ATLAS-Tevatron combination

ATLAS - Tevatron combination:

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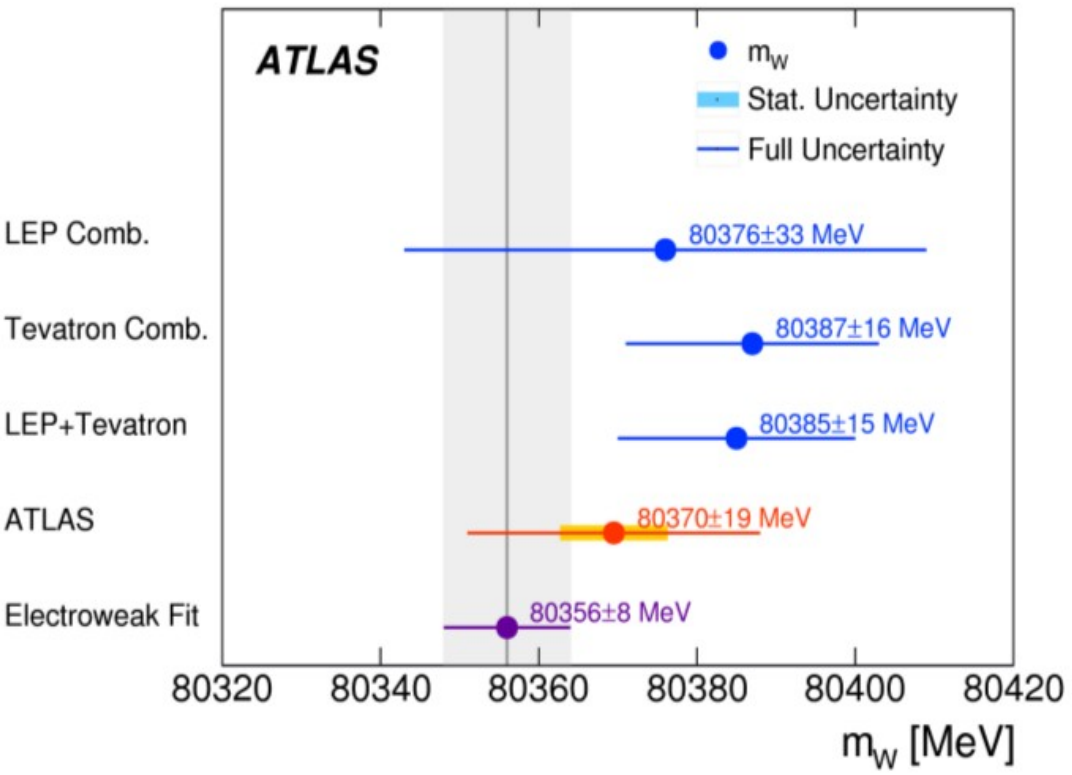
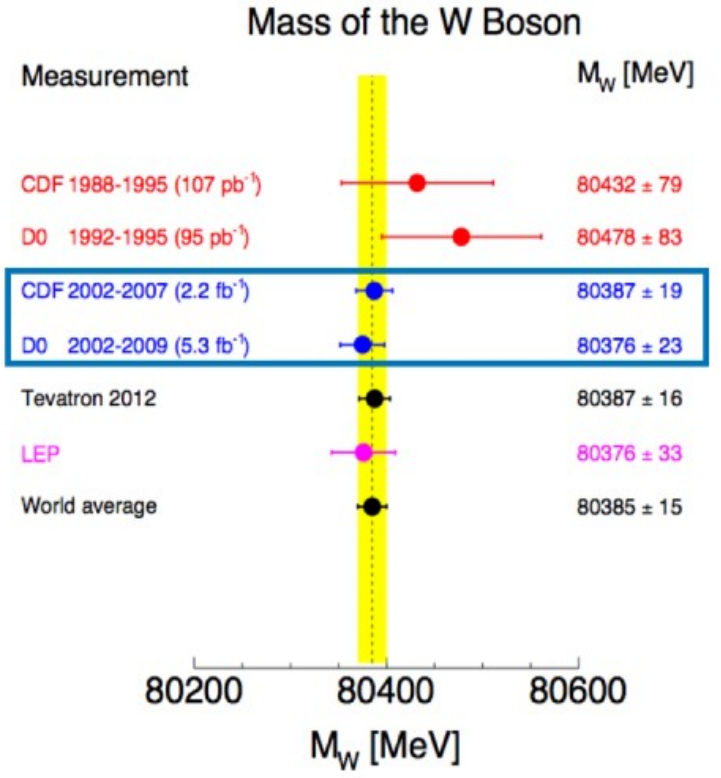
https://indico.cern.ch/category/3290/ discussion on LHC / Tevatron combinations of mW

