PDFs and top physics

Alberto Guffanti

Albert-Ludwigs-Universität Freiburg

Top2010

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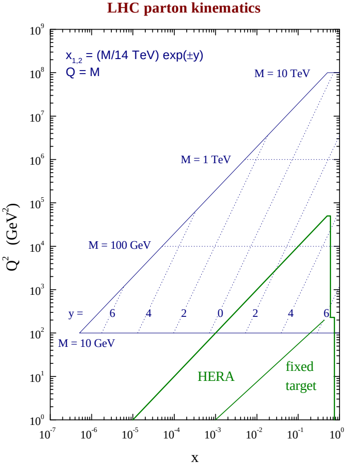
Why care about PDFs (and their uncertainties)?



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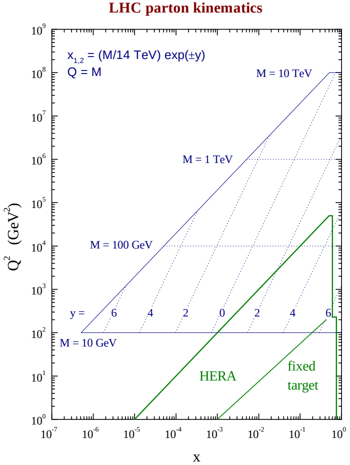

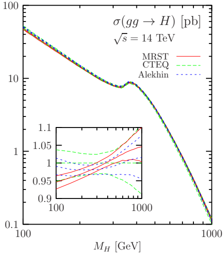

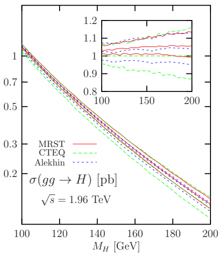

[A. Djouadi and S. Ferrag, hep-ph/0310209]

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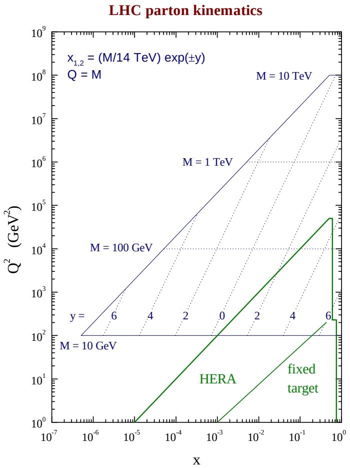

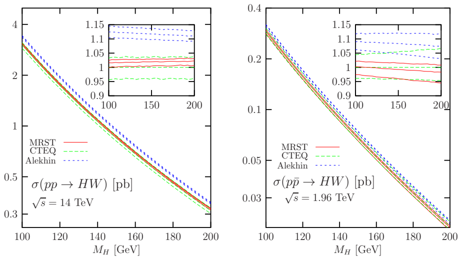

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Why care about PDFs (and their uncertainties)?

- Errors on PDFs are in some cases the dominating theoretical error on precision observables

Ex. $\sigma(Z^0)$ at the LHC: $\delta_{PDF} \sim 3\%$, $\delta_{NNLO} \sim 2\%$

[J. Campbell, J. Huston and J. Stirling, (2007)]

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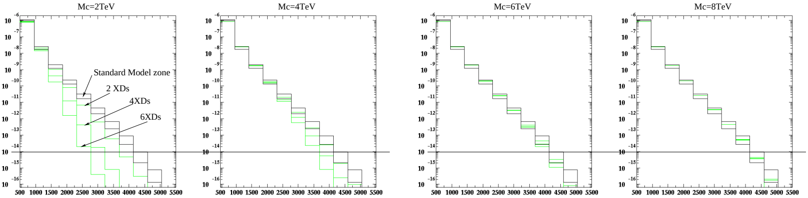
- Errors on PDFs might reduce sensitivity to New Physics

Ex. Extra Dimensions discovery in dijet cross section at the LHC:



[S. Ferrag (ATLAS), hep-ph/0407303]

PDF determination

Recent and ongoing effort

- Considerable **effort and progress** in understanding features of PDF fits in recent years
  - **HERA-LHC** Workshop (2004-2007)
  - **PDF4LHC** (2007-ongoing)
  - **Systematic bemchmarking** of predictions for Standard Candle processes from different PDF sets
  - **LHAPDF** as a common interface to easily access up-to-date PDF fits
- Discussion points:
  - Global vs. Restricted dataset fits
  - Parametrization bias
  - Heavy Flavour contributions treatment
  - Error determination
  - Handling of inconsistencies among datasets
  - Combination of PDF and α_s uncertainties
  - ....

