Impact of the LHC W lepton asymmetry data
on the determination of PDFs

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EW precision physics at the LHC
CERN, 4-5 April 2011

Outline of the talk

- Introduction
  - Constraints from hadronic data
  - W lepton asymmetry data @ LHC 7 TeV
  - Reweighting PDFs
- The W lepton charge asymmetry data at the LHC
  - Predictions and compatibility
  - Impact on PDFs' uncertainty
- Conclusions and outlook

Introduction
Motivation

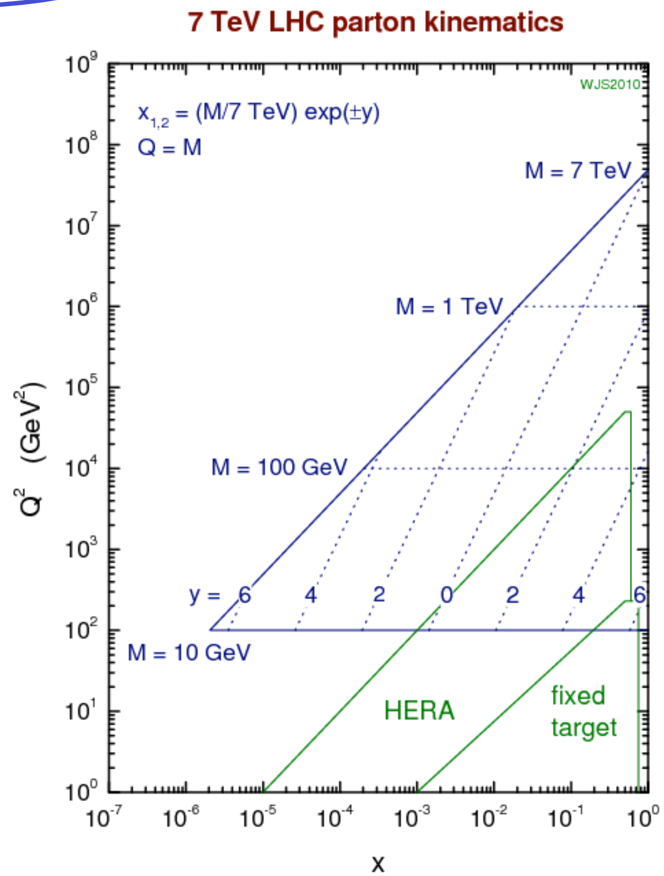
$$\sigma_X(s, M_X^2) = \sum_{a,b} \int_{x_{\min}}^{1} dx_1\, dx_2\, f_{a/h_1}(x_1) f_{b/h_2}(x_2)\, \hat{\sigma}_{q_a q_b \to X}\left(x_1 x_2 s, M_X^2\right)$$

- For most EW processes, PDFs represent dominant uncertainty

  PDFs uncertainty ~ 3-5%
  partonic σ uncertainty ~ 2-3%

- How do LHC data (here the W lepton asymmetry data) constrain PDFs?

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



Introduction

Motivation

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- For most EW processes, PDFs represent dominant uncertainty

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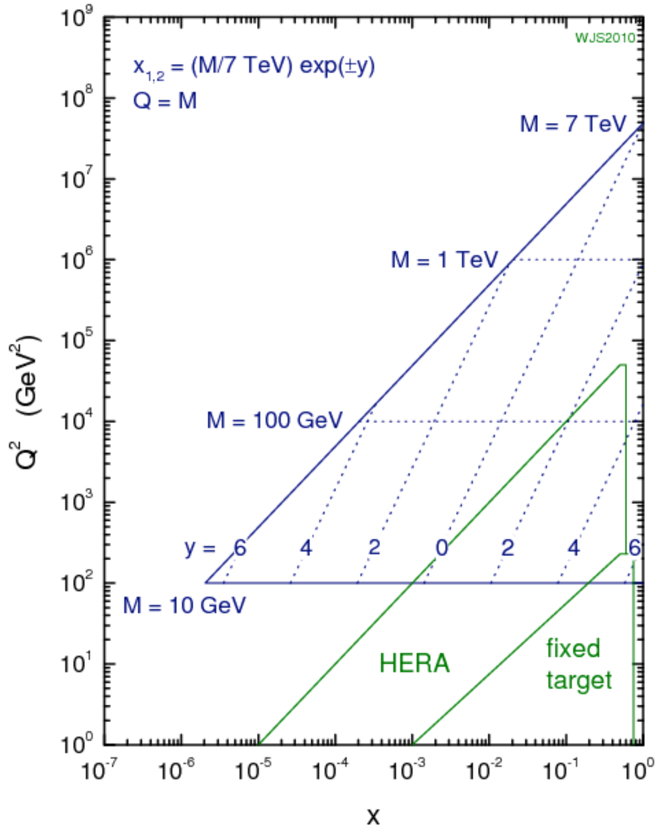
  partonic σ uncertainty ~ 2-3%

- How do LHC data (here the W lepton asymmetry data) constrain PDFs?

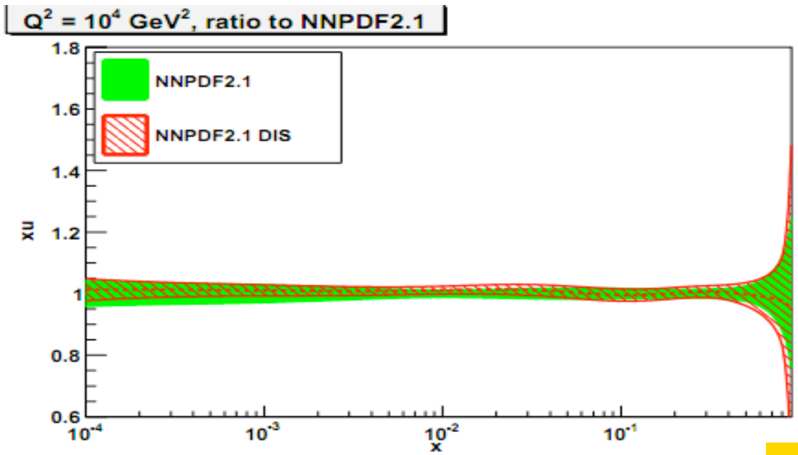
$$\boxed{\frac{u(x_1)\bar{d}(x_2) - d(x_1)\bar{u}(x_2)}{u(x_1)\bar{d}(x_2) + d(x_1)\bar{u}(x_2)}}$$

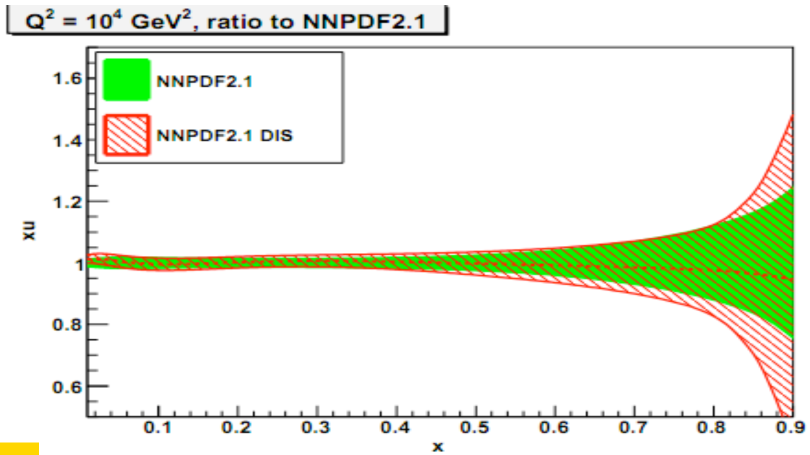
7 TeV LHC parton kinematics



Introduction
The up distribution

u





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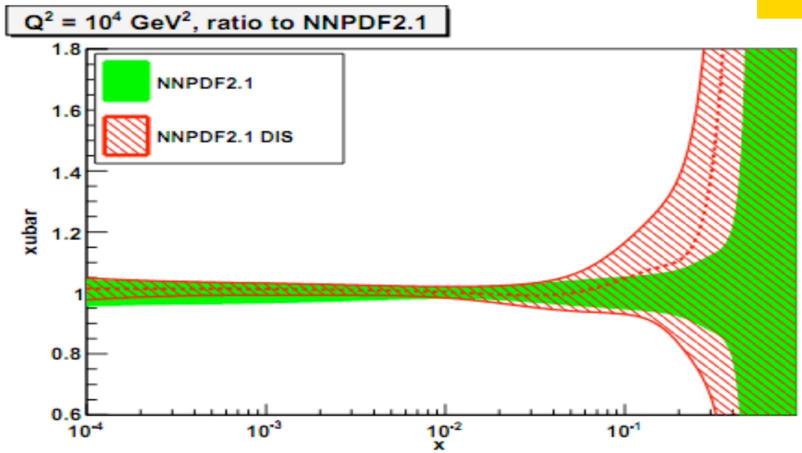
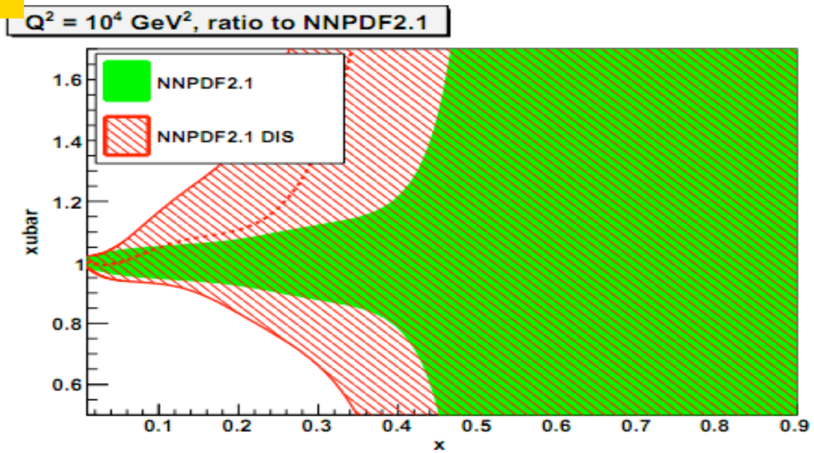
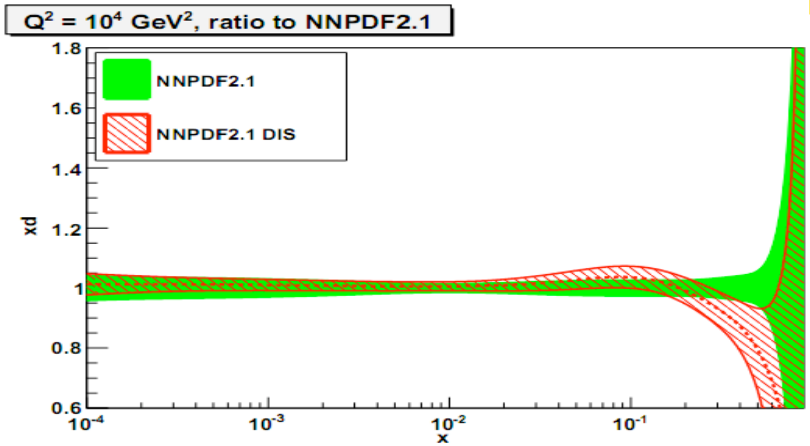


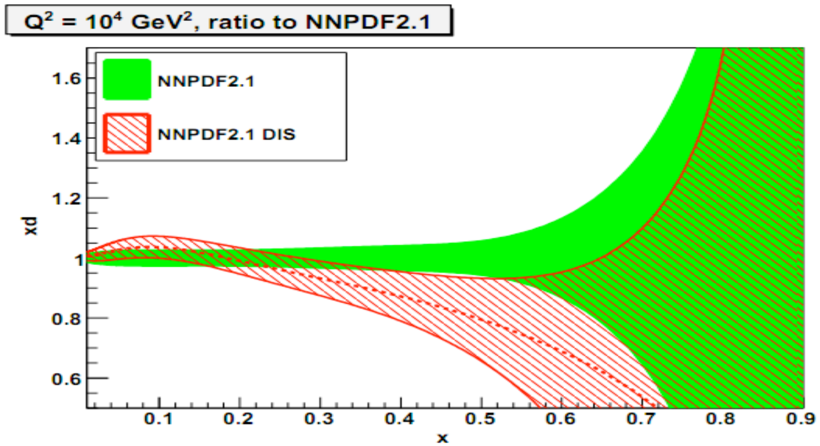


Introduction

The down distribution

d





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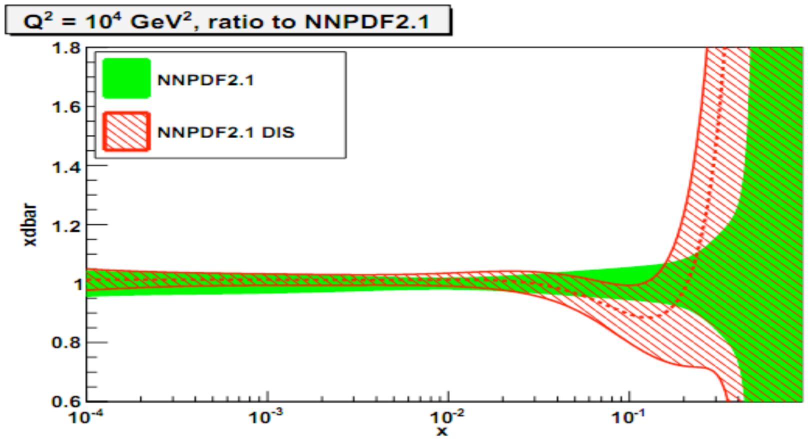
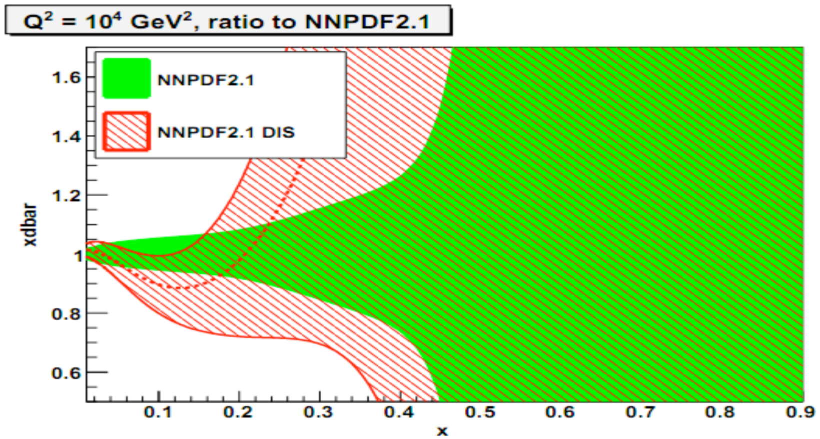


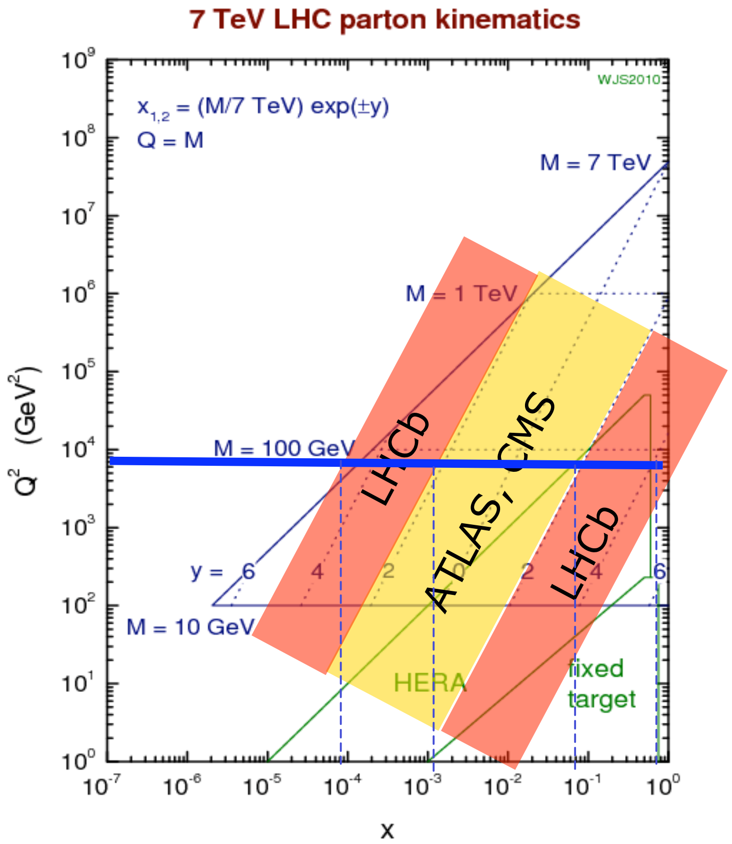


W lepton asymmetry data
@ LHC 7 TeV

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

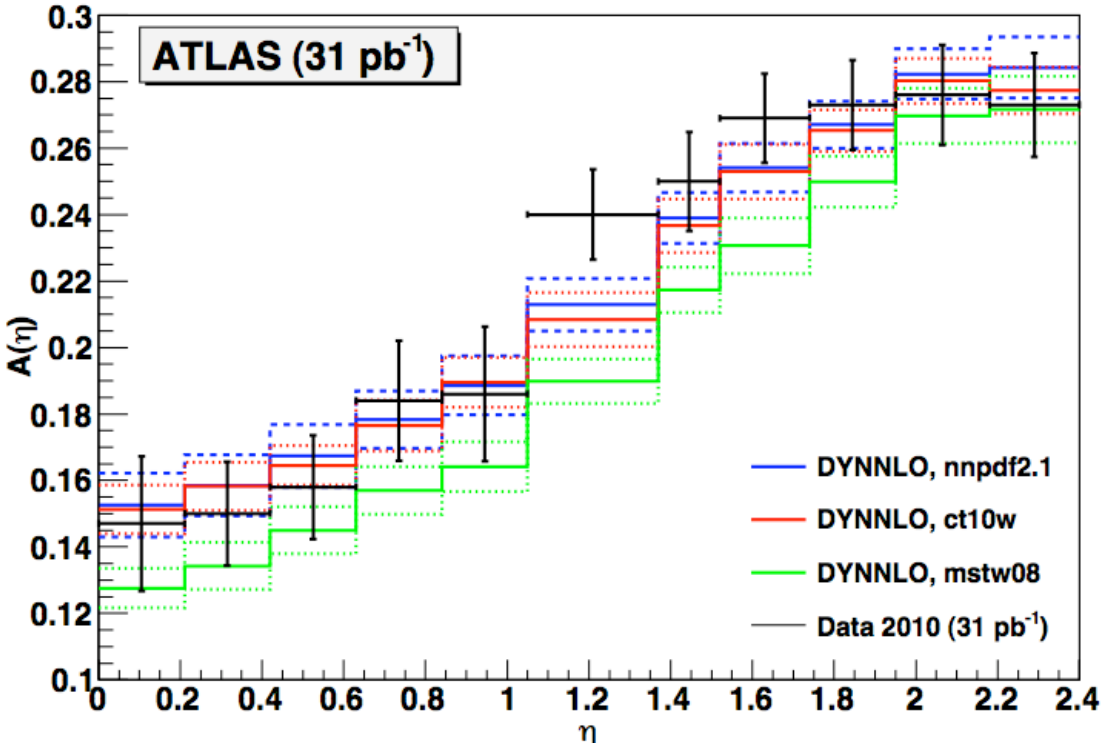
$$\boxed{\frac{u(x_1)\bar{d}(x_2) - d(x_1)\bar{u}(x_2)}{u(x_1)\bar{d}(x_2) + d(x_1)\bar{u}(x_2)}}$$