EWWG meeting, July 1st, 2019

Introduction





Aim: provide a new world average value combining the existing public results
(no change or improvement in the individual results is foreseen)

Relevance

- at least 3 unofficial, handwaving combinations around (EW fitters, PDG)

- Quantitatively addressing the question of PDF correlations among hadron collider measurements. This will become a major issue in the future:
  - Combinations : m_W or $\sin^2\theta_W$ measurements at different experiments / colliders
  - Interpretation : correlation between m_W and $\sin^2\theta_W$ measurements, in an EW fit for example
  - Beyond this, correlations Higgs properties, diboson rates, … will ultimately become significant and need to be accounted for when interpreting results

- Enable porting existing measurements to any existing or future PDF set

- Put in place a methodology for future combinations including fellow LHC experiments

Tevatron Results

CDF experiment:

Phys. Rev. Lett.108 (2012) 151803

electron/muon channels **1.1 M**
2.2 fb^{-1} integrated luminosity

m_W= 80387±12(stat)±15(syst) MeV

Source	Uncertainty (MeV)
Lepton energy scale and resolution	7
Recoil energy scale and resolution	6
Lepton removal	2
Backgrounds	3
$p_T(W)$ model	5
Parton distributions	10
QED radiation	4
W-boson statistics	12
Total	19

D0 experiment:

Phys. Rev. Lett. 108 (2012) 151804

electron channel **1.7 M**
~5.3 fb^{-1} integrated luminosity

m_W= 80375±11(stat)±20(syst) MeV

	ΔM_W (MeV)		
Source	m_T	p_T^e	$\not\!\!E_T$
Electron energy calibration	16	17	16
Electron resolution model	2	2	3
Electron shower modeling	4	6	7
Electron energy loss model	4	4	4
Hadronic recoil model	5	6	14
Electron efficiencies	1	3	5
Backgrounds	2	2	2
Experimental subtotal	18	20	24
PDF	11	11	14
QED	7	7	9
Boson p_T	2	5	2
Production subtotal	13	14	17
Total	22	24	29

