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MW measurement with forward muons: a PFD uncertainty perspective

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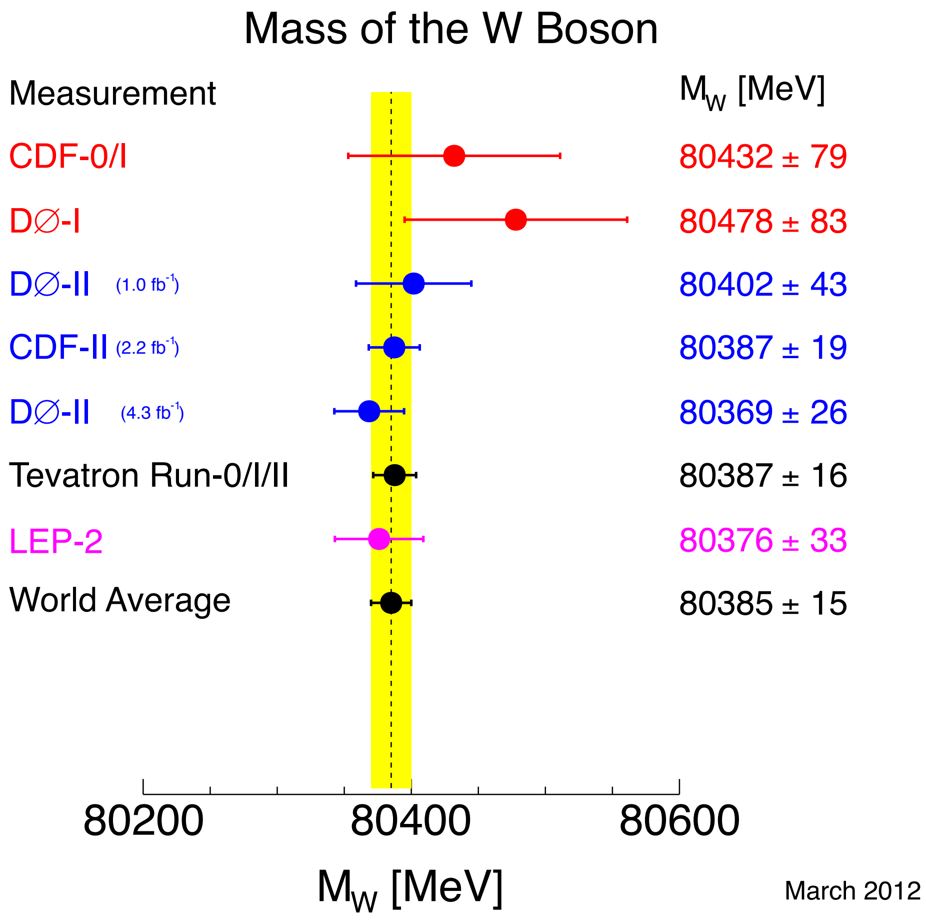
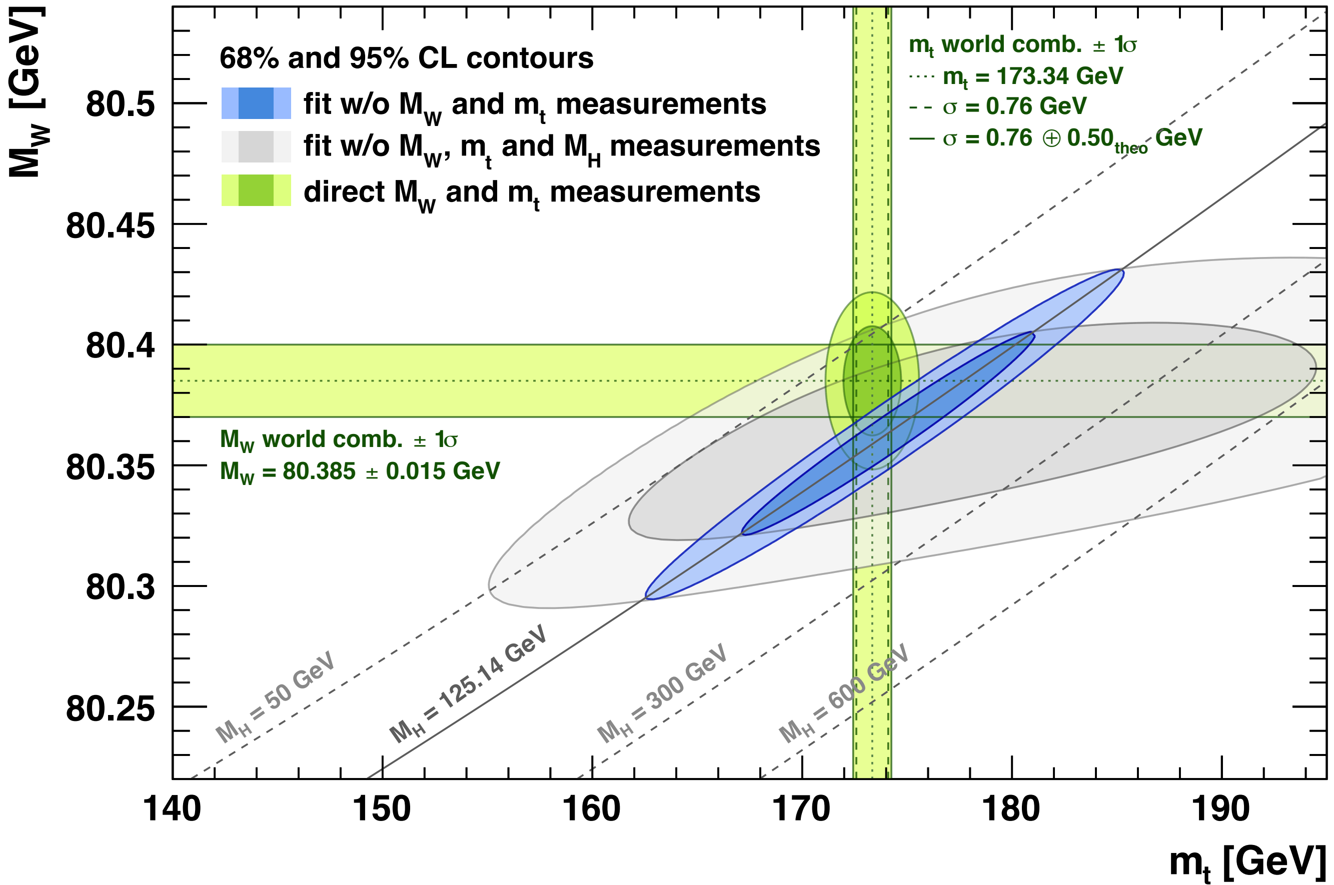
work in collaboration with G.Bozzi, L.Citelli, M.Vesterinen
based on arXiv:1501.05587, arXiv:1508.06954

Precision tests of the Standard Model





with the MH input the SM lagrangian (gauge sector) is assigned,

the EW fit can determine the preferred MW (2-loop EW+h.o.) and mtop (free parameter)

and check the compatibility of the SM hypothesis with the experimental measurements

the result of the global EW fit of the SM

yields a result for MW with an error ΔMW=8 MeV smaller than the one of the direct measurement

mtop=173.81 ±0.85 GeV compatible with the world average top mass

is the 1.5 sigma discrepancy in the above plot, between the data and the theoretical prediction,

