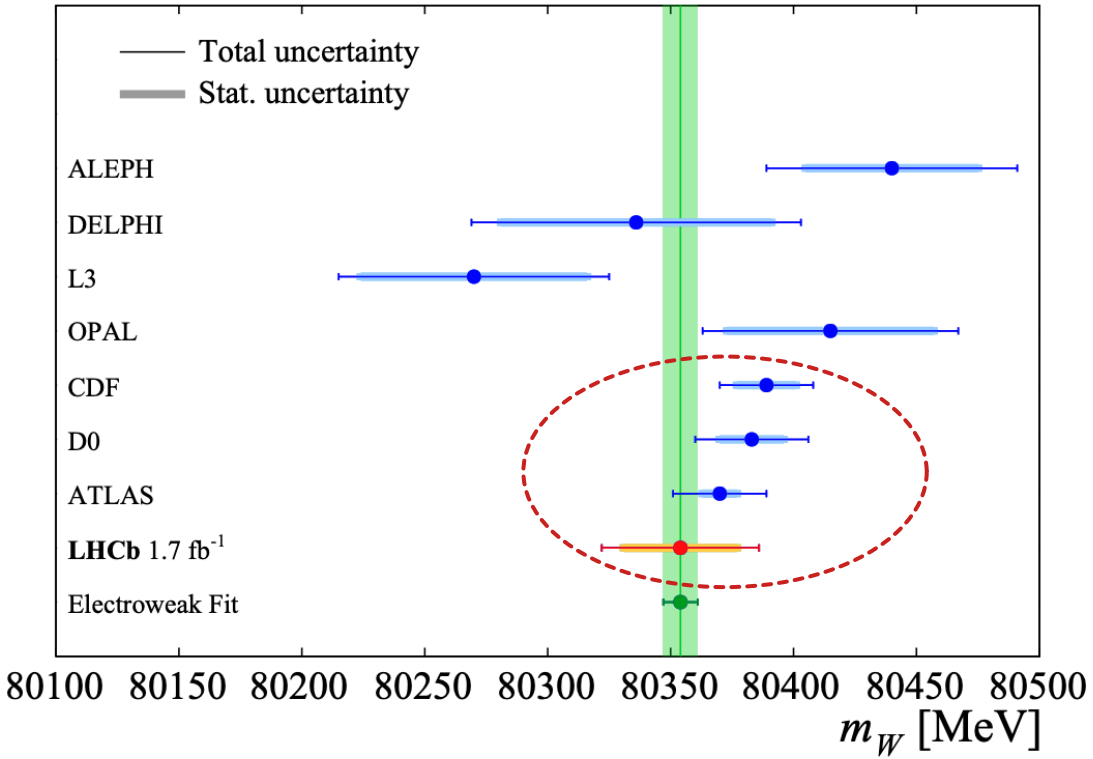
Status of the W-boson mass combination

- Objectives
- Reminders
- This year's developments
- Converging?
- Starting projects

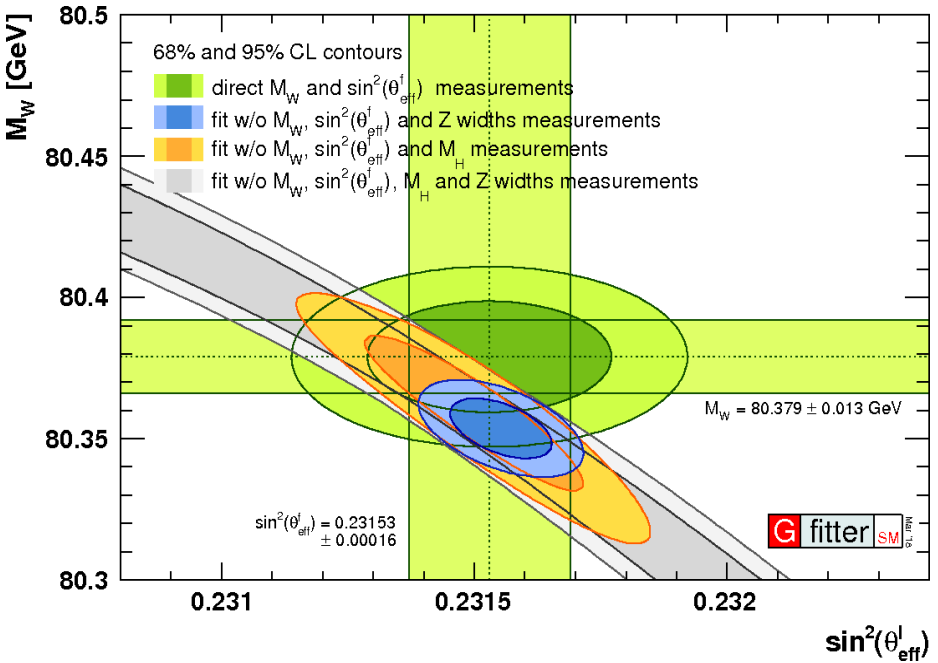


CDF : Chris Hays
D0 : Boris Tuchming, Chen Wang
ATLAS : Jan Kretzschmar, M.Boonekamp, S.Amoroso (now CMS) and Nancy Andari (left)
CMS : Josh Bendavid
LHCb : Mika Vesterinen, Menglin Xu

https://indico.cern.ch/category/3290/
lhc-tevatron-wmass-combinations@cern.ch

Goals

- Provide an endorsed world average combining existing hadron-collider results on m_W
  - Establish a methodology to combine present and future measurements
  - enable physics-modelling updates of past measurements (e.g. PDFs)
  - Properly correlate m_W and $\sin^2\theta_W$ measurements for global fits

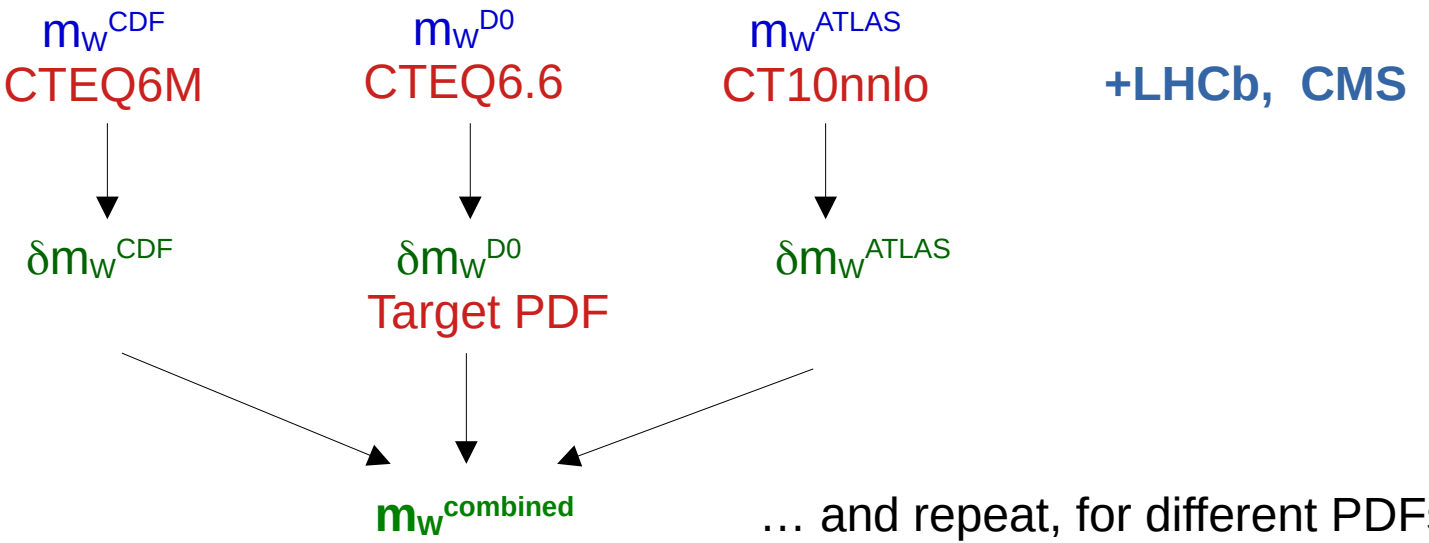


Outline

- Analysis strategy
- Measurement corrections, for improvements in QCD
- Extrapolations to modern PDFs

Analysis strategy

- PDFs are the main source of corrections and uncertainty correlations
  - other sources are either small (EWK corrections) or arguably decorrelated ($p_T^{W/Z}$)
  - Two-step procedure : correct to common PDF; combination including correlations
  - At this point, PDF extrapolations and uncertainties are calculated using Powheg.



… and repeat, for different PDFs

Measurement extrapolations

- Full procedure, decomposed into generator and PDF effects :

$$m_W^{updated} = m_W^{ref.} + \delta m_W^{QCD} + \delta m_W^{PDF}$$

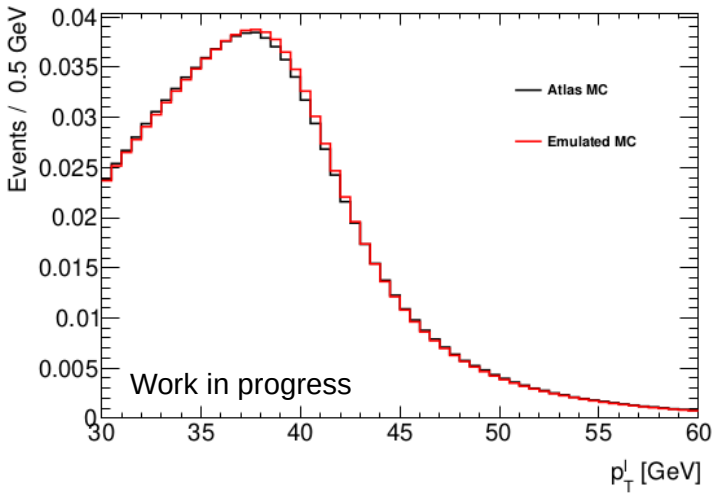
published — Improved predictions, for reference PDF — PDF extrapolation