PDF fits

CTEQ-TEA

[Q.-H. Cao, J. Houston, H.-L. Lai, P. Nadolsky, J. Pumplin, D. Stump, W. K. Tung and C.-P. Yuan]

- **Latest release**: CTEQ6.6
- **Dataset**: Global (DIS, Drell-Yan Inclusive Jet at Tevatron)
- **Perturbative order**: NLO (K factors for hadronic observables)
- **Heavy Flavours**: GM-VFNS (ACOT-χ)
- α_s: Fixed in the fit ($\alpha_s(M_Z) = 0.118$), sets with different α_s values avbailable
- **Parametrization**: Standard functional form (22 parameters)
- **Error treatment**: Hessian - Tolerance ($\Delta\chi^2 = 100$)

PDF fits

MSTW

[A. Martin, J. Stirling, R. Thorne and G. Watt]

- **Latest release**: MSTW2008
- **Dataset**: Global (DIS, Drell-Yan, Inclusive Jet at Tevatron)
- **Perturbative order**: LO/NLO/NNLO (K factors for Drell-Yan)
- **Heavy Flavours**: GM-VFNS (TR)
- α_s: Determined in the fit alongside PDF parameters
- **Parametrization**: Standard functional form (29 (20) parameters)
- **Error treatment**: Hessian - Tolerance ($\langle \Delta\chi^2 \rangle \sim 25$)

PDF fits

NNPDF

[R. D. Ball, L. Del Debbio, S. Forte, J. .I. Latorre, J. Rojo, M. Ubiali and AG]

- **Latest release**: NNPDF2.0
- **Dataset**: Global (DIS, Drell-Yan, Inclusive Jet at Tevatron)
- **Perturbative order**: NLO (Exact)
- **Heavy Flavours**: ZM-VFNS
- α_s: Fixed in the fit ($\alpha_s(M_Z) = 0.119$), sets with different α_s values avbailable
- **Parametrization**: Neural Networks (259 parameters)
- **Error treatment**: Monte Carlo

PDF fits

ABKM

[S. Alekhin, J. Blümlein, S. Klein and S. O. Moch]

- **Latest release**: ABKM09
- **Dataset**: DIS and Fixed Target Drell-Yan
- **Perturbative order**: NLO/NNLO (Exact)
- **Heavy Flavours**: 3F-/5F-FFNS
- α_s: Determined in the fit alongside PDFs parameters
- **Parametrization**: Standard functional form (24 parameters)
- **Error treatment**: CME ($\Delta\chi^2 = 1$)

PDF fits
HERAPDF

[H1 & Zeus Collaborations]

- **Latest release**: HERAPDF1.0
- **Dataset**: Only combined HERA-I data
- **Perturbative order**: NLO (Exact)
- **Heavy Flavours**: GM-VFNS (TR)
- α_s: Fixed in the fit ($\alpha_s(M_Z) = 0.1176$), sets with different α_s values available
- **Parametrization**: Standard functional form (11 parameters) + model variations
- **Error treatment**: Hessian/Offset ($\Delta\chi^2 = 1$)

PDF fits

GJR

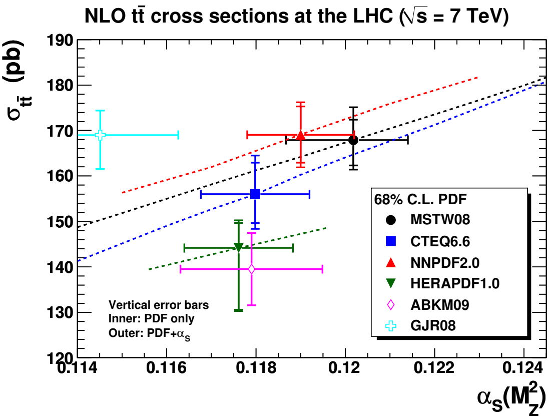
[M. Glück, P. Jimenez-Delgado and E. Reya]

