Status of W-boson mass combinations

Working group involving members of the ATLAS, CDF, D0 & CMS collaborations

https://indico.cern.ch/category/3290/

lhc-tevatron-wmass-combinations@cern.ch

- Reminders
- Recent discussions : measurement emulation ; PDF extrapolation studies; generator comparisons
- Plan to completion

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lhc-tevatron-wmass-combinations@cern.ch

- Contributions
  - N.Andari (overall emulation infrastructure), J.Kretzschmar, S.Amoroso (Generators and Predictions)
  - B.Tuchming, Chen Wang (D0 emulation, generator predictions)
  - C.Hays (CDF emulation and event generation)
  - Coordination C.Hays (CDF), B.Tuchming (D0), M.Boonekamp (ATLAS), J.Bendavid (CMS)

Objectives

- Experiment-endorsed world averages for published measurements of m_W, and corrections of existing measurements to newer PDFs
- Specific issues :
  - Measurements performed at detector level; no unfolded data
  - Strong role of PDFs in measurement uncertainties, and central values → Correlations, PDF model dependence
- Areas of development:
  - Existing / coming Tevatron / ATLAS measurements :
    - χ^2-based measurements with forward error propagation; no explicit profiling of uncertainties
    - Extrapolation from legacy to modern PDF sets using measurement emulation
  - “future” :
    - Harmonization of theory inputs
    - extension to measurements based on profile-likelihood fits [deferred], in view of LHC measurement combinations. Uncertainty decomposition – how to properly correlate measurement results?

Methods

- Measurement emulation
  - Physics modelling with the PDF sets and pTW models used for the publications
    - Main generator : Powheg + PHOTOS
  - Simplified parameterisation of the detector responses:
    - Lepton energy resolution and efficiencies → $p_T^{e,\mu}$
    - Recoil resolution → u_T, m_T, MET
    - Correlations between leptons and the recoil, when relevant:

      ”lepton removal” effects

      recoil-dependent lepton efficiencies
  - Analysis cuts

- by no means a way to reproduce measurements in full detail, but sufficient to calculate the relative effect of PDF variations with sub-MeV accuracy

Methods

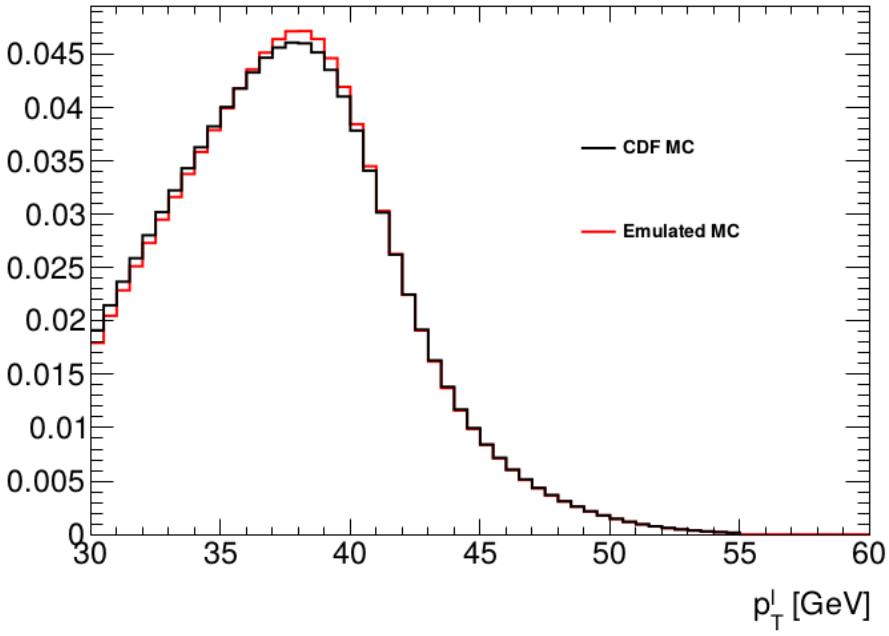
- Measurement emulation

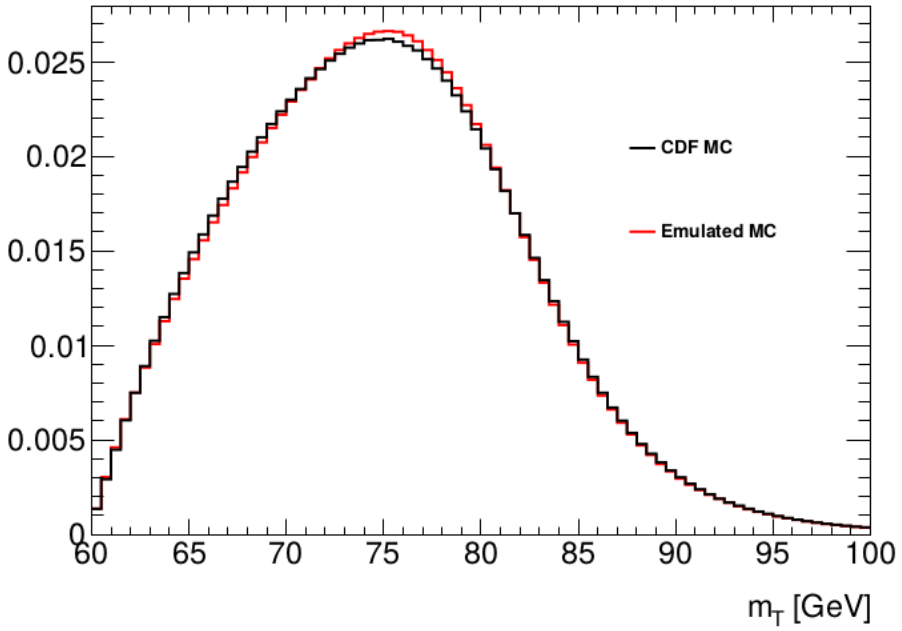
Experiment	Event selections	Fit ranges
CDF	$30 < p_T^\ell < 55$ GeV, $\lvert\eta_\ell\rvert < 1$ $30 < E_T^{miss} < 55$ GeV, $60 < m_T < 100$ GeV $u_T < 15$ GeV	$32 < p_T^\ell < 48$ GeV $32 < E_T^{miss} < 48$ GeV $65 < m_T < 90$ GeV
D0	$p_T^\ell > 25$ GeV, $\lvert\eta_\ell\rvert < 1.05$ $E_T^{miss} > 25$ GeV, $m_T > 50$ GeV $u_T < 15$ GeV	$32 < p_T^\ell < 48$ GeV $65 < m_T < 90$ GeV
ATLAS	$p_T^\ell > 30$ GeV, $\lvert\eta_\ell\rvert < 2.4$ $E_T^{miss} > 30$ GeV, $m_T > 60$ GeV $u_T < 30$ GeV	$32 < p_T^\ell < 45$ GeV $66 < m_T < 99$ GeV