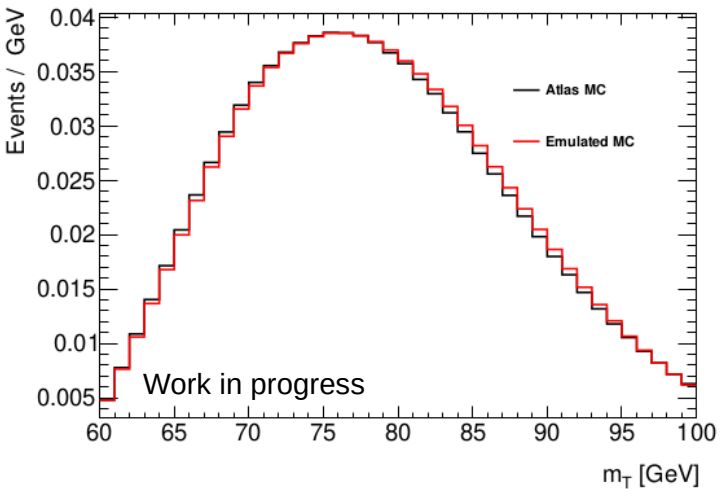
- Published measurements :
  - CDF : Resbos1 (NLO) CTEQ6M (NLO)
  - D0 : Resbos1 (NNLO) CTEQ6.6 (NLO)
  - ATLAS : Powheg+Pythia; rapidy+spin corr. at NNLO CT10 (NNLO)
  - LHCb : Powheg+Pythia; spin corr. at NNLO <NNPDF3.1,CT18,MSHT20> (NLO)
- Extrapolations (δm_W) evaluated using generator-level reweightings and "emulation" of detector effects

- δm_W^{PDF} Main PDF targets : modern NNLO sets
  ~Finalized, including generator dependence of PDF extrapolations.
- δm_W^{QCD} Applies when generators or QCD improvements are beyond the quoted uncertainties.
  Long neglected, and subject of ongoing work : Powheg, MiNNLO, New Resbos

Measurement emulation

- Parametrized detector response, following published information
  - Leptons : eta- and pT-dependent resolution curves & efficiencies
  - Recoil response and resolution, including dependence on boson pT and event activity



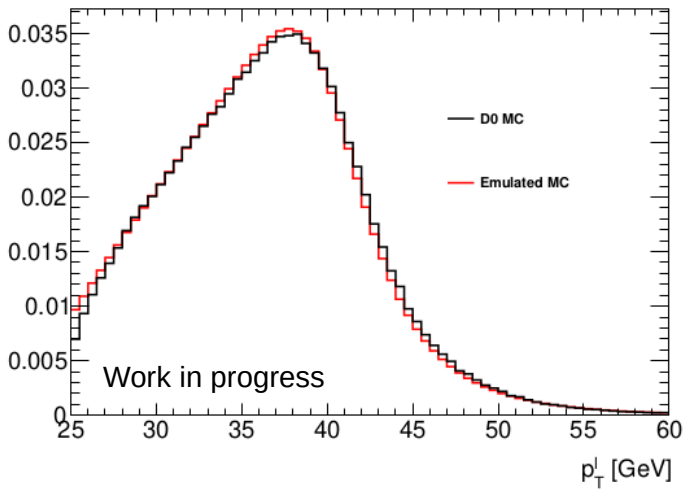


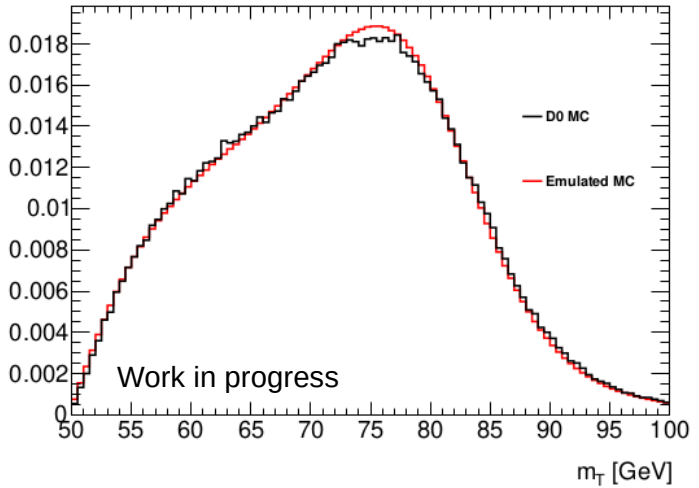
Reproduces published distributions at the % level, and allows propagating variations in the underlying physics with <1 MeV precision in m_W.

- Event selections and m_W fit ranges as in the publications.

Measurement emulation

- Parametrized detector response, following published information
  - Leptons : eta- and pT-dependent resolution curves & efficiencies
  - Recoil response, including “lepton removal” effects, dependence on boson p_T and event activity





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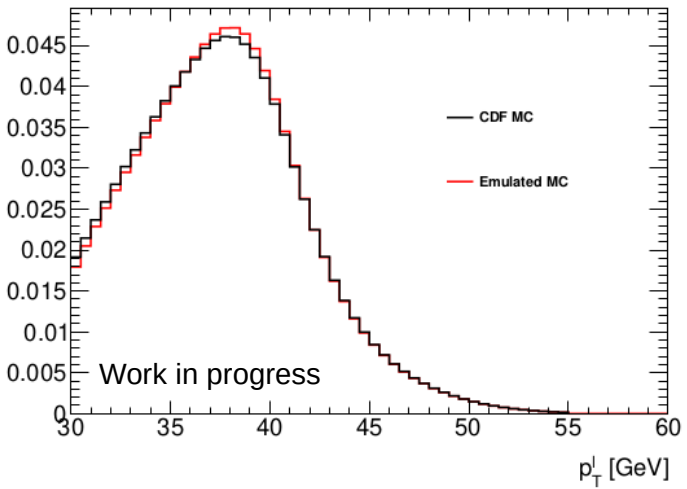
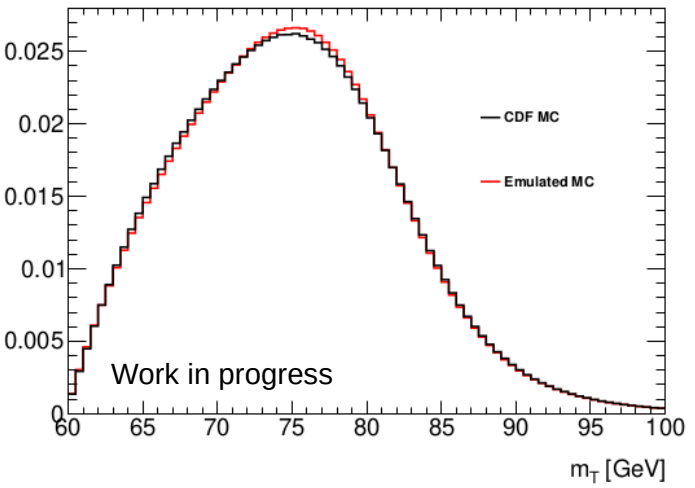




Reproduces published distributions at the % level, and allows propagating variations in the underlying physics with <1 MeV precision in m_W.

- Event selections and m_W fit ranges as in the publications.

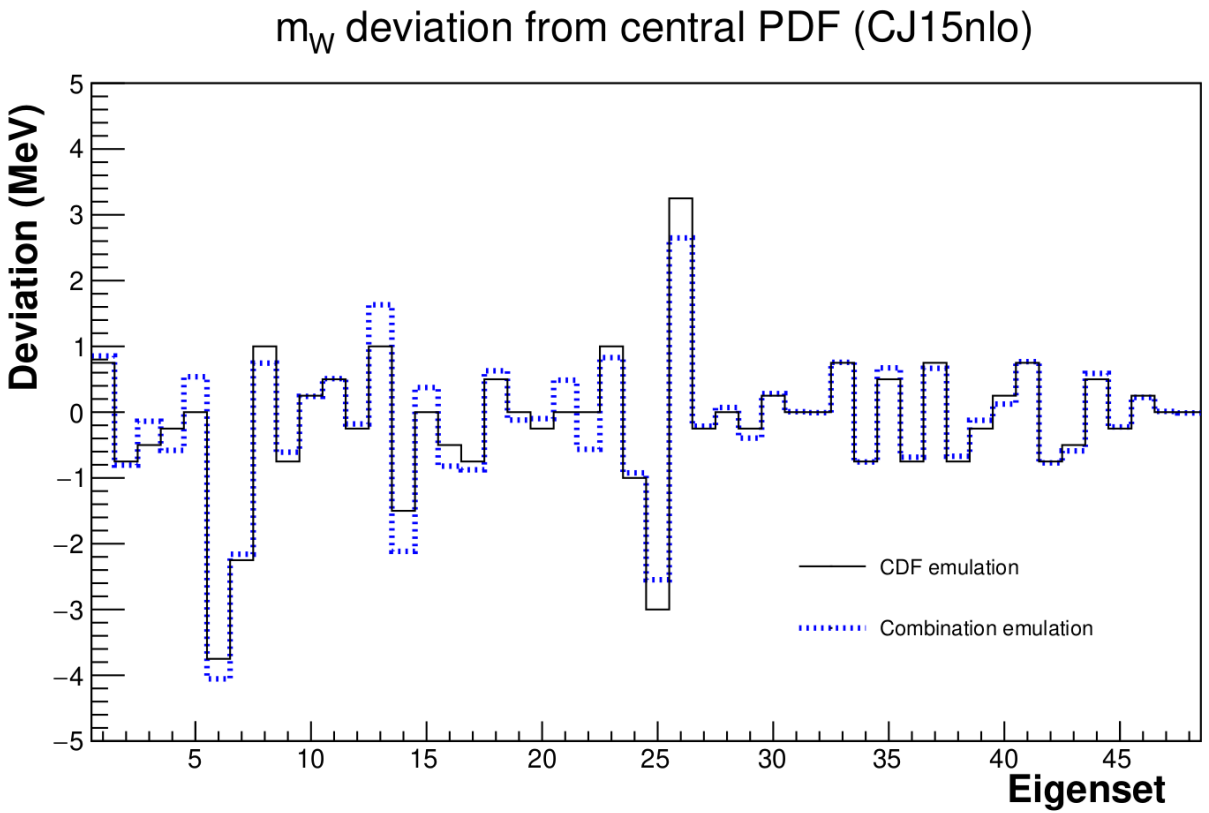
Validation (examples)

- Reproducing existing combinations using published information
  - PDF uncertainties re-calculated using smearing procedure, and used in combinations
  - PDF uncertainty found fully correlated between CDF and D0
  - Non-trivial correlations between the ATLAS measurement categories; accurately reproduced and combined result

	Tevatron	Tevatron+LEP	ATLAS
Published	80387 ± 16	80385 ± 15	80370 ± 19
Validation	80388 ± 16	80385 ± 15	80370 ± 19

Validation (examples)

- CJ15 uncertainty identical (2.9 MeV total) in the CDF and Combination emulations. Discrepancies <0.5 MeV for all eigenset variations



