PDF issues in MW measurement from the lepton transverse momentum distribution in charged-current Drell-Yan

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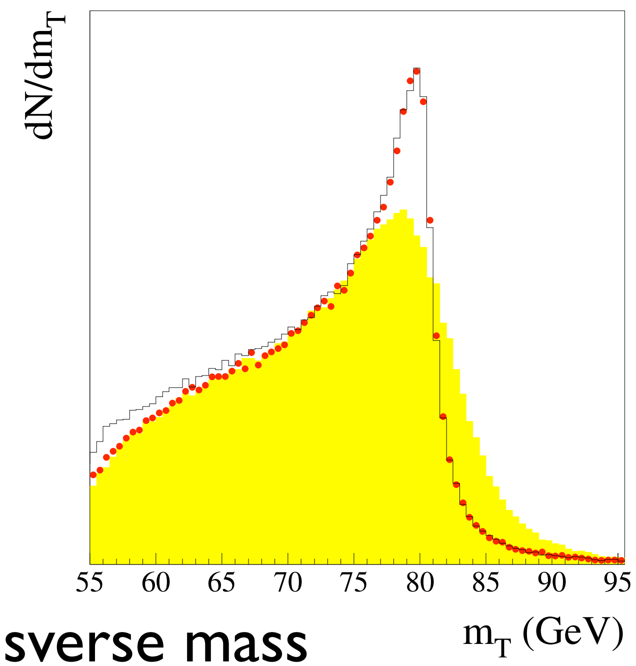
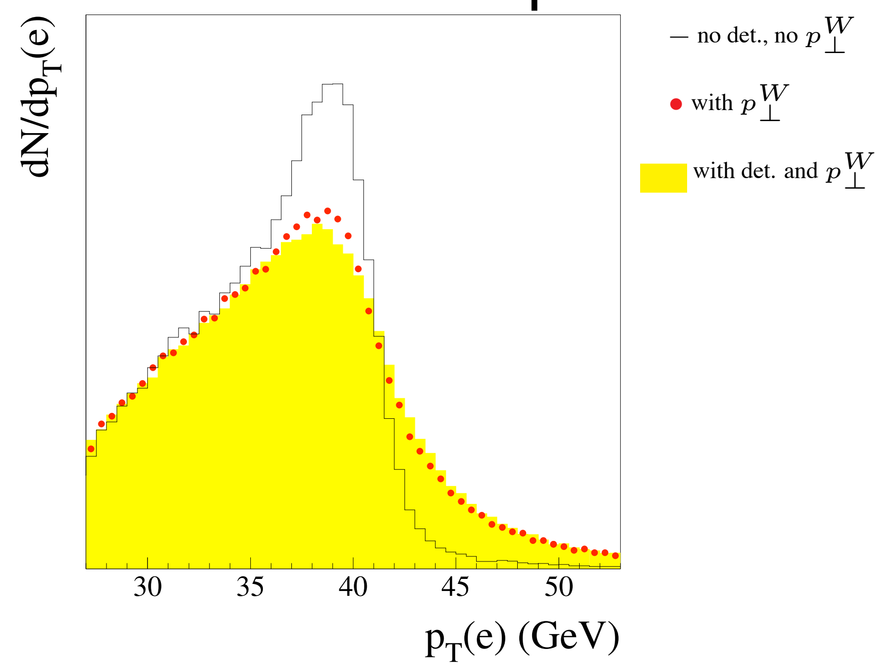
work in collaboration with G.Bozzi, L.Citelli, arXiv:1501.05587

MW measurement from Drell-Yan observables

- lepton-pair transverse mass $M_\perp^W = \sqrt{2 p_\perp^l p_\perp^\nu \ (1 - \cos\phi_{l\nu})}$
- charged lepton transverse momentum
- missing transverse momentum

- sensitivity to MW via the jacobian factor peaked at the physical mass value





lepton-pair transverse mass

- stable w.r.t. inclusion of radiative corrections
- problematic determination of the neutrino pt in presence of high pile-up (difficult modeling of hadronic recoil)
- moderate PDF uncertainty not exceeding O(10 MeV) see also Bozzi, Rojo, Vicini, Phys.Rev.D83 (2011) 113008

  the generator-level analysis can be quite different w.r.t. the detector-level one

  (cfr. Quackenbush, Sullivan, arXiv:1502.04671)