Methods

- Measurement emulation
  - CDF distributions

N.Andari

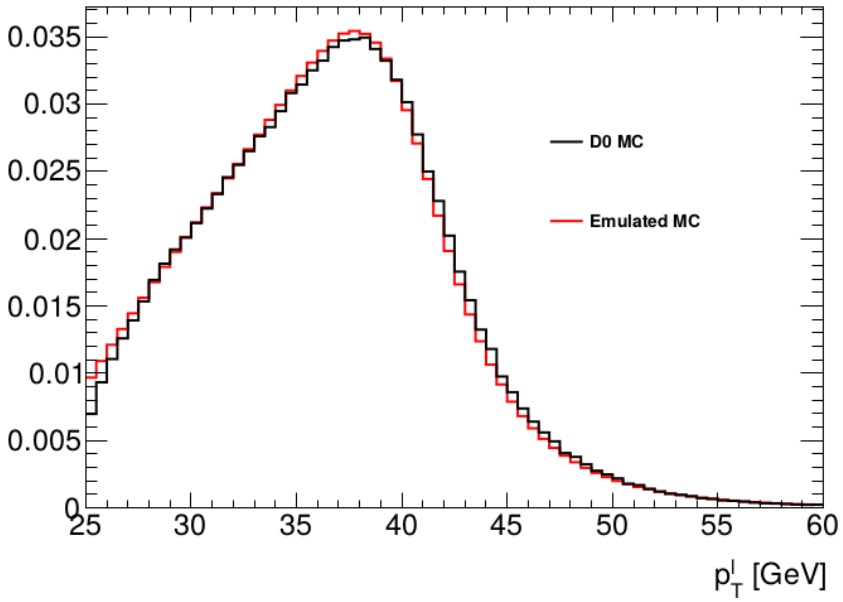


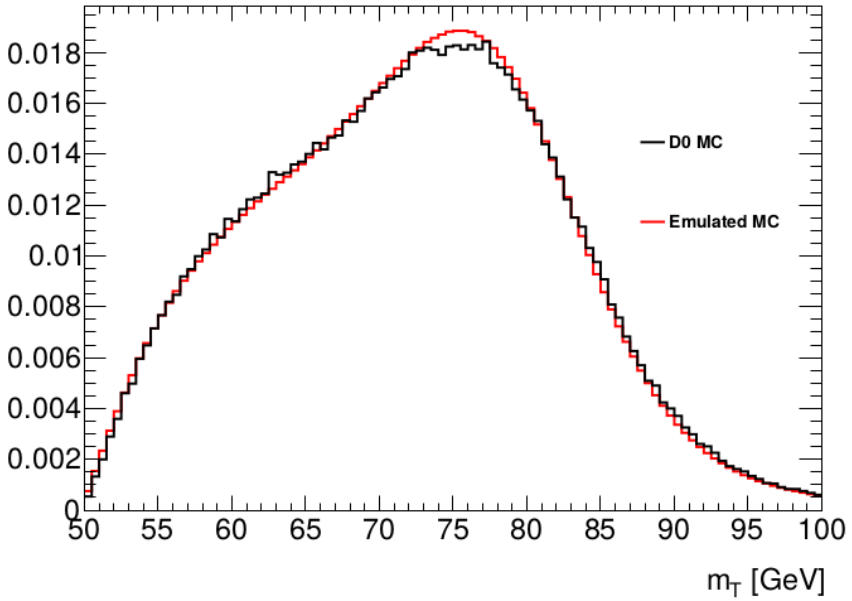


Methods

- Measurement emulation
  - D0 distributions

N.Andari

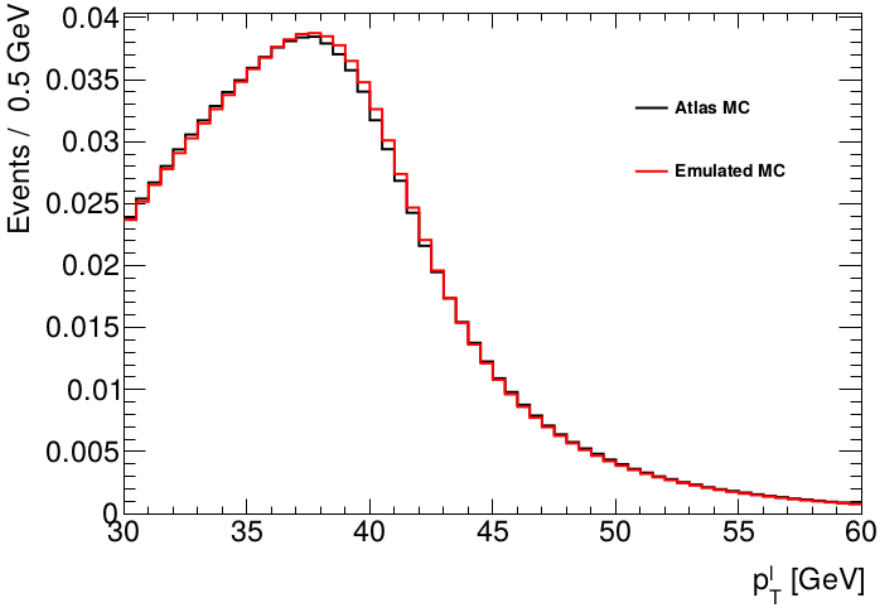


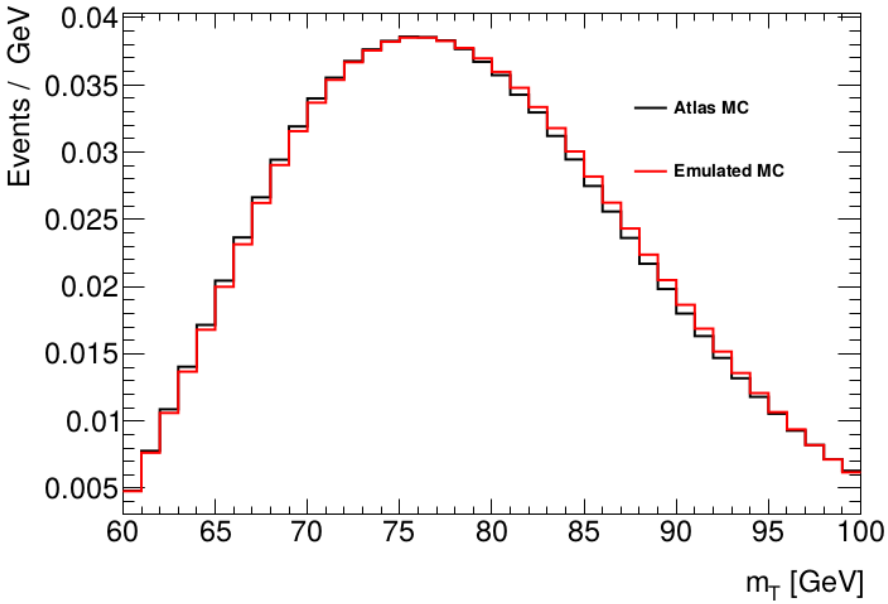


Methods

- Measurement emulation
  - ATLAS distributions

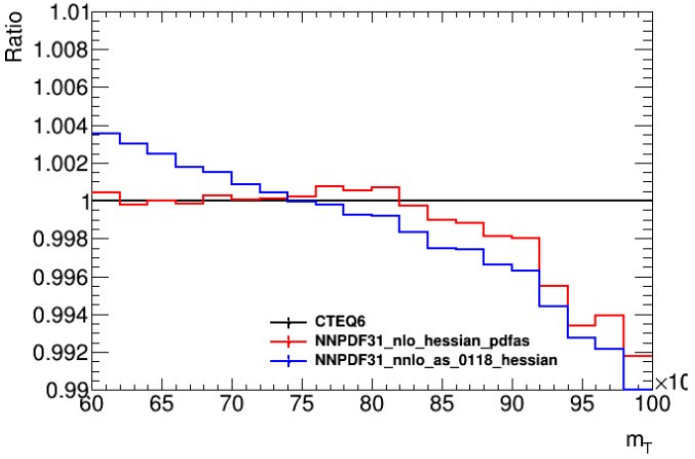
N.Andari

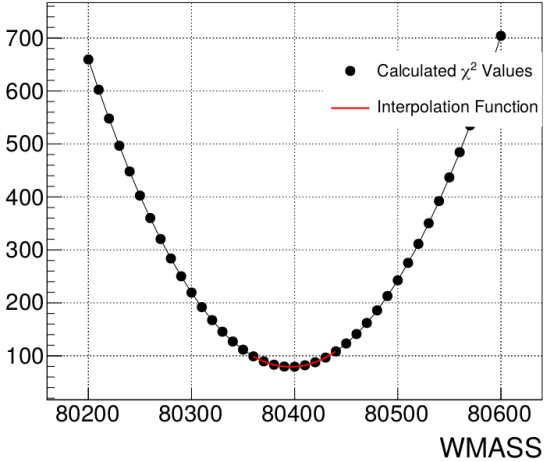




Methods

- PDF shifts and uncertainties
  - Shift in m_W when going from PDF_A to PDF_B
    - Templates with PDF_A and varying values of mW,
    - Pseudo-data with reference value of m_W and PDF_B ; χ^2 fit
    - $\delta m_W^{A\rightarrow B} = -(m_W^{fit} - m_W^{ref})$