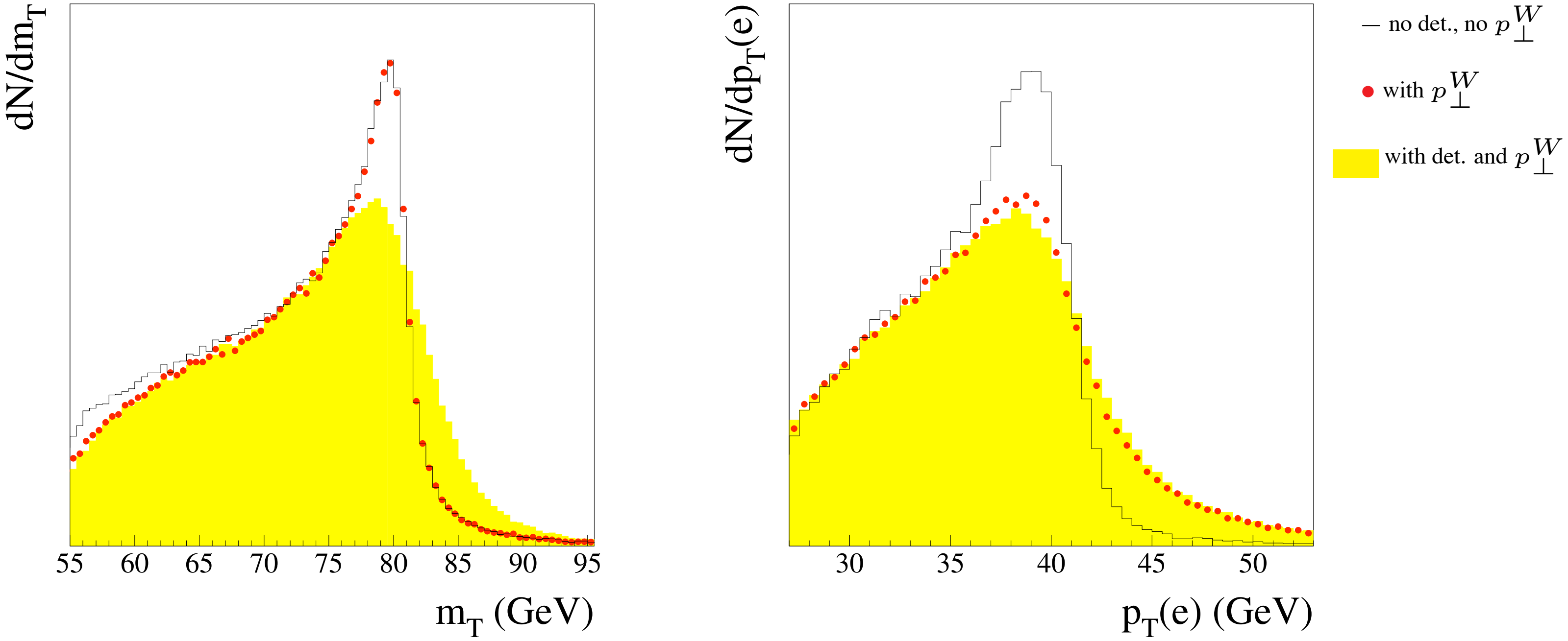
just a fluctuation, a systematic effect of the MW measurement at hadron colliders, a BSM hint?

can we aim at a MW measurement at the O(10 MeV) level of precision at the LHC ?

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 (modeling of hadr. 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

charged lepton transverse momentum

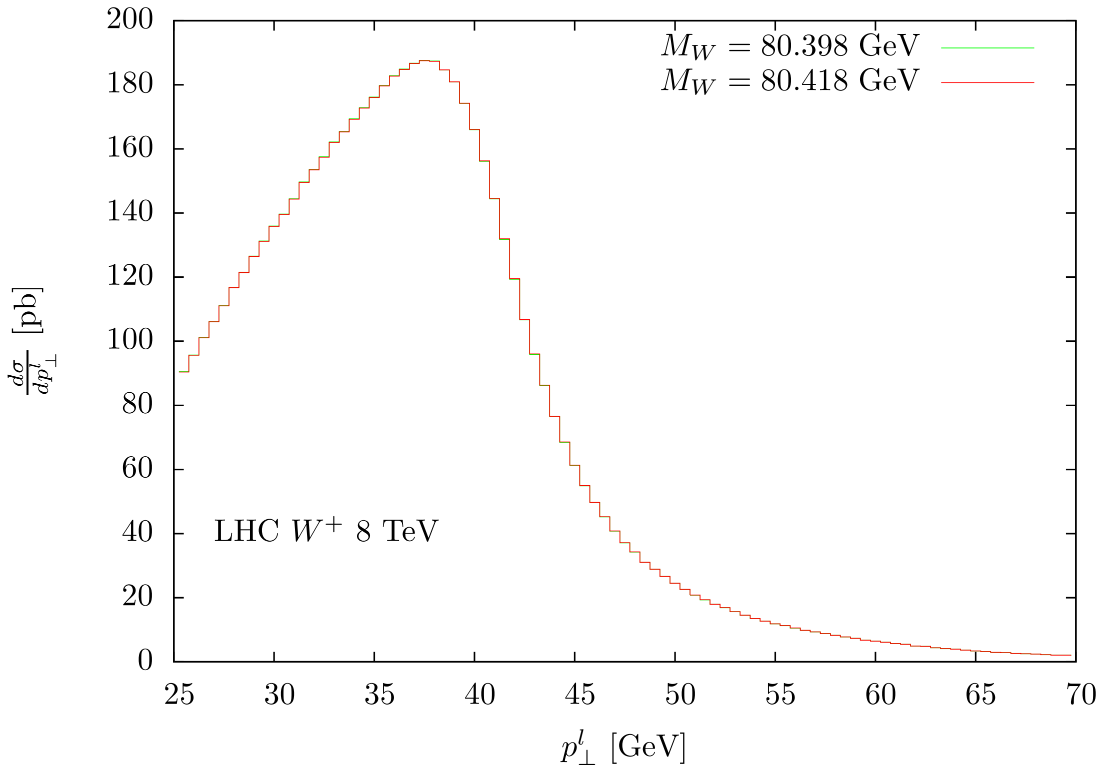
- highly sensitive to the details of QCD radiation (and thus also to PDFs)
- "simple" experimental determination (accurate lepton energy/momentum calibration)

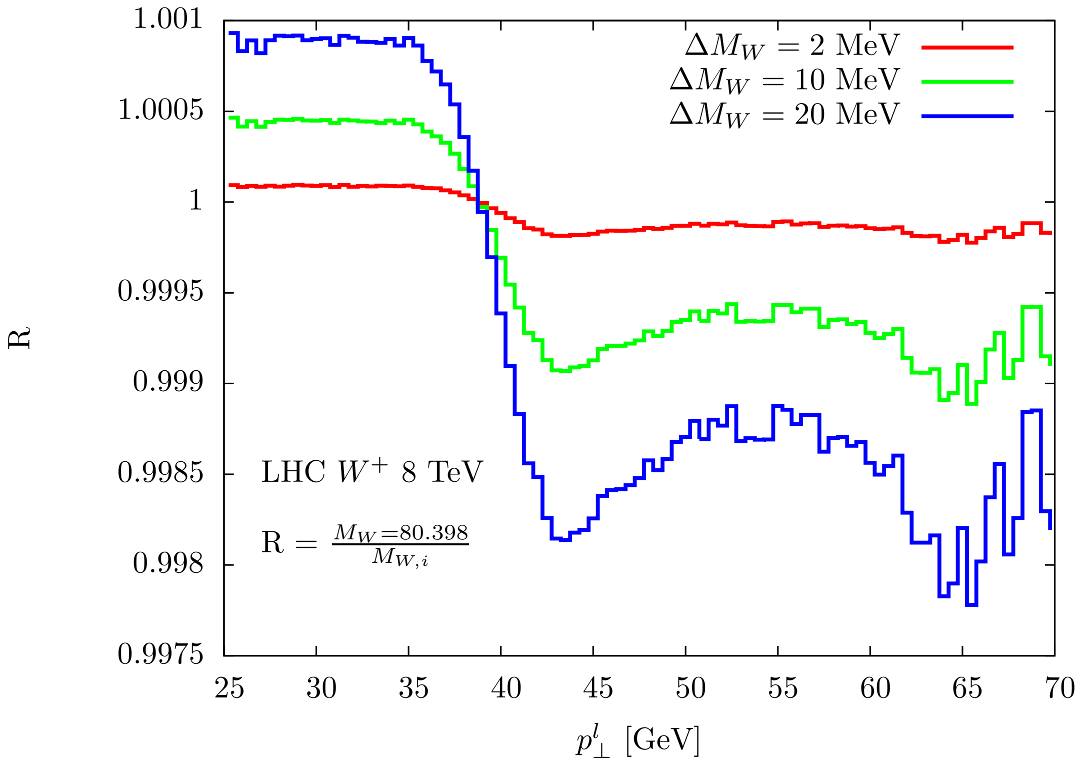
  moderate impact of detector effects

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

Sensitivity of the charged-lepton pt distribution to MW

- since the transverse mass distribution can not be reconstructed at LHCb
  we focus on the study of the lepton transverse momentum distribution





- 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?

