UNIVERSITÀ DEGLI STUDI
DI MILANO

INFN
Istituto Nazionale
di Fisica Nucleare

# Precision SM physics at the LHC
# QCDxEW effects on MW

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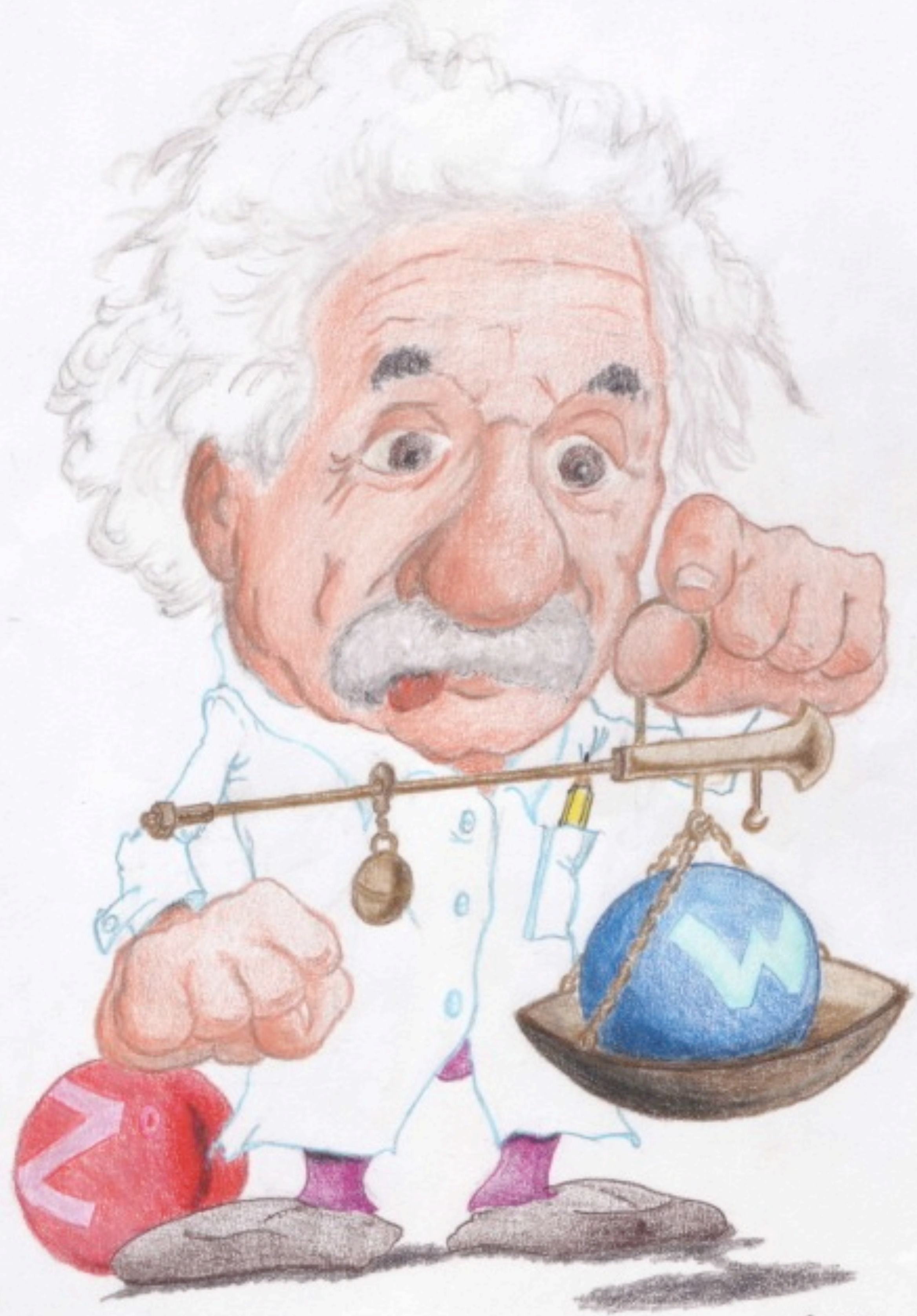
# The topics under discussion

- MW determination at hadron colliders: observables and techniques
- different classes of radiative corrections, theoretical uncertainties → impact on MW
    - final state QED corrections
    - EW and mixed QCDxEW corrections
    - PDF uncertainties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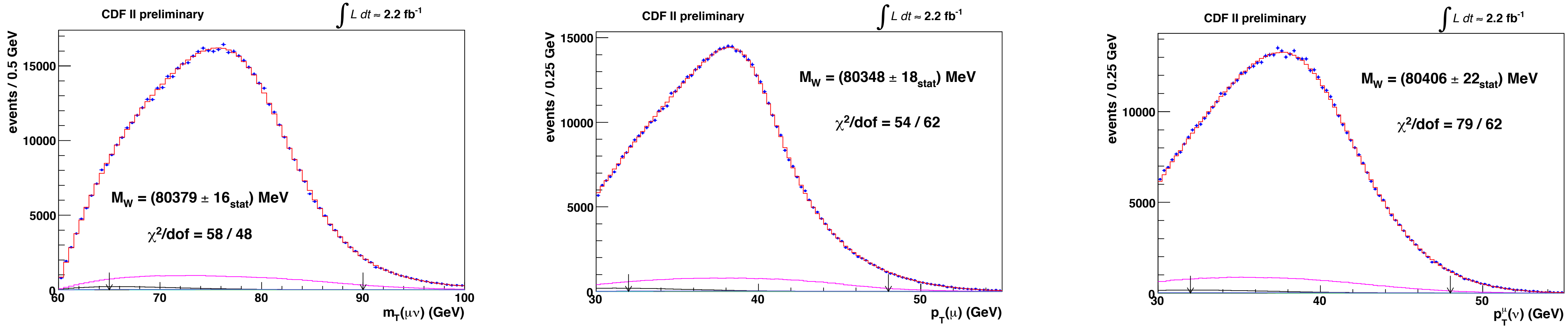
# MW determination at hadron colliders: observables and techniques




- MW extracted from study of the lepton-pair transverse mass, lepton transverse momentum, missing transverse momentum distributions thanks to the jacobian peak that enhances the sensitivity to MW

- MW is extracted with a template fit technique: the best available theoretical model (MC event generator including radiative corrections + detector simulation) is used to prepare templates (i.e. distributions) each with a different MW value;
  the template that best fits the data selects the corresponding MW value as the preferred MW

- The accuracy of the templates (missing higher order, PDF uncertainties, etc) is a source of theoretical systematic error on MW

- Challenging measurement:
  a distortion at the few per mil level of the distributions yields a shift of O(10 MeV) of the MW value

- Transverse mass: important detector smearing effects, moderate impact from the ptW modeling
  Lepton pt: moderate detector effects, extremely sensitive to the ptW modeling

# Available simulation tools

- analytic resummation of log(ptV/MV) with NNLL accuracy: ResBos arXiv:hep-ph/9704258
  with NNLO-QCD + NNLL accuracy DYRes arXiv:1507.06937
- QED FSR multiple photon description: Photos Comput.Phys.Commun. 79 (1994) 291-308
  HORACE 1.0 hep-ph/0303102, hep-ph/0502218
  PYTHIA QED arXiv:0710.3820
- NLO-EW corrections : WZGRAD hep-ph/9807417, hep-ph/0108274
  RADY hep-ph/0109062, arXiv:0911.2322
  SANC arXiv:hep-ph/0506110 , arXiv:0711.0625
- event generator with NLO-EW + QED-PS: HORACE 3.1 hep-ph/0609170, arXiv:0710.1722
- event generator with NLO-QCD + QCD-PS: POWHEG arXiv:0805.4802
- event generator with NLO-(QCD+EW) + (QCD+QED)-PS: POWHEG arXiv:1201.4804, arXiv:1202.0465, arXiv:1302.4606
- event generator with NNLO-QCD + QCD-PS accuracy: DYNNLOPS arXiv:1407.2940
  SHERPA@NNLO with UN$^2$LOPS arXiv:1405.3607

## The template-fit procedure applied to theoretical predictions

- the template fit allows to compare two theoretical models:
  one takes the role of the data and is used to generate one histogram (called pseudodata)
  with a fixed hypothesis for $MW_0$
  the other is used to generate several histograms (called templates) for different $MW_i$ values

- examples of "models": simulations using different PDF sets or including different sets of rad.corr.

- the comparison of the pseudodata with the different templates selects a preferred $M\hat{W}$ value

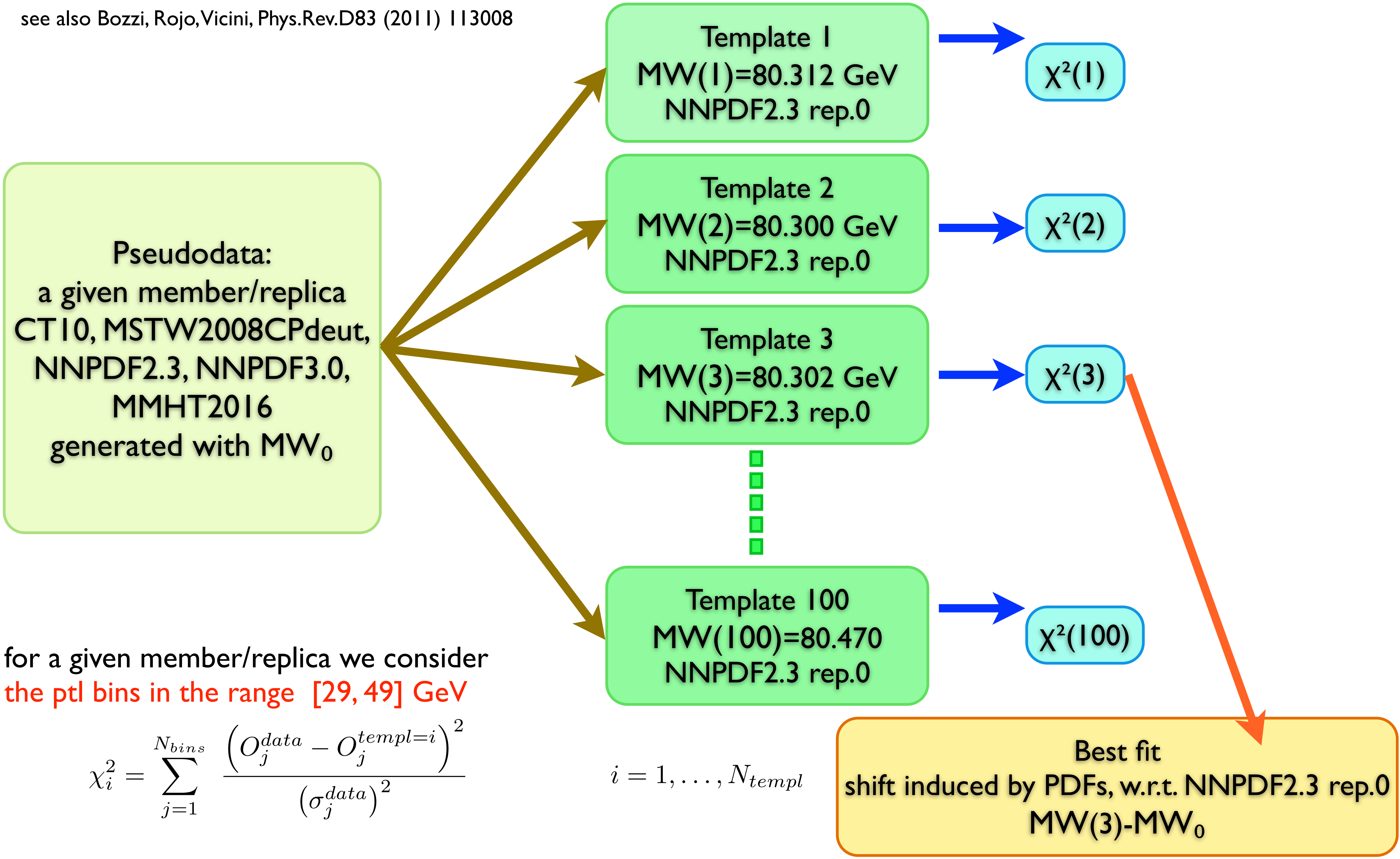
- the difference $M\hat{W}$ - $MW_0$ is an estimate of the difference that we would obtain
  if we would fit the real data once with model 1 and then with model 2