  - Used to calculate PDF uncertainties, and update measurement central values

Validation

CDF

	Published	Emulated			
	CTEQ6M† MSTW2008§	CTEQ6M†	CTEQ6.6	CT10nnlo	MSTW2008§
Central value	80 387	80 389	80 402	80 402	80 400
PDF	10	15	14	11	10
Total	19	22	22	20	19
χ^2/ndof	7/5	7/5	7/5	8/5	7/5

ATLAS

	Published	Emulated			
	CT10nnlo†§	CTEQ6M	CTEQ6.6	CT10nnlo†§	MSTW2008
Central value	80 370	80 343	80 357	80 371	80 351
PDF	9	8	8	10	5
Total	19	17	18	19	16
χ^2/ndof	29/27	29/27	31/27	29/27	40/27

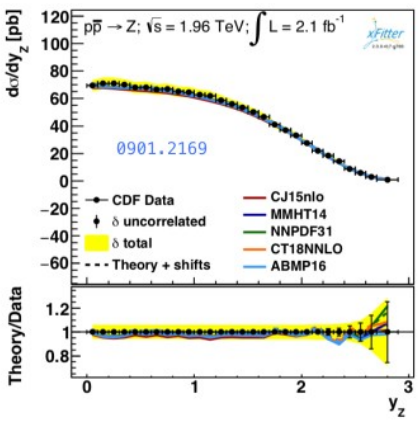
Validation

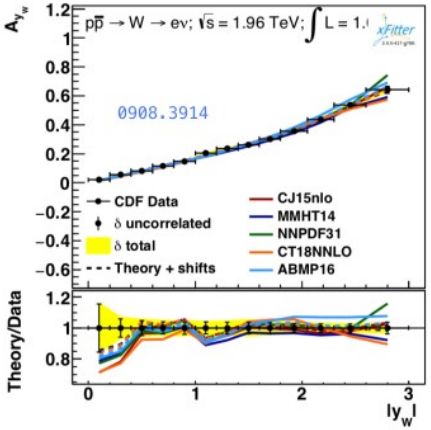
- Past combinations : Tevatron, Tevatron + LEP

	Tevatron	Tevatron+LEP
Published	80387 + 16	80385 + 15
Validation	80388 + 16	80385 + 15 (actually 14.47)

