NNPDF 2.0:
NLO global fit using the NNPDF methodology

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Terascale Alliance - PDF group
DESY, Zeuthen,
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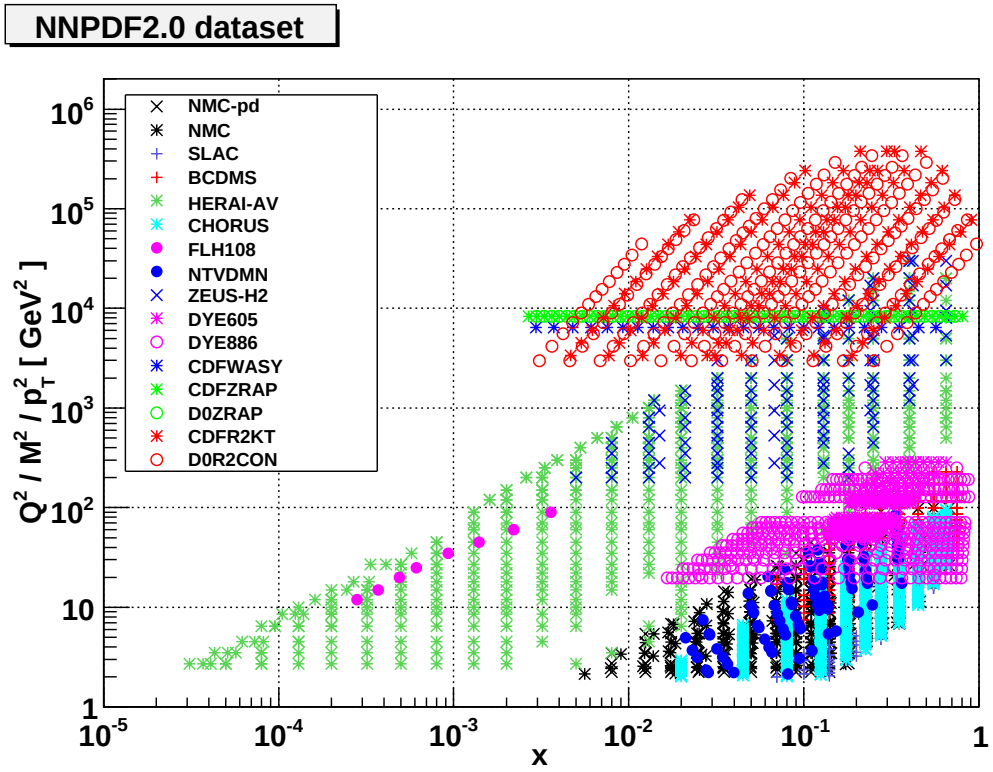
NNPDF Methodology

Main Ingredients

- **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

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
σ_{NC}^+	ZEUS H1
σ_{NC}^-	ZEUS H1
F_L	H1
σ_ν , $\sigma_{\bar{\nu}}$	CHORUS
dimuon prod.	NuTeV
Drell-Yan & Vector Boson prod.	
$d\sigma^{\rm DY} / dM^2 dy$	E605
$d\sigma^{\rm DY} / dM^2 dx_F$	E866
W asymm.	CDF
Z rap. distr.	D0/CDF
Inclusive jet prod.	
Incl. $\sigma^{(\rm jet)}$	CDF (k_T) - Run II
Incl. $\sigma^{(\rm jet)}$	D0 (cone) - Run II

NNPDF 2.0

Technical improvements

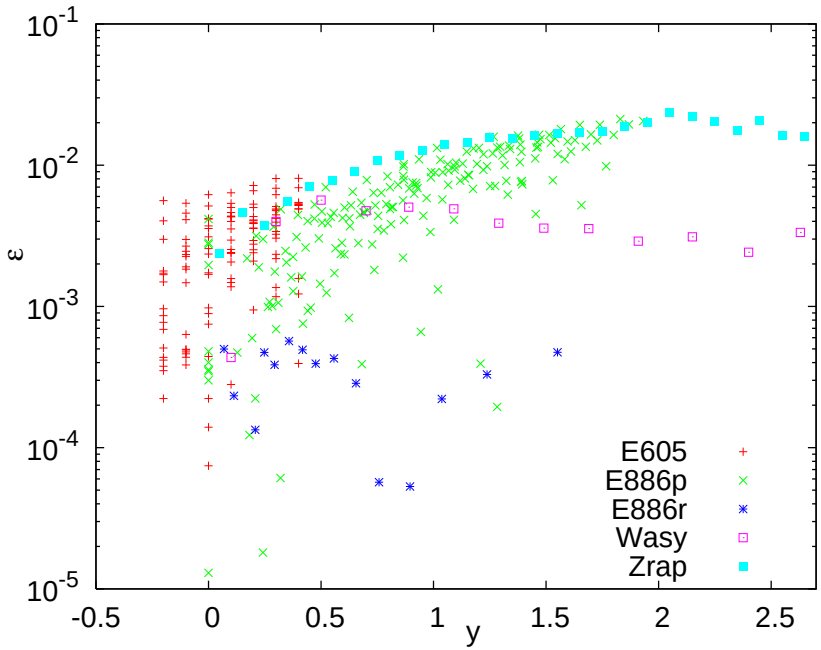
- Fast DGLAP evolution based on higher-order interpolating polynomials
- Improved treatment of normalization errors (t_0 method)
  - For details see [R. D. Ball et al., arXiv:0912.2276]
- Improvements in training/stopping
  - Target Weighted Training
  - Improved stopping for avoiding under-/over-learning

NLO QCD

FastDY

- Inclusion of higher order corrections to hadronic processes in parton fits is often too expensive
- Often higher order corrections are included as (local) K factors rescaling the LO cross section
- We use FastNLO for inclusive jet cross section
- We developed our own FastDY for fixed target Drell-Yan and vector boson production at colliders