- **ATLAS:**
  W muon charge asymmetry ($31 pb^{-1}$)
  ArXiv: 1103.2929
- **CMS:**
  W muon and electron charge asymmetry ($36 pb^{-1}$)
  ArXiv: 1103.3470
- **LHCb:**
  Preliminary forward W muon charge asymmetry ($16.5 pb^{-1}$) (courtesy of R. McNulty)



W lepton asymmetry data
ATLAS

$\sqrt{s}$ = 7 TeV
31pb^{-1} luminosity
p_T^{μ} > 20 GeV
M_T > 40 GeV
E_T^{miss} > 20 GeV
| η | < 2.4



NLO predictions obtained with DYNNLO [ArXiv: 0903.2120]

χ^2 /d.o.f

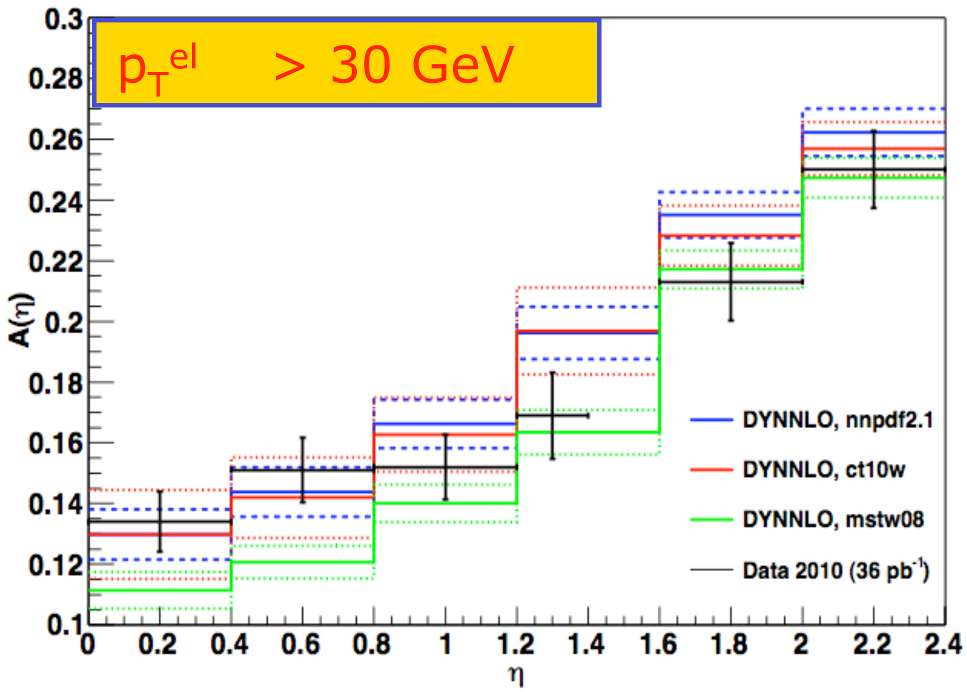
Data/χ^2	NNPDF2.1	CT10w	MSTW08
ATLAS(31pb^{-1})	0.68	0.81	3.25

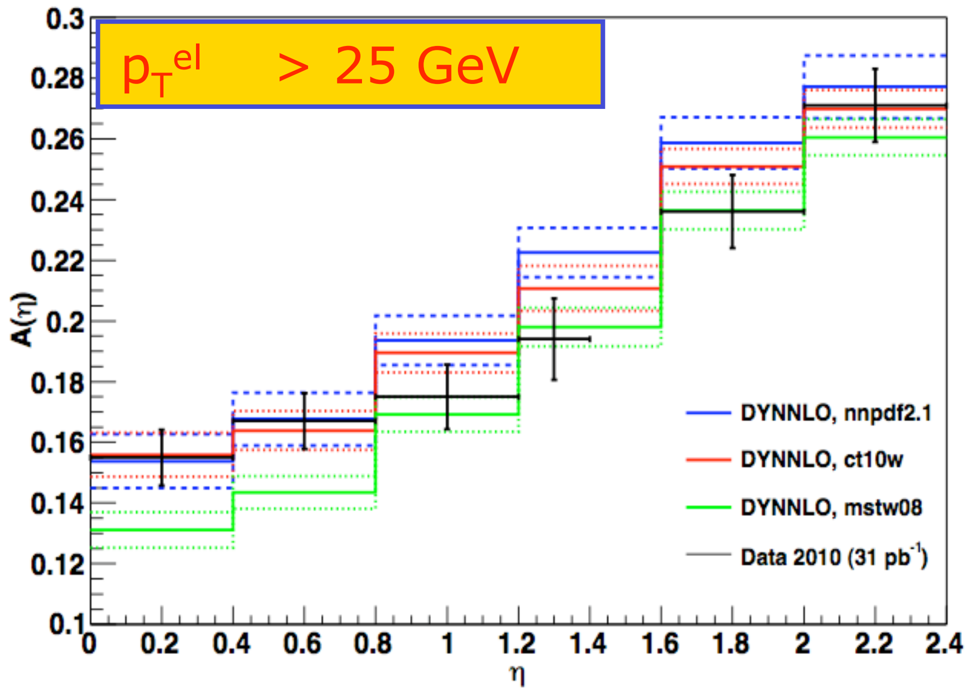
W lepton asymmetry data

CMS, electron

$\sqrt{s}$ = 7 TeV
36pb^{-1} luminosity
| η | < 2.1

Data/χ^2	NNPDF2.1	CT10w	MSTW08
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





W lepton asymmetry data

CMS, muon

$\sqrt{s}$ = 7 TeV
36pb^{-1} luminosity
| η | < 2.1

Data/χ^2	NNPDF2.1	CT10w	MSTW08
CMS(36pb^{-1}) electron $p_T > 25$ GeV	1.9	0.8	2.4
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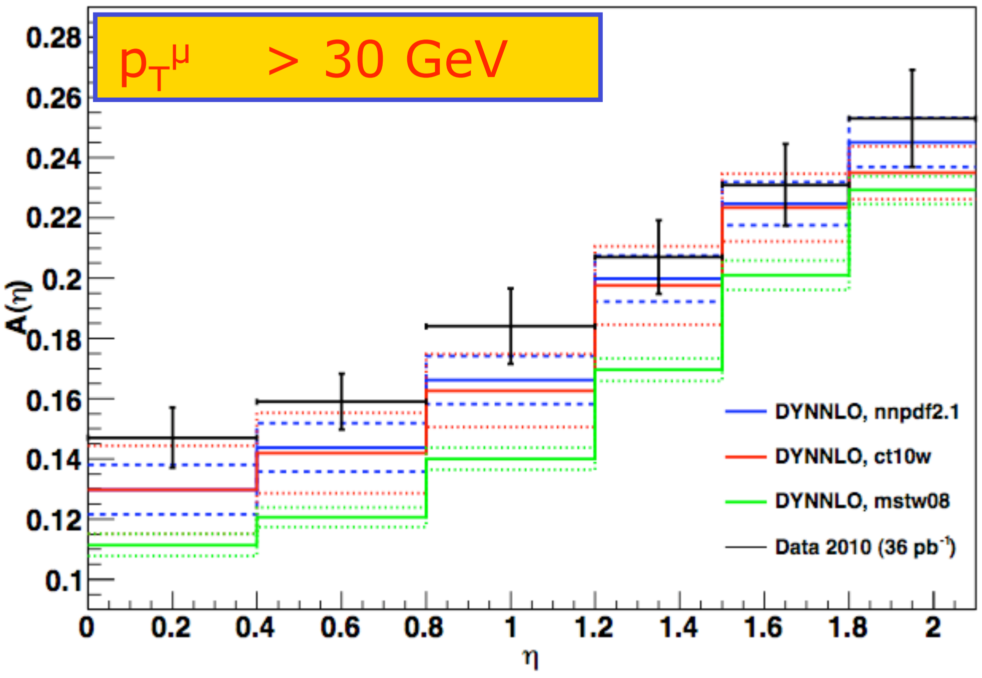
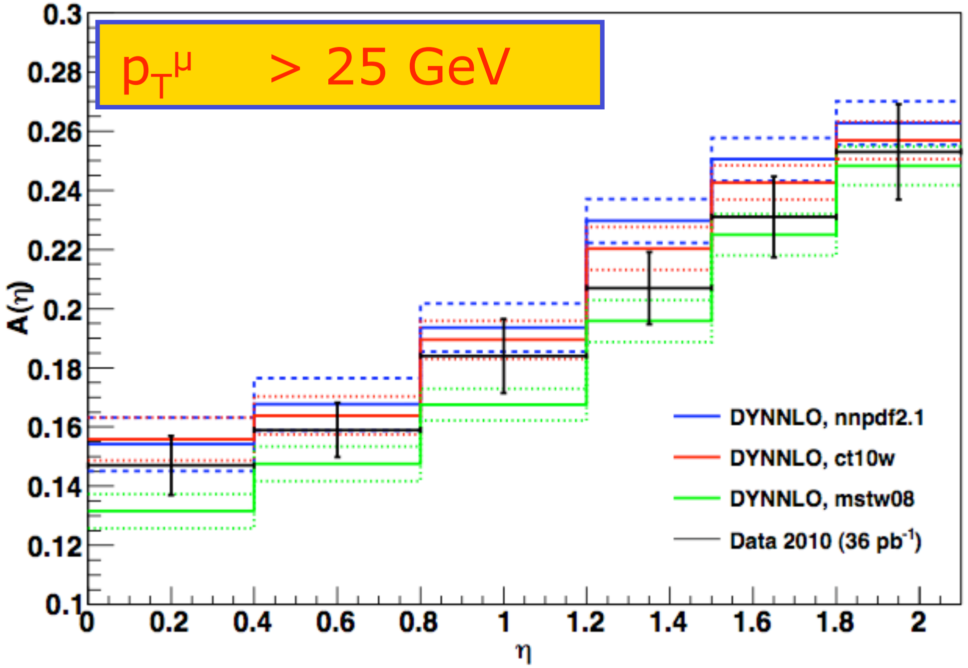
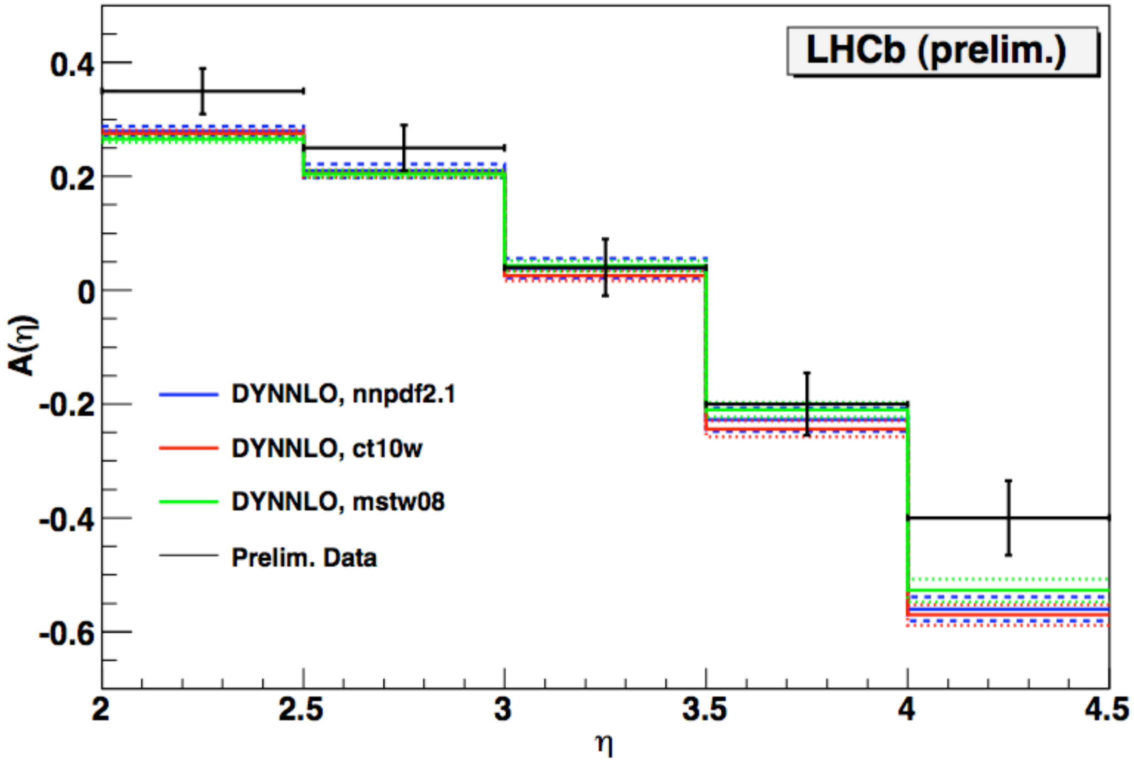




W lepton asymmetry data

LHCb

$\sqrt{s}$ = 7 TeV
p_T^{μ} > 20 GeV
2 < | η | < 4.5



NLO predictions obtained with DYNNLO [ArXiv: 0903.2120]

χ^2 /d.o.f

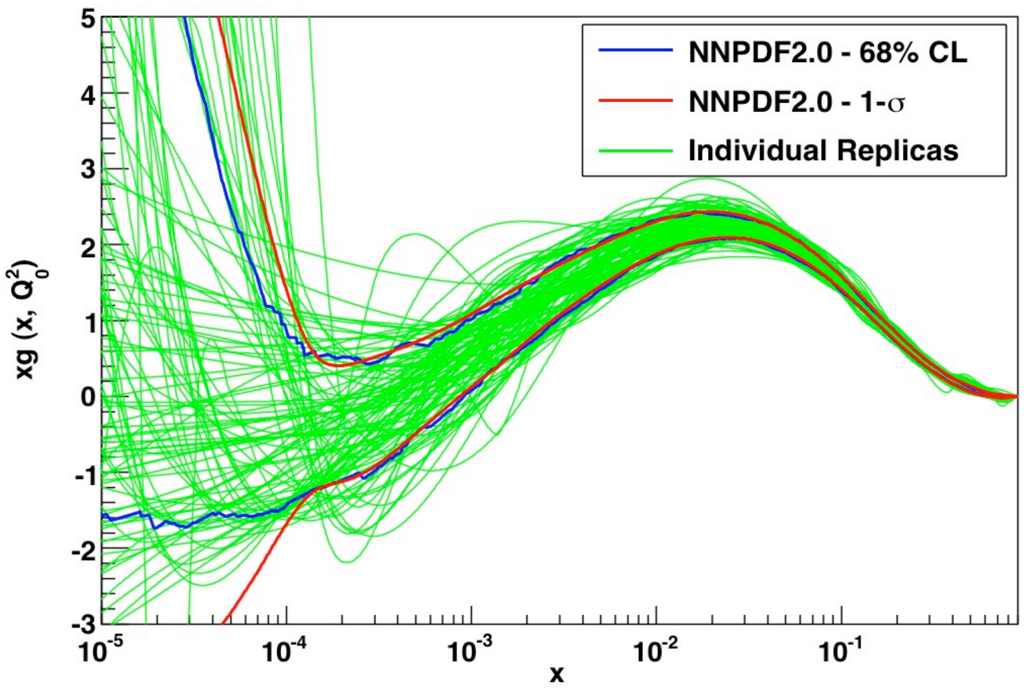
Data/χ^2	NNPDF2.1	CT10w	MSTW08
LHCb(prel.)	2.0	2.5	1.9

Reweighting PDFs

Updating the probability distribution

$$\langle \mathcal{O} \rangle = \int \mathcal{O}[f]\,\mathcal{P}(f)\,Df = \frac{1}{N}\sum_{k=1}^{N} \mathcal{O}[f^{(k)}]$$

- Straightforward with NNPDF which provides MC sets.
- The ensemble of replicas gives a representation of probability density.
- Also possible with standard parametrization and Hessian minimization.