- this approach is used to classify the role of radiative corrections in the MW measurement
  e.g. if you do not include a given set of corrections, the result of the fit will be shifted by XXX MeV

→ the absence in the MW fit of available corrections must be quoted as a theoretical systematic error;
residual unknown effects induce an additional component of the theoretical component of the error

# The template-fitting procedure: PDF example

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

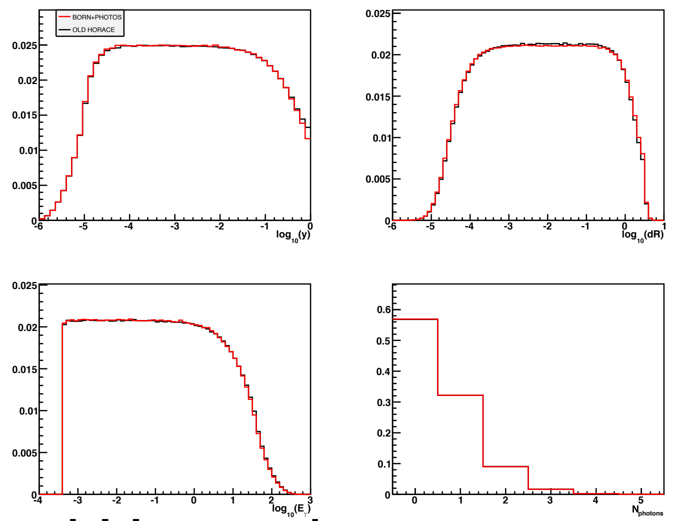
$$\chi^2_i = \sum_{j=1}^{N_{bins}} \frac{\left(O_j^{data} - O_j^{templ=i}\right)^2}{\left(\sigma_j^{data}\right)^2} \qquad i = 1, \ldots, N_{templ}$$

- 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

# Final state QED corrections

- Photos vs Horace

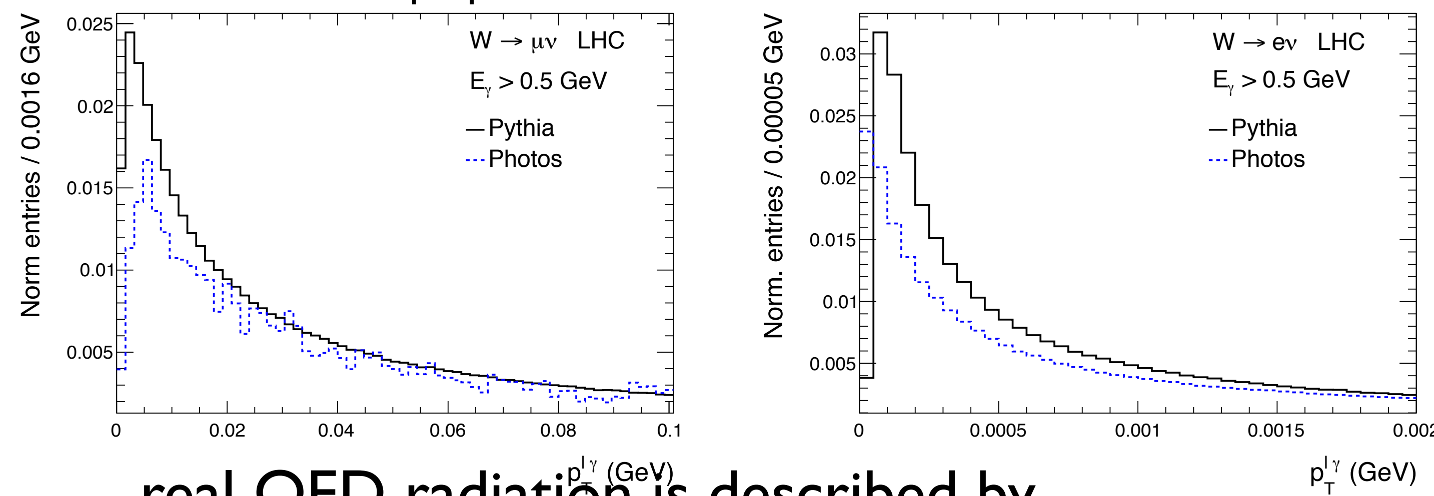
Kotwal, Jayatilaka, arXiv:1510.02458



Photos and Horace have very good agreement
differences on MW at 2 MeV level

- Photos vs PYTHIA QED-PS

CCMMNPV, in preparation




real QED radiation is described by
an angle in Photos and by the relative pt in PYTHIA
→ differences at small relative pt

- template fit based on HORACE LO templates (no detector simulation), bare leptons

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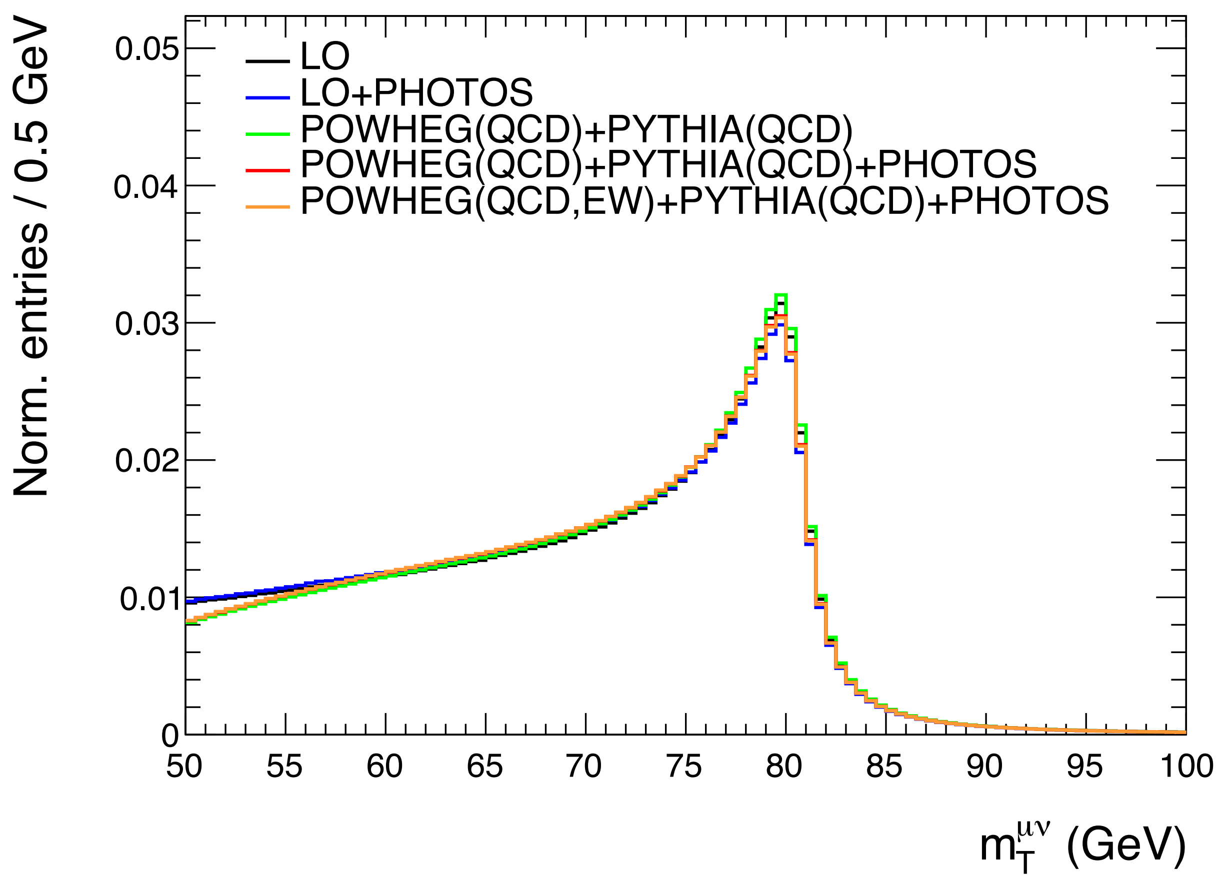
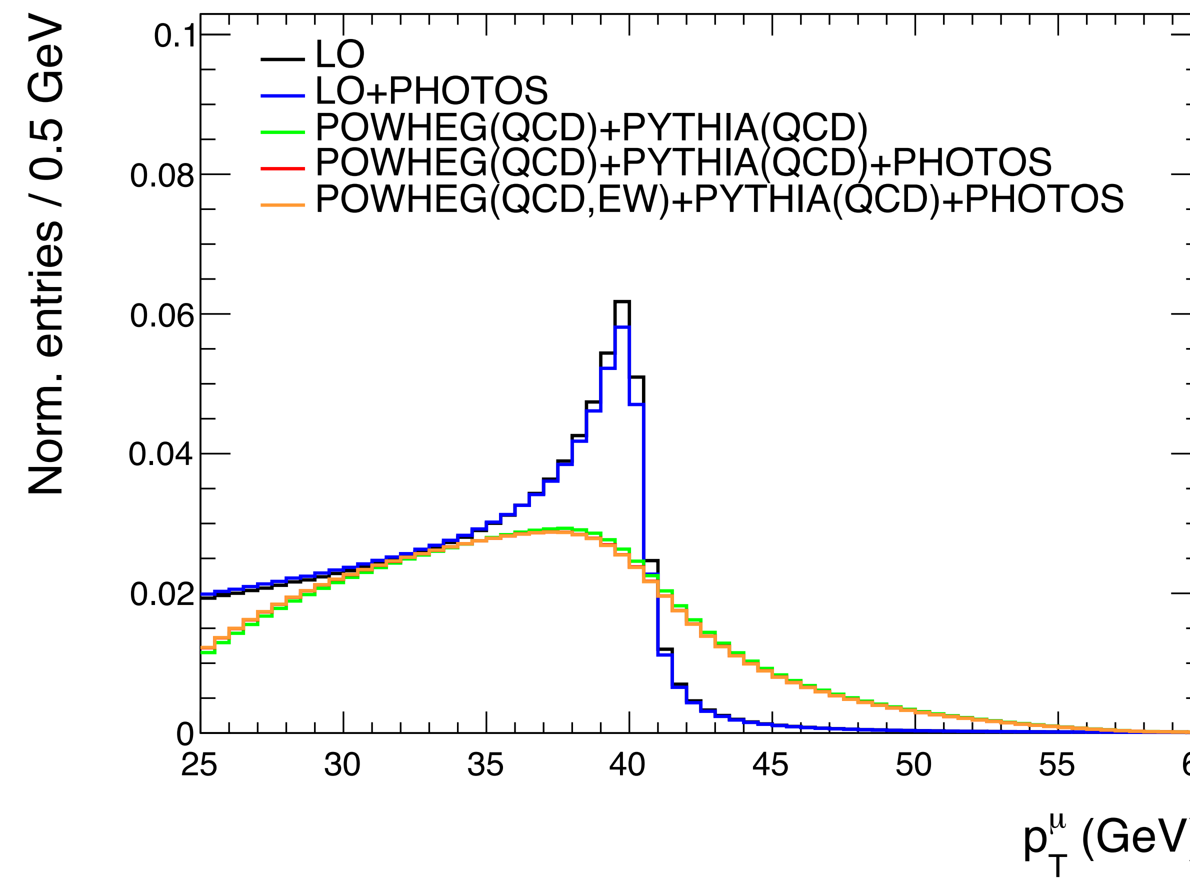
· shifts of O(100 MeV) for muons and of O(200 MeV) for bare electrons; similar shifts for MT and ptl
· multiple photon radiation reduce the impact of the first photon emission
· the effect of weak and subleading QED terms, in HORACE matched, at the few MeV level
· the emission of additional pairs yields a shift of O(3-5 MeV) with the same sign of the first photon
the shift depends on the emitting lepton