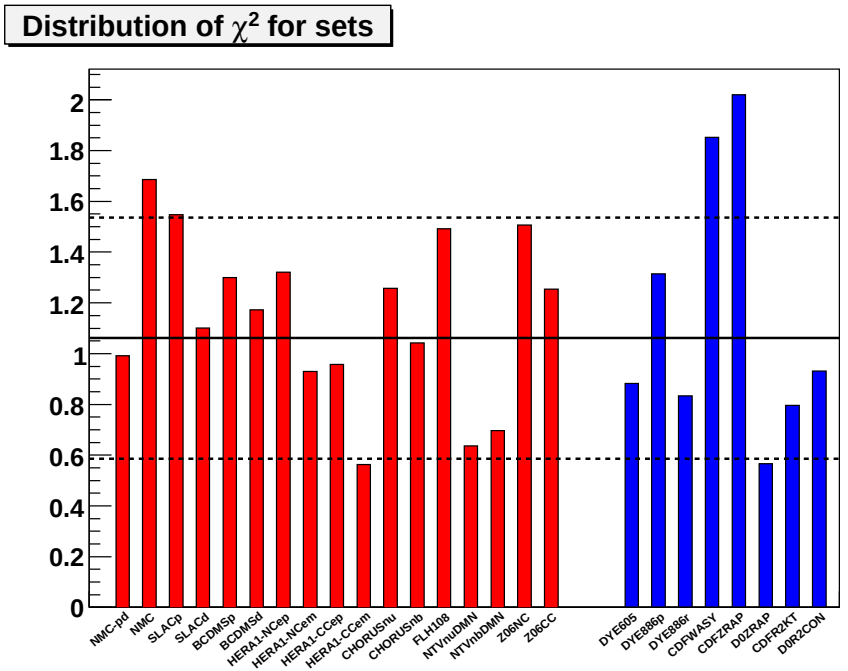
Relative Accuracy w.r.t to Exact calc.