- **Latest release**: GJR08/JR09
- **Dataset**: DIS, Fixed Target Drell-Yan
- **Perturbative order**: LO/NLO/NNLO (Exact)
- **Heavy Flavours**: FFNS/VFNS
- α_s: Determined in the fit
- **Parametrization**: Standard functional form (13 parameters), dynamical PDFs assumption
- **Error treatment**: Hessian ($\Delta\chi^2 = 1$)

$t\bar{t}$ cross-section

PDF sets comparison

[G. Watt, PDF4LHC Workshop]

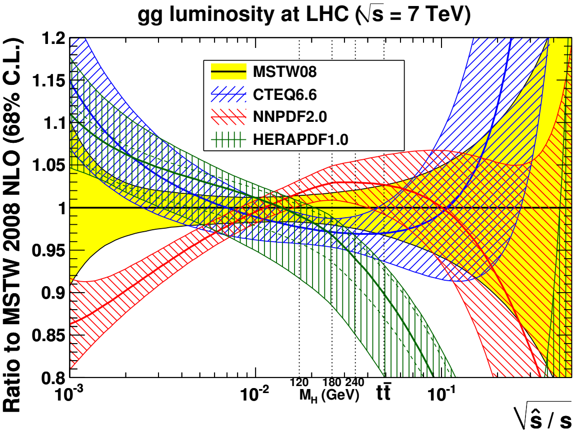


- Global fits predictions agree within $1-\sigma$ if combined $\alpha_s + PDF$ uncertainties are taken into account.

$t\bar{t}$ cross-section

PDF sets comparison

- The $t\bar{t}$ cross-section probes the *gg* luminosity



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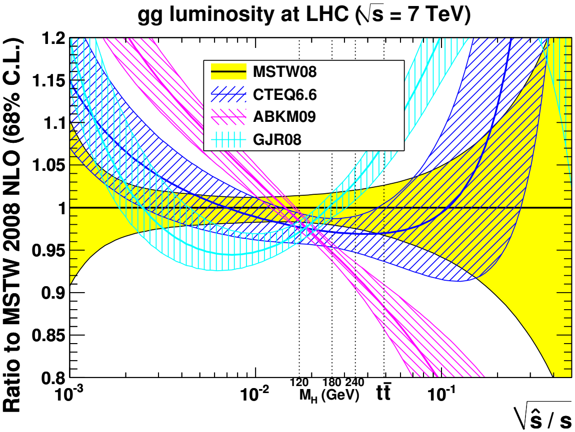


[G. Watt, PDF4LHC Workshop]

PDF Uncertainties for LHC analyses

PDF4LHC recomendation for Higgs Cross Section

At **NLO**

- Use **at least** the prediction of the 3 **global fits**: CTEQ, MSTW and NNPDF.
- Inclusion of other sets (ABKM, HERAPDF and GJR) is optional.
- Use the **envelope** provided by central values and **PDF+**α_S errors from the three groups.

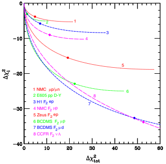
Top studies within the NNPDF framework

Shortcomings of the Standard approach

What is the meaning of a one-σ uncertainty?

- Standard $\Delta\chi^2 = 1$ criterion is **too restrictive** to account for large discrepancies among experiments.

[Collins & Pumplin, 2001]



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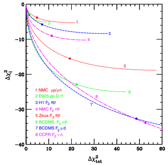
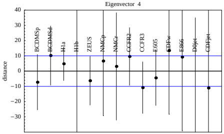


- Introduce a **TOLERANCE** criterion, i.e. take the envelope of uncertainties of experiments to determine the $\Delta\chi^2$ to use for the global fit (CTEQ).



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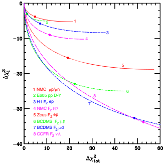

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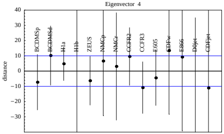
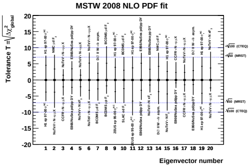


- Make it **DYNAMICAL**, i.e. determine $\Delta\chi^2$ separately for each hessian eigenvector (MSTW).

