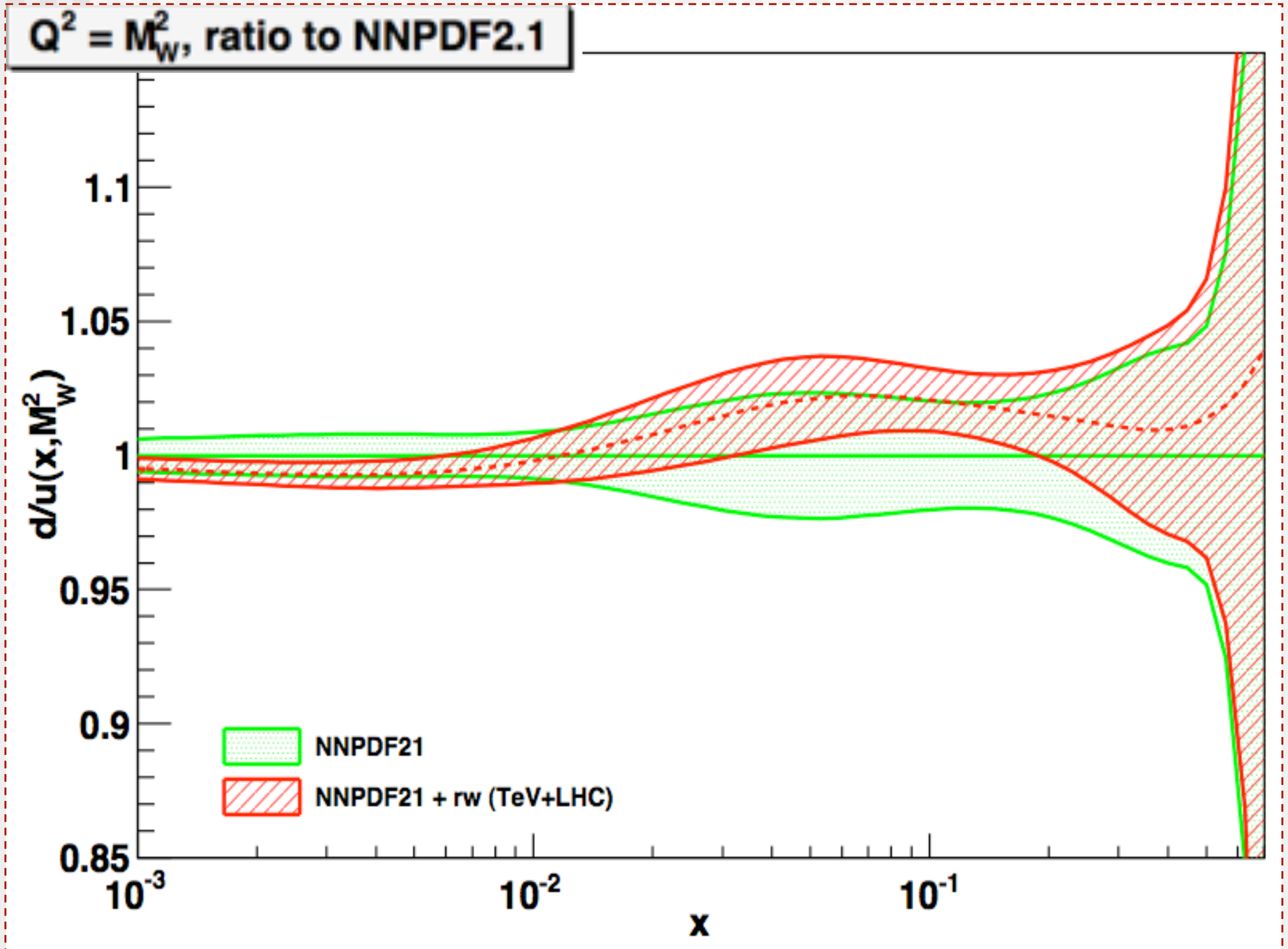


✓ Reduction of uncertainty of light quark and anti-quark PDFs in small-medium x region is driven by LHC data.

✓ Shift and reduction of uncertainty in light quark PDFs driven by D0 Tevatron data.

NNPDF2.2 parton set including these data is going to be available soon on LHAPDF

The W lepton asymmetry
Can we combine Tevatron and LHC data?