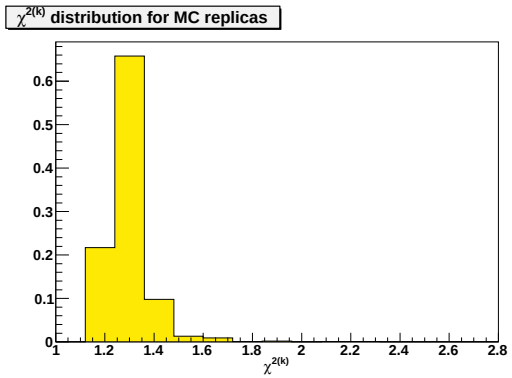


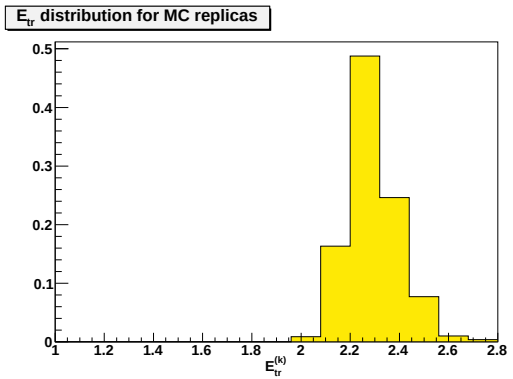
Results

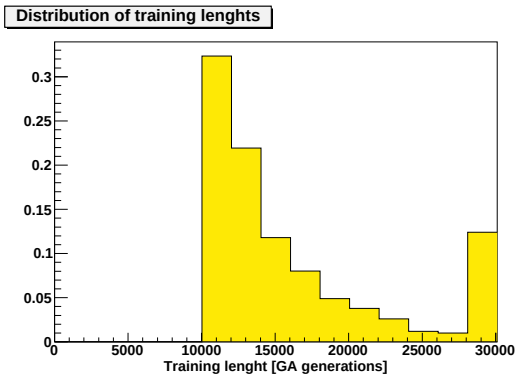
General features of the fit

$\chi^2_{\rm tot}$	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



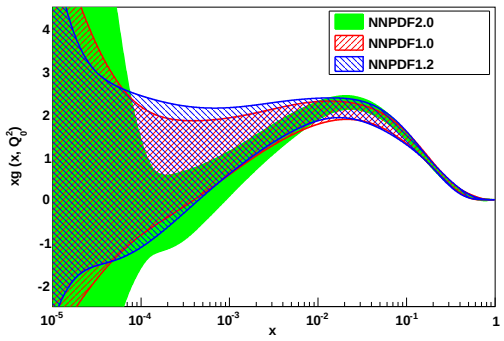


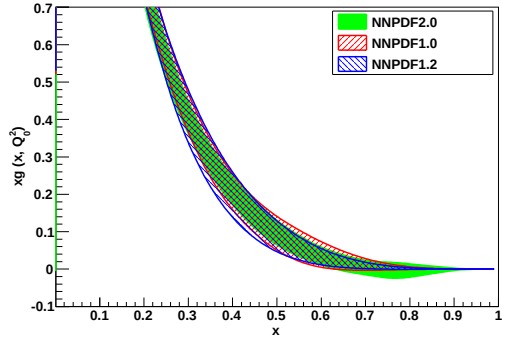


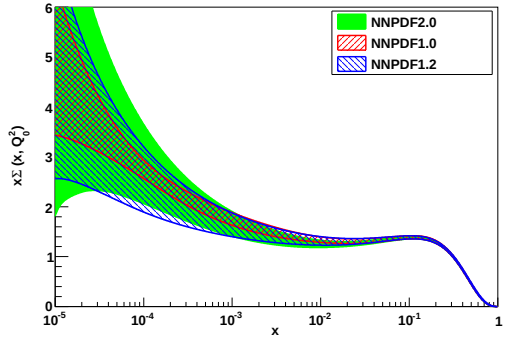


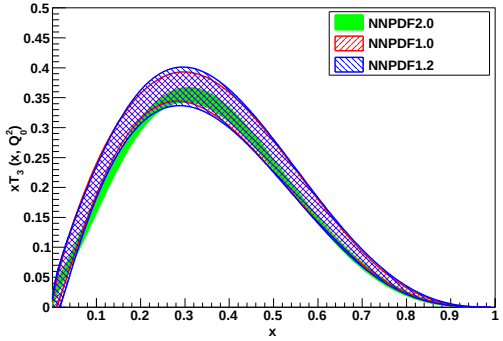
Results

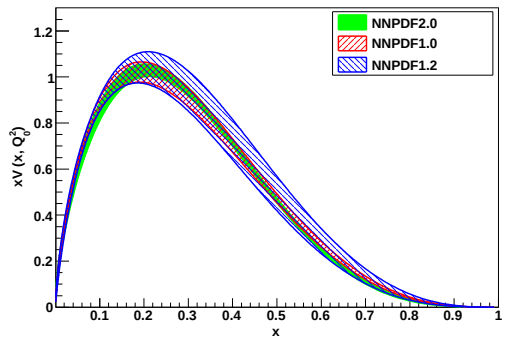
Partons - Comparison to older NNPDF set

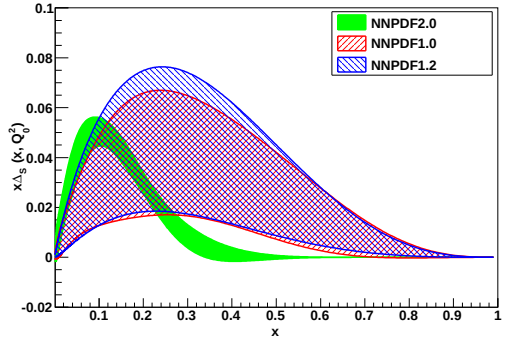


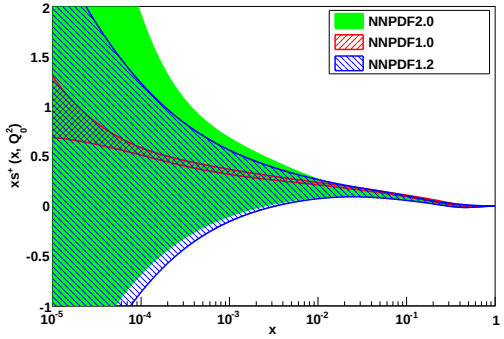


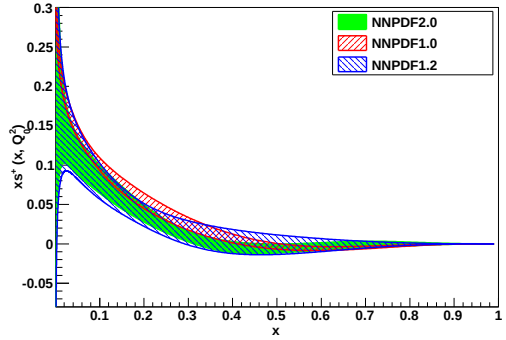


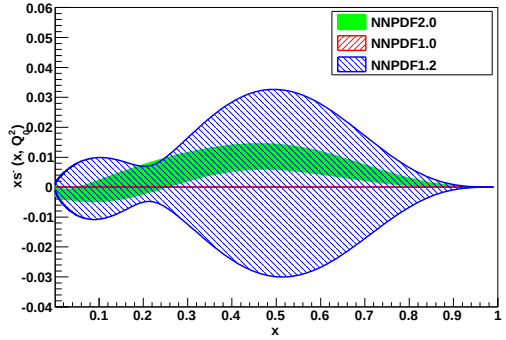






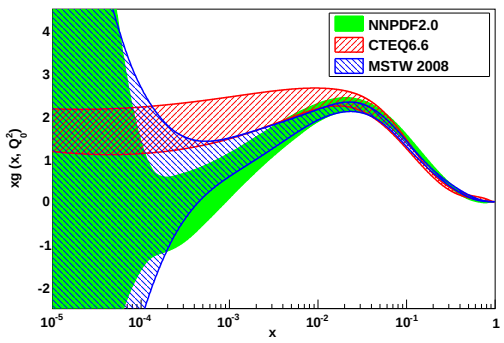


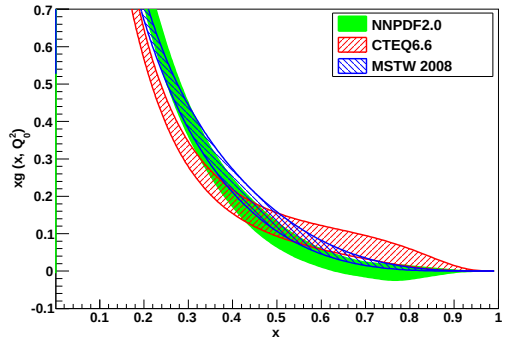