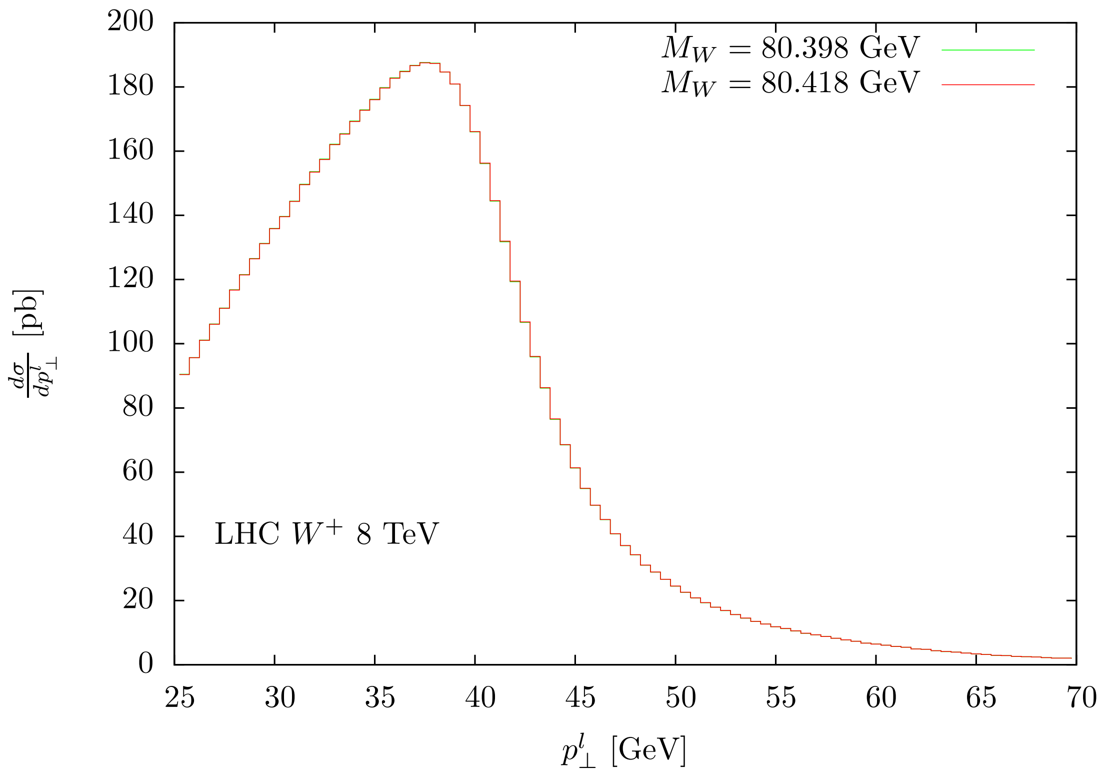
charged lepton transverse momentum

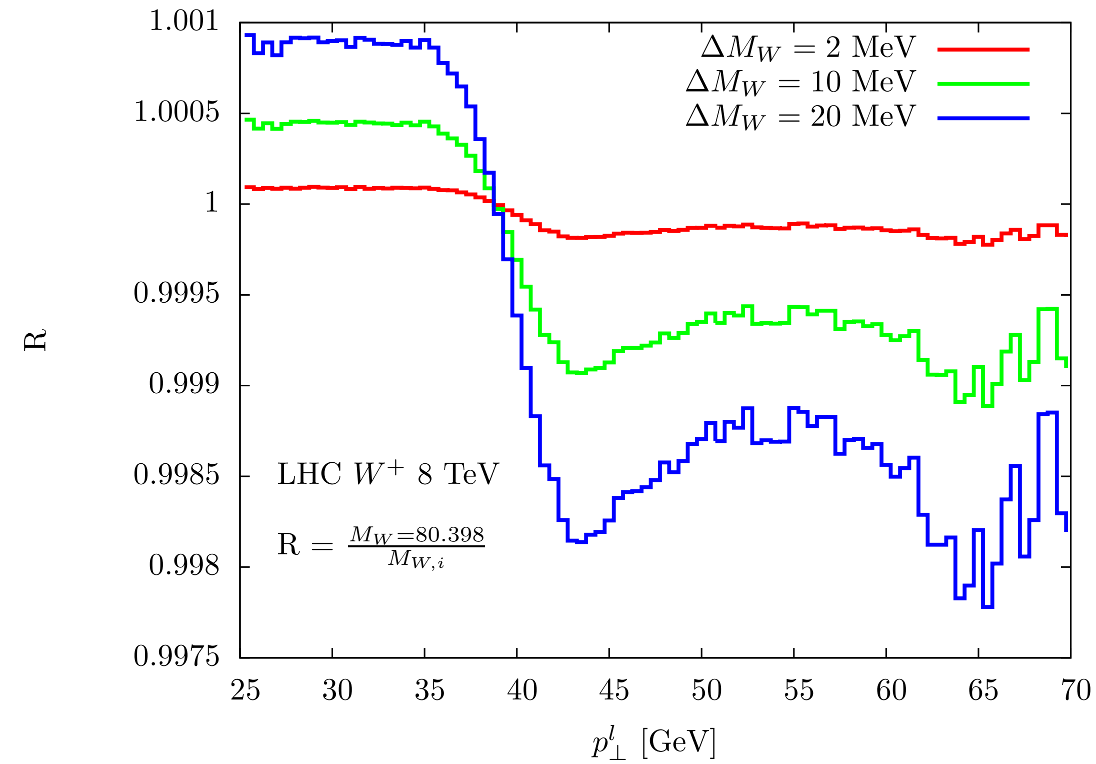
- highly sensitive to the details of QCD radiation (and thus also to PDFs)
- "simple" experimental determination (accurate lepton energy/momentum calibration)

  moderate impact of detector effects

  the generator level study should provide the correct order of magnitude of the PDF effects

Sensitivity of the charged-lepton pt distribution to MW





- a sensitivity to ΔMW=10 MeV
  requires the control of the shape of the distribution at the (sub-) per mill level

- challenging from different points of view
  - experimental
  - MC simulation (statistical fluctuations)
  - theoretical (highly sensitive to the details of QCD radiation description)

Impact of PDF uncertainties of EW precision measurements

- the extraction of masses and couplings, at hadron colliders, relies on a template fit procedure
- the uncertainties/ambiguities that affect the evaluation of the templates are theoretical systematics on the final value of the pseudo-observables that we want to extract
- the use of different PDF replicas yields in general a distortion of the template shapes and in turn a different value of the pseudo-observable
- are PDFs a limiting factor?

- goals of the study: 1) estimate of the PDF uncertainty on MW of different PDF sets

  2) relative difference between the central predictions of various PDF sets

Setup of the study

- PDF sets: CT10nlo,
  MSTW2008 (for comparison with previous studies), MSTW2008CPdeut, MMHT2014,
  NNPDF2.3_nlo_0119, NNPDF3.0

- simulation code: POWHEG + PYTHIA 6.4.21 (pure QCD, resummation effects via Parton Shower)

- Tevatron 1.96 TeV, LHC 8, 13, 33, 100 TeV

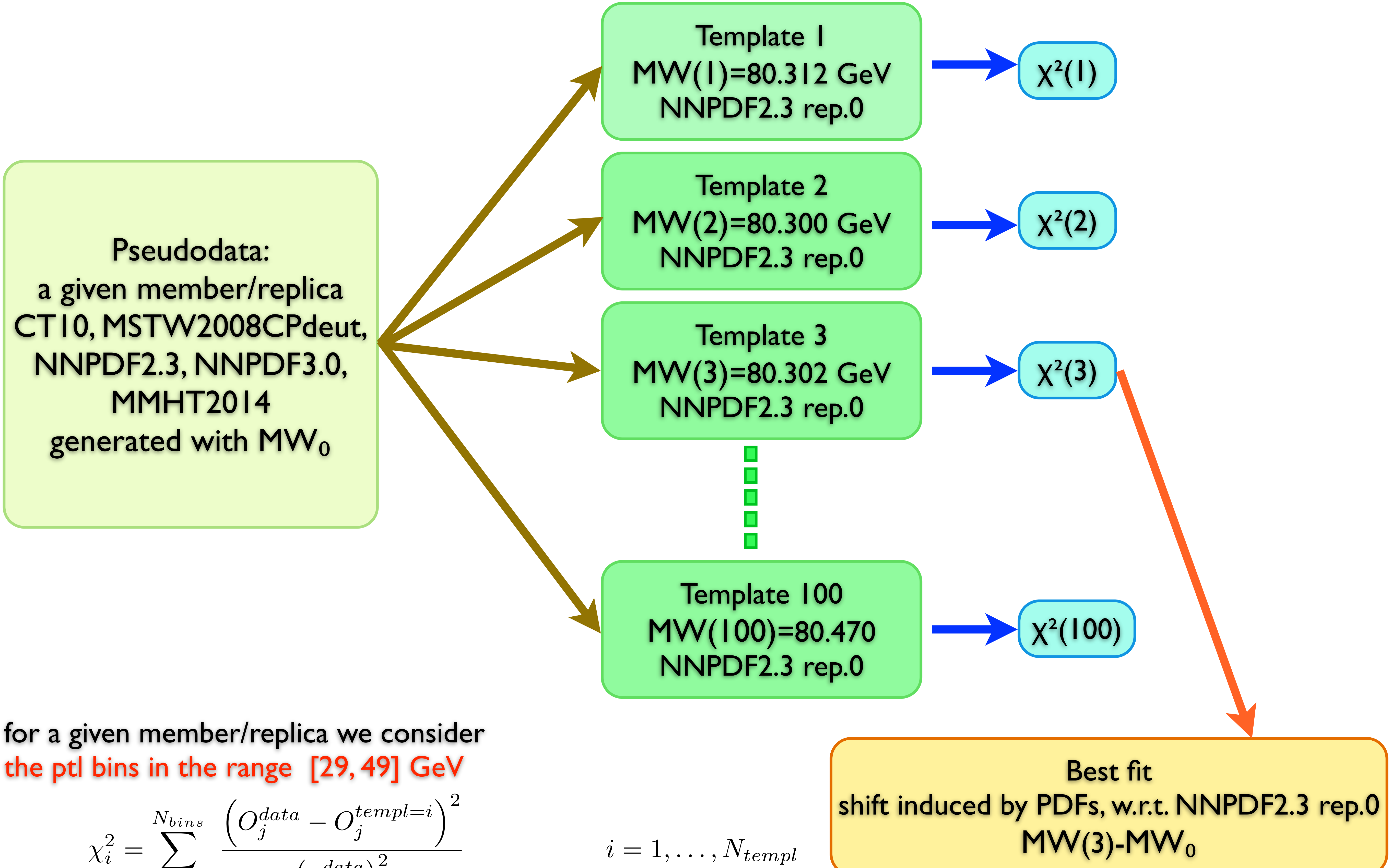
- acceptance cuts (called basic): ptl > 25 GeV, Et_miss > 25 GeV
  |eta_l| < 1.0 (Tevatron), |eta_l| < 2.5 (LHC)

- additional acceptance cuts: ptW < 15 GeV, M_T<100 GeV
  further analysis in rapidity bins

- study of absolute and of normalized distributions

The template-fitting procedure

see also Bozzi, Rojo, Vicini, Phys.Rev.D83 (2011) 113008



for a given member/replica we consider
the ptl bins in the range [29, 49] GeV

$$\chi_i^2 = \sum_{j=1}^{N_{bins}} \frac{\left(O_j^{data} - O_j^{templ=i}\right)^2}{\left(\sigma_j^{data}\right)^2} \qquad i = 1, \ldots, N_{templ}$$

The template-fitting procedure

- template distributions: generated with NNPDF2.3 (replica 0)
  with MW in the range [80.312, 80.470] GeV in 2 MeV steps

- pseudodata distributions: generated with the different sets/replicas with MW_0=80.398 GeV

- fit interval ptl $\in$ [29,49] GeV

- the template fitting procedure
  measures the relative distance between NNPDF2.3 replica 0 and all the other sets/replicas
  i.e.
  it is an estimate of the difference that we would find if we would fit the real data with different PDFs

Reweighting

- MC fluctuations at the per mill level are still present also in simulations with 1 billion of events when bin sizes have to be small