# Combining QCD and QED-FSR (I)



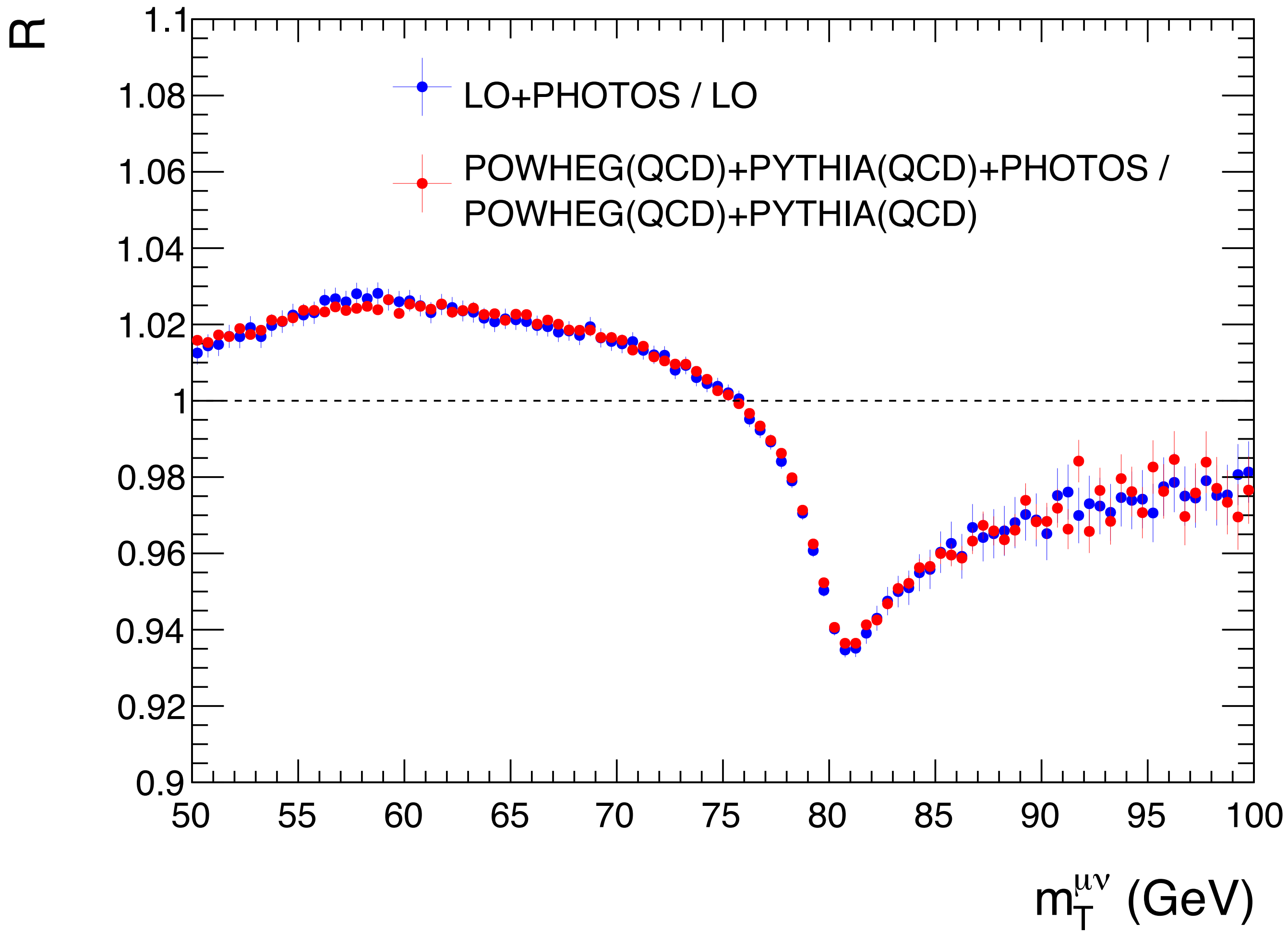

- the transverse mass does not receive large QCD corrections (the log(ptV/mV) terms cancel) the lepton pt instead requires the resummation to all orders of log(ptV/mV) enhanced terms (lepton pt stems from W decay but also from the W recoil against QCD radiation, coll.div.)

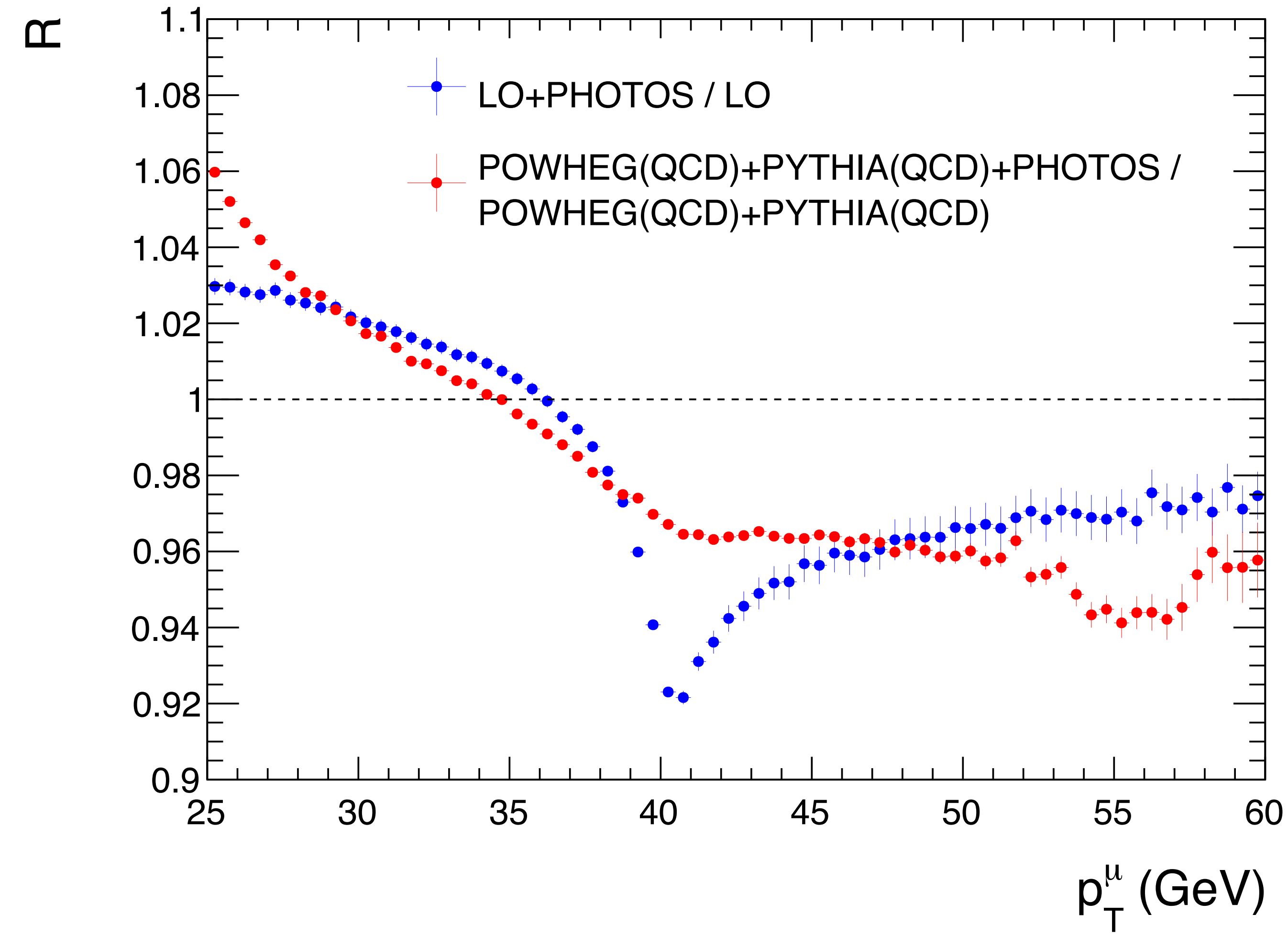
- we call "production model" the purely QCD description adopted as lowest order approximation to simulate all the relevant observables (at the Tevatron the choice was on ResBos) ; the templates used in the analysis are based on this model (the shifts are expressed in this unit) the following results are based on POWHEG NLO-QCD + QCD-PS (Pythia 8.1)

- → are QED-FSR effects preserved after the convolution with QCD radiation?
  → how large are the mixed $O(\alpha\alpha_s)$ QCDxQED effects induced by the convolution?
  → how sensitive are mixed corrections to the exact description of the kinematics of the process?

# Combining QCD and QED-FSR (I)

- comparison of the impact of QED FSR in presence of two different "production models":
  LO vs NLO-(QCD) + (QCD)-PS



# Combining QCD and QED-FSR (II)

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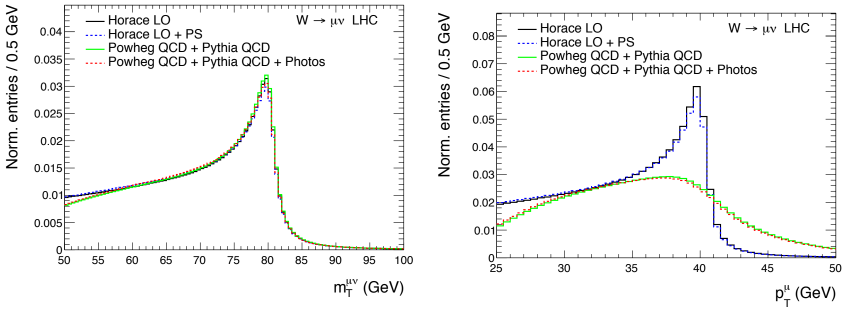


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| Templates: NLO-QCD+QCD$_{PS}$ | | | $M_W$ shifts (MeV) | | | | | |
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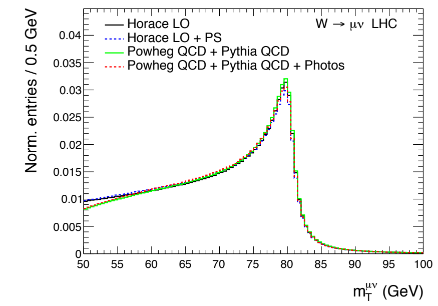


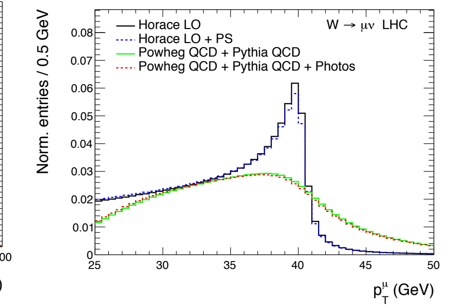


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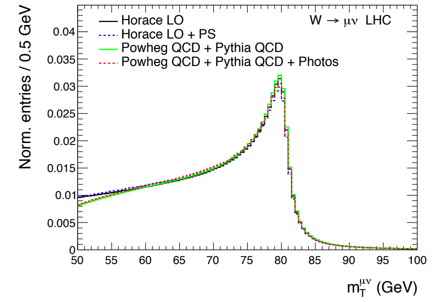