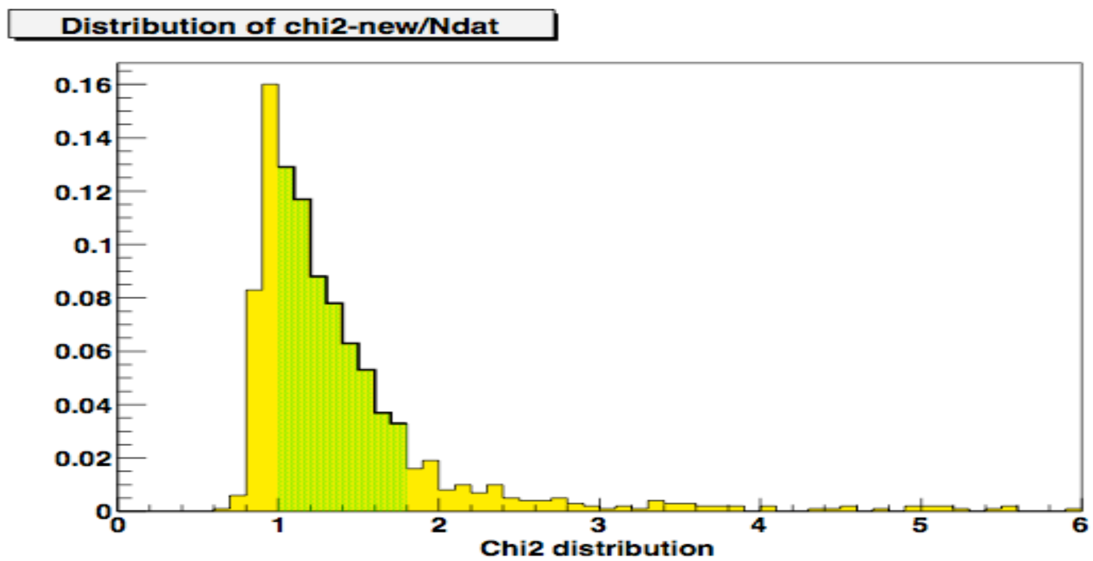


Reweighting PDFs

Updating the probability distribution

$$\langle \mathcal{O} \rangle_{\rm new} = \int \mathcal{O}[f] \mathcal{P}_{\rm new}(f) \mathcal{D}f = \frac{1}{N} \sum_{k=1}^{N} w_k \mathcal{O}[f^{(k)}]$$

Update the "old" probability density upon the addition of new data



$$\boxed{(\chi^2_k)^{n/2-1} \, e^{-\frac{1}{2}\chi^2_k}}$$

The weight w_k is the probability of the k^{th} replica given the χ^2 to the new data

The reweighted ensemble forms a representation of the probability density of PDFs conditional on both "old" and "new" data

Reweighting PDFs

Updating the probability distribution

$$\langle \mathcal{O} \rangle_{\rm new} = \int \mathcal{O}[f] \mathcal{P}_{\rm new}(f) \mathcal{D}f = \frac{1}{N} \sum_{k=1}^{N} w_k \mathcal{O}[f^{(k)}]$$

✓ Can be done quickly and easily by anybody: all you need to do is to compute the χ^2 to the new data for each replica

✓ Can determine

- Consistency of new data with the ones included in the prior fit
- Effect on PDFs errors and shapes without refitting
- Impact on predictions for any observable

Reweighting PDFs

Updating the probability distribution

$$\ln(N_{\text{eff}}) = \frac{1}{N}\sum_{k=1}^{N} w_k \ln\left(\frac{N}{w_k}\right)$$

$$\begin{aligned} \chi^2_\alpha &= \chi^2/\alpha \\ w_k(\alpha) &= (\chi^2_\alpha)^{n/2-1}\, e^{-\chi^2_\alpha/2} \\ P(\alpha) &= \frac{\mathcal{N}}{\alpha}\sum_{k=1}^{N} w_k(1)\cdot w_k(\alpha) \end{aligned}$$

Rescale covariance matrix by a factor α and compute probability for the rescaling parameter.

a) P (α) centered about 1 then data are consistent

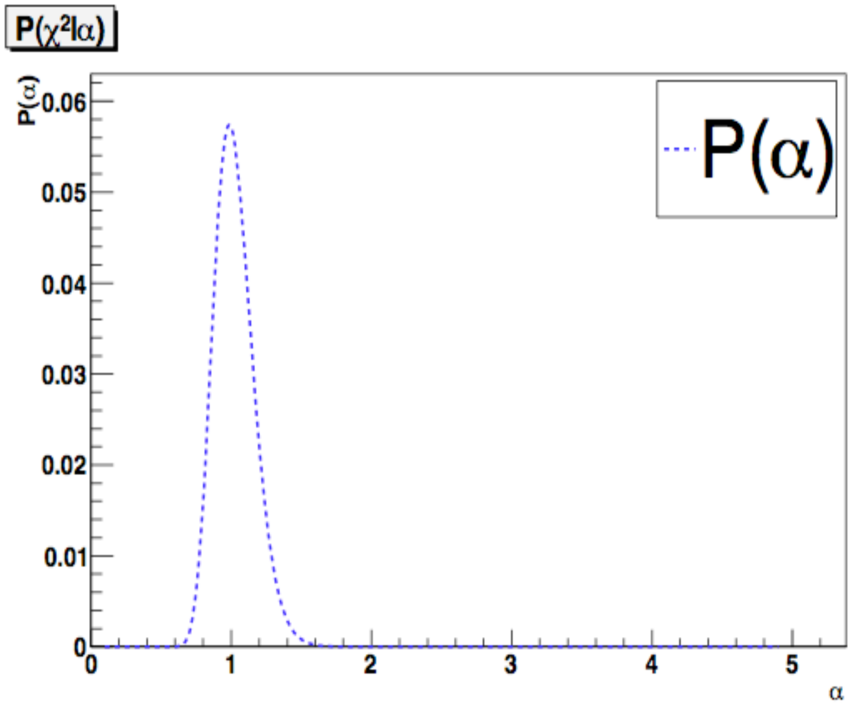
b) P (α) centered about value larger than 1, possible underestimation of uncertainties or sign of tension

Compute effective number of reps:

If N_{eff} small, two possibilities

a) new data are very constraining

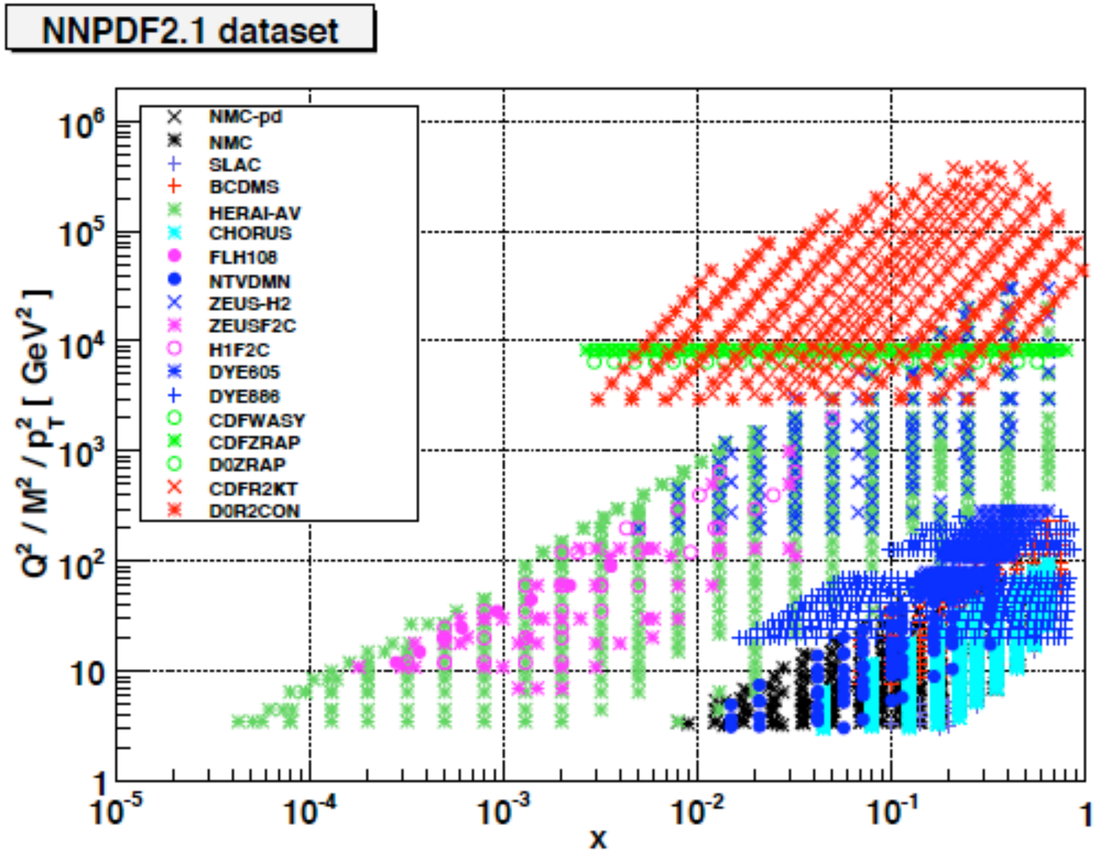
b) new data show some tension



The prior probability
The NNPDF2.1 parton set

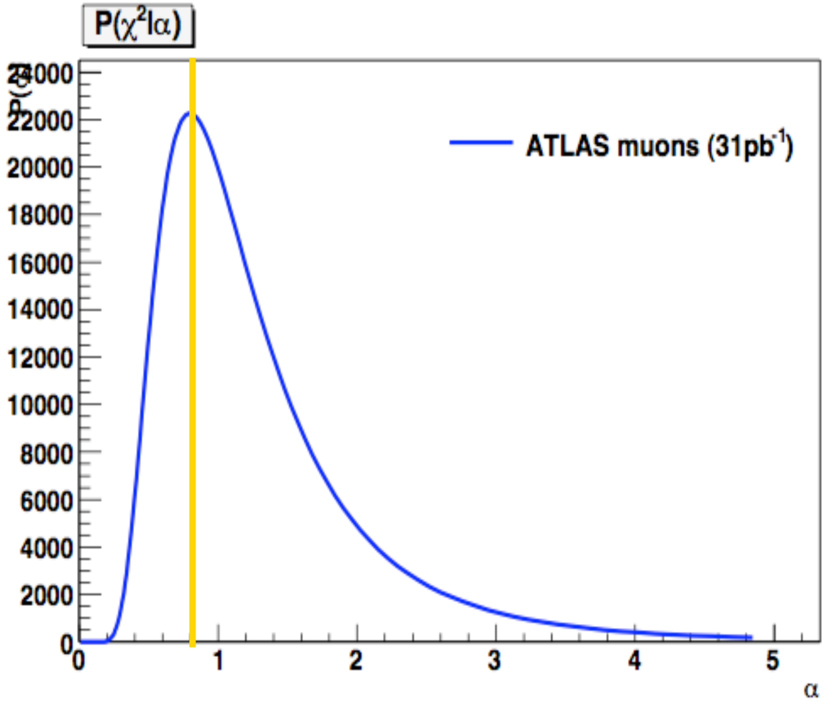
ArXiv:1101.1300

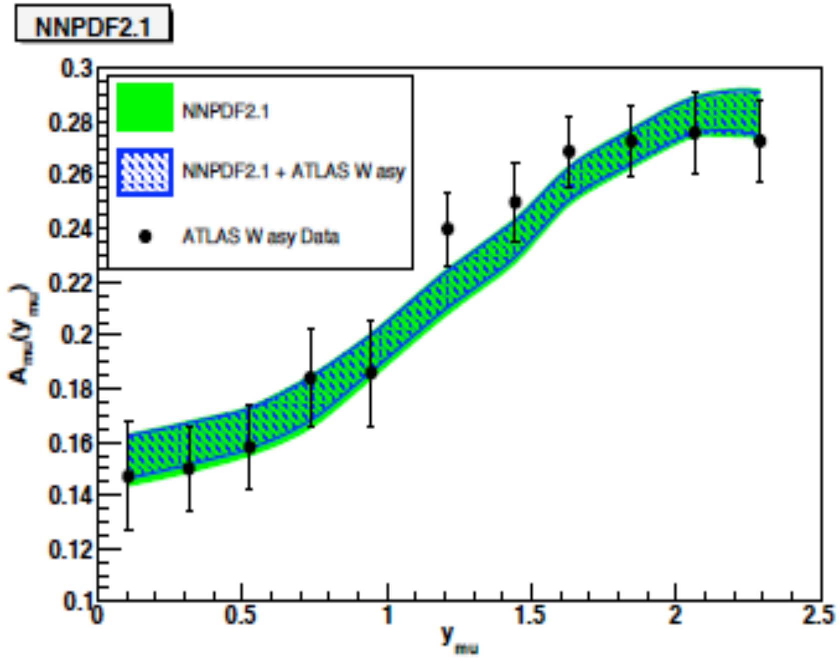
- Fit to DIS + DY (fixed target and collider) + Tevatron JETs data
- Exact NLO evolution
- HQ mass effects included, FONLL scheme [arXiv:1001.2312]
- Unbiased parametrization provided by large NNetworks: no need of tuning it to data
- Provides MC ensemble