Choice of modern “target” PDFs

- Comparisons between existing Drell-Yan data and “recent” NNLO PDFs
  - CDF





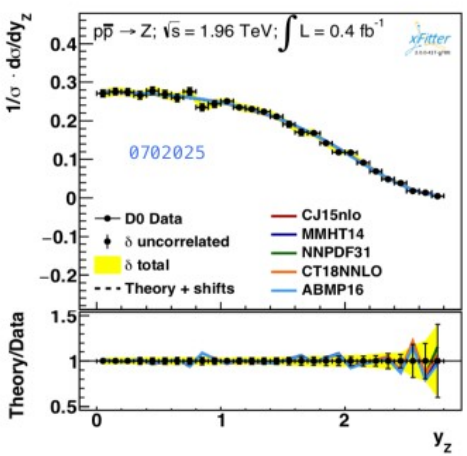
Dataset	CJ15nlo	MMHT14	NNPDF31	CT18NNLO	ABMP16
CDF W asymmetry 2009	18 / 13	12 / 13	11 / 13	13 / 13	17 / 13
Correlated χ^2	1.6	1.7	2.6	2.9	6.5
Log penalty χ^2	-0.00	-0.00	-0.00	-0.00	-0.00
Total χ^2 / dof	19 / 13	14 / 13	13 / 13	16 / 13	23 / 13
χ^2 p-value	0.11	0.37	0.43	0.25	0.04

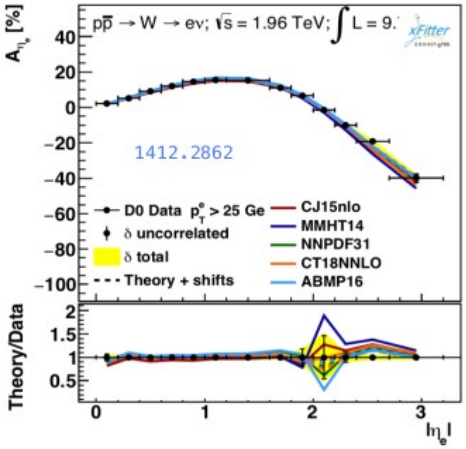
Dataset	CJ15nlo	MMHT14	NNPDF31	CT18NNLO	ABMP16
CDF Z rapidity 2010	29 / 28	30 / 28	25 / 28	27 / 28	30 / 28
Correlated χ^2	1.5	0.99	1.7	0.49	0.69
Log penalty χ^2	-1.16	-0.63	-0.44	-0.60	-0.90
Total χ^2 / dof	30 / 28	30 / 28	26 / 28	27 / 28	30 / 28
χ^2 p-value	0.37	0.36	0.55	0.53	0.36

S.Amoroso

Choice of modern “target” PDFs

- Comparisons between existing Drell-Yan data and “recent” NNLO PDFs
  - D0



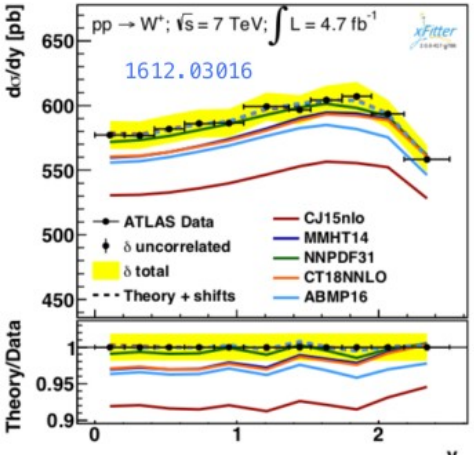


Dataset	CJ15nlo	MMHT14	NNPDF31	CT18NNLO	ABMP16
D0 W el nu lepton asymmetry ptl 25 GeV	32 / 13	24 / 13	19 / 13	17 / 13	23 / 13
Correlated χ^2	8.7	11	7.4	4.6	4.1
Log penalty χ^2	+0.00	+0.00	+0.00	+0.00	+0.00
Total χ^2 / dof	41 / 13	35 / 13	27 / 13	22 / 13	27 / 13
χ^2 p-value	0.00	0.00	0.01	0.05	0.01

Dataset	CJ15nlo	MMHT14	NNPDF31	CT18NNLO	ABMP16
D0 Z rapidity 2007	22 / 28	23 / 28	22 / 28	22 / 28	23 / 28
Correlated χ^2	0.0097	0.14	0.10	0.041	0.061
Log penalty χ^2	+0.01	-0.07	+0.10	+0.09	-0.17
Total χ^2 / dof	22 / 28	23 / 28	22 / 28	22 / 28	23 / 28
χ^2 p-value	0.76	0.74	0.76	0.79	0.75