- ✓ Reduction of uncertainty of light quark and anti-quark PDFs in small-medium x region is driven by LHC data.
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NNPDF2.2 parton set including these data is going to be available soon on LHAPDF

NNPDF2.1@NNLO

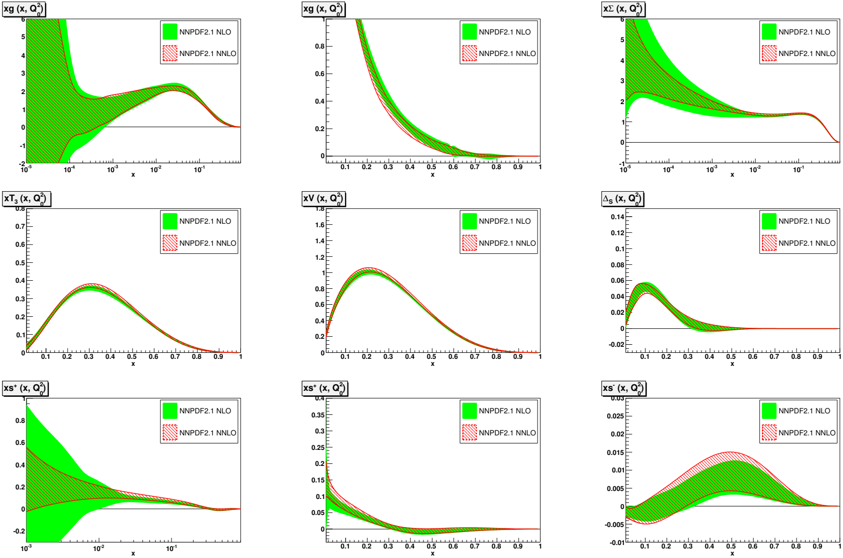
NNPDF2.1@NNLO

General Setup

- Same **dataset** as **NNPDF2.1 NLO**
  (DIS, Drell-Yan, EWB and Inclusive Jet production at colliders).
- **Heavy quark mass effects** treated in the **FONLL-C** General Mass Variable Falvour Number Scheme.
  ($\mathcal{O}(\alpha_S^2)$ massless + $\mathcal{O}(\alpha_S^2)$ massive contributions).
- **NNLO corrections** to fixed-target **Drell-Yan** and Electroweak Vector Boson production cross-sections implemented as **local NNLO/NLO K-factors**.
- PDFs at the initial scale are parametrized with the **same redundant paramertrization** used in the NLO fits (**259 parameters**)