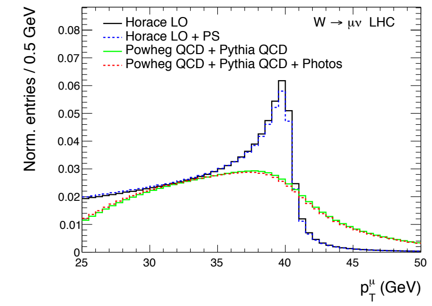


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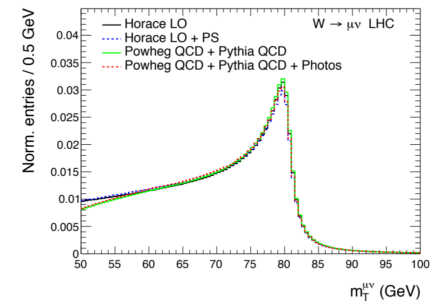


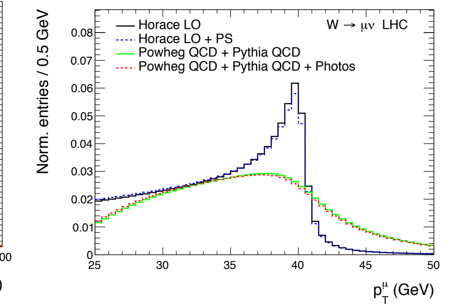


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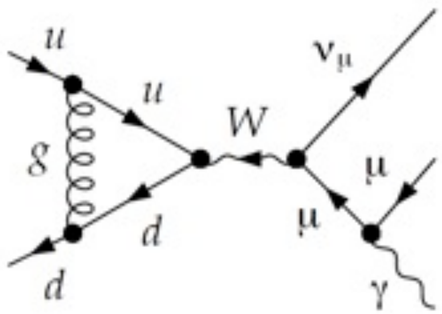
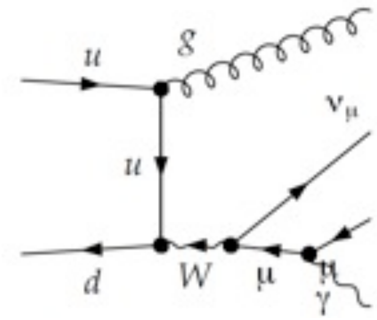
  → enhancement of the QED effects, sensitivity to QCD details)
  a large fraction of these effects already part of the current analyses
  (ResBos x Photos, POWHEG x Photos)
- the different QED modeling by Photos vs Pythia (at low emission angles / relative pt) is evident with bare leptons and disappears with dressed electrons

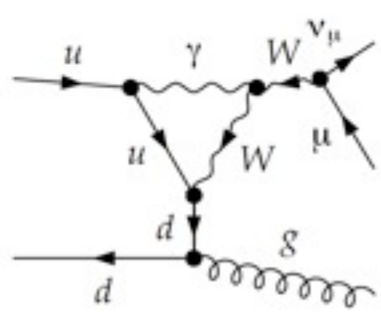
# Classification of mixed $O(\alpha\alpha_s)$ QCDxEW corrections

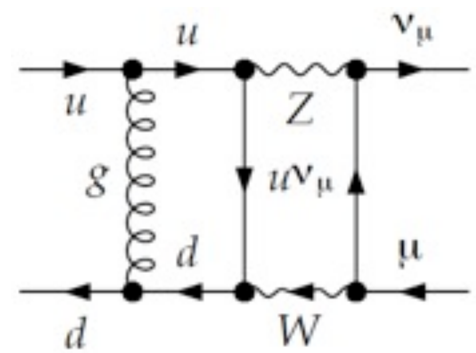
- The bulk of the $O(\alpha\alpha_s)$ corrections relevant for the MW determination, i.e. QCDxQED, can be obtained with a combination of QCD-ISR and QED-FSR codes




- The full set of $O(\alpha\alpha_s)$ corrections (challenging 2-loop calculation) is not yet available



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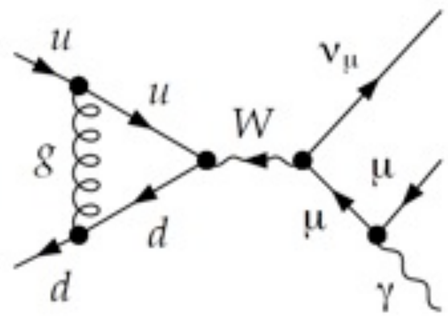


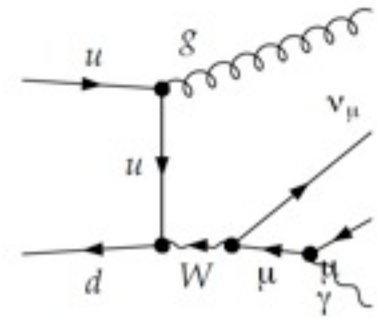


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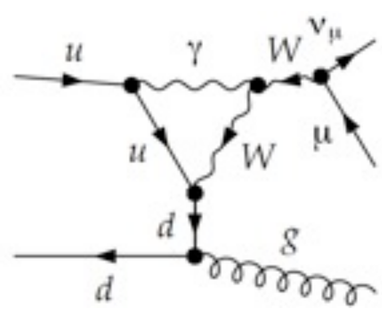
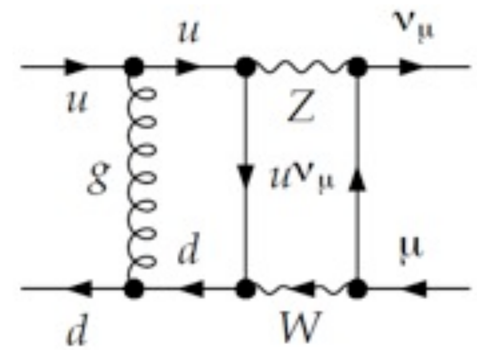



- POWHEG NLO-(QCD+EW)
  - it has NLO-(QCD+EW) accuracy on the total cross section
  - it describes with exact matrix elements the hardest parton (gluon, quark, photon) emission
  - it includes to all orders QCD and QED effects via Parton Shower

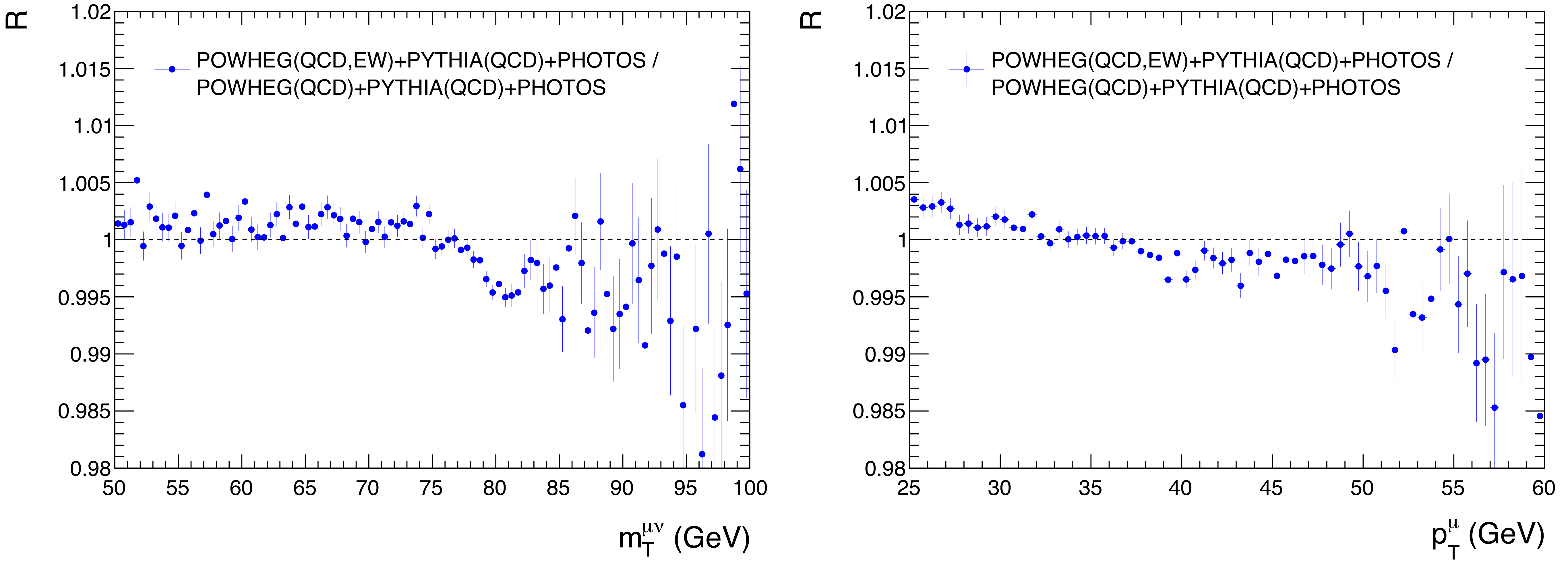
$$d\sigma = \sum_{f_b} \bar{B}^{f_b}(\mathbf{\Phi}_n)\, d\mathbf{\Phi}_n \left\{ \Delta^{f_b}(\mathbf{\Phi}_n, p_T^{min}) + \sum_{\alpha_r \in \{\alpha_r | f_b\}} \frac{\left[ d\Phi_{rad}\, \theta(k_T - p_T^{min})\, \Delta^{f_b}(\mathbf{\Phi}_n, k_T)\, R(\mathbf{\Phi}_{n+1})\right]_{\alpha_r}^{\bar{\mathbf{\Phi}}_n^{\alpha_r} = \mathbf{\Phi}_n}}{B^{f_b}(\mathbf{\Phi}_n)} \right\}$$

- non-trivial interplay between NLO-EW corrections and QCD radiation factors

  → a new subset of factorizable O(αα$_s$) subleading corrections is available
  (missing in the Tevatron analysis)

# Combining QCD and EW corrections

- comparison of the impact of full EW corrections
  as implemented in POWHEG NLO-(QCD+EW) + (QCD+QED)-PS
  with respect to
  POWHEG NLO-(QCD) + (QCD+QED)-PS



# Results (preliminary) for the Tevatron (generator level)

| Templates: NLO QCD+QCD$_{PS}$ Pseudodata: (+QCD$_{PS}$) ME accuracy | QED FSR | $M_W$ shifts (MeV) $W^+ \to \mu^+\nu$ $M_T$ | $W^+ \to \mu^+\nu$ $p_T^\ell$ | $W^+ \to e^+\nu$ $M_T$ | $W^+ \to e^+\nu$ $p_T^\ell$ | $W^+ \to e^+\nu$(dres) $M_T$ | $W^+ \to e^+\nu$(dres) $p_T^\ell$ |
|---|---|---|---|---|---|---|---|
| 1 NLO QCD | PYTHIA | -90±2 | -310±4 | -155±1 | -543±4 | -37±1 | -116±3 |
| 2 NLO QCD | PHOTOS | -83±2 | -281±3 | -166±1 | -563±4 | -37±1 | -117±3 |
| 3 NLO QCD+EW | PYTHIA | -96±1 | -318±4 | -159±2 | -558±3 | -42±1 | -128±4 |
| 4 NLO QCD+EW | PHOTOS | -89±1 | -295±3 | -171±1 | -576±3 | -42±1 | -129±3 |

- NLO-QCD vs NLO-(QCD+EW) POWHEG always with QCD-PS
  always with PHOTOS as QED final state shower

  the shift is due to the presence of
  - exact EW O(α)
  - mixed QCDxEW O($\alpha\alpha_s$) effects

  these effects are not accounted for in the approximation 2), i.e. in QCDx(QED-FSR)