Choice of modern “target” PDFs

- Comparisons between existing Drell-Yan data and “recent” NNLO PDFs
  - ATLAS



S.Amoroso

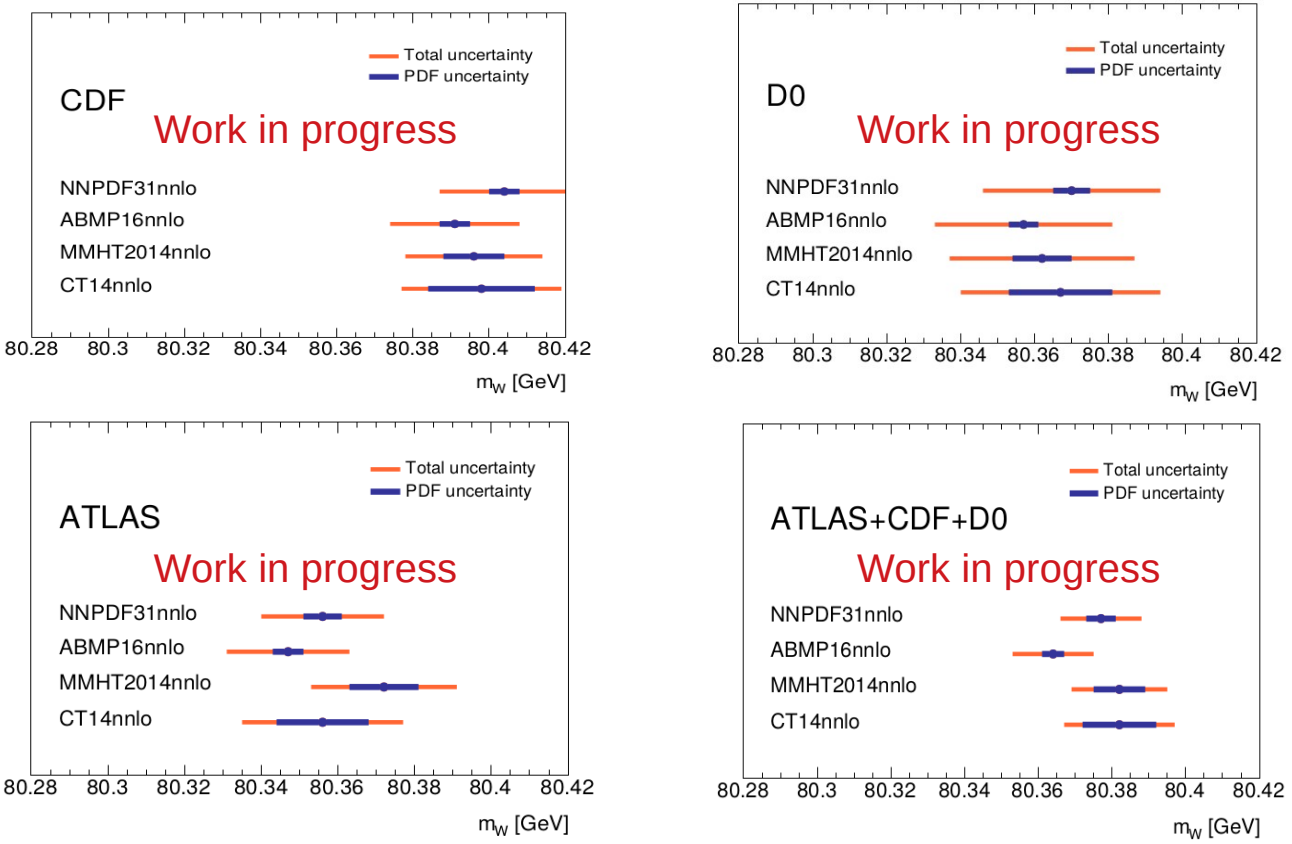
Dataset	CJ15nlo	MMHT14	NNPDF31	CT18NNLO	ABMP16
ATLAS low mass Z rapidity 2011	26 / 6	18 / 6	14 / 6	12 / 6	21 / 6
ATLAS peak CC Z rapidity 2011	52 / 12	21 / 12	12 / 12	16 / 12	24 / 12
ATLAS peak CF Z rapidity 2011	16 / 9	11 / 9	11 / 9	10 / 9	9.2 / 9
ATLAS high mass CC Z rapidity 2011	7.7 / 6	6.1 / 6	5.8 / 6	5.9 / 6	6.1 / 6
ATLAS high mass CF Z rapidity 2011	4.6 / 6	5.5 / 6	4.7 / 6	4.8 / 6	4.5 / 6
ATLAS W- lepton rapidity 2011	17 / 11	8.4 / 11	8.7 / 11	9.1 / 11	10 / 11
ATLAS W+ lepton rapidity 2011	16 / 11	11 / 11	11 / 11	10 / 11	13 / 11
Correlated χ^2	118	50	31	40	50
Log penalty χ^2	-9.09	-3.32	-2.45	-3.66	-4.22
Total χ^2 / dof	247 / 61	127 / 61	95 / 61	104 / 61	134 / 61
χ^2 p-value	0.00	0.00	0.00	0.00	0.00

→ consider MMHT14, NNPDF3.1, CT18NNLO, ABMP16
→ best overall description of the data by NNPDF3.1, CT18NNLO

Preliminary results

- Just an example – discussions ongoing [see later]

N.Andari



Correlation of PDF uncertainties

- CTEQ6

CDF/D0

-> Joint Total correlation

	mw_run2cdf	mw_run2d0	mw_run1cdf	mw_run1d0
mw_run2cdf	1	0.459247	0	0
mw_run2d0	0.459247	1	0	0
mw_run1cdf	0	0	1	0
mw_run1d0	0	0	0	1

-> Joint PDF correlation

	mw_run2cdf	mw_run2d0	mw_run1cdf	mw_run1d0
mw_run2cdf	1	0.998813	--	--
mw_run2d0	0.998813	1	--	--
mw_run1cdf	--	--	--	--
mw_run1d0	--	--	--	--

Tevatron/LHC

-> Joint Total correlation

	mw_atlas	mw_tevatron	mw_lep
mw_atlas	1	0.269722	0
mw_tevatron	0.269722	1	0
mw_lep	0	0	1

-> Joint PDF correlation

	mw_atlas	mw_tevatron	mw_lep
mw_atlas	1	0.71625	--
mw_tevatron	0.71625	1	--
mw_lep	--	--	--

- CTEQ6.1

CDF/D0

-> Joint Total correlation

	mw_run2cdf	mw_run2d0	mw_run1cdf	mw_run1d0
mw_run2cdf	1	0.457046	0	0
mw_run2d0	0.457046	1	0	0
mw_run1cdf	0	0	1	0
mw_run1d0	0	0	0	1

-> Joint PDF correlation

	mw_run2cdf	mw_run2d0	mw_run1cdf	mw_run1d0
mw_run2cdf	1	0.998901	--	--
mw_run2d0	0.998901	1	--	--
mw_run1cdf	--	--	--	--
mw_run1d0	--	--	--	--

CTEQ6.1

Tevatron/LHC

-> Joint Total correlation

	mw_atlas	mw_tevatron	mw_lep
mw_atlas	1	0.253547	0
mw_tevatron	0.253547	1	0
mw_lep	0	0	1

-> Joint PDF correlation

	mw_atlas	mw_tevatron	mw_lep
mw_atlas	1	0.700236	--
mw_tevatron	0.700236	1	--
mw_lep	--	--	--

CTEQ6.1

Correlation of PDF uncertainties

- Correlations
  - CTEQ6.6

Tevatron/LHC

	mw_atlas	mw_tevatron	mw_lep
mw_atlas	1	0.281416	0
mw_tevatron	0.281416	1	0
mw_lep	0	0	1

-> Joint PDF correlation

	mw_atlas	mw_tevatron	mw_lep
mw_atlas	1	0.741186	--
mw_tevatron	0.741186	1	--
mw_lep	--	--	--

  - CT10

-> Joint Total correlation

	mw_atlas	mw_tevatron	mw_lep
mw_atlas	1	0.409274	0
mw_tevatron	0.409274	1	0
mw_lep	0	0	1