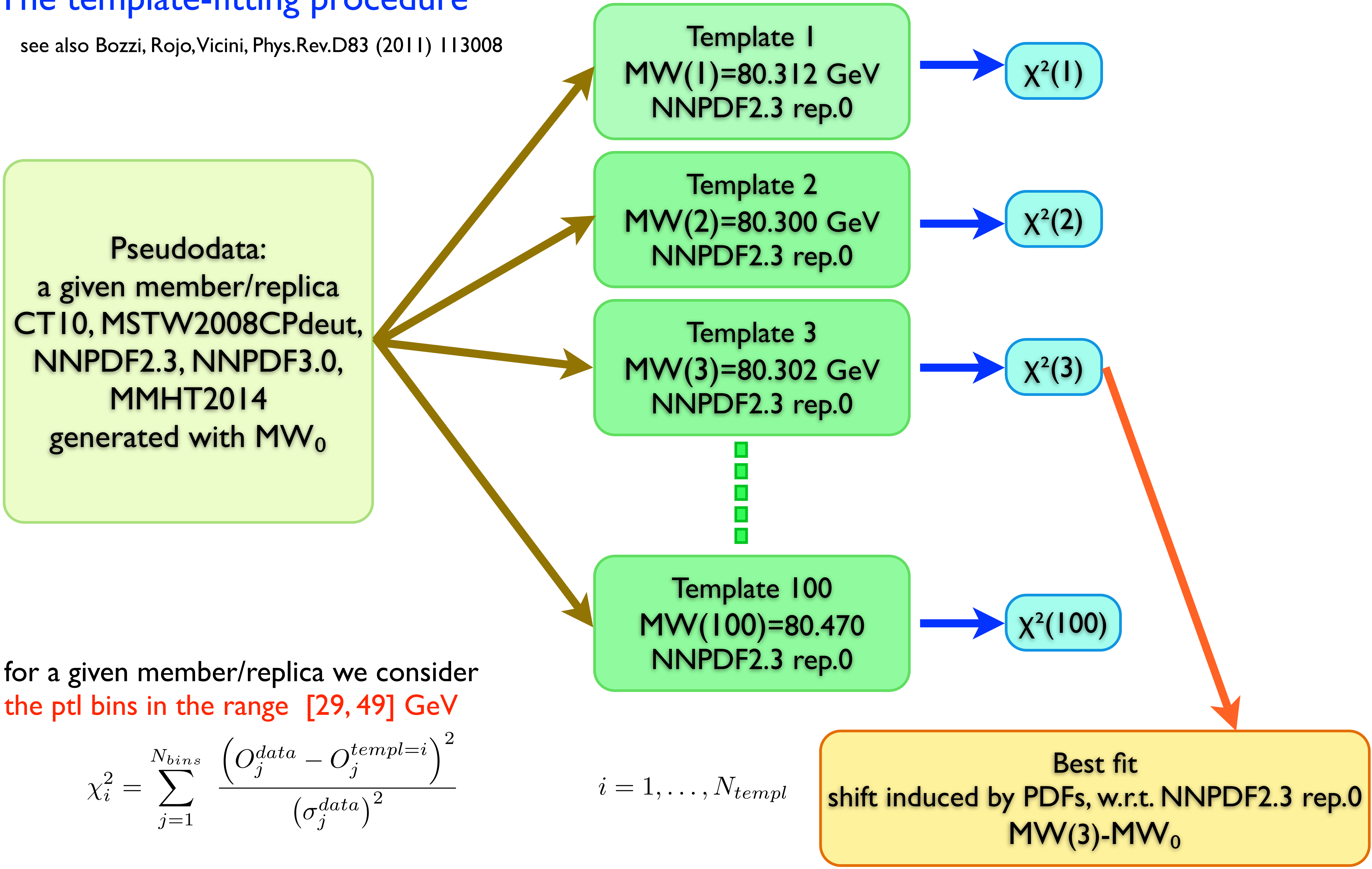
- goals of the present study:
  1) estimate of the PDF uncertainty on MW extracted from the lepton pt distribution

  2) study of the dependence of the uncertainty on the acceptance cuts

  3) evaluation of the impact of a W mass measurement at LHCb in the final LHC MW combination

The template-fitting procedure

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



Pseudodata:
a given member/replica
CT10, MSTW2008CPdeut,
NNPDF2.3, NNPDF3.0,
MMHT2014
generated with MW_0

Template 1
MW(1)=80.312 GeV
NNPDF2.3 rep.0

$\chi^2(1)$

Template 2
MW(2)=80.300 GeV
NNPDF2.3 rep.0

$\chi^2(2)$

Template 3
MW(3)=80.302 GeV
NNPDF2.3 rep.0

$\chi^2(3)$

Template 100
MW(100)=80.470
NNPDF2.3 rep.0

$\chi^2(100)$

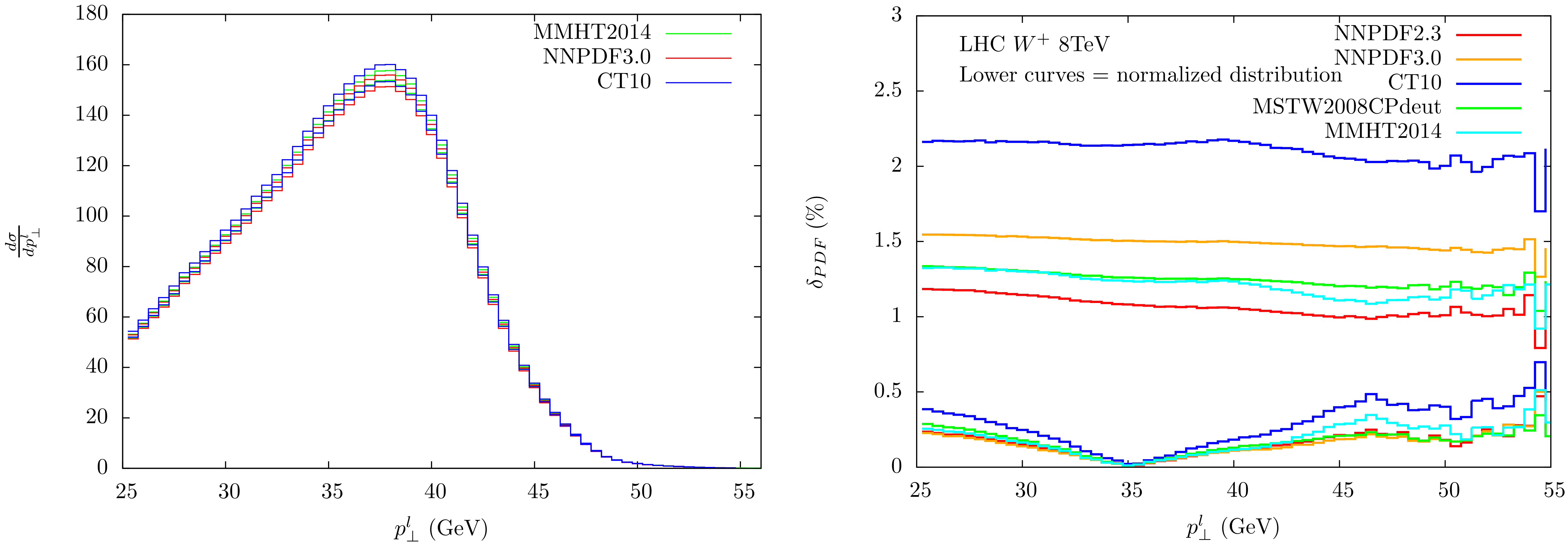
Best fit
shift induced by PDFs, w.r.t. NNPDF2.3 rep.0
$MW(3)-MW_0$