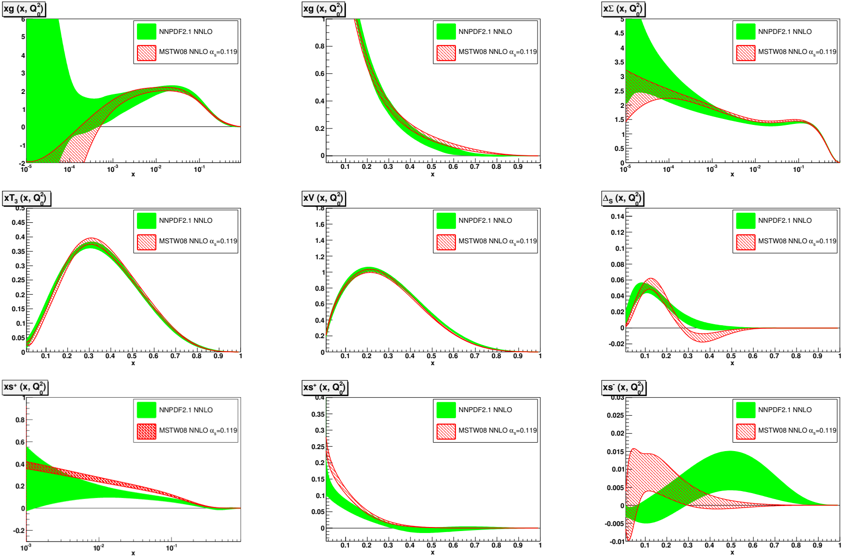
NNPDF2.1@NNLO

Partons - Comparison to NLO



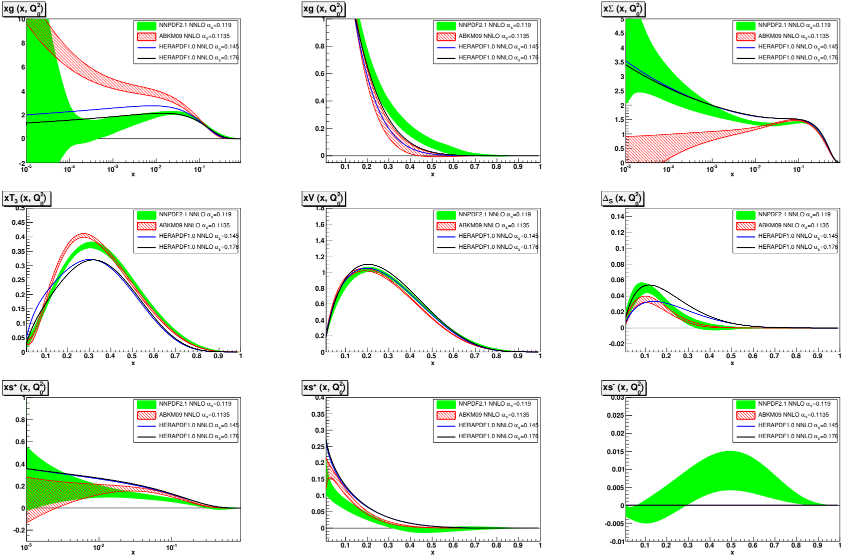
NNPDF2.1@NNLO

Partons - Comparison to MSTW08

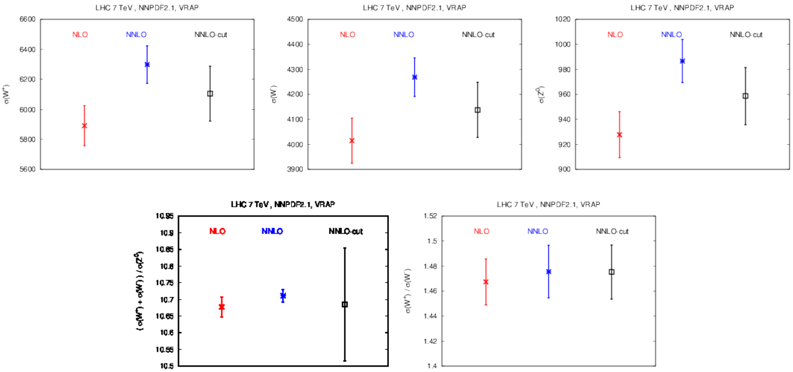


NNPDF2.1@NNLO

Partons - Comparison to ABKM09 and HERAPDF1.0



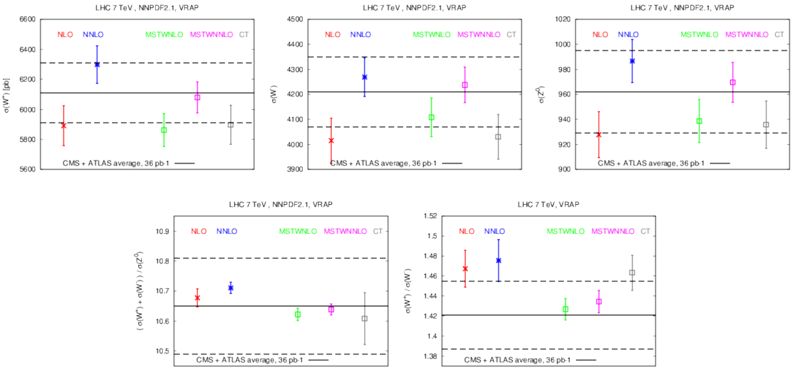
- Predictions for **LHC Standard Candles** compared to **NLO results**



NNPDF2.1@NNLO

Phenomenology - LHC Standard Candles

- Predictions for **LHC Standard Candles** compared to **LHC data**

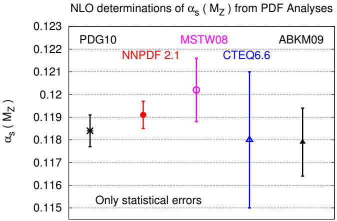


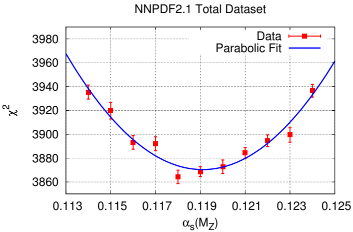
$\alpha_S(M_Z)$ determination from NNPDF analysis