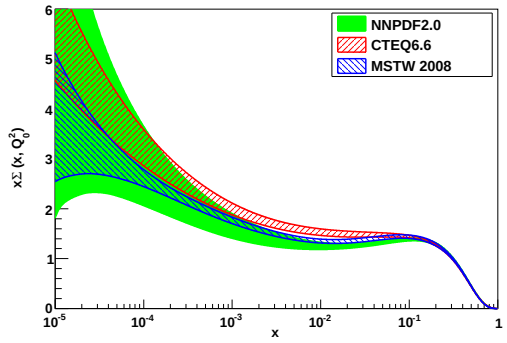


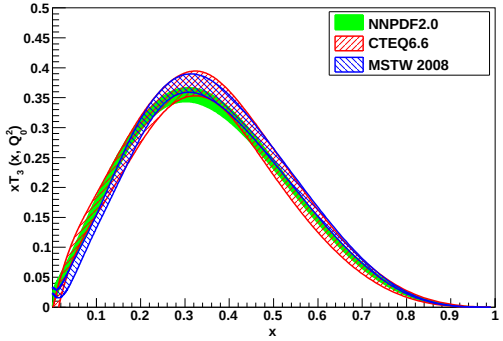
Results

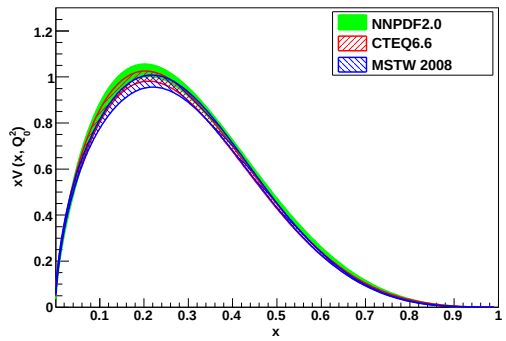
Partons - Comparison to other global fits

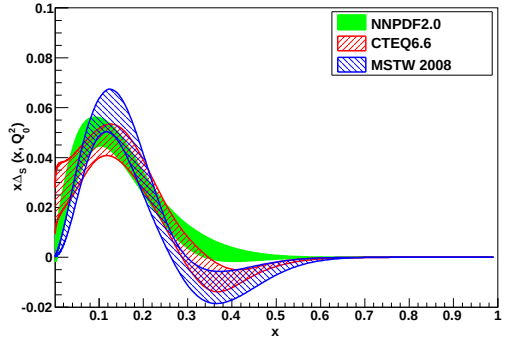


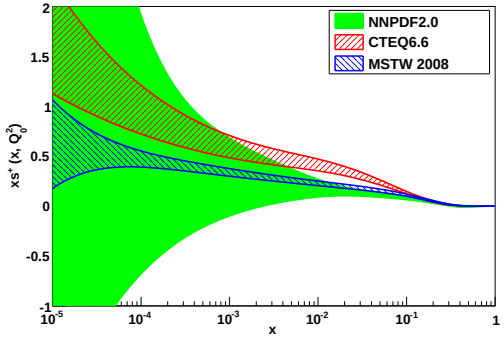


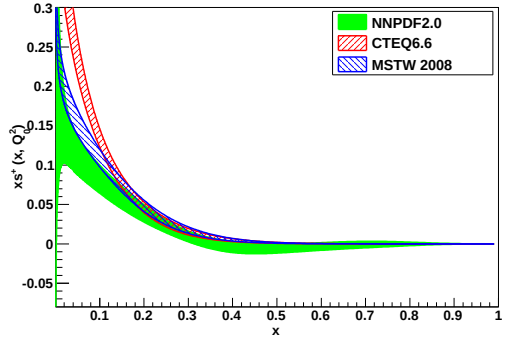


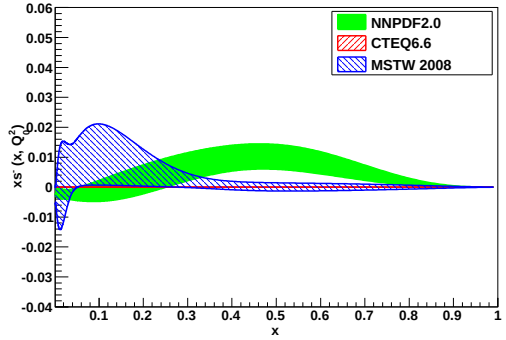








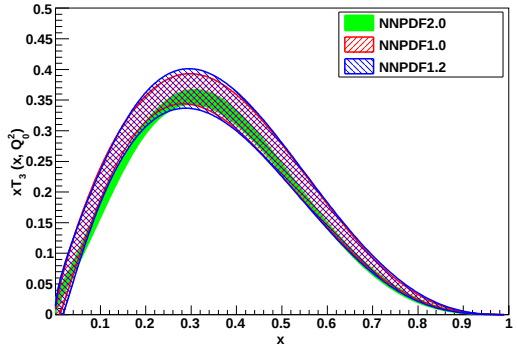




NNPDF2.0

Results - Partons - A couple of upshots

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



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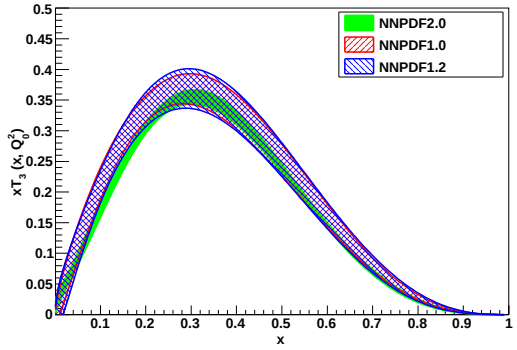
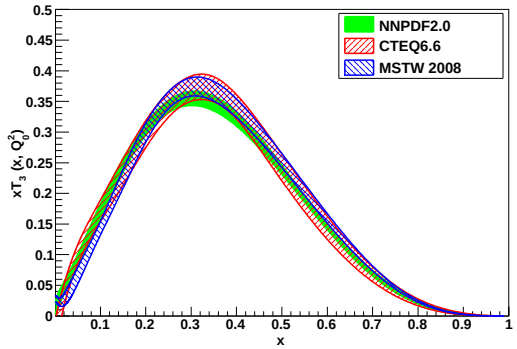


- **Uncertainties** on PDFs **competitive** with results from other groups ...