-> Joint PDF correlation

	mw_atlas	mw_tevatron	mw_lep
mw_atlas	1	0.751231	--
mw_tevatron	0.751231	1	--
mw_lep	--	--	--

Correlation of PDF uncertainties

- Correlations
  - CT10nnlo

Tevatron/LHC

```
-> Joint Total correlation
                mw_atlas     mw_tevatron          mw_lep
    mw_atlas           1        0.300246               0
  mw_tevatron   0.300246               1               0
     mw_lep            0               0               1
-> Joint PDF correlation
                mw_atlas     mw_tevatron          mw_lep
    mw_atlas           1        0.755786              --
  mw_tevatron   0.755786               1              --
     mw_lep           --              --              --
```

  - CJ15

```
-> Joint Total correlation
                mw_atlas     mw_tevatron          mw_lep
    mw_atlas           1        0.107284               0
  mw_tevatron   0.107284               1               0
     mw_lep            0               0               1
-> Joint PDF correlation
                mw_atlas     mw_tevatron          mw_lep
    mw_atlas           1        0.712279              --
  mw_tevatron   0.712279               1              --
     mw_lep           --              --              --
```

Correlation of PDF uncertainties

- Correlations
  - CT14nnlo

Tevatron/LHC

```
-> Joint Total correlation
                 mw_atlas    mw_tevatron        mw_lep
     mw_atlas        1        0.334286             0
  mw_tevatron     0.334286       1                 0
      mw_lep         0           0                 1
-> Joint PDF correlation
                 mw_atlas    mw_tevatron        mw_lep
     mw_atlas        1        0.710479            --
  mw_tevatron     0.710479       1                --
      mw_lep         --          --                --
```

  - CT14nlo

```
-> Joint Total correlation
                 mw_atlas    mw_tevatron        mw_lep
     mw_atlas        1        0.32786              0
  mw_tevatron     0.32786        1                 0
      mw_lep         0           0                 1
-> Joint PDF correlation
                 mw_atlas    mw_tevatron        mw_lep
     mw_atlas        1        0.807696            --
  mw_tevatron     0.807696       1                --
      mw_lep         --          --                --
```

Correlation of PDF uncertainties

- Correlations
  - MMHT2014nlo 68%CL

Tevatron/LHC

```
-> Joint Total correlation

                 mw_atlas    mw_tevatron        mw_lep
    mw_atlas            1       0.195674             0
  mw_tevatron    0.195674              1             0
      mw_lep            0              0             1

-> Joint PDF correlation

                 mw_atlas    mw_tevatron        mw_lep
    mw_atlas            1       0.626974            --
  mw_tevatron    0.626974              1            --
      mw_lep           --             --            --
```

  - MMHT2014nnlo 68%CL

```
-> Joint Total correlation

                 mw_atlas    mw_tevatron        mw_lep
    mw_atlas            1       0.226108             0
  mw_tevatron    0.226108              1             0
      mw_lep            0              0             1

-> Joint PDF correlation

                 mw_atlas    mw_tevatron        mw_lep
    mw_atlas            1       0.656986            --
  mw_tevatron    0.656986              1            --
      mw_lep           --             --            --
```

Remaining issue : central value extrapolations

- The present analysis, using Powheg, observes shifts between PDFs that can typically reach ~10 MeV at the Tevatron, up to 20 MeV at the LHC

CDF, D0

PDF	Shift wrt. CTEQ6M
CTEQ6.6	+11 MeV
CT18NNLO	+9 MeV
MMHT2014	+7 MeV
ABMP16	+2 MeV
NNPDF3.1	+12 MeV

ATLAS

PDF	Shift wrt. CT10nnlo
CTEQ6.6	-13 MeV
CT18NNLO	-8 MeV
MMHT2014	+1 MeV
ABMP16	-23 MeV
NNPDF3.1	-12 MeV

- Questions raised on generator dependence of these shifts. Studies performed using aMC@NLO+Pythia (shown here) and Resbos (TODO)

Remaining issue : central value extrapolations

- How much do the shifts in mW depend on the generator used to evaluate them?
  - Benchmark: CTEQ6M (CDF legacy) → NNPDF3.1 (NNLO, smallest unc.)
  - Generators at hand : Powheg, MiNNLO, aMC@NLO+Pythia