$$M_W = 80\,387 \pm 16 \text{ MeV}$$

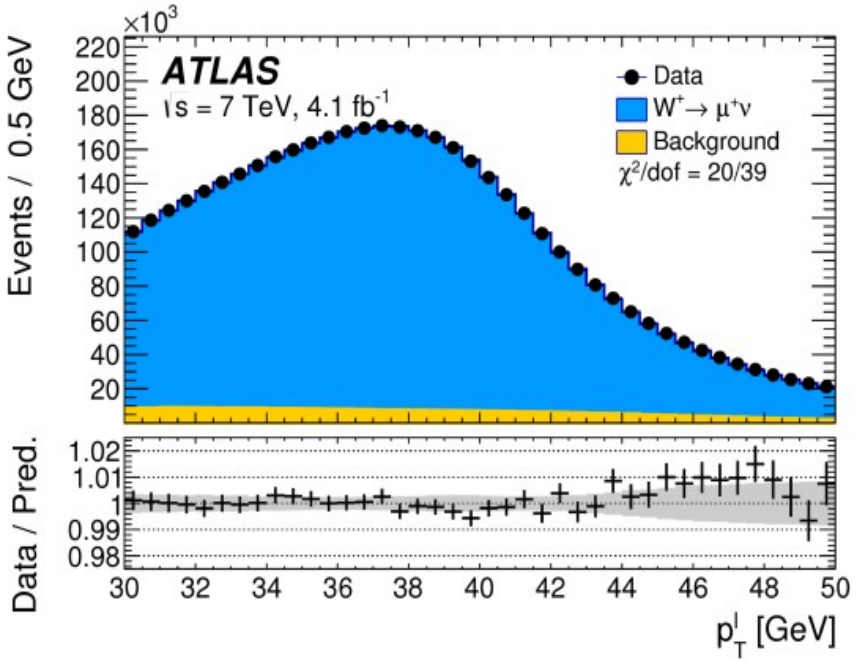
ATLAS Results

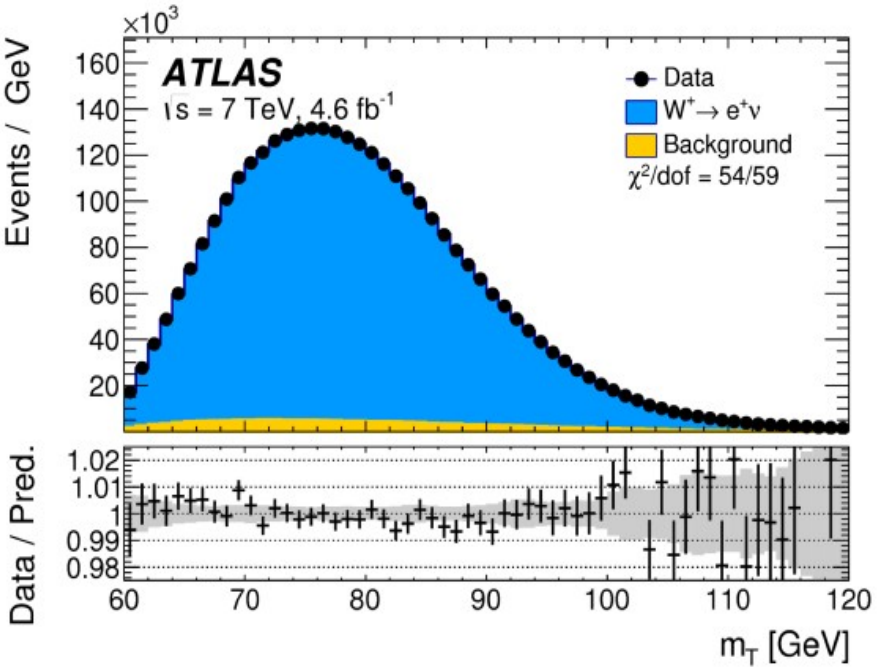
Eur.Phys.J.C (2018) 78:110

$$m_W = 80369.5 \pm 6.8\,\text{MeV(stat.)} \pm 10.6\,\text{MeV(exp. syst.)} \pm 13.6\,\text{MeV(mod. syst.)}$$
$$= 80369.5 \pm 18.5\,\text{MeV},$$

Combined categories	Value [MeV]	Stat. Unc.	Muon Unc.	Elec. Unc.	Recoil Unc.	Bckg. Unc.	QCD Unc.	EWK Unc.	PDF Unc.	Total Unc.	χ^2/dof of Comb.
m_T-p_T^ℓ, $W^\pm$, e-μ	80369.5	6.8	6.6	6.4	2.9	4.5	8.3	5.5	9.2	18.5	29/27