- the estimate of PDF uncertainty on MW requires to appreciate
  the difference of the value of the distribution in each bin
  → the use of fully correlated distributions reduces the sensitivity to MC fluctuations

- the weights for different templates/replicas have been generated in one single simulation

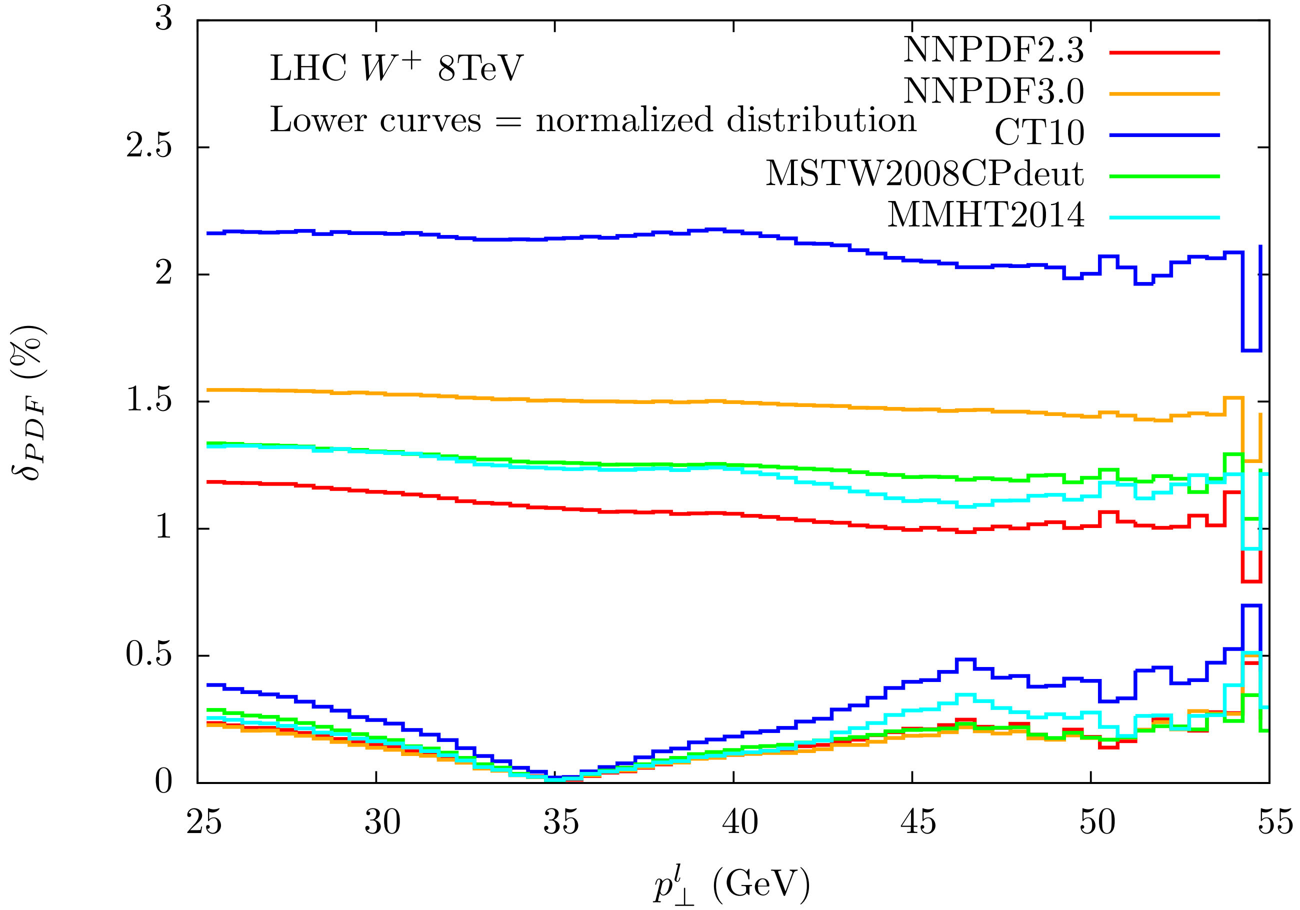
  given the weight w_0 of one event, computed with MW_0 and with NNPDF2.3 replica 0,
  we rescale

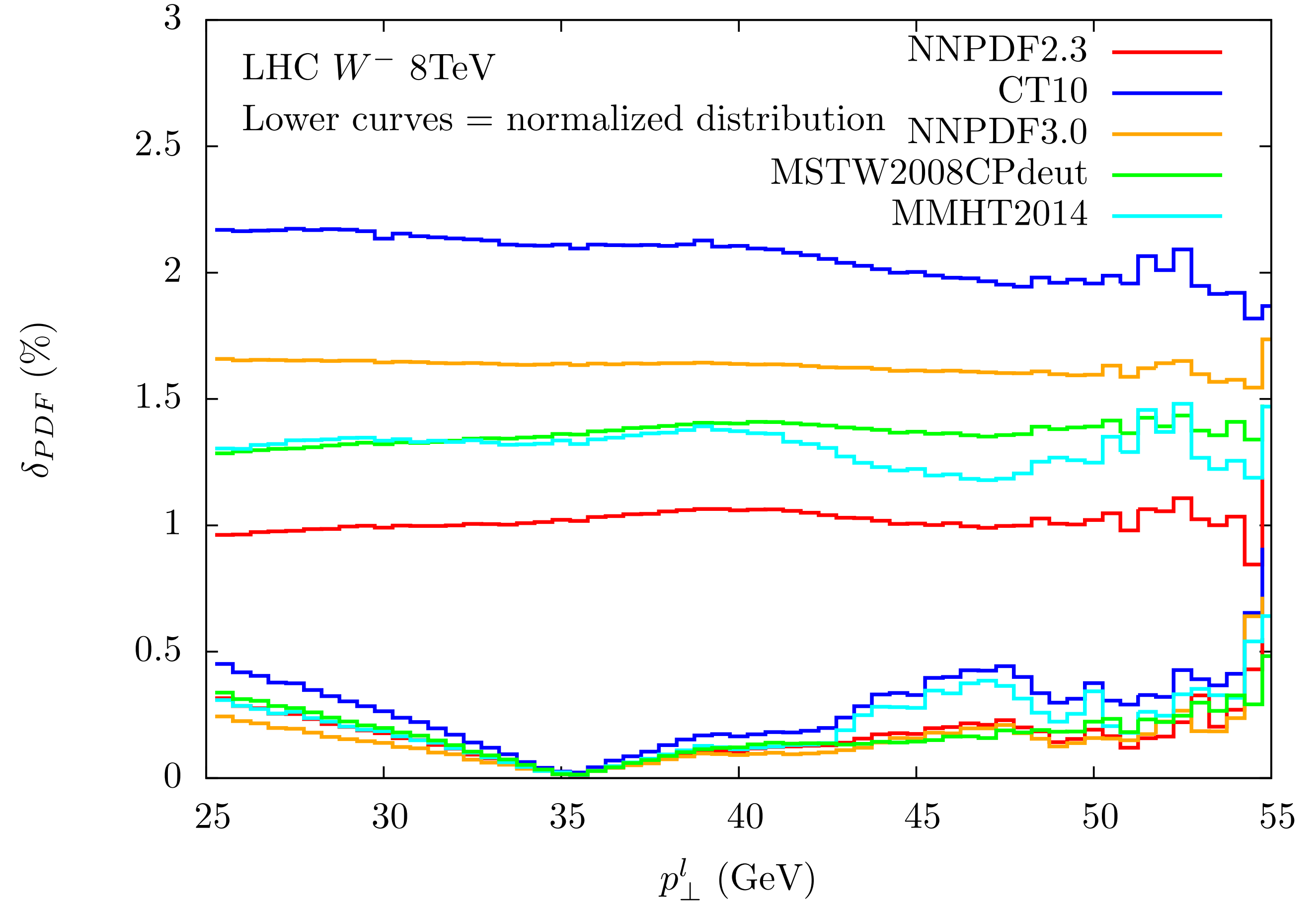
$$w_0 \quad \to \quad w_j = w_0 \frac{(\hat{s} - m_{W0}^2)^2 + \Gamma_W^2 m_{W0}^2}{(\hat{s} - m_{W,j}^2)^2 + \Gamma_W^2 m_{W,j}^2} \qquad \text{template} \quad j$$

$$w_0 \quad \to \quad w_i = w_0 \frac{f_i(x_1) g_i(x_2)}{f_0^{NNPDF}(x_1) g_0^{NNPDF}(x_2)} \qquad \text{replica} \quad i$$