W lepton asymmetry data

Inclusion of ATLAS data



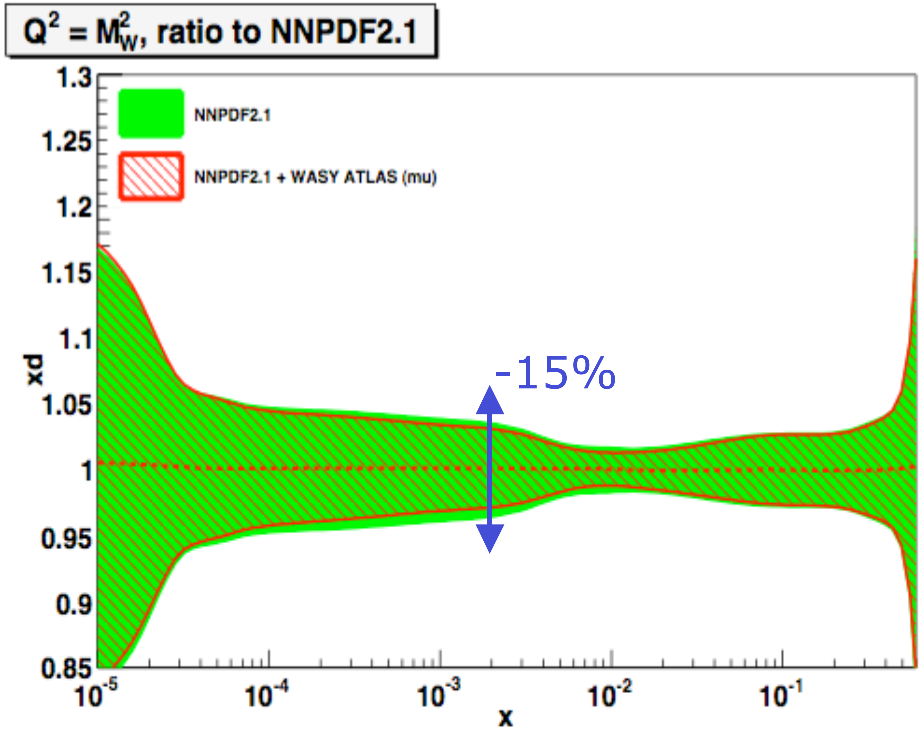


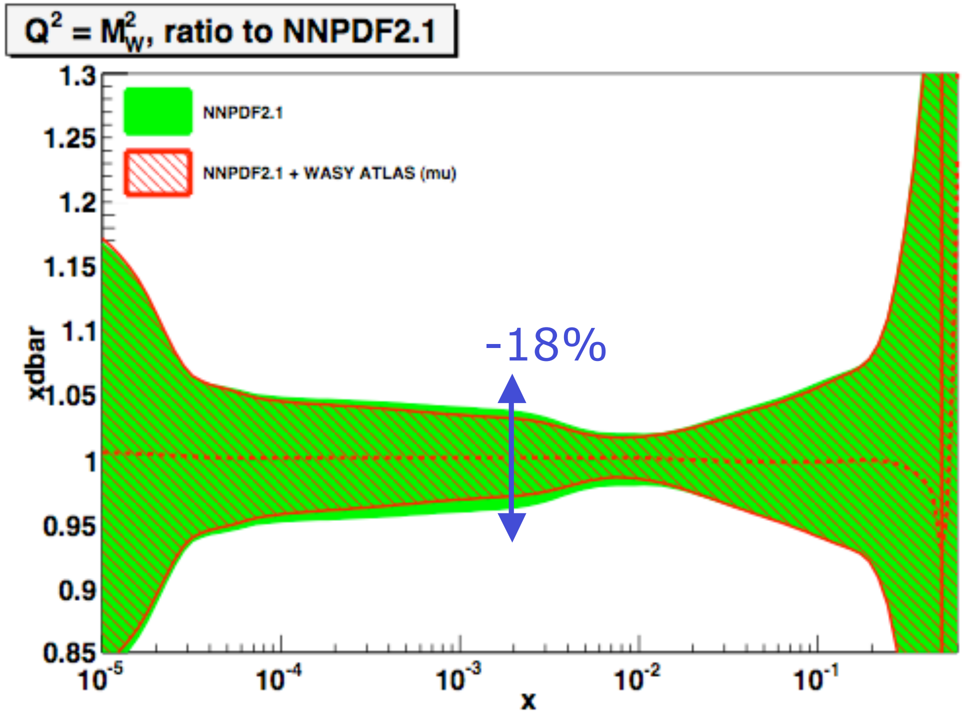
$N_{eff} = 93$
$N_{rep} = 100$

Data/χ^2	NNPDF2.1	NNPDF2.1 + rwt SET
ATLAS	0.68	0.63

W lepton asymmetry data

Inclusion of ATLAS data

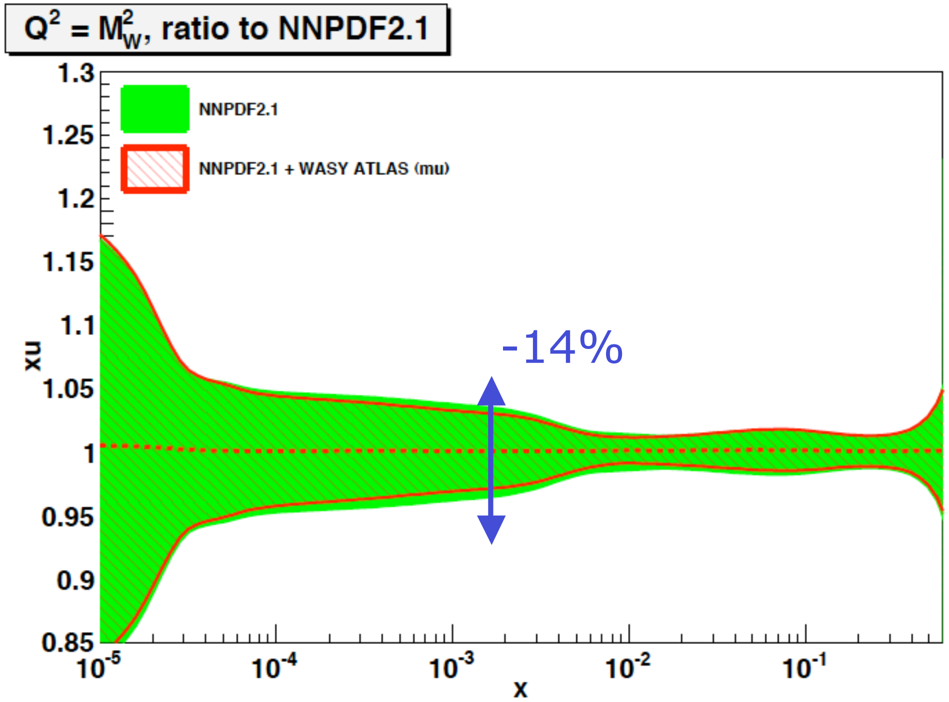


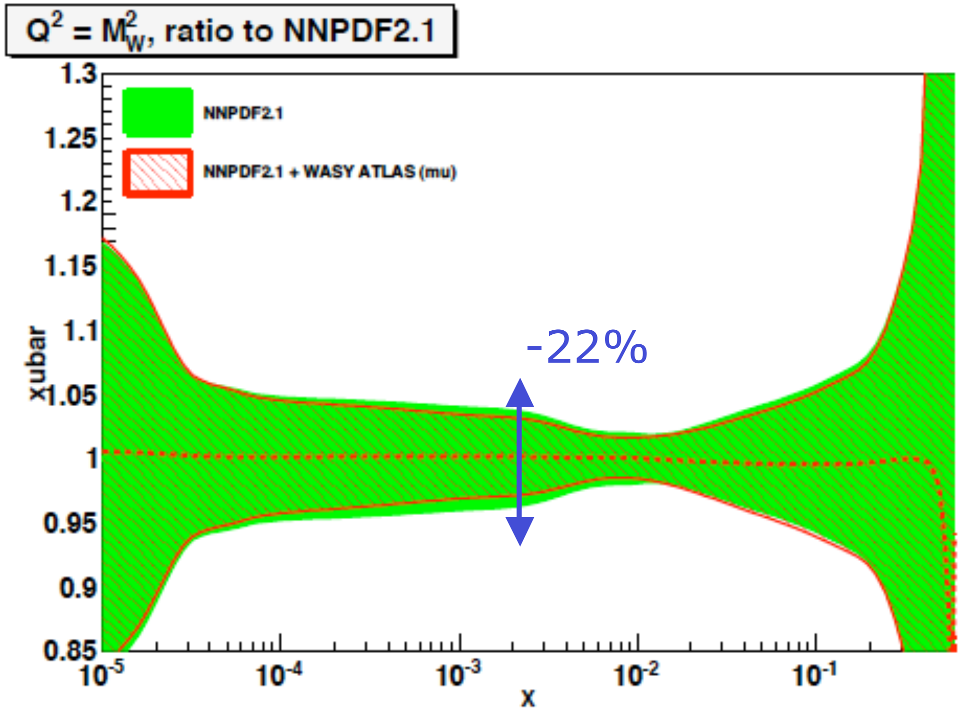


Slight reduction of uncertainty at medium-small x for light (anti)quark

W lepton asymmetry data

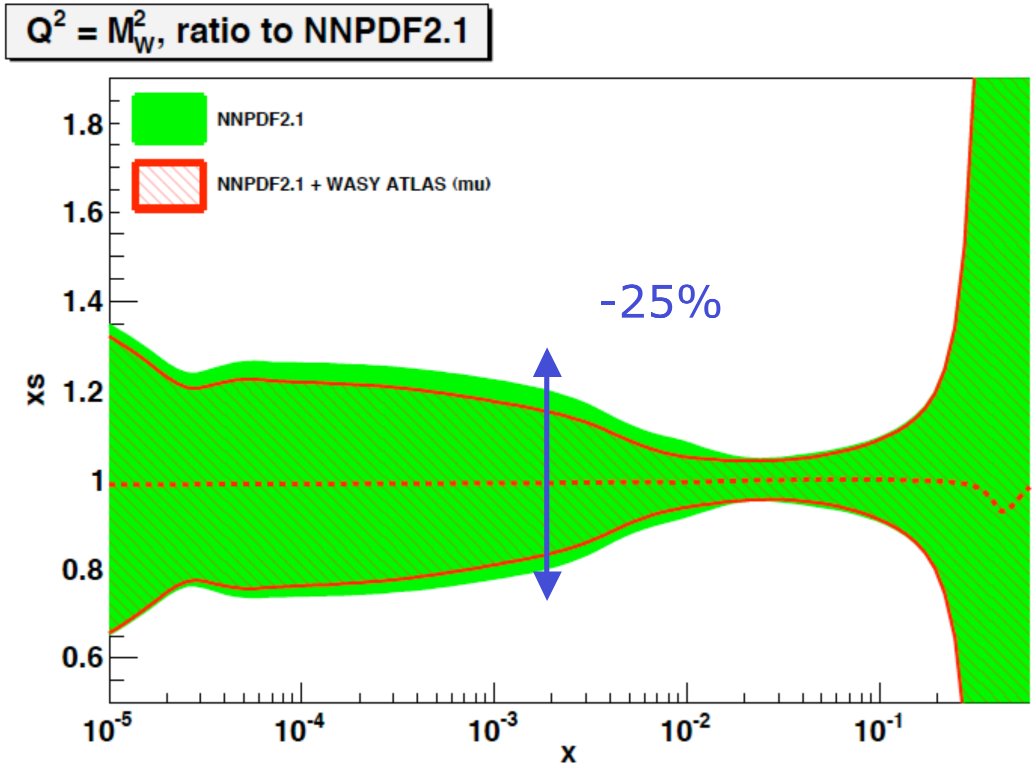
Inclusion of ATLAS data





Slight reduction of uncertainty at medium-small x for light (anti)quark

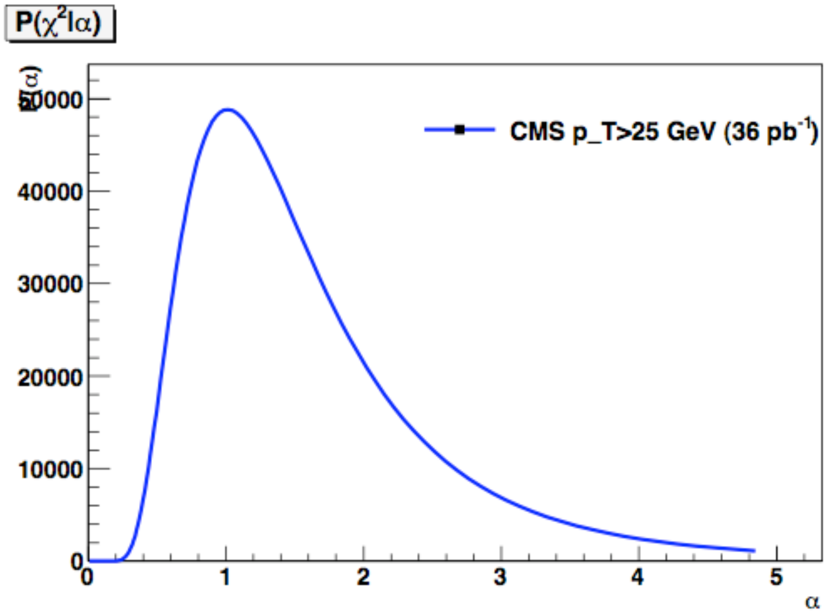
W lepton asymmetry data
Inclusion of ATLAS data

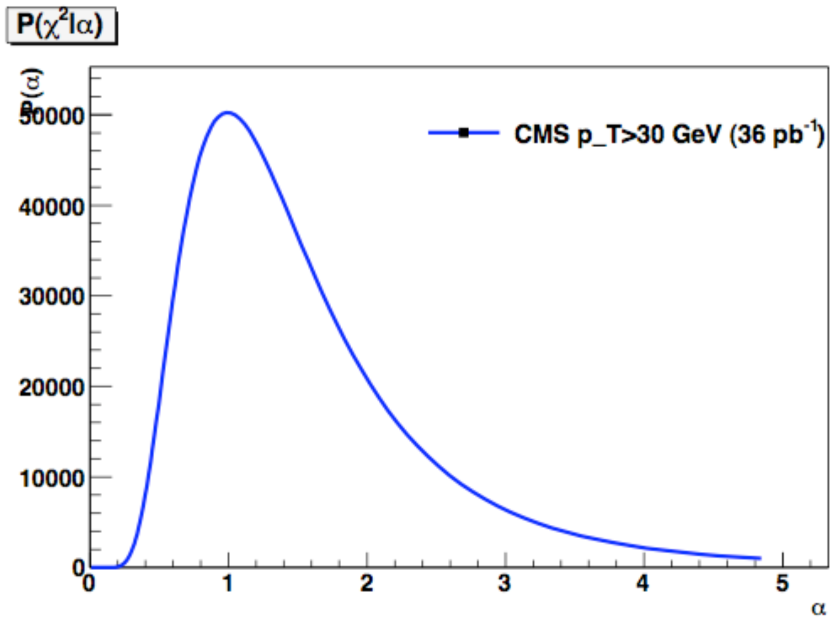


Slight reduction of uncertainty at medium-small x for light (anti)quark

W lepton asymmetry data

Inclusion of CMS data



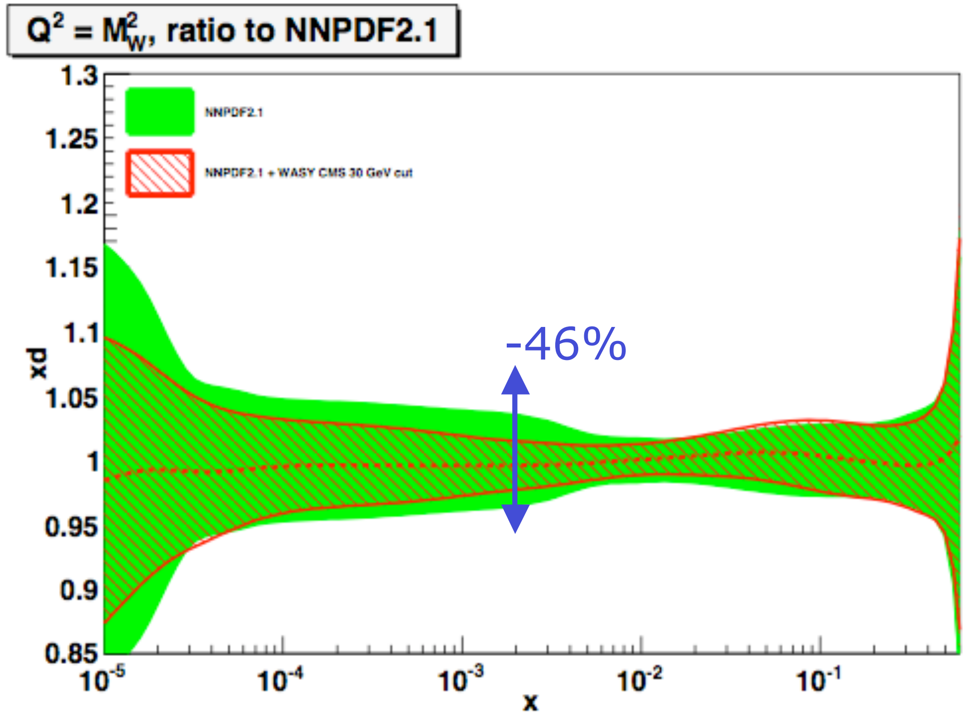


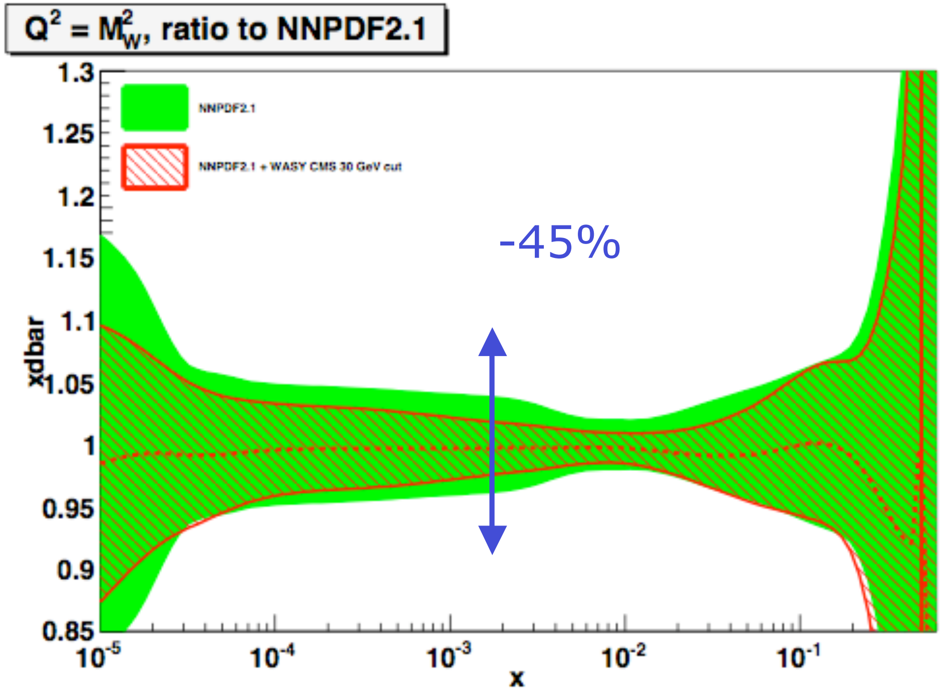
N_{eff} = 53 p_T^l> 25 GeV
N_{eff} = 68 p_T^l> 30 GeV
N_{rep} = 100

Data/χ^2	NNPDF2.1	NNPDF2.1 + rwt SET
CMS $p_T^l > 25$ GeV	1.6	0.9
CMS $p_T^l > 30$ GeV	1.2	0.9