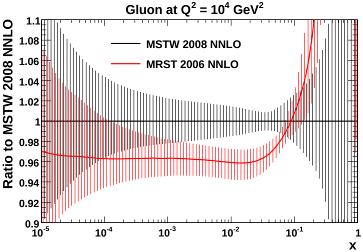


Shortcomings of the standard approach

What determines PDF uncertainties?

- Uncertainties in standard fits often increase when adding new data to the fit.
- Need of extending the parametriztion in order to accomodate the new data

Smaller high-x gluon (and slightly smaller α_S) results in larger small-x gluon – now shown at NNLO.



Larger small-x uncertainty due to extrat free parameter.

[R. Thorne, PDF4LHC]

PDF4LHCMSTW 24

NNPDF Methodology

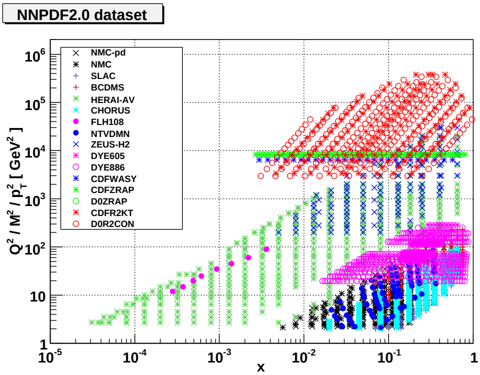
Main Ingredients

[R. D. Ball, L. Del Debbio, S. Forte, J. .I. Latorre, J. Rojo, M. Ubiali and AG]

- **Monte Carlo** determination of errors
  - No need to rely on linear propagation of errors
  - Possibility to test for non gaussianity of data
  - 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 2.0

Dataset



3415 data points

(for comparison MSTW08 includes 2699 data points)

OBS	***Data set***
Deep Inelastic Scattering	
F_2^d / F_2^p	NMC-pd
F_2^p	NMC SLAC BCDMS
F_2^d	SLAC BCDMS
$\sigma_{NC}^{\pm}$	HERA-I comb. ZEUS (HERA-II)
$\sigma_{CC}^{\pm}$	HERA-I comb. ZEUS (HERA-II)
F_L	H1
$\sigma_\nu , \sigma_{\bar{\nu}}$	CHORUS
dimuon prod.	NuTeV
Drell-Yan & Vector Boson prod.	
$d\sigma^{\mathrm{DY}}/dM^2dy$	E605
$d\sigma^{\mathrm{DY}}/dM^2dx_F$	E866
W asymm.	CDF
Z rap. distr.	D0/CDF
Inclusive jet prod.	
Incl. $\sigma^{(\mathrm{jet})}$	CDF (k_T) - Run II
Incl. $\sigma^{(\mathrm{jet})}$	D0 (cone) - Run II

NNPDF 2.0

Technical improvements

- Fast DGLAP evolution based on higher-order interpolating polynomials
- Improved treatment of normalization errors (t_0 method)
  - For details see [R. D. Ball et al., arXiv:0912.2276]
- Improvements in training/stopping
  - Target Weighted Training
  - Improved stopping for avoiding under-/over-learning
- All details given in [R. D. Ball et al., arXiv:1002.4407]

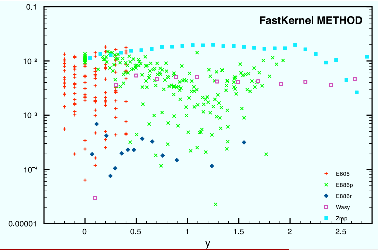
NNPDF 2.0

FastKernel

- NLO computation of hadronic observables too slow for parton global fits.
- MSTW08 and CTEQ include Drell-Yan NLO as (local) K factors rescaling the LO cross section
- K-factor depends on PDFs and it is not always a good approximation.