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

PDF uncertainty on the lepton pt distribution

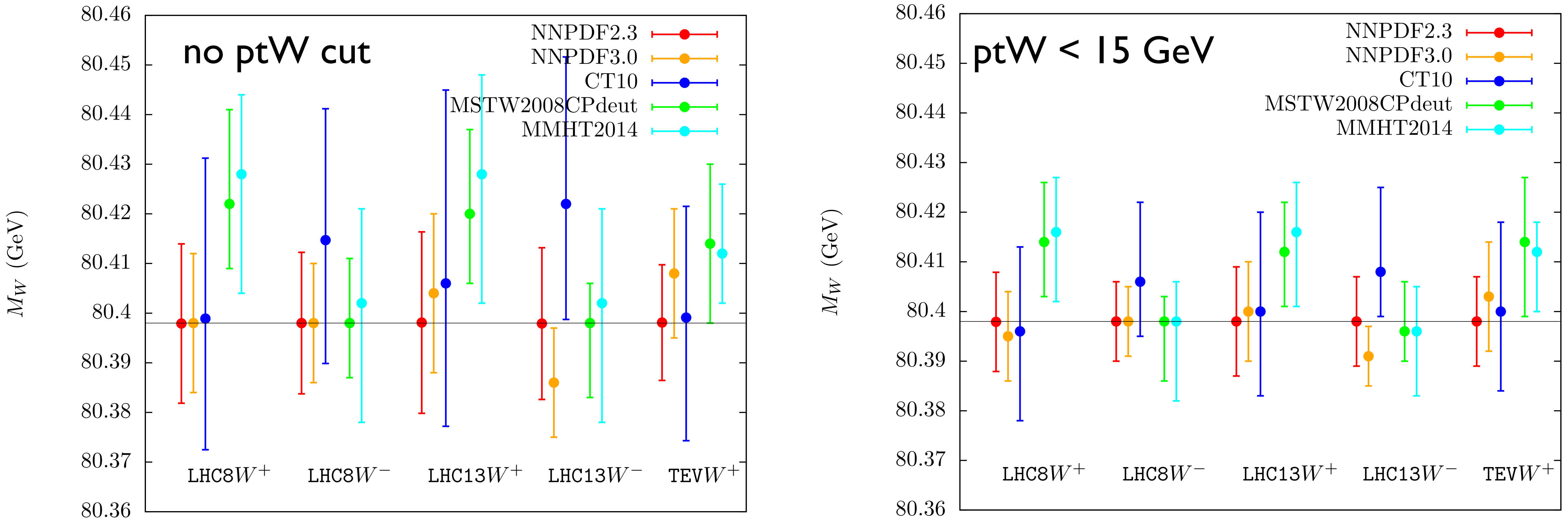


- all simulations with POWHEG matched with PYTHIA 6.4.21
  in these plots standard ATLAS/CMS acceptance cuts

- 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



- in these plots standard ATLAS/CMS acceptance cuts

- 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

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

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 NNPDF3.0 uncertainties are 15-20% smaller w.r.t. NNPDF2.3
  the MMHT2014 unc. are similar to those of MSTW2008CPdeut

- the NNPDF3.0 results might induce a moderate optimism:
  i.e. LHC data will help to reduce the PDF uncertainty on MW

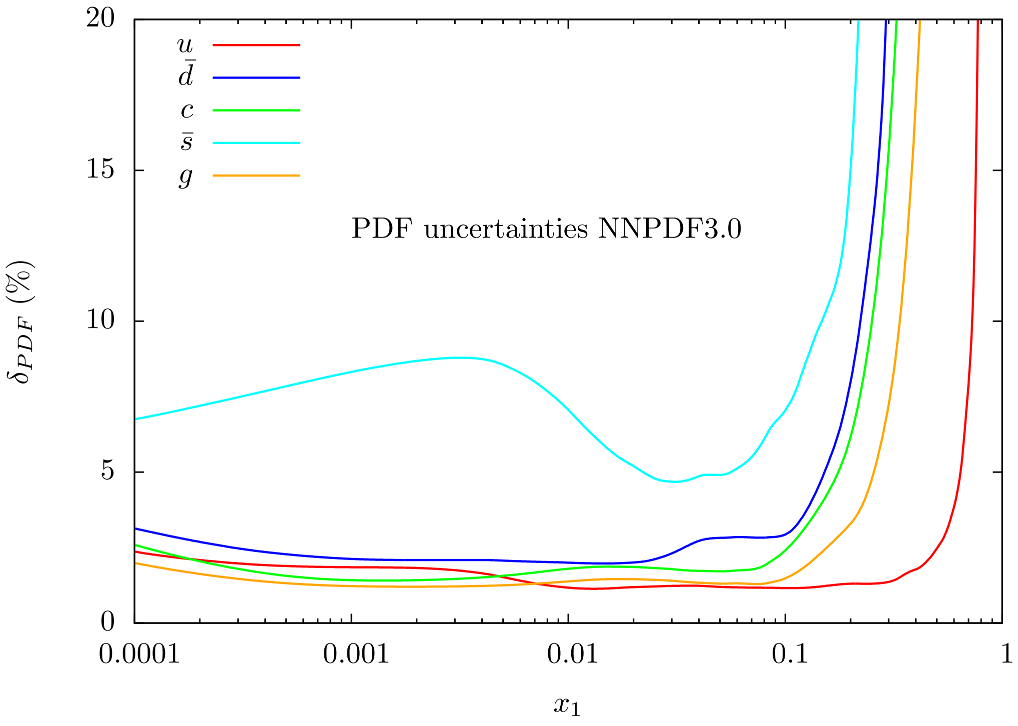
- on the other hand the spread of the central values in the W+ case is the most remarkable feature of the comparison
  and shows that different parameterizations, based on the same data,
  yield significantly different results (in a 10 MeV perspective for the final MW error)

PDF uncertainty affecting MW and acceptance cuts

G.Bozzi, L.Citelli, AV, arXiv:1501.05587

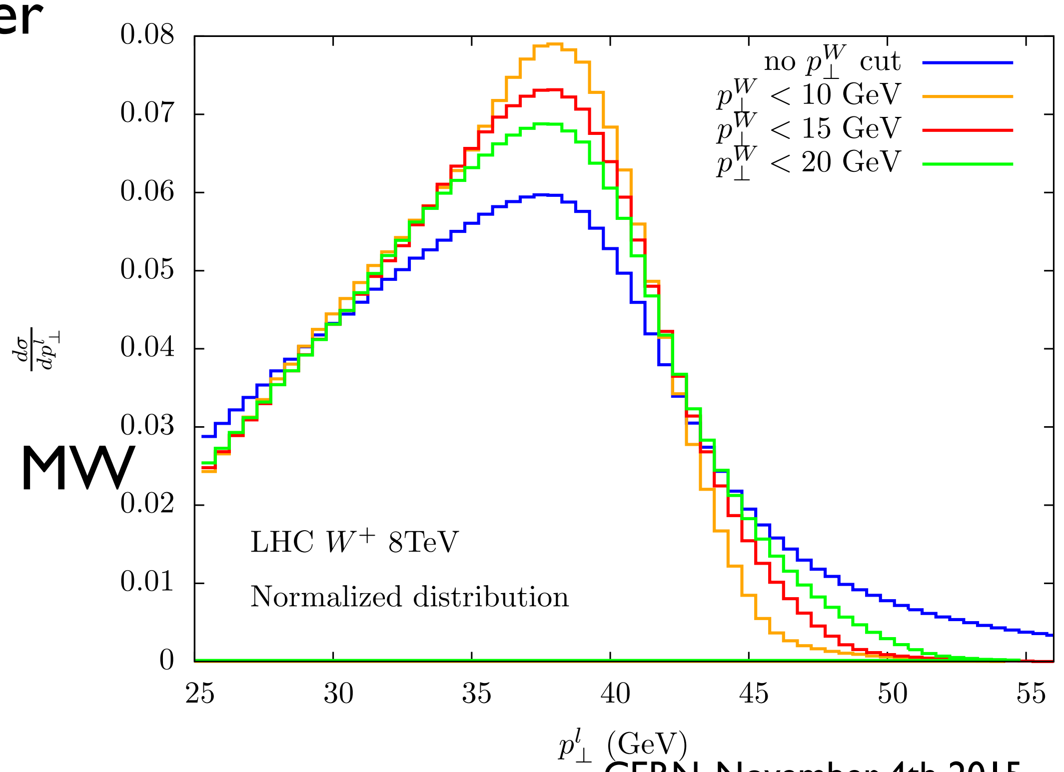
The dependence of the MW PDF uncertainty on the acceptance cuts provides interesting insights

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 PDF uncertainty on the single densities has a steep increase for x>0.1
  - the up density remains accurate up to x ~ 0.5
  - the strange density is O(3) times less accurate than the other for 0.001 < x < 0.01

- the additional cut on ptW reduces the MW uncertainty
  - suppression of the large-*x* region
  - steeper shape of the ptlep distribution = more sensitivity to MW



PDF uncertainty affecting MW and lepton pseudorapidity cuts

G.Bozzi, L.Citelli, AV, arXiv:1501.05587

normalized distributions			
cut on $p_\perp^W$	cut on $\lvert\eta_l\rvert$	CT10	NNPDF3.0
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$p_\perp^W < 15$ GeV	$1.0 < \lvert\eta_l\rvert < 2.5$	$80.392 + 0.025 - 0.018$	80.388 ± 0.012

- the normalized ptlep distribution, integrated over the whole lepton-pair rapidity range, does not depend on *x* and depends very weakly on the PDF replica