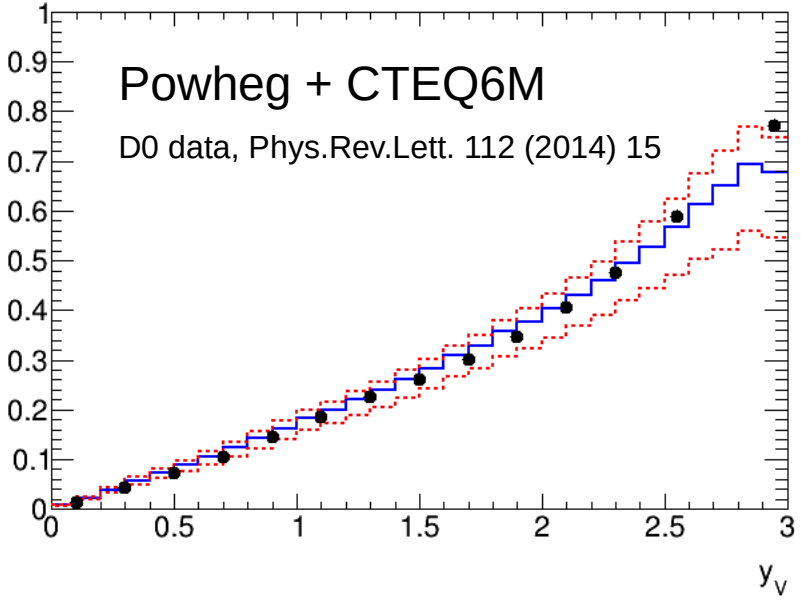
N.Andari

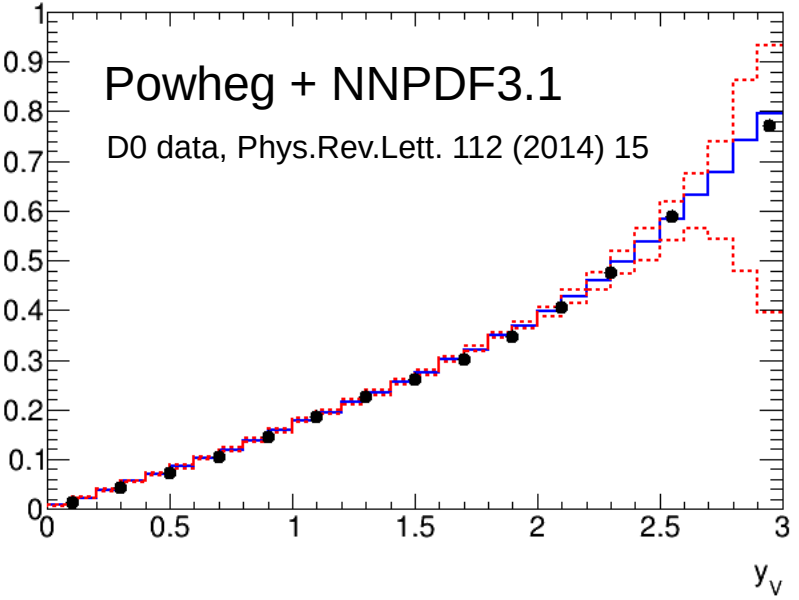
NNPDF/ CTEQ	Powheg Reweighted	Powheg Explicit generation	aMC@NLO+Pythia	MiNNLO
mT	*no ptw constraint:* -13.19 MeV *ptw constraint:* -12.19 MeV	*no ptw constraint:* -31.27 MeV *ptw constraint:* -12.07 MeV	*no ptw constraint:* -8.63 MeV *ptw constraint:* -6.56 MeV	*no ptw constraint:* -22.33 MeV *ptw constraint:* -12.73 MeV
pTl	*no ptw constraint:* -16.42 MeV *ptw constraint:* -13.61 MeV	*no ptw constraint:* -70.24 MeV *ptw constraint:* -12.85 MeV	*no ptw constraint:* -11.7 MeV *ptw constraint:* -7.26 MeV	*no ptw constraint:* -44.89 MeV *ptw constraint:* -14.96 MeV

Agreement between pTW-constrained Powheg (explicit generation and reweighting) and MiNNLO; smaller effect for aMC@NLO+Pythia.

Remaining issue : central value extrapolations

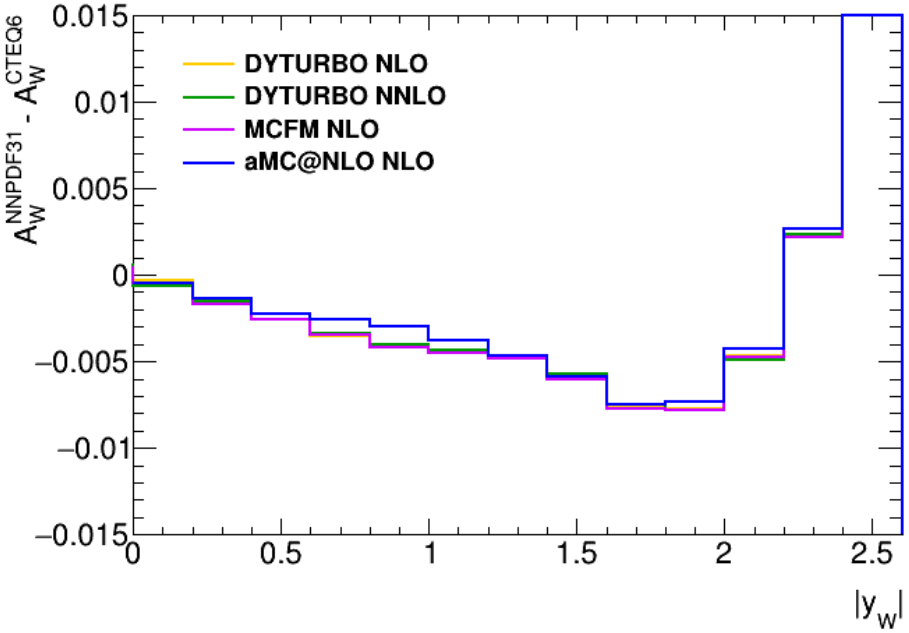
- The role of the W charge asymmetry at the Tevatron
  - Main driver of small residual PDF uncertainty (~3-4 MeV with NNPDF 3.1)
  - Important to verify that generator predictions with NNPDF3.1 reproduce the measurement data, since the latter are used in the NNPDF fit (closure!)



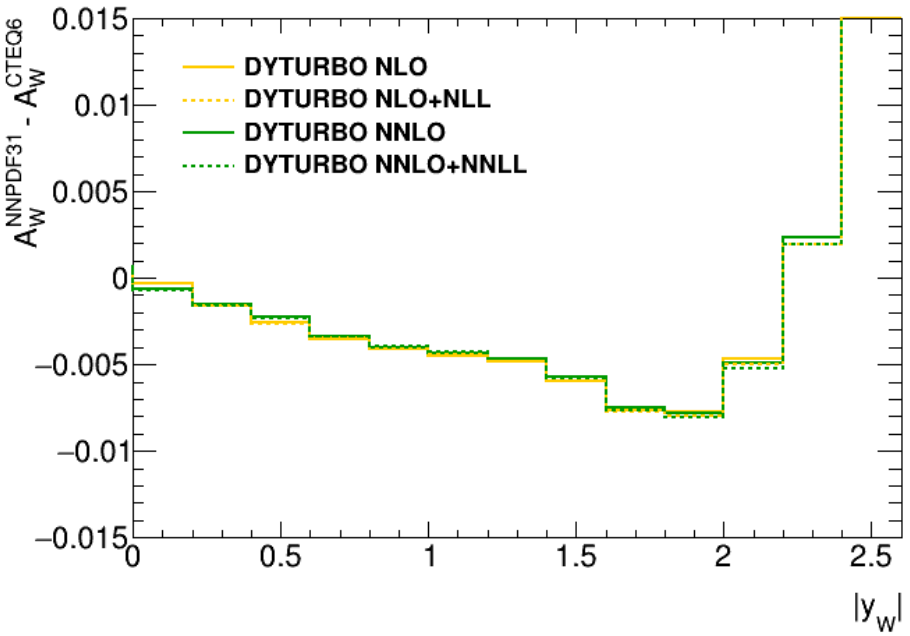


W charge asymmetry : CTEQ6M → NNPDF3.1

How well do various calculations agree, for the prediction of the PDF-dependence of this observable?