Chris Hays

Event samples

- Powheg
  - with PDF reweighting
    - Full PDF history for CTEQ, MSTW...MMHT, NNPDF; ABMP16; HERAPDF; …
    - NLO and NNLO, where applicable; uncertainty variations
    - 10M events per sample
  - Separate samples with different PDFs
    - All PDF sets used by existing mW measurements + modern sets
    - 2.5G events per sample
- MiNNLO, with PDF reweighting
    - All PDF sets used by existing mW measurements + modern sets
    - 50-100M events per sample
- Resbos
  - Resbos 1 : Legacy sample from CDF (50M events, CTEQ6M); legacy grids from D0 (CTEQ6.6)
  - “Resbos2” (actually, Resbos2 accuracy ported to Resbos generator):
    - All PDF sets used by existing mW measurements + modern sets (dedicated grids); NLO and NNLO
  - 1G → 2.5G events per sample

Outline

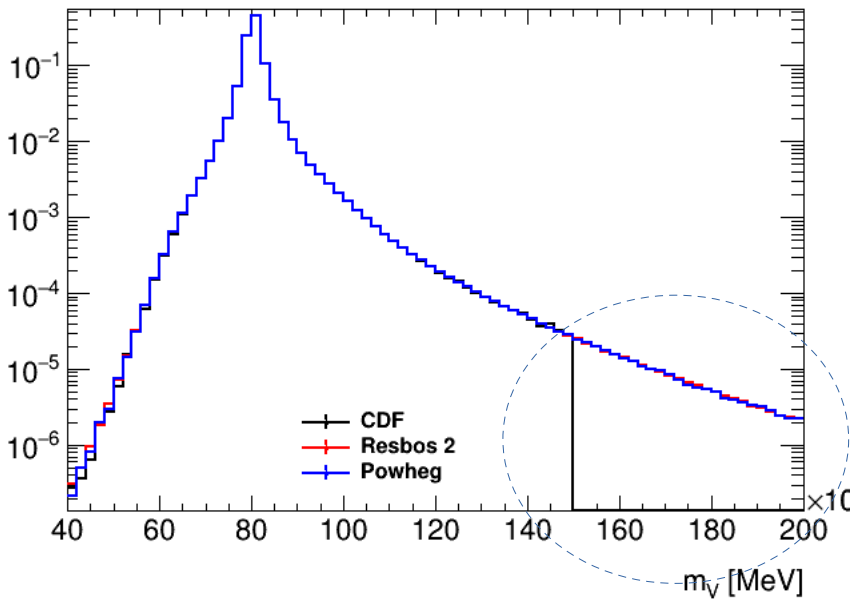
- Analysis strategy
- Measurement corrections, for improvements in QCD
- Extrapolations to modern PDFs

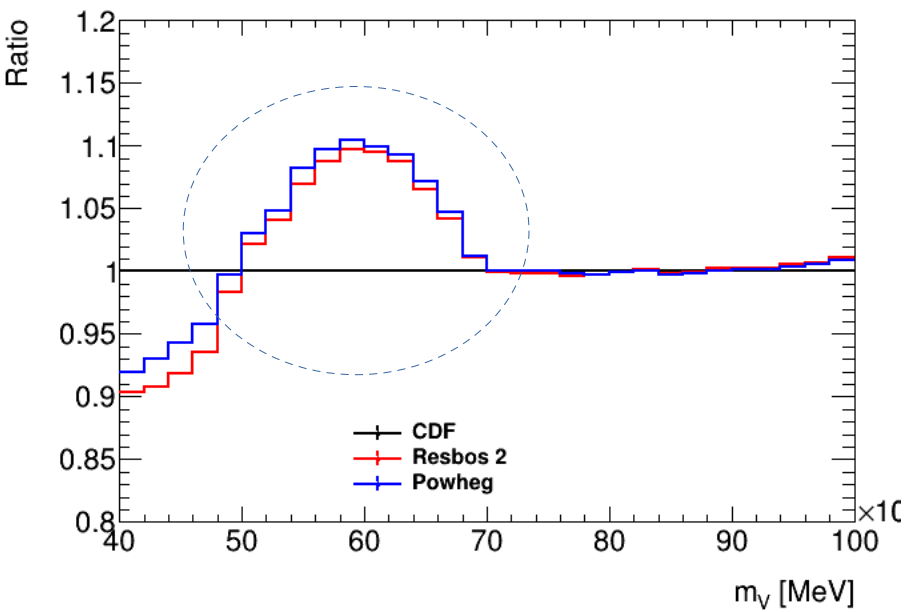
Generator corrections (δm_W^{QCD})

- Accuracy of Resbos1, compared to modern generators?
  - Resbos1 distributions obtained from the CDF publication sample, and D0 event generation grids (thanks for sharing!)
    - Resbos1 was a semi-private generator, and it is difficult to reproduce these distributions externally
  - Comparisons to Powheg, MiNNLO, and “Resbos 2”
    - “Resbos 2” is an upgrade of Resbos1, with (among others) improved NNLO QCD corrections, and improved treatment of spin correlations

Generator corrections (δm_W^{QCD})

- Invariant mass distribution in CDF events (before selections)

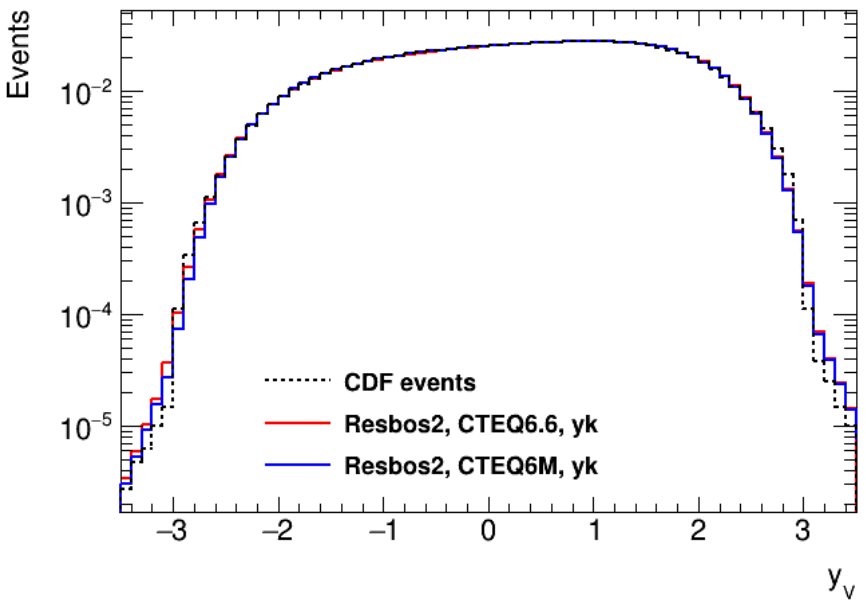


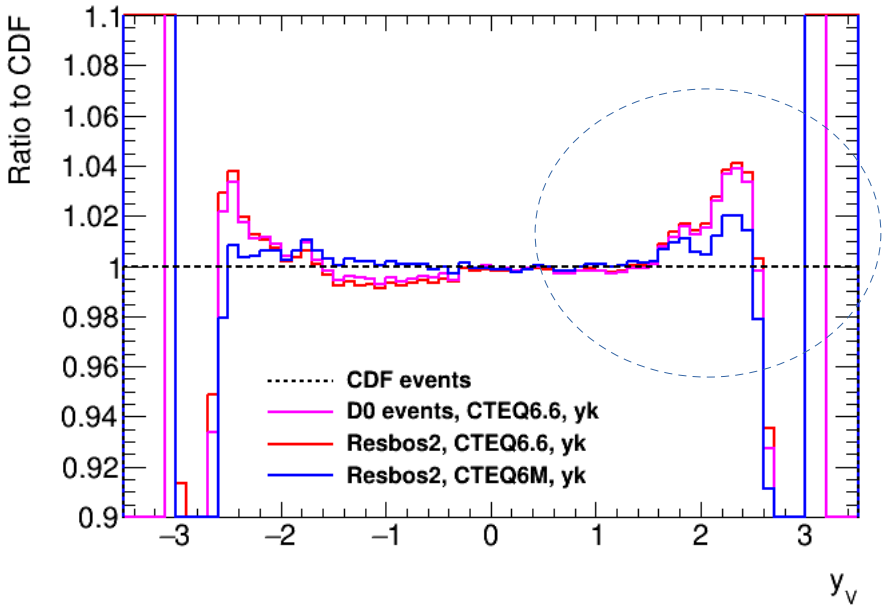


CDF events show deficit for m<70 GeV (then excess for m<50), compared to Powheg and Resbos2, for given m_W & Γ_W. Also, mass cut at 150 GeV

Generator corrections (δm_W^{QCD})

- W+ rapidity distribution for CTEQ6M (CDF setup), CTEQ6.6 (D0 setup)





→ CDF events match Resbos2+CTEQ6M, with 1-2% residuals
→ D0 events match Resbos2+CTEQ6.6 closely (<0.5%).

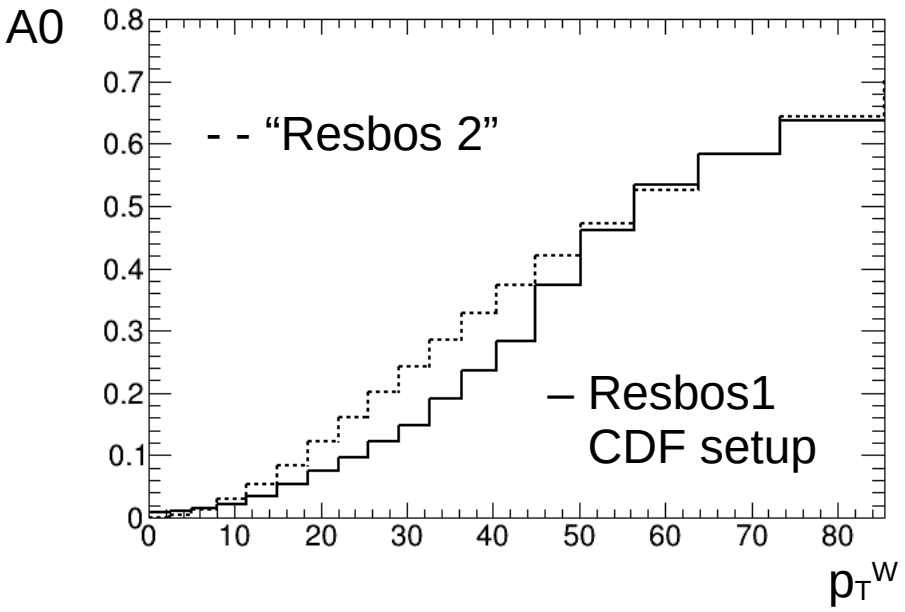
Generator corrections (δm_W^{QCD})

- Spin correlations.
  - General formula describing a spin-1 resonance production and decay:

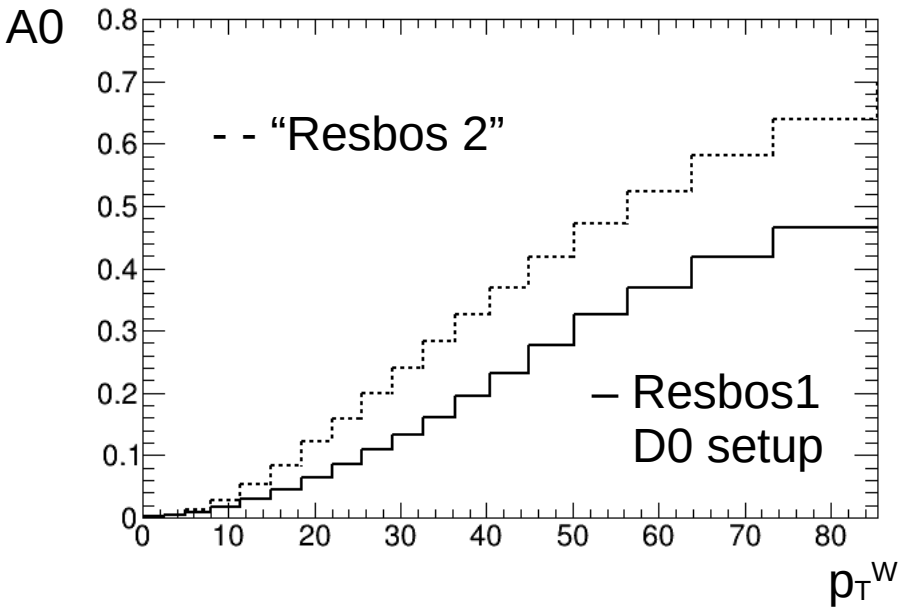
$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{dm dp_T dy}\,[\,(1+\cos^2\theta) + \frac{1}{2}A_0(1-3\cos^2\theta) + A_1 \sin 2\theta \cos\phi + \frac{1}{2}A_2 \sin^2\theta \cos 2\phi + A_3 \sin\theta \cos\phi + A_4 \cos\theta + A_5 \sin^2\theta \sin 2\phi + A_6 \sin 2\theta \sin\phi + A_7 \sin\theta \sin\phi\,],$$

Generator corrections (δm_W^{QCD})

- Spin correlations



CDF (Resbos1@NLO)

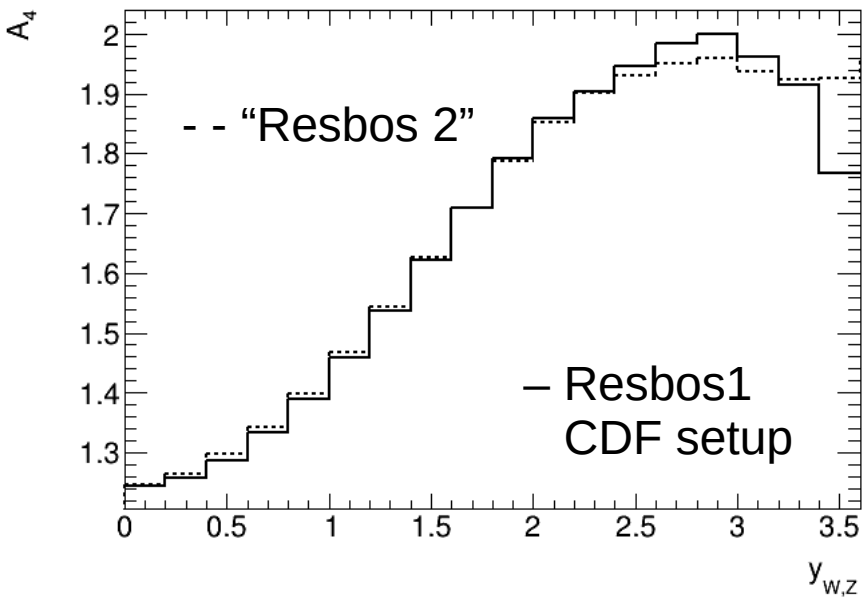


D0 (Resbos1@NNLO)

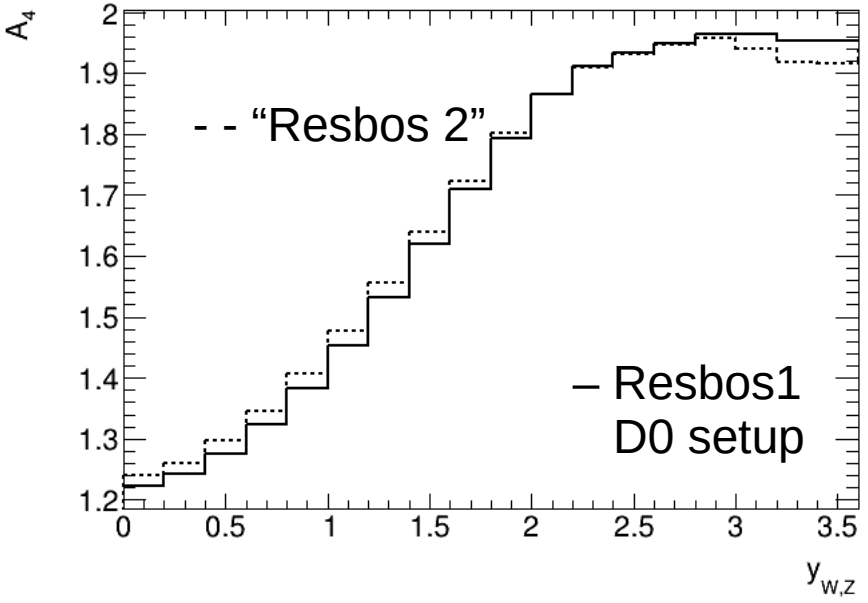
- In Resbos 1, only the unpolarised and A4 terms were resummed; others at fixed order. Universal treatment in Resbos 2

Generator corrections (δm_W^{QCD})

- Spin correlations



CDF (Resbos1@NLO)

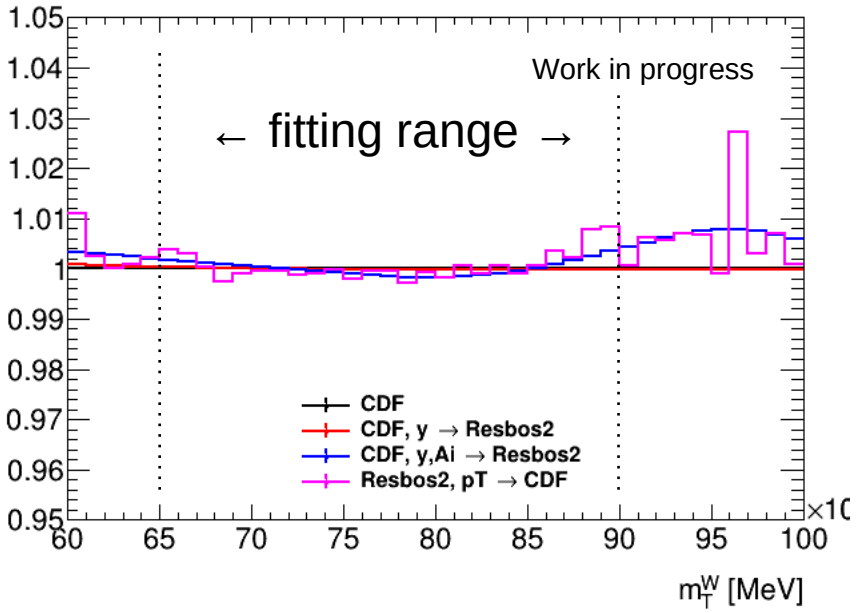


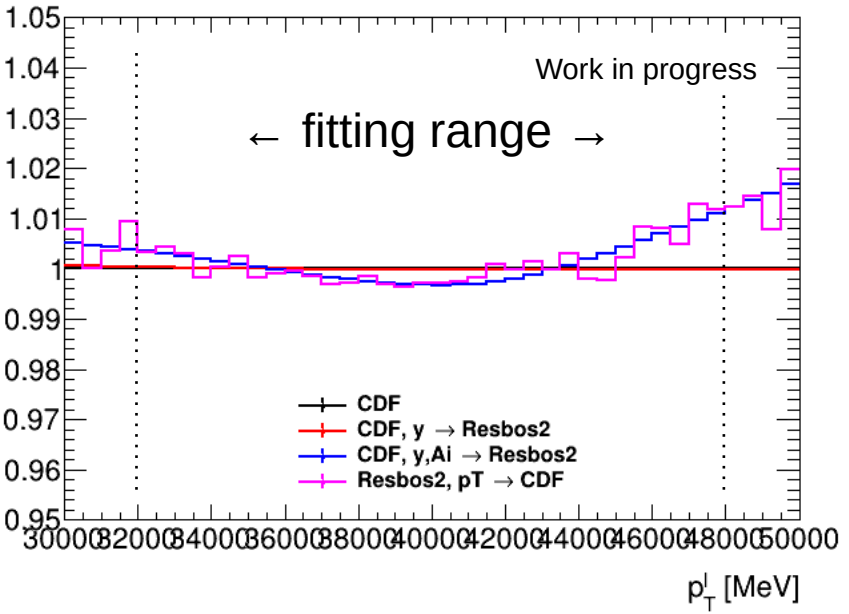
D0 (Resbos1@NNLO)

- Visible differences also in A4 (for a given PDF). Expected?