- this reweighting is almost NLO-QCD accurate:
  a dependence on the PDF via the POWHEG Sudakov is not included in this approach
  (see talk by P. Nason)

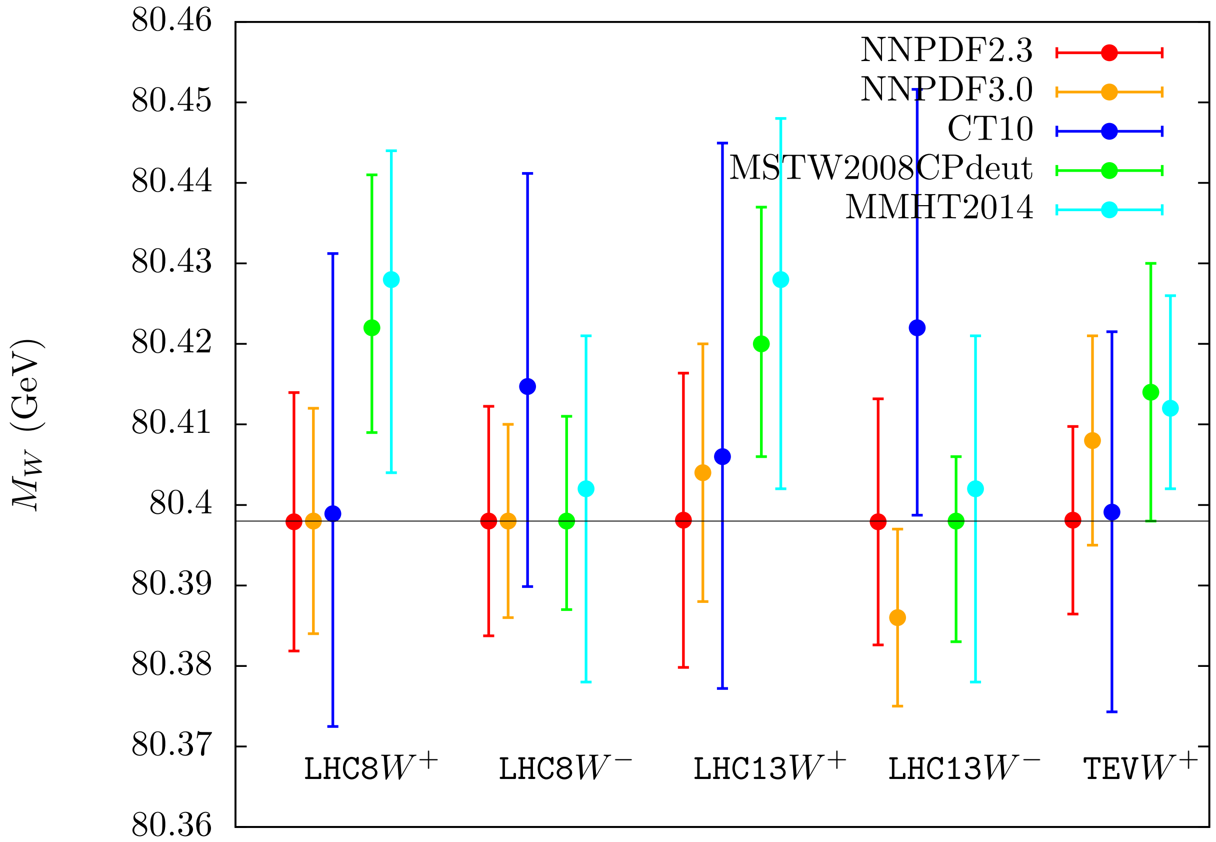
PDF uncertainty on the lepton pt distribution

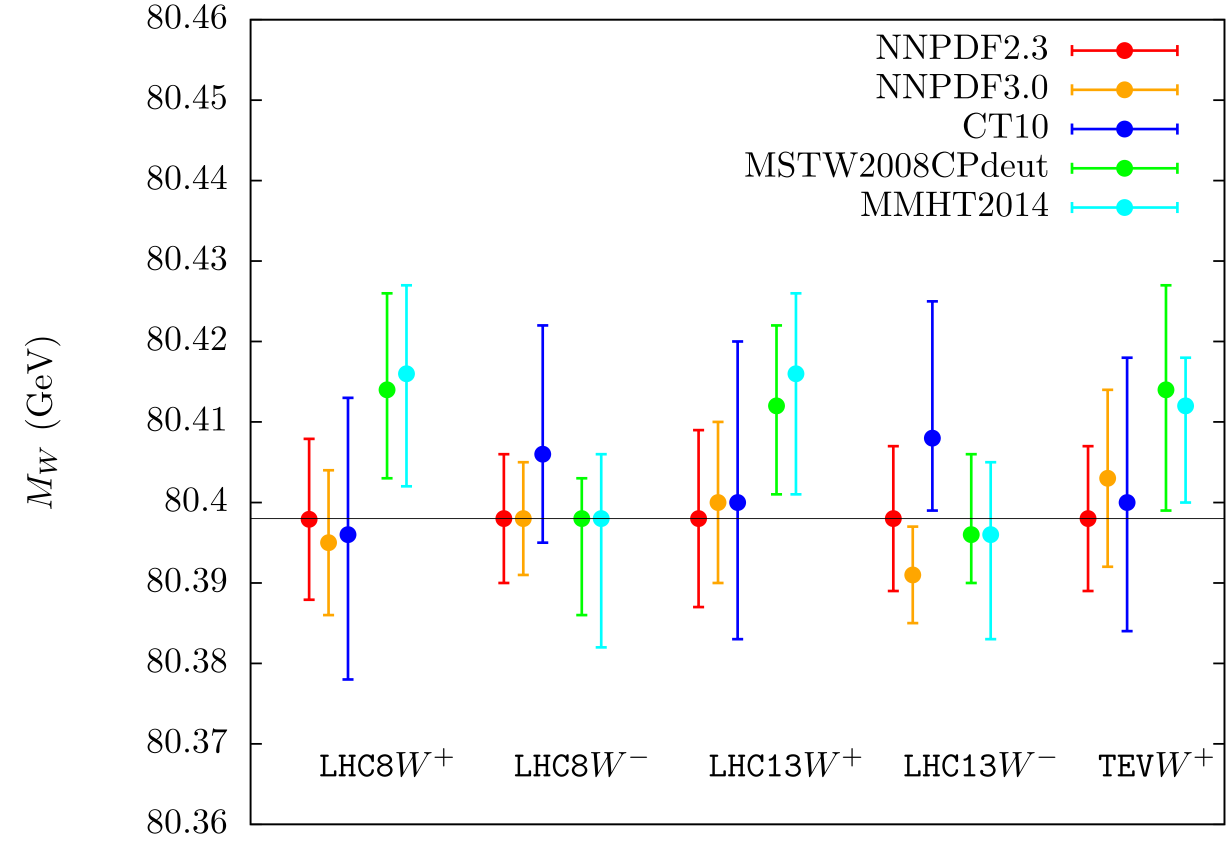




- basic acceptance cuts
- the use of a normalized distribution reduces the PDF uncertainty,
  leaving only the effects of distortion of the shape
  relevant for the MW determination
- an uncertainty at the few per mill level can still be problematic for a precision measurement

Numerical results for MW, with and without a PTW cut





- the predictions are in general compatible with each other, within their uncertainty bands, with some exceptions
- the uncertainty bands of the 3 sets differ by up to a factor 3;
  CT10nlo has in general larger uncertainties (C90 factor has been included!)
- spread of the central values Δ_{sets} not negligible, in view of a 10 MeV measurement
- important reduction of the uncertainty when a cut PTW < 15 GeV is applied
- different results between W+ and W- production

Numerical results: PDF4LHC envelope and spread of central values

δ_{PDF} is the half-width of the PDF4LHC envelope

Δ_{sets} is the spread (max-min) of the central values

CT10, MSTW2008CPdeut, NNPDF2.3

	no $p_\perp^W$ cut		$p_\perp^W < 15$ GeV	
	δ_{PDF} (MeV)	Δ_{sets} (MeV)	δ_{PDF} (MeV)	Δ_{sets} (MeV)
Tevatron 1.96 TeV	27	16	21	15
LHC 8 TeV W^+	33	26	24	18
W^-	29	16	18	8
LHC 13 TeV W^+	34	22	20	14
W^-	34	24	18	12

- no cut on PTW — envelope half-width larger than 27 MeV
  large spread of the central values (different parameterizations?)