W lepton asymmetry data

Inclusion of CMS data

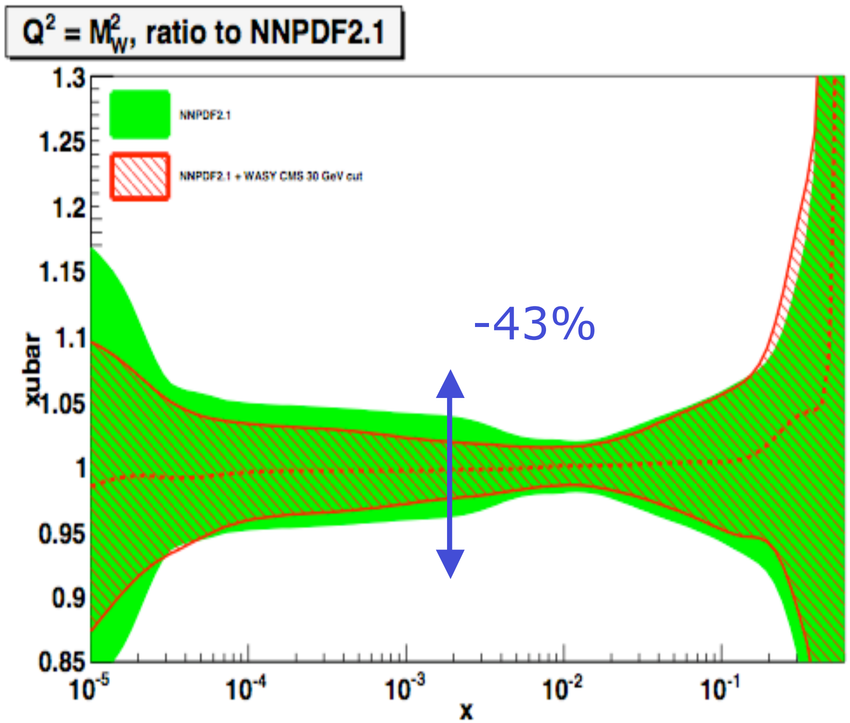


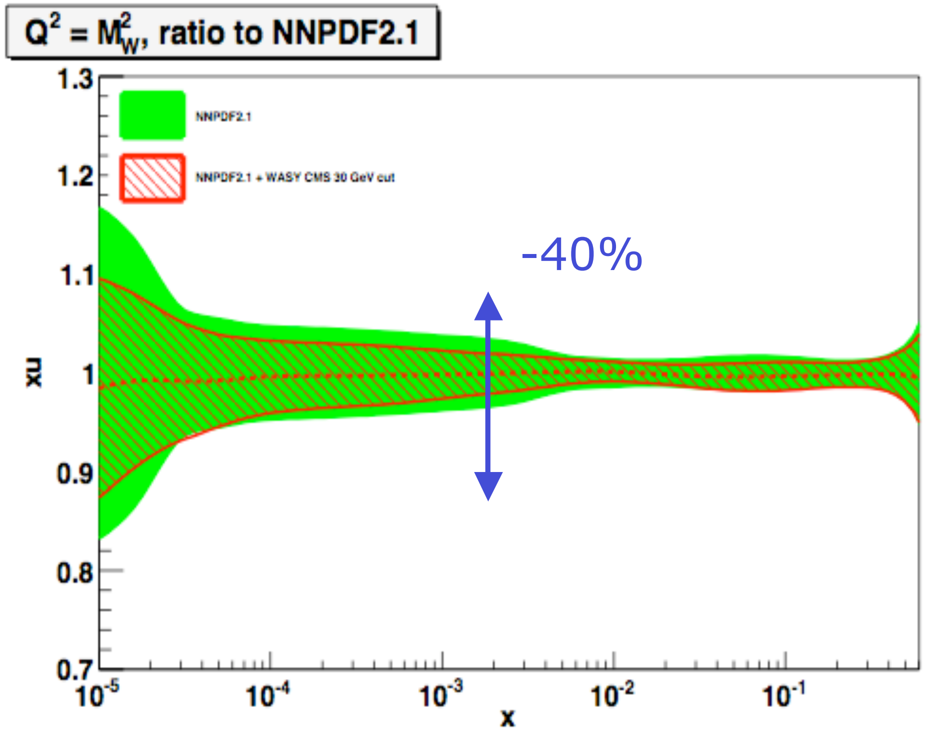


Significant reduction of uncertainty in the medium-small x region

W lepton asymmetry data

Inclusion of CMS data





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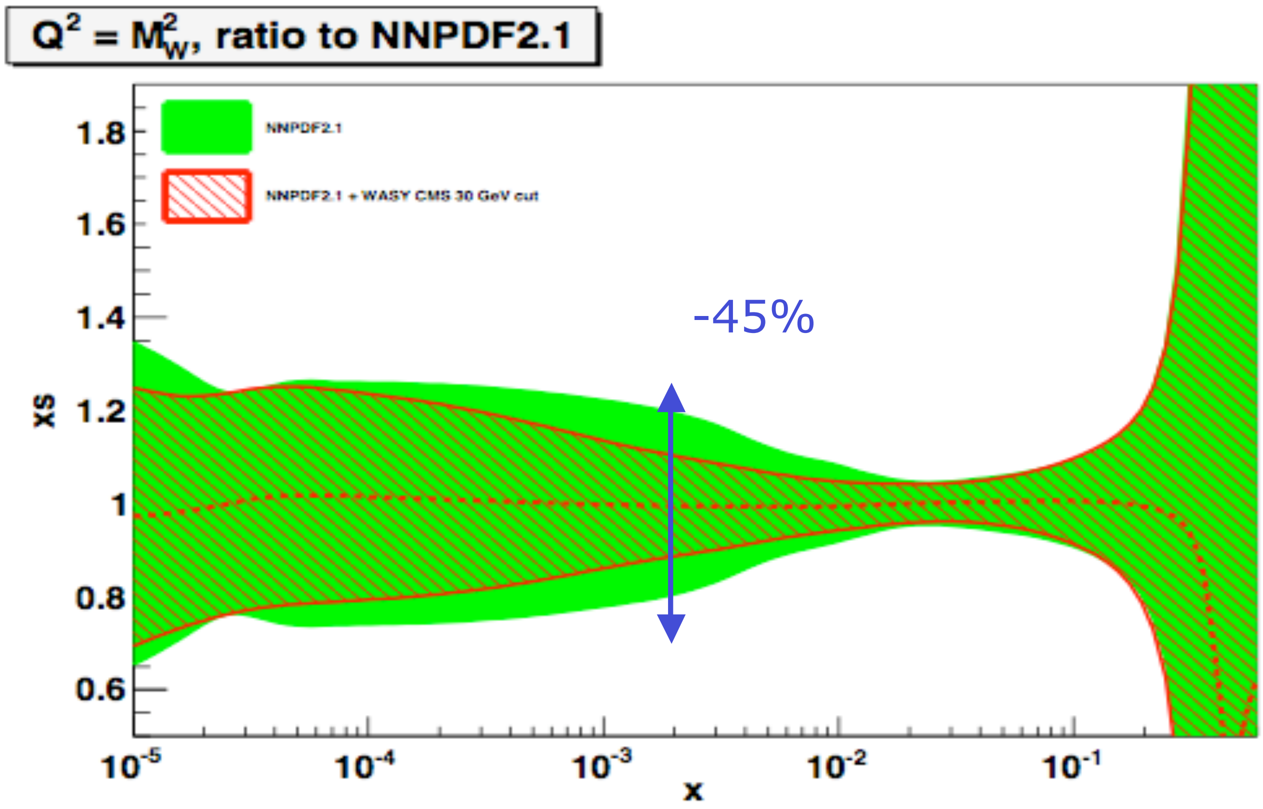
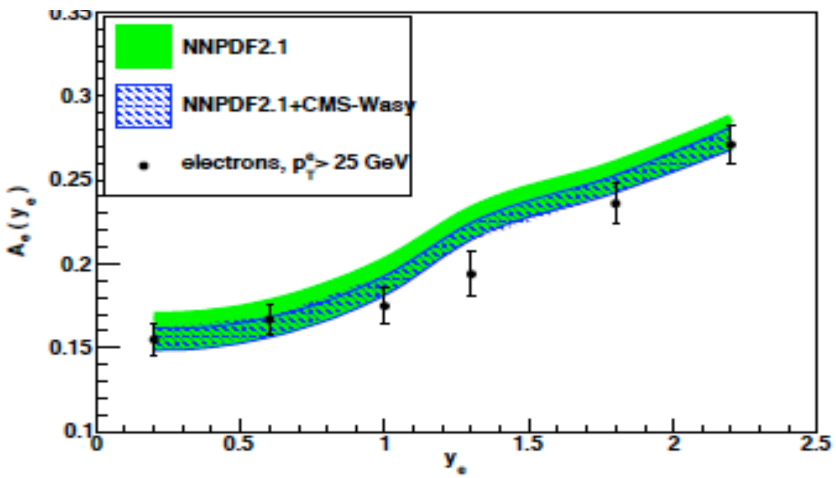
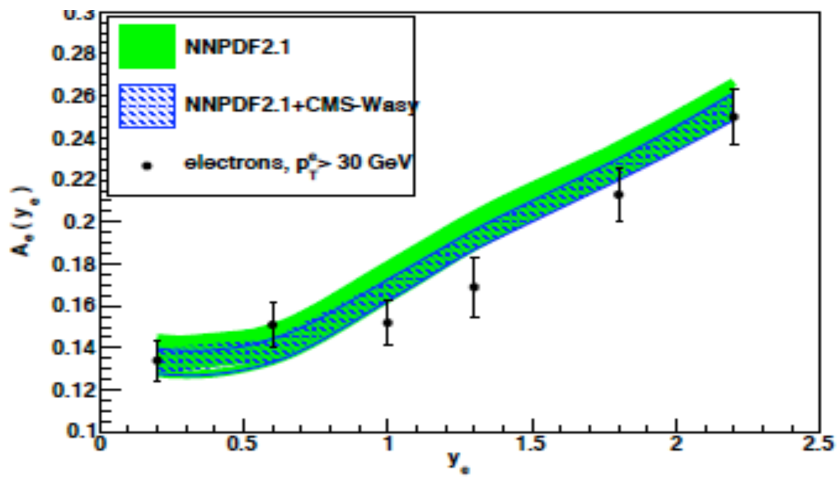


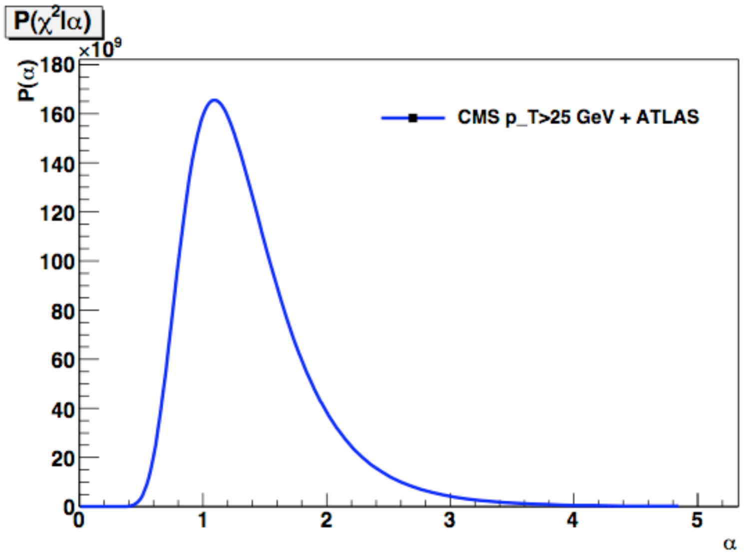
Significant reduction of uncertainty in the medium-small x region

W lepton asymmetry data

Inclusion of ATLAS+CMS data







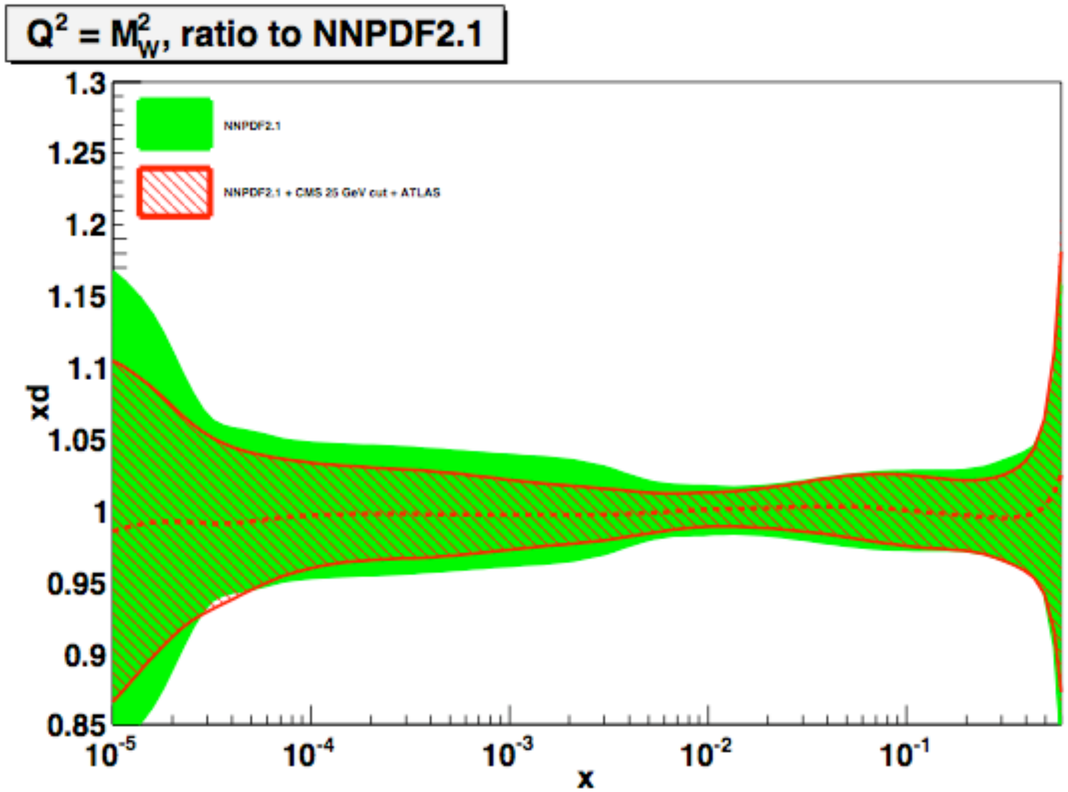
Data/χ^2	NNPDF2.1	NNPDF2.1 + rwt SET
ATLAS + CMS $p_T^l > 25$ GeV	1.0	0.9
ATLAS + CMS $p_T^l > 30$ GeV	1.2	1.0

ATLAS and CMS are perfectly compatible

N_{eff} = 68 p_T^l> 25 GeV
N_{eff} = 78 p_T^l> 30 GeV
N_{rep} = 100

W lepton asymmetry data

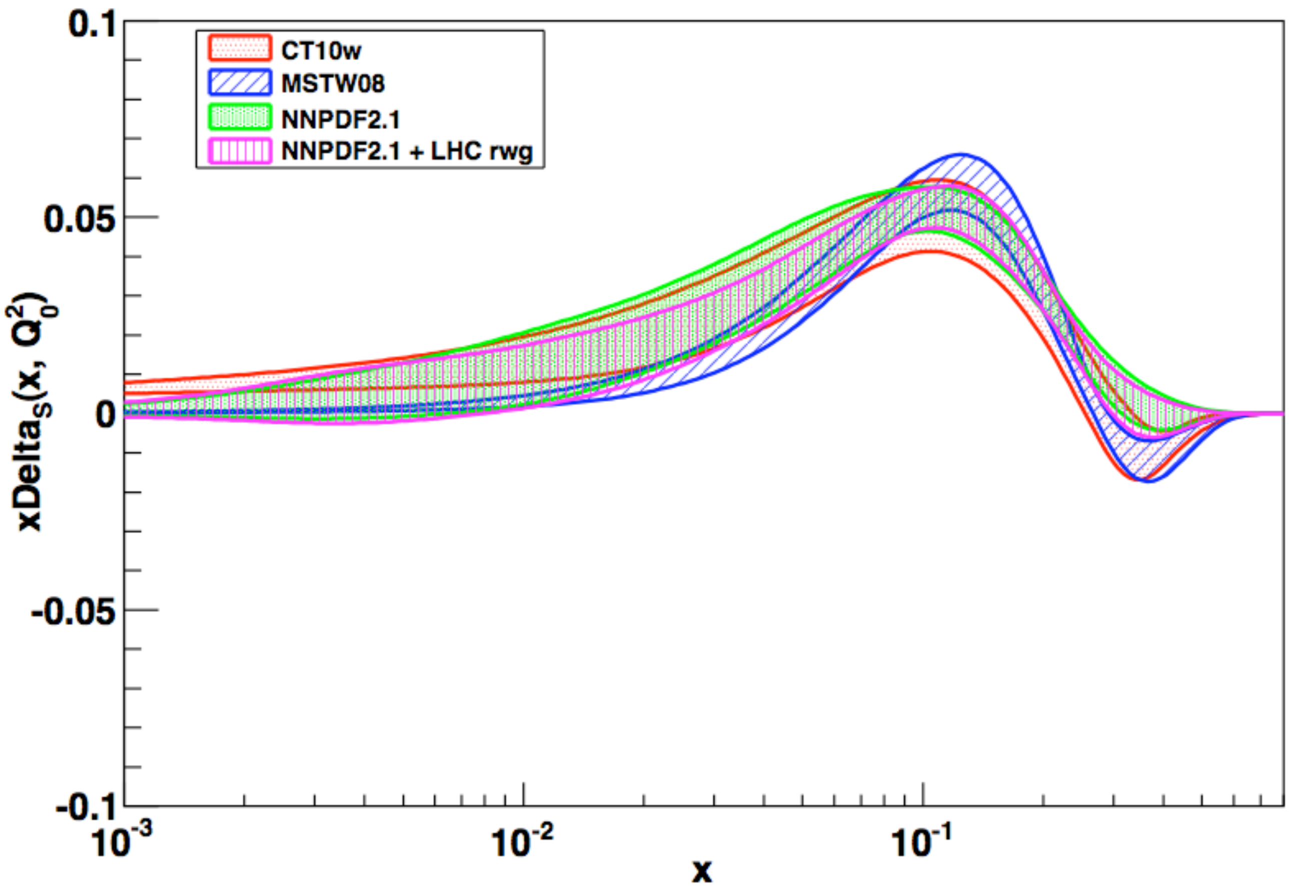
Inclusion of ATLAS+CMS data



- ATLAS and CMS data go in the same direction: no signs of tension
- Inclusion of data in PDFs fits reduces uncertainty of more than 40% in the small-medium x region for light (anti)quark PDFs
- CMS data are more constraining than ATLAS data.

W lepton asymmetry data

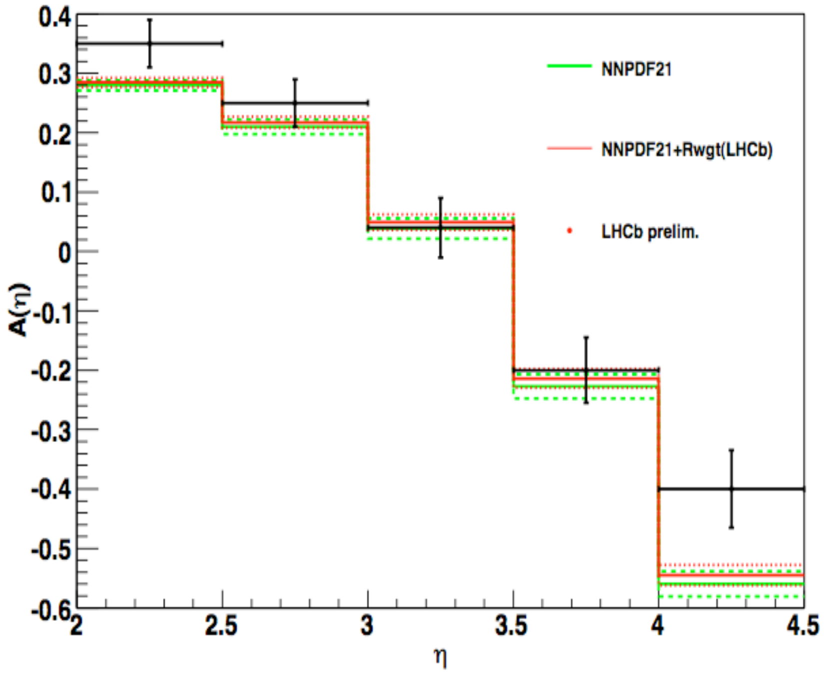
Inclusion of ATLAS+CMS data

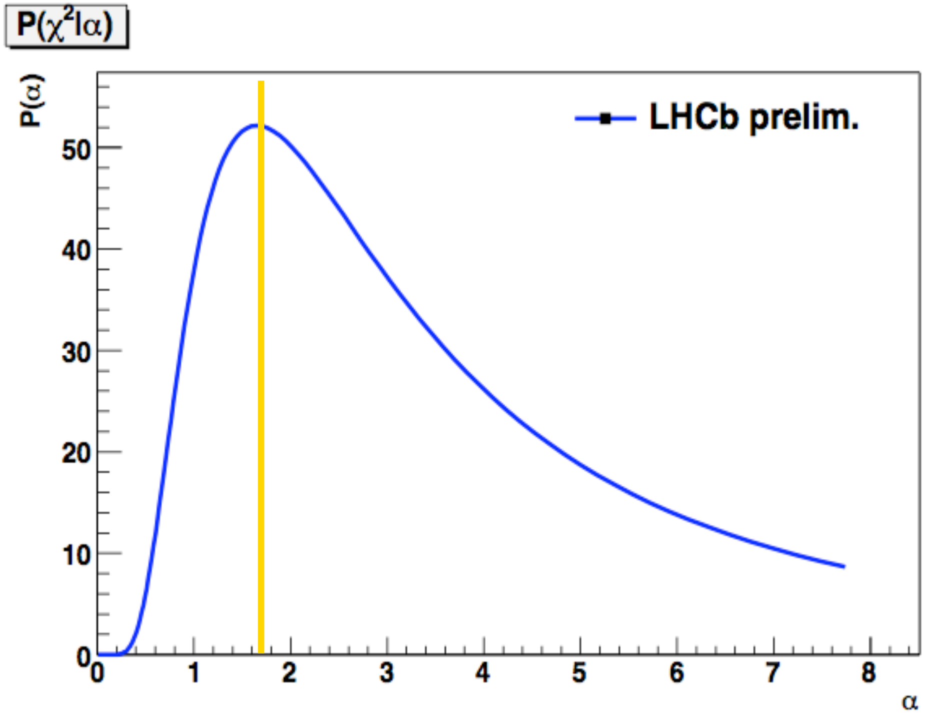


Precise measurements at the LHC allow better determination of the shape and discrimination between predictions.