- the effects are almost independent of the lepton flavor (mass) or of the bare/dressed definition
  larger for the ptl results

- effects not accounted for in the Tevatron analyses (ResBos x PHOTOS)
  nor in a combination (POWHEG-QCD x PHOTOS)

  ⇒ assessment of the uncertainty of the current Tevatron analyses (still generator level)

# Results (preliminary) for the LHC (generator level)

| Templates: NLO QCD+$\text{QCD}_{\text{PS}}$ Pseudodata: (+$\text{QCD}_{\text{PS}}$) | | | $M_W$ shifts (MeV) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | $W^+ \to \mu^+\nu$ | | $W^+ \to e^+\nu$ | | $W^+ \to e^+\nu$(dres) | |
| | ME accuracy | QED FSR | $M_T$ | $p_T^\ell$ | $M_T$ | $p_T^\ell$ | $M_T$ | $p_T^\ell$ |
| 1 | NLO QCD | PYTHIA | -95.4±0.6 | -399±2 | -164.1±0.6 | -727±3 | -37.8±0.6 | -149±3 |
| 2 | NLO QCD | PHOTOS | -87.8±0.6 | -368±2 | -162.5±0.6 | -685±2 | -38.2±0.6 | -153±2 |
| 3 | NLO QCD+EW | PYTHIA | -102.0±0.6 | -426±2 | -171.5±0.8 | -760±3 | -44.8±0.6 | -182±2 |
| 4 | NLO QCD+EW | PHOTOS | -94.4±0.6 | -391±3 | -170.5±0.6 | -715±3 | -45.6±0.4 | -181±2 |

# Results (preliminary) for the LHC (generator level)

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# Results (preliminary) for the LHC (detector level: simulation with DELFES)

| | Templates: NLO QCD+QCD$_{PS}$ Pseudodata: (+QCD$_{PS}$) ME accuracy | QED FSR | $M_W$ shifts (MeV) $W^+ \to \mu^+\nu$ $M_T$ | $p_T^\ell$ | $W^+ \to e^+\nu$ $M_T$ | $p_T^\ell$ |
|---|---|---|---|---|---|---|
| 1 | NLO QCD | PHOTOS | -114±3 | -199±5 | -333±2 | -571±4 |
| 2 | NLO QCD+EW | PHOTOS | -129±2 | -224±4 | -347±2 | -595±4 |

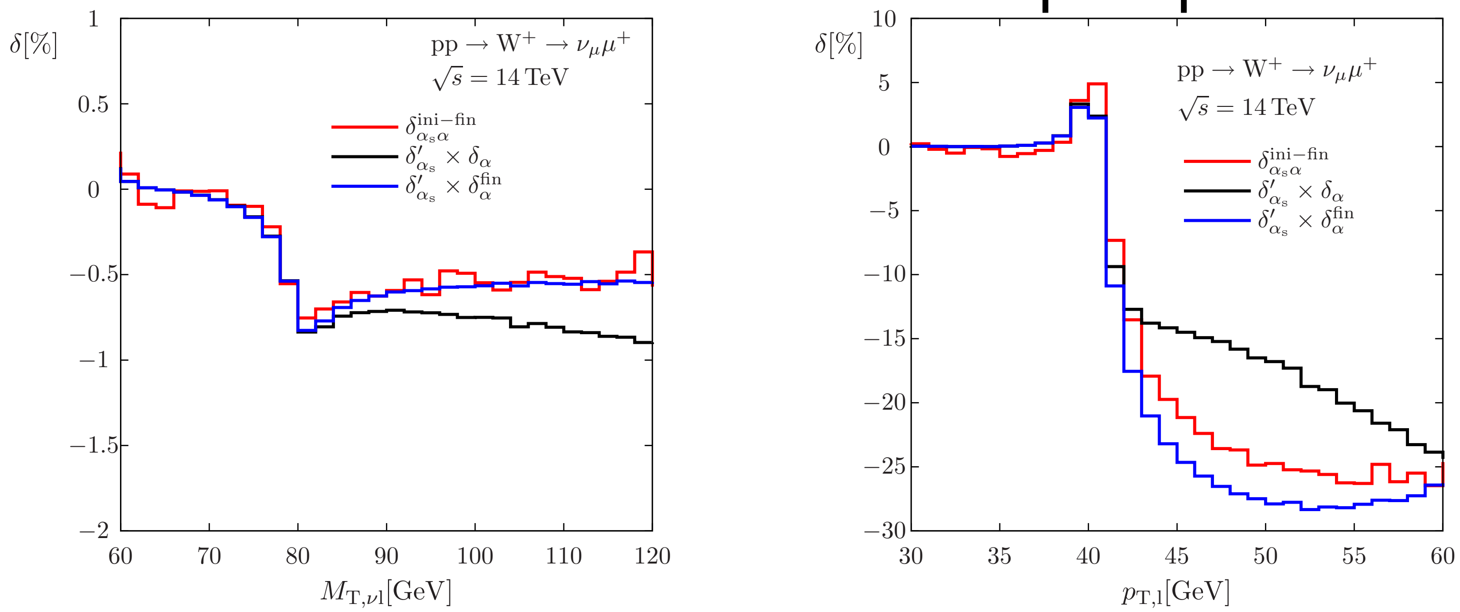
- transverse mass: distortion of the reference shape (POWHEG QCD x Photos)
  estimate of the additional QCDxEW effects amplified by a factor of O(2)

- lepton pt: distortion of the reference shape (POWHEG QCD x Photos)
  moderate change of the size of the additional QCDxEW effects

# Approximations of O(αα_s) corrections

- evaluation of the O(αα_s) corrections at the W resonance (pole approximation)
  Dittmaier, Huss, Schwinn, arXiv:1403.3216, arXiv:1405.6897
- non-factorizable corrections are estimated to be phenomenologically negligible for a measurement at the resonance (e.g. W mass)

- the factorizable corrections are computed in pole approximation and compared with the product of 1-loop correction factors
  → the "naive" 1-loop approximation reproduces the pole approximation for the transverse mass
  deviates in the lepton pt case



# Approximations of O(αα$_s$) corrections

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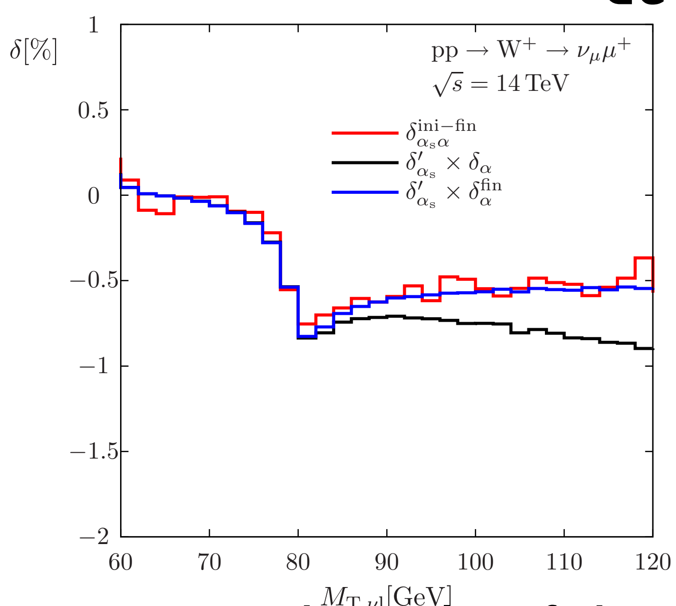
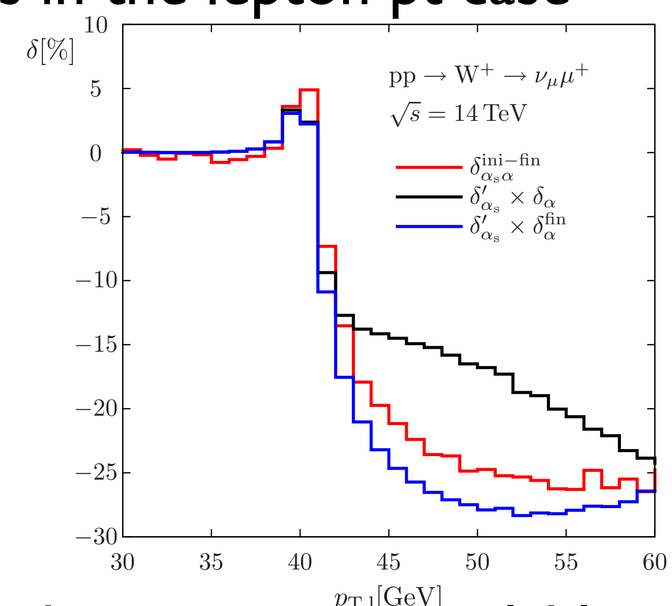
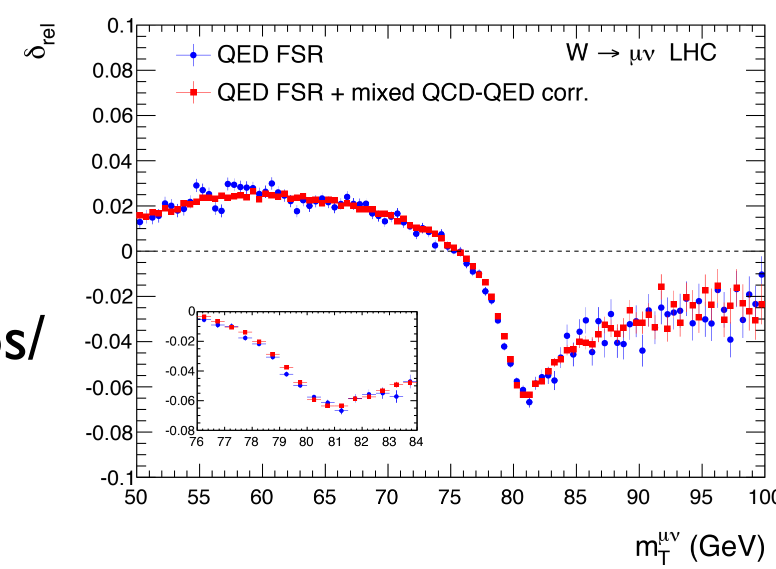
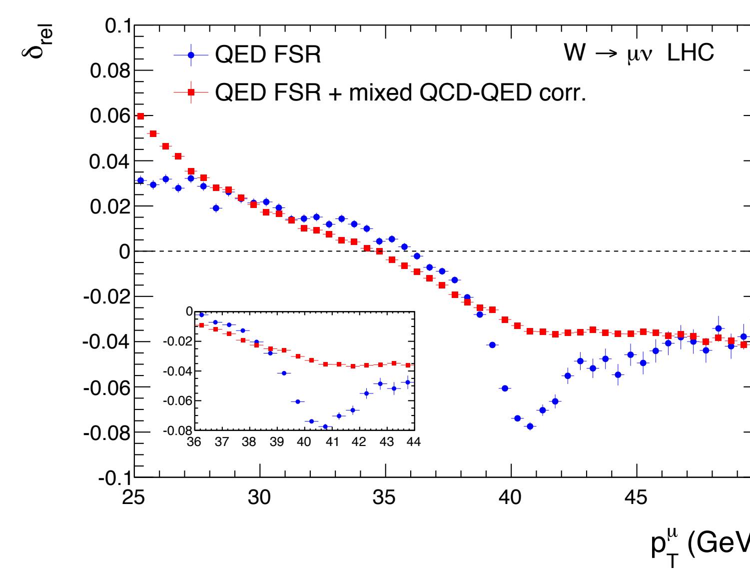