- PTW < 15 GeV — envelope half-width between 18 and 24 MeV
  spread of the central values between 8 and 18 MeV

- individual sets predict an uncertainty band of O(10 MeV)
  the spread of the central values spoils this optimistic conclusion

- different description of W+ (MSTW differs from CT10/NNPDF)
  and of W- (CT10 differs from MSTW/NNPDF)

Numerical results: NNPDF3.0 vs MMHT2014

δ_{PDF} is the half-width of the envelope
Δ_{sets} is the spread (max-min) of the central values

MMHT2014, NNPDF3.0

	no $p_\perp^W$ cut		$p_\perp^W < 15$ GeV	
	δ_{PDF} (MeV)	Δ_{sets} (MeV)	δ_{PDF} (MeV)	Δ_{sets} (MeV)
Tevatron 1.96 TeV	16	4	13	9
LHC 8 TeV W^+	32	33	21	21
W^-	22	6	12	0
LHC 13 TeV W^+	30	24	18	16
W^-	23	16	11	5

- the absence of a public set, evolution of CT10, makes impossible the comparison of this envelope with the one of the previous slide
- the NNPDF3.0 uncertainties are 15-20% smaller w.r.t. NNPDF2.3
  the MMHT2014 uncertainties are similar to the one with MSTW2008CPdeut
- the spread of the central values in the W+ case
  is the most remarkable feature of the comparison

Dependence of the MW PDF uncertainty on an additional PTW cut

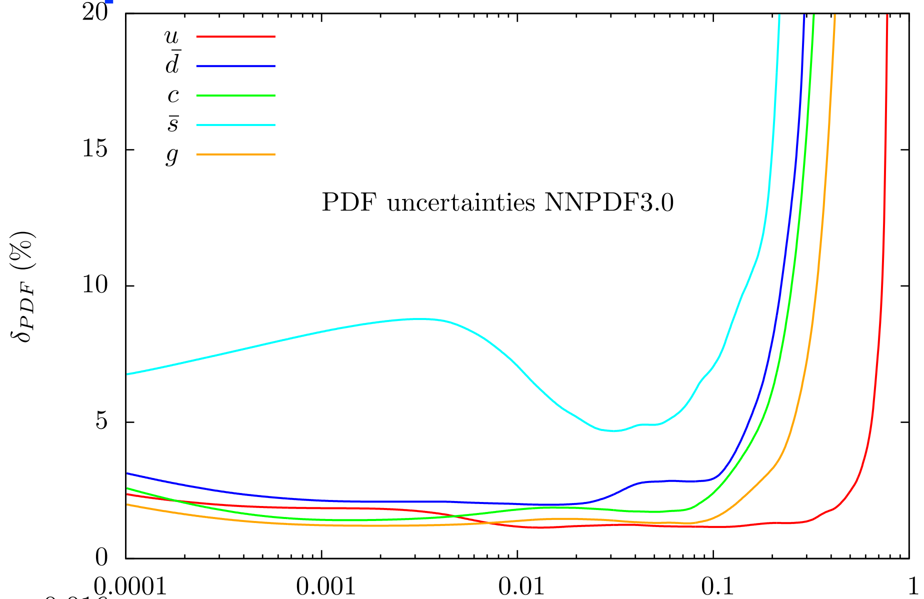
normalized distributions			
cut on $p_\perp^W$	cut on $\|\eta_l\|$	CT10	NNPDF3.0
inclusive	$\|\eta_l\| < 2.5$	$80.400 + 0.032 - 0.027$	80.398 ± 0.014
$p_\perp^W < 20$ GeV	$\|\eta_l\| < 2.5$	$80.396 + 0.027 - 0.020$	80.394 ± 0.012
$p_\perp^W < 15$ GeV	$\|\eta_l\| < 2.5$	$80.396 + 0.017 - 0.018$	80.395 ± 0.009
$p_\perp^W < 10$ GeV	$\|\eta_l\| < 2.5$	$80.392 + 0.015 - 0.012$	80.394 ± 0.007
$p_\perp^W < 15$ GeV	$\|\eta_l\| < 1.0$	$80.400 + 0.032 - 0.021$	80.406 ± 0.017
$p_\perp^W < 15$ GeV	$\|\eta_l\| < 2.5$	$80.396 + 0.017 - 0.018$	80.395 ± 0.009
$p_\perp^W < 15$ GeV	$\|\eta_l\| < 4.9$	$80.400 + 0.009 - 0.004$	80.401 ± 0.003
$p_\perp^W < 15$ GeV	$1.0 < \|\eta_l\| < 2.5$	$80.392 + 0.025 - 0.018$	80.388 ± 0.012

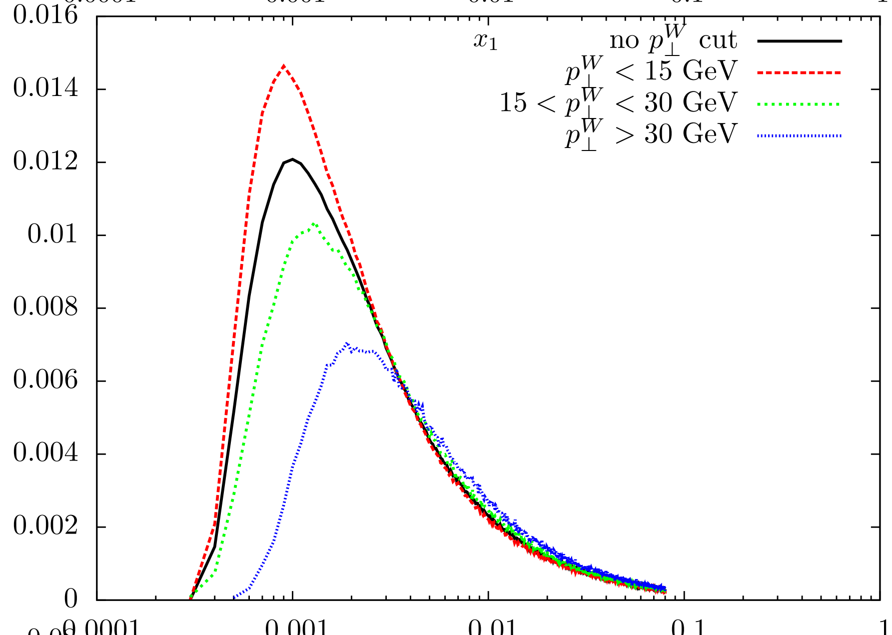
- the additional cut on PTW reduces the MW uncertainty

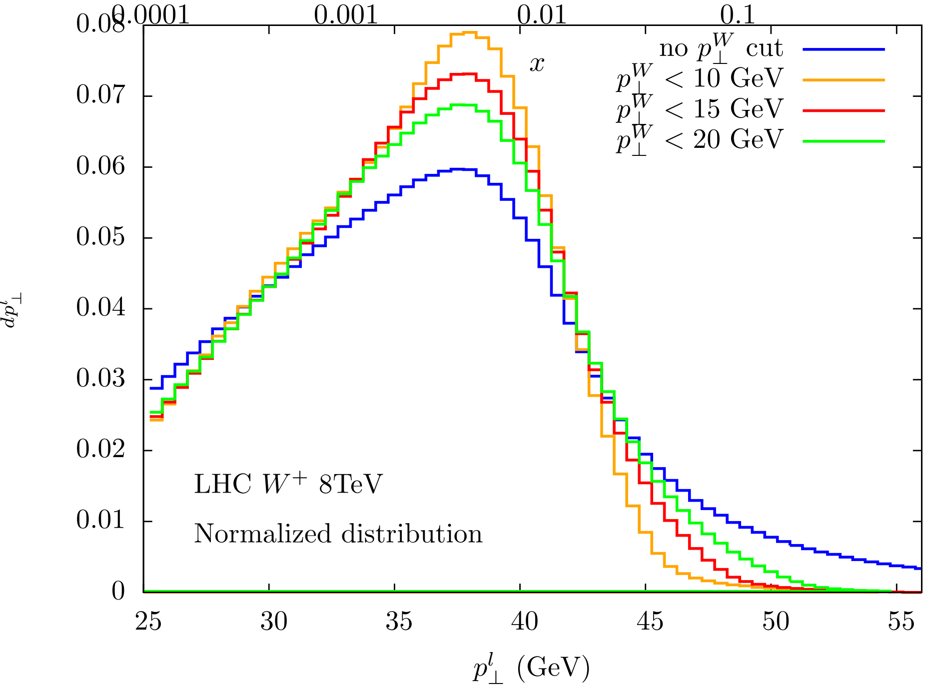
  → suppression of the large-*x* contributions, where PDFs are most uncertain