Generator corrections (δm_W^{QCD})

- Impact on final-state distributions : transverse mass, lepton p_T – CDF

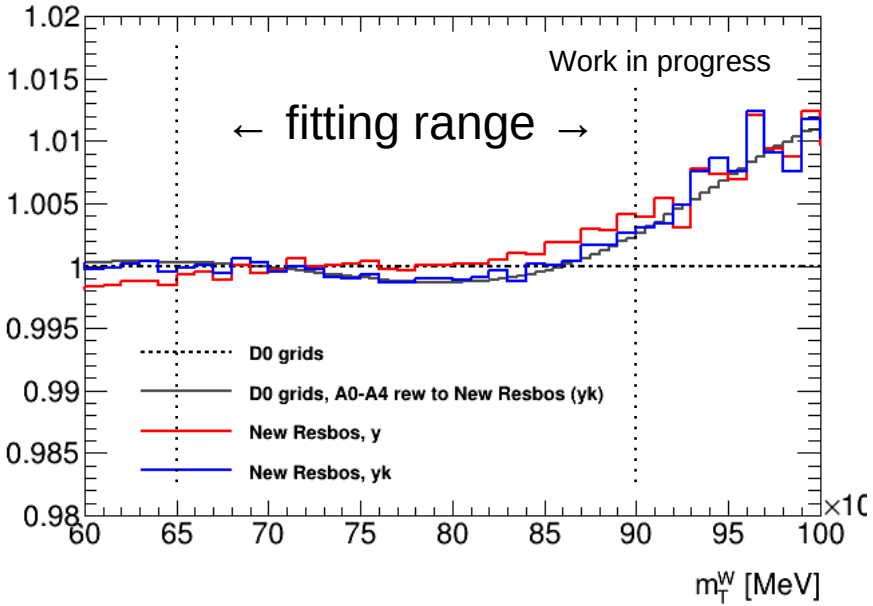


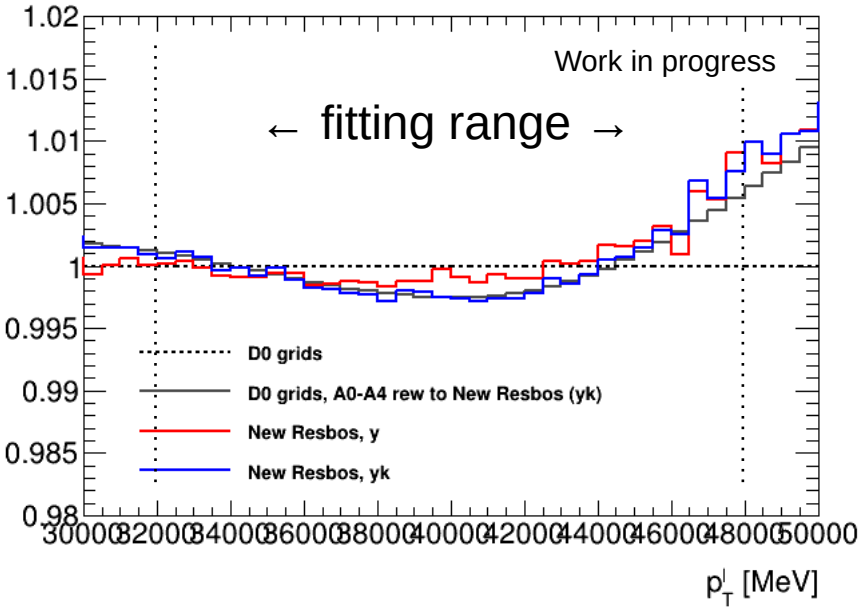


- CDF, "Resbos 2", CDF reweighted to Resbos2
- Effect up to 1% on the shapes from direct comparison between CDF and New Resbos (purple), qualitatively understood using reweighting studies (blue)
- Fluctuations in ratio are from limited size of CDF sample (=reference at 1)

Generator corrections (δm_W^{QCD})

- Impact on final-state distributions : transverse mass, lepton p_T – D0





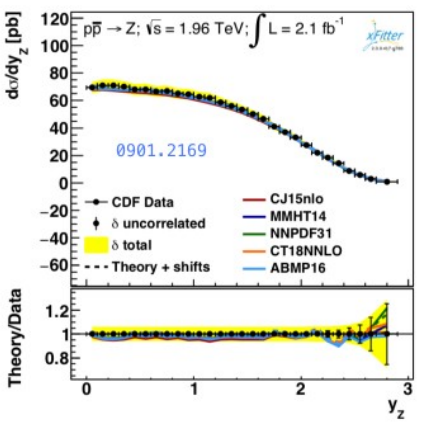
- Dashed – D0 reference at 1; full – D0 reweighted to New Resbos; blue – Resbos2
- Effect up to 1% on the shapes from direct comparison, qualitatively understood using reweighting studies

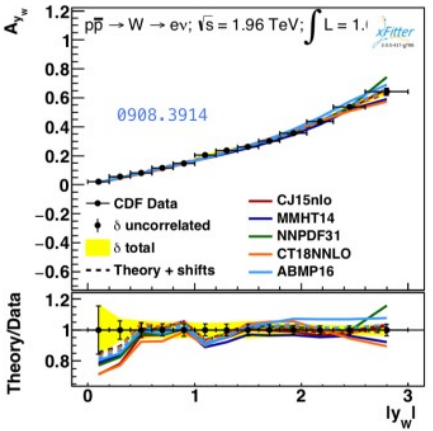
Outline

- Analysis strategy
- Measurement corrections, for improvements in QCD
- Extrapolations to modern PDF sets

Choice of target PDFs

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



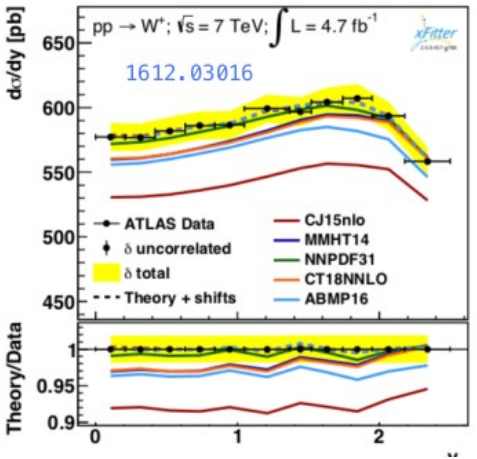


Dataset	CJ15nlo	MMHT14	NNPDF31	CT18NNLO	ABMP16
CDF W asymmetry 2009	18 / 13	12 / 13	11 / 13	13 / 13	17 / 13
Correlated χ^2	1.6	1.7	2.6	2.9	6.5
Log penalty χ^2	-0.00	-0.00	-0.00	-0.00	-0.00
Total χ^2 / dof	19 / 13	14 / 13	13 / 13	16 / 13	23 / 13
χ^2 p-value	0.11	0.37	0.43	0.25	0.04

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

Choice of 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
→ comparisons now extended to NNPDF4.0, MSHT20

PDF extrapolations (including generator dependence)

- Example, for CDF (defines reference PDF):

Generator		Powheg	Powheg	MiNNLO	Resbos	Resbos
Sample type		Reweighted	Direct	Reweighted	Direct	Direct
QCD accuracy		NLO+NLL	NLO+NLL	NNLO+NLL	NLO+NLL	NNLO+NNLL
PDF set				Shift		
CTEQ6M	NLO	0	0	0	0	0
CTEQ66	NLO	-15.4 ± 0.8	-15.8 ± 0.8	-14.0 ± 1.3	-17.8 ± 1.0	-16.6 ± 1.0
CT10	NLO	-6.3 ± 0.8	-6.2 ± 0.8	-4.2 ± 1.3	–	–
CT10nnlo	NNLO	-16.2 ± 0.8	-16.6 ± 0.8	-16.8 ± 1.3	–	–
CT14	NNLO	-4,1 ± 0.8	-3.9 ± 0.8	-6.8 ± 1.3	-7.1 ± 1.0	-6.9 ± 1.0
CT18	NNLO	-6.2 ± 0.8	-6.6 ± 0.8	-8.5 ± 1.3	-9.4 ± 1.0	-7.2 ± 1.0
CJ15	NLO	7.7 ± 0.8	7.9 ± 0.8	10.1 ± 1.3	–	–
MMHT14	NNLO	-6.2 ± 0.8	-6.4 ± 0.8	-6.9 ± 1.3	-8.1 ± 1.0	-3.5 ± 1.0
MSHT20	NNLO	-5.0 ± 0.8	-4.9 ± 0.8	-4.9 ± 1.3	–	–
ABMP16	NNLO	5.2 ± 0.8	5.0 ± 0.8	-0.2 ± 1.3	–	–
NNPDF3.1	NNLO	-13.8 ± 0.8	-14.3 ± 1.4	-14.1 ± 1.3	-15.8 ± 1.0	-8.0 ± 1.0

→ Significant difference between CTEQ6M and CTEQ6.6 (not accounted for this far)

PDF extrapolations (including generator dependence)

- Example, for CDF (defines reference PDF):

Generator		Powheg	Powheg	MiNNLO	Resbos	Resbos
Sample type		Reweighted	Direct	Reweighted	Direct	Direct
QCD accuracy		NLO+NLL	NLO+NLL	NNLO+NLL	NLO+NLL	NNLO+NNLL
PDF set				Shift		
CTEQ6M	NLO	0	0	0	0	0
CTEQ66	NLO	-15.4 ± 0.8	-15.8 ± 0.8	-14.0 ± 1.3	-17.8 ± 1.0	-16.6 ± 1.0
CT10	NLO	-6.3 ± 0.8	-6.2 ± 0.8	-4.2 ± 1.3	–	–
CT10nnlo	NNLO	-16.2 ± 0.8	-16.6 ± 0.8	-16.8 ± 1.3	–	–
CT14	NNLO	-4,1 ± 0.8	-3.9 ± 0.8	-6.8 ± 1.3	-7.1 ± 1.0	-6.9 ± 1.0
CT18	NNLO	-6.2 ± 0.8	-6.6 ± 0.8	-8.5 ± 1.3	-9.4 ± 1.0	-7.2 ± 1.0
CJ15	NLO	7.7 ± 0.8	7.9 ± 0.8	10.1 ± 1.3	–	–
MMHT14	NNLO	-6.2 ± 0.8	-6.4 ± 0.8	-6.9 ± 1.3	-8.1 ± 1.0	-3.5 ± 1.0
MSHT20	NNLO	-5.0 ± 0.8	-4.9 ± 0.8	-4.9 ± 1.3	–	–
ABMP16	NNLO	5.2 ± 0.8	5.0 ± 0.8	-0.2 ± 1.3	–	–
NNPDF3.1	NNLO	-13.8 ± 0.8	-14.3 ± 1.4	-14.1 ± 1.3	-15.8 ± 1.0	-8.0 ± 1.0

→ Most often, PDF shifts agree across generators, within 1 MeV

PDF extrapolations (including generator dependence)

- Example, for CDF (defines reference PDF):

Generator		Powheg	Powheg	MiNNLO	Resbos	Resbos
Sample type		Reweighted	Direct	Reweighted	Direct	Direct
QCD accuracy		NLO+NLL	NLO+NLL	NNLO+NLL	NLO+NLL	NNLO+NNLL
PDF set				Shift		
CTEQ6M	NLO	0	0	0	0	0
CTEQ66	NLO	-15.4 ± 0.8	-15.8 ± 0.8	-14.0 ± 1.3	-17.8 ± 1.0	-16.6 ± 1.0
CT10	NLO	-6.3 ± 0.8	-6.2 ± 0.8	-4.2 ± 1.3	–	–
CT10nnlo	NNLO	-16.2 ± 0.8	-16.6 ± 0.8	-16.8 ± 1.3	–	–
CT14	NNLO	-4,1 ± 0.8	-3.9 ± 0.8	-6.8 ± 1.3	-7.1 ± 1.0	-6.9 ± 1.0
CT18	NNLO	-6.2 ± 0.8	-6.6 ± 0.8	-8.5 ± 1.3	-9.4 ± 1.0	-7.2 ± 1.0
CJ15	NLO	7.7 ± 0.8	7.9 ± 0.8	10.1 ± 1.3	–	–
MMHT14	NNLO	-6.2 ± 0.8	-6.4 ± 0.8	-6.9 ± 1.3	-8.1 ± 1.0	-3.5 ± 1.0
MSHT20	NNLO	-5.0 ± 0.8	-4.9 ± 0.8	-4.9 ± 1.3	–	–
ABMP16	NNLO	5.2 ± 0.8	5.0 ± 0.8	-0.2 ± 1.3	–	–
NNPDF3.1	NNLO	-13.8 ± 0.8	-14.3 ± 1.4	-14.1 ± 1.3	-15.8 ± 1.0	-8.0 ± 1.0

→ Some counter-examples :
MMHT14, NNPDF3.1 : NNLO Resbos2 3-8 MeV different relative to other generators

PDF uncertainties & correlations

- PDFs are the main source of correlations
  - other sources are either small (EWK corrections) or arguably decorrelated ($p_T^{W/Z}$)
  - Two-step procedure : correct to common PDF; combination including correlations
  - At this point, PDF extrapolations and uncertainties are calculated using Powheg.