W lepton asymmetry data

Inclusion of LHCb data



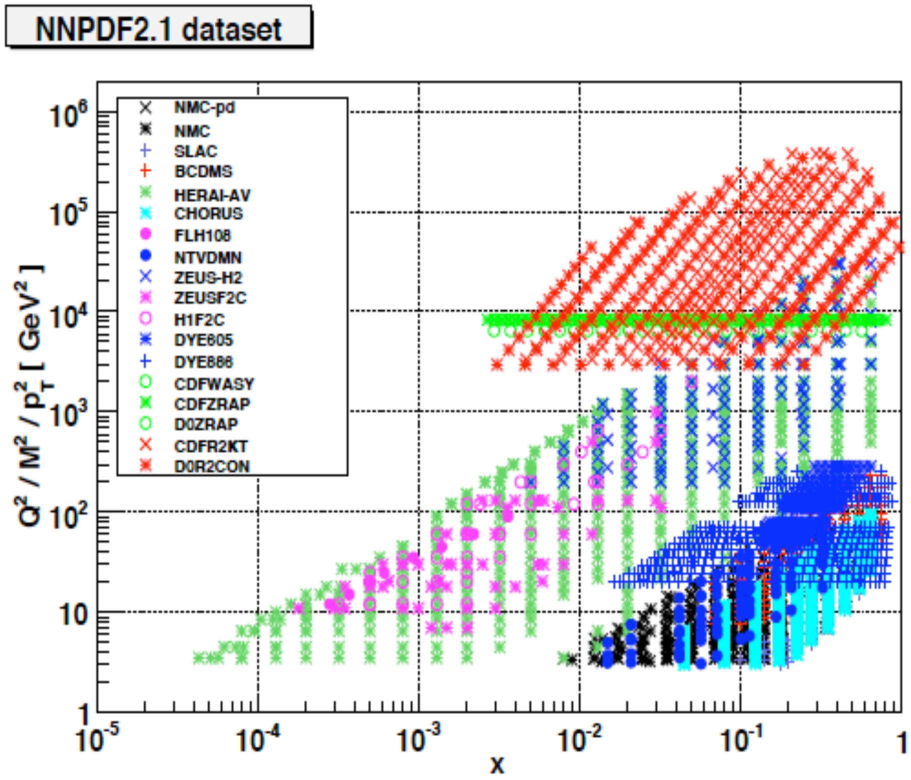


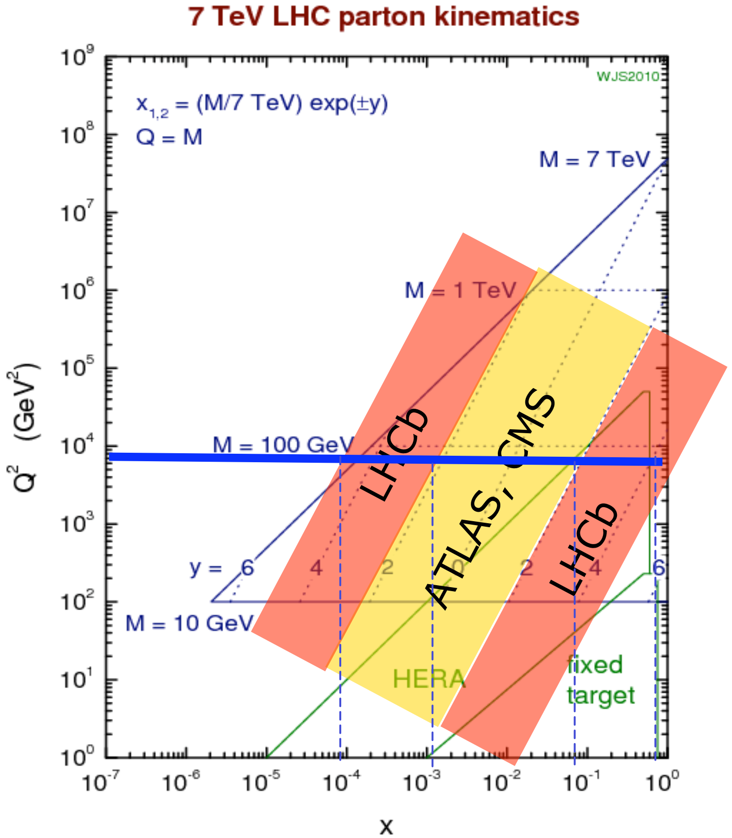
Data/χ^2	NNPDF2.1	NNPDF2.1 + rwt SET
LHCb prel.	2.03	1.68

$N_{eff} = 73$
$N_{rep} = 100$

W lepton asymmetry data

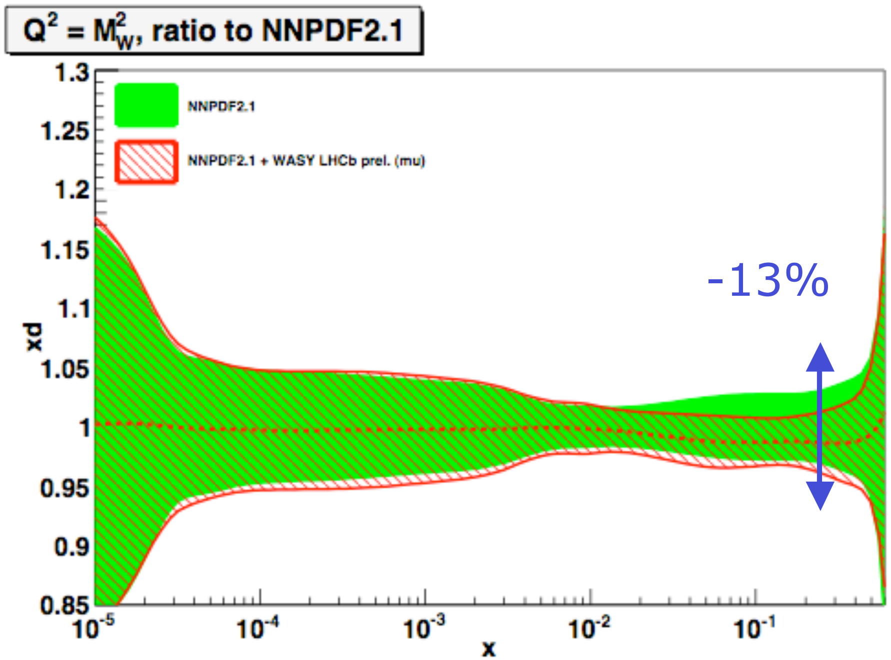
Inclusion of LHCb data

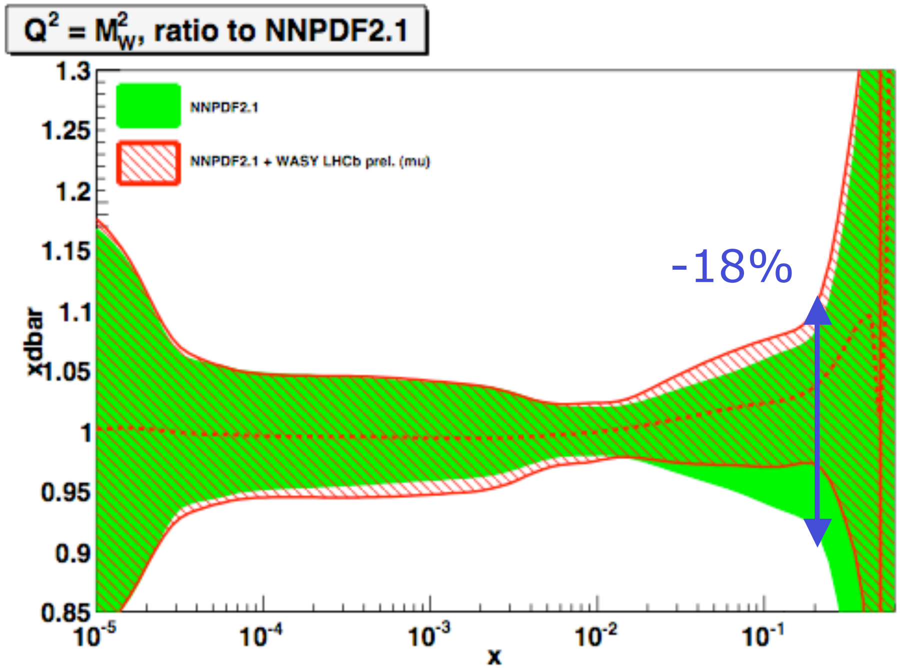




W lepton asymmetry data

Inclusion of LHCb data





Slight reduction of uncertainty in the large-x region, small-x unchanged

Conclusions

Reweighting PDFs:

- ✓ Check the impact of data without need of performing a new fit.
- ✓ Quick and easy: all you have to do is compute a χ^2 .
- ✓ Method can be used to check compatibility of a new measurement with old data.

The LHC @7 TeV data:

- ✓ Constrain significantly light (anti)quark at small and medium x (ATLAS and CMS)
- ✓ Mildly constrain large x region (LHCb)
- ✓ Potential for discriminating predictions from different PDF sets

Conclusions
and outlook

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Upcoming:

- ✓ NNPDF2.2 including ATLAS and CMS W lepton asymmetry data
- ✓ More studies as new data become available

BACK-UP

Bayesian inference

$$y = \{y_1, y_2, \cdots, y_n\} \qquad \sigma_{ij}$$ Experimental covariance matrix

Assume new data have Gaussian errors:
➔ relative probabilities for the new data for different {f} are proportional to the probability density of the chi2 to the new data conditional on {f}

$$\mathcal{P}(\chi^2|f) \propto (\chi^2(y,f))^{n/2-1} e^{-\frac{1}{2}\chi^2(y,f)}$$

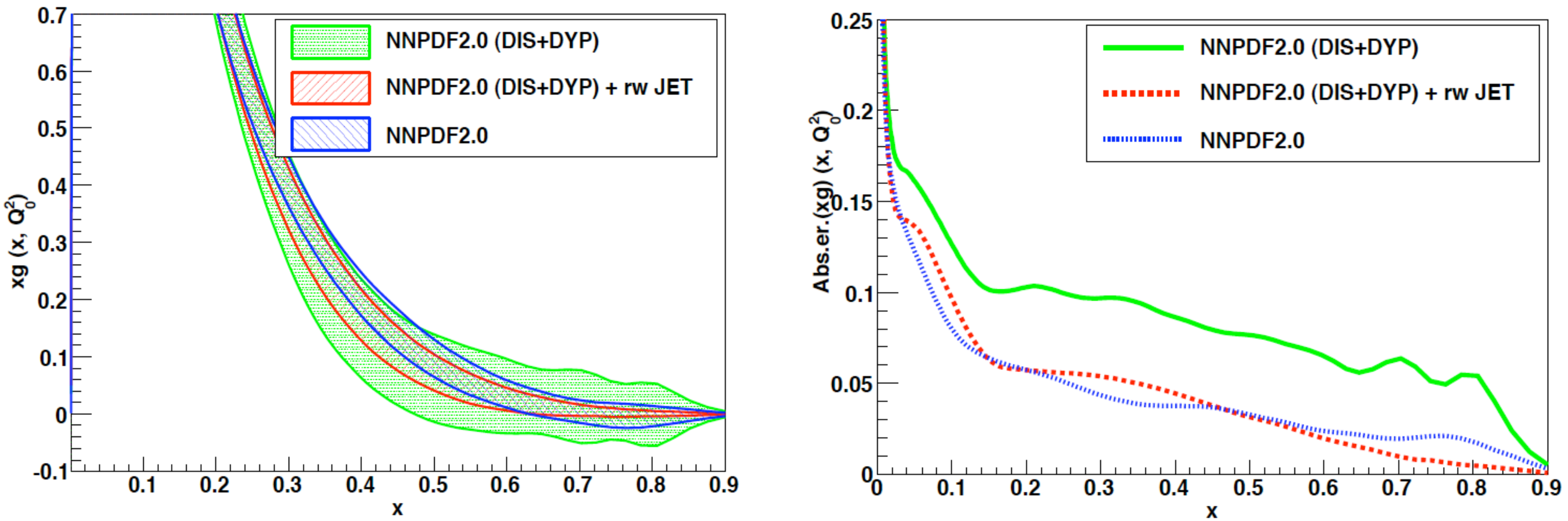
$$\chi^2(y,f) = \sum_{i,j=1}^{n} (y_i - y_i[f]) \sigma_{ij}^{-1} (y_j - y_j[f])$$

Chi2 depends on the predicted value of y given {f}

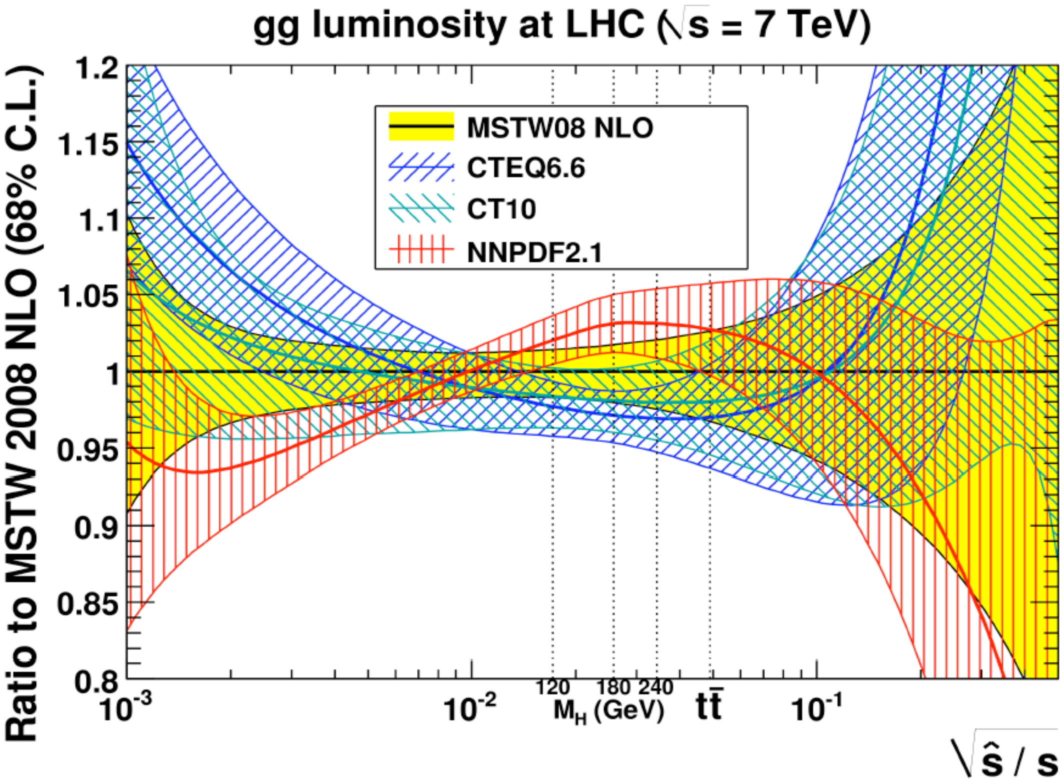
➔ $$\mathcal{P}_{\text{new}}(f) = \mathcal{N}_\chi \mathcal{P}(\chi^2|f)\, \mathcal{P}_{\text{old}}(f)$$

$\boxed{\text{Chi2 probability distribution}}$

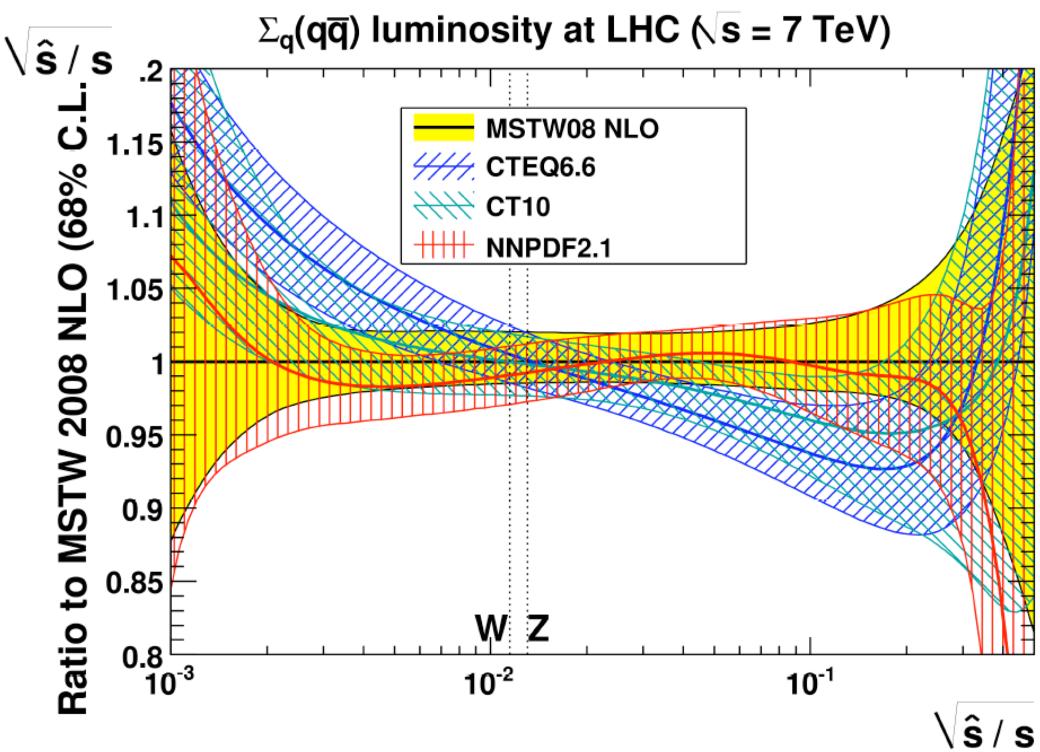
Reweighting PDFs
Tevatron JET data



- Start from DIS+DY fit (NNPDF20_DIS+DYP.LHgrid).
- Add CDF and D0 inclusive jet production data through reweighting
- Compare to refitting (NNPDF20.LHgrid)
- Results are the same within statistical fluctuations.