* NNPDF2.0 includes full NLO calculation of hadronic observables.
* Use available fastNLO interface for jet inclusive cross-sections.[hep-ph/0609285]
* Built up our own **FastKernel** computation of DY observables.

$$\int_{x_{0,1}}^{1} dx_1 \int_{x_{0,2}}^{1} dx_2\, f_a(x_1) f_b(x_2) C^{ab}(x_1, x_2) \to \sum_{\alpha,\beta=1}^{N_x} f_a(x_{1,\alpha}) f_b(x_{2,\beta}) \int_{x_{0,1}}^{1} dx_1 \int_{x_{0,2}}^{1} dx_2\, \mathcal{I}^{(\alpha,\beta)}(x_1, x_2) C^{ab}(x_1, x_2)$$



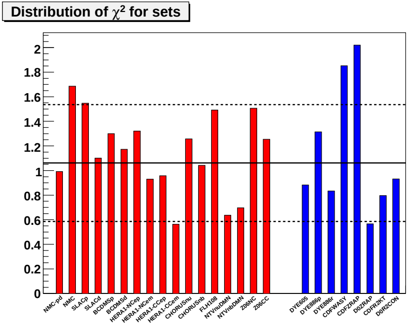
- Both PDFs evolution and double convolution sped up by
  - Use high-orders polynomial interpolation
  - Precompute all Green Functions

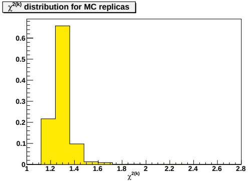
A truly NLO analysis

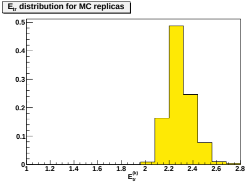
NNPDF 2.0

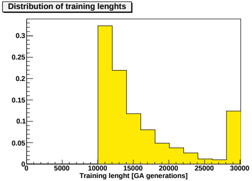
General features of the fit

$\chi^2_{\rm tot}$	1.21
$\langle E \rangle \pm \sigma_E$	2.32 ± 0.10
$\langle E_{\rm tr} \rangle \pm \sigma_{E_{\rm tr}}$	2.29 ± 0.11
$\langle E_{\rm val} \rangle \pm \sigma_{E_{\rm val}}$	2.35 ± 0.12
$\langle {\rm TL} \rangle \pm \sigma_{\rm TL}$	16175 ± 6257
$\langle \chi^{2(k)} \rangle \pm \sigma_{\chi^2}$	1.29 ± 0.09



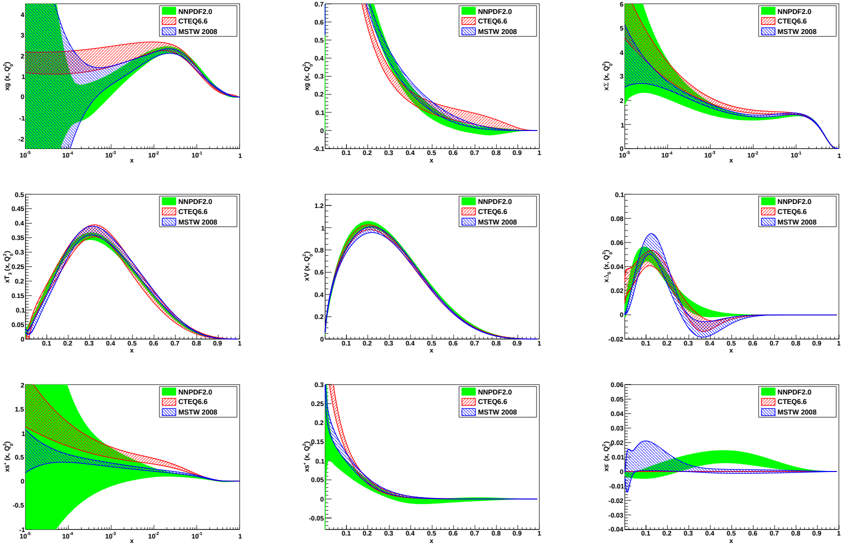




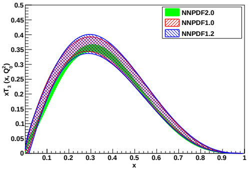


NNPDF 2.0

Partons - Comparison to other global fits



- **Reduction of uncertainties** with respect to older NNPDF sets due to **inclusion of new data**



NNPDF2.0

Results - Partons - A couple of upshots

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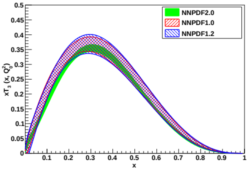
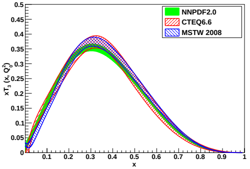


- **Uncertainties** on PDFs **competitive** with results from other groups ...