- the central pseudorapidity region is the most uncertain

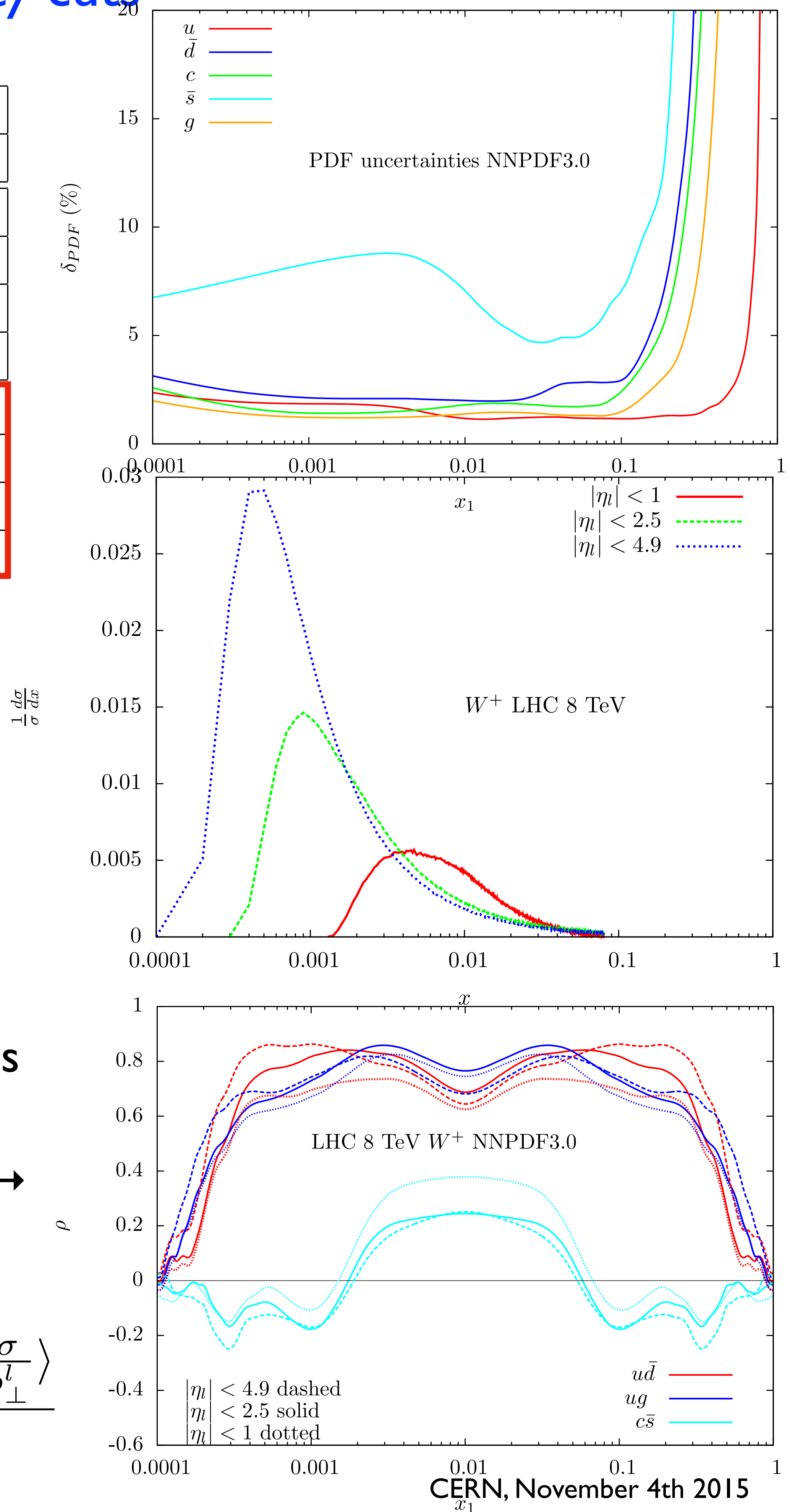
- PDF sum rules →

  non trivial compensations between different rapidity intervals

  among different flavors

  enlarging symmetrically the eta range → smaller average *x* → region where the csbar subprocess has negative correlation with the distribution

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



Why measuring MW at LHCb

G.Bozzi, L.Citelli, M.Vesterinen, AV, arXiv:1508.06954

- selecting muons at LHCb with forward pseudorapidities, we probe a different range of partonic *x* w.r.t. ATLAS/CMS standard central acceptance

- the lepton pt distribution and, in turn, the associated MW by ATLAS/CMS (central cuts) and by LHCb are anticorrelated w.r.t. PDF variations

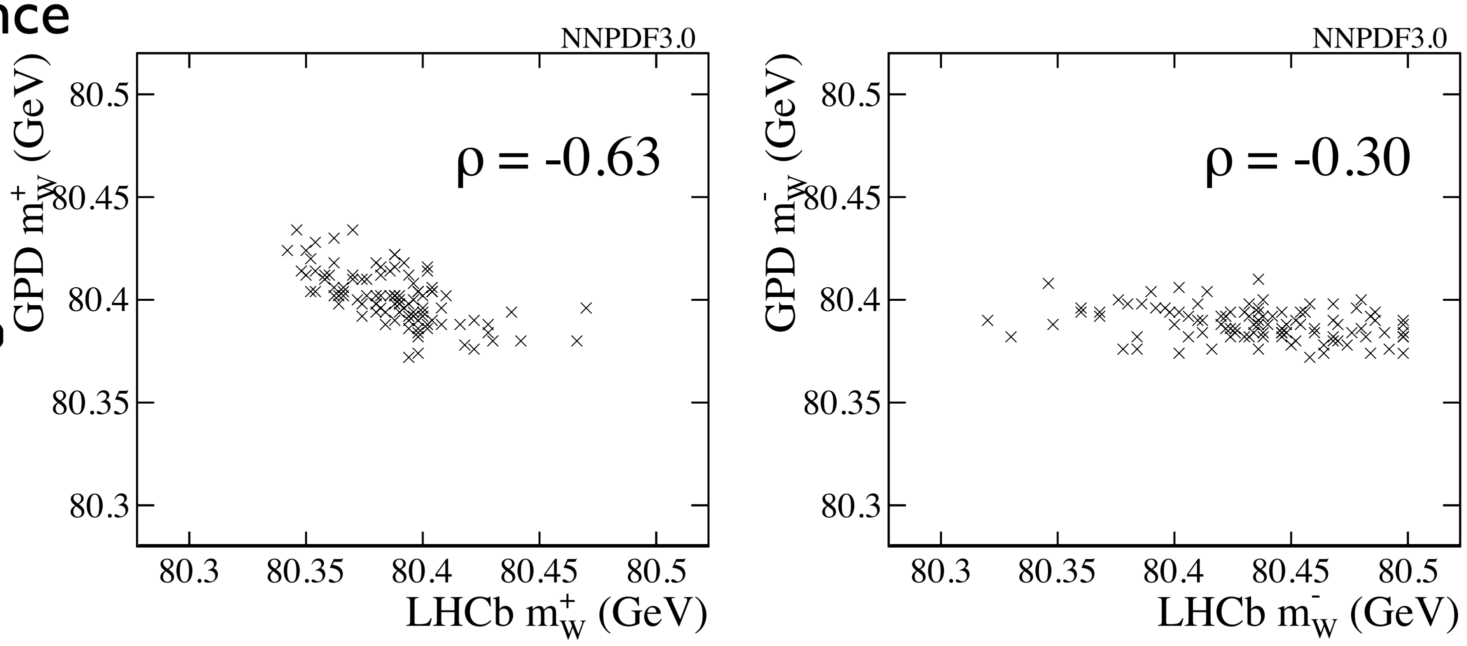
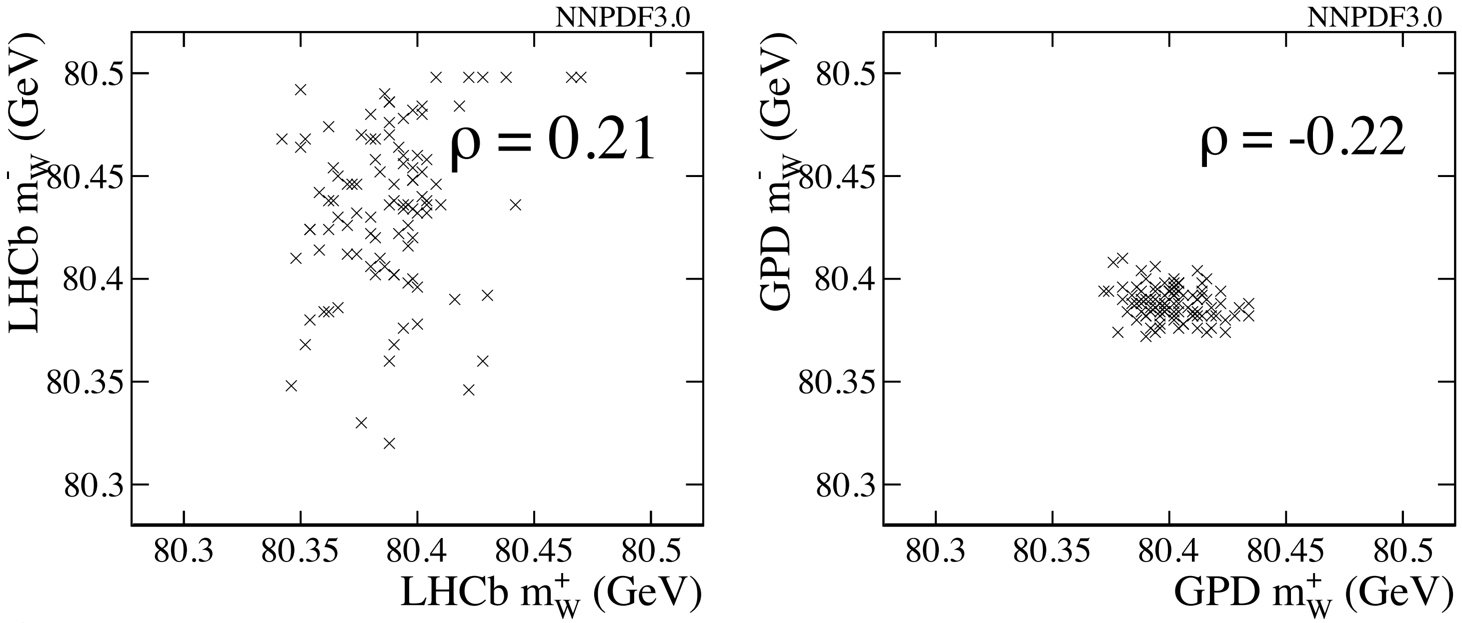