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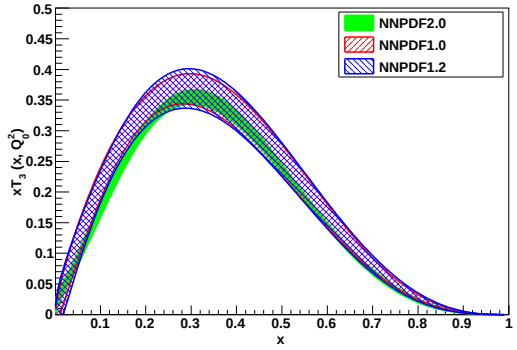

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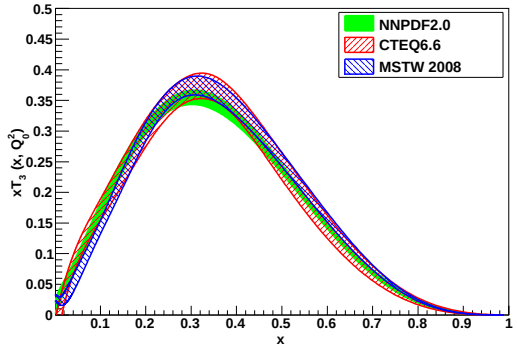
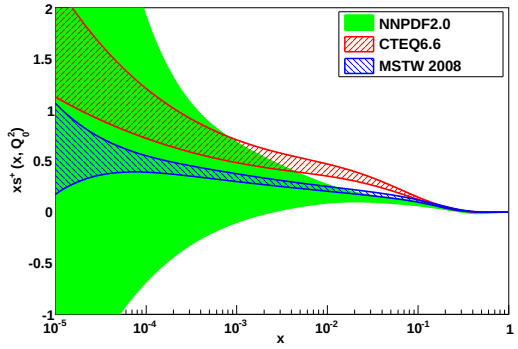


- ... but still retain **unbiasedness** in regions where there are little or no experimental constraints



- We define the **distance** between central values of PDFs

$$d(q_j) = \sqrt{\left\langle \frac{\left(\langle q_j \rangle_{(1)} - \langle q_j \rangle_{(2)}\right)^2}{\sigma_1^2[q_j] + \sigma_2^2[q_j]} \right\rangle_{N_{\rm part}}}$$

and the similarly for Standard Deviations.

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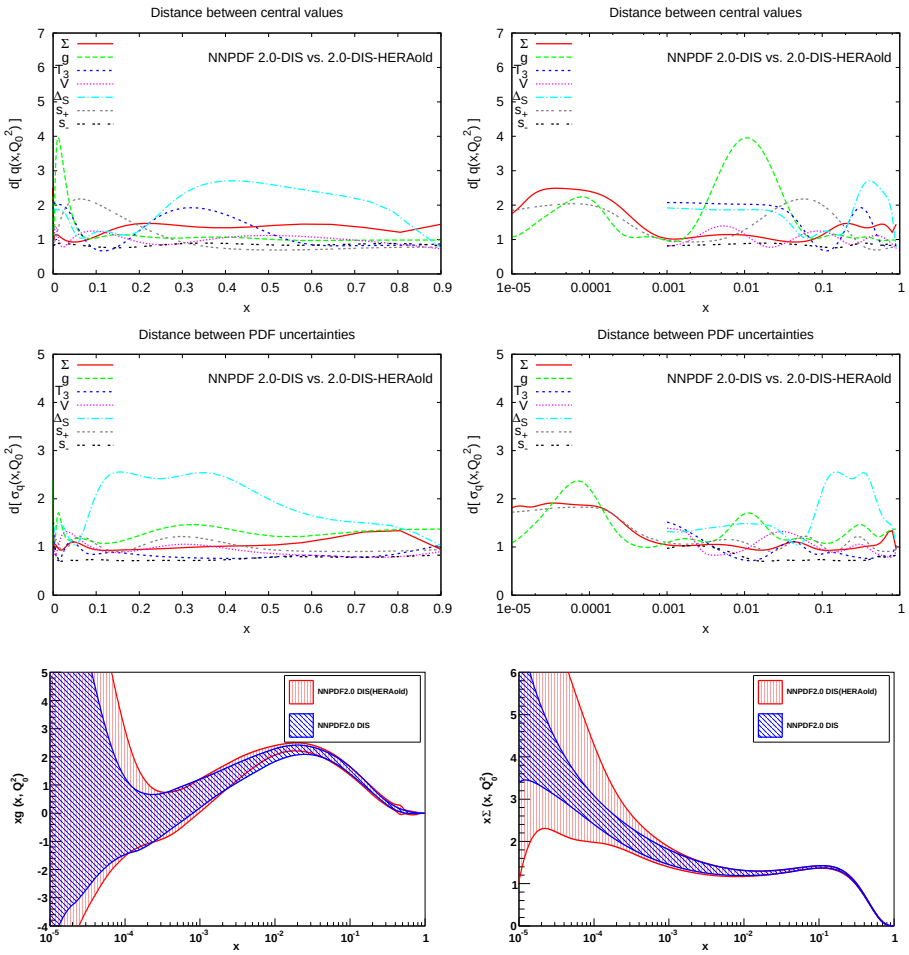
  and the similarly for Standard Deviations.

- Comparisons we have performed for NNPDF2.0
  - NNPDF1.2 vs. NNPDF1.2 + minimization/training improvements
  - Improved NNPDF1.2 vs. Improved NNPDF1.2 + t_0-method
  - Fit to DIS dataset with H1/ZEUS data vs. Fit with HERA-I combined
  - Fit to DIS dataset vs. Fit to DIS+JET
  - Fit to DIS+JET vs. NNPDF2.0 final