~6M/8M observed in the electron/muon channel





Sources of uncertainty & correlations

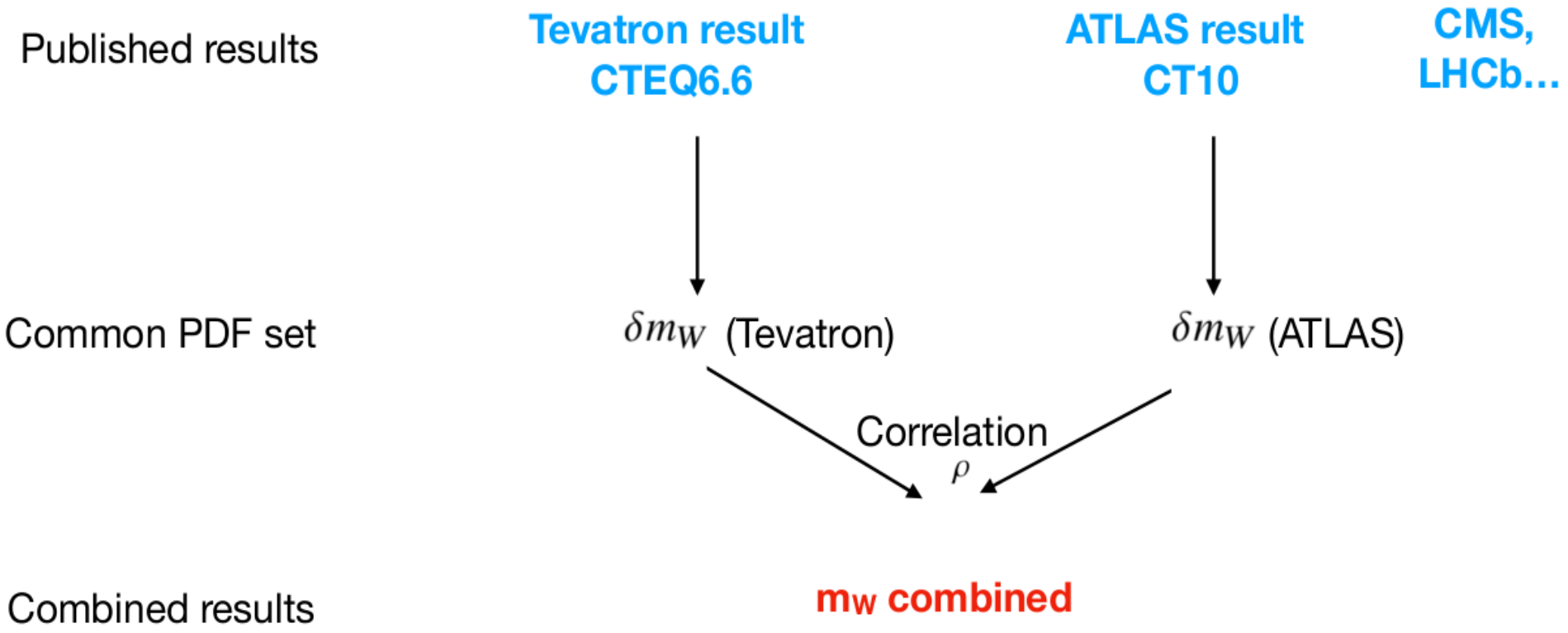
- All experimental : uncorrelated
  - Small caveat : $m_{Z,}$ the primary reference for calibration in ATLAS and D0 (CDF uses J/psi)

- Physics modelling : tools

	ATLAS	**Tevatron**
pT	Pythia8	RESBOS
pert. QCD	DYNNLO	RESBOS
PDF	CT10nnlo	CTEQ6.6
EW	Photos	Photos

Sources of uncertainty & correlations

- All experimental : uncorrelated
  - Small caveat : $m_{Z,}$ the primary reference for calibration in ATLAS and D0 (CDF uses J/psi)
- Physics modelling : correlations
  - QED / EW corrections
    - Photon radiation uncertainties fully correlated
    - Radiation of pairs only considered explicitly at ATLAS
  - Boson pT : can be assumed uncorrelated
    - Model purely based on Z data at the Tevatron
    - Combination of Z data and Z → W extrapolation at ATLAS
  - PDFs are the main source of correlations



To combine the results: need to address the correlations between the uncertainties —> PDF uncertainties

Lack of published CMS result = design methodology using ATLAS+Tevatron results

PDF variations are applied as event weights on the generator level, calculated internally in Powheg as the ratio of the event cross sections predicted by CT10 and alternative PDF sets: CT10, CTEQ6.6, MSTW2008, *CT14, MMHT2014, NNPDF31*