  → effect on the fitting procedure
  (the shape of the distribution becomes steeper and large shifts are more penalized)

Dependence of the MW PDF uncertainty on an additional PTW cut







- PDF uncertainty of different flavors relevant for W+ production

- normalized distribution $1/\sigma \, d\sigma/dx$, for different PTW cuts

- with PTW<15 GeV, the $x>3\ 10^{-3}$ contribution is suppressed excluding a large fraction of the PDF most uncertain region

- with increasing PTW cuts,
  the shape of the lepton ptl distribution becomes steeper,
  "Born-like", penalizing large mass shifts in the fit
  the χ^2 parabola become narrower

Dependence of the MW PDF uncertainty on different etal_l cuts

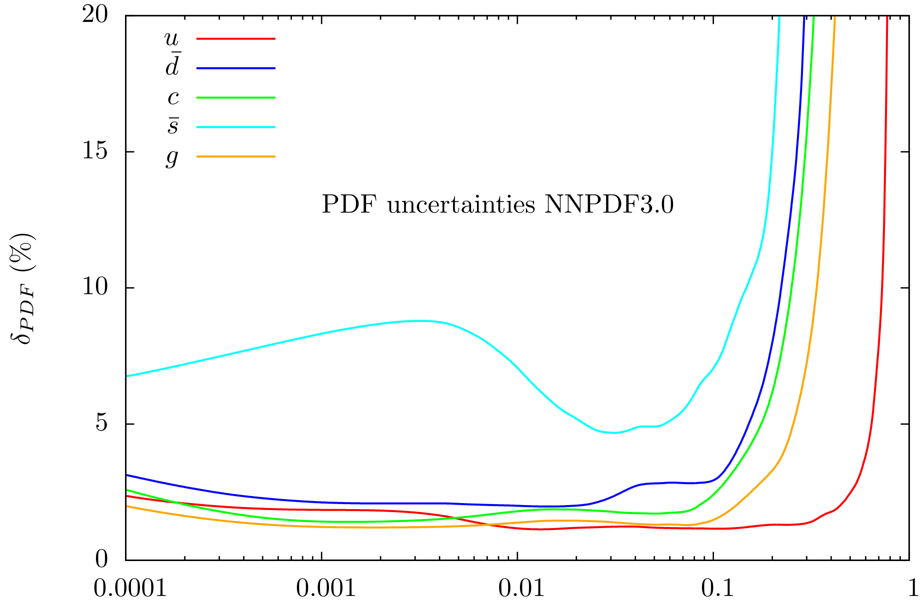
normalized distributions			
cut on $p_\perp^W$	cut on $\|\eta_l\|$	CT10	NNPDF3.0
inclusive	$\|\eta_l\| < 2.5$	$80.400 + 0.032 - 0.027$	80.398 ± 0.014
$p_\perp^W < 20$ GeV	$\|\eta_l\| < 2.5$	$80.396 + 0.027 - 0.020$	80.394 ± 0.012
$p_\perp^W < 15$ GeV	$\|\eta_l\| < 2.5$	$80.396 + 0.017 - 0.018$	80.395 ± 0.009
$p_\perp^W < 10$ GeV	$\|\eta_l\| < 2.5$	$80.392 + 0.015 - 0.012$	80.394 ± 0.007
$p_\perp^W < 15$ GeV	$\|\eta_l\| < 1.0$	$80.400 + 0.032 - 0.021$	80.406 ± 0.017
$p_\perp^W < 15$ GeV	$\|\eta_l\| < 2.5$	$80.396 + 0.017 - 0.018$	80.395 ± 0.009
$p_\perp^W < 15$ GeV	$\|\eta_l\| < 4.9$	$80.400 + 0.009 - 0.004$	80.401 ± 0.003
$p_\perp^W < 15$ GeV	$1.0 < \|\eta_l\| < 2.5$	$80.392 + 0.025 - 0.018$	80.388 ± 0.012

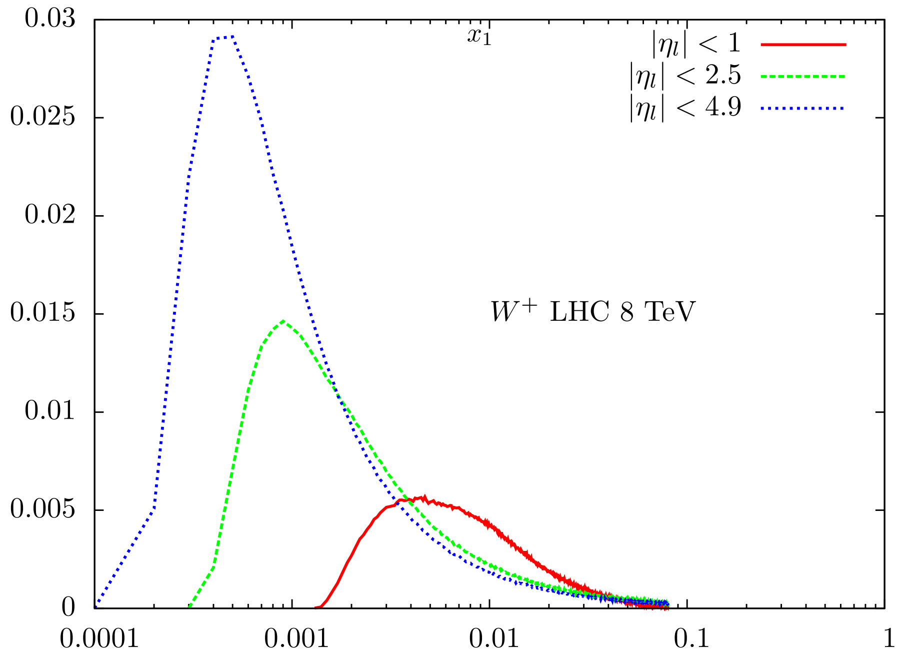
- the dependence on the PDFs decreases when enlarging the eta_l acceptance
  (effectively integrating over the whole partonic-*x* range,
  MW is extracted from normalized ptl distributions)

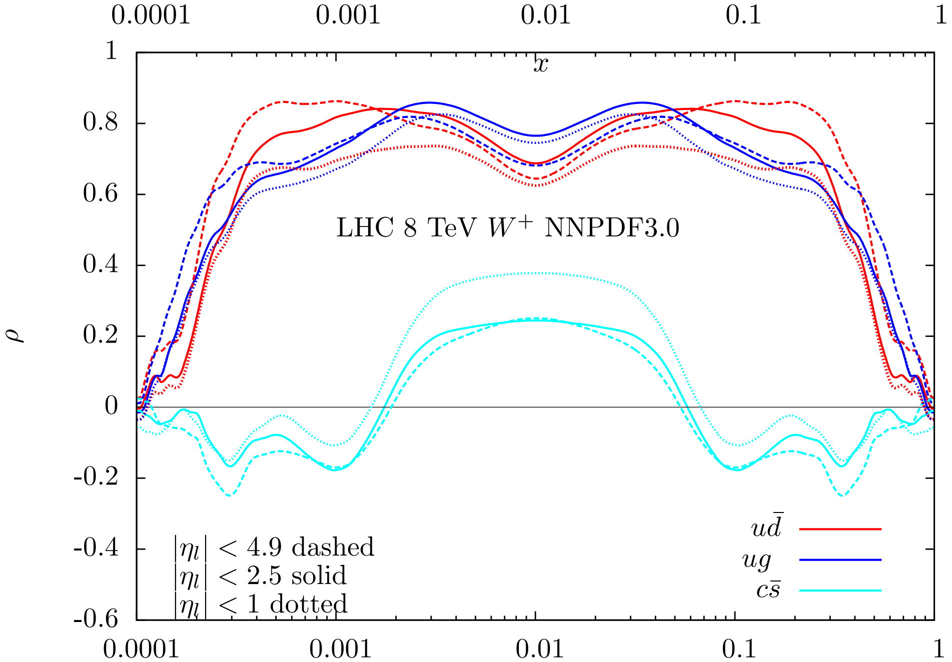
- the regions |eta_l|<1.0 and 1.0 < |eta_l| < 2.5 suffer of larger uncertainties compared to |eta_l|<2.5