Fig. 1 The fitted m_W in the GPDs versus LHCb for each NNPDF3.0 set, and for (left) W^+ and (right) W^-.



⇒ in a combination of LHCb with ATLAS/CMS results

we could gain a reduction of the final PDF uncertainty

Impact of a LHCb MW measurement in the combination with ATLAS/CMS results

G.Bozzi, L.Citelli, M.Vesterinen, AV, arXiv:1508.06954

- using the standard acceptance cuts and both W charges
  for ATLAS/CMS (called **G**) ptl > 25 GeV, | etal | < 2.5 (both electrons and muons), ptW < 15GeV
  for LHCb (called **L**) ptl > 20 GeV, 2.0 < etal < 4.5 (only muons), no ptW cut
  we study the MW determination from the lepton pt distribution
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- PDF uncertainty on MW according to PDF4LHC (NNPDF3.0, MMHT2014)
  · for **G**s larger uncertainty in the W+ case
  · for **L**s need of a sea quark at large *x* → large uncertainty e.g. from strange

$$\delta_{\mathrm{PDF}} = \begin{pmatrix} \mathbf{G}^+ & 24.8 \\ \mathbf{G}^- & 13.2 \\ \mathbf{L}^+ & 27.0 \\ \mathbf{L}^- & 49.3 \end{pmatrix}$$

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- correlation matrix ρ w.r.t. PDF variation of the replicas of the NNPDF3.0 set
  → non negligible anticorrelation

$$\rho = \left(\begin{array}{ccccc} & \mathbf{G}^+ & \mathbf{G}^- & \mathbf{L}^+ & \mathbf{L}^- \\ \mathbf{G}^+ & 1 & & & \\ \mathbf{G}^- & -0.22 & 1 & & \\ \mathbf{L}^+ & -0.63 & 0.11 & 1 & \\ \mathbf{L}^- & -0.02 & -0.30 & 0.21 & 1 \end{array}\right).$$

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- look for a linear combination of all the available **G** and **L** results
  that minimizes the final PDF uncertainty on MW
  expressed by the coefficients α_i

$$m_W = \sum_{i=1}^{4} \alpha_i m_{W\ i}$$

Impact of a LHCb MW measurement in the combination with ATLAS/CMS results

G.Bozzi, L.Citelli, M.Vesterinen, AV, arXiv:1508.06954

- MW PDF uncertainties from the simulated data

	$\mathbf{G}^+$	$\mathbf{G}^-$	$\mathbf{L}^+$	$\mathbf{L}^-$
Envelope	24.8	13.2	27.0	49.3
Δ_{sets}	20.9	5.7	12.1	22.9

- 2 sets = NNPDF3.0 and MMHT14

	$\mathbf{G}^+$	$\mathbf{G}^-$	$\mathbf{L}^+$	$\mathbf{L}^-$
Envelope	29.9	23.5	35.0	84.1
Δ_{sets}	22.0	23.7	24.0	74.0

- 3 sets = NNPDF3.0 and MMHT14 and CT10

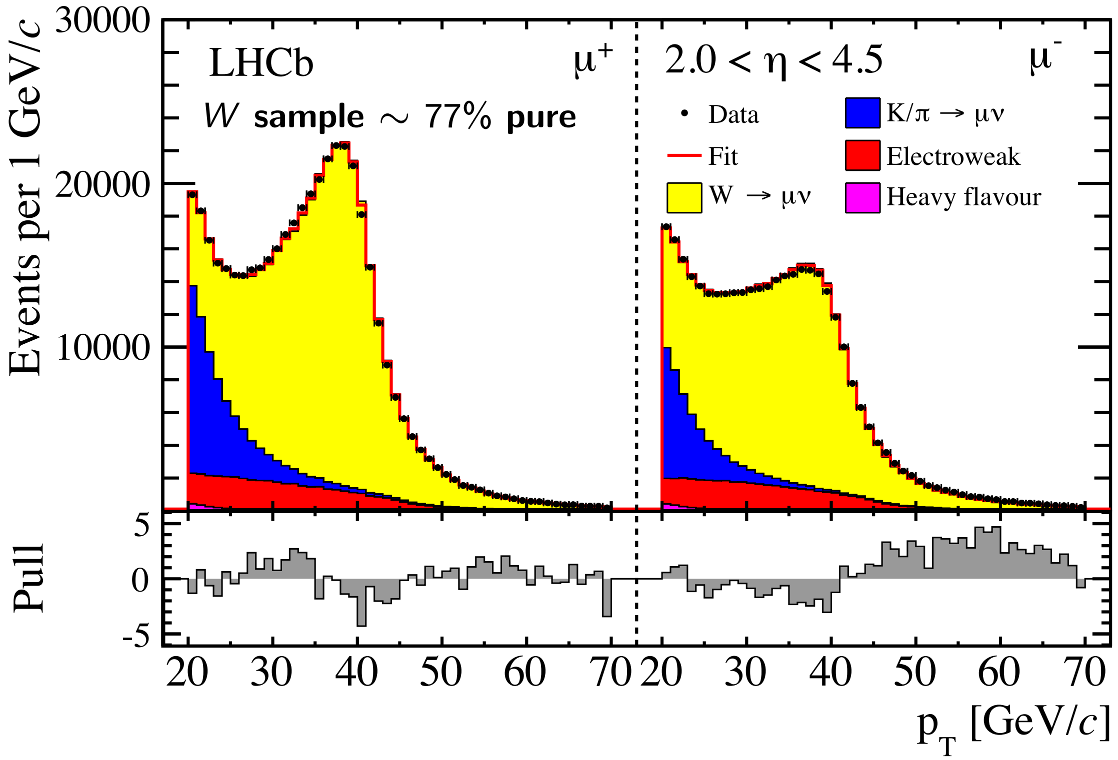
- results for the optimal combination of **G±** and **L±** results

PDFs	Experiments	δ_{PDF} (MeV)	α
PDF4LHC(2-sets)	2×GPD	10.5	$(0.26, 0.74, 0, 0)$
PDF4LHC(2-sets)	2×GPD + LHCb	7.7	$(0.30, 0.45, 0.21, 0.04)$
PDF4LHC(3-sets)	2×GPD	16.9	$(0.50, 0.50, 0, 0)$
PDF4LHC(3-sets)	2×GPD + LHCb	12.7	$(0.43, 0.41, 0.11, 0.04)$
NNPDF30	2×GPD	5.2	$(0.50, 0.50, 0, 0)$
NNPDF30	2×GPD + LHCb	3.6	$(0.35, 0.47, 0.16, 0.02)$
MMHT2014	2×GPD	9.2	$(0.45, 0.55, 0, 0)$
MMHT2014	2×GPD + LHCb	4.6	$(0.39, 0.14, 0.46, 0)$
CT10	2×GPD	11.6	$(0.33, 0.67, 0, 0)$
CT10	2×GPD + LHCb	6.3	$(0.38, 0.20, 0.40, 0.03)$