Detector effects implemented using parameterised simulation

Collaboration

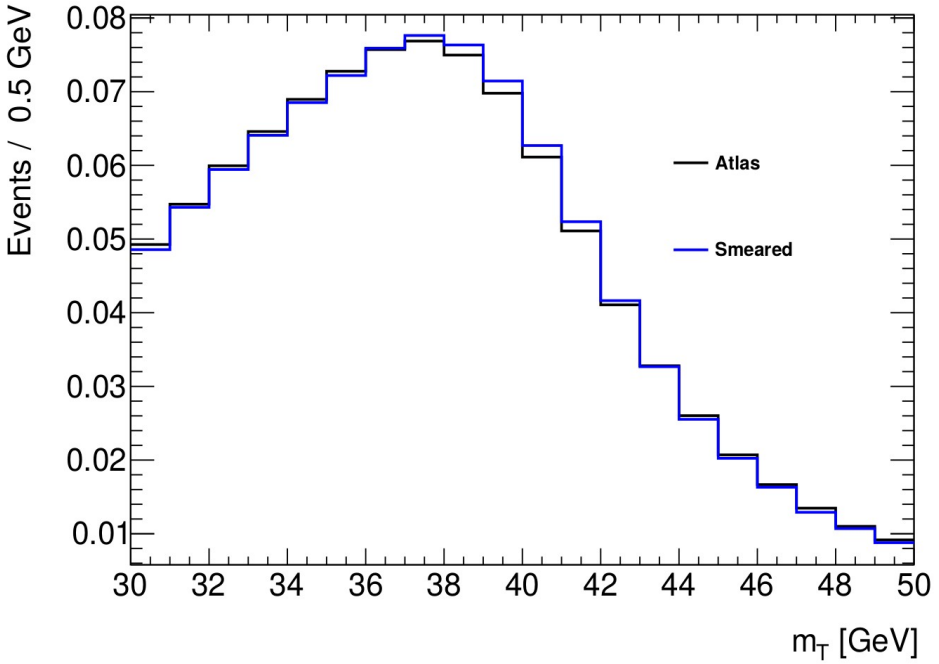
- Ongoing work mostly between ATLAS and CDF for now (2-3 individuals)
- D0
  - Porting current studies to D0 is straightforward : sufficient information regarding detector response in the publications; collaborators willing to validate what is being done
  - PDF uncertainties for CDF and D0 100% correlated; solving ATLAS/CDF means solving ATLAS/Tevatron
- CMS, LHCb
  - We are very interested (and strongly encouraged by our management) to start combination work in anticipation of the measurement results. See later
    - PDF correlations
    - P_T^W model?
    - EWK theory?
    - Uncertainty breakdown!!

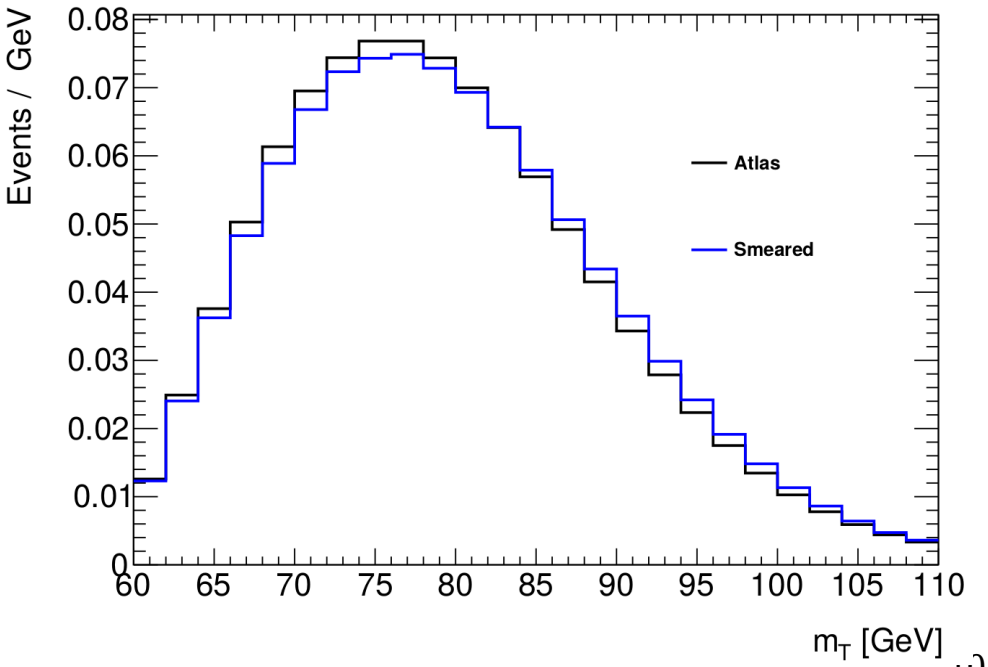
Parameterised vs. fully-simulated distributions

- For each experiment :
  - electron and muon eta-dependent resolution curves
  - Recoil response and resolution, including dependence on boson pT and event activity
  - Efficiency effects are generally neglected

  Does not allow a proper reproduction of central values of course, but sufficient for an accurate estimate of PDF uncertainties