CTEQ6.6	1.	2.	3.	4.
1. W^+ 2 TeV	1	1	0.37	0.45
2. W^- 2 TeV	1	1	0.36	0.46
3. W^+ 7 TeV	0.37	0.36	1	-0.42
4. W^- 7 TeV	0.45	0.46	-0.42	1

CT10	1.	2.	3.	4.
1. W^+ 2 TeV	1	0.99	0.26	0.51
2. W^- 2 TeV	0.99	1	0.31	0.52
3. W^+ 7 TeV	0.26	0.31	1	-0.23
4. W^- 7 TeV	0.51	0.52	-0.23	1

New combinations

- Preliminary combinations for ATLAS+CDF+D0.
  - Central values may need corrections : hidden for now!
    - Model-dependence of PDF extrapolations?
    - Impact of generator mis-modellings?
  - Total (PDF) uncertainties : 11–13 MeV (3–7 MeV).
  - CT18, MSHT20, NNPDF4.0 now available too.

	CTEQ6M	CTEQ6.1	CTEQ6.6	CT10nnlo	MSTW2008
Central value					
PDF	9	9	9	9	5
Total	14	14	14	14	12
$\chi^2/ndof$	47/35	46/35	50/35	48/35	60/35

Table 1: Combination summary: Legacy PDFs

	CT10	CJ15	CT14nlo	MMHT2014nlo	NNPDF3.1nlo
Central value					
PDF	11	2	9	6	4
Total	16	11	14	13	11
$\chi^2/ndof$	46/35	53/35	48/35	58/35	49/35

Table 2: Combination summary: NLO PDFs

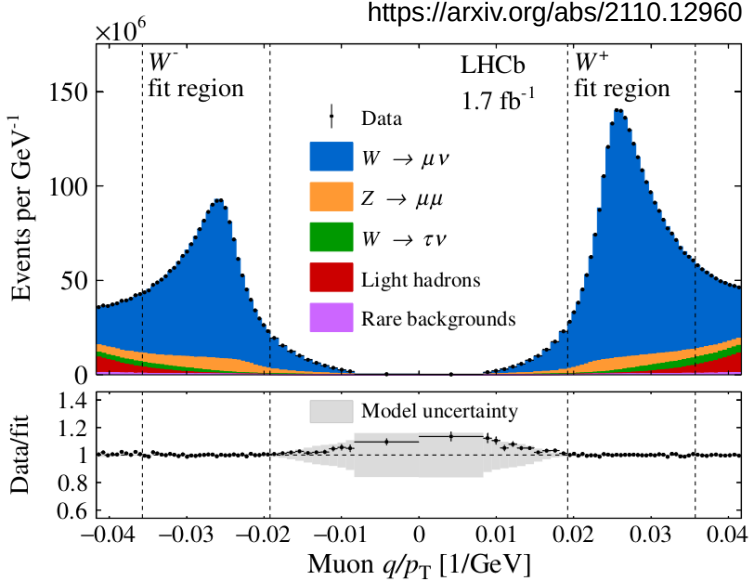
	CT14nnlo	MMHT2014nnlo	ABMP16nnlo	NNPDF3.1nnlo
Central value				
PDF	10	7	3	4
Total	15	13	11	11
$\chi^2/ndof$	45/35	45/35	55/35	50/35

Table 3: Combination summary: NNLO PDFs

Starting : ATLAS+LHCb PDF correlation studies

- Should be much simpler, and highly interesting. Starting.
  - Detailed information available for all used PDFs; up-to-date generators and a complete set of systematic uncertainties (including spin correlations)
  - Expect negative correlations of PDF uncertainties between ATLAS and LHCb (reminiscent of what we gained from the η categories in ATLAS)

https://arxiv.org/abs/2110.12960



$$m_W = 80354 \pm 23_{\text{stat}} \pm 10_{\text{exp}} \pm 17_{\text{theory}} \pm 9_{\text{PDF}}\ \text{MeV}$$

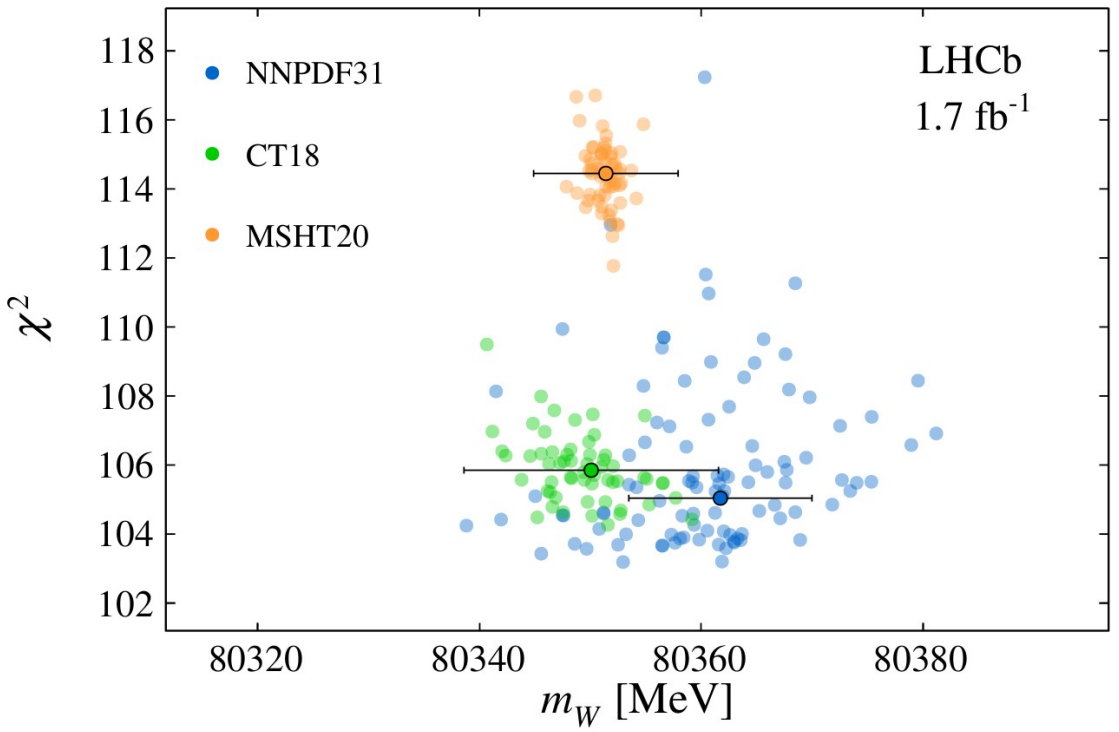
https://arxiv.org/abs/1508.06954

$$\rho = \begin{pmatrix} & \mathbf{G}^+ & \mathbf{G}^- & \mathbf{L}^+ & \mathbf{L}^- \\ \mathbf{G}^+ & 1 & & & \\ \mathbf{G}^- & -0.22 & 1 & & \\ \mathbf{L}^+ & -0.63 & 0.11 & 1 & \\ \mathbf{L}^- & -0.02 & -0.30 & 0.21 & 1 \end{pmatrix}$$

Starting : ATLAS+LHCb PDF correlation studies

- Detailed information available for NNPDF3.1, CT18, MSHT20 (all NLO).

  Corresponding samples produced and avalaible for ATLAS



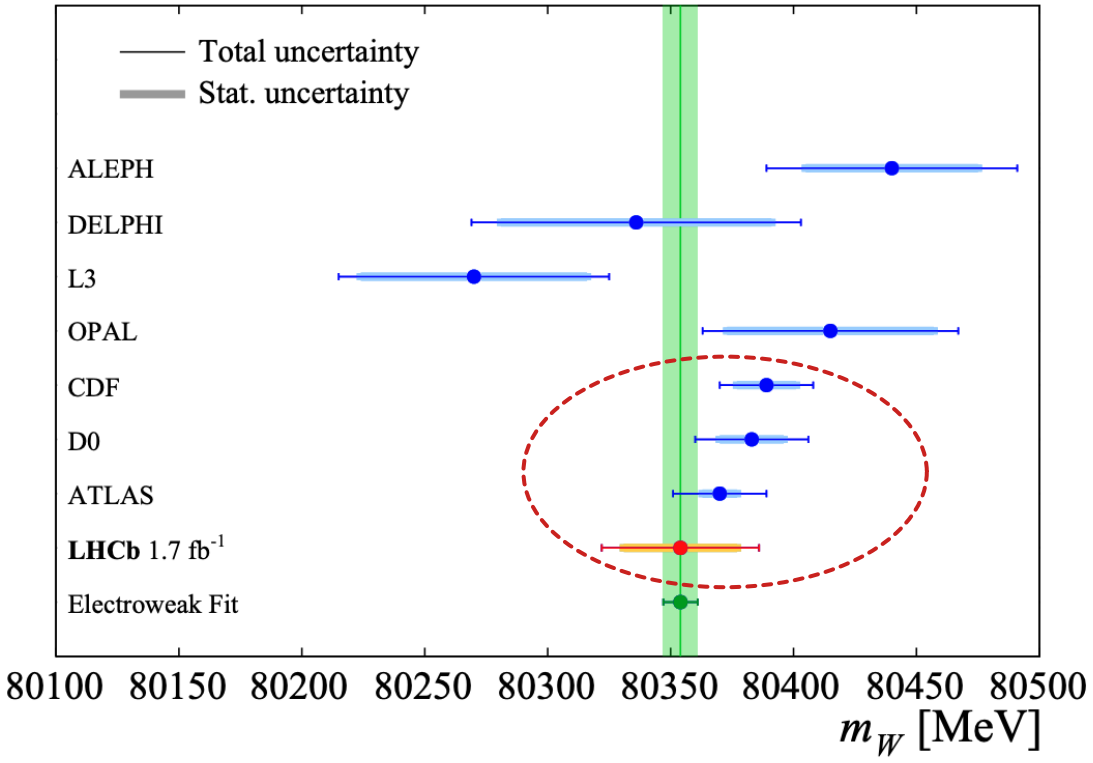
Summary

- ATLAS+Tevatron combinations
  - Still no definite numbers given today, sorry!
    - All infrastructure in place, but small effects still to be understood
  - Combinations with PDF extrapolations and in place since a few years; now including a detailed study of generator dependence
  - QCD corrections were the main topic of this year’s work; converging.
  - Final prescription for central value and uncertainties still to be decided.
- LHCb and other future projects
  - Quantitative studies of PDF correlations between LHCb, ATLAS and Tevatron can start.
  - Once QCD corrections are sorted out for the Tevatron, future updates should be more straightforward. Envision regular updates including new measurements, or new PDFs when they become available.