NNPDF2.0

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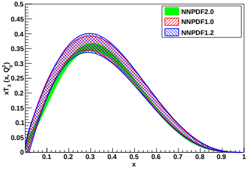

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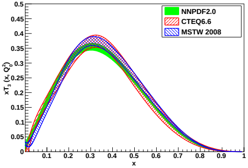
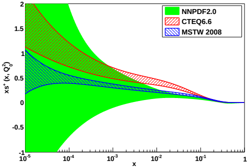


- ... but still retain **unbiasedness** in regions where there are little or no experimental constraints



PDF Uncertainties and Correlations

A practitioner's guide to NNPDF predictions

Central Value

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

Standard Deviation

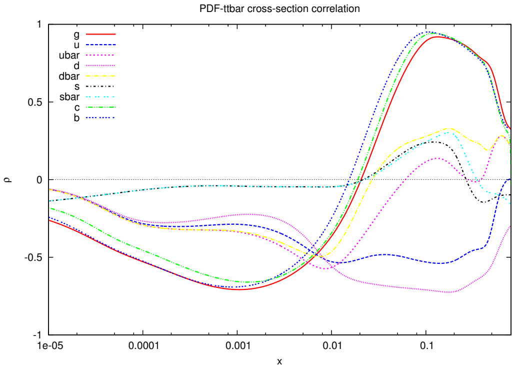
$$\sigma_{\mathcal{F}} = \left(\frac{1}{N_{N_{\text{set}}}} \sum_{k=1}^{N_{\text{set}}} \left(\mathcal{F}[\{q^{(k)}\}] - \langle \mathcal{F}[\{q\}] \rangle \right)^2 \right)^{1/2}$$

Correlation

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

PDF induced correlations

PDF$-\sigma_{t\bar{t}}$ correlation

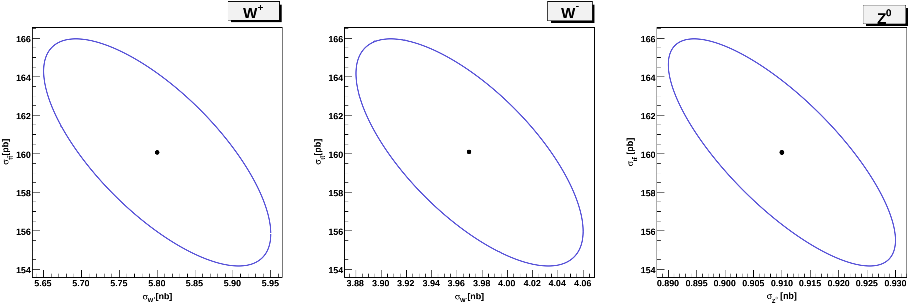


- Mostly correlated with gluon distribution at medium-x

PDF induced correlations

$\sigma_{W^\pm} - \sigma_{t\bar{t}}$ correlation

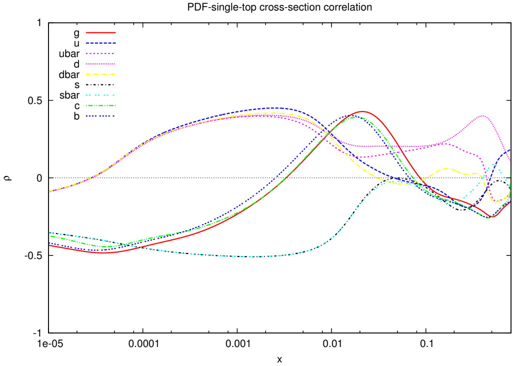
	σ_{W^+}	σ_{W^-}	σ_{Z^0}
ρ	-0.716	-0.694	-0.773



- **Strong anti-correlation** between the cross-sections
- Use the $W^{\pm}$, Z^0 cross-section (larger, known at NNLO) to normalize the $t\bar{t}$ cross-section