- ATLAS





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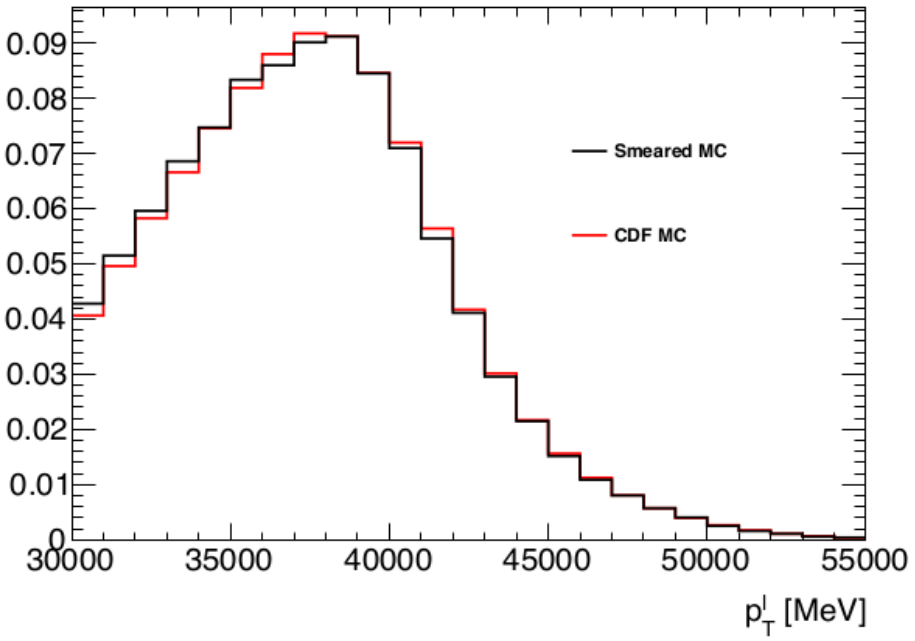
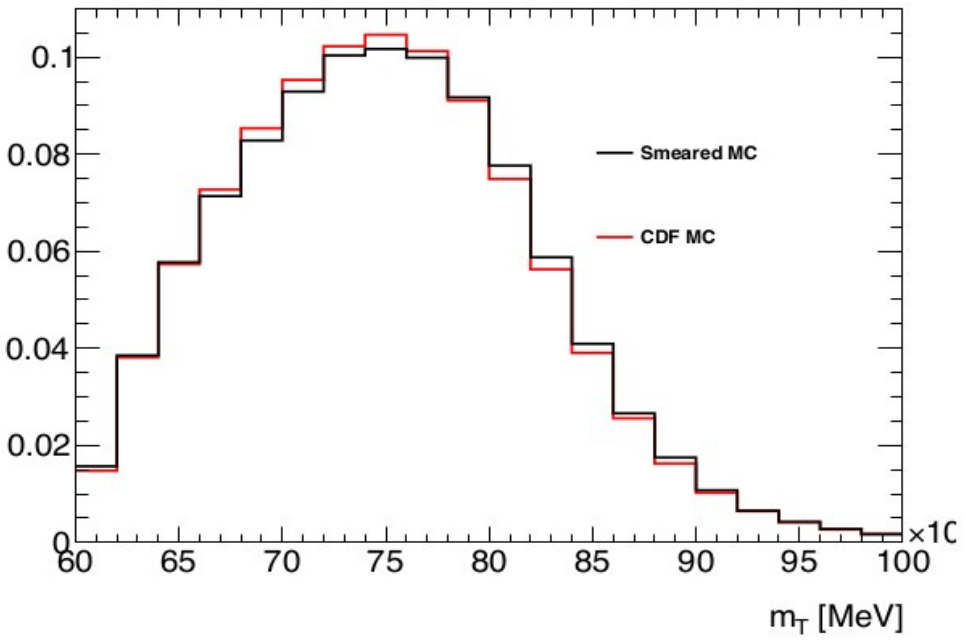