- the inclusion of LHCb results yields a reduction of the PDF uncertainty of O(30-40%) on the envelope stronger reduction for the individual sets MMHT2014 and for CT10

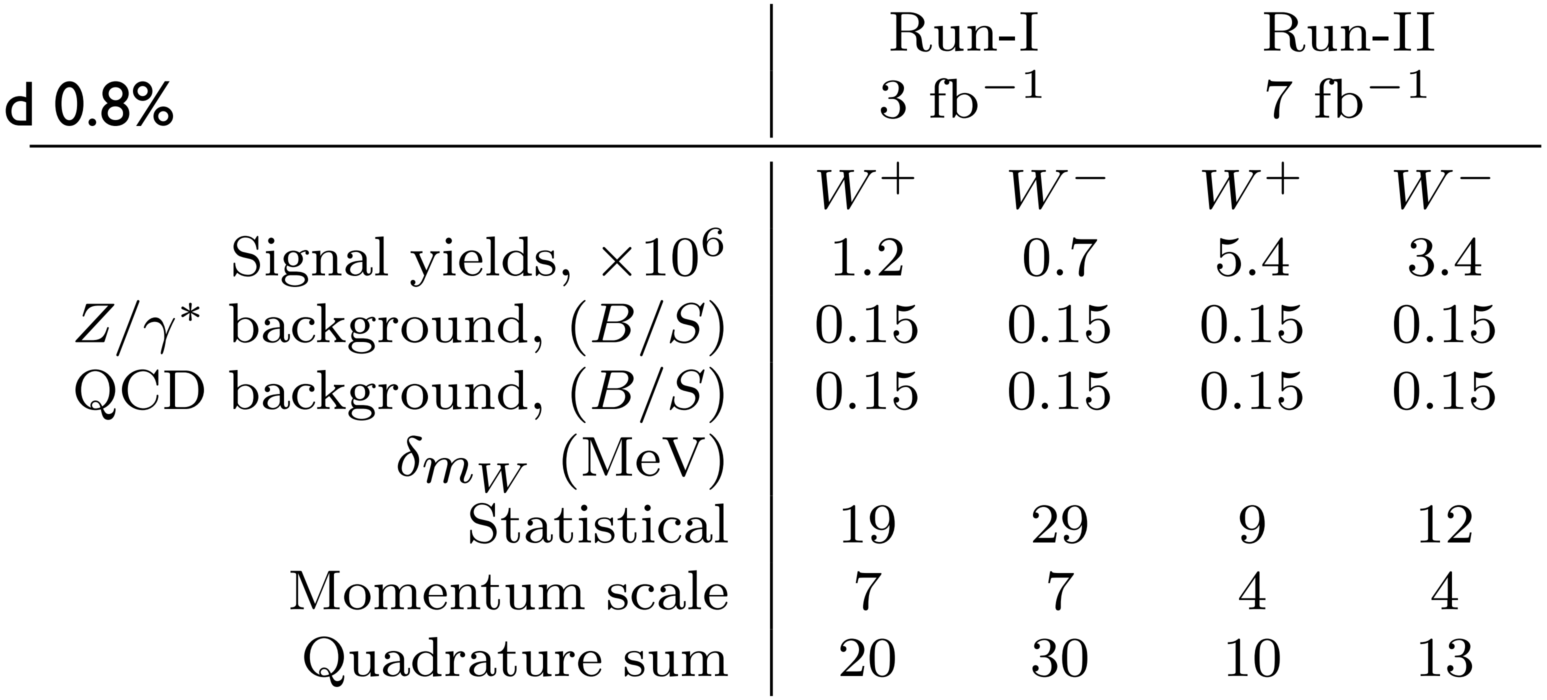
Feasibility of a LHCb MW measurement

G.Bozzi, L.Citelli, M.Vesterinen, AV, arXiv:1508.06954



- statistical sensitivity
  - in $1\,\mathrm{fb}^{-1}$ of luminosity at Run-I collected
    550k W+ and 350k W- with 70% of purity
    60k of candidate Z with almost perfect purity
    → extrapolation of the signal yield
    of the full Run-I and Run-II datasets
  - backgrounds
    low ptl: pions/kaons decays
    intermediate/large ptl: $Z/\gamma^* \to \mu\mu$ with one muon lost
    exponential parameterization, reproducing the estimates of arXiv:1505.07024
  - estimate of the statistical error obtained from signal+background fitting 500 pseudo-experiments

- muon momentum scale calibration
  - at LHCb very precise measurement of *b* and *c* hadron masses
    (arXiv:1302.1072, arXiv:1304.6865)
    momentum resolution between 0.2% and 0.8%
    momentum scale uncertainty of $3 \cdot 10^{-4}$
  - the full dataset, with 700k Z events,
    → calibration also at high pt
  - at Tevatron calibration using J/Ψ and ϒ



	Run-I $3\ \mathrm{fb}^{-1}$		Run-II $7\ \mathrm{fb}^{-1}$	
	W^+	W^-	W^+	W^-
Signal yields, $\times 10^6$	1.2	0.7	5.4	3.4
Z/γ^* background, (B/S)	0.15	0.15	0.15	0.15
QCD background, (B/S)	0.15	0.15	0.15	0.15
δm_W (MeV)				
Statistical	19	29	9	12
Momentum scale	7	7	4	4
Quadrature sum	20	30	10	13

Prospects for a combination of ATLAS, CMS and LHCb results

G.Bozzi, L.Citelli, M.Vesterinen, AV, arXiv:1508.06954

- we assume that the following set uncertainties will be confirmed at the end of run-II (same PDFs as today, hypothetical experimental errors)

$$\delta m_W^i = \begin{pmatrix} \mathbf{G}^+ & (7_{\rm exp} \pm 25_{\rm PDF}) \ \text{MeV} \\ \mathbf{G}^- & (7_{\rm exp} \pm 13_{\rm PDF}) \ \text{MeV} \\ \mathbf{L}^+ & (10_{\rm exp} \pm 28_{\rm PDF}) \ \text{MeV} \\ \mathbf{L}^- & (13_{\rm exp} \pm 49_{\rm PDF}) \ \text{MeV} \end{pmatrix} .$$

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- we vary each of the assumed values in a range from 0 to 2

  we then check how robust is the reduction of the PDF error under these variations

Scenario	Experiments	δm_W (MeV) Tot	Exp	PDF	α
Default	2×GPD + LHCb	9.0	4.7	7.7	$(0.30, 0.44, 0.22, 0.04)$
Default	1×GPD + LHCb	10.1	6.5	7.7	$(0.31, 0.40, 0.25, 0.04)$
Default	2×GPD	12.0	5.8	10.5	$(0.28, 0.72, 0, 0)$
PDF4LHC(3-sets)	2×GPD + LHCb	13.6	4.8	12.7	$(0.43, 0.41, 0.12, 0.04)$
PDF4LHC(3-sets)	1×GPD + LHCb	14.6	7.3	12.7	$(0.43, 0.40, 0.12, 0.04)$
PDF4LHC(3-sets)	2×GPD	17.7	5.5	16.9	$(0.50, 0.50, 0, 0)$
$\delta_{\rm exp}^{\rm LHCb} = 0$	2×GPD + LHCb	8.7	4.0	7.7	$(0.31, 0.41, 0.24, 0.04)$
$\delta_{\rm exp}^{\rm LHCb} = 0$	1×GPD + LHCb	9.8	5.9	7.9	$(0.31, 0.37, 0.28, 0.04)$
$\delta_{\rm exp}^{\rm LHCb} = 0$	2×GPD	12.0	5.8	10.5	$(0.28, 0.72, 0, 0)$
$\delta_{\rm exp}^{\rm GPD} = 0$	2×GPD + LHCb	7.9	1.9	7.7	$(0.29, 0.48, 0.19, 0.04)$
$\delta_{\rm exp}^{\rm GPD} = 0$	1×GPD + LHCb	7.9	1.9	7.7	$(0.29, 0.48, 0.19, 0.04)$
$\delta_{\rm exp}^{\rm GPD} = 0$	2×GPD	10.5	0.1	10.5	$(0.26, 0.74, 0, 0)$
$\delta_{\rm PDF} = 0$	2×GPD + LHCb	4.6	4.6	0.0	$(0.34, 0.34, 0.22, 0.10)$
$\delta_{\rm PDF} = 0$	1×GPD + LHCb	5.8	5.8	0.0	$(0.23, 0.23, 0.37, 0.17)$
$\delta_{\rm PDF} = 0$	2×GPD	5.5	5.5	0.0	$(0.50, 0.50, 0, 0)$
$\delta_{\rm exp}^{\rm LHCb} \times 2$	2×GPD + LHCb	9.6	5.6	7.7	$(0.29, 0.50, 0.17, 0.04)$
$\delta_{\rm exp}^{\rm LHCb} \times 2$	1×GPD + LHCb	10.8	7.6	7.7	$(0.30, 0.46, 0.20, 0.05)$
$\delta_{\rm exp}^{\rm LHCb} \times 2$	2×GPD	12.0	5.8	10.5	$(0.28, 0.72, 0, 0)$
$\delta_{\rm exp}^{\rm GPD} \times 2$	2×GPD + LHCb	11.2	7.9	8.0	$(0.32, 0.35, 0.29, 0.04)$
$\delta_{\rm exp}^{\rm GPD} \times 2$	1×GPD + LHCb	13.9	10.5	9.0	$(0.31, 0.26, 0.37, 0.05)$
$\delta_{\rm exp}^{\rm GPD} \times 2$	2×GPD	15.6	11.5	10.6	$(0.32, 0.68, 0, 0)$
$\delta_{\rm PDF} \times 2$	2×GPD + LHCb	16.0	4.7	15.3	$(0.30, 0.45, 0.21, 0.04)$
$\delta_{\rm PDF} \times 2$	1×GPD + LHCb	16.7	6.7	15.3	$(0.30, 0.44, 0.22, 0.04)$
$\delta_{\rm PDF} \times 2$	2×GPD	21.7	5.9	20.9	$(0.27, 0.73, 0, 0)$