Back up

Status of the W-boson mass combination

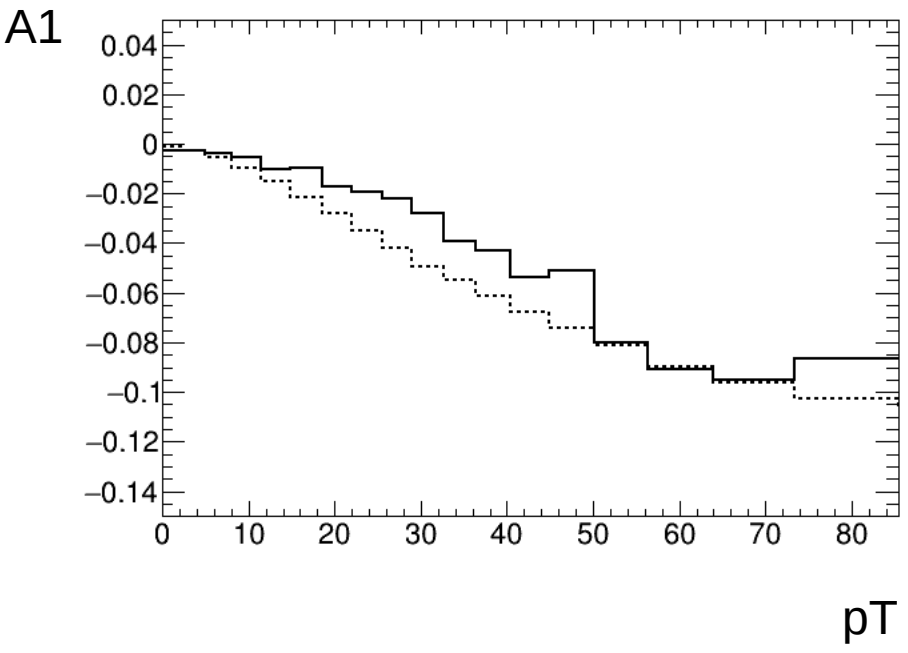
- Objectives
- Reminders
- This year's developments
- Converging?
- Starting projects



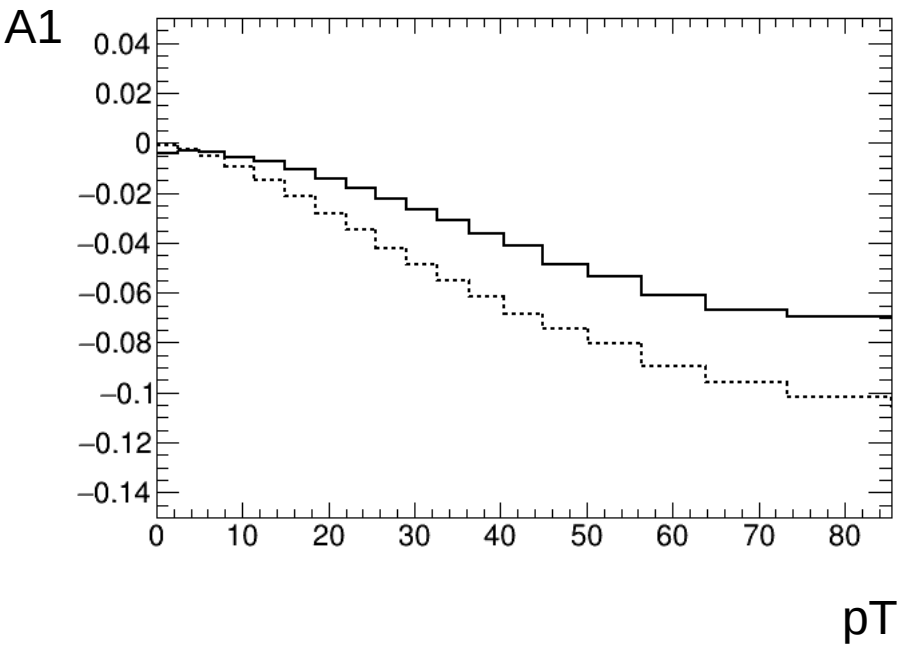
Previous presentations :

Dec. '21	https://indico.cern.ch/event/1097287/
Feb. '21	https://indico.cern.ch/event/1006071/
Oct. '20	https://indico.cern.ch/event/941711/