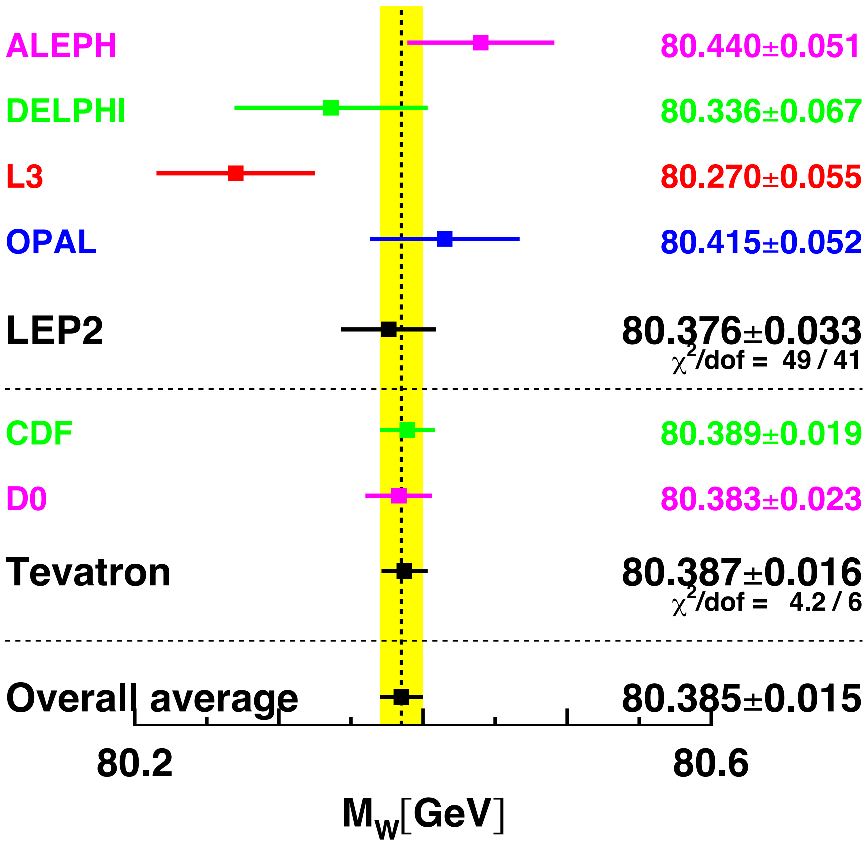

→ in the lepton pt case, the role of the exact kinematics, as available in Monte Carlo generators yields an estimate of mixed corrections closer to the pole approximation
on-going comparison with DHS

Photos/LO
vs
POWHEG QCD x Photos/
POWHEG QCD
CCMMNPV in preparation



# MW measurement: errors as in CDF paper arXiv:1311.0894




Are PDF uncertainties under control?

There is no pQCD uncertainty estimate

The treatment of NLO-EW effects must be updated

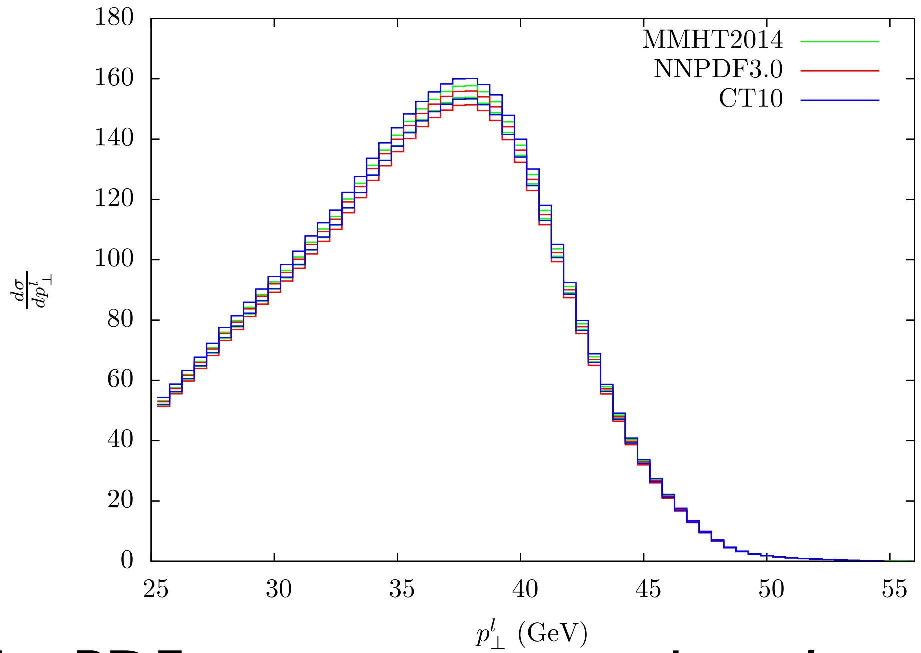
| $m_T$ fit uncertainties | | | |
|---|---|---|---|
| Source | $W \to \mu\nu$ | $W \to e\nu$ | Common |
| Lepton energy scale | 7 | 10 | 5 |
| Lepton energy resolution | 1 | 4 | 0 |
| Lepton efficiency | 0 | 0 | 0 |
| Lepton tower removal | 2 | 3 | 2 |
| Recoil scale | 5 | 5 | 5 |
| Recoil resolution | 7 | 7 | 7 |
| Backgrounds | 3 | 4 | 0 |
| PDFs | 10 | 10 | 10 |
| $W$ boson $p_T$ | 3 | 3 | 3 |
| Photon radiation | 4 | 4 | 4 |
| Statistical | 16 | 19 | 0 |
| Total | 23 | 26 | 15 |

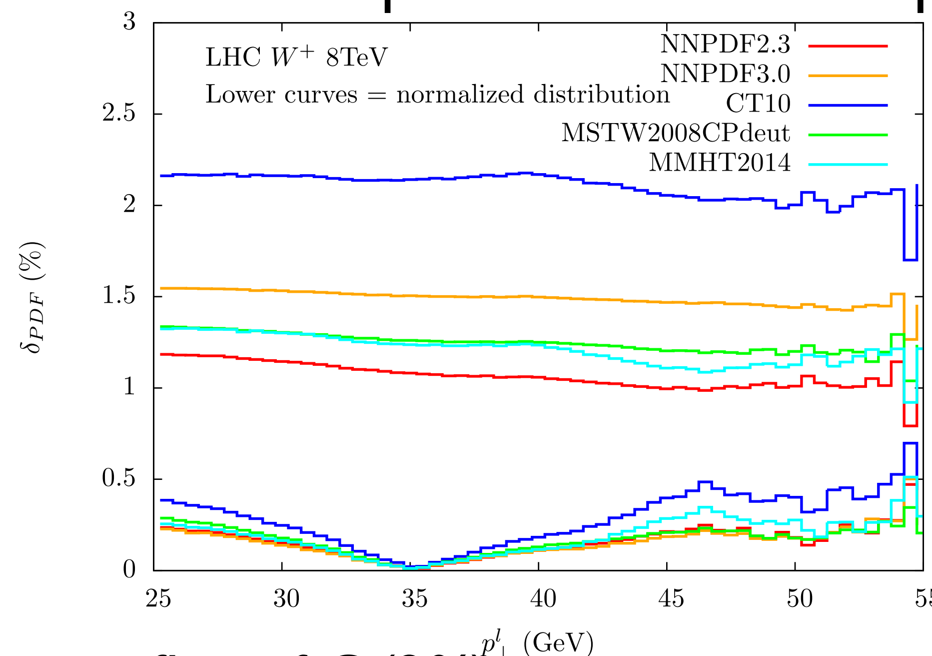
| $p_T^\ell$ fit uncertainties | | | |
|---|---|---|---|
| Source | $W \to \mu\nu$ | $W \to e\nu$ | Common |
| Lepton energy scale | 7 | 10 | 5 |
| Lepton energy resolution | 1 | 4 | 0 |
| Lepton efficiency | 1 | 2 | 0 |
| Lepton tower removal | 0 | 0 | 0 |
| Recoil scale | 6 | 6 | 6 |
| Recoil resolution | 5 | 5 | 5 |
| Backgrounds | 5 | 3 | 0 |
| PDFs | 9 | 9 | 9 |
| $W$ boson $p_T$ | 9 | 9 | 9 |
| Photon radiation | 4 | 4 | 4 |
| Statistical | 18 | 21 | 0 |
| Total | 25 | 28 | 16 |

# PDF uncertainty affecting MW extracted from the ptlep distribution

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

Conservative estimate of the PDF uncertainty, obtained from the CC-DY channel alone, using a template fit approach:
distributions obtained with POWHEG+PYTHIA 6.4, different PDF replicas are treated as pseudodata




- The PDF uncertainty over the relevant ptl range is almost flat, of O(2%)
  the normalized distributions have an uncertainty below the O(0.5%) level,
  still sufficient to yield large MW shifts

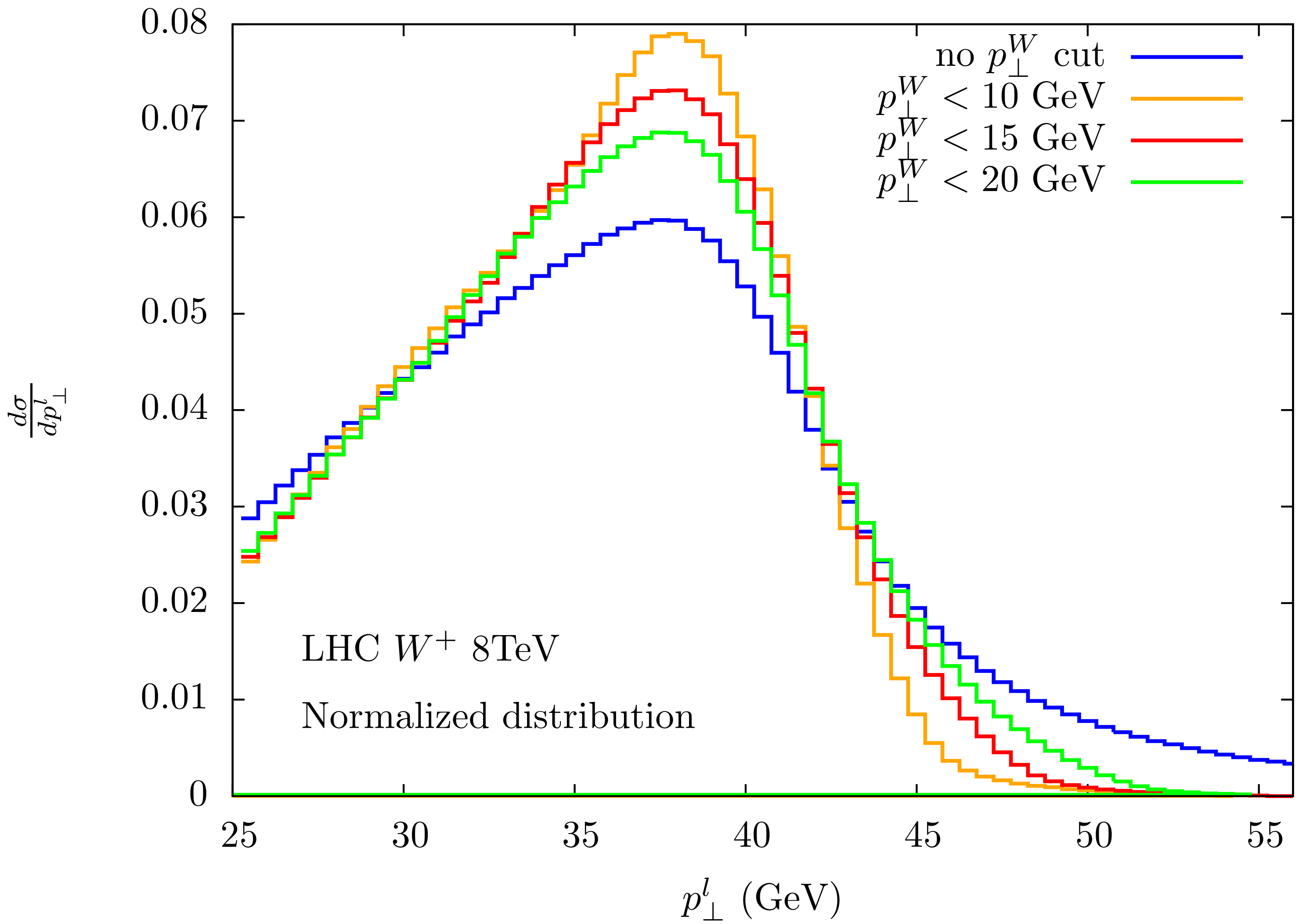
- Given a reference PDF set (NNPDF2.3 replica 0)
  we estimate which would be the difference in the fit of the data
  if we would use a different PDF replica in the preparation of the templates