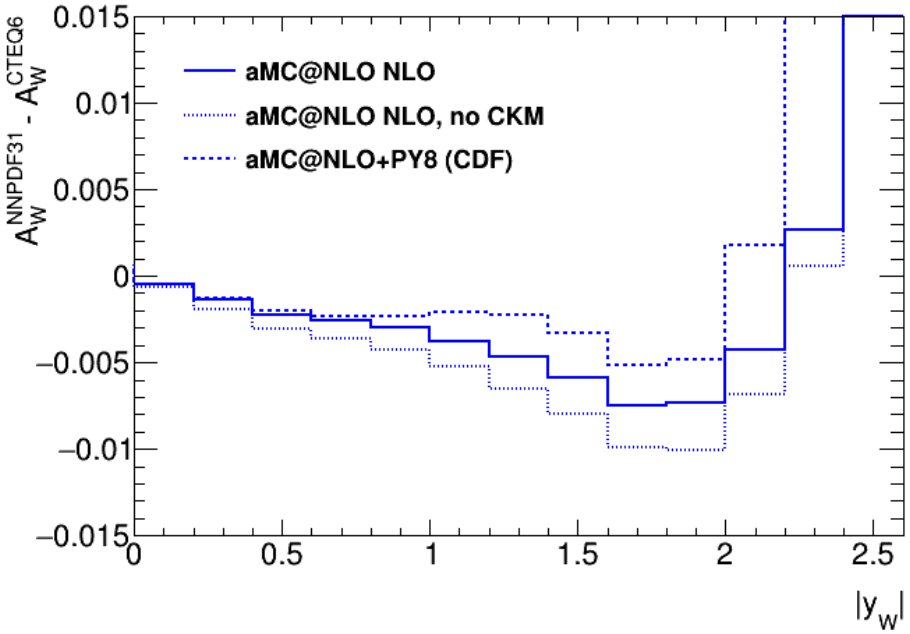
Fixed-order calculations



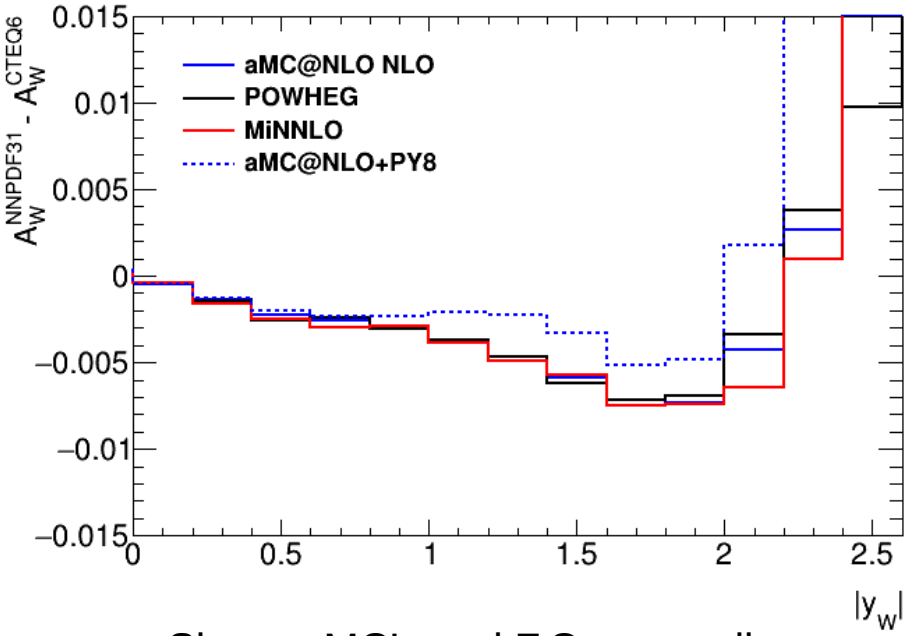
Dyturbo variations

W charge asymmetry : CTEQ6M → NNPDF3.1

How well do various calculations agree, for the prediction of the PDF-dependence of this observable?



aMC@NLO+Pythia variations



Shower MC's and F.O – overall consensus, except aMC@NLO+Py

Discussion and plan to completion

- Differences in mW extrapolations, between Powheg/MiNNLO and aMC@NLO+Pythia, relate to discrepancies in the predictions of W charge asymmetry. To be repeated with Resbos, for a complete picture.
- Predictions required for a complete set of comparisons :
  - theory/theory and theory/data comparisons for W charge asymmetry, as main probe of PDF accuracy (most constraining distribution)
  - Predictions :
    - Powheg with PDF reweighting, Powheg generated with diff. PDFs, MiNNLO
    - aMC@NLO+Pythia
    - Dyturbo, Resbos
    - aMC@NLO fixed-order, MCFM

Discussion and plan to completion

- Resbos is missing in all previous comparisons. Needed to compare shifts and uncertainties in mW, and predictions of basic W distributions
  - Available :
    - from Resbos authors : CT14, CT18, CTEQ6.6 all NLO
    - from D0 : CTEQ6.6
    - from CDF : CTEQ6M
  - Still needed
    - Correct NNLO grids for CT14, CT18, CTEQ6.6
    - CTEQ6M, NNPDF3.1, MMHT2014 from authors

Resbos predictions are the single missing piece in the present analysis, and required to “solve” the ongoing discussions and consolidate the theoretical description of this measurement

Summary

- Analysis almost complete
  - Numbers didn't significantly change since >6 months.
  - Refined emulations, with 1-2%-level agreement between emulated and published distributions
  - Predictions for all relevant PDFs (legacy, modern)
    - Collection of fixed-order and resummed/showered predictions for comparisons of Drell-Yan production at the Tevatron and LHC
    - Powheg, MiNNLO for PDF uncertainties and correlations in the mW analysis.

      Resbos is needed for the mW shift for CDF, per request from CDF.
    - Resbos critically needed to complete the analysis!
- Discrepancies in central value extrapolations : conclusions expected as soon as Resbos available.
- Synchronization between this study and the forthcoming CDF measurement under discussion.