$\alpha_s(M_Z)$ *from PDF analysis*

[S. Lionetti et al., arXix:1103.2369]

- **The Good**: Large dataset
  $\Longrightarrow$ **Small statistical errors**
- **The Bad**: Best fit α_S and PDFs are correlated
  $\Longrightarrow$ **Parametrization bias**? **Dataset Dependence**?
- **The Ugly**: Need to tame statistical fluctuations in χ^2
  $\Longrightarrow$ **Large replica samples!**

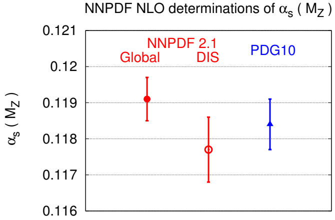




$\alpha_s(M_Z)$ *from PDF analysis*

Dependence of $\alpha_s\,(M_Z)$ on the dataset

	$\alpha_s\,(M_Z)$
NNPDF2.1	$0.1191 \pm 0.0006^{\mathrm{stat}}$
NNPDF2.1 DIS–only	$0.1177 \pm 0.0009^{\mathrm{stat}}$
NNPDF2.0	$0.1168 \pm 0.0007^{\mathrm{stat}}$
NNPDF2.0 DIS–only	$0.1145 \pm 0.0010^{\mathrm{stat}}$



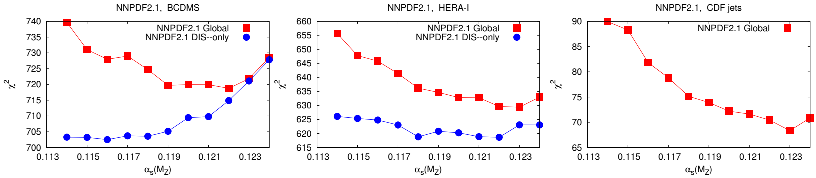
- Do DIS data prefer a smaller value of α_s?

  Maybe (but not much smaller), and anyway **compatible with the value from global fit** and with **larger uncertainties**.

- Theoretical uncertainties likely dominant (*Ex.* $\Delta\alpha_s^{\mathrm{HQ}} \sim 0.002$)

$\alpha_s(M_Z)$ ***from PDF analysis***

$\alpha_s\,(M_Z)$ from individual experiments



- BCDMS in a DIS–only fit sometimes has runaway direction at small $\alpha_s\,(M_Z)$, absent in the global fit
- HERA rather flat in α_s in DIS–only fit
- Tevatron jet experiments exclude small $\alpha_s\,(M_Z)$ values

Significant interplay between DIS and hadronic data

Conclusions

- Parton Distribution Functions are a fundamental ingredient for **precision LHC phenomenology**.
- The NNPDF Methodology combining Monte Carlo techinques and Neural Networks provides a way to address problems affecting standard fits.
- Inclusion of **Tevatron and LHC W asymmetry data in global fit** possible without generating a tension with other datasets $\Longrightarrow$ **NNPDF2.2** available soon in LHAPDF.
- **NNLO** is necessary for comparison to **high precision Benchmark measurements** $\Longrightarrow$ **NNPDF2.1@NNLO** analysis almost complete, available in LHAPDF soon.
- Extraction of strong coupling constant from NNPDF analysis performed at NLO. NNLO will come in due time.

BACKUP SLIDES

PDF Uncertainties and Correlations

A practitioner's guide to NNPDF predictions

Central Value

$$\langle \mathcal{F} \rangle = \frac{1}{N_{\rm set}} \sum_{k=1}^{N_{\rm set}} \mathcal{F}[q^{(k)}]$$

Standard Deviation

$$\sigma_{\mathcal{F}} = \left(\frac{1}{N_{N_{\rm set}}} \sum_{k=1}^{N_{\rm set}} \left(\mathcal{F}[\{q^{(k)}\}] - \langle \mathcal{F}[\{q\}] \rangle \right)^2 \right)^{1/2}$$