We combine the resulting MW values according to the prescriptions of the different groups

Hessian $$\sigma_X^2 = \frac{1}{4}\sum_{k=1}^{N}[X(S_k^+) - X(S_k^-)]^2$$

MonteCarlo (NNPDF) $$\sigma_X^2 = \frac{1}{N_{\rm rep}-1}\sum_i^{N_{\rm rep}}[X^i - X]^2$$

# Shape of the ptlep distribution as a function of a cut on PTW

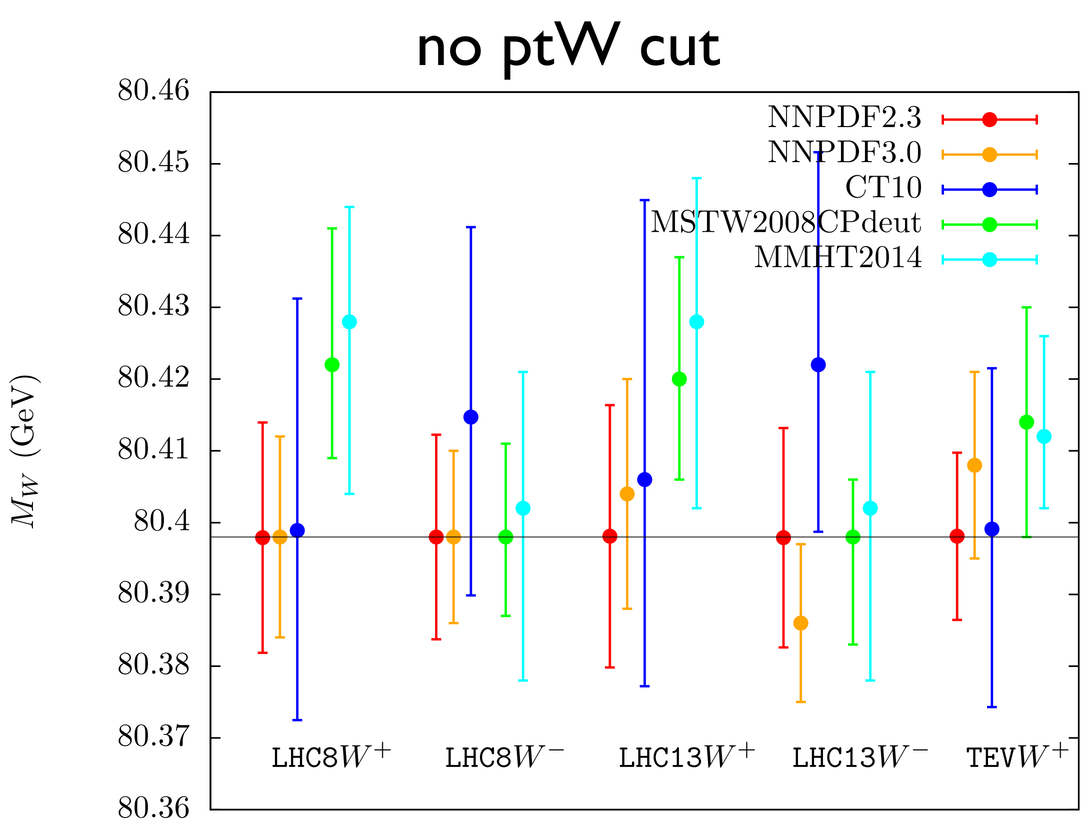


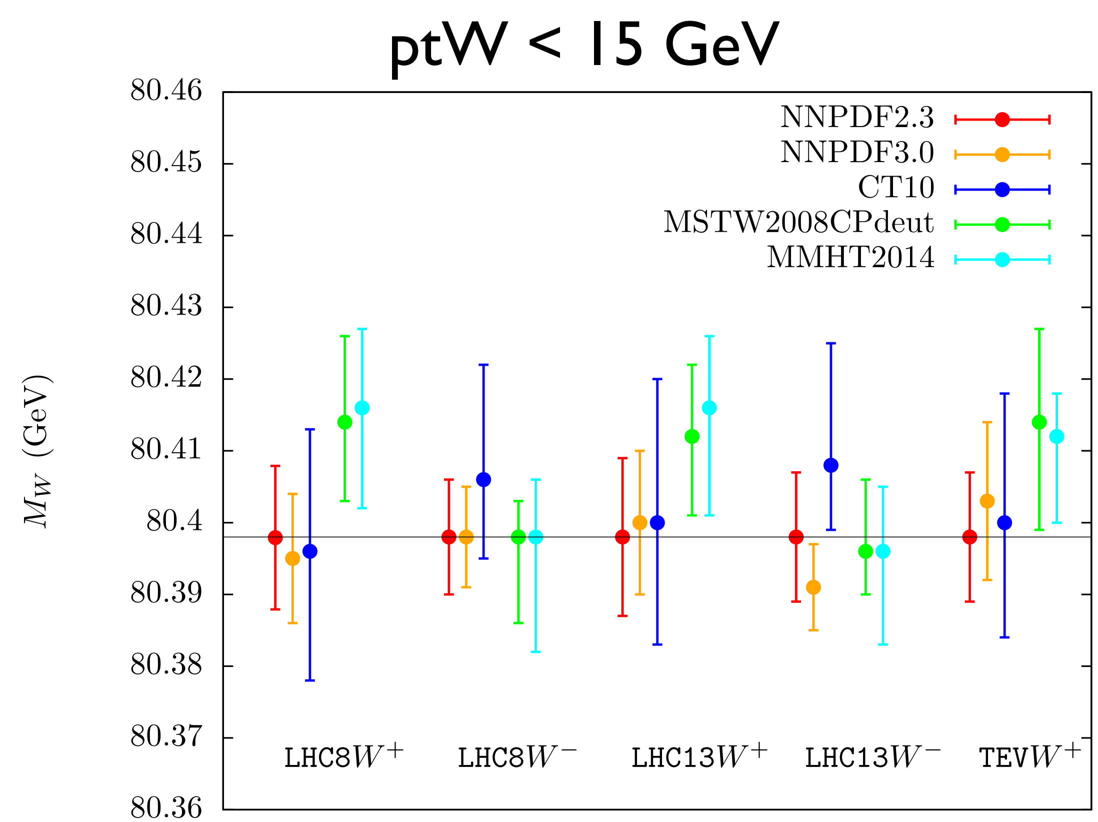

- The steeper the distribution, the stronger the sensitivity to MW

  large shifts are disfavored → the uncertainty is reduced

# PDF uncertainty affecting MW extracted from the ptlep distribution

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




| | no $p_\perp^W$ cut | | $p_\perp^W < 15$ GeV | |
|---|---|---|---|---|
| | $\delta_{PDF}$ (MeV) | $\Delta_{sets}$ (MeV) | $\delta_{PDF}$ (MeV) | $\Delta_{sets}$ (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 |

the PDF4LHC recipe defines
the half-width of the envelope $\delta_{PDF}$
and the spread of the central values $\Delta_{sets}$

- Contrary to the transverse mass case, we do not expect large detector effects on these results

- Modern individual PDF sets provide not-pessimistic estimates , ΔMW ~ O(10 MeV), but the global envelope still shows large discrepancies of the central values

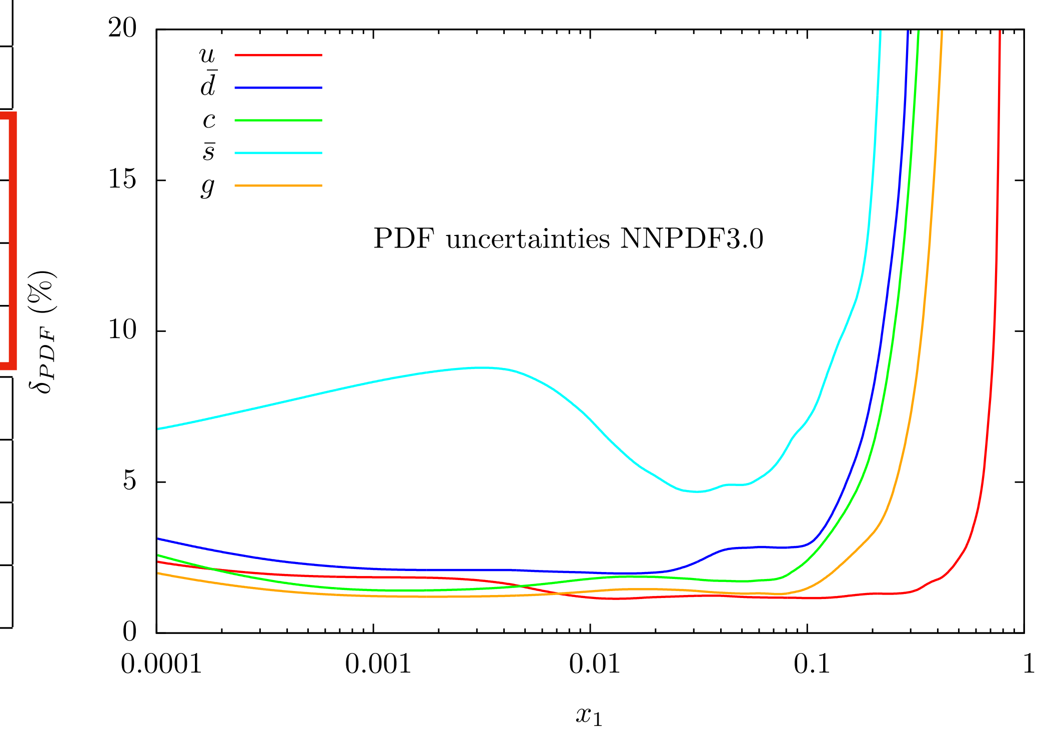
- The Tevatron analyses did not adopt the PDF4LHC approach