Spin correlations : “Old” vs “New” Resbos



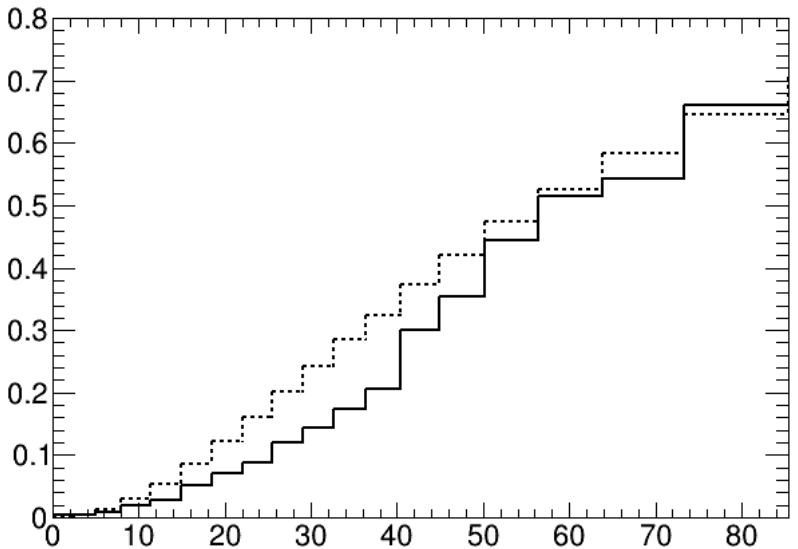
CDF, NLO



D0, NNLO

Spin correlations : “Old” vs “New” Resbos

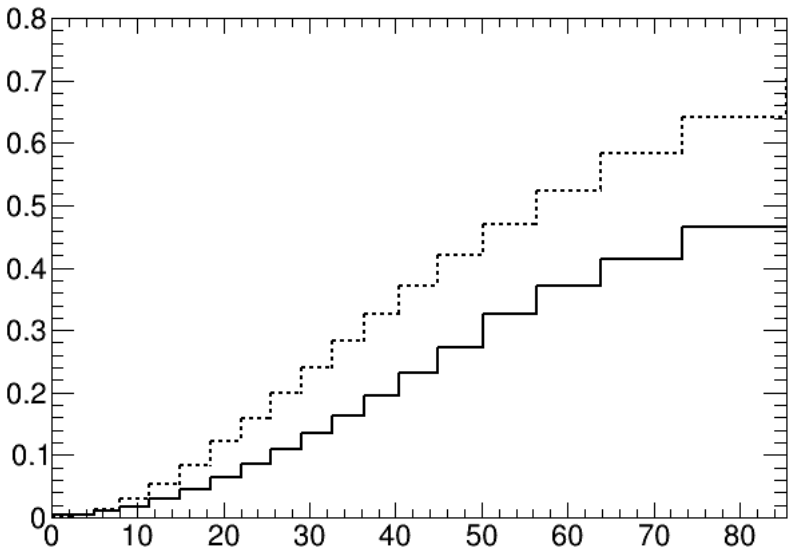
A2



pT

CDF, NLO

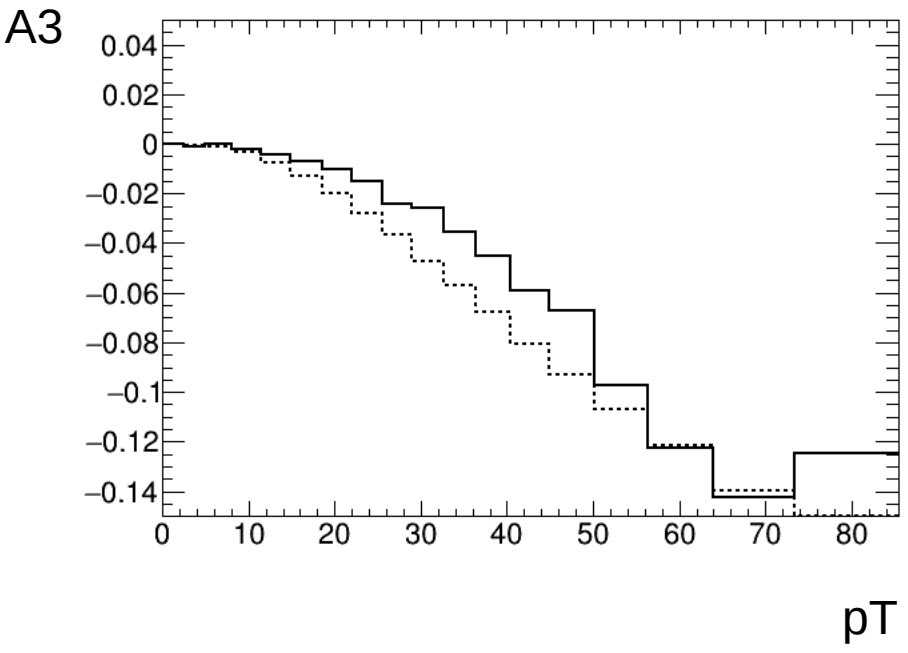
A2



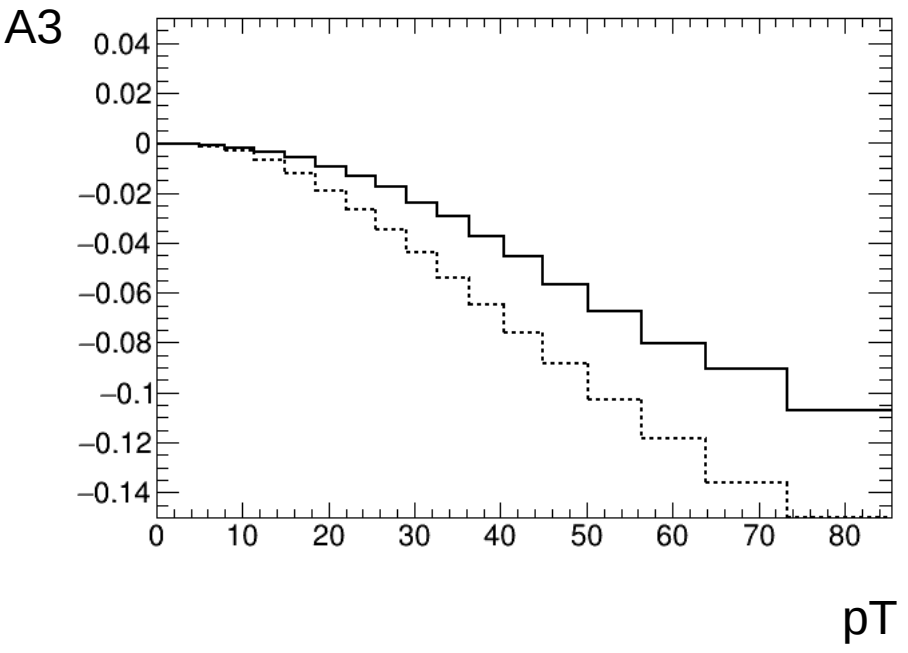
pT

D0, NNLO

Spin correlations : “Old” vs “New” Resbos



CDF



D0, NNLO

Discussion with Resbos authors

- Resbos 1 :
  - Unpolarised cross section is resummed
  - The polarised cross sections are at fixed order
- New resbos (and other MC's)
  - All helicity cross sections are resummed, assuming resummation effects universal
  - Universality proven for Z+j (and probably W+j), not for inclusive production
- Consequences
  - Recovers fixed-order behaviour of angular coefficients

$$A_i^{old}(p_T) = \sigma_i^{FO}(p_T)/\sigma_{unpol}^{Res}(p_T)$$

$$A_i^{new}(p_T) = \sigma_i^{Res}(p_T)/\sigma_{unpol}^{Res}(p_T) = \sigma_i^{FO}(p_T)/\sigma_{unpol}^{FO}(p_T) = A_i^{FO}(p_T)$$

Discussion with Resbos authors

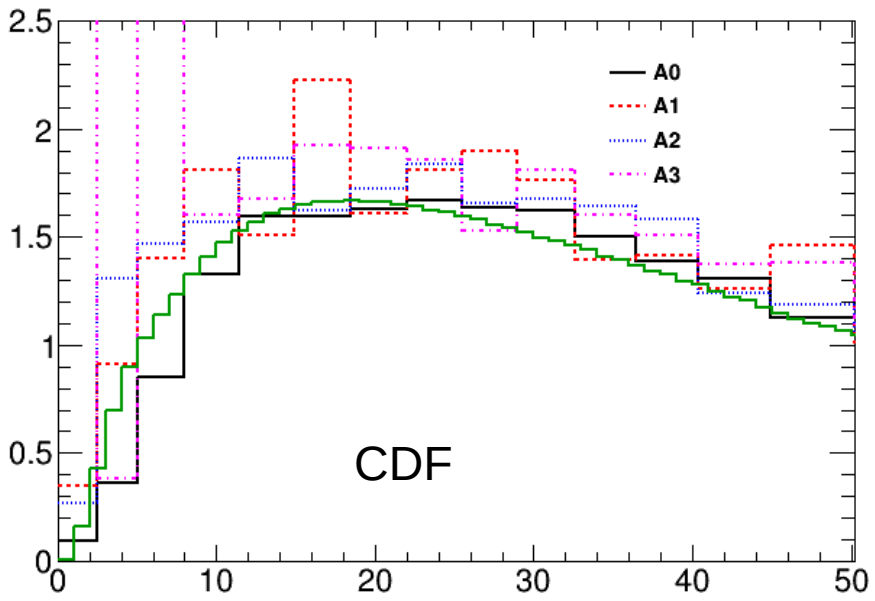
- Resbos 1 :
  - Unpolarised cross section is resummed
  - The polarised cross sections are at fixed order
- New resbos (and other MC's)
  - All helicity cross sections are resummed, assuming resummation effects universal
  - Universality proven for Z+j (and probably W+j), not for inclusive production
- Consequences
  - "prediction" : the ratio between "old" and "new" Ai's should match the ratio between resummed and fixed-order pT distributions

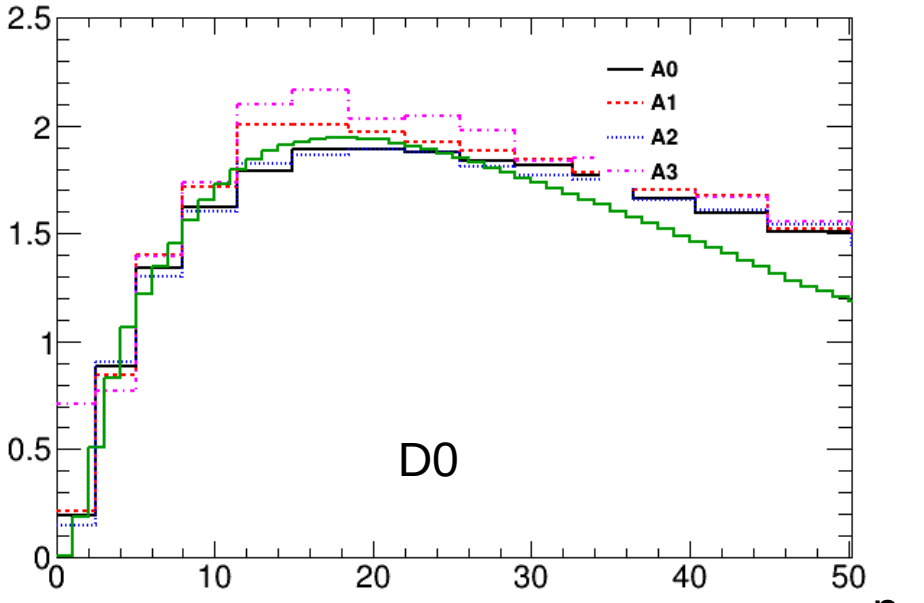
$$A_i^{new}(p_T)/A_i^{old}(p_T) = \sigma_i^{Res}(p_T)/\sigma_i^{FO}(p_T) = \sigma_{unpol}^{Res}(p_T)/\sigma_{unpol}^{FO}(p_T)$$

Discussion with Resbos authors

- Consequence: ratio between new and old angular coefficients should be universal, and match the ratio of resummed and fixed-order pT distributions

A_i^{new} / A_i^{old}



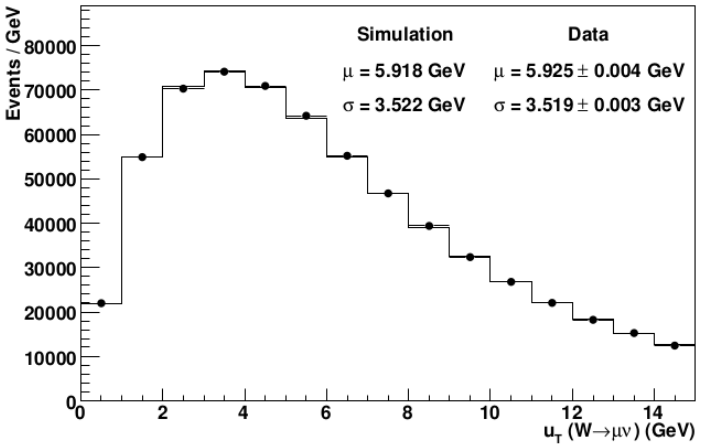


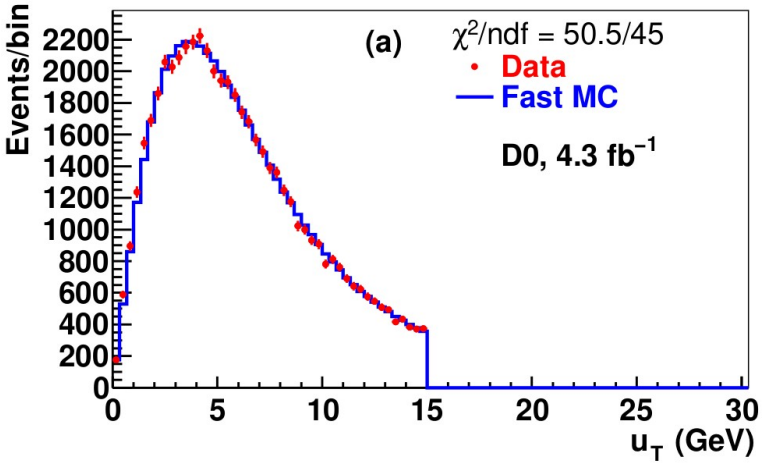
p_T

→ Universality : ✓. Note difference between CDF and D0 events at high pT.
→ with Resummed / FixedOrder pT distribution ratio. Not perfect, but qualitatively explains

Generator corrections ($\delta m_W^{gen_{0\to i}, PDF_0}$)

- Corrections evaluated, through reweightings or cuts :
  - Invariant mass shape and range
  - Rapidity
  - Angular coefficients, $A_0 \rightarrow A_4$
- In addition, direct comparisons are made between old and new samples, for same physics (PDF, QCD order, m_W and Γ_W)
- Note : all variations are studied assuming that the true p_T^W distribution does not change after selections, by virtue of successful u_T control plot in the Tevatron publications.
  - Control plots however do not have infinite statistics, so p_T^W has *some* freedom. Effects shown are therefore a lower bound





New combinations

- PDF uncertainty correlations, for various PDFs :
  - Overview, to be updated (CT18, MSHT, NNPDF)

PDF set	Tevatron/LHC correlation	
	NLO	NNLO
CTEQ6M	72 %	
CTEQ6.1	70 %	
CTEQ6.6	74 %	
CT10	75 %	76 %
CJ15	71 %	
CT14	81 %	71 %
MMHT14	63 %	66 %

… and summed over charges