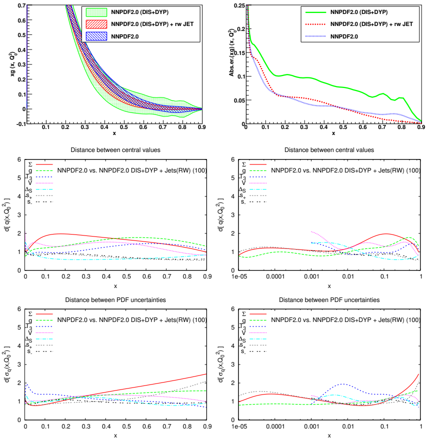
Correlation

$$\rho \equiv \cos \varphi(\mathcal{F}, \mathcal{G}) = \frac{< \mathcal{F}\, \mathcal{G} >_{\rm rep} - < \mathcal{F} >_{\rm rep} < \mathcal{G} >_{\rm rep}}{\sqrt{< \mathcal{F}^2 >_{\rm rep} - < \mathcal{F} >^2_{\rm rep}} \sqrt{< \mathcal{G}^2 >_{\rm rep} - < \mathcal{G} >^2_{\rm rep}}}$$

Reweighting PDFs

Proof-of-concept: Inclusive Jet data, reweighting vs. refitting

- Use **DIS+DY-fit** as **prior** probability distribution
- Add Tevatron Inclusive Jet data through refitting and through reweighting
- **Reweighting** and **refitting** yield **statistically equivalent** results

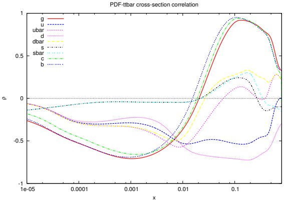


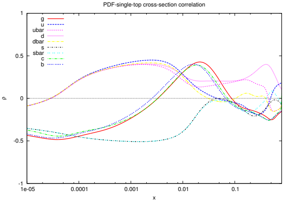
PDF induced correlations

Ex.: Top-quark studies within the NNPDF framework

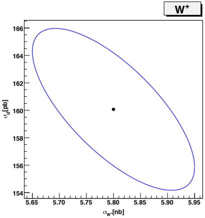
[J. Rojo and AG, arXiv:1008.4671]

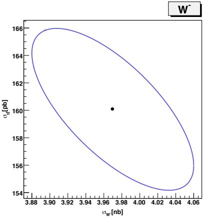
- It is easy to compute **correlations** between **PDFs and observables**

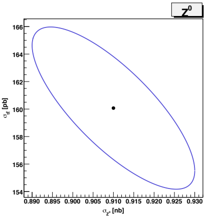




- ... or **pairs of observbles**



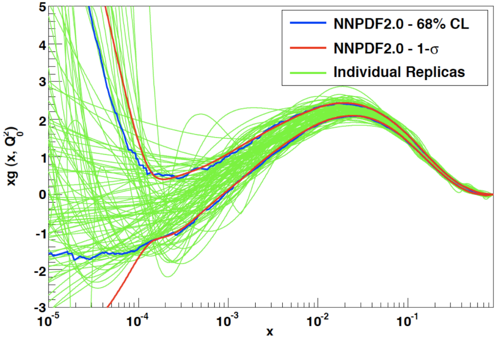




Confidence Level Intervals

Testing for non gaussian distribution of fitted PDFs

- **Confidence Level intervals** can be computed directly from the replicas distribution
- Comparison of 68% C.L. and symmetric 1σ especially in extrapolation regions where theory constraints dominate on experimental information



- A **generic DIS observable** in the FONLL scheme is written as:

$$F^{FONLL}(x,Q^2) = \mathcal{D}(Q^2)F^{(d)}(x,Q^2) + F^{(n_l)}(x,Q^2)$$

where the **threshold damping factor** is given by

$$\mathcal{D}(Q^2) = \theta(Q^2 - m^2)\left(1 - \frac{m^2}{Q^2}\right)$$

and the **subtraction term** is

$$F^{(d)} = \left[F^{(n_l+1)}(x,Q^2) - F^{(n_l,0)}(x,Q^2)\right]$$

with the massless limit of the massive contributions being

$$F^{n_l,0}(x,Q^2) = x\int_x^1 \frac{dy}{y} \sum_{i=q,\bar{q},g} B_i^{(0)}\left(\frac{x}{y}, \frac{Q^2}{m^2}, \alpha_S^{(n_l+1)}(Q^2)\right) f_i^{(n_l+1)}(y,Q^2)$$

with

$$\lim_{m\to 0}\left[B_i\left(x,\frac{Q^2}{m^2}\right) - B_i^{(0)}\left(x,\frac{Q^2}{m^2}\right)\right] = 0$$