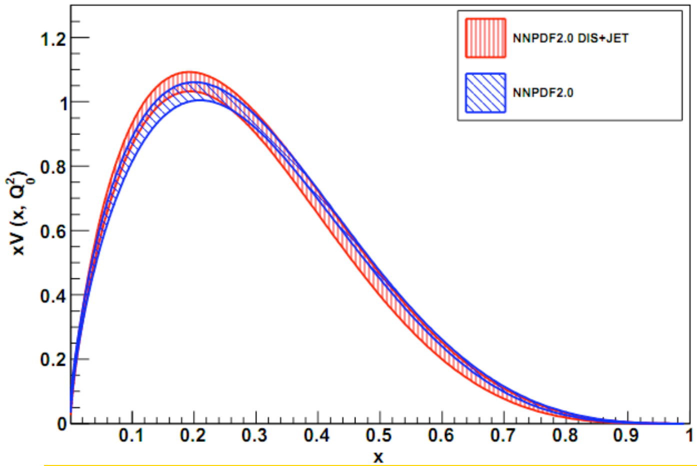
gluon-gluon luminosity



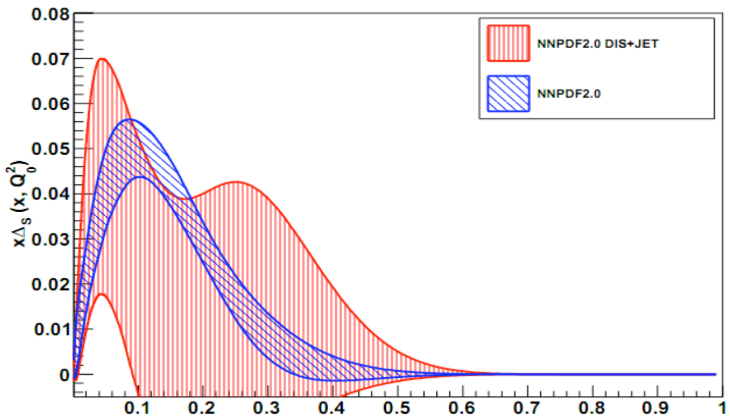
quark-quark luminosity

The NNPDF2.1 parton set

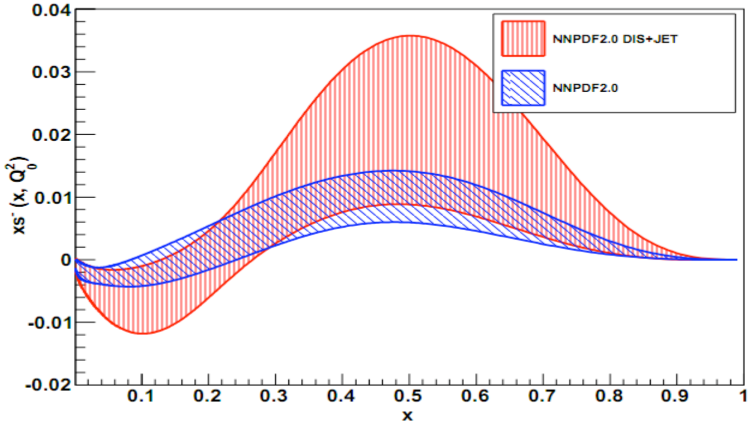
Impact of the old DY data



$xV = \Sigma\, x(q_i - \bar{q}_i)$



$x\Delta_S = x(\bar{d} - \bar{u})$



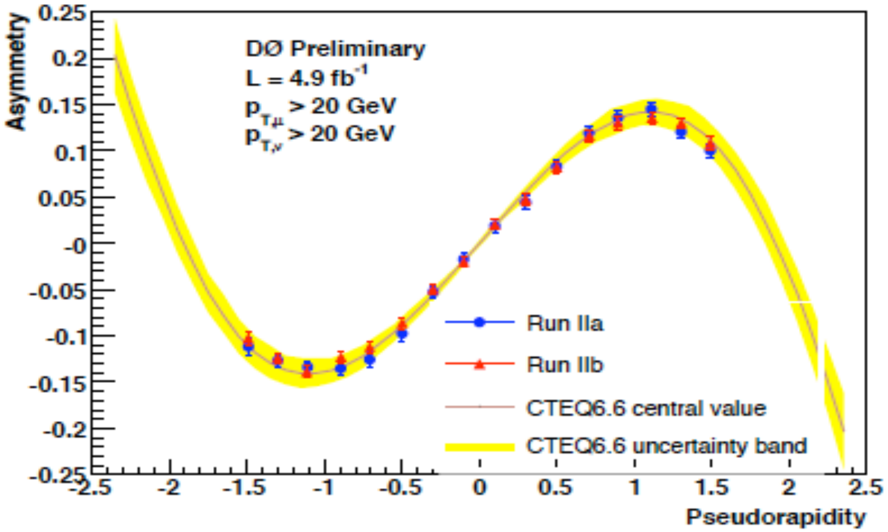
$xs^- = x(s - \bar{s})$

- Unbiased parametrization provided by large NNetworks: no need of tuning it to data

W lepton asymmetry data @ Tevatron

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

- CDF W charge asymmetry
- CDF electron charge asymmetry
- D0 muon charge asymmetry in single p_T^μ bin
- D0 electron charge asymmetry combined and separated p_T^e bins
- D0 muon charge asymmetry combined and separated p_T^μ bins



(a) $p_{T,\mu} > 20$ GeV, $p_{T,\nu} > 20$ GeV

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

➔ Constrain on d/u: 0.01 < x < 0.7

Tevatron DATA

d/u: $0.01 < x < 0.7$

✓ CDF W charge asymmetry: [arXiv:0901.2169]
Fitted in NNPDF2.0 $\chi^2_{NNPDF2.0} = 1.85$

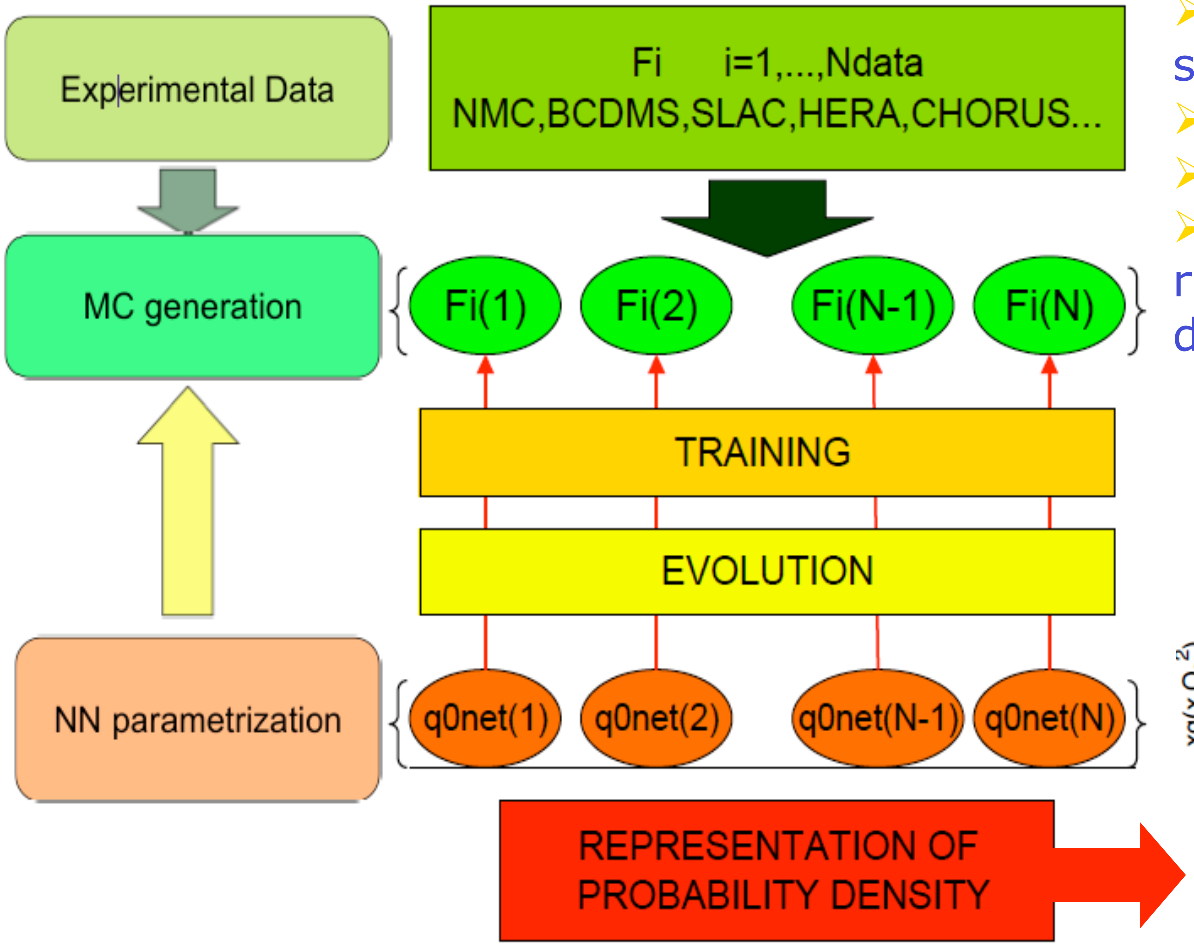
× CDF electron charge asymmetry [hep-ex/0501023]

✓ D0 muon charge asymmetry in single p_T^μ bin [arXiv:0709.4254]
Reweighted: compatible, little constraint

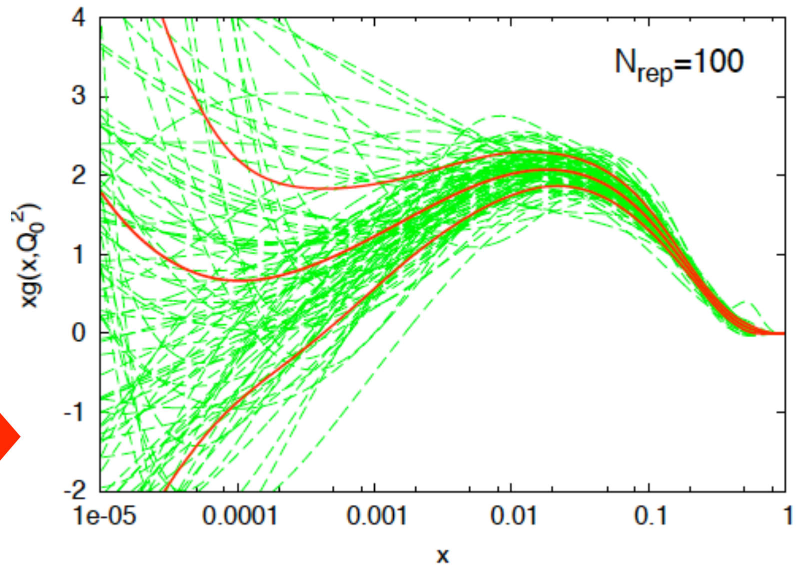
✓ D0 electron charge asymmetry in separated p_T^e bins [arXiv: 0807.3367]
Reweighted: inclusive bin provides constraints and
it is compatible, problem with exclusive measurements

× D0 muon charge asymmetry in separated p_T^μ bins [D0 Note 5976-conf]

PDFs probability density
by Monte Carlo sampling

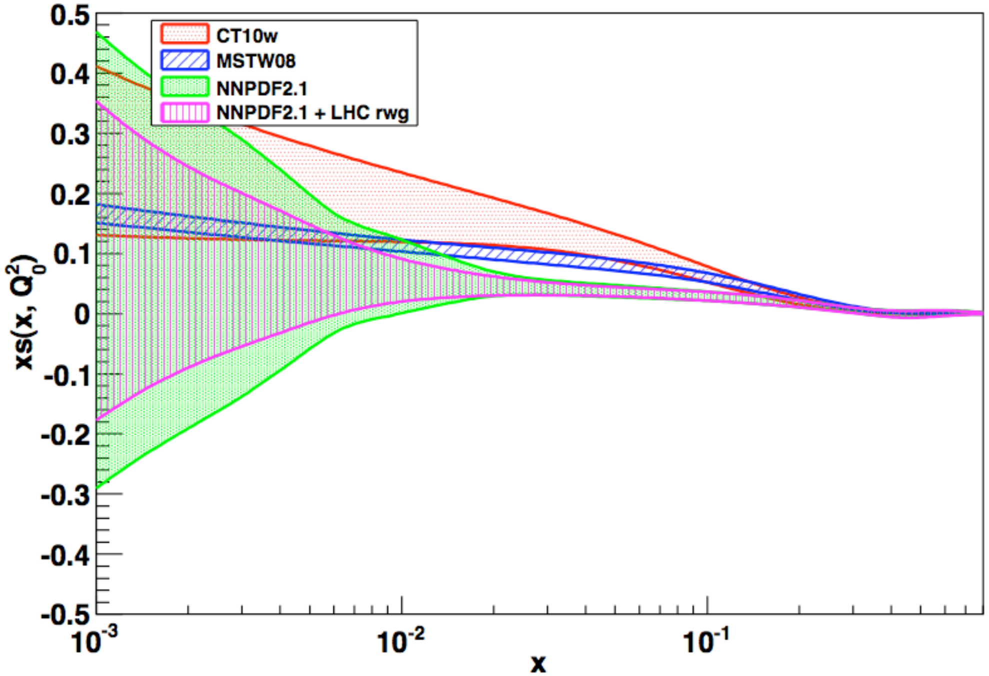


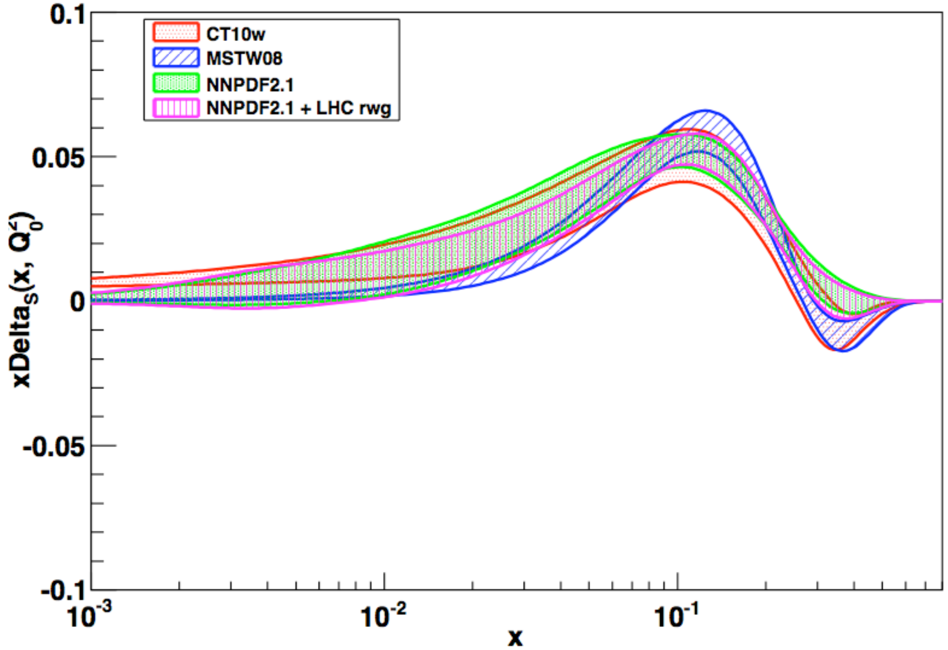
- Monte Carlo ensemble in the space of data
- Projected in the space of PDFs
- NN and cross-validation method
- The N replicas provide representation of probability density in the space of PDFs



W lepton asymmetry data

Inclusion of ATLAS+CMS data





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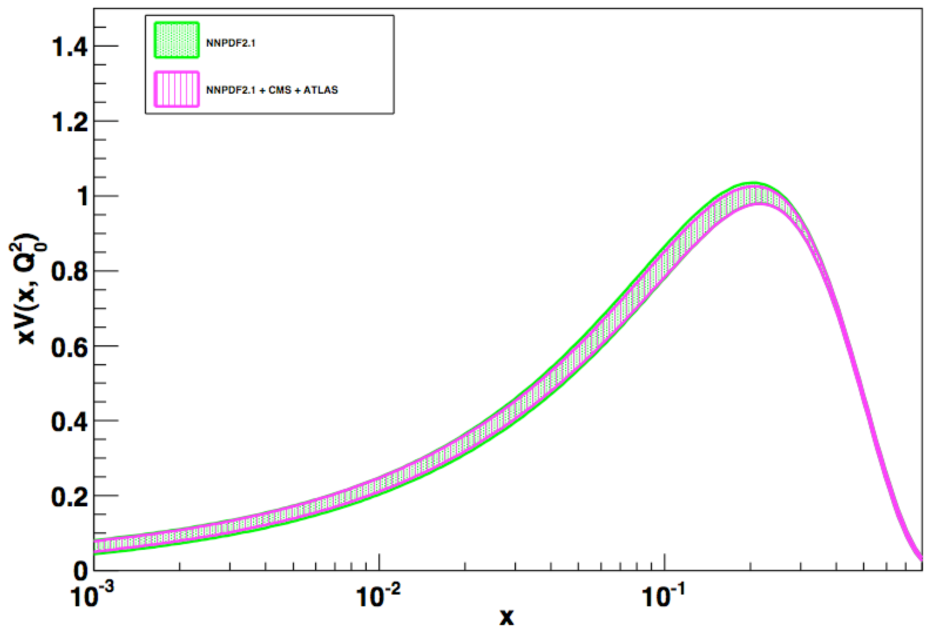

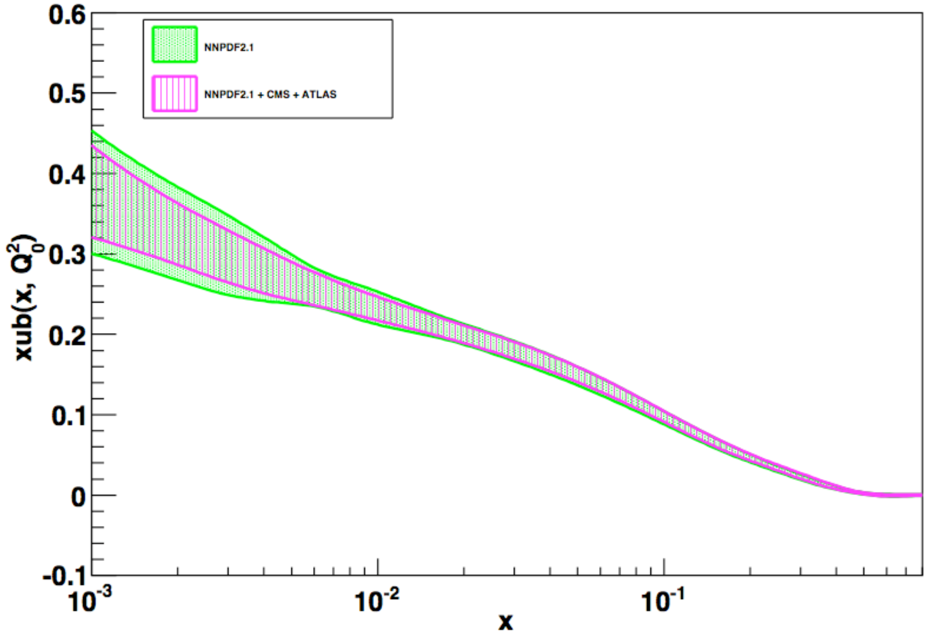

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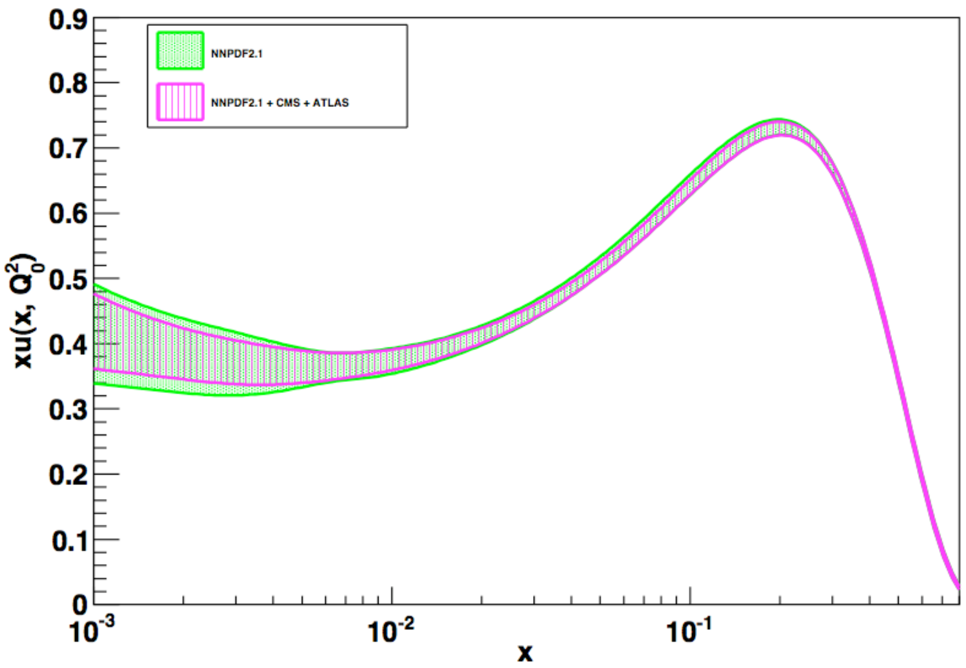