PDF induced correlations

PDF$-\sigma_{t+X}$ (t-channel) correlation

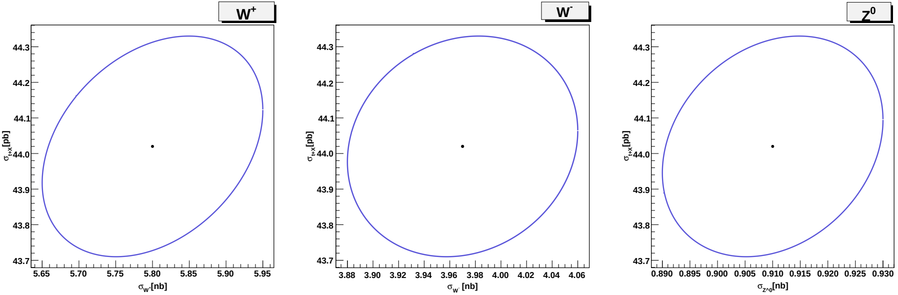


- Mostly correlated with gluon and quark distributions at medium-/small$-x$

PDF induced correlations

$\sigma_{W\pm} - \sigma_{t+X}$ (t-channel)correlation

	σ_{W^+}	σ_{W^-}	σ_{Z^0}
ρ	0.330	0.140	0.240



- **Mild correlation** between the cross-sections
- More difficult to use the Vector Boson cross-section as normalization

Reweighting PDFs

Assessing the impact of new data on PDF fits

- 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

[W. Giele and S. Keller, hep-ph/9803393]

- According to **Bayes Theorem** we have

$$P_{\rm new}(\lambda) = P(\lambda|x^e) = \frac{P(x^e|\lambda)P_{\rm init}(\lambda)}{P(x^e)}\,, \quad P(x^e|\lambda) = e^{-\frac{\chi^2_{\rm new}(\lambda)}{2}}$$

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

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

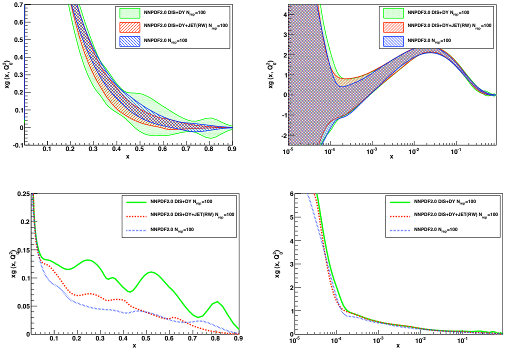
where the **weights** are

$$w_k = \frac{e^{-\frac{1}{2}\chi^2_{\rm new}(\lambda^k)}}{\sum_{i=1}^{N_{\rm rep}} e^{-\frac{1}{2}\chi^2_{\rm new}(\lambda^i)}}$$

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

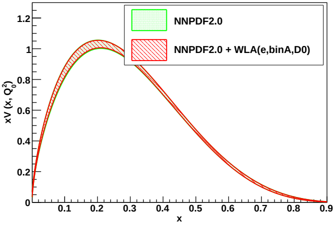
Reweighting PDFs

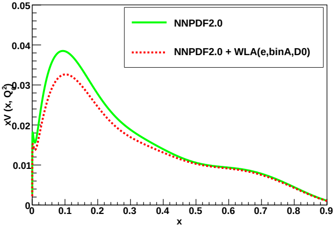
Reweighting real data: W lepton asymmetry

- In the NNPDF2.0 fit we only included CDF W asymmetry data
- We evaluated W electron asymmetry with NNPDF20 1000 replicas set using **DYNNLO**

  [Catani et al., arXiv:0903.2120].

- .. and included D0 W electron asymmetry data points through reweighting.
- Main impact on reduction of middle-x Valence uncertainty.
- **No** need of **refitting**





Conclusions and Outlook

- A **precise determination** of PDF with **reliable error estimation** is crucial to fully exploit the physics potential of LHC experiments
- Interesting overlap between PDF and top physics
  - Use PDF induced correlations to improve measurements
  - Impact of higher-order corrections
  - Use single-top to constrain the $b-$quark distribution ...
- **NNPDF2.0** is the first **global NNPDF fit**
  - Exact inclusion of NLO corrections
  - **No** sign of **strong tension** among different datasets
  - Next steps: improved treatment of Heavy Flavour contributions, inclusion of higher order contributions (NNLO-QCD, EW, ..)