- constrained behavior (PDF sum rules) of each replica in the two eta_l regions:
  if the distribution is smaller than average in one interval, it is then larger than average in the other,
  the sum of the contributions of the two intervals is more stable (w.r.t. replica variations)

Dependence of the MW PDF uncertainty on different etal_l cuts







- PDF uncertainty of different flavors relevant for W+ production
  the strange uncertainty is a factor ~3 larger than the other
  csbar contributes 20% of the xsec

- normalized distribution 1/σ dσ/dx, for different eta_l cuts

- with |eta_l|<1.0, the average *x* value peaked around 5 10^{-3}
  corresponding uncertainties of the individual densities are consistent with the large MW spread

- with |eta_l|< 4.9, the average *x* peaked around 5 10^{-4},
  the PDF uncertainties are not much different than in the previous case
  but
  the interplay between the different densities is not trivial and helps to reduce the uncertainty

$$\mathcal{P}_{ij}(x,\tau) = f_i(x,\mu_F^2) f_j(\frac{\tau}{x},\mu_F^2) + f_j(x,\mu_F^2) f_i(\frac{\tau}{x},\mu_F^2)$$

$$\rho(x,\tau) = \frac{\langle \mathcal{P}_{ij}(x,\tau)\frac{d\sigma}{dp_\perp^l}\rangle - \langle \mathcal{P}_{ij}(x,\tau)\rangle\langle\frac{d\sigma}{dp_\perp^l}\rangle}{\sigma^{PDF}_{\mathcal{P}_{ij}}\,\sigma^{PDF}_{d\sigma/dp_\perp^l}}$$

Which actions to reduce the uncertainty?

- dependence of the uncertainty on the flavors?   the answer is not trivial
  → at LO, 8 TeV the W+ cross section is given for 80% by udbar and for 19.8% by csbar subprocesses

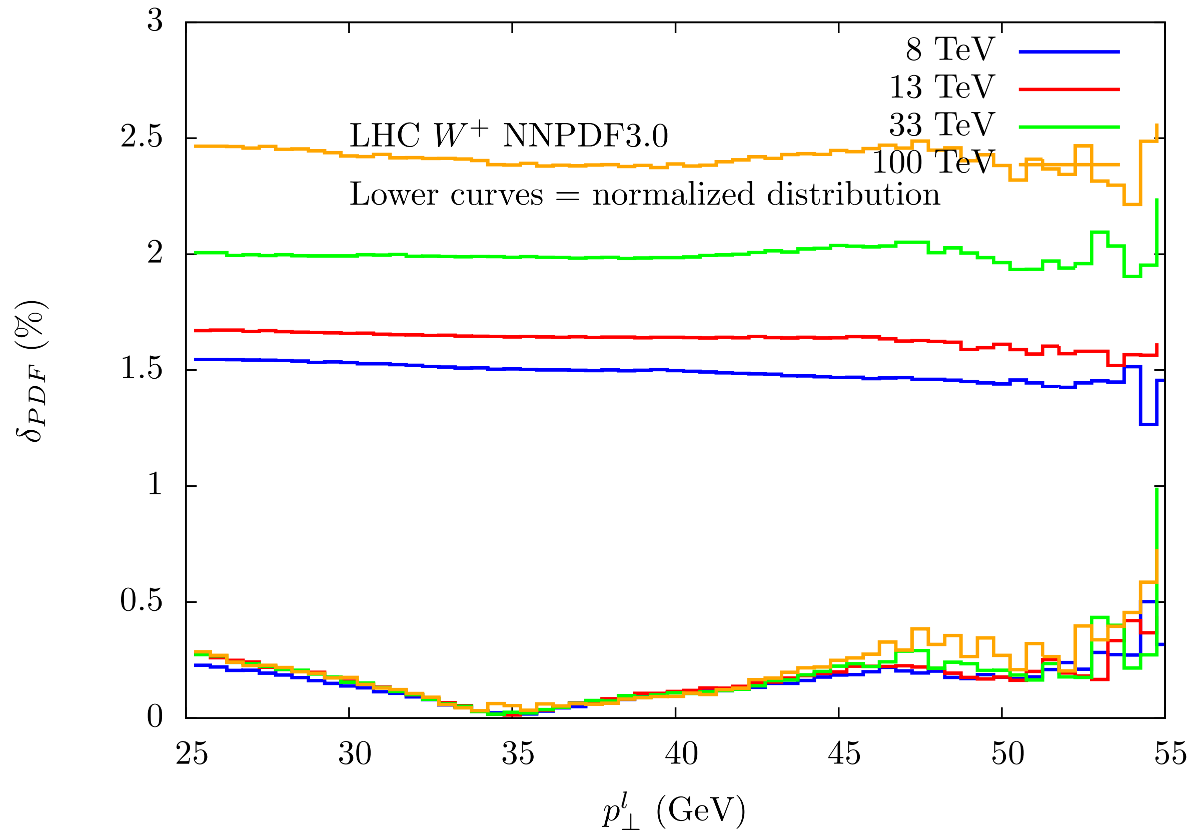
  → one natural candidate as source of uncertainty is the strange density,   but
  "switching the strange off" (artificial, consciously wrong, exercise of setting the strange to 0
  both pseudodata and templates have been generated with s=sbar=0)
  yields a large increase of the uncertainty on MW

  non trivial (anti-)correlation between the different flavors
  automatically embedded in the PDF during their global fit
  ⇒ any improvement of the PDFs in the central eta_l region is welcome (e.g. from W charge asy)

- dependence of the uncertainty on partonic-*x*
  → the study on the cuts on eta_l is sensitive to the *x* dependence
  and shows the anti-correlation between different eta_l, i.e. *x*, intervals
  ⇒ possible definition of new sub-observables?

the sum rules that constrain the PDFs seem to play an important role
making the decomposition of the uncertainty components difficult

Numerical results: extrapolation at future collider energies



normalized distribution, additional cut $p_\perp^W < 15$ GeV				
	8 TeV	13 TeV	33 TeV	100 TeV
W^+	80.395 ± 0.009	80.400 ± 0.010	80.402 ± 0.010	80.404 ± 0.013
W^-	80.398 ± 0.007	80.391 ± 0.006	80.385 ± 0.007	80.398 ± 0.011

- resonant W production occurs at partonic-*x* values decreasing with the energy
- with higher collider energies the PDF error on the normalized distribution almost does not change
- the cut PTW<15 GeV has been imposed

Conclusions

- results of an exercise to estimate the PDF uncertainty on MW from the lepton pt distribution in CC-DY

- stable numerical simulation of the lepton transverse momentum distribution in CC-DY with control of physical effects at the per mill level

- comparison of CT10nlo, MSTW2008CPdeut, MMHT2014, NNPDF2.3 and NNPDF3.0 predictions study of the impact on MW