Results

Impact HERA-I combined dataset

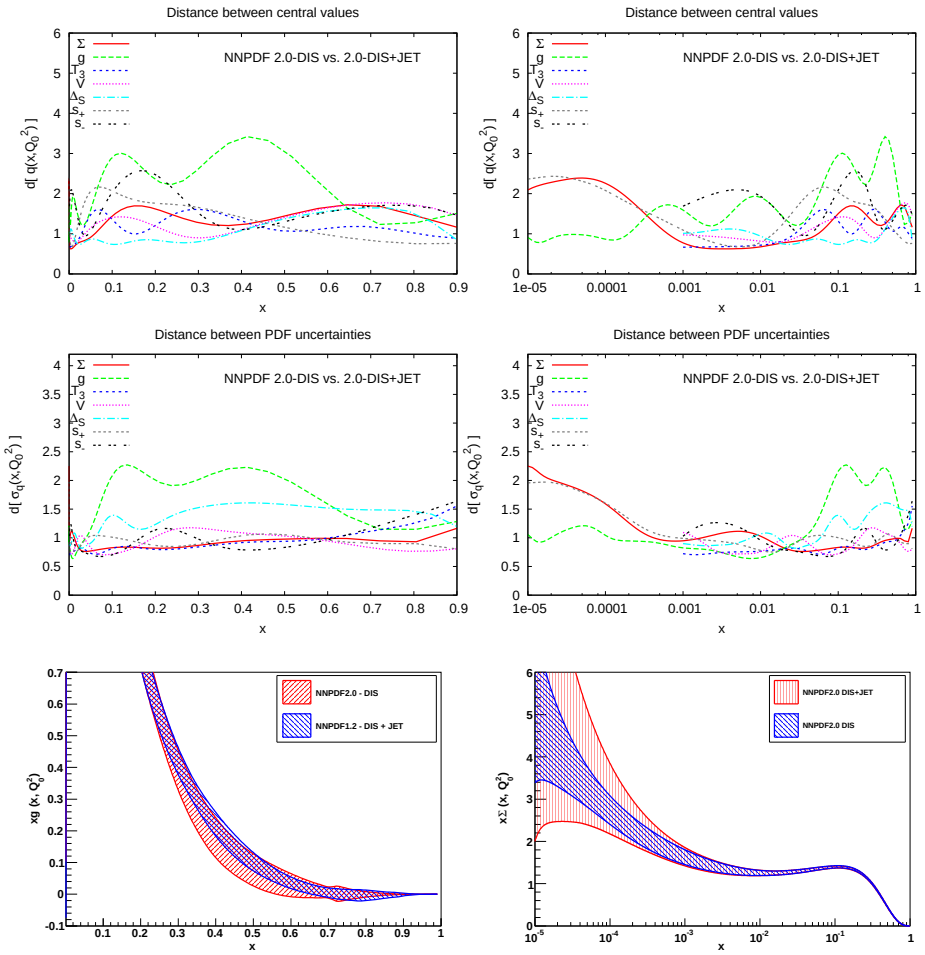
- Overall fit quality to the whole dataset is good ($\chi^2 = 1.14$)
  - $\sigma^{+}_{\rm NC}$ dataset has relatively high $\chi^2 \sim 1.3$
  - $\sigma^{-}_{\rm CC}$ dataset has very low $\chi^2 \sim 0.55$
- Same χ^2-pattern observed in the HERAPDF1.0 analysis
- Impact on PDFs is moderate, affecting mainly Singlet and Gluon at small-x



Results

Impact of Tevatron inclusive Jet data

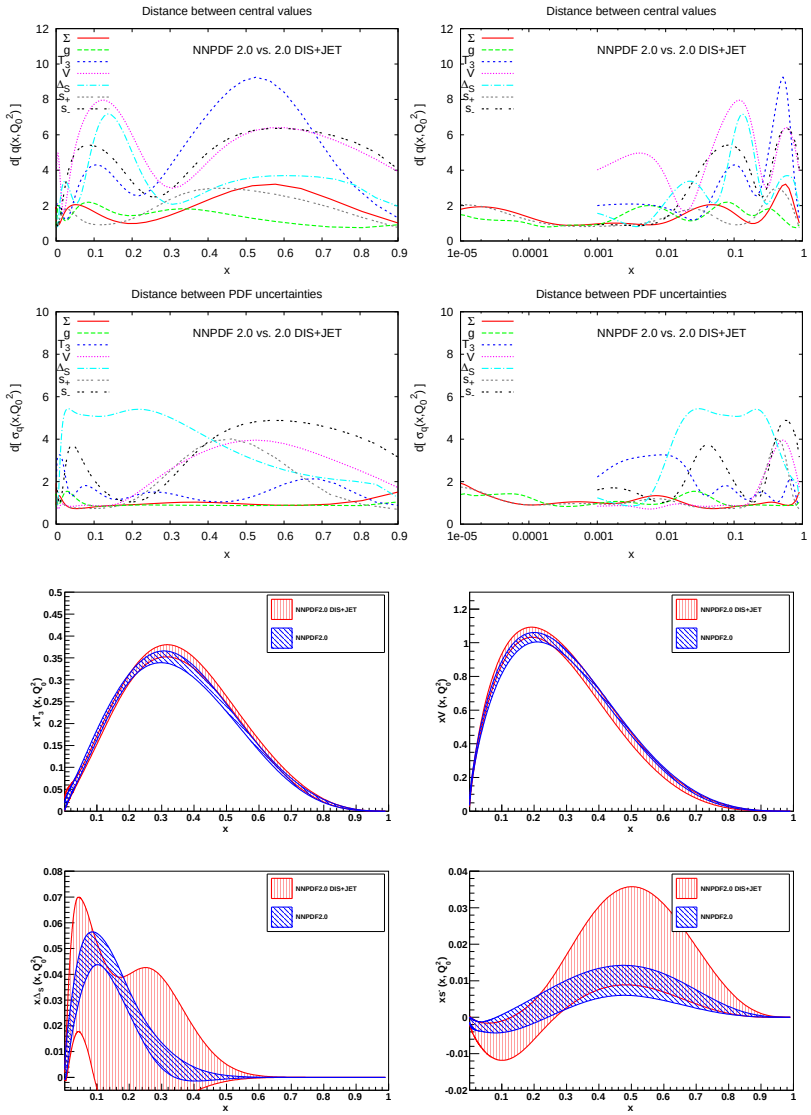
- We include Tevatron Run-II inclusive jet data
- They provide a valuable constrain on large-x gluon
- No signs of tension with other datasets included in the analysis
- Run-I data not included but compatibility with the outcome of the fit has been checked