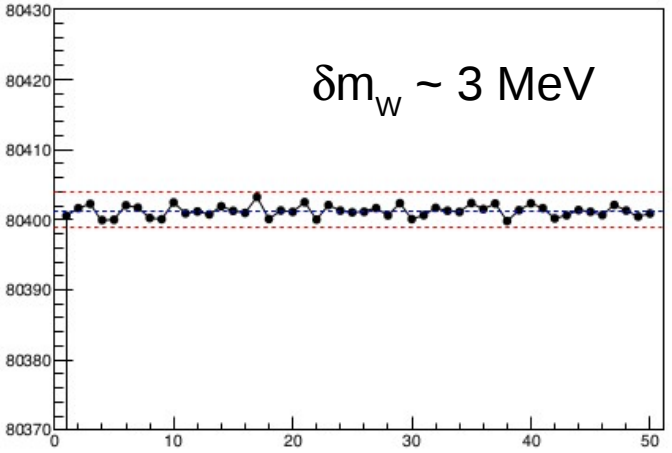
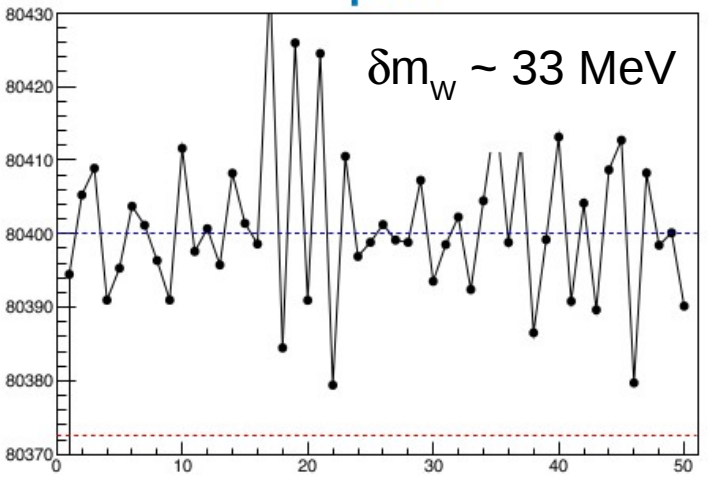
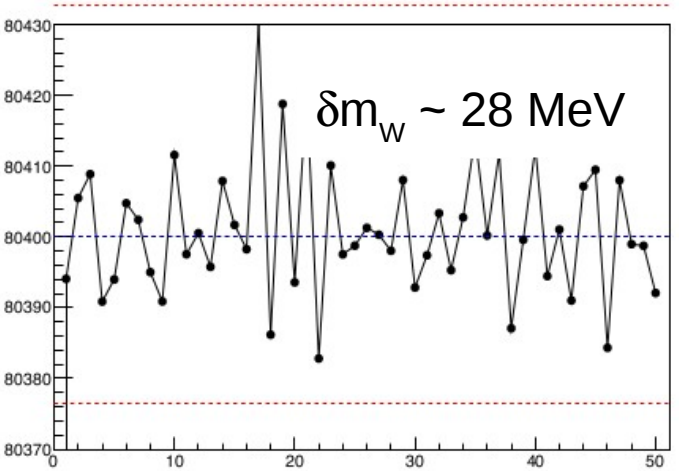
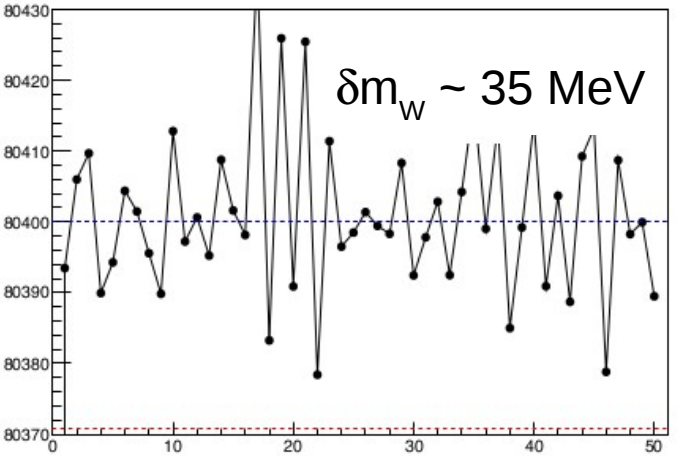
- CDF