# PDF uncertainty affecting MW and acceptance cuts

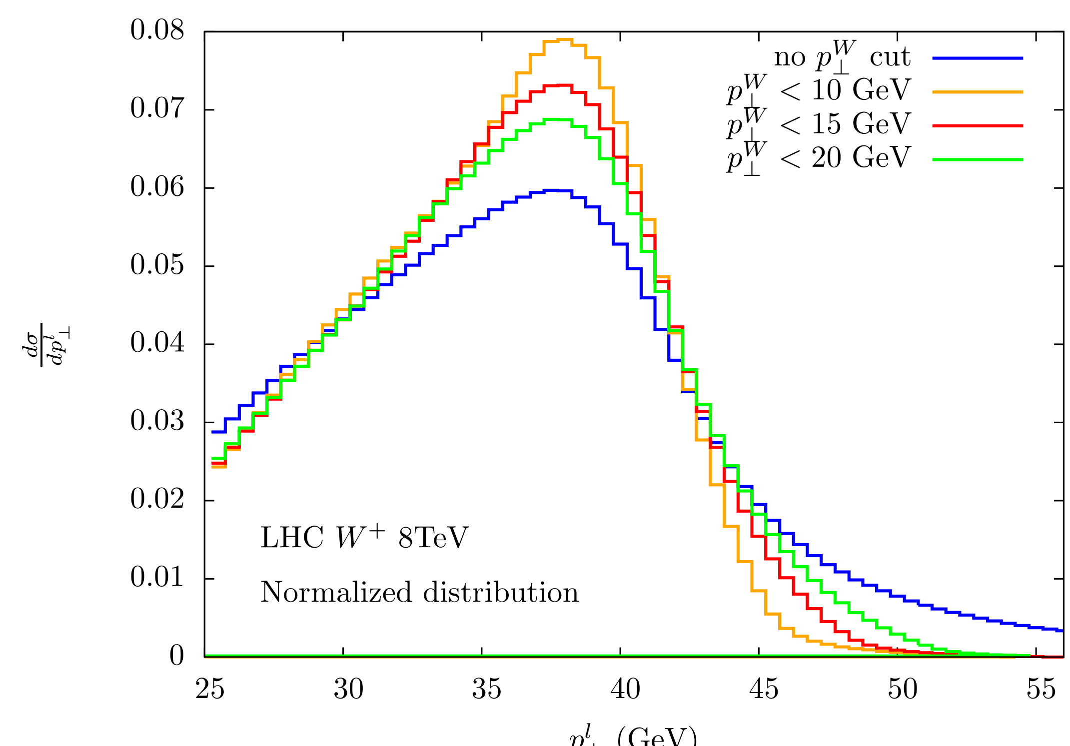
G.Bozzi, L.Citelli, AV, arXiv:1501.05587

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 | $\|\eta_l\| < 2.5$ | $80.400 + 0.032 - 0.027$ | $80.398 \pm 0.014$ |
| $p_\perp^W < 20$ GeV | $\|\eta_l\| < 2.5$ | $80.396 + 0.027 - 0.020$ | $80.394 \pm 0.012$ |
| $p_\perp^W < 15$ GeV | $\|\eta_l\| < 2.5$ | $80.396 + 0.017 - 0.018$ | $80.395 \pm 0.009$ |
| $p_\perp^W < 10$ GeV | $\|\eta_l\| < 2.5$ | $80.392 + 0.015 - 0.012$ | $80.394 \pm 0.007$ |
| $p_\perp^W < 15$ GeV | $\|\eta_l\| < 1.0$ | $80.400 + 0.032 - 0.021$ | $80.406 \pm 0.017$ |
| $p_\perp^W < 15$ GeV | $\|\eta_l\| < 2.5$ | $80.396 + 0.017 - 0.018$ | $80.395 \pm 0.009$ |
| $p_\perp^W < 15$ GeV | $\|\eta_l\| < 4.9$ | $80.400 + 0.009 - 0.004$ | $80.401 \pm 0.003$ |
| $p_\perp^W < 15$ GeV | $1.0 < \|\eta_l\| < 2.5$ | $80.392 + 0.025 - 0.018$ | $80.388 \pm 0.012$ |




- the additional cut on PTW reduces the MW uncertainty
  - suppression of the large-*x* region
  - steeper shape of the ptlep distribution



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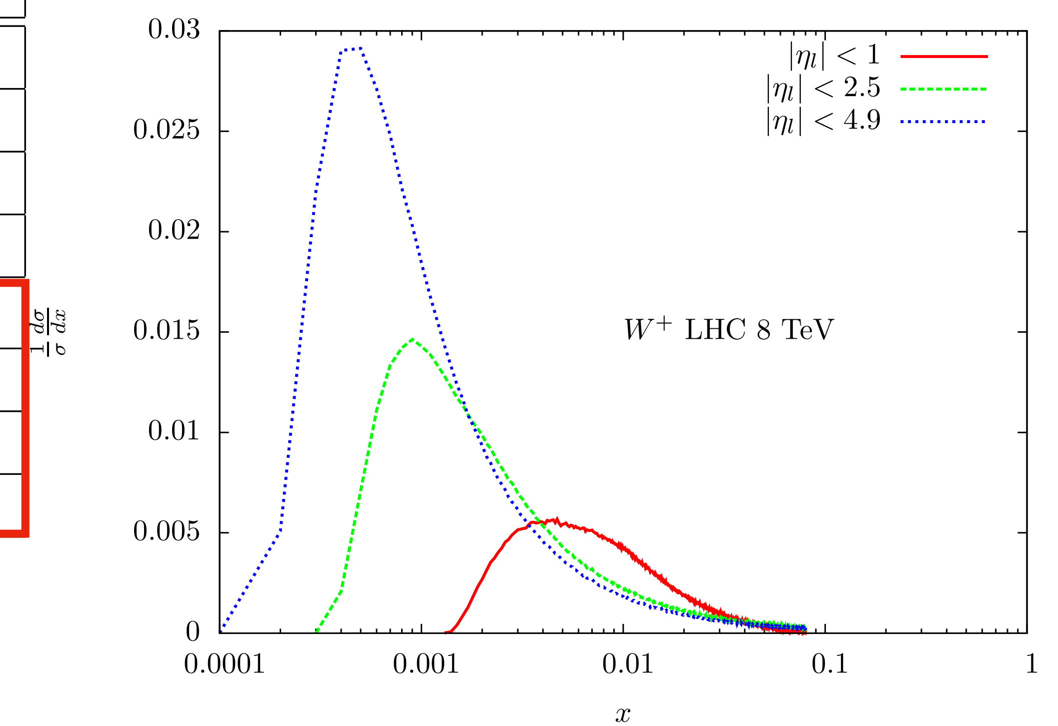
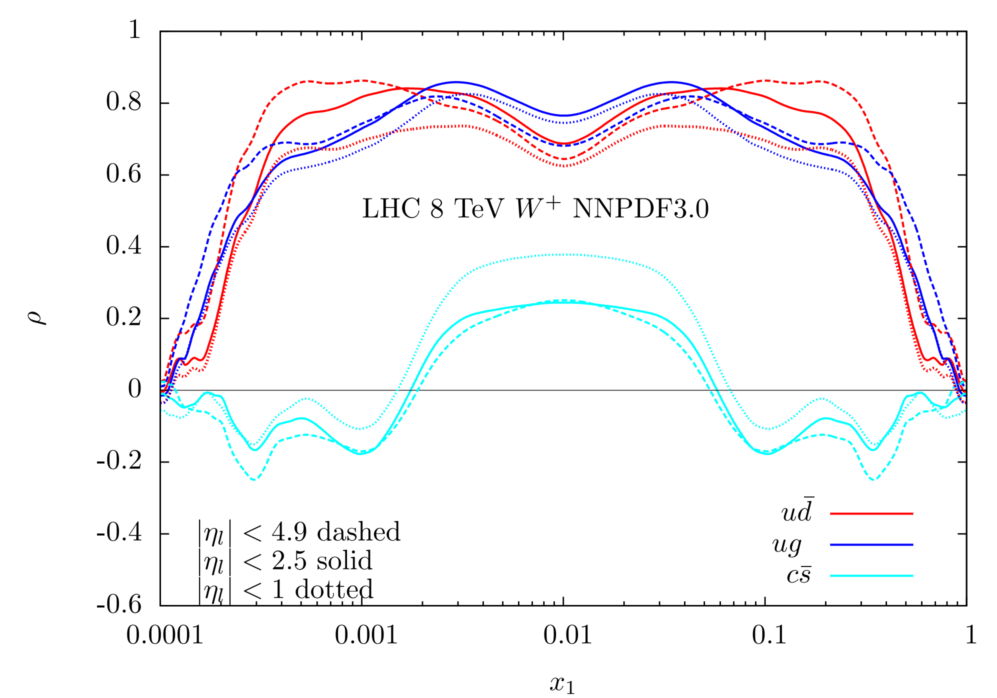
| $p_\perp^W < 15$ GeV | $\lvert\eta_l\rvert < 2.5$ | $80.396 + 0.017 - 0.018$ | $80.395 \pm 0.009$ |
| $p_\perp^W < 15$ GeV | $\lvert\eta_l\rvert < 4.9$ | $80.400 + 0.009 - 0.004$ | $80.401 \pm 0.003$ |
| $p_\perp^W < 15$ GeV | $1.0 < \lvert\eta_l\rvert < 2.5$ | $80.392 + 0.025 - 0.018$ | $80.388 \pm 0.012$ |




- cut on the lepton pseudorapidity
  - 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 region is the most uncertain
  - PDF sum rules → non trivial compensations between different rapidity intervals among different flavors



# Attempts to reduce the PDF uncertainties on MW

are PDFs a bottleneck for MW? can we improve over the present status? 3 complementary answers:

1) more inputs to the PDF fit (e.g. NNPDF2.3 vs NNPDF3.0)

2) use of the ptZ info (ratios W/Z) in order to account for the correlations between CC and NC
more in general look for observables sensitive to MW and/or to the uncertainty source

3) exploit different kinematical regions of the CC-DY process

G.Bozzi, L.Citelli, AV, arXiv:1501.05587
S.Quackenbush, Z.Sullivan, arXiv:1502.04671
A.Bodek, J.Y.Han, A.Khukhunaishvili, W.Sakumoto, arXiv:1507.04965, arXiv:1507.02470
G.Bozzi, L.Citelli, M.Vesterinen, AV, arXiv:1508.06954

# 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
  for ATLAS/CMS (called **G**) and for LHCb (called **L**) and both W charges
  we study the MW determination from the lepton pt distribution
  assuming that a LHCb measurement becomes available

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

  - PDF uncertainty on MW according to PDF4LHC (NNPDF3.0, MMHT2014)

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

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

  - the linear combination that minimizes the final uncertainty on MW
    is given by the coefficients α

$$m_W = \sum_{i=1}^{4} \alpha_i m_{W\ i} \qquad \alpha = \begin{pmatrix} \mathbf{G}+ & 0.30 \\ \mathbf{G}- & 0.45 \\ \mathbf{L}+ & 0.21 \\ \mathbf{L}- & 0.04 \end{pmatrix}$$

- the exercise is robust under conservative assumptions for the LHCb main systematic uncertainties and guarantees a reduction by 30% of the PDF uncertainty estimated for ATLAS/CMS alone

- potential serious bottleneck for a measurement based on ptl: ptW modeling in the LHCb acceptance

# Conclusions

- preliminary results for the
  quantitative assessment of the effect on MW of QED and mixed QCDxEW radiative corrections
  based on the comparison of distributions generated with
  Horace, Photos, POWHEG NLO-QCD and POWHEG NLO-(QCD+EW)
  → non negligible contribution (in a 10 MeV perspective)
  of additional lepton pairs and of mixed QCDxEW terms;
  these effects should be included in the analysis (or accounted for in the th. systematic error)

- the combination of QCD and EW corrections still suffers of (matching) ambiguities
  that only explicit analytical results at $O(\alpha\alpha_s)$ may fix

- important progresses in the development of pQCD simulation tools
  what is the correct strategy to estimate the QCD error MW?
  how can we discuss the interplay between perturbative and non-perturbative effects
  W, Z and other observables?
  (i.e. the transfer of information from other processes to CC-DY and
  the estimate of the associated error)
- a global analysis with the simultaneous variation of all the different non-pert QCD factors
  may be the correct approach to achieve a realistic estimate of the corresponding errors

- the MW measurement is a very complex problem and a training ground of our tools and techniques
  that could be applied to other precision observables at the LHC in the future
  a precise determination of MW might help us to recognize BSM signals or provide an additional
  validation of the Standard Model