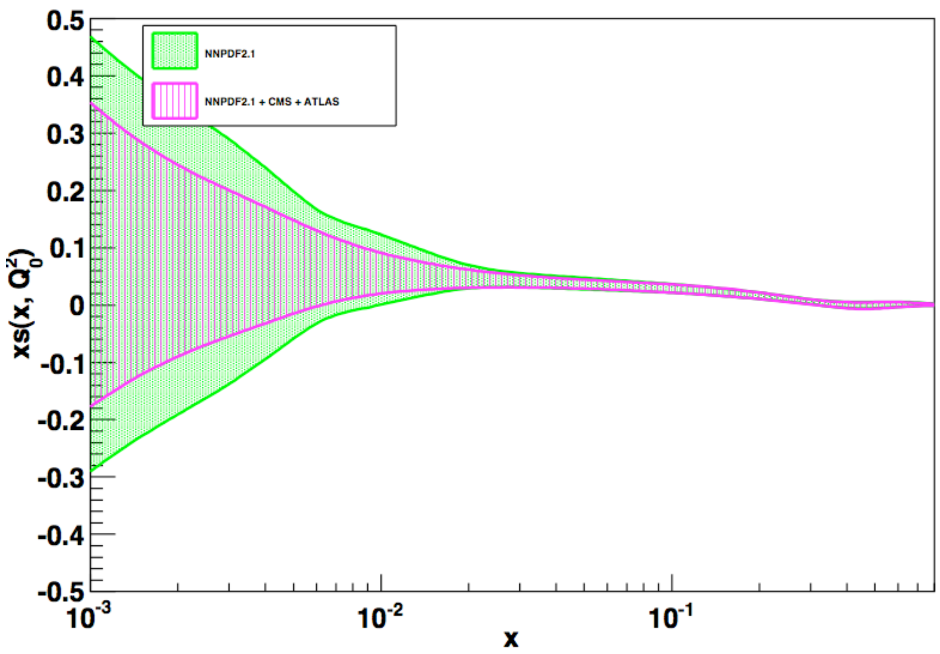

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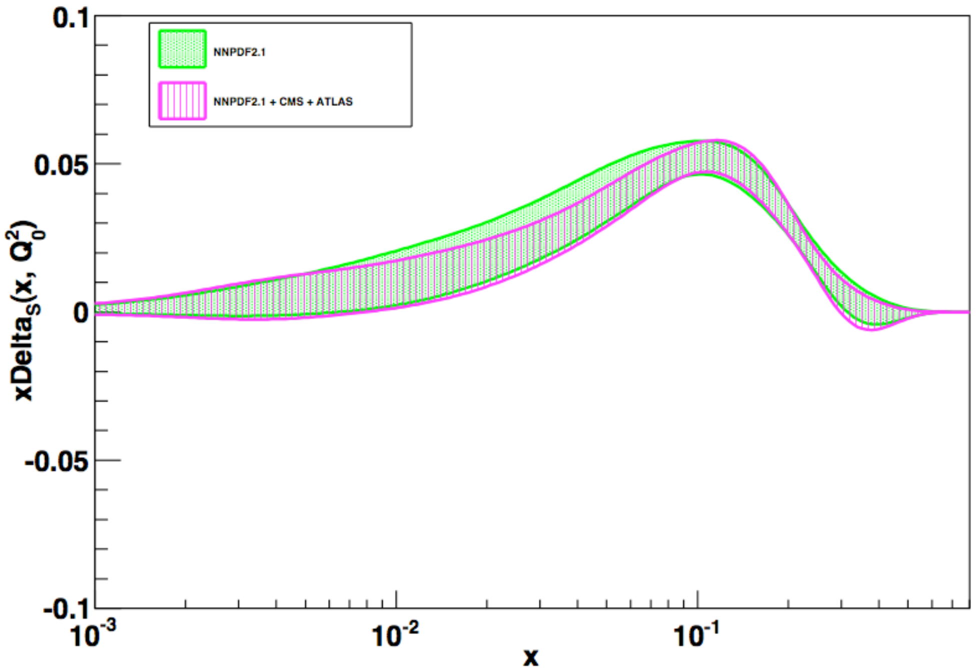
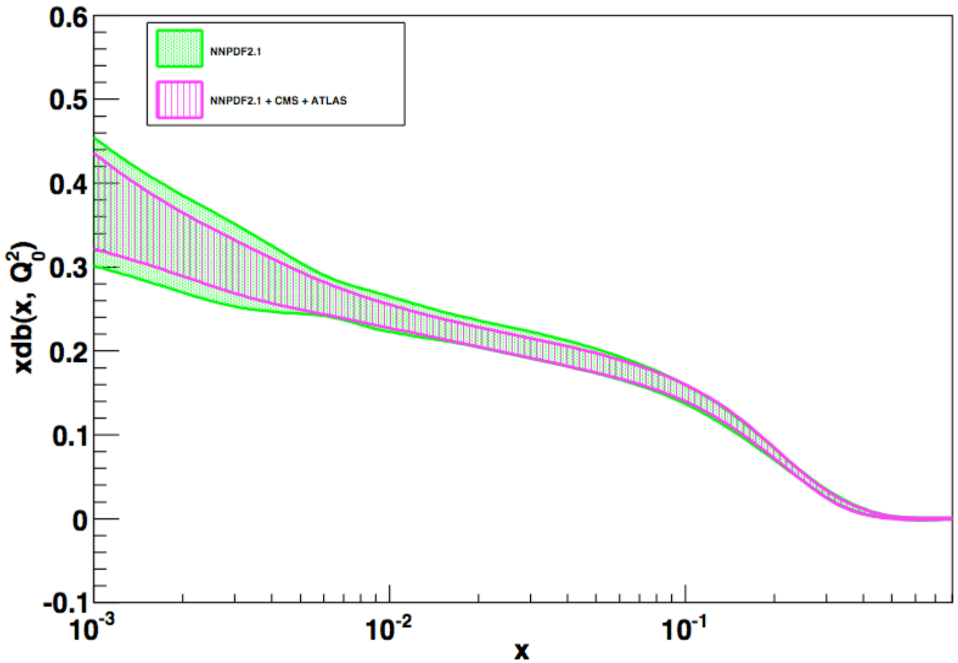
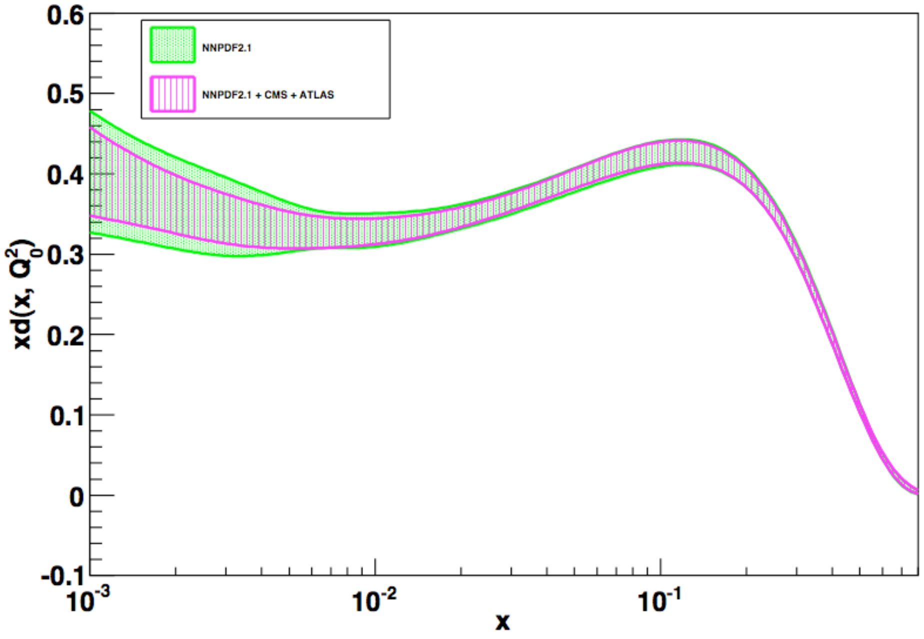
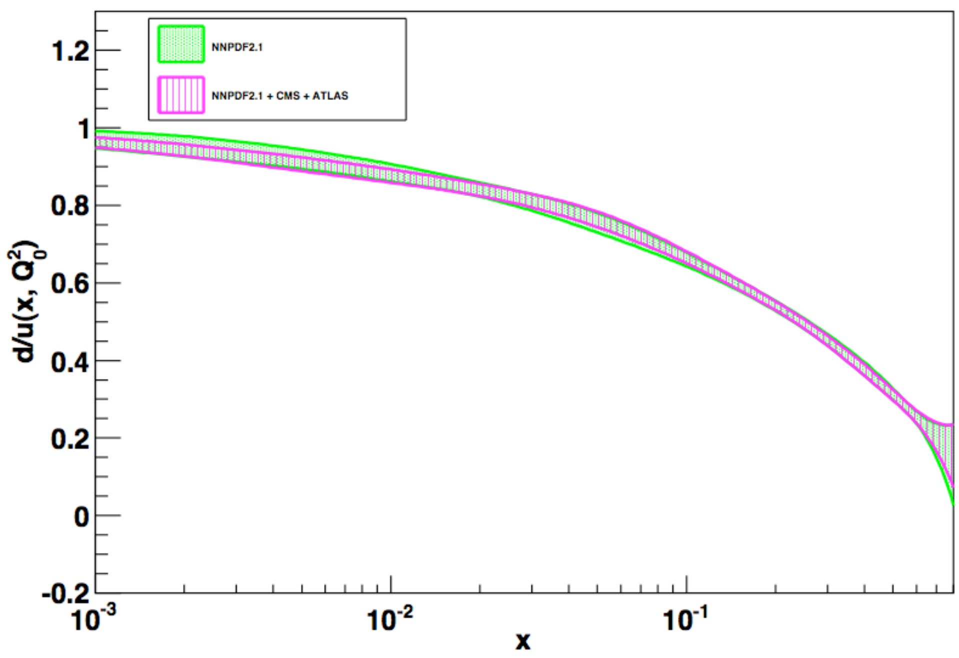




W lepton asymmetry data

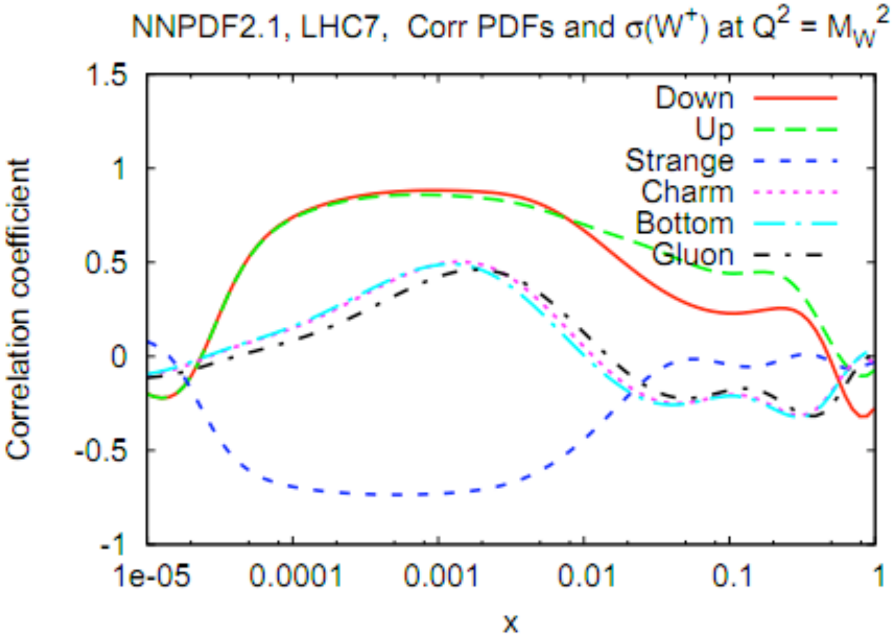
Inclusion of ATLAS+CMS data

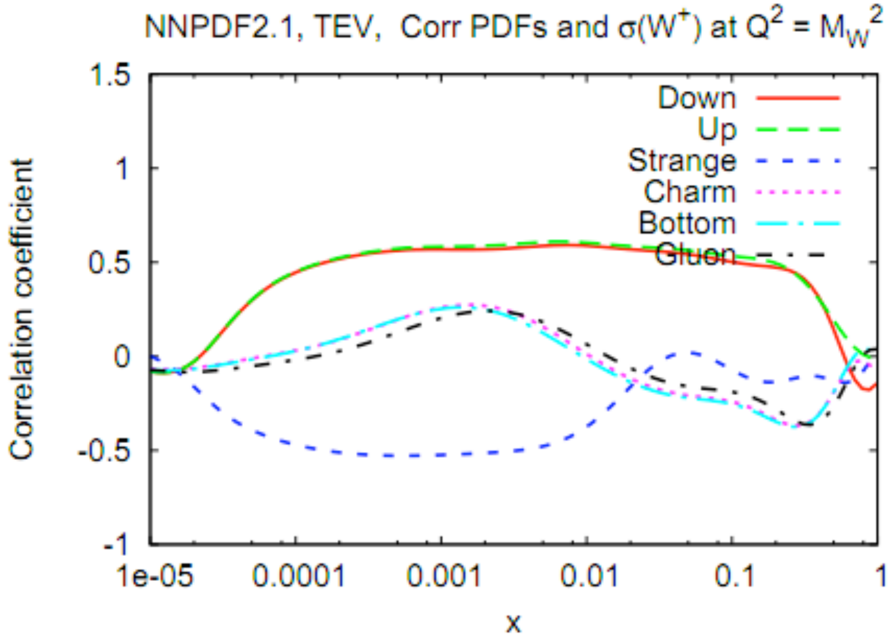




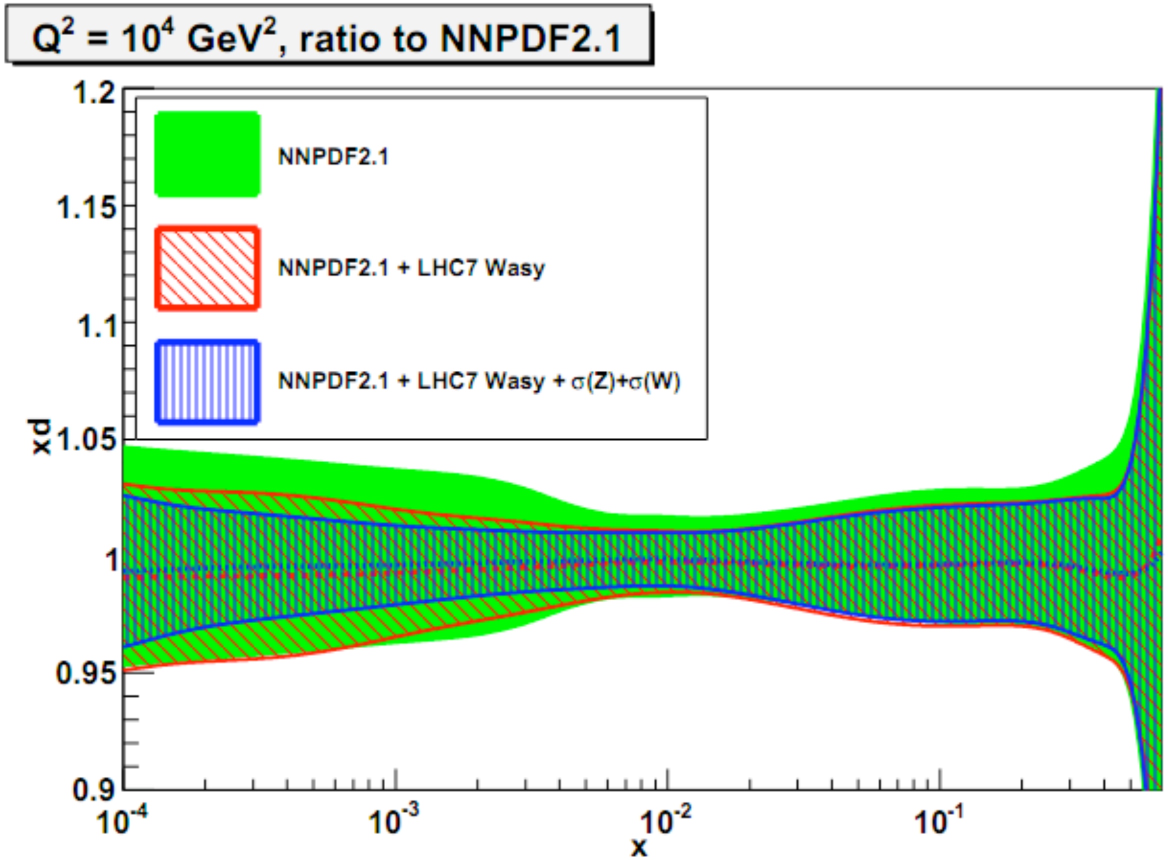
Correlations

W production





W lepton asymmetry data
and W/Z production



With W and Z measured with 2% accuracy