Smearing to reco-level

Mimic recoil and lepton resolution effects through a smearing approach of the truth level distributions to the one published in the measurements

	mT	pTl
Generator Level		
After detector effects		

Parameterised simulation approaches actual simulation to within <5% of the difference between generator level and simulation.
Systematic from this approximation <1 MeV; negligible in quadrature

ATLAS validation

- Combination of measurement categories in ATLAS with CT10
  - Caveat : not a 100% fair comparison as Smeared used CT10 and Published CT10nnlo; however these sets are very close. Will be harmonised in next iteration
  - Weights

Weight (%)	Smeared	Published
pTl / mT	85 / 15	86 / 14
W+ / W-	48 / 53	52 / 48
Electron / muon	46 / 54	43 / 57

  - Shift in central value : ~1 MeV

    (fitted using templates from CT10, and pseudo-data from CT10nnlo)

CDF validation

- PDF uncertainty estimates

mW uncertainties (MeV)

2 TeV CTEQ6.6	p_T^{l+}	p_T^{l-}	m_T^{+}	m_T^{-}	pT&mT
Stat	19.7	19.3	17.3	17.3	9.4*
PDF	14.8	15.9	11.9	11.9	12.9
Total	24.3	25.0	21.0	21.0	16.0

PDF uncertainties here scaled from 90 to 68%CL with 1.645; however in Tevatron results it is scaled from MSTW2008 with 2.15 —> 10 MeV in agreement with the published result

Shifts under PDF variations

- Exercise : upgrade published measurements to newer PDFs.

  Typically done using templaces of initial PDF, and pseudo-data from target PDF.

  All very preliminary!!

- CDF
  - CTEQ6.6 : 80387 MeV (published)
  - CT10 : +8 MeV
  - MMHT2014 : +5 MeV
  - CT14 : +5 MeV
- ATLAS
  - CT10nnlo : 80370 MeV (publiched)
  - CT10 : +1 MeV
  - CT14 : -4 MeV
  - MMHT2014 : -19 MeV

Caveat : no pTZ constraint applied!

pTl observable

Correlations

Preliminary

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

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

To be updated with final parameterisations and larger statistics.

Initial discussions with CMS

- Uncertainties
  - Uncontroversial (since uncorrelated): statistics, experimental
    - Maybe one exception : dependence of recoil calibration on hadronization model

      Tested this using Powheg+Herwig as pseudo-data (Powheg+Pythia baseline)

  - PDFs
    - ATLAS : uncertainties from baseline set (CT10nnlo) + envelope (CT14, MMHT)
    - Agree on a set of PDFs to be used for the measurements; combine for each

      → baselines : last versions of CT ; MMHT ; NNPDF

      → HeraPDF; special sets (eg NNPDF w/o collider data, etc)

      then decide what to quote as final number

  - Spin correlations
    - Specific uncertainty for the prediction of the angular coefficients (beyond what comes from the PDFs).
    - ATLAS used experimental precision of Z-based measurements (conservative)

      Better NNLO-NLO, or N^3LO – NNLO if available

Initial discussions with CMS

- Uncertainties

  - EW higher orders
    - IFI and radiation of pairs matter; FSR OK
  - pTW
    - Should properly account for freedom in the W/Z ratio
    - ATLAS:

      Z-based tune uncertainty (AZ)

      Z → W extrapolation. Degrees of freedom in Pythia:

      shower PDF

      factorization scale (with HF decorrelation)

      charm-quark mass
    - CMS : under discussion.

Initial discussions with CMS

- Technicalities
  - Different techniques used
    - Forward error propagation + BLUE for the combination of measurement categories
    - Full profile likelihood
  - Even when all physical sources of uncertainties are covered on all sides, they will be addressed with different models and different (number of) sources of uncertainty corresponding to a given effect.

    Need to regroup into consistent subsets. Can this be discussed ahead of the actual publication?
    - Most likely not, at least for the modelling of the boson pT

    Correlation model?

Initial discussions with CMS

- Technicalities
  - Option 1
    - Consistently decompose post-fit uncertainty into uncorrelated components (the pre-fit NP's)
      This is an open question for the Profile likelihood, but should be possible.
    - Regroup individual uncertainty into consistent categories; discuss correlation case by case
    - Combine, again using BLUE and/or likelihood maximization
  - Option 2
    - Produce post-fit covariance matrices
    - Rebin to common base
    - Combine as above
  - Others?

Summary and next steps

- ATLAS – Tevatron
  - Machinery in place for the combination of published results, and evaluation of PDF uncertainties
    - Smearing procedure, to estimate PDF uncertainties including detector effects, are finalized
    - W+/W- and ATLAS/Tevatron PDF correlations depend on PDF set → model dependence
  - Evaluate the correlations and the mW combined value and uncertainty for other PDF sets.
    Agreed on CTEQ6.6, CT10 (legacy); CT14, MMHT, and NNPDF3.1.
    Also evaluate CJ15 which includes W charge asymmetry data.
- LHC
  - Initial discussions with CMS regarding these matters
  - 1st exercises could be put in place in the near future, including expected experimental and PDF uncertainties, to solve the technical issues.
  - The modeling of pTW is the most difficult question, and can most likely not be discussed concretely before results are published.