Results

Impact of Drell-Yan and Vector Boson production data

- Good description of fixed target Drell-Yan data (E605 proton and E886 proton and p/d ratio)
- Vector boson production at colliders (CDF W-asymmetry and Z rapidity distribution) harder to fit
- All valence-type PDF combinations are affected by these data
- Sizable reduction in the uncertainty of the strange valence (possible impact on NuTeV anomaly)



Results

Phenomenological implications

- LHC standard Candles

	$\sigma(W^+)\mathrm{Br}\left(W^+ \to l^+\nu_l\right)$	$\sigma(W^-)\mathrm{Br}\left(W^- \to l^+\nu_l\right)$	$\sigma(Z^0)\mathrm{Br}\left(Z^0 \to l^+l^-\right)$
NNPDF1.2	11.99 ± 0.34 nb	8.47 ± 0.21 nb	1.94 ± 0.04 nb
NNPDF2.0	11.57 ± 0.19 nb	8.52 ± 0.14 nb	1.93 ± 0.03 nb
CTEQ6.6	12.41 ± 0.28 nb	9.11 ± 0.22 nb	2.07 ± 0.05 nb
MSTW08	12.03 ± 0.22 nb	9.09 ± 0.17 nb	2.03 ± 0.04 nb

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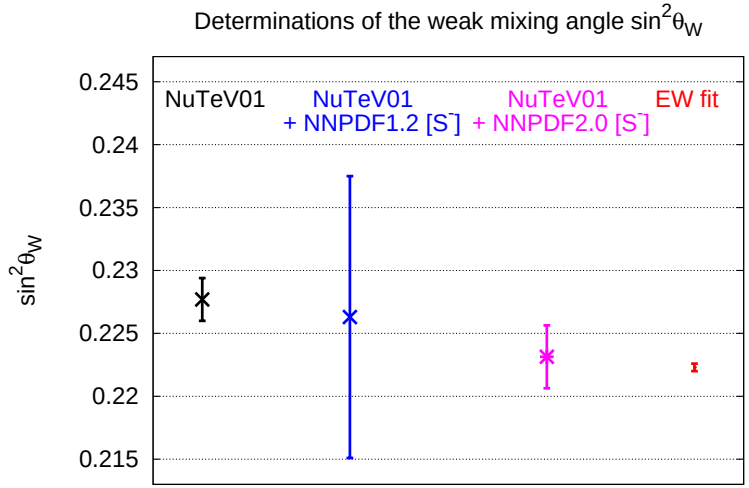
MSTW08	12.03 ± 0.22 nb	9.09 ± 0.17 nb	2.03 ± 0.04 nb

- Impact on NuTeV determination of $\sin^2\theta_W$



Conclusions and Outlook

The way ahead of NNPDF fits ...

- **NNPDF2.0** is the first **global NNPDF fit**
- **Competitive errors** on PDF and **precision studies** of observables (see NuTeV anomaly) possible
- **No** sign of **strong tension** among different datasets
- Officially **released** NNPDF sets (NNPDF 1.0/1.2/2.0) are available within the **LHAPDF** interface.
- Next steps:
  - Improved treatment of Heavy Flavour contributions (FONLL, FFNS), NNPDF 2.x
  - Inclusion of higher order contributions (NNLO QCD and EW effects), NNPDF x.x
  - ...