Prospects for a combination of ATLAS, CMS and LHCb results

G.Bozzi, L.Citelli, M.Vesterinen, AV, arXiv:1508.06954

- we assume that the following set uncertainties will be confirmed at the end of run-II (same PDFs as today, hypothetical experimental errors)

$$\delta m_W^i = \begin{pmatrix} \mathbf{G}^+ & (7_{\rm exp} \pm 25_{\rm PDF})\ \mathrm{MeV} \\ \mathbf{G}^- & (7_{\rm exp} \pm 13_{\rm PDF})\ \mathrm{MeV} \\ \mathbf{L}^+ & (10_{\rm exp} \pm 28_{\rm PDF})\ \mathrm{MeV} \\ \mathbf{L}^- & (13_{\rm exp} \pm 49_{\rm PDF})\ \mathrm{MeV} \end{pmatrix}.$$

- we vary each of the assumed values in a range from 0 to 2

  we then check how robust is the reduction of the PDF error under these variations

- the introduction of LHCb always yields a reduction of the PDF error and in turn of the total error of O(25-40%) w.r.t. the 2 GPDs case

- the combination of LHCb with 1 GPD is more convenient, in a PDF perspective, than the sum of 2 GPDs

- when including CT10, the impact of LHCb on the combination is stronger

Scenario	Experiments	δm_W (MeV) Tot	Exp	PDF	α
Default	2×GPD + LHCb	9.0	4.7	7.7	$(0.30, 0.44, 0.22, 0.04)$
Default	1×GPD + LHCb	10.1	6.5	7.7	$(0.31, 0.40, 0.25, 0.04)$
Default	2×GPD	12.0	5.8	10.5	$(0.28, 0.72, 0, 0)$
PDF4LHC(3-sets)	2×GPD + LHCb	13.6	4.8	12.7	$(0.43, 0.41, 0.12, 0.04)$
PDF4LHC(3-sets)	1×GPD + LHCb	14.6	7.3	12.7	$(0.43, 0.40, 0.12, 0.04)$
PDF4LHC(3-sets)	2×GPD	17.7	5.5	16.9	$(0.50, 0.50, 0, 0)$
$\delta_{\rm exp}^{\rm LHCb} = 0$	2×GPD + LHCb	8.7	4.0	7.7	$(0.31, 0.41, 0.24, 0.04)$
$\delta_{\rm exp}^{\rm LHCb} = 0$	1×GPD + LHCb	9.8	5.9	7.9	$(0.31, 0.37, 0.28, 0.04)$
$\delta_{\rm exp}^{\rm LHCb} = 0$	2×GPD	12.0	5.8	10.5	$(0.28, 0.72, 0, 0)$
$\delta_{\rm exp}^{\rm GPD} = 0$	2×GPD + LHCb	7.9	1.9	7.7	$(0.29, 0.48, 0.19, 0.04)$
$\delta_{\rm exp}^{\rm GPD} = 0$	1×GPD + LHCb	7.9	1.9	7.7	$(0.29, 0.48, 0.19, 0.04)$
$\delta_{\rm exp}^{\rm GPD} = 0$	2×GPD	10.5	0.1	10.5	$(0.26, 0.74, 0, 0)$
$\delta_{\rm PDF} = 0$	2×GPD + LHCb	4.6	4.6	0.0	$(0.34, 0.34, 0.22, 0.10)$
$\delta_{\rm PDF} = 0$	1×GPD + LHCb	5.8	5.8	0.0	$(0.23, 0.23, 0.37, 0.17)$
$\delta_{\rm PDF} = 0$	2×GPD	5.5	5.5	0.0	$(0.50, 0.50, 0, 0)$
$\delta_{\rm exp}^{\rm LHCb} \times 2$	2×GPD + LHCb	9.6	5.6	7.7	$(0.29, 0.50, 0.17, 0.04)$
$\delta_{\rm exp}^{\rm LHCb} \times 2$	1×GPD + LHCb	10.8	7.6	7.7	$(0.30, 0.46, 0.20, 0.05)$
$\delta_{\rm exp}^{\rm LHCb} \times 2$	2×GPD	12.0	5.8	10.5	$(0.28, 0.72, 0, 0)$
$\delta_{\rm exp}^{\rm GPD} \times 2$	2×GPD + LHCb	11.2	7.9	8.0	$(0.32, 0.35, 0.29, 0.04)$
$\delta_{\rm exp}^{\rm GPD} \times 2$	1×GPD + LHCb	13.9	10.5	9.0	$(0.31, 0.26, 0.37, 0.05)$
$\delta_{\rm exp}^{\rm GPD} \times 2$	2×GPD	15.6	11.5	10.6	$(0.32, 0.68, 0, 0)$
$\delta_{\rm PDF} \times 2$	2×GPD + LHCb	16.0	4.7	15.3	$(0.30, 0.45, 0.21, 0.04)$
$\delta_{\rm PDF} \times 2$	1×GPD + LHCb	16.7	6.7	15.3	$(0.30, 0.44, 0.22, 0.04)$
$\delta_{\rm PDF} \times 2$	2×GPD	21.7	5.9	20.9	$(0.27, 0.73, 0, 0)$

Potential bottlenecks

- the measurement of MW from the lepton pt distribution strongly relies on the knowledge of the neutral-current Drell-Yan, in particular the ptZ distribution, to model ptW and eventually to simulate the lepton pt

- the lepton pt distribution is extremely sensitive to the details of QCD radiation, in particular at low ptV values (a distortion at the few per mil level yields O(20 MeV) MW shift)

- the assumption that the information obtained from the Z is universal and can be transferred to the W is violated by several factors:
  different parton-parton luminosities (and heavy-quark content), different energy scales,
  dependence of ptZ modeling on the lepton-pair rapidity, EW corrections

⇒ a dedicated study of ptZ and of the ptW ↔ ptZ interplay at LHCb is needed

Conclusions

- PDF uncertainties are a potential bottleneck of a precision MW measurement at the LHC
  in view of a final precision goal at the O(10 MeV) level

- the measurement of MW from the lepton pt distribution at LHCb
  and its combination with the ATLAS/CMS results
  can help to reduce the PDF uncertainty by 25-40%
  thanks to the anticorrelation w.r.t. PDFs of the two sets of results

- in a preliminary study
  we tried to assess the feasibility of an MW measurement at the LHCb and
  we checked the robustness of the PDF uncertainty reduction
  under pessimistic increases of the different error sources

- these encouraging results motivate
  further, more detailed studies of all the requirements needed to bring
  the experimental error in the 10-15 MeV ballpark
  and to control the other theoretical systematics (beyond PDFs) at a similar level

  special attention should be payed to the study of the ptZ distribution at LHCb
  and to the ptW/ptZ interplay

- the MW measurement at LHCb could offer a rich set of informations,
  complementary to those from ATLAS/CMS
  for the precision measurement of EW parameters at the LHC!

back-up

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

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

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)