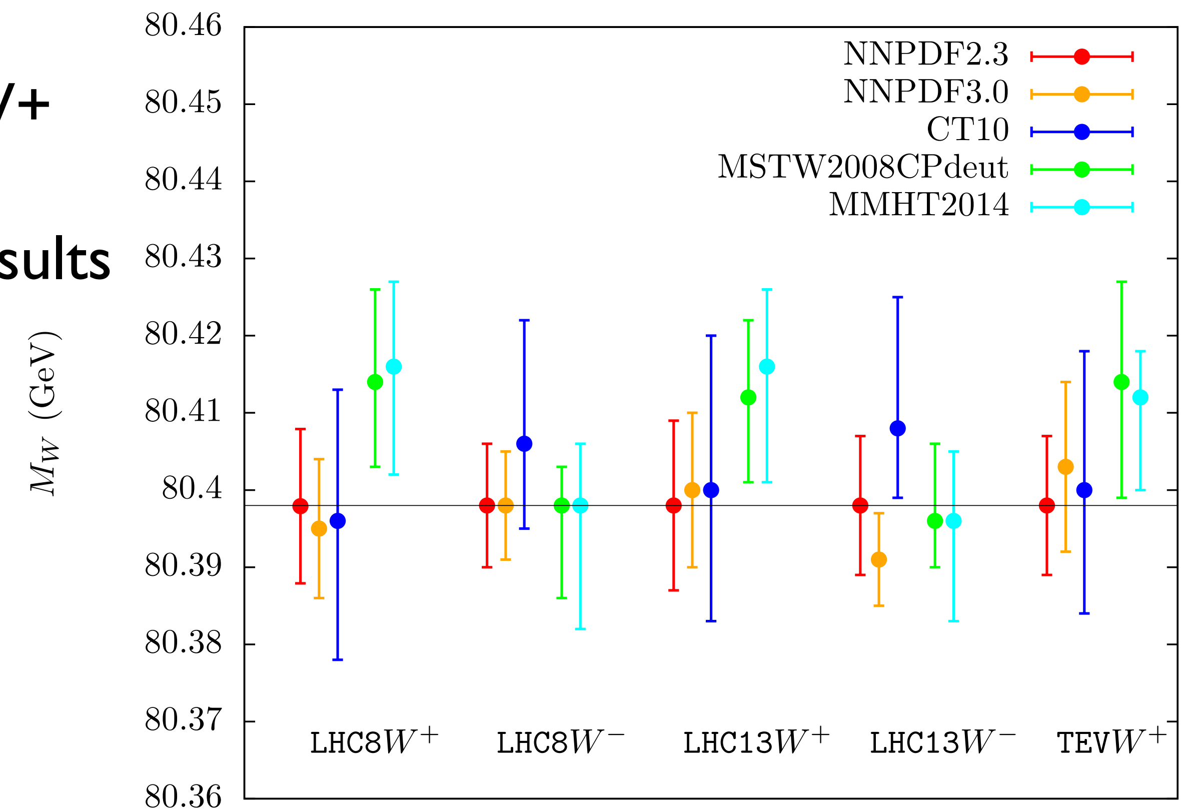
- template fit approach to study 1) the PDF error on MW of each set
  2) the spread of the MW central values

- even if the individual PDF sets predict uncertainties on MW of O(10 MeV) the spread of the central values is larger than 12 MeV and remains a crucial issue to be understood

- the W- final state seems to be in better shape than the W+

- more checks and studies are needed to confirm these results

- need to include a simplified detector simulation especially in the MT analysis



Numerical results, with and without a PTW cut

absolute distributions					
collider/channel	CT10	MSTW2008CPdeut	NNPDF2.3	NNPDF3.0	MMHT2014
Tevatron, W^+	$80.406 + 0.043 - 0.046$	$80.428 + 0.025 - 0.017$	80.400 ± 0.030	80.427 ± 0.018	$80.430 + 0.022 - 0.022$
LHC 8 TeV, W^+	$80.394 + 0.040 - 0.029$	$80.422 + 0.025 - 0.016$	80.398 ± 0.020	80.406 ± 0.019	$80.428 + 0.027 - 0.022$
W^-	$80.444 + 0.055 - 0.062$	$80.390 + 0.038 - 0.036$	80.398 ± 0.030	80.441 ± 0.027	$80.404 + 0.041 - 0.048$
LHC 13 TeV,W^+	$80.396 + 0.045 - 0.034$	$80.416 + 0.020 - 0.020$	80.398 ± 0.022	80.414 ± 0.022	$80.422 + 0.030 - 0.024$
W^-	$80.416 + 0.088 - 0.065$	$80.374 + 0.044 - 0.033$	80.398 ± 0.031	80.426 ± 0.037	$80.384 + 0.037 - 0.049$

normalized distributions					
collider/channel	CT10	MSTW2008CPdeut	NNPDF2.3	NNPDF3.0	MMHT2014
Tevatron, W^+	$80.400 + 0.022 - 0.025$	$80.414 + 0.016 - 0.016$	80.398 ± 0.012	80.408 ± 0.013	$80.412 + 0.014 - 0.010$
LHC 8 TeV, W^+	$80.398 + 0.032 - 0.026$	$80.424 + 0.014 - 0.019$	80.398 ± 0.016	80.395 ± 0.014	$80.428 + 0.016 - 0.024$
W^-	$80.416 + 0.026 - 0.025$	$80.398 + 0.011 - 0.014$	80.398 ± 0.014	80.396 ± 0.012	$80.402 + 0.019 - 0.024$
LHC 13 TeV,W^+	$80.406 + 0.039 - 0.029$	$80.420 + 0.017 - 0.014$	80.398 ± 0.018	80.404 ± 0.016	$80.428 + 0.020 - 0.026$
W^-	$80.422 + 0.030 - 0.023$	$80.398 + 0.008 - 0.015$	80.398 ± 0.015	80.386 ± 0.011	$80.402 + 0.019 - 0.024$

absolute distributions, additional cut $p_\perp^W < 15$ GeV					
collider/channel	CT10	MSTW2008CPdeut	NNPDF2.3	NNPDF3.0	MMHT2014
Tevatron, W^+	$80.412 + 0.024 - 0.024$	$80.424 + 0.018 - 0.017$	80.399 ± 0.014	80.420 ± 0.014	$80.426 + 0.009 - 0.021$
LHC 8 TeV, W^+	$80.392 + 0.026 - 0.021$	$80.414 + 0.020 - 0.011$	80.398 ± 0.015	80.403 ± 0.014	$80.418 + 0.019 - 0.017$
W^-	$80.422 + 0.039 - 0.034$	$80.394 + 0.019 - 0.023$	80.399 ± 0.018	80.423 ± 0.017	$80.400 + 0.023 - 0.028$
LHC 13 TeV,W^+	$80.392 + 0.028 - 0.022$	$80.410 + 0.012 - 0.016$	80.398 ± 0.016	80.408 ± 0.014	$80.414 + 0.016 - 0.019$
W^-	$80.408 + 0.042 - 0.037$	$80.386 + 0.019 - 0.021$	80.398 ± 0.016	80.410 ± 0.018	$80.388 + 0.021 - 0.025$

normalized distributions, additional cut $p_\perp^W < 15$ GeV					
collider/channel	CT10	MSTW2008CPdeut	NNPDF2.3	NNPDF3.0	MMHT2014
Tevatron, W^+	$80.400 + 0.018 - 0.016$	$80.414 + 0.013 - 0.015$	80.399 ± 0.010	80.403 ± 0.011	$80.412 + 0.006 - 0.012$
LHC 8 TeV, W^+	$80.396 + 0.017 - 0.018$	$80.414 + 0.012 - 0.011$	80.398 ± 0.011	80.395 ± 0.009	$80.416 + 0.011 - 0.014$
W^-	$80.406 + 0.016 - 0.011$	$80.398 + 0.005 - 0.012$	80.398 ± 0.010	80.398 ± 0.007	$80.398 + 0.008 - 0.016$
LHC 13 TeV,W^+	$80.400 + 0.020 - 0.017$	$80.412 + 0.010 - 0.011$	80.398 ± 0.012	80.400 ± 0.010	$80.416 + 0.010 - 0.015$
W^-	$80.408 + 0.017 - 0.009$	$80.396 + 0.010 - 0.006$	80.399 ± 0.010	80.391 ± 0.006	$80.396 + 0.009 - 0.013$

Checks

- in Bozzi, Rojo, Vicini, Phys.Rev.D83 (2011) 113008
  we studied the PDF impact on MW extracted from the lepton-pair transverse mass distribution
  using DYNNLO with NLO-QCD accuracy

  a fixed-order simulation is sufficient to describe the MT but not the ptl distributions

- we reproduce with POWHEG+PYTHIA the DYNNLO results for MT
  (but now we can also study the ptl distribution)

- the PDF uncertainty on MW from the MT distribution is smaller than
  the one from the ptl case
  but there can be important differences in the estimate between a generator level
  and a detector level estimate

Ratio of normalized shapes, with different PTW cuts