Backup Slides

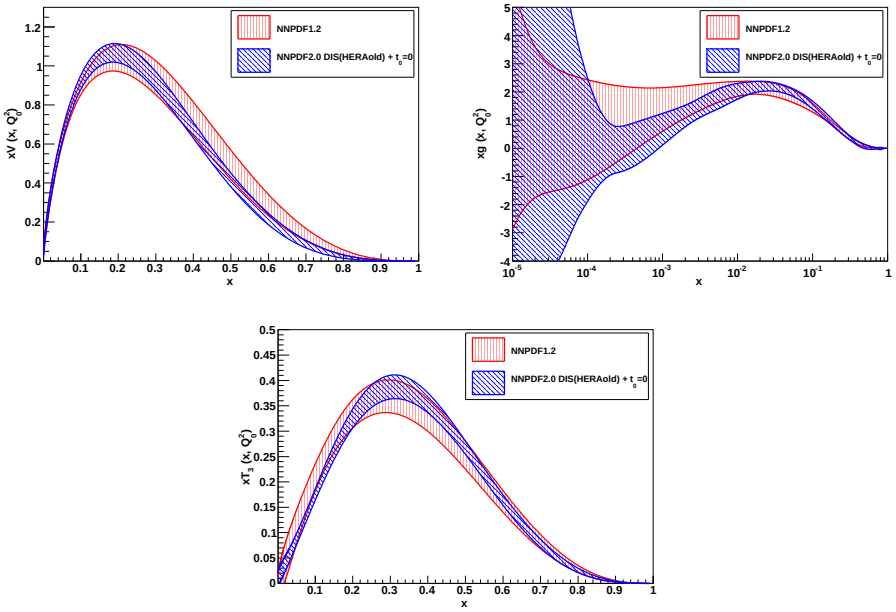
NLO QCD

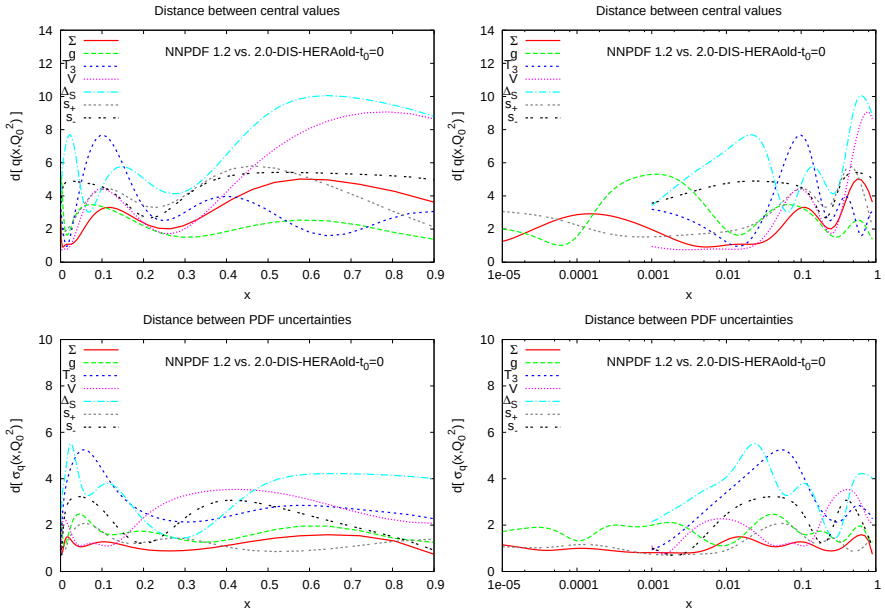
Fast Evolution

- Implementation of a new strategy to solve DGLAP evolution equation
- Evolution is performed as interpolation using higher-oder interpolating polynomials (Hermite polyonomials)
- Implementation benchmarked against the Les Houches tables
- Gain in speed by a factor 30 (for a fit to 3000 datapoints)
- Speed of the evolution scales with number of points in the interpolating grid (compare to older implementations which scaled with number of datapoints).

Methodology

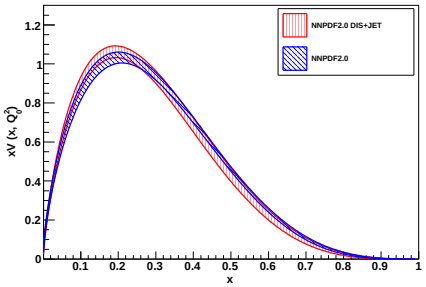
Impact of improved trainig/stopping

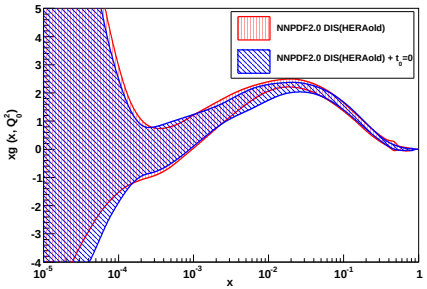


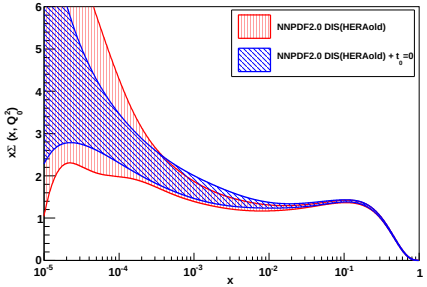


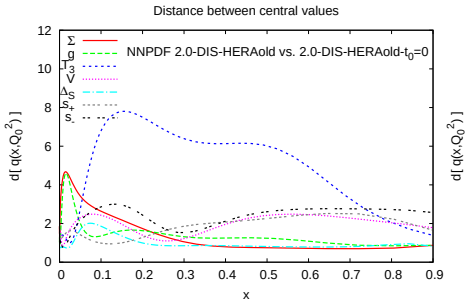
Methodology

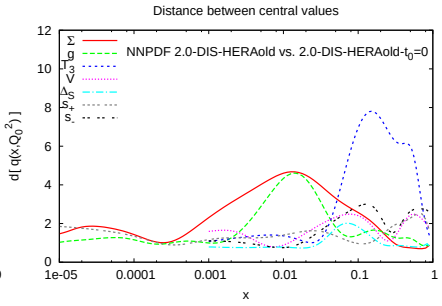
Impact of t_0-method

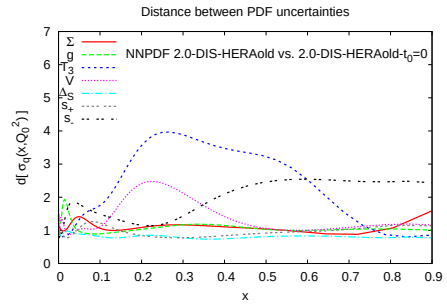


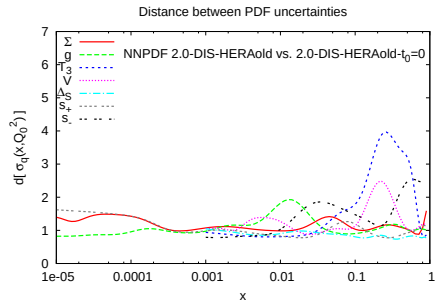












Results

Some more phenomenological implications

	$\sigma(t\bar{t})$	$\sigma(H, m_H = 120\,\mathrm{GeV})$
NNPDF1.2	901 ± 21 pb	36.6 ± 1.2 pb
NNPDF2.0	913 ± 17 pb	37.3 ± 0.4 pb
CTEQ6.6	844 ± 17 pb	36.3 ± 0.9 pb
MSTW08	905 ± 18 pb	38.4 ± 0.5 pb

Results

Vector Boson production at colliders

- Z rapidity distribution:
  - Very good description of D0 data ($\chi^2 = 0.57$)
  - Poor description of CDF data ($\chi^2 = 2.02$)
  - MSTW08 has the same pattern
  - Possible inconsistency of the two datasets?
- CDF W-asymmetry
  - We fit the direct W-asymmetry data, not the leptoinc asymmetry
  - Poor description of the data ($\chi^2 = 1.85$)